8.882 LHC Physics

Experimental Methods and Measurements

Detectors: Muons

[Lecture 11, March 11, 2009]

Organization

Project 1 (charged track multiplicity)

- no one handed in so far... well deadline is tomorrow

Recitation this week

- usual time: 12pm at MIT == 17:00 CERN

Project 2 (upsilon cross section)

- project is out
- due April 6

Physics Colloquium Series

'09 Spring

The Physics Colloquium Series

Thursday, March 12 at ***4:15 pm*** *in room* ***10-250***

Margaret Murnane

JILA, University of Colorado at Boulder and NIST

"Harnessing Attosecond Science in the Quest for Coherent X-Rays "

For a full listing of this semester's colloquia, please visit our website at **web.mit.edu/physics**

Lecture Outline

Detectors: Electron/Muon Detection and Particle Id

- electromagnetic calorimetry
- muon chambers
- particle identification systems
  - dE/dx in drift chamber
  - TOF – Time-Of-Flight detectors
  - RICH – Ring Imaging CHerenkov detectors
  - DIRC – Detection of Internal Reflected Cherenkov light

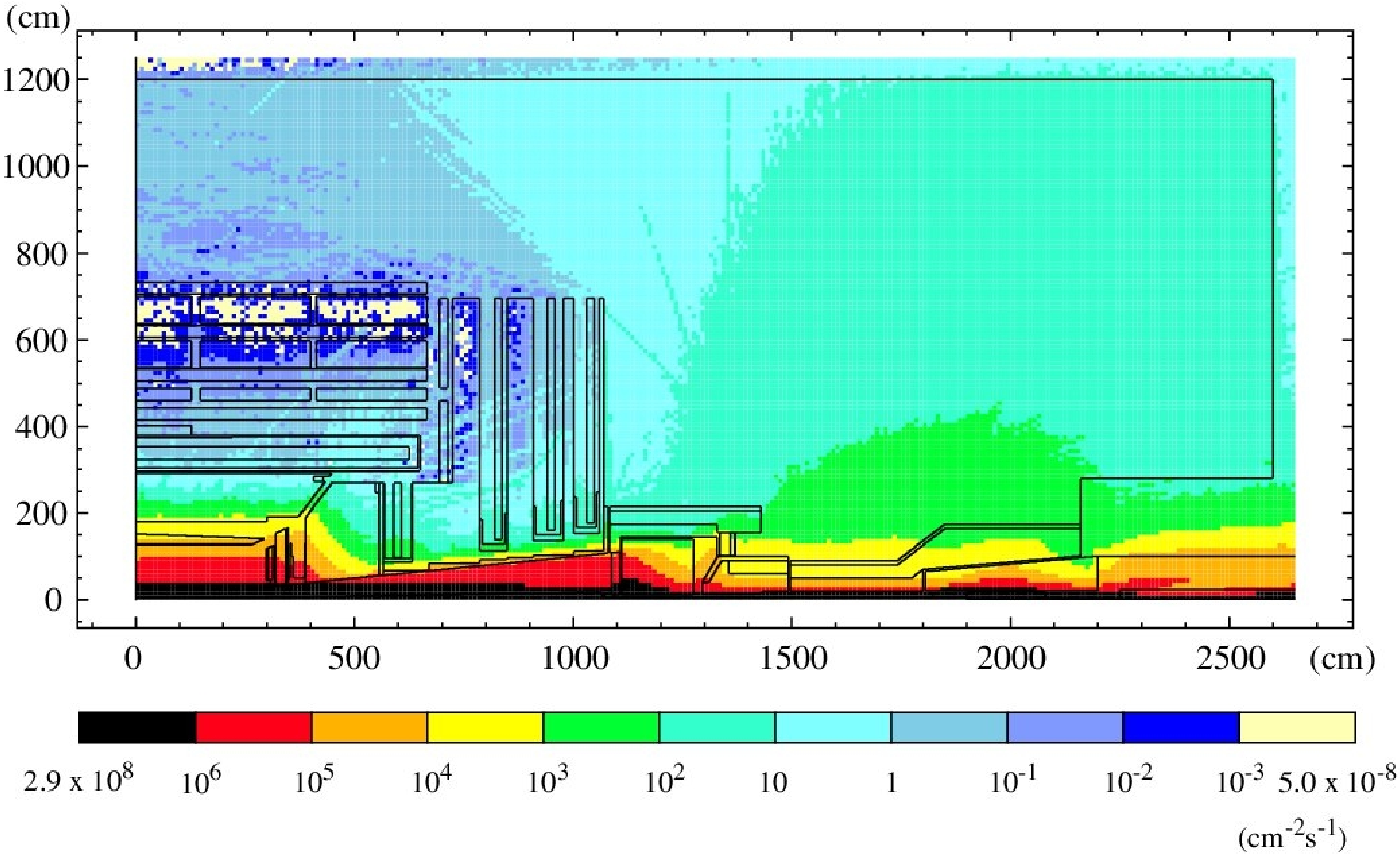
Why Muons and Electrons?

Leptons

- rare in *pp* (<1% of the tracks), often related to very interesting physics processes
- taus special case (m = 1.777 GeV, $c\tau$ = 87.11 μm)
  - decay well before they reach the silicon detector, lifetime more then a factor of five smaller then for *B* mesons
  - can also produce hadrons in decay, more difficult to identify
  - always involve neutrino in decay (incomplete reconstruction)
- muons have very characteristic signature
  - penetrate the calorimetry, are detected in the muon chambers
  - leave minimally ionizing signature
- electrons have very characteristic signature
  - maximal ionization in tracking system
  - get absorbed completely in ECAL no signature in the HCAL
  - shower shape in ECAL is short and broad

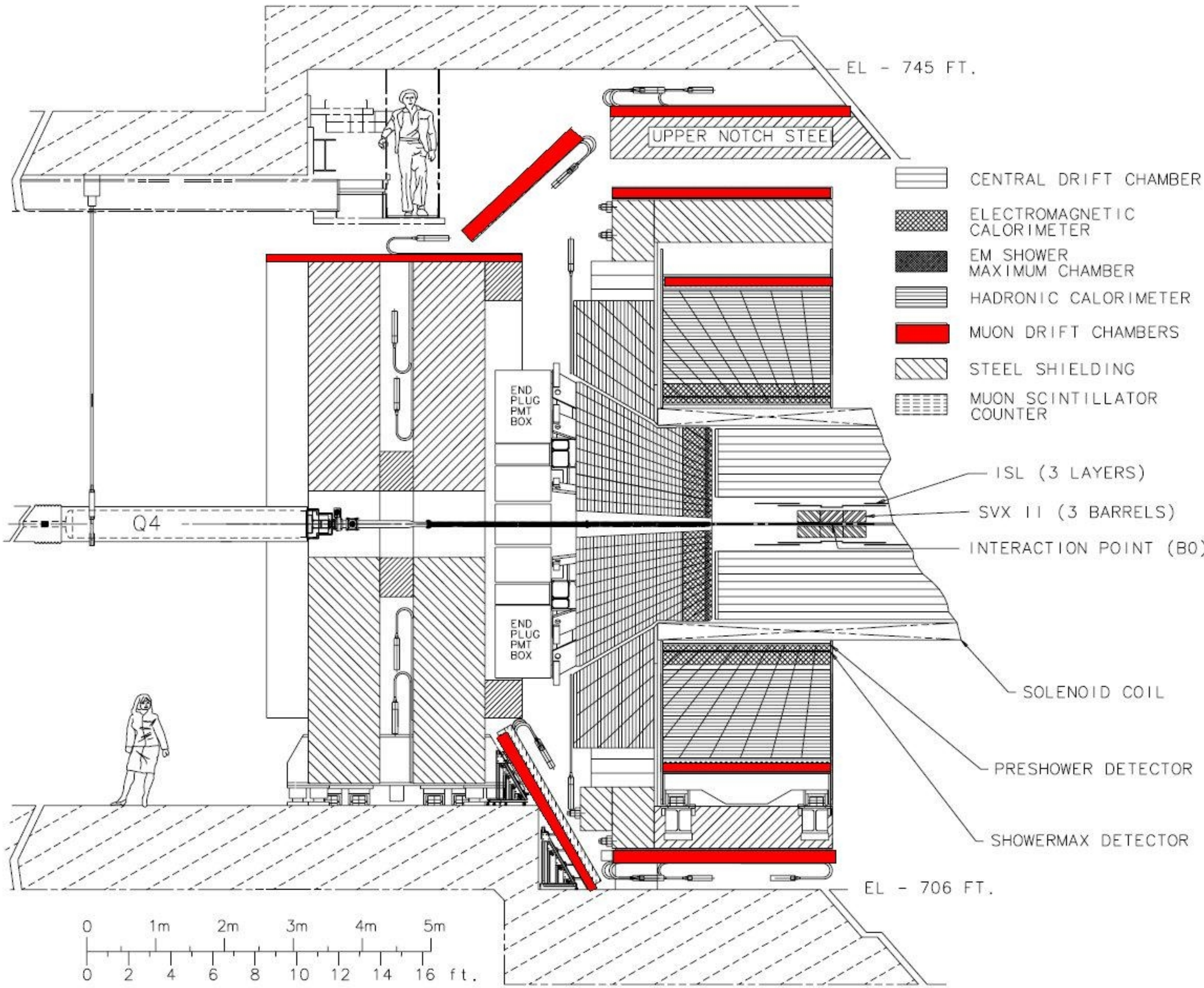
Particle Flux Predicted for CMS

Charged particle flux (hadrons and muons) at full LHC lumi (10^{34} $cm^{-2}s^{-1}$) from simulation



