Latest developments in improving the specific energy loss measurement in the tracking detector as a variable for future exotic searches at ATLAS

Helmholtz Alliance Meeting „Physics at the Terascale“, Hamburg,
28th of November 2017

Philipp König (University of Bonn)
on behalf of the ATLAS TRT dE/dx group

ATLAS EXPERIMENT

Physikalisches Institut

UNIVERSITÄT BONN

BMBF-Forschungsschwerpunkt
ATLAS-EXPERIMENT
Physik bei höchsten Energien mit dem ATLAS-Experiment am LHC

FSP 103
ATLAS

Overview

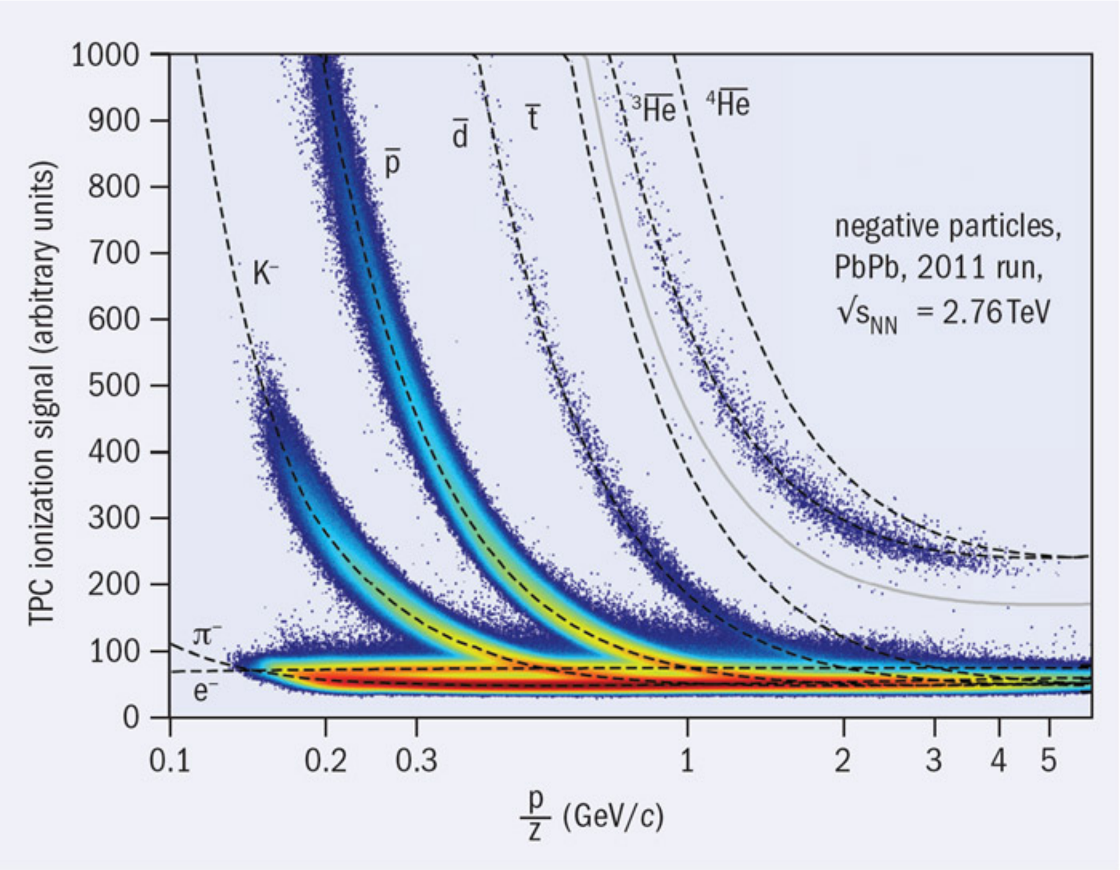
- explain the theoretical background and the procedure of how TRT dE/dx is derived
- present current dE/dx performance of the Inner Detector
- mention a few analyses who could (possibly) use TRT dE/dx
- progress on calibration at high occupancy

Bethe-Bloch formula

- Describes the mean energy loss per path length of charged particles

- is used to distinguish between different particle types

- as it is a function of $\beta\gamma = \frac{p}{m}$ predictions can be made for all particles as a function of momentum



source: CERN Courier June 2012, p. 14

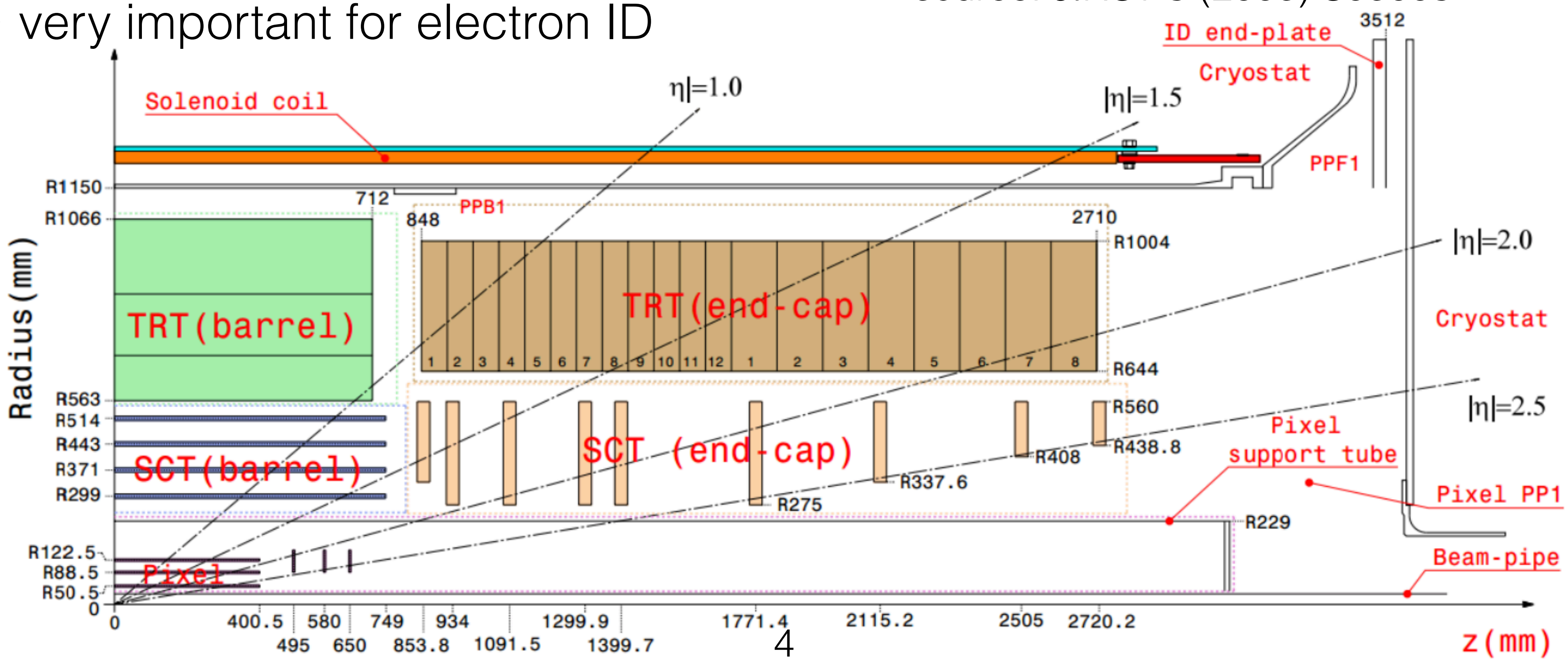
$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi n z^2 e^4}{m_e c^2 \beta^2 (4\pi\epsilon_0)^2} \left[\ln \frac{2 m_e c^2 \beta^2 \gamma^2}{I} - \beta^2 \right]$$

Transition Radiation Tracker

- Approx. 300,000 gas-filled straw tubes, gas mixture: 70% Xenon, 27% CO_2, 3% O_2
- two main purposes
  - tracking: on average 30 points per charged particle
  - transition radiation: equipped with radiator material which causes electrons to emit transition radiation

➡ very important for electron ID

source: JINST 3 (2008) S08003

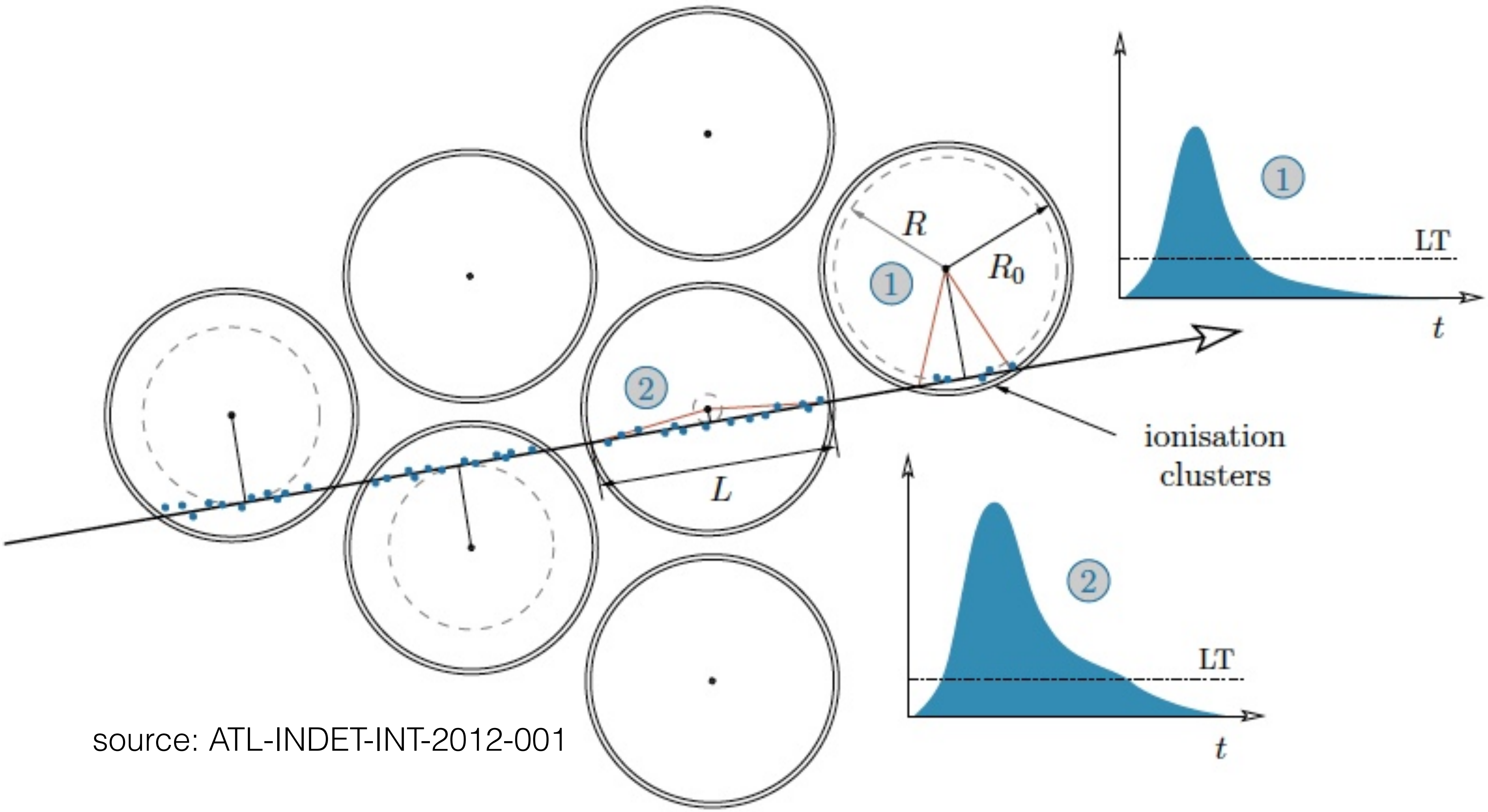


How to calculate TRT dE/dx

1. Time over Threshold (ToT) is derived based on bit pattern (different algorithms possible)
2. ToT/L: Divide by length of track within the straw
3. r-S calibration (take geometrical effects into account): Normalize the ToT/L to pions (MIP)
4. Build the truncated mean
5. Occupancy correction
    - up to now global mu correction
    - under investigation
        - track based correction
        - hit based correction

How to calculate TRT dE/dx

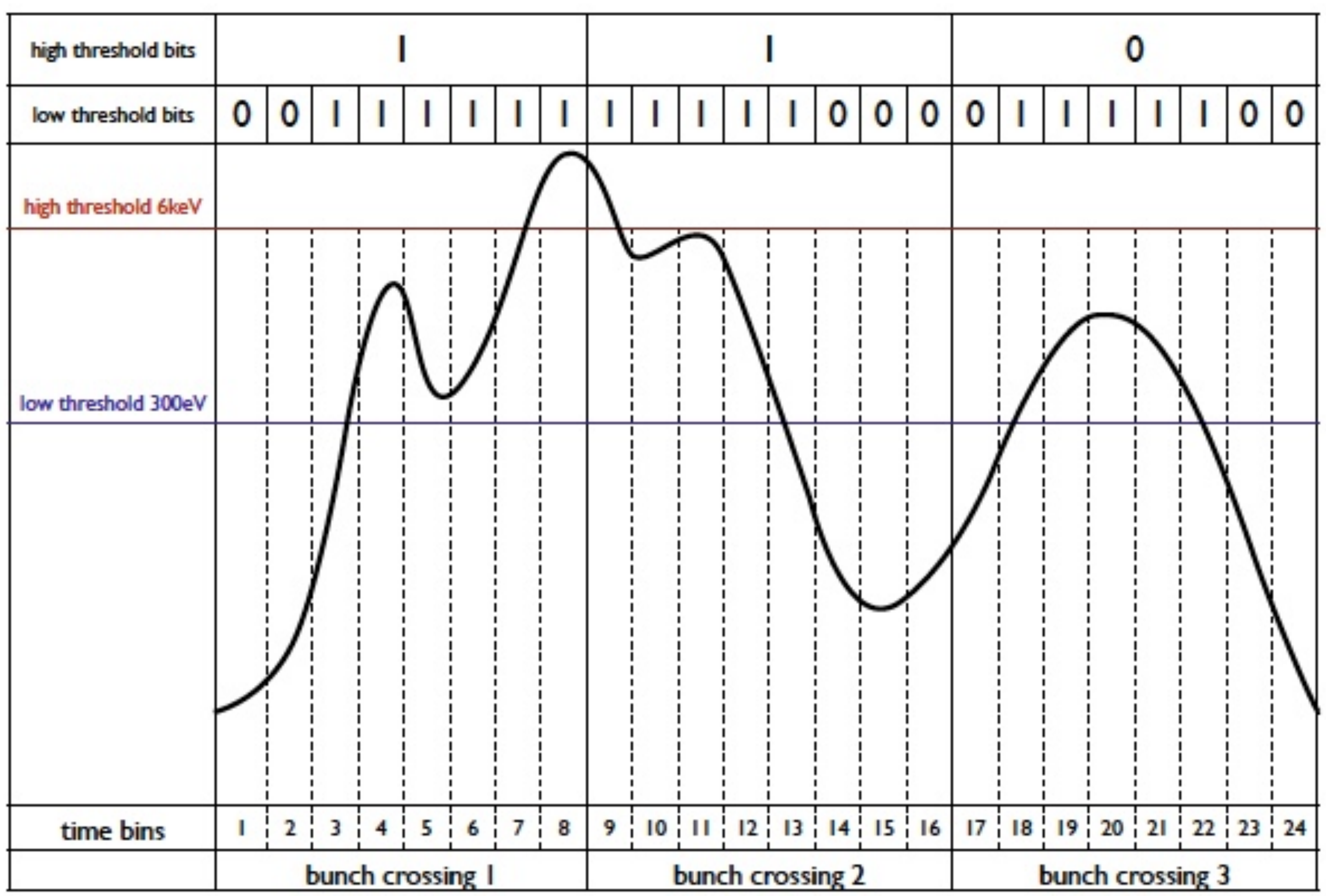
- particle traversing straws create ionisation clusters



source: ATL-INDET-INT-2012-001

How to calculate TRT dE/dx

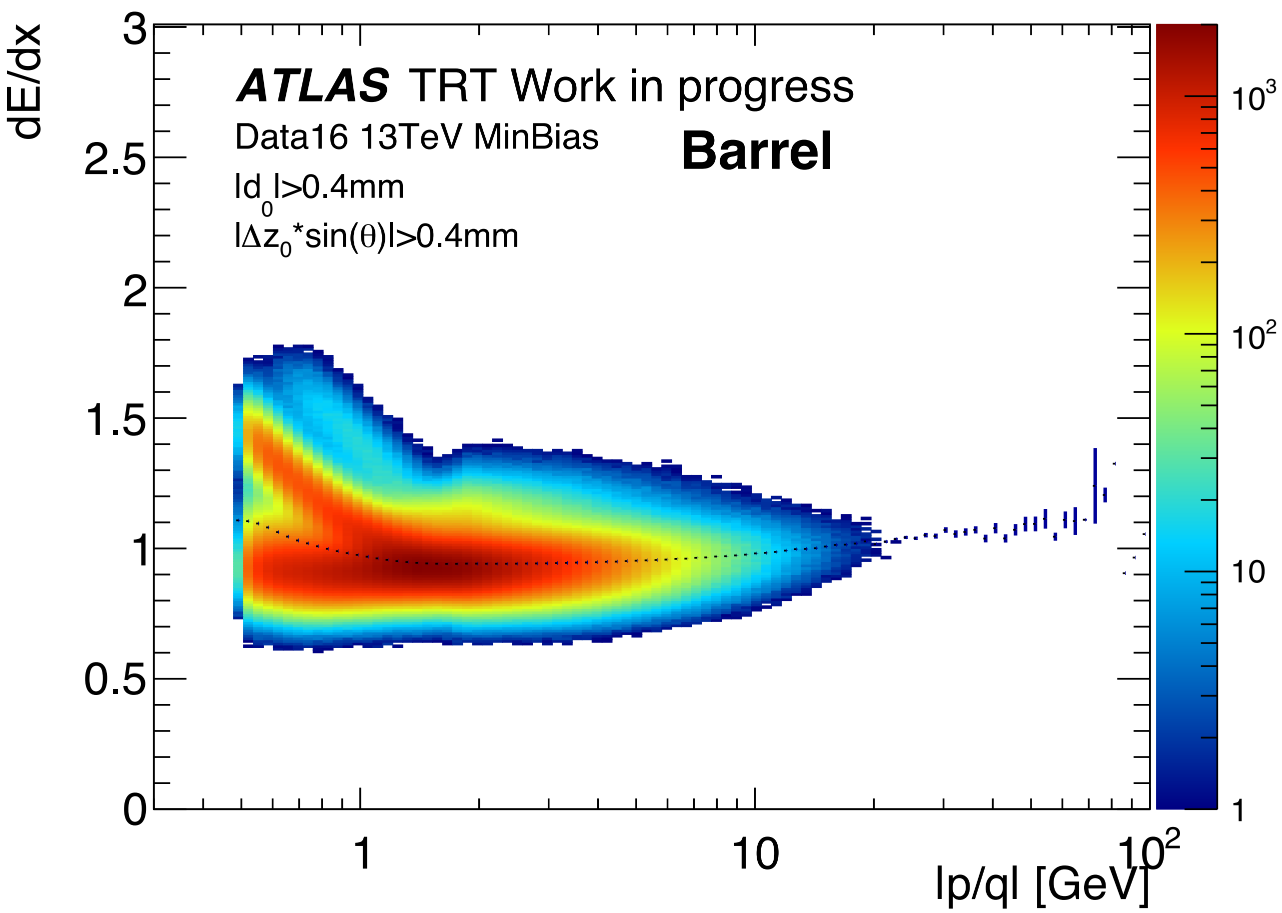
- electrical signal is discriminated against two thresholds
  - low threshold (LT) at 300eV
  - high threshold (HT) at 6keV
- each bin is set to 1 if the signal is above the corresponding threshold at least once during the readout

