Particle Detection: Trackers

Lecture 2

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Outline

Lecture 1

1. Interaction of charged particle with matter
2. Momentum measurement
3. Drift and Diffusion in Gases
4. History of Tracking Detectors
5. Proportional Chambers

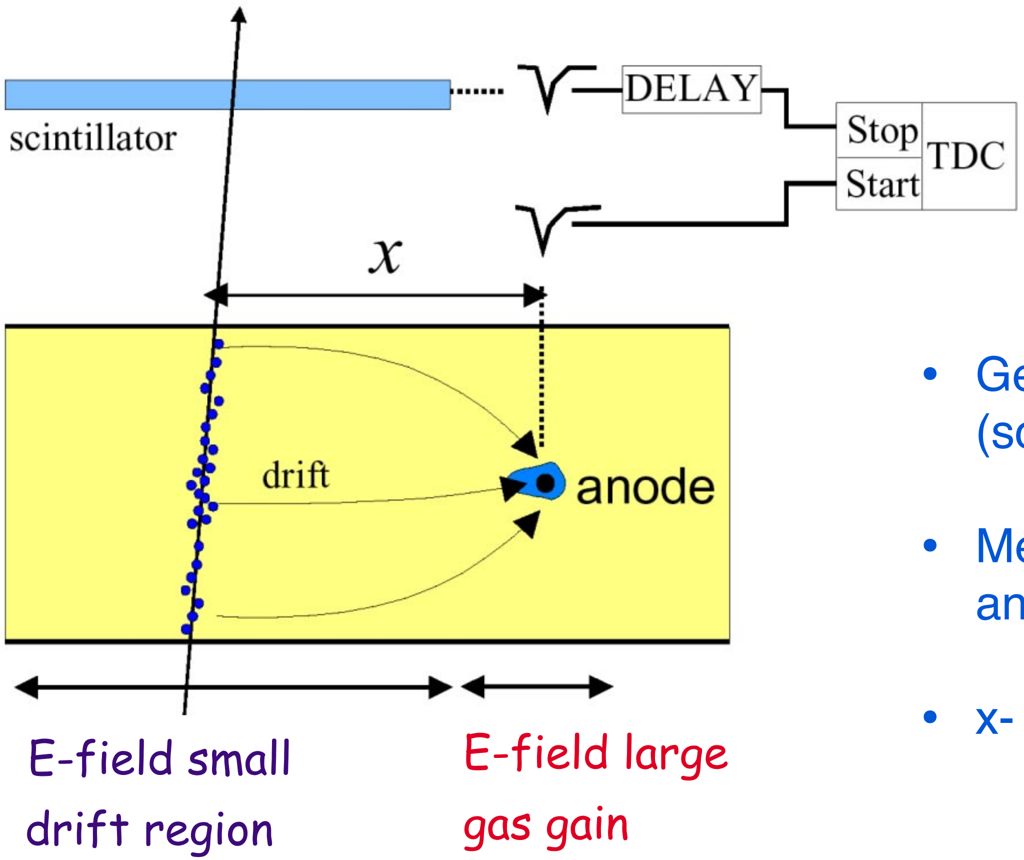
Lecture 2

6. Drift Chambers
7. Micro Pattern Gas Chambers
8. Limitations of Gaseous Detectors

Lecture 3

9. Vertex Reconstruction
10. Semiconductor Detectors
11. Silicon Strip and Pixel Detectors
12. Radiation Damage of Silicon Detectors
13. New Semiconductor Detector Concepts
14. Tracking Systems: ATLAS, CMS

6. Driftchamber



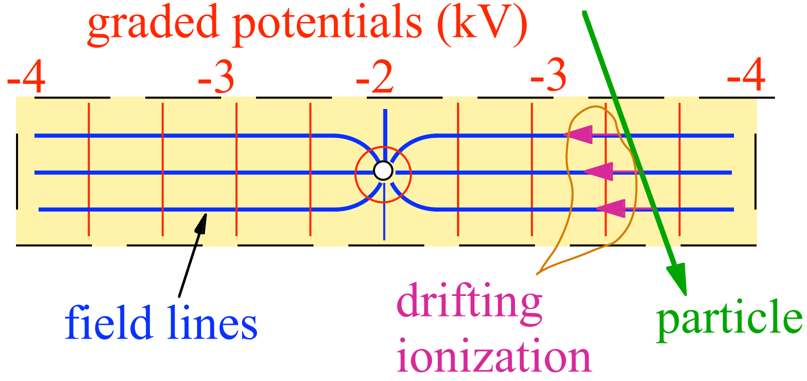
TDC: Time to Digital Converter

- Get external time reference t_0 (scintillator)
- Measure arrival time of electrons at anode t_1
- x- coordinate given by $x = \int_{t_0}^{t_1} v_D(t)\ dt$
- advantage of drift chamber: much larger sensitive volume per readout channel.

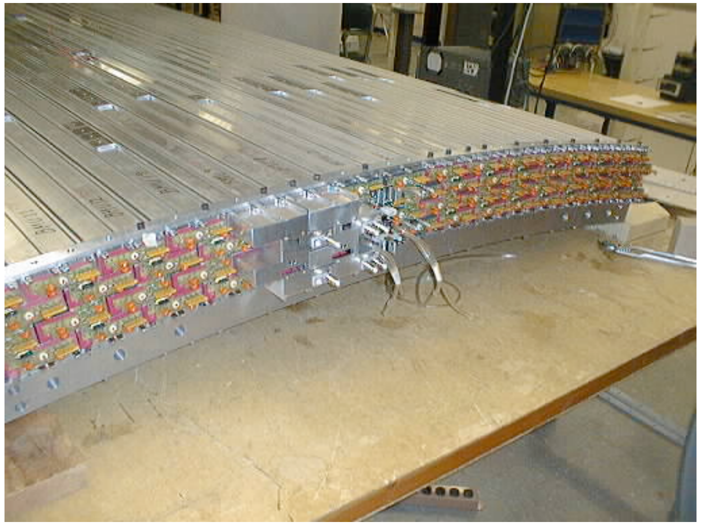
6. Driftchamber

- Use graded potential to get uniform drift field.
- Gas amplification near anode wire.
- Position resolution (σ= 50 - 200 μm)
  - v(t) distortions near wire
  - ionisation fluctuations
  - diffusion
  - electronic noise

drift cell



CDF muon chambers



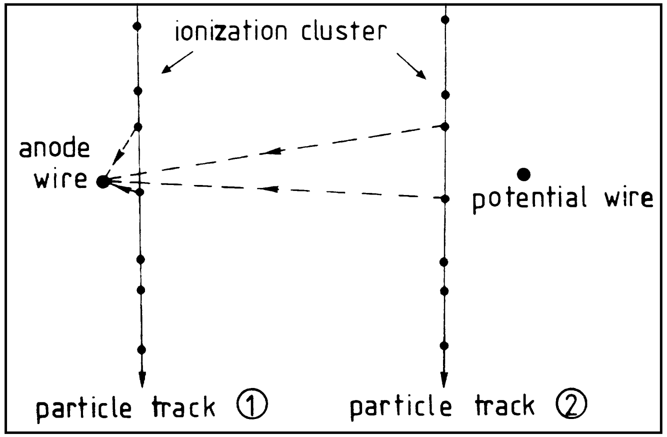
6. Driftchamber - Intrinsic Resolution

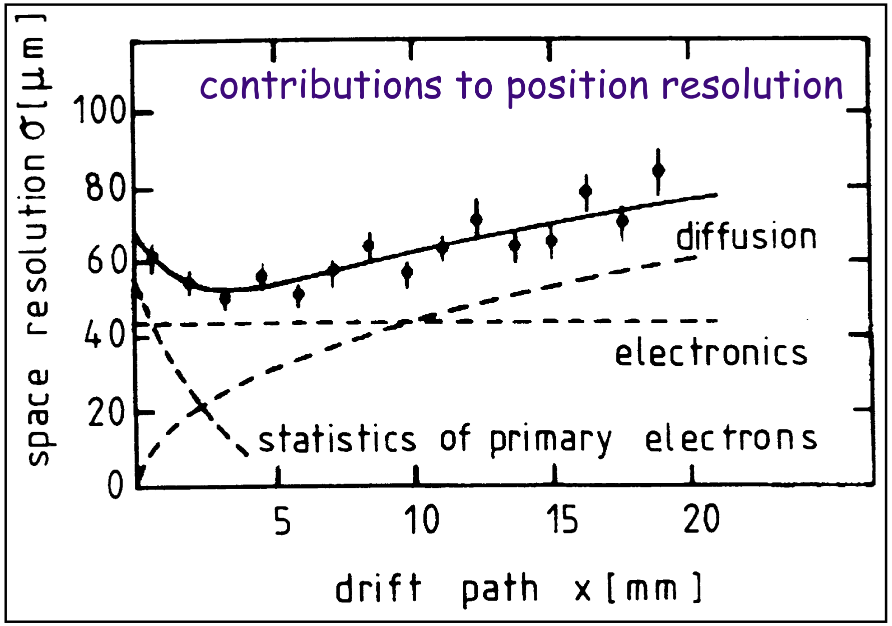
- Statistics of primary ionisation: 100 μm separation

- diffusion of electron cloud

$$\sigma = \frac{1}{\sqrt{n}}\sqrt{\frac{2Dx}{\mu E}}$$

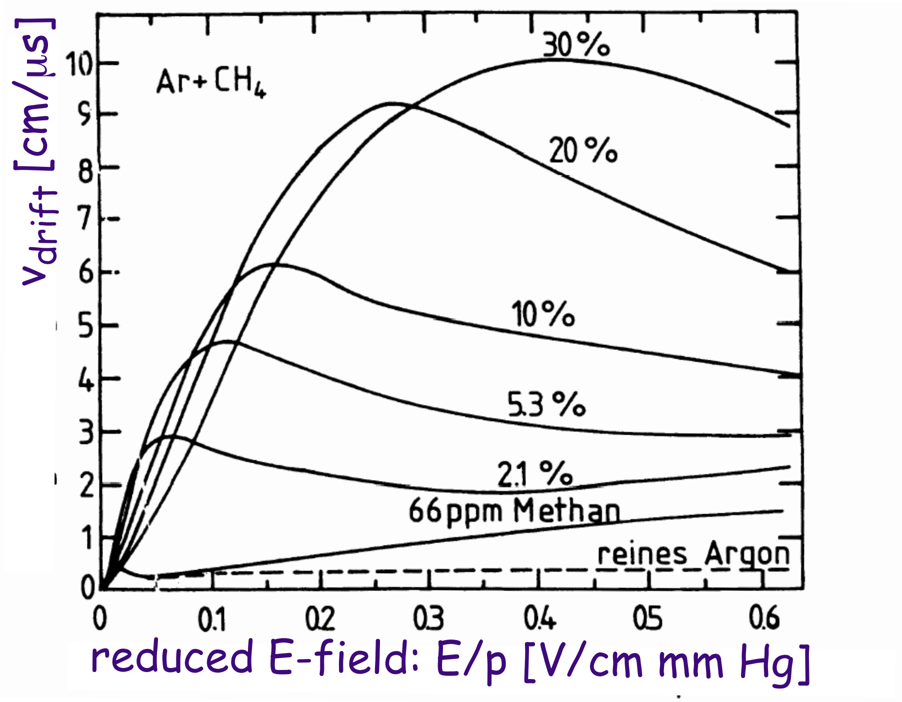
- time jitter in electronics

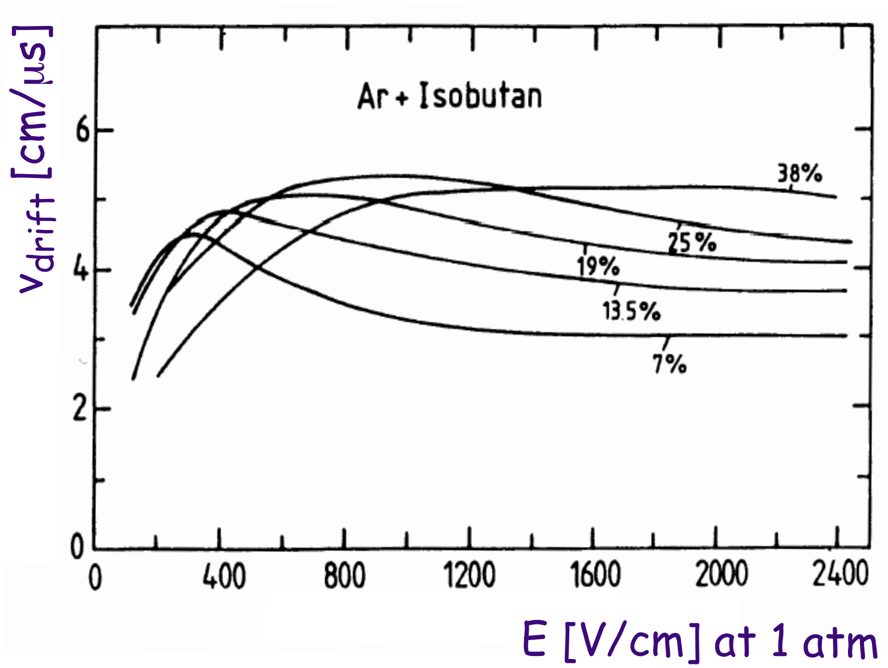




Particle Detectors 2

6. Driftchamber - Drift velocity



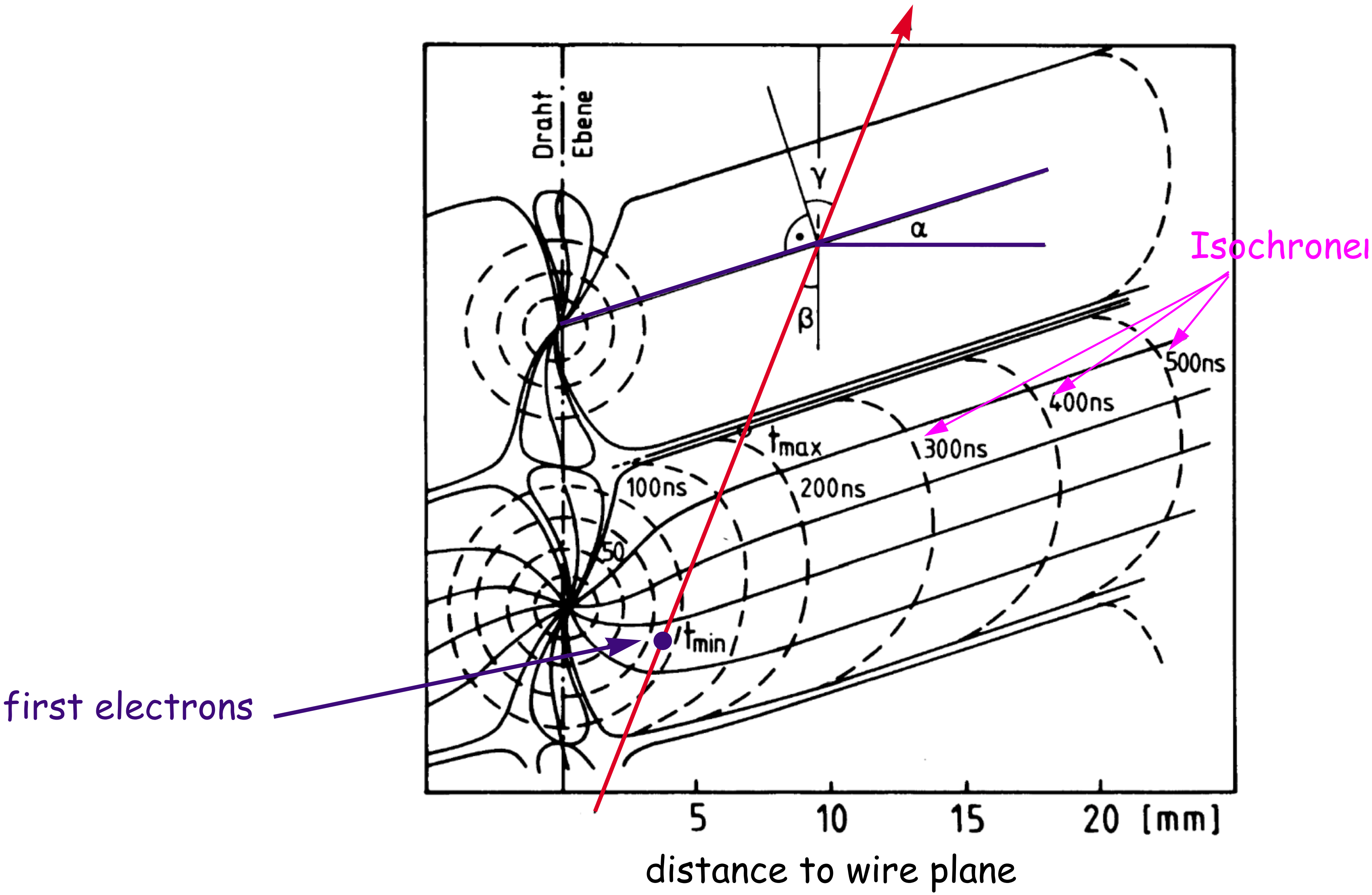


Some gas mixtures have a strong variation of drift velocity as function of E-field.

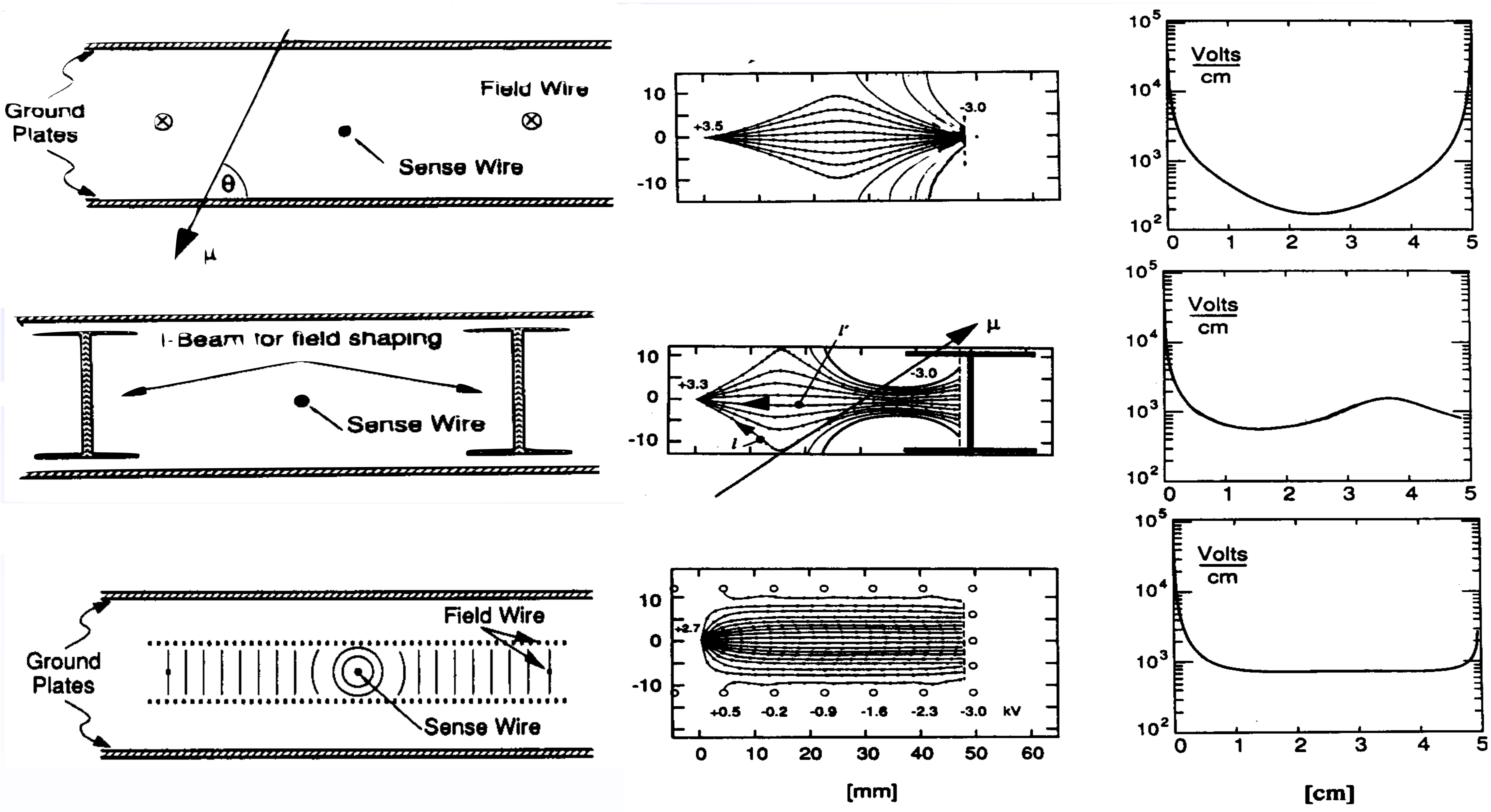
For stable operation it is useful to operate at maximum / plateau.

Typical drift velocities: 2-10 cm/μs = 20-100 ~m/ns.

