ATLAS NA 2024 report

Francesco Cirotto *on behalf of ATLAS NA team*
Università degli Studi di Napoli Federico II & INFN Napoli

ATLAS NA

ATLAS Napoli

2024 and 2023 Group overview

Acampora Giovanni
Aloisio Alberto
Alviggi Mariagrazia
Auricchio Silvia
Camerlingo Maria Teresa
Canale Vincenzo
Carlino Gianpaolo
Casolaro Pierluigi
Cirotto Francesco
Conventi Francesco
Corvino Antonio
D'Avanzo Antonio
D'Onofrio Adele
de Asmundis Riccardo
Della Pietra Massimo
Di Donato Camilla
Doria Alessandra
Iengo Paolo
Izzo Vincenzo
Massarotti Paolo
Merola Leonardo
Perna Simone
Rossi Elvira
Russo Guido
Sabella Gianluca
Schiattarella Roberto
Spisso Bernardino
Sekhniaidze Givi
Vitiello Autilia

2 + 1
PhD students

3 + 1
Theses: 2 master e 2 bachelor

7 + 5
Partecipation at international conferences

~180
Published papers

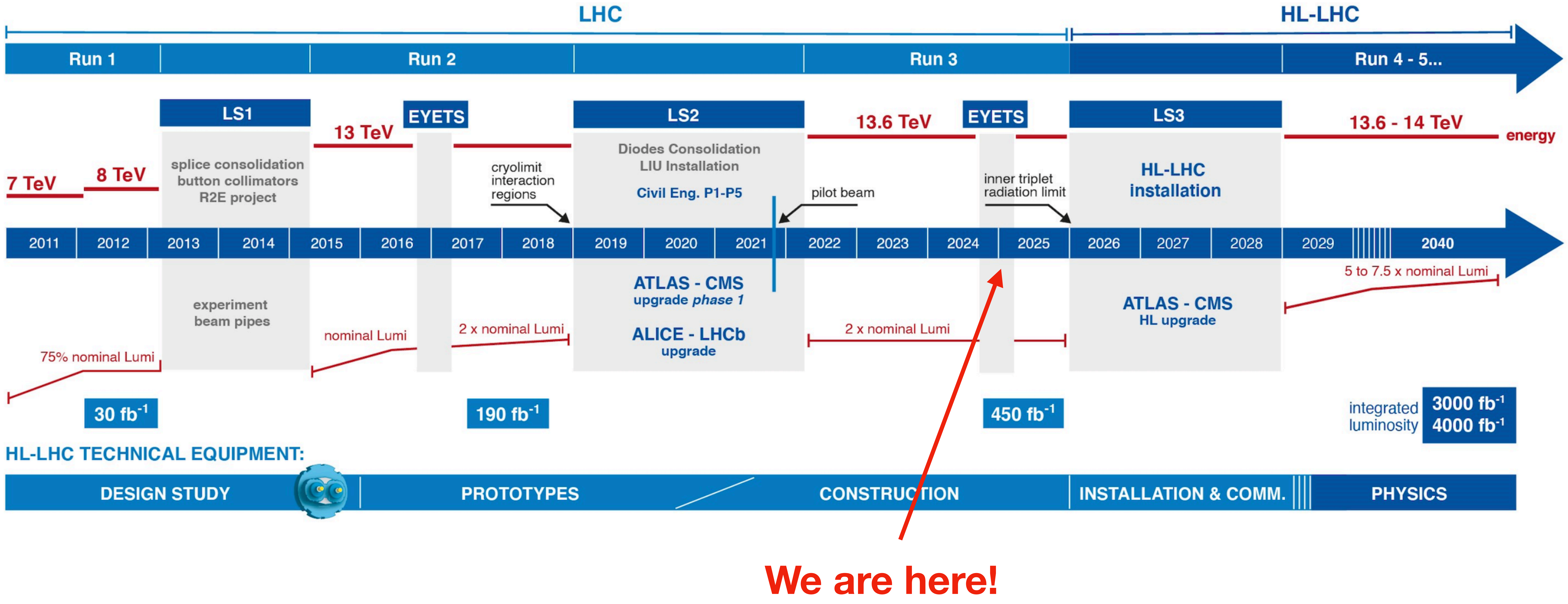
6
Official responsibilities inside Collaboration

360
Hours as shifter in ATLAS Control Room in 2024

~220
Days as detector on-call experts in 2024

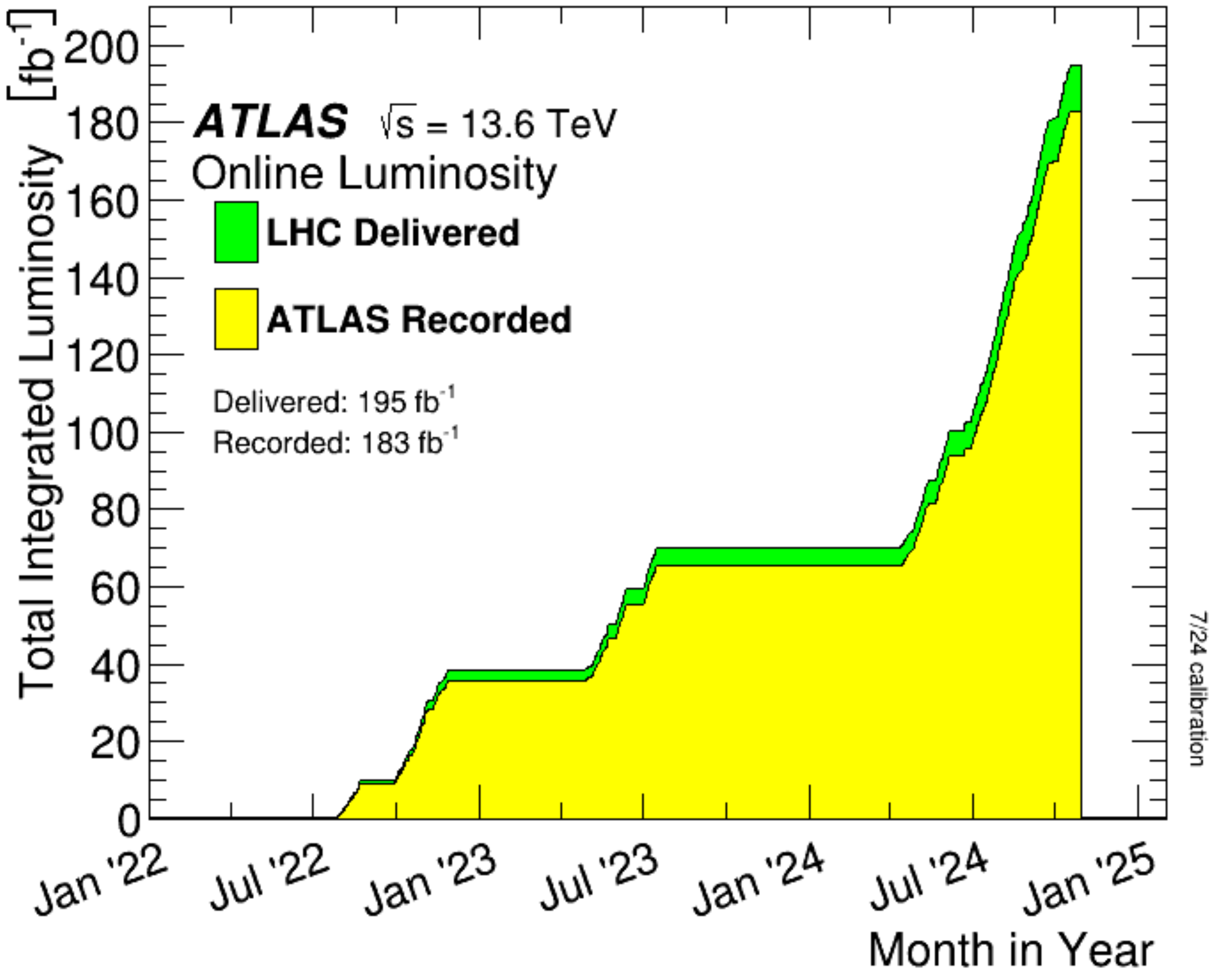
LHC Schedule

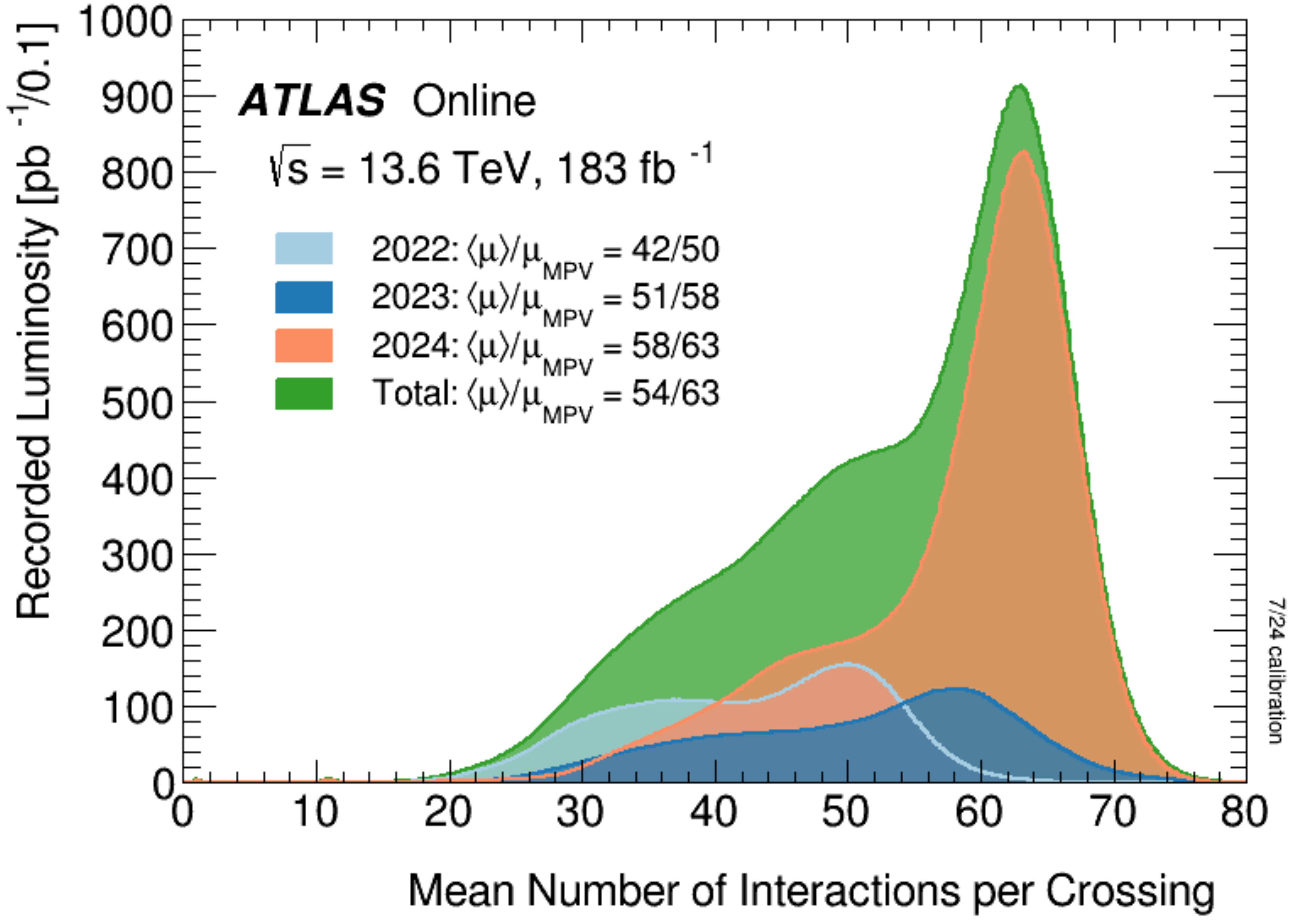
- **Run1**: 2011 – 2012 - 7 & 8 TeV collisions
- **Run2**: 2015 – 2018 - 13 TeV collision
- **Run3**: 2022 - 2026 - 13.6 TeV collisions (ongoing)



ATLAS IN RUN3

- 2022-2024: LHC is delivering as scheduled, at 13.6 TeV
  - ↪ATLAS was running at **94% recording efficiency**
  - ↪LHC had μ=63 for Run3 (x2 larger than Run2)

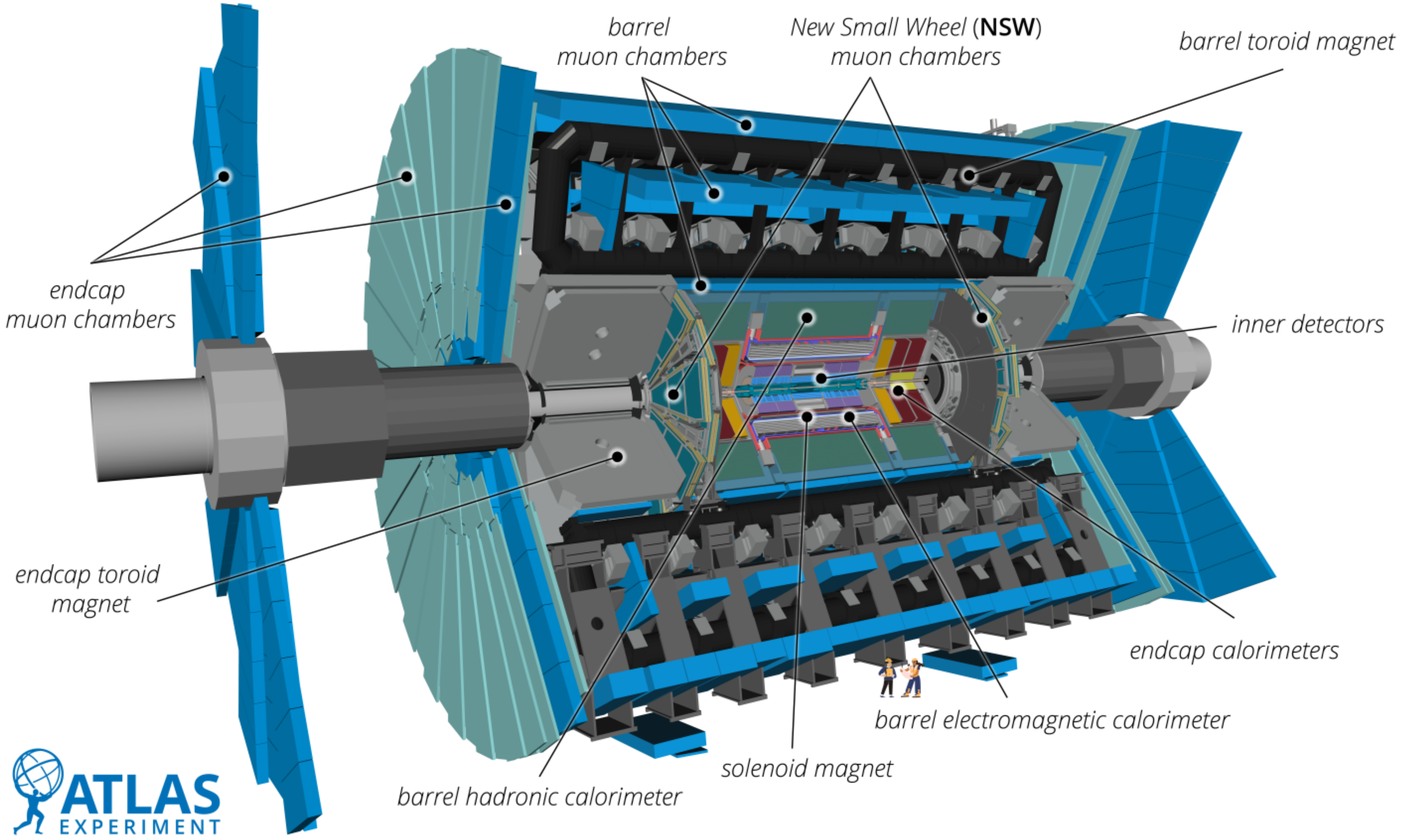




DETECTOR IMPROVEMENT FOR RUN3

- Muon New Small Wheel system included in data resulted in increased efficiency for muons in 2023
- Improved Large Radius Tracking (LRT) for Run 3
- Calorimeter timing information to reject contributions from pileup to topoclusters (used for jets)
- Machine-Learning (ML) entering all stages of the reconstruction/calibration chains

  ↪Improved flavor tagging using ML ("GN2")



Focus on Naples activities!

Physics Analyses

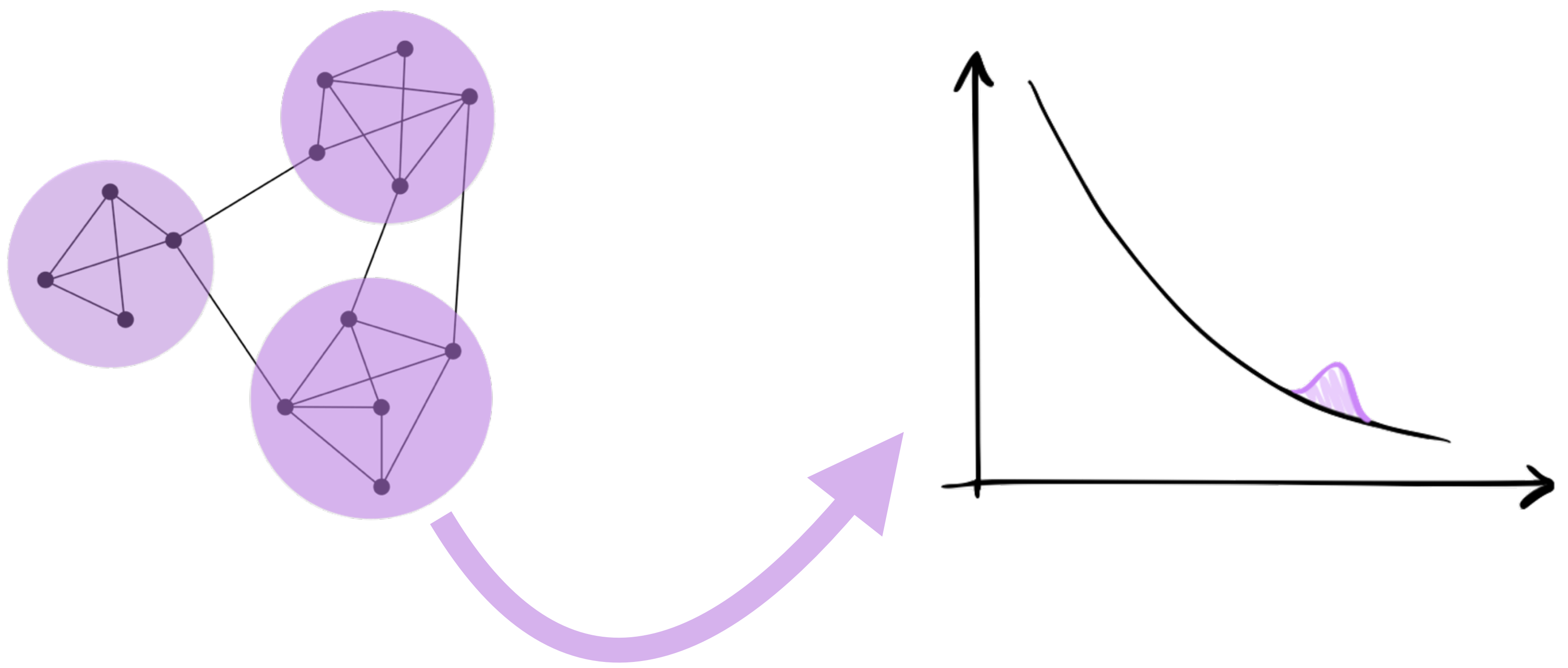
Rossi E., Conventi F., D’Onofrio A., Cirotto F, D’Avanzo A., Acampora G, Schiattarella R., Vitiello A.

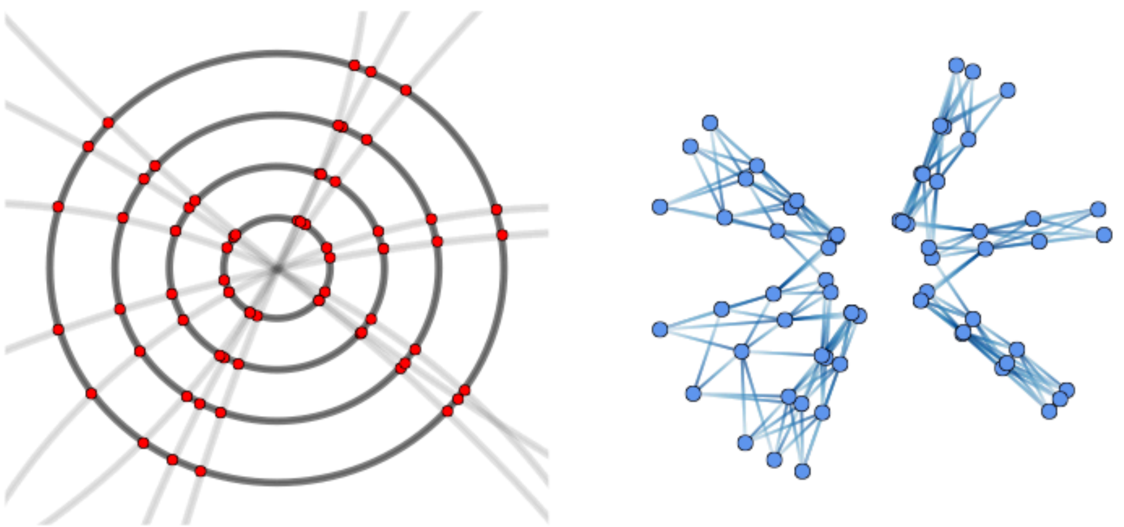
Graph Anomaly Detection for New Physics Searches

- Graph-structured data are ubiquitous across science, engineering, and many other domains
  - ↪Used to describe and analyze relations and interactions
  - ↪Can encapsulate object or event information
  - ↪Can be employed in particle physics!

