Muons in ATLAS Overview

Muon physics
Muon spectrometer
Muon trigger
Muon reconstruction
Muon validation

www.slac.stanford.edu/~cla/Leptons/Muons.html

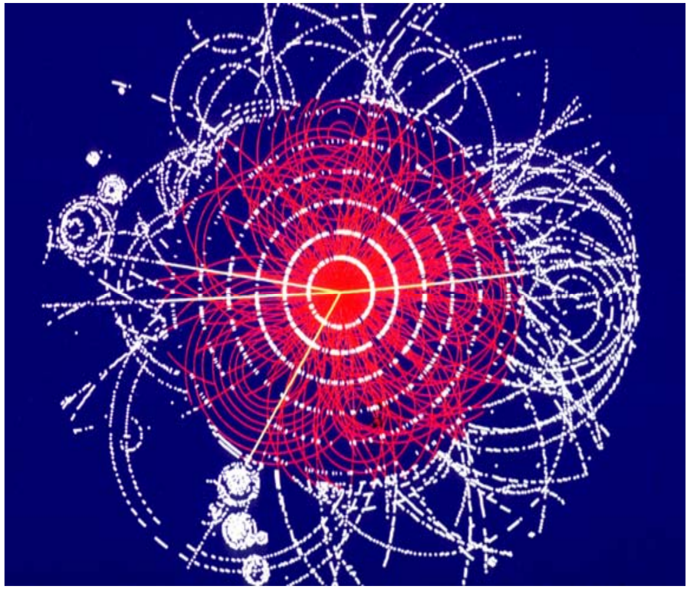
Muon Physics

High p_T muons appear in many interesting physics signatures:

- ❑ SM Higgs
- ❑ MSSM Higgs, A–>μμ
- ❑ Z', W'
- ❑ b decays
- ❑ t decays

c1

H–>ZZ*–>μμμμ



Needs: high trigger efficiency and
good momentum resolution

Different types of muons:

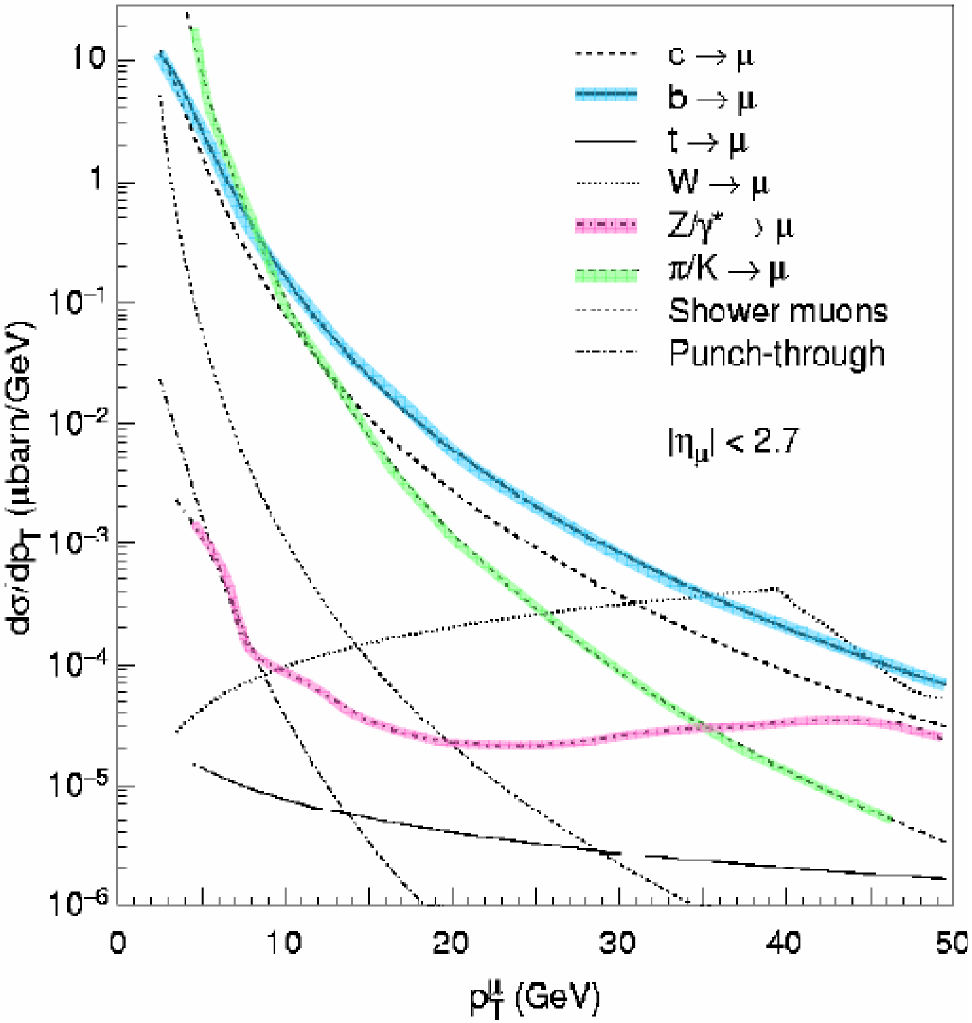
- ❑ isolated (high p_T/low p_T)
- ❑ in jets
- ❑ cosmics
- ❑ halos

3-10 GeV muons
are important for b-physics

c1 connection signatues <-> isolated/in jets

cla, 3/3/2007

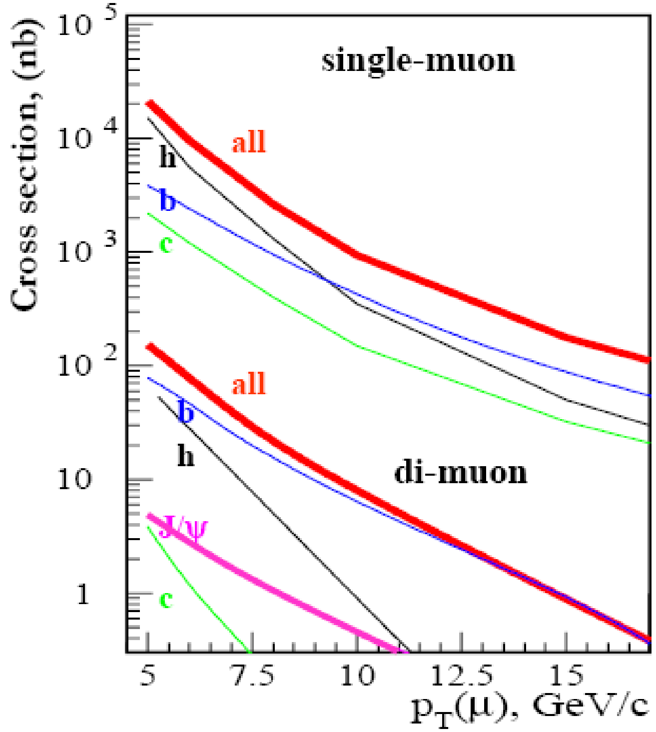
Muon cross section @ E_{cm}=14TeV



Muon rates @ 10^{-34} $cm^{-2}s^{-1}$:

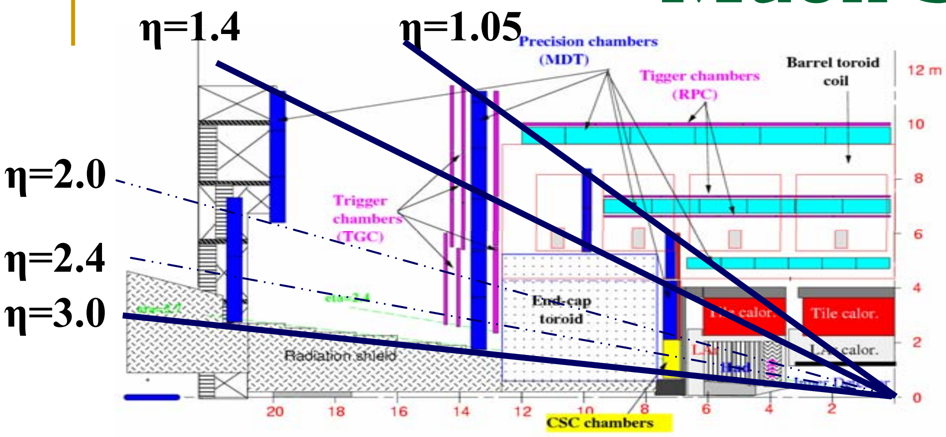
30 kHz for p_T>8 GeV
1 kHz for p_T>20 GeV

Event rate after trigger: ~100 Hz



p_T<10 GeV: pion/Kaon decays dominate
p_T>10 GeV: b,c decays dominate

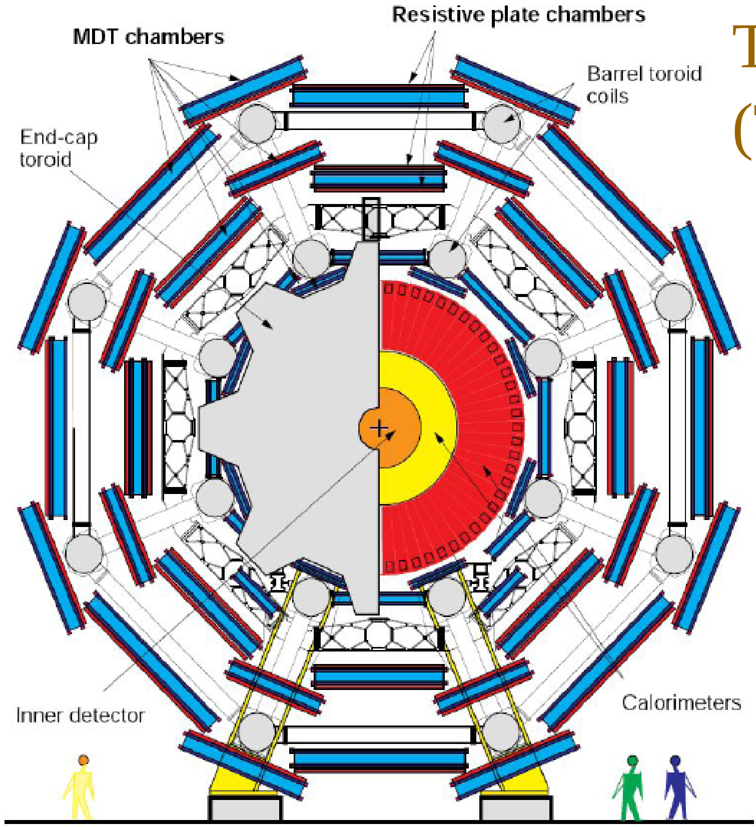
Muon Spectrometer



Barrel: $|\eta|<1$

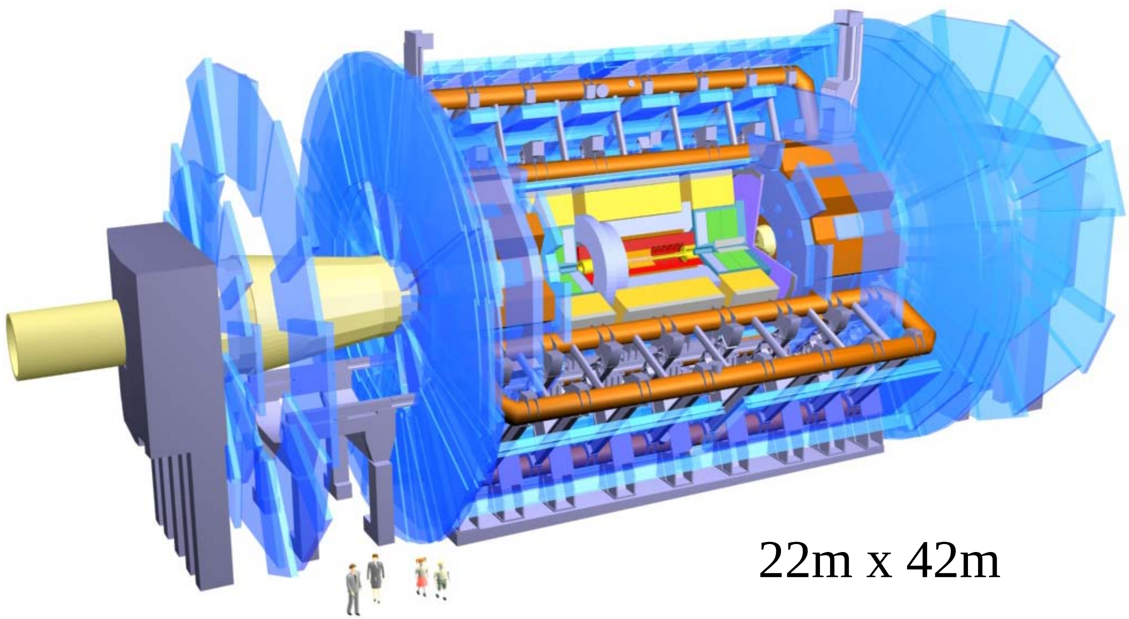
Transition region: $1<|\eta|<1.4$

End-caps: $|\eta|<2.7$



Three layer structure both for barrel and end-caps

(The EE(=extra end-cap) ring was canceled)

