My Research activity

Daniel Magdalinski
4-12 October 2023

Background

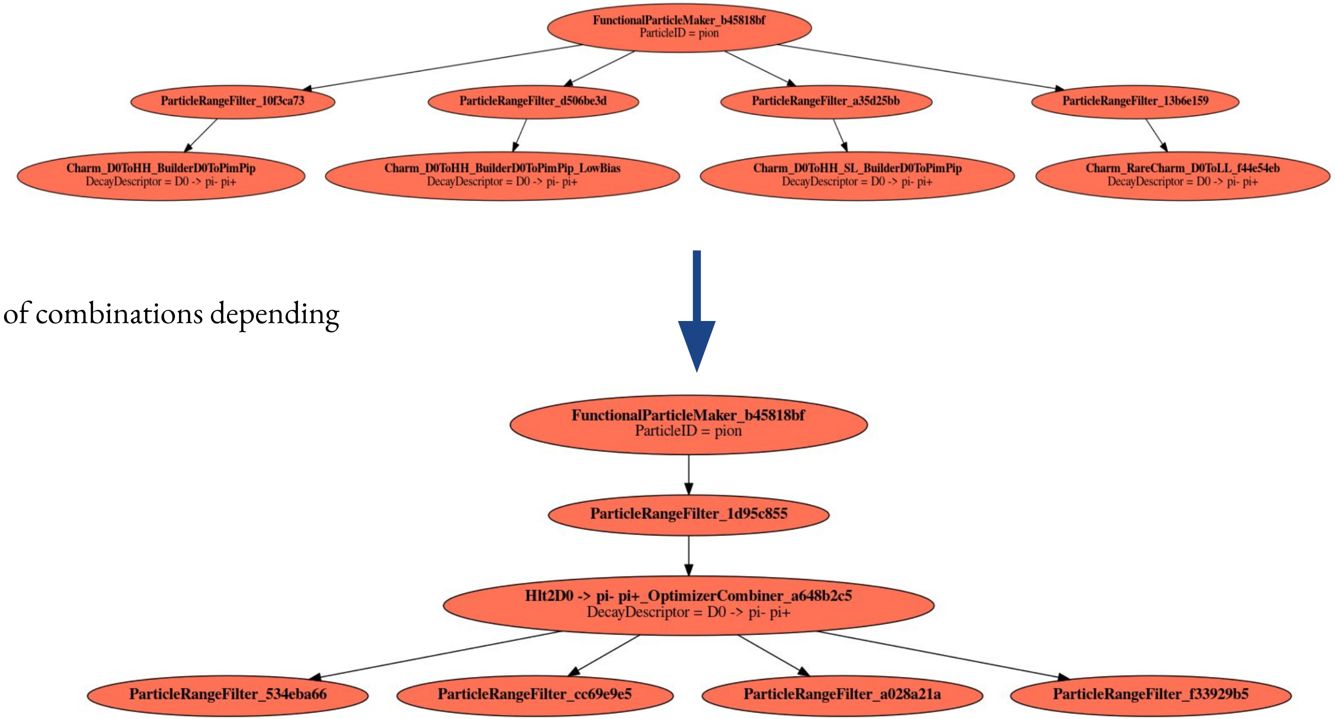
- Bachelor(Physics) and Master(Particle Physics) at Lund University
  - **Bachelor:** Convolutional neural nets for energy regression at LDMX
  - **Master:** Doubly charged higgs analysis at ATLAS
- Summer Student at CMS in 2022
  - Analysis of metrics for track characterization in the High-Granularity Calorimeter
- PhD, since October 2022, at LHCb
  - Nikhef/VU Amsterdam
  - SMARTHEP network
- Research:
  - **Trigger:** Optimization of combiners within HLT2 trigger lines
  - **Analysis:** Measurement of $\Delta\Gamma d$ parameter at LHCb

Optimization of combiners

- LHCb trigger consists of ~1200 lines
- Lines consists of mainly filters and combiners:
  - Filters: Applies cuts on particles, ex: pt, eta or pid
  - Combiners: Iterates through all input combinations(2,3,4-body) and applies cuts
- Selection algorithms: ~30% of HLT2
- Lines consist of combiners that are quite similar
- Opportunity to reduce computational resources by combining these combiners

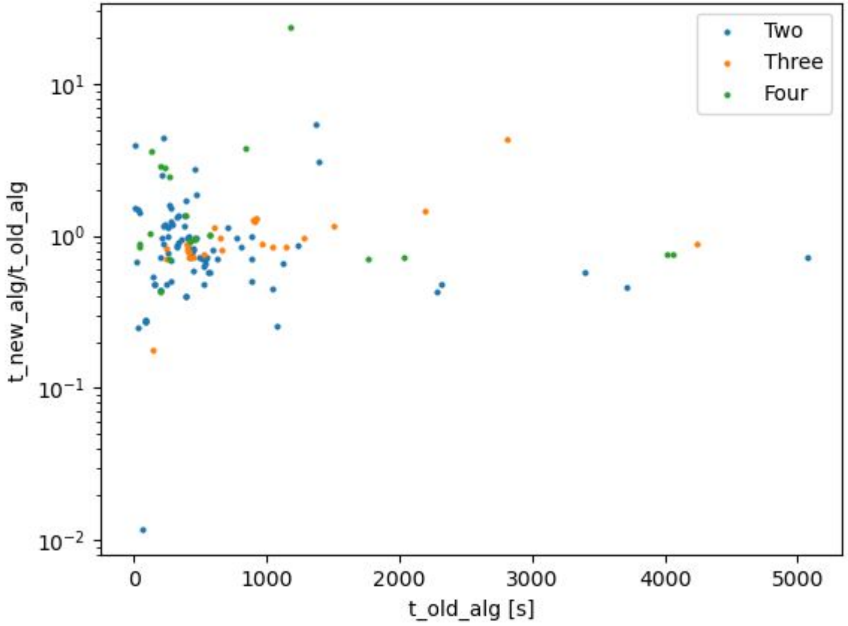
Example: D0 -> pi- pi+

- Old version
  - 4 combiners
  - 10 lines
- New version
  - Superset
  - OR operator on cuts
  - Reduction or increase of combinations depending on overlap of inputs



Performance before optimizing

- 134 sets of combiners
- Blind combination
- Optimization ongoing
  - Input overlap
  - Cut complexity
  - etc?



Towards the design optimization of a Muon Collider Calorimeter

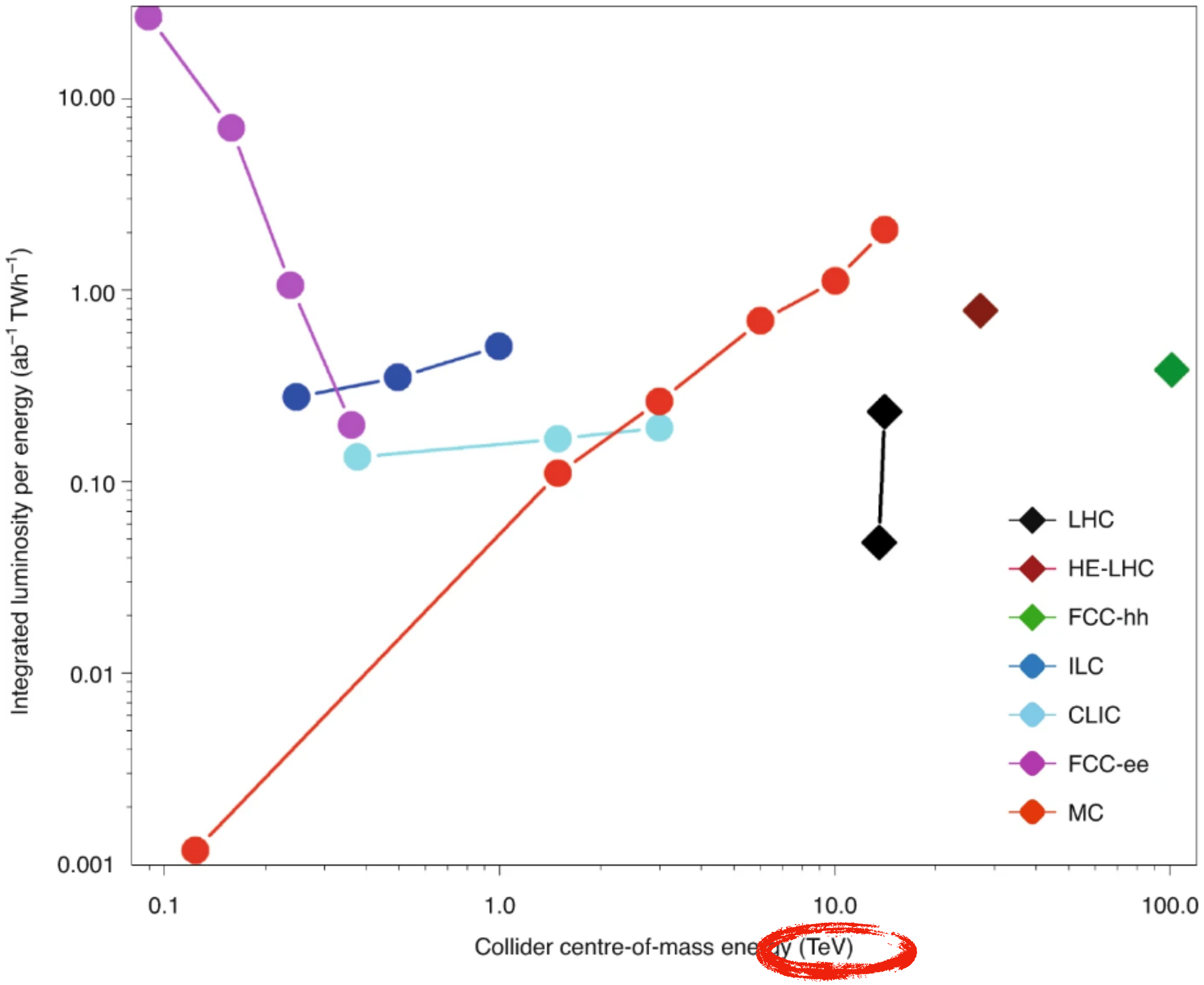
ESC2023 Lightning talk

Federico Nardi

Introduction

Why a Muon collider?

