LHeC : Muon Systems

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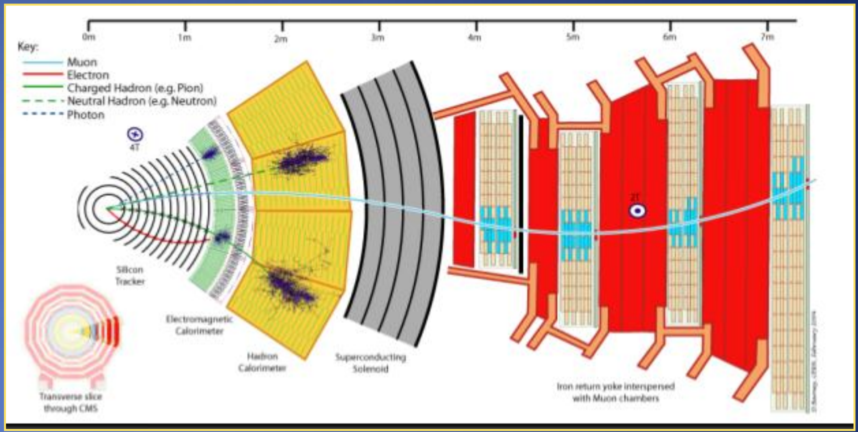
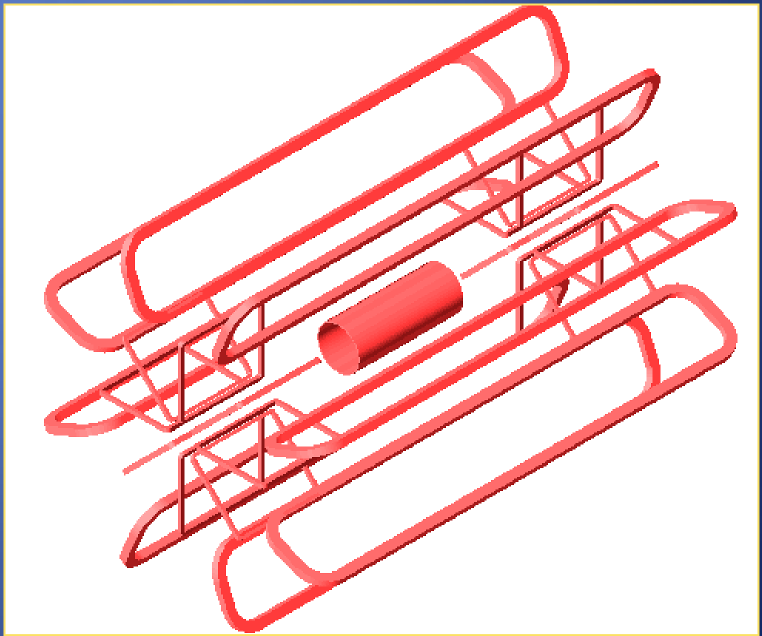
Outline

- Review of LHC Muon Systems
  - Different Magnetic Field configurations
  - ATLAS & CMS
  - Installation and Commissioning
  - Performance
- Review of Muon Detector Technologies
  - Technologies considered for the LHC experiments Upgrades.
- Muon Physics at LHeC
- Possible Muon System for LHeC

The magnetic field choice

- Central solenoid with muon measurement in the Iron used for Flux return (CMS)
  - Compact detector
  - Very good muon identification capability
  - No need of very high resolution detectors
  - High precision muon measurement rely on the inner tracker (ITK) measurement.
  - Pt resolution quite dependent on η
- Air Core Toroid (ATLAS)
  - Excellent **Stand Alone** momentum measurement
  - Quite uniform resolution even at large η
  - But… Need very large detector
  - Very not-uniform Field Map
  - Very demanding on detectors performances, calibration and alignment





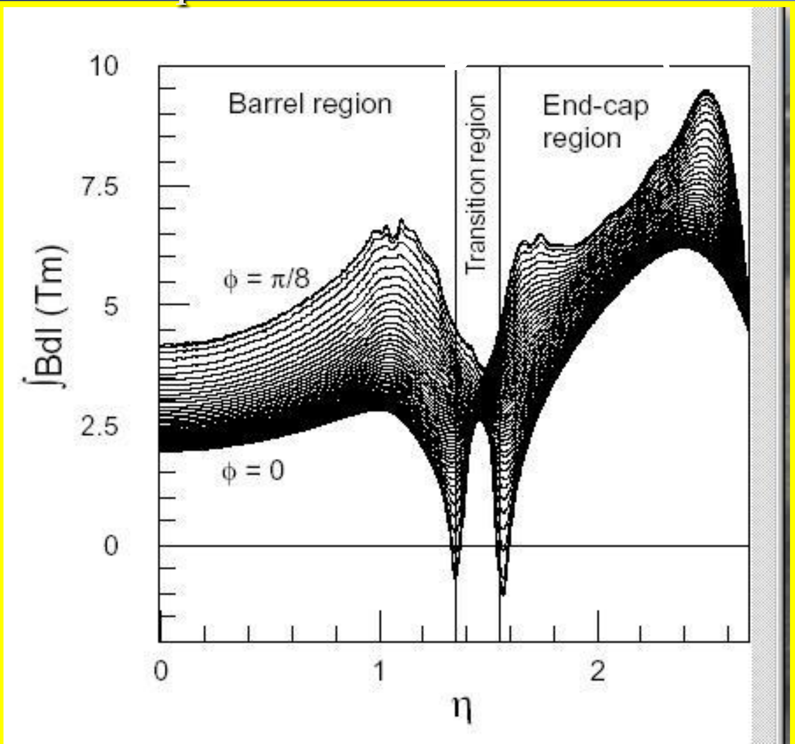
The magnetic field choice

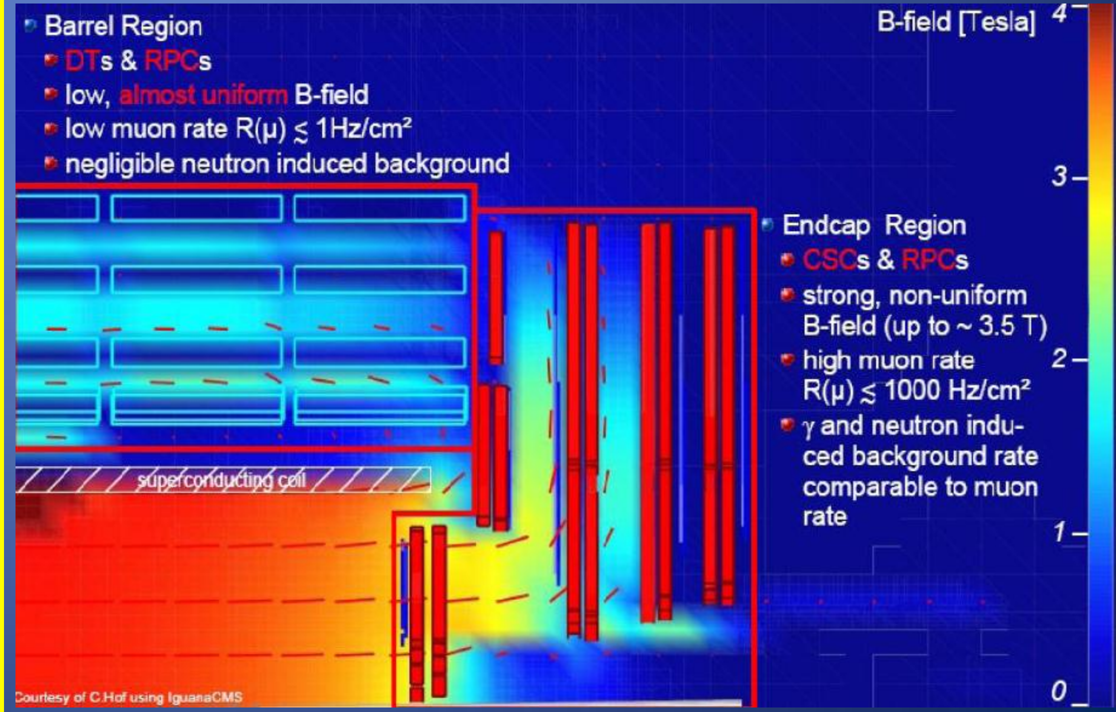
Air Core Toroids:

•Inhomogeneous Field integral in the tracking volume
•Calibration dependent from the non bending coordinate
•Precision tracking more difficult: very accurate knowledge of B field required

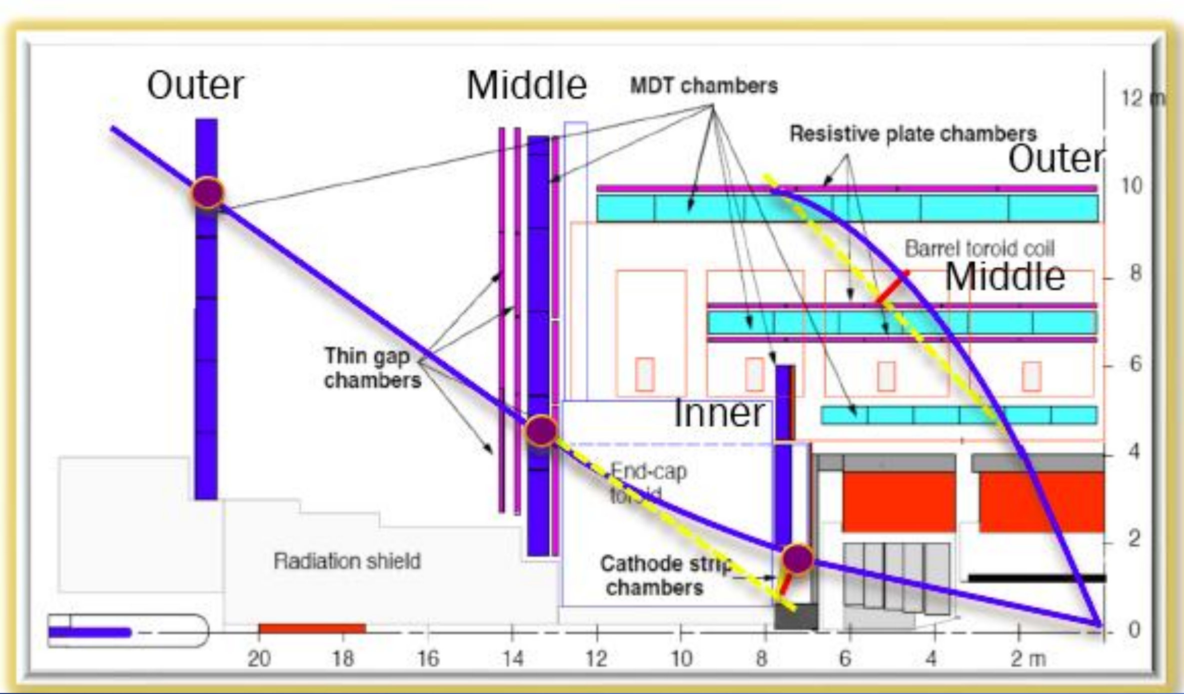
Central Solenoid with Iron return Flux:

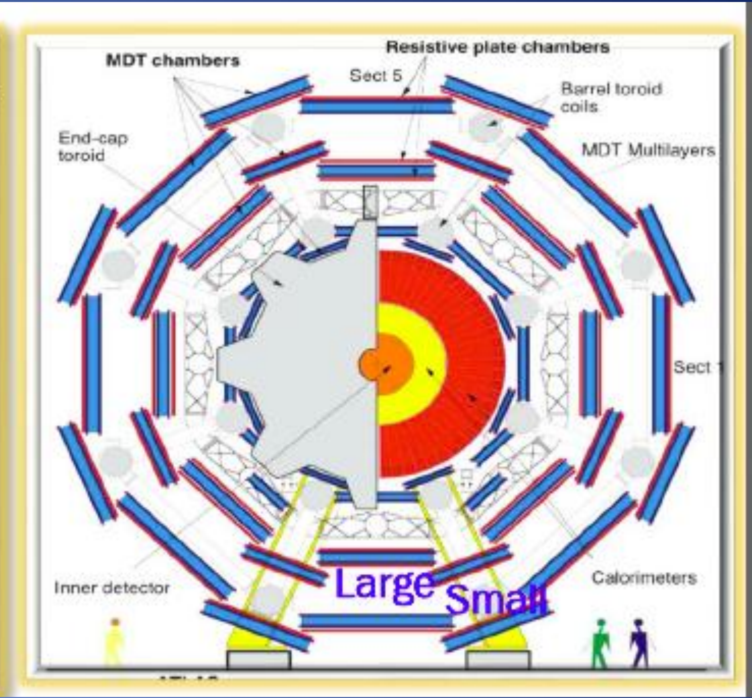
•Very homogeneous in the Central region, but high gradients in the Forwards Region.
•The Bending Power in the ITK is small in the Forward: Pt resolution is limited by MS in the Iron Yoke .





