ATLAS Muon Reconstruction and MuonSpectrometer Performance

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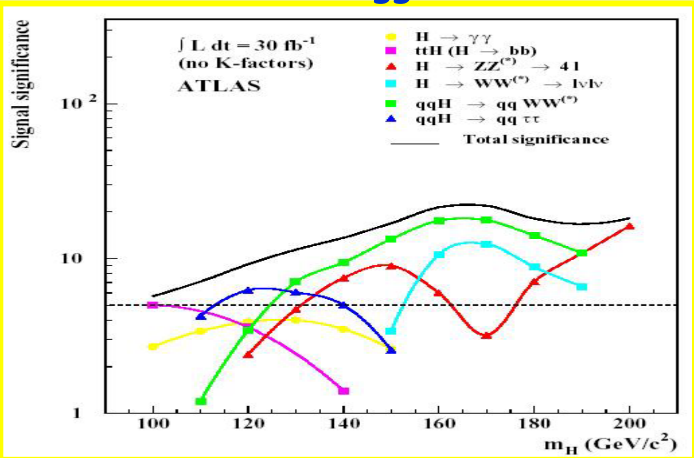
Outline

- **Physics involving muons in ATLAS**
  - "Benchmark" processes involving muons have driven LHC detector and trigger designs:
    - mainly ⇒ SM and SUSY Higgs decays
    - but also ⇒ new vector bosons discovery
      b-quark physics and CP violation
      heavy quarkonium decays
- **Muon Identification systems in ATLAS**
- **Muon Reconstruction Packages**
  - **Reco Event Types**
- **Muon Identification Performances**
  - Muon Reconstruction
  - Reconstruction Performances
- **Conclusions - Plans**

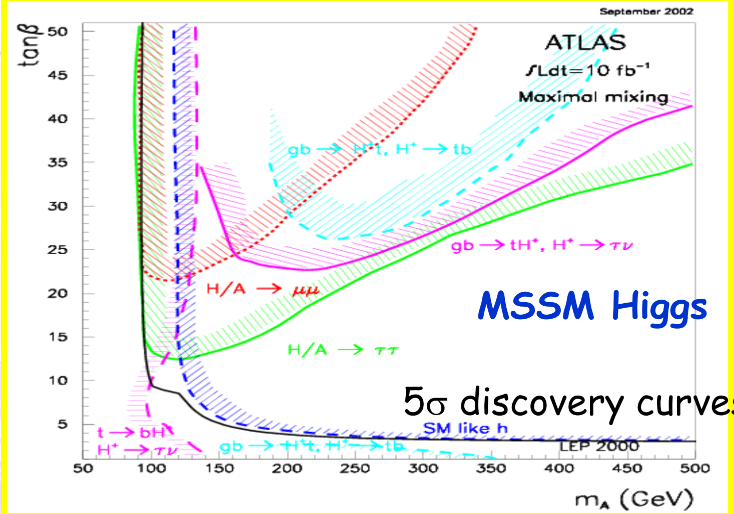
Physics involving muons @ ATLAS/LHC

Standard Model Higgs



The signal for Higgs boson must be extracted from a background several order of magnitude higher.
The channels experimentally cleaner are the ones having leptons in the final states

Many different signatures in this mass region: more relevant are
- $H \to \gamma\gamma$ $\sigma \times BR \sim 45$ fb (LO for M_H=130 GeV)
- $H \to 4l$ e.g. $H \to ZZ^*$ $\sigma \times BR \sim 1$ pb (LO for M_H=130 GeV)

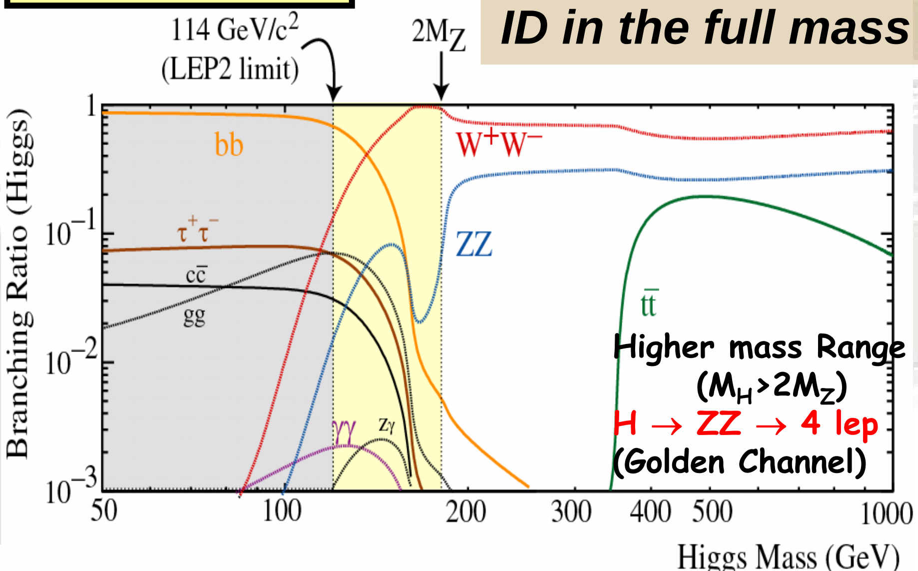


MSSM Higgs

5σ discovery curves

Intermidiate Range
($130 < M_H < 2M_Z$)
$H \to WW^* \to l\nu l\nu$
$H \to ZZ^* \to 4$ lep

Muons are fundamental for trigger and signature ID in the full mass range

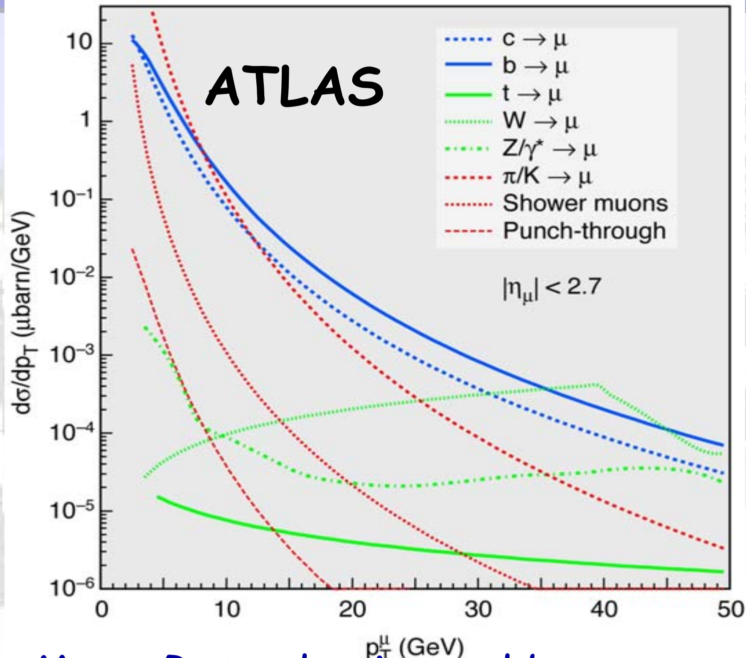


Higher mass Range
($M_H > 2M_Z$)
$H \to ZZ \to 4$ lep
(Golden Channel)

$A/H \to \mu\mu$:
- covers good part of region not excluded by LEP
- can be discovered even at very large masses
- experimentally easier than $A/H \to \tau\tau$,
  - this compensates the reduced rate
- relevant for mass and couplings measurement

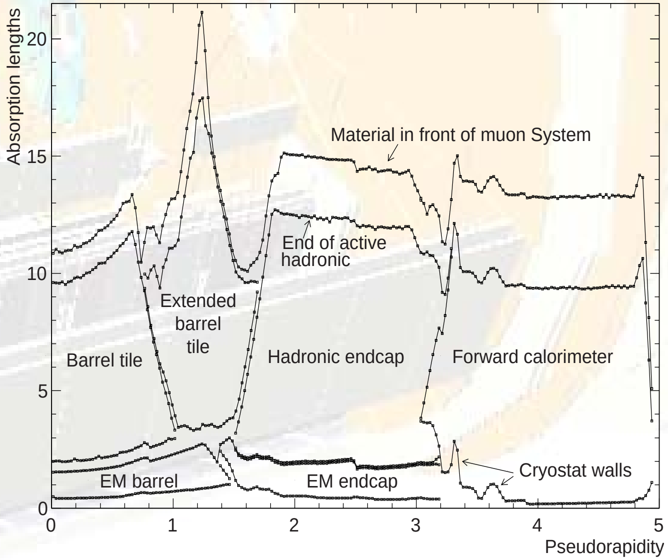
crucial point: reconstruct high-p_T muons from narrow resonance → 5σ sensitivity reachable in 1 year ($10 fb^{-1}$) @low luminosity ($10^{33} cm^{-2}s^{-1}$)

Muon rates and Background

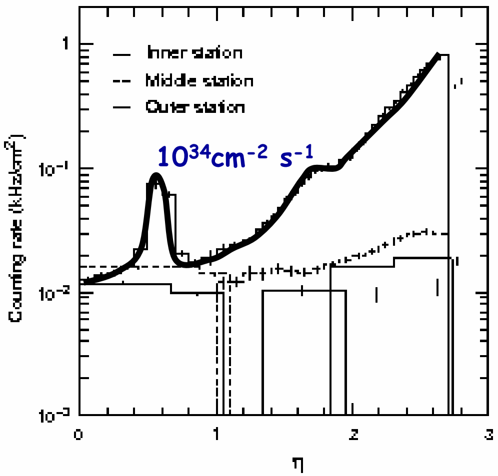


Particles produced in the interactions of primary hadrons from p-p collisions with the material of the Detector.
The result of these interactions **is mainly the production of neutrons that diffuse throughout the hall producing secondary particles when interacting with matter**.

A Gas of Photons (E < 1 MeV) and low energy Neutrons (E < 100 KeV) is the main source of uncorrelated background in the MS (cavern bkgr.)



Muon Rate dominated by:
b,c,light mesons and W decays



total counting rates, obtained by multiplying the background rates with the detector efficiencies, as a function of η

Single counting rate (ATLAS,high Lum.):
Barrel < 40 Hz/cm²
End Cap 20-1000 Hz/cm²

Muon Identification systems in ATLAS Detector

❑When a charged particle(μ) moves through a detector it leaves **a set of hits** in the Inner Detector(ID) and in the MuonSpectrometer(MS). A hit provides **information about the track parameters** at the measurement location.

❑ The **reconstruction goal** is to find the track associated to the hits and perform a fit in order to obtain the better estimate of the trajectory parameters describing the particle.

•**MS:**

B toroïdal (inhomogeneous)~0.5 T

⇒p_T : with high p_T

⇒Problems for low p_T

⇒Muon(μ) Identification

•**Calorimeters:**

Loss of energy (sometimes catastrophic)

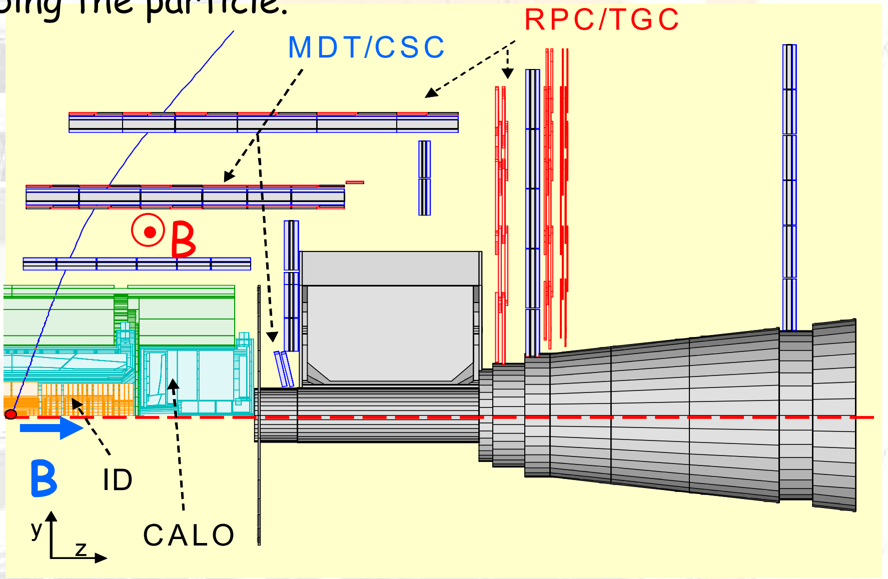
Fluctuations of E_loss

Electromagnetic showers

•**ID:**

Solenoid B ~2 T

⇒Precise measurements at low pT, **but muon Identification is needed**



➢**Why Pattern Recognition?**

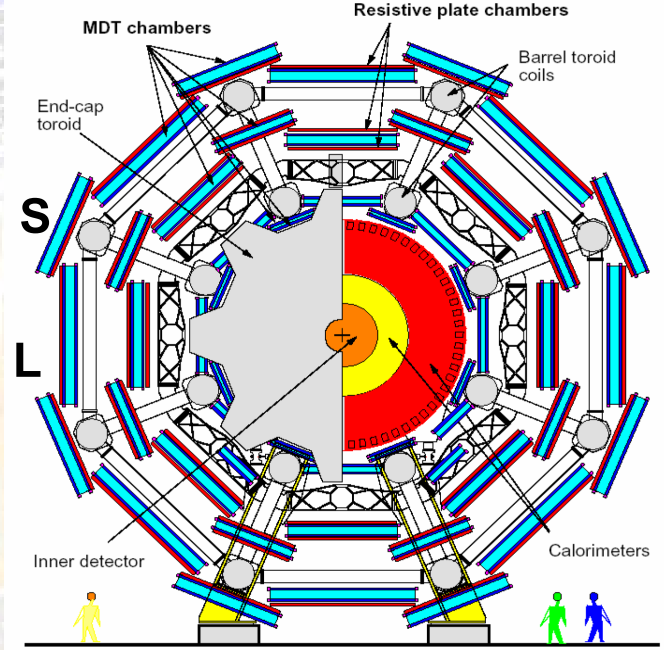
There are several sources of hits: Tracks from interaction in LHC, coming from different bunch crossing, cosmic particles, electronic noise, Radioactivity

➢**The pattern recognition main task** is to properly associate hits to particle trajectories in order to find the full set of track parameters by searching for the best fit of a physically valid track.

ATLAS Muon Spectrometer

- Barrel divided in 16 φ sectors (small(**S**) and large(**L**))
- **3 air-core** (to minimize multiple scattering) superconducting toroids: 1 barrel (BT) + 2 End Caps toroids (ECT) →**track curvature in r-z plane**.
- **bending of the muons**:
  - $|\eta| < 1$ for toroid of the **barrel**
  - $1.4<|\eta|<2.7$ from the magnets of the **endcap**
  - $1.0<|\eta|<1.4$ in the **transition region.** This Radial Overlap of the BT and ECT fields *ensures the widest acceptance for single muons*
- **Equipped with trigger and precision chambers(4 technologies)**
  - Trigger selectivity: threshold pT > 6GeV/c for b-physics and pT > 20GeV/c for high momentum particle
  - **Low pT muons** ⌫ ID and Tile calorimeter (for these momenta pT resolution is dominated by inner tracker ⌫ for B physics the MS is primarily used as a Level 1 muon trigger or to validate the muon candidate and match it with inner tracker)
  - Second coordinate measurement (in the non bending plane) for reliable momentum determination.

