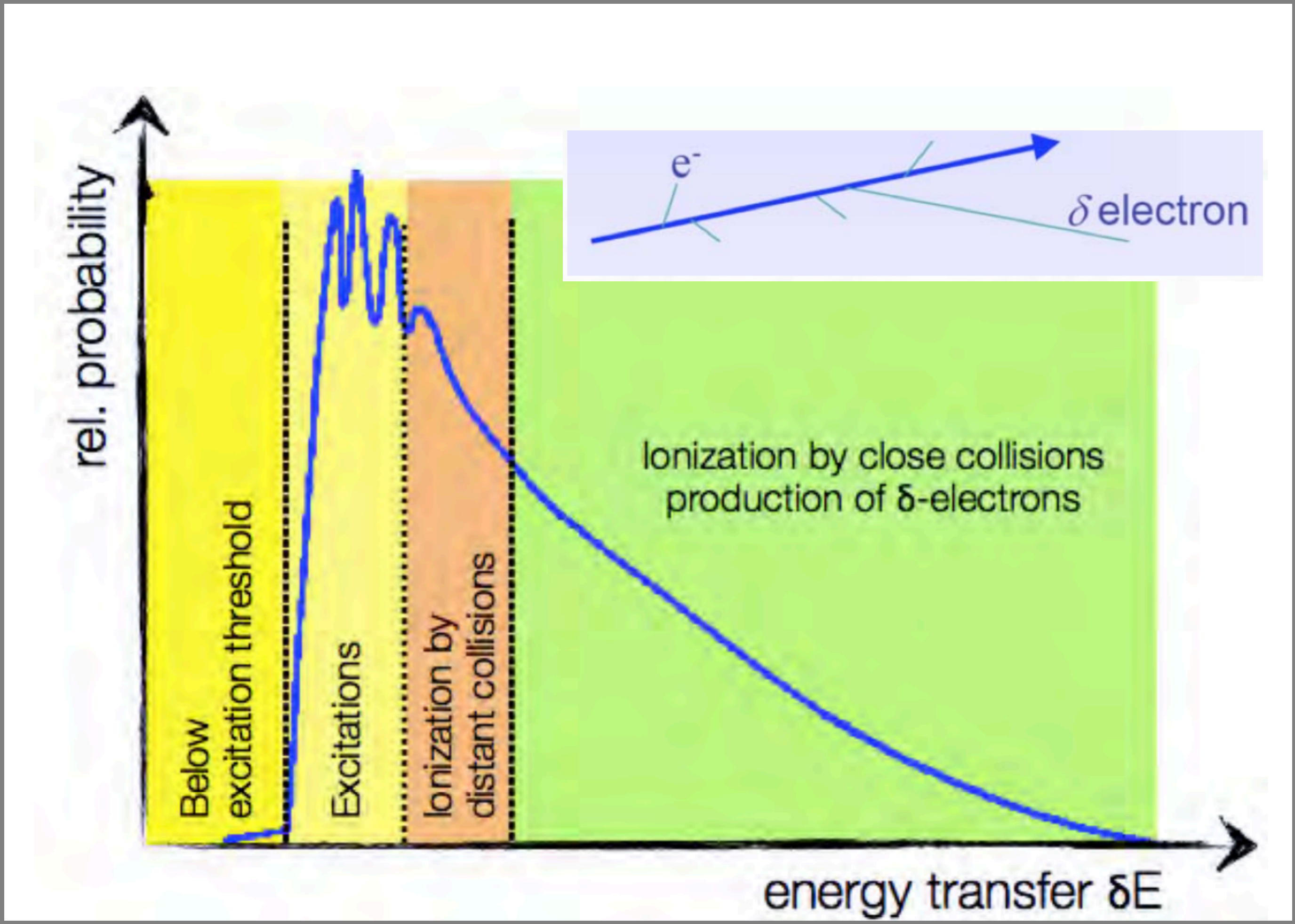
Lecture 2 - Muon Detectors
The detectors - and their issues

Melissa Franklin August 2020

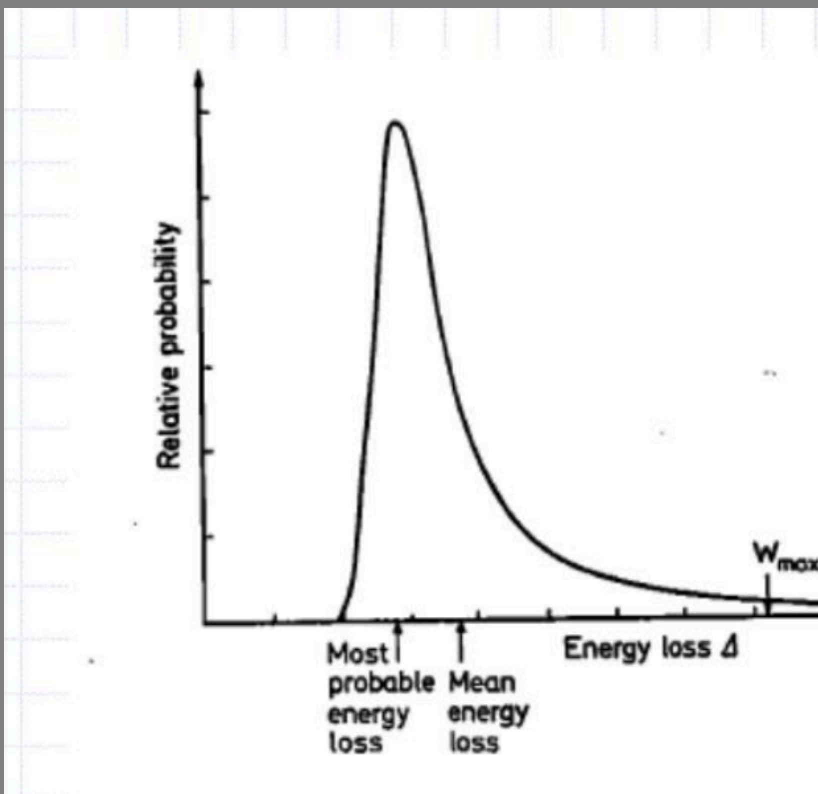
Energy loss fluctuations in material affect our measurements

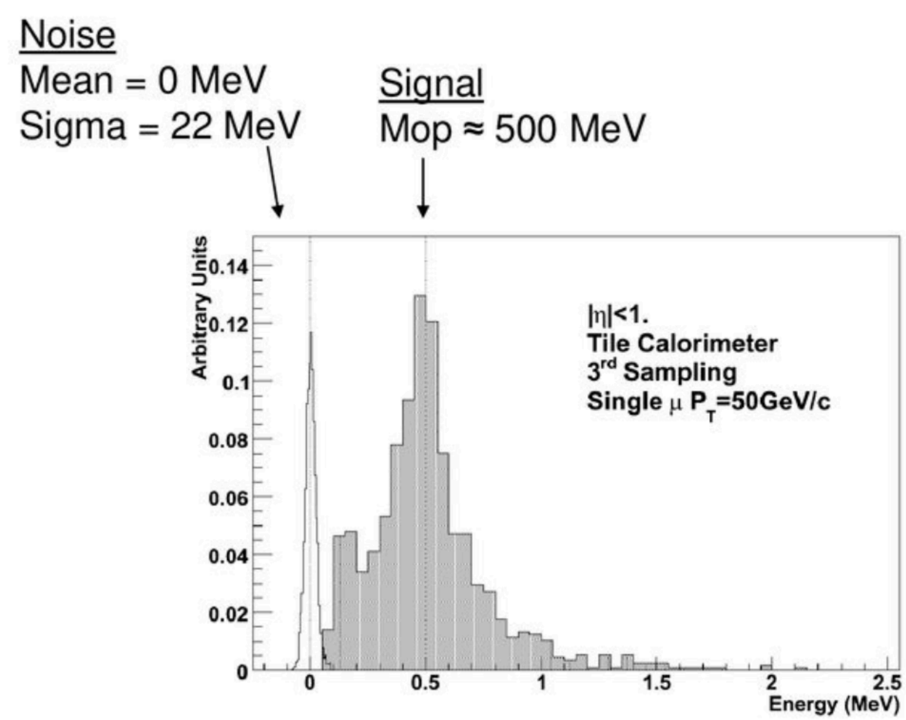


Especially at low momentum

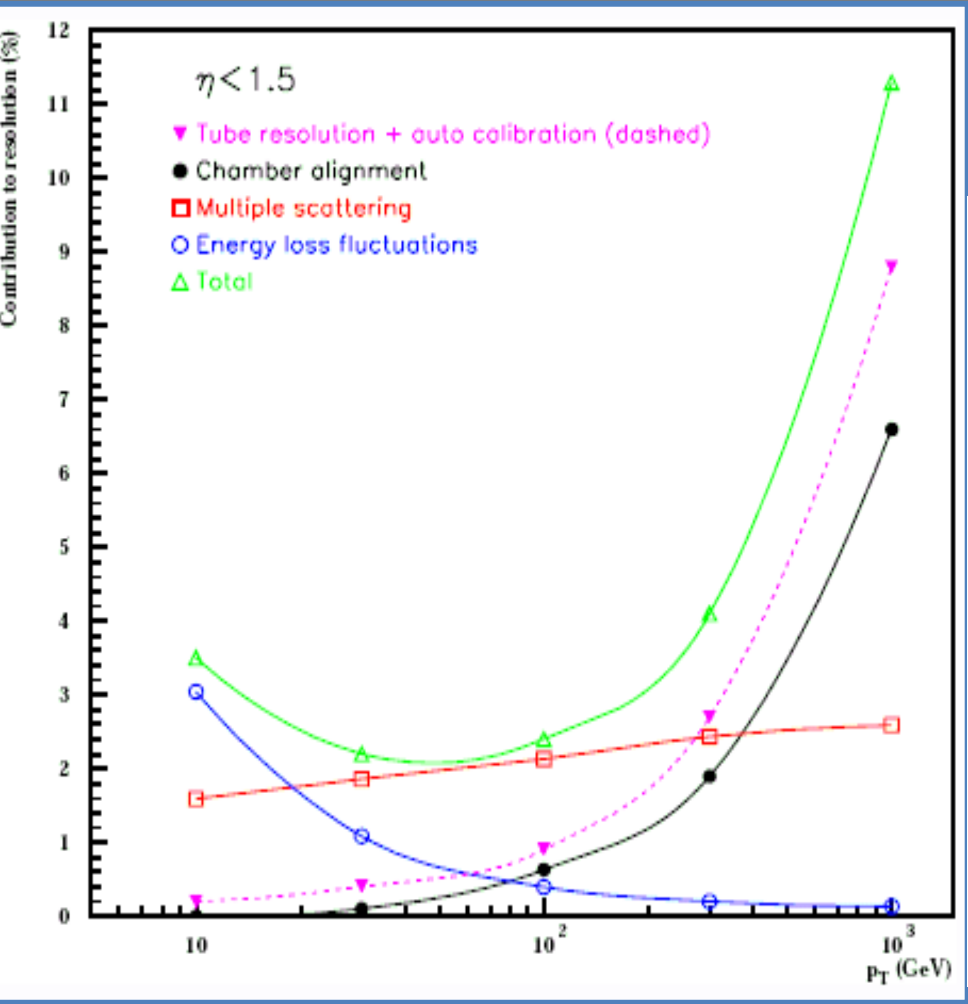
Energy loss distributions

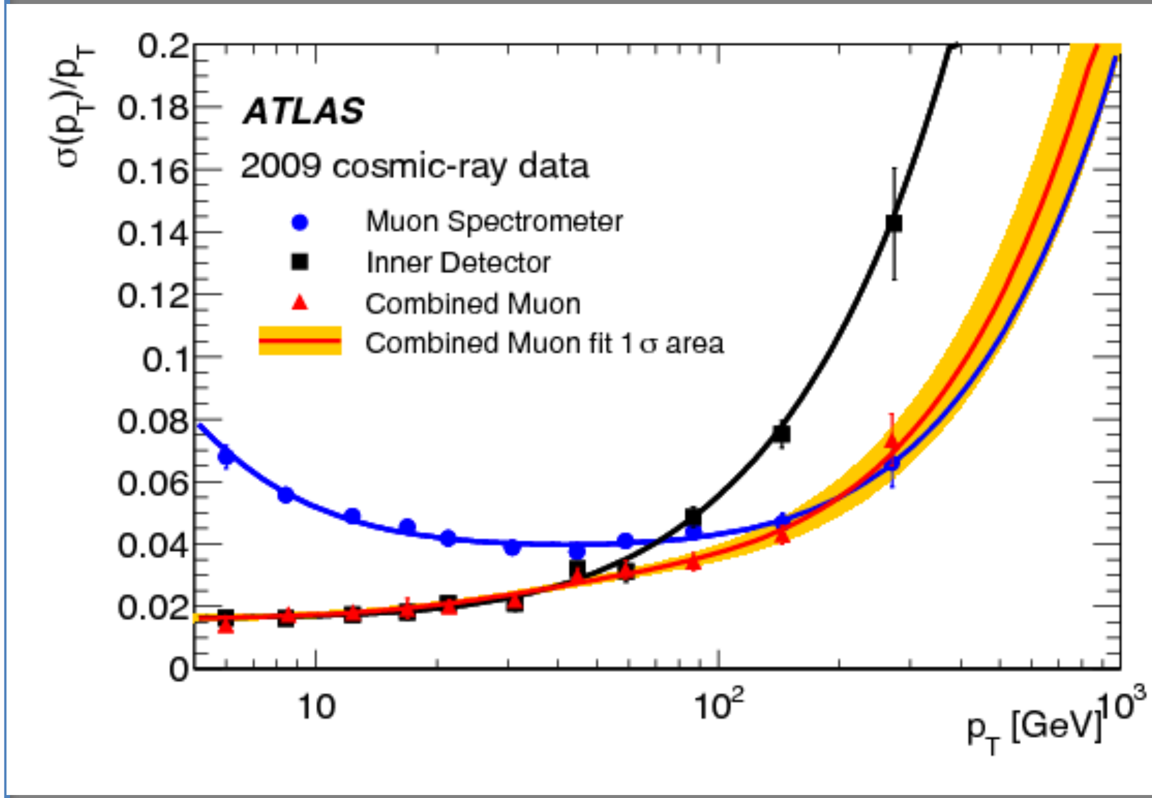
B-B is average energy loss, there are fluctuations due to close collisions. Muon leaves minimum ionizing deposit in calorimeter

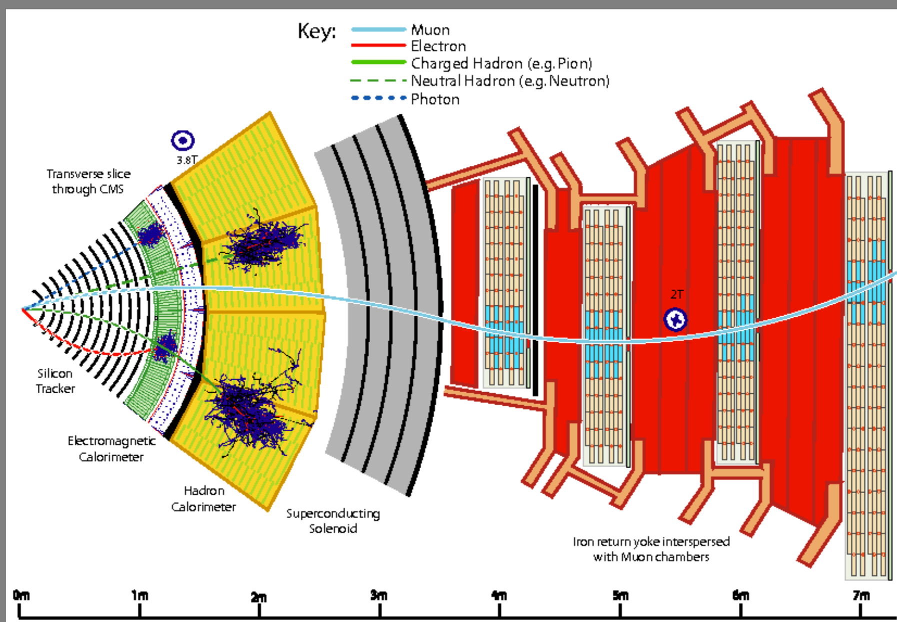


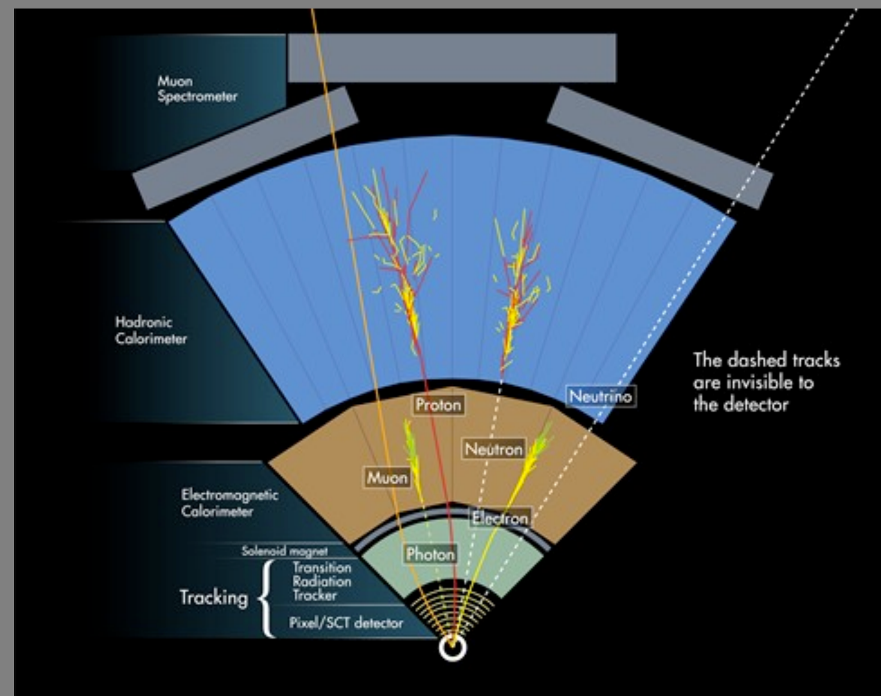


Momentum resolution





- Need B fields precision detector, trigger.
- 



Both ATLAS and CMS have an inner detector immersed in a solenoidal field and a Muon spectrometer with a B field - return field of solenoid for CMS - Air core toroid for ATLAS
The combined resolution is best.

