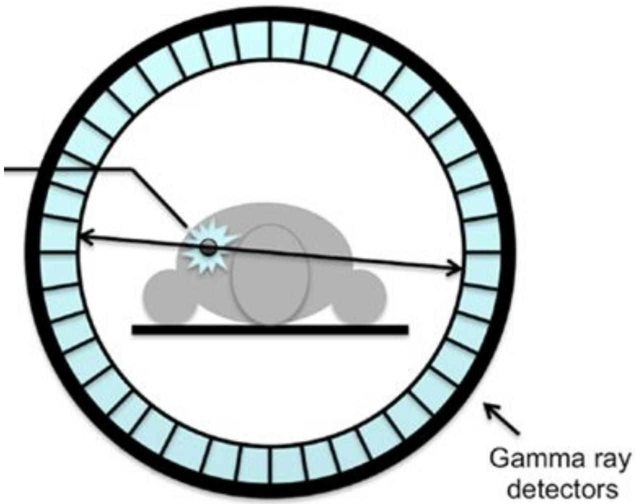
Exploiting at best the CMS detector **and developing** new technologies for the HL-LHC upgrade

Fisica delle Particelle:
opportunità per tesi magistrali 2022

Marco Lucchini - marco.lucchini@unimib.it
Università degli Studi di Milano Bicocca and INFN
per il gruppo CMS - MiB