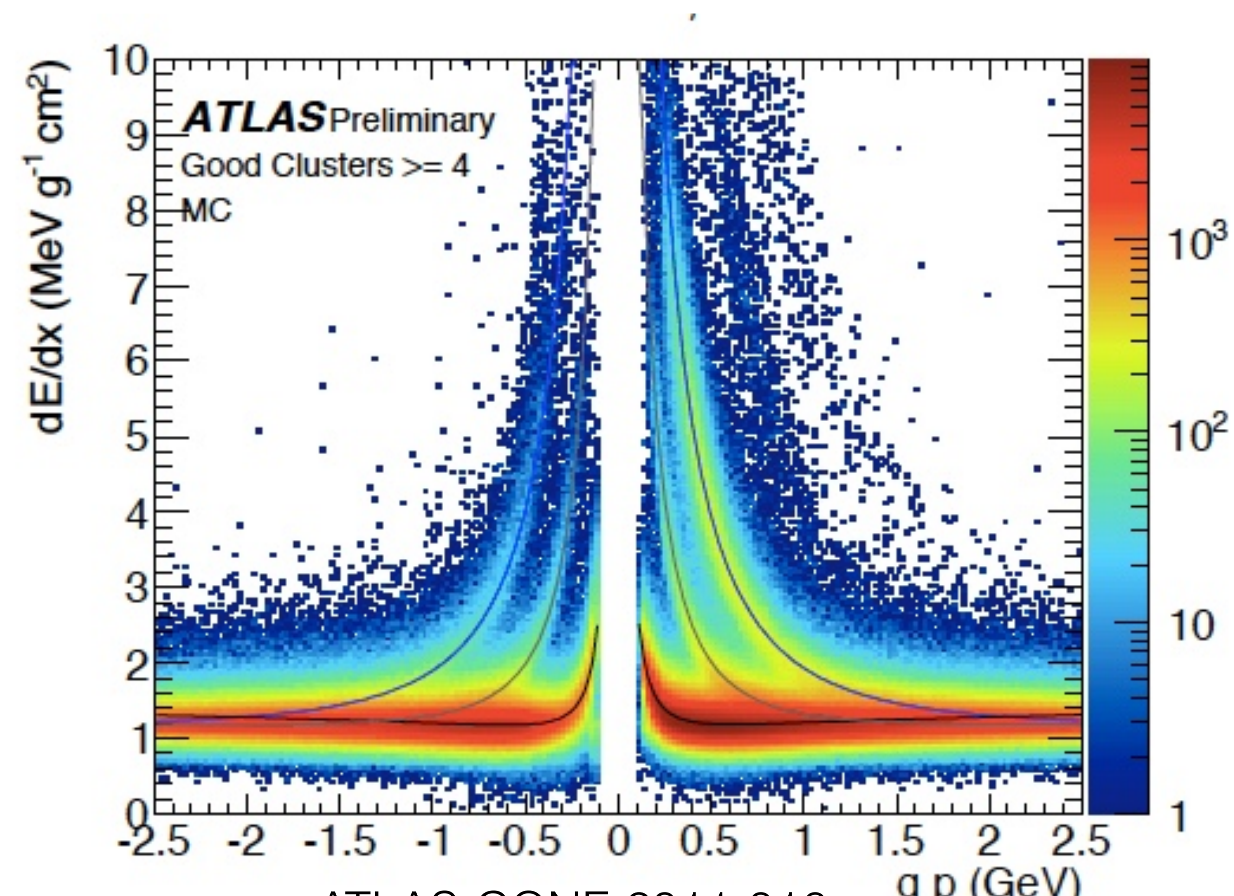


source: ATL-INDET-INT-2012-001

dE/dx performance in the Inner Detector of ATLAS

- Pixel can separate pions, Kaons and protons very clearly
- not the case for TRT
  - ➡ low momentum tracks are not extended to TRT!

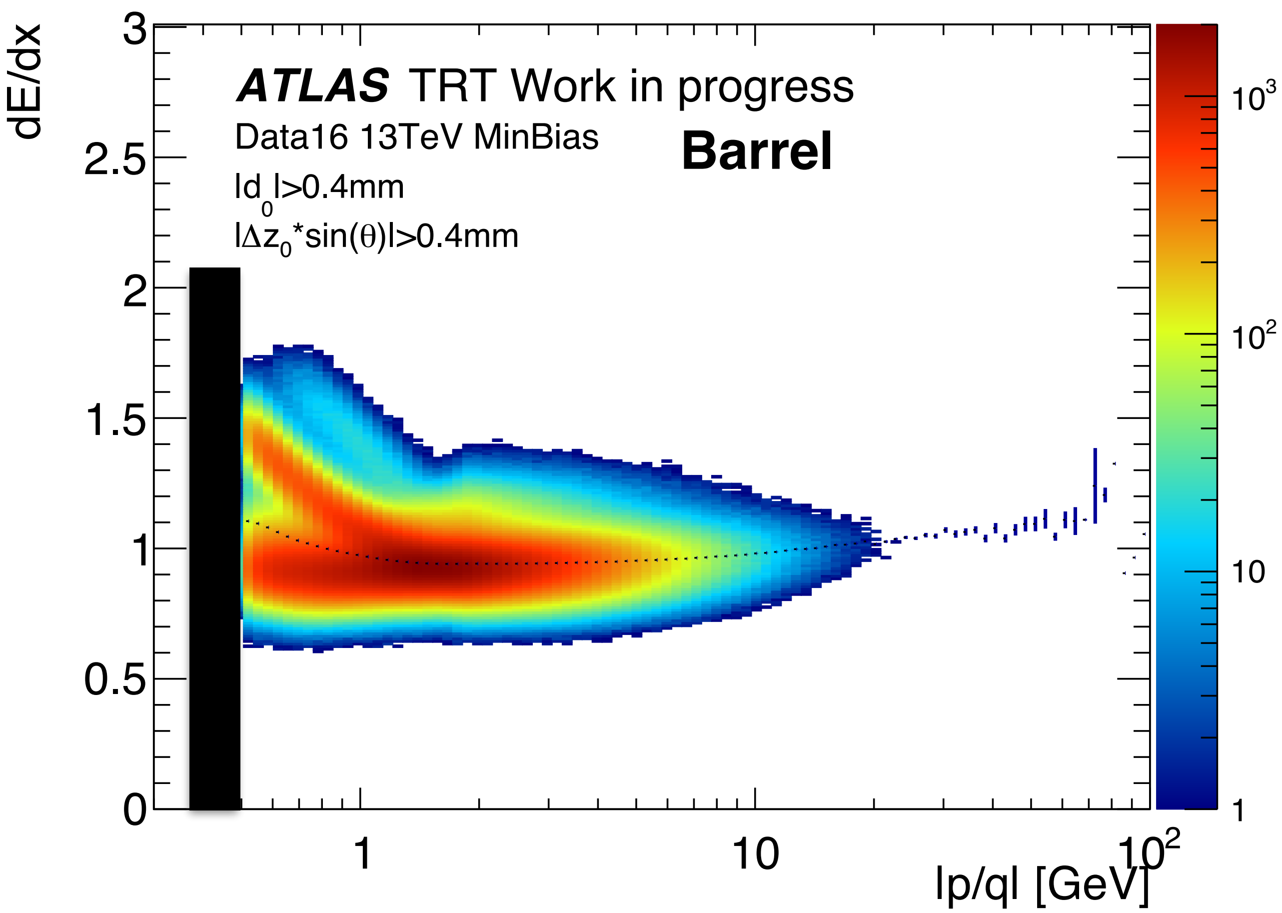


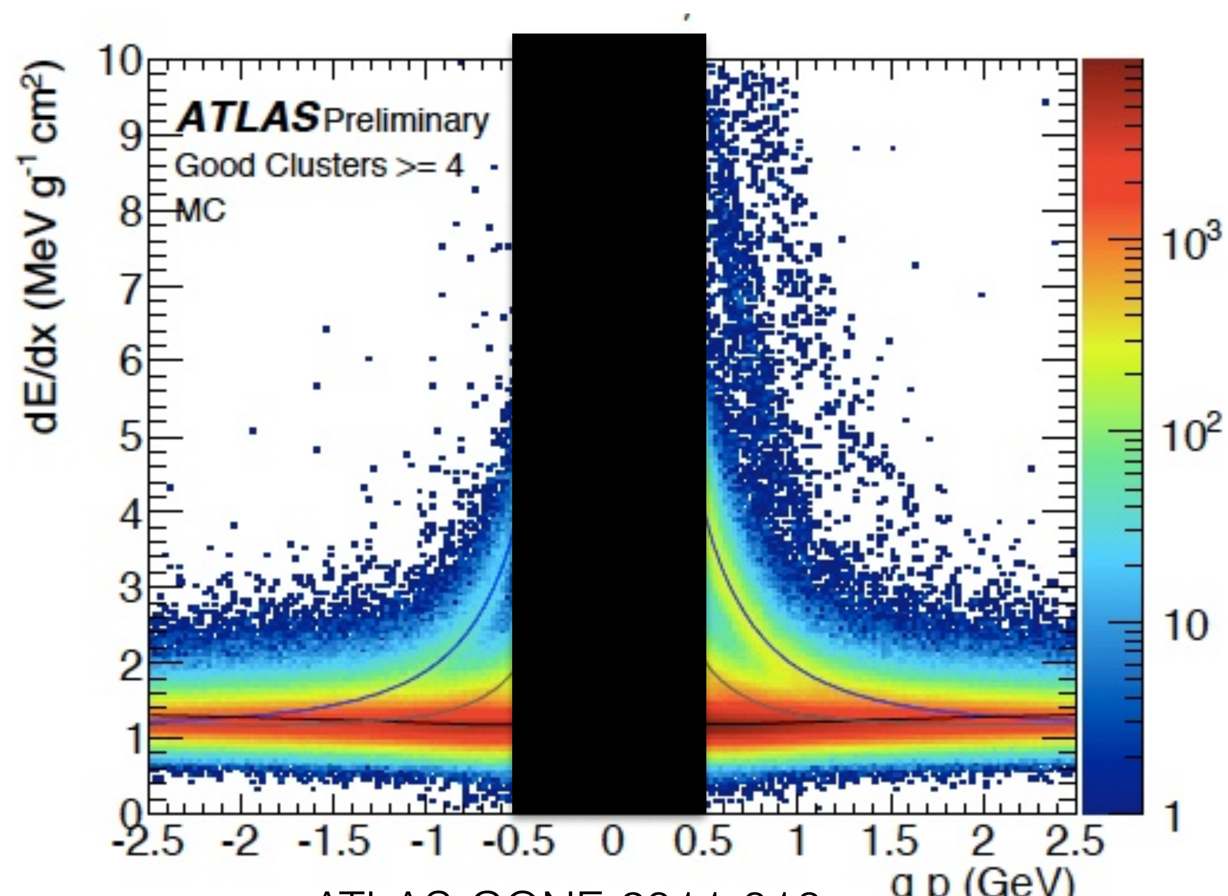


source: ATLAS-CONF-2011-016

dE/dx performance in the Inner Detector of ATLAS

- mask tracks lower than 500 MeV
    - ➡ looks more comparable
- Pixel is not suffering so much from high occupancy due to the better spatial resolution, drawback is that they have less hits per track (max. 4 and then they truncate 1-2)





source: ATLAS-CONF-2011-016

Analyses using TRT dE/dx

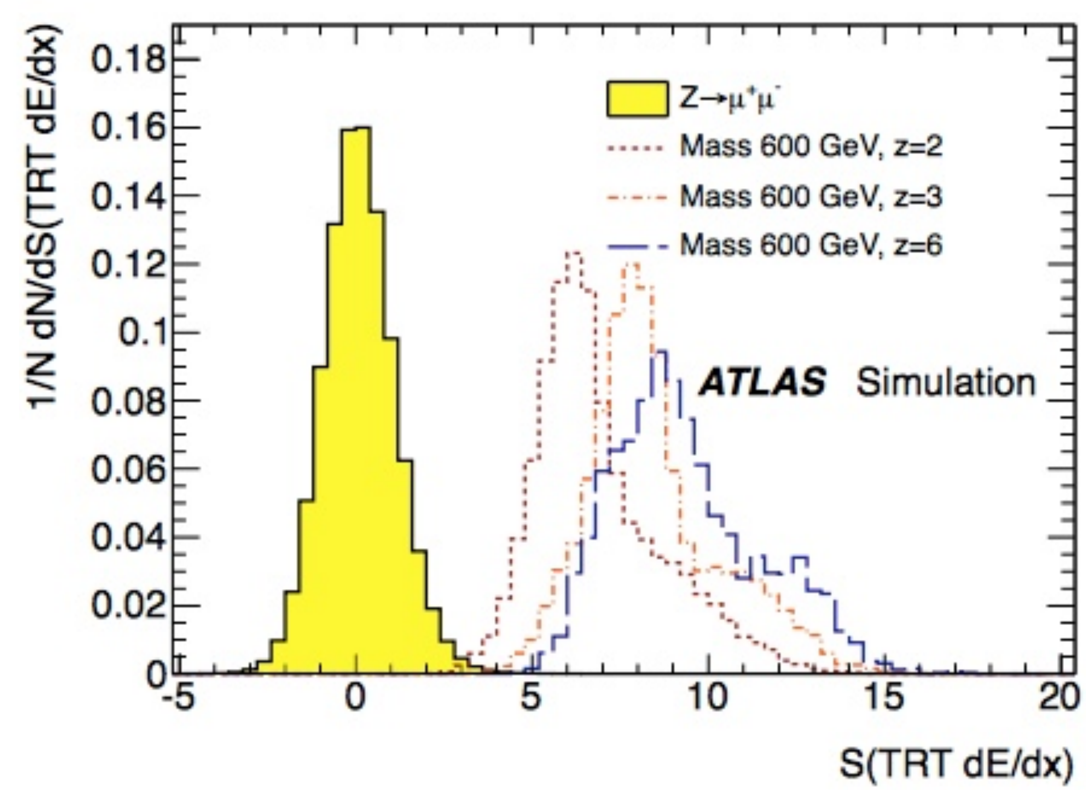
- only one published result using TRT dE/dx
  - used significance of TRT dE/dx as a discriminating variable

source: arXiv:1504.04188

Search for heavy long-lived multi-charged particles in *pp* collisions at $\sqrt{s}$ = 8 TeV using the ATLAS detector