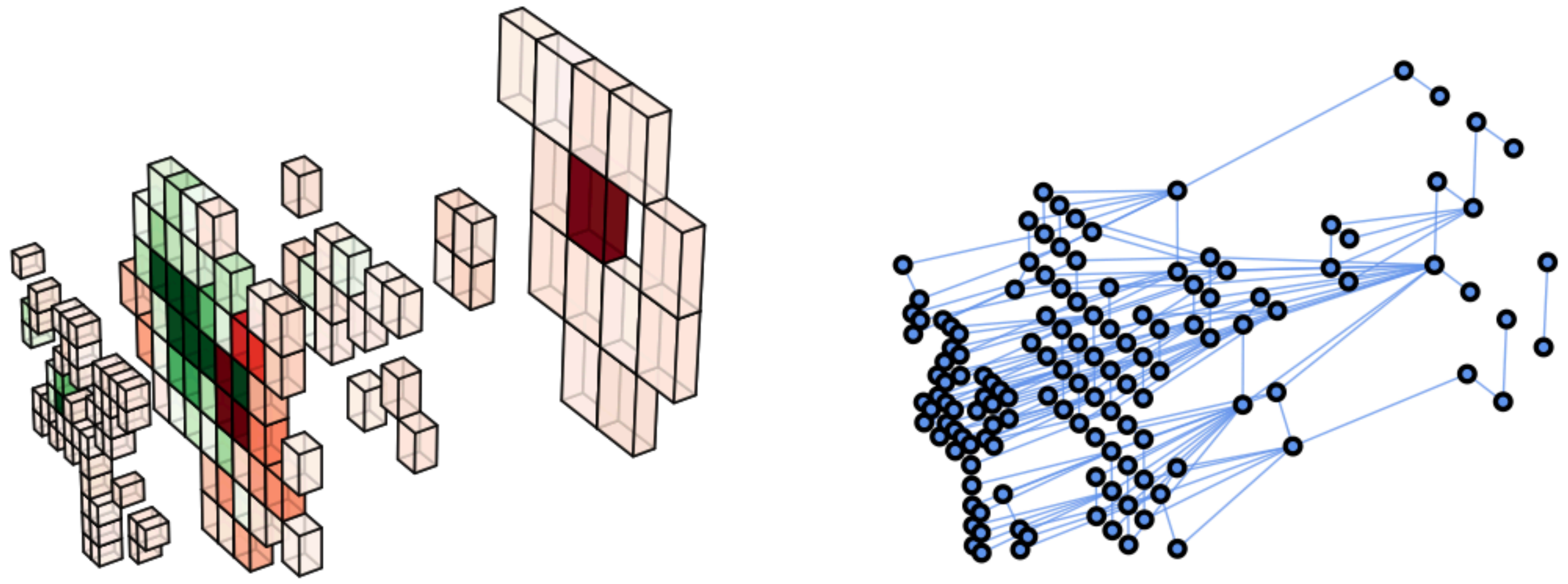
- Our strategy: **to represent jets as graphs and then apply machine learning to build an anomaly detection algorithm**
  - ↪Targeting heavy resonance searches with hadronic final states in Run-3
  - ↪Exploit event-based graphs to detect anomalies

- Jet information can be used as input features for neural network architectures.
  - ↪A significant improvement in performances can be achieved by employing a set of features with basic information (**low-level**) such as information coming directly from the detectors.
  - ↪Jet constituents represent challenging input features to achieve this goal





(a)



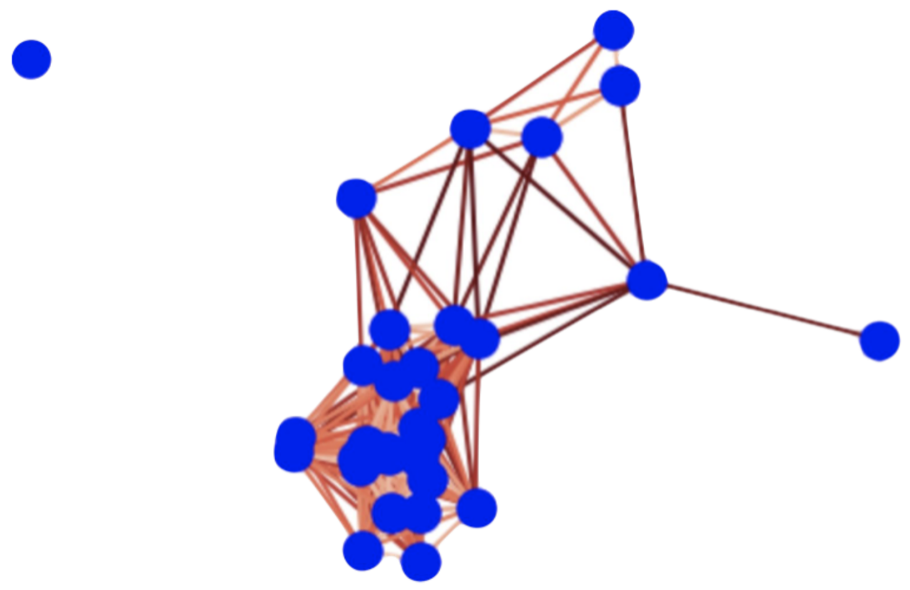
Graph Anomaly Detection for New Physics Searches

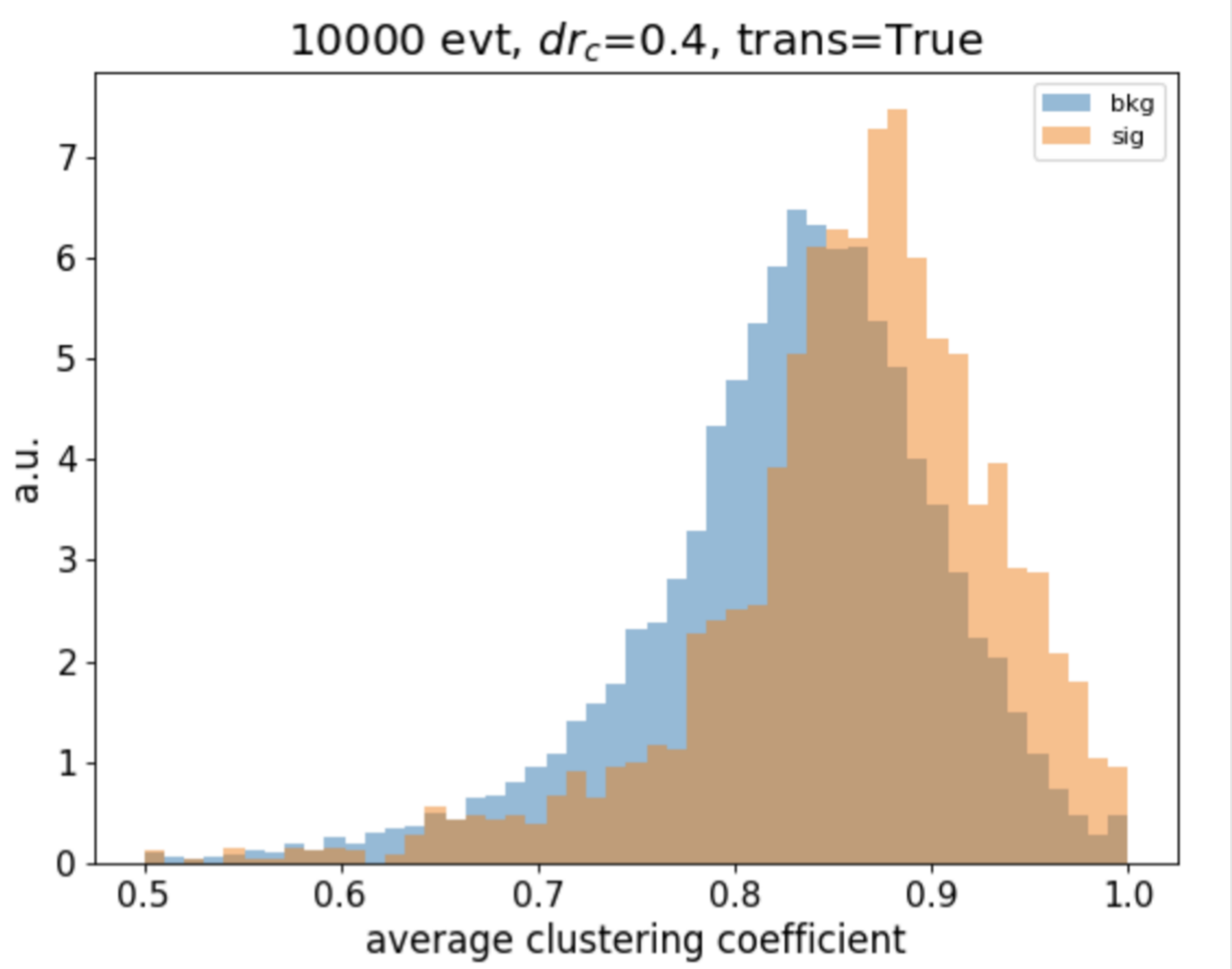
Graph definition

- What is a node?
  - ↪Using jet constituents
  - ↪Fraction of jet pt, eta, phi

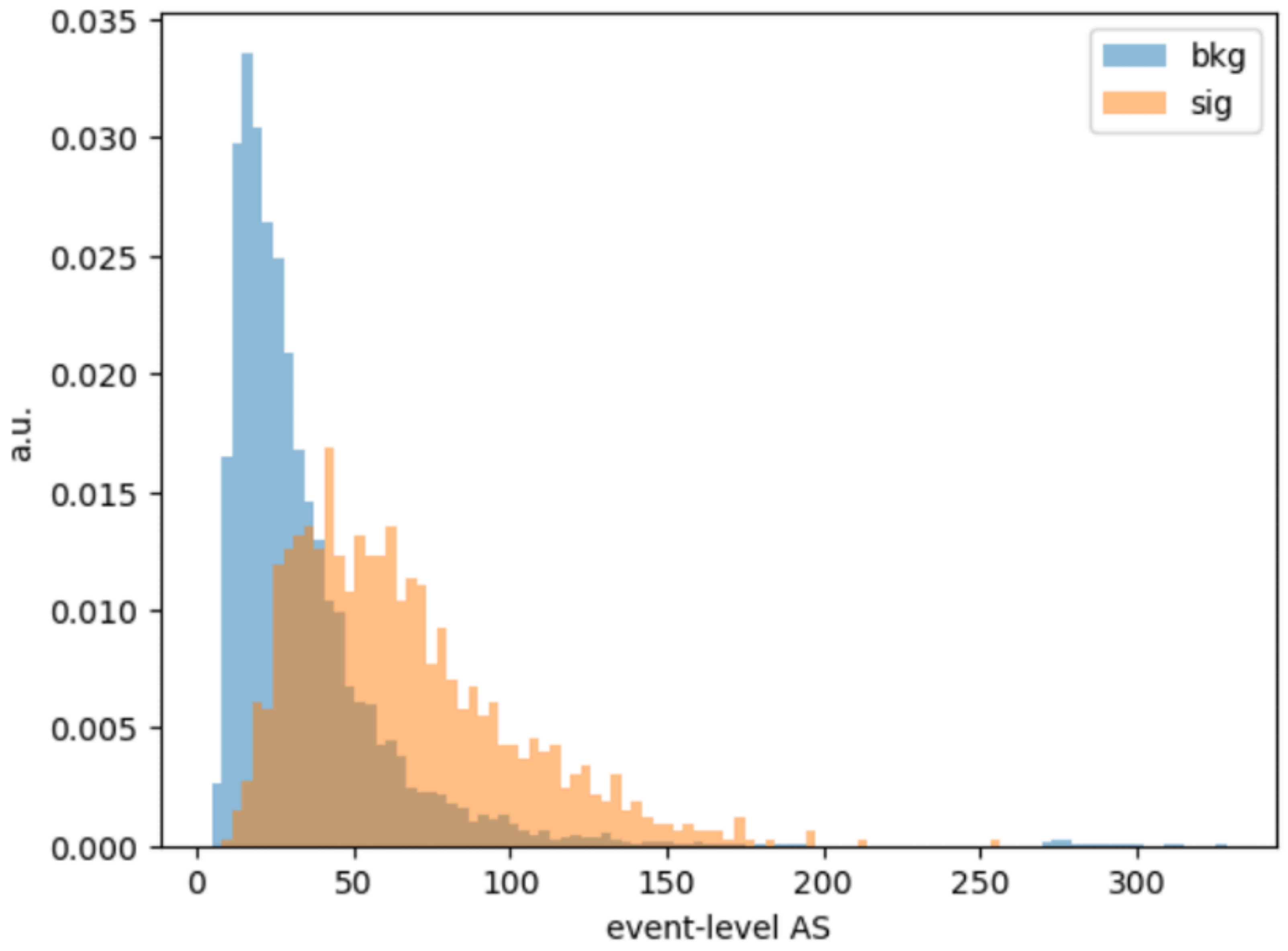
- What is an edge?
  - ↪Weight message from neighboring nodes
  - ↪Using "distance" between jets

- How are they connected?
  - ↪No self loops, DR cut = 0.4





Measure of the degree to which nodes tend to cluster together



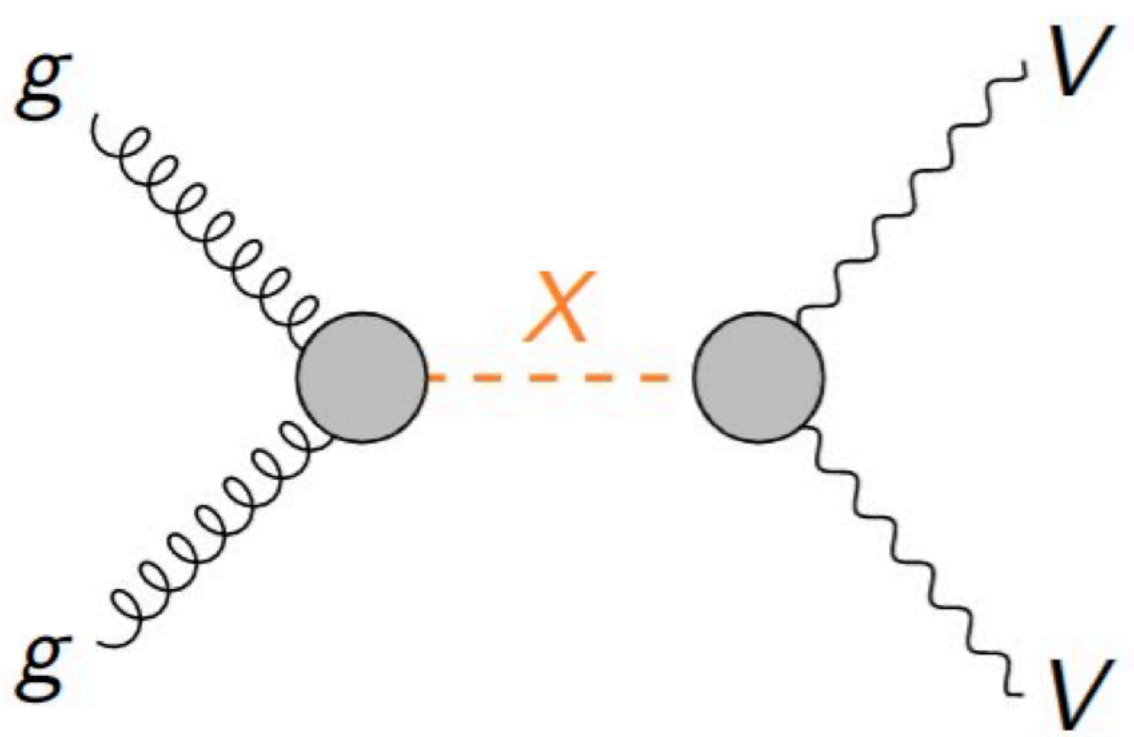
VBF-RNN TAGGER

A new tagger for diboson analyses

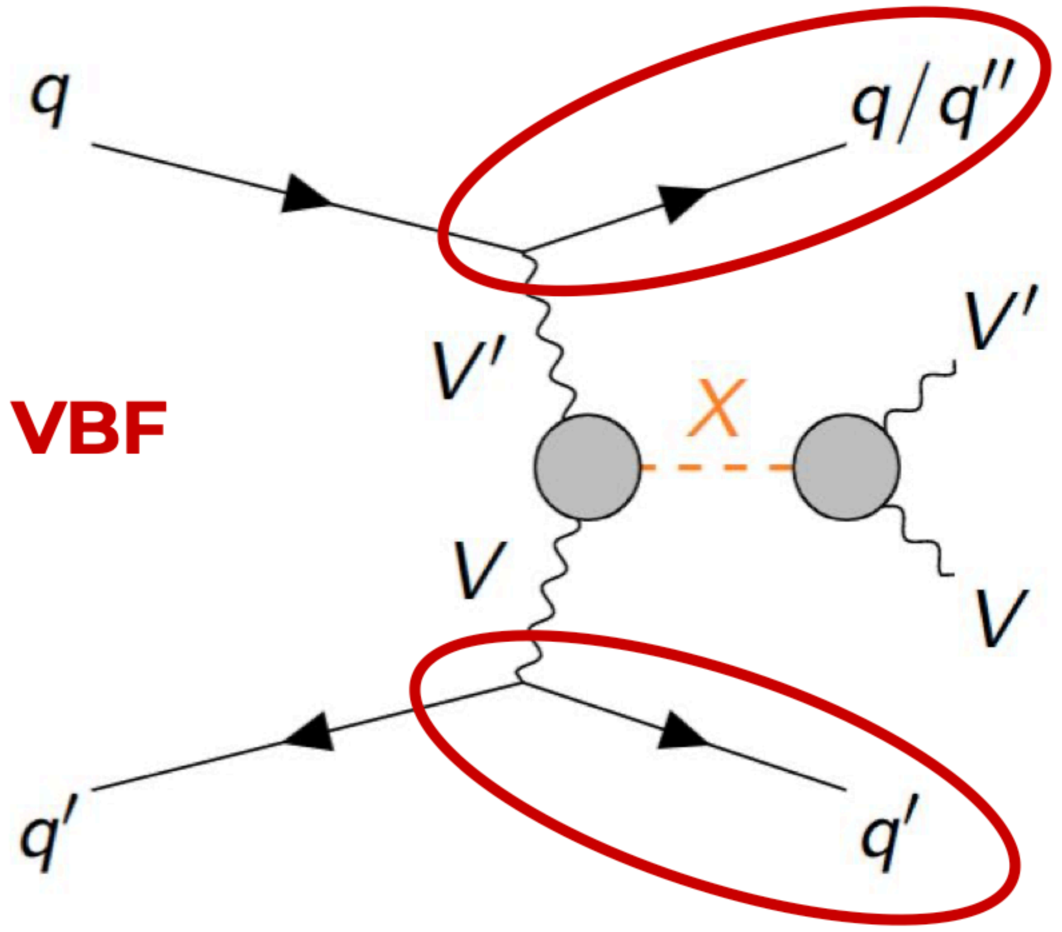
- Searches for new heavy resonances X decaying into pairs of SM bosons (X -> VV, with V = Z or W) or a V boson and a SM Higgs (X -> VH)
  - ↪Leptonic, semileptonic and fully hadronic final states
  - ↪Possible signal interpreation: charged Higgs boson of the Georgi – Machacek model (GM), Radion (R, spin-0) and Graviton (G, spin-2) of the Randall Sundrum model, Z' and W' (spin-1) of the Heavy Vector Triplet framework, A boson (spin-0) of the 2HDM model

- A ML approach to solve the VBF vs ggF/DY physics classification task
  - ↪developed (in Naples) for the full run-2 pass of the high mass VV semi-leptonic search, Eur. Phys. J. C 80 (2020) 1165

ggF/DY



VBF



2 additional jets (***VBF jets***) with opposite high η in the final state

pro: tighter phase space, less SM background
cons: lower signal xSection

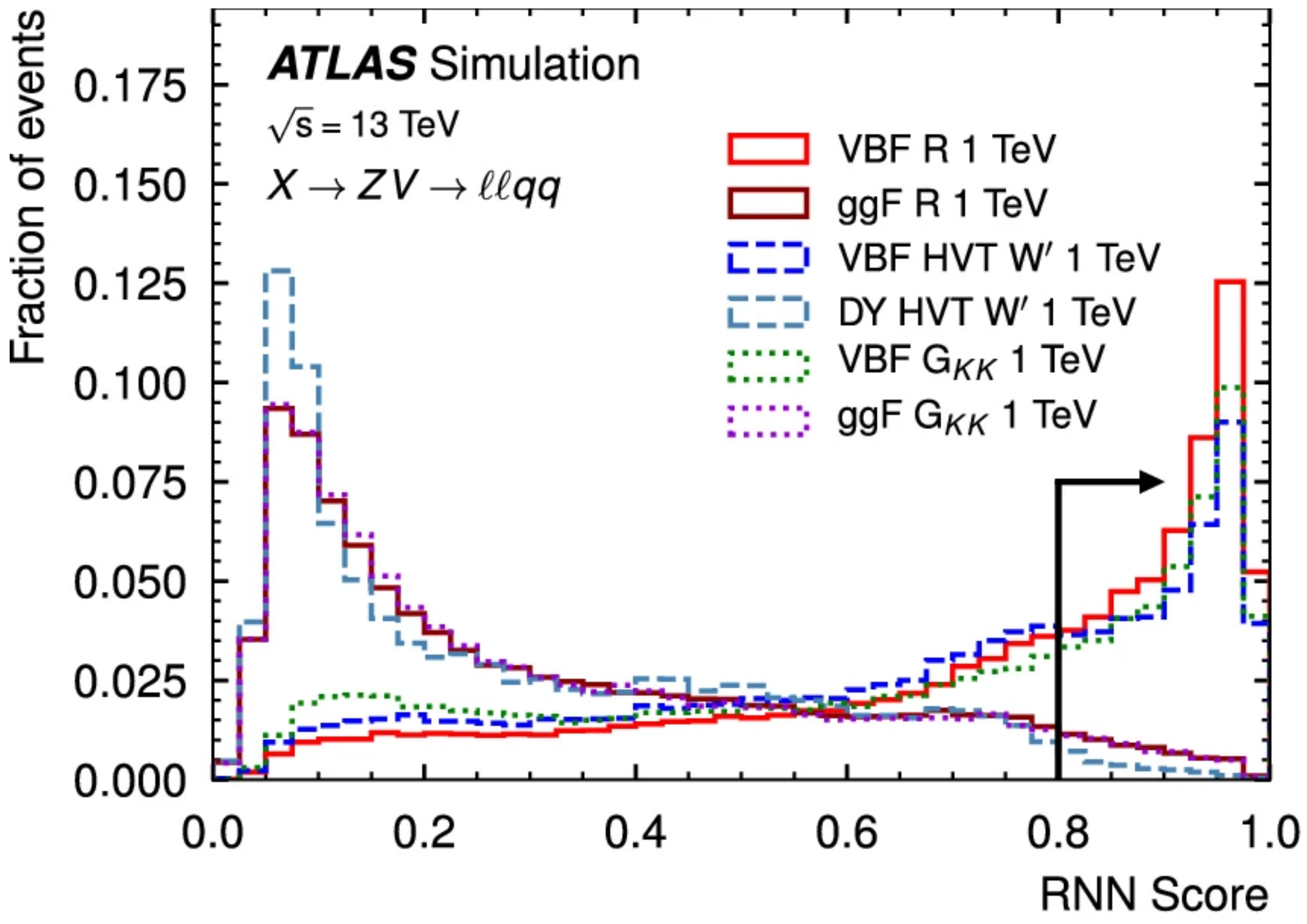
VBF-RNN TAGGER

A new tagger for diboson analyses

- Developed a Recurrent Neural Network architecture
  - ↪ RNN are usually used for language transplantation, time series prediction, etc
- Main improvements:
  - ↪ up to **60% improvement** w.r.t the previous cut-based approach
  - ↪ **1-jet category recovery**: significant part of the VBF signal is not fully reconstructed in ATLAS since outside the detector acceptance
  - ↪ the RNN approach represents a natural way to recover this signal