CDF Muon Detection System

Muon detection starts at the muon chambers



CMU

- on HCAL
- $|\eta| < 0.6$

CMUP

- add steel
- $|\eta| < 0.6$

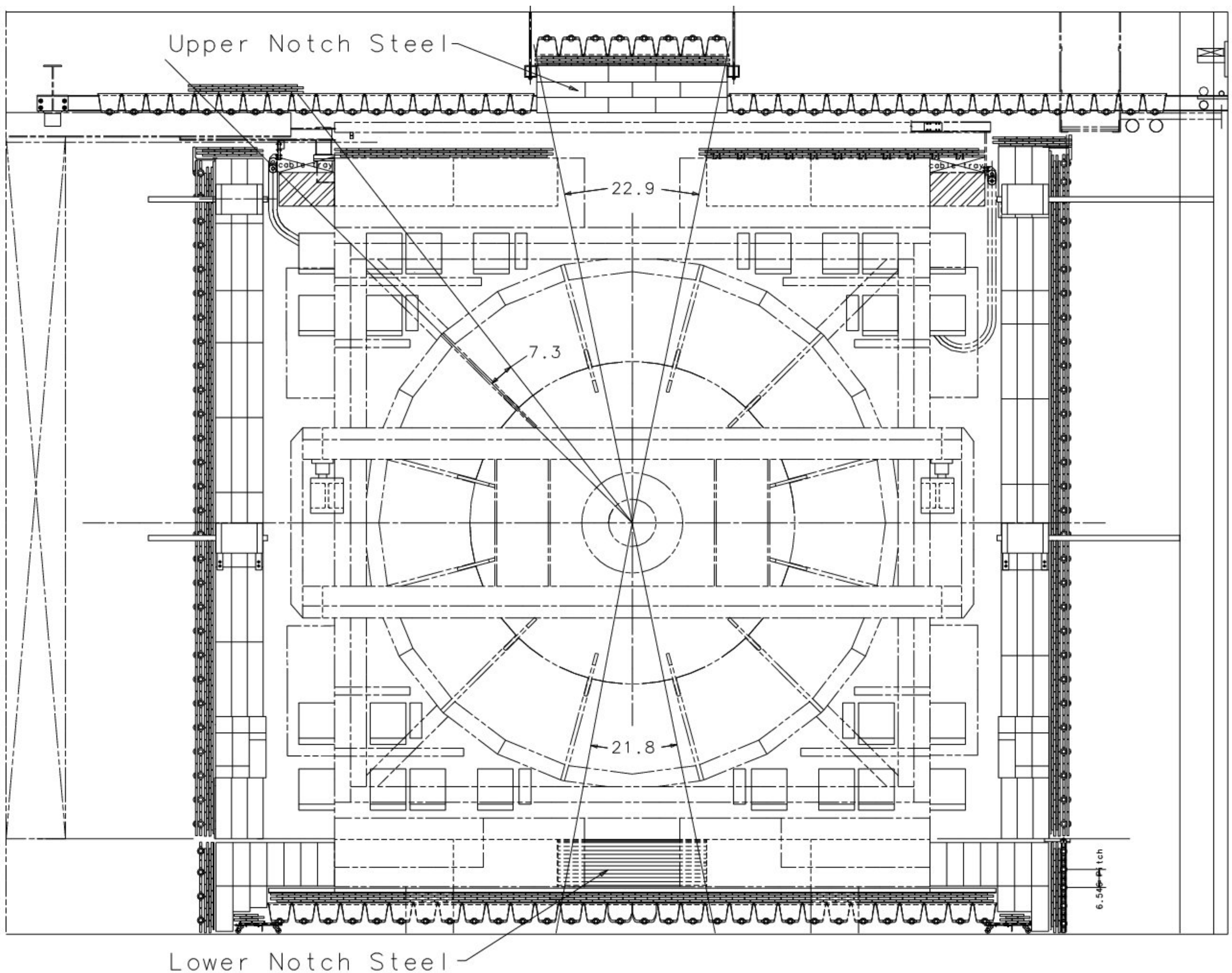
CMX

- $0.6<|\eta|<1.0$

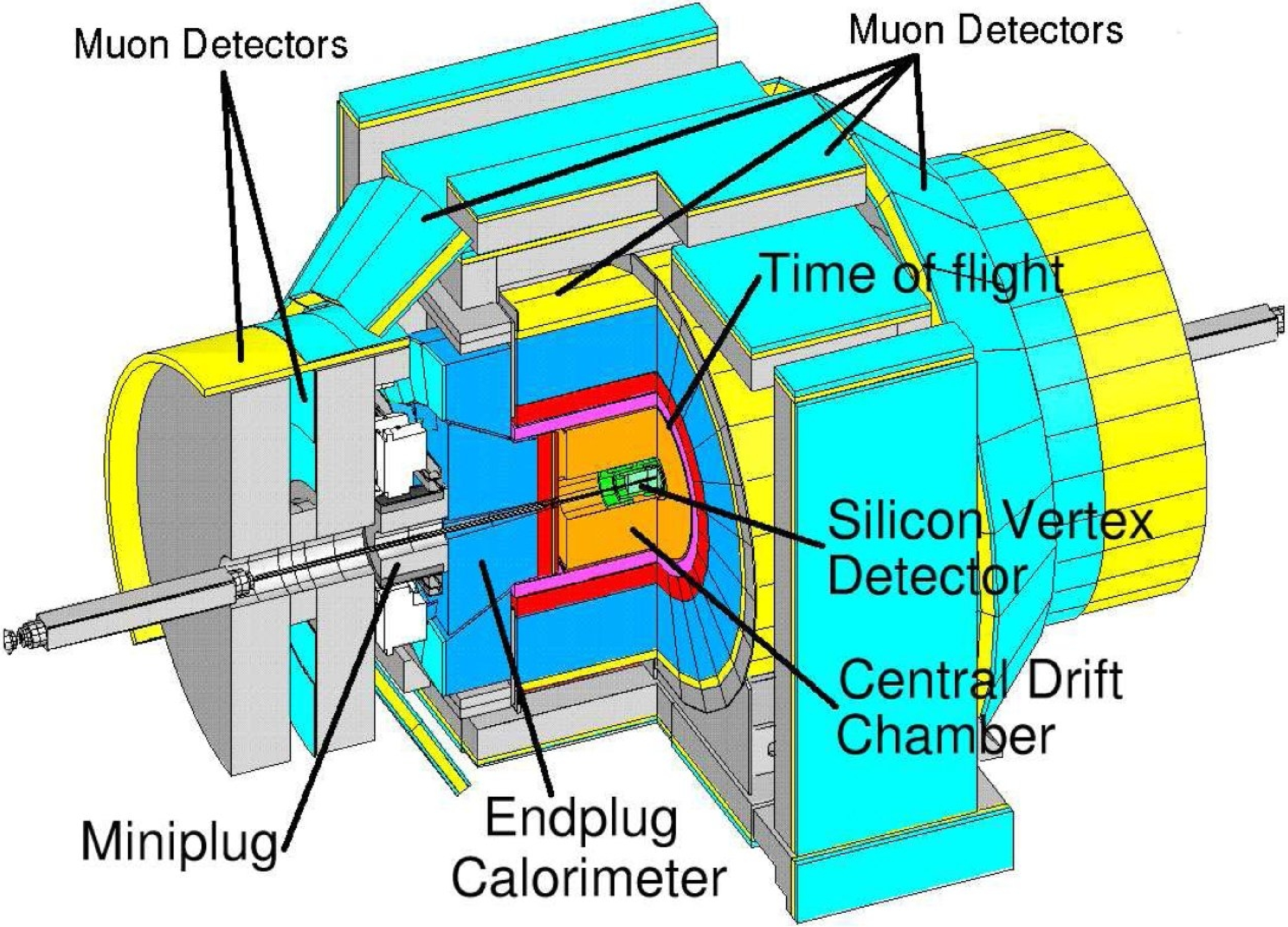
IMU

- $1.0<|\eta|<1.5$
- no trigger

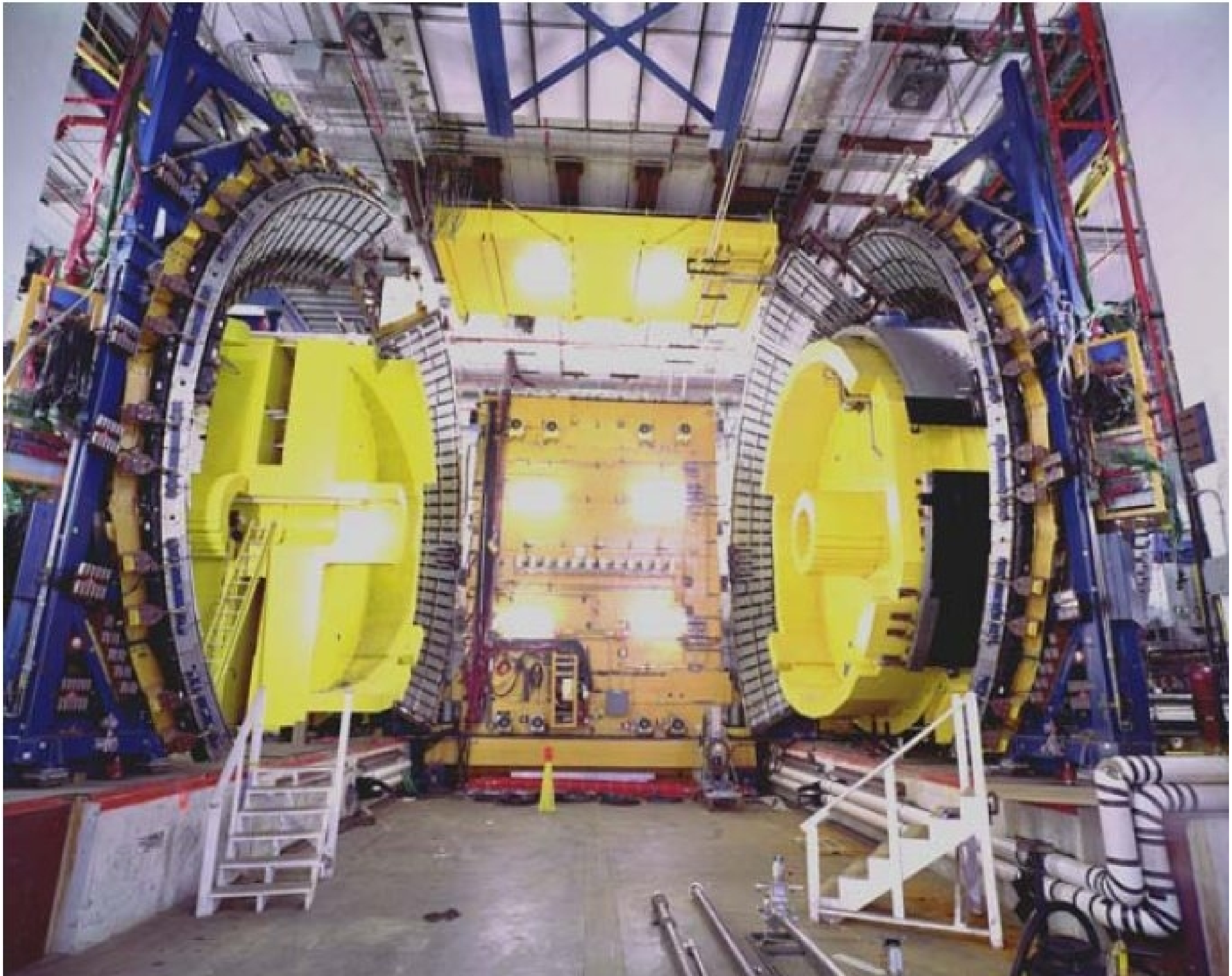
CDF Muon Detection System



CDF Muon Detection System



CDF Muon Detection System



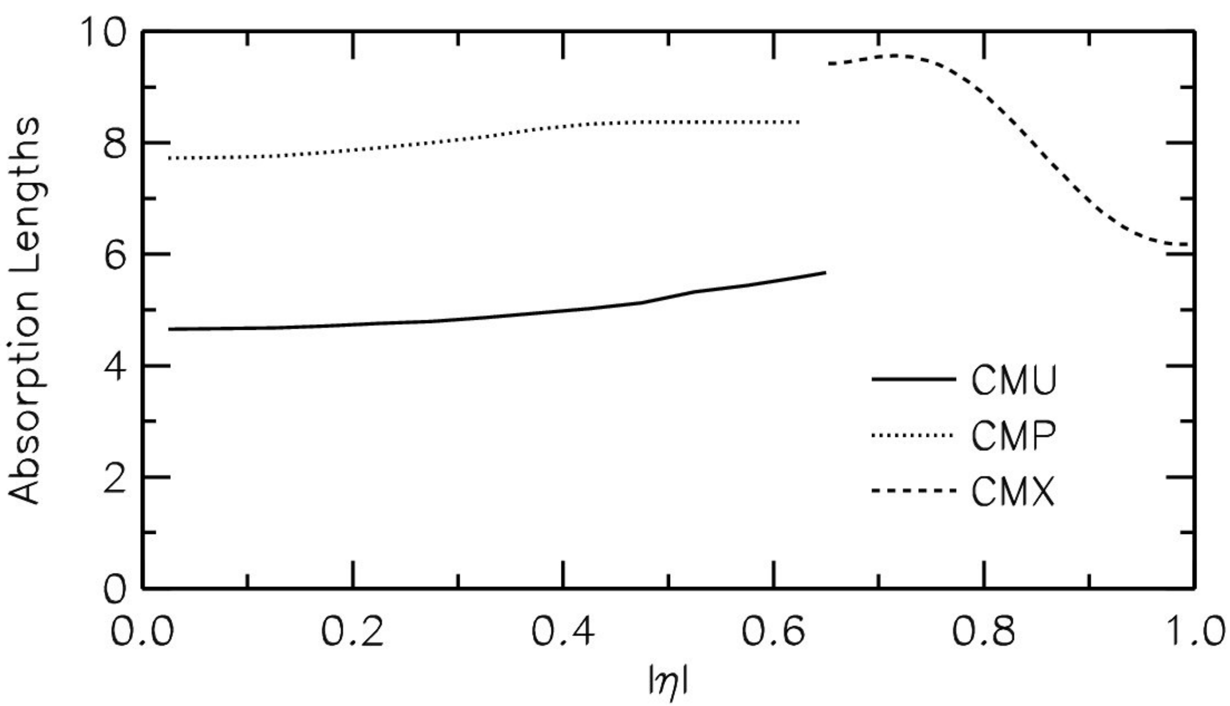
CDF Muon Detection System

More details on CMU(P)/CMX:

- up to 8 drift chamber planes
- 1-2 scintillator layers
- incorporated in the trigger (low+high momentum muons)

More details on IMU

- 4 planes of drift chambers
- 2 scintillator layers
- high backgrounds prevent triggering on those counters



CDF Muon Detection System

	CMU	CMP/CSP	CMX/CSX	IMU
Pseudo-rapidity coverage	$\|\eta\| \leq\sim 0.6$	$\|\eta\| \leq\sim 0.6$	$\sim 0.6 \leq \|\eta\| \leq\sim 1.0$	$\sim 1.0 \leq \|\eta\| \leq\sim 1.5$
Drift tube cross-section	2.68 x 6.35 cm	2.5 x 15 cm	2.5 x 15 cm	2.5 x 8.4 cm
Drift tube length	226 cm	640 cm	180 cm	363 cm
Max drift time	800 ns	1.4 μs	1.4 μs	800 ns
Total drift tubes (present)	2304	864	1536	none
Total drift tubes (Run II)	2304	1076	2208	1728
Scintillation counter thickness		2.5 cm	1.5 cm	2.5 cm
Scintillation counter width		30 cm	30-40 cm	17 cm
Scintillation counter length		320 cm	180 cm	180 cm
Total counters (present)		128	256	none
Total counters (Run II)		269	324	864
Pion interaction lengths	5.5	7.8	6.2	6.2-20
Minimum detectable muon p_T	1.4 GeV/c	2.2 GeV/c	1.4 GeV/c	1.4-2.0 GeV/c
Multiple scattering resolution	12 cm/p (GeV/p)	15 cm/p	13 cm/p	13-25 cm/p