6. Driftchamber in B-field

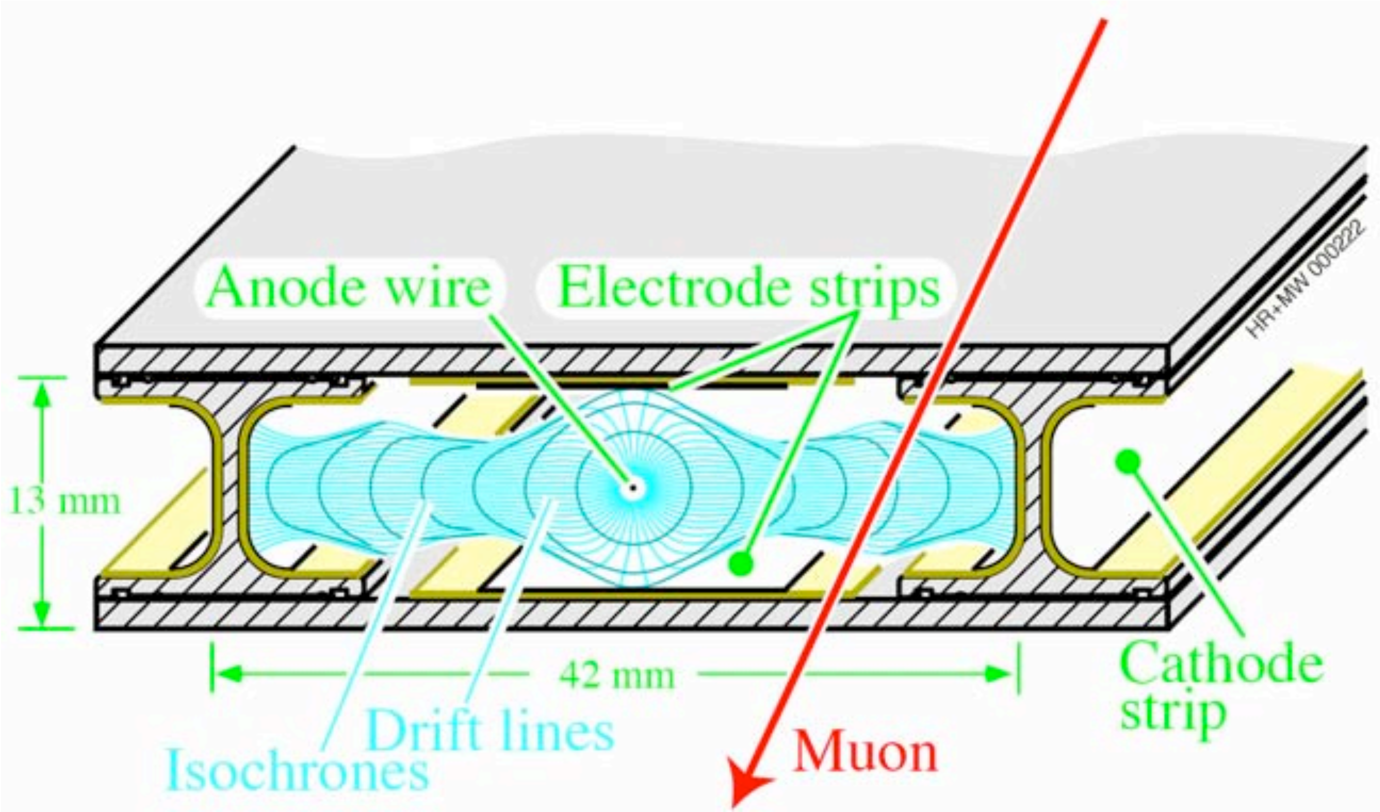


6. Planar Drift Chamber Types



U. Becker

6. CMS Muon Drift Tubes Chambers



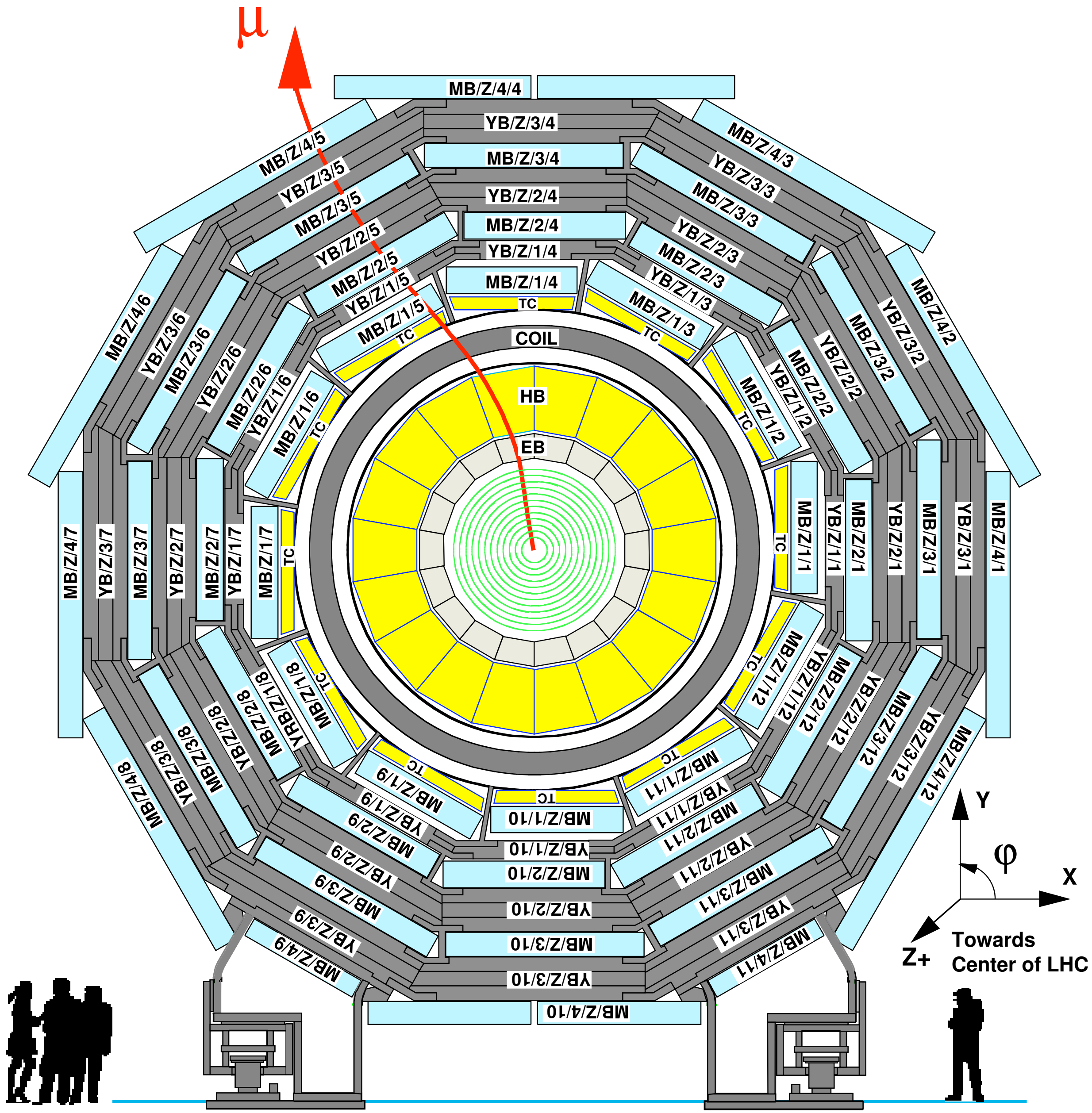
Anode wire 50 μm diameter gold-plated stainless steel wire.

Field electrode on top and bottom: 16 mm wide, 50 μm thick aluminium tape.

+ 3600 V on wires, + 1800 V on strips, -1200 V on cathode.

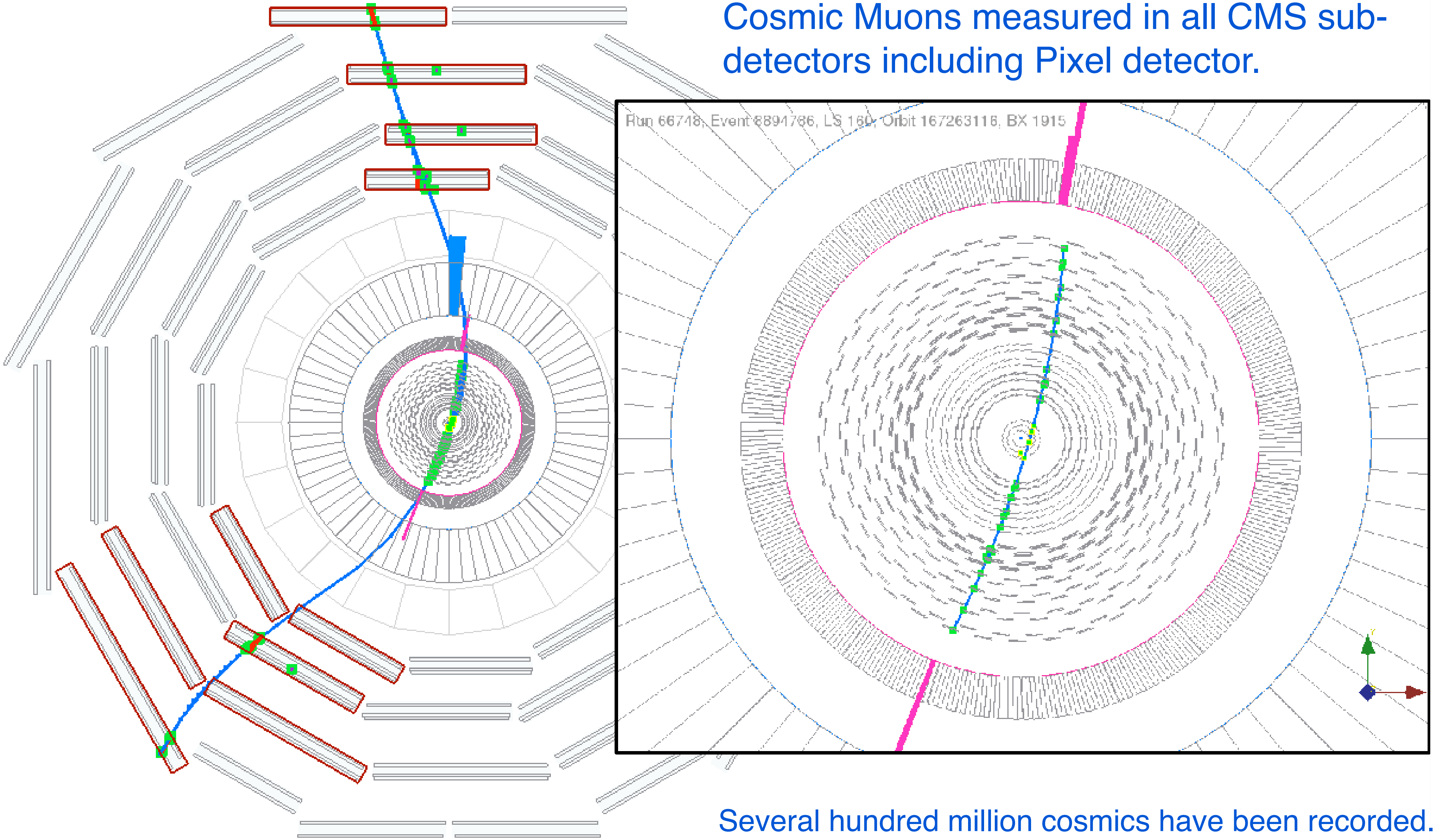
Ar/CO2 gas mixture, e.g. 85%/15%

6. CMS Muon Drift Tube System



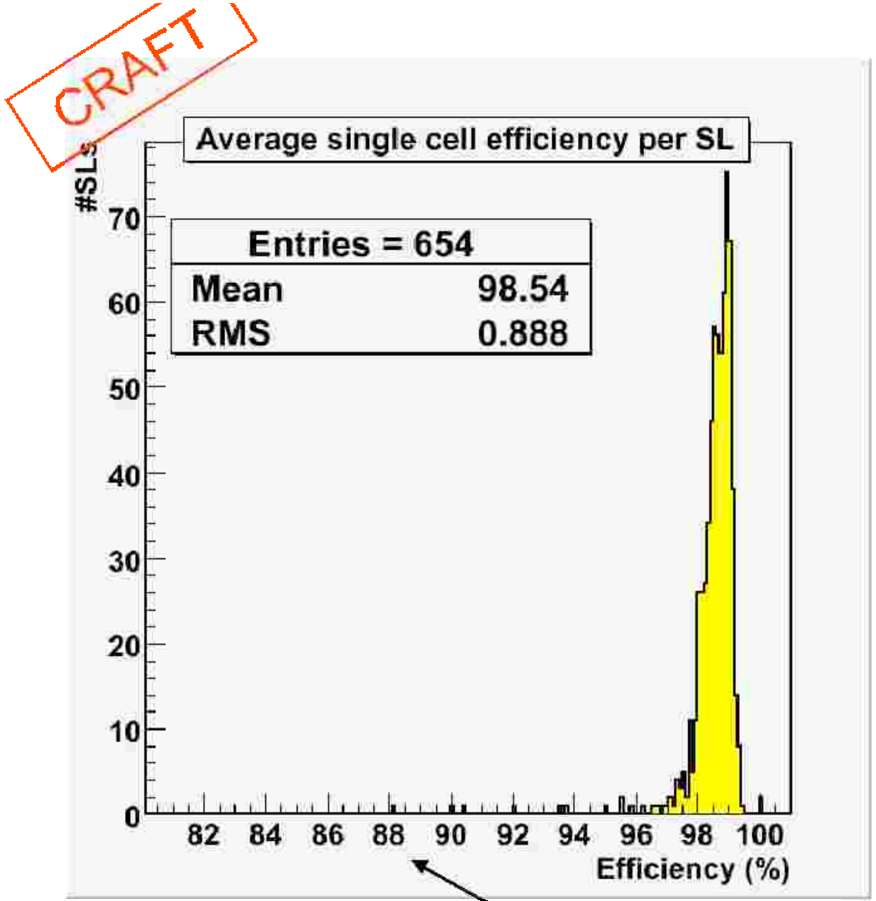
6. CMS Commissioning with Cosmics

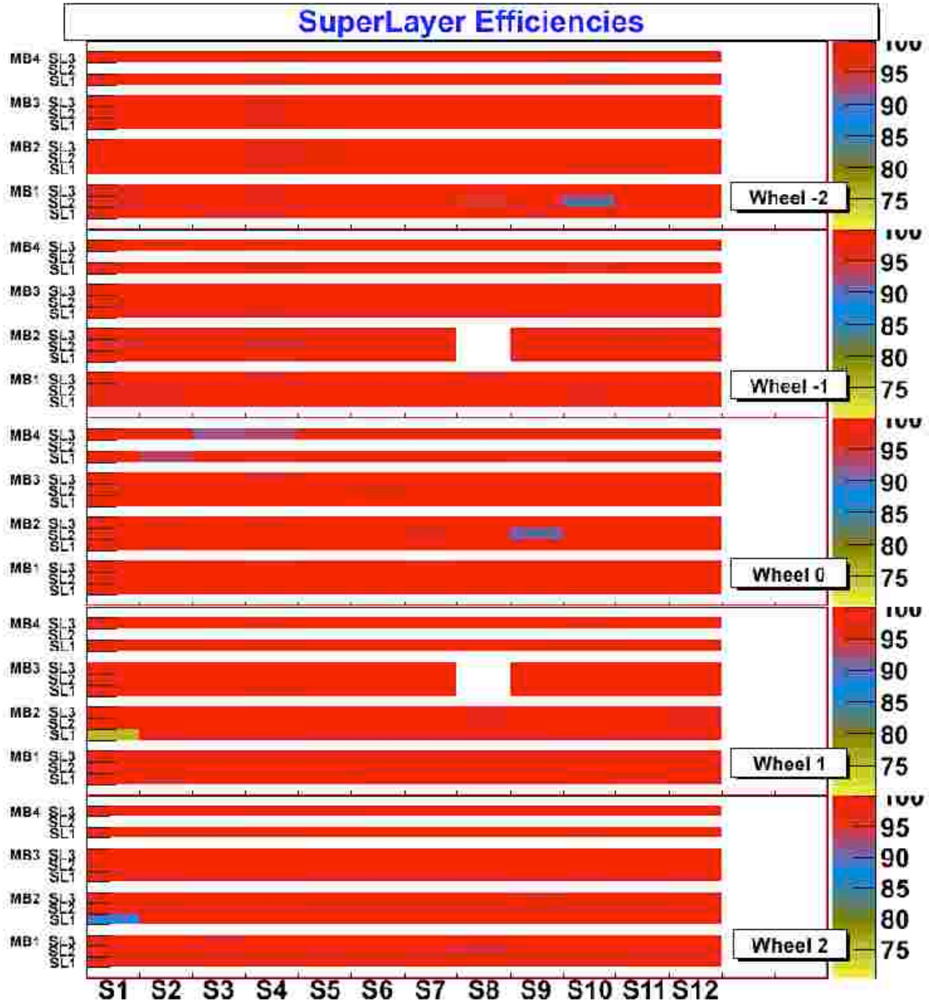
Cosmic Muons measured in all CMS sub-detectors including Pixel detector.



Several hundred million cosmics have been recorded.

6. CMS Muon DT Efficiency



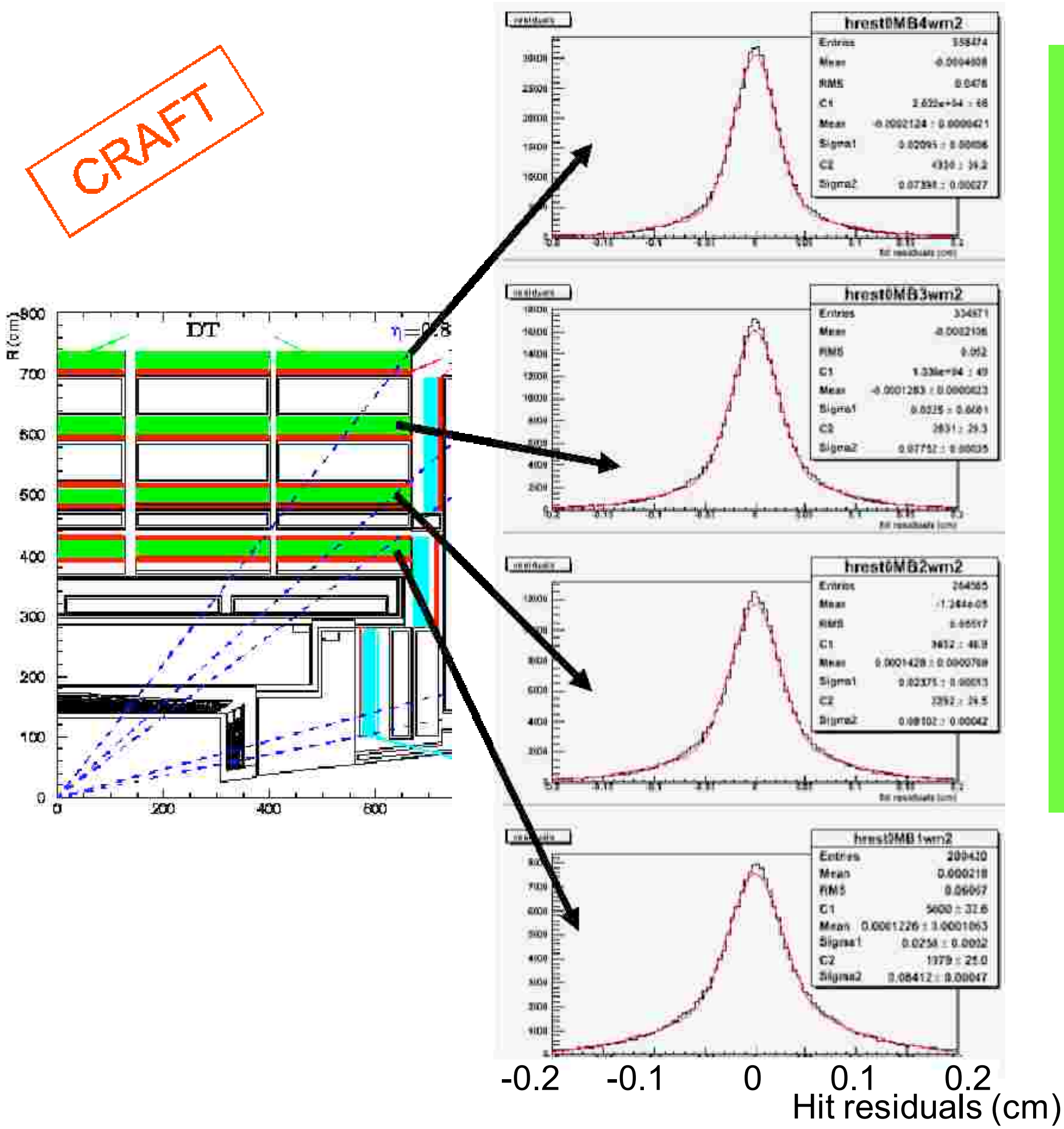


Drift Tubes layer efficiency. Lower values correspond groups of 6 temporarily disconnected channels.

F. Cavallari, Elba 2009

6. CMS Muon DT Hit Resolution

CRAFT



The hit resolution is computed from the residuals between the DT hits and the track segments in the muon spectrometer.

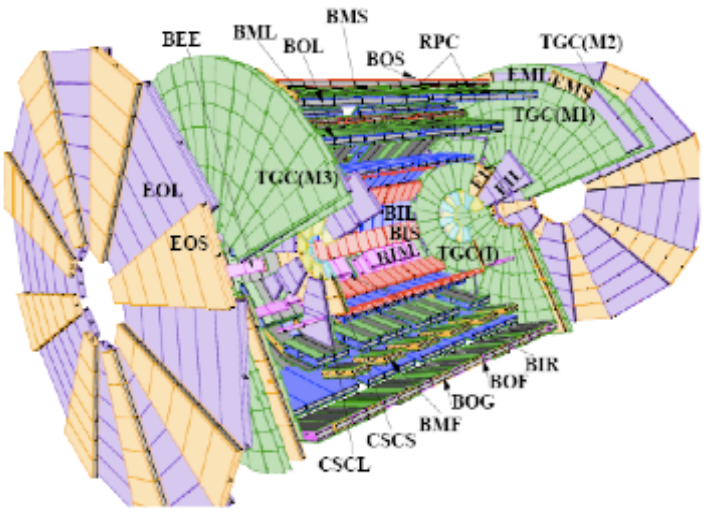
Typical values
$\sigma \sim 200 – 260\ \mu m$

Good agreement with MC

Magnetic field degrades the resolution in the inner chamber in the external wheels.

