Use of Gas Detectors in Modern HEP Experiments

A view biased towards CMS

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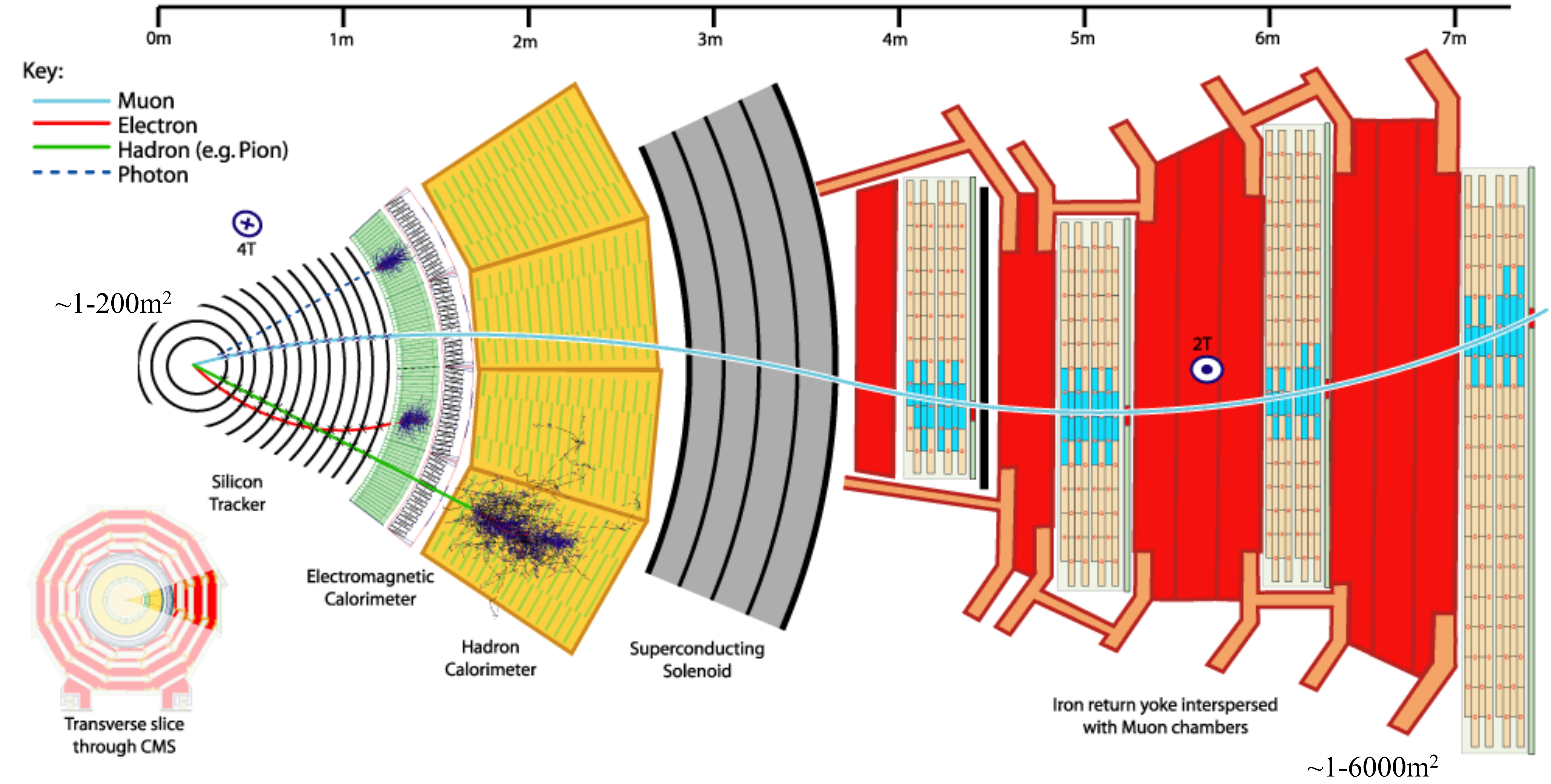
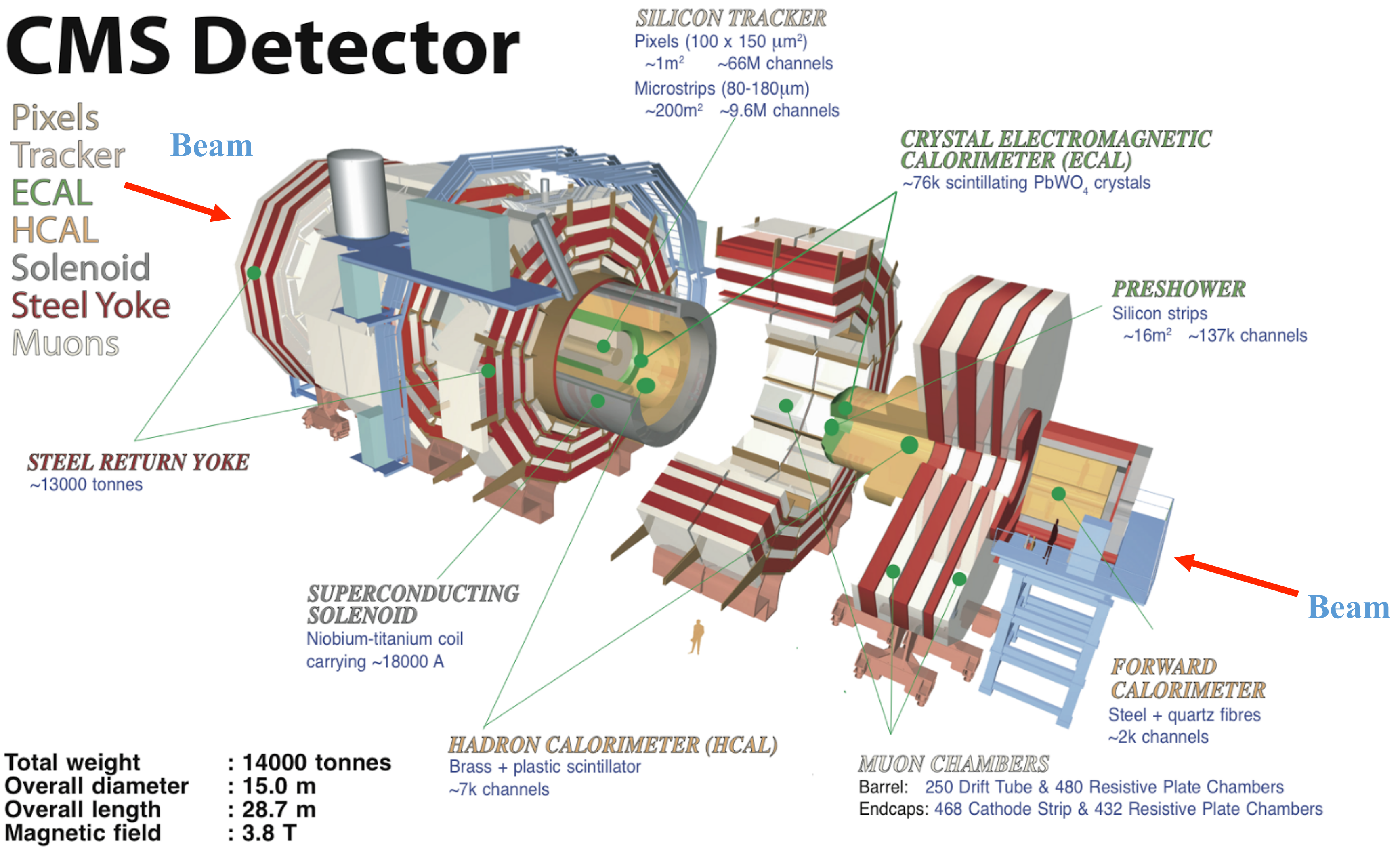
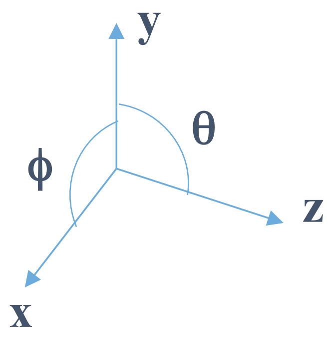
11.11.2015