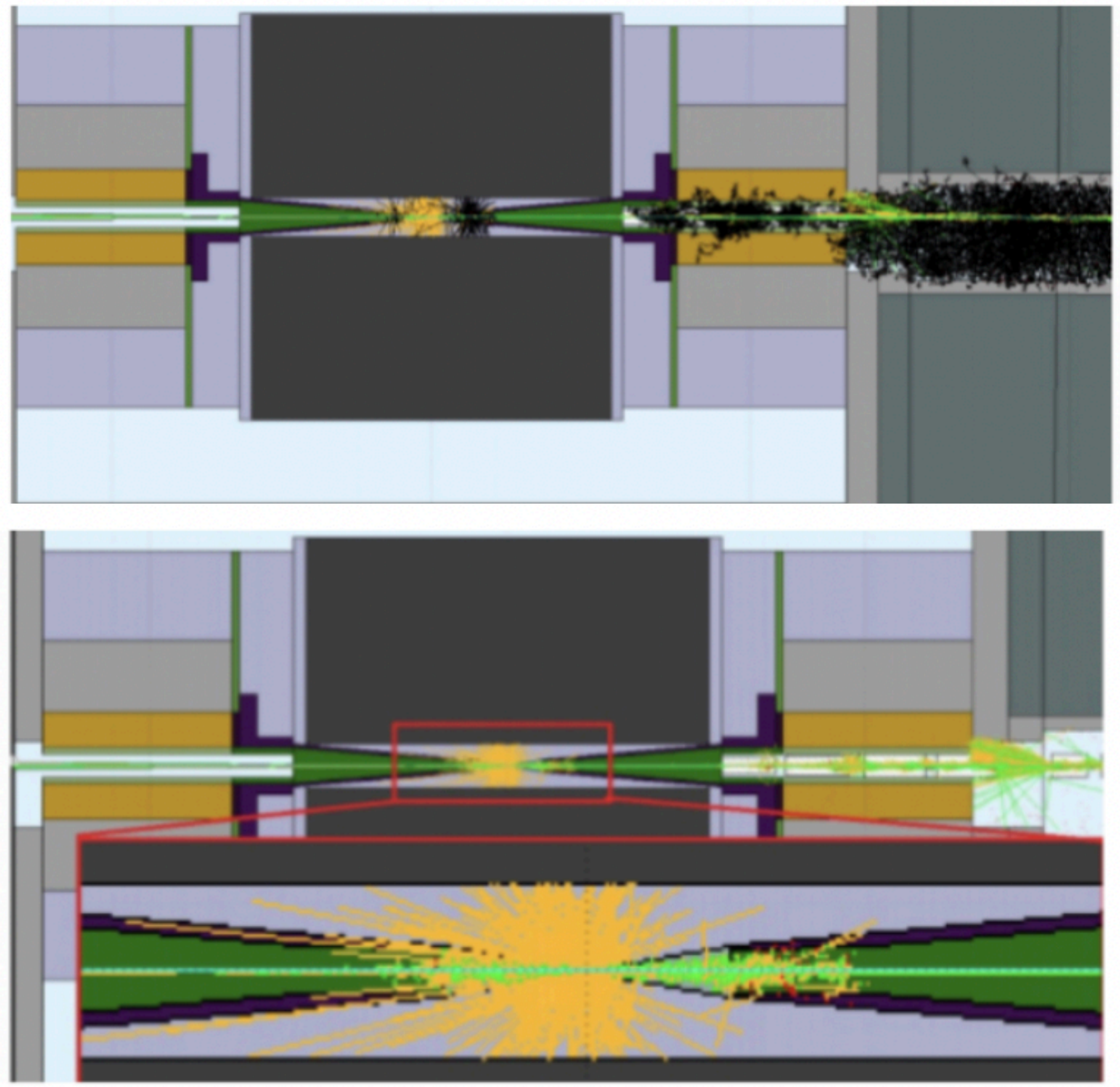
- Luminosity increases with center-mass energy
  - Competitive with LINACs
  - Most ‘physics-per-dollar’ potential
- Heavier than electrons: less radiative losses
- Lepton Collider: no pile-up effects
- Rather old concept, regained interest with the Snowmass Process
- Higgs Factory
  - $\sigma(\mu\mu \to H) \simeq 40000\ \sigma\ (ee \to H)$
- Dark Matter portals



Muon Collider

The BIB problem

- TeV-scale Muon Collider as strong candidate among proposed Future Colliders (no pile-up, access to DM portals, Higgs factory)
- Finite lifetime of the muon (2.2μs) implies a cloud of high-energy decay product along the beamline, which interferes with the instrumentation (Beam-Induced Background - BIB)
- During preliminary Machine-Detector Interface design, a double-cone nozzle has been included to shield the detector from BIB radiation

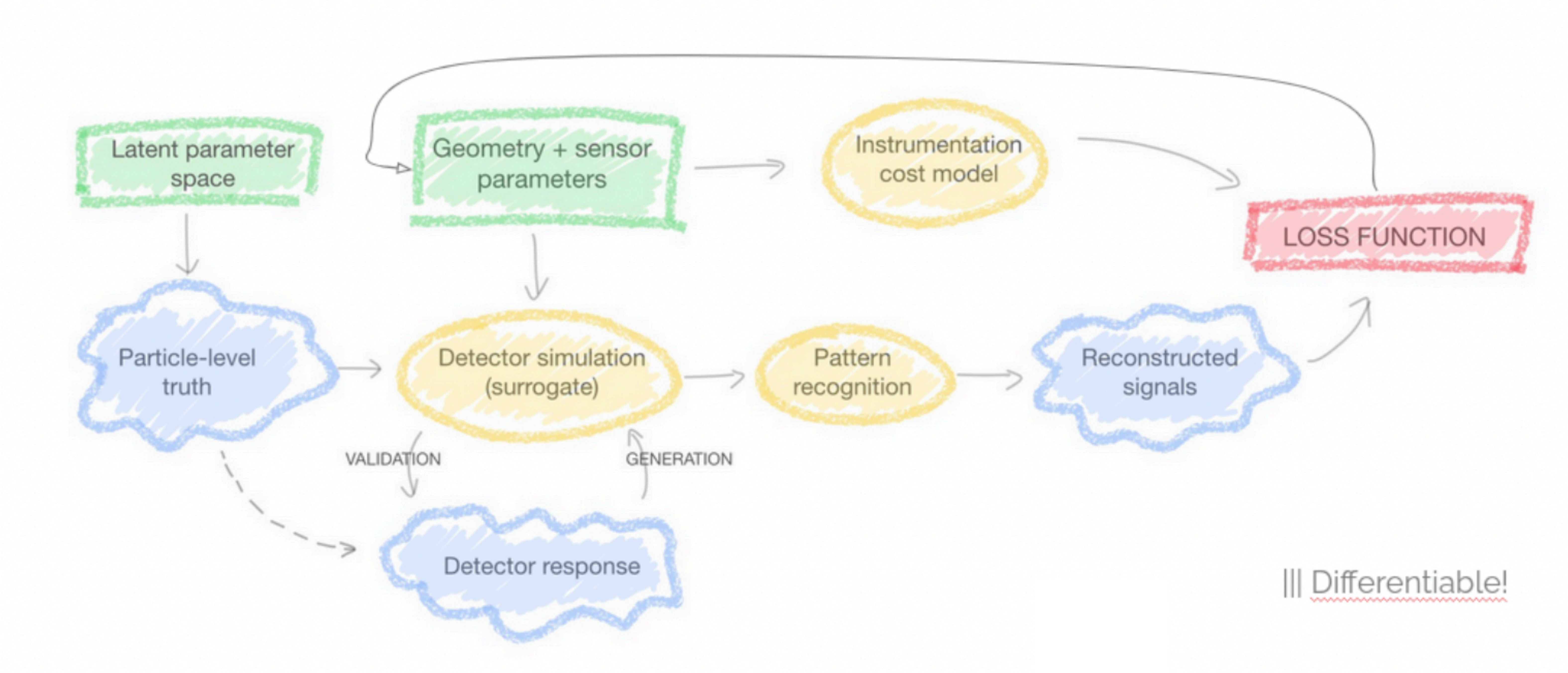


Visualizations from FLUKA BIB simulation. Black: neutrons, other: photons

Muon Collider

Optimization Workflow

- End objective: design optimization study approached with AD techniques
- Development of a pipeline to propose an optimal configuration in terms of signal-to-background discrimination and instrumentation cost



- Based on 3 main core methods
- Provide information encoded in a utility function
- Minimized using AD libraries (PyTorch, Tensorflow)

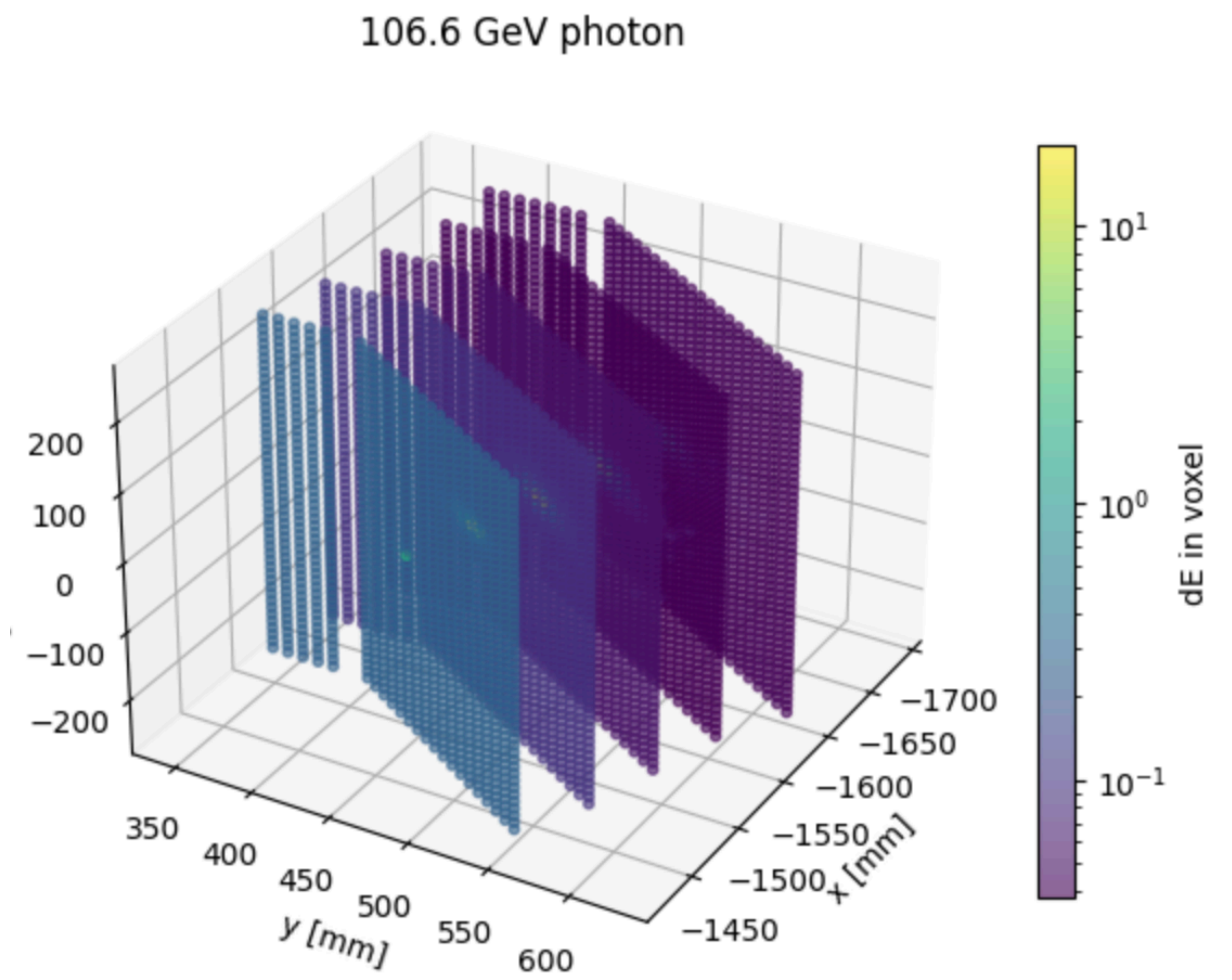
Object Condensation

Setup

- To reconstruct signals in ECal we test DeepJetCore, a package developed for the reconstruction of jets in the High-Granularity Calorimeter developed for the CMS upgrade for the High-Luminosity LHC runs

- Core is a Graph Neural Network that clusters the data, whose dimensionality has been reduced by filter layers.

