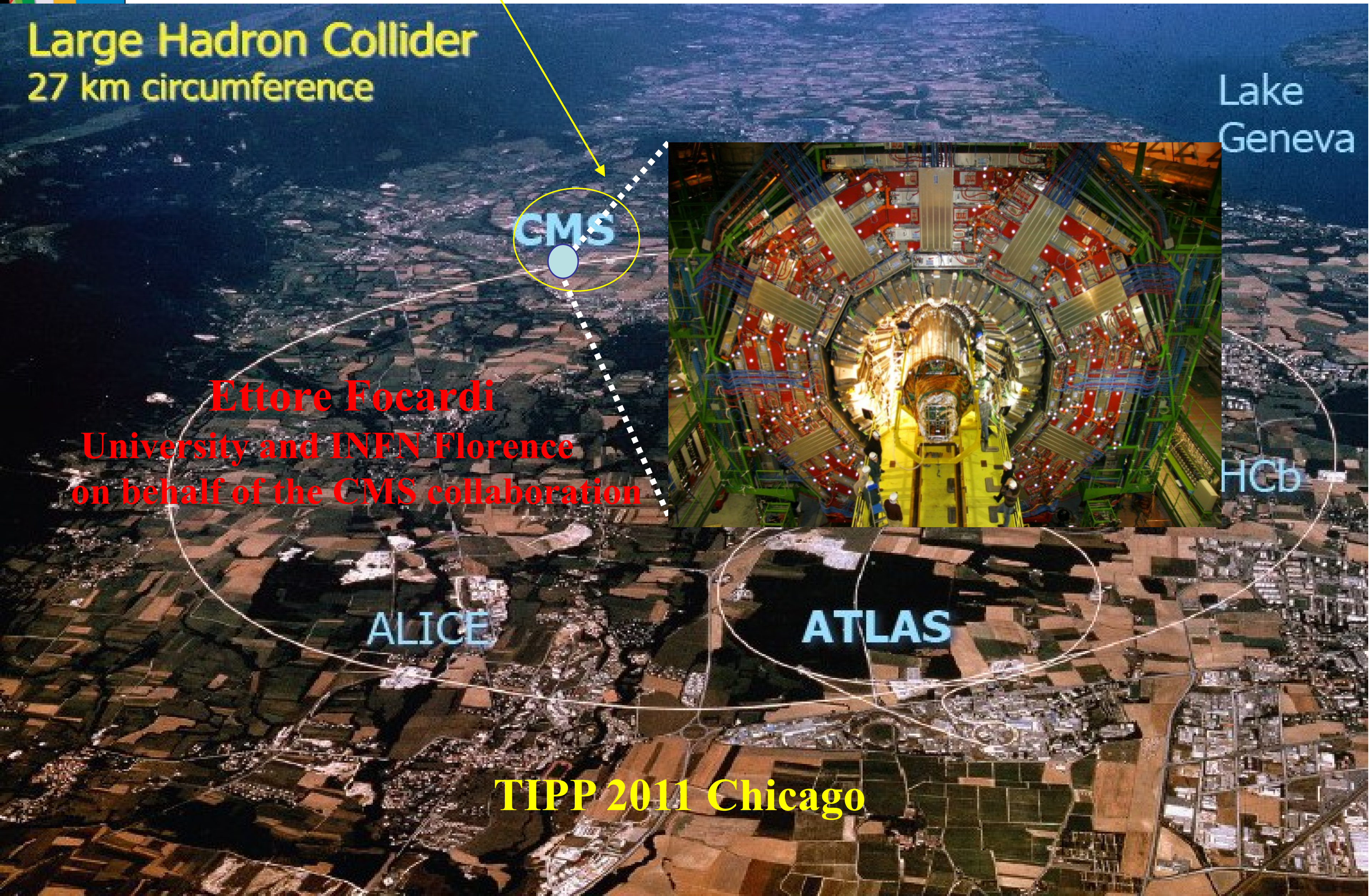
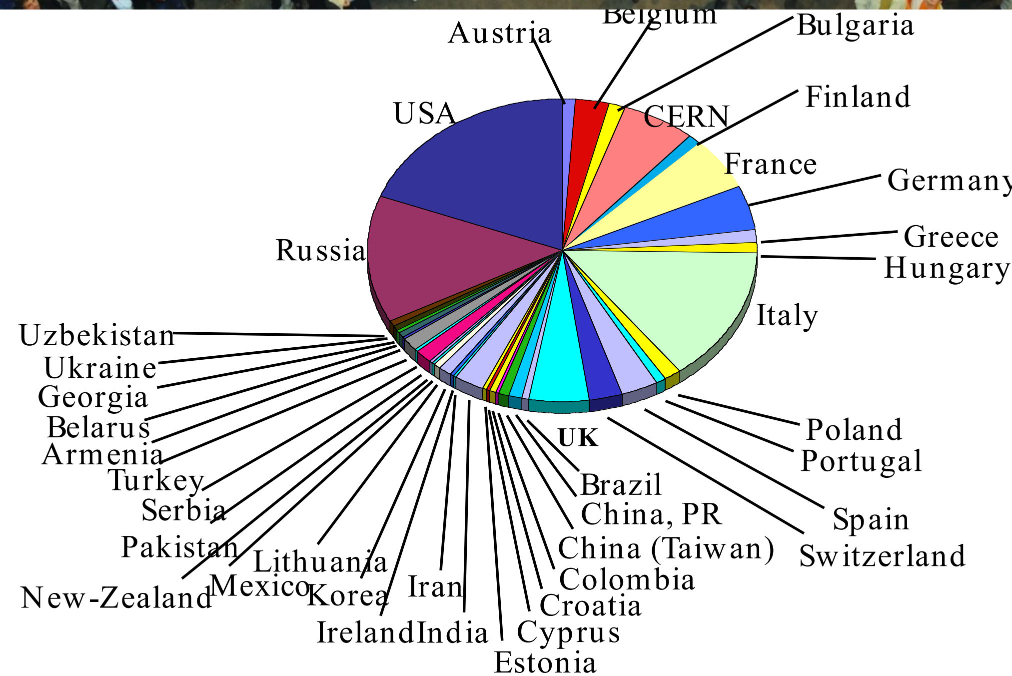
CMS detector status



Ettore Focardi
University and INFN Florence
on behalf of the CMS collaboration

TIPP 2011 Chicago

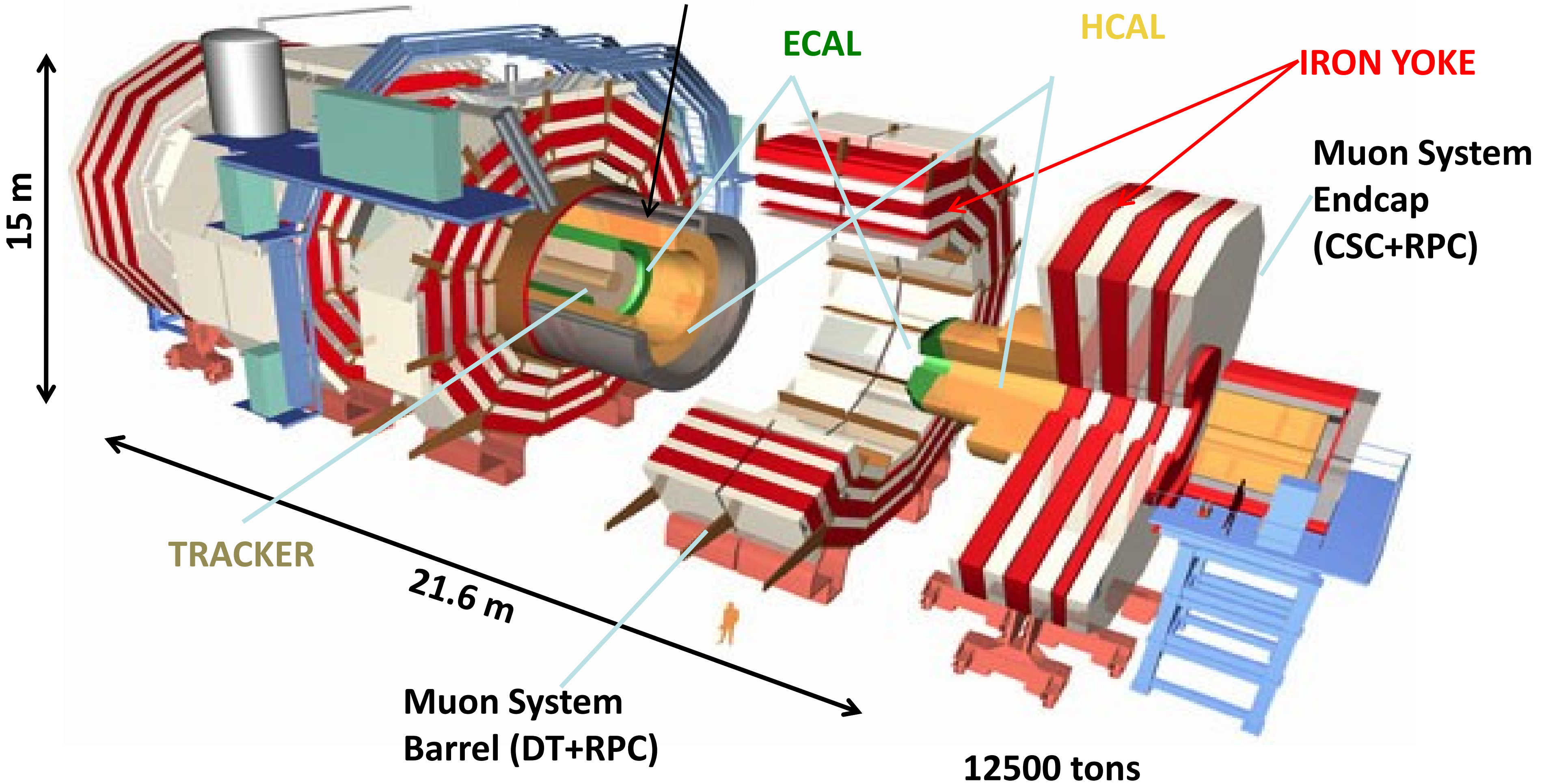
Outline



- Description of the CMS detector
- 2010, 2011 data taking
- Performance
- Conclusions

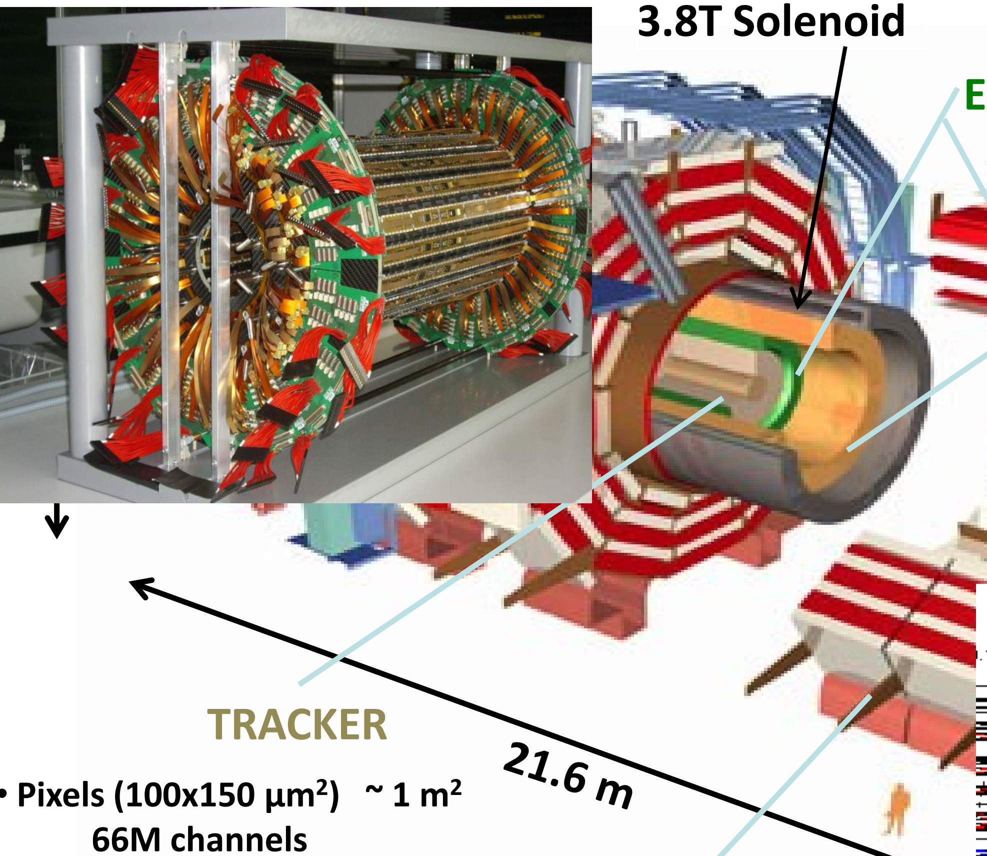
The CMS Detector

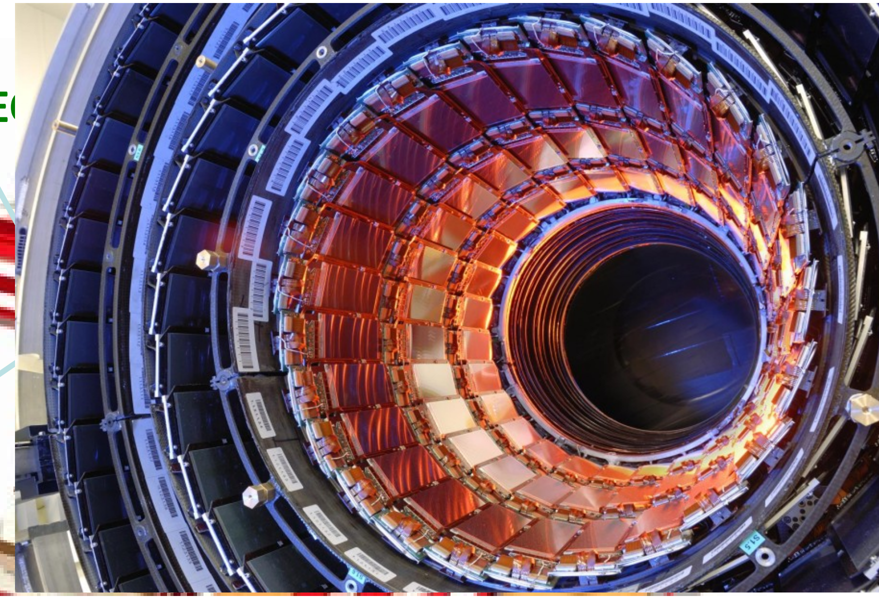
General purpose, hermetic experiment. Compact fully solenoidal design.
All central tracking and calorimetry inside a superconducting solenoid (B=3.8T)-> Large BL^2