ATLAS vs CMS Muon resolution

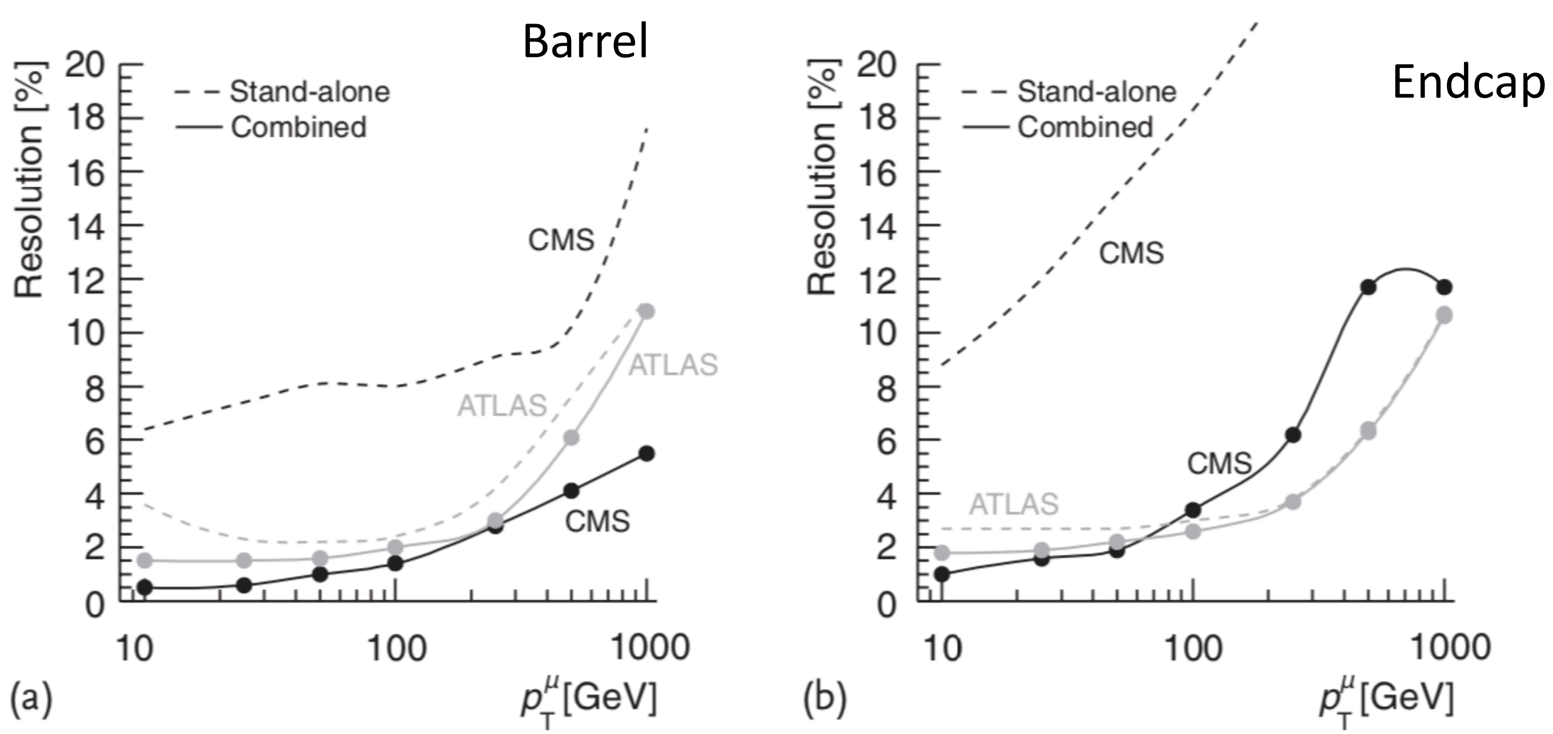
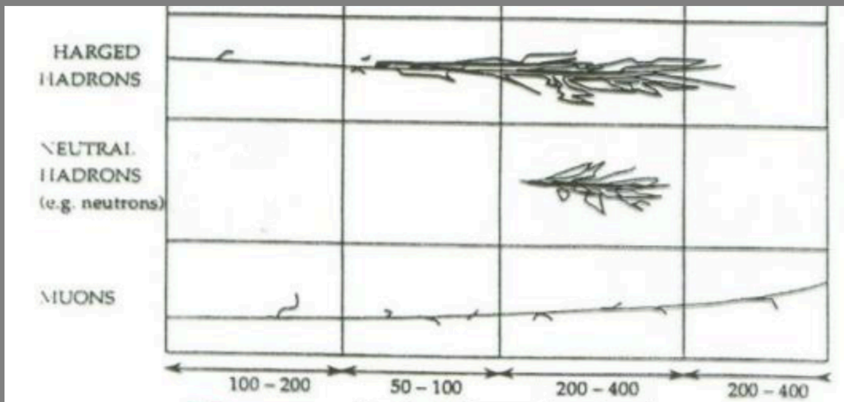
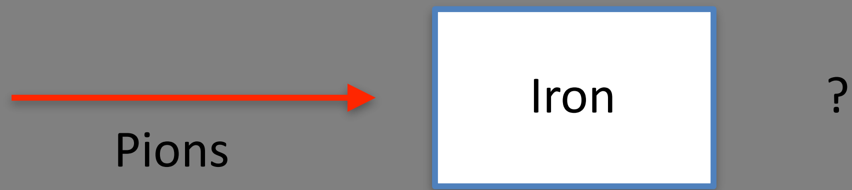


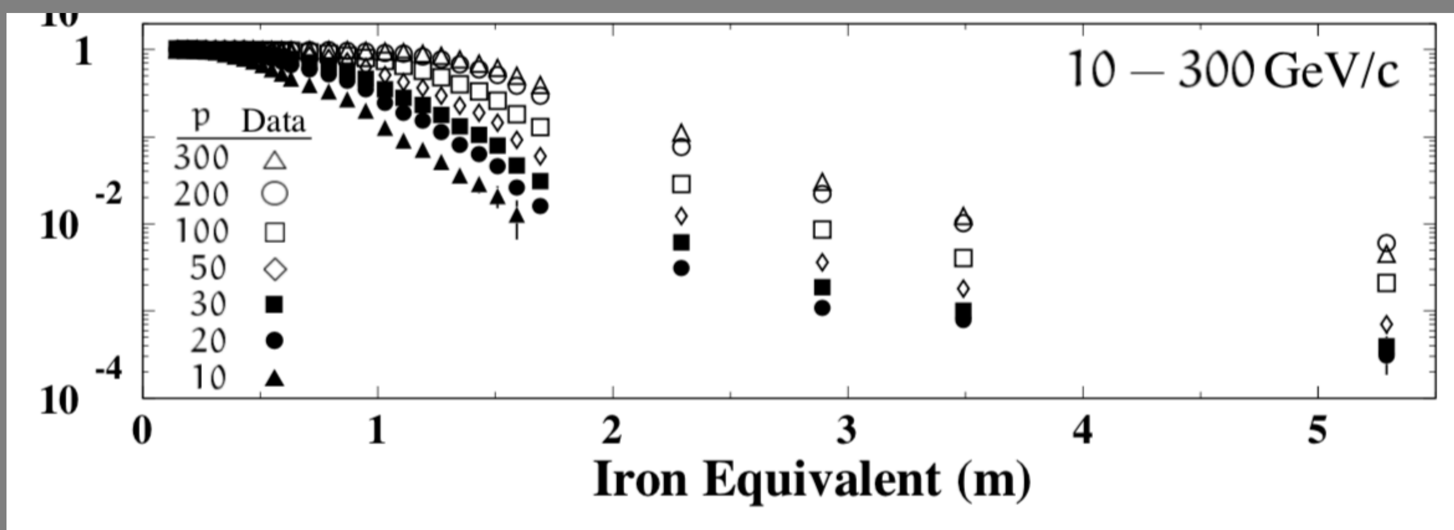
Figure 16.4 Momentum resolution of the ATLAS and CMS detectors after combining the momentum measurements of the inner (a) momentum resolution for muons in the barrel region; (b) momentum resolution for muons in the endcap region.

Pion punch through

When does a pion look like a muon?







Pion Punchthrough probability - RD5

Why talk about resolution and punch through

We need to design the next pp experiment at the FCC

We can measure the track Sagitta in the inner detector

We can measure the bending of the track after the magnetic field coil.

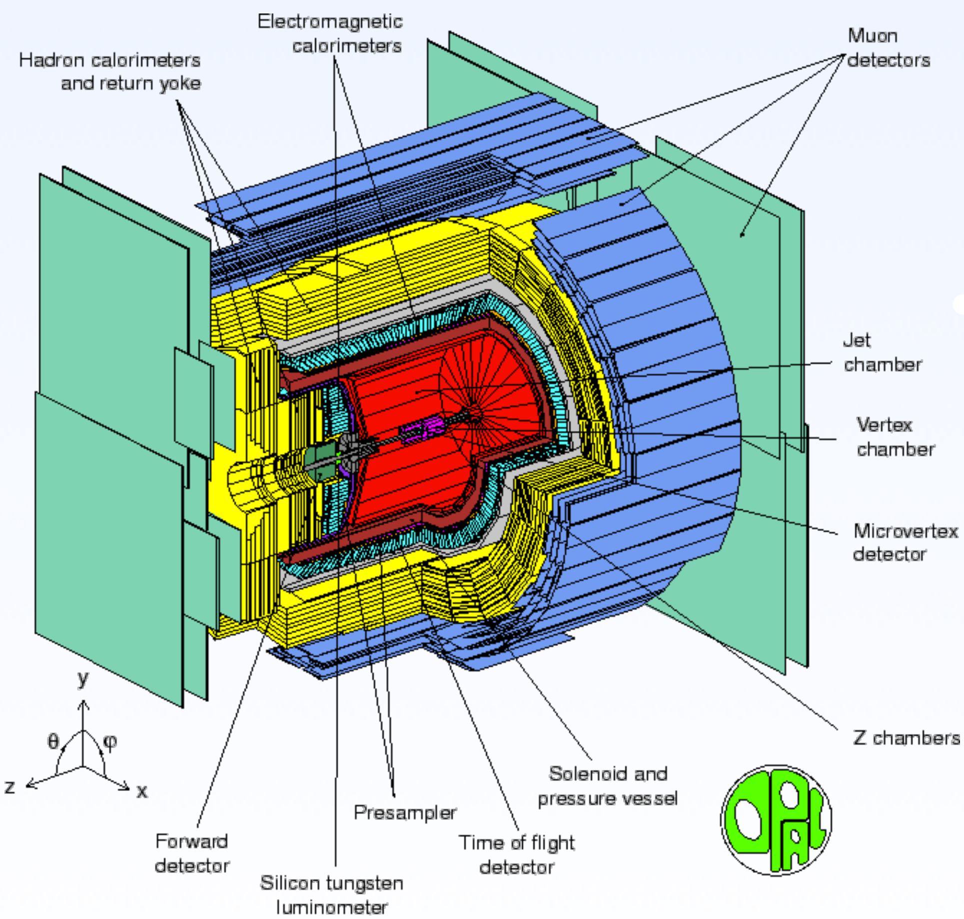
We can measure the Sagitta in the instrumented return yoke

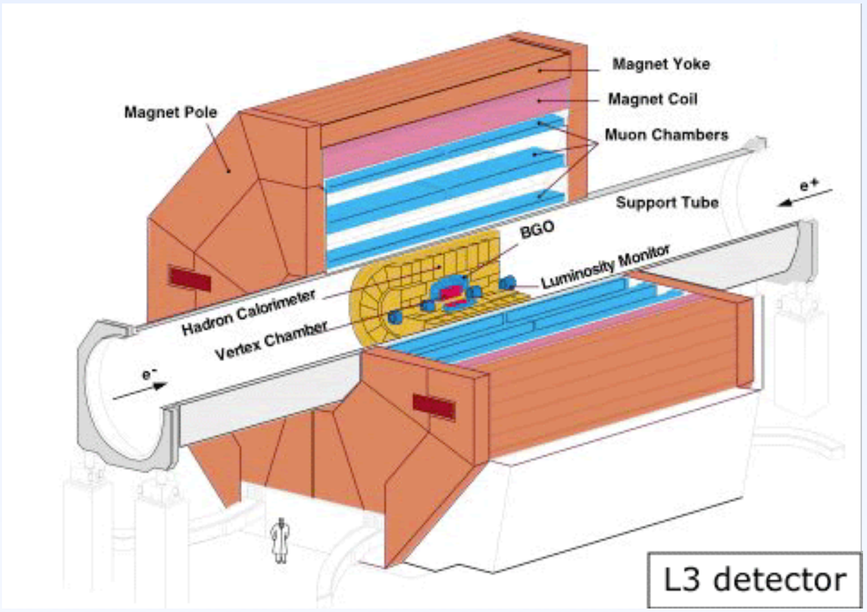
We can measure the muon independently after the calorimeter in a dedicated muon spectrometer with its own magnetic field

What should we do?

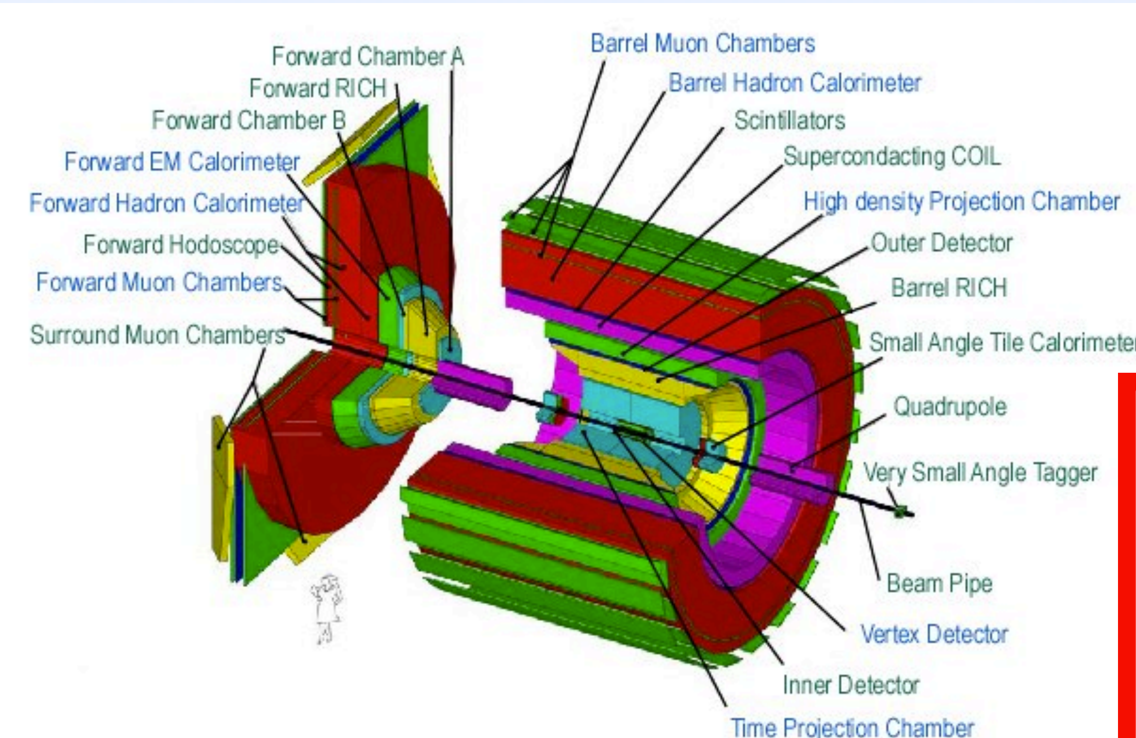
LEP experiments. e+e-
Trigger rate low
Only need to identify muons after data taking