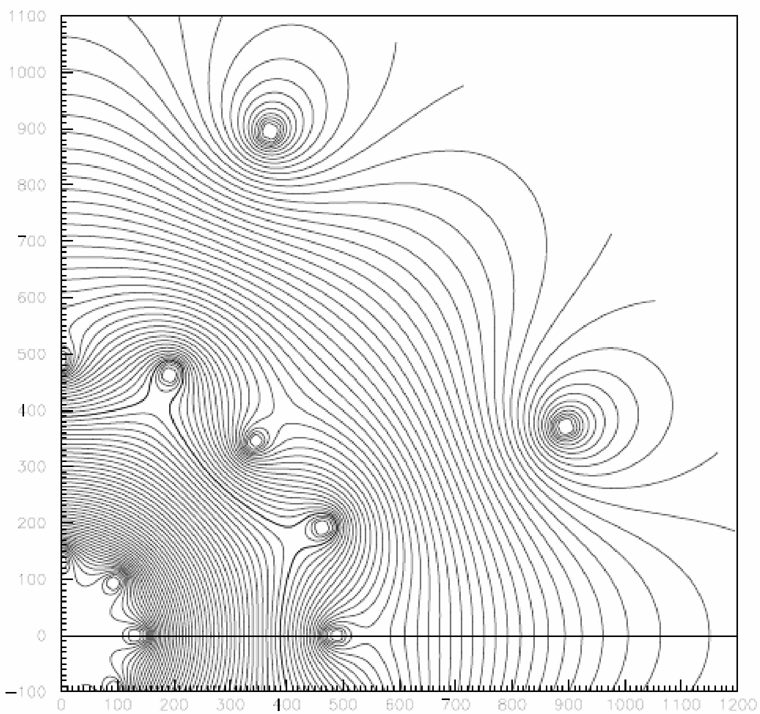


22m x 42m

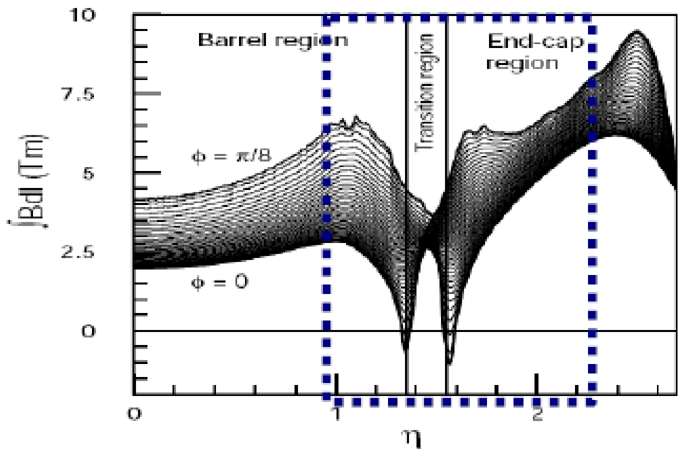
Magnetic Field

- Inner detector: solenoid field of B_z~2T
- Muon system: toroidal field to measure muon trajectories:
  - 8 superconducting coils in barrel and each end-cap
  - main field component: B_ϕ~0.5 T

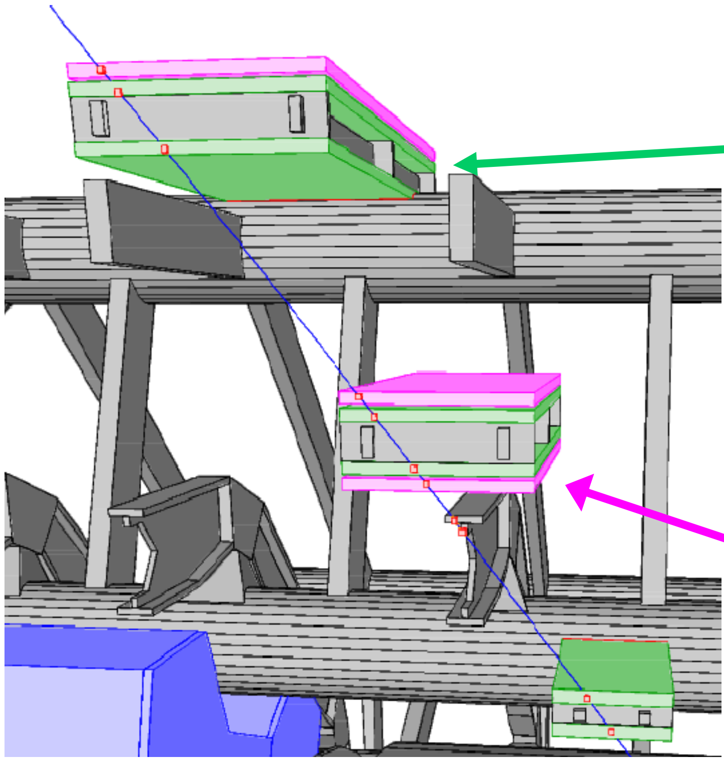
Magnetic field lines in x-y:

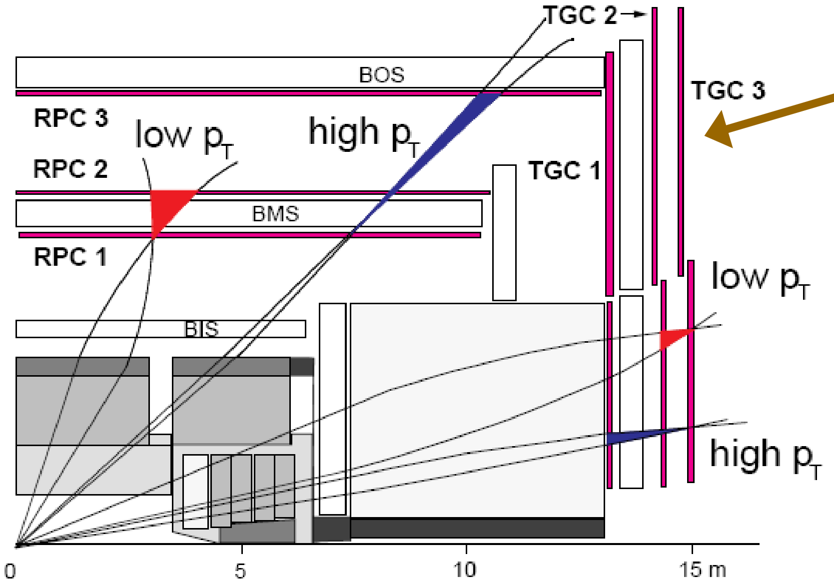


Bending power:



- Increases with eta
- Complicated transition region





Tracking detectors:

Monitored Drift Tube chamber (MDT)

- Three stations, resolution: 50 μm

Cathode Strip Chamber (CSC)

- replace MDTs in inner station for $2<\eta<2.7$ (better rate capacity and radiation harder)

Trigger system:

Resistive Plate Chamber (RPC)

- At two outer stations of the barrel
- Time resolution: <2ns

Thin Gap Chamber (TGC)

- For end-cap triggers $\eta<2.4$

Low p_T trigger: $p_T > 6$ GeV

High p_T trigger: $p_T>20$ GeV

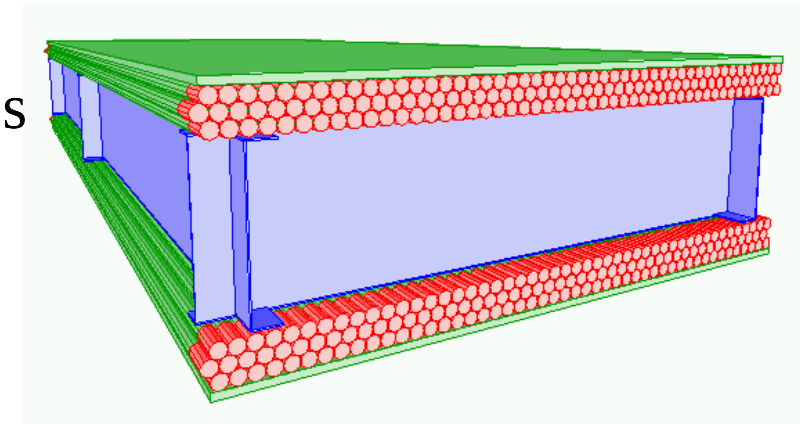
Number of readout channels:

400k for tracking, 900k for trigger

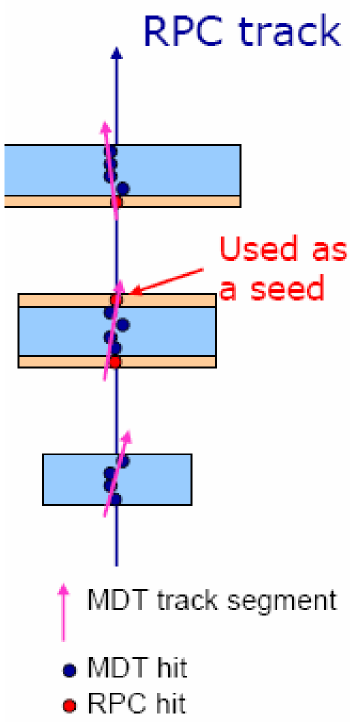
MDT chamber:

- Two separated multilayer of drift tubes
- Tube diameter: 3cm

Number of chambers: 1194



Track reconstruction:

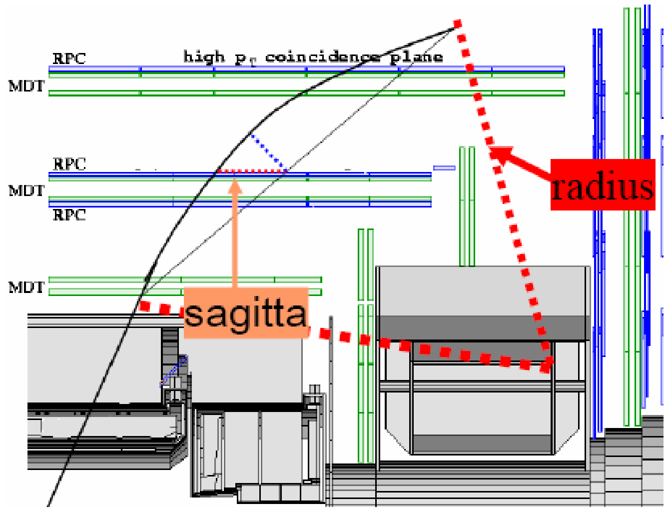


1. Segment finding
2. Fitting min χ^2

Chamber naming:

B=barrel, E=end-cap
I=inner, M=middle, O=outer
S=small, L=large; F=feet, R=rail
and: BOG+BOH=BOF

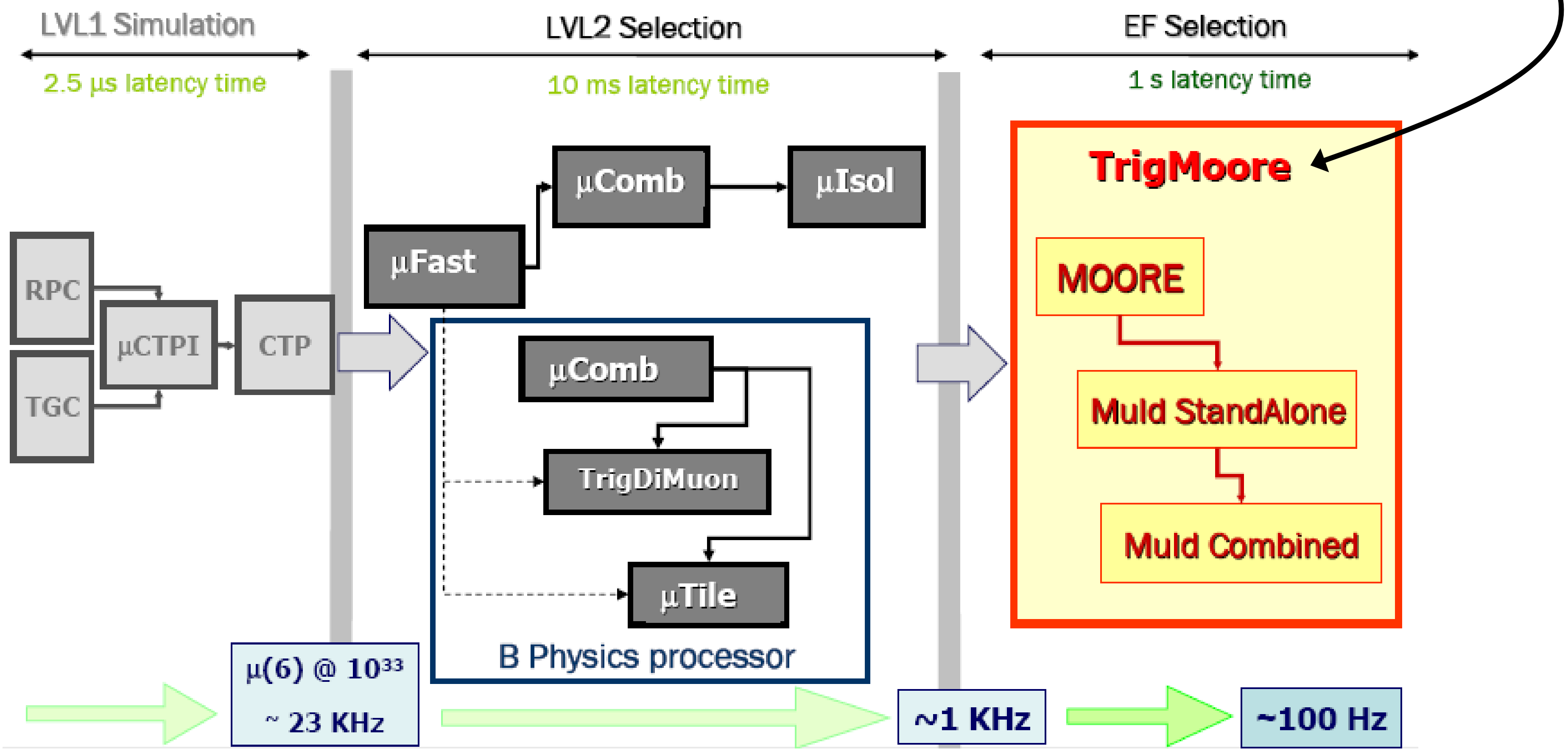
p_T measurement from sagitta in magnetic field:



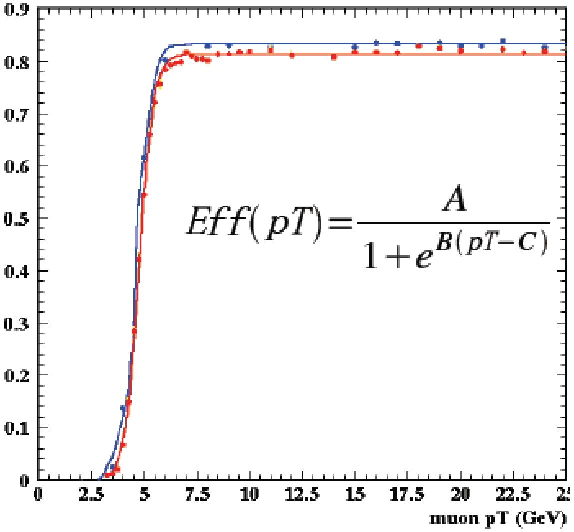
Muon Triggering

Reconstruction algorithms were adapted to run in HLT on ROIs.

Full trigger chain:



Low pT trigger turn on at 6 GeV



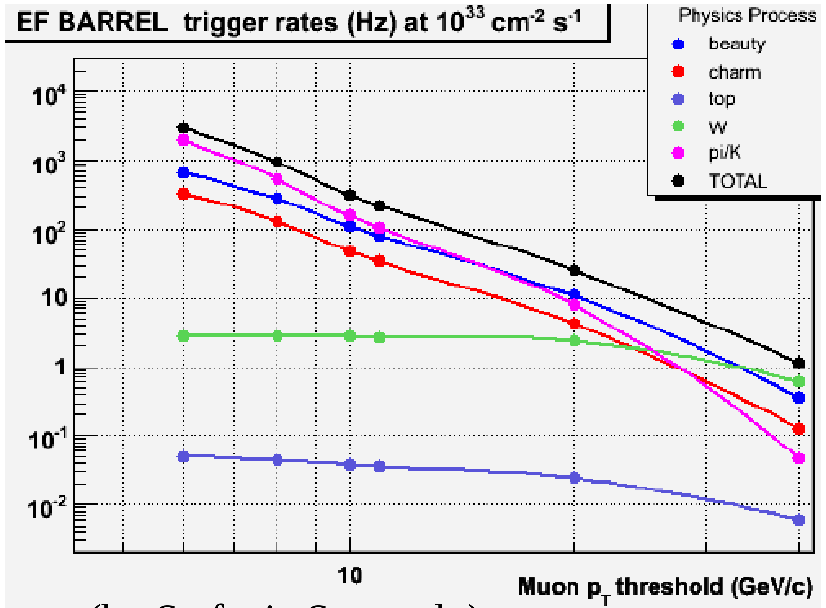
$$R_i = \mathcal{L} \int_{p_T\_\inf}^{p_T\_cutoff} \frac{d\sigma_i}{dp_T} \cdot \varepsilon(p_T)\, dp_T$$

Total rate for typical scenarios:

mu(6): 3000 Hz

mu(20): 25 Hz

Event Filter output rates:



(by Stefania Spangolo)

Muon sources	5 GeV/c threshold kHz	6 GeV/c threshold kHz
π/K	5.0	1.9
b	1.2	0.67
c	0.65	0.34
W	0.003	0.003
t	negligible	negligible
Total	**6.9 kHz**	**3.0 kHz**

Muon Reconstruction

Two containers in AOD: StacoMuonCollection MuidMuonCollection

	StacoMuonCollection	MuidMuonCollection
Using muon system only:	Muonboy	MOORE
Combined with Inner Detector:	STACO	MuID
Low p_T algorithm: (muons don't reach outer stations)	MuTag	MuIDLowPt

New: MuGirl: started as independent low pT algorithm, now extending to become a complete id tool

Finally only one should be chosen, maybe combination ?

c2

STACO / Muonboy / MuTag

Muonboy: 3D pattern recognition, proceeding outwards

Oldest algorithm, started in Fortran, now converted to C++

STACO (STAtistical COmbination) principle:

Combined InDet & MuSp parameter fitting using covariance matices

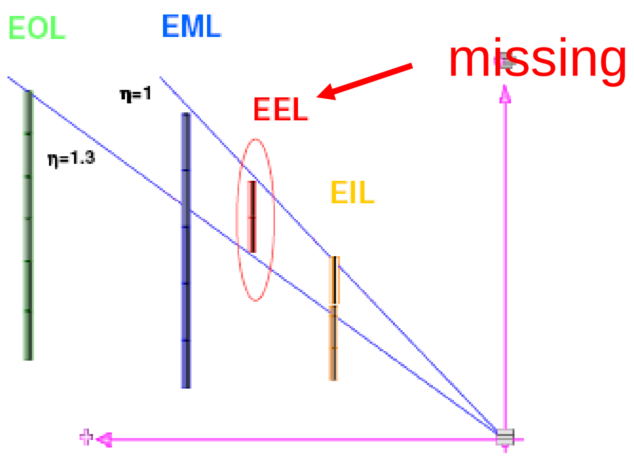
$$\left(C_1^{-1} + C_2^{-1}\right) \times P = C_1^{-1} \times P_1 + C_2^{-1} \times P_2$$

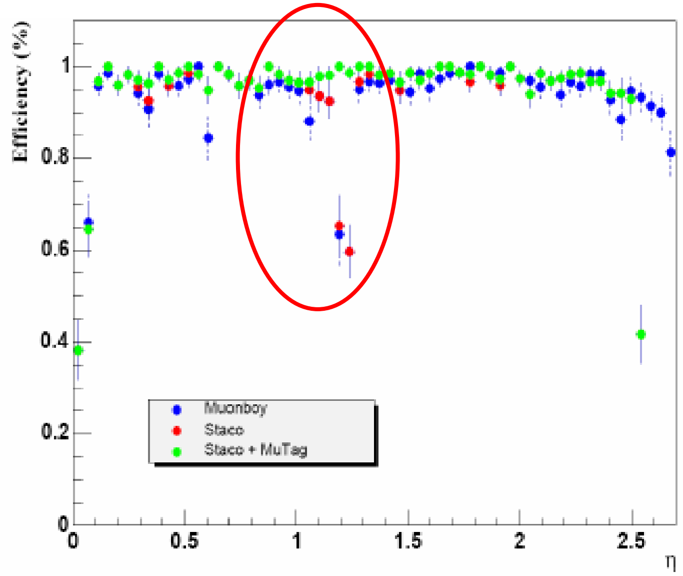
$$C = \left(C_1^{-1} + C_2^{-1}\right)^{-1}$$

P_i: track parameter vectors

C_i: their covariance matrices

MuTag: Instead of sagitta, extrapolate InDet tracks to medium station and compare to hit.





