Muon HLT status with emphasis on μFast for endcap

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On behalf of the ***HLT Algorithm Group***

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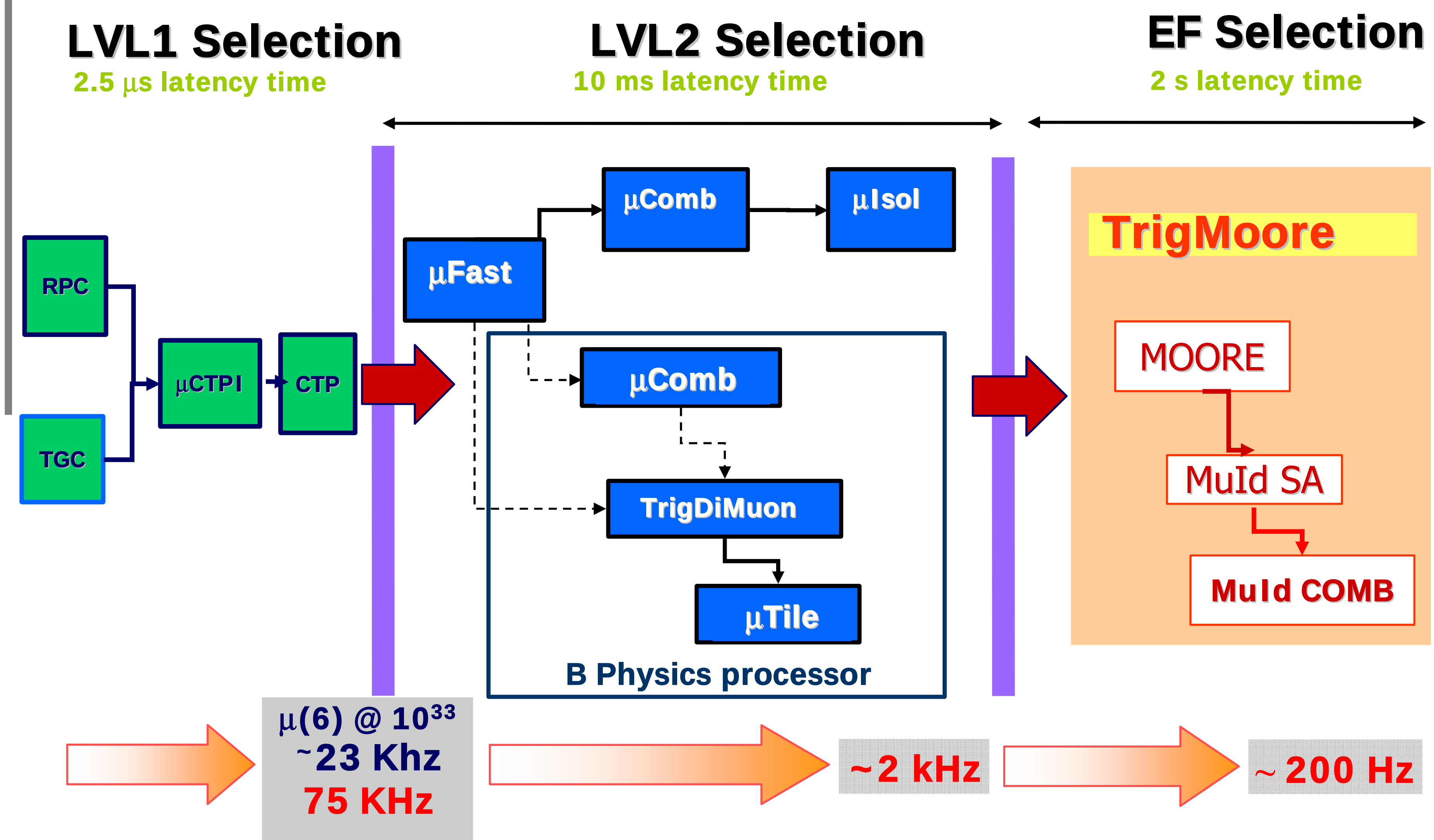
Introduction



μFast: standalone muon reconstruction

First task of the Level-2 muon trigger:

- Confirm the Level-1 trigger with a more precise p_t estimation within a "Region of interest (RoI)".
- Contribute to the global Level-2 decision.

To perform the muon reconstruction in the Barrel, RoI data are gathered together and processed in three steps:

1) "Global Pattern Recognition" involving trigger chambers and positions of MDT tubes (no use of drift time);
2) "Track fit" involving drift time measurements, performed for each MDT chamber;
3) Fast "p_t estimate" via a Look-up-table (LUT) with no use of time consuming fit methods.

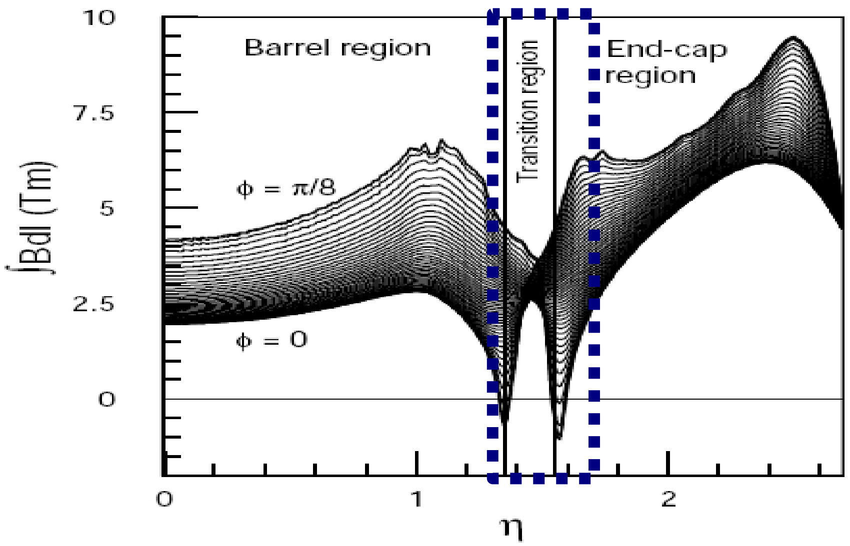
Result → η,ϕ,direction of flight into the spectrometer, and p_T at the interaction vertex.

Barrel vs Endcap

Barrel schema:

- track model from RPC triger data;
- identification of MDT muon data;
- momentum recontruction using both two and three precision track point measurements

→ field homogeneity allows for very good performance: only a factor of about 2 worse than offline!



Endcap: can't use the same schema

- different arrangment of the trigger chambers;
- field inhomogeneity breaks all the attempts to build a track model as in the barrel;
  - use only middle station data?

! backtrack is needed by the combined reconstruction !

  - use innermost TGC station to help pattern recognition in MDT?

! innermost TGCs cover only half of the endcap !

Solution: parametrize the track path using the muon p_T as a seed.

μFast status and updates

Barrel:

- Final update of the LUT available: optimized with respect to the momentum resolution and to the efficiency.

Endcap:

- TGC data processing fully implemented, output is a line segment in middle station and a point in the inner station;
  - fetches RDO in RoI
  - decodes using standalone LUT for the geometry to increase speed;
  - performs line fit for middle stations (removing outliers)
  - finds hits in inner station and calculates super-point position (uses a large road, to be replaced by the back extrapolation when this will be available).
- **Estimate of the muon p_T provided by using the TGC data of the Middle station:**
  - **RoI processing available for the full Muon Spectrometer: endcap muon feature available to seed the next step.**

Ongoing work:

- Finalizing the pattern recognition model;
- Study "offline" the momentum resolution obtained from MDT.

Parametrize the track using TGC data

- Between Innermost and middle, low p_T tracks are bent in phi.
- Full 3D path too difficult to be described: disentangle the description of the two projections (r-η and x-y).
- Field inhomogeneity is very large in both Eta and Phi direction;
  - minimum LUT granularity is Eta x Phi=15 x 10;
- There are harsh regions around η=1.3/1.4/1.5 (depending on Phi position) where the integrated bending power is near to zero.
- Among the quantities inspected, results show that the best ones that describe the track path are (for the definition see next slide):
  - Difference between innermost slope and middle slope;
  - Bending angle calculated from middle station only;
- Check if the difference in eta is useful to describe track path in the region η=1.3/1.4/1.5.
- Once a minimal set of parameters will be identified, the description will be extrapolated in the regions where there is no TGC hit.