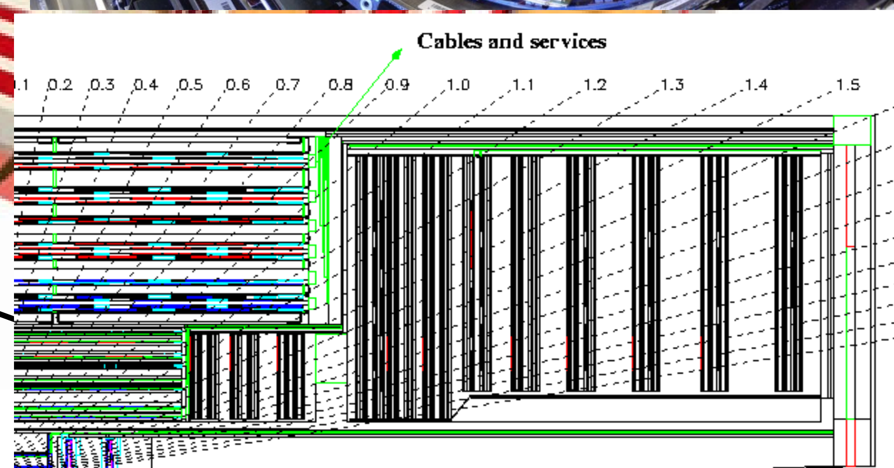


The CMS Detector

Pixel detector for precise reconstruction of secondary vertexes,
Strip Tracker with excellent tracking efficiency and resolution Δp/p<1% @ 100GeV

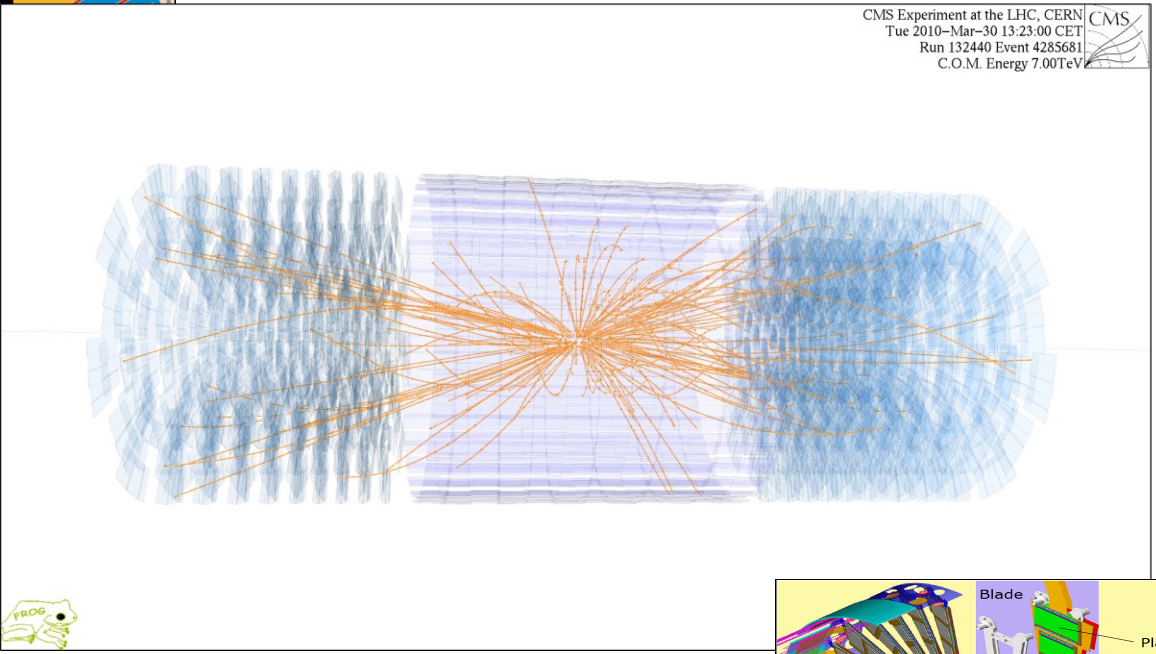




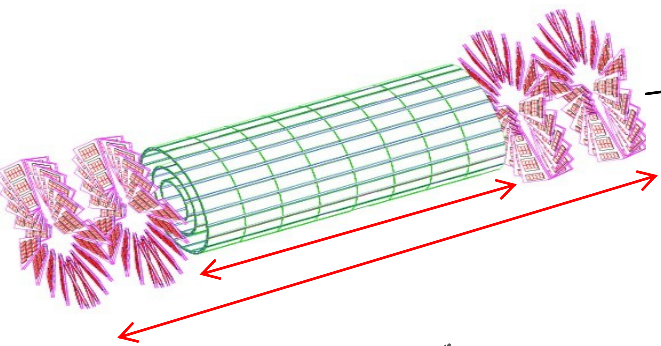


- Pixels (100x150 μm²) ~ 1 m²
  66M channels
- Silicon Microstrips ~210 m²
  (80-200 μm pitch)
  9.6M channels

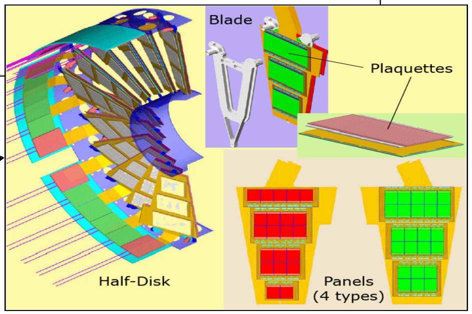
CMS Tracker



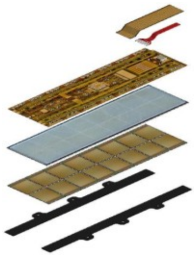
SST
15148 modules
24244 Silicon sensors
75000 readout chip
9.6 M readout channels
~25 M bondings
206 m² Silicon active area
29 modules types, 16 sensor designs
12 hybrids types
~150 km fibers/cables
1944 powers supply modules
356 control modules
37 K optical links
24 m³ volume



The CMS Pixel Detector



Panels of the Forward Pixel Detector



Modules of the Barrel Pixel Detector

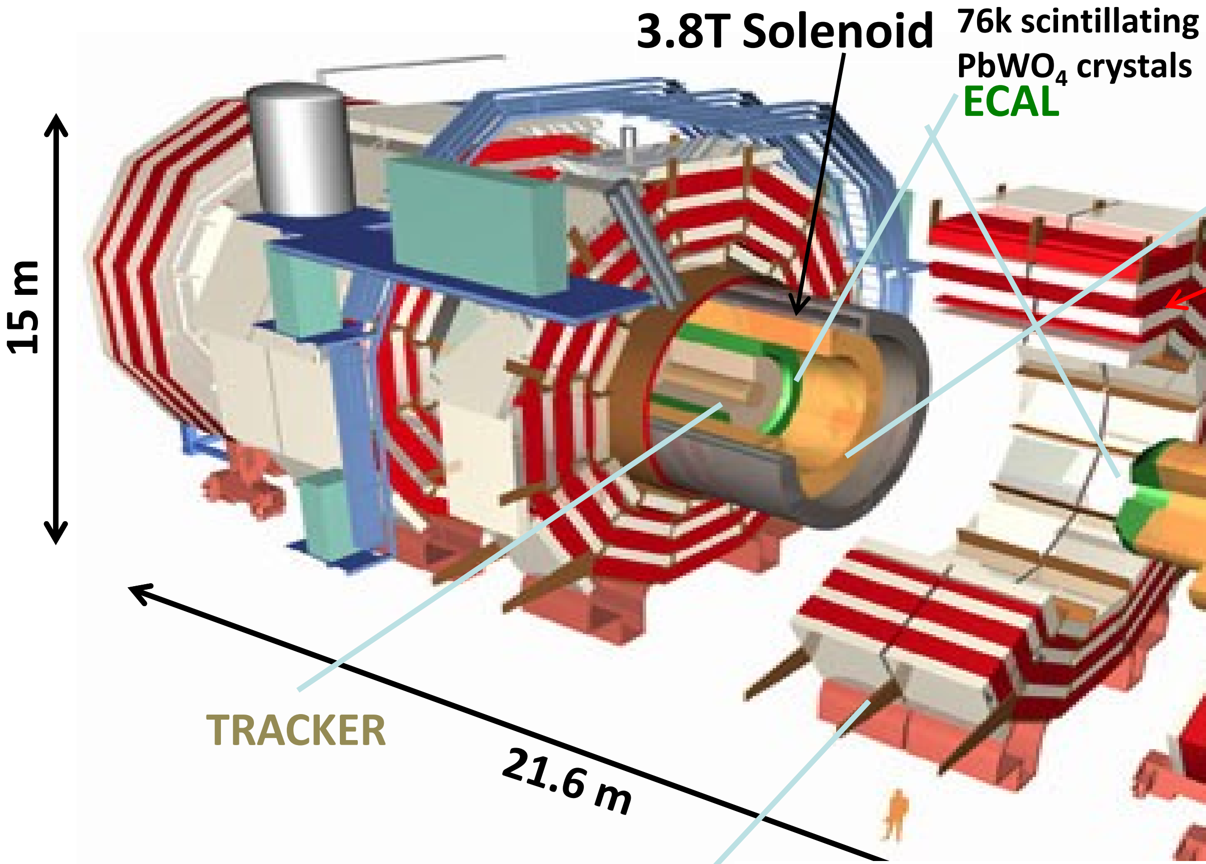
- Forward Pixel Detector (**FPix**) has **two** disks on each side at **34.5 cm** and **46.5 cm**
- FPix has **672** modules

- Barrel Pixel Detector (**BPix**) has **3** layers of radii **4.3 cm**, **7.2 cm** and **11.0 cm**
- BPix has **768** modules

- Total of **1440 modules**
  1.1 m² Si sensors

The CMS Detector

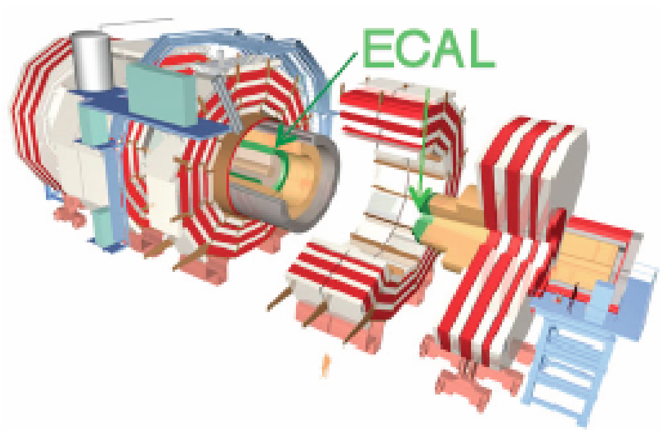
ECAL with high granularity, extremely good resolution, low noise, good uniformity/intercalibration

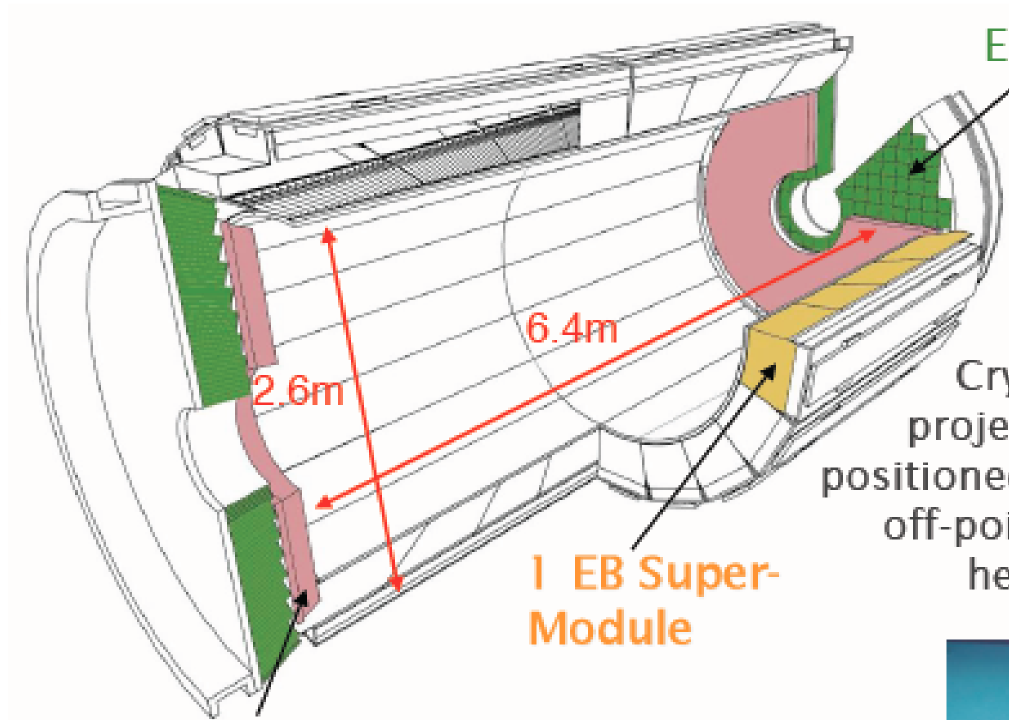


Energy resolution: (~ 0.5% @ ET ~ 50 GeV)

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E}}\right)^2 + \left(\frac{0.12}{E}\right)^2 + (0.3\%)^2$$