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
~1-200m²
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
~1-6000m²

Multipurpose detector



Coordinate convention:



θ: Polar angle
ϕ: Azimuthal angle
x: radially inward toward the LHC center
y: vertically upward
z: along the beam line, from LHC Point 5 toward the Jura Mountains

Pseudorapidity:

$$\eta = -\ln \tan \theta/2$$

Table of Muon Technologies

Muon Chamber Technology	Deployment	Comments
Drift Tubes with field shaper electrodes	Barrel Tracking & Triggering Cell resol'n ($r\phi$) < 250 μm	CMS
MDT (Monitored Drift Tubes) 3 cm dia.	Barrel Tracking Tube resol'n ($r\theta$) ~ 150 μm resolution	ATLAS
Small Diameter MDT 1.5 cm dia.	Tracking in some special regions of barrel	ATLAS
Cathode Strip Chambers (CSC)	Endcaps Tracking & CMS Triggering ATLAS: η strip pitch 5.5 mm, ϕ strip pitch 13 - 21 mm	CMS and ATLAS ($2<\|\eta\|<2.7$)
Micromegas	Endcaps Tracking & Triggering Readout pitch ~ 0.4 mm	ATLAS Phase I Upgrade New Small Wheel
Thin Gap Chambers (TGC)	Endcaps Triggering & Tracking 2nd coordinate	ATLAS 1st and 2nd stations Endcap
Small-strip Thin Gap Chambers (sTGC)	Endcaps Triggering & Tracking Fast enough for BC tagging 95% τ < 25 ns; 3 mm strip-pitch	ATLAS Phase I Upgrade New Small Wheel
Resistive Plate Chambers (RPC)	Barrel and Endcaps Triggering Fast τ ~ 3ns ATLAS: η strip pitch ~ 30 mm, ϕ strip pitch ~ 30 mm	ATLAS and CMS
Low Resistivity RPC	Higher rate capability 10^{10} Ωcm	R&D
Multi-gap Resistive Plate Chamber	Very fast τ ~ 50 ps	ALICE and R&D
GEMs (3 layer)	Endcaps Rate ~ 10^5Hz/cm^2 Fast τ ~ 4-5 ns	CMS Phase I Test & Phase II

John Sealy Townsend Circa 1900

Muon System Design Goals

Exploit full potential of LHC physics with muons

Higgs decays (4μ, 2μ), SUSY (multi-lepton), top, Z', B physics

Quarkonia in Heavy Ion collisions

Requires reliable offline muon identification for $\eta < 2.4$

Muon trigger capability for $\eta < 2.1$, with p_T thresholds from a few GeV to 100 GeV

Precision $\Delta p_T / p_T$ measurements for muons with $p_T < 100$ GeV :

~2% resolution in combination with the central tracker

~10% standalone resolution

Muon sign determination with 99% confidence level up to the LHC kinematic limit ($p < 7$ TeV)

