Neutron stars and pulsar glitches

Alessandro Montoli

Università degli Studi di Milano &
Istituto Nazionale Fisica Nucleare

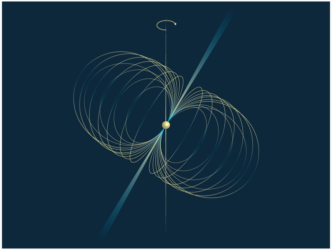
INFN School on Efficient Scientific Computing

Bertinoro, October 2018

Neutron stars and pulsars

Extreme features of neutron stars:

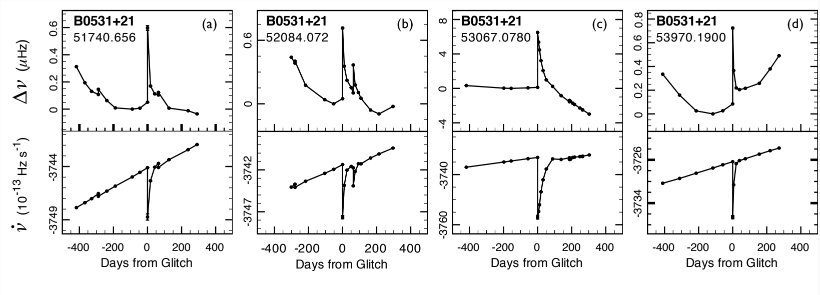
- $R \approx 10$ km
- $M \approx 1 - 2\, M_\odot$
- $\rho_c \gtrsim 10^{14}$ g / cm^3
- $P \approx 10^{-3} - 10^{1}$ s
- $B \approx 10^{8} - 10^{15}$ G



Lighthouse model:

- Magnetic field axis misaligned with respect to the rotational axis
- Conversion of rotational energy into electromagnetic radiation
- Pulse frequency = rotational frequency

Pulsar glitches



Four glitches of the Crab pulsar, Espinoza et al. (2011)

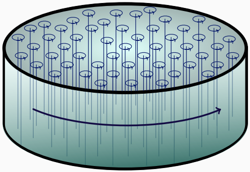
Two components: a normal charged one (visible) and a superfluid one.

Long recoveries $\Rightarrow$ Effect due to superfluid components.

Diverse phenomenology:

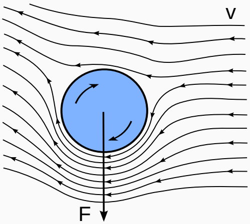
- Mostly radiopulsars, but also magnetars and millisecond.
- Periodic glitchers vs single glitchers.
- Similar size vs. different size.

Glitch mechanism

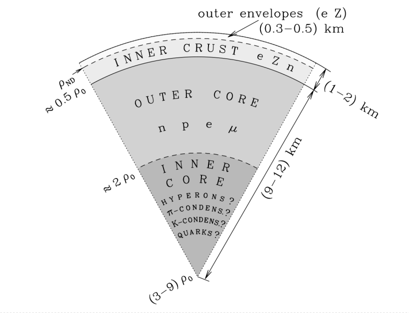


- The normal component loses angular momentum.
- The superfluid rotates by forming an array of quantised vortices.
- These vortices may pin to impurities of the crust.

The relative motion between the vortices and the superfluid itself causes a Magnus force. If the Magnus force is strong enough to overcome the pinning force, vortices detach and a glitch occurs.



Computational interest



- The dynamical system is cylindrical, while physical quantities have a spherical dependence.
- Dynamical equations for the description of a glitch are usually complicated.
- Bayesian comparison between the model and the observations.

Nicola Mori

INFN Florence

- I work in experimental cosmic rays
  - Space-based experiments like PAMELA, CALET, HERD
- Main interests (in decreasing order of preference):
  - Software development
  - Data analysis
  - Detector development

Software activities

- Effort towards standard frameworks
  - I work in many experiments and R&D, I really appreciate generic software
  - But simple enough for cosmic rays!
  - Generic Geant4 simulation framework
  - Generic data analysis framework
    - Inspired by Gaudi

Software activities

- Interests towards modern computing approaches
  - Modern C++
  - Multithreading
  - Deep learning
- Still exotic beasts in cosmic rays
  - But we are starting to need them

ESC 2018
Lorenzo Périssé

PhD Student in Particle Physics, CEA
Modeling of reactor antineutrino spectra

DE LA RECHERCHE À L'INDUSTRIE
cea

BONJOUR !

ACADEMICS

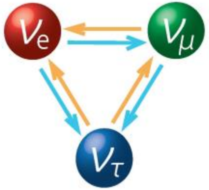
- Fundamental Physics Licence degree
- Theoretical Physics Master degree
- 1st year PhD at CEA, the french institute for nuclear and alternative energies
  - Particle Physics

PhD RESEARCH

- About the **NEUTRINO** (ν)
- Project NEνFAR (New Evaluation of ν Fluxes At Reactors)
- Experimental anomalies to investigate
- Origin of the anomalies, new Physics or inexact models?

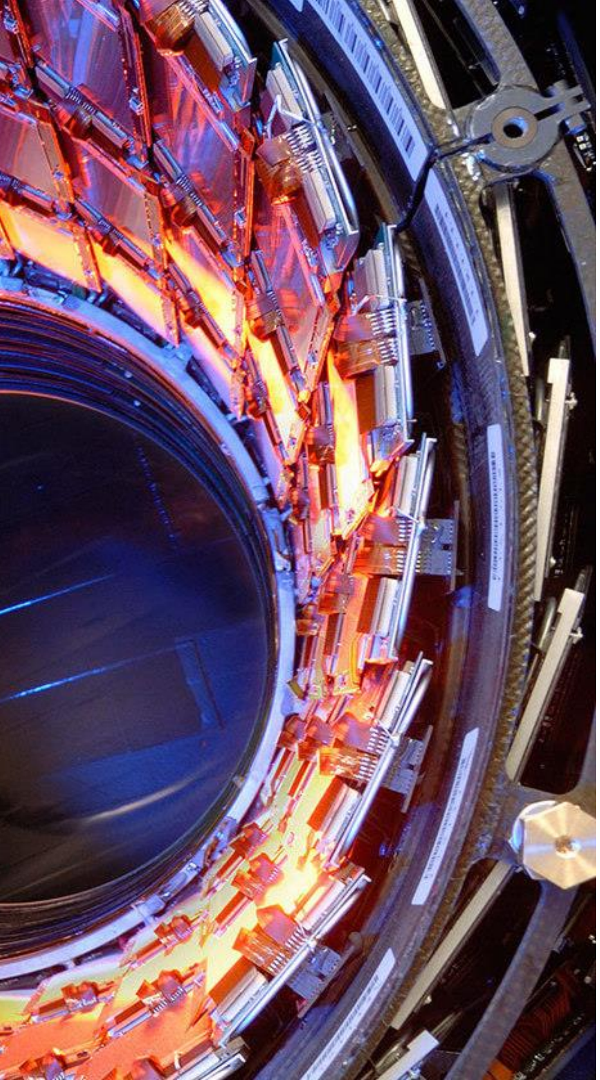
WHAT IS A ν ?

