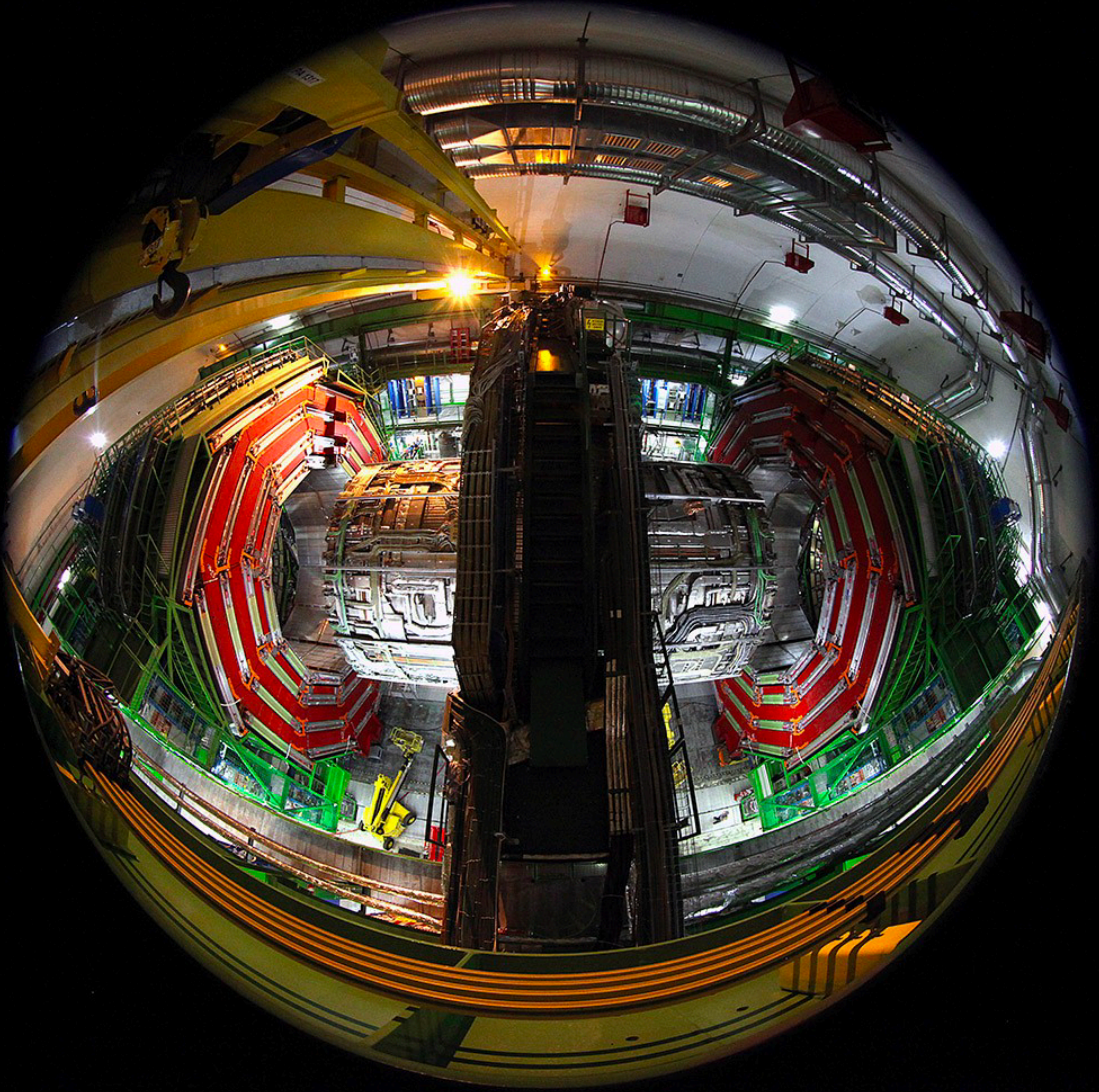


Introduction to the CMS experiment

Gautier Hamel de Monchenault

CMS Induction courses
Monday September 20, 2021

Spokesperson Team

Luca Malgeri
CMS spokesperson

Gautier
Hamel de Monchenault

Jim Olsen

CMS deputy spokespersons

Introduction to the CMS experiment

Gautier Hamel de Monchenault
on behalf of the **SP Team**

CMS Induction courses
Monday September 20, 2021

CMS: A Truly Global Project

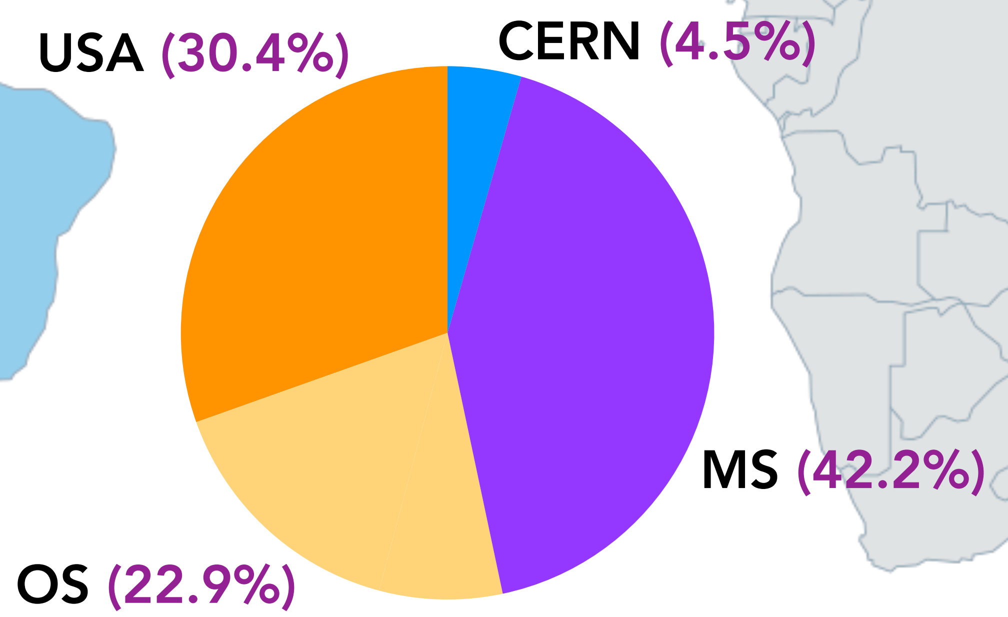
(approximate numbers, 2021)

The CMS Collaboration

2100 Authors

>5200 Members

240 Institutes
from
55 Countries



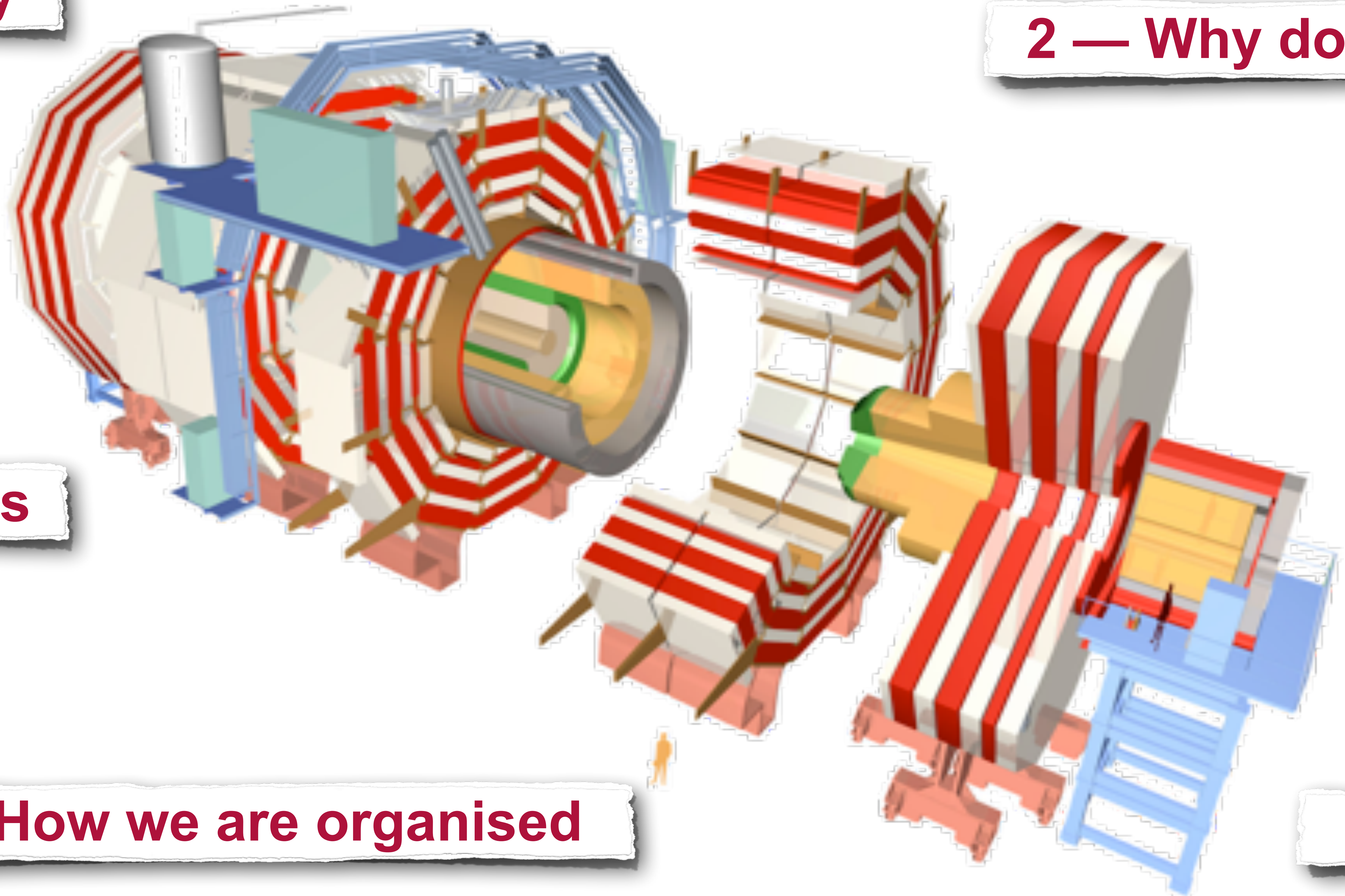
1900 PhD Physicists (18% ♀)
1000 PhD Students (23% ♀)
900 Undergraduate Students (26% ♀)
1000 Engineers (12% ♀)

Membre States: **Italy** (12%), **Germany** (8%), UK (3%), France (3%), Switzerland (3%), Spain (3%), Belgium (3%) …
Other States: **Russia** (5%), India (3%), Korea (3%), Turkey (2%), China (2%), …

Outline

1 — A bit of history

2 — Why does CMS look like this?



3 — CMS at P5

4 — Future plans

5 — How we are organised

Just an overview: much more details in the other presentations to come…

A Bit of History

The First 25 Years

- **1984** Workshop on a Large Hadron Collider in the LEP tunnel, Lausanne
- **1987** "Long-Range Planning Committee" recommends LHC as the right choice for CERN's future
- **1990** ECFA LHC Workshop, Aachen

  CMS design first presented!
- **1992** Meeting on LHC Physics and Detectors, Evian
- **1993** Letters of Intent

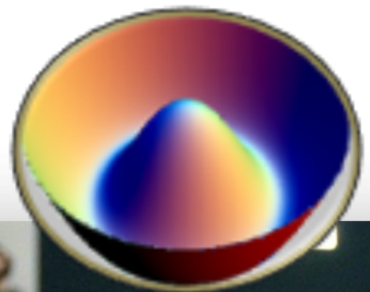
  CMS selected by LHCC
- **1994** Technical Proposals approved
- **1996** Approval to move to construction
- **1998** Memoranda of Understanding signed
- **1998** Construction begins (after approval of Technical Design Reports)
- **2000** CMS assembly begins above ground. LEP closes
- **2004** CMS Underground Caverns completed
- **2008** CMS ready for LHC beams

  LHC "incident" 19th Sept
- **2009** CMS records first collisions

10 years of construction

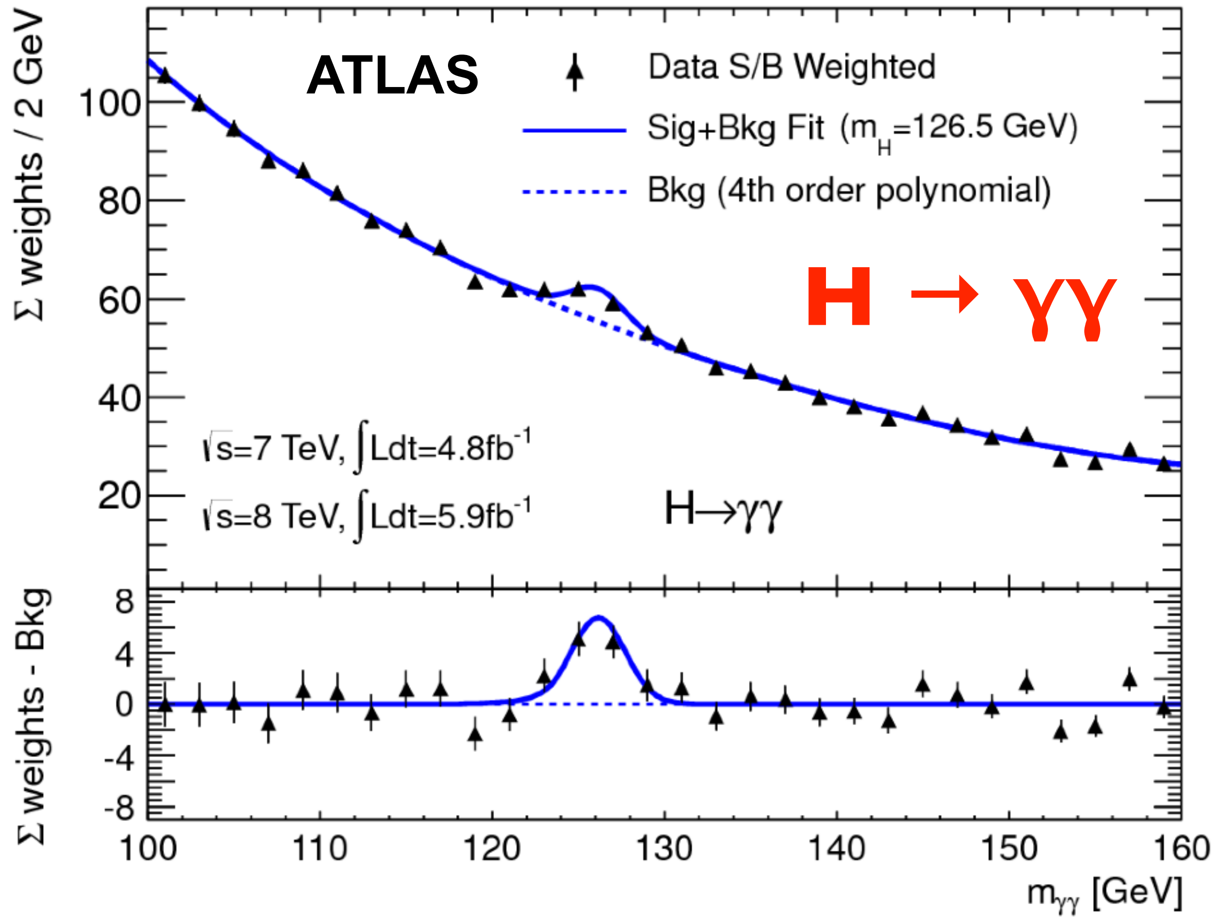
2012 Discovery of a "Higgs-like" Boson

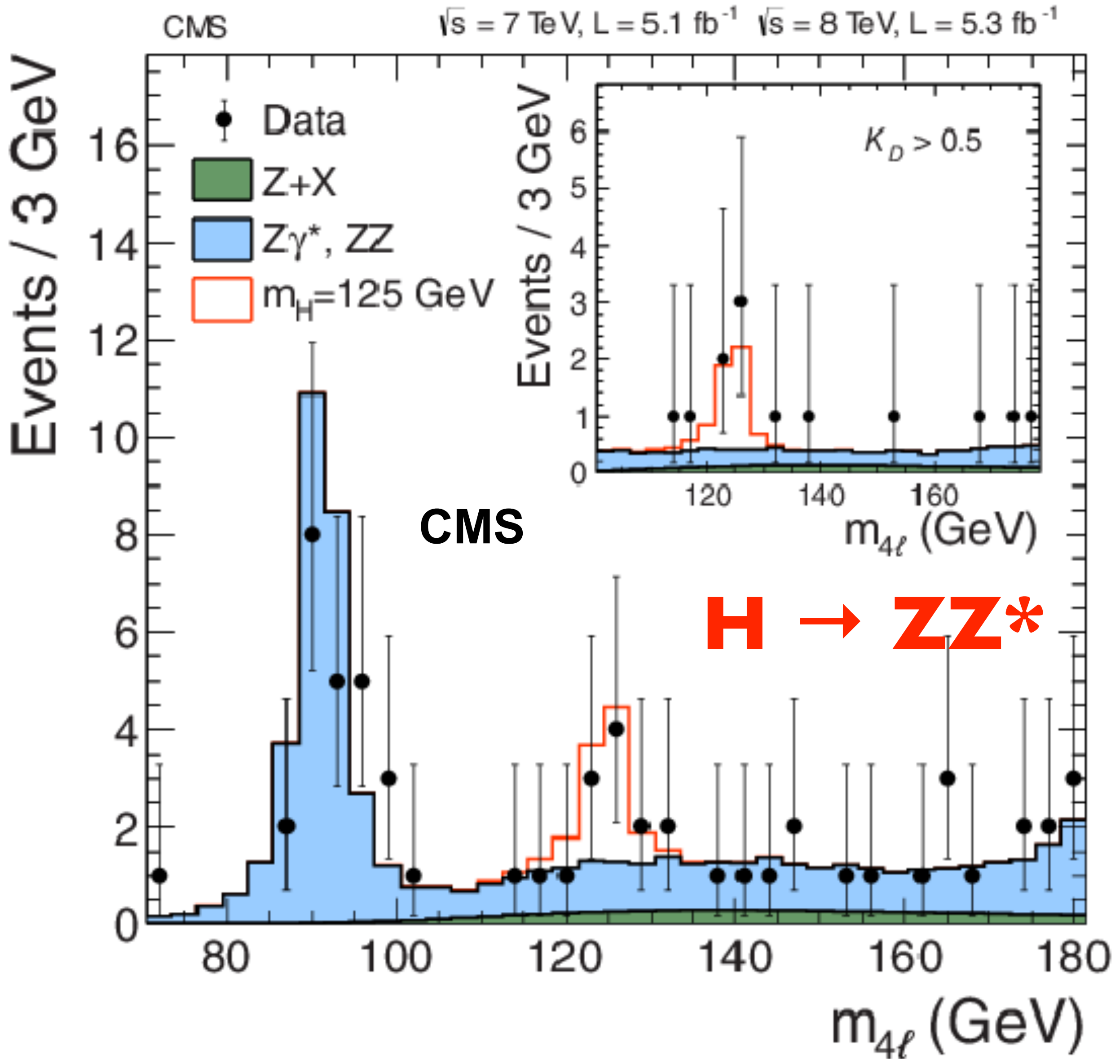
4 July 2012

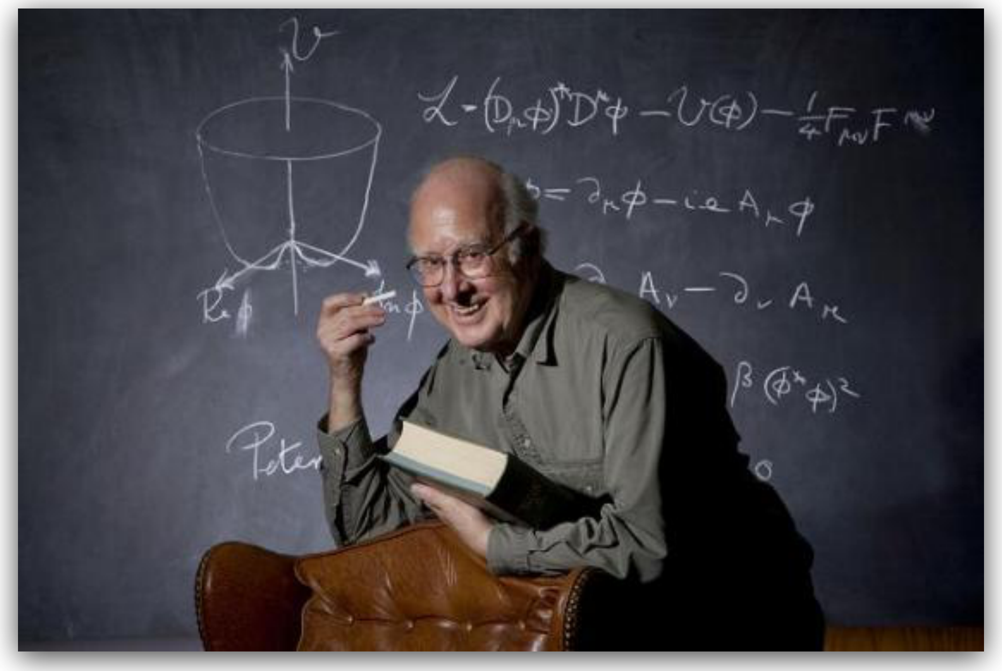


Now clearly identified as
THE Higgs boson

ATLAS and CMS



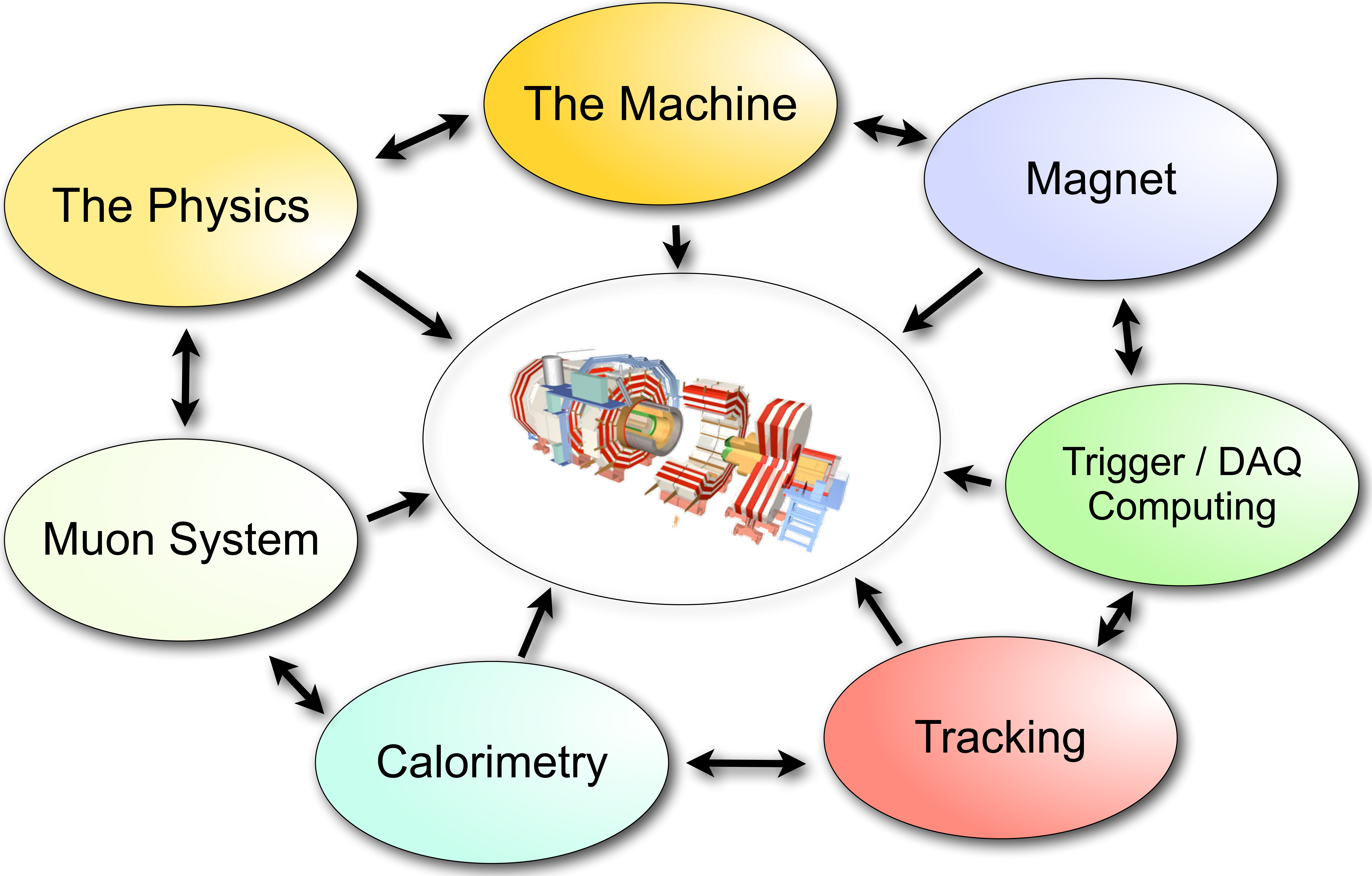




The discovery of the
Higgs boson proves
the physical existence
of the Higgs field

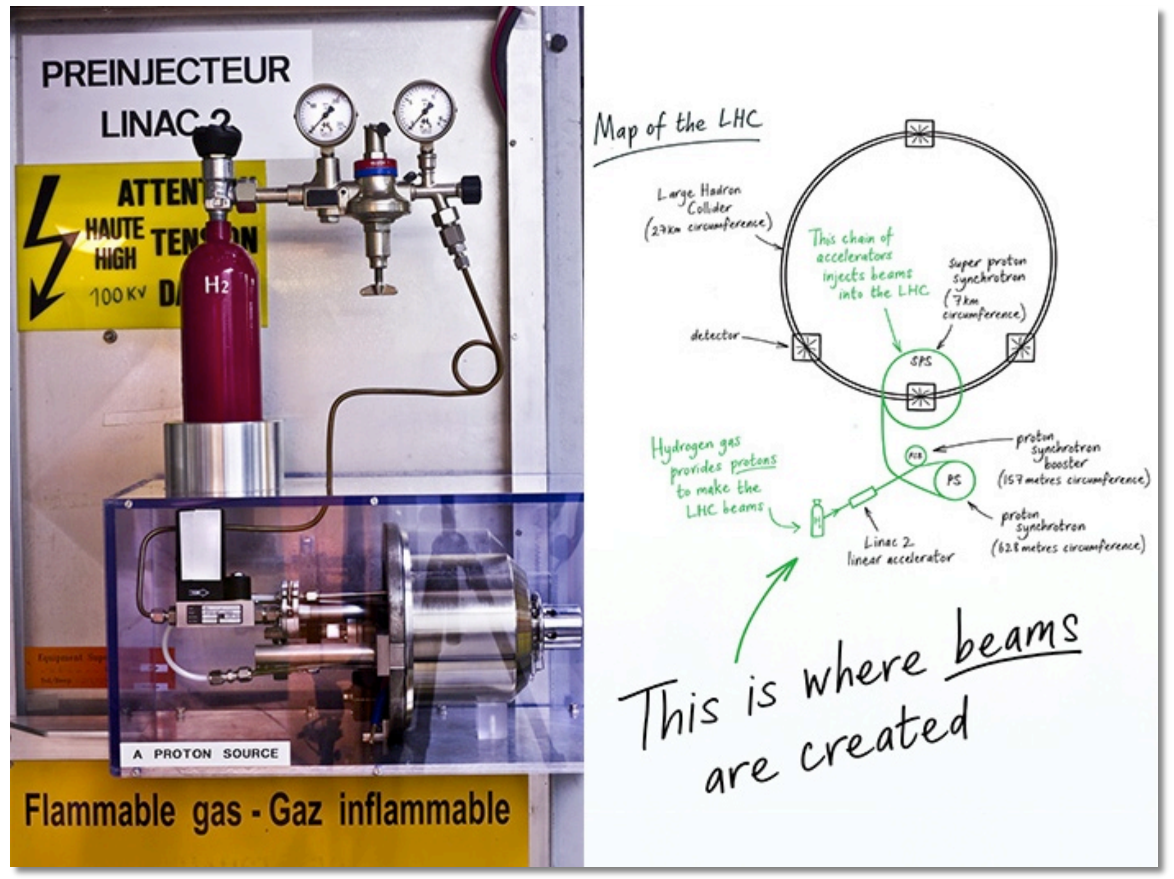
Why does CMS look like this?

How to Design a Detector at the LHC?

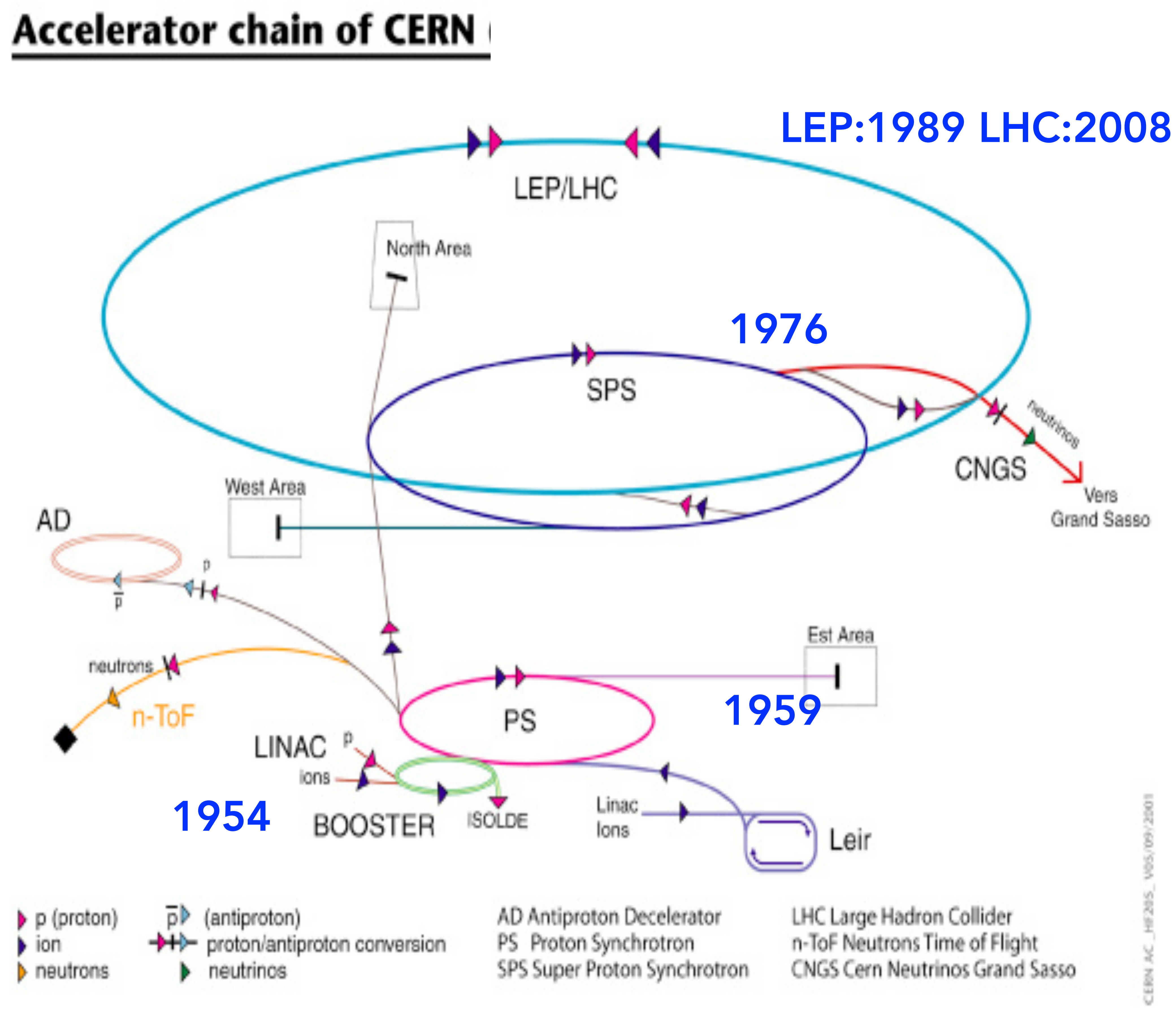


The Accelerator Complex @ CERN

The CERN accelerator complex is formed by a succession of accelerators of increasing energy

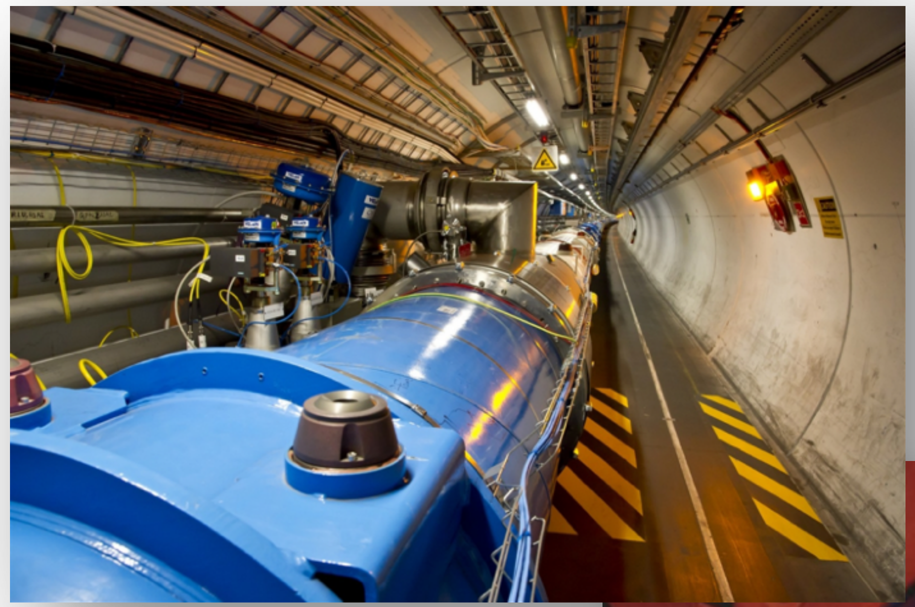


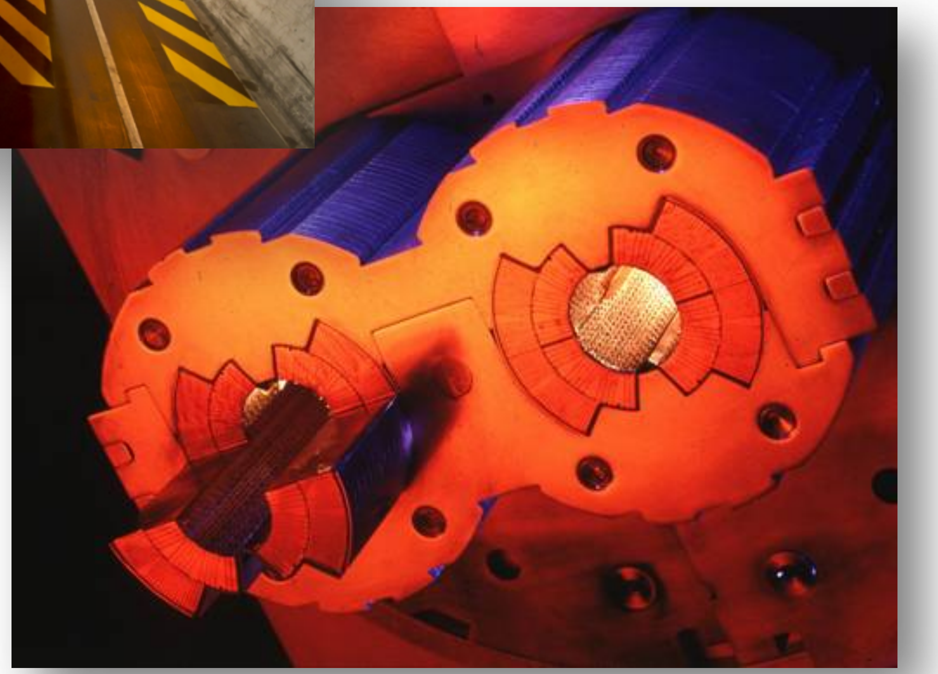
- PS Booster : 1.4 GeV
- PS : 25 GeV
- SPS : 450 GeV
- **LHC** : 6.5 TeV



The Large Hadron Collider

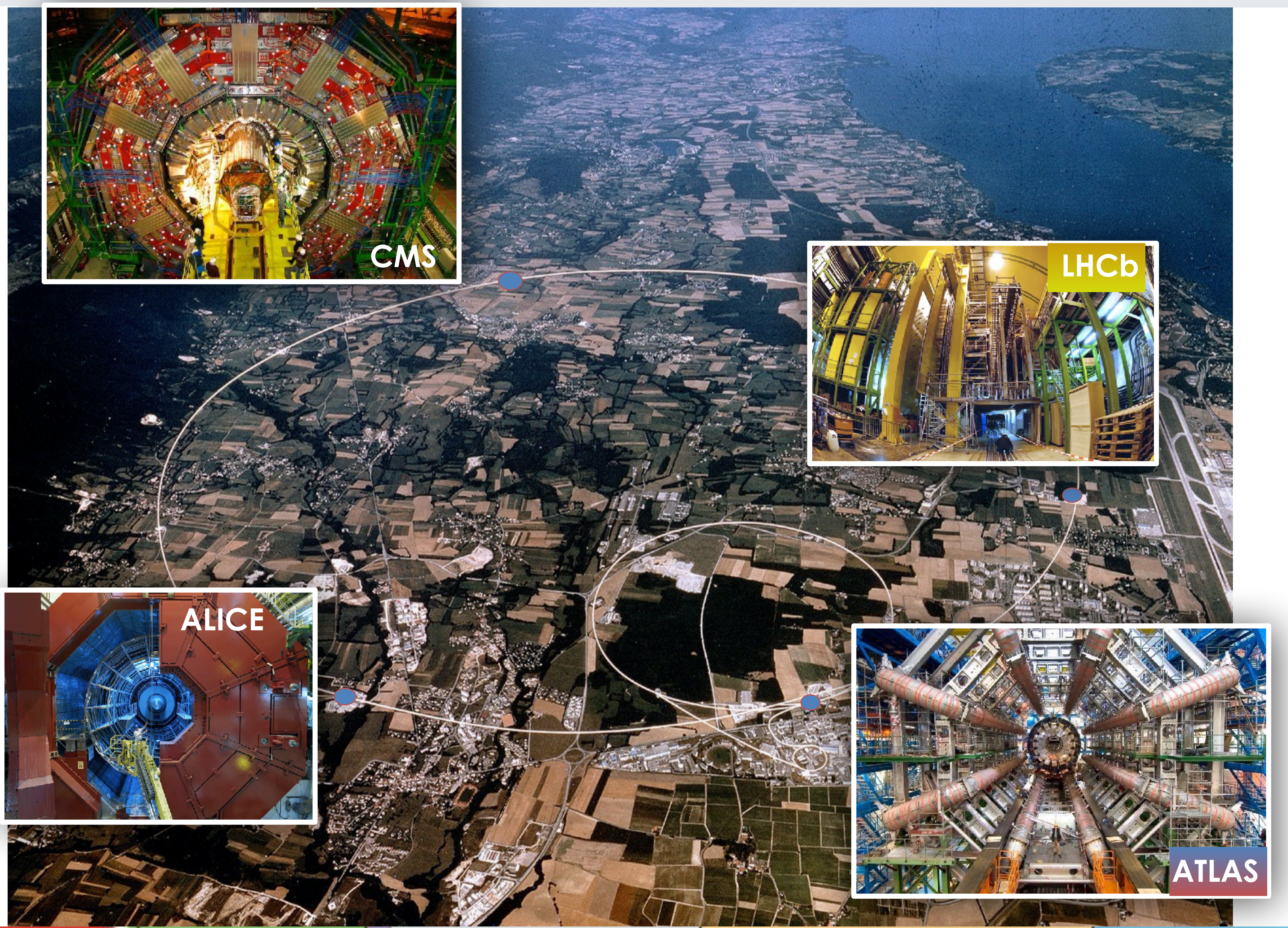
A high-energy proton-proton and heavy ion collider





- 27 km in circumference
- 1232 superconducting 15-m-long dipoles (8.3 T)
- 10 000 superconducting magnets
- 150 t of superfluid helium (1.9 K)
- cryogenic vacuum (10^{-13} atm)

The Large Hadron Collider



A high-energy proton-proton and heavy ion collider

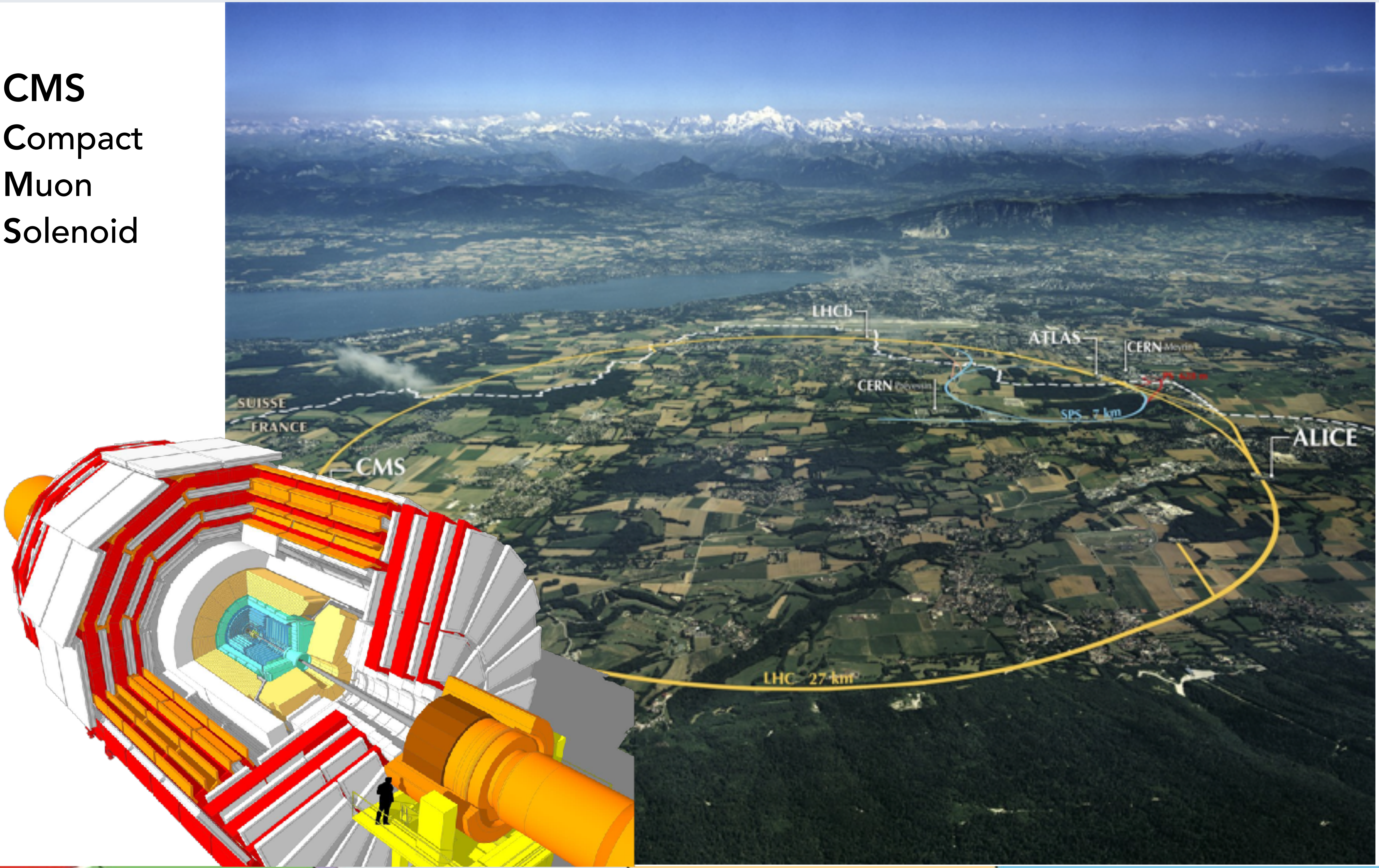
4 large experiments

General Purpose Detectors
- ATLAS
- CMS

Specialised Detectors
- LHCb
  (*flavour physics*)
- ALICE
  (*heavy ion physics*)

CMS at the Large Hadron Collider

CMS
Compact
Muon
Solenoid



100 m underground at LHC Point-5 (P5)

