Experimental techniques in high-energy nuclear and particle physics

"Dottorato di Ricerca in Ingegneria dell'Informazione"

LECTURE 6c.

CMS at LHC

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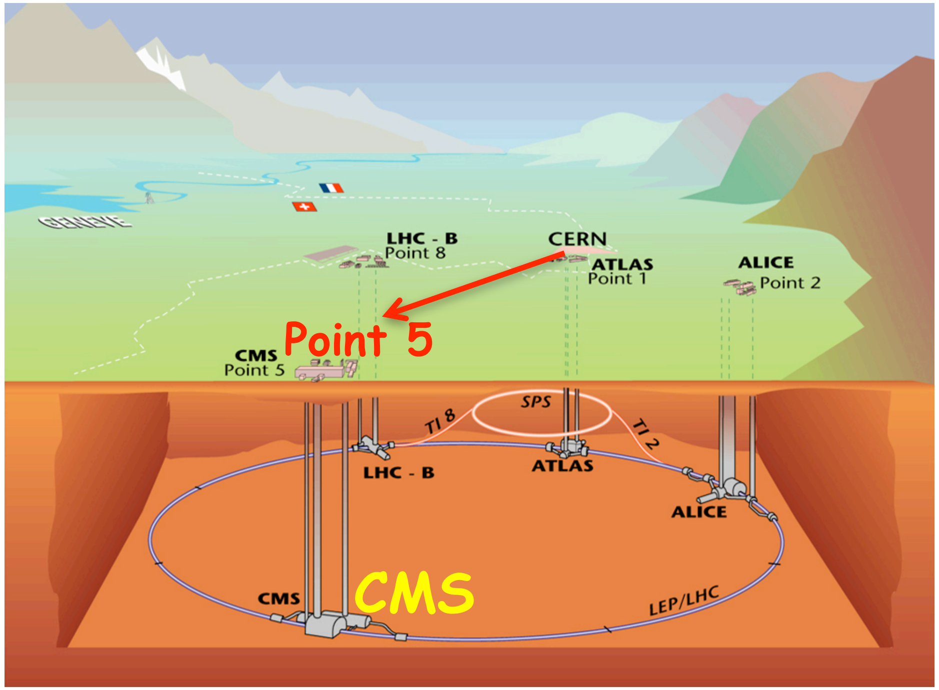
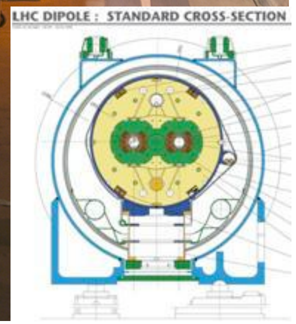
CMS closed ready for data

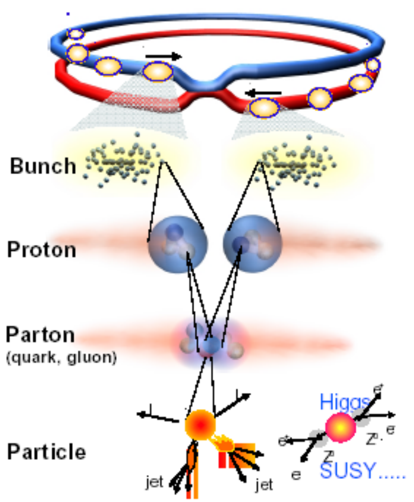
The CERN Large Hadron Collider

9300 Superconductor magnets
1232 Dipoles (15m, 1.9°K) 8.4Tesla 11700 A
448 Main Quads, 6618 Correctors.
Circonference 26.7 km





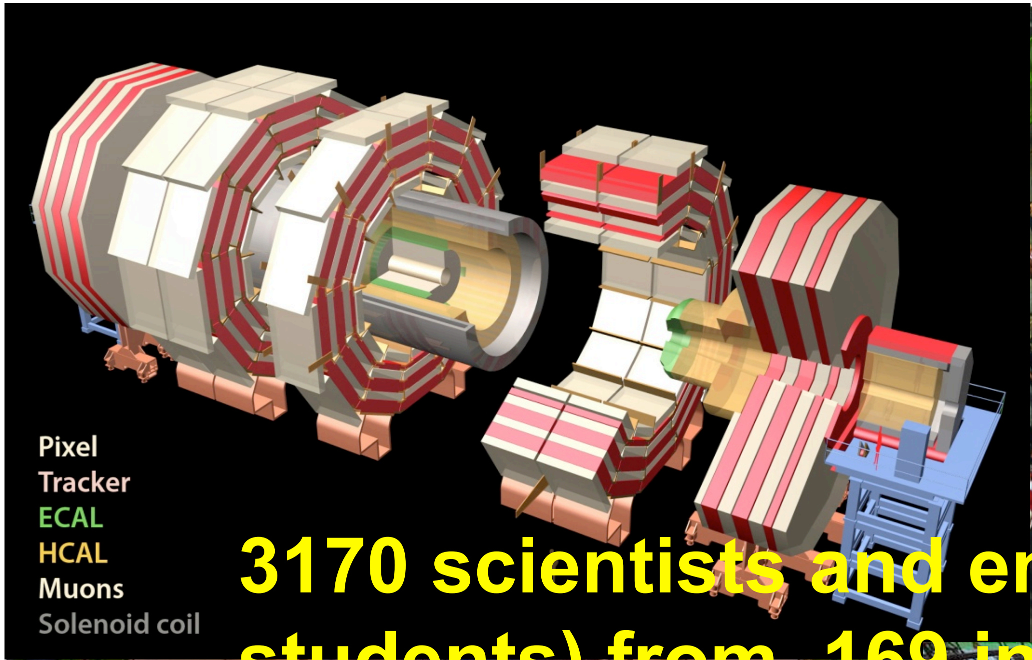
Collisions at LHC



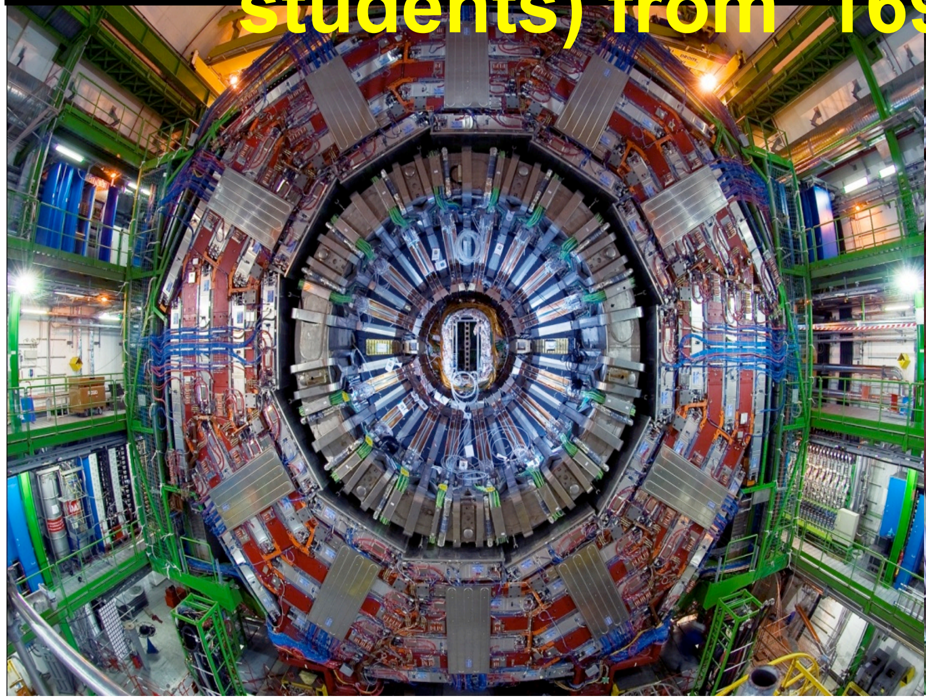
Proton-Proton	2835 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV ($7x10^{12}$ eV)
Luminosity	10^{34} $cm^{-2}s^{-1}$
Crossing rate	40 MHz
Collisions rate ≈	10^{7} - 10^{9} Hz
New physics rate ≈	.00001 Hz

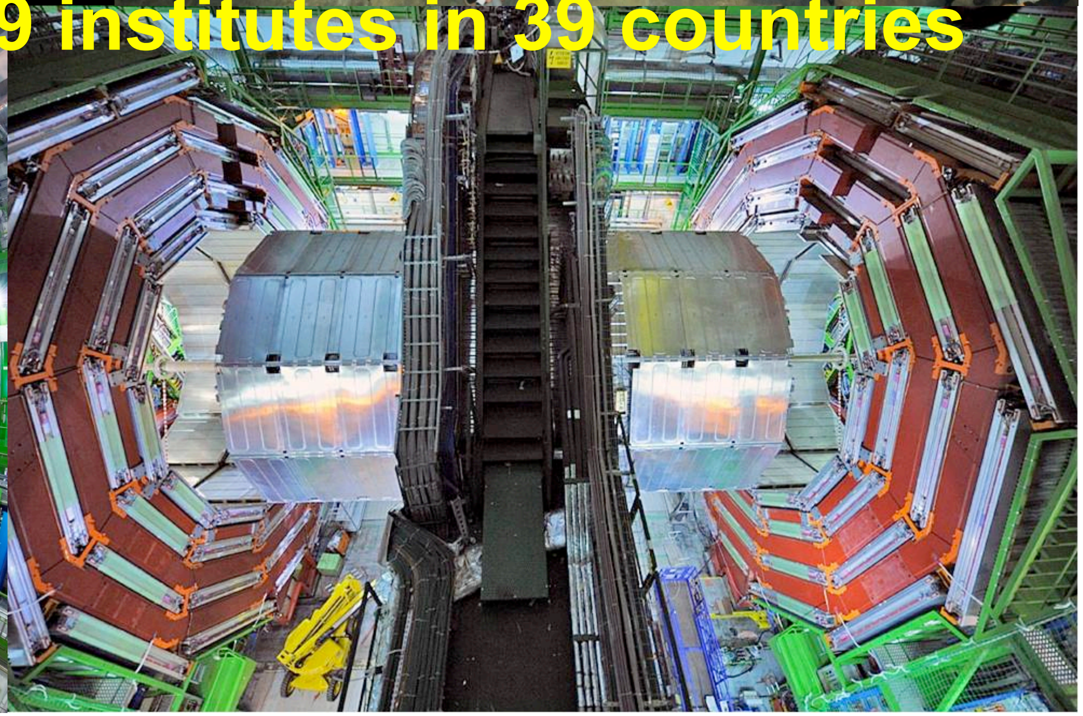
Event selection:
1 in 10,000,000,000,000

The CMS Collaboration

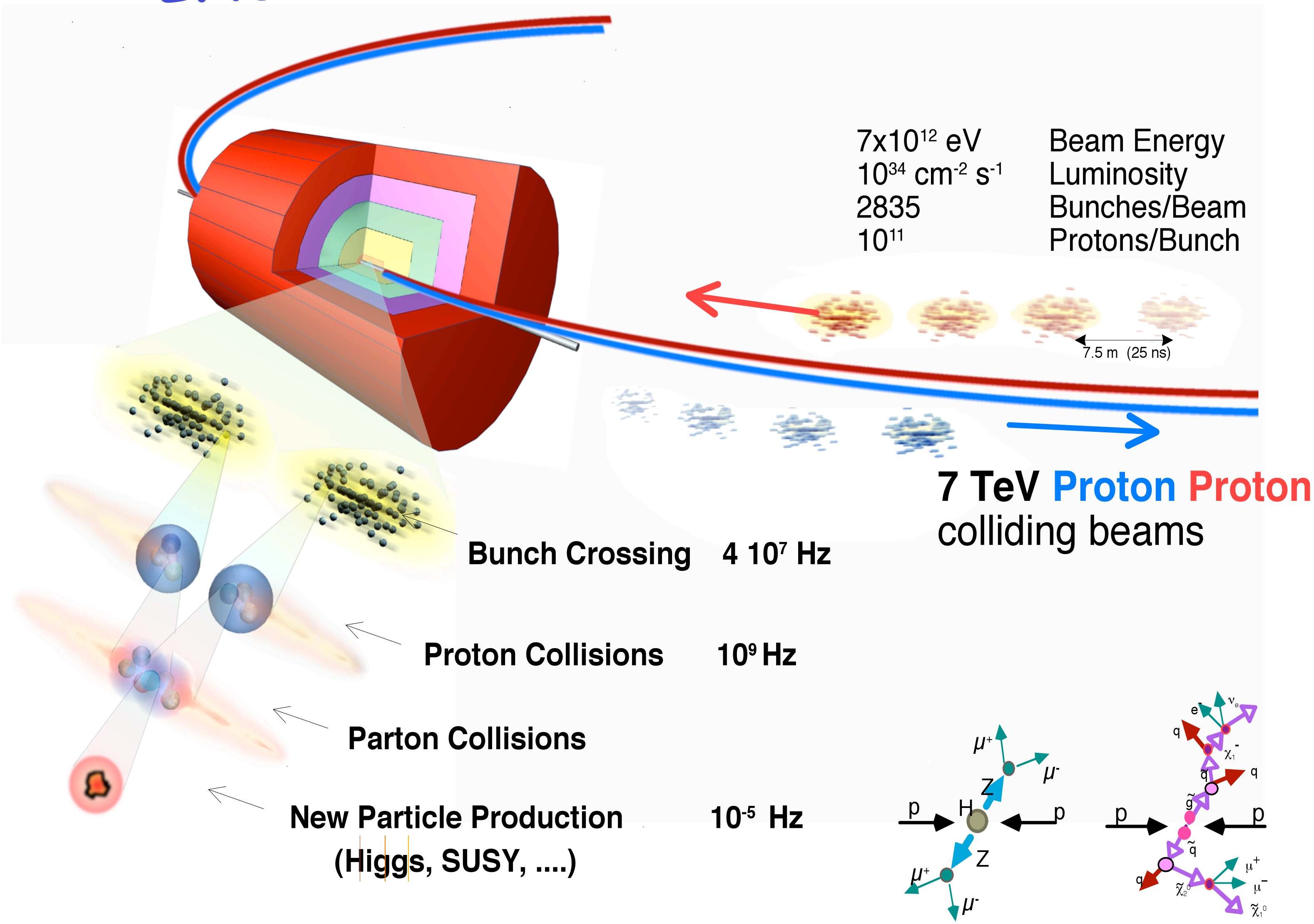


3170 scientists and engineers (including ~800 students) from 169 institutes in 39 countries





Collisioni protone-protone at LHC



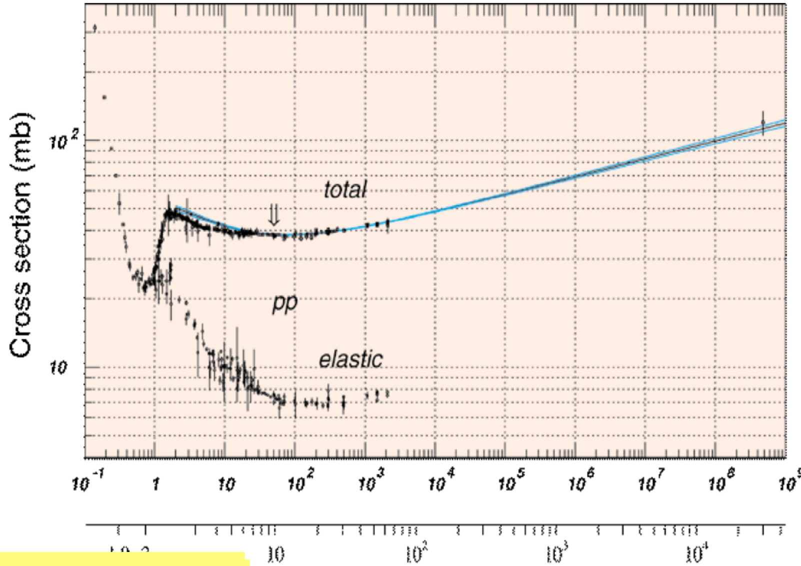
Selection of 1 event in 10,000,000,000,000

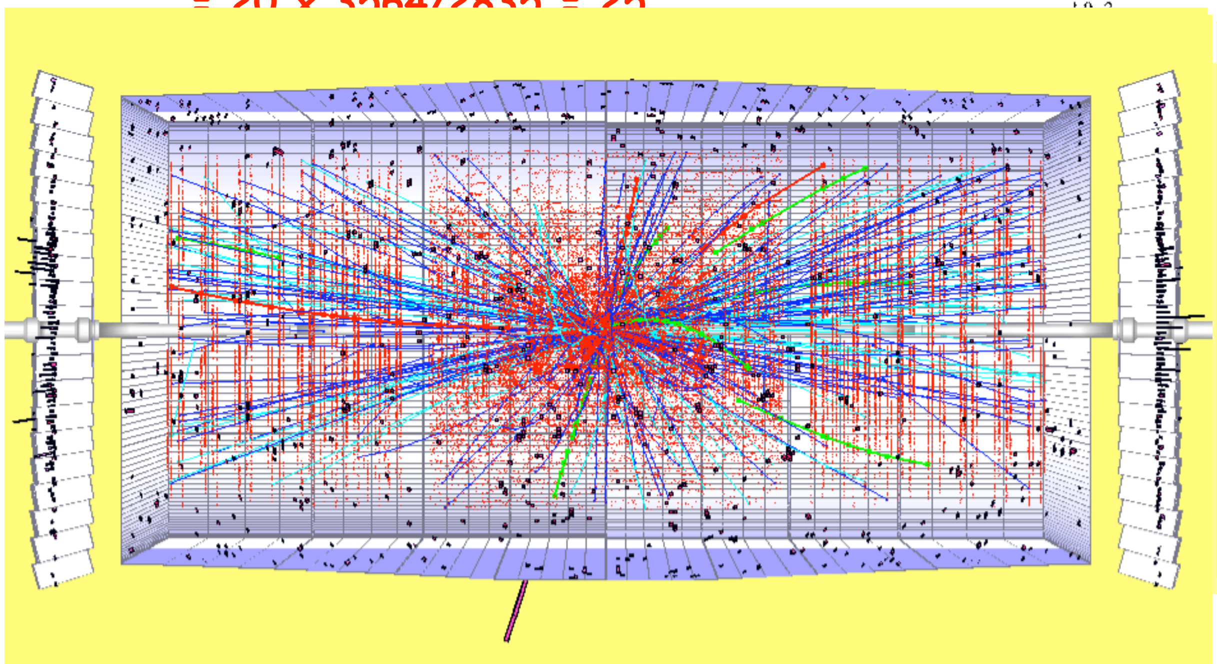
pp cross-sections and minimum bias

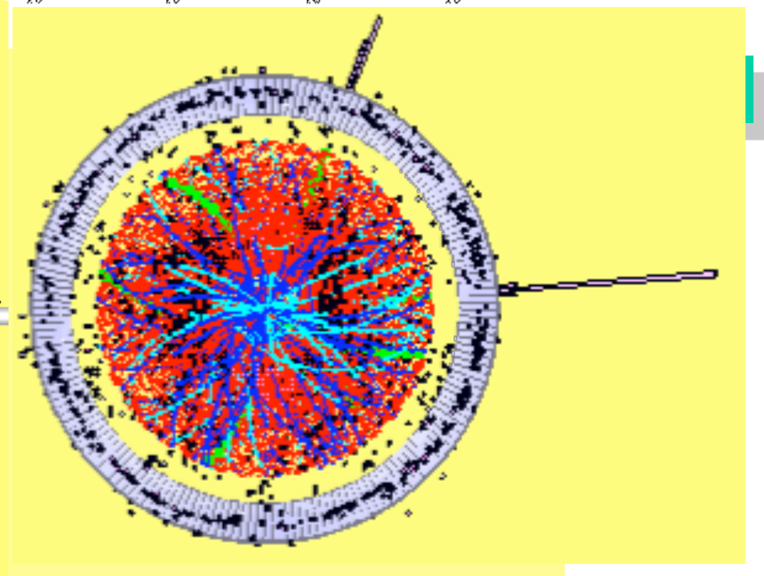
of interactions/crossing:

- Interactions/s:
  - Lum = 10^{34} $cm^{-2}s^{-1}$=$10^{7}mb^{-1}Hz$
  - $\sigma_{inel}(pp)$ = 80 mb
  - Interaction Rate, R = $8x10^{8}$ Hz
- Events/beam crossing:
  - Δt = 25 ns = $2.5x10^{-8}$ s
  - Interactions/crossing=20
- Not all p bunches are full
  - 2835 out of 3564 only
  - Interactions/"active" crossing =
  - = 20 x 3564/2835 = 25

$\sigma_{inel}(pp) \approx 80$ mb@14TeV





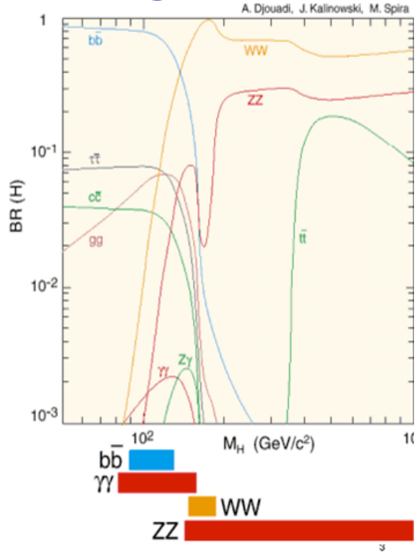


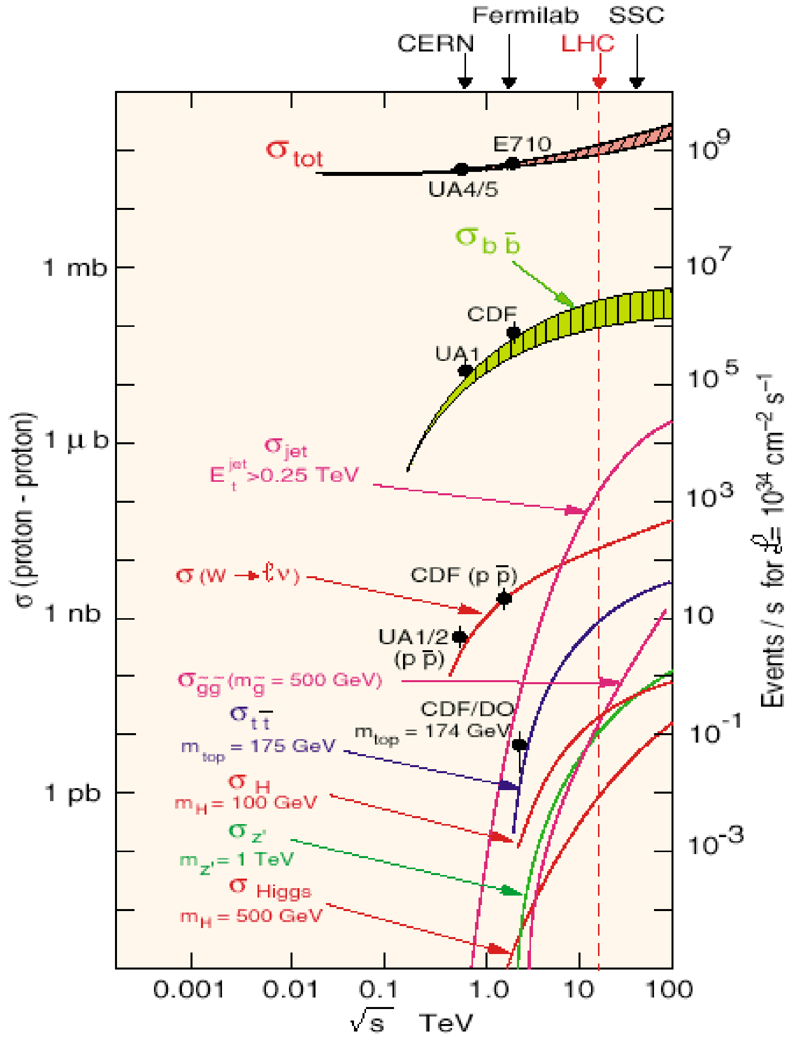
Signal and background → $\mathcal{L}=10^{34}\ cm^{-2}s^{-1}$

Cross sections for various physics processes vary over many orders of magnitude

Higgs (600 GeV/c^2): 1pb @10^{34} → 10^{-2} Hz
Higgs (100 GeV/c^2): 10pb @10^{34} → 0.1 Hz
t t production: → 10 Hz
$W \to \ell\nu$: → 10^2 Hz
Inelastic: → 10^9 Hz

Selection needed: $1:10^{10-11}$
Before branching fractions...





⇒ Needle in a Hay Stack

Impact on detector design

CMS detectors must have fast response

Otherwise will integrate over many bunch crossings

→ large "pile-up"

Typical response time : 20-50 ns

→integrate over 1-2 bunch crossings

→ pile-up of 25-50 min-bias

→ very challenging readout electronics

CMS detectors must be highly granular

Minimize probability that pile-up particles be in the same detector element as interesting object

→ large number of electronic channels

→ high cost

CMS detectors must be radiation resistant:

high flux of particles from pp collisions

→ high radiation environment

Basic principles

Need "general-purpose" experiments covering as much of the solid angle as possible ("4π") since we don't know how New Physics will manifest itself

→ detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

Momentum / charge of tracks and secondary vertices (e.g. from b-quark decays) are measured in central tracker (Silicon layers).

Energy and positions of electrons and photons measured in electromagnetic calorimeters.

Energy and position of hadrons and jets measured mainly in hadronic calorimeters.

Muons identified and momentum measured in external muon spectrometer (+central tracker).

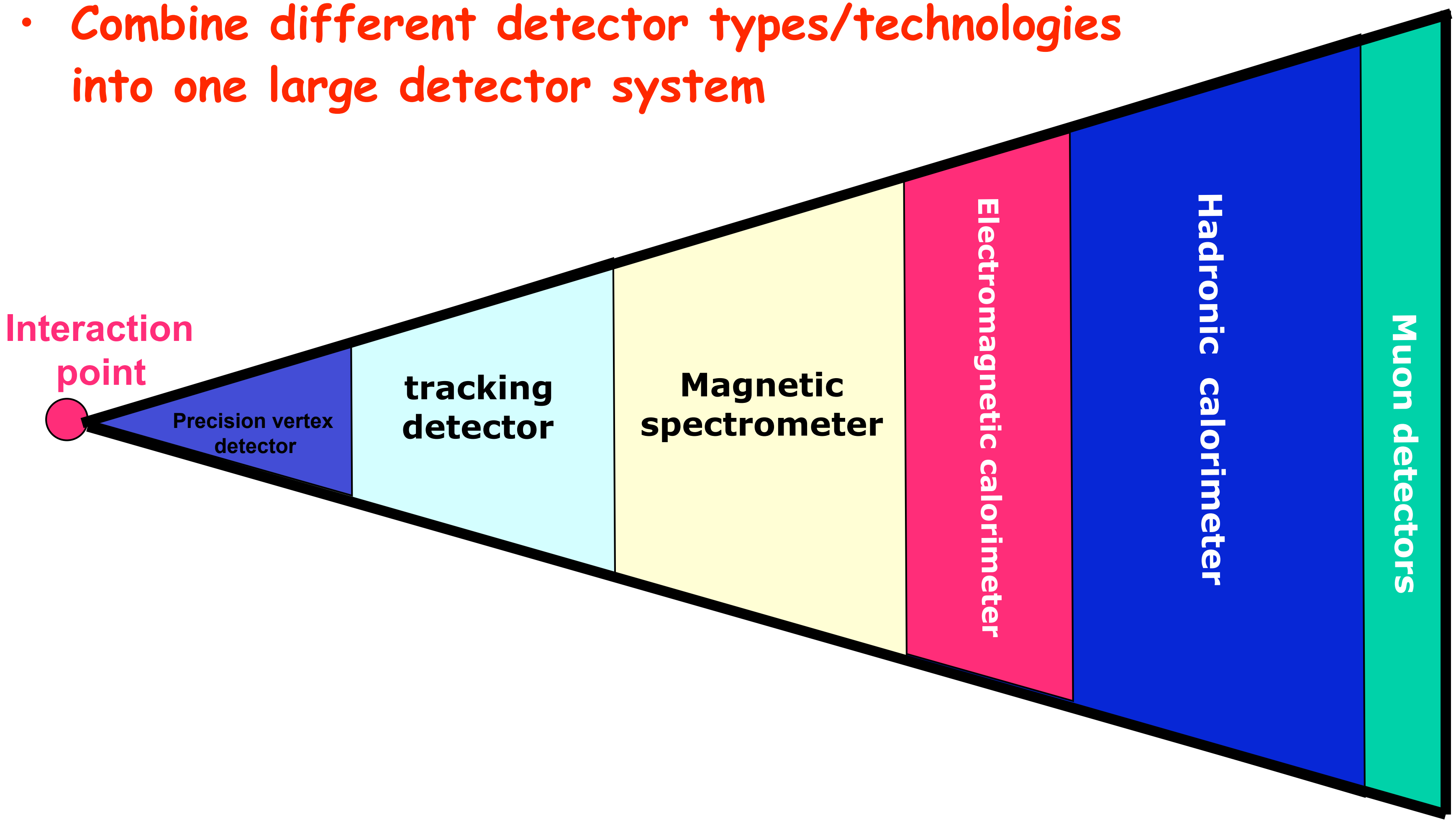
Neutrinos "detected and measured" through measurement of missing transverse energy (E_T^{miss}) in calorimeters.

CMS: Detector Requirements

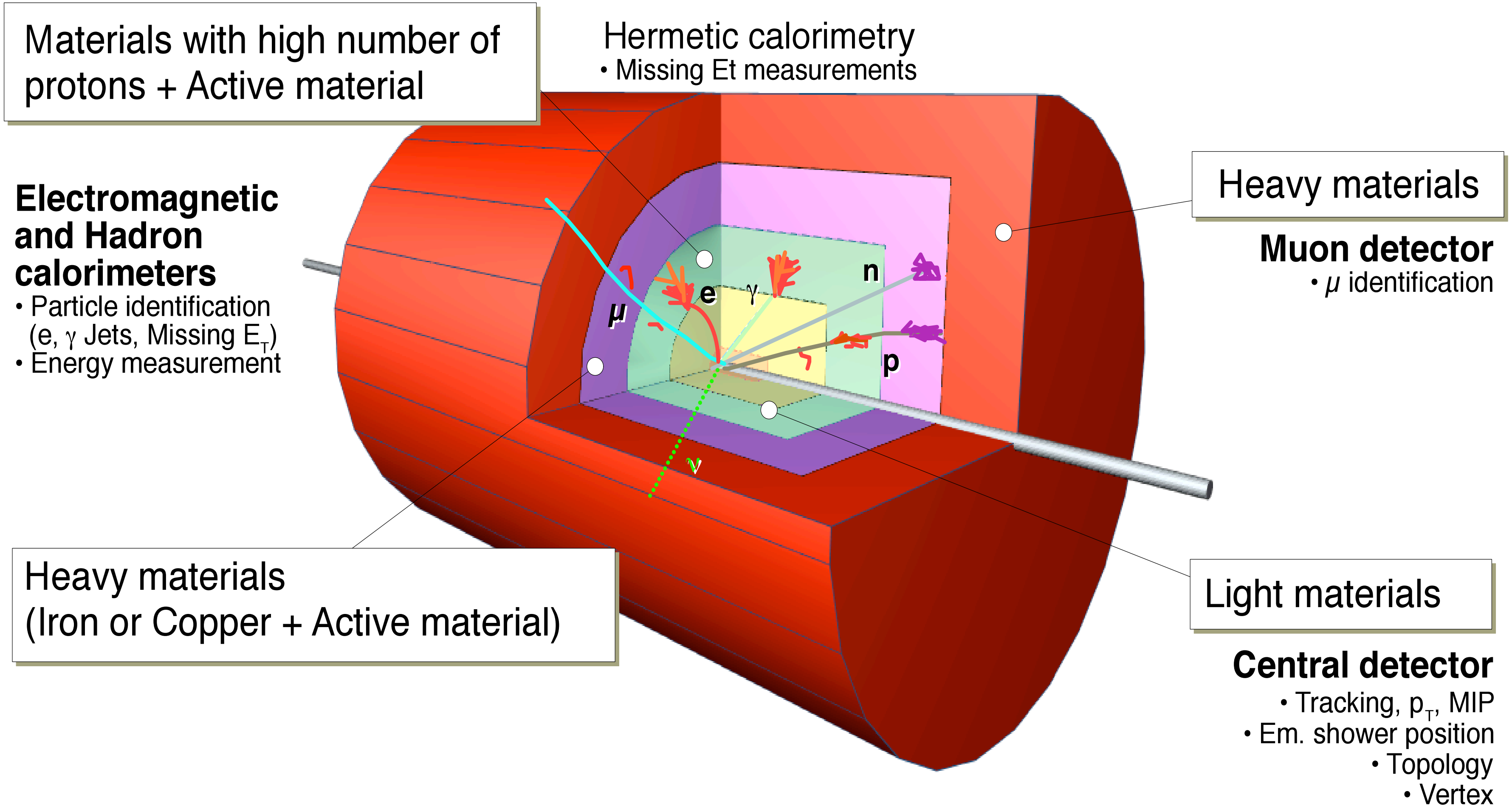
- Excellent muon identification with precise momentum reconstruction
- Efficient and high-resolution tracking for particle momentum measurements, b-quark and τ tagging, vertexing (primary and secondary vertex)
- Very good electromagnetic calorimetry for electron and photon identification
- Ermetic hadronic calorimeter jet reconstruction and missing transverse energy measurement

Typical detector concept

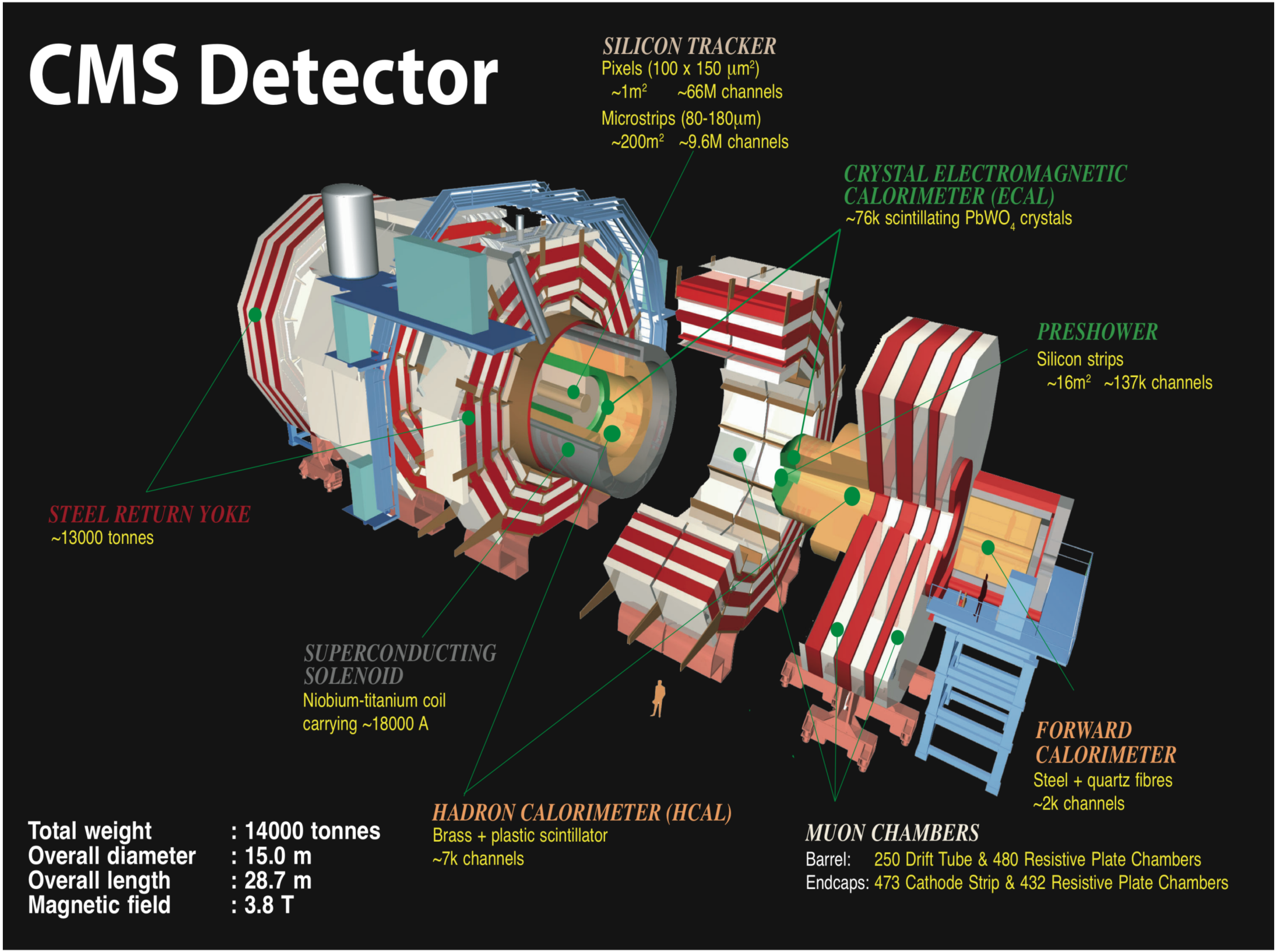
- Combine different detector types/technologies into one large detector system



Detectors at LHC

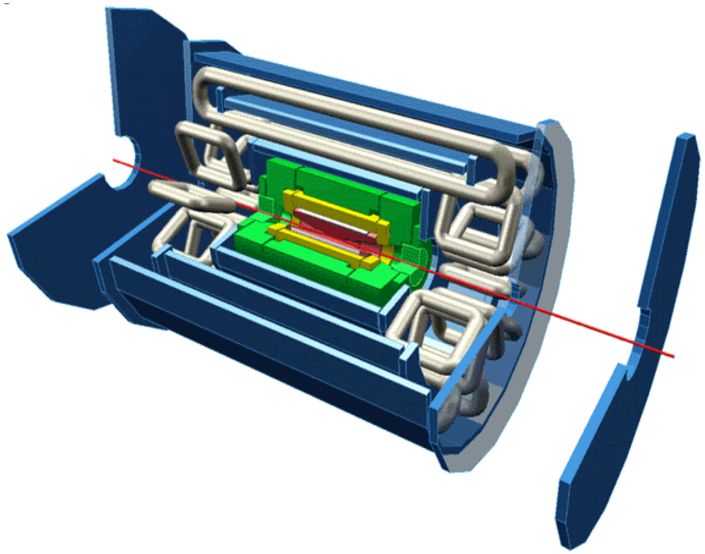


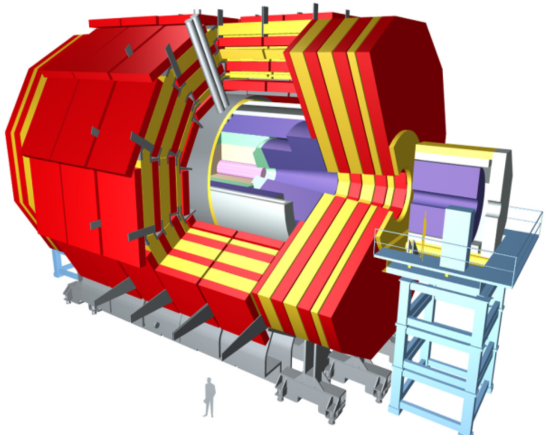
Each layer identifies and enables the measurement of the momentum or energy of the particles produced in a collision

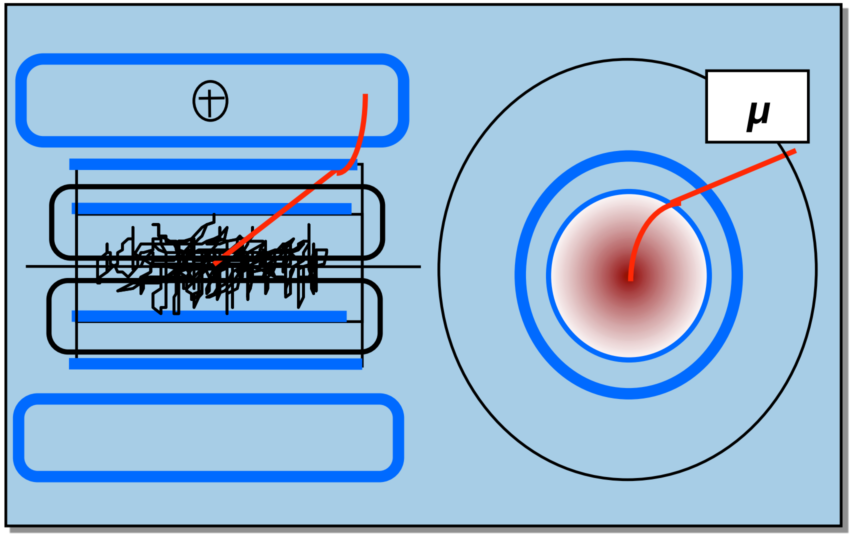

CMS Detector
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² ~137k channels
STEEL RETURN YOKE
~13000 tonnes
SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A
FORWARD CALORIMETER
Steel + quartz fibres
~2k channels
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 473 Cathode Strip & 432 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

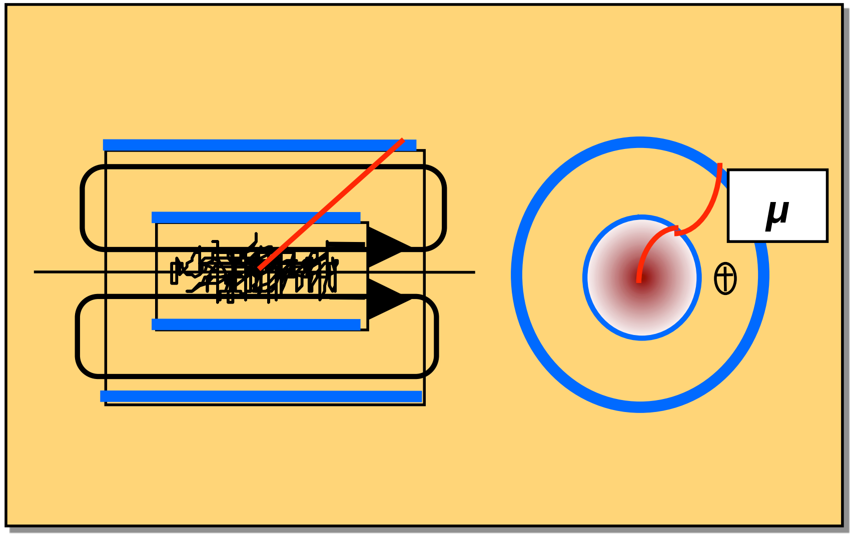
LHC pp experiments

ATLAS A Toroidal LHC ApparatuS **CMS** Compact Muon Solenoid

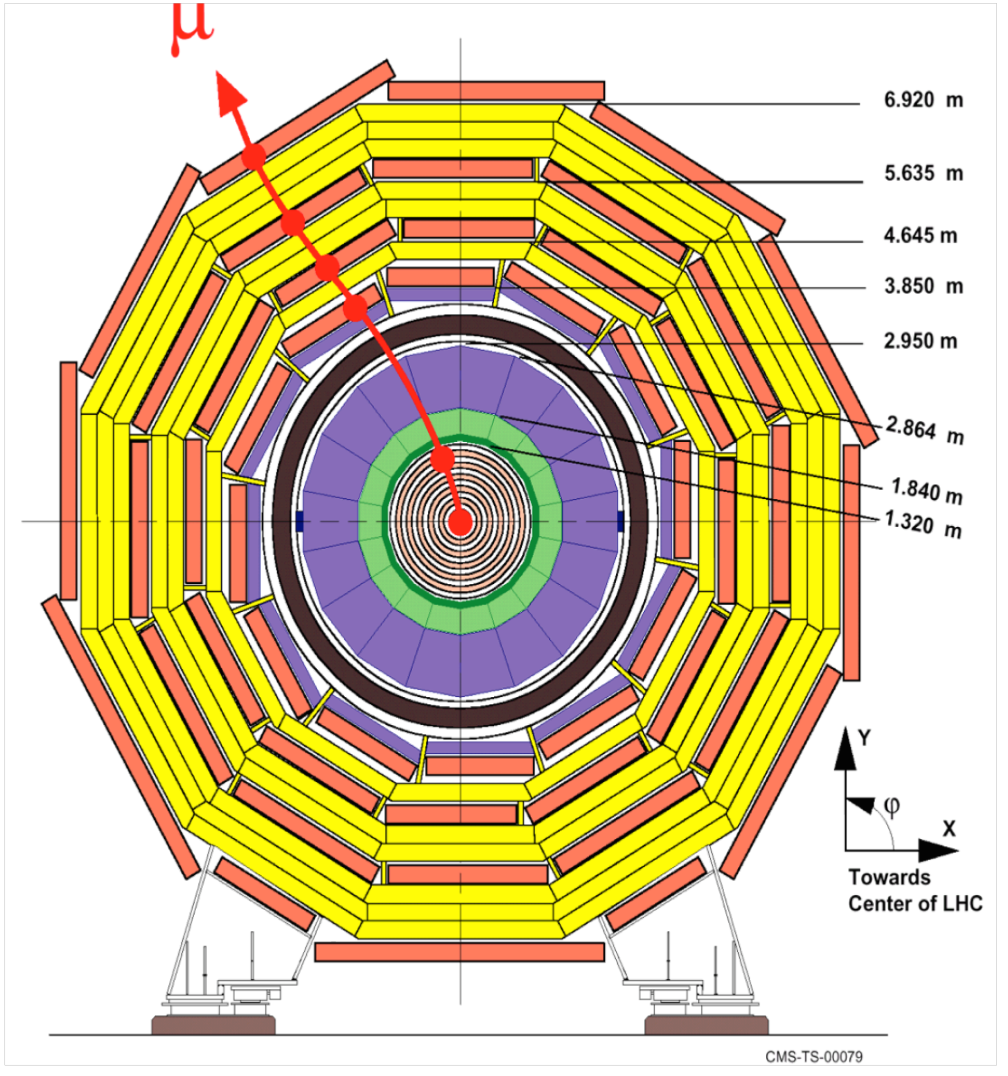


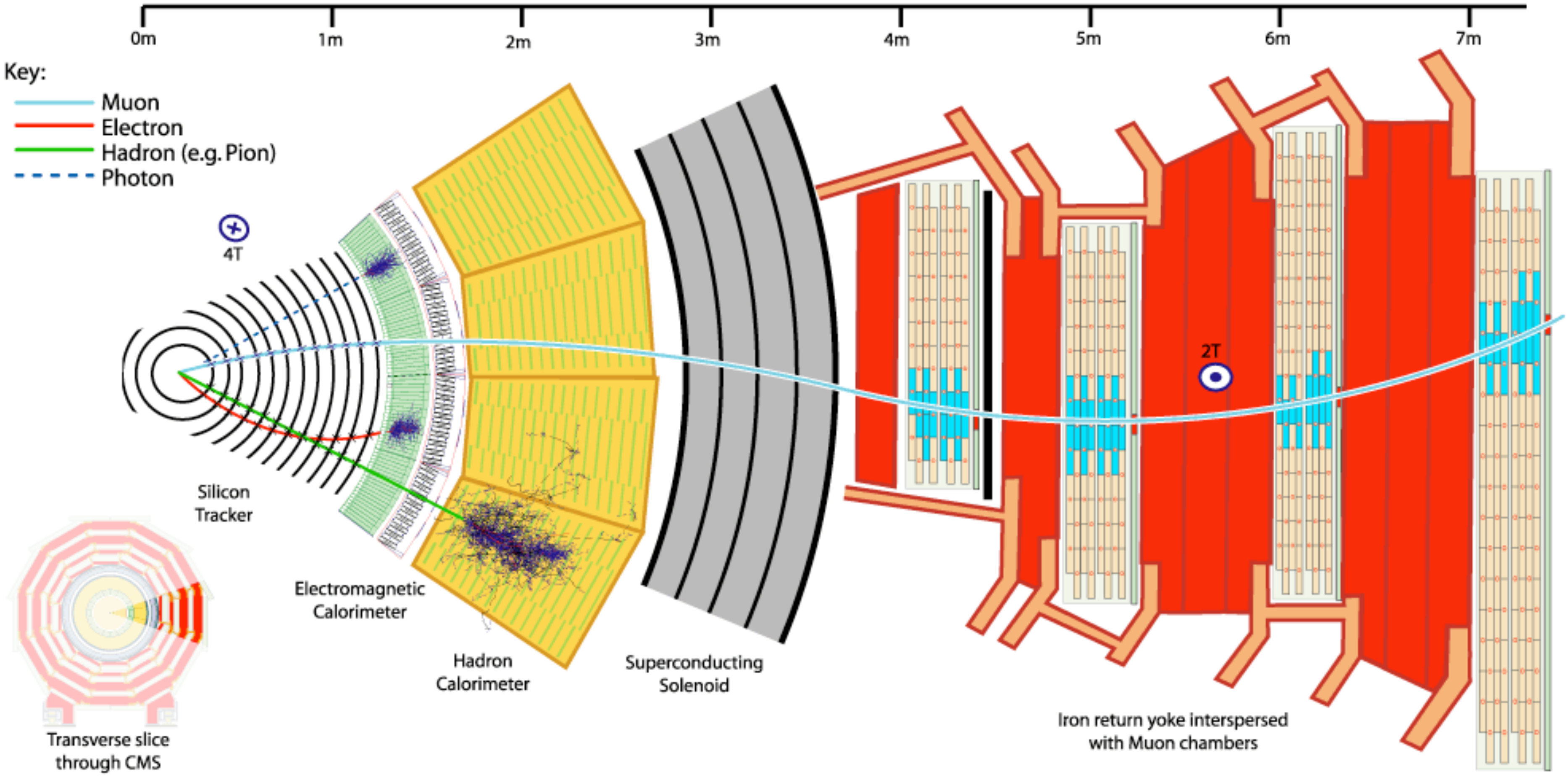




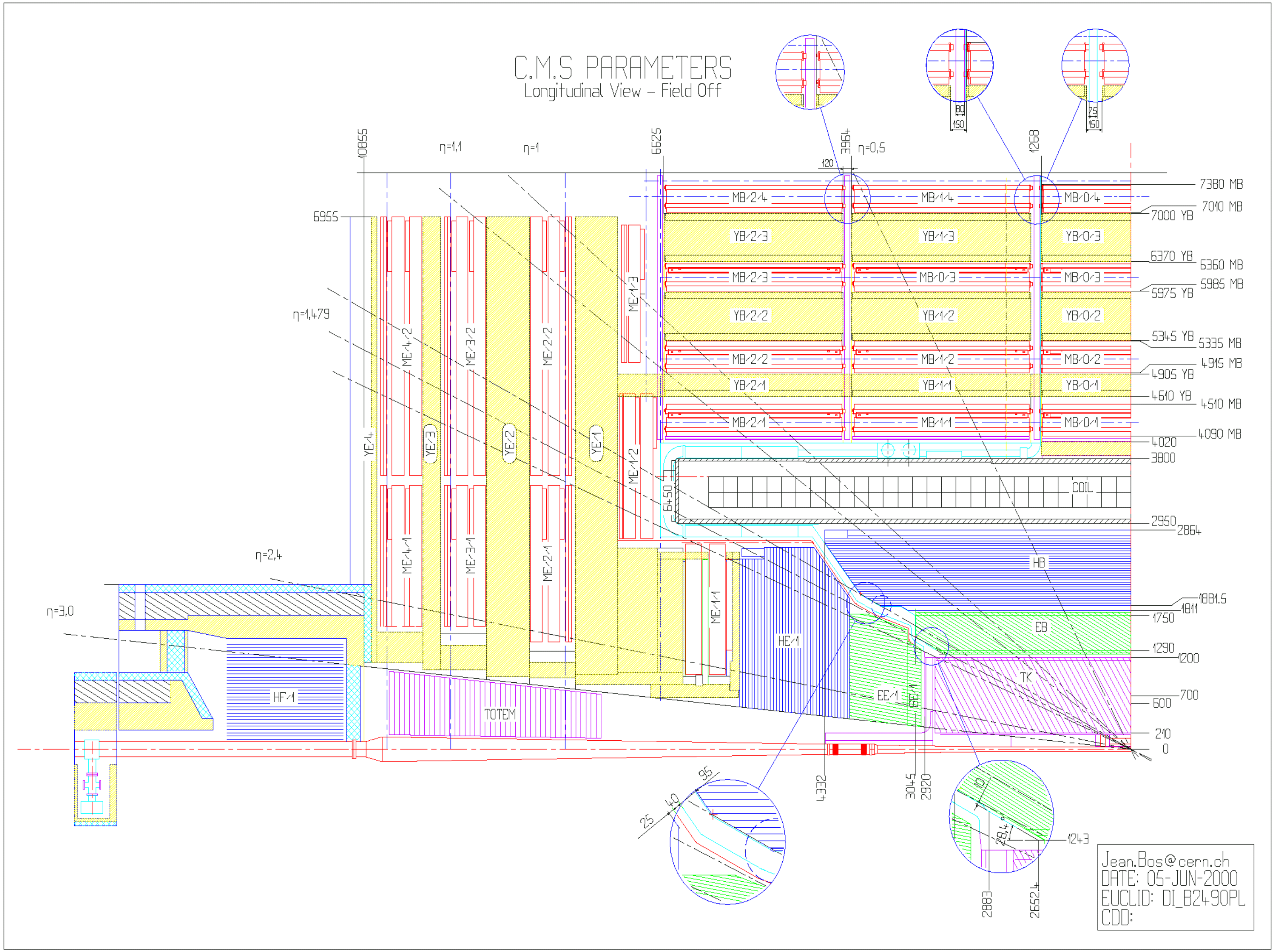


Transverse Wiew of CMS

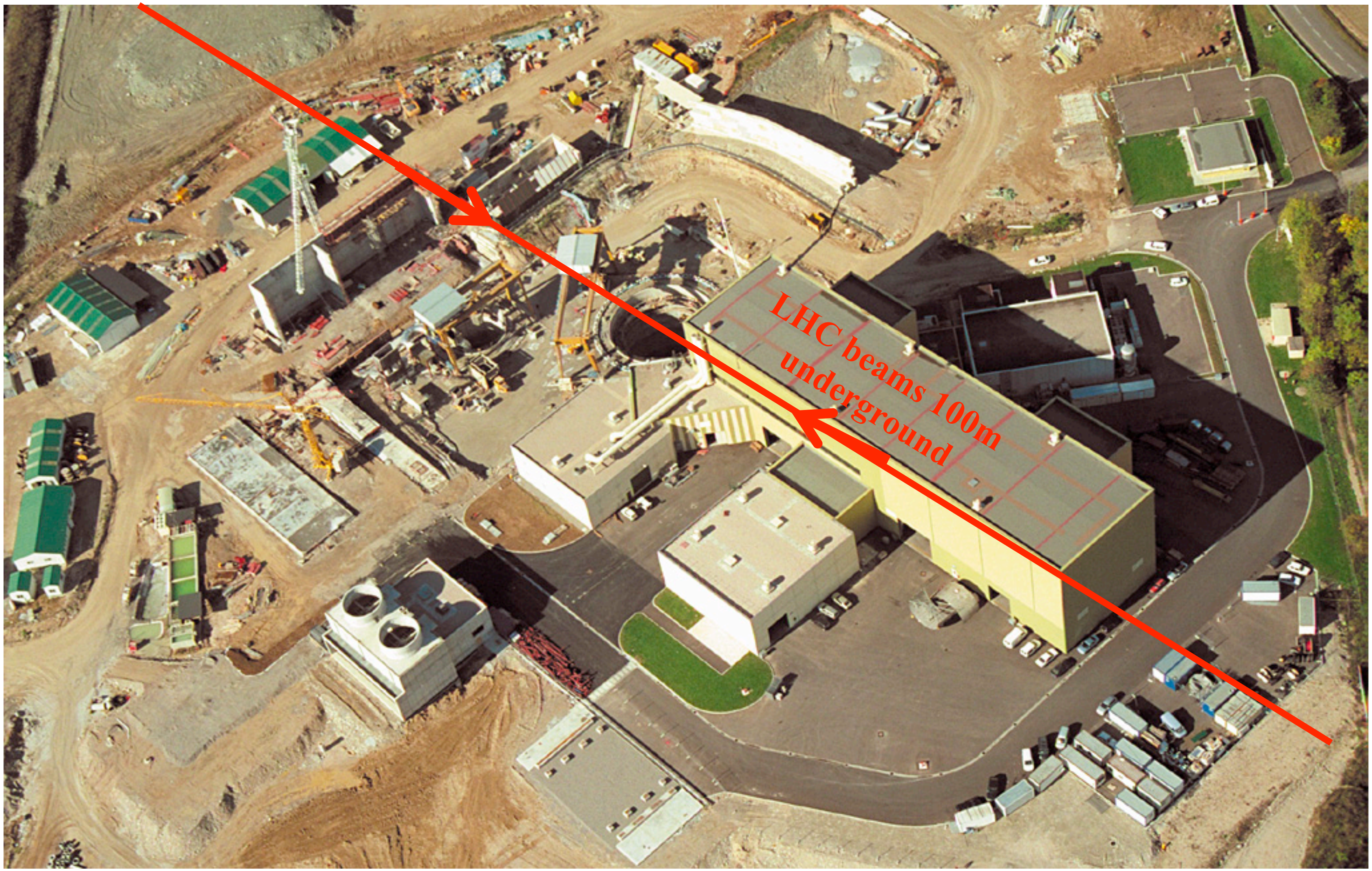



0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

Longitudinal Wiew of CMS

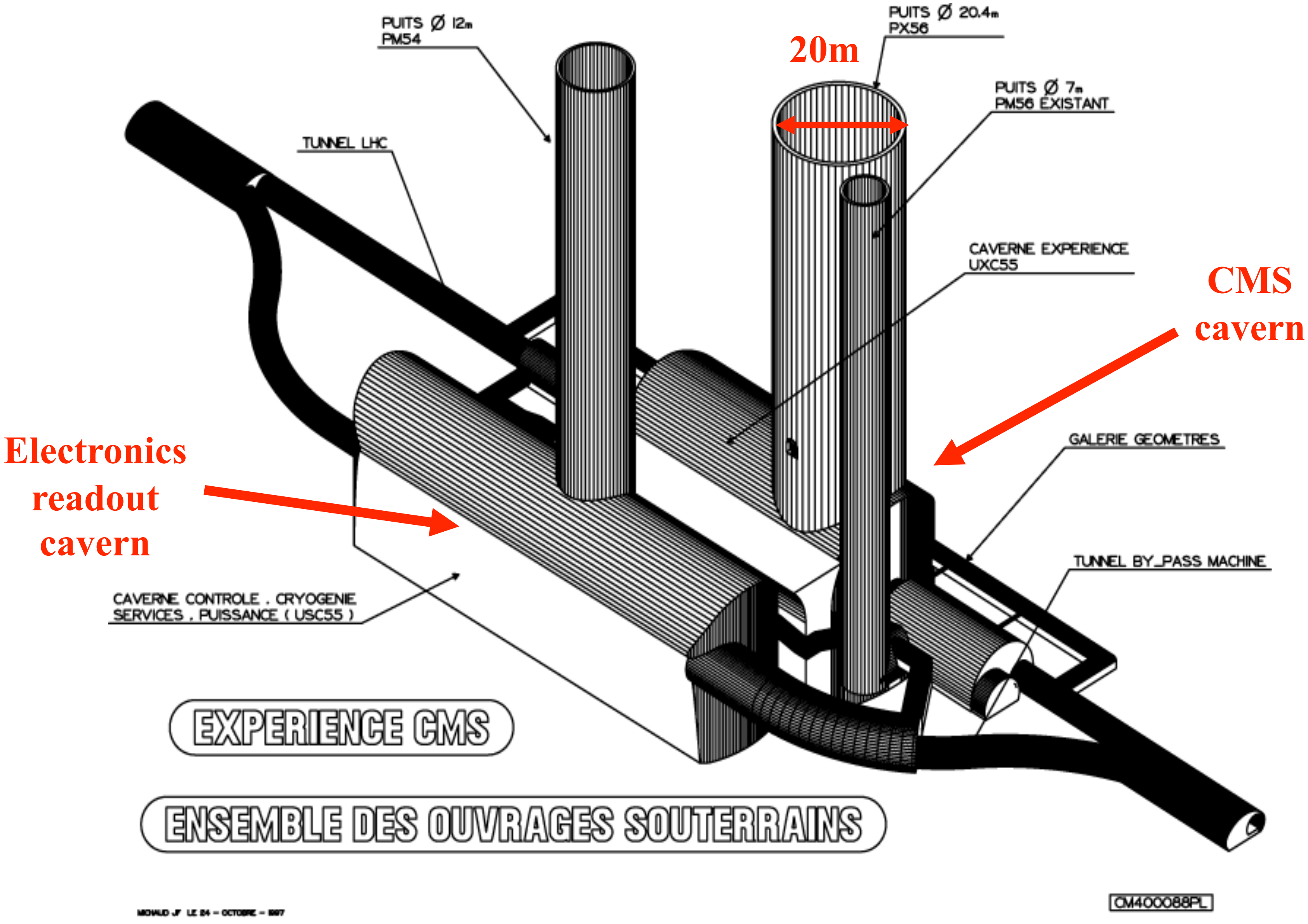


CMS -Surface Site in 2000



The surface building for the pre-assembly of CMS and the LHC access shafts

The Underground Areas



The Large Hadron Collider (LHC)