OPAL

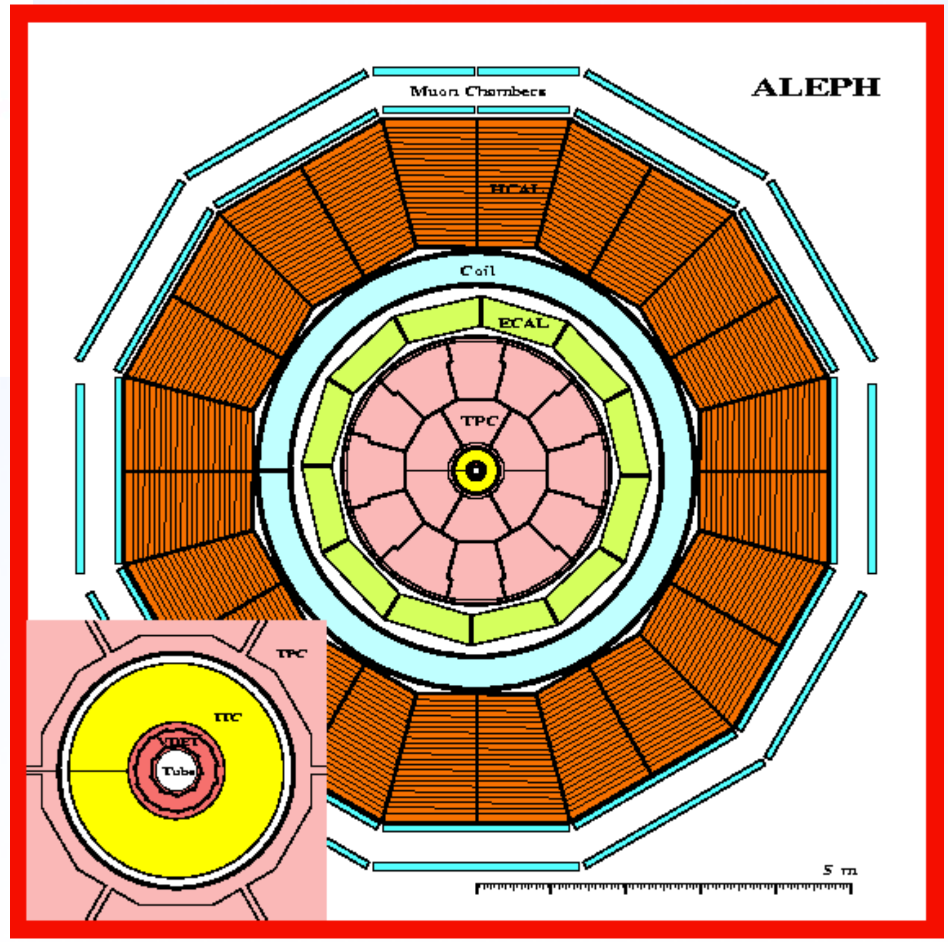




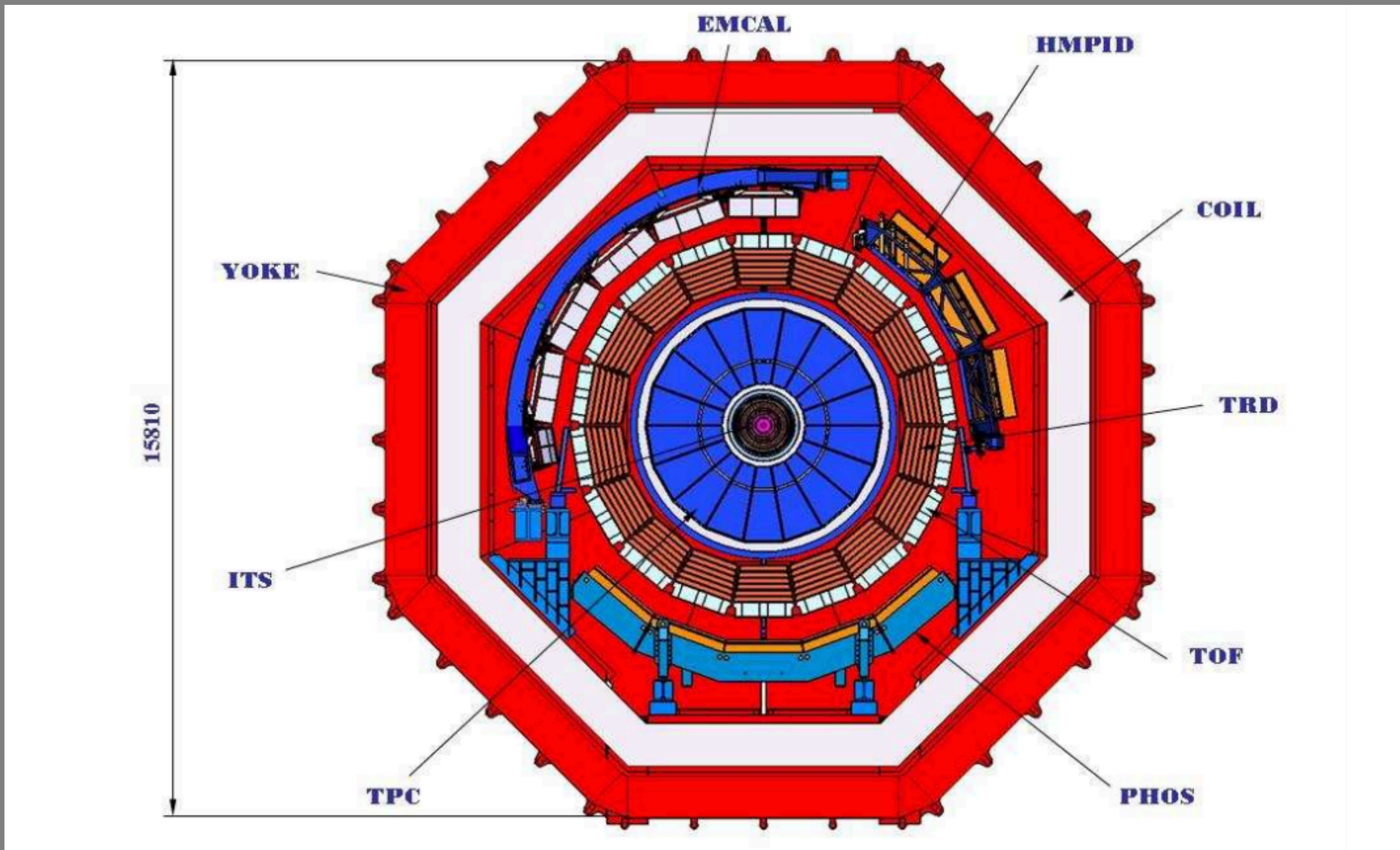
LEP detectors



Delphi

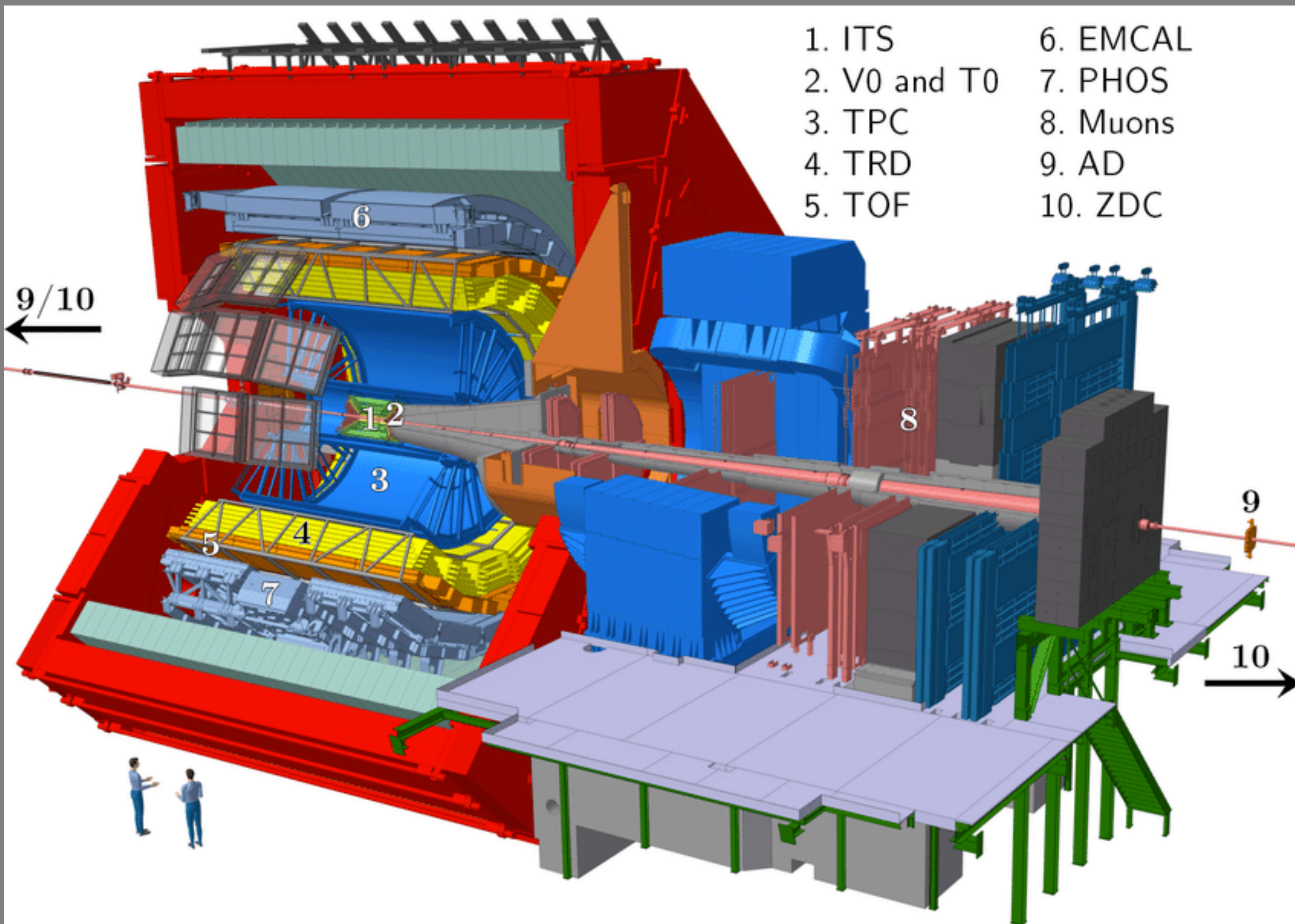


ALICE detector for heavy ion collisions

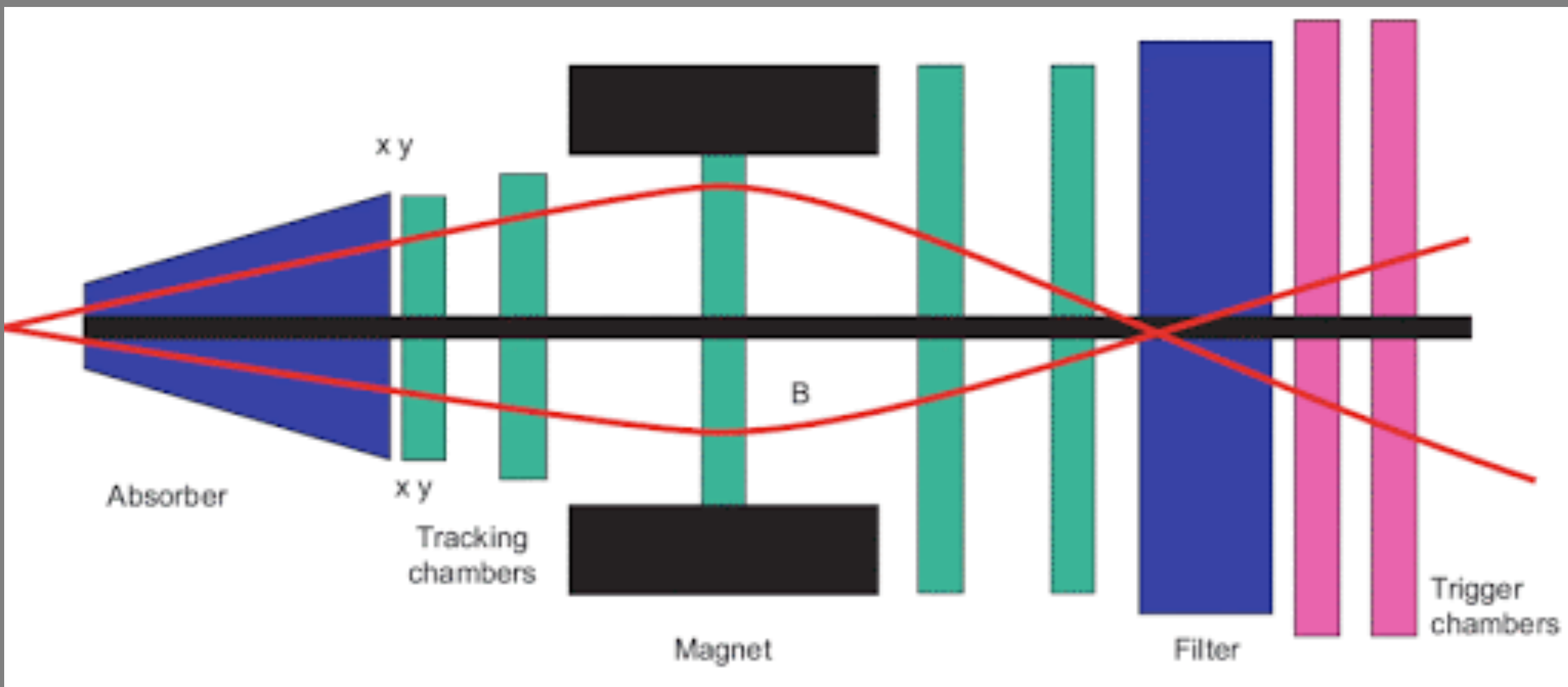


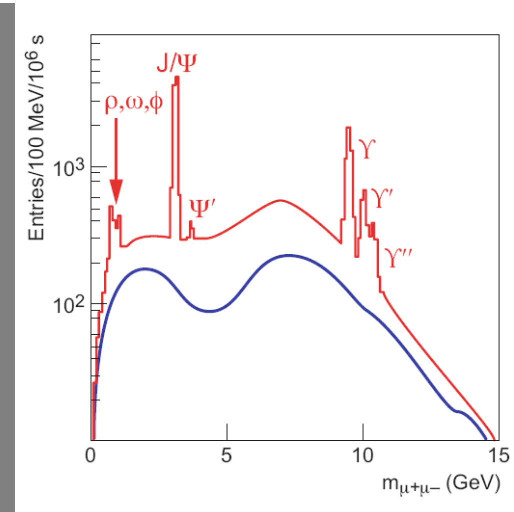
Central detector has no muon detection

ALICE dedicated solid angle for muon detector



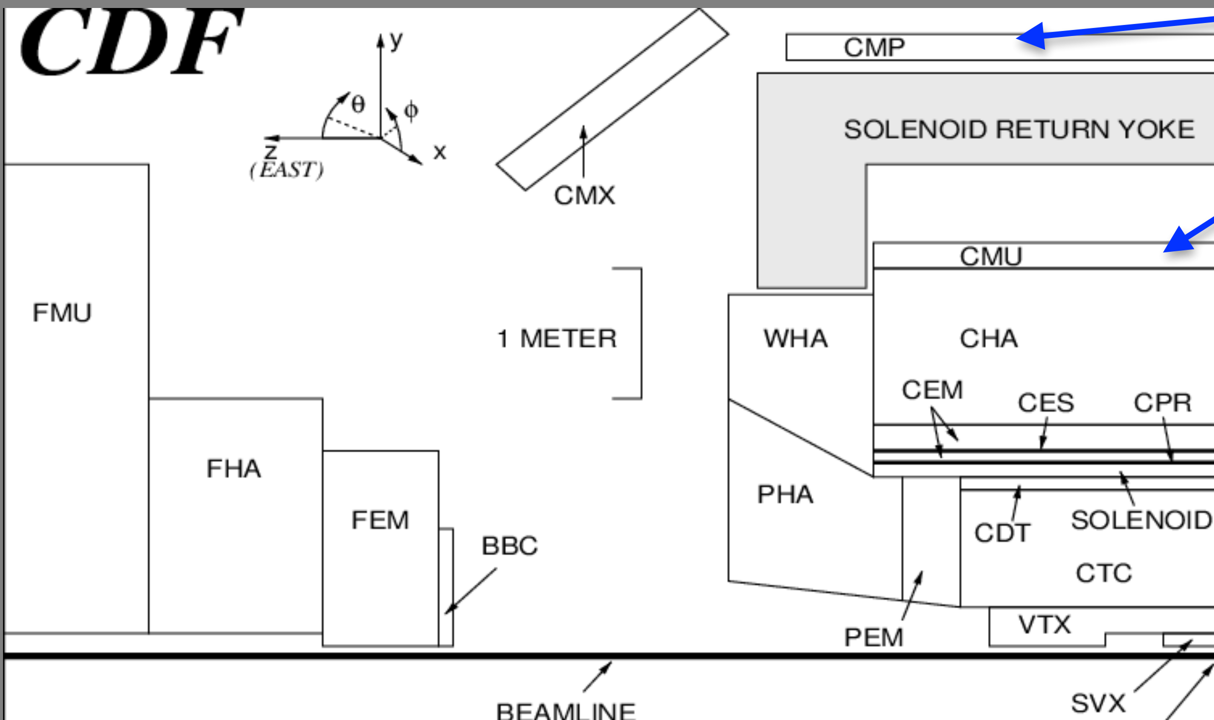
ALICE muon spectrometer - dipole magnet





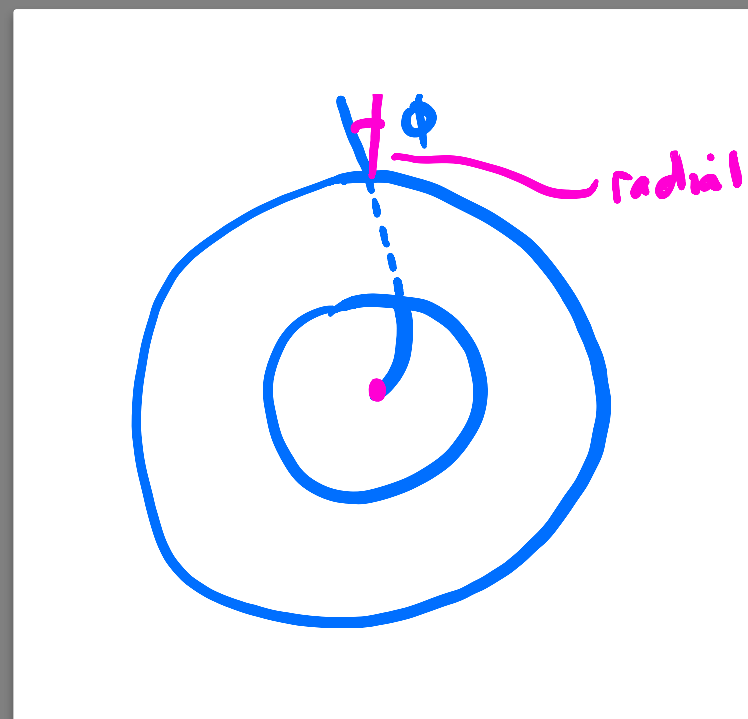
Mass spectrum.

How to identify muons CDF

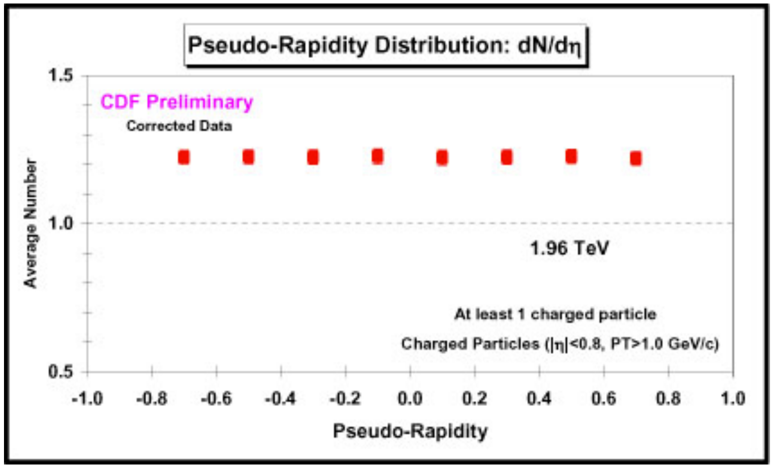


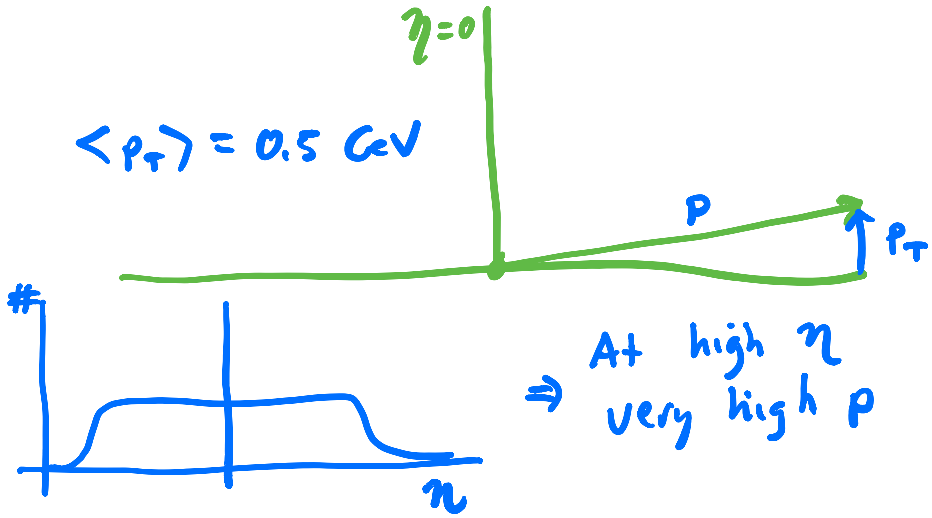
Muon chambers
CMP added to help
with punch through

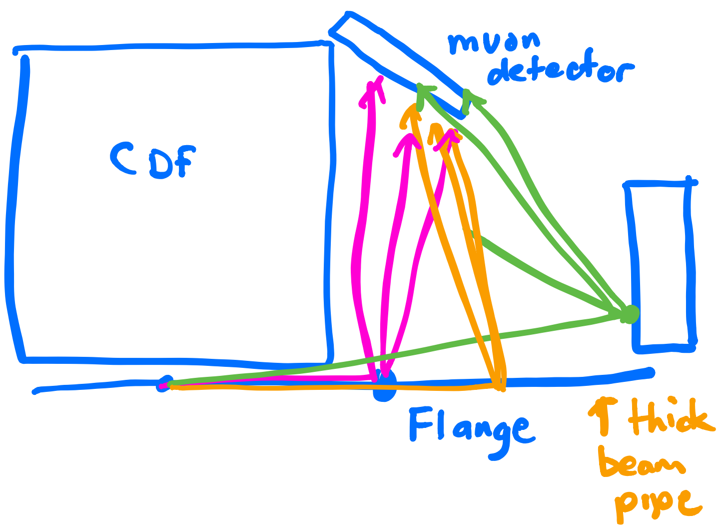
Use muon detector to tag muons



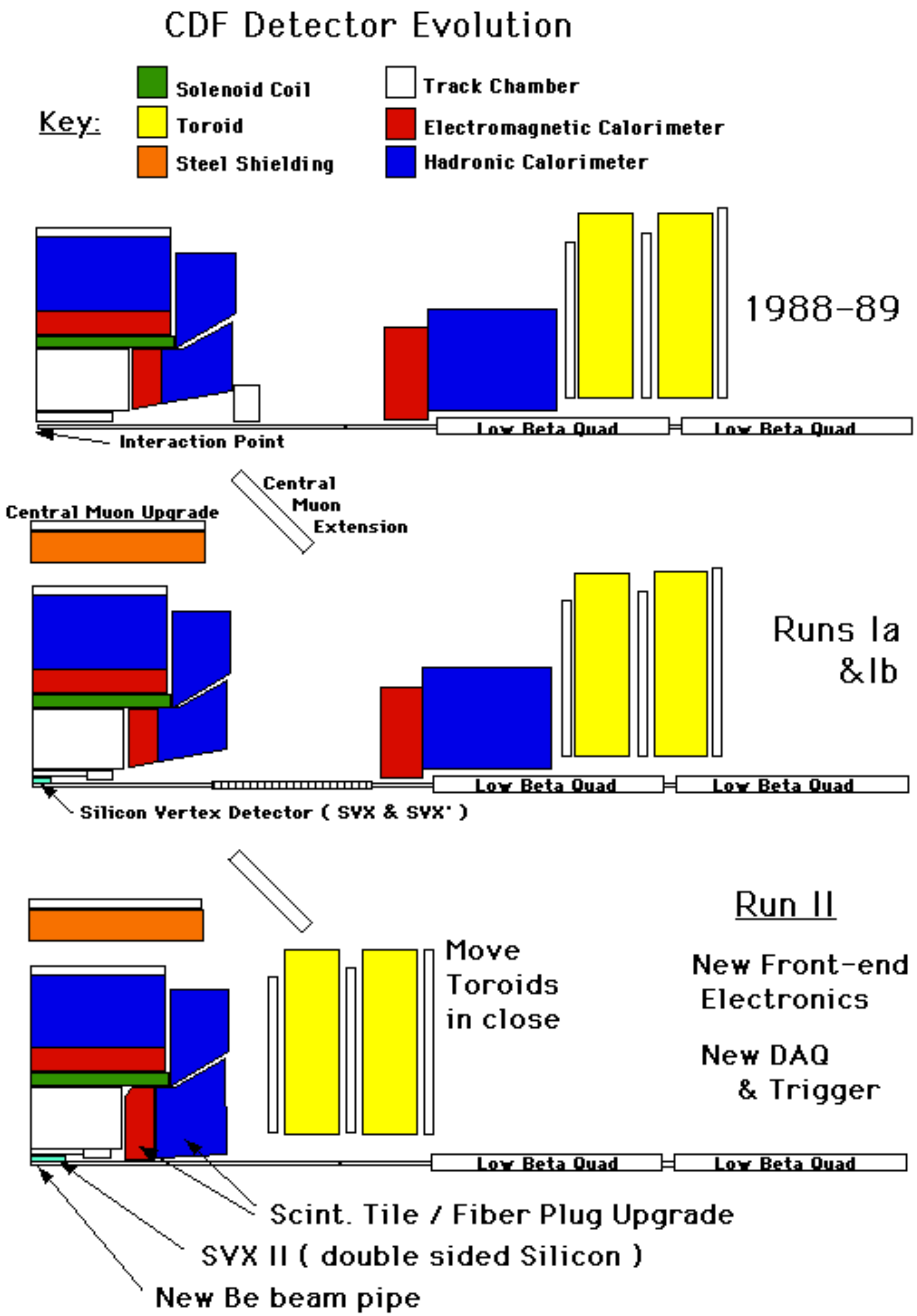
The number of charged particles per unit of rapidity is constant over a long plateau
The average pt of those particles is ~ .5 GeV