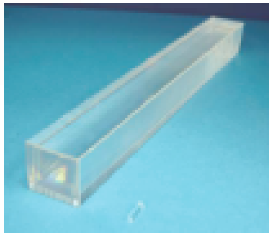
CMS Electromagnetic calorimeter





Homogenous $PbWO_4$ Crystal Calorimeter + Pb-Si Preshower

Crystals are projective and positioned slightly off-pointing for hermeticity



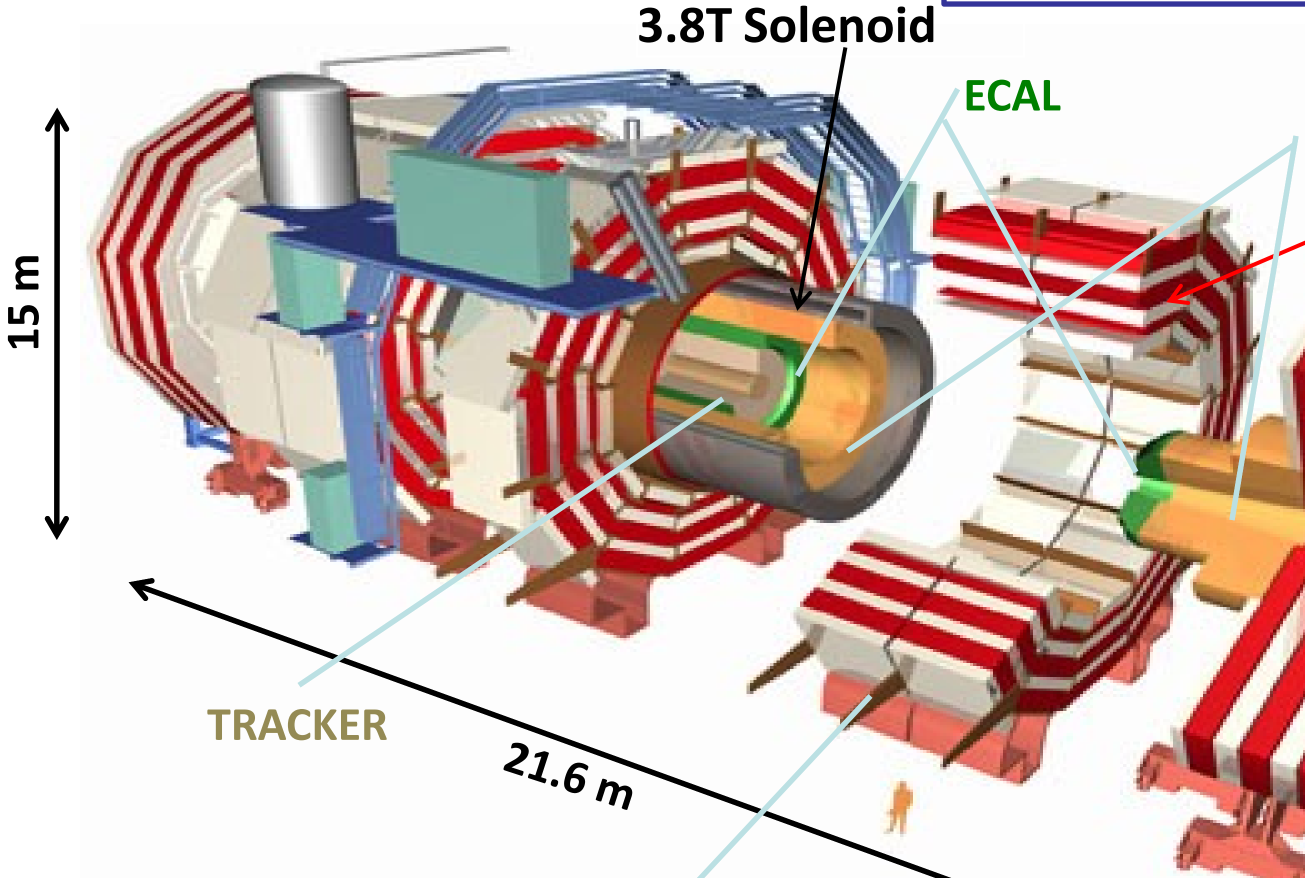
BARREL (EB) $|\eta|<1.48$
61200 crystal
(2.2 x 2.2 x 23 cm³) - $26X_0$
36 Super Modules
Avalanche Photo Diodes

ENDCAP (EE) $1.48 <|\eta|< 3.0$
4 Dee's
14648 crystals
(3 x 3 x 22 cm³) – $25X_0$
Vacuum Photo Triodes

PRESHOWER (ES) $1.6<|\eta|<2.6$
4 Planes
Total of 137216 Si strips
Pb/Si - $3X_0$

The CMS Detector

HCAL compact, hermetic, good segmentation and coverage ($|\eta|<5.2$)
Jet angular resolution ~ 20 (30) mrad in φ (θ) at ET $\geq$ 100 GeV



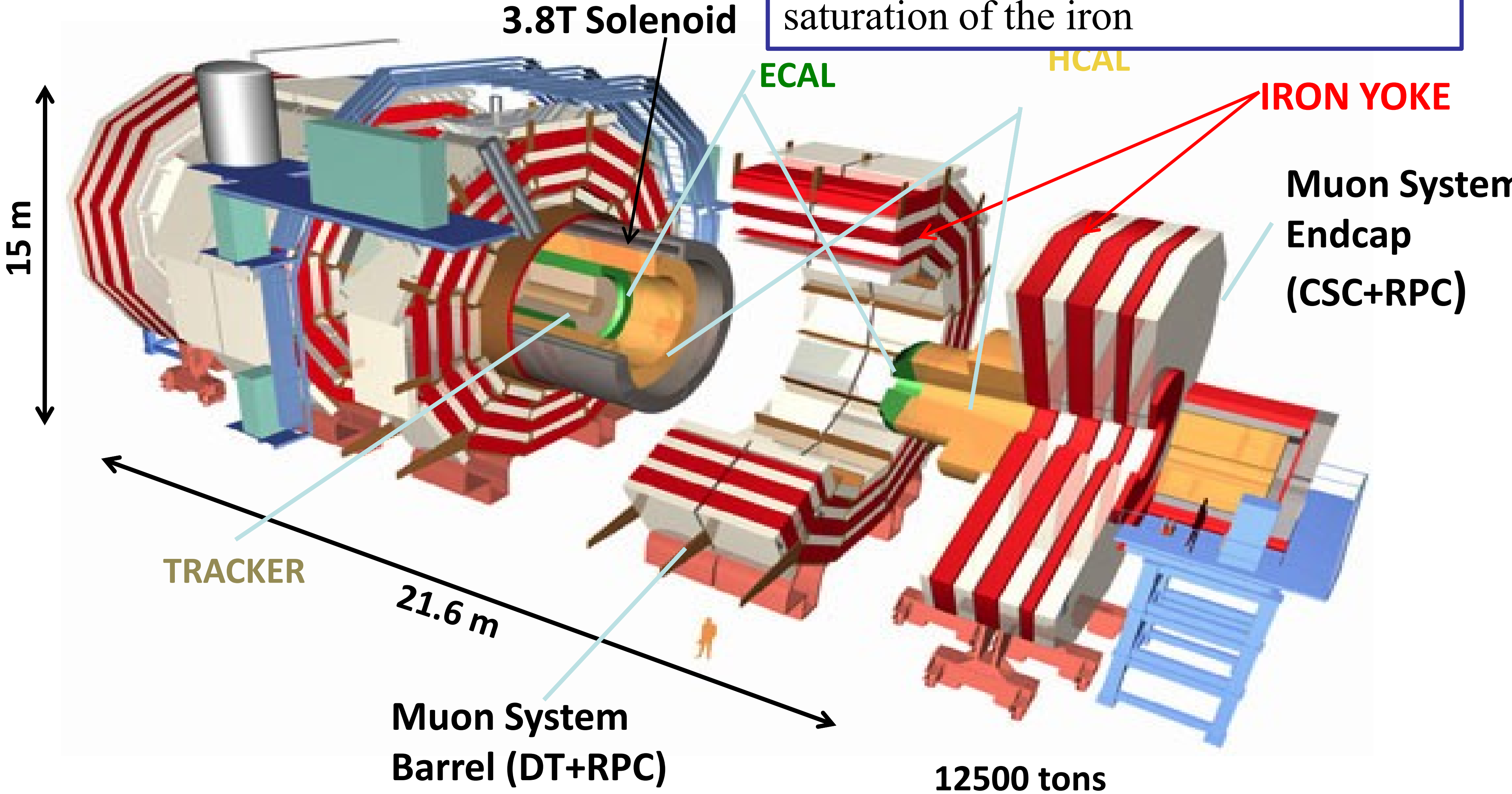
Scintillator/brass
Interleaved tile cal.

Jet transverse energy resolution
barrel ECAL+HCAL only

$$\left(\frac{\sigma}{E_T}\right)^2 = \left(\frac{1.25}{\sqrt{E_T}}\right)^2 + \left(\frac{5.6}{E_T}\right)^2 + (3.3\%)^2$$

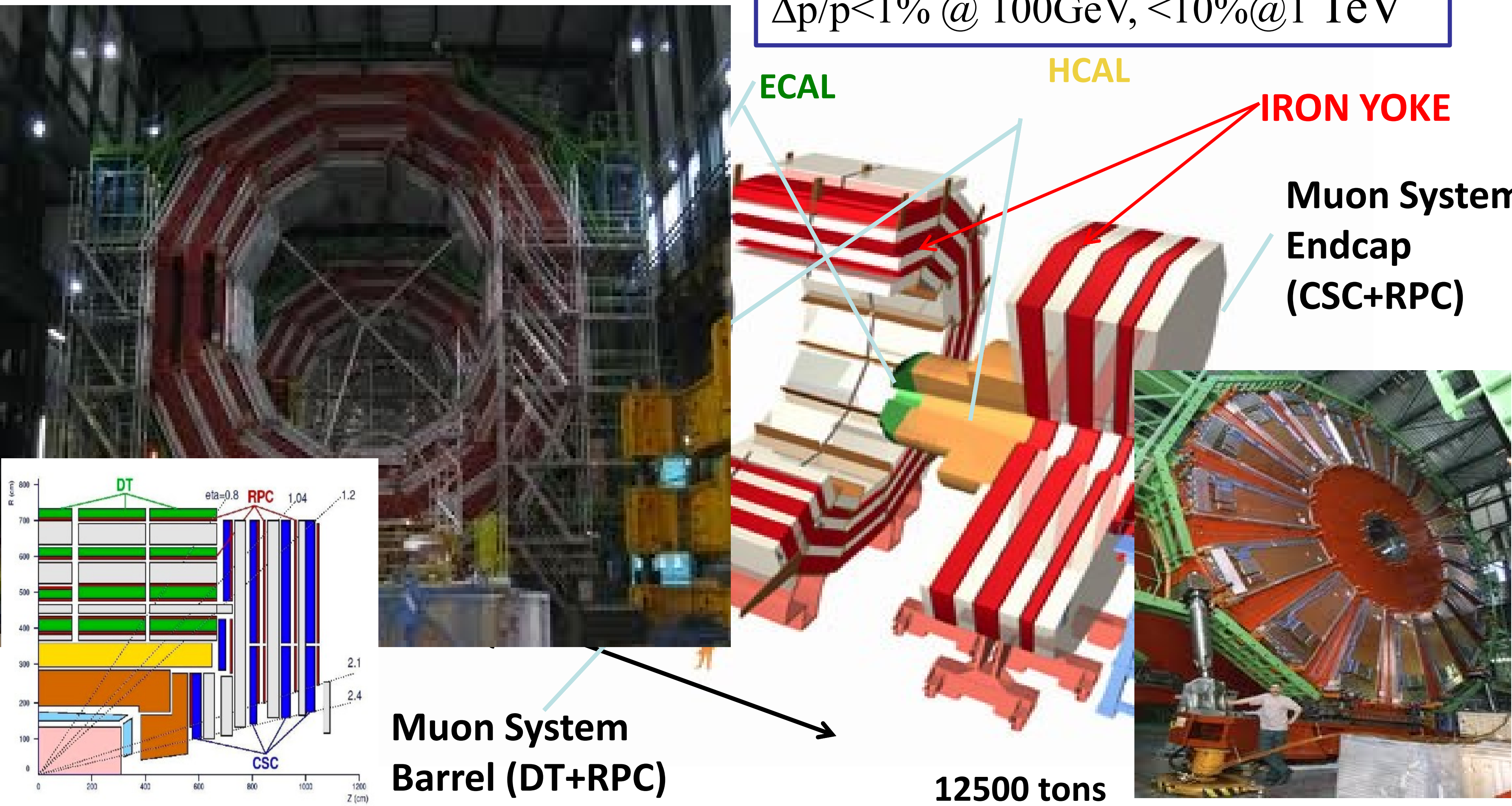
The CMS Detector

Iron yoke instrumented to host the muon spectrometer => Measurement of muon momentum thanks to the saturation of the iron



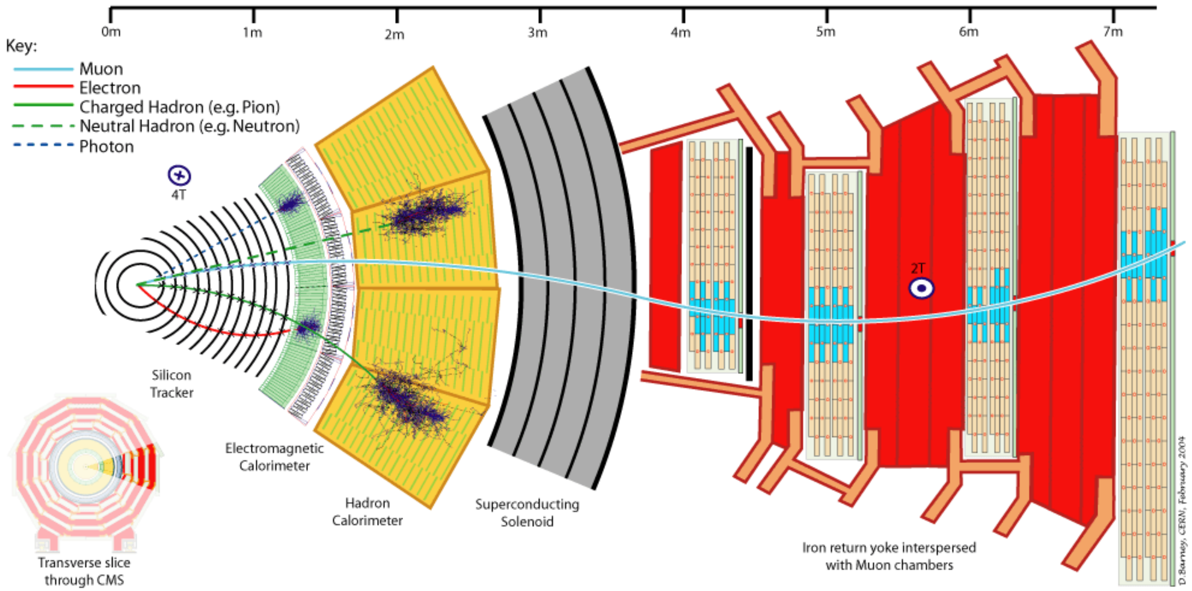
The CMS Detector

Robust, efficient and redundant muon triggering system (RPC+DT, CSC)
Efficient muon identification and reconstruction
$\Delta p/p < 1\%$ @ 100GeV, $< 10\%$@1 TeV