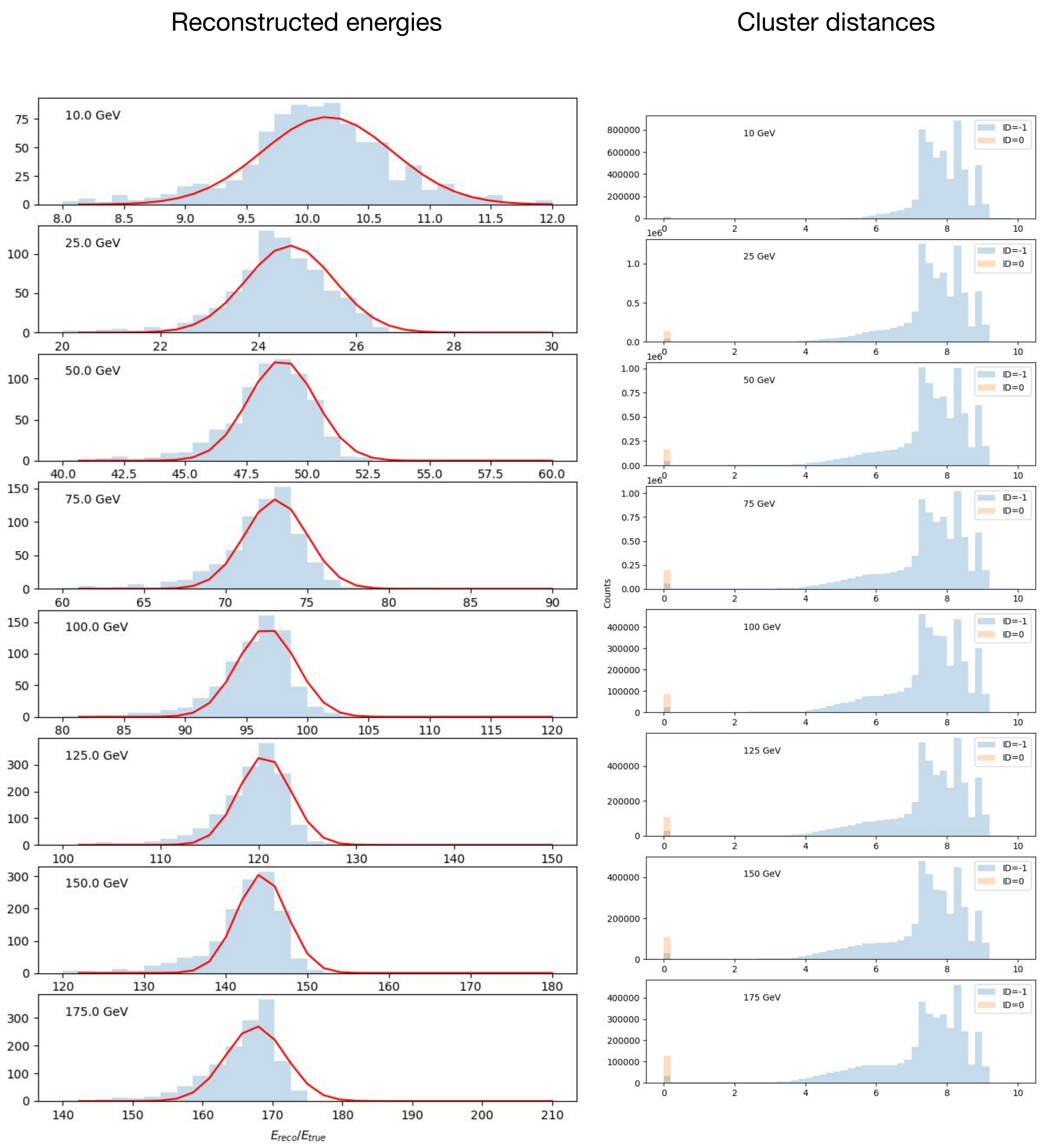
- Clustering performed through the identification of one condensation point for each object, and the subsequent minimization of a loss function

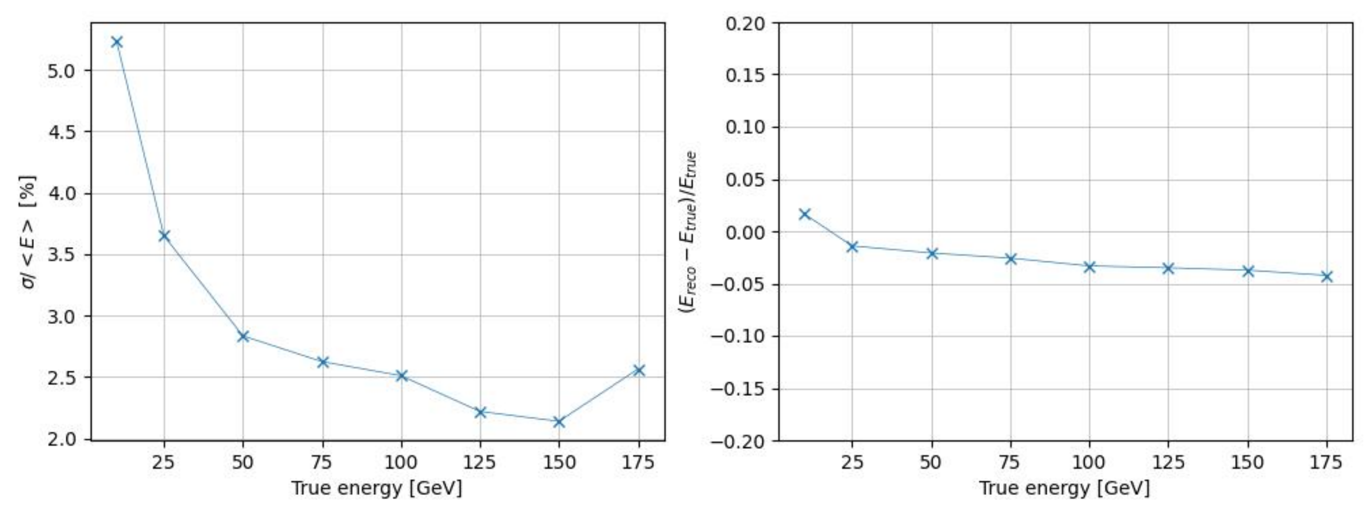


Muon Collider

OC: Preliminary results - Clustering

- Decent reconstruction efficiencies, comparable with ParticleFlow for simple monochromatic events
- Acceptable clustering performances for signal vs background classification
- Core was originally developed for jets, might perform even better with more complex events (next step!)





Muon Collider

OC: Preliminary results - Clustering

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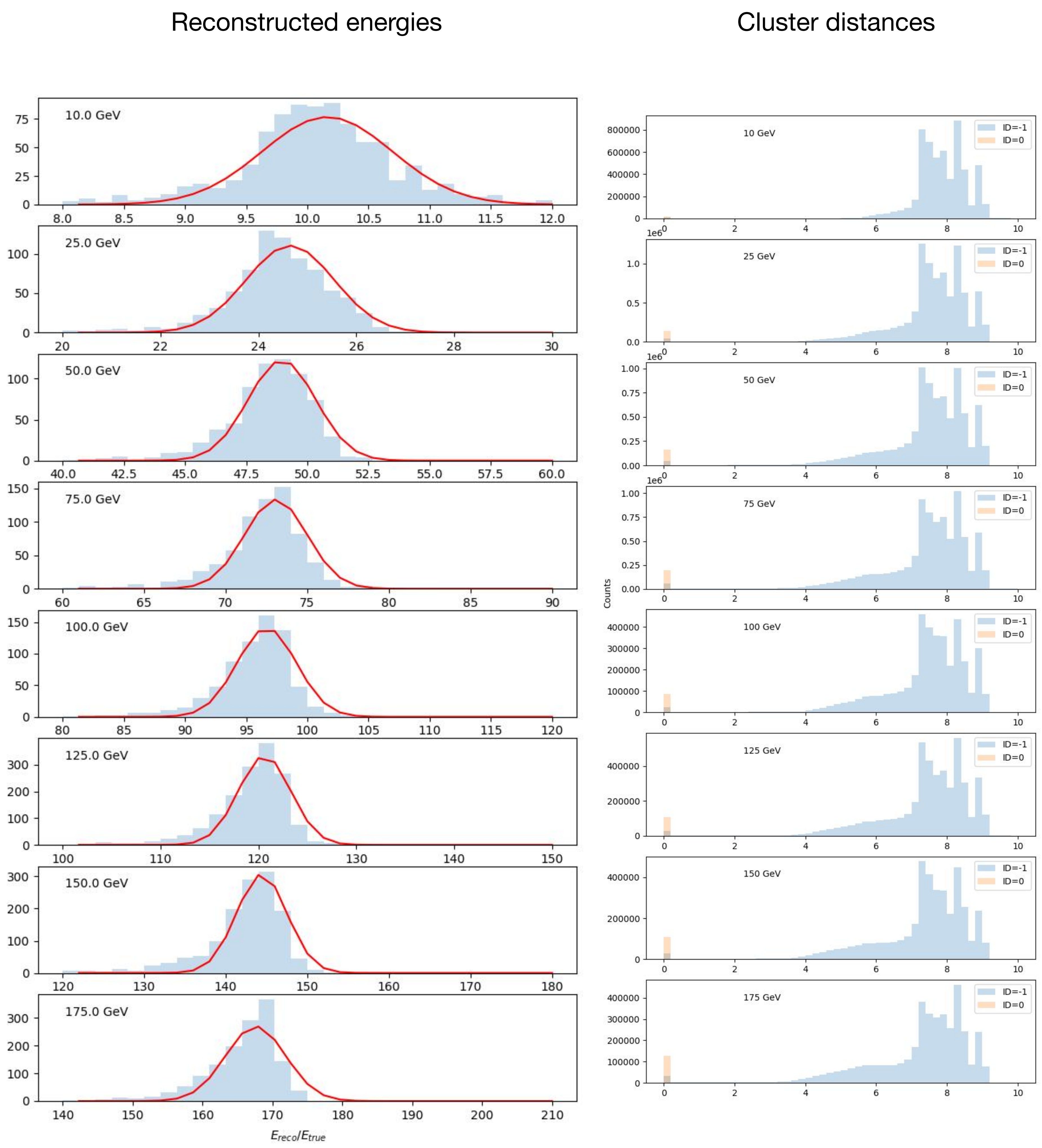
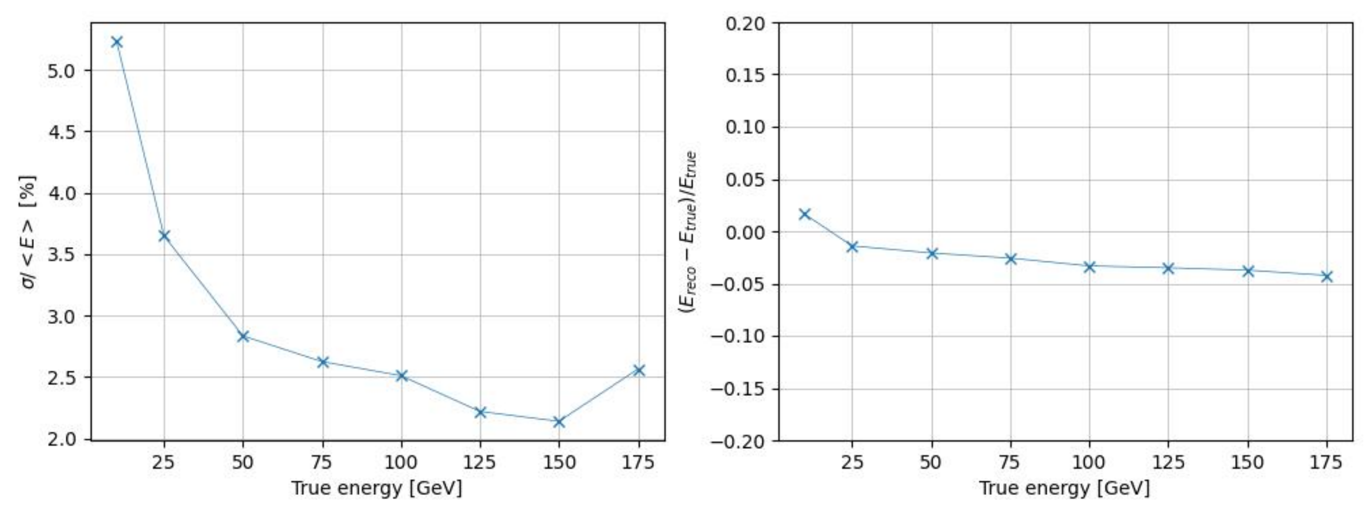
Thank you!