TALK

6. ATLAS Monitored Drift Tubes (MDT)



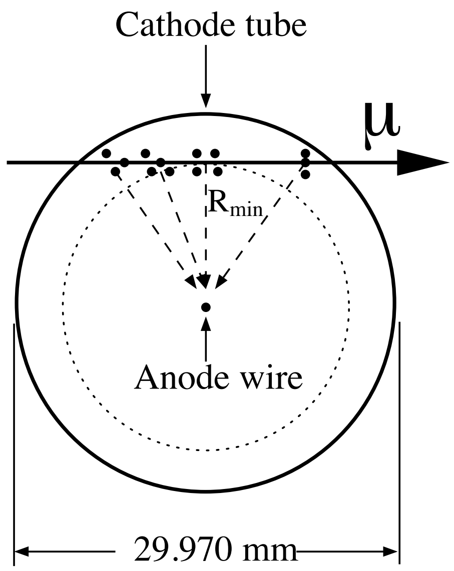
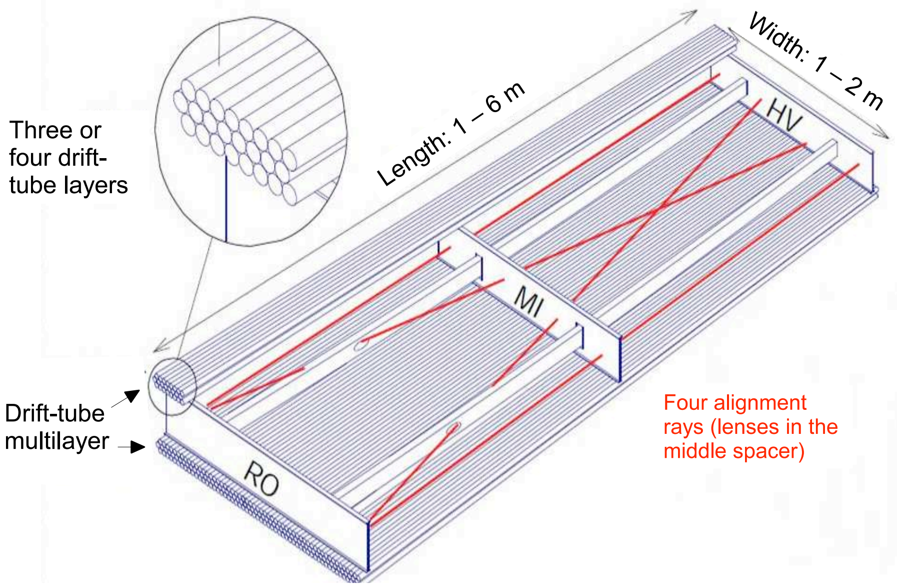
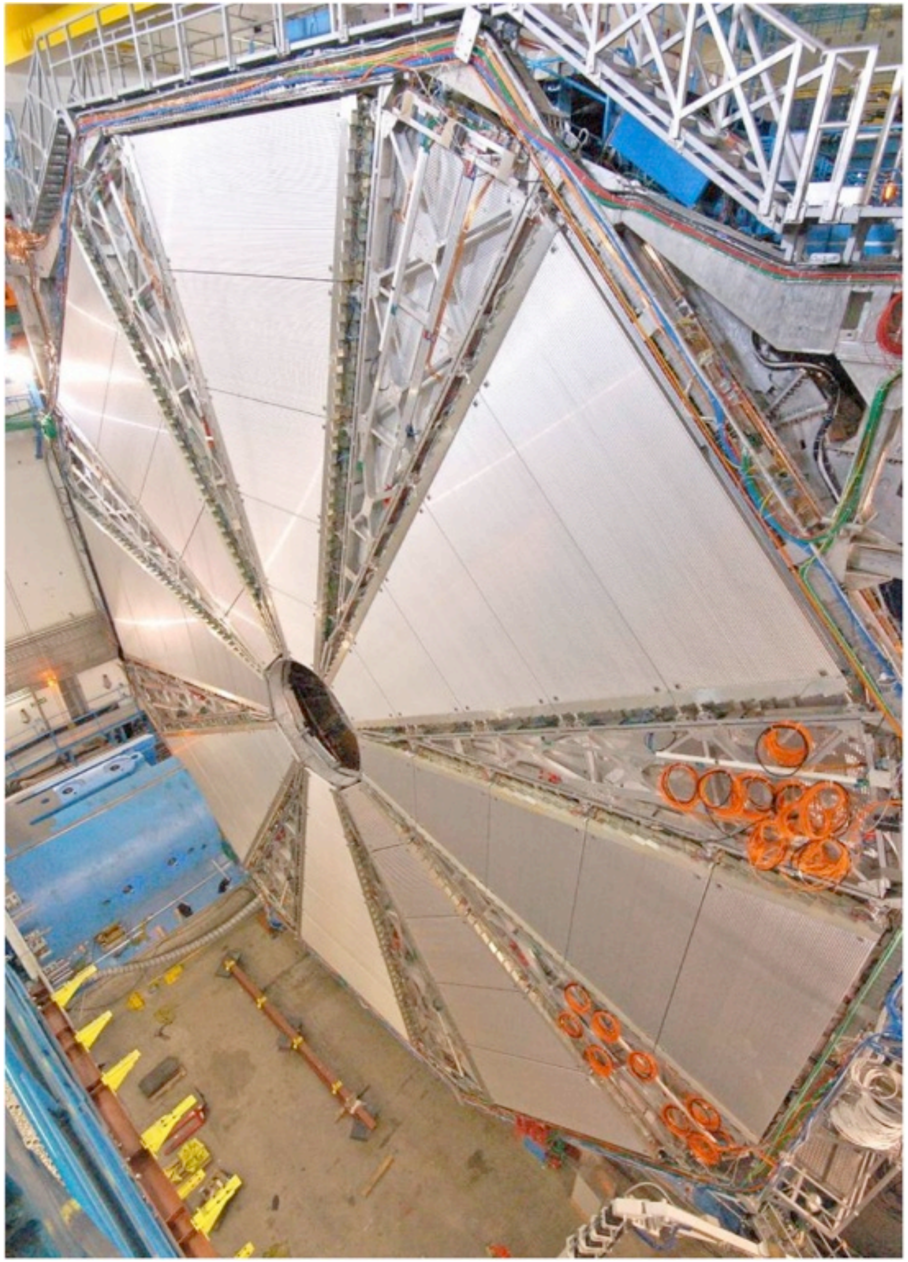


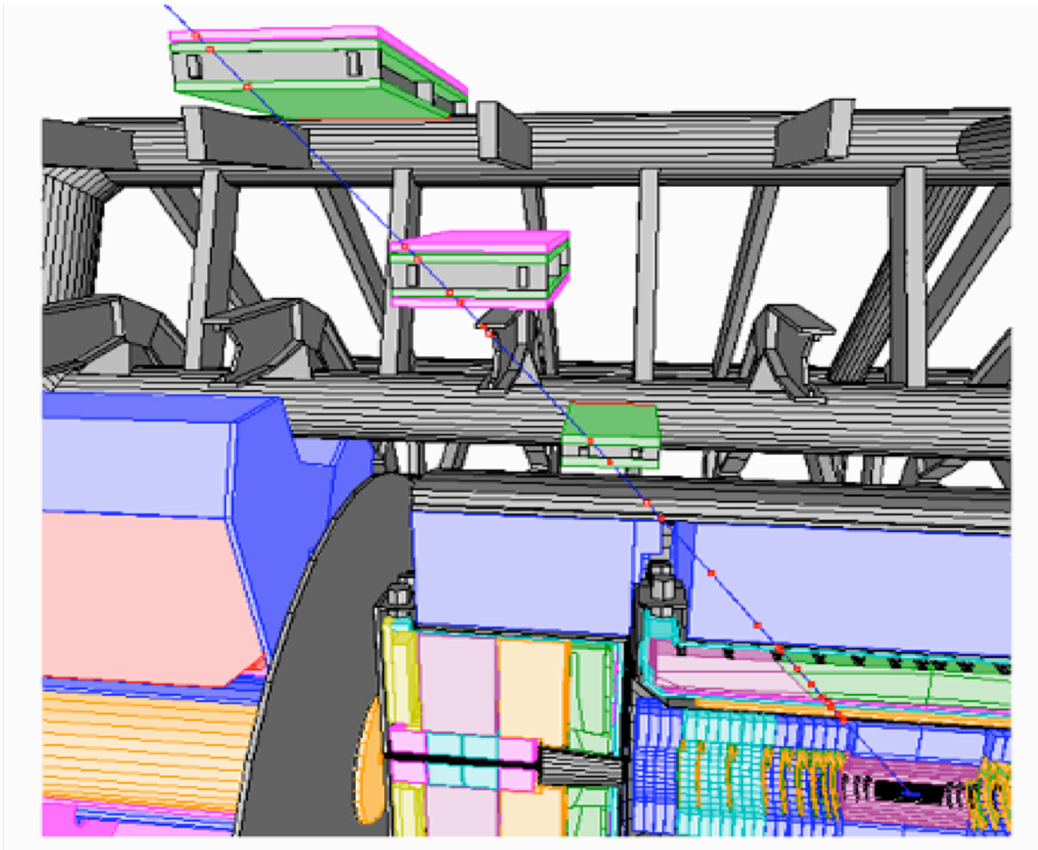
Table 6.2: Main MDT chamber parameters.

Parameter	**Design value**
Tube material	Al
Outer tube diameter	29.970 mm
Tube wall thickness	0.4 mm
Wire material	gold-plated W/Re (97/3)
Wire diameter	50 μm
Gas mixture	$Ar/CO_2/H_2O$ (93/7/$\leq$ 1000 ppm)
Gas pressure	3 bar (absolute)
Gas gain	2 x 10^4
Wire potential	3080 V
Maximum drift time	$\sim$ 700 ns
Average resolution per tube	$\sim$ 80 μm

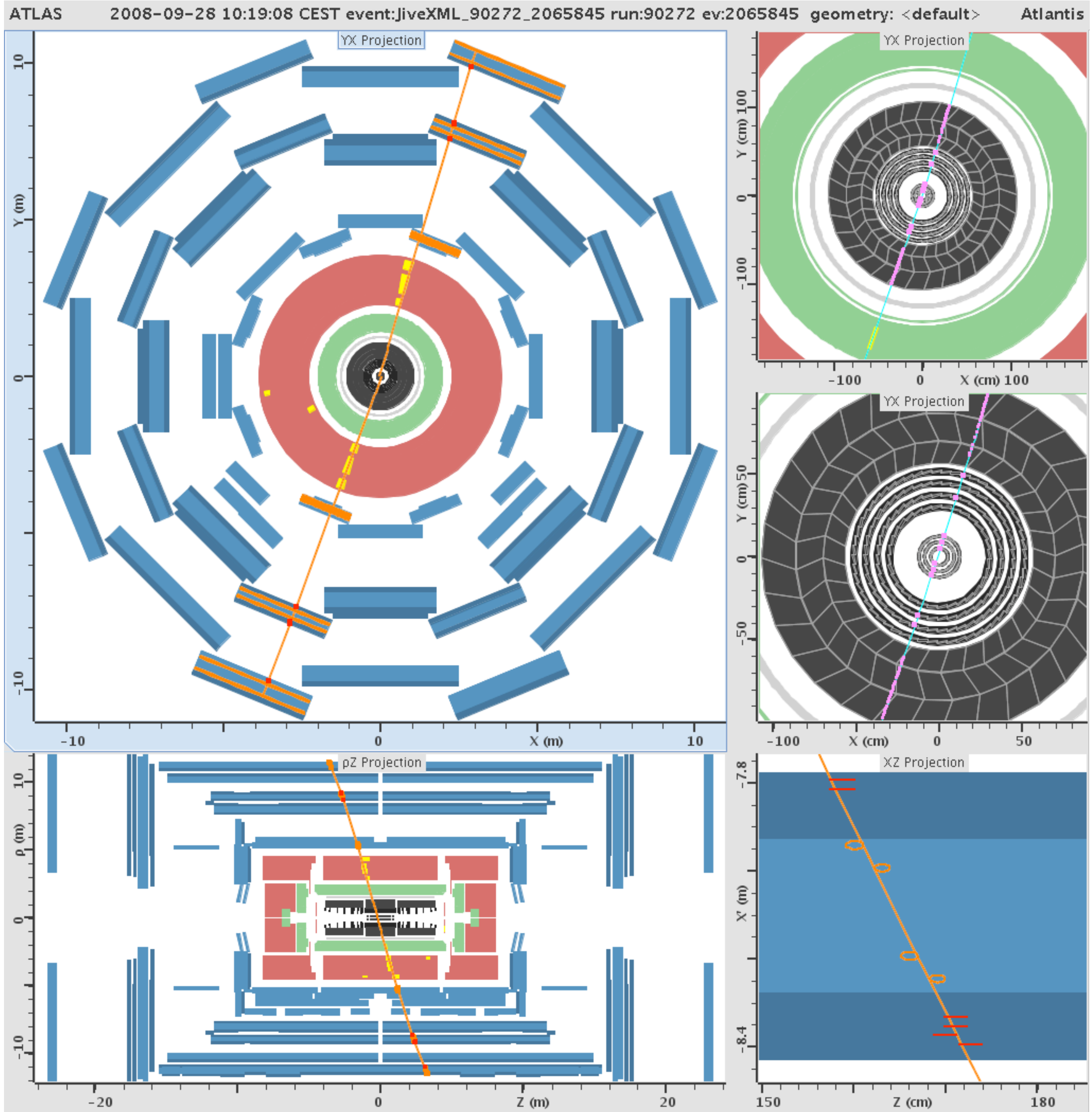


14. ATLAS Muon System

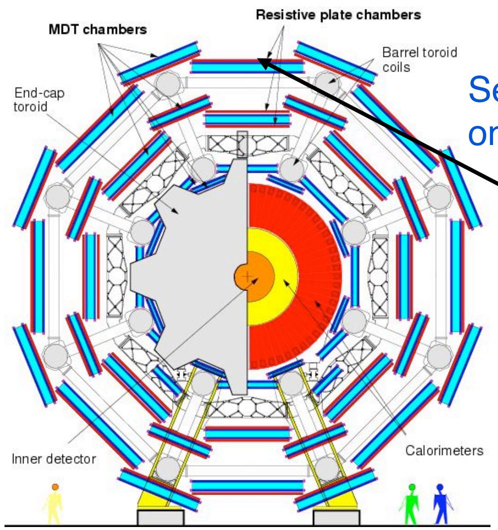




14. ATLAS Cosmic Event

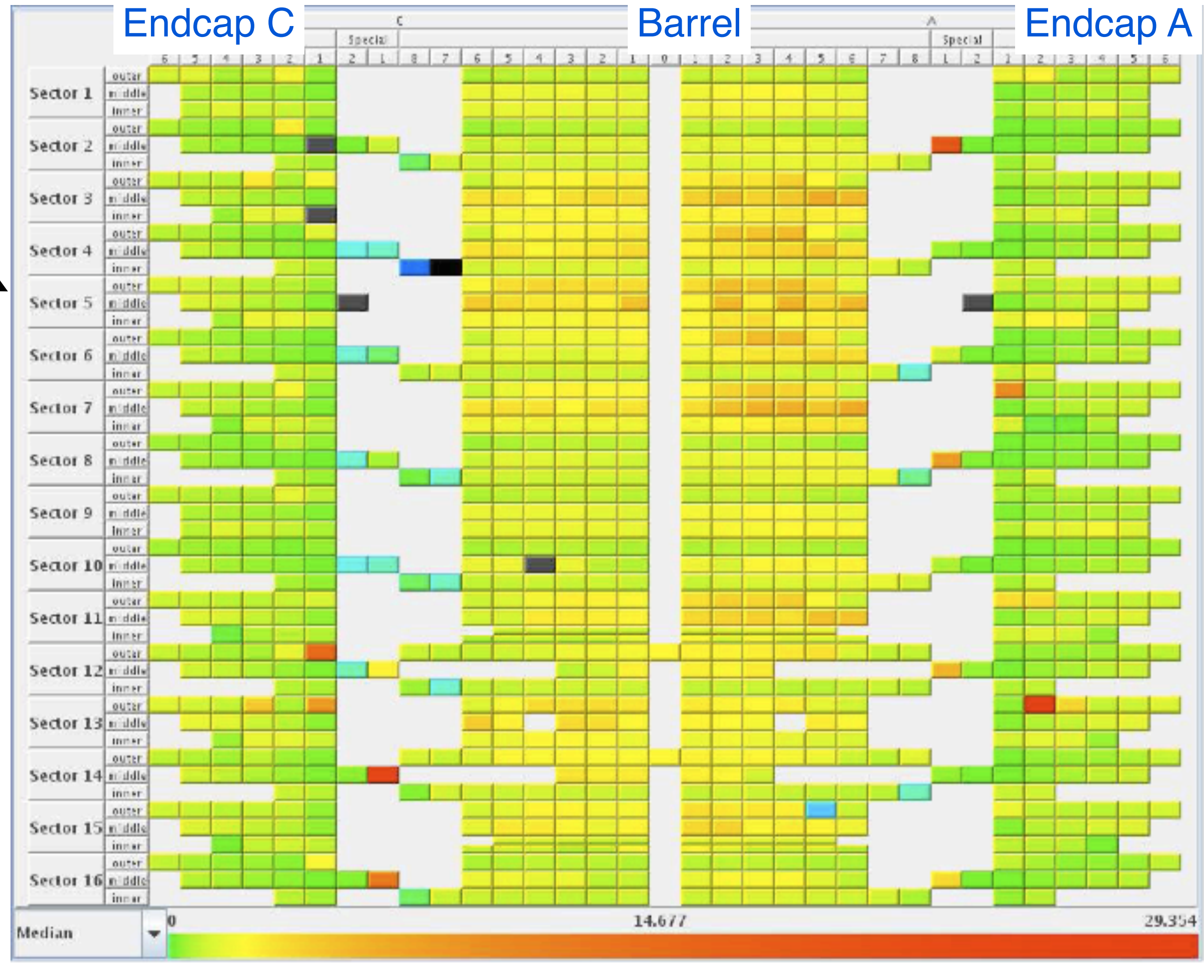


6. ATLAS MDT System Performance



Sector 5 on top

Statistics/chamber in one long 2008 run

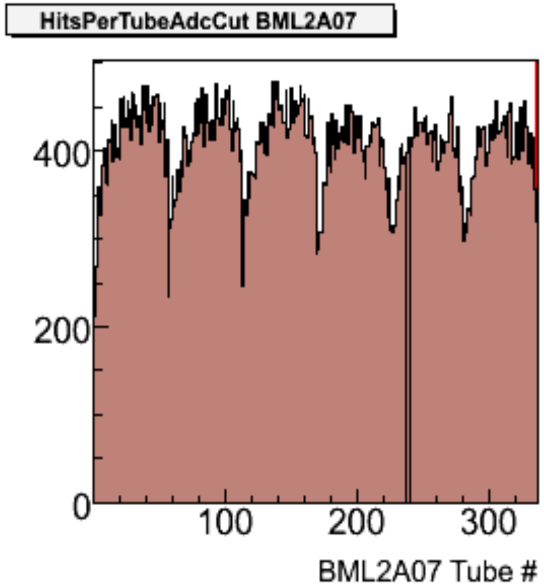


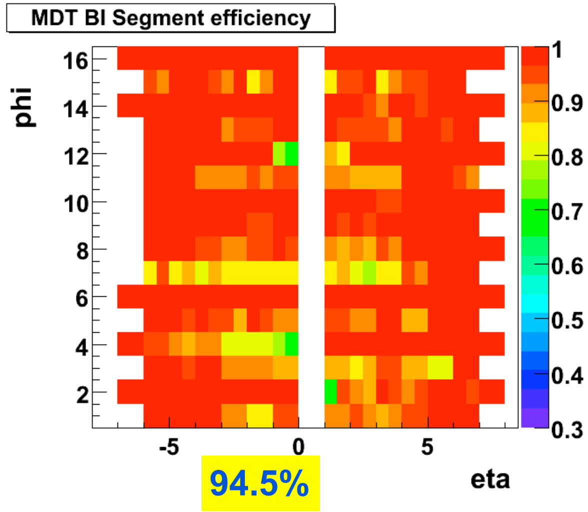
No data available
O(1M)
O(100k)
O(10M)

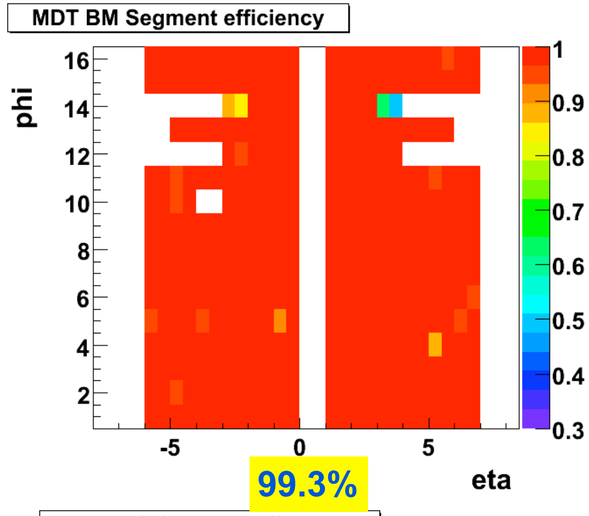
Out of 1100 chambers:

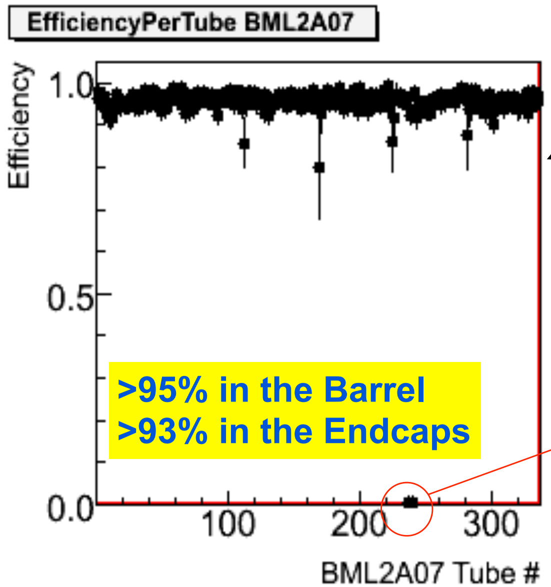
- 3 chambers not readout (gas system problems)
- 2 chambers with HV off
- 32 chambers with HV off for 1 of the 2 multilayers

6. ATLAS MDT Efficiency

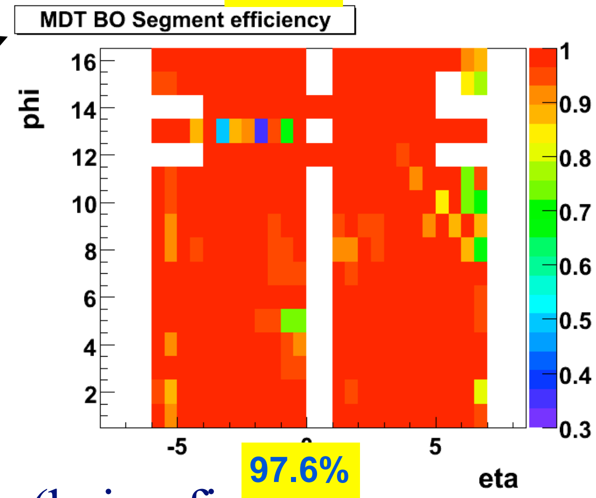








Tube & segment efficiencies in cosmic ray events

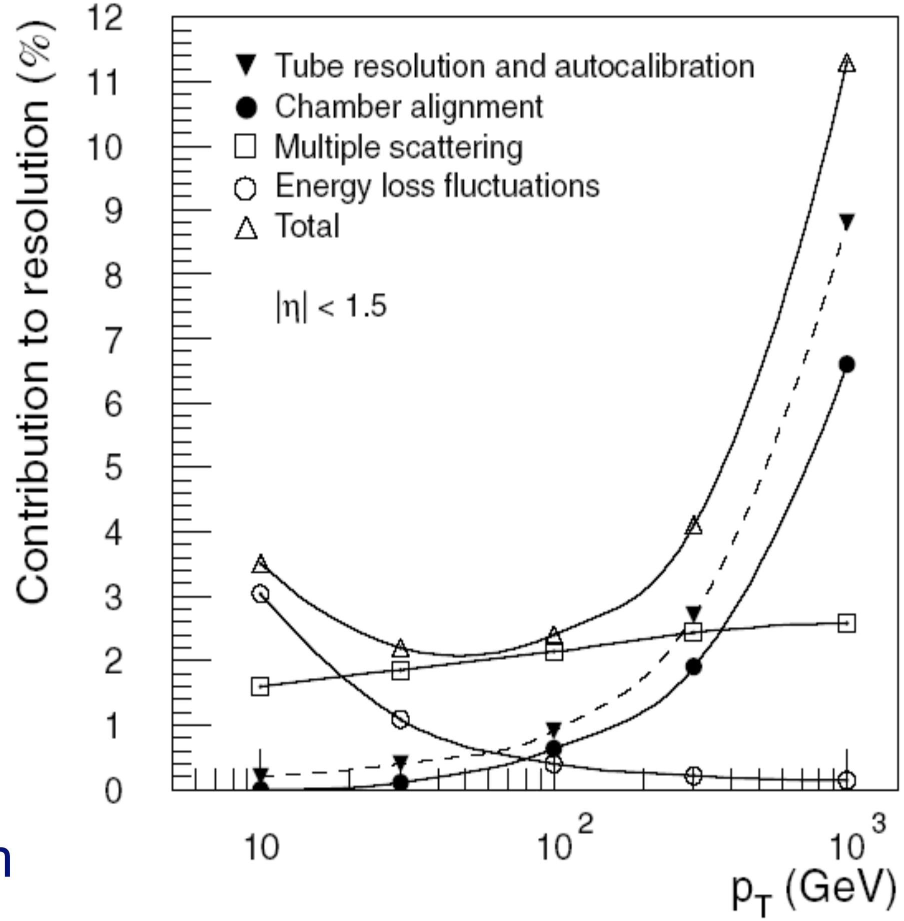


- 0.1% single dead channels
- 1% clustered dead channels (being fixed)
- Noisy channels (> 5% occupancy) < 0.2%

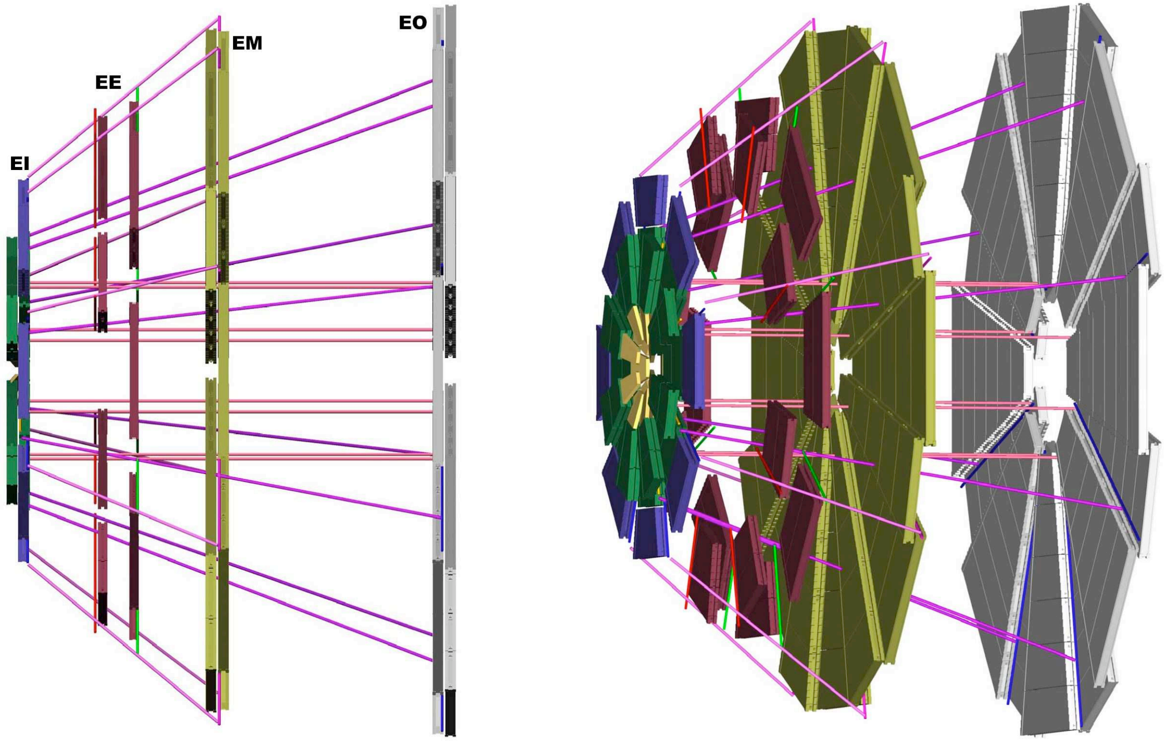
6. ATLAS MDT Expected Momentum Resolution

•10% resolution at 1TeV dominated by position measurement resolution
•Sagitta ~500μm
•Position measurement ~50μm (obtained from 3 or 4 hits with 80-90μm resolution)
•Systematics must not spoil the overall accuracy
•Calibrations and alignment better than 30μm!

