R-hadron and long lived particle searches at the LHC

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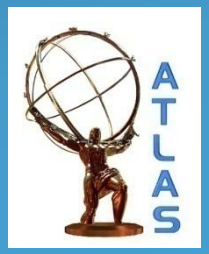
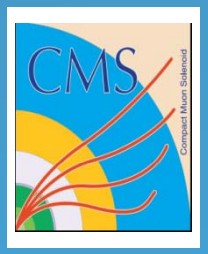
On behalf of the ATLAS and CMS collaborations





Outline

- Motivation
- The unique signature in the LHC
- Trigger
- Discovery methods*
- Conclusions

* The CMS TOF method is discussed in detail in a later talk

Motivation

- Long lived Charged particles are allowed by many models beyond the SM:
  - GMSB, split SUSY, mSUGRA, AMSB, ED…
- **A unique signature which is model independent**

- A “Non conventional” study - Hardware and data acquisition issues have to be considered

The unique signature in the LHC

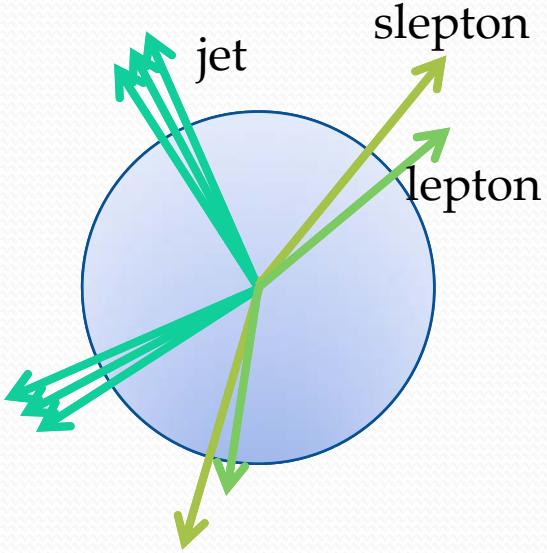
- **The signal to look for at the LHC is a charged particle with low β**
  - Interacts in the detector like a heavy muon – neither EM showers nor substantial hadronic showers
- A very slow particle would lose a lot of energy by ionization
- Medium β particles will arrive to the muon spectrometer with a different beam crossing

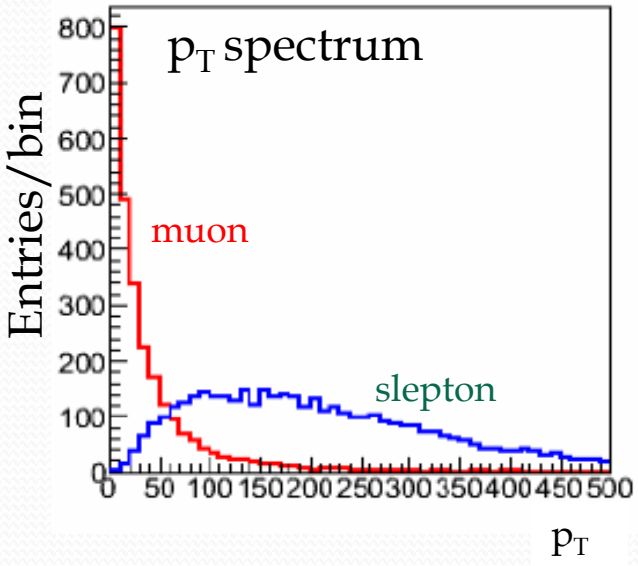
- A particle with β~1 looks just like a high p_T muon
  - We may be able to see an excess of high p_T "muons" but not measure their mass

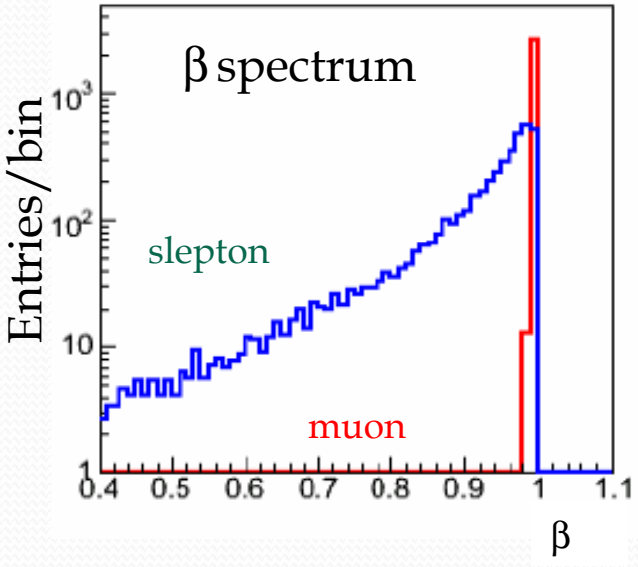
- The background is high p_T muons

An example model context: GMSB5

- The stau and selectron are co-NLSP
  - $M(\tau_1)$=102.2GeV, $M(e_R)$=100.3GeV
  - $M(\chi_1^0)$=113.7GeV
- The NLSPs are long lived
- The cross section is 23pb
- 2 sleptons in each event



