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PEOPLE
MARIE CURIE ACTIONS

Intra-European Fellowships (IEF)
Call: FP7-PEOPLE-2012-IEF

PART B

"POT*ex*HEP"

Precise Online Tracking
for
Experimental High Energy Physics

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B1 SCIENTIFIC AND TECHNOLOGICAL QUALITY

Research and technological quality, including any interdisciplinary and multidisciplinary aspects of the proposal

State-of the-art of the research topic. - An unprecedented set of events will dominate the experimental exploration of the fundamental constituents of the universe in the next years; at the top of the list is the physics program of ATLAS and CMS experiments at the Large Hadron Collider (LHC) at CERN. The present phase, that held just few months ago at the announcement of the discovery of a new particle candidate for being the long-searched Higgs boson, will be followed by a second phase, indicated with SuperLHC (SLHC), where both the detectors and the accelerator will be upgraded to ampliate the physics reach. LHC is in an excellent position to give conclusive answers to many open questions: observation of the Higgs boson and verification of the symmetry breaking at the electroweak scale. The limit of the Standard Model (SM) will be probed at energy frontiers not directly explored before, verifying the theory on the mass hierarchy problem and the origin of the CP asymmetry. Over the next years, an impressive harvest of data will be collected and analyzed at LHC. Processes important for these areas of research very often contain heavy quarks as well as tau-leptons – the so-called third fermion generation. Events rich in heavy flavors and tau-lepton are particularly relevant to test the limits of the SM and study its possible extensions.

At the same time R&D at the technological frontier will be pursued for SLHC, since the detector's occupancy, already impressive today, will increase with the upgrades. While the LHC conditions are upgraded to increase the collected number of events enlarging the physics reach, the observation and measurement of interesting events will become more and more challenging. Not only new interesting events are rare and hidden in an extremely large background, but the single event produced in the proton collision will be confused by many overlapping soft events produced in concurring proton collisions (pile-up). It would be nice to compare Tevatron's environment (the previous generation hadron collider at Fermilab, Chicago) to the LHC environment to quantify the increase of event complexity and, as a consequence, of the detectors. The Tevatron collision rate was ~2 MHz at an instantaneous luminosity (ILum) of $3\times10^{32}\text{cm}^{-2}\text{s}^{-1}$ and the average number of soft interactions per bunch crossing overlaying the interesting interaction was 6 (396 ns bunch spacing). The LHC environment will be much more demanding: a bunch spacing of 25 ns at high ILum (10^{34} cm^{-2} sec-^{1}) produces ~30 pile-up interactions. The precise conditions for SLHC are not yet completely specified however it will have more even more challenging conditions with a pile-up of up to hundreds of events at the ILum of 10^{35} cm-^{2} sec^{-1}.

Tracking devices play an essential role fighting against so high densities of particles, in particular the silicon devices, the preponderant tracking technology today. On the other side the electronics required to process the detector signals is taking an important role. Implementing the most powerful selections in real-time is essential to fully exploit the physics potential of experiments, where only a very limited fraction of the produced data can be stored on tape. A drastic real-time data reduction must be obtained. This makes online event reconstruction a critical component of any hadron collider experiment. The trigger must be extremely intelligent and powerful. This project directly addresses the main technological challenges of hardware, software and data surrounding tracking issues at trigger level. We can exploit a very important advantage: digital electronics is becoming so powerful that the difference between the performance of the algorithms executed in real-time and in the offline analysis has been significantly reduced, even in the extremely hard conditions of high data rates and limited processing time. Since the kind of background suppression we need at trigger level is becoming similar to that of the usual offline analysis, the offline quality is required to be applied at trigger level. This proposal will show that our goal is challenging, but not a dream.

The CDF (Collider Detector experiment at Fermilab) experiment has been the best of the state-of-the-art for hadron collider triggering . It had a strong tradition in this field, since a large trigger part was implemented with dedicated hardware, and was operational for many years, constrained to work within very short latencies (few μs). It was upgraded during the 20-year CDF life, to exploit technology advances. The hadron collider requires a multi-level trigger as an effective solution for an otherwise impossible problem. The level-1 (L1) trigger is based on custom processors and reduces the rate from ~2 MHz to ~ 30 kHz at CDF and from 40 MHz to ~100 kHz at LHC. The level-2 (L2) is based on dedicated hardware at CDF and standard CPUs at LHC with an output rate of~1 kHz for both. The Level-3 (L3) is performed by CPU farms, which write to tape about 100 events/second (at LHC L2 and L3 are called High Level Trigger, HLT).

Very powerful devices are available in CDF, among them the Silicon Vertex Tracker (SVT). It is the most powerful trigger processor operating at a collider so far and it is a perfect baseline for our project. It performs online track reconstruction in the silicon detector (SVX) and the central drift chamber (COT) with sufficient accuracy, almost the offline resolution, to identify tracks from b-quark decays by their large impact parameters (IP>100 μm). SVT had an extremely significant impact on the CDF physics program. It has been essential for the B_0s mixing frequency measurement, new heavy baryon and meson observations, and the first observation of the rare charmless decay modes of the B_0s. These extremely challenging measurements would have been completely out of reach without SVT. Since B-physics has a limited rate budget, the better purity allows CDF to increase by several orders of magnitude its efficiency for the hadronic B decay modes. Historically, B-physics events have been selected at hadron colliders using lepton identification. The online reconstruction of secondary decay vertices greatly increase the b-quark identification efficiency and allow collecting otherwise inaccessible hadronic decay modes. The hadronic decay modes available at CDF determined the quality of the CDF B_0s mixing measurement. Also for high transverse momentum (pT) physics, CDF successfully used purely hadronic channels in Higgs searches (Hbb→bbbb), and even in the reconstruction of the Z boson, thanks to the secondary vertex b-tagging.

The 2009 W.K.H. Panofsky Prize was awarded to SVT recognizing "the leading role ….. enabling broad advances in knowledge of the top quark, b-hadrons, and charm-hadrons….". SVT is a high-performance "supercomputer" using a combination of two technologies: powerful FPGAs (Field Programmable Gate Arrays) working with standard-cell ASICs (Application-Specific Integrated Circuits) for utmost gate integration density. Optimal partitioning of complex algorithms on a variety of computing technologies proved to be a powerful strategy, which turned CDF into a major player in the field of B-physics, on par with dedicated experiments at electron-positron colliders. SVT was built for B-physics at the Tevatron intermediate ILum RUN IIA ($10^{32}cm^{-2}s^{-1}$). It was upgraded to keep up with the increasing Tevatron ILum and to be extended at RUN IIB with ILum approaching $3x10^{32}cm^{-2}s^{-1}$. SVT reconstructs all tracks with pT> 2.0 GeV/c with the maximum spatial resolution allowed by the silicon vertex detector. We hope to build on the success of SVT a second generation processor, Fast Track (FTK), much more advanced to cope with the extreme complexity of the LHC new detectors and the extreme working conditions of the new accelerator. FTK should also extend its physics reach from B-physics and hadronic τ-phyics to high-pT physics involving the most important High Energy Physics (HEP) searches, first of all the Higgs (Standard Model or SUSY) searches.

The SVT architecture, the Associative Memory and FTK, the new processor - There is an enormous difference in the use of tracking detector information at trigger level in the CDF and LHC experiments. While CDF has always intensively exploited tracking from the lowest level selections, at LHC the L1 tracking is totally missing and a late use of tracking is made even in the High Level Trigger (HLT) filters. Tracking at CDF is provided by powerful processors at L1 and L2: the L1 eXtremely Fast Tracker (XFT) and the already mentioned L2 SVT. XFT finds L1 tracks with PT above 1.5 GeV/c in the COT (96% efficient), pT resolution σ(1/PT) = 1.7% and angular resolution σ(φ0)=5 mrad. In addition, to be used in the L1 trigger decision, the XFT tracks are distributed to SVT where the Associative Memory (AM, a dedicated VLSI device) associates them to the hits on the five silicon detector layers. FTK has been studied for 10 years as a second generation device, as precise as SVT, but much more able to provide typical offline tracking performance. While SVT covers only the central region (|η|<1) and its efficiency is affected by many cracks, FTK exploits the whole ATLAS tracking acceptance (|η|<2.5) and implements "overlap regions" at any detector subdivision, where the border could create inefficiencies. FTK finds 3-D tracks, while in SVT the measurement along the beam (z coordinate and polar angle q) is extremely uncertain. FTK uses a much larger number of very precise silicon layers (8 strip layers and 3 pixel layers, for a total of 14 independent coordinates, to be compared to the 5 silicon strip layers of SVT), in order to be more effective in rejecting fake tracks even in very crowded conditions. FTK is more than 90% efficient for muons and more than 80% for pions, with a χ^2 cut severe enough to reduce the fake rate to a negligible level even at very high luminosities.

The tracking algorithm, both in SVT and in the new FTK, is subdivided into 2 sequential steps of increasing resolution. At the first step, a dedicated device called Associative Memory (AM) finds track candidates with low spatial resolution, called roads. In step 2, the real tracks are searched within the roads and fitted to determine their parameters with the best resolution (σ(IP)=35 μm, σ(1/PT) = 0.3 % and $\sigma(\varphi_0)$=1 mrad measured on CDF data). Tracks with pT>2 GeV/c in SVT and pT>1 GeV/c in FTK are finally selected to tag secondary vertices. These algorithms can be implemented using different technologies. Commercial CPUs offer flexibility, standardization and ease of upgrade but they are slow. The CPU flexibility is a great advantage for the full resolution tracking because it must handle many variables and specific situations such as local corrections, alignment effects, exceptions etc. However, programmable logic today is flexible enough to successfully replace the CPUs even in high resolution computations. A coarse resolution pattern recognition, however, does not profit much from CPU flexibility. A large fraction of the CPU time needed to reconstruct HEP events is wasted in data sorting with a lot of random accesses to a large storage containing all the data. By contrast, the AM performs the most CPU intensive part of the pattern recognition (a very large number of regular and highly structured loops of simple logical operations, always identical) with dedicated highly parallel structures. The AM exploits the idea of a pattern matching algorithm based on pre-calculated and stored track candidates, compared in parallel with the actual event.

The first basic AM chip was made with ASIC full-custom technology and was specific to the 5-layer CDF silicon detector. In particular, it was unsuitable for the complexity of the LHC tracking . Any redesign would imply a large investment in terms of time, personnel, and costs. For simple applications, we designed a low density AM chip based on the programmable devices available on the market (FPGA). Commercial FPGAs allows easy development and update of the project. It is also straightforward to test and debug the prototype. Programmable chips are 100% tested at the factory. System performance can be fully simulated. Boundary-scan allows a full test of printed board connections. The only aspect for which programmable devices are inferior to a full custom ASIC is the achievable logic density. In some cases, such as the AM chip, ASICs can still be the better technology. For an extremely high “pattern” density, a standard-cell ASIC can be a very good compromise between the easy FPGA design and the full custom ASIC logic density. To minimize the human and monetary investment, the circuit description uses high-level languages, independent of the hardware substrate and compatible with an easy recompilation into standard-cell chips. We developed the new AM as a standard-cell chip. It played a key role in the upgraded SVT and it was the baseline for FTK.

SVT and FTK include important pre/post processing functions, complementary to the intensive pattern-recognition. Pre-processing corresponds to (a) cluster finding in the silicon data (FTK needs roughly 3 crates of 9U VME boards called Data Formatters, DF) and (b) smart database for immediate retrieval of full resolution information called Data Organizers, DOs. Post-processing includes (a) the track fitting, TF, and (b) duplicate-track cleanup, called Hit Warrior (HW). FTK needs 128 Processing Units (PUs), each one made of a 9U VME board and an AUXiliary (AUX) card on the back. Each PU contains 10 Millions pattern AM on the front board and 4 DOs, 4 TFs and 4 HWs on the AUX board. One of the most important function is the TF, which refines the candidate tracks in order to determine the track parameters with the full detector resolution. It uses methods based on local linear approximations and learn-from-data techniques for online misalignment corrections. The fit calculation consists of many scalar products. Our experience in SVT and FTK shows that the approximations introduced for speed do not significantly affect the fit performance.