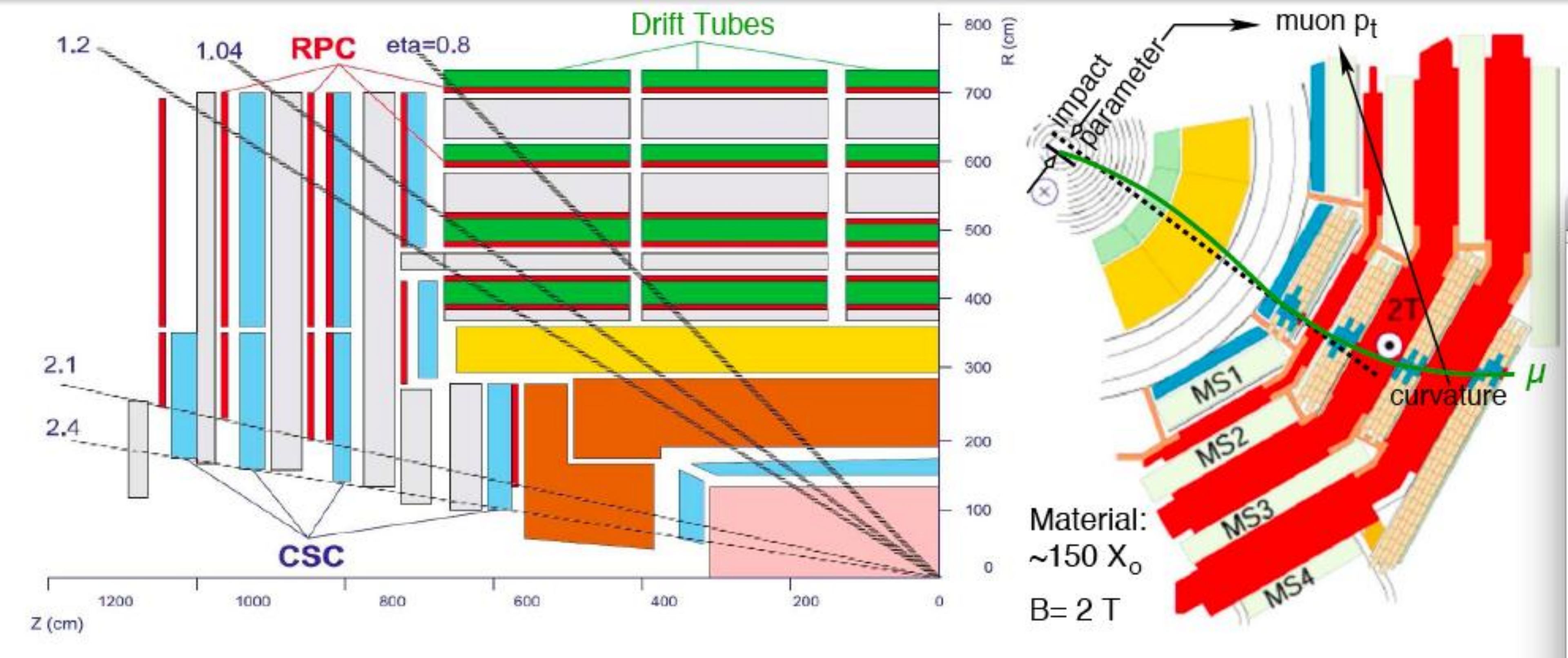
The ATLAS muon spectrometer





- Precision Chambers: from 3 Stations Sagitta in **bending plane -> measure P**
  - Monitored Drift Tubes (**MDT**)+ Cathode Drift Chambers (**CSC**) $2.0<\eta<2.7$
- Trigger Chambers: **LVL1 μ trigger + coordinate in non-bending plane**
  - Resistive Plate Chambers **(RPC)** **$|\eta|<1$**+Thin Gas Chamber **(TGC)** **$2.4>|\eta|>1$**

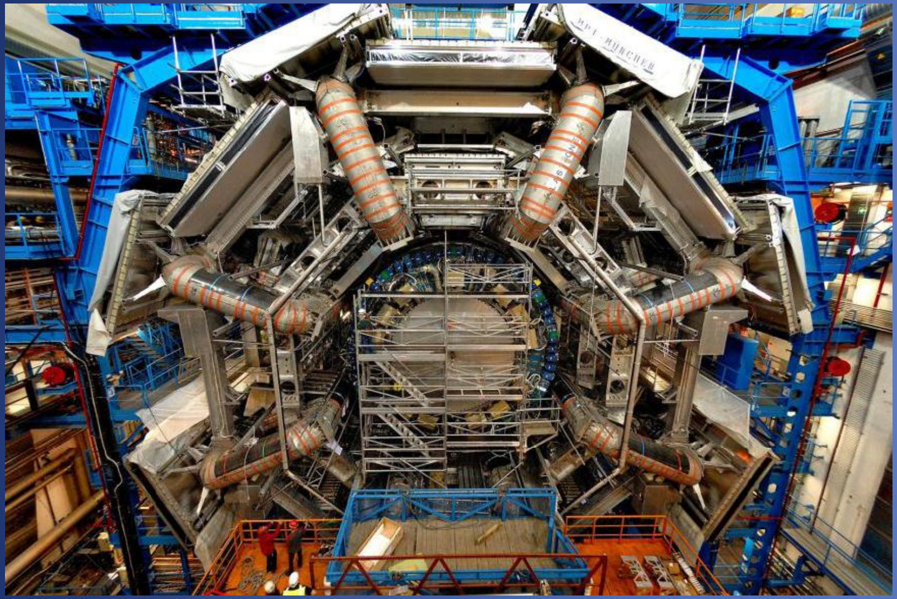
The CMS Muon Spectrometer

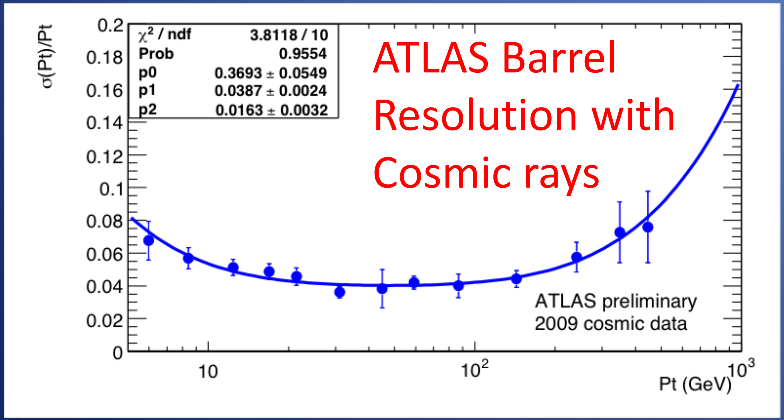


- Fast trigger chambers: **RPC** (<10 ns time resolution).
- Tracking detectors: **CSC, DriftTubes** (100 μm spatial resolution).
- Laser alignment of muon and ITK with 200 μm precision.
- Pseudorapidity coverage: $|\eta|<2.4$.

Installation and Commissioning

- Installation of both ATLAS and CMS took years
  - Ex. The Construction of the ATLAS Muon Spectrometer started in 2005 (Barrel) and ended in 2008 (End Cap).



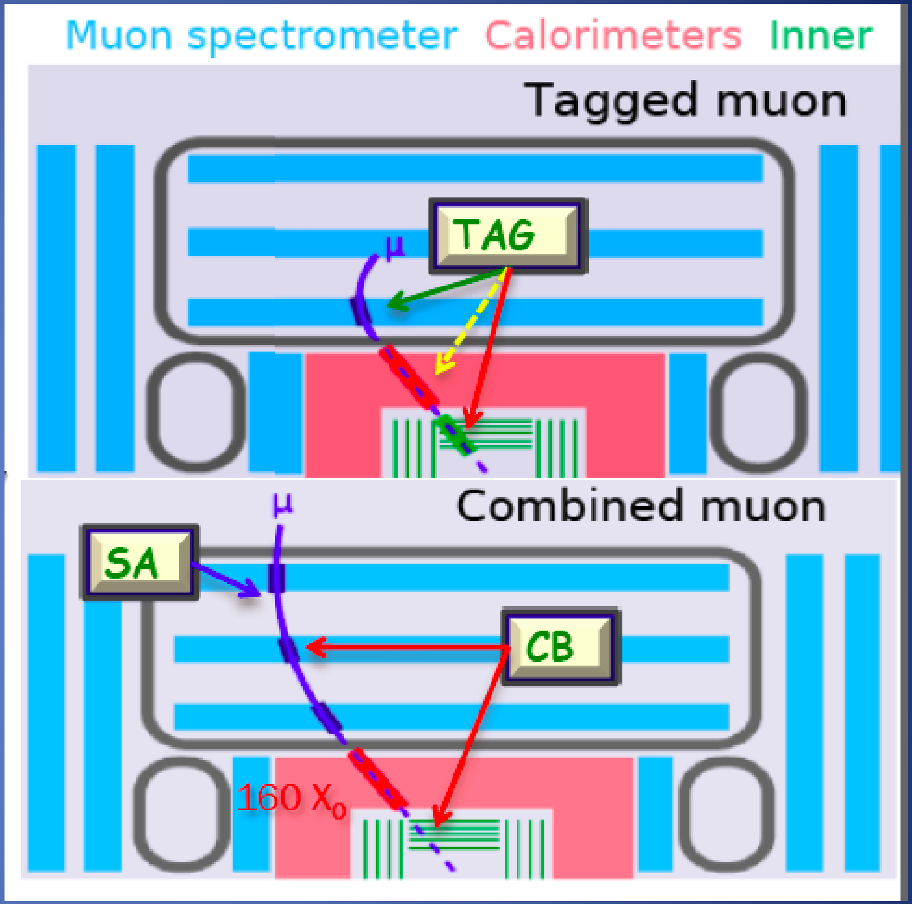


Very long years of commissioning with Cosmic rays were essential to be able to efficiently record and understand data from the very first collision.

This has to be considered in building the schedule for the construction and commissioning of the LHeC detector

Muon Reconstruction

- 1. Definition of regions of activity (RoA).
- 2. Reconstruction of local straight segments in the RoA.
- 3. Combination of local segments.
- 4. Global fit in the muon system.
- Final combination/global fit with the Inner Tracker (ITK)
  - - to refine the momentum measurement
  - - to identify low-pt muons
  - - to identify isolated muons and remove fakes (π, K decays)



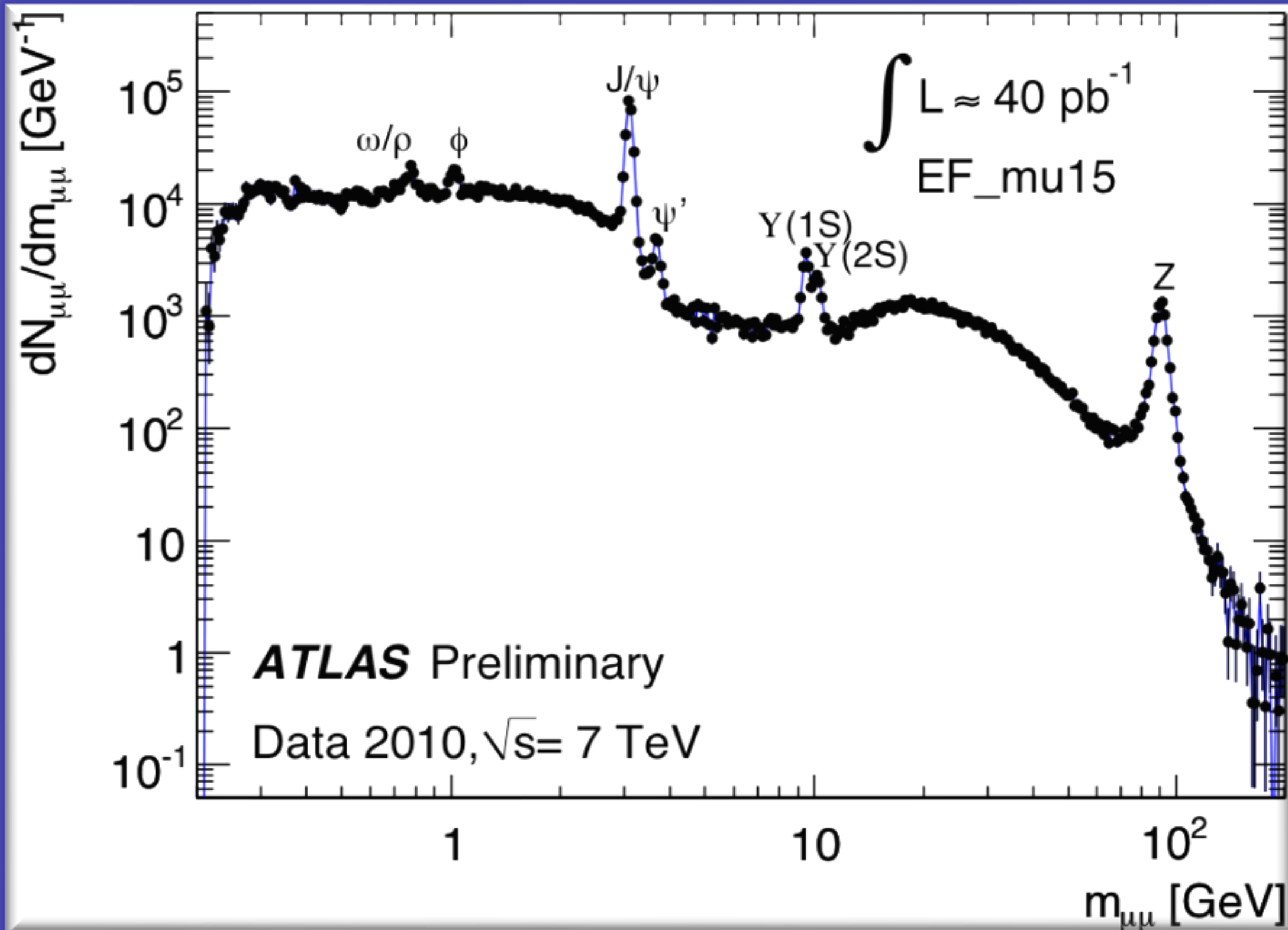
Muon Definitions

Segment tagged (Tag) : Pt Measured only by ITK, high efficiency

Combined (CB): Pt measured combining ITK and MS, best Momentum determination over the full range high purity