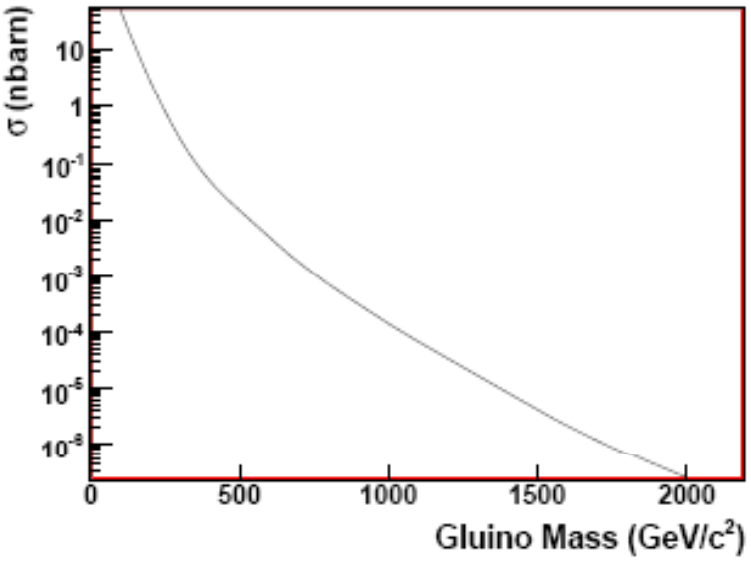




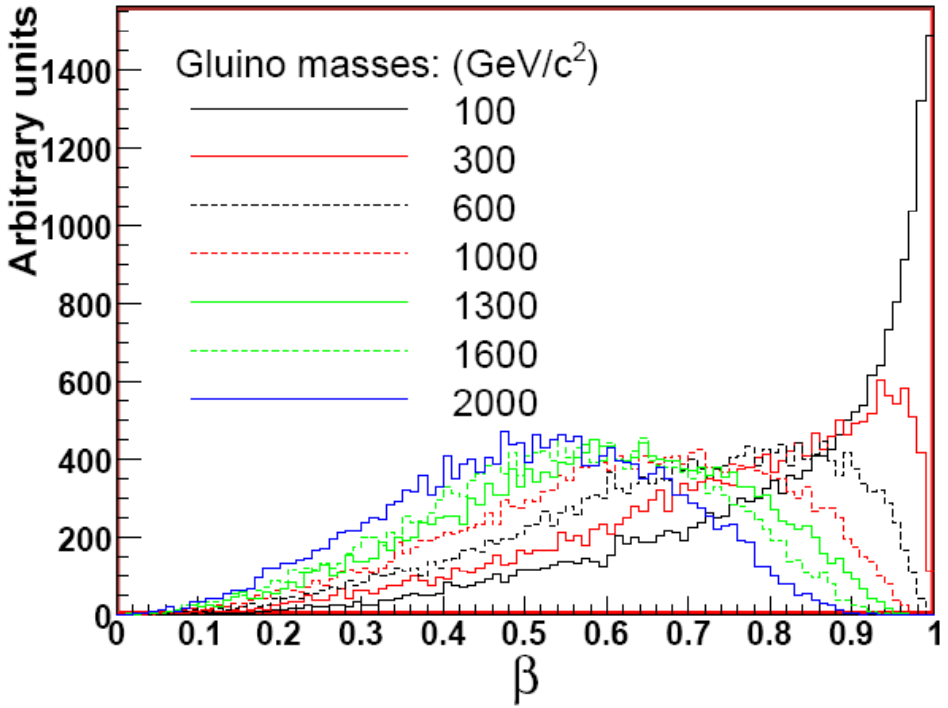
An example model context: Split SUSY

- Gluino NLSP hadronizes to long lived R-Hadron
- The R-Hadron may flip charge when it passes through matter, for example, between the Inner Detector and the muon spectrometer

Total cross-section of gluino pair production at the LHC as a function of gluino mass (using pythia)



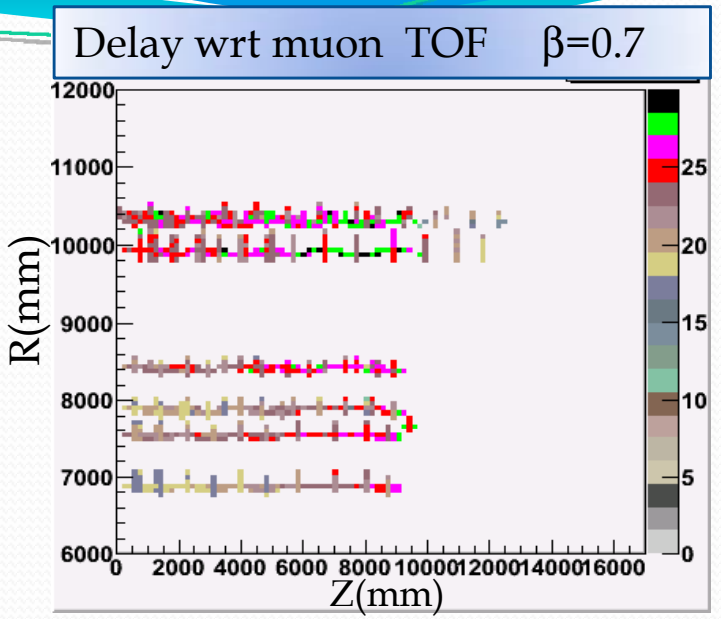
β distribution for different gluino mass