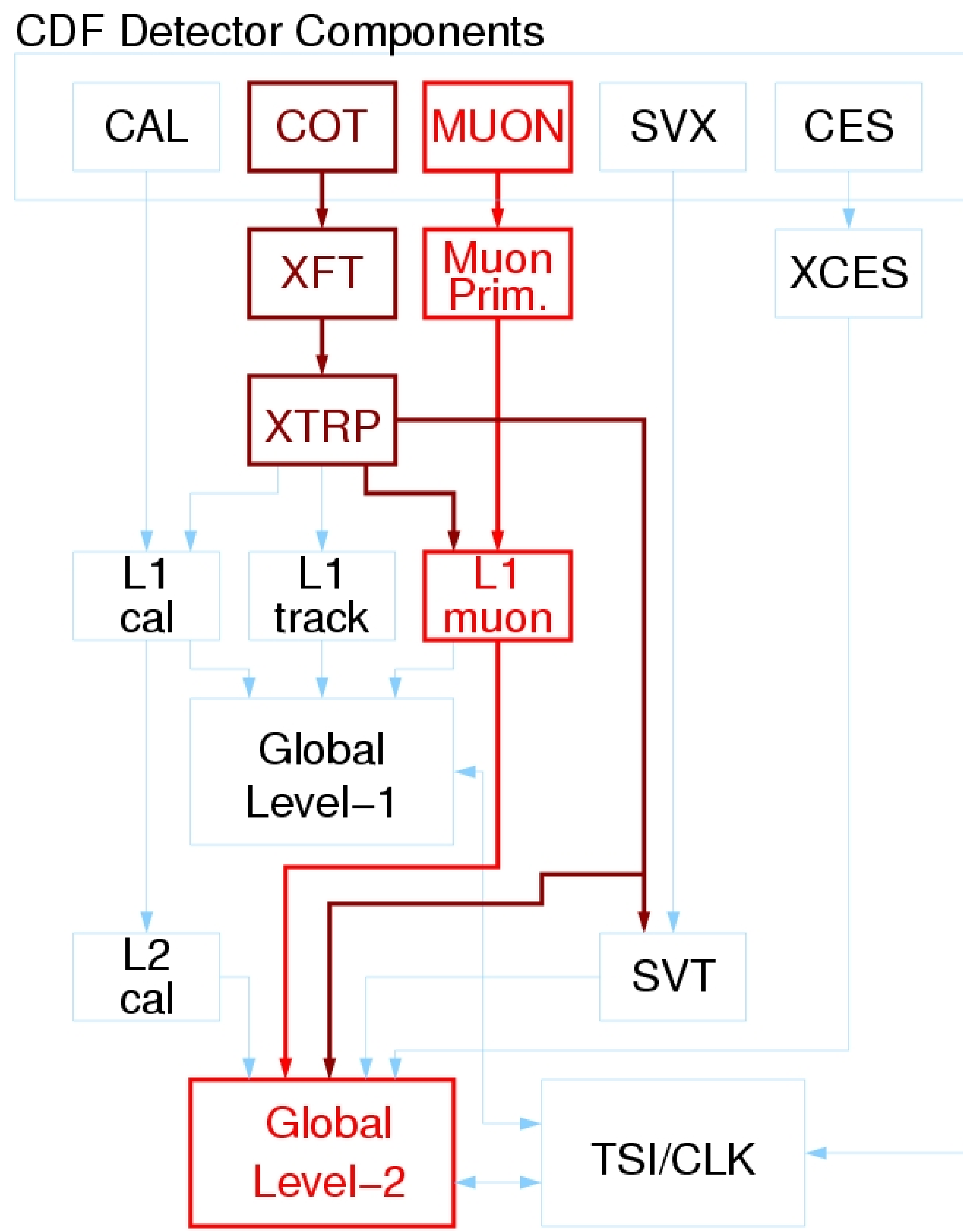
Table 1.4: Design Parameters of the CDF II Muon Detectors. Pion interaction lengths and multiple scattering are computed at a reference angle of $\theta = 90°$ in CMU and CMP/CSP, at an angle of $\theta = 55°$ in CMX/CSX, and show the range of values for the IMU.

taken from the design report for the CDF II detector

CDF Muon Triggers

Trigger at hadron colliders
ex. Tevatron, LHC

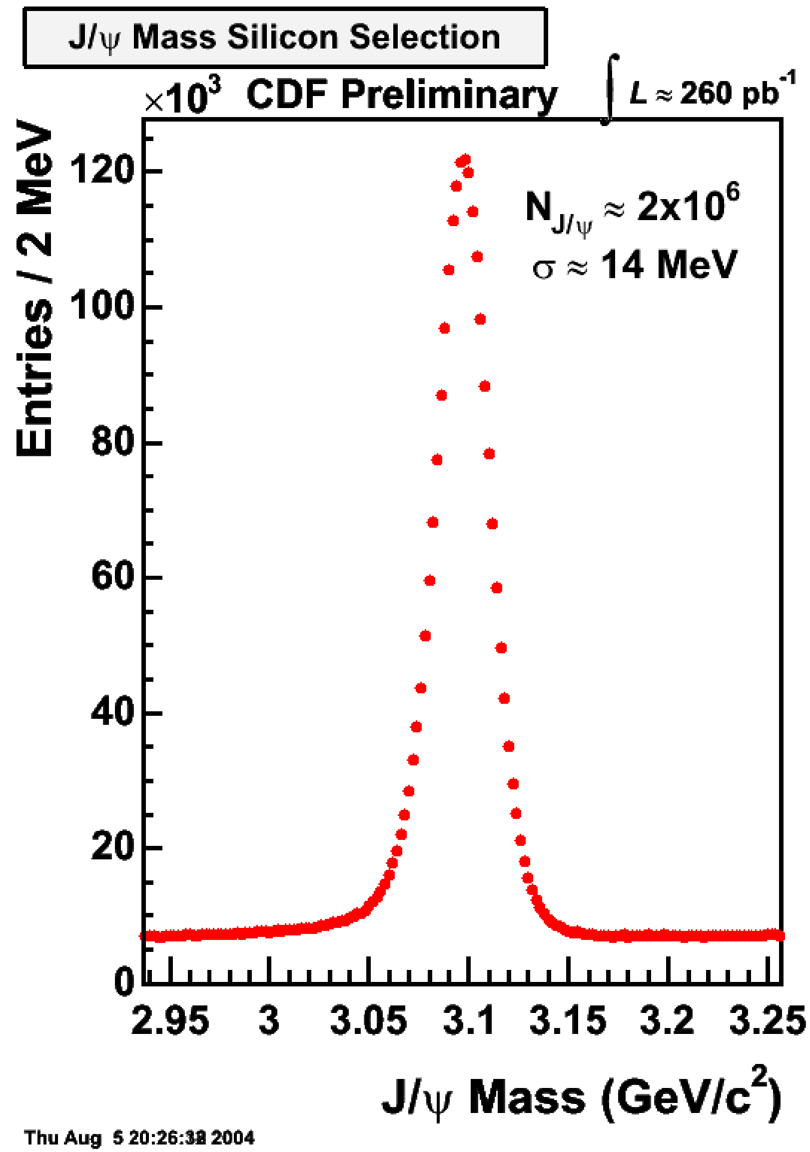
- collision rate 3-40 MHz
- writing rate: order 100 Hz
- trigger absolutely crucial to see muons
- muons are ideal candidate for trigger
- muons often connected to interesting physics
- muon trigger in CDF already at level 1 needs tracker information



Muons for the Analysis

How do I get a clean and unbiased muon?

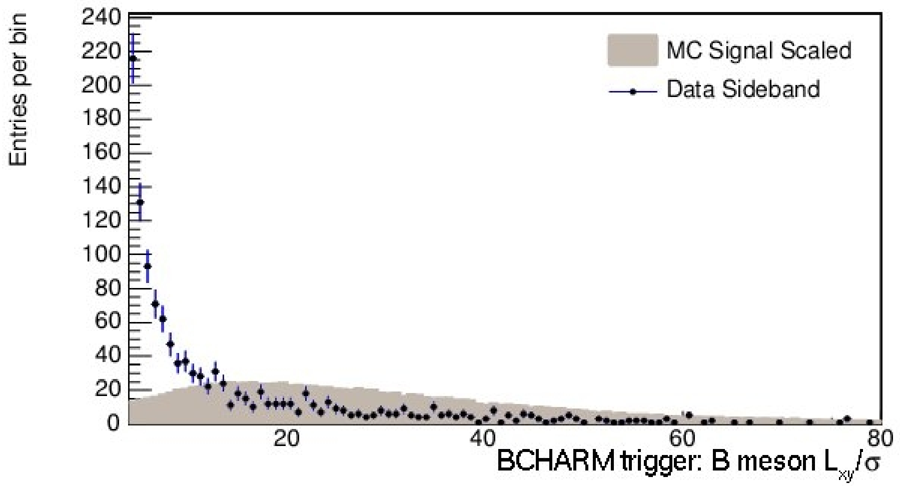
- no way for single muon
  - irreducible background
    - decays (kaons, pions)
    - punch though, sail through
- clean muon?
  - use clean muon based signal
    - $J/\psi \rightarrow \mu\mu$, many, O(10M)
    - Upsilon $\rightarrow \mu\mu$, higher momenta
  - apply sideband subtraction
  - subtract irreducible background
- unbiased muon? (trigger)
  - use single muon trigger
  - use independent trigger

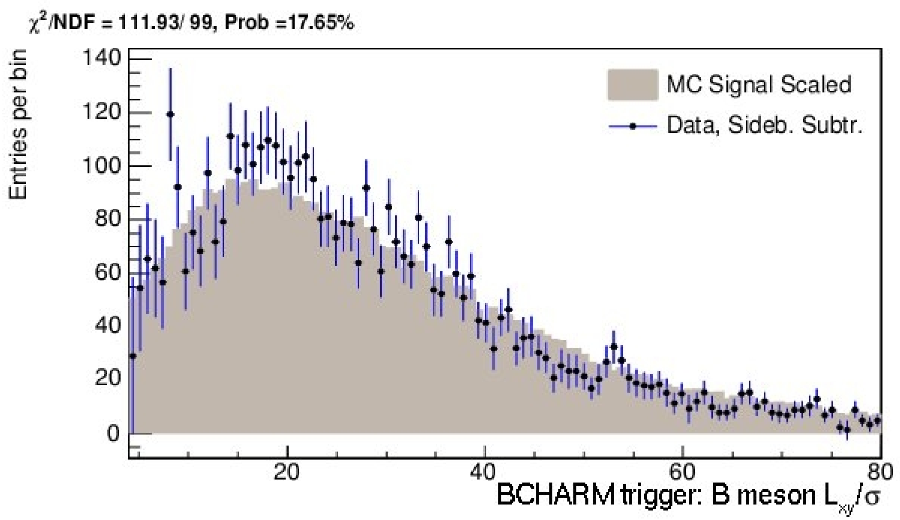


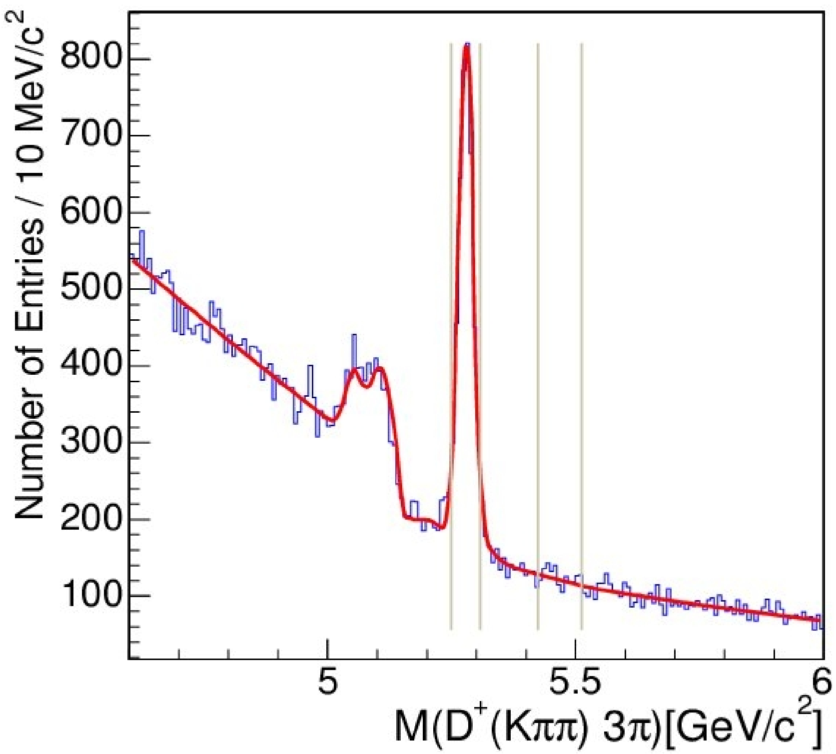
Example for Sideband Subtraction

Determine primary distribution (mostly masses)

