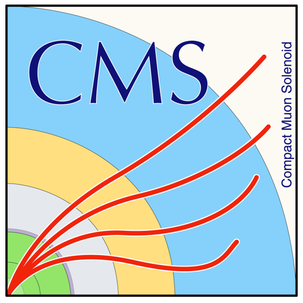
HL-LHC: CMS

Ksenia de Leo for the CMS Trieste group

INFN Trieste in the European Strategy

November 20, 2024

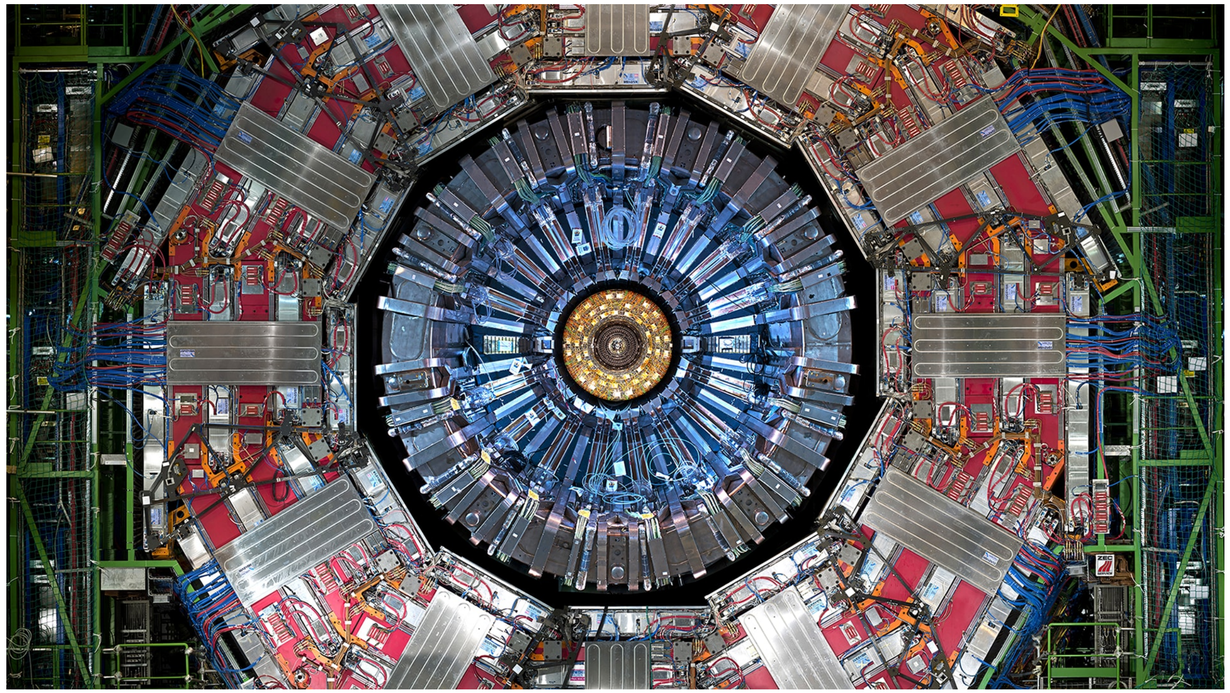


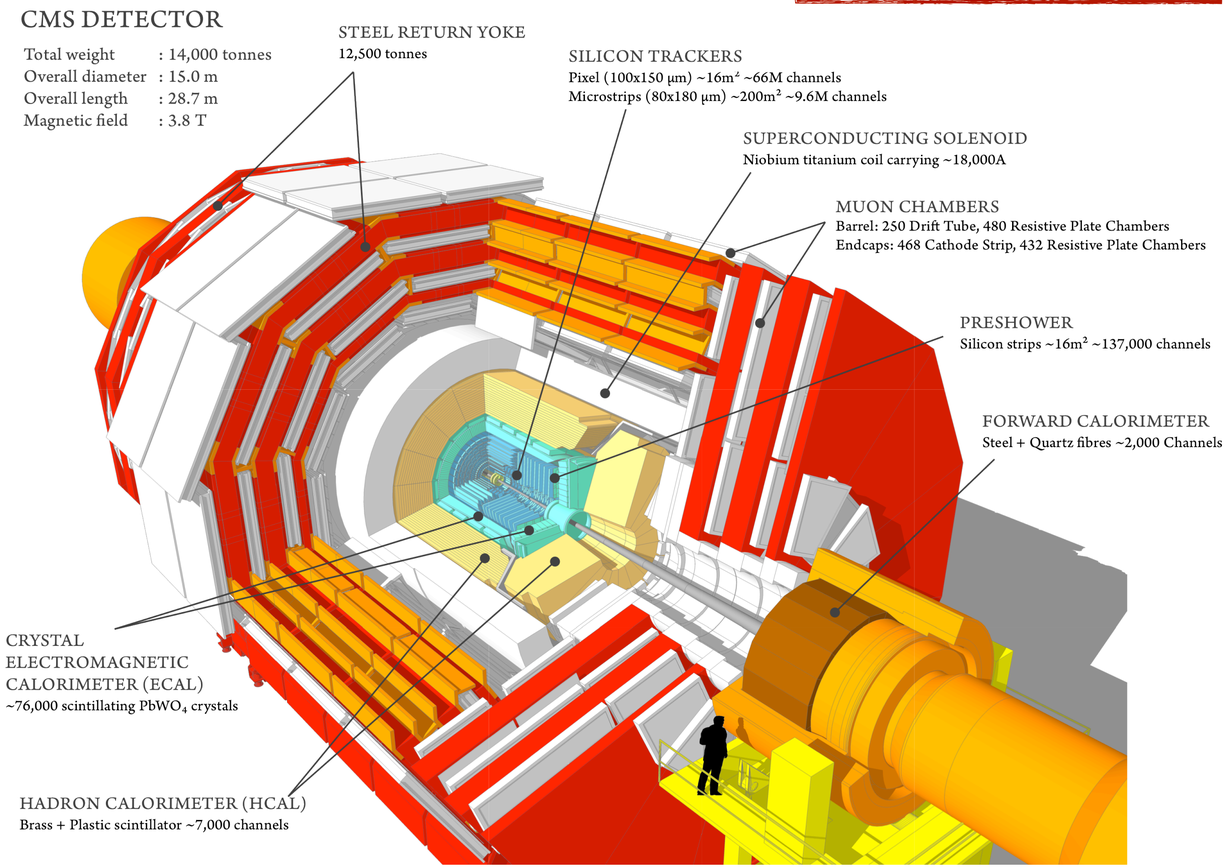
The CMS experiment

3.8 T solenoid
15 m diameter
28 m length

Compact Muon Solenoid (CMS)

- General-purpose detector @ LHC
- Different layers of sub-detectors to measure the energy or the trajectory of different particles (electrons, muons, photons, …)

