Primary vertex reconstruction with the ATLAS detector

PIXEL 2016 – Sestri Levante, 6 September 2016

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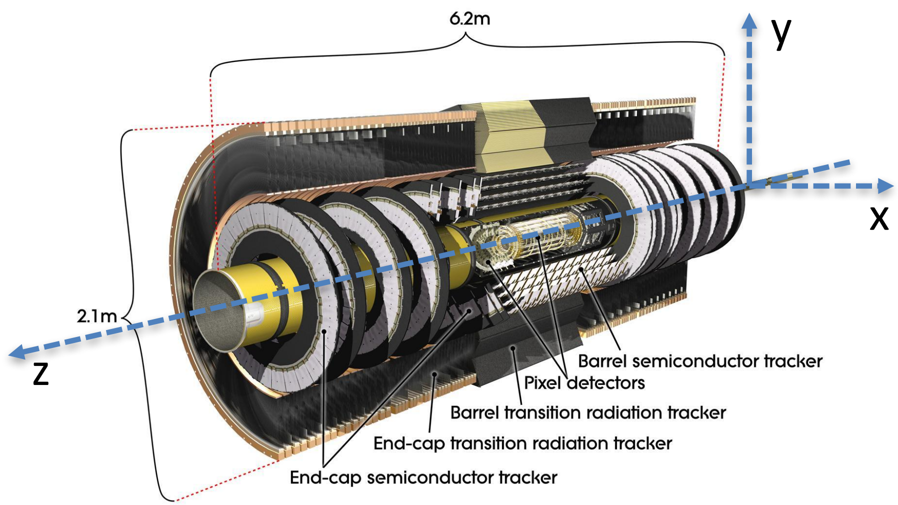
Vertex reconstruction at ATLAS

Vertex reconstruction uses reconstructed tracks to determine the locations of **primary interactions** and secondary decays.

Three major steps:

- **Seeding**
- **Track assignment**
- **Fitting**



TRACK REQUIREMENTS

- p_T > 400 MeV, $|\eta| < 2.5$
- ≥ 1 hits in the IBL+B-layer
- ≥ 9 hits in the pixel+SCT if $|\eta| \leq 1.65$
- ≥ 11 hits in the pixel+SCT if $|\eta| > 1.65$
- Maximum of 1 shared module
- Pixel holes = 0
- SCT holes ≤ 1

SCT = Semi Conductor Tracker

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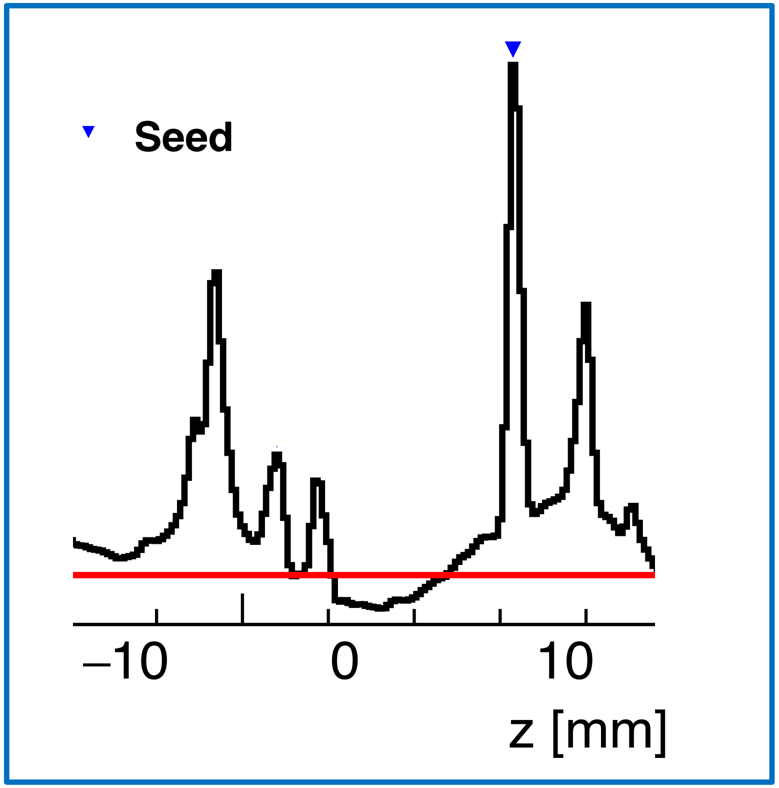
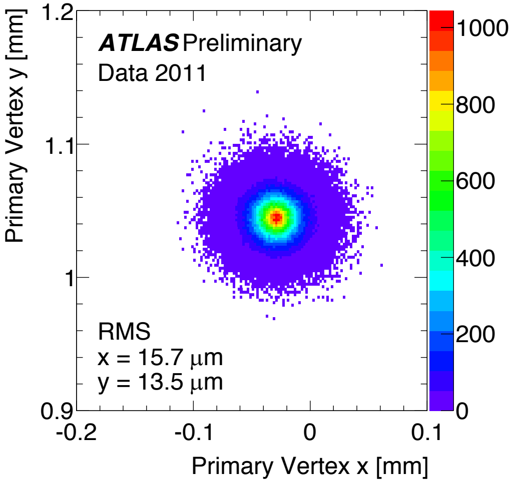
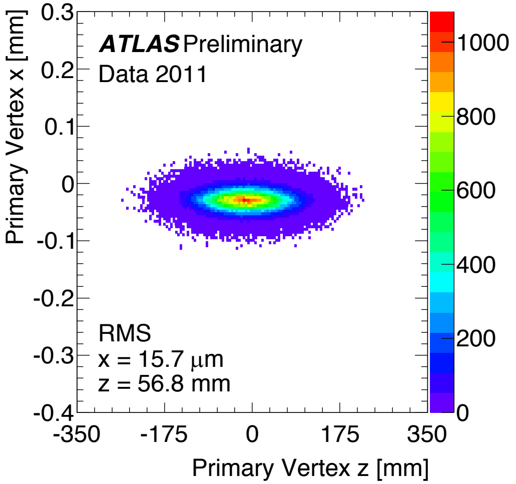
Vertex reconstruction at ATLAS

