Performances of the muon identification at the ATLAS experiment

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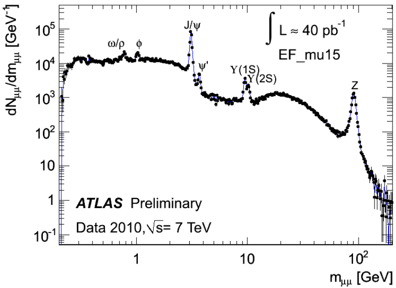


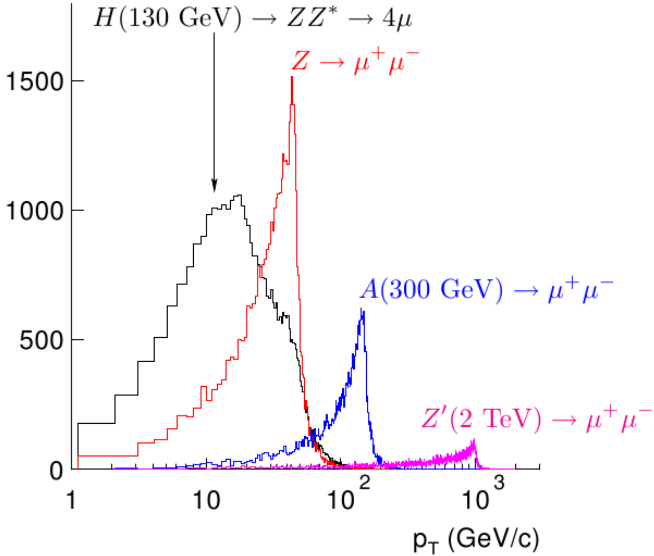
Using muons in analyses

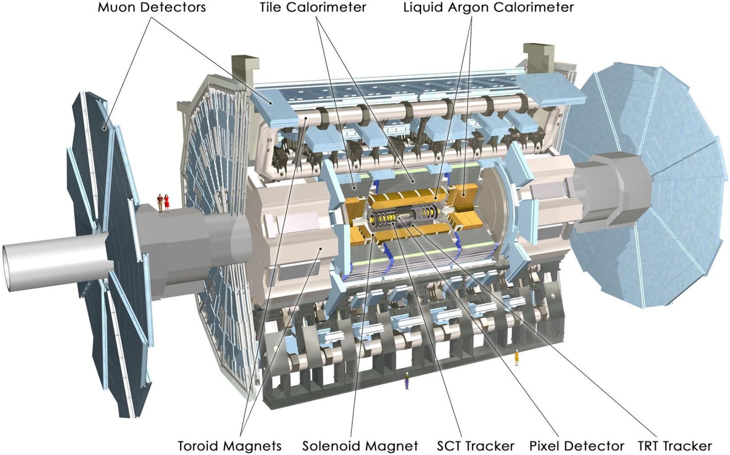
Motivation

- Muons fundamental for most analyses
- In ATLAS need to identify muons up to 1 TeV with $\approx 10\%$ resolution
- Alignment: crucial task for momentum resolution
- Performance studies needed both to improve quality of measurements and to give fundamental inputs to analysis groups

Performance work

- Reconstruction efficiency determination
- Trigger Efficiency determination
- Misidentification rate measurement
- Momentum resolution determination





Subdetectors

- Inner Detector (solenoidal field)
  - Silicon tracker up to $|\eta| < 2.5$
- Calorimeters
  - EM up to $|\eta| < 3.2$
    - Liquid Argon sampling calorimeter
  - Hadronic up to $|\eta| < 4.9$
    - Tile sampling calorimeter
    - Liquid Argon Calorimeter (forward)
- Muon Spectrometer (toroidal field)
  - Tracking up to $|\eta| < 2.7$
  - Trigger up to $|\eta| < 2.4$

