Statement of Research Interests

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In this short article I am going to describe my interests as an experimental particle physicist and motivation to apply to the INFN fellowship.

1 General interests in particle physics and experiments

The Standard Model of particle physics (SM) is the best successful phenomenology in describing the phenomena of subatomic scale with excellent agreement with experimental tests. The backbone of the SM is the quantum field theory with the local gauge principle. An essential feature of the gauge symmetry is that it forbids fermions and gauge bosons to have a mass. The known solution to allow masses to particles is to assume a gauged scalar field which is spontaneously broken to give condensation of the scalar field at a certain expectation value in the vacuum (VEV), and the interaction of the quantum field of each particle with the scalar filed with a certain coupling constant plays the same role as the mass term of the Lagrangian. The model is theoretically consistent and renormalizable, though it does not explain why the VEV is at 246 GeV, and why each particle has its own coupling constant, and in particular why the mass spectrum of particles is such like. In this point of view the SM provides a mechanism to originate mass of particles, but it does not provide the answer to a fundamental question - how we can understand the spectrum of masses (or what is the factor that characterize the mass of each particle)? It is remarkable that the heaviest quark, top quark, has mass of the same order as VEV, called electroweak scale, and the mass of weak bosons, Higgs, and top quark are within a few factors amongst the wide mass scale of known particles.

Supersymmetry (SUSY) remarks the relation between the huge gap between the electroweak scale and the Planck scale, and the fact that bridging of the two scales using renormalization group equation within the SM results in a fine tuning of the Higgs mass, known as the hierarchy problem. SUSY offers a way of solving this with assuming supersymmetric partner particles which cancel the quantum loop correction on Higgs mass of the SM particles. The SUSY phenomenology is, in some sense, a subtle theory. In one hand it holds a very strongly constraining symmetry of SUSY, on the other hand it requires itself to be spontaneously broken *weakly*. However, the discovered Higgs mass of 125.09 GeV [1] as well as having no evidences of SUSY in the LHC Run1 are strong constraints on SUSY in order to keep it as the solution to the hierarchy problem.

It can be found that the reason of having the hierarchy problem is that there is a large scale gap between the Planck scale and the electroweak scale, *and* the coupling of the fermions to the Higgs is too-strong. If all fermions have the mass scale of neutrinos, the quantum loop correction to Higgs mass is much smaller and the fine tuning problem should be much mitigated. In other words, the hierarchy problem has the second question that why fermions, especially top quark, are so massive to create the hierarchy problem. SUSY phenomenology often thinks the mass balance between the chiral (SM) fermions and scalar particles like an expectation of that the third generation sfermions are lighter than the first and second generation ones, but it doesn't explain the massiveness of the top quark. The composite Higgs model is a different theoretical approach to the hierarchy problem with providing a “similar” loop cancellation by assuming partner particles to chiral fermions. The interesting part of this model is that it considers the massiveness of the top quark as the degree mixing with the composite sector.

There are more essential questions to be explored in the LHC, though my particular interests are in the mass scale of particles. We have to see the result of the LHC experiments to know if we can obtain any hints to the above questions with testing theoretical possibilities. Only the nature knows it, but I would like to stress that the LHC is the unique experiment which can study the mystery of the electroweak scale directly in the lab at the beginning of the 21st century. The beauty exists here: ultimately, experiments can test things using a tool which are realizable in the world governed by fundamental physics. And the subject to study in the collider experiments is fundamental physics. What I am fascinated in the collider experiments is that, the design of the collider experiments is targeted to achieve better testing and understanding of fundamental physics. In other words, it is fundamental physics that spontaneously determines the optimal way to test itself via human being's arts. I have to say that this beautiful relation between fundamental physics and experiments has been certainly driving myself to keep an enthusiasm to contribute to the LHC project as an experimental physicst.

2 Research projects at INFN Genova

My work in the ATLAS experiment [2] started in July 2013 in the current position, CERN Research Fellow, after acquiring PhD in March 2013. At that moment the LHC was during Long Shutdown 1 (LS1), and I coordinated myself around the upgrade activities of the detector, in particular for the Insertable b-Layer (IBL) [3]. The IBL is the additional innermost layer of the Pixel Detector comprising 14 staves mounting 32 front-end chips of FE-I4 [4]. In the past 2.5 years, I have been deeply involved in construction, installation and commissioning of the IBL, and relevant tracking performance studies. The detail of these works are described in Appendix A.