- Neutral, oscillates (Nobel 2015) , very light (<1 eV), cross section ~10^{-42} cm²



- They come from:

COSMOS



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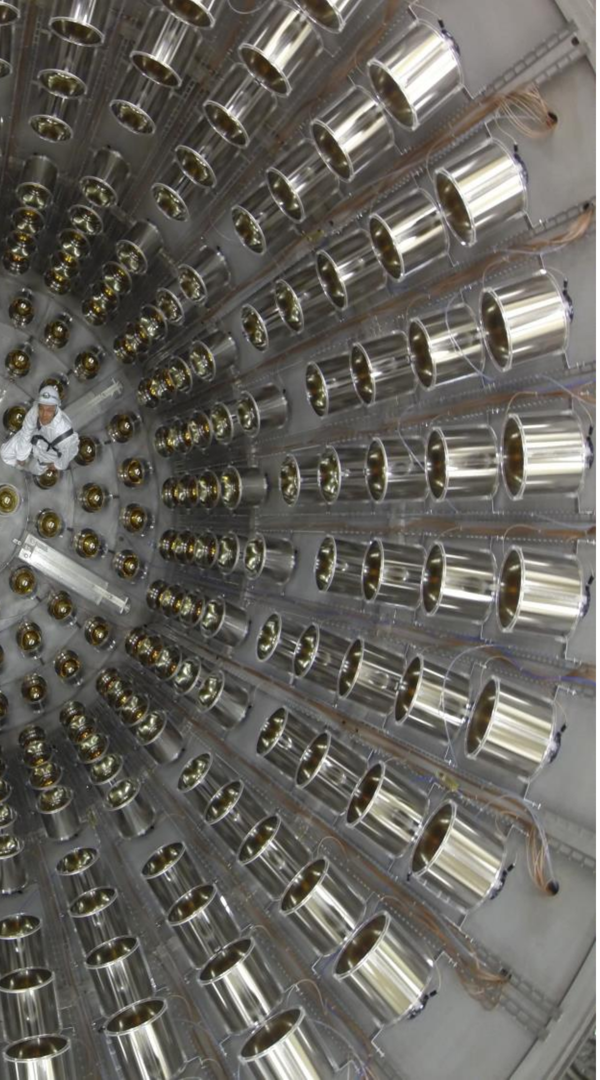
NUCLEAR REACTOR

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}X' + e^{-} + \bar{\nu}_e$$

$$\boxed{2 \times 10^{20}\ \bar{\nu}_e/s/GW_{th}}$$



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PARTICLE ACCELERATOR

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- We detect them (energy + rate): IBD

$$^{A}_{Z+1}X' + \bar{\nu}_e \rightarrow {}^{A}_{Z}X + e^+$$

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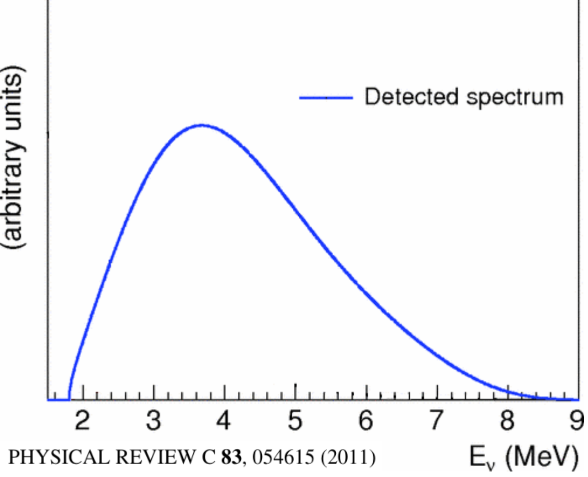
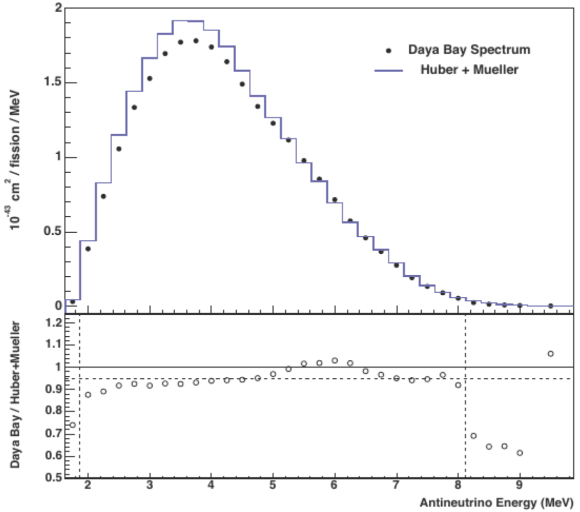
NUCLEAR REACTOR

- We detect them (energy + rate): IBD
- Disagreement Measurements/Theory (shape and rate anomalies)



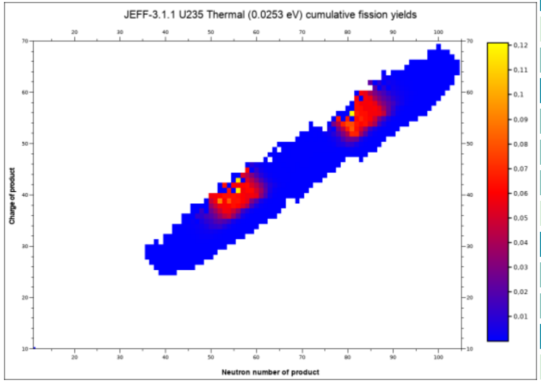
PHYSICAL REVIEW C **83**, 054615 (2011)



Nuclear and Particle Physics Proceedings 273–275 (2016) 1847–1853

PhD WORK

$$S_f^b = \underbrace{K_f^b}_{\text{Norm.}} \times \underbrace{\mathcal{F}(Z_f, A_f, E)}_{\text{Fermi function}} \times \underbrace{pE\left(E - E_{0f}^b\right)^2}_{\text{Phase space}}$$
$$\times \underbrace{C_f^b(E)}_{\text{Shape factor}} \times \underbrace{\left(1 + \delta_f^b(Z_f, A_f, E)\right)}_{\text{Correction}} .$$



Improve modeling

- Precise theory of β-decay
- Higher order approximations
- New or more physics approximations

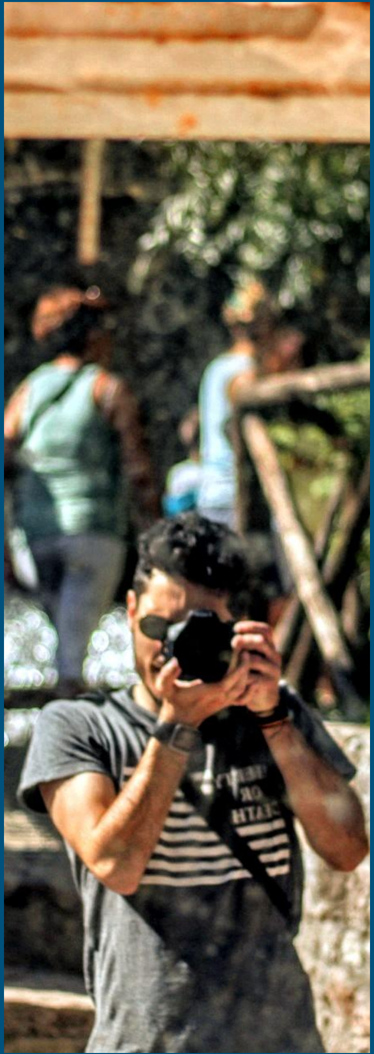
Refine prediction

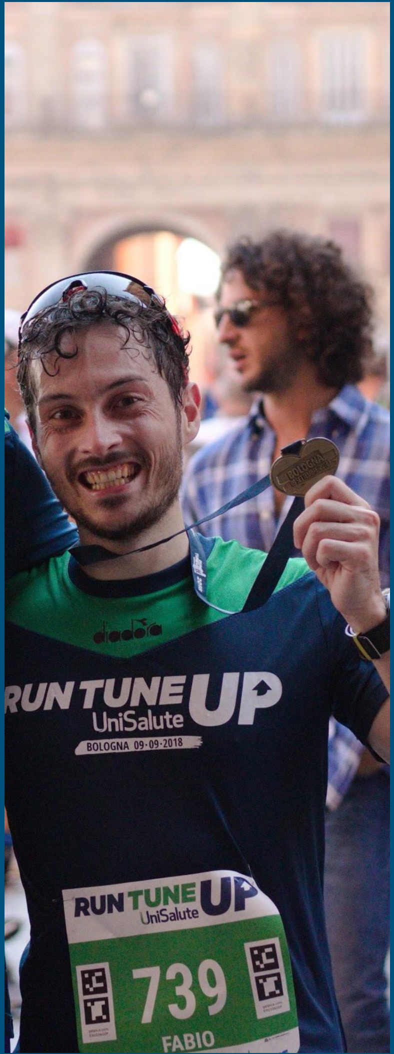
High performance computing techniques

- Modeling ~10 000 nuclear reactions
- 1 spectrum ~ 10^2 -10^7 pts
- Uncertainties propagation

- Faster
- Dedicated software (modular, GUI, ...)
- Better estimation of error budget

Understand the anomalies





Who am I?