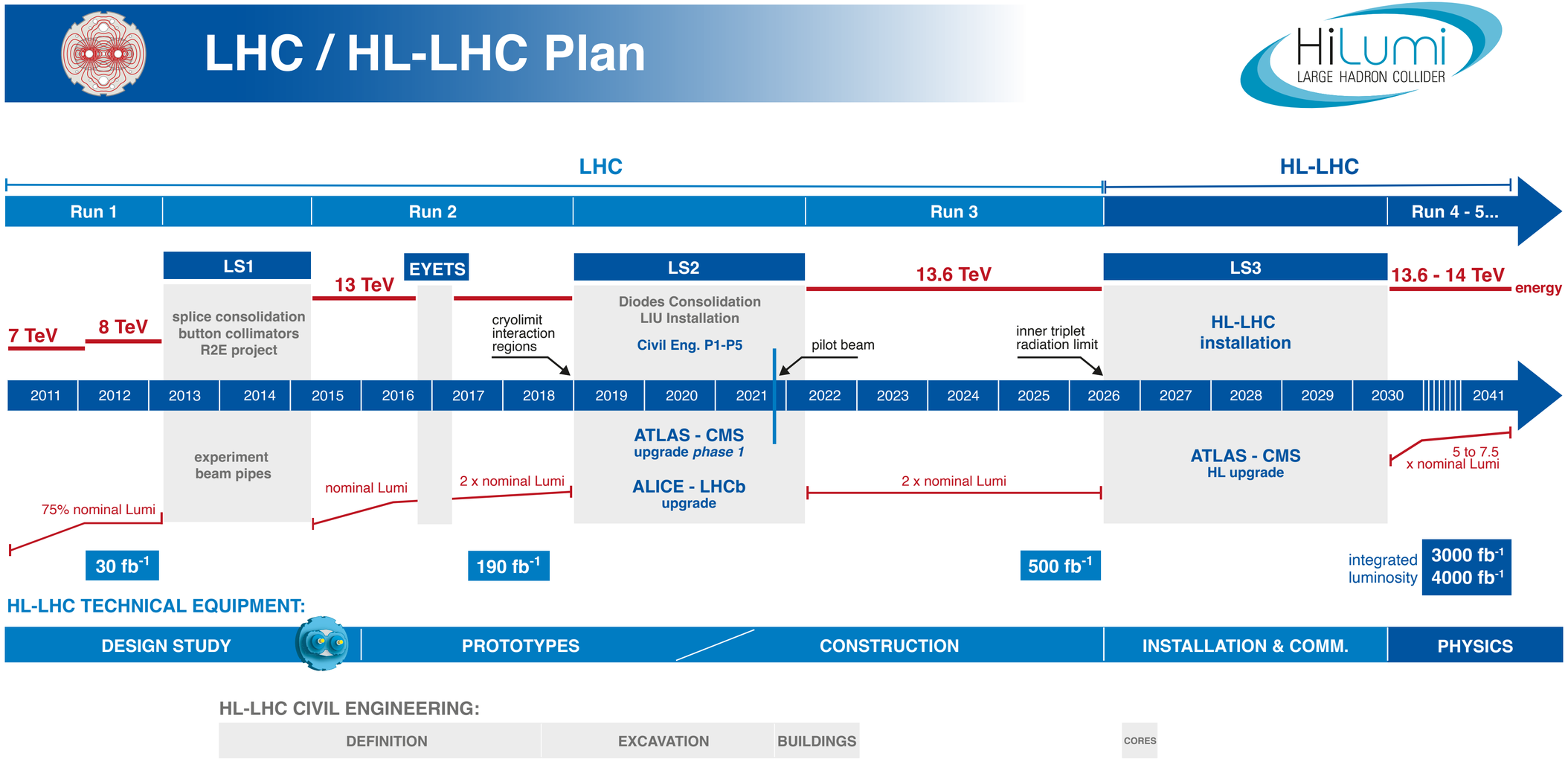




Trieste in CMS since 2005

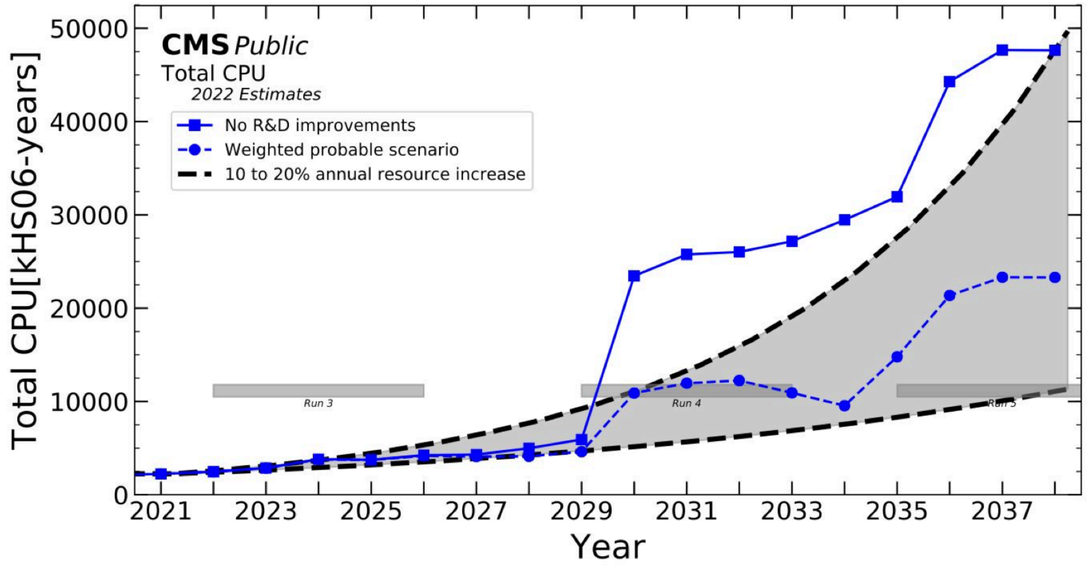
The High-Luminosity LHC

- **High-luminosity** LHC era (HL-LHC) starting in 2030 ➜ precise measurements of the Standard Model and searches for new physics



The High-Luminosity LHC

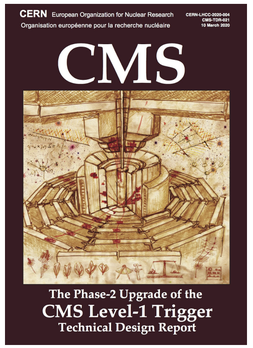
- **High-luminosity** LHC era (HL-LHC) starting in 2030 ➜ precise measurements of the Standard Model and searches for new physics
- Higher integrated luminosity (~4000 fb^{-1}) ➜ more statistics ✓
  ➜ radiation damage ✗
- Higher instantaneous luminosity ➜ more pileup ✗
- Increased granularity and event complexity ➜ computational challenge



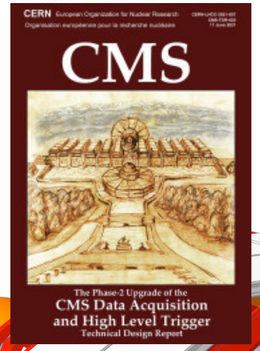
- Increase computing resources
- Improve computing models and software tools
- Speed up simulation and reconstruction