- **The final aim is to reach the highest efficiency with standalone momentum resolution of a few % level at 10-100 GeV/c and ~10% at 1 TeV/c**



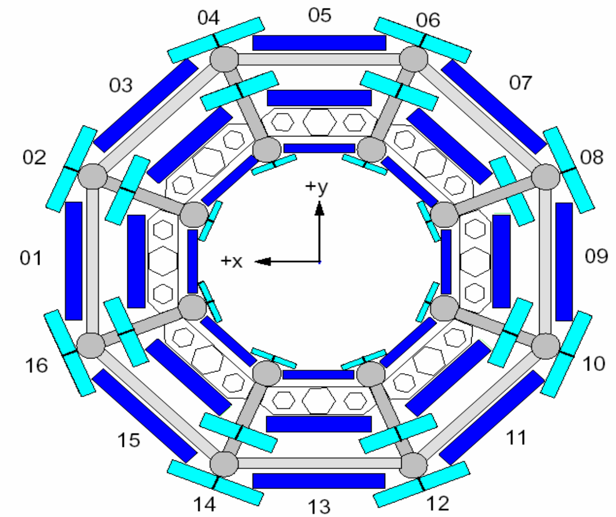


Figure 3-5 Definition of sectors; view into +z direction

Precision Muon Chambers

Precision measurement in the bending direction of the Magnetic Filed (MF)

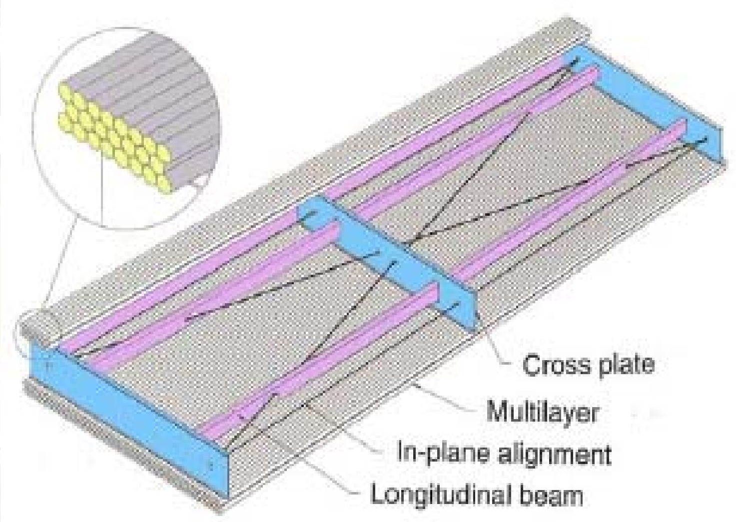
❑**MDTs (Monitored Drift Chambers)**

➢The basic elements are **drift tubes** with a diameter of 3 cm and a variable length from 70 cm to 630 cm

➢The tubes are organized in multi-layers of 3

➢(4 for inner stations)

➢single wire average spatial resolution ≈ 80 μm



❑**CSCs (Cathode Strip Chambers)**

➢Placed in the inner ring of the endcap region, **2 < |η| < 2.7** where an high density of tracks is to be expected

➢MWPC with readout on the segmented cathode strips perpendicular to the anode wires

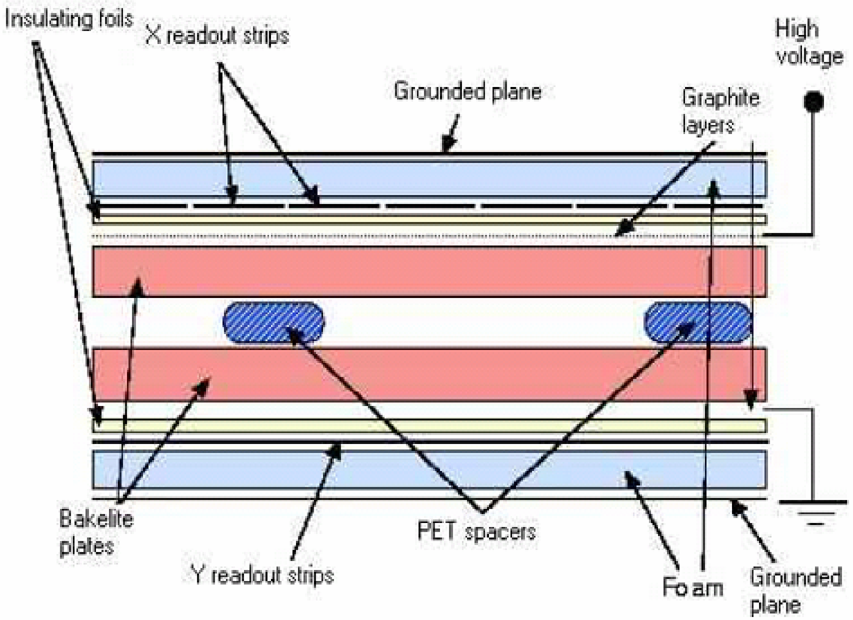
➢Spatial resolution ≈ **60 μm**, small drift time **(30 ns)**, good time resolution ≈ **7 ns**

➢Transversal coordinate measurement is given by cathodical strips parallels to anode wires

Muon Trigger chambers

Muon trigger chambers are used in ATLAS for selecting bunch crossings containing interesting interactions (μ trigger), and for measuring the second coordinate (ϕ). The *trigger* system cover the $|\eta|<2.4$ region.

Barrel RPCs (Restistive Plate Chambers): on both sides of MDT in the "middle" stations and directly above or immediatly below the "outer" stations .



Endcap TGCs (Thin Gap Chambers) : 3 stations close to MDT "middle" stations. MWPC (with wires parallels to MDTs) and read-out strips perpendicular to the second coordinate measurement.

Time resolution $\approx$ 1 ns

Space resolution in $\phi \approx$ 1 cm

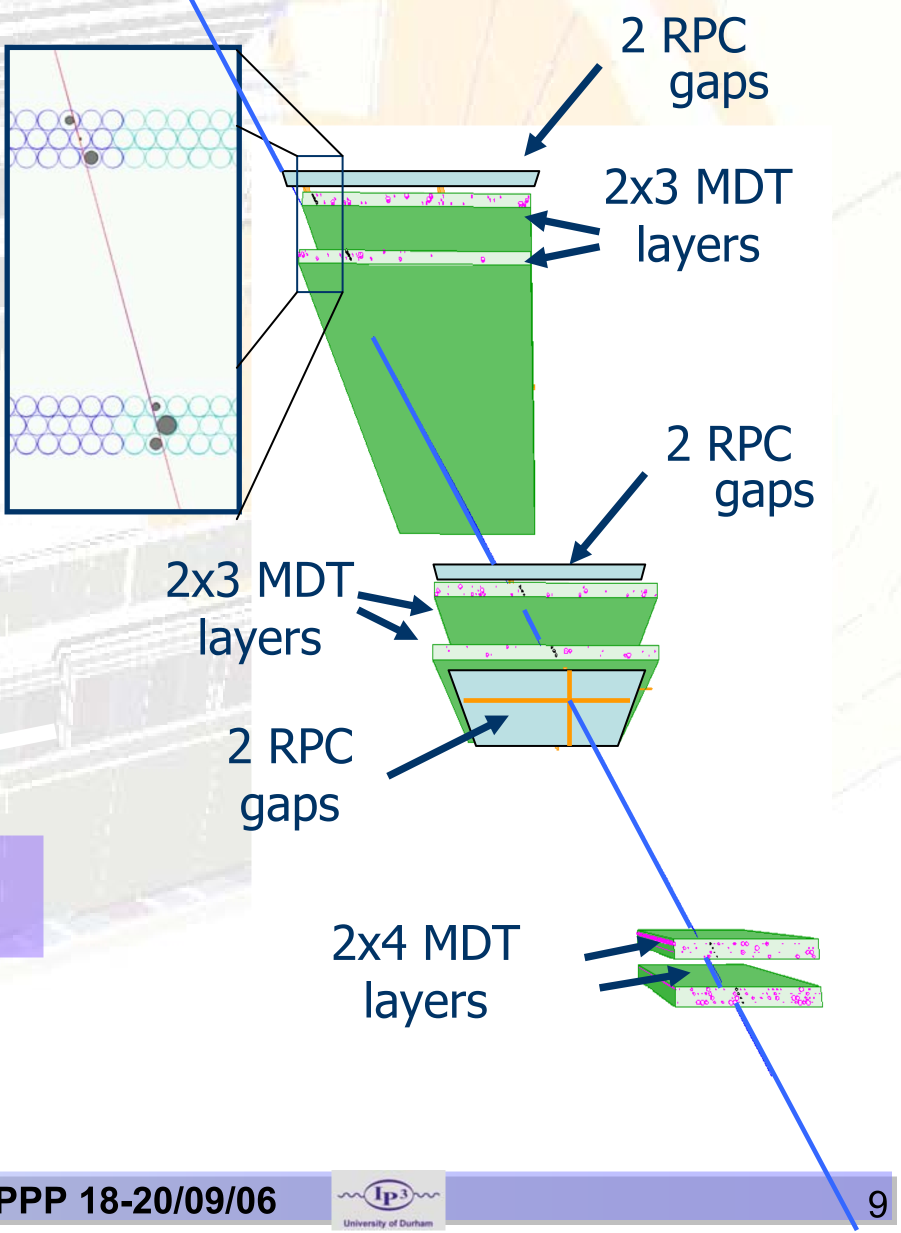
Very short drift time due to the thin gap → good time resolution needed for Bunch Crossing ID

Wire (//to the MDT wires) signal used to provide the trigger, strip (⊥ to the wires) signals used for the second coordinate

Fine granularity is needed since trigger chambers are outside B and will have a short lever arm

Measuring muons in MS Barrel sector

- Precision measurements of z in the bending direction of the MF (σz=80μm) with 3 MDT stations
- MDT station: 2 multilayers of 3 (4 in the inner station) layers of monitored drift tubes
- Trigger and measurements of z-ϕ coord. ($\sigma z\phi$ ~ 1cm) with 2 RPC layers in the middle station + 1 RPC layer in the outer station
- RPC layer: 2 gas gaps read independently



Total: ~ 20 precision z measurements + ~ 6 z-ϕ measurements

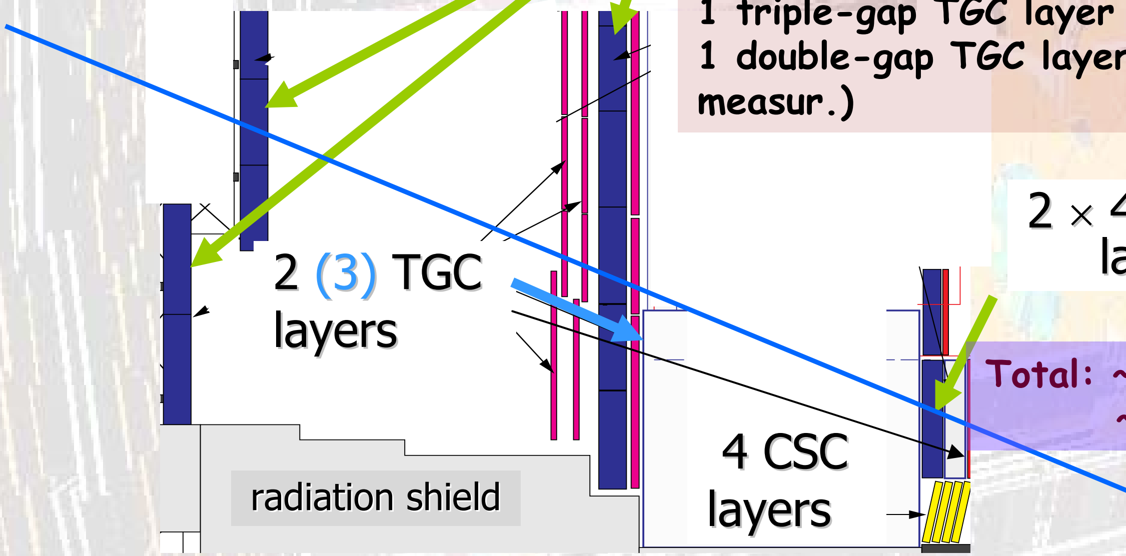
Measuring muons in MS Endcap sector

|η| < 2.0

- Precision measurements of r (σr=80μm) with 3 MDT stations with 2 multilayers of 3 (4 in the inner station) layers of tubes

2 × 3 MDT layers

Trigger and measurements of r-ϕ (σϕ ~ 1cm) with:
2 double-gap TGC layers
1 triple-gap TGC layer
1 double-gap TGC layer in the innermost station (only measur.)