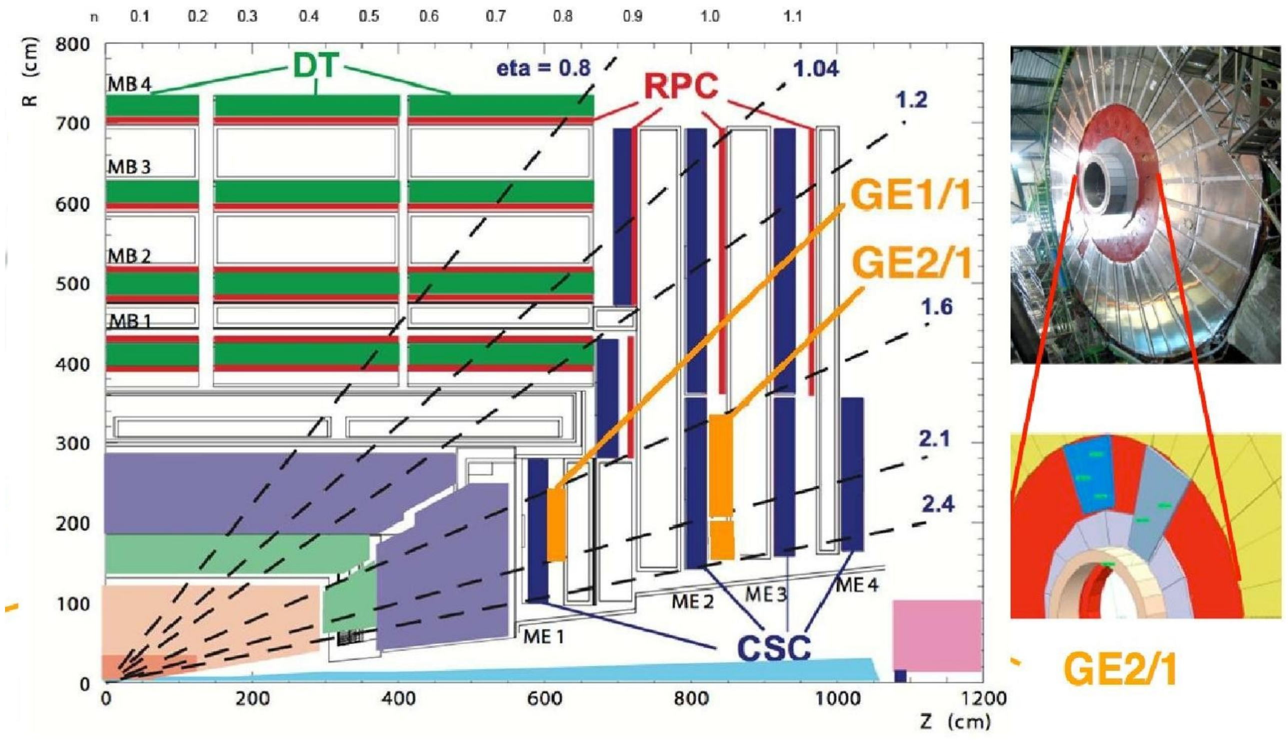
Gas Detector technologies

Drift Tubes (DT)
- Central coverage: $|\eta| < 1.2$
- Measurement and triggering
- 12 layers each chamber: 8 in φ, 4 in z

Cathode Strip Chambers (CSC)
- Forward coverage: $0.9 < |\eta| < 2.4$
- Measurement and triggering
- 6 layers each chamber: each with φ, z

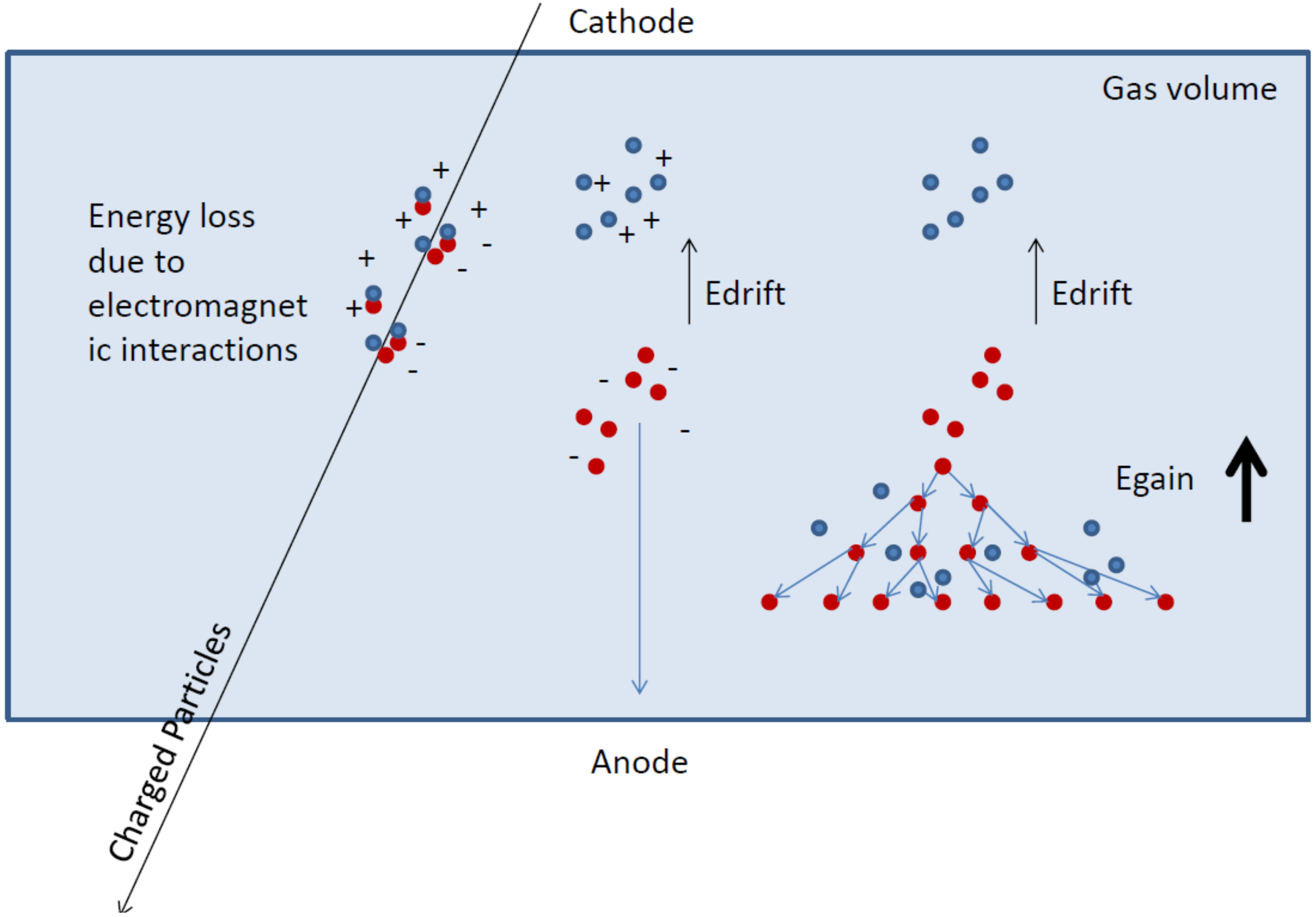
Resistive Plate Chambers (RPC)
- Central and Forward coverage: $|\eta| < 2.1$
- Redundancy in triggering
- 2 gaps each chamber, 1 sensitive layer