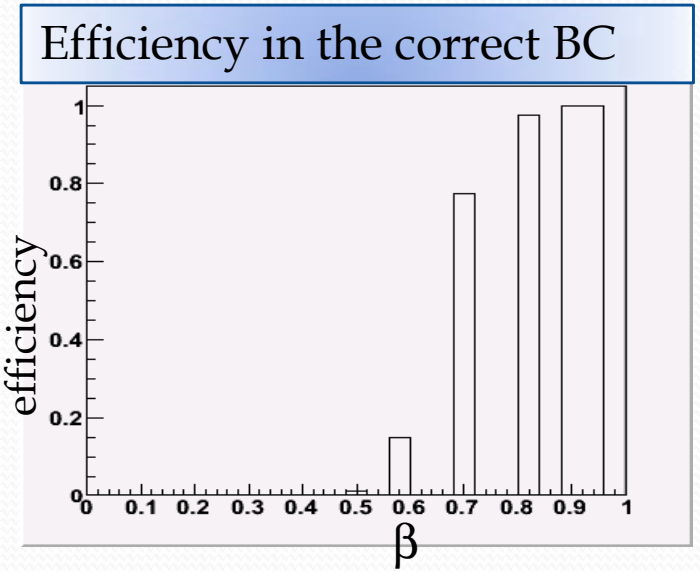


The unique signature in the LHC

BCID

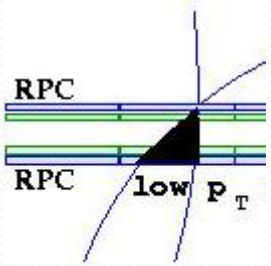
- ATLAS length > 20m & Collision period = 25 ns → 3 events coexist in the detector at the same time
- To match correctly event fragments from different sub-detectors **BCID (bunch crossing identification) is crucial**
- BCID is based on time measurements, each detector unit is calibrated with respect to particles which move almost at the speed of light (β=1)
- When β<1 hits may be marked with a wrong BCID
- CMS is smaller than ATLAS



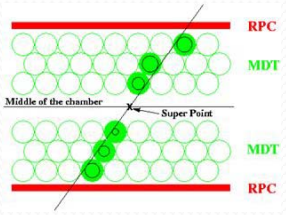


Trigger –
An event must pass all trigger levels to “survive”

ATLAS trigger



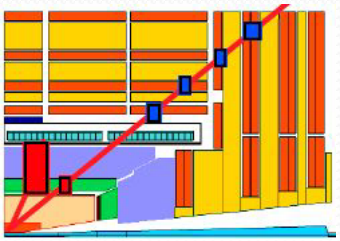
Level 1:
- 40MHz to < 75KHz
- Defines RoI
- Custom HW



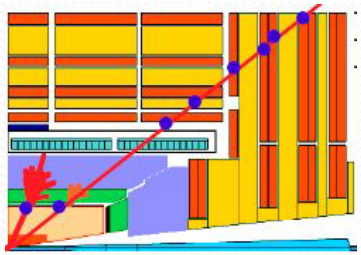
Level 2:
- 75KHz to ~1KHz
- Process RoI
- Quick SW

Event filter:
- 1KHz to ~100Hz
- Full event data
- Offline code

CMS trigger



Level 1:
- 40MHz up to 100KHz
- Custom HW



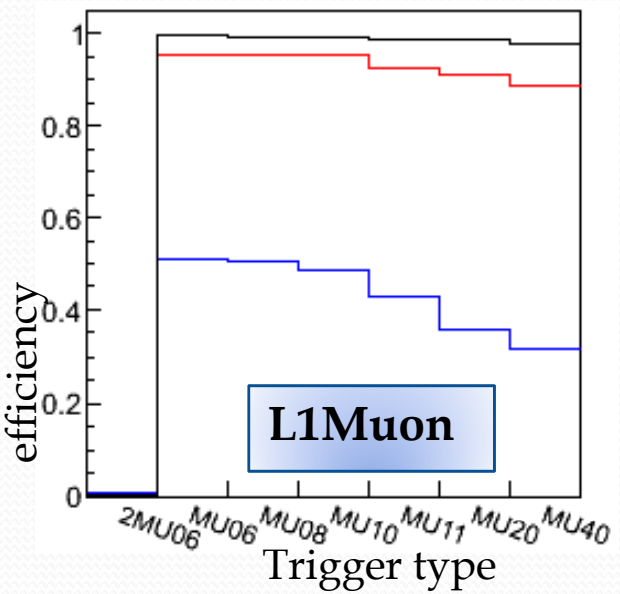
High level trigger:
- 100KHz to ~100Hz
- SW

Trigger for slow particle

- A long lived charged particle is most likely to trigger as a muon
- GMSB - Cascade decay:
  - Other triggers are also possible
  - 2 sleptons with different β
- Split SUSY - Direct production of gluinos:
  - Both R-Hadron may be slow
  - The trigger may be on the wrong BC

- **An event containing long lived charged particle is likely to pass all trigger levels**
- **Some event data might be lost**

- Example:
  GMSB5 in ATLAS



2 sleptons with β > 0.7
1 slepton with β > 0.7
0 sleptons with β > 0.7

Discovery methods – Event flow

1. Collision: the particle is created
2. Propagation: the particle leaves hits in the detector
3. Digitization (HW): the hit transforms into an electronic signal - digit
   - A digit contains position and **time info**.
4. Trigger (HW and SW)
5. Reconstruction (SW): Digits are combined into tracks
   - Digit information is lost
   - Common algorithms – not accessible by the users
6. Analysis: the particle is discovered
   - Too late for the long lived charged particle