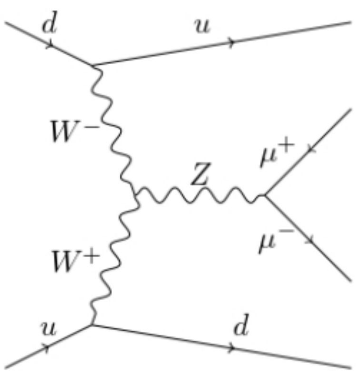
14th EFFICIENT SCIENTIFIC COMPUTING" ESC22

04/10/23 - 12/10/23

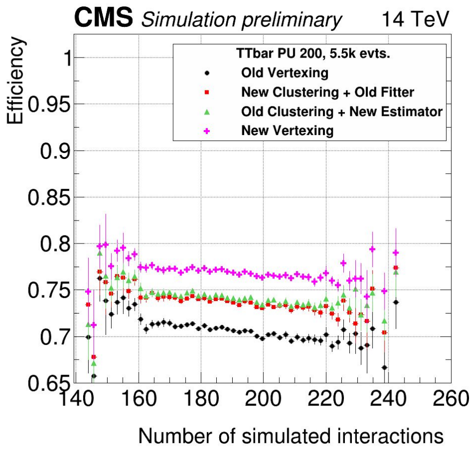
Giorgio Pizzati

Research activities

- I'm a second year Ph.D. student in Milano-Bicocca working for CMS
- Mainly working on the Vector Boson Fusion of the Z analysis for Run 2 with Effective Field Theory interpretations
- Have been working on the speedup of the primary vertex offline reconstruction of CMS with the main target being Phase 2 of LHC



VBF-Z topology



Algorithm label	P.V. Producer Time per event [ms]
Old Vertexing	913.0 ± 3.5
New Clustering + Old Fitter	368.0 ± 1.3
Old Clustering + New Estimator	512.6 ± 3.3
New Vertexing	145.7 ± 0.7

Offline Primary Vertex Reconstruction

- Primary vertex reconstruction in CMS is a two steps process:
  - Clustering of tracks impact points -> initial vertices position
  - Fit vertices parameters
- In CMS the Deterministic Annealing is used for the clustering step and an Adaptive Vertex Fitter[1] for the fitting
- We developed two algorithms to speed up both steps and to leverage parallel execution (GPU porting ongoing):
  - For the clustering we split tracks into blocks (based on z position) and perform the DA independently
  - For the fitting we adopted a weighted mean with outlier rejection that is run independently between vertices
-

[1] Kalman Filter with outlier rejection

A novel drift-chamber tracking system for ν-interaction studies

Alessandro Ruggeri on behalf of the Nu@FNAL Bologna group

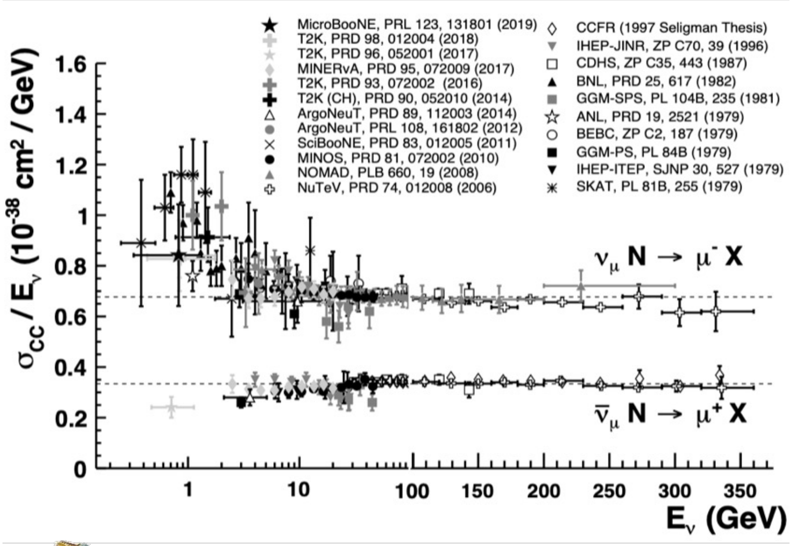
ESC2023

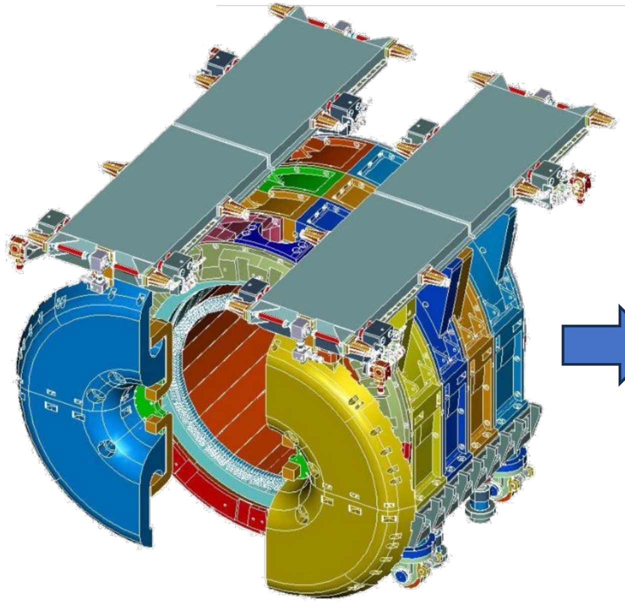
Bertinoro, 5/10/2023

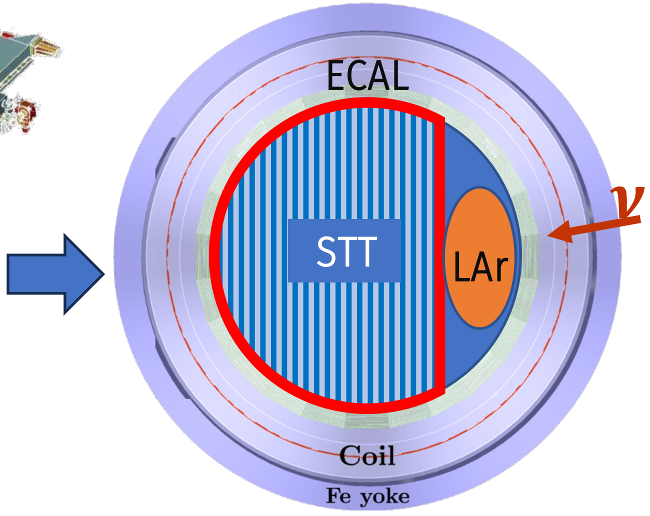
INFN
BOLOGNA
Istituto Nazionale di Fisica Nucleare
Sezione di Bologna

Cross-section measurements at DUNE-ND

- Uncertainties in neutrino cross sections at the energy range of the future DUNE and HK are currently of 10-30%.
- GeV neutrino cross section measurements on different targets needed to complement FD/ND cancellation.
- At the ND-complex of DUNE, the SAND multi-purpose detector aims at measuring $\nu/\bar{\nu}$ cross sections on different targets with its tracking system.
- This study is alternative to the base tracker design, currently using Straw Tubes.

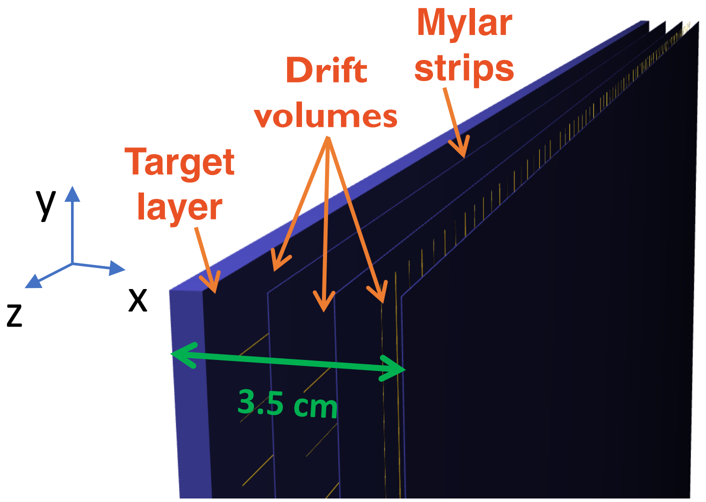


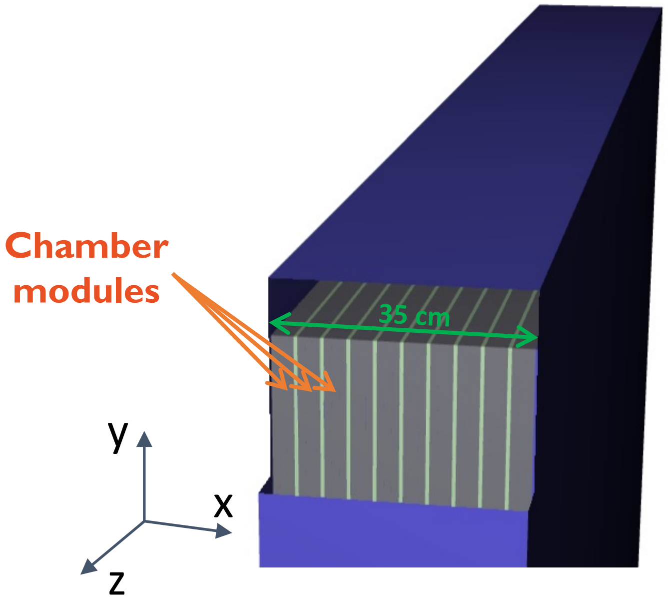




Detector concept

- Modular tracking system based on drift chambers with distributed target mass.
- Separation of ν and $\overline{\nu}$ interactions in the magnetized volume.
- Chamber modules consisting of:
  - A target layer of the required material.
  - Three wire planes in a $-5°$, $0°, +5°$ configuration with respect to the B-field axis.
- L-R ambiguity reduction and an optimal spatial resolution in the bending direction.