Having contributed significantly for establishing the Pixel and IBL detectors and their performances in LS-1 and the first year of the LHC Run2 in 2015, I am strongly interested in analyzing physics data decently to explore the landscape of the energy frontier at $\sqrt{s} = 13$ TeV using the upgraded ATLAS detector. INFN-Genova, to which I am applying for the fellowship, is an institute which has been persistently and strongly committing to the ATLAS Pixel detector and relevant project since 90's in various aspects of hardware, data acquisition, and detector performances and upgrades. Since my current activities in ATLAS are deeply involved in the Pixel and IBL detectors, I and staffs and students in Genova have known personality each other already in the collaboration. Therefore a quite smooth and efficient transition will be expected if I were granted to have this fellowship to work at INFN-Genova. The most likely starting date of the fellowship will be June 2016 following the end of the current contract at CERN at the end of May 2016.

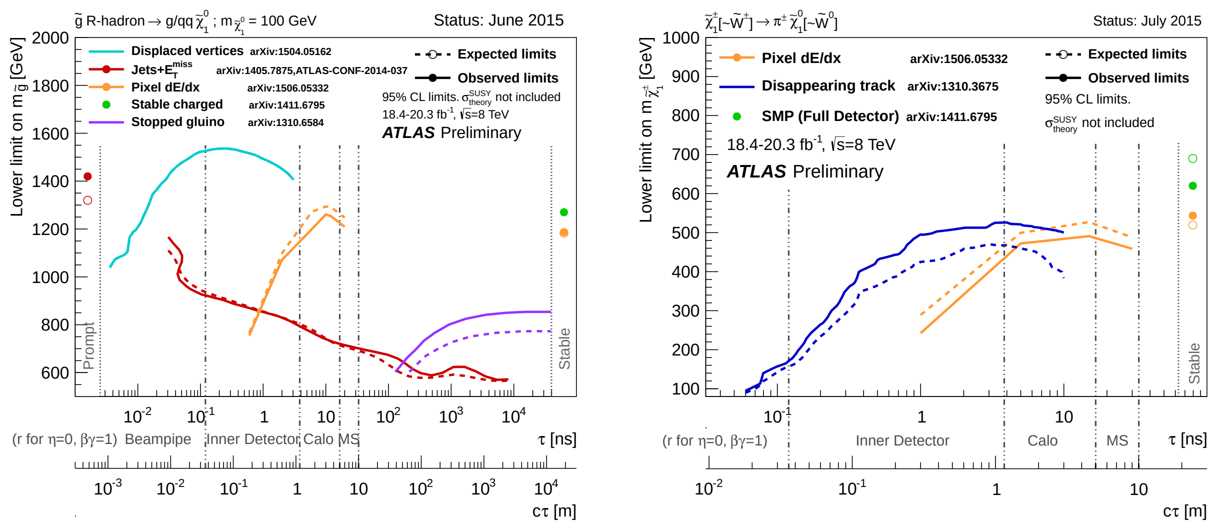
For physics analysis, the group has been committing to a particularly interesting search of long-lived massive charged particles (LLPs) as a signature of new physics. Usually predicted charged massive new particles, like gluionos, $\tilde{g}$, or charginos, $\tilde{\chi}^{\pm}_{1,2}$ in supersymmetric standard model, are considered to decay promptly. However, there could be a particular case that they may be stable to pass through the detector outside muon chambers, or they may be meta-stable which decay inside the detector volume. There are theoretical scenarios which predict this signature known as anomaly mediated supersymmetry breacking (AMSB) (charginos as the LLP) or split-SUSY (R-hadrons containing gluinos as the LLP).

Searches of such signature have been made through 7 TeV and 8 TeV pp collisions in the LHC, but no evidences of existence of them have been found so far. There are multiple complementary methods of searching LLPs:

1. direct search of massive LLPs,

2. direct search of disappearing tracks, and
3. search of decays of LLPs using daughter tracks and reconstruction of displaced vertices.