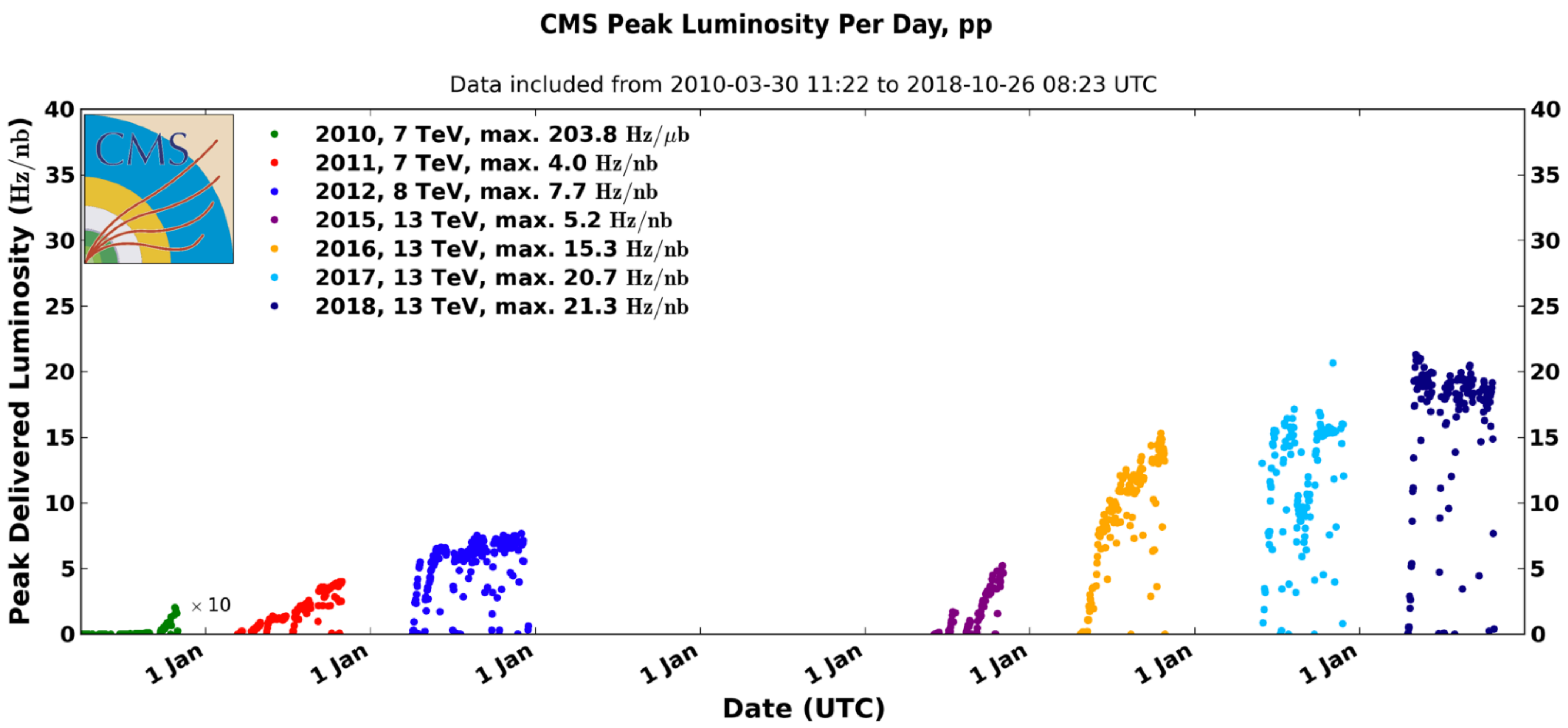
close to the village of Cessy

at the foot of the Jura mountains

LHC Luminosity

LHC performance

- $\sqrt{s}$ = 13 TeV (Run-2)
- bunch separation: 25 ns (40 MHz)
- up to 2 x 2556 circulating bunches
- > 100 billion protons / bunch
- $\mathscr{L} = 2 \times 10^{34}$ cm^{-2} s^{-1} reached



Seven-fold the center-of-mass energy and a **hundred-fold** increase in luminosity compared to the TeVatron

Delivered integrated luminosity

expressed in inverse-femtobarn (fb^{-1})

Run-1

5 fb^{-1} at 7 TeV (2011)

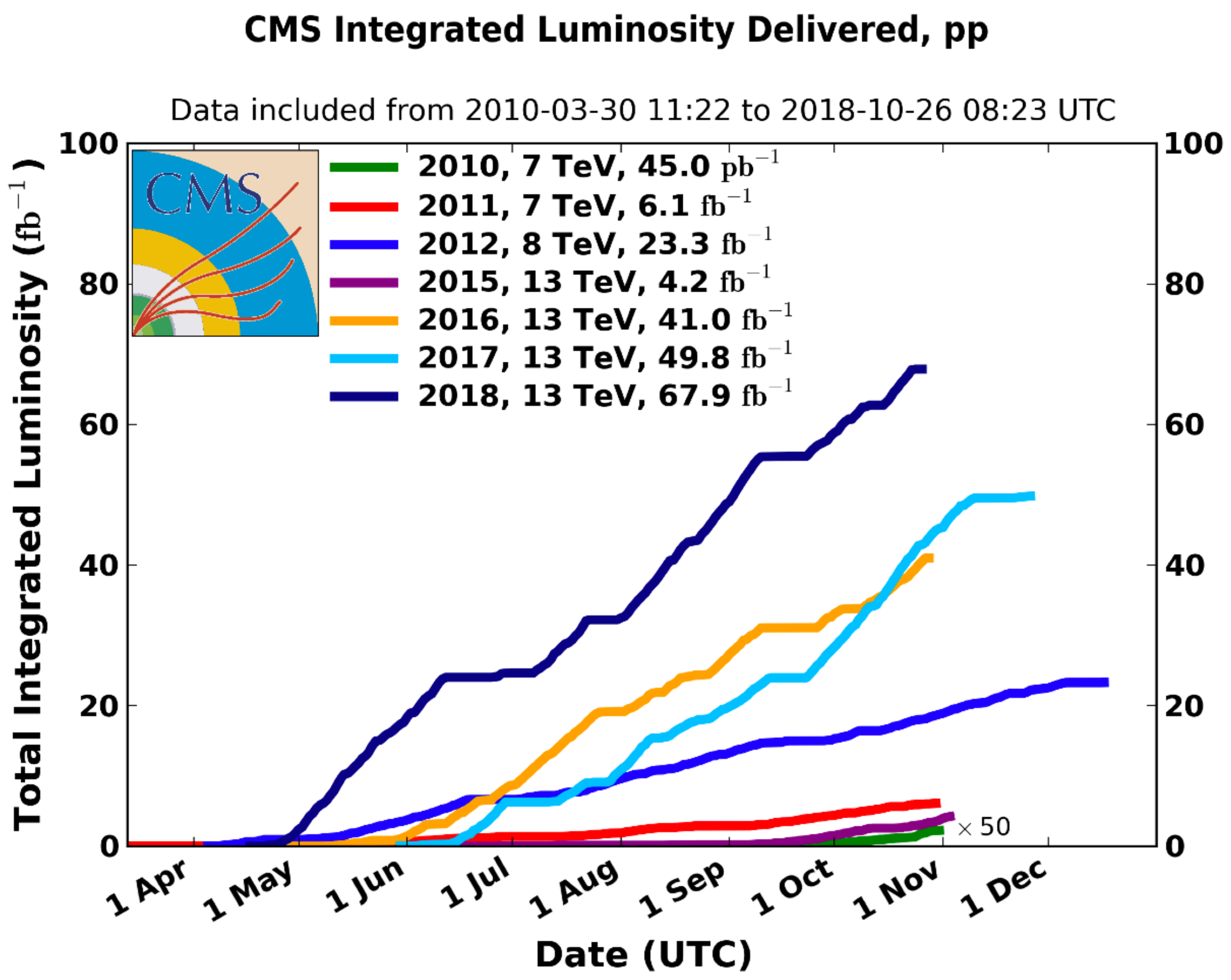
20 fb^{-1} at 8 TeV (2012)

Run-2

140 fb^{-1} at 13 TeV (2015-2018)

Run-3 (expected)

190 fb^{-1} at 13.6 TeV (2022-2024)



At 13 TeV, σ_{tot} ~ 100 mb, 1 fb^{-1} corresponds to **one hundred thousand billion** proton-proton interactions

Pile-up: an Experimental Challenge

Pile-up (*PU*) = <μ> = number of inelastic p-p interactions per bunch crossing (every 25 ns)

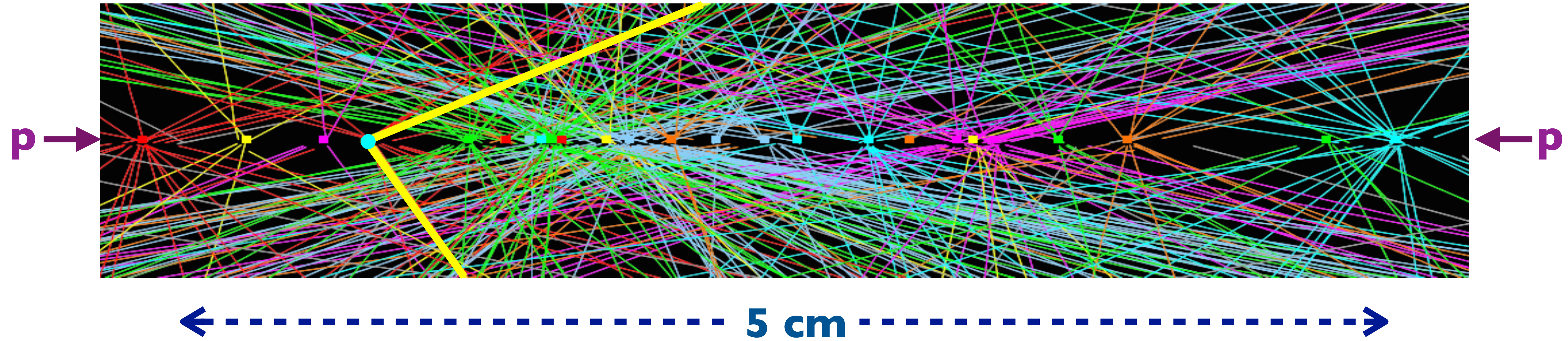
For instance, for Run-2 in 2018

$\langle\mu\rangle \sim \sigma_{inel} \times \mathscr{L}$ x bunch crossing separation time

$\langle\mu\rangle \sim 80\ \text{mb} \times 2{\times}10^{34}\ \text{cm}^{-2}\text{s}^{-1} \times 25\ \text{ns}$

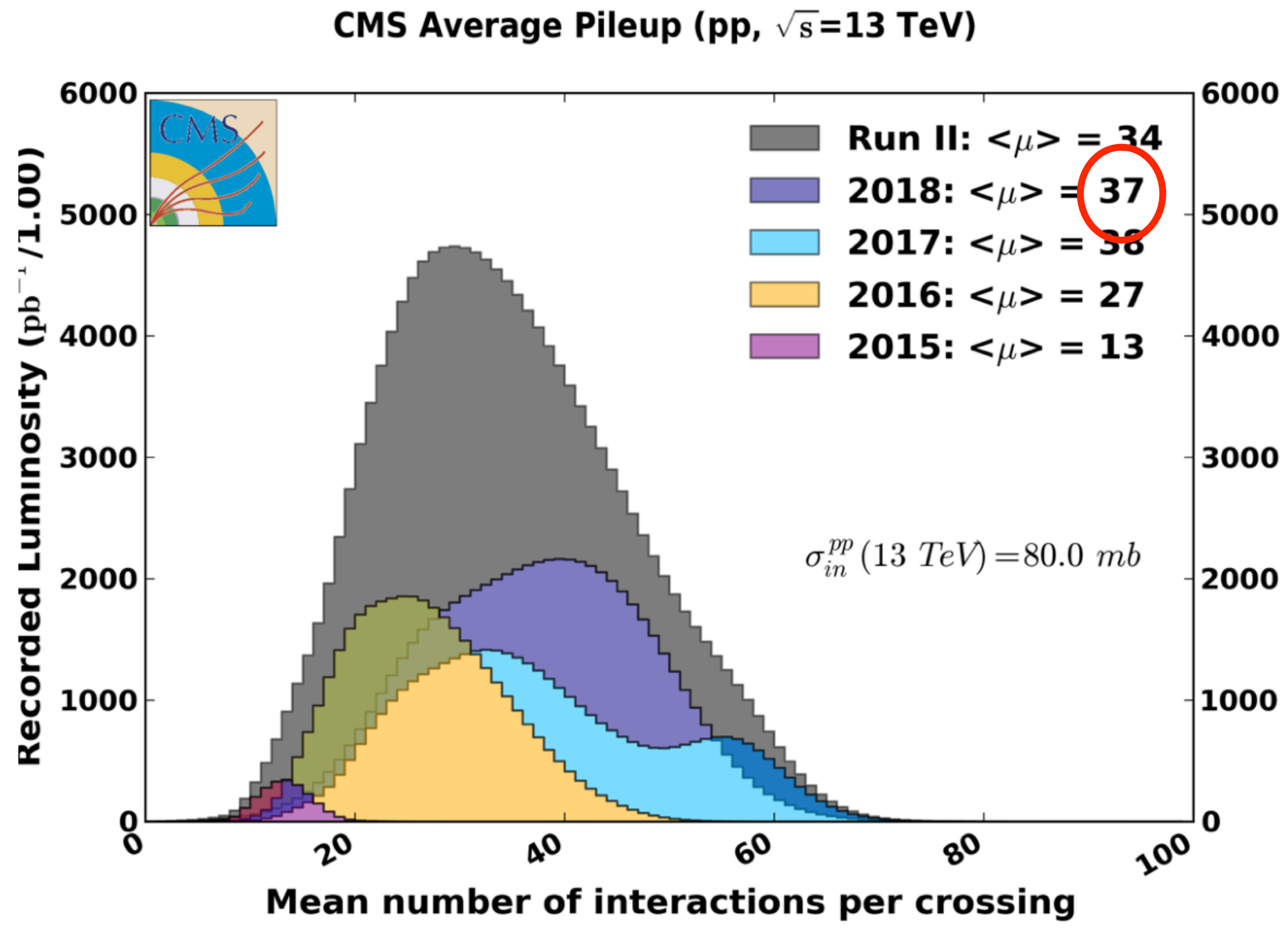
$\langle\mu\rangle \sim$ **40**

➠ about 40 inelastic collisions are superimposed on the event of interest



(zoom of the interaction region)

40 × 40 MHz = 1.6 billion proton-proton interactions per second!

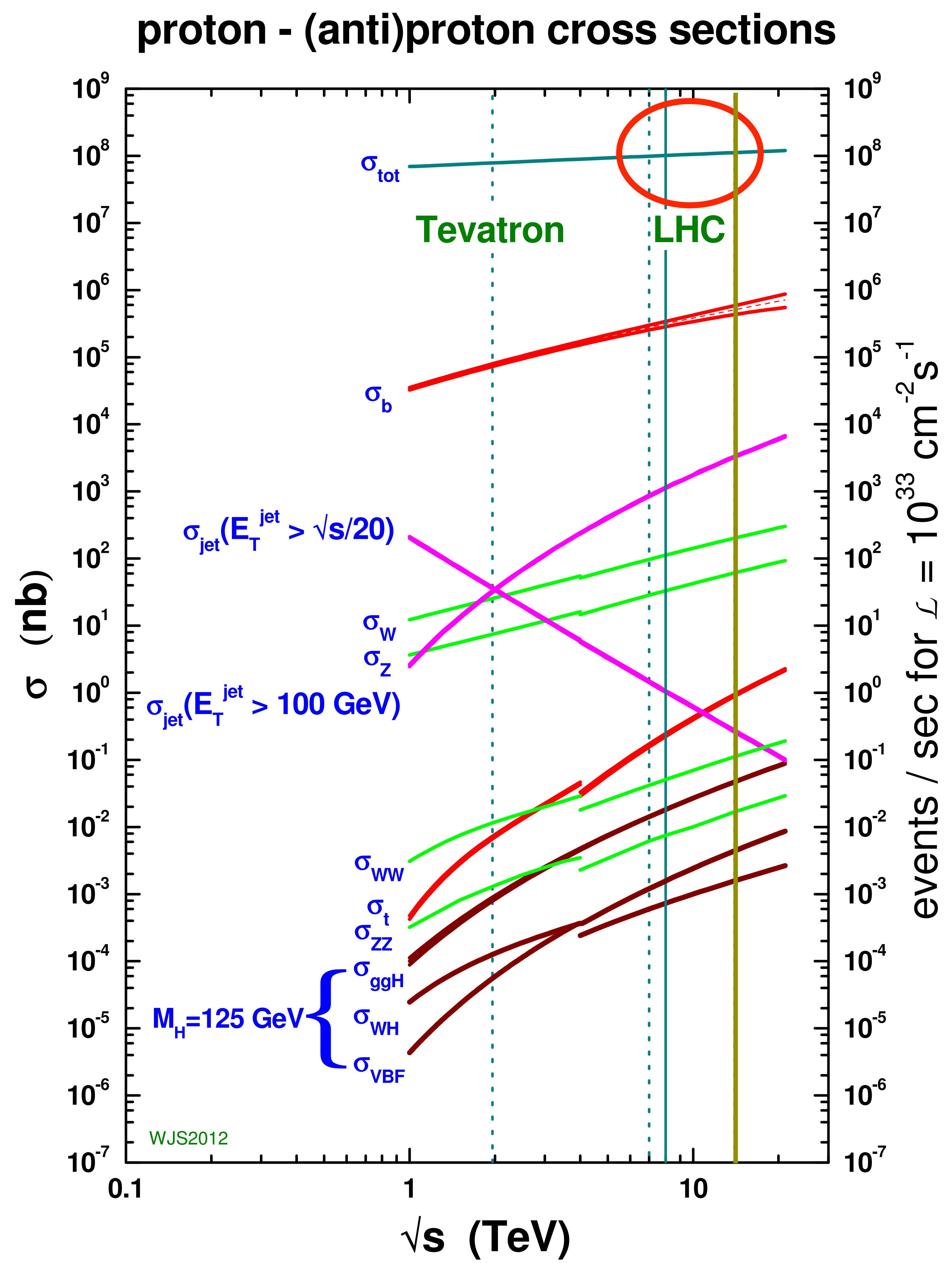


O(1000) particles emerge from the interaction region every 25 ns

This implies

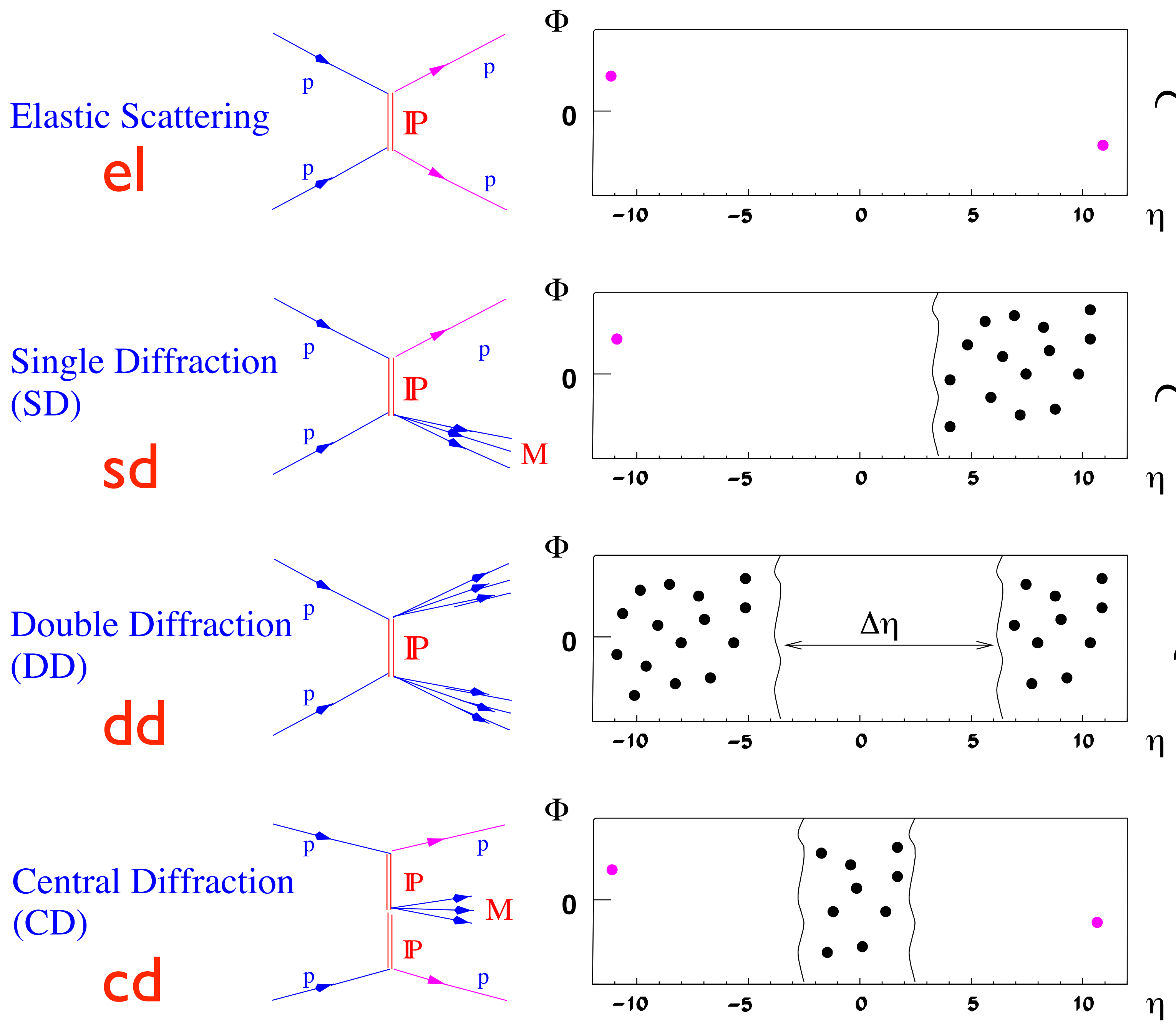
- **high-granularity detectors** with good time resolution, resulting in low occupancy
- **millions of electronic channels** with good synchronization
- **radiation hardness**

pp Interactions at the LHC



99.9999% of LHC events are QCD

$$\sigma_{\rm tot} = \sigma_{\rm el} + \sigma_{\rm sd} + \sigma_{\rm dd} + \sigma_{\rm cd} + \sigma_{\rm nd} \qquad \sim 100\ {\rm mb}$$



~ 20 mb

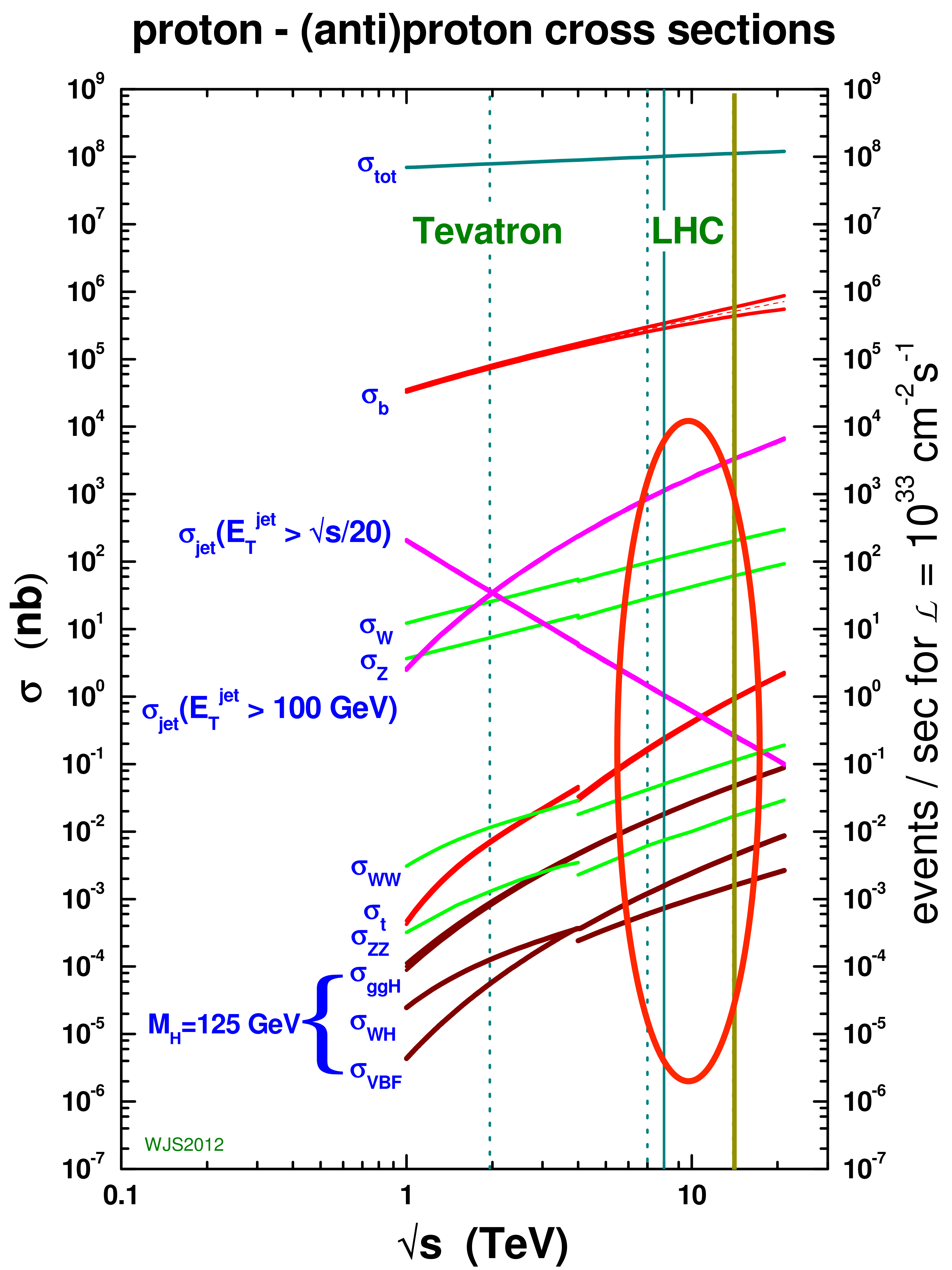
~ 15 mb

~ 10 mb

~ 1 mb

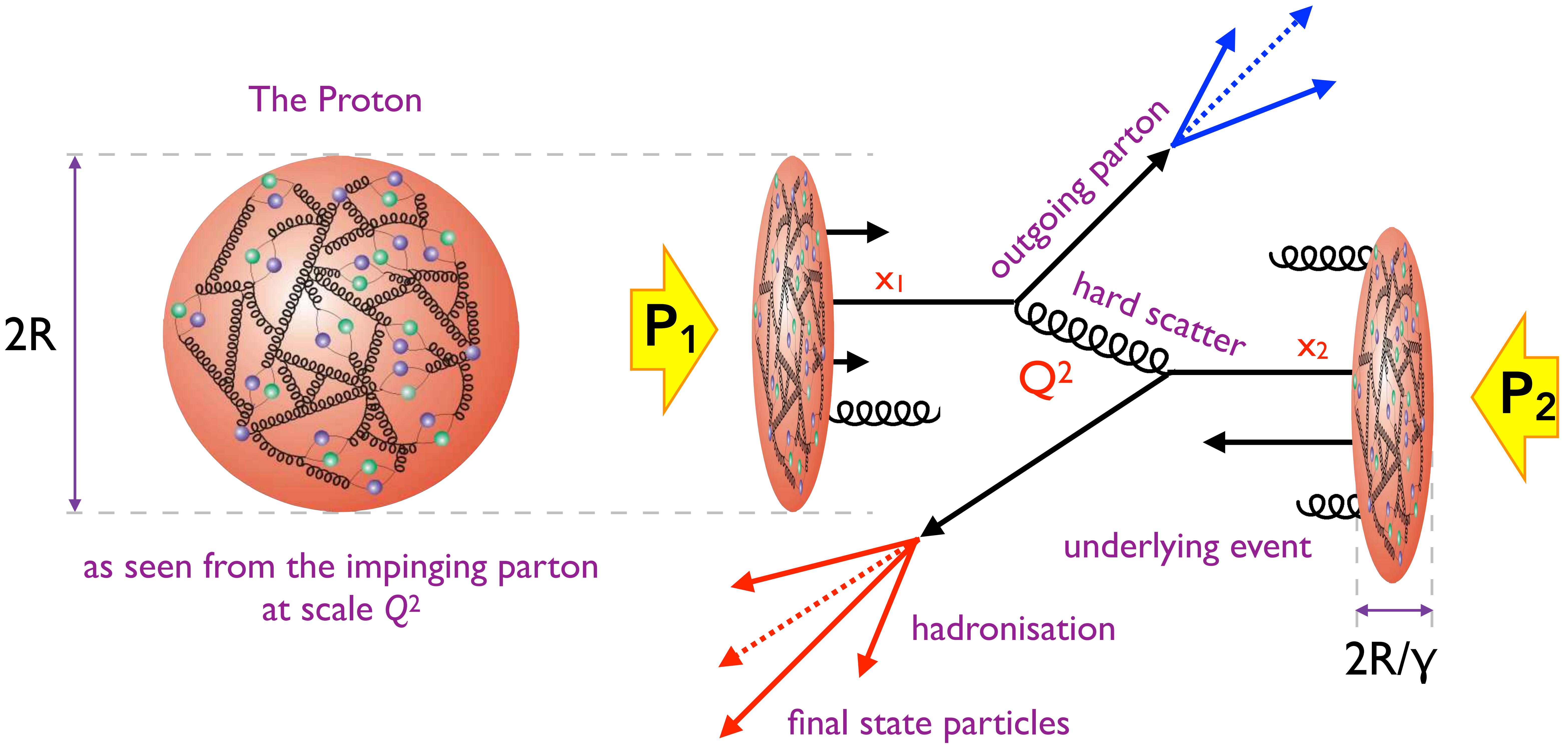
The rest (almost) is **non-diffractive** (nd)
with particles distributed over the full range
= minimum bias events

Hard Scattering at the LHC



Hard Scattering =

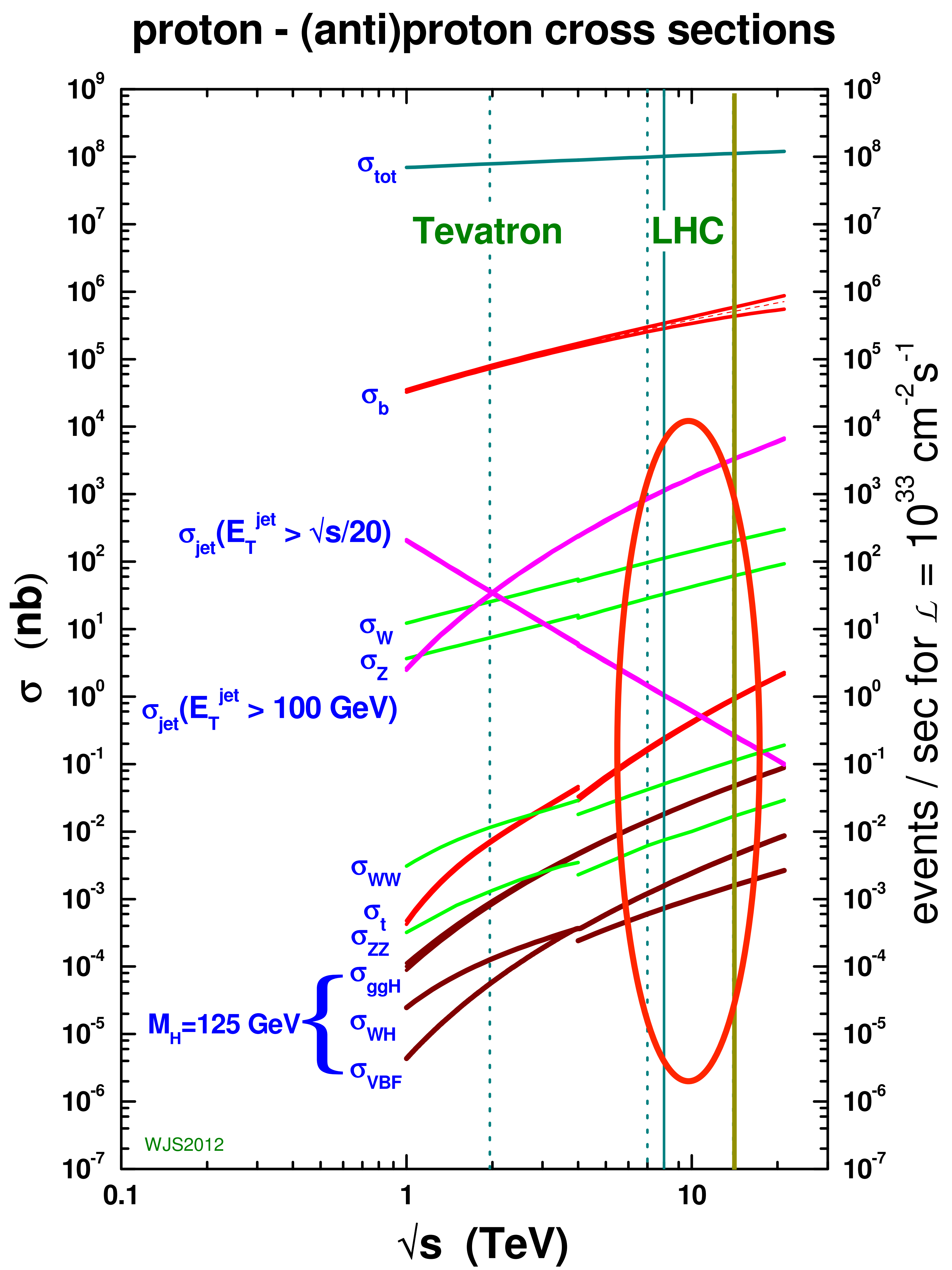
processes with large momentum transfer (Q^2)



only a **tiny tiny fraction** of the total inelastic pp cross section!

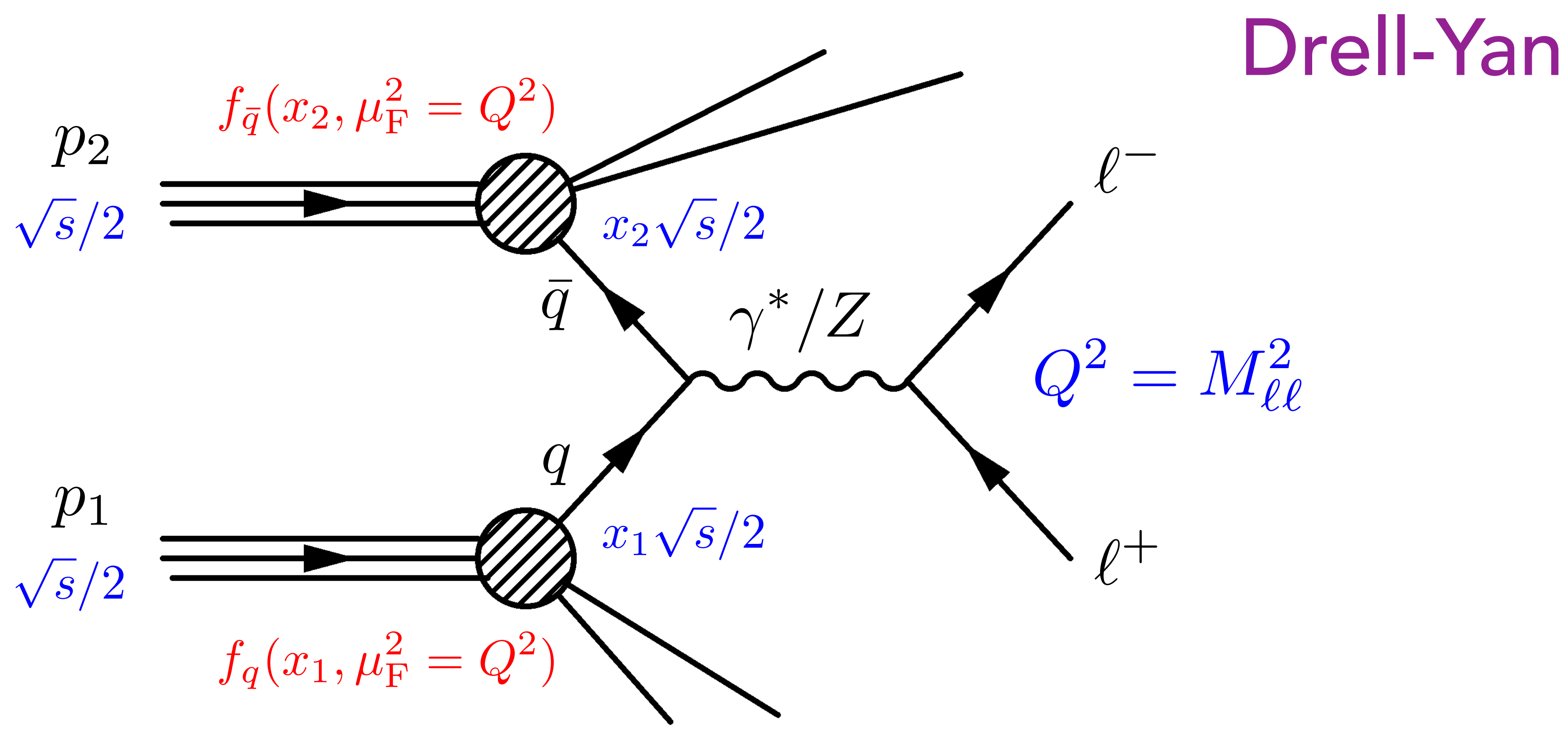
The LHC seen as a **parton collider**

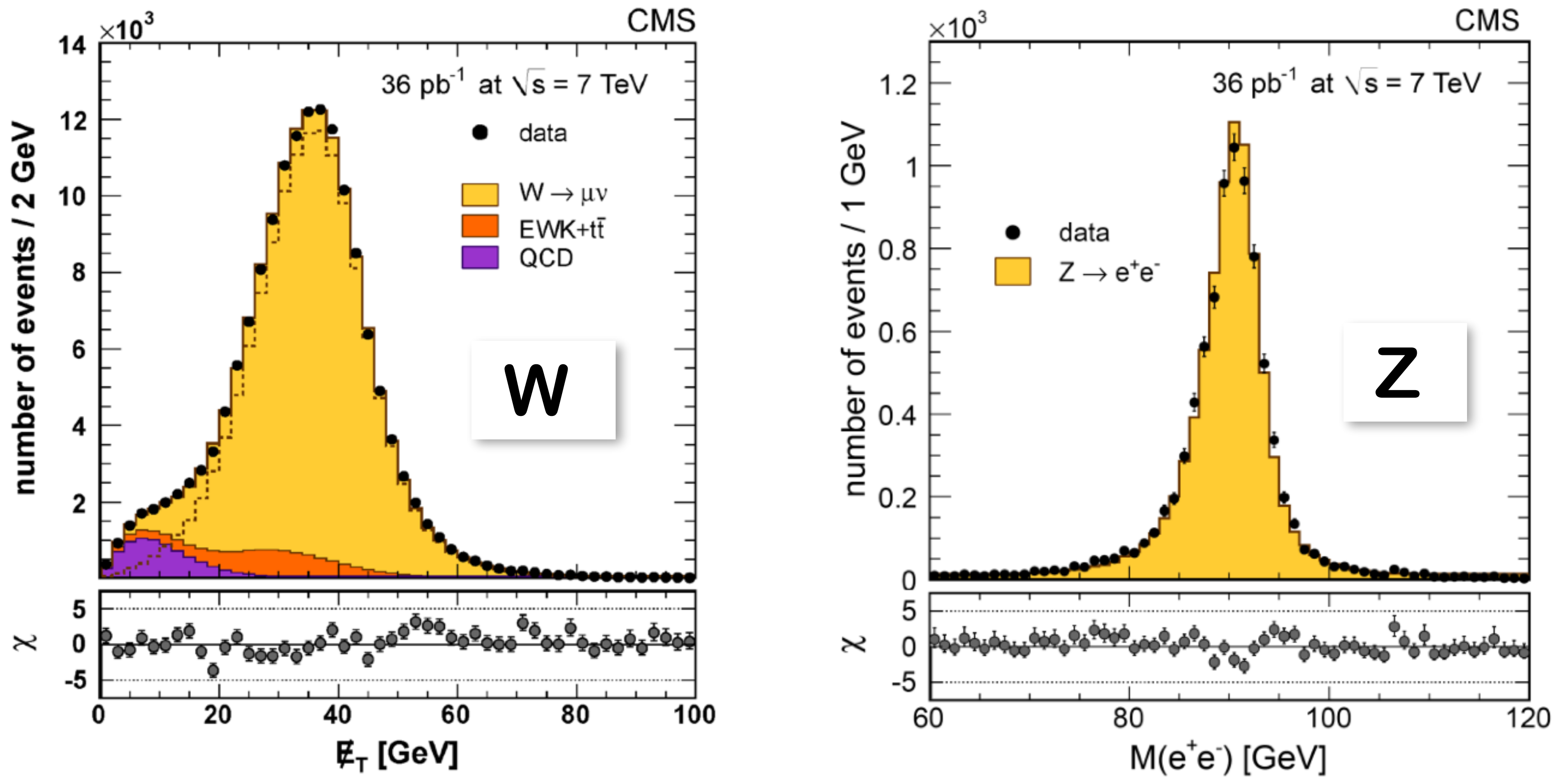
Hard Scattering at the LHC



- jet with E_T > 100 GeV
  3 μb
- W and Z
  200 and 60 nb
- top quark pair
  1.0 nb
- WW
  100 pb
- H(125 GeV)
  60 pb
- ZZ
  20 pb

$$q(x_1) + \bar{q}(x_2) \to \gamma^*/Z \to \ell^+\ell^-$$

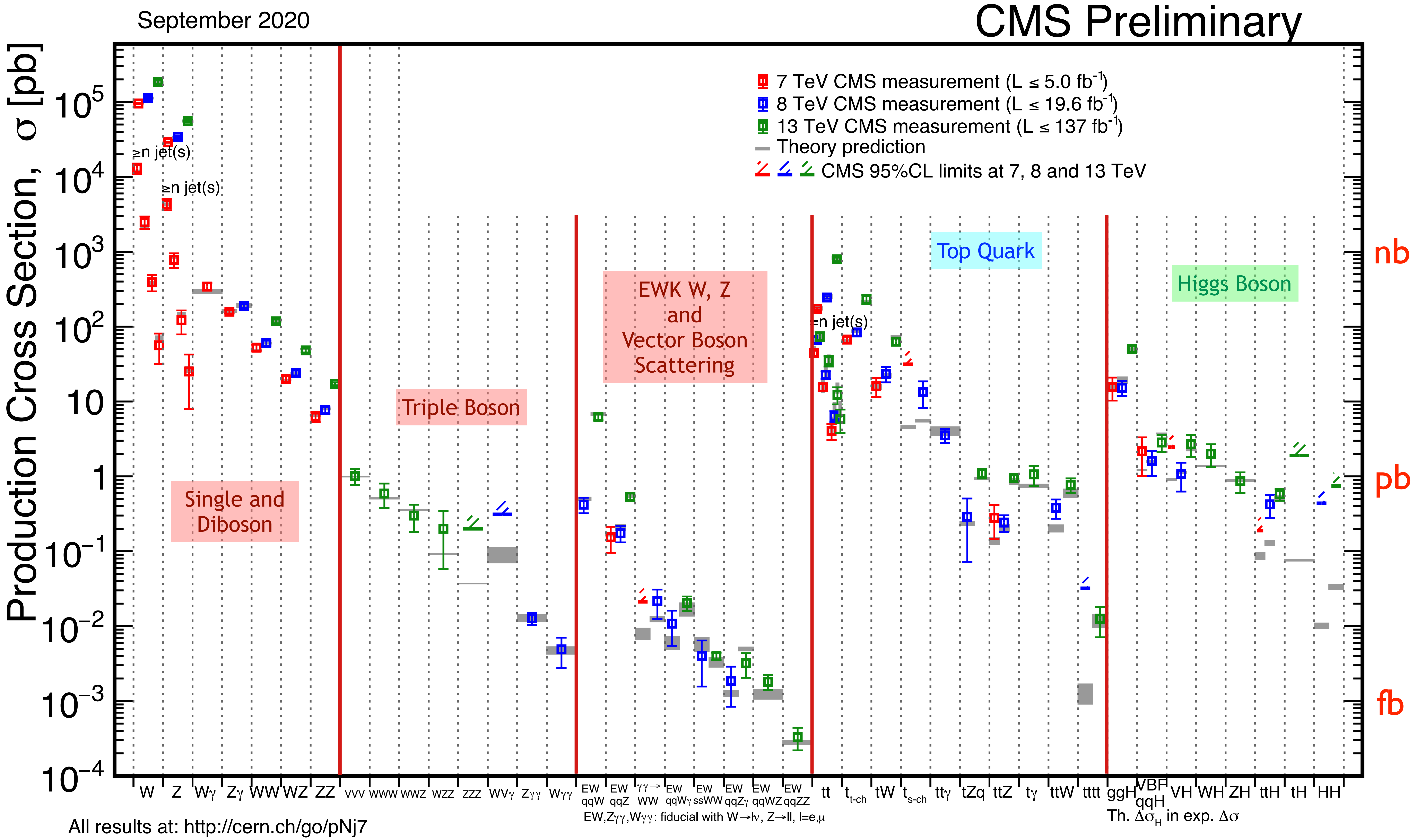




- **σ**(pp → W) x *B*(W → ℓν) = 20 nb
- **σ**(pp → Z) x *B*(Z → ℓℓ) = 2 nb

Stairways to … ?