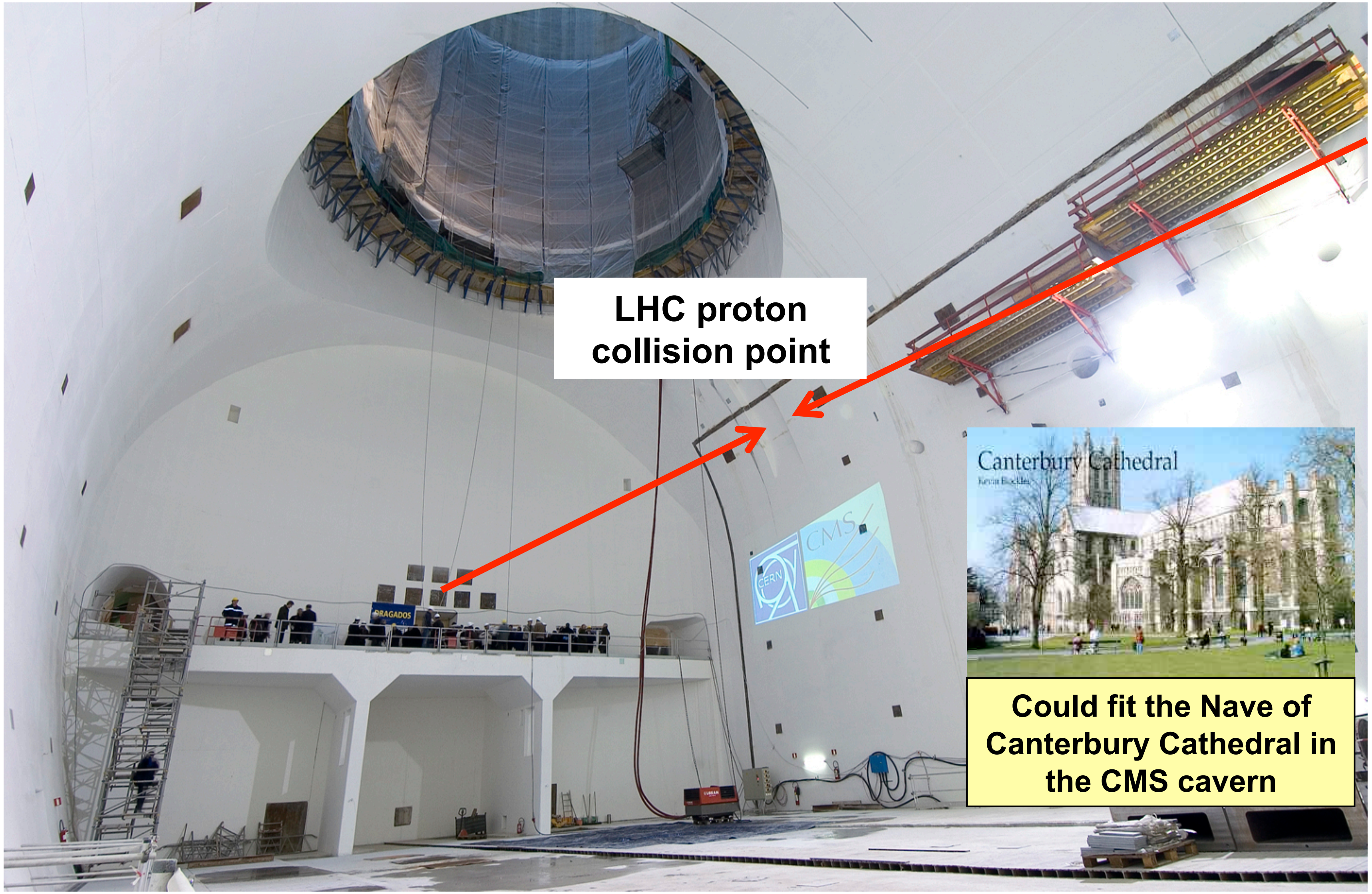
The tunneling machine and early conditions in one of the proton transfer tunnels

Lavori di scavo a “Point 5”

Point 5 - Excavation of pillar - November 22, 2000 - CERN ST-CE

Point 5 - Installation ventilation in PM54 - September 18, 2000 - CERN ST-CE

CMS – Compact Muon Solenoid



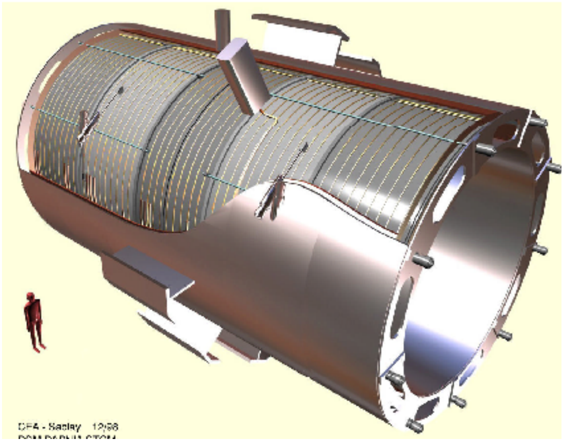
The CMS Underground cavern

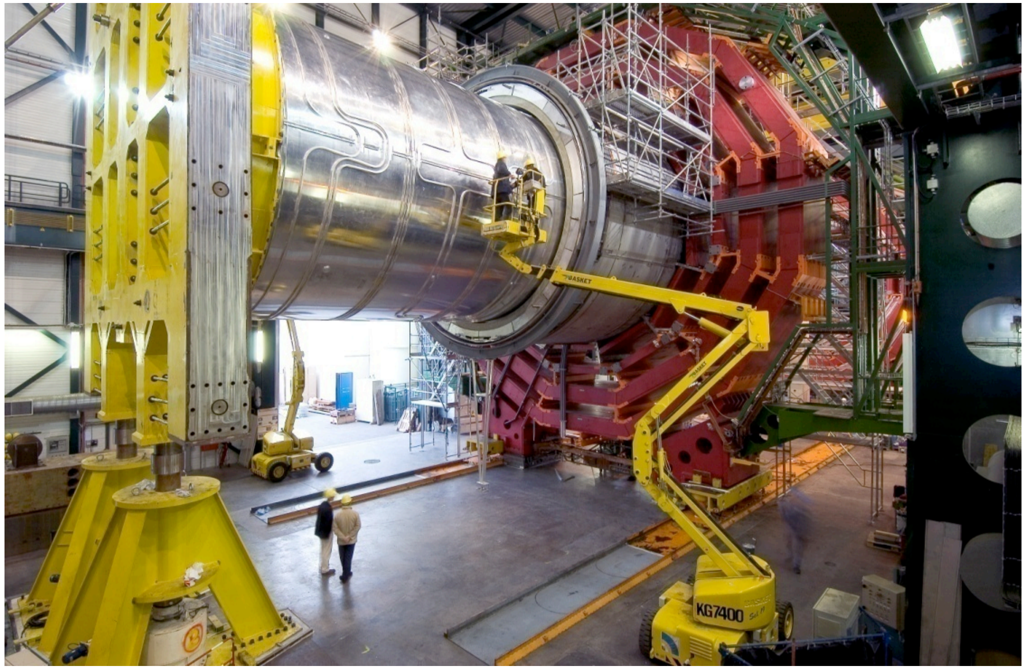
UXC/USC5: CMS caverns

Delivered to the experiment on February 1-st 2005.

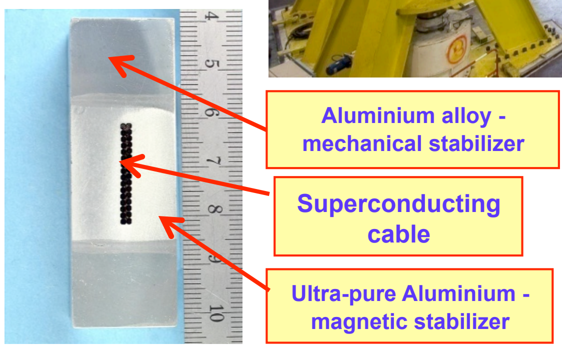
CMS (Compact Muon Solenoid)

The CMS magnet is a superconducting solenoid around which the full detector has been built. Basic goal: measure 1 TeV muons with 10% resolution →B=4T
The coil has an overall length of 13m and a diameter of 7m, and a magnetic field about 100,000 times stronger than that of the Earth. The magnet stores enough energy to melt 18 tons of gold and has the largest coil of its type ever constructed and allows the tracker and calorimeter detectors to be placed inside the coil, resulting in a detector that is, overall, “compact”, compared to detectors of similar weight.

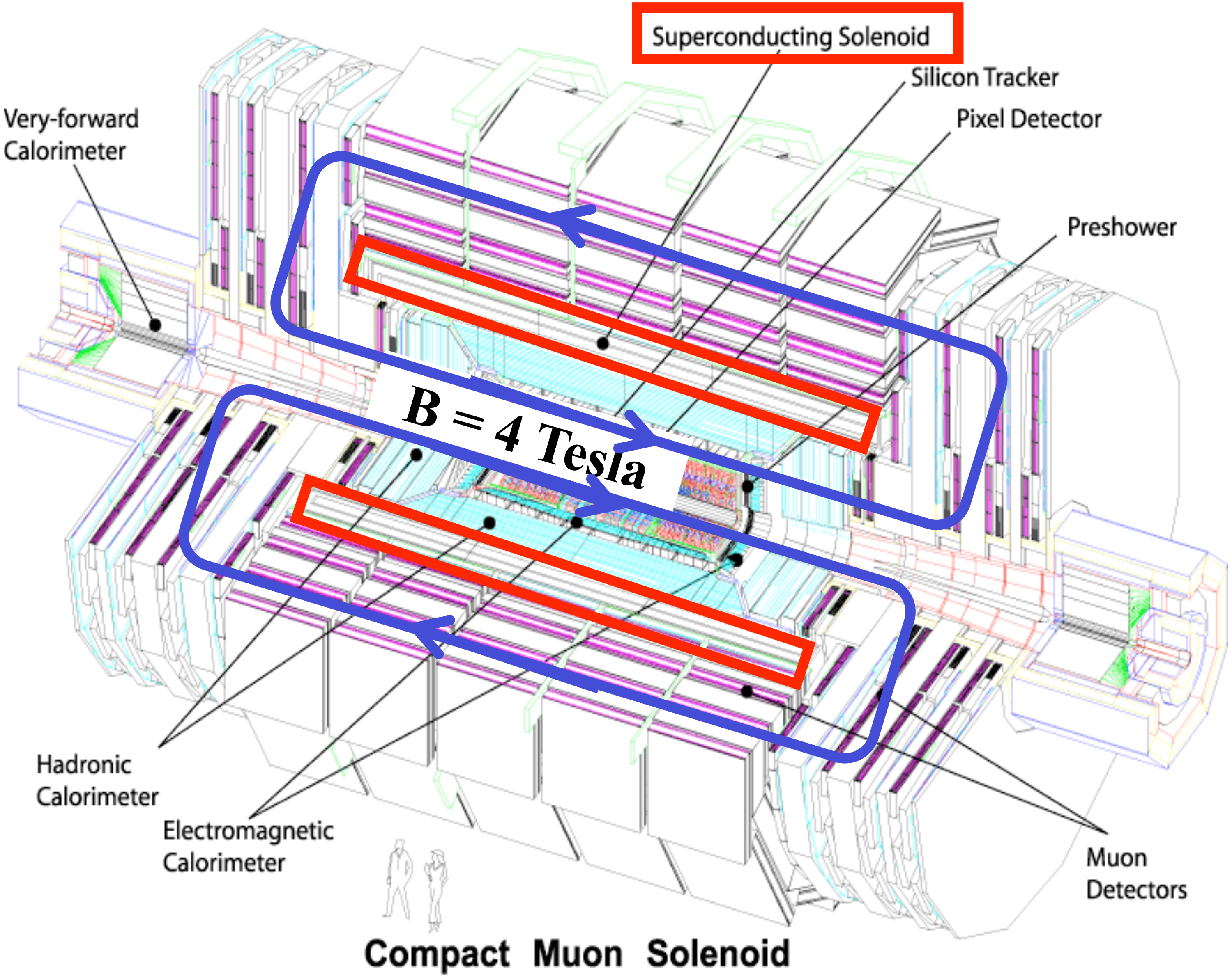




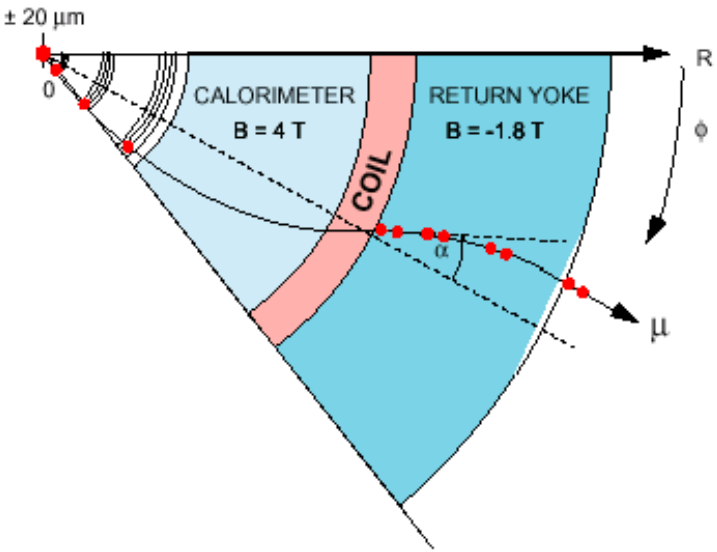
4-layer winding of superconducting reinforced cable cooled to ~ 4K to carry enough current (~ 20kA).
The superconductor chosen is Niobium Titanium (NbTi) wrapped with copper

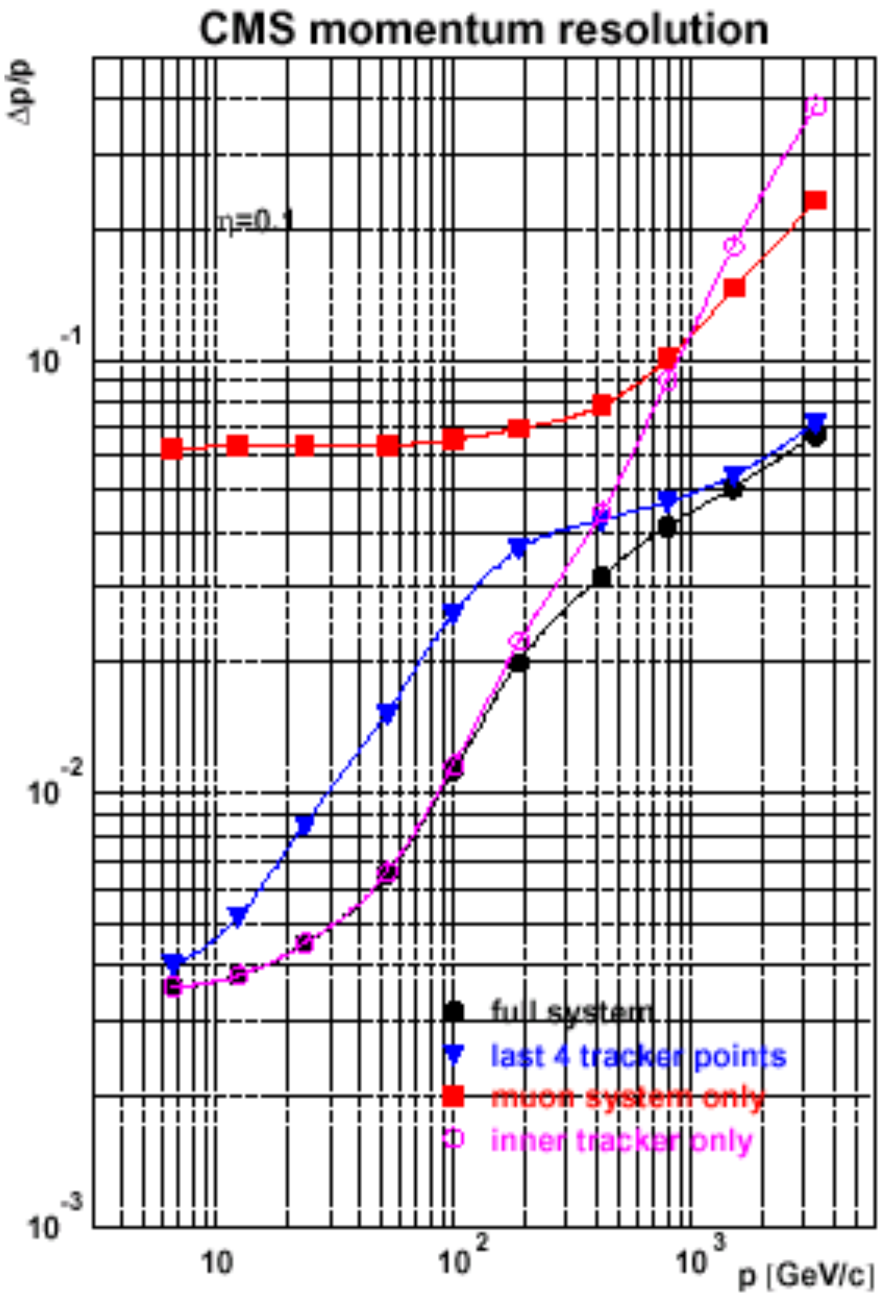


CMS – Compact Muon Solenoid



Choice of solenoid

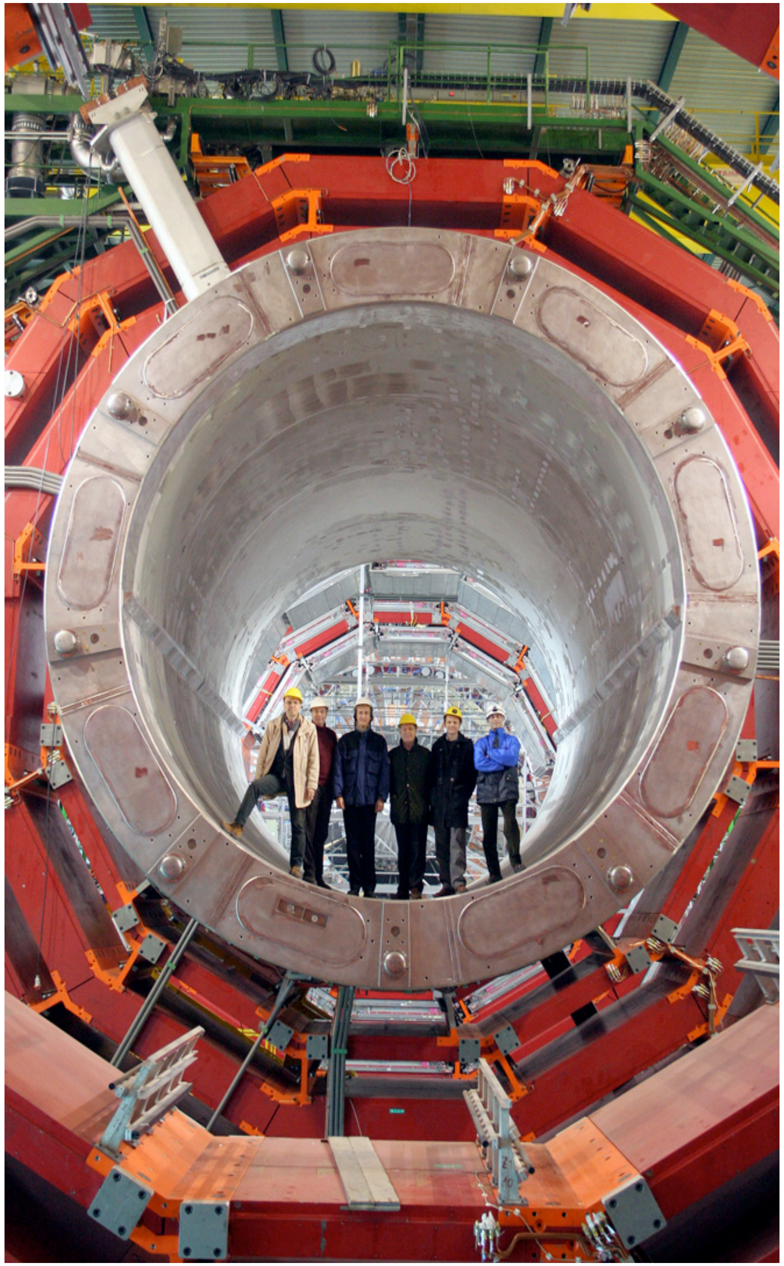




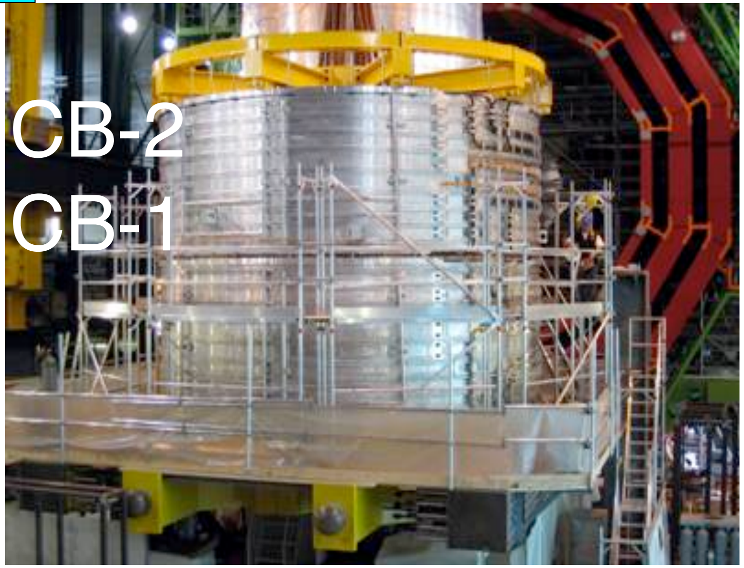
- Bending in the transverse plane
- Use 20µm beam spot
- Excellent momentum resolution when combined with the tracker

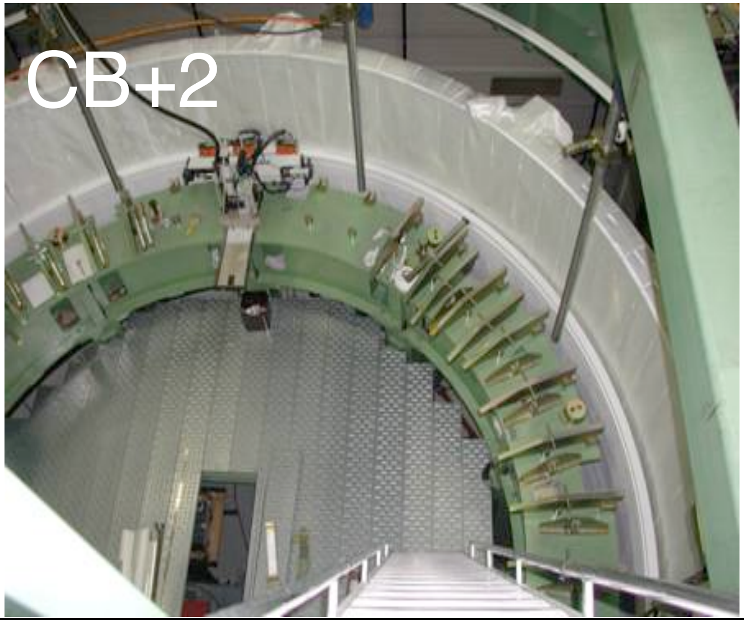
BUT no PM tubes in CMS (4T)

The Superconductor for 4T !



Magnet construction





The barrel yoke

Connecting pieces from Czech republic

Main pieces from Russia

Feet: ~35 tonnes each; from Pakistan (outer rings) or Germany (central ring)

Inside SX5 – the central barrel ring

Central ring supports solenoid

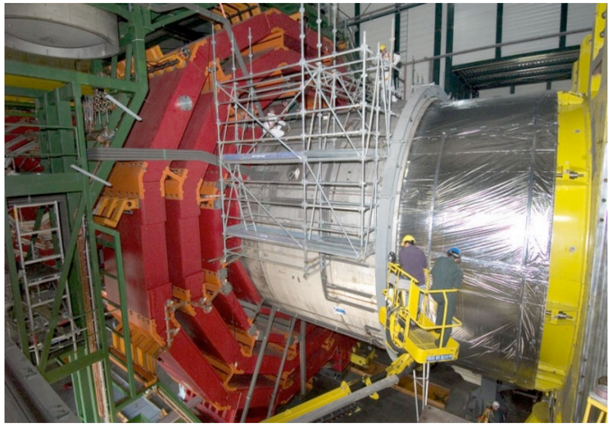
Outer vacuum vessel for solenoid
- manufactured in Lons Le Saunier by France Comte Industrie
- Transported to CERN in pieces and welded together at Cessy

Air-pads for moving rings etc.
-from Noell GmbH, Germany
-Use compressed air at 24 atmospheres from cylinders
-Each pad can lift ~350 tonnes
-4 pads per side
-Rails used to guide the movement
-Air-powered pistons push the rings

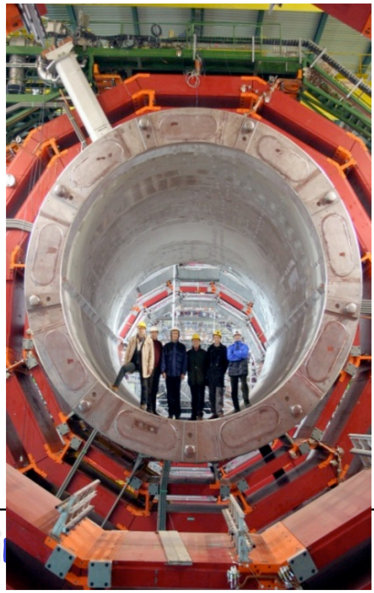
CMS Solenoid

Swivelling of coil 25 Aug

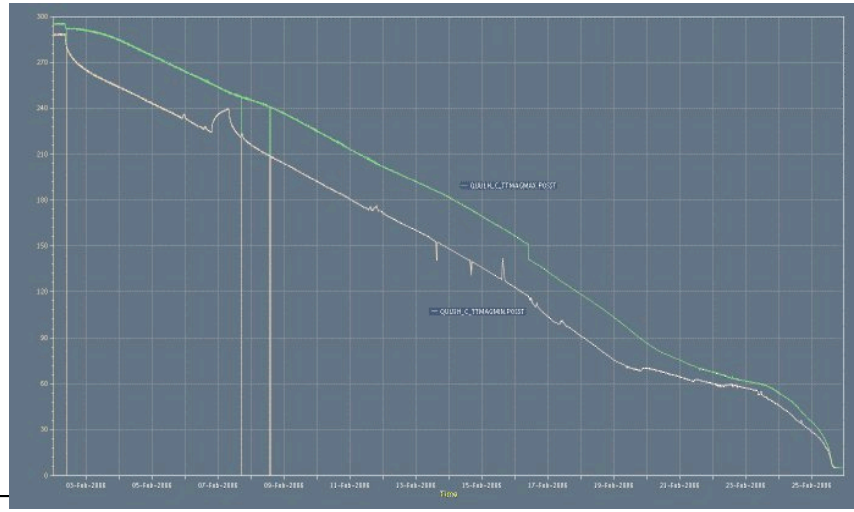
Coil inserted 14 Sep.



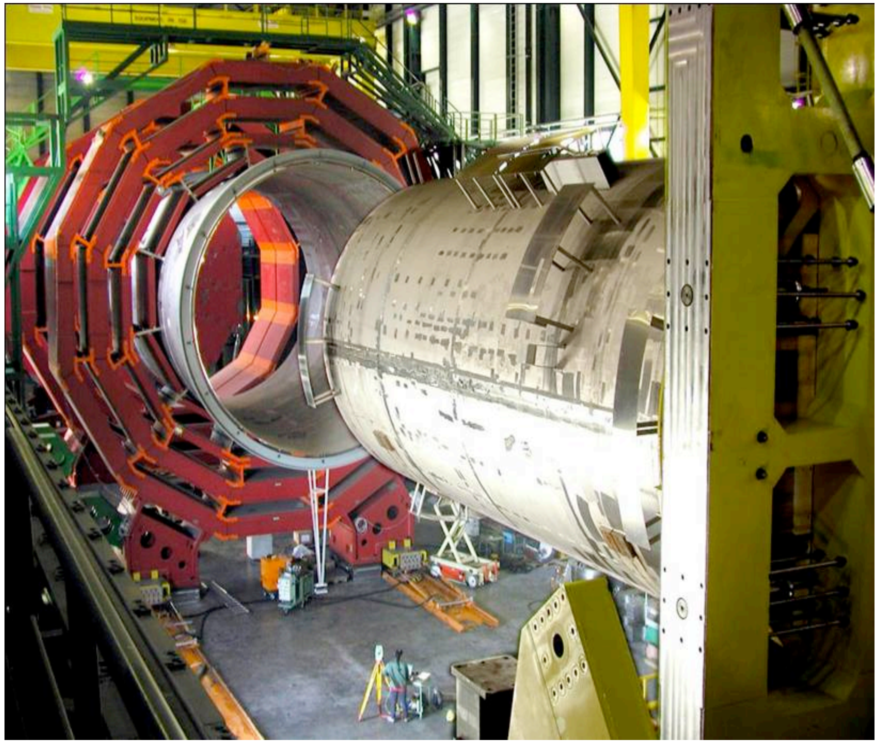
Vacuum Tank welded (Nov-Jan)



Coil Cooled to 4.5K in 25 days (Feb).
Test on Surface (May-Aug)



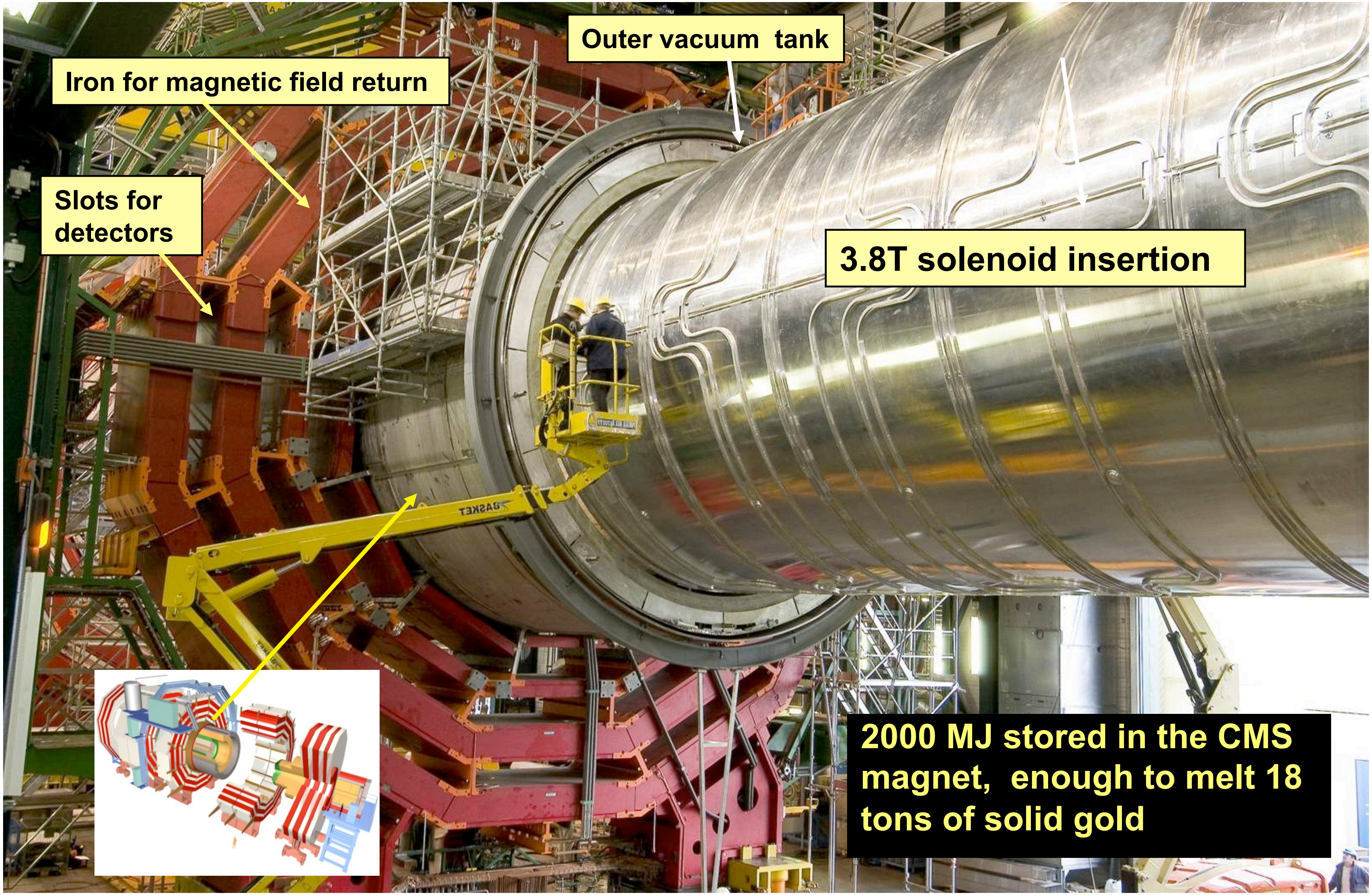
Inside SX5 – inserting the inner vacuum vessel



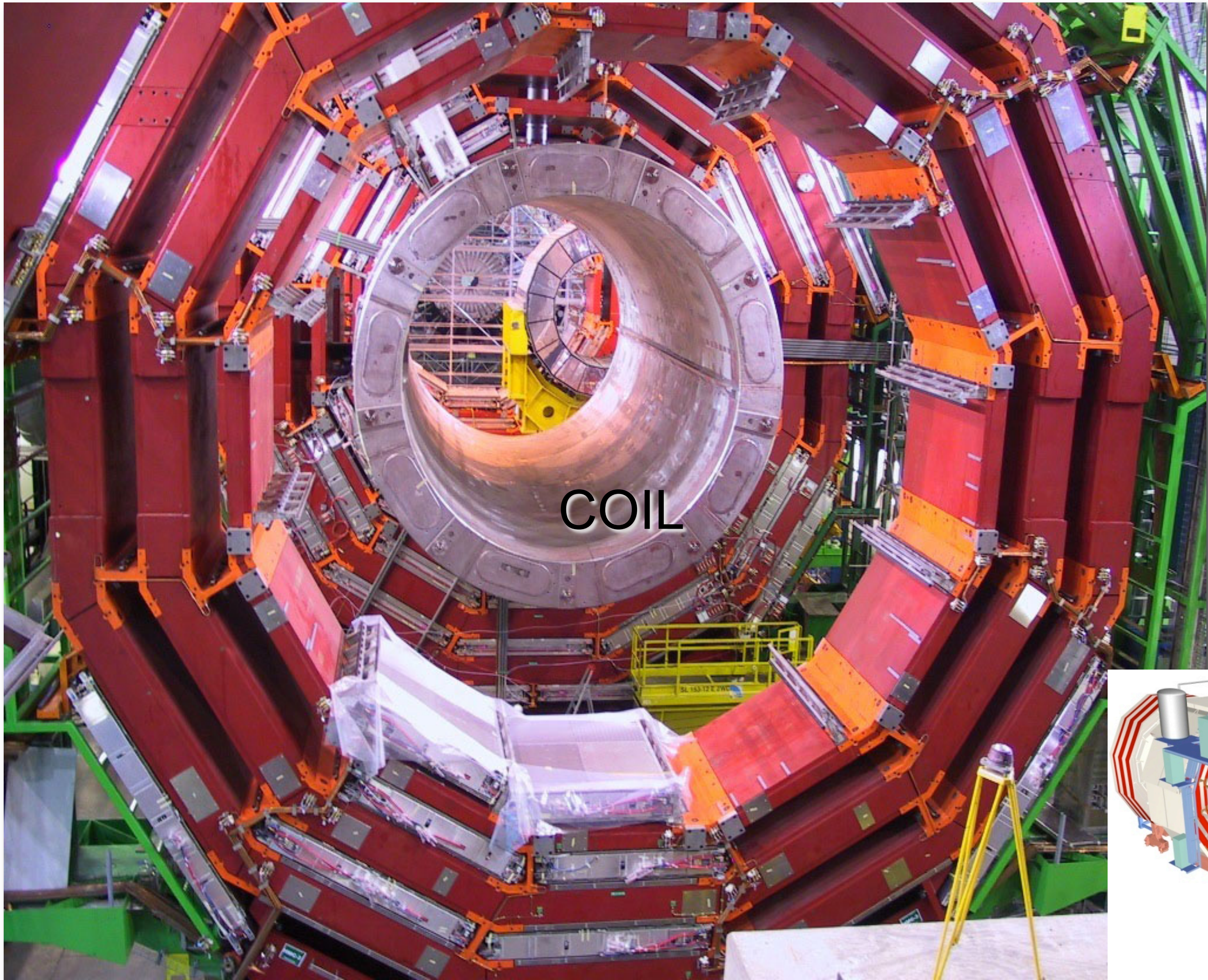
Inner vacuum vessel
-Manufactured by FCI as a single piece and transported by road to Cessy
-Supported and rotated by platform made in Korea

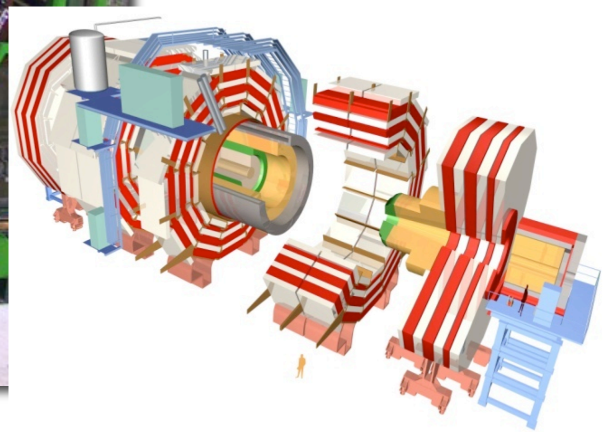
Assembling of the Solenoid of CMS

CMS – Compact Muon Solenoid

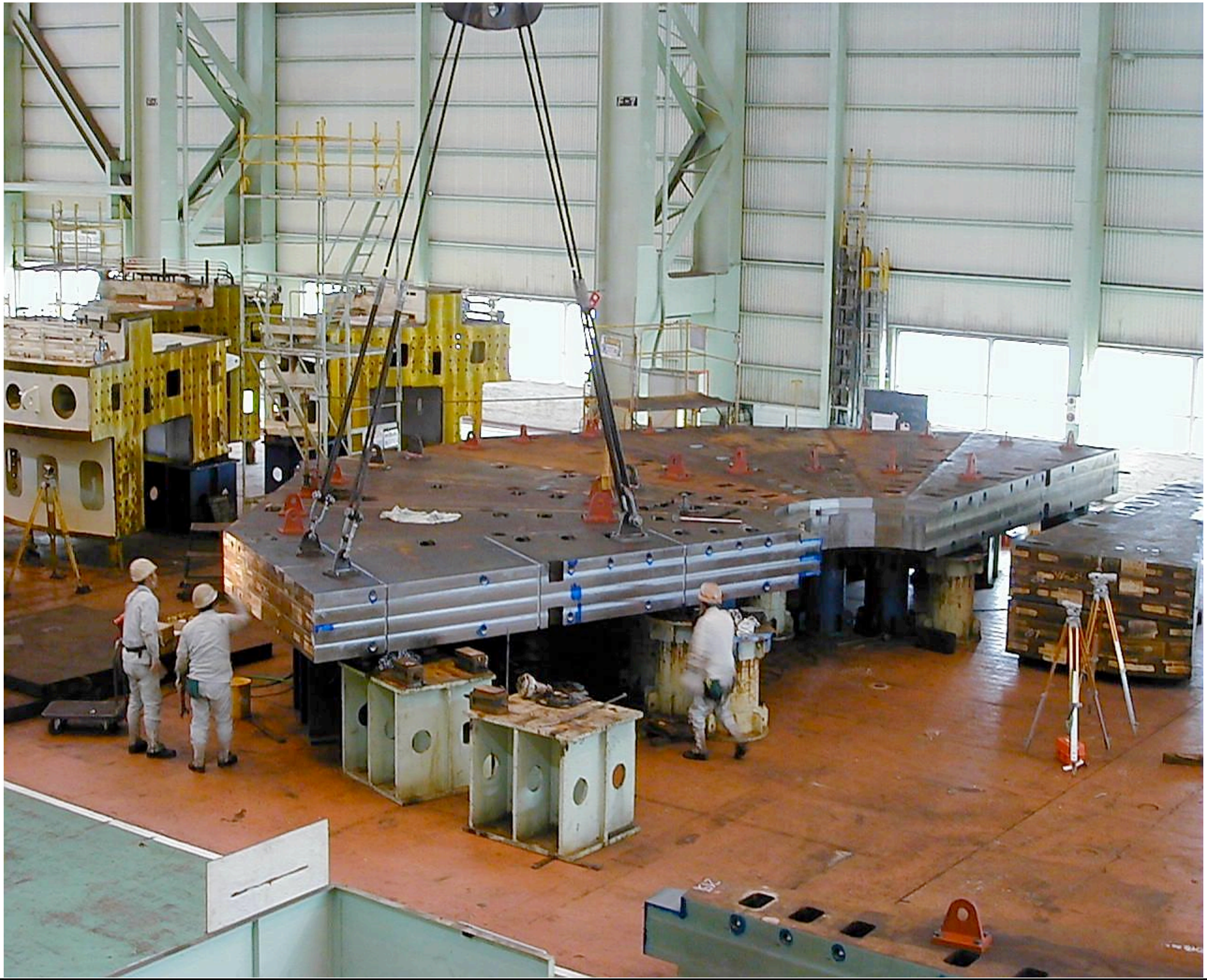


Surface Hall in Feb 2006





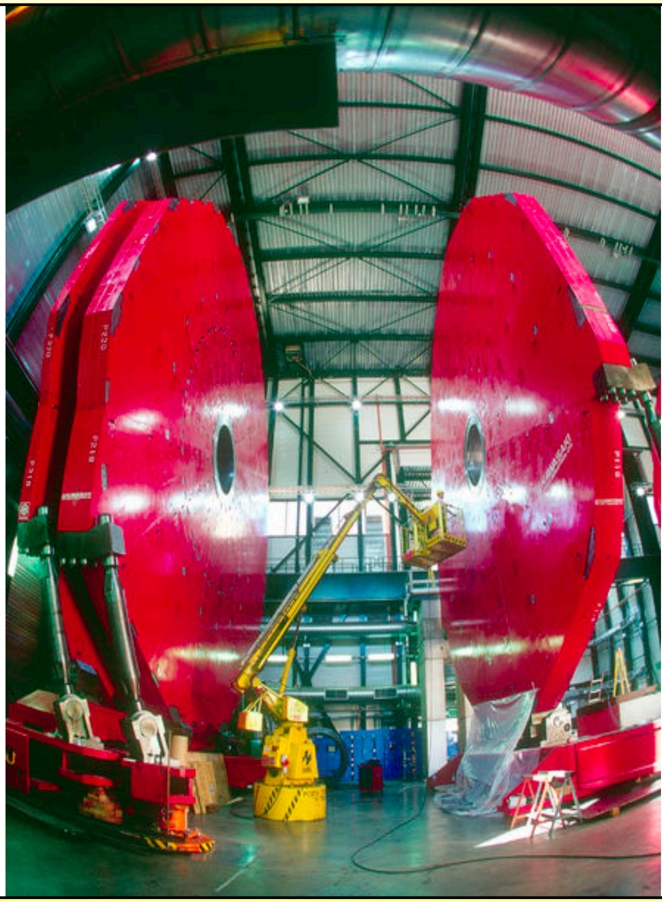
Half Disk Assembly at Kawasaki (15 Feb "00)



Endcap disk

Inside SX5 – the endcap yoke disks

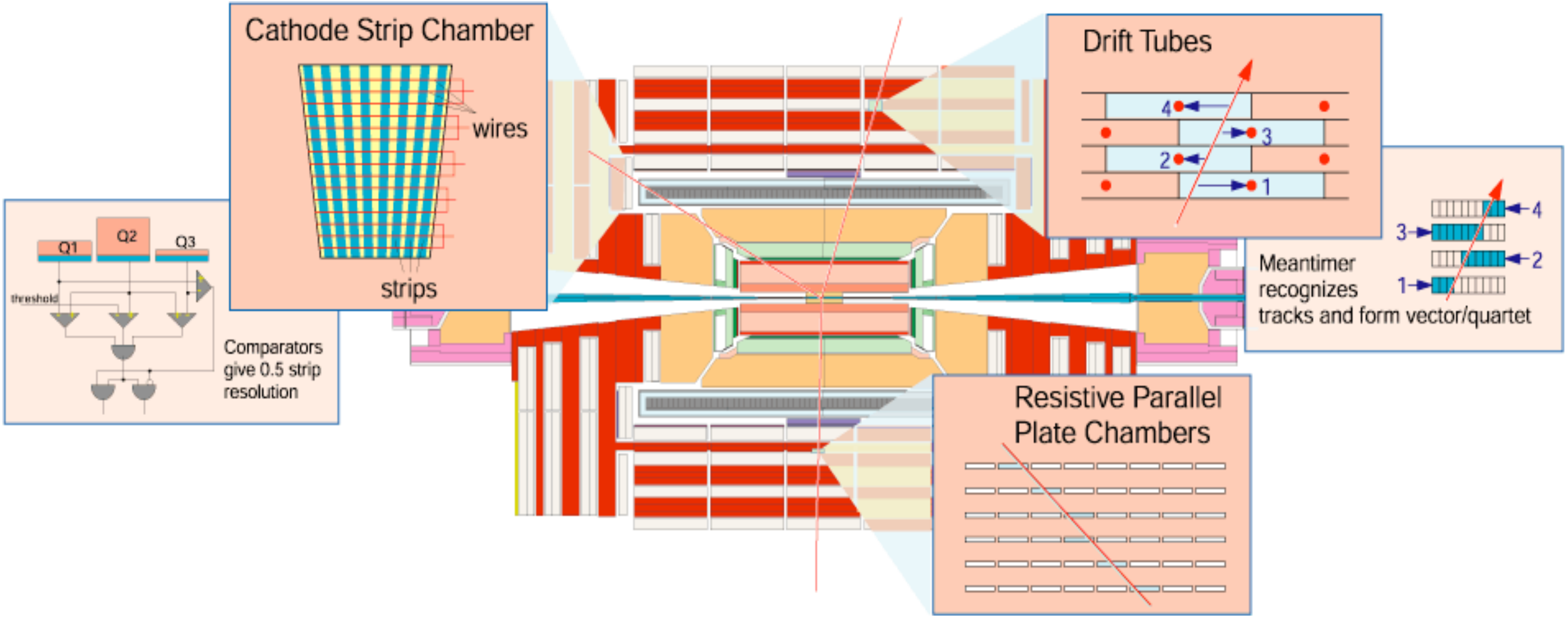
Three disks for one endcap



- Disks constructed from wedges made in Japan, assembled @ CERN
- “Carts” made in China

One disk loaded with CSCs

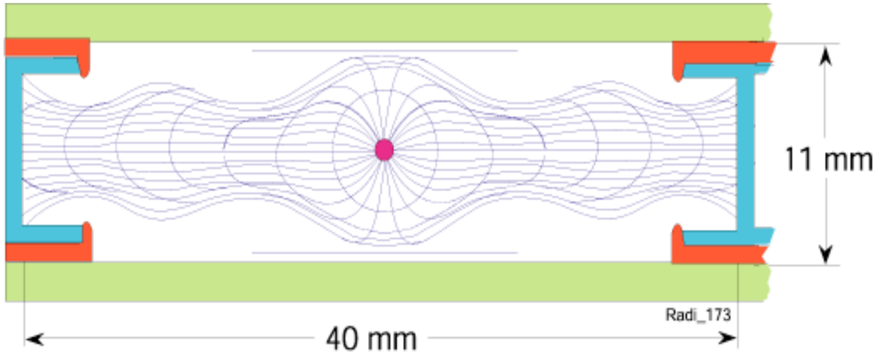
Muon Detectors



CMS will use three types of gaseous particle detectors for muon identifica-tion: Drift Tubes (DT) in the central barrel region, Cathode Strip Chambers (CSC) in the endcap region and Resistive Parallel Plate Chambers (RPC) in both the barrel and endcaps. The DT and CSC detectors are used to obtain a precise measurement of the position and thus the momentum of the muons, whereas the RPC chambers are dedicated to providing fast informa-tion for the Level-1 trigger

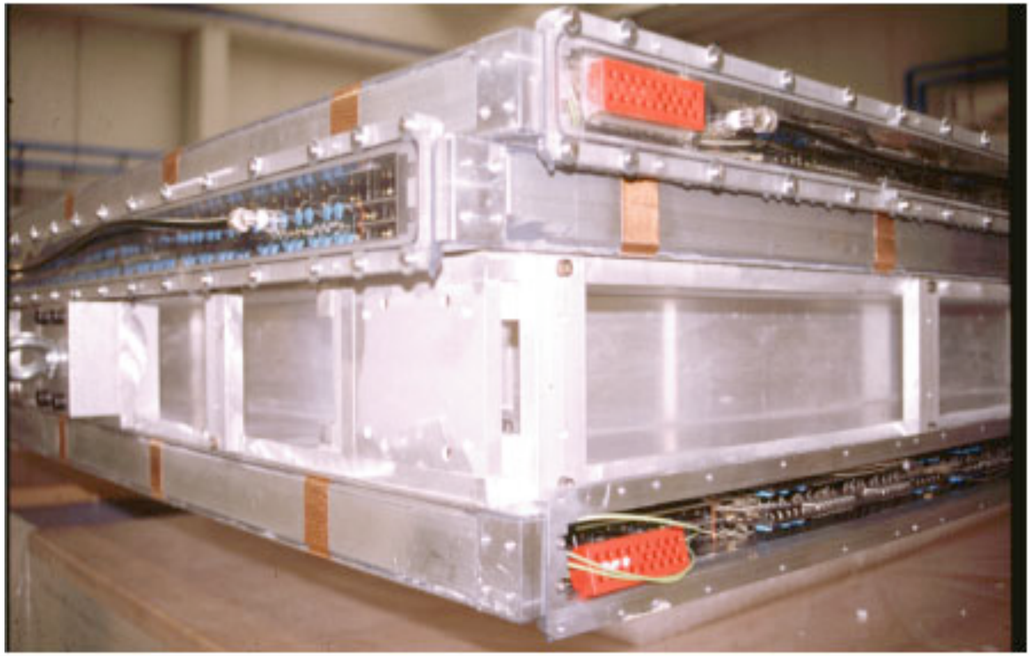
Muon Detectors: Drift Tubes

Drift Tubes are used in the Barrel where the Magnetic field is guided and almost fully trapped by the iron plates of the Magnet Yoke. Each tube contains a wire with large pitch (4 cm), and the tubes are arranged in layers. Only the signals from the wires are recorded - resulting in a moderate number of electronic channels needed to read out the detectors. When an ionizing particle passes through the tube, it liberates electrons which move along the field lines to the wire, which is at positive potential. The coordinate on the plane perpendicular to the wire is obtained with high precision from the time taken by the ionization electrons to migrate to the wire. This time (measured with a precision of 1ns), multiplied by the electron drift velocity in the gas, translates to the distance from the wire.

