Detectors at LHC

CMS

Detector Guidelines

Go for:

Excellent muon tracking
Excellent e.m. calorimetry
Vertexing

Large acceptance
High momentum/energy resolution
High vertex resolution

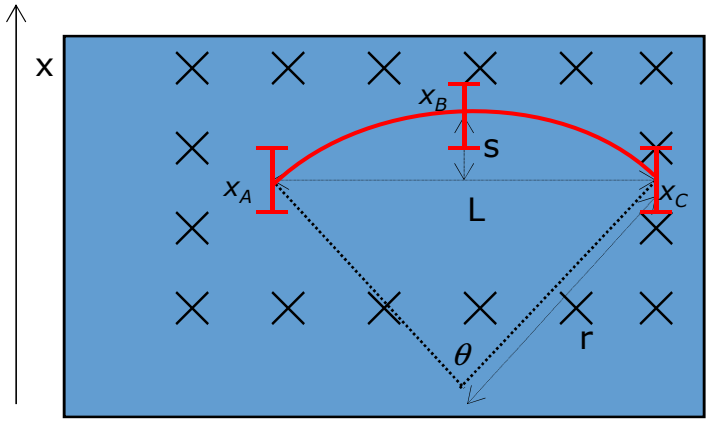
Case study:

Muon, Tracking & EM Calorimetry in CMS

Magnetic Analysis & Accuracy - I

Motion of a charged particle in a uniform magnetic field: Cylindrical helix coaxial to ***B***

$$r = \frac{p_\perp}{0.3B} \qquad r:\ m,\ p_\perp:\ GeV,\quad B:\ T$$



$$\sin\frac{\theta}{2} = \frac{L}{2r} \underset{L \ll 2r}{\rightarrow} \frac{\theta}{2} \approx \frac{L}{2r} \rightarrow \theta \approx \frac{0.3BL}{p_\perp}$$

$$s = r - r\cos\frac{\theta}{2} \approx r\left[1 - \left(1 - \frac{1}{2}\left(\frac{\theta}{2}\right)^2\right)\right] = r\frac{\theta^2}{8} \approx \frac{0.3BL^2}{8p_\perp}$$

$$\rightarrow p_\perp \approx \frac{0.3BL^2}{8s}$$

Magnetic Analysis & Accuracy - II

Take 3 measured points, with single point accuracy σ

Then: $s = x_B - \frac{x_A + x_B}{2}$

$$\rightarrow \sigma_s^2 = \sigma^2 + \frac{1}{2}\sigma^2 = \frac{3}{2}\sigma^2$$

$$\frac{\sigma_{p_\perp}}{p_\perp} = \frac{\sigma_s}{s} = \sqrt{\frac{3}{2}}\frac{\sigma}{s} = \sqrt{\frac{3}{2}}\frac{\sigma 8 p_\perp}{0.3BL^2} = \sqrt{\frac{300\cdot 64}{18}}\frac{\sigma p_\perp}{BL^2}$$

$$\rightarrow \frac{\sigma_{p_\perp}}{p_\perp} \approx 32.7\frac{\sigma p_\perp}{BL^2}$$

$N \geq 10$, uniformly spaced points:

$$\frac{\sigma_{p_\perp}}{p_\perp} \approx 28.3\frac{\sigma p_\perp}{BL^2\sqrt{N+4}}$$

Magnetic Analysis & Accuracy - III

$B = 4T, L = 2m, p_{\perp} = 50GeV$:

$$\rightarrow s \simeq \frac{0.3 \cdot 4 \cdot 4}{400} m \approx \frac{1.2}{100} m \approx 1\ cm$$

$$\sigma \sim 100 \mu m$$

$$\rightarrow \left.\frac{\sigma_p}{p}\right|_{p=30GeV} \sim 30\ 10^{-4} = 0.3\%$$

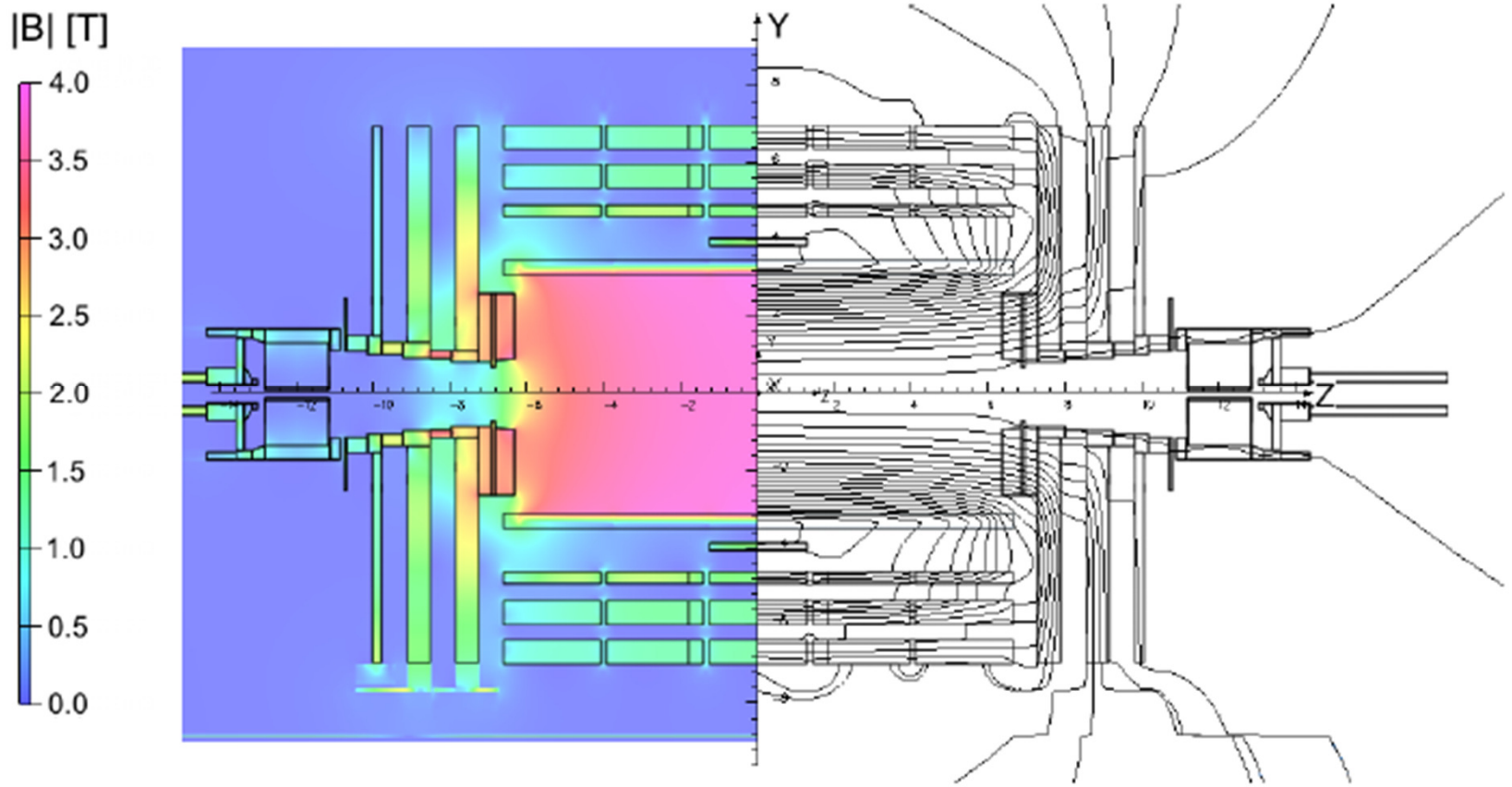
$$\rightarrow \left.\frac{\sigma_M}{M}\right|_{4tracks} \sim 0.6\%$$

$$\rightarrow \frac{\sigma_{\langle M \rangle}}{\langle M \rangle} \sim 0.6‰ \rightarrow \sigma_{\langle M \rangle} \geq 80MeV$$

Does not include many additional factors → Quite optimistic..