2 × 4 MDT layers

Total: ~ 20 precision r measurements + ~ 9 r-ϕ measurements

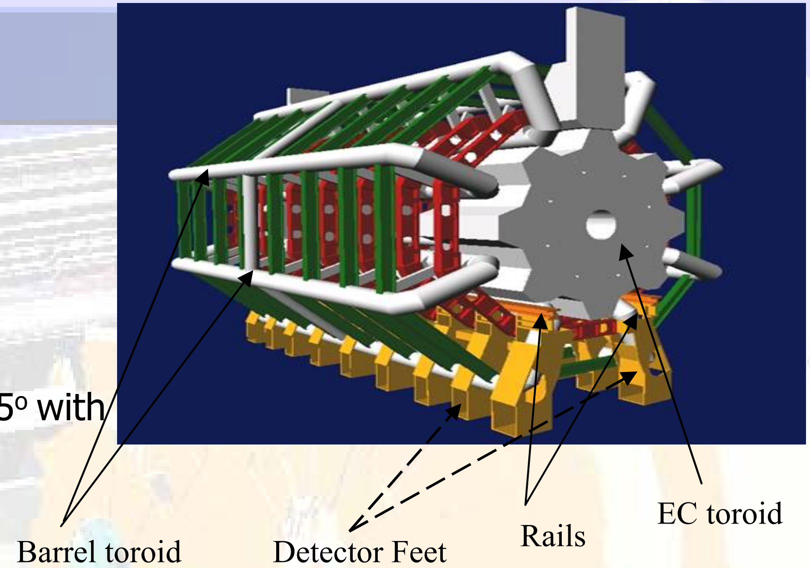
2.0 < |η| < 2.7

- Precision measurements of r with:
  - 4 CSC layers (σr=60μm) +
  - 2 MDT stations with 2 multilayers of 3 layers of tubes +
  - 4 ϕ measurements (CSC ϕ strips, σ ϕ < 1cm)

Total: ~ 16 precision r measurements + ~ 7 r-ϕ + 4 ϕ measurements

Trigger and measurements of r-ϕ with 3 outermost TGC stations

ATLAS Muon Magnet System



BT: |η|<1
- 26 m long
- Internal/External radii: 9.5m/20m
- 8 separate coils,1 cryostat per coil
- bending power ∫Bdl=2-6 Tm

ECTs: 1.4< |η| <2.7
- Inserted into the BT edges, 8 coils per ECT, rotated of 22.5° with respect to BT coils
- 5 m long
- Internal/External radii: 1.7m/10.7m
- 1 cryostat per ECT
- bending power ∫Bdl=4-8 Tm

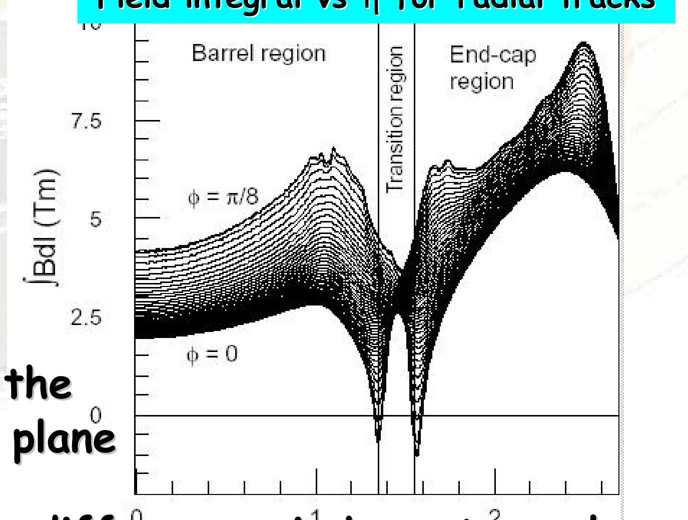
ECT → p_T resolution constant up to |η| <2.7

BT Open structure → allows for chambers installed inside and for alignment optical corridors to cross it

Long barrel+short EC → minimize magnetic forces and costs

B field measured with 5000 Hall probes but global calibration of the energy scale is needed

Field integral vs η for radial tracks

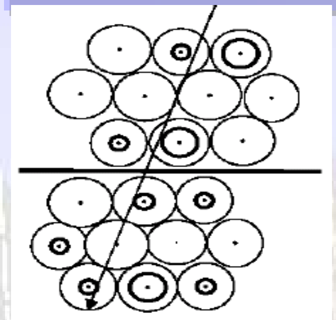


Field integral inhomogeneous in the tracking volume

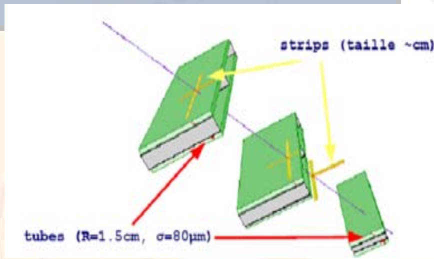
Need to measure accurately the coordinate in the non bending plane

Need to take into account the differences in Lorentz angle for the calibration of the tracking chambers

Muon Reconstruction principles



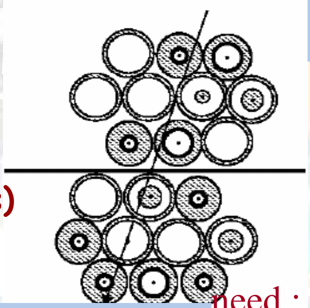
- precise, but very distant local measurements
- field very inhomogeneous
- material, to be taken into account
- "noise"
- RPC: strips in η and φ (cm)
    - areas of activity in which one will seek the **segments**



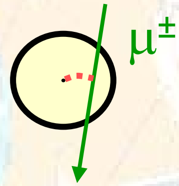
Drift time + RT = ring (80µm)
Segment = tangent with all these rings

BUT

- **zone ineffective (center, edge)**
- **"noise" , "Dead time" (~700ns ~ Rayon tubes)**

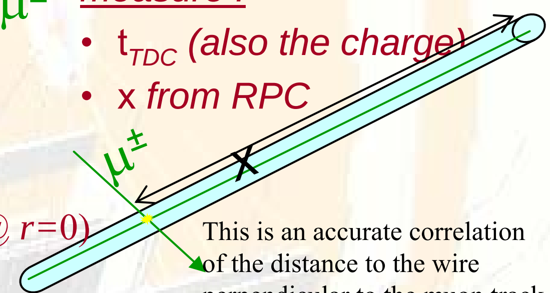


t_o and r/t relation



measure :

- t_{TDC} *(also the charge)*
- *x from RPC*



need :

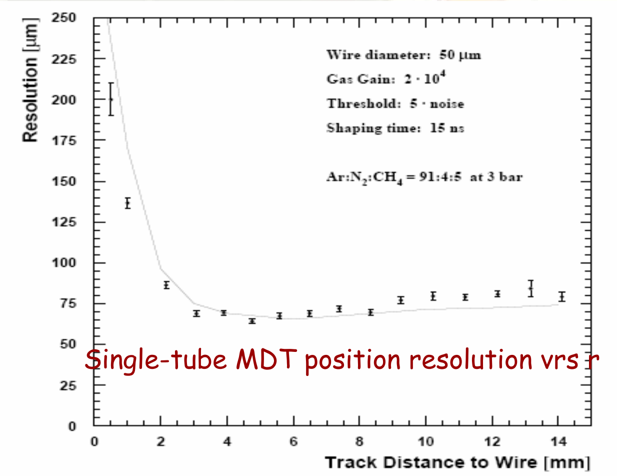
- t_o (i.e. t_{TDC} @ r=0)
- r/t relation (i.e. math function $t \rightarrow r$)

This is an accurate correlation of the distance to the wire perpendicular to the muon track, which is the shortest distance and called **drift distance (*r*)**

From a Precision Digit to a Precision Hit

The creation of an MDT hit starts by subtracting from the digits drift time, the time it takes to the signal for propagating along the tube-wire to the front-end electronics.

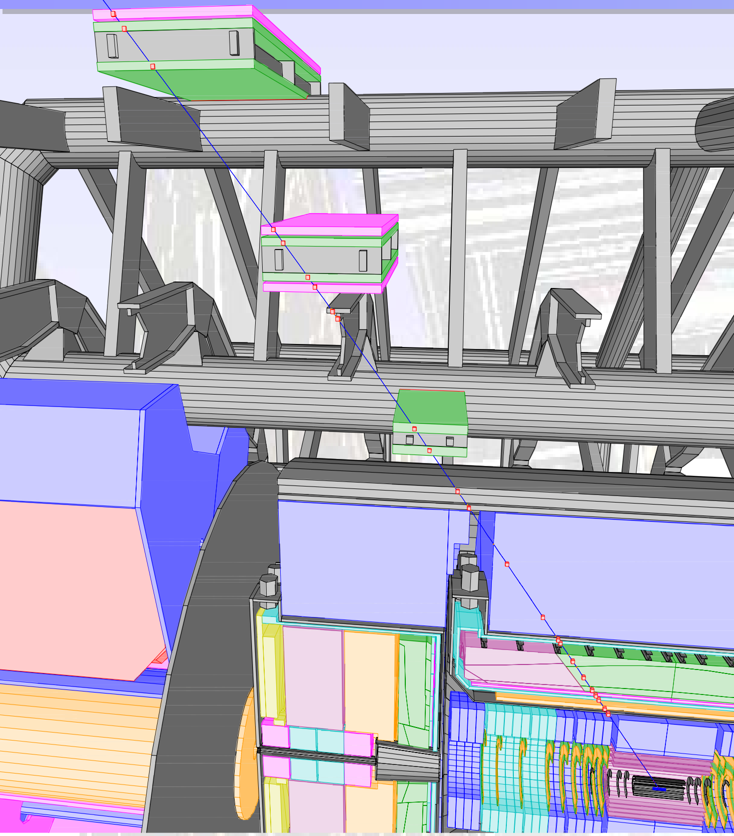
The MDT chambers do not measure the azimuthal coordinate along the wire, so to determine this propagation time, the overlap region of the wire with the trigger chambers φ measurements is used together with a signal-speed. The time is then corrected for the tof from the interaction point to the MDT tube. ***The resulting drift time** is subsequently converted **to a distance** and a correction for the Lorentz angle is applied*.



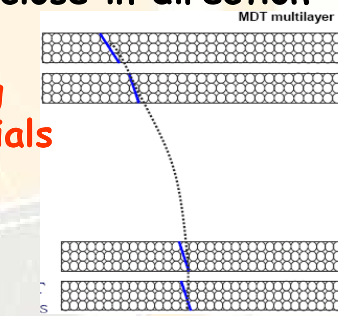
Single-tube MDT position resolution vrs r

The r-t relation is used to obtain a position measurement from the time measurements.

StandAlone (SA) Muon Reconstruction



- Fast identification of "regions of activity" in the muon detector guided by the trigger chambers where exist an intersection of η and ϕ strips.
- Reconstruction of local straight track segments in the bending plane in each station:
  - drift distance calculation from R-T relation
  - corrections for time propagation along the wire by using the 2nd-coord. from RPC and TGC and for Lorentz angle
  - linear fit
- Combinations of compatible segments in the same MDT station and in different stations to identify track candidates.
- These segments are combined if they are close in direction
- Track fit:
  - takes into account multiple scattering and energy loss in the MS inert materials
  - track parameters and the relative covariance matrix are given at the first measured point inside the MS



- Track extrapolation back to the interaction region:
  - takes into account multiple scattering (parametrized by means of scattering planes in the Calos) and
  - energy loss in the calorimeters (as a function of (η,p))
  - track re-fit and new parameters at the interaction vertex

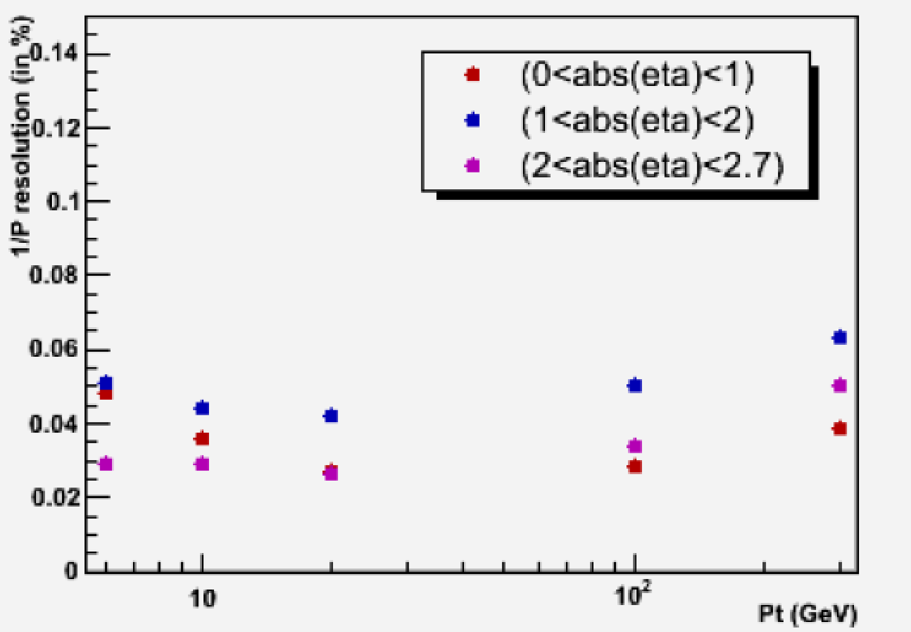
- Track parameters:
  - a0: the transverse impact parameter.
  - z0: the longitudinal impact parameter.
  - Φ: the azimuthal angle Φ=py/px
  - cot(θ) : cotangent of the polar angle cot(θ)=pz/pT
  - 1/pt: reciprocal of the transverse momentum. It is signed according to the charge of the particle.

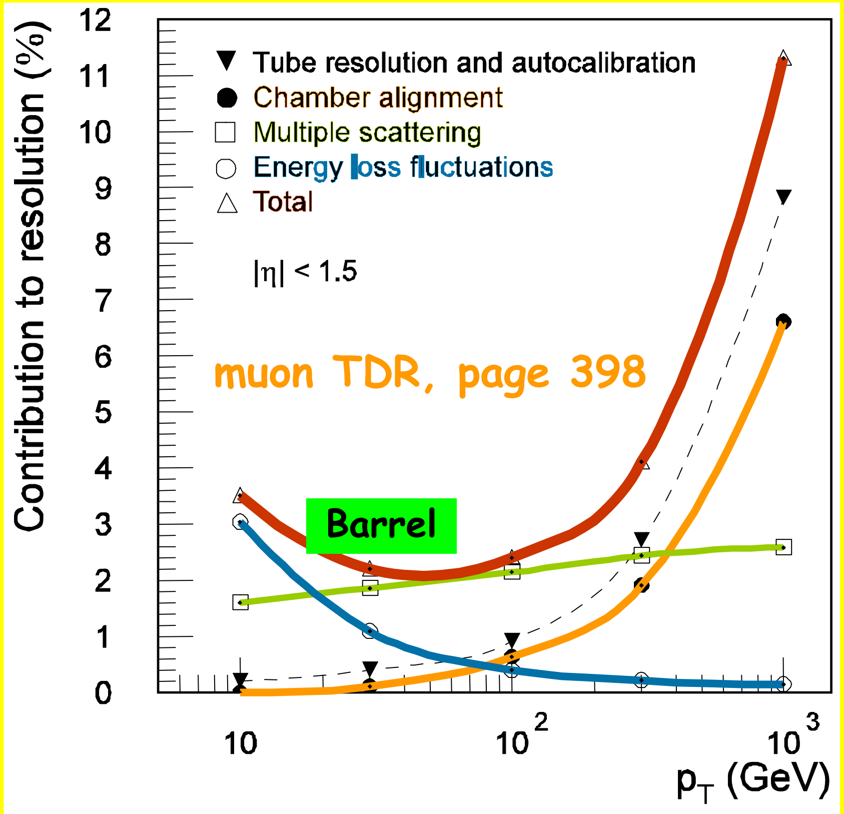
p_T resolutions

The muon spectrometer resolution dominates for P_T > 100 GeV/c

Resolution limited by :

- Mult.Scatt. and Energy Loss Fluct. for P_T<30 GeV/c
- Mult.Scatt. for 30<P_T<300 GeV/c
- Chamber Resolution, calibration and alignment for P_T>300 GeV





$\Delta p_T/p_T$ = 0.1 @ p_T = 1TeV/c
p_T = 1TeV/c -> 500μm sagitta;
Δs=50μm

- Chamber Spatial Resolution (per point) ~ 80μm
- Accurate calibration: time-to-distance relation within ~ 20μm
- Wire positionning inside tracking chambers within ~ 20μm
- CSC strip ~ 100 μm for |η| > 2
- Chamber Alignment within ~ 30-40μm (barrel - endcaps)
- Magnetic field knowledge @few permille