Upgrades to the CDF trigger have been necessary as the Tevatron instantaneous luminosity increased producing large pile-up. The more complex events require more trigger processing time, in particular the track trigger, reducing the amount of data CDF could record. As already mentioned, the SVT was upgraded to keep up with the increasing luminosity of the Tevatron and this work was perfect R&D for FTK. The most relevant changes were: (a) a 40 times larger AM, implemented as a 0.18 μm standard-cell; (b) all the SVT pre/post functions have been implemented in the same general purpose board, the PULSAR whose design philosophy is based on a motherboard (with a few powerful FPGAs and SRAMs), which can be interfaced to many industrial standard links through custom mezzanine cards. The PULSAR has been used in many applications, even outside CDF. Our goal for FTK is to exploit as much as possible this idea of a standard board used in many applications: a standard system could work both at L1 and L2. Standardization will reduce costs and manpower needed to develop and maintain the system. The SVT upgrade was completed finally with the GigaFitter, (GF), a very new track fitter, a good starting point for the FTK fitting needs. The GF is a single Pulsar board enhanced by four mezzanines able to replace 16 9U VME boards in CDF. The algorithm core has been implemented in a modern FPGA chip placed on each mezzanine containing memories for a total of several Mbytes, and hundreds of 18x25-bits multipliers and adders (DSP arrays) (500 MHz clock). The DSP-like processors, packaged in large number inside modern FPGAs, can perform many fits in parallel reducing the time necessary to fit a set of coordinates almost to zero.

Information on interdisciplinary / multidisciplinary aspects of the proposal. - As a spin-off of our online development activity, we would like to use our crate of electronics with the Associative Memory along with all FPGA ancillary logic for applications outside HEP:

(a) Real time image analysis has undergone a rapid development in the last few years, due to the increasing computational power available at low cost. However computing power is still a limiting factor for some high quality applications. High-resolution medical image processing, for example, is strongly demanding for both memory (~250 MB) and computational capabilities to allow 3D processing in affordable time. We propose the reduction of image processing execution time exploiting the computing power of parallel FPGAs arrays. We could use our online 2-D clustering algorithm devised for cluster reconstruction in the ATLAS pixel detector to find clusters of contiguous pixels above a programmable threshold and to process them to produce measurements that characterize their shape. We can measure the spot size, but also quantities of interest in medical applications, like how circular or irregular the spot is. It is a fast general-purpose algorithm for high-throughput clustering of data "with a two dimensional organization", designed to be implemented with FPGAs or cheaper custom electronics.

(b) The associative memory processor for real-time pattern matching applications can be used for brain studies. The brain is certainly the most complex, powerful and fast processing engine and its study is challenging. The most convincing models that try to validate brain functioning hypothesis are extremely similar to the HEP real time architectures. A multilevel model seems appropriate to describe the brain organization to perform a synthesis that is certainly much more impressive than what done in HEP triggers. The AM pattern matching function has demonstrated to be able to play a key role in high rate filtering/reduction tasks. We want to test the AM device capability as the first level of this process, dedicated to external stimuli pre-processing. We follow the conjecture of reference [Punzi & Del Viva (2006) "Visual features and information theory" JOV 6(6) 567]: the brain works by selecting for higher-level processing and long-term storage only those input data that match a particular set of memorized patterns (dramatic reduction). We will use an AM-based processor for a hardware implementation of fast pattern selection/filtering of the type studied in these human vision models (see the work plan in section B4 for a more detailed description) taking from there instructions to choose the "meaningful" or "relevant" info to be selected for higher level processing.

Appropriateness of research methodology and approach

The methodology and working of the research objectives are described as following:

A) design optimization, FTK tests on real data;

B) development of software for management, monitoring, diagnostics and control of FTK;

C) development of trigger selections based on FTK tracks and new analysis on collected data to confirm the advantages predicted by the FTK use.

A) *Design optimization, FTK tests on real data*: Dedicated trigger hardware usage has been reduced at LHC, in favor of large, commercial CPU farms to reduce the risks associated with it. In fact the dedicated hardware is often considered powerful and economic but difficult to upgrade and inflexible. We have shown in CDF that the use of FPGAs and ASICs does not suffer from these disadvantages if the design and the commissioning are pursued with the correct methodology. Board standardization and FPGA flexibility allowed rapid system improvement since we could reuse many times the same hardware (Pulsar) and the same procedures, just developing new firmware. The commissioning of the upgrades took place while the experiment was taking data. A very careful test procedure was devised to reduce to a negligible level the impact of the commissioning on detector operation and functionality. We will follow the same procedure for the FTK development and for the gradual introduction of its use in ATLAS. A large effort will be required at the beginning to optimize and standardize the architecture as much as possible and to produce all the needed firmware and software. After that later improvements will be much easier. FTK optimization can be longer or shorter depending on the experimental needs and the rate of funding. In any case, below we are listing the most critical items concerning next years since they are relevant to understand the system's critical points:

1. *Determine the optimal size of the AM system as a function of ILum*: there is a trade-off between the width of the pattern recognition roads (governing the size of the associative memory banks) and the number of required track fits due to hit combinatorial (impacting the complexity or latency of the track fitter boards). We will make the choice for any luminosity by optimizing with respect to the size of the system and to the event execution time. FTK will grow with the LHC Ilum.
2. *Test, commissioning:* in order to understand system issues and develop the needed control software, we start early a parasitic commissioning of a small proto-FTK, able to reconstruct tracks inside a tower of the detector. This will be a "FTK vertical slice" (indicated in the following with vertical slice) in the sense that it will be functionally complete, from the detector inputs up to the track output available for the L2 CPUs but small (operating on a detector slice). While the new processor is designed for the most demanding LHC conditions and exploiting the best technology, for the vertical slice we want to use already existing boards or prototypes, developed in the past for CDF and ATLAS. The EDRO board (Event Dispatch and Read-Out) receives, on a clustering mezzanine able to calculate the pixel and SCT cluster centroids, detector raw data on S-links. The raw data will initially be produced by a "pseudo front-end" (a CPU). The clusters are transferred to the AM board that finds roads, to be provided back to the EDRO. Initially the EDRO delivers back to the CPU the found roads using an S-link connection. We will take the first real data

before next long LHC shutdown (beginning of 2013). For the 2015 data taking, after the shutdown, a more powerful system called “demonstrator” will substitute the vertical slice. The vertical slice will become the test stand where all the new boards and new ideas will be integrated and tested together parasitically on real data.

B) *Development of software for management, monitoring, diagnostics and control of FTK*: The vertical slice will be also serving as a powerful tool for software development. We already had a complete set of software tools for CDF. We are adapting our system to the new experiment’s needs. The vertical slice is also very usefull since requires early development for the integration of the FTK system in the ATLAS TDAQ. We will test all the new prototypes and important features before production begins and make any needed change.

C) *Development of trigger selections based on FTK tracks and new analysis on collected data to confirm the advantages predicted by the FTK use*: FTK has a strong physics case. We will verify with data the foreseen gain in physics reach. We have shown that even single high pT lepton triggers get in trouble into high pile-up conditions. They rely traditionally on calorimeter isolation to suppress backgrounds from real or fake leptons in hadronic jets. At high luminosity, with calorimetric measurement deteriorated by the high pile-up, this strategy deteriorates. If the isolation threshold is kept low for good background rejection, the lepton efficiency drops. On the contrary if the threshold is raised, lepton efficiency is maintained, but at the price of decreased background rejection. An alternative strategy is to apply track-based isolation. For tracking, unlike calorimeter deposition, the pile-up and hard-scatter particles can be separated by associating tracks to the interaction vertices. We analyzed a track-based isolation using only FTK tracks that have an intercept with the beam direction (z_0) close to that of the lepton candidate. Since the rate of multi-jet QCD production, both for light and heavy quark jets, is much higher than the production rate of isolated muons it is critical to suppress reach a high background suppression while maintaining high efficiency for isolated muons.

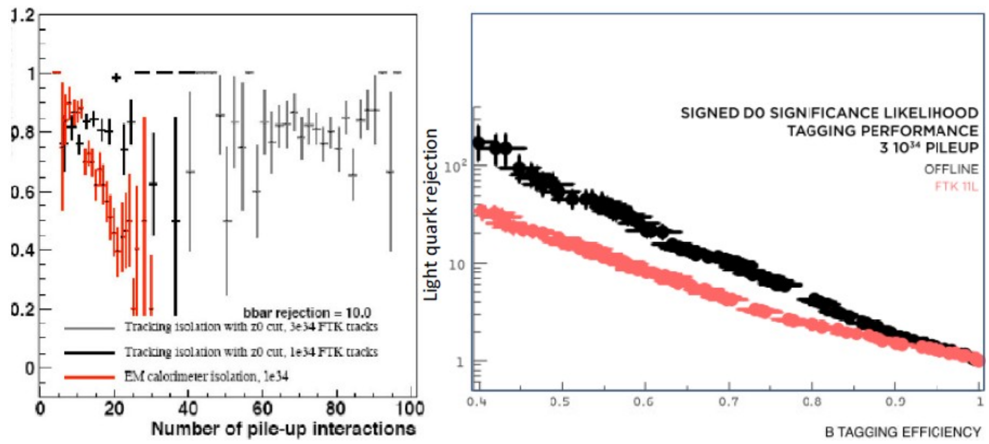

Figure 1: (a) The W→μν efficiency using FTK track isolation (black) or EM calorimeter isolation (red) vs. the number of pile-up interactions. (b) The light-quark rejection vs. b-jet e for offline (black) and FTK (red).

In order to clarify the idea we show an example of a possible trigger strategy that could exploit the FTK trigger power. We have tuned the selection criteria so that the trigger rejection factor for $b\bar{b}$ events is 10.

Figure 1.a shows the isolated muon trigger efficiency as a function of the number of pile-up interactions ($3\times10^{34}cm^{-2}s^{-1}$) using only electromagnetic (EM) calorimeter isolation (red points). The trigger efficiency quickly deteriorates with increasing pile-up. Equivalent results are obtained when the EM cell energy threshold is increased by a factor of two. Using FTK tracks to calculate the track-based isolation yields good trigger efficiencies for W→μν events (black points). The efficiency as a function of pile-up is constant for a large number of pile-up events using FTK tracking (up to 100 pile-up events). Other reasons for early track reconstruction is the selection of events containing third-generation fermions, either a b-quark or a τ-lepton. The L1 trigger selects a generic jet for the former, a narrow jet for the latter. In either case, there is enormous background from multi-jet QCD processes. Discrimination of the signal relies in large part on track information – in b-jets the presence of a secondary vertex, in τ-jets an isolation region without tracks surrounding a signal cone with no more than 3 tracks. The FTK goal is to provide high efficiency on real objects and high rejection power on QCD fakes at very high

event input rates, opening access to new phase-space regions (low pT b-jets and τ-jets) not accessible for the baseline architecture. High-quality FTK performances are provided for b-jets tagging. **Figure 1.b** shows the inverse of the probability to tag a light-quark jet as a b-jet versus the b-tagging efficiency for WH events with 0 pile-up and 3×10^{34} pile-up.

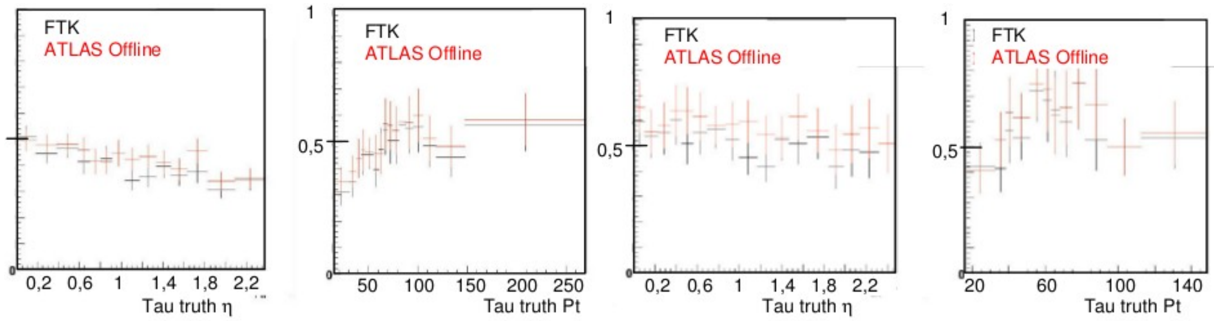

Figure 2: In the left-side plots are single-prong efficiency vs. rapidity and transverse momentum, the latter for |η| <0.8. On the right-side plots the same results are shown for triple-prongs. FTK tracking (black) is compared with ATLAS offline (red) at $1\times10^{34}cm^{-2}s^{-1}$.