Fabio Proietti

27 years old

fabio.proietti@cnaf.infn.it

DEGREE: Computer Science

JOB: SW Dev at INFN-CNAF

CHNet

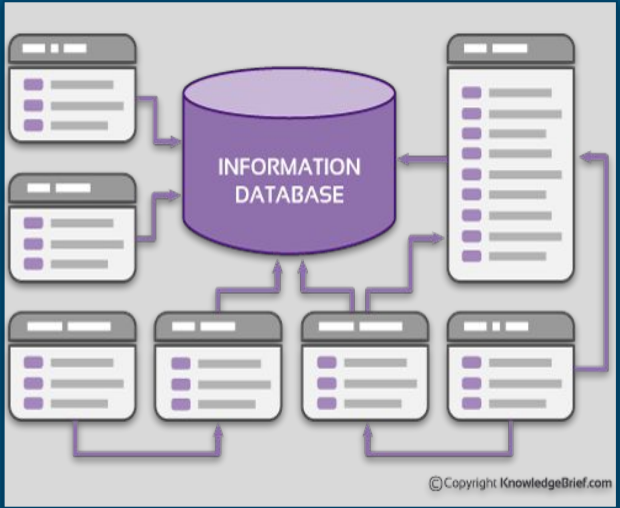
Cultural Heritage Network*

*

*

* Source: http://chnet.infn.it/

Main Responsibilities:



* Source: https://www.kbresearch.com/

Data Management

```
image.width = xDim;
image.height = yDim;
image.DataMatrix = new Array(xDim);

for (let i: number = 0; i < xDim; i+
  image.DataMatrix[i] = new Array(yD
  for (let j: number = 0; j < yDim;
    image.DataMatrix[i][j] = new Arr
    for (let k: number = 0; k < imag
      image.DataMatrix[i][j][k] = 0;
    }
  }
}
```

Software Development

```
        ______      1. token request       ______
 O   |        |                           |CHNet-IAM
-|-  |Client|  ------------------->       |ID provider
/ \  |______|  <-------------------       |______
User     |           2. Response              ^    |
         |                                    |    |
         |       4. Token validation          |    |
         |          (Authentication)          |    | 5. Re
         |                                    |    |
         |                                    |    V
         |                                   ______
         |                                  |  Nginx
         |-------------------------------->|  Server
                3. Dav Request              |______
              (providing token)
```

Architecture Management

Time Based Reconstruction of Hyperons at PANDA at FAIR

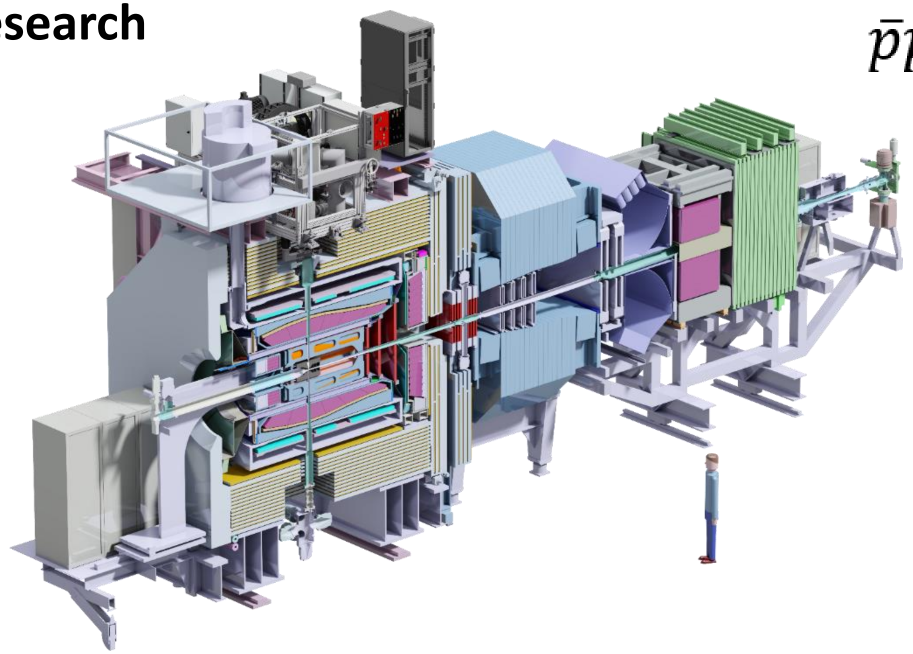
Jenny Regina
Uppsala University

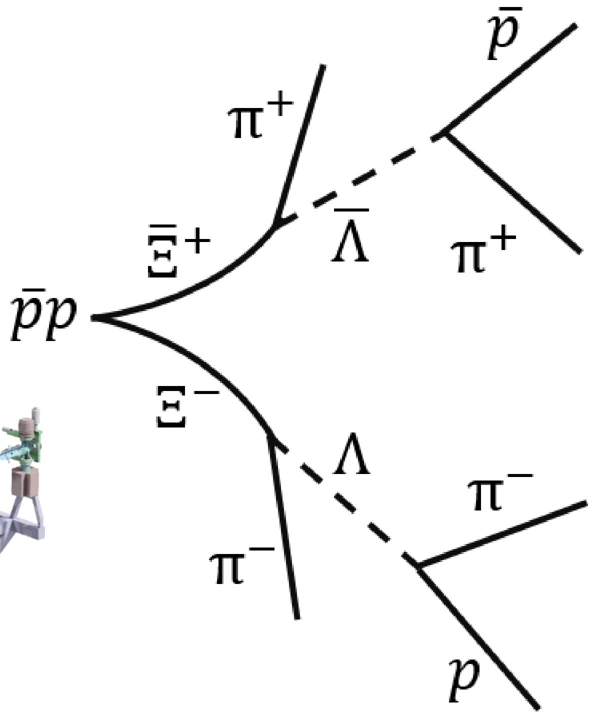
ESC18, Bertinoro

PANDA at FAIR

anti-Proton ANihillation at DArmstadt
Facility for Anti-proton and Ion Research

- $\bar{p}$ beam, 1.5-15 GeV/c
- Fixed target, p
- Physics programme: charmonium and exotics, hypernuclei, **hyperons** etc...