ATLAS TOF - RPC

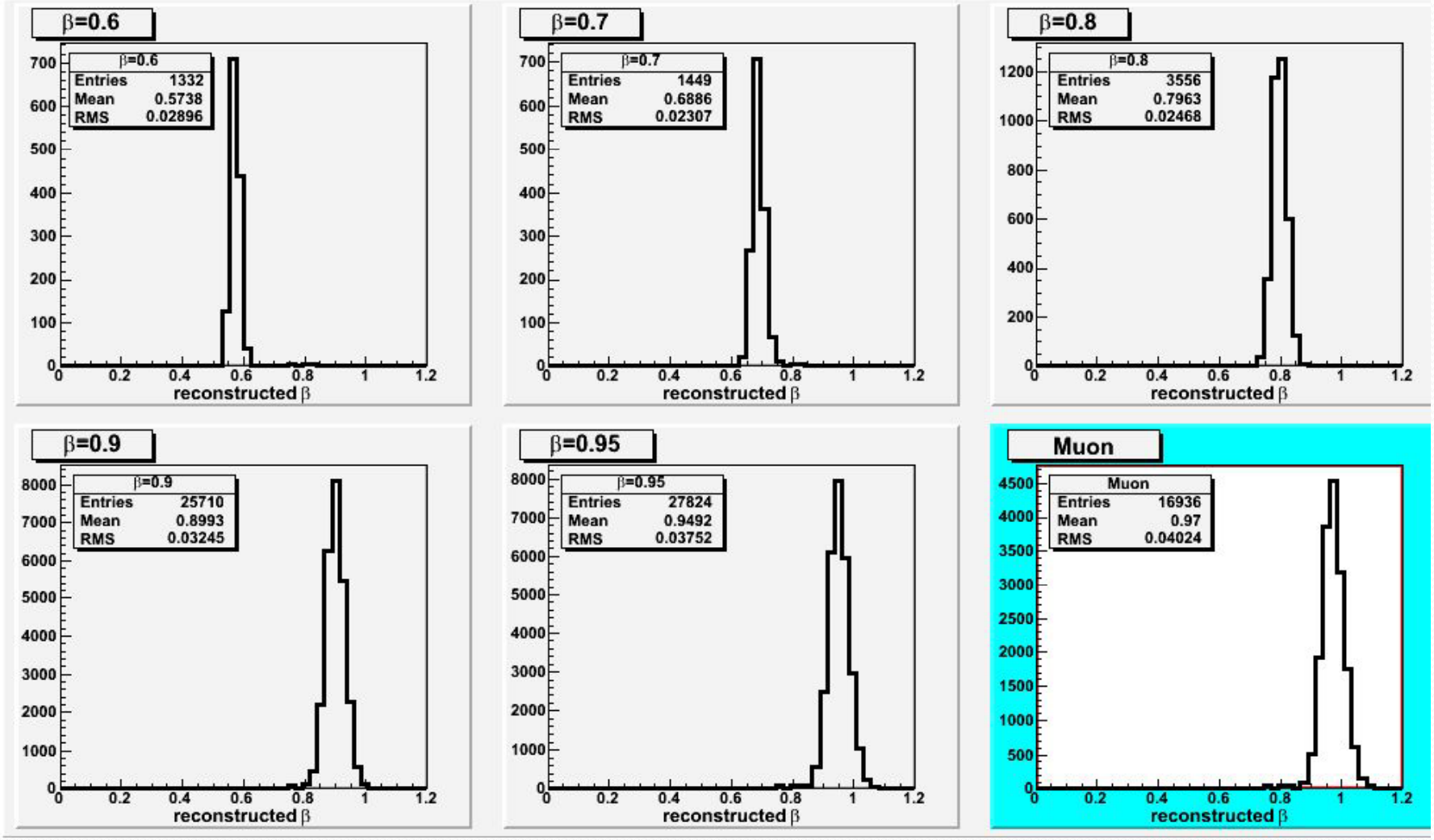
β and mass reconstruction @ level 2

- The muon barrel trigger chambers (RPC) of ATLAS have a time resolution of 3.125ns
- TOF calculation was added to the barrel LVL2 algorithm muFast to get initial estimation of the particle's speed
- A slepton hypothesis based on mass measurement was added

- All slow particles would pass a standard muon hypothesis – no increase in trigger rate