Describing track path and measuring p_T

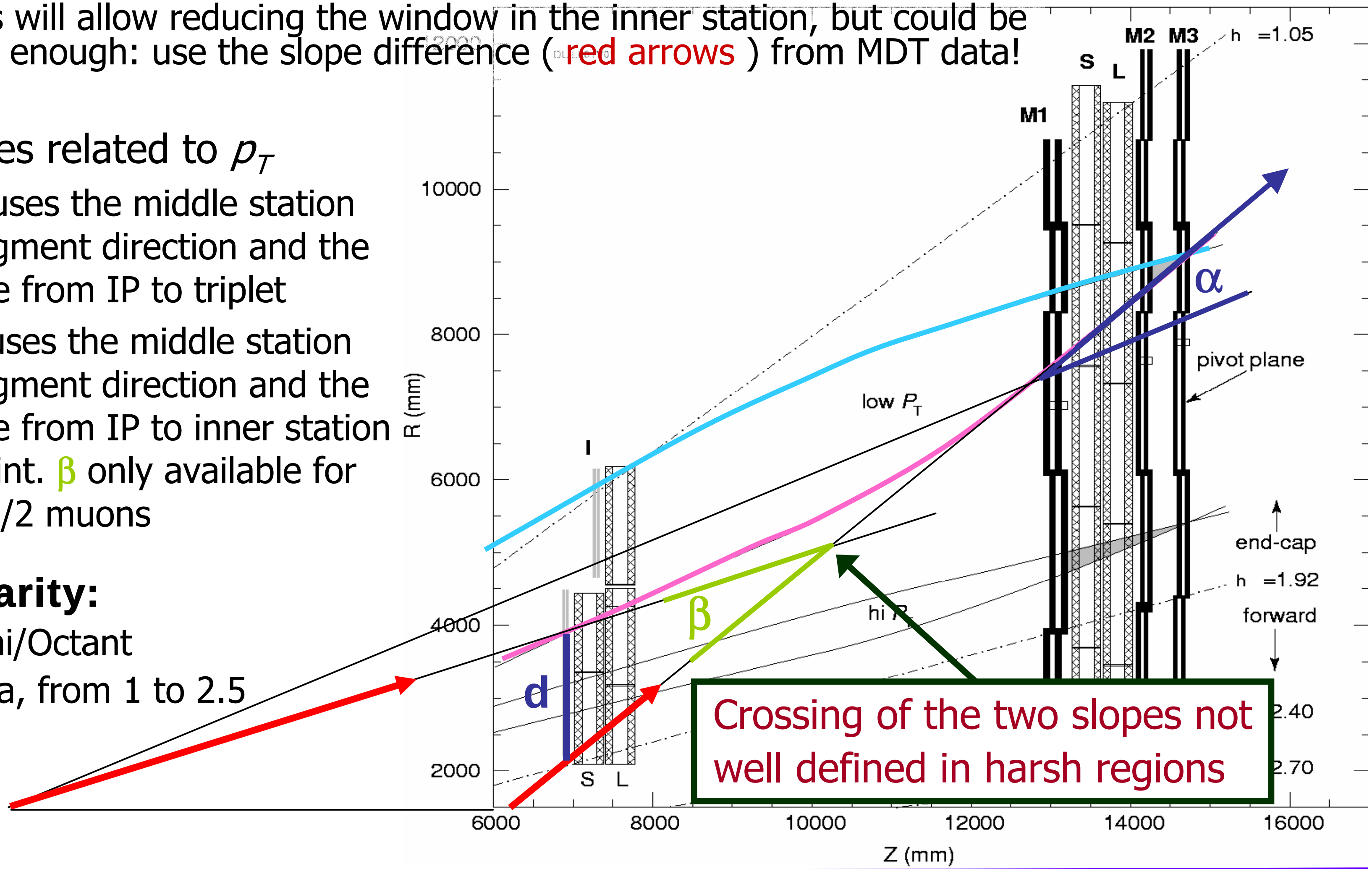
- Two quantities related to the misposition of the Innermost hit with respect to the Middle slope segment:
  - distance **d**, related to the track p_T;
  - this will allow reducing the window in the inner station, but could be not enough: use the slope difference (red arrows) from MDT data!

- 2 angles related to p_T
  - α uses the middle station segment direction and the line from IP to triplet
  - β uses the middle station segment direction and the line from IP to inner station point. β only available for ~1/2 muons

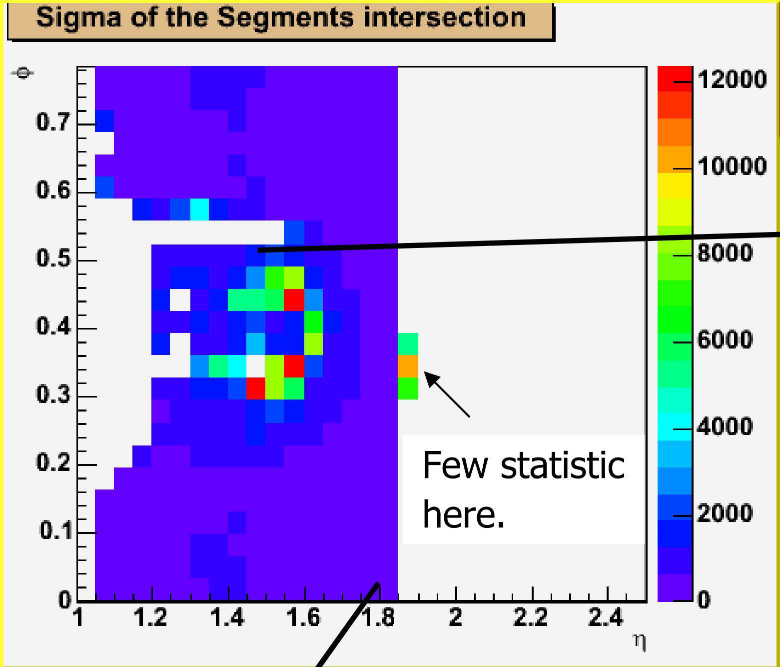
LUT granularity:

24 bin in phi/Octant

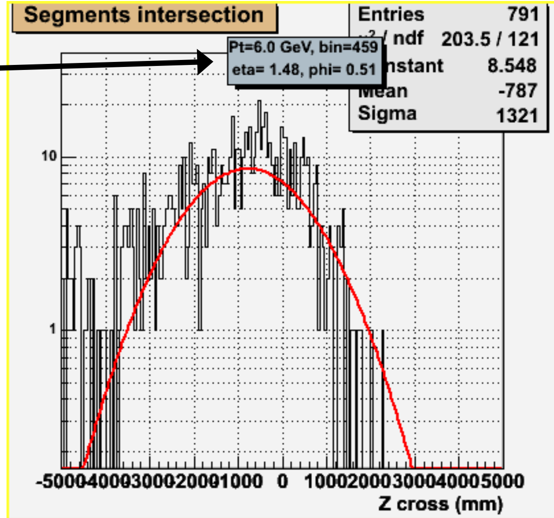
30 bin in eta, from 1 to 2.5

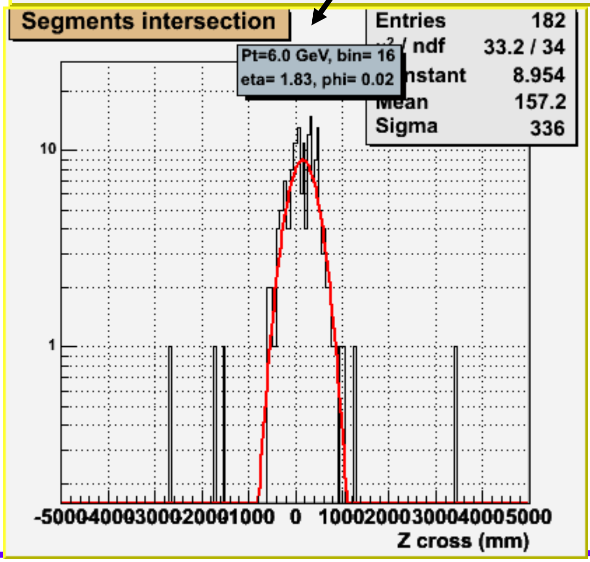


Failure of the track model (6 GeV p_T)



Field inhomogeneity doesn't allow to describe everywhere the track with radius and/or sagitta





Harsh regions:

- position of the segment intersection higly variable;
- sigma of the measurement not precise enough

