

Probing the Standard Model: Machine Learning and More!

Thesis opportunities with the CMS Experiment @ LHC

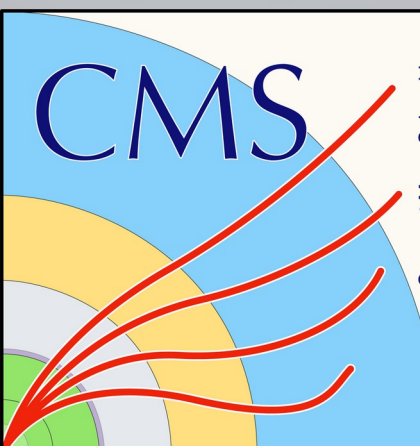
Matteo Pisano, Alessio Boletti

matteo.pisano@tecnico.ulisboa.pt - boletti@lip.pt

9th mini-school on Particle and Astroparticle Physics
Oeiras, 6th Feb 2024



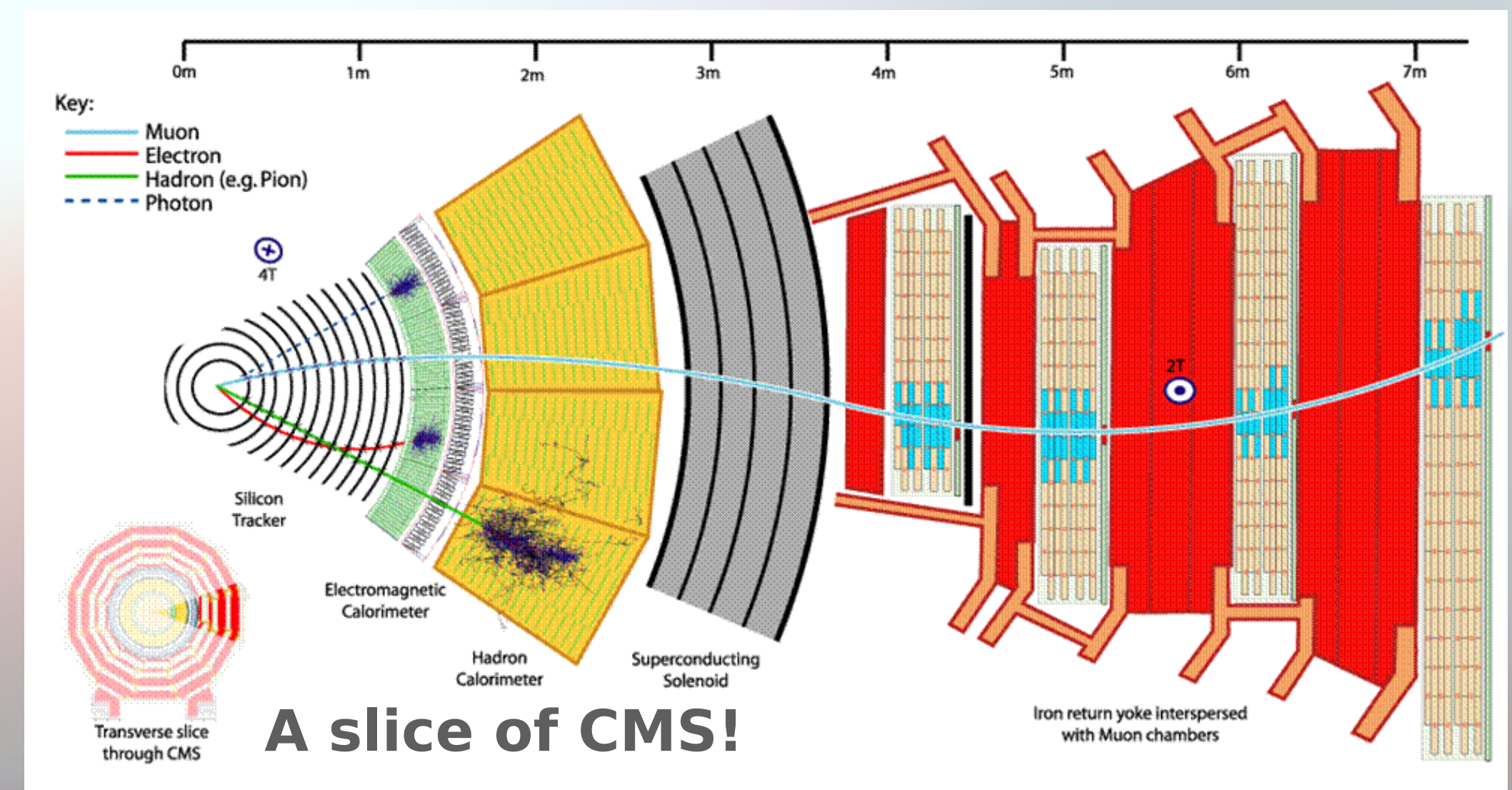
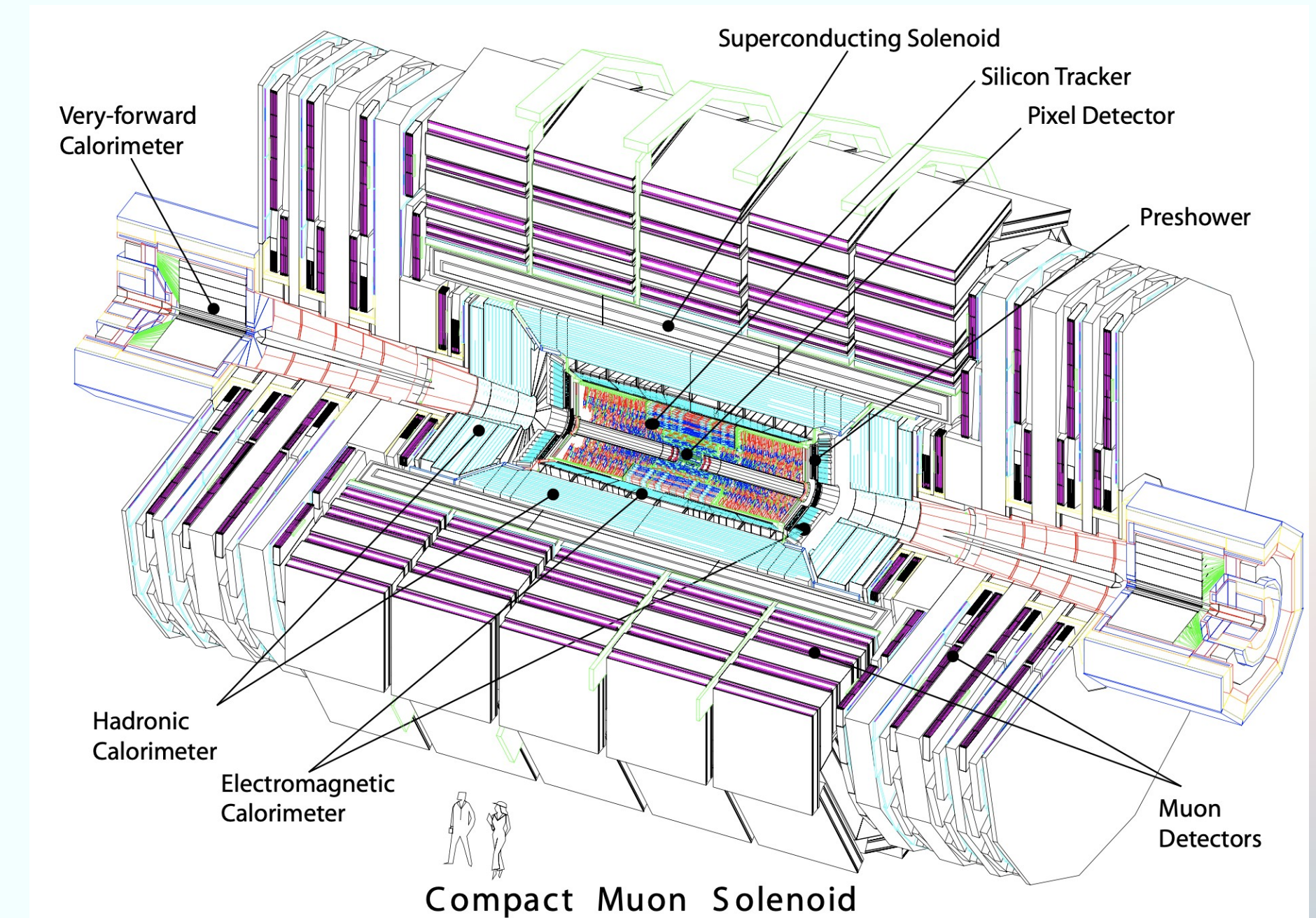
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