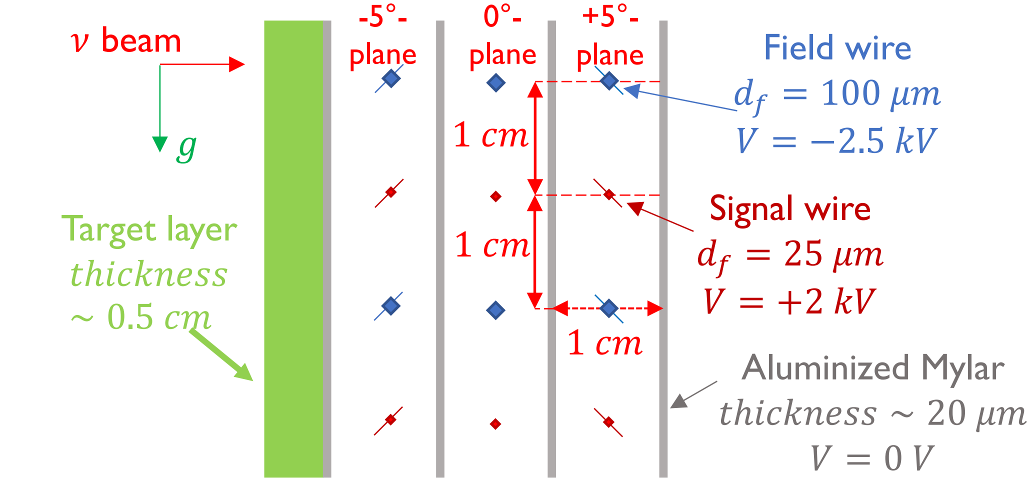


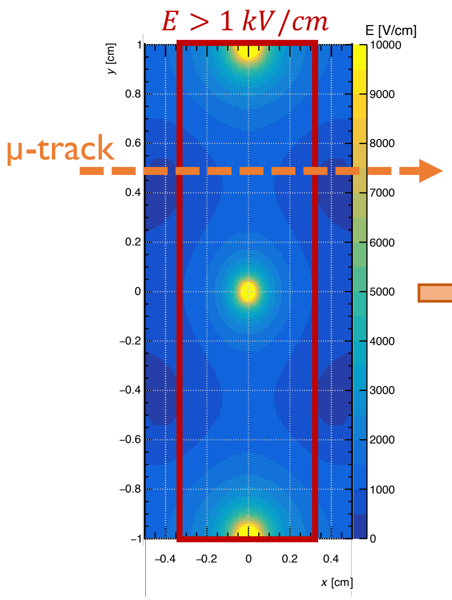
Cell layout

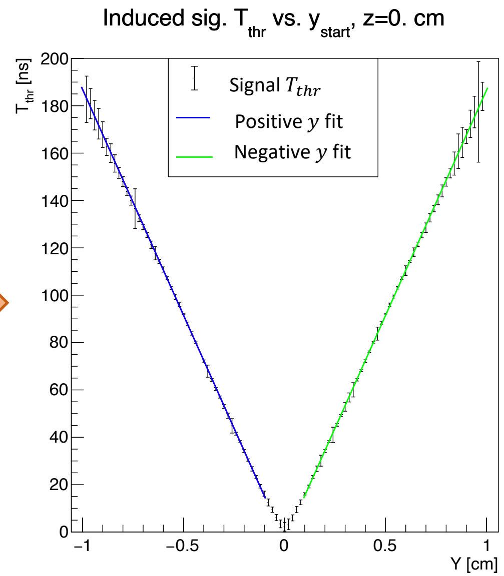
- Optimized the base drift cell layout by implementing a small-scale model of each plane in Garfield++.
- Alternating anode sense wires and cathode field wires with a 1 cm step. Cells are closed by grounded strips (1 cm thick).
- Gas mixture and voltages fixed aiming at sufficient gas gain ($\sim 10^5$) and ~constant v_{drift} along the wire plane.
- Signal time scales linearly with the wire distance in orthogonal tracks:

⇩

Precise reconstructed position thanks to equivalent $v_{drift} \sim 52\ \mu m/ns$.

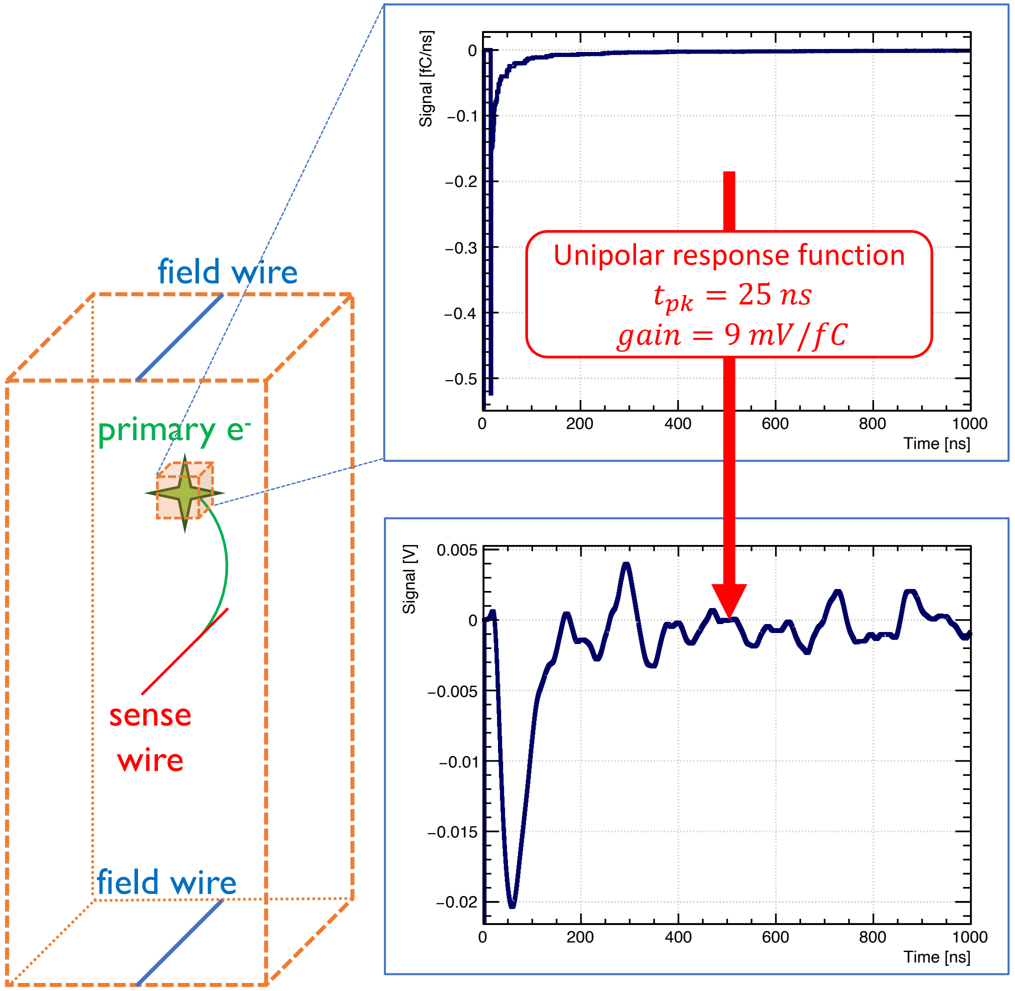






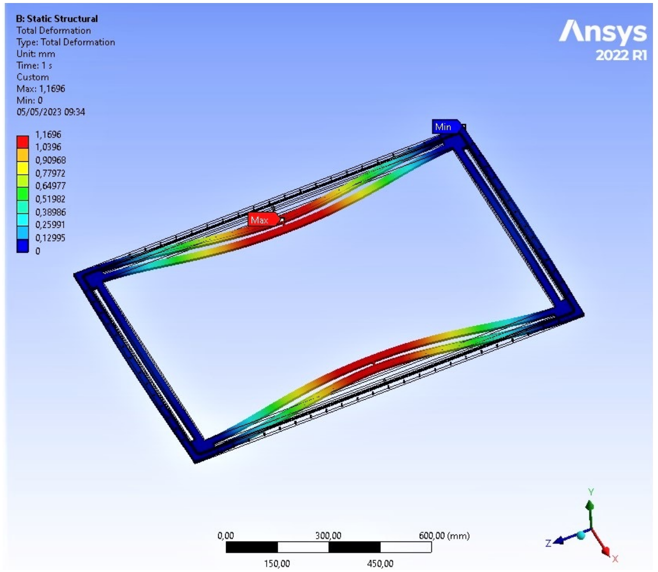
Towards track reconstruction

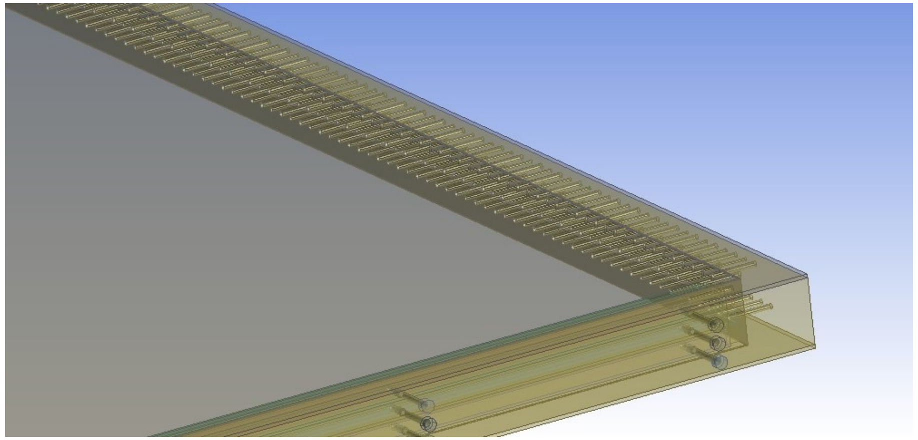
- Ionization by charged particle tracks and detector response is simulated in Garfield++.
- Detector response will be integrated in the edep-sim simulation under development.
- Towards a "Fast" simulation of the detector response by:
  1. Voxelizing a base detector cell,
  2. mapping the ionization signal of primary electrons at each point of the grid.
- Overall response obtained from summing the waveforms, assuming a uniform energy deposition within an edep-sim hit segment.



Prospects

- Ongoing activities on the design of the module frames and construction procedure.
- Implementation of the detector response in the simulation chain is to be completed.
- Aiming at building a small-scale prototype to verify the performance at a test-beam.
- Performance comparison with the Straw Tube prototype will be possible: the aim is to reach a 3% resolution on μ-momenta.
- Designs to be evaluated by 2024 depending on performance, construction time and costs.





Thank you for your attention

Muon Momentum resolution

PRELIMINAR

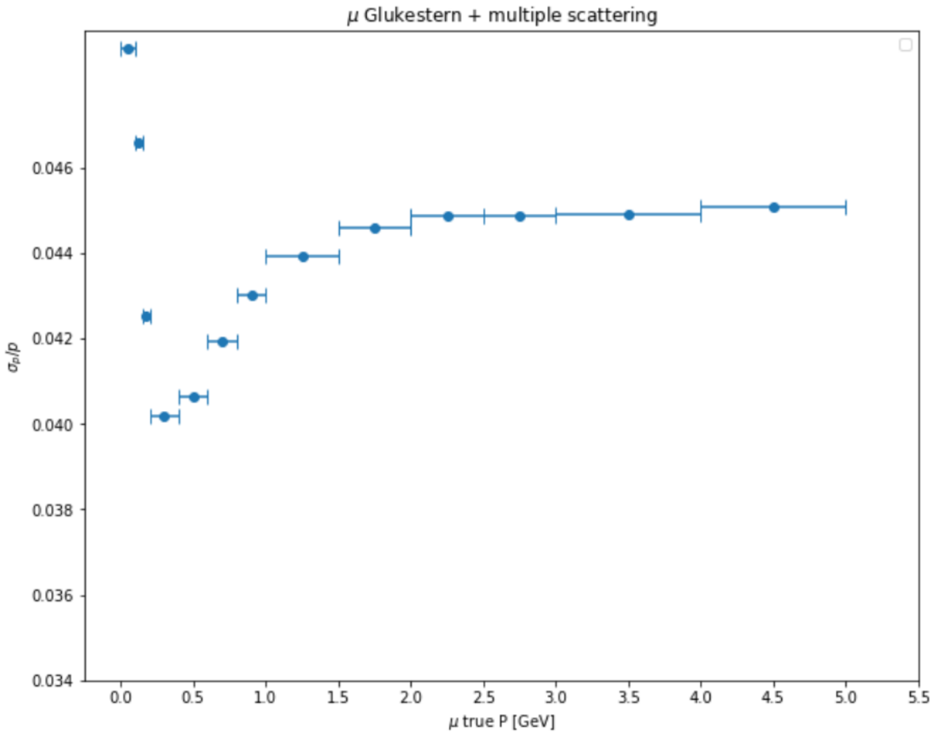
True muon momentum

$$\left(\frac{\sigma_p}{p}\right)^2 = \left(\sqrt{\frac{720}{n+4}}\frac{\sigma_y p \sin\theta}{(0.3BL^2)}\right)^2 + \left(\frac{52.3\times10^{-3}}{\beta B\sqrt{LX_0 \sin\theta}}\right)^2$$

Position resolution — Multiple scattering

Angle between track and B field

Number of hits — Path length in tracker — Radiation length



- Primary muons with at least 4 hits have been selected
- 1 hit is any muon energy deposit in a single drift volume
- Resolution: Glukestern term + multiple scattering