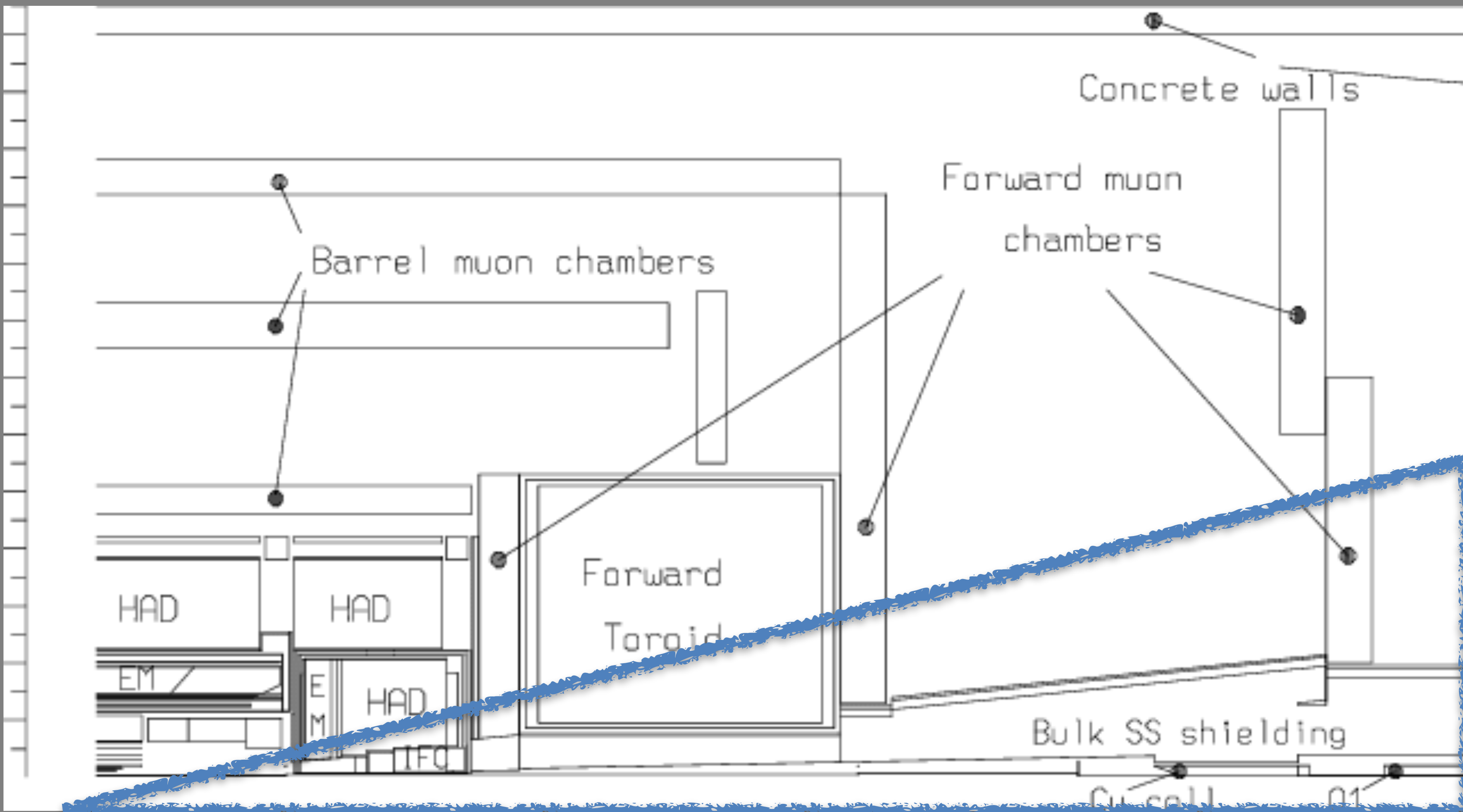
This leads to particles emitted from pp at high eta and very high momentum hitting the beam pipe and causing hadronic showers



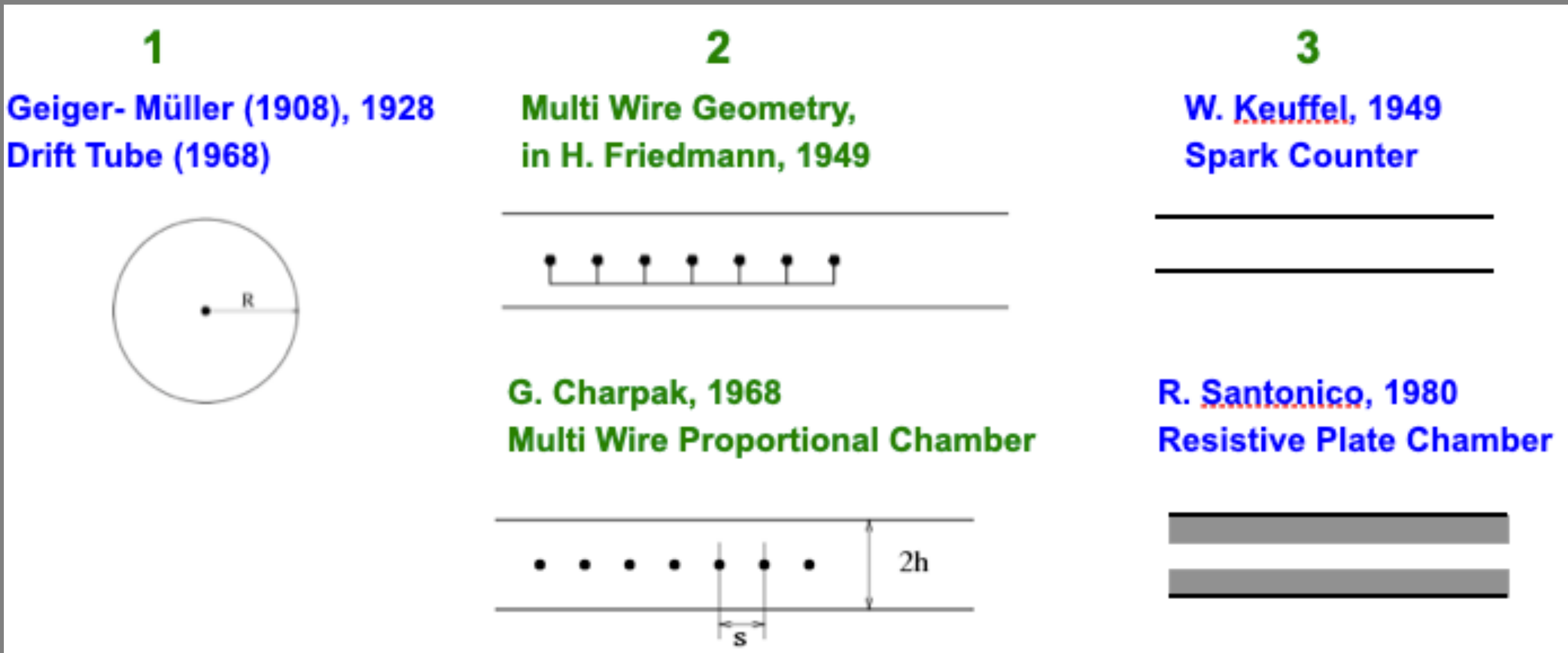
Replaced beam pipe

Added shielding

ATLAS beam line shielding



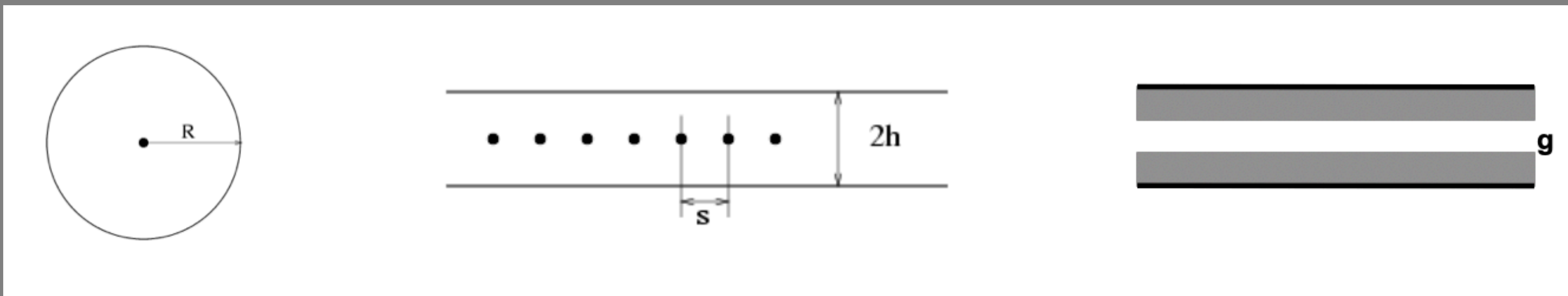
History of detectors



Stolen From Werner Riegler Academic Lectures 2008

Tomorrow: Muon detectors I have known and weird problems they have had and New detector technologies.

- g=2mm, 2mm Bakelite
- 355k channels
- $C_2F_4H_2$/Isobutane/SF_6 96.7/3/0.3
- 50-100kV - fast 1 ns



MDT monitored drift tubes

- R=15mm
- 370k anode channels
- Ar/CO_2 93/7 (3 bars)
- < 80μm

CSC, TGC

Cathode strip chambers

Thin gap chambers

- h=1.4mm, s=1.8mm
- 440k cathode and anode channels
- n-Pentane /CO_2 45/55
- Fast

RPC

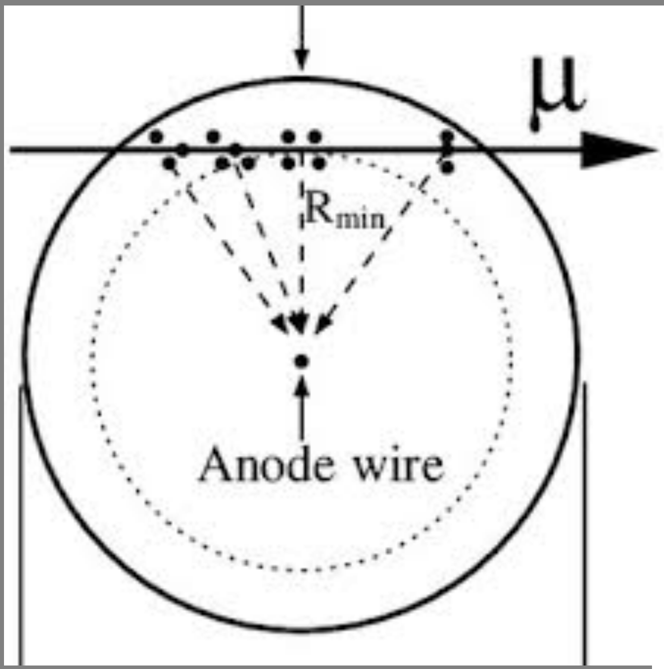
Resistive Pad chambers

This is what we have now - drift tubes, RPC's, CSC's, TGC's

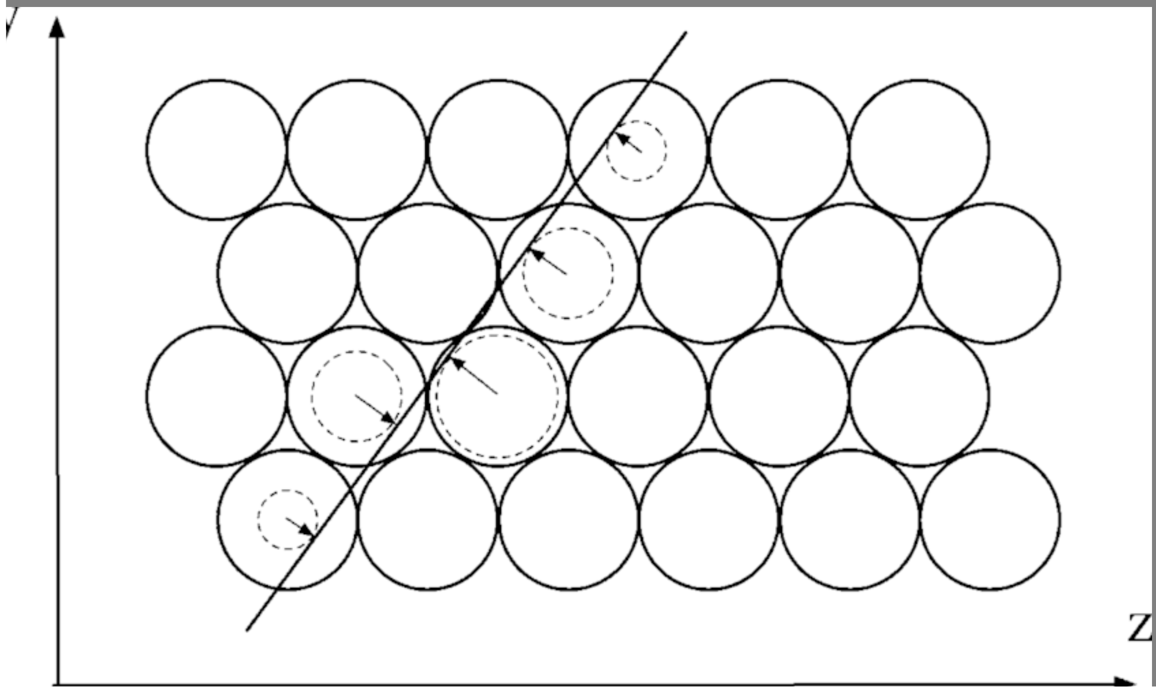
What's next? And why?

Monitored drift tubes

r=1.5cm. 700 ns drift time. AR-Ethane 93-7. 80μ resolution



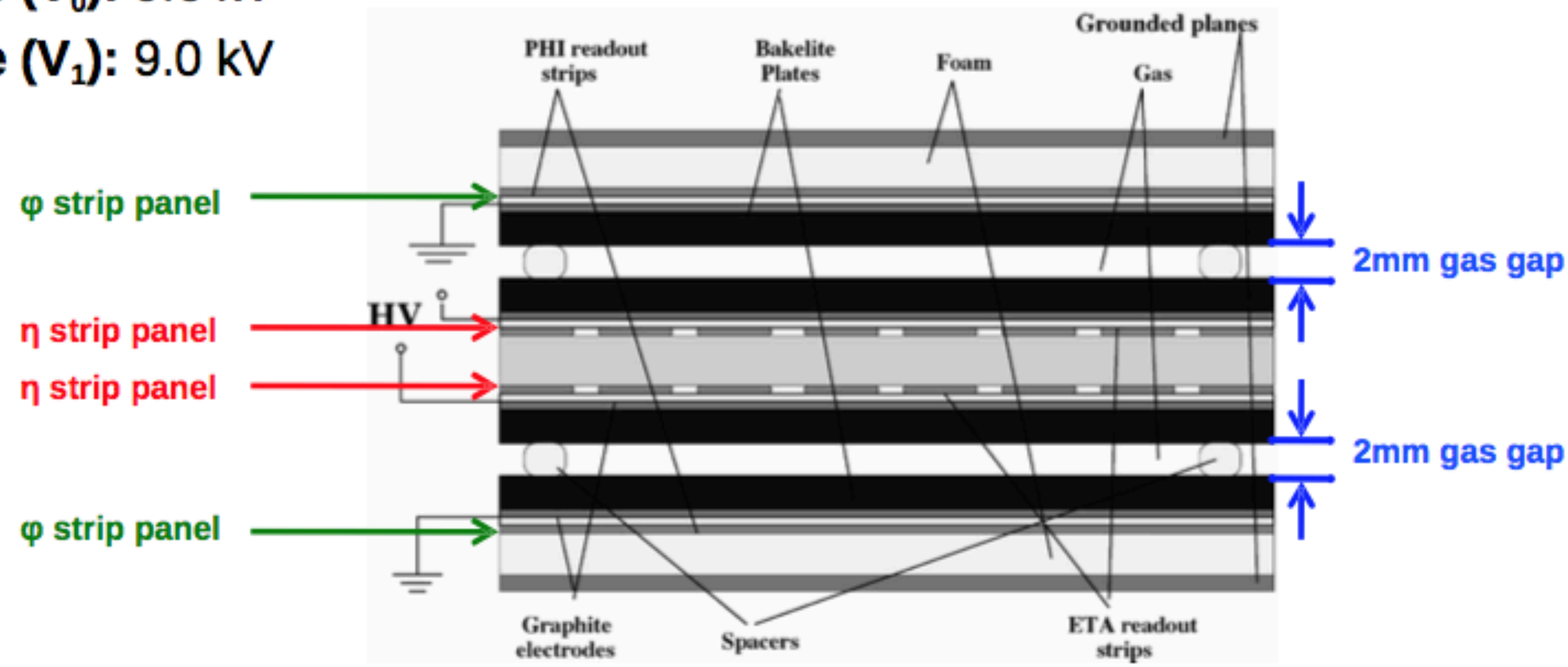
Beam cross every 25ns.