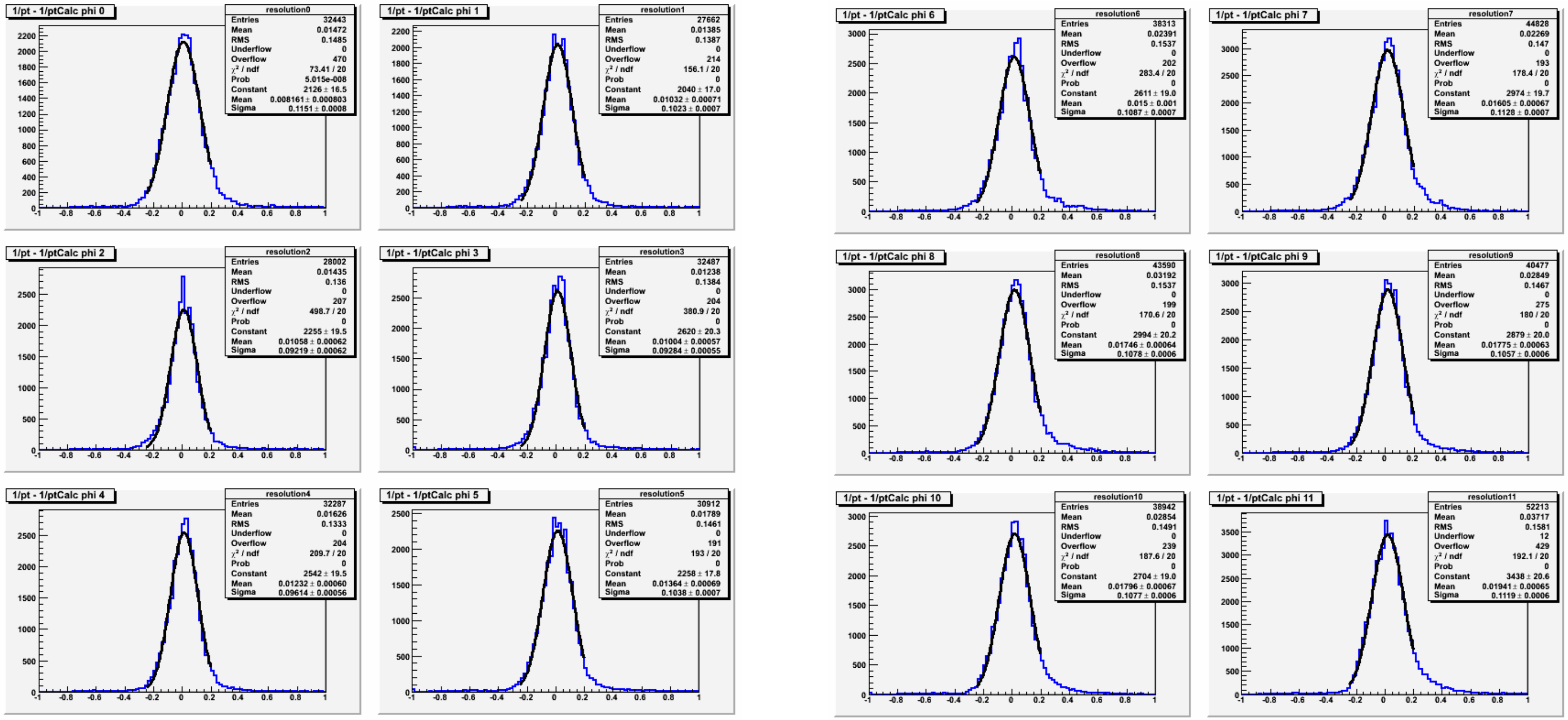
Large eta region:

- position of the segment intersection is constant;
- sigma of the measurement is also constant and allows to set roads of 20/30 cms.

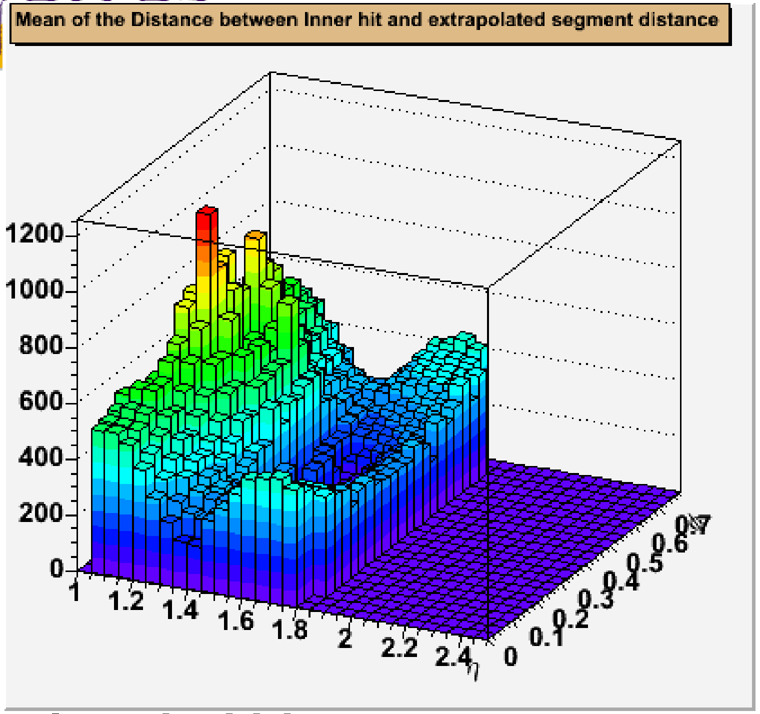
→ Model can work only at large eta

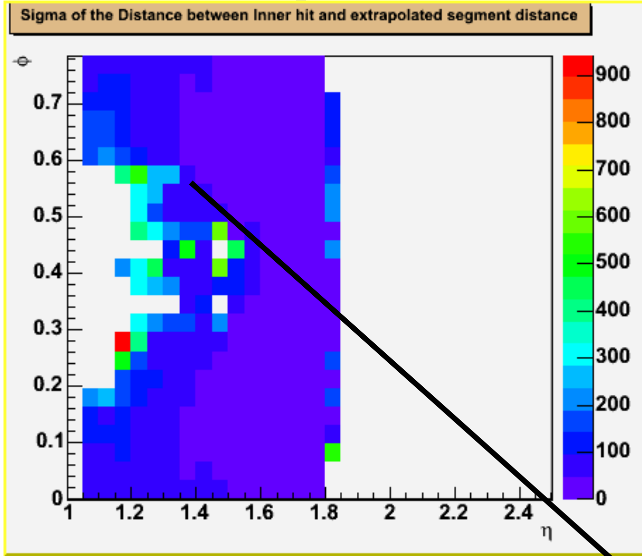
Resolution from α - 6 GeV

- Performance on 6 GeV muons ranges between 9% and 11% depending on the selected phi slice;
- Performance for 40 GeV is poor (20-30%) because the TGC Middle slope is not precise enough; expected to improve a lot when MDT data is used;
- β angle measurement do not improve the performance because the innermost measurement is not precise enough due to TGC spatial reslution;



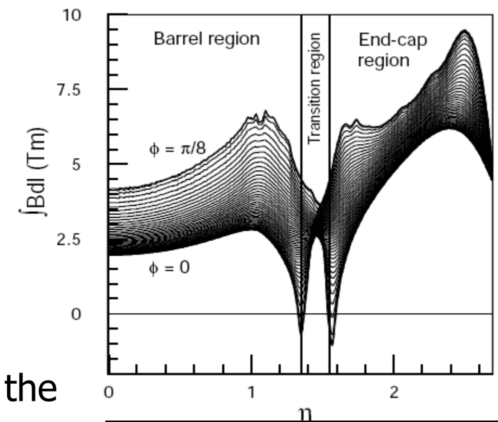
Pattern recognition in the innermost stations: use “d” to describe the path

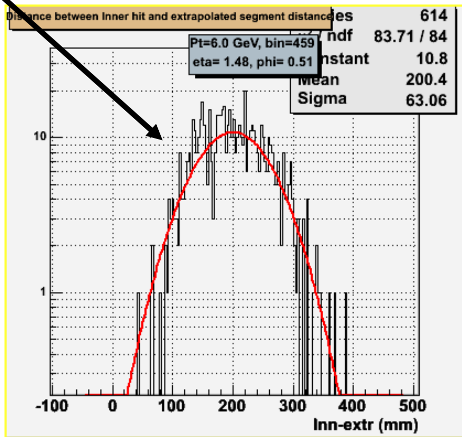




(6 GeV p_T)

Intrinsec limit of the measurement of d coming from TGC resolution is 2 cm.