Standard Model production cross-sections



$$\sigma \times \mathcal{B} = \frac{N_{\mathrm{sig}}}{A \times \varepsilon \times L}$$

one million events per inverse-femtobarn for a cross section of **one nanobarn**

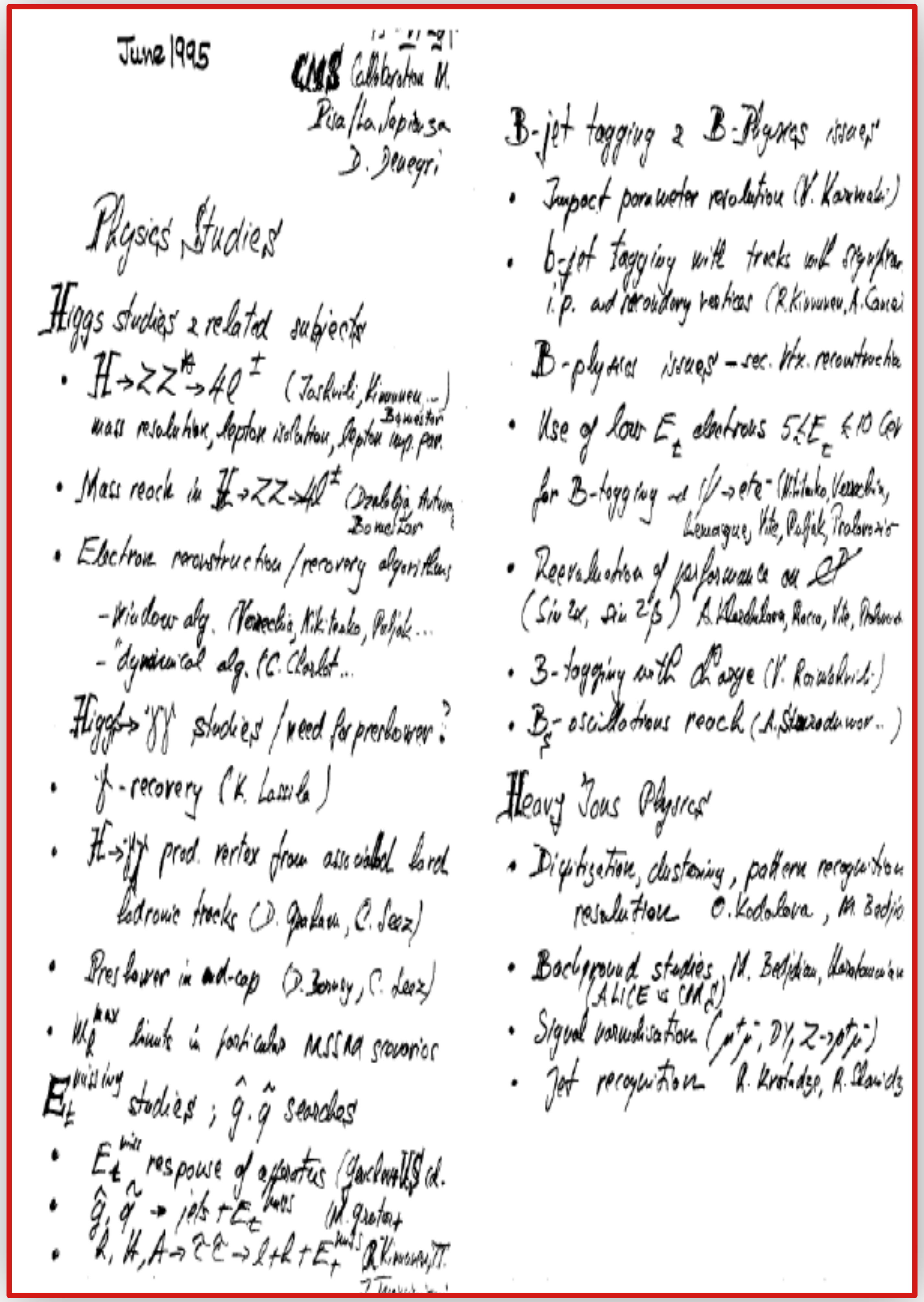
Other main physics motivation
- explore the energy domain around 1 TeV
- study the yet unknown physics at the TeV energy scale

see lecture by Florencia Canelli

Main Detector Requirements

… to meet the goals Physics goals of the LHC physics programme

1995



June 1995

CMS Collaboration M.
Pisa
D. Denegri

Physics Studies

Higgs studies & related subjects

- $H \to ZZ^* \to 4\ell^\pm$ (Jaskuli, Kinnunen ...)
  mass resolution, lepton isolation, lepton imp. par.
- Mass reach in $H \to ZZ \to 4\ell^\pm$
- Electron reconstruction / recovery algorithms
  - window alg.
  - "dynamical" alg. (C. Charlot ...

Higgs → γγ studies / need for preshower?

- γ-recovery (K. Lassila)
- $H \to \gamma\gamma$ prod. vertex from associated hadronic tracks
- Preshower in end-cap
- m_h^{max} limits in particular MSSM scenarios

$E_t^{missing}$ studies ; $\tilde{q}, \tilde{g}$ searches

- E_t^{miss} response of apparatus
- $\tilde{g}, \tilde{q} \to jets + E_t^{miss}$
- $h, H, A \to \tilde{\chi}\tilde{\chi} \to \ell + \ell + E_t^{miss}$

B-jet tagging & B-Physics issues

- Impact parameter resolution (V. Karimäki)
- b-jet tagging with tracks with significant i.p. and secondary vertices (R. Kinnunen, A. Caner)

B-physics issues – sec. vtx. reconstruction

- Use of low E_t electrons $5 \le E_t \le 10$ GeV for B-tagging and $J/\psi \to e^+e^-$
- Reevaluation of performance on CP ($\sin 2\alpha$, $\sin 2\beta$)
- B-tagging with charge
- B_s-oscillations reach

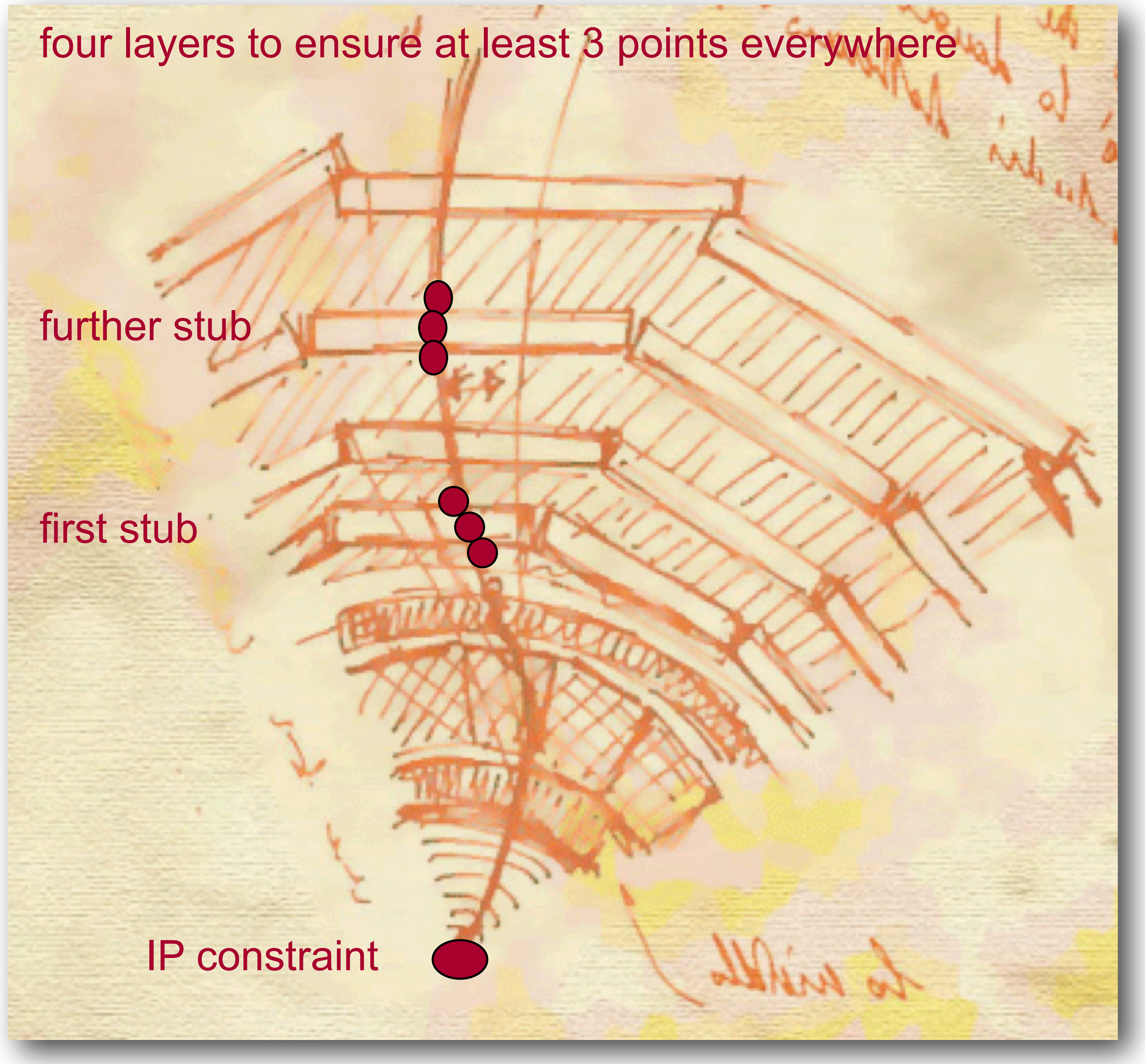
Heavy Ions Physics

- Digitization, clustering, pattern recognition resolution
- Background studies (ALICE & CMS)
- Signal normalisation ($\mu^+\mu^-$; DY, $Z \to \mu^+\mu^-$)
- Jet recognition

1. Good muon identification and momentum resolution over a wide range of momenta and angles, good dimuon mass resolution (1% at 100 GeV), and the ability to determine unambiguously the charge of muons with $p < 1$ TeV
2. Good charged-particle momentum resolution and reconstruction efficiency in the inner tracker. Efficient triggering and offline tagging of τ's and b-jets, requiring pixel detectors close to the interaction region
3. Good electromagnetic energy resolution, good diphoton and dielectron mass resolution (1% at 100 GeV), wide geometric coverage, π^0 rejection, and efficient photon and lepton isolation at high luminosities
4. Good missing-transverse-energy and dijet-mass resolution, requiring hadron calorimeters with a large hermetic geometric coverage and with fine lateral segmentation

Main Detector Requirements

… to meet the goals Physics goals of the LHC physics programme



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Muon Spectrometer

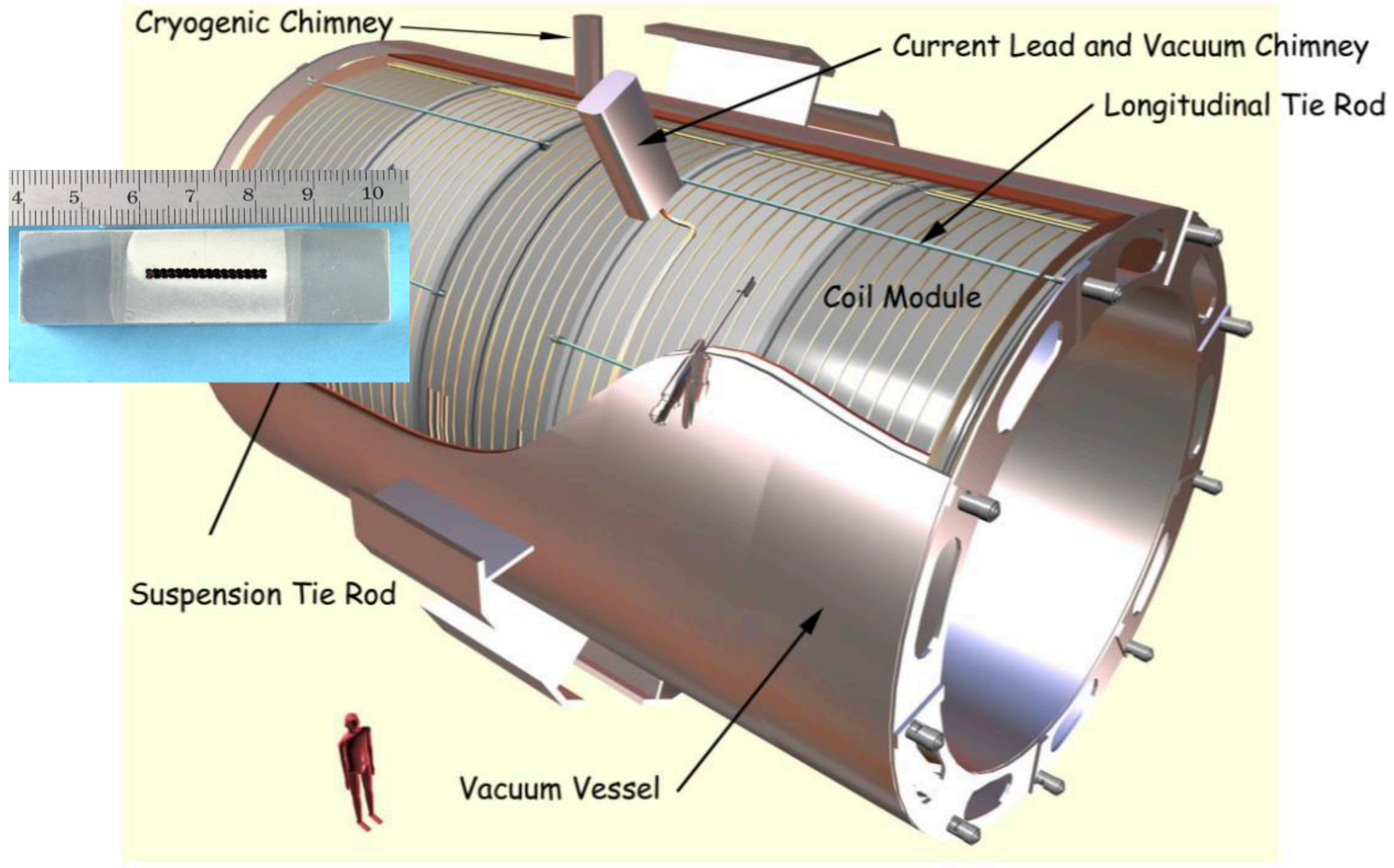
The choice of the **magnetic field** for the measurement of muons has driven the design of the CMS experiment

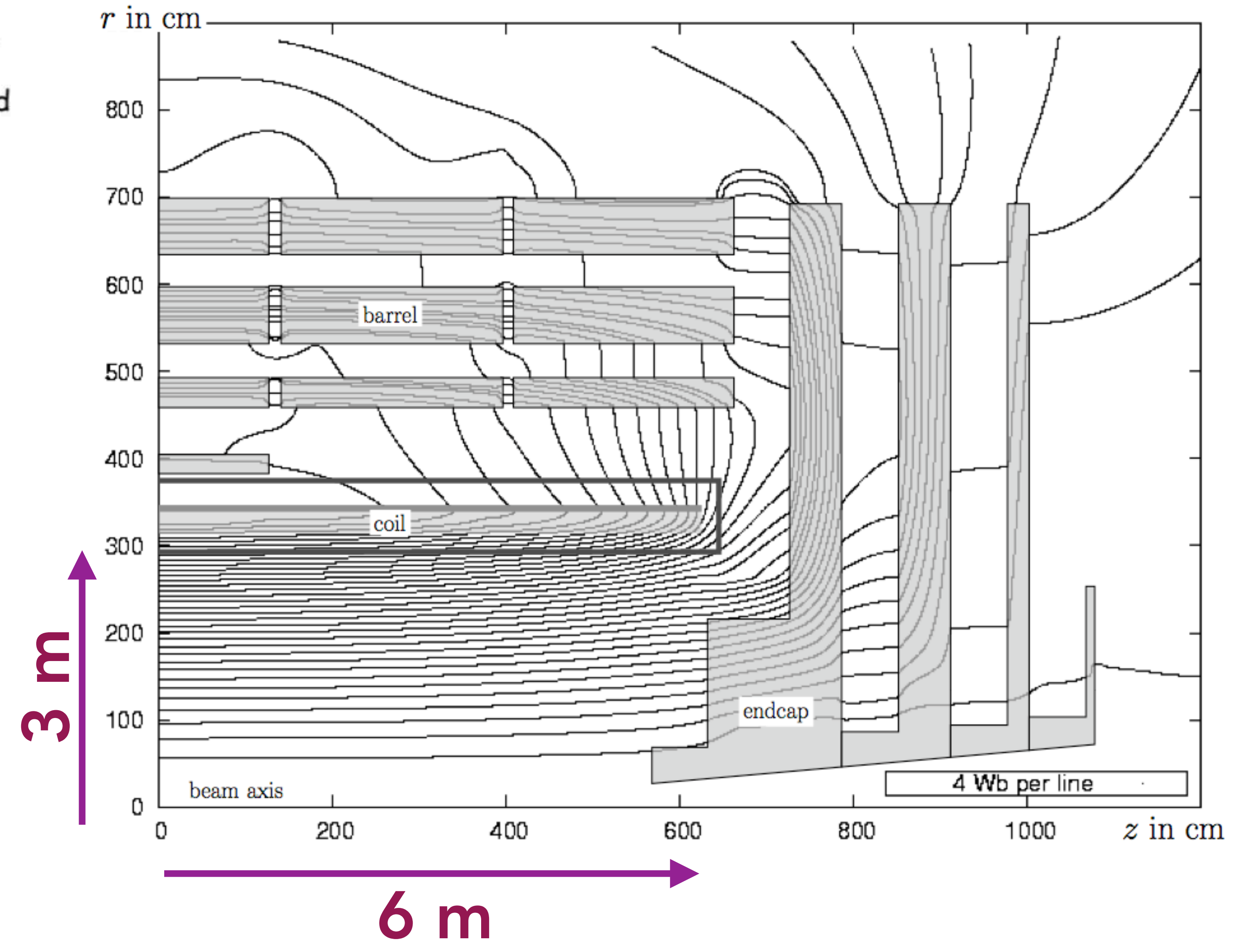
- high-field **superconducting solenoid**
- large bending power (12 Tm)
- long enough to cover a wide pseudorapidity range
- possibility of reasonable standalone muon transverse momentum measurement in the B flux return (Fe)

➠ Must maximise L^2B
… but cost typically grows as L^3

CMS Solenoid

- 12-m long
- 6-m inner diameter
- operation B field: 3.8 T
- current: 20 kA
- Wold's largest superconducting solenoid
- magnet with largest stored energy (2 GJ)





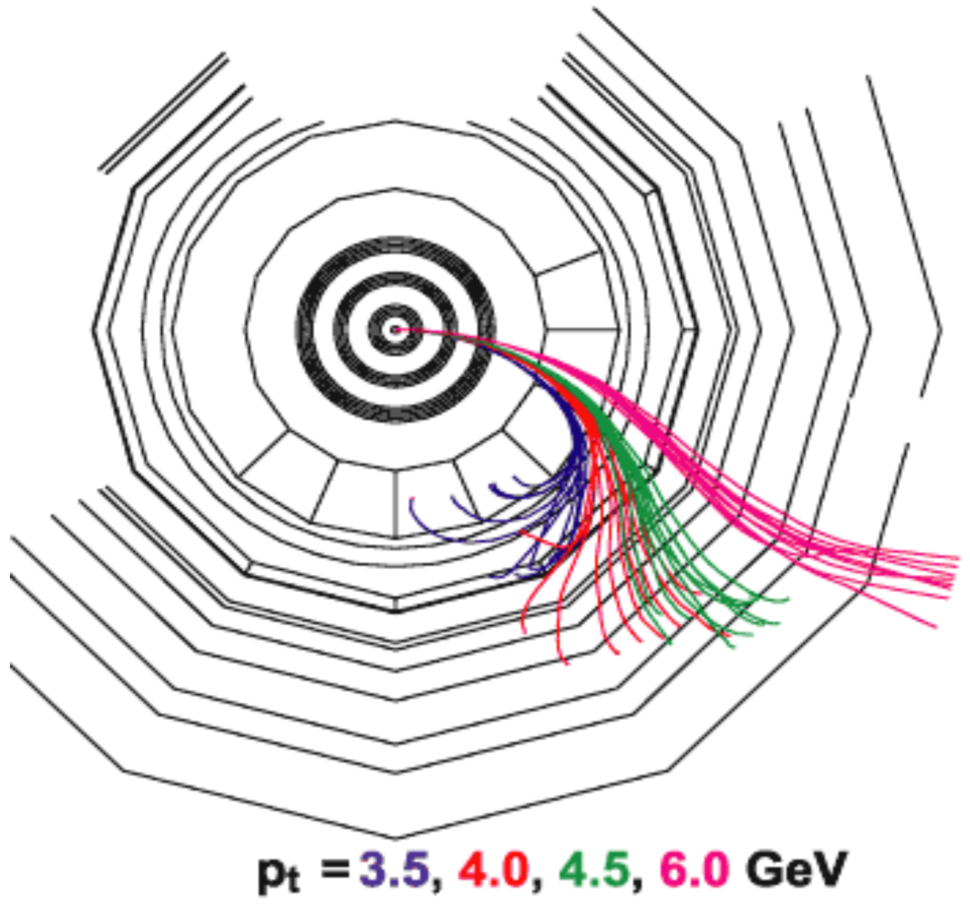
The bore of the magnet is large enough to accommodate both the inner tracker and the full calorimetry inside

The return field is such to saturate 1.5m of iron, allowing four stations of muon chambers to be inserted

CMS Muon System

Main requirements

- reconstruct 1 TeV muons with 10% precision over a wide pseudorapidity range
- good muon identification a dense environment
- Measure and trigger on muons in standalone mode, for momenta above ~ 5 GeV (possibly using the Interaction Region as a constraint)



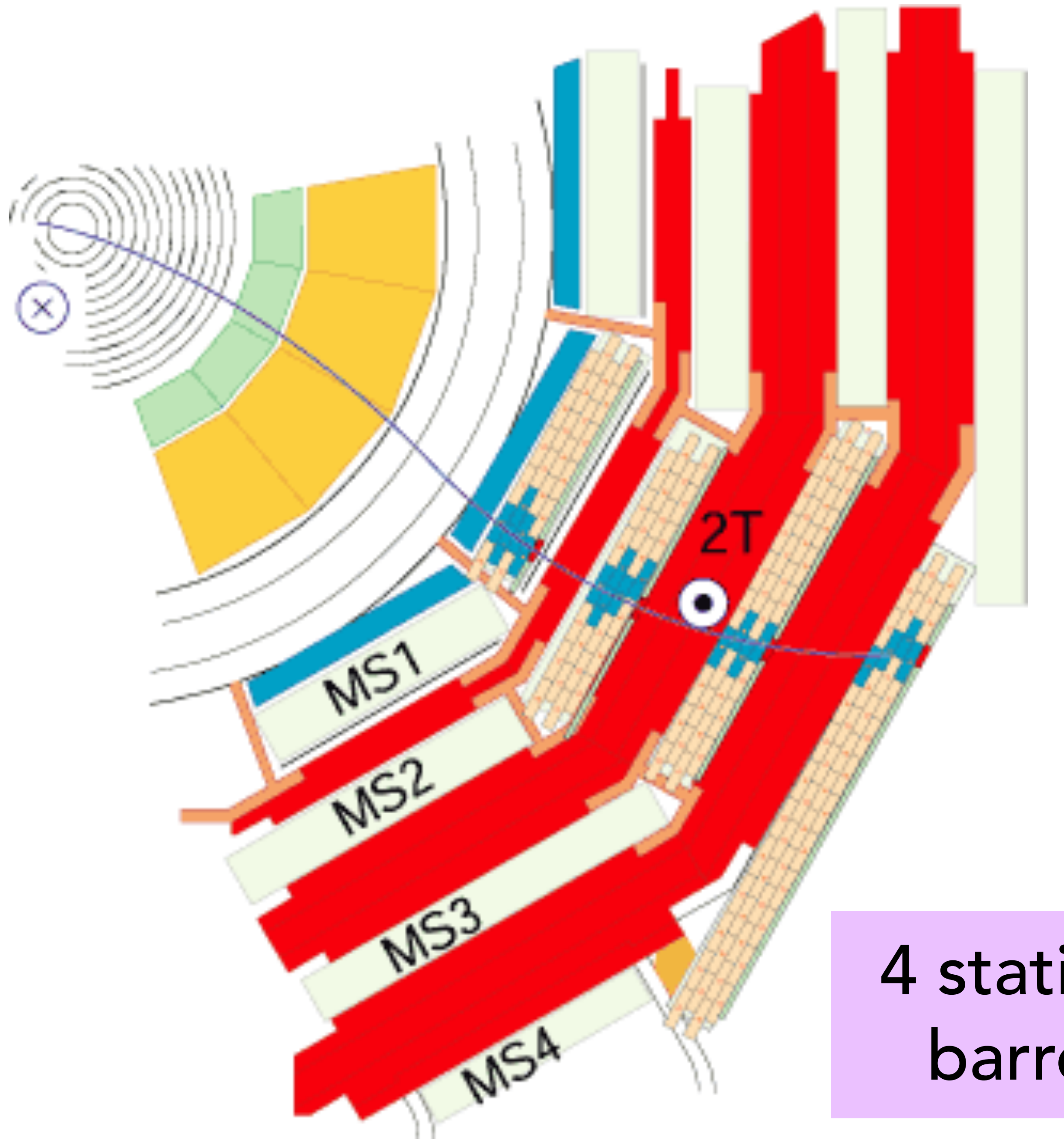
the *B* field sweeps away low momentum tracks

CMS Strategy

Combine different technology for muon chambers

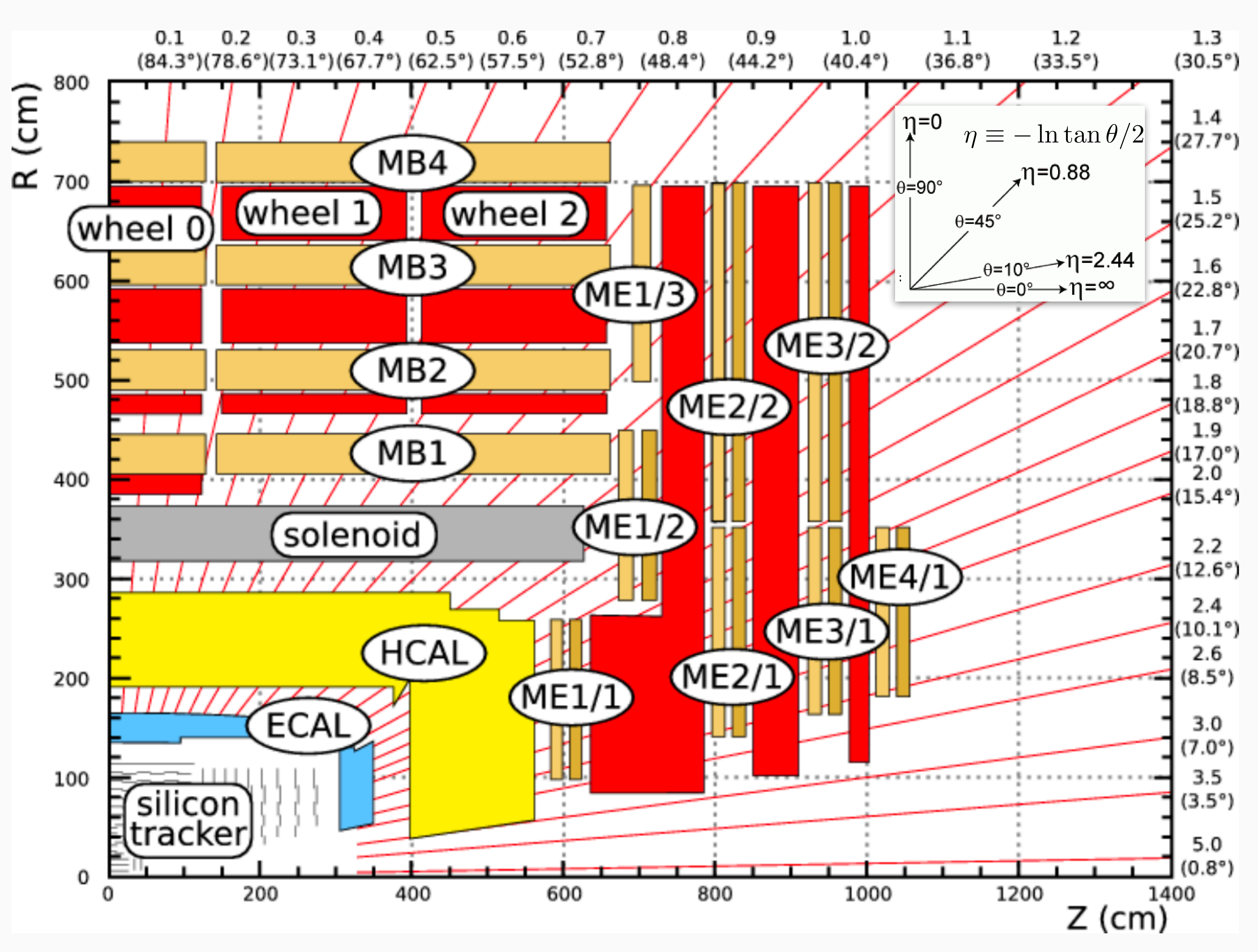
- redundancy, robustness, different speeds, radiation hardness

The CMS muon stations consist of several layers of aluminum **drift tubes** (DT) in the barrel region and **cathode strip chambers** (CSC) in the endcap regions, competed by **resistive plate chambers** (RPC)



4 stations in the barrel region

CMS Muon System



- 12,000 tons of iron absorber
- standalone trigger information from muon tracking in flux return (B = 2T)
- link with inner tracker

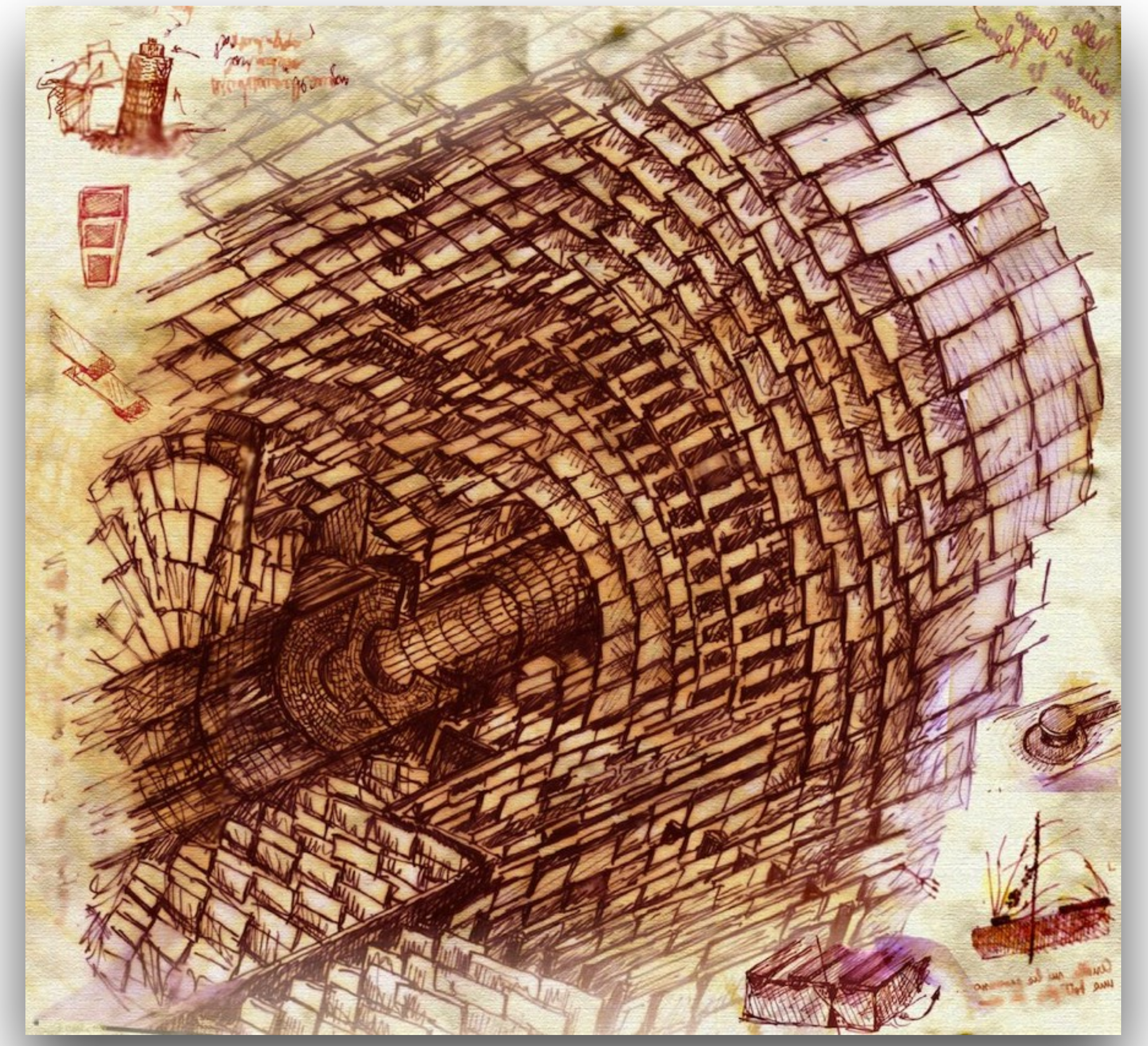
Issues/challenges

- alignement
- punch through
- multiple scattering

$$\left(\frac{\delta p}{p}\right)_{\mathrm{MS}} \approx 5\%$$

Main Detector Requirements

… to meet the goals Physics goals of the LHC physics programme



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CMS Tracker

$$\frac{\delta p_T}{p_T} < 1\% \text{ for } p_T < 50\,\text{GeV}$$

$$\frac{\delta p_T}{p_T} < 10\% \text{ for } p_T = 1\,\text{TeV}$$

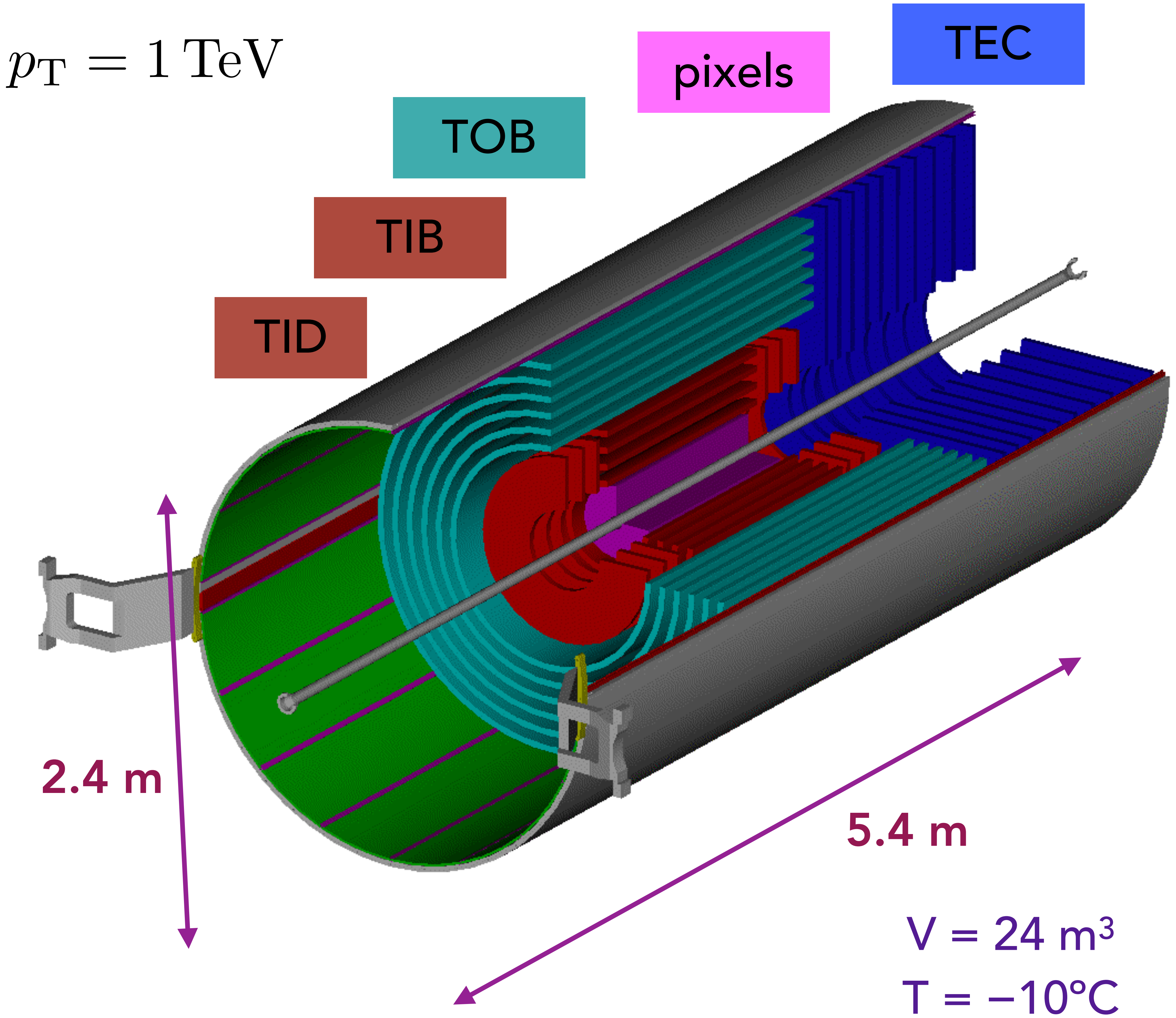
see presentation by Kristian Hahn

Main requirements
- robust and efficient pattern recognition
- precise reconstruction of charged tracks up to pseudorapidity ~ 2.5
- impact parameters of charged tracks (b-jet tagging)
- secondary vertices (from e.g., B hadron or tau decays)
- hadronic tau-lepton decays (thin jets)
- smallest possible material budget in front of the calorimeters

CMS Strategy
- *B* field very useful to reduce occupancy at larger radius
- ~2000+: choice of all-silicon tracker with coarser strips at higher R

Barrel tracker
- 10 layers of strips
- 3 layers of pixels

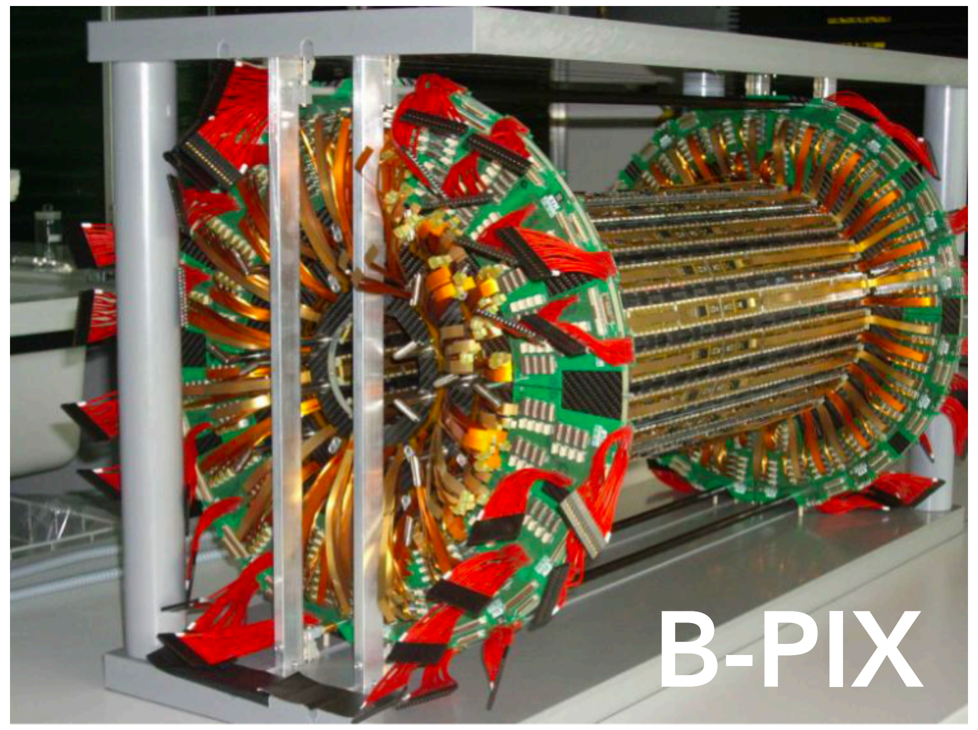
Forward tracker
- 12 rings of strips
- 2 disks of pixels



V = 24 m^3
T = −10°C

200 m^2 of strip detectors
10M electronic channels

CMS Tracker

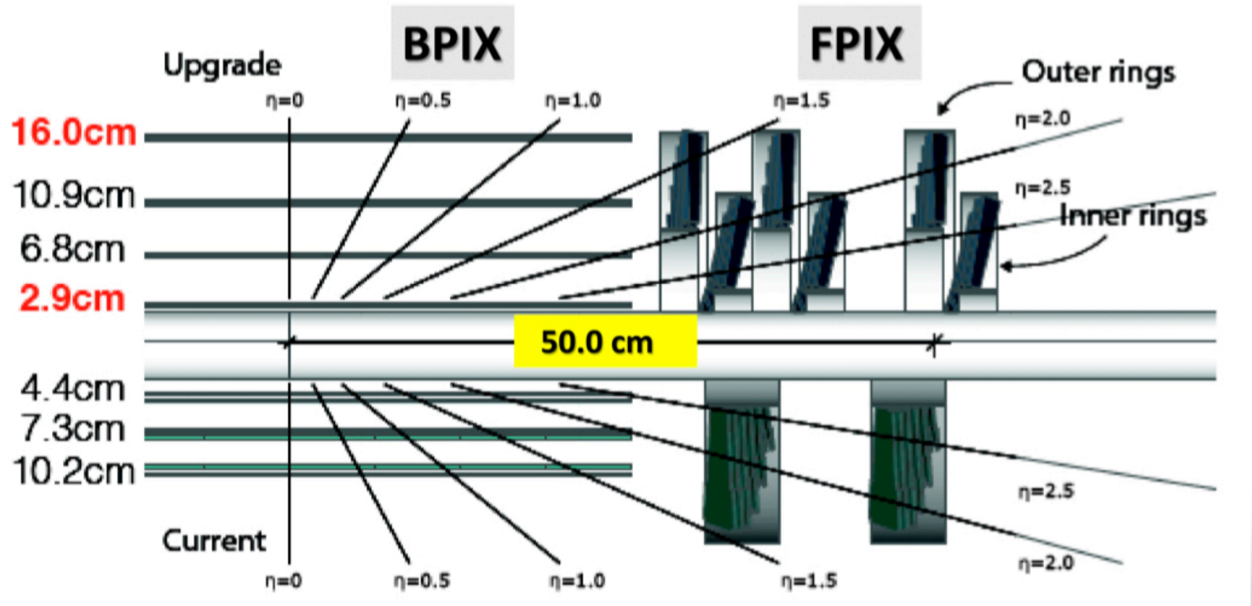


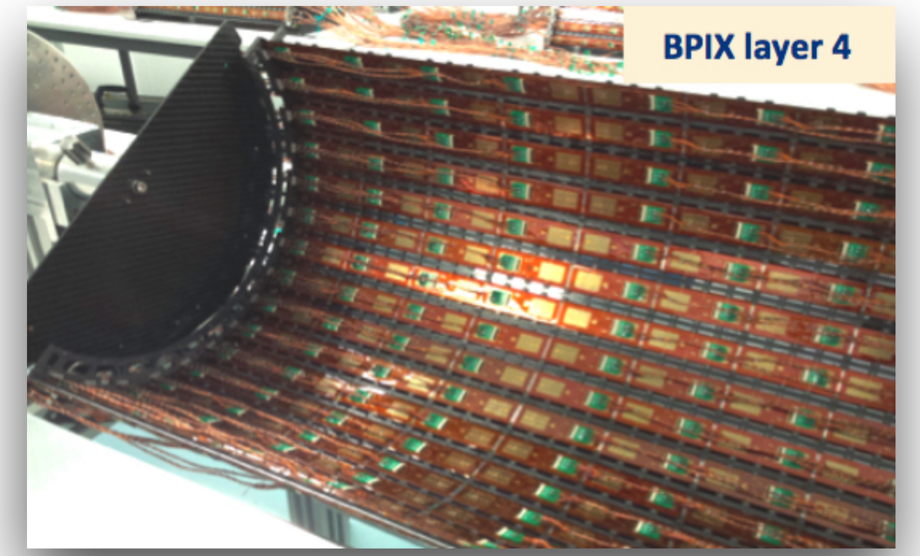
During EYETS 2017

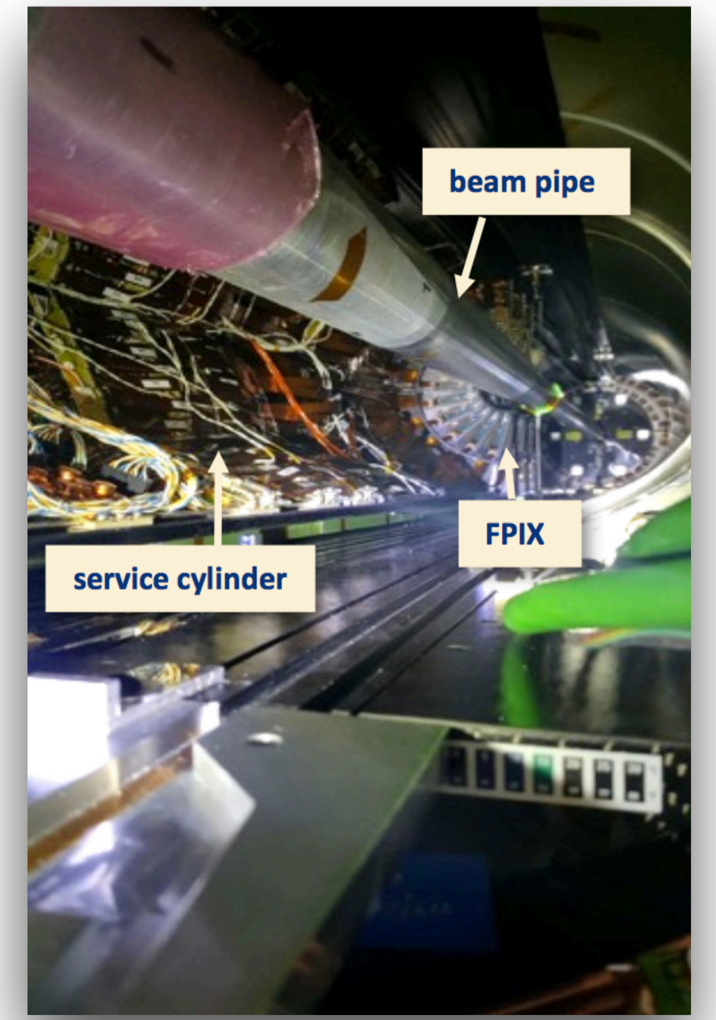
- Pixel Phase1 upgrade

During LS2 (2019-2021)