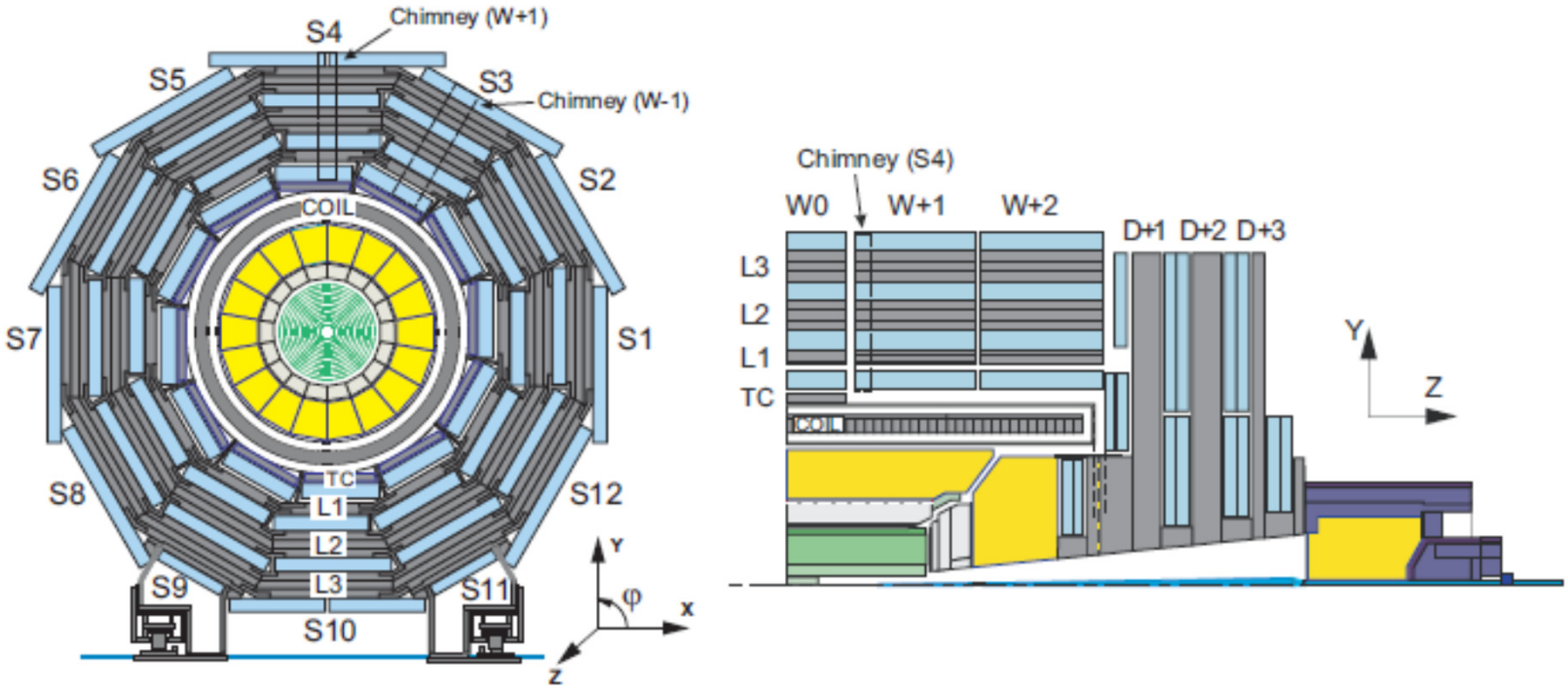
Magnetic Analysis & Accuracy - IV

CMS mag field: SC Solenoid



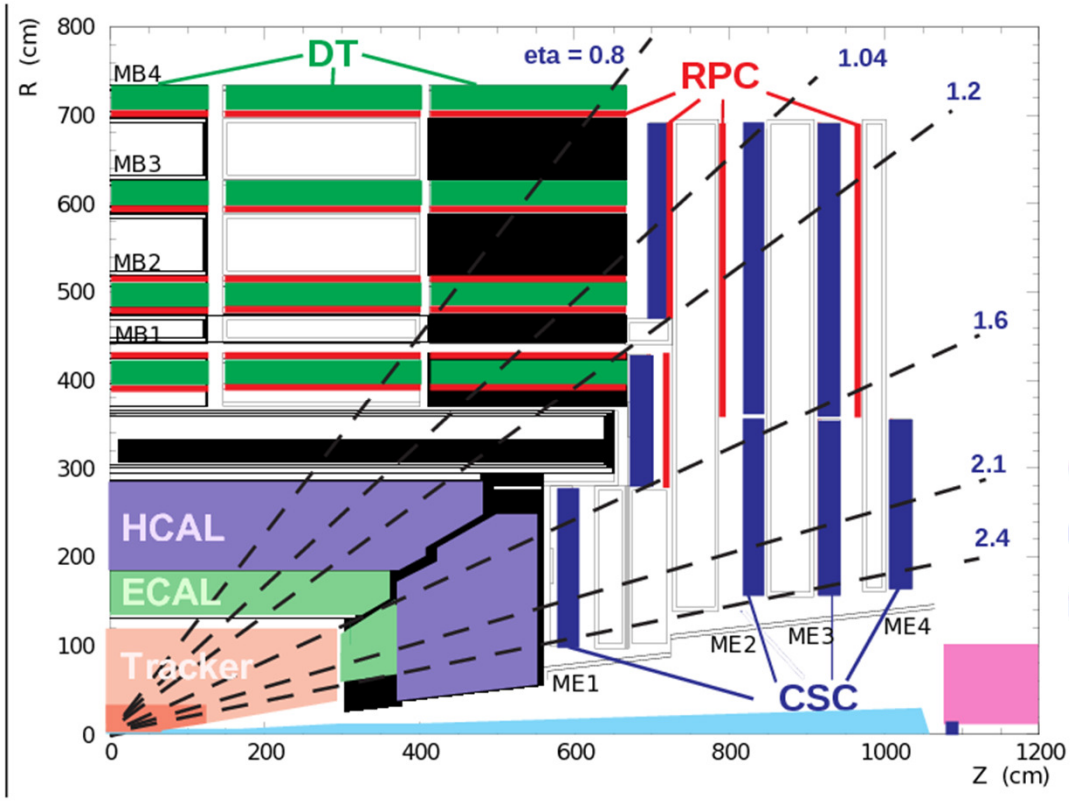
Muon Spectrometer - I

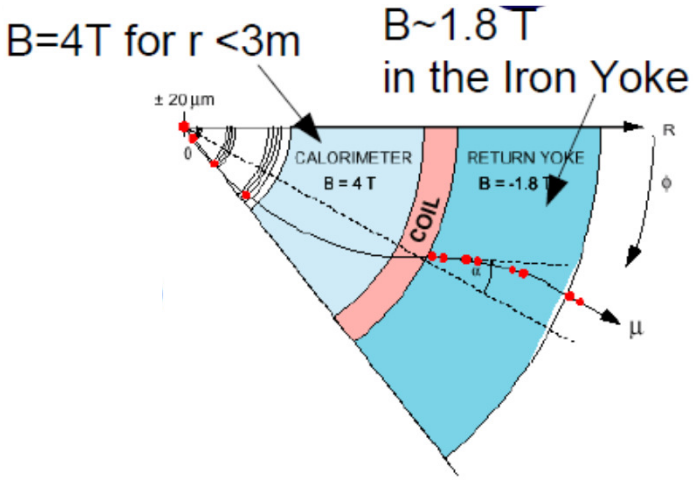
CMS return yoke & external tracking (μ chambers)