Muon identification with the ATLAS detector

Standalone

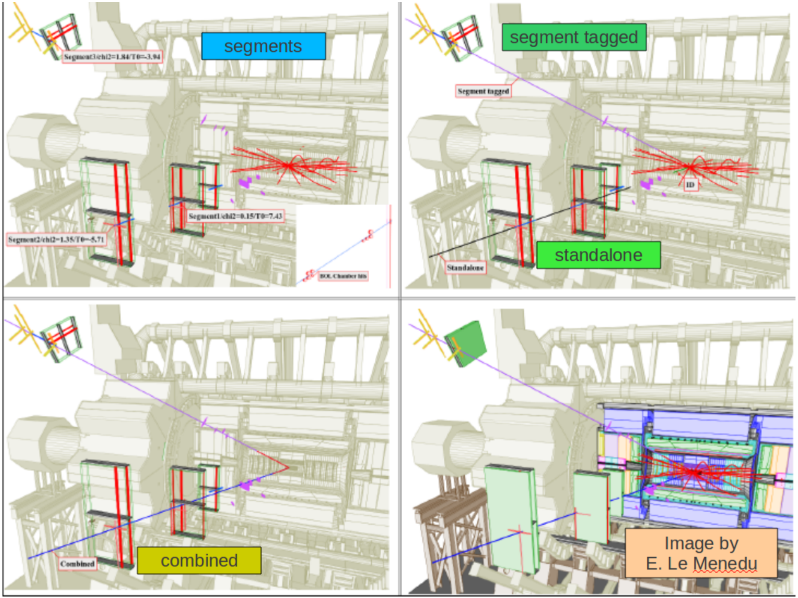
- Use Muon Spectrometer only
- Maximal acceptance

Segment tagged

- Inner Detector track tagged using Muon Spectrometer
- Increase efficiency in poorly instrumented regions

Combined

- Use Inner Detector + Muon Spectrometer
- Best momentum resolution



Efficiency measurement: the Tag and Probe method

To measure muon reconstruction efficiency, dimuons decay of Z, J/ψ are used.
The total reconstruction efficiency can be factorized as $\epsilon^{reco} = \epsilon^{MS}\epsilon^{comb}\epsilon^{ID}$
Its measurement is performed in two steps, using the Tag and Probe method:

- One combined muon: TAG
- One track on the other side of the detector: PROBE

$\rightarrow$ Search for a reconstructed muon track associated to the probe: MATCH

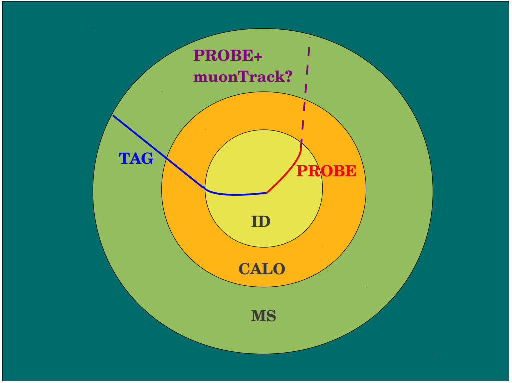
$$\epsilon = \frac{N_{Probes}^{Matched}}{N_{Probes}}$$

measure of $\epsilon^{MS}\epsilon^{comb}$

- Inner Detector track as probe
- Combined track as match

measure of ϵ^{ID}

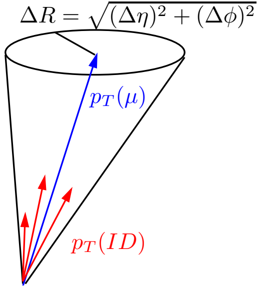
- Muon Spectrometer track as probe
- Inner Detector track as match



An example, with Inner Detector tracks used as probe and combined tracks as matching tracks

First step: measure $\epsilon^{MS}\epsilon^{comb}$ using Inner Detector tracks as probe:

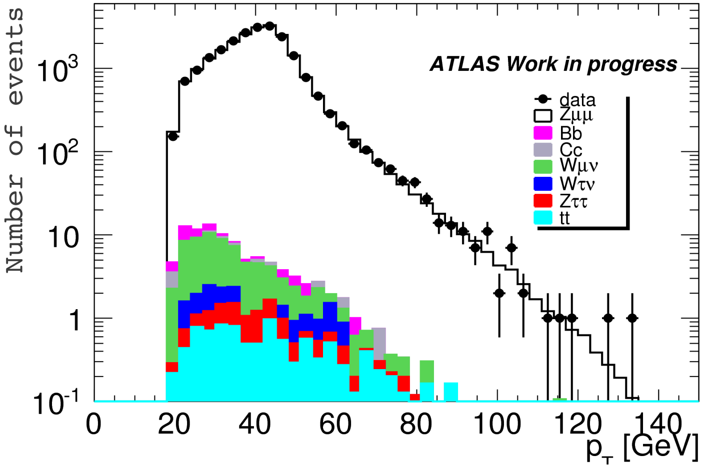
- Vertex with 3+ tracks (to avoid cosmic background)
- TAG - Combined muon
  - $p_T > 20\ GeV$, $|\eta| < 2.4$
  - Muon fired trigger (to avoid biased efficiency)
  - Isolation cut: $\frac{\sum p_T^{\Delta R<0.4}}{p_T^{\mu}} < 0.2$
- PROBE - Inner Detector track
  - From same vertex as tag
  - Opposite charge
  - $p_T > 20\ GeV$, $|\eta| < 2.5$
  - Isolation cut: $\frac{\sum p_T^{\Delta R<0.4}}{p_T^{IDtrk}} < 0.2$
  - Invariant mass: $|m_{\mu\mu} - m_Z| < 10\ GeV$
  - Azimuthal separation of tag and probe tracks, $|\Delta\phi| > 2$
- MATCH - Combined Track associated to Probe
  - $\Delta R < 0.1$ between probe track and reconstructed muon



Results on Pythia samples

Sample	Contribute
$Z \longrightarrow \mu\mu$	99.62%
$W \longrightarrow \mu\nu$	0.21%
$b\bar{b}$	0.059%
$t\bar{t}$	0.042%
$W \longrightarrow \tau\nu$	0.029%
$Z \longrightarrow \tau\tau$	0.025%
$c\bar{c}$	0.021%

- High purity sample of $Z \longrightarrow \mu\mu$ is selected
- Small background contribution, most of it at low p_T
- Good data-MC simulation agreement