Method-1 is inclusively sensitive to both of the scenarios of AMSB (charginos) and split-SUSY (gluinos). Method-2 is aiming at AMSB scenario particularly with assuming the decay of $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 + \pi^{\pm}$ where the decay pions are considered to be very soft that are not reconstructed. Method-3 assumes large multiplicity of daughter particles. Figure 1 summarizes the search limit of LLPs in the ATLAS experiment using these methods.



(a) Limits on gluino R-hadrons

(b) Limits on AMSB charginos

Figure 1: (a) Constraints on the gluino mass-vs-lifetime plane for a split-supersymmetry model with the gluino R-hadron decaying into a gluon or light quarks and a neutralino with mass of 100 GeV. The solid lines indicate the observed limits, while the dashed lines indicate the expected limits. The area below the curves is excluded. For the displaced vertices result the expected and observed limits are identical. For the stopped gluino result the limit extends to larger lifetimes (not quoted here, see reference). The analyses have sensitivity at lifetimes other than those shown, but only the limits at tested lifetimes are shown. The dots represent results for which the particle is assumed to be prompt or stable. In this context, stable means escaping the detector. (b) Constraints on the chargino mass-vs-lifetime plane for an AMSB model with $\tan(\beta) = 5$ and $\mu > 0$. The wino-like chargino is pair-produced and decays to the wino-like neutralino and a very soft charged pion. The solid lines indicate the observed limits, while the dashed lines indicate the expected limits. The area below the curves is excluded. The analyses have sensitivity at lifetimes other than those shown, but only the limits at tested lifetimes are shown. The dots represent results for which the particle is assumed to be stable. In this context, stable means escaping the detector.

INFN-Genova has strong contribution to Method-1, with tagging massive long-lived charged particles with taking advantage of the fact that slow (low-β) massive charged particles have larger energy deposit when they traverse materials. In particular an inclusive search using only Inner Detector tracks doesn't depend on characteristics of such particles inside calorimeter materials of R-hadrons e.g. charge exchanging Regge reaction and hadronization. In order to perform such a measurement, detectors which are able to measure the energy deposit on the material is needed. In the ATLAS Inner Detector, the Pixel detector and the Transition Radiation Tracker (TRT) are capable of performing the energy loss, denoted as $\mathrm{d}E/\mathrm{d}x$. The method of estimating the mass of the possible new particles as well as a data-driven background estimation was established in Run1 7-8 TeV analyses. The method has also potential extension of search ability by addition of the IBL.

One thing which has not been optimized for this search is triggering. A signal of large missing transverse energy (MET) has been used in the Run-1 search, but it is not always the case that the signal events have large MET. This is because such new particles are considered to be created as pairs, if they are SUSY particles, and when the center of mass system of the pair is considered to be sizable compared to $\sqrt{s} = 13$ TeV then the momenta of the two particles tend to balance especially when they are stable. In the present way of triggering, the trigger efficiency is estimated to be less than 10 % for R-hadrons with mass of 500-1500 GeV. A better way of triggering will be to use a track-based trigger to directly select large $\mathrm{d}E/\mathrm{d}x$ tracks in the high-level trigger (HLT). This idea is possible to be realized when a new hardware-based middle-level trigger system, called Fast TracKer (FTK) is commissioned in 2016. If a high momentum (transverse momentum, $p_{\mathrm{T}} \gtrsim 50$ GeV), well-isolated tracks are selected in the FTK, the HLT can process to discriminate large $\mathrm{d}E/\mathrm{d}x$ tracks from others. A preliminary study shows that about a factor of three improvement of the trigger efficiency can be expected with this new schema of triggering. In order to realize such an idea of improvement, a significant amount of studies is necessary using simulation to accurately quantify the configuration to achieve such triggering. The study is aiming at exploiting the full potential of the ATLAS detector for the new particle search. I plan to divide approximately 75 % of the full-time effort (FTE) for the development of the new trigger and downstream analysis for the result.