Total road width @ 6 Gev:

- 50 cm at 1.1 η;
- 20 cm at 1.8 η;

Efficiency (to get TGC Innermost hit):

97.3% @ 3 sigmas, because of poor definition of the TGC slope; to be improved with the use of MDT data.

Schema:

need to have a p_T seed: linear interpolation of LUTs at 6 and 40 GeV to get the correct shift in the innermost st.

d is proportional to muon p_T: crosscheks with the resolution obtained with TGC are fine.

NEXT STEPS

- **Finalize the Pattern Recognition to fetch the muon MDT hits;**
- **Create MDT segment in each station**
- **eventually refine parametrization for the track path by use of MDT: use of slope difference**
- **use MDT data to measure the muon** p_{T}.

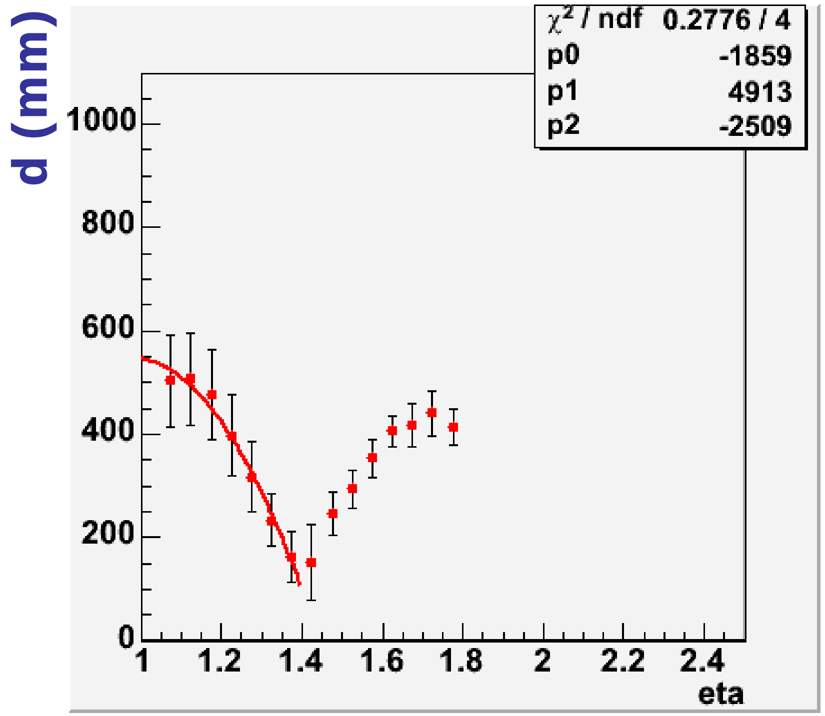
Ideas for extrapolating the track behaviour

Large eta region:

- use the track model if possible → the corresponding precision of the road width must be checked againt CSC data with background;
- if not, do the same job as for TGC;

Low eta region:

- try to extrapolate the track parametrization by fitting the existing points in eta and phi slices and assuming a certain behaviour of the field integral
  - preliminary results of this procedure exists, but correctness needs to be checked against MDT data;
- if not, extract the parameters directly from MDT data;



μFast processing sequence in the endcap

No model to describe the track path

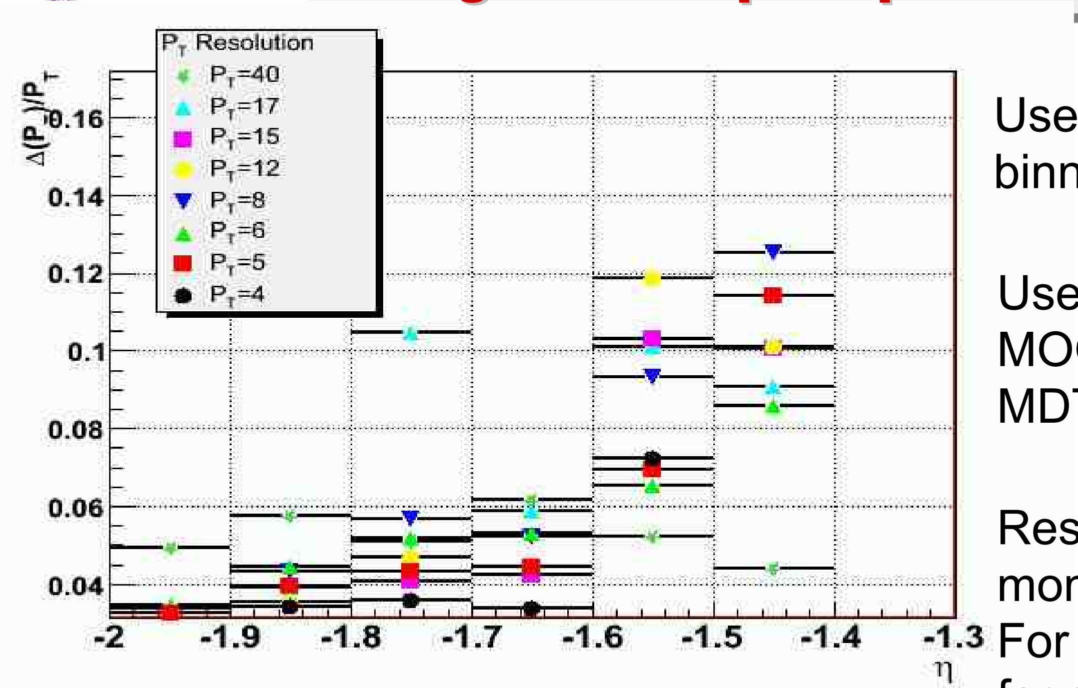
→ momentum estimation refined through several steps!

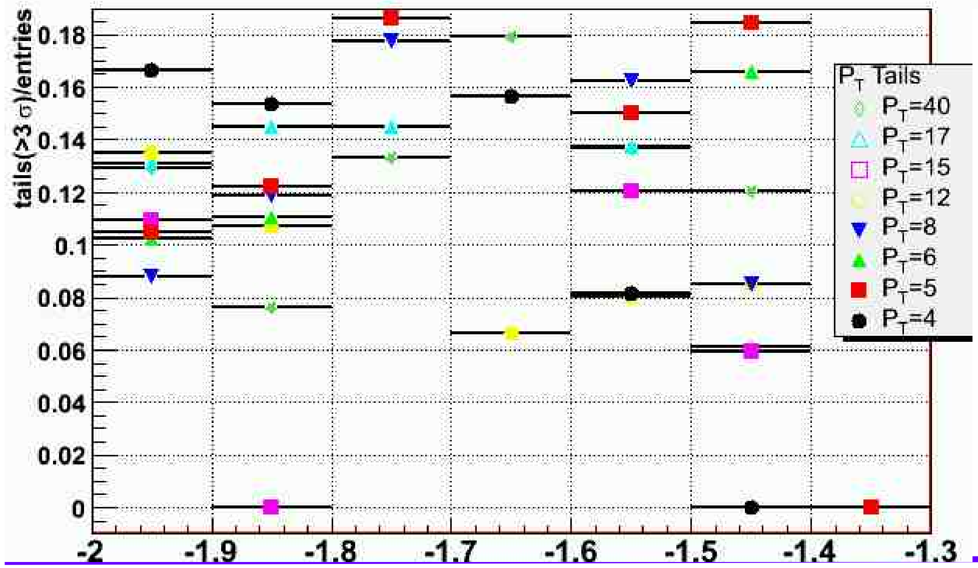
- provide robusteness against possible failures of both hardware and software:

The processing sequence is:

1) decode and process the TGC data to provide the Middle slope;
2) provide a first estimatation of the muon p_T using the α angle LUT;
3) collect MDT data from Middle and Outer station and perform a linear fit to provide a better slope definition;
4) refine estimation of the muon p_T via the α angle LUT;
5) uses the LUT for pattern recognition to back extrapolate the track and collect hits from the innermost stations of TGC (hopefully, because the method implemented so far uses very large roads) MDT and CSC;
6) perform a linear fit in the innermost precision data to provide a the slope measurement just after the calorimeter;
7) perform the final p_T estimation using the innermost precision data? Only if tis method will increse the performance obtained with the angle α measurement.

Using MDT – prospects from offline study





Use offline to explore resolution, LUT binning etc.