Hole closed now!

c2 people: saclay muon groupe
cla, 3/5/2007

MOORE / MuID

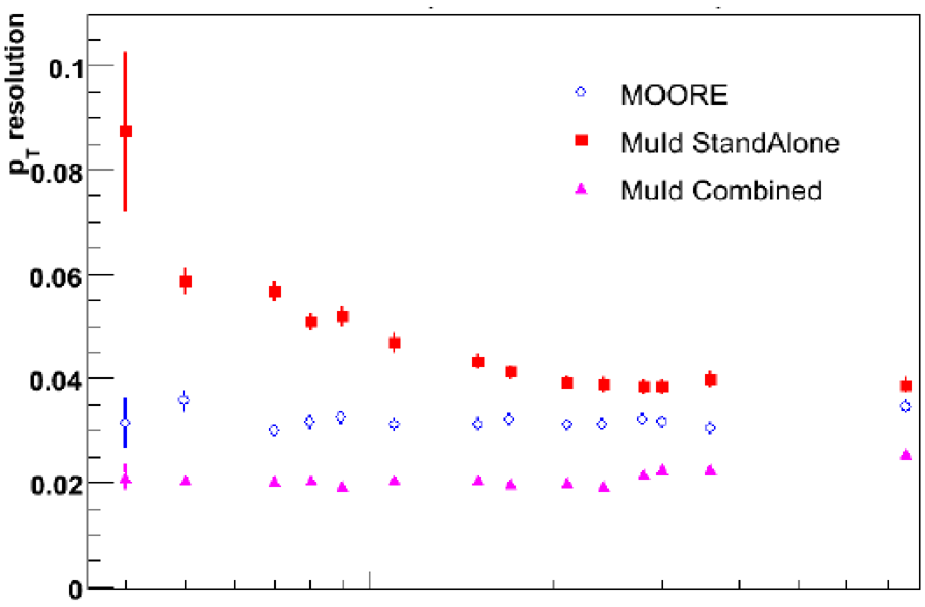
MOORE (Muon Object Oriented REconstruction)

- ❑ Pattern recognition from regions of activity in MS
- ❑ Parameters given at first measured point

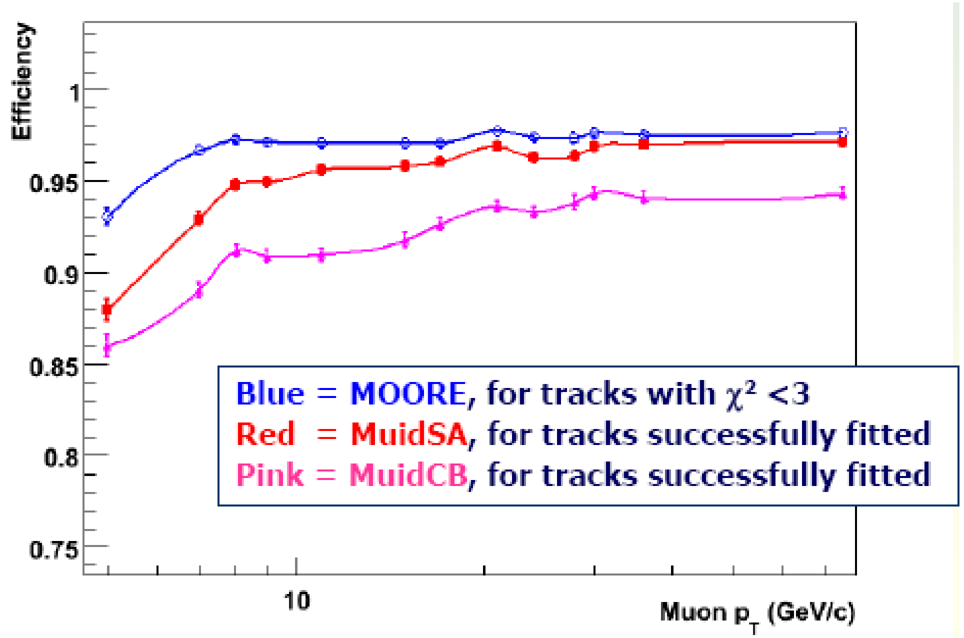
MuID (Muon IDentification):

- ❑ using MuSp, InDet and calorimeter
- ❑ track matching with $\chi^2 <$ cut-off
- ❑ parameters given at interaction point

Performance:

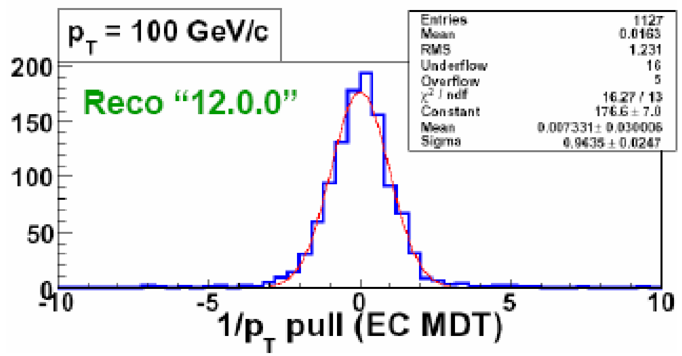


(by Steffaia Spangolo)



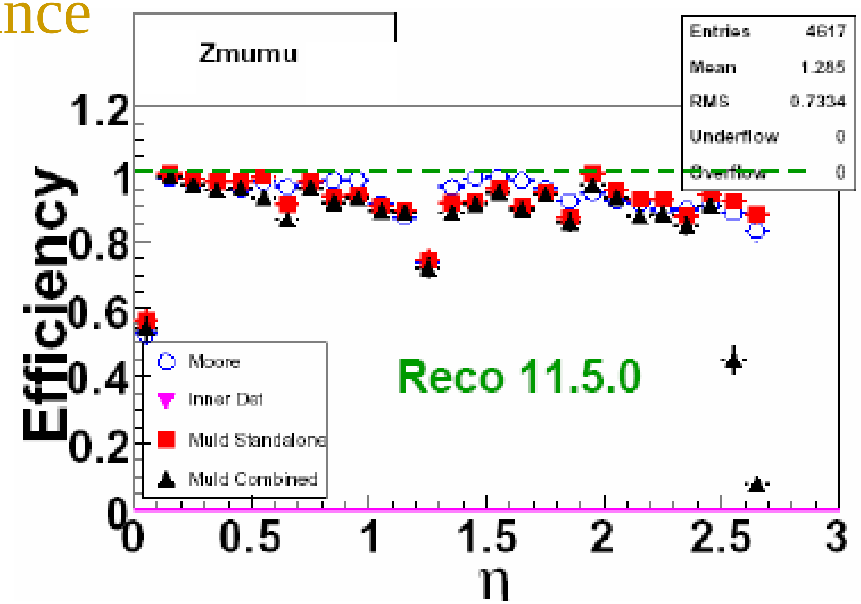
More MOORE examples

MOOR pull for $1/p_T$:



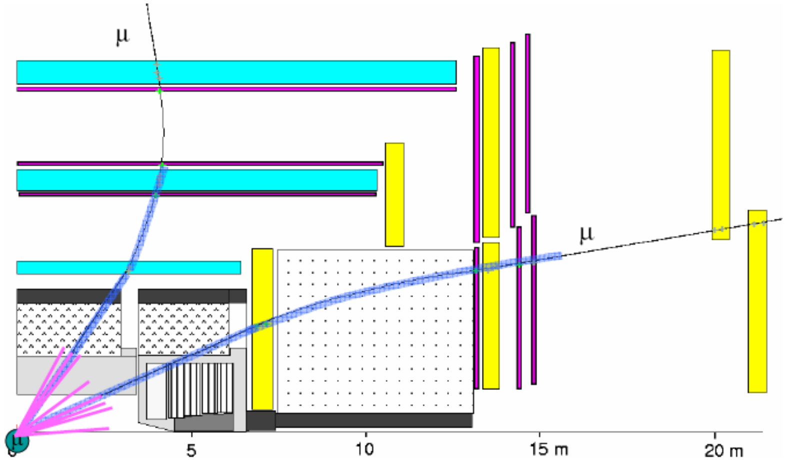
(by S. Willocw)

Moore/Muid performance against eta for Z–>μμ:



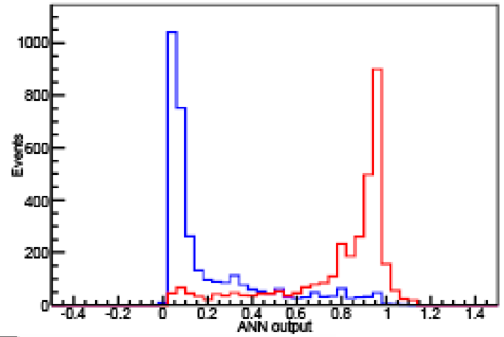
MuGirl

Procedure: Start with ID –> extrapolate to MS –> find segments

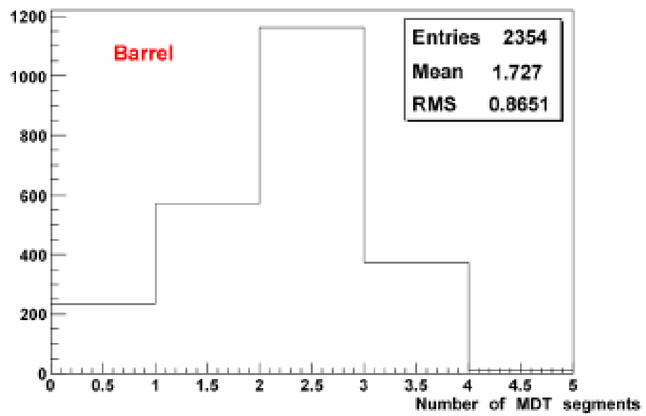


ANN trained against cavern background using variables:

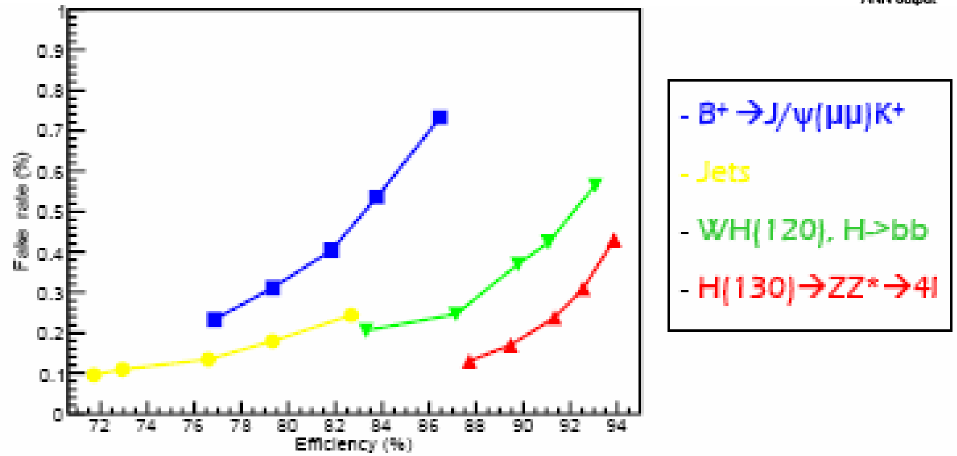
- # hits (MDT,TCG,RPC)
- # segments
- # hits/segment



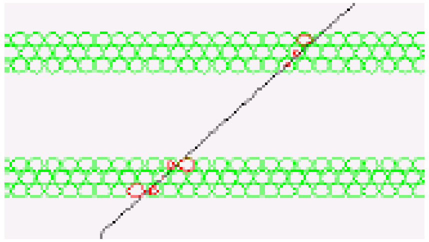
Number of MDT segments per track



Performance:



Muon Tracks



4 types of tracks:

- inDetTrackParticle
  - Inner detector track e.g. from low-pT algorithm (InDet only)
- muonSpectrometerTrackParticle
  - From standalone muon finding (MuSp only)
  - Parameters at entrance to the muon system
- muonExtrapolatedTrackParticle
  - Previous extrapolated to interaction point
- combinedMuonTrackParticle
  - Combination of inner and standalone muon tracks

(exist for both algorithm containers)