Operation of the detector system for data taking is the core of the experiment, and I would like to allocate about 25 % of the FTE for the commitment of the operation of the Pixel and IBL system, including the Run Manager role as well as various supports of the team in system trend monitoring, improvement of the calibration management, maintenance of the timing adjustment. Also the operation team has been shrinking in the past months, it is highly desired to improve the existing daily operation framework to be more simplified and organized, so that the operation is sustainable with securing safety and high efficiency of data taking, with lowering the threshold to gain expertise to new comers to the operation team.

Appendices

A Past works in the ATLAS Experiment

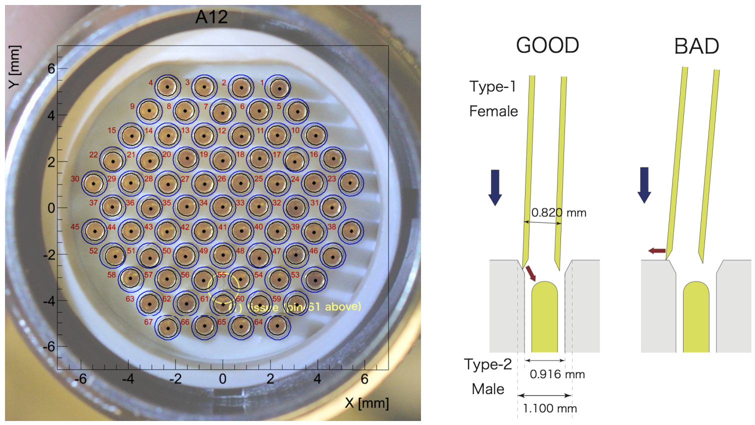
Construction of IBL I worked for documentation of the tests of produced staves publishing to internal web server to provide an organized way of browsing various quality and quantities of the test using MySQL and PHP services. Using the defect pixel map data summarized in the database, I proposed an algorithm to select the 14 staves out of 20 produced to be integrated as the real IBL as well as mapping arrangement of the staves using 2-point correlation function of defect pixels in η-ϕ space, and the algorithm was employed [6].

I also worked for quality assurance of a service cable of the IBL and its selection. The connector of this cable is mounting 67 pins in a small radius, and there was a certain risk of breaking pins during connection which would result in disabling a part of staves. In order to assure alignment control of these pins and the cleanness of the connector, I have developed an image analysis program to feed the photograph of the connector for visual inspection of dusts as well as measurement of the misalignment size within a precision of 5 μm as shown in Figure 2, and also assessed the depth of the connection. The connection of all staves was successfully made without any failure in the end.

Inner Detector material budget As a part of authorship qualification, I worked on examination of the beam pipe material budget which is installed with the IBL. The beam pipe can be the best known material in the Inner Detector which is to be the standard candle to probe the material budget of the detector. Investigation ranges from the survey of the beryllium pipe thickness measurement to measurement of X-ray absorption of each component composing the beam pipe, like heaters, aerogel thermal insulators, etc with development of a dedicated survey jig. A precision of 1% was quoted in the end of the work of four months. This is a factor of three improvement compared to the knowledge of the previous beam pipe's material budget. The study and result was presented in relevant internal meetings including the Weekly plenary collaboration meeting.

In 2015, I have been committing to Inner Detector material studies using collision data in the tracking performance group. Since the composition of the detector components changed since Run-1, new studies have to be made *in-situ*. The study is performed using three complementary techniques of tracking of photon conversion, hadronic interaction, and track extrapolation efficiency. I am mainly analyzing hadronic interaction vertex reconstruction, which gives a minute position resolution of $O(200\ \mu\mathrm{m})$ and provides very detailed radiography of the Inner Detector components as shown in Figure 3, even tiny surface mount devices on the Pixel detector chips. Works include understanding of the minimum bias proton-proton collisions, re-writing of the vertex reconstruction and analysis code for the new ATLAS analysis framework, and detailed examination of the real material components compared to the simulation geometry model. This is an ongoing work to be published as a paper, but studies have already fed back to the ATLAS geometry model promptly in June 2015 (a few weeks after the Run2 collision started), with finding discrepancy of the real detector and the geometry model especially for the IBL stave positions and missing components in the model. Studies show that the updated geometry model reflecting our feedback gives more reasonable understanding of the track reconstruction performances compared to data. The study is contributing to the analysis of Run2 minimum bias charged particle multiplicity which is one of the first results of the ATLAS using early Run2 data [8, 9].