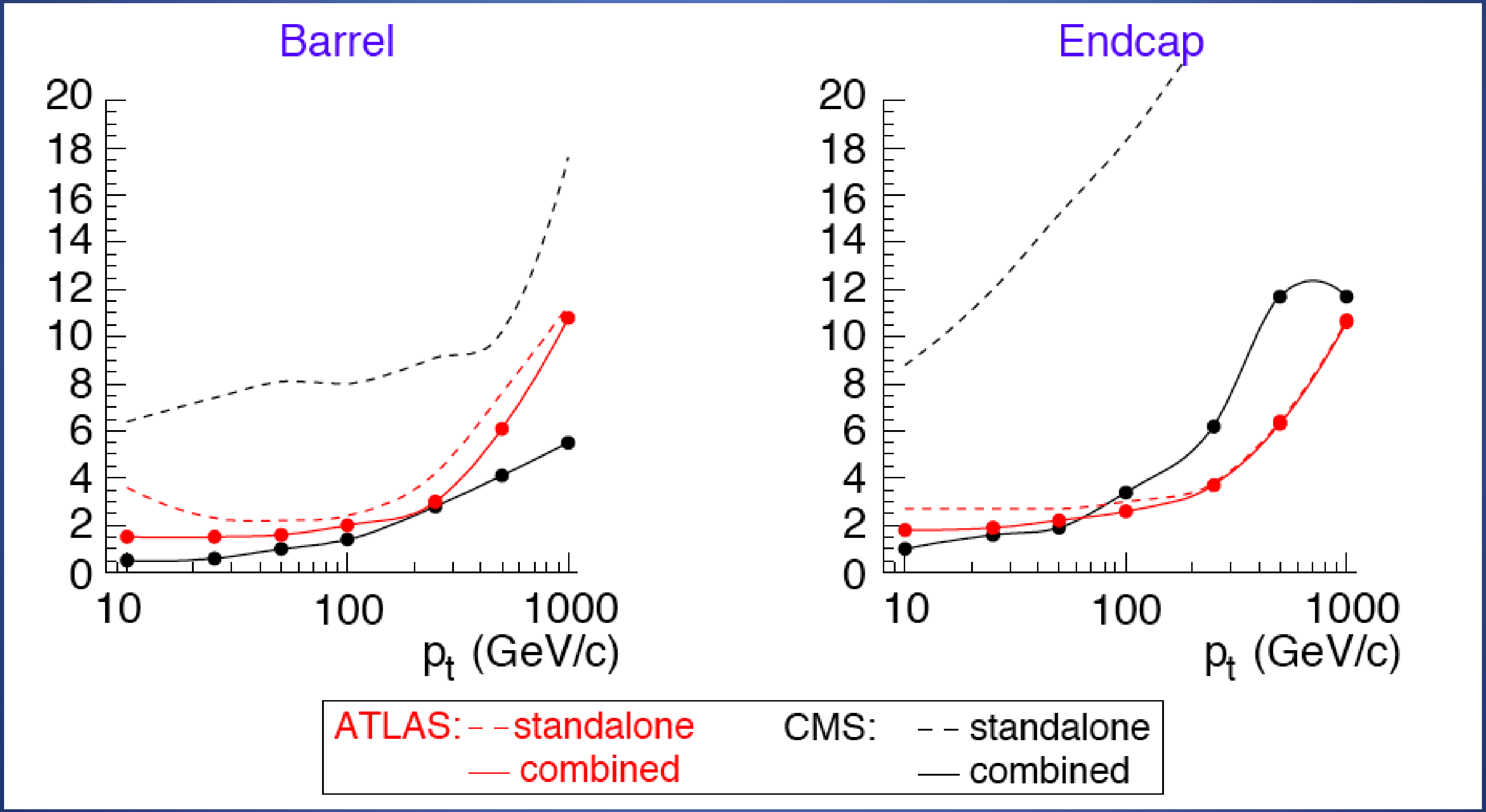
Stand Alone (SA): Muon measured only in the MS (High eta region in ATLAS)

Performance



Combined Pt Resolution

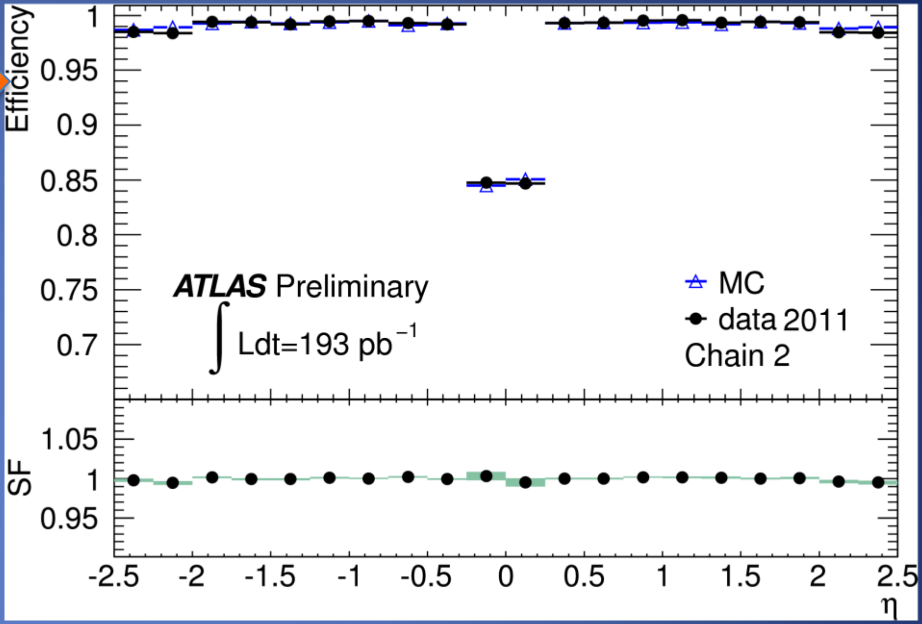
- Combined Muons:
  - excellent Pt measurement up to 1 TeV $\sigma(p_t)/p_t < 12\%$.

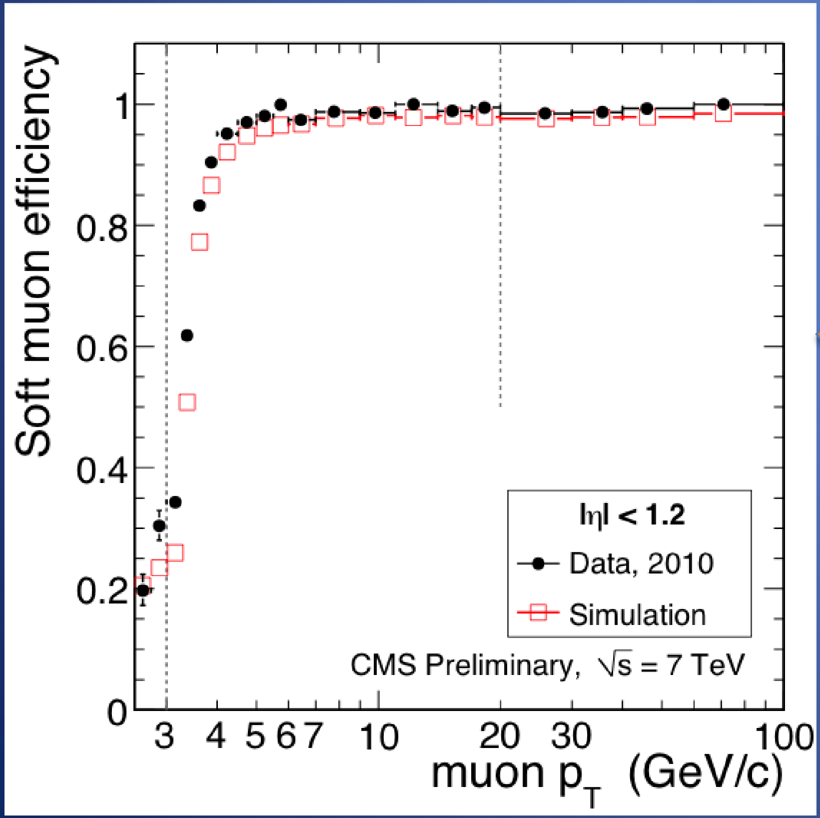


Better Combined resolution in CMS Barrel mainly due to higher B field.
Better Combined End Cap Resolution in ATLAS due to Air Core Toroid

Tracking efficiency: Tag and Probe

- Combined + segment tagged muons
  - very high and uniform tracking efficiency

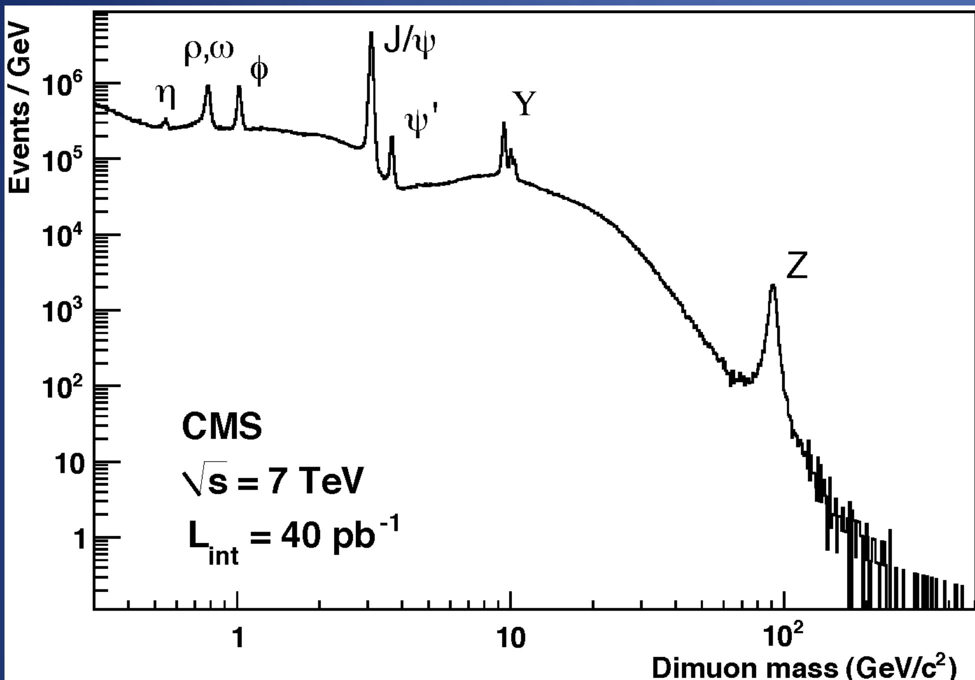




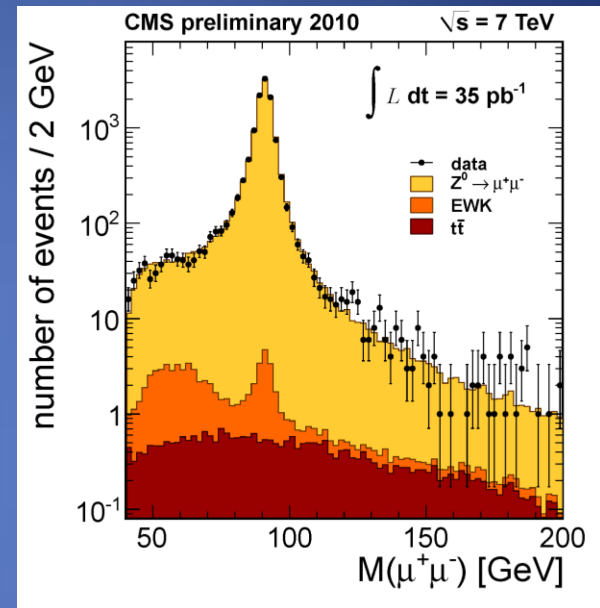
- Very high efficiency down to low transverse momenta.

