Introduction to CMS

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Two chapters

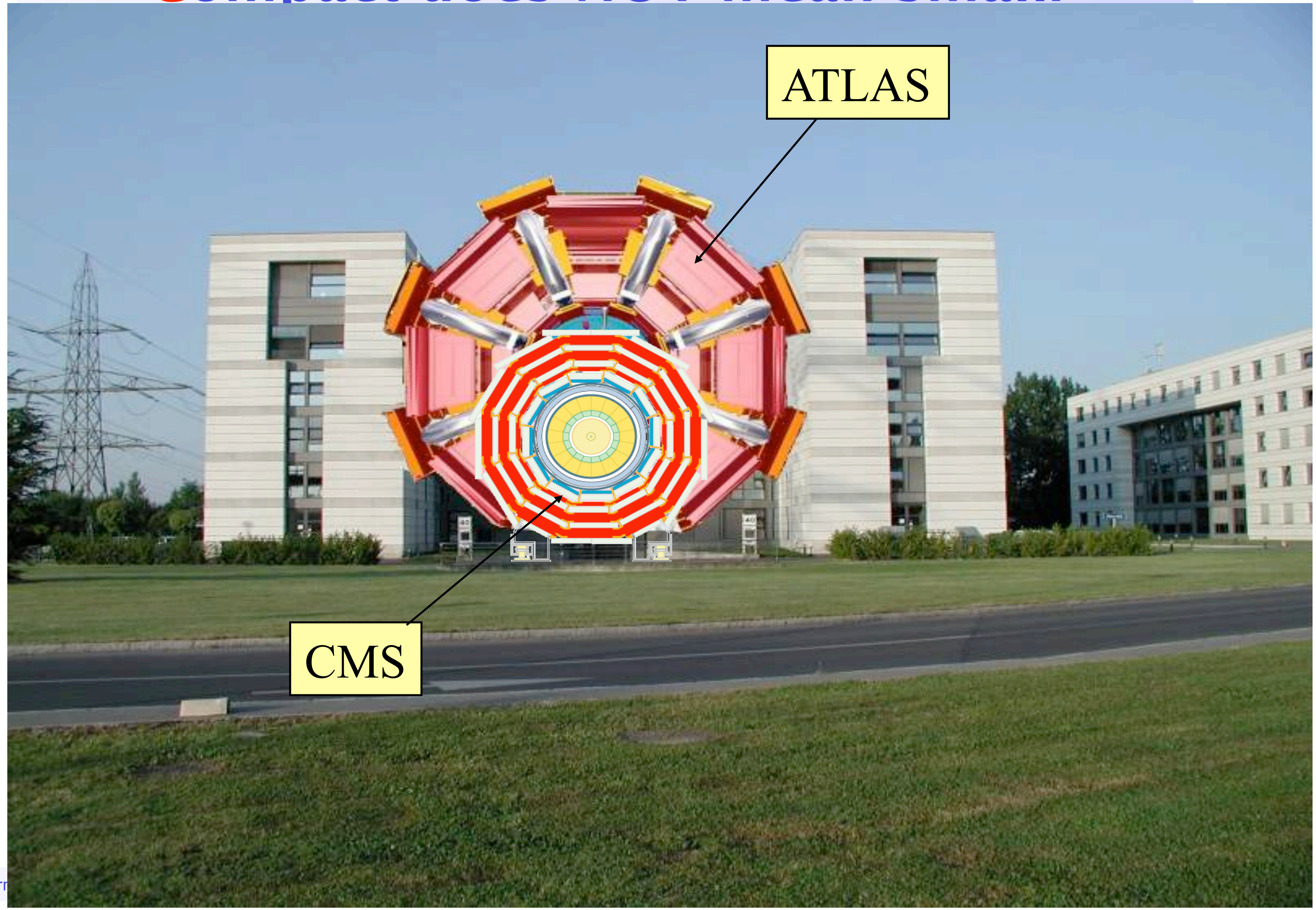
The CMS detector: concept

Status of the detector (as you'll see it tomorrow)

Selecting interesting events: the trigger

The CMS detector

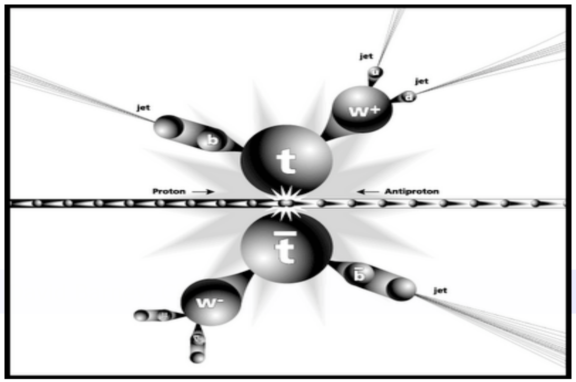
Compact does NOT mean small!

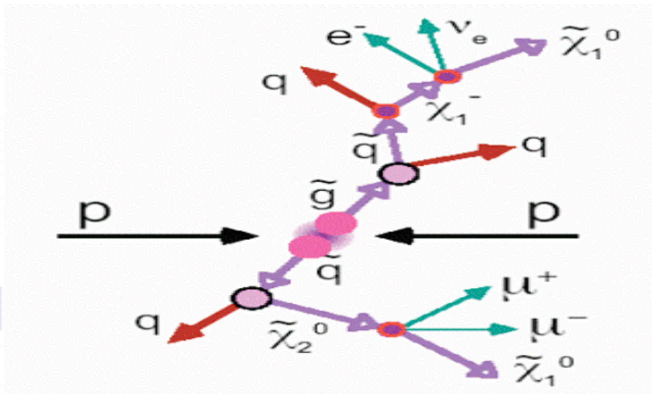


Muons are important

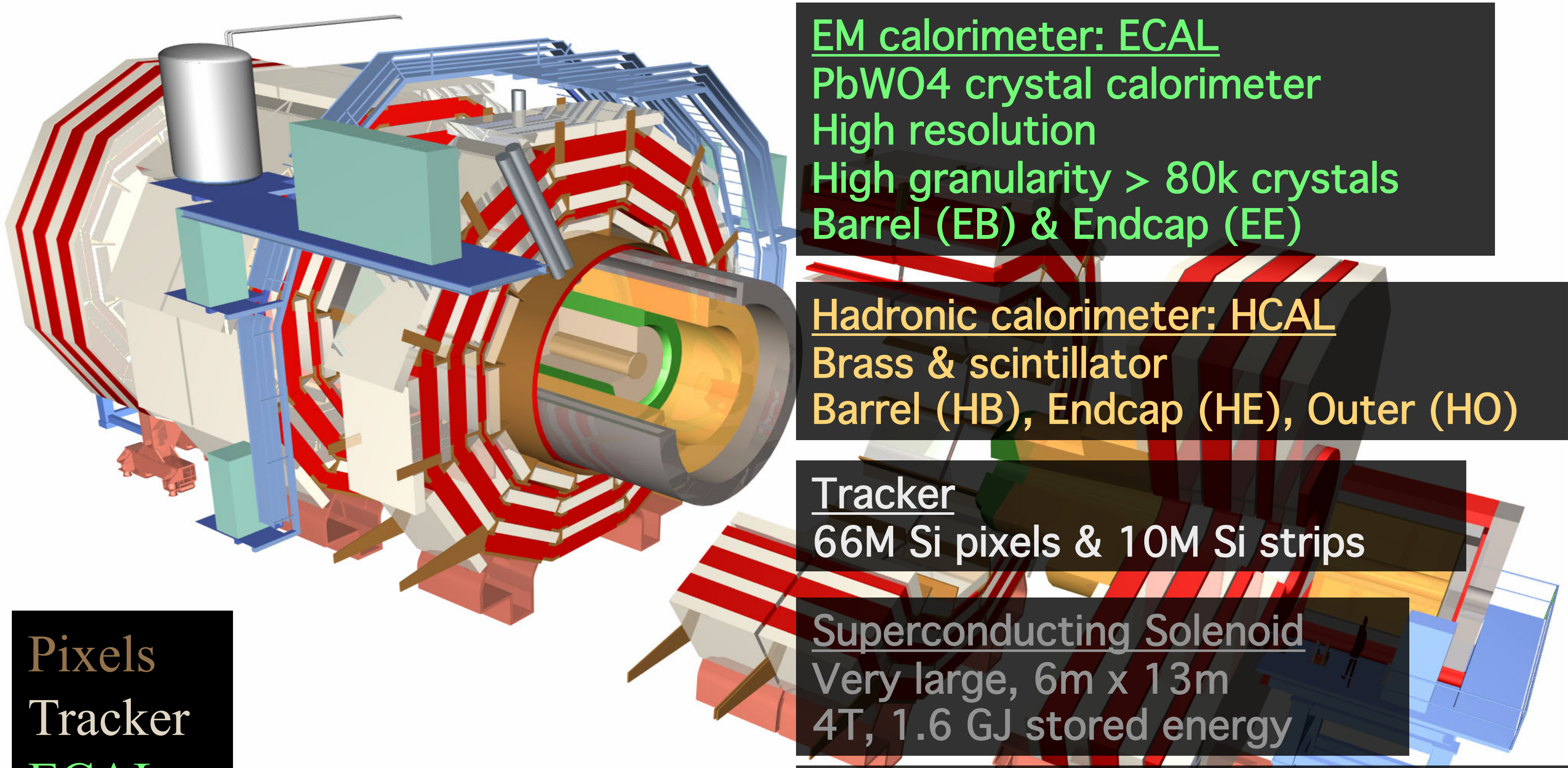
Physics Goals
CMS in 3 mins
CMS Detector
Tracker
ECAL
HCAL
Solenoid
MUON
Lowering
Point 5
Outside
Inside
Gallery
Underground
Resources
Q & A

- In CMS, high energy muons can only originate from the decay of a heavier particle – something that might be potentially interesting!
- Muons are easy to identify (see later)
  - Can quickly decide if we want to keep data from a collision or throw it away
- Interesting/unobserved particles decay very quickly to long(ER) lived or stable particles. Those:
  - Electrons, muons, hadrons, mesons, ptotons
- are to be directly detected to infer the presence of their interesting ancestors





The CMS Detector



EM calorimeter: ECAL
PbWO4 crystal calorimeter
High resolution
High granularity > 80k crystals
Barrel (EB) & Endcap (EE)

Hadronic calorimeter: HCAL
Brass & scintillator
Barrel (HB), Endcap (HE), Outer (HO)

Tracker
66M Si pixels & 10M Si strips

Superconducting Solenoid
Very large, 6m x 13m
4T, 1.6 GJ stored energy

Muon System
Barrel: Drift Tubes (DT)
Endcap: Cathode Strip Chambers (CSC)
Barrel & Endcap interleaved with Resistive Plate Chambers (RPC)

Pixels
Tracker
ECAL
HCAL
Solenoid
Muons

Compact, Modular
Weight: 12500 t
Diameter: 15m
Length: 21.6 m

ATLAS vs CMS (the magnets!)

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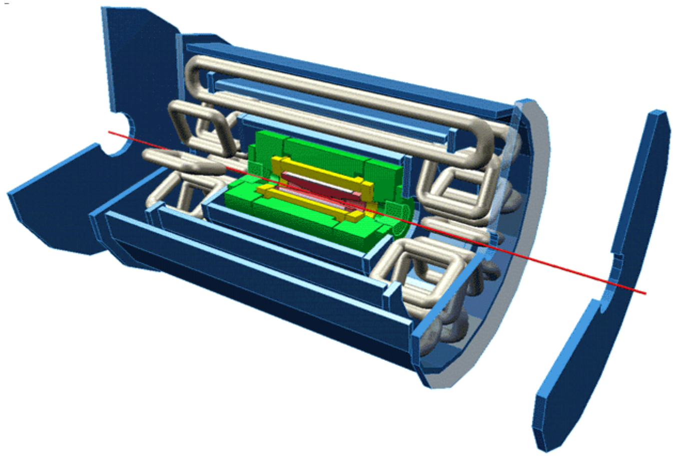
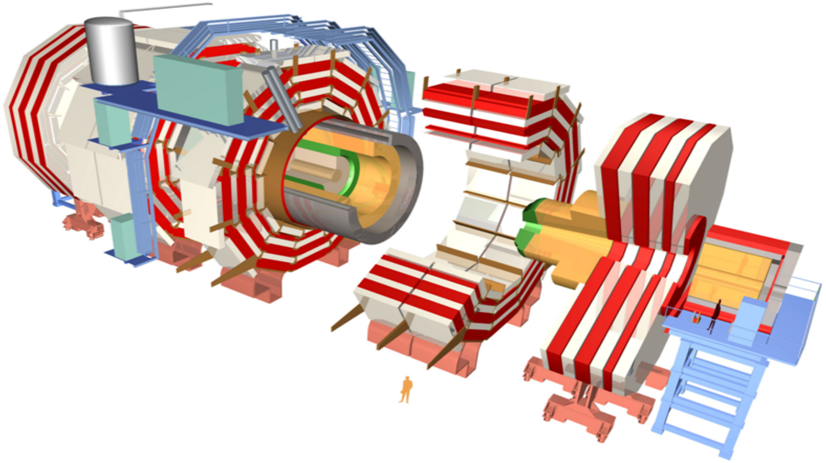
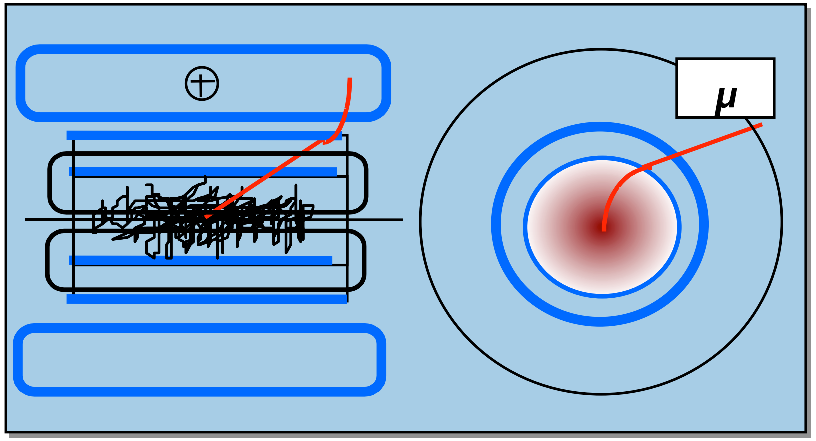
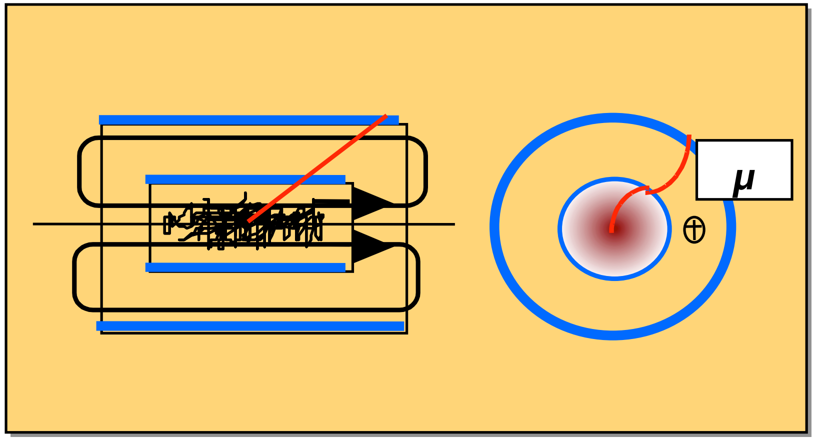
ATLAS A Toroidal LHC Apparatus