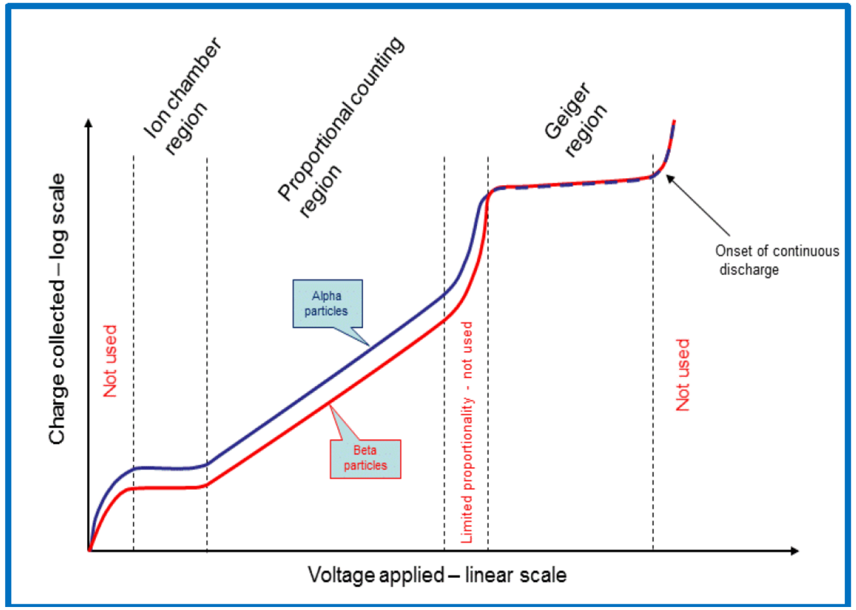
Gas Electron Multiplier (GEM)
- Fast triggering and precise tracking
- Endcap coverage : $1.6 < |\eta| < 2.4$



Phase-II

How do “typical” gaseous detectors work?





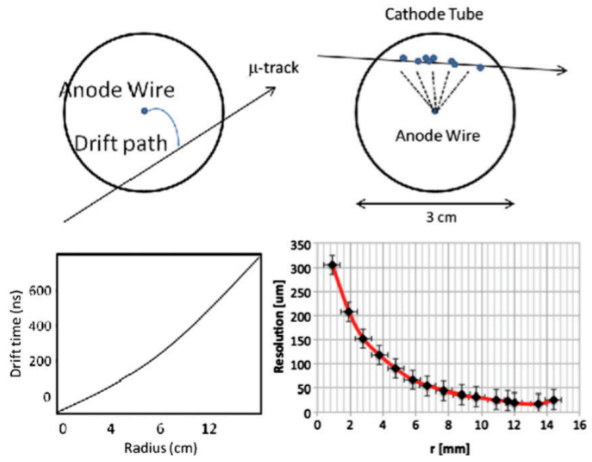
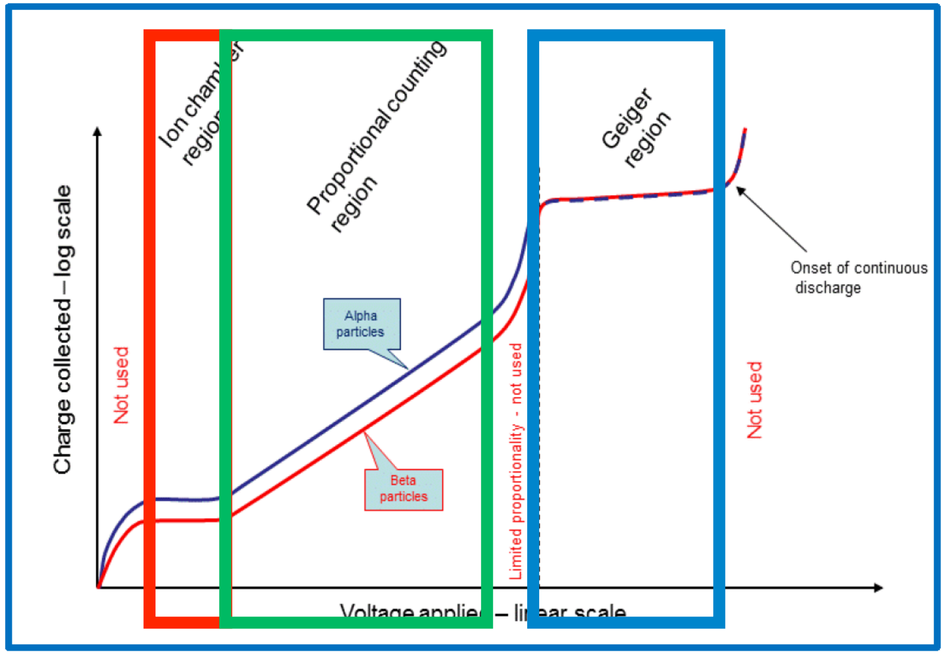


Fig. 26. With a radius of 1.5 cm, a gas mixture of Ar/CO_2 at 3 bar pressure, the space time relationship and results of resolution measurement for the ATLAS MDTs.



- In **Proportional counters** the output current pulse generated is proportional to the energy deposited by the radiation. The Multiwire chamber is an example of proportional counter used as a research tool.

Pros:

- Can measure energy of radiation and provide spectrographic information
- Can discriminate between alpha and beta particles
- Large area detectors can be constructed

Cons:

- Anode wires delicate
- Time resolution limited by distance between the wires
- Aging

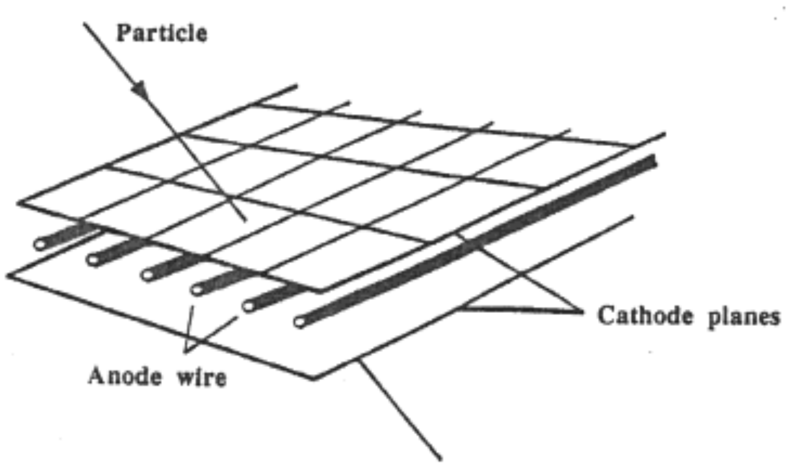
- **Ionization chambers** operate at a low voltage, → no gas multiplication takes place.