Desired p_T Resolution

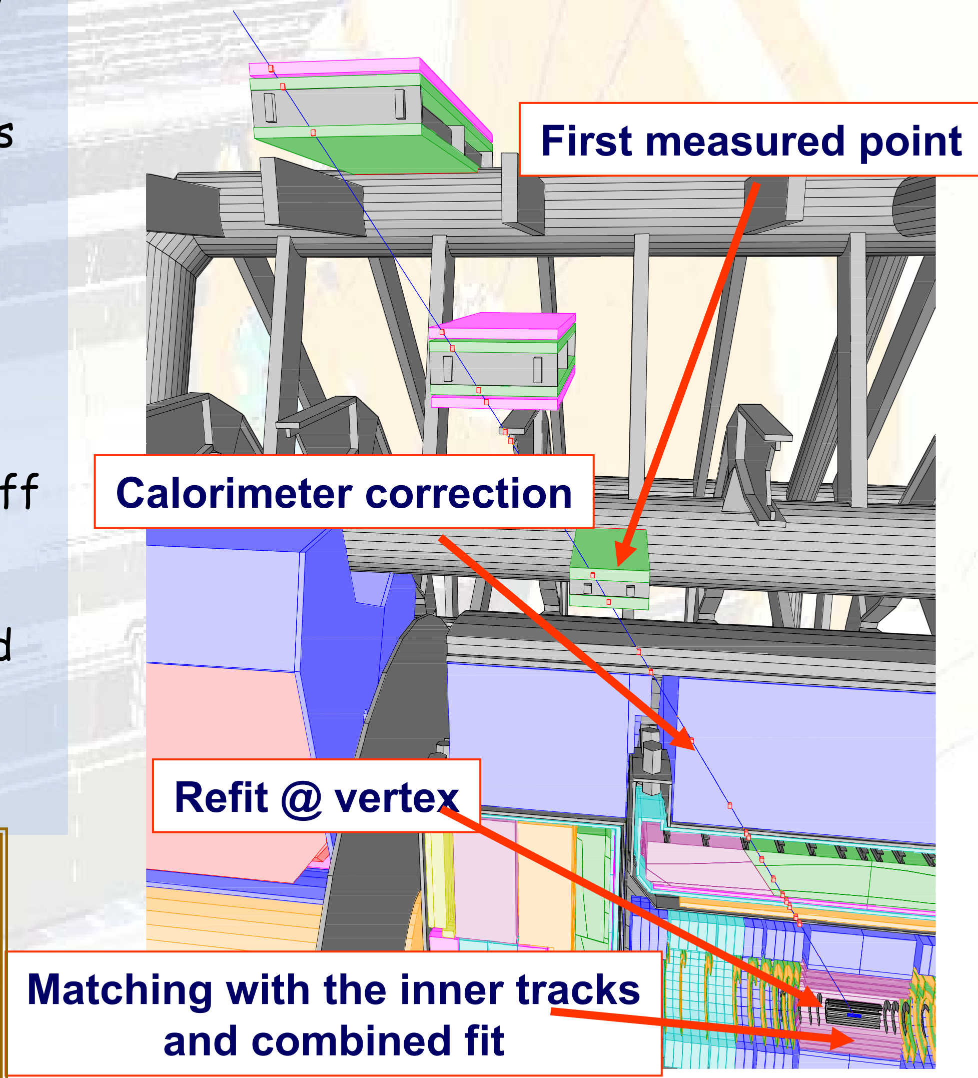
H, Susy, b, t, W	p_T<100 GeV	$\delta p_T/p_T$~2%
Exotics, W'	p_T~1TeV	$\delta p_T/p_T$~10%

Combined Muon Reconstruction and Identification

- Track extrapolation from MS to the IP
  - Multiple Scattering parameterized by means of scattering planes in the calorimeters
  - The Energy loss in the calorimeters is
  - evaluated from calorimeters reconstruction as a function of (η,p)
  - Re-fit: the track parameters are expressed to the vertex

- The tracks coming from the MS and from the ID are combined by means of a χ^2 cut-off construction
  - χ^2 constructed starting from the differences from track parameters and covariance matrix

- Fit of combined track



Important aspects:

- Alignment μ-System/ID,
- Measuring accuracy of E_loss in the calorimeters
- Scale of energy of the ID and the μ-System

Why Combined Reconstruction (I)

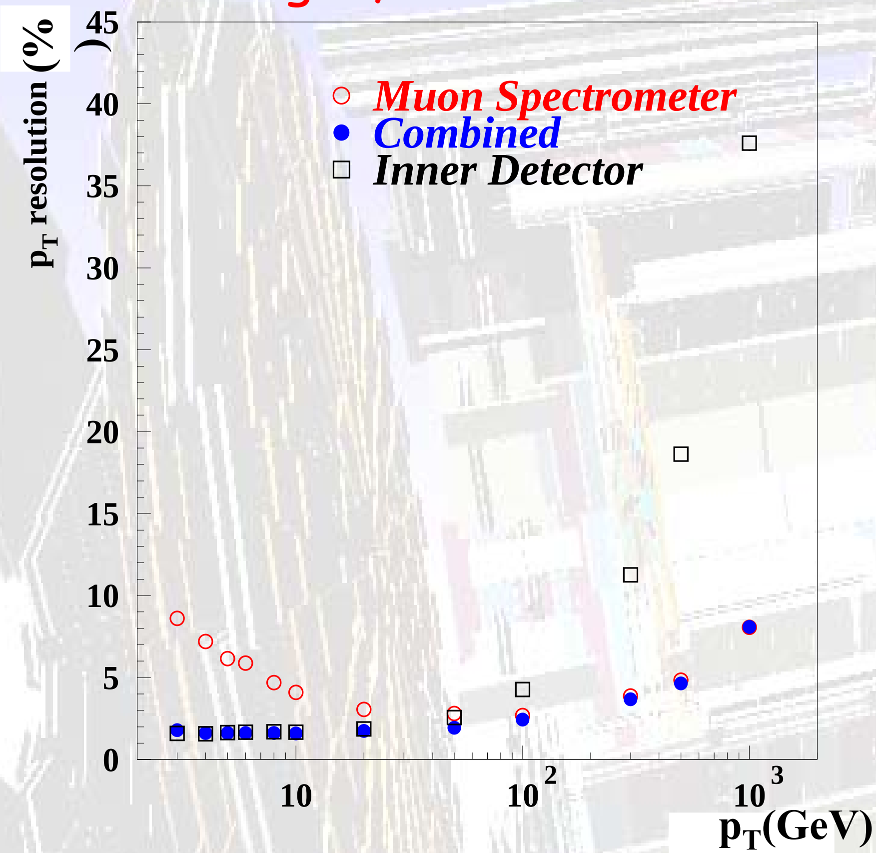
- **Improves the parameters measured by the track**
  - Allows a better momentum resolution
    - 20 GeV < pT < 100 GeV
  - Reduces the tails in the muon spectrometer resolution, mainly related to fluctuations in the calorimeters energy deposition

- **Improves Muon Identification**
  - Reduction of fakes reconstruction, particularly in presence of cavern background
  - Reconstruction of low pT muons that do not reach all the spectrometer stations
  - Rejection of μ coming from K,π decay requiring that the tracks are generated at the vertex
  - Discrimination of muon in hadronic jet from hadrons. A good μ identification for non isolated muons is needed for an efficient b-tagging.

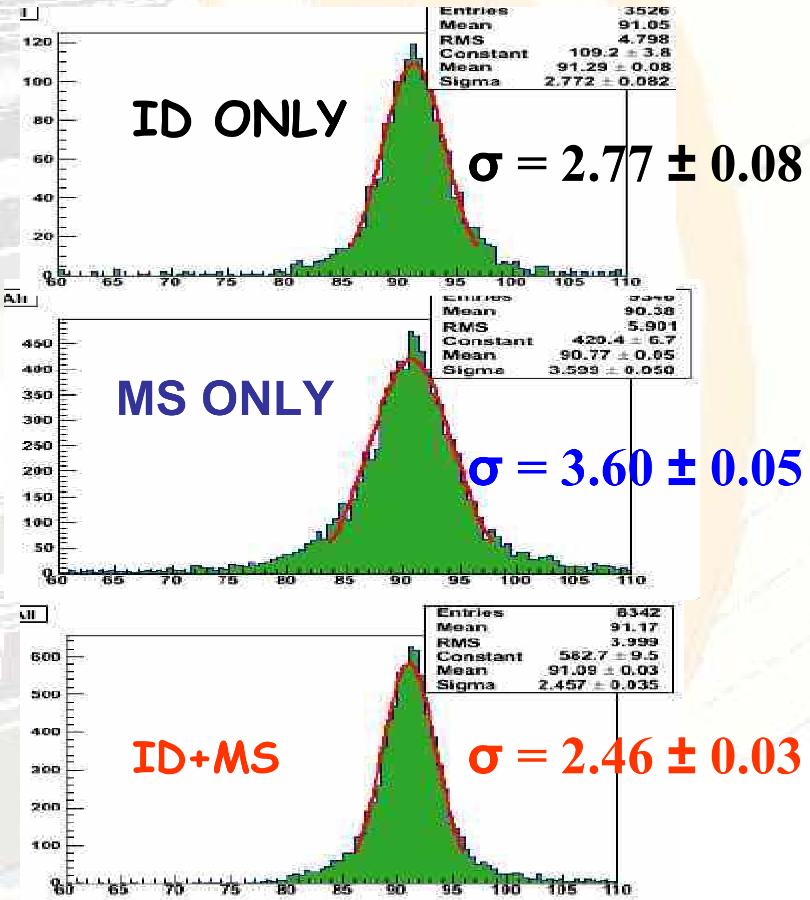
- **Allows a better understanding of the experimental apparatus**
  - Test of calorimeter calibration
  - Cross check for Inner Detector and spectrometer results

Why Combined Reconstruction (II)

Single μ



$Z \to 2\mu$ (DC3)



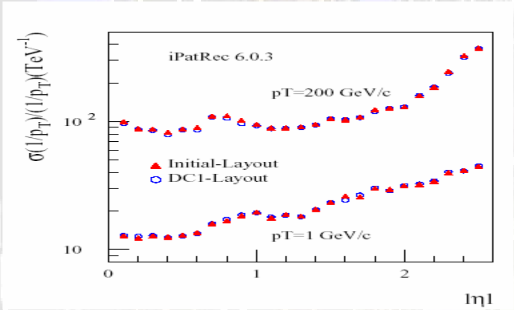
Improvement in momentum resolution

20 GeV < pT < 100 GeV

- Improvement of σ(Zmass) by ~10% (~30%) compared to ID (MS)

pT resolution: variation with pT and η

- $(\Delta p_T/p_T)$ is sum of measurement component (increases with pT) and Coulomb scattering component (constant)
- Inner Detector



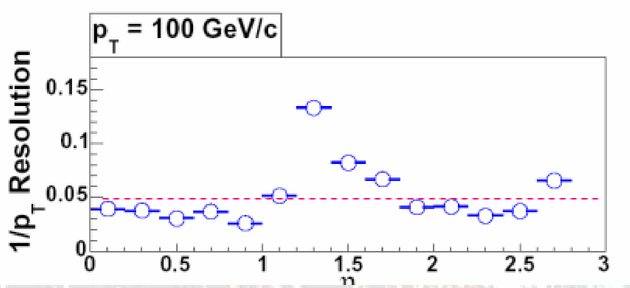
Resolution in extended barrel region (η < 1.9)

Measurement: ~40%*p_T (TeV)

Scattering: ~1.5% constant term

Rising to 200%*p_T + 3% at η = 2.5 (acceptance limit) as track exits solenoid with smaller traversed radial lenght Resolution approximately Gaussian

- Muon Spectrometer



In barrel and endcap toroids

Measurement: ~10%*p_T (TeV)

Scattering: 2~3% in barrel

3~4% for η > 1.8

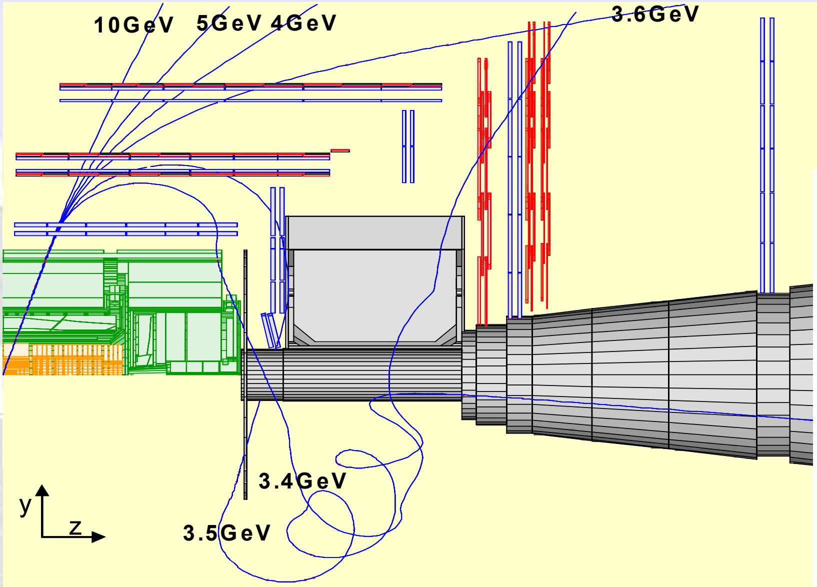
Scattering dominates for p_T below ~300 GeV

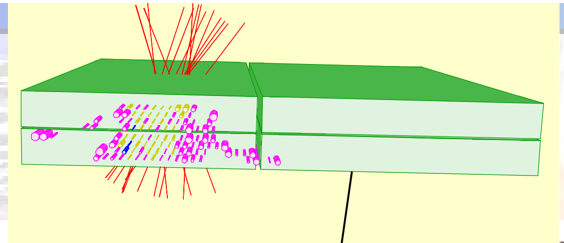
~150X_0 material traversed => non-Gaussian tails when back-tracked to vertex region