↪ Goal: extension to other final states

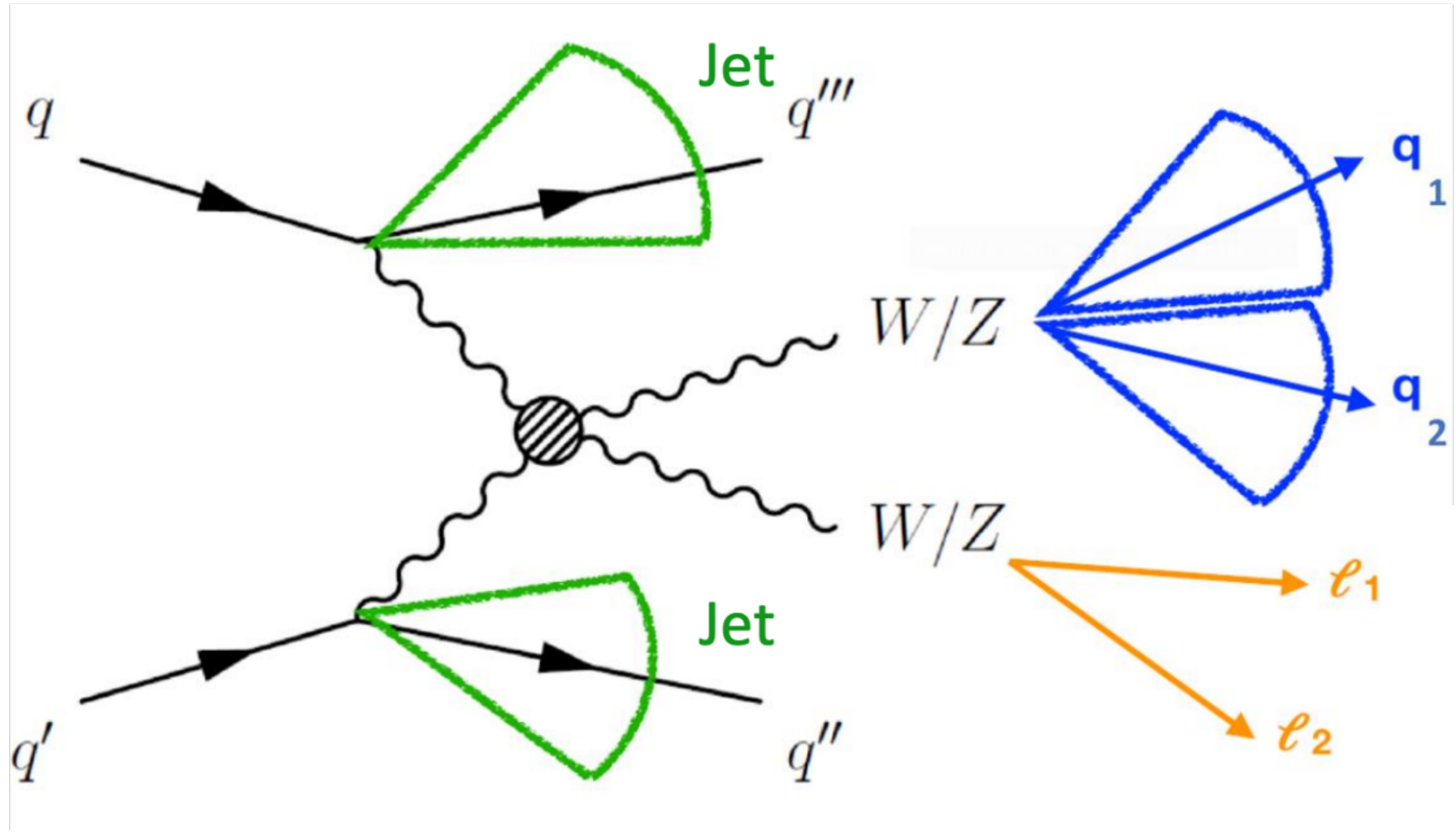
- ↪ VBF topology does not (strongly) depend on decay channel
- ↪ Dedicated tool for many diboson analyses



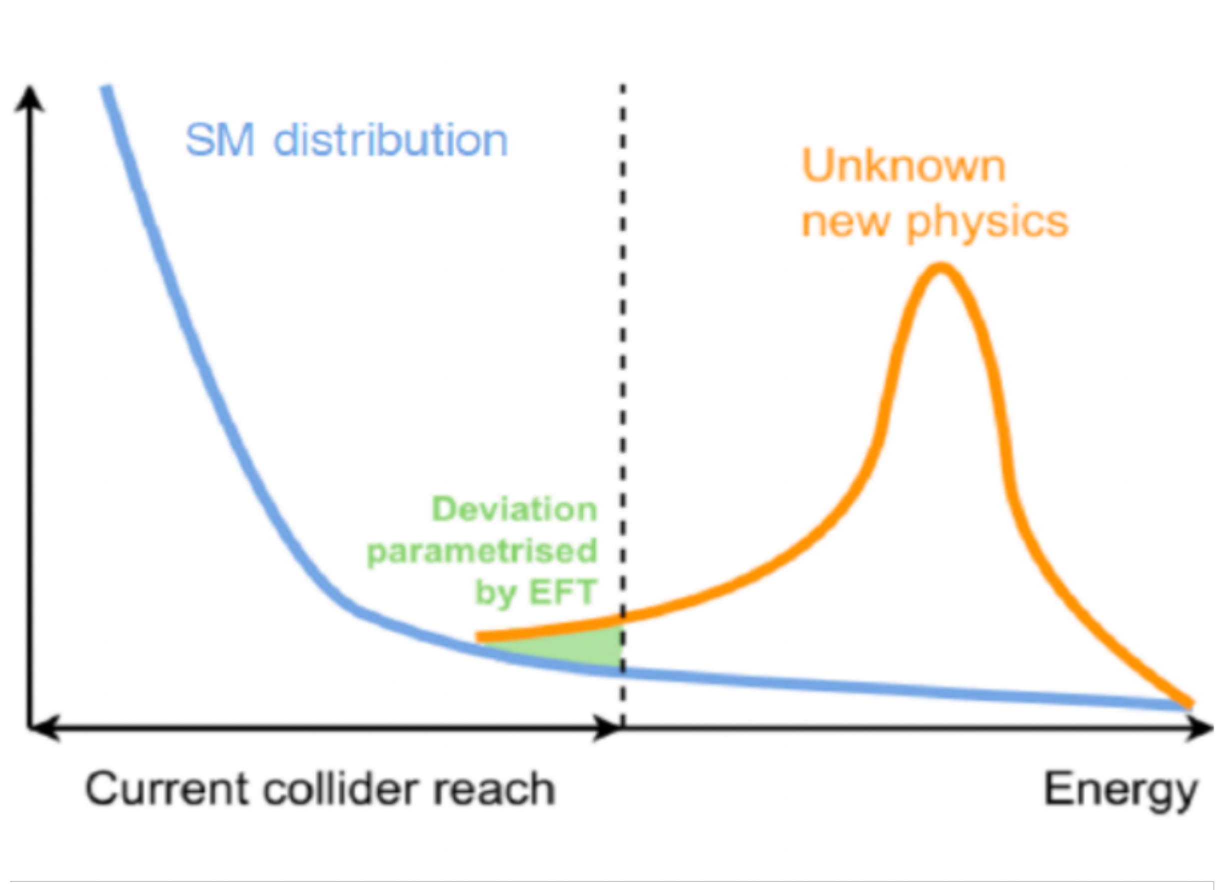
VBS VV SEMI-LEPTONIC

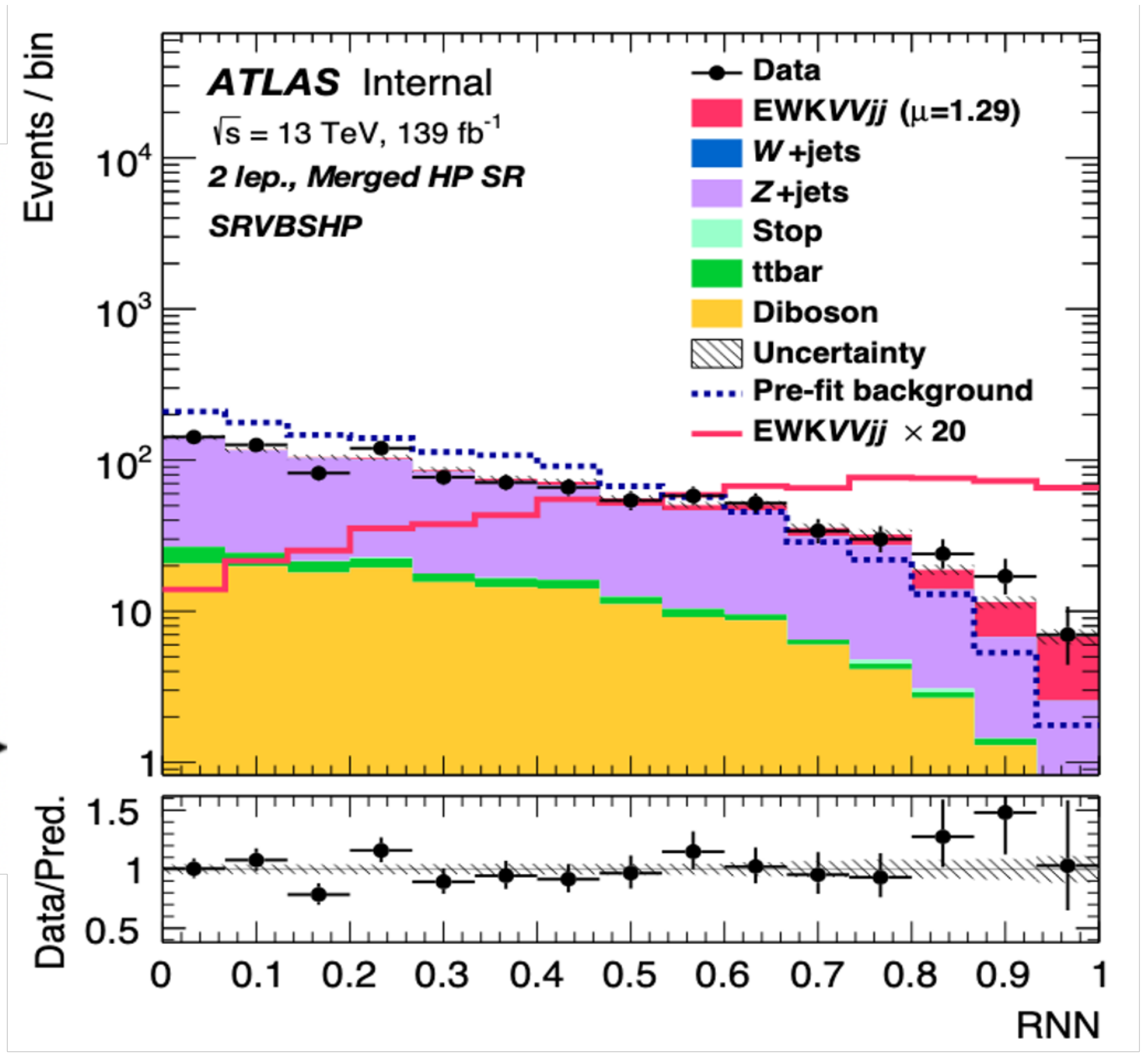
Study EW WW/WZ/ZZ production in semi-leptonic final states

- Focus on SM Vector Boson Scattering (VBS): Observation of inclusive electroweak production of VVjj (V=W,Z) in semileptonic final states (one gauge boson decays hadronically and the other one decays leptonically) in a VBS enhanced phase space and cross-section measurement using full Run-2 ATLAS data;
- EFT interpretation: Limits on anomalous Quartic Gauge Coupling (aQGC)
- Non resonant signal
- **ML approach to build the final discriminant with RNN** to discriminate between signal and background —> final discriminant RNN
- Previous analysis on 36 fb-1 dataset with observed 2.7σ (PhysRevD.100.032007)
- **Aim for observation!**



The final significance and the EWK $V_{\text{lep}}V_{\text{had}}\,jj$ cross section measurements will be soon public (Moriond 2025)

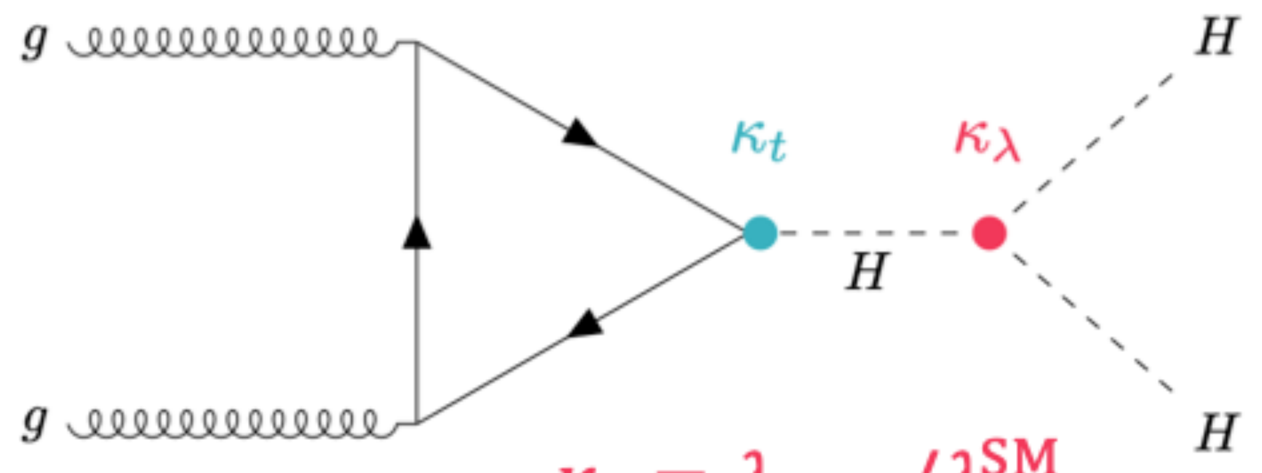




SEARCH FOR NON-RESONANT HIGGS BOSON PAIR PRODUCTION IN $bb\gamma\gamma$

- The Higgs potential in SM has not been experimentally measured at enough significance
- Measurements of the Higgs self-coupling constant are crucial to directly determine the shape of the Higgs potential.
- Run2 + partial Run3 analysis ongoing
  ↪Contribution in kinematic fit, which improves the mass resolution

$$V(\phi) = -\mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$$
$$= -\frac{1}{2}m_H^2h^2 - \lambda_{HHH}vh^3 - \lambda_{HHHH}h^4$$

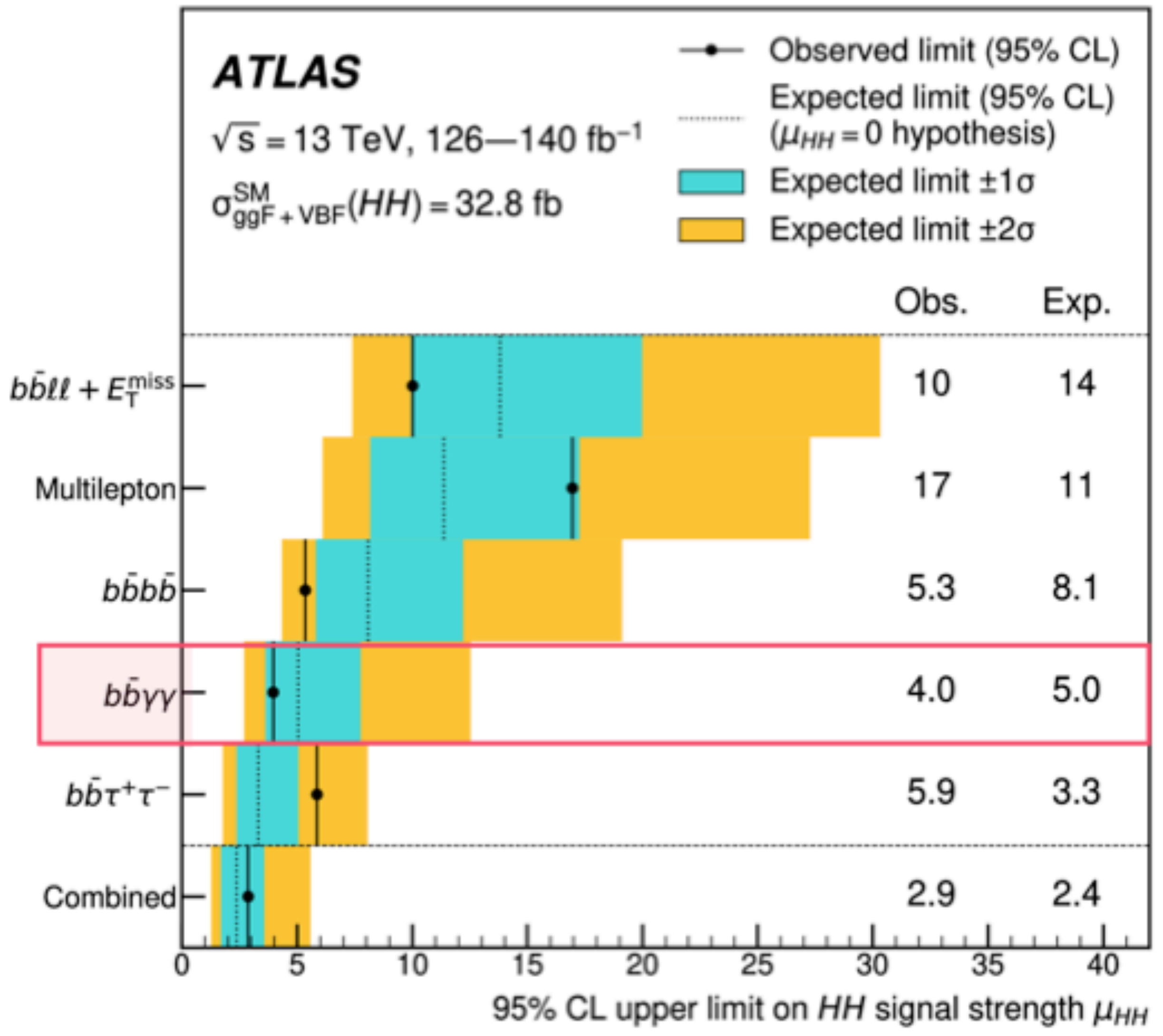


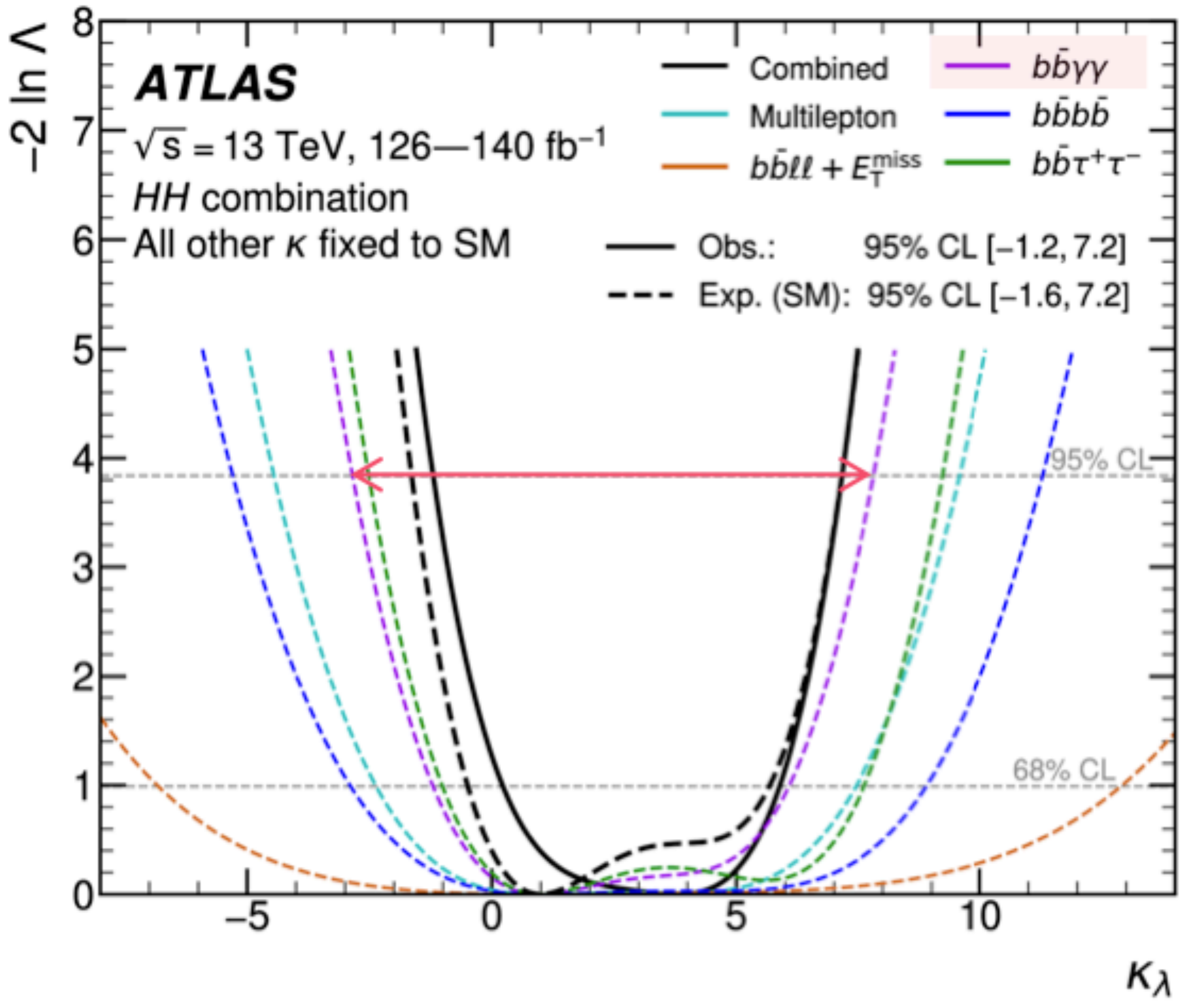
$$\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$$

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

Why $HH \to b\bar{b}\gamma\gamma$?