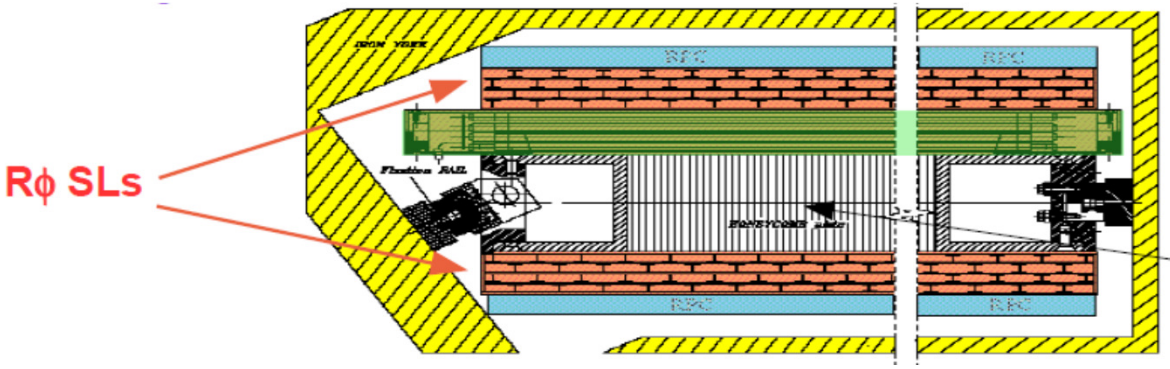
Muon Spectrometer - II

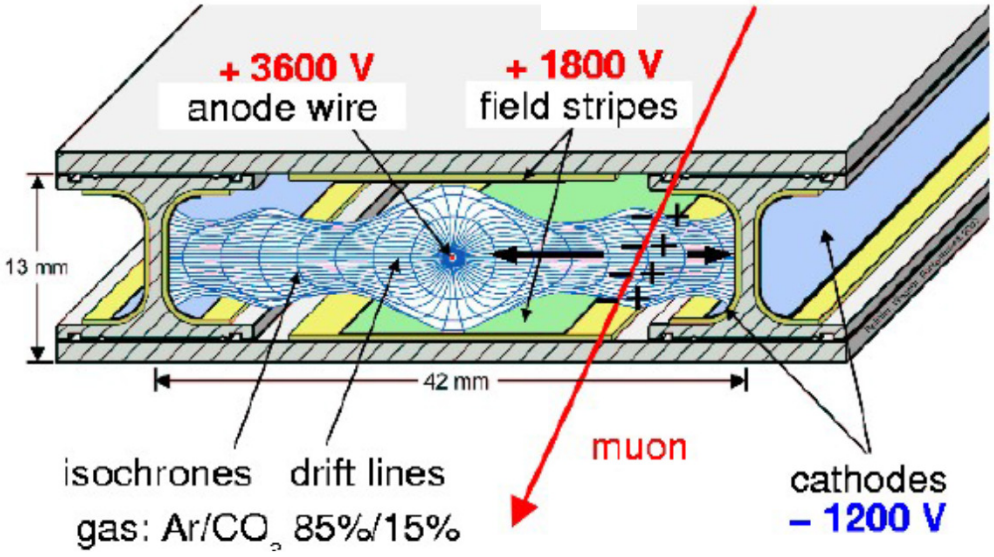
CMS Muon System



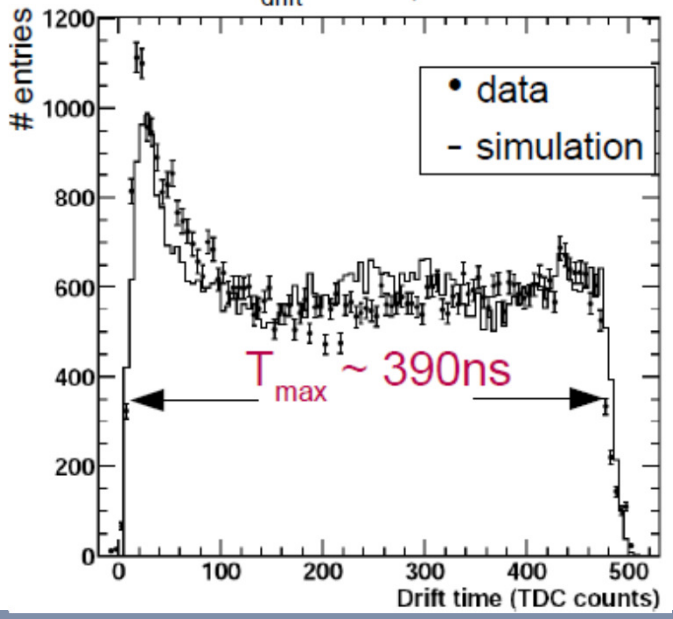


Muon Spectrometer - III

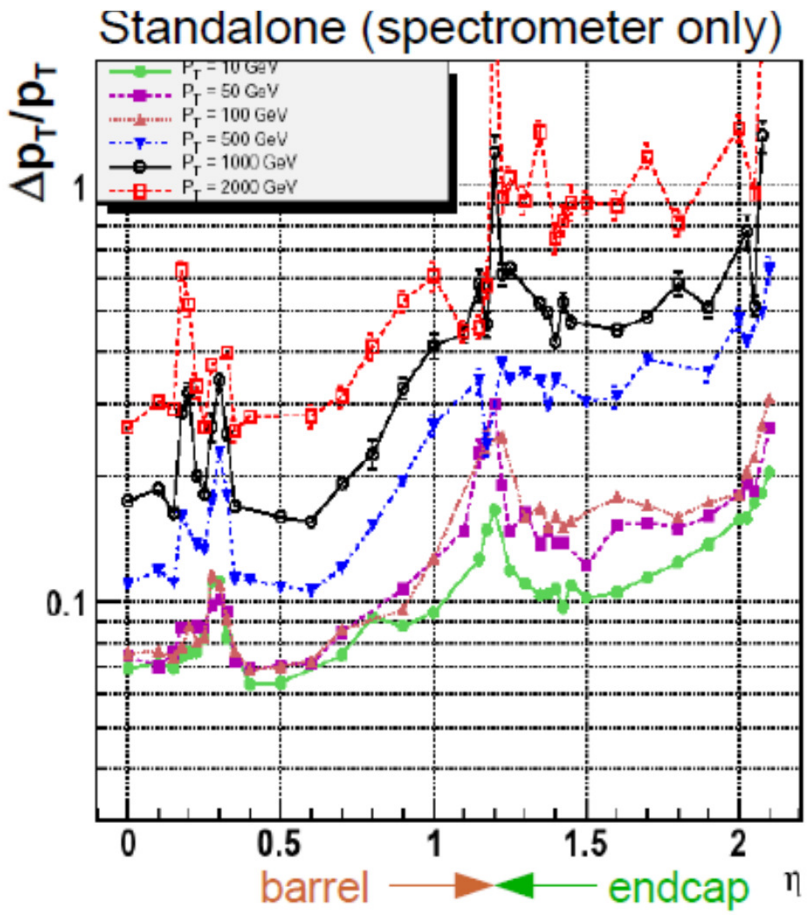


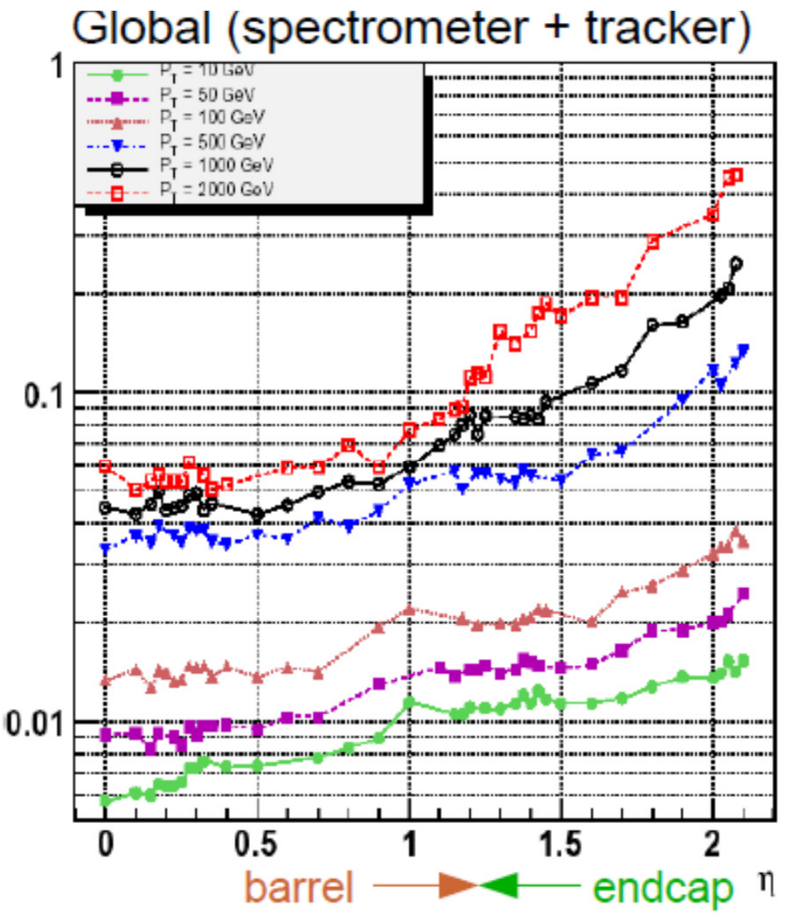


V_{drift} ~ 54 µm/ns

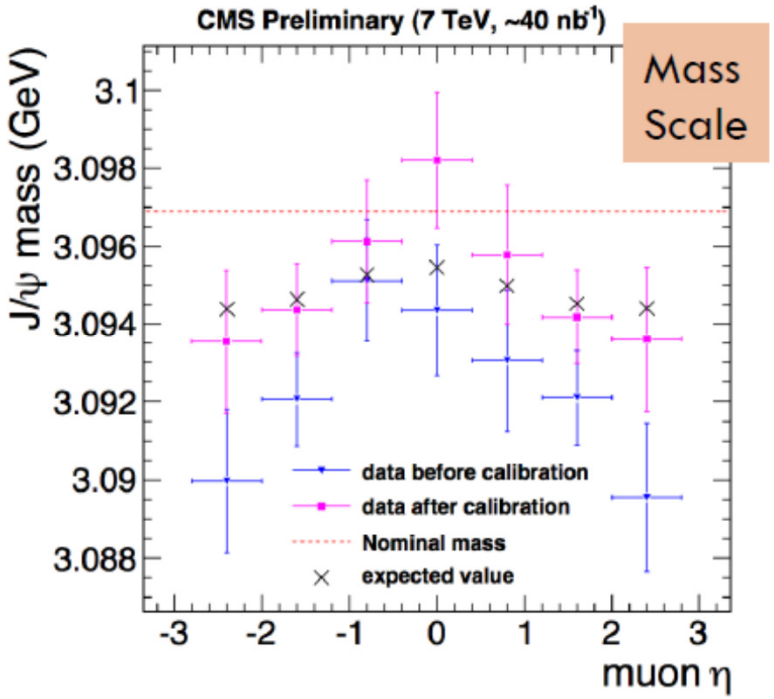


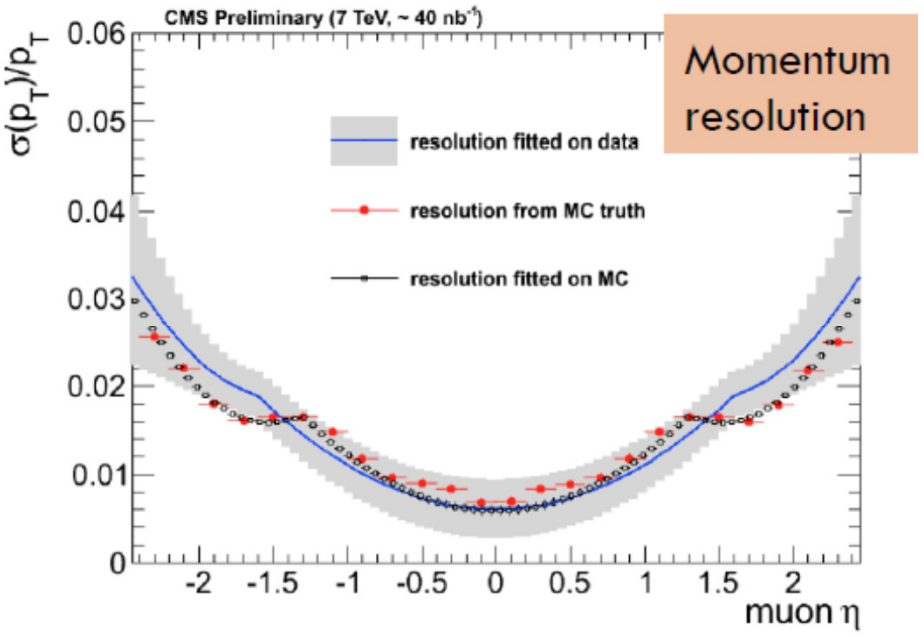
Muon Spectrometer - IV