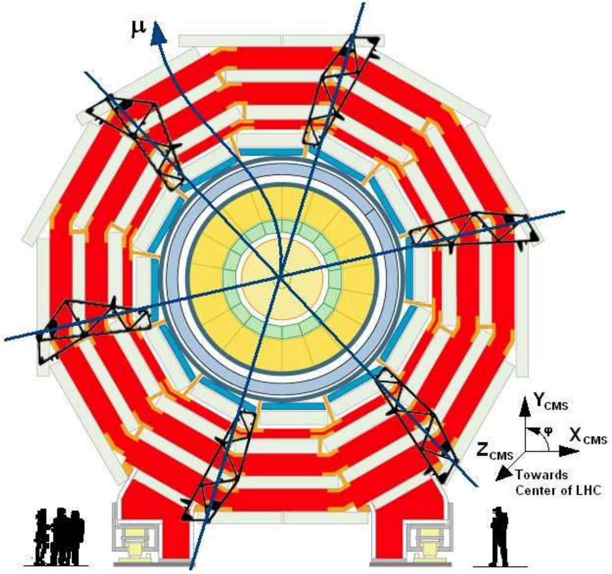
Spot the differences

Positron Emission Tomography Scanner for cancer imaging



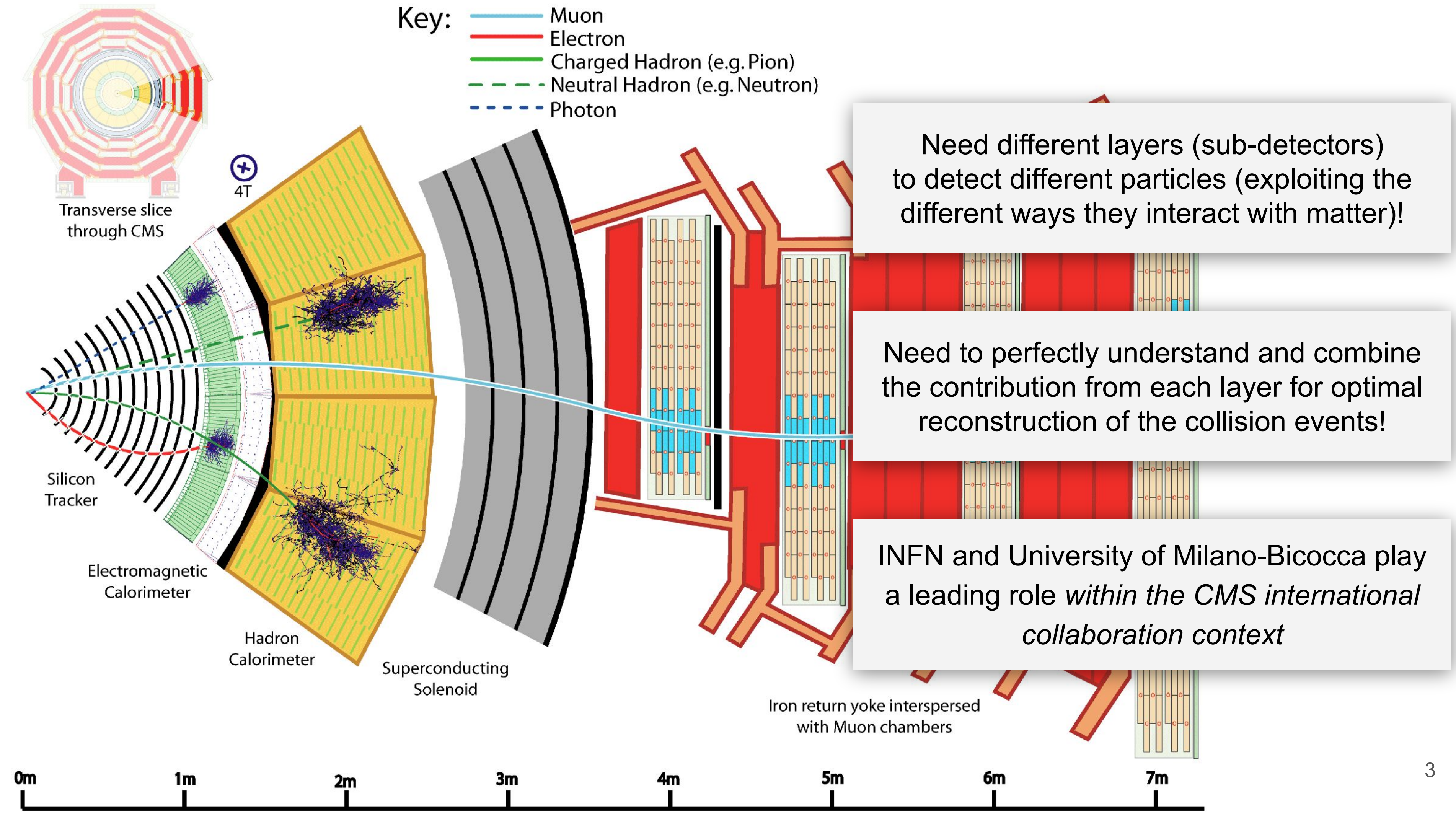
Single-layer detector

The CMS detector for imaging of LHC collision events



Multi-layer detector

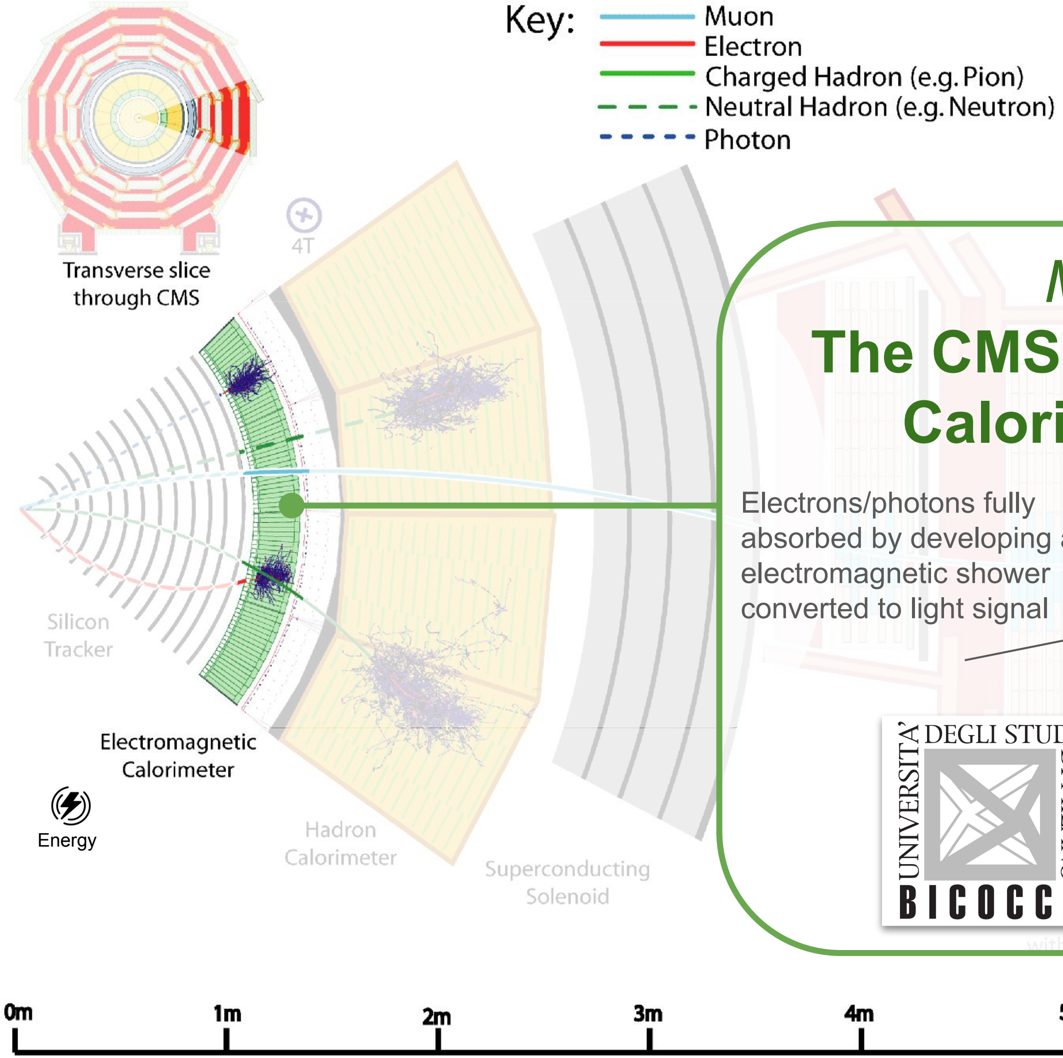
Onion



Need different layers (sub-detectors) to detect different particles (exploiting the different ways they interact with matter)!

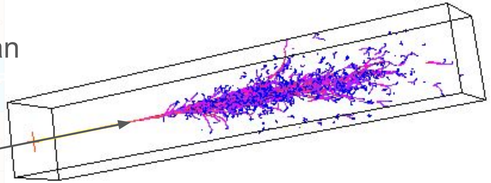
Need to perfectly understand and combine the contribution from each layer for optimal reconstruction of the collision events!

INFN and University of Milano-Bicocca play a leading role *within the CMS international collaboration context*



Mastering
The CMS Electromagnetic Calorimeter (ECAL)

Electrons/photons fully absorbed by developing an electromagnetic shower converted to light signal



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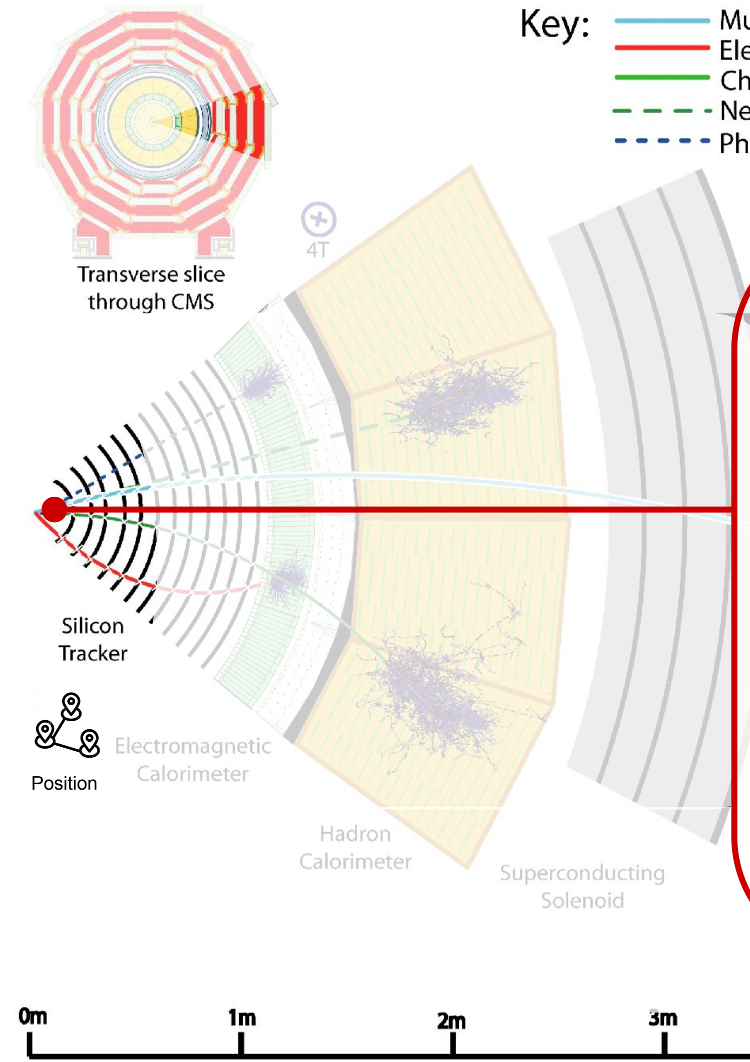
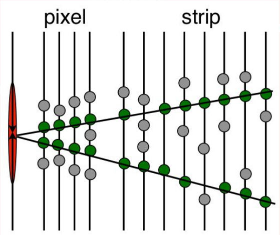


Upgrade of the

Inner tracker pixel detector

('the heart of CMS')

Tracks of charged particles and collision vertices reconstructed using Kalman filter based algorithms