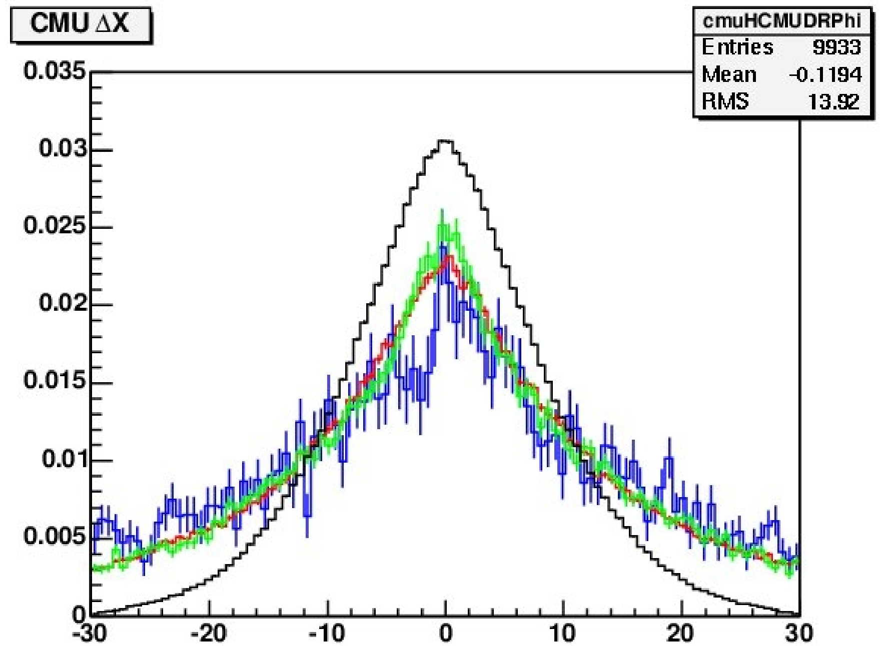
- select signal, sideband areas
- make histograms for both areas
- scale sideband and subtract from signal area plot

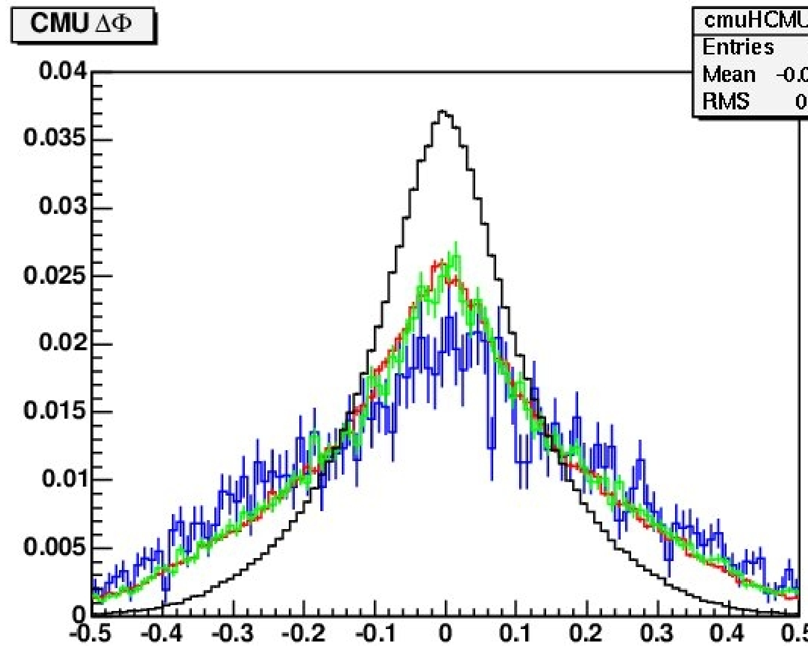


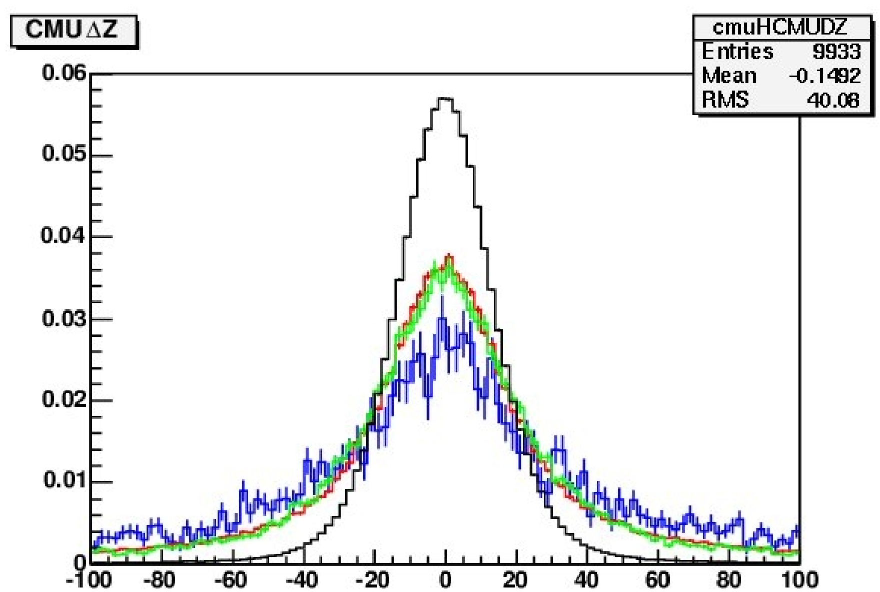




Muon Signatures in Muon Detector





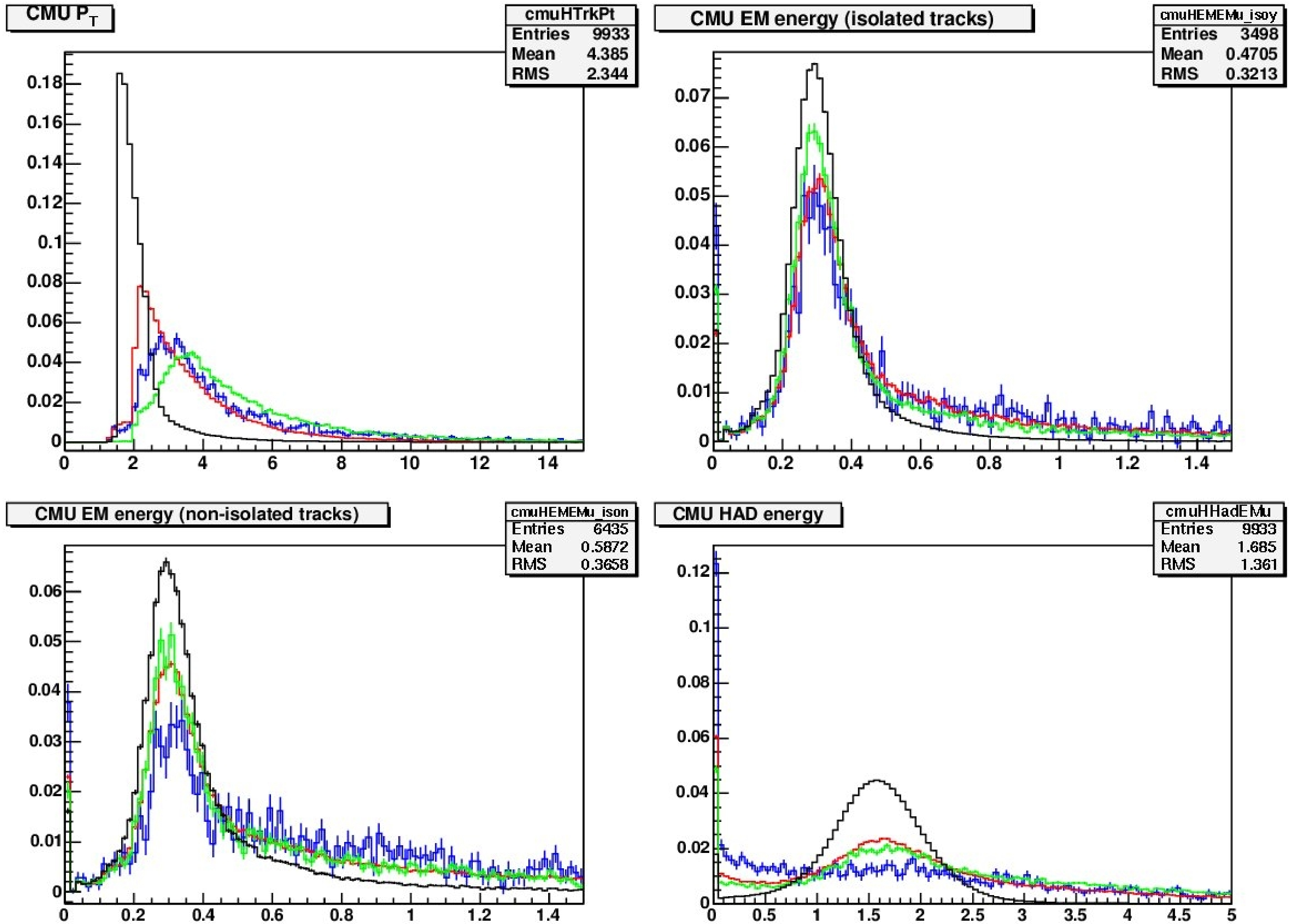


Colors: muon, pion, kaon, proton

Distance of muon stub from extrapolated position

Tracker is needed

Signature in Non-Muon Detectors

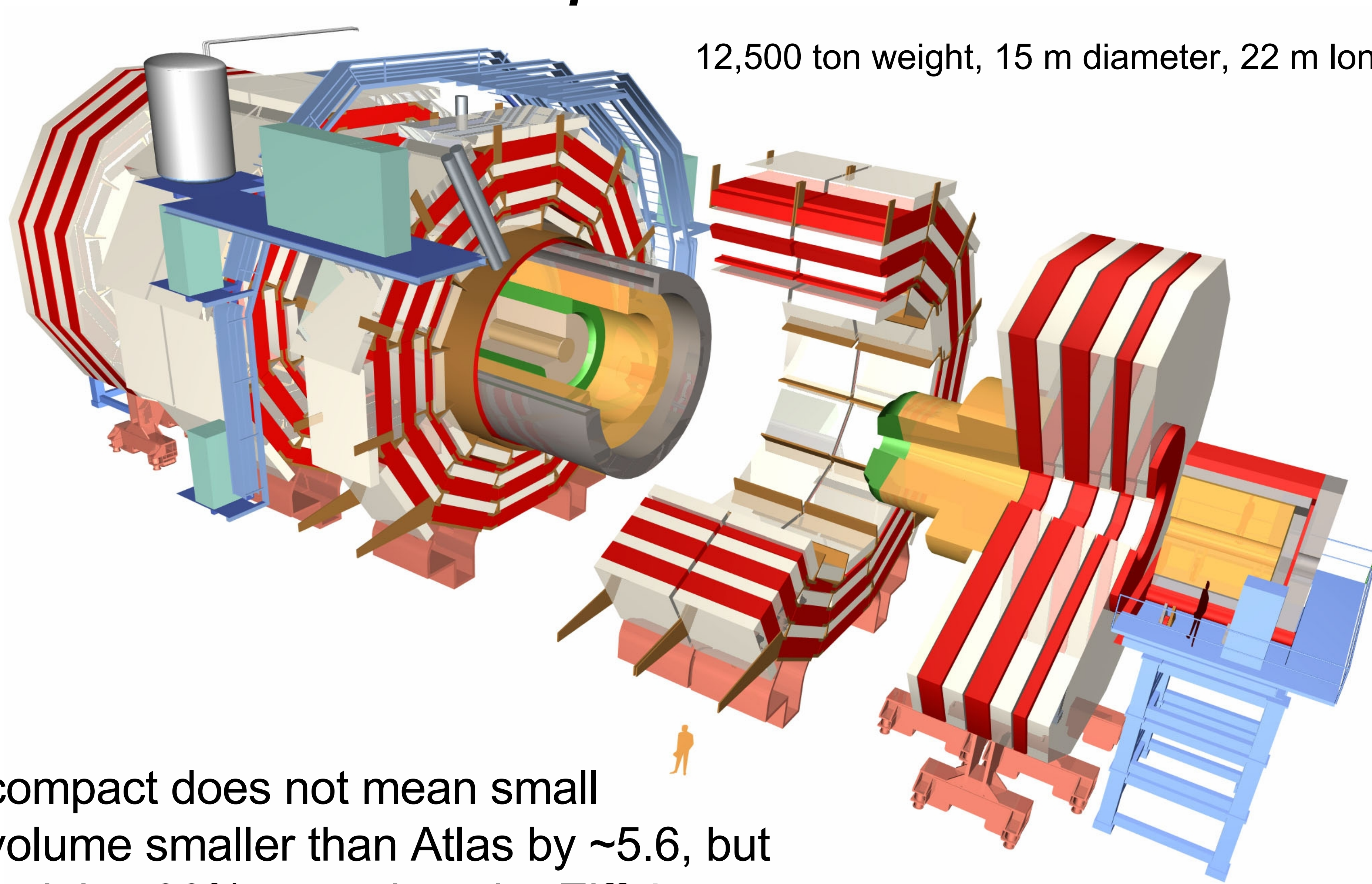


Colors: muon, pion, kaon, proton

Look at CMS

the future

CMS – Compact Muon Solenoid



12,500 ton weight, 15 m diameter, 22 m long

compact does not mean small
volume smaller than Atlas by ~5.6, but
weights 30% more than the Eiffel tower
eye catcher: brilliant design in separately removable slices