ATLAS TOF –

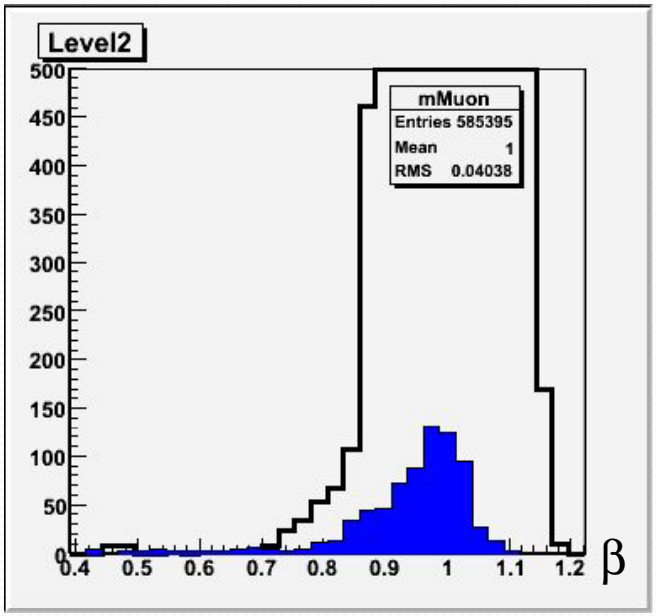
β resolution @ level 2

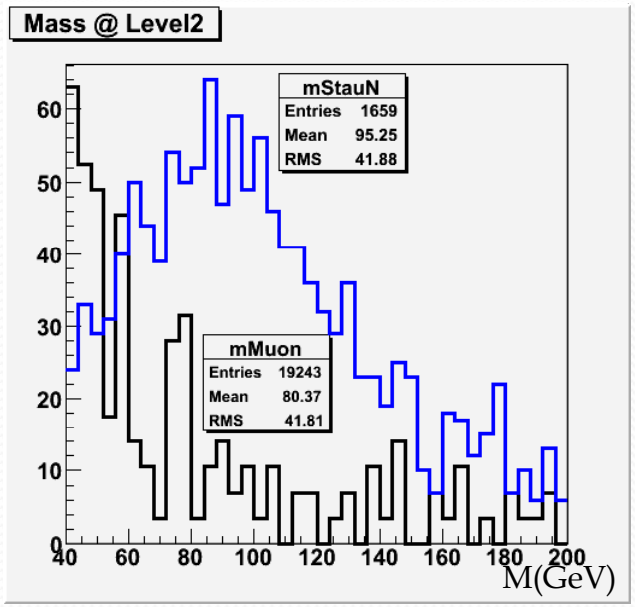


Signal Vs. BG @ level 2: GMSB5

- The BG from high p_T muons overwhelms the signal in β
- Almost no overlap in reconstructed mass

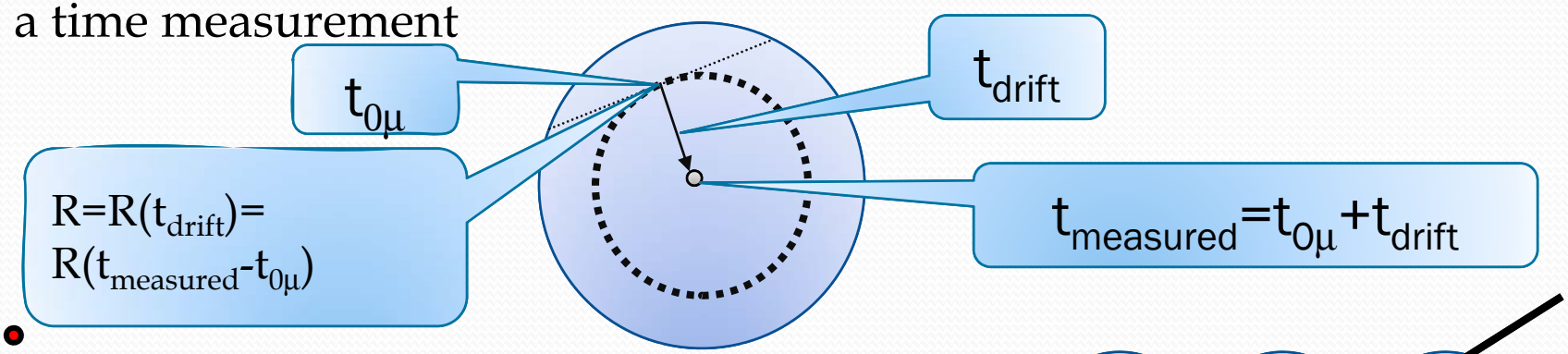
- For Stau hypothesis with the cuts
  - p_T>40 GeV
  - M>40 GeV
  - β<0.97





Hit radius reconstruction in the MDT – μ

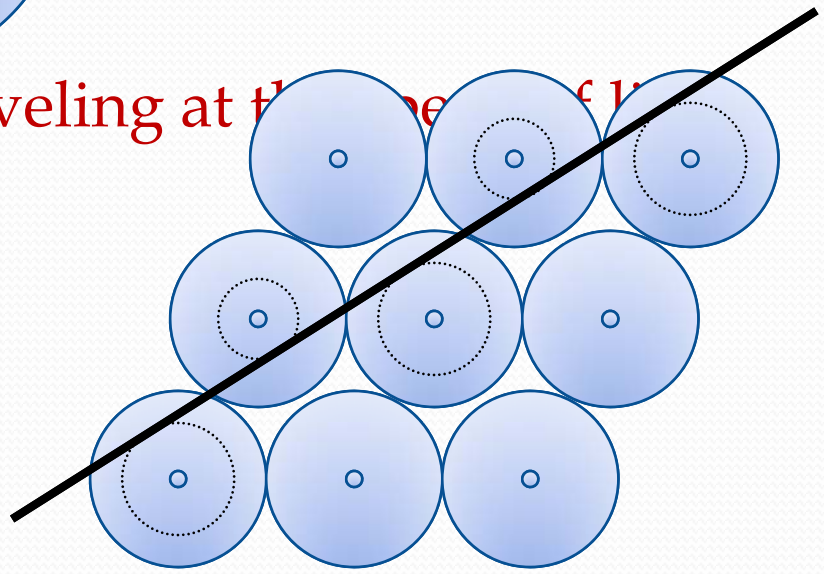
- A charged particle passing the MDT will leave clusters of ionized atoms
- The electrons drift to the wire in the center of each tube
- The radius from which the electrons drift to the wire is calculated from a time measurement



- $t_{0\mu}$ is estimated for a muon traveling at th[illegible]