Necessary **upgrades** for CMS - **Phase-2 upgrade**

CMS Phase-2 upgrade

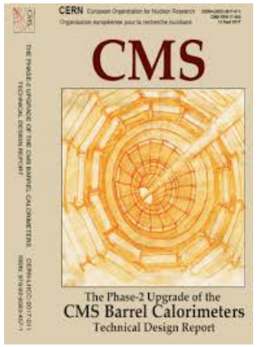


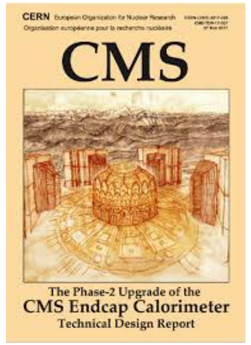
L1 trigger
Tracks at 40 MHz
750 kHz L1



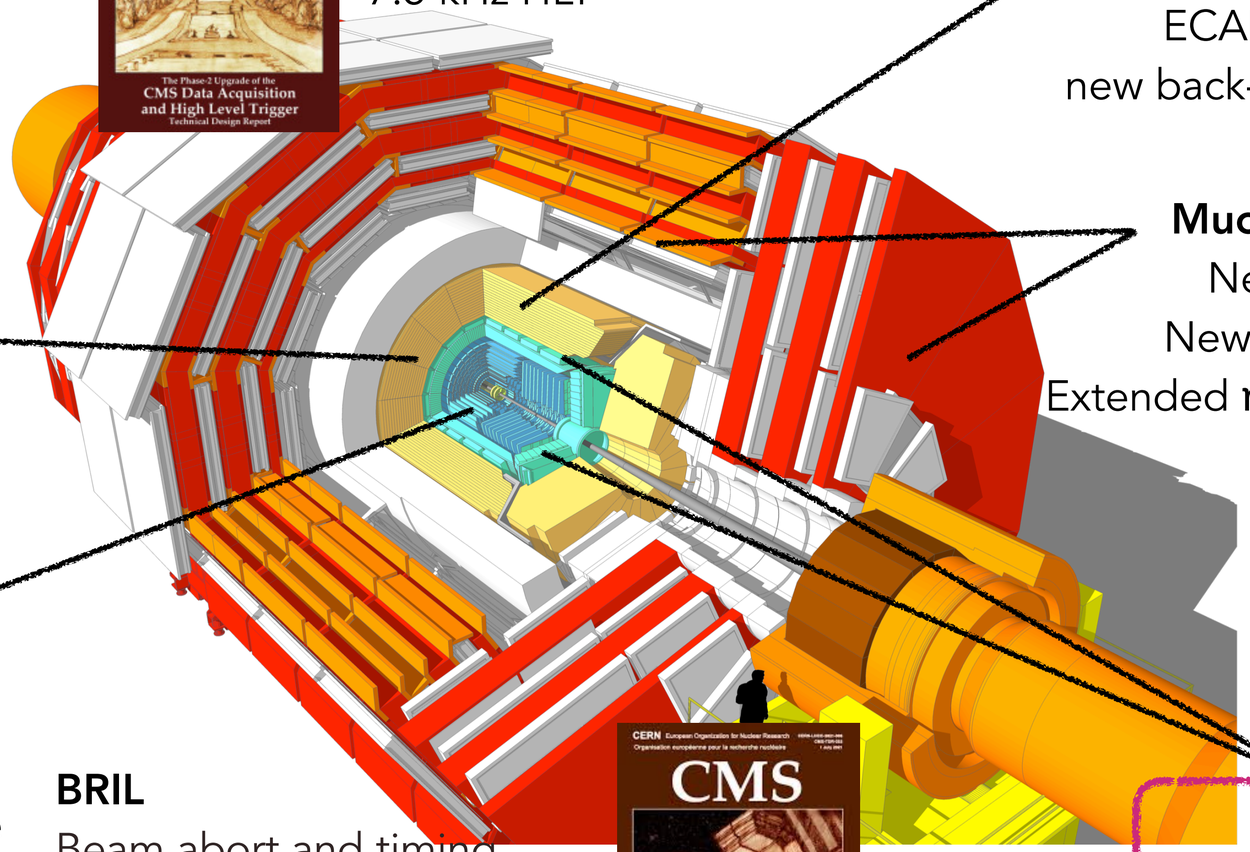
DAQ and High-Level Trigger
Full optical readout
Heterogeneous architecture
7.5 kHz HLT

Barrel Calorimeters
precise timing for e/γ at 30 GeV
ECAL and HCAL new back-end boards

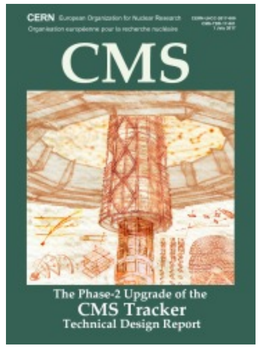




Endcap Calorimeter
3D showers and precision timing

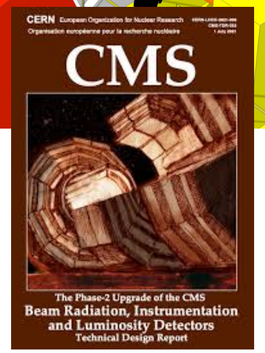


Muon systems
New readout
New GEM/RPC
Extended η coverage

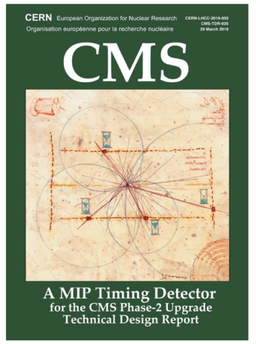


Tracker
Increased granularity
Extended η coverage

BRIL
Beam abort and timing
Beam-induced background
Bunch-by-bunch luminosity
Radiation monitoring