ATLAS RPC's trigger in barrel

nominal voltage (V_0): 9.6 kV

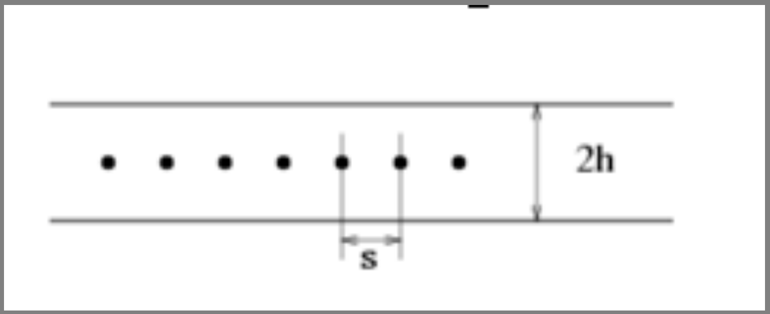
standby voltage (V_1): 9.0 kV

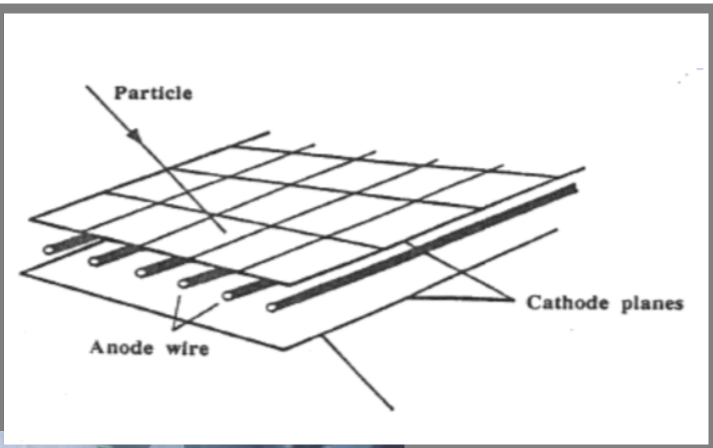


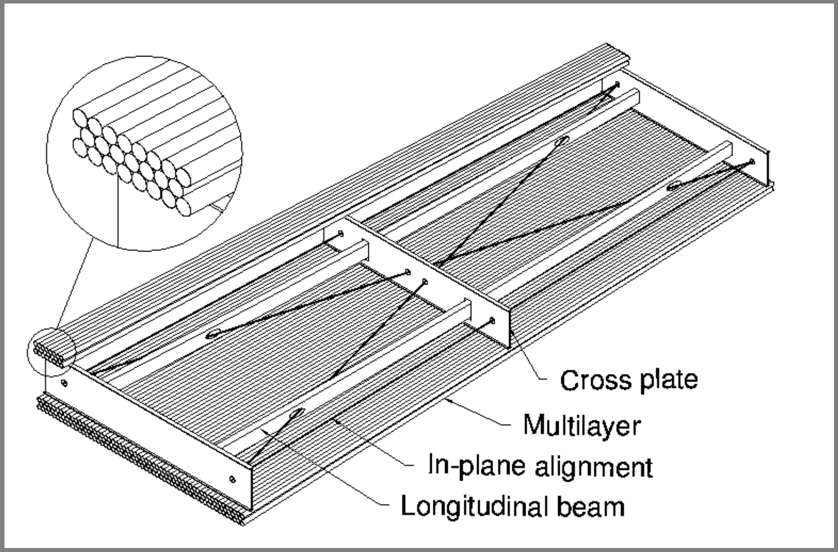
Space charge effects drop the voltage

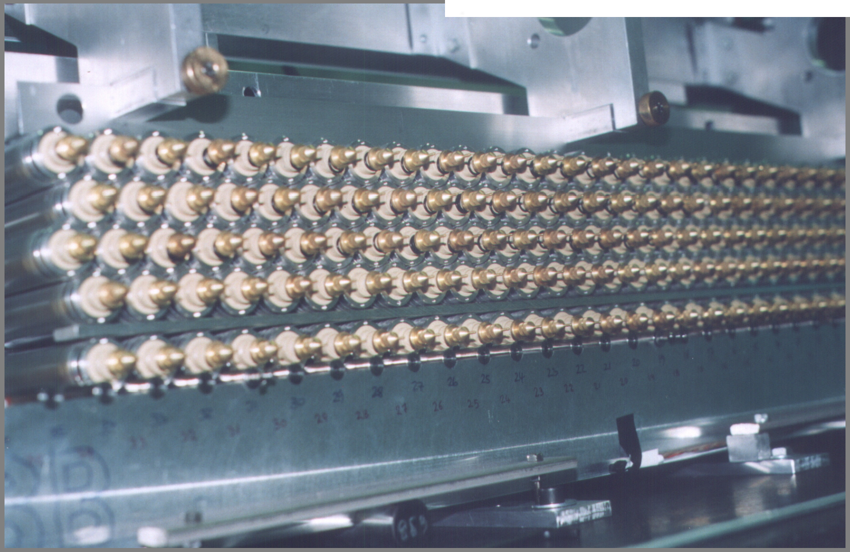
ATLAS MDT's & CSC's

CSC's 60μ
45ns drift
No trigger

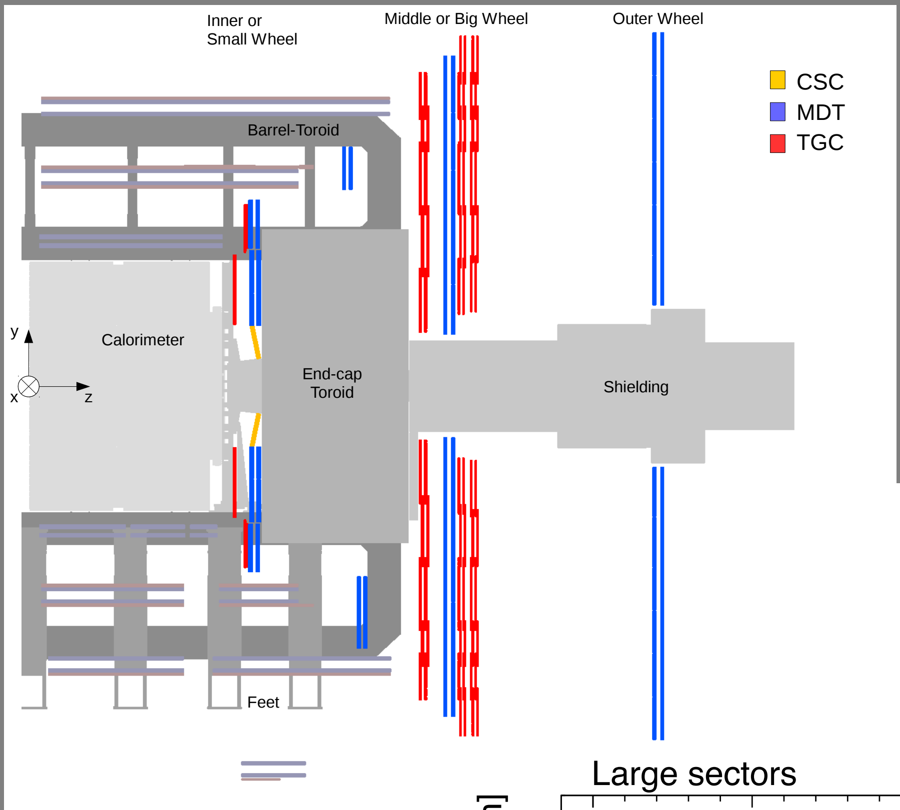


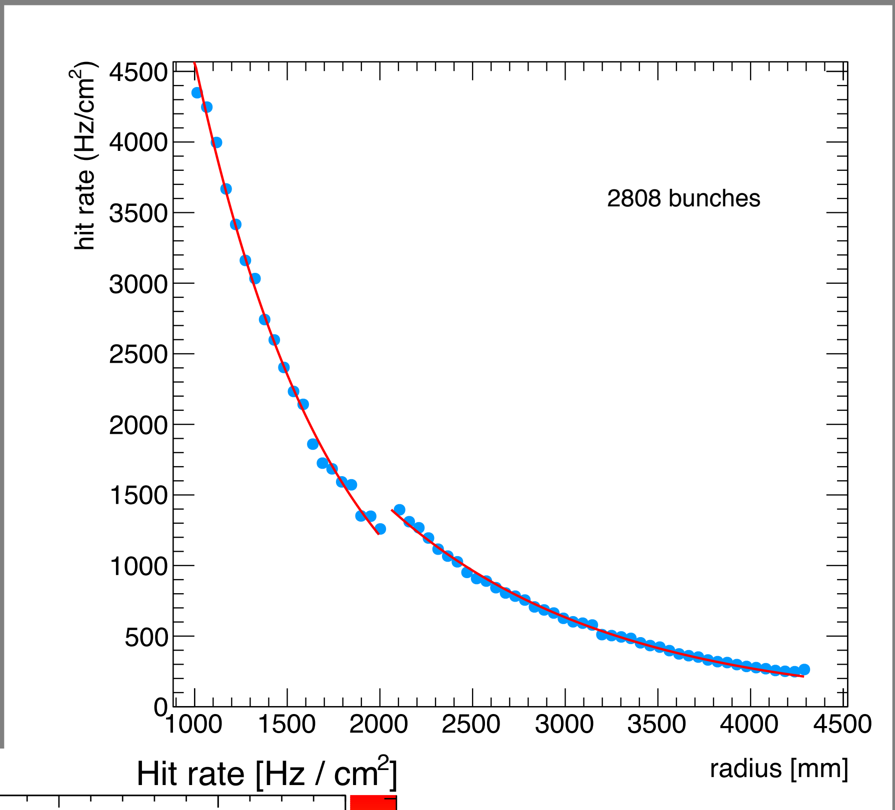


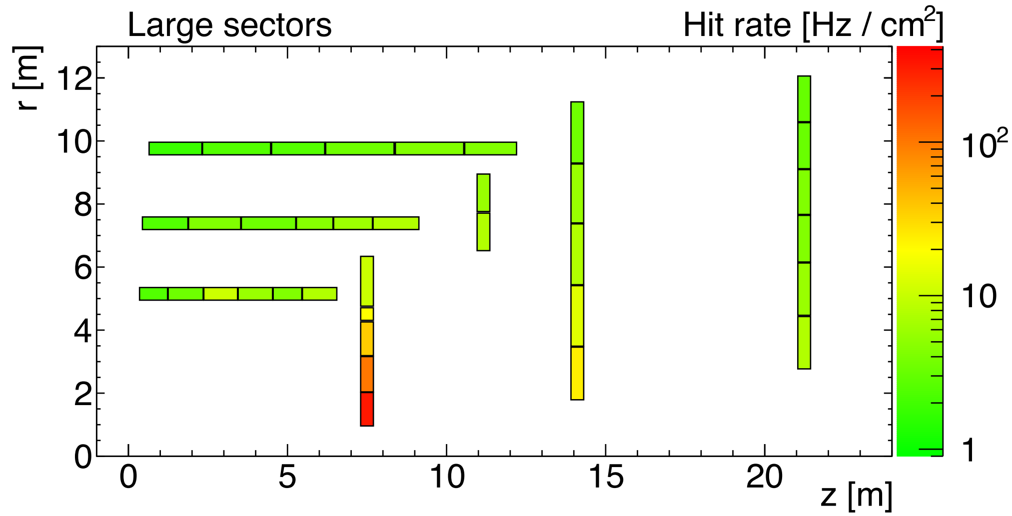




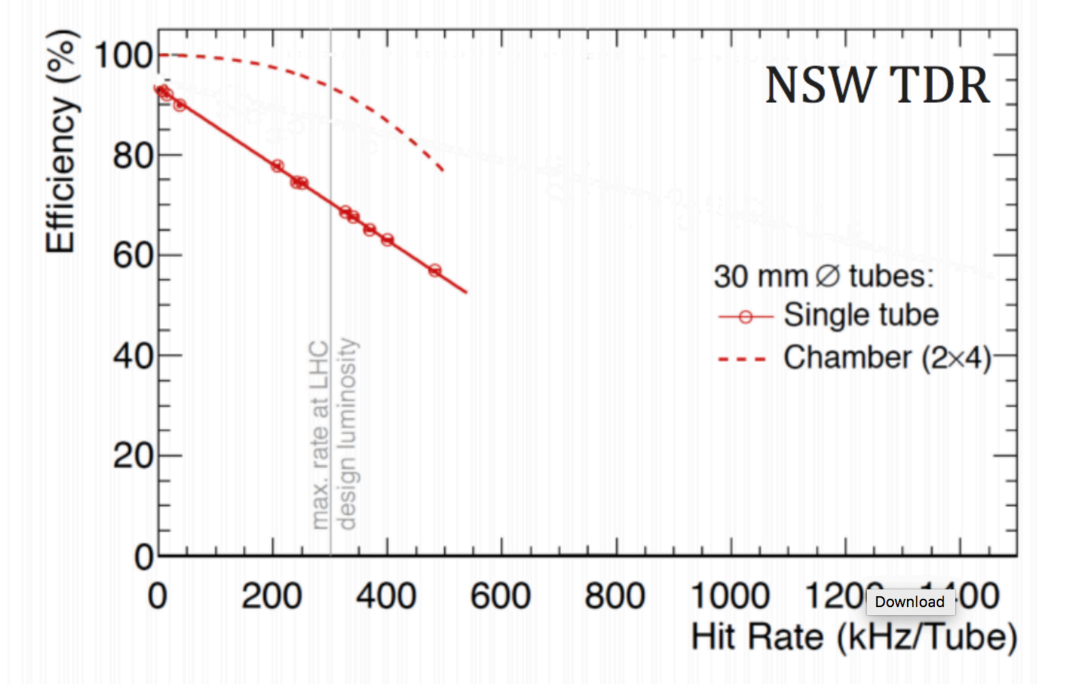
ATLAS hit rates

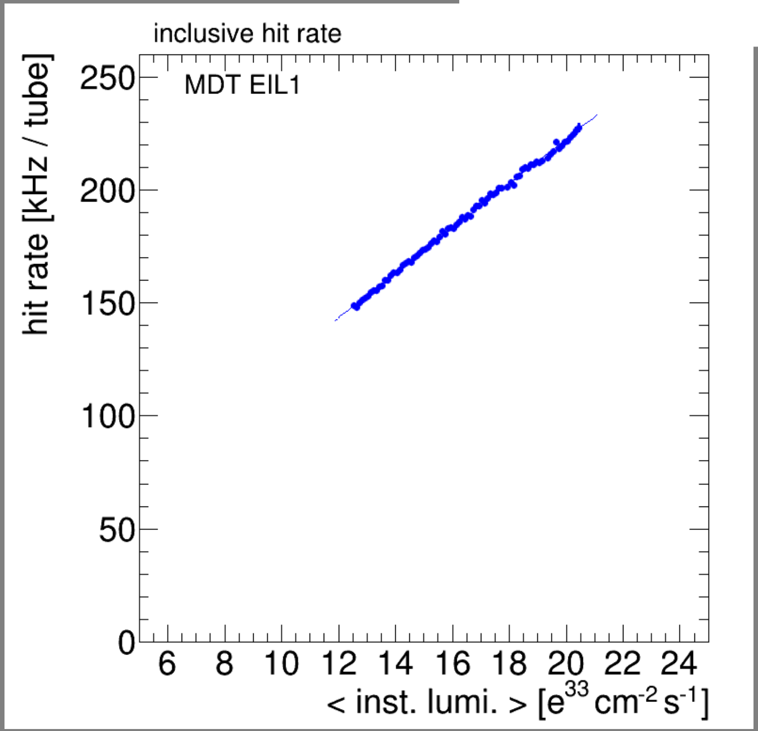




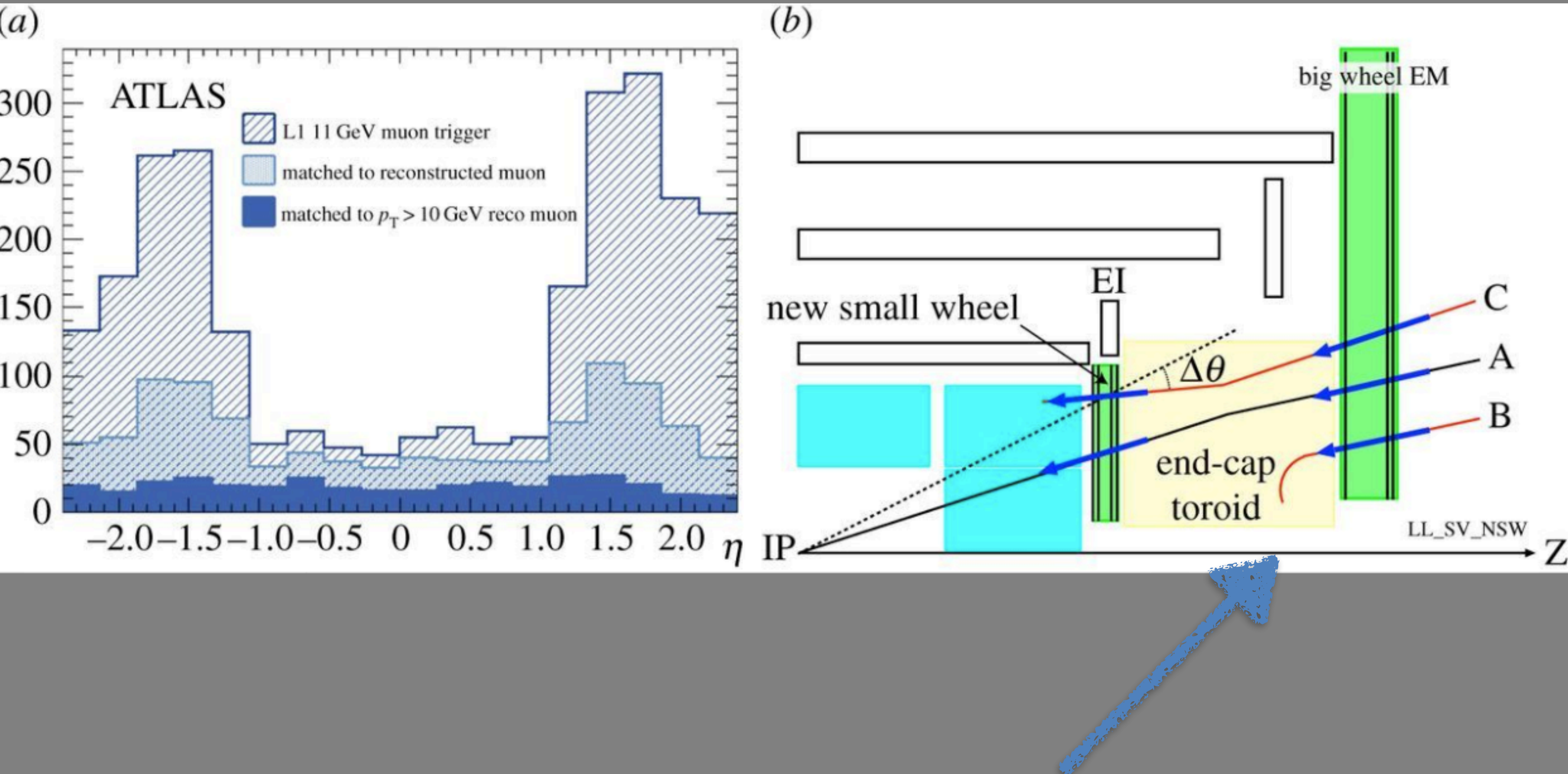


Why build a new muon detector
MDT Singles tube hit rate decreases efficiency



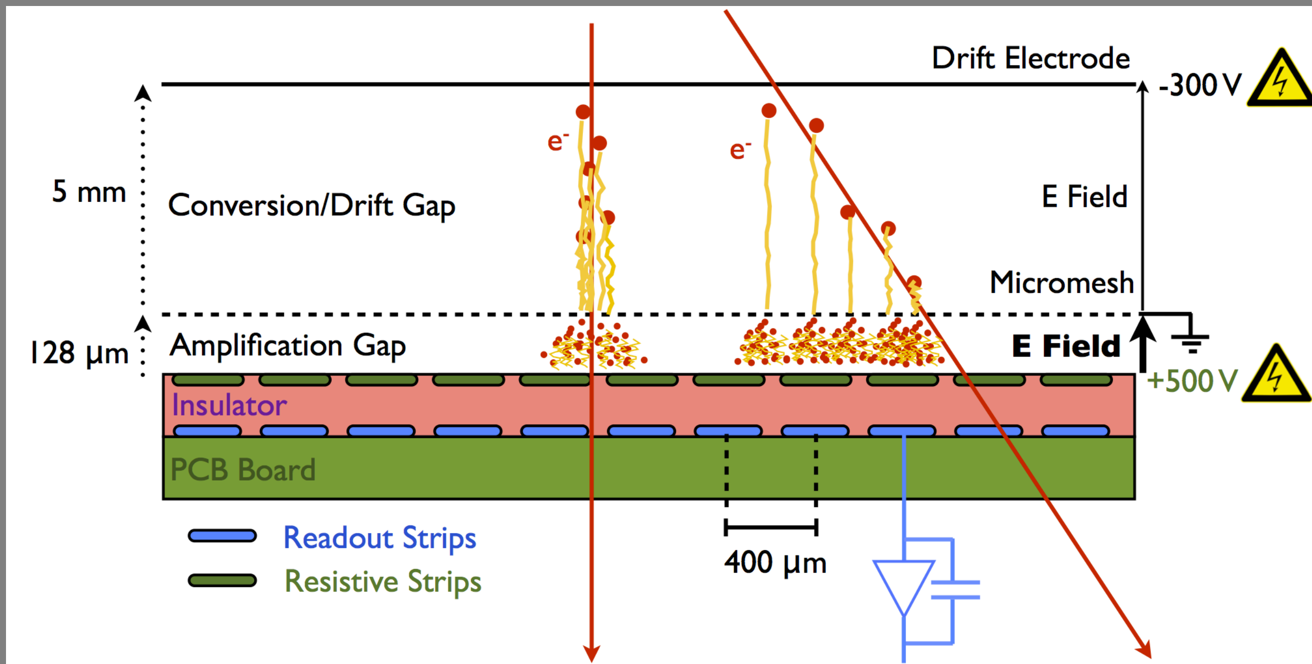


The trouble with ATLAS muon end cap triggers



From the beam line and cracks in the shielding

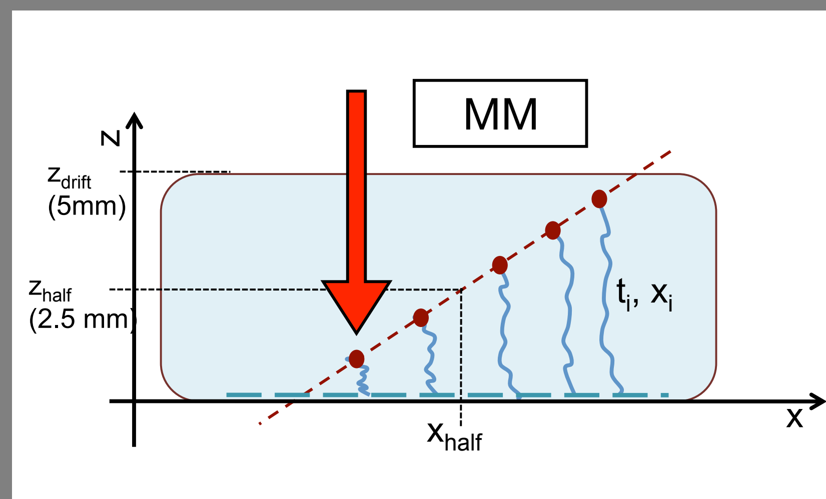
New muon detectors- GEM CMS & Micromegas ATLAS



Micromegas
200ns drift time

100μ resolution?