CMS Compact Muon Solenoid







Charged particles “bend” in a magnetic field; the amount they bend tells us ~ how fast they are travelling

Components of CMS: the TRACKER

Physics Goals

CMS in 3 mins

CMS Detector
- **Tracker**
- ECAL
- HCAL
- Solenoid
- MUON
- Lowering

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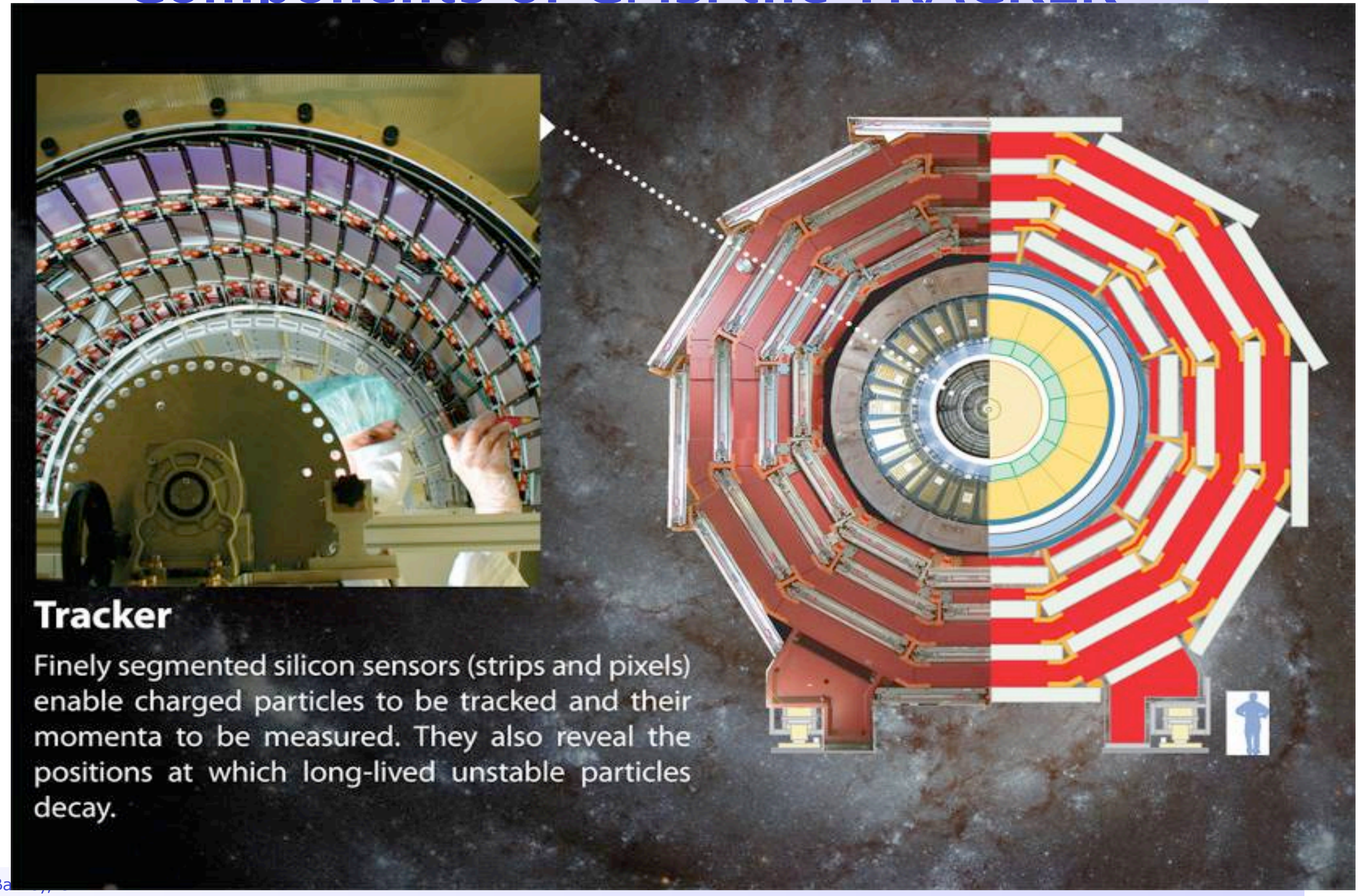
Q & A



Numbers & Status: TRACKER

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- Largest silicon-sensor system ever made
  - More than 220m^2 of sensors
  - More than 60 million electronics channels (pixels and microstrips)
  - 6m long, ~2.2m diameter, operates at -15^{o}C
- Status
  - Strip tracker is completely built; installed since early 2008
  - Pixel detectors complete and installed since spring 2008

Components of CMS: the ECAL

Physics Goals

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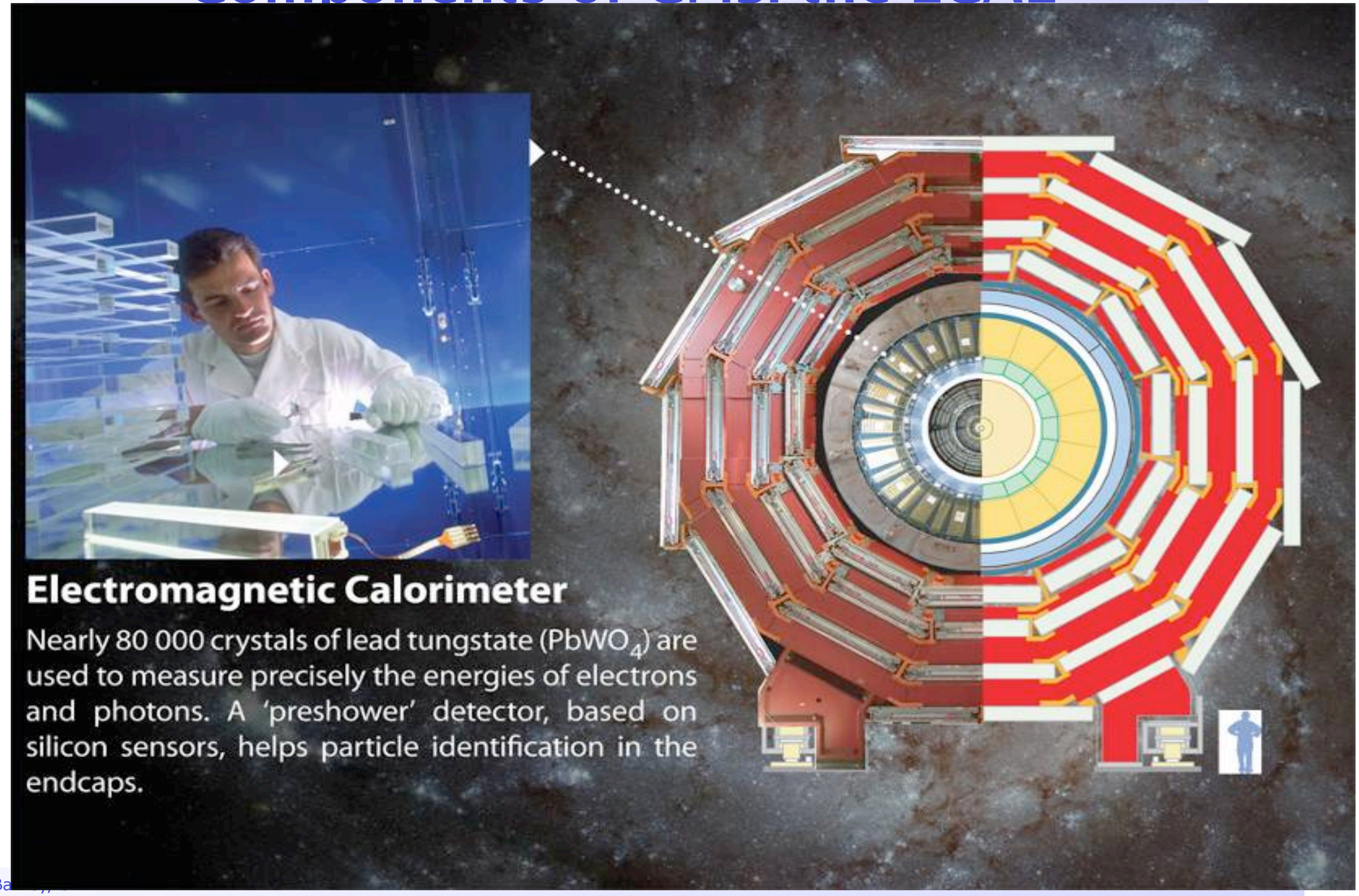
Q & A



Numbers & Status: ECAL

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- Homogeneous calorimeter
  - Lead tungstate ($PbWO_4$) crystals create electromagnetic showers and produce scintillation light
  - Barrel: ~64000 crystals constructed in 36 "supermodules" (1700 crystals each); light detected by avalanche photodiodes
  - Endcaps: ~16000 crystals constructed as "supercrystals" – 5x5 arrays; light detected by vacuum phototriodes
- Status
  - All barrel and Endcap part to be installed by 2008.
  - Preshower just been installed:
    - Silicon device, tracking and calorimeter at the same time
    - Last piece installed in CMS

Components of CMS: the HCAL

Physics Goals

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- **HCAL**
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- MUON
- Lowering

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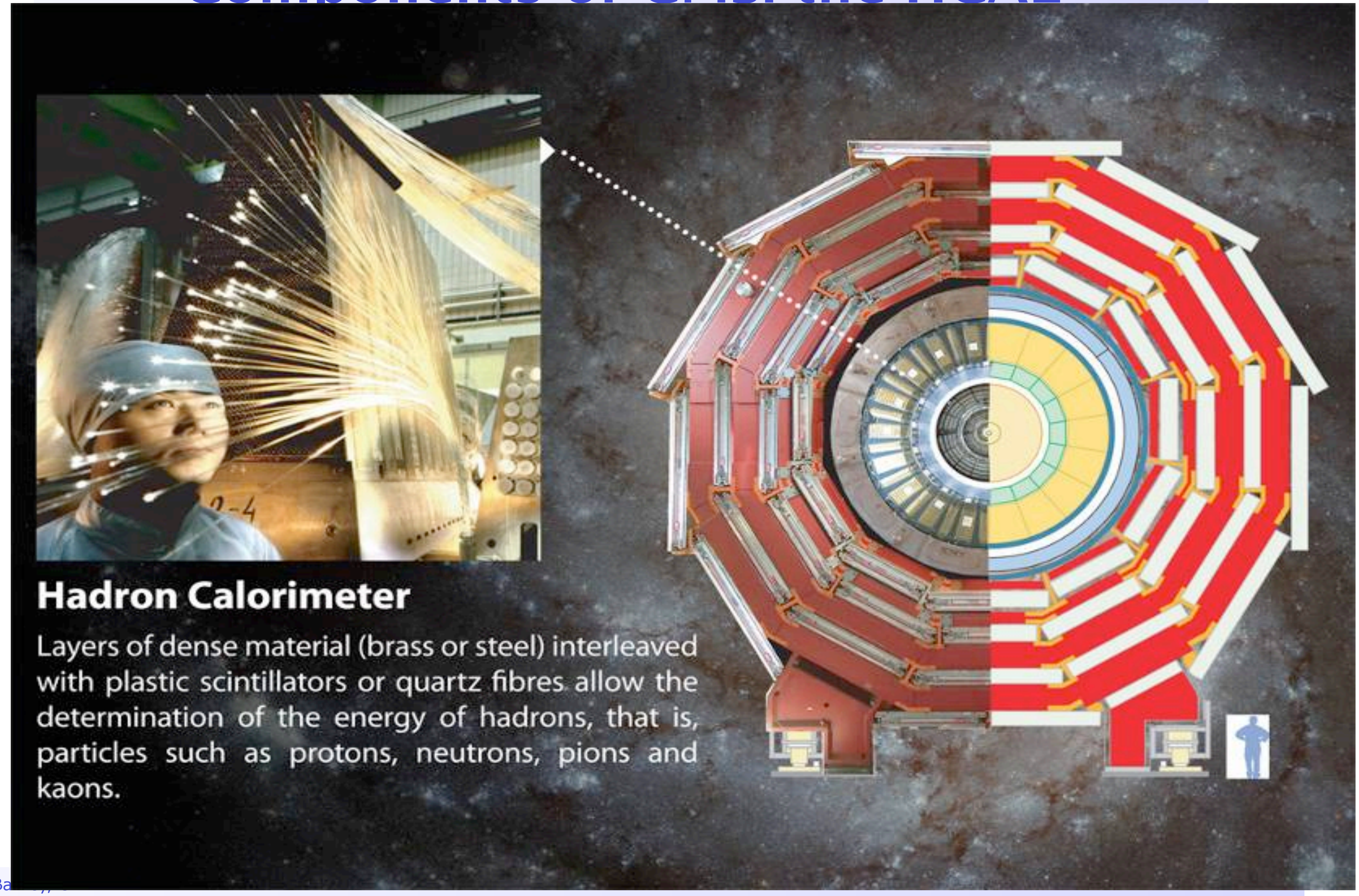
Q & A