- replacement of PIXEL layer 1
- refurbishment of DCDC converters

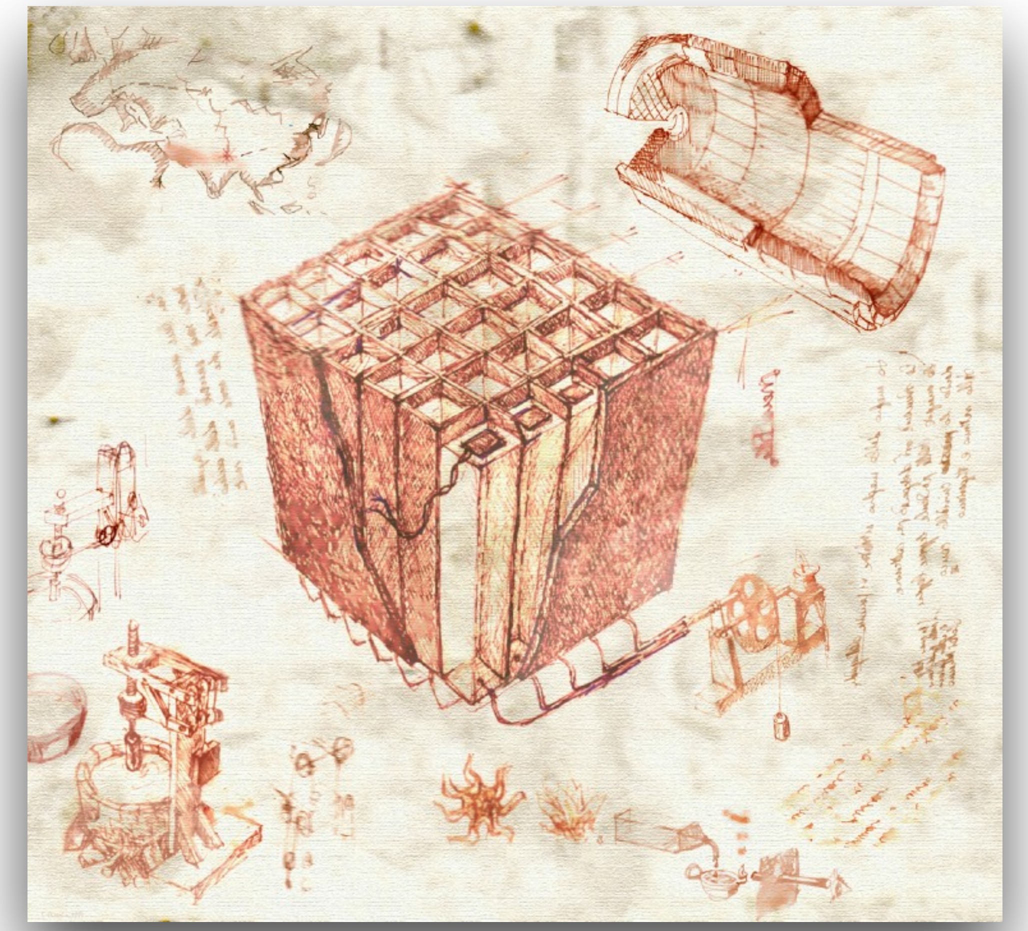






Main Detector Requirements

… to meet the goals Physics goals of the LHC physics programme



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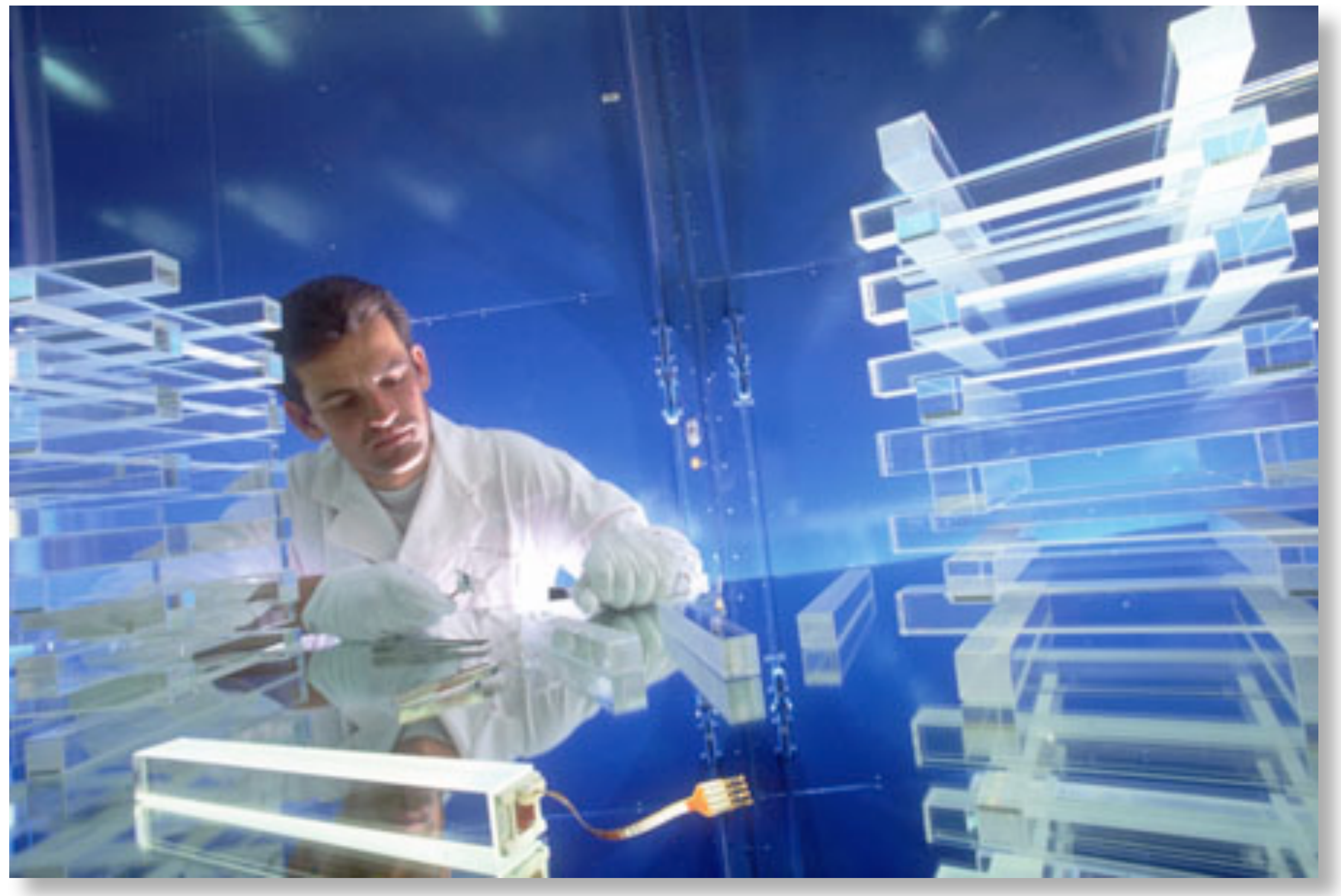
4. Good missing-transverse-energy and dijet-mass resolution, requiring hadron calorimeters with a large hermetic geometric coverage and with fine lateral segmentation

CMS Electromagnetic Calorimeter



Main requirements

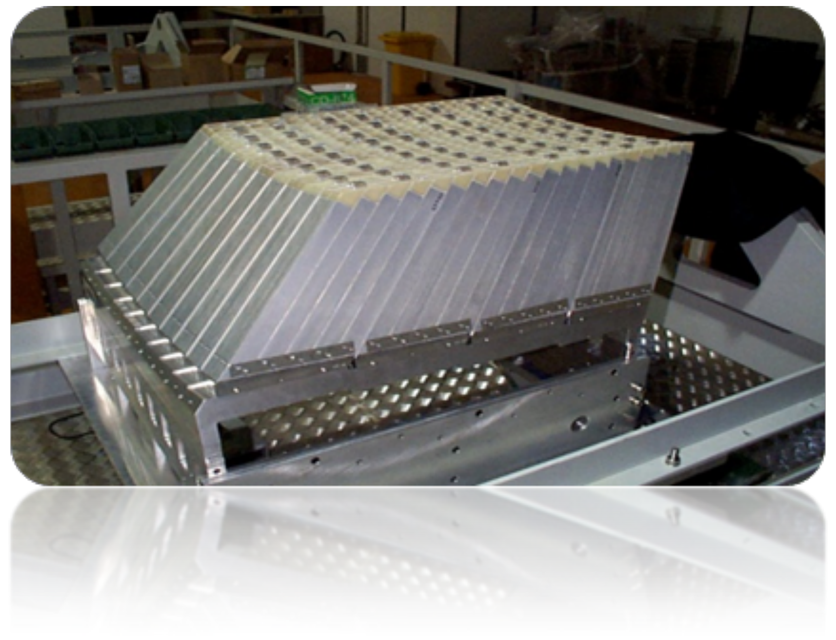
- trigger on high-pT electrons and photons
- excellent energy measurement of electrons, photons, jets

CMS Strategy

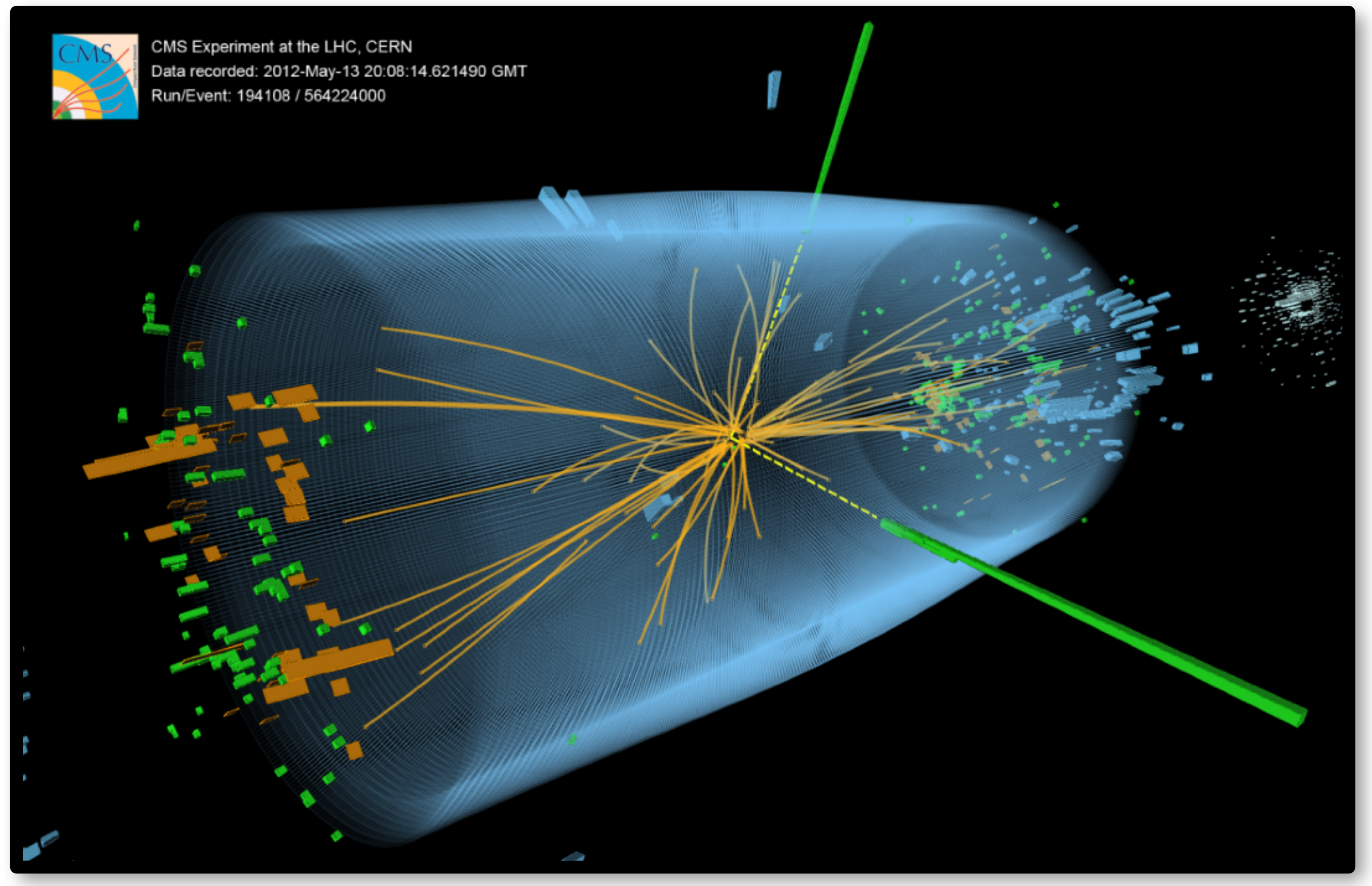
- compact and hermetic crystal calorimeter

The CMS electromagnetic calorimeter (ECAL)

- 77,000 lead-tungstate crystal ($PbWO_4$) 25 X_0
- coverage in pseudo-rapidity up to 3
- detection of scintillation light
  - Avalanche Photo-Diodes (APDs) in the barrel region
  - Vacuum Photo-Tridodes (VPTs) in the endcap regions
- laser monitoring of crystal transparency
- preshower system inserted between in front of the endcap ECAL for π^0 rejection

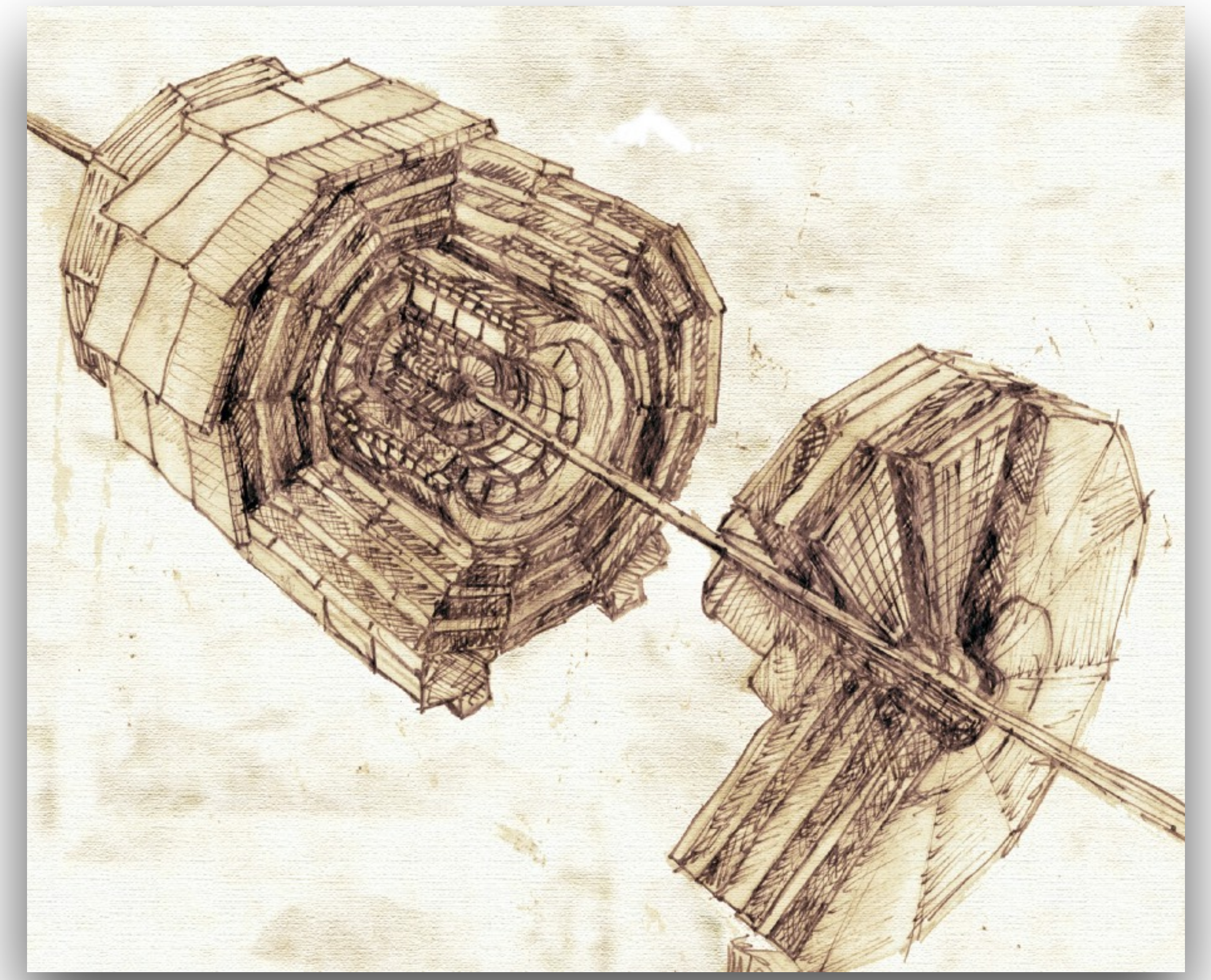


see presentation by Stefano Argiro



Main Detector Requirements

… to meet the goals Physics goals of the LHC physics programme



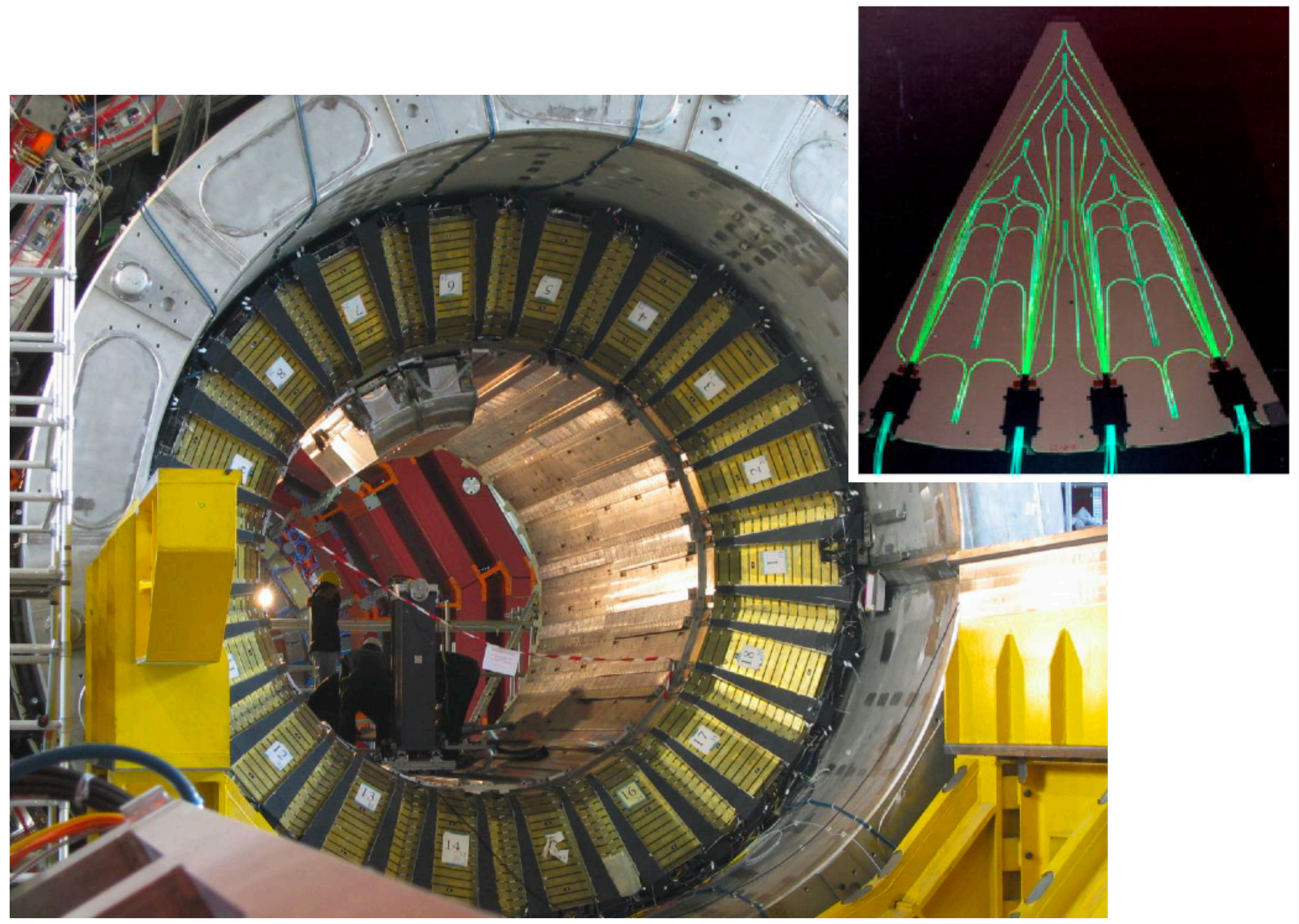
1. Good muon identification and momentum resolution over a wide range of momenta and angles, good dimuon mass resolution (1% at 100 GeV), and the ability to determine unambiguously the charge of muons with $p < 1$ TeV
2. Good charged-particle momentum resolution and reconstruction efficiency in the inner tracker. Efficient triggering and offline tagging of τ's and b-jets, requiring pixel detectors close to the interaction region
3. Good electromagnetic energy resolution, good diphoton and dielectron mass resolution (1% at 100 GeV), wide geometric coverage, π^0 rejection, and efficient photon and lepton isolation at high luminosities
4. Good missing-transverse-energy and dijet-mass resolution, requiring hadron calorimeters with a large hermetic geometric coverage and with fine lateral segmentation

CMS Hadron Calorimeter

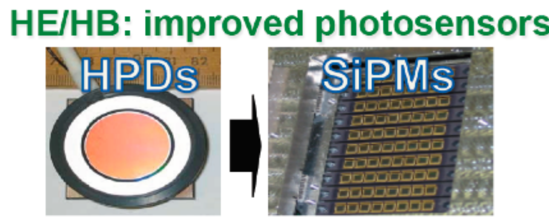
Main requirements
- good hermiticity
- good longitudinal granularity
- decent energy resolution on jets
- sufficient depth for shower containment

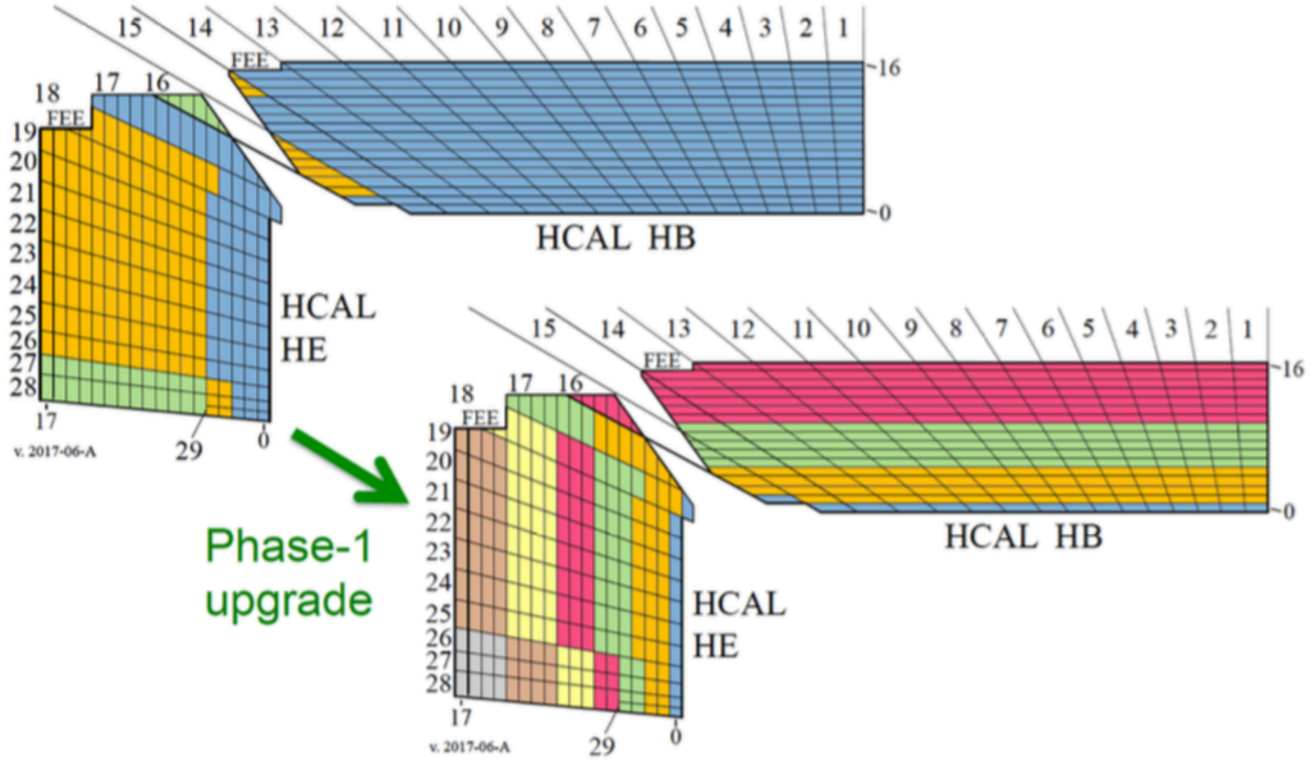
CMS Strategy
- brass/scintillator sampling calorimeter

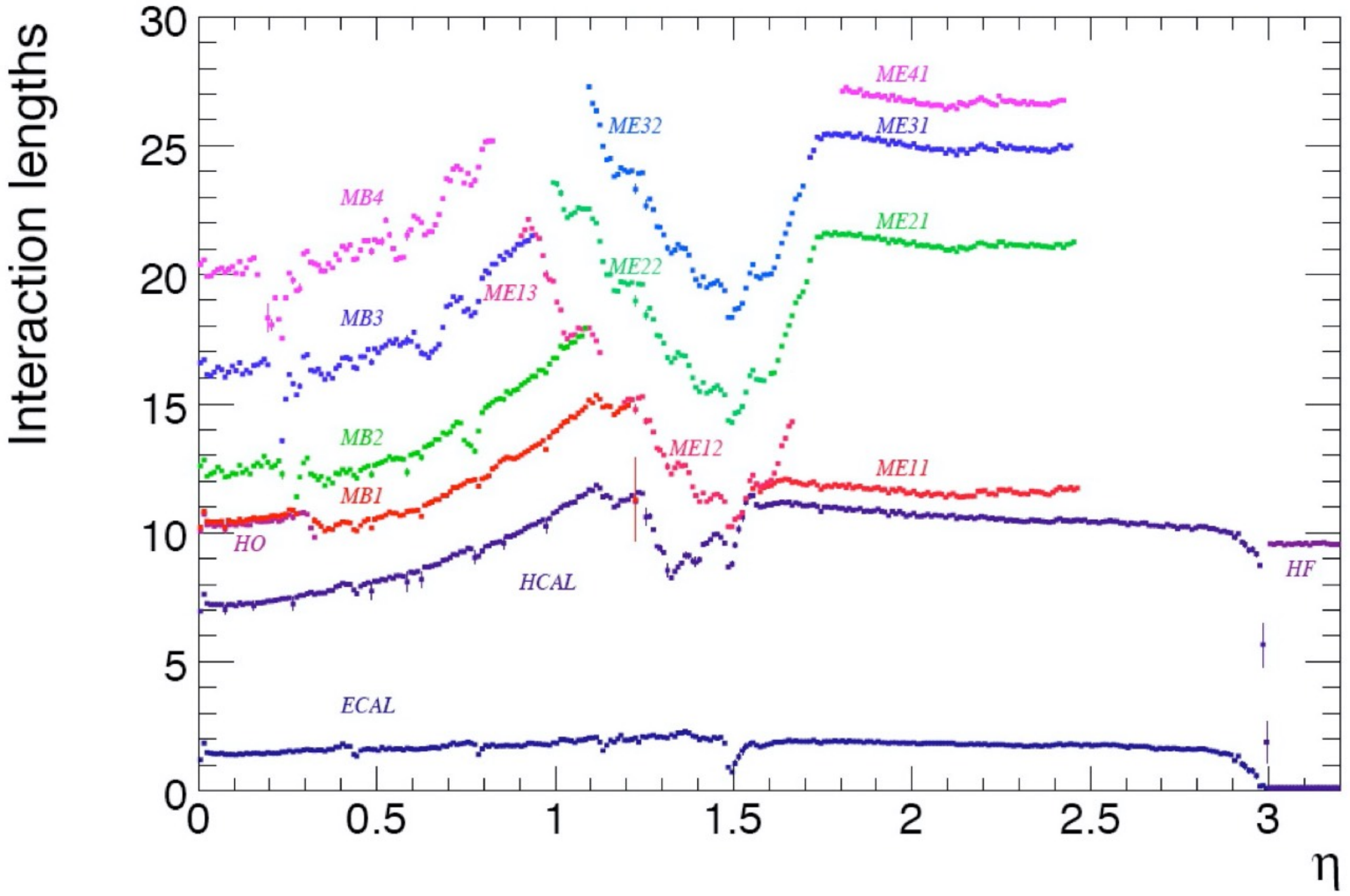
The CMS hadronic calorimeter (HCAL)
- 17 layers in barrel, 5.8 λ_{int} at $\eta = 0$
- 19 layers in endcaps, 10 λ_{int}
- coverage up to pseudordrapidity of 3
- scintillation light converted by WLS fibres and detected by photodetectors
- a tail-catcher in the barrel region (HO)



During LS2 (2019-2021)
- HPD → SiPM readout
- improved longitudinal segmentation





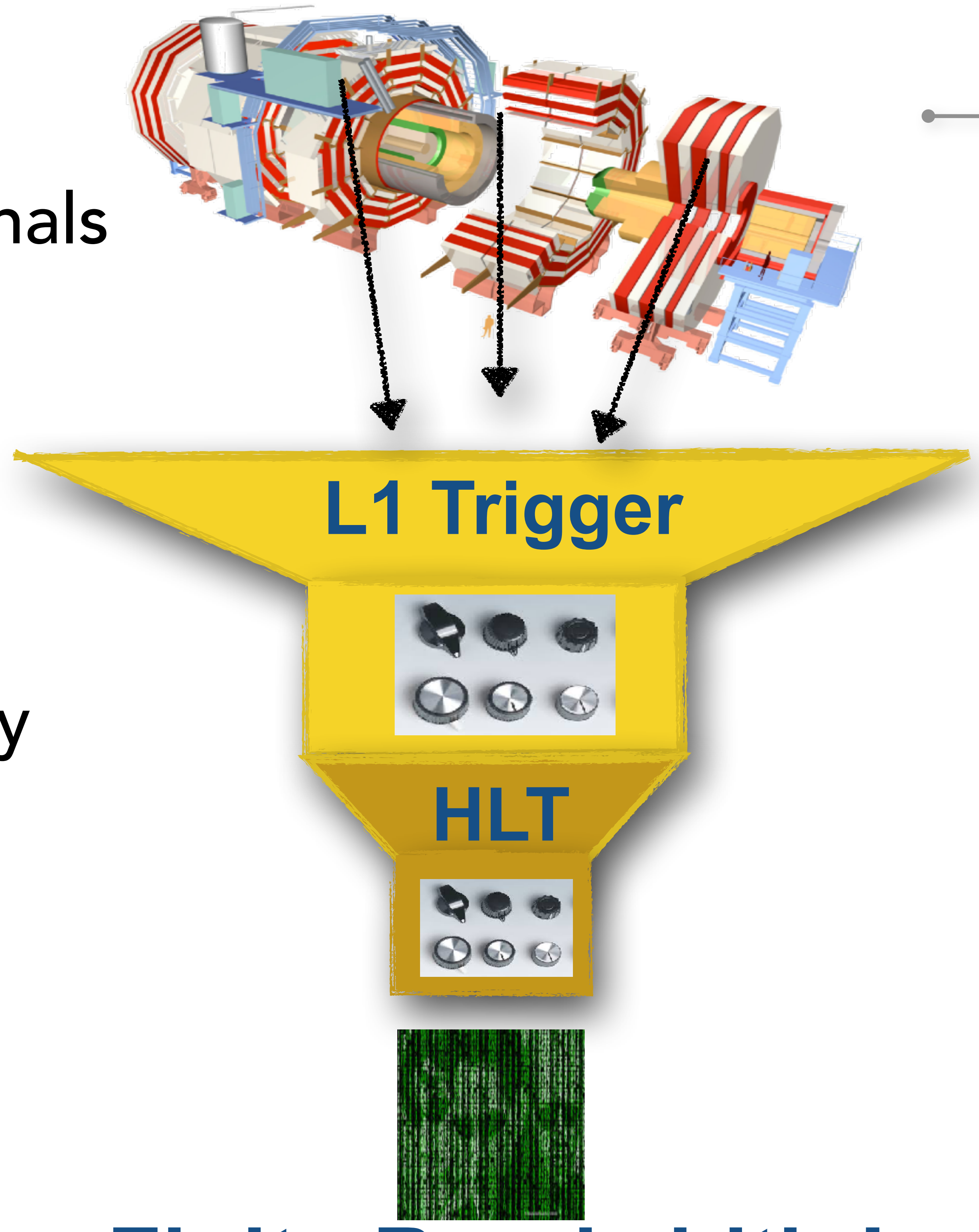


HCAL Forward (HF)
- iron/quartz fibre calorimeter
- from 3 to 5 in η
- Cerenkov light detected by photomultipliers

Trigger and DAQ

see presentation by Tom Williams

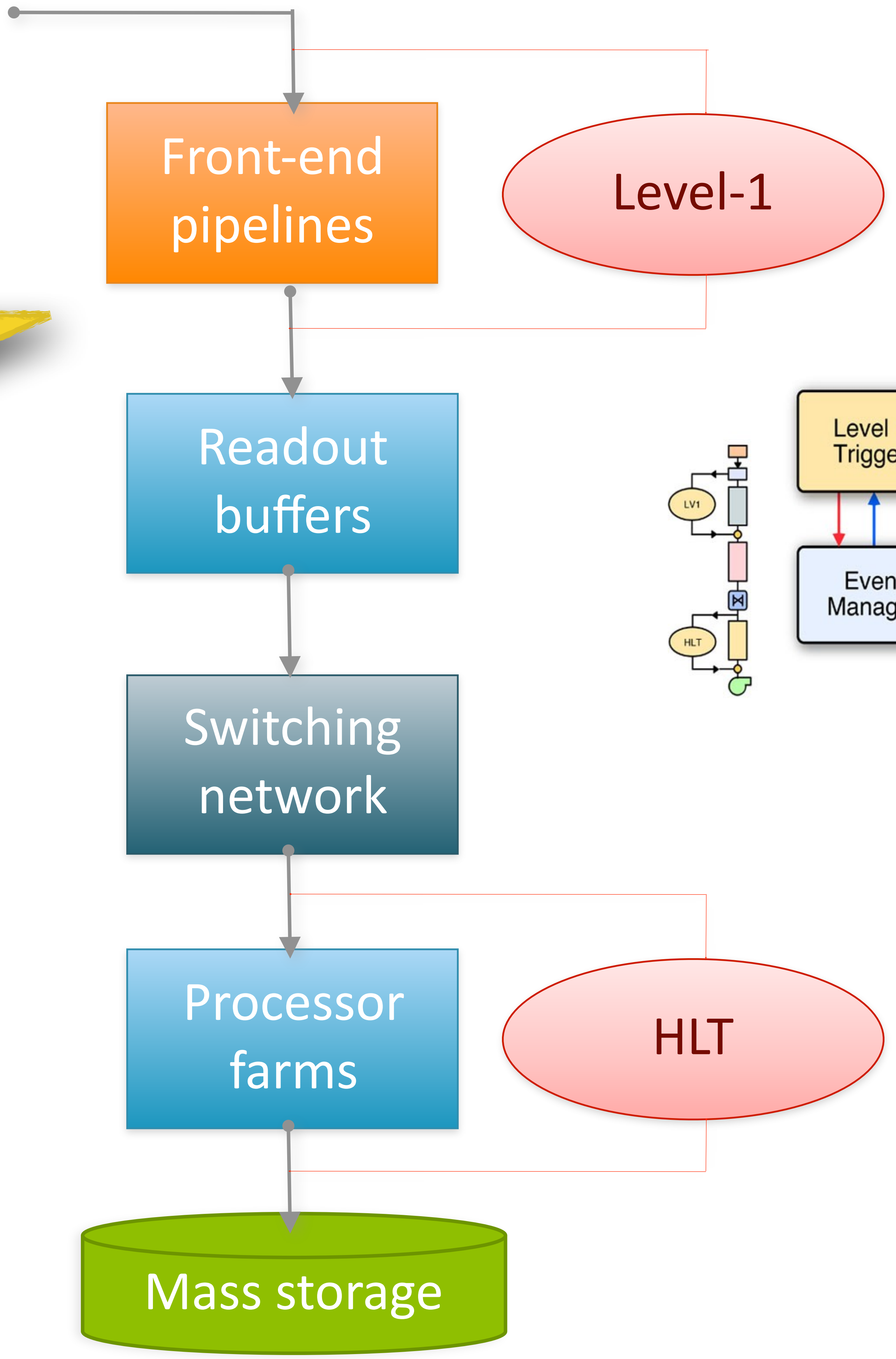
Detector signals
40 MHz



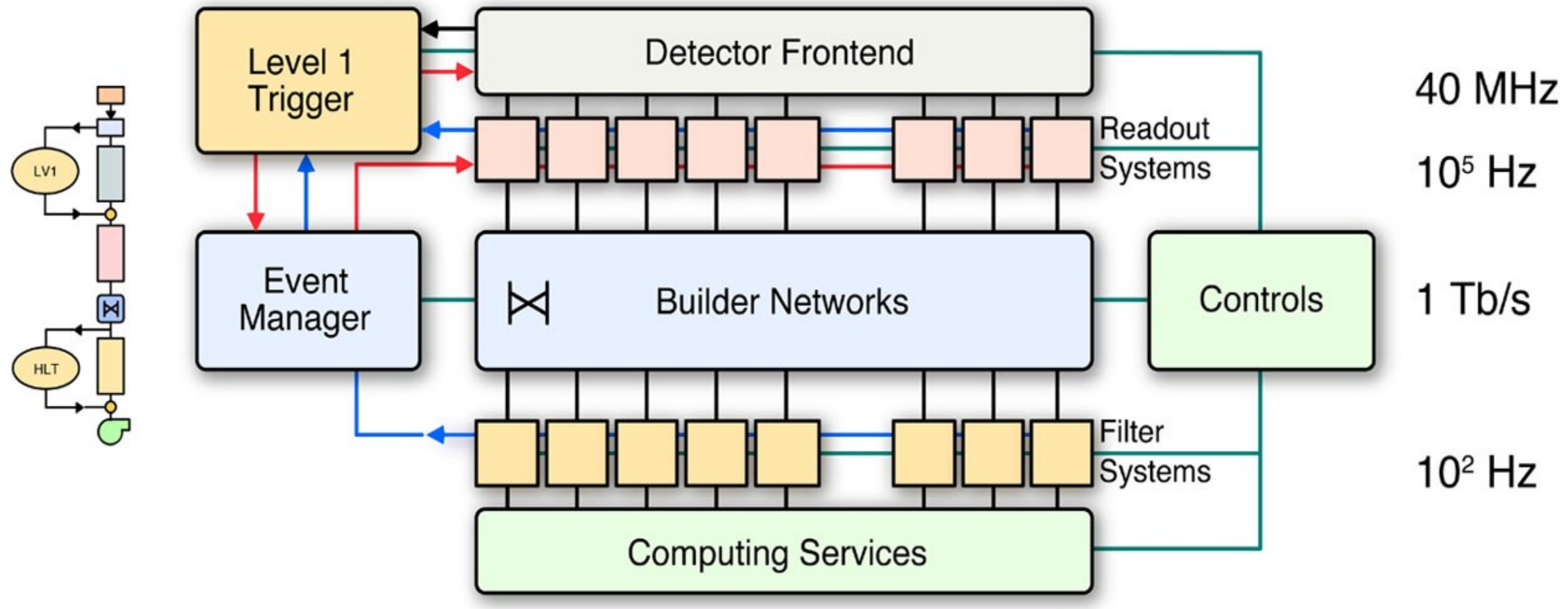
100 kHz
3.6 μs latency

1 kHz

Finite Bandwidth !



The Level-1 Trigger consists of custom-designed, largely programmable electronics (FPGA)

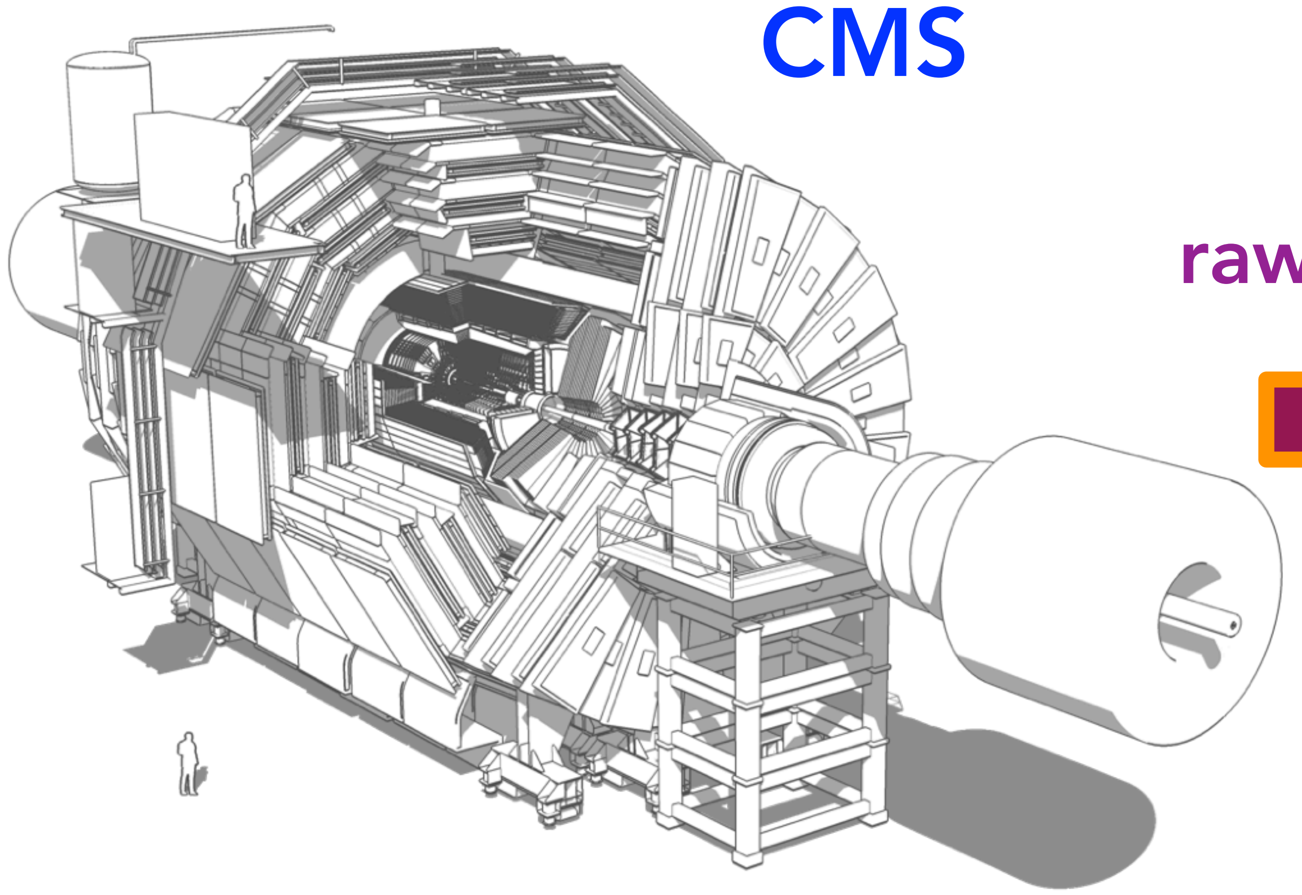


The HLT is a software system implemented in a compute farm
- 2000 CPUs,
- full event available,
- same software as offline
- maximal flexibility
- soon equipped also with GPUs

see presentation by Benjamin Radburn-Smith

CMS Computing and Data Preparation

CMS



raw data

TIER-0

processed data
AOD,
mini-AOD,
nano-AOD

TIER-1,2,3

analysis
data

end user

Basic parameters for (e.g.) 2018

- data taking @ 1 kHz + 2 kHz parked
  → 3 kHz of events, 6 months a year
- 20 B events/y
- each event ~1 MB
- 40 PB (2 copies) of raw data

For each data event

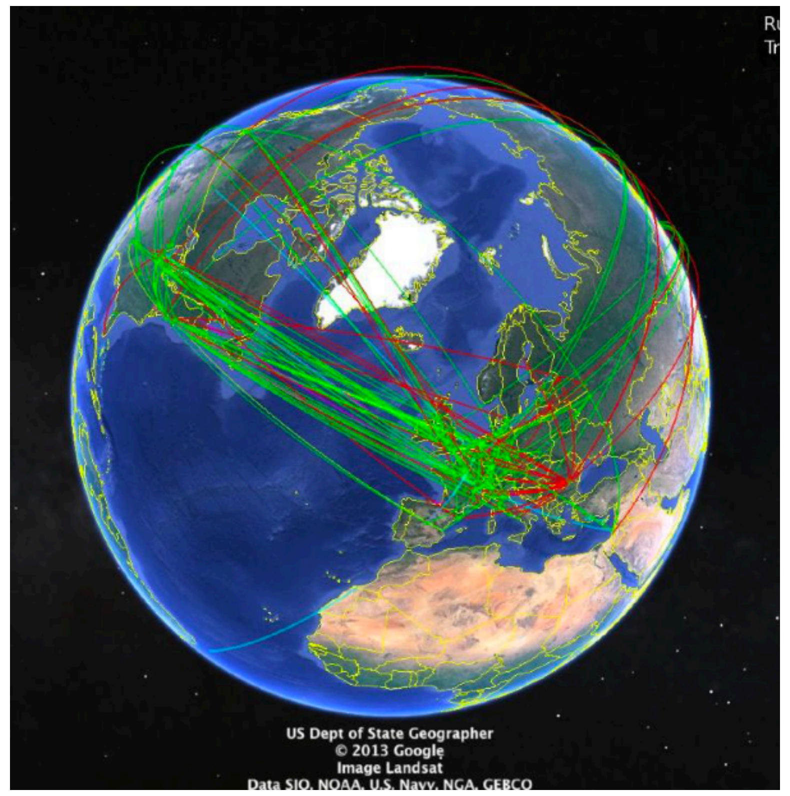
- 1 to 2 MC events to process
  (40 sec/ev)
- processing RAW → AOD
  (30 sec/ev)
- CPUs for analysis etc.