Seeding

- A seed is placed at the location of the estimated *mode* in *z*, considering the track's impact parameters z_0 with respect to the beam spot.







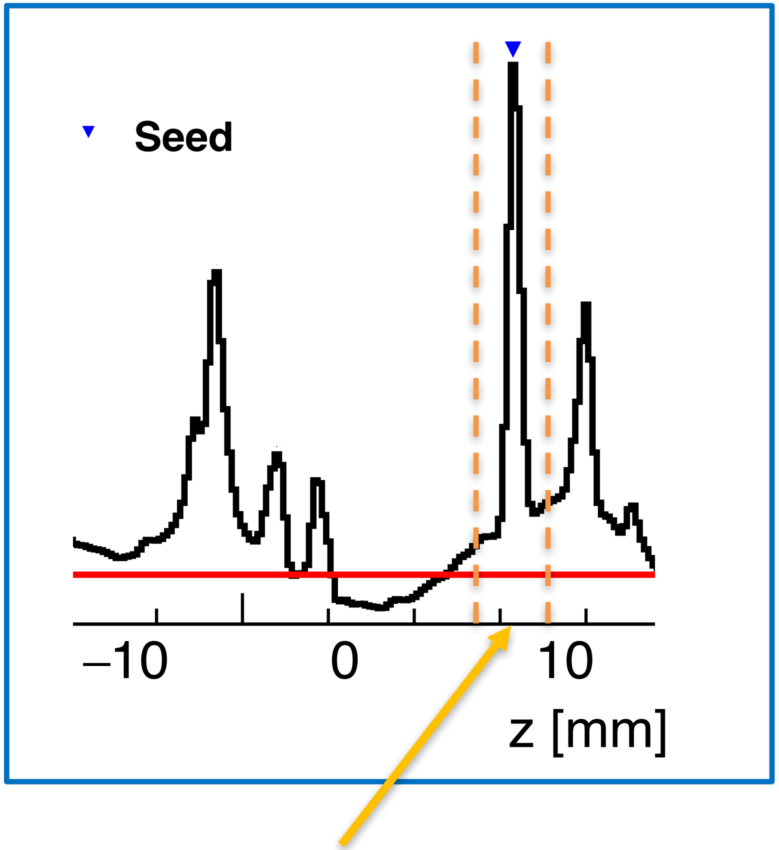
Vertex reconstruction at ATLAS

Track assignment

- Tracks compatible with the seed are grouped together for fitting.

Adaptive Fitting

- Fit nearby tracks to the seed.
- The fit is an iterative procedure, and in each iteration less compatible tracks are down-weighted and the vertex position is recomputed.



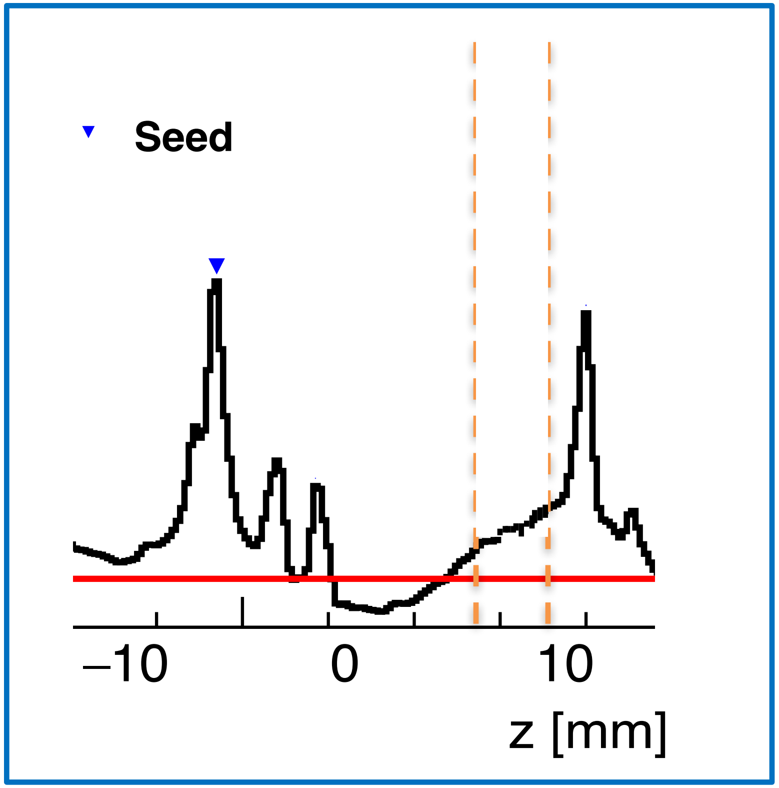
window based on **3D IP significance** wrt $(x,y)_{beamspot}$ and z_{seed}

Vertex reconstruction at ATLAS

Next iteration

- Tracks that are not already fit to vertices are then used to repeat the process from the seeding step.
- Repeat the process until all tracks are assigned to a vertex OR a seed is generated which has no compatible tracks for fitting.