O. Bulekov[a], C. Marino[b], A. Romaniouk[a], Y. Smirnov[a], S. Zimmermann[c]

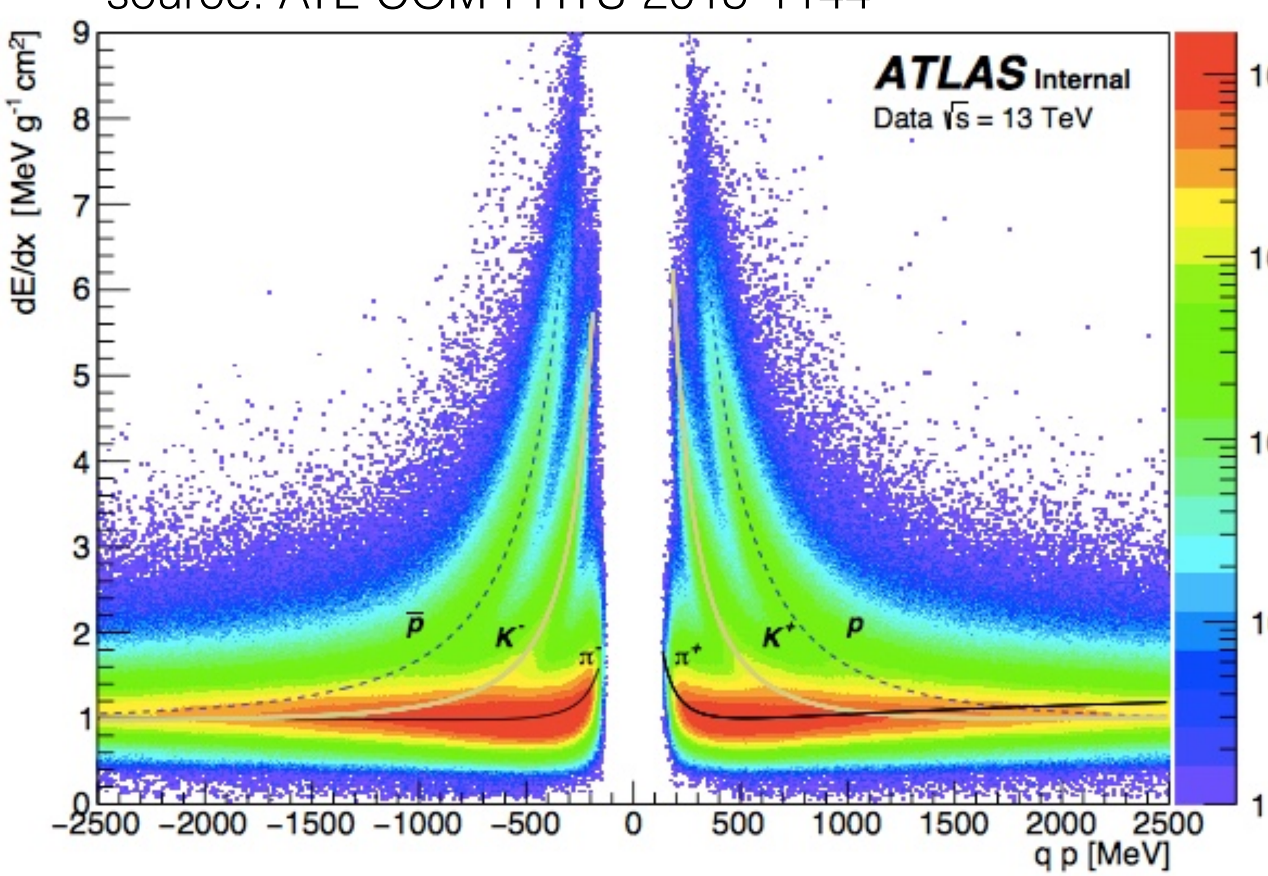
[a]*Moscow Engineering Physics Institute*
[b]*University of Victoria*
[c]*University of Bonn*



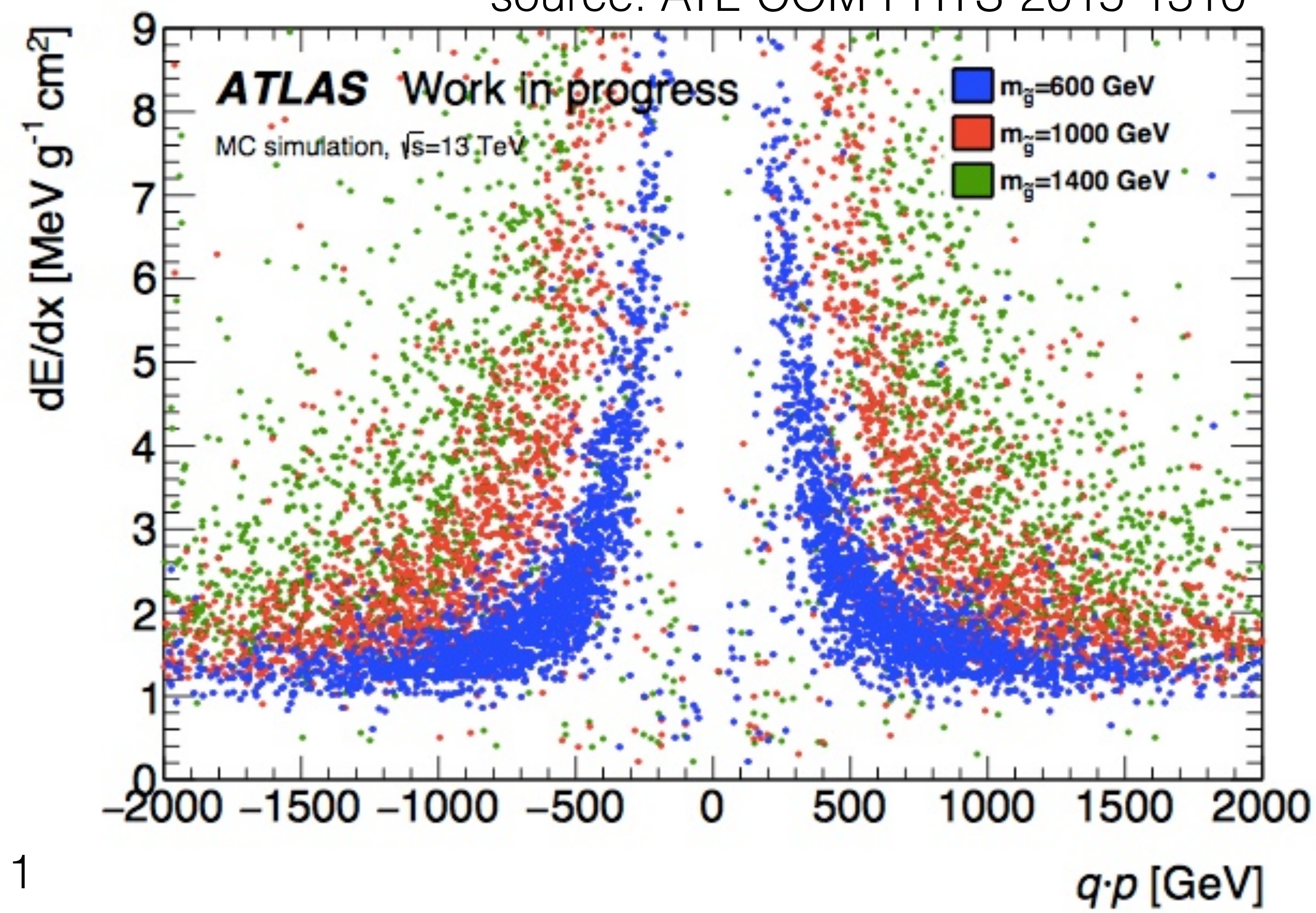
Analyses who could potentially use TRT dE/dx

- possible analyses who could use TRT dE/dx: SUSY RPV and LL subgroup
  - ➡ Analysis searching for stable massive particles are using Pixel dE/dx
  - ➡ need to improve TRT dE/dx and advertise it

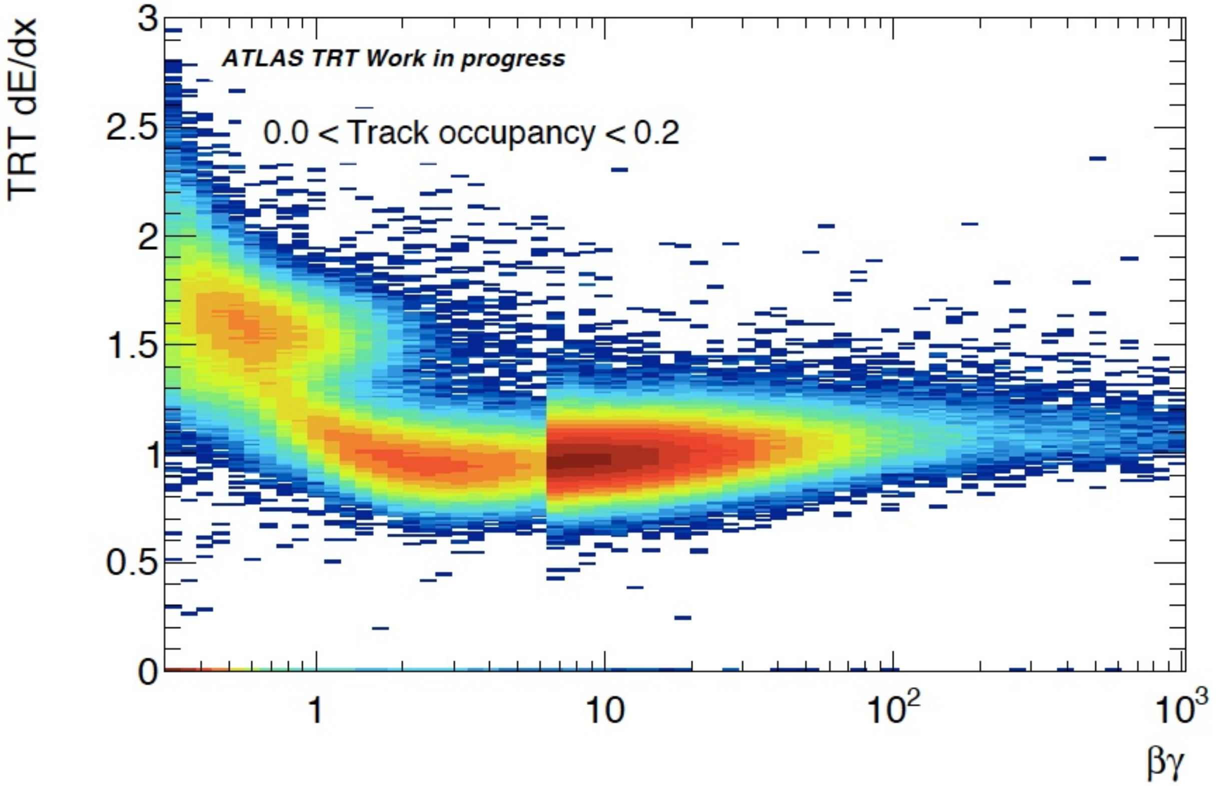
source: ATL-COM-PHYS-2015-1144

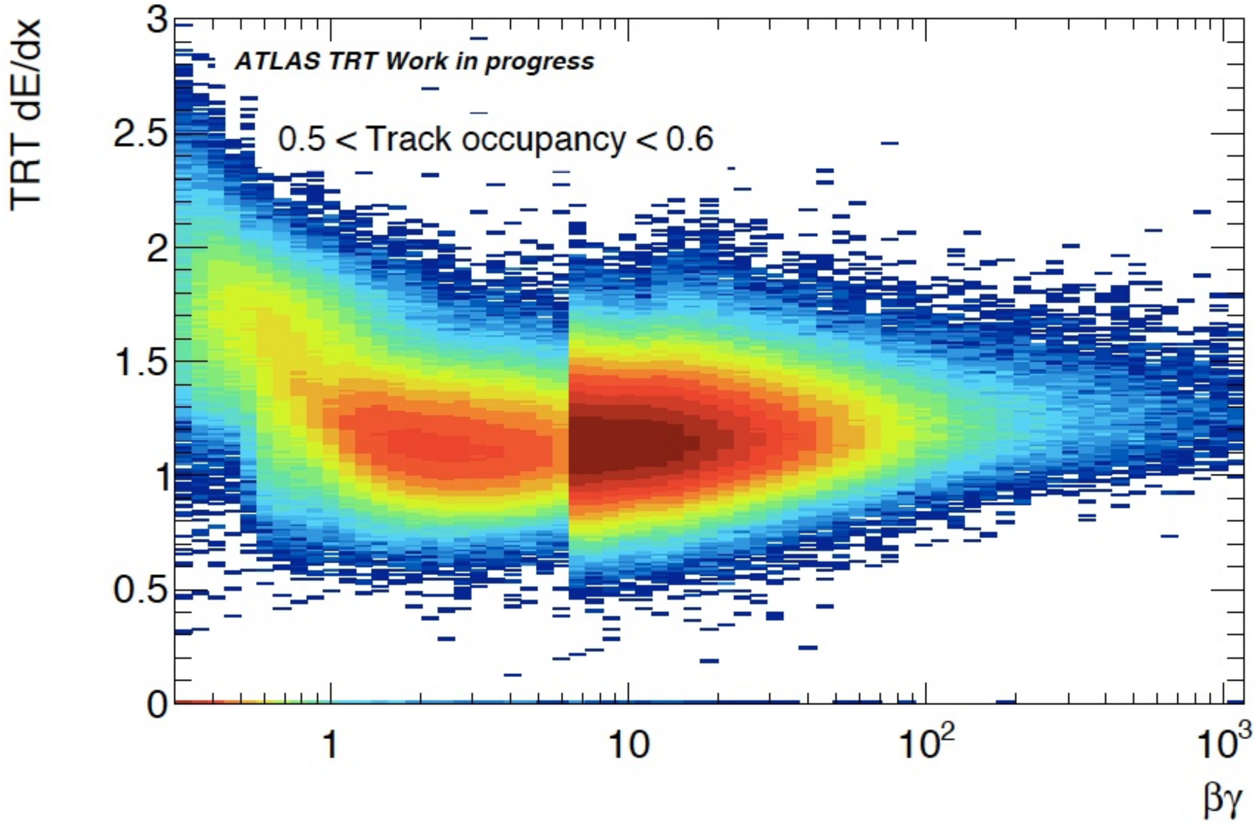


source: ATL-COM-PHYS-2015-1310



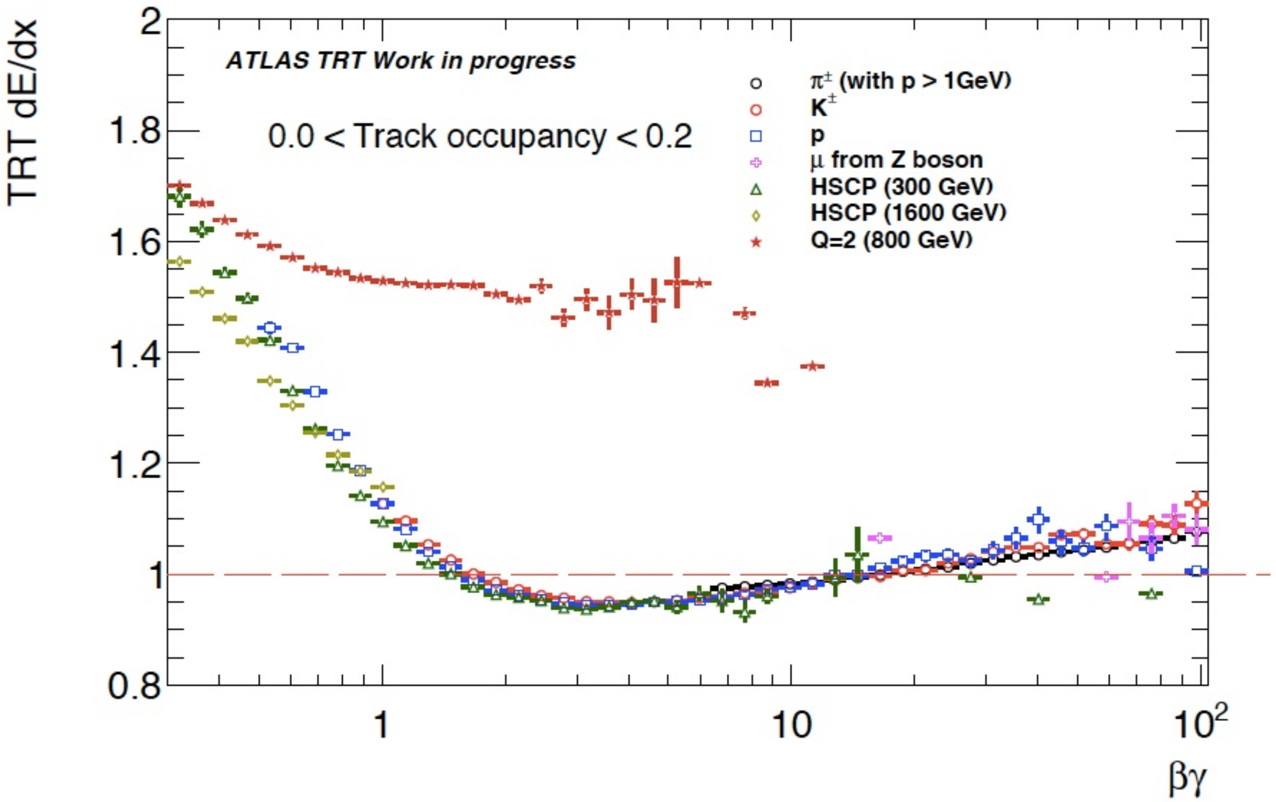
Obstacles at high occupancy

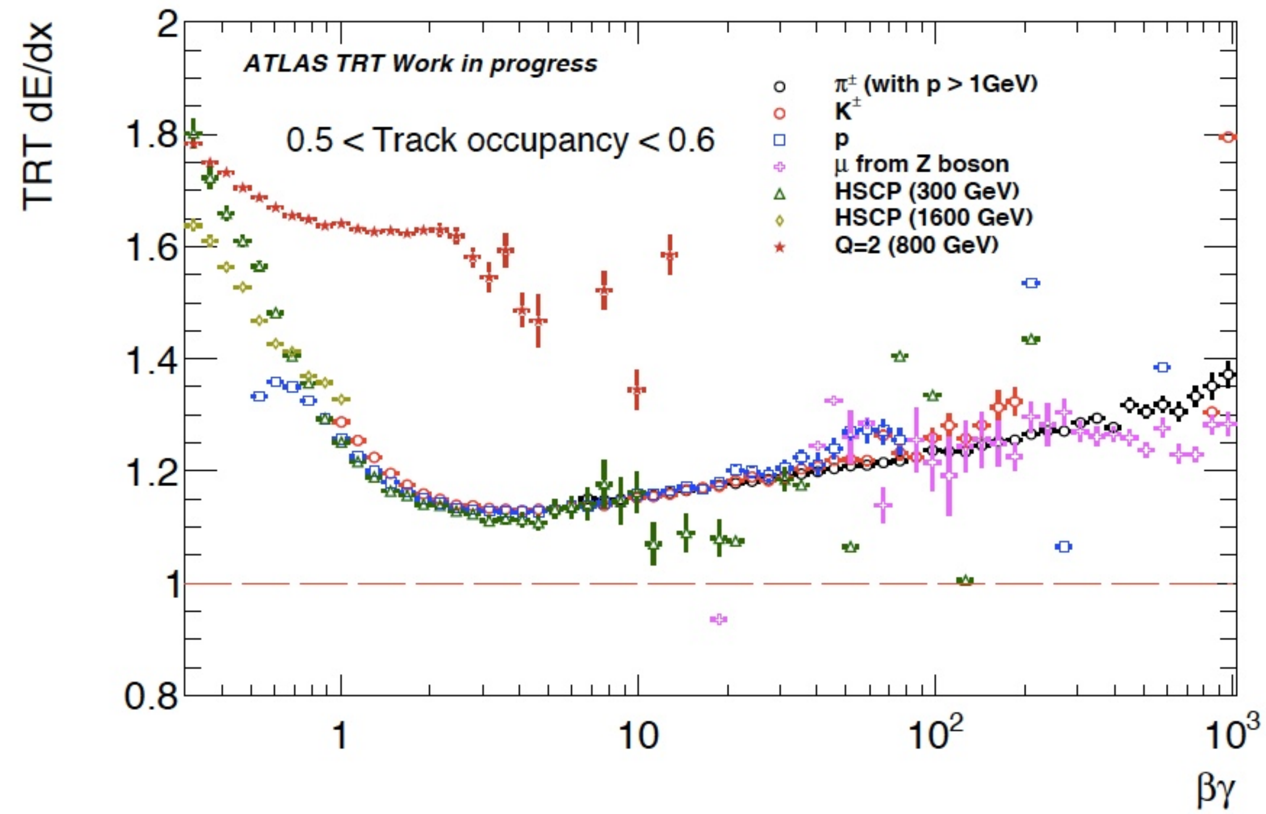




- Separation between different bands vanishes for higher pile-up
- currently no useful PID from dEdx at high pile-up

