Measurement of muon misidentification rates in $Z \to \mu\mu$ events for the ATLAS detector

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MAX-PLANCK-GESELLSCHAFT

$\Delta p \cdot \Delta q \geqslant \frac{1}{2} \hbar$

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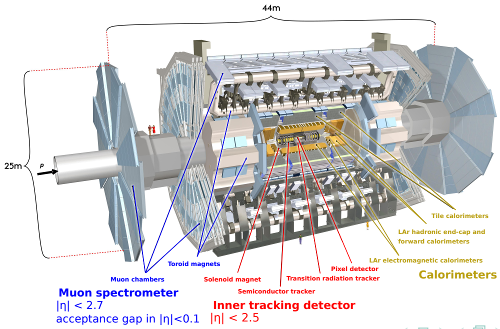
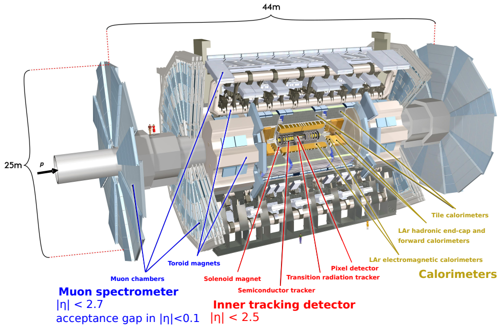
Outline

- Multipurpose detector at the LHC at CERN (Geneva)
- Record proton proton collisions at $\sqrt{s} = 7$ TeV (2011) and 8 TeV (2012)
- After 2015 up to 13 TeV
- High instantaneous luminosity $7 \cdot 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, after upgrade $1 \cdot 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
- 3 main components
  - inner detector
  - calorimeters
  - muon spectrometer



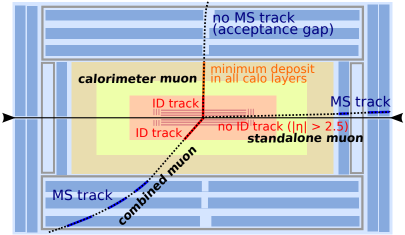
- Use of all subdetectors
- Inner detector: tracking & momentum measurement with a solenoid magnetic field
- Calorimeter: isolation and energy loss
- Muon spectrometer: tracking & momentum measurement with a toroidal magnetic field & muon identification
- Performance goal: Momentum measurement with a 10 % accuracy for 1 TeV Muons



Ideal case: combination of two tracks in the inner detector and the muon spectrometer

Combined muons

- 95 % of all cases
- Highest resolution and purity
- All subdetectors need to be instrumented and operational
- Acceptance loss in uninstrumented regions of the muon spectrometer



Muon reconstruction

Recover efficiency in incompletely instrumented regions through additional algorithms

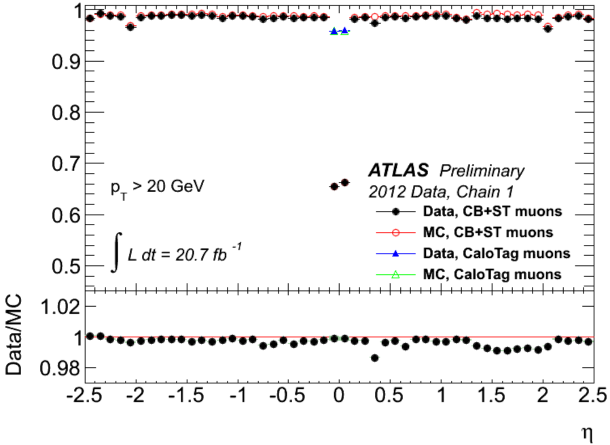
→ Combination of inner detector track with spectrometer hits that don't form an independent track (**segment tagged muons**)

→ Muon spectrometer track with no associated inner detector track (**standalone muon**)

→ Combination of inner detector track with minimum energy deposit in the calorimeter (**calorimeter muon**)

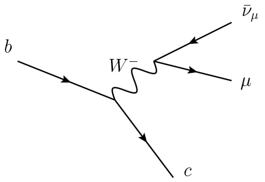
Efficiency gained at the price of reduced purity

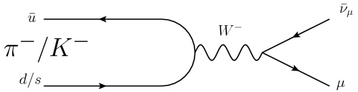
Efficiency of combination of combined and segment-tagged muons