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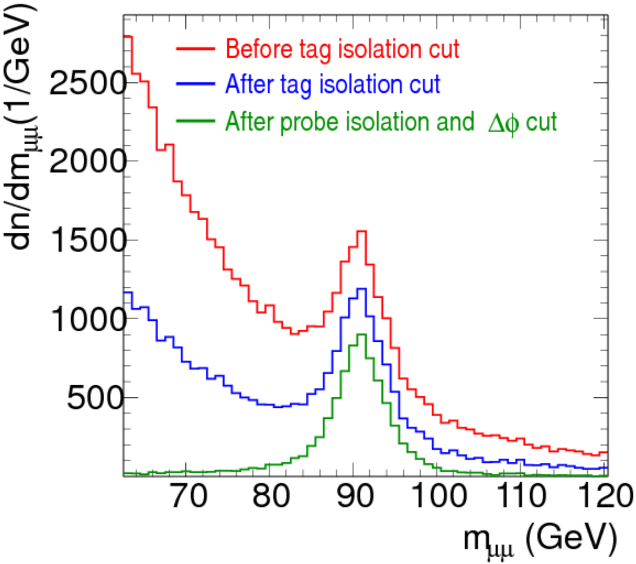
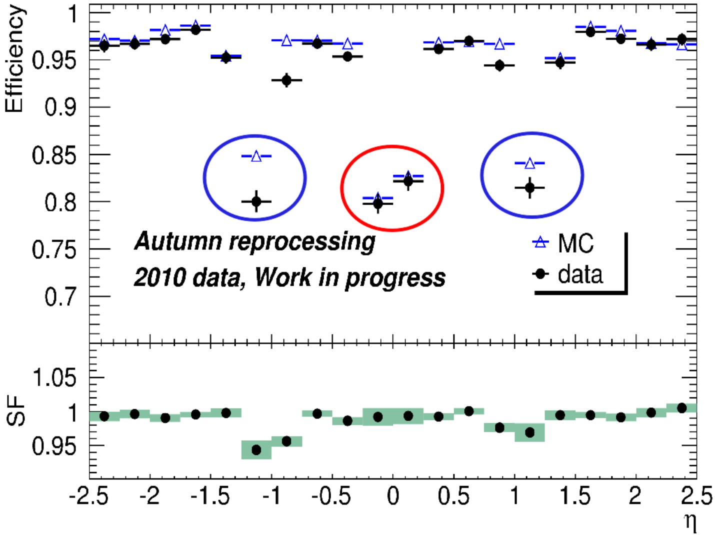
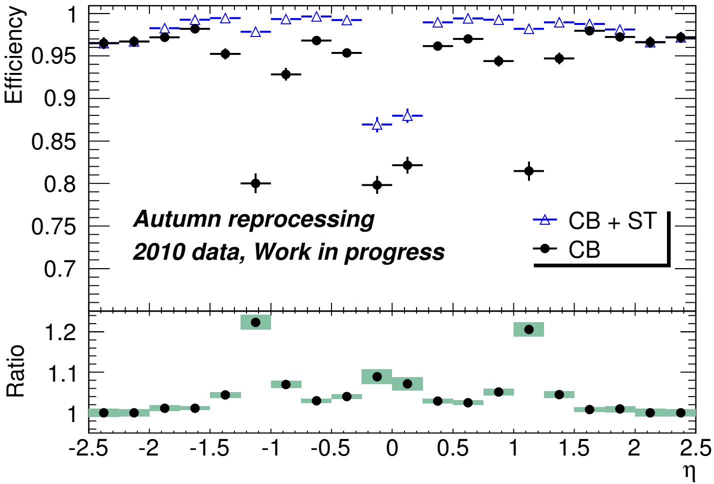


Results on Combined Muons using $Z \longrightarrow \mu\mu$ events



Efficiency vs η

- Data/MC ratio (Scale Factor, SF) flat and compatible with 1
- $|\eta| \approx 0$ Acceptance gap to allow space for services
- $|\eta| \approx 1.1$ Region with not enough chambers to provide momentum measurement in the Muon Spectrometer
- Inefficiency in those regions can be recovered with different reconstruction strategies

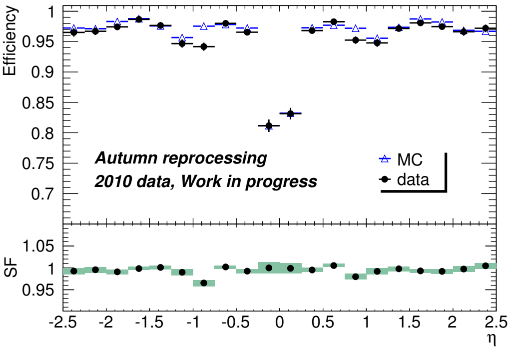


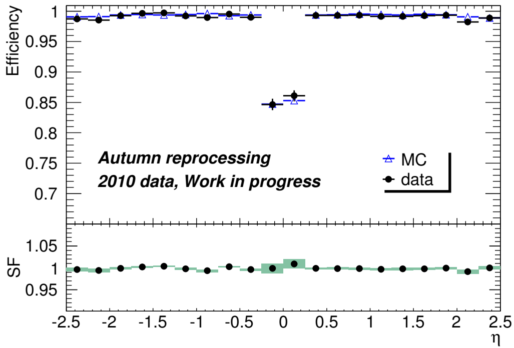
Efficiency recovery with Segment Tagged muons

- Adding Segment Tagged (ST) muons to Combined (CB) muons allow for a recovery of the efficiency in the poorly instrumented regions
- Full recovery around $|\eta| \approx 1.1$
- Partial recovery around $|\eta| \approx 0$
- CB+ST muons are the ones that will be used in physics analysis on 2010 and 2011 data

Efficiency with different muon tightness definition

Both plots show Combined + Segment Tagged muons.