Pros:

- Good uniform response to gamma radiation
- Accurate overall dose reading
- Sustains very high radiation rates

Cons:

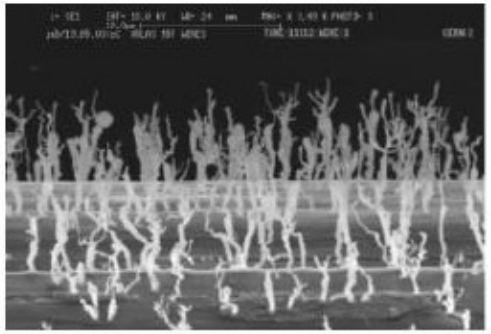
- Very low electronic output

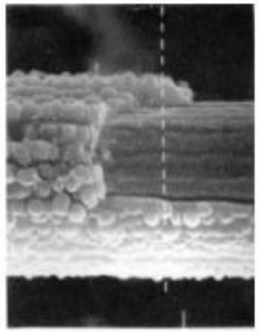


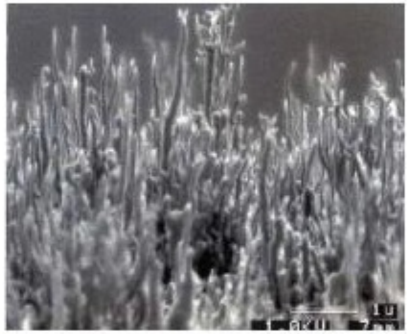
Advantages and limitations of “typical” gaseous detectors

Pros

- Large area at low price
- Flexible geometries
- Good spatial, energy & time resolution



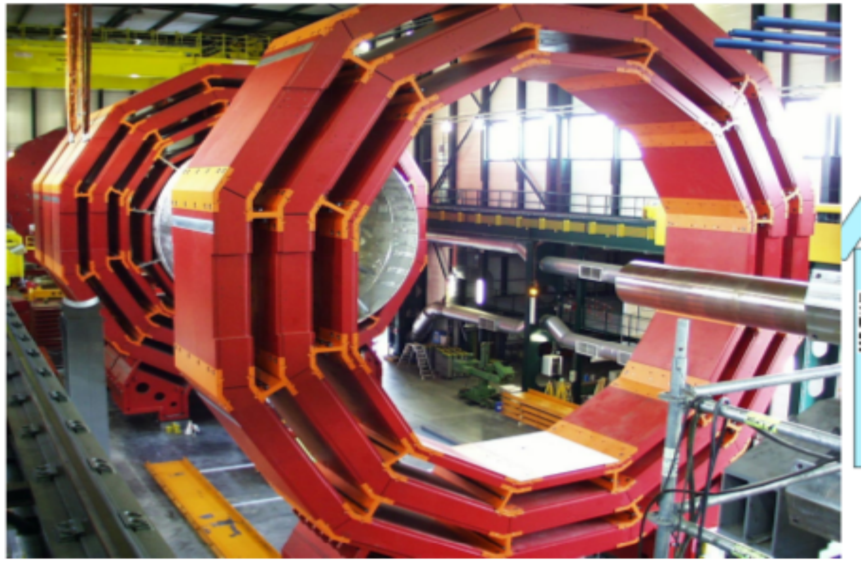


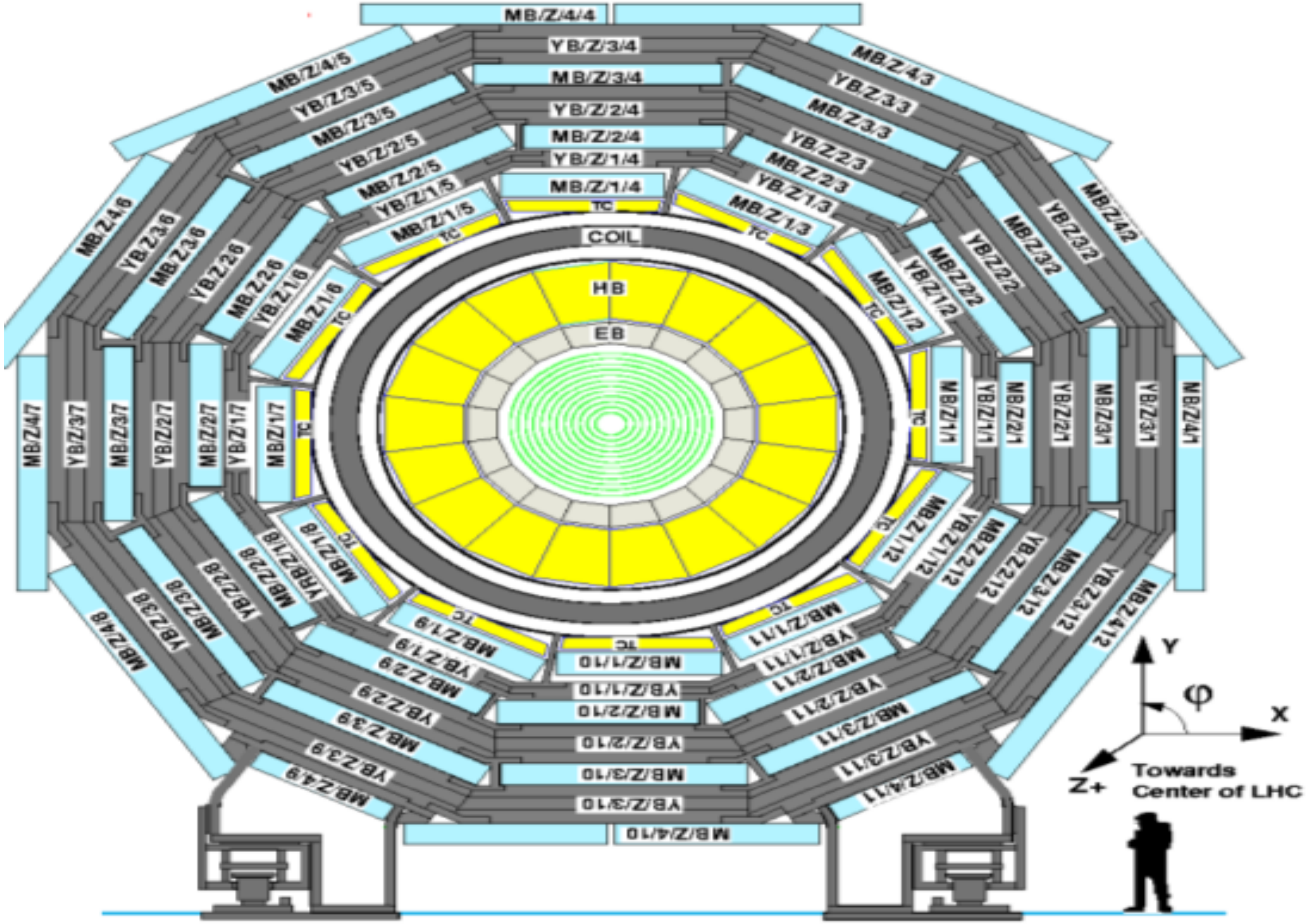


Cons

- Slow ion motion → fast gain drop at high fluxes:
  - Space charge accumulation, distortion of electric field…
- Limited multi-track separation: minimum wire distance ~1mm
- Aging