Muon background in physics analysis

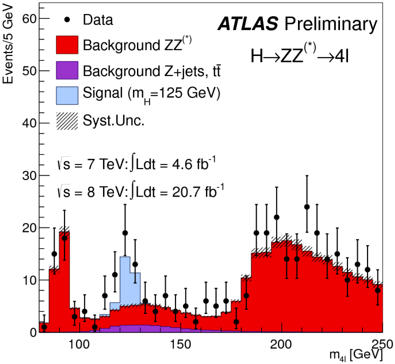
- Real muons out of heavy flavour decays
  - → b-lifetime: Muon displaced from primary vertex
  - → Surrounding jet activity in the calorimeter
- Real muons out of pion / kaon decays
  - → Characteristic kink in the track at pion / kaon decay point
- Fake muons from jets (punch-through)
  - → Recognizable through large energy deposit in the calorimeter
- Cosmic muons
  - → Tracks do not emerge from primary vertex





- High muon efficiency required for 4μ final state
  - $\to$ Combine all previously mentioned reconstruction methods to obtain maximum efficiency
- Main background ZZ diboson production
  - $\to$ Low below $m_{4\mu} \sim 180$ GeV
- But: Processes with non-prompt muons become important
  - $\to$ $t\bar{t}$ and Z + jets

$\to$ Understanding of these muons important for measuring the new Higgs properties

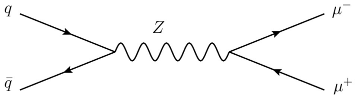


Analysis strategy

- Goal: Study appearance of non-prompt muon background

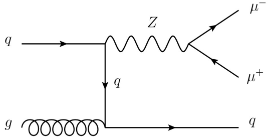
$\rightarrow$ Validate the prediction of the detector simulation

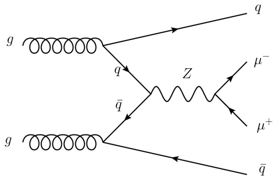
- Observe background-like muons in a well controlled environment



- Use $Z \rightarrow \mu\mu$ decays
  - well known physics process

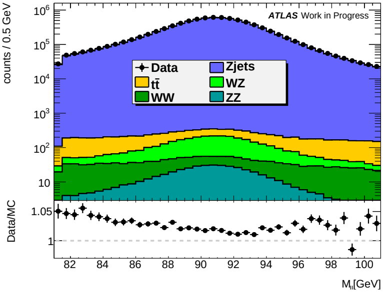
  $\rightarrow$ Know that any additional muons must be non-prompt
  - High statistics at LHC
  - Easy to select with high purity
  - Comparable environment to Higgs search





Analysis strategy

1. Selection of $Z \to \mu\mu$ samples
   - Require presence of two reconstructed combined muons
     - from the primary vertex
     - no surrounding jet activity
   - Require opposite muon charges
   - Require invariant dimuon mass within 10 GeV of the Z mass



Analysis strategy

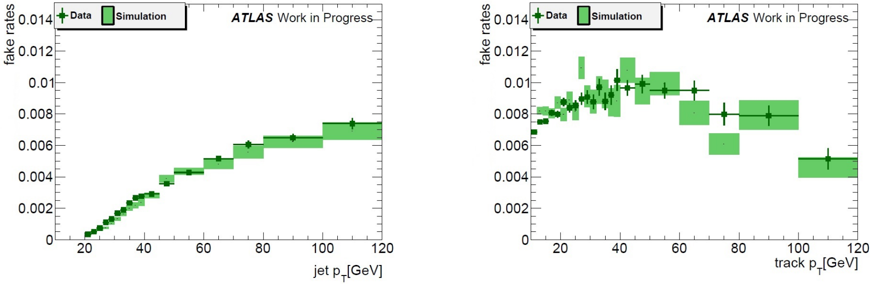
1. Selection of $Z \to \mu\mu$ samples
2. Collect background candidates
   - In selected events look for presence of objects that could give rise to non-prompt muons
   - For the contribution of pion / kaon decays use **inner detector tracks**
     - any track with transverse momentum above 10 GeV
   - For the contribution of secondary muons from heavy flavor decays and punch-through use **jets**
     - any reconstructed jets above 20 GeV
   - Use all events that have at least one such candidate for further study