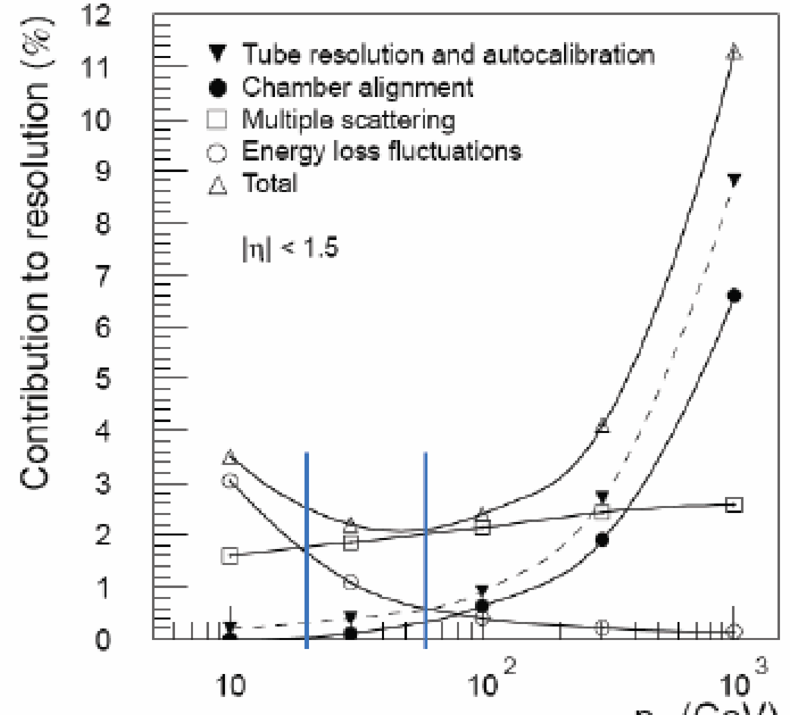
Kinematics and quality cuts:

- Number of hits
- $p_T > 3$ GeV, $|z^0|<$
- χ^2/dof
- isolation

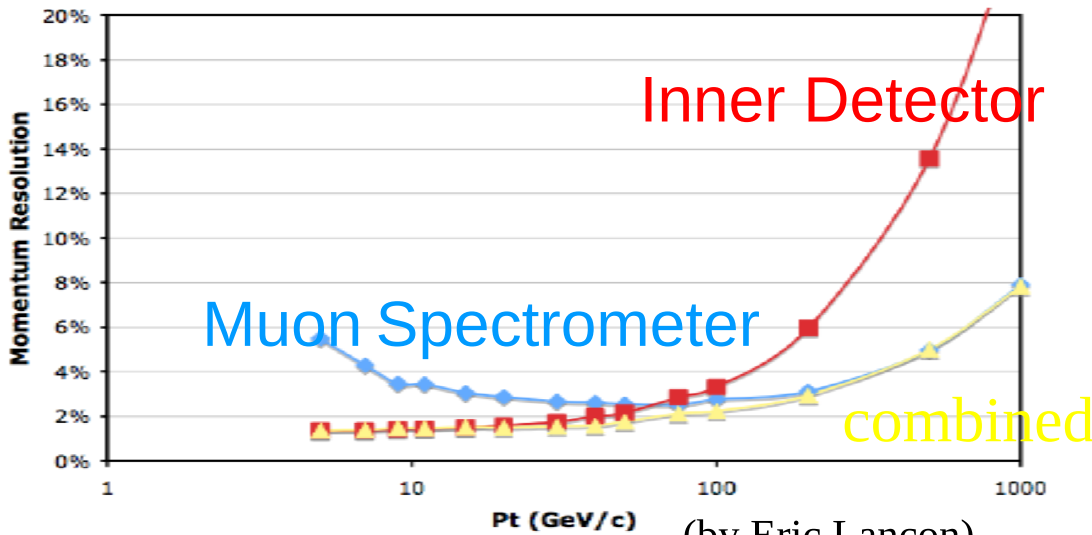
Momentum resolution

From single muon simulation:

Resolution in MuSp only

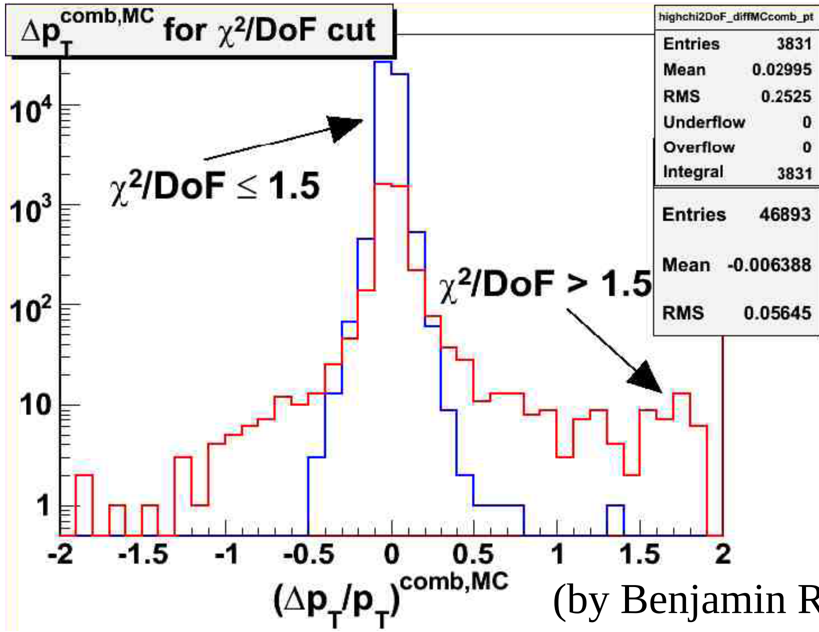


(from TDR)



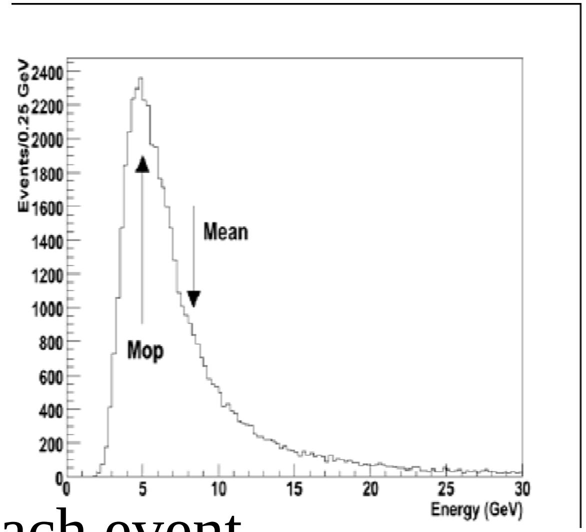
(by Eric Lancon)

Influence of track quality on p_T:

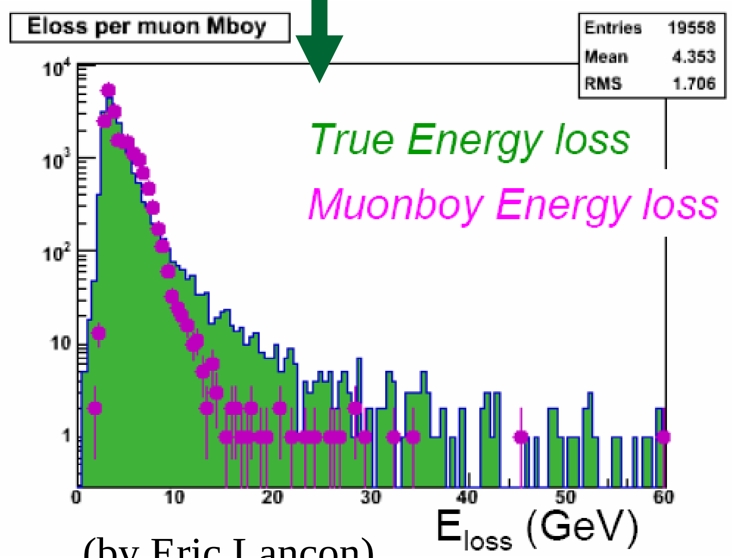


(by Benjamin Ruckert)

Calorimeter energy loss



Standard approach uses parameterization in (ϕ,η)



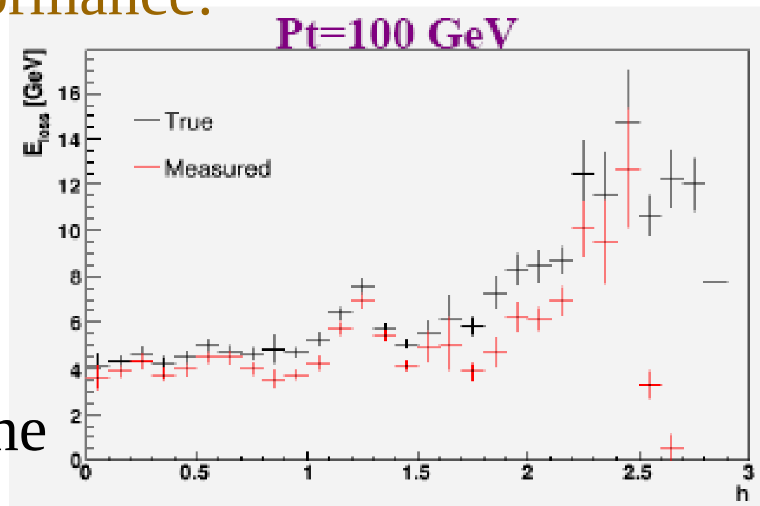
(by Eric Lancon)

Description worsens towards higher energies

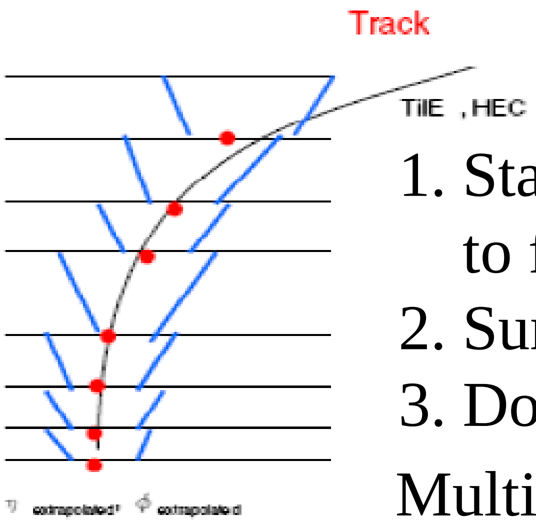
New approach:

use measured energy in each event (only used in high energy tail)

Performance:



(by K. Bachas)



Procedure:

1. Start from track extrapolated to first calorimeter layer
2. Sum up energy deposited in cone
3. Do this for each layer

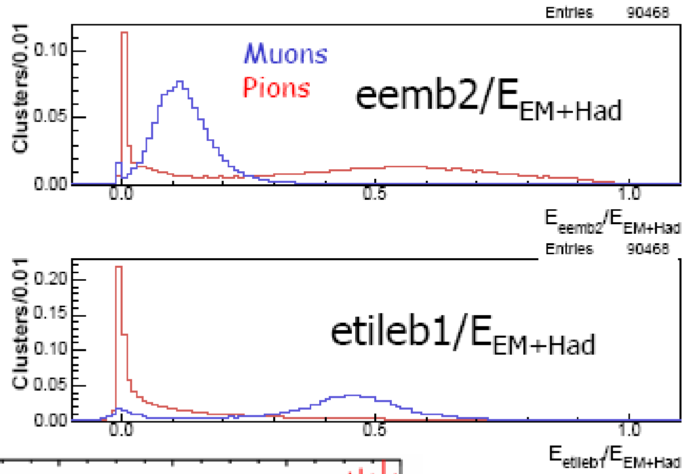
Multiple scattering parameterized at each layer

Calorimeter based muon id

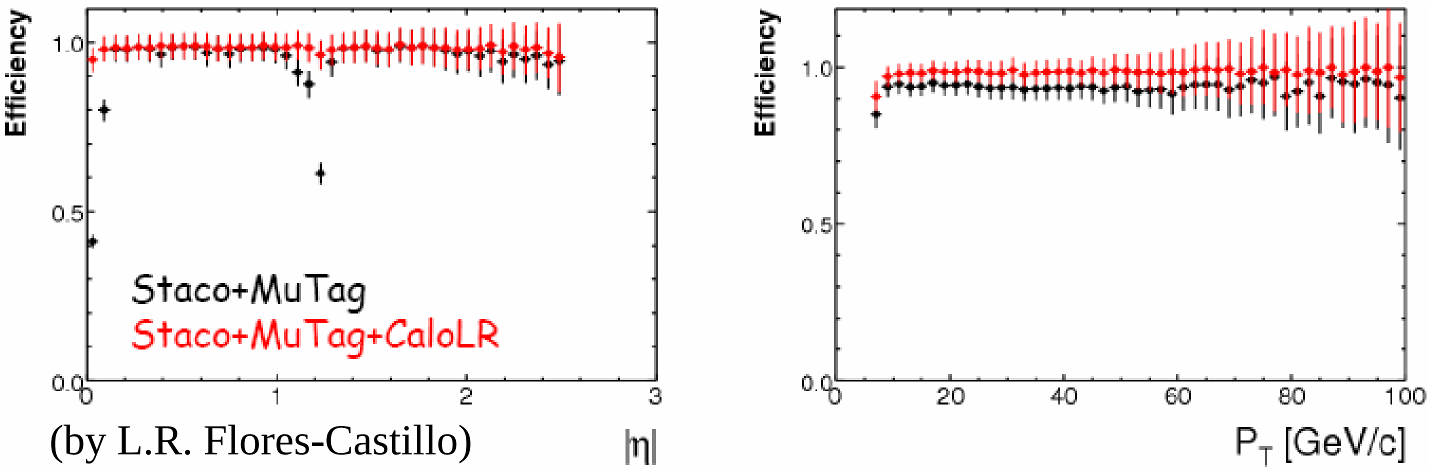
Use pattern of energy deposition for μ/π seperation.