CMS Muon Systems

Drift Tubes, DT, barrel only

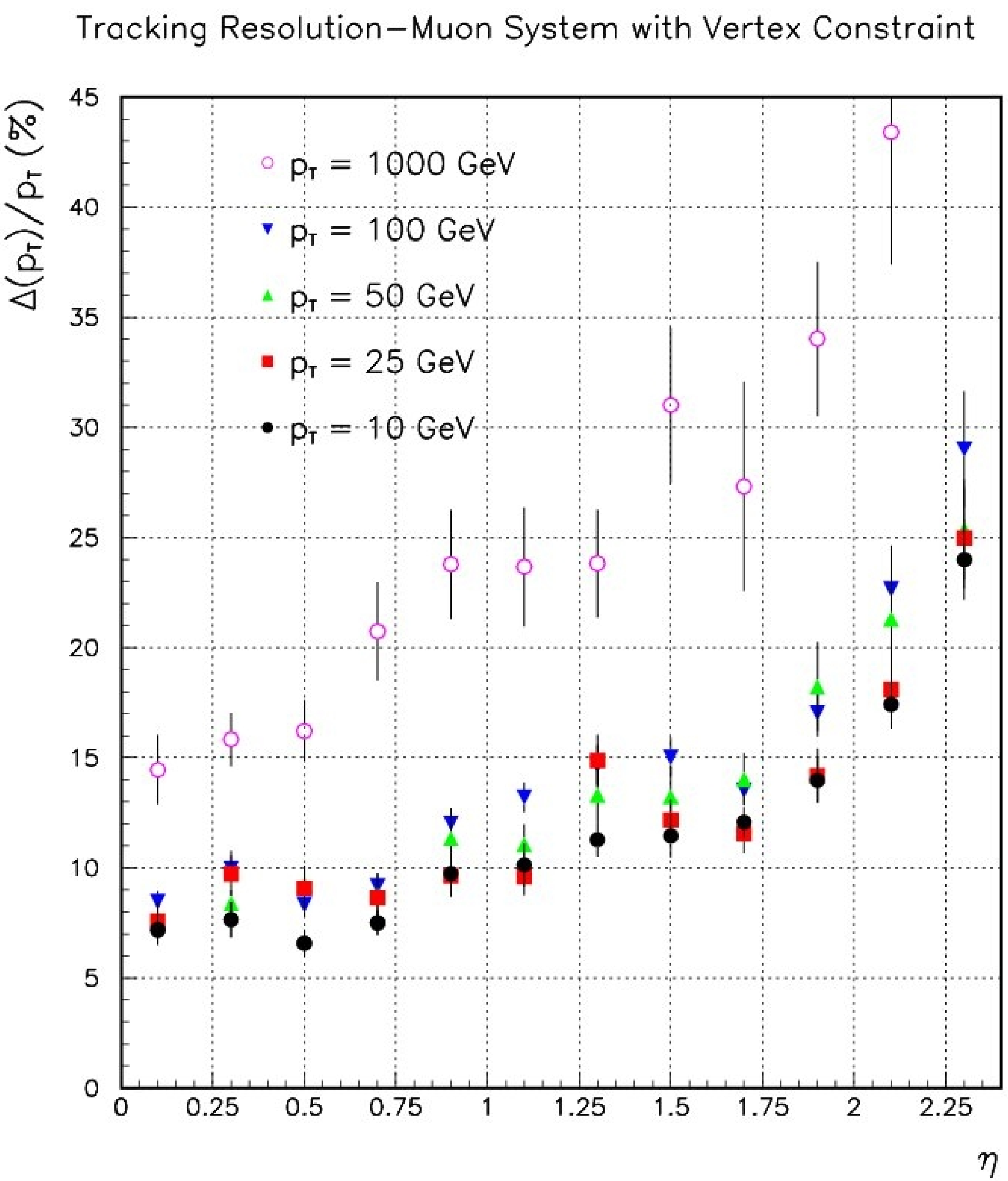
Cathode Strip Chambers, CSC, endcap only

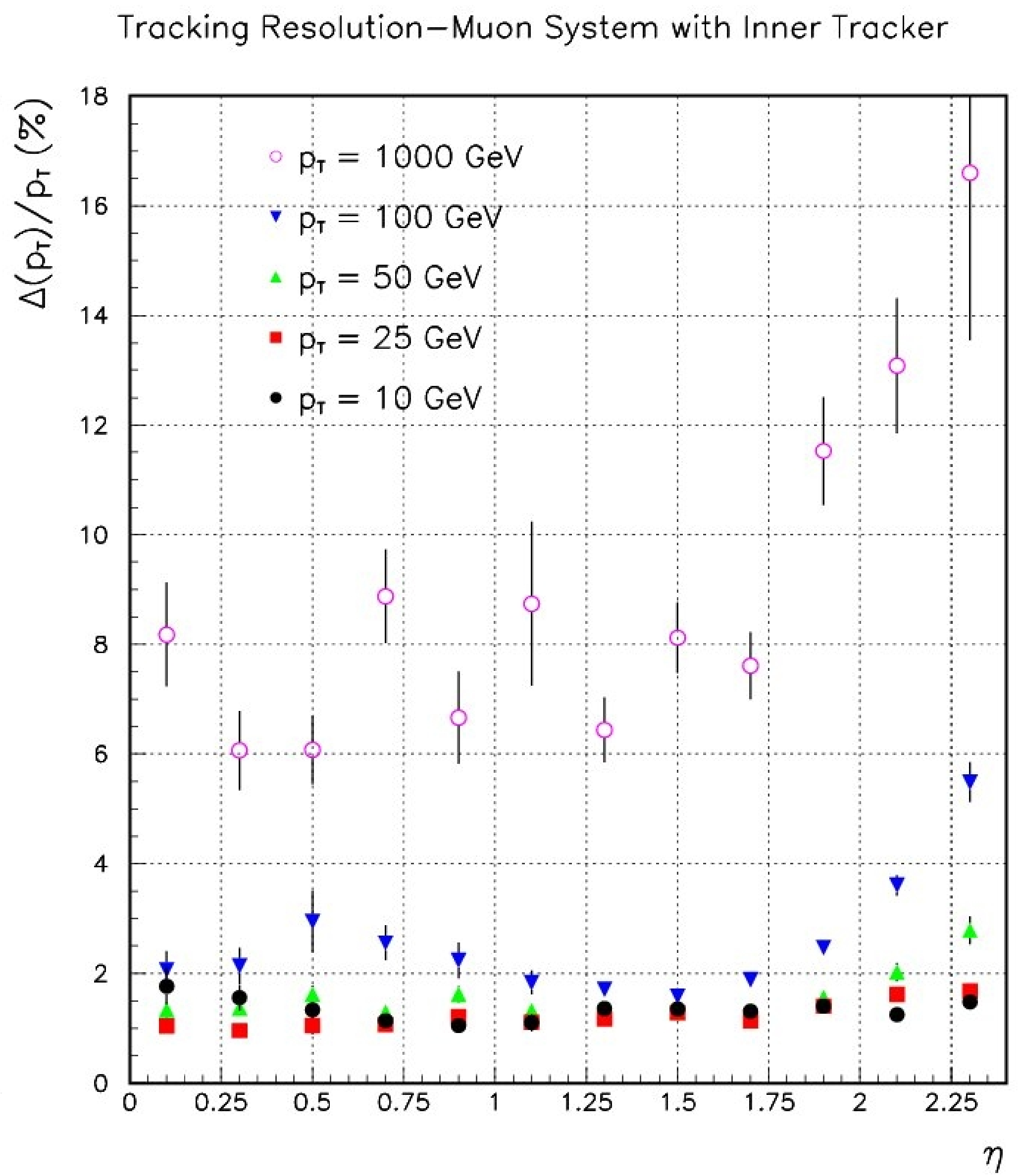
Resistive Plate Chambers, RPC, barrel and endcaps

Chamber properties and statistics

Detector	Drift Tubes	Cathode Strip Chambers	Resistive Plate	
Function	Tracking p_T trigger BXID	Tracking p_T trigger BXID	BXID p_T trigger Resolve tracking ambiguities	
η region	0.0 - 1.3	0.9 - 2.4	0.0 - 2.1	
Stations	4	4	Barrel 6	Endcap 4
Layers	RΦ 8, Z 4	6	2	
Chambers	250	540	360	252
Channels	195000	Strips 273024 Wire groups 210816	80640	80642
Spatial resolution (σ)	per wire 250 μm RΦ (6/8 pts) 100 μm Z (3/4 pts) 150 μm	RΦ (6 pts) 75 μm (outer CSCs) 150 μm R(6pts) (15-50)/$\sqrt{72}$ μm	Cell size	
Time resolution	5 ns	6 ns	3 ns	
Within 20 ns window	> 98% (station) no parallel B field	> 92% (station)	98%	