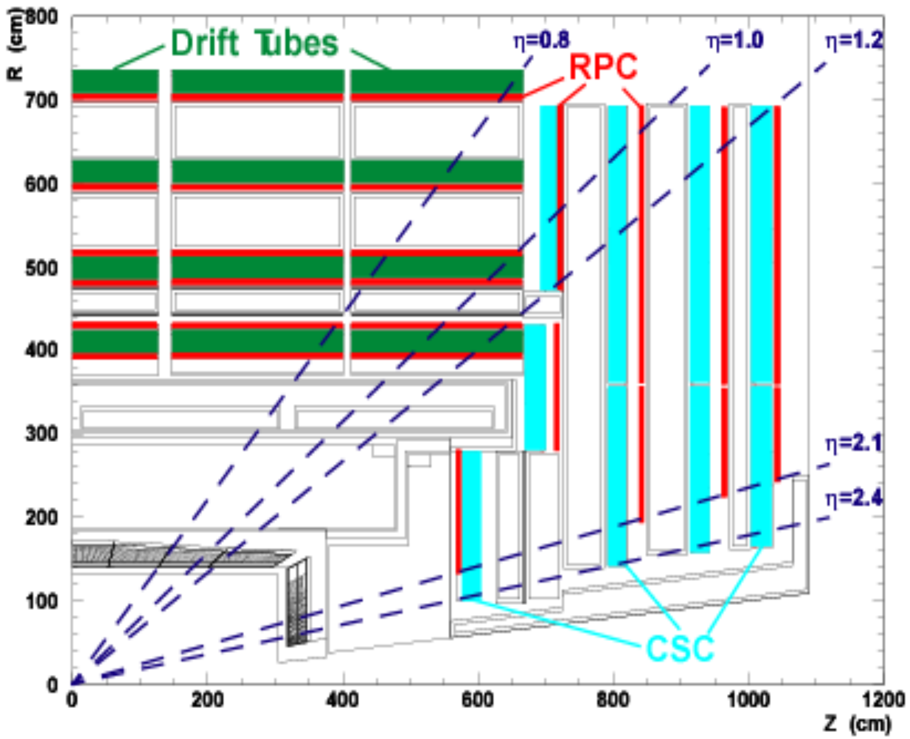


A DT layer is put together gluing to an aluminium plate a set of parallel aluminium I beams. The wires are stretched, held by appropriate end plugs, and the layer is closed by another aluminium plate.

Groups of four layers are grown in this way on a precision table. Copper strips are previously glued to the Al plates in front of the wire to better shape the electrostatic field. A full-size final prototype of a DT chamber is shown below. The chamber is 2m x 2.5m in size. The largest DT chambers to be used in CMS will have dimensions of 4m x 2.5m in size.

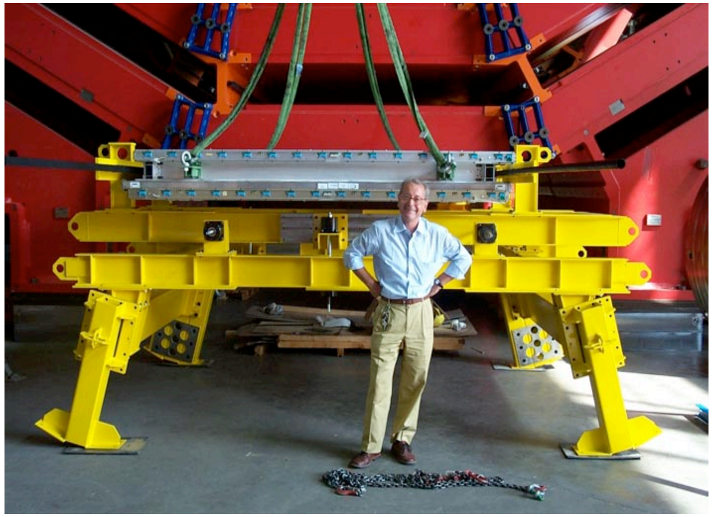


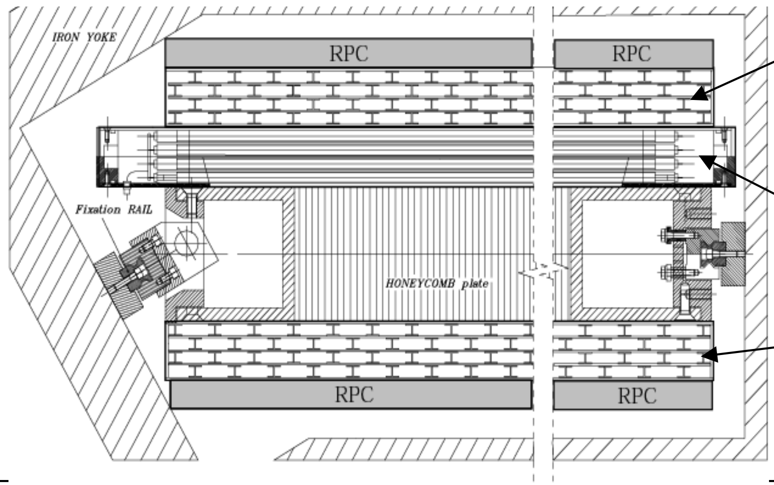
The Muon Chambers



Position measurement:
Drift Tubes (DT) in barrel
Cathode Strip Chambers (CSC) in endcaps

Trigger:
Resistive Plate Chambers (RPCs) in barrel and endcaps





195000 DT channels
210816 CSC channels
162282 RPC channels

CSC layout

540 Chambers

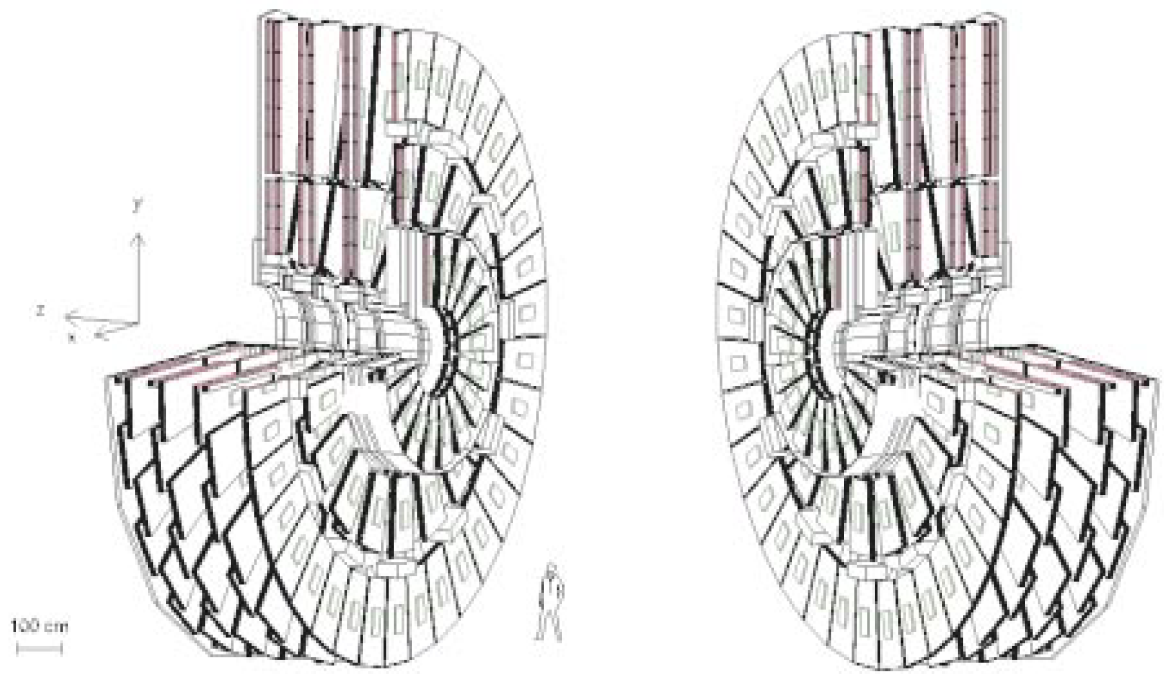
400,000 readout channels

Sensitive area 6,000 m^2 (all planes)

Offline spatial resolution ~100 μm

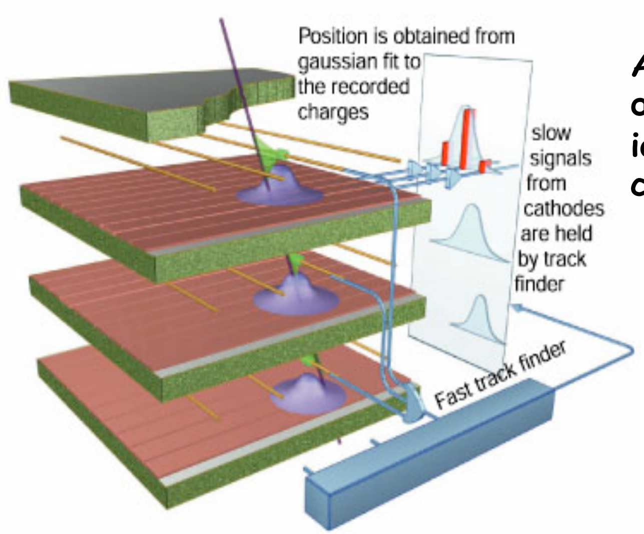
Trigger spatial precision ~1-2 mm

Trigger bunch-tagging efficiency ~99%



Muon Detectors: Cathode Strip Chambers

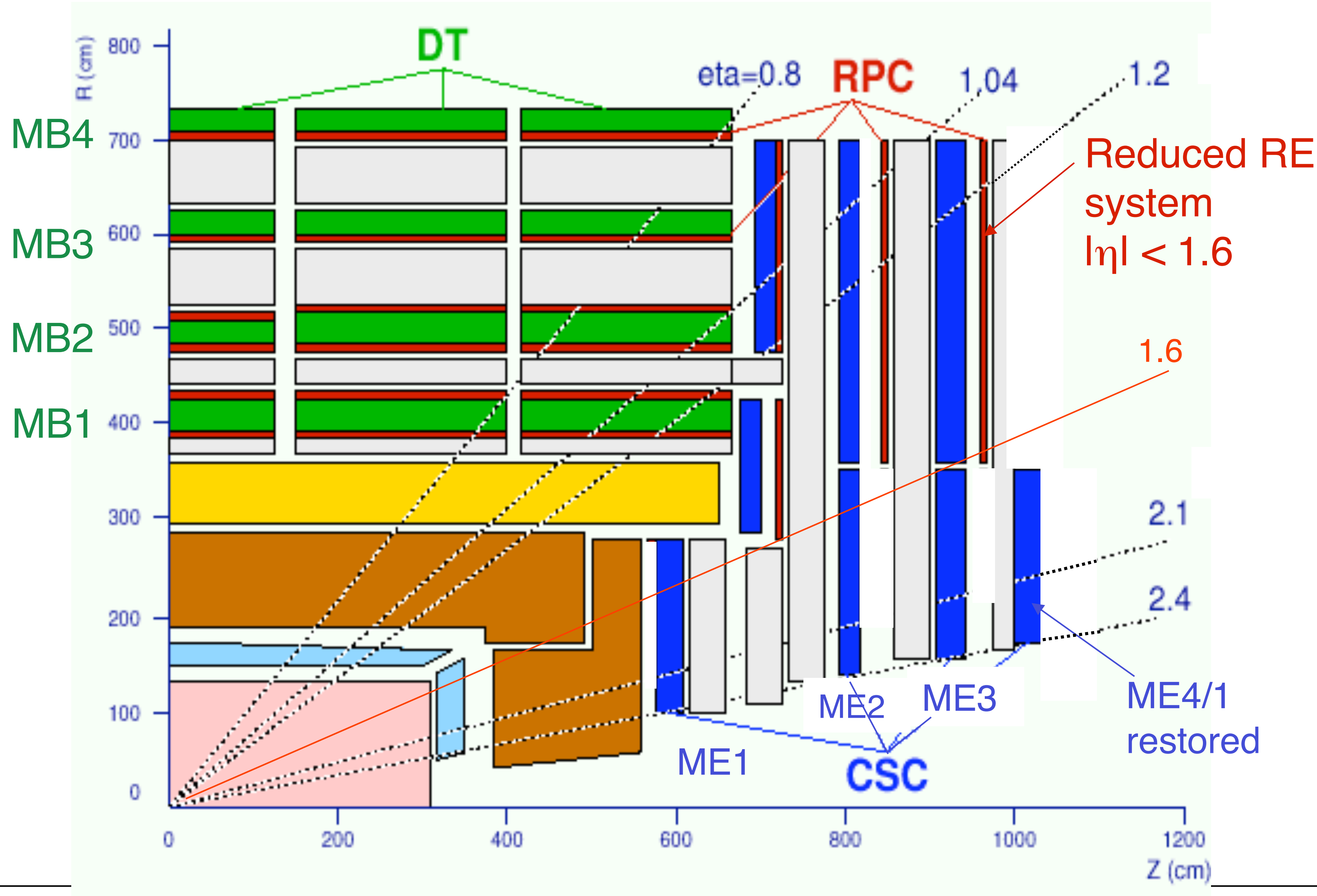
Cathode Strip Chambers are used in the Endcap regions where the magnetic field is very intense (up to several Tesla) and very inhomogeneous. CSCs are multiwire proportional chambers in which one cathode plane is segmented intro strips running across wires. An avalanche developed on a wire induces a charge on several strips of the cathode plane. In a CSC plane two coordinates per plane are made available by the simultaneous and independent detection of the signal induced by the same track on the wires and on the strips. The wires give the radial coordinate whereas the strips measure ϕ.
In addition to providing precise space and time information, the closely spaced wires make the CSC a fast detector suitable for triggering. CSC modules containing six layers provide both a robust pattern recognition for rejection of non-muon backgrounds and also efficient matching of external muon tracks to internal track segments.



Artist scheme of a CSC chamber, with a sketch of the mechanism of signal detection. The electrons are collected by the wire, whereas a cloud of positive ions moving away from the wire of the wire and toward the cathode induces a current on the cathode strips perpendicular to the wire direction.

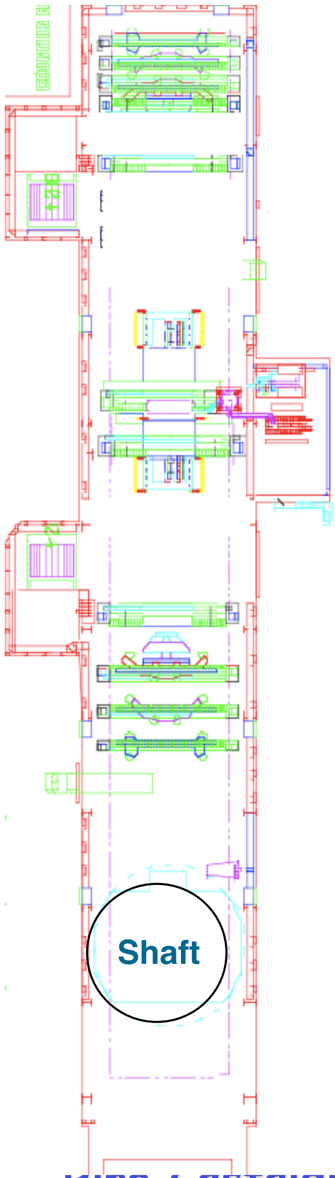
A six-layer CSC is built assembling together 7 Honeycomb panels. Three of them support two wire planes each, one on each face of the plate, wired at the same time as shown in the photograph below. The other four plates have the etched strip. The two inner plates have strips on both faces, whereas the two outer plates (closing the chamber) have strips on only one face.

Muon System

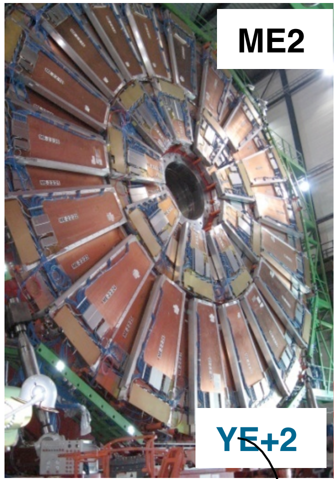

DT
eta=0.8
RPC
1,04
1.2
MB4
MB3
MB2
MB1
R (cm)
800
700
600
500
400
300
200
100
0
Reduced RE system
lηl < 1.6
1.6
2.1
2.4
ME1
ME2
ME3
CSC
ME4/1 restored
0
200
400
600
800
1000
1200
Z (cm)

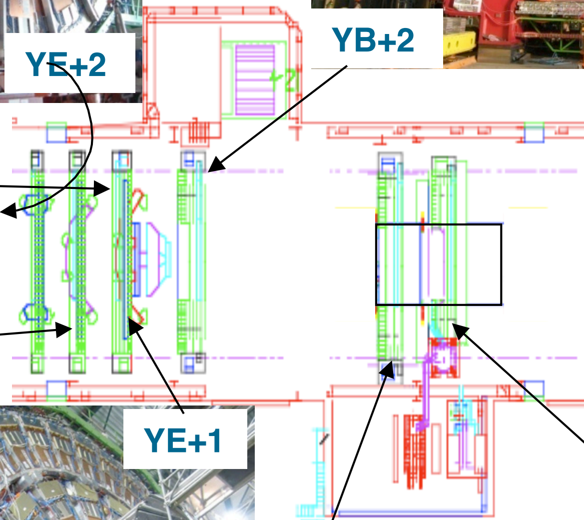
Muons Installation and Commissioning

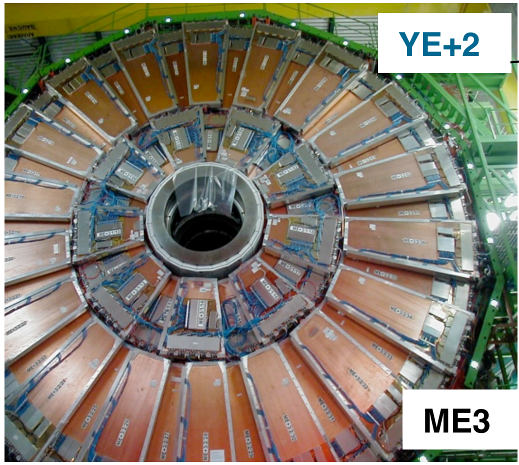
Surface Hall
SX5

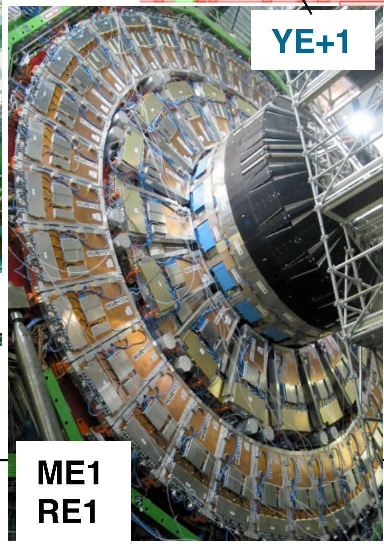


50% of RPCs
installed on YE disks.





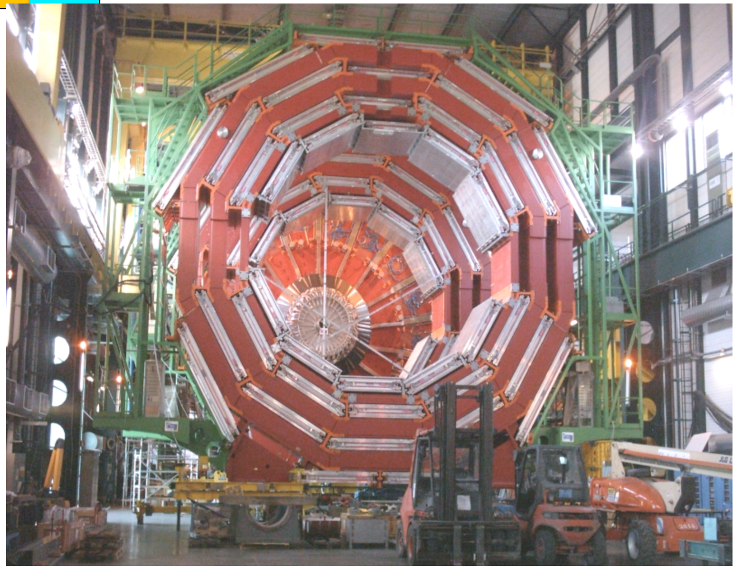


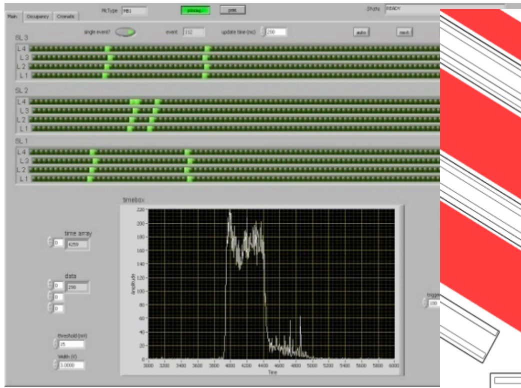


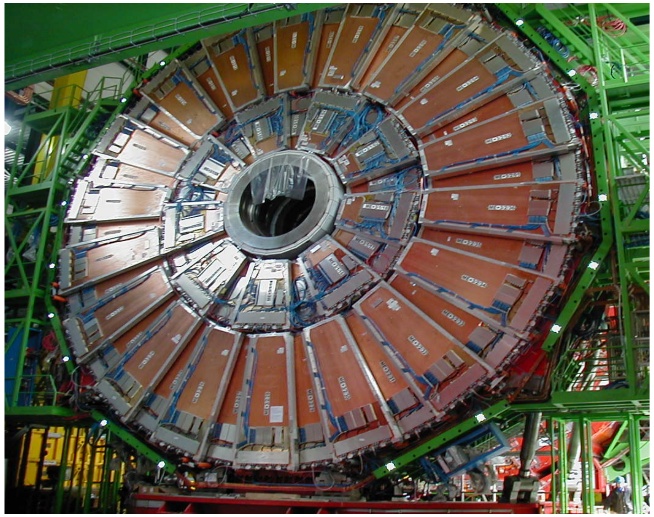
> 90% CSCs installed on YE disks.

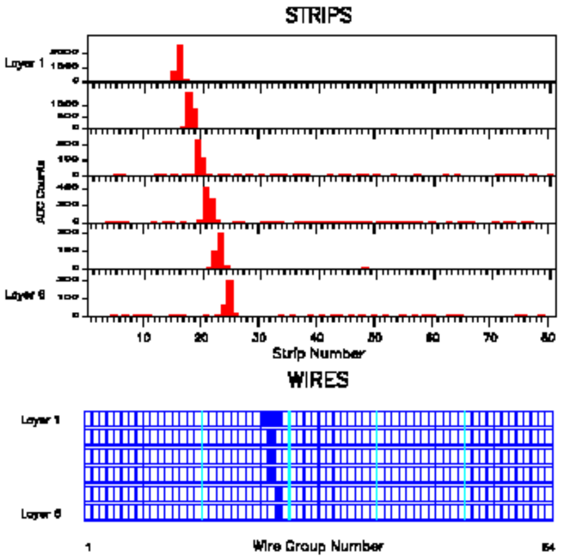
3 out of 5 YB wheels done (DTs, RPCs)

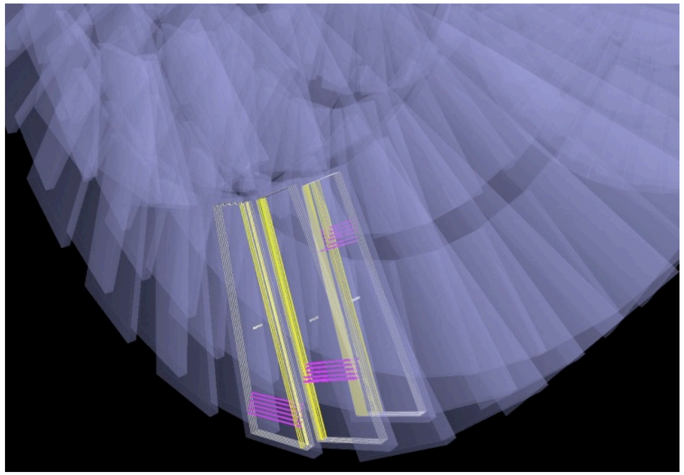
DTs and CSCs commissioning with cosmics











30 Nov: YE+3 leaves SX5 and 11 hours touches down safely in UXC

EM Calorimetry requirements

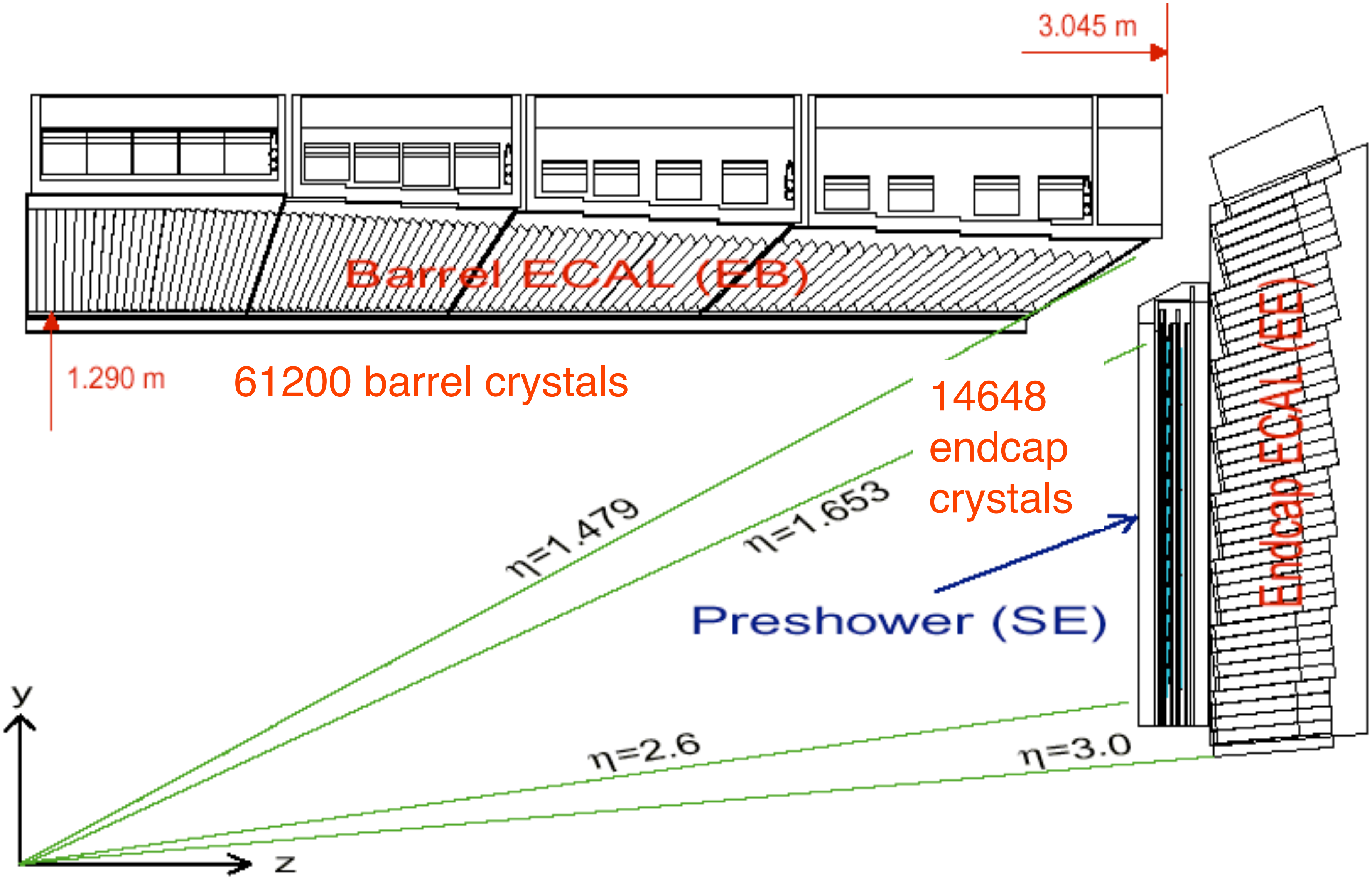
In several scenarios moderate mass narrow states decaying into photons or electrons are expected:

SM : intermediate mass $H \rightarrow \gamma\gamma$, $H \rightarrow Z Z^* \rightarrow 4e$
MSSM: $h \rightarrow \gamma\gamma$, $H \rightarrow \gamma\gamma$, $H \rightarrow Z Z^* \rightarrow 4e$

In all cases the observed width will be determined by the instrumental mass resolution. Need :

- good e.m. energy resolution
- good photon angular resolution
- good two-shower separation capability

ECAL


3.045 m
Barrel ECAL (EB)
1.290 m
61200 barrel crystals
14648
endcap
crystals
Endcap ECAL (EE)
Preshower (SE)
η=1.479
η=1.653
η=2.6
η=3.0
y
z

ECAL

75.000 lead tungstate crystals (very compact); fast (95% light emitted in 25ns; highly granular (2.19cm Moliere radius)

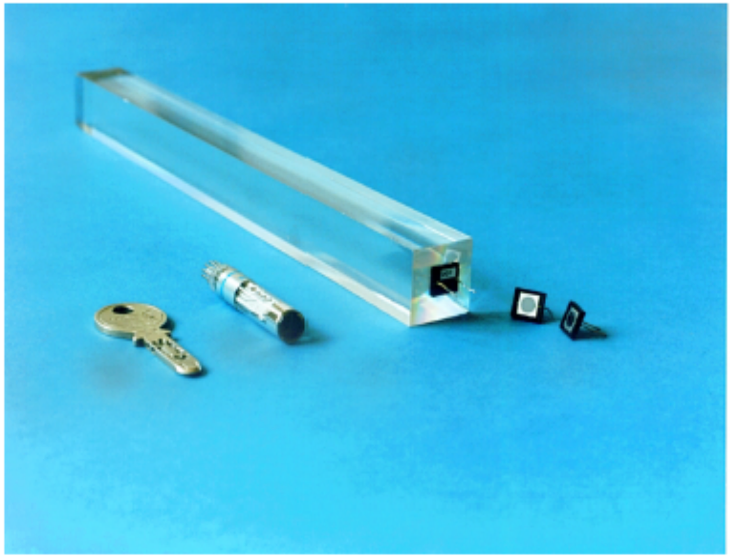
Excellent energy resolution

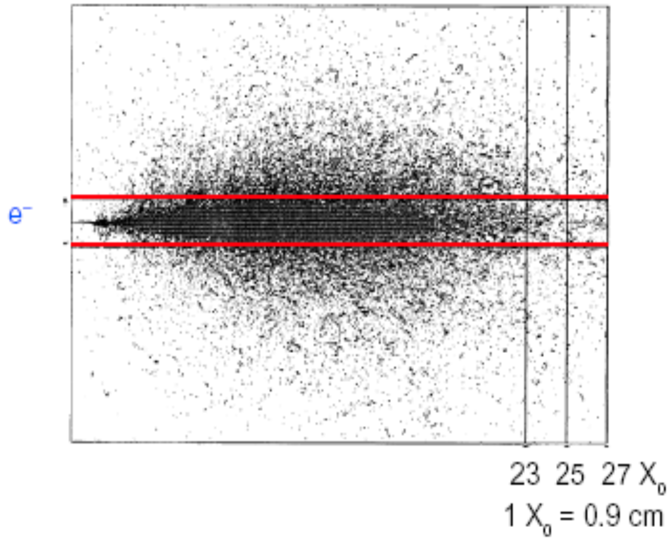
Stochastic term (Photostatistics APD 4p.e./MeV)

Noise (electronics and pile-up)

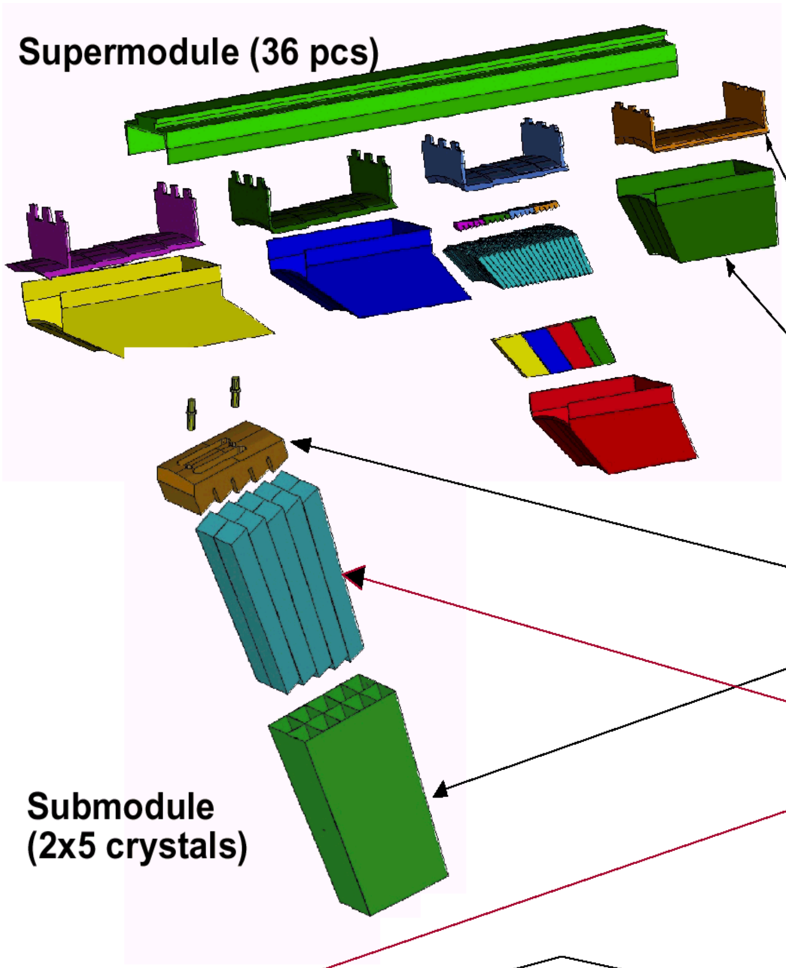
Constant term (uniformity and calibration)

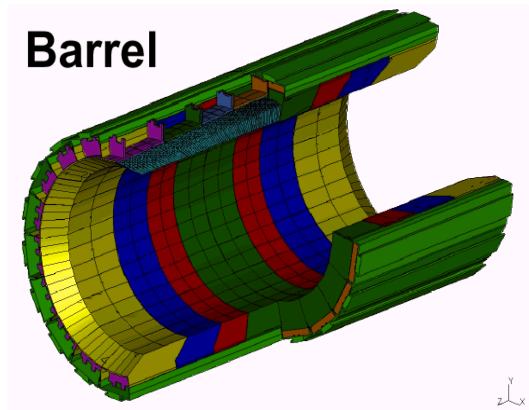
$$\frac{\sigma(E)}{E} = \frac{3\%}{\sqrt{E}} \oplus \frac{150MeV}{E} \oplus 0.40\%$$





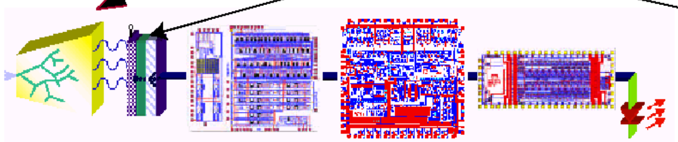
ECAL: EB Exploded View





Mechanics
Modules (144 pcs)
Tendering in 2000
Submodules (2448 pcs)
Contracts signed in 1999
Total value of 3MCHF

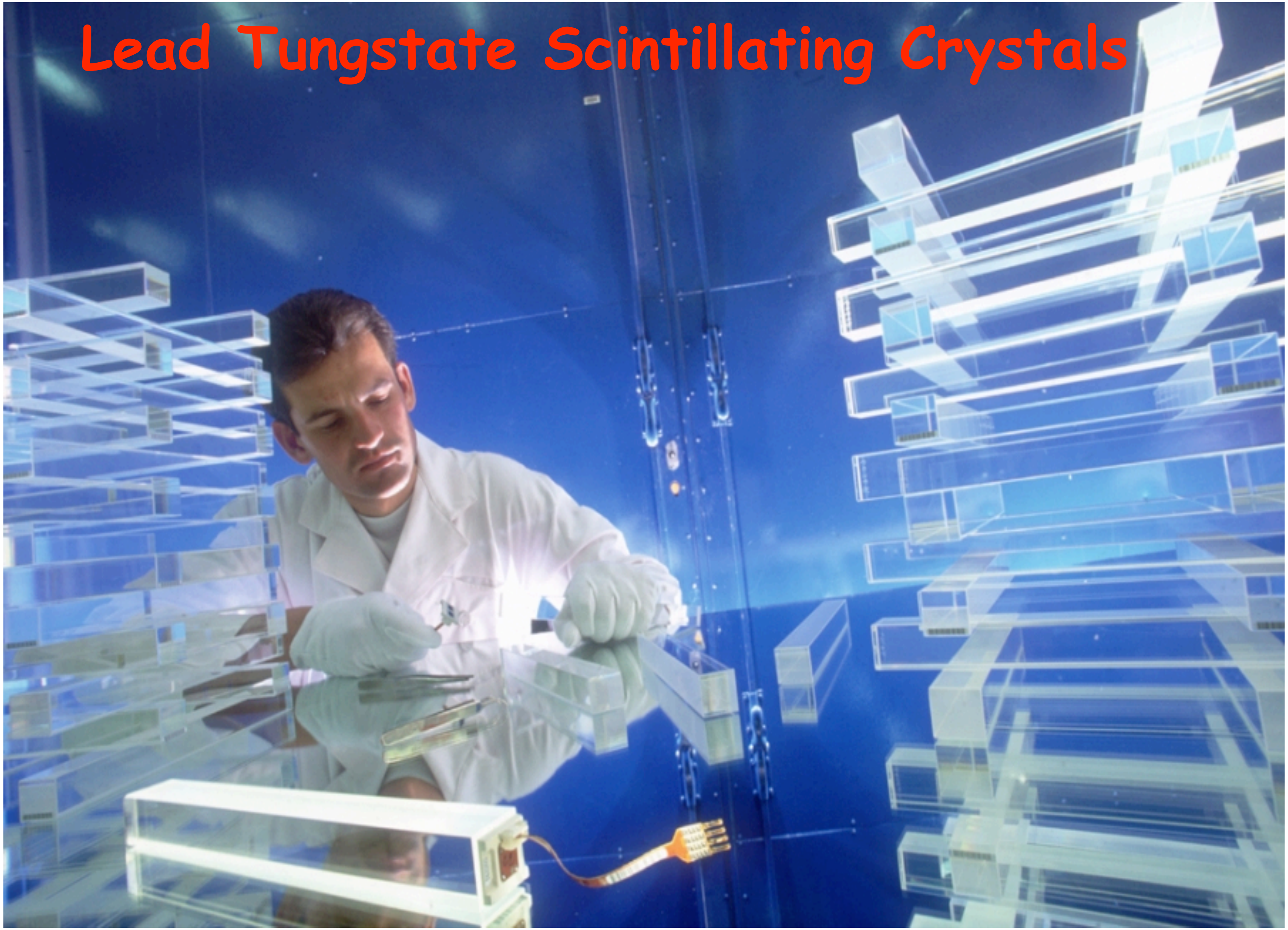
PbWo4 Crystals
Preproduction in Russia, R&D in China
Production agreement signed in Russia
Letter of Intent signed in China
both at 1.6 $/cc
Total Volume11 m^3(77400 crystals)



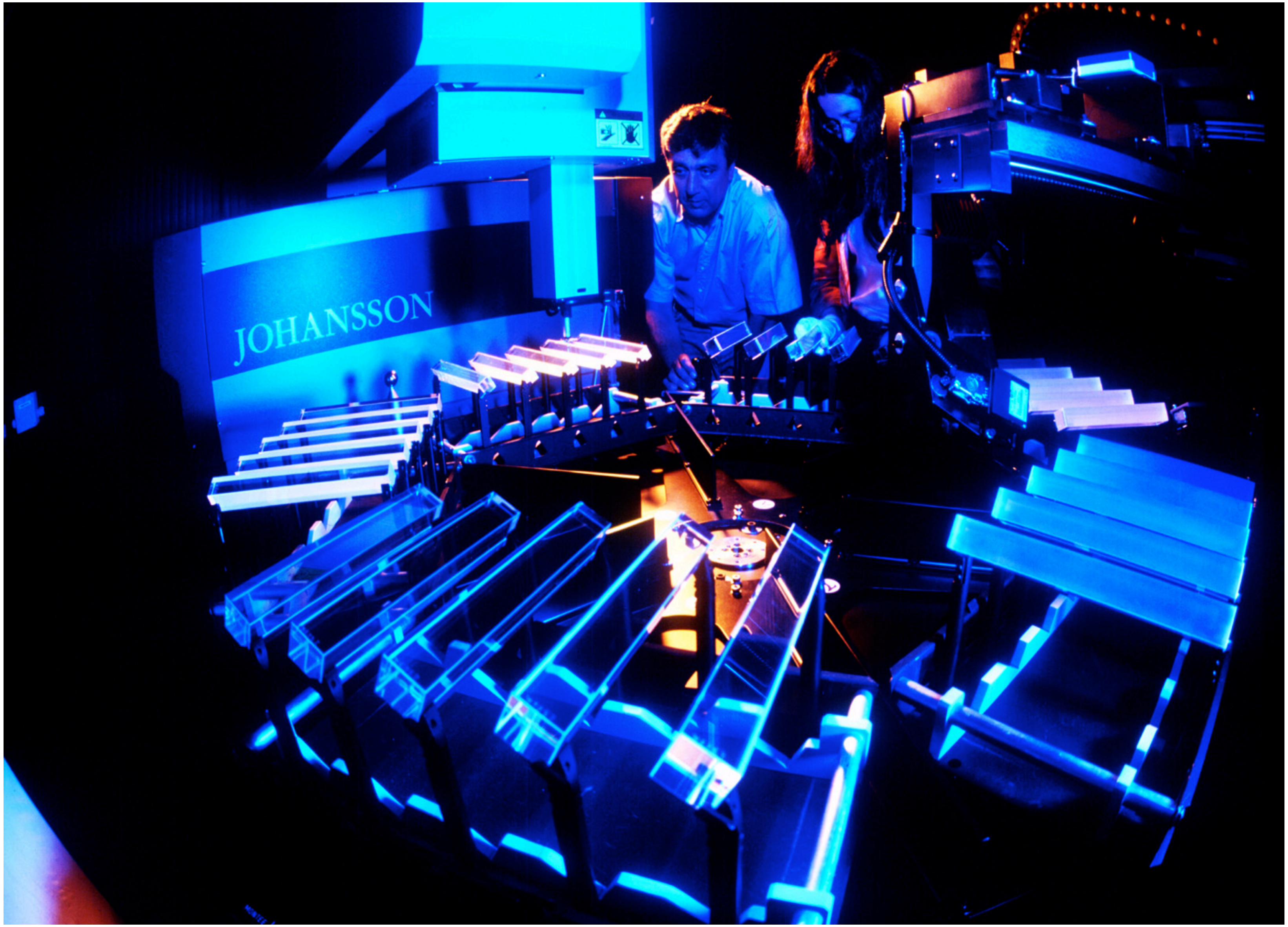
Electronic Channel (80.000 pcs)

Avalanche PhotoDiode (120000 pcs)
Hamamatsu
Contract Oct 1999. 7 MCHF

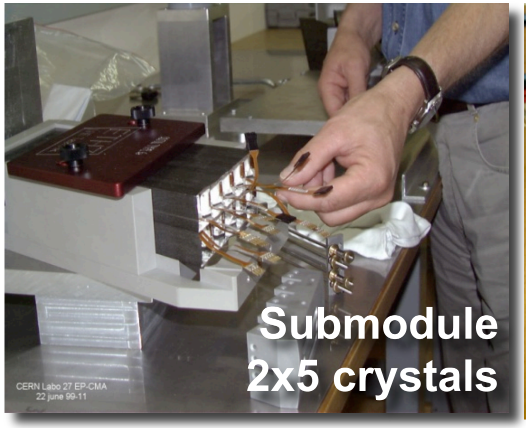
Electromagnetic Calorimeter

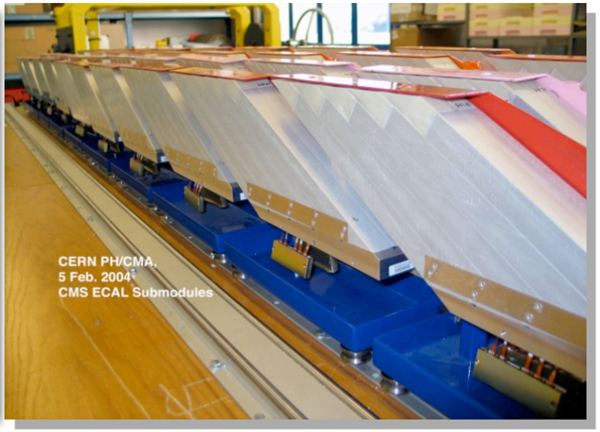


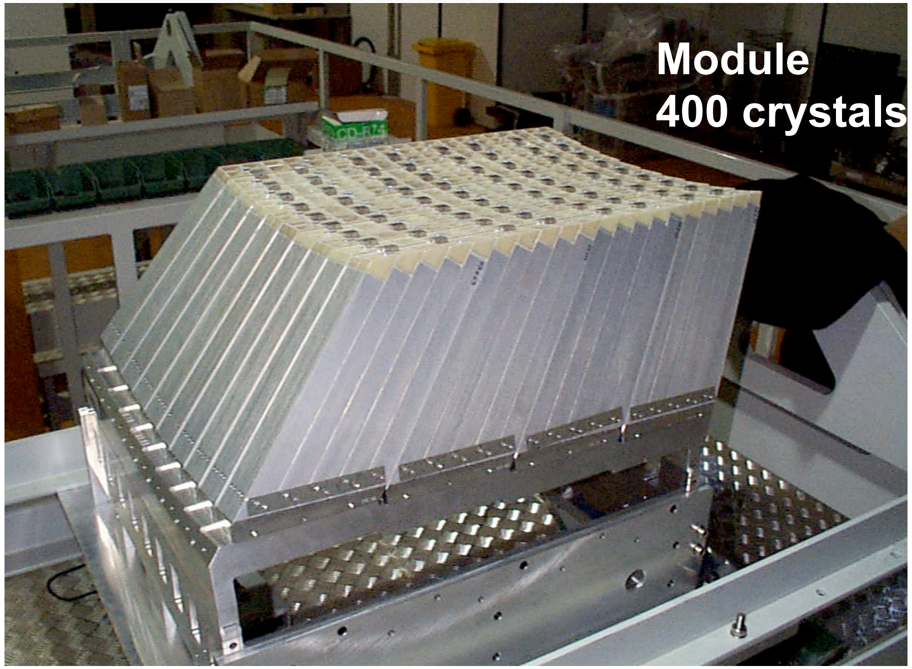
Produzione dei cristalli in Russia

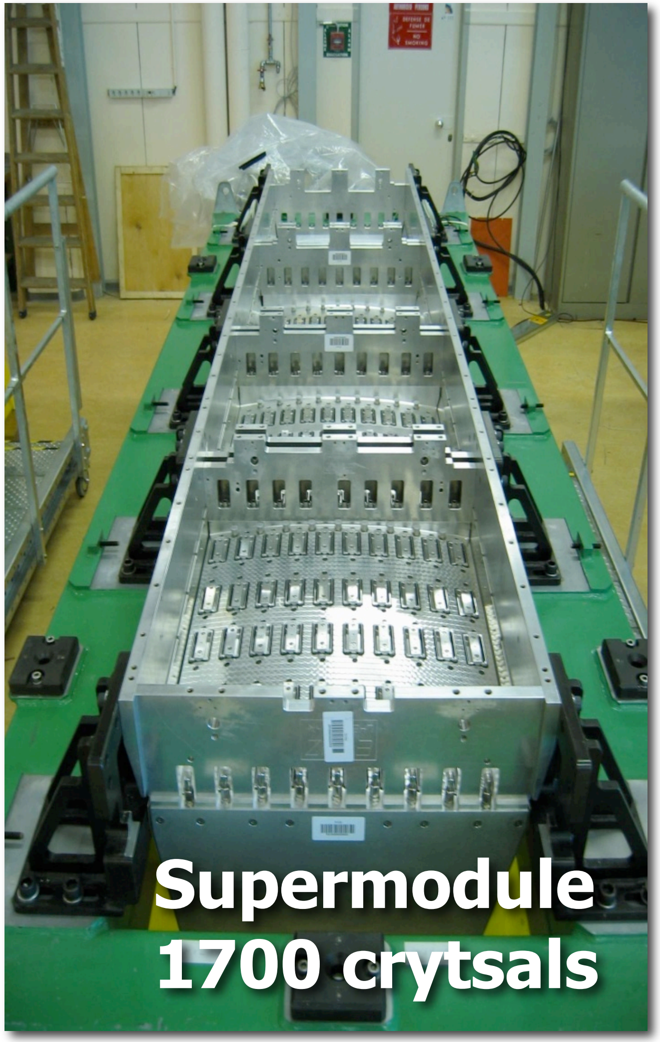


Assembling the Calorimeter



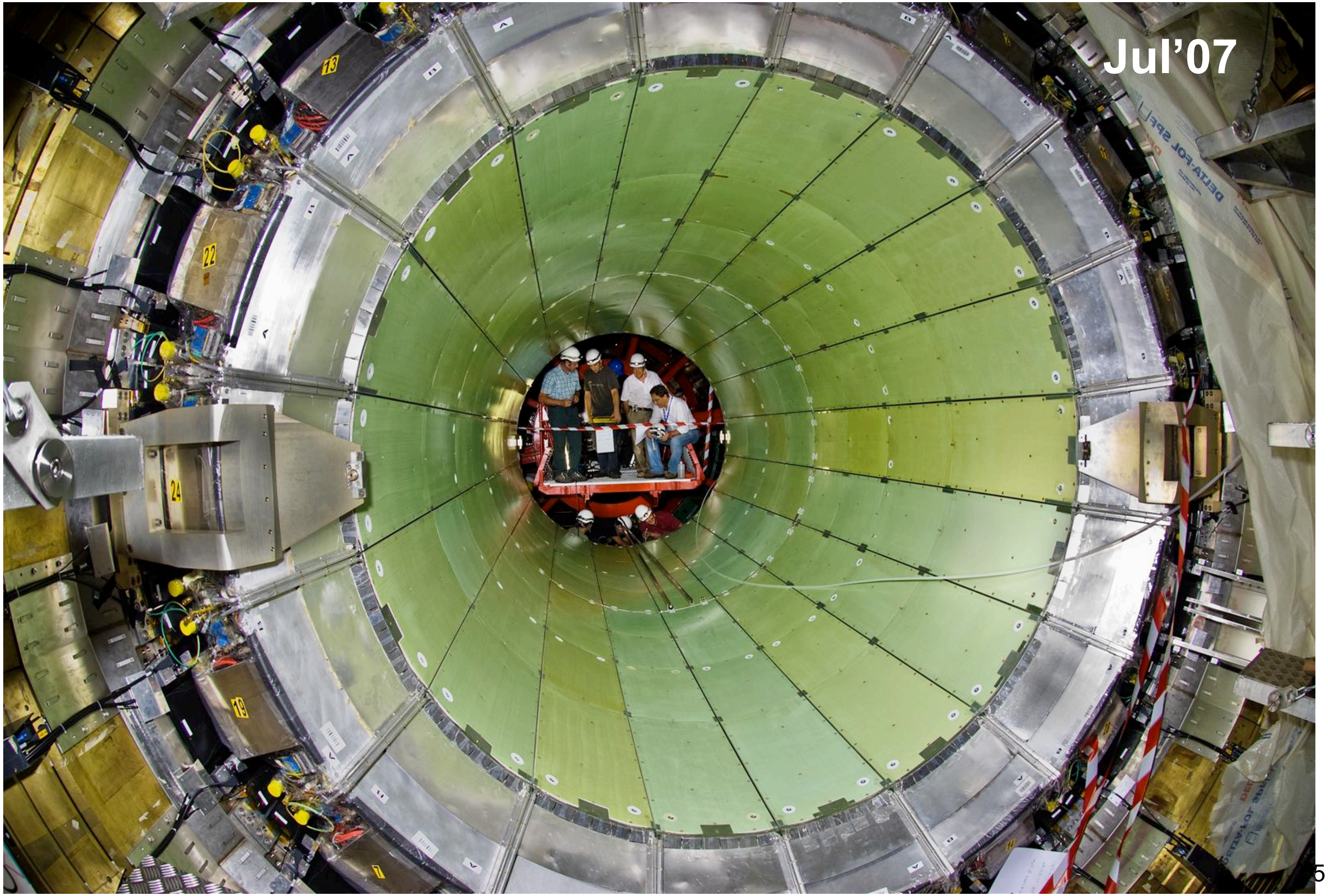




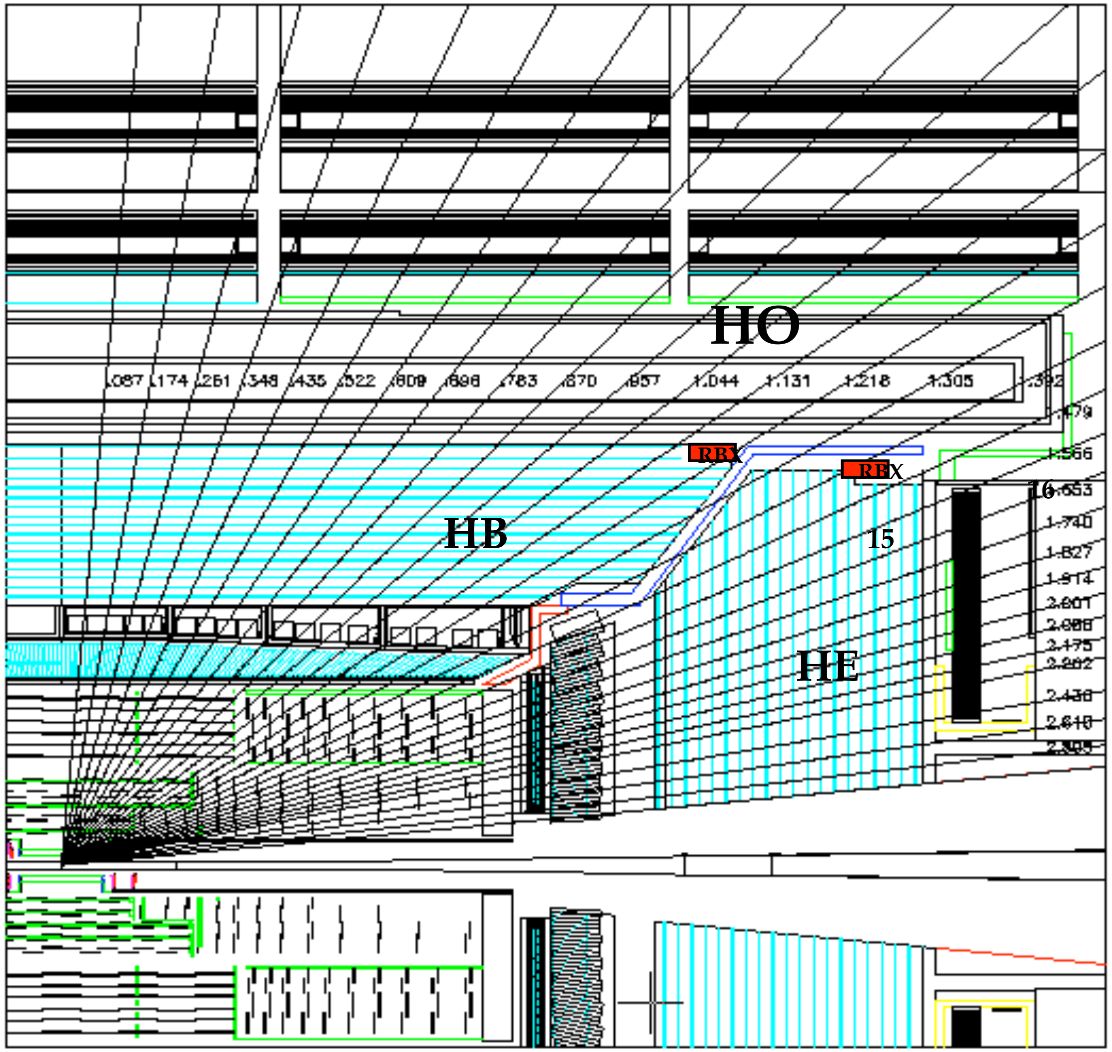


Total 36 Supermodules

Insertion of Barrel ECAL



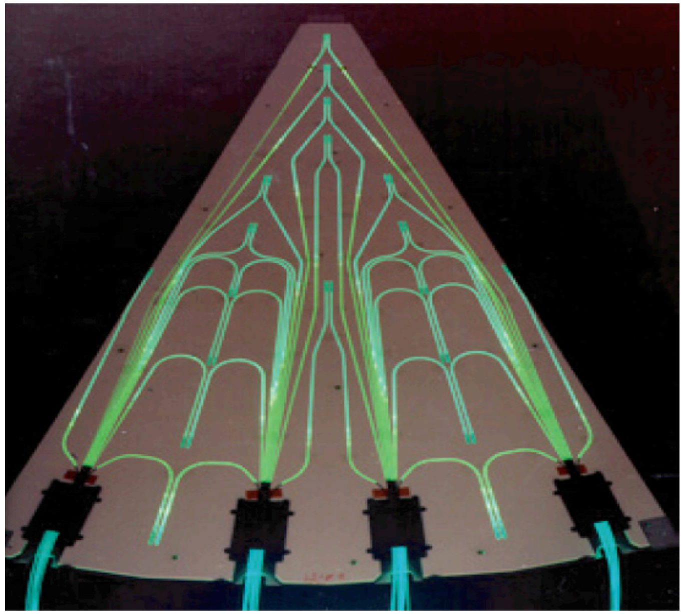
HCAL: il Calorimetro Adronico



The hadron calorimeter HCAL

CMS HCAL is constructed in 3 parts:

- Barrel HCAL (HB)
- Brass plates interleaved wit plastic scintillator embedded with wavelength-shifting optical fibres (photo top right)
- Endcap HCAL (HE)
- Brass plates interleaved with plastic scintillator
- Forward HCAL (HF)
- Steel wedges stuffed with quartz fibres ~10000 channels total



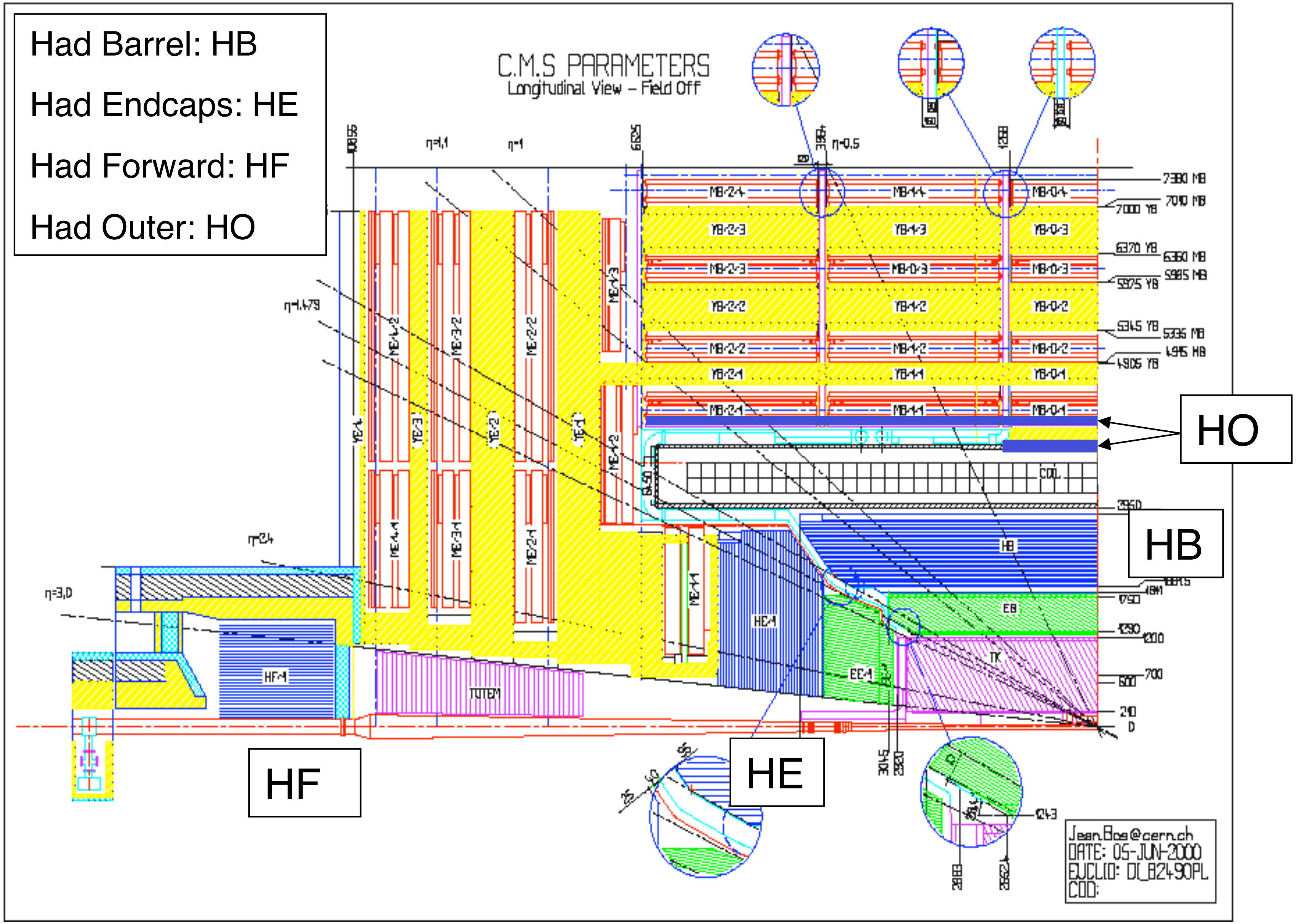
Hadronic Calorimeter: HCAL

Had Barrel: HB

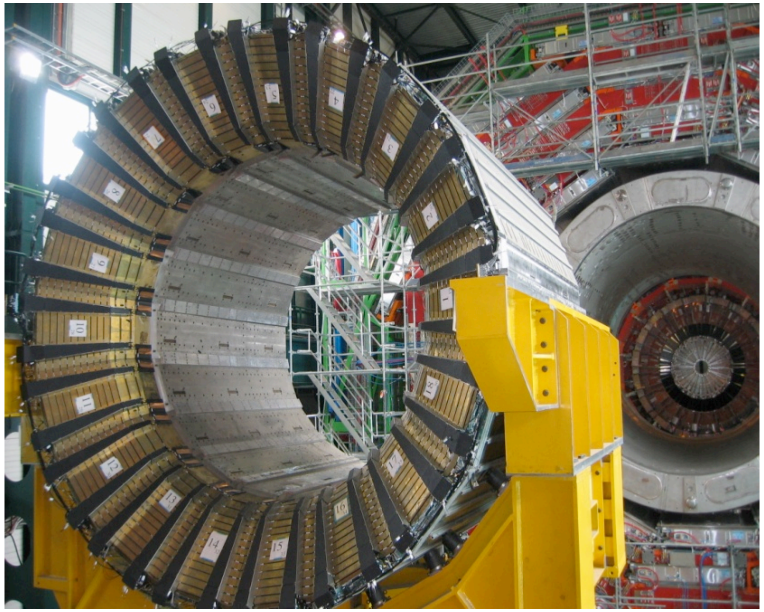
Had Endcaps: HE

Had Forward: HF

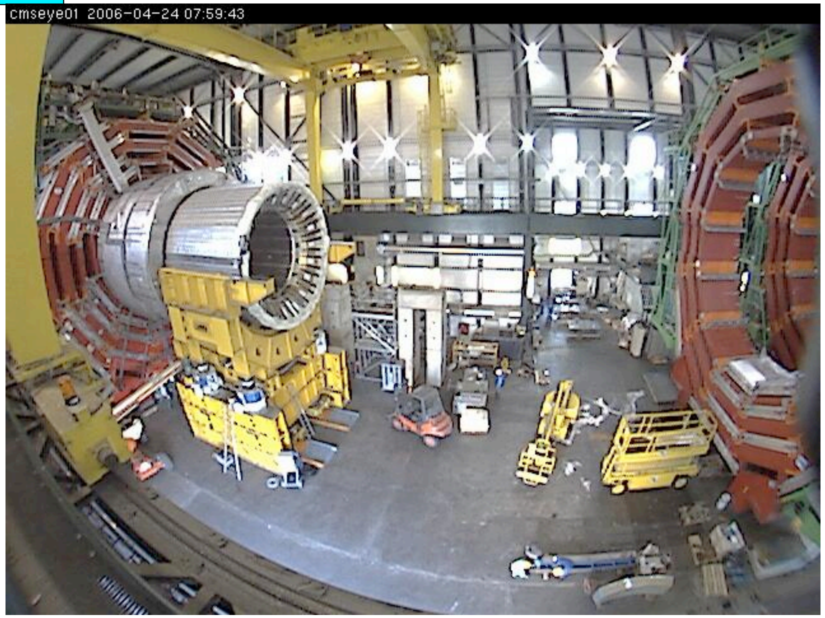
Had Outer: HO

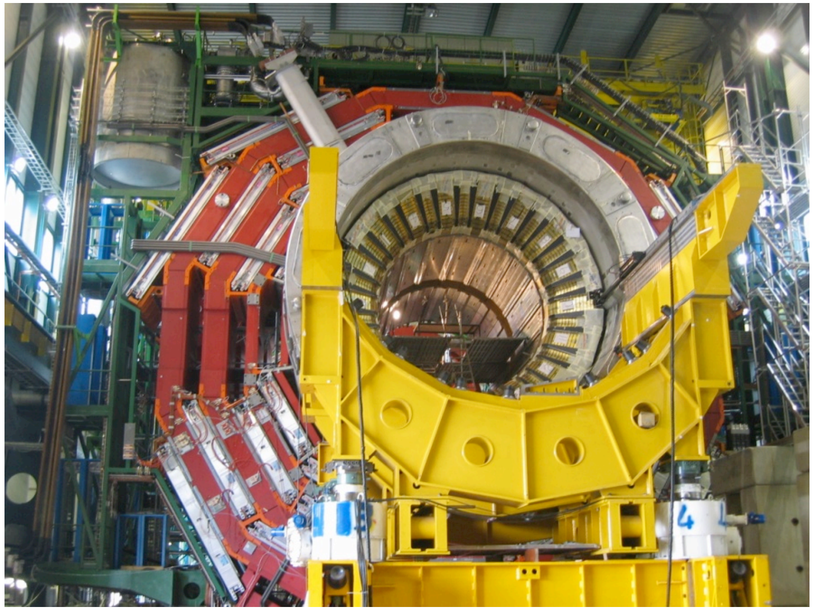


HB+ insertion complete on 3 April



HB- insertion complete 27 April



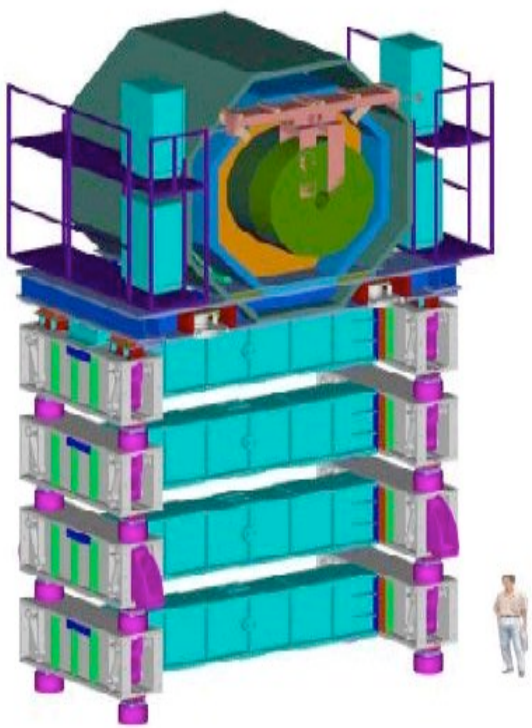


Hadronic Forward (HF) calorimeter

Steel absorbers, embedded quartz fibers // to the beam.
Fast (~10 ns) collection of Cherenkov radiation.

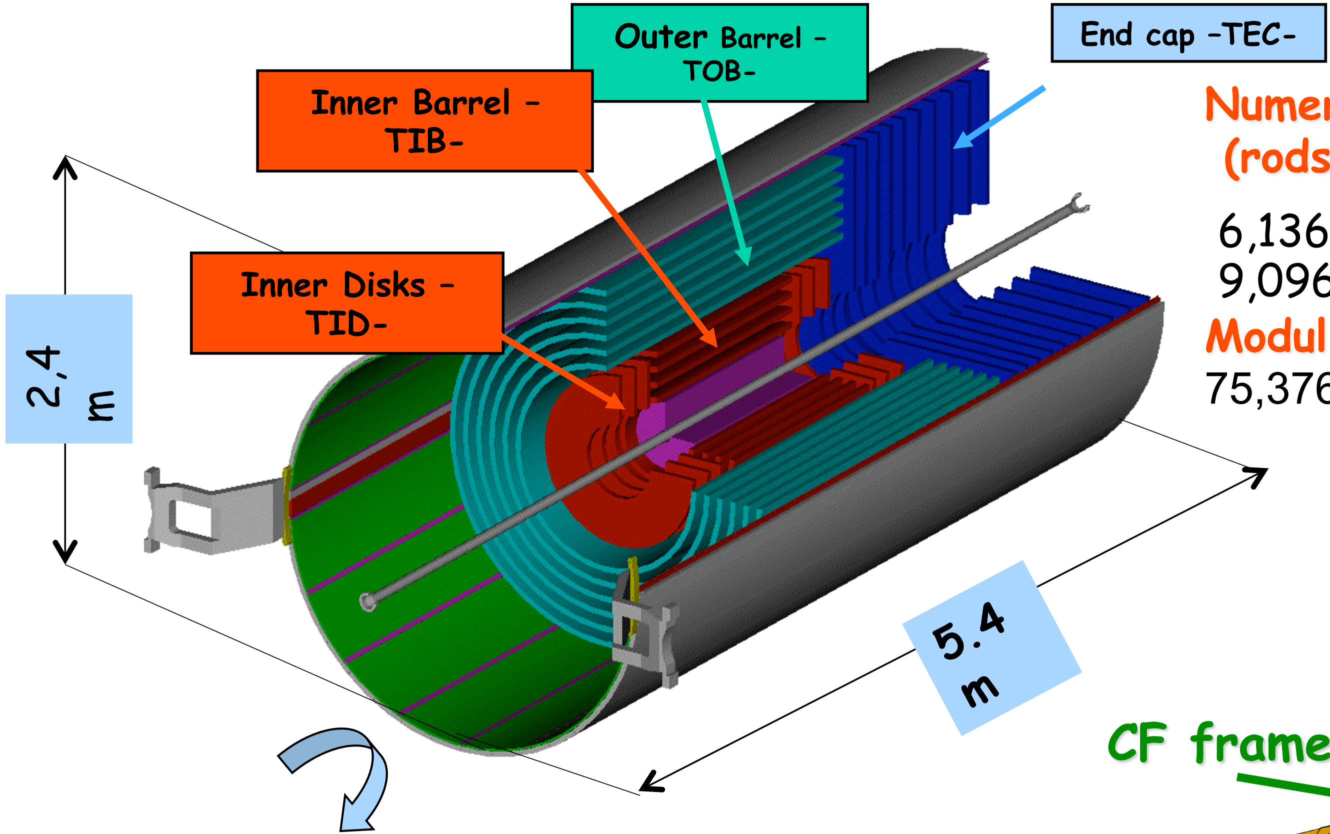
Coverage: $3<|\eta|<5$ $\Delta\phi \times \Delta\eta = 10^o \times 13\ \eta$ towers
Depth: 10 λ**int**

CMS Forward Calorimeter



CMS: HF in Bat 186

Silicon Strip Detectors



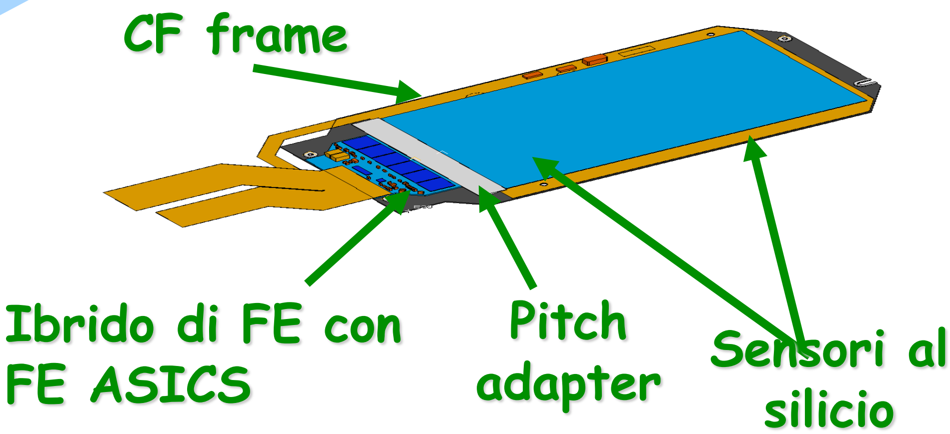
Numero elevato di sensori (rods, petals, shells)

6,136 Thin 300 μm (1 sensor)
9,096 Thick 500 μm (2 sensors)

Moduli e elettronica Rad-hard

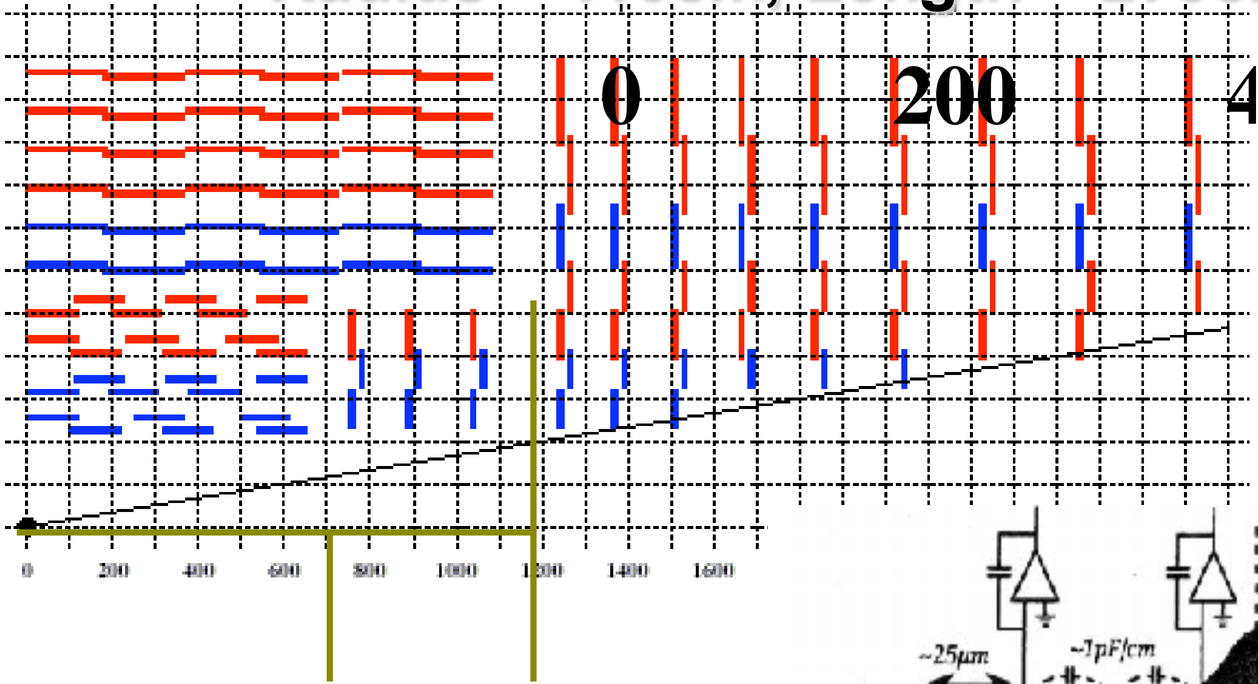
75,376 APV chips

volume 24.4 m^3
temperatura - 10 ^0C



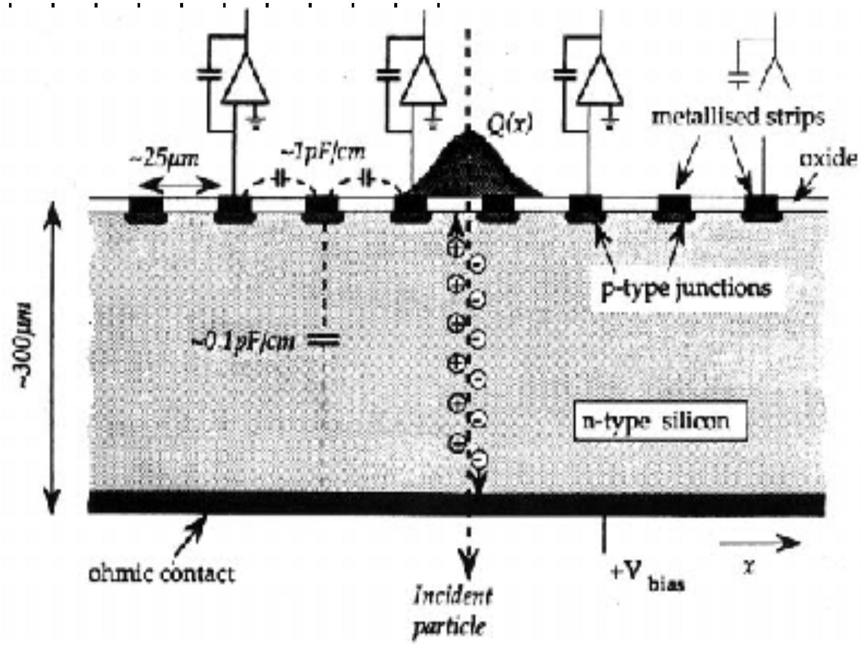
Extreme longitudinal segmentation

Radius ~ 110cm, Length ~ 270cm



6 layers
TOB

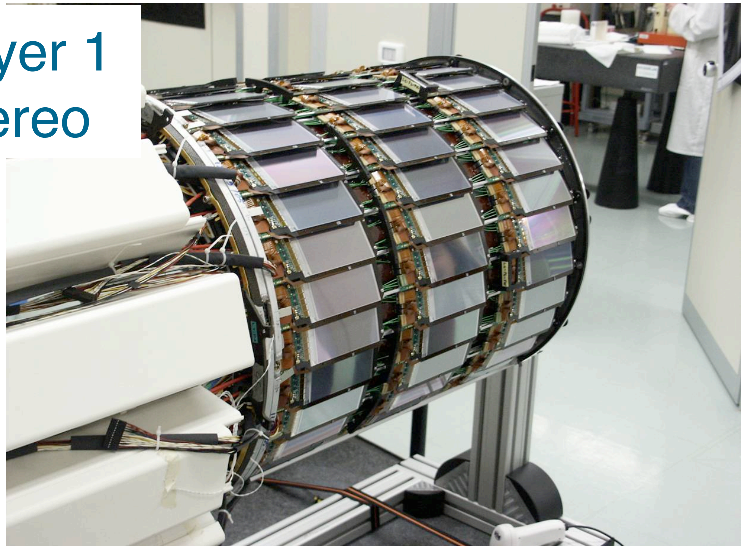
4 layers
TIB

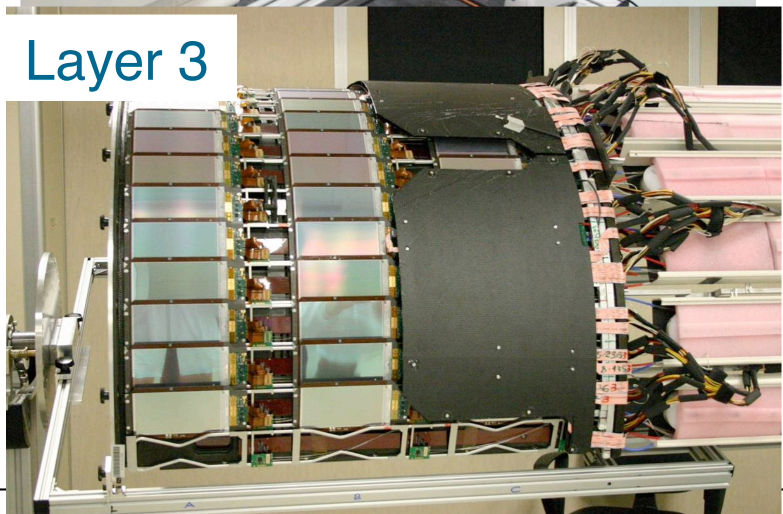


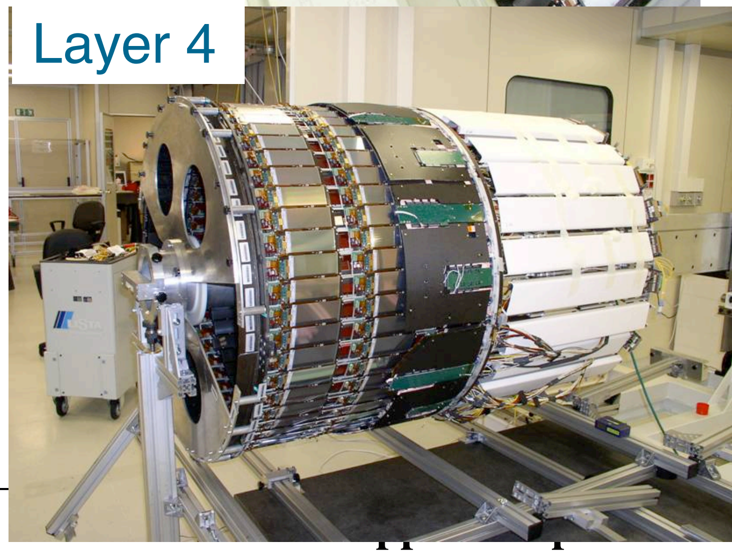
High granularity Silicon
Microstrip and Pixel detectors

TIB integrated in Italy

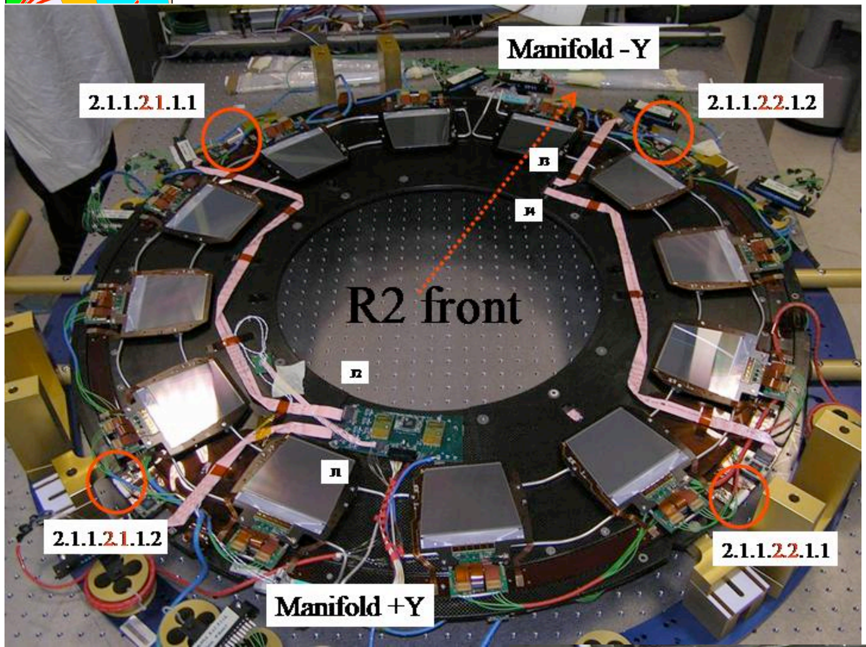
TIB/TID+ moved to CERN 30 May. TIB/TID- at CERN in August. Start full TIB+ commissioning at CERN in June (TIF).

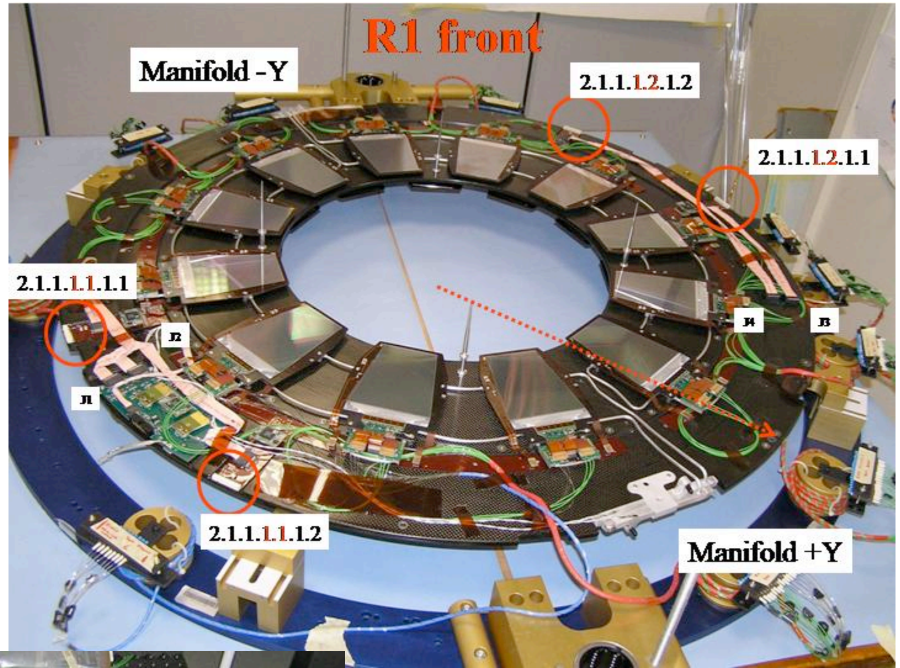


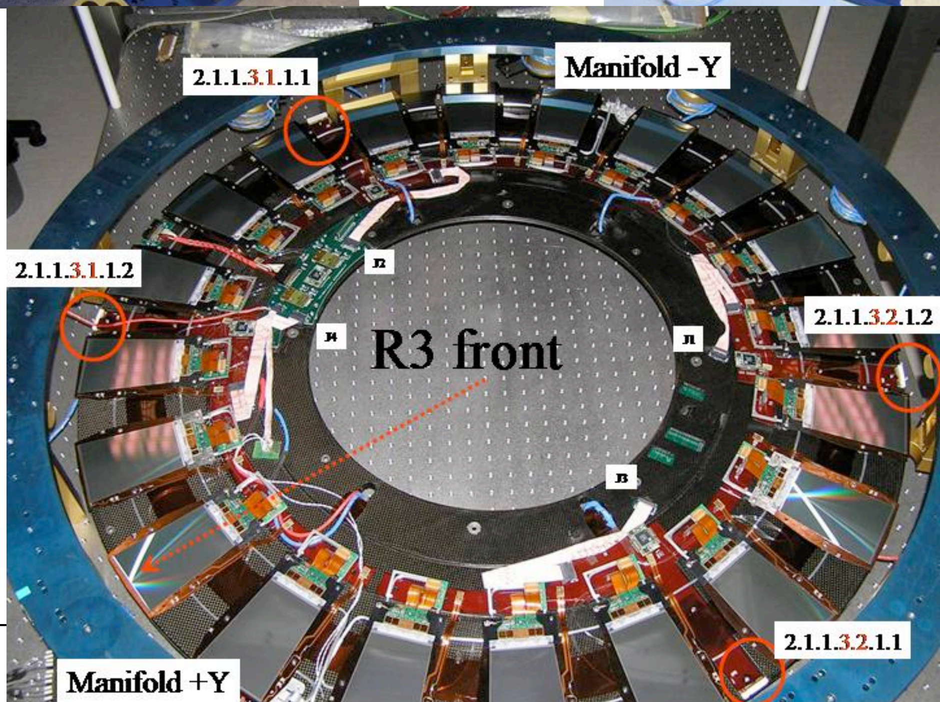




TID components: the rings







TOB: Rods insertion and cabling in TIF

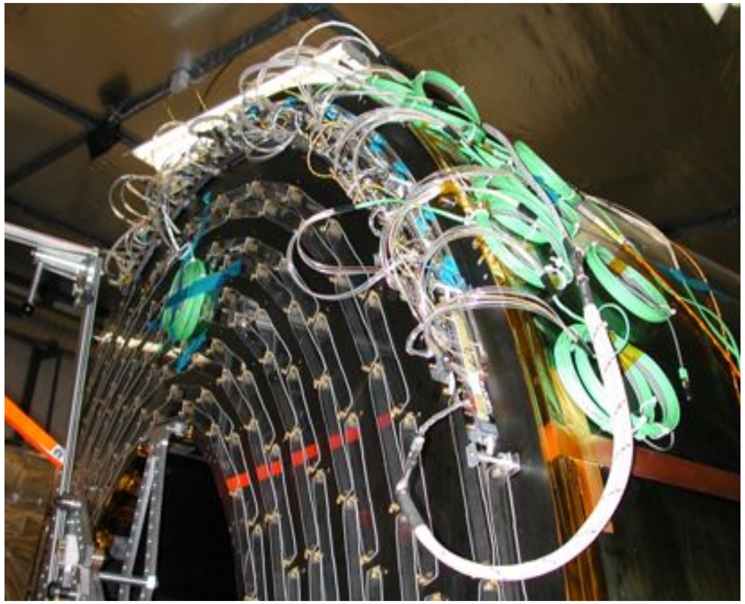
6 layers of Rods.

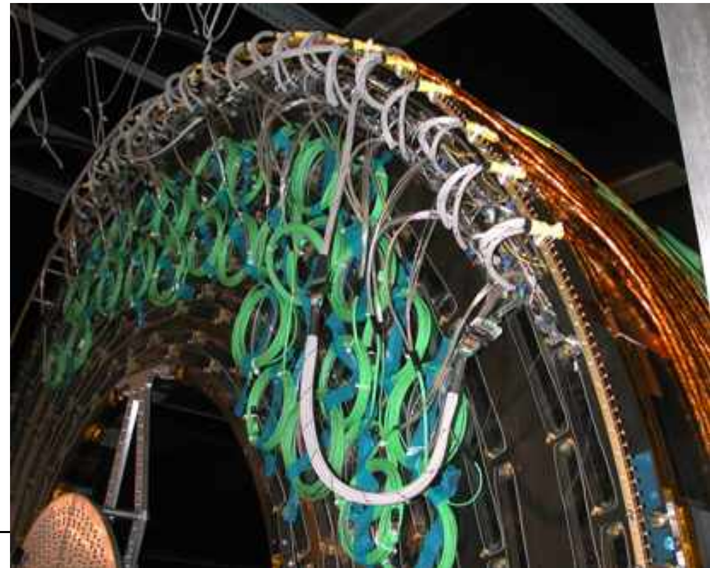
Today : 97 rods integrated/688 (14%);

38 rods validated (2 cooling segments / 44)

Rods are produced at a rate of 40 rods/week in US.

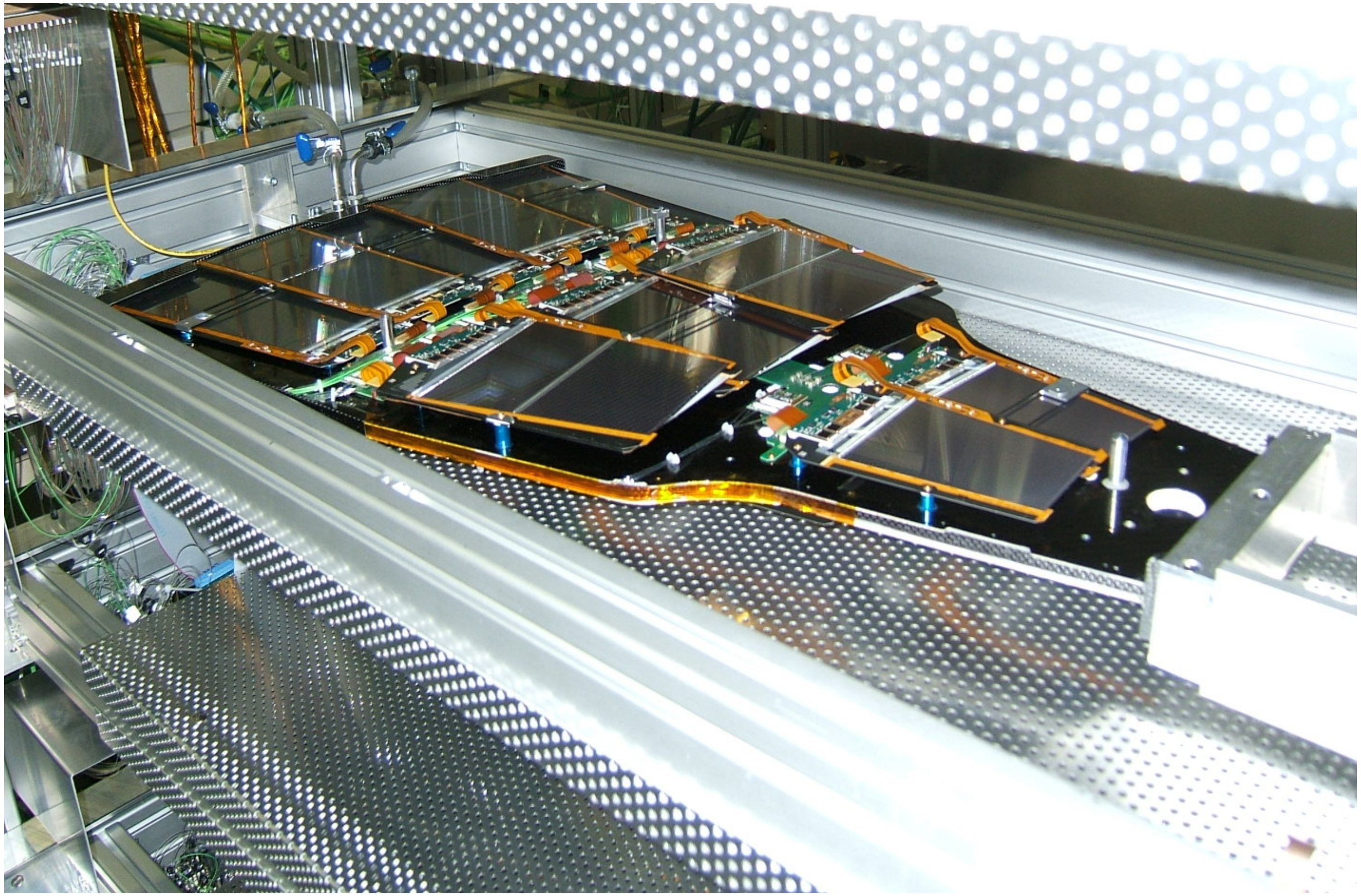
TOB+ complete: Aug, TOB- : Oct with shift operation.





TEC: Petals

Today : 116 petals integrated/288 (40%) ; petals produced at a rate of 10petals/week (Fr, Ge, Be).
18 petals integrated in the TEC sector test as pilot integration run.

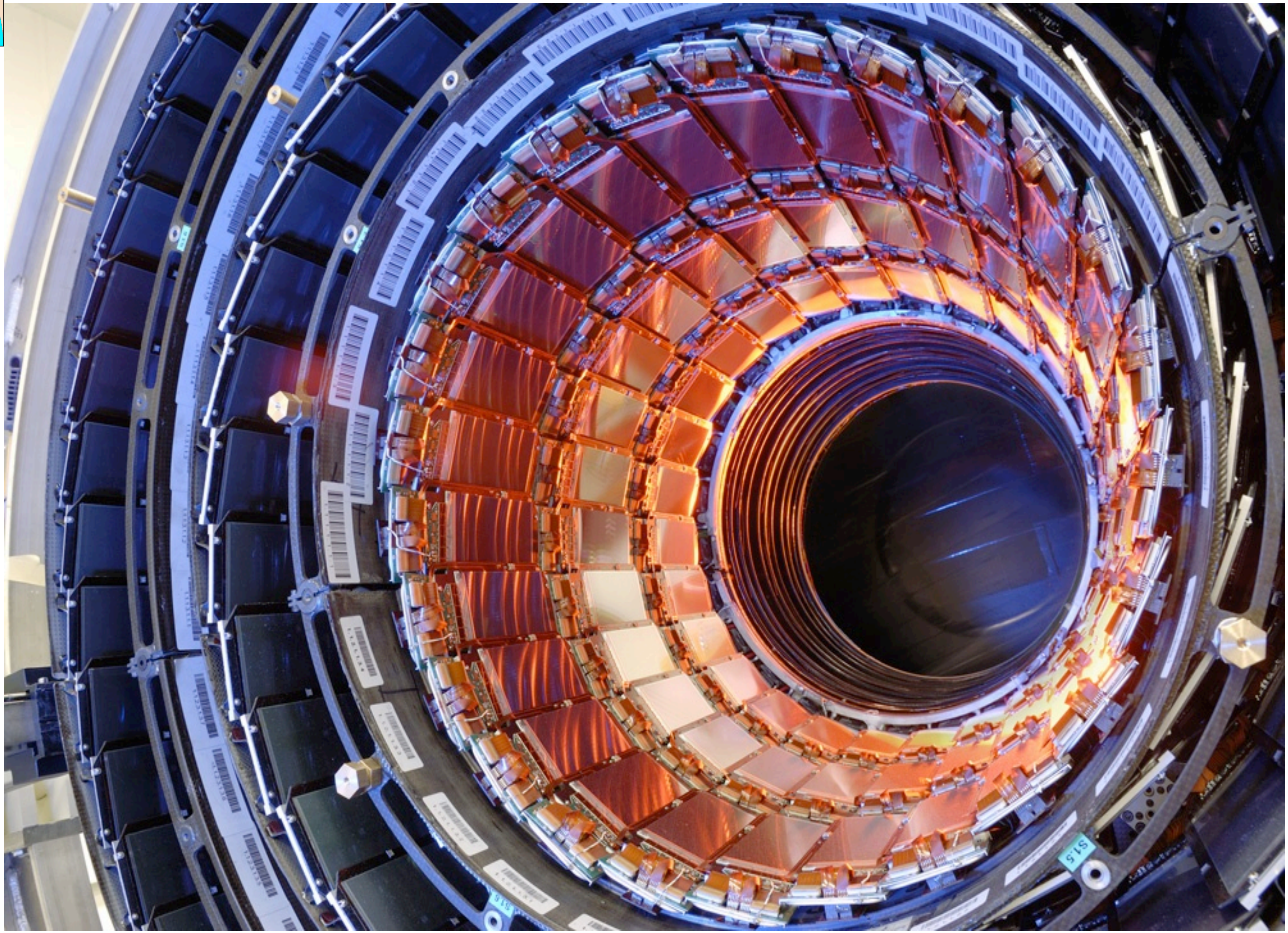


TEC: Integration

TEC- at CERN

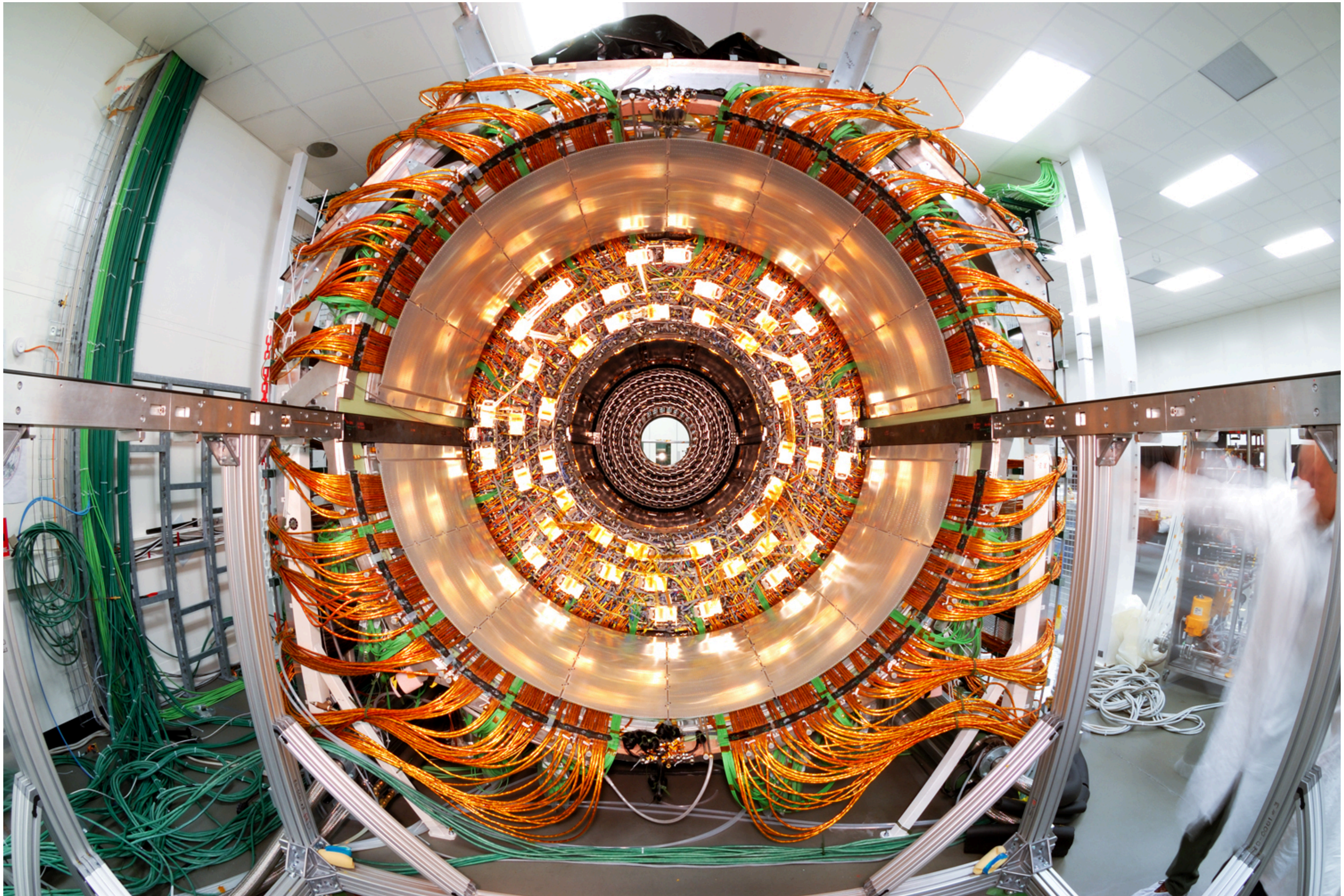
TEC+ at Aachen

- ❑ Each TEC is made of 9 disks.
- ❑ TEC+ complete: Sep, TEC- complete: Nov
- ❑ TEC integration is critical. Aim to gain > 1 month.