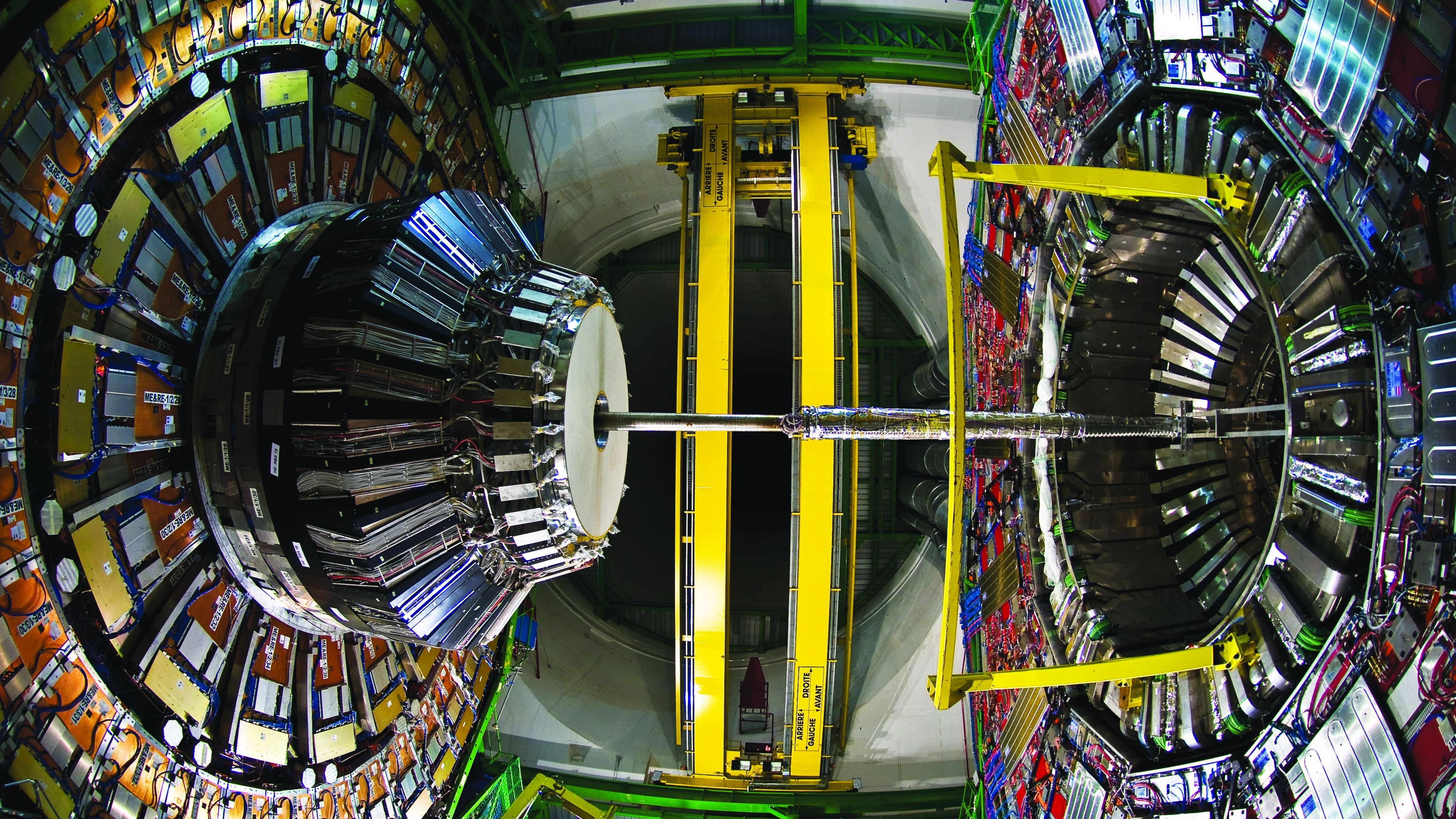


The CMS Experiment at the LHC

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- CMS is located at one of the **LHC interaction points**:
 - where the LHC beams are colliding
- CMS is a **General Purpose Experiment**:
 - Study a large spectrum of physics processes at the LHC
- **Layered design** to distinguish particles
- **LIP-CMS** group contributions: ECAL, HGAL, MTD, PPS

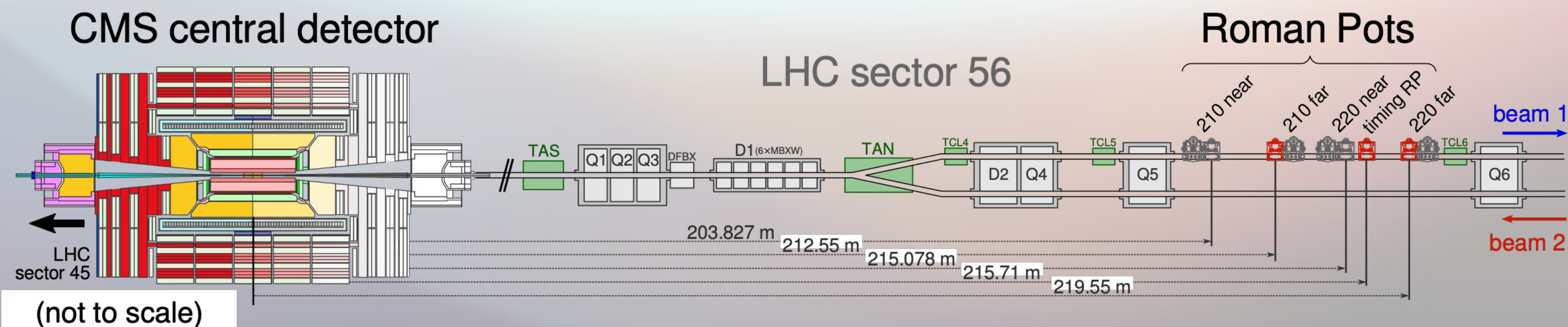




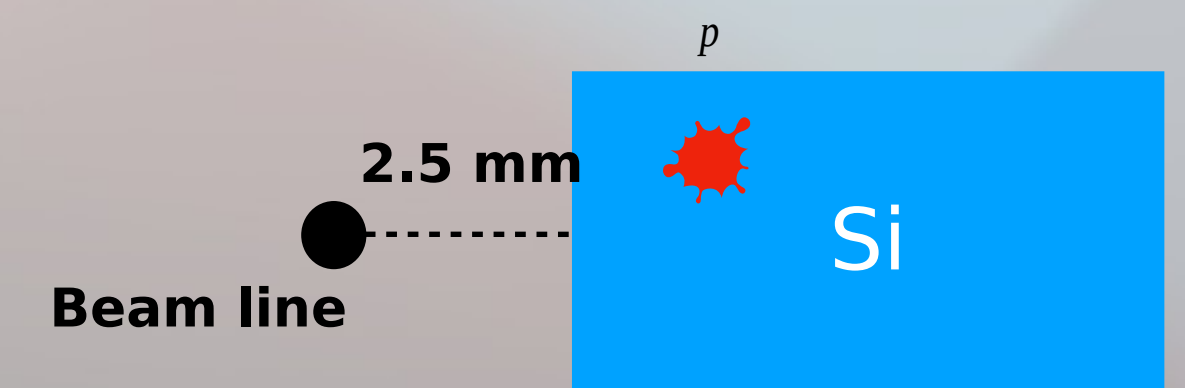
PPS: looking for intact protons!

4

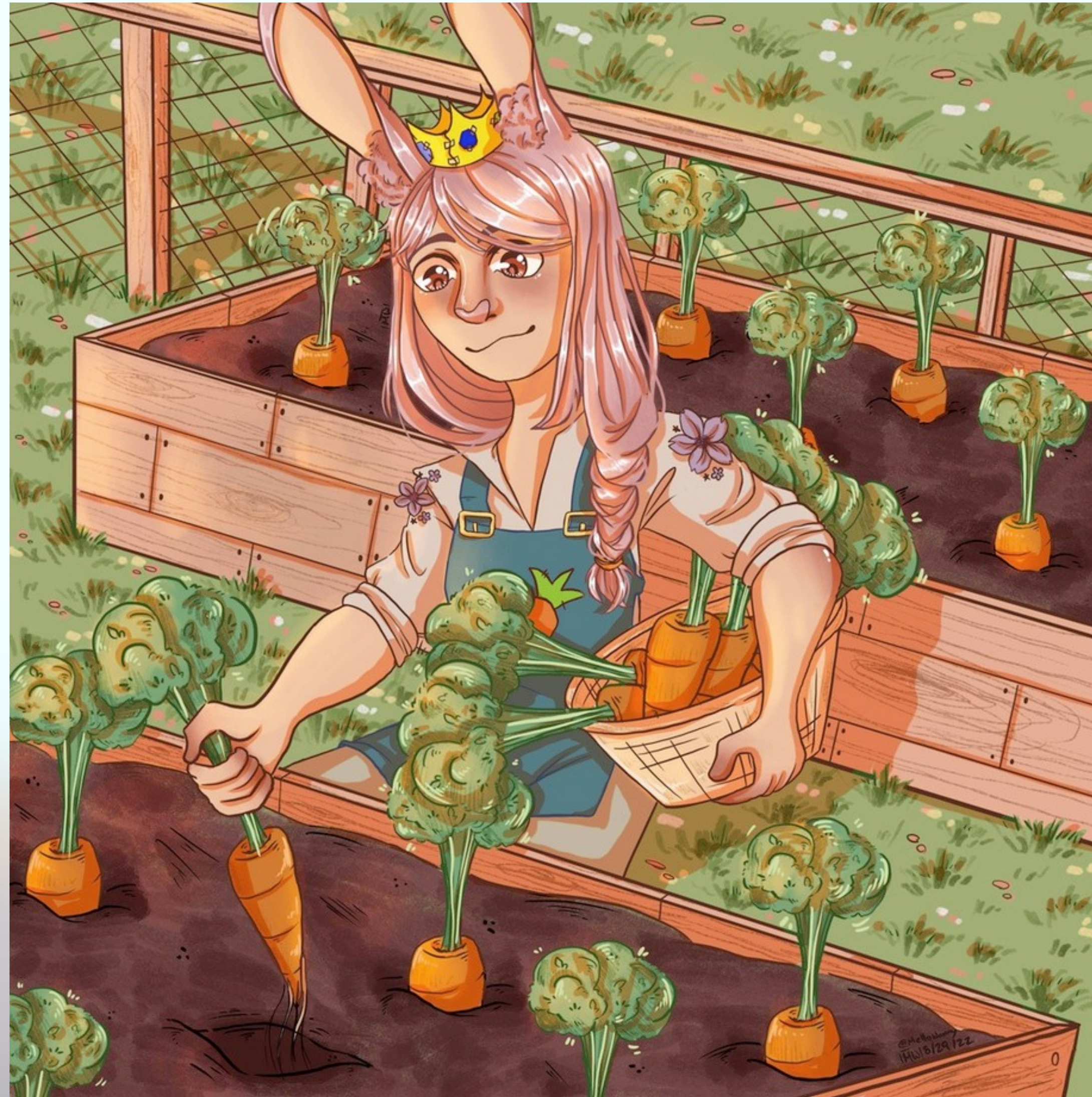
- **Precision Proton Spectrometer** to tag very forward protons
 - protons that do not break in the interaction can be tagged by PPS
- **Symmetrical detector** at **~200 m** from the interaction point
- Each side of PPS is composed by:
 - Two pixel **tracking** stations: allow to track protons
 - Two **timing** stations: to determine the interaction vertex
- A member of the group is **coordinating** the PPS project