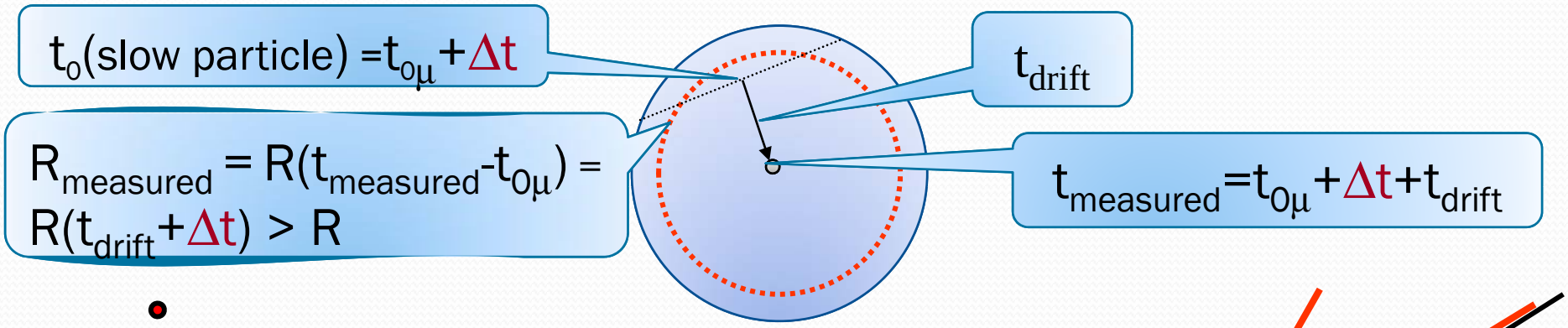
Segment reconstruction

- The segment is tangent to the radii
- Some hits from "noise" are ignored



Radius reconstruction in the MDT – slow particle

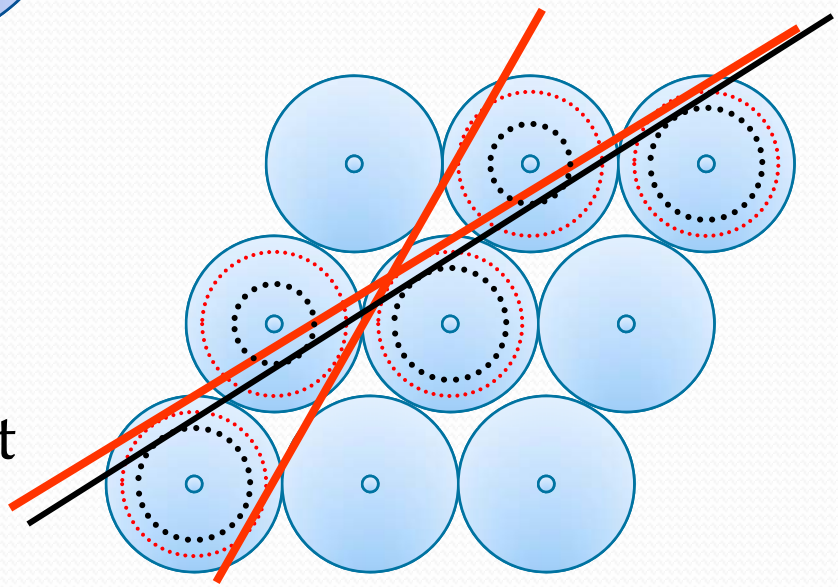
- The long time window of the MDT guarantees that data of low β particles will be saved.
- The measured hit radius is incorrect