Data analysis for Neutrino Physics: the LEGEND Experiment

Giovanna Saleh - giovanna.saleh@phd.unipd.it

ESC23, Bertinoro, 4-12 October 2023

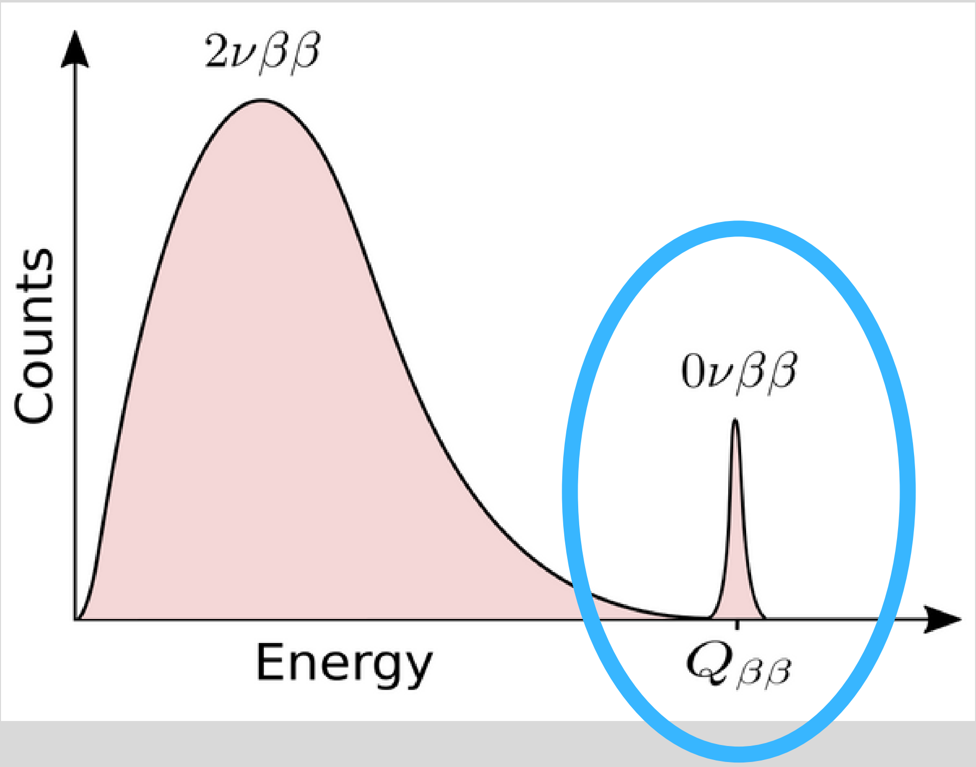
Neutrinos are

Dirac particles

Cannot undergo neutrinoless double beta decay

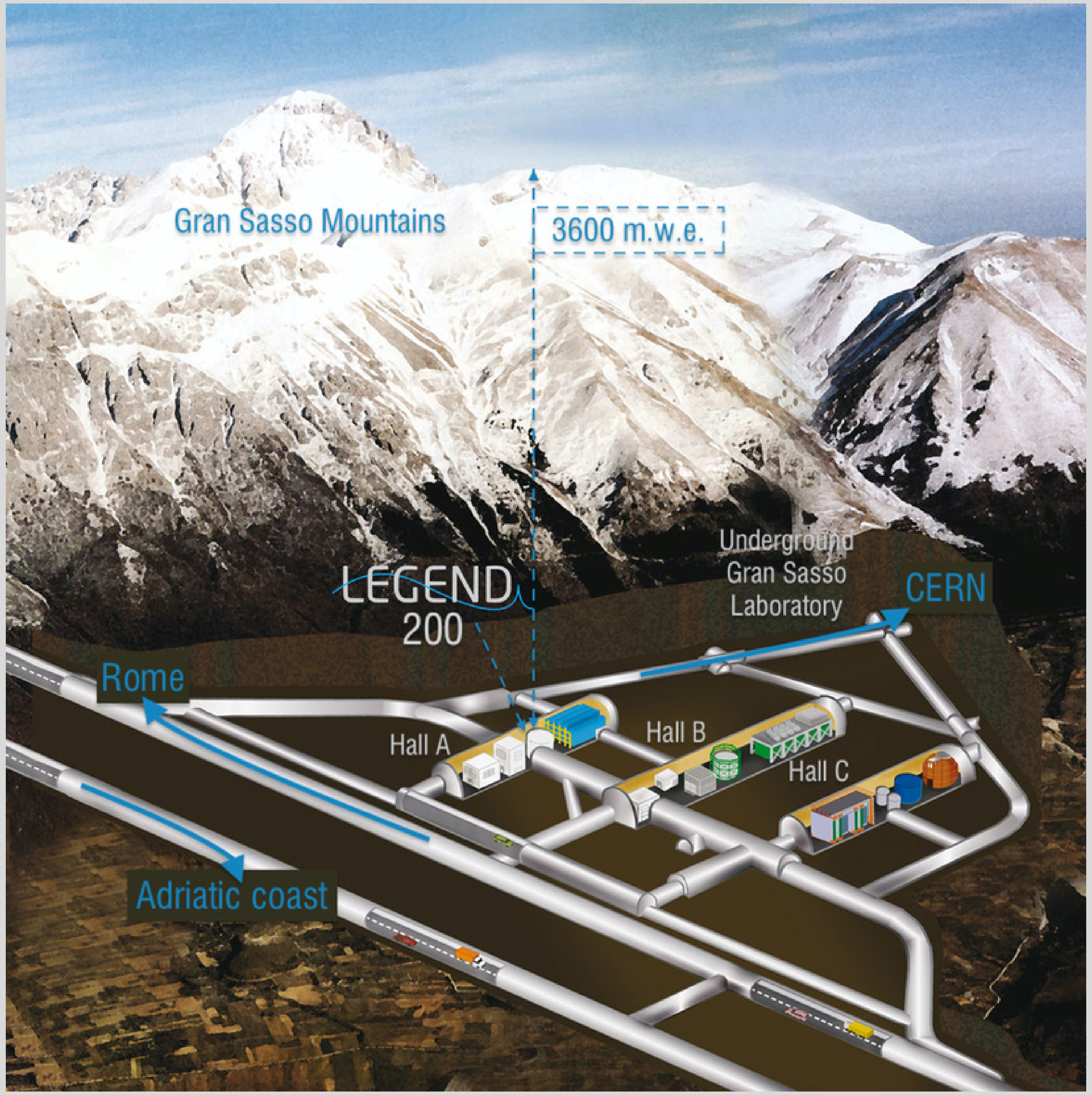
Majorana particles

Can undergo neutrinoless double beta decay



Experimental signature of neutrinoless double beta decay

The LEGEND Experiment

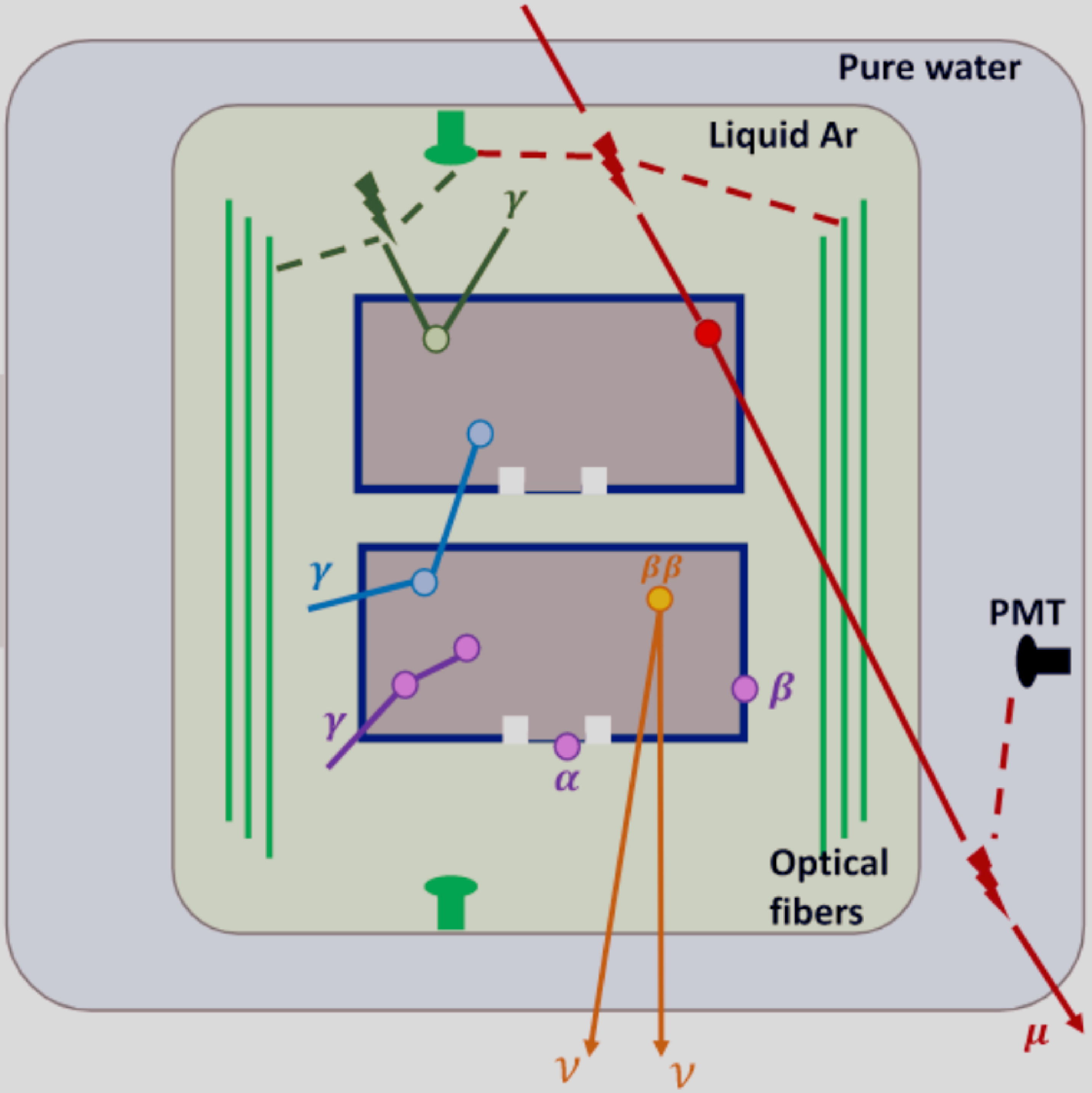


The location:
Gran Sasso National Laboratories

Inside the experiment

The analysis strategy

$\beta\beta$ decay signal: single-site event energy deposition in a 1 mm^3 volume