CMS Muon System Performance

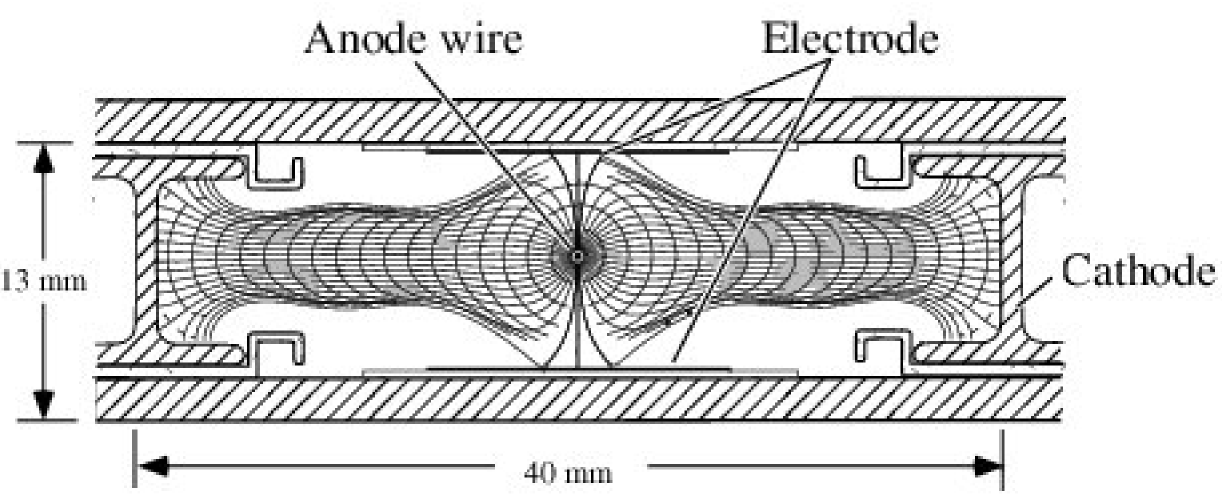


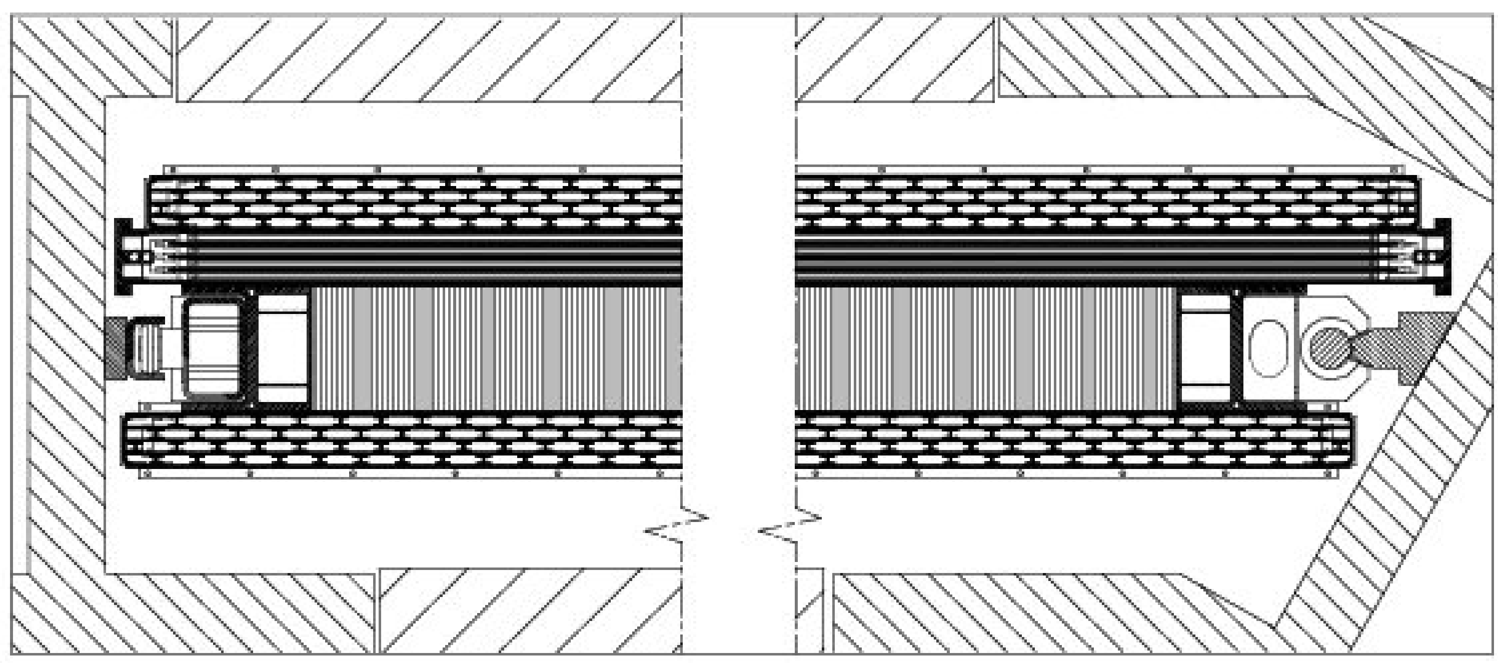


CMS Drift Tubes

Drift tube design

- layers for effective production
- again geometry and wire position crucial

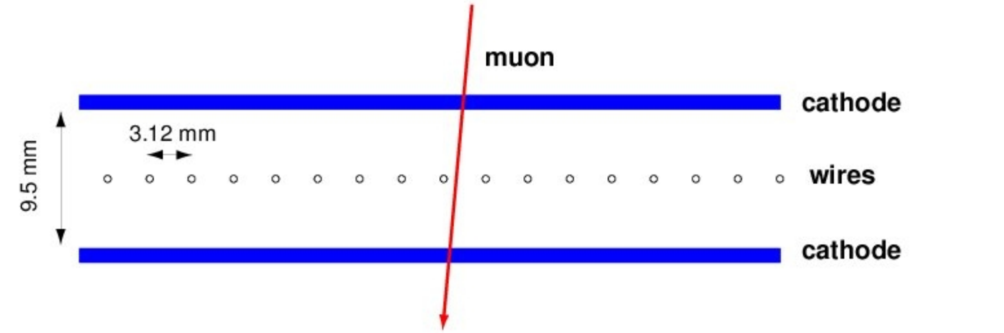


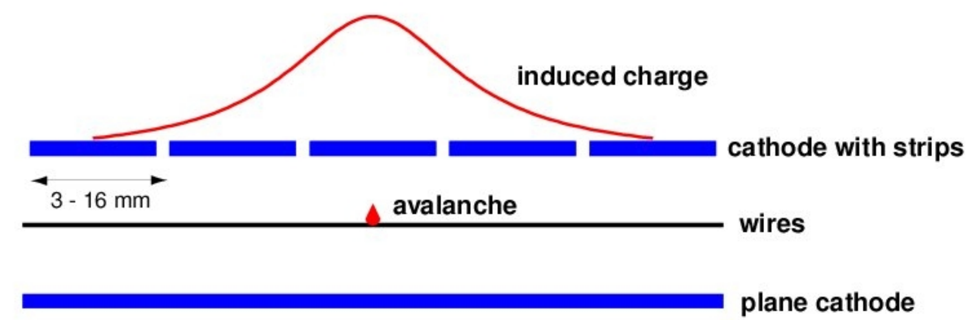


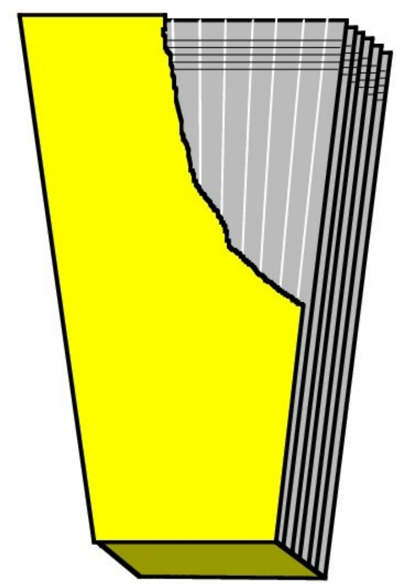
Cathode Strip Chambers

Advantages

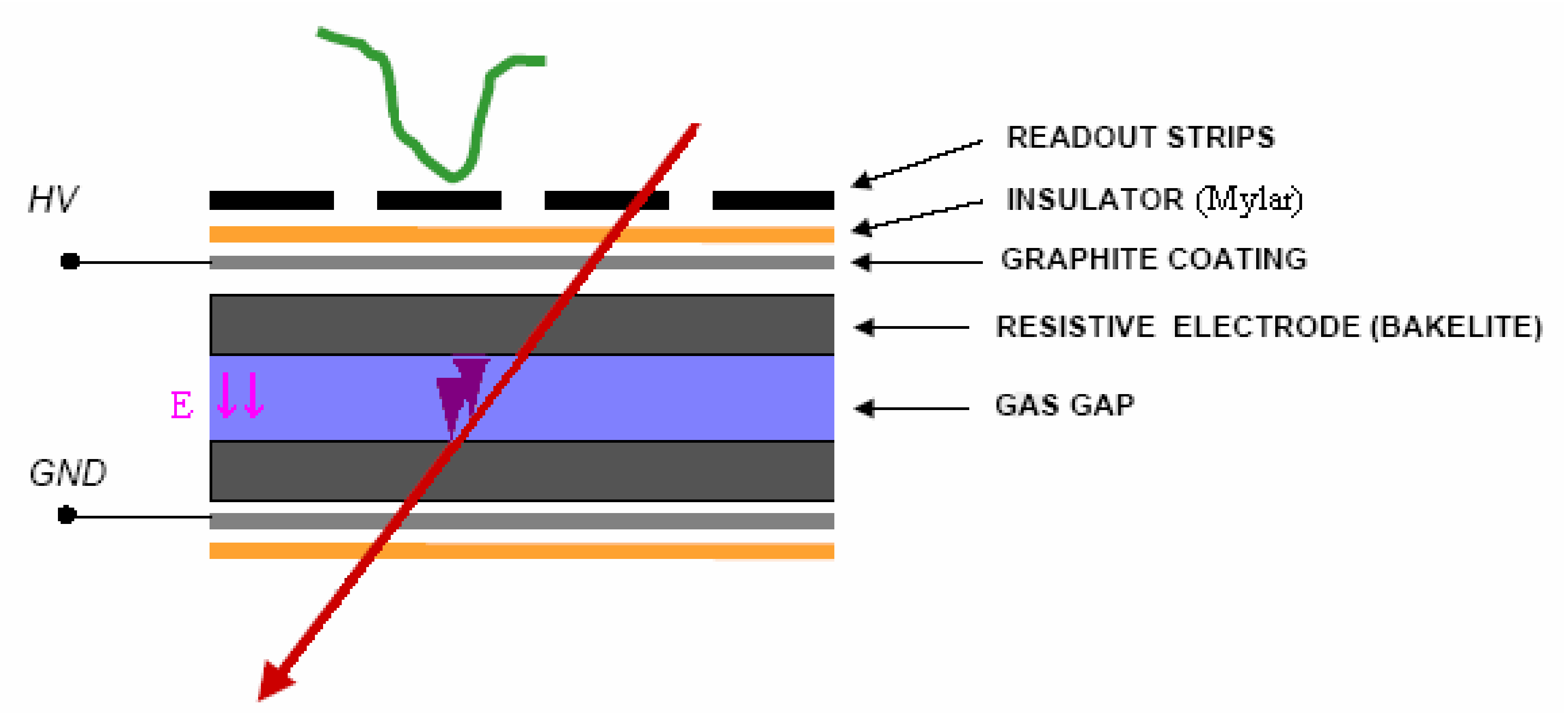
- good spacial resol. (50µm)
- fast (close wire spacing)
- readout: strips and wires
- two dimensional position
- strips can align such that azimuthal angle measured
- loose conditions for gas system
- intrinsic alignment very precise







RPC Principle

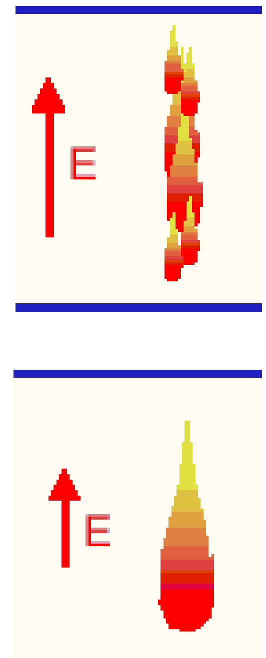


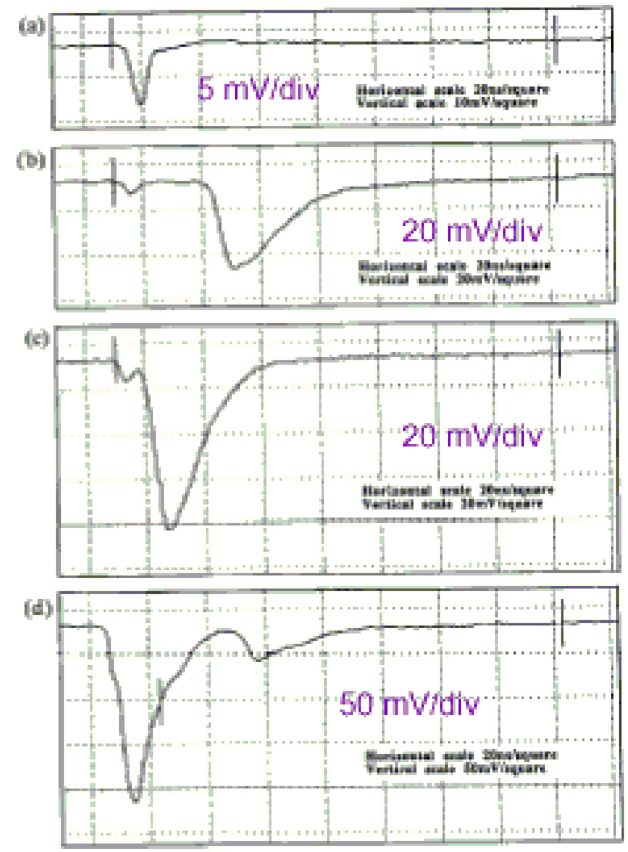
The signal is induced on the read-out electrodes

RPC Principle

Mode to operate gas detector

- usually: streamer mode
  - high field
  - intense enough to initiate spark breakdown
- CMS runs in avalanche mode
  - lower field but multiplication
  - multiplication proportional