The τ algorithm based on FTK tracks is able to identify τ-jets in vector boson fusion (VBF) Higgs events (Higgs mass=120 GeV, decaying into two hadronic τs) with an efficiency roughly 50% for 1-prong (one single track in the signal cone), 60% for 3-prong decays (2 or 3 tracks in the signal cone) and efficiency on fake τs from QCD of 2×10^{-3} at a baseline ILum ($10^{34}cm^{-2}s^{-1}$). These results are shown in **Figure 2**. Good performances are maintained also for SLHC luminosities: roughly 30% for both single and triple prongs at $3\times10^{34}cm^{-2}\ s^{-1}$. The efficiency on QCD fake τs would be below 5×10^{-3} for single prongs and $\sim10^{-3}$ for triple prongs. These results have to be compared to a trigger efficiency of ~10% measured today with only ~20-30 pile-up events with an algorithm that is affected by a fake rate of $\sim5\times10^{-2}$.

Other important examples of CPU-intensive track usage are: (1) primary vertex, beam spot identification, (2) isolated heavily ionizing particles and (3) B-physics events, where final state hadrons have to be found outside of the specific regions identified by L1 objects (Regions of Interest, ROIs). We will perform these algorithms also with the vertical slice: (a) identification of the high-pT primary vertex and leptons (e and τ), including the track-based isolation. We will study its impact on di-boson samples (WW, ZZ, ZW) to estimate the gain on Higgs samples, (b) search of high ionizing particles requiring clean clusters in the pixels, characterized by high energy release, and (c) measurement of the channel B→ K*μμ to demonstrate FTK's capability in B-physics, to increase the experiment acceptance.

As already stated the vertical slice will be substituted by the demonstrator in 2015, a processor with a detector coverage large enough (barrel) to select a few processes in order to demonstrate the capability of FTK in complicated events. These will include Z→ bb events for a calibration channel, to get prepared for Hbb→4b's for events whose distinguishing characteristic is multiple secondary vertices, and Z→ ττ to become ready for VBF production of Higgs decaying to hadronic τ-pairs. We will quantify the FTK hadronic τ reconstruction capability.

Originality and innovative nature of the project, and relationship to the 'state of the art' of research in the field

The experience gained at the CDF experiment is undoubtedly precious to LHC experiments. The philosophy of performing almost offline selections at rates of the order of 20-40 kHz, or even more, is absolutely new. The idea of using dedicated mixed-technology supercomputers is innovative in a world where the use of dedicated hardware has been strongly reduced. As already underlined, there is an enormous difference in the use of tracking detector information at trigger level in the CDF and LHC experiments. Our proposal to transfer the CDF experience to LHC fits perfectly in this scenario. We want to improve the functionality of the online tracking to match the luminosity increase and to foster the use of these powerful online processors to more complex future applications. New and outstanding Supercomputers increase the discovery potential of current and future HEP experiments. They will use FPGAs and ASICs to complement CPUs. CPU-based sequential reconstruction programs usually waste the CPU flexibility when carrying out a serialization of long simple repetitive logical operation sequences, that once optimized will remain largely unchanged. The problem is generally referred to as the "combinatorial challenge". Supercomputers beat the combinatorial challenge with powerful dedicated programmable devices, where parallelism can be exploited to the maximum level. Thus the FTK can be considered a highly parallelized extension of the front-end, executing only data unpacking and solving the huge hit combinatorial problem to filter out the few relevant hits from the plethora of silicon data due to the low pT tracks and noise. The HLT CPUs, freed of the huge tracking job, could more easily exploit offline-quality algorithms to increase rejection power, solve high-level-object combinatorial problems, or make intensive use of tracks in all selection algorithms. The developed devices will be general enough to be adapted to other research fields where efficient and fast real time reconstruction of data is needed, as described in section “Scientific and technological quality”.

Timeliness and relevance of the project

This is a perfect timing to demonstrate to the HEP community the capability of the FTK online tracker. The very precise LHC silicon detectors, which contain hundreds of thousands or millions of channels, increase the problem of complete tracking in large numbers of high multiplicity events. With tens or hundreds of particles produced by multiple primary collisions and traversing many detector layers in all directions, this is a formidable challenge even for offline analysis. The feasibility of complete high-quality tracking for real time event selection was considered impossible, before the FTK proposal, in LHC experiments at very high rates. As a consequence, real-time tracking is planned for a limited detector region or on a small subset of events, selected previously using other detectors. Many physicists dismiss the possibility of complete online tracking in LHC experiments because they see the problem as too formidable. The FTK proposal had a large impact on the ATLAS TDAQ community. The goal of this research is to continue to change this opinion by demonstrating that up-to-date technology, exploited with suitable organization and algorithms, permits the development of high-performance tracking triggers able to save isolation criteria in a environment where no object will be seen isolated in the calorimeter. FTK triggers will be also sensitive to secondary vertices and complex structures like τs. The FTK strategy has a particularly relevant impact now that the LHC community is touching the effect on physics of very high pile-up conditions, and is also considering the design of new architectures for the SLHC upgrade. The CDF experience with data, in particular the online tracking at CDF and the FTK R&D project, had already a significant impact on the discussion of future architectures.

The scientific, technological or socio-economic reasons for carrying out further research in the field covered by the project – The first very general reason is the HEP research advancement. It focuses on the fundamental nature of matter and energy, space and time. Any discovery in this field will help to deepen our understanding of nature and to answer compelling questions about the origin of particle masses, the existence of new symmetries of nature as well as extra dimensions. Answers to such fascinating questions can be found at particle accelerators and collider facilities and will influence the philosophy of science and more broadly human thought. Moreover, these HEP experiments are becoming so incredibly complex and expensive that any specific work in the trigger and Super-Computer research area becomes every day more important to increase the efficiency for sample collection and save money. These experiments, as explained below, need enormous computing power, therefore ideas for making them powerful at low cost are very important.

Other important reasons lie also outside HEP. The electronics we use in this work is extremely flexible and powerful, but also underused and not well enough known. The strategy of the "optimal mapping of a complex algorithm in different technologies" is a general approach that can speed up enormously any kind of calculation by providing the capability of a high degree of parallelism. The trend of using a combination of CPUs and FPGAs for systems continuously requiring increasing computing power has been expanding not only in physics experiments, but even in non-academic fields, like for example financial applications. It could be very important in the area of medical imaging for real-time and fast diagnosis when the patient is under examination. It can be very relevant for astrophysical and meteorological calculations. It could be fundamental for neurophysiologic studies of the brain or for security applications. The use of this electronics is more difficult than the use of a multi-core CPU, since it requires the FPGA hardware and the knowledge of computer-aided-design (CAD) tools. It requires the capability to exploit these instruments at the highest level. The power of the result is a strong function of the creativity and experience of the designer. For this reason I think the HEP work in this area is important for showing the potential of these devices and spreading the skills needed to use them efficiently. If people become expert with these tools the world computing power could make an incredible jump and we could save money (less expensive systems), energy (minor consumption), and space (much more compact systems).

Host scientific expertise in the field

The University of Geneva (UNIGE) is an institution devoted to promote research, teaching and dialogue. It is a site of academic creativity and the transmission of knowledge. Since its foundation in 1559 the UNIGE has developed ever higher ethical standards and steadily increased in quality and the will to innovation. Today, it is one of Europe's leading universities. The UNIGE also shares the international calling of its host city, Geneva, a center of international and multicultural activities with a venerable cosmopolitan tradition. Its desire to expand its collaboration with partner institutions and broaden its appeal to researchers and students from around the world has made the UNIGE a "globalized university", a meeting place for academic disciplines and various cultures, and a forum for ideas.

I will work at the Department of Particle Physics (DPNC). The Particle Physics Department participates strongly in the experimental aspects of this scientific adventure. It has the tremendous advantage of proximity to CERN, the largest accelerator laboratory in the world enabling studies of particle interactions as very small distances. The experimental activity is also supported by theorists working at the Department of theoretical physics (DPT). The Institute has a mechanical design group along with a machine shop and areas for construction of large detector components. There are Tier-2 and Tier-3 computing clusters for ATLAS. There is also a very good electronics design group that has produced electronic systems also for the SVT tracker at CDF. The faculty are working or worked recently on many international collaborations: L3 at LEP, CDF at Tevatron, PSI, heavy ions, ATLAS at LHC, and IceCube/CTA.

Quality of the group/scientist in charge

The supervisor of "Maitre d' Enseignement et de Recherche" Xin Wu and his group headed by Prof. Giuseppe Iacobucci, have a large experimental experience in physics analysis, trigger and detector construction. In the last 20 years they participated to many important physics searches at hadron colliders: CDF at the Tevatron and ATLAS at LHC. At CDF they produced many results in B-physics, QCD, lepto-quark searches, photons and diboson measurements. They also participated to the following important construction activities: (a) the Silicon Vertex Tracker, (b) High Pt B-jet Trigger for Run II,(c) Photon plus B-jet Trigger for Run II , (d) MC@NLO for b production at CDF, (e) Diamond detectors for beam abort, and (f) scintillator counters for beam halo studies.

The UNIGE participated in ATLAS since the beginning participating to the construction of the ATLAS detector. The group has been involved in the design, assembly and commissioning of the Semiconductor Tracker, one of the system of the Inner Tracking detector, and in the readout and commissioning of the Liquid Argon Calorimeter. In addition to detector related research the group has played a central role in the development of the High Level Trigger (HLT) system. The group continues to lead in the implementation of HLT selection algorithms and has set up a large computing cluster for physics analysis and trigger commissioning activities. The wide expertise acquired in the detector construction has allowed the group to give important contributions in many areas of physics research from initial Standard Model measurements to inclusive SUSY searches, exotic processes and also heavy ion physics. These physics research topics have naturally focused the group in the direction of perfecting the reconstruction of electrons and photons within the ATLAS detector. While physics analysis preparations proceed in contributing to the analysis of the data of the first LHC physics run, the group is also carrying out further detector research needed for higher luminosity running. In this direction is the recent interest of this group for FTK.

B2 Training

Clarity and quality of the research training objectives for the researcher

Training objectives of the proposal – Research training objectives of the proposal include:

- Very advanced use of programmable logic (FPGAs). High level firmware development (VHDL and Verilog description language), simulation and test capabilities, timing and implementation optimization.
- Development of code for the level 2 CPUs at very advanced level, to optimize the final level 2 decision.

- "Cost versus performance" evaluation and comparison of different technologies: VLSI devices, FPGAs, commercial CPUs.
- LHC trigger selections knowledge and study of its dependence on the accelerator luminosity. Understanding bandwidth and processing problems. Efficiency and rejection power optimization.
- Capability to realize new triggers exploiting the hardware upgrades.
- Understanding of the ATLAS online/offline tracking system problems, relative solutions and standardization of the system to be able to transfer the best of this technology to the future.
- Capability to improve flexibility and ease of use for the trigger devices, to allow application to different experiments with minimum tailoring and minimum engineering effort.
- Development of a complete set of diagnostic tools, to be used within the ATLAS monitoring system but also in future applications.
- Realization of simple expert systems to monitor and find problems in the system.
- Exercise automation of technological follow-up of digital electronics developments, producing clean project descriptions by high level languages and automatic compilation into the most advanced devices at time of construction. This will simplify further developments and applications to future experiments.
- Learning about the μreconstruction in the ATLAS experiment, both online and offline, on particular learning from the UNIGE group that has a large experience in this field.
- Participation to the first data taking of the FTK vertical slice and analysis of data to show the effect of the FTK track-based isolation on efficiency of important resonances. The Bosons (W and Z) will be used as benchmark.
- Capability to adapt the experience gained on "supercomputers" developed for HEP to pattern recognition problems outside HEP, such as medical imaging.
- Capability to duplicate the vertical slice at UNIGE: a test stand has will be installed to be used by students.