Resolution

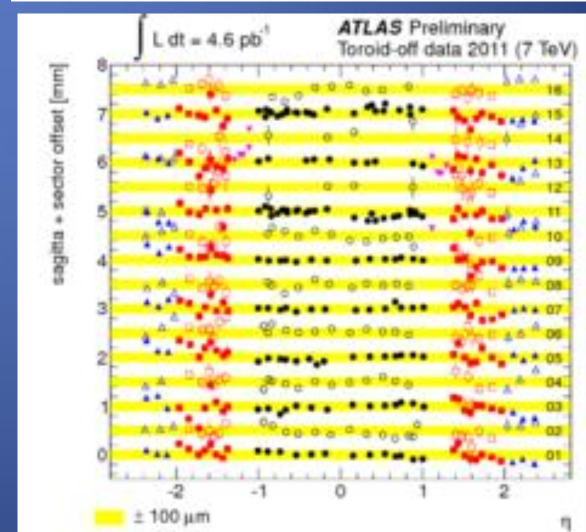
- Spectacular Di-muon Spectrum



- Well understood Z mass resolution



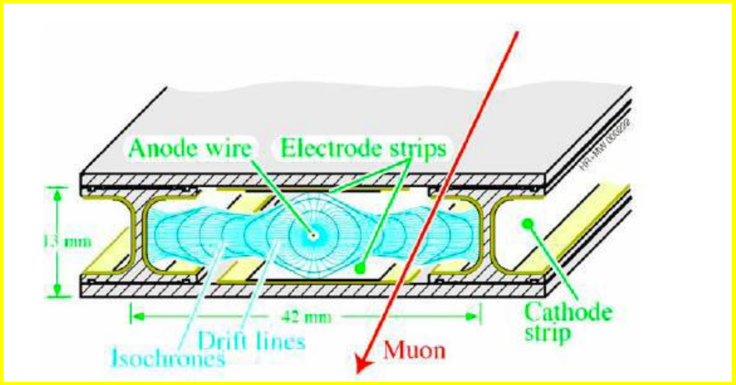
- Resolution at High Momentum very close to design value
- Limited by alignment and calibration accuracy
  - Muon Chambers alignment in ATLAS < 100 μm

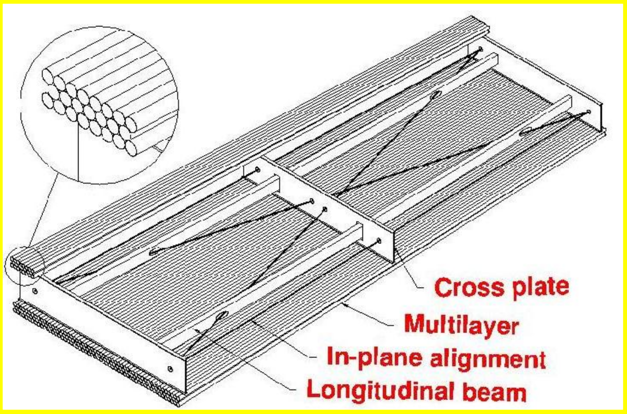


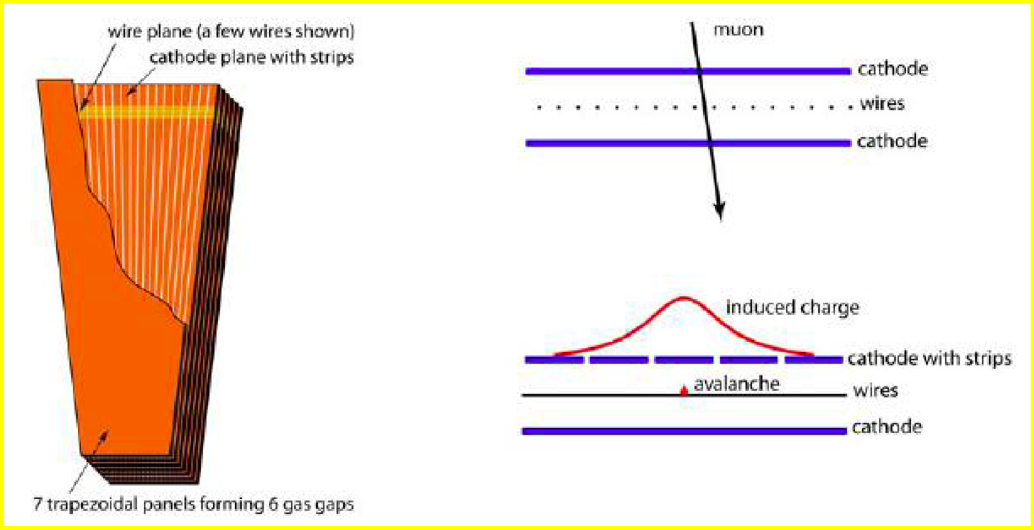
Detector technologies: Tracking

All the detector technologies used for the present LHC detectors can be re-used (at least in the Central-End Cap Region) in a LHeC muon system.

- Both CMS and ATLAS are Using Drift Tubes and CSC for precision tracking.

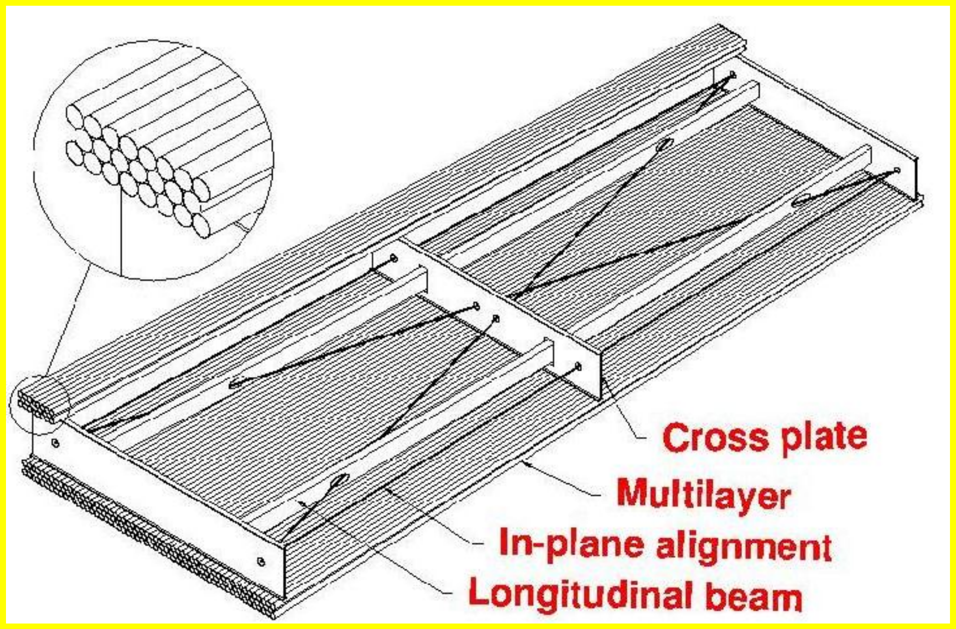






Detector technologies: Tracking

➢ Drift Tube Example: ATLAS MDT.



Operating Conditions

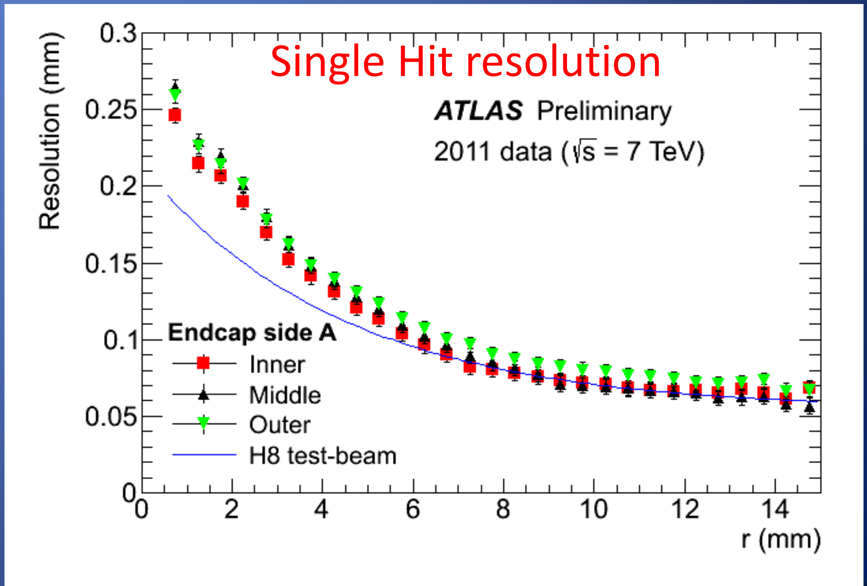
Gas Mixture: 93 % Ar 7% CO_2

Absolute pressure: 3 Bar

HV: 3080 V

Gas Gain: 2×10^4

Threshold: 25 electrons

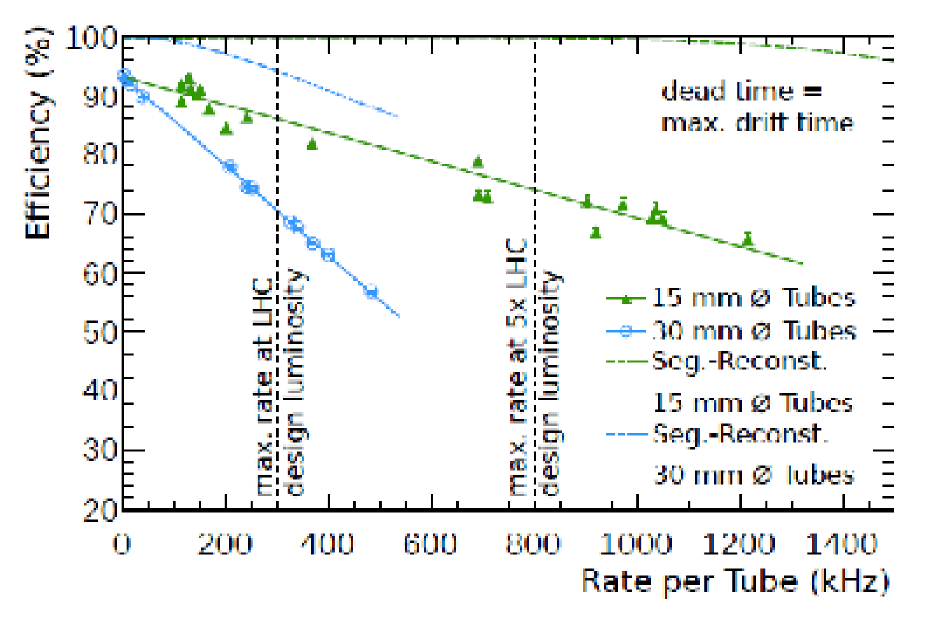


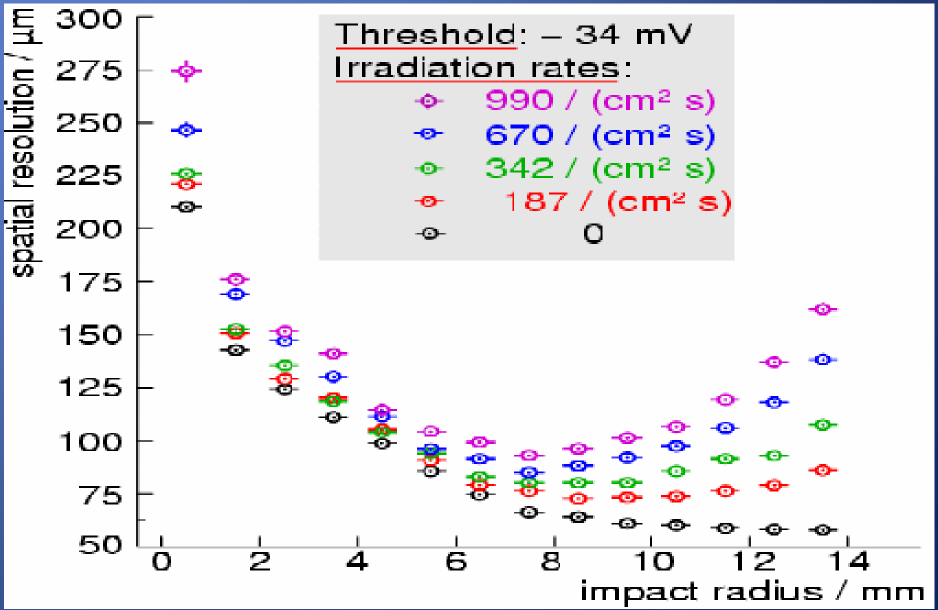
Drift tubes mechanical parameters:

Tube Radius : 15 mm
Tube thickness 400 μm
Wire diameter. 50 μm
Tube length: 1-6 mt
Chamber mech. Precision 20 μm
Two Multilayers of 3 or 4 layers each.