•Alignment system: 12232 optical sensors
•Autocalibration with dedicated data stream



6. ATLAS Muon Endcap Chamber Alignment



Layers of tracking detectors have to be aligned with respect to each other.

Precision in alignment should be comparable to sagitta error.

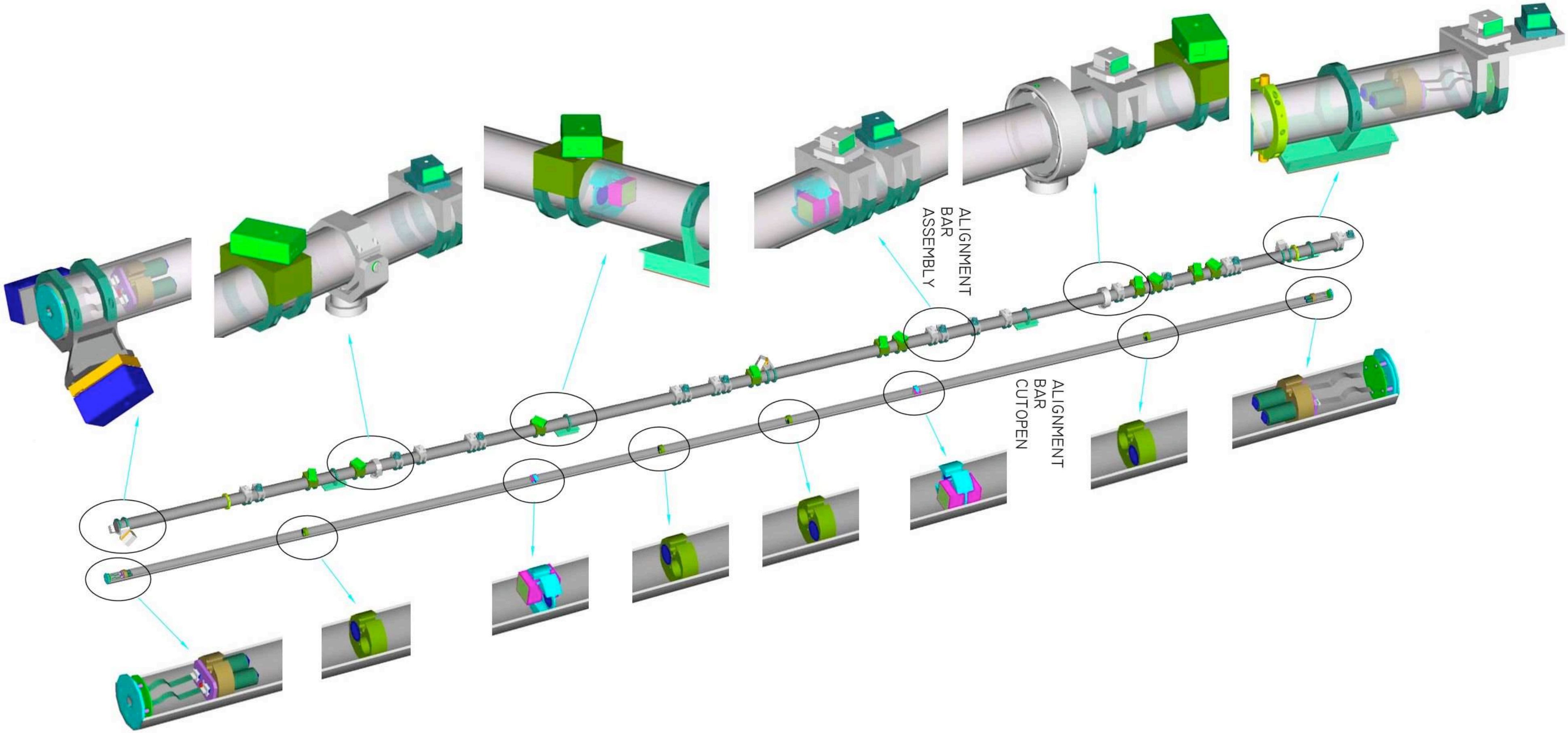
Inner Tracker: mainly use tracks.

Muon system: optical alignment and tracks.

Example: ATLAS endcap muon system

With CCD cameras (BCAM) the relative position of chambers is measured. The optical sensors are mounted on chambers and alignment bars, which serve as precise 3D calibration devices.

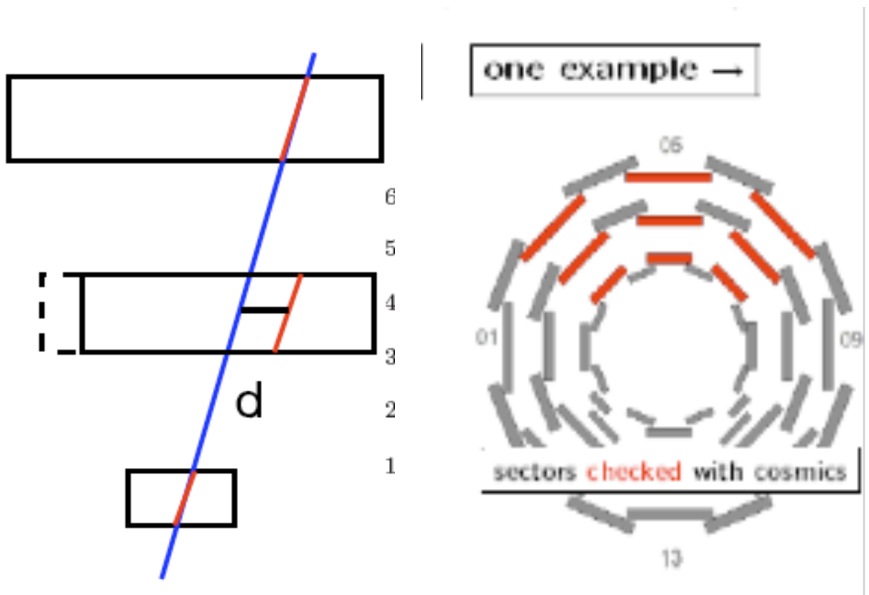
6. ATLAS Muon Endcap Chamber Alignment



Alignment bars are up to 10 m long. The 3D position of every platform is measured with a precision of 10 μm. Since the position of every sensor (BCAM) on the bar is know the sensor reading is used to determine the position of chambers. The alignment error of chambers will be about 30 μm. An optical system inside the bars measures the deformation of the bar.

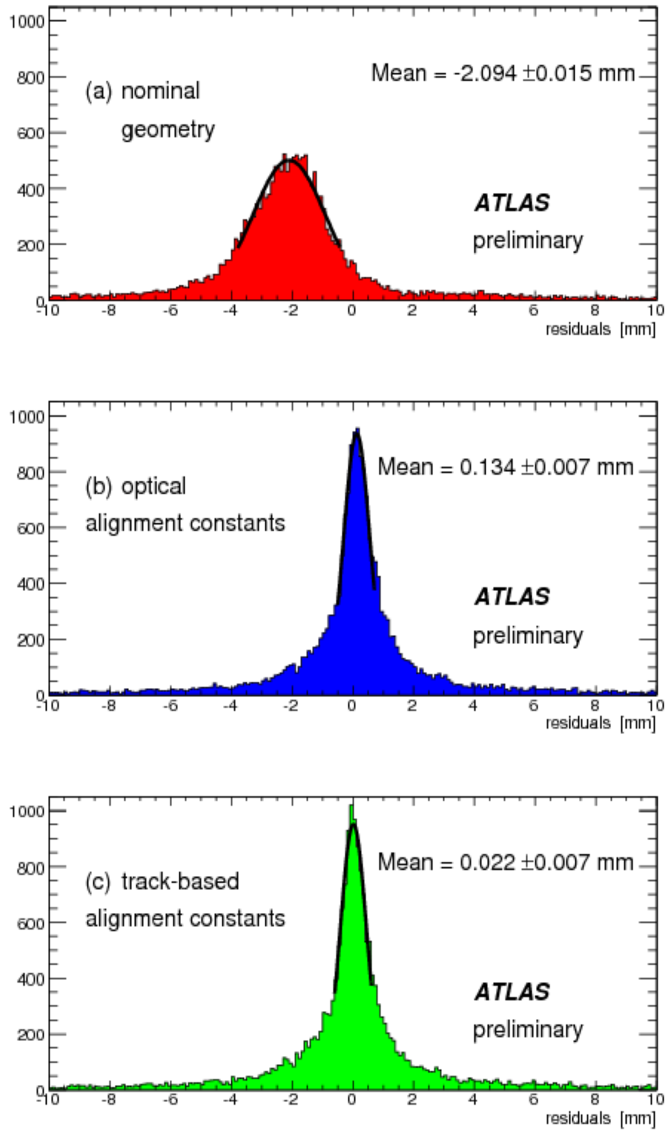
14. ATLAS Muon MDT Chamber Cosmic Analysis

BARREL

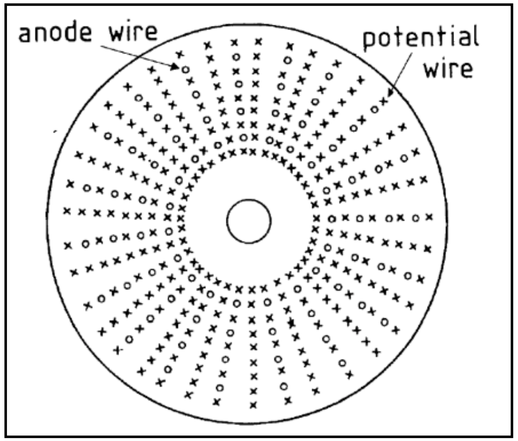


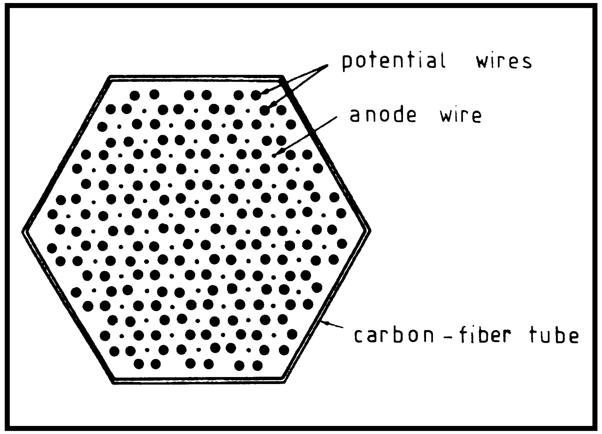
•Barrel Optical Alignment: at 200 μm level for large sectors (0.5-1mm for small ones)
•Track based alignment : improvement to <50 μm level

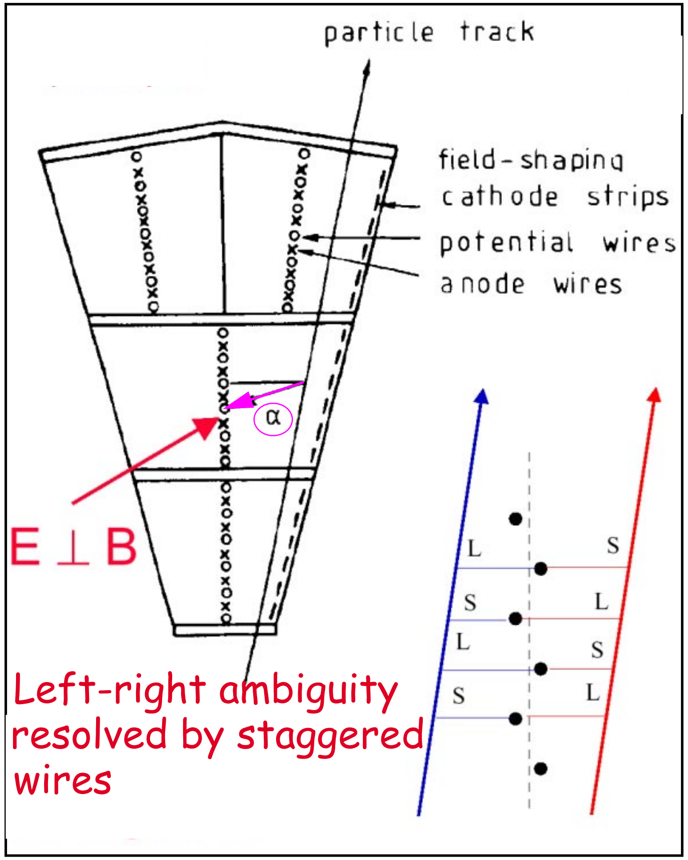
Residuals



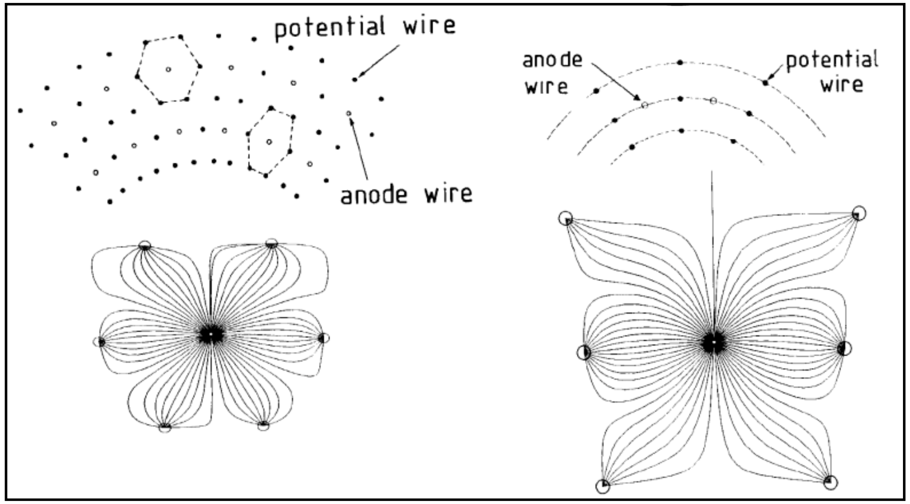
6. Cylindrical Driftchambers



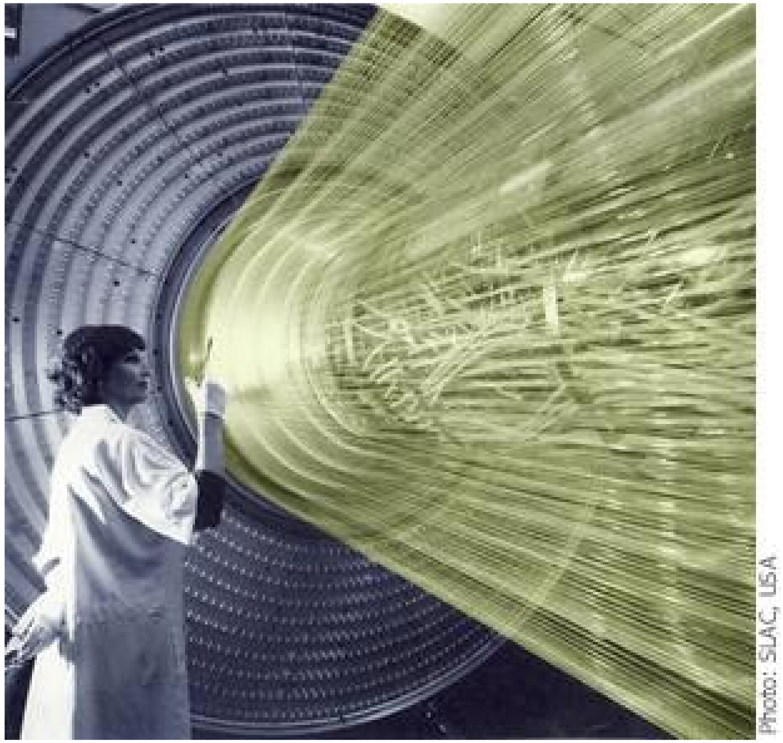




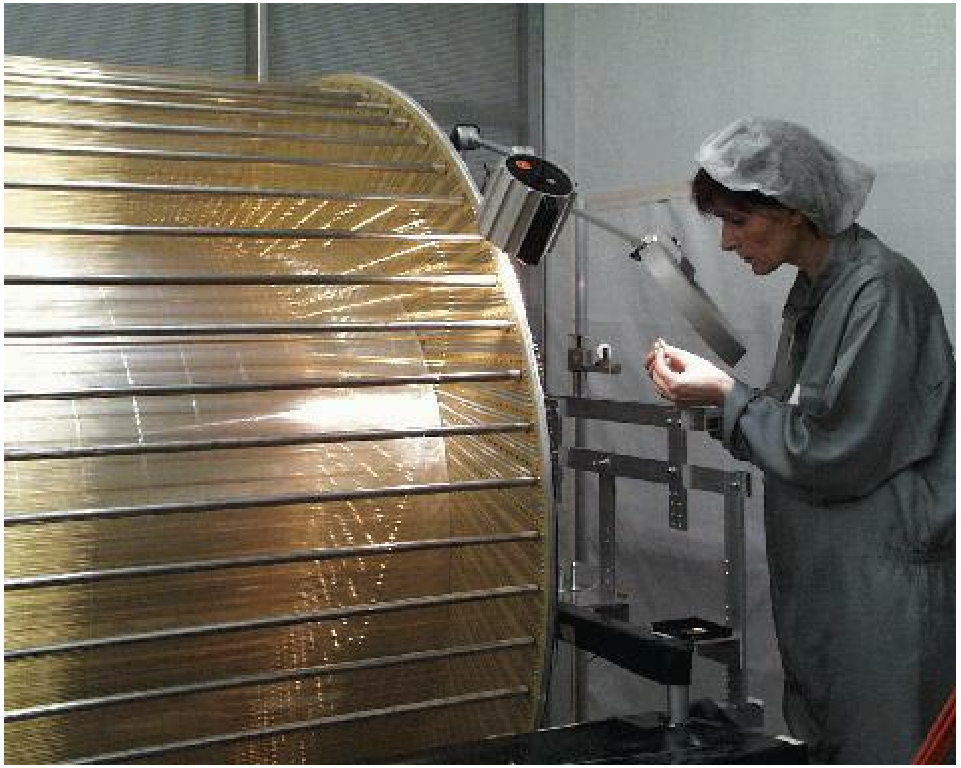
cell of a "jet"-driftchamber



6. Cylindrical Driftchamber



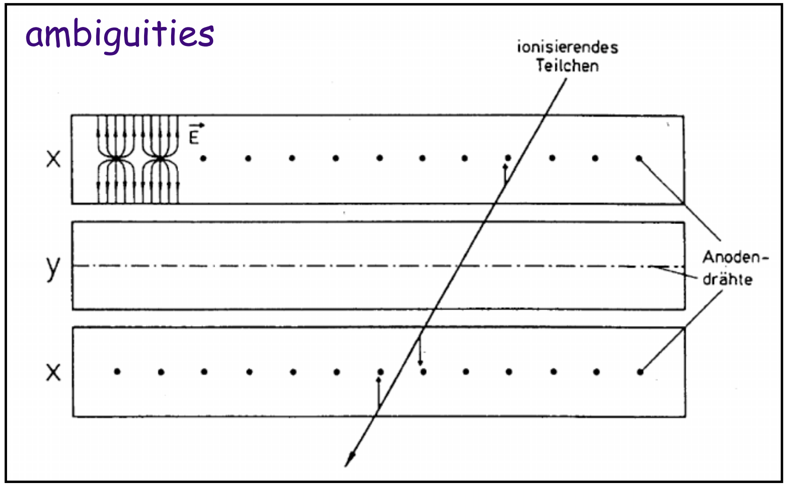
H1 Central Jet Chamber



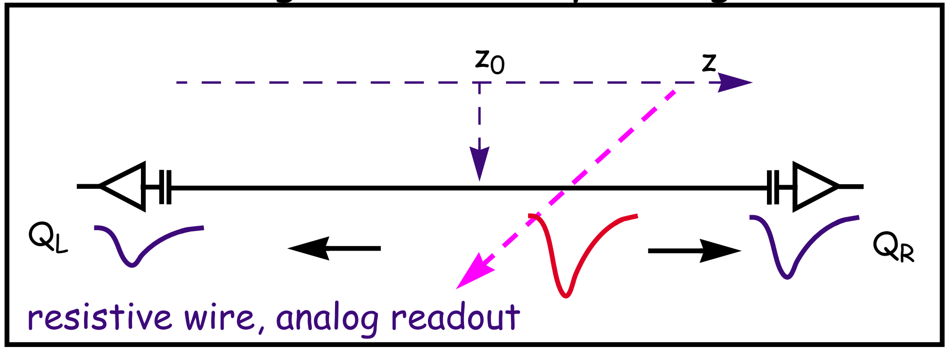
- ≈ 15000 wires
- total force from wire tension ≈ 6 tons