Pulse shape discrimination (PSD) for multi-site and surface α, β events

Ge detector anti-coincidence

LAr veto based on Ar scintillation light read by fibers and PMT

Muon veto based on Cherenkov light and plastic scintillator

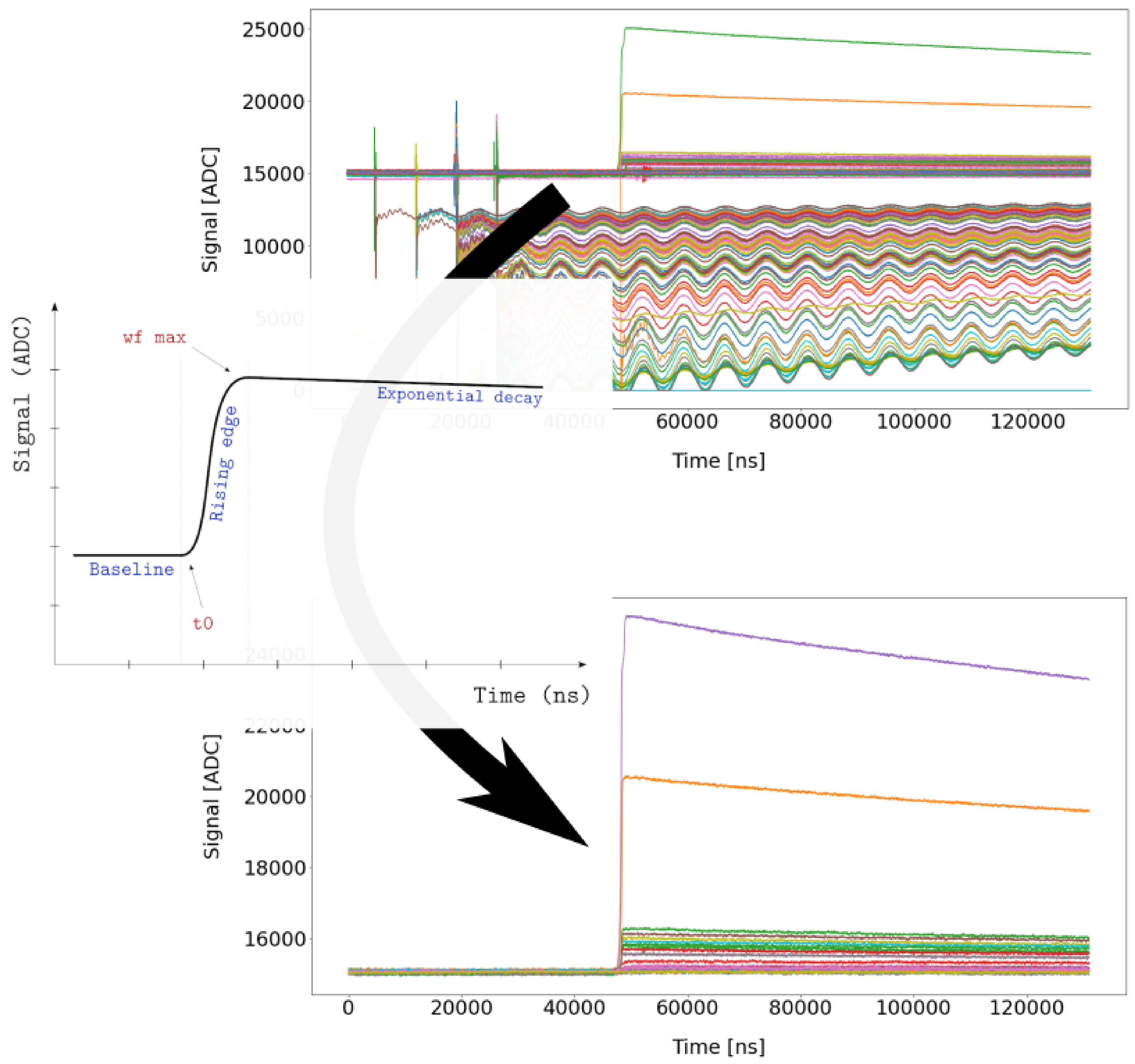
Implementation of the strategy

Event selection based on the shape of the waveform

↓

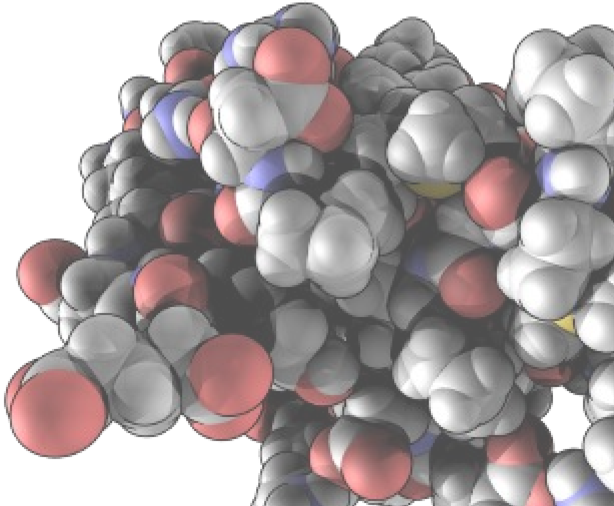
Need to develop tools to make the event selection more:

- **Efficient**
- **Fast**
- **Automatized**
- **Reliable**



Research activity:
Topological entanglement in proteins

Leonardo Salicari – ESC23



$whoami

Who am I?

- Ph.D. student in Physics at University of Padova – Statistical Mechanics group
- Associate member of INFN Complex Network project (Lincoln)

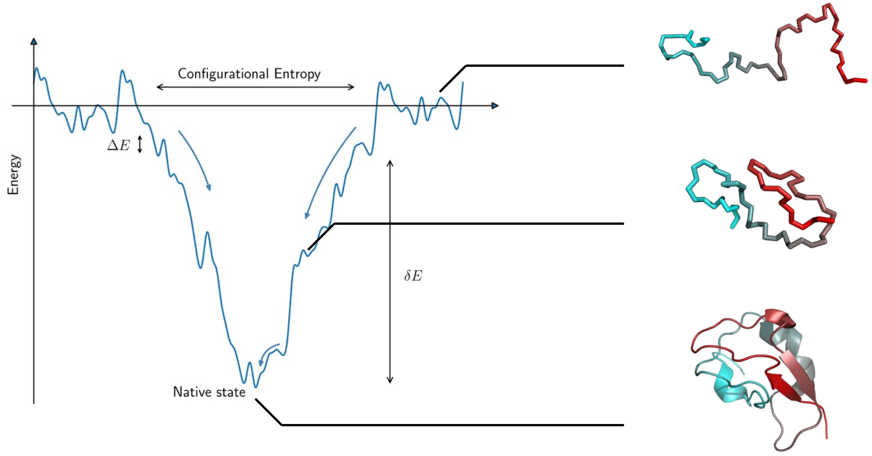
Computing interests

- Numerical simulations, data analysis, software engineering

Research activities

- **Numerical/theoretical**: Newtonian dynamics and statistical mechanical models of interacting spins simulations to probe equilibrium and refolding properties of proteins with a non-trivial topology
- **Bioinformatics**: topology analysis of protein structures datasets

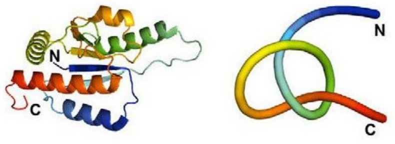
Research activities: an introduction



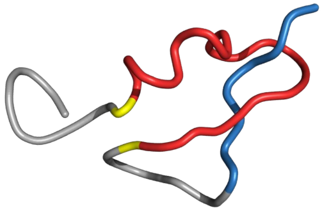
Proteins for a physicist: heteropolymers with an "optimized" network of interactions

Chain refolding happens in an exponentially large phase space. However, real proteins can be framed in the **funnel-shaped free energy landscape** picture

3_1 Knot



Non-covalent lasso



Challenge to the framework:
naturally occurring **topologically entangled motifs** in proteins

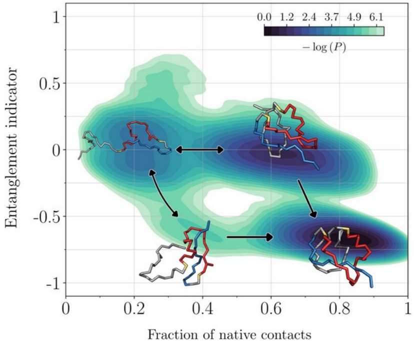
How does the entanglement change the landscape?
How these structures avoid being trapped in local minima?

Anfinsen, Science 1973 | Ferreiro, Q. Rev. Biophys. 2014 | Lim, Condens. Matter 2015 | Baiesi, Sci. Rep. 2019

Computing activities

Molecular Dynamics (MD) refolding simulations with coarse-grained, structure-based models

$$V = \sum_{i=1}^{N-1} \varepsilon_r^i \left(r^{i\,i+1} - r_0^i\right)^2 + \sum_{i=1}^{N-2} \varepsilon_\theta^i \left(\theta^i - \theta_0^i\right)^2 + \sum_{i=1}^{N-3} \varepsilon_\phi^i \left\{\left[1-\cos\left(\phi^i-\phi_0^i\right)\right] + \frac{1}{2}\left[1-\cos\left(3\left(\phi^i-\phi_0^i\right)\right)\right]\right\} + \sum_{i+3<j}^{\mathrm{NAT}} 4\varepsilon_C^{ij}\left[\left(\frac{\sigma^{ij}}{r^{ij}}\right)^{12} - \left(\frac{\sigma^{ij}}{r^{ij}}\right)^{6}\right] + \sum_{i+1<j}^{\mathrm{NON}} V_{\mathrm{NN}}\left(r^{ij}\right)$$



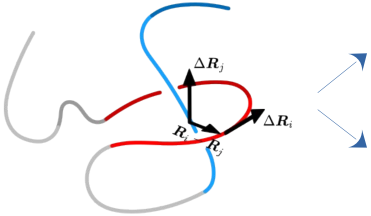
WSME model using Monte Carlo Markov chains (MCMC)

$$\beta H^{\mathrm{eff}} = -\lambda \sum_{i=1}^{N} \sum_{j=i+1}^{N} n_{ij}\Delta_{ij} \prod_{k=i}^{j} m_k + q \sum_{i=1}^{N} m_i - \Lambda \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{H_i}{Q_i^{\mathrm{TOT}}} n_{ij}\Delta_{ij} \prod_{k=i}^{j} m_k$$

Data analysis of protein structure datasets

Gaussian Entanglement

$$G'(\gamma_i, \gamma_j) := \frac{1}{4\pi} \sum_{i=i_1}^{i_2-1} \sum_{j=j_1}^{j_2-1} \frac{\boldsymbol{R}_i - \boldsymbol{R}_j}{\left|\boldsymbol{R}_i - \boldsymbol{R}_j\right|^3} \cdot \left(\Delta\boldsymbol{R}_i \times \Delta\boldsymbol{R}_j\right)$$



RCSB PDB PROTEIN DATA BANK

AlphaFold 2

Wako J. Phys. Soc. Jpn. 1978 | Clementi, JMB 2000 | S., IJMS 2023 | S., BiorXiv 2023 | GH repo: pyge

Personal goals for ESC

Improve OOP in modern C++ to design and extend open source MD software (e.g. LAMMPS)

Learn parallelization (CPU and GPU-based) with C++ for MCMC applications

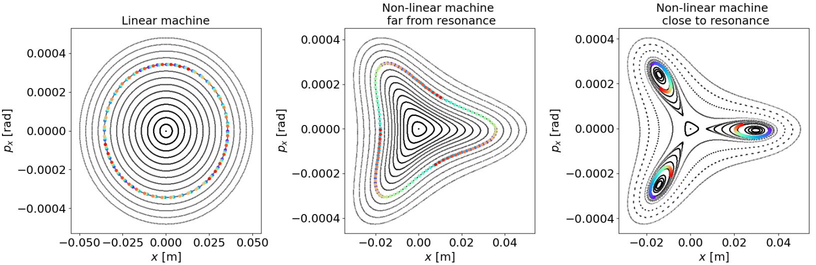
Research activities and interests

Dora Veres

- **Master of Physics**, University of Oxford, UK (2018-2022)
  - Optimising the Higgs to Charm Quarks Decay Analysis Using Machine Learning
- **PhD in Physics**, Goethe Universitat Frankfurt am Main, Germany (2022-)
  - Manipulating charged particle beams using stable islands and crystals