Tracking system



Harvesting the data

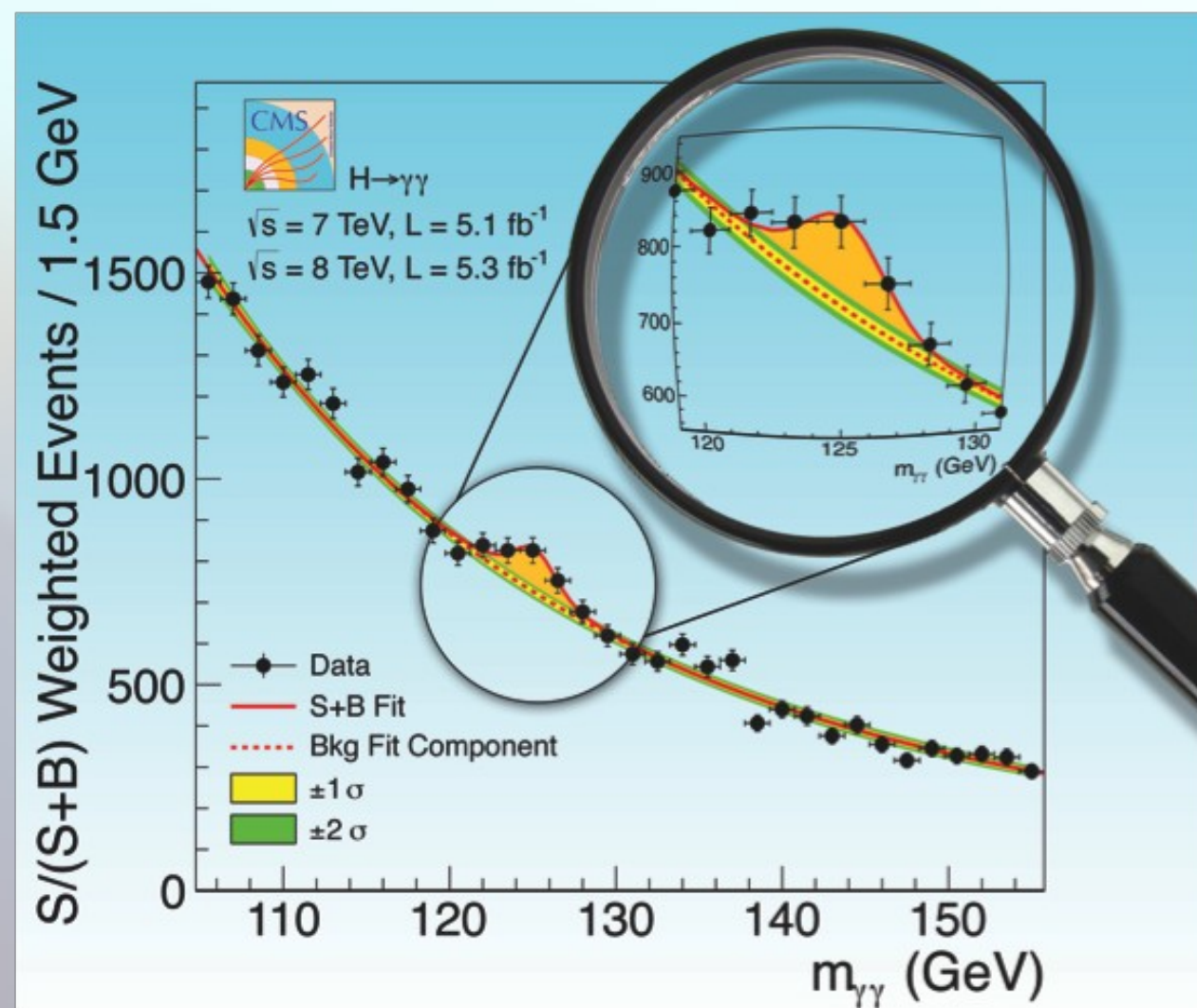


The Higgs Boson

- Discovered in 2012: studying its properties will probe the Standard Model
- Deviations would be indication of **New Physics**
- The LIP-CMS group is working on this front and Machine Learning tools are extensively used

Higgs Discovery & Couplings

Discovery of the Higgs boson in the diphoton channel and Higgs properties measurements



[PLB 716\(2012\)30](#), [JHEP 08\(2016\)045](#)

Machine Learning:

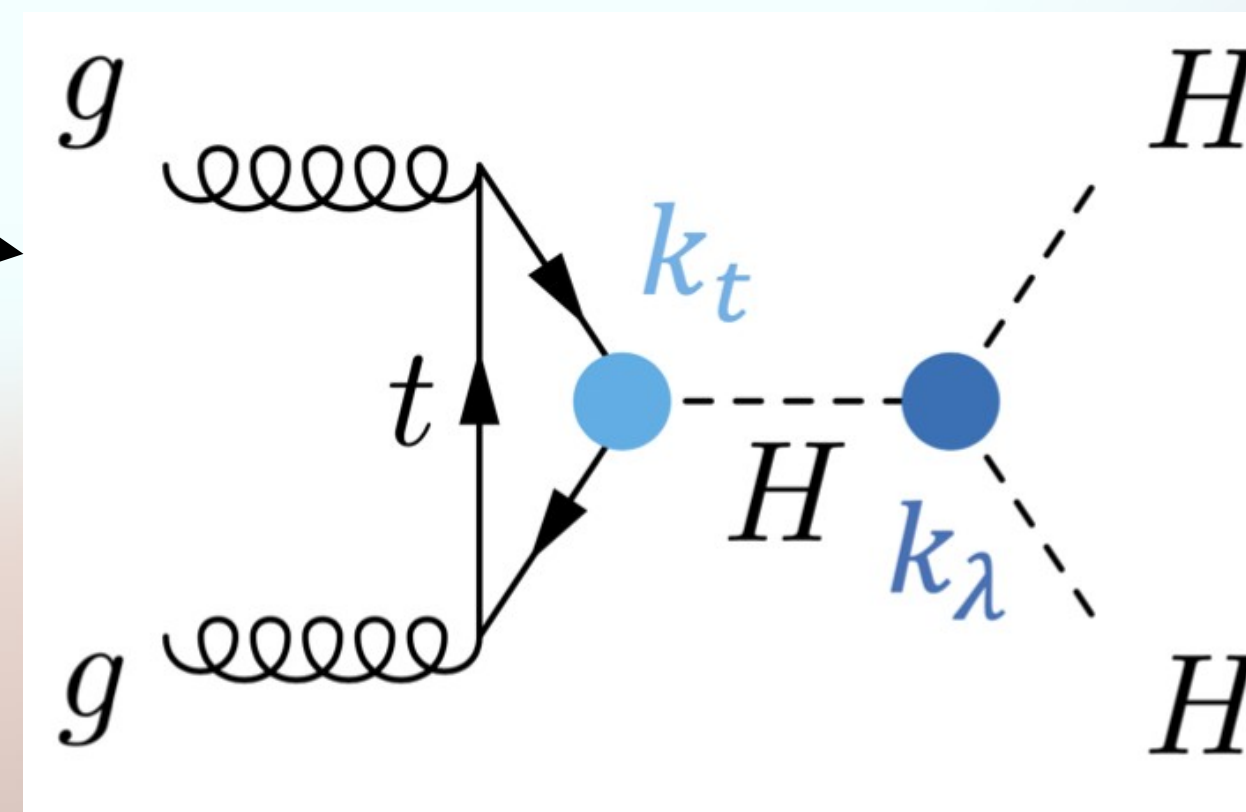
- Advanced Neural Network techniques, such as parametric NN
- NN for b-jet ID, event classification and signal extraction

Machine Learning:

- Multivariate tool is trained for photon reconstruction
- BDT used for di-photon event selection/classification

Higgs Pairs

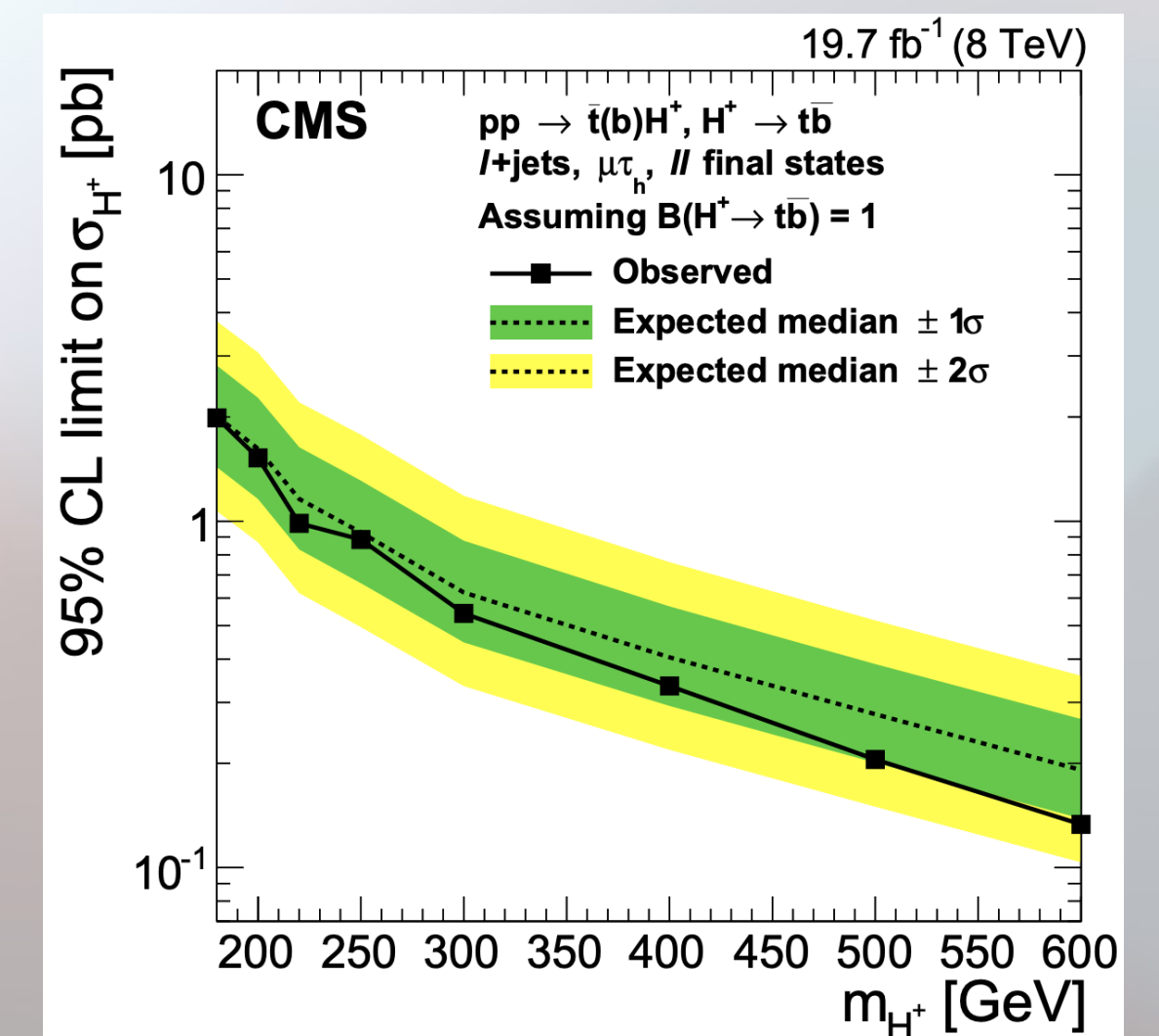
ML tools to find HH processes
→ Higgs self-coupling