The reconstructed vertex with the highest Σp_T^2 is assigned as the default primary interaction.



The luminosity challenge

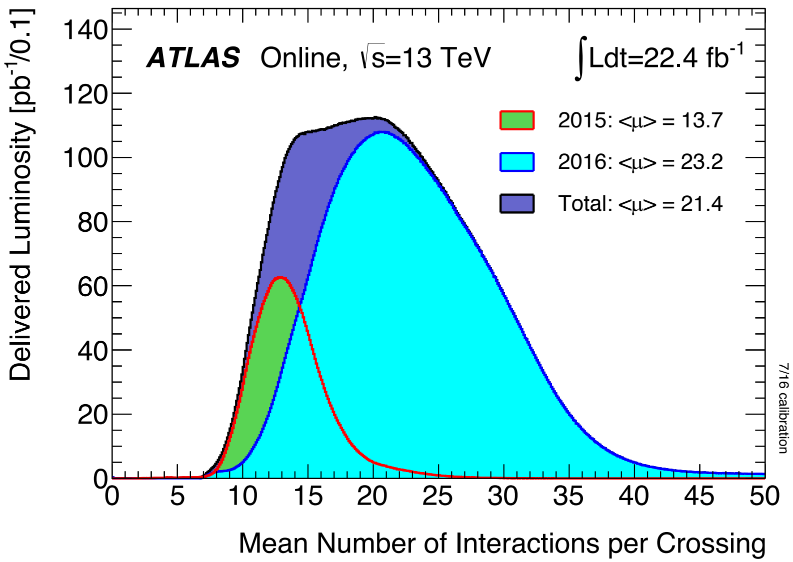
Outstanding LHC performance

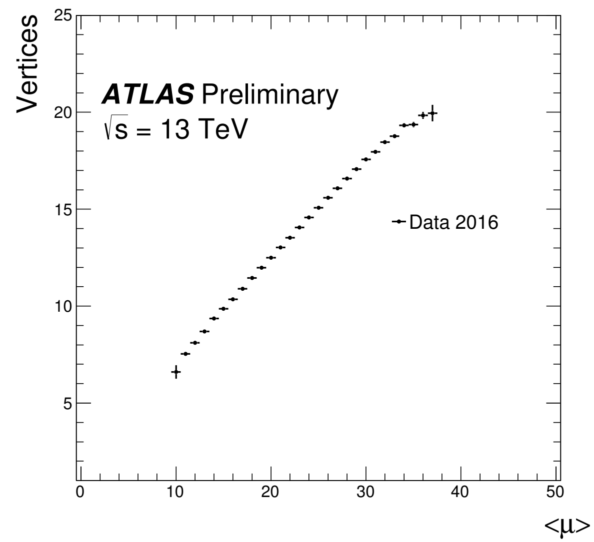
- Peak lumi: 11.6×10^{33} $cm^{-2}s^{-1}$

The vertex reconstruction **depends mostly on the number of interactions per bunch crossing**, not the centre-of-mass energy.

The main effects are:

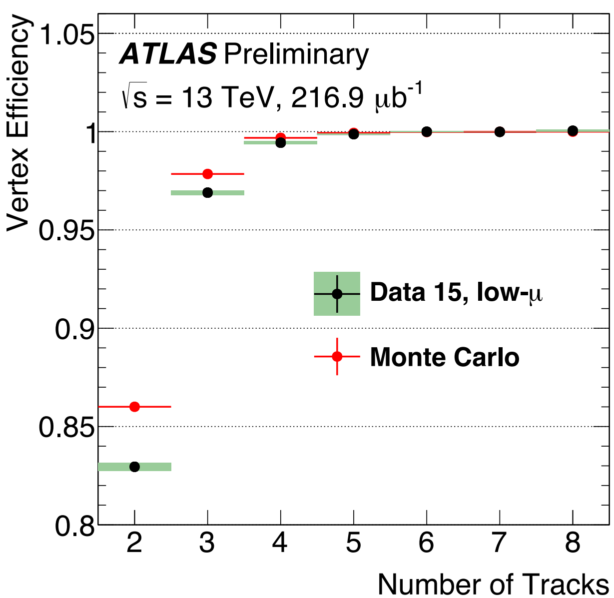
- Merging
- Splitting
- Fakes

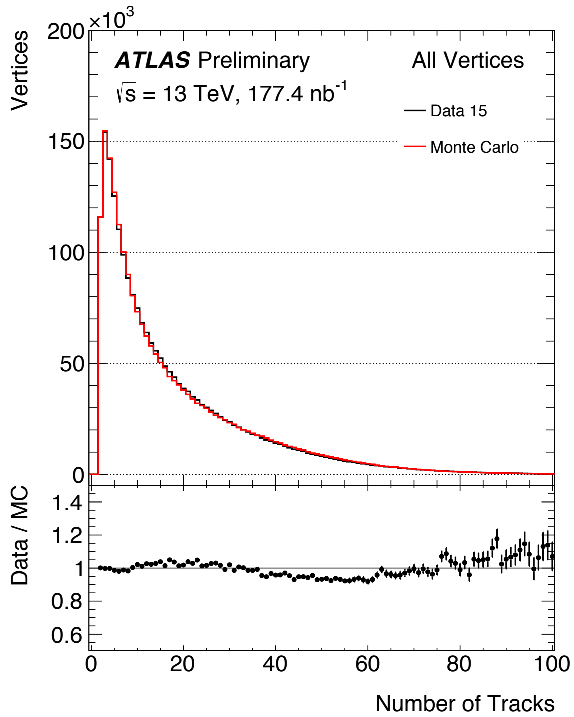


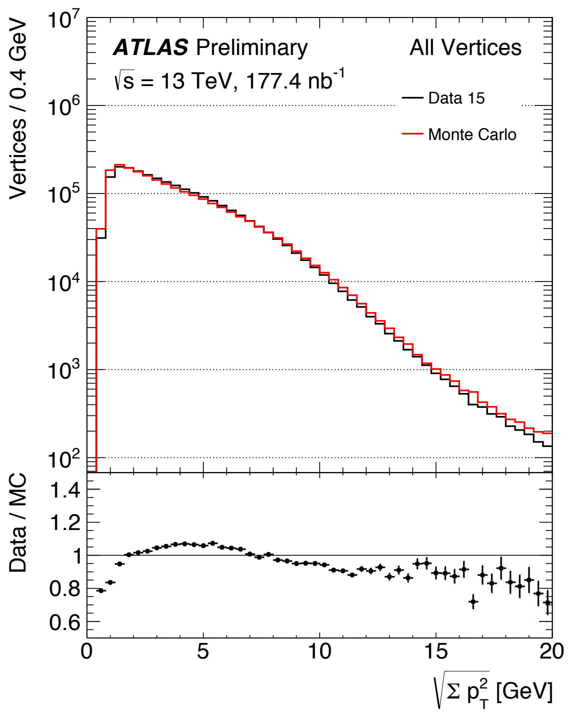


Efficiency and basic quantities

- Vertex reconstruction efficiency measured in special “low-μ” runs in events with at least two tracks
- The data are reproduced well by simulation (Pythia 8.185 with A2 tune), with some disagreement in the charged track multiplicity and p_T spectra (within 20%)







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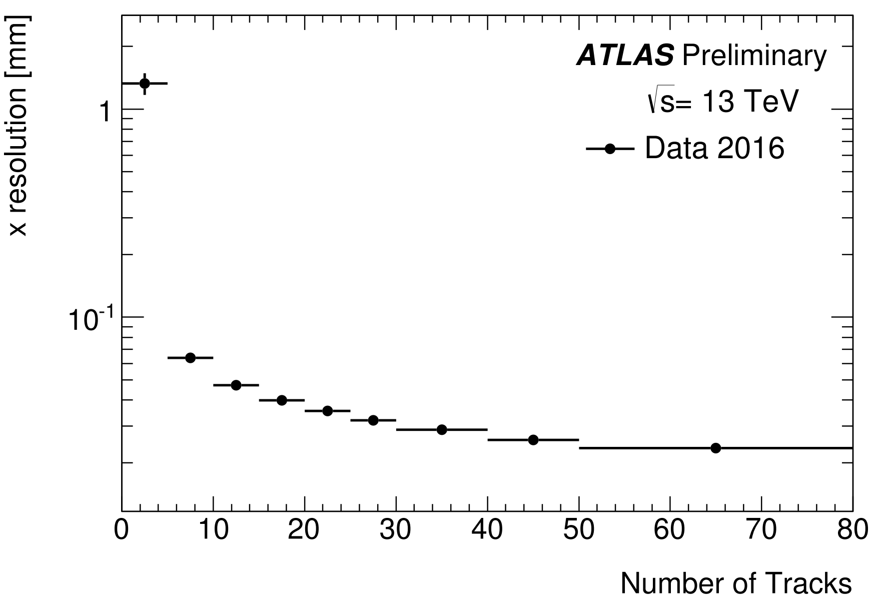
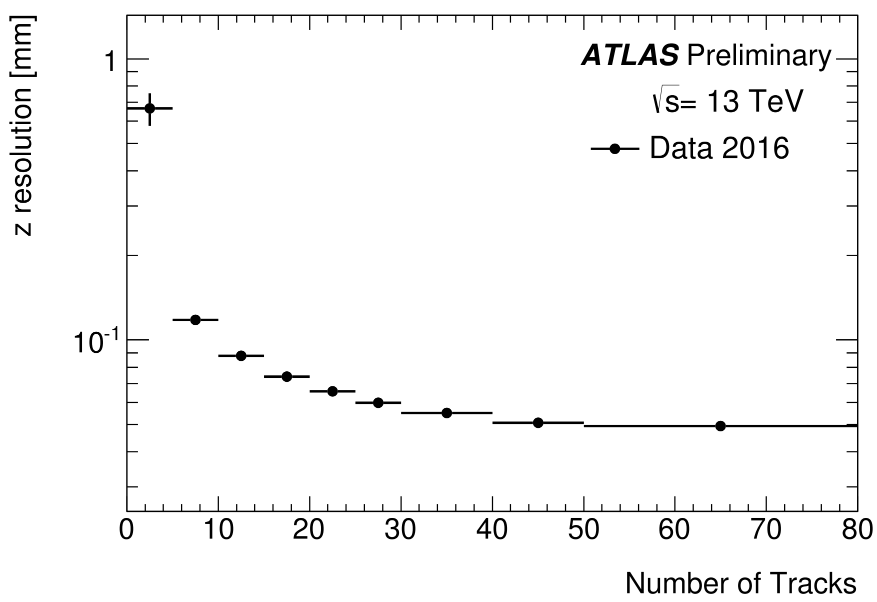
Vertex position resolution