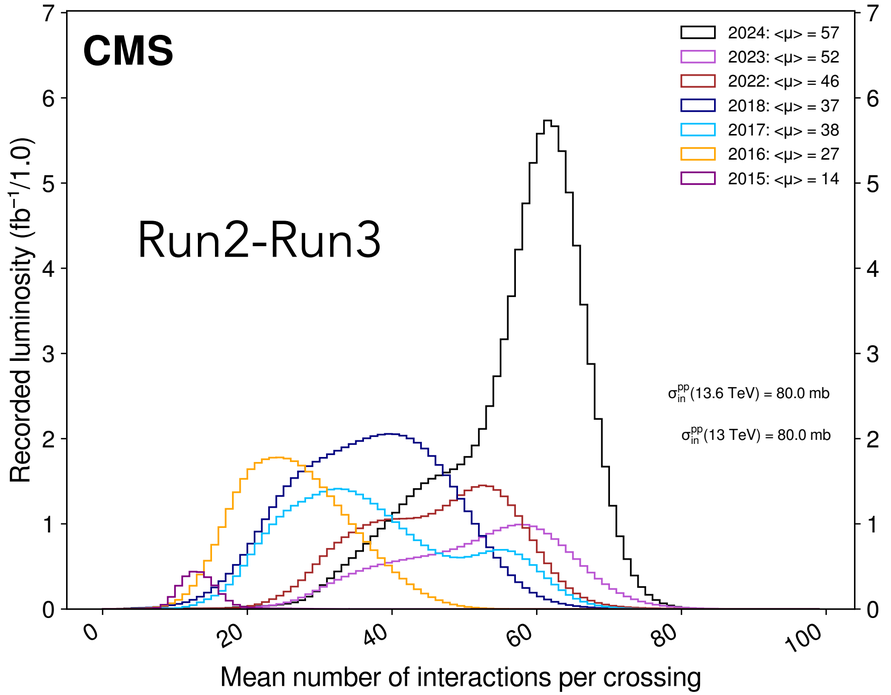


MTD
Precision timing

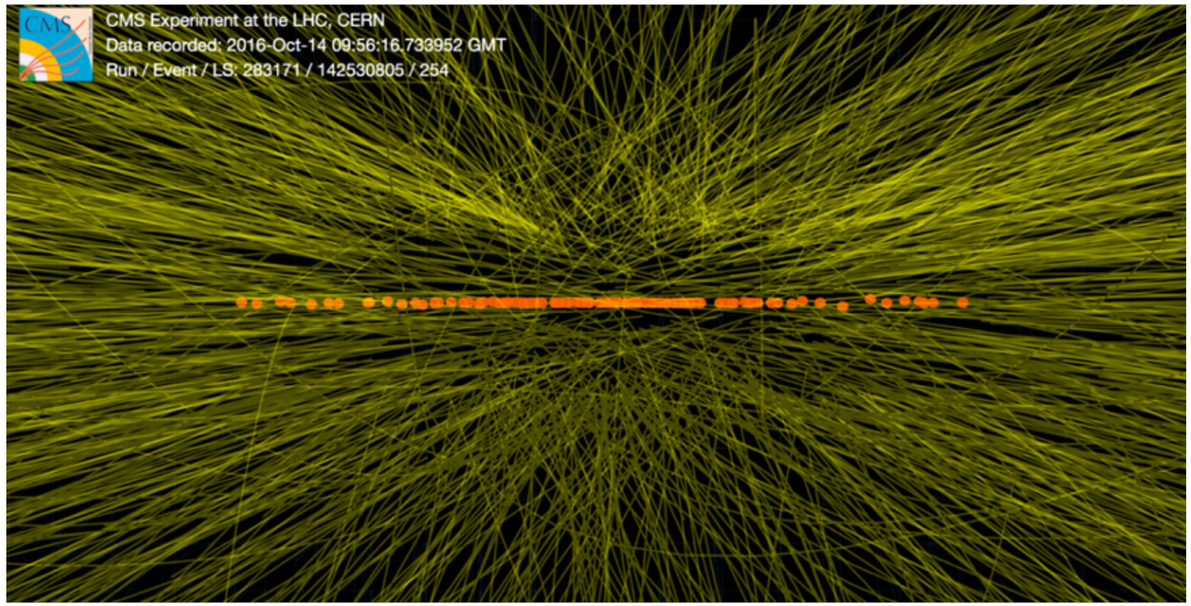


Pileup @ HL-LHC

- Higher instantaneous luminosity ➜ **higher** number of **pileup** (PU) interactions <PU>=140-200
- Crucial to isolate **interaction of interest** and mitigate **effects of PU** on object reconstruction
- Essential for any physics analysis at HL-LHC
- How? **Track-vertex association**