Analysis strategy

1. Selection of $Z \rightarrow \mu\mu$ samples
2. Collect background candidates
3. Look for reconstructed muons matching the background candidates
    - Exclude muons from the $Z \rightarrow \mu\mu$ candidates
    - Study fraction as function of several observables
        - transverse momentum, pseudorapidity
        - Activity surrounding the muon
        - Muon impact parameter
    - Processes with additional prompt muons: estimate using MC simulation
    - Plot the **fake rates** as the fraction of background candidates with a matching muon

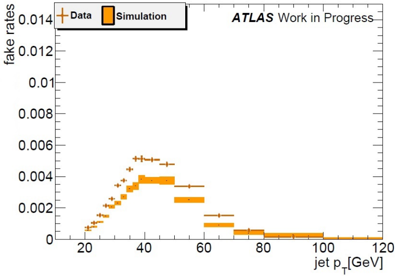
Combined and segment tagged Fake rates

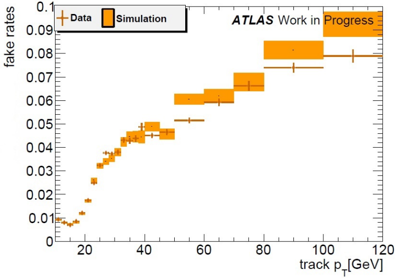
Fake rates as a function of transverse momentum



- Order of magnitude below 1 % in both cases
- Excellent agreement between simulation and data
- Jets: increase with p_T (probability of emitting a muon with sufficient momentum or punch-through)
- Tracks: Maximum at 40 GeV decrease to lower and higher momentum

Fake rates as a function of transverse momentum

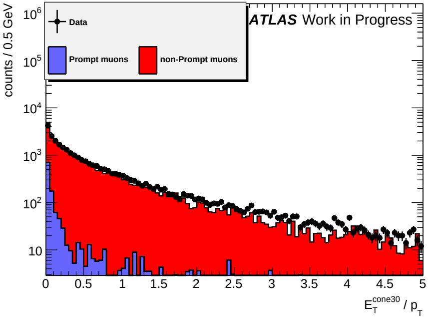


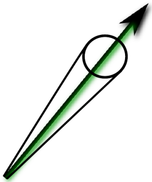


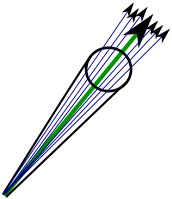
- Fake rates for tracks much higher
- Jets: similar to combined muons up to 40 GeV, then decrease due to reconstruction level requirements
  - $\rightarrow$ High energy deposit in calorimeter prevents identification as calorimeter muon
- Simulation underestimates the fake rates for jets
- Tracks: increase with p_T

Muon isolation

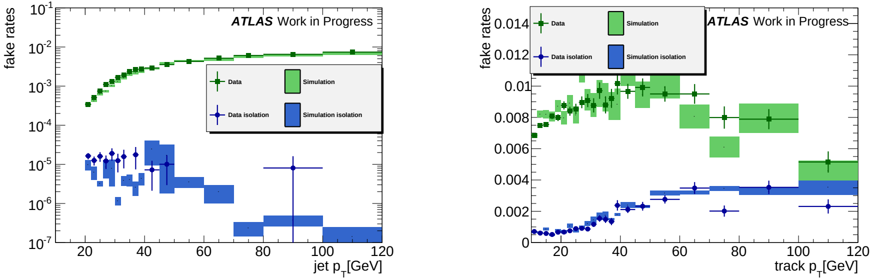
- Require low activity in an angular cone around the muon
- Prompt muons: no surrounding activity, high efficiency
- Non-prompt muons: often part of jets, high rejection





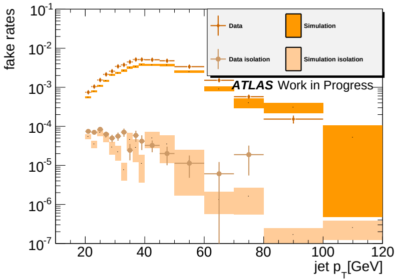


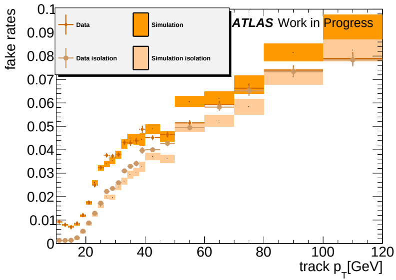
Fake rates as a function of transverse momentum