- The vertex position uncertainty is estimated in Monte Carlo simulation
- N_{tracks} and Σp_T-dependent corrections to account for the simulation mismodellings, to the fitted vertex uncertainty ($\sigma_{x,fit}$) can be obtained from data with the "split vertex method"
- Average correction of about 10%





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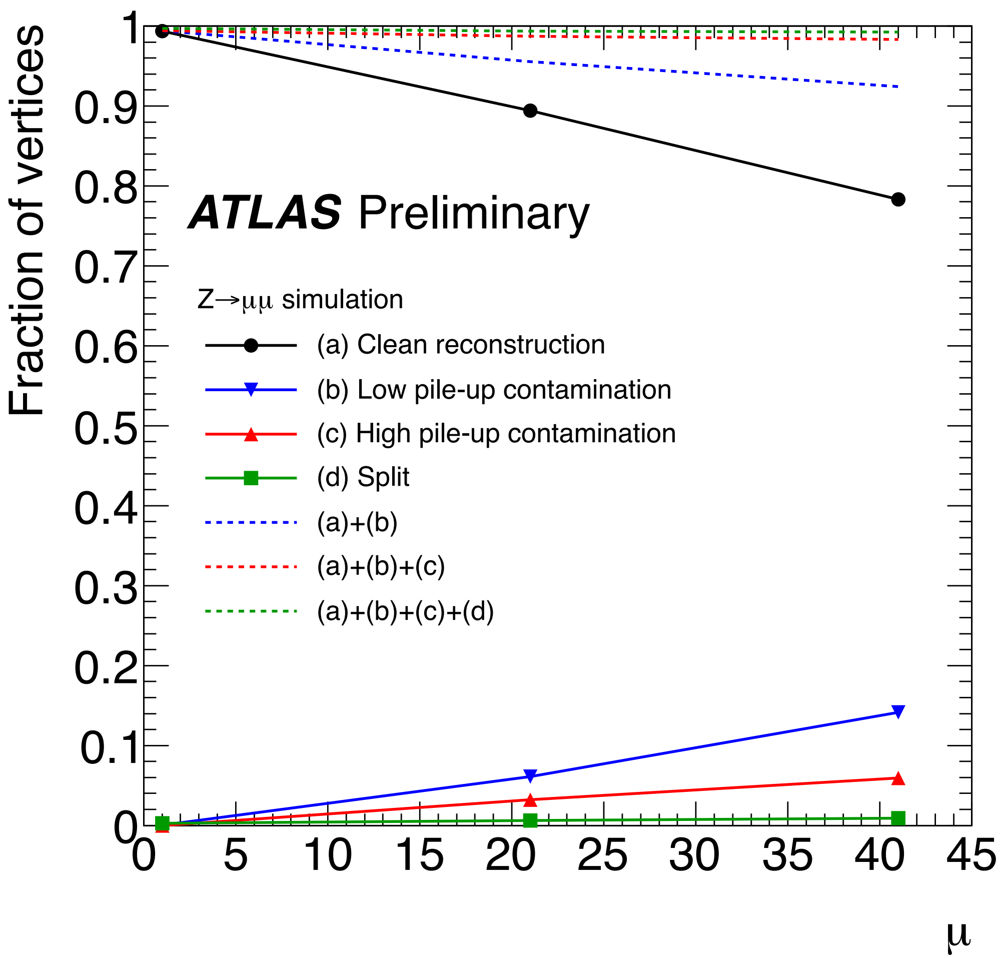
Dependence on pile-up