Numbers & Status: HCAL

Physics Goals

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Q & A

Three parts to the puzzle

- Barrel HCAL made of 36 brass wedges, each of which is ~35 tonnes
- Endcap HCAL made from brass recuperated from Russian military
- Forward HCAL (known as HF) made from steel embedded with quartz fibres

Status

- Barrel and Endcaps installed
- HF first objects to be lowered into the cavern; also first parts to be commissioned with cosmic rays

Components of CMS: the SOLENOID

Physics Goals

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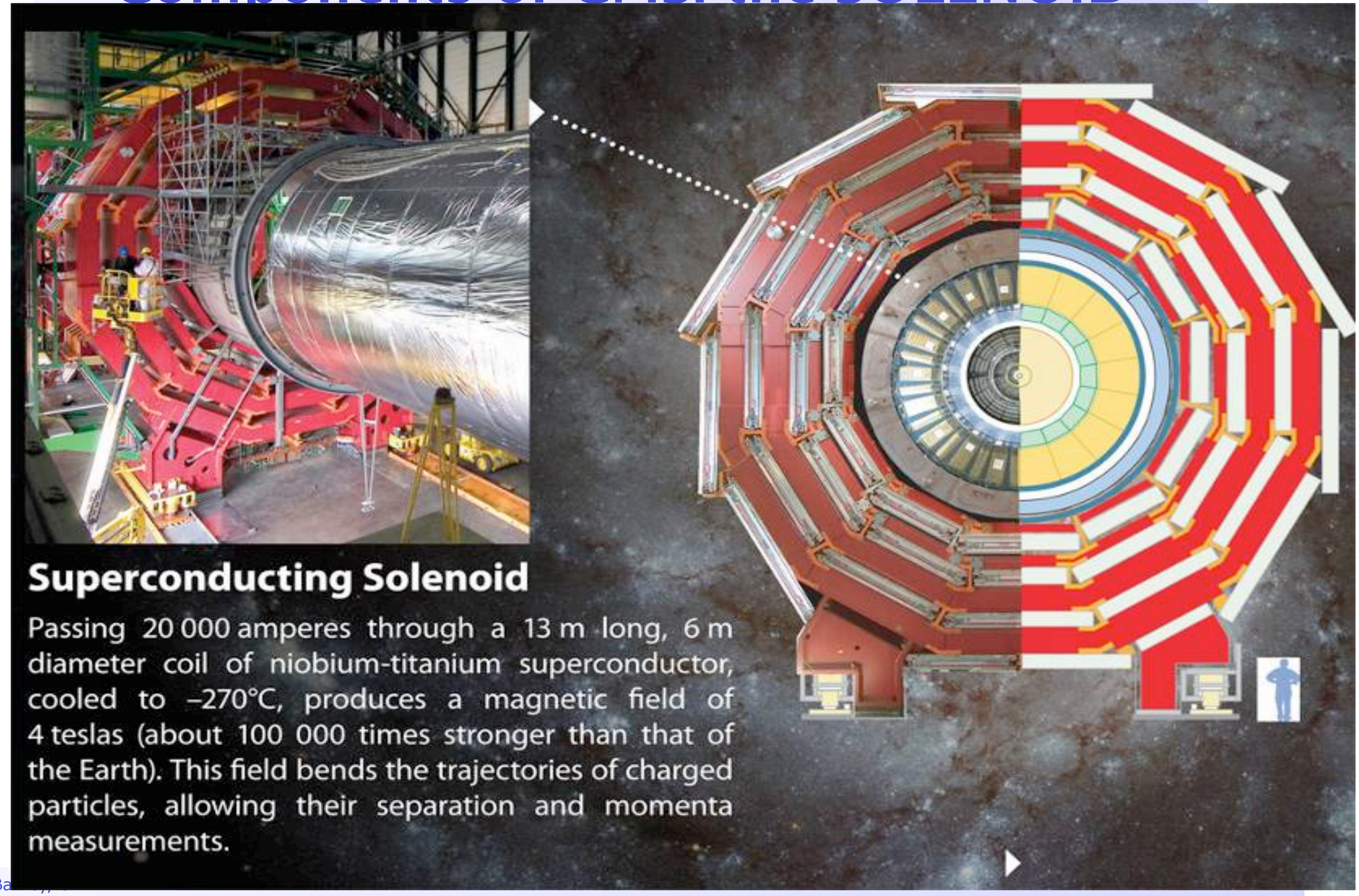
Q & A



What is a Solenoid?

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- A solenoid is essentially a cylinder of wire. Passing an electric current down the wire creates a magnetic field
- The CMS solenoid is designed to provide an axial magnetic field of 4 teslas – about 100000 times that of the earth
- The current required is ~20 k amperes → need to use a superconducting wire (zero resistance)
- The superconductor chosen is Niobium Titanium (NbTi) wrapped with copper – needs to be cooled to ~4K
- The CMS solenoid is 13m long with an inner diameter of 5.9m
- The solenoid is sufficiently large that the tracking and all central calorimeters can fit inside
  - The full potential of the inner detectors can be realised
- Charged particles only bend in one projection (looking along the beam line – see next page)
  - Makes life easier for the physicist!

Numbers & Status: Solenoid (1)

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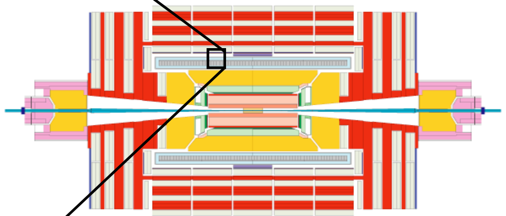
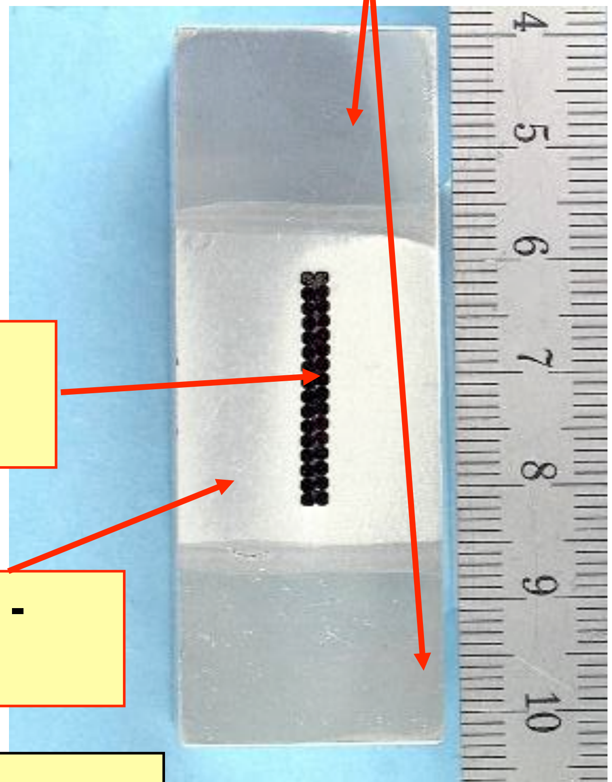
Solenoid piece at Cessy





Aluminium alloy - mechanical stabilizer

Superconducting cable - NbTi

Ultra-pure Aluminium - magnetic stabilizer

Approx: 1 million km of NbTi filaments!

http://cmsinfo.cern.ch/outreach/CMSdocuments/MagnetBrochure/MagnetBrochure.pdf

Transporting and constructing the solenoid

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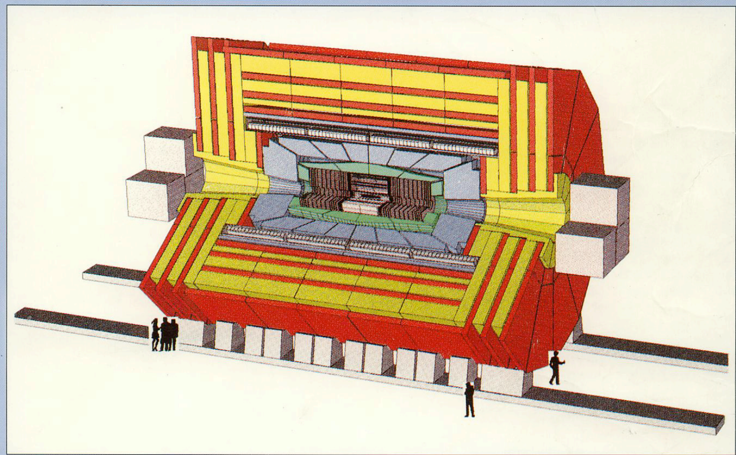
It’s happening (aka: commissioning)

LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES

CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CMS

The Compact Muon Solenoid

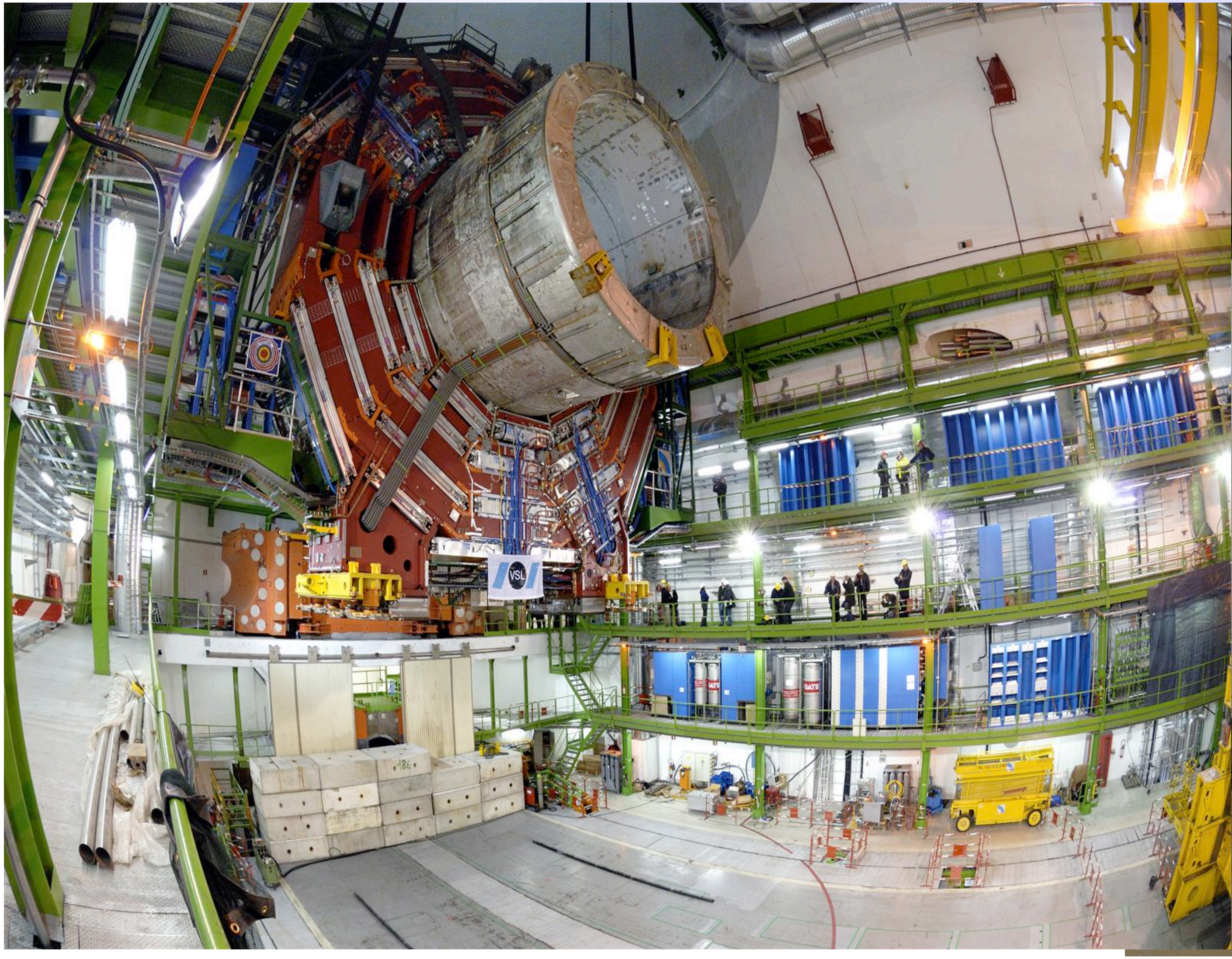


Letter of Intent

CERN/LHCC 92-3
LHCC/I 1
1 October 1992

Safety: foam test

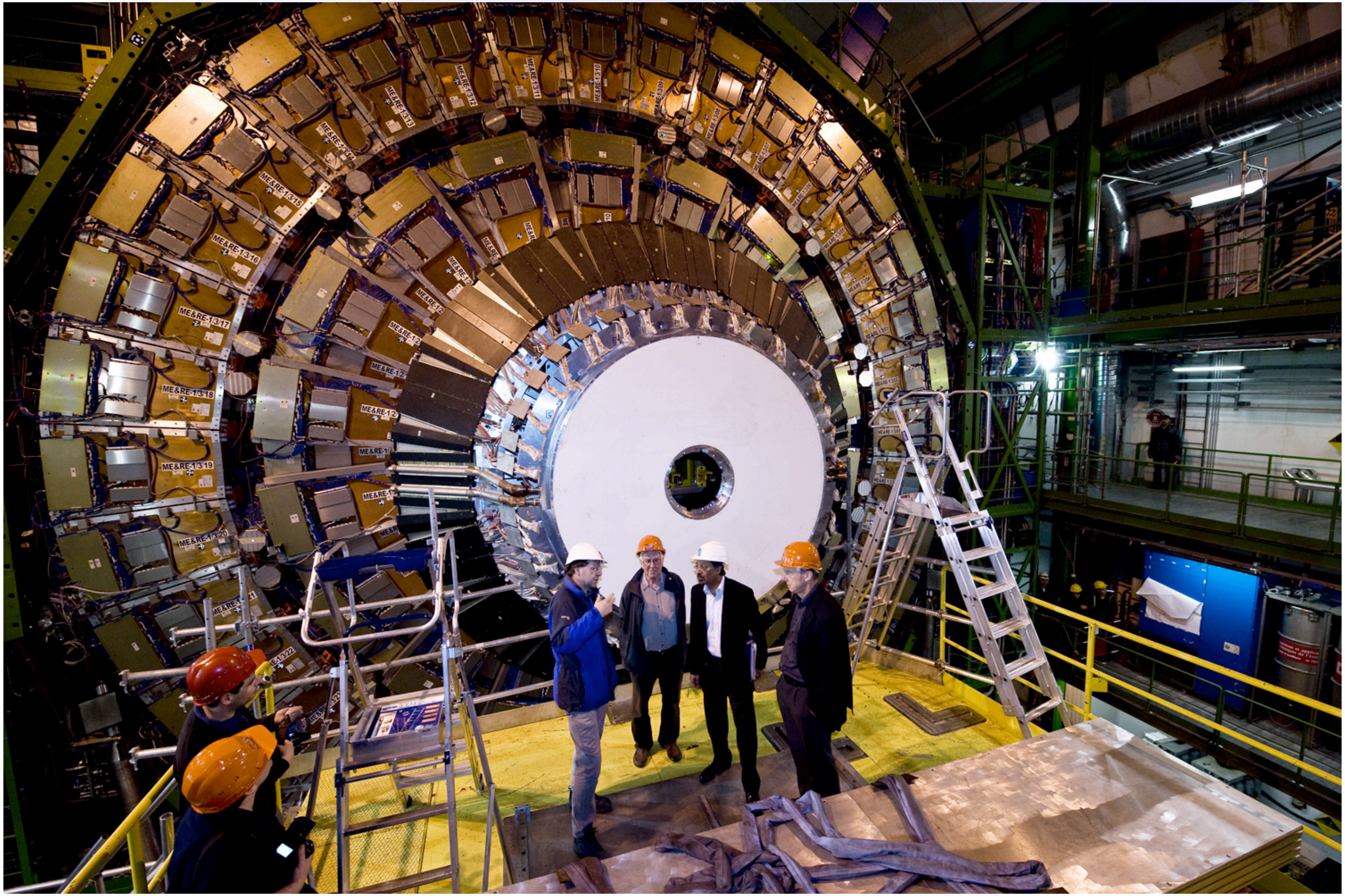
The lowering



The commissioning

Integrating all the systems and “making CMS happen” is a huge ongoing effort, downstairs at the pit every day. A significant fraction of the collaboration involved in getting the whole system running, tuned, in shape for collisions expected this year

CERN open day



Routing of ES services:

Tower racks (LV)

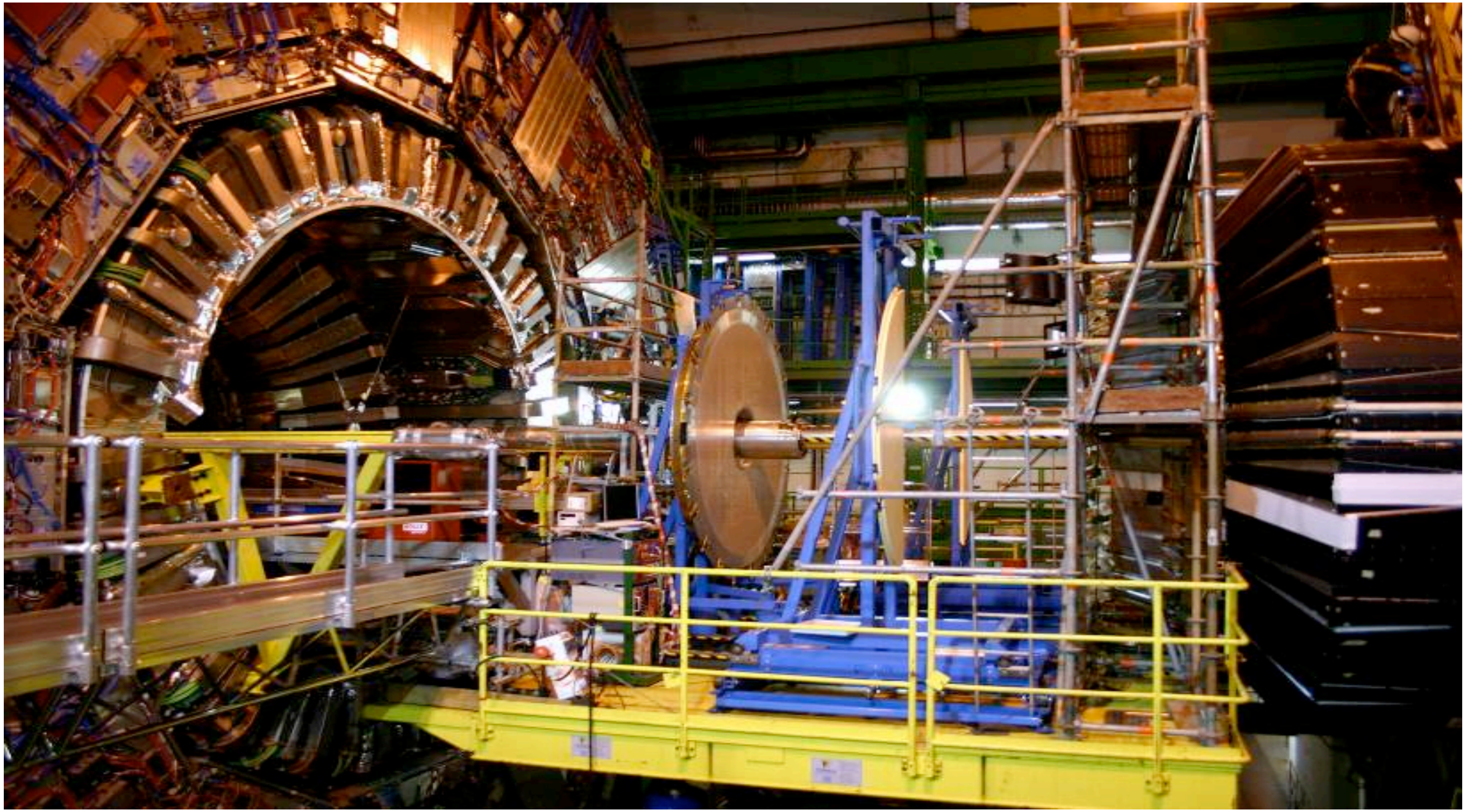
ES

Cables (1.run) from ES to IPP/tower racks

Intermediate ppanel (IPP) (start of cable chain) at feet of YE1

Installation sequence (4)

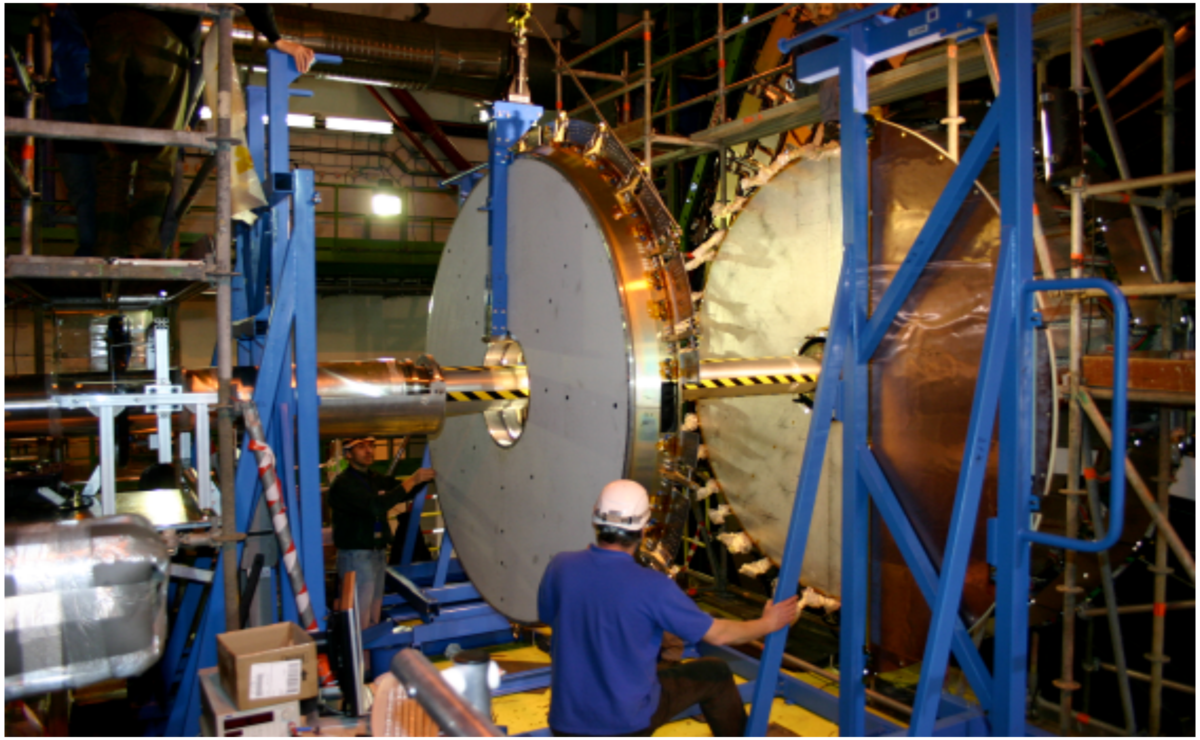
Closing ES in parking position with rear window:



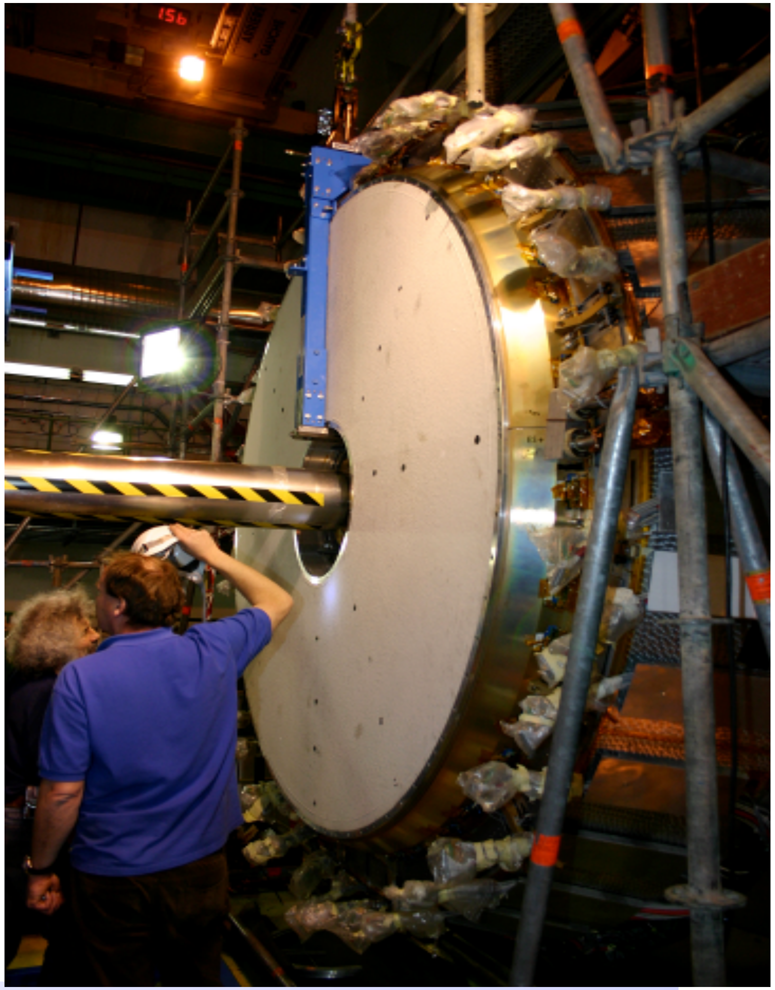
Completed ES assembly in parking position