Detector technologies: Tracking

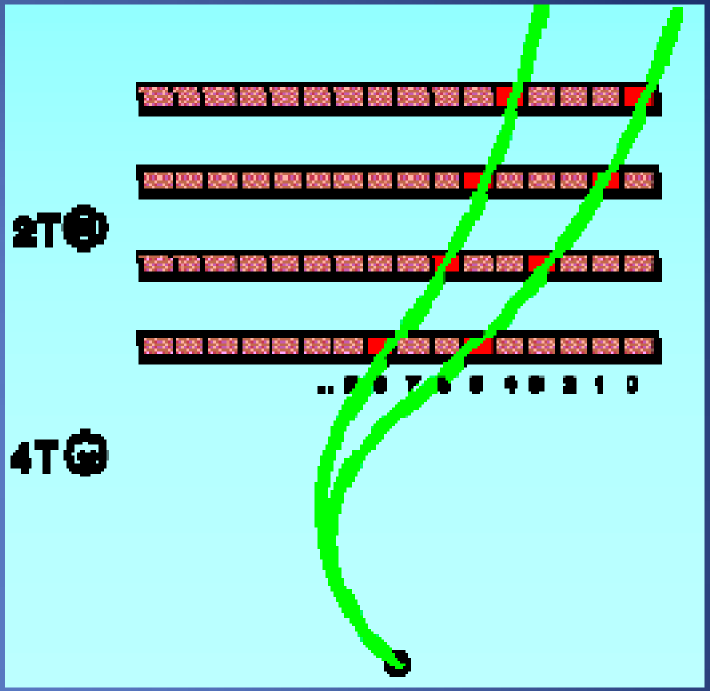
- MDT performance vs hit rate
  - Perfectly adequate for the rates foreseen in the Barrel and part of End Cap region
  - Not enough rate capabilities for the inner region of the End Cap at luminosities exceeding $2x10^{34}$ $cm^{-1}s^{-1}$
  - Using smaller diameter tubes can enhance the rate performance
  - **Using Drift Tubes in the Central-Forward region of an LHeC muon detector should not be a problem.**

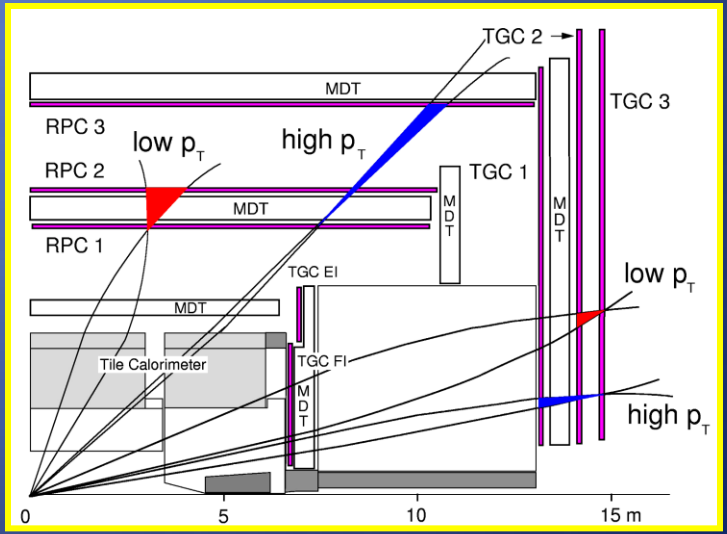




Detector Technologies: Trigger

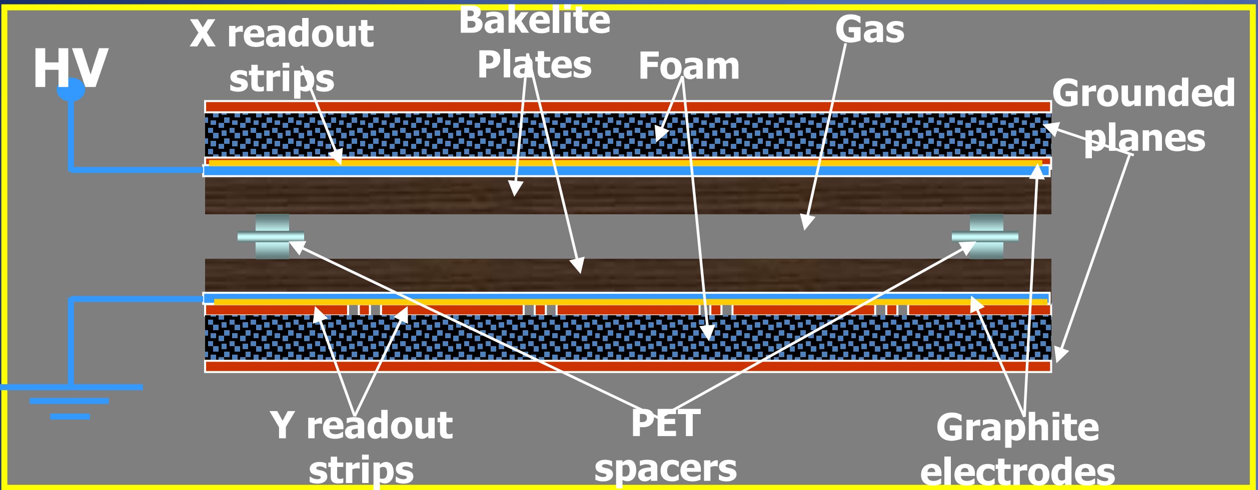
- Trigger chambers requirements:
  - Time resolution adequate to resolve the Bunch ID (few ns)
  - Moderate Space resolution to define Coincidence Roads (cm)
- Both ATLAS and CMS use RPC (+DT, CMS) in the Barrel Region
- ATLAS uses TGC (|η|<2.4) due to better rate capabilities and CMS uses RPC in the End Cap region (|η|<1.6).
- New developments on RPC and TGC will improve both Spatial and Time resolution on these Detectors
  - **Possibility to use these detectors both for triggering and tracking in the Central-Forward region of the LHeC Muon detector**





Detector Technologies: Trigger

➢ RPCs: High efficiency and excellent time resolution



Operating Conditions

(E_{gas}~ 5 KV/mm)

Gas: $C_2H_2F_4$ 95% - C_4H_{10} 4.5% - SF_6 0.5% ;

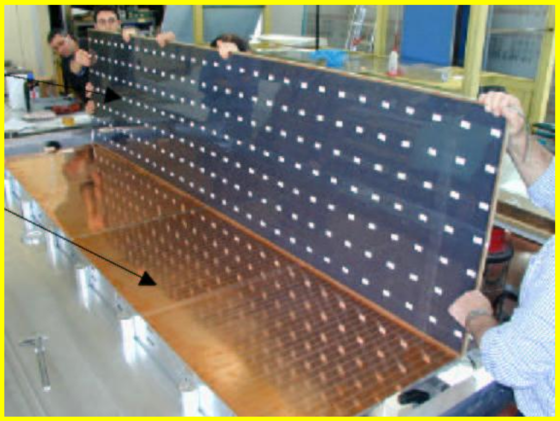
$\rho_{bakelite}$ ~ $2x10^{10}$ Ωcm ;

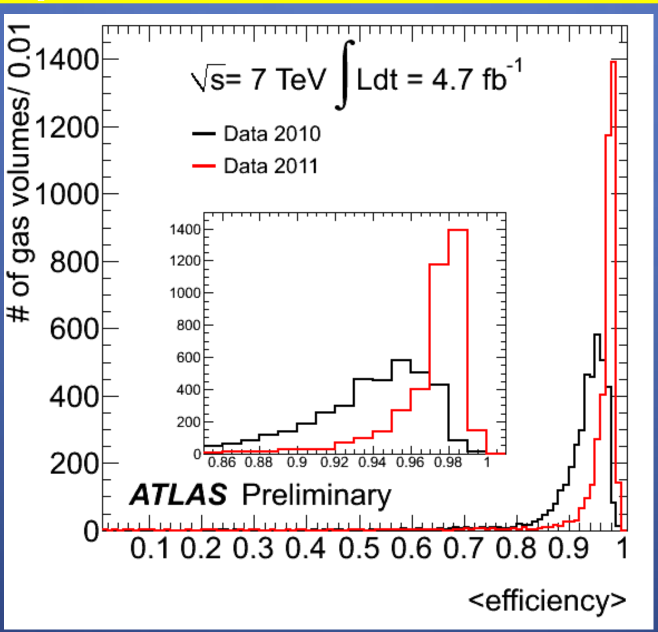
Gas Gap d = 2 mm ;

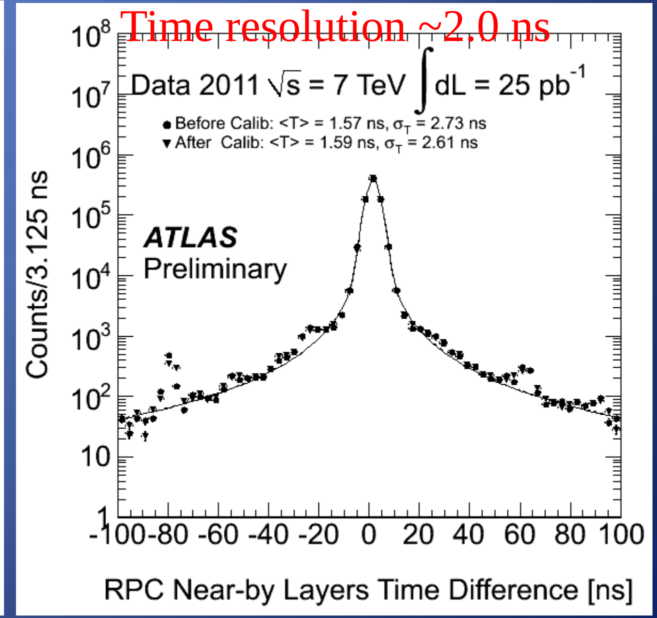
Graphite coated HV electrodes

Cu read out strips 30 mm pitch

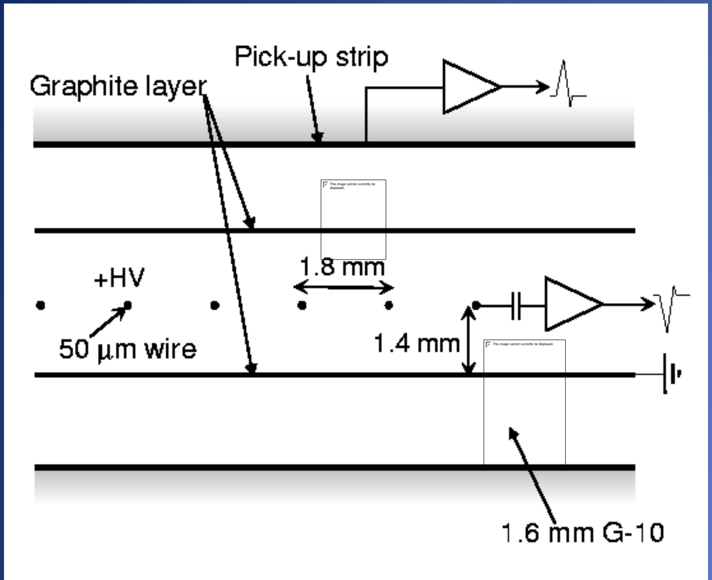
Time resolution ~2.0 ns







Detector Technologies: Trigger



MWPC with small cathode-cathode distance:

Anode pitch: 1.8 mm

Anode-Cathode dist: 1.4 mm

Cathode-Cathode dist: 2.8 mm

Operating conditions

Gas : 55 % CO_2 , 45 % N-Pentane

HV: 3.1 KV

Saturated avalanche mode

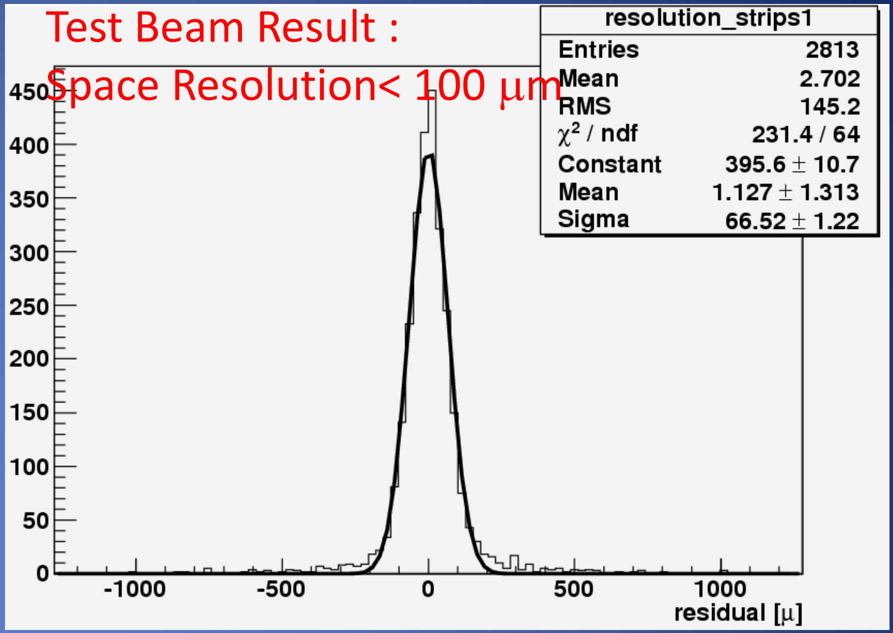
Very short drift time due to the thin gap: ensures the good time resolution needed for Bunch Crossing ID

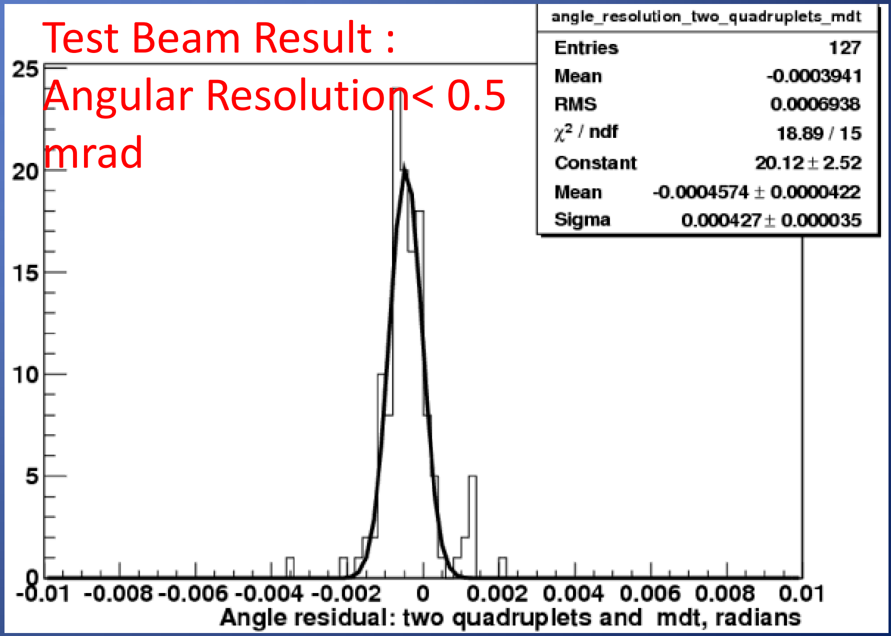
Wire signal used to provide the trigger

Strip signals used for the second coordinate (< cm resolution)

Detectors for the Upgrade

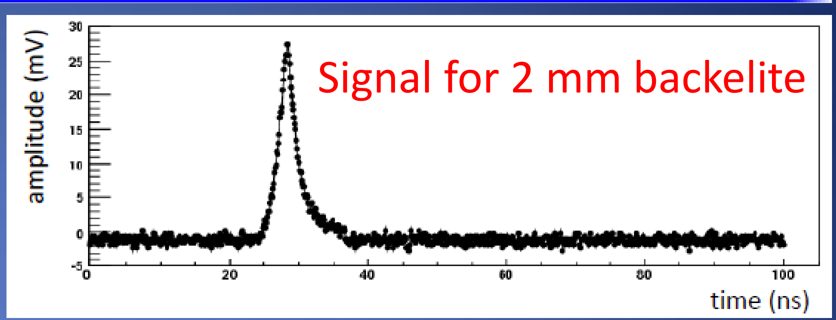
- sTGC:
  - Small strips TGC are considered for tracking and trigger in the ATLAS New Small Wheel project.
  - Charge on 3 mm strips, read-out with Time over Threshold technique will ensure ~100 μm space resolution at trigger level.
  - Time resolution (same as for Standard TGC) adequate for BC ID.