Commissioning and operation of ATLAS Pixel and IBL detectors Commissioning of the detector system is a one-time event in a decade. Integration of hardware, data acquisition (DAQ) and software reconstruction have to work together. I have worked for DAQ and offline reconstruction support through validating the raw data format and offline object data by crosschecking them each other. Identification of first cosmic ray



(a) (b)

Figure 2: (a) An example of the imaging analysis of the connecter pins of the IBL service cable to evaluate the control of the alignment. (b) Illustration of good and bad conditions of pins depending on the misalignment size. In the bad case, the connection stress works to deviate the misalignment larger which would result in catastrophic breaking of the pin.

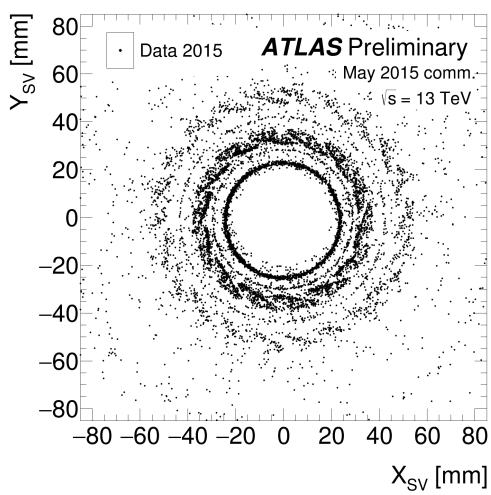


Figure 3: The vertex position distribution in the xy-plane for hadronic interaction candidates reconstructed from multiple tracks with $> 5\sigma$ transverse impact parameter significance. The distribution exhibits peaks consistent with hadronic interactions occurring within the new ATLAS beam pipe and the Insertable B-Layer (IBL) in addition to the original three Pixel layers. The hadronic interaction candidates are required to be reconstructed within $r > 20$ mm and $|z| < 300$ mm. [7]

hits on IBL was not straightforward, since there was a mistake in the geometry of the IBL stave description, and the mapping of the data to ATLAS coordinate system was wrong, and offline reconstruction couldn't find hits to be associated to tracks. This problem of the geometry was realized when I was making crosscheck of the raw data information of which staves should have hits and where the hits are mapped in after reconstruction, and comparing the hit map with the design drawing. This was the breakthrough milestone of the IBL commissioning to enable tracking with IBL as demonstrated in the event display in Figure 4.

I also worked for timing adjustment of Pixel and IBL front-end chips [10].

After Run2 has started, I have been also committing to the operation of the Pixel and IBL detectors as a Run Manager in rotation with other experts, and supporting the Pixel Run Coordinators.