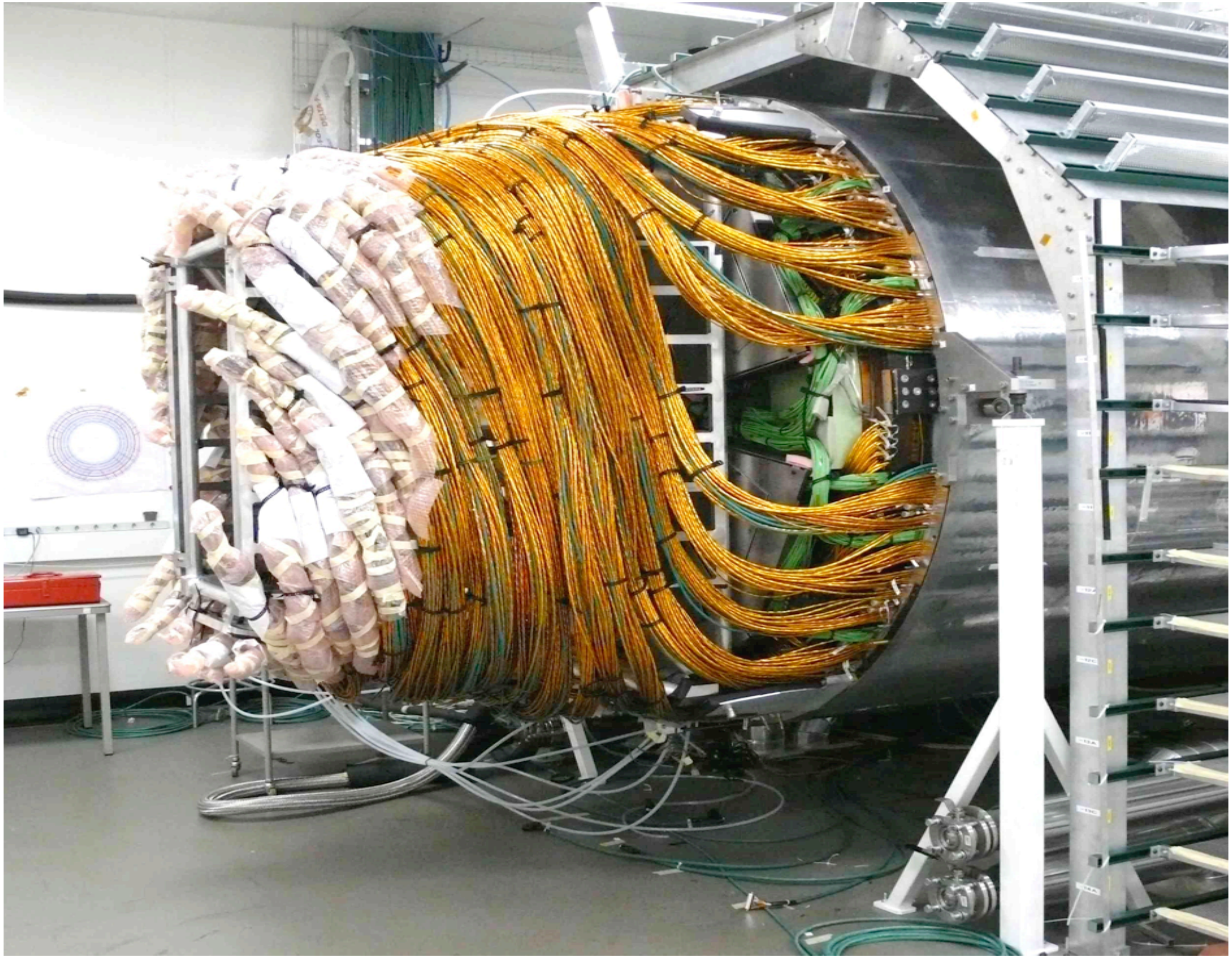


Si Tracker

Si Tracker

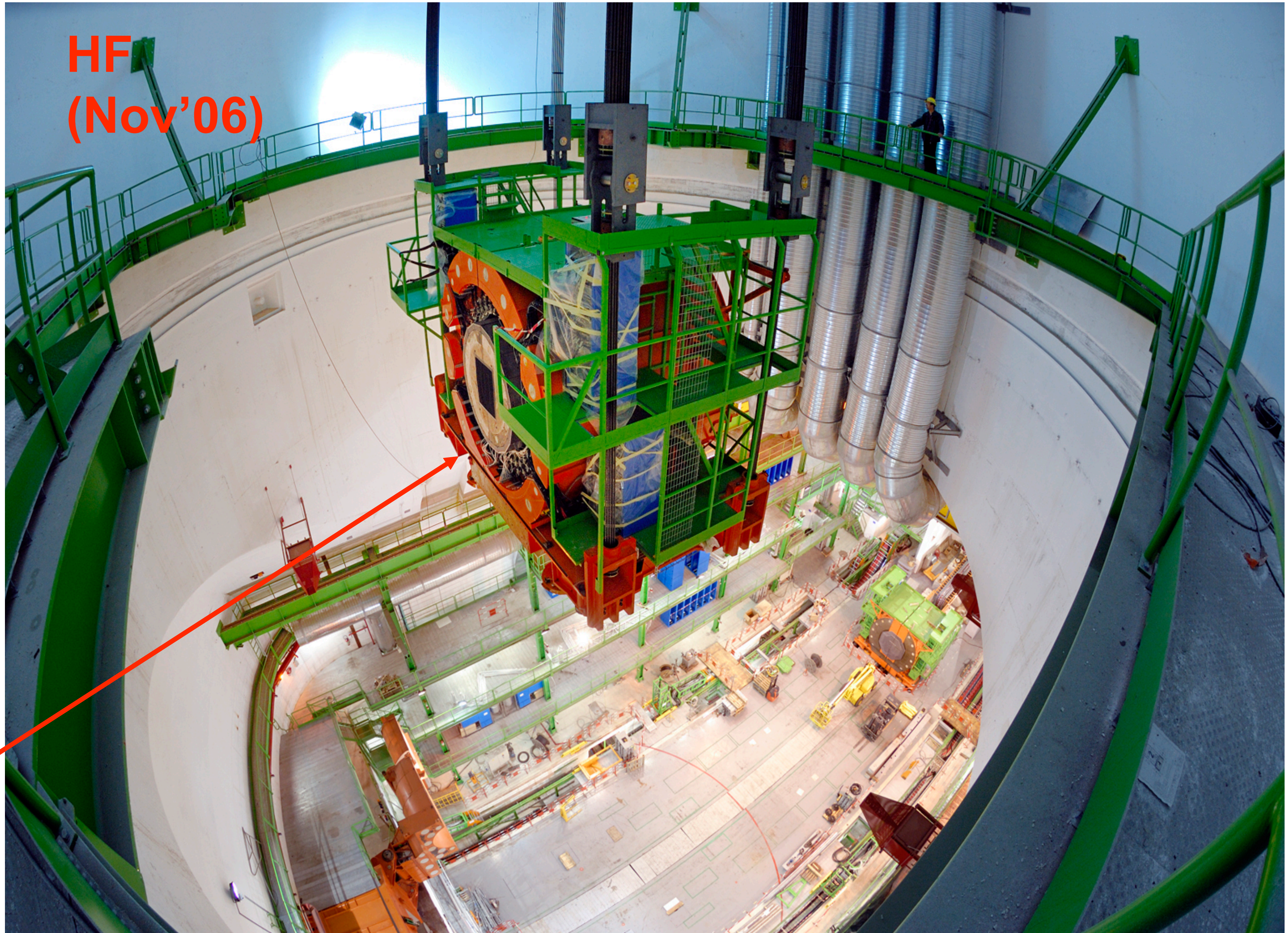


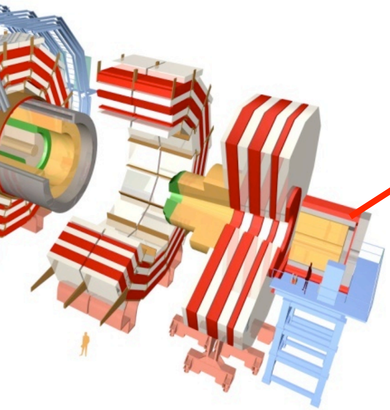
Tracker Ready for Installation



First HF landing into UXC55 (2 Nov 06)

Lowering of Heavy Elements

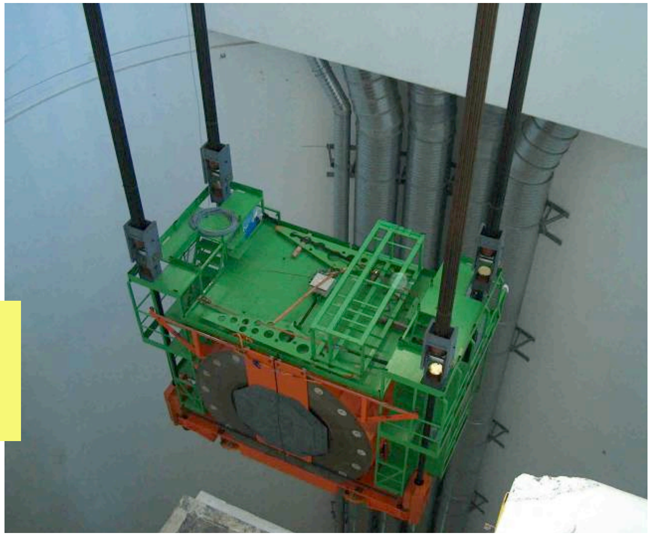




Heavy Lowering: HFs

2 Nov

HF+ en route for UXC

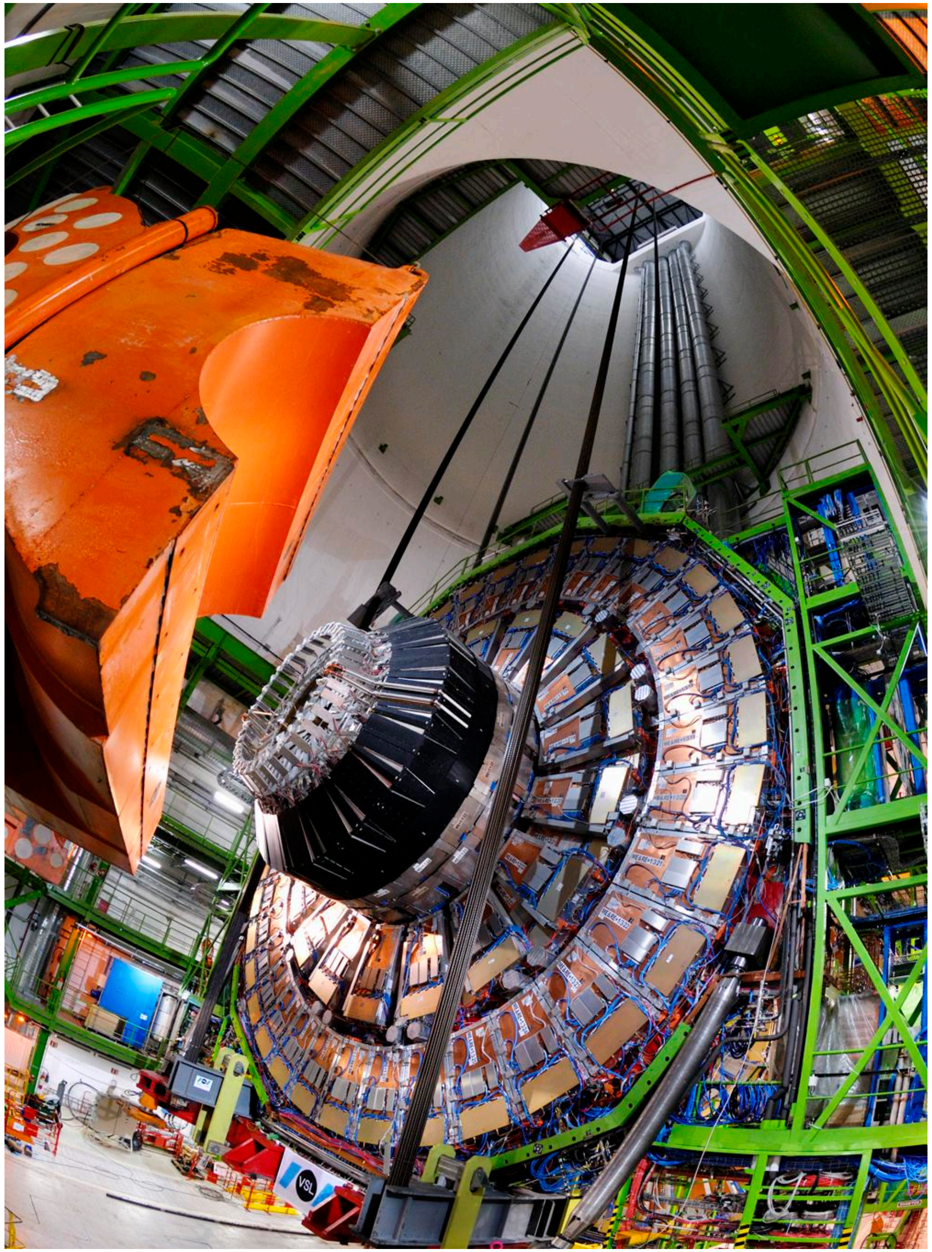


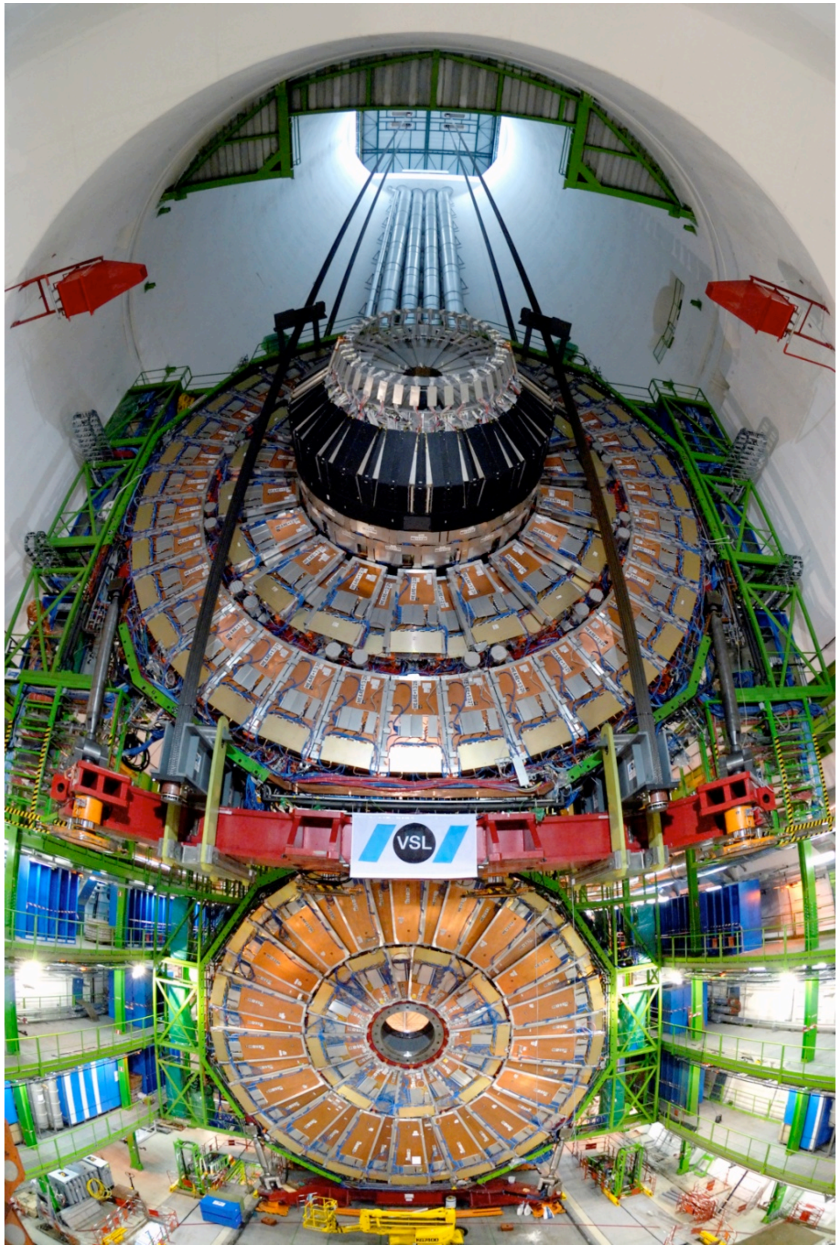
HF+ arriving safely in UXC

9 Nov

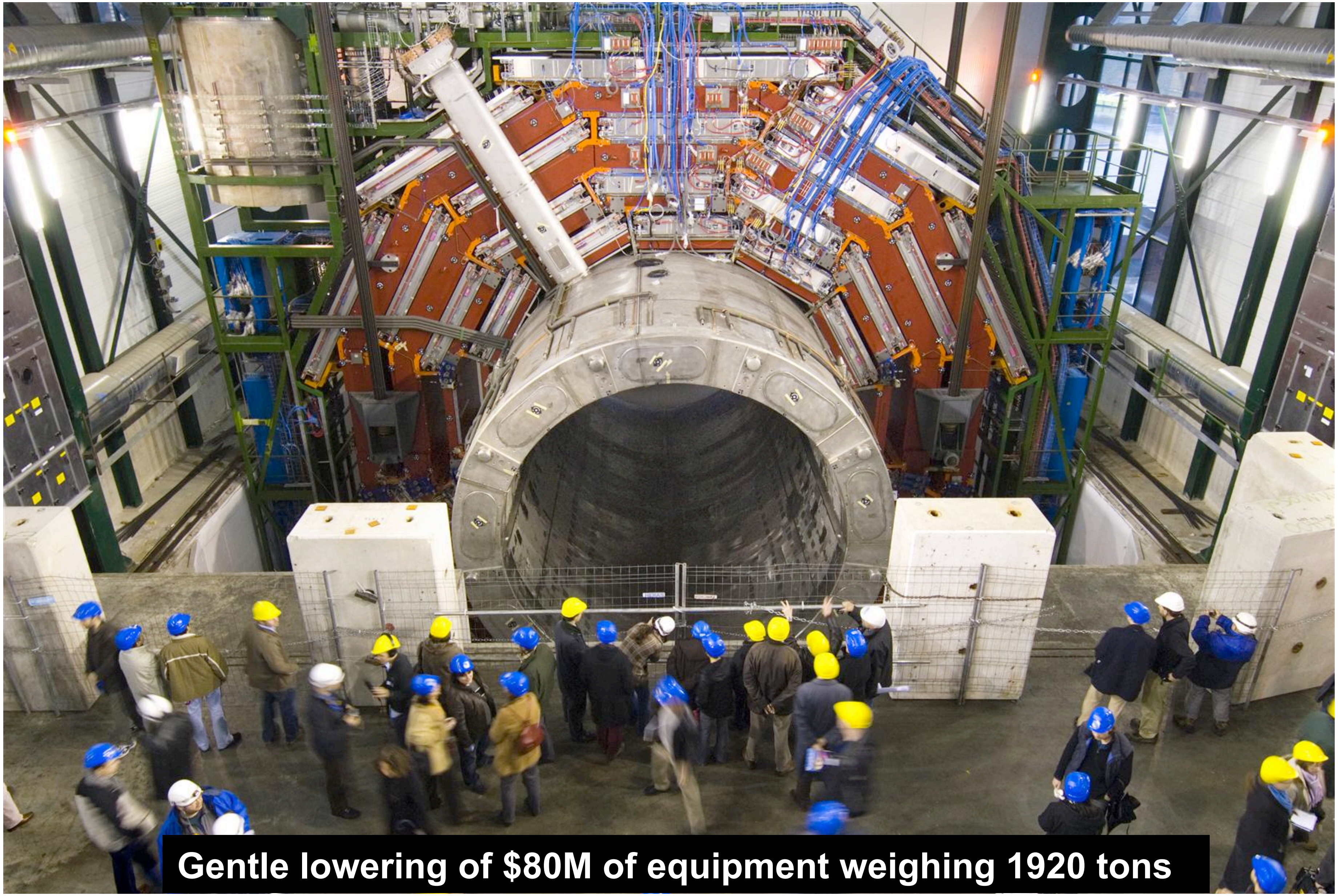
both HF in UXC

Heavy Lowering: the Endcap



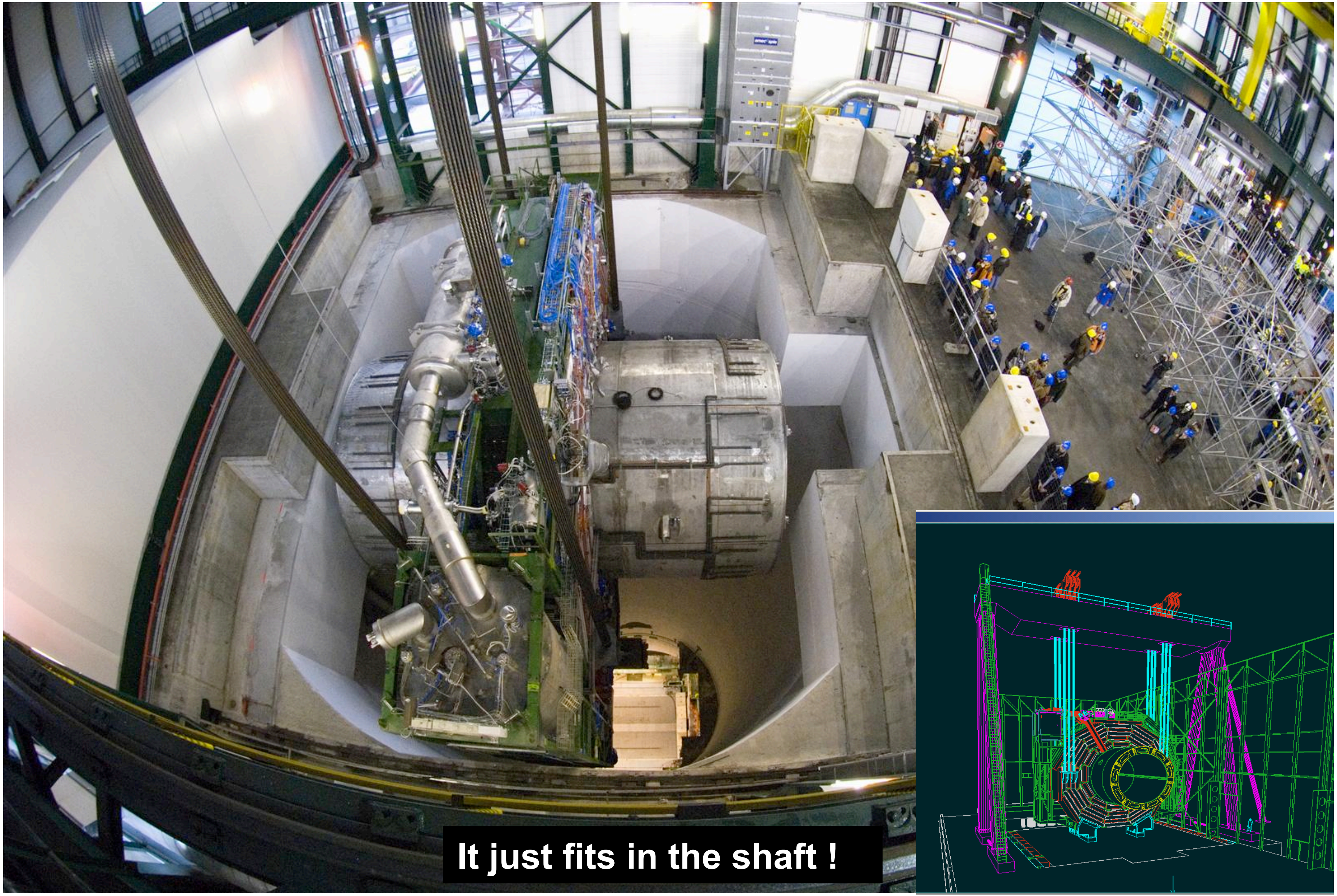


CMS - Compact Muon Spectrometer



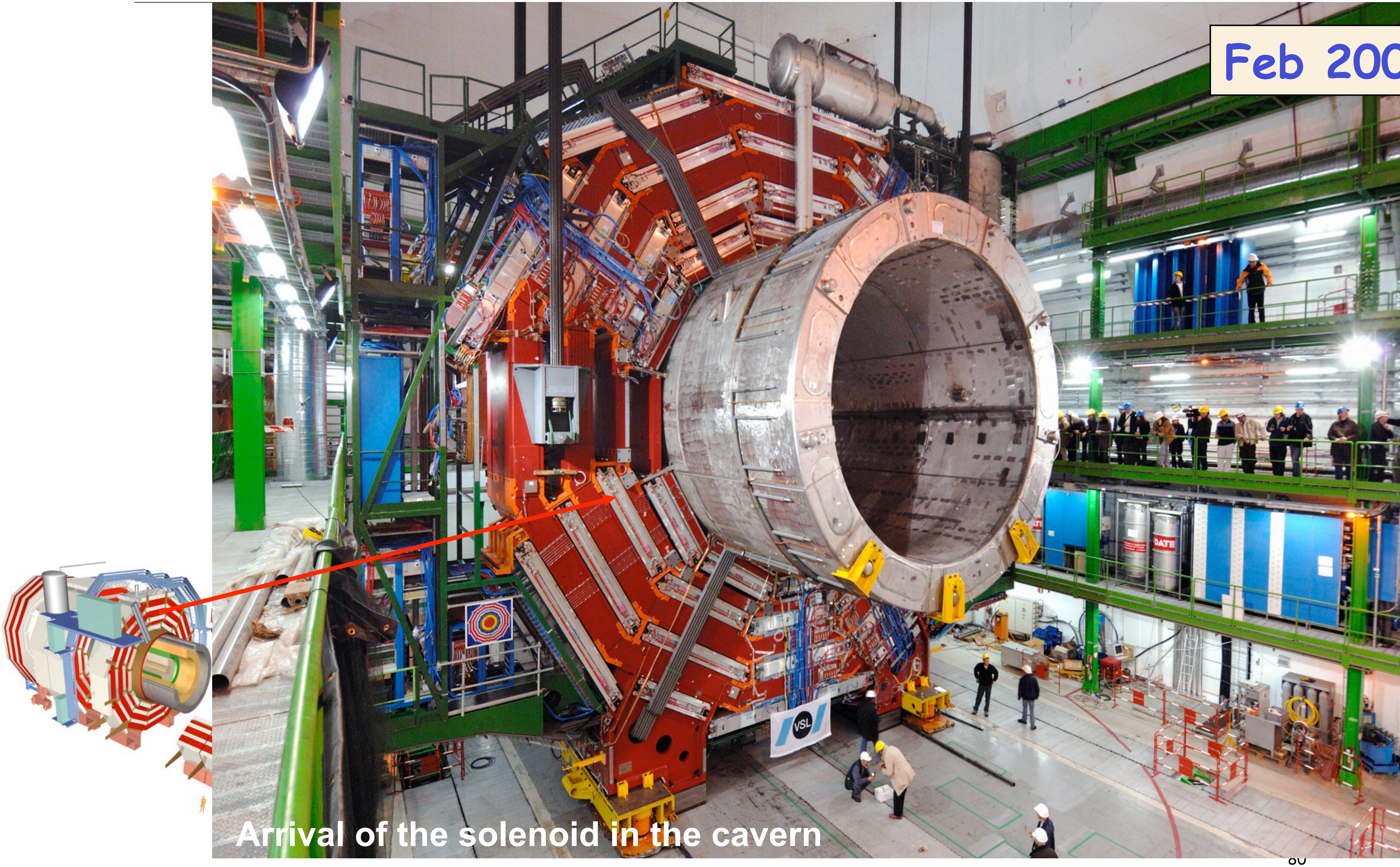
Gentle lowering of $80M of equipment weighing 1920 tons

CMS – Compact Muon Solenoid



Spectacular Operations

Feb 2007



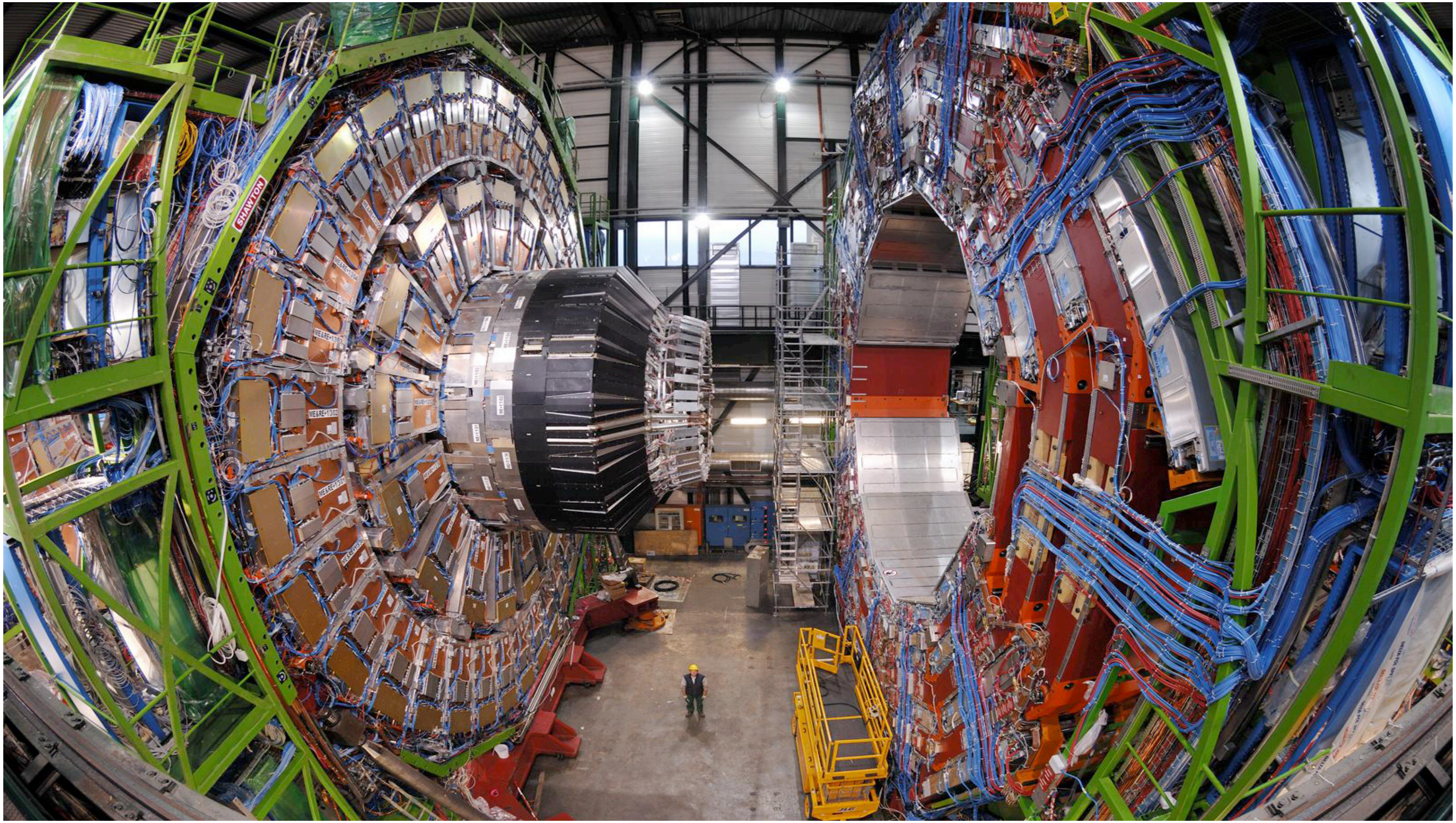
Arrival of the solenoid in the cavern

Cables, Pipes and Oprical Fibres !

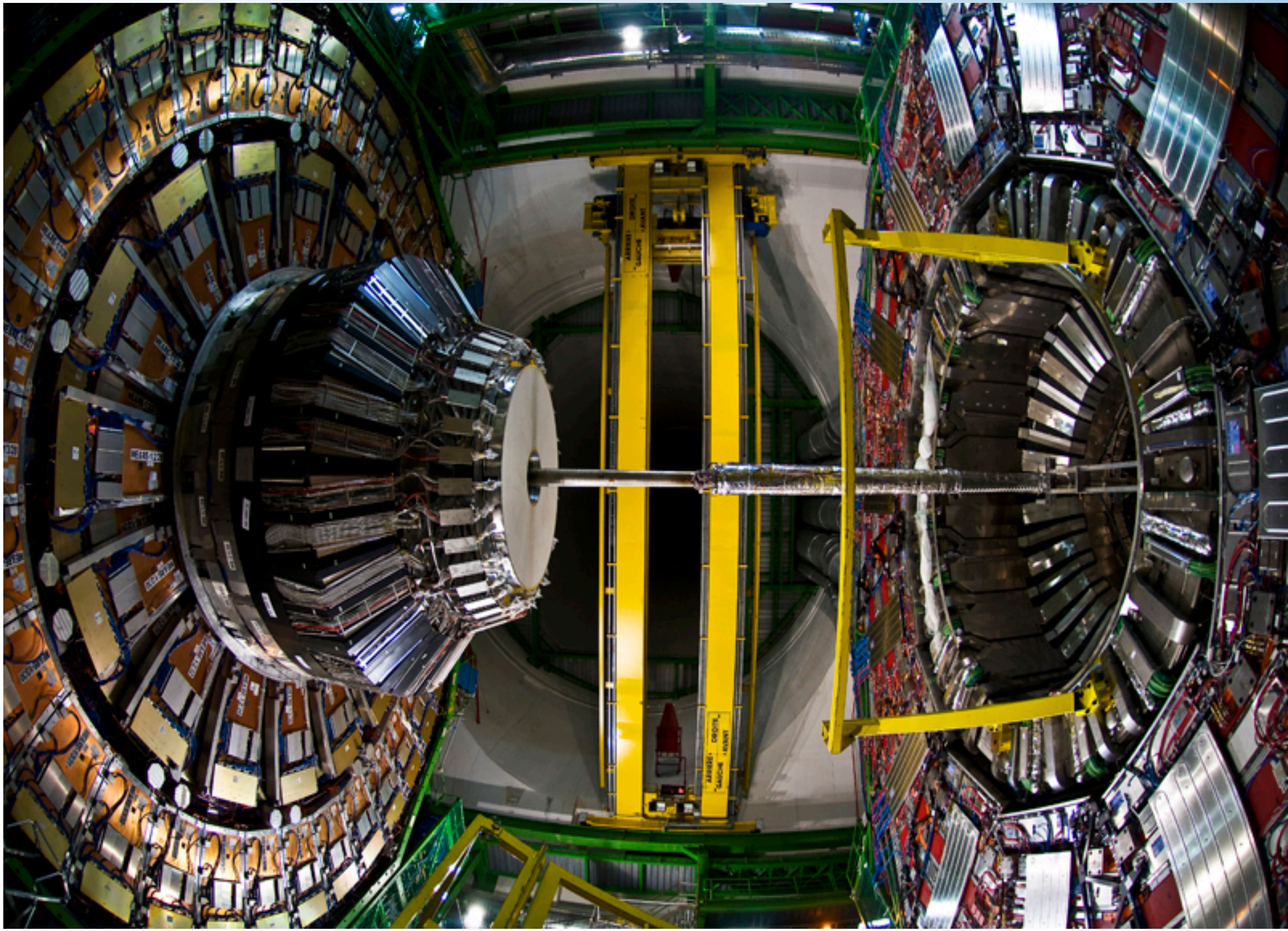
Nov 2007

Took 50'000 man hours

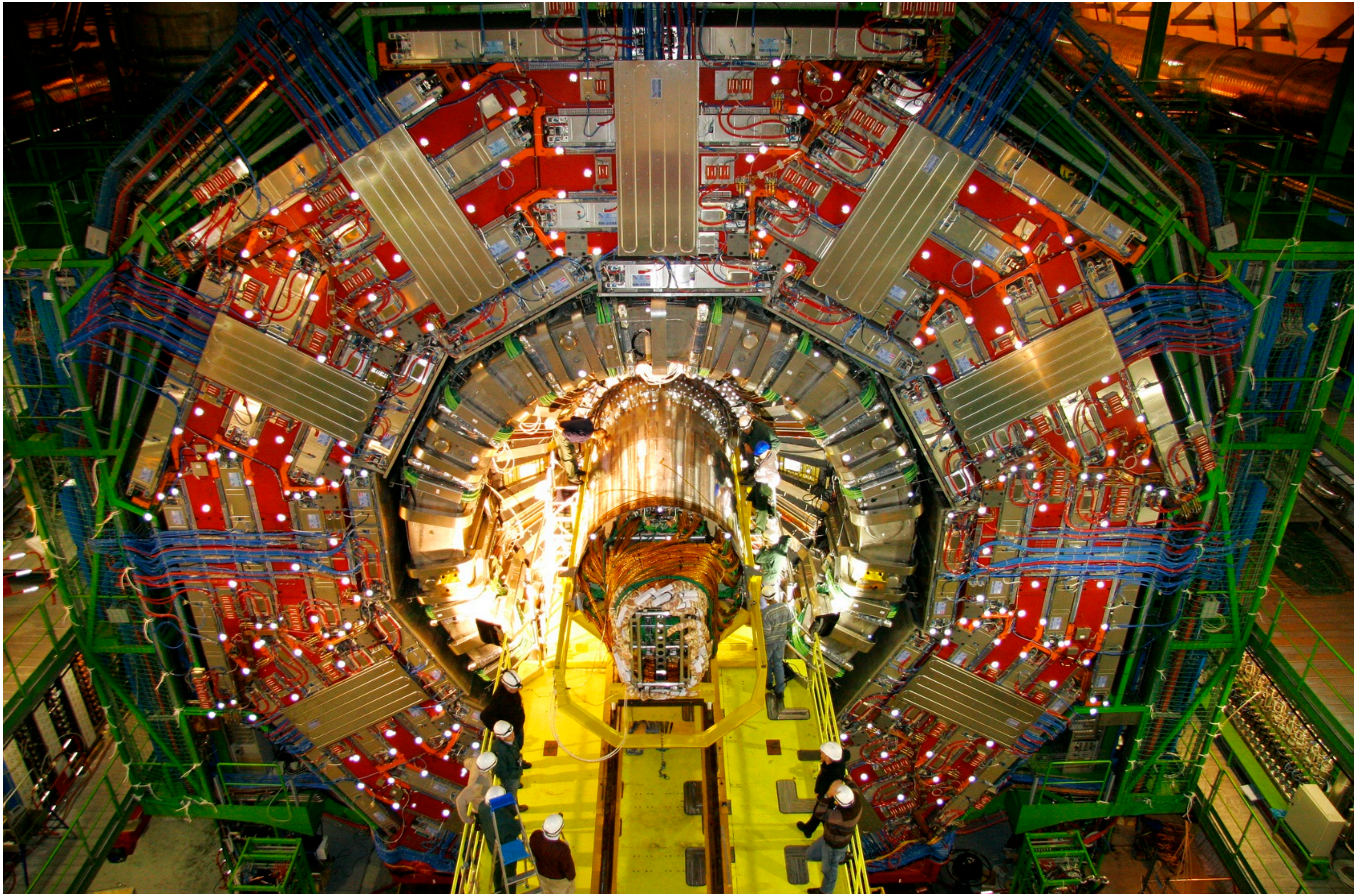
CMS

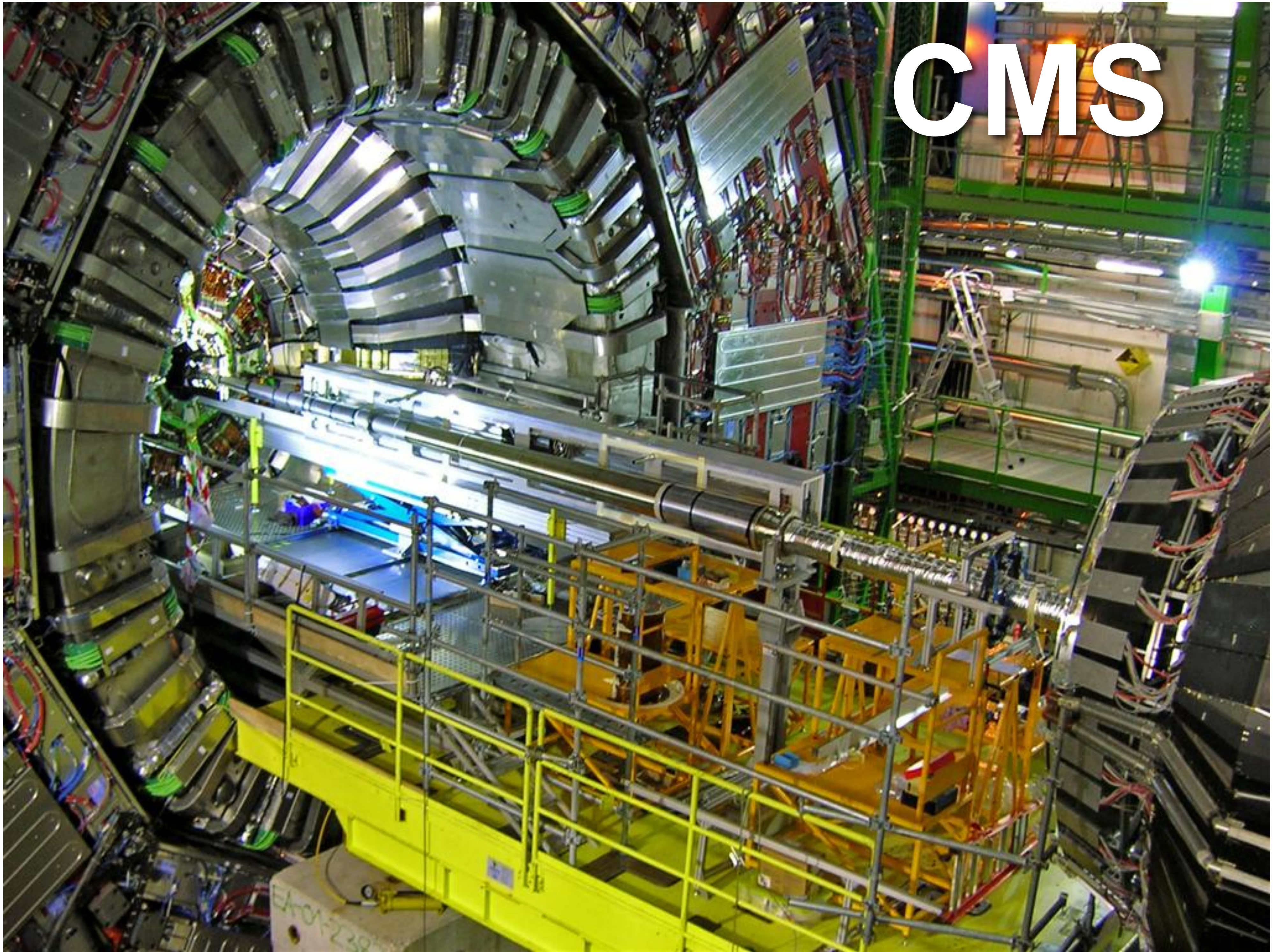


Almost Ready to Go!

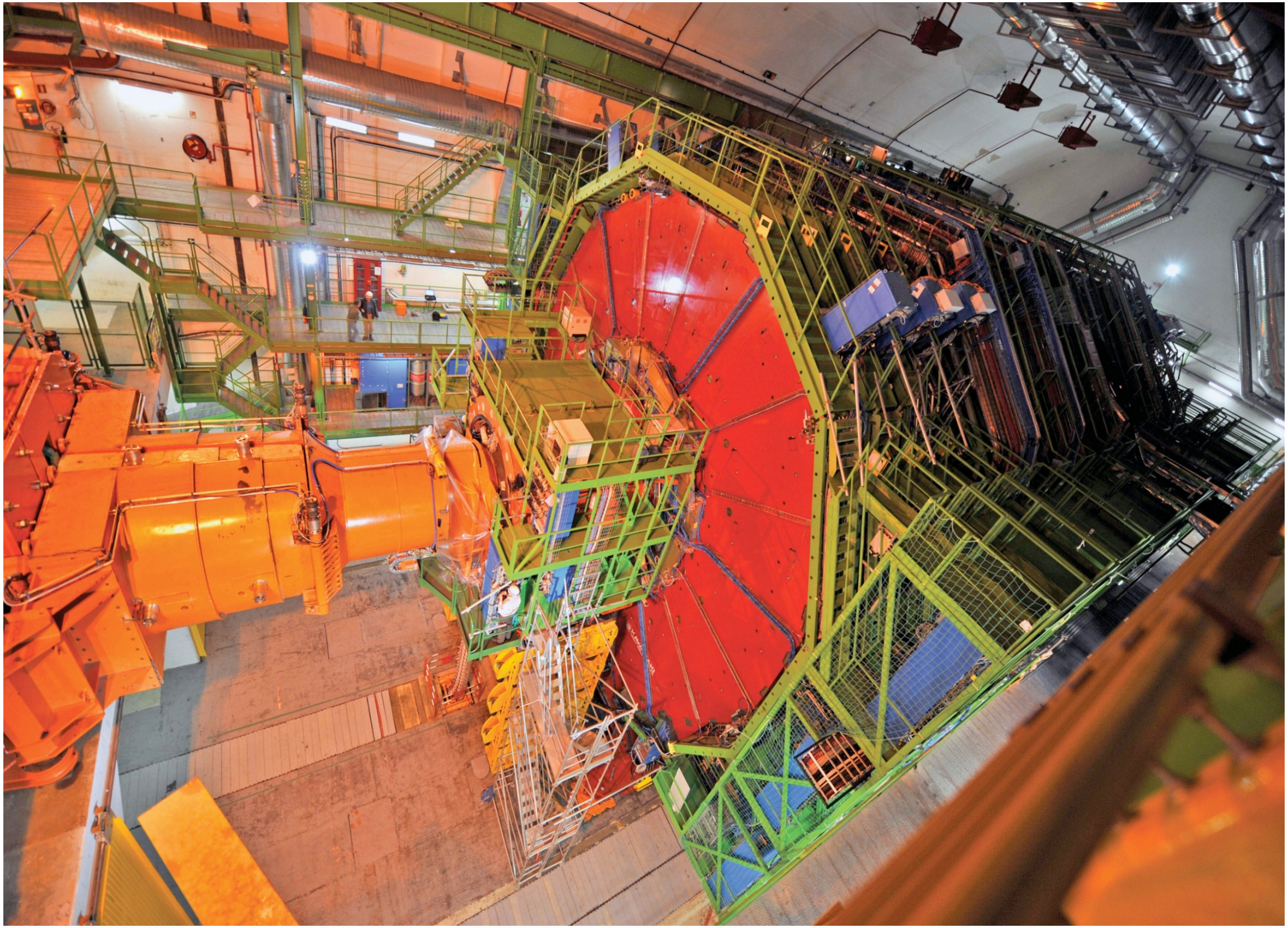


CMS



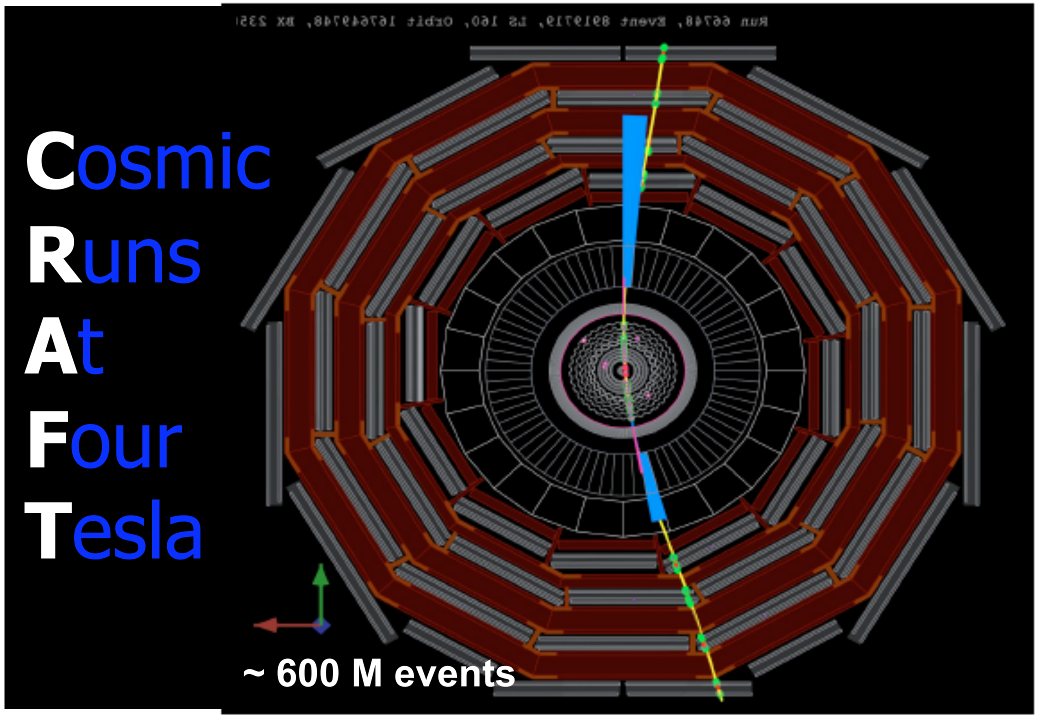

CMS

CMS ready to take data

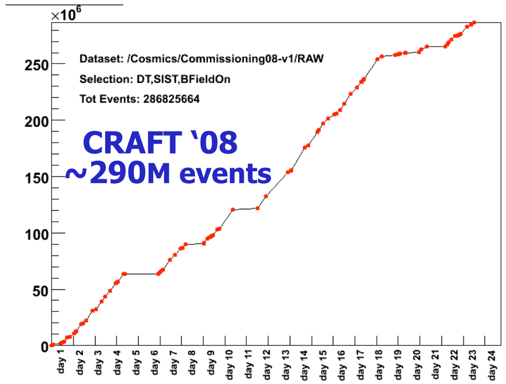


10/09/2008

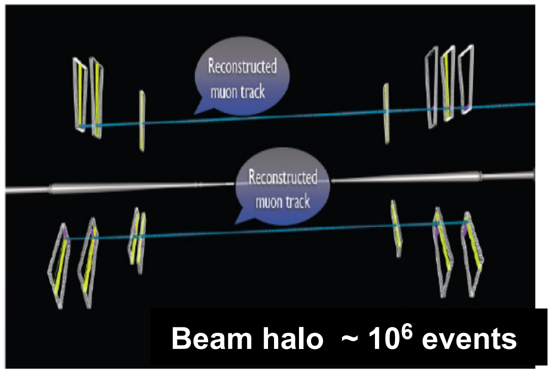
CRAFT: 2008-2009 Commissioning with Cosmics

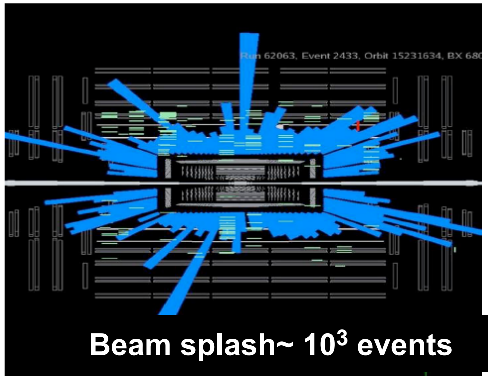


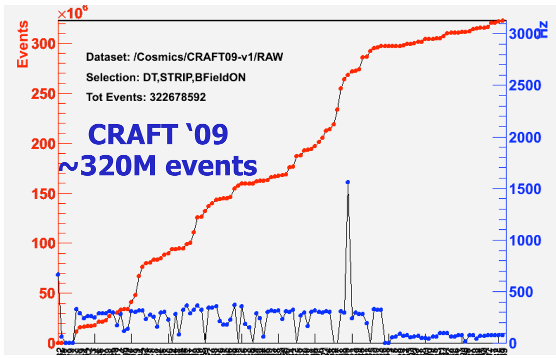
- ✓ Alignements
- ✓ Calibrations
- ✓ Timing
- ✓ Studies of magnetic field



+

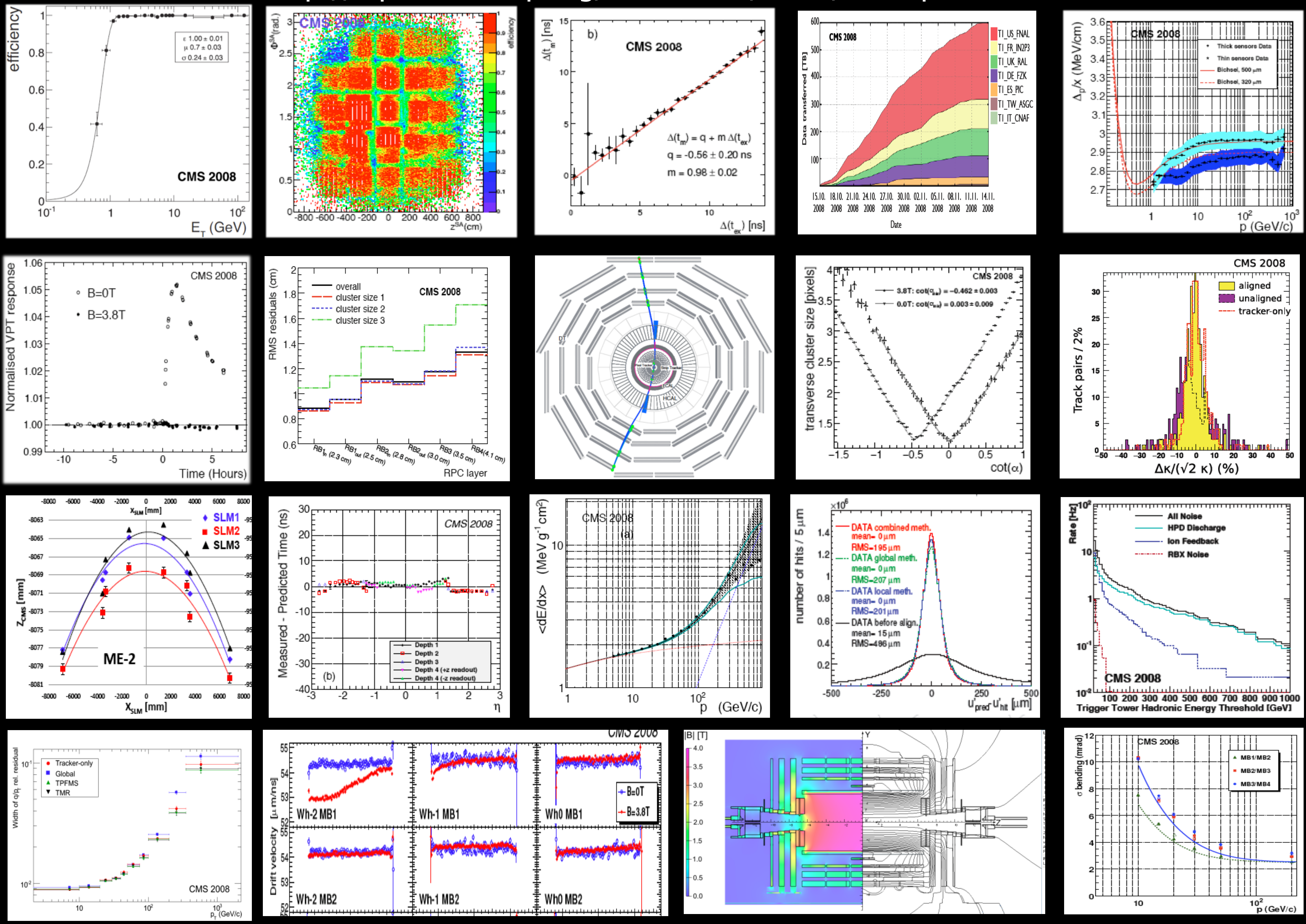






23 “CRAFT” Papers Published in JINST

http://iopscience.iop.org/1748-0221/focus/extra.proc6



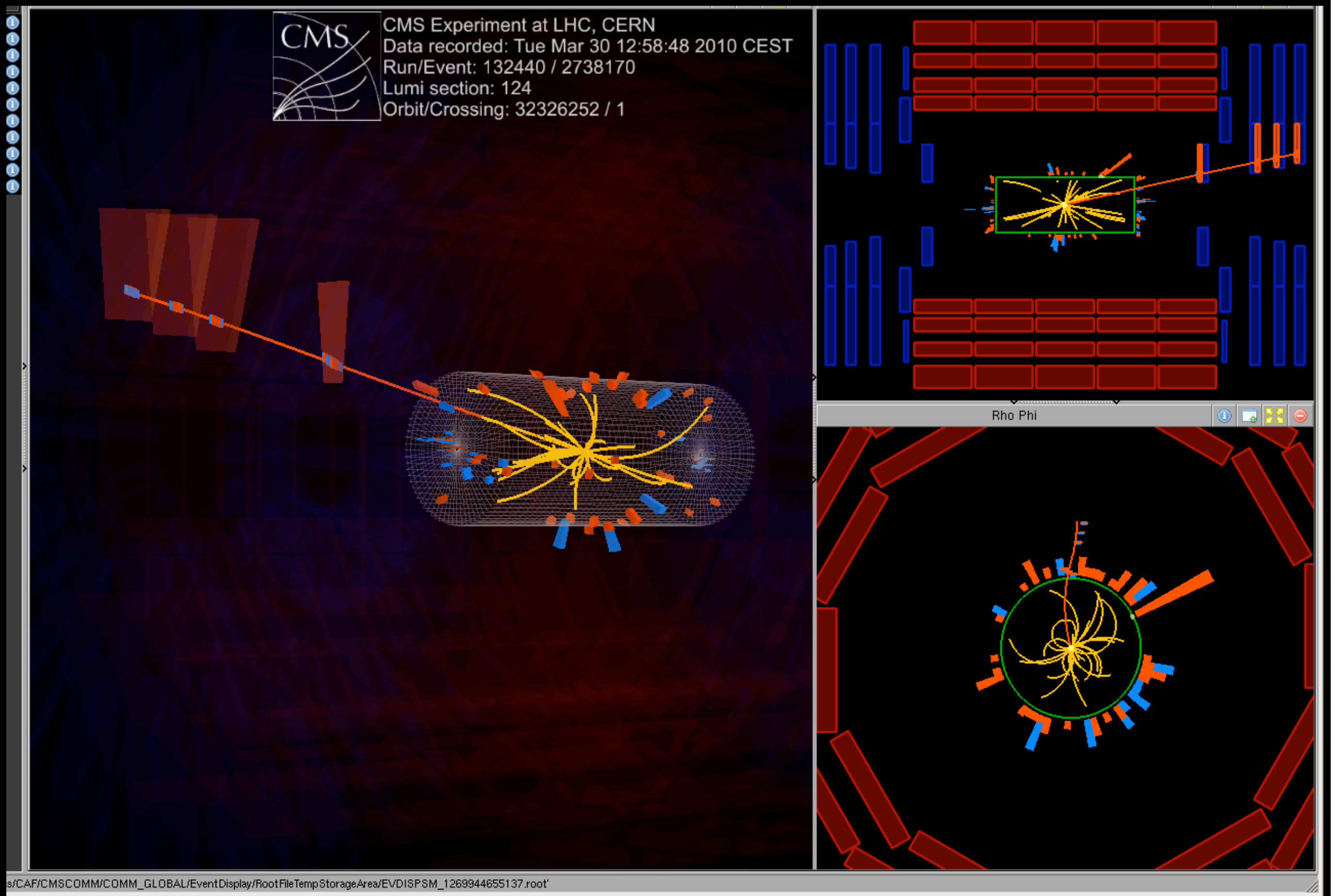
Commissioning with Collisions

Pilot Runs:

- **23/11/2009**
  - $\sqrt{s}$ = 0.9 TeV
  - $\mathcal{L}$ = 10μb^{-1}
  - 3.9x10^5 events
- **14/12/2009**
  - $\sqrt{s}$ = 2.36 TeV
  - $\mathcal{L}$ = 0.4 μb^{-1}
  - 2.0x10^4 events

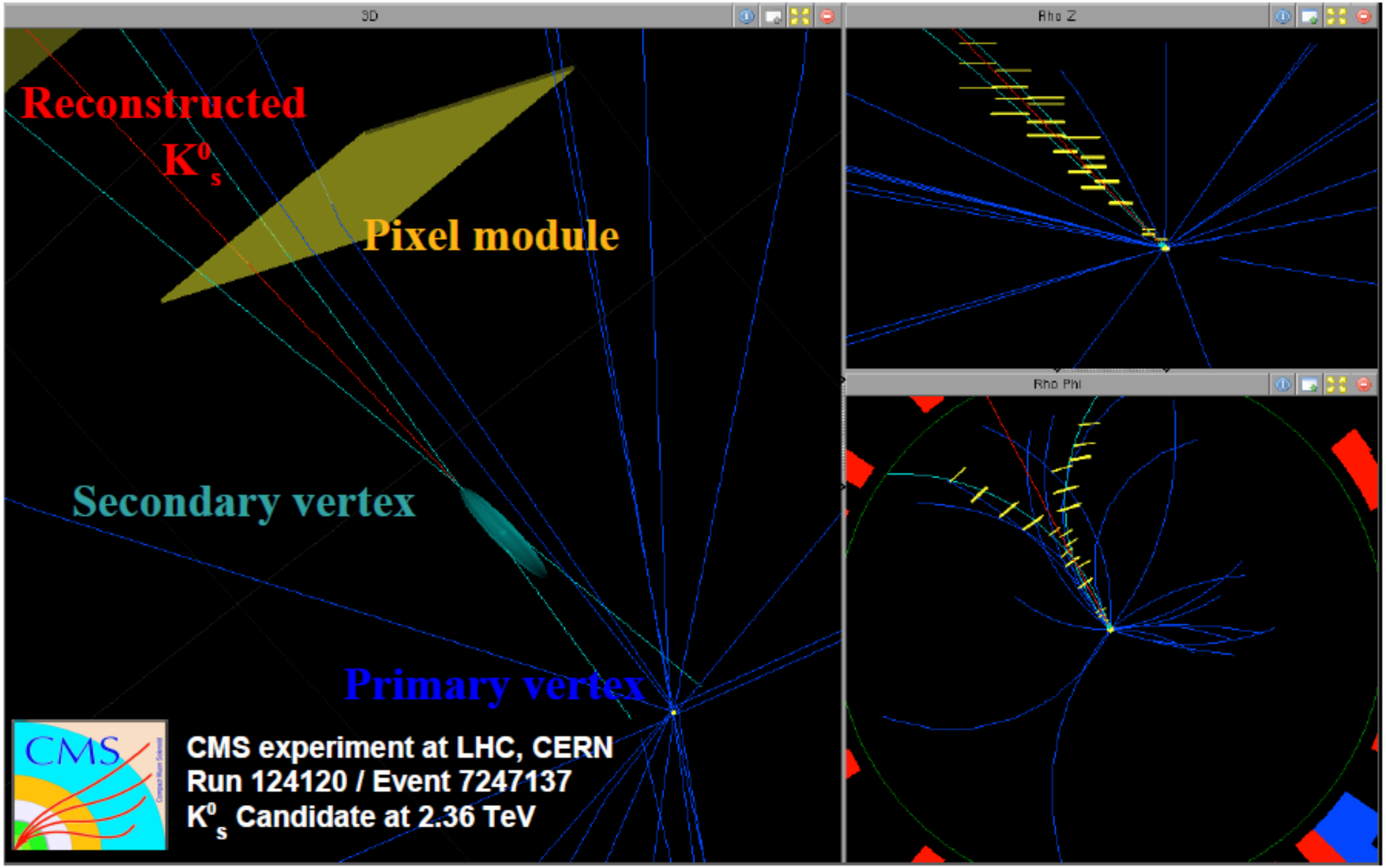
Physics Run Start-up:

- **30/03/2010**
  - $\sqrt{s}$ = 7 TeV

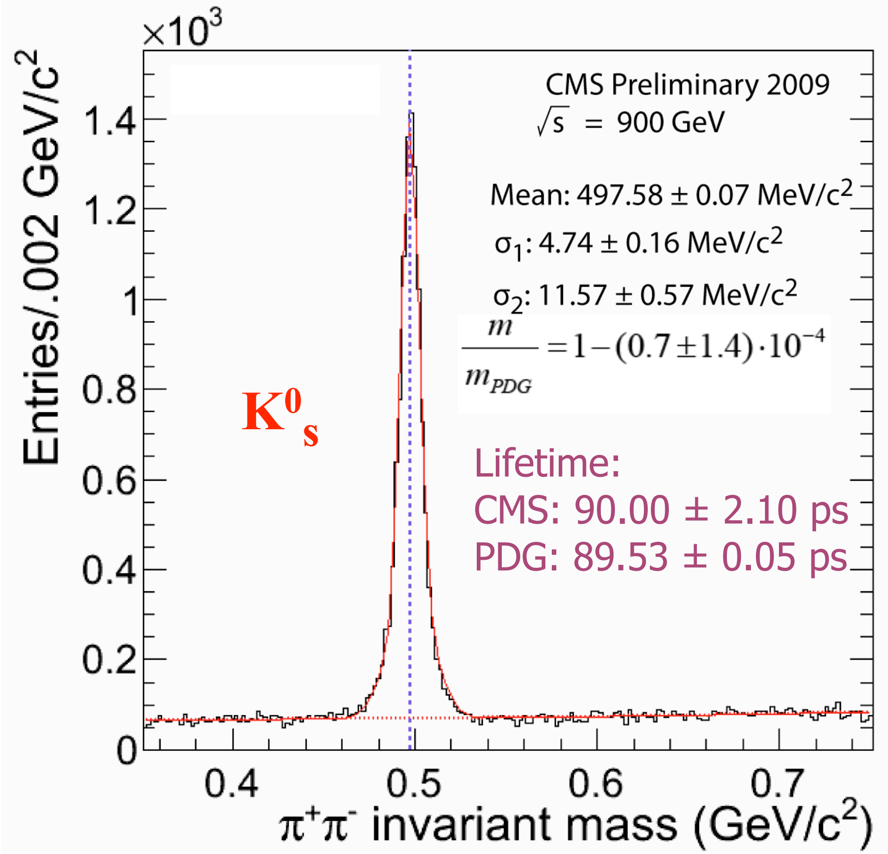


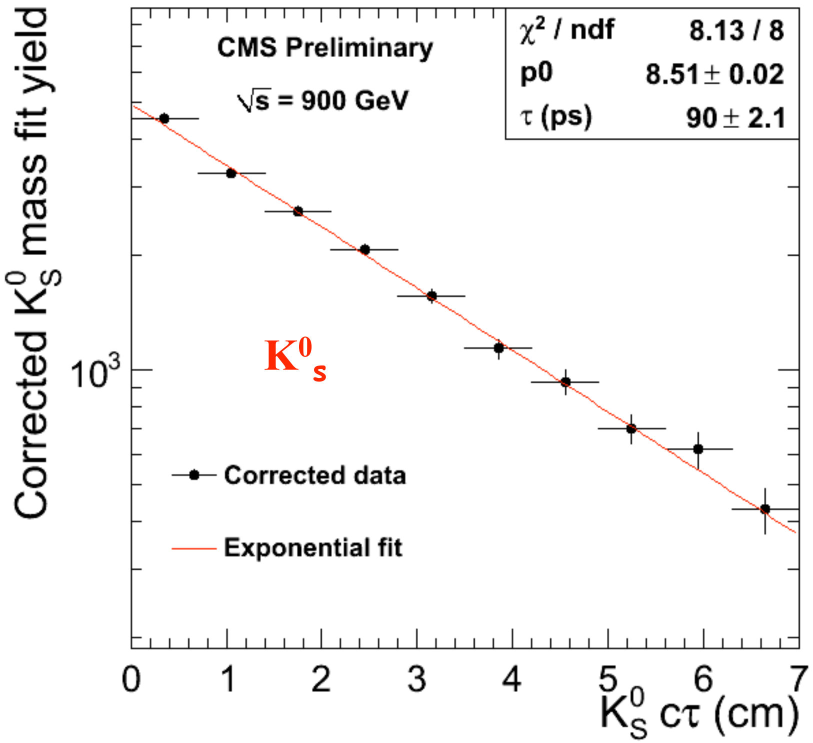
30/03/2010 first collision at $\sqrt{s}$ = 7 TeV

K^0_s candidate event at $\sqrt{s}$ 2.36 TeV



Resonances @ √s = 900 GeV

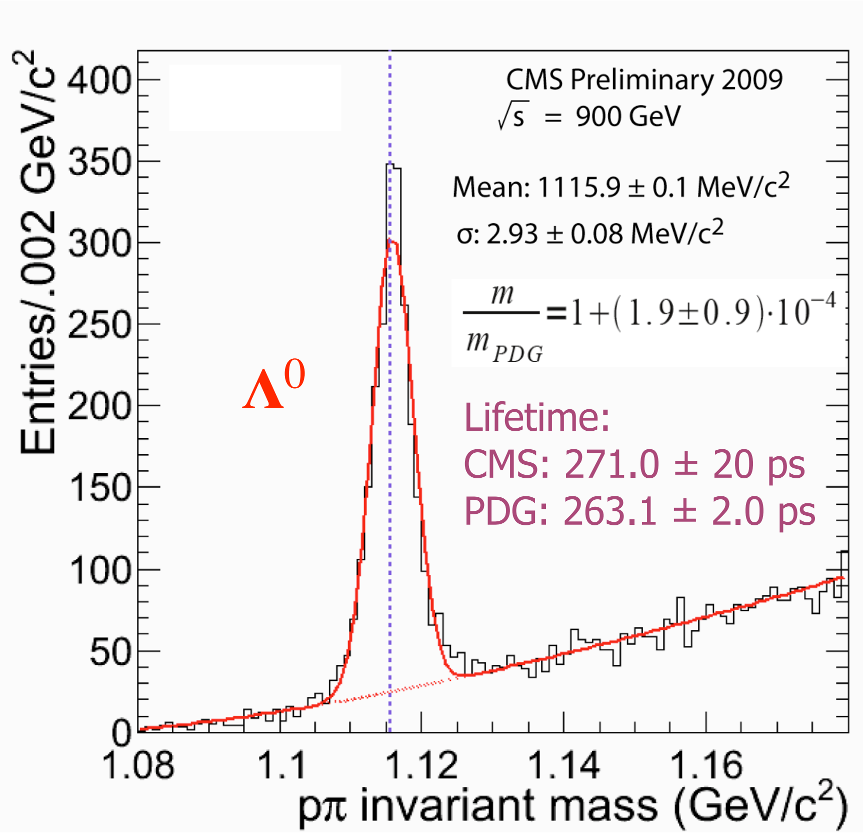


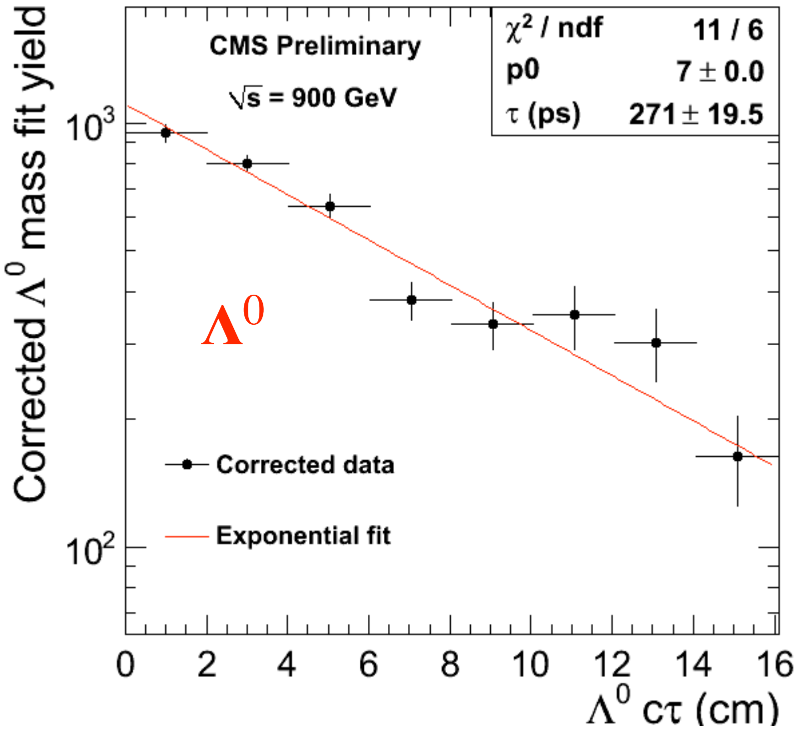


Excellent understanding of the momentum scale for low mass resonances

⟹ Accurate tracking, vertexing, alignment, magnetic field, ….

Resonances @ √s = 900 GeV

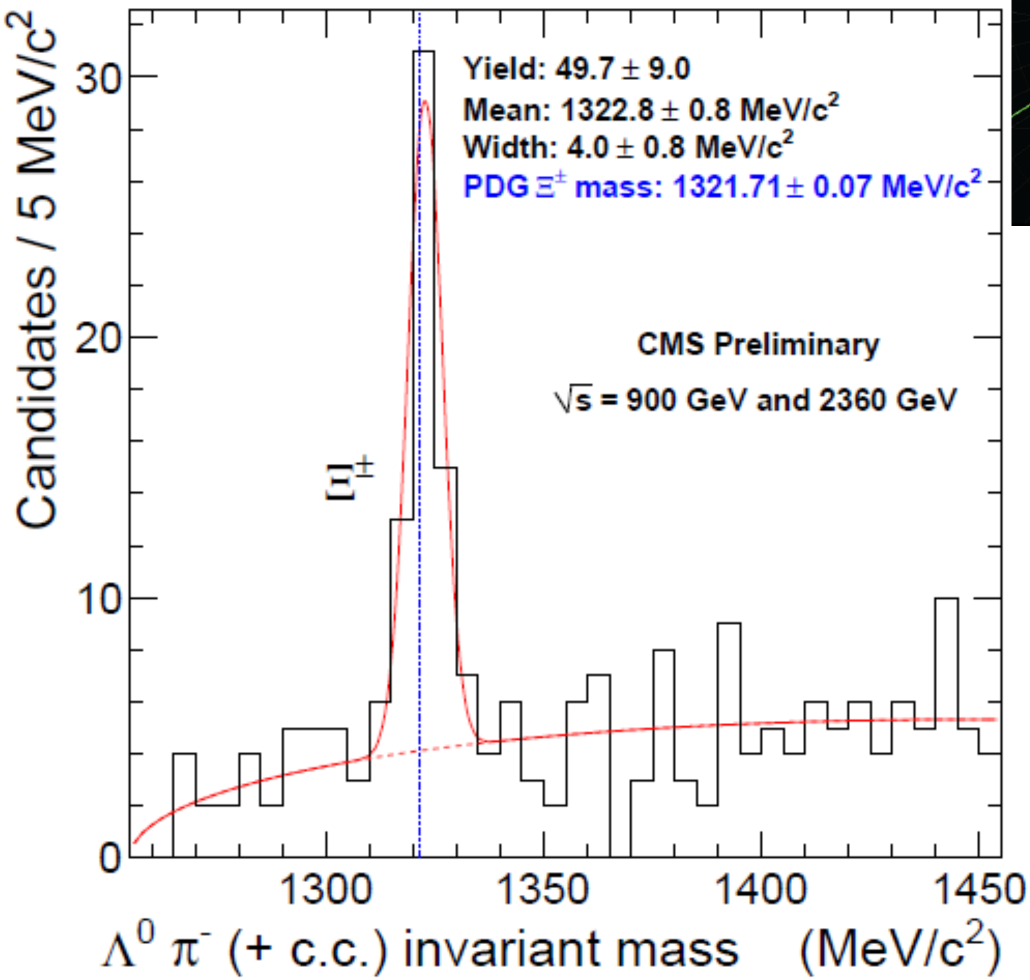


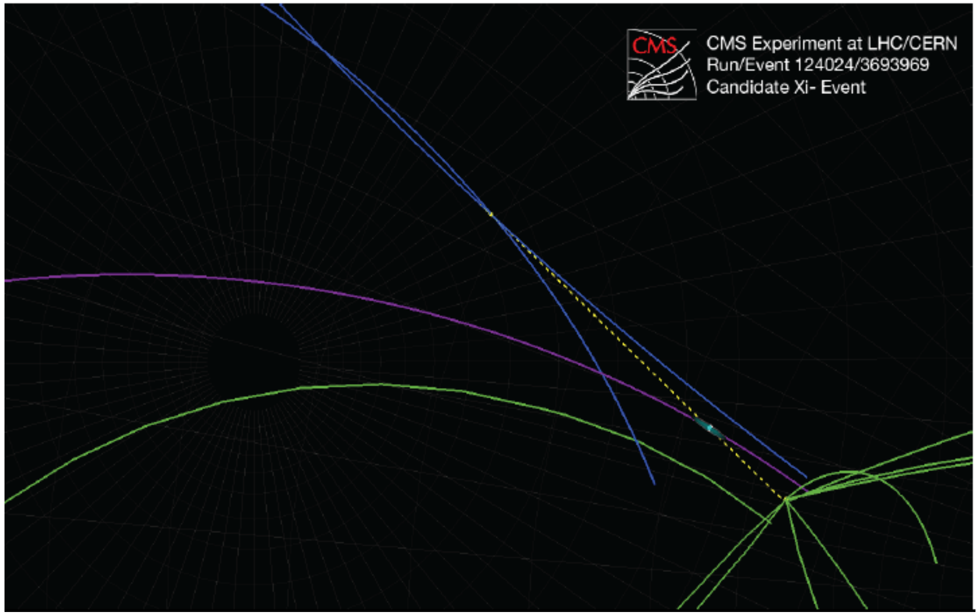


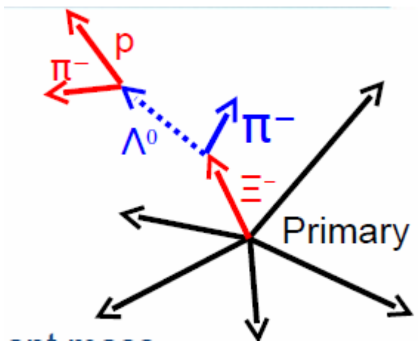
Excellent understanding of the momentum scale for low mass resonances

⟹ Accurate tracking, vertexing, alignment, magnetic field, ….

… and the $\Xi^{\pm}$





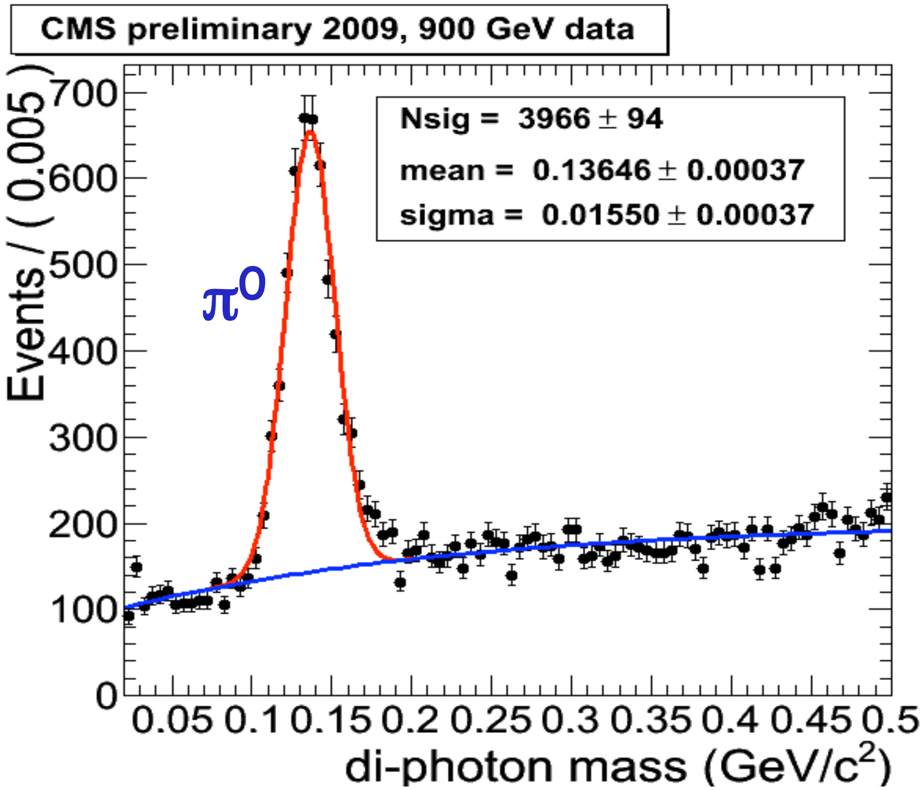


$\Xi^{\pm} \longrightarrow \Lambda\pi^{\pm}$

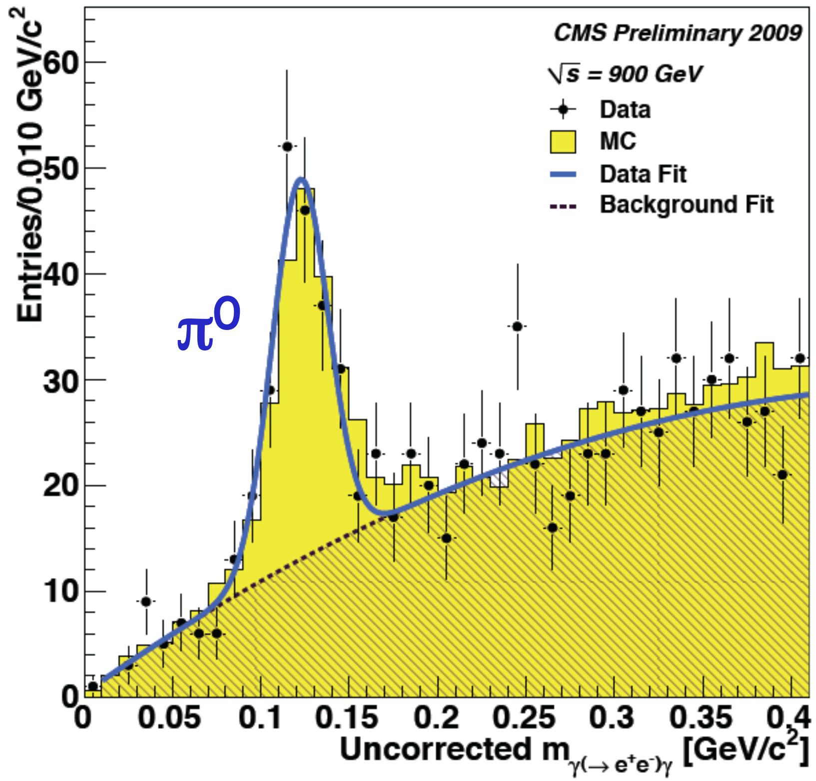
$\Lambda\pi$ Invariant mass

- tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- constrain Λ mass to PDG world average value in Ξ fit
- require same sign π's

First $\gamma\gamma$ Resonance in CMS

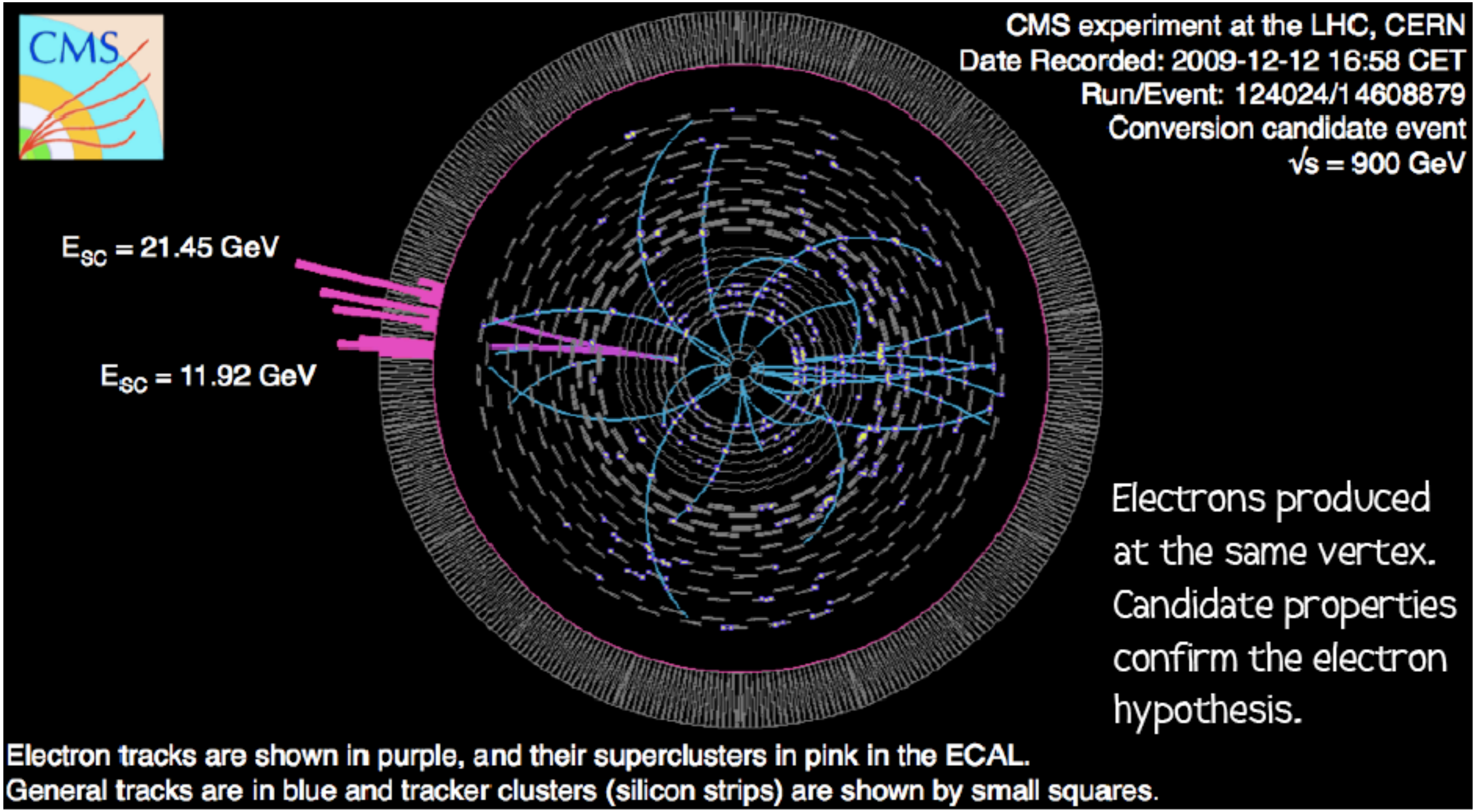


With MC corrections (zero suppression): within 2% of PDG mass …

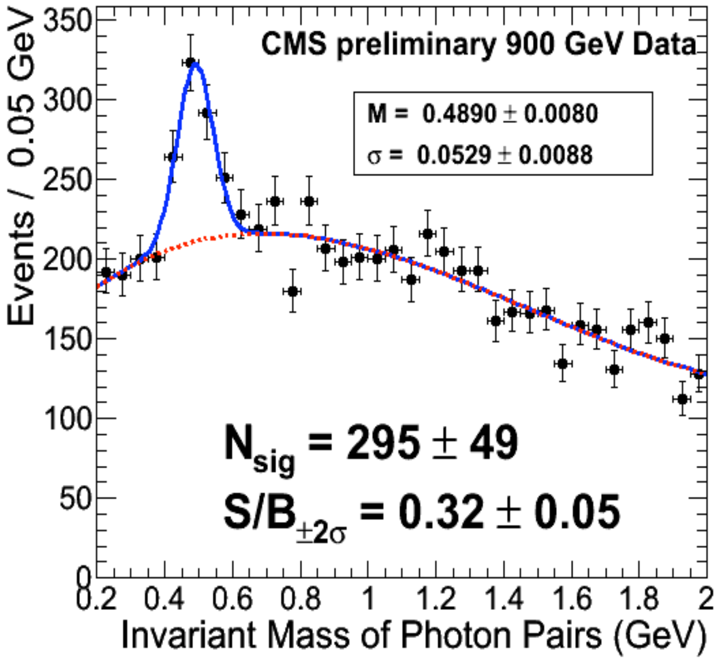


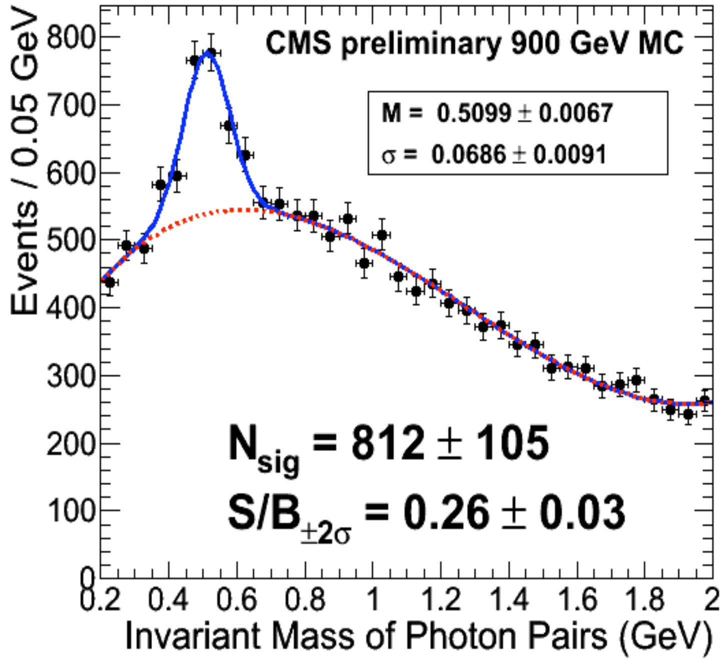
$\pi^0 \rightarrow \gamma\gamma$ with one leg reconstructed from conversion $\gamma \rightarrow e^+e^-$ candidates

$\gamma \rightarrow e^+e^-$ Conversion candidate



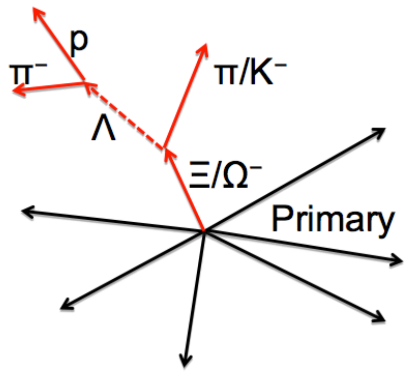
η resonance





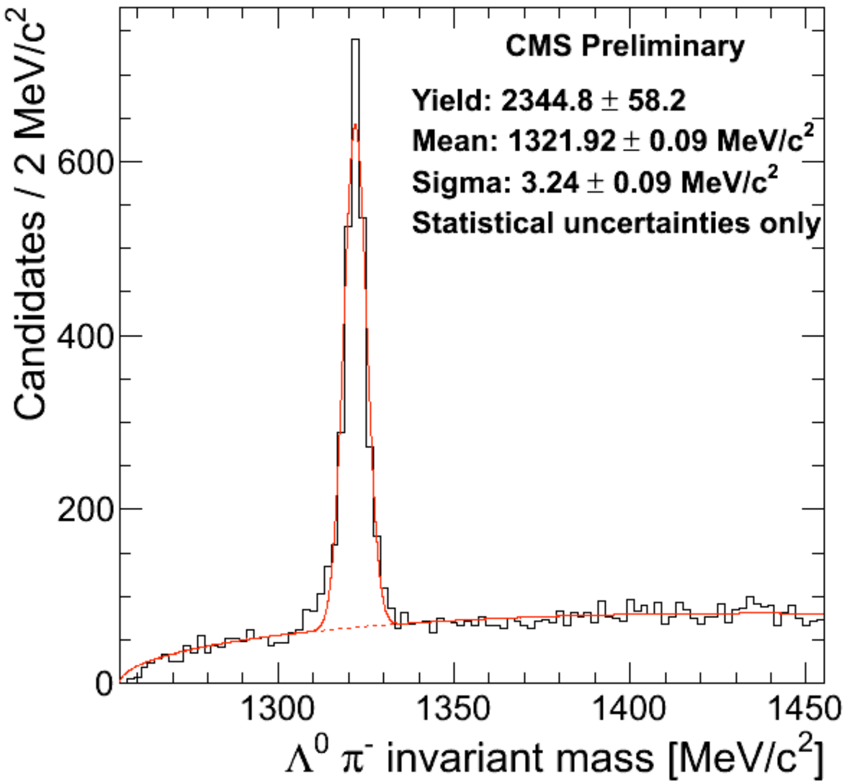
- Mass and width compatible with MC
- η yield scale as expected versus π^0

7 TeV Data: Resonances



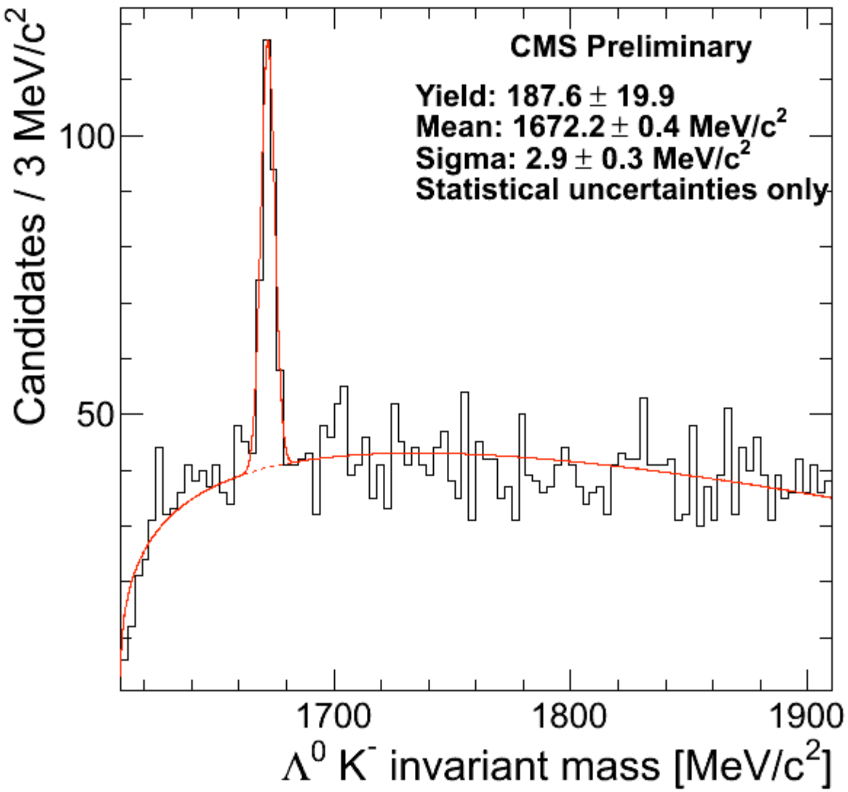
$\Xi^{\pm} \longrightarrow \Lambda\pi^{\pm}$

$\Lambda\pi^-$ or anti-$\Lambda\pi^+$ invariant mass



$\Omega^{\pm} \rightarrow \Lambda K^{\pm}$

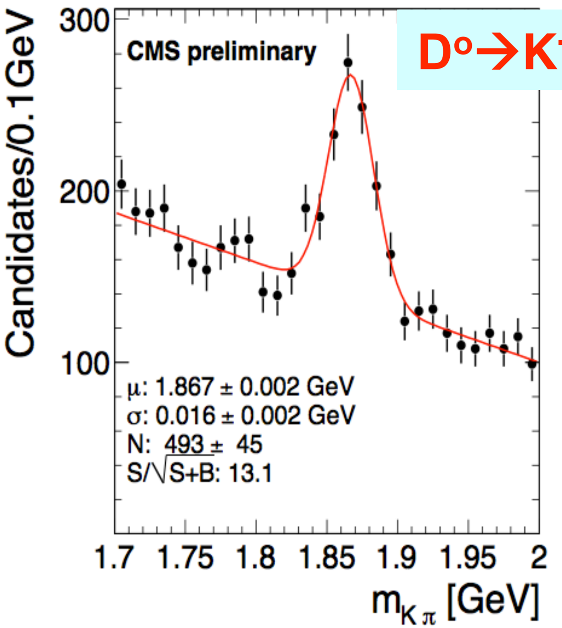
ΛK^- or anti-ΛK^+ invariant mass



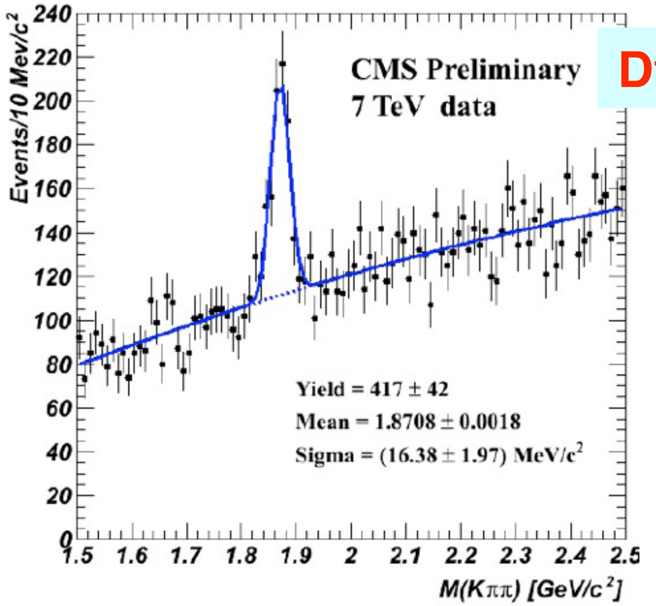
Charm Production

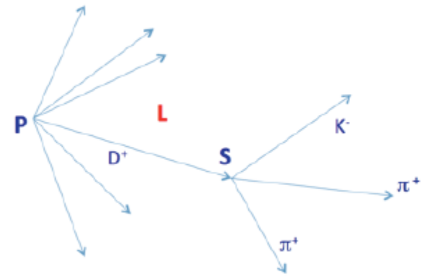
7 TeV DATA

$D^o \to K^- \pi^+$

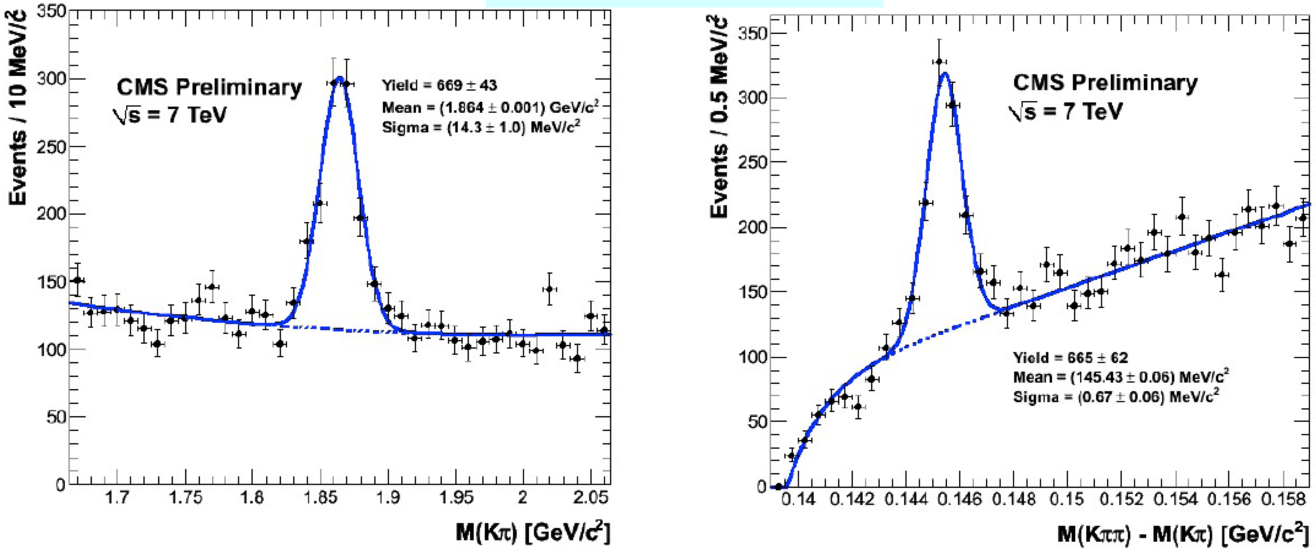


$D^+ \to K^- \pi^+ \pi^+$





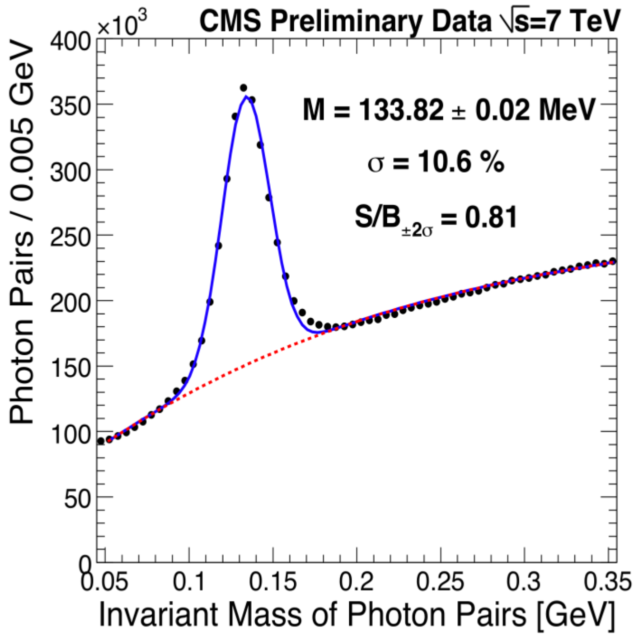
$D^{*+} \to D^o(K^- \pi^+)\pi^+$

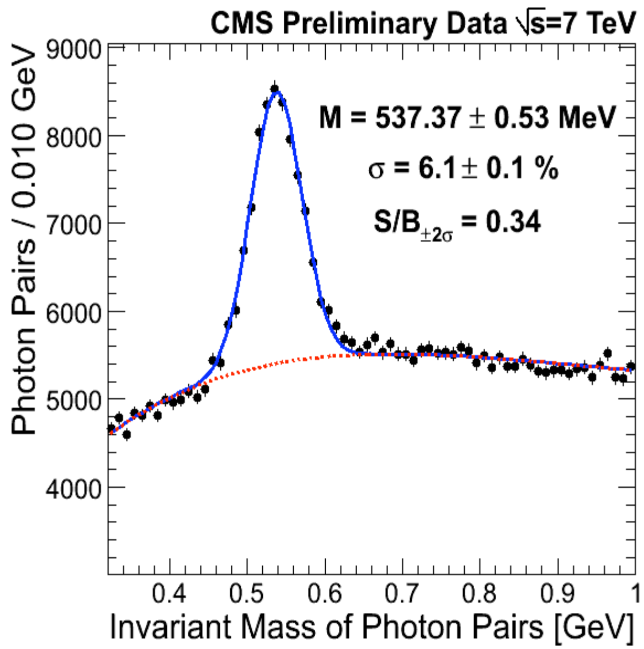


ECAL calibration

$\mathcal{L} > 1\ nb^{-1}$: beginning to use π^0's and η's in ECAL calibration.

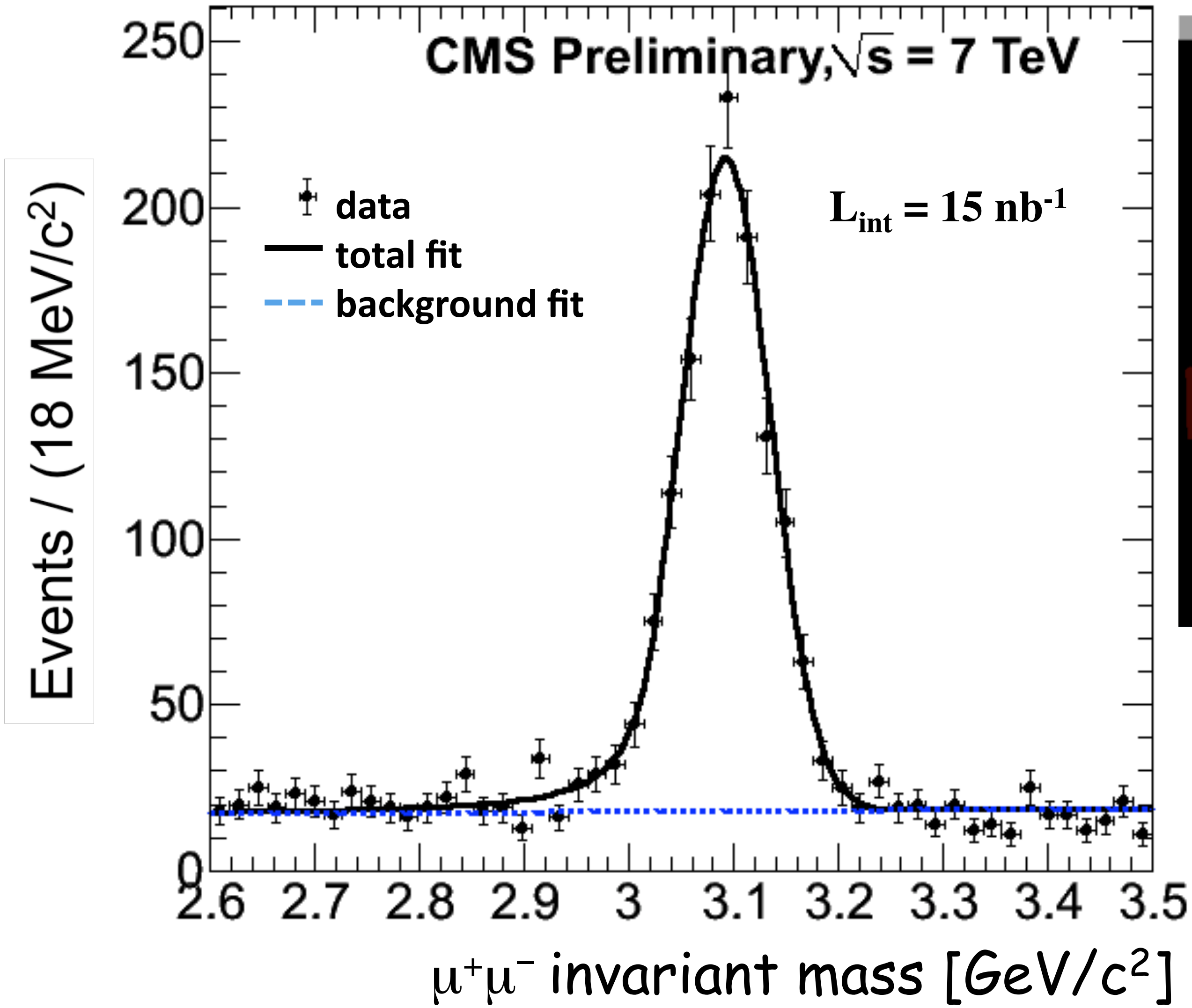
1.46M $\pi^0 \rightarrow \gamma\gamma$ pairs **7 TeV DATA** **25.5k $\eta \rightarrow \gamma\gamma$ pairs**

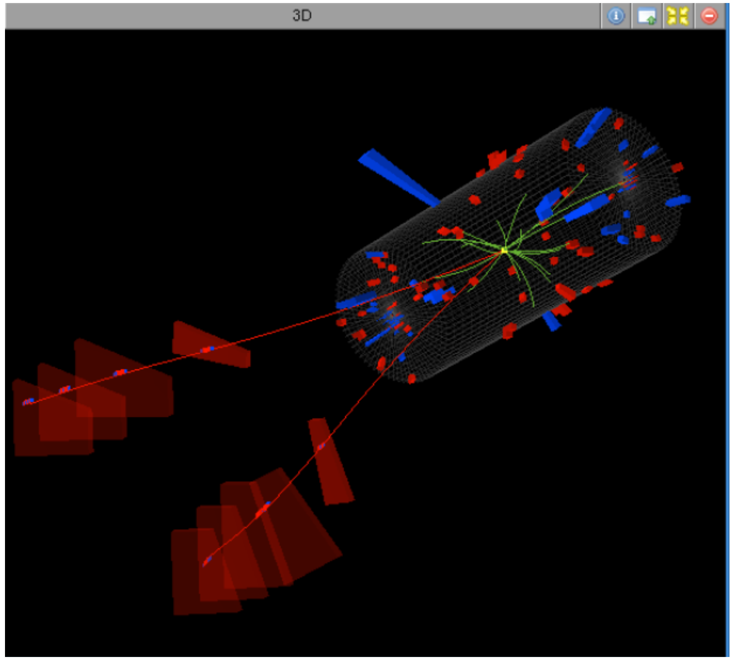




Di-muon resonances: $J/\psi \rightarrow \mu^+\mu^-$

7TeV data from $\mathcal{L}_{int} \approx 15\ nb^{-1}$

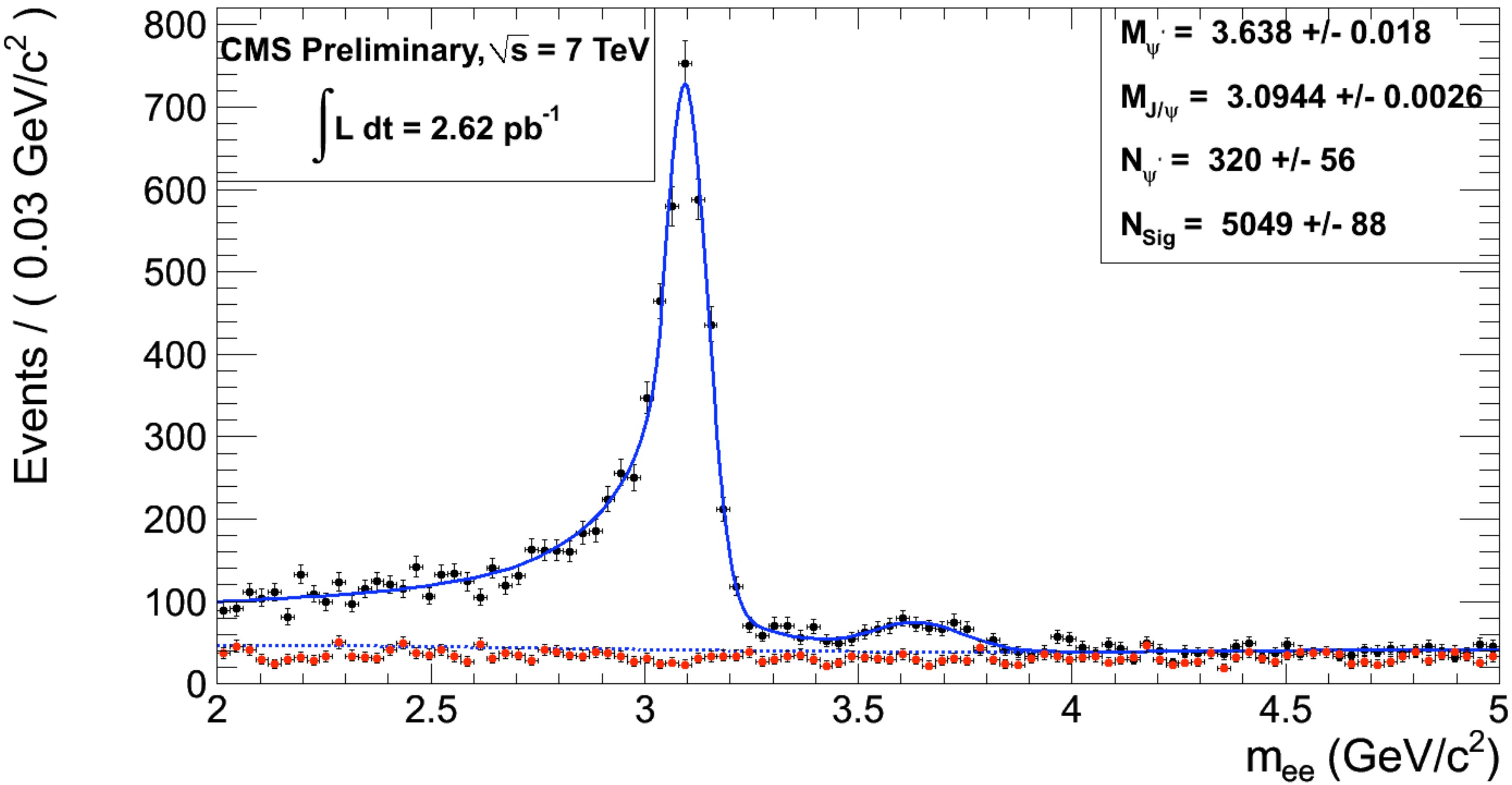




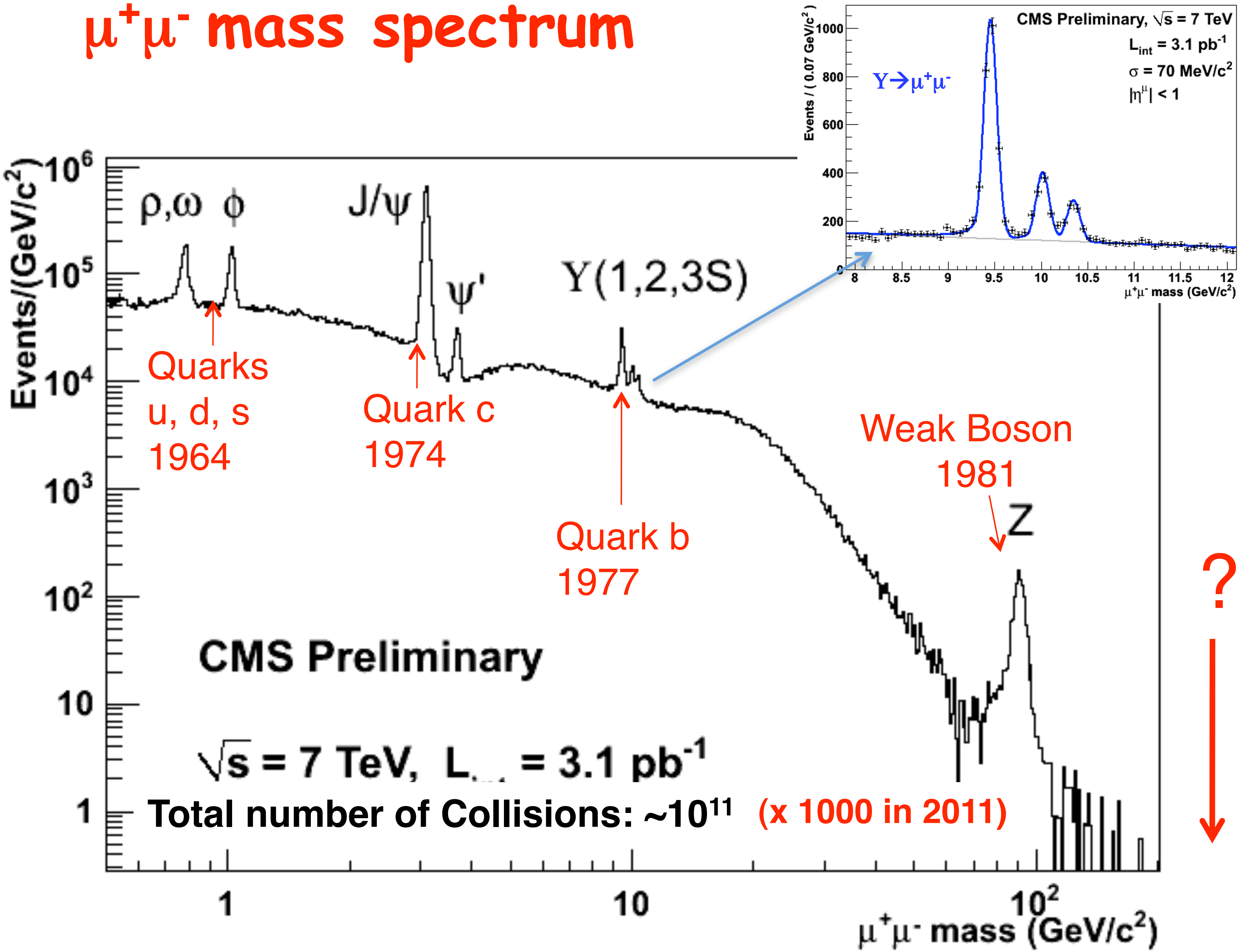
Signal events: 1230 ± 47
Sigma: (42.7 ± 1.9) MeV
M_0: 3.092 ± 0.001 GeV
S/B = 5.4 (M_0 ± 2.5σ)
χ^2/ndof = 1.1

Di-electron resonances: $J/\psi \rightarrow e^+e^-$

7TeV data from $\mathcal{L}_{int} \approx 2.62\ pb^{-1}$



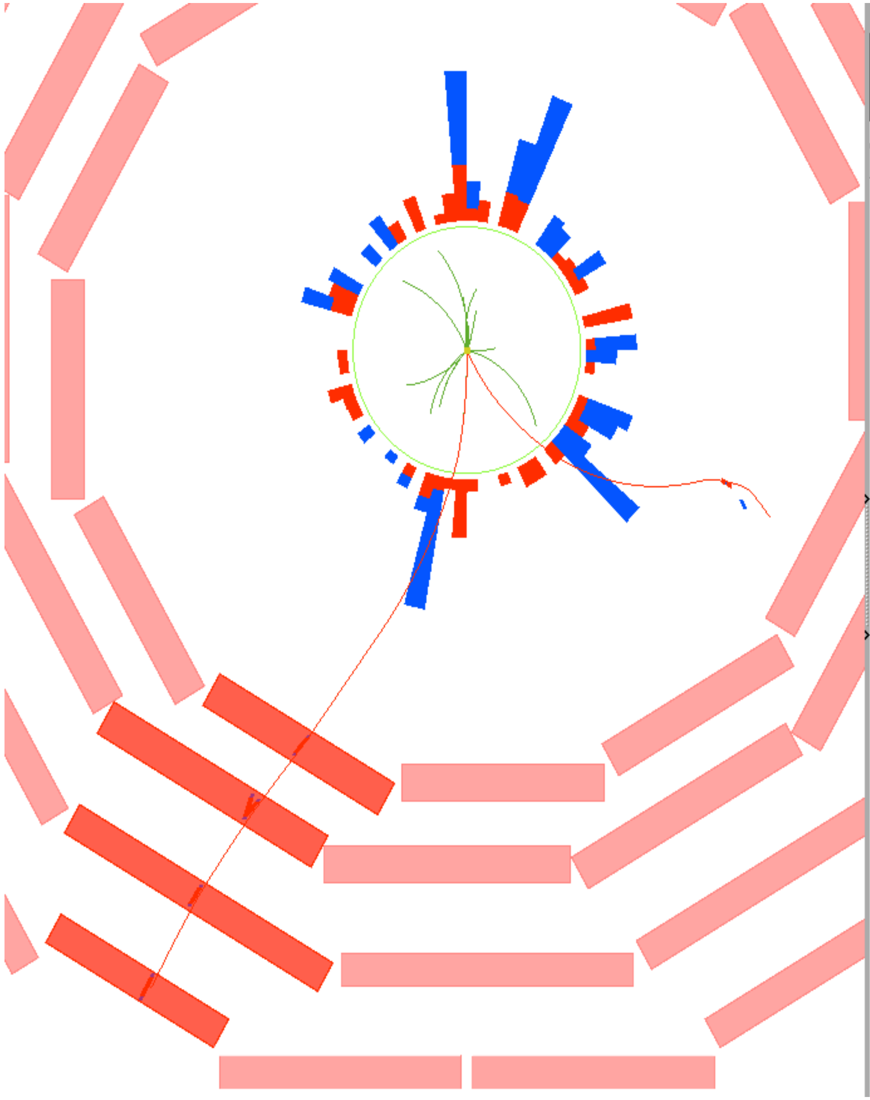
$\mu^+\mu^-$ mass spectrum



Total number of Collisions: ~10^{11} (x 1000 in 2011)