Obstacles at high occupancy

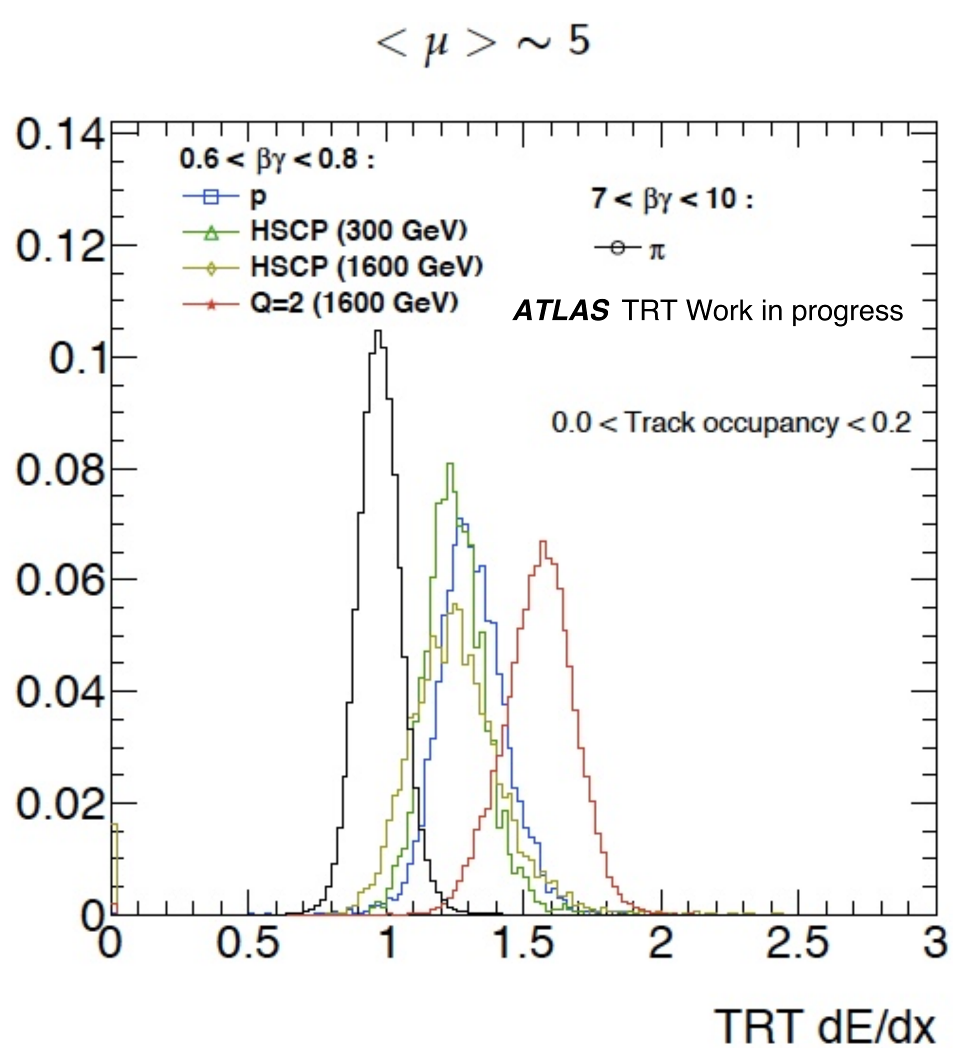


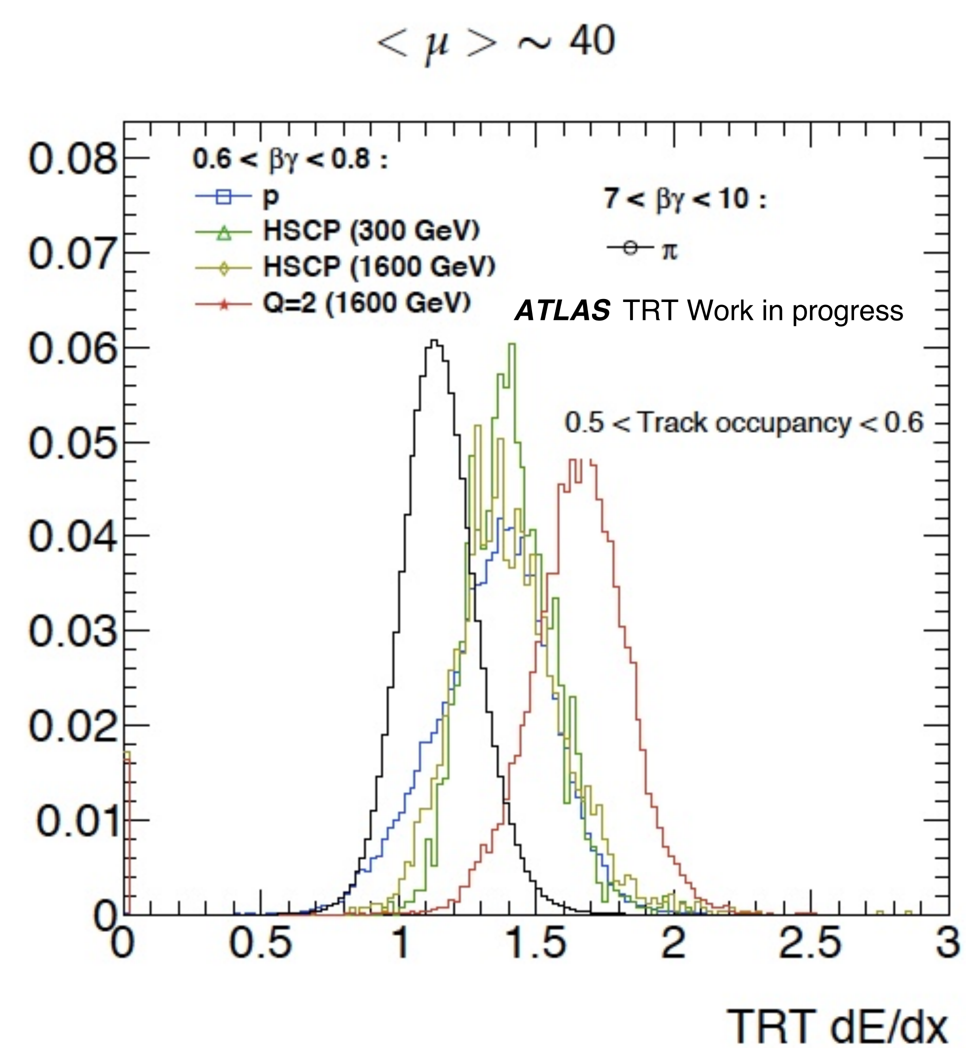


- Separation between different bands vanishes for higher pile-up

- currently no useful PID from dEdx at high pile-up

Separation between HSCP and mulit-charged particles



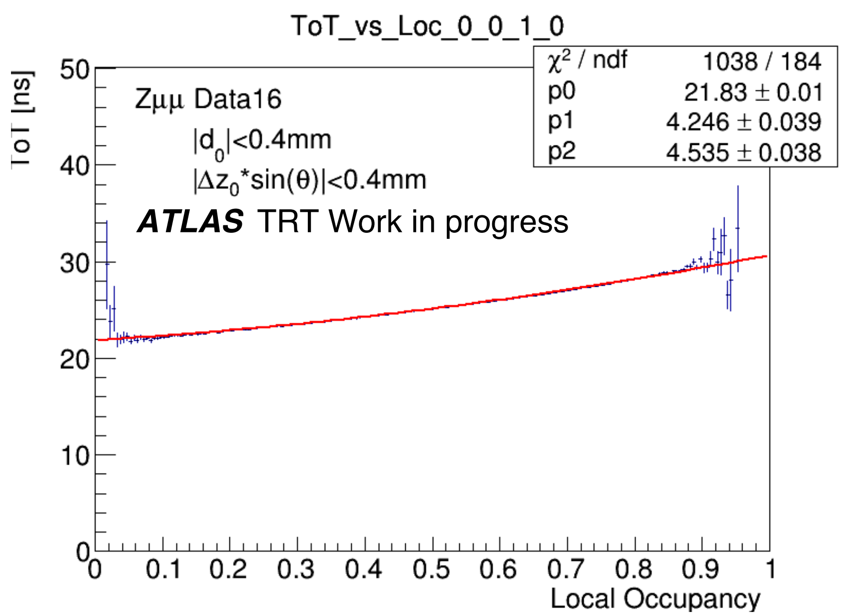


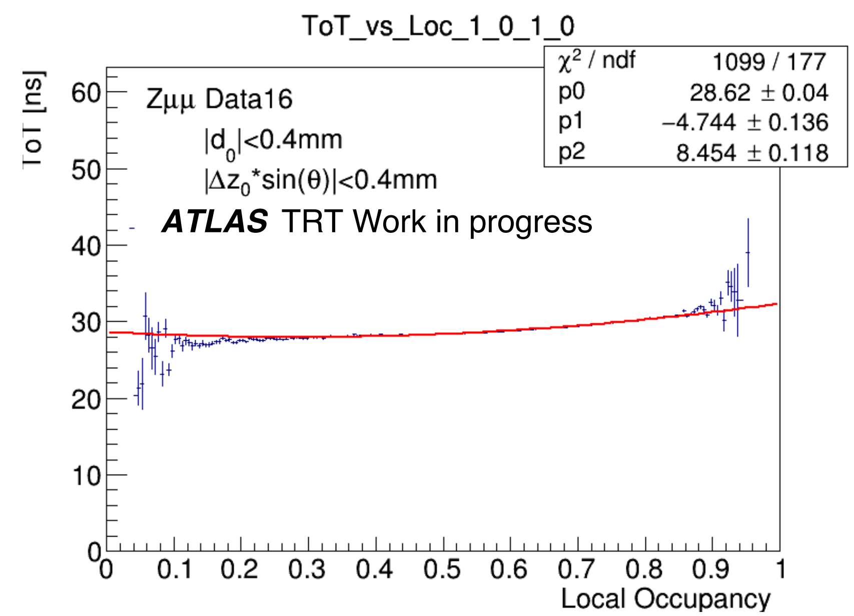
- even without occupancy calibration separation is visible