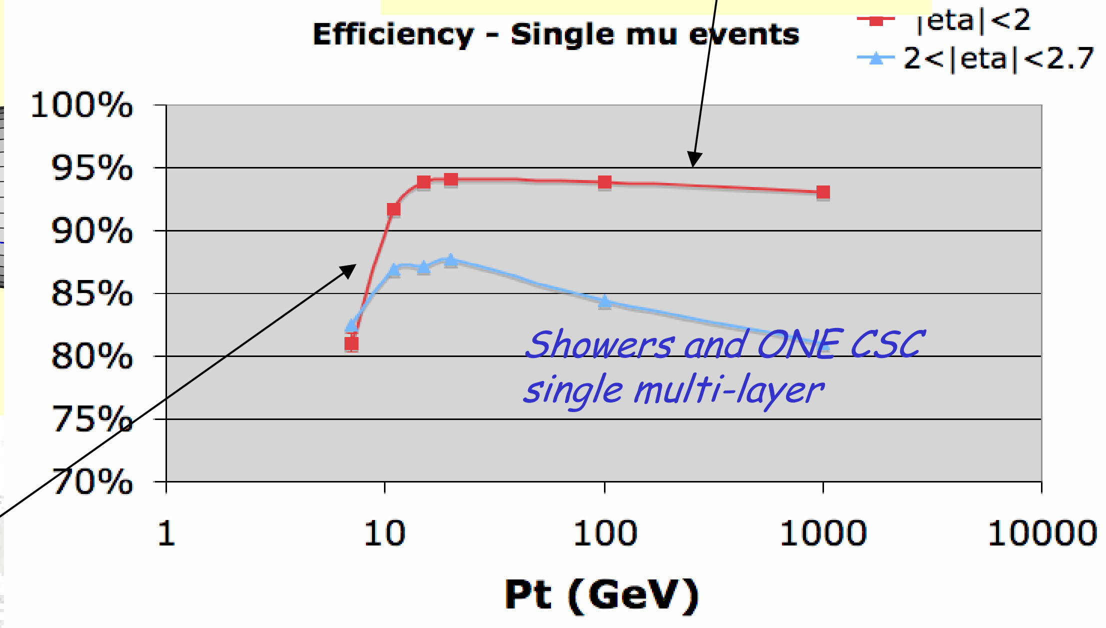
- **Inner Detector more precise at low momenta**
  - barrel toroid region : for p_T below 40~80 GeV
  - at substantially higher p_T for toroid transition region (1.2 < η < 1.8)
  - endcap toroid region
    - cross-over at ~80 GeV at η ~ 1.8
    - falls with increasing η to below 20 GeV at InDet acceptance limit η = 2.5)

low p_T MuonIdentification

'Drop' : muon showers in Calos





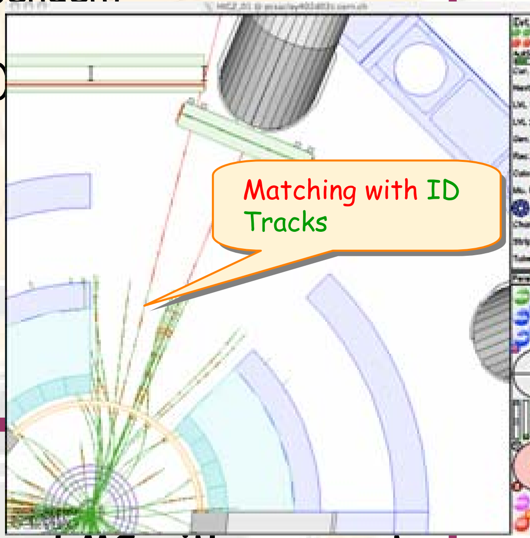


Low Pt algorithms must be used to recover efficiency

- **Reconstruction (SA-Combined) efficiency decreases very quickly at low p_T**
- Muon reconstruction at low pT in a very inhomogeneous MF is delicate
  - "complicated" trajectories, increased rate of "noisy" tracks
- Many μ's leave the calorimeters with a very weak energy and they don't reach at "medium" or "outer" stations
  - large fraction of the E_loss in the Calorimeters (3 GeV), at low η

Muon Reconstruction Algorithms

- **Muonboy** ≡ fully integrated in ATHENA software framework
  - standalone reconstruction in the MS
- **STACO** ≡ track extrapolation to the Interaction point (IP) and combined reconstruction with Inner Detector and muon id
  - **Statistical combination** of two measurements using the parameters of the reconstructed tracks and their covariance matrixes
    - works because the ID and Muon System measurements are independent
      - reminder: propagation down to beam line of the MS track
        - (accounting for Eloss corrections, multiple scattering)
- **MuTag** ≡ low pT muon identification
  - starting from ID reconstructed tracks, at the perigee
  - Track extrapolation to the inner and middle MS stations
    - To fill the hole around η≈1.3 → EE chambers are missing
  - try to associate ID tracks with segments which were not already associated with a combined track (STACO)
  - apply additional cuts to the quality of the segments



- **MOORE** ≡ Muon Object Oriented Reconstruction:
- **MuID** ≡ Muon Identification
- Global fit of muon tracks by using the hits measured separately by ID and MS with muons at the time of the SA Reconstruction
- **MuidLowPt**: extrapolated tracks at the MS chambers (MDT, RPC, CSC), and their hits are associated ID-tracks according to their proximity in η and φ
  - Similar reconstruction strategies

- **Fully integrated in the new Reconstruction EDM requirements**
- **Modular and Flexible Structure**
- **Can be used, integrated and expanded for other applications:**
  - **TestBeam, Commissionning, etc..**

Reconstruction Output – Event Types

- **ESD (Event Summary Data)** - This is the output of combined reconstruction
  - Contains reconstruction output data, at the level of hits on track and calo cells
  - Calibration, alignment studies, refitting tracks, track extrapolation, analyses
    - Size ~ 1 Mb / event
- **AOD (Analysis Object Data)** - This is the reduced event representation output of reconstruction on ESD suitable for most physics analysis.
  - Contains reconstruction output data, at the level TrackParticles and CaloClusters, very loosely identified particles
  - the final event data objects used for analysis. - about 100 kB.
- **TAG** - This is an *event-level meta-data* which is a thumbnail to give efficient identification and selection of events of interest to a given analysis.
  - Size: ~2 kB per event.

Web page and documentation:
https://uimon.cern.ch/twiki/bin/view/Atlas/PhysicsAnalysisTools

Muons in the ESD/AOD

- "high Pt" and "low Pt" algorithms "give" muons which are merged and placed inside a **MuonContainer** (i.e. Data access key :"MuidMuonCollection", "StacoMuonCollection")
  - StoregateKeysForESD , StoregateKeysForAOD , Muon in the EventTag
  - The class that stores the muons can be found at: AOD Muon Class
  - Below is a list of some of the functions and what they return
    - muonEvent
  - MuonAnalysisTutorial

Reconstruction Performances

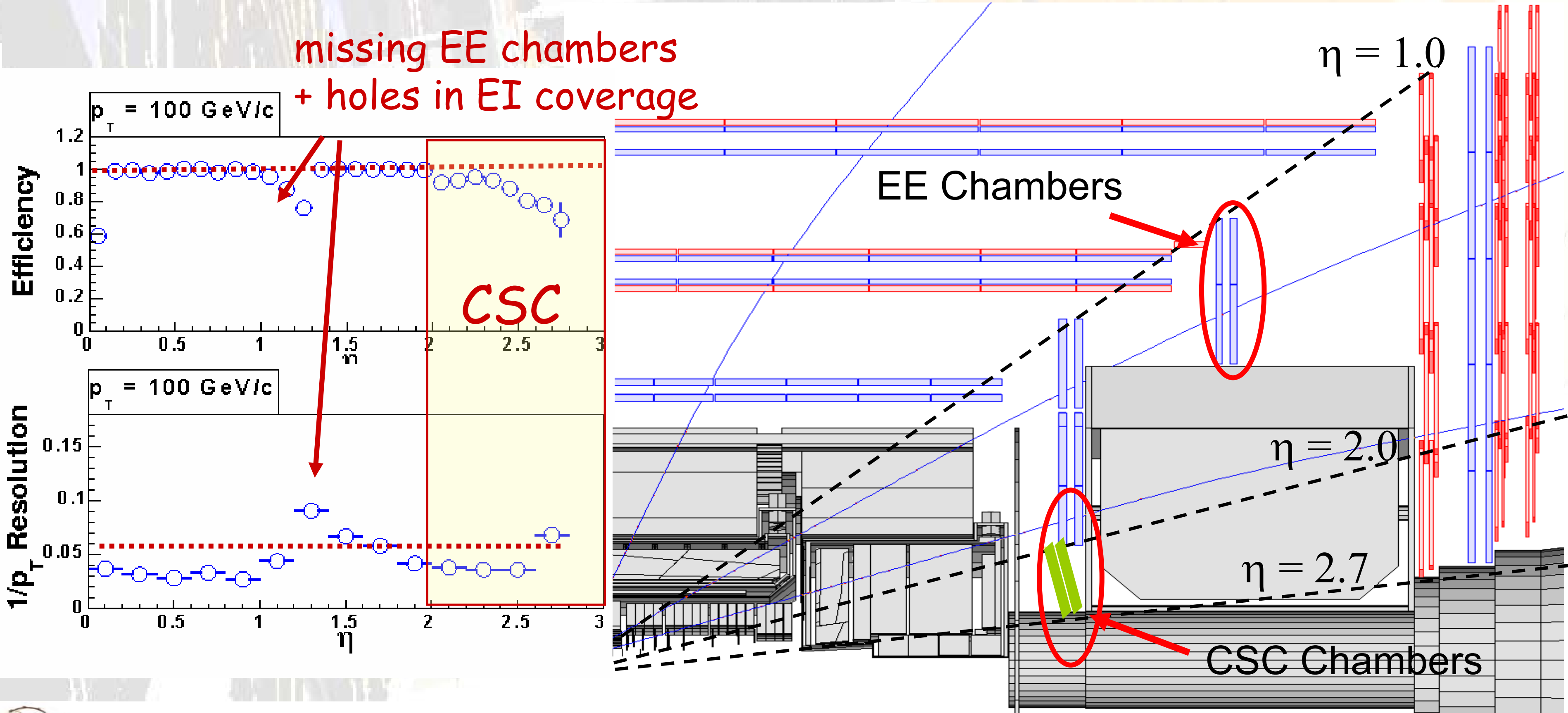
Several MC data samples have been used

- **Single muon samples for a fixed pT**
  - **(from 3 GeV/c up to 1 TeV/c)**
- **$Z \rightarrow \mu\mu$ (Jimmy)**
- **$H \rightarrow ZZ^* \rightarrow 4\mu$**

MuonSpectrometer Layout

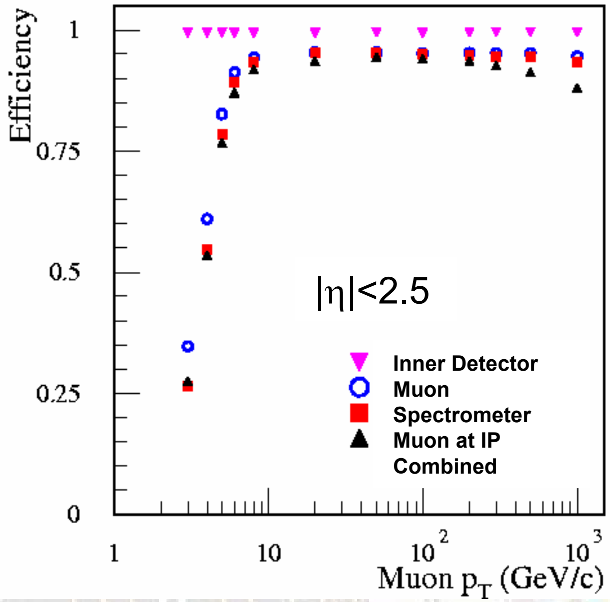
Initial Layout main modifications wrt DC1/2:

- EES and EEL chambers have been removed:
  - performance degradation is expected for 1.0 < eta < 1.4
- Half as many CSC chambers (single layer)



Single muons : efficiency vrs pT

Single muons, no backg.



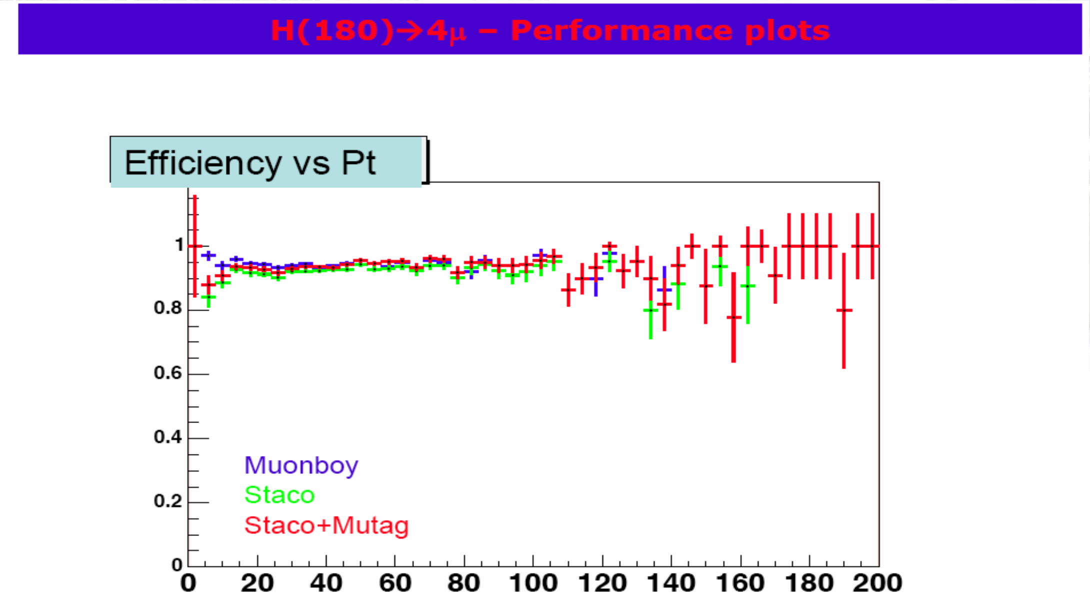
Efficiency plateau ~ 95%

Low p_T :