[PLB 778\(2018\)101](#), [arXiv:1902.00134](#),
[PLB 842\(2023\)137531](#), [CMS-TDR-020](#)

Charged Higgs

Some BSM theories predict the existence of a charged Higgs



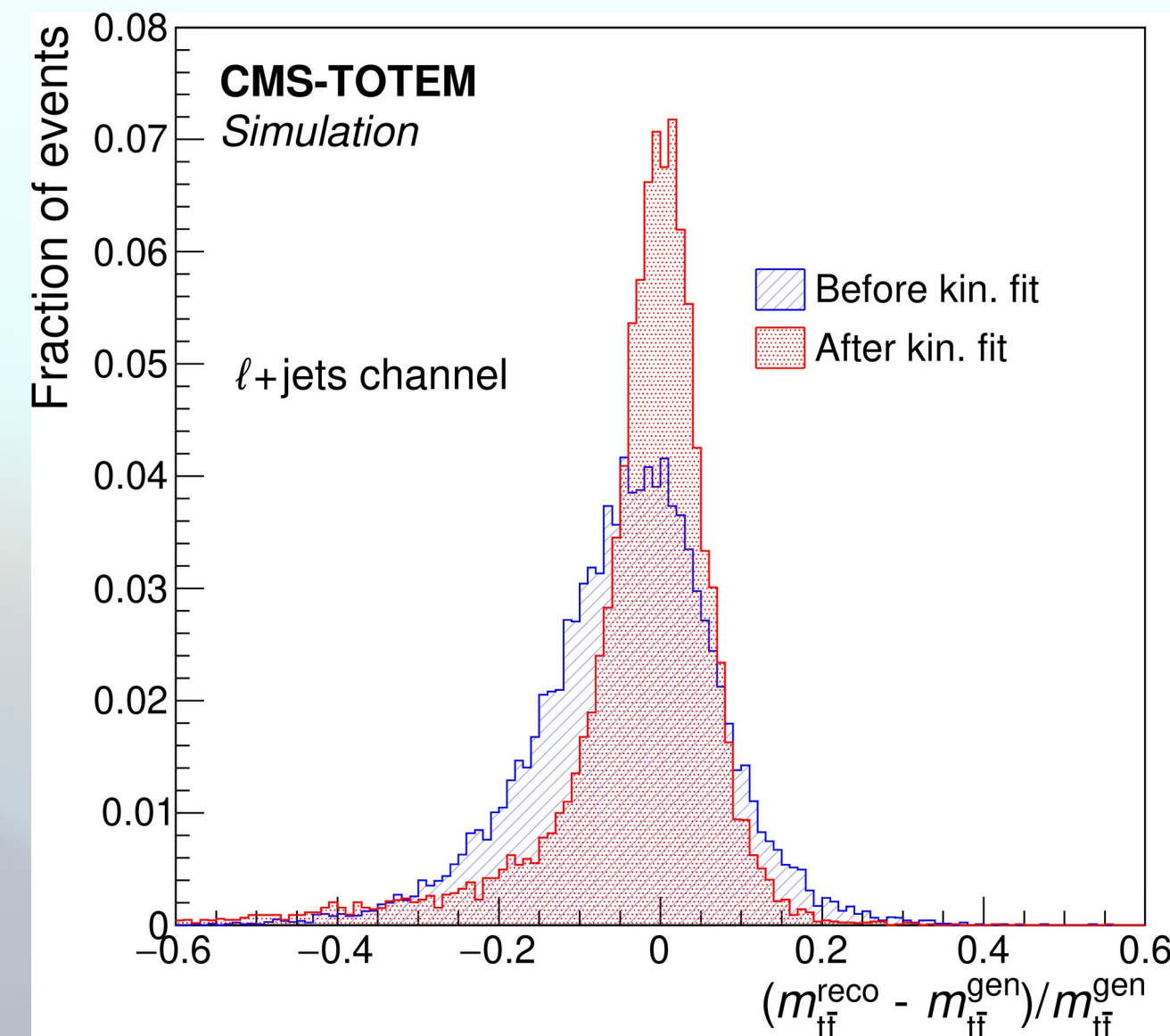
[JHEP 11\(2015\)018](#)
[JHEP 06\(2023\)060](#)

Probing the Standard Model

- Precise measurement of SM processes and the study of rare decays, searching for deviations from SM expectations → Indication of new physics
- The LIP-CMS group involved on data analysis on many fronts

Central Exclusive Production

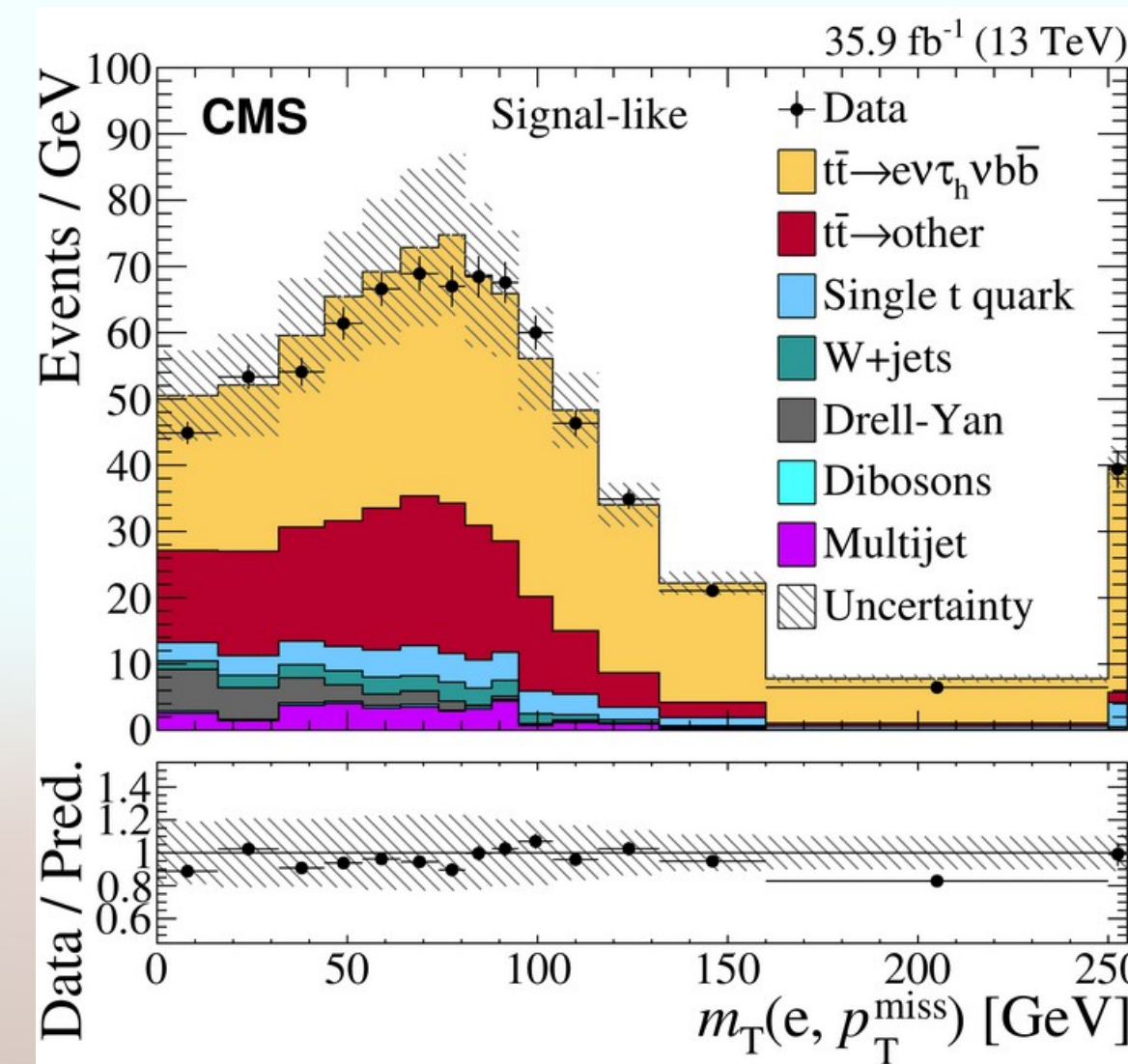
Use PPS to tag events where protons remain intact.
→ cleaner event and precise final-state kinematics



[JHEP 07\(2018\)153](#), [JHEP 2307\(2023\)229](#),
[JINST 18\(2023\)P09009](#)