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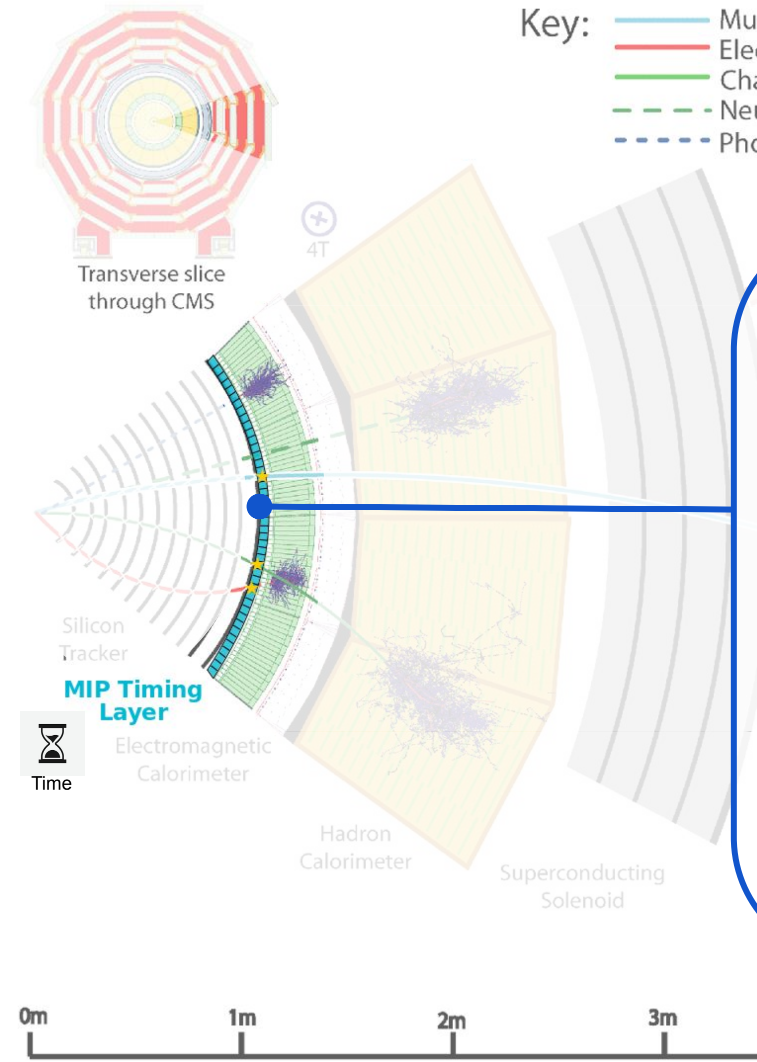
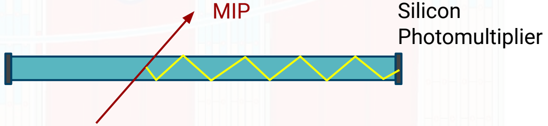


Development of the new

MiP Timing Detector MTD

('the stopwatch of CMS')

Charged particles generate a fast light pulse while traversing a scintillating crystal



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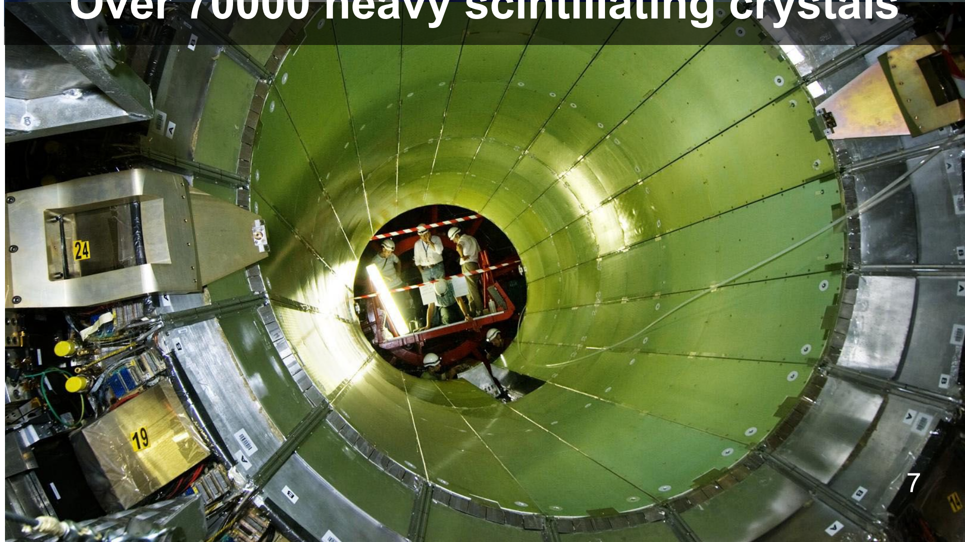
The CMS Electromagnetic Calorimeter (ECAL)

- **Calibration of the 70000+ ECAL channels** with complementary approaches:
  - Comparing the electron energy with its momentum measured by the tracker
  - Exploiting the detector cylindrical geometry (φ-symmetry method)

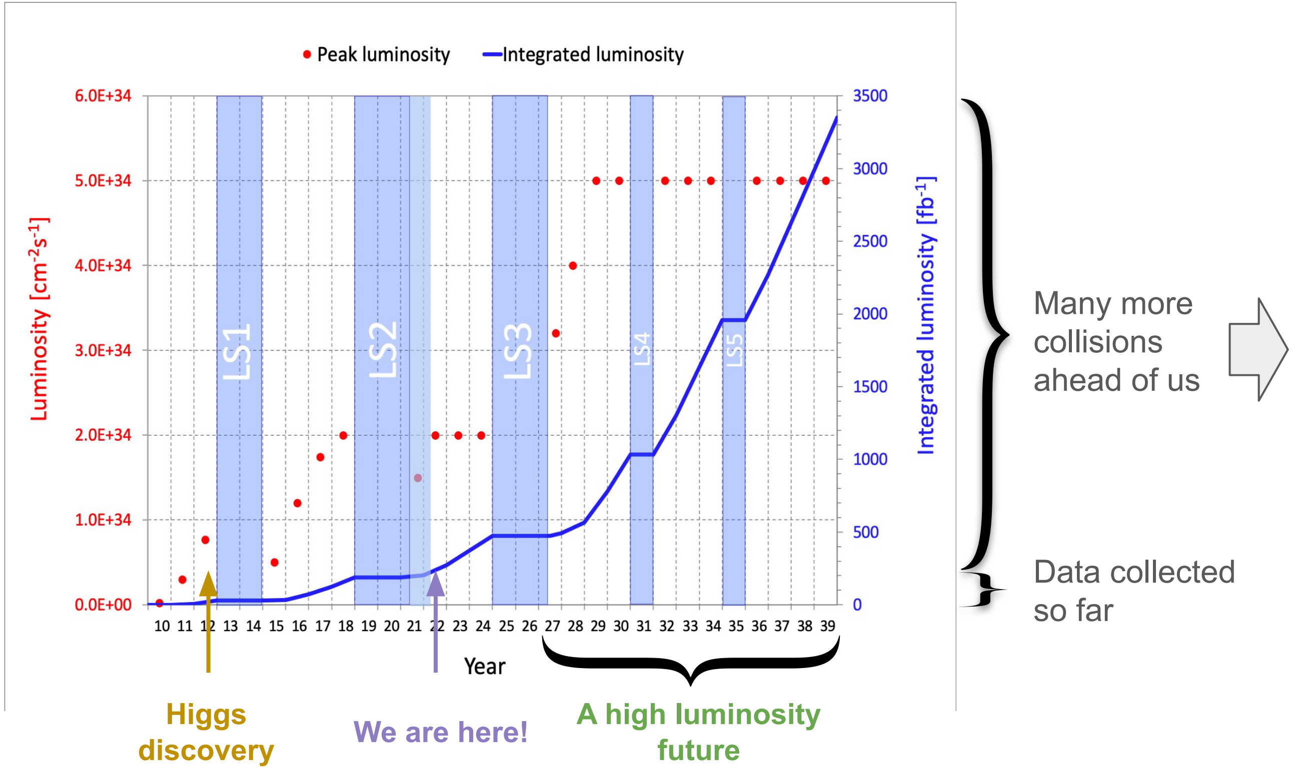
- **Prediction** of the ECAL crystal transparency loss **and optimization** of clustering and noise reduction **exploiting machine learning techniques**

[thesis opportunity!]