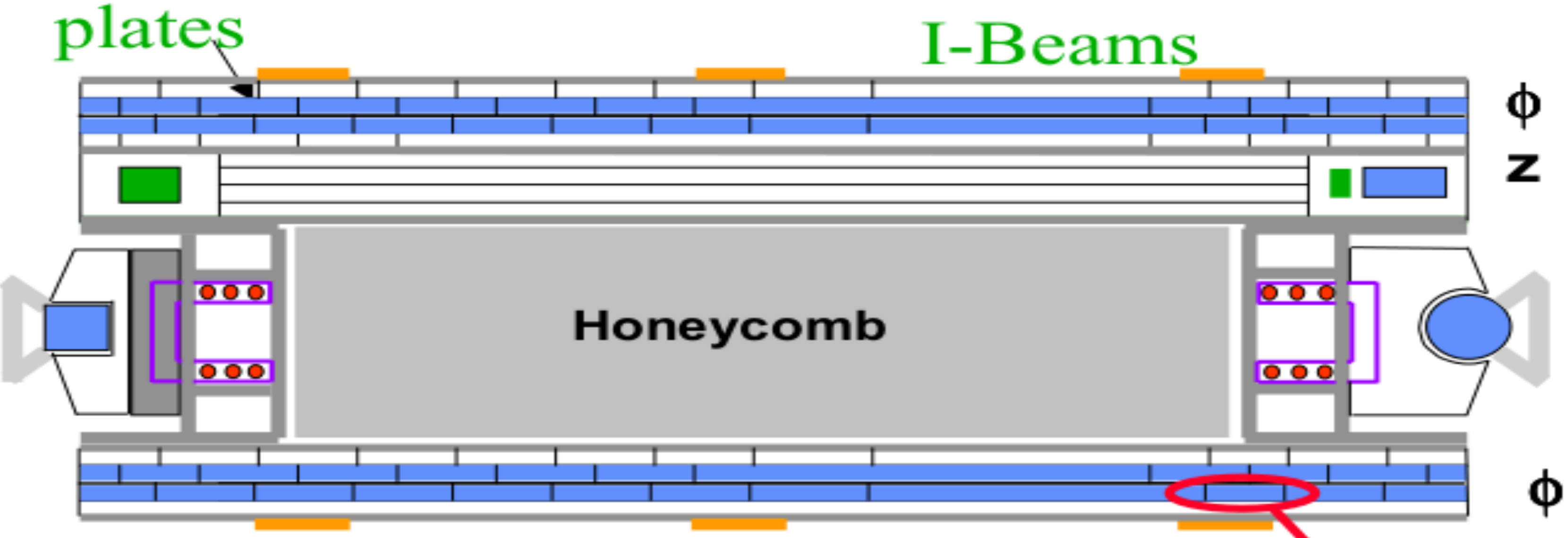
DT Barrel Muon System : MDT





4 stations in radius
5 wheels in z
250 drift chambers

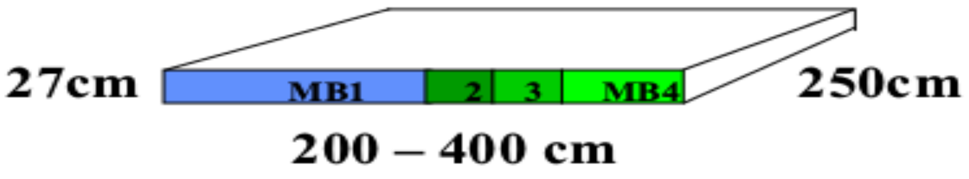
DT Chamber – XY View



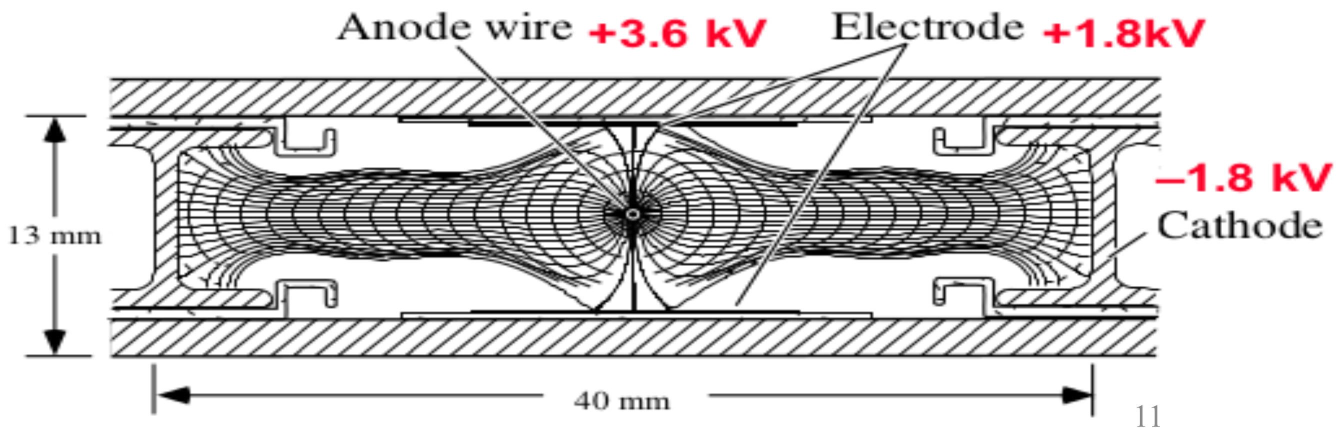
2 superlayers in ϕ
1 superlayer in z

Each superlayer has 4 layers of drift-tubes

Dimensions:



Ar/CO_2 gas mixture
400 ns maximum drift time
250 μm resolution for single cell
100 μm resolution for chamber