The CMS Detector

- Able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

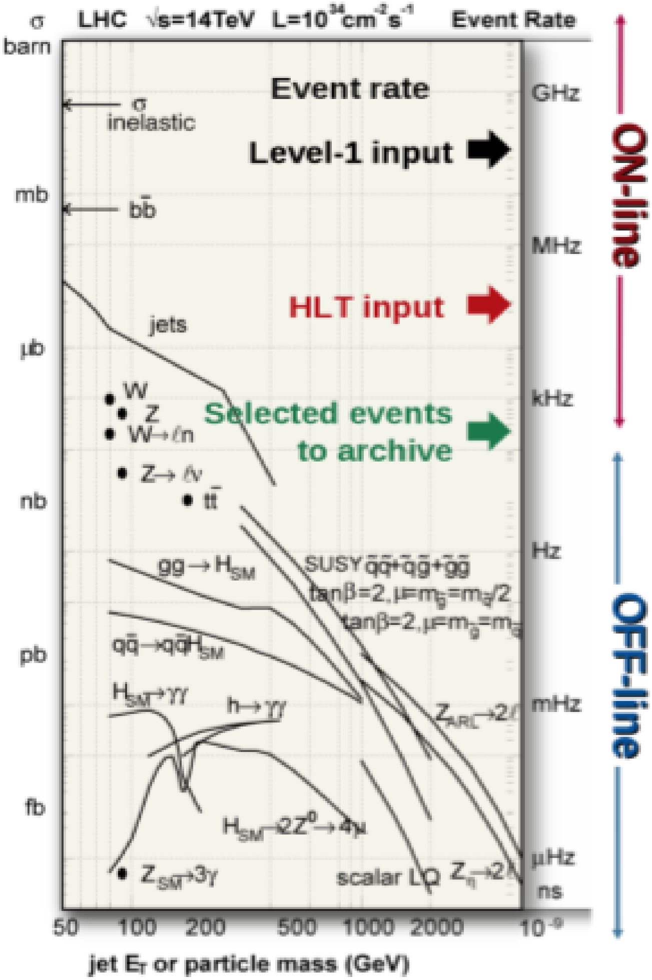


- Momentum / charge of tracks and secondary vertices (e.g. from b-quark decays) are measured in central tracker (Silicon layers).
- Energy and positions of electrons and photons measured in high resolution electromagnetic calorimeters. (~ 0.5% @ ET ~ 50 GeV)
- Energy and position of hadrons and jets measured mainly in hadronic calorimeters
- Muons identified and momentum measured in external muon spectrometer (+central tracker) dp/p<1% @ 100GeV and <10%@1 TeV
- Neutrinos "detected and measured" through measurement of missing transverse energy (ETmiss) in calorimeters (hermeticity; good Missing ET resolution)

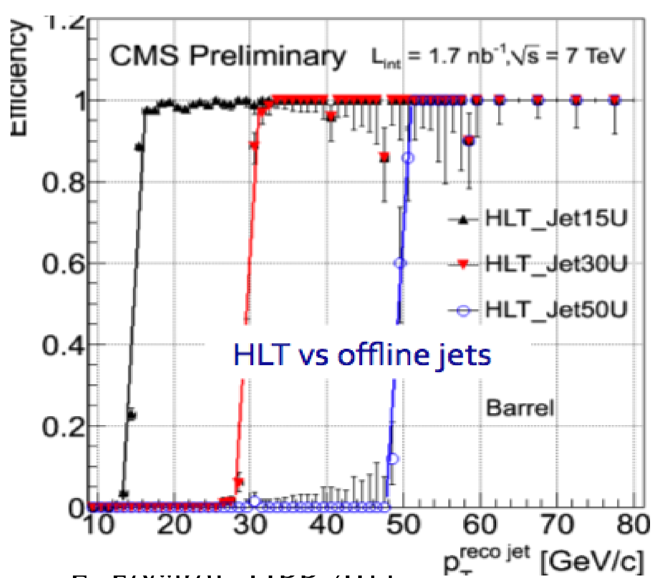
The CMS Detector

started operations from summer 2008: a set of cosmic runs provided calibration constants(alignment..)

Trigger system



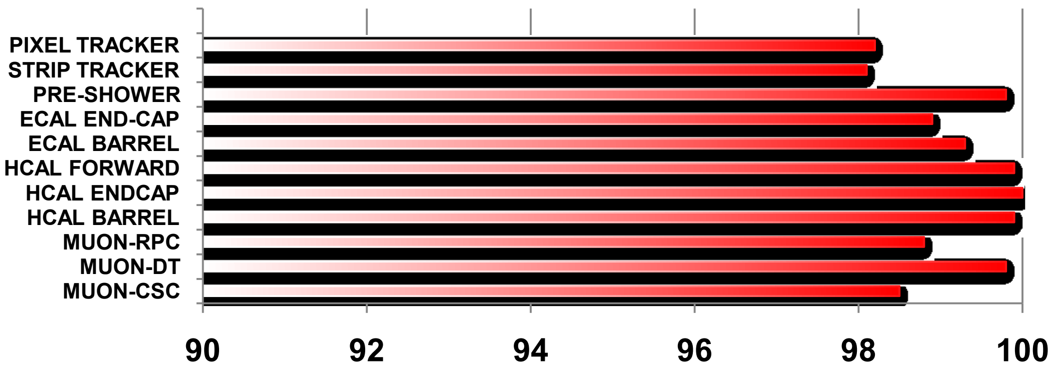
- Hardware L1: Based on muon detectors and calorimeters
  - Timing precision ≤1ns;
  - L1 45-70kHz
- Software HLT. Flexible
  - Fast (~50ms) full event reconstruction using also tracker information.
  - Data logging 200-600Hz.
- High efficiency and sharp turn-on curves



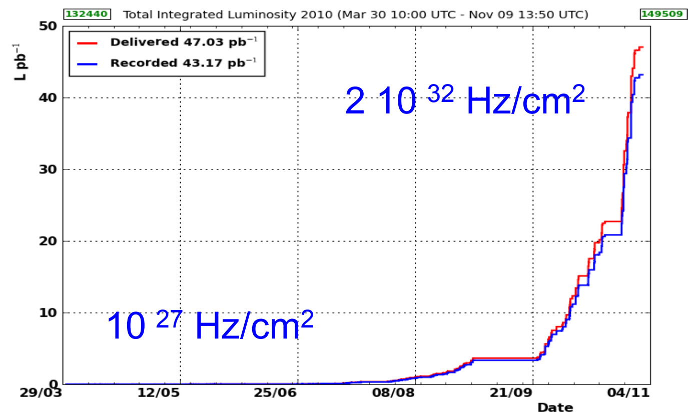
see P. Klabbers yesterday's talk

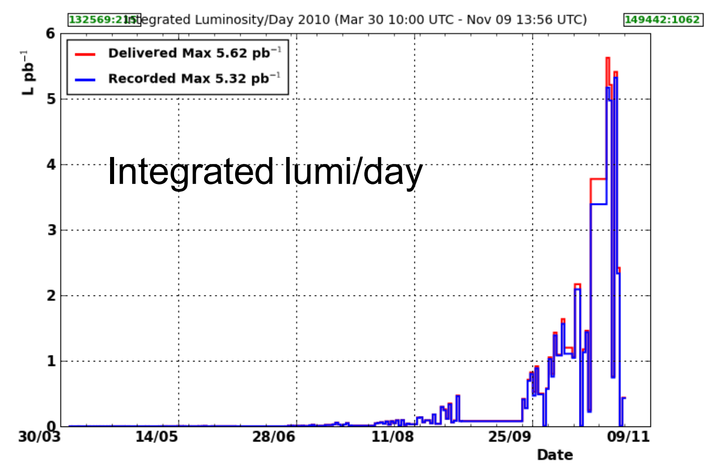
Data taking 2010

- pp- collisions: 7 TeV from March 2010
  - LHC Delivered 47 pb^{-1}, CMS recorded 43 pb^{-1}.
  - Great flexibility of trigger system.
  - Overall data taking efficiency 92%, ~85% with all subdetectors in perfect conditions



	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

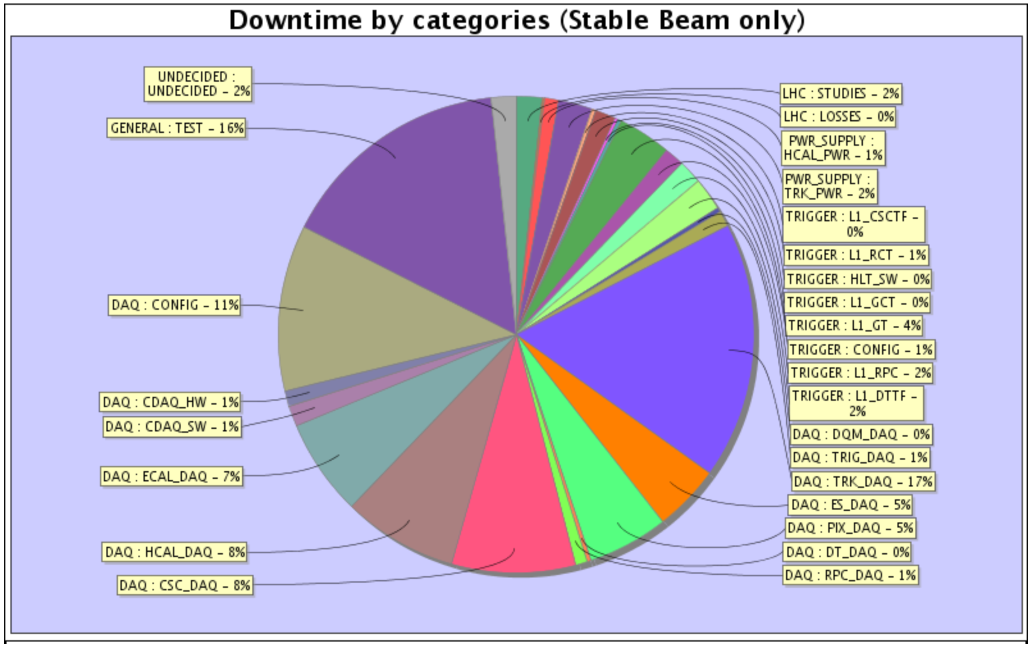


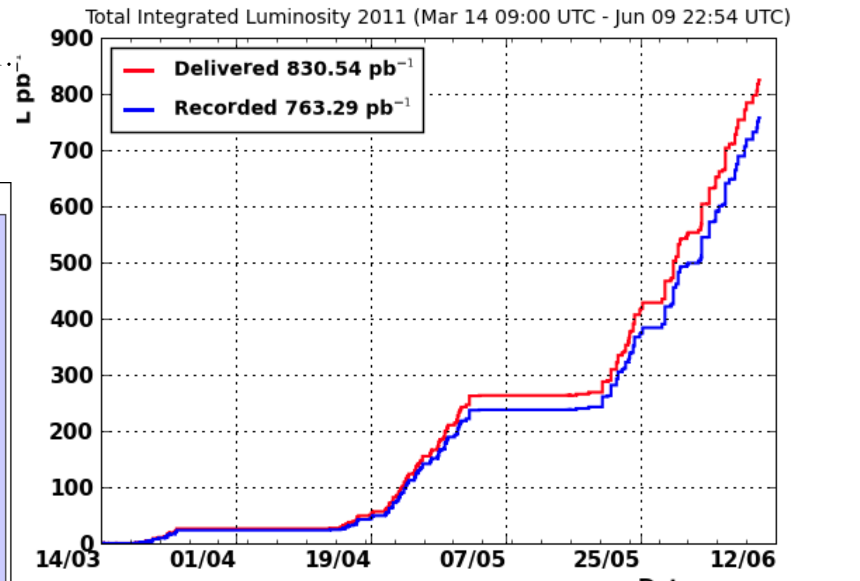


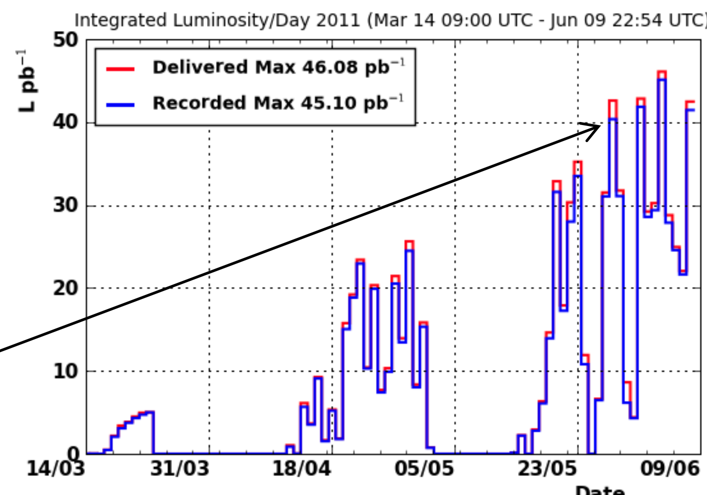
- Heavy Ions: 8th November
  - Delivered ~ 8.4 μb^{-1}, efficiency ~ 93%