6. Readout of Second Coordinate

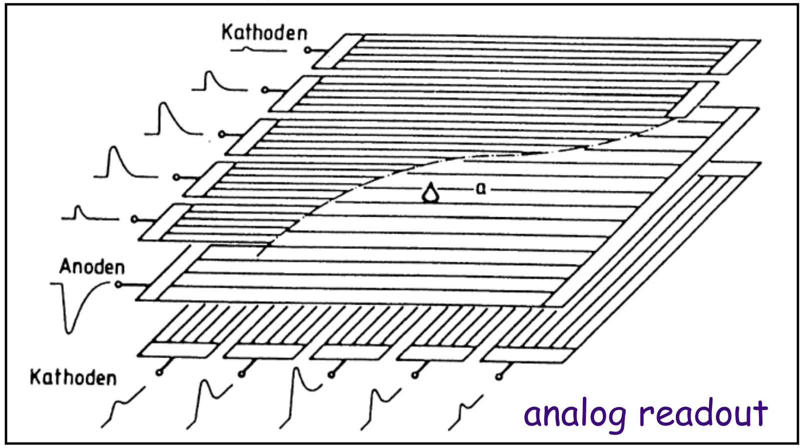
Crossed Planes



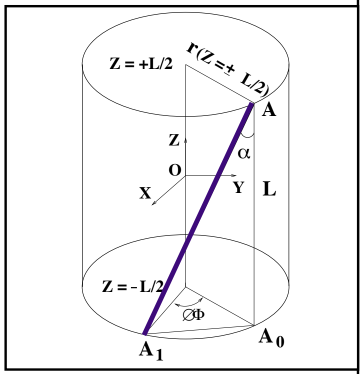
Charge Divison, z-by-timing

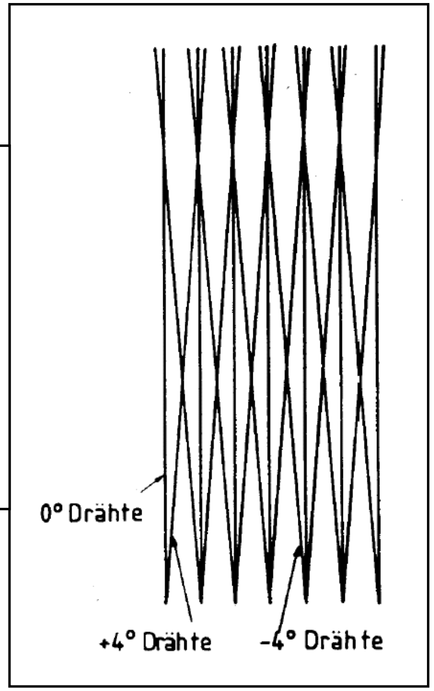


Segmented Cathodes



Stereo Wires

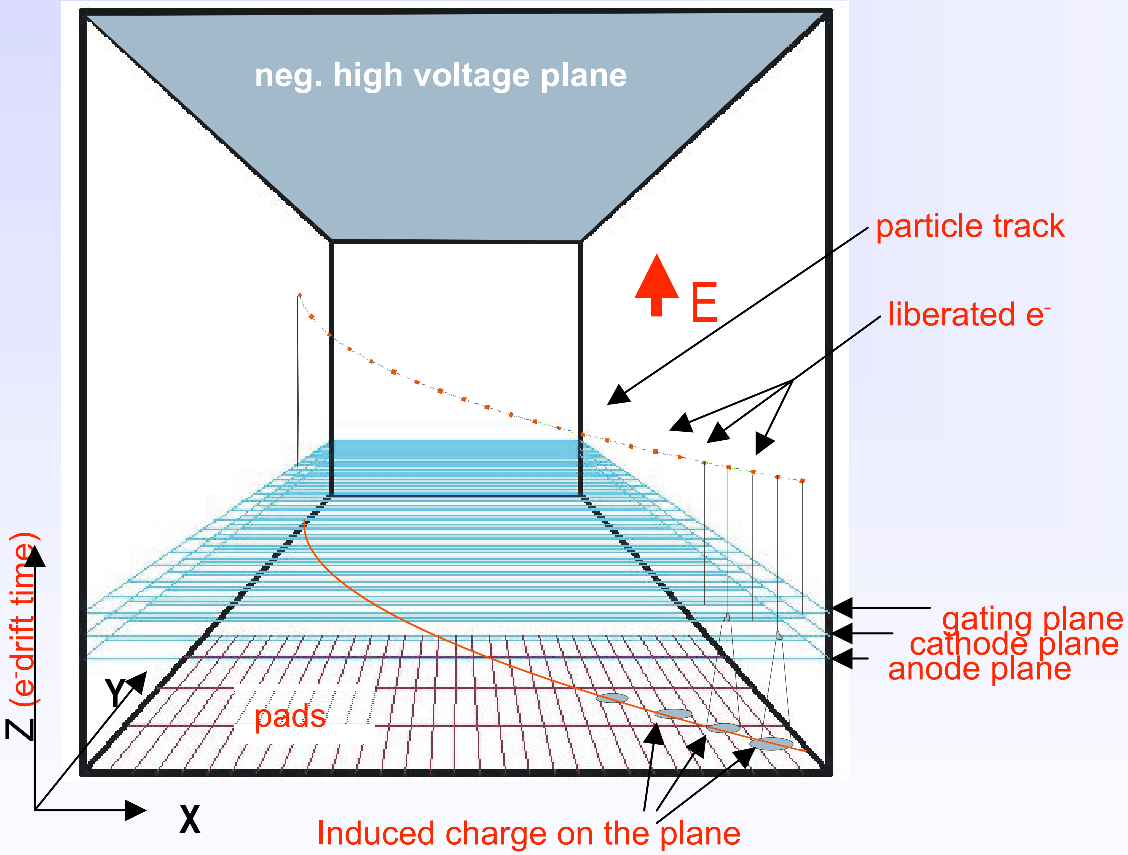




$\rightarrow \sigma_z \approx 0.1$ mm

6. TPC - Time Projection Chamber

from L. Ropelewski



Time Projection Chamber

full 3D track reconstruction:

x-y from wires and segmented cathode of MWPC (or GEM)

z from drift time

- momentum resolution
  space resolution + B field
  (multiple scattering)
- energy resolution
  measure of primary ionization

6. TPC - Time Projection Chamber

Developed by D. Nygren in the 70's.

Large gas volume with central electrode.

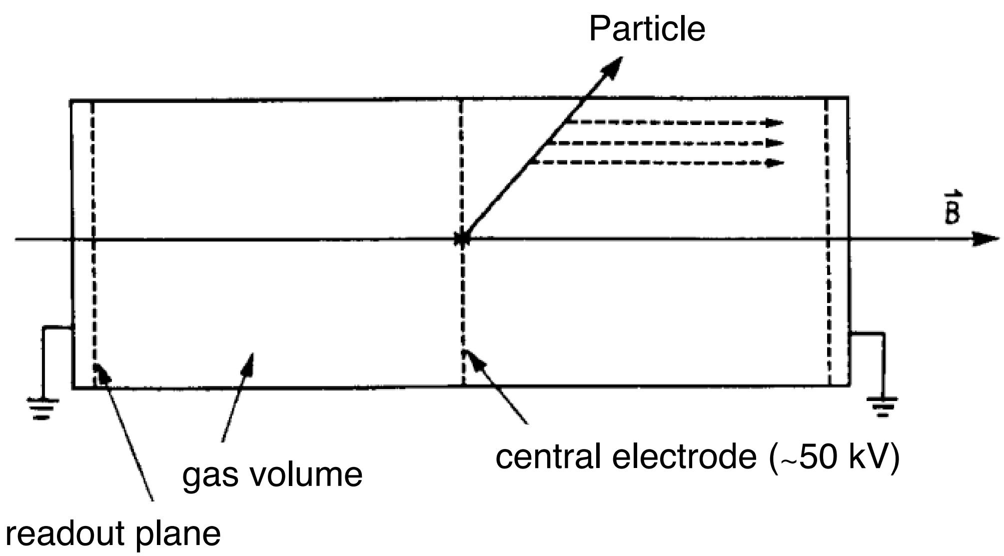
Drift distance of several meters.

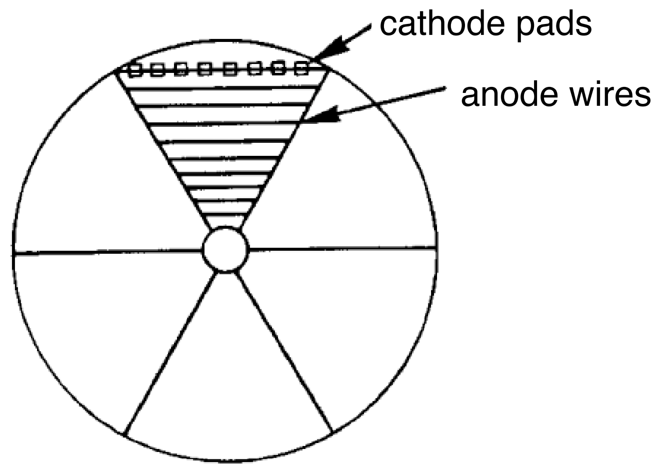
Signal registered with MWPC, anode wires and cathode pads provide x,y ; drift time gives z.

Transverse diffusion reduced (electrons spiral around E-field, since E ll B, Lamor radius < 1 μm)

Very good 3D hit resolution and dE/dx.

Long drift times ($\approx$ 40 μs), thus rate limitations and very good gas quality required.





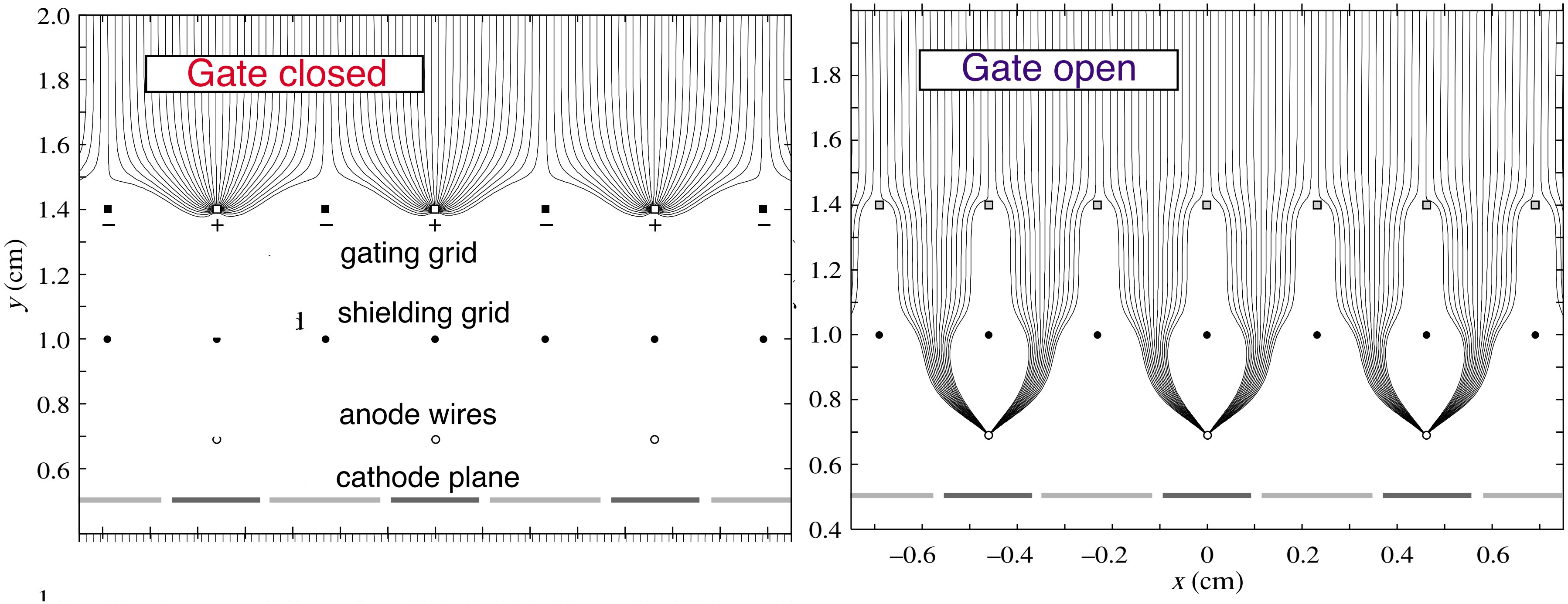
6. Gating in TPC

Problem:

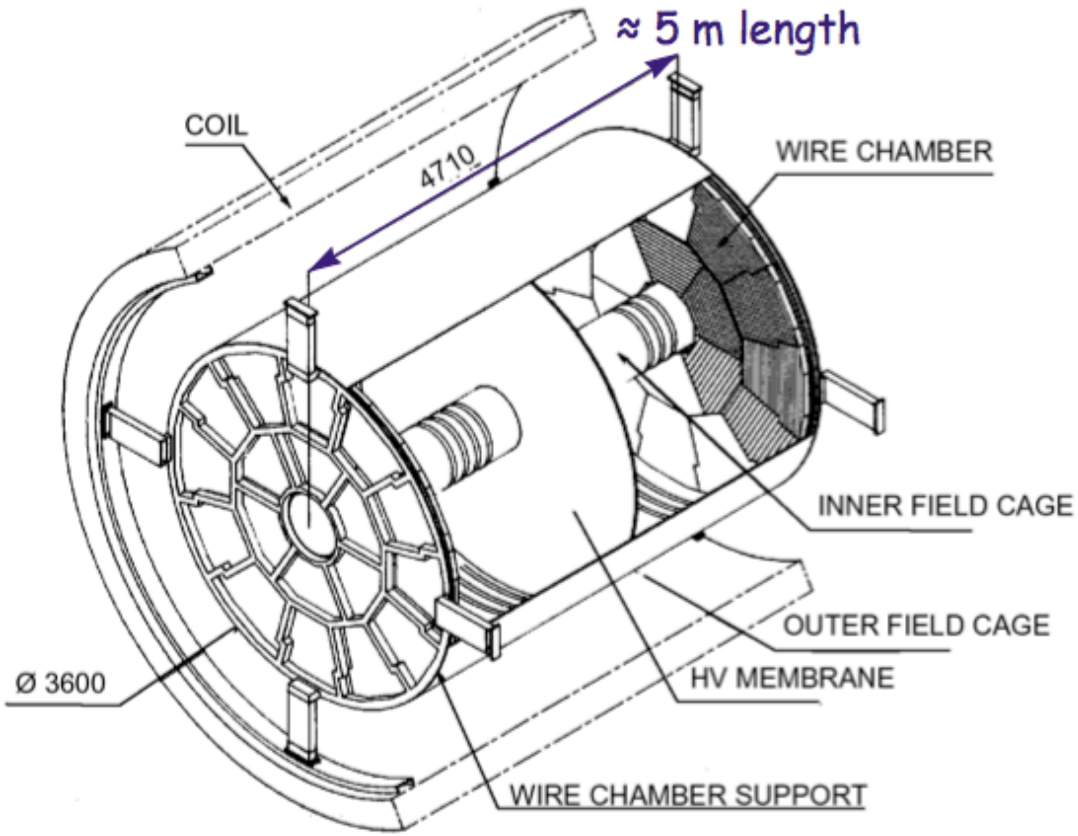
- Ions drift back to central electrode
- Disturbs homogeneity of electric field in drift region.

Solution:

- ions are collected on shielding grid
- only electrons from triggered events reach amplification region, others are collected at gating grid.
- external trigger required.



6. ALEPH TPC at LEP

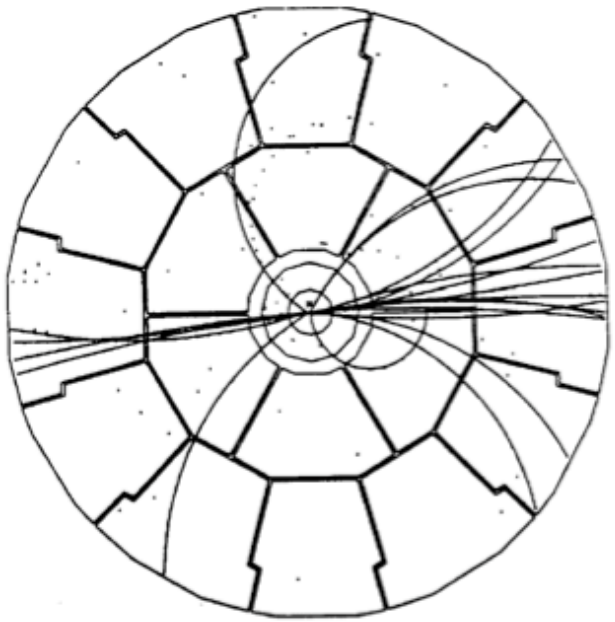


achieved resolutions:

$\sigma_{r\phi}$ = 170 μm

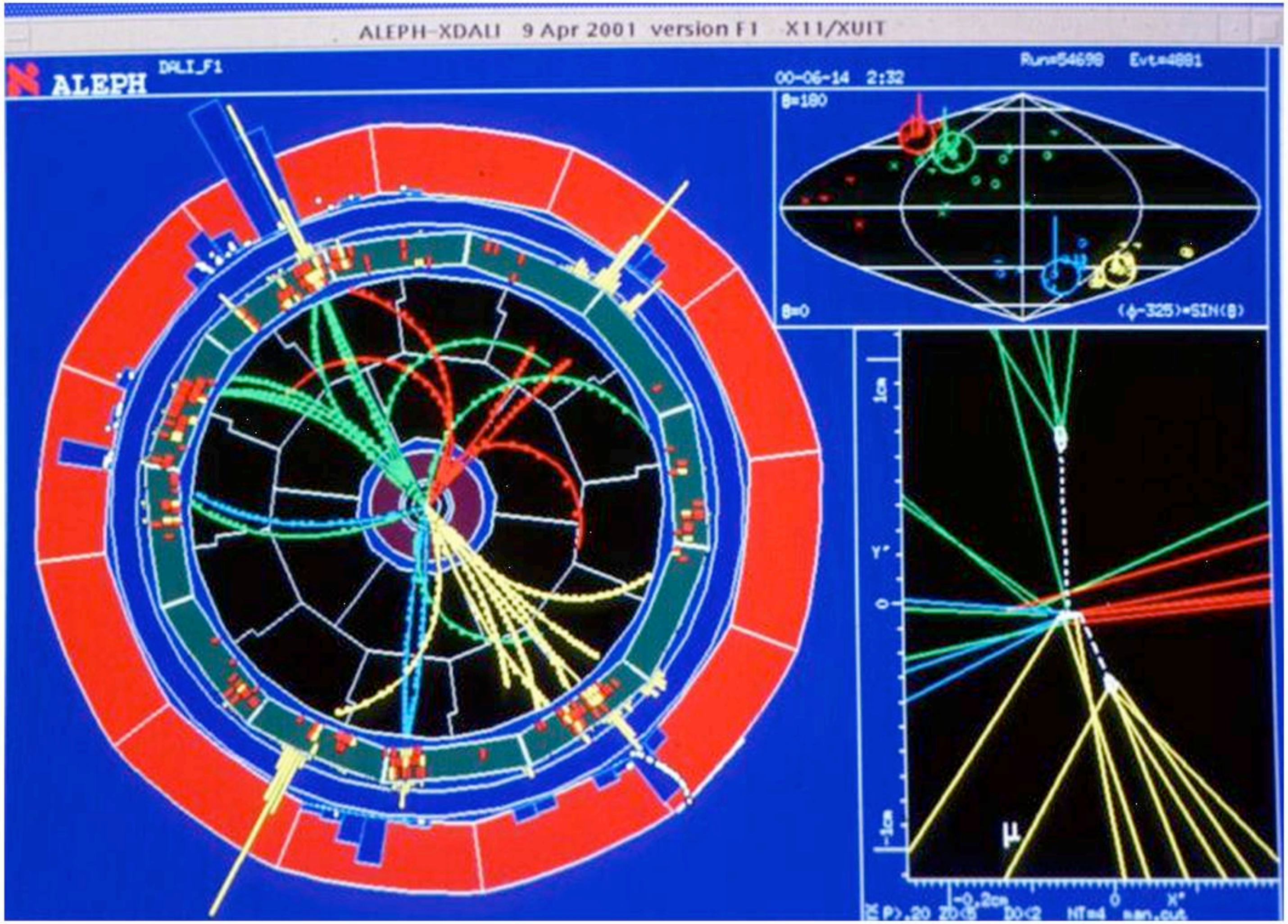
σ_z = 740 μm

r–ϕ projection



6. ALEPH TPC at LEP

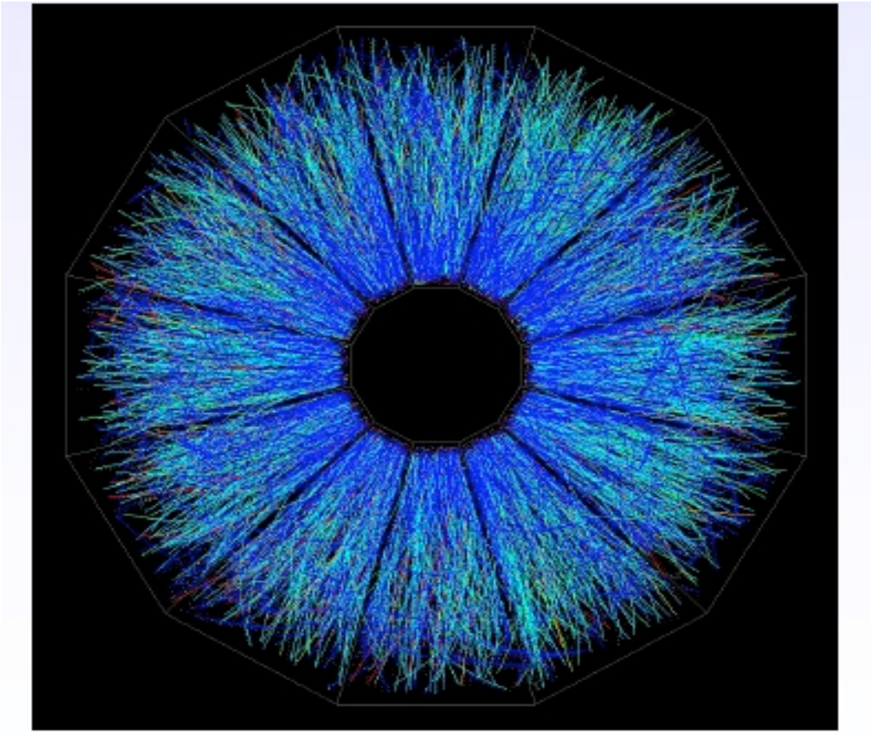
Aleph Higgs Candidate Event: $e^+ e^- \rightarrow HZ \rightarrow b\bar{b} + jj$