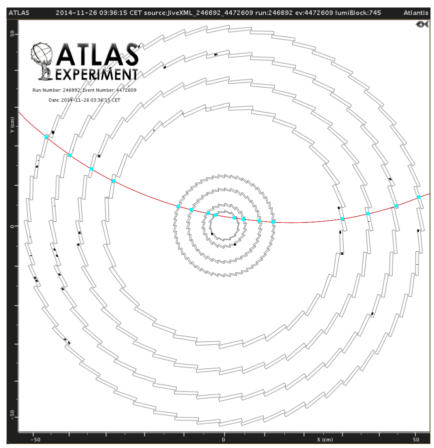
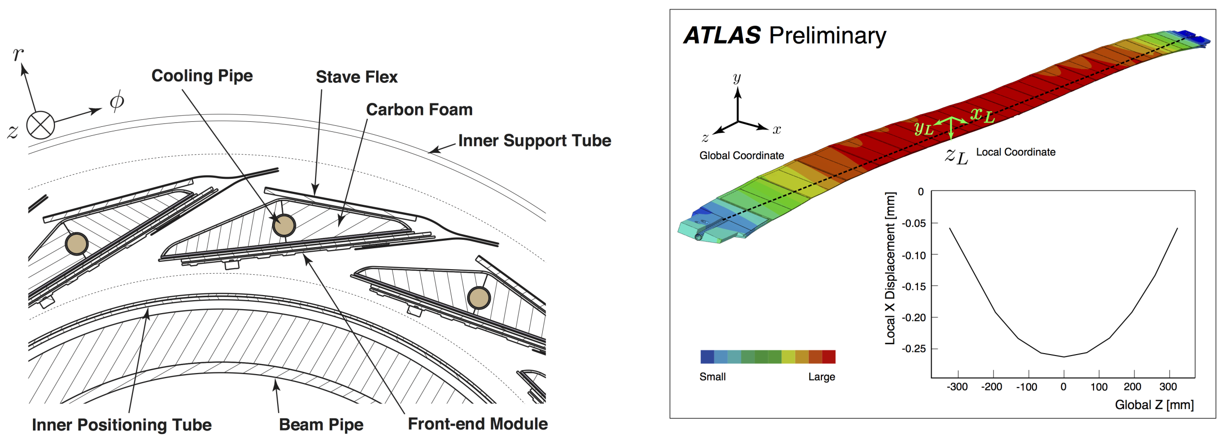


Figure 4: Atlantis event display of cosmic ray event 4472609 from run 246892. A cosmic ray is shown passing through the IBL, the newly installed pixel layer of the ATLAS detector, in the presence of a solenoidal magnetic field. The IBL is the inner-most layer in the display. The three layers surrounding the IBL are the other layers of the Pixel detector, and the four outer-most layers seen are the Semiconductor Tracker (SCT). These data were recorded during milestone run 7 (M7) which is being used to re-commision the ATLAS detector for Run2 startup.

Overcoming IBL distortion In the cosmic ray data of the commissioning campaign in December 2014, a first sign of the unexpected shape change of the IBL was observed by the alignment group; the staves bowed along with ϕ-direction, as illustrated in Figure **??**. The cause of the shape change was sourced down to be correlated with temperature in February 2015, and understanding and controlling of the bowing feature has become an urgent program in the collaboration. The ATLAS has launched a dedicated joint task force, named *IBL Distortion Task Force*, to understand the impact of distortion in various aspects of the experiment, and I have been working for this task force since March 2015 as a coordinator. A program of temperature scan was performed immediately in March 2015 using the last cosmic ray data taking campaign before the Run2 collision starting, as well as simulation and mock-up studies of the thermo-mechanical analysis by expert engineers. All of the shape measurement by the alignment of the temperature scan, thermo-mechanical simulation and mock-up studies show agreement that the distortion is driven by the mismatch of coefficient of thermal expansion between the carbon foam structure of the stave and the flex bus glued behind the stave [11]. The task force also evaluated the stability of temperature and the sensor position. New monitoring of the distortion magnitude, as well as various detector control variables (temperature, power consumption, etc.) was implemented [12]. Based on the coefficient of the distortion magnitude and temperature, the impact of misalignment by distortion change was evaluated involving track-based triggers, tracking, b-tagging, beam spot determination.

It was considered that the power consumption of the front-end chips depending on instantaneous luminosity is small and the effect to the distortion was considered subdominant compared to the cooling system's stability, and such a picture has been valid until September 2015. However the IBL has started to exhibit large fluctuation of the low voltage current consumption since September, and time-dependent distortion change has been clearly observed [13]. At the moment of writing this article, it is understood that the drift of the low voltage current is due to radiation doze pile-up which induces increase of leakage current in the transistor of the front-end chip. The alignment correction is therefore required to feedback correction very frequently in order to mitigate the shape change. Monitoring of long-term trend of the IBL status in distortion shape, current consumption and temperature has become crucially important.



(a) (b)

Figure 5: (a) Cross-section view of the IBL Layout seen from the interaction point to +z-direction. (b) Visualization of the distorted stave with magnified distortion size. The size of the distortion is magnified for visualization. The color represents the magnitude of the displacement. The right bottom graph shows the relative displacement size in local-x direction (xL) as a function of the global z-position at the face plate surface of the stave.

References

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