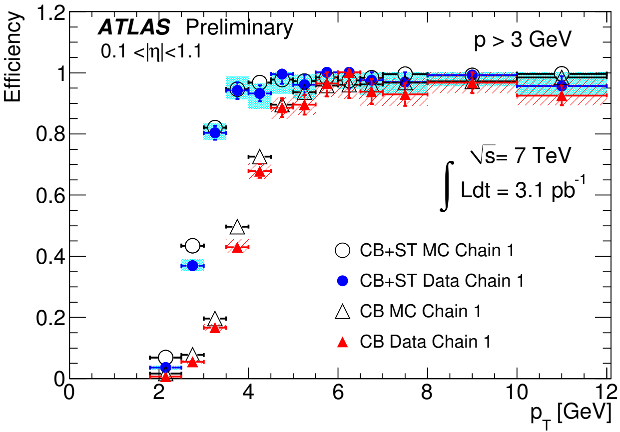


Tighter definition of muons

- High efficiency in the whole detector
- Very good agreement with MC

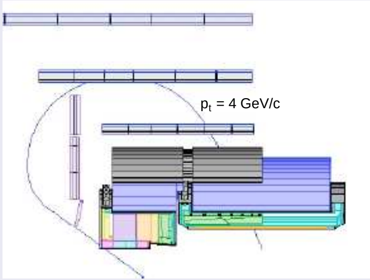
Looser definition of muons

- Very high efficiency in the whole detector
- Perfect agreement with MC
- Efficiency flat in the whole detector (apart from acceptance gap at $\eta \approx 0$)

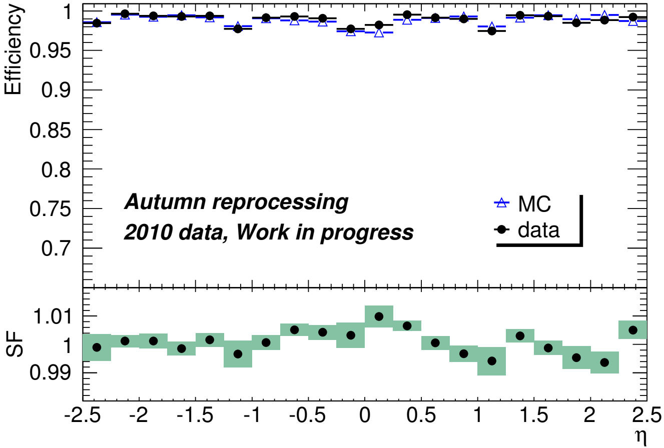


Efficiency at low p_T

- To study efficiency at low p_T , $J/\Psi \longrightarrow \mu\mu$ is used
- Allow for a measurement of the efficiency turn on curve
- Adding Segment Tagged muons to the Combined rises the efficiency especially for very low p_T muons



Final step: the ID efficiency



Inner Detector efficiency

- Average efficiency, $99.1\% \pm 0.1\%$
- Data/MC ratio compatible with 1 within less than 1%

The results of the efficiency study

- The reconstruction efficiency was measured on 2010 data showing $\epsilon^{reco} = (97.2 \pm 0.2)\%$
- Data and MC simulations are in very good agreement for the reconstruction efficiency, in good agreement for trigger efficiency
- The outcome of this sutdies were MC/data ratio Scale Factors (binned in η and p_T) to correct the MC simulation reconstrucion to what is expected from the data measurements

As an example of a performance study, here I will present a very simple study, performed during the early data taking period, that helped finding and understanding a problem that was then solved.

- Deflection angle α of a muon with momentum p and electric charge q after a path $\mathcal{P}$:

$$\alpha = \frac{q}{p} \int_{\mathcal{P}} B_\perp \, dl$$

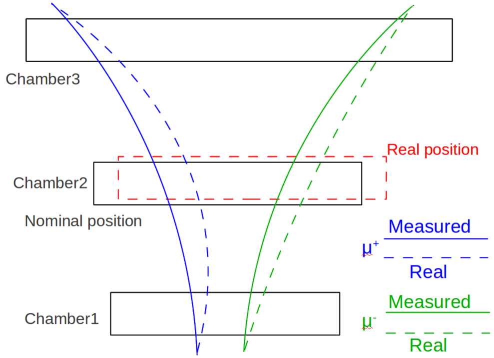
$B_\perp$: magnetic field component orthogonal to $\mathcal{P}$.