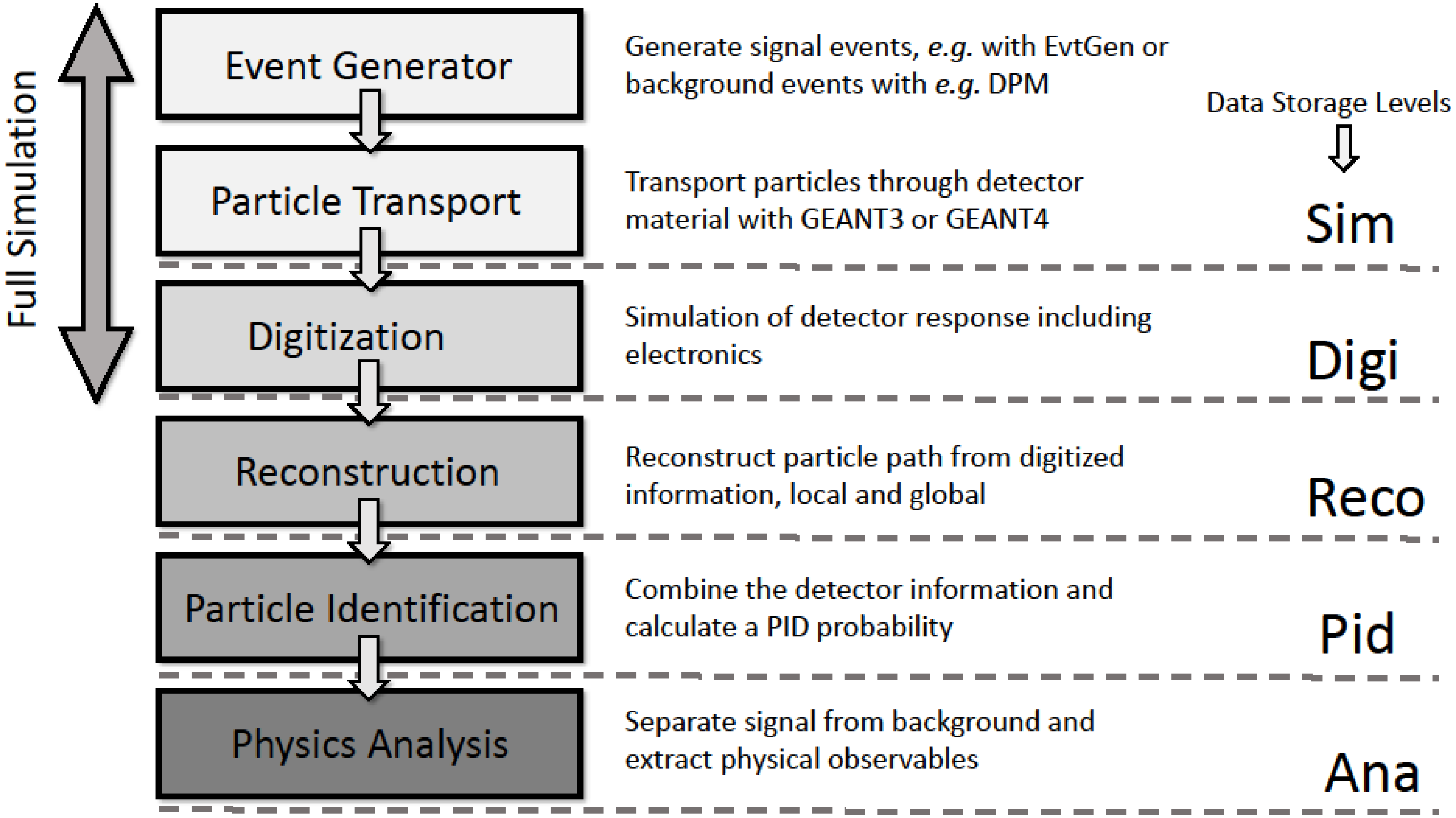


Hyperons

- Baryons, e.g. proton or neutron with one *u* or *d* quark replaced by an *s* quark
- Probe strong interaction
- Most often identified via their decay products
- Relatively long lived, large cτ

PandaRoot

- Official PANDA software since 2006
- Based on ROOT and VMC (Virtual Monte Carlo)



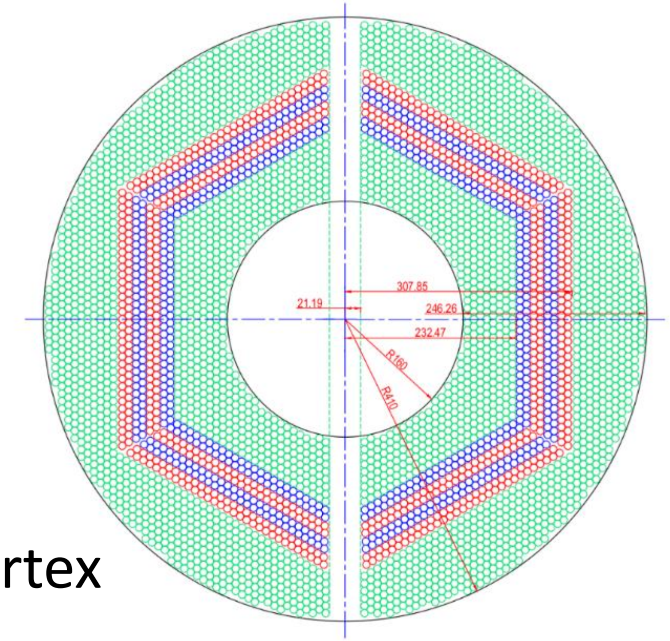
C++

Detector geometry descriptions, event display, track followers e.g. Geane ...

Track Finder Based on Cellular Automaton

Straw Tube Tracker of PANDA

- 4224 single channel read out drift tubes
- 27 radial layers
- Mainly XY information
- 8 layers of tilted tubes for z-reconstruction



- **Secondary tracks**, no assumption of track origin

– works well for hyperon decay products with displaced vertex

- Parallelizable, candidate for **online tracking**
- **Modular** design
  - Main task with classes handling input data, tracklet generation, extrapolation etc.
  - Additional tasks for fine tuning of tracks which can also be used with other tracking algorithms

Figure from [1] PANDA Collaboration, Technical Design Report for the: PANDA Straw Tube Tracker, https://arxiv.org/abs/1205.5441v2, 2012

SttCellTrackFinder

- **Track finding**: cellular automaton, spatial and temporal neighborhod relations to cluster STT hits
- **Track fitting**: Riemann fit to extract circle parameters by fitting plane
- **Extrapolation** of tracks to other detectors to include in tracking or for t_0 determination

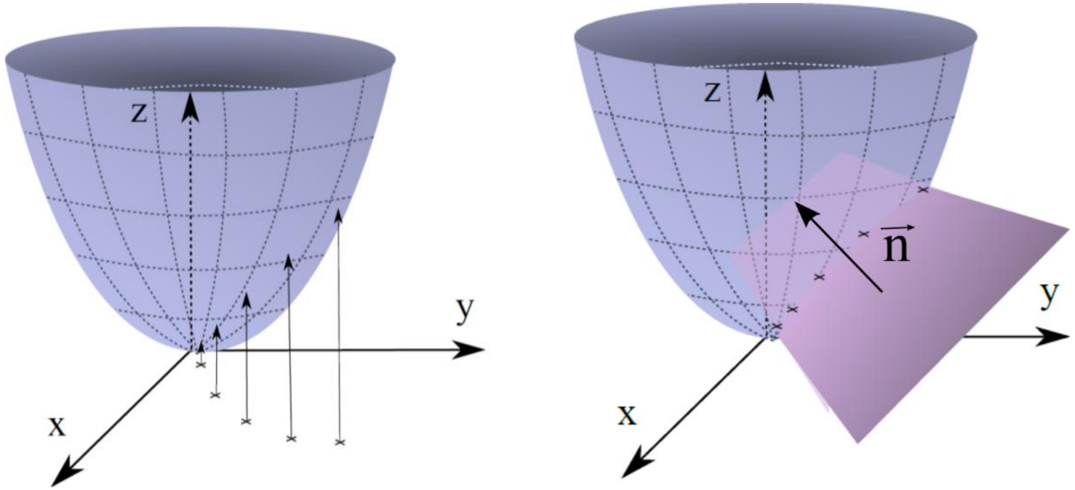


Figure from [2] Jette Shumann, Entwicklung eines schnellen Algorithmus zur Suche von Teilchenspuren im "Straw Tube Tracker" des PANDA-Detectors, 2013

