A Muon Identification and Combined Reconstruction Procedure for the ATLAS Detector at the LHC at CERN

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Outline

- The ATLAS Detector
- Muon Combined Reconstruction method
- Performance on single $\mu$
- Performance on physics channels $Z \rightarrow \mu\mu$, $H \rightarrow 4\mu$
- Conclusions
The ATLAS Detector

- General purpose apparatus
- Length of 46 m, diameter of 22 m
- Onion shell structure, two endcaps and one barrel
- Inner tracker, calorimeters, muon spectrometer
- Inner tracker contained in a solenoid (max 2 T), muon spectrometer in a toroid (air core, max 3.9 T for barrel, 4.1 T for endcap)
The Muon Spectrometer

- 16 sectors in $\phi$ (small and large)
- Instrumented with trigger and precision chambers
- Muon bending
  - $|\eta| < 1$ from barrel toroid
  - $1.4 < |\eta| < 2.7$ from two endcap magnet
  - $1.0 < |\eta| < 1.4$ transition region
- Design performances
  - $\Delta p_t / p_t \approx \text{few } \%$ up to 100 GeV/c
  - $\Delta p_t / p_t \approx 10\%$ for 1 TeV/c

Traversing Atlas a $\mu$ is detected in

- 2 high precision tracking systems: Inner Detector and Muon Spectrometer
- EM and hadronic Calorimeters

- Muon Spectrometer: best at higher $p_T$
- Calorimeters: E loss $>3$ GeV
- Inner Detector: best at lower $p_T$
Muon Reconstruction

- **Moore** (Muon Object Oriented REconstruction)
  - reconstruction in the MuonSpectrometer

- **Muon Identification**
  - Muon combined reconstruction and identification
  - Divided in two parts:
    - **Muid Stand Alone:**
      - Back tracking of the MOORE tracks to the interaction point
    - **Muid Comb:**
      - Combination of the muon and the inner detector tracks
  - Both work in ATHENA (= the ATLAS reconstruction framework)
Muon Spectrometer Strategy for Pattern Recognition

- Software MOORE (Muon Object Oriented REconstruction)
- Identification of regions of activity in the $\phi$–projection and RZ-projection
- Reconstruction of local straight track segments in the bending plane using the MDT hits
- Track segment combination
- Track fit
  - Multiple scattering and energy loss in the dead matters of the Muon System taken into account
  - track parameters ($a_0$, $z_0$, $\phi$, $\cot\theta$, $1./pt$) are expressed at the first measured point.
Muon Combined Reconstruction Strategy

**Muon Identification (MUID)**

- Backtracking from Muon System down to beam region
  - multiple scattering parameterised as scattering planes in calorimeters
  - energy loss from truth, or from Calo Reconstruction, or from parametrization as function of $(\eta, p)$
  - Refit: muon track parameters expressed at vertex
- Muon/ID tracks matching with a $\chi^2$ cut-off
  - $\chi^2$ based on track covariance matrices and on the difference in track parameters
- Combined track fit
Moore Architecture

- Pattern recognition is divided in several steps.
- Each step is driven by an Athena top-algorithm.
- Algorithms independent, imply less dependencies, code more maintainable, modular, easier to develop new reconstruction approaches.

Basic idea: Separation of the algorithmic classes from data objects.
MUID Architecture

- **MuidInit**
- **MuidStandAlone**
- **MuidComb**
- **MuidNtuple**
- **MuidIDNtuple**
- **MuidCombNtuple**

**Containers**:
- **MooTrackContainer**
- **MCEventCollection**
- **MuidTrackContainer**
- **CaloCellContainer**
- **iPatTrackContainer**
- **MuidTrackContainer**

**Ntuples**
Single $\mu$ performances

- Plateau efficiency $\sim 95%$
- Low efficiencies @ low $p_T$
  - Only $\mu$ with $E>3-4$ GeV reach the Spectrometer
  - Few measurements
  - Multiple scattering and magnetic field effects are dominant $\rightarrow$ pattern recognition more difficult
- Combined efficiency @ high $p_T$
  - Pattern recognition perturbed by possible em shower accompanying high $p_T$ muons

Rather good agreement with Physics TDR results
The Inner Detector measurements dominate the combined transverse momentum below 10 GeV/c.

The Muon System dominate at high $p_T$. 

1/Pt Resolution vs Pt

Moore
Muld Standalone
iPat
Muld Combined

Pt (GeV) vs 1/Pt Resolution (GeV)
Loss at low $\eta$ due to the Muon Spectrometer central crack

2nd coordinate of CSC missing in simulation $\rightarrow$ low efficiency at $|\eta|>2$

Tracking in the high inhomogeneous field in the transition region $\rightarrow$ low efficiency in the range $1<|\eta|<1.5$ for low pt muons

Uniform efficiency vs phi
Z→μμ

5000 events

Backtracking → mass correction
Combination → mass resolution improvement

σ = 4.26 GeV

σ = 2.86 GeV

Phy TDR σ = 2.5 GeV
Reconstruction with Muon Spectrometer Standalone (Moore + MUID Standalone)

Combined Reconstruction (Moore + MUID + iPat)

- $H \rightarrow 4\mu$ (with $m_H = 130$ GeV)
- $\sim 10$ K evt.

**Without Z constraint**

**Without Z constraint**

\[
\sigma = (3.12 \pm 0.07) \text{ GeV}
\]

\[
\sigma = (1.86 \pm 0.03) \text{ GeV}
\]

**Phy TDR $\sigma = 2.7$ GeV**

**Phy TDR $\sigma = 1.6$ GeV**
Conclusions

- Muon reconstruction at ATLAS is very challenging
  - Muon System very large and complex \(\rightarrow\) extrapolation uncertainties
  - Rather inhomogeneous Magnetic Field
    - Precise propagation required
    - Problems at low pt
  - High level of background
- OO software for ATLAS muon Reconstruction has been developed
  - For standalone Muon Spectrometer reconstruction (Moore)
  - For muon combined reconstruction (Muid)
- Performances have been tested
  - For single \(\mu\)
  - For physics channels

- Alternative tracking methods to be inserted in Moore (e.g. Kalman Filter) and optimize efficiency for low energy muons (use of muon signal in TileCal) are under development