Idea for a hit-based calibration

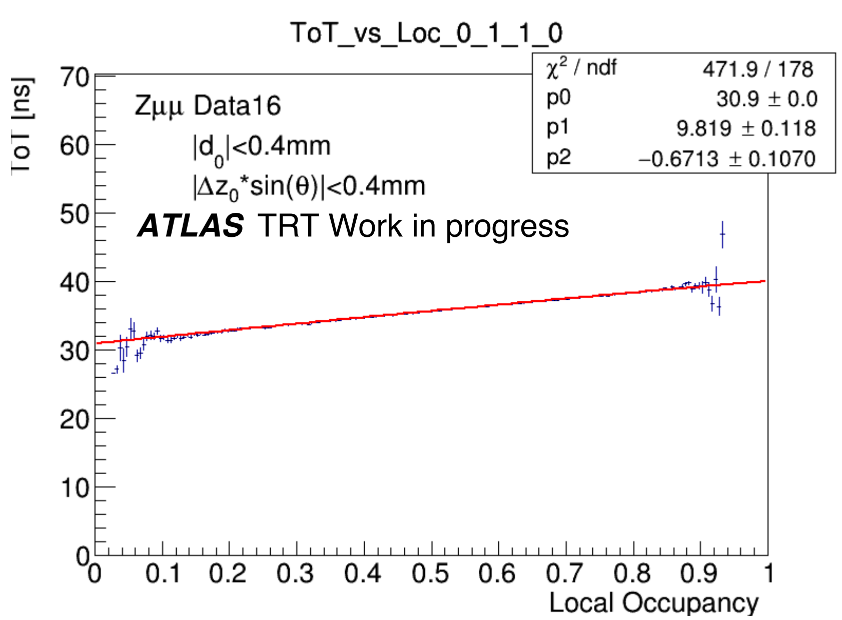
non-shared | shared

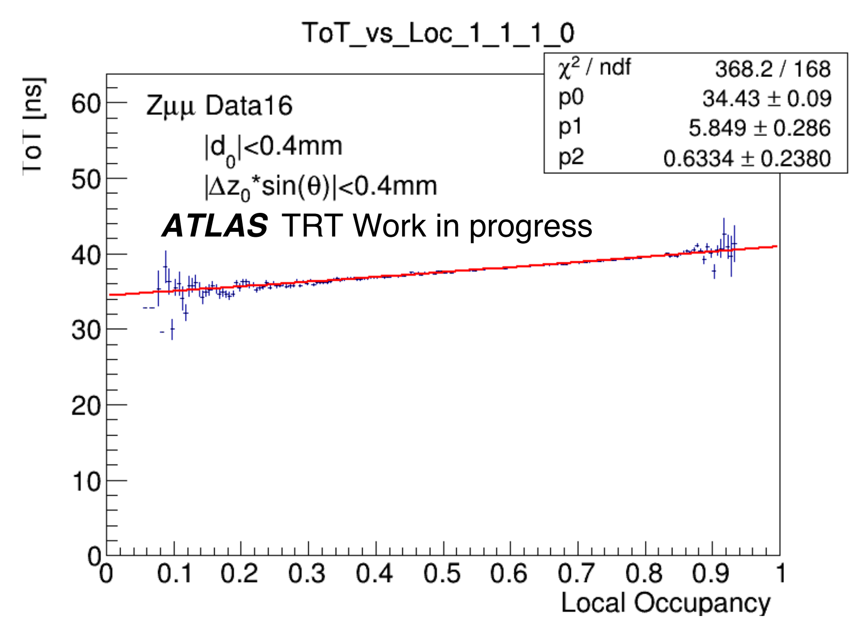
LT





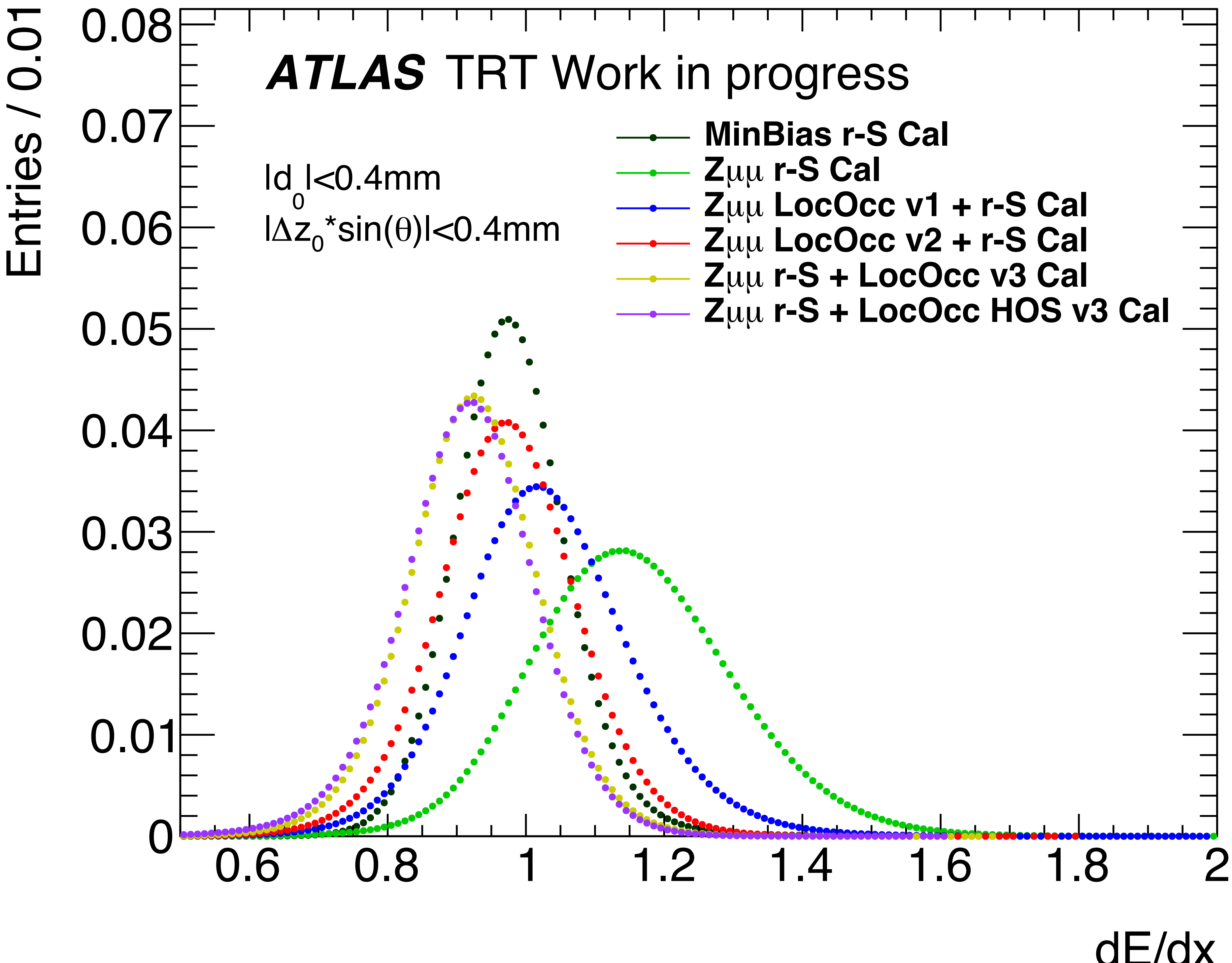
HT





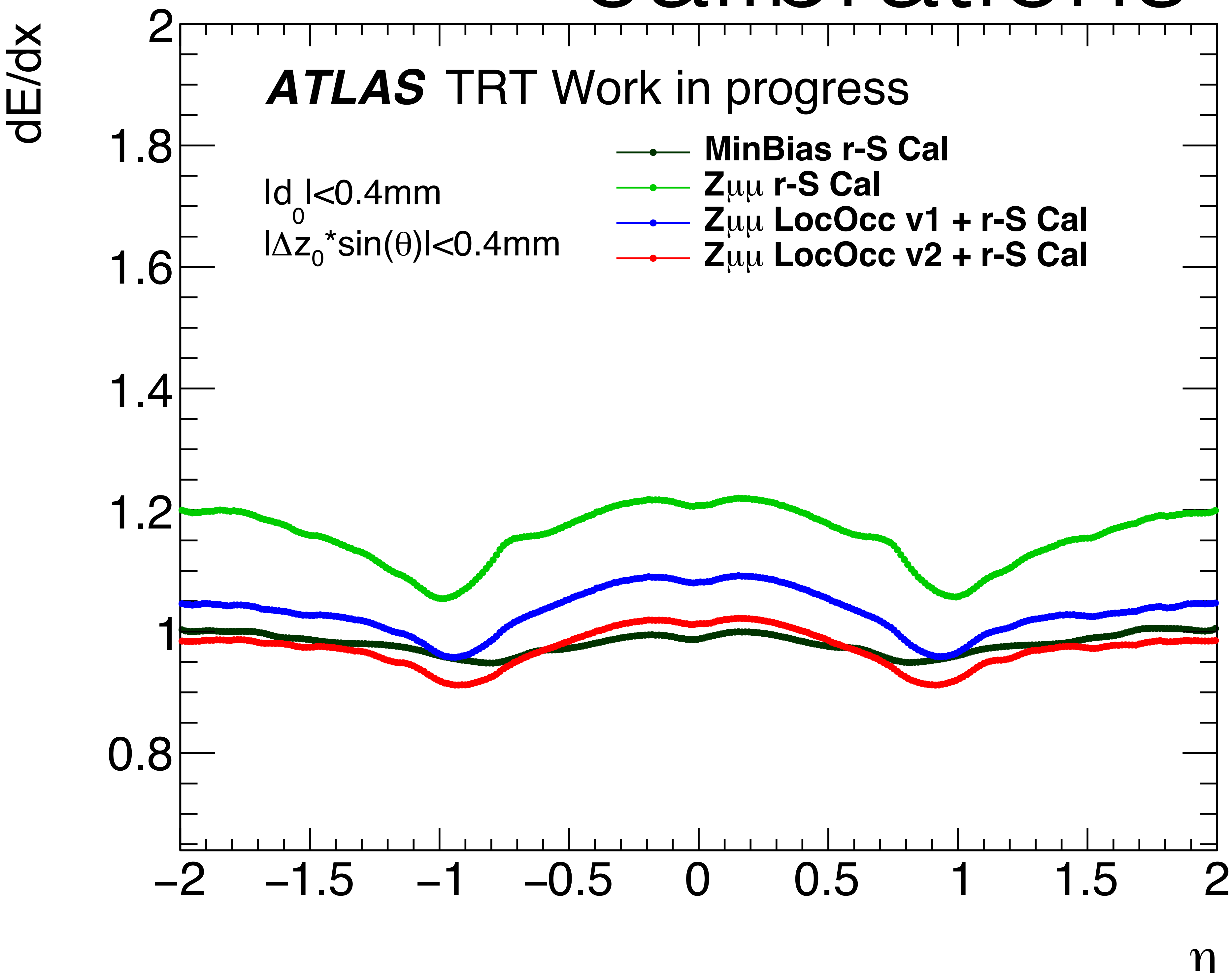
- correct for the slope of ToT over LO (blue curves)
- correct in addition for the intercept to non-shared/LT conditions and do the calibration a second time without the highest corrected ToT value (truncated hit) of the first calibration (red curves)

Performance of new calibrations



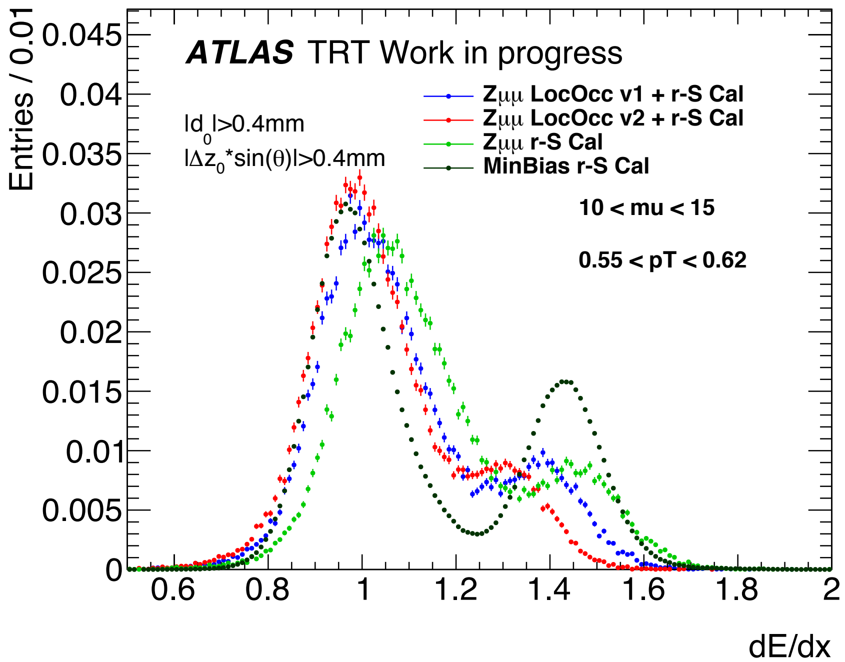
- red calibration peaks more or less exactly at the MinBias center
- blue calibration is higher and broader

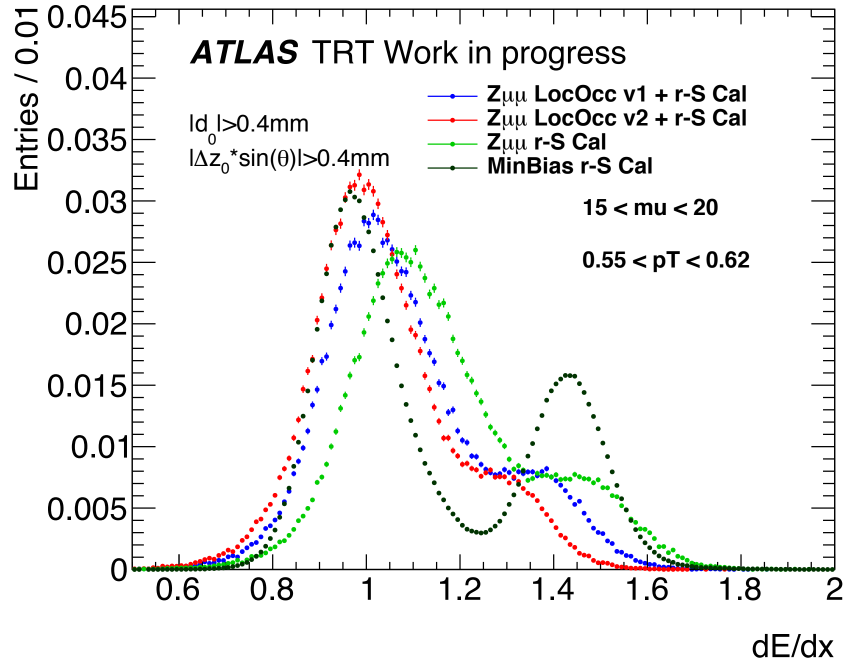
Performance of new calibrations

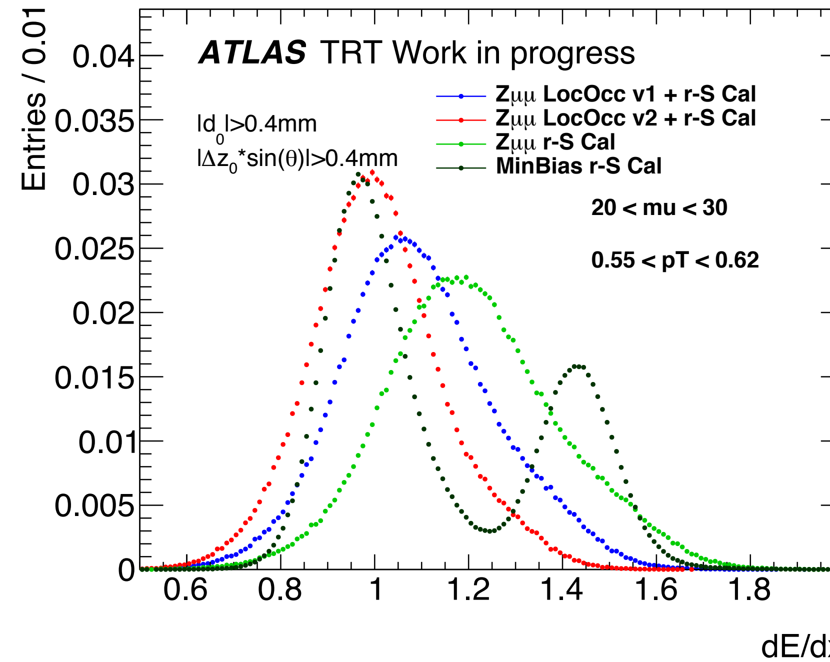


- eta dependence for Zmumu higher than for MinBias, but okayish for red one
- red looks best, a bit too high in the central part and too low in the endcap region
- biggest difference still the transition region

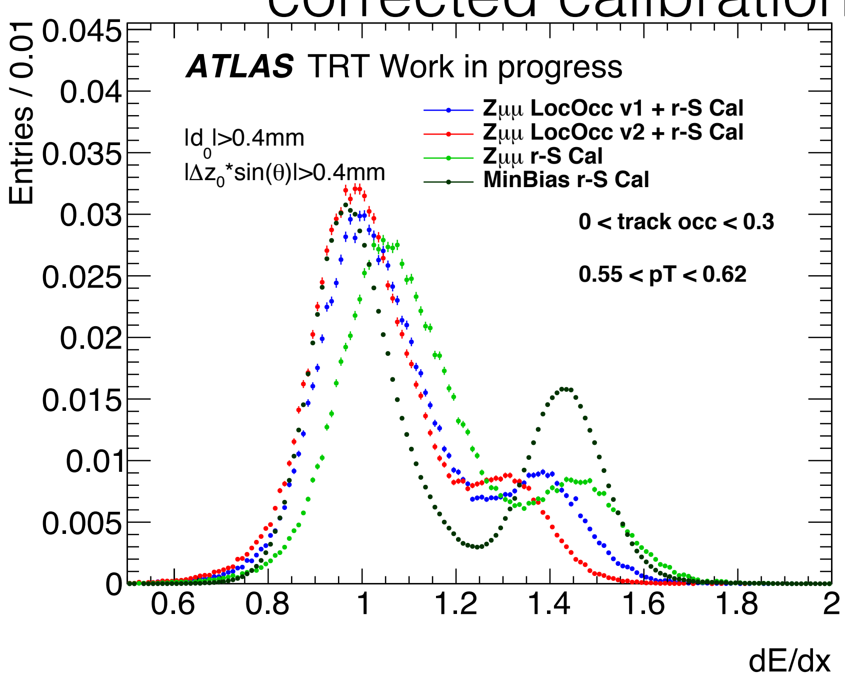
Separation power of new calibrations

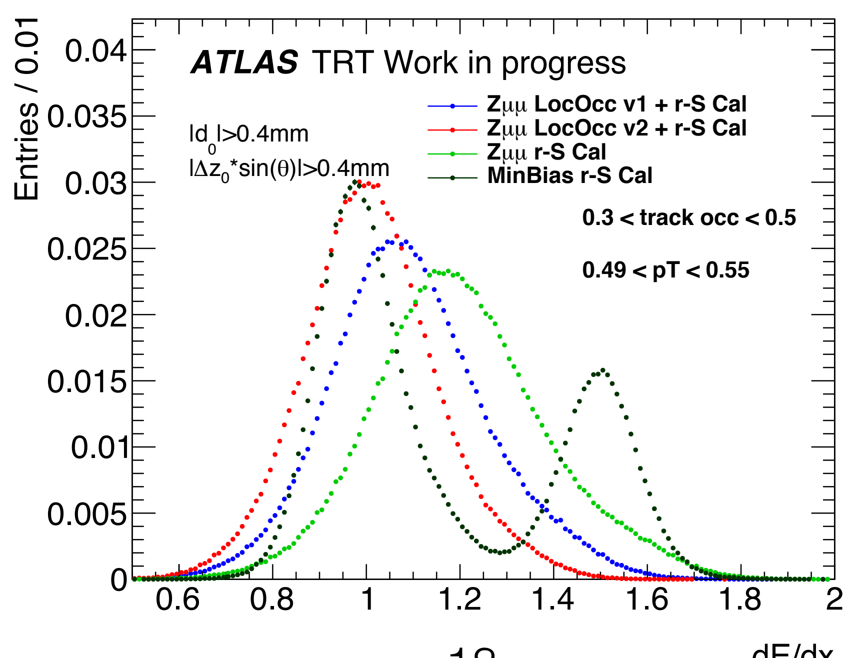


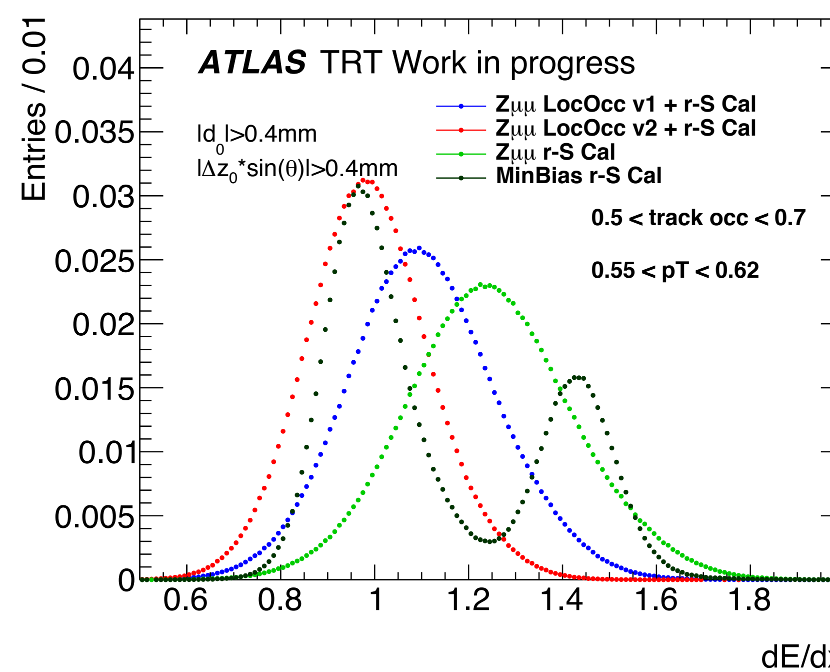




- no improvement in terms of separation visible between corrected and not corrected calibrations