- Fully reconstructable final state, no combinatoric issues for H identification
- $H \to b\bar{b}$: Highest BR for a SM Higgs bosons (59%)
- $H \to \gamma\gamma$: Excellent trigger and reconstruction efficiency for photons with ATLAS
- $H \to \gamma\gamma$: Excellent di-photon invariant mass $m_{\gamma\gamma}$ resolution (1-2 GeV)





Quantum Fuzzy Logic

Quantum Machine Learning in HEP

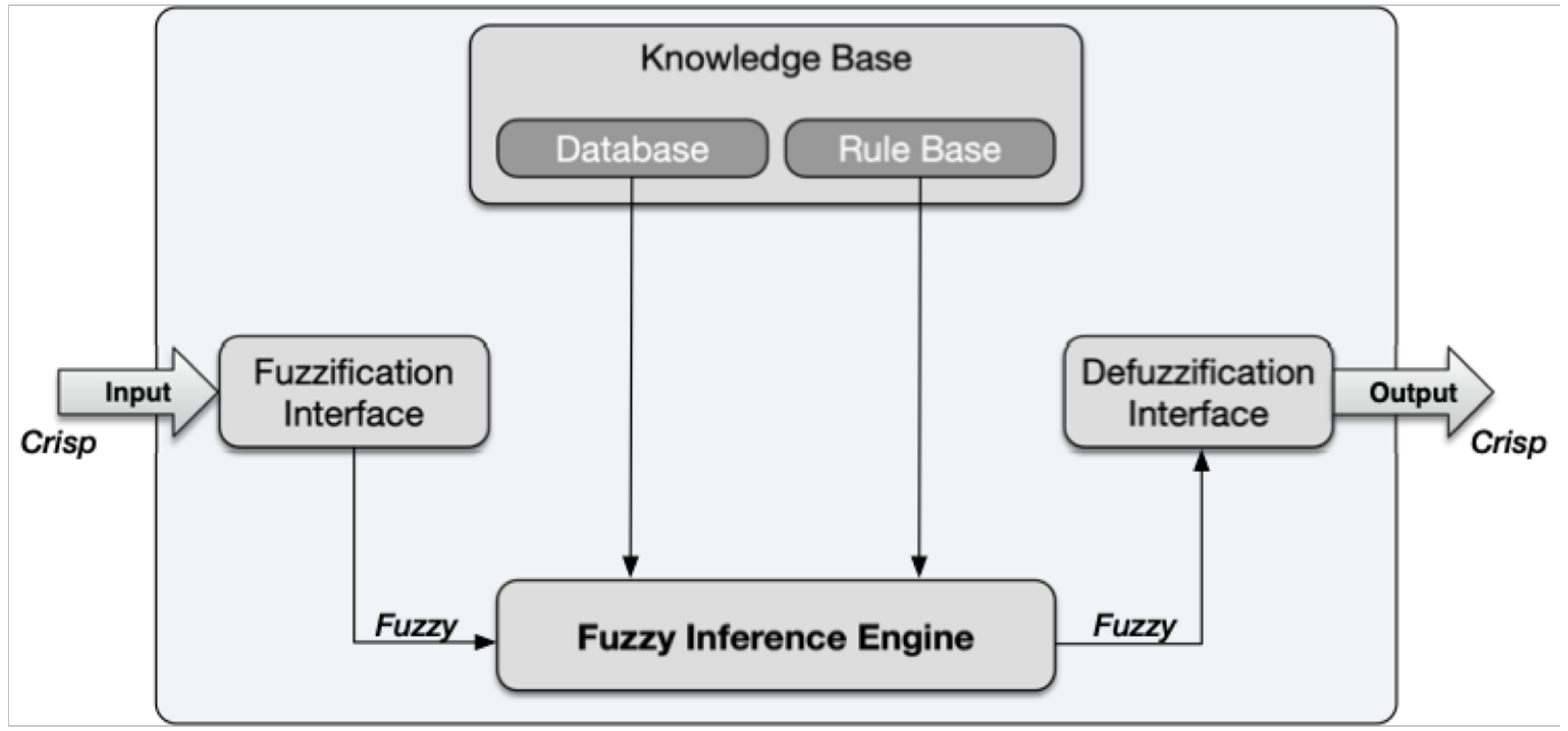
- Classical Fuzzy Logic is a theory introduced by Lofti Zadeh with the idea to give computers the capability of dealing with uncertainty.

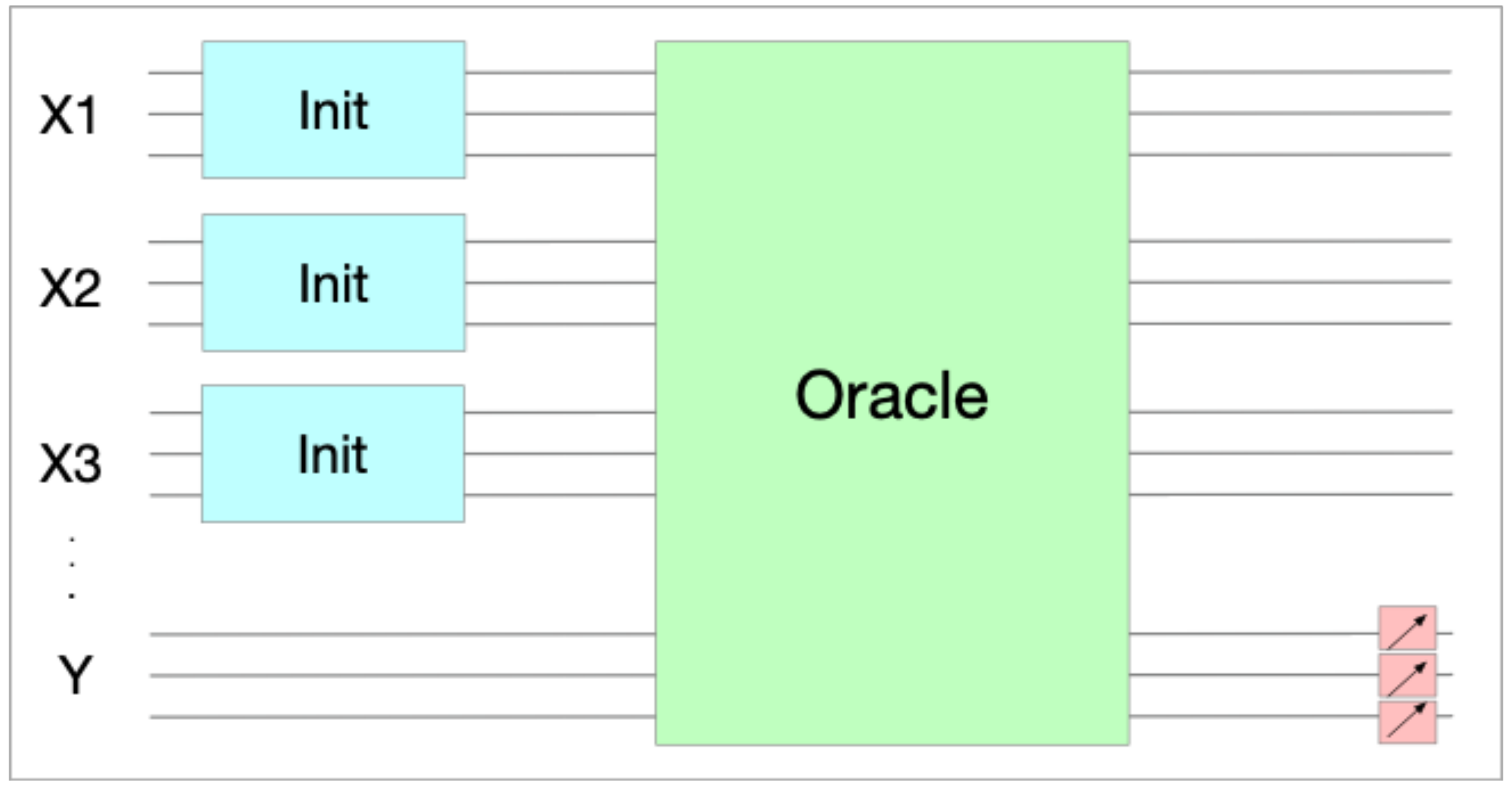
- Fuzzy Logic is used to develop Control Systems based on linguistic rules, which are therefore highly interpretable.

- A Quantum Fuzzy Control System is proposed. The main goal achieved by this approach is the exponential advantage in computing fuzzy rules on quantum computers over their classical counterpart.

- The Quantum Fuzzy Control System has been tested for controlling the trajectory of particle beams in two real particle accelerator facilities at CERN:
  - ↪T4 target station at the CERN SPS fixed target physics beam lin
  - ↪Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE)

- Experimental results carried out on the real accelerators show the suitability of this approach in controlling these systems.



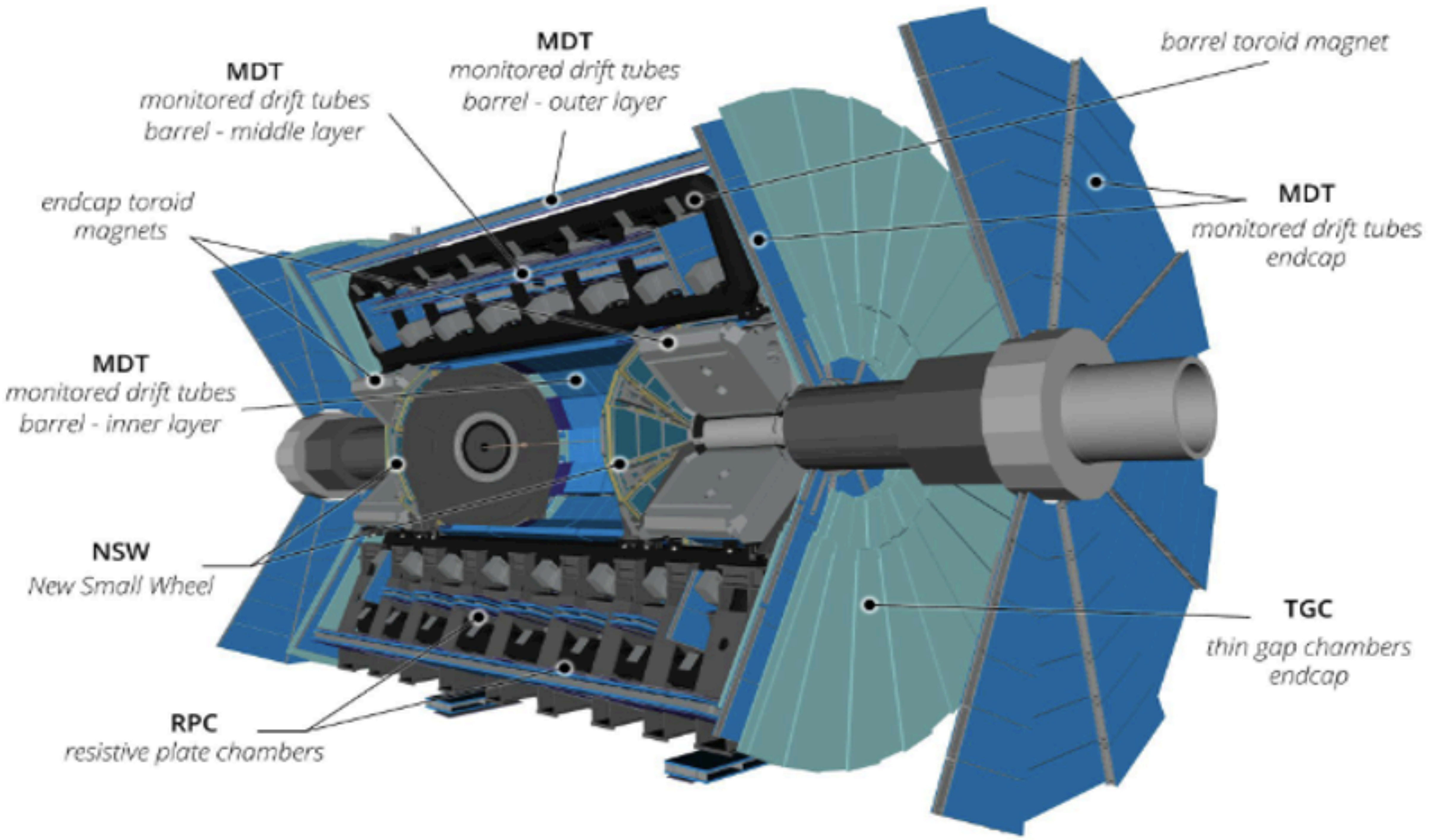


Muon detector

Alviggi M., Canale V., Della Pietra M., Di Donato C., Iengo P., Izzo V.,
Massarotti P., Sekhniaidze G.

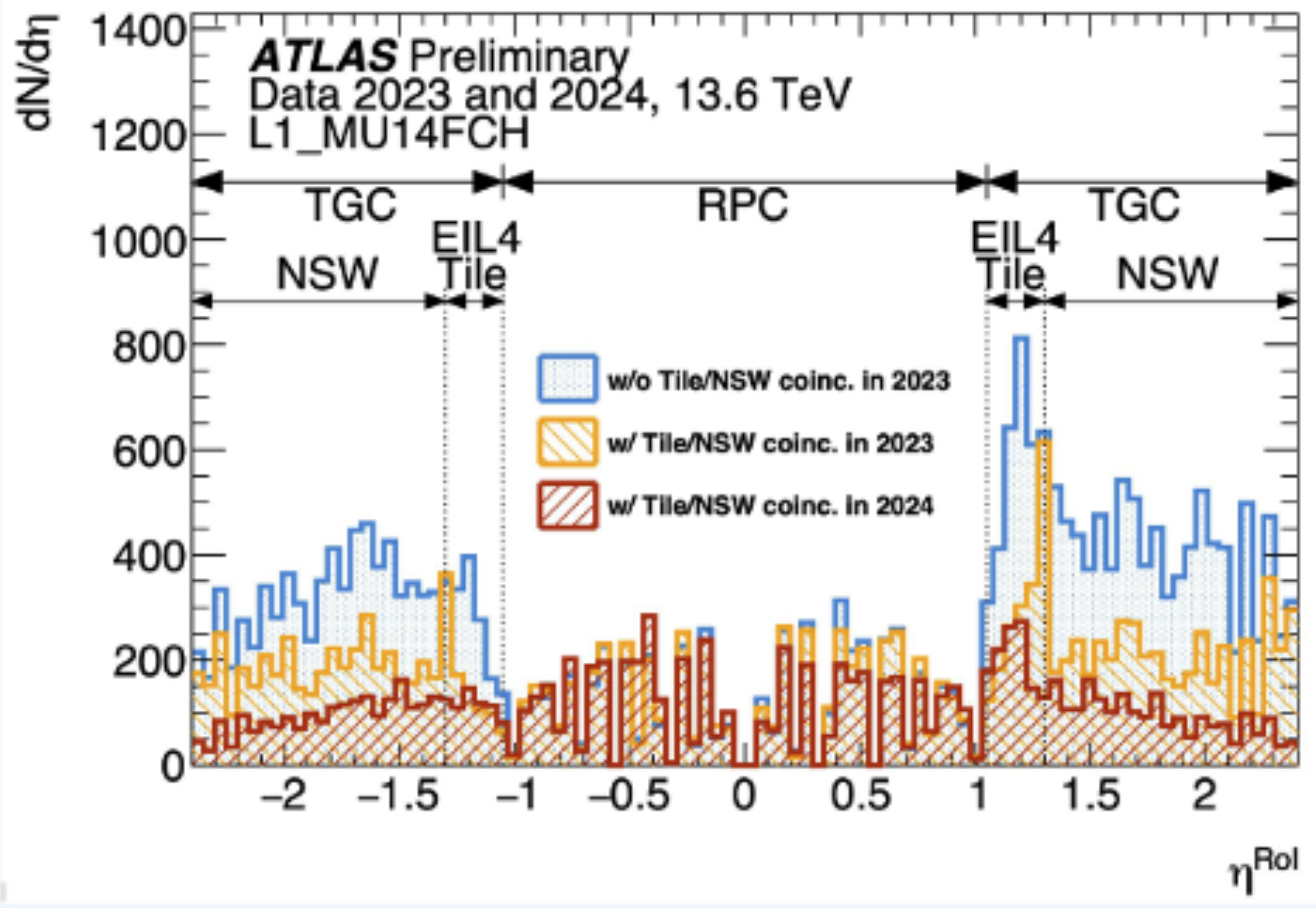
THE ATLAS MUON SYSTEM

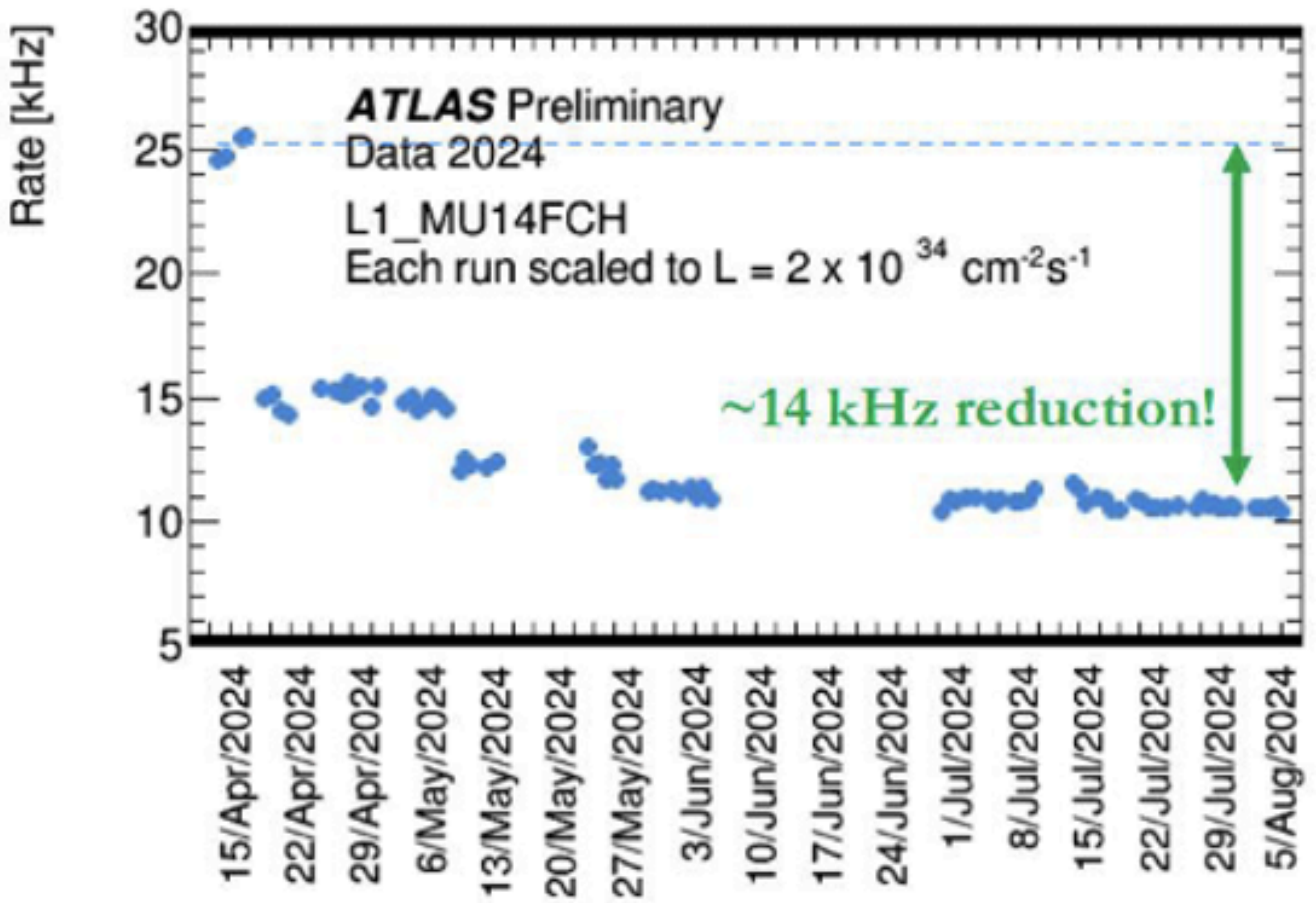
- The largest detector system of the largest LHC experiment…
  - ↪Napoli deeply involved over the years: RPC, MM, NSW
- Some numbers for 2024
  - ↪~More than 300 collaborators from 64 Institutes
  - ↪~900 Muon desk shifts in Atlas Control Room
  - ↪~3000 Expert on-call shifts
- **Paolo Iengo project leader**: steer the collaboration, coordinate activities, set priorities, ensure operations and maintenance of the system, collaborate with Institutes to provide adequate coverage for the different activities



MAJOR ACHIEVEMENTS IN 2024

- Excellent data taking efficiency in 2024
- Change in RPC gas composition to limit GWP: 2024 pp run confirmed good performance of new gas with 30% of CO2
- Physics potential of the NSW (major Phase-1 upgrade) fully exploited in 2024 for tracking and triggering capabilities
- Very good tracking efficiency
- In 2024 NSW has been fully integrated in the ATLAS trigger with the effect of reducing the L1 Muon trigger rate by 15 kHz → ATLAS was able to efficiently run with pilup levelled at 64 at 2.15x10ˆ34 cm-2s-1



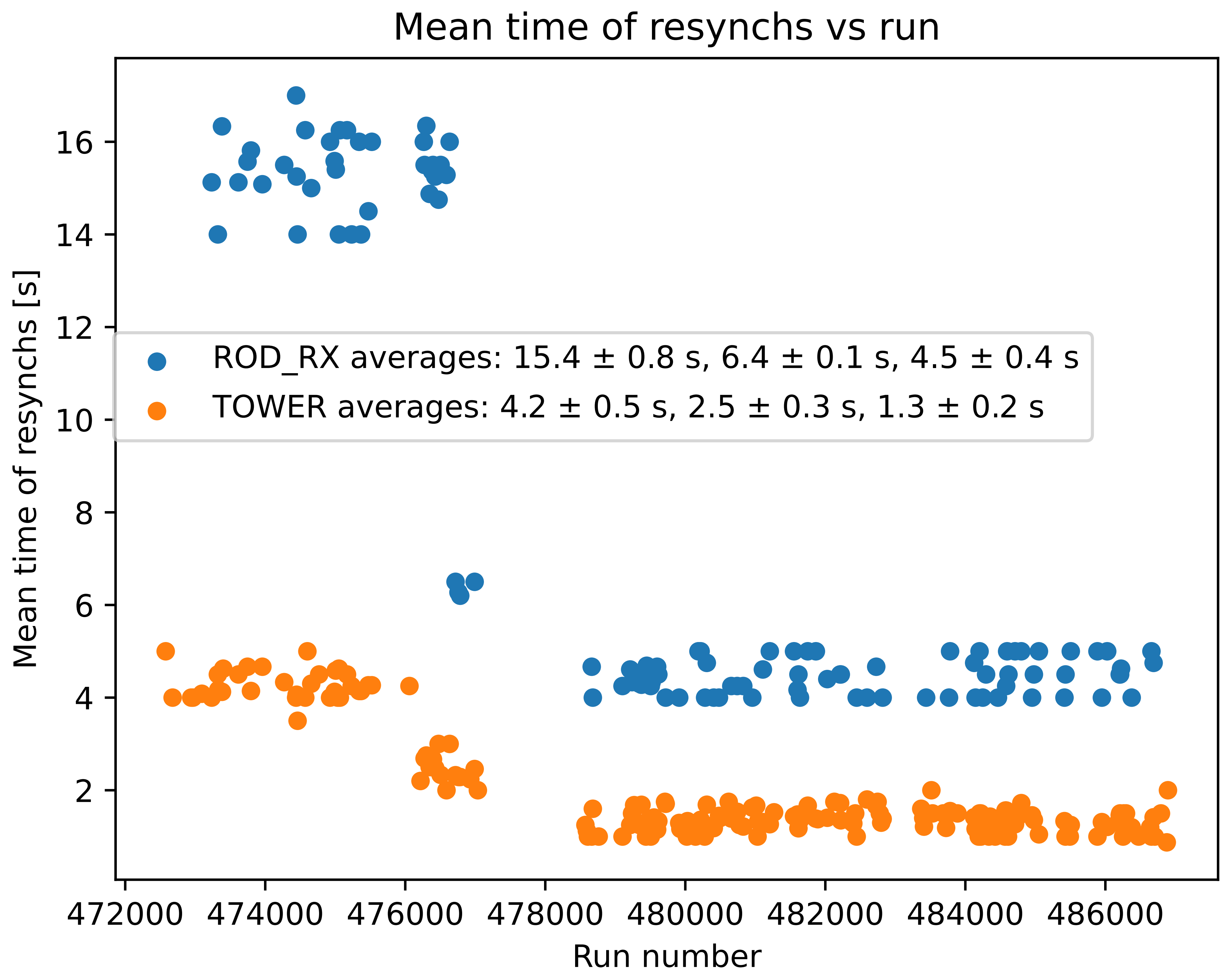


Lv1 Trigger

Della Pietra M., Izzo V., Rossi E., Conventi F., D'Avanzo A.