Over 70000 heavy scintillating crystals

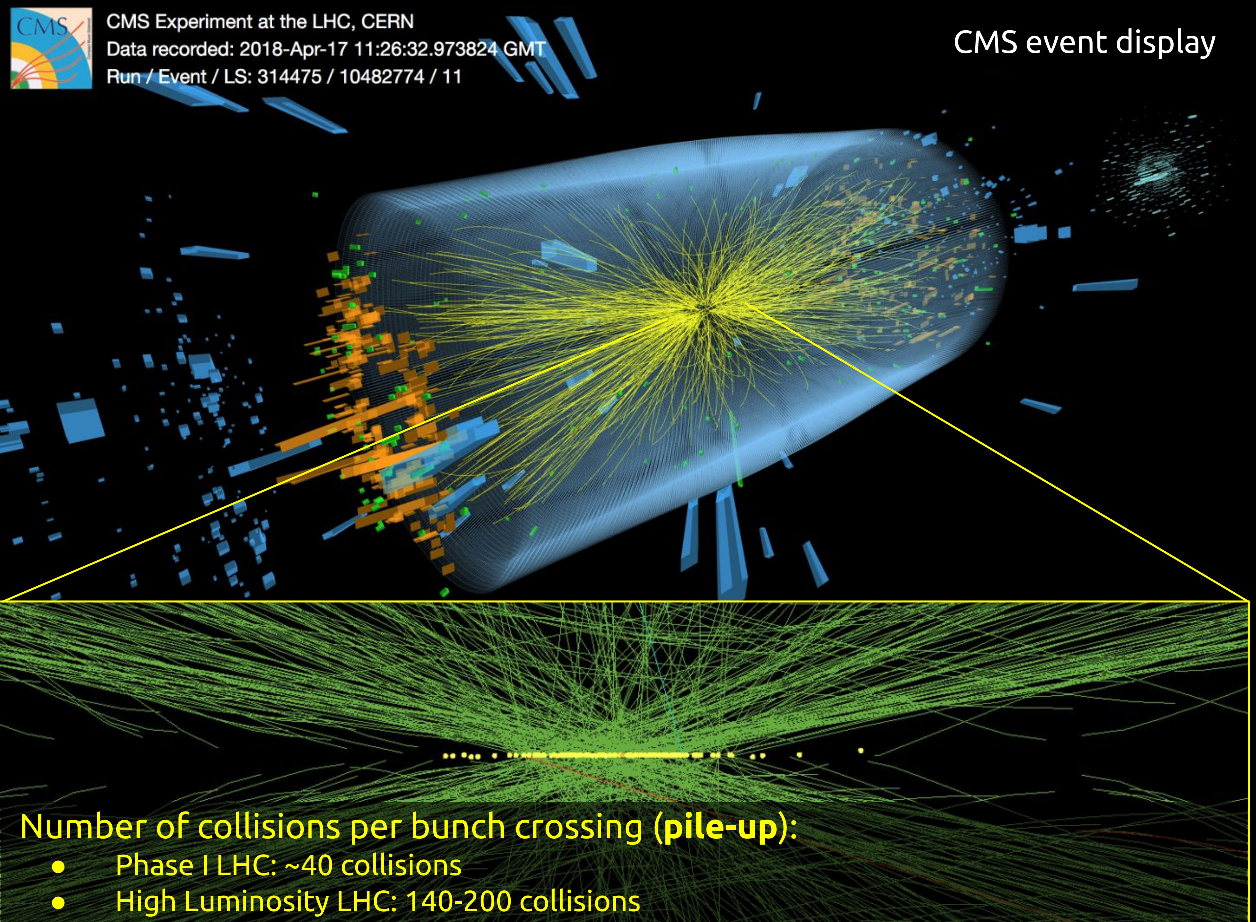


The High Luminosity LHC program:
a major upgrade of the accelerator



More data are required to search for **rare processes** and for precision measurements of the **Higgs boson**: a “portal” to physics **beyond the standard model** (e.g. **dark matter**)

High Luminosity LHC challenges



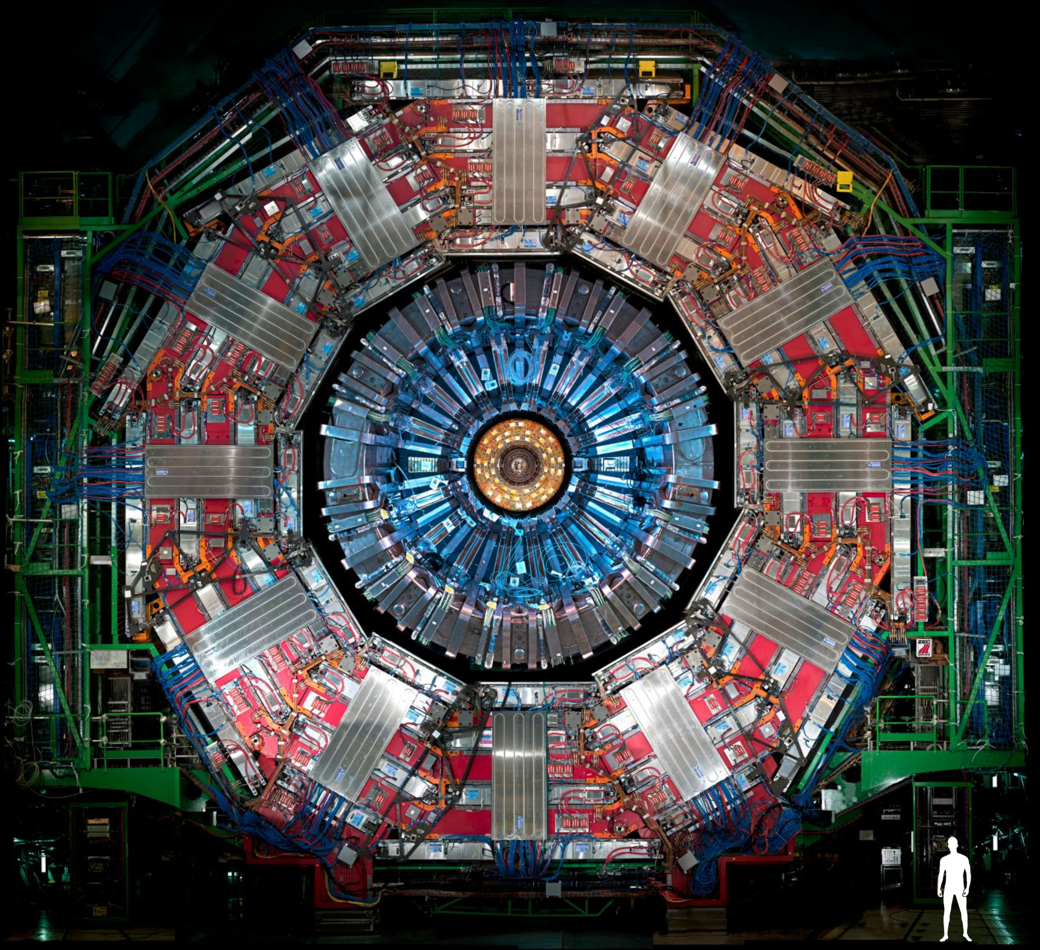
Number of collisions per bunch crossing (**pile-up**):