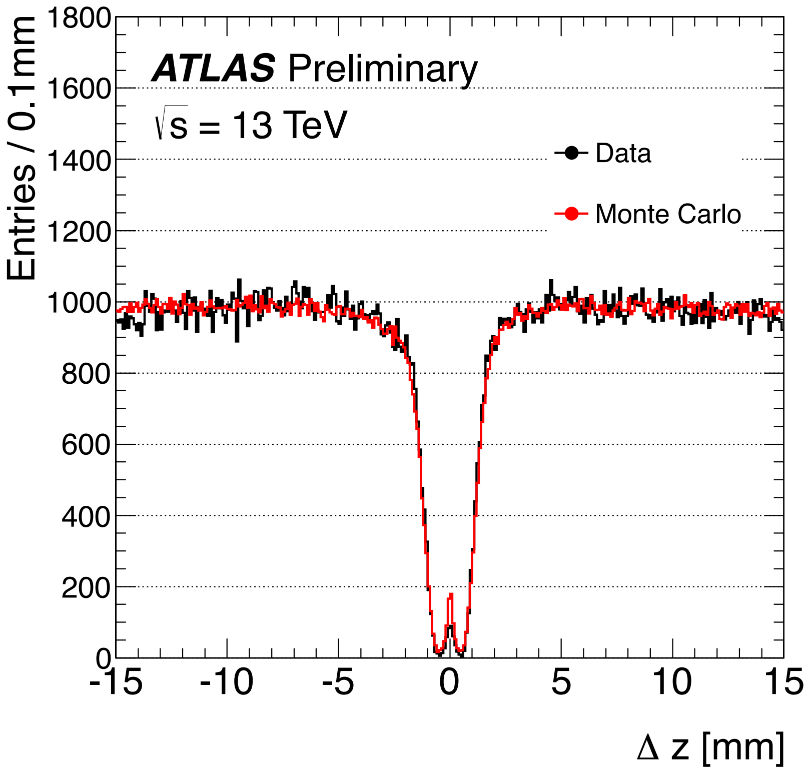
The current algorithm is optimised to **minimise** the occurrence of **split vertices**.

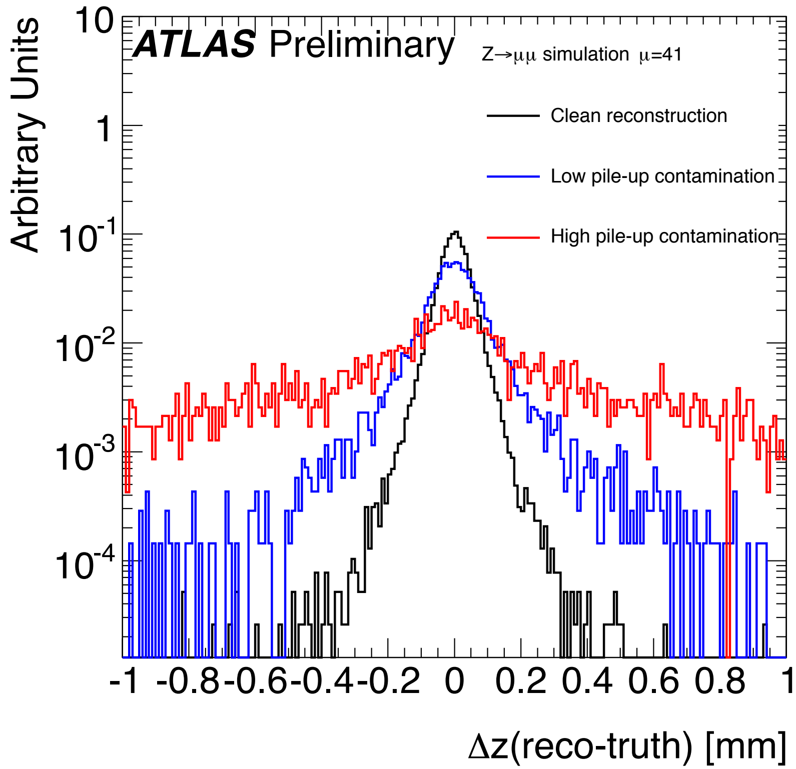
However, as the amount of **pile-up increases**, **merging** of tracks from two close-by interactions into a single reconstructed vertex **becomes more common.**

Vertex merging

Vertices within about 3 mm of each other along the z (beam) axis **are generally merged**.

- This can significantly degrade the resolution on the vertex position.