ONLINE DAQ AND TRIGGER STATUS

- Activities: L1 muon trigger configuration, monitoring software
- In 2024 developed new tools to face critical issues appeared during runs
- Improved Tower (on-detector electronics) and ReadOut Driver (off-detector electronics) resynchronization
  ↪Less busy time for detector during data taking
- This improvement has been obtained optimizing the operations on the VME bus communication
- The modifications have been done in two steps, reaching the current mean values of 1.3 +/- 0.2 s for a single Tower-Resynch and 4.4 +/- 0.3 s for a ROD-Resynch



Online DAQ and Trigger Status

Work in progress

- Complete a set of tools for the on-call expert to face-off with critical situation:
  - ↪Including – excluding a single tower
  - ↪Including – excluding many towers at once
  - ↪Including – excluding a whole trigger sector or a ROD (two sectors).
- Many of this tools already exist but we need to finalize/debug/integrate them.
- After all this new settings in hardware and software configuration that have been done following the urgence of the problems that raised, we need to redefine which are the online histograms that must be checked by the shifters, and which are the real faulty condition that must be taken in account.

Computing

Carlino G., Doria A., Spisso B., D'Onofrio A., Sabella G., Rossi E.

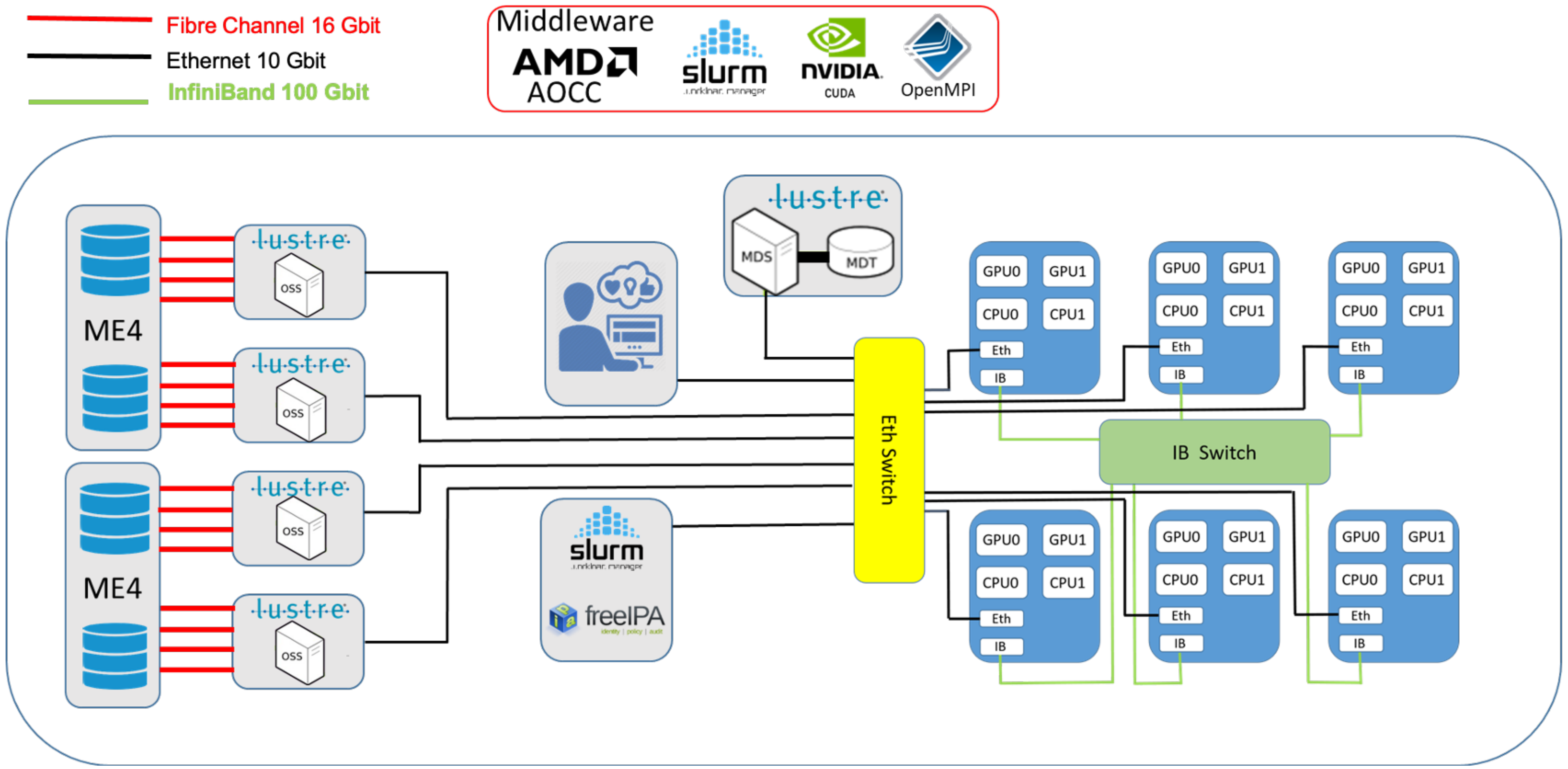
COMPUTING INFRASTRUCTURE

- ATLAS Tier2: usual operation for ATLAS offline activities (MonteCarlo production, reconstruction and analysis, data storage)
  - ↪Annual resources have been incremented
- Both Tier2 and local resources have been integrated in ICSC (Centro Nazionale di Ricerca in High Performance Computing, Big Data e Quantum Computing).
  - ↪Available for ATLAS and other collaborations in Naples
- Local clusters for INFN users
  - ↪HTC cluster: batch sys condor and interactive
  - ↪HPC GPU cluster
  - ↪Experimental cluster of 5 virtual Kubernetes nodes

<u>HTC cluster</u>

- **Used for "standard" ATLAS analyses**
- 5 compute nodes with 144 virtual cores
- RAM DDR4 3.5 GB/core
- Base architecture:
  - ↪Operating sys Alma9
  - ↪Batch sys HTC Condor
  - ↪interconnection Eth 10 Gbit/s
  - ↪NFS file system

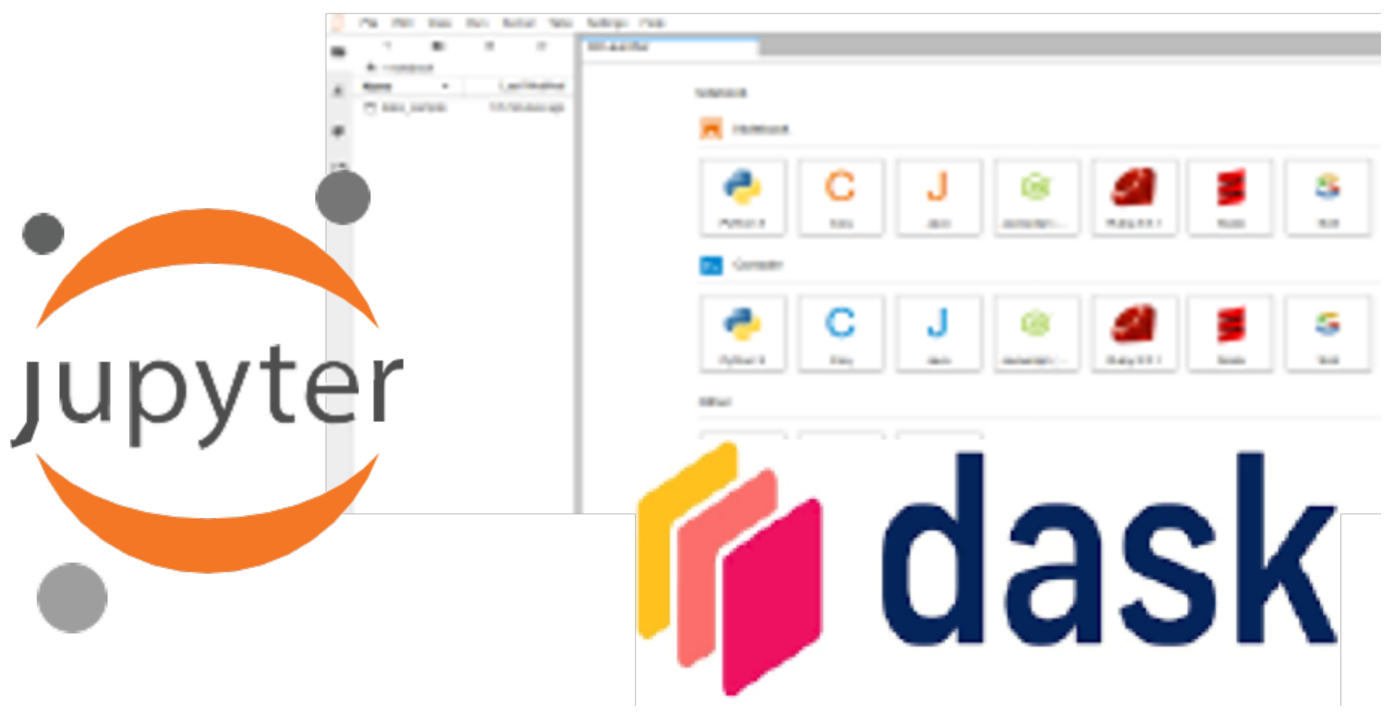
INFN NAPLES HPC GPU CLUSTER



- 6 compute nodes with 128 physical cores + 2GPUs NVIDIA V100 16 GB
- RAM DDR4 9 GB/core
- Base architecture:
  - ↪Operating sys Alma9
  - ↪Batch sys SLURM
  - ↪Interconnection Infiniband 100 Gbit/s
  - ↪GPU libs: CUDA toolkit
  - ↪Lustre file system (ongoing)
- **Used for GNN training in AD ATLAS analysis**

Basic tools for the ATLAS workflows (such as CvmFS, Miniconda, Apptainer, etc…) and :

- Jupyter HUB on the UI
- Jupyter Notebook on the nodes
- Dask



BENCHMARKING DISTRIBUTED-INTERACTIVE HEP ANALYSIS

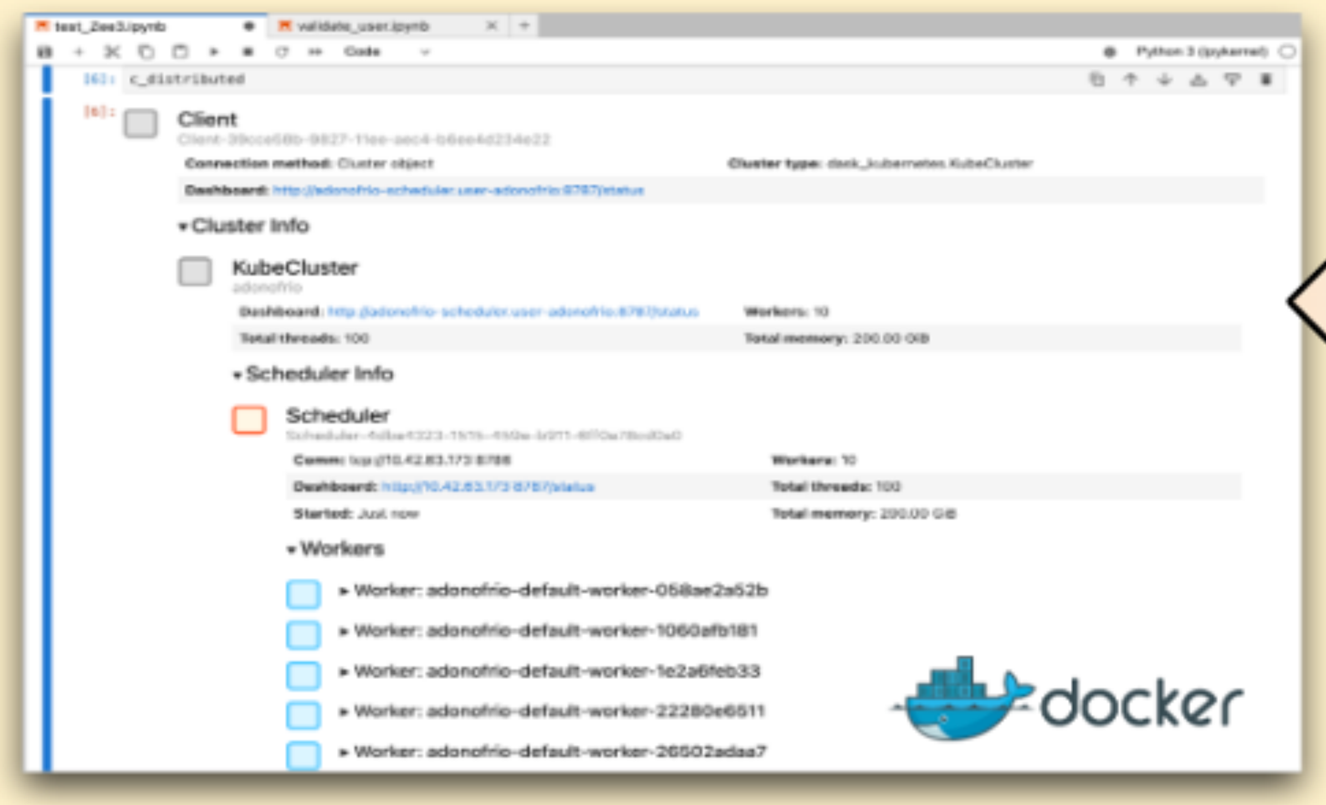
- Challenges of LHC, HL-LHC and of the Future Colliders are pushing to re-think the HEP computing models having strong impact on several aspects, from software to the computing infrastructure
- From the software perspective, interactive/quasi interactive analysis is a promising paradigm
  - ↪User-friendly environment
  - ↪Adopting open-source industry standards: Dask, Jupyter Notebooks and HTCondor
  - ↪Validating new frameworks (e.g. ROOT RDataFrame with multi-threading)

Access and security

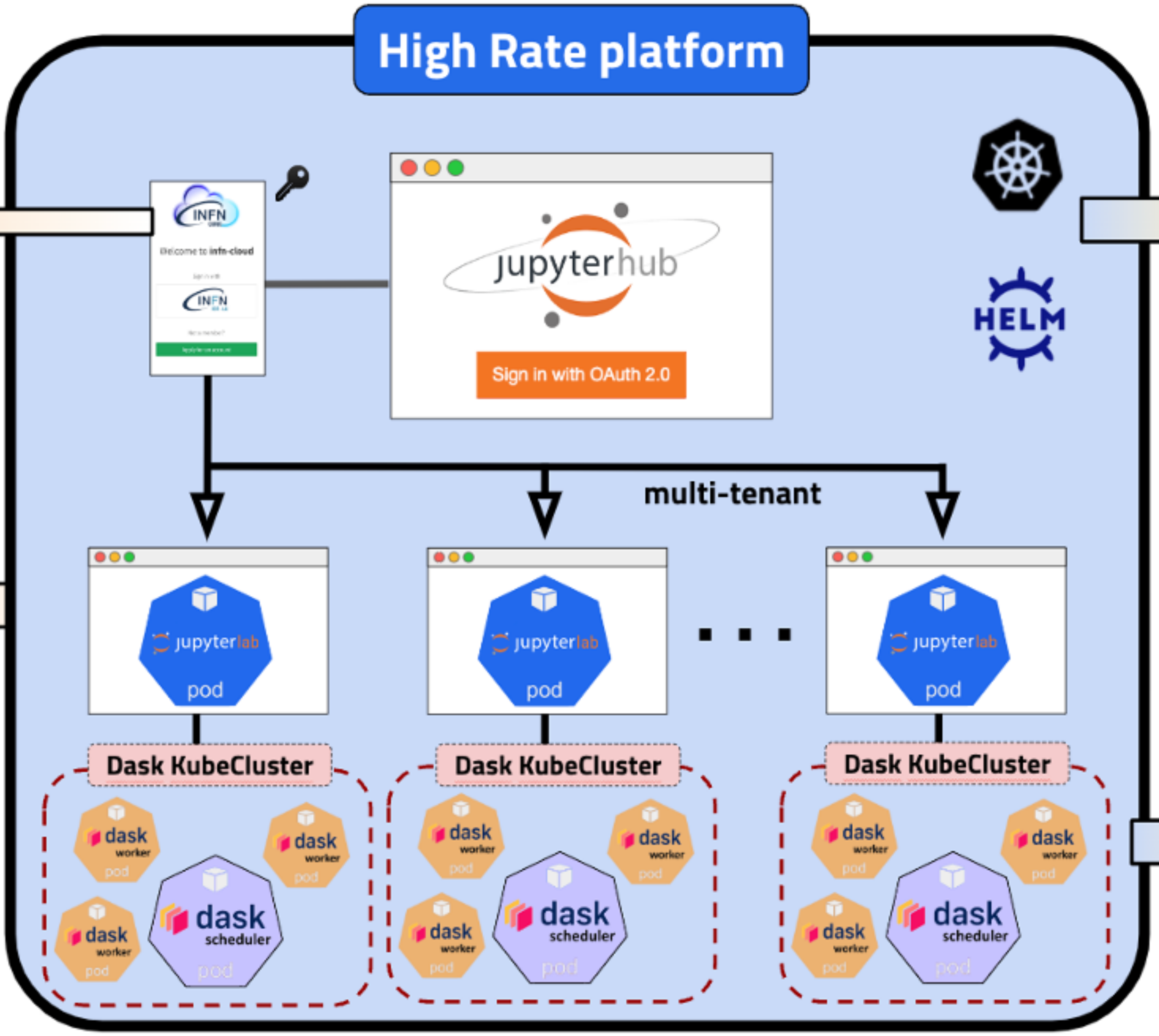
After connecting to an entrypoint URL, the user reaches a **Jupyterhub** instance that, after authentication and authorization via INDIGO-IAM, allocates the required resources for the user's working area

User Interface

The user interface is based on **Jupyterlab**, customised with specific plugins for specific purposes (e.g. Dask).



The working environment is highly customizable, using tailored Docker containers. This is important when analyses require specific software (collaboration-wise)



Deployment

The deployment of the **Kubernetes** resources needed for the spawning of this platform, is handled via **HELM charts** available in the GitHub organization.

Check the docs!

This allows a seamless, flexible, scalable and fault-tolerant deployment on the available resources, with a limited impact on the admin's work time

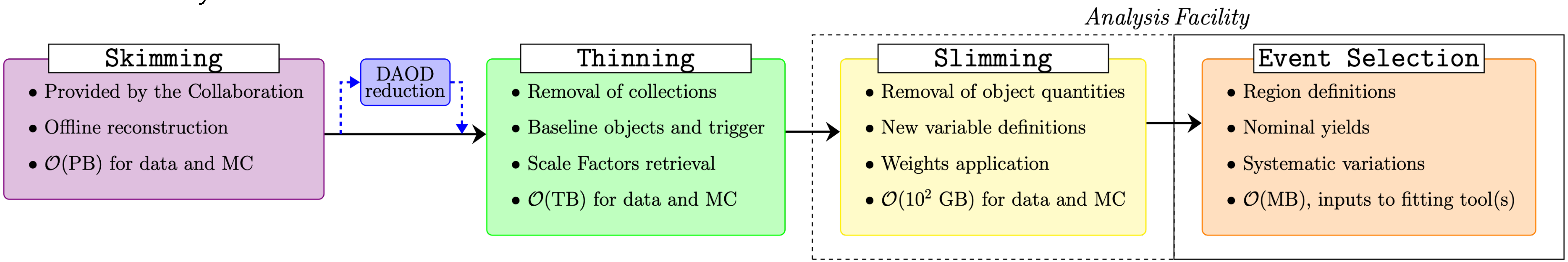
Software

From the software perspective, interactive/quasi interactive analysis is a promising paradigm

- User-friendly environment
- Adopting open-source industry standards: *Dask, Jupyter Notebooks* and *HTCondor*
- Validating new frameworks (e.g. *ROOT RDataFrame* with multi-threading)

BENCHMARK ATLAS USE-CASES

4-body SUSY Search



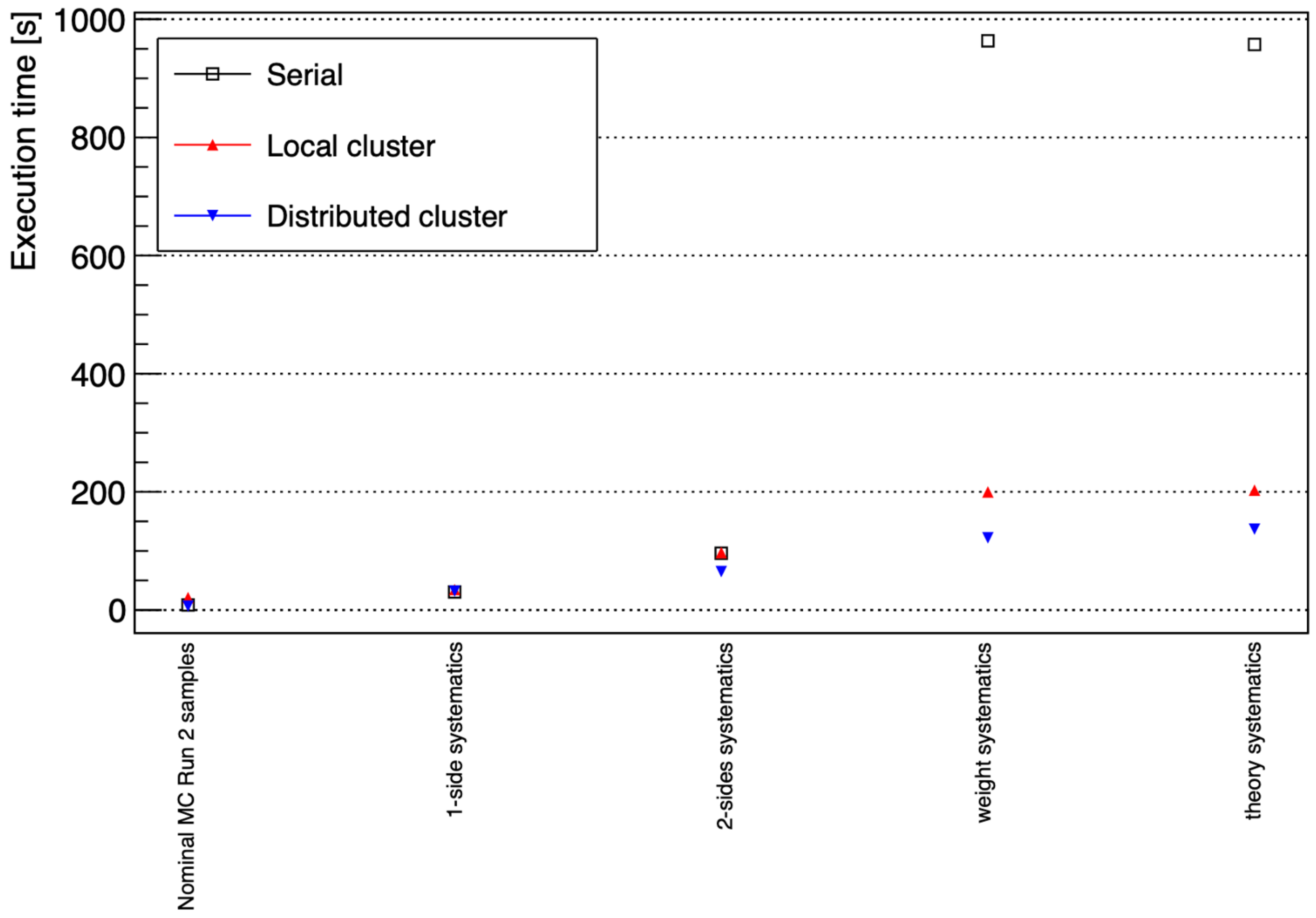
Slimming

ATLAS slimming code already in RDataFrame, but entirely written and compiled in C++ —> NO dask distributed approach