- Misalignment of the tracking detector leads to a constant mismeasurement $\delta\alpha$ of α

⇒ The measured momentum systematically deviates from the right momentum p by

$$-\frac{1}{q \int_{\mathcal{P}} B_\perp \, dl} \delta\alpha \cdot p^2 =: -K \cdot p^2.$$

$\underline{q > 0}$: $p_{meas.} = p - K_+ \cdot p^2$.
$\underline{q < 0}$: $p_{meas.} = p - K_- \cdot p^2 = p + K_+ \cdot p^2$.

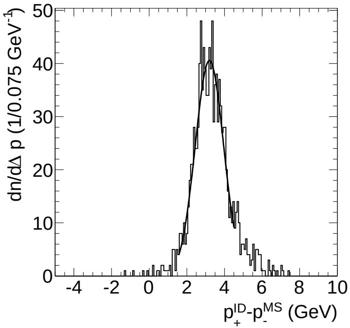


The equations

$\underline{q > 0}$: $p_{meas.} = p - K_+ \cdot p^2$.
$\underline{q < 0}$: $p_{meas.} = p - K_- \cdot p^2 = p + K_+ \cdot p^2$.

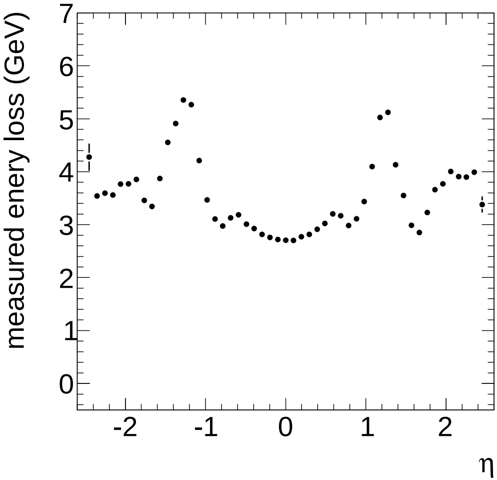
- $p^{MS} = p + E_{loss}$ (E_{loss}: energy loss in the calorimeters).
- $$< p_+^{MS} - p_+^{ID} >= E_{loss} + (K_+^{ID} - K_+^{MS}) \cdot p^2$$ $$< p_-^{MS} - p_-^{ID} >= E_{loss} - (K_+^{ID} - K_+^{MS}) \cdot p^2$$
- Solve the system to find E_{loss}, ΔK

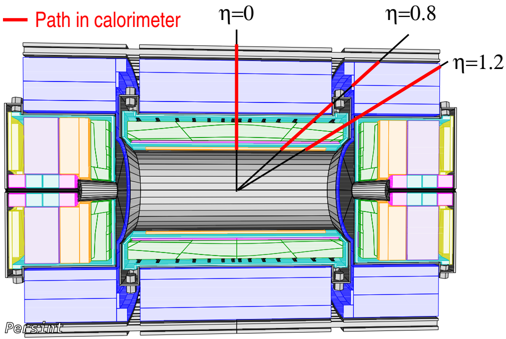
The method: Produce a measurement of $< p_\pm^{ID} - p_\pm^{MS} >$ in different regions of the detector to identify eventual problematic regions