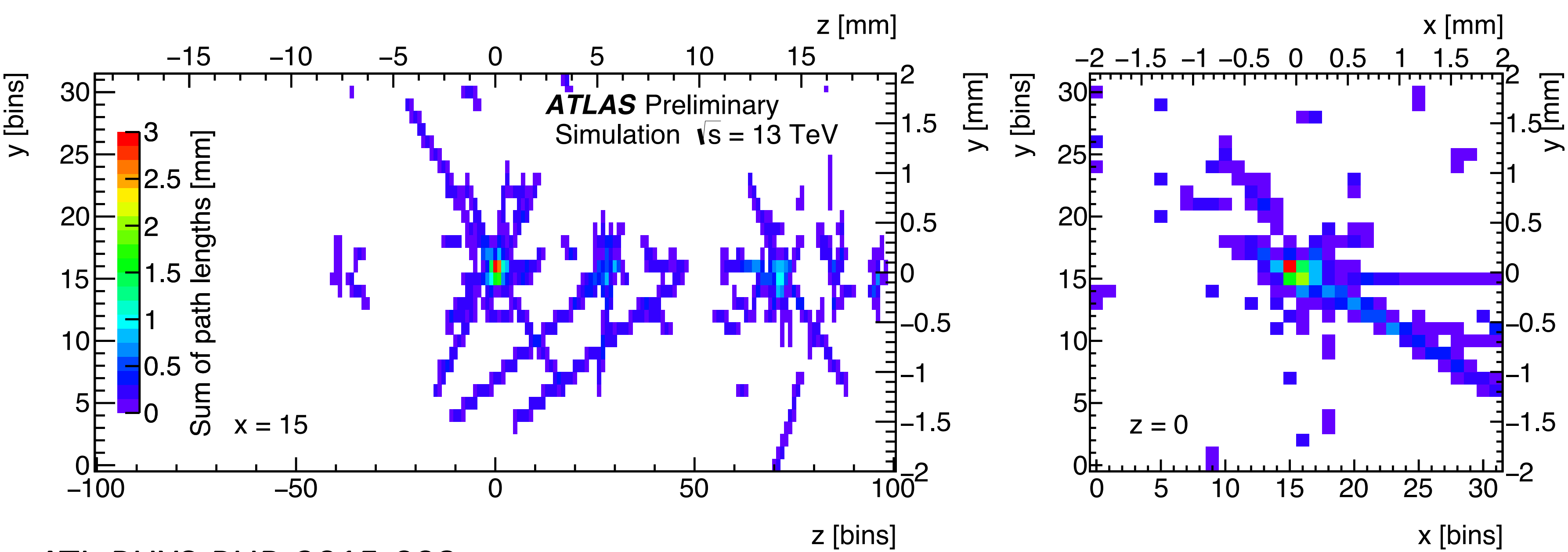




Imaging seeding: algorithm

We hope to improve this behavior in Run II with a **new seed finding method based on techniques used in medical imaging**.

- In this method, we take all tracks which pass a good track selection and use them to fill a 3D spatial histogram centered around the beam axis



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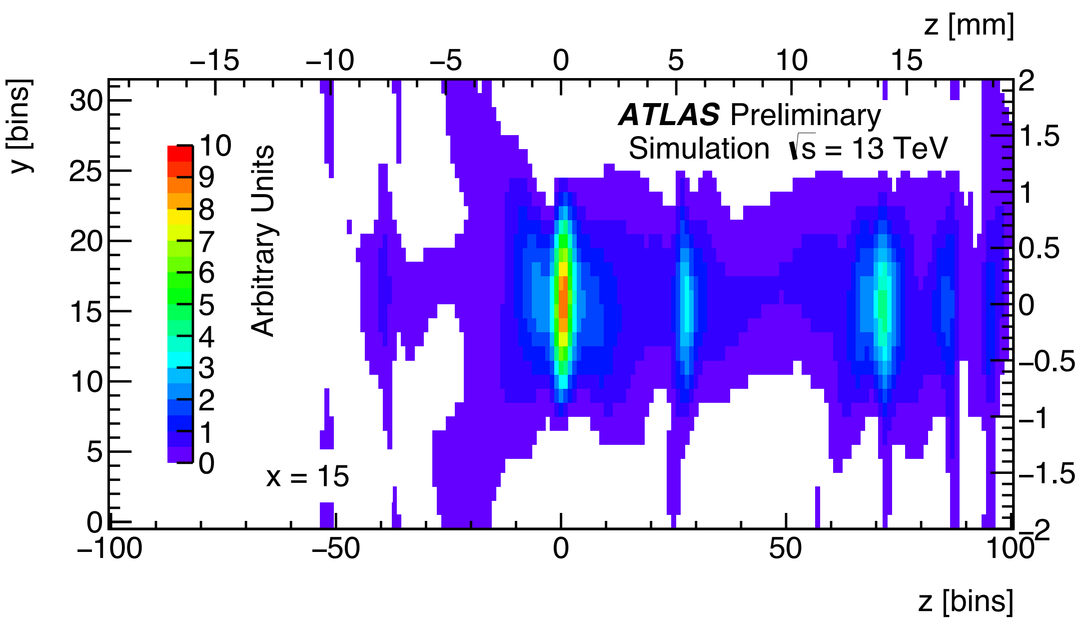
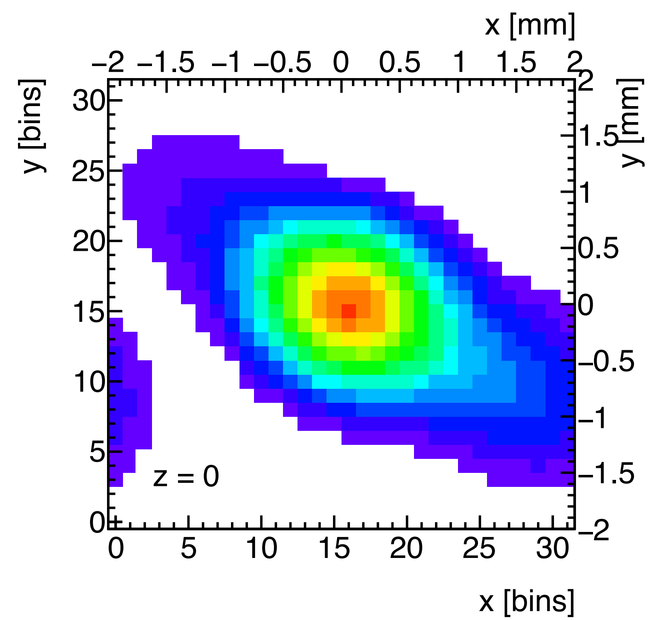
Imaging seeding: algorithm

- This histogram is sent through a FFT algorithm, a frequency filter is applied, then the FFT is reversed.
- This histogram is collapsed onto the z axis, with bins weighted by distance from the axis, and local maxima are taken as vertex seeds.