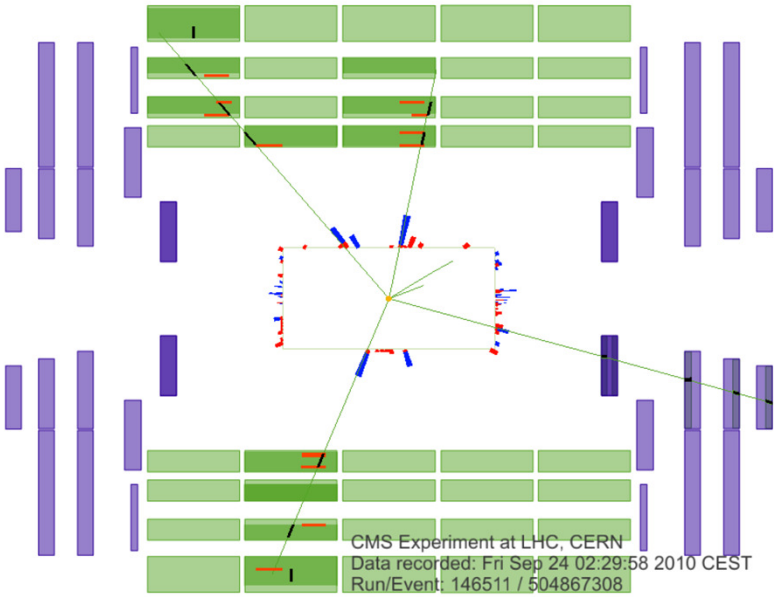
Muon Spectrometer - V

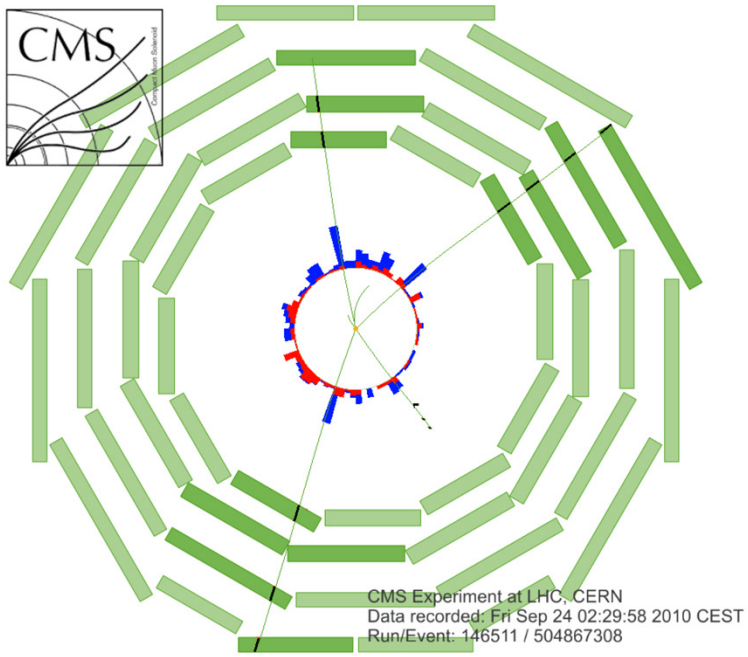




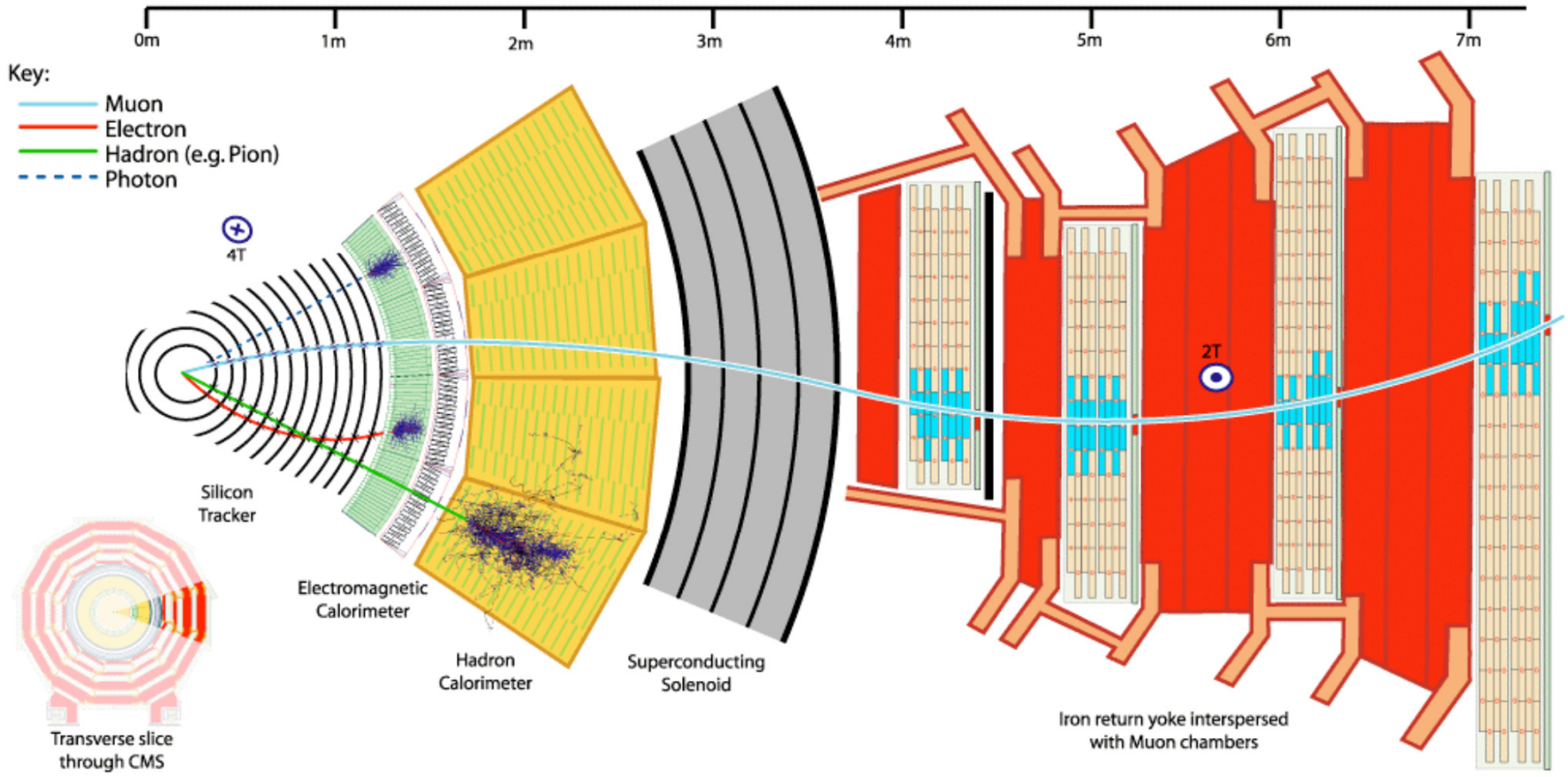
Muon Spectrometer - VI

4 Muons candidate event

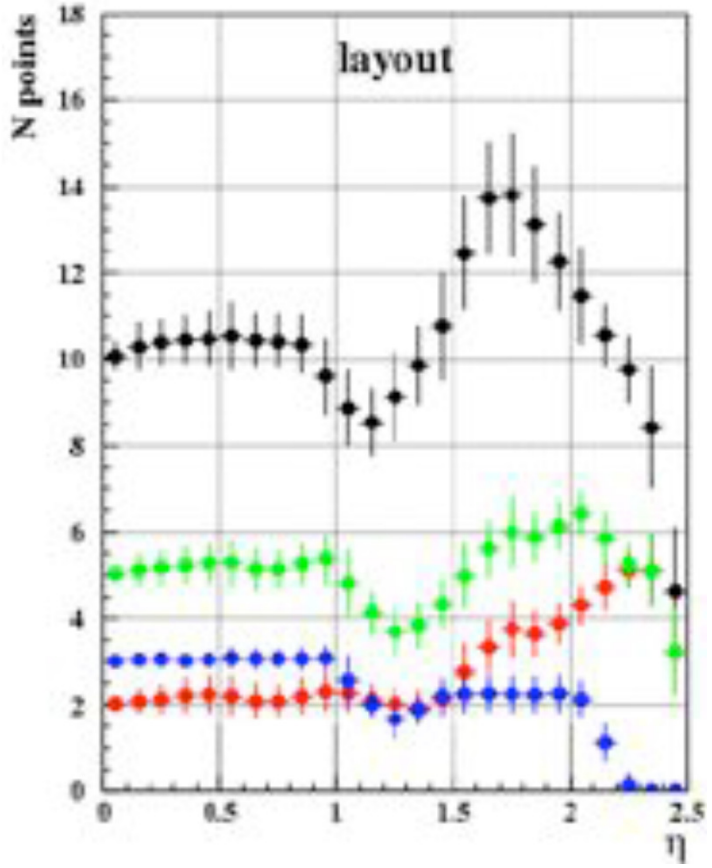




Tracking - I

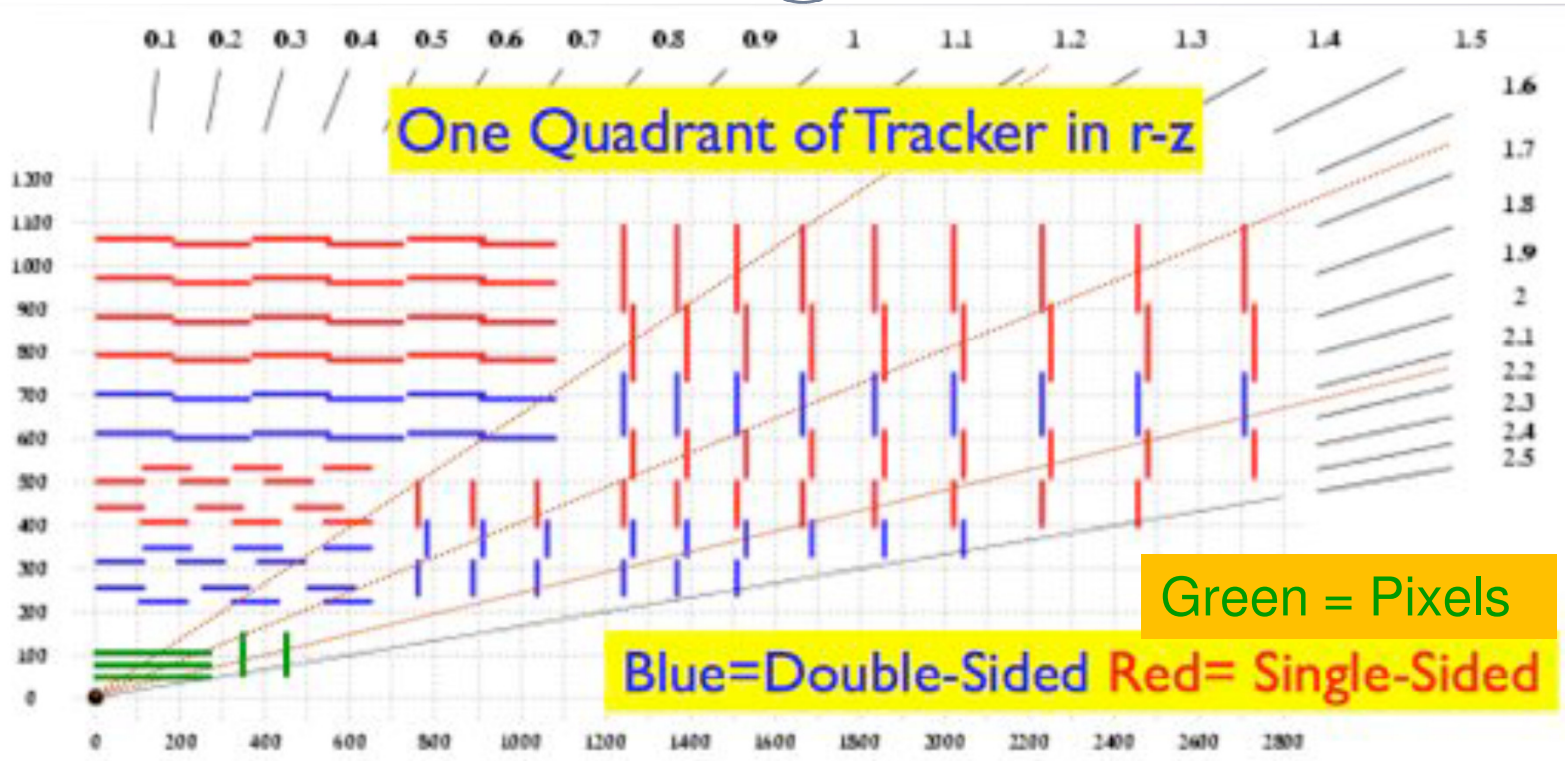

0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

Tracking - II



Sub-Detector	*Channels*
Pixels	66 x 10^6
Silicon microstrips	11.4 x 10^6
ECAL crystals	0.076 x 10^6
Preshower strips	0.137 x 10^6
HCAL	0.01 x 10^6
Muon chambers	0.576 x 10^6
TOTAL	78.2 x 10^6

Tracking - III



- 3 Barrel Pixel Layers, 2 Forward Pixel Disks
- 4 Inner Barrel Layers (TIB), 6 Outer Layers (TOB)
- 3 Forward Inner Disks (TID), 9 Outer Disks (TEC)

Tracking - IV

Pixels:

$$\underbrace{100\mu\text{m}\times 150\mu\text{m}}_{pad}\times\underbrace{300\mu\text{m}}_{thickness}$$