Top Physics

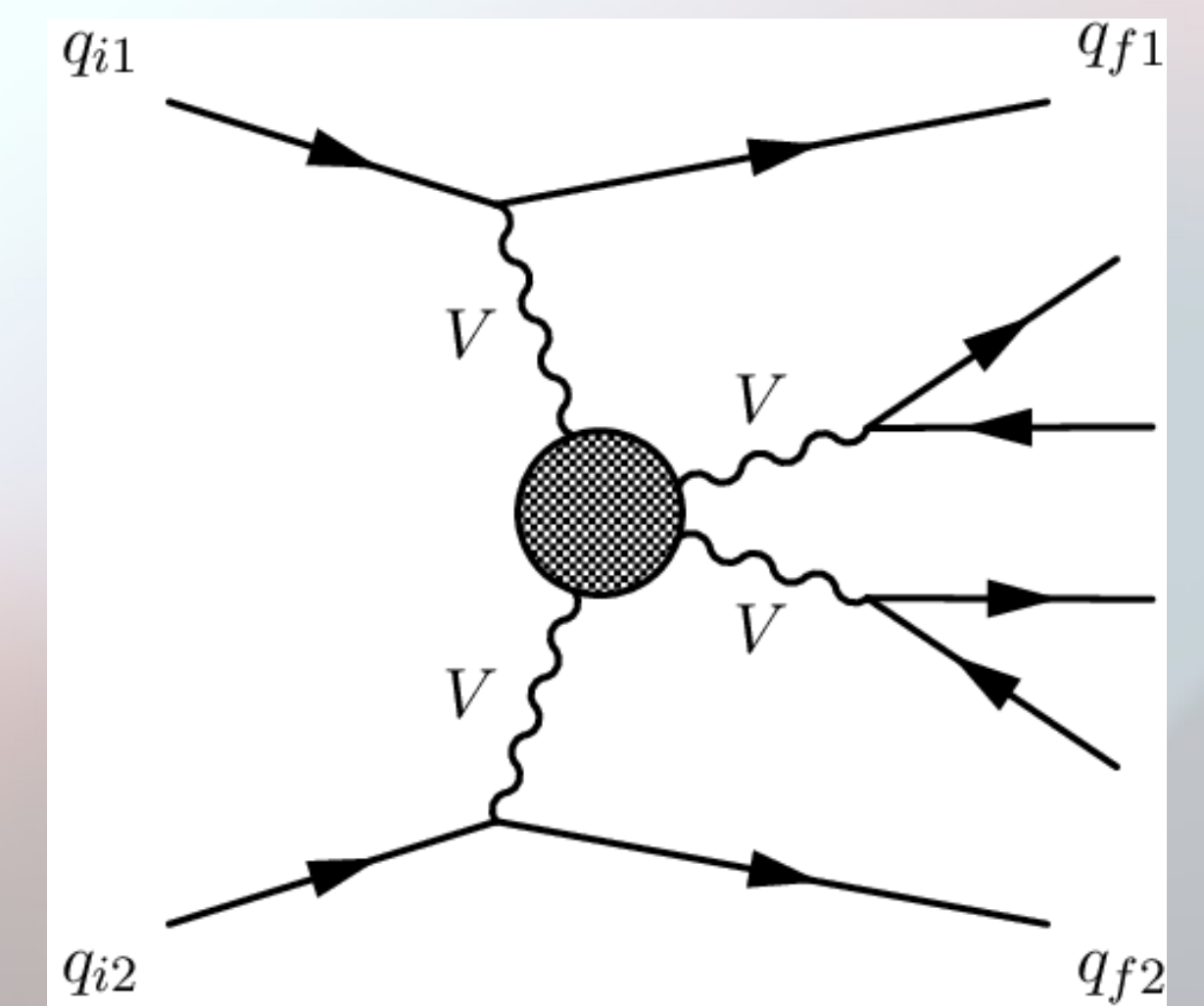
Lepton Flavour Universality - Does the top quark decay at same rate to all lepton flavours?



[JHEP 02\(2020\)191](#)
[arxiv:2310.11231](#)

Vector Boson Scattering

Deviations from SM would be evidence of New Physics → ML will play an important role



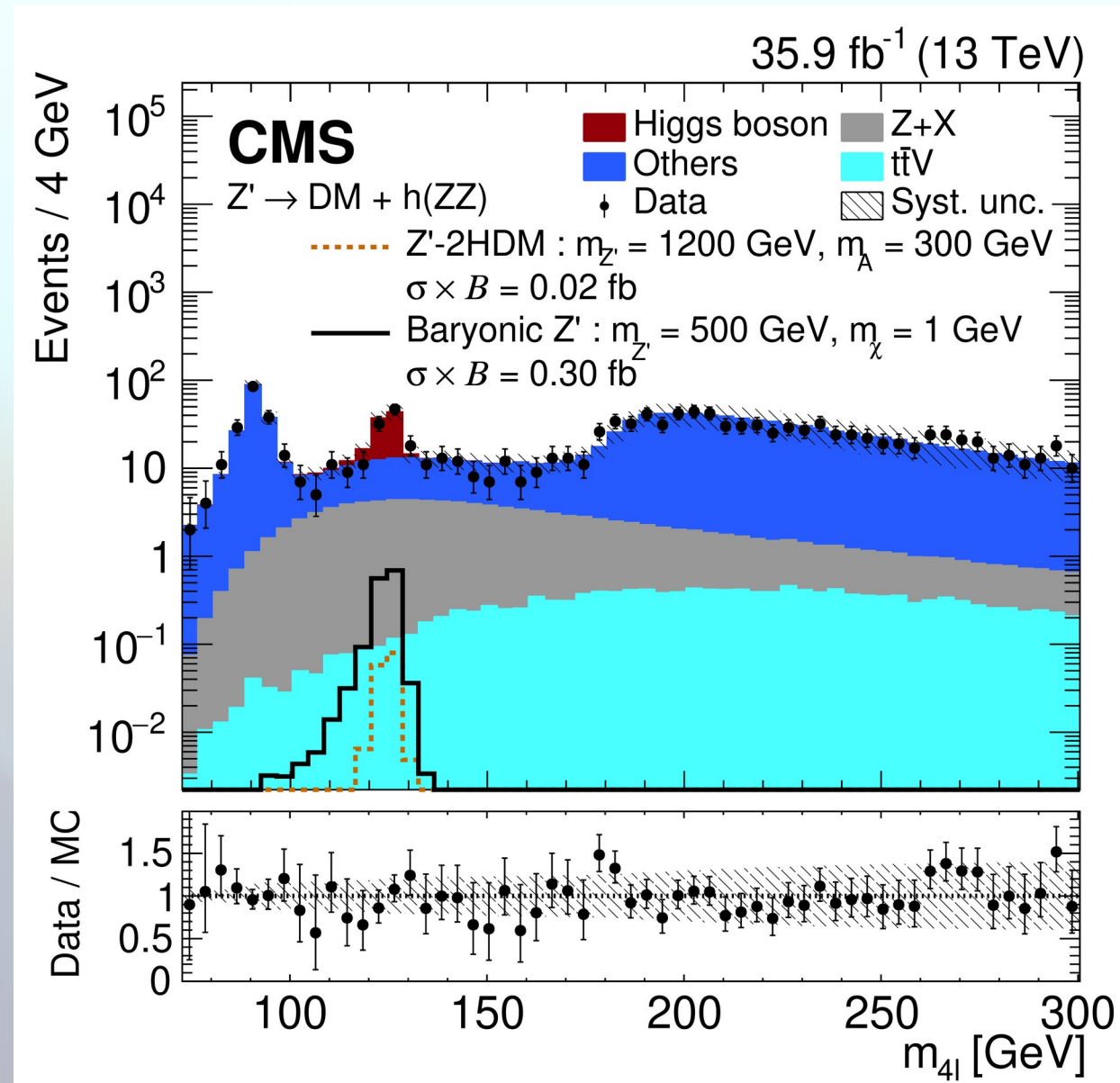
[Rev.Phys. 8 \(2022\) 100071](#)
[CMS-PAS-SMP-22-008](#)

Probing the Standard Model

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Dark matter

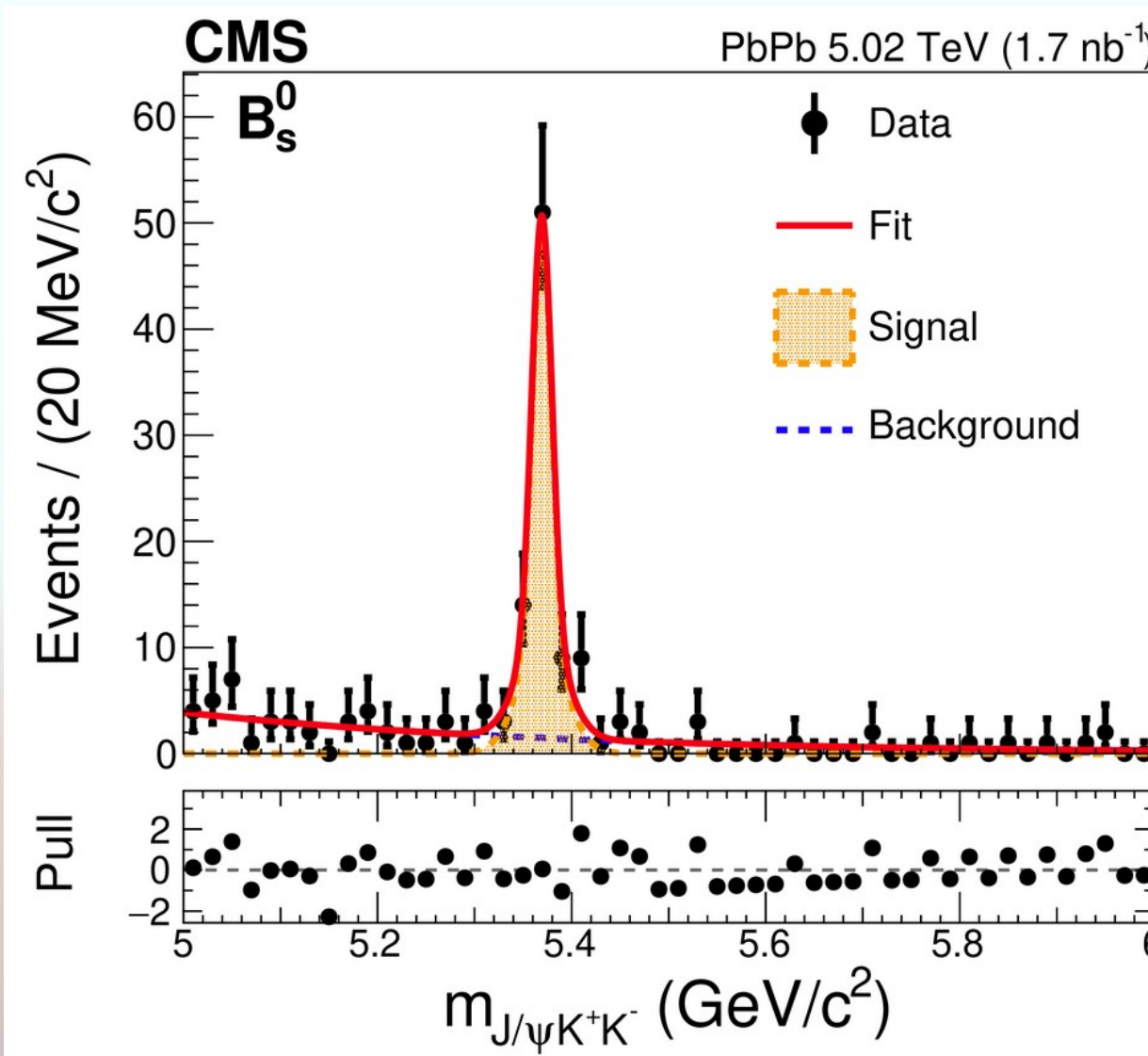
Direct search for dark matter produced in association with a Higgs boson