- Phase I LHC: ~40 collisions
- High Luminosity LHC: 140-200 collisions

- **Extreme pile-up** impacts the current CMS capability to reconstruct physics events: need novel methods and detectors
- **Unprecedented levels of radiation exposure:** a threat for many detector components

The CMS experiment **upgrade** for HL-LHC

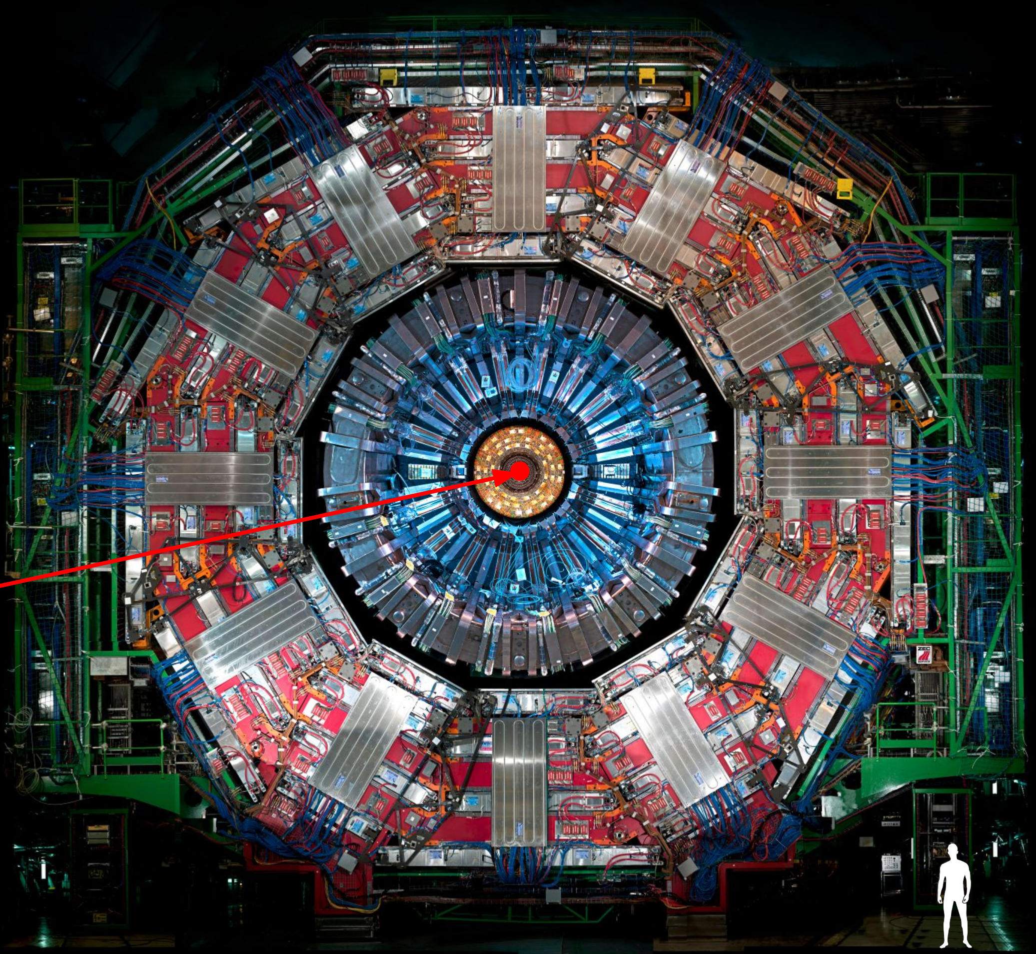
- CMS has foreseen an **upgrade** in all sub-detectors **to tackle the HL-LHC challenges**



The CMS experiment **upgrade** for HL-LHC

- CMS has foreseen an **upgrade** in all sub-detectors **to tackle the HL-LHC challenges,** which include:
  - *Upgrade* of the **inner tracker pixel detector**

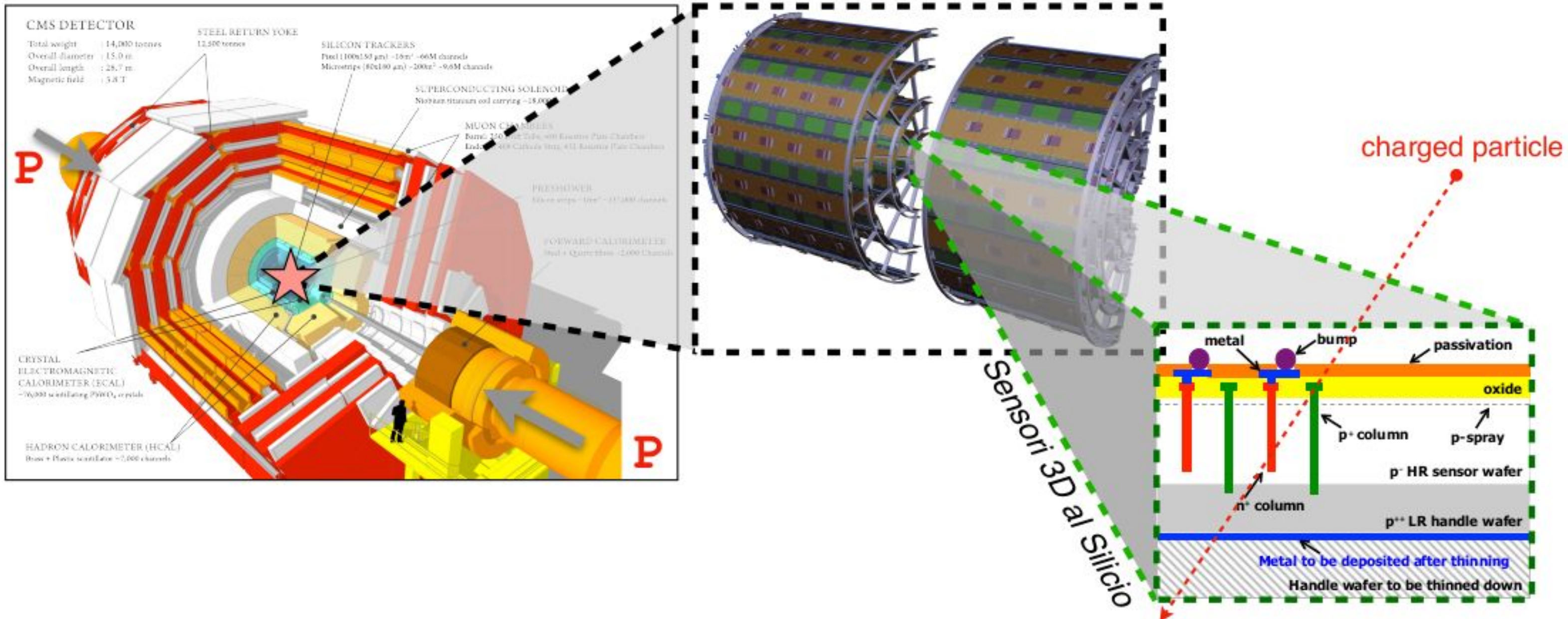
    [thesis opportunity!]



A novel pixel detector is needed!