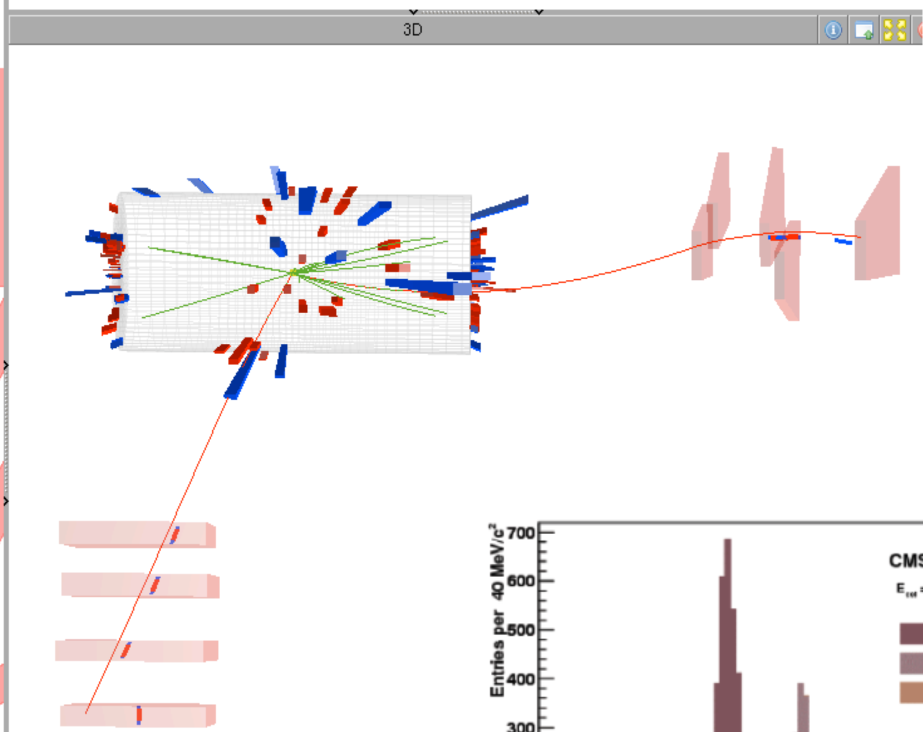
Looking for higher mass di-muon resonances: $\Upsilon \rightarrow \mu^+\mu^-$

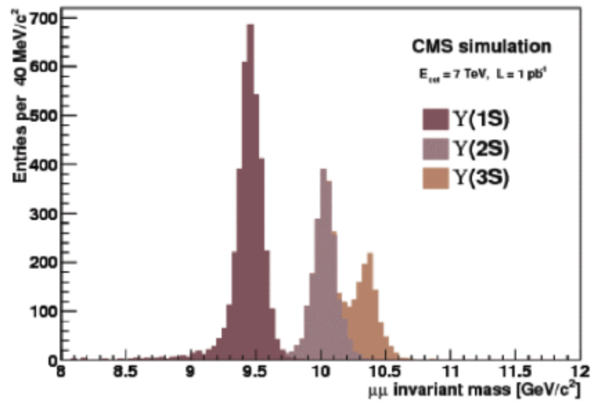
M=9.35GeV; p_t=8.41GeV



Collection Muons

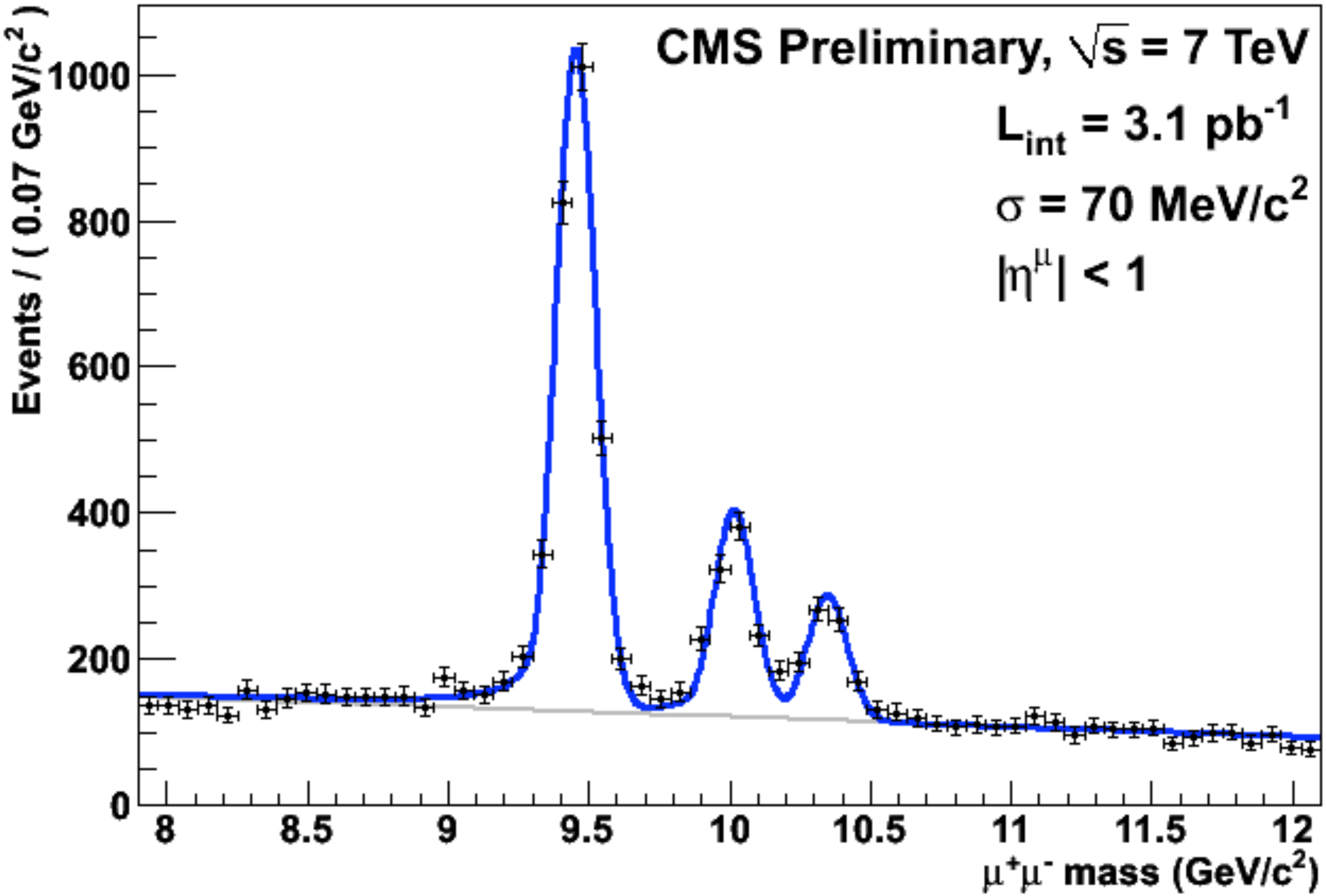
▽pT	global	tracker	SA	calo	tr pt	eta	phi	matches	d0	d0 / d0Err	charge
6.0	true	true	true	false	6.0	0.462	-1.559	4	-0.098	-26.396	1
2.6	true	true	true	false	2.6	-1.527	-1.135	2	-0.096	-13.627	-1



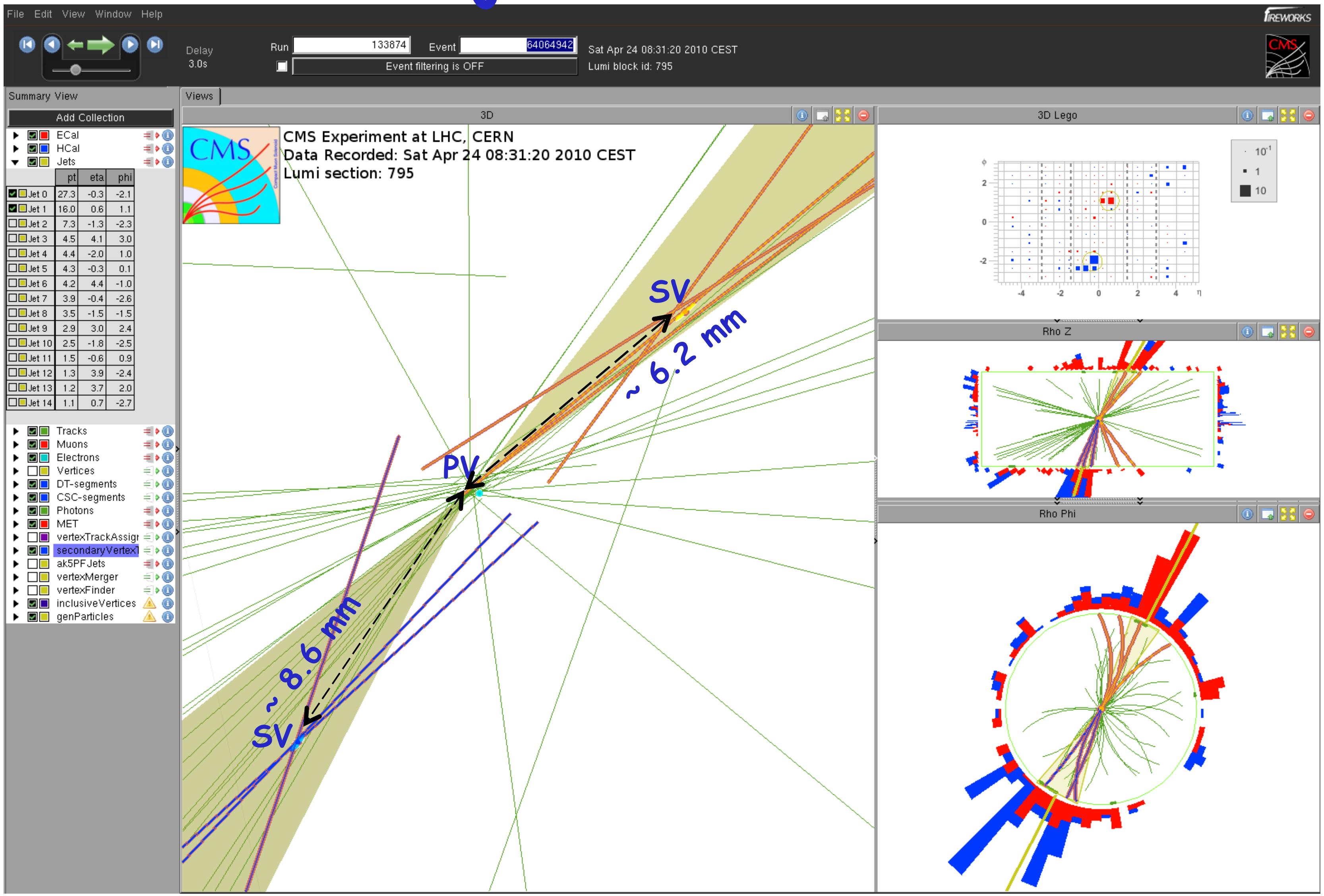


Expecting a few thousand $\Upsilon(nS) \rightarrow \mu^+\mu^-$ in CMS per pb^{-1}

$\Upsilon \rightarrow \mu^+\mu^-$



double b-jet candidate



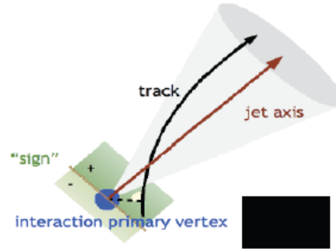
Jets: p_T = 43.7 GeV (top right) / 40.3 GeV (bottom left)

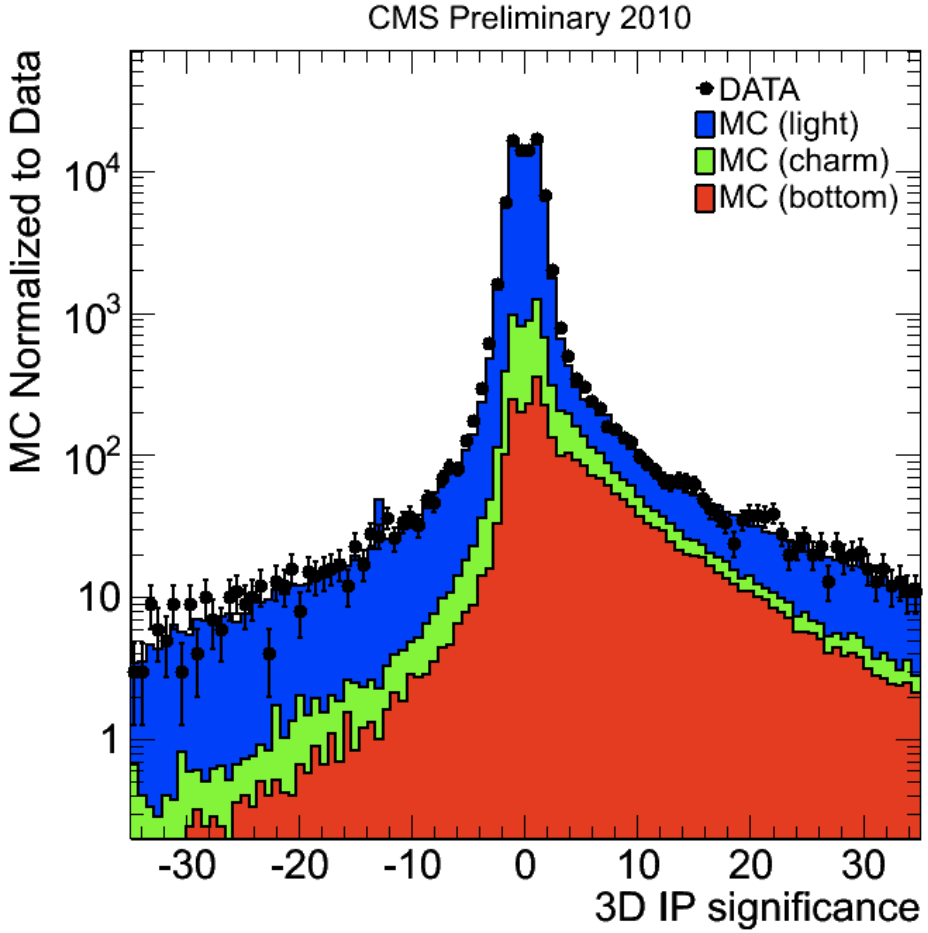
Secondary vertices

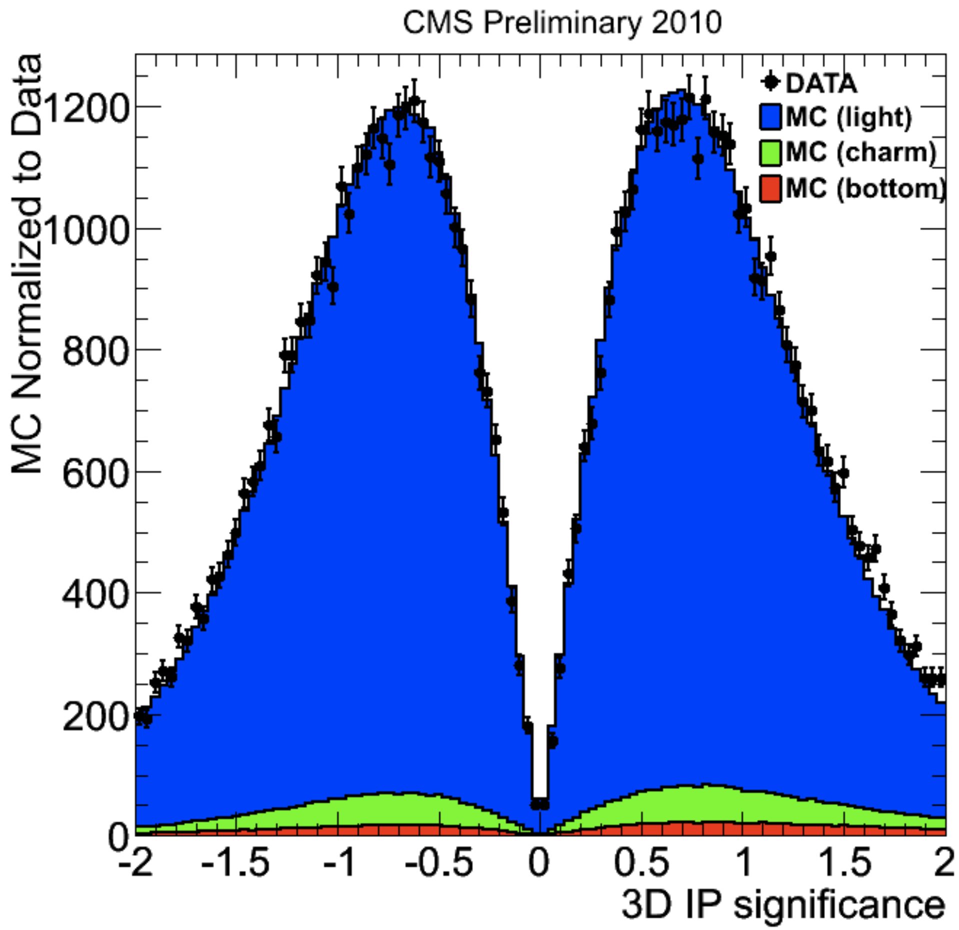
top-right: 3D flight distance (value/ significance) = 6.2 mm / 43 m_{SV} = 2.9 GeV, p_T = 25.7 GeV

bottom left: 3D flight distance (value / significance) = 8.6mm / 55 m_{SV} = 3.1 GeV, p_T = 17.2 GeV

Validation at 7 TeV: b-tagging





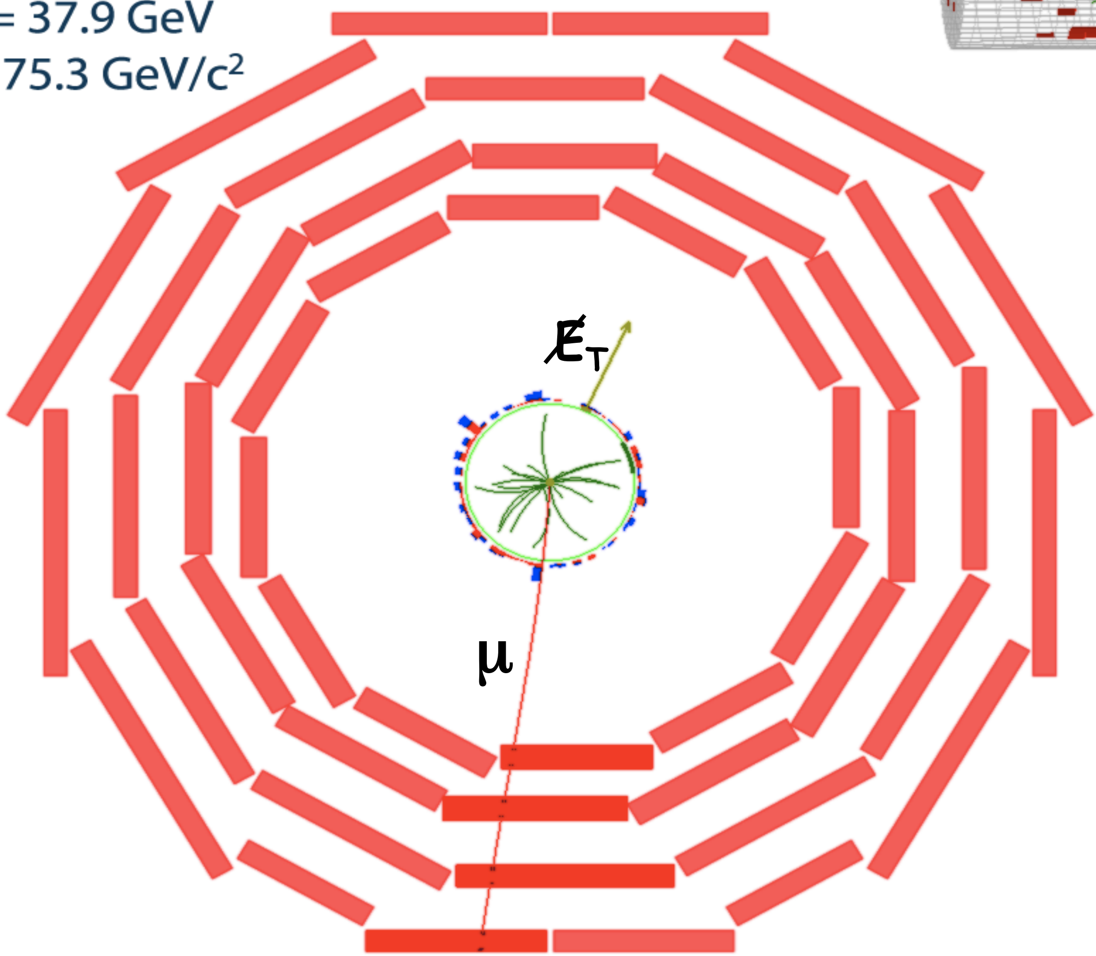


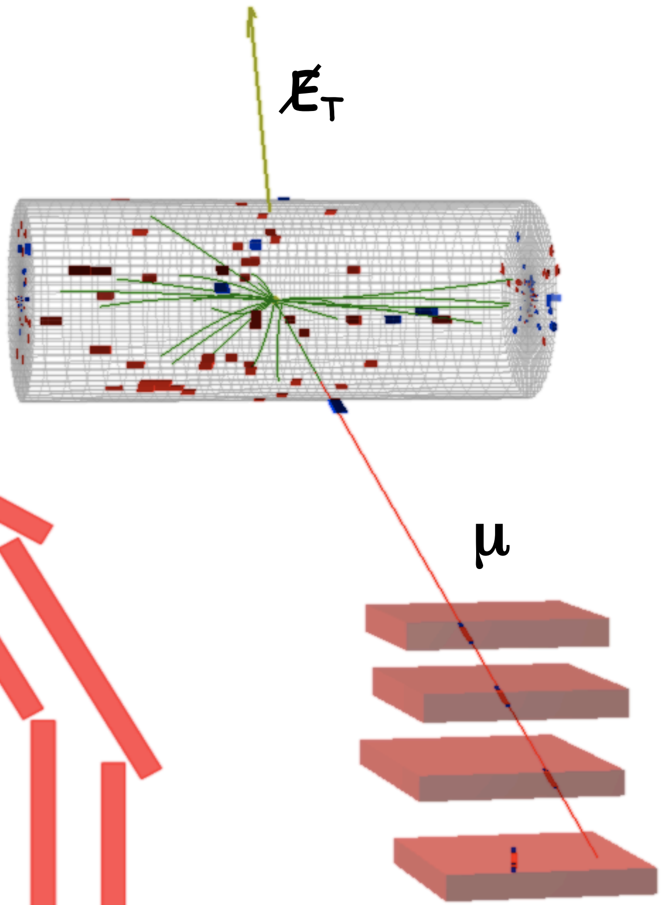
- Left: Significance of the signed 3D impact parameter for all tracks selected for b-tagging, for jets with p_T > 40 GeV and $|\eta|$ < 1.5
- Right: zoom in the region close to 0.
  - ➢ Good agreement between data and MC

W→μν candidate

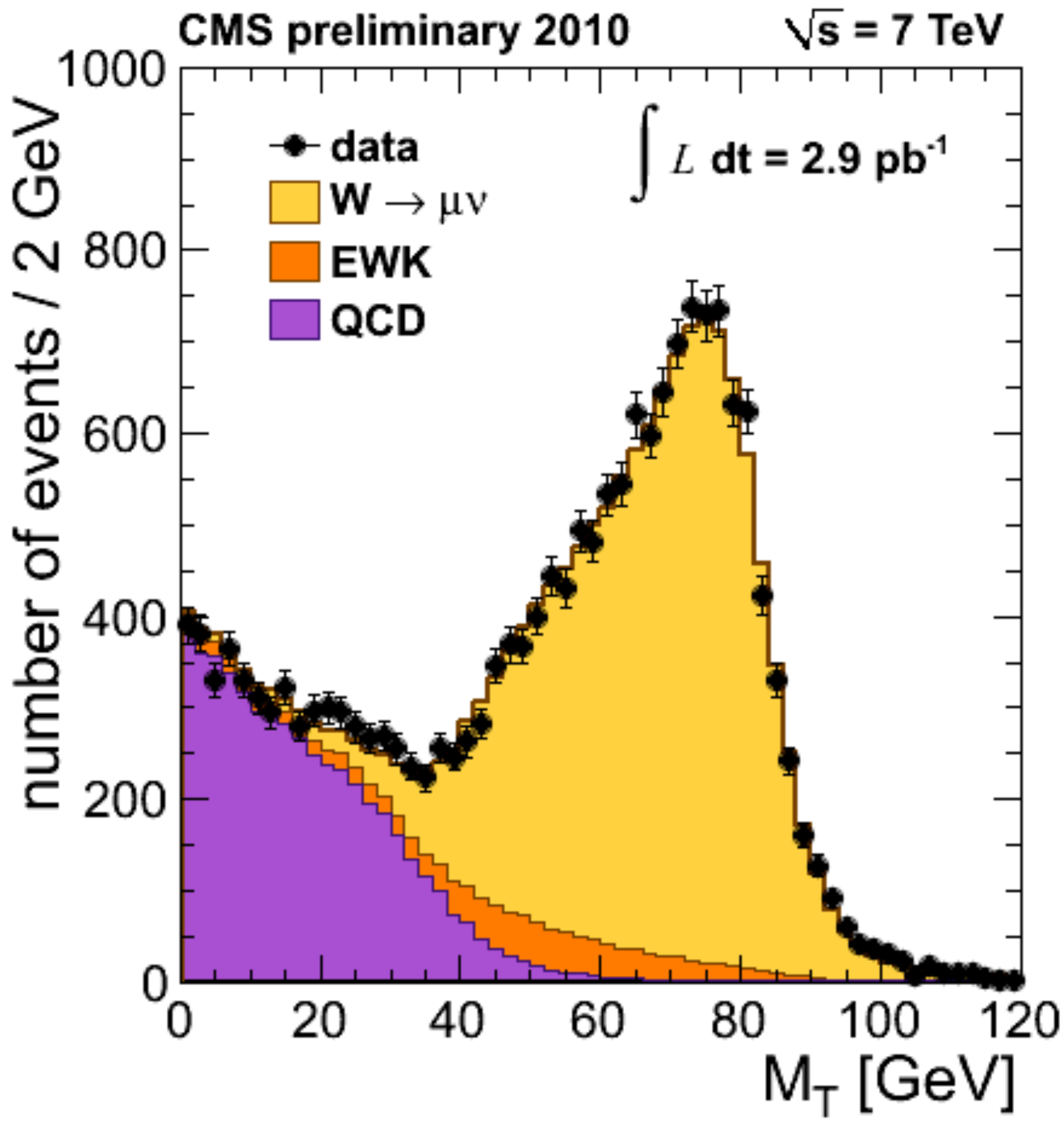
CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

Muon p_T= 38.7 GeV/c
ME_T= 37.9 GeV
M_T= 75.3 GeV/c^2





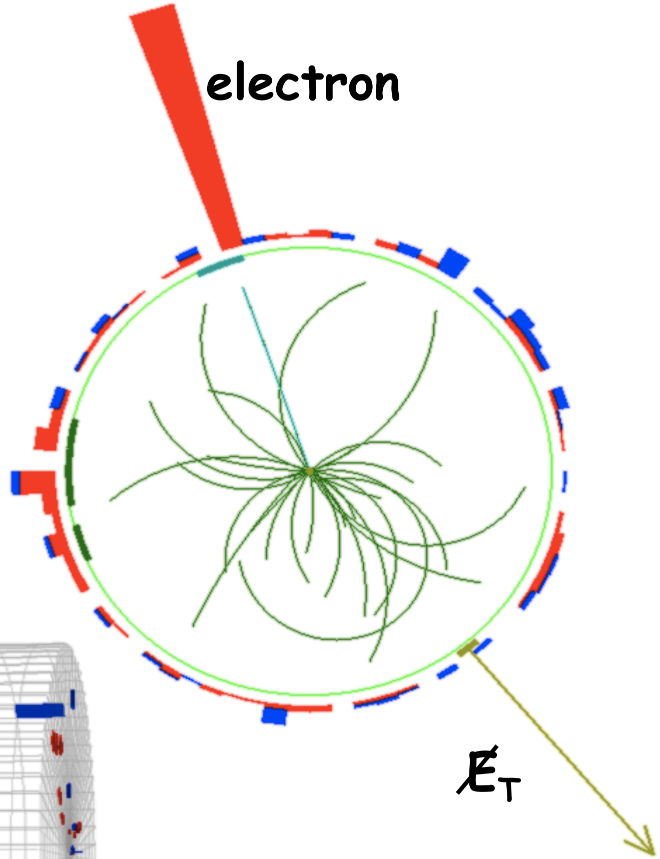
Looking for Vector Bosons: $W \to \mu\nu$ M_T distribution
7TeV data from $\mathcal{L}_{int} \approx 2.9\ pb^{-1}$

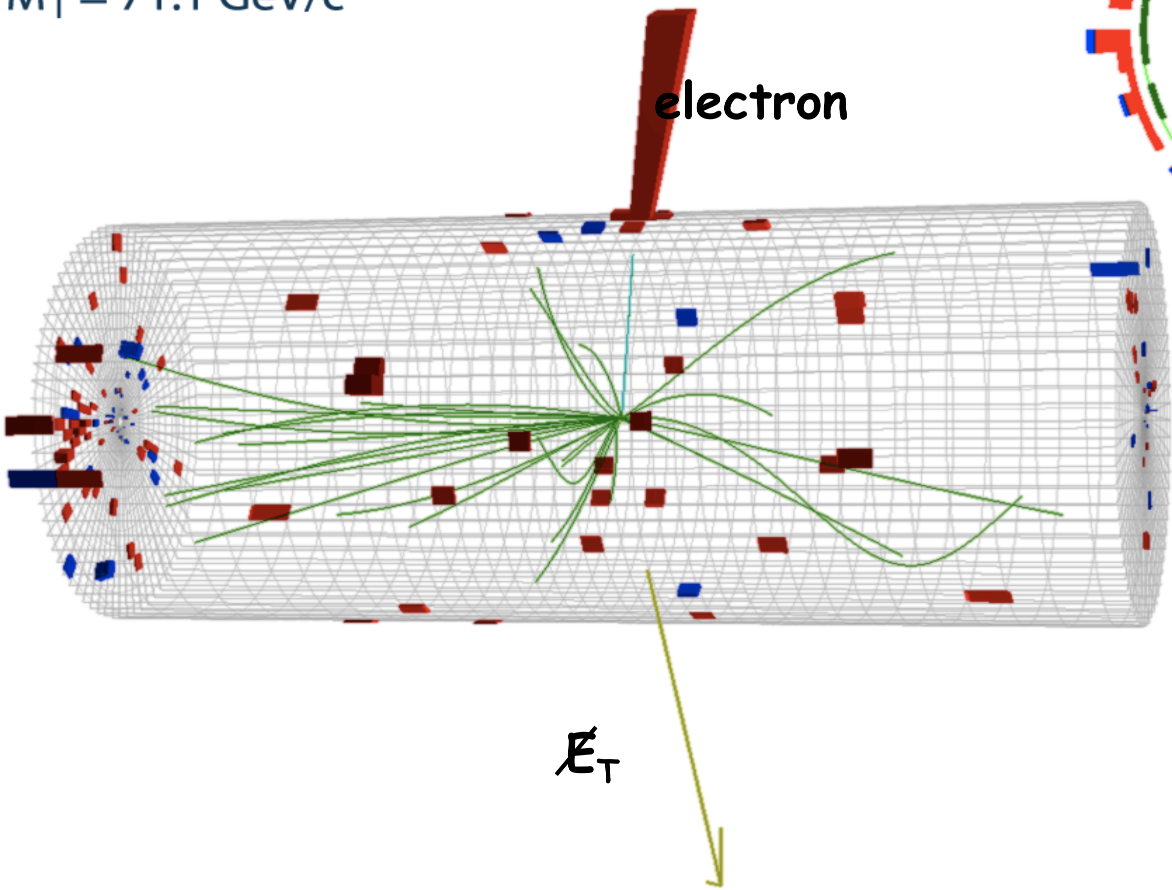


W→eν candidate

CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

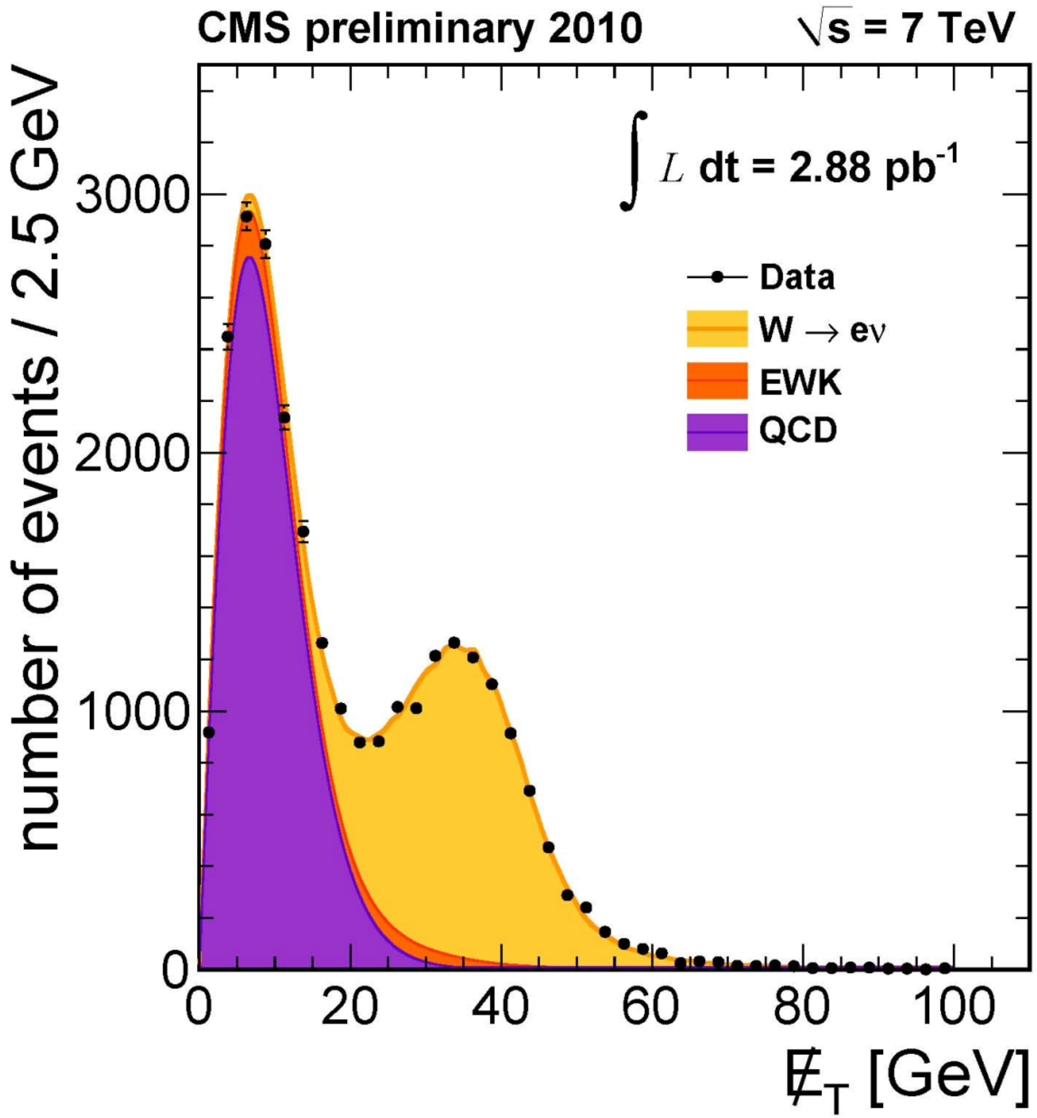
Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2





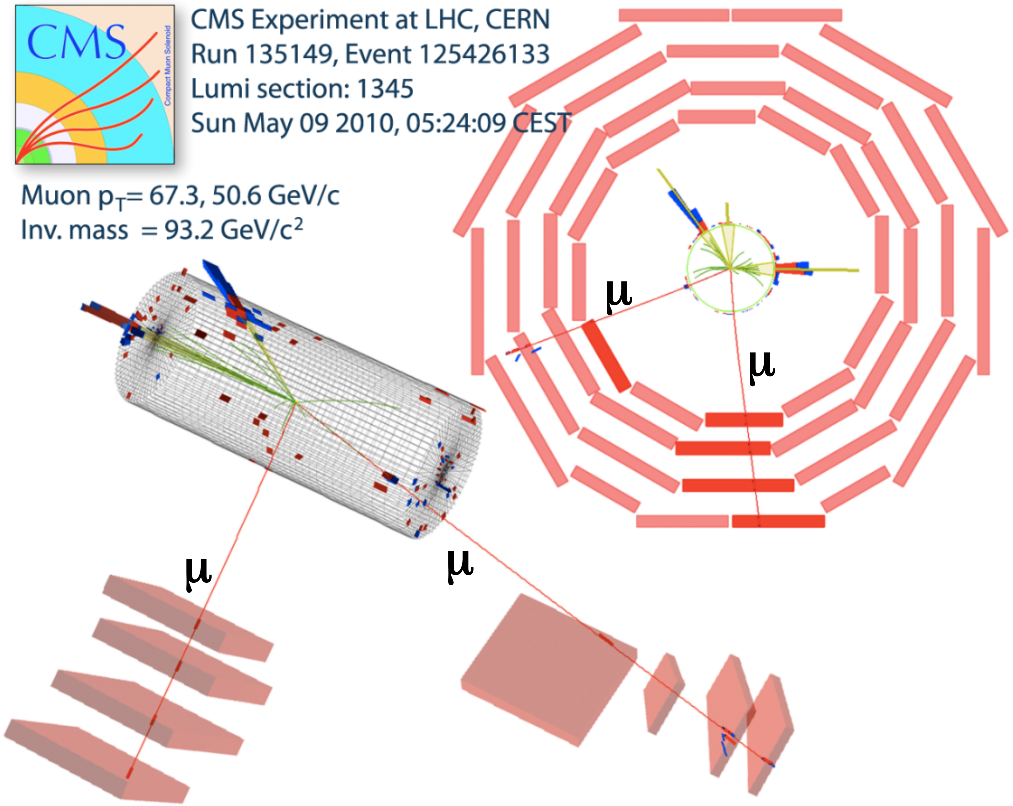
Looking for Vector Bosons: W→eν

7TeV data from $\mathcal{L}_{int} \approx 2.88\ pb^{-1}$

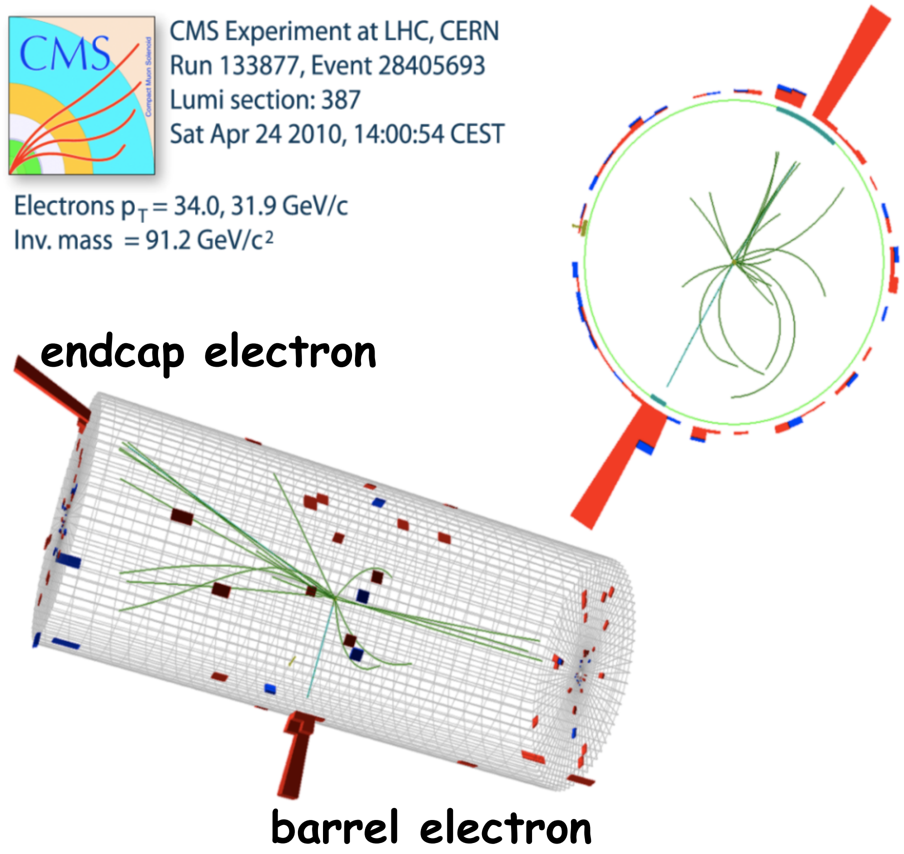


Looking for Z candidates:

$Z \rightarrow \mu^+\mu^-$

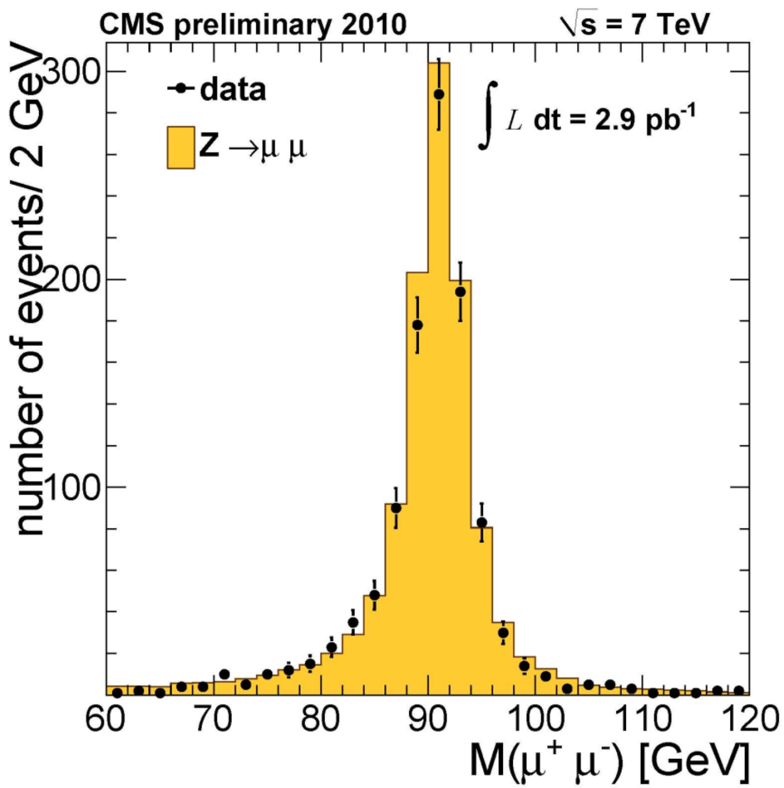


$Z \rightarrow e^+e^-$

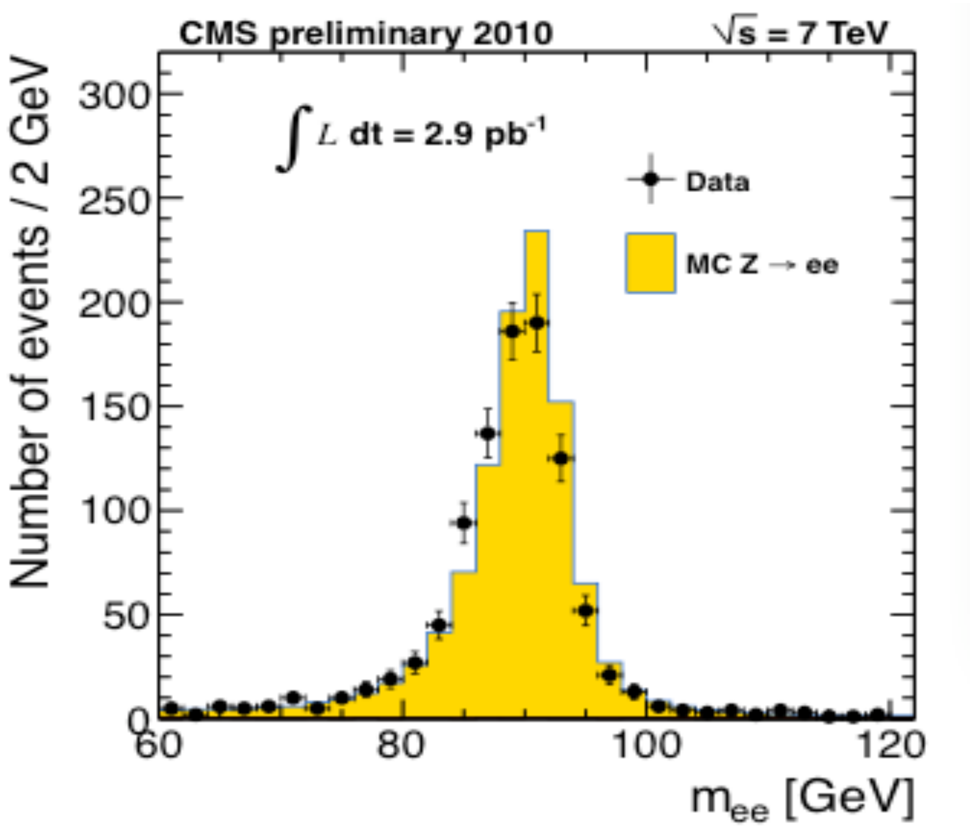


Z candidates at 7 TeV

$Z \rightarrow \mu^+\mu^-$: $\mathcal{L}_{int} \approx 2.9\ pb^{-1}$

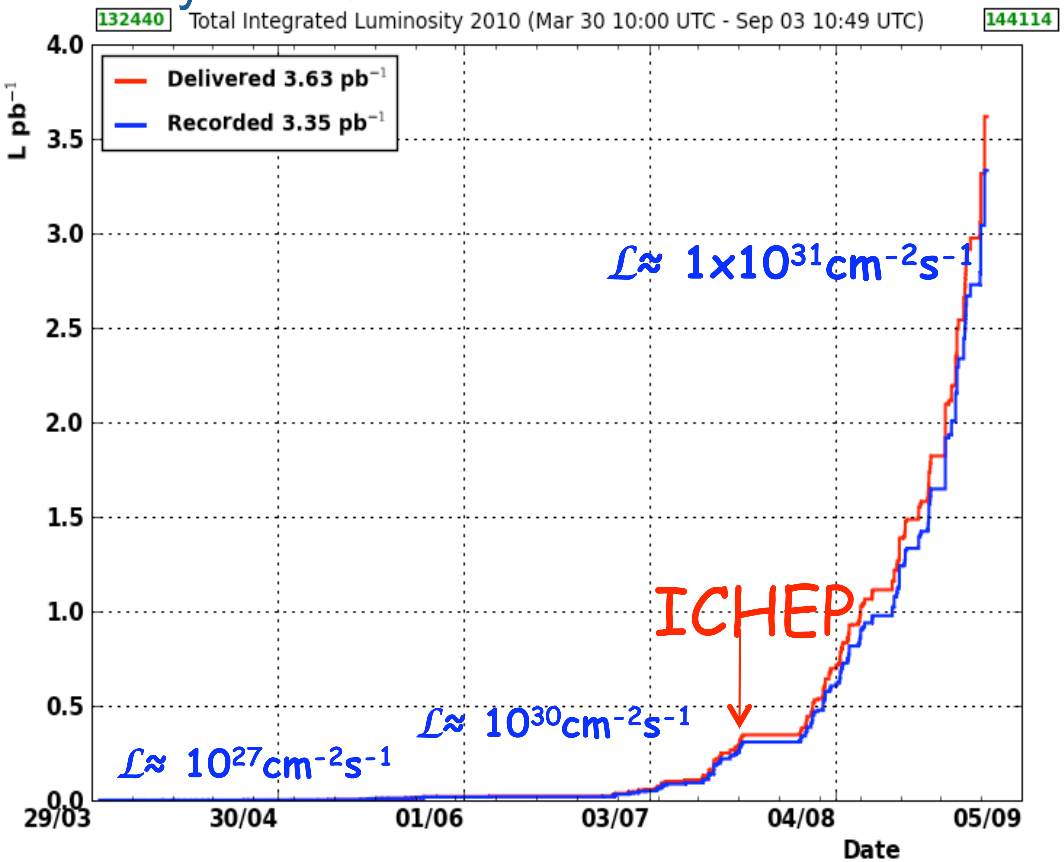


$Z \rightarrow e^+e^-$: $\mathcal{L}_{int} \approx 2.9\ pb^{-1}$



7 TeV operations since March 30

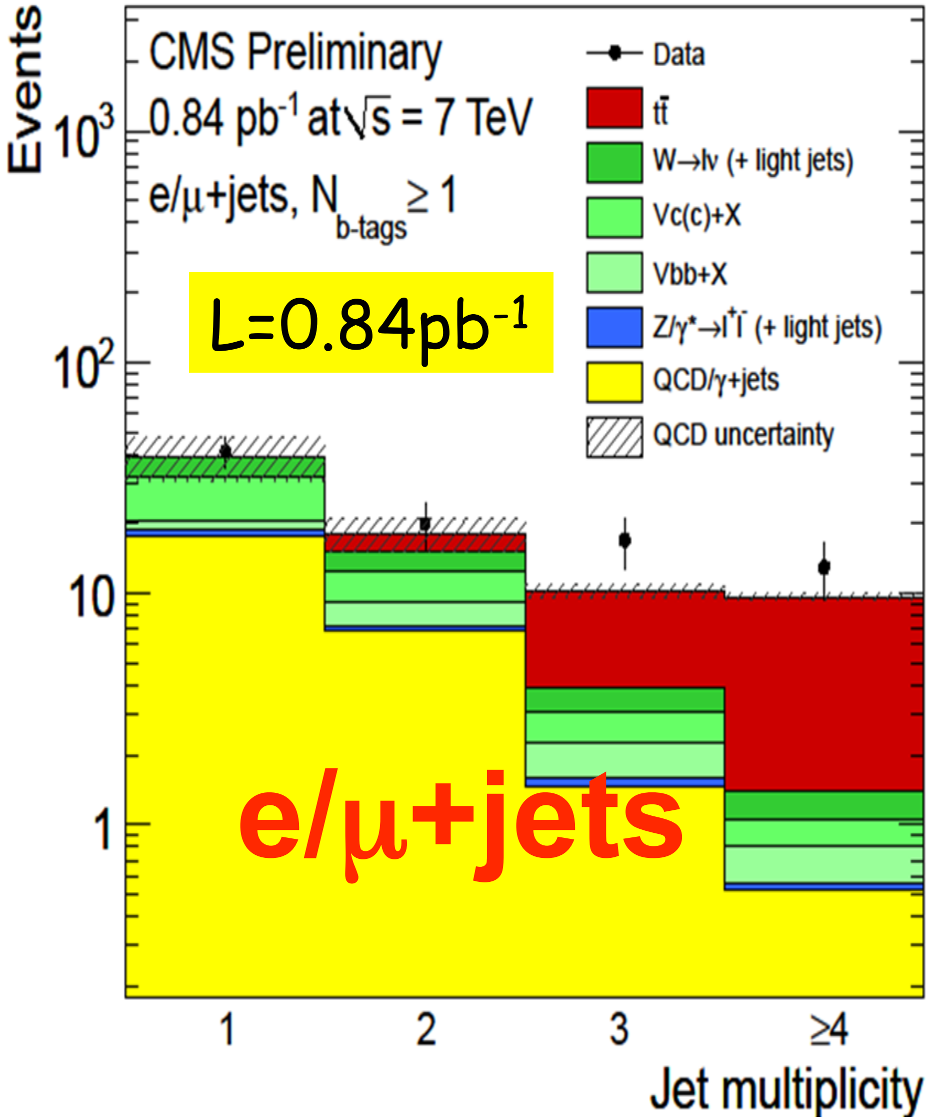
About **3.6pb^{-1}** delivered by LHC and **~3.3pb^{-1}** of data collected by CMS. Overall data taking efficiency **>92%.**



Good performance of CMS in coping with 4 orders of magnitude increase in instantaneous luminosity. Since ICHEP we have recorded another **3.0pb^{-1}** of data: **2.9pb^{-1} validated for physics in total (86% of the recorded data)**

Lepton+jets top selection

Using the full statistics currently validated (0.84pb^{-1}) and **requiring at least 1 jet b-tagged** (secondary vertex tagger with ≥2 tracks; high efficiency with ~1% fake rate)

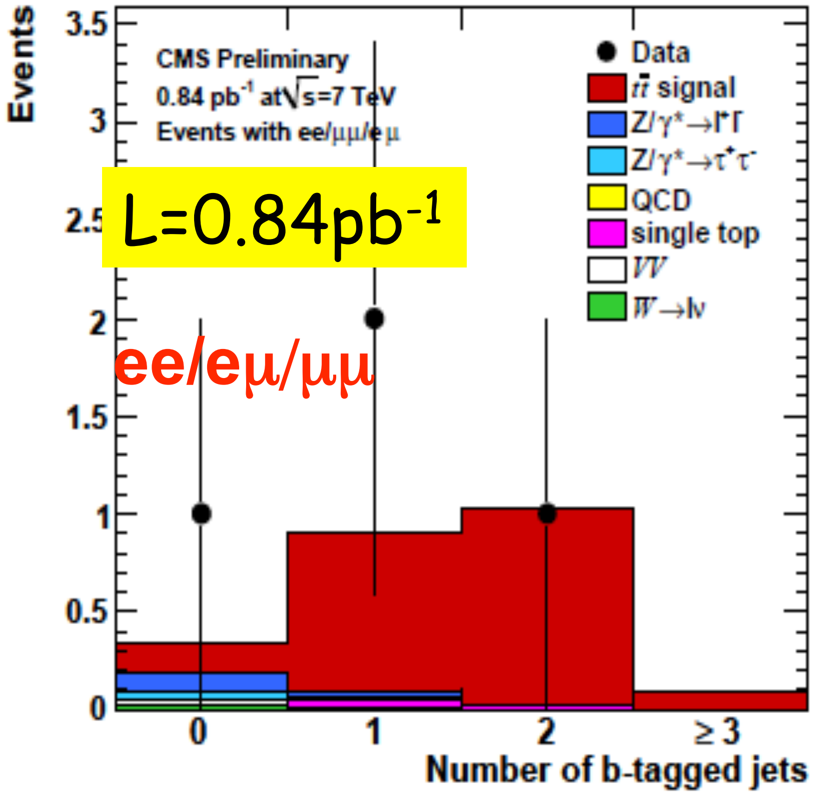


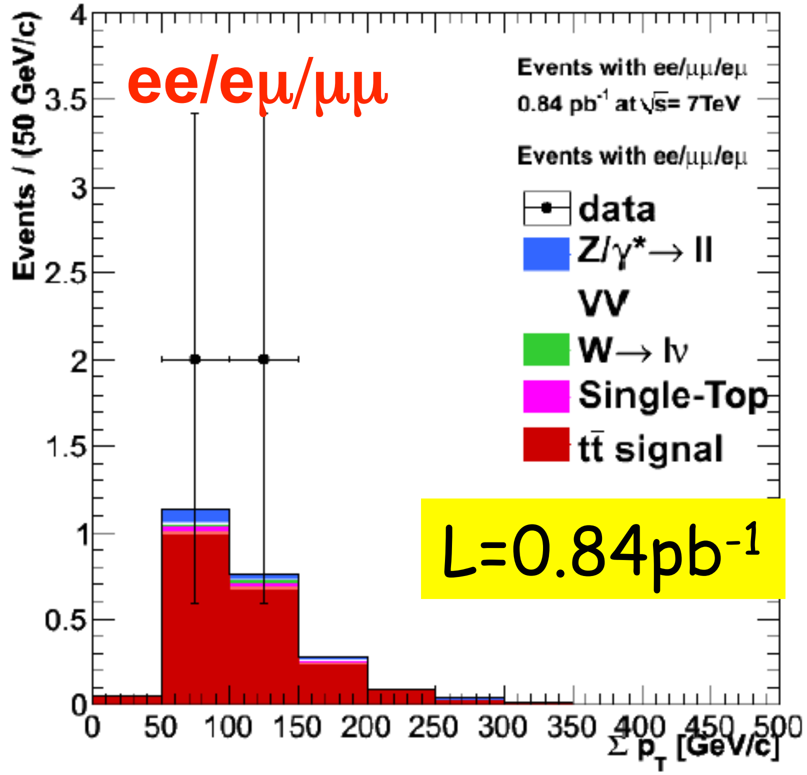
For N(jets)≥3 we count **30 signal candidates over a predicted background of 5.3**

t-tbar events are observed in CMS at a rate consistent with NLO cross section, considering experimental (JES, b-tagging) and theoretical (scale, PDF, HF modelling, …) uncertainties.