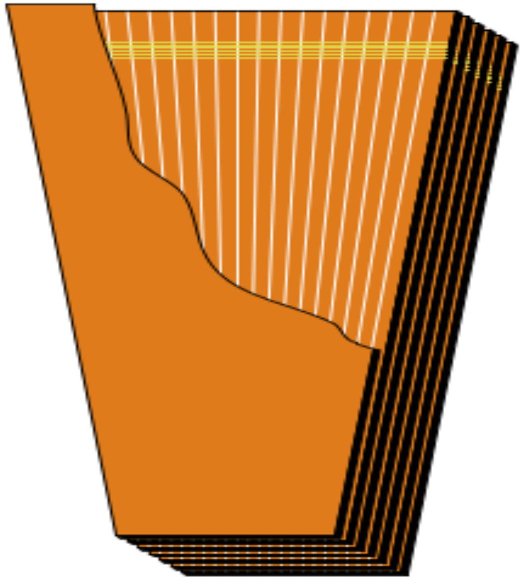
CSC Endcap Muon System

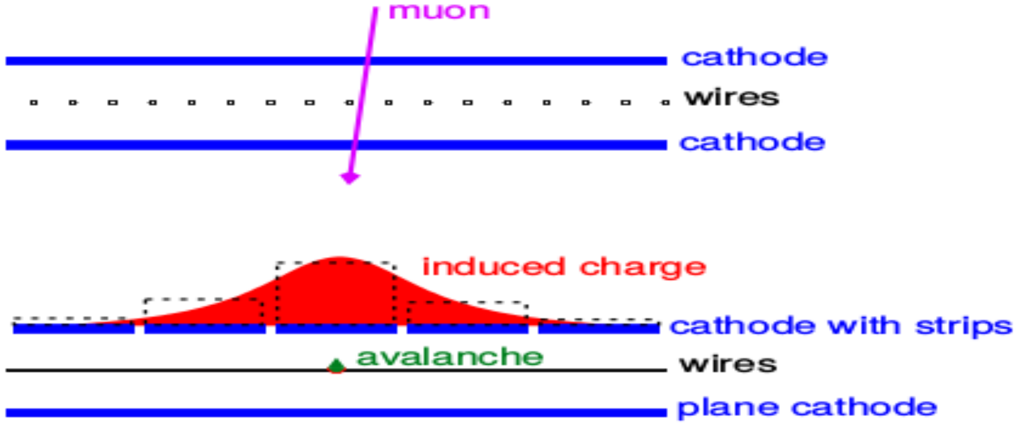
- Up to 3.4 m long, 1.5 m wide
- 6 planes per chamber
- 9.5 mm gas gap (per plane)

- 50 µm wires spaced by 3.2 mm
- 60 ns maximum drift-time per plane
- 5 to 16 wires ganged in groups
- Wires measure r

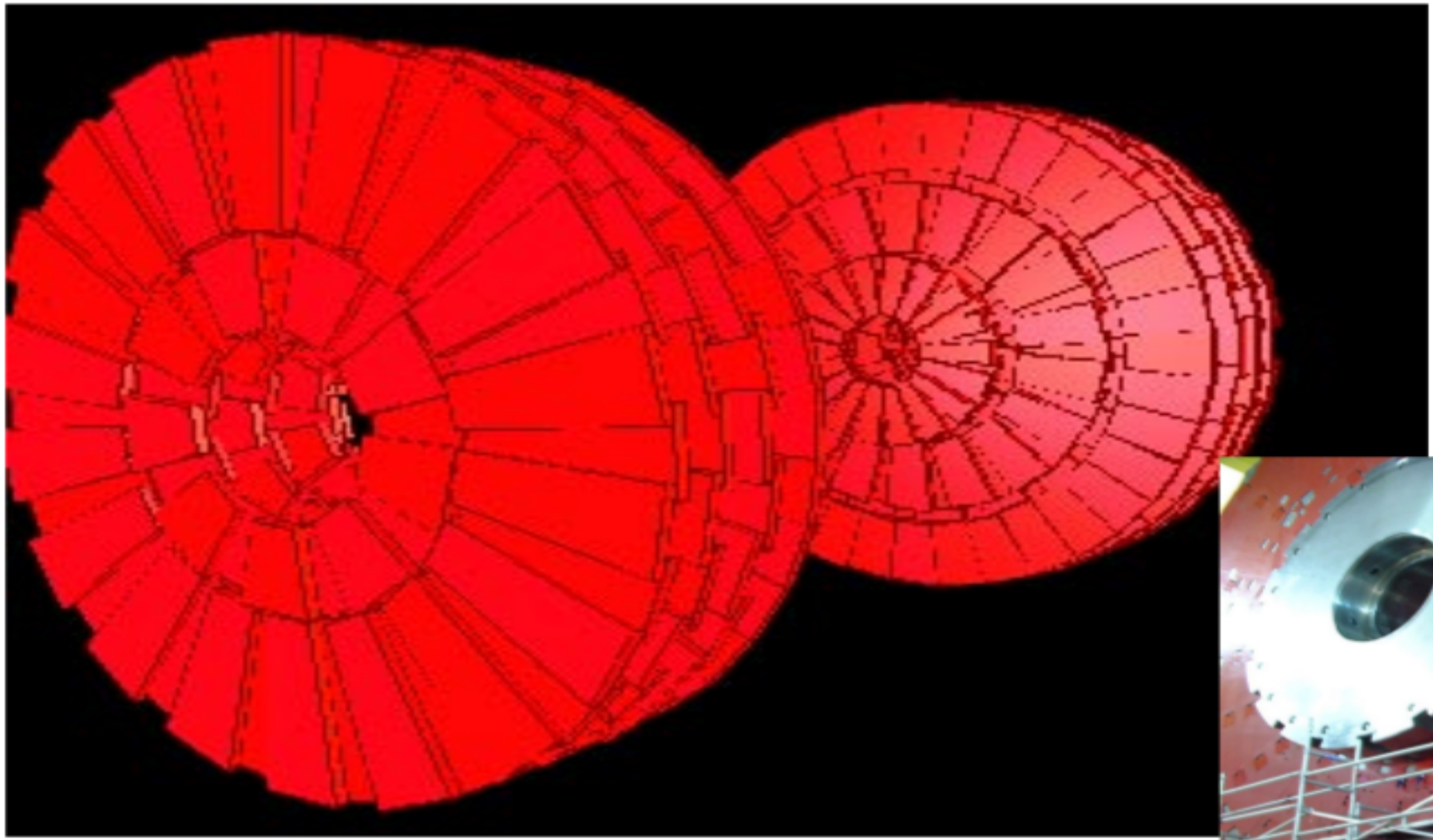
- 6.7 to 16.0 mm strip width
- Strips run radially to measure φ
- 150 µm resolution for chambers (75 µ m in station 1)

- Gas: Ar(40%)+CO_2 (50%)+CF_4 (10%)
- HV ~3.6 kV
- B-field up to 3 T in station 1