Use "d" distance extrapolating from MOORE segments in middle and outer MDT stations

Resolution vs eta for μ- from different momentum bins
For |eta|<1.6 resolution larger than ~8% for some momenta

Fraction of events out of 3-sigma wrt total vs eta for different eta bins
Tails smaller than ~20%

Will degrade if outer station segment is not required (increasing geometrical and efficiency)

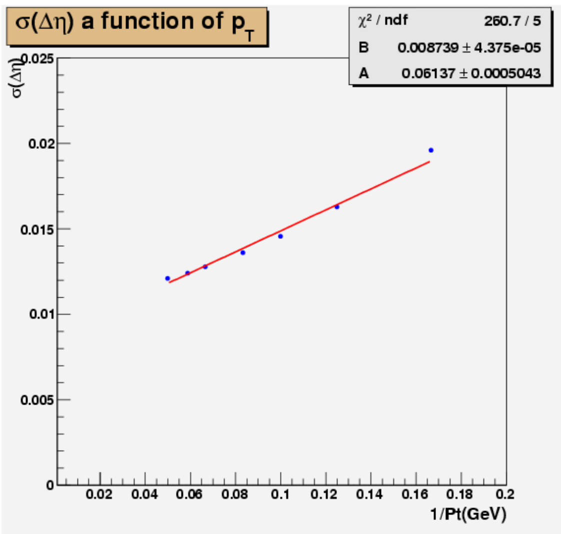
μComb

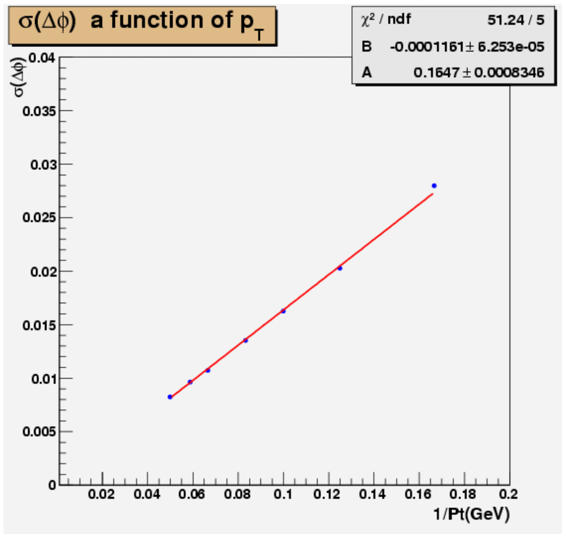
Second task of the Level-2 muon trigger:

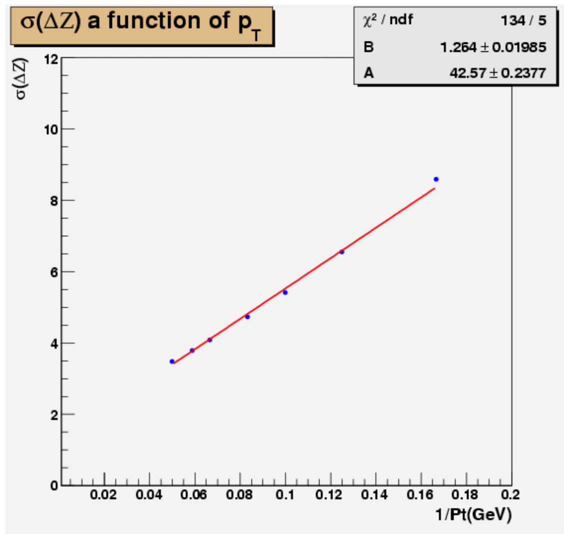
– Refine the μFast p_T by means of ID data → more sharpness on the **6 GeV** th.
– Identify the muon track in ID to ease the search for secondary muon tracks.

Status

- Algorithm for the barrel finalized into 12.0.3;
- Related hypotheis algorithm still missing, but will be in place for 12.0.4;
- Matching with the ID track happening in the external surface of the CALO
  - all studied with respect the muon p_T: Eta match , Phi match , Zeta match;
  - matching eff: 99.2% with 3.3 σ

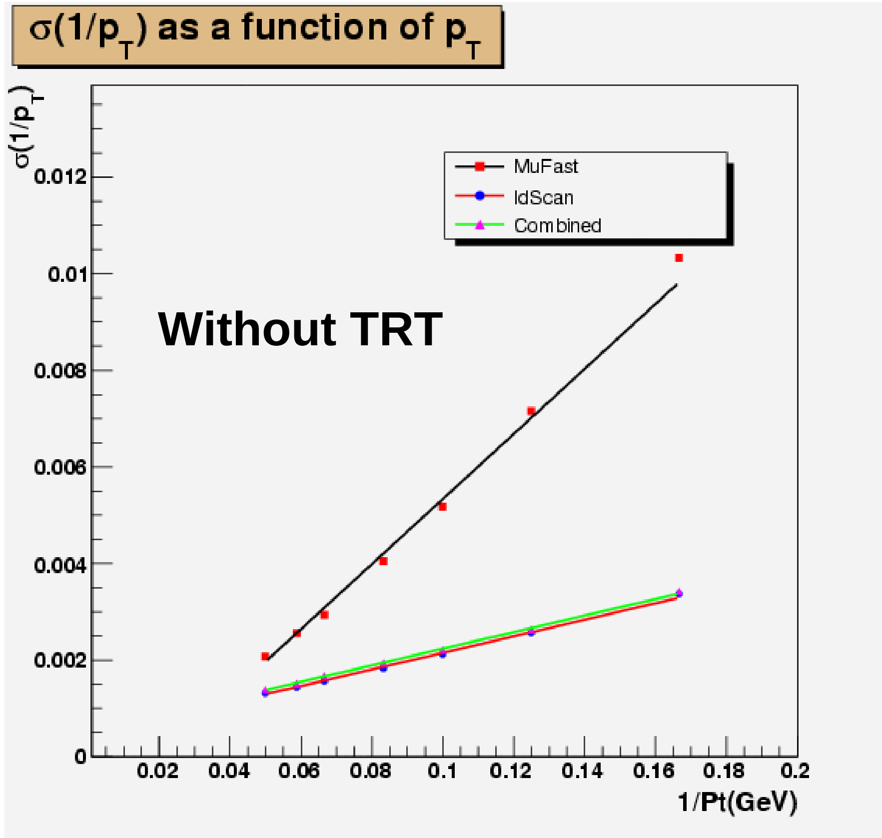






μComb performance: resolutions

- performance checked with a new single muon production (11.0.6 + fix for RPC digitization);
- used ~ 1.5 10^6 events produced with the IV spread;
- cut on the matching window optimized for the single muon track having p_T of 6 GeV



Results for single muons are better than what we achieved for the TP time.

Expected more reduction on the single muon rate!

Plans

- Extensive testing of Physics performance:
  - Computing the trigger efficiency curve for single muon;
  - Checking rejection against muon from π/k decay using CSC data;
- Start to study the match between ID tracks as soon as mFast back extrapolation will be ready.

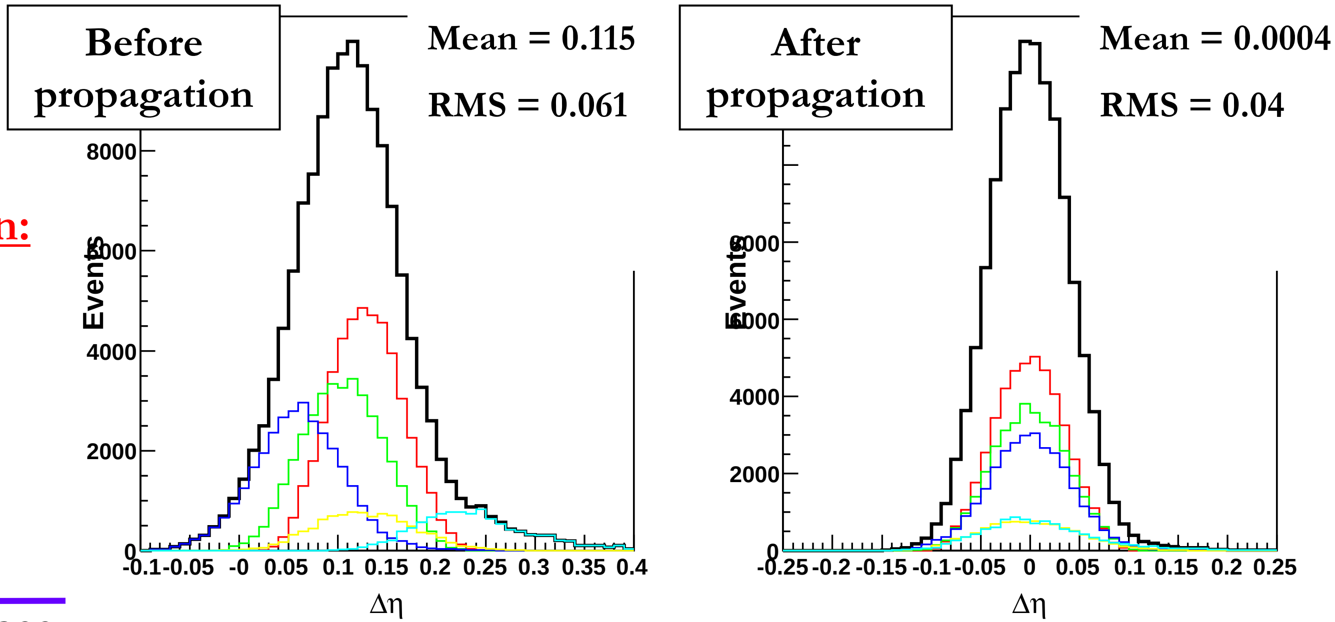
TrigDiMuon update – Shlomit Tarem and Natalia Panikashvili