6. TPC for Heavy Ion Collisions

Au+ Au+ collision in the STAR Experiment/RHIC

Up to 2000 tracks

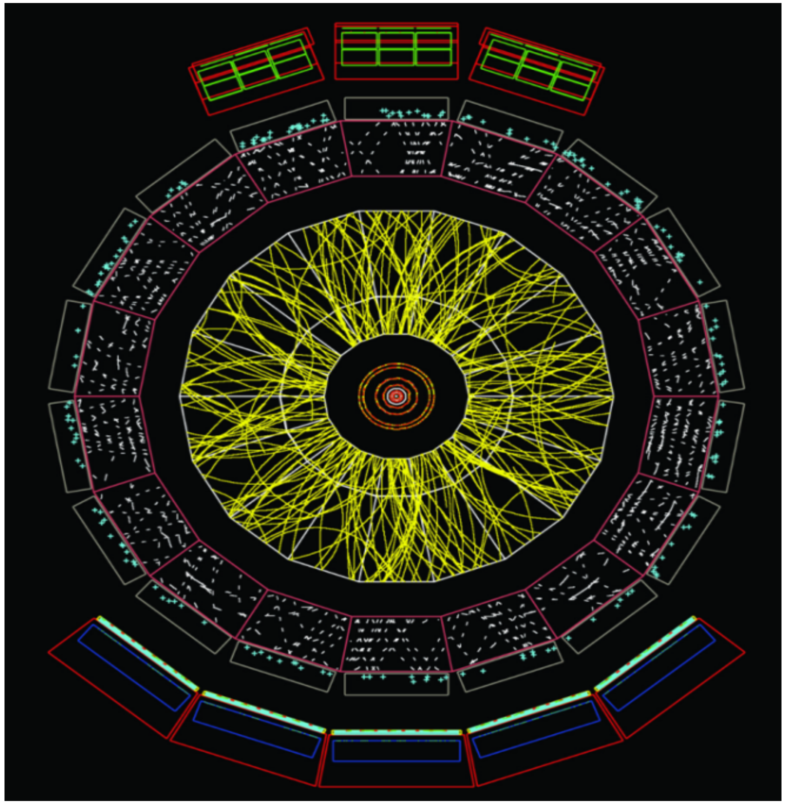


Pb+ Pb+ Kollision in the ALICE Experiment/LHC

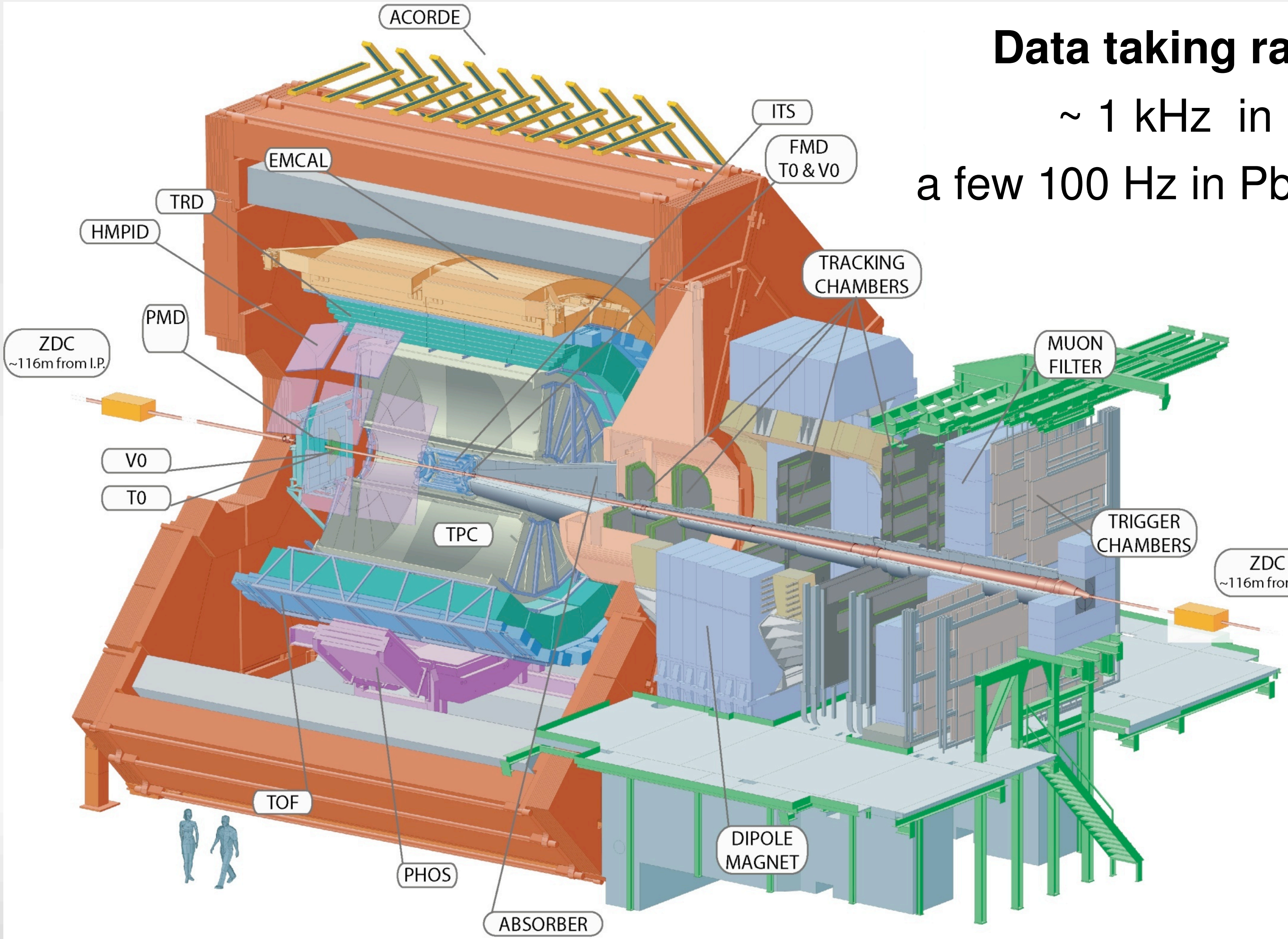
Simulation for

Angle Θ=60 to 62º

Up to 40 000 tracks/collision



ALICE – A Large Ion Collider Experiment – at LHC



Data taking rate:

~ 1 kHz in pp

a few 100 Hz in PbPb

The ALICE Time Projection Chamber

in numbers

Most challenging TPC ever built

Central HV electrode

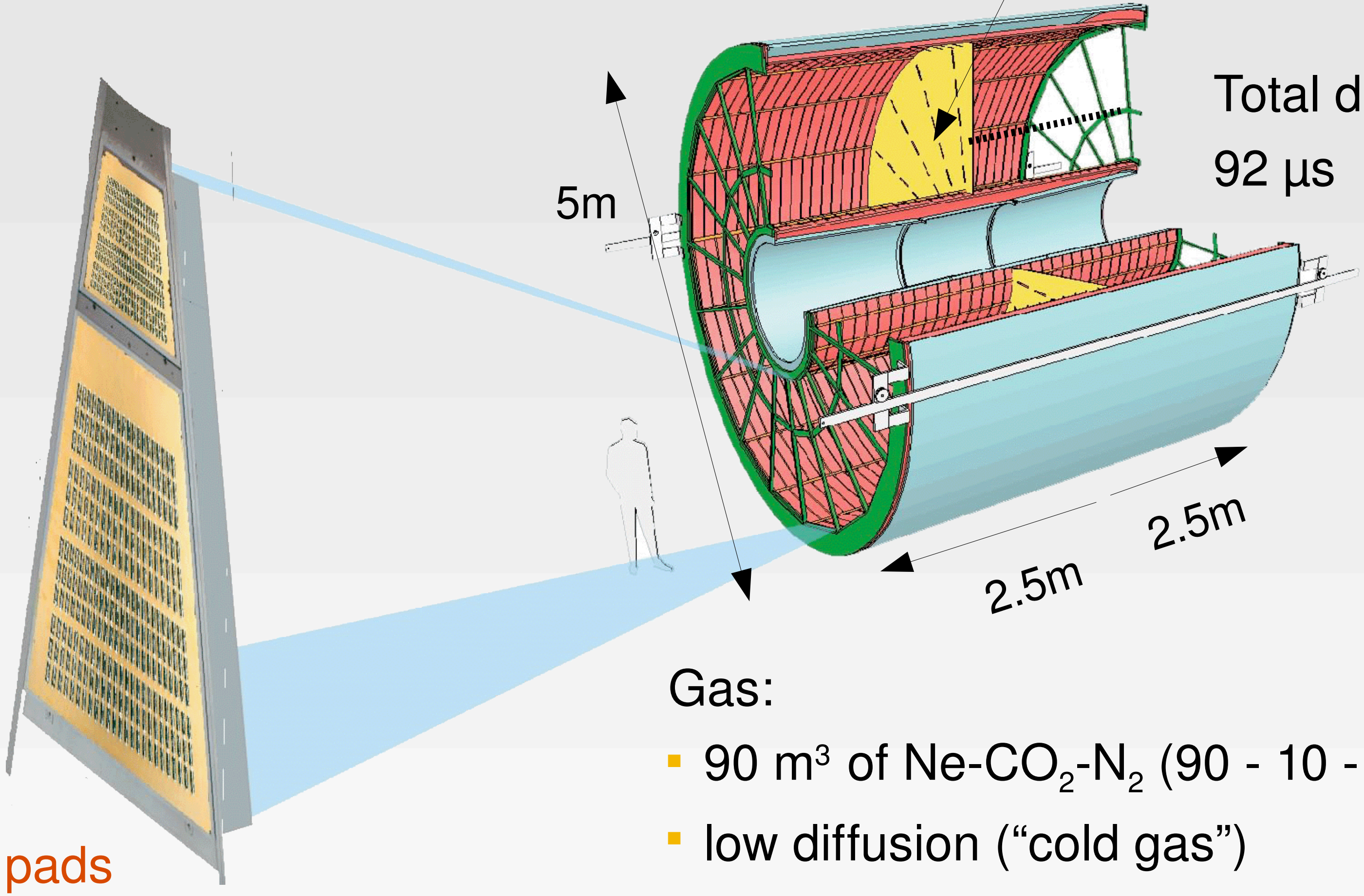
100kV

Total drift time

92 µs

2x18 Inner Readout Chambers

2x18 Outer Readout Chambers



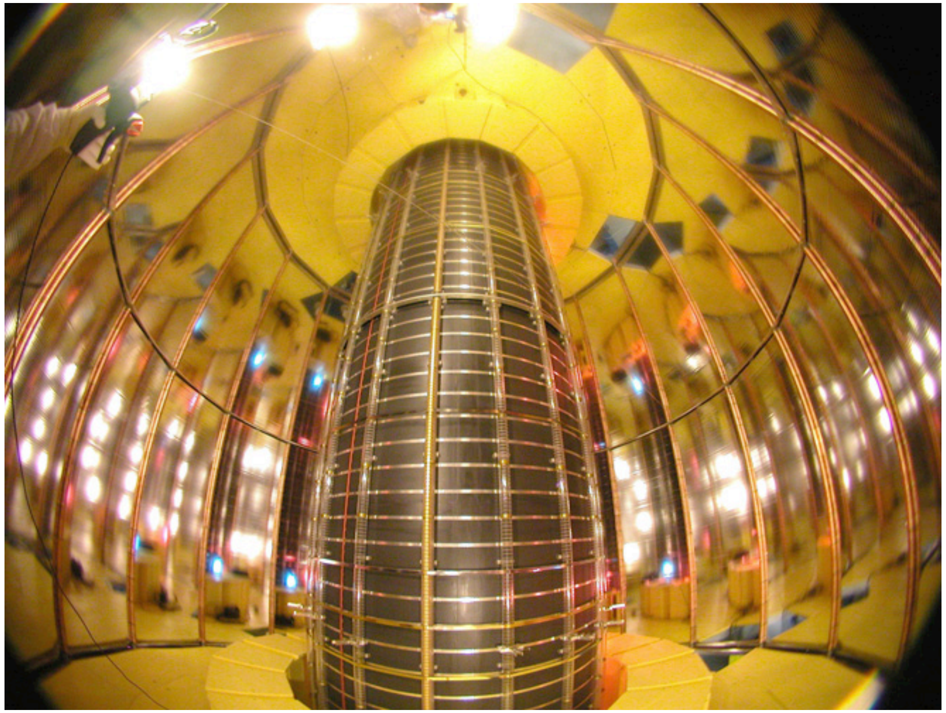
557568 readout pads

1000 samples in time direction

Gas:

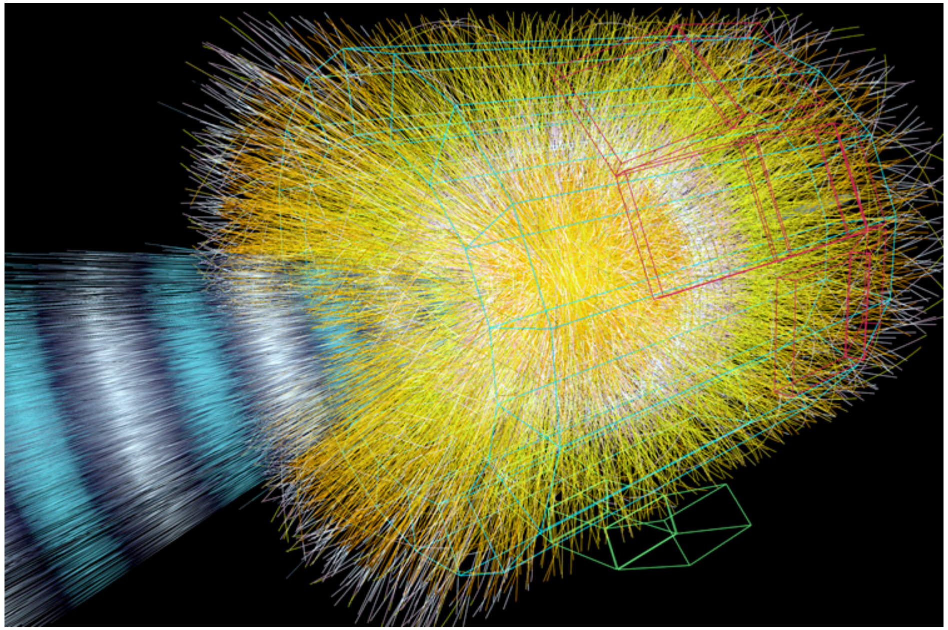
- 90 m^3 of Ne-CO_2-N_2 (90 - 10 - 5)
- low diffusion ("cold gas")
- drift velocity non saturated
  - temp. stability of 0.1K required

6. ALICE TPC



View inside the ALICE TPC

Simulated heavy ion collision in the ALICE TPC.

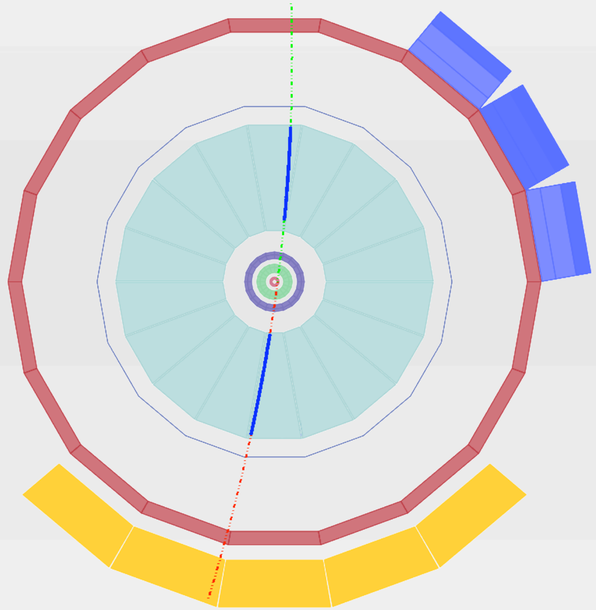


TPC performance

momentum resolution

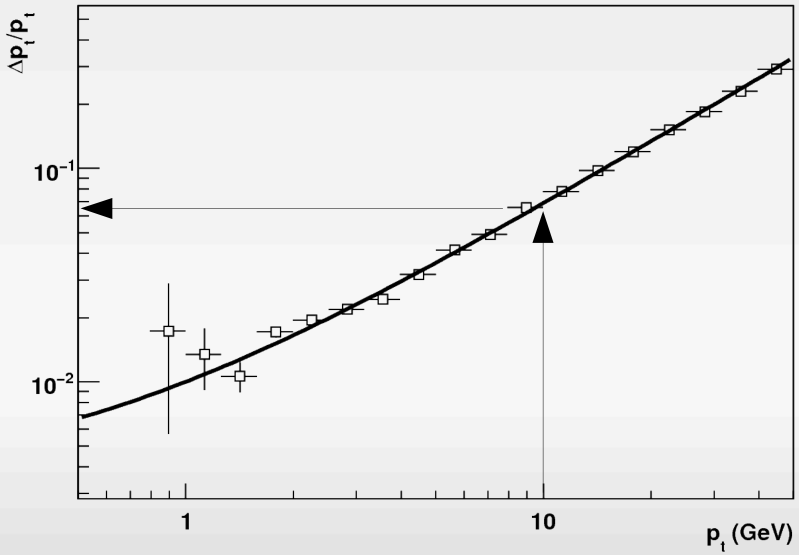
Resolution determination

- cosmic muons reconstructed as two tracks
- use relative track information at vertex
- ~ 5×10^6 events available

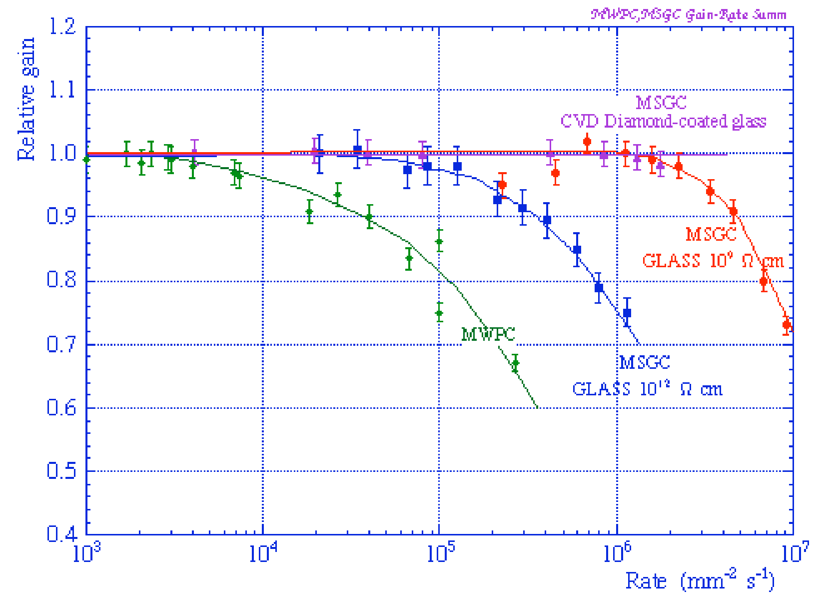


p_t resolution

- measured: 6.5% at 10 GeV
  ~1% below 1 GeV
- design value: 4.5% at 10 GeV



7. Micropattern Gas Chamber (MPGC)



from L. Ropelewski

Advantages of gas detectors:

- low radiation length
- large areas at low price
- flexible geometry
- spatial, energy resolution …

Problem:

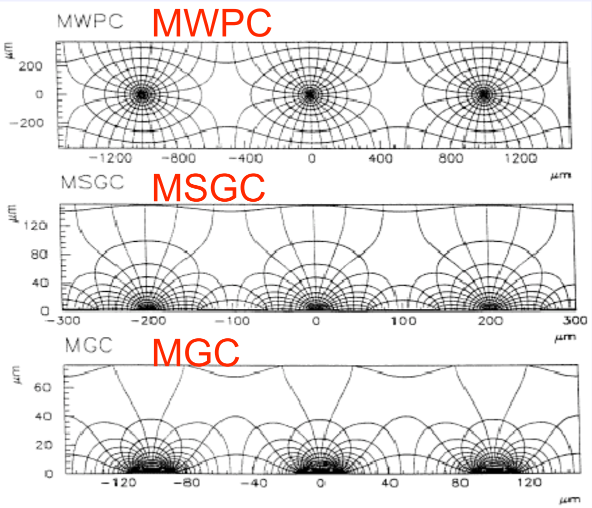
- rate capability limited by space charge defined by the time of evacuation of positive ions

scale factor

1

5

10

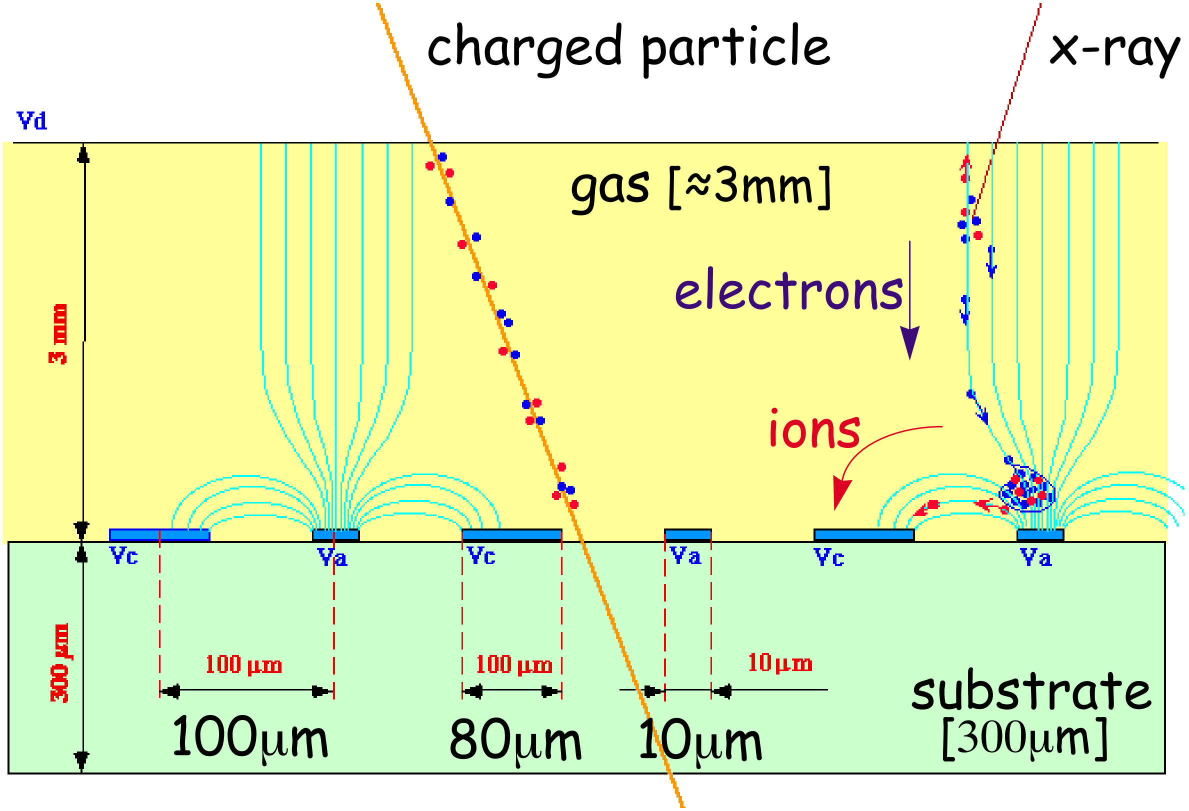


R. Bellazzini et al.

Solution:

- reduction of the size of the detecting cell (limitation of the length of the ion path) using chemical etching techniques developed for microelectronics and keeping at same time similar field shape.