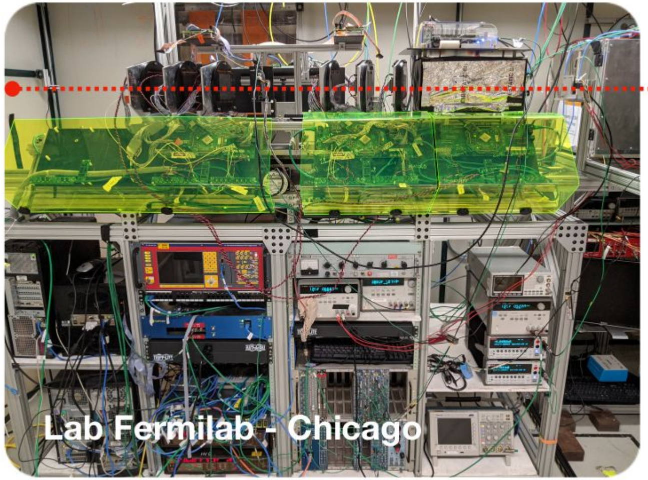
- **Main requirements/challenges**:
  - 15x number of pixels (up to 2 billions)
  - **10x radiation tolerance** (equivalent to about 40 millions PET exams/year!)

- **Strategy**:
  - Development of a new technology of silicon detectors (e.g. 3D pixels)

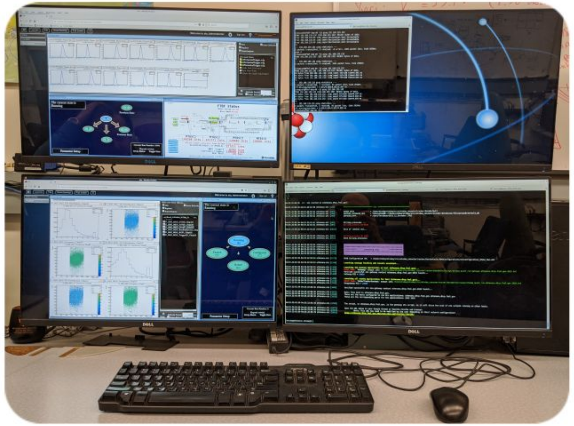


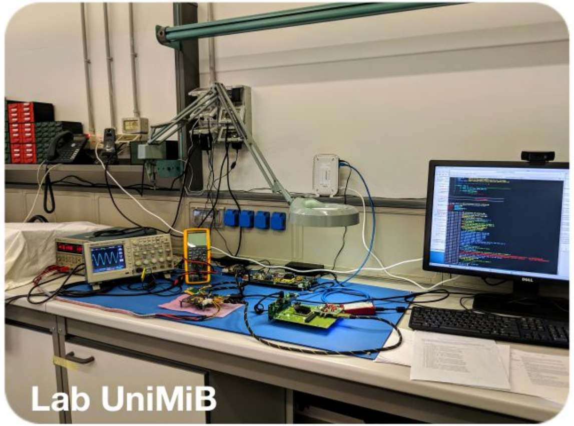
Pixel tracker upgrade

New detector prototypes are studied with **simulation**, in **laboratory** and with **test beam** at international facilities

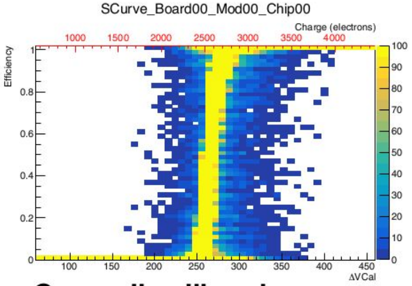


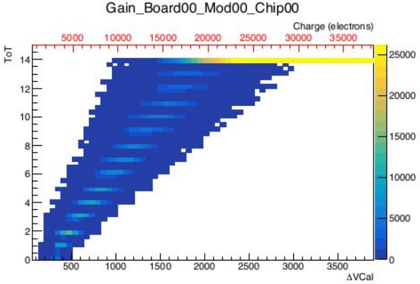
120 GeV protons





Sviluppiamo sistema di controllo e acquisizione dati per rivelatore a pixel per HL-LHC (C++ avanzato e uso di microchip FPGA)