Data taking 2011

- pp- collisions: 7 TeV from 14 March 2011
  - LHC Delivered **830** pb^{-1}, CMS recorded **763** pb^{-1}.
  - Overall data taking efficiency **91**%





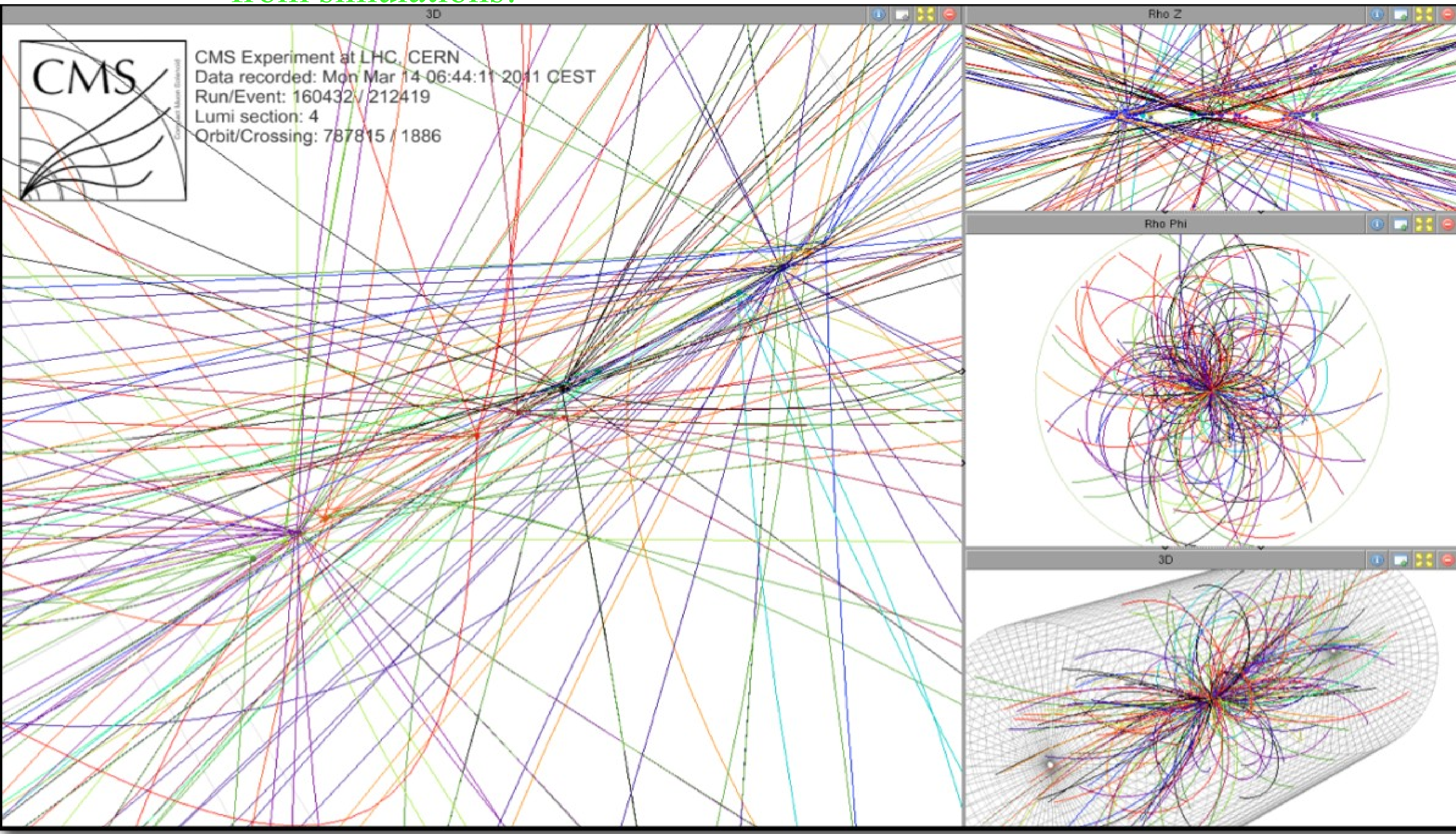


Several days with year 2010 lumi

Detector performance

Start as: "Don't expect everything to work at first. . . "

- BUT… even such a complex apparatus do seem to be working as expected from simulations!



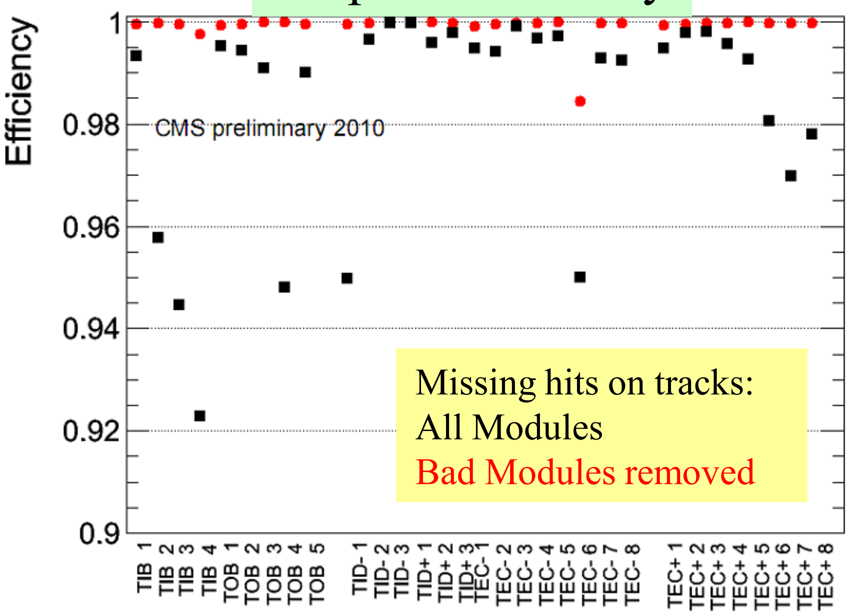
Tracker Basic Performance

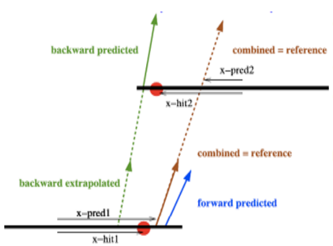
see also
J. Agram talk

- Fraction of active detector:
  - Pixel: **97.3%** Strips: **97.8%**
  - high hit efficiency: >**99.9%**
- Reconstructed hit signals match with expectation and MC
  - Strip S/N: ~19 (thin sensors), ~23 (thick sensors)
- Estimated intrinsic hit resolutions match with MC
  - tracks in overlap: cosmics and collisions

- Offline Calibrations:
  - Lorentz Angle
  - Dead/Noisy channels
    - Efficiency
  - Analog Signal equalization

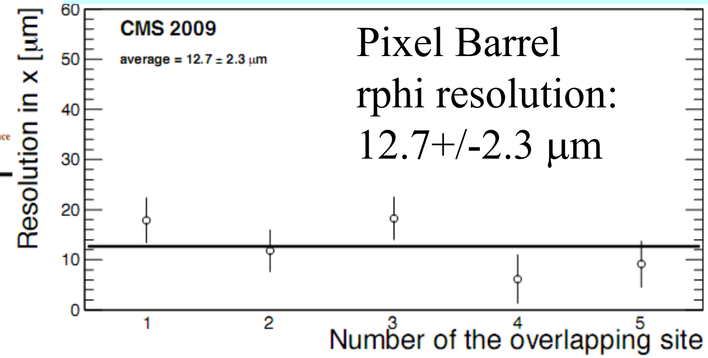
Strip hit efficiency

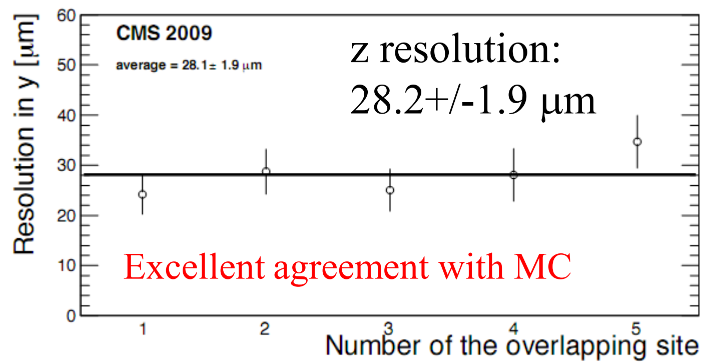




typical rphi resolutions are better!! (track angle)

Hit resolution from overlaps





Tracker Power system

- Power System: it provides 1.25 and 2.5 Volts to the Fe electronics and up to 600 V to the Si modules. There are ~1200 electronics CAEN modules to power up the system: 356 control groups, 1944 power groups, 3888 HV channels.

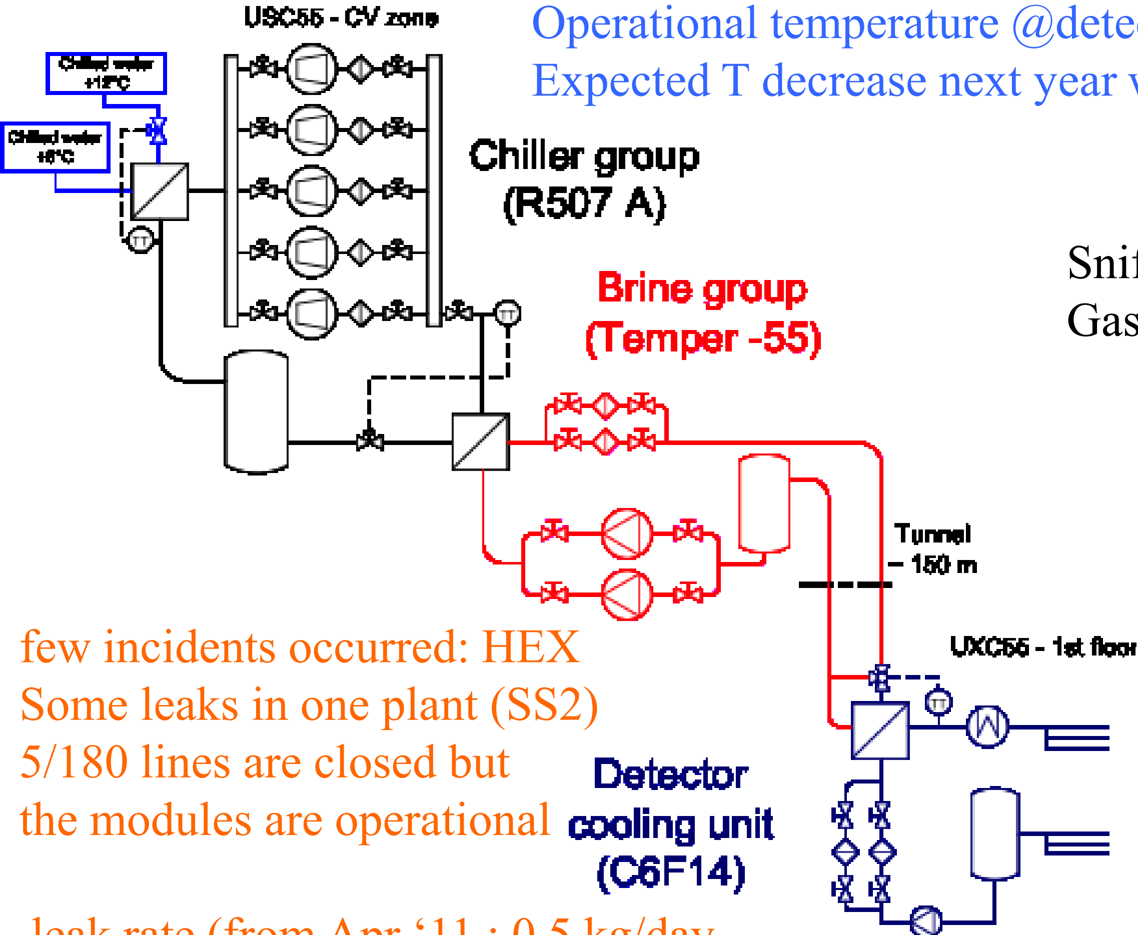
  The Tracker can do the HV OFF to HV ON transition in ~75''.

  The total power is 36-49 KW.

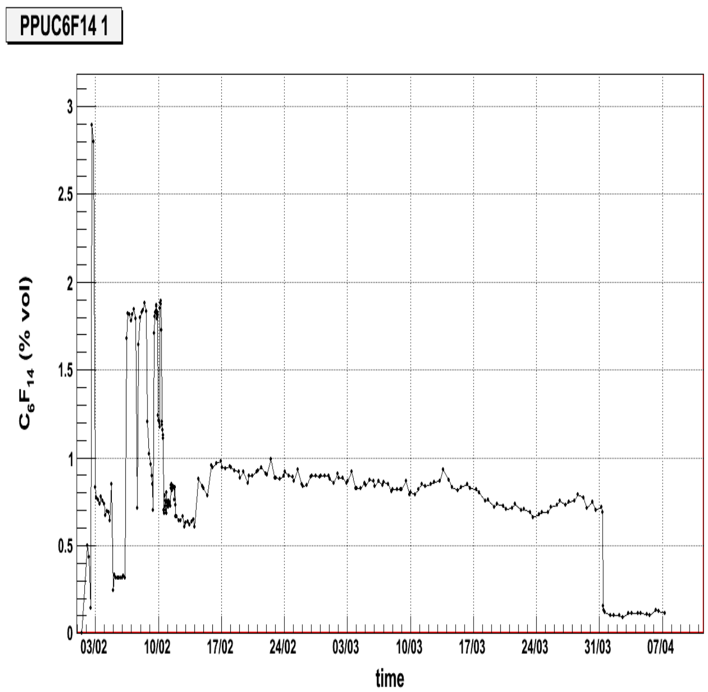
The system is stable and the overall exchange rate is at 1% level/year.