- We want to estimate Δt

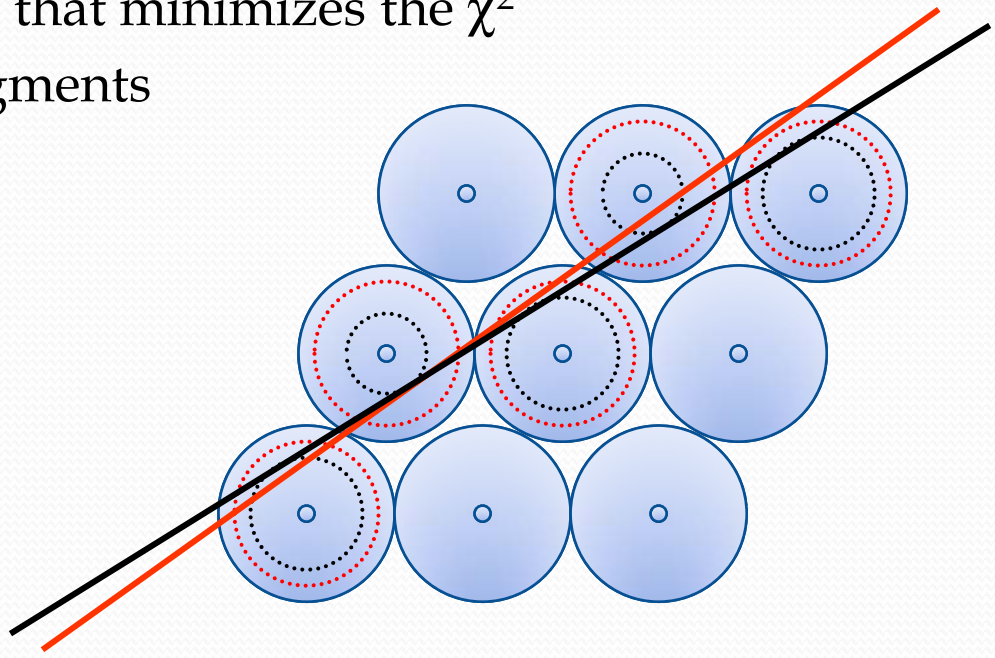
Segment reconstruction

- Larger radii result in
  - Badly fitted segment
  - Wrong direction of segment



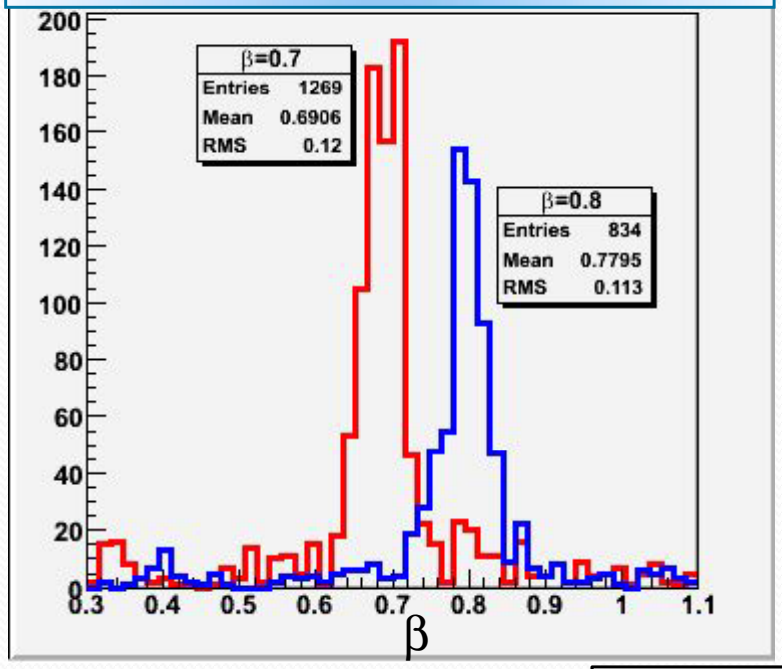
A β reconstruction algorithm (1)

- Relies on long time window of MDT and BCID from ID
- Identify penetrating particle by associating muon hits and segments with extrapolated ID track
- Loop over possible Δt
  - Change MDT digits' time and hence radii
  - Create MDT segments from the re-timed digits
- Estimate t_0 (TOF) from the Δt that minimizes the χ^2
- Include information from segments in trigger chambers
  - RPC tof
  - TGC direction
- Calculate β and M

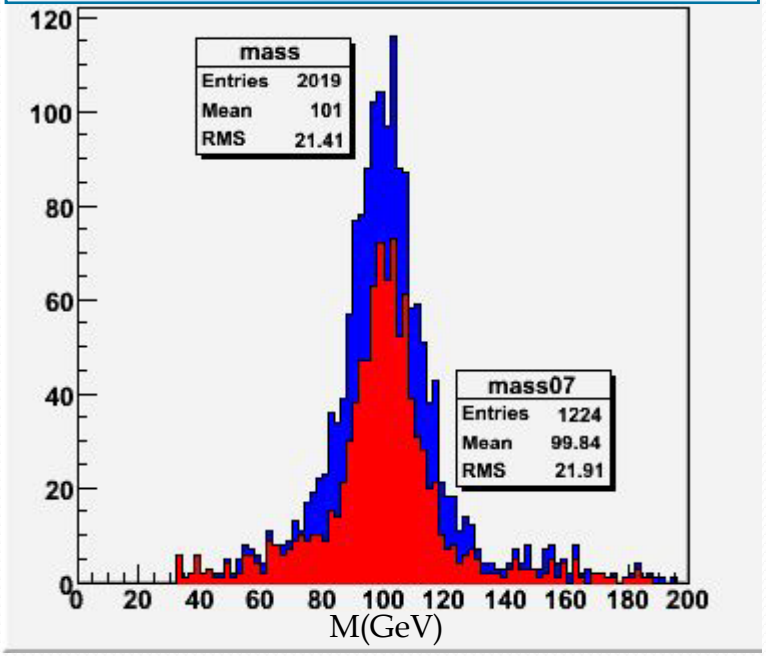


ATLAS - β and mass @ reconstruction

β reconstruction



Mass reconstruction

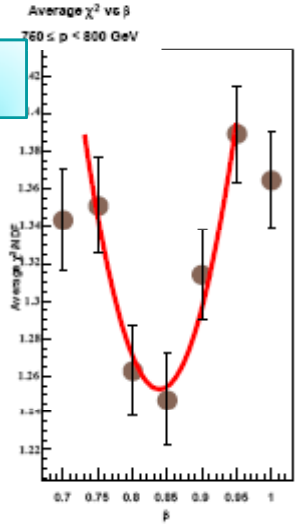


ATLAS preliminary

A β reconstruction algorithm (2)

1. Divide R-Hadrons in momentum bins
2. In each bin find β minimizing the average χ^2
3. Fit β as a function of the momentum - β(p)
4. Calculate the mass, m=p/γ(p)β(p)

2



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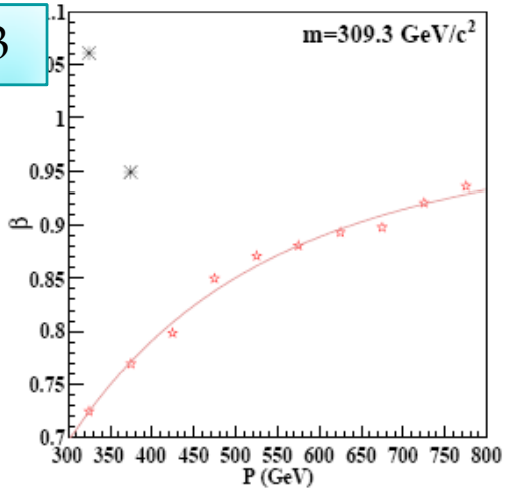