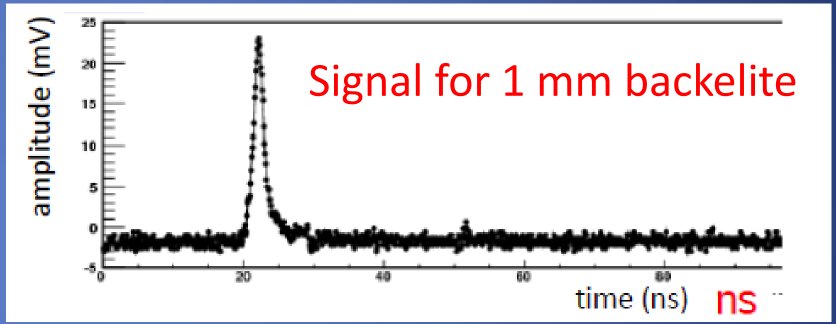


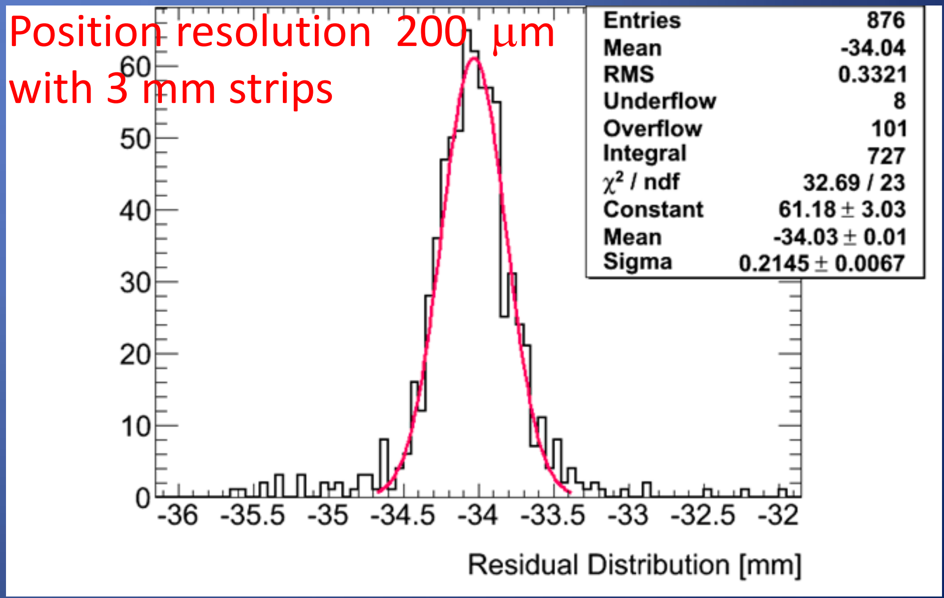


Detectors for the Upgrade

- mRPC:
  - Use of new Front End electronics extends the Rate Capability in the 10 KHz/cm^2 range
  - Time resolution improvements down to sub ns range (New electronics and smaller backelite thickness)
  - Space resolution using COG technique with 3 mm strips in the 100 μm range

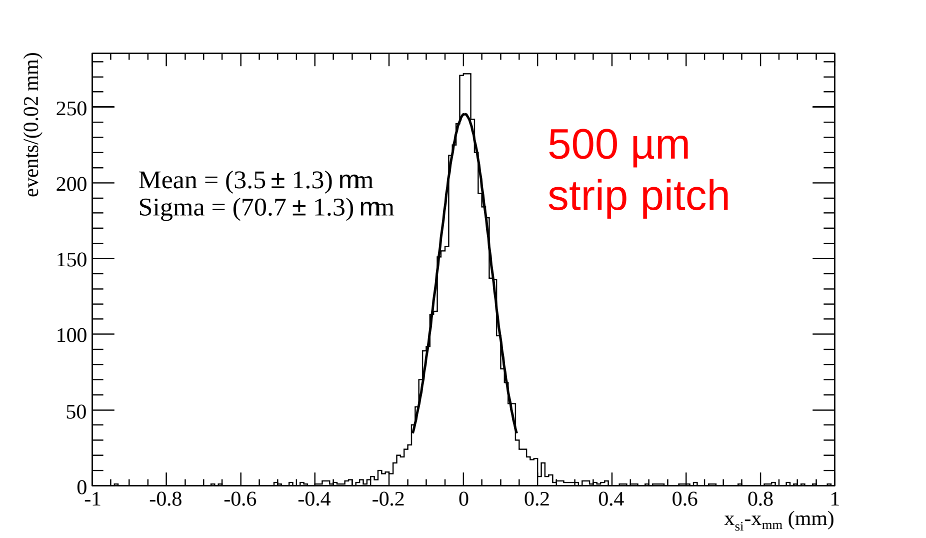


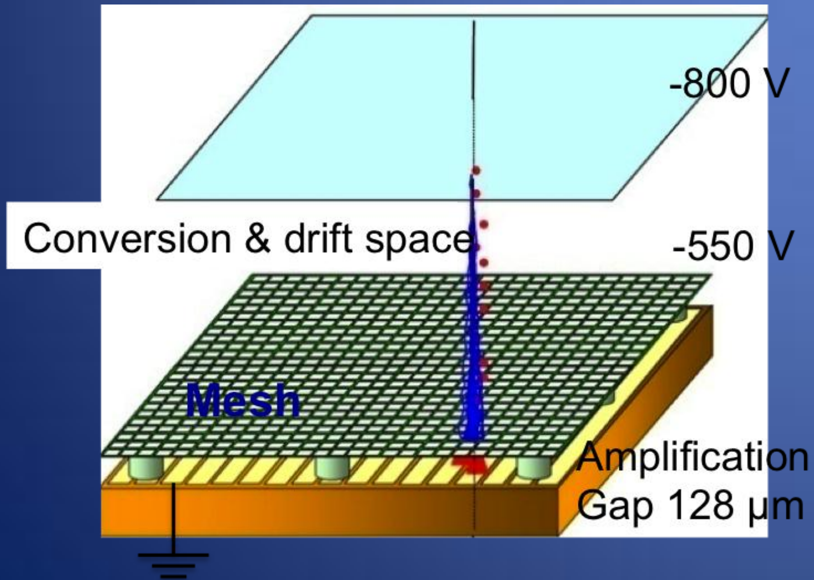


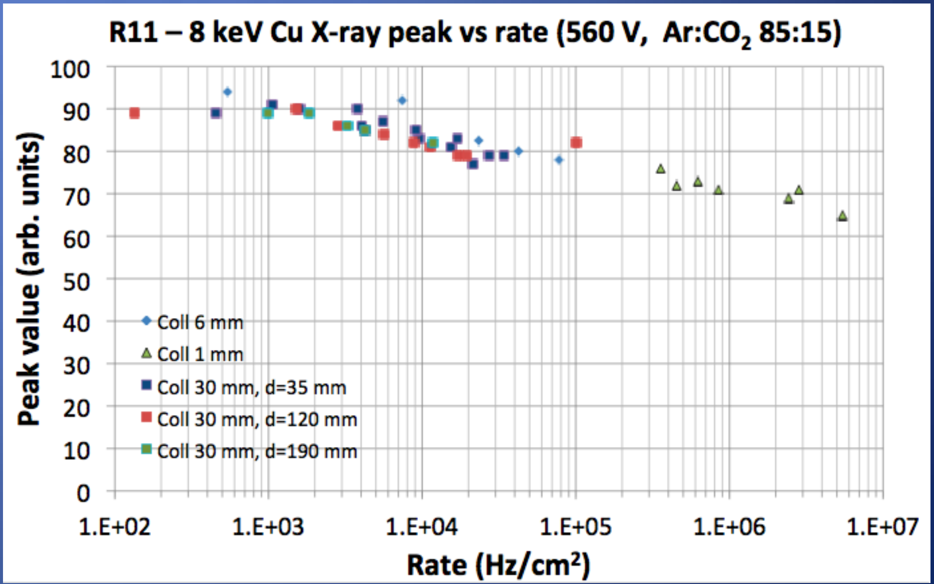


Detectors for the Upgrade

- Micromegas: Tracking (+Trigger)
  - Excellent Position resolution
  - Very high granularity (excellent 2 track separation)
  - Very good rate capability.
  - Use of resistive strips improved dramatically Spark behaviour
  - **Chosen for the ATLAS Phase 1 upgrade: Technology under development**

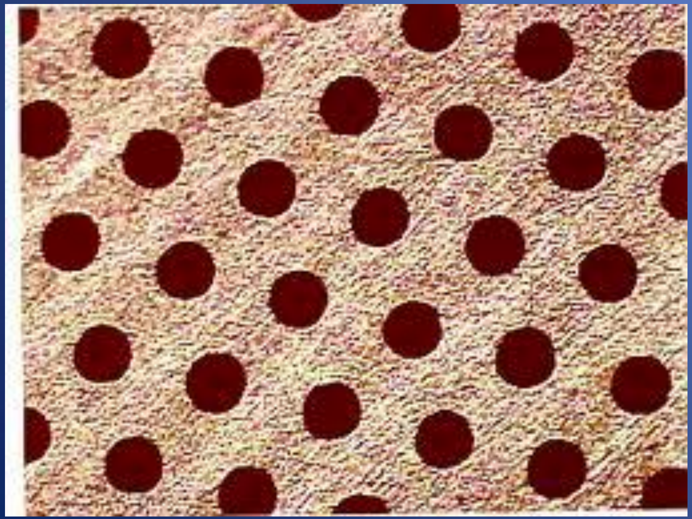


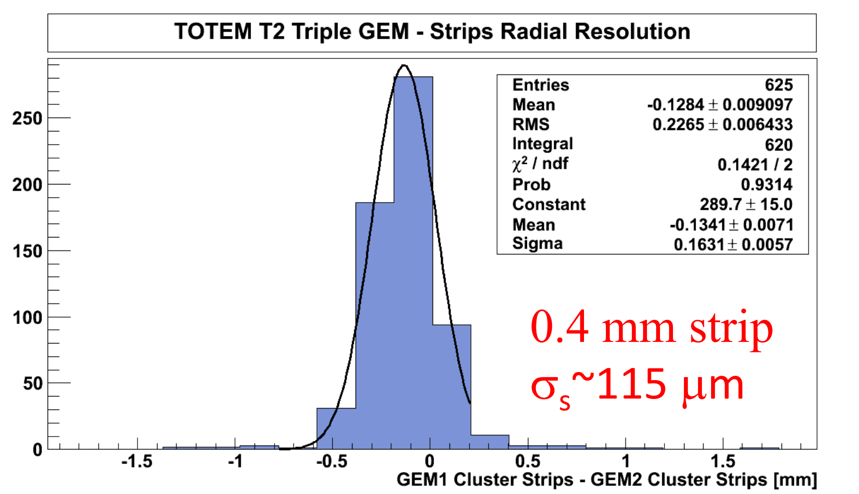


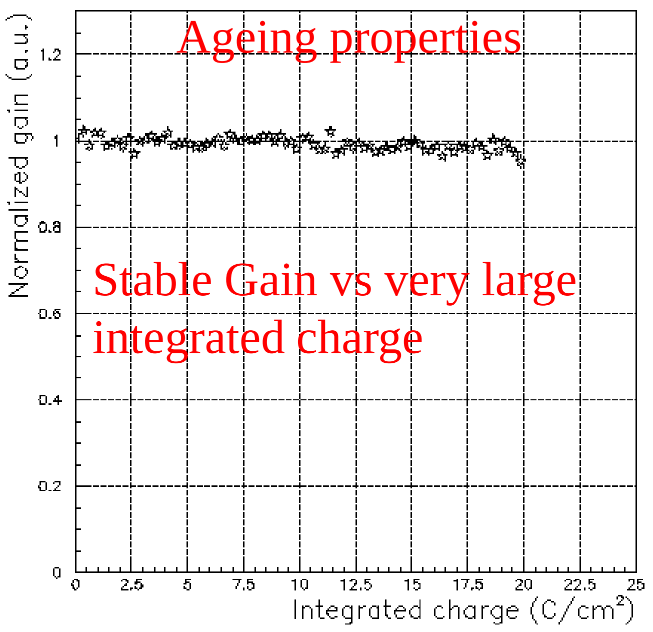


Detectors for the Upgrade

- Triple GEMs: Tracking+Trigger
  - Good Position and time resolution
  - Very high granularity (excellent 2 track separation)
  - Very good rate capability.
  - **Chosen for the CMS Phase 1 upgrade: Technology under development**