Use cases: Tagging muons (isolated / second muon in B jets)
Cross check muon system
Derive efficiency from data

9 different regions (in η and energy) with specific set of variables for likelihood, e.g.:



Result for H–>4μ sample:



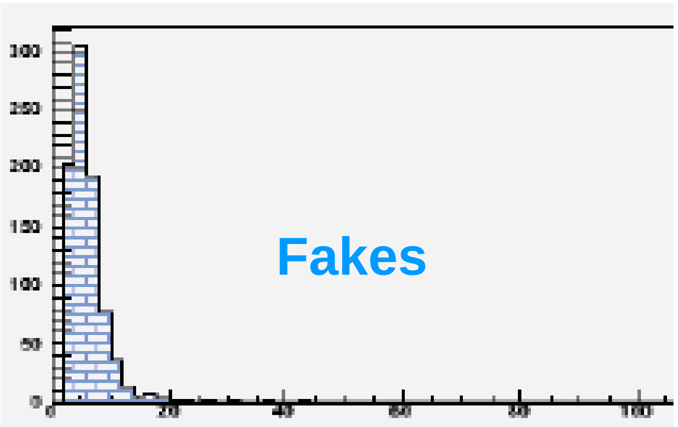
(by L.R. Flores-Castillo)

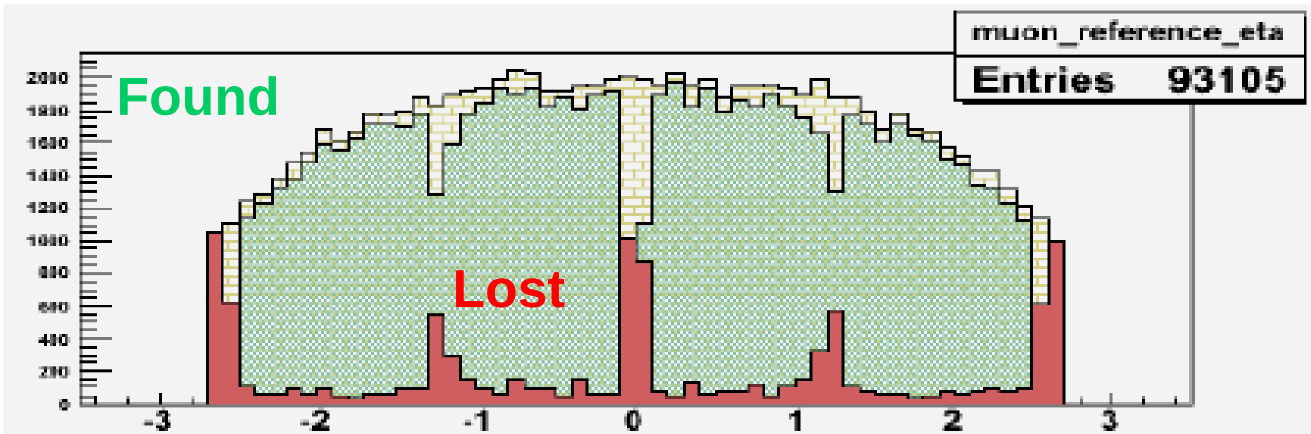
Muon Validation

Activities:

- ❑ Check supostious effects event by event
- ❑ Compare hits with extrapolation from previous station
- ❑ Pile-up events for: tuning, evaluation, developments
- ❑ Check for software bugs

MC truth muons → matching ⇒ found, lost, fake
Reconstructed muons → matching

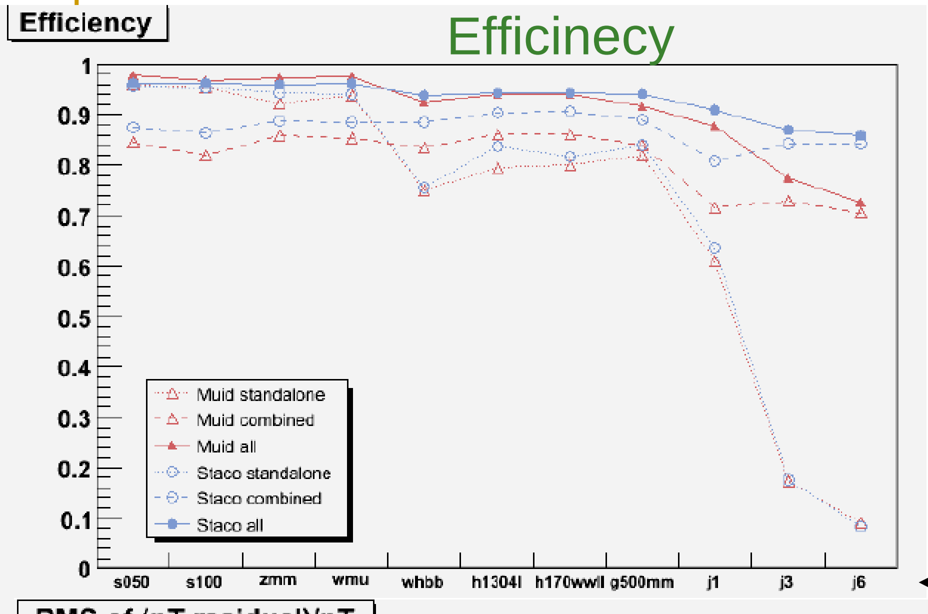


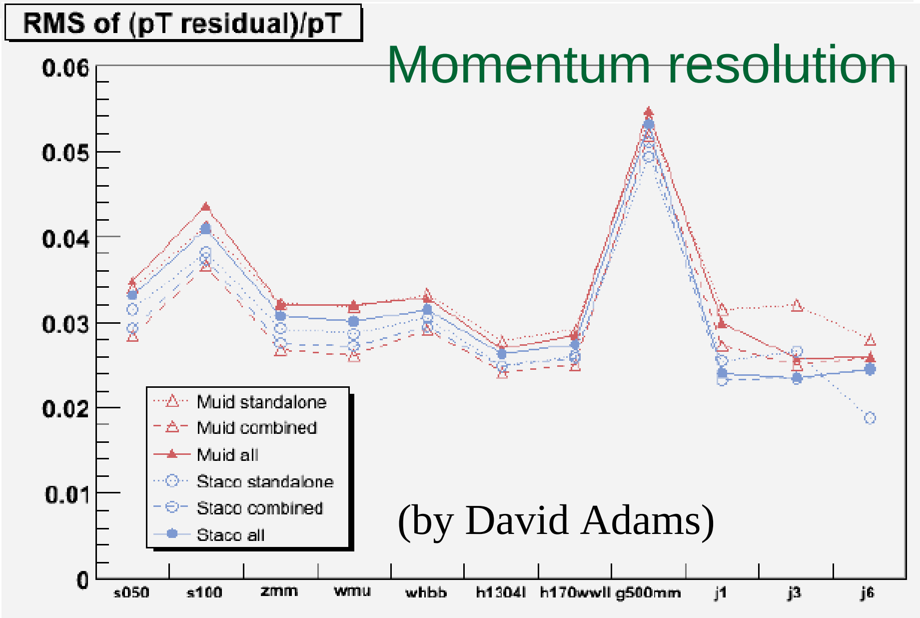


(by David Adams)

(by N Benekos)

Comparing muon algorithms for different physics samples





Package by David Adams

Classification into:

- Combined: MuSp & InDet tracks with good fit
- Split: combined with bad fit
- Standalone: MuSp tracks propagated to ip.
- Inner: only InDet track

← different processes

Both STACO and MuID show good performance

Efficiency 80-95%

Fakes around 0.01/event

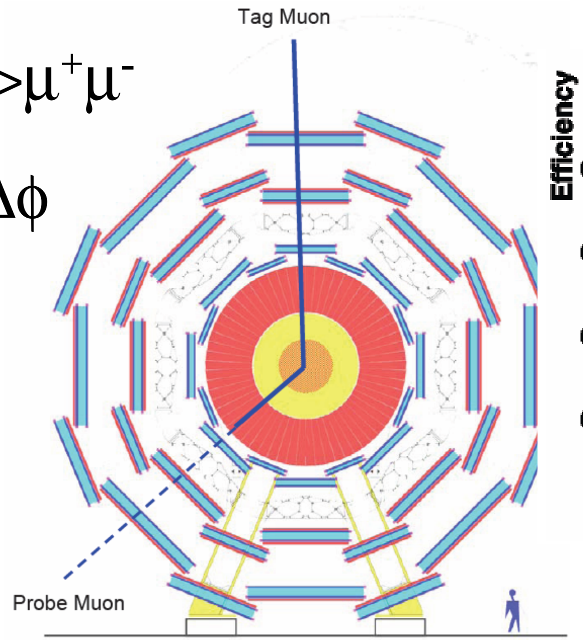
Working less well in high-pT jets (STACO 86%, MuID 73%)

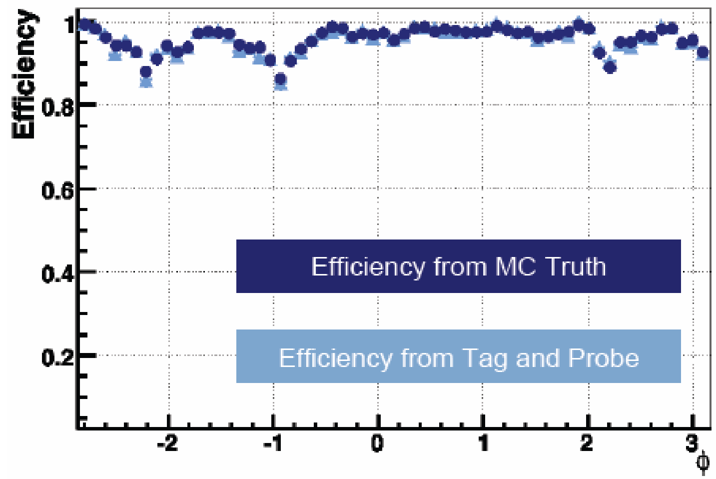
Muon efficiency and resolution from data