- Jets: very strong reduction (Factor 10 - 100)
  - Jet includes extra activity by definition
- Tracks: Strong reduction (Factor 2 - 10)
- Tracks: increase with p_T
  - Some tracks may not be part of jets
  - High p_T contamination by prompt muons ($WZ \rightarrow 3\mu\ \nu$)

Fake rates as a function of transverse momentum

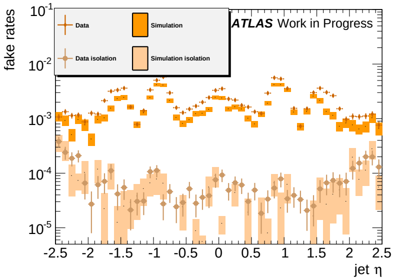


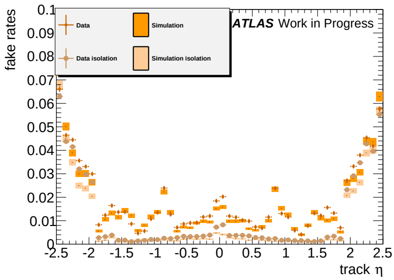


- Reduction not as strong as for combined muons
  - All calorimeter muons have to pass a loose isolation cut at reconstruction
  - → Further reduction not as strong
- Still noticeable reduction (Jets: Factor 5 - 100, Tracks Factor 2)

- Decompose into **detector effects** and **physics effects**
- Work currently in progress

Fake rates as a function of pseudorapidity





Conclusions & Outlook

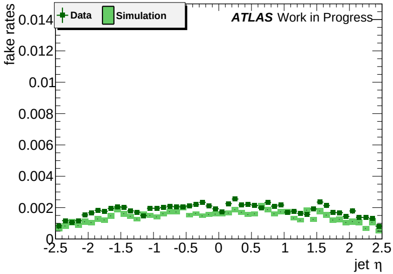
- Background from non-prompt muons need to be well understood in physics analysis
  - Example Higgs properties
- Appearance of non-prompt muons was studied in $Z \rightarrow \mu\mu$ events
- Behavior of non-prompt muons well described by simulation
  - Excellent agreement for combined and segment-tagged muons
  - Fair agreement for calorimeter tagged muons
- Isolation cuts provide strong suppression of non-prompt background
  - Behavior well predicted by simulation

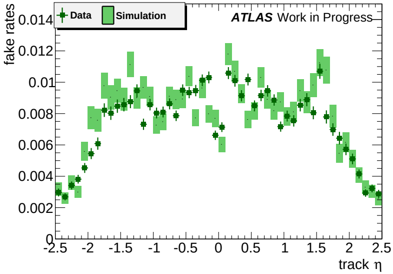
Future plans:

- Use this method to optimize muon selection recommendations for ATLAS physics analysis
- Interpret the observed behavior of non-prompt muons in the scope of physics and detector effects

Combined and segment tagged Fake rates

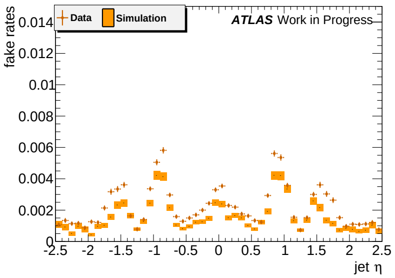
Fake rates as a function of pseudorapidity

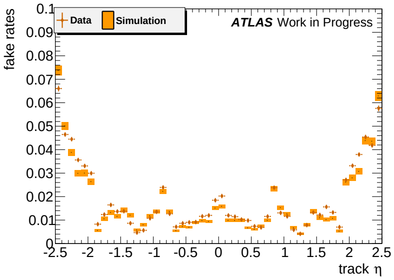




Calorimeter tagged Fake rates

Fake rates as a function of pseudorapidity





Effect of Isolation on Combined and segment-tagged muons

Fake rates as a function of pseudorapidity