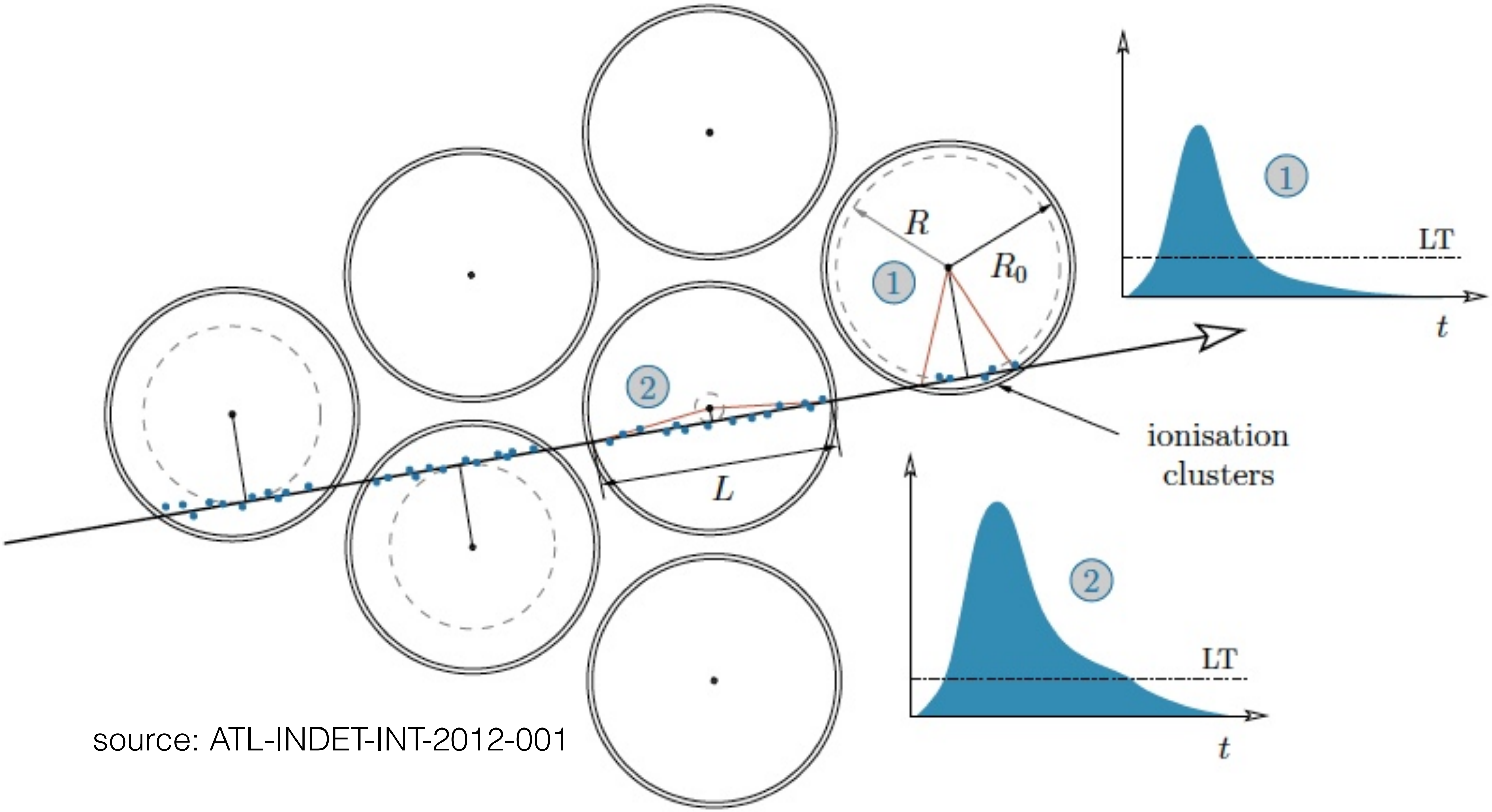
Summary and Outlook

- have a look on how occupancy calibration can have an impact for the separation of low momentum heavy particles/multi-charged particles
- need to investigate the electron to hadron(pion) separation
- compare track-based to hit-based calibration

Backup

1. Derivation of ToT

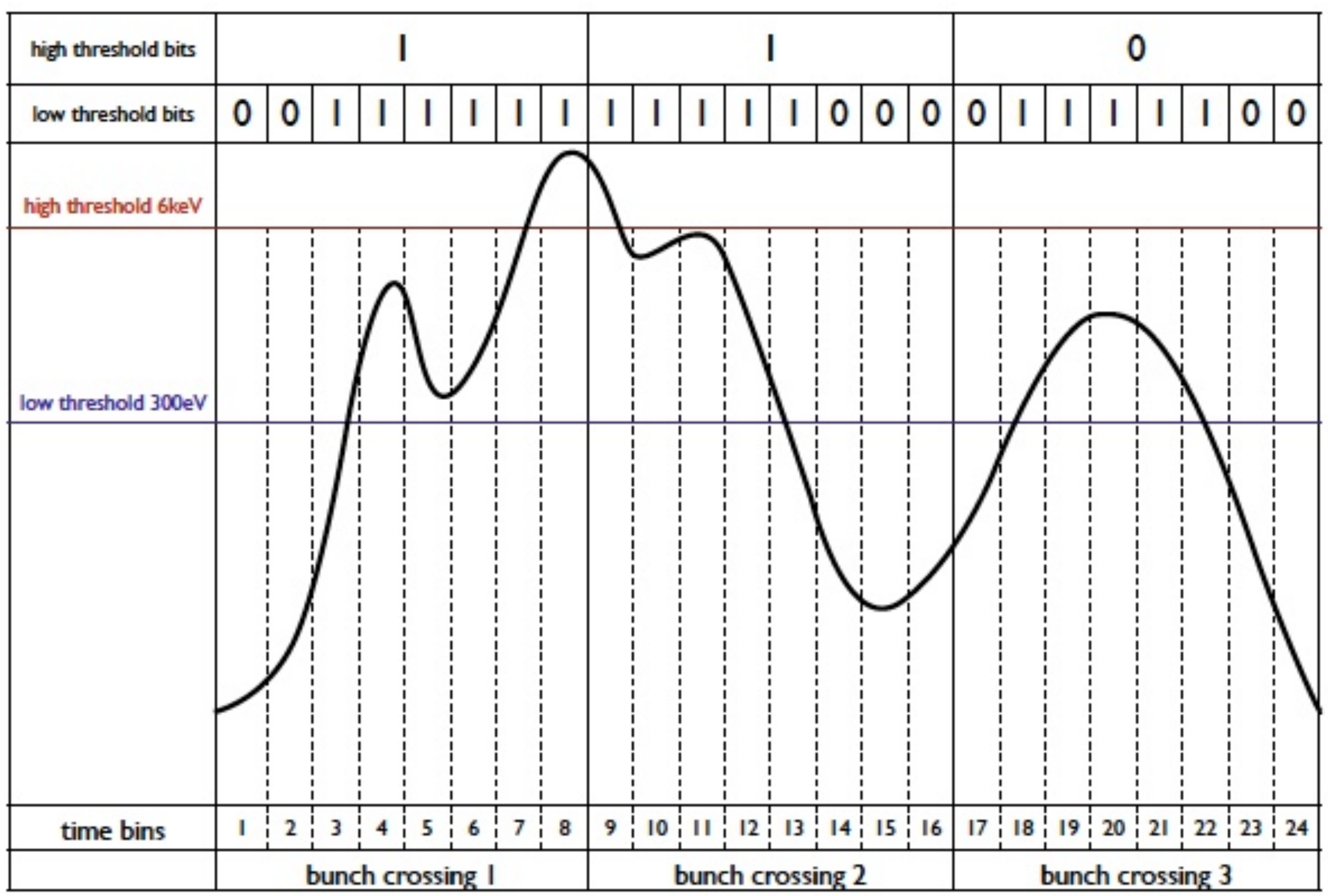
- particle traversing straws create ionisation clusters



source: ATL-INDET-INT-2012-001

1. Derivation of ToT

- electrical signal is discriminated against two thresholds
  - low threshold (LT) at 300eV, 24 bins a 3.125ns (currently last 4 bits masked)
  - high threshold (HT) at 6keV, 3 bins a 25ns
- each bin is set to 1 if the signal is above the corresponding threshold at least once during the readout



source: ATL-INDET-INT-2012-001

1. Derivation of ToT

ToT estimation from bitpattern

- getToTlargerIsland()

High threshold	0								0								0							
Low threshold	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0
Time bins	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

- searches for the largest island of consequent bins set to 1

- getToTHighOccupancy()

High threshold	0								0								0							
Low threshold	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0
Time bins	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

- takes the sequence between the trailing and the leading edge

- getToTHighOccupancySmart()

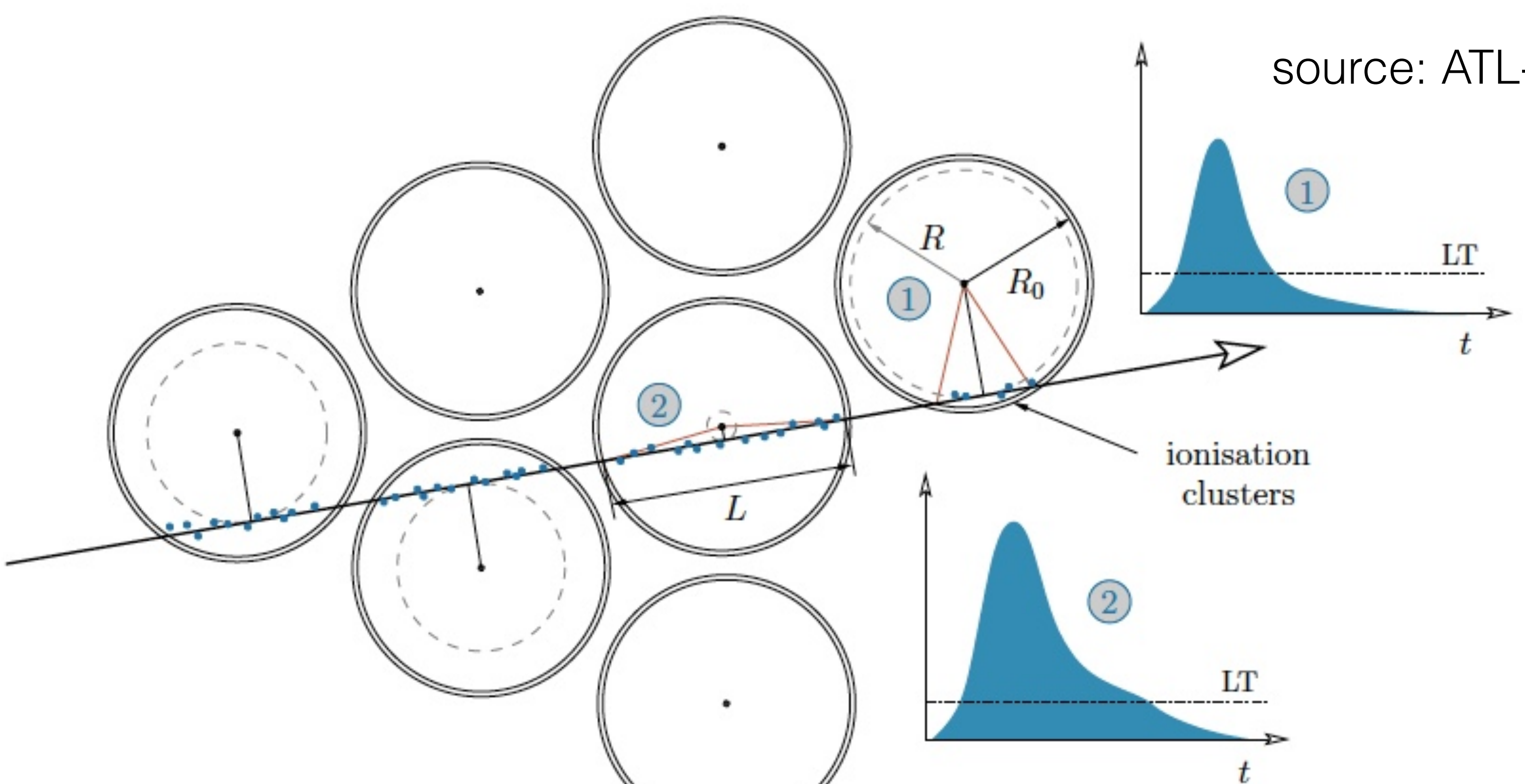
High threshold	0								0								0							
Low threshold	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0
Time bins	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

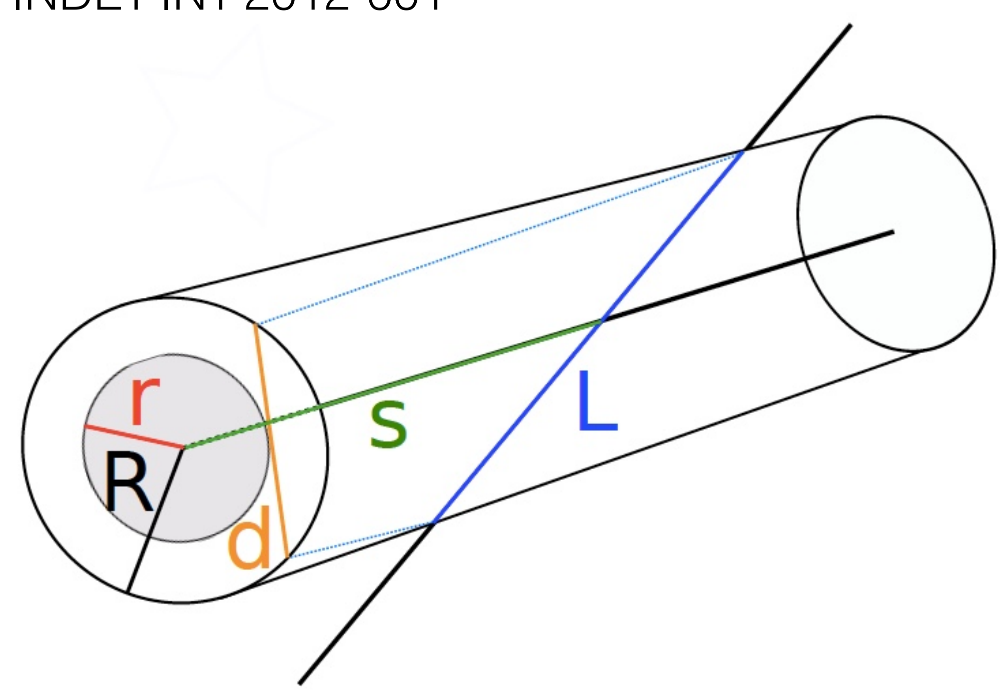
- same as HighOccupancy, but leading edge is the first 0 to 1 transition looking from backwards

2. Divide by length in the straw

1. drift radius is rather large/length in the straw rather short
2. drift radius is rather short/length in the straw rather long
   - ➡ divide by length (L) to take this effect into account
   - ➡ unit is now something like ns/mm

source: ATL-INDET-INT-2012-001

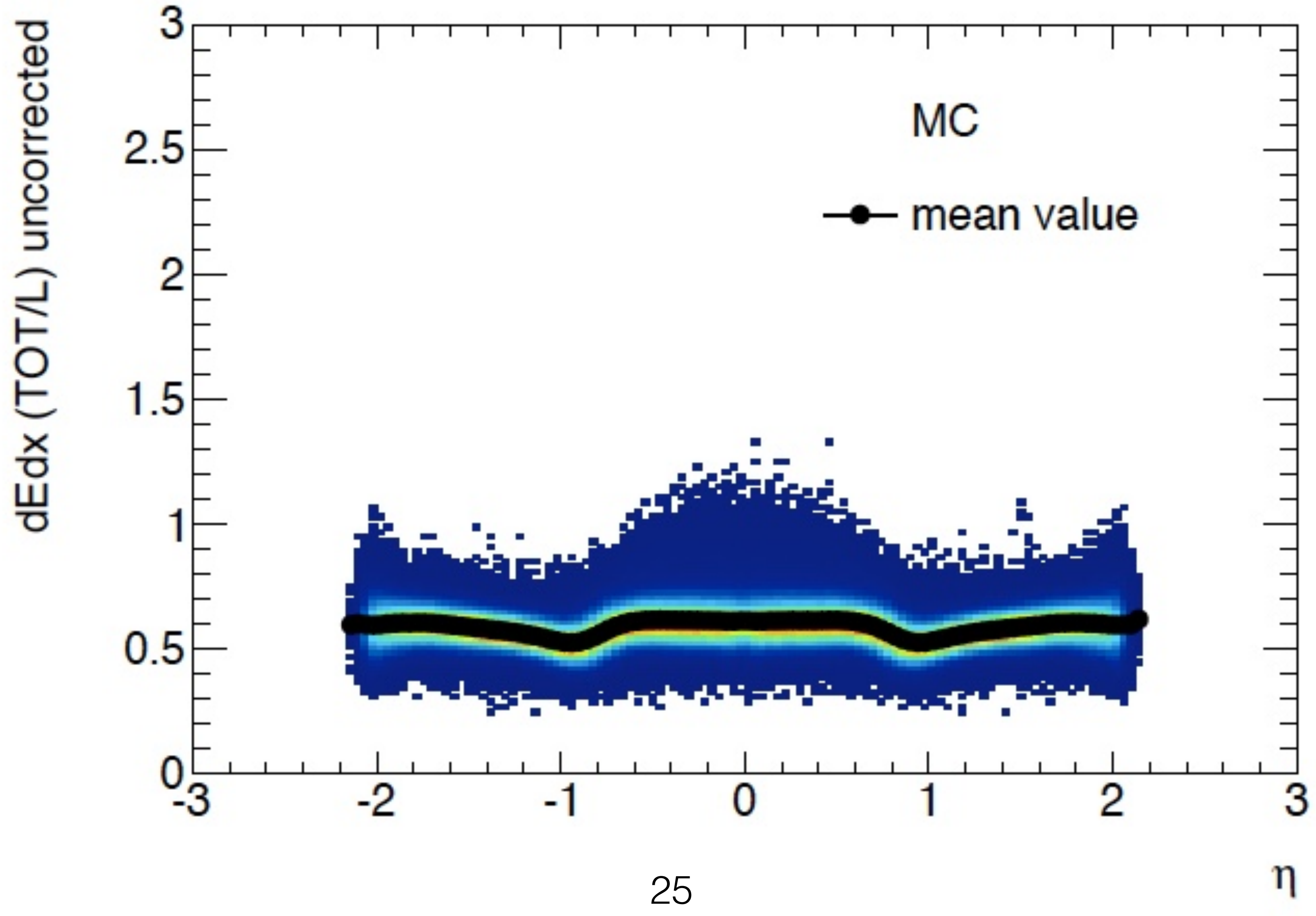




3. r-S calibration

- observed dependence of dE/dx on eta
- can be explained by the geometrical position of the hit in the detector due to different electronic responses or material distributions