Tag and probe method: $Z \to \mu^+\mu^-$

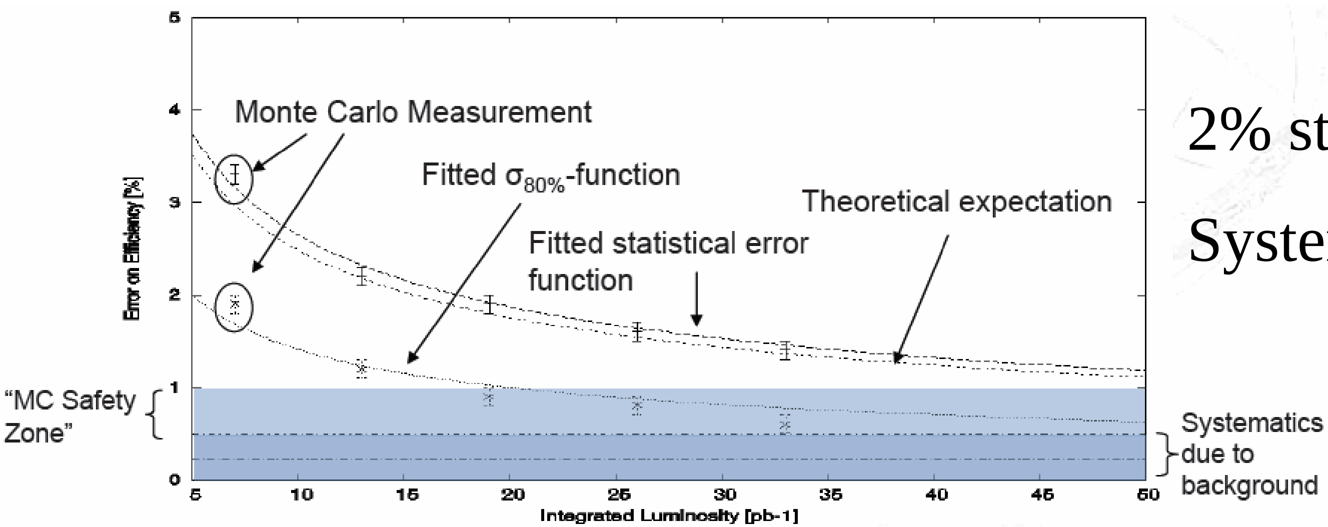
Cut on invariant mass and $\Delta\phi$

Tag muon requires track
in InDet <u>and</u> MuSp





(by Matthias Schott)



2% stat. precision with $30pb^{-1}$!

System. error: 0.23%+0.25%

Physics Studies

Processes under investigation:

1. single-muon events with range of pT values (2 to 2000 GeV/c)
2. J/psi → mu mu, Upsilon → mu mu
3. Z → mu mu, W → mu nu
4. H → 4 mu
5. Z' → mu mu (M = 1 and 2 TeV)
6. t tbar
7. dijets

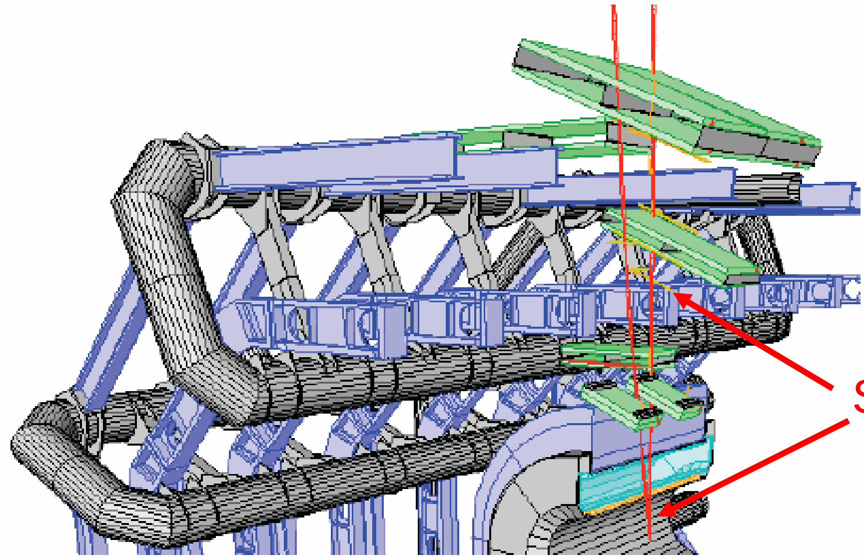
micro black holes decay isotropically to a lage number of high pT muons

Muon event Visualization with PERSINT

PERSINT readable output can be produced with athena jobOptions flag from ROD, AOD and ESD.

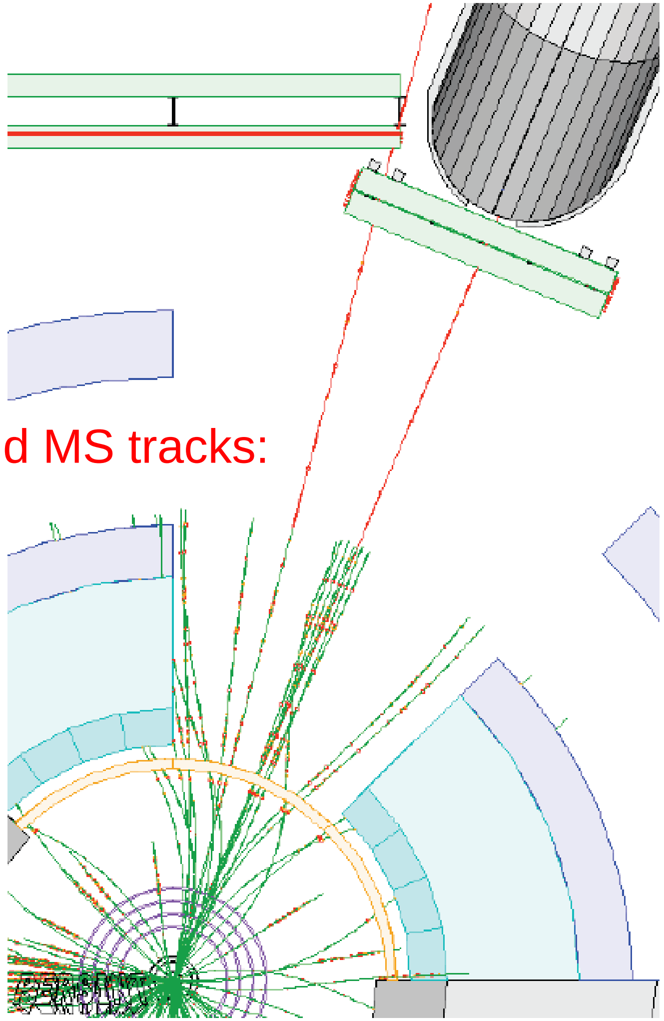
Can display:

- ❑ Muon containers (standalone & combined)
- ❑ Calorimeter objects (CaloCells, Egamma)
- ❑ Inner detector tracks
- ❑ MC truth



STACO track

Matching of ID and MS tracks:



Work in progress

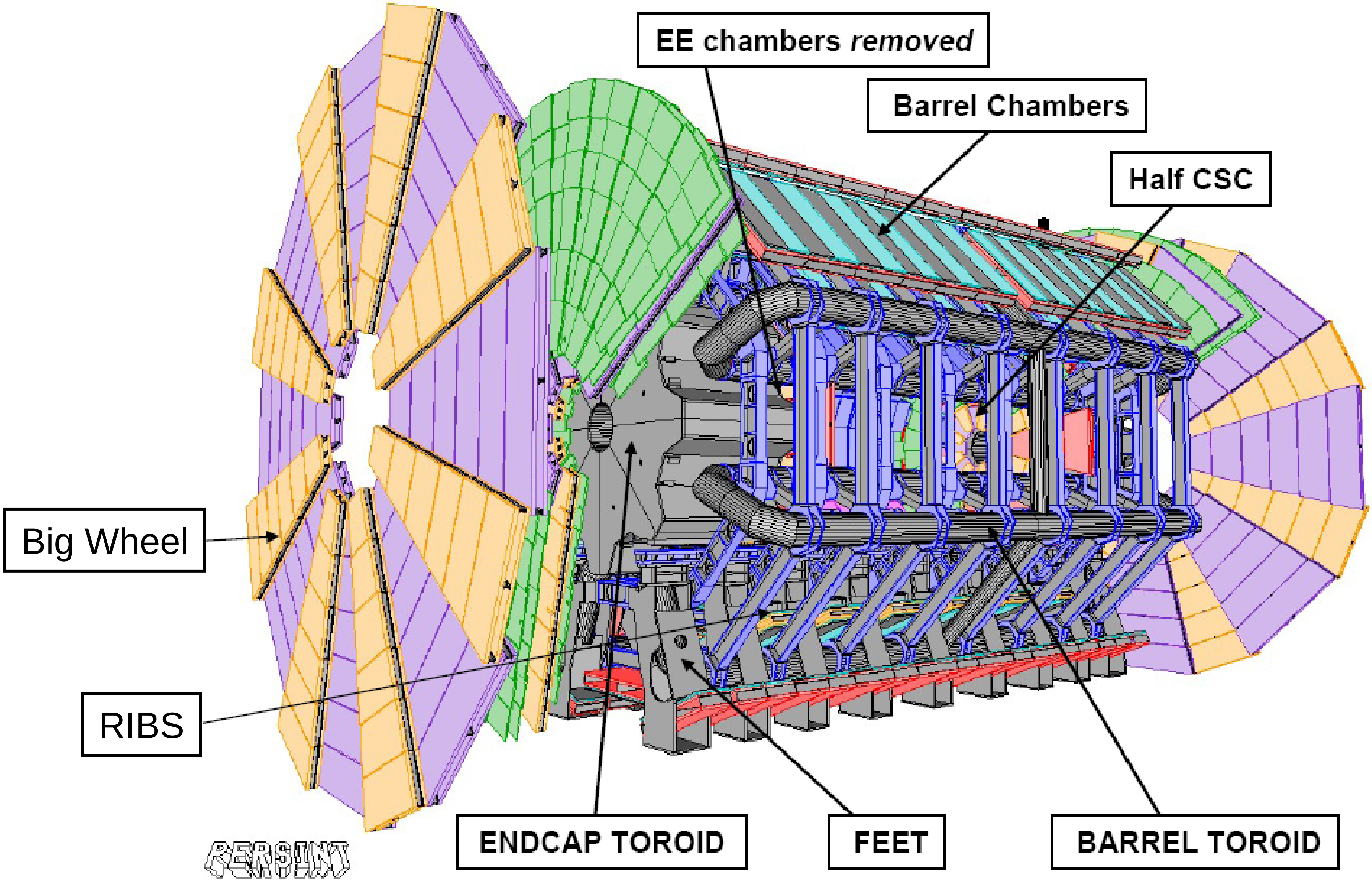
- Fix BOG MDT shift digitization bug
- Check for Moore efficiency drop near η=2.0
- Material map need optimization for low p_T muons
- Restructuring of reconstruction software
- Use NN for calorimeter based muon id
- Improve magnetic field description