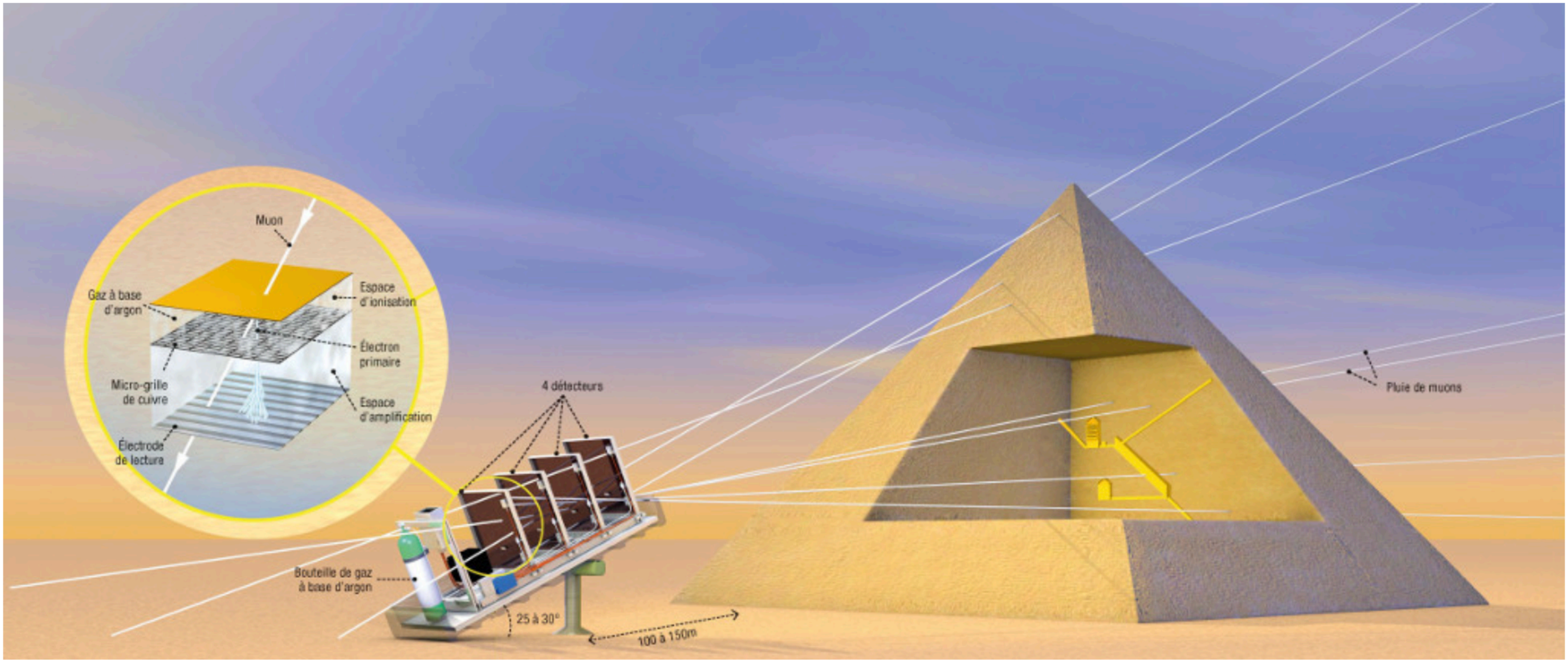
Can also produce a segment for a trigger
Take first electrons.



Look for missing matter

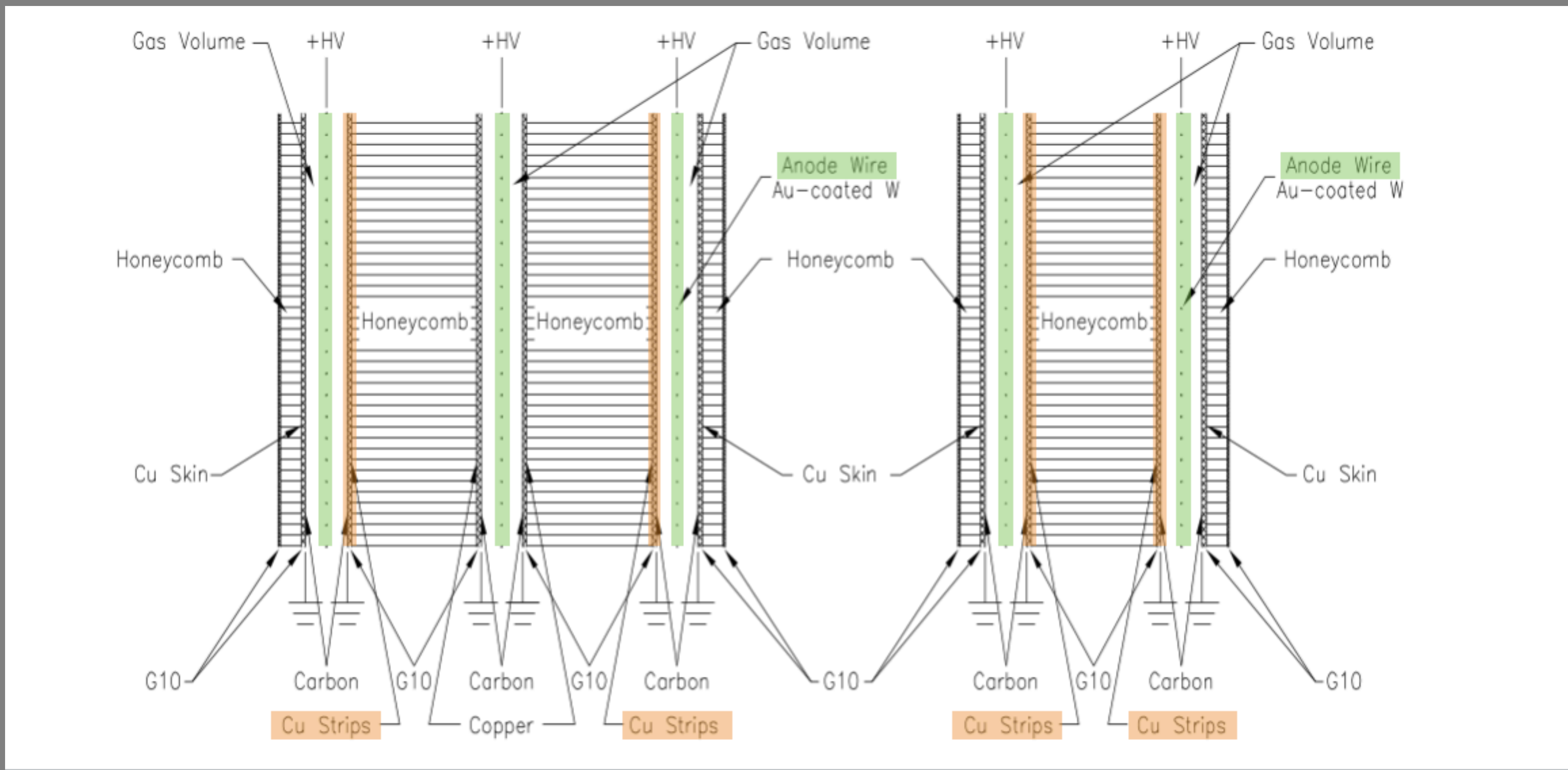
#ScanPyramids project

15 December 2016



With micromegas detectors! Tomorrows lecture.

Thin gap chambers: TGC’s —> sTGCs
Add pads to strips



Precision coordinate φ - ns timing - 10ns drift - gap 1.4mm

CMS muon upgrade - trigger rate

Improves p resolution in highest B field region - so lowers trigger rate

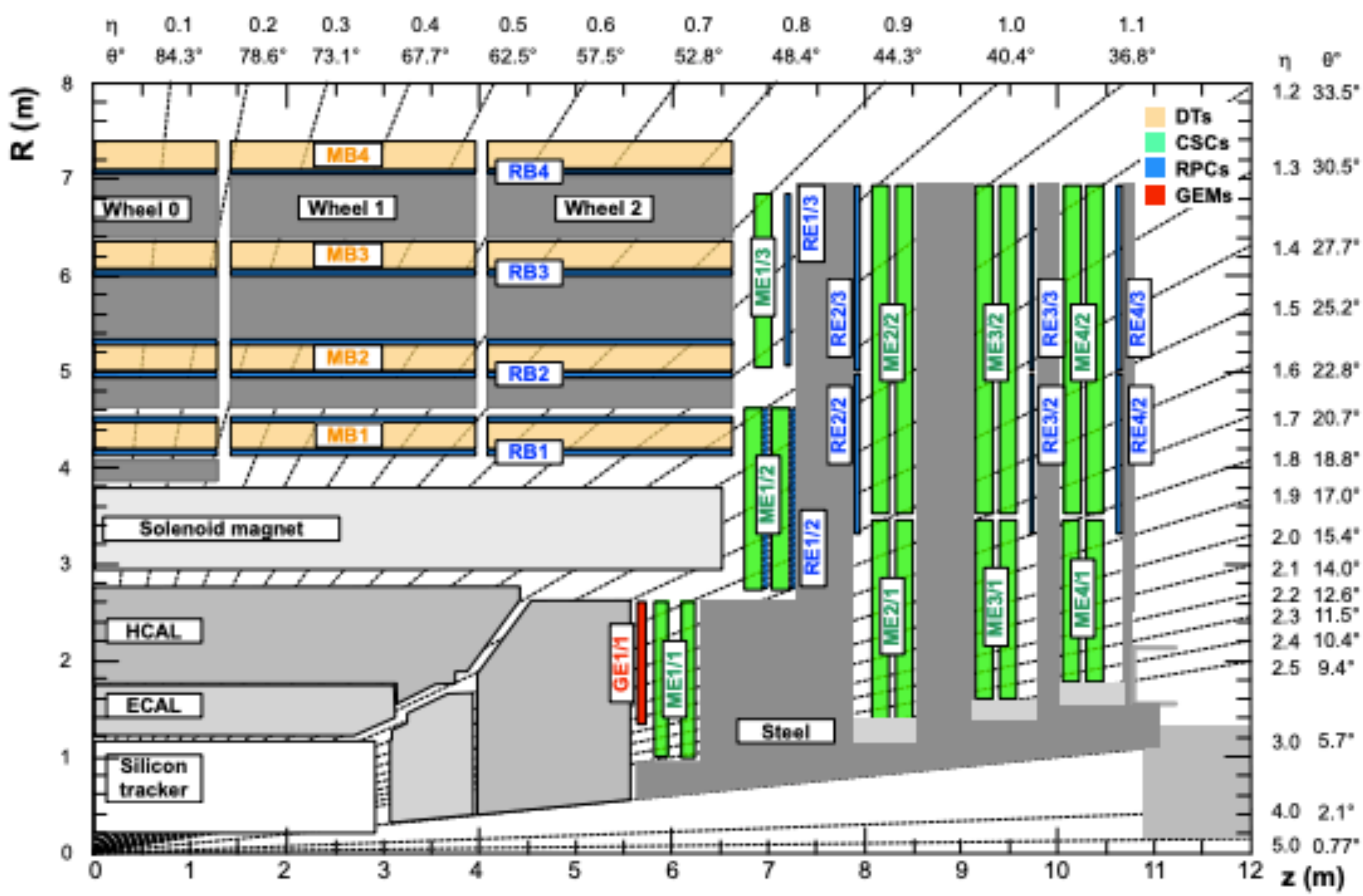
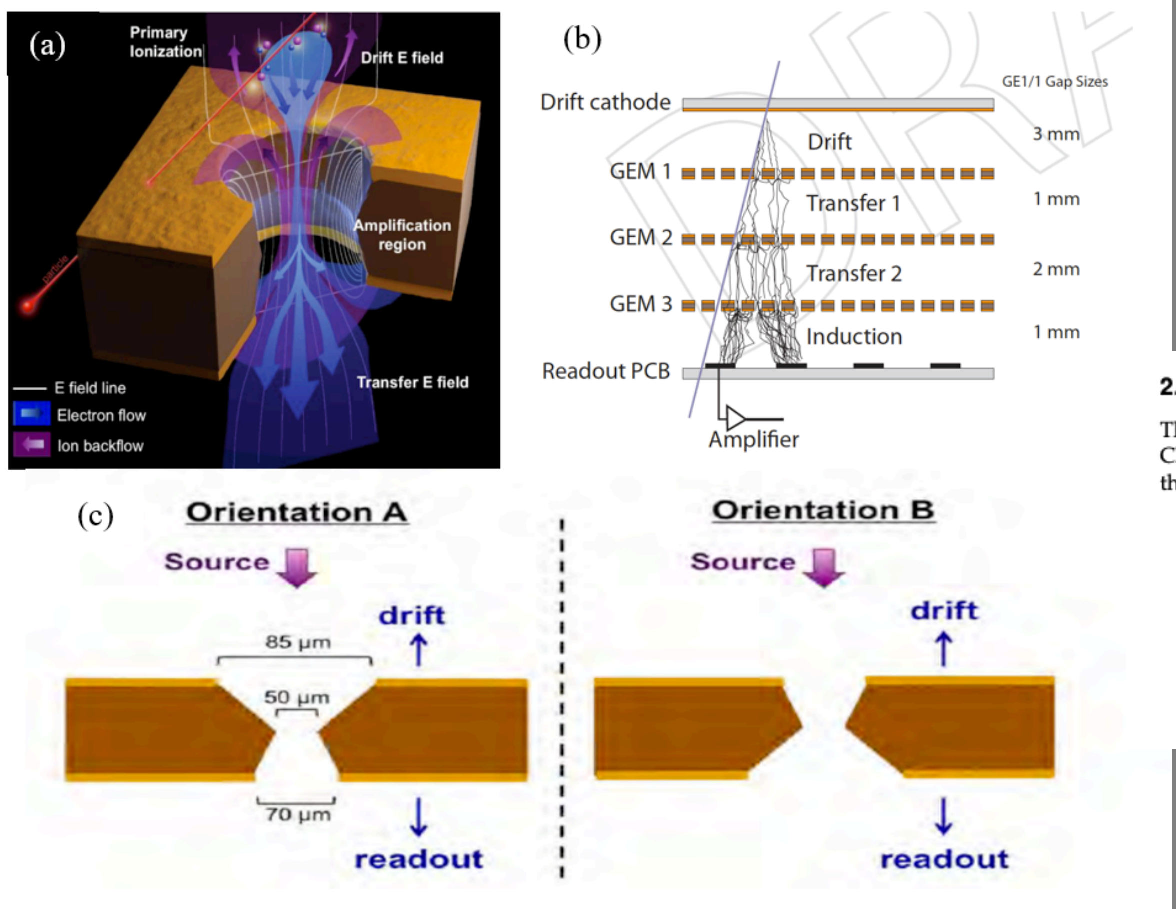
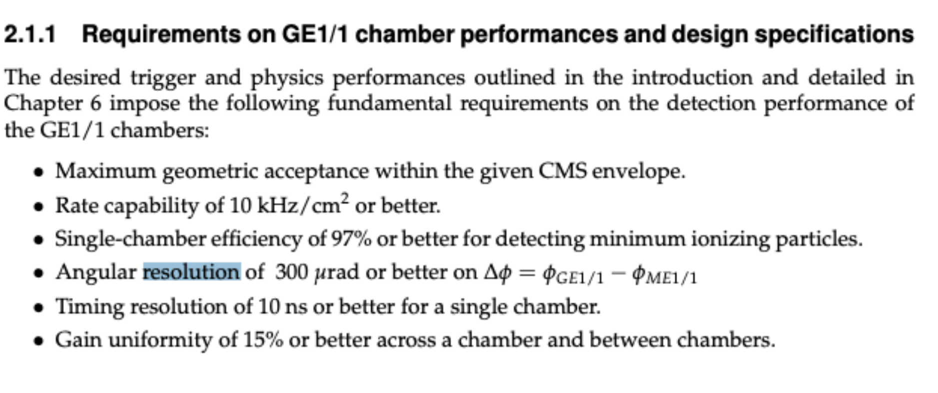


Figure 1.1: A quadrant of the $R - z$ cross-section of the CMS detector, highlighting in red the location of the proposed GE1/1 detector within the CMS muon system.

GEM: CMS Muons



Many stages - each with modest gain



2.1.1 Requirements on GE1/1 chamber performances and design specifications

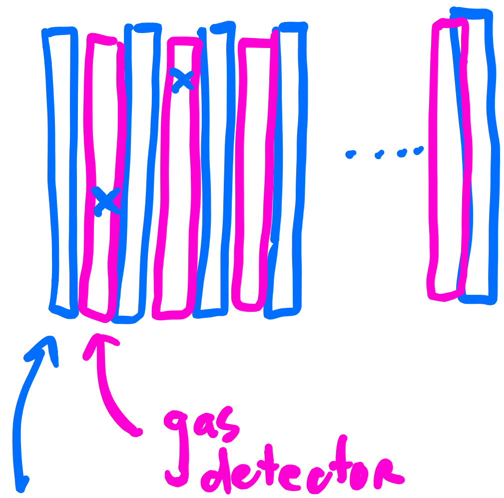
The desired trigger and physics performances outlined in the introduction and detailed in Chapter 6 impose the following fundamental requirements on the detection performance of the GE1/1 chambers:

- Maximum geometric acceptance within the given CMS envelope.
- Rate capability of 10 kHz/cm^2 or better.
- Single-chamber efficiency of 97% or better for detecting minimum ionizing particles.
- Angular resolution of 300 μrad or better on $\Delta\phi = \phi_{GE1/1} - \phi_{ME1/1}$
- Timing resolution of 10 ns or better for a single chamber.
- Gain uniformity of 15% or better across a chamber and between chambers.

Metallized foil with ≈50μm holes. < 5ns timing. Potential difference on the foil produces large electric field in the holes. Electrons avalanche induces a signal on the strips. Foils are very thin and hard to stretch in large areas.

CDF gas calorimeters informs ATLAS muon gas detectors

Calorimeter



gas detector

absorber

We sample

$\sim \frac{1}{20,000}$ of energy

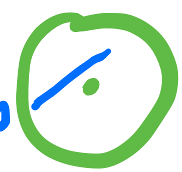
E_{low} neutron → proton

highly ionizing

argh.