How the objectives can be beneficial for the development of an independent research career – The project guarantees the ability to work for two years in this important research area and thus play an important role in the trigger community of the ATLAS experiment. I will take advantage of the knowledge obtained at UNIGE, and in particular the expertise of its ATLAS group in trigger techniques. This will effectively assist in integrating my research capacities, both hardware and software. Returning to Italy, or more generally to other European countries, I expect to be able to find a good position in the research field I am expert. I would like to continue on the trigger issues, to manage a small group of people working with me for hardware development and physics related studies.

Relevance and quality of additional research training as well as of transferable skills offered with special attention to exposure to industry sector, where appropriate

Adding different/complementary scientific competencies to the fellow career - The most important scientific competence I will add to my curricula will be a deep experience in hardware implementations and trigger techniques. The UNIGE group is very experienced on the related techniques and being a member of this group I will have the opportunity to integrate my scientific profile in hardware as well. Also, I will be able to gain scientific competencies outside experimental HEP. The UNIGE is one of the world's great intellectual communities and it is enormously stimulating in many different fields. It is easy to attend at seminars and classes of extremely high interest and quality.

The department of Physics is enriched by the Department of Condensed Matter Physics (DPMC). Condensed matter physics is without doubt, at this time, the domain of physics which employs the largest number of researchers and producing the largest number of results of potential industrial and economical interest. These are the phenomena which have revolutionized this research area during the last three decades: High temperature superconductivity, ferro-electricity, magnetism, quantum conductance to mention just a few.

The Group of Applied Physics (GAP) was set up in 1980 to provide a path between the academic and industrial worlds. Its centres of interest are voluntarily varied to multiply the chances for technology transfer. Physics in fact brings much to society, the economy and the environment, through the many applications arising from its discoveries. Today the GAP consists of four groups, active in the fields of biophotonics, optics, the physics of climates, as well as superconductivity and materials. The first group develops new methods for monitoring and even controlling biological systems and atmospheric phenomena. Primary goals are the identification of bacteria in air, air pollution measurements, early detection of cancer and lightning control. The second group works on classical and quantum communication in optical fibres; it is also heavily involved in the very promising field of the quantum cryptography, whose security is based on the fundamental laws of quantum physics. The third group focuses on the functioning of the climate system through numerical modelling techniques, and seeks to assess the environmental and economic impacts of a climate perturbed by human activities during the course of the 21st century. Finally, the third group concentrates on the latest developments in the field of materials and superconductivity to develop those aspects likely to be of interest to industry. Two companies participate to the FTK tests, production and commissioning: the Italian CAEN and the Greek PRISMA Electronics. Both these companies had a wide experience in developing instruments and electronics devices for high energy physics. They had an important role in the development of the readout and power supplies for the LHC detectors. The researcher will have the occasion during his fellowship to collaborate with them at CERN where boards will be designed, tested and commissioned, and learning about the companies' organization and working style.

The Faculty of Sciences of the UNIGE offers more than 400 courses, seminars, and lab sessions in biology, chemistry, computer science, physics and astrophysics, mathematics, pharmaceutical sciences, and earth and environmental sciences to some 2000 undergraduate, graduate and post-graduate students, of whom 48% are women. It is considered among the best in the world according to international rankings. The Faculty houses three National Centres of Competence in Research (NCCRs): one in biology, «Frontiers in Genetics», one in physics, «Materials with Novel Electronic Properties-MaNEP» and the other in chemistry «Chemical Biology – Visualisation and Control of Biological Processes Using Chemistry». UNIGE is the institute of higher learning which, for a number of years now, has received the most grants from the Swiss National Science Foundation, grants which are distributed based on competitions. The Faculty is internationally recognized for its excellence in research.

Measures taken by the host for providing quantitative and qualitative mentoring/tutoring

The work style in the Geneva groups is wonderful. Organization and continuous scientific discussions are the bases of the high research productivity of the relatively small, but excellent research groups. Each member has individual responsibilities and is required to discuss its work weekly with the rest of the group. Seminars in front of the whole scientific community of the institute are periodically taking place. This style is a strong stimulus to acquire clarity, independence, management capability, and presentation skills. The strong communication/discussion between all group members, provides a continuous stimulus to improve "leadership capability". Presentations at conferences are strongly encouraged, even the dissemination of ideas and results that for a long time have been not particularly popular in the HEP community (FTK, for example, suffered of the large LHC online farms competition). The area is intellectually very active and offer seminars and possible interactions on a wide range of topics in HEP, technological areas related to the experiments/accelerators, and also in totally different fields. The fellow work will have the opportunity to be presented to a large and international scientific community. Independence and management capabilities are strongly encouraged and rewarded.

The group has trained as phd student or post docs a lot of physicists that now have important positions in Atlas and HEP in general: Dr. Christian Couyoumtzelis, Dr. Hisanori Kambara, Dr. Thomas Speer, Dr. Lorenzo Moneta, Dr. Federica Strumia, Dr. Andras Zsenei, Dr. Yanwen Liu, Dr. Monica D'Onofrio, Dr. Mario Campanelli (Maitre Assistant), Mauro Donega (Assistant Doctorant), Anna Sfyrla (Assistant Doctorant), Shulamit Moed (Assistant Doctorant), Sofia Vallecorsa (Assistant Doctorant).

B3 RESEARCHER

Research experience

Research experience and activities

My research field is High Energy and Particle Physics in colliding experiments with emphasis on high-quality data mining implementations, large-scale data manipulation and data analysis, and results interpretation of very precise measurements and searches of new physical phenomena.

Before joining the experimental HEP as a graduate student and later as a researcher, I studied nuclear physics. Particularly, I searched for potential new phenomena in heavy ion collisions. I was involved in the HADES experiment at GSI in Germany, which became a highly regarded research center both domestically as well as internationally. My main research activity was the investigation of hadron properties inside nuclear matter at normal and high densities and temperatures in heavy ion collisions at energies 1-2 AGeV. I studied the hadron induced reactions on heavy nuclei (C, Ca, Au, Pb) in Monte Carlo simulated events probing electron-positron final states and compared the theoretical results to the experimental findings. Furthermore, I was responsible for a massive production of simulated events using a high performance cluster computing linux farm. Through these activities I was able to strengthen my programming skills, gain experience with data mining and Monte Carlo simulation, and improve my analytical and problem solving abilities.

After completing my undergraduate studies, I decided to pursue a Masters degree in Physics, which gave me the opportunity to develop my research interests in the field of HEP in colliding experiments. Such was the CMS experiment, one of the two multi-purpose detectors installed in the Large Hadron Collider ring at CERN. At that time, the LHC was under construction and the CMS detector was in the phase of assembling and installing it in its hosting cavern in the LHC tunnel. Since the LHC accelerator did not operate at the time hence it was not delivering any collision data the attempts of the scientific community were concentrated on performing accurate feasibility studies in different physics areas using simulated data. During the second and third year of the Masters program I was researching the physics at the Planck energy scale beyond the Standard Model. More specifically, I tried to explore the possible existence of higher dimensional mini black holes at the TeV-scale by using repetitive and extensive Monte Carlo studies with the CMS detector in proton-proton collisions at LHC. Many phenomenological models permit the creation of short-living microscopical black holes in proton collisions under specific assumptions; that the spatial dimensions of the world can extend beyond the existing three plus one, and that the Planck scale where gravity is the dominating force can be as low as at TeV energies which are certainly accessible with the LHC machine. In order to simulate the creation, decay and evolution of the microscopic black holes I used different Monte Carlo programs incorporated in the CMS software framework so as to fully simulate the evolution of the physics events. Different analysis strategies and techniques were developed in order to separate the signal events from the background processes. An extension of this study was the discovery and measurement of the single top quark. Since the black holes are blind to any degree of freedom of the fundamental particles, they democratically emit all known particles with the same probability. This fact offered the opportunity for observing and measuring the top quark singly produced for the first time. All research activities evolved during this period reinforced my technical knowledge in Monte Carlo simulations and programming skills, in manipulating and analyzing large-scale data, and in interpreting the physics results. Finally, my engagement in research helped me to improve my communication skills while working in a high-demanding collaboration environment with other scientists and extending the practical and theoretical understanding of new discoveries.

After a few years of working in this area, I developed the desire to build a career in research and to pursue a PhD. The PhD at University of Pisa was a four-year structured program funded by the ARTEMIS RTN European program (Marie Curie FP6). The first year involved intensive courses and seminars related to HEP followed by final exams. In addition, I collaborated with my supervisor throughout the year to develop the PhD research proposal. The primary objective of my thesis was the search of the Standard Model Higgs boson in the ATLAS detector at LHC, decaying into a central hadronic tau lepton pairs in association with two forward-backward jets. In the low mass range, $110 < m_H < 160$ GeV, the Vector Boson Fusion mechanism (VBF) together with gluon-gluon fusion are the dominant channels to produce Higgs in proton-proton collisions at high center-of-mass energies. The distinctive signatures of the event topology and its kinematic characteristics indicated a promising potential for a discovery in the low mass range. However, several background processes affected this measurement, the most important being the QCD multi-jet production [14].

During the initial stage of these Higgs searches while LHC had not delivered any data yet a wide range of the event topology characteristics and kinematic features of the fully-hadronic channel were being investigated for signal and backgrounds processes using Monte Carlo fully simulated events. However, the challenge of predicting the expected size of the QCD background with simulated data hardened the possibility of reporting on an estimated sensitivity for that channel. Measurement-related systematics and large theoretical uncertainties could limit the ability for signal discovery and for an estimation of the product of cross-section and branching ratio of the Higgs particle. Therefore, in the thesis framework particular emphasis was reasonably placed on the development of data-driven estimation techniques of QCD multi-jet background satisfying the specific Higgs topology requirements. The main focus was on the estimation of the associated uncertainties in the background normalization and shape. The results were based on an improved detector description, including sub-detector misalignments, displaced interaction vertex, the most up-to-date reconstruction software and Monte Carlo event generation.

The year 2009 was an exceptional benchmark with LHC setting a new world record opening a new era in hadron collider physics. The LHC became the world's highest energy particle accelerator by accelerating its twin beams of protons to an energy of 1.18 TeV and exceeding the previous world record of 0.98 TeV, which had been held by the US Fermi National Accelerator Laboratory's Tevatron collider since 2001. This achievement marked an important milestone on the road to first physics at the LHC in 2010, followed by a second great achievement of delivering collision data at even higher energies of 7 TeV center-of-mass energy. QCD multi-jet events are generally being produced in large abundance and multi-jet cross sections are among the first measurements that are possible to perform with real data collected by the ATLAS detector. The LHC physics program with proton-proton collisions at $\sqrt{s}$ = 7 TeV allowed QCD physics to be tested in an entirely new high energy regime, the highest ever achieved in history of the experimental HEP. Jet production and properties are generally key observables in high-energy particle physics. They have been measured in many beam colliders so far. They have provided accurate measurements of the strong coupling constant α_S, they have been used to obtain information about the structure of the proton, and have become important tools for understanding the strong interaction and search for physics within and beyond the Standard Model. I was strongly involved in the task of measuring the jet cross-section and characteristics in proton-proton collisions at an unprecedented center-of-mass energy of 7 TeV at LHC, performed by the ATLAS experiment. The work for my PhD thesis represented a part of these measurements; an endeavor to understand some of the most important experimental aspects of the QCD theory, and in particular the production of multi-jet events in proton-proton collisions. My attempts were to describe the analysis set up to measure the multi-jet production rates and their kinematic features in early data provided by LHC. A comparison was made between the theoretical predictions and the experimental results obtained by the dedicated analyses performed on the data collected by the ATLAS experiment. Special emphasis was laid on understanding the various sources of systematic uncertainties on the experimental results, together with the uncertainties of the theoretical calculations. I was actively involved in many efforts during the first acquisition of $\sqrt{s}$ = 0.9, 2.36 TeV and then $\sqrt{s}$ = 7 TeV proton-proton collision data, and in several jet measurement analyses using the full 2010 dataset. Starting in 2009, I studied the kinematic properties of jets produced in proton-proton collisions at $\sqrt{s}$ = 900 GeV [j, 11] and later I participated in the first observation of energetic jets in $\sqrt{s}$ = 7 TeV data collected in 2010 [12]. I also made a significant contribution to the first measurement of inclusive jet production cross-section [g, 9] and had a major role in the first measurement of multi-jet production cross-sections [g,7]. Finally, in 2011, special emphasis was placed on the measurement of the multi-jet cross-sections with a larger data sample [c, 5, 6, 8].