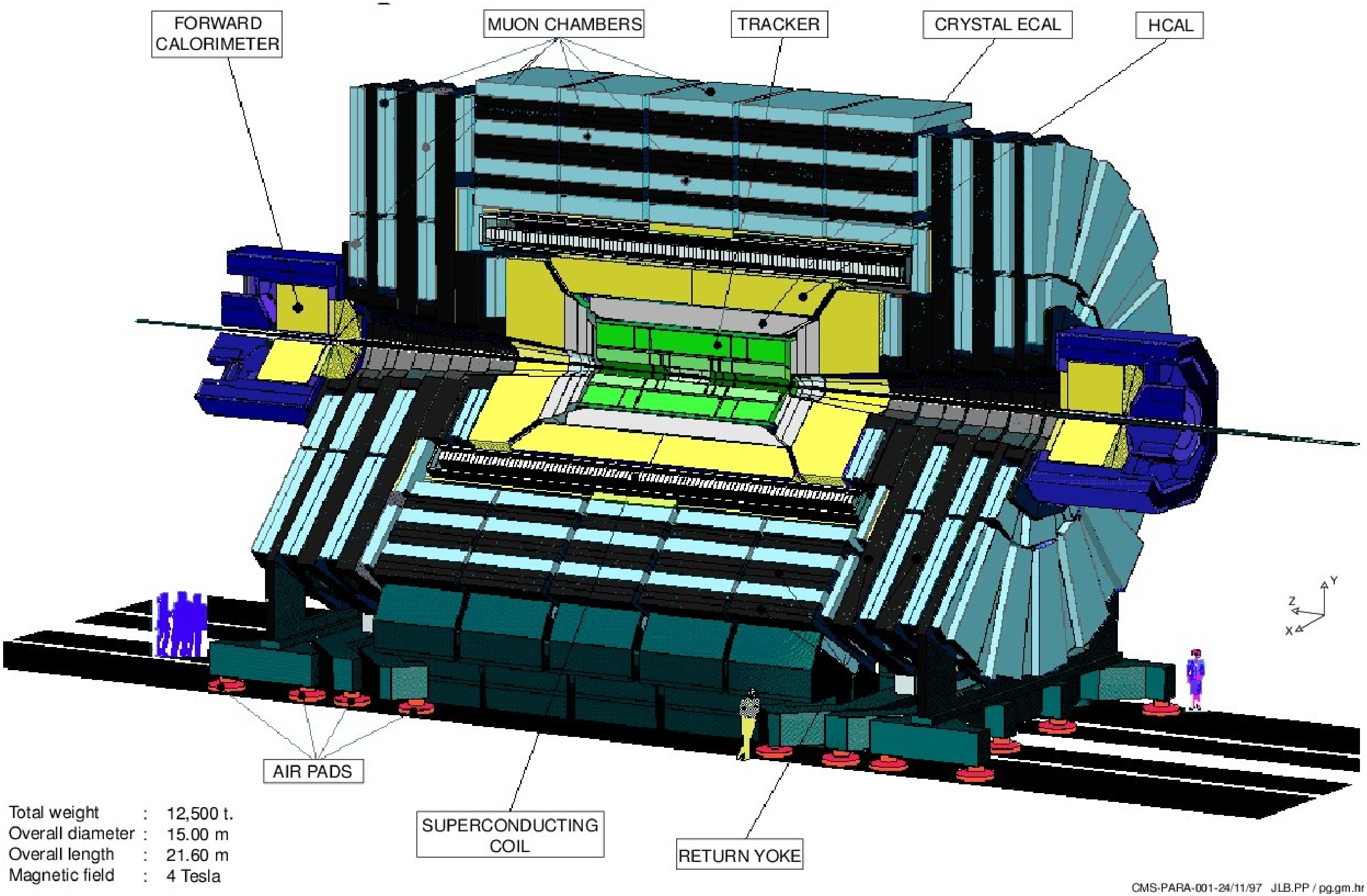


Performance

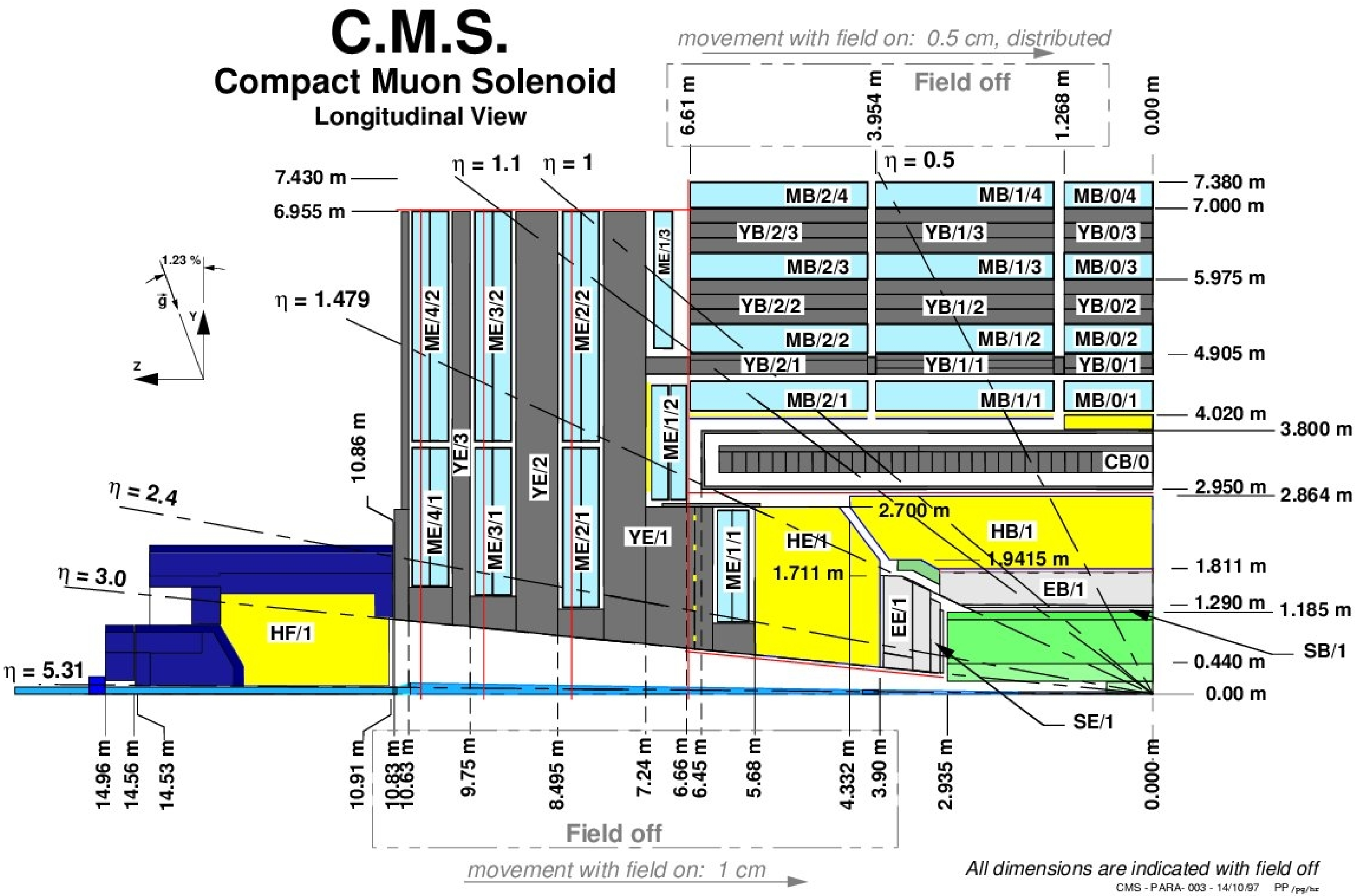
- timing resolution 1-2 ns

space resolution ≈ cm
rate capability good (avalanche mode)
low cost design and arbitrary shapes possible

CMS Muon Detector



CMS Muon Detector



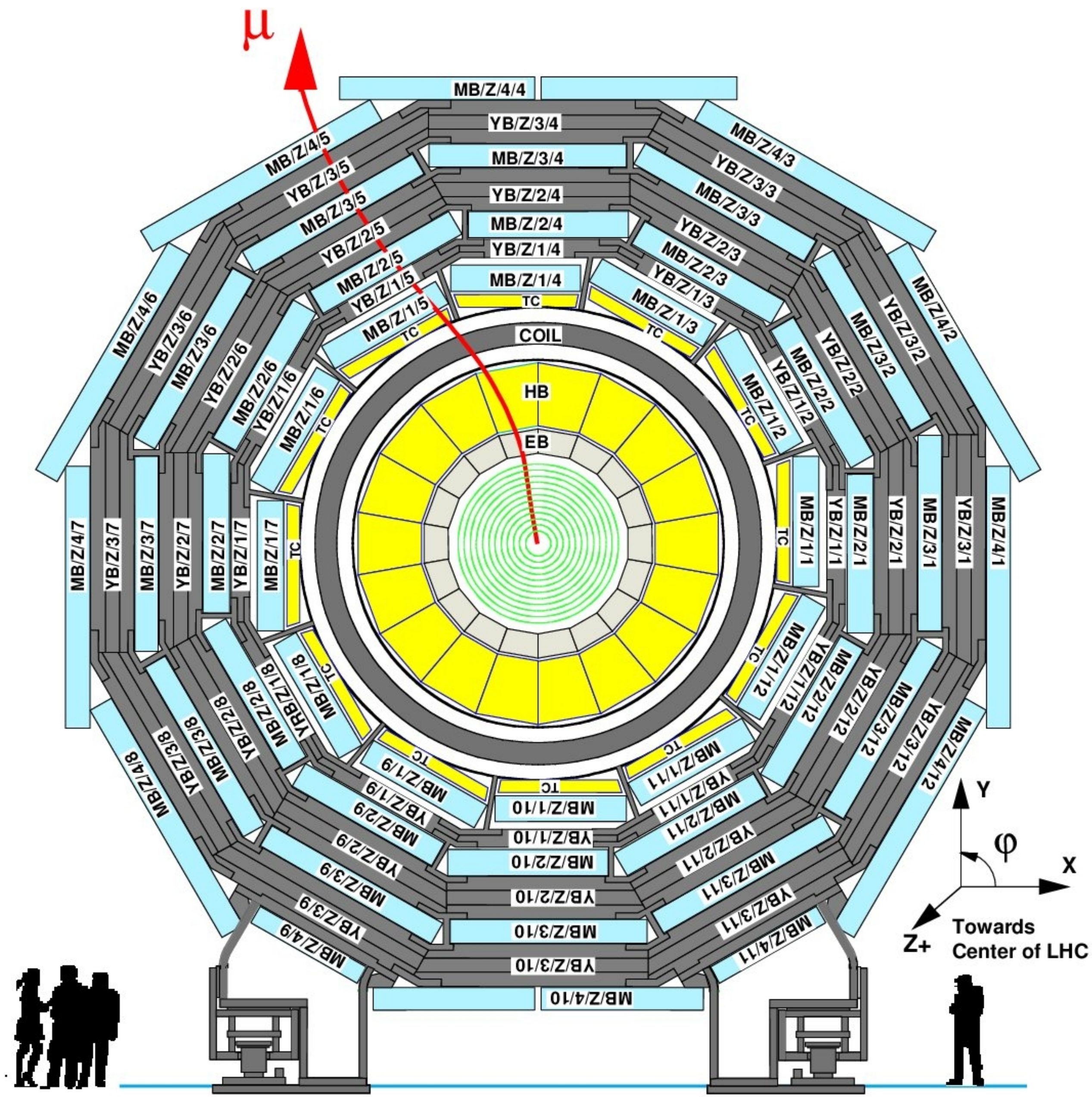
CMS Muon Detector

Watch the muon

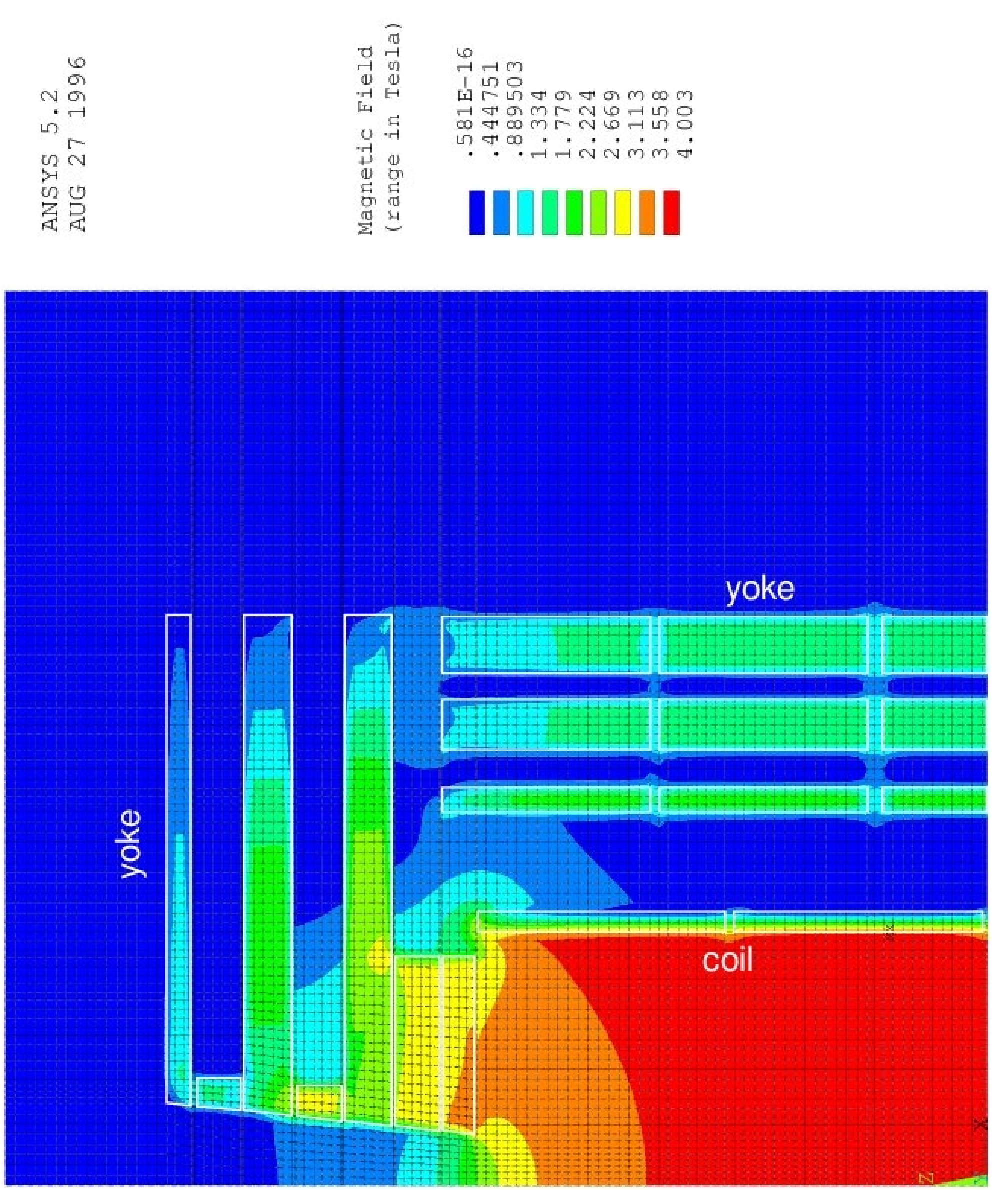
- curving left initially
- curving right outside
- hmm ....