Installation sequence (5)

Installation of ES in final position on EE:



Transporting ES towards EE

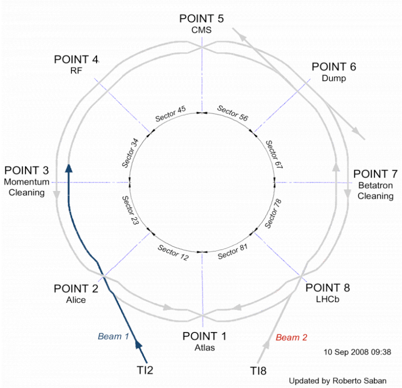


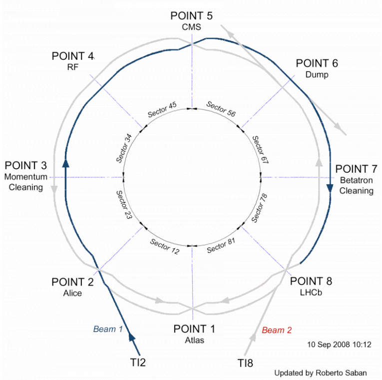
ES attached to support cone

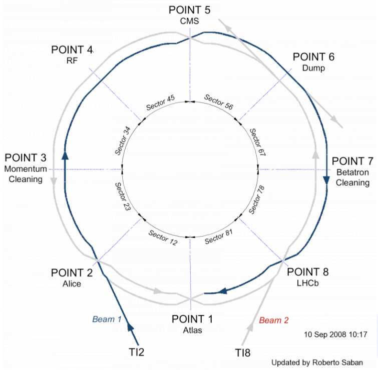
Running:

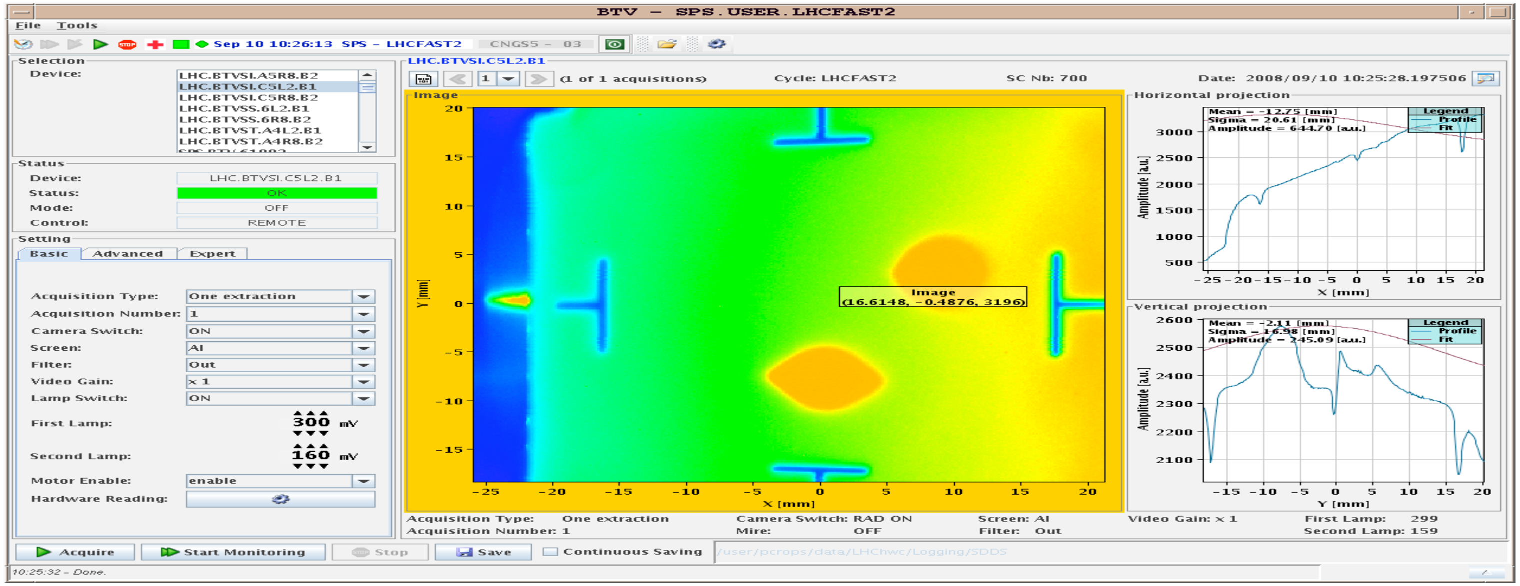
2008-now

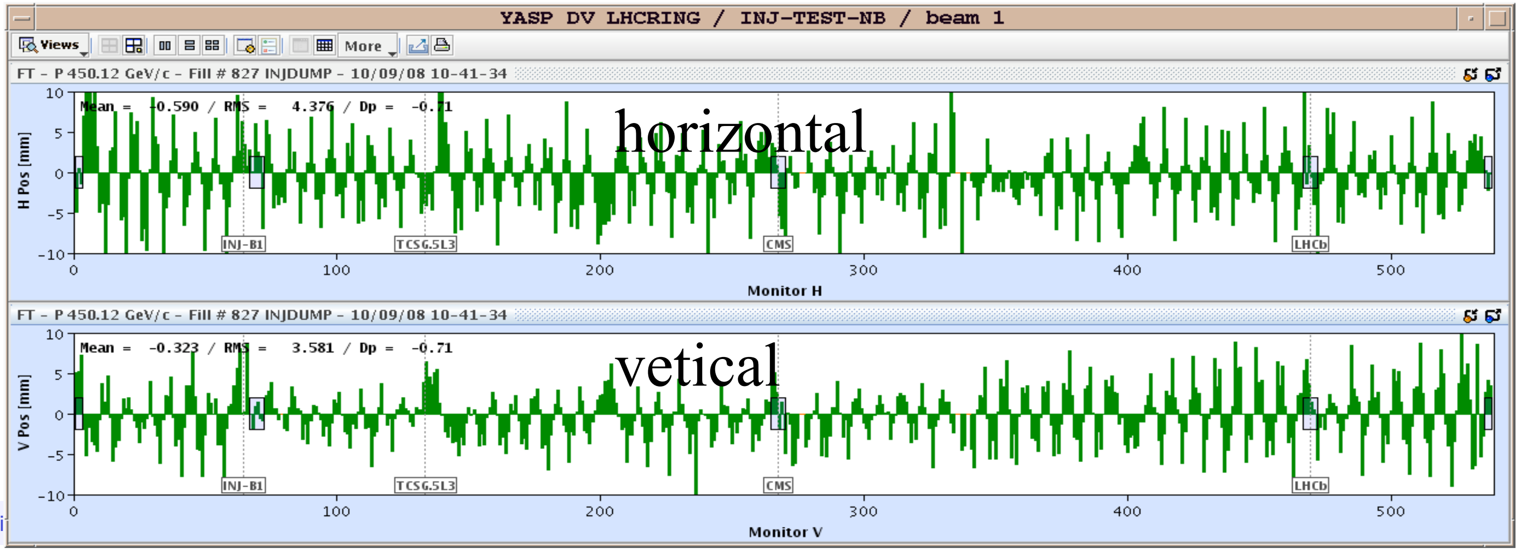
Sept 10th: beams find their way











September 10th excitement

L'ESPERIMENTO DEL CERN

Parte il test del Big Bang a Ginevra, festa e applausi per gli scienziati | Foto

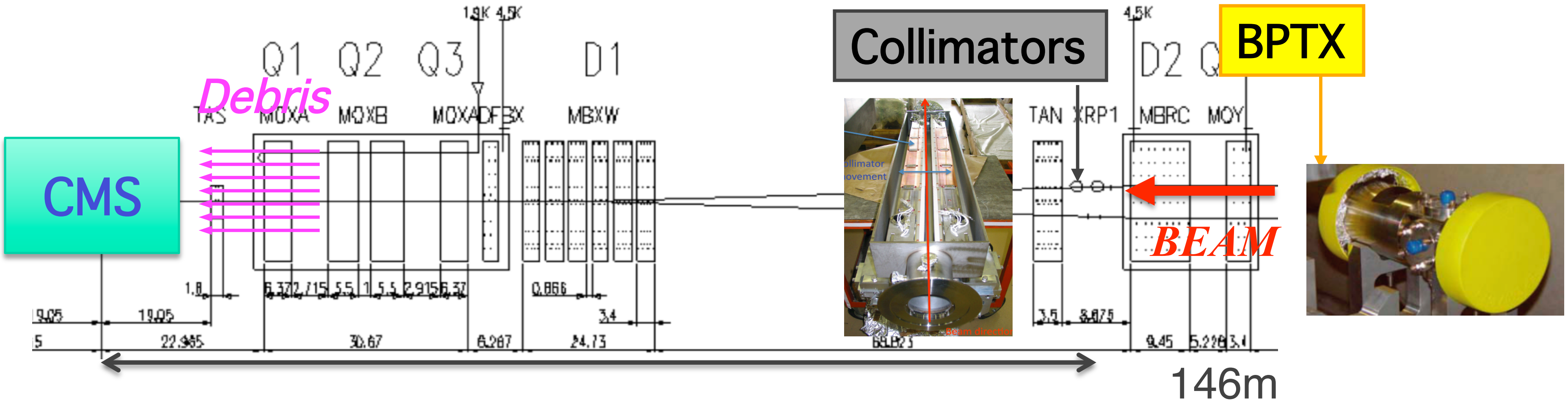
08:44 | SCIENZE | Al via il progetto più ambizioso della fisica moderna, alla ricerca della «particella di Dio». I primi scontri tra nubi di protoni a novembre. Ma Monsignor Sgreccia frena gli entusiasmi sulla particella Higgs: «Dio non si può trovare con gli esperimenti» *Caprara* Video

- Scheda - Il ritorno alle origini dell'universo e le prime stelle
- Il Cosmo visto con gli occhi di Spinoza *di Giulio Giorello*
- Video - L'avventura di Lhc: ecco come funziona e a che serve
- L'Istituto di fisica nucleare: «Nel mondo miliardi di Lhc naturali»

Video · Il blog - Guarda le vignette · Vota

Beam Splash Events

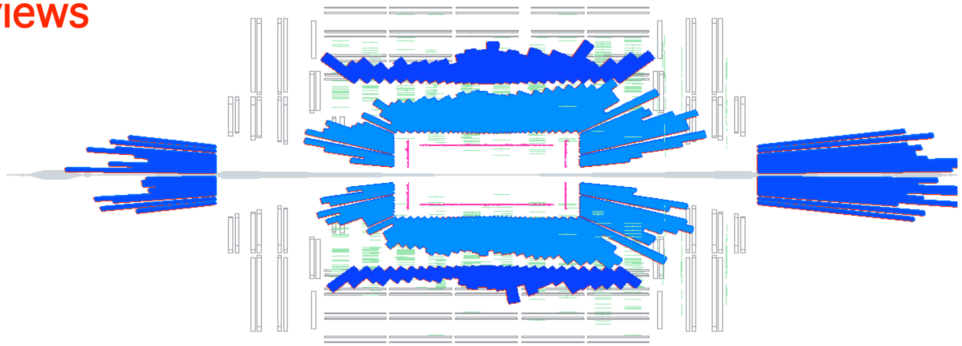
- **Single beam shots of 2*10⁹ protons onto closed collimators ~150m upstream of CMS**
  - Hundreds of thousands of muons pass through CMS per event
  - Enormous amount amount of energy deposited in calorimeters
- Allowed synchronization of triggers (previously with cosmic muons)
  - Muon end caps, BPTX beam time pick up, etc
- Internal synchronization of sub-detectors