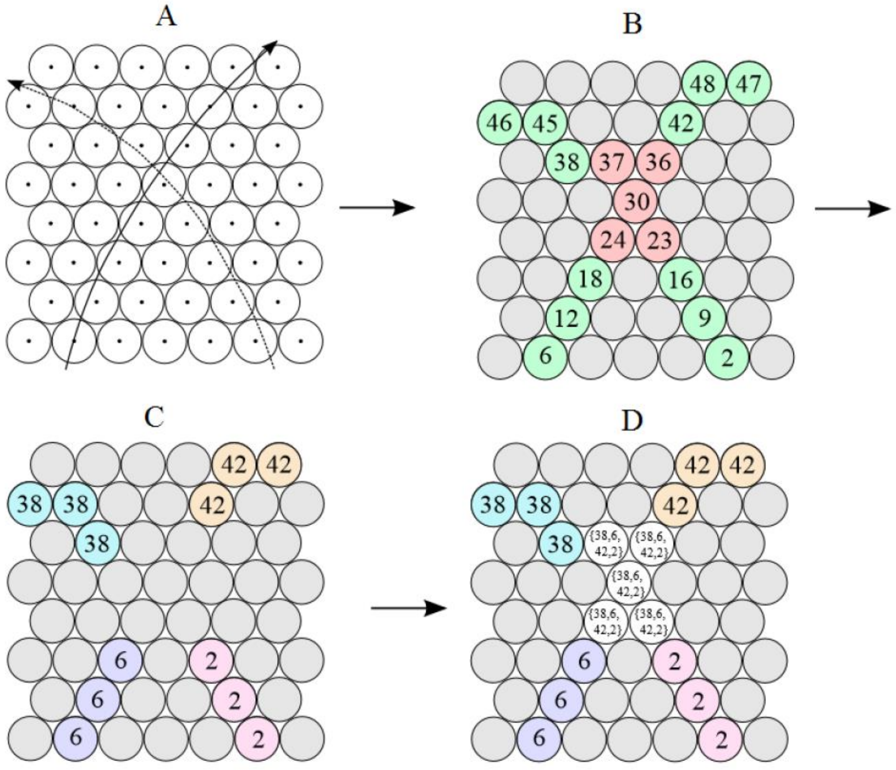
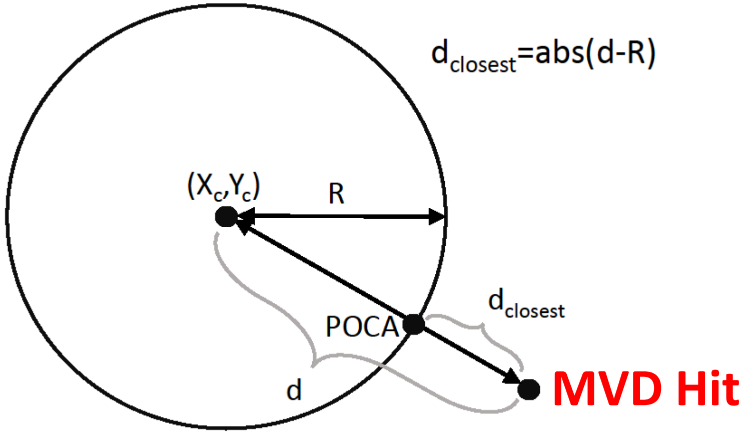


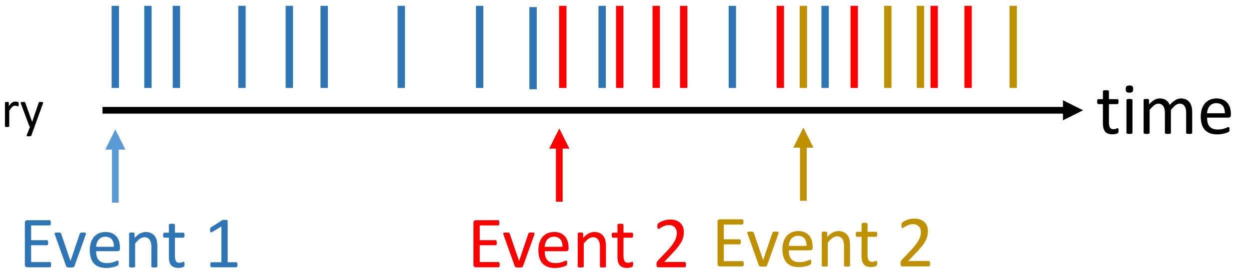
Figure adapted from [2]

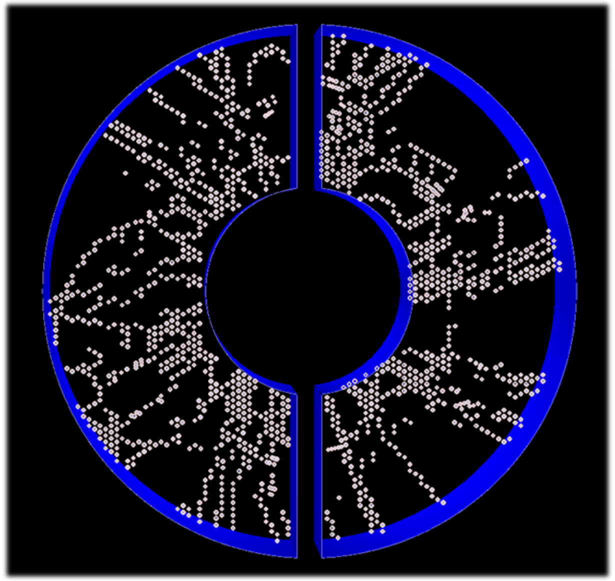
Riemann Fit

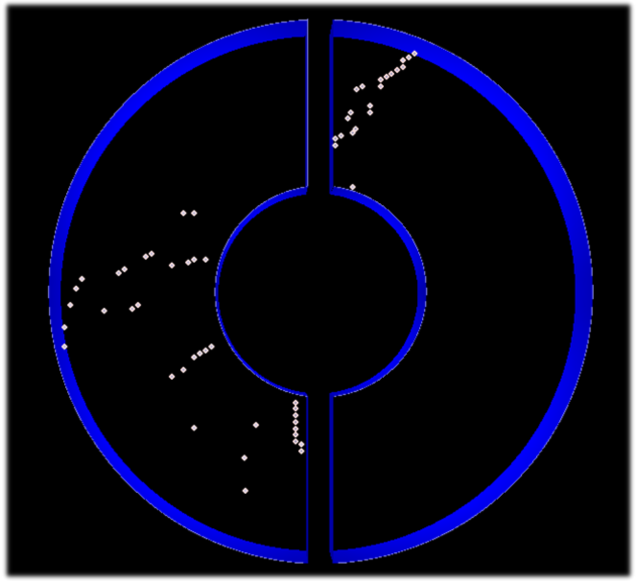


Time Based Reconstruction

- 20 MHz mean interaction rate
- Event mixing
- Software trigger based on tracking and calorimetry







SttCellTrackFinder must be able to handle mixing of 5-6 events!

Thank You!