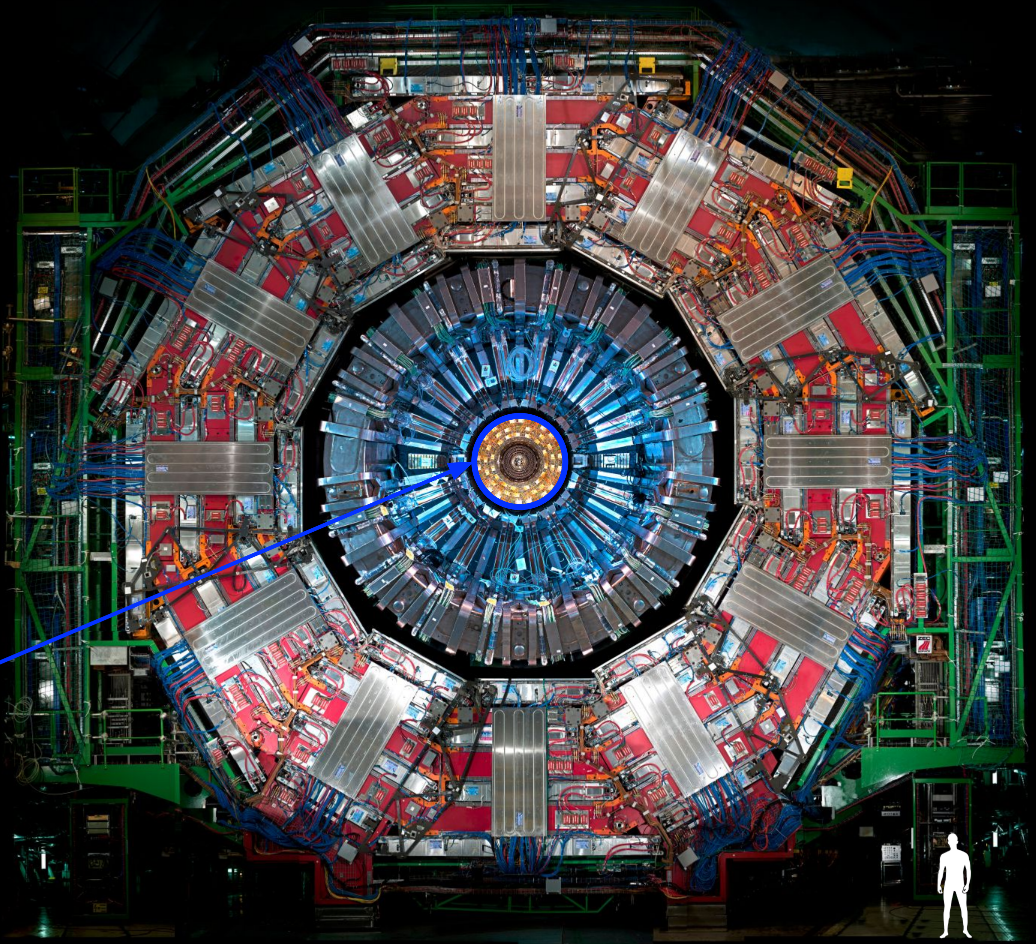


Curve di calibrazione

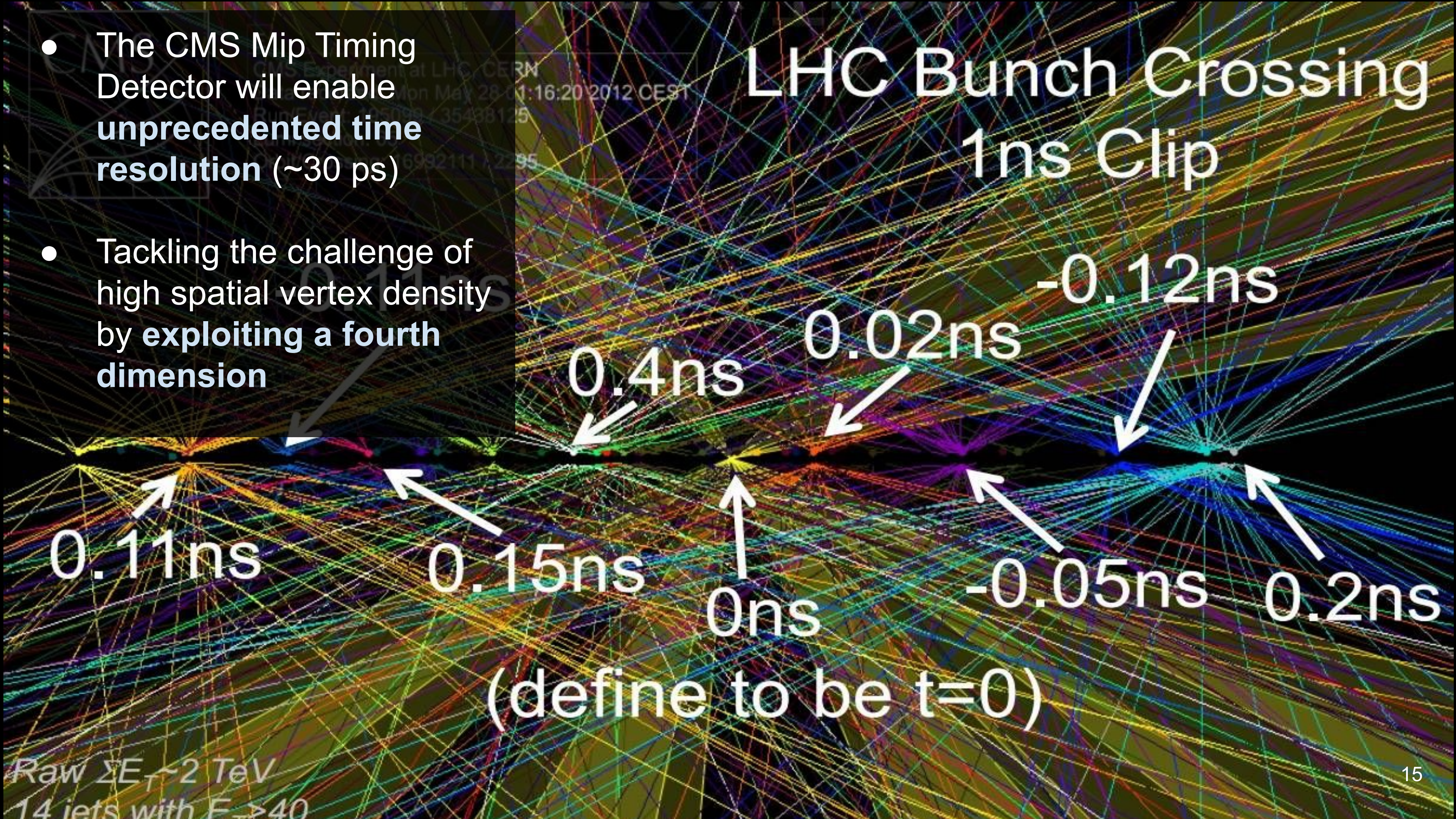
The CMS experiment **upgrade** for HL-LHC

- CMS has foreseen an **upgrade** in all sub-detectors **to tackle the HL-LHC challenges,** which include:
  - *Addition* of a new sub-detector designed for high precision time tagging of charged particles (the **MiP Timing Detector MTD**)

    [thesis opportunity!]



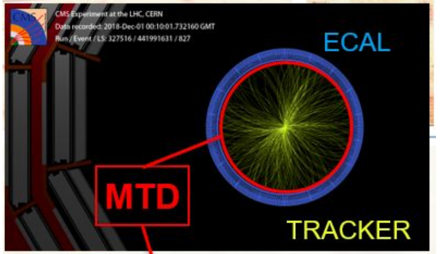
- The CMS Mip Timing Detector will enable **unprecedented time resolution** (~30 ps)
- Tackling the challenge of high spatial vertex density by **exploiting a fourth dimension**

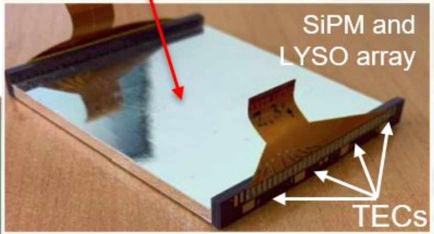


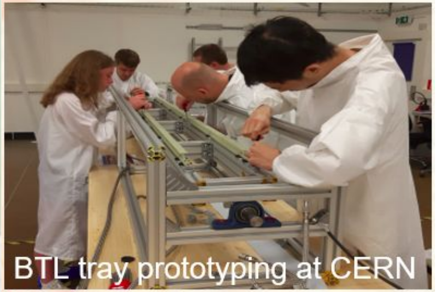
People, cables and timing detectors

Activities at the University laboratories and at CERN

- **Significant room for groundbreaking contributions**
  - Event reconstruction and exploitation of timing in searches and Higgs boson characterization with modern computing techniques
  - Development of the Barrel Timing Layer
  - Sensor and ASICs characterization, module prototyping, system tests and performance characterization with particle beams
  - SW interfaces for detector control and data acquisition







Skills acquired at the end of these thesis

- Field work in particle physics and instrumentation
- Python, C++, modern analysis methods
- Radiation detectors and readout systems
- Ability to work in collaborative efforts
- Ability of independent thinking

Don't miss the opportunity!

- **Inventing and exploring** new sophisticated methods to exploit the CMS detector for better event reconstruction in continuously growing challenges

- Hands on with the **construction and testing of new particle detectors** for the CMS Upgrade, **paving the road for future** collider experiments beyond HL-LHC

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> **Argomenti per la prova finale della laurea magistrale - Fisica delle Particelle**

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Le tesi magistrali che proponiamo richiedono circa otto mesi di lavoro a tempo pieno.

Ultimo aggiornamento 13/06/2022, prossimo aggiornamento 13/07/2022

Esperimento CMS

Referenti: M. Dinardo, P. Dini, S. Gennai, A. Ghezzi, S. Malvezzi, A. Massironi, L. Moroni, P. Govoni, M. Paganoni, D. Pedrini, T. Tabarelli de Fatis

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Don’t miss the opportunity!