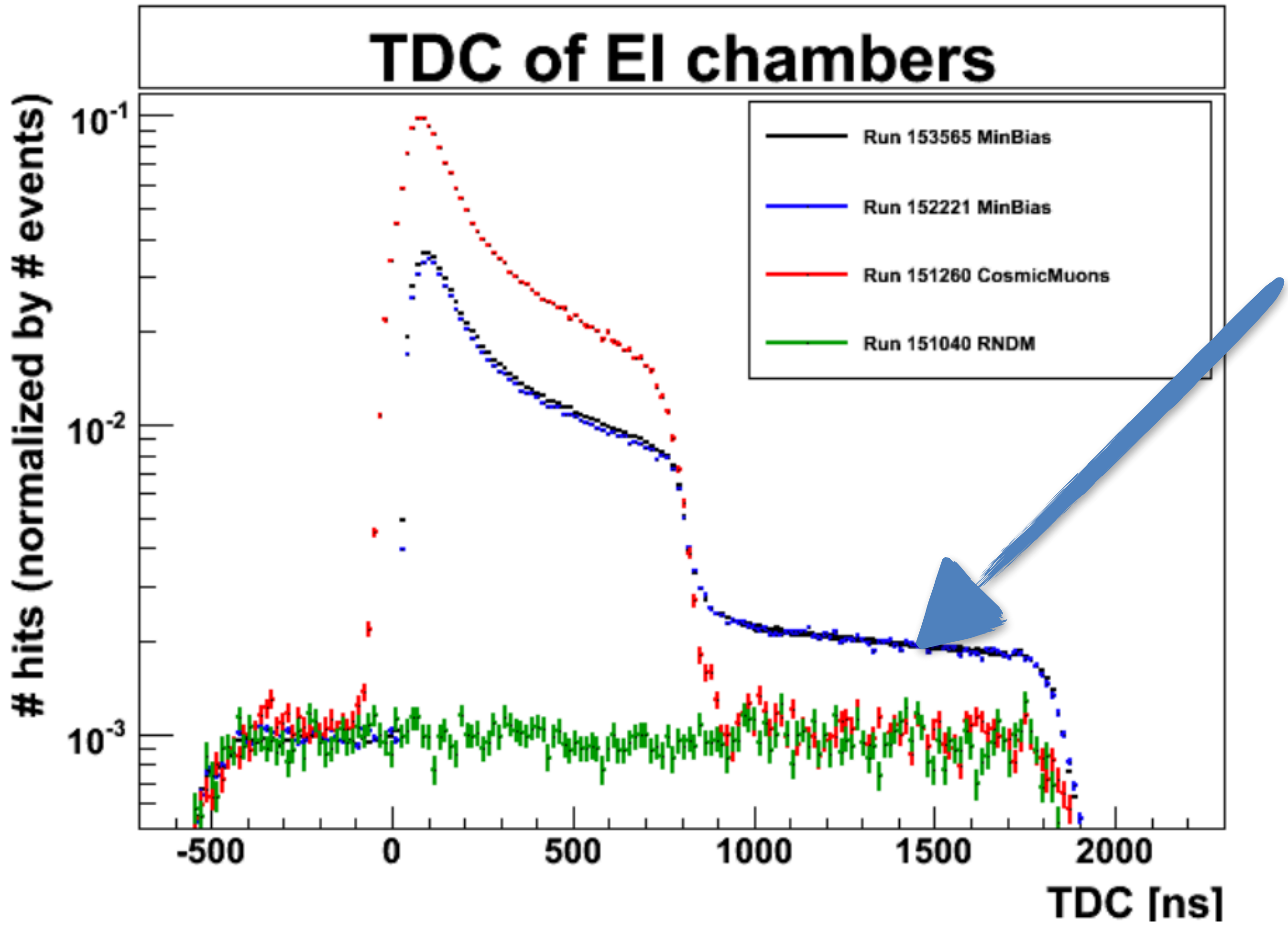
T

n→p

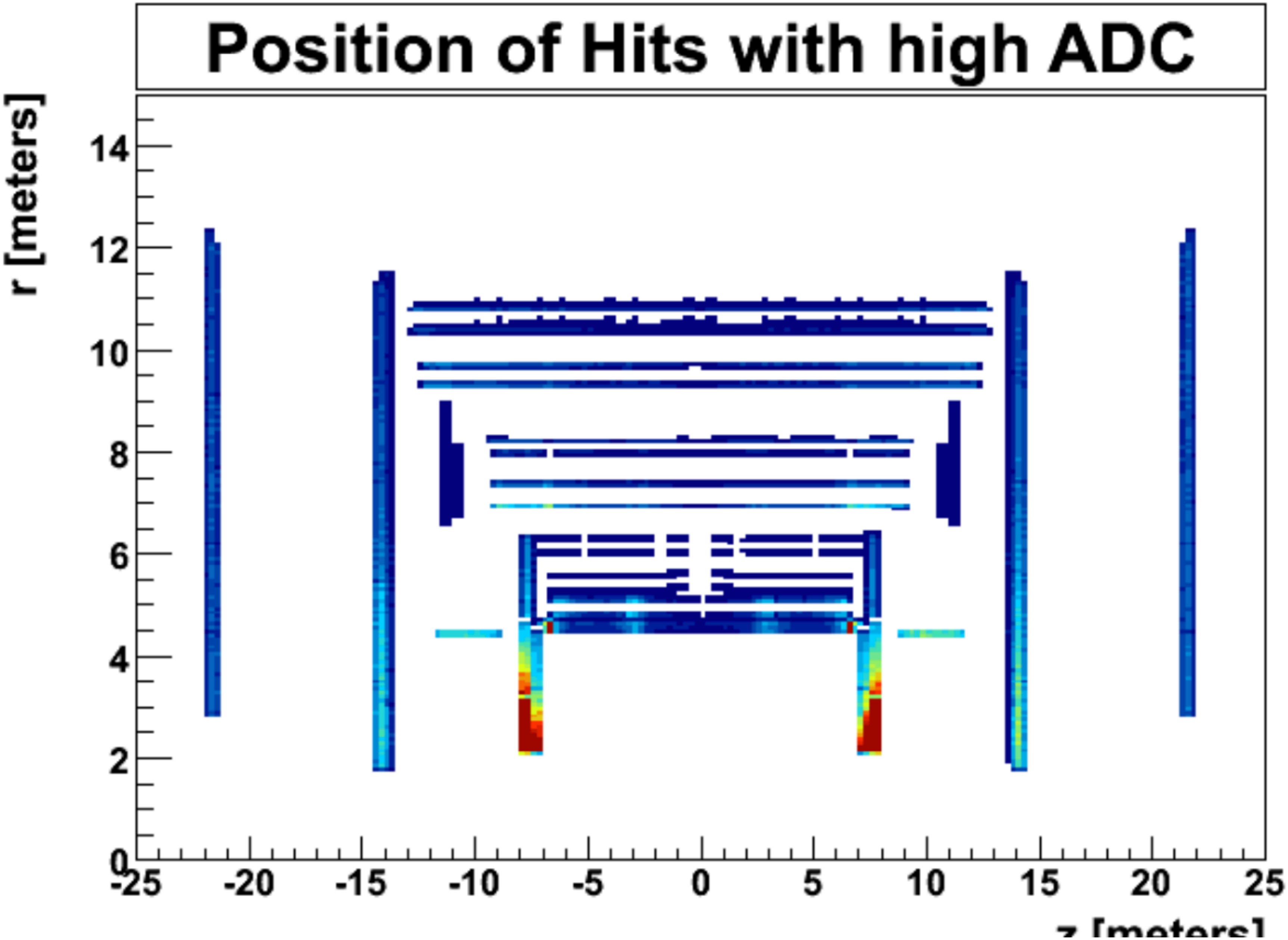


neutrons can be seen as single tube hits.

Fun with muon detectors:
Neutrons first seen in muon detectors at ATLAS



Neutrons are created in hadronic collisions - jets, spray from beam pipe, etc
They take time to moderate -

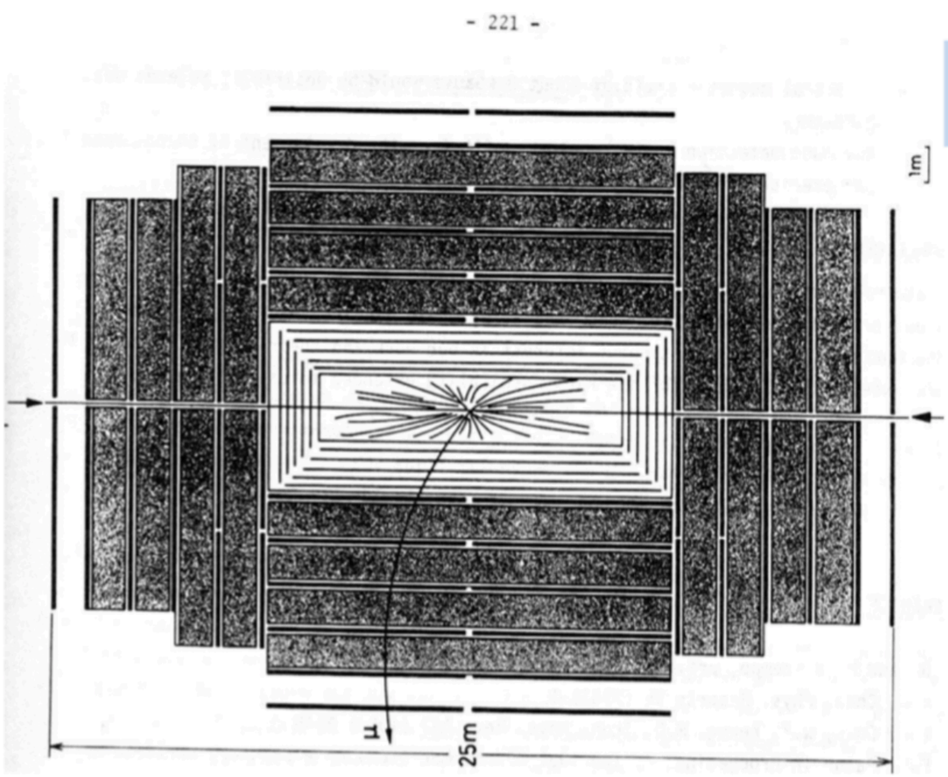


How to design a collider detector

An early design meeting in 1984. Carlo Rubbia's(?) iron ball proposal

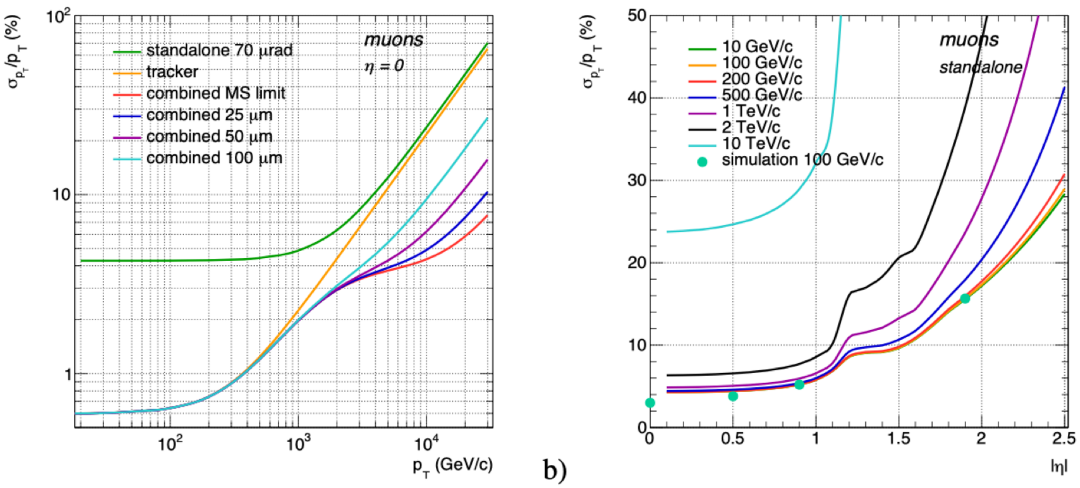
Detectors discussed at Lausanne

- Magnetized Iron ball
- Tracking a la « UA1 »

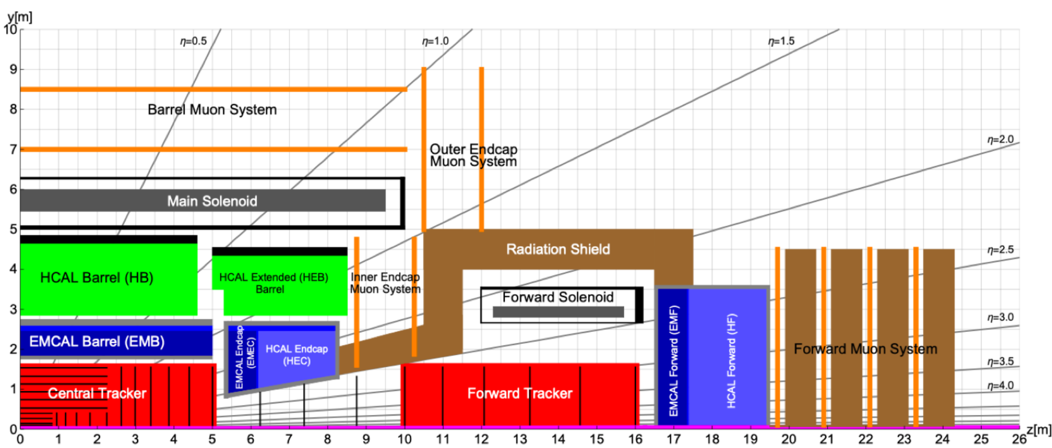


FCC-kickoff Geneva Feb13-2014 28

Muon Systems



b)



'Standalone' muon performance is not any more a very important criterion. Future detectors rely on a combined tracker/muon system performance.

The task of the muon system is triggering and muon identification.

4-5% standalone momentum resolution can be achieved in at η=0, 30% at η=2.5 by simply measuring the angle at which the muon exits the calorimeters.

In the forward muon system, standalone momentum measurement and triggering can only be achieved when using a forward dipole (like ALICE, LHCb).

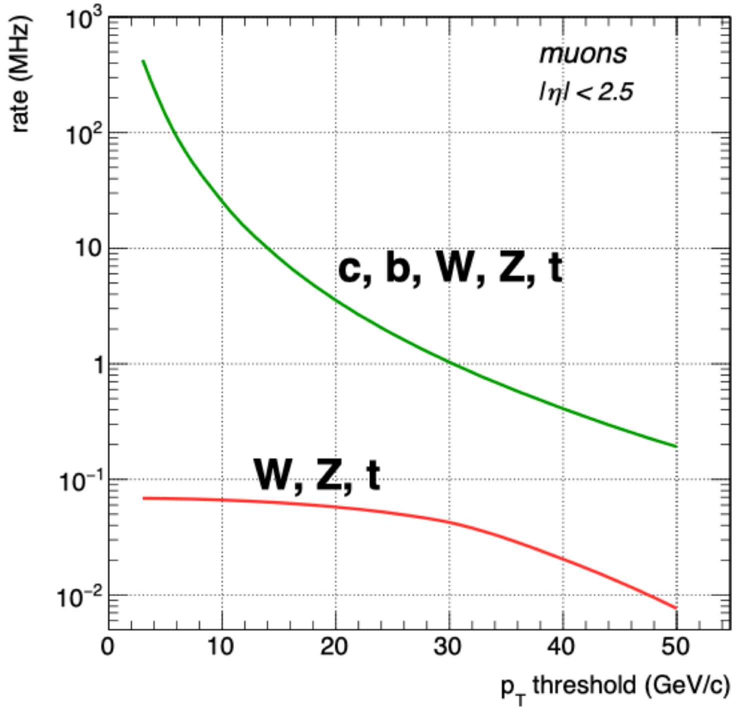
The combined muon momentum resolution (tracker + muon system) can better than 10% even for momenta of 20TeV/c at η=0.

Gas detectors similar to the ones employed for HL-LHC are good candidates for the muon systems.

From FCC design group via Werner Riegler

Muon Systems

Rate of muons for L=3x10^35 cm^-2s^-1



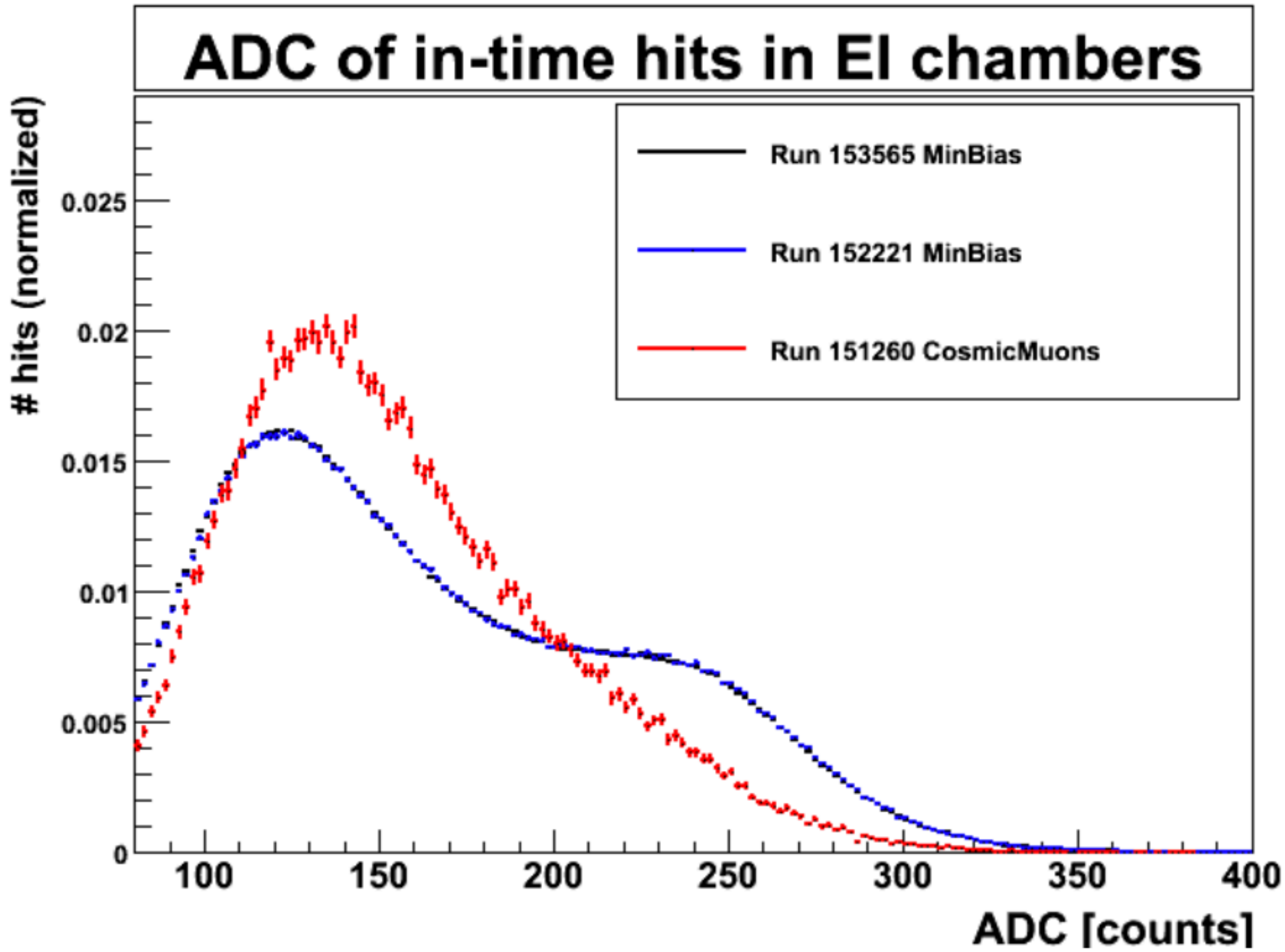
The muon rate is dominated by c and b decays.