Conclusions

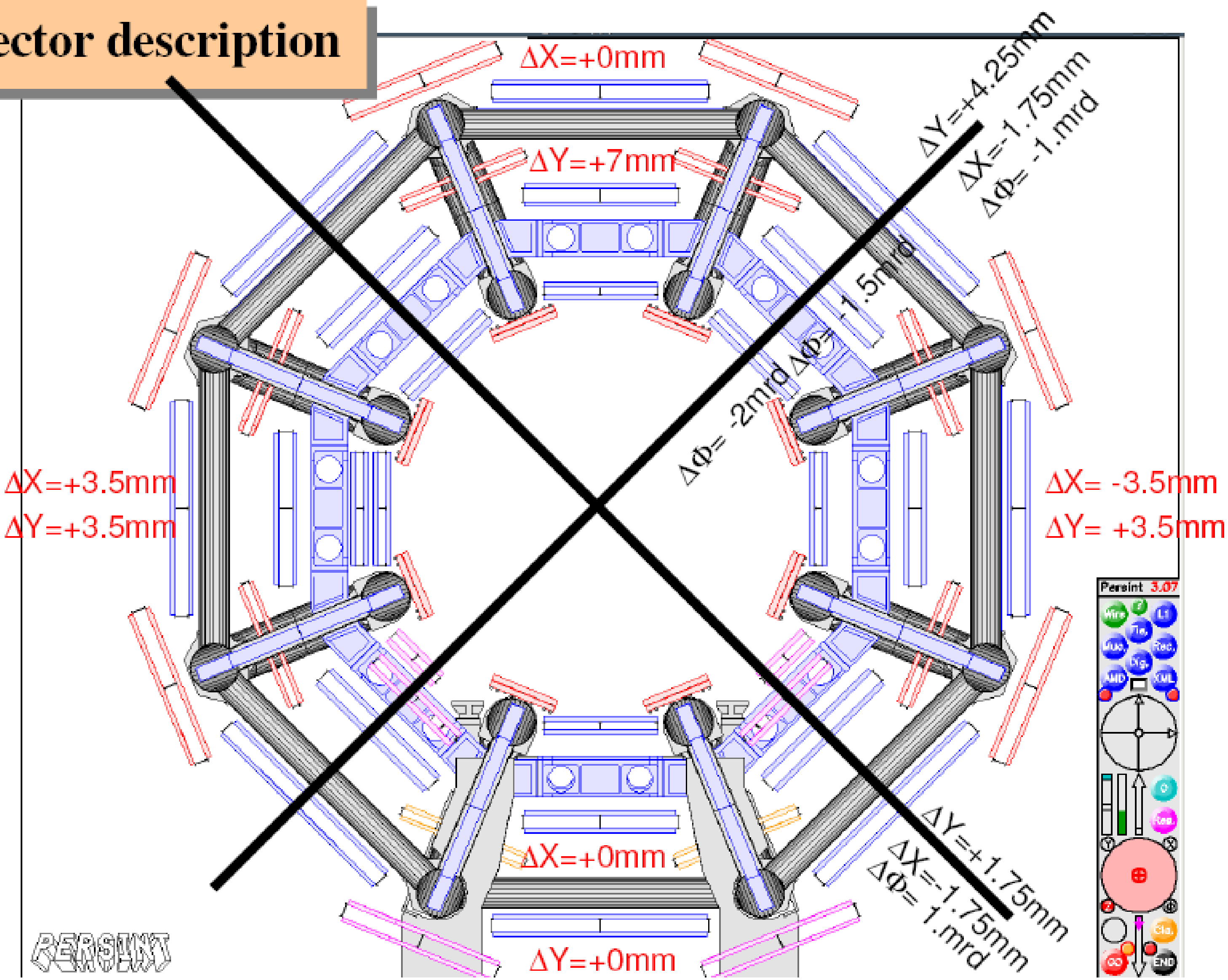
- Muons are important for new discoveries
- ATLAS has a powerful muon spectrometer
- Many different reconstruction algorithms with good performance
- Interesting new projects

www.slac.stanford.edu/~cla/Leptons/Muons.html

Additional Information

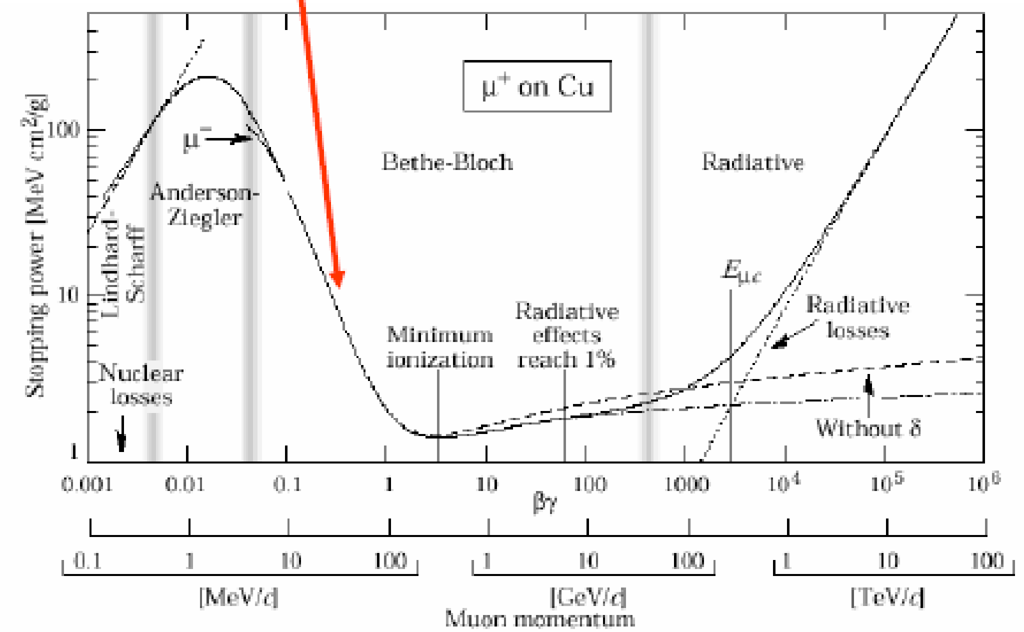

EE chambers *removed*
Barrel Chambers
Half CSC
Big Wheel
RIBS
ENDCAP TOROID
FEET
BARREL TOROID
PERSINT

Detector description

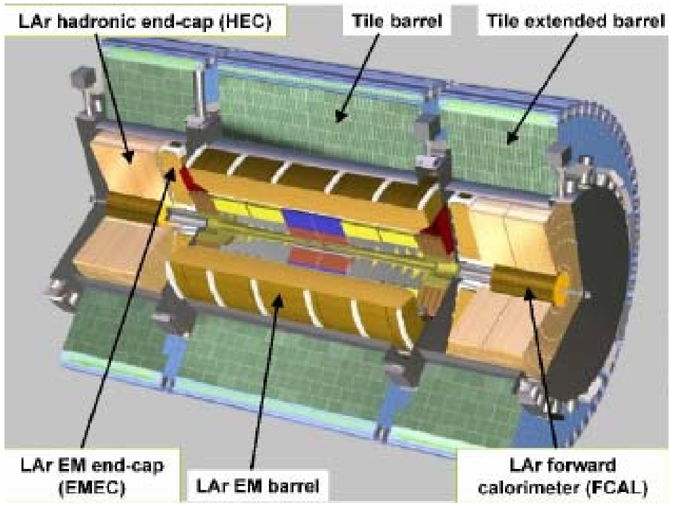


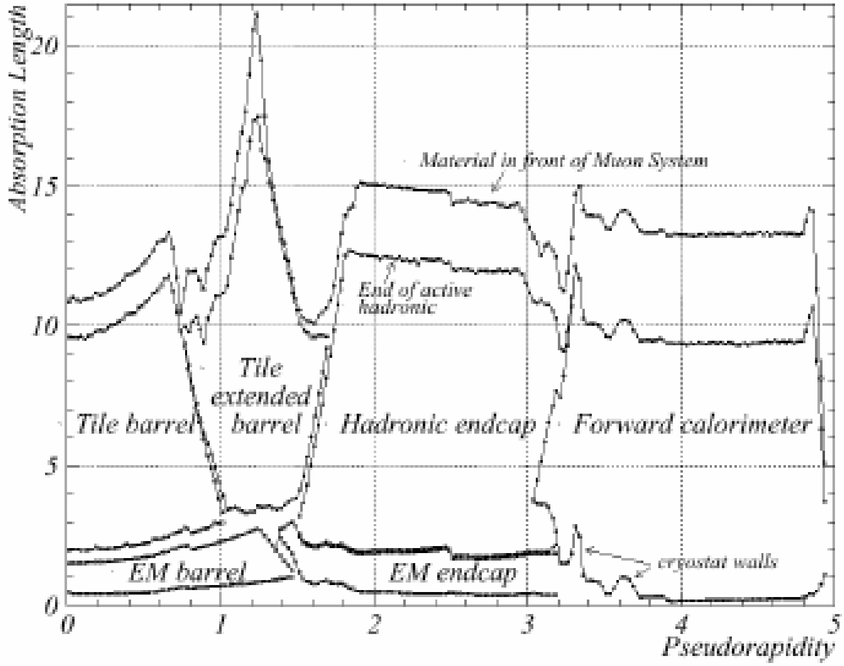
Energy loss after Bethe and Bloch:

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

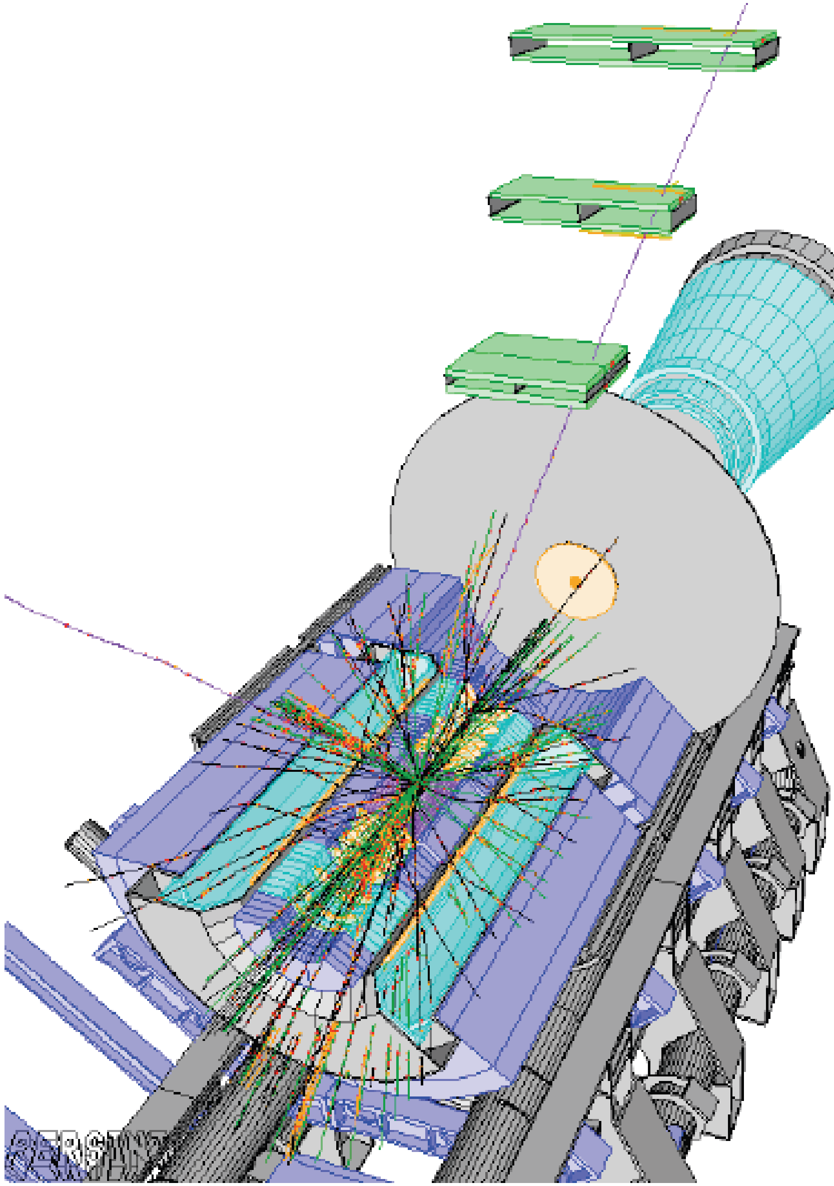


Material in front of muon system:





Another PERSINT example



$t\bar{t}$ event

Get detailed info by clicking on:

- Spectrometer tracks
- ID tracks
- Calorimeter deposits (Tile/LArg)
- Hit positions

MC Truth
μ in violet
$e^{\pm}$ in orange
γ in green
others In black

References

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N. Benekos (MPL): Muon Sftware Validation Algorithms, Okt. 06
S. Willocq (UMass): Moore and Muid status, 30th May 2006
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