Tracker cooling system

Operational temperature @detector: 4 ^{0}C
Expected T decrease next year with intervention on bulk head sealing



Sniffing system inside TK volume:
Gas chromatograph installed (summer ‘10)



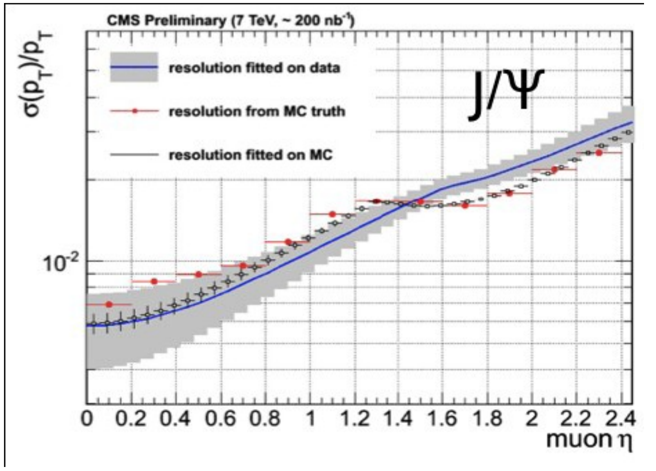
few incidents occurred: HEX
Some leaks in one plant (SS2)
5/180 lines are closed but
the modules are operational

leak rate (from Apr ‘11 : 0.5 kg/day
~0.1% C_6F_{14} measured inside TK

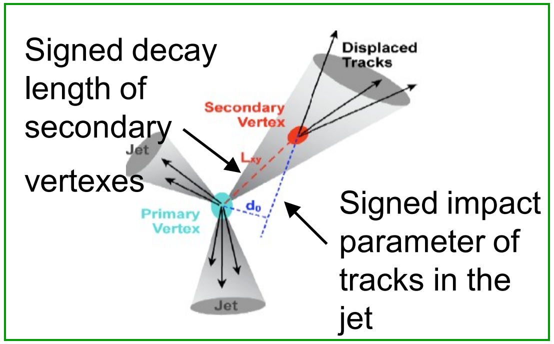
Interventions started to stabilize
the operation: VFD, P reduction,…

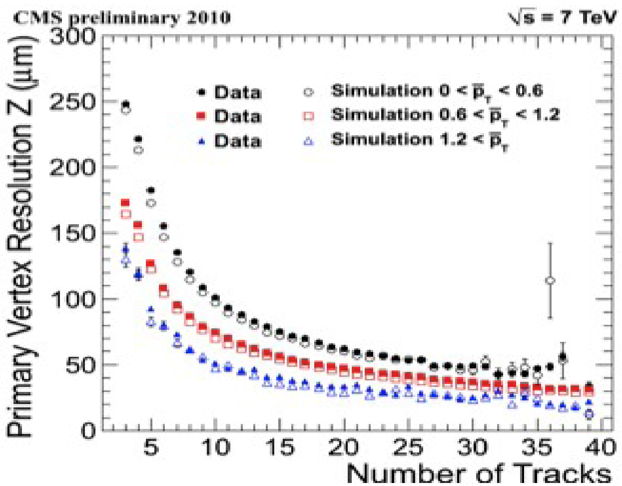
Tracking and muon performance

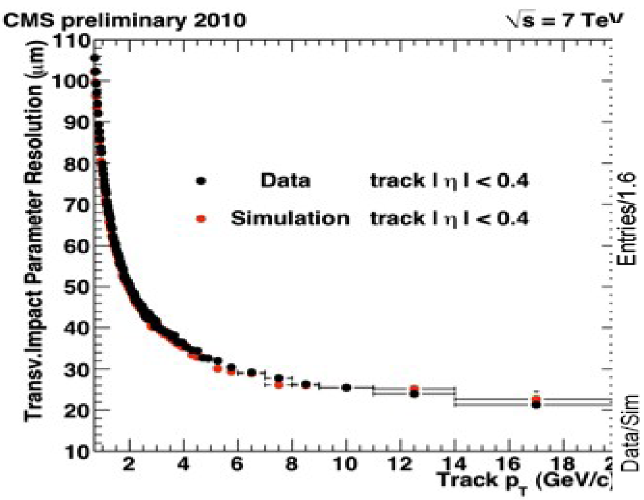
- Muon momentum resolution extracted from resonances, ‘almost’ as simulation (corrections ~10^{-4})

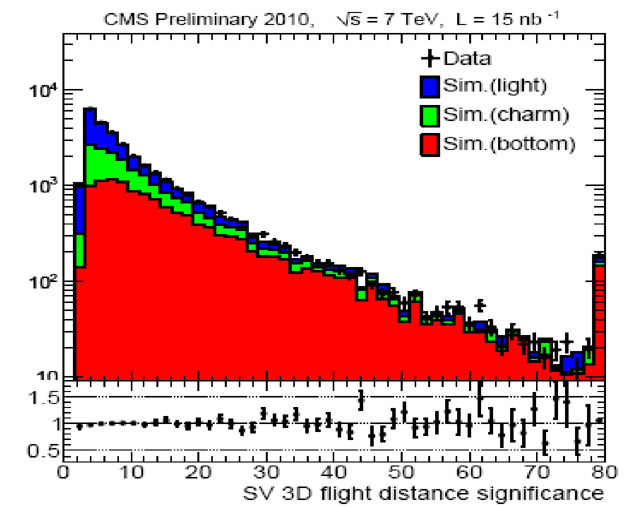


- Excellent resolution for Primary Vertex reconstruction and tranverse impact parameter
- B-tagging operational already at 15nb^{-1}





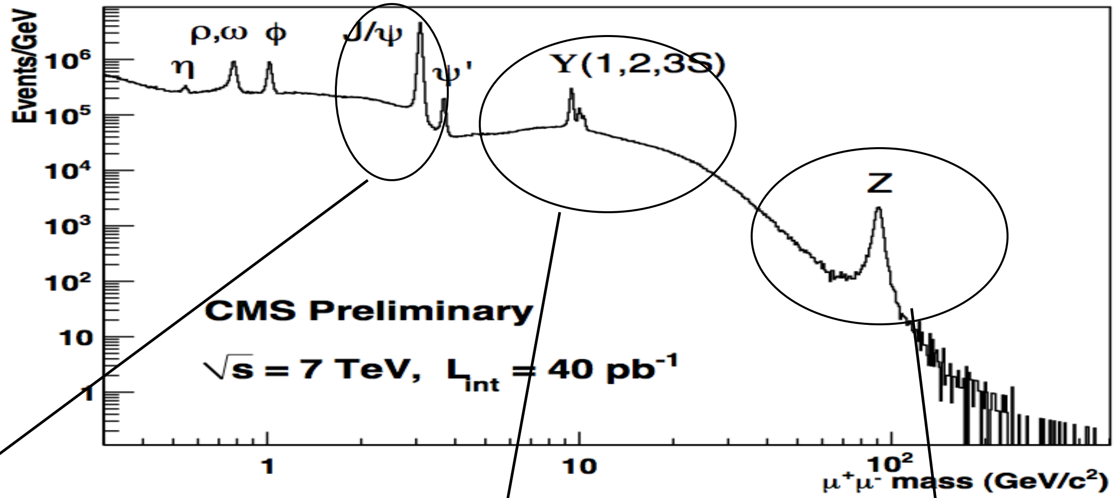


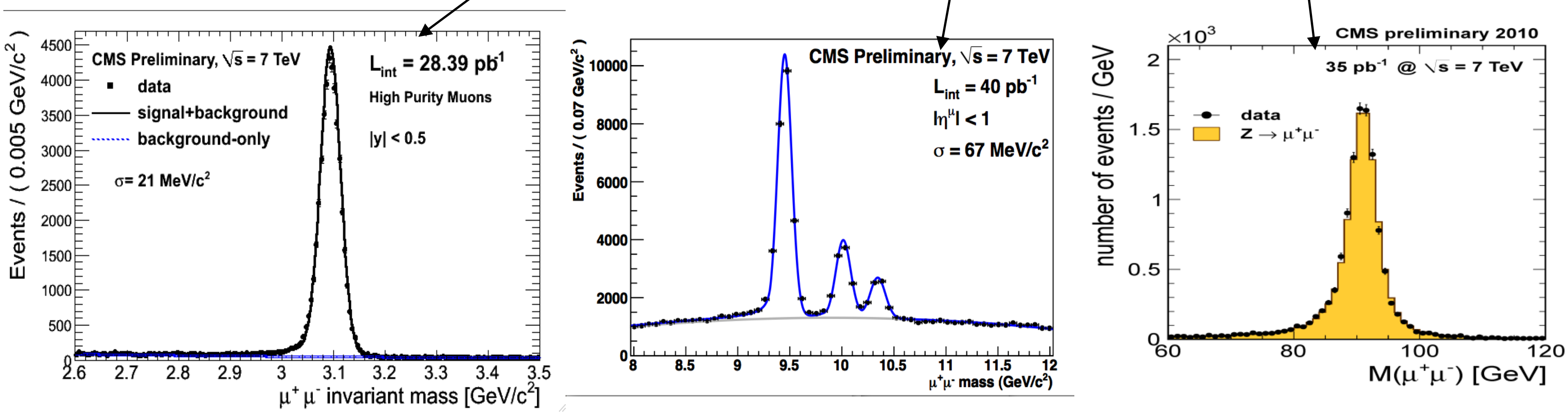


Tracking and muon performance

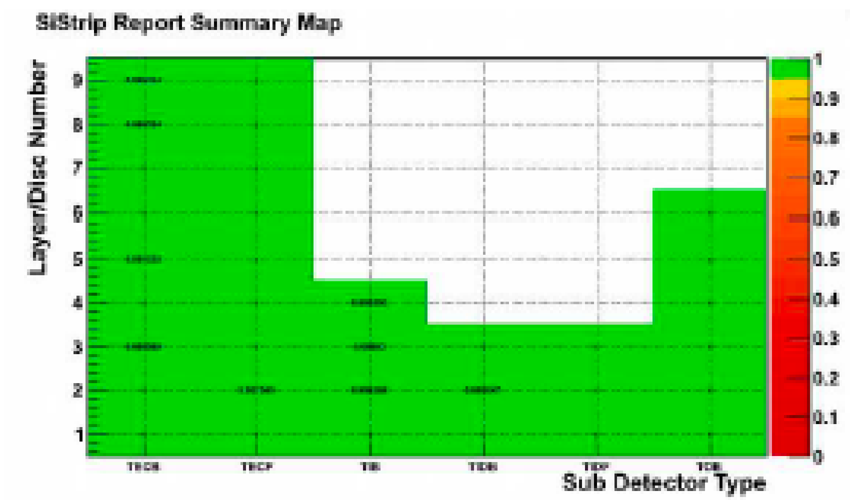
- Thanks to high flexibility of trigger system!
- Excellent tracking resolution and alignment shows in resolution of $M_{\mu\mu}$

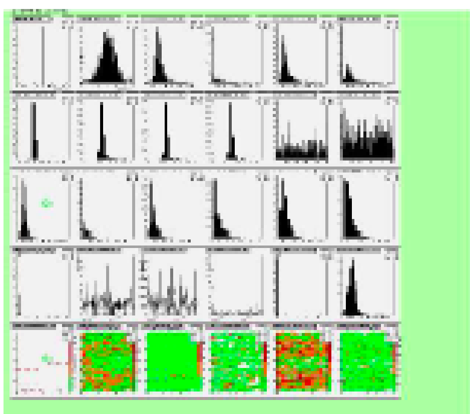
see also
N. Beni's talk later





Data Quality monitoring



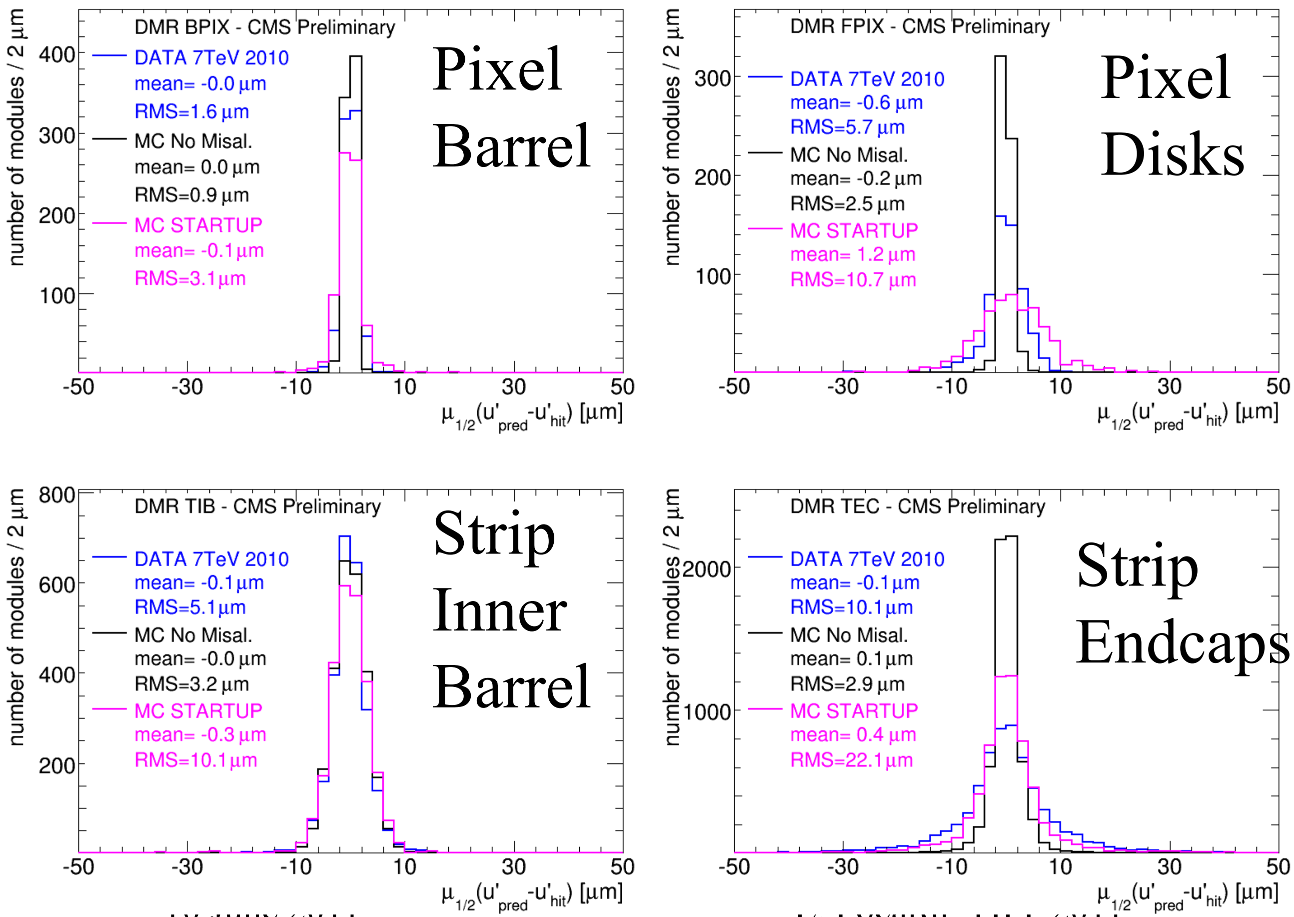


- Detector performance are monitored using the DQM system
  - online to give prompt feedback during data taking
  - offline to analyse the full statistics and certify data
- The full tracker reconstruction chain is monitored through histograms on
  - Status of Feds , Occupancy, Clusters, Track parameters
- Module level histograms are further processed to
  - Create summary histograms
  - Perform Quality Test
  - Produce global DQM flags