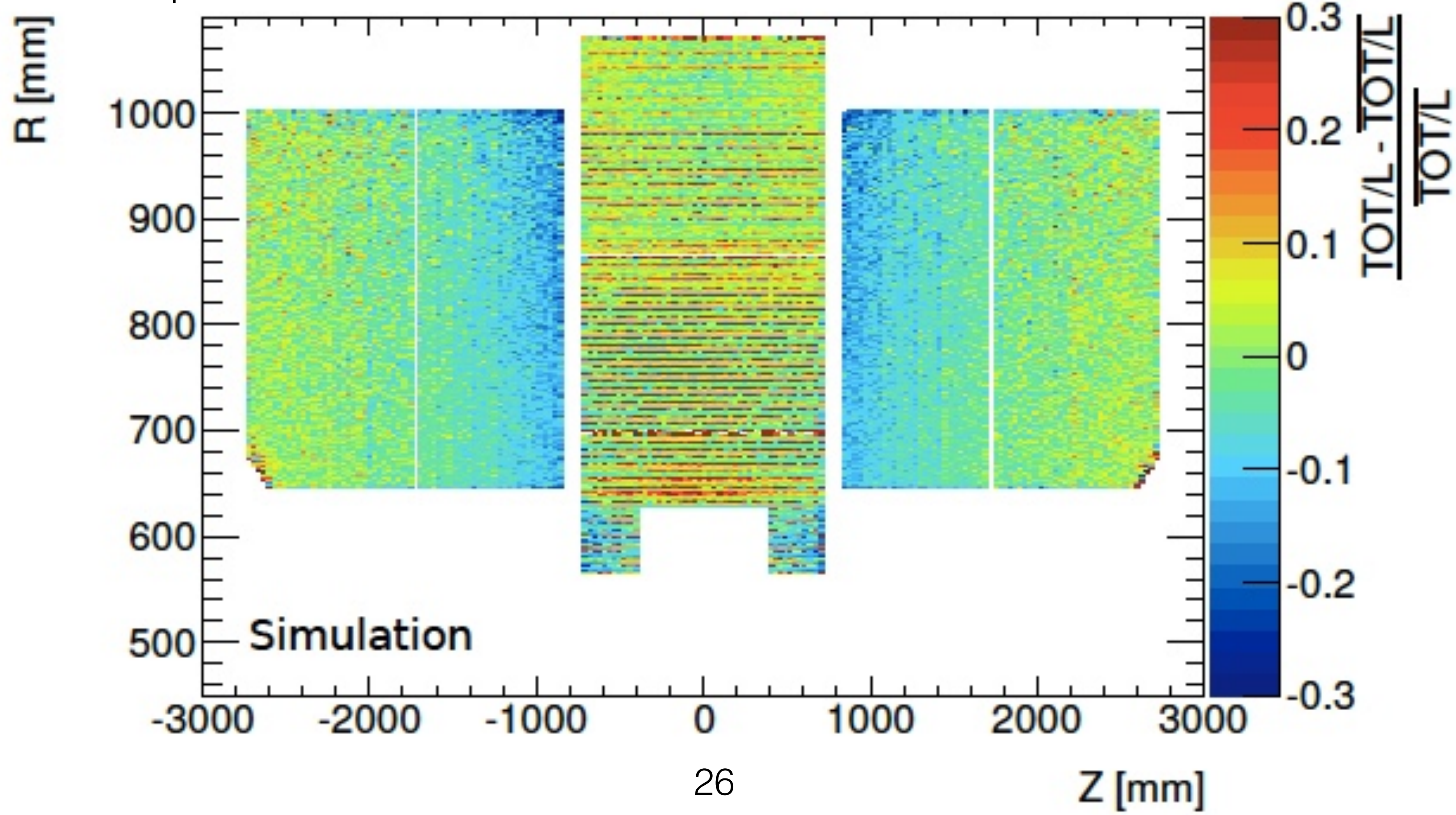
source: ATL-INDET-INT-2012-001



3. r-S calibration

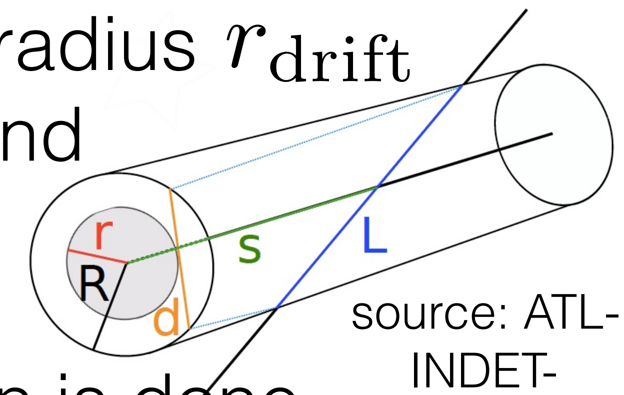
- time difference between the first and the last ionization cluster arriving becomes smaller for larger drift radius
- the straw's length and position in the detector have a large impact on ToT/L
- deviations of up to 20% seen

source: ATL-INDET-INT-2012-001



3. r-S calibration

- corrections to ToT/L applied as a function of the drift radius r_{drift} and the position on the wire s derived for all layers and strawlayers separately



source: ATL-INDET-INT-2012-001

- eta can be expressed as a function of s, so correction is done intrinsically

- parametrization of calibration functions
  - endcap: $T(r_{\mathrm{drift}}, s) = T_0^{'}(r_{\mathrm{drift}}) + p(r_{\mathrm{drift}}) \cdot s$
  - barrel: $T(r_{\mathrm{drift}}, s) = T_0^{''}(r_{\mathrm{drift}}) + q(r_{\mathrm{drift}}) \cdot s^2$

3rd order polynomial

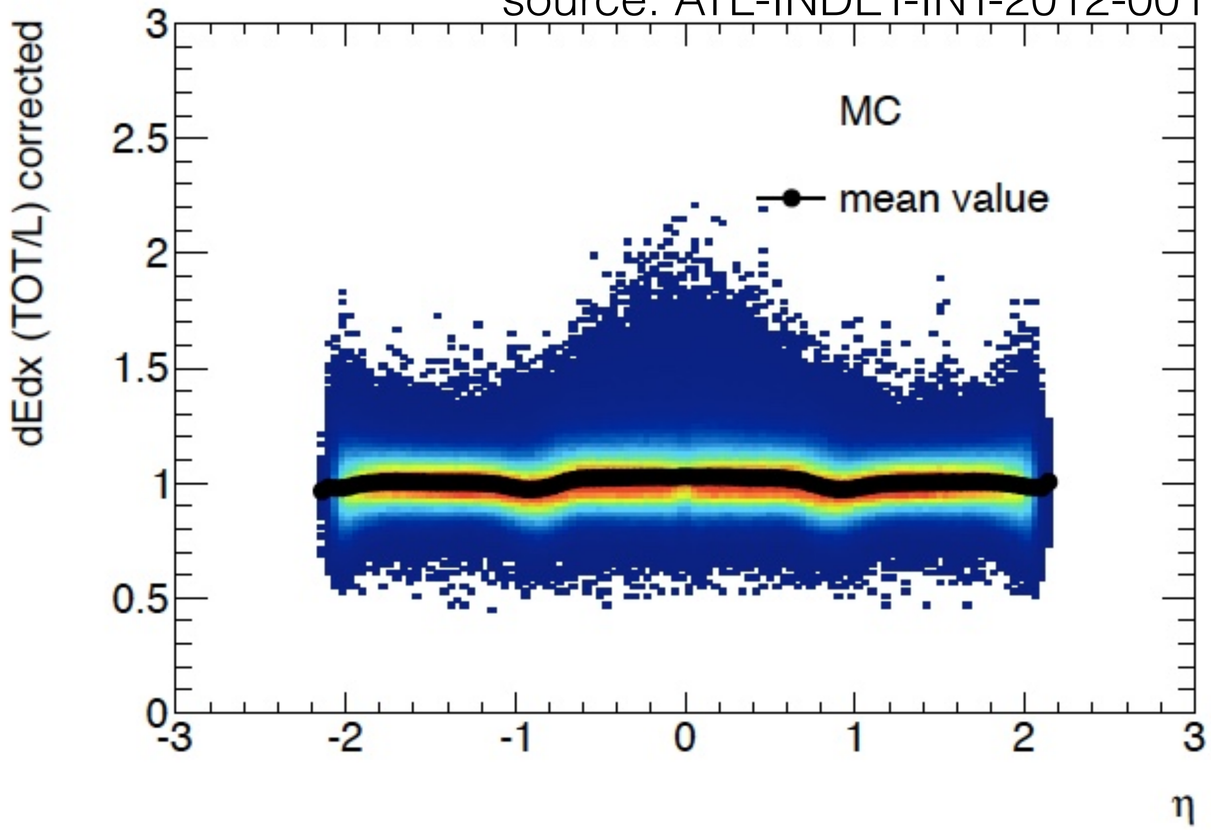
5th order polynomial

- iterative fit procedure to assure stability and convergence of the fit

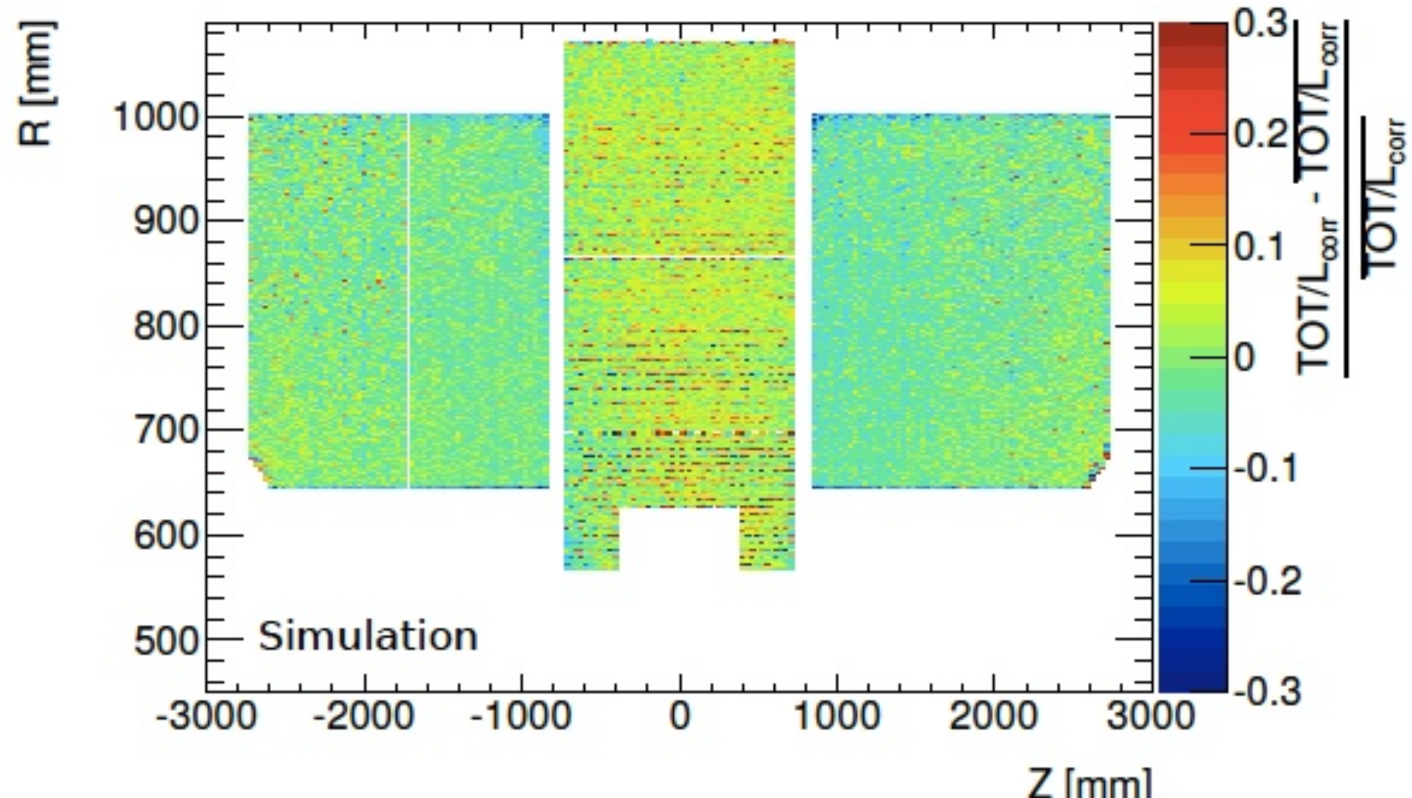
3. r-S calibration

- after calibration deviations less than 5%
- Problems
  - performed on a sample with no pile-up
  - HT hits are not taken into account for this calibration

source: ATL-INDET-INT-2012-001

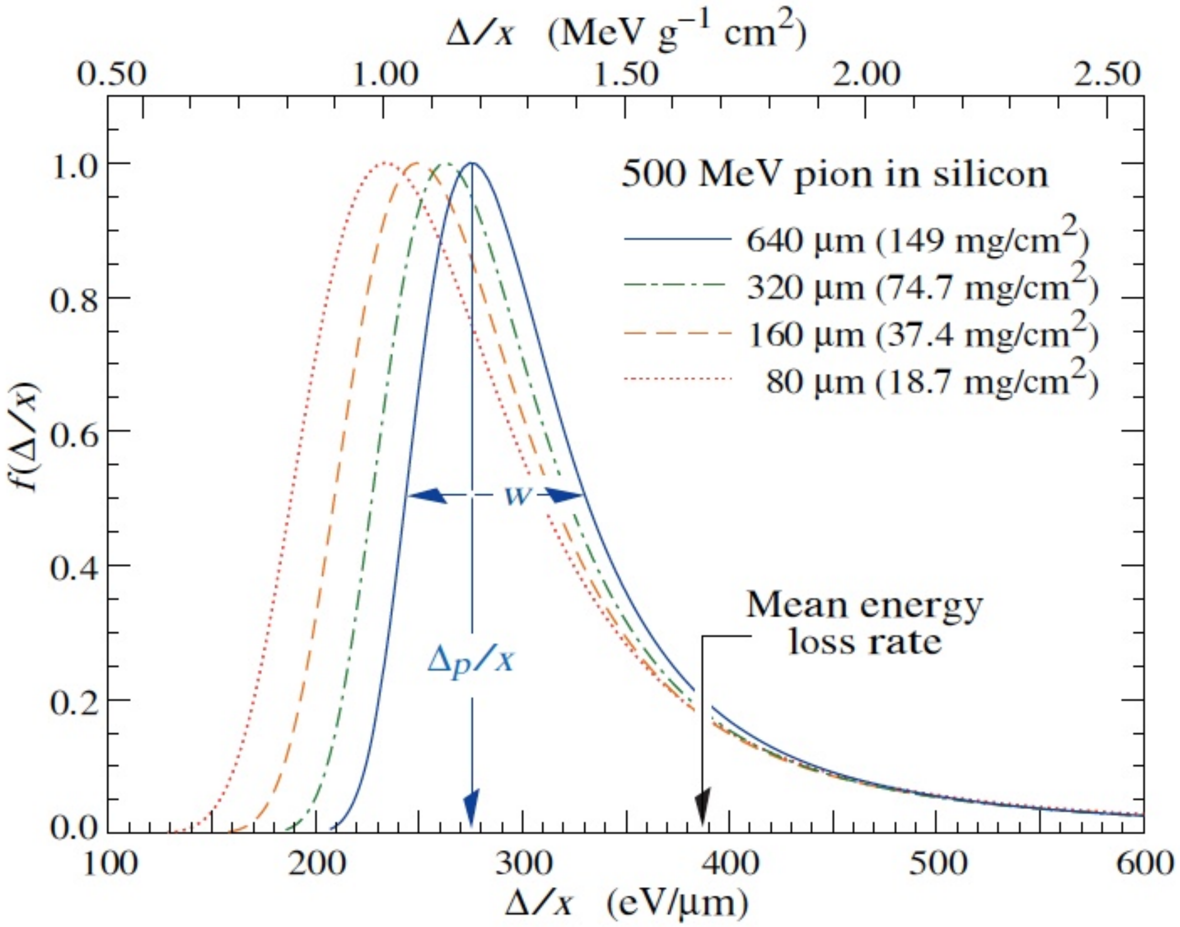


source: ATL-INDET-INT-2012-001



4. Truncation

- Distribution of single energy deposit is more Landau-like
  - ➡ average is dominated by few entries in the tail and not close to the most probable value (peak)
- reject a certain number of the hits with the highest ToT in order to keep the loss of hits at a minimum and to maximize the separation power of the variable
  - ➡ it turned out that it is sufficient to drop only the highest ToT hit



source: ATL-INDET-INT-2012-001

Data samples and track selection

- used sample for MinBias (mu<1), „ideal case“:
  - data16 MinBias: group.det-indet.00299390.physics_MinBias.daq.TRTxAOD.f701_trt099-01_EXT0/
- samples with Zmumu (10<mu<40), „actual situation“:
  - data16 Zmumu: group.det-indet.00304128.physics_Main.daq.TRTxAOD_Z.f716_trt099-00_EXT0/
- Track selection

- min pT/GeV: 0.5
- max eta: 2
- min nIBLhits+nBLayhits: 0
- min nPixhits: 1
- min nSCThits: 5
- min nTRThits: 15
- max D0: 0.4mm
- max Deltaz0*sin(theta): 0.4mm
- min used TOT hits: 5
- min pOverQ: 0.5

Hit selection

- Check if localTheta and localPhi are filled properly:

  Trt_HitTheta>-999. && Trt_HitPhi>-999.