[JHEP 03 \(2020\) 025](#)

Flavour physics in heavy-ion collisions

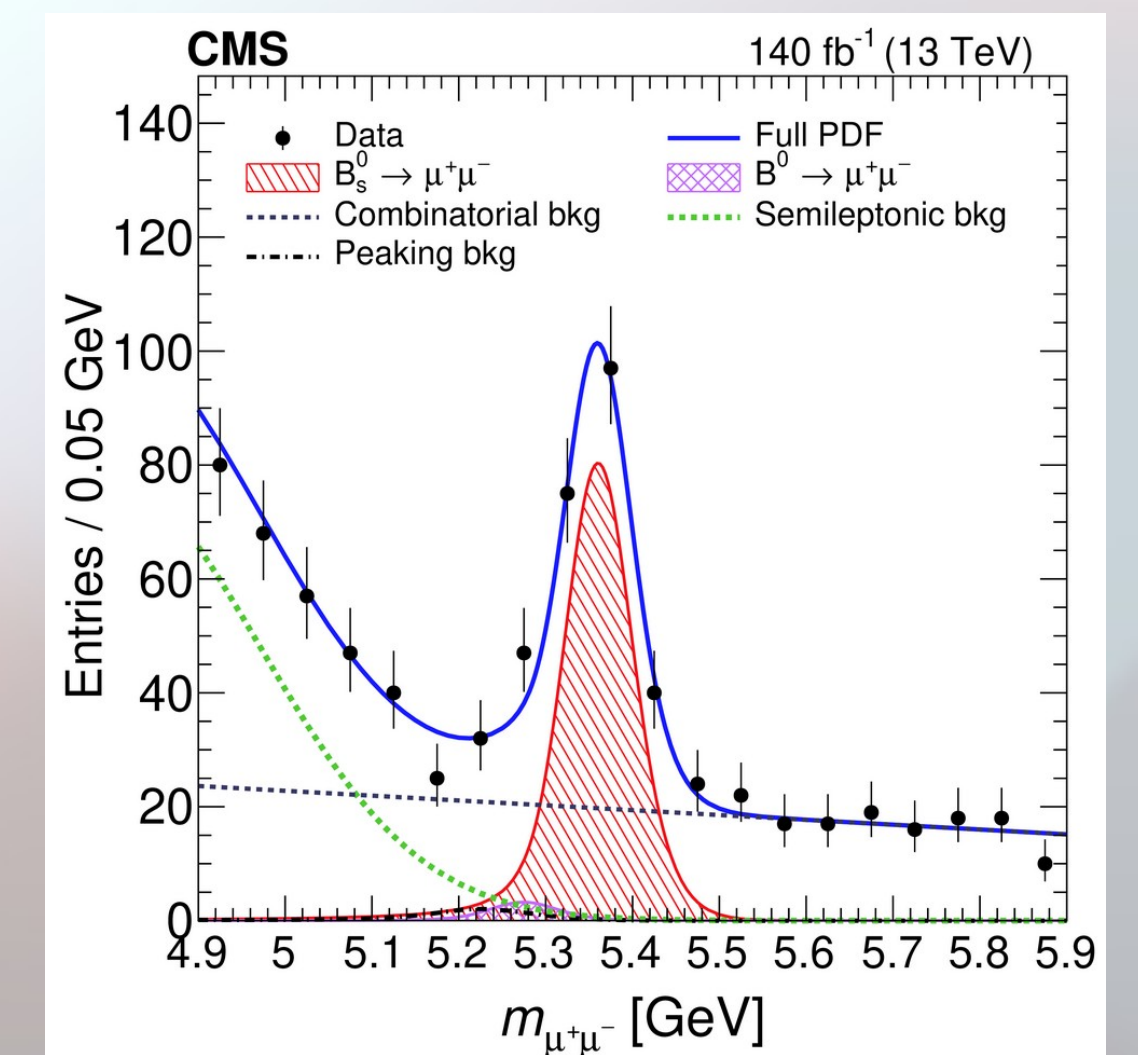
Precise measurements of rare decays and effects of the Heavy Ions collision environment



[arXiv:1812.07638](#), [PLB 829 \(2022\) 137062](#)

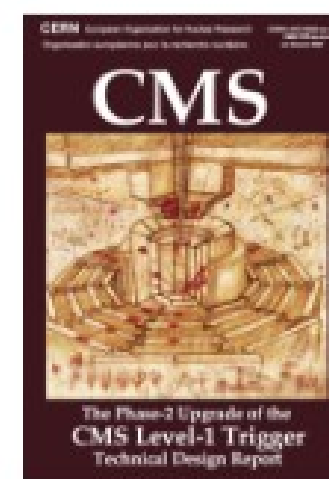
B-Physics & quarkonia

Search for rare decays of hadrons with heavy quarks and study of their properties, to understand the Flavour Anomalies



[PRL 124\(2020\)162002](#) [PLB 781\(2018\)517](#)
[PLB 842\(2023\)137955](#)

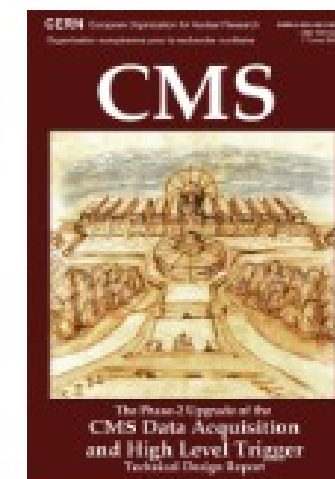
Detector Upgrades for HL-LHC



L1-Trigger

<https://cds.cern.ch/record/2714892>

- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger

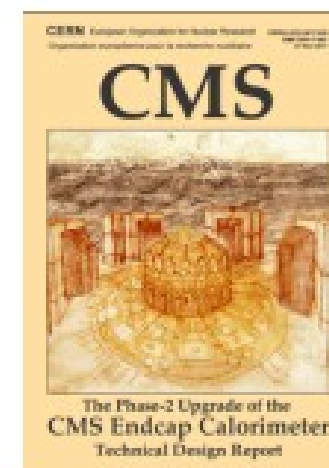
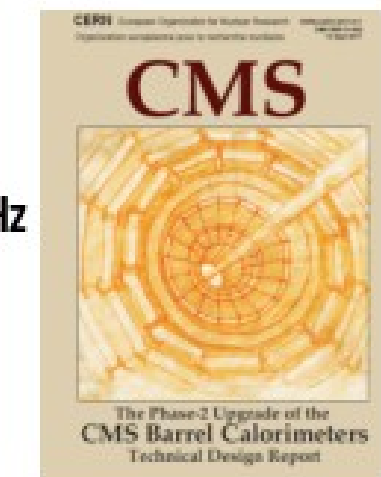
<https://cds.cern.ch/record/2759072>

- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters

<https://cds.cern.ch/record/2283187>

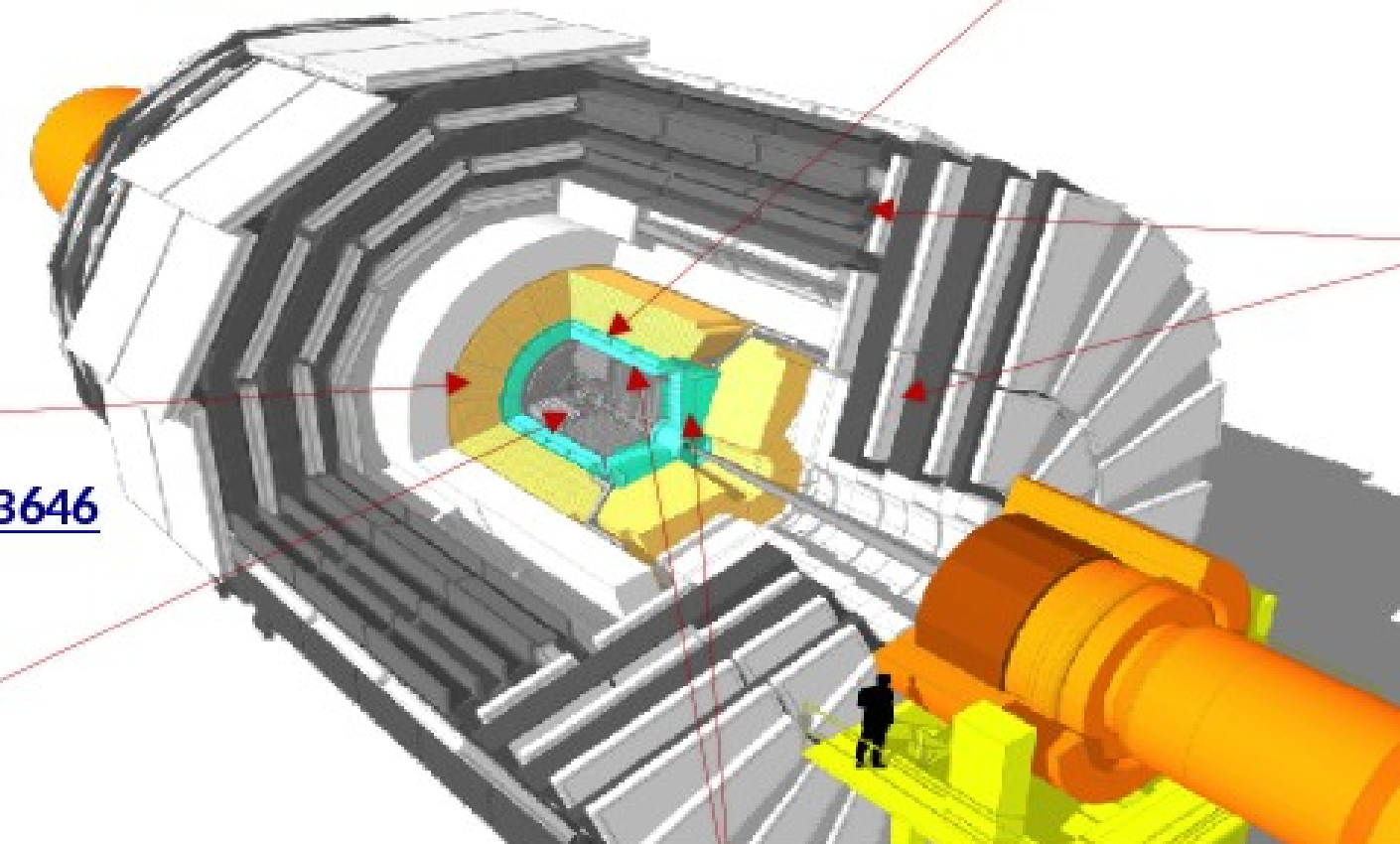
- ECAL crystal granularity readout at 40 MHz with precise timing for e/ γ at 30 GeV
- ECAL and HCAL new Back-End boards