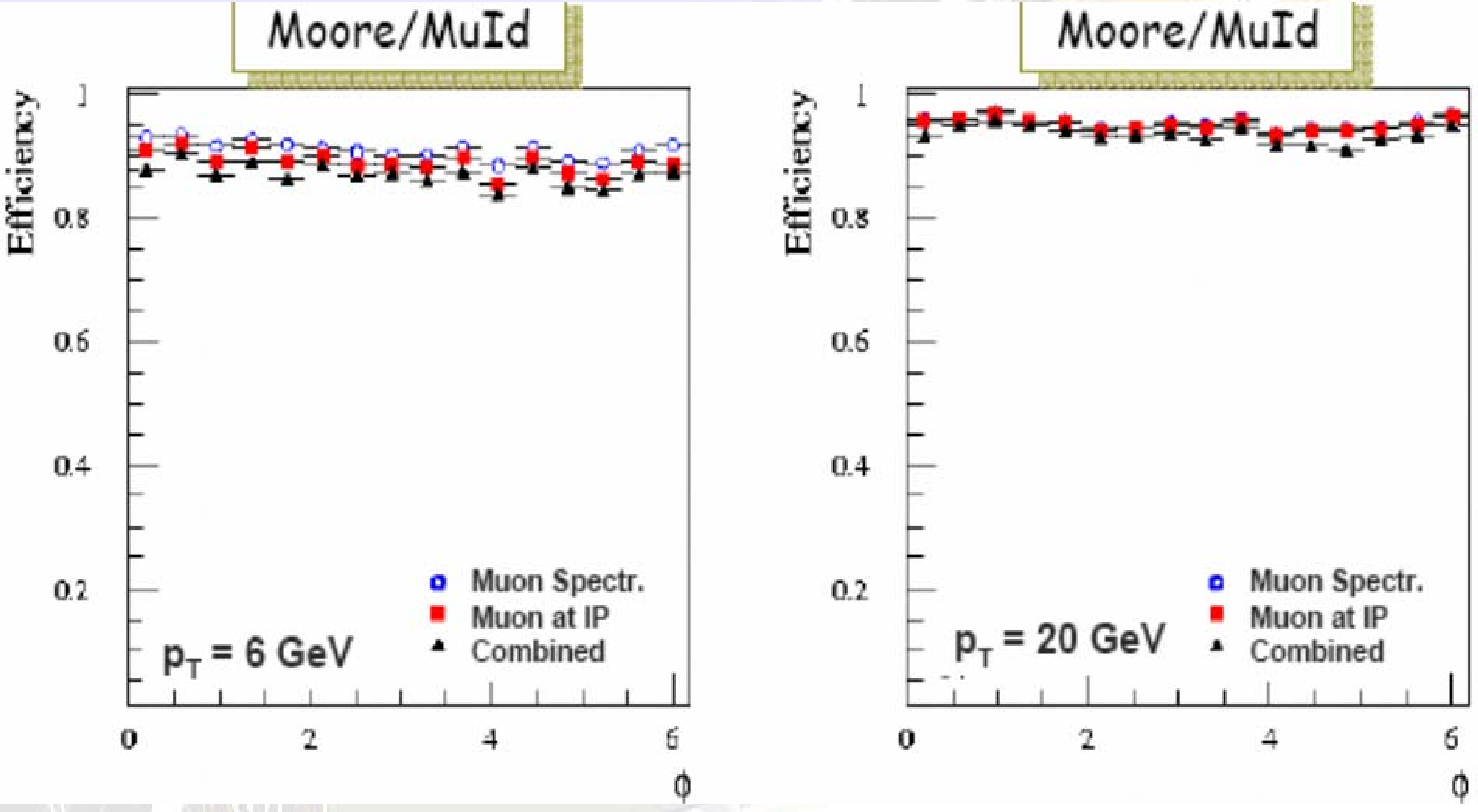
- Only μ with E>3-4 GeV/c reach the MS
- These muons don't reach the MS external station → few measurements
- Multiple scattering and inhomogeneous B make the pattern recognition more complicated

High p_T :

- decreased efficiency of combined reconstruction at very high p_T since pattern recognition suffers of possible e.m. showers accompanying high p_T muons

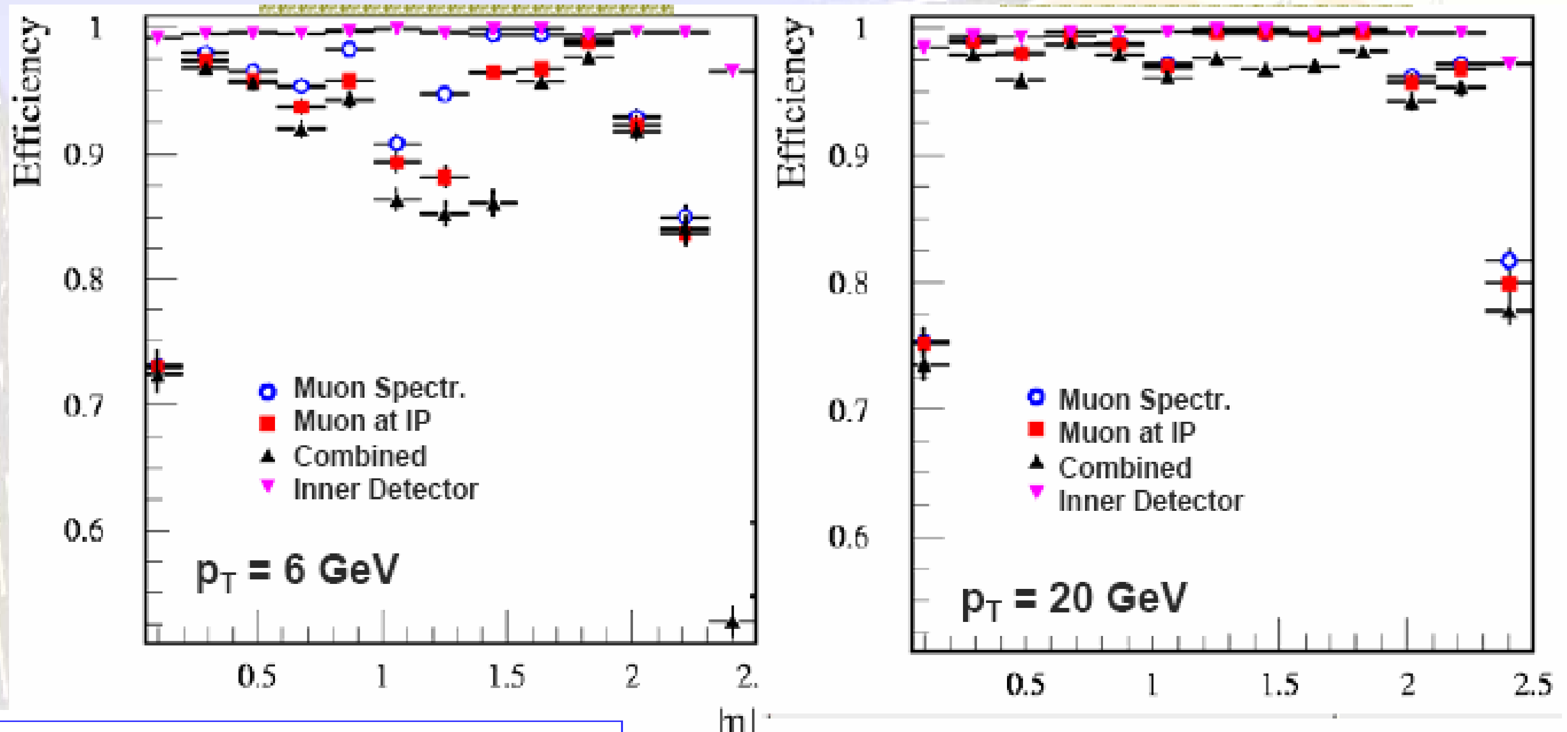


Single muons : efficiency vrs φ



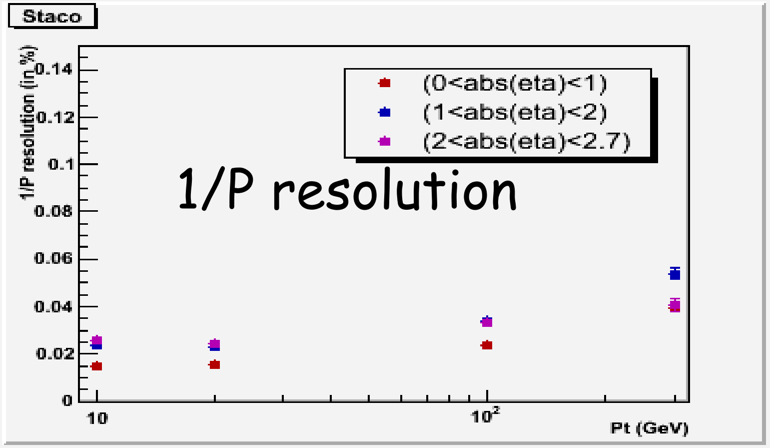
Uniform eff vrs φ

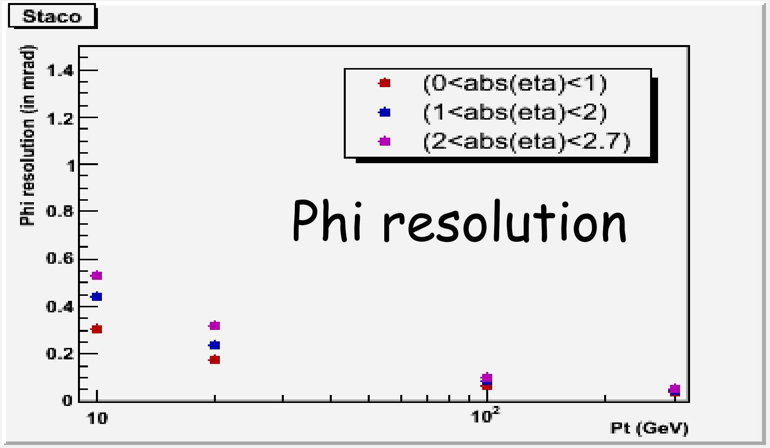
Single muons : efficiency vrs η

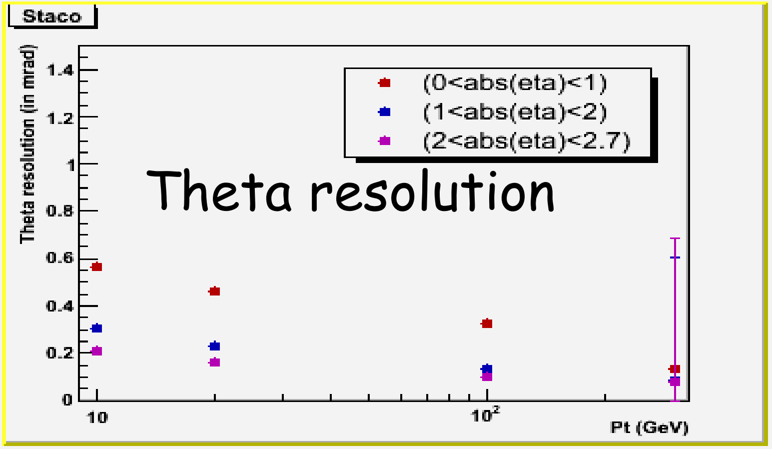


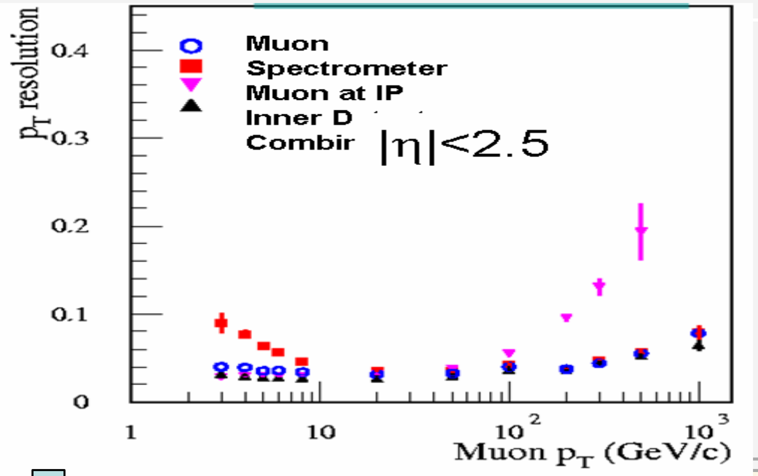
- Low Efficiency at η≈0 due to a central *crack* needed for cables and services (not present in *layout wrt* TDR)
- Second coordinate of CSC missed in the simulation → low efficiency for |η|>2
- Magnetic field tracking hard in the region 1<|η|<1.5 → low efficiency for low p_T μ

Single muons : momentum resolutions



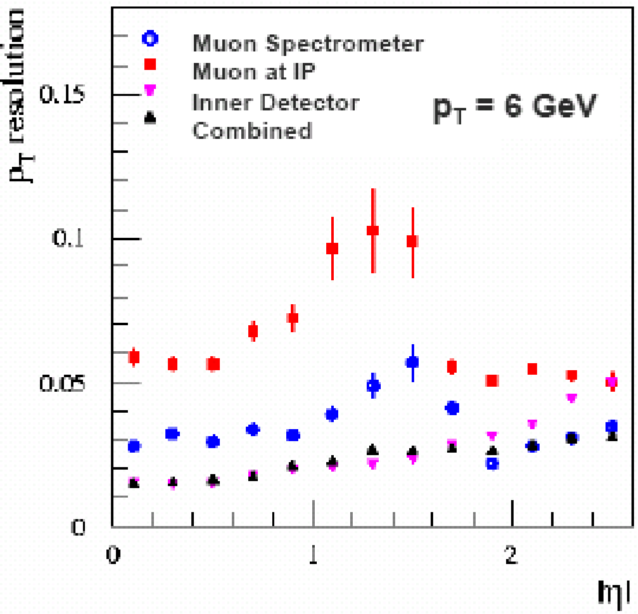


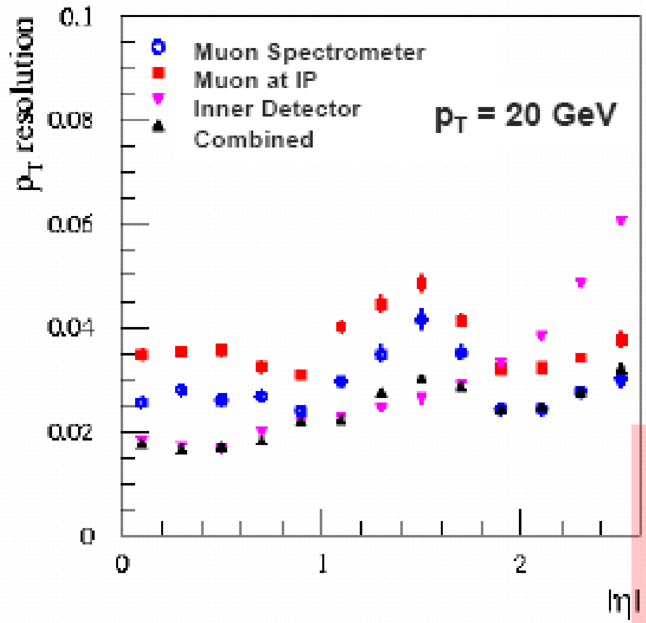


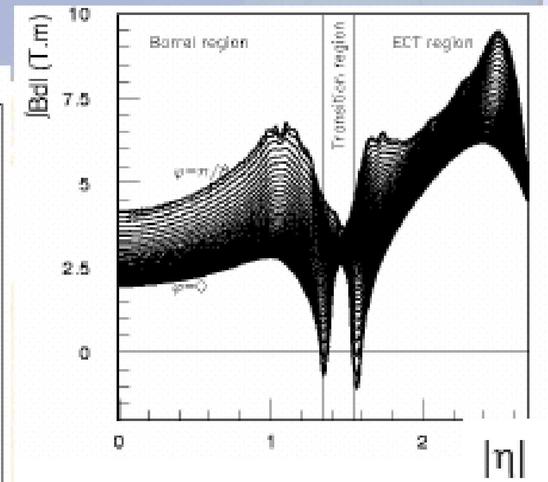


- Inner Detector dominates below 20 GeV/c
- MS dominates at high p_T

pT resolution vrs η



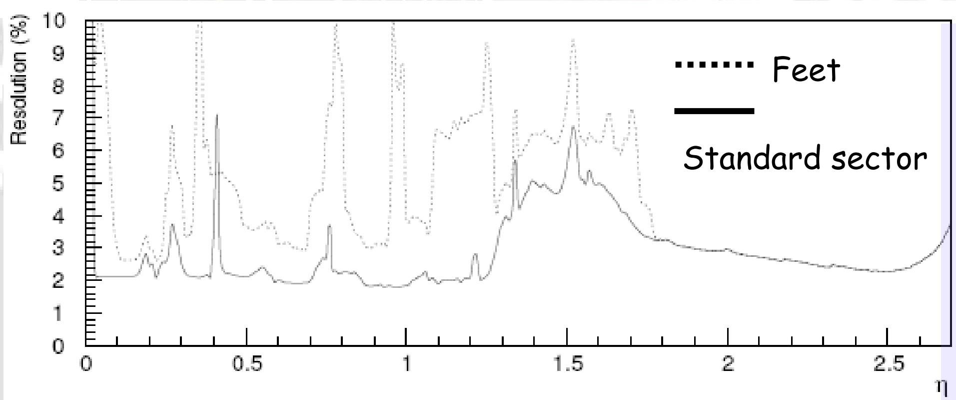




Degradation of pT resolution in the transition region caused by a magnetic field highly inhomogeneous and from the fluctuations related to the absorption material in the calorimeters (mainly for μ at low pt)