I participated in all phases of the multi-jet cross-section measurement taskforce, from the first measurement to the most recent publications, and had many responsibilities during these efforts. Without doubt, this achievement would not be possible without the outstanding competence, dedication and the efforts of a lot of people collaborating together. Most of the produced results are the outcome of cooperation of which I had a leading role. In particular, I was the direct responsible for the multi-jet trigger performance studies and the trigger design for the event selection. My occupation with the jet triggers brought me closer to understanding better the functionality of the data acquisition system in colliding experiments working under high pressure and in ultra-dense environments.

I was also responsible for calculating the total integrated luminosity corresponding to the data periods used in the analysis. I developed the Monte Carlo machinery for generating all multi-jet observables and I had the responsibility of the massive production of simulated events with different leading-order Monte Carlo programs, such as PYTHIA, SHERPA and ALPGEN, attached to numerous tuning parameters. During the Monte Carlo production, several studies were focused particularly on understanding the differences observed between the simulated samples with different Monte Carlo tunes. Emphasis was put on studying the effects resulting from the choice of the parton distribution functions (PDFs) implemented in the simulation. Moreover, I was also responsible for the estimation of the non-perturbative QCD correction factors needed for the next-to-leading-order theoretical calculation using an enormous amount of simulated events. These duties helped me to advance my abilities to deal with large data. A lot of emphasis was given in understanding the impact of implementing the non-perturbative QCD corrections in the theoretical predictions at next-to-leading-order and their effect on the overall theoretical systematic errors. These tasks demanded effective multidisciplinary technical skills in the field of parallel computing processing and network, producing and maintaining large amount of data and required proven abilities in driving and supporting large scale simulation programs. Furthermore, I participated in the special validation tasks undertaken to control the theoretical calculations at leading-order and next-to-leading-order of the perturbative QCD calculation, to test data correction factors, to extract the jet energy scale uncertainty in the data, to understand the impact of multiple interactions on the measurements and to make estimations of the overall systematic uncertainty bands. I had also a major role in designing the analysis cut-flow, in constructing comparison tables, performing final cross-checks of all findings and presenting the final results at the scientific community.

After completing the PhD program, my long-term objective was to seek a research position in a research organization or academic institution where I could share my experience and knowledge with others who are equally excited about HEP and where I can research, identify, and provide new challenges, perspectives, and approaches. The CERN-INFN fellowship I owned last year and the present post-doctoral position based at CERN in association with the University of Pisa, helped to achieve my goals. The year 2011 was full of excitement and significant progress towards the discovery of the Standard Model Higgs boson. I was actively involved in the search efforts for the Standard Model Higgs Boson in the fully hadronic di-tau final state with the proton-proton data at $\sqrt{s}$ =7 TeV collected by ATLAS [4]. I had a primary role in structuring the event selection strategy and the design of the analysis, and in developing statistical models to interpret the final results. I was also acting as liaison between the Higgs physics community and the hadronic tau trigger group. More specifically, I was responsible for understanding the performance and efficiency of the hadronic di-tau triggers and for an in-depth understanding their ability to select signal events and their rejective power against fake or background hadronic tau candidates. This particular contact with the functionality of the hadronic tau triggers made me realize that they could be further improved and optimized in terms of selection efficiency and event rate. While previous hadron collider experiments, such as CDF at Tevatron, had always intensively exploited tracking from the lowest trigger level selections, at LHC the L1 tracking is totally missing and a late use of tracking is made even in the High Level Trigger (HLT) filters. Therefore, a possible implementation of tracking algorithm at the earliest stage of the ATLAS trigger system could simultaneously increase the event rate and reduce the fake rate to a negligible level even at very high luminosities. I am currently leading the efforts of re-optimizing the analysis at $\sqrt{s}$ = 7 TeV and also carrying out the analysis with the newly-collected data at $\sqrt{s}$ = 8 TeV. Re-optimized results have been already published [1] and there are ongoing efforts to analyze the full 2012 dataset.

Beyond my involvement in physics analyses I am also participating in the detector operation and data acquisition. I am particularly involved in the data quality validation tasks and in improving the offline tools which are used to monitor the data acquisition flow, the data quality and its impact on physics analyses. Moreover, my duties extend to the control of the operation of the hadronic calorimeter sub-detector during all phases of the data acquisition.

I am very optimistic about the future of searches with hadronic taus in the final state and the development of the hadronic tau triggers, and in general the outcome of the research program at colliding experiments. CERN developed an outstanding research infrastructure so I hope that the prospects will continue to grow for the following decades. I am really interested in the area of research I am working on at the moment, so would love to continue investigating new methods, exchanging experience and taking innovative initiatives.

Academic Development

Graduate studies:

- ▸ Doctor of Philosophy in Physics – 2007-2011. Thesis: “Measurement of multi-jet cross sections in proton-proton collisions at a 7 TeV center-of-mass energy with the ATLAS detector”, Universitá di Pisa, Italy. Supervisor: Vincenzo Cavasinni.
- ▸ Master of Science in Physics – 2004-2007;Thesis: “Exploring higher dimensional mini black holes with the CMS detector at LHC”, University of Cyprus. Supervisor: Fotis Ptochos.

Undergraduate studies:

- ▸ Bachelor of Science in Physics, University of Cyprus – 2000-2004;
- ▸ Member of the Nuclear Physics Laboratory and the HADES experiment at GSI in Germany;

Awards

▸ 2011-2012 CERN–INFN Fellowship “Posizioni di Associate INFN”. Research topic: “Measurement of multi-jet cross sections in proton-proton collisions at a 7 TeV center-of-mass energy with the ATLAS detector”. Host organization: CERN. Supervisor: Daniel Froidevaux.

▸ 2007-2011 PhD position with an ARTEMIS Research Training Network scholarship. Funded by the Marie Curie FP6 program, WP3: “Direct/Indirect Higgs searches and Interpretation”. Host organization: University of Pisa.

▸ 2004-2007 Graduate scholarship program. Funded by the Cyprus Research Promotion Foundation. Host organization: University of Cyprus.

▸ 2012-present Postdoctoral fellowship, Universitá di Pisa and INFN-Sezione di Fisica.

Skills and Training

Operating systems, programming languages and scientific software:

- ▸ Advanced and comprehensive knowledge of GNU/Linux/Unix systems;
- ▸ Strong background in Object Oriented C++, C and Python programming languages used in conjunction with the most common scientific libraries; ability to develop independent and standalone packages or work within

large frameworks, such as the ATHENA/Gaudi framework of the ATLAS experiment which requires high-level programming skills of both C++ and Python;

▸ Very good knowledge of shell-scripting: BASH, TCSH, AWK to perform fast and efficient algorithmic tasks;

▸ Good knowledge of debugging and code testing tools; GDB, Valgrind and profiling software to dynamically optimized programs;

▸ Strong capacity in data analysis and data management (formatting, storage, hierarchy), and graphical interpretation and presentation of results using the ROOT environment, an object oriented framework for large scale data analysis;

▸ Advanced abilities in parallel data processing using PROOF and Condor; great expertise in building softwares to run on multi-CPU computing machines and to interactively analyze large sets of ROOT files;

▸ Excellent knowledge of languages used to create documents and analytic reports to present results in different formats; LaTeX, PHP, HTML, XML and CSS;

▸ Long-standing experience in manipulating large-scale data, performing grid-based analyses and to efficiently analyze very large databases; a large experience has been gained in the ATLAS experiment by exploiting the LHC Computing Grid (LCG) and all associated tools (Ganga, Panda tools, DQ2);

▸ High level of expertise in data production and manipulation, and mining implementations to benchmark and validate model outputs; ability to simulate hadron collision events with most important Monte Carlo softwares (PYTHIA, HERWIG, SHERPA, ALPGEN) and frameworks (RIVET) to validate physical measurements obtained in the experiment;

Military Service:

▸ Mandatory 26-month military service at the National Guard of the Republic of Cyprus (1998-2000);

▸ I received a special training in Infantry's Heavy Weapons and particularly in operating with mortars of all types, where good knowledge of mathematics and computational abilities are strongly required.

Research results including patents, publications, teaching etc., taking into account the level of experience

Outline of Research Results

Research results can be expanded into two major categories according to the content of the research activity: (a) QCD jet production rates and properties measurement with LHC early collision data, and (b) the Higgs boson hunting with 2011 and 2012 LHC data delivered at $\sqrt{s}$ = 7 and 8 TeV, respectively. The first part was mainly unfolded during my PhD studies, while the second one started evolving after the completion of my PhD when LHC began operating at higher luminosities and delivering more data. Most of the research results were documented in scientific reports, published in physics journals and presented at international conferences and workshops.

QCD Jet Measurements

Jet kinematic properties have been first studied with proton-proton collision data at $\sqrt{s}$ = 0.9 TeV (published at [11] and presented at [j]). Jet inclusive cross-sections have been measured with LHC early data at $\sqrt{s}$=7 TeV (published at [9, 10, 12] and presented at [g, h]). Multi-jet cross-sections have been measured with two different LHC datasets at $\sqrt{s}$=7 TeV (published at [5, 6, 7, 8] and presented at [c, e, h]).

Higgs Searches

The searches of the standard Model Higgs boson in di-tau hadronic final states have been performed with the full 2011 dataset sample of an integrated luminosity of 4.7 fb^{-1} at $\sqrt{s}$ = 7 TeV (published at [1, 2, 3, 4] and presented at [a, b]). Older searches were performed exclusively with Monte Carlo simulation (published at [13, 14] and presented at [l, o, q]).

Selected Publications

[1] *"Re-optimized Search for the Standard Model Higgs Boson in the Fully Hadronic di-tau final state with 4.7 fb^-1 of ATLAS data at √s=7 TeV"*. ATLAS Collaboration, 12 Jul 2012, ATL-COM-PHYS-2012-1037 (editor)

[2] *"Search for the Standard Model Higgs boson decaying to di-tau channel with fully hadronic mode in ATLAS experiment"*. Z. Zinonos (Presented at IFAE 2012 11-13 April and to be appeared in Nuovo Cimento C – SIF)

[3] *"Search for the Standard Model Higgs boson in the H to tau+ tau- decay mode in sqrt(s) = 7 TeV pp collisions with ATLAS"*. ATLAS Collaboration, Jun 2012, 30 pp., CERN-PH-EP-2012-140, FERMILAB-PUB-12-321-E, e-Print: arXiv:1206.5971 [hep-ex]

[4]*"Search for the Standard Model Higgs boson decaying to di-tau channel with fully hadronic mode in ATLAS experiment".* ATLAS Collaboration, 45 pp., ATL-COM-PHYS-2012-051 (presented at Rencontres de Moriond EW, 10th-17th March 2012)
[5]*"Measurement of multi-jet cross sections in proton-proton collisions at a 7 TeV center-of-mass energy".* ATLAS Collaboration, Jul 2011, 16 pp., Eur.Phys.J. C71 (2011) 1763, DOI: 10.1140/epjc/s10052-011-1763-6, CERN-PH-EP-2011-098 , e-Print: arXiv:1107.2092 [hep-ex]
[6]*"Measurement of multi-jet cross-sections in proton-proton collisions at 7 TeV center-of-mass energy".* ATLAS Collaboration. ATLAS-CONF-2011-043 (presented at 46th Rencontres de Moriond on QCD and High Energy Interactions, La Thuile, Italy, 20 - 27 Mar 2011)
[7]*"Measurements of multijet production cross sections in proton-proton collisions at 7 TeV center-of-mass energy with the ATLAS Detector".* ATLAS Collaboration. ATLAS-CONF-2010-084 11 Oct 2010. 15 p. (presented at Hadron Collider Physics Symposium, August 2010, Toronto, Canada)
[8]*"Measurement of multi-jet cross-sections in proton-proton collisions at 7 TeV center-of-mass energy in ATLAS".* Zinonos, Z., ATL-PHYS-PROC-2011-086 (presented at PisaJet2011 Workshop, JPCS IOPscience, Jet Reconstruction and Spectroscopy at Hadron Colliders", May 2011)
[9]*"Measurement of inclusive jet and dijet cross sections in proton-proton collisions at 7 TeV centre-of-mass energy with the ATLAS detector".* ATLAS Collaboration , Sep 2010. 67 pp. Published in Eur.Phys.J. C71 (2011) 1512, CERN-PH-EP-2010-034, DOI: 10.1140/epjc/s10052-010-1512-2,e-Print: arXiv:1009.5908 [hep-ex]
[10]*"Jet production cross section and jet properties in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector".* Zinonos, Z. (Pisa U. & INFN,Pisa). Oct 2010. 3 pp (presented at the HCP2010 Conference C10/08/23.3 (Toronto) e-Print: arXiv:1010.0871 [hep-ex])
[11]*"Kinematic properties of jets produced in pp collisions at 900 GeV center-of-mass energy at LHC with the ATLAS detector".* Zinonos, Z. (presented at IFAE2010 and published by Societá Italiana di Fisica" (SIF), Nuovo Cimento C, Colloquia on Physics, 2011)
[12]*"Observation of Energetic Jets in pp Collisions at $\sqrt{s}$=7 TeV using the ATLAS Experiment at the LHC".* ATLAS Collaboration. ATLAS-CONF-2010-043, 13 Jul 2010. - 8 p.
[13]*"Statistical Combination of Several Important Standard Model Higgs Boson Search Channels".* ATLAS Collaboration. ATL-PHYS-PUB-2009-063; ATL-COM-PHYS-2009-222. 2009. - 34 p.
[14]*"Search for the standard model Higgs boson via vector boson fusion production process in the di-tau channels".* ATLAS Collaboration, ATL-PHYS-PUB-2009-055, ATL-COM-PHYS-2009-214, May 2009. 36pp.