HPC for Cosmology

Alessandro Renzi (INFN Padova)

Why Cosmology needs HPC

Cosmology is essentially an image signal processing activity

Maps of the Universe at different energies are different images to be analyzed

Images have O(10M) of pixels

Catalogs have O(1G) of objects

O(100k) Simulations are needed to properly analyse cosmological data

<u>Memory management is the main bottleneck</u>

Road to Exascale: impact on Cosmology

While the increase number of computational core is a good news

The flattening of memory-per-node is an unwelcome news

The HPC challenge for Exascale Cosmology is threefold

Optimize the internode communication

Exploit OpenMP/MPI hybrid parallelization (GPGPU?)

Optimize the disk I/O operations

Iason D. Rodis

About

- Works in Beam instrumentation @ CERN
- Software background: studied in University of Athens
- Interests: RT Software, Recommender Systems
- Previously : Research Associate / Software Engineer @ University of Athens, Department of Informatics & Telecommunications
- More at : https://jasrodis.tk

Maciej Szymański

current research activities

University of Chinese Academy of Sciences

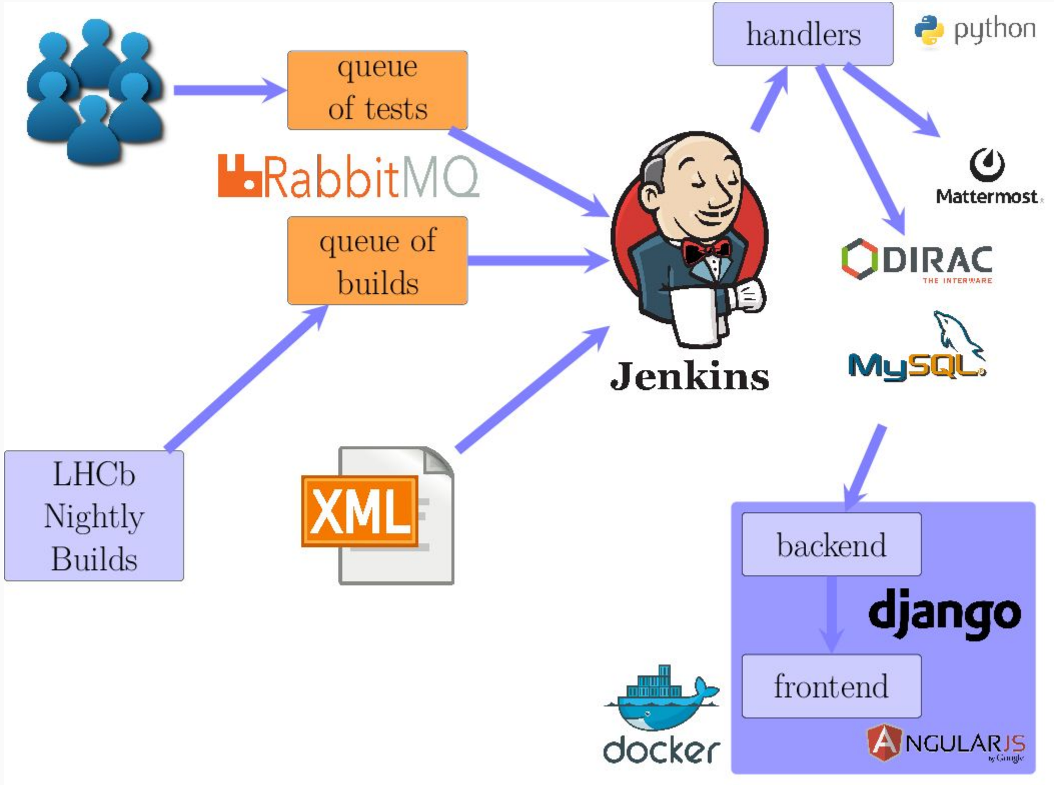
School on Efficient Scientific Computing
Bertinoro, 22 Oct 2018

Current scientific interests

- **Upgrade of the LHCb** experiment from 2019 for the next stage of data taking at LHC
- Significant **impact on computing** systems to fully **exploit the capabilities** of the LHCb detector
- Current data storage capacity and computing power **insufficient** to process data at the rate expected after the upgrade
- Development the **software performance** measurement infrastructure to keep track of the optimisation activities

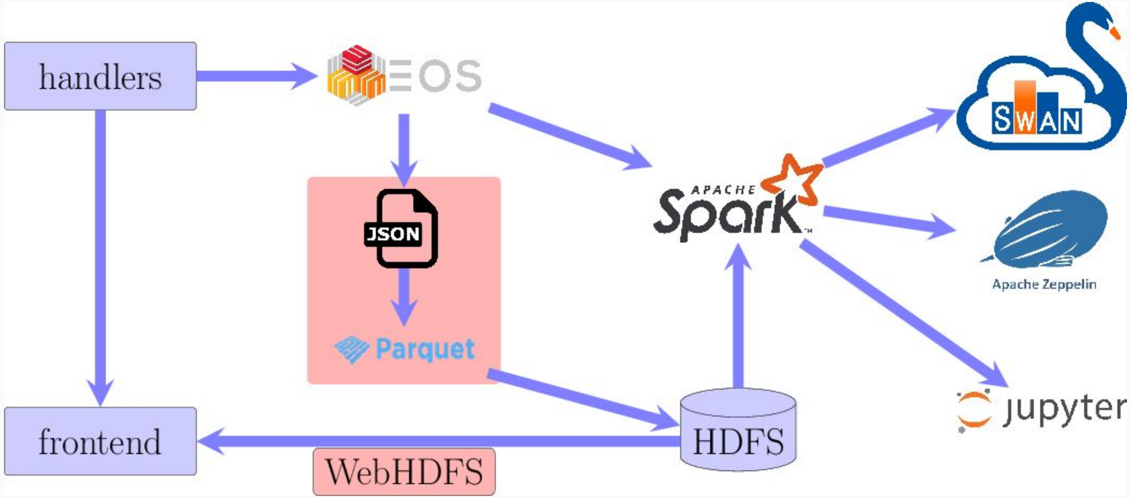
LHCb Performance and Regression framework

- Framework for systematic **monitoring** of the LHCb software
- Performance baseline in **controlled conditions**
- **Inspect changes** due to new merge requests, new external libraries, etc.
- **Compare results** across various compilers and architectures
- Not only to monitor **resource consumption**, but also to measure the **physics performance**
- **Microservices** architecture



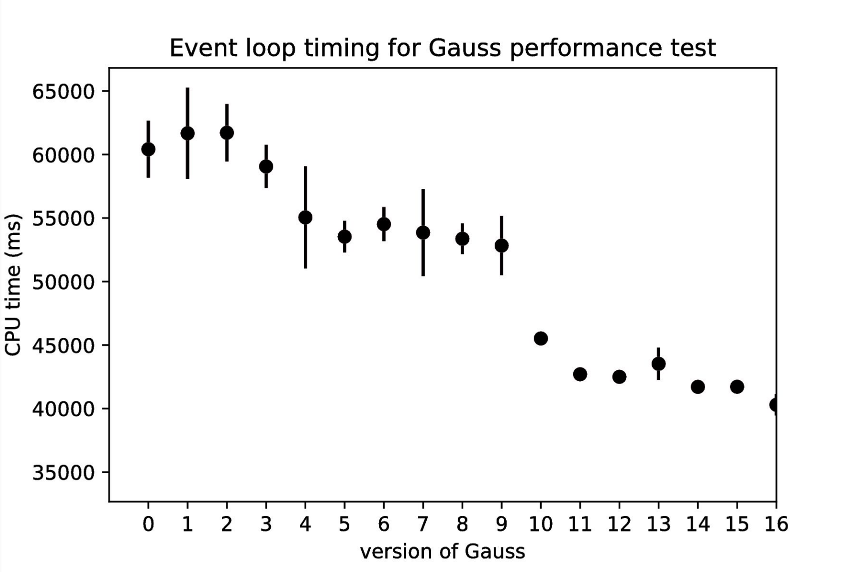
Recent developments

- Applying technologies developed to support the analysis of **Big Data** for LHCbPR
    - **Hadoop**, set of components for large scale data processing
- **Interactive** data exploration, **fast turn-around**, flexible reports
- Apache **Spark** used as an engine for data processing, data in **Parquet** format on **HDFS**
- **Collaboration** and **reproducibility** thanks to **shared notebooks**
    - SWAN, jupyter, Zeppelin