- **ECAL:** Andrea Massironi, Alessio Ghezzi, Pietro Govoni
- **Pixel:** Luigi Moroni, Mauro Dinardo, Simone Gennai
- **MTD:** Andrea Benaglia, Martina Malberti, Federico De Guio, Marco Lucchini, Tommaso Tabarelli de Fatis, Alessio Ghezzi

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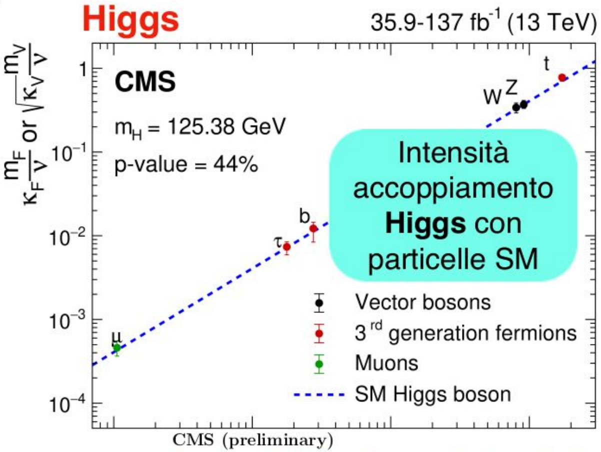
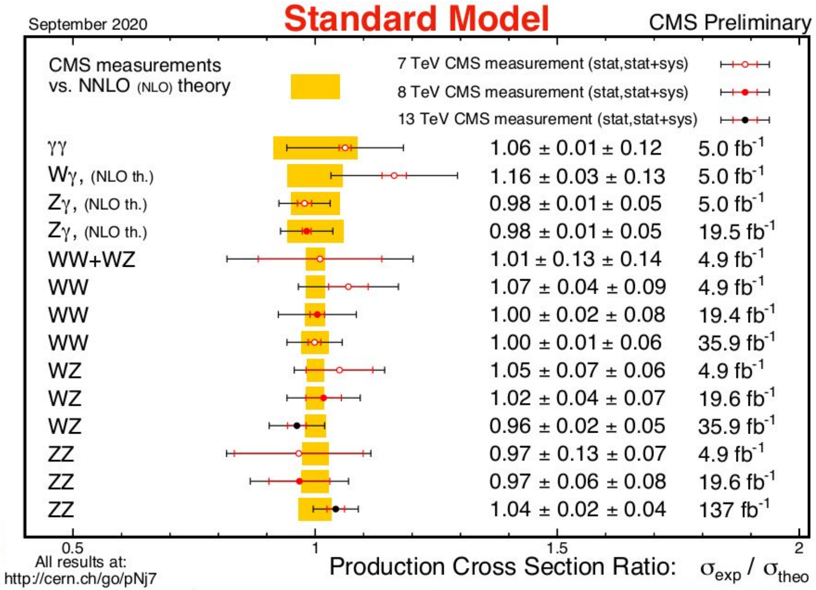
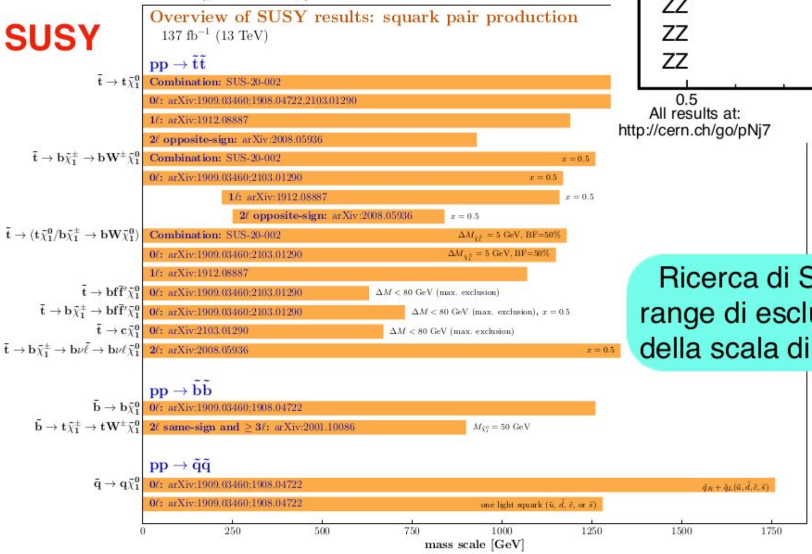
CMS Physics results



Intensità accoppiamento **Higgs** con particelle SM



Probabilità di vari processi che coinvolgo bosoni vettori



Ricerca di Super-Simmetrie: range di esclusione in funzione della scala di energia esplorata

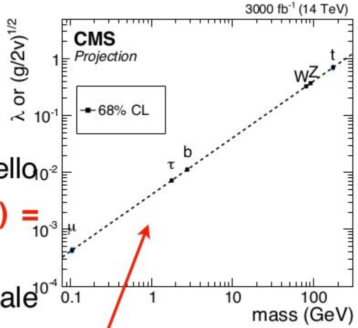
Per ottenere questi risultati e` necessario il pieno controllo del rivelatore

Standard Model yet to be fully explored

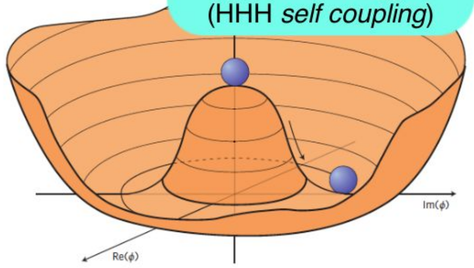
$$\delta m_H^2 = \frac{3\Lambda^2}{8\pi v^2}(6M_W^2 + 3M_Z^2 + 3M_H^2 - 12M_t^2)$$

Λ scala di energia dello SM

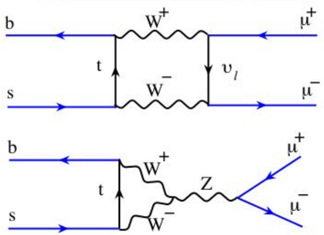
- Correzioni quantistiche (**δm_H**) alla massa dello Higgs sono "piccole", infatti misuriamo **m(H) = 125 GeV**. Quindi:
  - o **Λ** e\` "piccola" (~TeV), dopo la quale dovrebbe manifestarsi nuova fisica
  - oppure **Λ** e\` "grande", ma in questo caso nella determinazione di **δm_H** dovrebbero rientrare nuove particelle
- Misure proprietà Higgs non ancora sufficientemente precise ➜ potrebbero manifestarsi deviazioni dallo SM a causa di interazioni con altre particelle (e.g. dark matter)

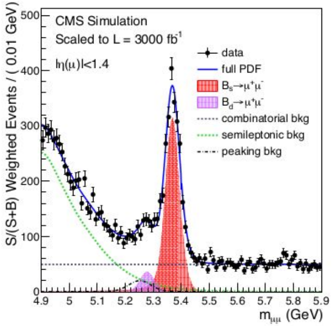


Potenziale di Higgs ➜ (HHH *self coupling*)

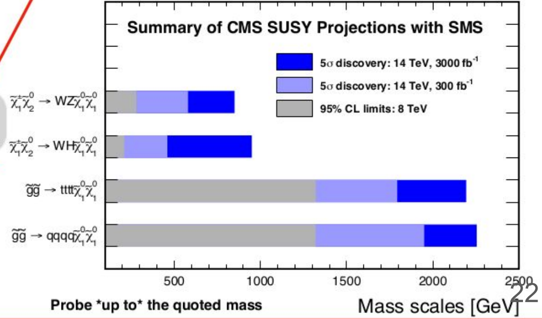


Lowest order diagrams





- Test di precisione SM e settore di Higgs
- Test dello SM con processi rari, fisica del sapore, eg ➜ **B → μμ**, $B^0 \rightarrow K^{*0}\mu\mu$
- Ricerca di nuovi fenomeni rari o in regioni inesplorate



Servono più dati! ➜ Aumentare numero collisioni / (tempo · A)