Conferences, Workshops and Seminars

[a]2012 IAFE Ferrara "Search for the Standard Model Higgs boson decaying to di-tau channel with fully hadronic mode in ATLAS experiment" (poster)
[b]2012 VI ATLAS Italia Workshop Roma "Searches of the SM Higgs boson in fully hadronic di-tau final states with the 2011 LHC data" (talk)
[c]2011 PisaJet2011 Jet Reconstruction and Spectroscopy at Hadron Colliders,"Measurement of multi-jet cross sections in proton-proton collisions at 7 TeV center-of-mass energy" (talk)
[d]2011 V ATLAS-Italia Physics Workshop Napoli "Jet Cross-Section measurements in ATLAS" (talk)
[e]2010 SIF2010 XCVI Congresso Nazionale Societá Italiana di Fisica, Bologna, "Measurements of multijet production cross sections in proton-proton collisions at $\sqrt{s}$=7 TeV with the ATLAS Detector" (talk)
[f]2010 HCW2010 ATLAS Hadronic Calibration Workshop, Pisa (attendance)
[g]2010 HCP2010 Hadron Collider Physics Symposium, Toronto, "Jet production cross-section and jet properties in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector" (poster)
[h]2010 Jet Spectroscopy Workshop Universitá di Pisa, INFN Sezione di Fisica, "Measurement of multi-jet cross sections in proton-proton collisions at a $\sqrt{s}$=7 TeV" (talk)
[i]2010 IPR Training Marie Curie Intellectual Property Rights Training, Munich (attendance)
[j]2010 IFAE2010 Incontri di Fisica delle Alte Energie Conference , Sapienza Rome, "Inclusive jet production at LHC; first measurements and perspectives for the future", (poster)
[k]2009 ATLAS Tutorial First software tutorial on LHC data, CERN, Geneva (participation)
[l]2009 ARTEMIS RTN Annual Meeting Universitá di Pisa, "QCD multi-jet events in topologies with central di-tau and edge jets" (talk)
[m]2009 MCnet School on MC generators CERN, Geneve (attendance)
[n]2009 FERMILAB-CERN Hadron Collider Physics Summer School CERN, Geneva (attendance)
[o]2008 ARTEMIS MB/IB Meeting "Status of VBF Higgs$\rightarrow \tau(h) \rightarrow \tau(h)$" (talk)
[p]2008 ARTEMIS School on Calibration and performance of ATLAS detectors MPI, Munich (attendance)
[q]2008 Artemis RTN Annual Meeting Paris, "Searching VBF H(120GeV) $\rightarrow \tau\, \tau \rightarrow$h h in ATLAS" (talk)
[r]2007 II Physics Workshop ATLAS Italia, Udine (attendance)

[s]2007 ARTEMIS RTN Annual Meeting, Aristotle University of Thessaloniki, Greece (attendance)
[t]2006 CERN Summer School, CERN, Geneva, “Extra-dimensional microscopic black hole production at LHC with Charybdis MC Generator and detection with CMS detector” (project)

Academic competences: supervision and teaching assistant

▸ *2011-2012* Thesis supervision, “Study of the multi-jet production and search of the Standard Model Higgs in the ATLAS experiment at LHC”, D. Puddu, Corso di laurea specialistica in Scienze Fisiche, Universitá di Pisa.
▸ *2010-2011* Thesis supervision, “Multijet studies with the ATLAS experiment at the LHC”, C. Debenedetti, Corso di laurea specialistica in Scienze Fisiche, Universitá di Pisa.
▸ *2004-2007* Teaching Assistant (TA) at University of Cyprus. Undergraduate courses: High energy and particle physics I/II, Computational Methods I/II laboratory, Nuclear Physics laboratory, Classical Electromagnetism I/II.

Independent thinking and leadership qualities

Being a researcher in experimental HEP offers the opportunity to work in a collaborative environment however, it also demands a self-directed independent working style. It is a dynamic environment which encourages innovation and appreciates the ability to develop pioneer approaches and ideas. The ATLAS collaboration's working style, which is structured into many groups with different qualifications and purposes, greatly assisted in promoting independent thinking and leadership qualities. From the beginning of my research career I worked within such groups but I always took initiatives while having primary roles in taking decisions. In the multi-jet cross-section measurement working group I had a leading role in all phases of the data analysis and in demonstrating and publishing the results. I had always a key-position since I was responsible for the analysis structuring, the event selection strategy, the validation of the experimental results with high-statistics Monte Carlo simulated events and finally for documenting the research findings in reports and papers. Particularly, the trigger selection technique I proposed was something new in the analysis and served to maximize the sample statistics. In parallel to my research duties, I was supervising two graduate students in completing their research project at the University of Pisa. Later, I joined the Higgs working group in which I immediately undertook crucial responsibilities and obtained a leading role. I was responsible in implementing the hadronic di-tau trigger in the event selection procedure, in investigating the data results and comparing them to the theoretical predictions, and demonstrating our observations to the scientific community. The implementation of a data-driven technique to calculate one of the irreducible background processes, the QCD jet background was of a particular importance. This was the ABCD method which was originally used during the World War II to decode enemy's radar signals. I suggested that an alternative form of this application can be appropriately applied in predicting background rates whereas Monte Carlo statistics are inadequate. Finally, by being a part of a dynamic academic department which encouraged high quality research I had the opportunity to participate in many physics conferences, and to organize several local workshops and meetings, such as the ARTEMIS annual meeting at Pisa [l], the Jet Spectroscopy Workshop at Pisa [h] and the PisaJet Workshop [c].

Match between the *fellow*'s profile and project

The FTK project, as a new model organism, appears as a perfect occasion to apply previous knowledge and skills developed during my procession in research. I have gained a lot of expertise in software-oriented techniques and I have developed my analysis-level working knowledge in physics searches essentially. In particular, my exposure to various disciplines of research served to substantially become expert in the following areas:

- programming and debugging skills (C/C++, Python, Valgrind);
- computational methods and analytical thinking;
- large-scale data mining, management and analysis (LHC data, large Monte Carlo simulated samples);
- grid-based and distributed data analysis (LCG grid, DQ2 tools);
- data analysis using facilities of parallel programming (PROOF, Batch system);
- statistical methods to analyze data (RooFit, MVA analysis);
- illustration and interpretation of physics results (ROOT);
- project and team management skills (Jet/Multi-jet measurements, VBF Higgs searches, Higgs/Multi-jet working groups in ATLAS);
- supervision and teaching abilities (supervision of graduate students at Pisa, TA).

This multidimensional background in performing physics analyses and developing new techniques can be dynamically expanded in the proposed research domain. Since my involvement in the Higgs searches with hadronic tau final states I have gained a lot of experience regarding the tau triggers and their usage in physics analyses. Now, the FTK project enables the possibility to work to improve the performance of the tau triggers using innovative online tracking technology. This project can thus help to potentially broaden the horizons for absorbing new knowledge and addressing novel scientific questions which are complementary to those that I have addressed so far in my research course.

Potential for reaching a position of professional maturity

Being involved in the research of experimental HEP, which encourages constant academic development, autonomy, flexibility and independence, established the need to seek professional integration. The proposed program offers now an ideal chance to reach a position of professional maturity.

During my research development, a great emphasis was placed on learning new software-level techniques for data manipulation, data analysis and quantitative/qualitative interpretation of the physics results. As I already have such a solid background in physics analysis, the proposed project can be therefore the potential linkage between two large areas that experimental colliding physics lies on: the software-based and hardware-based research. The FTK project will certainly allow me to develop my capacities in the following areas:

- comprehension of the underlying hardware technology of electronics and applications;
- development and application of novel online tracking algorithms in detectors at colliding experiments;
- in-depth understanding of how data acquisition systems function in colliding experiments;
- optimization of data acquisition colliding experiments at very high luminosities and dense environments;
- overall impact on physics results due to the good performance or mis-functionality of the online data acquisition system;
- driving and supporting large scale development programs.

For these reasons, the FTK project is an excellent way to accomplish a twofold plan; to apply current knowledge in a new research area and to extend my knowledge in the sector of hardware, integrating this way my overall research profile which will lead to professional maturity.

Potential to acquire new knowledge

During my career as a researcher in experimental HEP I continuously persisted in absorbing new skills and taking advantage of opportunities to gain key-knowledge and dissemination expertise.

Throughout my PhD studies, a lot of the experimental challenges and the analysis aspects were completely new to me. Working within the ATLAS software framework I significantly developed my programming skills in C++ but I also learned programming in a new language, Python. In order to analyze the enormous amount of data, I specialized in large-scale data analysis, grid-based analysis, manipulation of large sets of data and in parallel programming. To meet these high standards of data mining and data analysis I attended numerous training schools and software tutorials [I, k, m, n, t]. Beyond the required technical skills I had the opportunity to enrich my background in theoretical physics and especially in Quantum Chromodynamics (QCD), the theory of the strong interaction, which describes the interaction between quarks and gluons making up hadrons. To continue, many of the modeling programs I used to simulate the physics of jets in colliding experiments were originally unknown to me. After being involved in the searches of the Higgs boson I substantially enriched my knowledge regarding the theoretical aspects of the Higgs mechanism and acquired several research techniques. Also, my knowledge on building statistical methods to interpret final results was developed during the last years. The ability I gained to prepare analytic reports and technical documents and give presentations in physics conferences and workshops is also essential.

Seizing upon my will to acquire new knowledge, I plan to direct my efforts to raise the quality of my technical background as well. The FTK project offers an excellent opportunity to exploit the software experience and research methodologies gained so far, towards the integration of my hardware capacities as well. The interdisciplinary emphasis of the host organization's program on data acquisition and trigger, electronics and computing, supplemented by the renowned research center, offers invaluable resources and opportunity to learn the multi-disciplinary aspects of electronics hardware, to conduct innovative hardware design and have thereby significant impact on the physics research in colliding experiments.

B4 Implementation

Quality of infrastructures/facilities and international collaborations of host

Available infrastructure at the host institution and how these can respond to the needs set by the project – The Department of Physics at the UNIGE is large and diverse. In Geneva, fundamental and applied research of the highest level is conducted in different areas of physics. Geneva is a top choice for researchers and students alike because of the superior level of its research and the excellent training and supervision offered. For these reasons in the last years the University of Geneva has always been ranked among the top 100 best Universities in the world.