Tracker Alignment

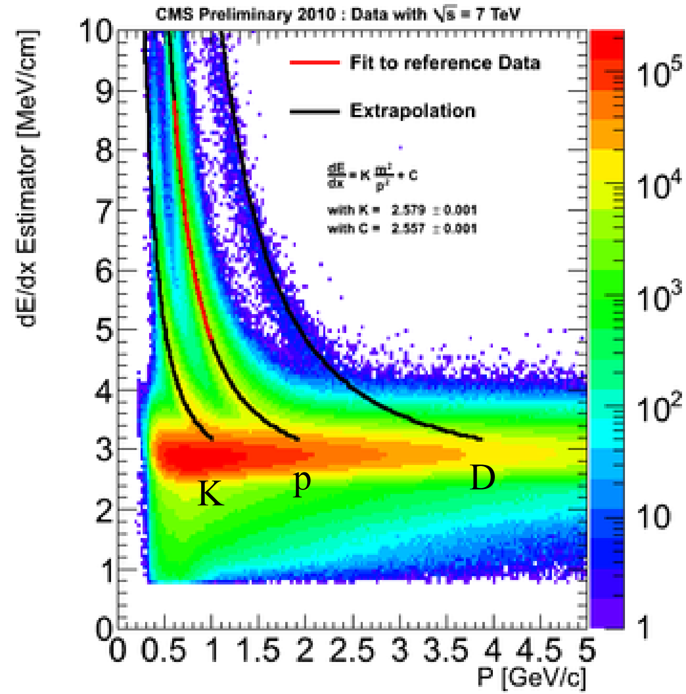
- 15148+1440 sensors : 6 degrees of freedom each, O(10µm) accuracy
- Distributions of Mean Residual (DMR): median of the residual distributions in each sensor (N_{hit}>200)

  less affected by track, hit and multiple scattering uncertainties

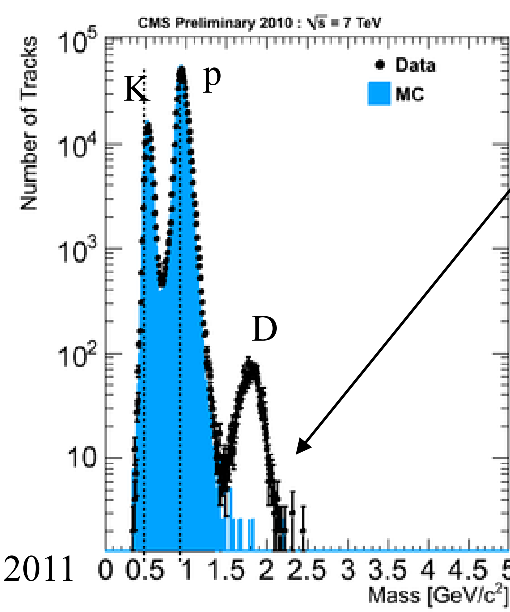


- Minimization hit/track residuals χ^2
  - track parameters and sensor positions
- Two approaches:
  - Millipede (II): Global minimization, custom track model
  - "Hits and Impact Points" (HIP): local minimization of sensor position, iterative, detailed track model
  - Applied sequentially from large substructures to sensor level
- DMRs spreads Barrel: < 6µm Endcaps:<10µm
- Good complementarity between cosmics and minimum bias collision events

Particle Identification



- Energy loss in Si strip sensors used for particle ID
- Fundamental for searches of exotica particles
- Mass of candidate evaluated starting from the relation between the particle momentum and dE/dx estimator

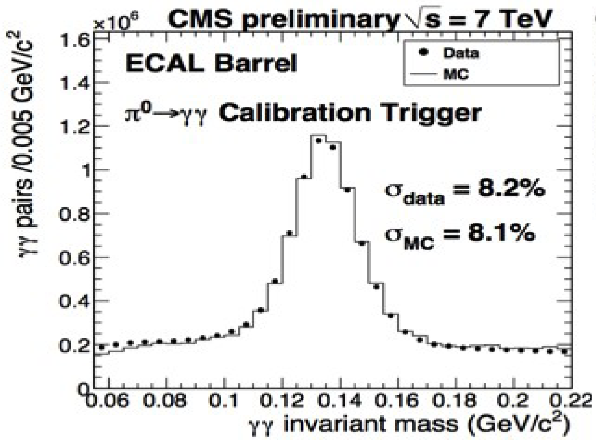


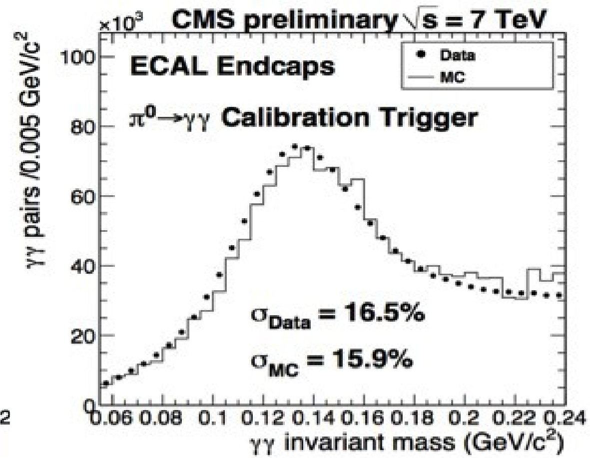
Deuterons: not simulated

ECAL, photon and electron performance

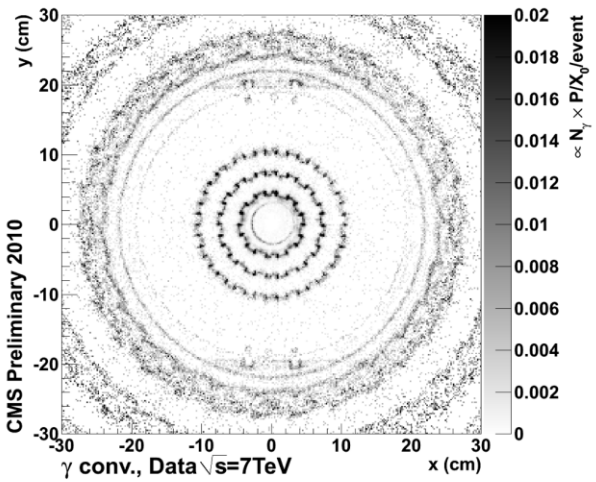
Status: EB: **99.08%**, EE: **98.56%**, ES: **96.08%**

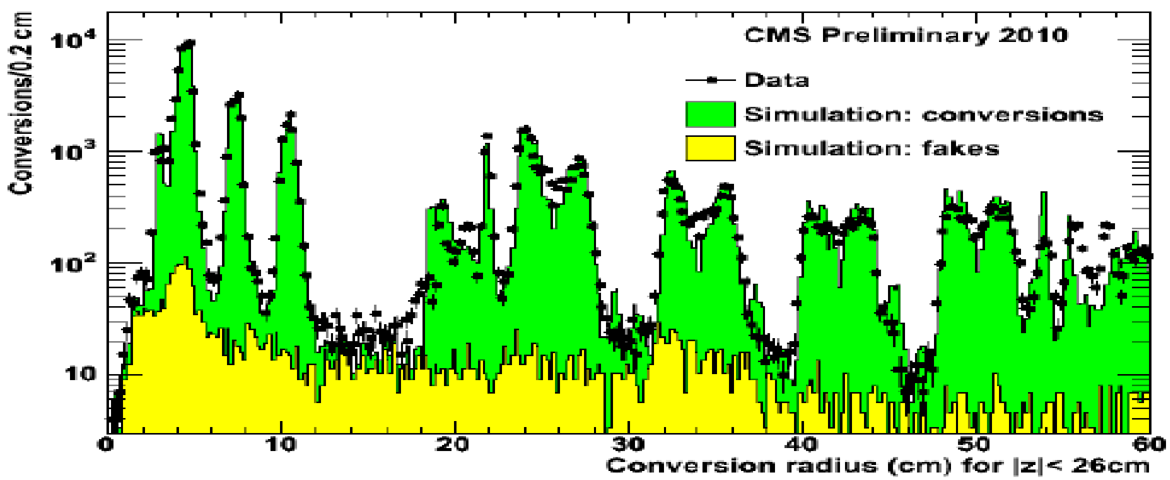
- ECAL provides very good energy resolution down to low energies
- Performance in agreement with expectations
- At high ET the scale in the barrel region is now set by the π^0 calibration (correct to 1%); 3% shift in the endcap region





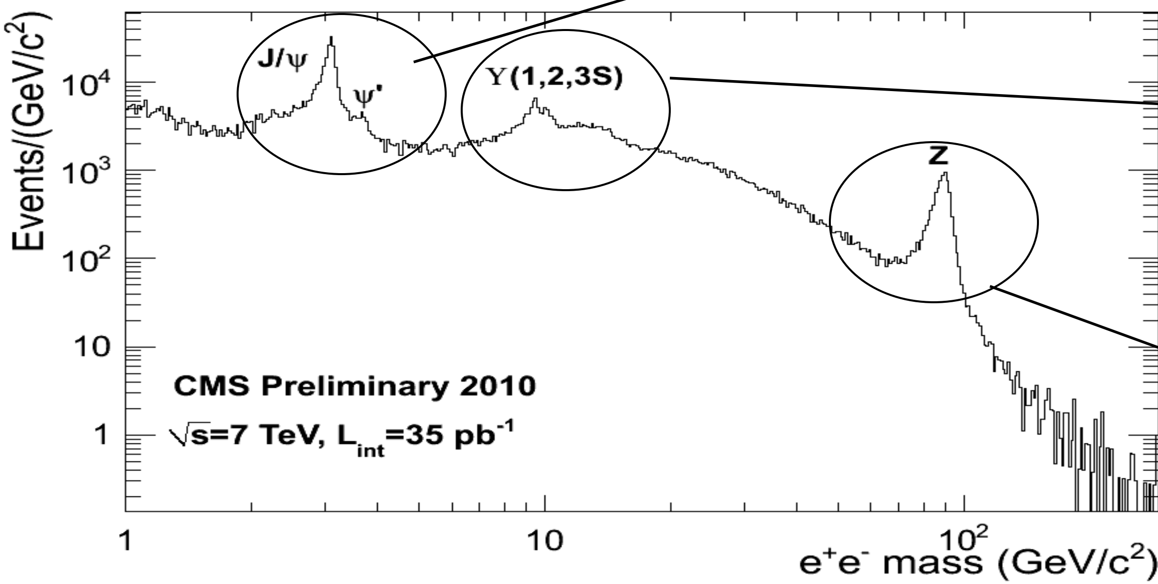
- Good knowledge of material budget (conversions, NI)

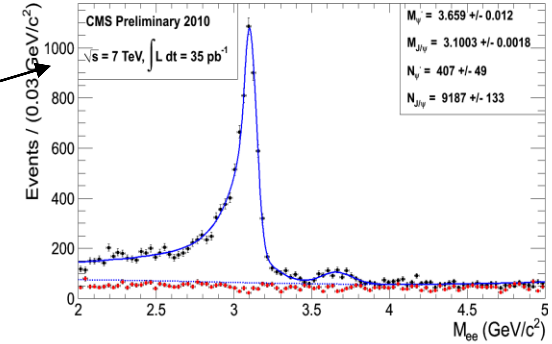


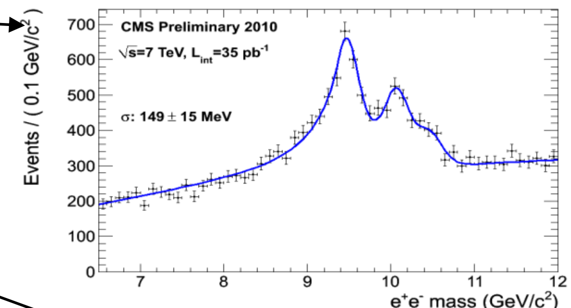


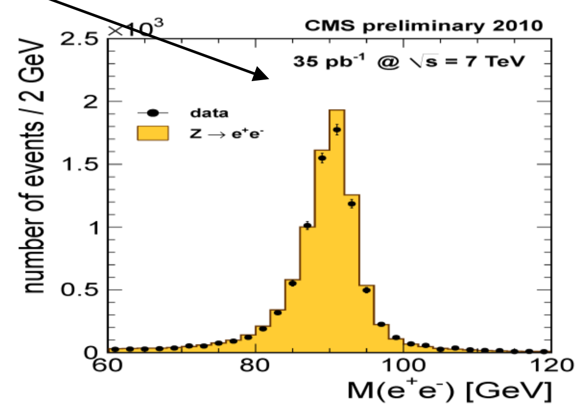
ECAL, photon and electron performance

- Di-electron mass spectrum









Conclusions

- CMS detector is operated since 2008: several millions of cosmics data have been collected until the LHC startup at the end of 2009.
- Since 2010 CMS has collected ~ 900 pb^{-1} of integrated luminosity in pp collisions at 7 TeV.
- No major problems occurred during the two years LHC pp operation.
- Detector performance are excellent, as expected from the simulations.