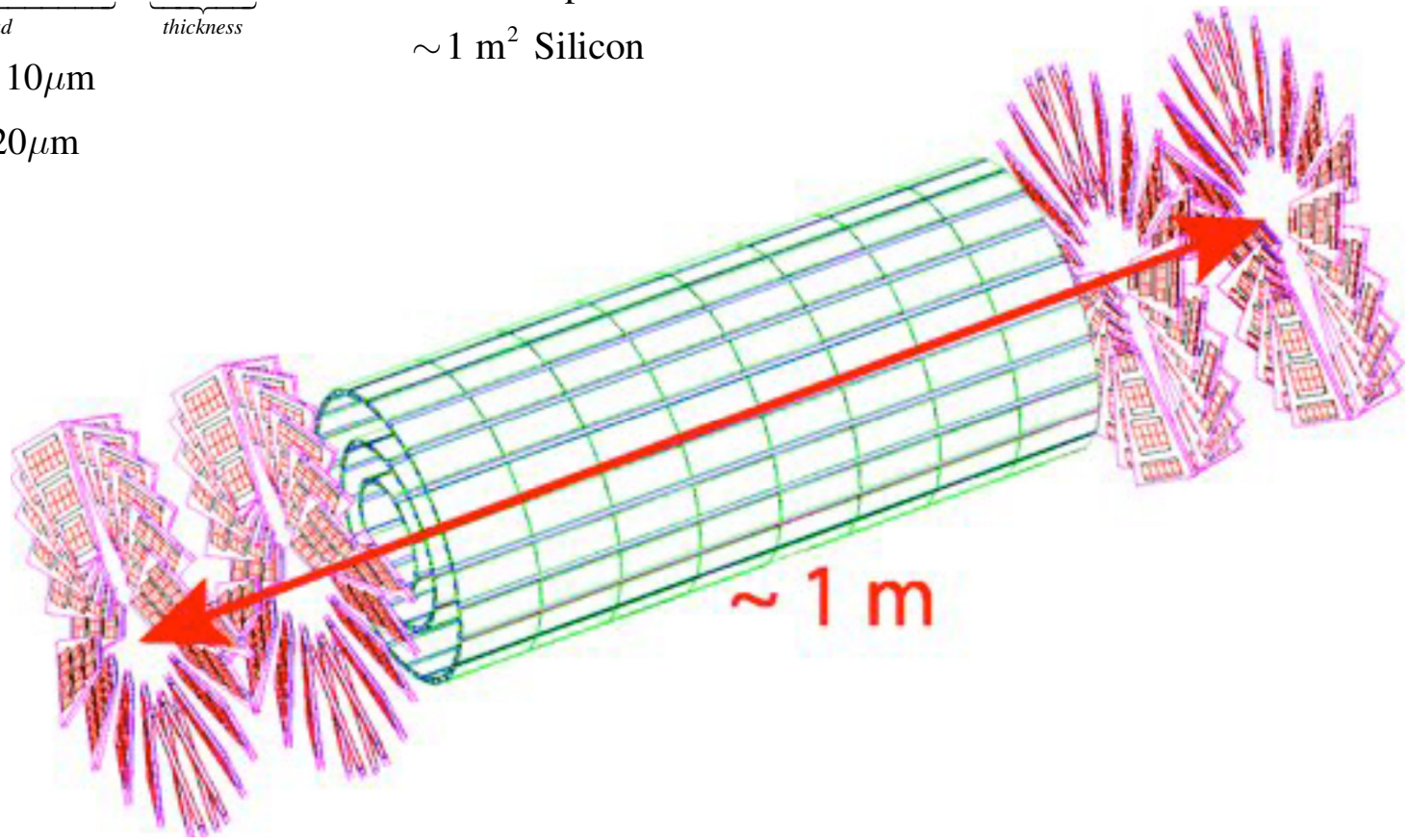
$$\sigma(r\phi)\sim 10\mu\text{m}$$

$$\sigma(z)\sim 20\mu\text{m}$$

Numbers:

$\sim 66\ 10^6$ pixels

$\sim 1\ \text{m}^2$ Silicon



Tracking - V

Strips:

$$\underbrace{10 \div 20\ \text{cm}}_{length} \times \underbrace{80 \div 200\ \mu\text{m}}_{pitch} \times \underbrace{320 \div 500\ \mu m}_{thickness}$$

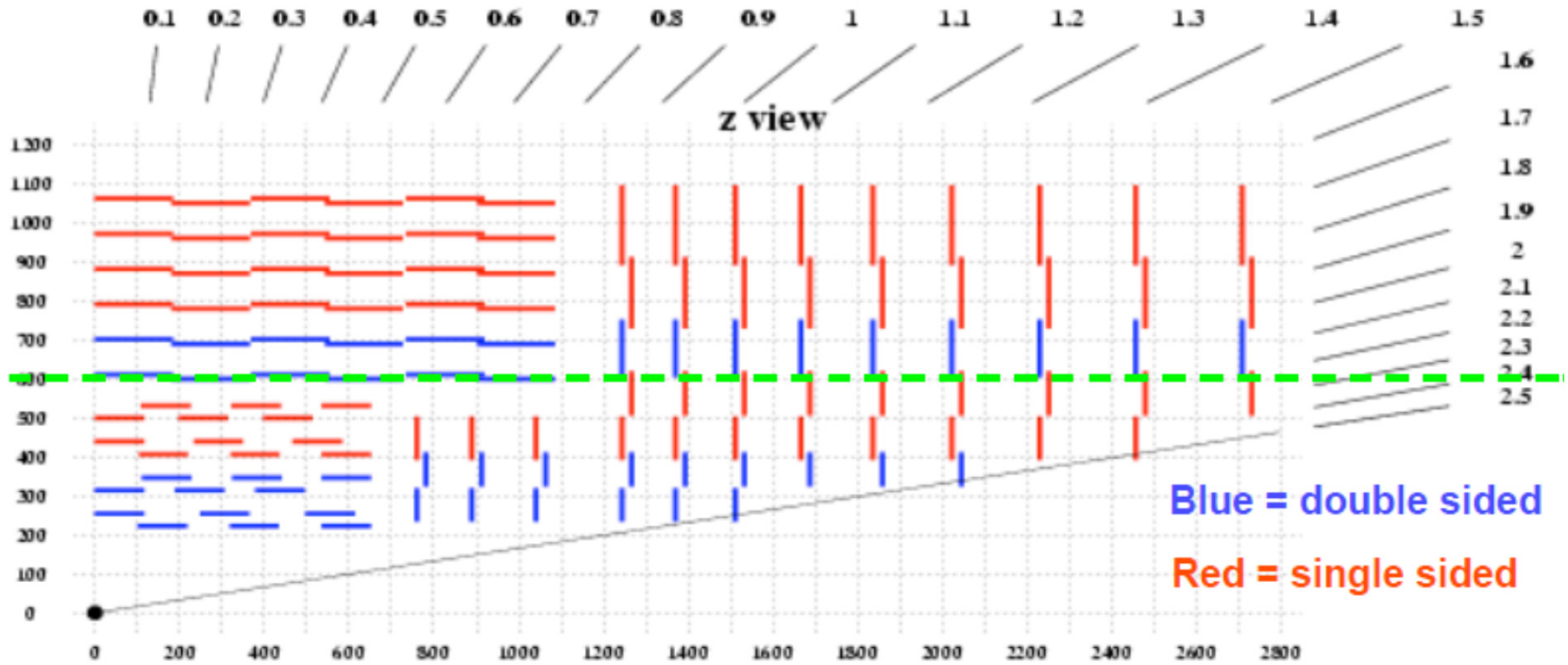
Numbers:

$\sim 10^7$ strips

$\sim 8\ 10^4$ readout chips

$\sim 25\ 10^6$ bonded wires

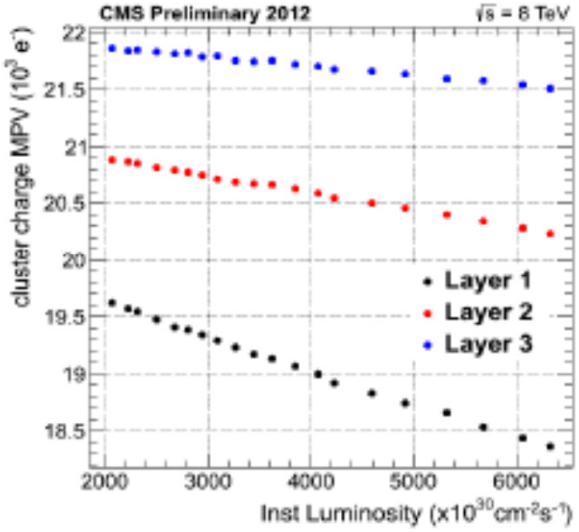
$\sim 200\ m^2$ / $\sim 100\ kg$ Silicon

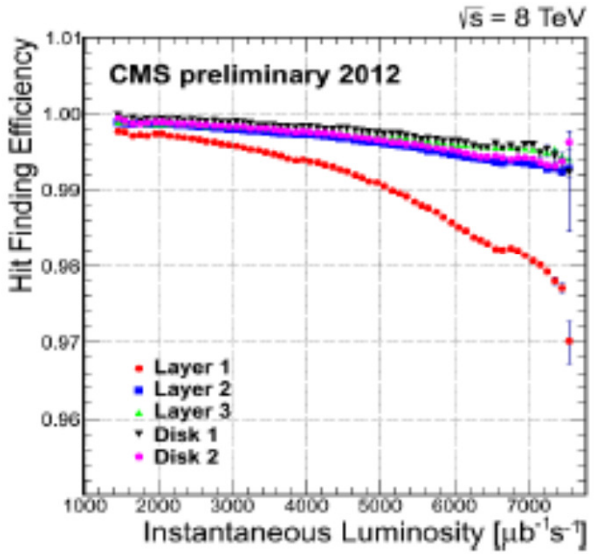


Tracking - VI

Effect of instantaneos luminosity:

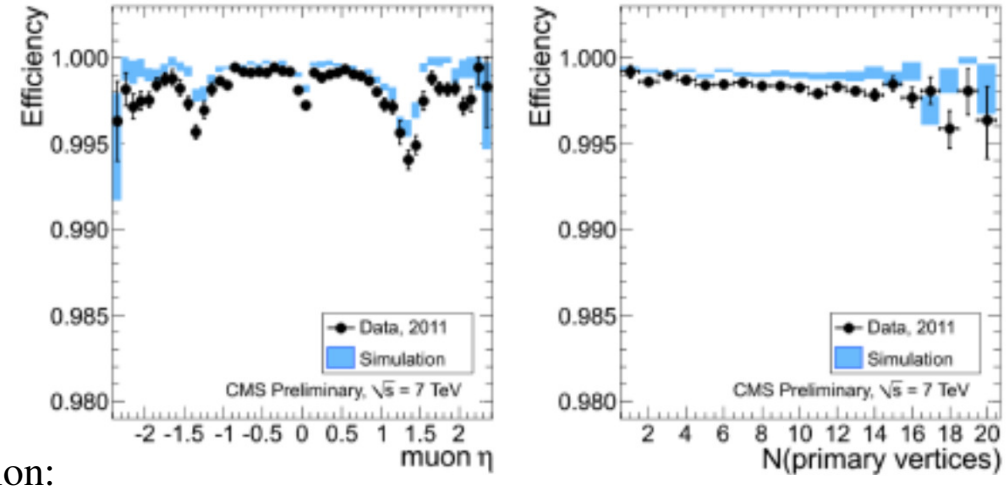
Calibration, Efficiency



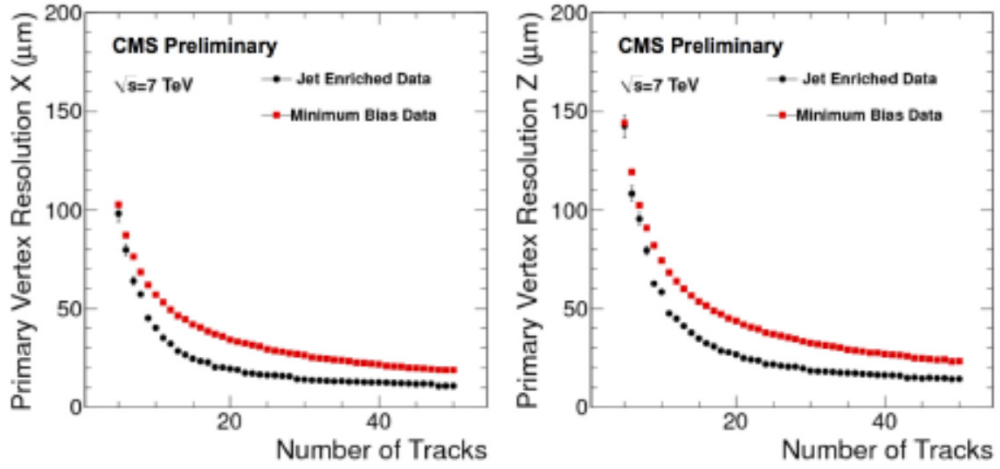


Tracking - VII

Muon efficiency:



Vertex resolution:



Electromagnetic Calorimetry - I

Typical performance (homogeneous):

Technology (Experiment)	Depth	Energy resolution	Date
NaI(Tl) (Crystal Ball)	$20X_0$	$2.7\%/\mathrm{E}^{1/4}$	1983
$Bi_4Ge_3O_{12}$ (BGO) (L3)	$22X_0$	$2\%/\sqrt{E} \oplus 0.7\%$	1993
CsI (KTeV)	$27X_0$	$2\%/\sqrt{E} \oplus 0.45\%$	1996
CsI(Tl) (BaBar)	16–$18X_0$	$2.3\%/E^{1/4} \oplus 1.4\%$	1999
CsI(Tl) (BELLE)	$16X_0$	1.7% for $E_\gamma > 3.5$ GeV	1998
$PbWO_4$ (PWO) (CMS)	$25X_0$	$3\%/\sqrt{E} \oplus 0.5\% \oplus 0.2/E$	1997
Lead glass (OPAL)	$20.5X_0$	$5\%/\sqrt{E}$	1990
Liquid Kr (NA48)	$27X_0$	$3.2\%/\sqrt{E} \oplus 0.42\% \oplus 0.09/E$	1998

Homogeneous

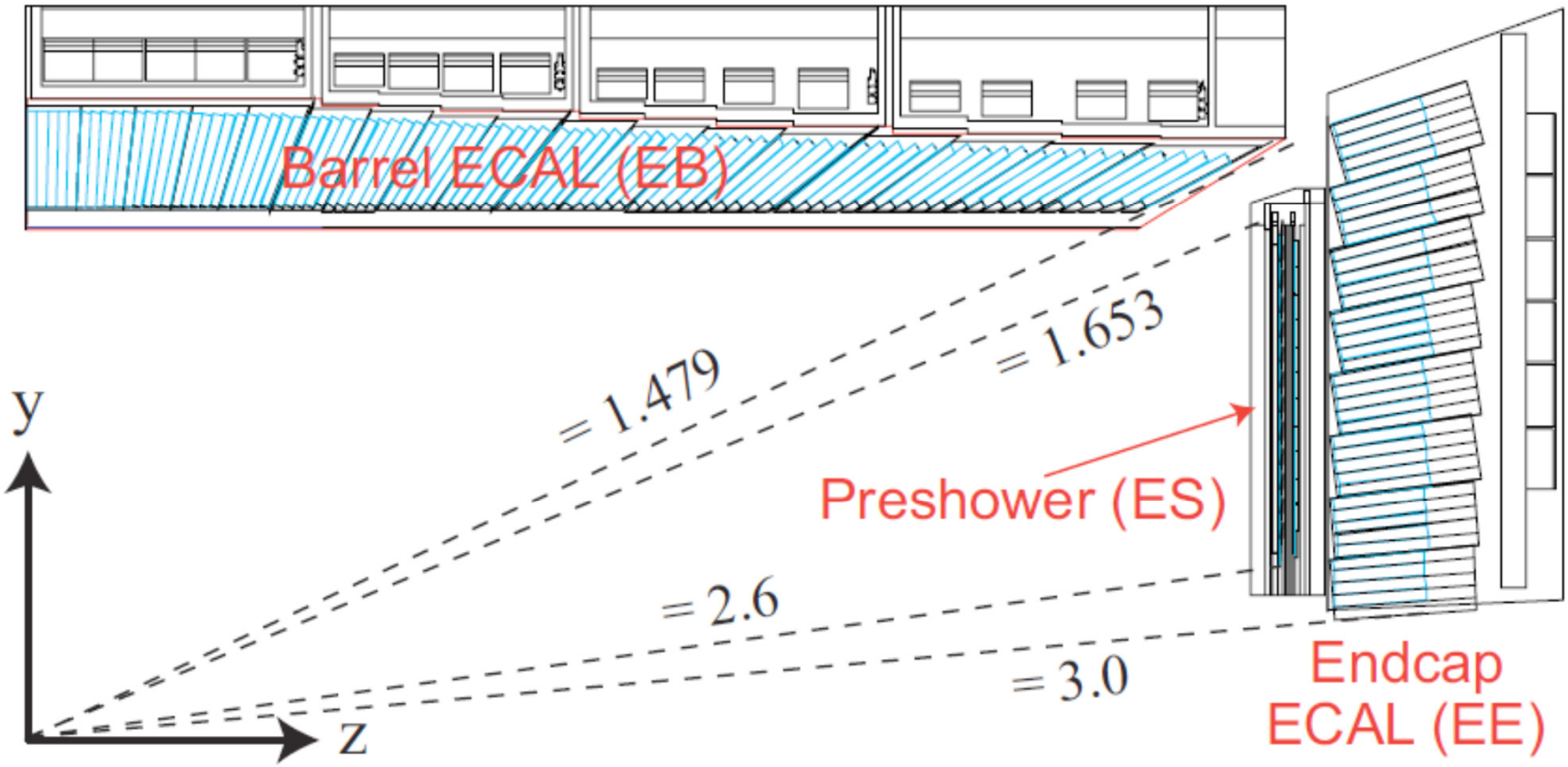
Electromagnetic Calorimetry - II

Typical performance (sampling):