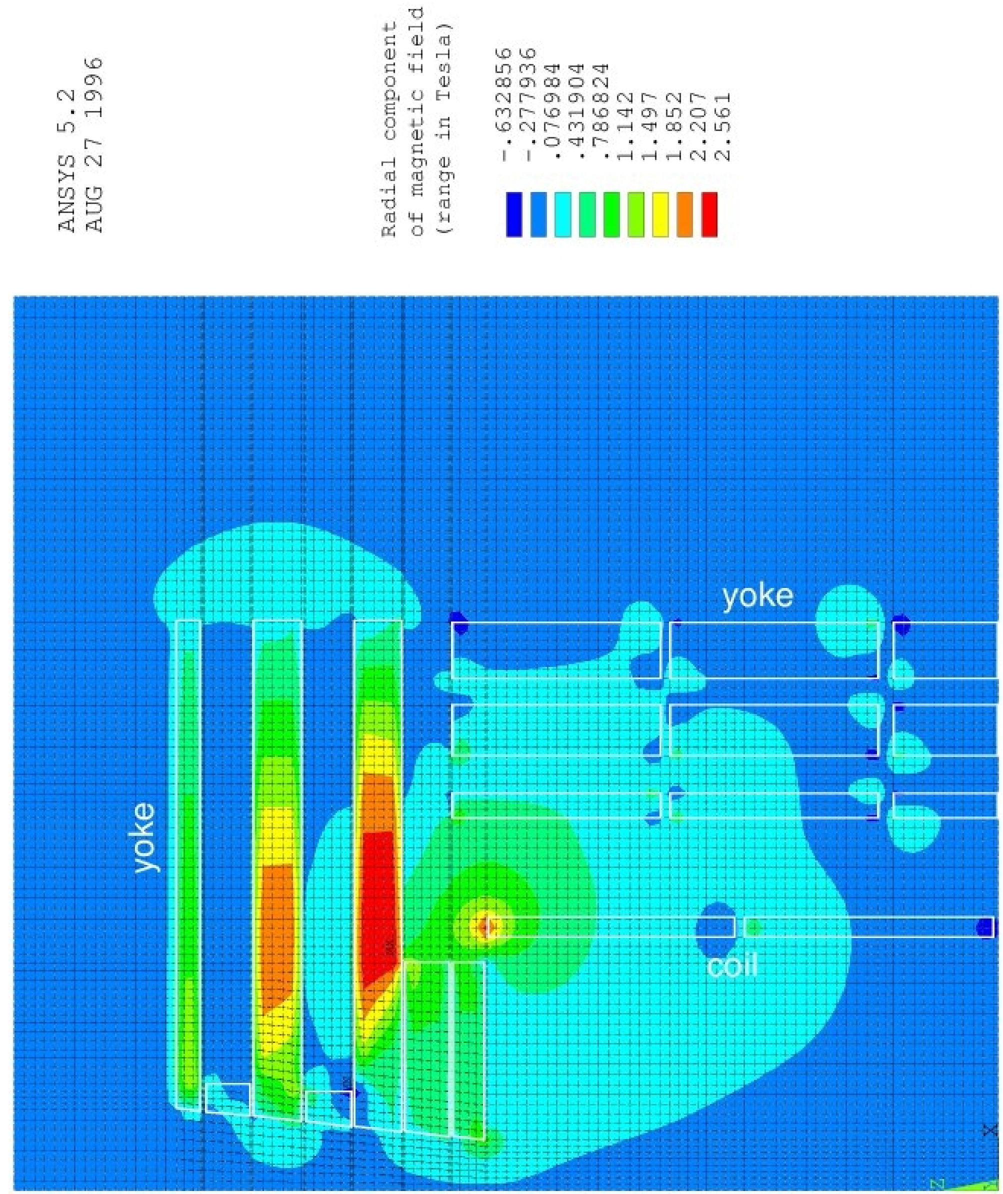
Magnetic field

- inside: homogeneous solenoidal field
- outside: iron yoke arranges for reflux so opposite direction field in the yoke material



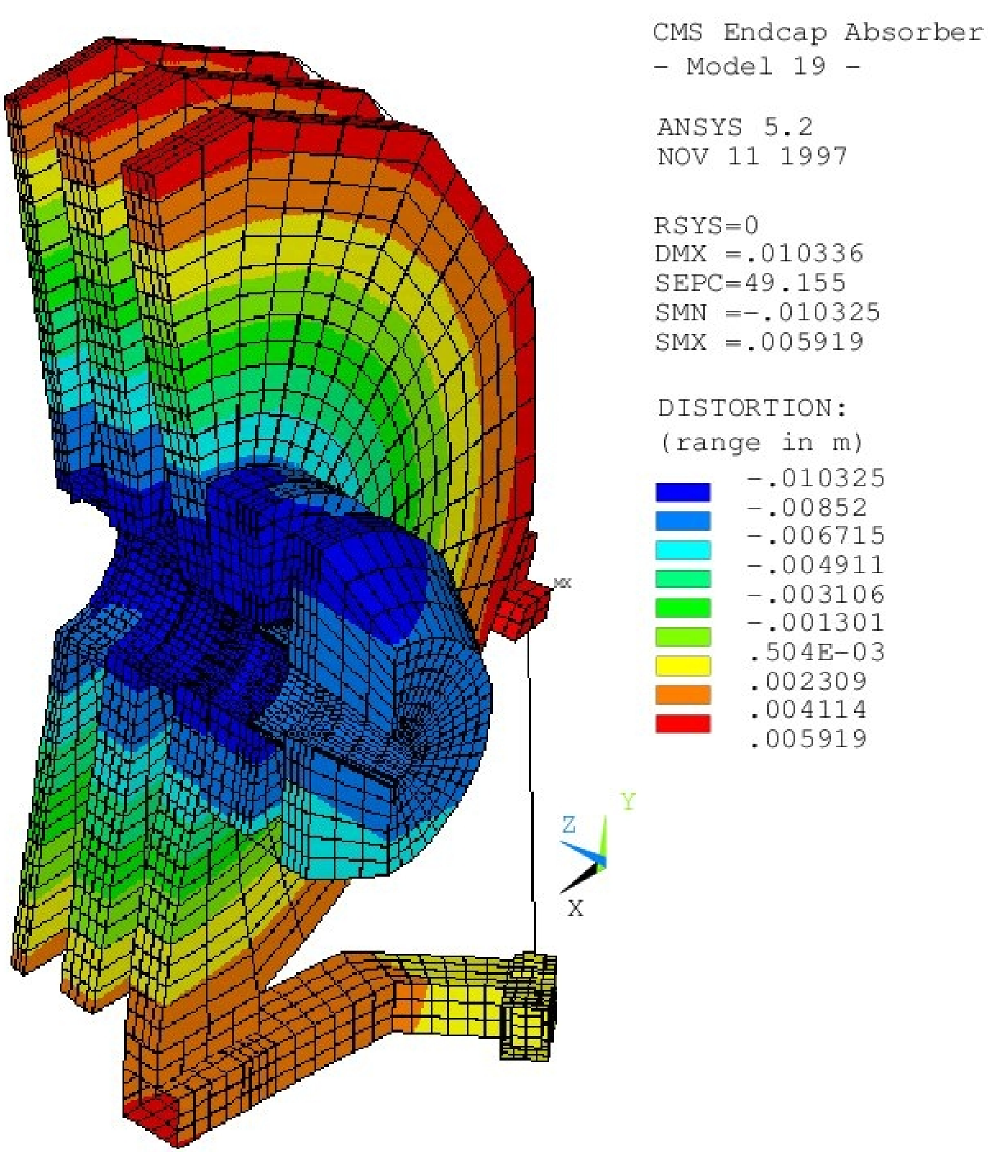
CMS Muon Detector: Magnetic Field

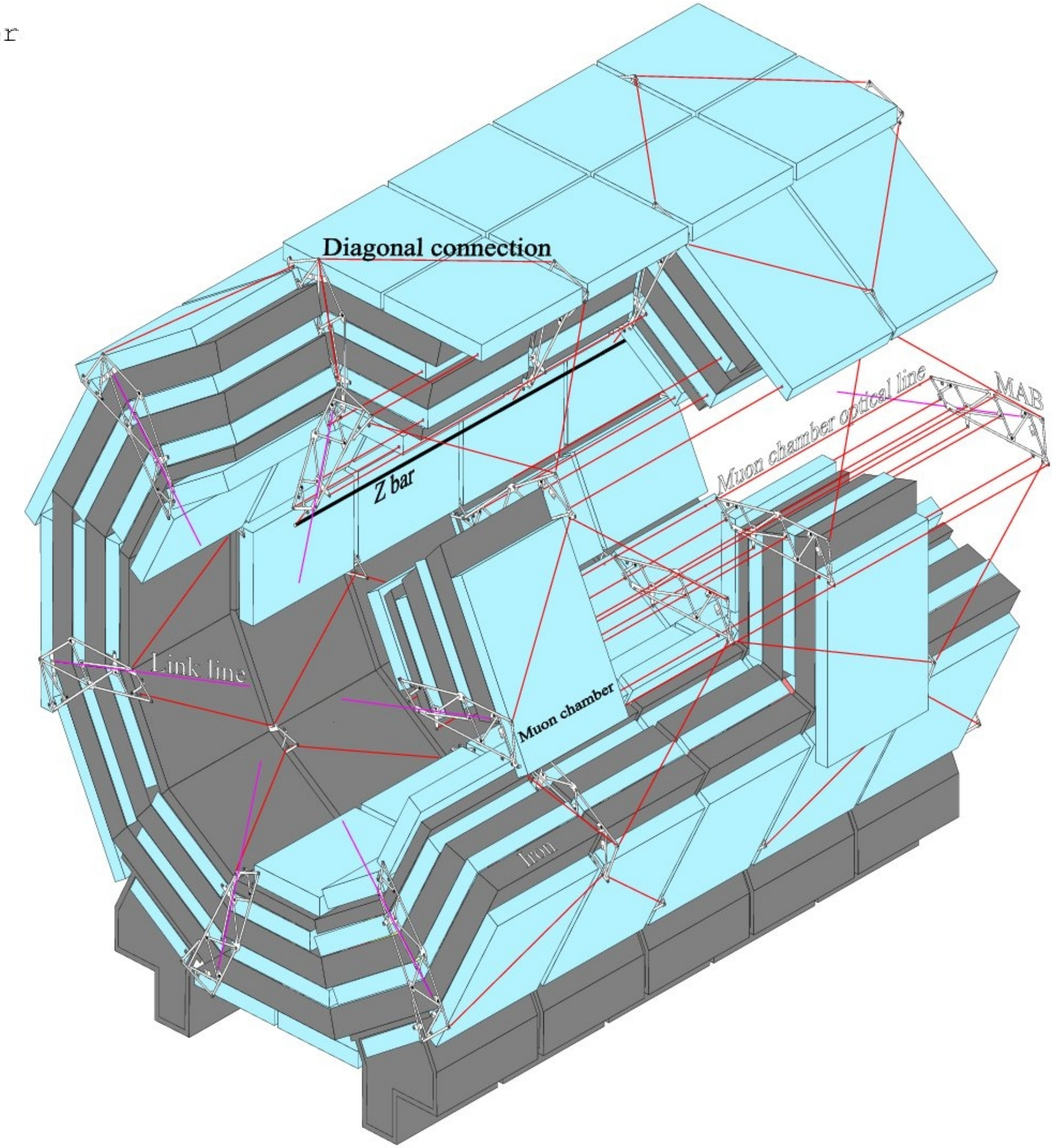




B field: transverse radial

CMS Muon Detector: Distortions





Distortion due to forces: detailed online detector position monitor needed

Conclusion

Muons in hadron colliders

- provide a very clean signature
  - muons pass in minimal ionizing fashion through dense material
  - leave signal in chambers outside of calorimeters
  - leave characteristic signal in calorimeters
- essential for reducing general rate of events: trigger
- fundamental tool to trigger on interesting physics
- very clean reconstruction and excellent resolutions up to very high momenta

Next Lecture

Continue detector discussion

- electrons
- particle Id