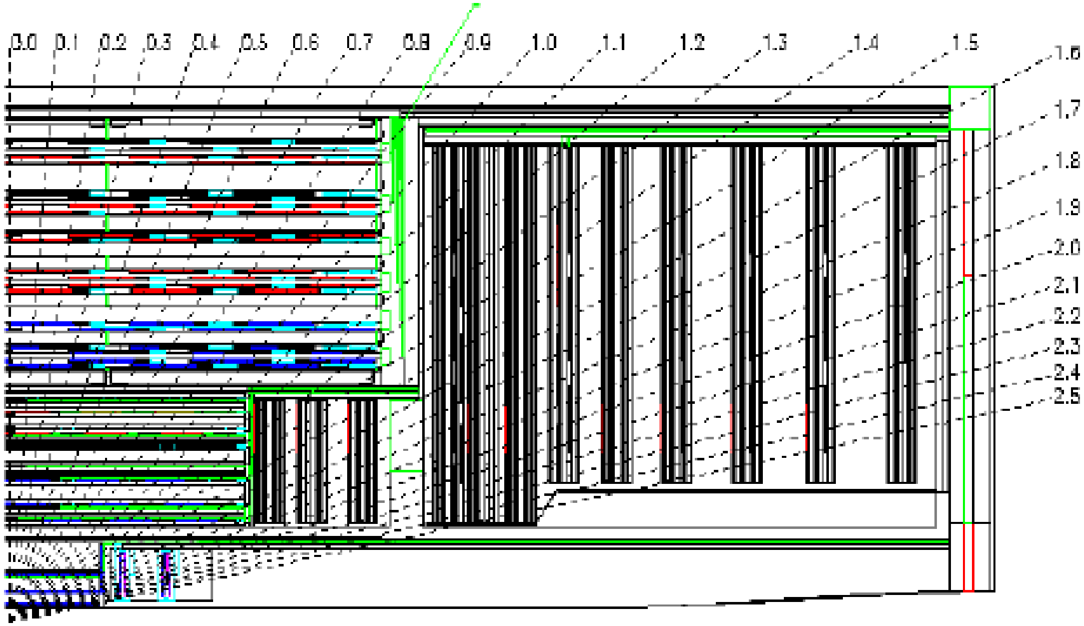
- Given the good LHC luminosity performance, stay tuned for new physics results soon !!!!.

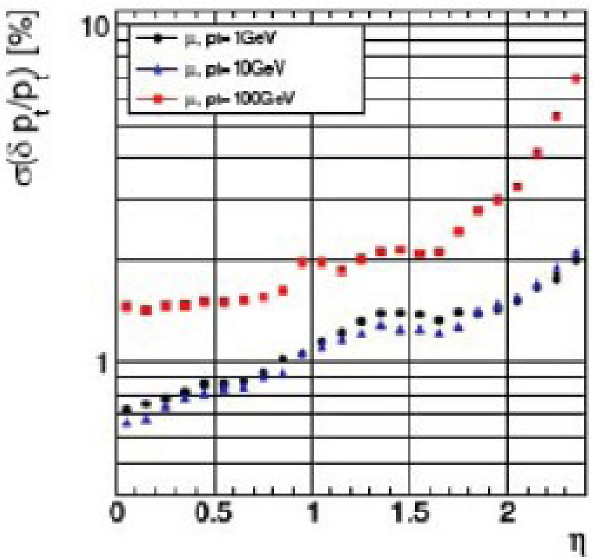
Back-up slides

The CMS design: goals

- Good muon identification and momentum resolution:
  - Redundant measurements and redundant trigger systems
  - $\Delta M_{\mu\mu} / M_{\mu\mu} \approx 1\%$ at 100 GeV
  - Unambiguous determination of the charge for $p^T_\mu < 1$ TeV
- Precise and efficient inner tracking, including vertex capabilities:
  - Efficient triggering and offline tagging of taus and b-jets
  - Pixel detectors close to the interaction region
- Good electromagnetic identification and photon/electron energy resolution:
  - $\Delta M_{ee} / M_{ee}$, $\Delta M_{\gamma\gamma} / M_{\gamma\gamma} \approx 1\%$ at 100 GeV
  - Large coverage and good granularity, π^0 rejection
- Good jet and missing transverse energy resolution:
  - Hermetic coverage, fine lateral segmentation

CMS inner tracking system





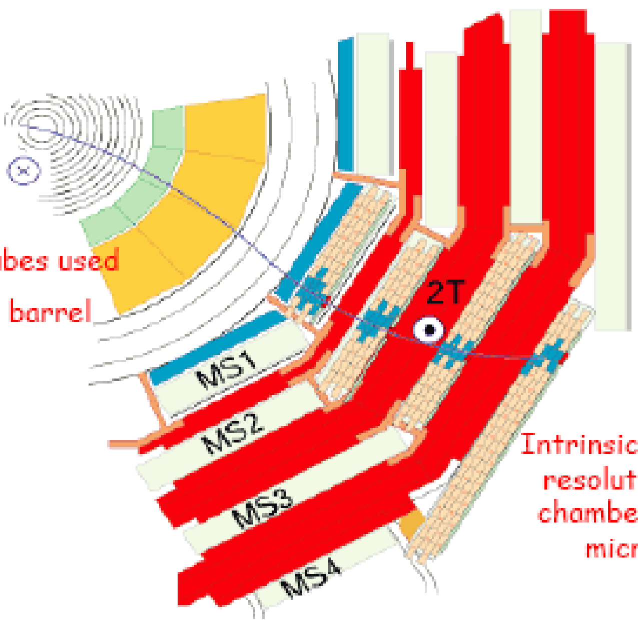
A huge, ultra-precise silicon tracker system:

- For $p_T \leq 100$ GeV, $\Delta p_T / p_T \approx 0.5\text{-}2\%$ ($|\eta|<1.6$)
  - Muon resolution dominated by inner tracking resolution for $p_T < \approx 100$ GeV
- $\Delta d_{xy} \approx 10$ μm resolution at very high p_T
- $\Delta z \approx 20\text{-}40$ μm resolution at very high p_T ($|\eta|<2$)

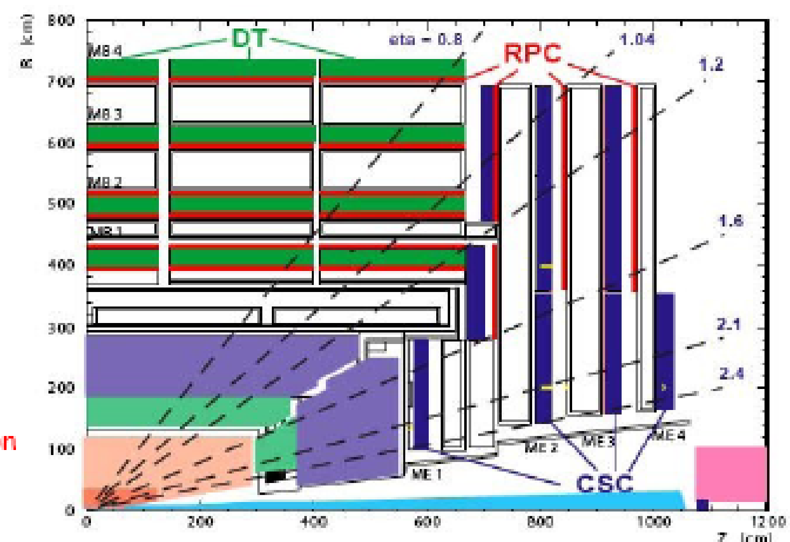
CMS: a special muon system

- The CMS muon system (barrel and also endcap) is optimized for:
  - Robust, efficient and redundant muon triggering system (chambers+RPCs)
  - Efficient muon identification and reconstruction (|η|<2.4, redundant coverage)
  - Precise measurement (< 10%) for TeV momenta (good alignment + level arm)

Drift tubes used in the barrel



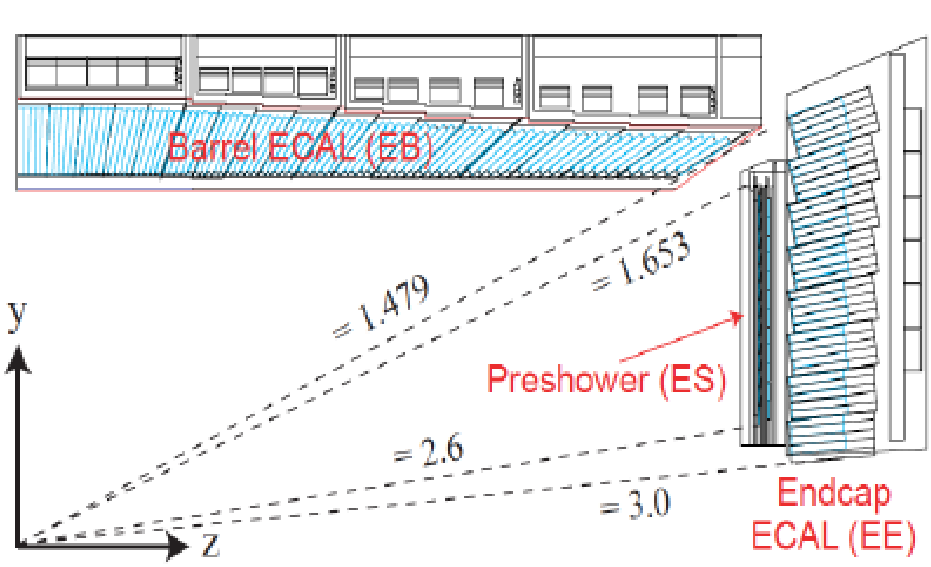
Intrinsic position resolution per chamber ~ 100 microns

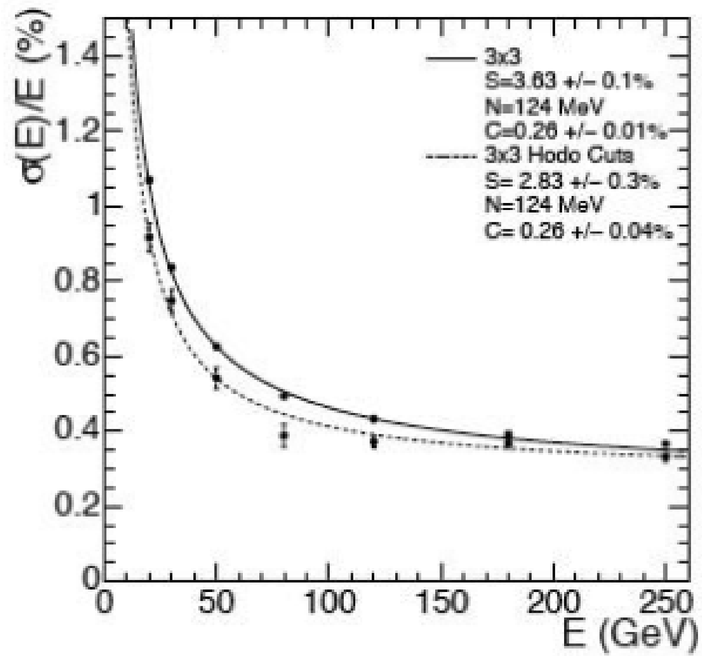


Cathode Strip Chambers (CSC) used in the end-caps

RPCs for fast timing and trigger response

CMS Electromagnetic Calorimeter

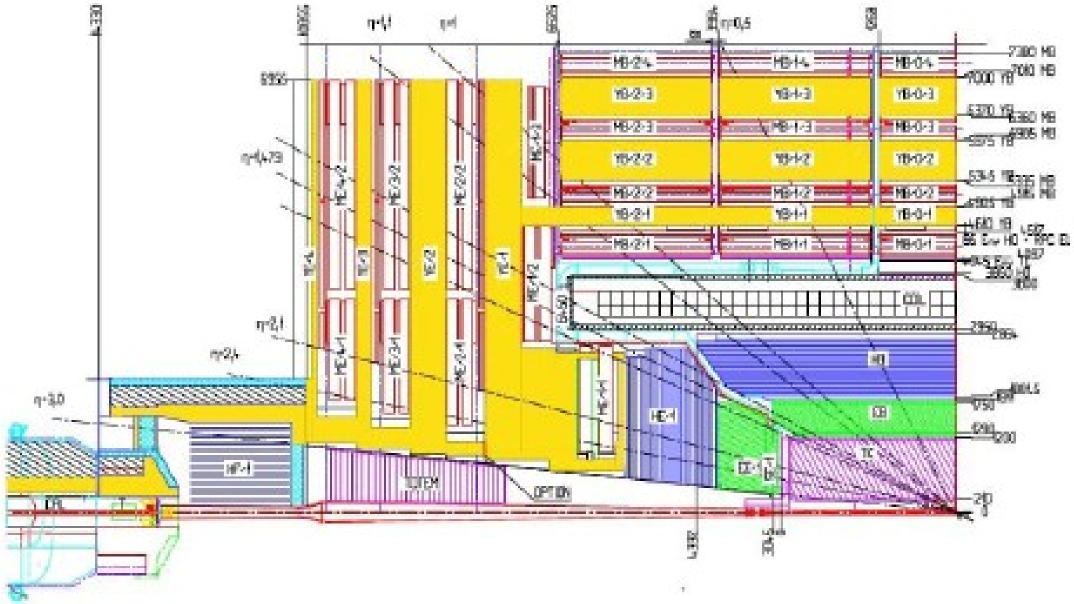




- A crystal calorimeter ($PbWO_4$): extremely good resolution (stochastic term ≈ 2.8% at 1 GeV), low noise (noise term ≈ 120 MeV), good uniformity/intercalibration (uniformity ≈ 0.3% from test-beam studies):

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E}}\right)^2 + \left(\frac{0.12}{E}\right)^2 + (0.3\%)^2 \quad \text{(E in GeV)}$$

CMS Hadronic Calorimetry



- Scintillator-brass/steel tile calorimeter: compact, hermetic, good segmentation and coverage (|η|<5.2)
- Jet angular resolution ~ 20 (30) mrad in φ (θ) at $E_T \geq 100$ GeV
- Jet transverse energy resolution (using ECAL+HCAL only, barrel):

$$\left(\frac{\sigma}{E_T}\right)^2 = \left(\frac{1.25}{\sqrt{E_T}}\right)^2 + \left(\frac{5.6}{E_T}\right)^2 + (3.3\%)^2$$