Event Selection

- Event selection for fitting tools
- RDataFrame + Dask applied to Wt bkg sample ~ 1.8 GB
- Code ready to play with other backgrounds

Exploiting the distributed approach, the execution time improves wrt the standard/ serial approach if we iterate over a significative number of systematic variations (each step in the x-axis includes previous contributions)



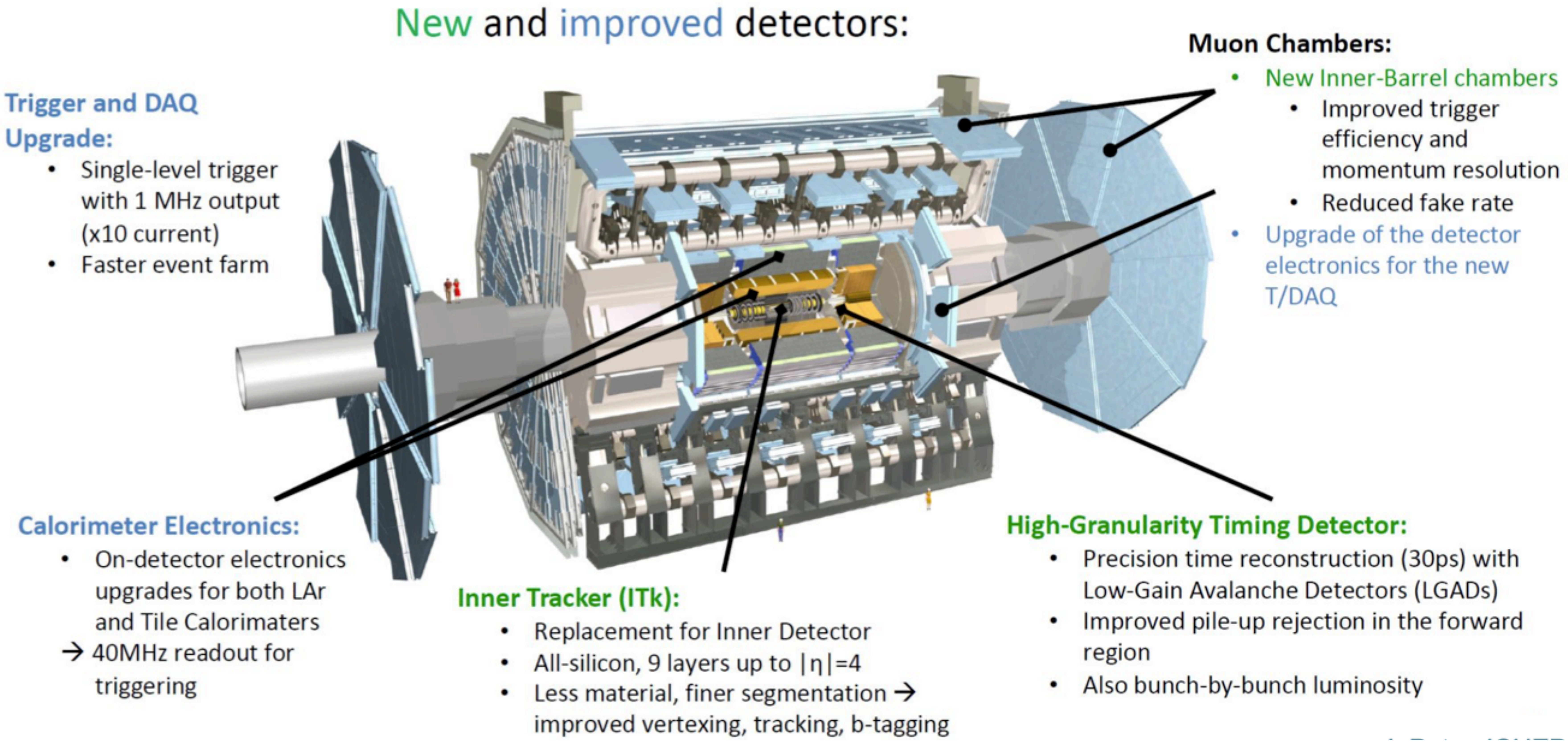
Phase II

Izzo V., Aloisio A., Casolaro P., Massarotti P., Della Pietra M.

WHAT IS PHASE 2?

High Luminosity LHC

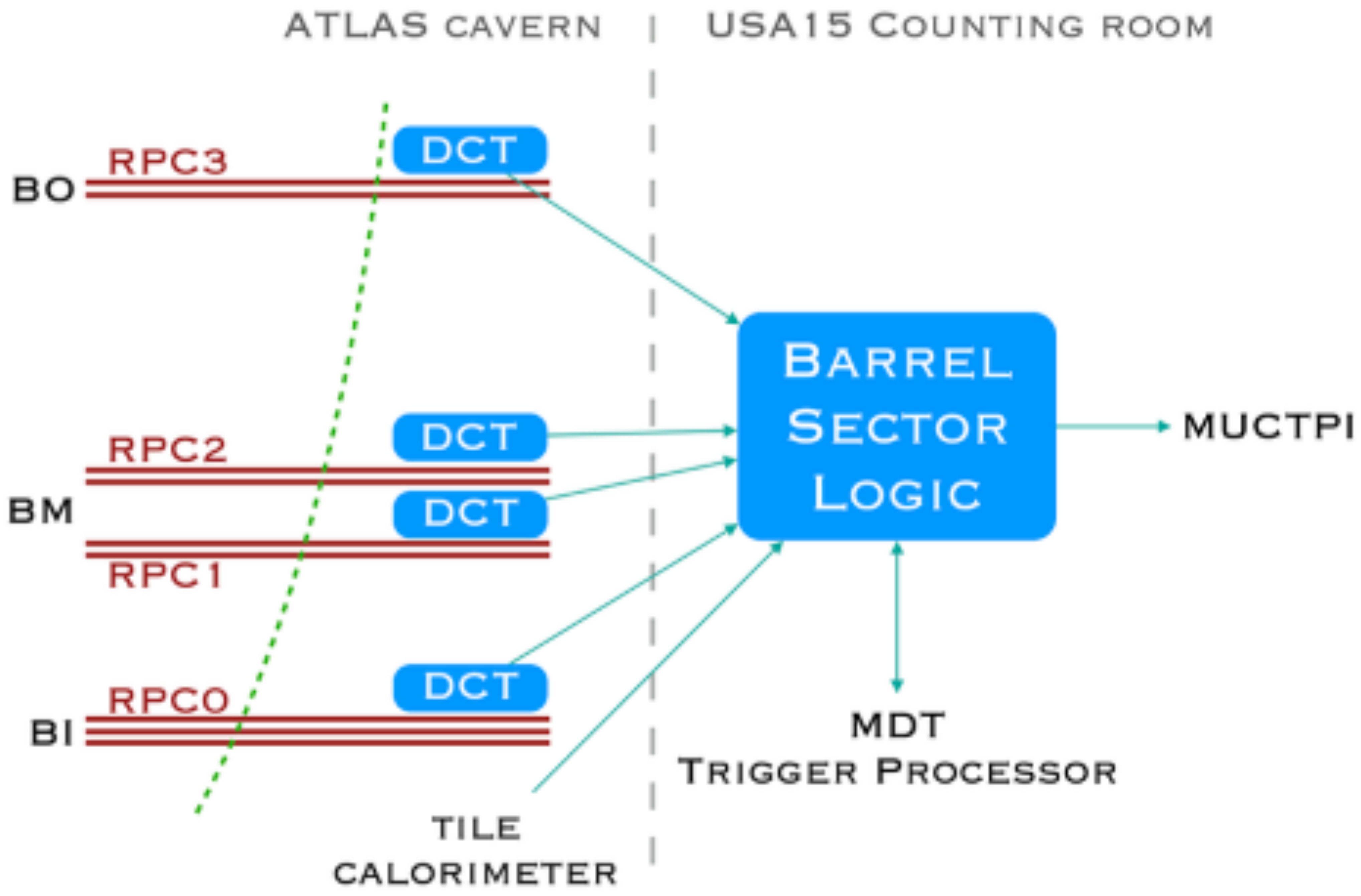
- Higgs factory (350M Higgs bosons produced) for precise Higgs coupling measurements, access to Higgs self-interaction and longitudinal vector boson scattering, and increased overall rare & new physics sensitivity
- The HL-LHC's luminosity requires unprecedented detector and computing technologies and thus significant experiment upgrades
  - ↪Increased luminosity —> Increased pile-up:
  - ↪Increased readout rates
  - ↪Increased luminosity—>Increased radiation damage



ACITIVITIES IN ENVIRONMENT WITH RADIATIONS

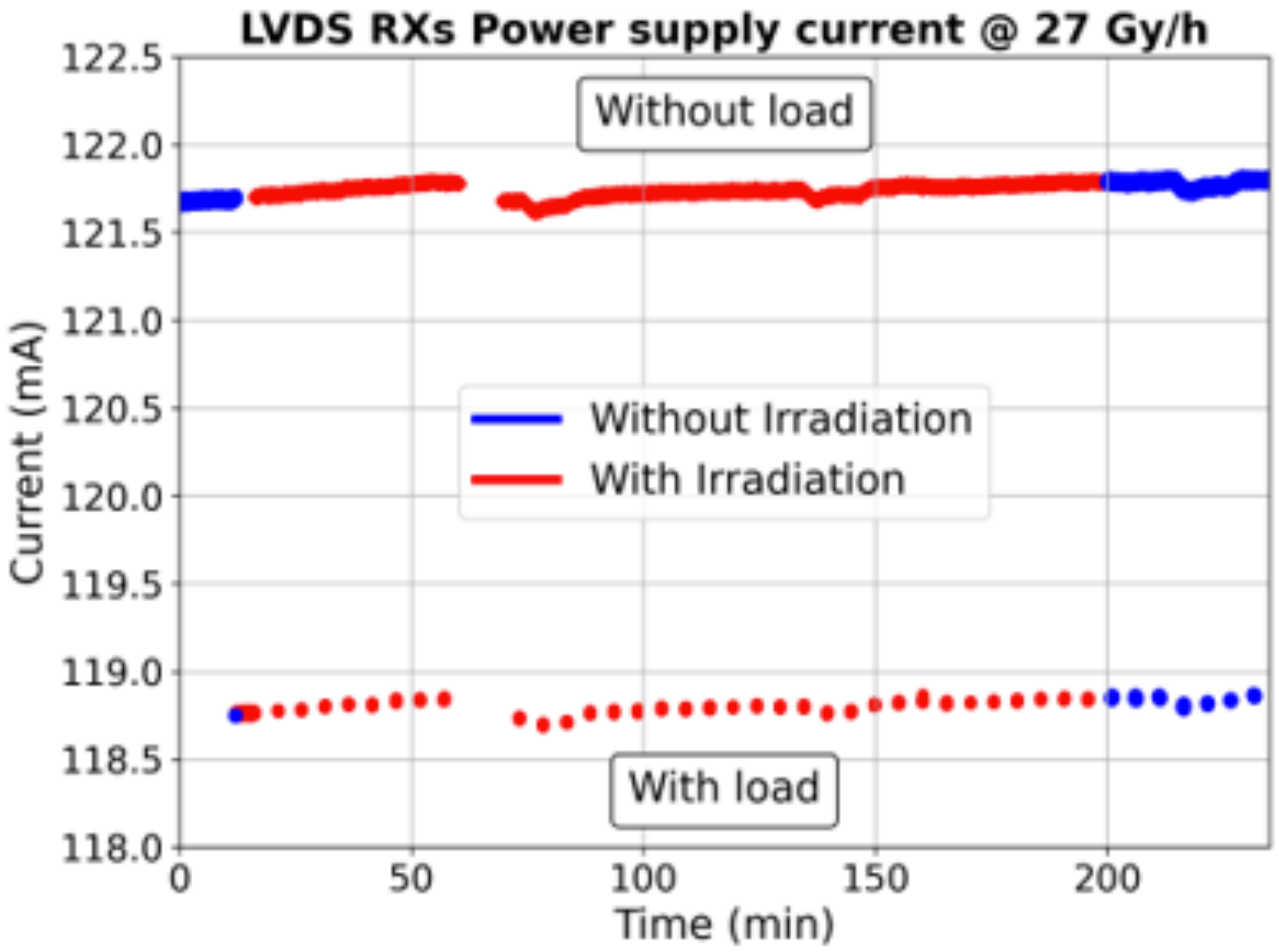
Radiation testing of read-out electronics of the muon trigger

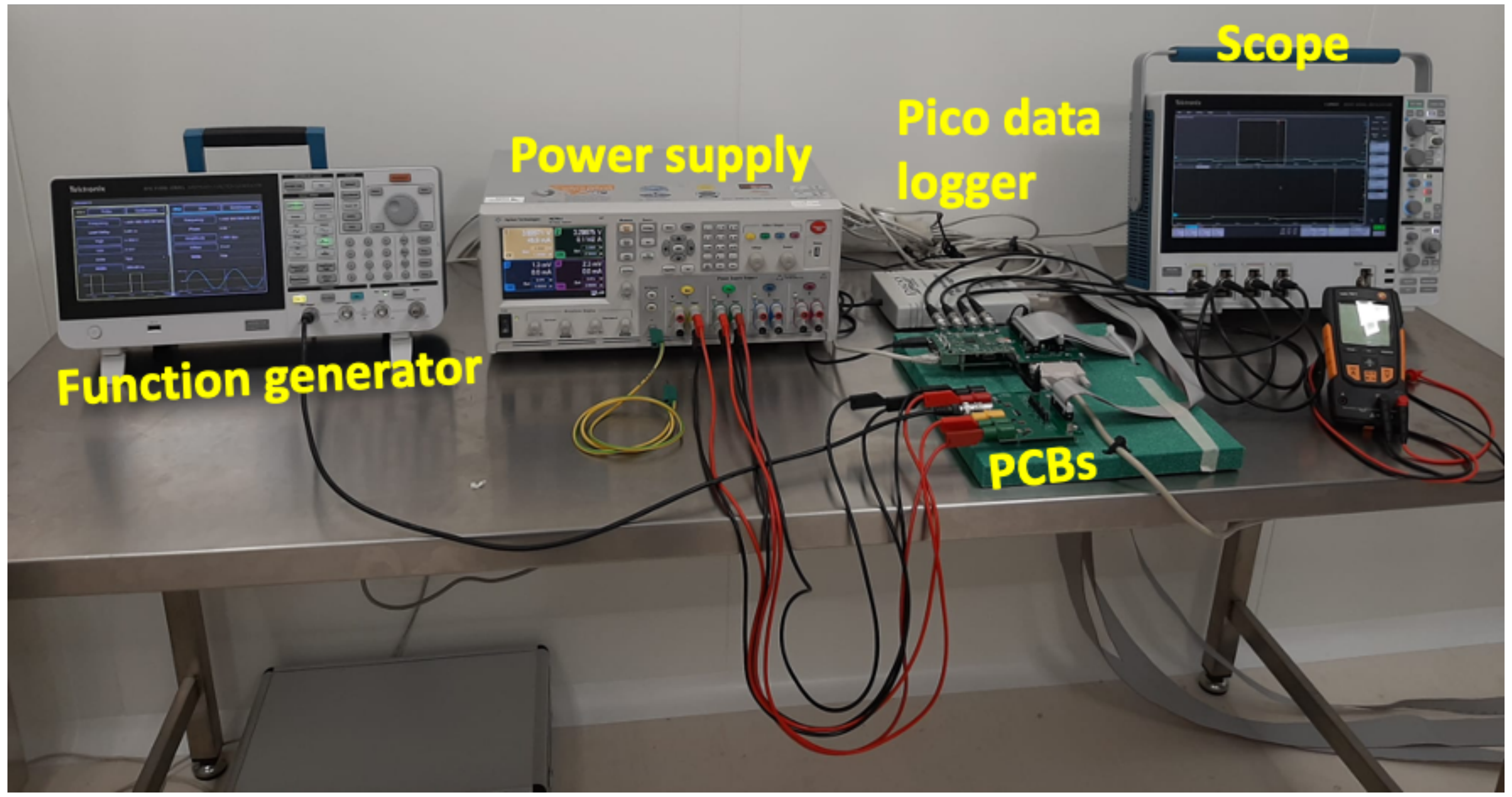
- New RPC read-out system
- Data Collector Transmitter (DCT) boards process RPC hit data and send it to the Barrel Sector Logic via optical fibers
  - ↪1600 DCT boards will be part of the HL-LHC muon trigger front-end electronics.
- Data-Collector-Transmitter (DCT) boards will receive the RPC front-end strips signals and adapt them to the LVDS standard
- Total Ionizing Dose (TID) test of LVDS receivers

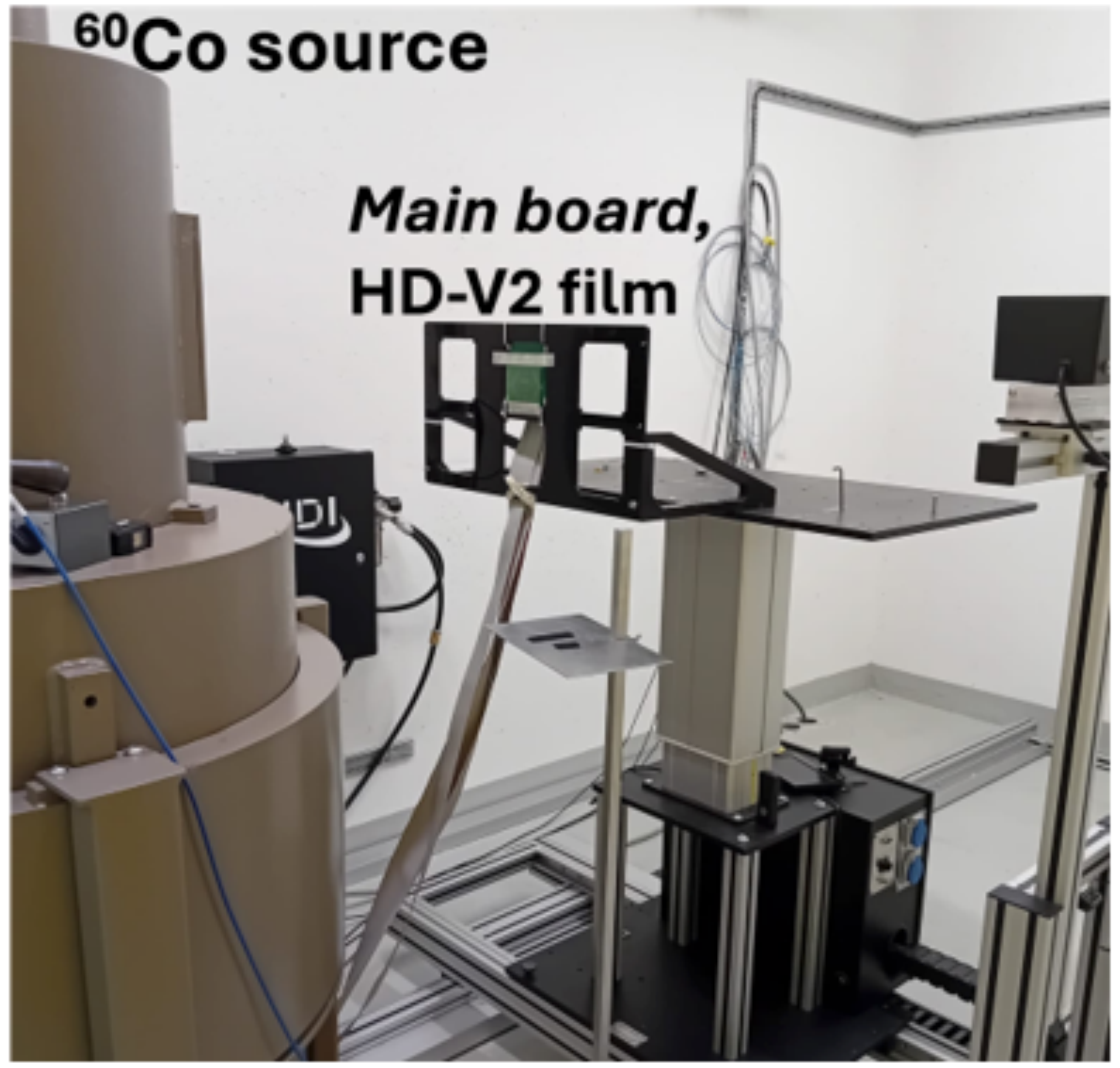


ACITIVITIES IN ENVIRONMENT WITH RADIATIONS

- Activities in our clean room
- Activities at CERN with gamma source
- Power consumption unaltered by irradiation