CSC Endcap Muon System



2 endcaps
4 stations (disks) in z
2 or 3 rings in radius
540 chambers
6000 m^2 active area
2.5 million wires
0.5 million channels

Chambers overlap in ϕ and η

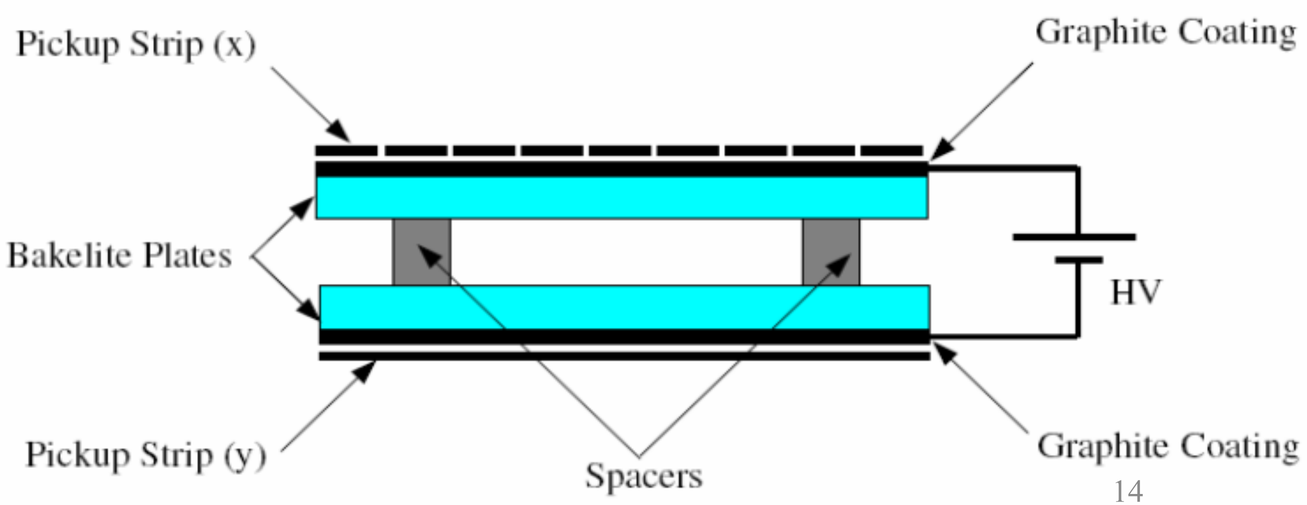
Resistive Plate Chambers

Endcap RPCs contain trapezoidal shaped HPL gas gaps, that are organized in a double-layer configuration with a copper strip readout panel placed in between

Each CMS RPC endcap station consists of three concentric rings, called REx/1-3 (station x=1,2,3)

CMS RPC requirements.

Parameters	Allowable ranges
Efficiency	>95%
Time resolution	$\leqslant$ 1 ns
Average cluster size	$\leqslant$ 2 strips
Rate capability	2 kHz/cm^2
Mean avalanche charge	2.5–5 pC



Limitations

RPC rate capability which is limited by space charge

Problem of Aging

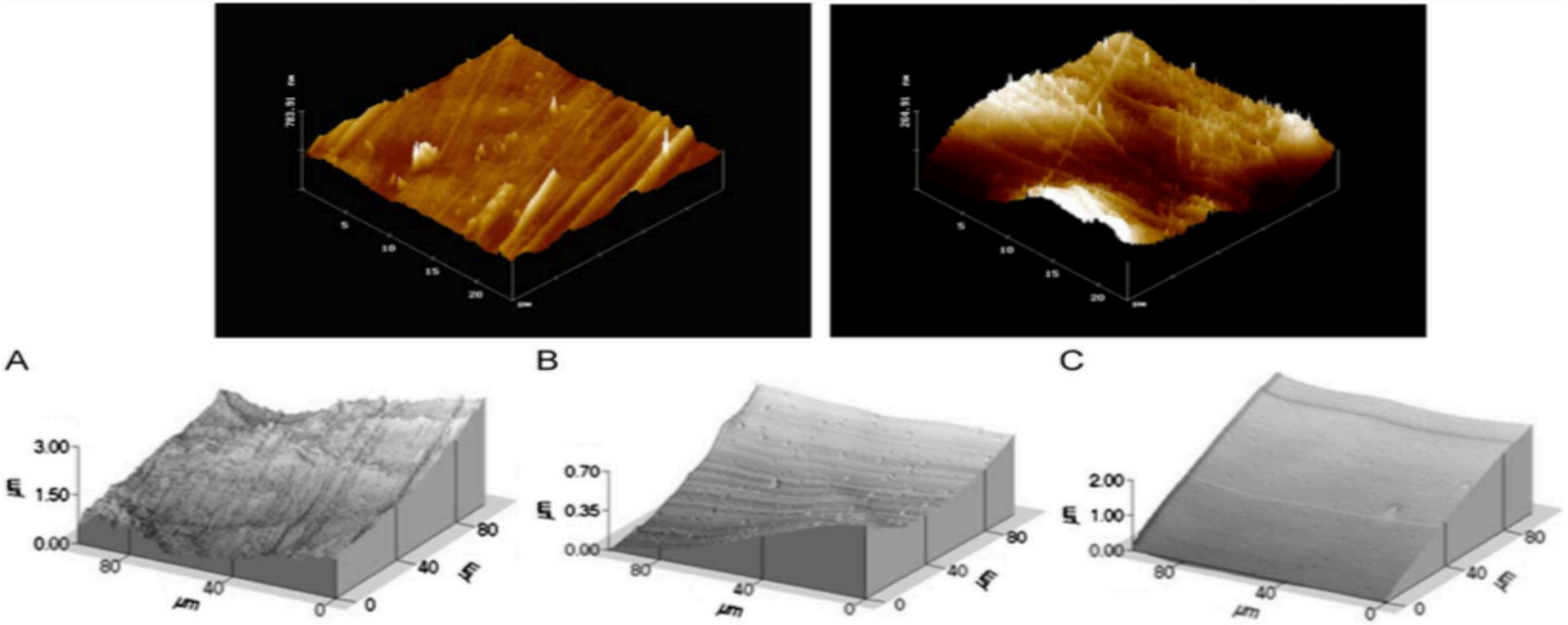


Fig. 53. Surface quality of (top left) Beijing phenol/melamine plastic laminate and (top right) Italian LHC like phenol/melamine plastic laminate. Comparison of the three photos (bottom) demonstrate the successive surface improvement due to the deposition of a uniform linseed oil layer; the scale is in µm.