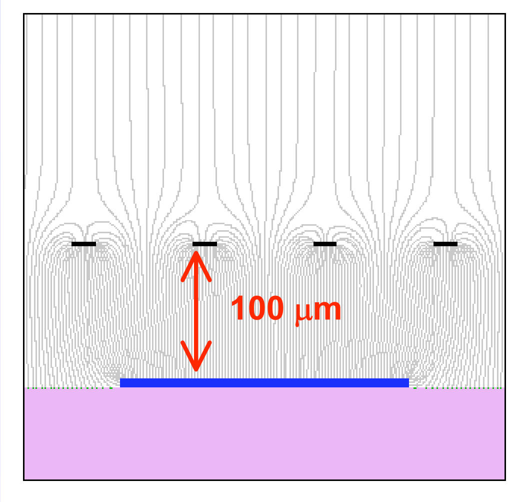
7. Microstrip Gas Chamber (MSGC)

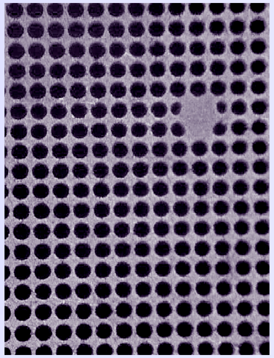


Advantages:

- Very precise and small anode/cathode structures can be produced with lithographical methods. Thus very good position resolution is possible.
- MSGC provide high mechanical stability
- small drift distance for ions, thus high rate capability.

7. Micromegas - Micromesh Gaseous Structure



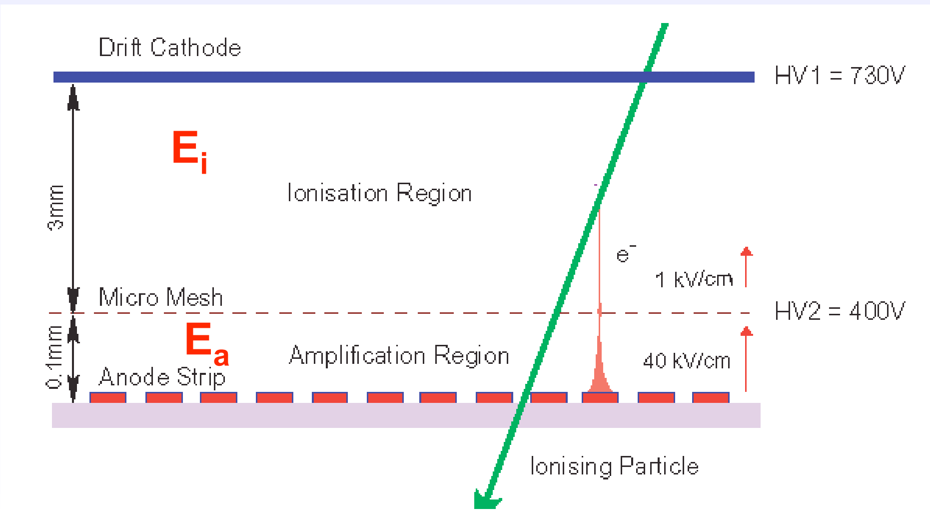


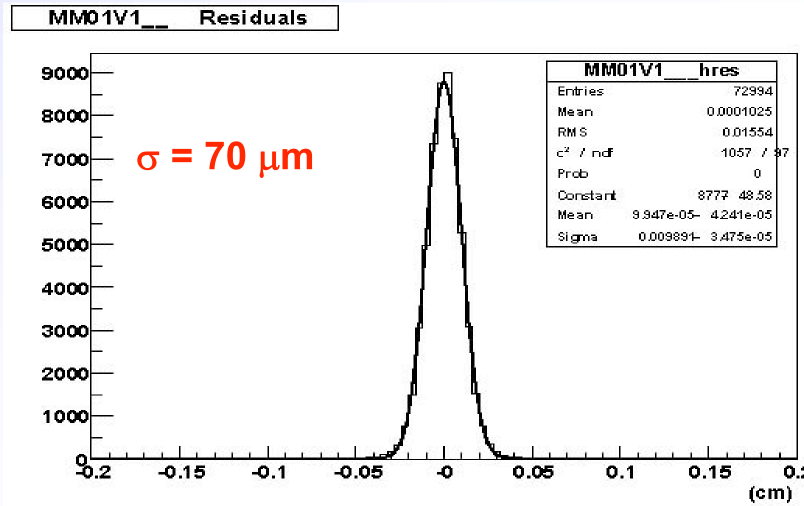
micromesh

Micromesh mounted above readout structure (typically strips).

E field similar to parallel plate detector.

E_a/E_i ~ 50 to secure electron transparency and positive ion flowback supression.



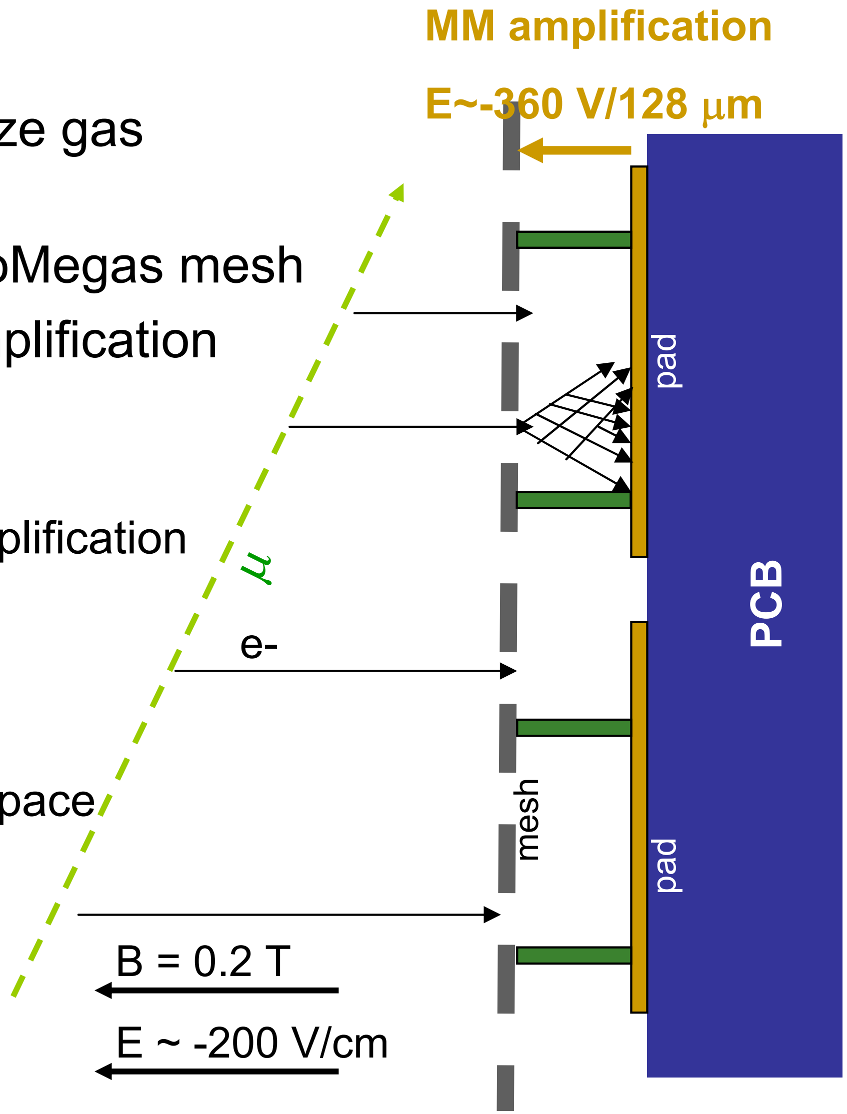


Space resolution

from L. Ropelewski

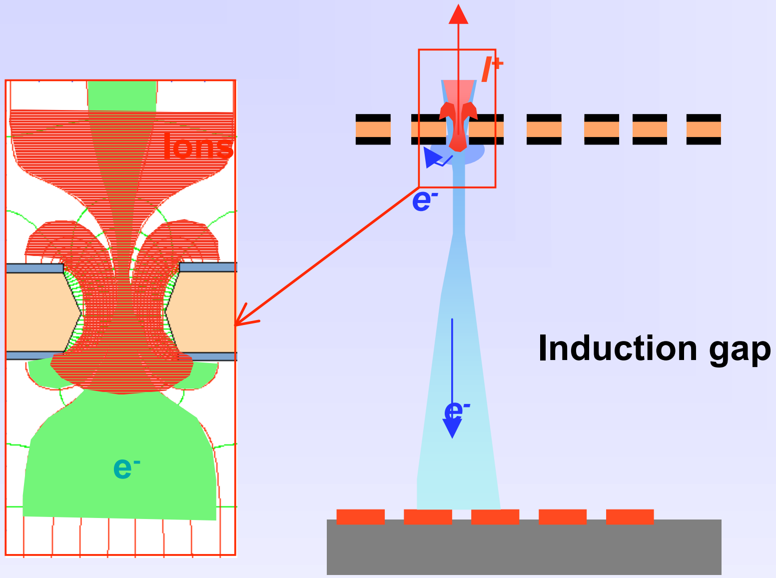
7. TPC Readout with Micromega

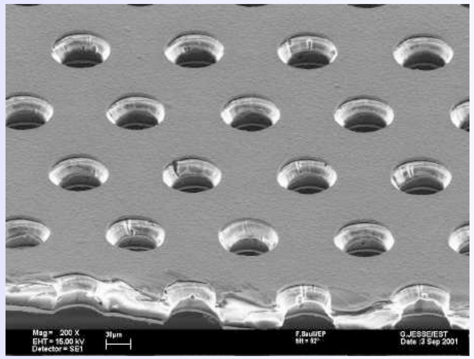
- Charged particles crossing the TPC ionize gas molecules
- The produced electrons drift to the MicroMegas mesh
- Once on the mesh the e^- enter in the amplification region where avalanches are generated
  - **Gain ~ 10^3 - 10^4**
  - **~ 100% collection efficiency** (if drift/amplification field is high enough)
  - Small gap → short rise time
- Ions flow back to the mesh
  - Only few ions permil go back to the drift space
  - Avoids space charge effects

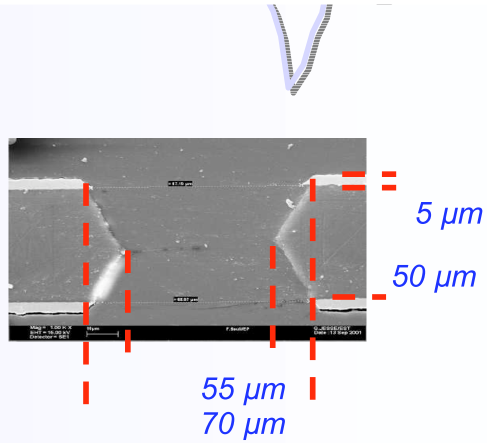


C. Giganti

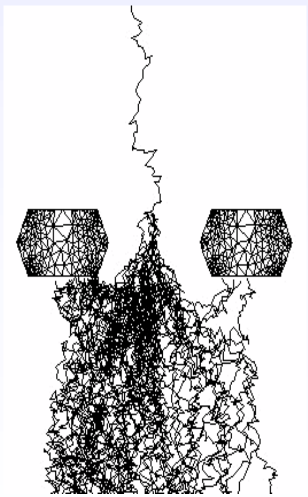
7. GEM - Gas Electron Multiplier







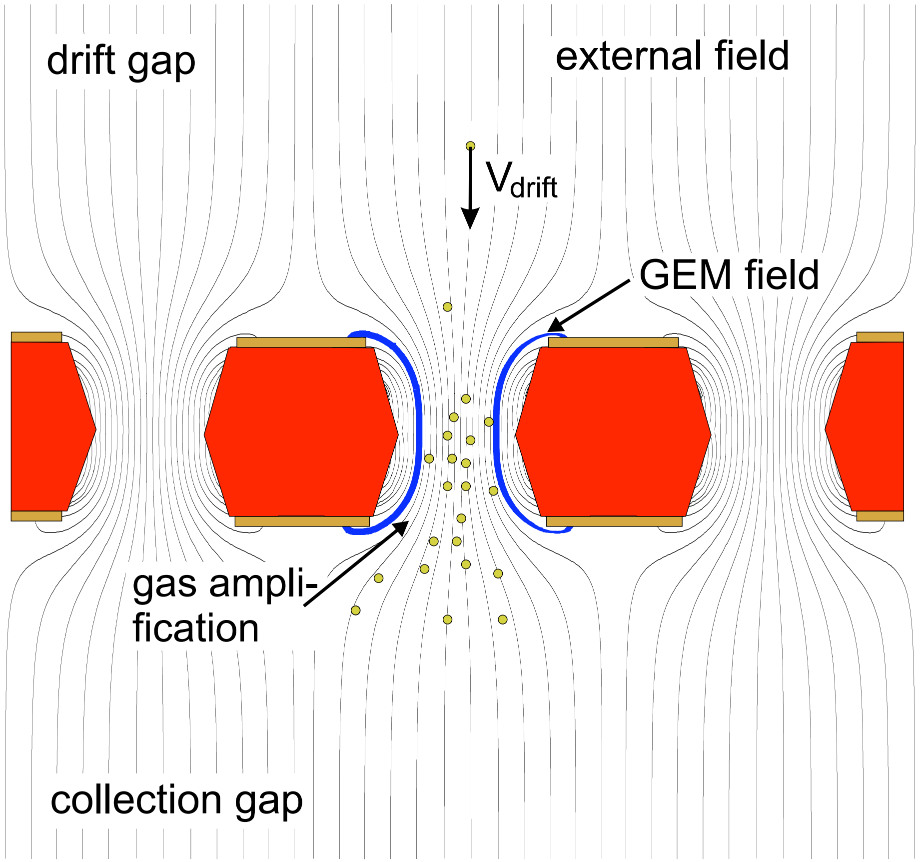
Thin, metal coated polyimide foil perforated with high density holes.

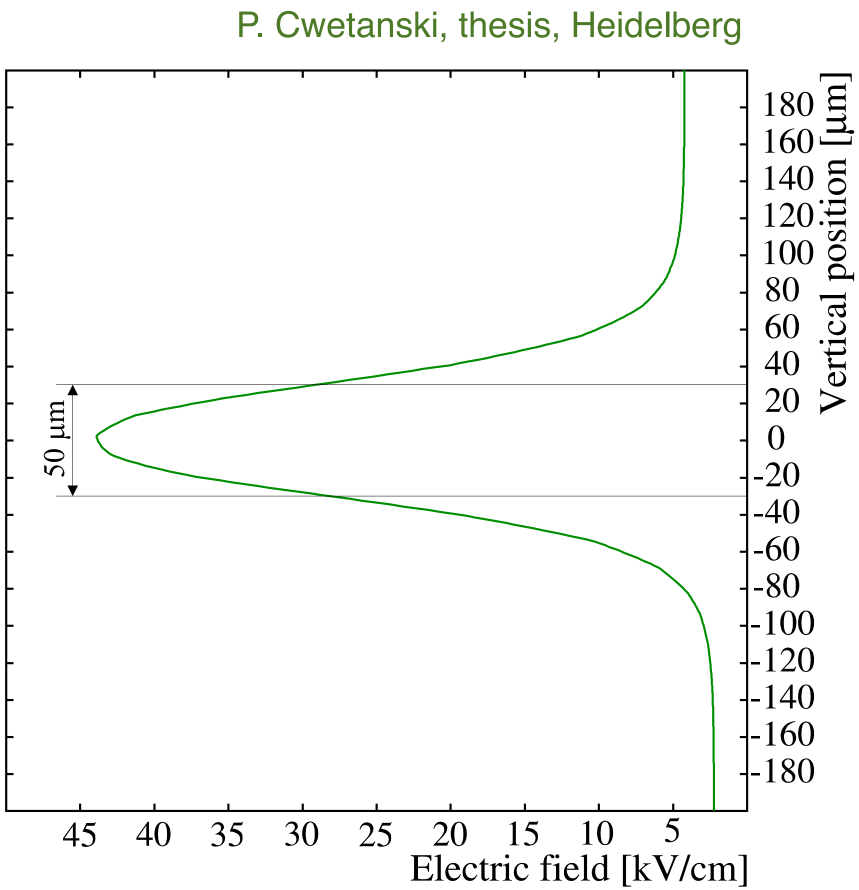


Electrons are collected on patterned readout board.
A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
All readout electrodes are at ground potential.
Positive ions partially collected on the GEM electrodes.

from L. Ropelewski

7. GEM - Gas Electron Multiplier



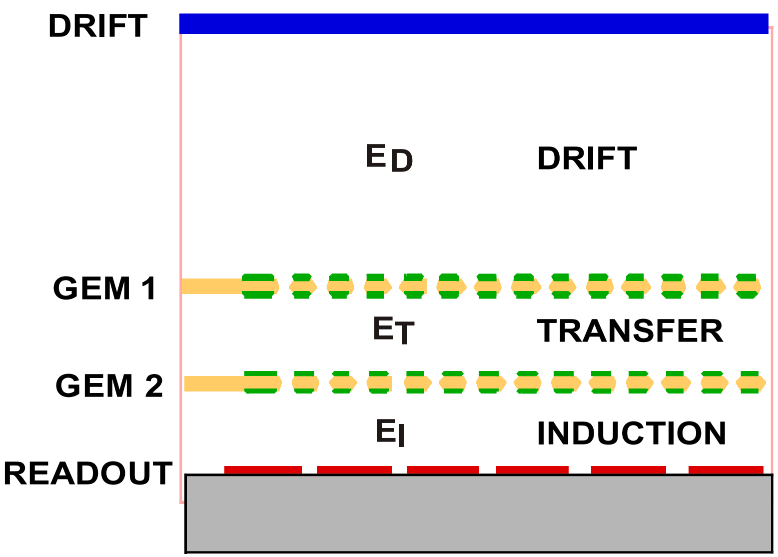


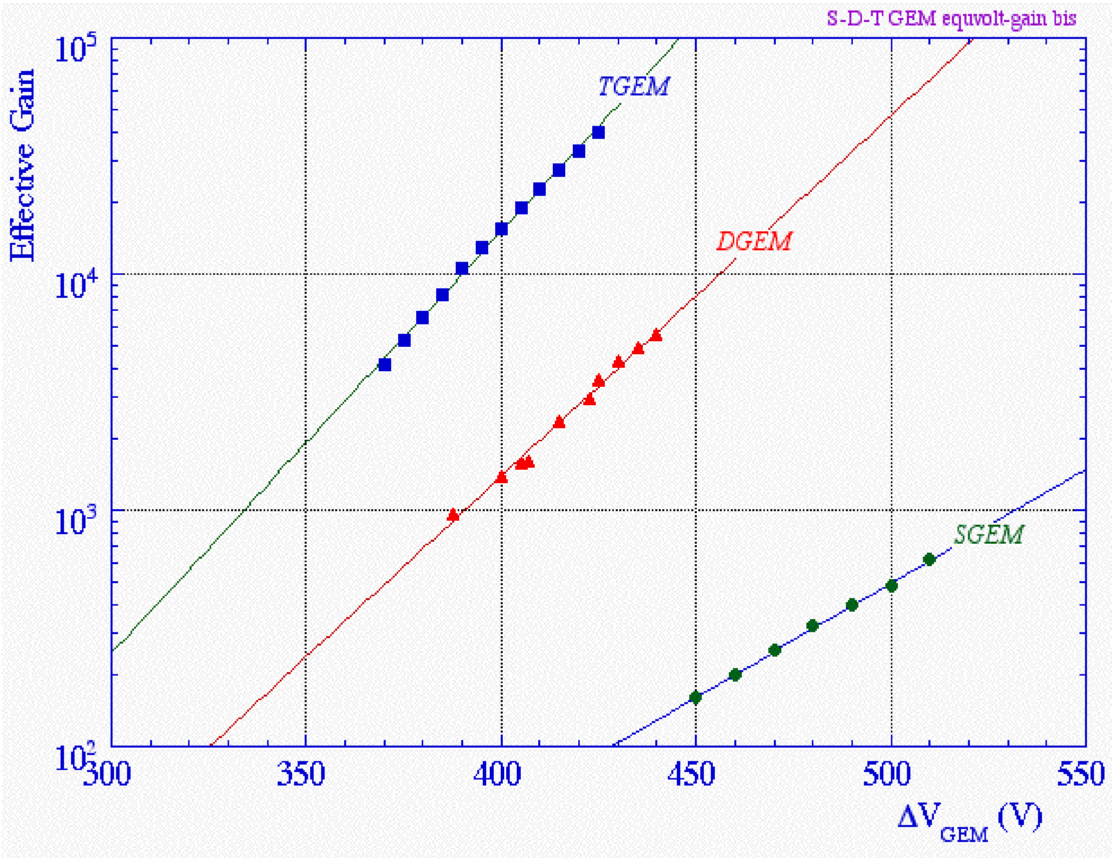
For a voltage between the GEM foils of 360 V the E-Field inside the gap reaches very high values, which cause gas amplification.