- RpcDigitContainer → PadRpcContainer
- LUT-RPC:
  - ϕ_{min}, ϕ_{max}, η_{min}, η_{max}, → vector of PAD id
- LUT – TGC RDO's
  - TGC raw data (online identifiers) → LUT → eta/phi position of hits
- New propagation through solenoidal/toroidal field in Barrel and End-Cap
- Timing performance < 2ms (tested on bb→J/ψX sample)

Example of Propagation:

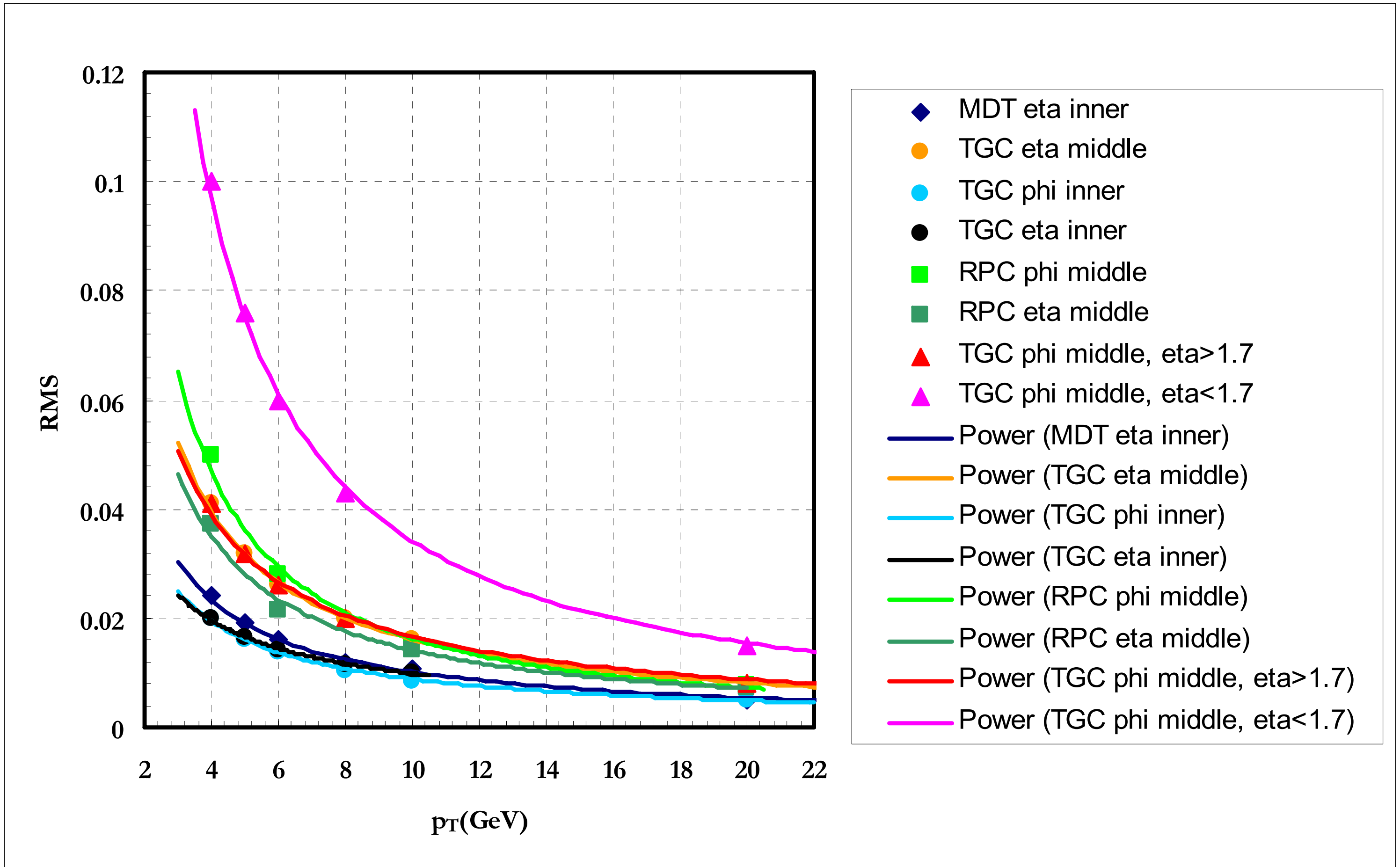
Distance in η between ID track and TGC η hits (Middle stations)

4GeV muons



Window vs. p_T

Window in η/ϕ opened around ID track extrapolated to different stations of MS vs. p_T of ID track



Extrapolation is not yet optimized

Plans

- Extensive testing of Physics performance
  - Starting from a muon level-1 RoI
  - Starting from a μFast RoI
  - With/without cavern background and pileup
- Timing performance
  - Starting from a muon level-1 RoI
  - Starting from a μFast RoI
- Prepare poster to NSS conference

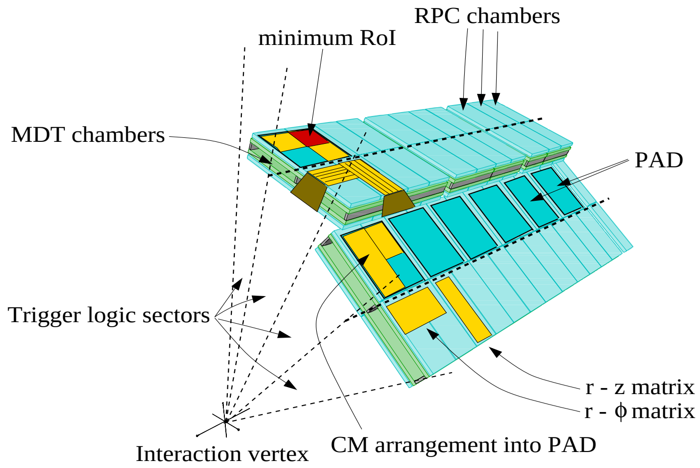
Event Filter : TrigMOORE

- The offline packages Moore and MuId have been adapted for working in the **H**igh **L**evel **T**rigger (by means of the TrigMoore package)

- MOORE → reconstruction in MS
- MuId → extrapolation of tracks back to the interaction point (Muid StandAlone) and to combination with tracks in the Inner Detector, performing a global refit (Muid Combined).

- Driven by HLT steering
  - reconstruction starts only if there is a valid TriggerElement as input
  - can be started both from LVL1 and from LVL2 *RoI*s

- It can work in two different main modes:
  - **Seeded**
    - Reconstruction performed only in the geometrical regions provided by the RoIs of previous levels.
  - **Full scan**
    - Full reconstruction, ~equivalent to the offline working mode



- Both in barrel and endcap regions

TrigMoore Status

- New tag provided to get TrigMoore working in rel 12.0.3 (and 12.3.0)
  - TrigMoore-00-00-63
  - Main dev. : code adapted to use the new version of MuidCombined
  - Combined reconstruction can get as input both inner detector (iPat)Track and Trk::Tracks (iPatRec and new tracking)
    - By default the fit uses Trk::Track

Event Filter performance

- **TrigMoore** reconstruction performance has been tested in **Athena 11.0.5** all over the pseudorapidity range **$|\eta|<2.5$** using the **seed from LVL1**.
- ***MuId StandAlone*** used for *MS* track extrapolation.
- ***MuId Combined*** for combination with *ID* track.