Calorimeter Endcap

<https://cds.cern.ch/record/2293646>

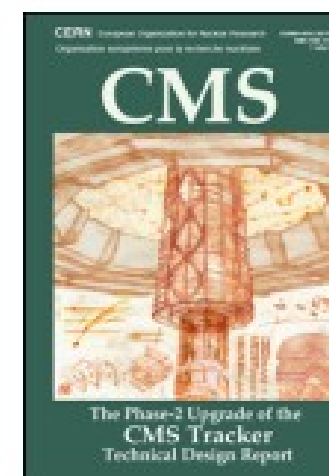
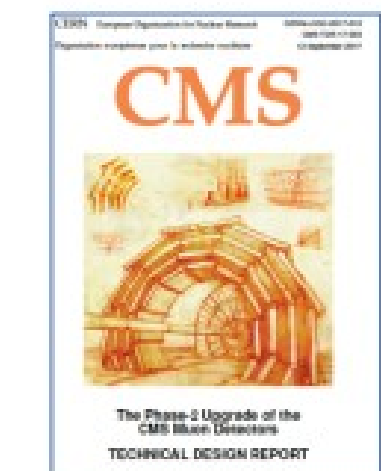
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



Muon systems

<https://cds.cern.ch/record/2283189>

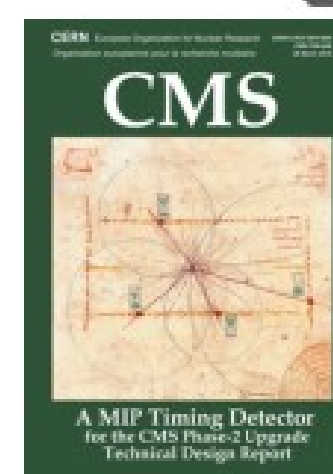
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$



Tracker

<https://cds.cern.ch/record/2272264>

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \approx 3.8$



MIP Timing Detector

<https://cds.cern.ch/record/2667167>

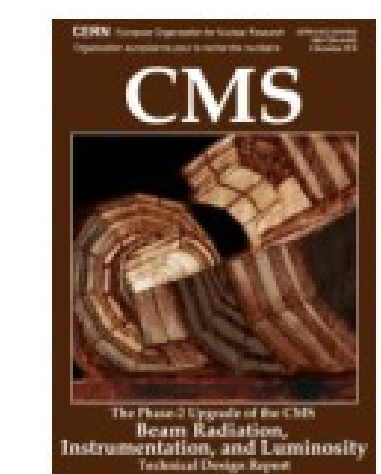
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Beam Radiation Instr. and Luminosity

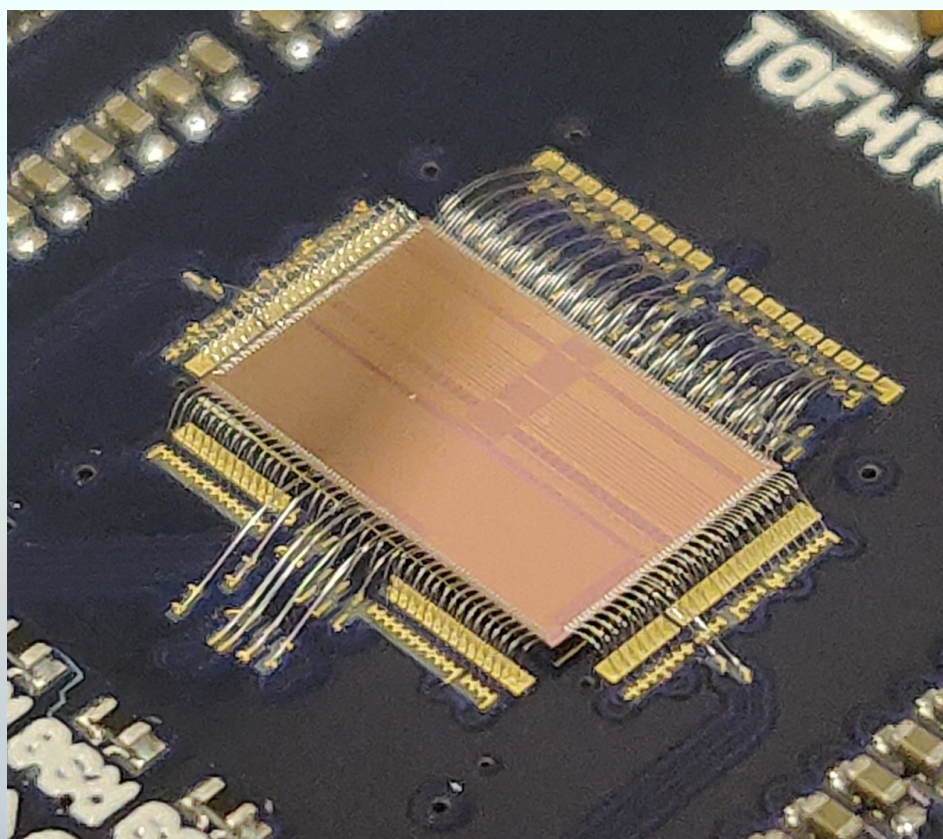
<http://cds.cern.ch/record/2759074>

- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity:
1% offline, 2% online
- Neutron and mixed-field radiation monitors

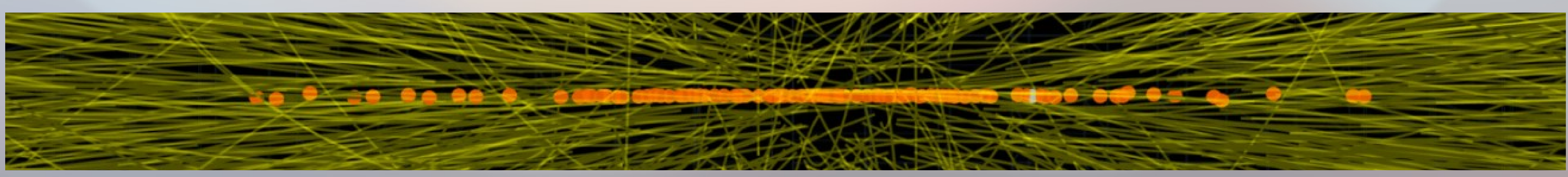
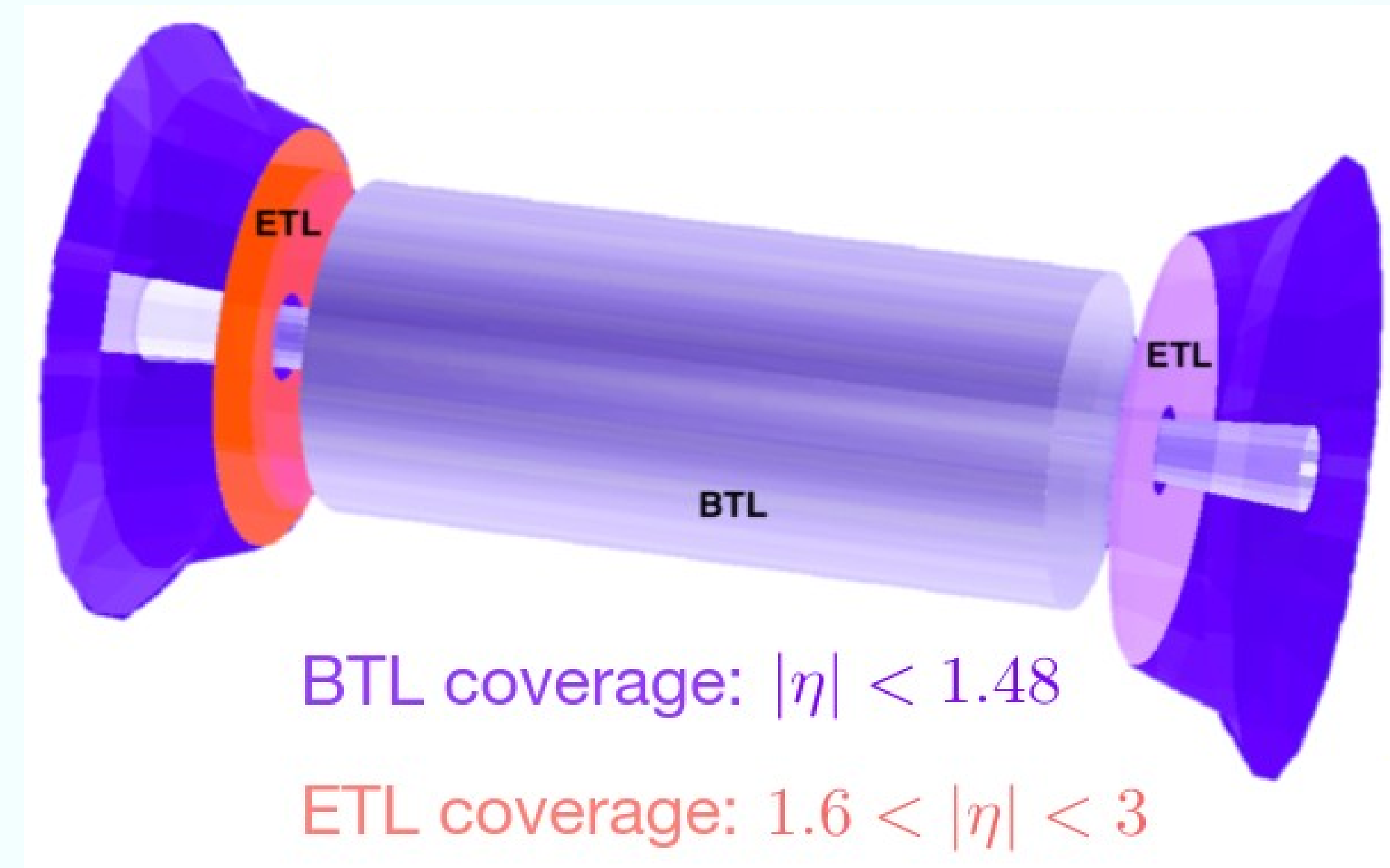