7. GEM - Characteristics

- Rate capability ~ 1 MHz mm^{-2}
- Position accuracy (MIPs) σ ~ 60 μm
- Radiation tolerance > 100 mC mm^{-2}
  - corresponds to ~ 10^{14} MIPs cm^{-2}

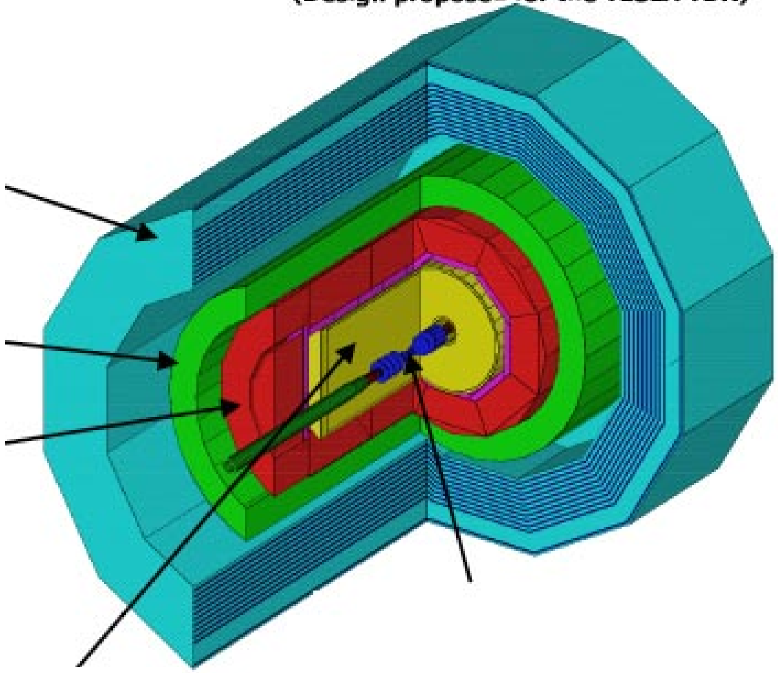
Double-Gem

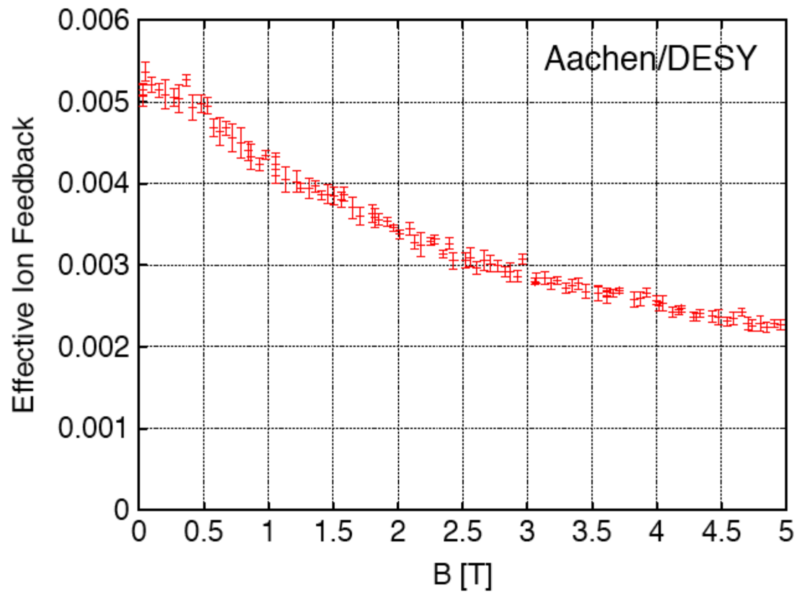


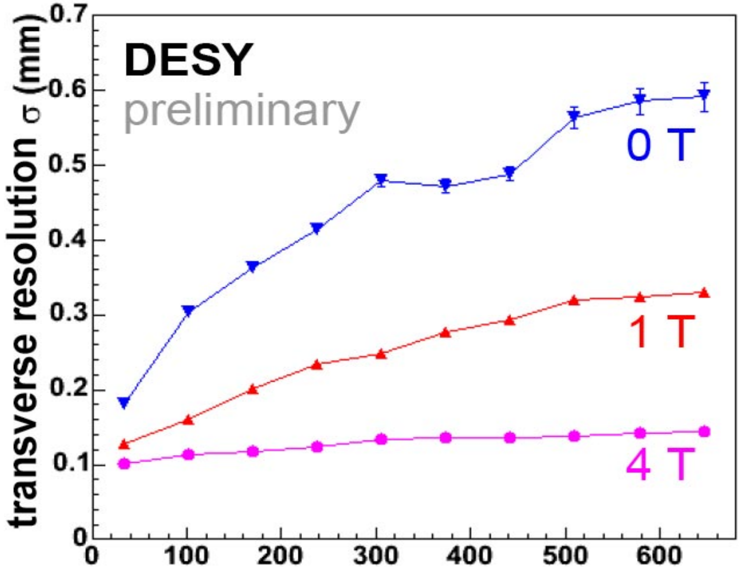


7. TPC Readout with GEM

- Narrow pad response function: $\Delta s \sim 1$ mm
- Fast signals (no ion tail): $\Delta t \sim 20$ ns
- Very good multi-track resolution: $\Delta V \sim 1\ mm^3$
  - Standard MWPC TPC ~ 1 cm^3
- Ion feedback suppression: I+/I- ~ 0.1%



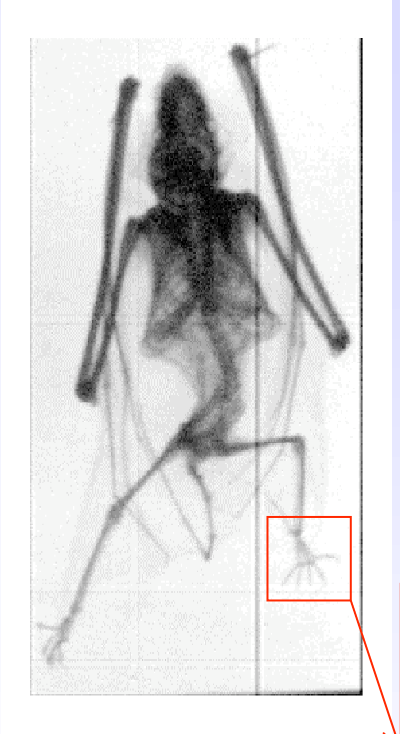


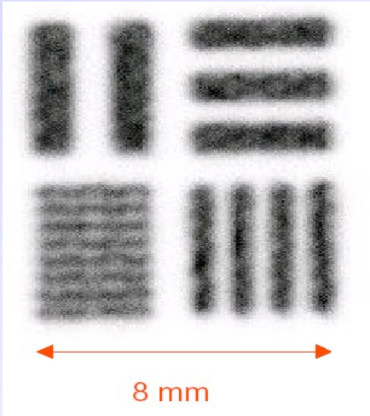


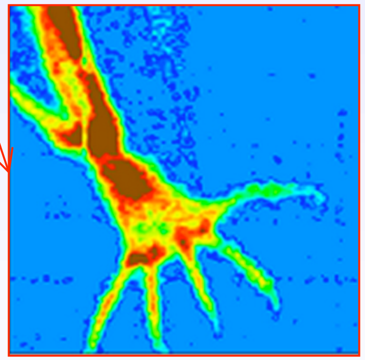
from C. Niebuhr

Other (than tracking) Applications

Radiography with GEM (X-rays)



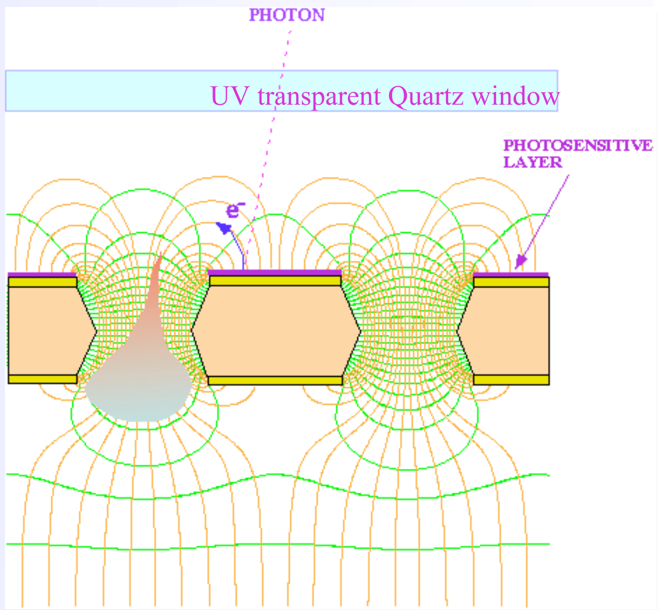


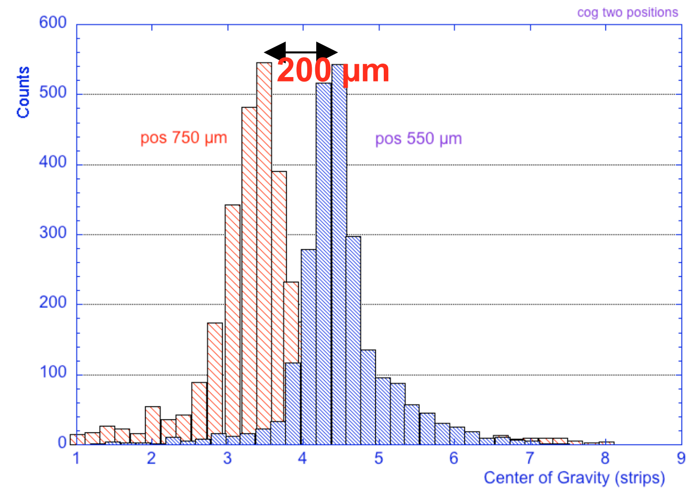


Trigger from the bottom electrode of GEM.

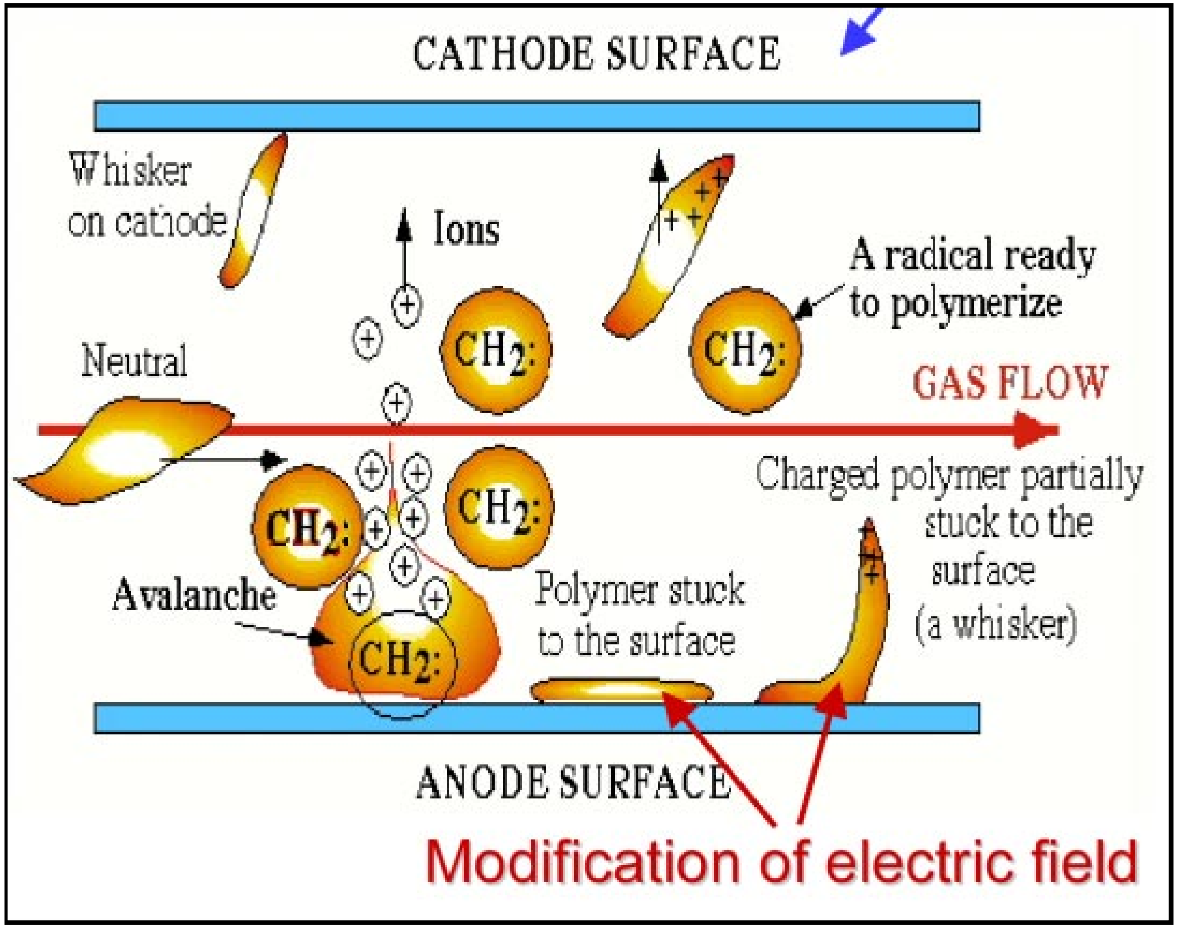
from L. Ropelewski

UV light detection with GEM





8. Limitations of Gaseous Detectors: Aging - Deposits



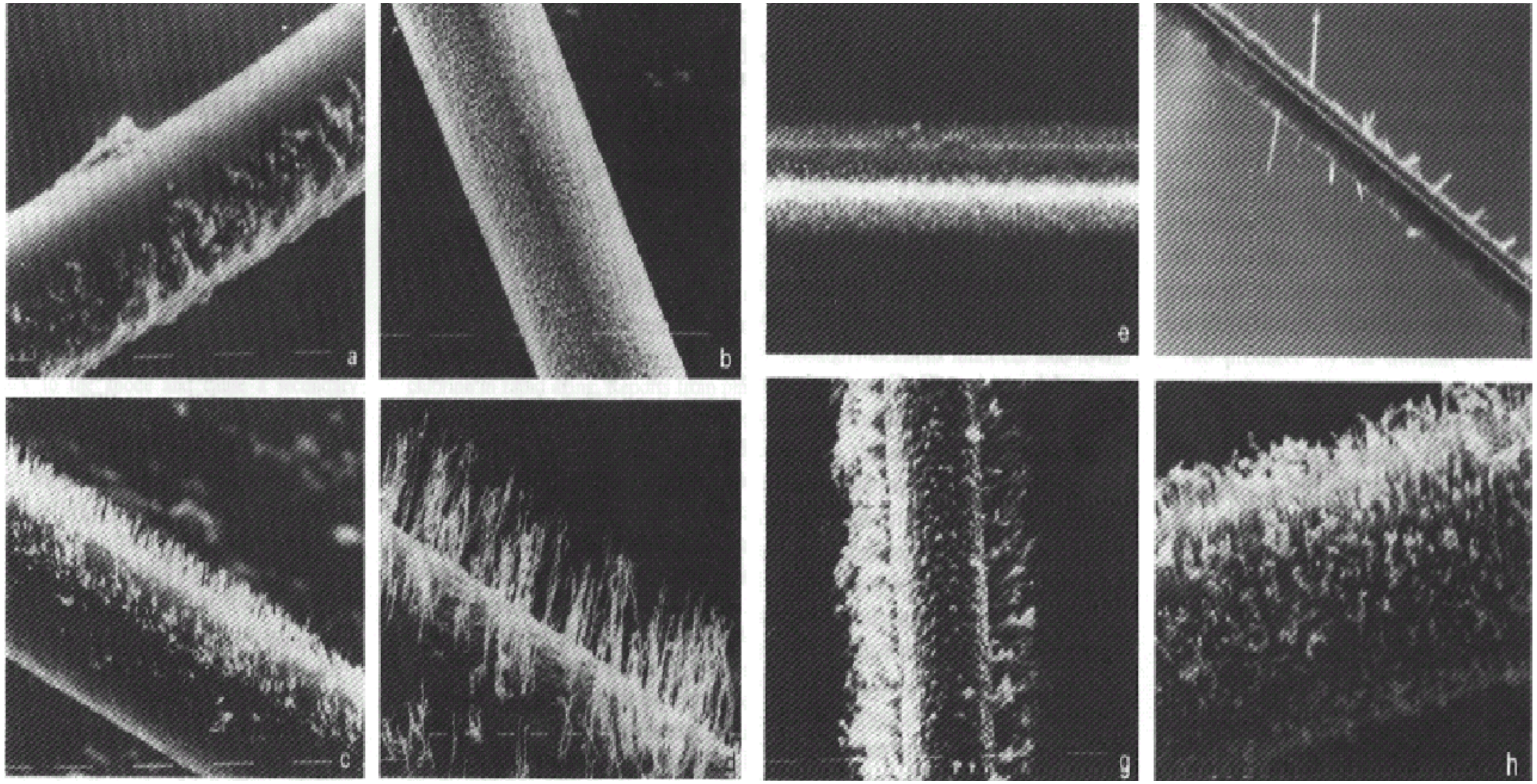
Complex plasma-chemical reactions in the avalanche can lead to polymerization.

Deposits on anode and cathode.

Deposits reduce electric field, which leads to reduced signal amplification (efficiency loss).

Malter effect:
Positive ions form a layer on cathode, high E-fields cause continuous electron extraction from cathode.
Leads to continuous discharge current.

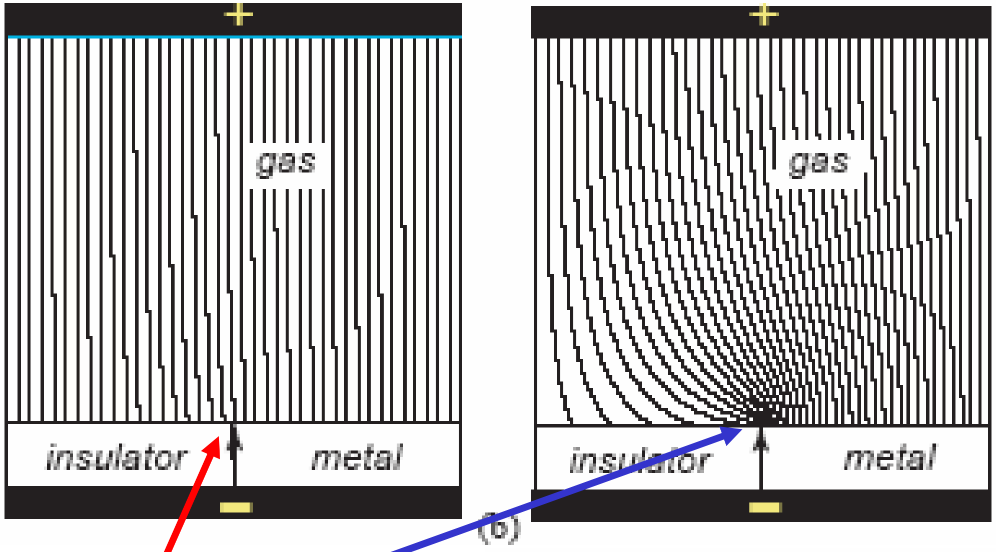
9. Limitations of Gaseous Detectors : Deposits



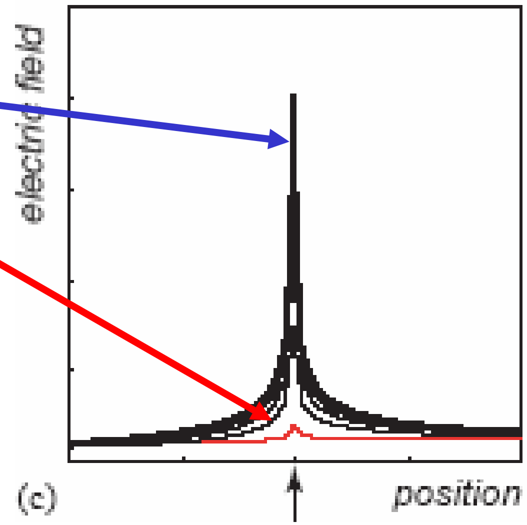
Wiskers are produced on the anode wire. They absorb the electrons. Thus electrons do not reach the main amplification region very close to the wire. This leads to efficiency loss.

8. Discharges

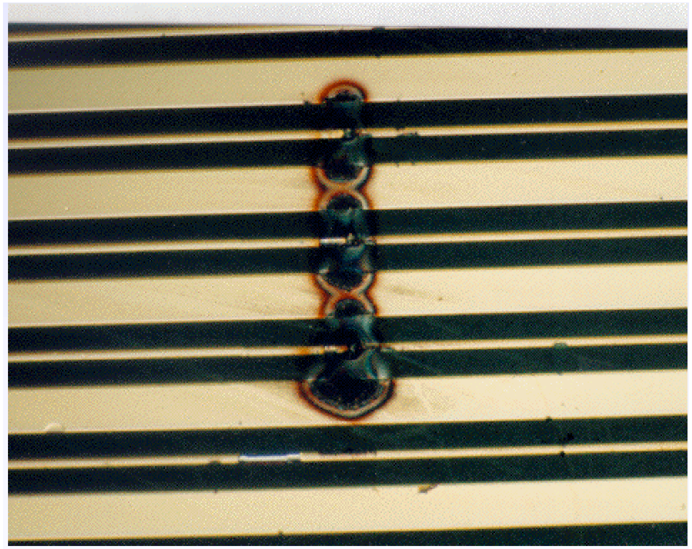
(B.Schmidt NIMA515(2003))



1:10 10:1
conductivity gas
to insulator



E-field at junction gas-insulator-metal as function of con-ductivity of the gas

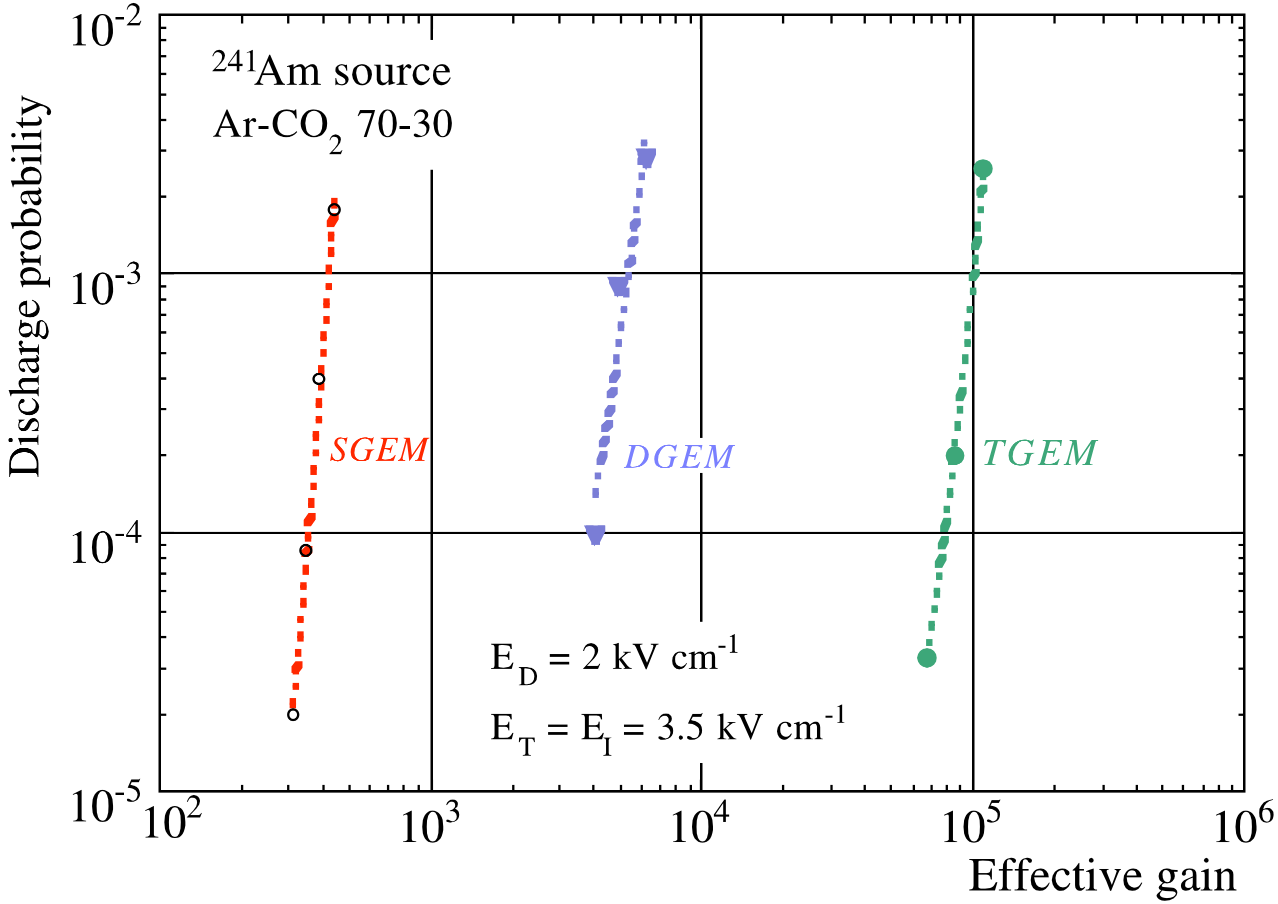


Regions in the detector with large E-fields can lead to a sparks and to a break-down of the detector.

Insulators can charge up and produce high E-fields. Adding water to the gas can increase the conductivity of the surfaces.

8. Discharges in GEM Detectors

S. Bachmann, CERN-EP/2000-151



E_D : drift field
E_T : transfer field (between GEMs)

Discharge probability for GEM detectors can be reduced with SGEM and TGEM (smaller voltage across each GEM foil).

8. Avoiding Aging

Material for construction:

- Use only material, which is certified in ageing test (high irradiation). Don't rely on manufacturers.
- Avoid glue, some type of plastic, PVC
- Be careful with O-rings (can contain silicone), printed circuit boards.
- Absolutely no silicone grease (often found in gas valves).

During construction:

- Absolute cleanliness
- No finger prints
- Clean all components before assembly, do not rely on cleaning by manufacturer.
- Perform aging tests with highly ionizing particles as early as possible, before mass production starts.

Operation:

- Use gas, which does not polymerize (noble gas, CO2, ..)
- Gas additives ca help (water, alcohol, ...)
- Avoid high currents (low gas gain)

Don't expect immortality:

B. Schmidt: " Detectors are like us: aging is unavoidable, surviving in good shape is the main issue.