- tracking is complicated in the region 1.< |η| < 1.4

for *p*T=100 GeV

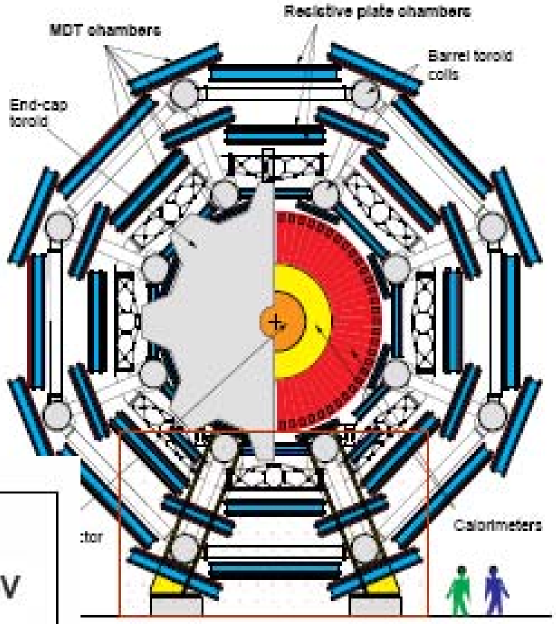


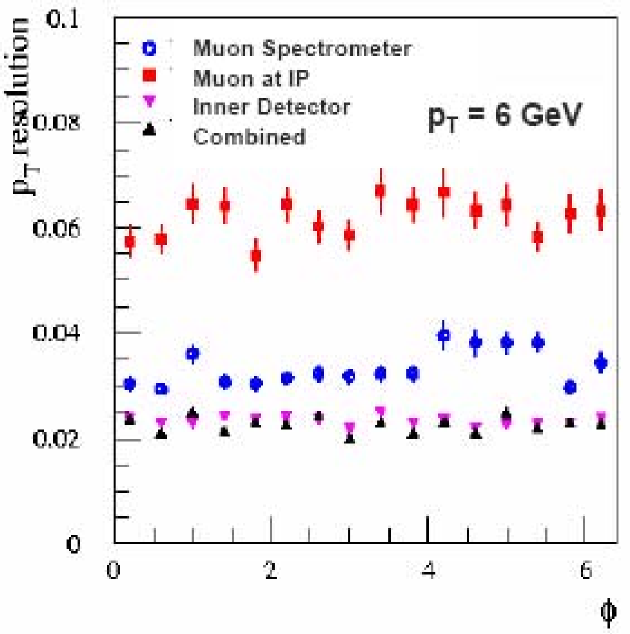
a theoretical prediction of the momentum resolution curve, averaged over the φ-angle, as a function of η

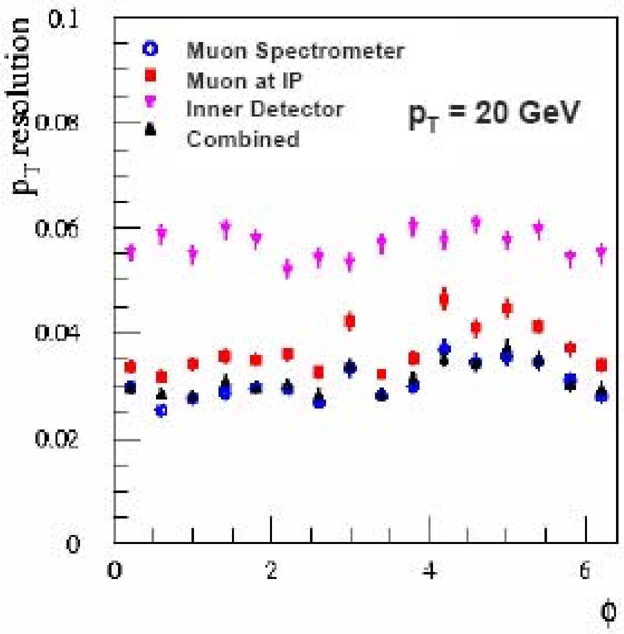
Complicating items that have been taken into account are the

- three-dimensional magnetic field,
- resolution on position measurements,
- detailed chamber layout, and
- a simplified material distribution in order to take material effects into account.

Single Muons: p_T Resolution Vs ϕ

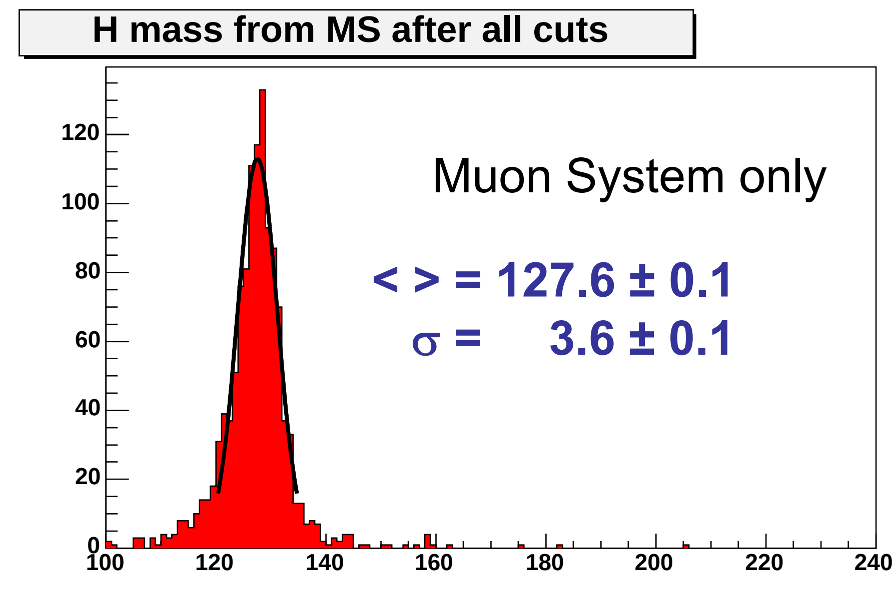


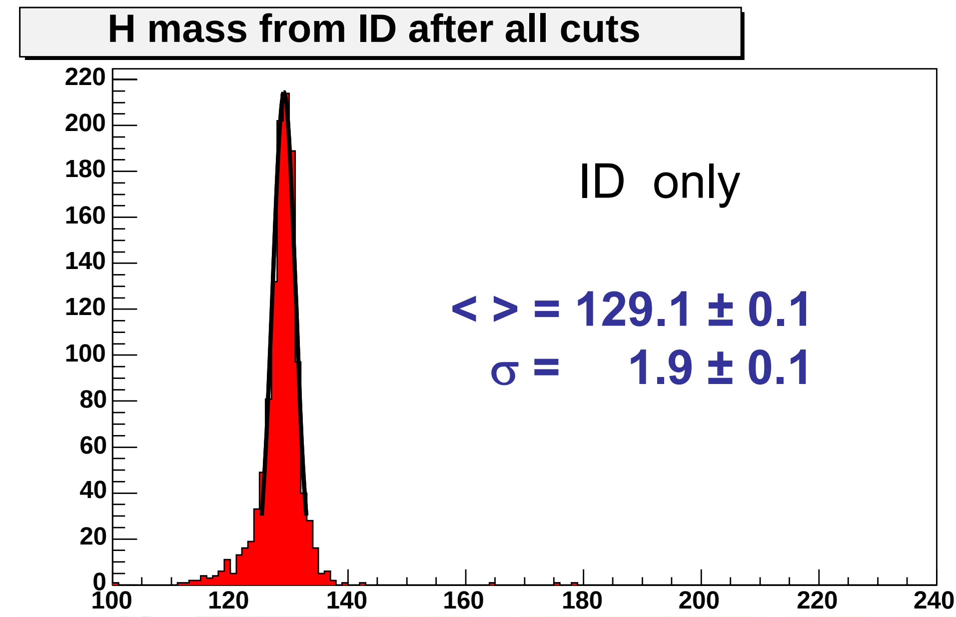


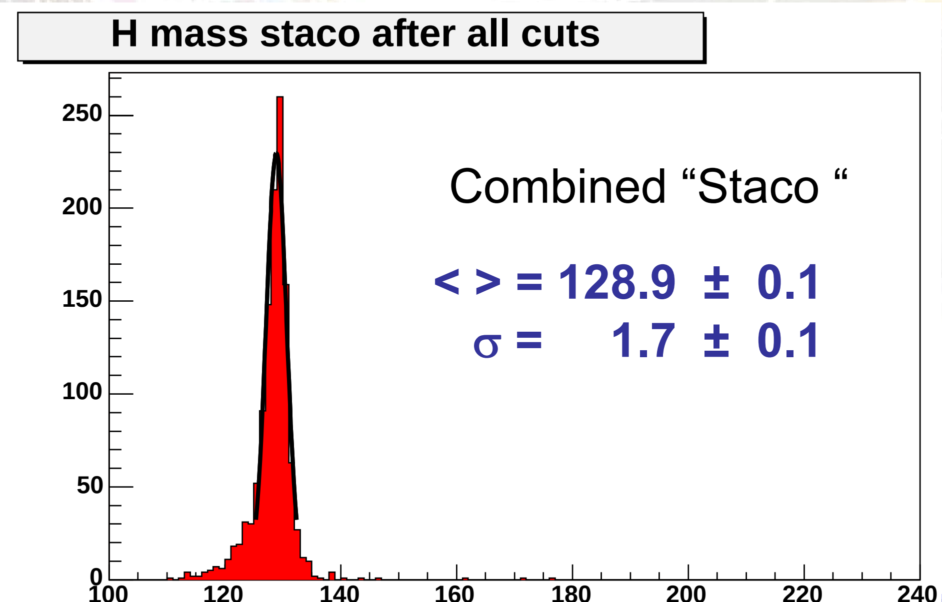


- Uniform resolution Vs ϕ
  - Small effect in the feet region

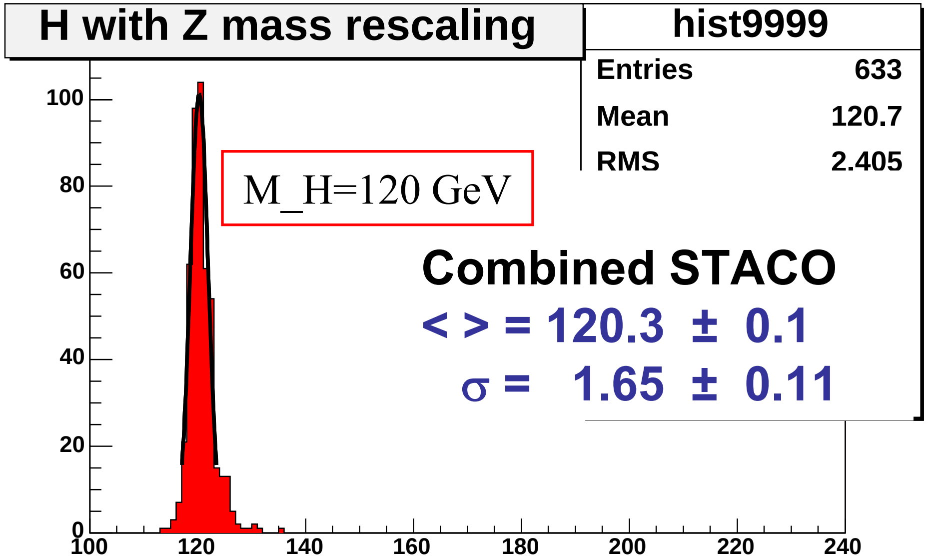
Higgs (130) mass before applying constraint on the Z mass