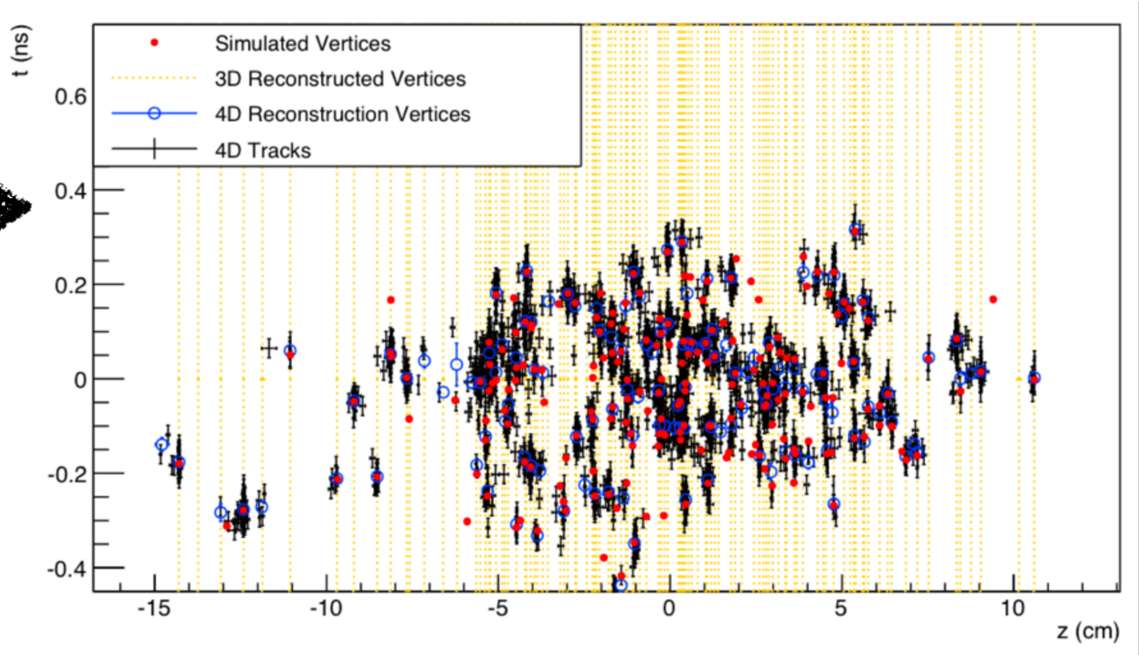
[CMS Luminosity - Public Results]

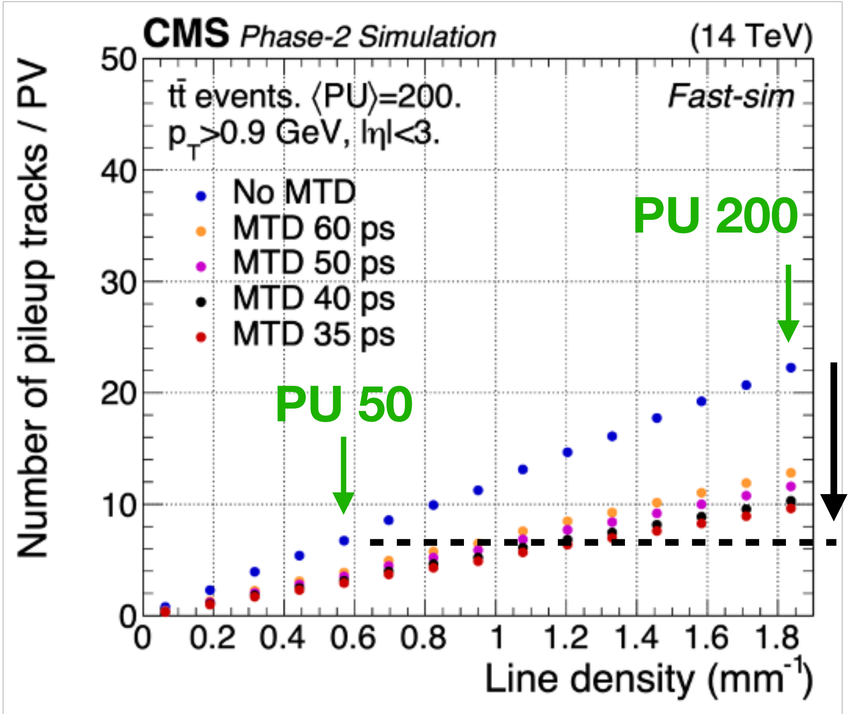


~130 pp collisions - recorded by CMS in 2016 during a high PU run

Precision Timing at CMS

- Use timing information to **separate vertices** that **overlap in space**
- Modern detector technologies allow **~30 ps time resolution** ➜ smaller than the pp collision spread in time of 180-200 ps (longitudinal spread around 5 cm)
- Possible effective separation!
- New detector proposed in 2017