Needed resources for 2018

- 250 k computing cores
- 130 PBytes on disk
- 250 PBytes on tape

see presentation by
Sal Rappoccio

Distributed computing



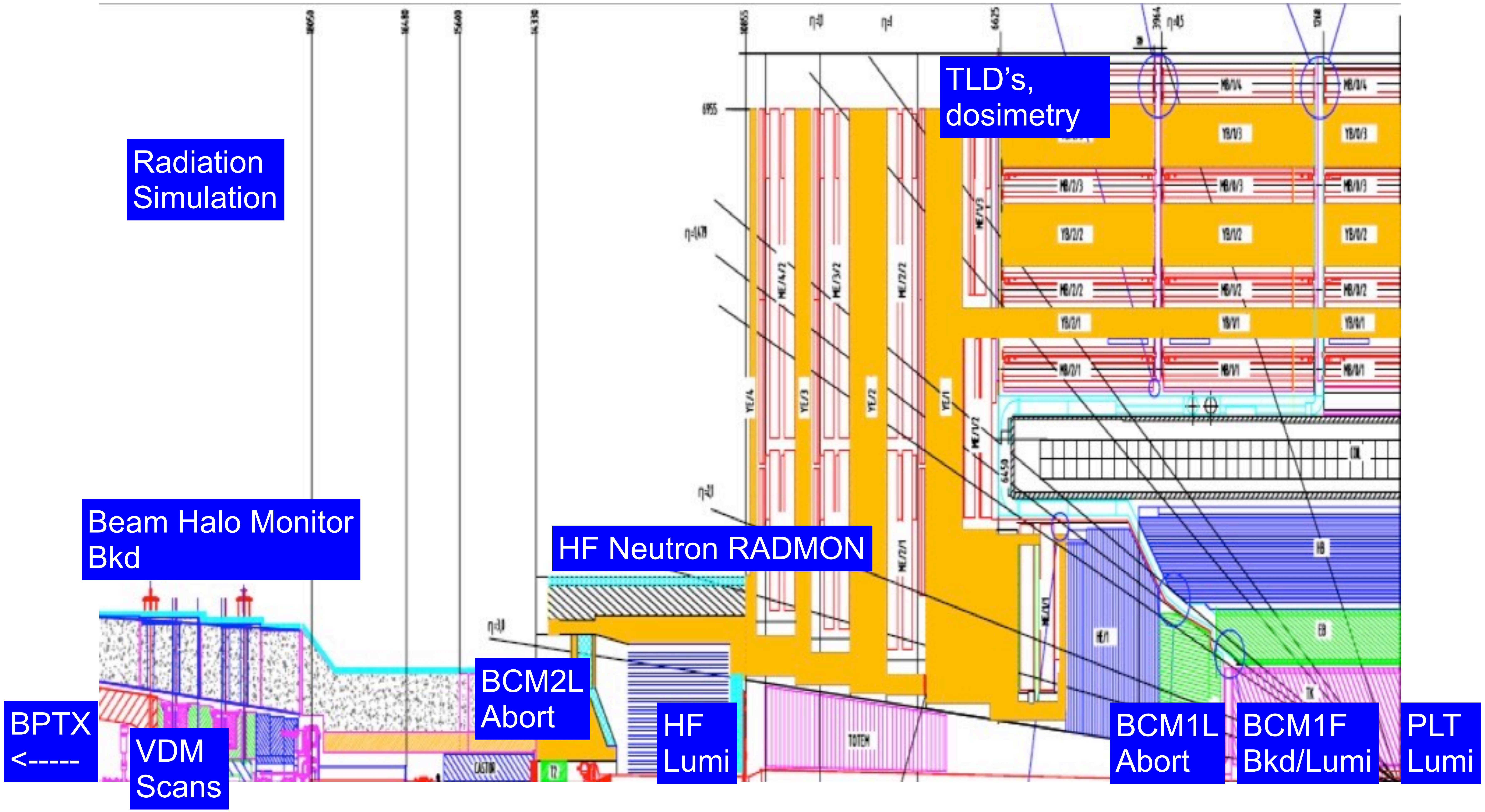
WLCG

Wordwilde LHC Computing Grid

- 200+ sites
- storage: ~1000 PBytes
- CPU: ~1M cores
- rate: > 40 GBytes/s 24x7

Beam Radiation Instrumentation and Luminosity

Covering anything related to interfacing CMS to the LHC



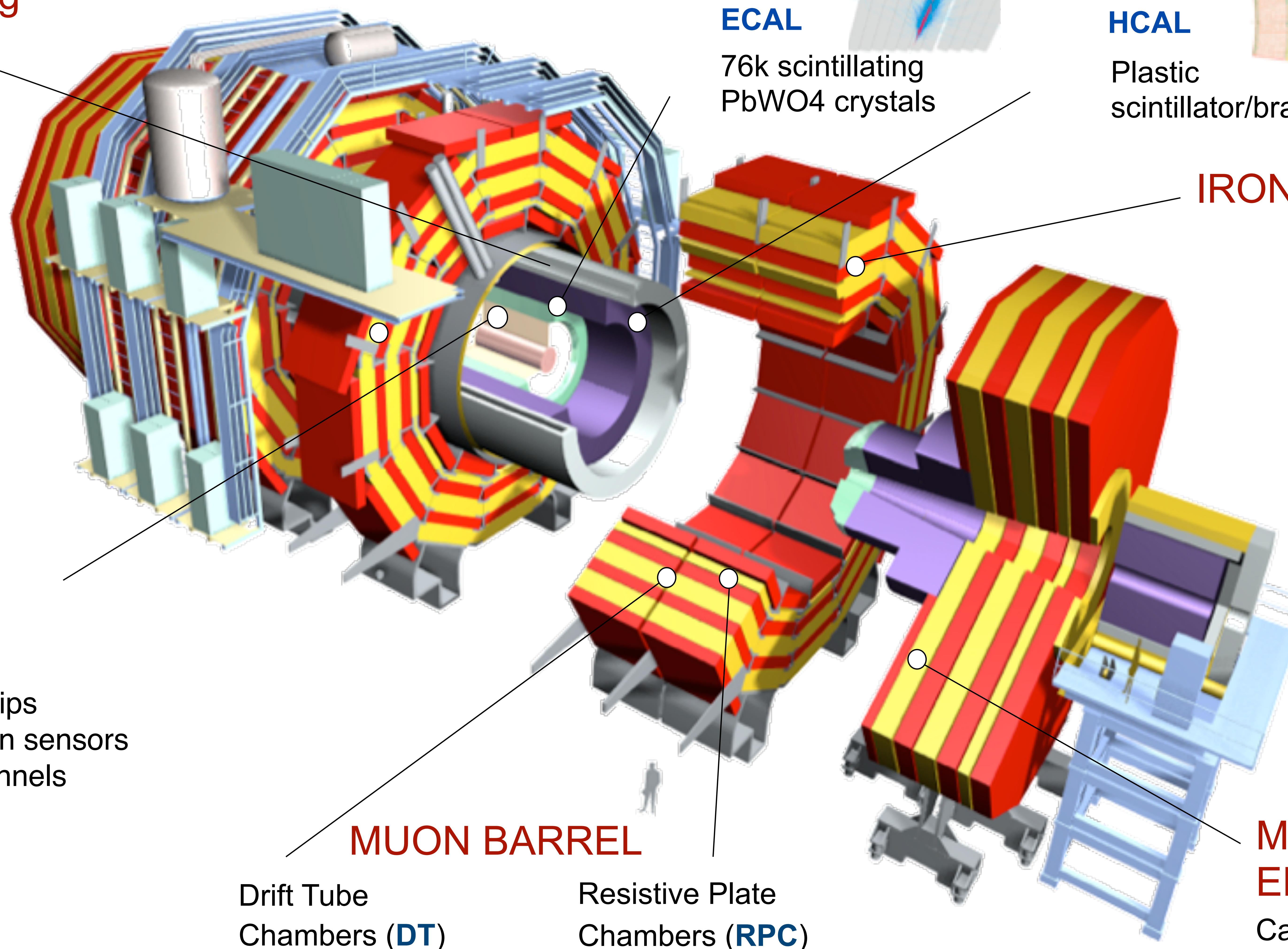
and also

- CASTOR
- ZDC
- CT-PPS (ex. TOTEM)

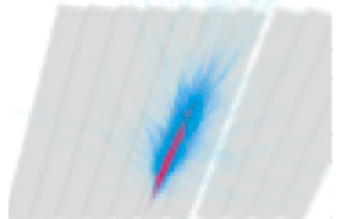
Finally: the Compact Muon Solenoid Detector

Total weight	14000 t
Overall diameter	15 m
Overall length	21 m

Superconducting Coil, 3.8 Tesla

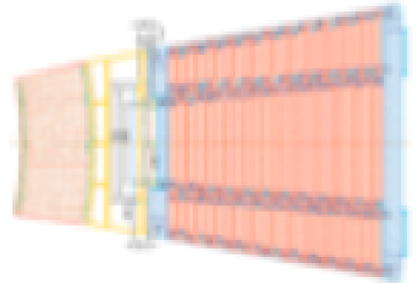


ECAL



76k scintillating PbWO4 crystals

HCAL

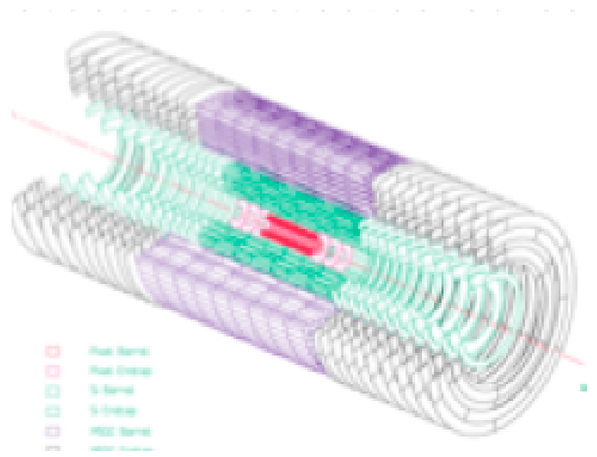


Plastic scintillator/brass sandwich

CALORIMETERS

IRON YOKE

Most parts of CMS "easily" accessible during shutdowns (incl. pixels)



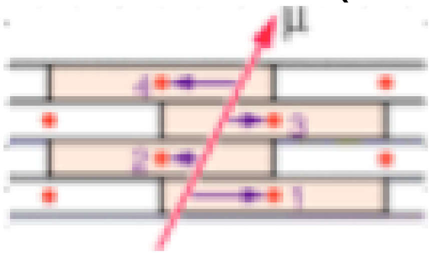
TRACKER

Pixels
Silicon Microstrips
202 m² of silicon sensors
124+9.6 M channels

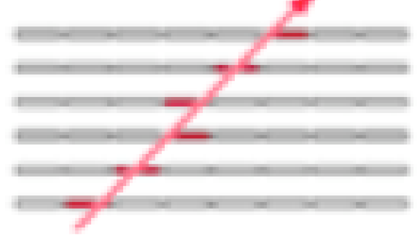
Modular structure
- Barrel (13-m long)
  5 independent wheels
- 2 endcaps (3 rings)

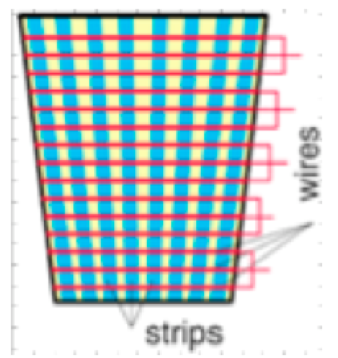
MUON BARREL

Drift Tube Chambers (**DT**)



Resistive Plate Chambers (**RPC**)



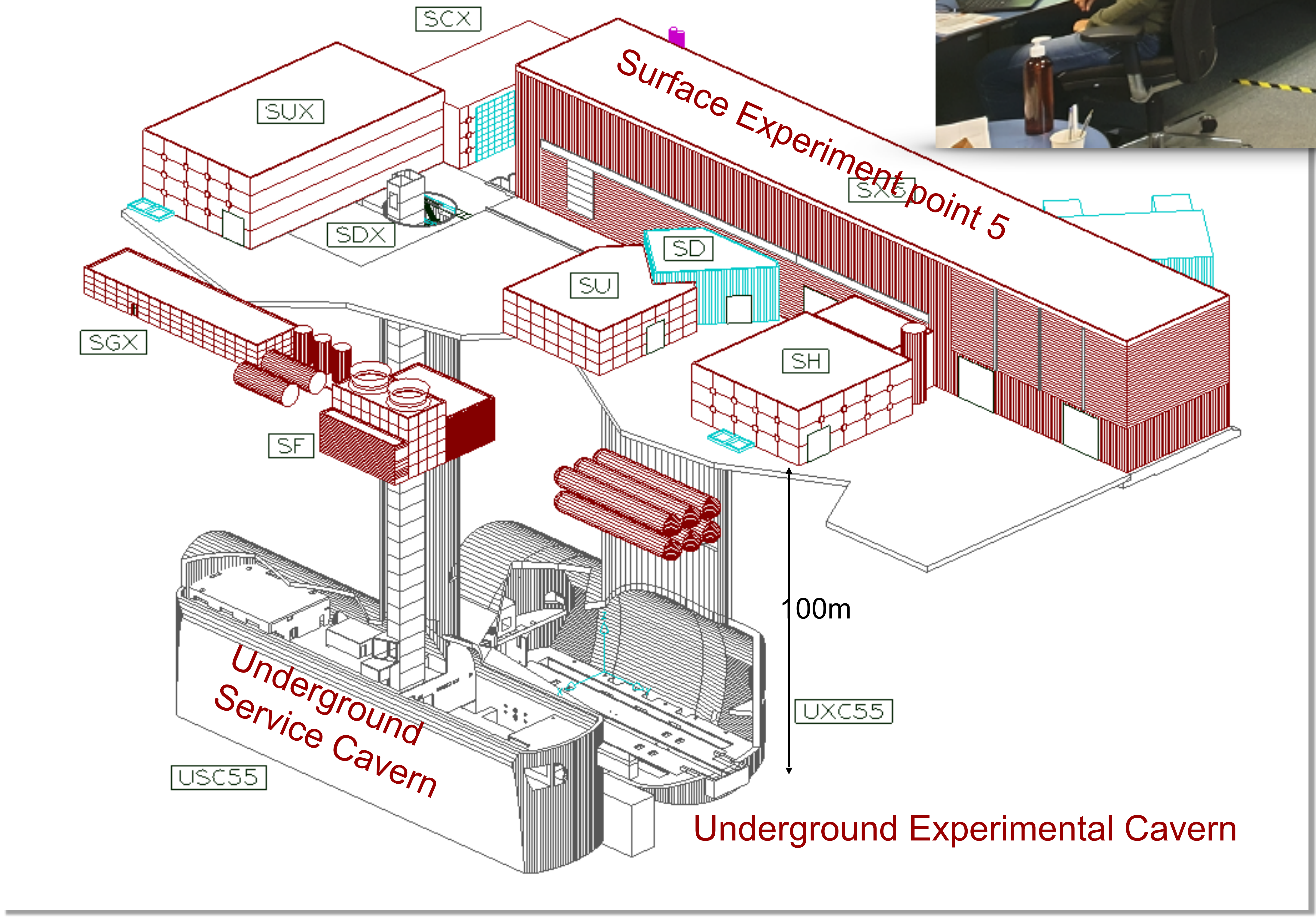


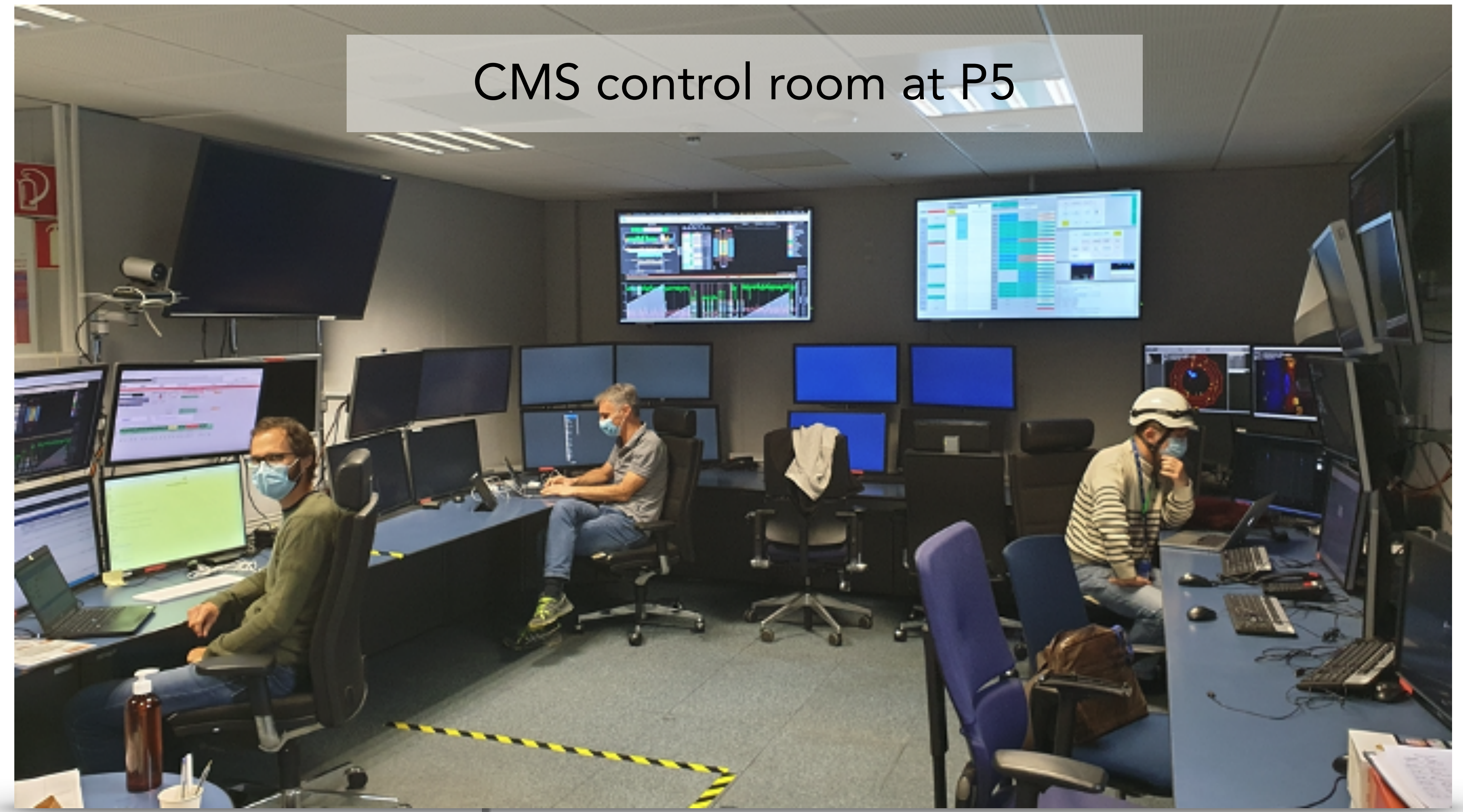
MUON ENDCAPS

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

CMS at P5

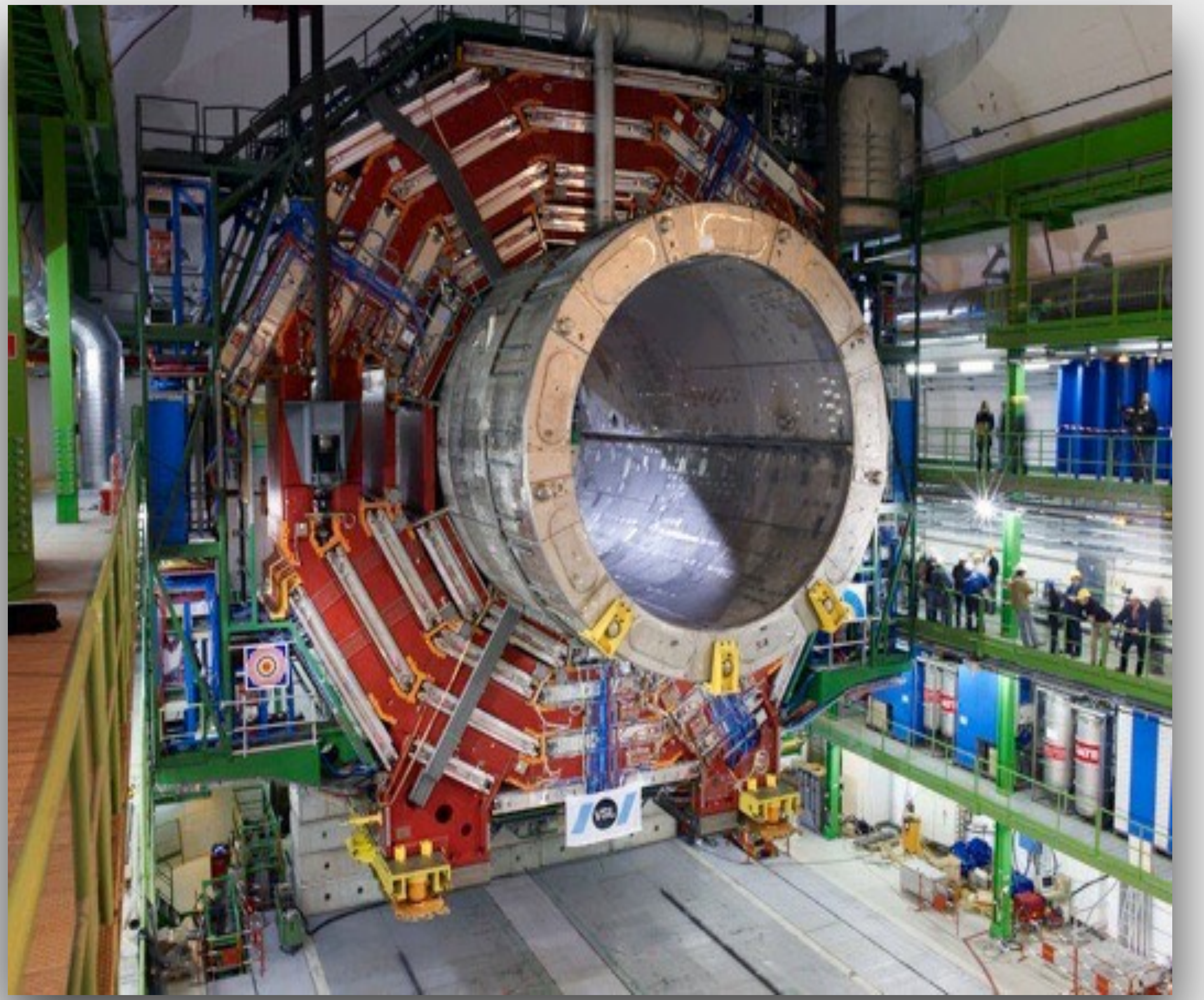
Life at P5

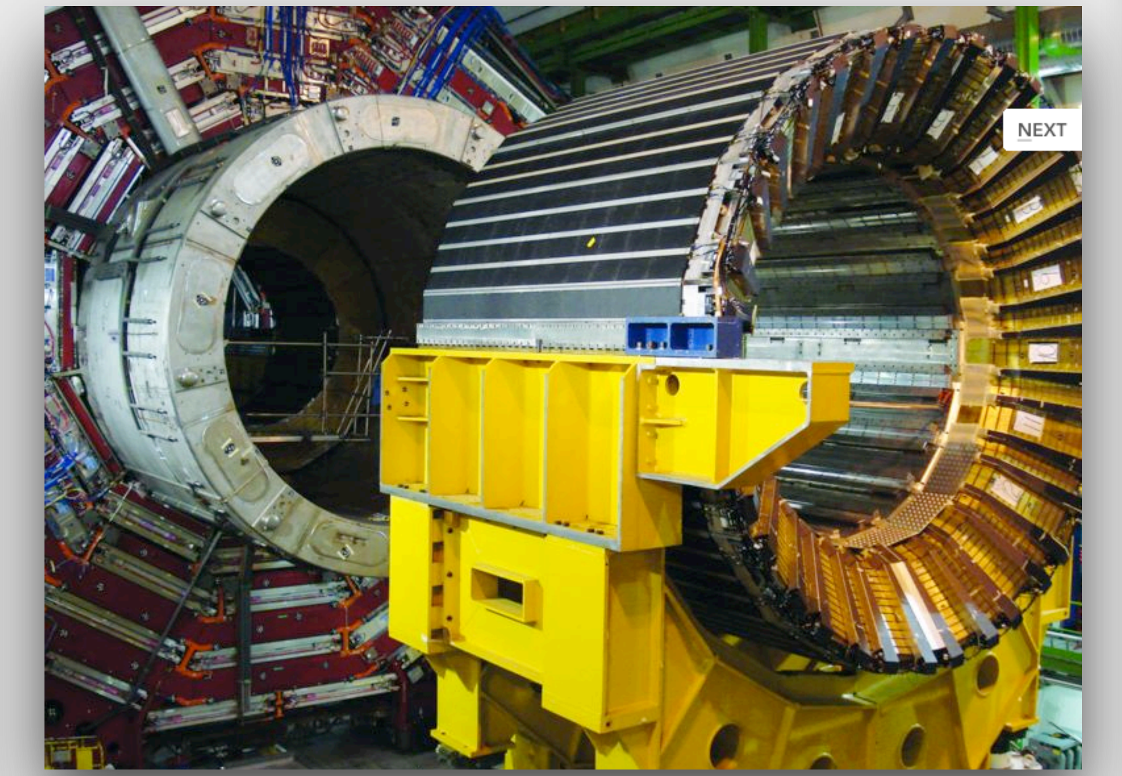


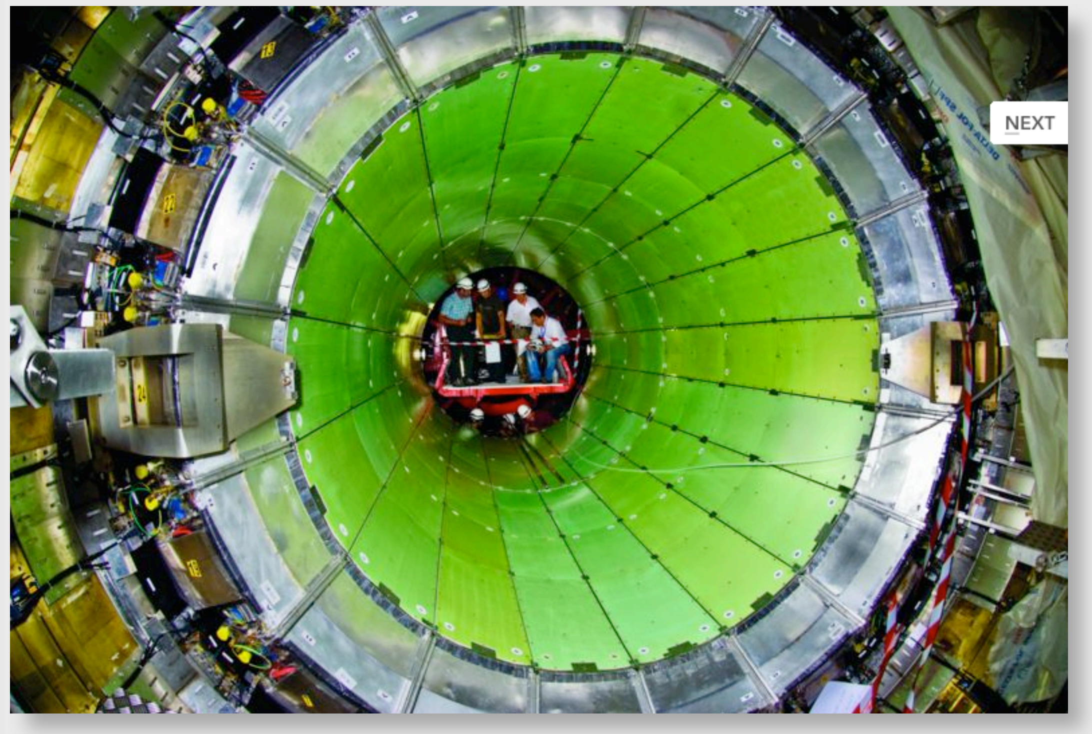


see presentations by
Andrea Massironi
and Roberto Perruzza

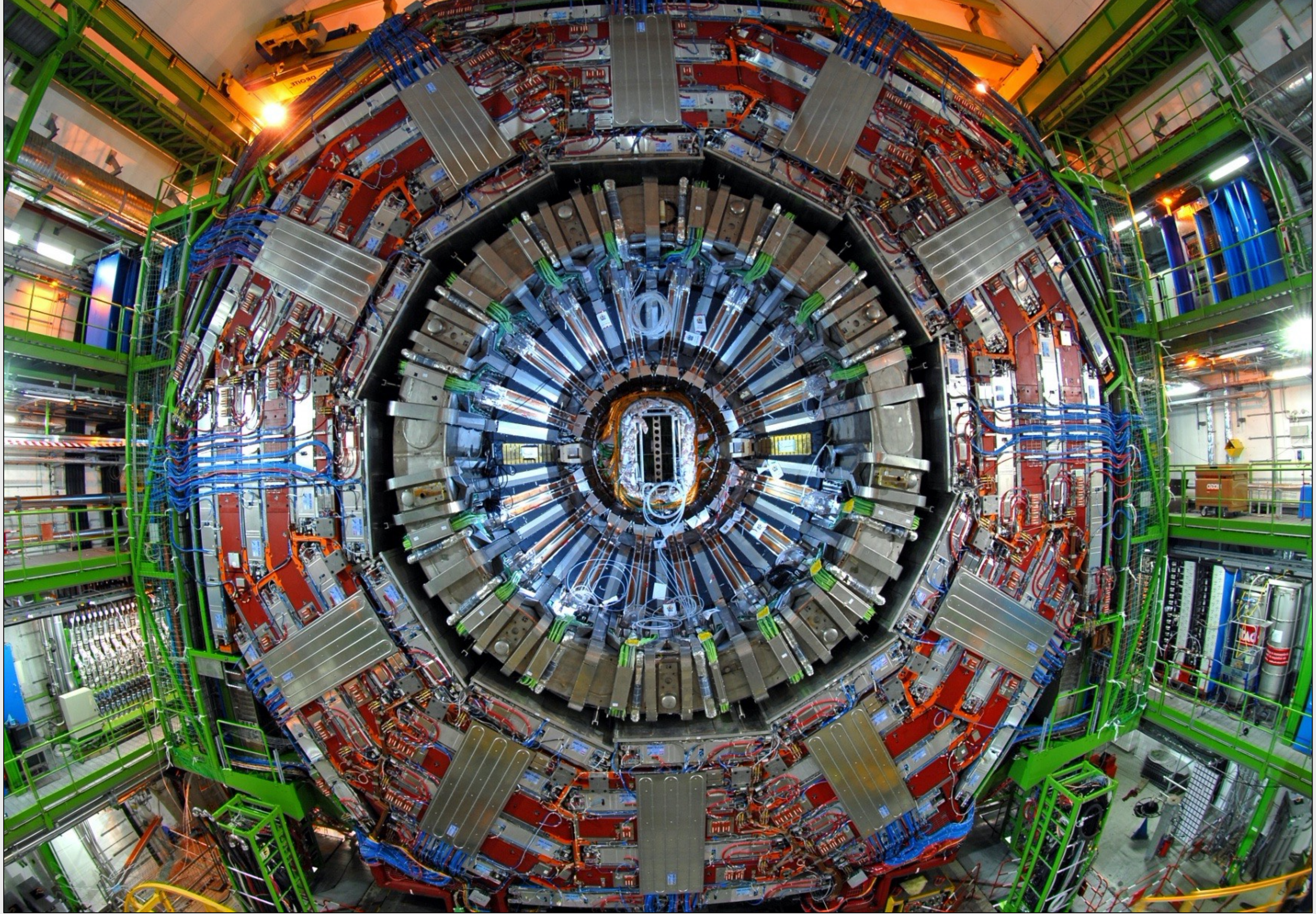
Lowering and assembly of CMS in the cavern (2007-2008)

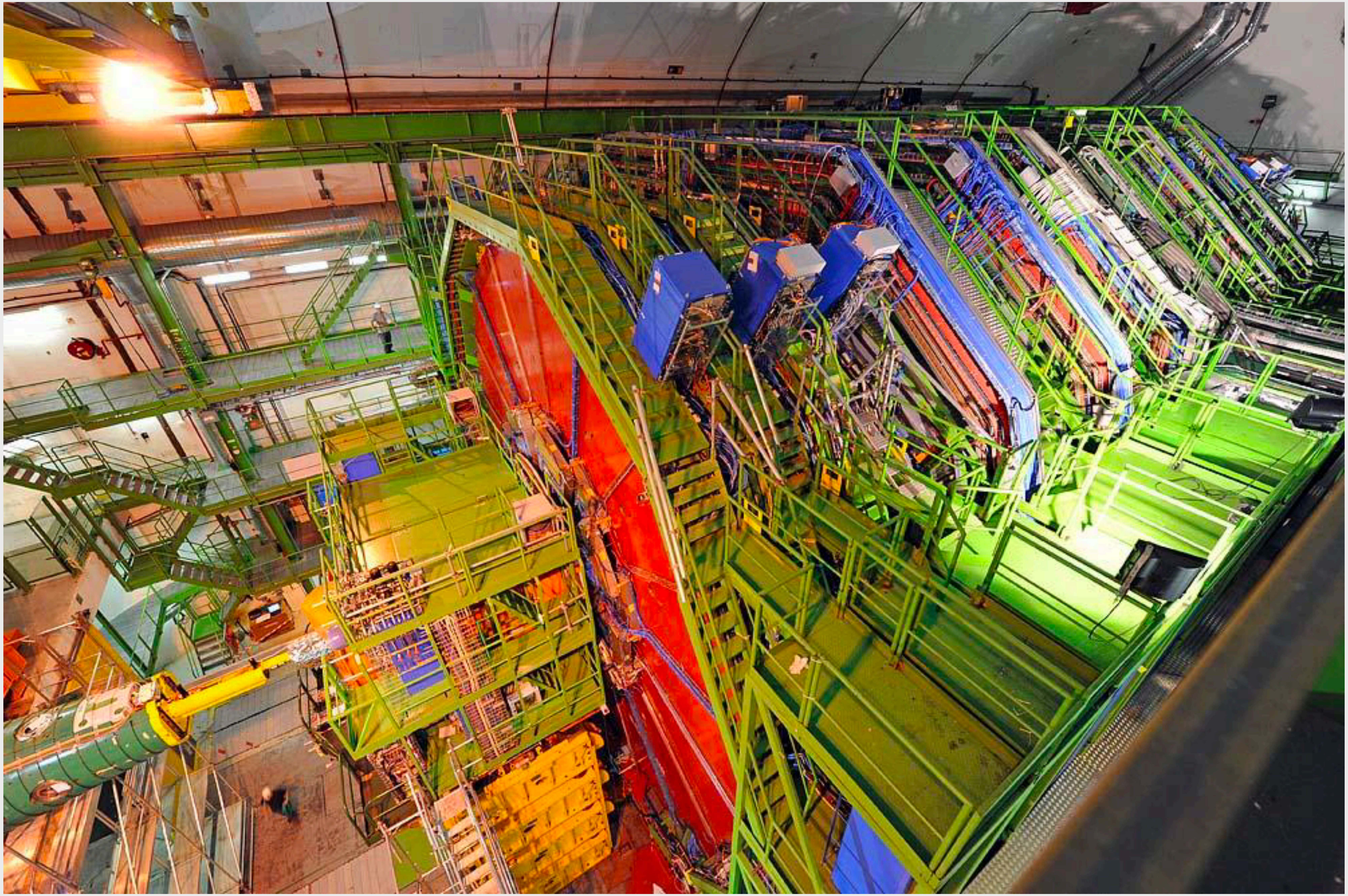


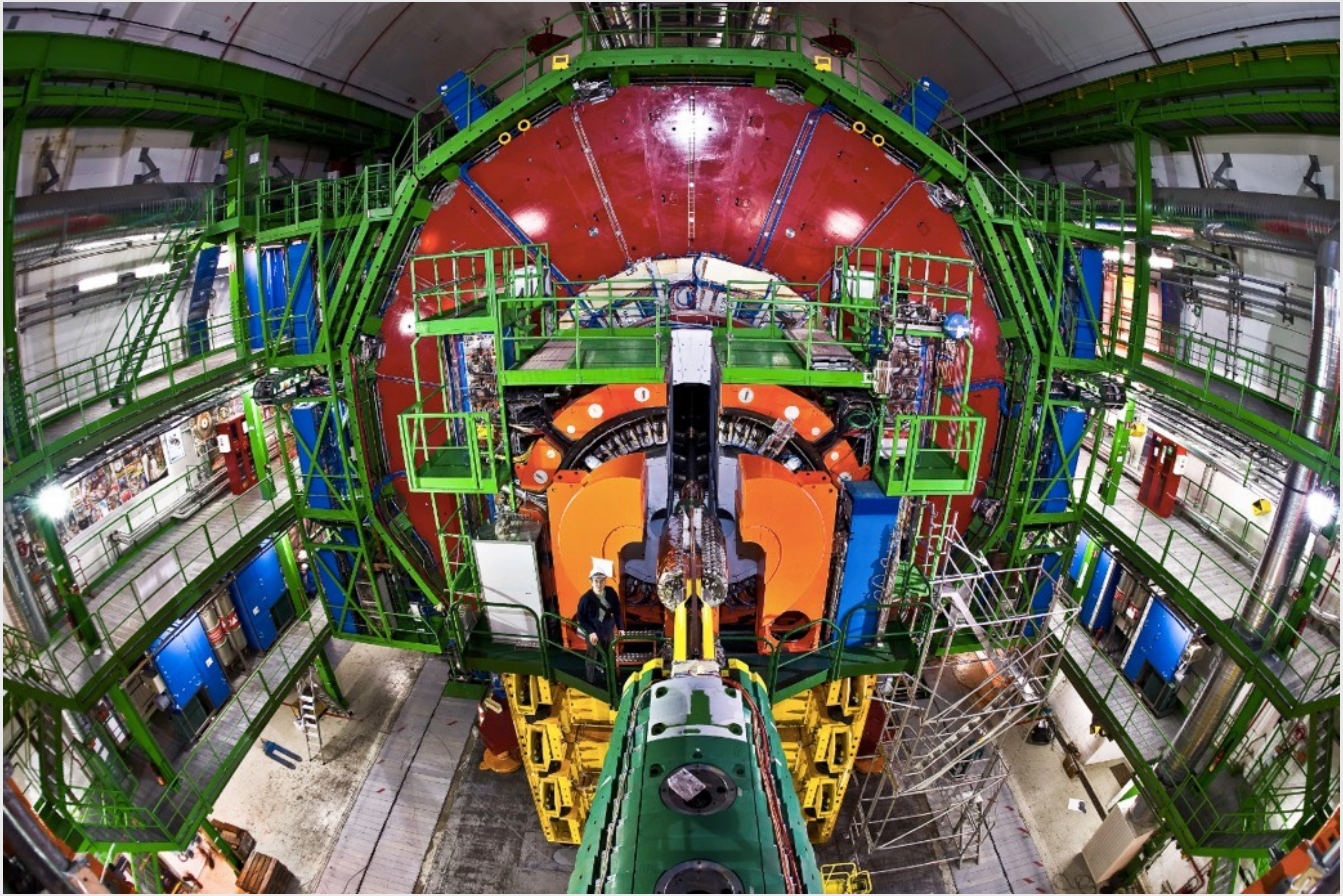




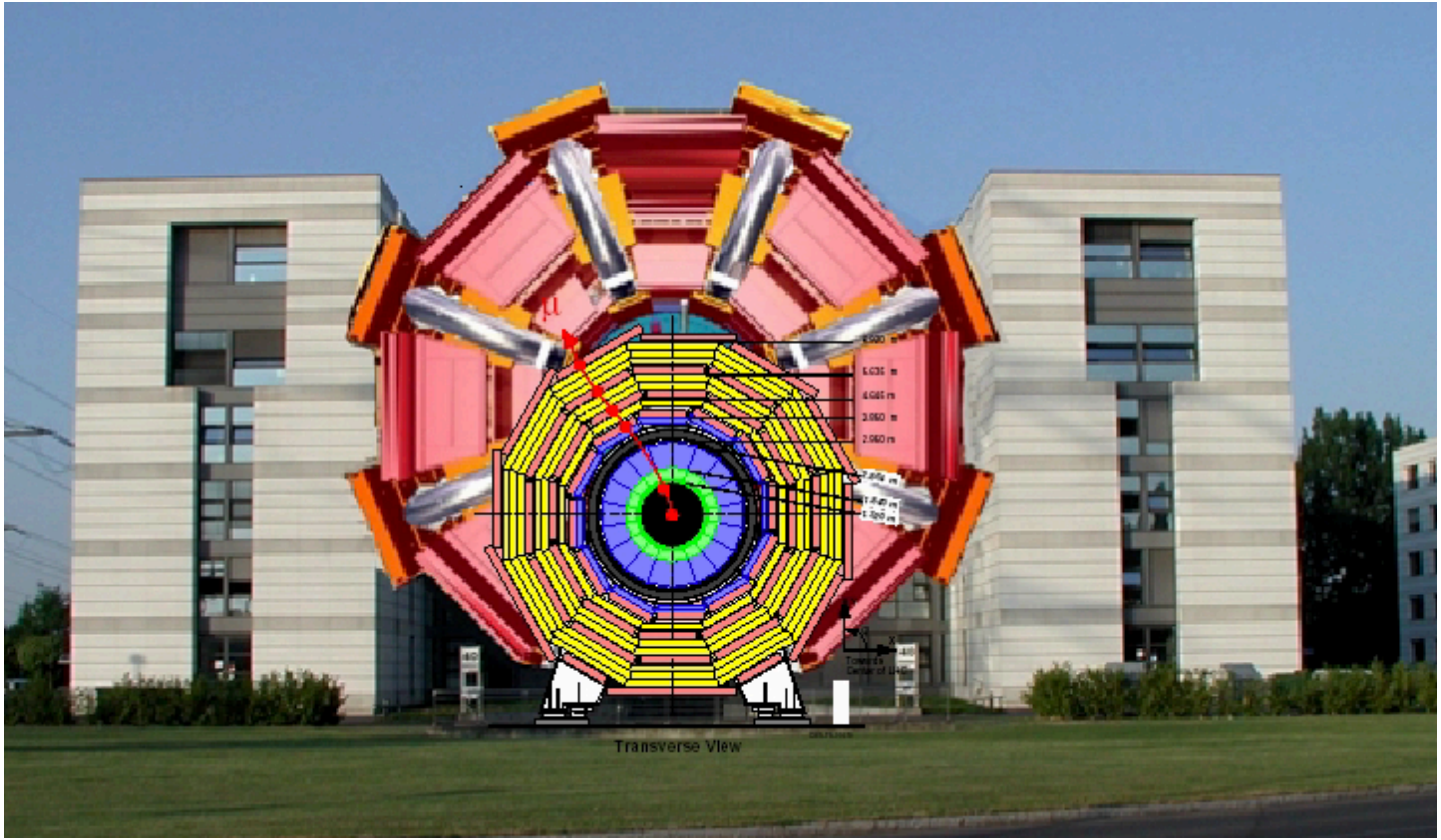

ME&RE-1/3/05
ME&RE-1/3/04
ME&RE-1/2/04
ME&RE-1/2/03
ME&RE-1/2/02
ME&RE-1/2/36
ME&RE-1/3/34
ME&RE-1/3/33







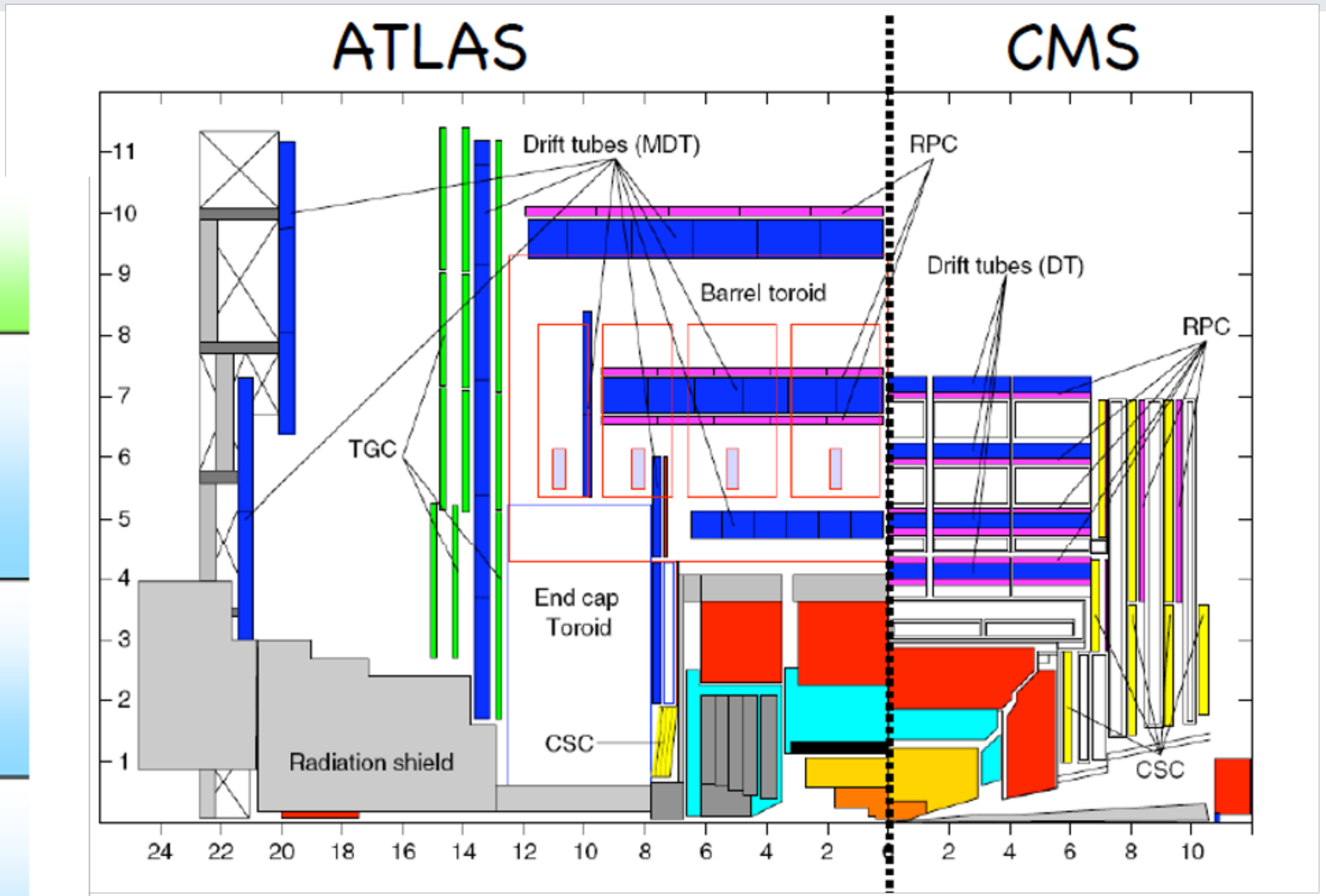
Comparison with ATLAS



Comparison with ATLAS

	ATLAS	CMS
INNER TRACKER	• Silicon pixels + strips • TRT with particle identification • $B = 2$T • $\sigma(p_T)$ ~ **3.8%** (at 100 GeV, $\eta = 0$)	• Silicon pixels + strips • No dedicated particle identification • $B = 3.8$T • $\sigma(p_T)$ ~ **1.5%** (at 100 GeV, $\eta = 0$)
MAGNETS	• Solenoid + Air-core muon toroids • Calorimeters outside field • 4 magnets	• Solenoid • Calorimeters inside field • 1 magnet
EM CALORIMETER	• Pb / Liquid argon accordion • $\sigma(E)$ ~ **10–12% / $\sqrt{E}$ ⊕ 0.2–0.35%** • Uniform longitudinal segmentation • Saturation at ~ 3 TeV	• $PbWO_4$ scintillation crystals • $\sigma(E)$ ~ **3–5.5% / $\sqrt{E}$ ⊕ 0.5%** • No longitudinal segmentation • Saturation at 1.7 TeV
HAD CALORIMETER	• Fe / Scint. & Cu-liquid argon • $\sigma(E)$ ~ **45% / $\sqrt{E}$ ⊕ 1.3%** (Barrel)	• Brass / scintillator • $\sigma(E)$ ~ **100% / $\sqrt{E}$ ⊕ 8%** (Barrel)
MUON	• Monitored drift tubes + CSC (fwd) • $\sigma(p_T)$ ~ **10.5 / 10.4%** (1 TeV, $\eta = 0$) (standalone / combined with tracker)	• Drift tubes + CSC (fwd) • $\sigma(p_T)$ ~ **13 / 4.5%** (1 TeV, $\eta = 0$) (standalone / combined with tracker)

Ann.Rev.Nucl.Part.Sci.56:375-440,2006.