Use cases

- **Simulation** (physics validation, timing and memory measurements)
- Rate and **throughput** from the High Level Trigger
- **Code profiling** using perf and IgProf
- **Trend** of the metric of interest as a function of the software version



Evolutionary Algorithms with Neural Networks to optimize Big Data Cache

Mirco Tracolli

INFN section Perugia

Ph.D. Student

at University of Florence and University of Perugia

in MATHEMATICS, COMPUTER SCIENCE, STATISTICS

Ph.D. Project

With my Ph.D. project, I will develop an **Artificial Intelligence** (AI) for a **smart data cache orchestrator**:

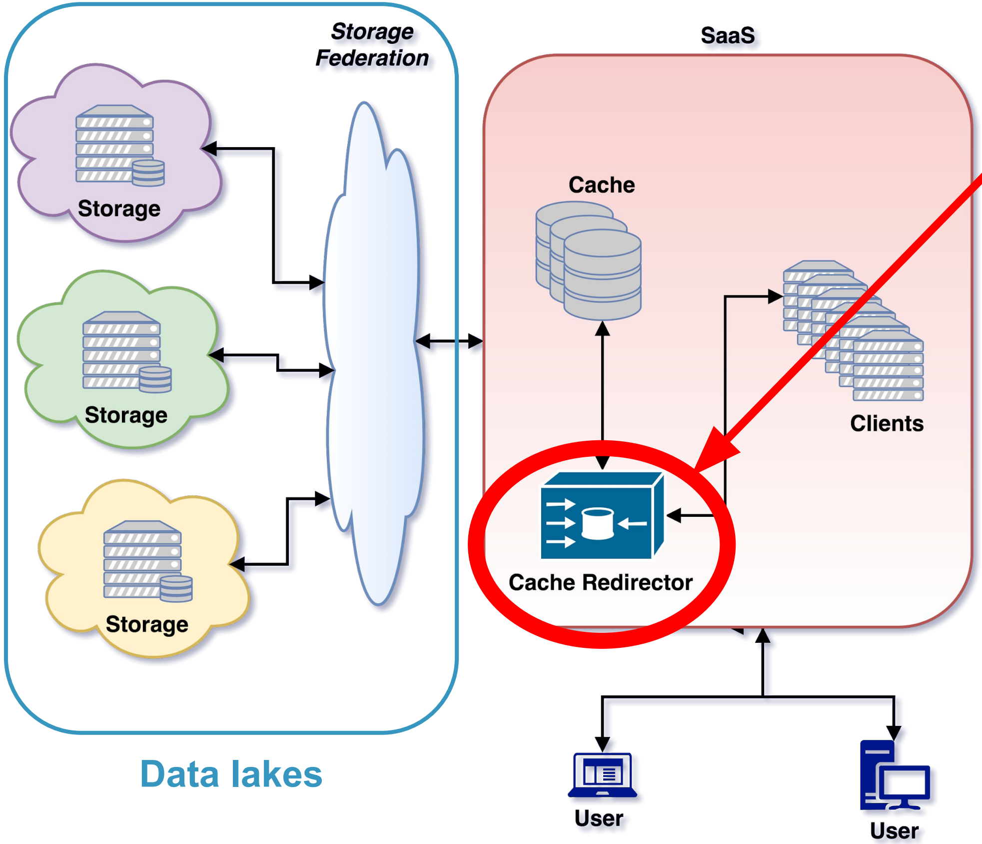
- To orchestrate a system of worldwide distributed caches
- To manage the cache quality of service

The results of the project will be **benchmarked into the Compact Muon Solenoid (CMS) computing scenario** within the Worldwide LHC* Computing Grid (WLCG):

- Big data management (the hot topic in the High Energy Physics)
- CMS experiment and relative experiments

* Large Hadron Collider

Objective and strategy



Data lakes

The target will be an **original orchestrator** that interacts with clients and caches.

The system will draws on federated data in multiple storage according to the **data lake model** explained before.

This manager will be **autonomous**.

Objective and strategy

Cache access data are **strongly time dependent**. You have to treat them as a **time series**. For such kind of input is needed a **Neural Network with memory** such:

- Recurrent Neural Networks (**RNNs**)
- Long Short-Term Memory Networks (**LSTM**)

In a dynamic environment like cache management can be used also a **different approach to Machine Learning**, e.g. the **Reinforcement Learning**.

This type of **approximate dynamic programming**, or **neuro-dynamic programming**, can be used to find an optimal agent to orchestrate the caches.

In this area an **Evolutionary Algorithm approach** could be investigated to get a better sub optimal solution in runtime orchestration.

Ph.D. Workplan

ANALYSIS

Extract the features and formalize the problem

EXPERIMENT

Test different types of Neural Networks and Machine Learning techniques

TEST

Use the prototype in a simulation environment to test performances

APPLY

Try directly the AI on the testbed to get ready to production

DATA → MODEL → PROTOTYPE → SMART CACHE AI → AI ON PRODUCTION

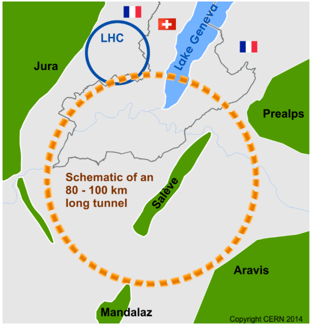
DETECTOR DESIGN FOR FUTURE CRICULAR COLLIDER HADRON–HADRON EXPERIMENTS

Anna Zaborowska
CERN

ESC 2018
October 22-27, 2018

Future Circular Collider (FCC)

- ~100 km circumference
- studied collider options:
  - hadron-hadron (FCC-hh)
  - lepton-lepton (FCC-ee)
  - hadron-lepton (FCC-he)



http://fcc.web.cern.ch

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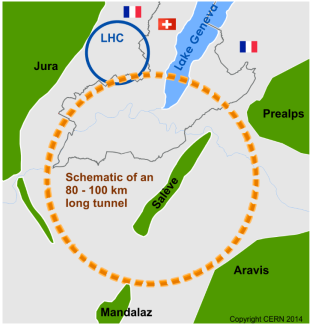
  - hadron-lepton (FCC-he)
- goal 100 TeV for FCC-pp
  - more particles produced ($\times$1.5 more than 14 TeV)
  - large detector (~20 m x 50 m)
  - more pile-up events (~1000 events)
  - **FCC-hh an extremely high luminosity machine.**



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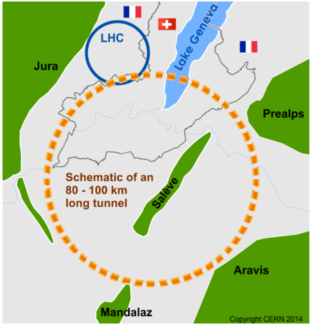