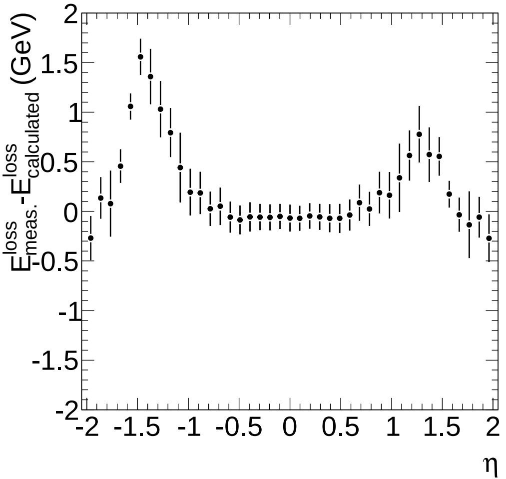
The fit:

- Fit a normal distribution to the peak of the Δp distribution in $[\mu - 2\sigma, \mu + 1.5\sigma]$.
- Take the mean of the fitted Gaussian as the value for $< p_\pm^{ID} - p_\pm^{MS} >$ to be unaffected by tails of the distribution.





- Measured energy loss proportional to path length in calorimeter material.
- Central region: $E_{loss} \sim 3$ GeV.
- Calorimeter transition region: $E_{loss} \sim 5$ GeV.
- Forward region: $E_{loss} \sim 3.5$ GeV.



- Dots display mean of $E^{meas.}_{loss} - E^{expt.}_{loss}$.
- Error bars display RMS of $E^{meas.}_{loss} - E^{expt.}_{loss}$.

Barrel

- $E^{meas.}_{loss} - E^{expt.}_{loss} < 0.1$ GeV.

Spectrometer transition region

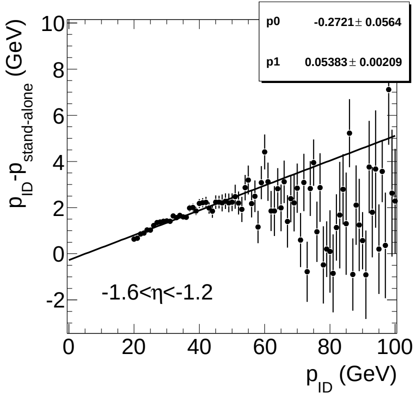
- $E^{meas.}_{loss} - E^{expt.}_{loss} \sim 1$ GeV.

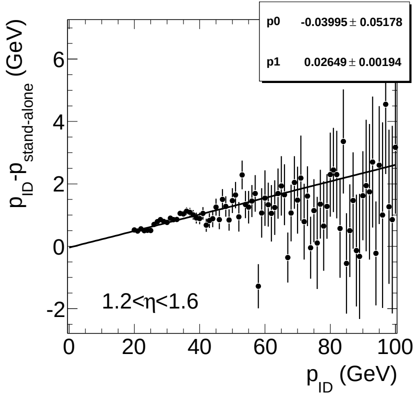
What is the origin of this problem?

- Wrong Muon Spectrometer momentum measurement due to wrong magnetic field map?
- Wrong material distribution used for energy loss calculation?

$E_{loss}^{meas.} - E_{loss}^{expt.} \sim 1$ GeV in the muon spectrometer transition region

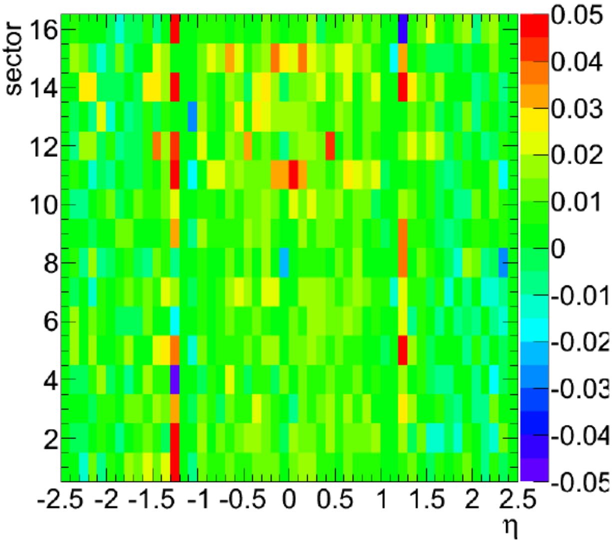
$E_{loss}^{meas.} - E_{loss}^{expt.}$ as a function of the muon energy





⇒ Energy dependence of the deviation of the measured from the predicted energy loss may be related to a unprecise $\int B\,dl$ in the transition region:

- $\int B\,dl$ too large by $(5.4 \pm 0.3)\%$ for $\eta \in [-1.6, -1.2]$,
- $\int B\,dl$ too large by $(2.6 \pm 0.2)\%$ for $\eta \in [1.2, 1.6]$?