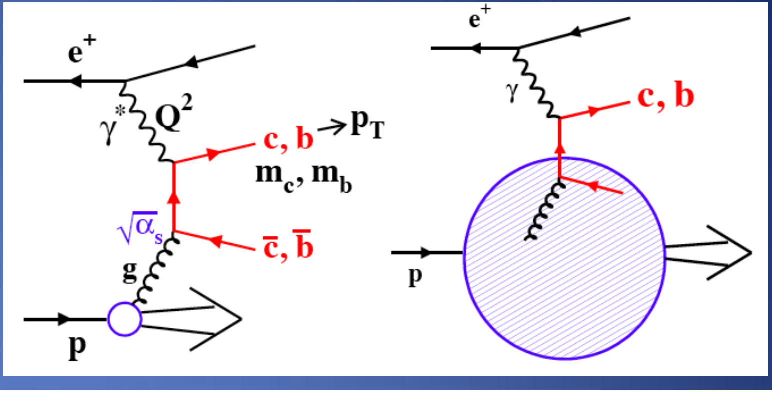


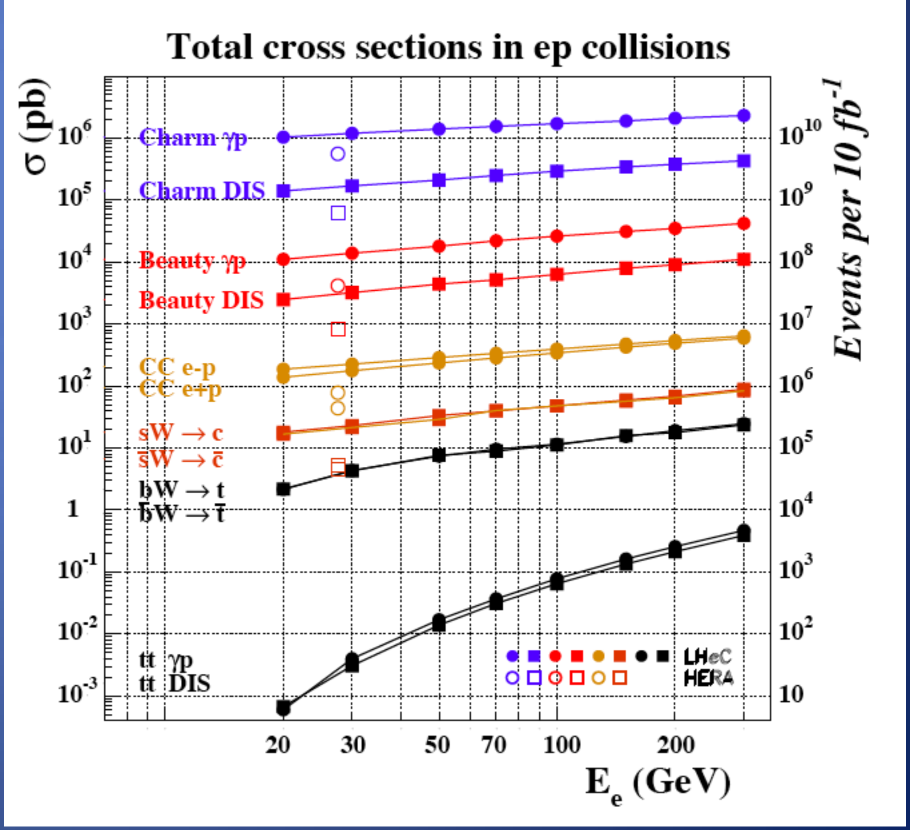


Examples of Muon Physics at LHeC

- Heavy Flavour production and Gluon PDFs
- Top Production
  - Precision measurement of Mass and Cross Section
- Vector mesons: J/Psi and Y
- Higgs
  - Possibility to study Higgs coupling (e.g to bb) in a cleaner environment wrt LHC

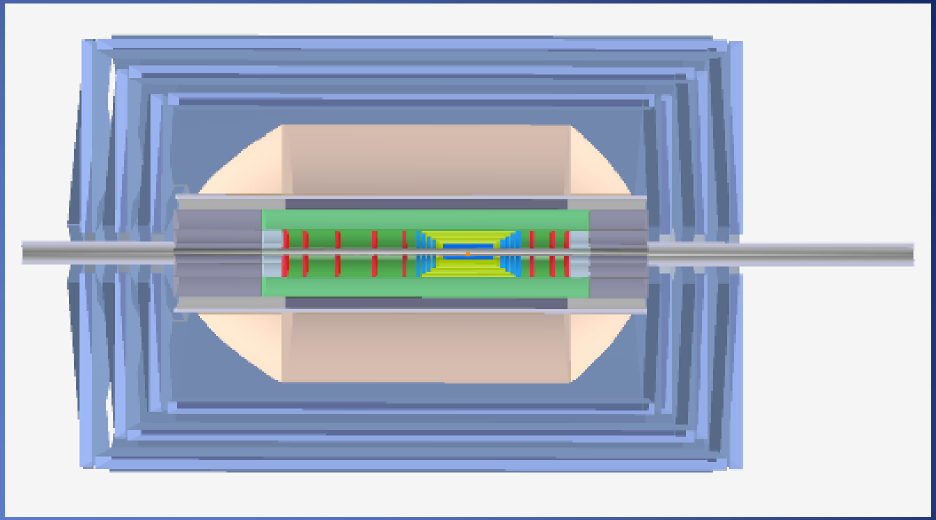
- General features: Interesting events at very small/large polar angle, high momentum muons emitted very forward.
  - Need to further study and simulate these physics channels to better asses the muon detector requirements

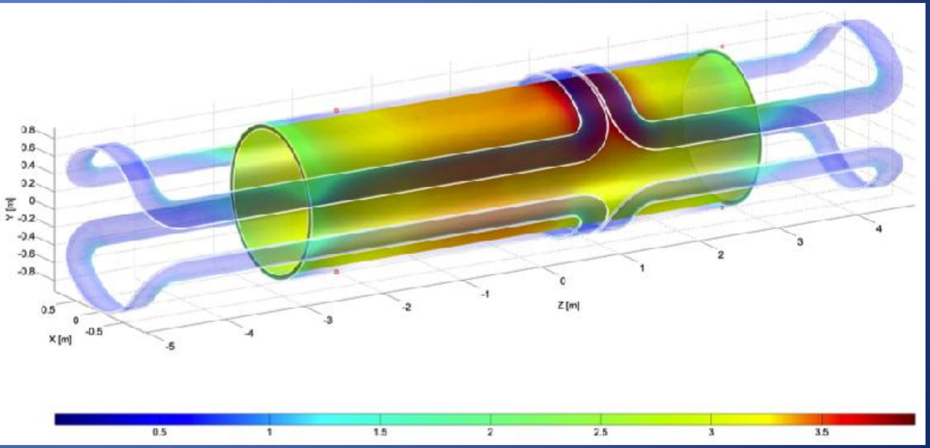




LHeC Muon Detector requirements

- Very large acceptance down to 1º and 179º
- Muon Identification through matching of Inner tracker track with muon Segments in the muon system.
- Stand alone muon measurement in the very forward region
- Muon trigger
- Integration in the proposed magnet systems (Central Solenoid + 2 Dipoles)

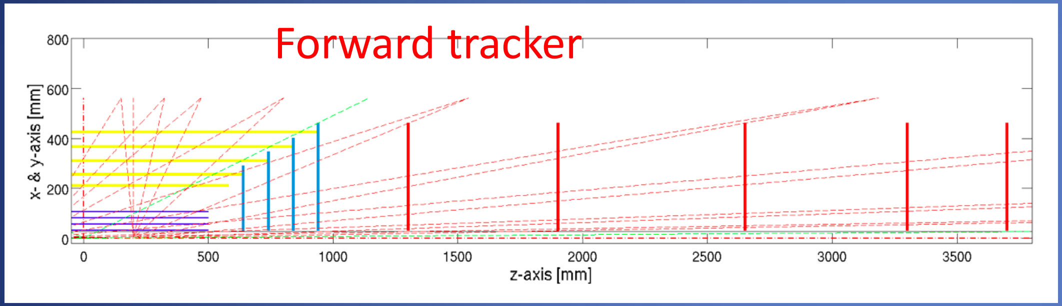


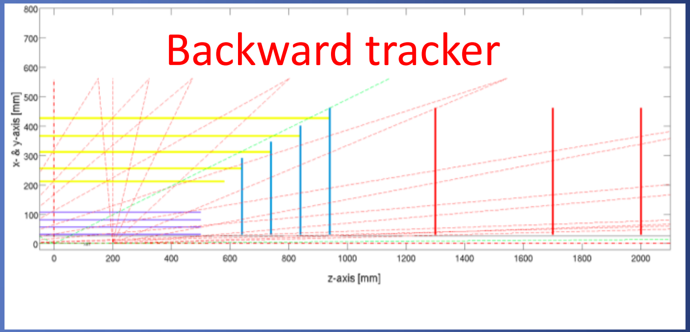


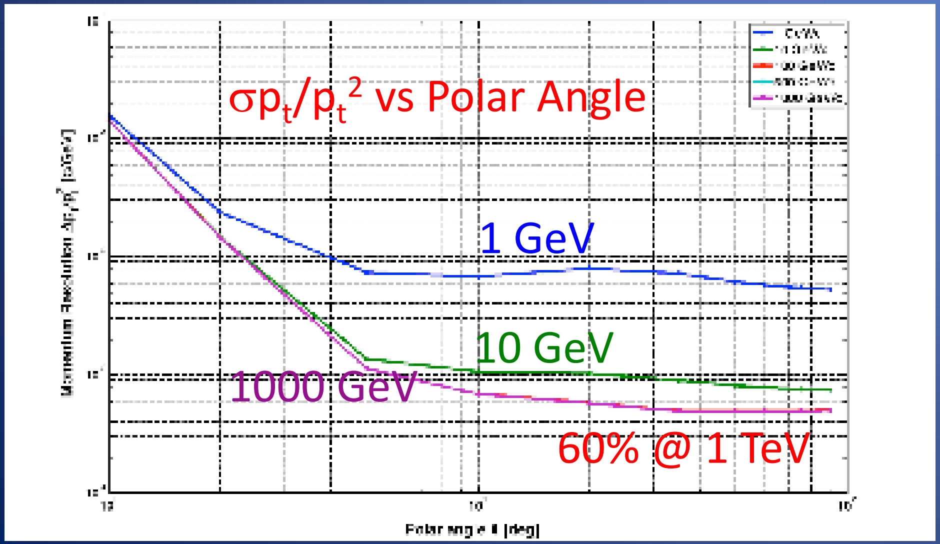
Very mild requirements on rate capabilities compared with LHC muon detectors

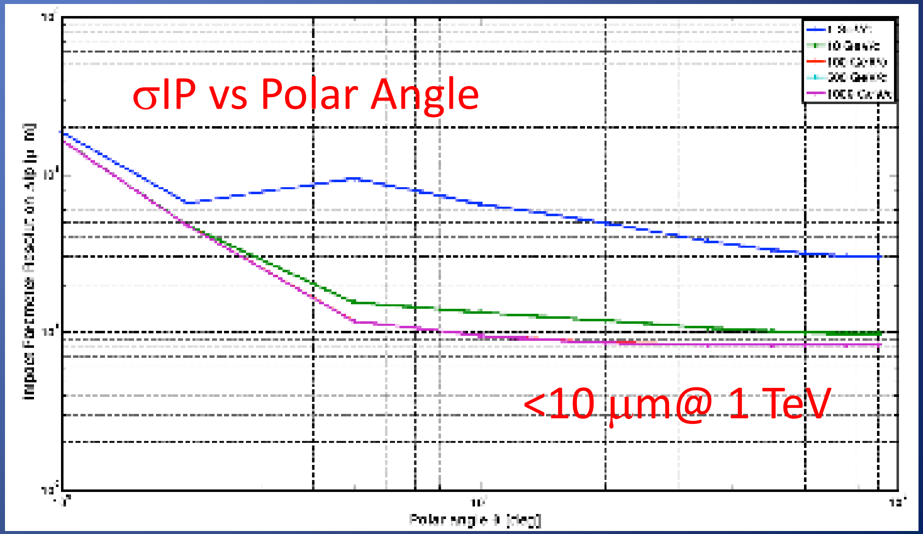
Possible Muon Systems

- Barrel and End Cap Region (up to 10º<θ< 170º)
  - Region Covered by Inner Tracker Acceptance
  - Good momentum, impact parameter and polar angle measurement up to ~TeV. → Need Muon identification