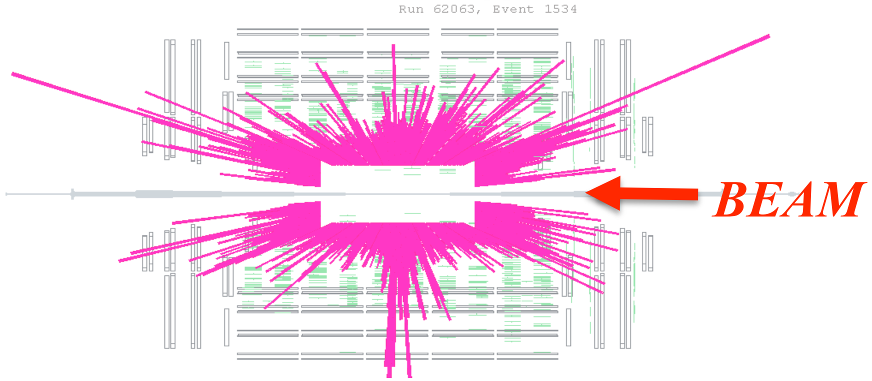
Beam Splash Event Display

Longitudinal views

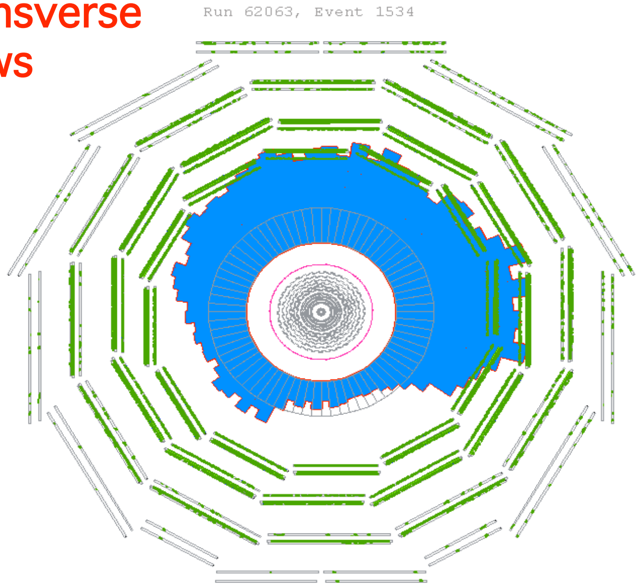
HCAL energy



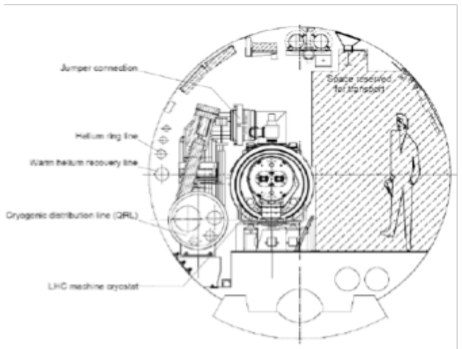
ECAL energy



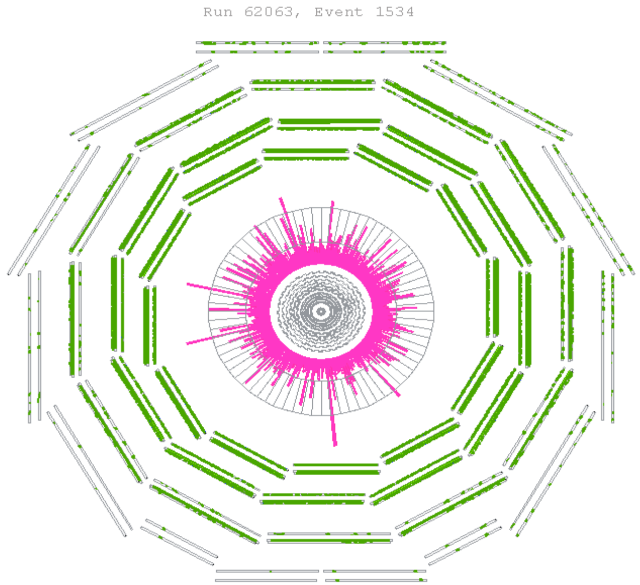
Transverse views



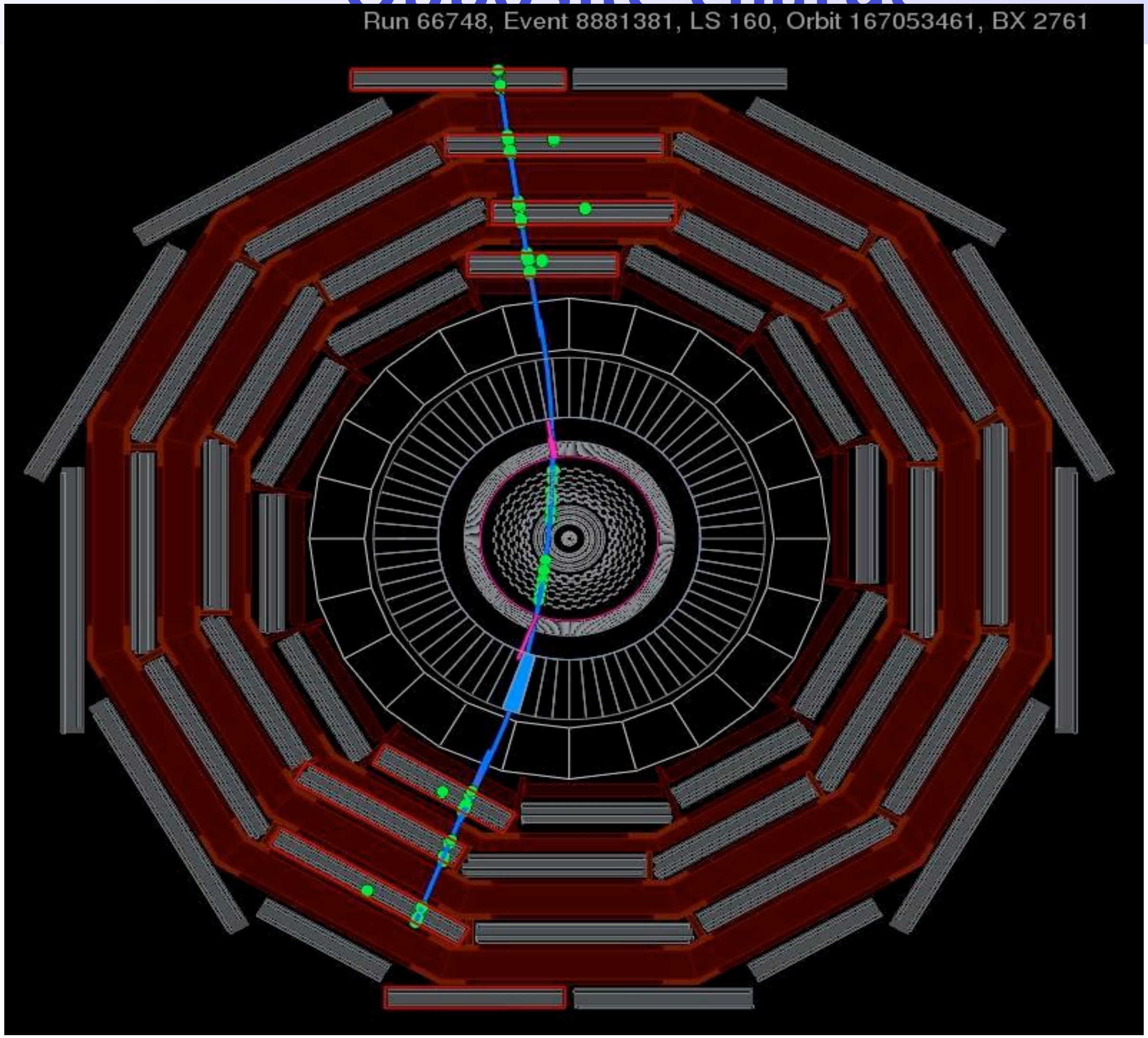
DT muon chamber hits



LHC Tunnel profile visible



Opposite charge



- ECAL in magenta, HCAL in blue, tracker and muon hits in green

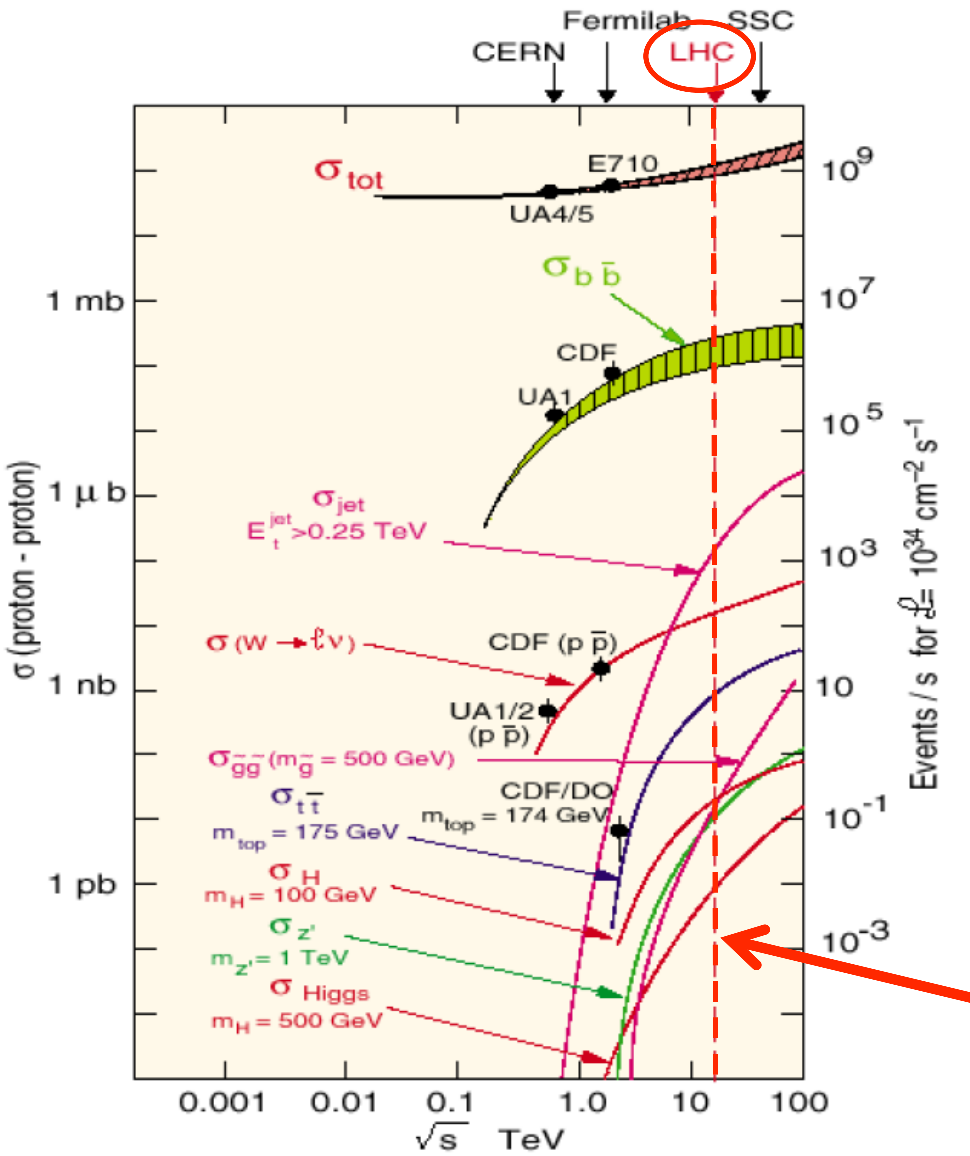
Selecting interesting collisions: the ‘trigger’

What are we trying to do?

- Find the most interesting physics signals at LHC
- Store them for off-line processing

What do we expect to see?

$$\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$



You are here

Process	σ (nb)	Production rates (Hz)
Inelastic	10^8	10^9
$b\bar{b}$	5×10^5	5×10^6
$W \to \ell\nu$	15	100
$Z \to \ell\ell$	2	20
$t\bar{t}$	1	10
H(100 GeV)	0.05	0.1
Z' (1 TeV)	0.05	0.1
$\tilde{g}\tilde{g}$ (1 TeV)	0.05	0.1
H(500 GeV)	10^{-3}	10^{-2}

What is the problem?