- Reject non precision hits:

  hit_error<1. && Trt_Rtrack+residual_biased!
  =0

- Drift radius close to wire or wall:

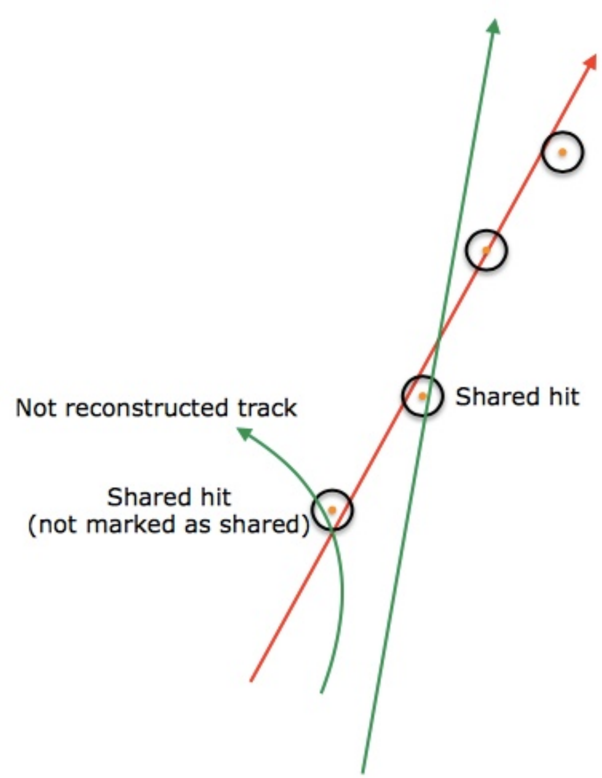
  0.15mm< fabs(Trt_Rtrack) < 1.85)

- Length in straw longer than 1.7: m_L > 1.7

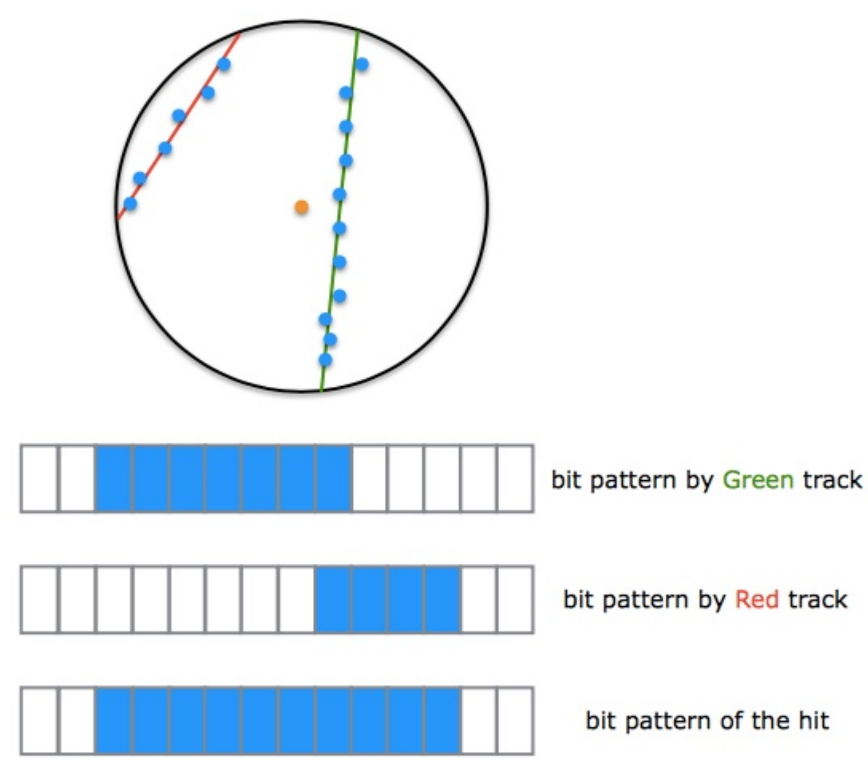
- ToT>0

TRT shared hits

- interesting variable: can help us to understand high occupancy effect on a straw
- how does ToT changes for a straw associated with more than 1 track

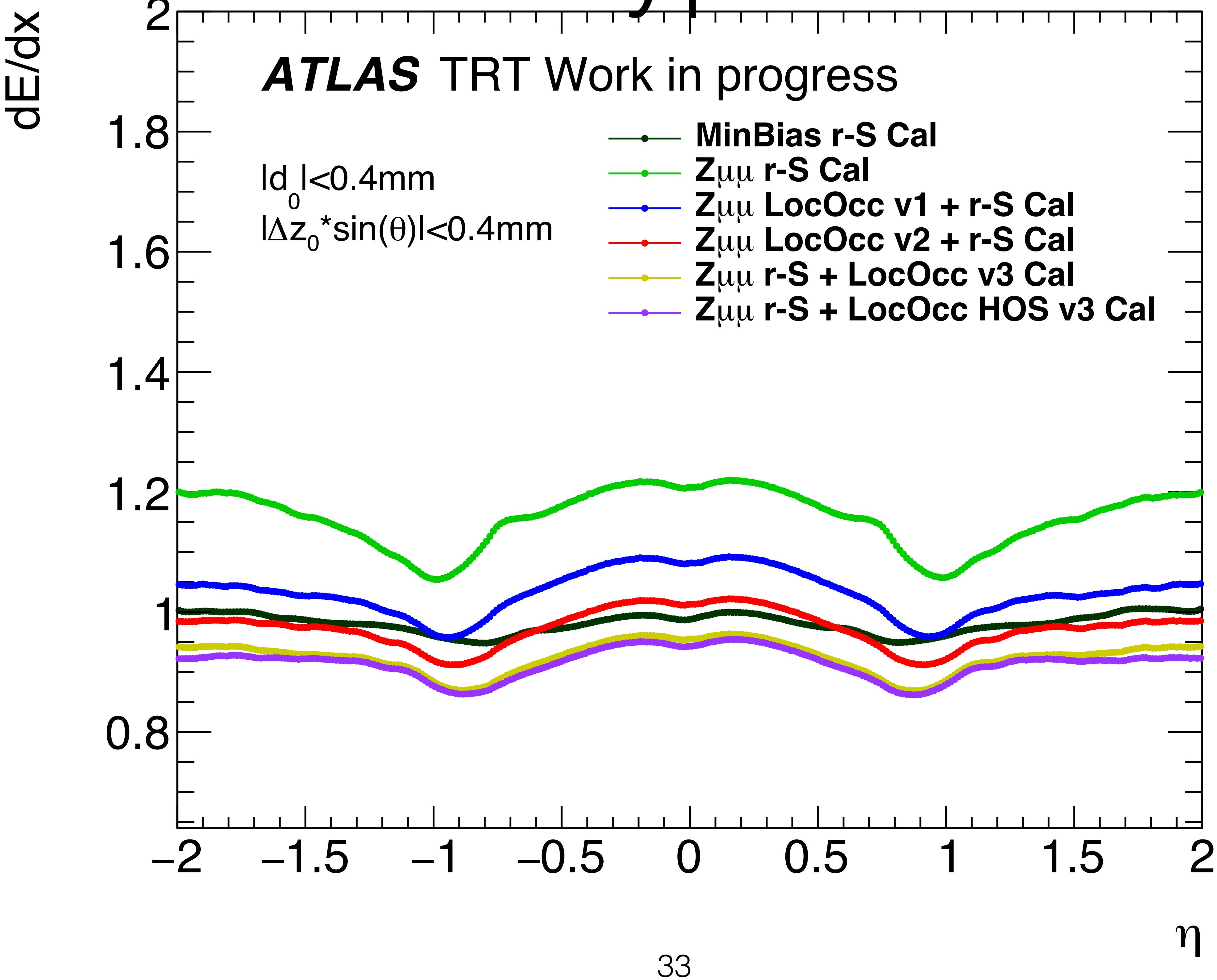


by KyungEon

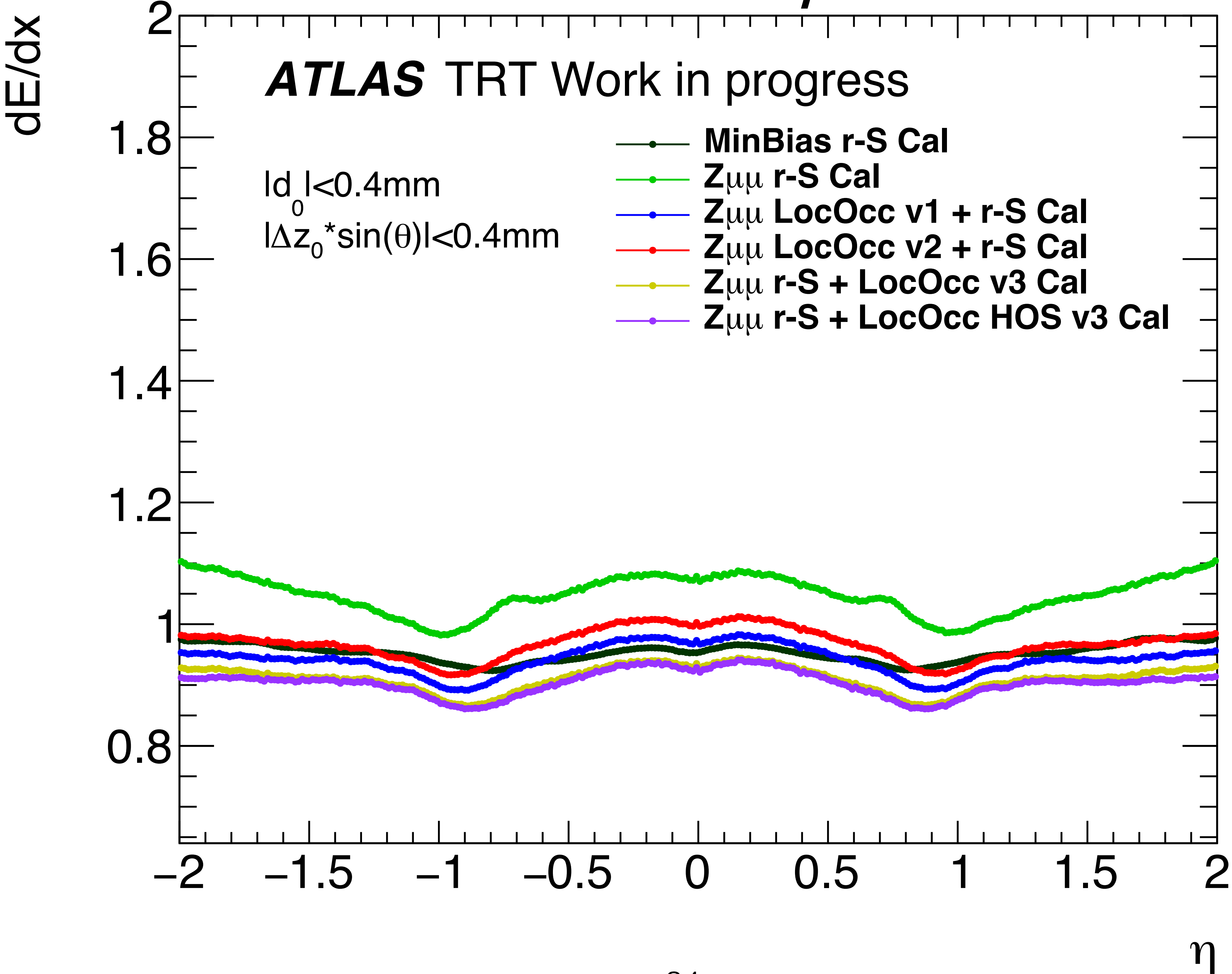


* bit pattern of the hit is not exactly correct since bit pattern is generated from electron clusters.

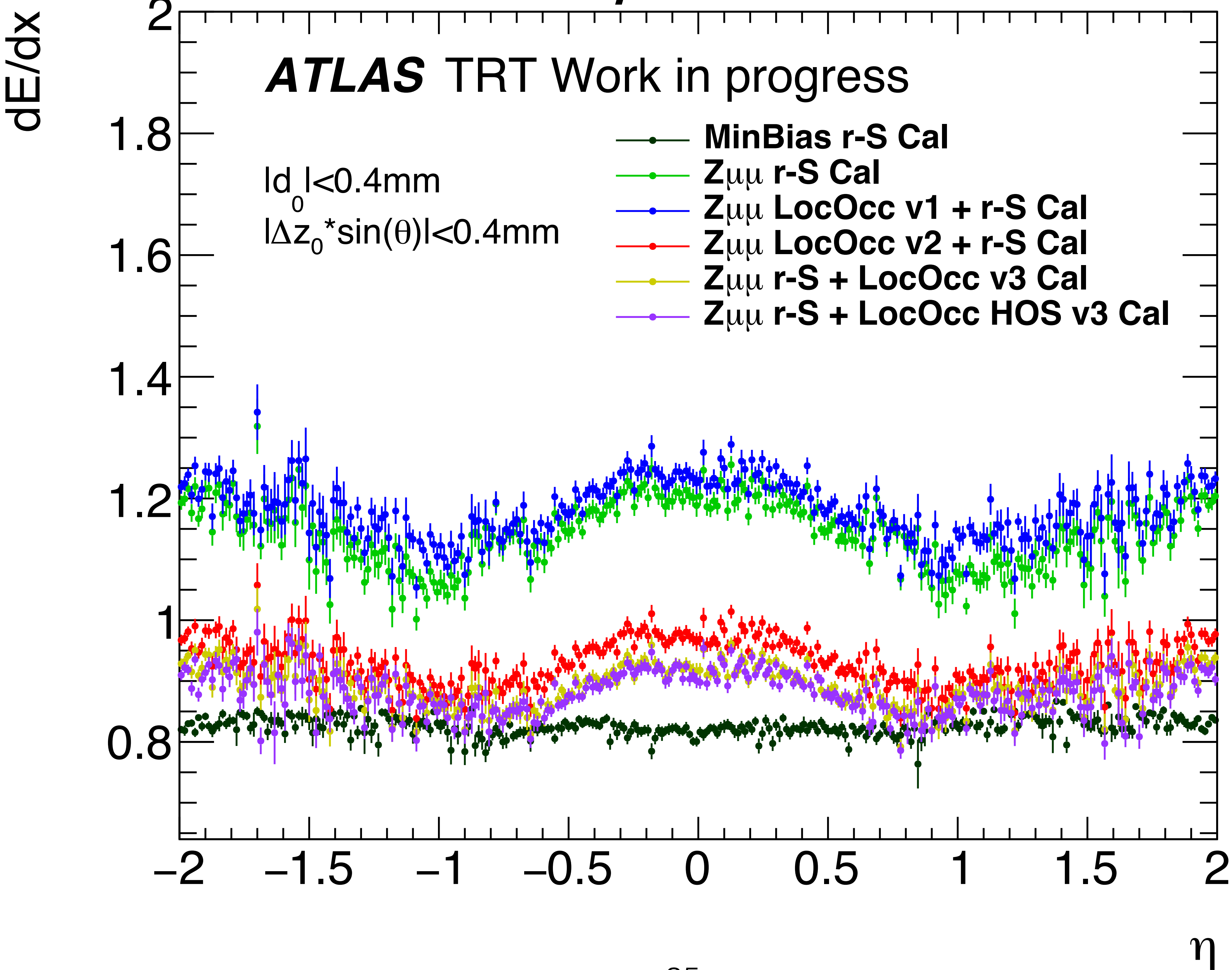
Tracks consisting out of different types of hits



Tracks consisting only out of non-shared/LT hits



Tracks consisting only out of shared/LT of hits



Quality hit criteria

- 1) Check if localTheta and localPhi are filled properly:

```
double Trt_HitTheta =  itr->auxdata<float>("localTheta");
 double Trt_HitPhi = itr->auxdata<float>("localPhi");

 if ( (Trt_HitTheta<-999.) II (Trt_HitPhi<-999.)) return false;
```

- 2) Reject non precision hits

```
 double hit_error = sqrt(0.5*(residual_unbiased*residual_unbiased/(pull_unbiased*pull_unbiased)+residual_biased*residual_biased/(pull_biased*pull_biased)));
 double residual_biased = itr->biasedResidualX();
 double residual_unbiased = itr->unbiasedResidualX();
 double pull_biased = itr->biasedPullX();
 double pull_unbiased = itr->unbiasedPullX();
 double Trt_Rtrack = itr->localX();

if ( (hit_error>1.) && (Trt_Rtrack+residual_biased==0) ) return false;
```

- 3) Drift radius close to wire or wall

```
 if ( (fabs(Trt_Rtrack) >= 1.85) II (fabs(Trt_Rtrack) <= 0.15) ) return false;
```

- 4) Length in straw longer than 1.7 (the calculation looks good in your email, but I'm not sure about the strawphi)

```
 double strawphi = driftcircle->auxdata<float>("strawphi");
 if (fabs(bec)==1){ //Barrel
   m_L = 2*sqrt(4-Trt_Rtrack*Trt_Rtrack)*1./fabs(sin(Trt_HitTheta));
 }
 else if (fabs(bec)==2) { //EndCap
   m_L = 2*sqrt(4-Trt_Rtrack*Trt_Rtrack)*1./sqrt(1-sin(Trt_HitTheta)*sin(Trt_HitTheta)*cos(Trt_HitPhi-strawphi)*cos(Trt_HitPhi-strawphi));
 }

if (m_L < 1.7) return false;
```

- 5) ToT>0

```
if (ToT==0) return false;
```

Old requirements

- `if (driftcircle_radius==0) return false; // reject tube hits`
- `if (distance2 > error2) return false; // Select precision hit only`
- `distance2 = (track_to_wire_distance - driftcircle_radius)^2`
- `error2 = 2*error_on_driftcircle_radius`

New requirements

- `if ( (driftcircle_radius==0) && (error_on_driftcircle_radius >1.15mm) ) return false; // reject tube hits and select precision hits only`