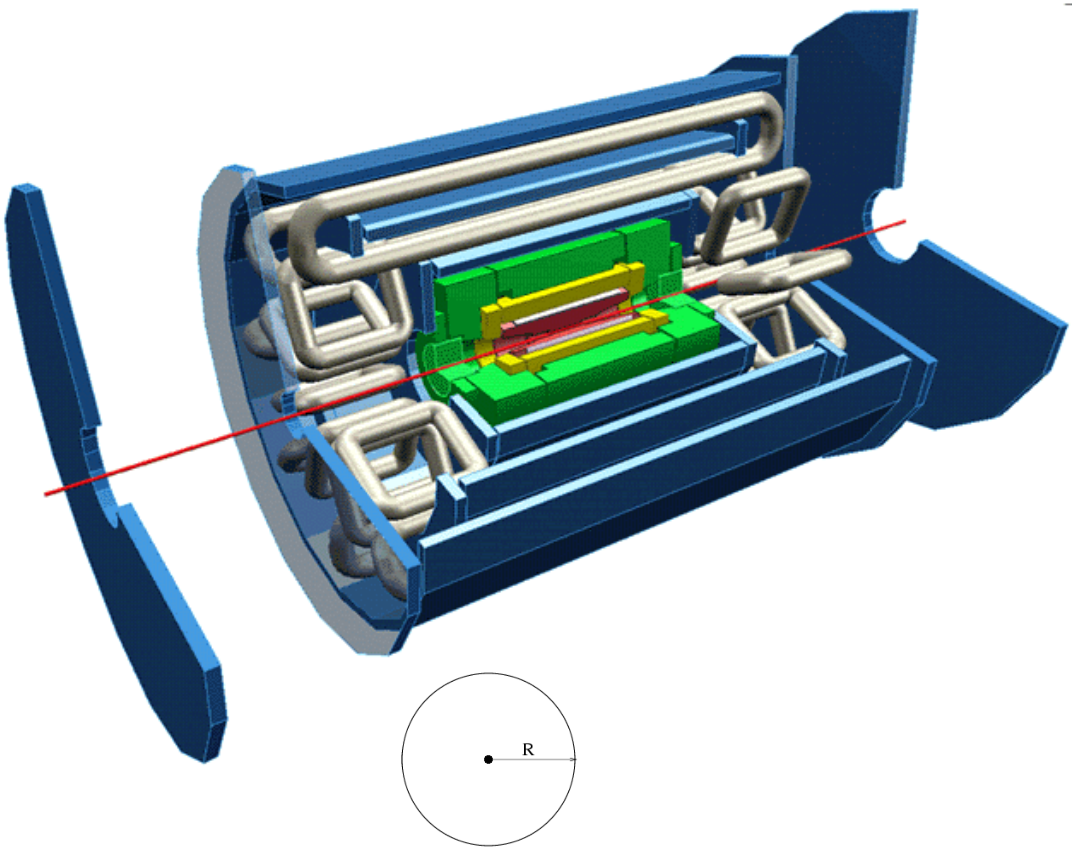
In contrast to leptonic decays from W, Z, t (→W→l) these muons are not isolated but accompanied by particles that are seen in the calorimeters.

'Isolation' by using calorimeter information in addition the the muon system is key for W/Z/t triggering.

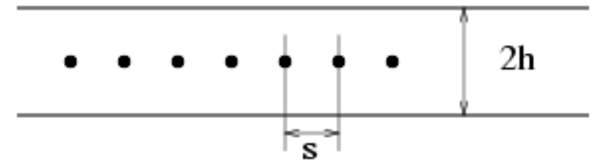
From FCC design group via Werner Riegler

Back Up


ADC of in-time hits in EI chambers
Run 153565 MinBias
Run 152221 MinBias
Run 151260 CosmicMuons
hits (normalized)
0
0.005
0.01
0.015
0.02
0.025
100
150
200
250
300
350
400
ADC [counts]



ATLAS

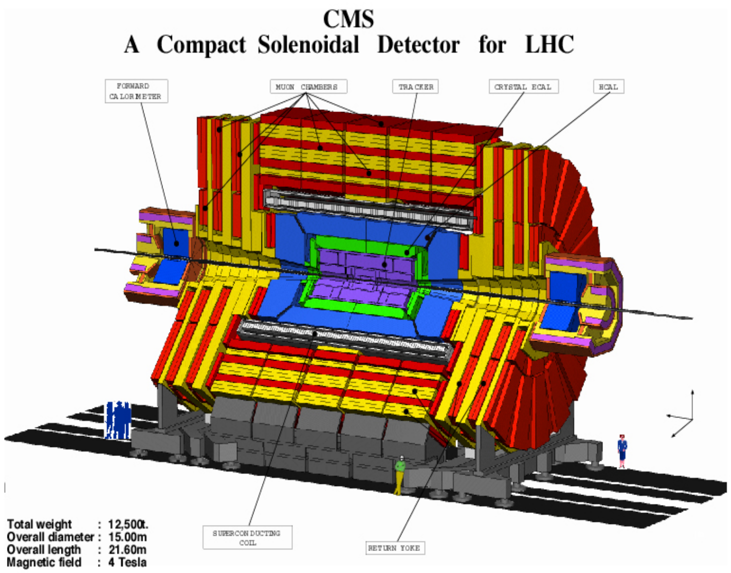


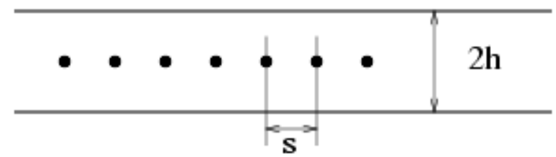
- **Cathode Strip Chambers (Tracking):**
  - **h=2.54mm, s=2.54mm**
  - **67k cathode channels**
  - **$Ar/CO_2/CF_4$**
  - $<$ **60 μm**
- **Thin Gap Chambers (Trigger)**
  - **h=1.4mm, s=1.8mm**
  - **440k cathode and anode channels**
  - **n-Pentane /CO_2 45/55**
  - $<$ **99% in 25ns with single plane**

- **Monitored Drift Tubes (Tracking)**
  - **R=15mm**
  - **370k anode channels**
  - **Ar/CO_2 93/7 (3 bars)**
  - $<$ **80μm**
- **Transition Radiation Tracker (Tracking)**
  - **R=2mm**
  - **372k anode channels**
  - **$Xe/CO_2/CF_4$ 70/10/20**
  - **$Xe/CO_2/O_2$ 70/27/3**
  - $<$ **150 μm**

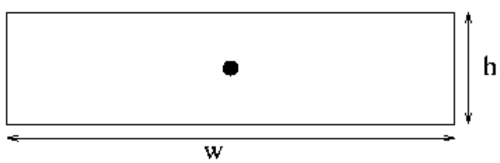
- **RPCs (Trigger):**
  - **g=2mm, 2mm Bakelite**
  - **355k channels**
  - **$C_2F_4H_2$/Isobutane/SF_6 96.7/3/0.3**
  - $<$ **98% with a single plane in 25ns**

CMS





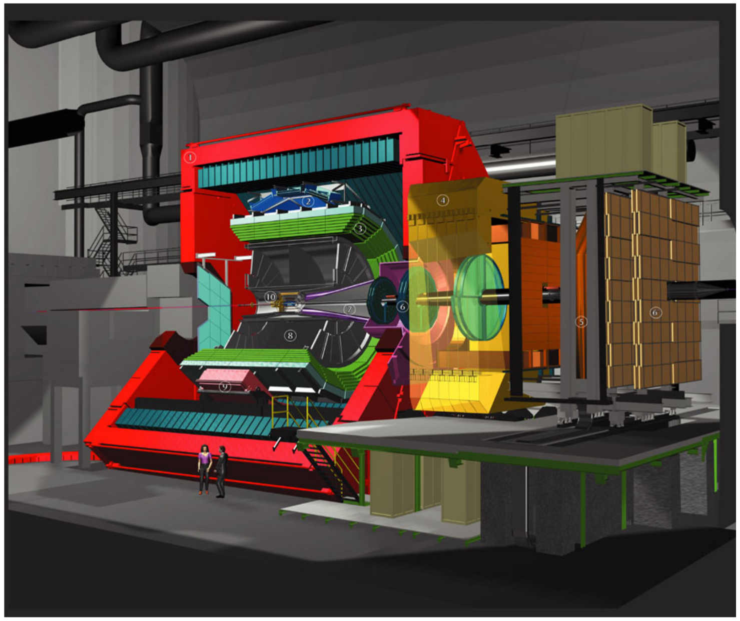
- **Cathode Strip Chambers (Trigger, Tracking):**
  - h=4.25mm, s=3.12mm
  - 211k anode channels for timing
  - 273k cathode channels for position
  - $Ar/CO_2/CF_4$ 30/50/20
  - $<$ 75-150 μm

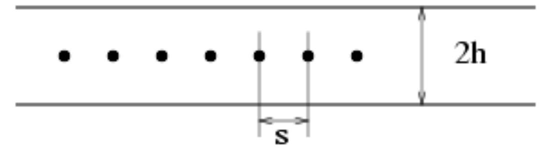


- **Rectangular 'Drift Tubes' (Trigger, Tracking)**
  - w=42mm, h=10.5mm
  - 195k anode channels
  - Ar/CO_2 85/15
  - $<$ 250 μm

- **RPCs (Trigger):**
  - g=2mm, 2mm Bakelite
  - Many k channels
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
  - < 98% with a single plane in 25ns

ALICE

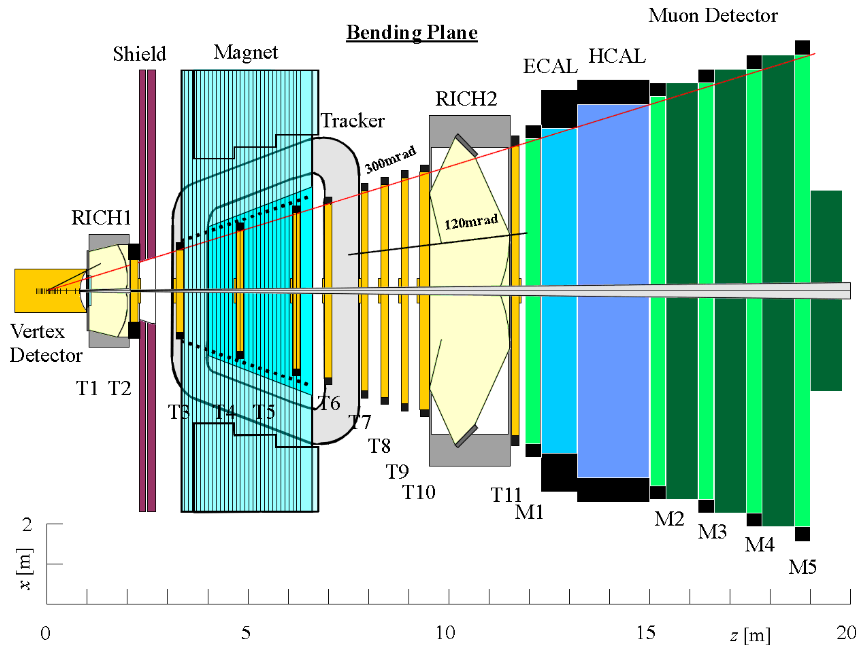


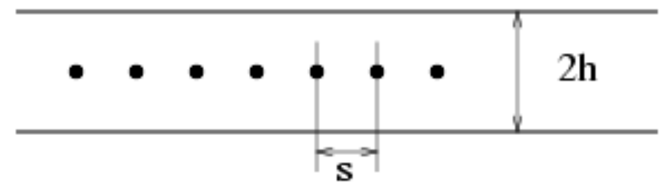


- **TPC with wire chamber cathode pad readout**
  - 1.25-2.5mm wire pitch
  - 2 - 3 mm plane separation
  - 570k Readout Pads
  - Ne/CO_2 90/10
- **TRD**
  - 1160 k channels
  - Xe/CO_2 85/15
  - s=5mm, h=3.5mm
- **HMPID**
  - s=2mm, h=2mm
  - Methane
  - 160k channels
- **Muon Chambers**
  - 1000k channels
  - <100um
  - S=2.5mm, h=2.5mm
  - Ar/CO_2 80/20

- **TOF RPCs**
  - G=0.25mm, 0.4mm glass, 10gaps
  - 160k channels
  - <50ps/10gaps
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
- **Trigger RPCs**
  - G=2mm, 2mm bakelite
  - Ar/Isobutane/$C_2F_4H_2$/SF_6 49/7/40/4
  - 21k channels

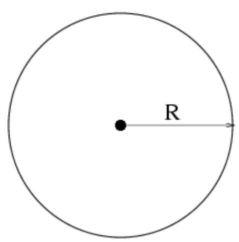
LHCb



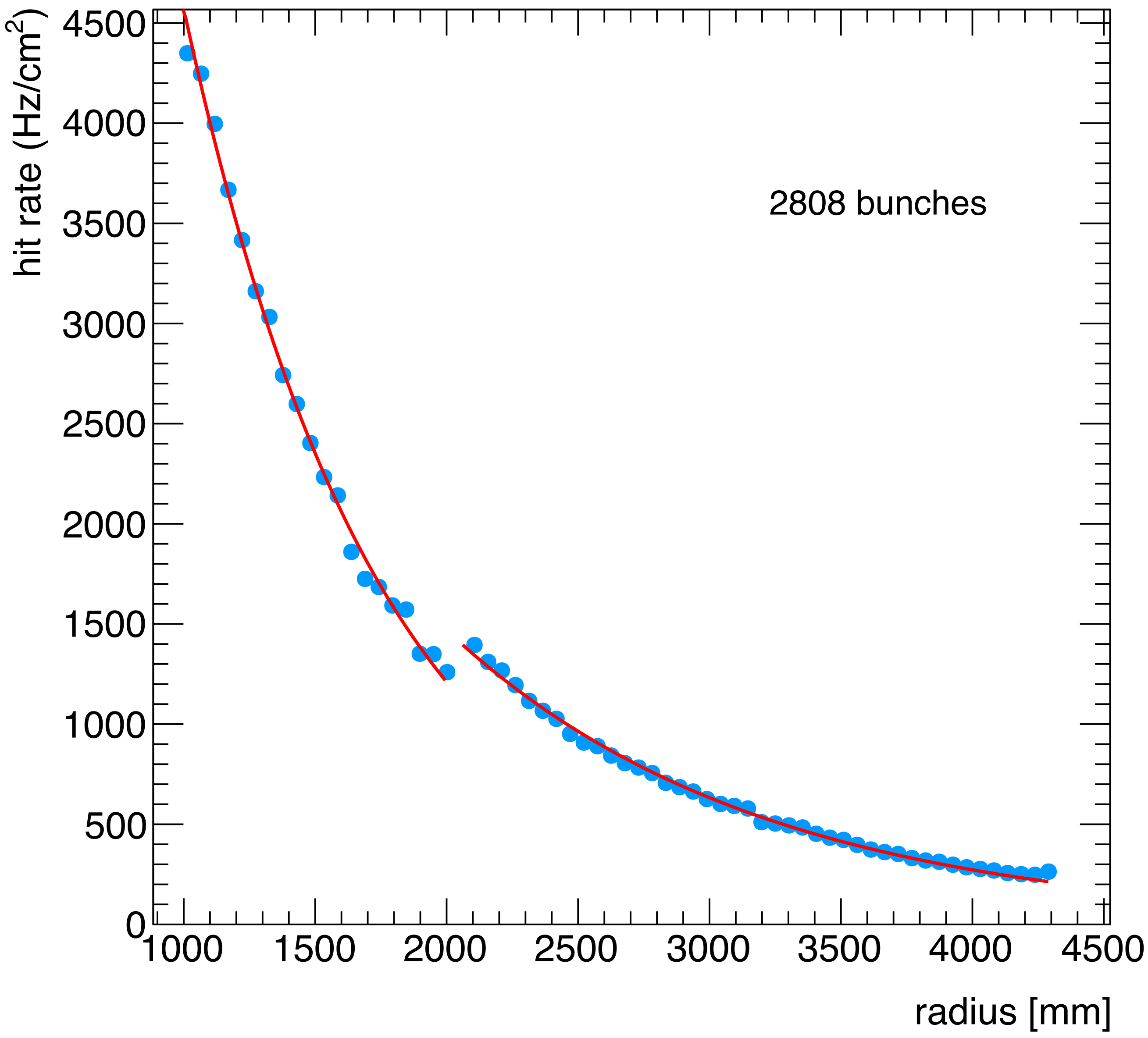


- **Muon Chambers (Trigger):**
  - h=2.5mm, s=2mm
  - 125k cathode and anode pads
  - $Ar/CO_2/CF_4$ 40/55/5
  - < 3ns for two layers

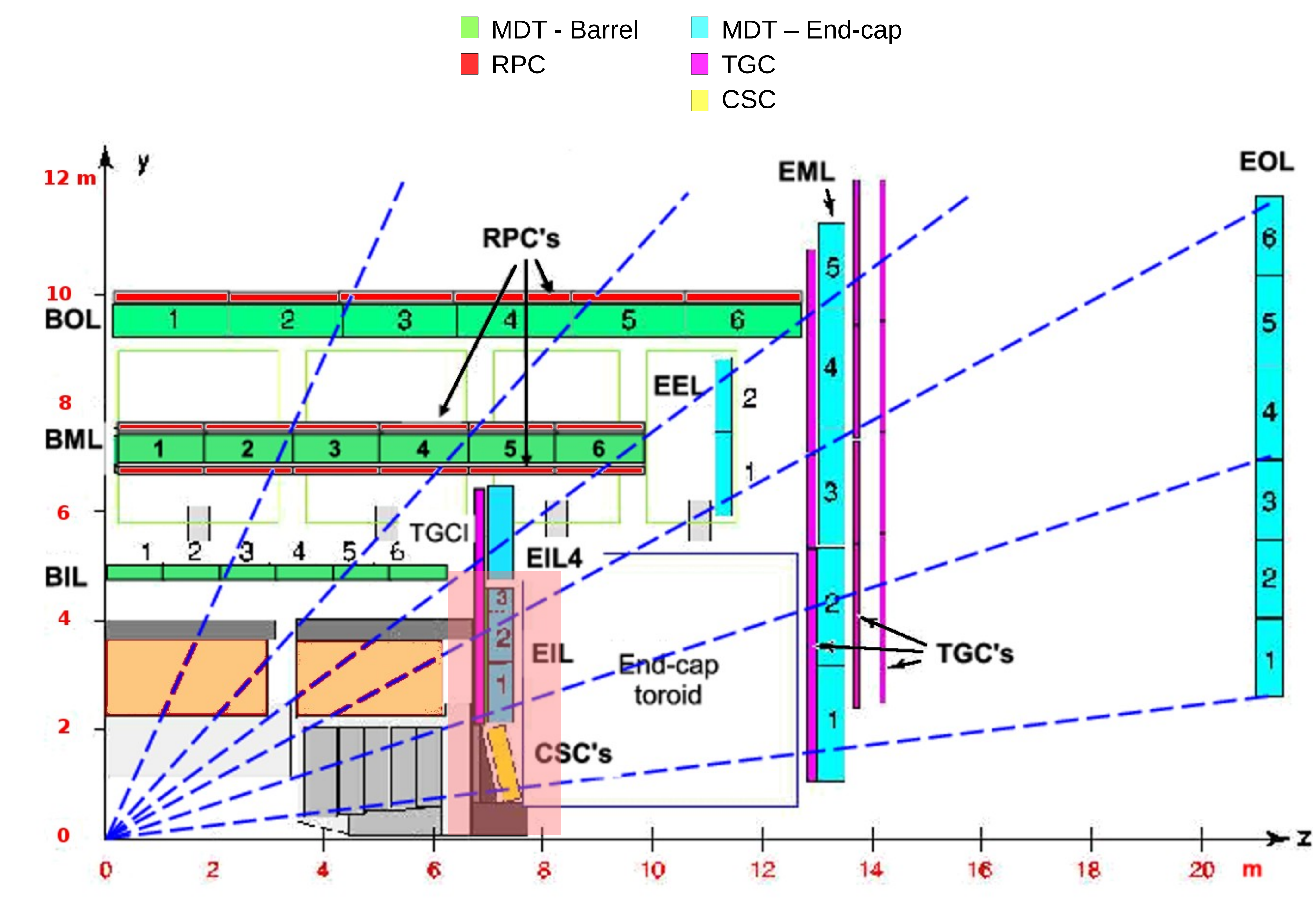
- **GEM (Trigger):**
  - 5k channels
  - $Ar/CO_2/CF_4$ 75/10/15
  - <4.5 ns for one triple GEM



- **Outer Tracker (Tracking):**
  - R=2.5mm
  - 51k anode channels
  - $Ar/CO_2/CF_4$ 75/10/15
  - < 200 μm



hit rate (Hz/cm^2)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1000
1500
2000
2500
3000
3500
4000
4500
radius [mm]
2808 bunches



MDT - Barrel
RPC
MDT – End-cap
TGC
CSC
12 m
y
10
BOL
8
BML
6
BIL
4
2
0
RPC's
EML
EOL
EEL
TGCI
EIL4
EIL
End-cap
toroid
CSC's
TGC's
0
2
4
6
8
10
12
14
16
18
20
m
z