1) We don't keep all these events → Selection
2) Old Physics happens more often than New Physics
3) New Physics buried under a tons of Old/known Physics

We don’t keep all these events

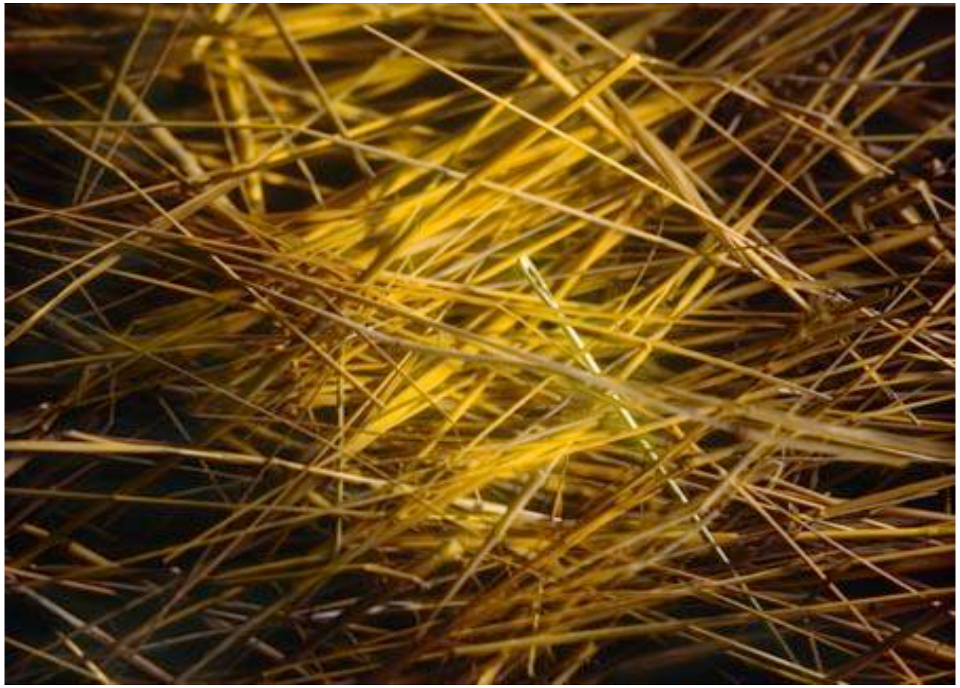
- How many do we keep? About 150-300 Hz

- Why only so few? Not enough resources!
  - 300 Hz at 1-2 MB/event → Up to 36 GB per minute
  - Up to 6´000´000 GB of storage needed per year
  - Plus: about 30 secs to reconstruct every event off-line

- “Interesting” physics occurs at ~10, 1 or < 1 Hz
  - We are only interested in a (tiny) fraction of all events
  - We *don’t* really want to keep all these events

Old Physics: more likely than New Physics

$\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



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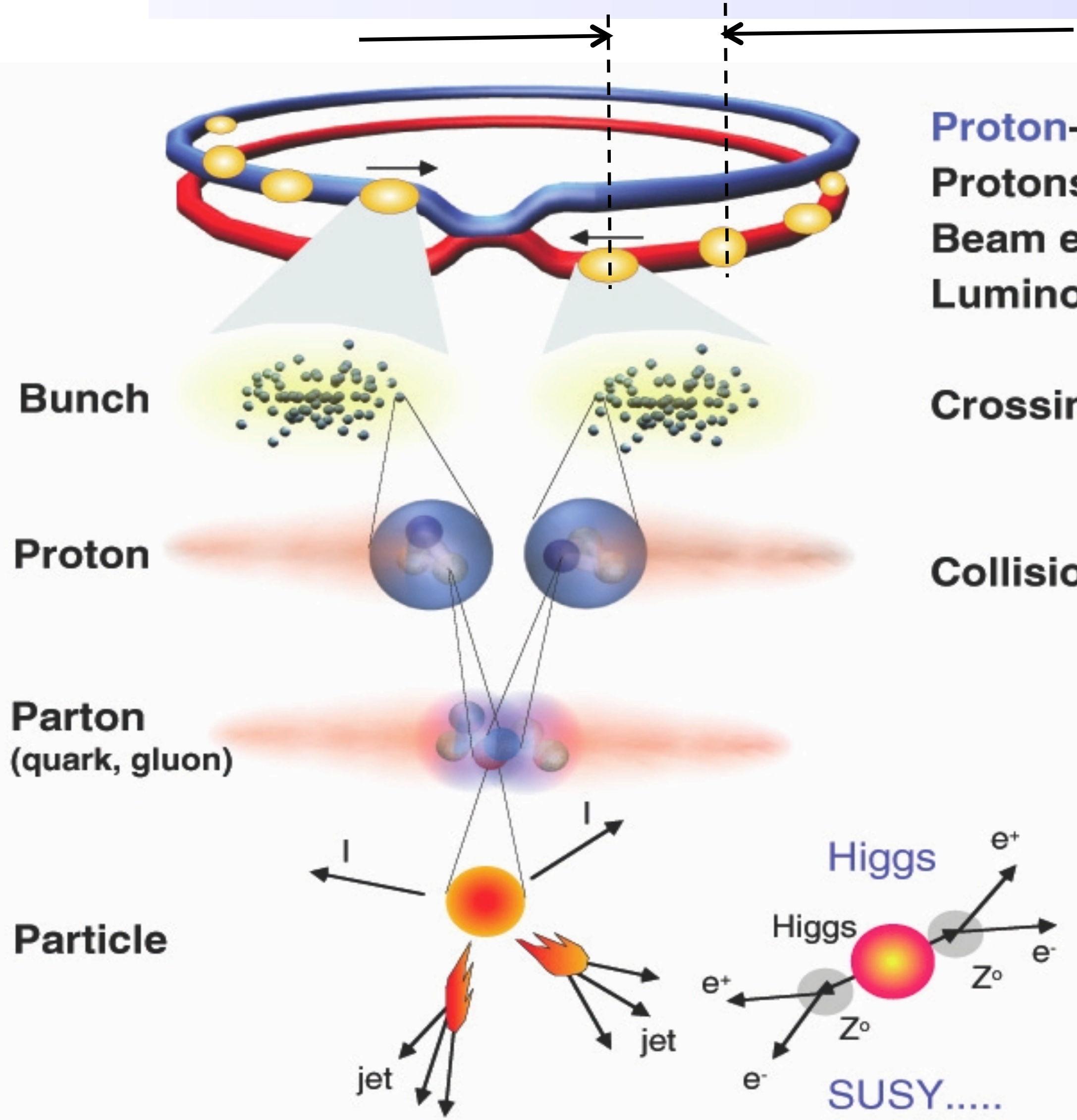
$W \to \ell\nu$	15	100
$Z \to \ell\ell$	2	20
$t\bar{t}$	1	10
H(100 GeV)	0.05	0.1
Z' (1 TeV)	0.05	0.1
$\tilde{g}\tilde{g}$ (1 TeV)	0.05	0.1
H(500 GeV)	10^{-3}	10^{-2}

It is challenging (to say the least) to find these rare exciting events (keep in mind: we'll start with luminosity of O(10^{29}))

LHC reference numbers

25 ns or 7.5 m



Proton-Proton	2835 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV ($7x10^{12}$ eV)
Luminosity	10^{34} cm^{-2} s^{-1}
Crossing rate	40 MHz
Collisions ≈	10^{7} - 10^{9} Hz

New Physics buried under Old Physics

- Interaction rate:

$$R = \mathcal{L} \times \sigma_{\rm tot} = 10^{34}\ {\rm cm}^{-2}{\rm s}^{-1} \times 80\ {\rm mb}^{(*)} \sim 0.8\ {\rm GHz}$$

(*) Total inelastic cross section (±20%)

- Distance between bunch crossings:

$$\Delta t = 25\ {\rm ns}\ ({\rm or}\ 7.5\ {\rm m})$$

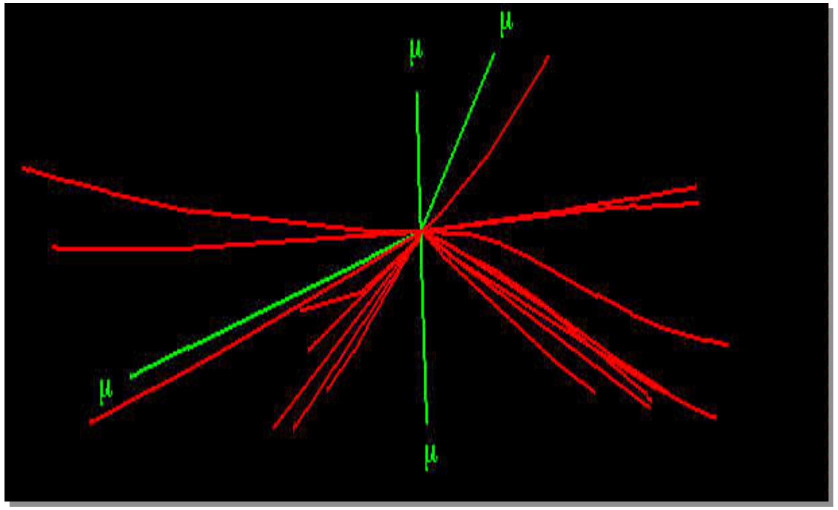
- Non-empty bunch crossings:

$$2835\ {\rm out\ of}\ 3564\ ({\rm or}\ \epsilon = 79.5\%\ )$$

- Average # of interactions per (non-empty) crossing:

$$\bar{n} = R \times \Delta t/\epsilon \sim 25$$

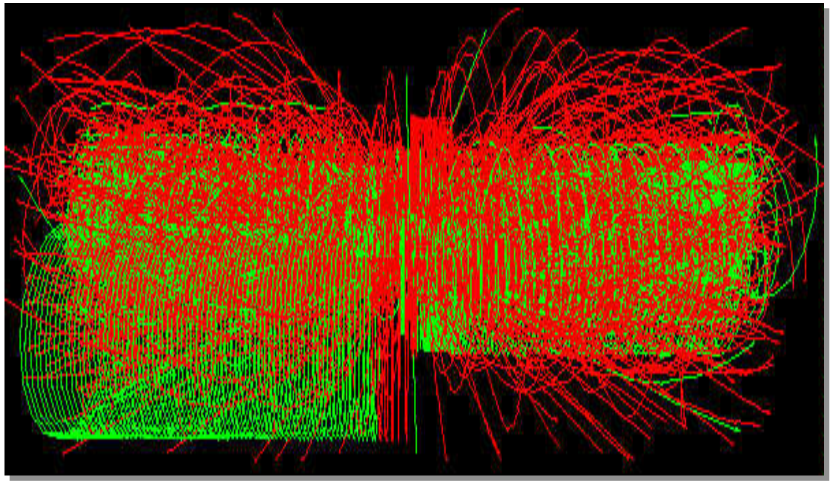
New Physics buried under Old Physics



For every exciting interaction…

$$H \rightarrow ZZ \rightarrow 4\mu$$

Reconstructed tracks with $p_T > 25$ GeV



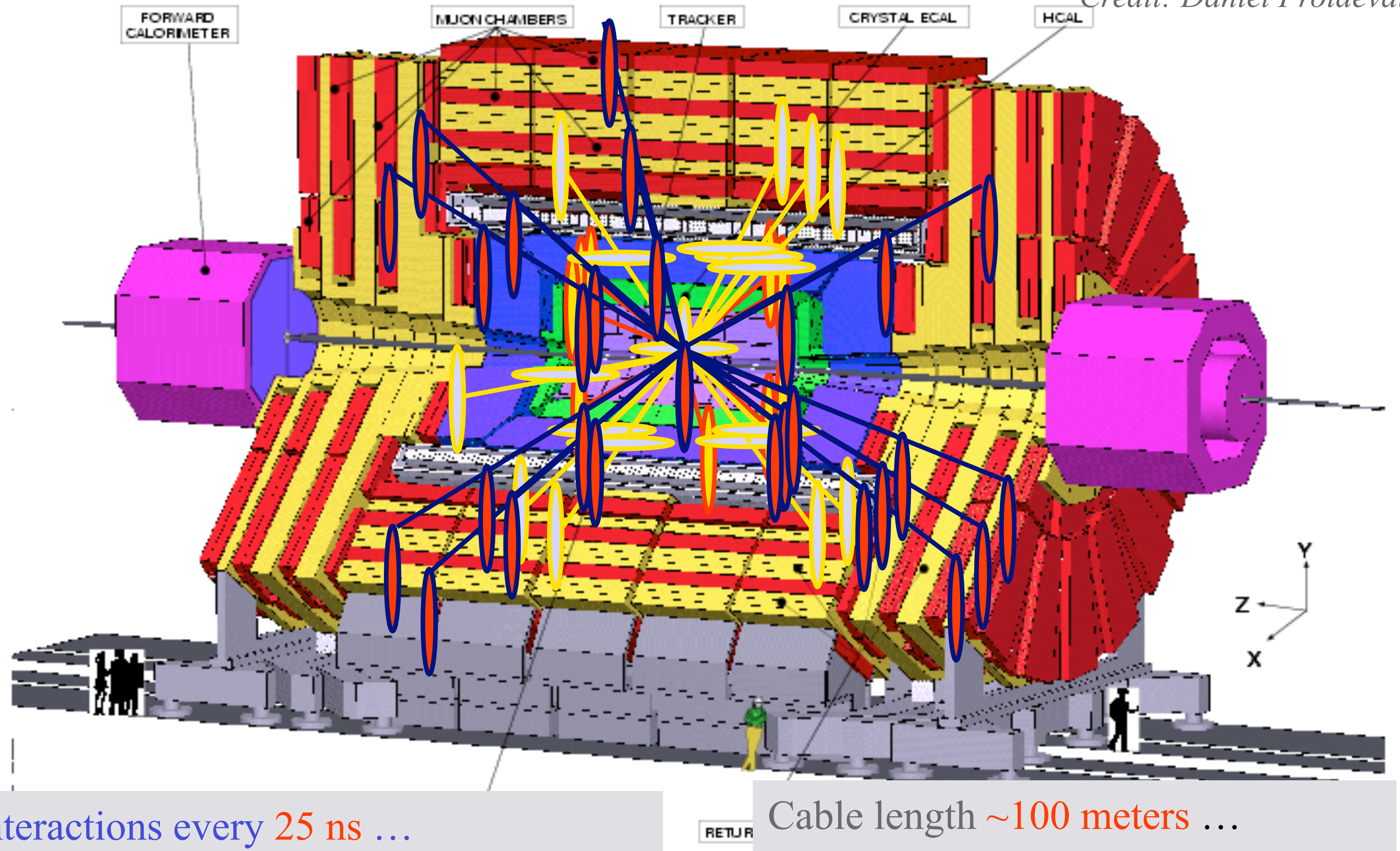
…expect 25 non-exciting *overlaid* interactions (at ~1000 tracks per event)