The fields of research covered at the Physics Department are varied and cover different branches. The Researchers at the National Center of Competence in Research (MaNEP) study the model and development of new electronic materials. These new compounds, with their exceptional properties, will play a key role in the technologies of the future. Particle physicists, who benefit from the proximity with the CERN Laboratory, with which the university works in close collaboration, study the basic constituents of matter in an effort to better understand the universe that surrounds us. In theoretical physics, studies on gravitation and cosmology are conducted alongside those on nanoscopic systems. The latter systems have properties in which the undulatory nature of electrons plays a key role and causes surprising and remarkable behaviors, which could be used, for example, in quantum computers. In the Group of Applied Physics, both fundamental and applied researches are conducted, in quantum optics, bio-photonics, and on superconducting materials. In the field of optics, studies on quantum communication and teleportation are opening up amazing possibilities for the safe and secure transfer of information. The fact that only a limited number of students per year is accepted allows to guarantee teaching, training and supervision of the highest quality. The Section of Physics offers a complete range of programs: bachelor, master, and doctorate in accordance with the Bologna system.

The host institution indicates to which extent the applicant can benefit from the host institution's participation in the international collaboration described in B1 - The UNIGE group has participated in the CDF experiment. The CDF is an international collaboration of about 800 physicists from about 60 American and European Institutions. Some important discoveries and measurements have been performed at CDF, such as the discovery of the top quark (1995), the most precise measurements of top and W masses, many important B-physics results such as the discovery of the Ω^-_b baryon and the observation of the B^0_s oscillations.

Many members of the CDF group at the UNIGE have joined the ATLAS experiment at LHC. ATLAS is a "virtual United Nations" of 37 countries and about 2900 physicists from more than 170 institutions. The collaboration includes more than 700 students. ATLAS is one of the largest collaborative efforts ever attempted in the physical sciences. The ATLAS detector consists of four major components: the inner tracker, particularly relevant for the proposed project - measures the momentum and the trajectory of each charged particle; the calorimeter - measures the energies of neutral and charged particles and helps in the identification of electrons, photons and hadrons; the muon spectrometer - identifies and measures the momentum of muons. The fourth component is the magnet system that produces the magnetic field in which the inner tracker and the muon detectors are immersed allowing the measurement of the particles momenta. The signals produced by the proton-proton interactions in the ATLAS detectors will create a huge data flow. In order to digest this enormous amount of data a very powerful triggering, data acquisition and computing system are required: a trigger system capable of selecting 100 interesting events per second out of the about 1000 million produced every second; a data acquisition system - channeling the data from the detectors to storage and a computing system capable of analyzing about 1000 million events recorded per year. The proposed project concerns the upgrade of the trigger system needed to cope with highly increased rates expected in the next LHC phase.

The UNIGE participated in ATLAS since the beginning, well before FTK had been conceived and proposed. From the early stages of construction of the ATLAS detector the UNIGE group has been involved in the design, assembly and commissioning of the Semiconductor Tracker (SCT), one of the system of the Inner Tracking detector, and in the readout and commissioning of the Liquid Argon Calorimeter. In addition to detector related research the group has played a central role in the development of the High Level Trigger (HLT) system. The experience gained in this past activity it gives a very important support to the work proposed in this project. The group plays a leading role in the implementation of HLT selection algorithms and has set up a large computing cluster for physics analysis and trigger commissioning activities.

Drawing from tracking, calorimeter, and trigger expertise the group is evolved in many areas of physics research from initial Standard Model measurements to inclusive SUSY searches, exotic processes and also heavy ion physics. These physics research topics have naturally focused the group in the direction of perfecting the reconstruction of electrons and photons within the ATLAS detector. While physics analysis preparations proceed in contributing to the analysis of the data of the first LHC physics run the group is also carrying out further detector research needed for higher luminosity running.

The proposed project involves electronics design, tests and commissioning together with analysis. It is therefore clear that it will exploit the expertise and facilities available in the host group. In fact both the human expertise in the Inner Detector, the HLT activities and the analysis are closely related to the content of the proposed project. Moreover, the experience gained in building large computer facilities will help in setting up the test benches needed for the project.

The final installation, test and commissioning of the FTK will be at CERN; the vicinity of the UNIGE to CERN is perfectly suited to closely follow all phases of the FTK implementation in the ATLAS detector. However, the test of the board prototypes will be done at different sites with dedicated test benches. The UNIGE will host one of these test benches exploiting the electronic infrastructures in Geneva, in terms of space, instrumentation, contacts with industries and capability to support the researcher's work with internal services. In particular, the electronics services are extremely good at CERN since the electronic group of CERN have extensive experience in electronics design from printed circuit boards to firmware for programmable devices (PLDs, FPGAs, DSPs) and to design of full custom ASICs. They can provide support of the researcher's work ranging from technical support for modifications on printed circuit boards to providing tools for simulation and compilation of firmware for programmable devices.

Practical arrangements for the implementation and management of the research project

The applicant and the host institution must be able to provide information on how the implementation and management of the fellowship will be achieved. The experts will be examining the practical arrangements that can have an impact on the feasibility and credibility of the project. – The UNIGE will provide the researcher an office with computing facilities and access to the Tier2-Tier3 computing grid facilities necessary to undertake all software studies. The researcher will be trained in using the CAD program for electronic board and chip design. Laboratory space will be also provided to install a vertical slice and to perform various tests. The vertical slice allows tests of the data flow and its integration in the ATLAS data acquisition system. The vertical slice tests are foreseen to take place before the end of the 2012 data taking.

The researcher will use laboratory facilities both at UNIGE and at CERN for electronic tests, equipped with one rack with a VME crate, an oscilloscope, a digital analyzer, and computers and terminals for access, control, monitoring of the available test stands. Standard 9U VME crates will be used for board housing and the VME protocol for CPU-crate communication. A computer will be available with CAD software to download new firmware directly through Boundary Scan.

The standards of the FTK project are uniformly distributed among the member institutions of the project: CPU interfaces, crate organization, basic packages to develop software, basic boards for providing data input and collection output (the Filar and Tilar boards which provide the standard connections to the prototypes are already under test). In this way, everything done in one institution can be easily repeated and checked in others. Weekly video meetings will take place in which all the FTK institutions connect to discuss and plan the near term work.

Feasibility and credibility of the project, including work plan

Provide a detailed work plan that includes the objectives and milestones that can help assess the progress of the project. – The UNIGE is interested in the long R&D study for the FTK project, with particular emphasis on the architecture definition and its performance evaluated by simulation. ATLAS has approved the FTK project in 2011. The design, construction, implementation, testing and operation of the FTK are scheduled to take place during the next four years. The project is subdivided into the following phases (a) a hardware design phase, during which the final optimization will be done, especially to reduce execution time as much as possible while maintaining high processor performances (b) the insertion of a small proto-FTK in the experiment in order to collect data in parasitic mode and understand the FTK timing performance with real data, to start the development of the control and monitoring software inside TDAQ, to implement the new track-based lepton isolation and observe its impact on boson samples (c) analysis of the ATLAS data to verify the FTK physics improvement, and (d) testing new prototypes and their commissioning. A test stand will be installed at UNIGE or at CERN allowing the researcher work on the construction, installation, and testing of the vertical slice.

A roadmap with the most specific tasks of the project is given here :

1. Use FPGAs and test procedures to complete and make work the vertical slice test stand. This implies the implementation in the EDRO board the Data Organizer function, to add the GigaFitter function exploiting the CDF board and learn the use of the 2-D clustering algorithm for pixels. Complete the design and participate in the tests. Evaluate the relative costs of the FPGA solution and a small standard cell device;
2. Implement the connection of the vertical slice to CPUs through the use of the new boards Tilars, recently developed for TDAQ interconnection improvements;
3. Vertical slice data taking starts and operates stability;
4. Perform efficiency and fake rate measurements for the high pT lepton track-based isolation, evaluating the gain for boson and di-boson samples.
5. Participate in the analysis of W/Z + 2 jets events to study di-boson events;
6. Participate in the Higgs searches with hadronic τ-leptons in the final state;
7. Participate in the optimization efforts of the hadronic tau triggers;
8. Exercise with parasitic input data and apply significant efforts to develop the software for maintenance/control/monitoring, adopting the SVT experience gained at Fermilab and learning all new features of the online ATLAS experiment. This work will clarify the path for a full FTK system integration;
9. Continue with the simulation studies for the final definition and optimization of the architecture, which will drive important decisions on the boards to be constructed. They can be organized in many different ways, each one offering particular advantages. These studies will have also to check the performance of the system at the SLHC Phase II luminosity, $10^{35}cm^{-2}s^{-1}$;
10. Develop and test new prototypes at the vertical slice for the final FTK. The fellow will be responsible of the test stand and integration of new boards, and participate to the testing of new prototypes and their commissioning;
11. The vertical slice will be installed and operate with the researcher's supervision at UNIGE.

Points (1), (2), (3) and (4) will be part of the first fellowship year, since they are strongly coupled to the idea of exploiting as much as possible the 2012 data taking. Tasks (5)-(7) related to physics analyses will be evolving during the whole period of the fellowship. Points (8) and (9) will be developed during the second year since new ideas and unforeseen detector or collider behaviours can influence the final design and its optimization. Point (10) will be realized as soon as new prototypes become available (end of year 2013). Point (11) is very important because it will allow UNIGE students to participate to the activities for the development of the vertical slice.

Activities parallel to the main objectives are given below:

1. Production of prototypes handling all the necessary contacts with the involved industries. Depending on the LHC schedule, the commissioning and testing of the whole system will mainly take place during the second year;
2. Test a first version of the new prototypes in the vertical slice;
3. Try to use the developed processors to analyse 2D images in other applications outside HEP: (a) Sets of pictures can be selected and the measure the rate of each possible 3x3 pixel pattern appears in the picture. Only the ones that appear in the frequency range defined by the conjecture of reference [Punzi & Del Viva (2006) Visual features and information theory JOV 6(6) 567] will be stored in the associative memory. Finally, the processor to filter the image will be used. The 2D clustering algorithm can be applied on the filtered image to find spots and analyse their shape. Execution times will be measured. Effects on reconstruction quality due to bit losses in the input or different shape patterns or different pattern frequency range selections can be studied quickly in the future to provide real time input to higher level analysis systems. This would be a first step in an activity that could become important when FTK is almost ready.

The work plan includes participation in conferences and related publication of results. Participation in major physics and technological conferences is planned (IEEE, ISOTDAQ, etc).

The work plan also includes frequent presentations inside the TDAQ/Physics group and seminars to the ATLAS collaboration, UNIGE, Pisa and elsewhere. It will include also supervision/tutoring of students participating in ATLAS.

Where appropriate, describe the approach to be taken regarding the intellectual property that may arise from the research project - Publications in international journals is the standard way for collection and dissemination of research results, scientific knowledge and information. IEEE, TNS and NIM are used for technological publications and Physical Review Letters for physics results.

Task\Month	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Hardware design of FTK												
FTK simulation studies												
Vertical slice test stand at CERN												
Vertical slice data taking at CERN												
Insertion of proto-FTK the ATLAS												
Data taking and analysis												
Commissioning of new prototypes												
Vertical slice test stand at UNIGE												
Simulation studies for SLHC												
Tau trigger analysis												
Boson & diboson analysis												
Higgs di-tau analysis												

Table 1: FTK workplan: design, development, implementation and data taking/analysis.

Practical and administrative arrangements and support for the hosting of the *fellow*

Describe the practical arrangements in place to host a researcher coming from another country. What support will be given to him/her to settle into their new host country (in terms of language teaching, help with local administration, obtaining of permits, accommodation, schools, childcare etc.) - The UNIGE which in 2009 celebrated its 450th anniversary, has a student body of 14,500 students. More than one-third of all students come from abroad, attracted by the University's location in the heart of an international and multi-language city, which is home to many international organizations. Renowned for its high level of excellence, our University offers a wide spectrum of academic courses in divers fields of study such as the exact and natural sciences, medicine, social sciences and the arts. As most classes are taught in French a good command of the language is required. The academic year is divided into two semesters, beginning mid-September and ending mid-June.

The UNIGE means benefiting from an infrastructure whose excellence is regularly confirmed. Rated among the best European universities in international rankings, the UNIGE, among whose professors is a winner of the Field Medal, the equivalent of a Nobel Prize in mathematics, offers a range of programs unique in French-speaking Switzerland. Comprising eight faculties - Science, Medicine, Arts, Social Science and Economics, Law, Theology, Psychology and Educational Sciences, Translation and Interpretation – the UNIGE also boasts several inter-faculty centers and offers a program in Environmental Studies.