Single muons

- CSC pre-production files (~10^6 events)
- muon p_T = **6**, **8**, **10**, **15**, **17**, **20**, **40** GeV/c

/castor/cern.ch/user/m/muonprod/1105/digit/atlas-dc3-02.00*.digit.mu*_pt*GeV/*.pool.root

Single muons with background

- Rome initial Layout, **G4** simulation (~10^5 events).
- muon p_T = **5**, **7**, **11**, **20**, **40**, **100** GeV/c
- Luminosity: **10^{33}** and **$5 \cdot 10^{33}$** $cm^{-2}s^{-1}$
- Safety factors: **x1** and **x5**

/castor/cern.ch/user/l/lancone/muon/RomeSimulation/Rome1001PileUp/lumi0X.sf0Y/*.pool.root

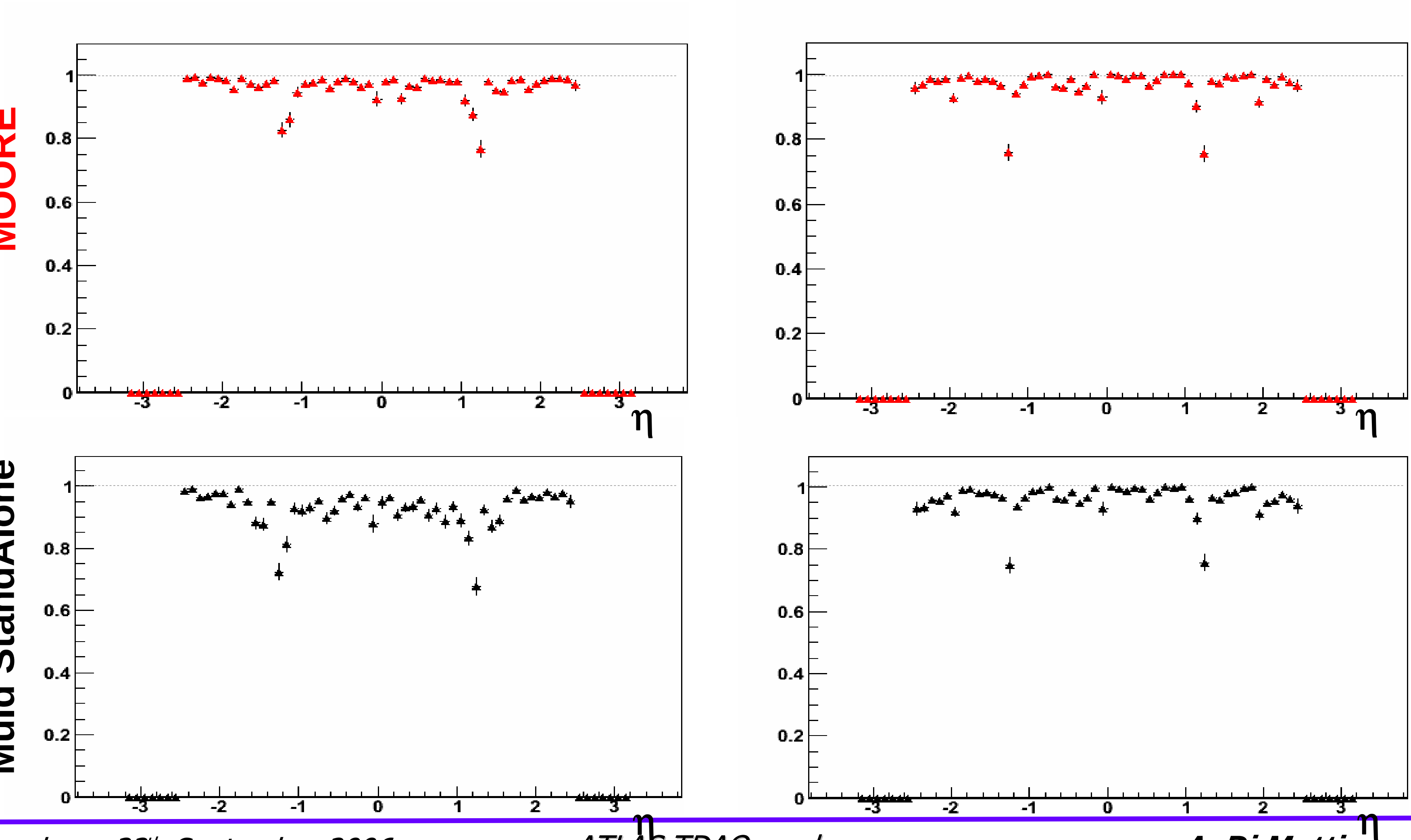
Moore and MuId SA efficiency

Muons p_T=8 GeV/c

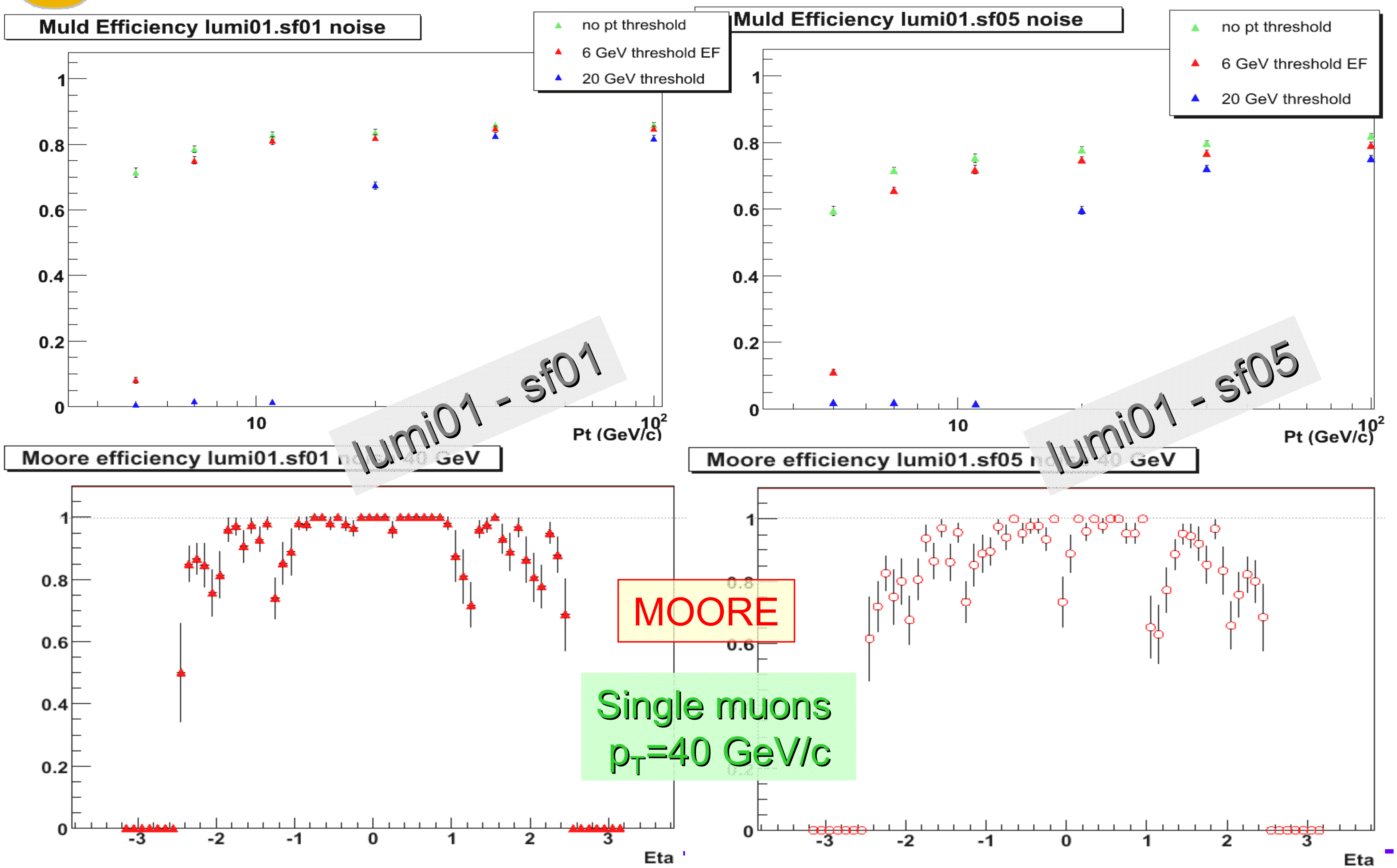
Muons p_T=40 GeV/c

MOORE

MuId StandAlone

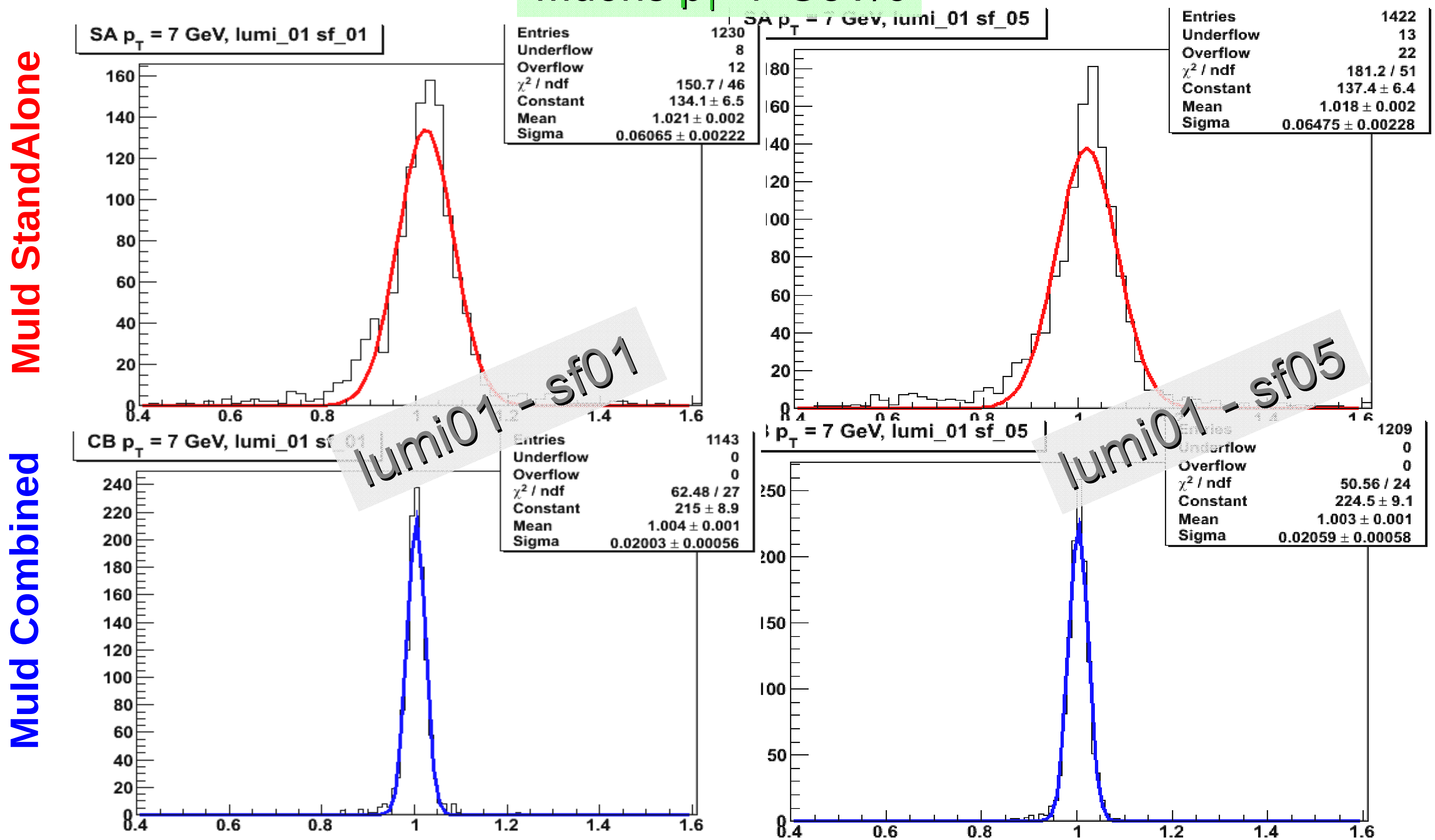


Efficiencies vs. p_T and η w/ background



$1/p_T$ resolution w/ background

Muons p_T=7 GeV/c



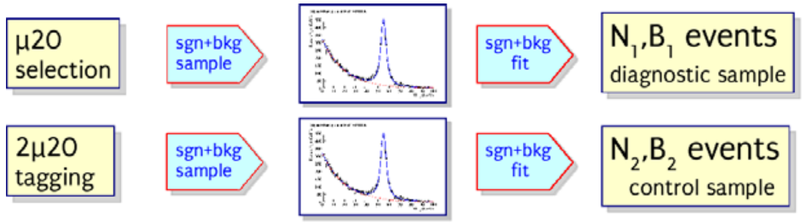
- Significative improvement observed from **StandAlone** to **Combined** reconstruction
- Increase of cavern background don't affect $1/p_T$ core resolution of ***Muld Combined***

Plans