Reconstructed tracks with $p_T > 2$ GeV

Pileup: serious problem at LHC at high luminosities

The 25 ns challenge

Credit: Daniel Froidevaux



Interactions every 25 ns …

- In 25 ns particles travel 7.5 m

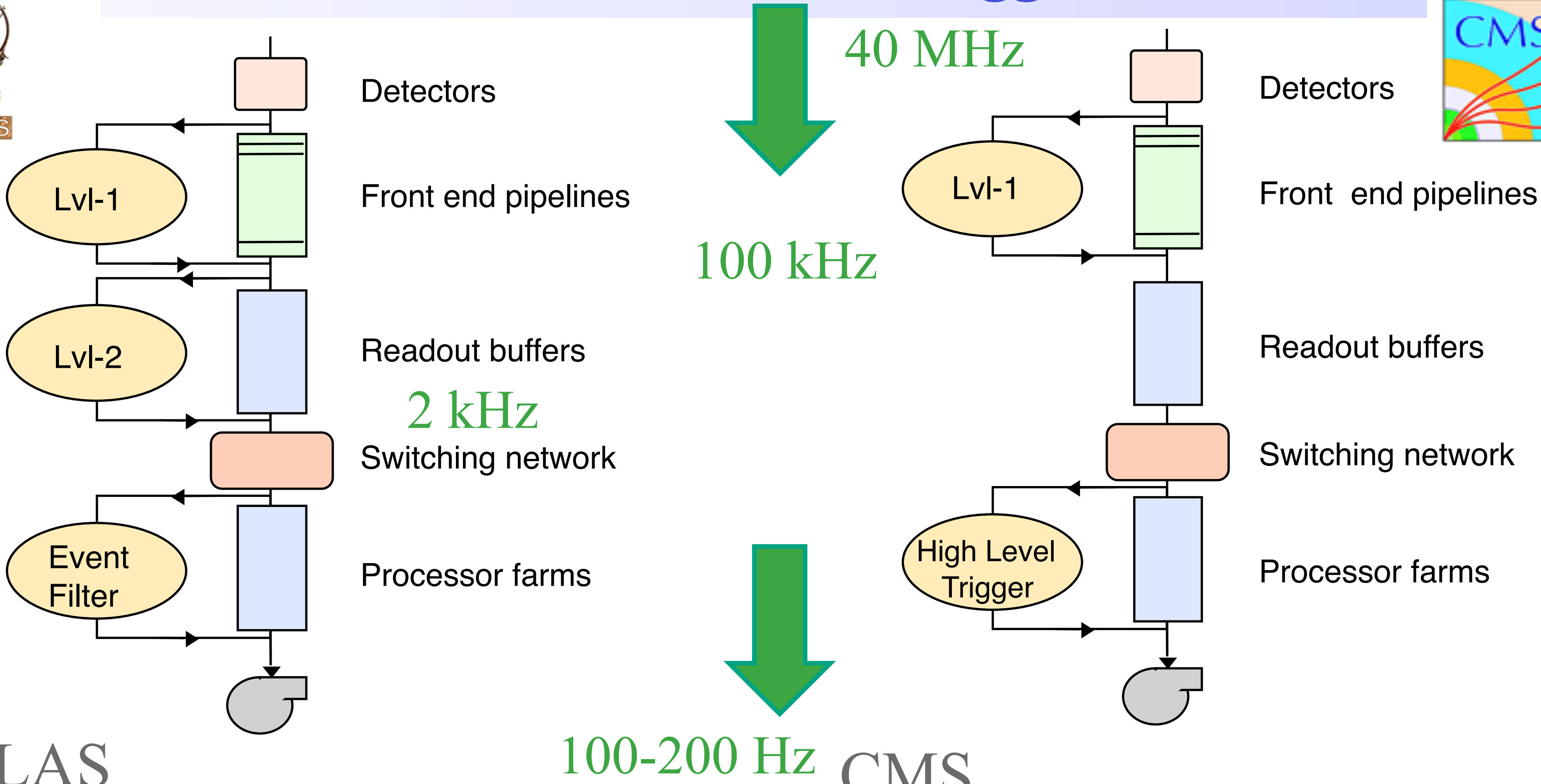
Cable length ~100 meters …

- In 25 ns signals travel 5 m

Background is a Disease

Meet the Cure

ATLAS and CMS triggers



ATLAS

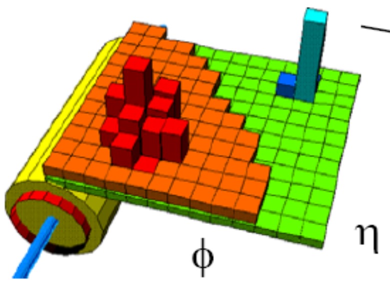
- 3 levels (traditional design)
- L1: hardware, firmware
- L2 + EvF: high-level software

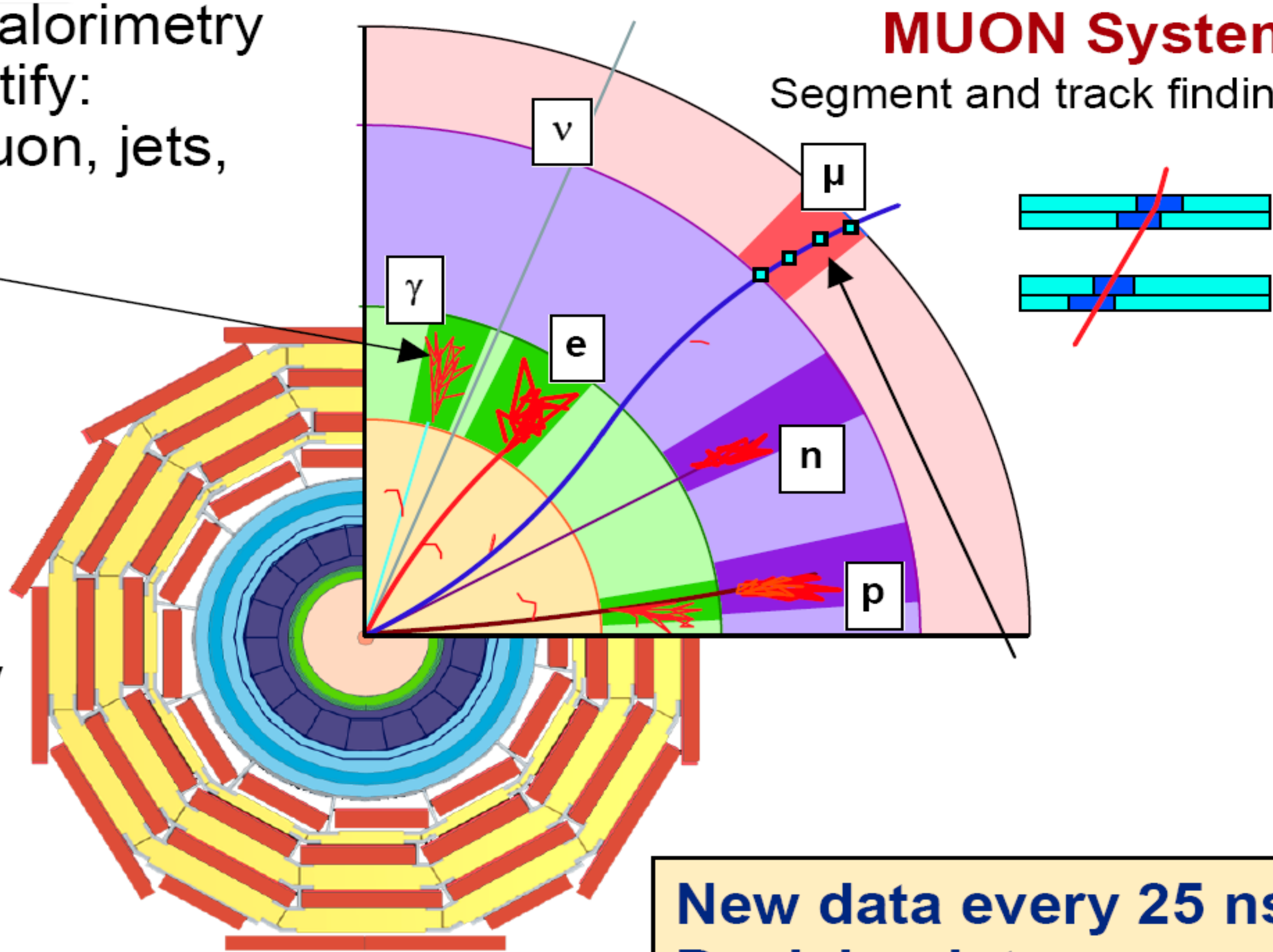
CMS

- L2, L3: merged into HLT
- L1: hardware, firmware
- HLT: high-level software

Particle-id at Level-1

Use prompt data (calorimetry and muons) to identify:
High p_t electron, muon, jets, missing E_T





MUON System

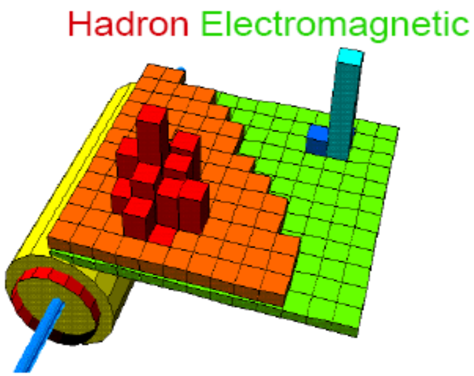
Segment and track finding

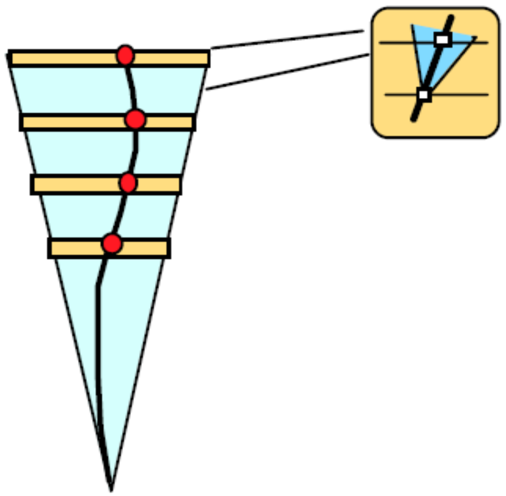
CALORIMETERs

Cluster finding and energy deposition evaluation

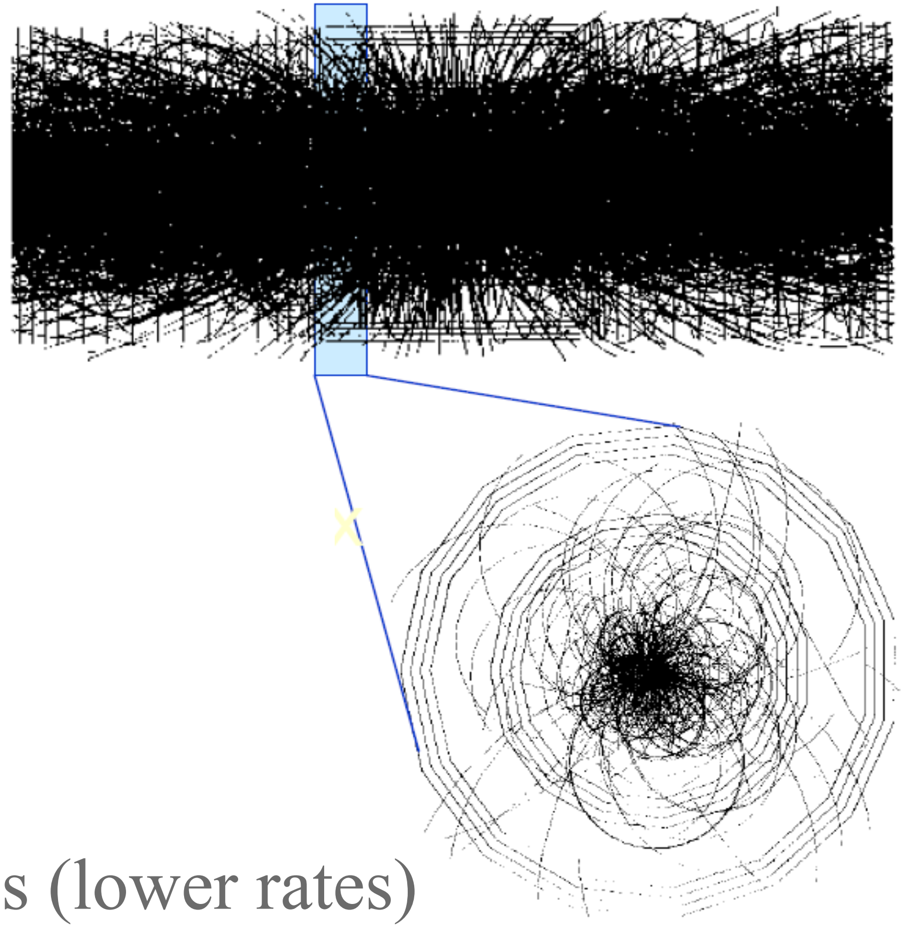
New data every 25 ns
Decision latency ~ µs

Why not use tracker info at Level-1?





Thoughts of including tracker info at L1 for SLHC



Calorimeter, muon detectors:

- Thousands of channels
- Patter recognition fast

Tracking, vertexing detectors:

- Millions of channels
- Patter recognition slow
- Reserved for later triggering stages (lower rates)