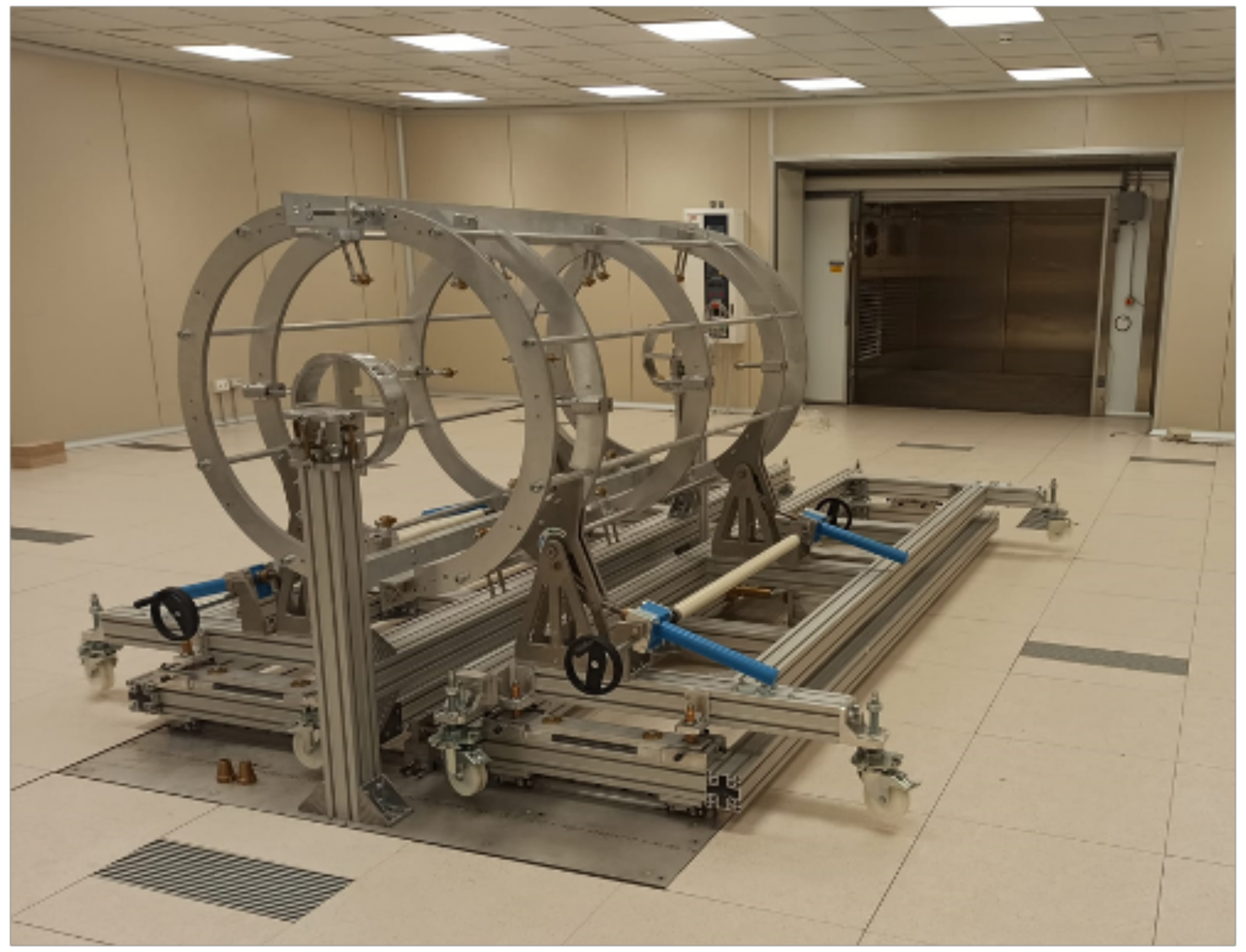


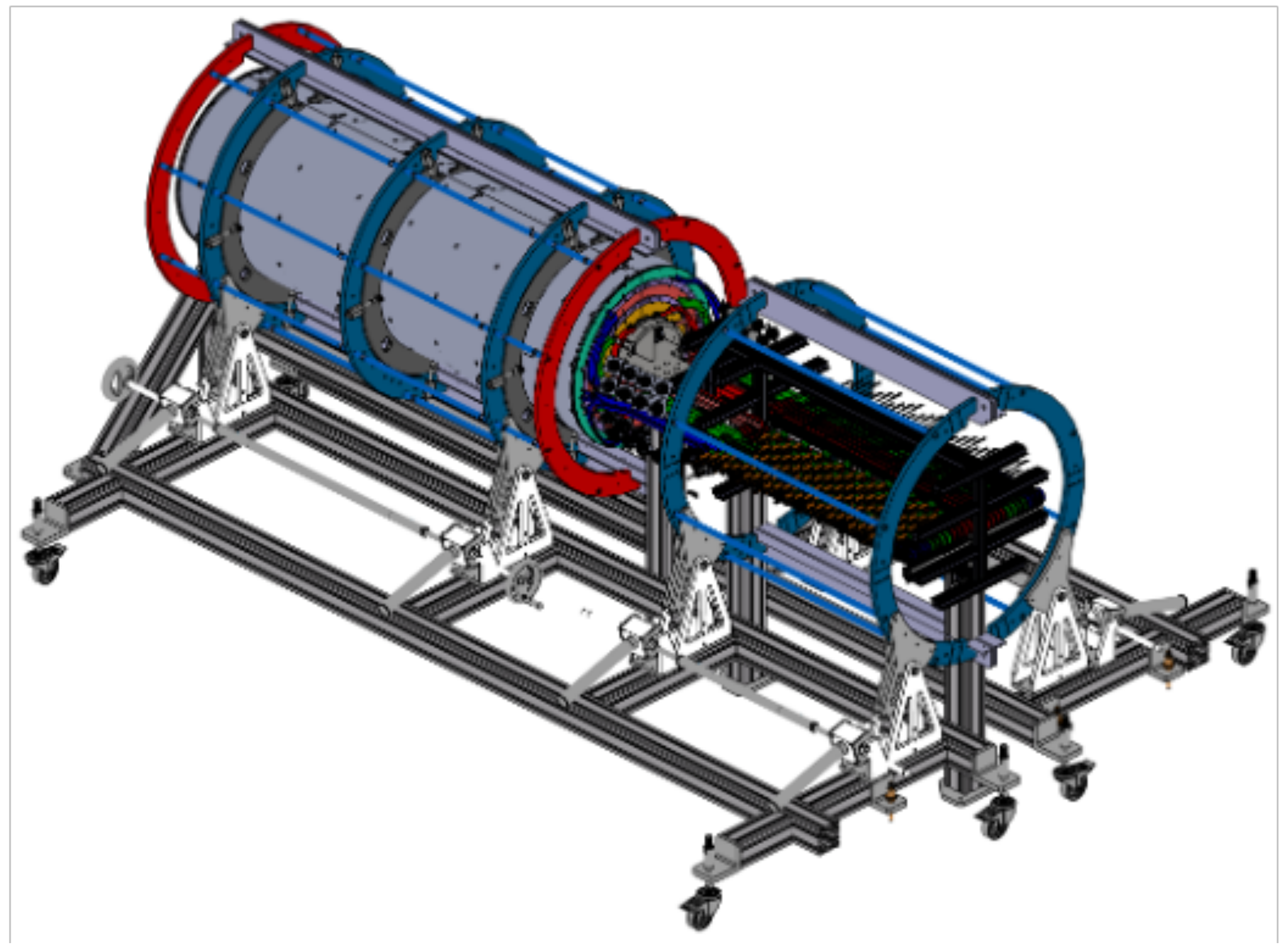


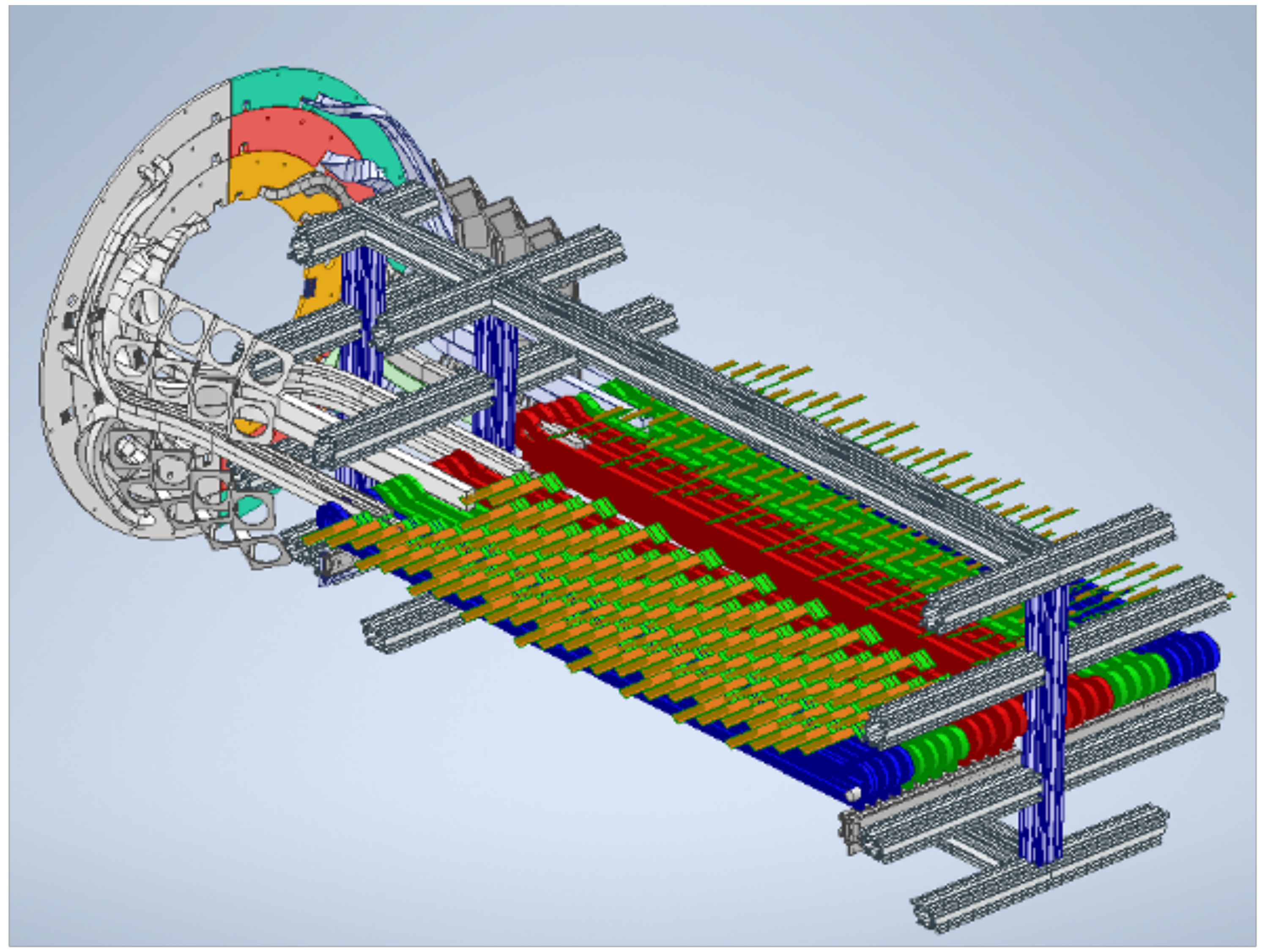
ITk Project

ATLAS new Inner Tracker

- ITk pixel system has been designed for operation at the HL-LHC
- In Italy one of the two End Caps will be constructed ad tested.
- The construction, integration and tests will be done @ LNF.
- Naples Team is working on the mechanics (service trolley and service integration procedure) with the Edimburg Team
- M. Della Pietra and P. Massarotti members of Italian steering committee
- P. Massarotti is the responsible of the cables testing and assembling @LNF







Outreach

Di Donato C., Massarotti P., Cirotto F. And many more…

OUTREACH

- Massive involvement in outreach events:
  - ↪Masterclass 2024
  - ↪Art&Science
  - ↪Futuro Remoto
- Interdisciplinary and "local" activities
- NEW: HEPscape in Naples from 2023
  - ↪By solving hidden clues, visitors learn about the role of particle accelerators and the nature of high-energy physics experiments through a fun activity

CONCLUSION

- ATLAS NA proactive in many fields:
  - ↪Physics Analyses
  - ↪Detector
  - ↪Computing
- Responsibilities inside collaboration
- New students are joining in the next months
- **ATLAS Week organized in Paestum next October**

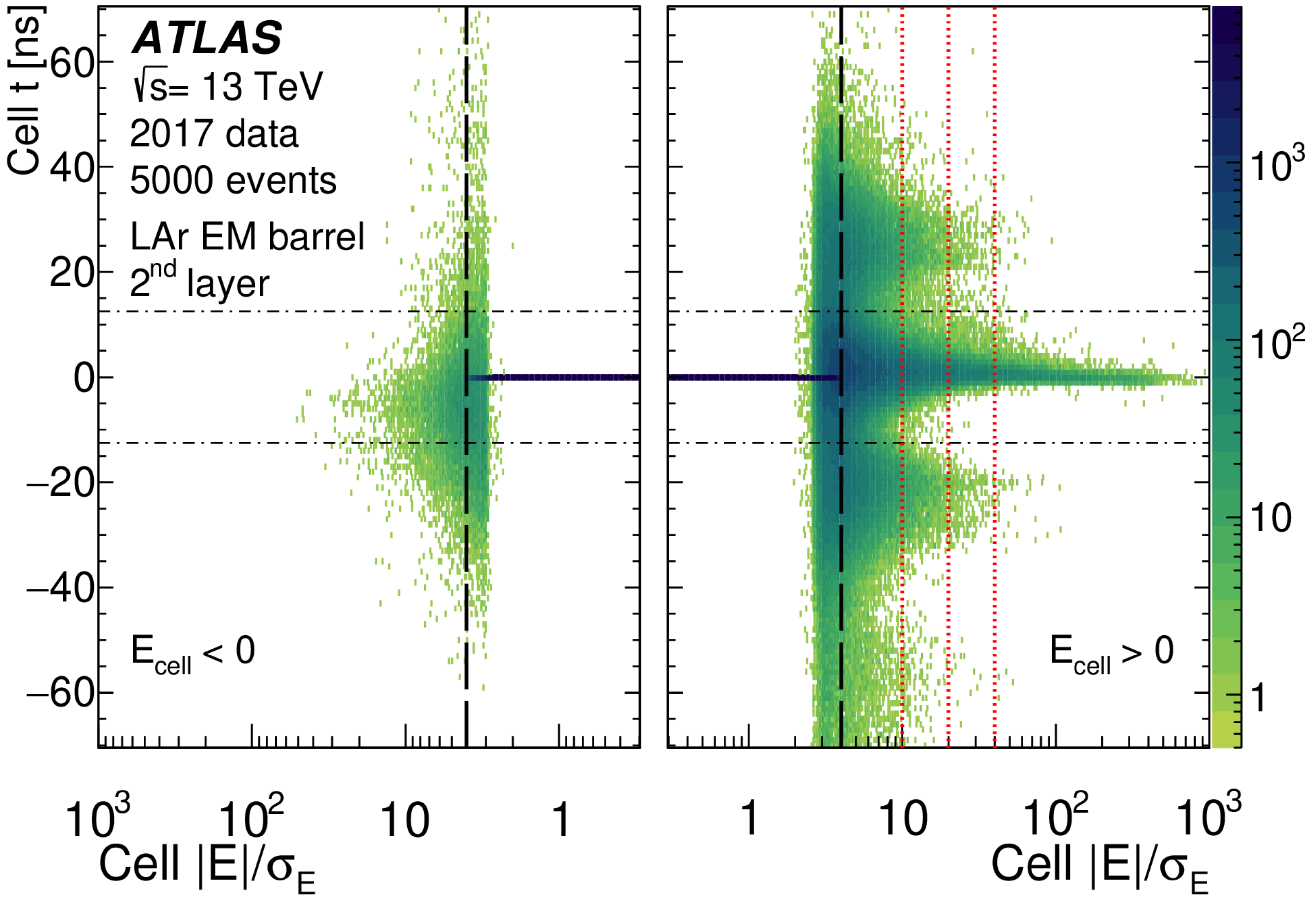
Thanks to all people who contributed to this talk!

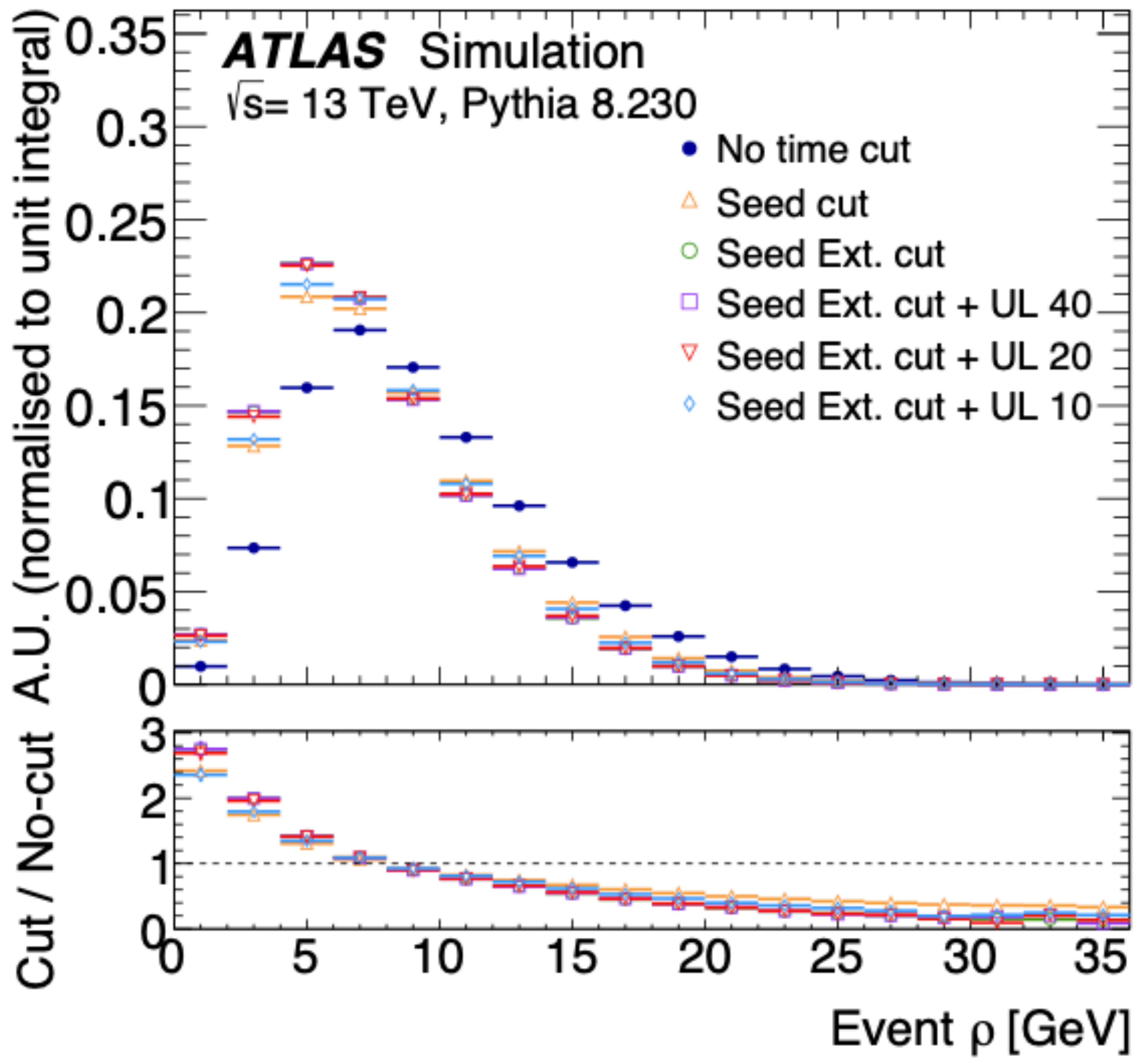
Backup

Cell Timing Cut

A new criterion in jet inputs

- New requirement in addition to cell energy significance ($\xi^{EM}_{cell} > 4$)
  - ↪Use cell time information
- Removes cells compatible with out-of-time pile-up signals
- Cut at |t| < 12.5 ns for any cell with $\xi^{EM}_{cell} > 4$ and restrict to those cells with $\xi^{EM}_{cell} < 20$
  - ↪Delayed calorimeter signals with energy can also arise from new physics (LLP)





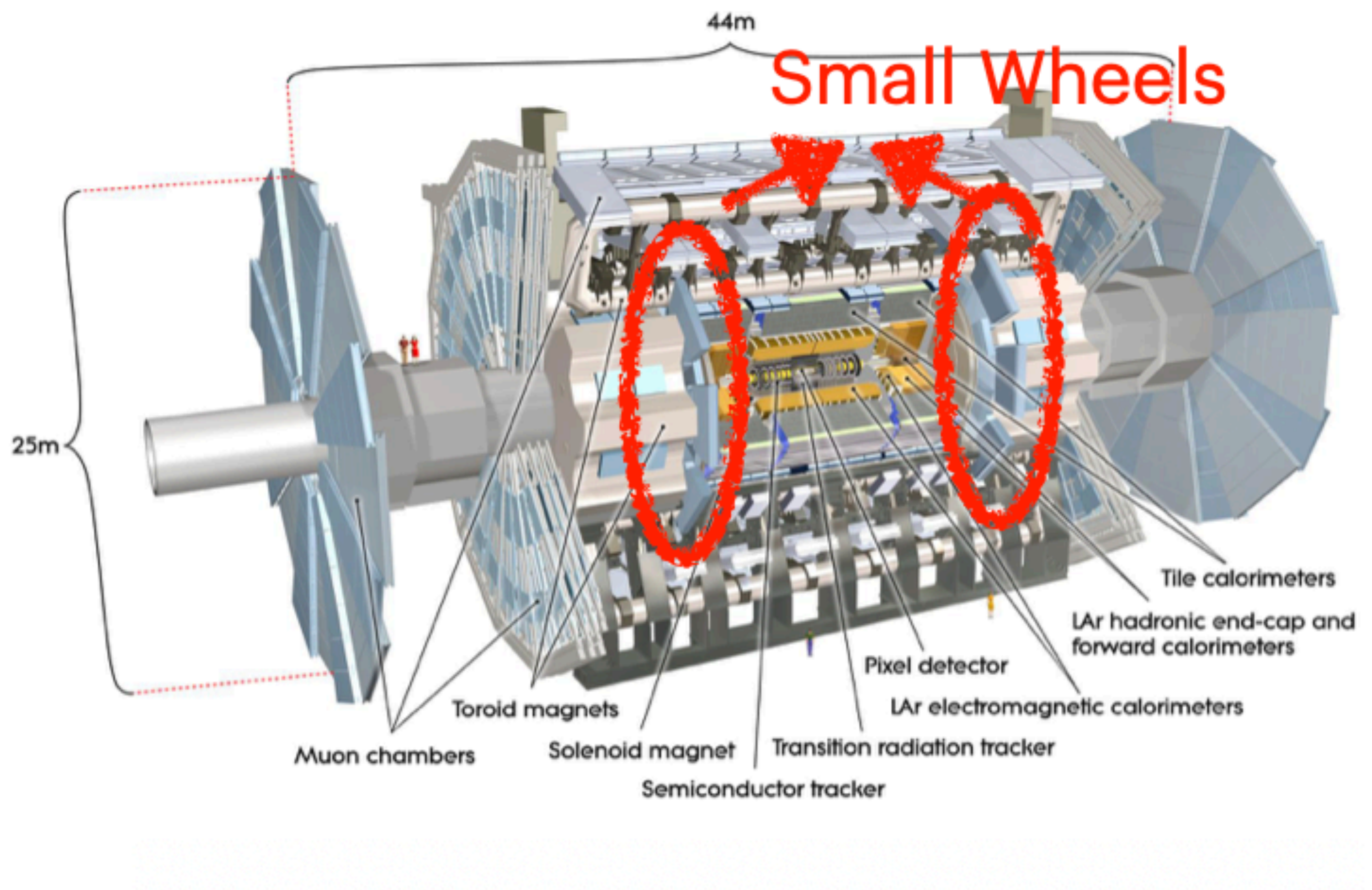
Average pile-up energy per event, ~20% smaller when applying time cut