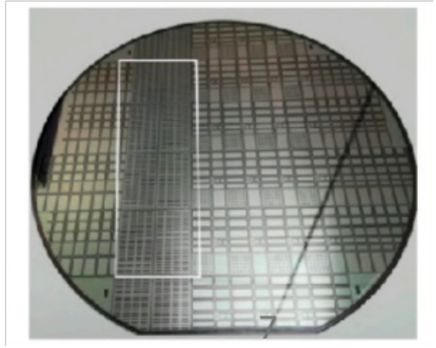


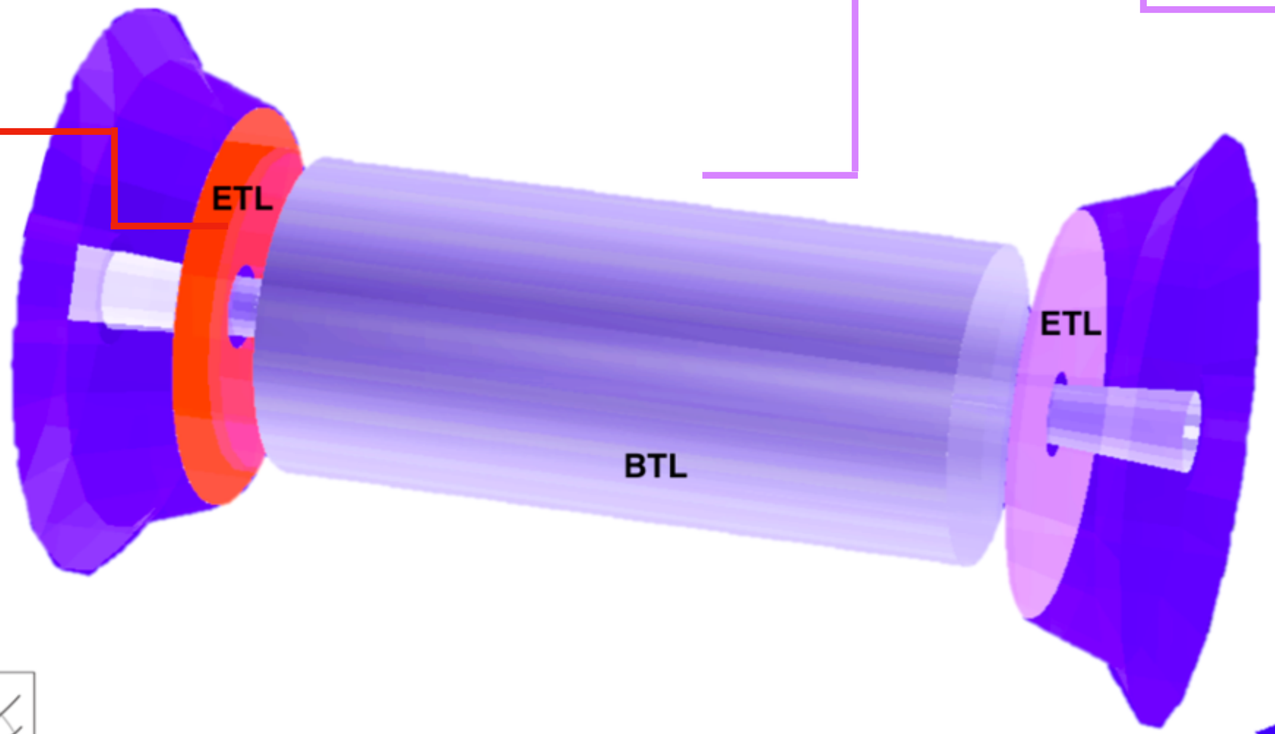
From 3D to 4D vertex reconstruction
➜ effective PU as in Phase-1

Mip Timing Detector

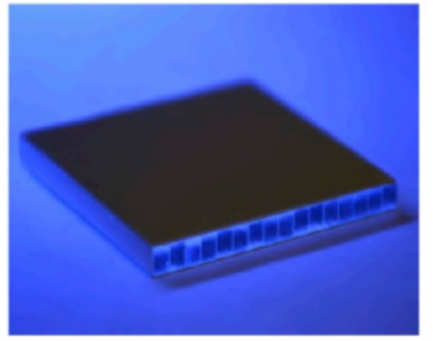
- Mip Timing Detector (MTD) [CMS MTD Technical Design Report (2019)] to measure time of charged particles
- Placed between tracker and calorimeter
- Almost hermetic coverage with $|\eta| < 3$

Endcap Timing Layer (ETL)
- LGADs
- $1.6 < |\eta| < 3$
- Active area ~14 m^2





Barrel Timing Layer (BTL)
- LYSO bars + 2 SiPM/bar
- $|\eta| < 1.45$, $p_T > 0.7$ GeV
- Active area ~38 m^2



MTD @ Trieste

- Trieste group heavily involved in the MTD project since the beginning in 2017, contribution to software development for the TDR (2019)