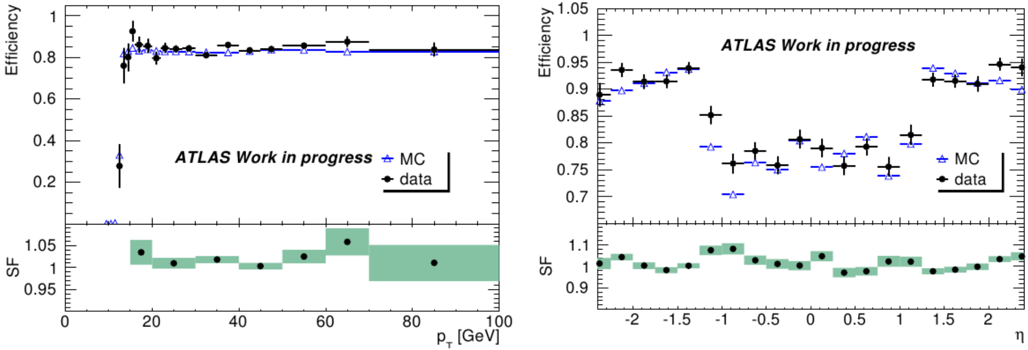


2D map of $p^{ID} - p^{MS}/p^{ID}$ with the new magnetic field map. Plot by P. Kluit.

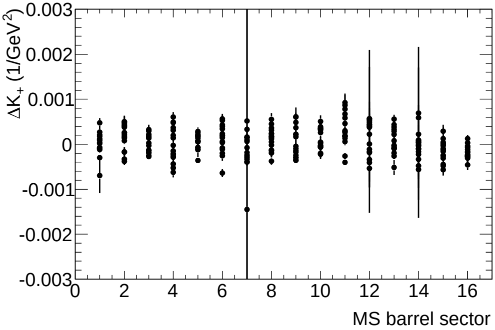
Conclusions

- In the first part of the talk, shown part of a complete study on the performances of the muon identification at the ATLAS experiment
- In the second part, shown a simple exercise that led to spot a problem that was then fixed
- The message: one crucial task when you work with a detector is understanding the detector itself

BACKUP

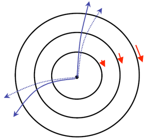


Using as a probe a Combined Track to match to a triggerd muon, it is possible to maesure the trigger efficiency for the muons. The trigger efficiency was measured as well to be $\approx 80\%$ in the central region, $\approx 95\%$ in the forward region



- Results restricted to the MS barrel towers($|\eta| < 0.97$).
- No sector independent offset of ΔK_+ from 0.

$\Rightarrow$ No indication of a clocking effect in the ID alignment.



- Alignment of the muon spectrometer sectors seems to be on the same level.
- Large sectors show a smaller spread of the corrections.

Evaluation of corrections with $Z \to \mu^+\mu^-$ events

- Hypothesis 1: $K_+^{ID} = 0 \to$ Stand-alone mass resolution $\frac{\sigma m_{\mu\mu}}{m_{\mu}\mu}$ improves from $(4.1 \pm 0.6)\%$ to $(3.6 \pm 0.5)\%$ by applying alignment corrections.
- Hypothesis 2: $K_+^{MS} = 0 \to$ Inner detector mass resolution $\frac{\sigma m_{\mu\mu}}{m_{\mu}\mu}$ is unchanged at $(3.4 \pm 0.6)\%$ after applying alignment corrections.

$\rightarrow$ ΔK_+ at tower level dominated by muon spectrometer misalignment.