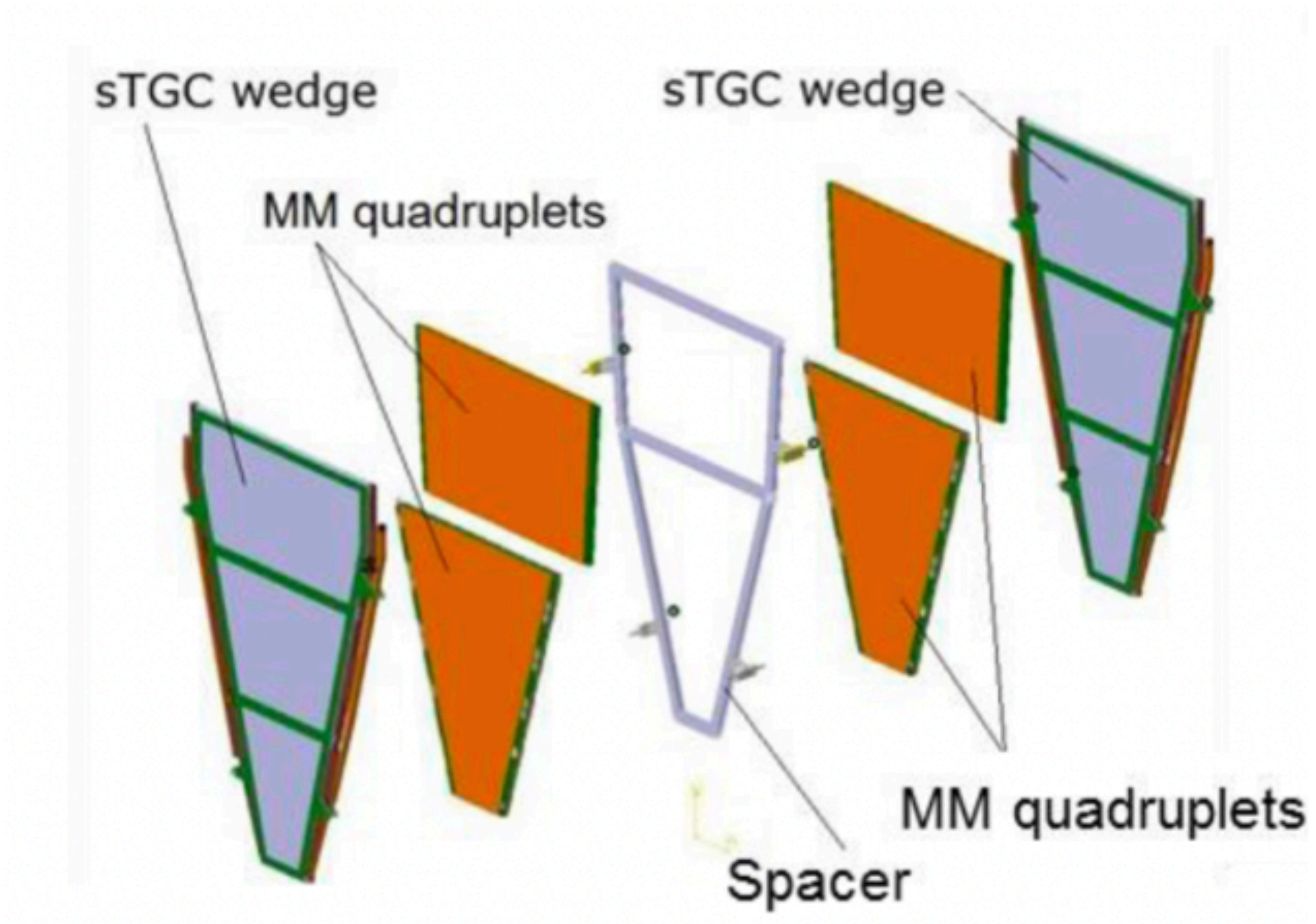
EPJC84(2024)455

NEW SMALL WHEEL

- Installed during the LS2 ATLAS phase-I upgrade for commissioning and operation in LHC Run 3
- In Run 3 instantaneous luminosity and the average pile-up increased compared to Run 2 values
  - ↪Expected increase of the muon trigger rates in the forward regions
  - ↪the sustainable ATLAS level-1 (L1) trigger rate will remain at 100 kHz (20 kHz for muons)
  - ↪need to reduce the rate of fake-muon triggers to be able to keep the L1 threshold of muon pT > 20 GeV and the L1 rate at 20 kHz
  - ↪Expected MDT efficiency drop with the higher hit rates

- 2 end cap muon stations.
  - ↪16 detector sectors per station (8 large, 8 small).
  - ↪16 detector planes per sector:
- 8 small-strip Thin Gap Chambers wedges (sTGC)
- 8 micromegas (MM) wedges

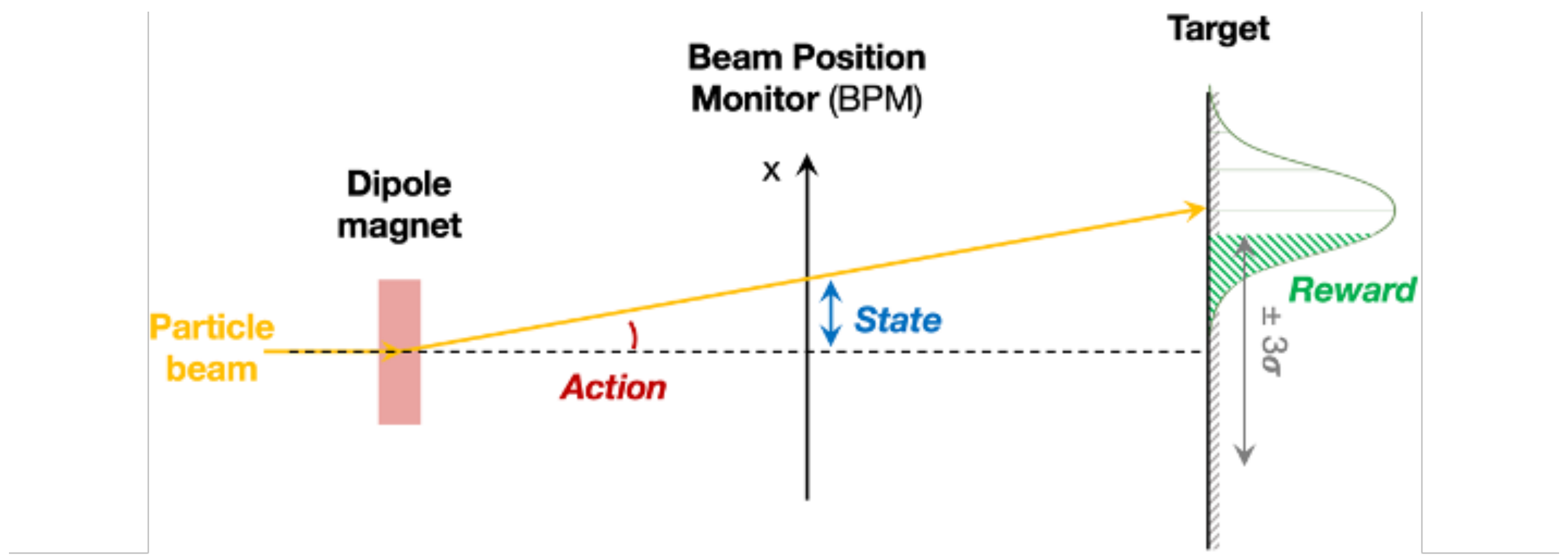


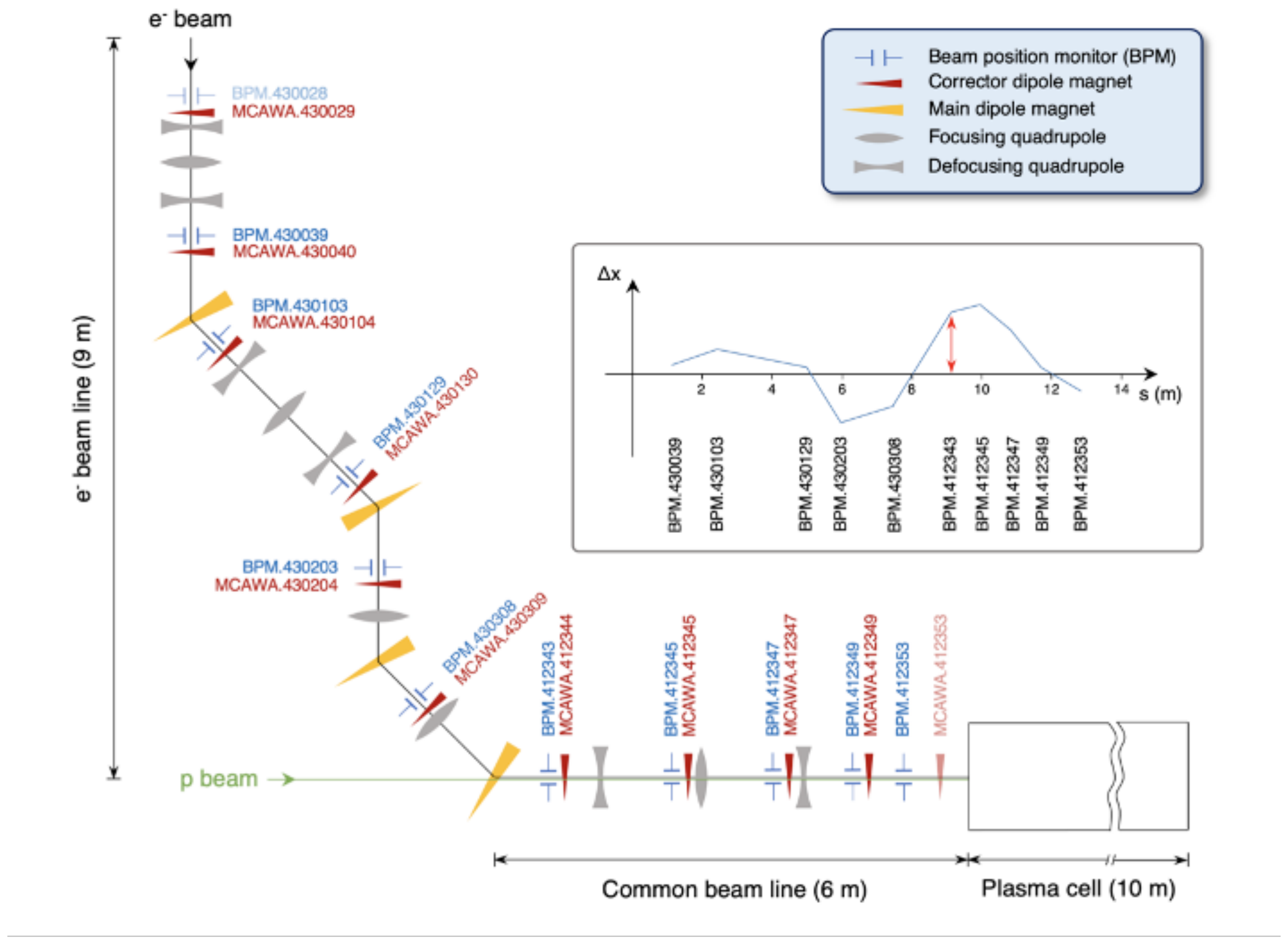


Quantum Fuzzy Control Systems For Particle Accelerators

- The Quantum Fuzzy Control System proposed in [1] has been tested for controlling the trajectory of particle beams in two real particle accelerator facilities at CERN:
  - ↪T4 target station at the CERN SPS fixed target physics beam lin
  - ↪Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE)

- Experimental results carried out on the real accelerators show the suitability of this approach in controlling these systems.





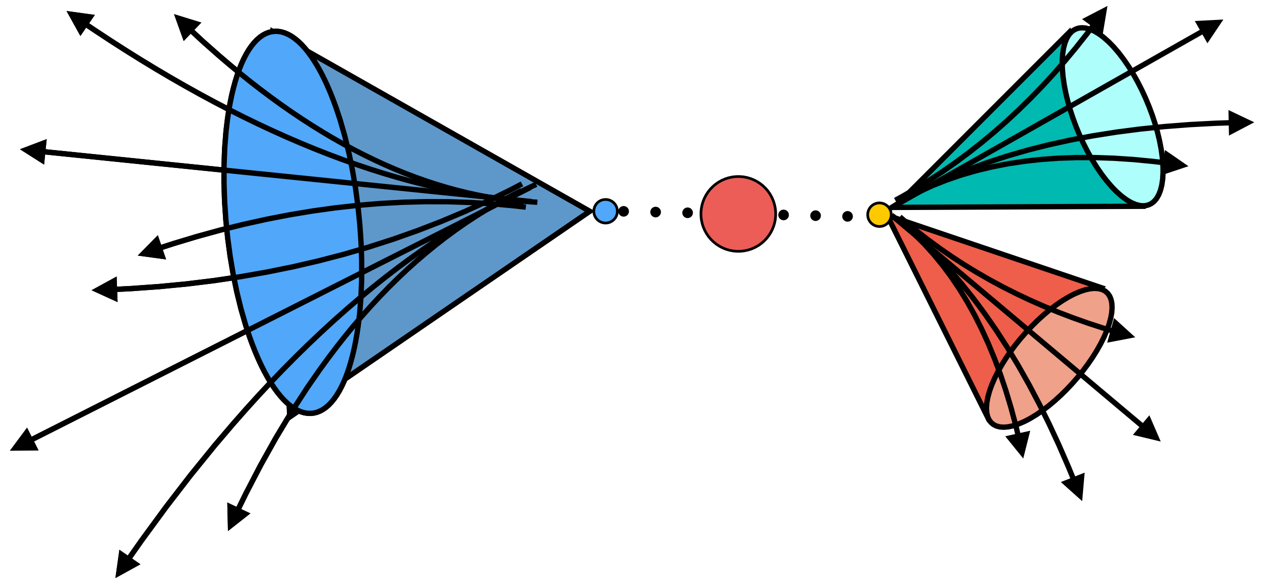
Graph Anomaly Detection for New Physics Searches

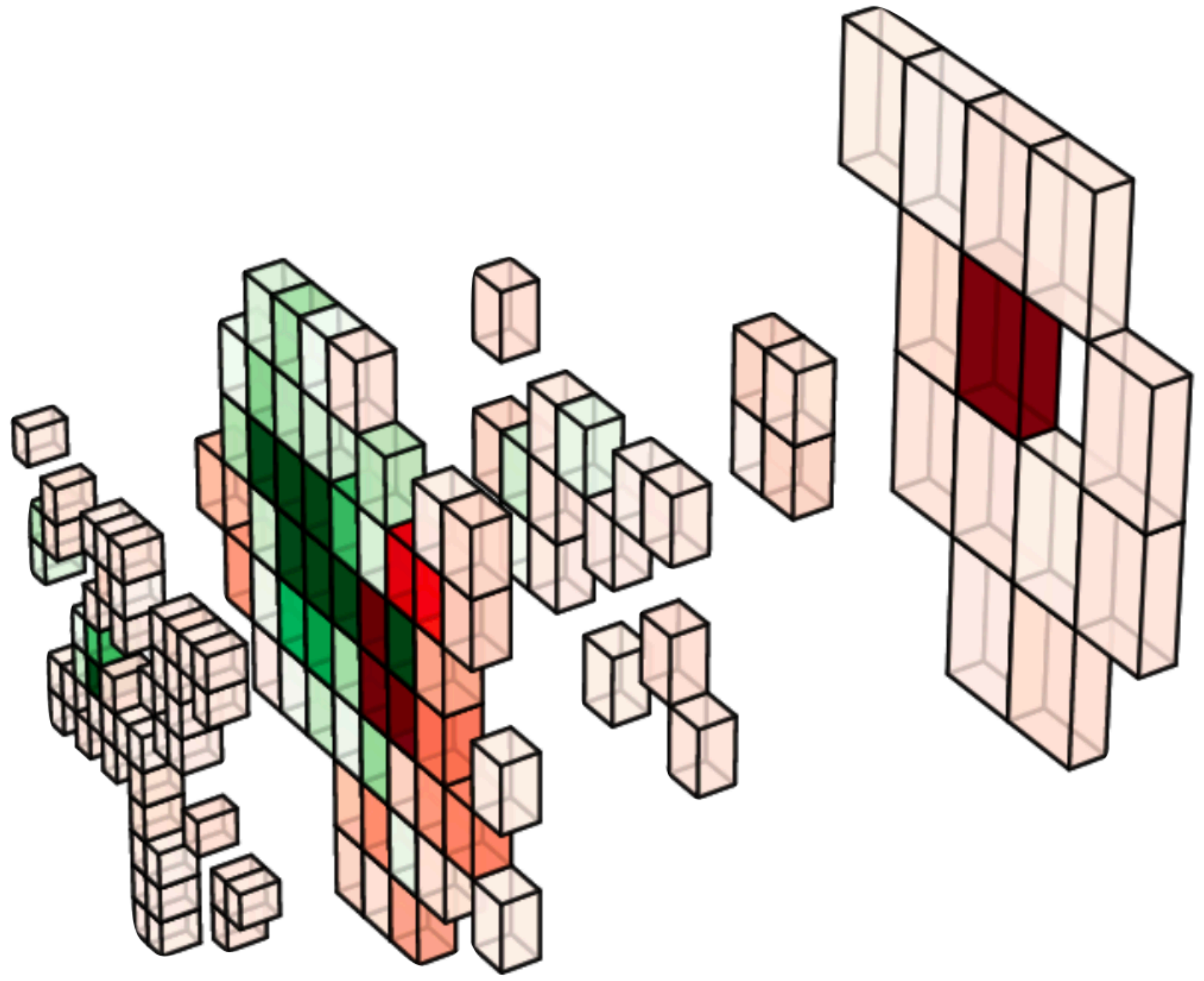
Jets as tools!

- Many Beyond Standard Model theories predict new massive resonances which can decay hadronically, leading to final states involving jets.

- For massive particles, their decay products become collimated, or 'boosted', in the direction of the progenitor particle.
  - ↪It is advantageous to reconstruct their hadronic decay products as a single large-radius (large-R) jet.

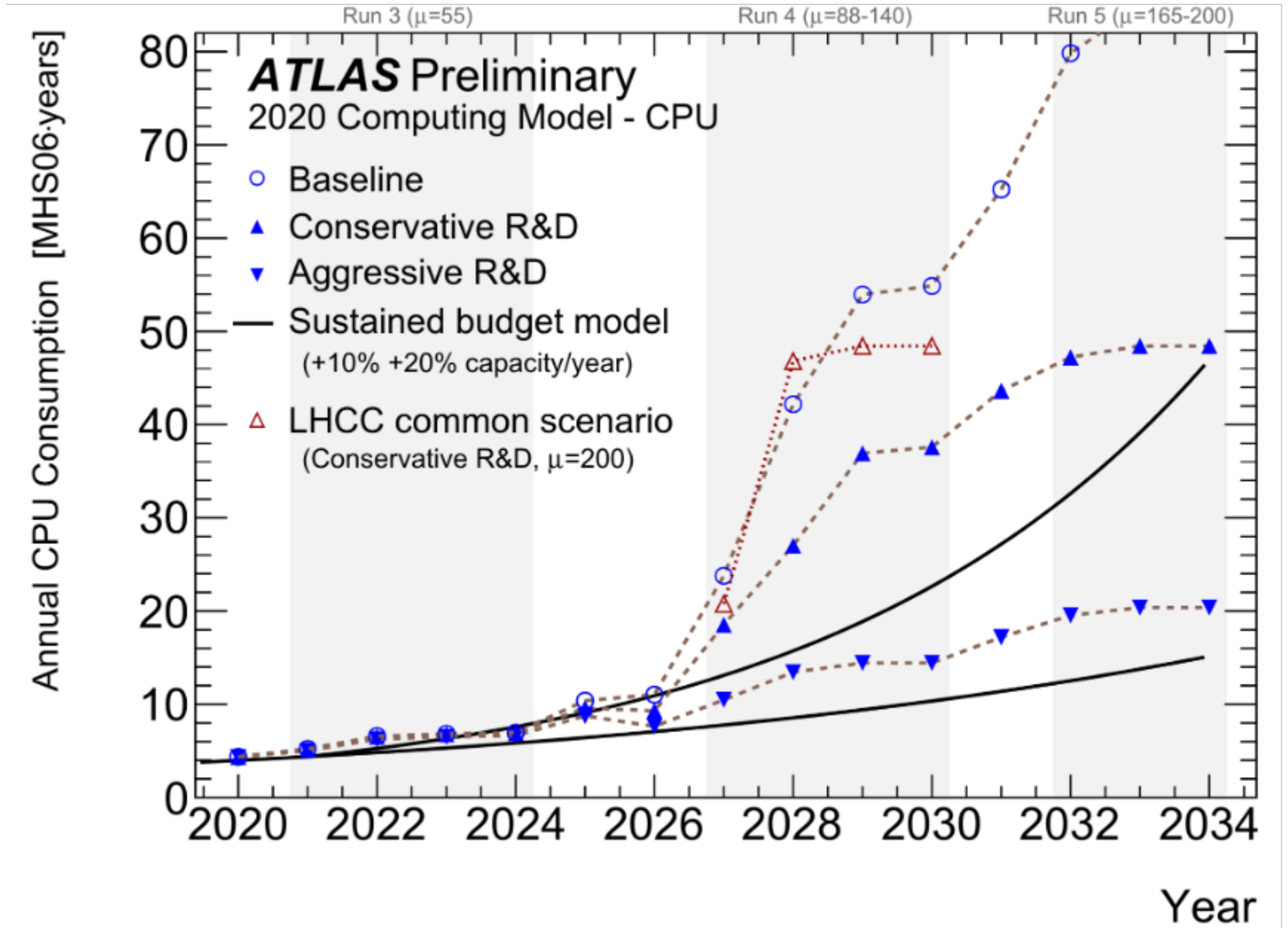
- Jet information can be used as input features for neural network architectures.
  - ↪A significant improvement in performances can be achieved by employing a set of features with basic information (low-level) such as information coming directly from the detectors.
  - ↪Jet constituents represent challenging input features to achieve this goal





BENCHMARKING DISTRIBUTED-INTERACTIVE HEP ANALYSIS

- Challenges of LHC, HL-LHC and of the Future Colliders are pushing to re-think the HEP computing models having strong impact on several aspects, from software to the computing infrastructure
- From the software perspective, interactive/quasi interactive analysis is a promising paradigm
  - ↪User-friendly environment
  - ↪Adopting open-source industry standards: Dask, Jupyter Notebooks and HTCondor
  - ↪Validating new frameworks (e.g. ROOT RDataFrame with multi-threading)



- To efficiently analyze this increasing amount of Big Data:
  - ↪Optimize the usage of CPU and storage;
  - ↪Promote the usage of better data formats;
  - ↪Develop new analysis paradigms!

- New software based on declarative programming and interactive workflows;
- Distributed computing on geographically separated resources