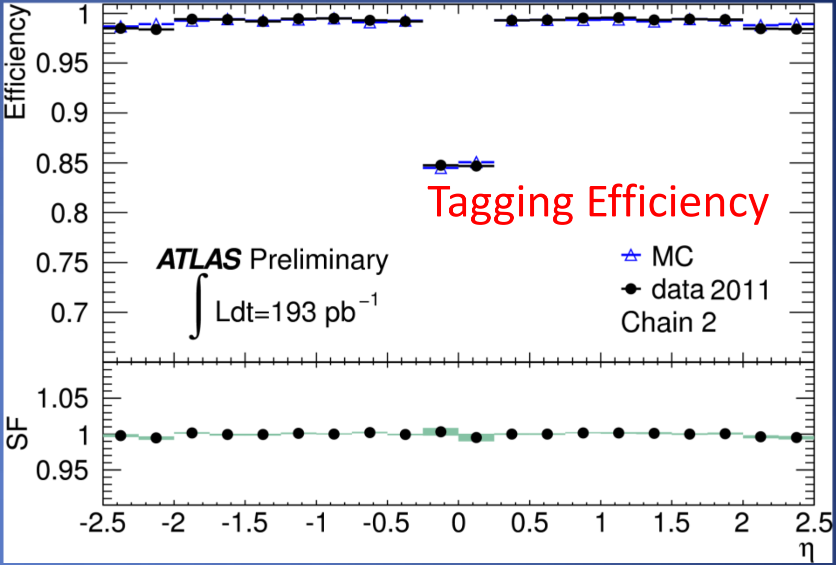


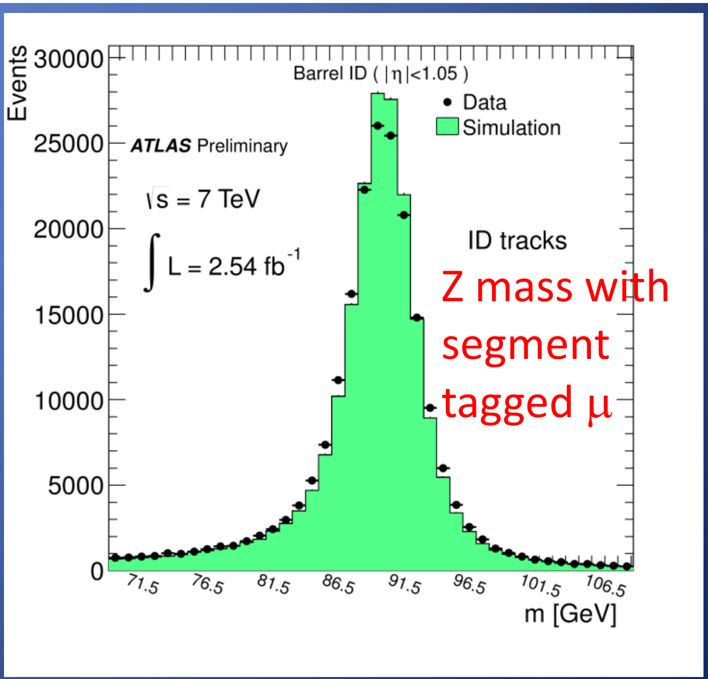
Possible Muon Systems

- Barrel and End Cap Region
- Option 1)
  - Muon Tagger
    - Trigger and tracking detectors with good time resolution and rough space resolution
      - mRPC or sTGC good candidates (see previous slides)

        OR

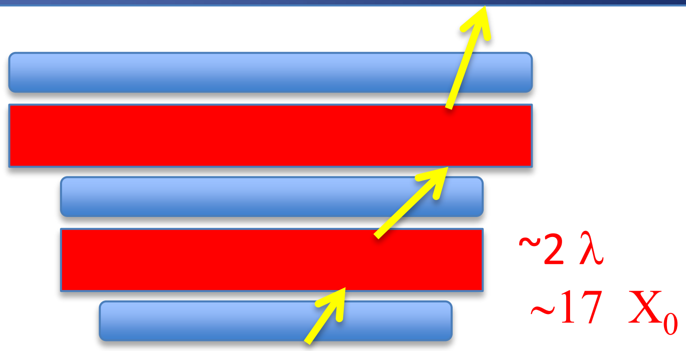
      - Drift Tubes and RPC for triggering
    - Matching the ID muon track with the Muon catcher segments using only position information (within a given time window)
    - No Pt matching.





Possible Muon Systems

- Barrel and and End Cap Region
- Option 1 cntd)
  - Three stations of triggering and tracking detectors spaced by iron absorbers.
  - Can possibly profit from an Existing Magnet As Absorber



Iron 30-40 cm

Density 7.87 g/cm^3

Radiation length 1.76 cm

Interaction Length 131.9 g/cm^2

dE/dx 1.45 MeV/g/cm^2

3 Stations

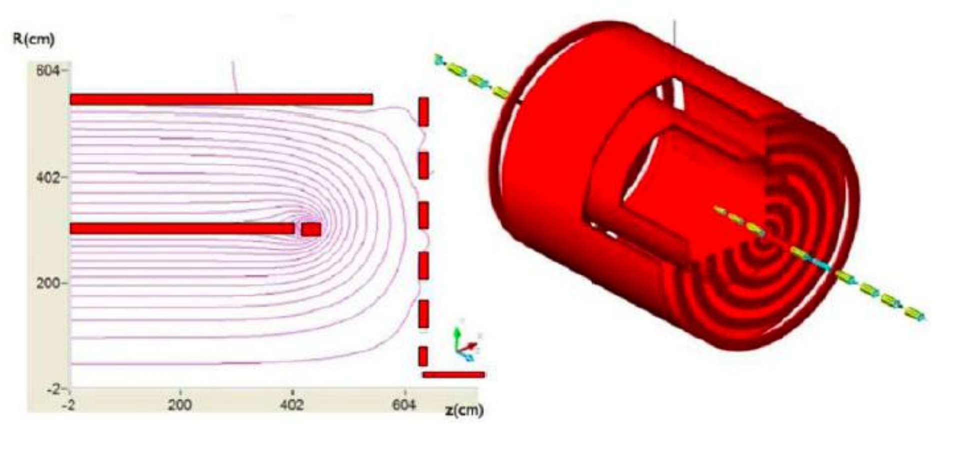
3-4 layers of measuring planes per station

No momentum selection from trigger only geometrical coincidences.

Pointing to IP

Possible Muon Systems

- Barrel and End Cap Region (up to10°<θ< 170°)
- Option 2) (Ferrari Solution)



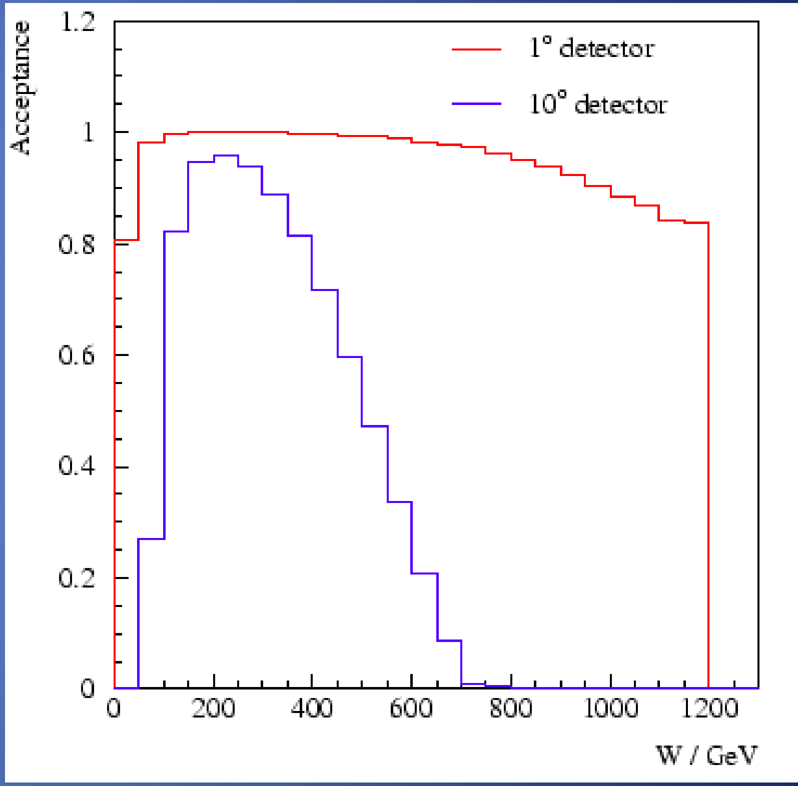
- Muon Spectrometer with Stand Alone capabilities
  - Use of 2 coupled Solenoid one in the inner region (ID) and the other one in the Muon Region.
  - Excellent Field configuration (very uniform) 1.5 T. Coverage of bending power down to very small angles.
  - Precise momentum measurement from few GeV to 500 GeV.

- Trigger and tracking detectors with good time resolution and excellent space resolution
- Matching the ID muon track with the Muon Spectrometer track both in position and in momentum
- Three stations of triggering and tracking detectors
- Need sophisticated and excellent alignment system to exploit the stand alone capability.

Very Forward region

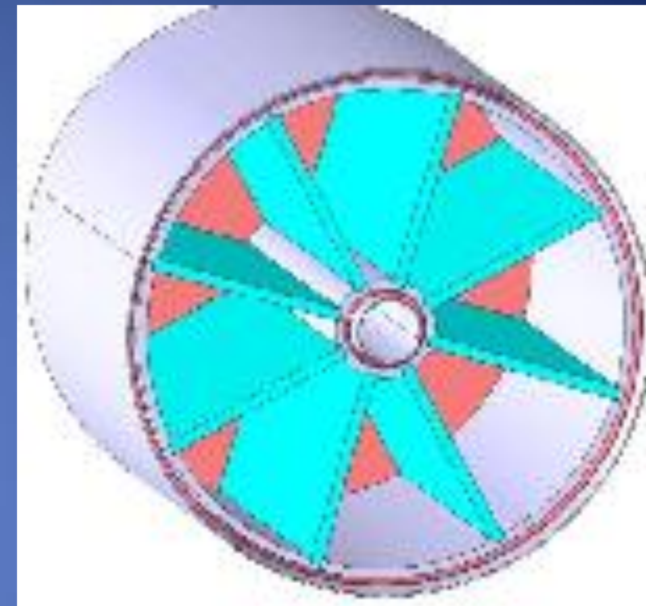
- Coverage up to $1^o<\theta < 10^o$ and $170^o<\theta<179^o$ for superior acceptance of vector mesons, Top decay products, Leptoquarks etc.
- Stand alone momentum measurements needed
  - Poor performance of Inner tracker in this region
- Some overlap with the Forward region
  - needed to understand efficiencies, fakes and resolution of Stand Alone muons.
- In Forward direction high momentum muons, opening angles between muons very small
  - Very good two tracks resolution
    - Highly segmented detectors
    - Micromegas or GEMs
- High momentum resolution can be achieved with air core toroids.

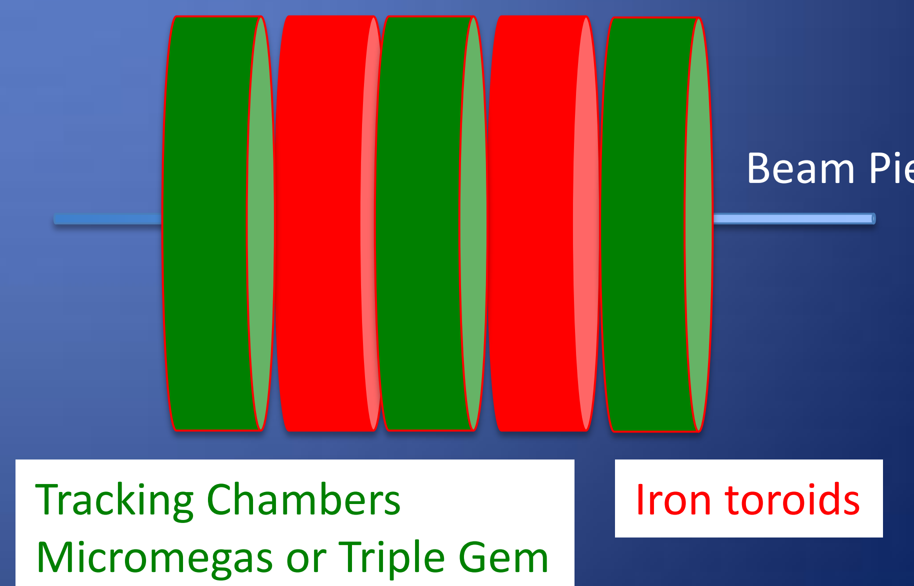
Vector meson Acceptance



Possible Magnetic configurations

- Air Core Toroid
  - Excellent stand alone momentum resolution
  - Need of excellent space resolution, segmentation and alignment on detector side
  - More Complex
  - Possible interference of the fringe field on Beam
- Iron Toroid
  - Easy and Chip
  - No Fringe Field on Beam
  - Limited Pt resolution due to Multiple Scattering: > 10%
  - Higher production of δ rays
  - Need of average spatial resolution and mild requirements on alignment.





Conclusions

- The LHeC muon detector has to be further studied and optimized against the relevant physics channels.
- The present technologies used for the LHC detectors are perfectly adequate for most of the acceptance
  - No special requirements on resolution or alignment, a good Muon Catcher combined with the Inner tracker should be enough for the physics goals.
- Need very high angular coverage
  - Very segmented detectors coupled with Toroids should allow stand alone muon measurement in the very forward region.

On a personal note: It was very interesting for me to prepare this talk and I wish you all

Good Luck

Back Up

Momentum measurements basic formulae

- $(\Delta p/p)_{Mis}$: Gets better for larger L ($1/L^2$)
- $(\Delta p/p)_{MS}$: Gets better for low mass detectors
- For the Best part of ATLAS air core spectrometer
  - B=0.6 T L= 5 m σ= 50 μm x = 0.2 X_0
  - $\Delta p/p_{MS}$ dominates resolution up to 250 GeV

$\Delta p/p_{MS}$ = 2.7 %

$\Delta p/p_{Mis} = \Delta p/p_{MS}$ @ 270 GeV

$\Delta p/p_{Mis}$ = 10 % for p = 1 TeV/c