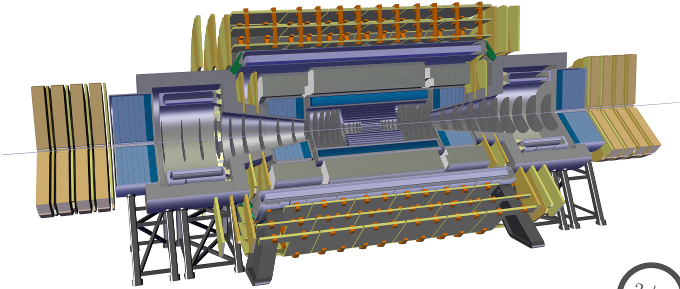

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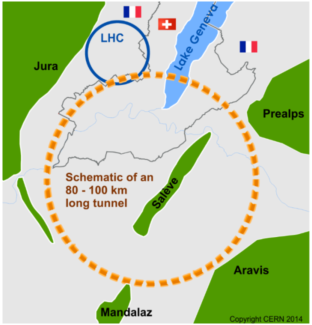
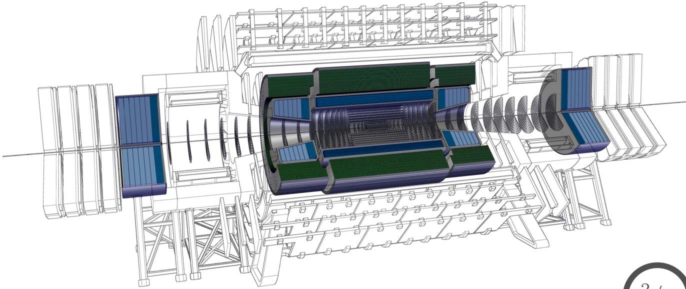
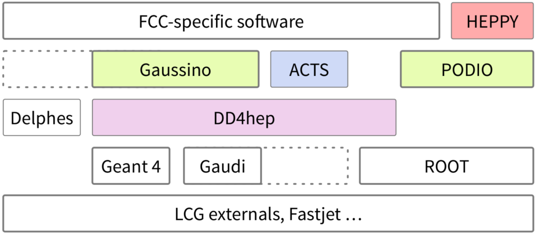


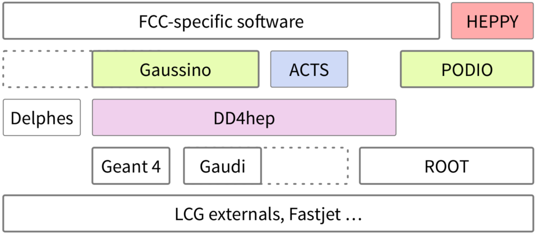


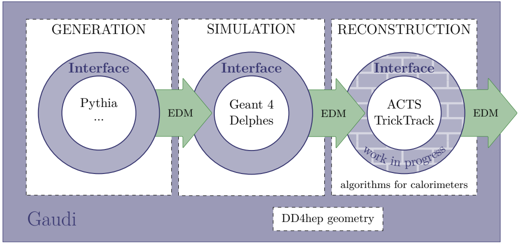
http://fcc.web.cern.ch

FCC Software



FCC Software





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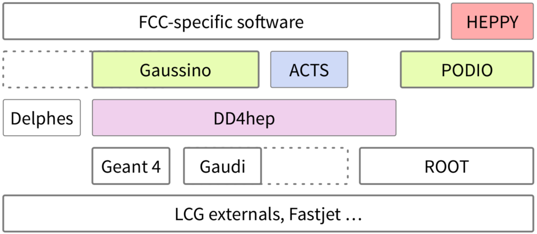

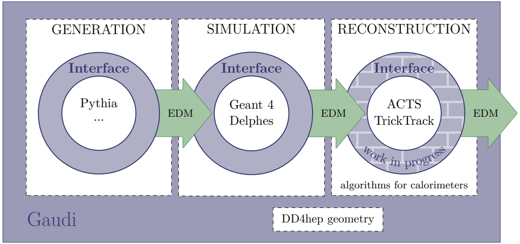

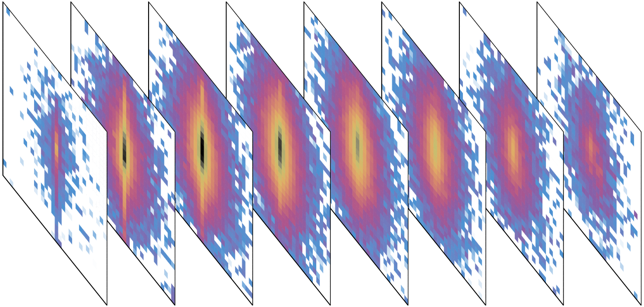

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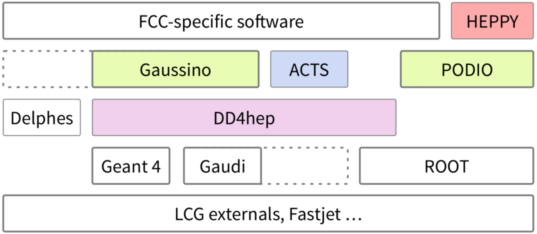
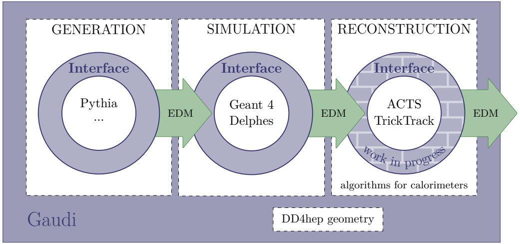
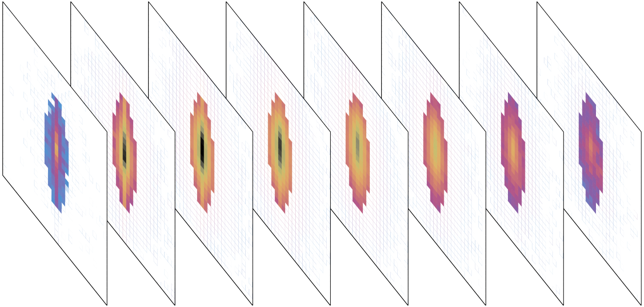
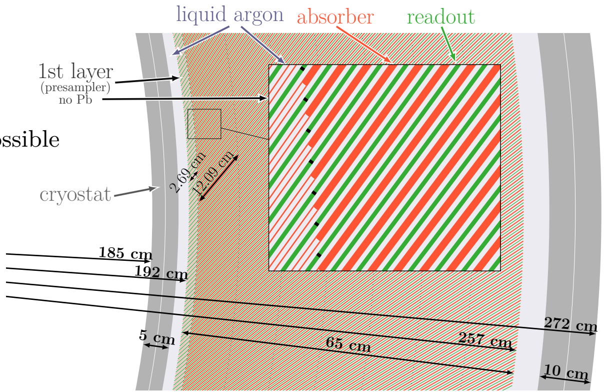






LAr electromagnetic calorimeter

- High granularity.
- High longitudinal and lateral segmentation possible with straight, multilayer electrodes.



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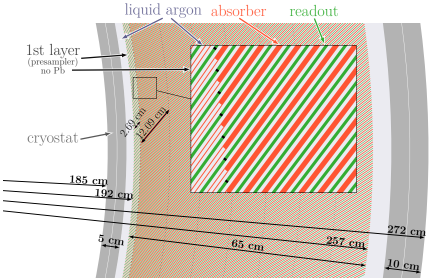

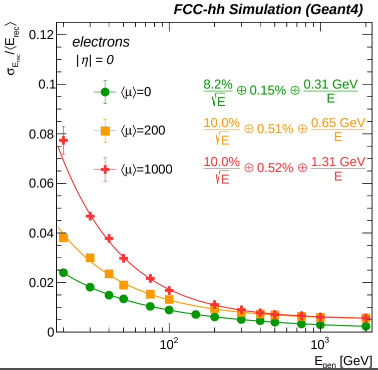

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