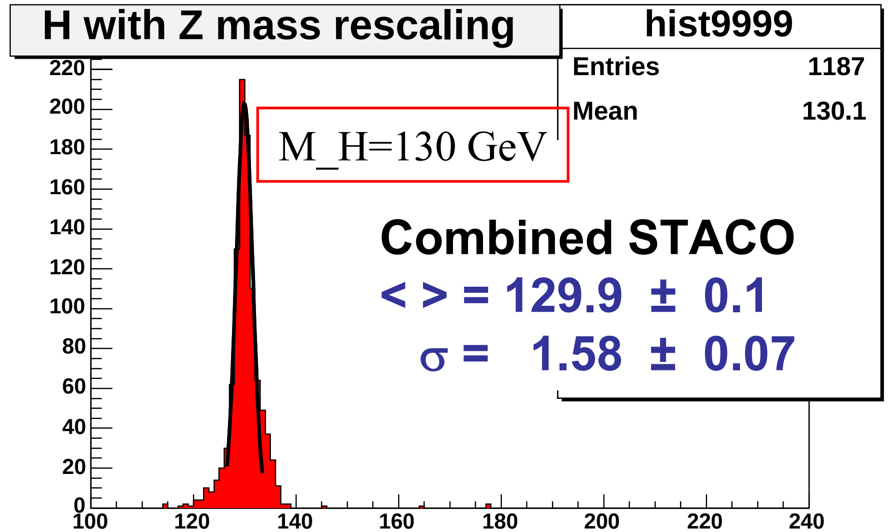


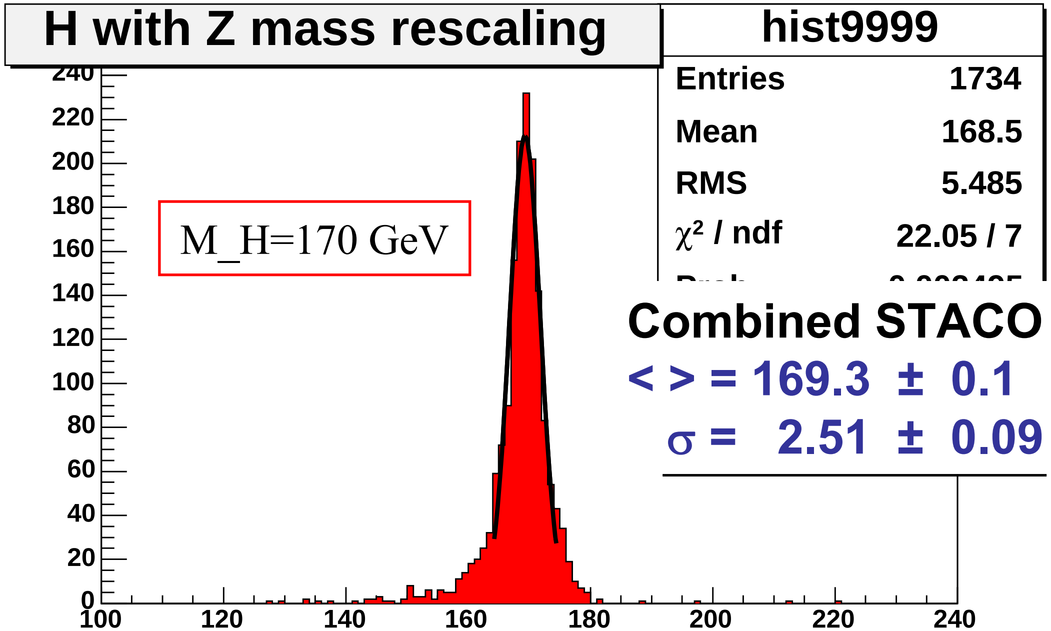




Higgs mass when applying constraint on the Z mass

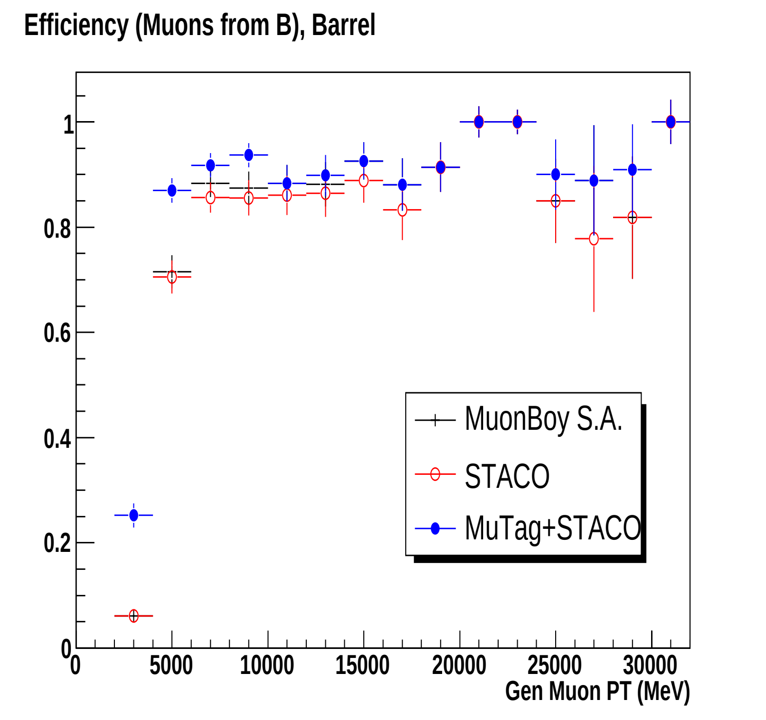


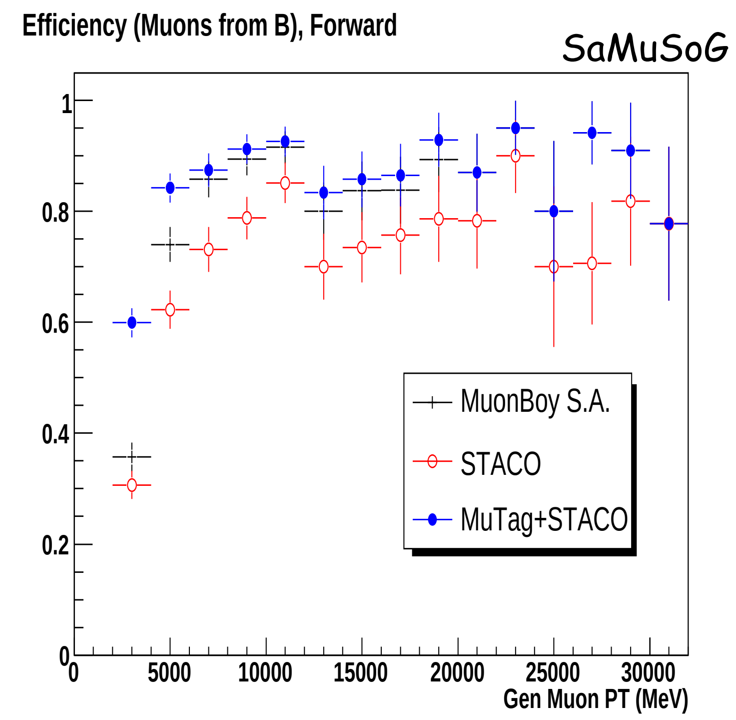




Potential of low-pT Algorithms as a Soft Muon b-tagger

- Study STACO / MuTag performance in jet environment
- Use (WH, mH=120GeV, H->bbbar) rome samples





High efficiency of STACO/MuTag down to p ~ 4GeV in jets

Keeping in mind

- Muon reconstruction efficiency and resolution depends on the knowledge of the following effects :
  - Chambers Positions (Alignment)
  - Chamber Deformations (Including Temperature Effects)
  - Wire Sag
  - T0, R-T Relations
  - B Field
  - Dead / Noisy / Anomalous Channels
  - neutron / γ Cavern Background
  - Geometric Material Distribution
  - Reconstruction Algorithm Optimization

- We plan to address all of these issues before LHC start-up.

Conclusions

- A **robust and reliable muon identification and momentum measurement** is crucial to fully exploit the physics potential of LHC over a large momentum range, starting from few GeV (B-physics study) to few TeV, where the presence of new physics might be expected.

- Atlas Muon spectrometer presents *complementary designs with* **large pseudorapidity coverage (|η| < 2.7 for track reconstruction)**

- Magnetic Field configuration determines the main features of the MS:
  - **good pT resolution up to high η → air-core toroids: low bending power → very good resolution of the muon chambers, alignment and calibration are crucial items**
  - **Flat resolution in η, σpT/pT of few % up to 100 GeV/c**

- Muon Reconstruction **Algorithms** follow similar approaches: local reconstruction of segments in the multi-layer chambers, then extrapolated in defined detector regions.
  - standalone track reconstruction in the spectrometer, then matching with inner detector tracks

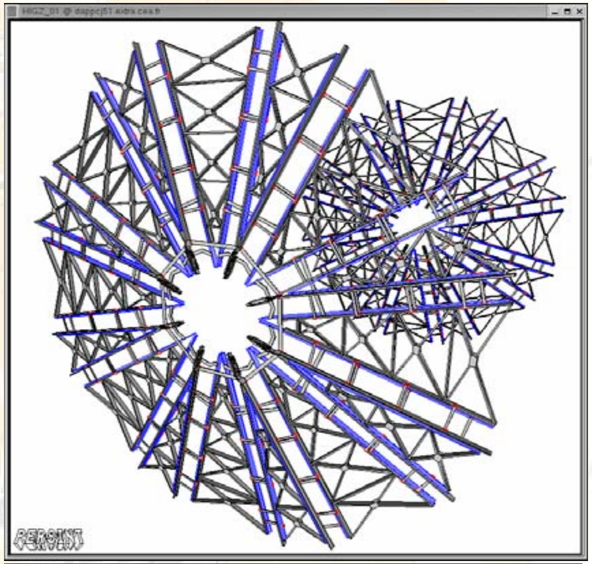
Plans

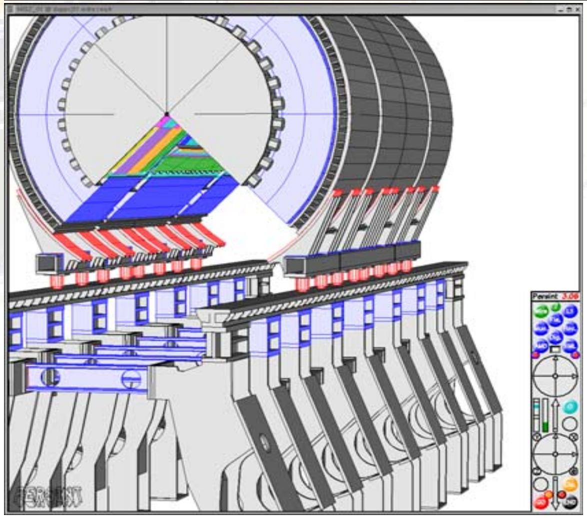
- **Muon CSC notes** studying
  - the **effects of misalignment, magnetic field and miscalibration of the MDT-chambers** on the efficiency, fake-rate and momentum resolution of the ATLAS Muon Spectrometer.
  - In a first step these effects are estimated on the basis of Monte-Carlo Truth information to provide an overview of the importance of these effects and a limit to which these effects must be understood to achieve the required performance.
  - In a second step we study different approaches to determine the resolution and the efficiency of the ATLAS Muon Spectrometer with data only not relying on any MC information.
  - These methods are based on the one hand on the study of well known resonances and their decay into two muons like Z->$\mu\mu$ or Y->$\mu\mu$ and J/Ps->$\mu\mu$ and on the other hand on in-situ use of single muons.
  - How to the presented methods for the correction of misalignment and miscalibration of the MDT-chambers.

A big effort is now concentrating on tuning geometry model, simulation (detectors and trigger), calibration, tracking, event-selection and analysis and on preparing detector commissioning before the data taking startup, with the very good colaboration with Muon Simulation Team

MuonSimulation Plans of Mis-Alignment

- Plans for Release 13
  - Larger Random Displacements
    - σ_θ up to 3 mrad and σ_{xyz} up to 4 mm
  - Global Barrel and Big Wheel displacements
    - Details Under Discussion
  - Additional Inert Material Decriptions
    - Saddle, Big Wheel Supports, ID Patch Panel, Access Platforms
  - Resolution of Some GEANT4 Issues
    - Handling Complex Chamber Shapes without Using Up Allotted Memory
  - A More realistic implementation of Cavern Backgound in GEANT4
- Not for GEANT4
  - Chamber deformations (sag, torsion, cross-plate expansions, global temperature expansion…etc)
  - Deformation Corrections to be applied at Reconstruction





Documentation

- TDR - ATLAS Muon Technical Design Report
- Muon Software Repository (All Versions)

Wiki pages

- Atlas MuonSpectrometer HomePage
- MuonSoftware HomePage
- MuonSoftwareTutorials
- MuonSpectrometerSimulation
- MuonCalibAlign
- MuonReconstruction
- Combined Muon Reconstruction
- MuonSoftwareValidation
- MuonSoftwareHyperNews

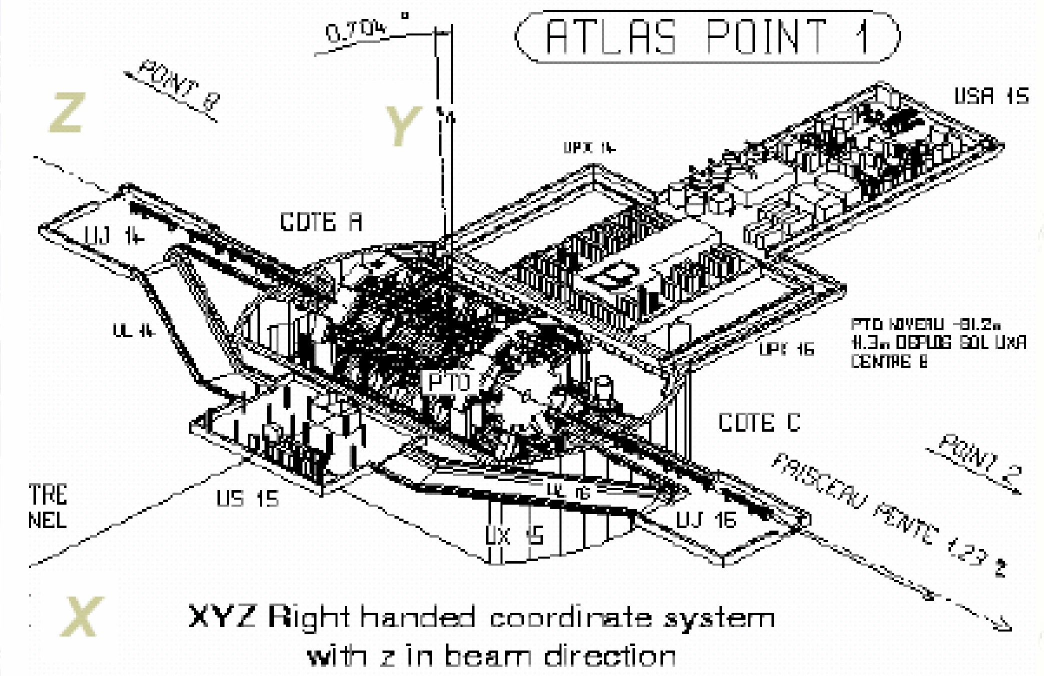
Acknowledgements

- Many thanks to those who shared their knowledge, and helped me directly or indirectly to make this talk possible and in particular to my colleagues of the SaMuSog, MOORE and MuonSimulation Team in ATLAS Collaboration
- the Organizers of this School, for inviting me to give this talk

BACKUP SLIDES

ATLAS Conventional Coordinate System

- **z-axis** directed along the tunnel (beam axis)
- **x-y** define the plane perpendicular to the beam direction
- **x-axis** pointing from the interaction point to the center of the LHC ring
- Given the symmetry, **cylindrical coordinates** are more useful : **φ, θ, R**
- Instead of the polar angle θ, the so called **pseudorapidity η** is often used:
  - $\eta = -\ln(\tan(\theta/2))$



ATLAS Offline Software

- **Requirements**
  - Description of geometry and Event
  - Visualization
  - Simulation of detector
  - Reconstruction of physical objects starting from raw data
    - output by the Event Filter (The final level of the Atlas Trigger) with <1.5 MB> arriving at a rate of about 200 Hz.
      - The data format is a **"byte-stream"** - that is a organized set of packed bits containing all the information about the event
  - Data store - Data analysis
- **Characteristics**
  - High complexity
  - Long lifetime of the experiment (20 years)
  - Large Data Volume (1 Pbyte/years)
  - Several Developers - Scattered all around the world
- **Need of**
  - Flexibility, abstraction, maintainability, uniformity, modularity, reusability, computing mechanism and development distributed.
- Development of a software framework common to all the applications:
  - ATHENA (ATLAS realization of a High Energy and Nuclear physics data analysis Architecture)
    - Detector Geometry, Data Description and Maintenance, Calibration Services, Databases, Simulation, Reconstruction.
    - Choice of using GRID technology