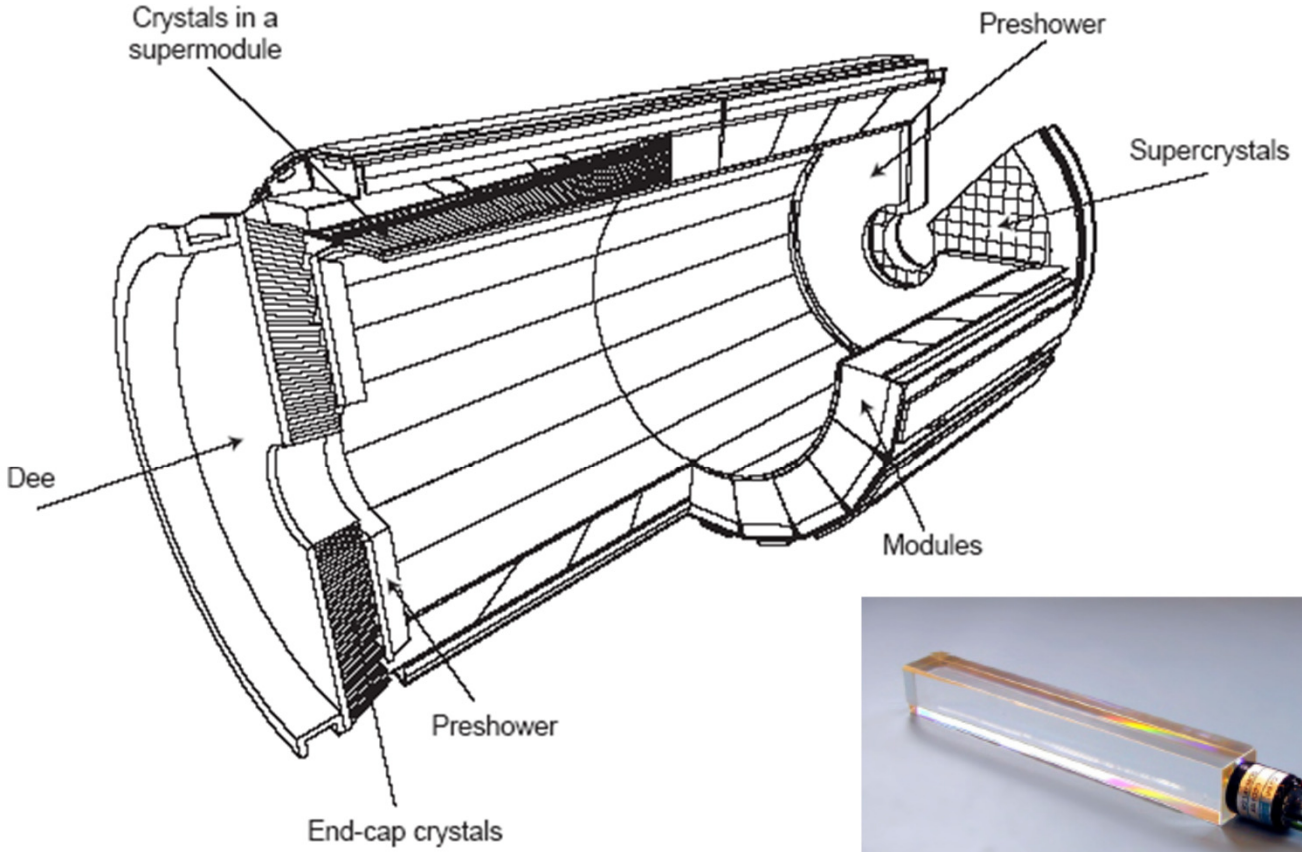
Technology (Experiment)	Depth	Energy resolution	Date
Scintillator/depleted U (ZEUS)	$20–30X_0$	$18\%/\sqrt{E}$	1988
Scintillator/Pb (CDF)	$18X_0$	$13.5\%/\sqrt{E}$	1988
Scintillator fiber/Pb spaghetti (KLOE)	$15X_0$	$5.7\%/\sqrt{E} \oplus 0.6\%$	1995
Liquid Ar/Pb (NA31)	$27X_0$	$7.5\%/\sqrt{E} \oplus 0.5\% \oplus 0.1/E$	1988
Liquid Ar/Pb (SLD)	$21X_0$	$8\%/\sqrt{E}$	1993
Liquid Ar/Pb (H1)	$20–30X_0$	$12\%/\sqrt{E} \oplus 1\%$	1998
Liquid Ar/depl. U (DØ)	$20.5X_0$	$16\%/\sqrt{E} \oplus 0.3\% \oplus 0.3/E$	1993
Liquid Ar/Pb accordion (ATLAS)	$25X_0$	$10\%/\sqrt{E} \oplus 0.4\% \oplus 0.3/E$	1996

Sampling

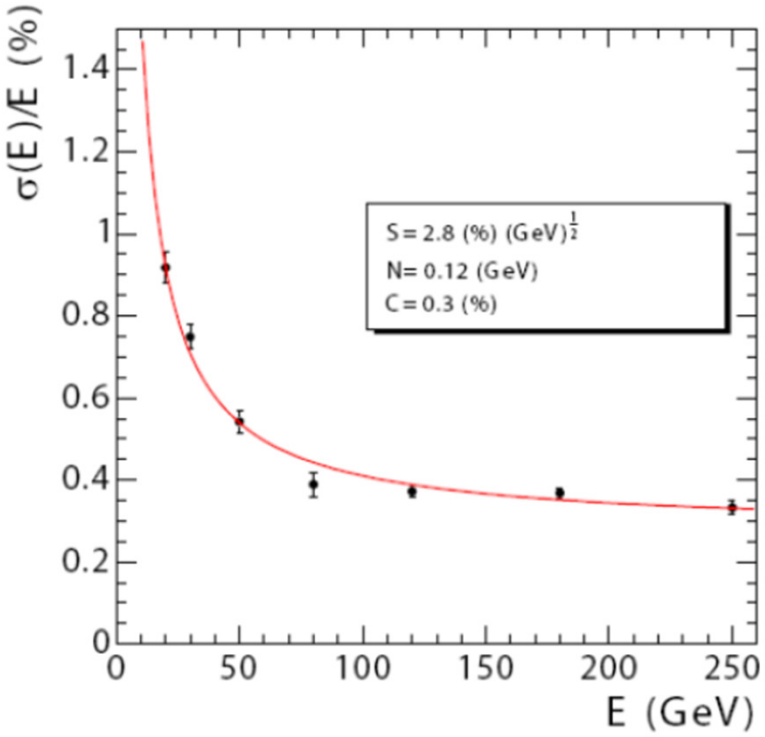
Electromagnetic Calorimetry - III



Electromagnetic Calorimetry - IV



Electromagnetic Calorimetry - V



$$(\frac{\sigma}{E})^2 = (\frac{S}{\sqrt{E}})^2 + (\frac{N}{E})^2 + C^2$$

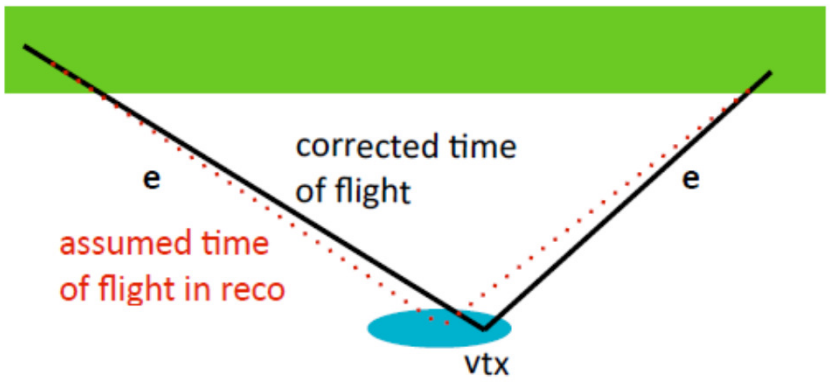
S: Shower fluctuactions
N: Electronic noise
C: Intercalibration

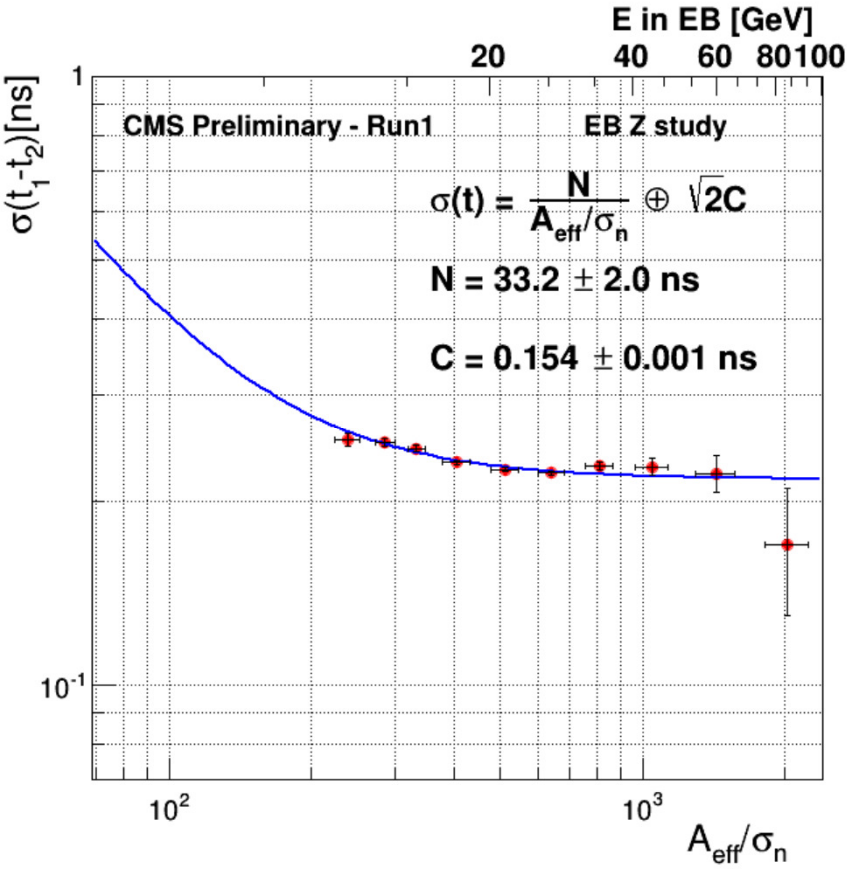
$$\left.\frac{\sigma_E}{E}\right|_{E=50GeV} \sim 0.5\% \rightarrow \frac{\sigma_M}{M} \sim .7\%$$

$$\rightarrow \frac{\sigma_{\langle M \rangle}}{\langle M \rangle} \sim 1\text{‰} \quad \rightarrow \quad \sigma_M \geq 130\ MeV$$

Electromagnetic Calorimetry - VI

Time resolution: From Z decays to electron + positron





Electromagnetic Calorimetry - VII

Laser used to calibrate out time dependent effects

Stability monitored with W electrons:0.1 (0.4)%

Global scale from π^0, η and Z decays