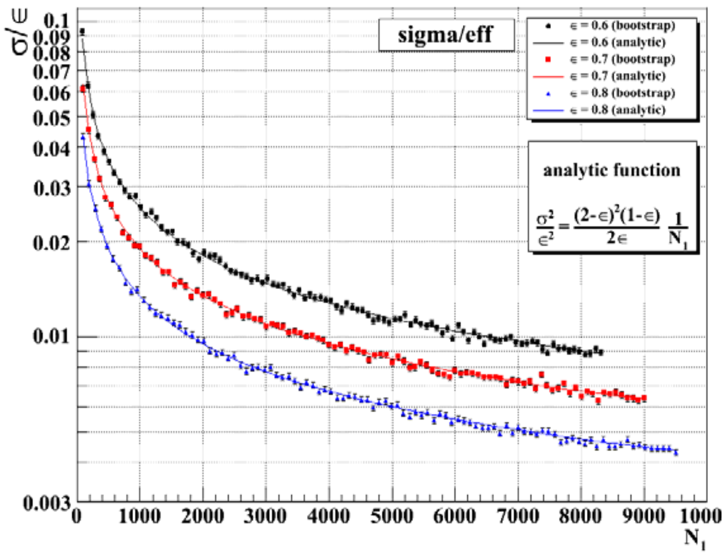
- Exhaustive performance EF studies including endcaps both seeding from LVL1 and with the full vertical slice
- Definition and simulation of muons from K/π in-flight decays for trigger rate reduction studies
- Migration to the new Moore integrated in the tracking EDM

Trigger efficiency from $Z \to \mu^+\mu^-$

Double Object (DO) method

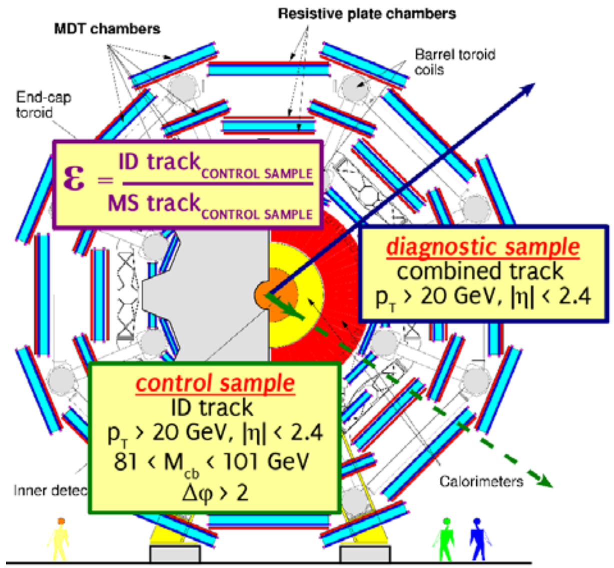


$$\epsilon_{\mu 20} = \frac{2(N_2 - B_2)}{(N_1 - B_1) + (N_2 - B_2)}$$



Assuming an HLT μ20 trigger efficiency greater than 70 %, after 30 mins of DAQ the efficiency can be estimated with about 1-2 % statistical uncertainty

Double Object with orthogonal Signature (DOS) method



Results with CSC samples, Athena 11.0.5

Muon Trigger Slice L1+EF

- *Statistic signal L_i = 14.8 pb^{-1}*
- *Backgrouds from $BB\mu\mu X$, $W\mu\nu$, $Z\tau\tau$*

Reconstruction		DO [%]	DOS [%]	MC [%]
Standalone	ϵ^{EF}	$= 92.1 \pm 0.2$		
(MS only)	ϵ^{L1+EF}	$= 77.0 \pm 0.3$	79.7 ± 0.3	78.1 ± 0.2
Combined	ϵ^{EF}	$= 94.2 \pm 0.2$		
(MS + ID)	ϵ^{L1+EF}	$= 78.7 \pm 0.3$	81.0 ± 0.3	80.6 ± 0.2
$\epsilon_{L1} = 83.6 \pm 0.2$				