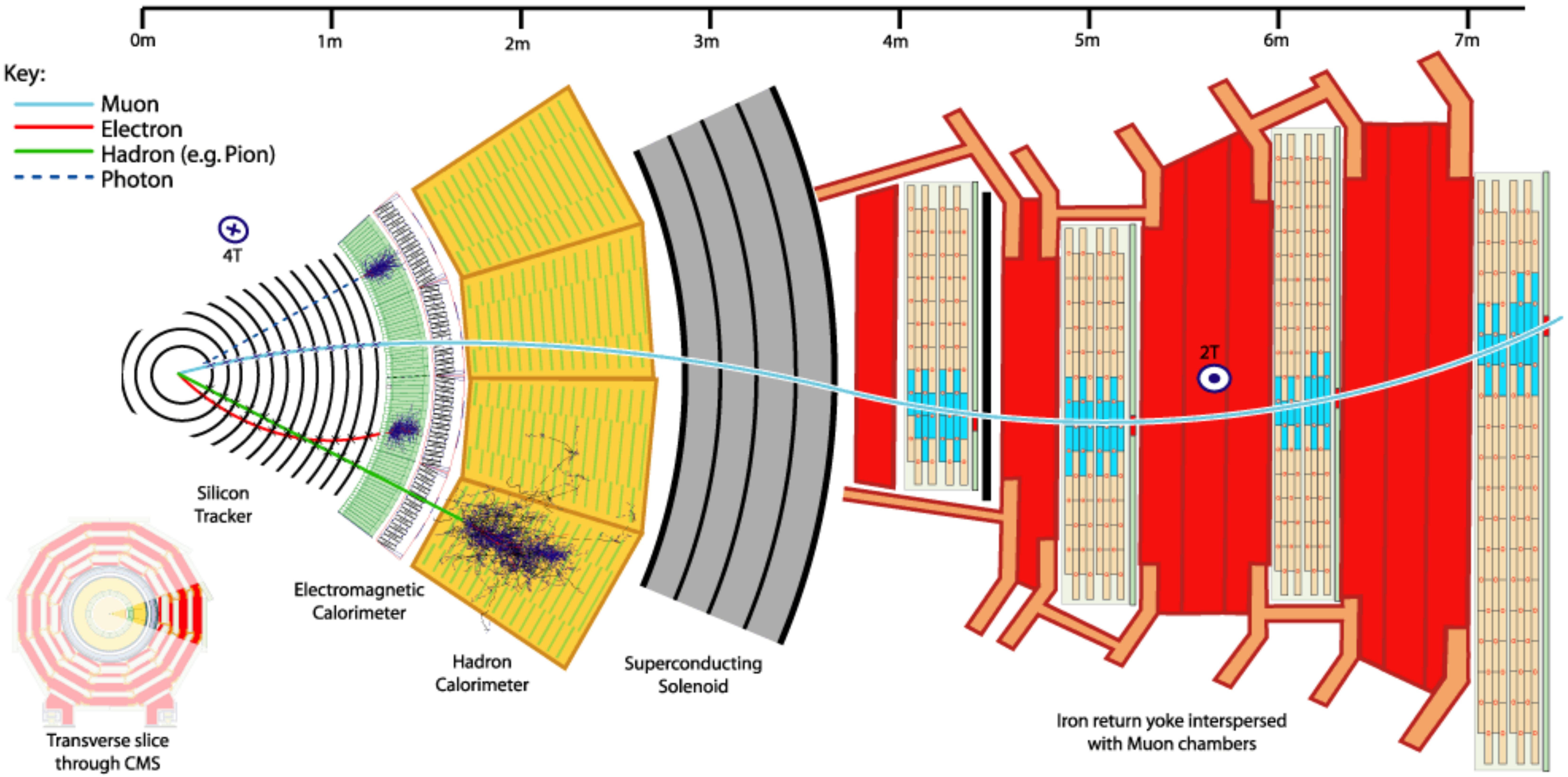
Despite being based on very different concepts, the two detectors perform equally well

Particle Flow

A global description of the event, using optimal combination from all sub detectors

Reduces the impact of energy resolution in HCAL

- in multijet events, only 10% of energy goes to stable neutral hadrons



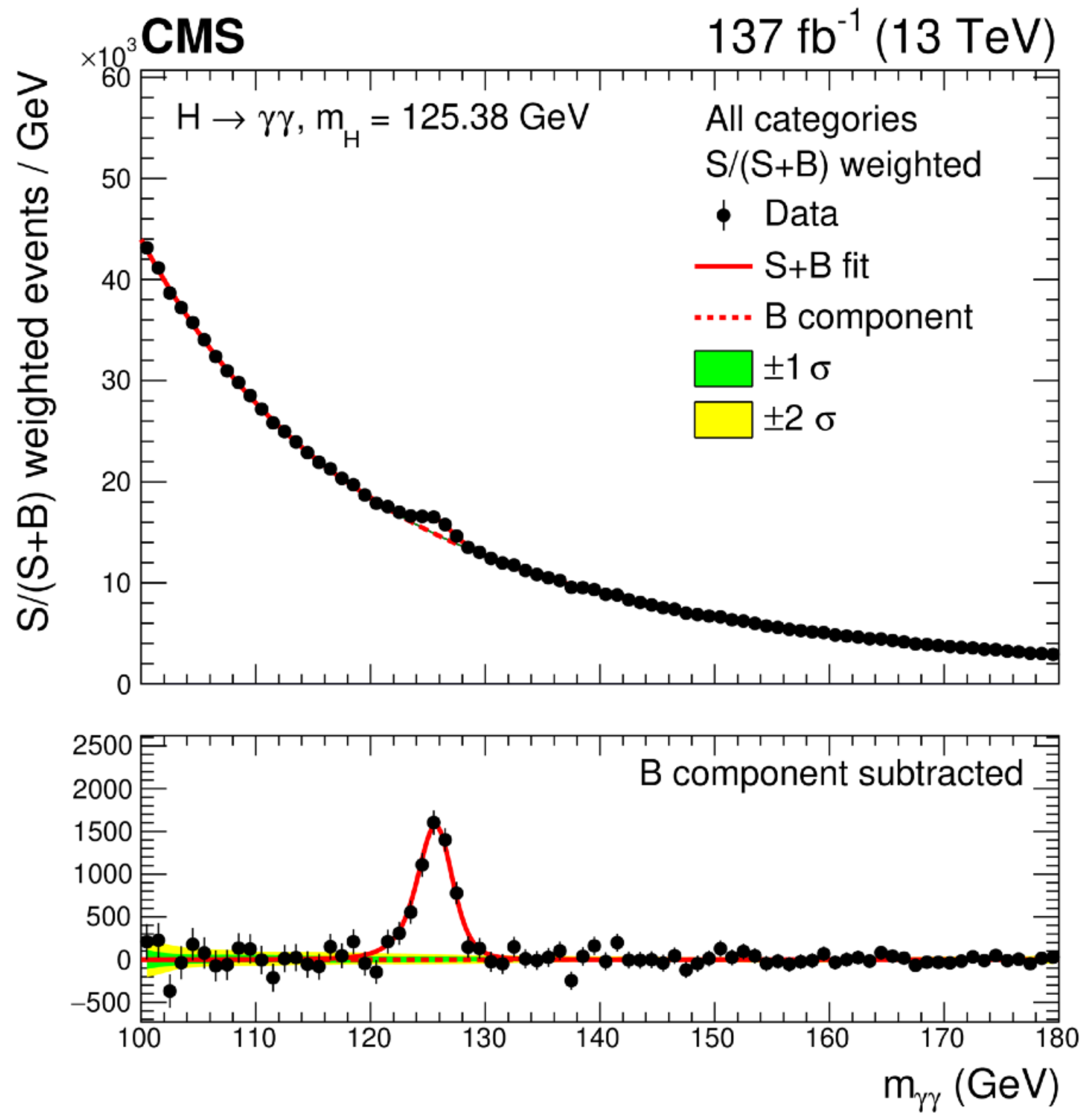
Detection and measurement of "particules" produced at the interaction point

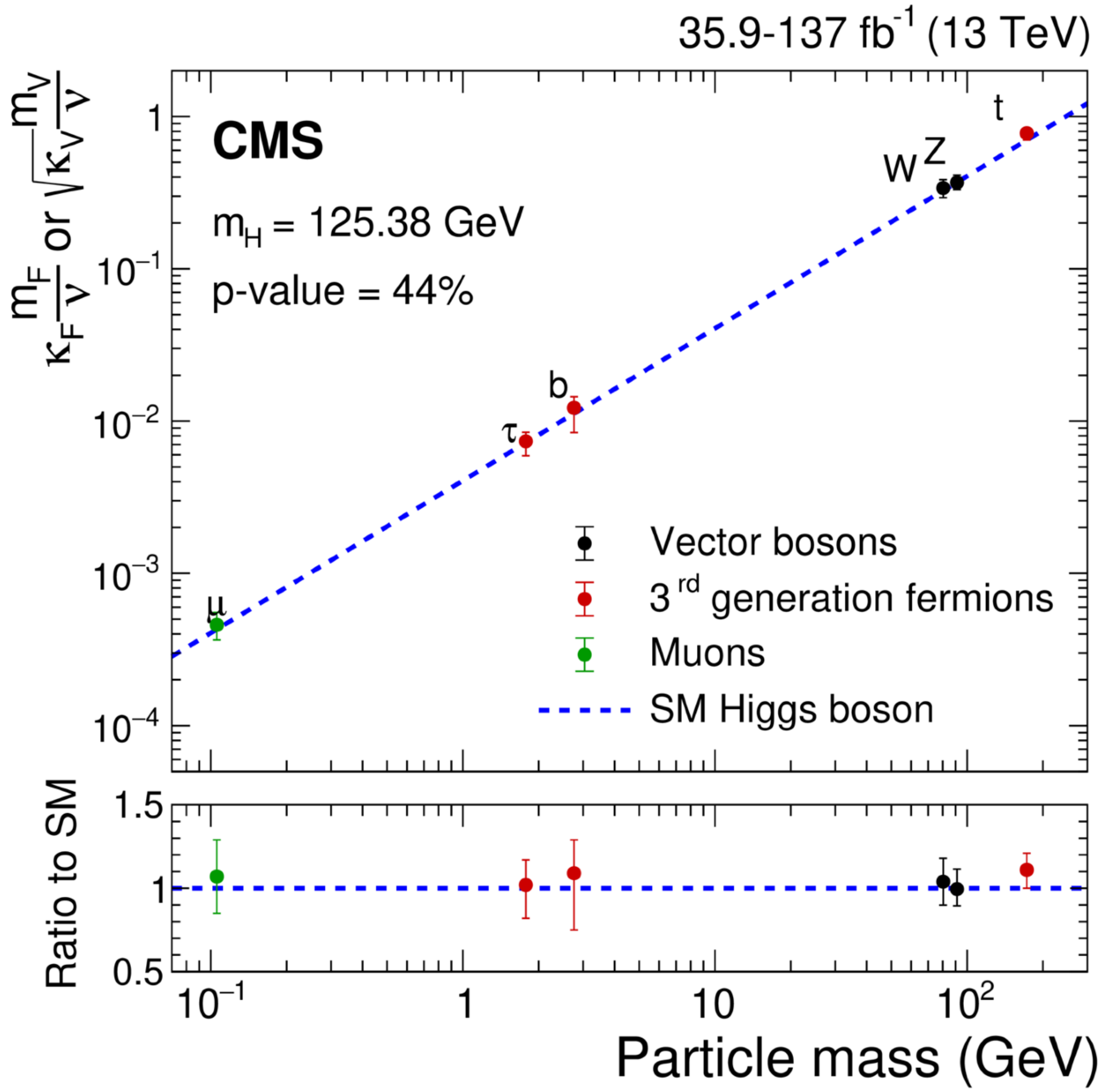
- muons
- electrons
- charged hadrons
- photons
- neutral hadrons

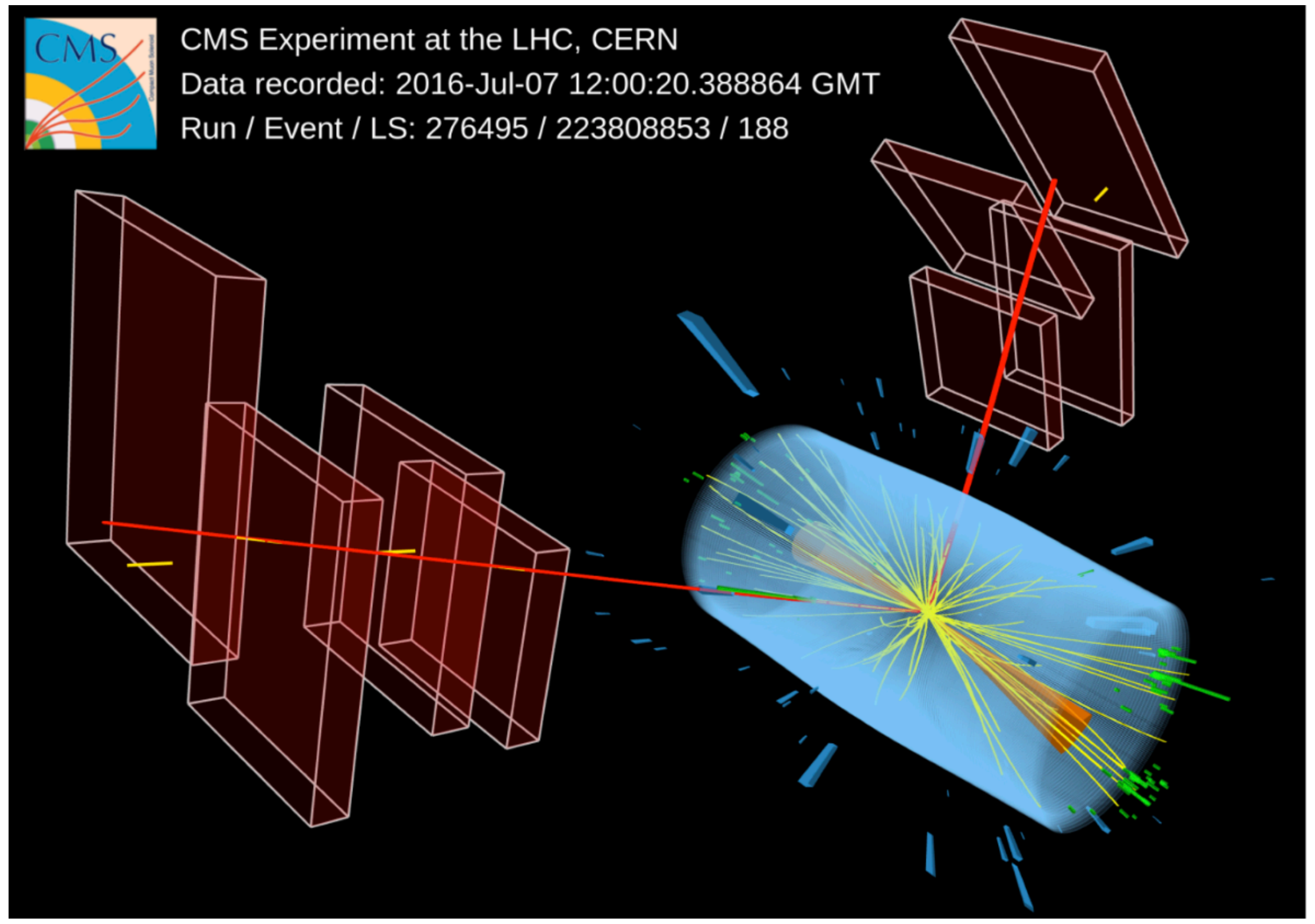
- light-flavour jets (u, d, s quarks or gluon)
- heavy-flavour jets (c or b quarks)
- tau-lepton jets
- "fat" jets with sous-structures (W/Z, H, t…)
- missing transverse momentum (neutrino, DM…)

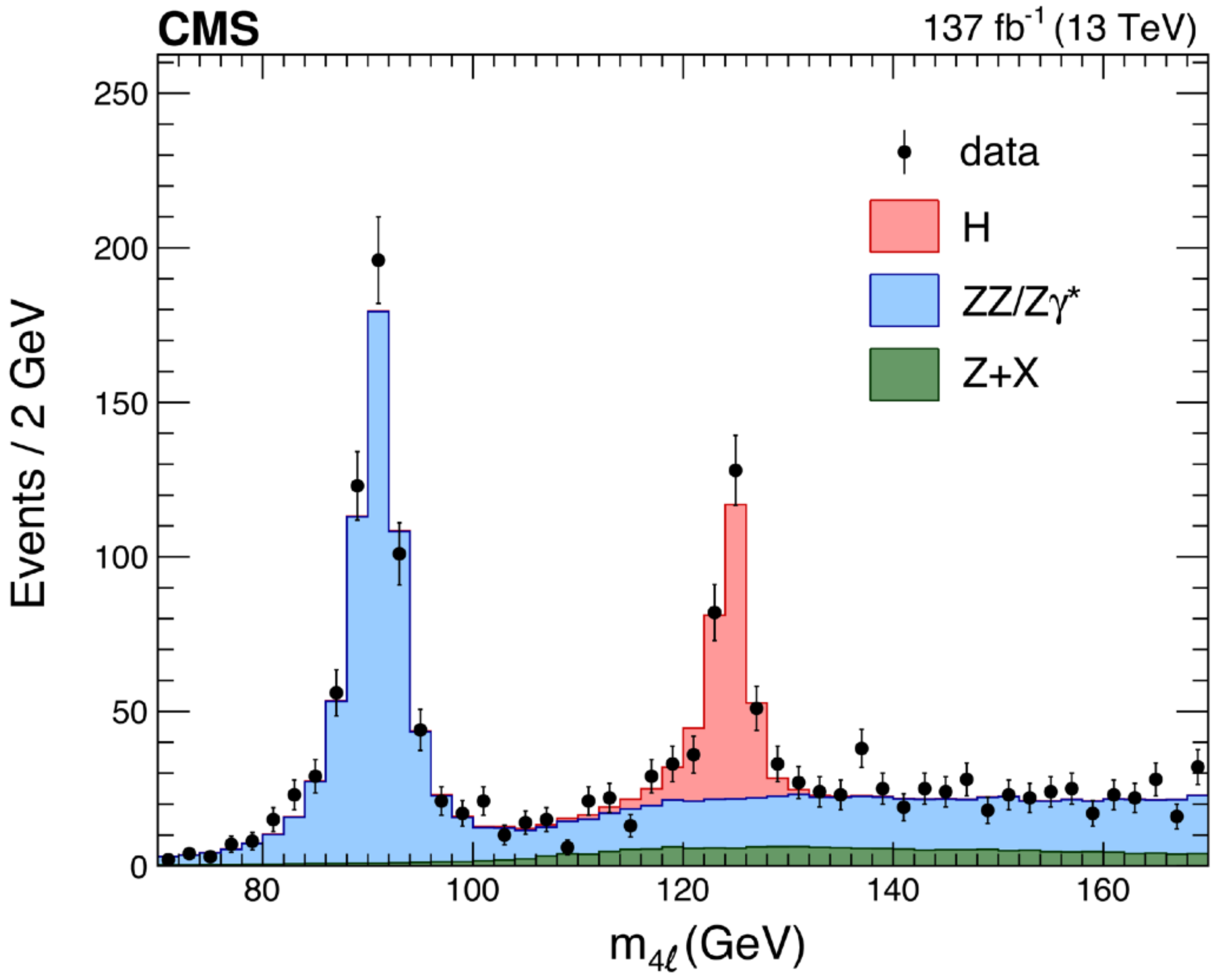
for each object specific energy and position calibrations are applied

An Unprecedented Physics Harvest

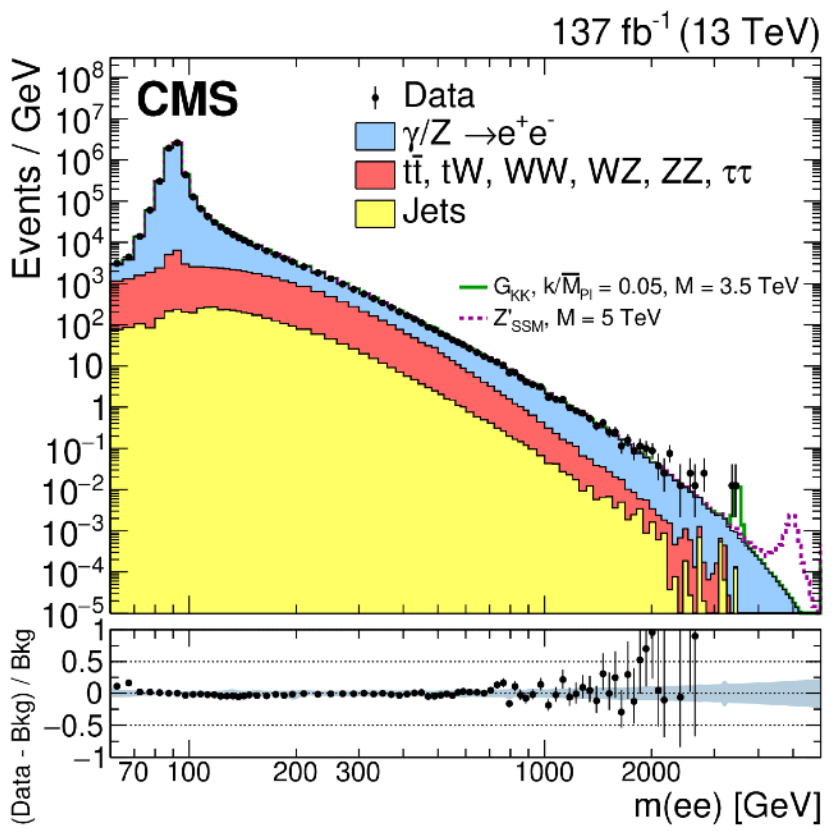


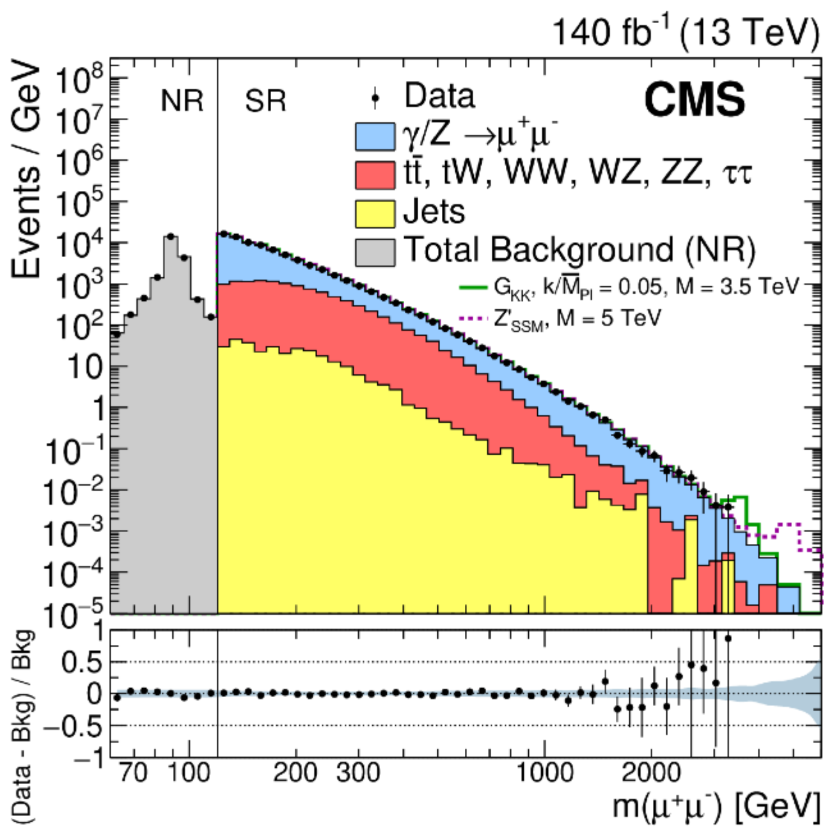






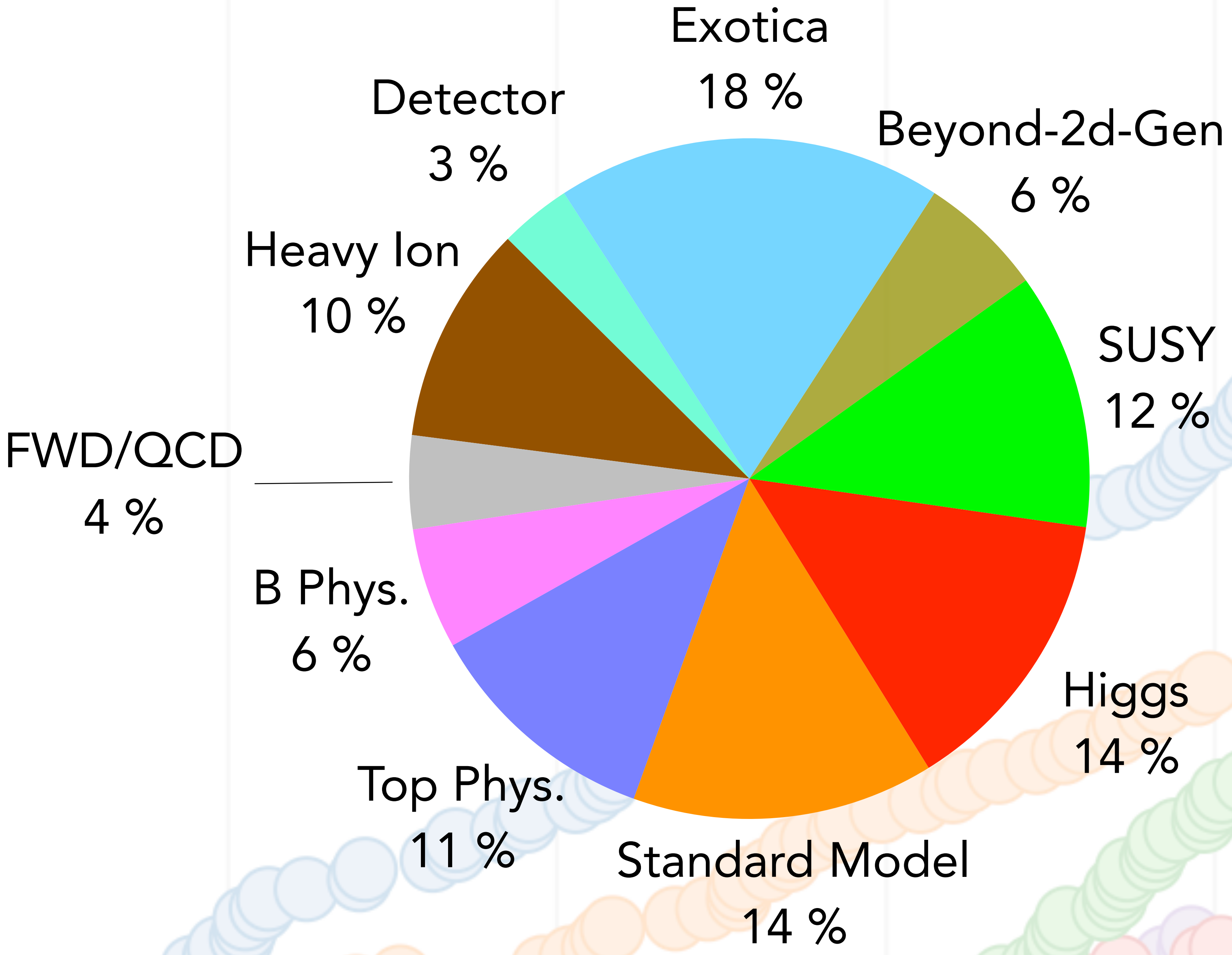
see lecture by
Florencia Canelli

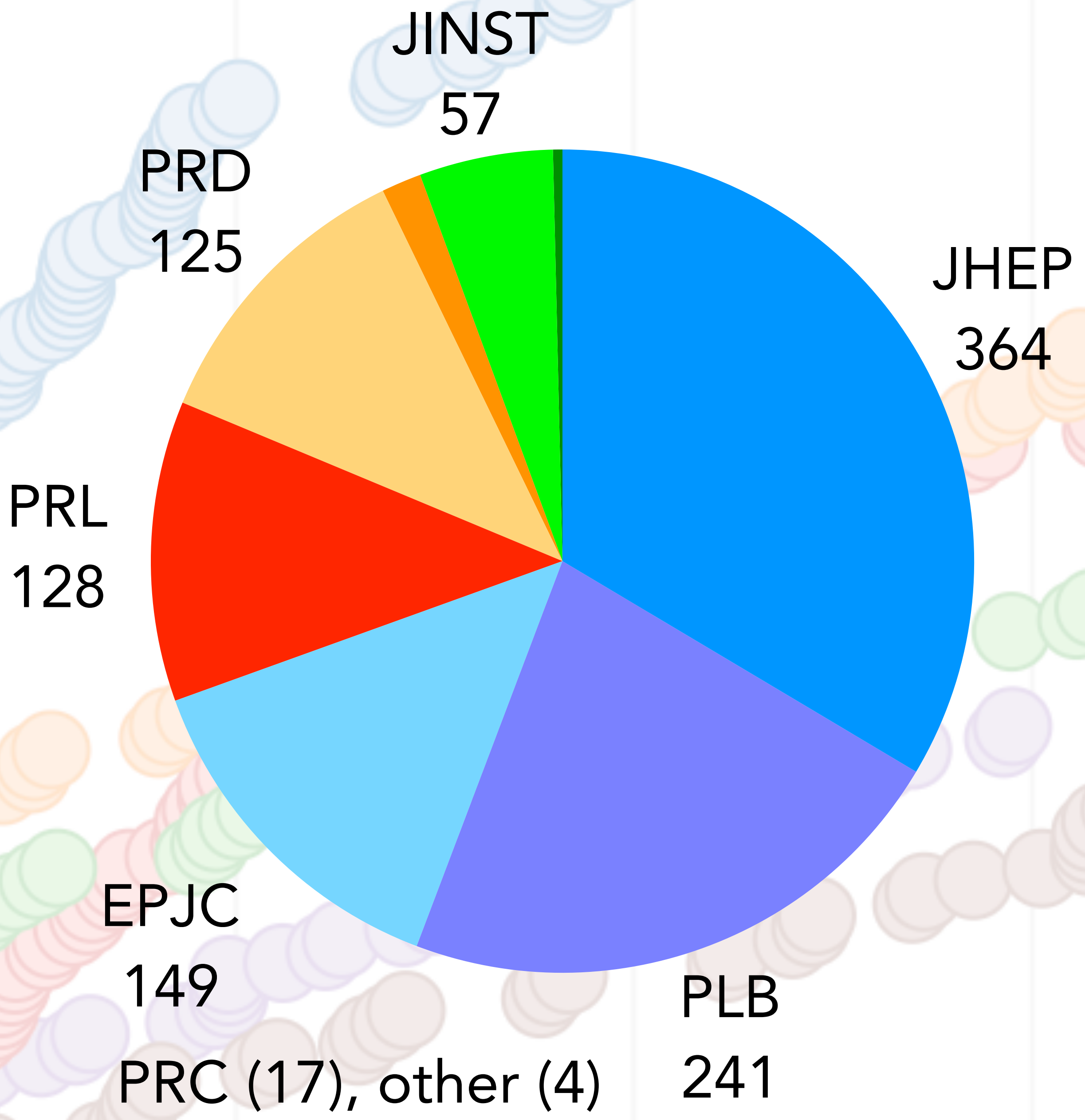




CMS Publications

An unprecedented publication rate in high-energy physics



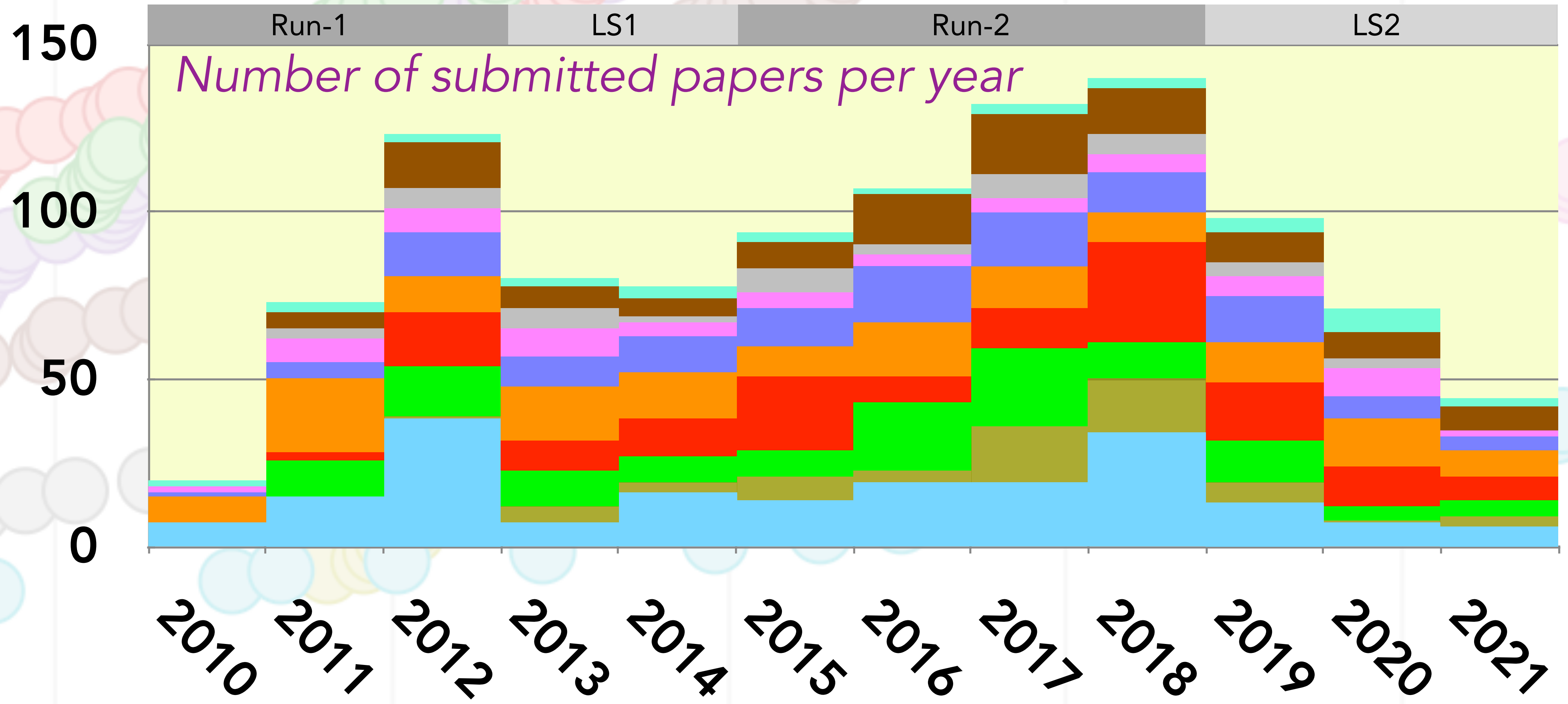


1084 CMS papers
- **1053** published

1059 papers based on **collision data**
- **1028** published
- 574 based on Run-1 data
- 484 based on Run-2 data

CMS titles
- 530 "Search for"
- 39 "Observation"
- 18 "Evidence"
- 310 "Measurement"

CMS with friends
- **ATLAS**: 5 (4 JHEP, 1 PRL)
- **LHCb**: 1 (Nature)
- **Totem**: 3 (1 JHEP, 2 EPJC)



see lecture by Florencia Canelli

As of Aug 25, 2021

Future plans

En Route to Higher Luminosity

LS3 = Long shutdown 3

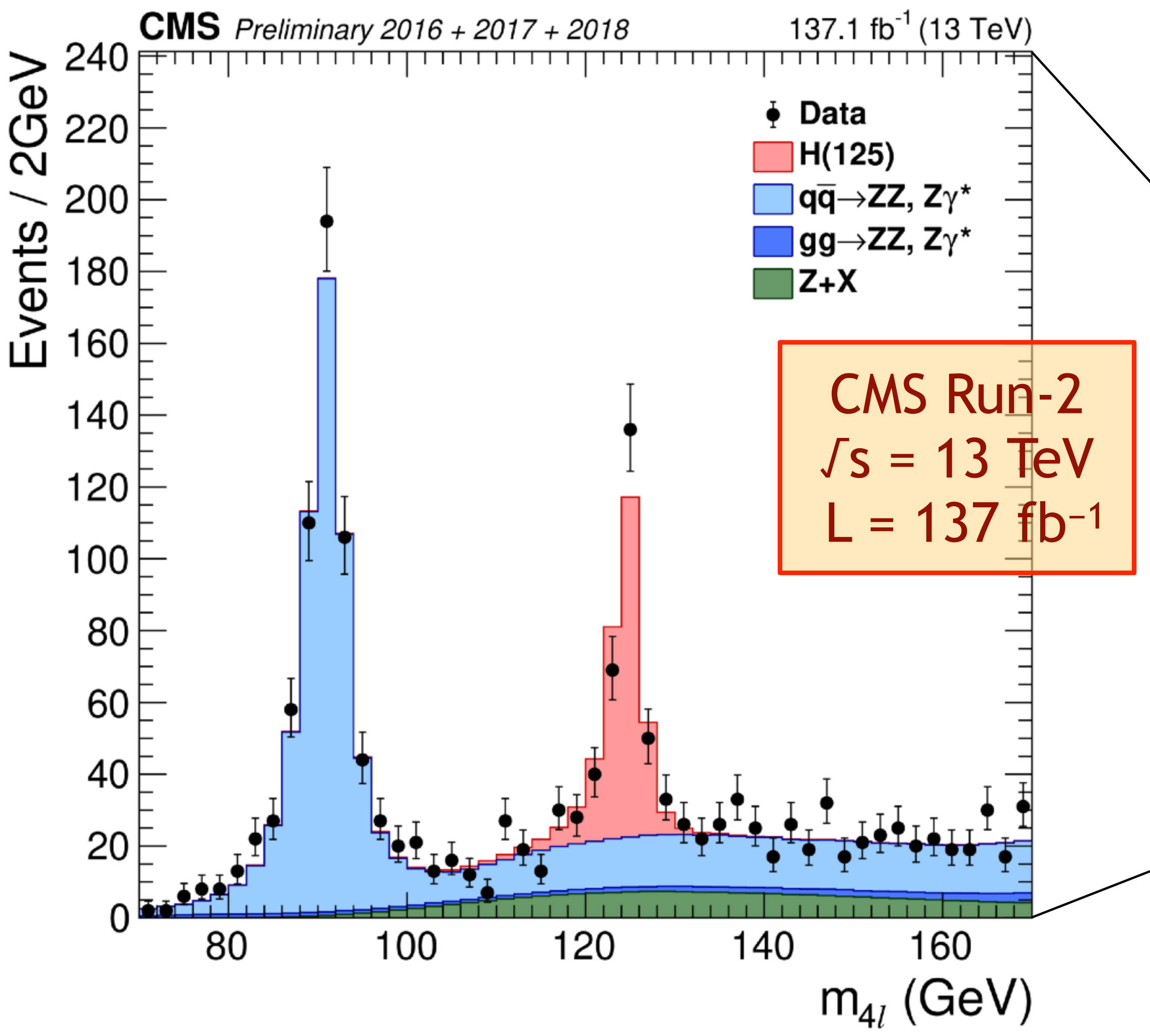
- 2.5 years
- starting end of 2024
- upgraded detectors