Management

- F. Cossutti **L2 convener** of MTD DPG (Detector Performance group) since 2020 & Trieste group representative in the Institutional Board
- K. de Leo **L3 convener** of Simulation and Reconstruction in MTD DPG since 2024
- R. Delli Gatti **contact person** for Validation in MTD DPG since 2024

Software

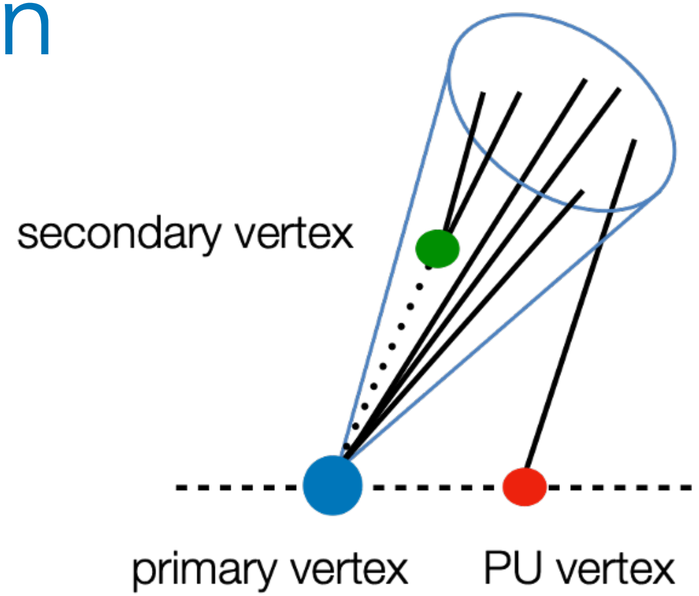
- **Leading role** in MTD software development (F. Cossutti, K. de Leo, R. Delli Gatti, M. Casarsa, J. Babbar + in the past G. Sorrentino)
- Essential contributions to **geometry**, **simulation** and **reconstruction** up to high level

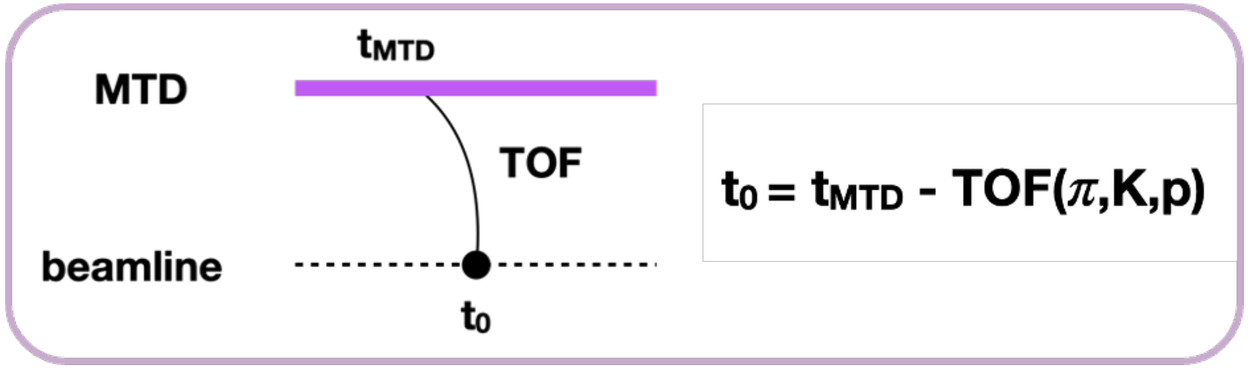
Hardware

- Participation in BTL **test beams** @ CERN
- Forthcoming involvement in BTL **assembly** @ Milano Bicocca

4D vertex reconstruction

- 4D vertexing important for **pileup rejection**
  - crucial for object reconstruction in HL-LHC
  - primary goal of MTD
- **4D vertex reconstruction** and **particle identification** go hand in hand
- Measure track time @ MTD and momentum, velocity depends on the mass hypothesis
- Same vertex constrain provides hypothesis discrimination





- Trieste group involved in recent **improvement** in **4D vertex** algorithm (CMS-DP/2024-085)
- Actively exploring new strategies with **machine learning** techniques

CMS @ Trieste

The group

- Staff members: Giuseppe Della Ricca, Fabio Cossutti, Vieri Candelise, Massimo Casarsa, Stefano Belforte
- Post-docs: Ksenia de Leo, Jyoti Babbar
- PhD students: Raffaele Delli Gatti, Carlo Giraldin

Data analysis

- **High precision** measurements of the Standard Model with W/Z bosons
- Searches for **new physics**

MTD

- Studies of **new detectors** for the CMS upgrade: MTD (MIP Timing Detector)
- Heavy involvement in software

Advanced **statistical** methods and **data analysis** with ROOT, C++, python and **machine learning** techniques: DNN, GNN, tensorflow, PyTorch, Keras, ONNX, …