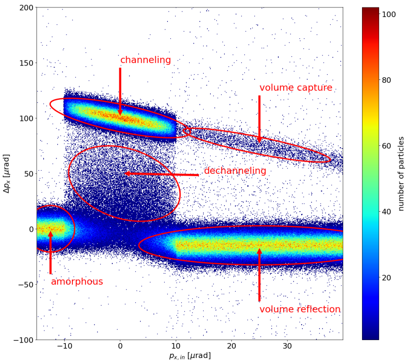
Research

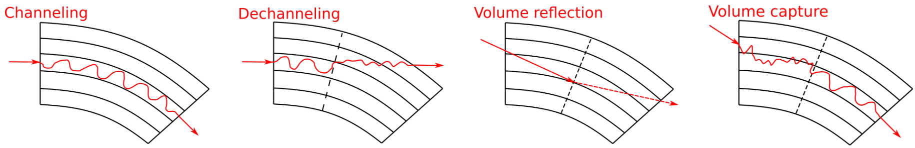
- Stable islands in particle accelerators:
  - Linear machine (dipoles and quadrupoles only): particle orbits are ellipses in phase space
  - Non-linear machine (higher order multipoles): particle orbits distorted
  - If fractional betatron tune is close to $\frac{1}{\text{integer}}$, resonances occur
  - Stable islands form close to resonances
- Particle tracking simulations:
  - Can use mathematical models (e.g. Henon map) – quick, but doesn't capture all properties of machine
  - Model accelerator as sequence of maps corresponding to single elements – tracking through many elements is time-consuming



Research

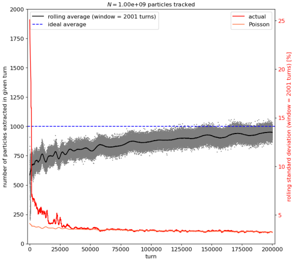
- Modeling charged particle interaction with bent crystals
  - Need fast routines for high statistics simulations
  - Implementations exist in popular particle tracking codes SixTrack (Fortran) and Xsuite (C)
  - Particles propagated in crystal based on probabilities of scattering and coherent interactions

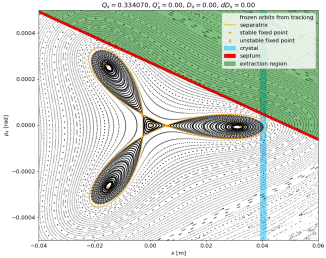


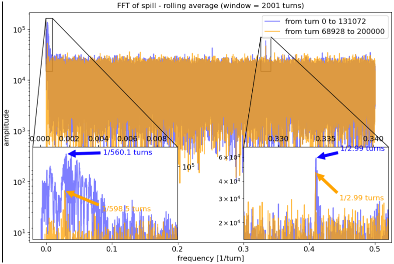


Research

- Usecases of stable islands + crystals
  - Capturing and channeling beam halo particles for LHC fixed target experiments
  - Reducing losses during resonant slow-extraction







Goals

- Improve C++ skills
- Learn efficient memory handling
- Learn efficient parallelization
- GPU computing
- Use the skills learnt to contribute to particle tracking codes developed at CERN and improve my own simulations

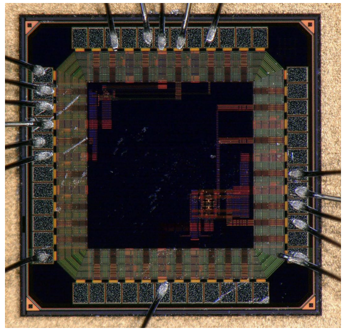
The Tangeine project: Development of high-resolution pixel sensors

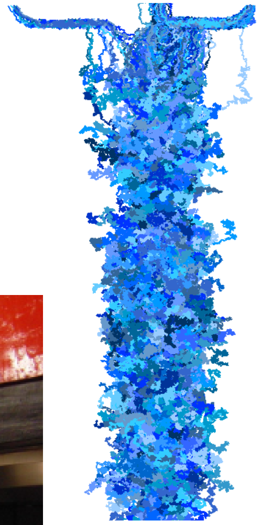
H. Wennlöf, DESY

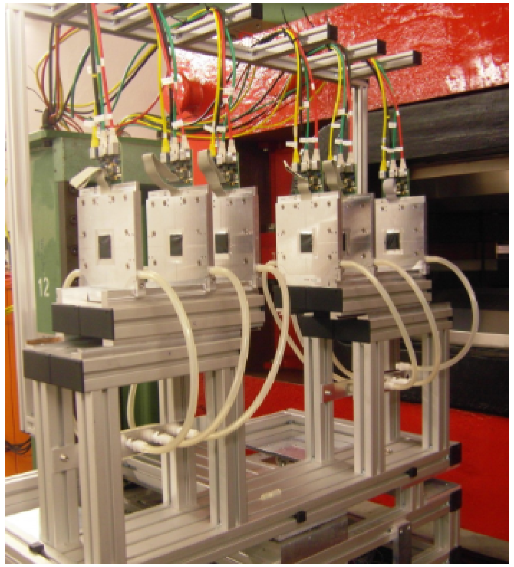
Efficient Scientific Computing, 2023

The Tangerine project (Towards next generation silicon detectors)

- Started in 2021 with the aim of **developing and investigating particle detection sensors in new silicon technologies**
- Long-term goal: development of sensors for vertexing and tracking detectors in **future electron-ion and lepton colliders**
- The project encompasses all aspects of sensor developments: electronics design, sensor design, prototype test chip characterisation
  - Combination of lab tests and **simulations**
- The goal is development of a sensor with **high precision and low material**
  - Spatial resolution below 3 μm
  - Time resolution of less than 10 ns
  - Very low material budget, corresponding to at most 50 μm of silicon (0.05% X/X_0)
  - Per-pixel charge measurement
- Primary initial goal (2023): development of a sensor for telescope use, for testbeams
  - This will **demonstrate the capabilities of the 65 nm CMOS imaging technology in a particle physics context**





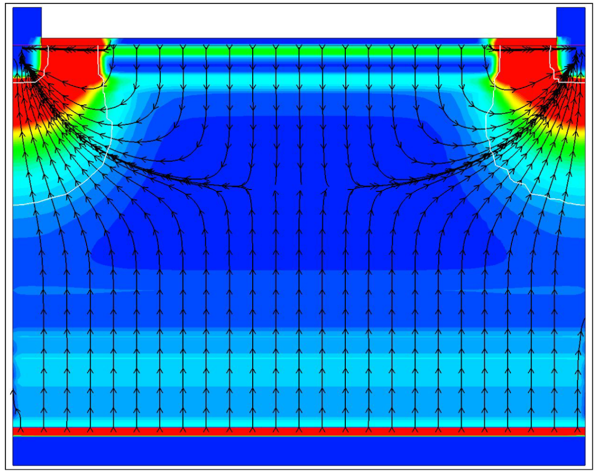


Tools used in the simulation approach (my TIPP23 presentation holds more details)

Sentaurus TCAD
SYNOPSYS® Silicon to Software™
Technology Computer-Aided Design

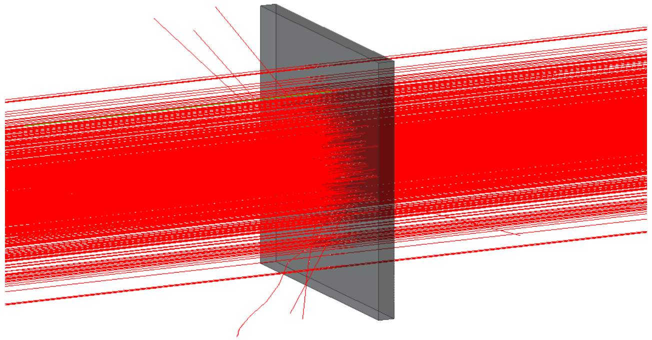
Allpix Squared: a Monte Carlo simulation framework for semiconductor detectors
https://allpix-squared.docs.cern.ch/

- Models semiconductor devices using **finite element methods**
- Calculates realistic and accurate **electric fields and potentials** from doping concentrations



Example electric field in TCAD

- Simulates **full detector chain**, from energy deposition through charge carrier propagation to signal digitisation
  - Interfaces to **Geant4** and **TCAD**
- Simulation performed **quickly** - allows for **high-statistics** data samples across a full detector



Particle beam passing through a single sensor in Allpix^2

Allpix Squared

A Monte Carlo simulation framework for semiconductor detectors

- Simulates **charge carrier motion** in semiconductors, using **well-tested** and **validated** algorithms
  - Includes different models for e.g. charge carrier mobility, lifetime and recombination, trapping and detrapping
  - Support for several semiconductor materials and pixel and sensor geometries
- Provides a **low entry barrier** for new users
  - Simulations are set up via **human-readable configuration files**
- **Steady development** over many years
  - Framework is **easily extendable** and **widely used**
  - **Open-source**, and written in **modern C++**
  - Version 3.0.2 released on the 28th of September this year
- User workshop presentations hold many example applications

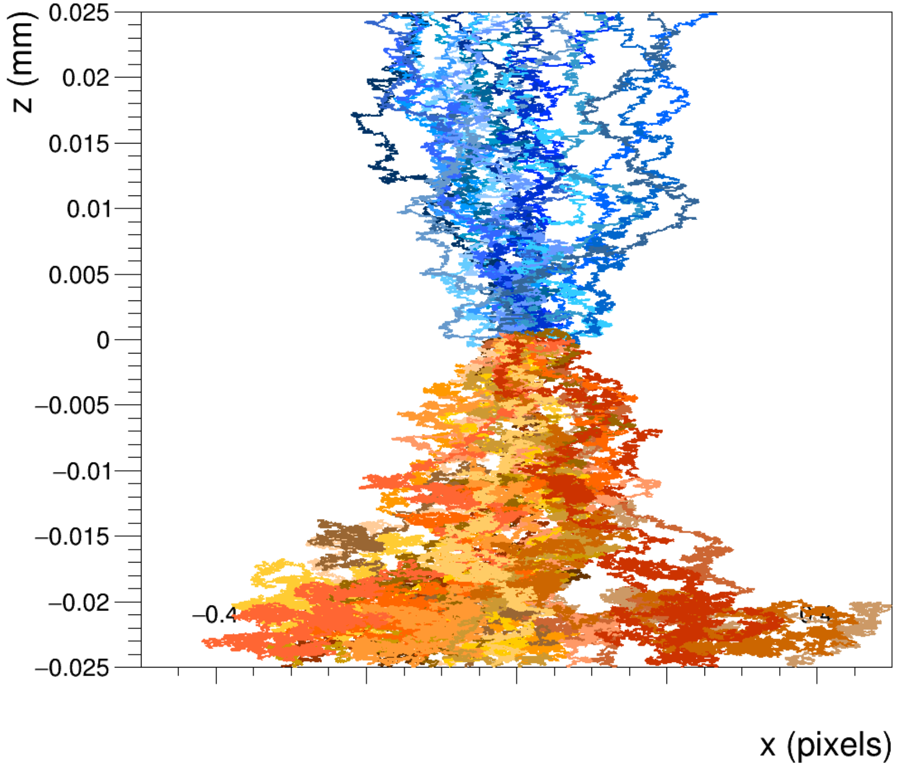
Website and documentation:
https://allpix-squared.docs.cern.ch/

```
[AllPix]
number_of_events = 10000
detectors_file = "telescope.conf"

[GeometryBuilderGeant4]
world_material = "air"

[DepositionGeant4]
particle_type = "Pi+"
number_of_particles = 1
source_position = 0um 0um -200mm
source_type = "beam"
beam_size = 1mm
beam_direction = 0 0 1

[ProjectionPropagation]

[SimpleTransfer]

[DefaultDigitizer]
```

Minimal simulation configuration example

Allpix Squared - striving for increased efficiency

- The framework is mostly multithreaded, but so far **only on CPUs**
- The simulation of individual charge carriers takes time, but is in theory **highly parallelisable**
  - The main bulk of the simulation time is spent in charge carrier propagation
  - If this were to be reduced, simulations would be significantly quicker/use less resources
- My interest lies in learning to **identify bottlenecks** and **increase the performance** of the framework
  - Some known bottlenecks are not straightforward to sort out, but I look forward to learning about possibilities
- Simulations are **essential** for increasing understanding of sensor behaviour and designing new prototypes



Simulated **motion paths** of individual electrons and holes deposited in the centre of a silicon sensor with a linear electric field