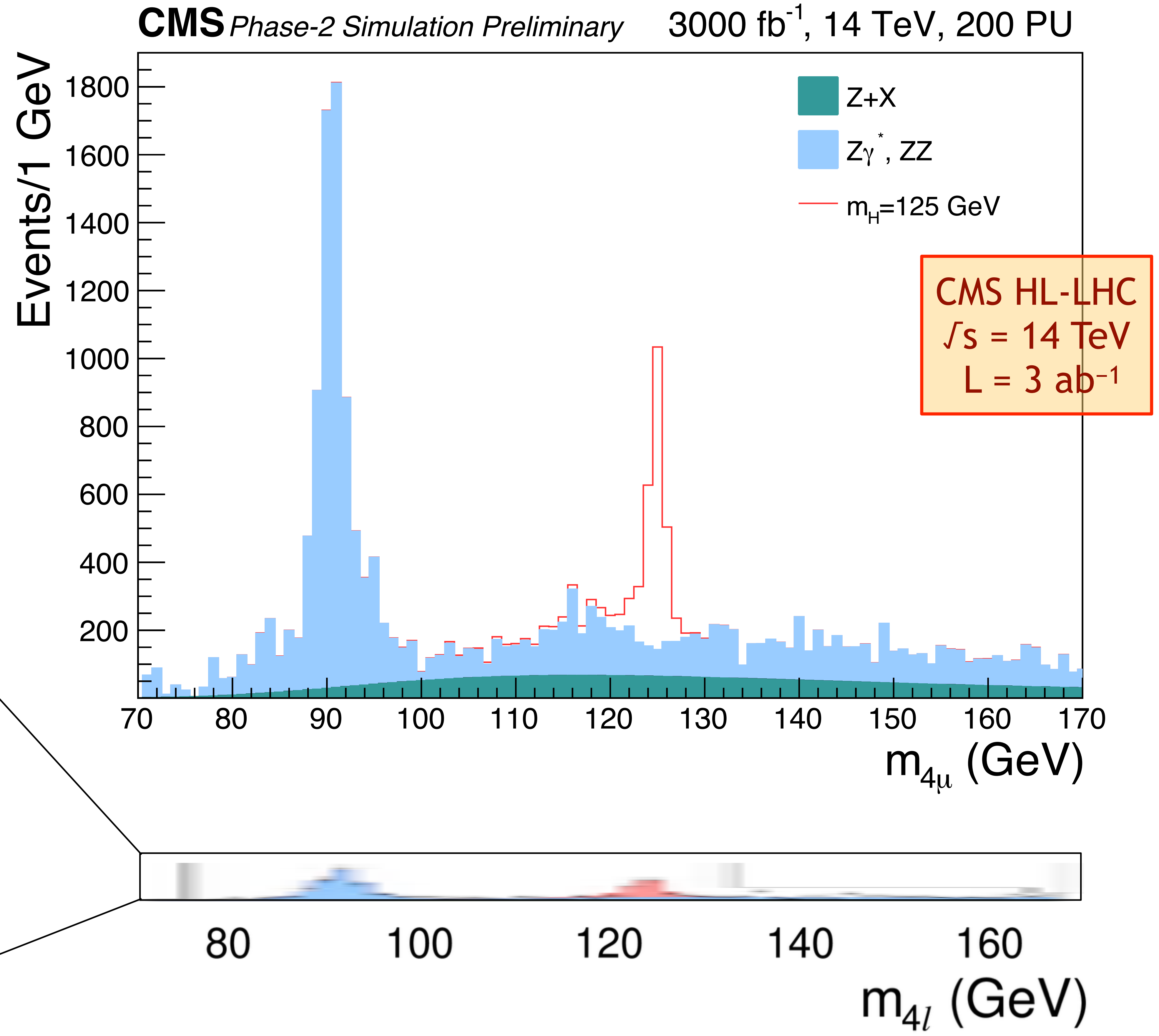
HL-LHC (Run 4-5)

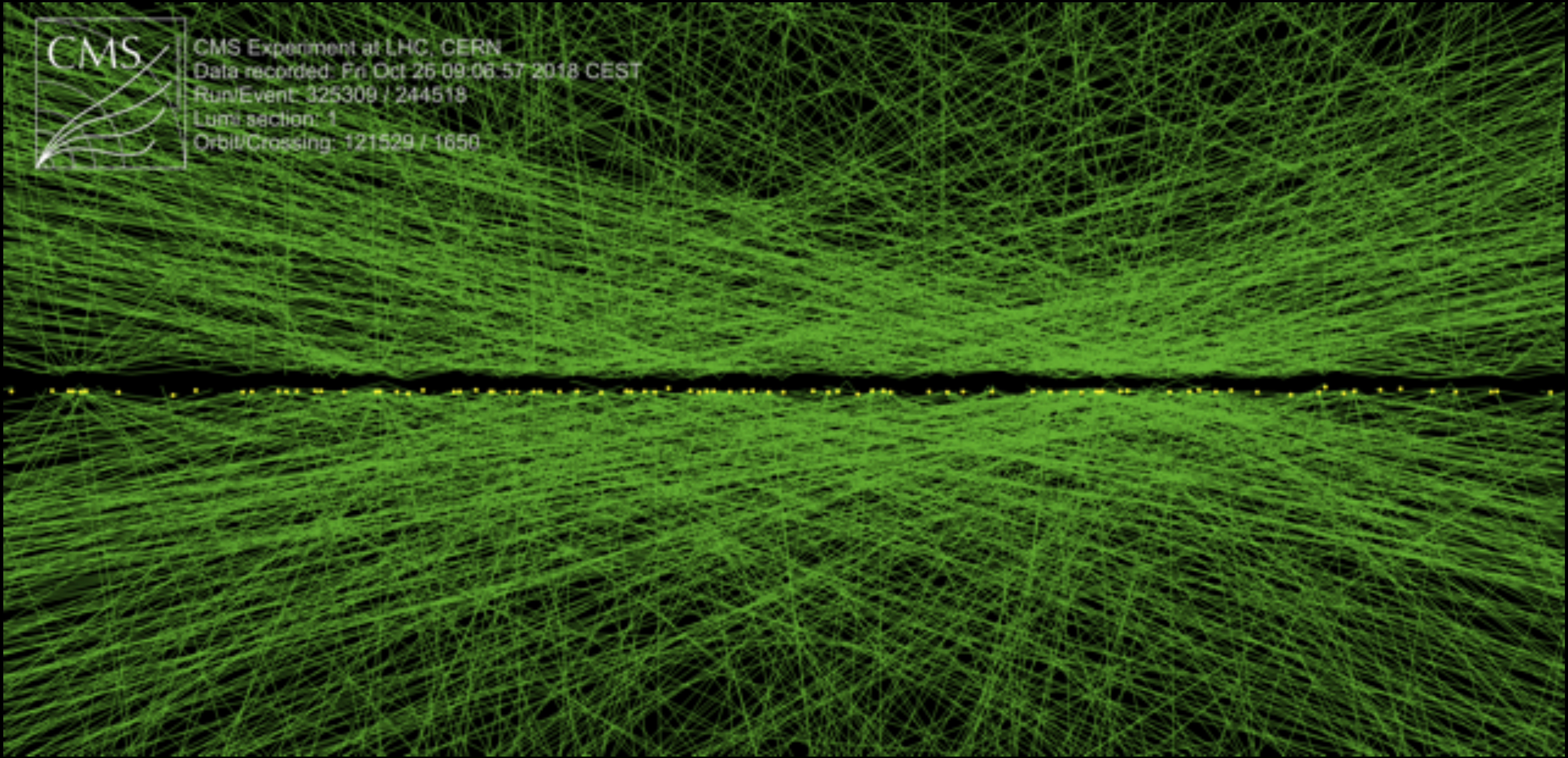
- starting mid-2027
- $\sqrt{s}$ = 14 TeV
- $<\mu>$ = 140-200
- $\mathscr{L}$ up to 7.5 10^{34}
- L > 3000 fb^{-1}

It's Only the Beginning!

so far, "only" < 5%
of the total
expected dataset

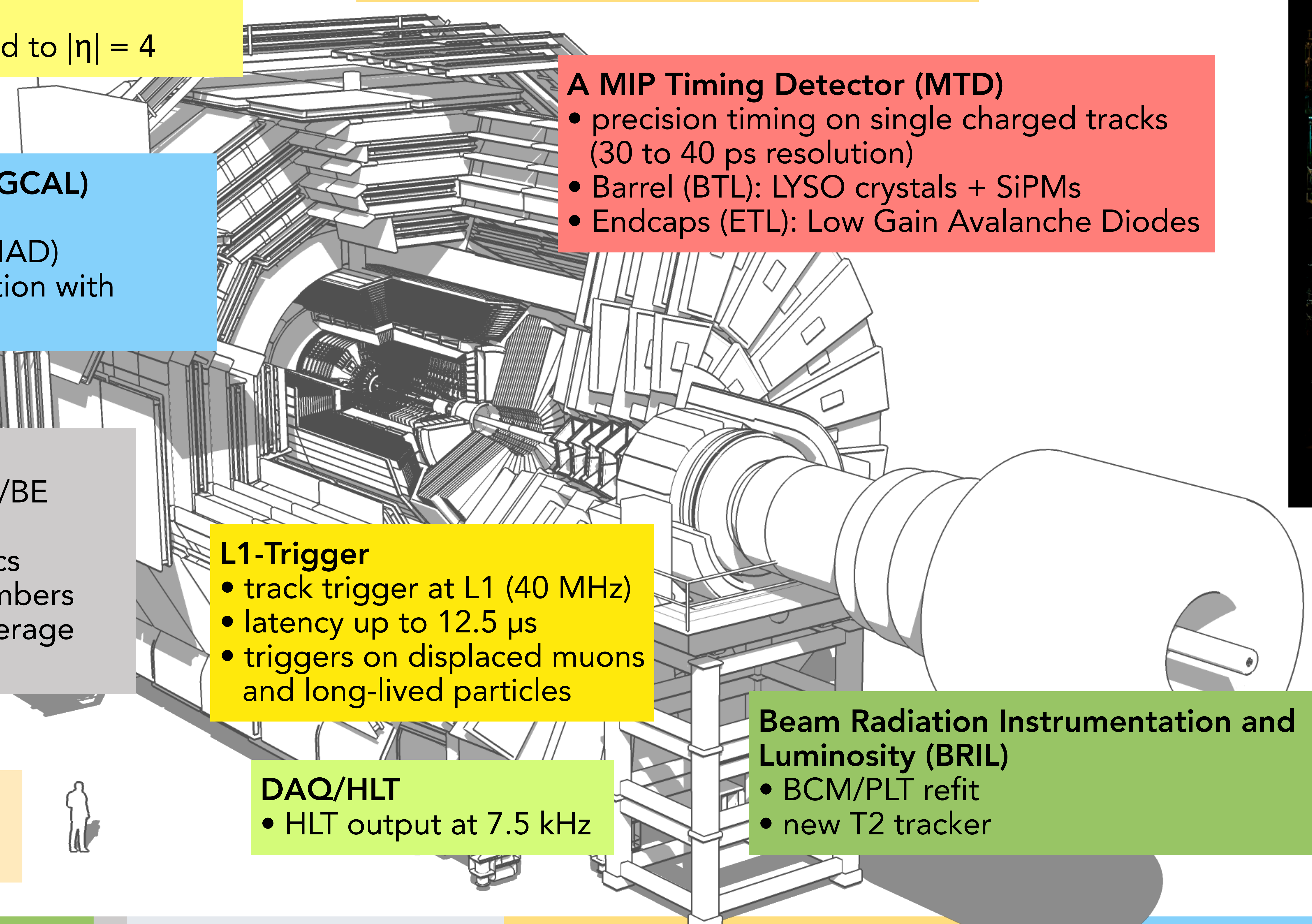






136 pile-up event BX
(CMS, October 2018)

CMS Phase-II Upgrades



Tracker
- all silicon (strips and pixels)
- higher granularity (>2B channels)
- less material
- coverage extended to $|\eta| = 4$

Barrel Calorimeters
- crystal granularity readout at 40 MHz
- precise timing for $e/\gamma > 30$ GeV
- ECAL operation at low temperature (10°)
- upgraded laser monitoring system

A MIP Timing Detector (MTD)
- precision timing on single charged tracks (30 to 40 ps resolution)
- Barrel (BTL): LYSO crystals + SiPMs
- Endcaps (ETL): Low Gain Avalanche Diodes

Endcap Calorimeter (HGCAL)
- silicon pixels (EM) and scintillators + SiPMs (HAD)
- 3D shower reconstruction with precise timing

Muon Detectors
- DTs & CSCs: new FE/BE readout electronics
- RPCs: new electronics
- new GEM/iRPC chambers
- extended muon coverage to $|\eta| = 3$

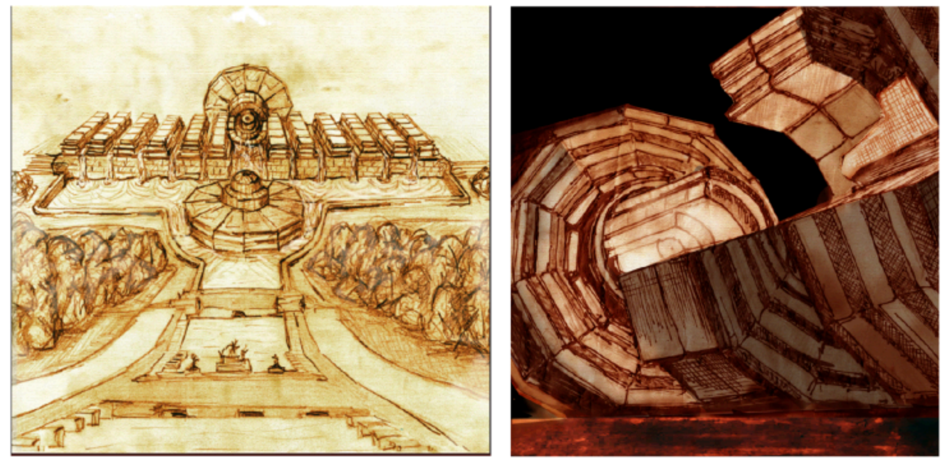
L1-Trigger
- track trigger at L1 (40 MHz)
- latency up to 12.5 μs
- triggers on displaced muons and long-lived particles

DAQ/HLT
- HLT output at 7.5 kHz

Beam Radiation Instrumentation and Luminosity (BRIL)
- BCM/PLT refit
- new T2 tracker

see presentation by Frank Hartmann

recently approved:



DAQ/HLT BRIL

How we are organised

Our "Constitution"

"The Parliament"

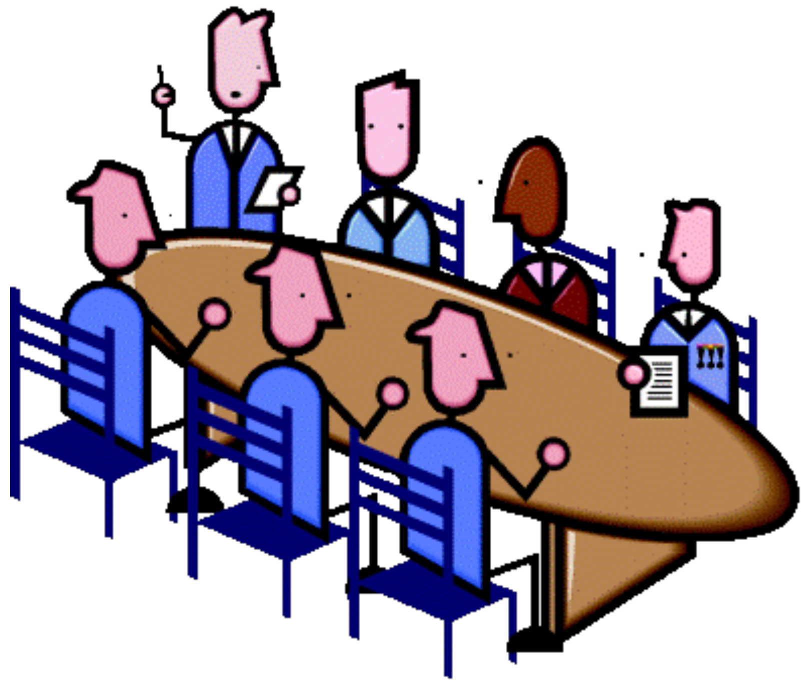
Collaboration Board

"The Government"

Management Board

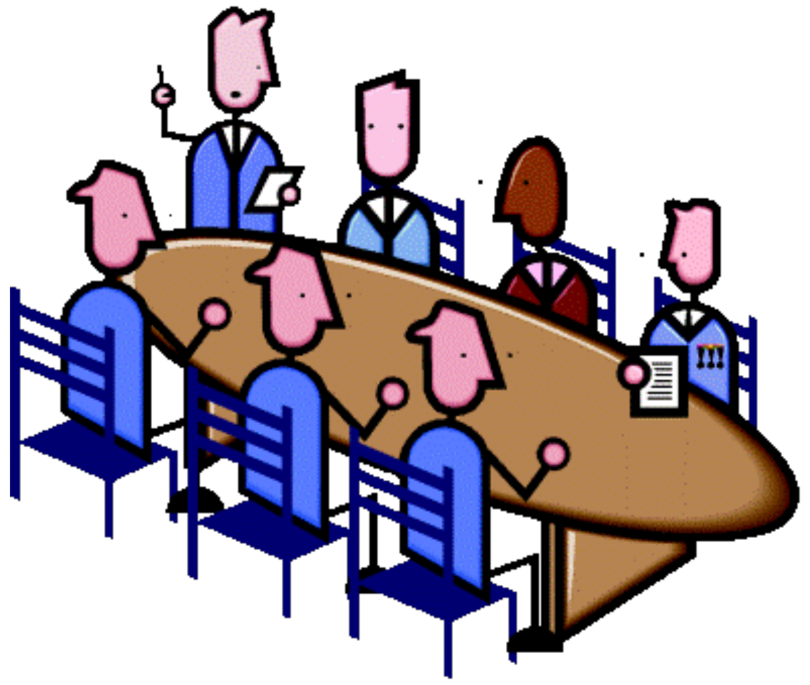
Committees

Conference Committee



etc.

Publications Committee



Extended Executive Board

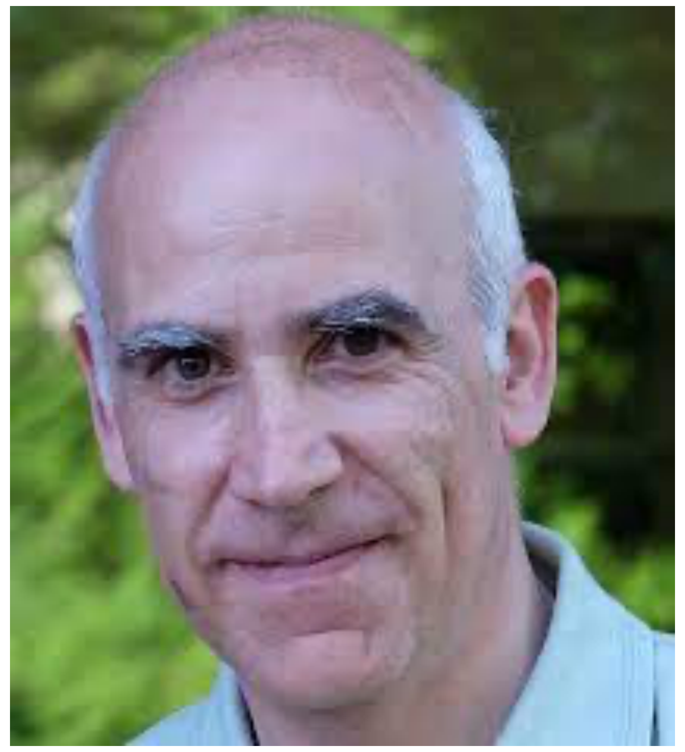
How do we function?

The Collaboration is led by the **Spokesperson**

The Spokesperson (SP)
- is elected by the Collaboration
- is responsible for the scientific and technical direction of the experiment, in agreement with the Collaboration Board
- chairs the Management Board and the Extended Executive Board
- interacts with CERN and its scientific committees, with other experiments
- is the principal representative of CMS with the physics community and the general public

The CMS Collaboration Board (CB)
- is the "parliament" body of the experiment
- is composed of representatives of each institute participating in CMS
- makes/endorses all major decisions within the Collaboration

see presentation by Claudia Wulz



Luca Malgeri
CMS Spokesperson
2020-2022

Claudia Wulz
CMS Collaboration Board Chair
2021-2023

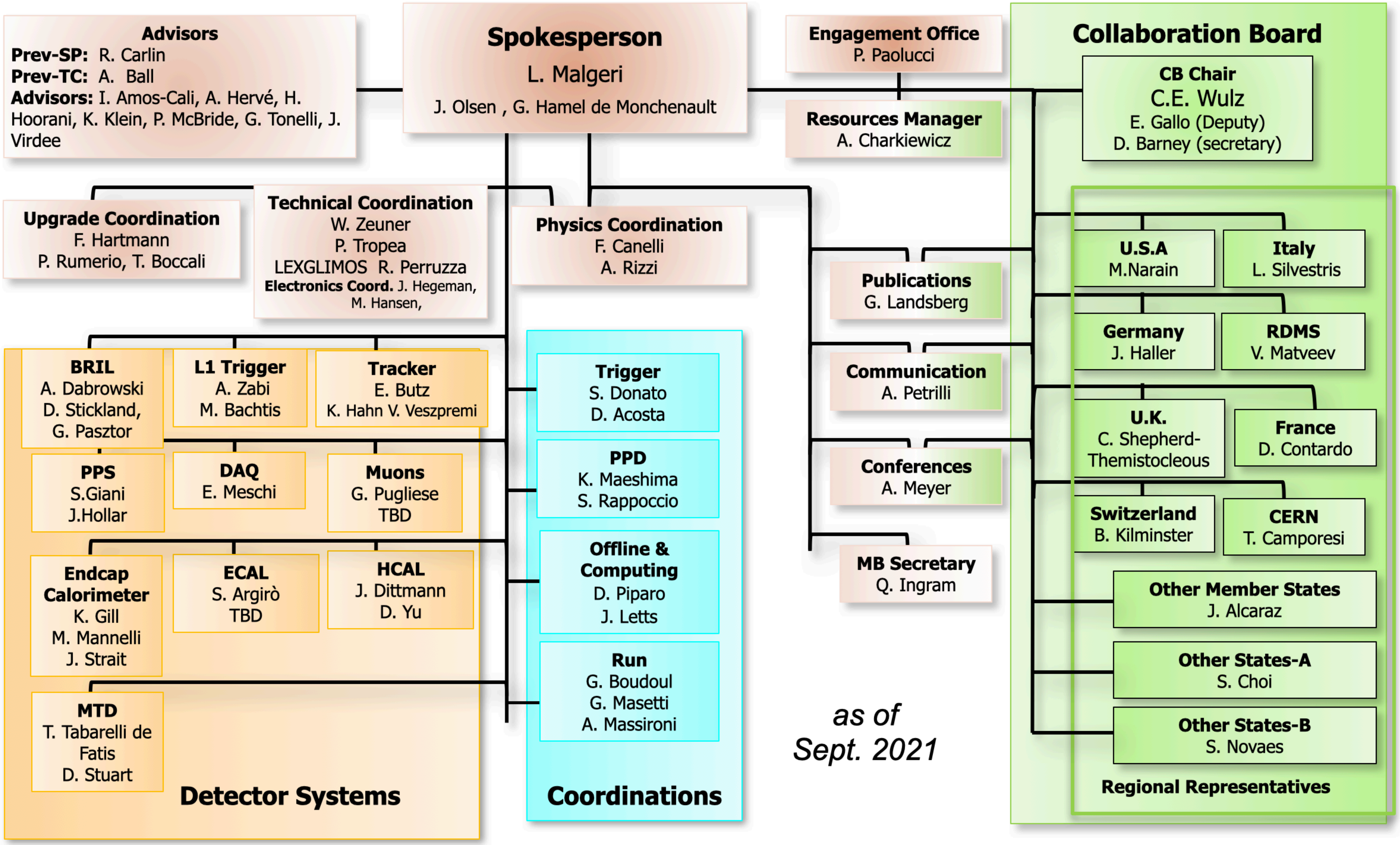
Executive Board & Management Board

The Extended Executive Board (XEB)

- chaired by the SP
- area coordinators
- system managers
- meets every week
- day-to-day operation of the experiment

The Management Board (MB)

- chaired by the SP
- XEB + regional representatives + advisors
- meets 8-10 times a year
- directs the experiment and draws up the policy for the future



The Really Important Ones

Last, but not least…

Our friendly CMS secretariat!

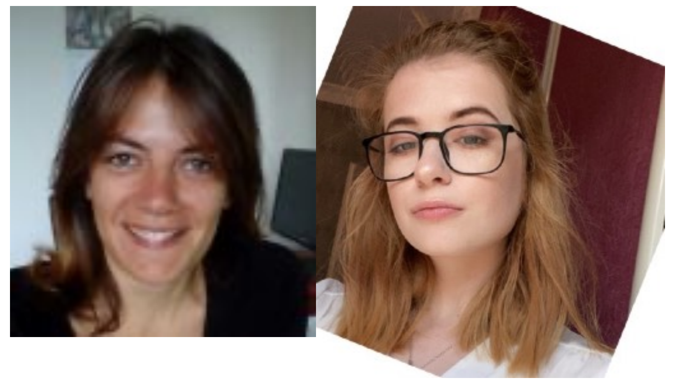
Zsuzsanna Garai

Tania Pardo

Josephine Bengtsson

and…

CMS Communication!



see presentation by
Federica Baldassari

Laetitia Pommepuy

Ekaterina Osipova

see presentation by
Ekaterina Osipova

Welcome to CMS!!!

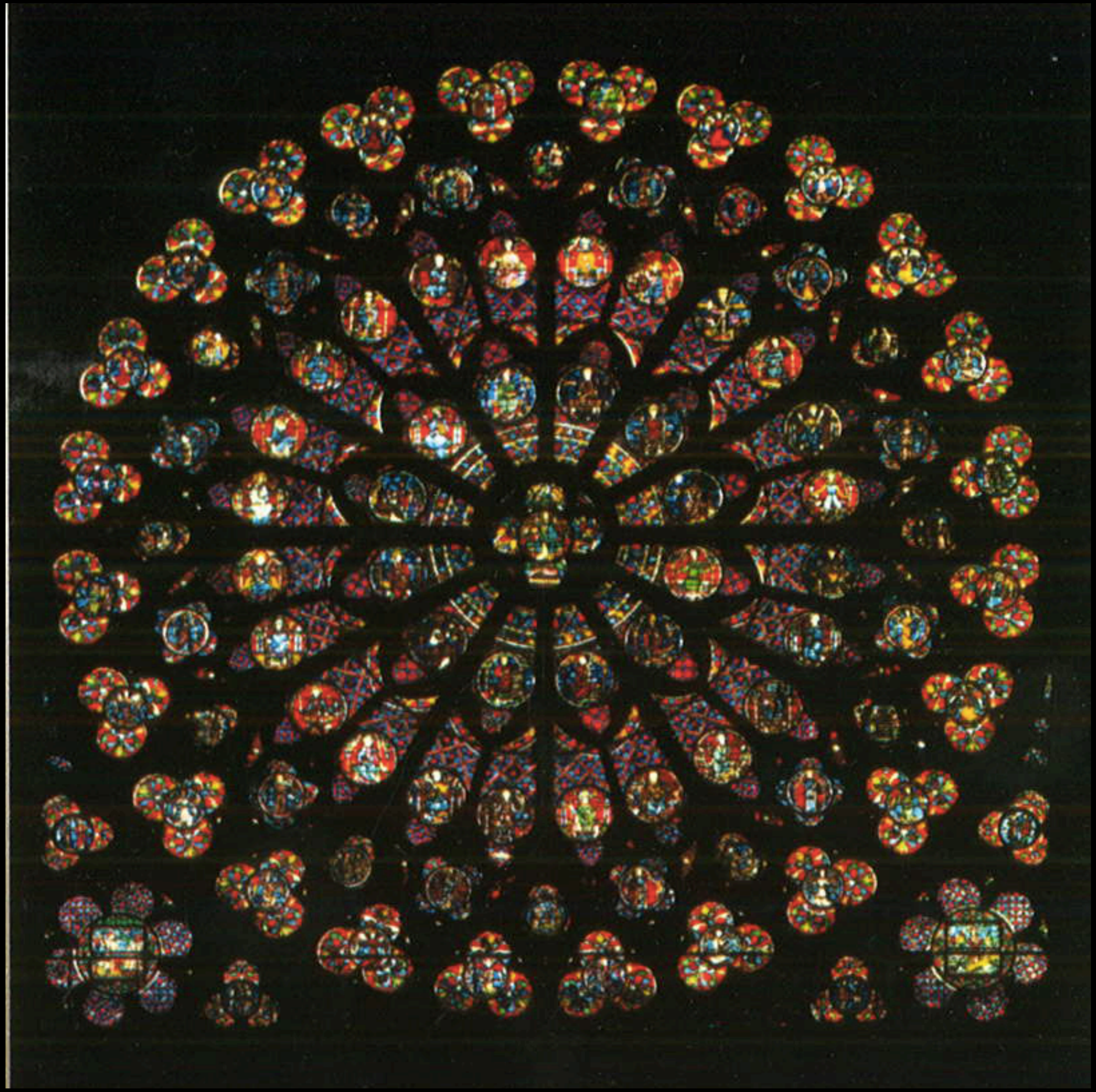
We wish you a wonderful experience for the rest of your Induction into CMS, and *of course* during your future activities in our Collaboration

The **excellent performance of the CMS Detector** is only possible **thanks to** the ingenuity, expertise and hard work of **all CMS collaborators**

Note on the pandemic

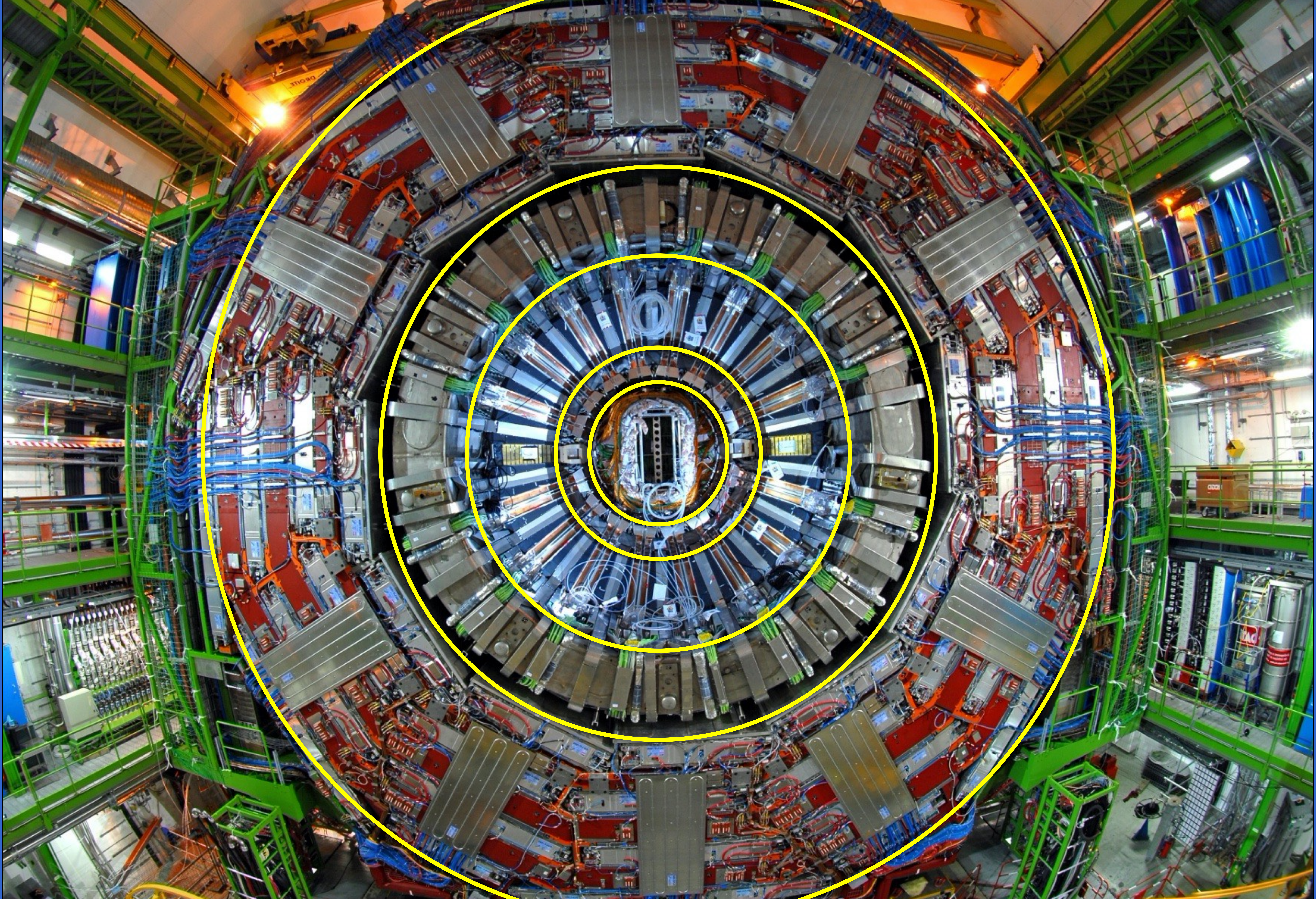
- massive telework, lack of in-person meetings and absence of social interaction, may induce **stress**, especially among our younger collaborators
- We are continuously monitoring the **impact of the pandemic** on our activities and our collaborators
  We are mindful of the **long-term effects** that the pandemic may have

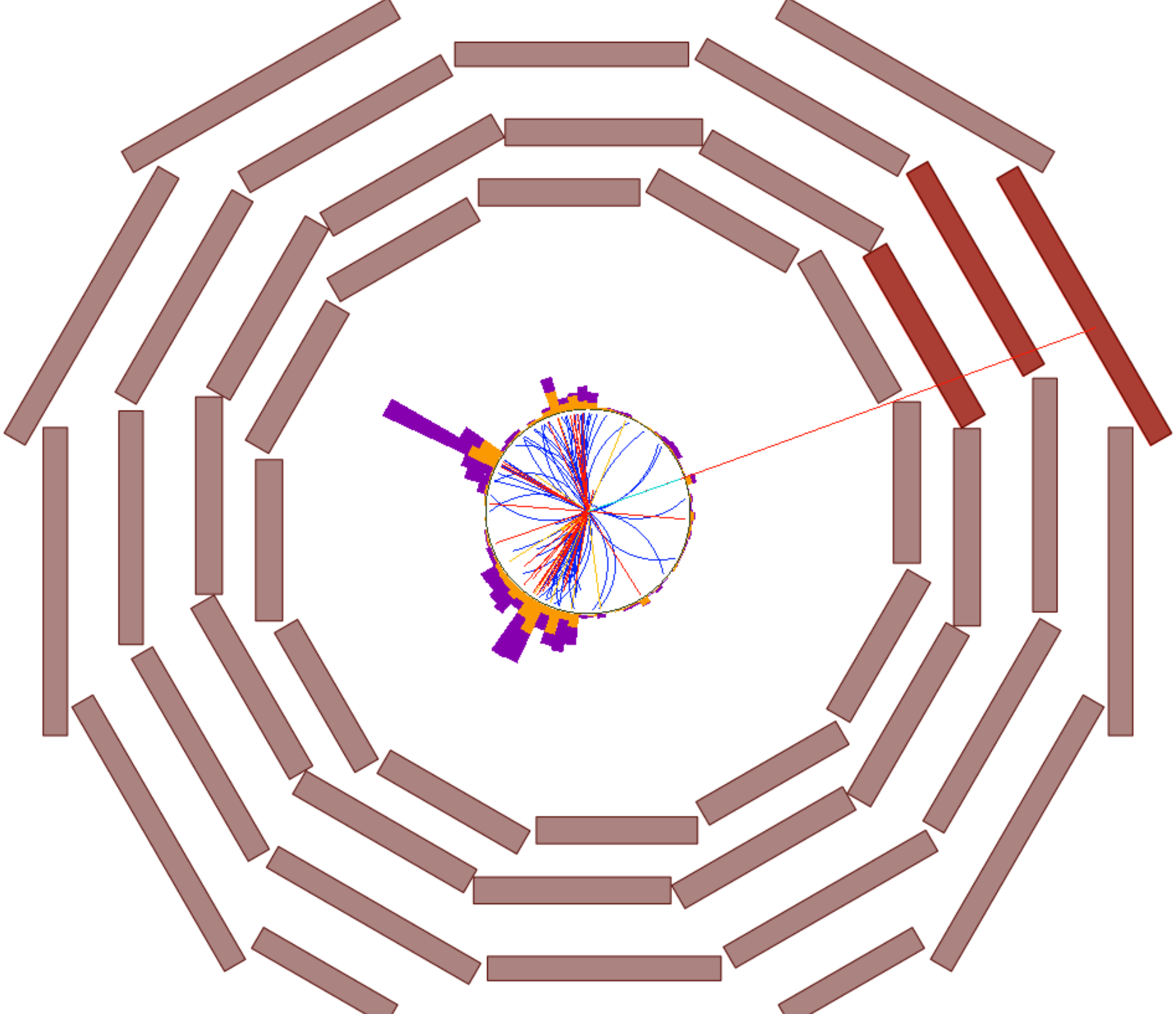
Thank You

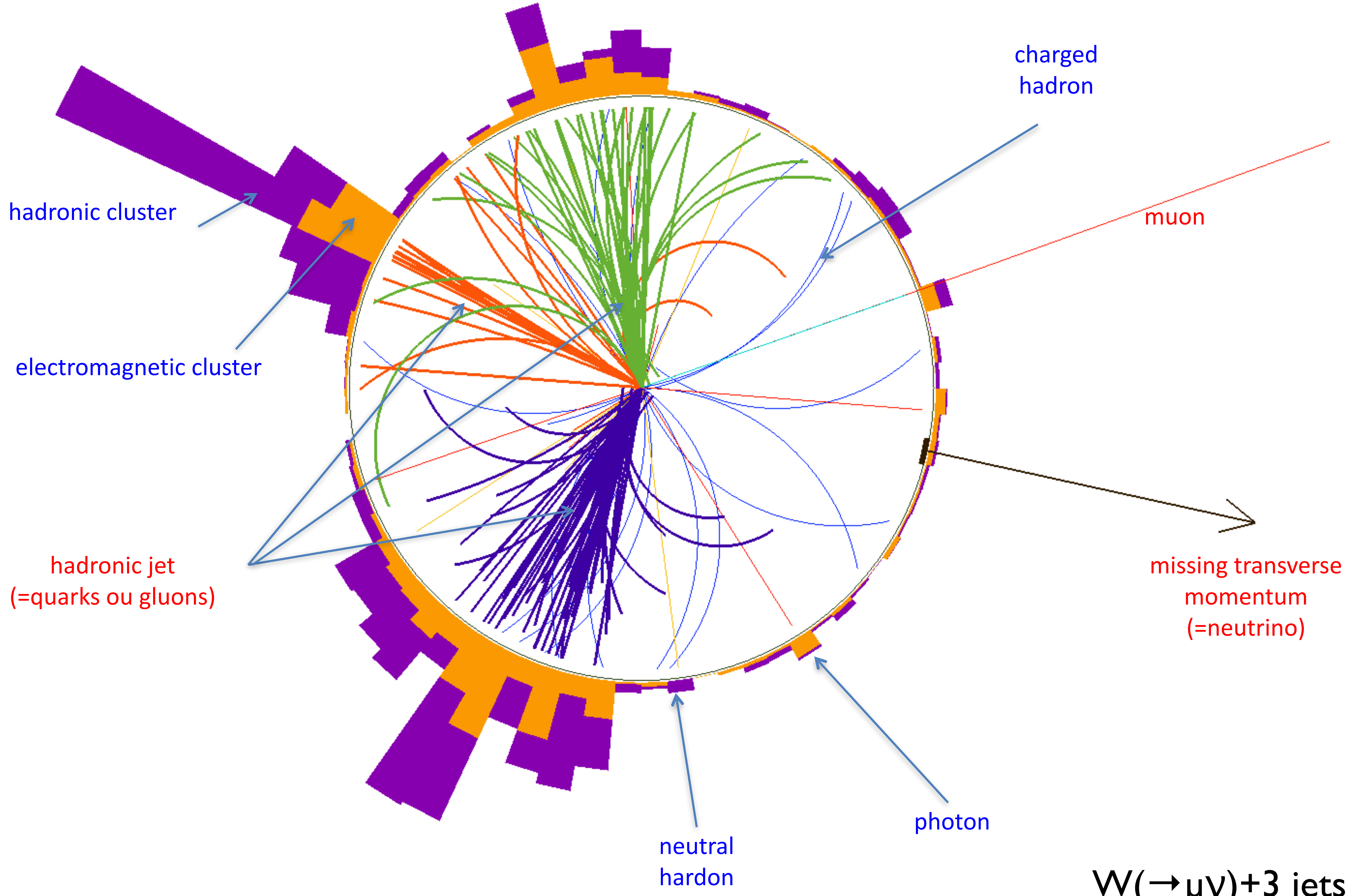


D. Denegri

Back up slides →



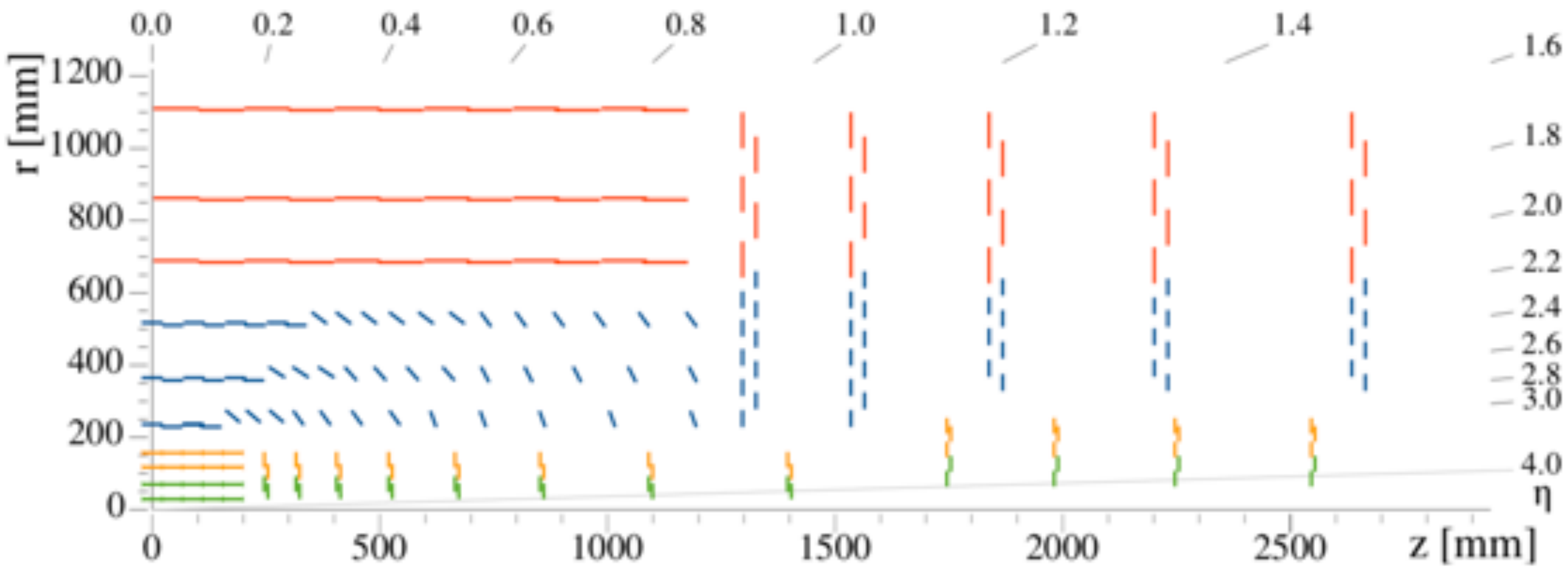


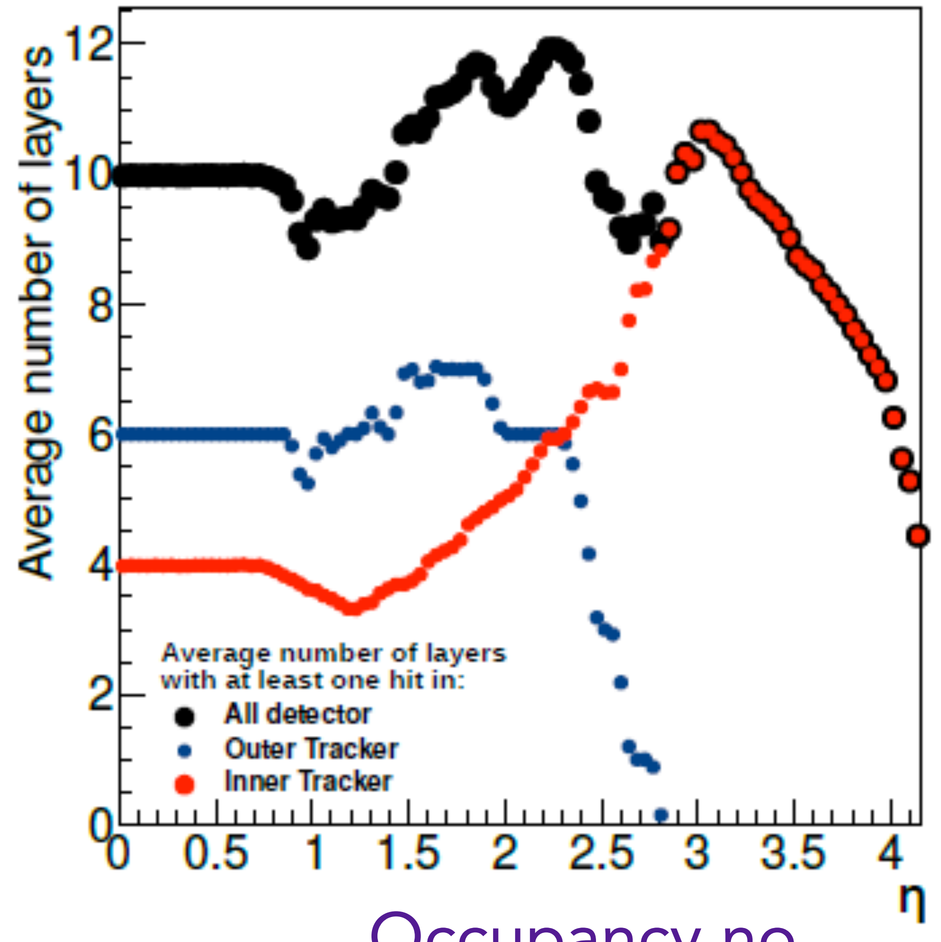

charged
hadron
muon
hadronic cluster
electromagnetic cluster
hadronic jet
(=quarks ou gluons)
missing transverse
momentum
(=neutrino)
neutral
hardon
photon