The UNIGE hosts six national research centers. It shares with the Institute of International and Development Studies (IHEID) an Academy of Human Rights and participates actively in the establishment of a Swiss network of international studies in Geneva.

Students in Geneva enjoy a unique setting. Rated third highest in international surveys of quality of life, the city of Calvin is only a few hours by train from the major European capitals. Geneva is also host to the European headquarters of the United Nations (UN) and the world headquarters of the World Health Organization (WHO), the International Committee of the Red Cross (ICRC), the International Telecommunication Union (ITU), and the European Organization for Nuclear Research (CERN), as well as offices of such multinationals as Procter&Gamble, Merck-Serono and Firmenich. Its population is accordingly multicultural, and its public life is distinguished by open-mindedness and tolerance. Furthermore, thanks to its prime geographic location – on the shores of Lake Geneva and less than an hour from Mont Blanc, the highest peak in the Alps – the city enjoys an abundance of parkland and offers a wide range of leisure activities. Geneva is also home to a wealth of cultural institutions, such as the Grand Théâtre, an internationally acclaimed opera house, and many musical, cinematic and artistic venues.

The UNIGE's various facilities are situated in the heart of the city. The Science Faculty has their headquarters in three main buildings on the banks of the Arve. In addition to the many services intended to ease student entry into the academic world, the UNIGE also offers a range of sport and cultural activities. Affordably priced courses are available in everything from visual arts to paragliding, including dance, photography, tennis and football. The UNIGE accommodates some 14,500 students from more than 130 countries and offers many facilities to easy the foreign student integration such summer French courses and social aid. The Geneva academic community boasts around 50 specialist libraries. The University' veritable nerve-centers, they house two million volumes between them, most of which are freely accessible. All of the libraries belonging to the University and its institutes are equipped with the latest IT and connected to the Western Switzerland Library Network (RERO), which has a combined catalog of more than 4.5 million bibliographical references or roughly nine million documents. The catalogs and IT resources can be consulted from the reading rooms, from any workstation on the Geneva campus, and even at home.

The UNIGE has considerable IT resources available for its researchers and students to use. Most workstations have internet access. Students can use some 20 public computer rooms with on-site support. Computers are also available in the University's libraries, along with multimedia workstations that can display high-resolution digital content on demand from the media libraries stored on video servers. Students with laptops of their own can access the Internet in most University buildings via the Wi-Fi network. Last but not least, the UNIGE provides public information terminals with free Internet access.

B5 Impact

Impact of competencies acquired during the fellowship on the future career prospects of the researcher, in particular through exposure to transferable skills training with special attention to exposure to the industry sector, where appropriate

Describe the impact that competencies and skills acquired during the fellowship will have on the prospects of reaching and/or reinforcing a position of professional maturity and/or research independence - This fellowship will allow the researcher to gain experience in both electronics development and HEP searches, integrating thus his professional curriculum. As an experimental physicist, in fact, it is very important to be able to combine the knowledge of performing physics analyses with the ability of finding the most appropriate technical instruments to execute such physics measurements. The solid electronics background that the researcher will obtain during the project, the experience acquired in developing HLT algorithms and tools for online and offline data processing, will be very useful in establishing a career in the experimental HEP research field.

The researcher will work in a new environment collaborating directly with experts in electronics and TDAQ. He will contribute to the development of an innovative and modern trigger system dedicated for the ATLAS physics program. Moreover, the knowledge in electronics and advanced analysis techniques will fit in other spin-off projects, such as medical applications and brain simulation studies. It is expected that joining the present experience gained in physics analyses with hardware-oriented capacities will greatly assist to reach research integration and professional maturity.

Finally, at Geneva the researcher has a unique opportunity to live in a multi-language and multicultural environment which allowing him to obtain new ideas and experiences.

Contribution to career development or re-establishment where relevant

How will the fellowship contribute in the medium- and long-term to the development of the Fellow's career? – The fellowship will develop characteristics that will aid the fellow in finding a professional position in either his home-country or other European countries with research background in experimental HEP and long-term participation in HEP research programs, such as CERN. Also, the acquired skills described previously apply to many different fields outside HEP providing thus flexibility to the fellow to establish a professional career in areas not directly related to HEP, such as astrophysics, nuclear physics, biophysics, neuroscience, accelerator physics and medical physics. The high level of technology involved in the realization of the program provides the fellow the ability to develop a professional career in industry. For example, the fellow will be able to work in areas which demand high analytical and computing skills, such as financial and consulting industries.

In the case of a fellow returning to research, how will his/her re-establishment be helped by the fellowship? - As already mentioned, the fellowship is expected to provide the fellow managerial and independent thinking skills that not only will improve the probability of obtaining a staff research position in a European institution, but also will broadly advance his career. This is also due to the specific nature of the project, which is totally innovative; it combines knowledge and capacities specialized in experimental HEP, at software and hardware level as well. The specific project has also wide capability of application outside HEP, and this characteristic increases the fellow's possibilities to establish in research areas relative to HEP.

Benefit of the mobility to the European Research Area

Describe how the proposed mobility is genuine and therefore beneficial to the European Research Area. Genuine mobility is considered to allow the researcher to work in a significantly different geographical and working environment, different from the one in which he has already worked before – After the completion of my Masters degree at my home-country, I had the opportunity to pursue a four-years PhD program at the University of Pisa in Italy. Pisa, a historic Italian town located on the west side of the beautiful Tuscany, is wide-known for its the genuine and traditional Italian life style, its extraordinary monuments such as the Leaning Tower, and of course for the high-level of education provided by three different universities: Scuola Normale Superiore, University of Pisa and Scuola di Sant' Anna. While staying at Pisa I grasped the opportunity to learn Italian at CLI, one of the most famous language learning centers in Italy, and be exposed to a different culture and lifestyle. Since last year, I am periodically living at Pisa, close to my home-institute, and at Prevessin in France close to CERN.

This fellowship is now giving me a great opportunity to live at Geneva in Switzerland, privileged with a unique feature of being in the center of Europe. Geneva, reputed as a multi-lingual and multi-cultural town, has the privilege to host many International Organizations, Companies and Banks. The modern lifestyle and the excellent conditions of working at Geneva, will allow me to develop a more efficient, independent and dynamic way of thinking, being thus able to transfer to other countries in the future. Among my priorities will be also the learning of the French language.

Working at UNIGE is also a privilege for me due to the vicinity at the CERN facilities. Researchers working in such international and modern environment are strongly motivated to complete their professional competences, participating seriously to both innovative hardware projects and physics data analyses. Having a larger spectrum of competencies it is easier to communicate between the different sectors of experimental HEP and similar research fields. Mobility is one of the best mechanisms to create evolution towards the best research organization because it allows the comparison of very different cultural realities.

Development of lasting cooperation and collaboration with other countries

What is the likelihood of creating collaboration between the host country and other countries after the end of the fellowship? - The FTK collaboration is an international collaboration, including USA, Japanese, Italian and recently German institutions. The USA component is very strong and includes institutions like the University of Chicago, the University of Illinois, and Argonne and Fermilab Laboratories. This is a stable beneficial collaboration that started at the beginning of the CDF experiment (1985-86) and produced a lot of beautiful achievements. The UNIGE will therefore benefit of this international environment and of the large experience gained in CDF by many collaborators. The fellowship program will help in tightening the connection between UNIGE and all other parties and it will pose the base for a lasting collaboration. Moreover, supercomputers can have wide applications even outside HEP. For this reason, the proposed research project has a strong potentiality to favour the enlargement of the collaboration behind the development of the trigger technology in HEP.

Contribution to European excellence and European competitiveness regarding the expected research results

Describe the extent to which the expected results of the project will increase European excellence and ERA competitiveness and produce long-term synergies and/or structuring effects – One of the main goals of this project is the use of our supercomputers, upgraded with the latest available technologies and aligned to the baseline ATLAS configuration having the flexibility to adapt future complex applications. The fellowship's asymptotic and very challenging goal is to standardize a single processor that will be able to work in both L1 and L2 applications in present and future HEP experiments. A lot of interest is growing around this project: the FTK collaboration does exist for the L2 trigger application in ATLAS. It is a very high level international collaboration, including USA institutions like the University of Chicago, University of Illinois, and Argonne and Fermilab Laboratories. Recently a Japanese institution, Waseda, joined the FTK collaboration.

Nowadays, the popularity of the FTK project is quickly increasing in Europe and its influence on L1 tracking ideas is strong, both for physics and technological developments. The interest for similar technology applied at L1 has been shown by the Italian collaboration SLIM5 ["The associative memory for the self-triggered SLIM5 silicon telescope", the Slim5 collaboration, Nuclear Science Symposium Conference Record, 2008. NSS '08. IEEE19-25 Oct. 2008 Page(s):2765 – 2769] and is quickly evolving at LHC. The Heidelberg Institution, which recently joined the efforts, designed the new AMchip. It is believed that the quick-growing FTK influence is going to have a significant impact both on the hardware development and the physics program at LHC.

Impact of the proposed outreach activities

Describe the outreach activities of the proposal to be implemented by the researches during the project duration – Significant outreach activity took place in the past to convince the LHC community that a hardware tracker is a fundamental tool for triggering at hadron colliders, especially for high-demanding collision environments. This was devoted mainly to the HEP community but allowed to develop web sites that could help to enlarge the knowledge of Super Computers outside HEP. The FTK project is now approved by the ATLAS Collaboration therefore the outreach work can now be reinforced by results on LHC data. In fact, up to now the FTK project was based on performances measured on simulation results or extrapolated from the successful performance of the SVT tracker. In the next years, the FTK demonstrator will offer the opportunity to give the first examples of the FTK potentialities on data acquired in the real experimental environment. In parallel, the first real prototypes promising the capability to exploit best of the available technology will be produced and tested, giving a concrete proof of the computing capability that the project can provide.

We believe that the technique can be used not only in HEP but is matured enough to be exported outwards, such as in medical science. Another aim of the FTK project is to convince the medical community about the impact of Super Computing can have in many aspects of medicine. At the moment, the possibility that image reconstruction can perform also at very high rates and in real time is not well-distributed in medical science. We think that the success of applying this technique in HEP will also be a boost to grasp the attention of other scientific communities as well.

We will continue our outreach by developing dedicated web sites, participation to shows like the European initiative "Night of the Research" with posters, samples of hardware material and discussing directly with visitors.

B6 Ethical Issues

The proposed project does not cope with any ethical issue as confirmed by the answers in the following table .

MAIN ETHICAL ISSUES THAT MUST BE ADDRESSED

None.

AREAS EXCLUDED FROM FUNDING

None.

ETHICAL ISSUES TABLE

(Note: Research involving activities marked with an asterisk * in the left column in the table below will be referred automatically to Ethical Review)

	Research on Human Embryo/ Foetus	YES	Page
*	Does the proposed research involve human Embryos?		
*	Does the proposed research involve human Foetal Tissues/ Cells?		
*	Does the proposed research involve human Embryonic Stem Cells (hESCs)?		
*	Does the proposed research on human Embryonic Stem Cells involve cells in culture?		
*	Does the proposed research on Human Embryonic Stem Cells involve the derivation of cells from Embryos?		

	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	√	

	Research on Humans	YES	Page
*	Does the proposed research involve children?		
*	Does the proposed research involve patients?		
*	Does the proposed research involve persons not able to give consent?		
*	Does the proposed research involve adult healthy volunteers?		
	Does the proposed research involve Human genetic material?		
	Does the proposed research involve Human biological samples?		
	Does the proposed research involve Human data collection?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	√	

	Privacy	YES	Page
	Does the proposed research involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?		
	Does the proposed research involve tracking the location or observation of people?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	√	

	Research on Animals	YES	Page
	Does the proposed research involve research on animals?		
	Are those animals transgenic small laboratory animals?		
	Are those animals transgenic farm animals?		
*	Are those animals non-human primates?		
	Are those animals cloned farm animals?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	√	

	Research Involving Developing Countries	YES	Page
	Does the proposed research involve the use of local resources (genetic, animal, plant, etc)?		
	Is the proposed research of benefit to local communities (e.g. capacity building, access to healthcare, education, etc)?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	√	

	Dual Use	YES	Page
	Research having direct military use		
	Research having the potential for terrorist abuse		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	√	

ENDPAGE

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PART B

"POT*ex*HEP"