MIP timing detector

- Data taking conditions will be challenging
 - Number of collisions up to 200
- Must exploit additional time dimension
- MIP Timing Detector measures time of charged particles (~ 50 ps resolution)



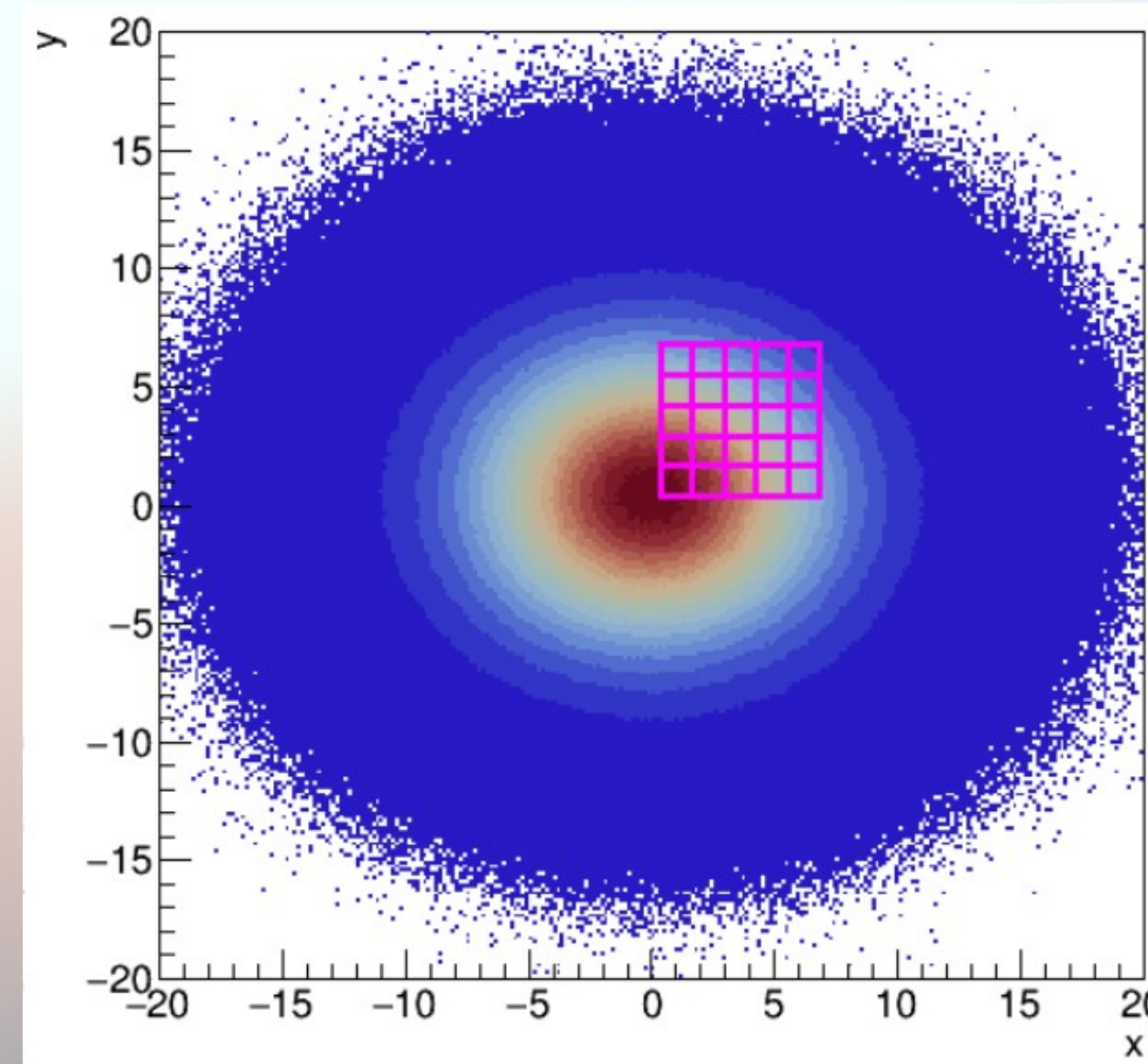
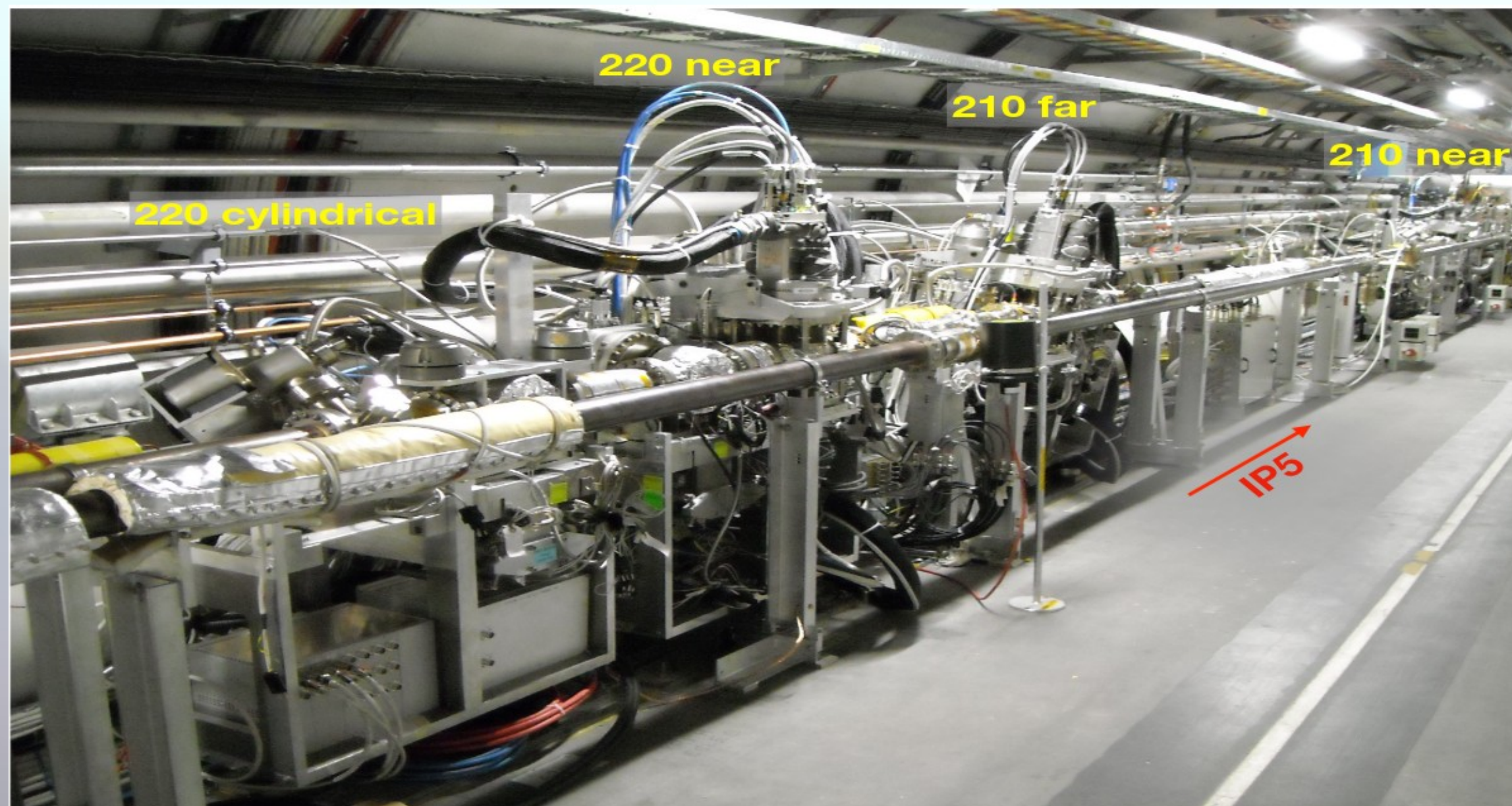
LIP-CMS group responsible for BTL readout electronics for precise time measurement of charged particles



PPS Upgrade

- CMS will re-install the PPS Roman Pots at 196m, 220m, and 234m from interaction point for HL-LHC: work has begun on R&D
- The only forward proton detector program planned for the HL-LHC (Run 4)

LIP- CMS group developing new timing detectors to deliver improved timing resolution and withstand HL-LHC conditions



Summary

- LIP-CMS group activities on several fronts:
 - **Data analysis**: exploiting new analysis techniques (ML, etc.)
 - **Detector Upgrades**: strong involvement in timing detectors (MTD, PPS)
 - **Detector Operations**: maintenance and data taking
- A lot to learn and contribute
 - **PIC, Master and PhD theses available**
 - Your contribution will have an impact

[Registrations open](#)



COURSE ON
PHYSICS at the LHC

4 March 2024 to 13 July 2024
Europe/Lisbon timezone

Enter your search term

The banner features a background image of the LHC tunnel with a bright light source. The text 'COURSE ON PHYSICS at the LHC' is prominently displayed in the center. Below the banner, the dates '4 March 2024 to 13 July 2024' and the timezone 'Europe/Lisbon timezone' are listed. At the bottom right, there is a search bar with the placeholder text 'Enter your search term' and a magnifying glass icon.