W(→μν)+3 jets

Phase-II Tracker Upgrade

Key features
- more granularity
- lower material budget
- extended coverage
- tracking included at L1-trigger level

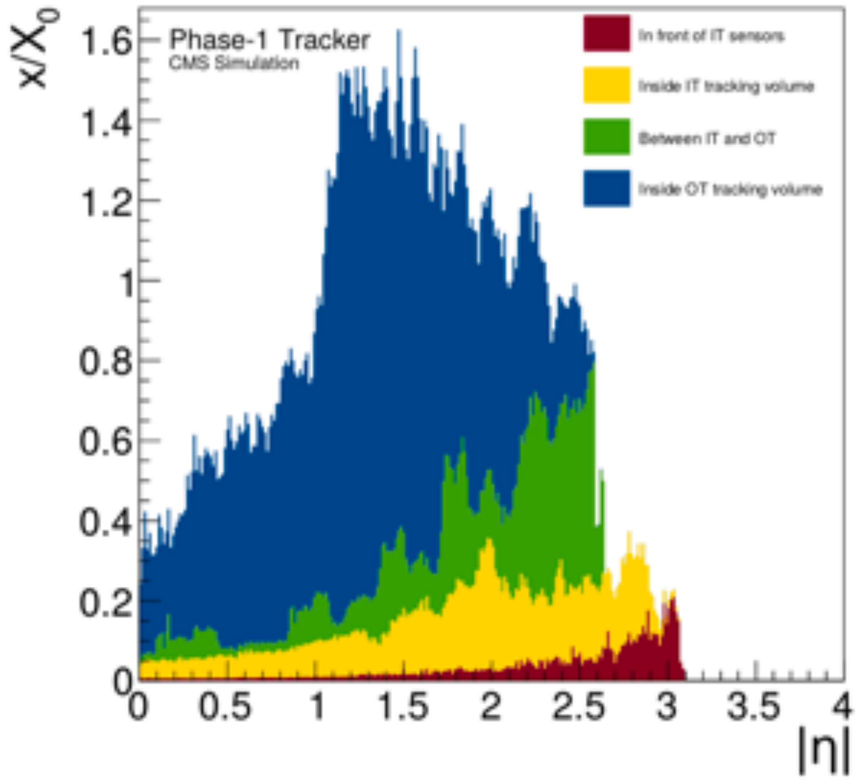




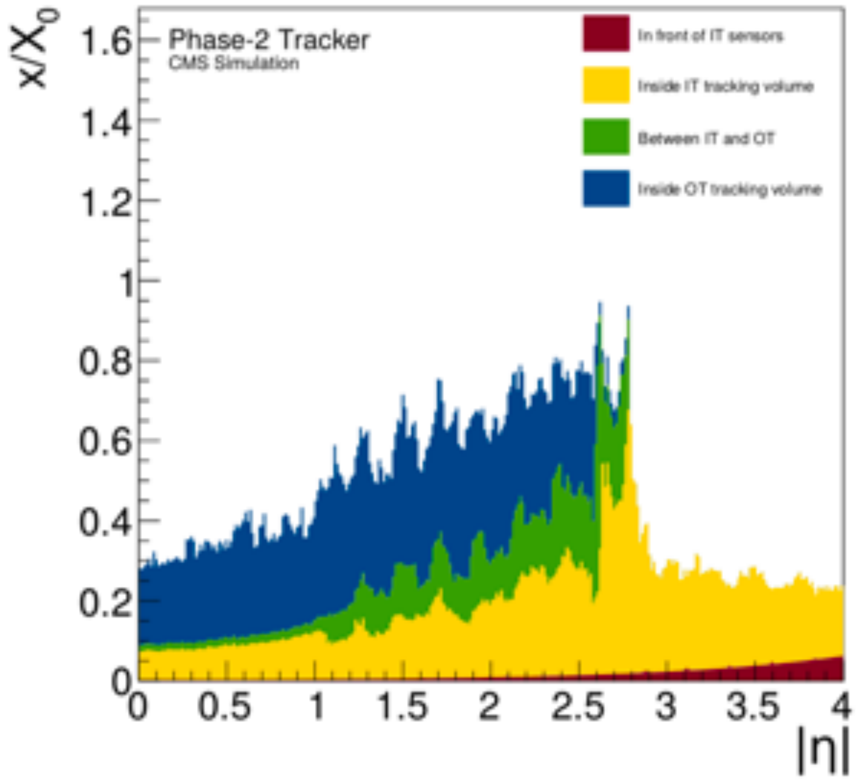
Occupancy no larger than 3%

Material budget

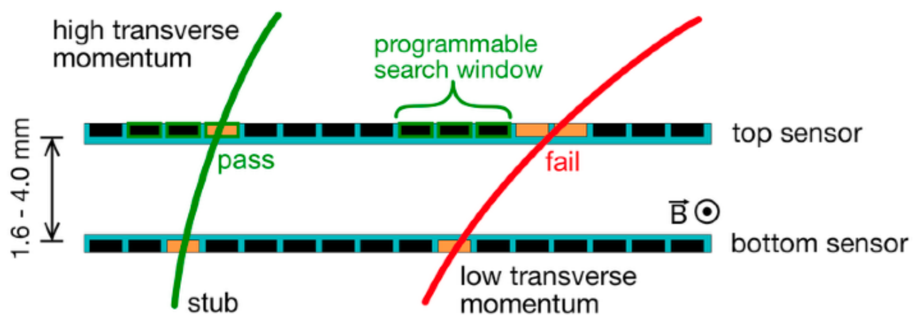
present tracker



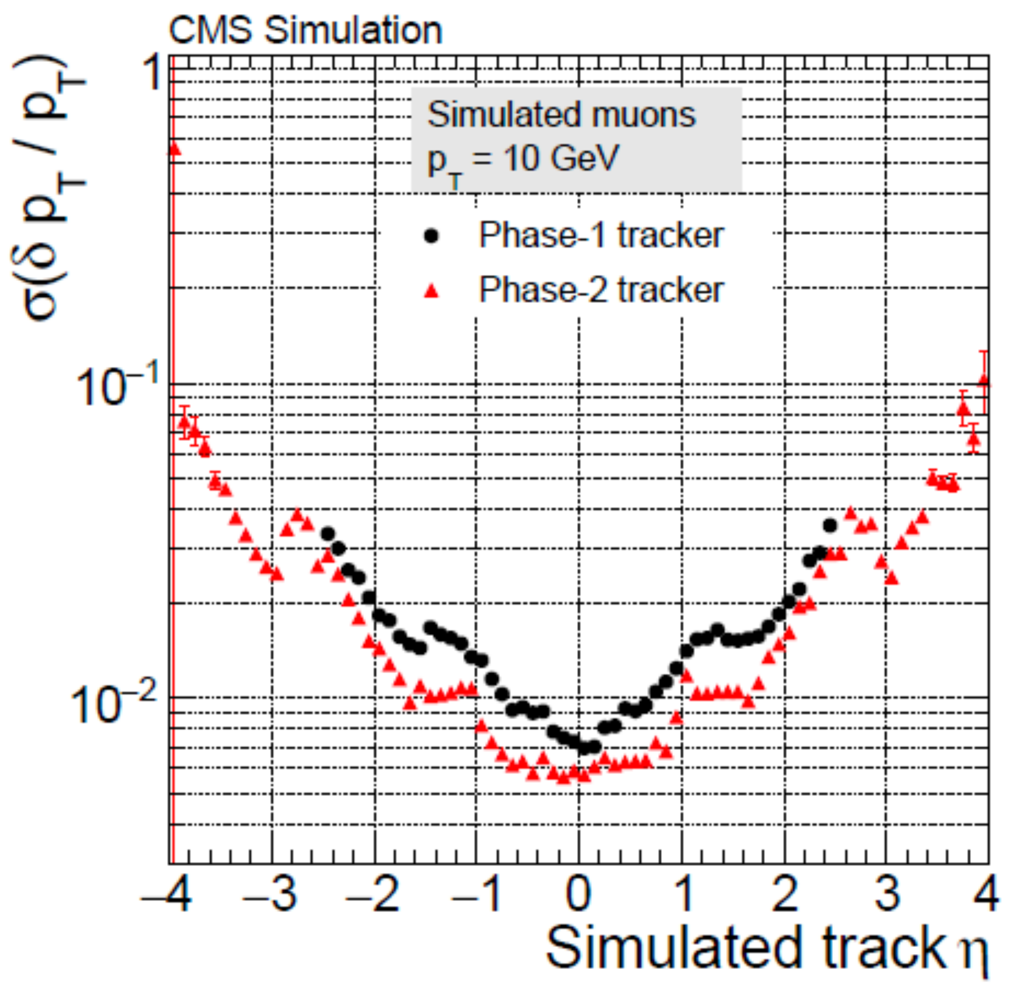
upgraded tracker



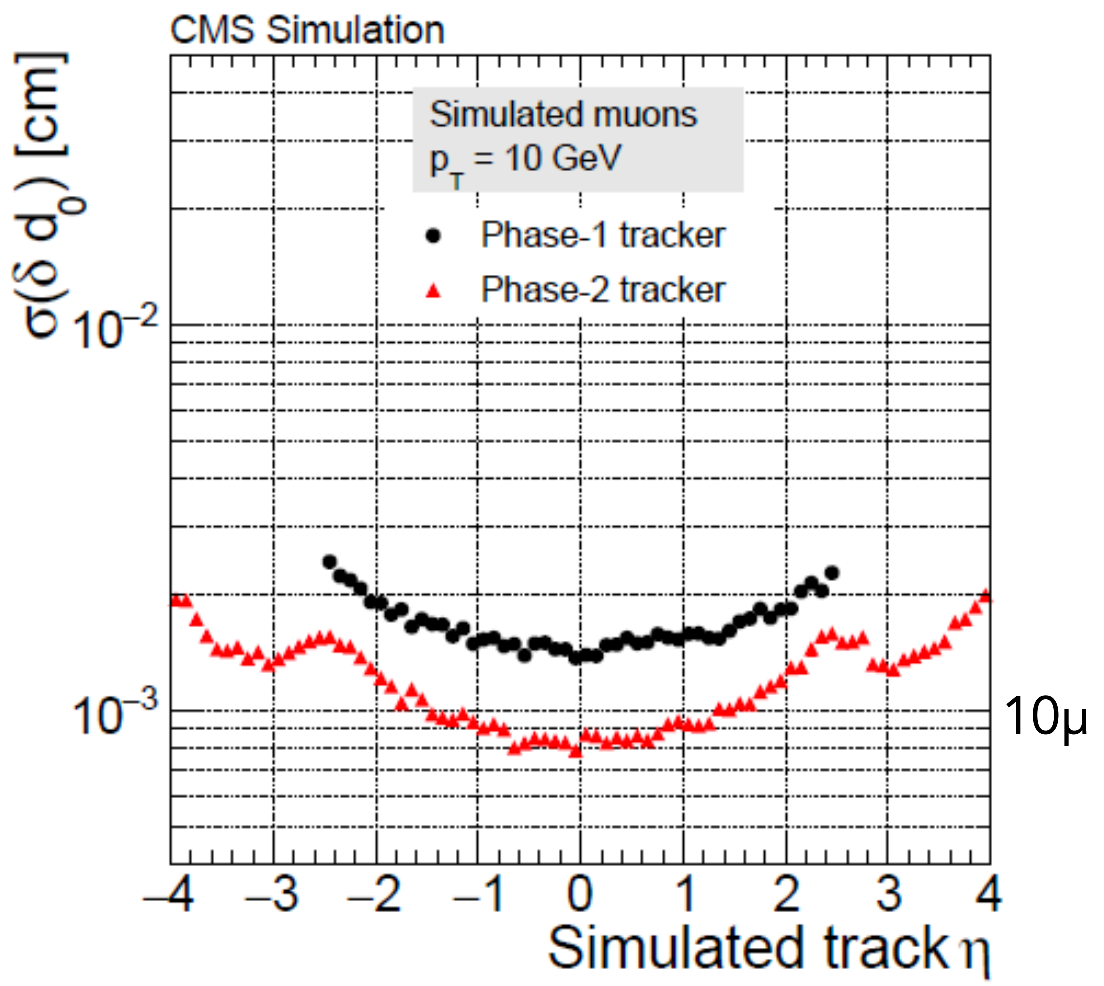
Local rejection of low p_T tracks



Expected performance
compared to present tracker

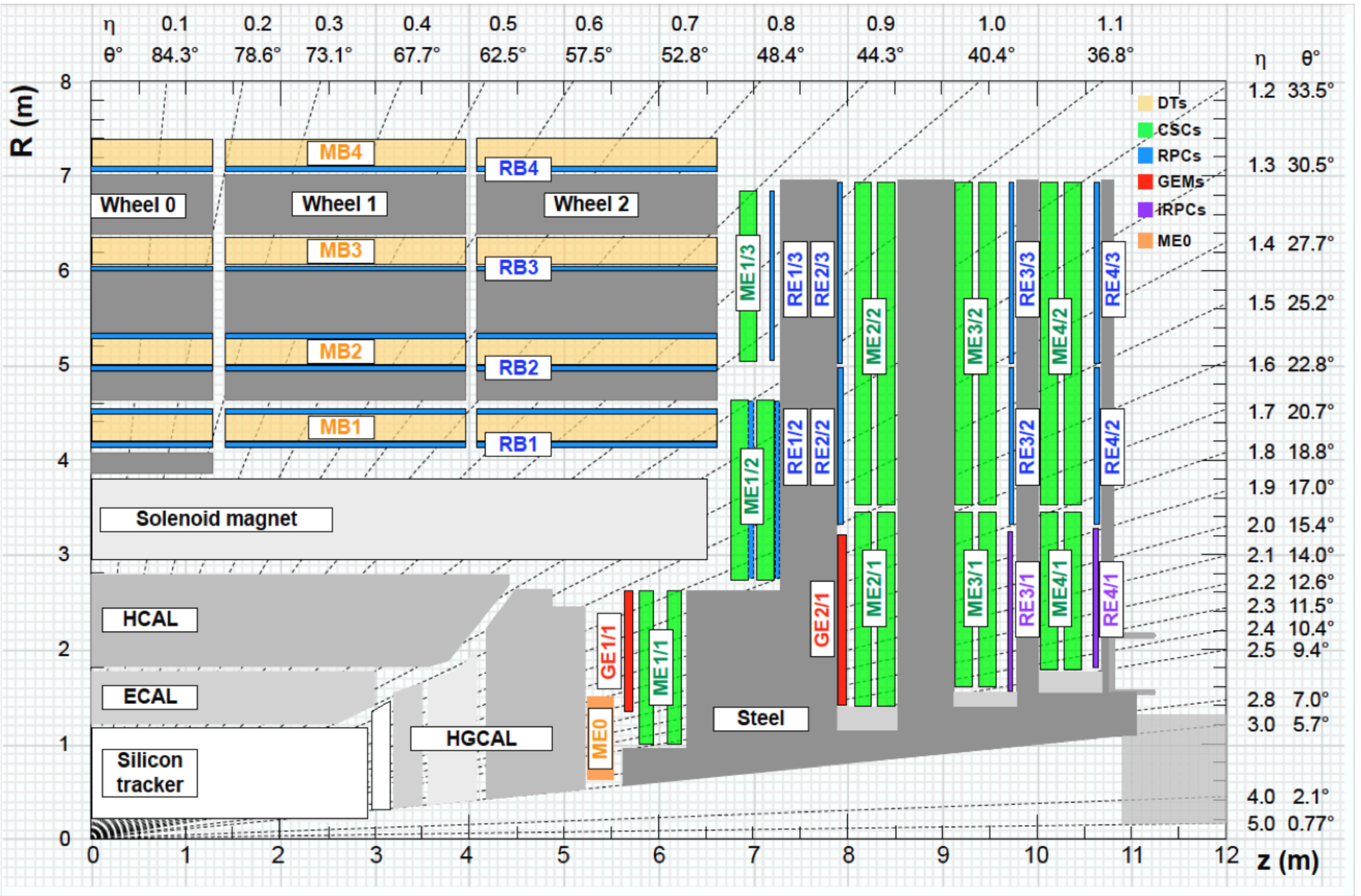


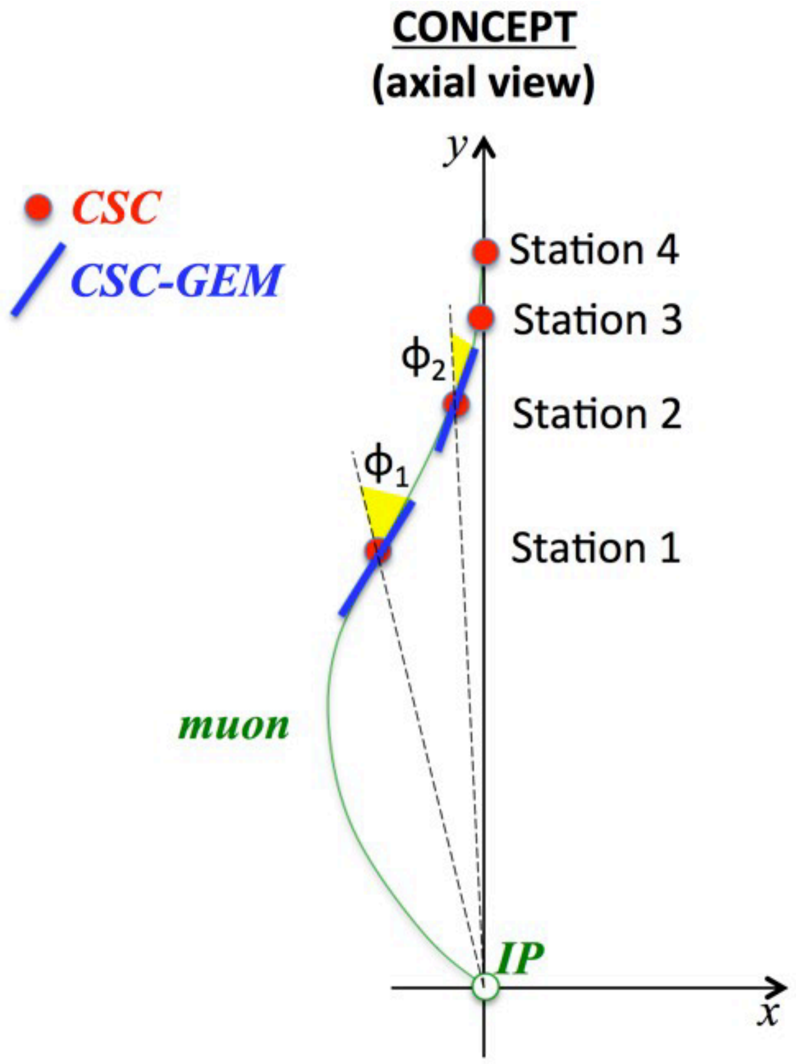
transverse momentum

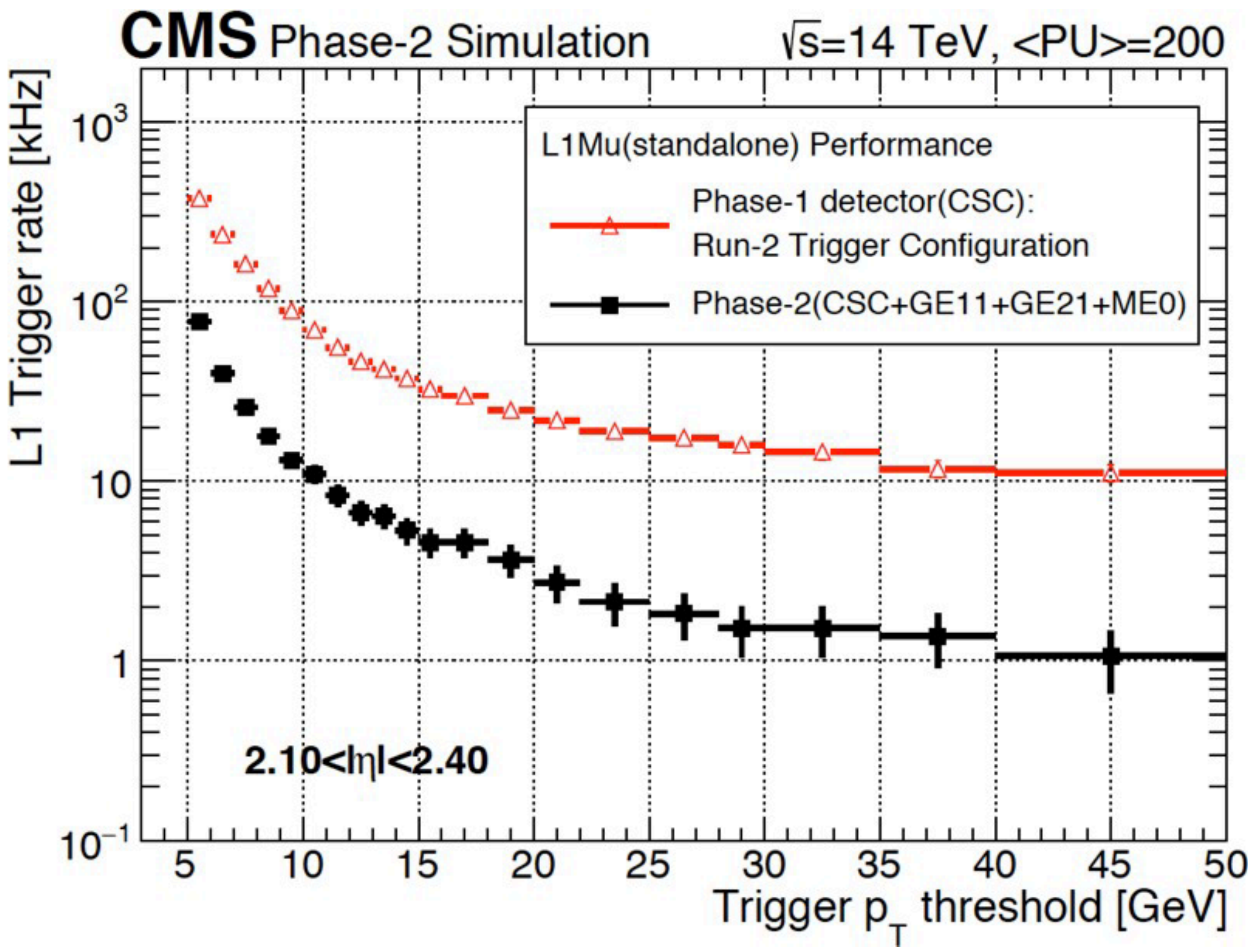


transverse impact parameter

Muon Detectors







Barrel and Endcaps

- Replacement of readout electronics for the new L1 trigger conditions

Endcaps

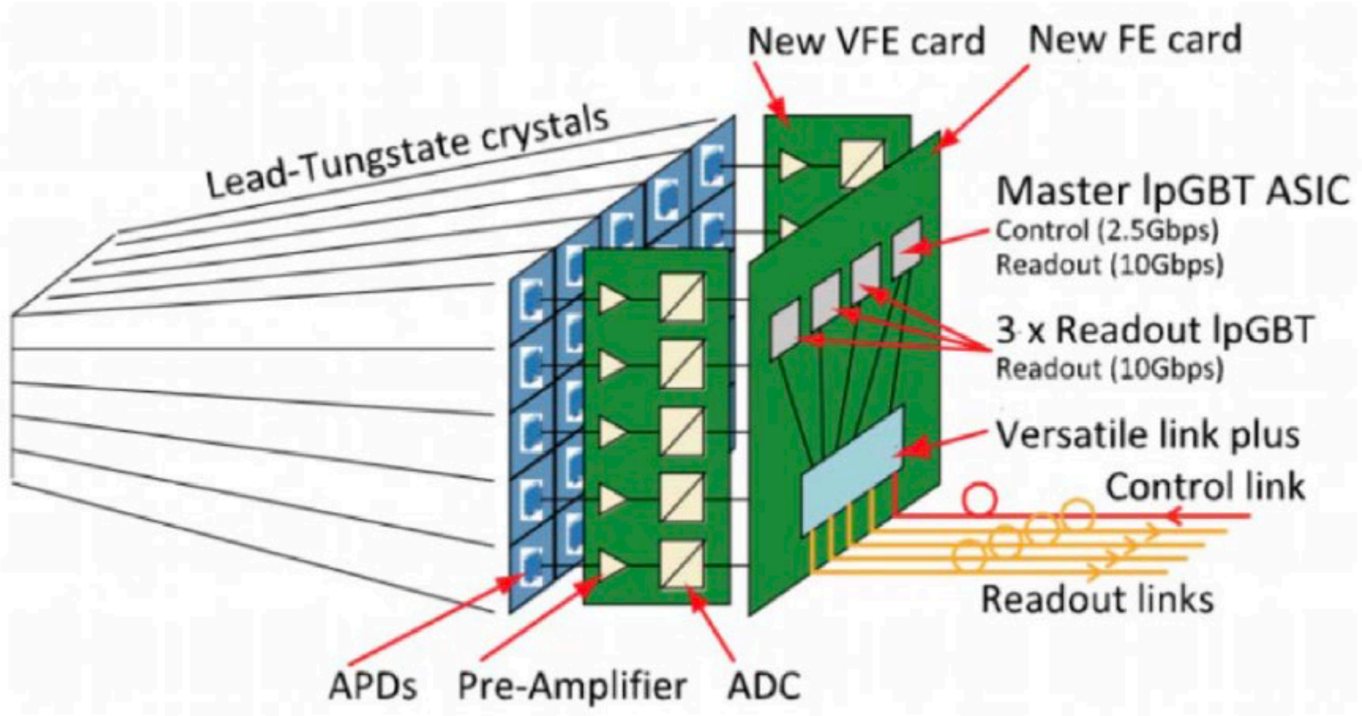
- Robust trigger up to |η| = 2.4 thanks to **RPC stations** RE3/1 and RE4/1 and 2-layer **GEM stations** GE1/1 and GE2/1
- Trigger extension up to |η| = 2.8 6-layer **GEM station** ME0

2 GEM/CSC "tandems"

- measurement of "local" μ direction (sensitive to p_T)
- standalone L1-trigger rate drops by factor up to 10
- important for off-pointing muon triggers (search for LLPs)

Calorimeters

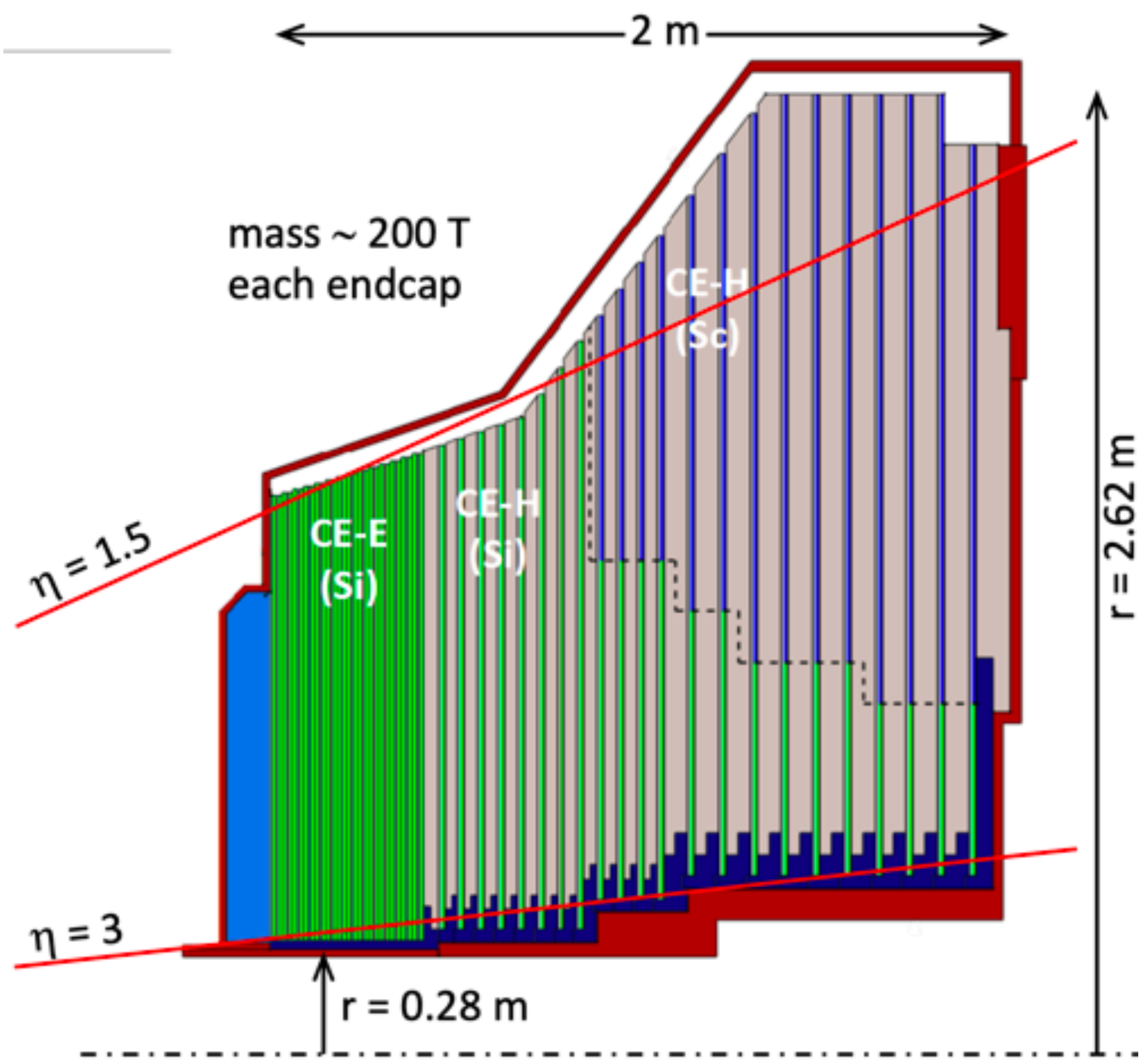
Barrel

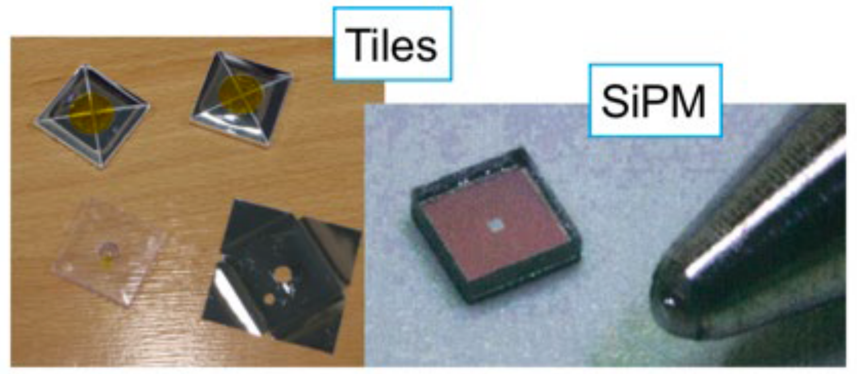


New ECAL on-detector electronics

- digitisation at 160 MHz
- online pulse shape discrimination against spikes
- trigger granularity = single crystal
- 30 ps time resolution ($E_\gamma > 50$ GeV)
- cooled at 9°C to mitigate APD ageing

Endcaps: High-Granularity Calorimeter (HGCAL)





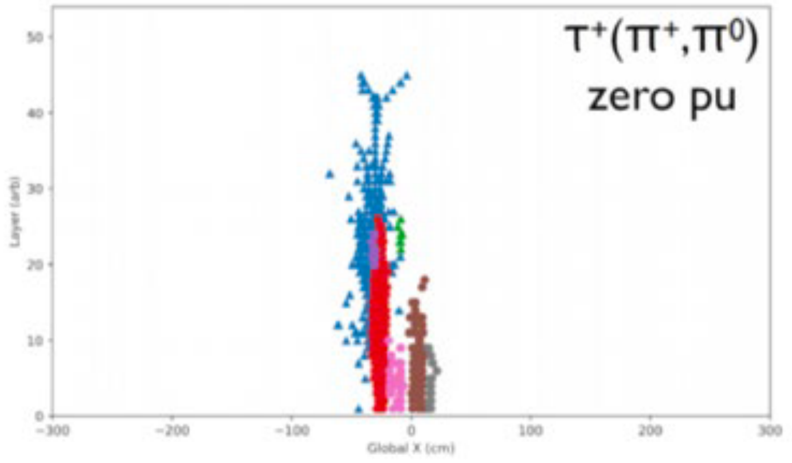
Electromagnetic (CE-E)

- Cu/CuW/Pb absorbers
- Si sensors, hexagonal modules
- 28 layers
- 25.5Xo and 1.7λ

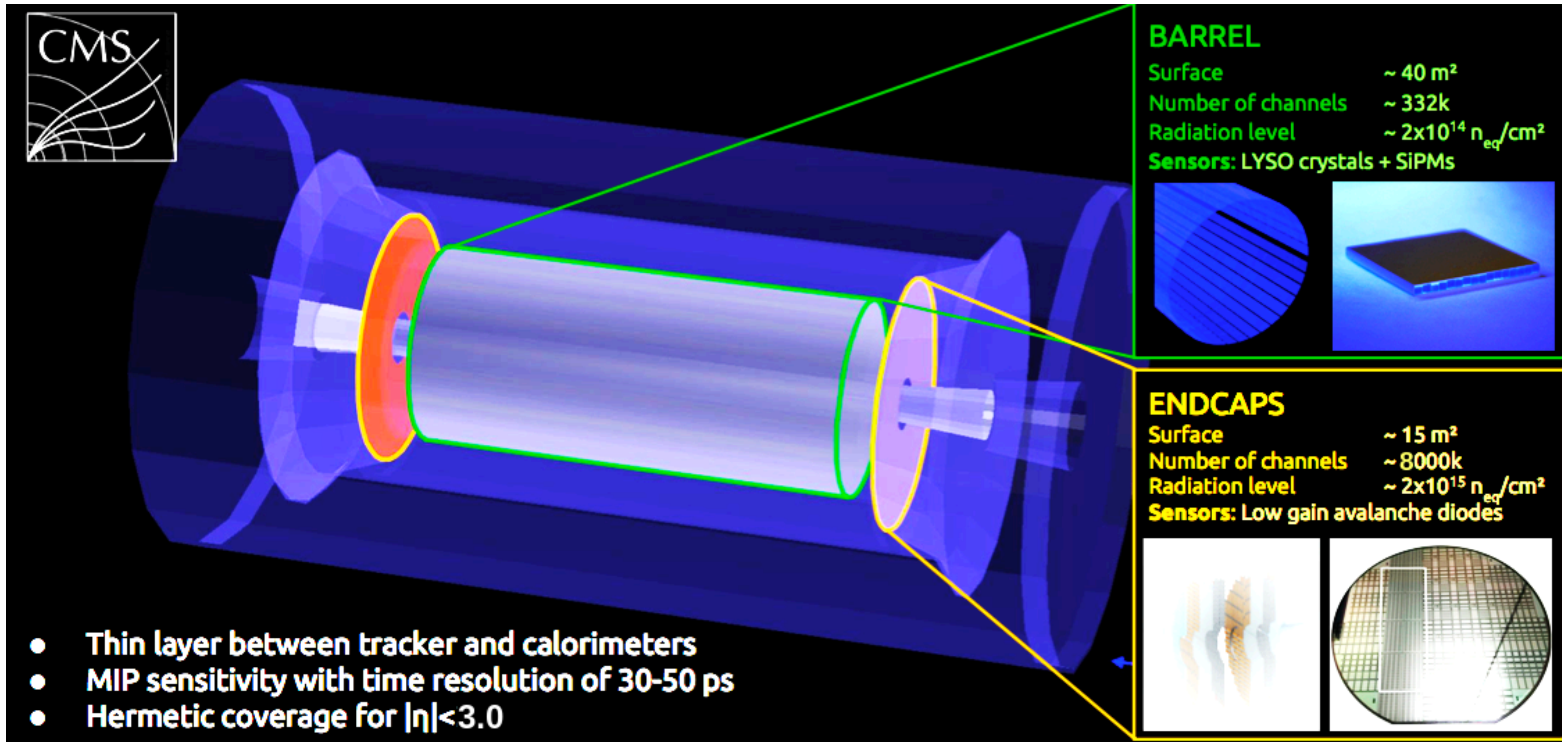
Hadronic (CE-H)

- steel absorbers
- High-radiation regions: Si sensors
- Low-radiation regions: scintillation tiles with SiPM readout
- 22 layers
- 9.5λ (including CE-E)

6M Si channels
240k scint. channels

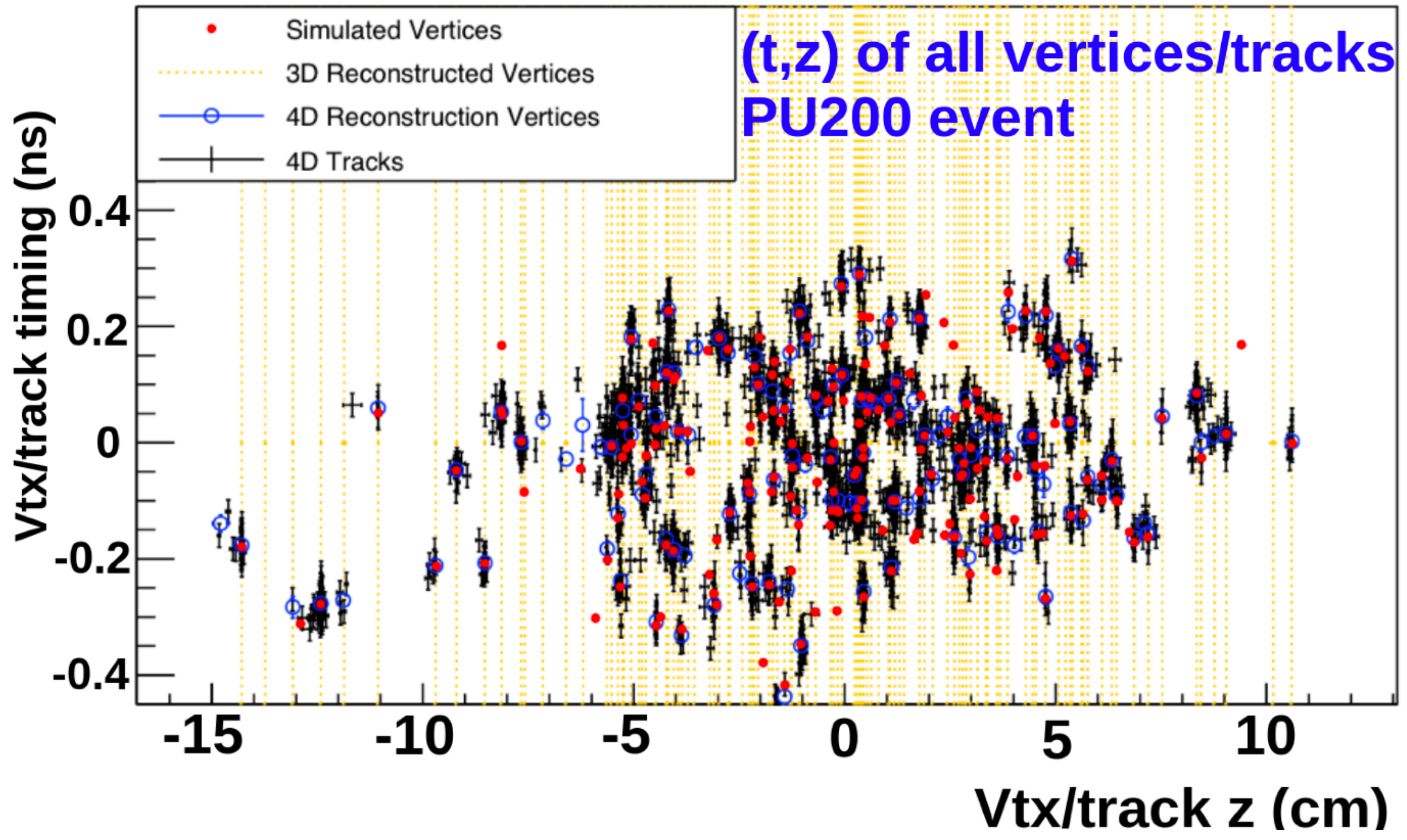


MIP Timing Detector



The MTD features

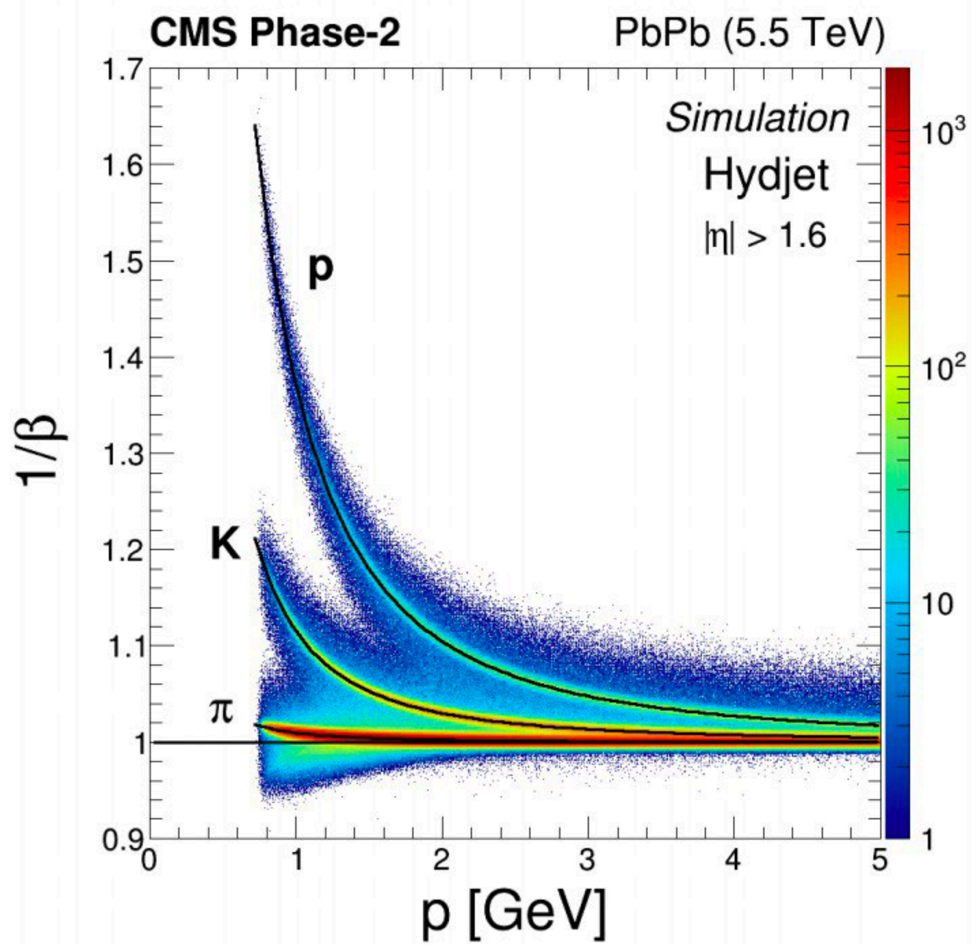
- a time resolution of 30-50 ps for MIPs
- a 4th dimension for PU rejection



Precise timing allows for the removal of spurious tracks from PU, this improving on

- lepton isolation and identification
- jet reconstruction and flavour tagging
- missing p_T reconstruction

Precise timing also offers time-and-flight identification at low momenta (relevant in HI)



The MTD uses well-established technologies

- Barrel:

  LYSO crystals with dual end SiPM readout
- Endcaps:

  Low Gain Avalanche Detectors (LGAD)