Di-lepton+jets top selection

- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2



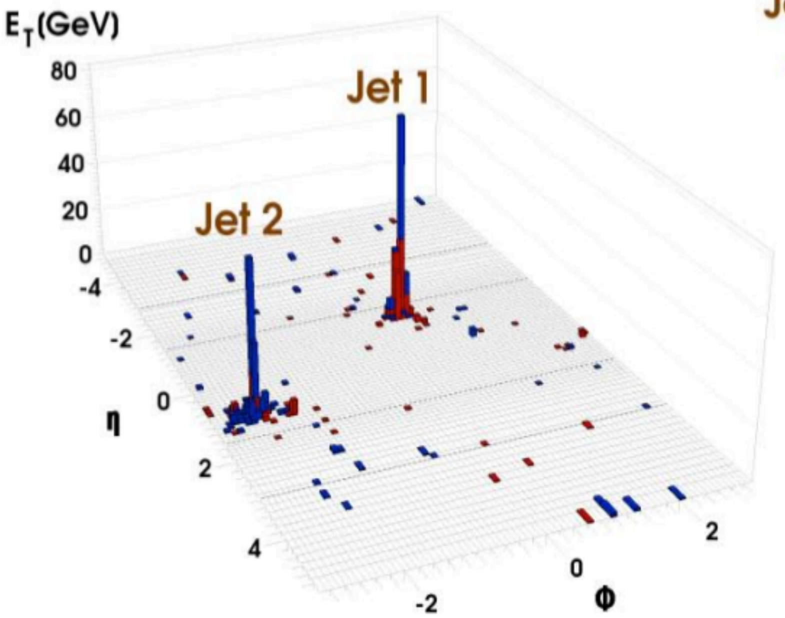


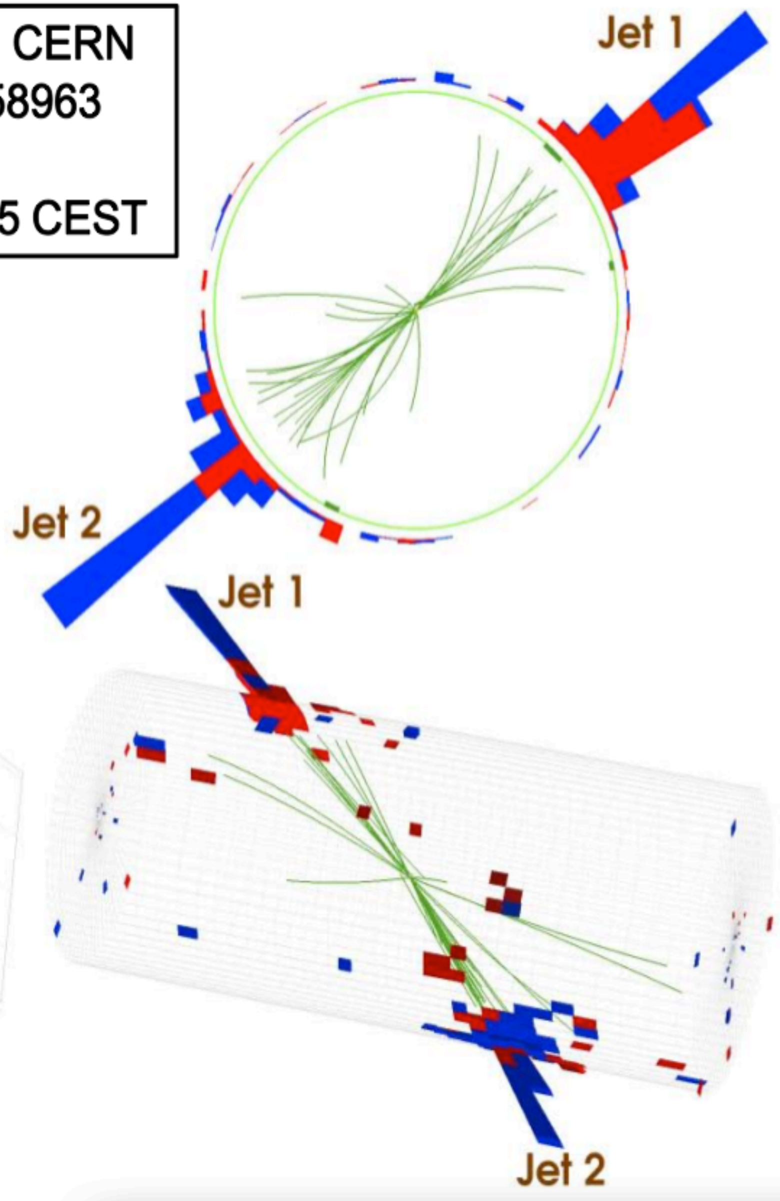
4 ttbar candidates (1eμ, 1ee, 2μμ) over a negligible background.
Top signal at LHC established.
First cross sections will come soon!

High Dijet Mass Event at 7 TeV

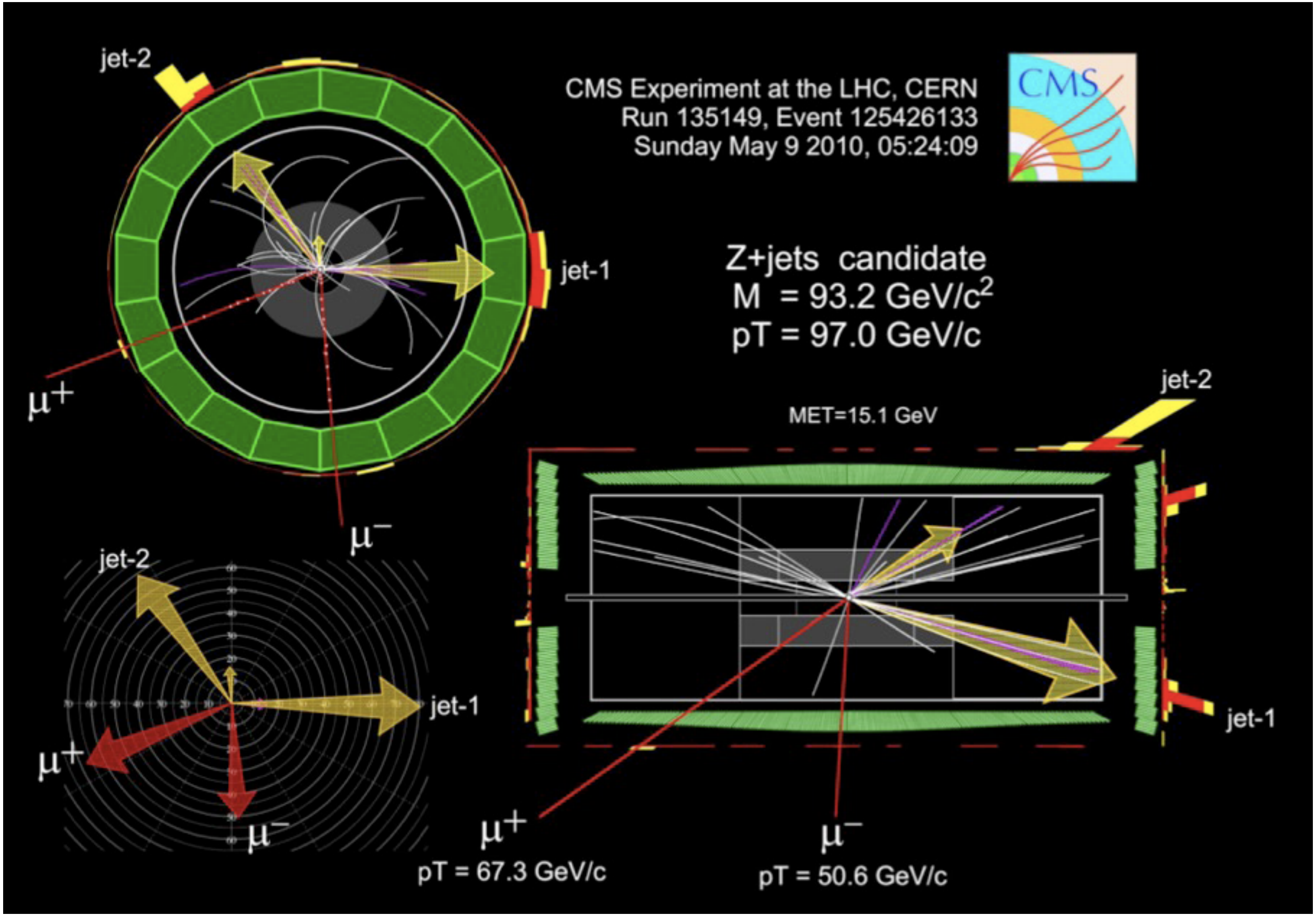
CMS Experiment at LHC, CERN
Run 133450 Event 16358963
Lumi section: 285
Sat Apr 17 2010, 12:25:05 CEST

Jet1 p_T : 253 GeV
Jet2 p_T : 244 GeV
Dijet Mass : 764 GeV

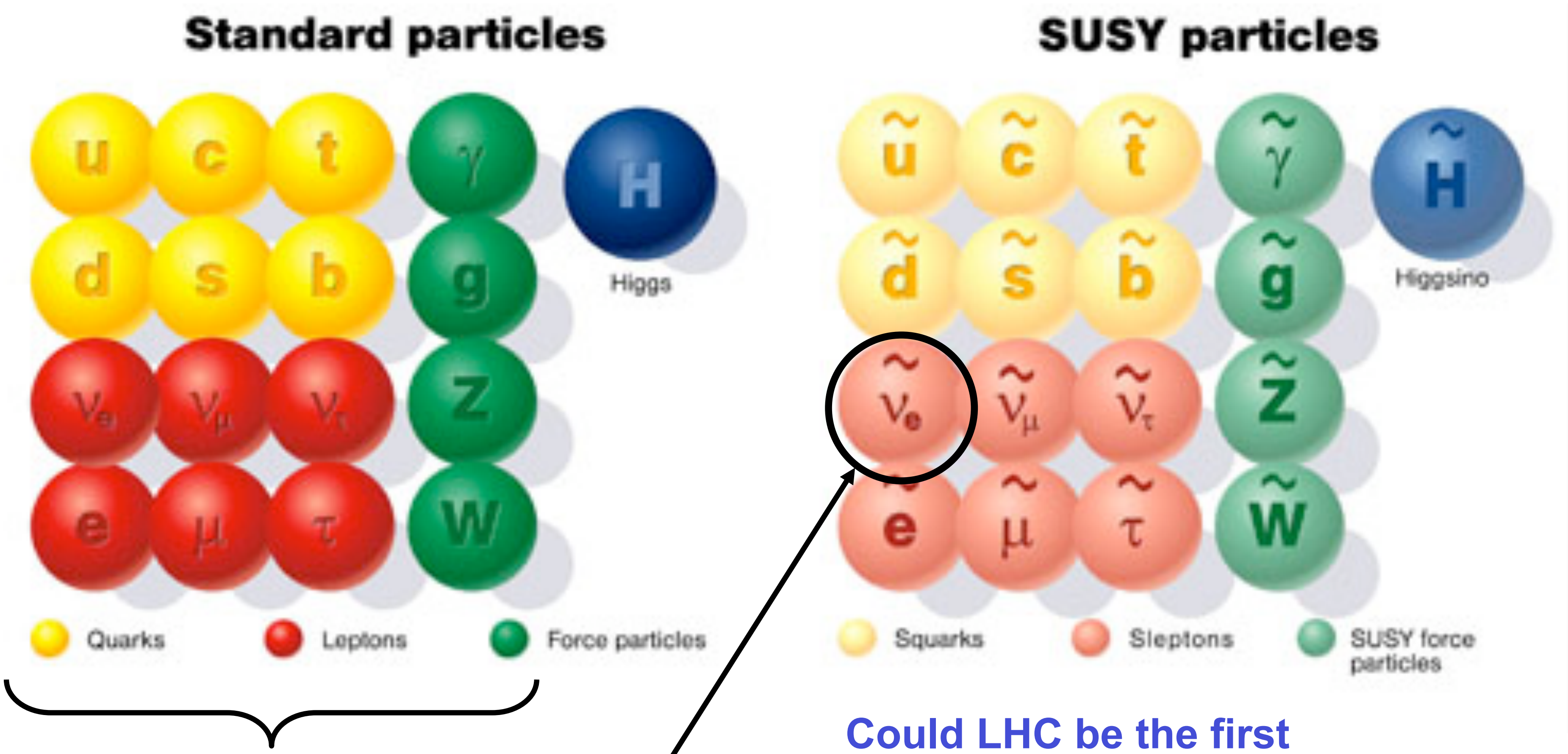




Z+jets candidate



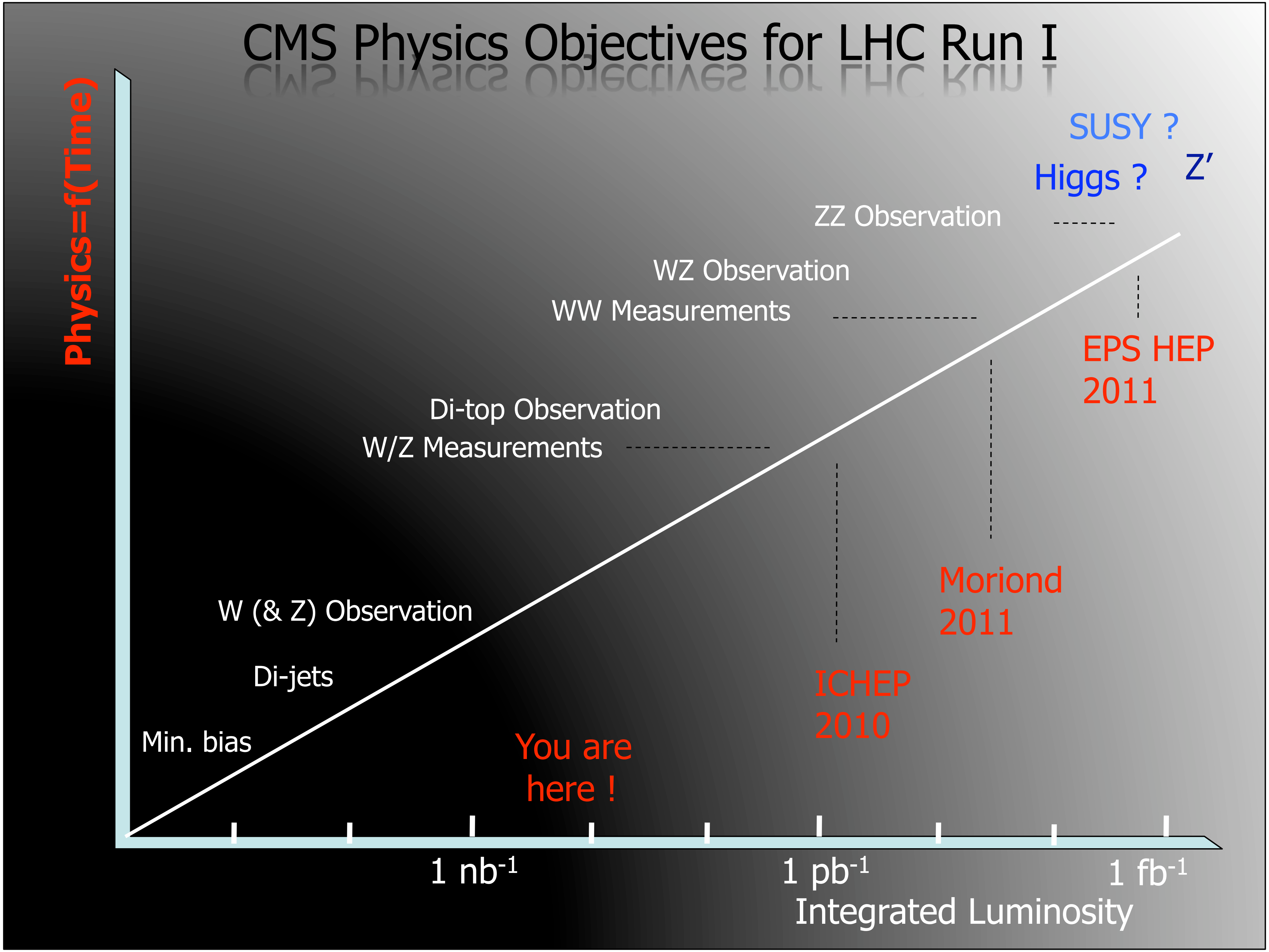
A quantum of physics – Supersymmetry?



The ‘Standard’ particles which have been discovered

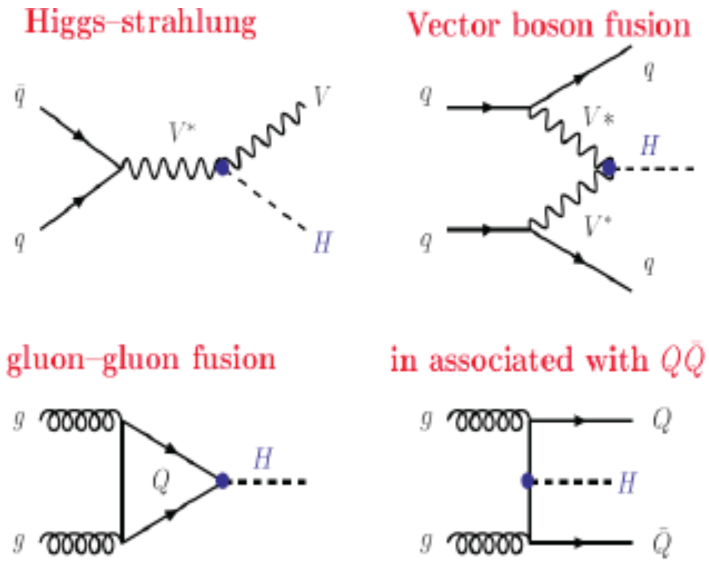
Possible candidate for the dark matter particle

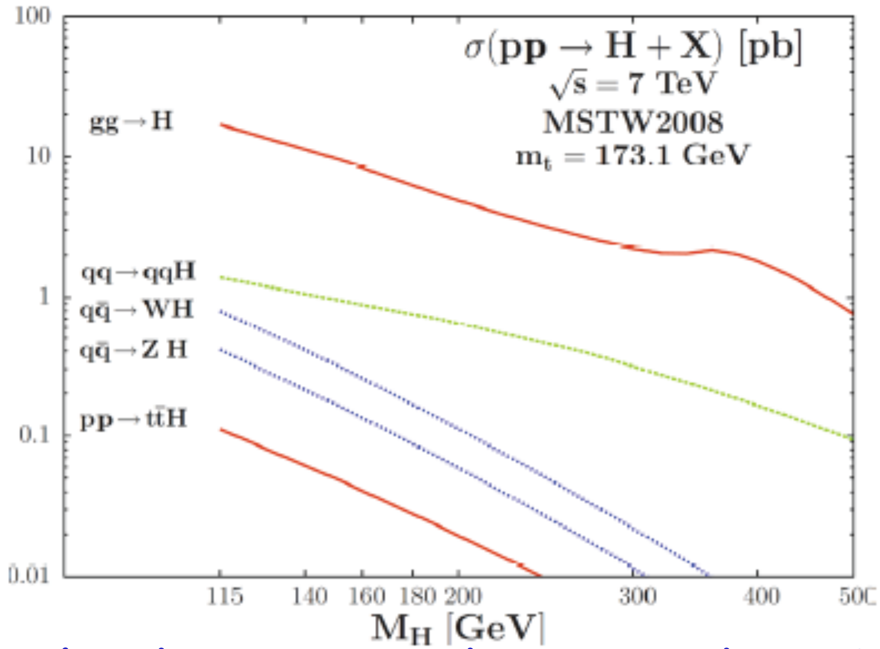
Could LHC be the first accelerator to discover a corresponding world of ‘Supersymmetric’ particles?


CMS Physics Objectives for LHC Run I
Physics=f(Time)
SUSY ?
Higgs ?
Z′
ZZ Observation
WZ Observation
WW Measurements
EPS HEP 2011
Di-top Observation
W/Z Measurements
Moriond 2011
W (& Z) Observation
Di-jets
ICHEP 2010
Min. bias
You are here !
1 nb-1
1 pb-1
1 fb-1
Integrated Luminosity

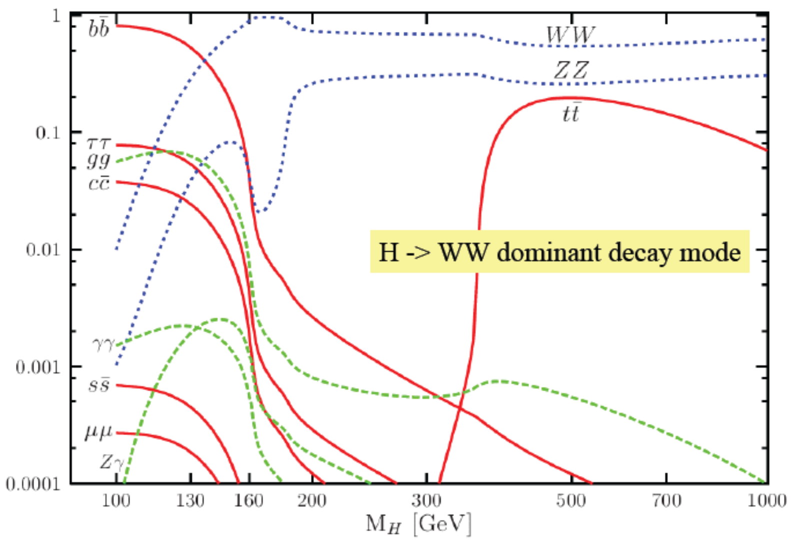
Backup slides

Higgs Production and Decay @ 7 TeV





As at Tevatron, gg -> H is the dominant production mode at LHC

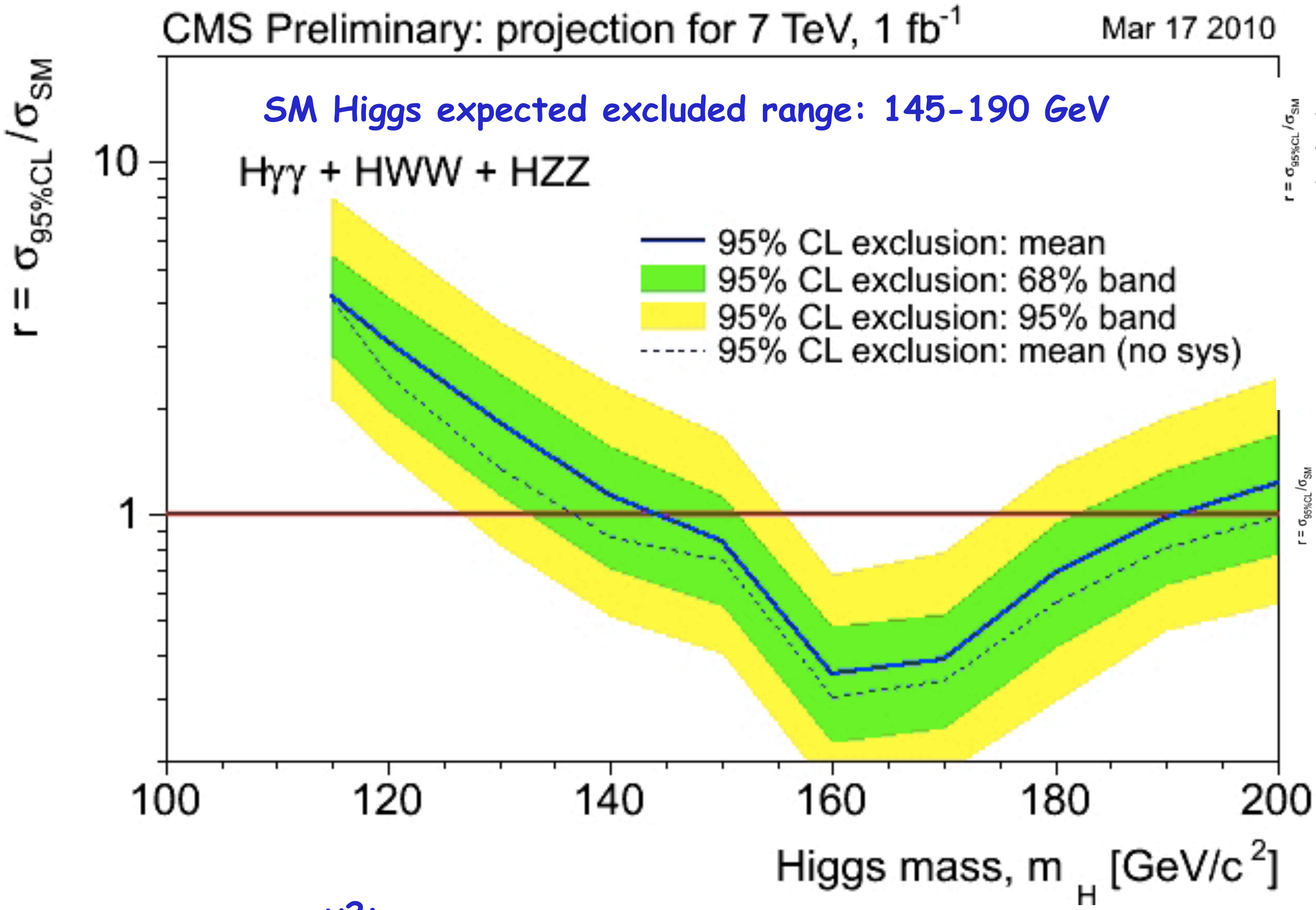


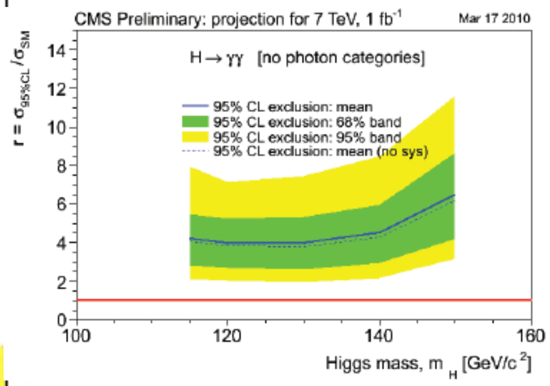
H->WW dominant decay mode for m_H>140 GeV (BR ≈ 1 at m_H = 160 GeV)

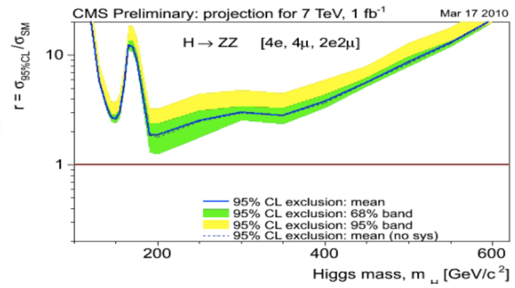
- ✓ bb suffers from the huge QCD background
- ✓ τ+τ- is promising at low m_H values
- ✓ γγ is relatively easy to detect, but very low BR
- ✓ ZZ has a lower BR than WW, but a clearer signature

SM Higgs Boson

Inclusive Channels for 7 TeV, $1fb^{-1}$

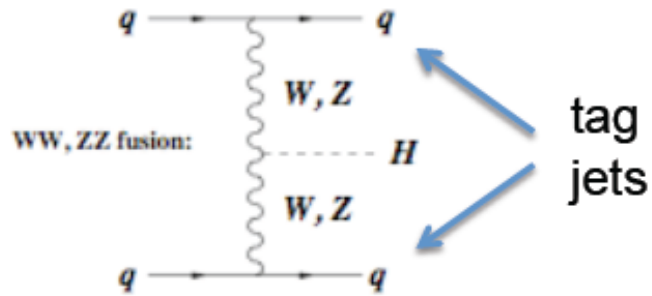






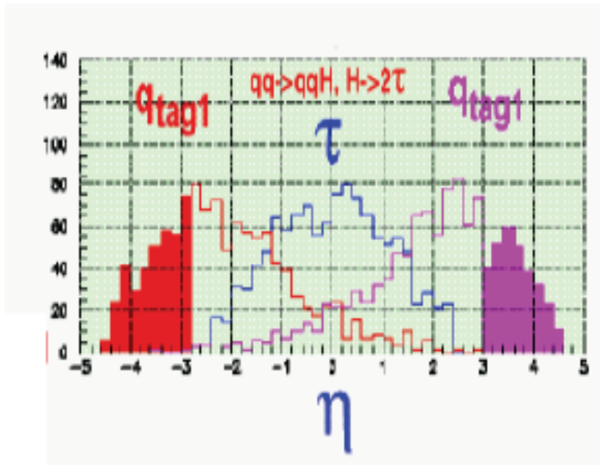
x2:
- SM Higgs expected excluded range approx: 140-200 GeV
- Discovery range approx: 160-170 GeV

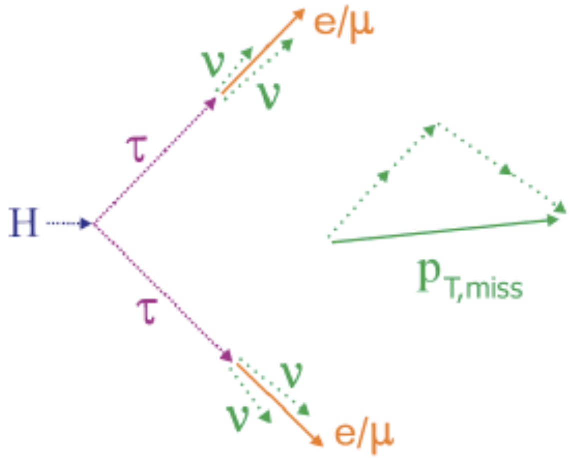
VBF $H \rightarrow \tau^+\tau^-$



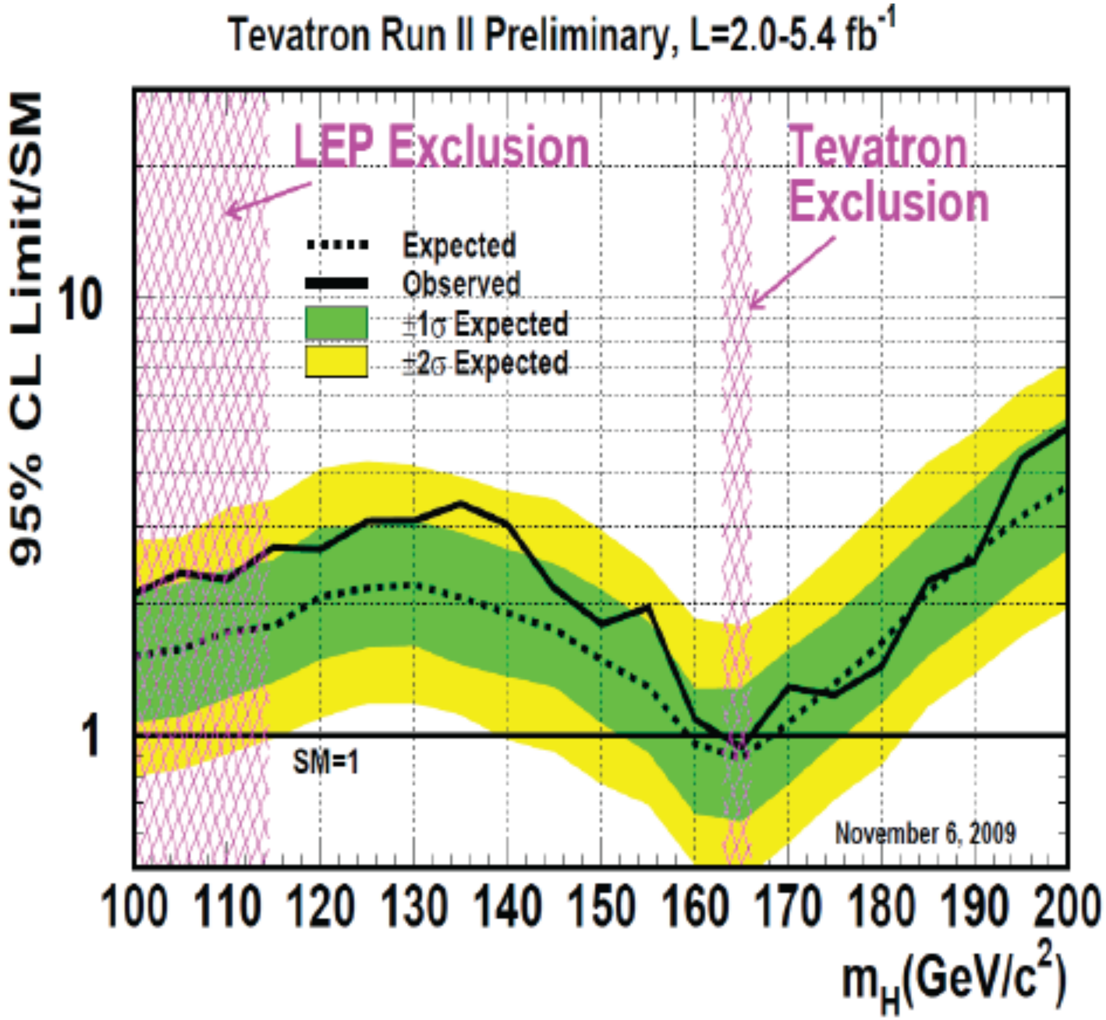
$H \rightarrow \tau^+\tau^-$ is promising at low m_H values

- ❑ 3 final states: lepton-lepton, lepton-hadron, hadron-hadron
- ❑ Signature:
  - ✓ 2 leptons or τ-jets in the central region
  - ✓ MET
  - ✓ 2 forward tag jets in opposite hemispheres (used as tag)
- ❑ The invariant mass $M(\tau\tau)$ can be calculated in the collinear approximation: ν's collinear to τ's
- ❑ Backgrounds:
  - ✓ QCD, reduced with the Central Jet Veto
  - ✓ W/Z + jets
  - ✓ $Z/\gamma^* \rightarrow \tau^+\tau^-$, estimated from $Z \rightarrow \mu^+\mu^-$
  - ✓ tt suppressed by performing b-jet ID





SM Higgs Boson at Tevatron



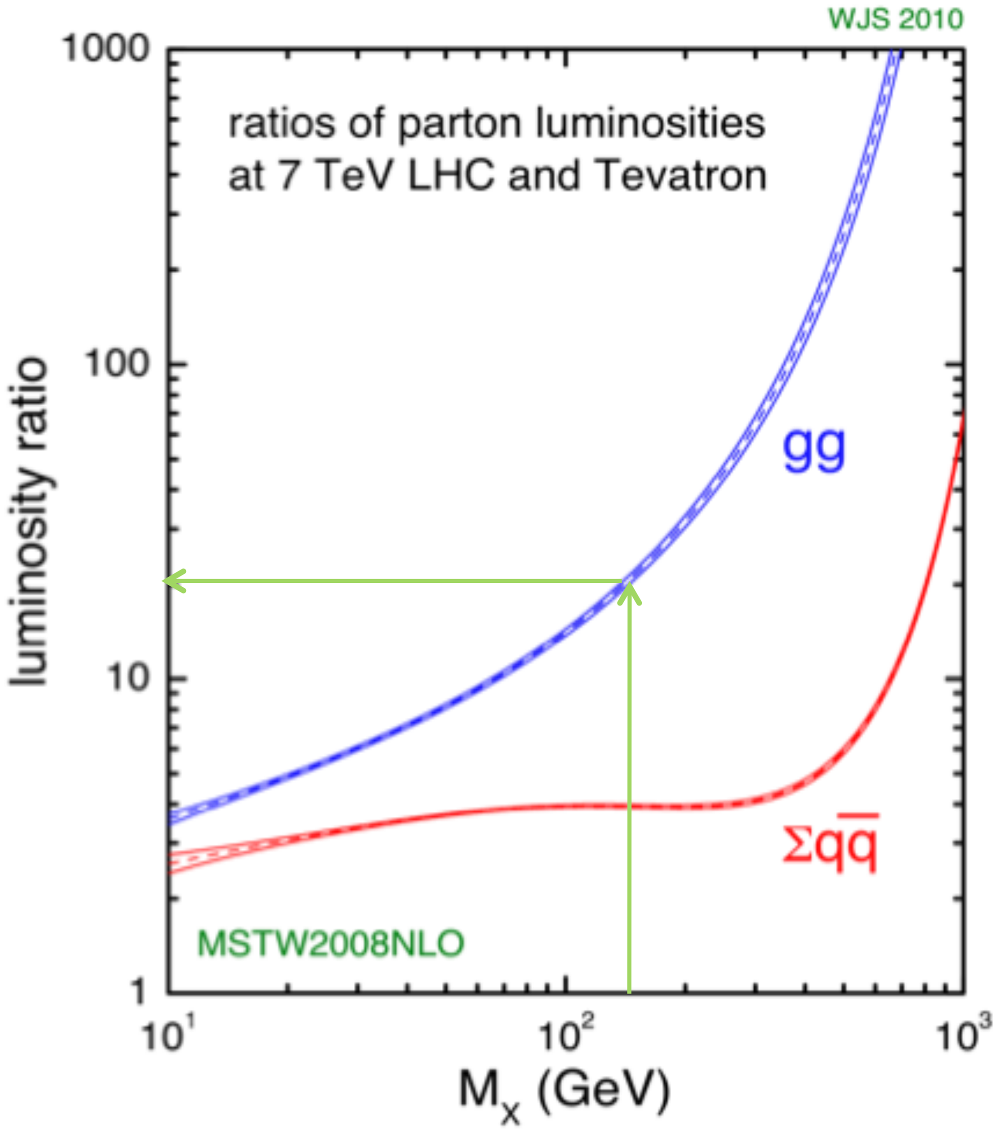
arXiv:1001.4162

LHC & Tevatron : A Comparison

For M_X > 140 GeV:

- ❑ gg → H at 7 TeV > x15 that at Tevatron
- ➢ Higher rate for Higgs production

- ❑ Irreducible Higgs background (WW, ZZ) originate from qqbar which rises relatively slowly
- ⇒ S/N rises , LHC competitive @ $1fb^{-1}$



For M_X < 140: slow rise in qqbar

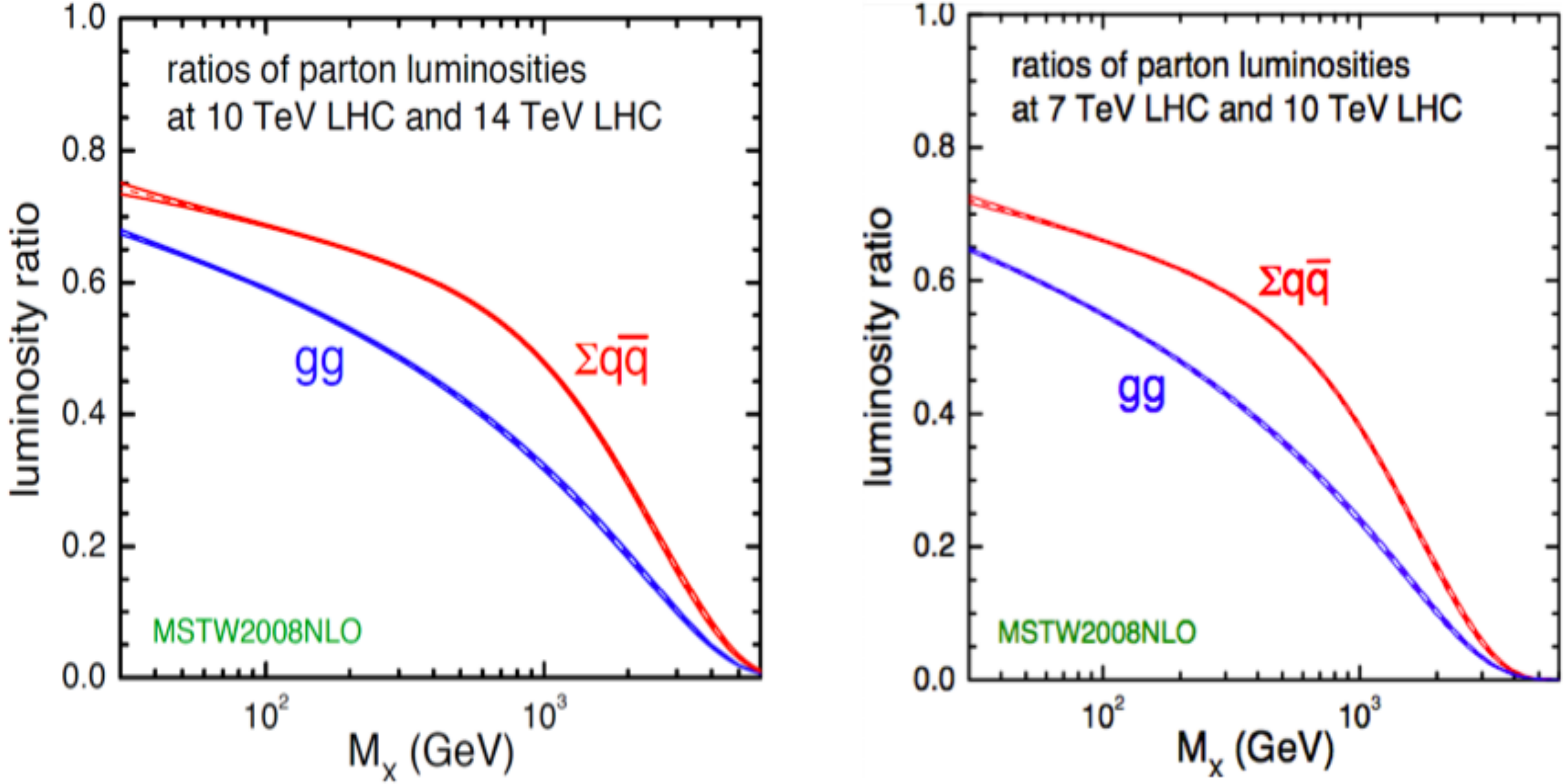
- ❑ Higgstrahlung (pp → VH) rate at 7 TeV not much larger than Tevatron
- ❑ Major backgrounds are W/Zbbbar & ttbar which rise sharply due to rapid rise in gg ⇒ smaller rate & S/N
- ❑ gg → H → γγ favored in production but Br(H → γγ) ≈ 0.2%
  ⇒ tiny signal over large QCD γγ

Conclusions

- The full CMS Detector was operational for the first LHC beams in 2008
- CMS could profit from extensive Cosmic Data taking campaigns in 2008 and 2009 for commissioning
- Data taking with LHC pilot runs in December 2009 was a great success, with performances validated within hours, and extensive analyses performed within one day !
- The experiment currently runs with LHC collisions at $\sqrt{s}$ = 7 TeV at a peck luminosity of ~ 2×10^{29} $cm^2 sec^{-1}$ with 13 bunches… and ≈ 100 EWK Boson candidates observed !
- A first production of physics results (EWK, QCD, …) is expected by ICHEP 2010 (with 1-10 pb^{-1} integrated luminosity ?)
- Di-boson observation and first significant constraints (or hints) on the SM Higgs boson are expected in 2011

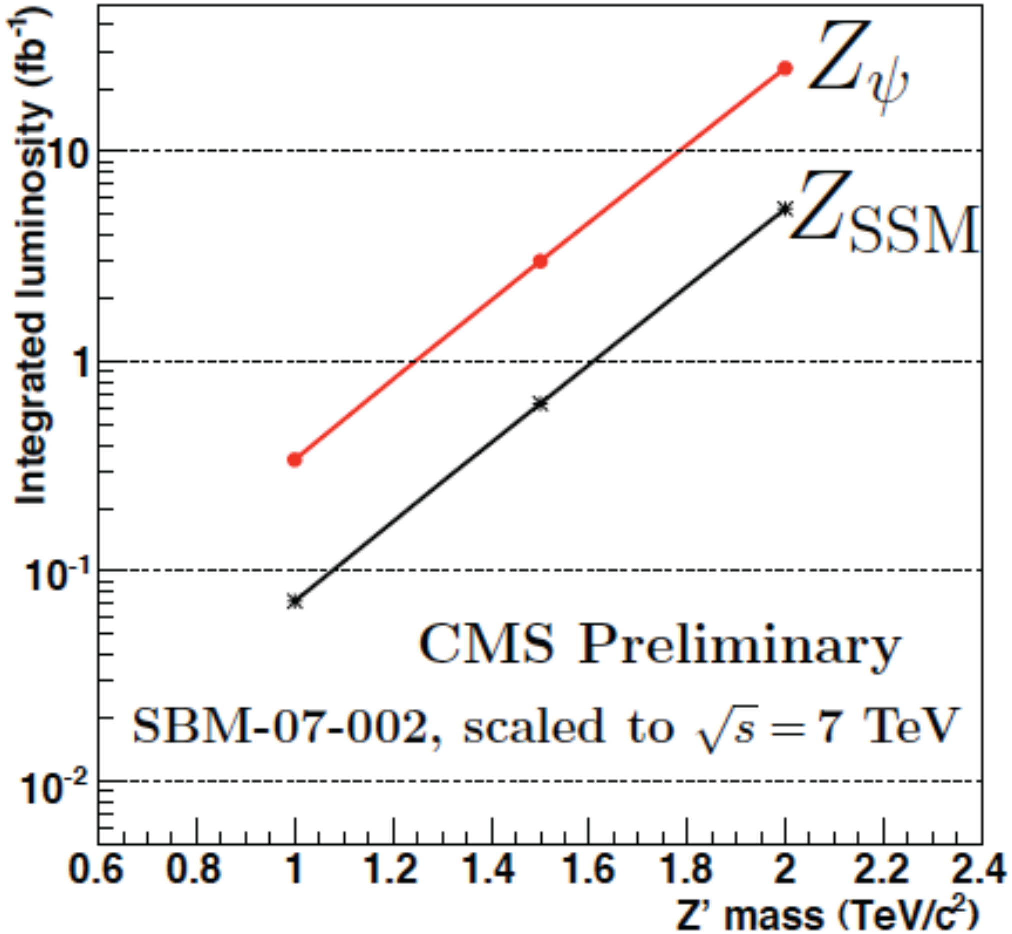
Special thanks to Simone Gennai for providing me some very useful slides on Particle Flow.

Parton Luminosities



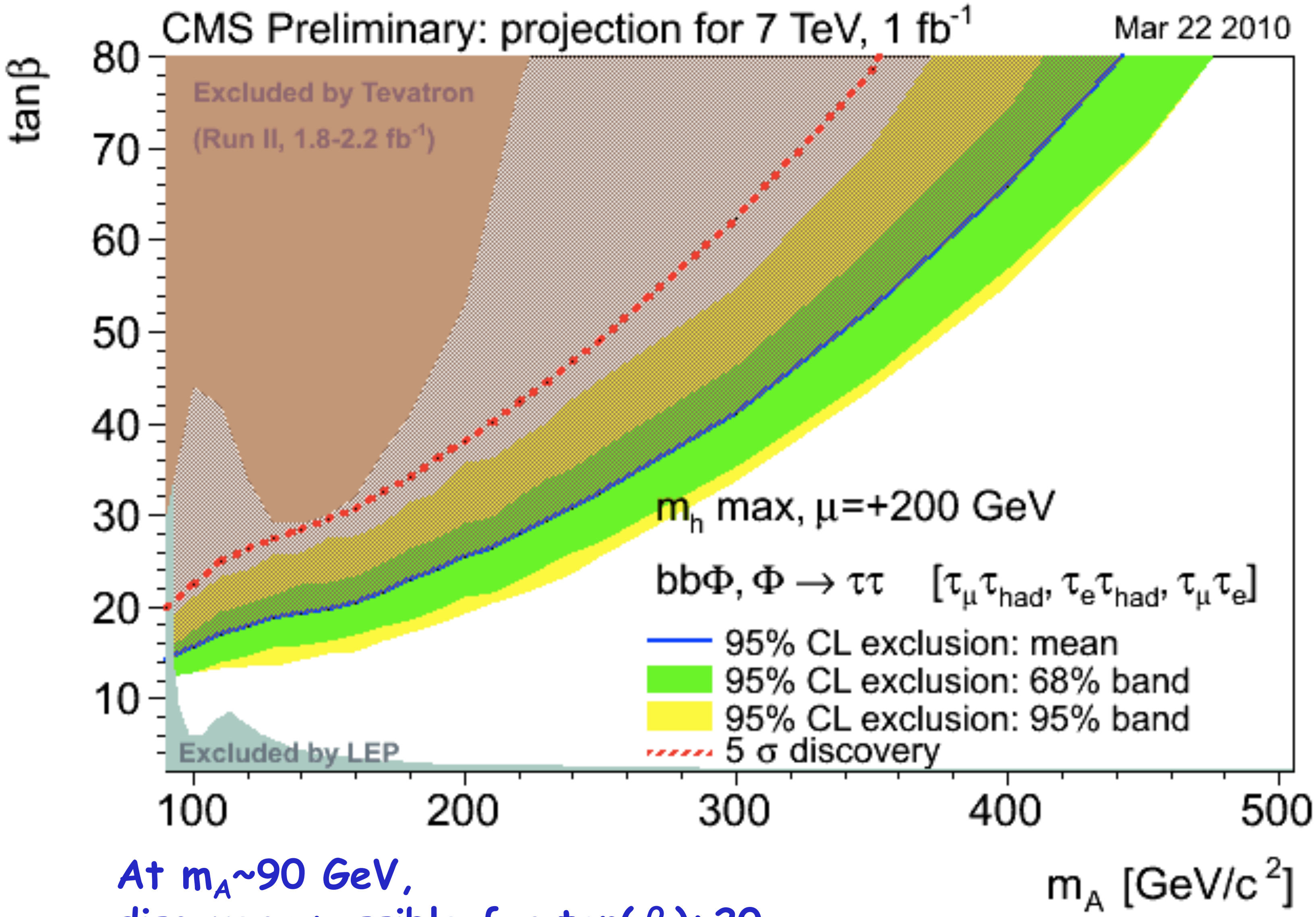
High mass dilepton resonances

5σ discovery reach as a function of mass
$\mu\,\mu$ channel
(scaled from 10 TeV to 7 TeV)



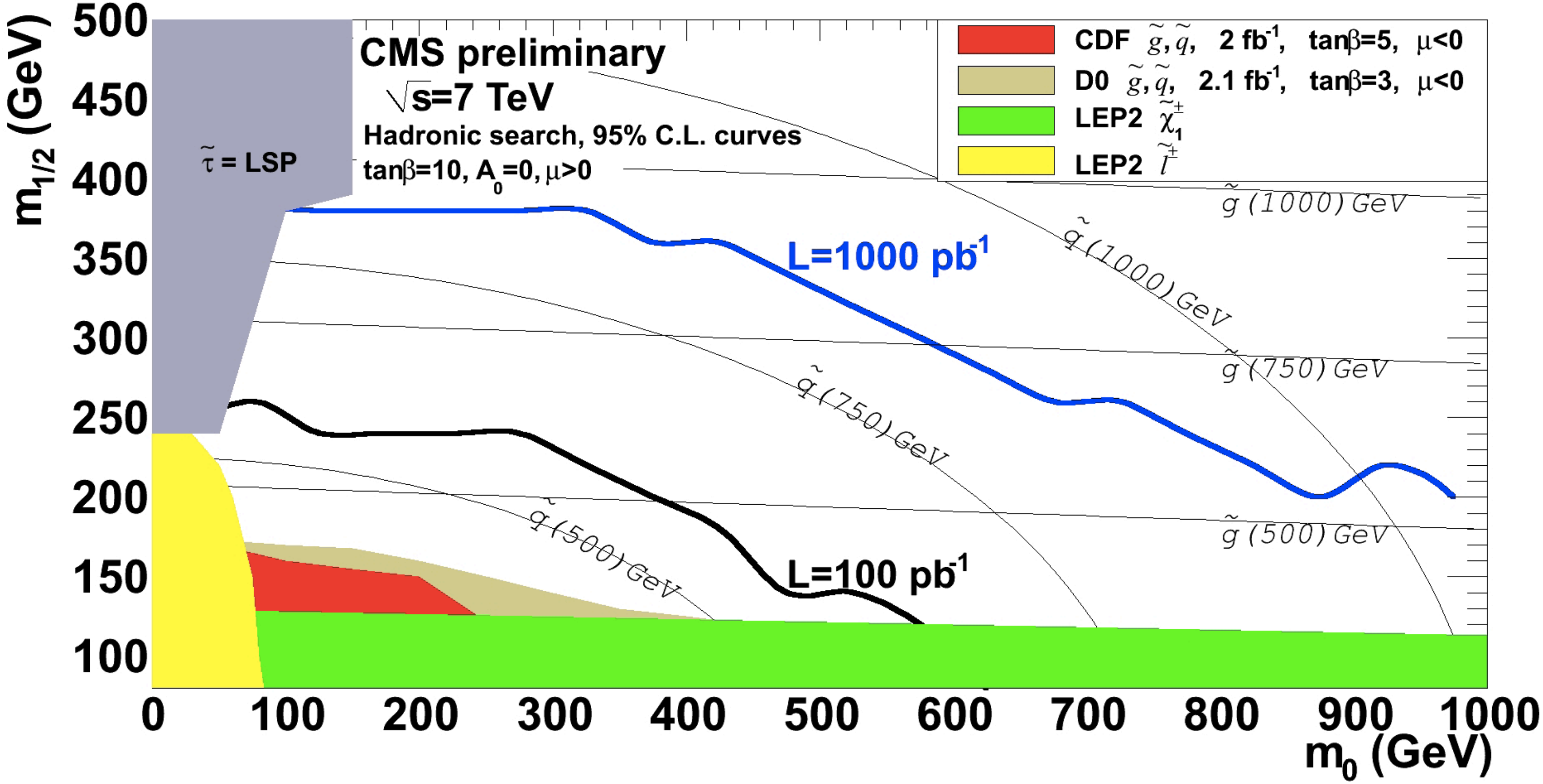
Already sensitivity at 1 TeV with ~ 100 pb^{-1}

MSSM Higgs Boson: pp → bbΦ, Φ →ττ



At m_A~90 GeV,
discovery possible for tan(β)>20,
exclusion for tan(β)~15

Supersymmetry – Jets + MET



95% exclusion limits for inclusive searches with jets and missing energy expressed in the mSugra parameter space
assumes 50% syst. uncertainty on backgrounds