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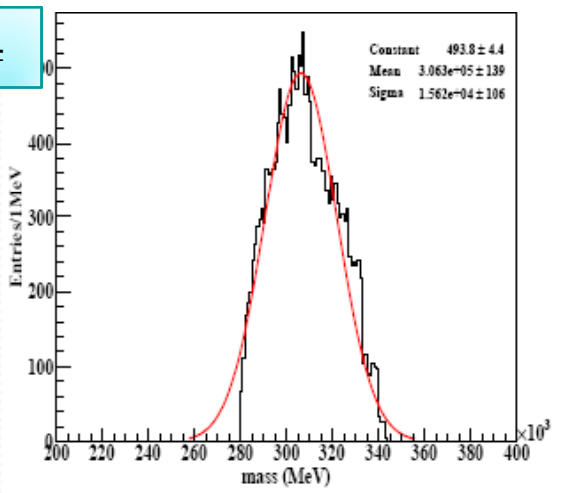


ATLAS preliminary

This study requires a large pure sample of sparticles and, therefore, it was done for R-Hadrons

CMS TOF* and dE/dx

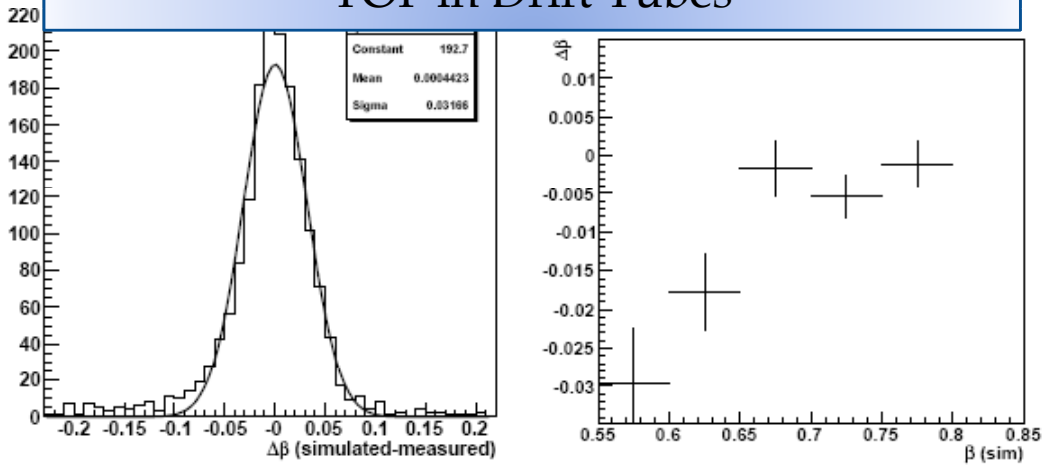
- CMS uses dE/dx in the tracker in addition to TOF in the drift tubes
- CMS beta resolution is shown for

  $0.6 < \beta < 0.8$
- The β measurement is restricted by the size of CMS.

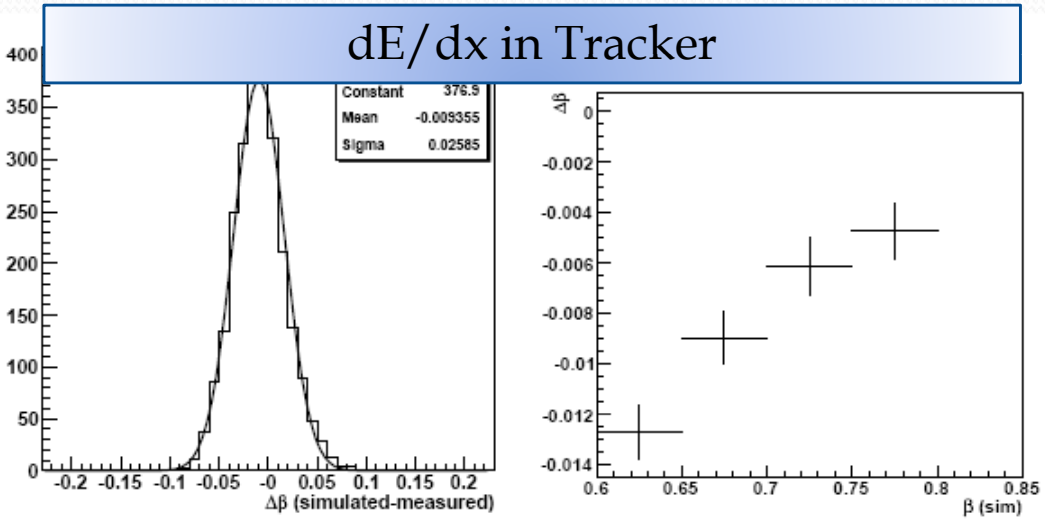
- See talk of

  Piotr Zalewski

TOF in Drift Tubes



dE/dx in Tracker



Conclusions

- If nature cooperates, we have a chance to find a new charged long-lived particle
- However, this requires paying attention to details of detector and trigger operation
- Some modifications are needed to previously envisioned operation
  - In particular reading out data of additional BCs will increase efficiency for the lower β range