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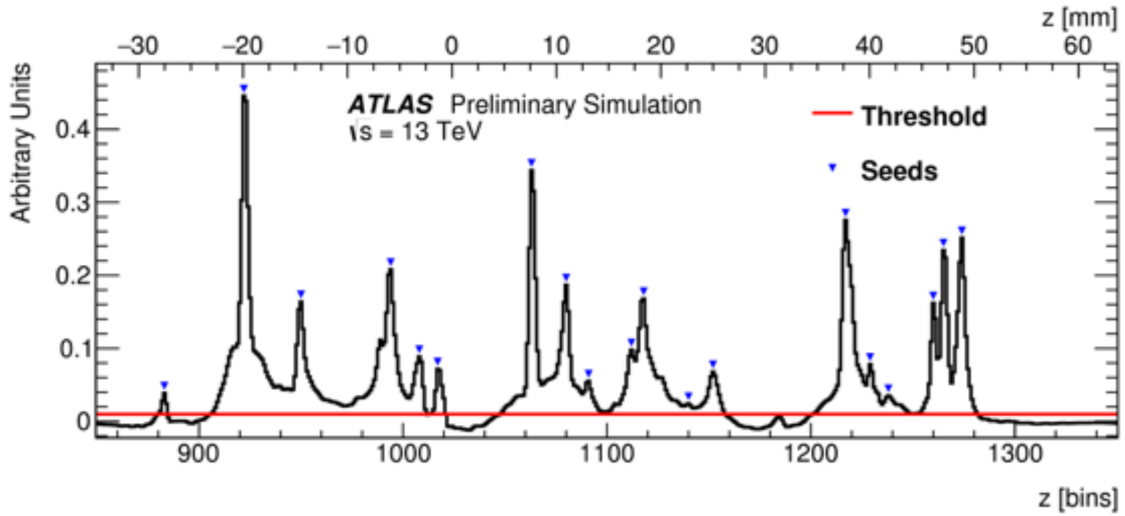
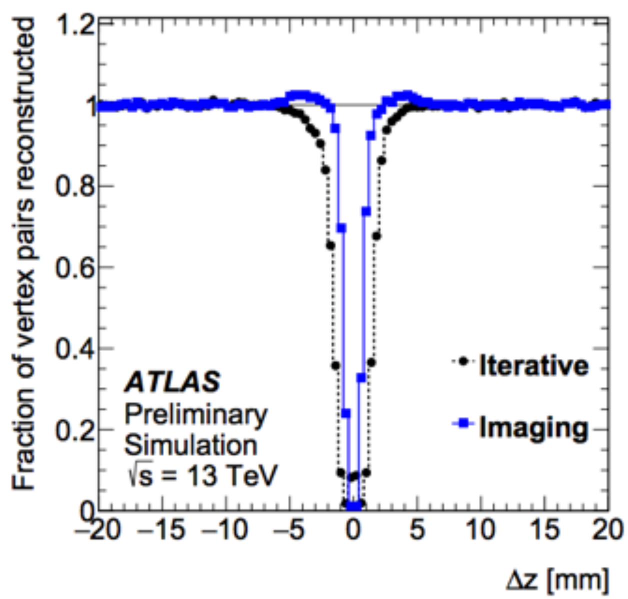
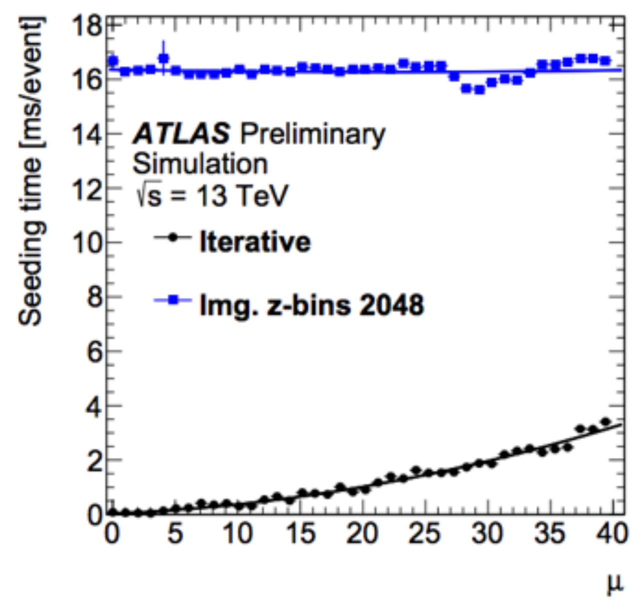
Imaging algorithm: results

The new seeder can produce seeds with finer spatial resolution but:

- more **splits**
- computationally more expensive







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Vertex merging parameterisation

An analytical parameterisation of the average number of reconstructed vertices $\langle n_{Vx} \rangle$ as a function of the number of interactions has been derived.

$$\langle n_{Vx} \rangle = p_0 + \varepsilon \cdot \mu - F\left(\varepsilon \cdot \mu, p_{mask}\right)$$

- $\mathbf{p_0}$ = beam halo and cavern backgrounds
- **ε** = vertex reconstruction efficiency
- $\mathbf{p_{mask}}$ = vertex merging probability

F($\boldsymbol{\varepsilon\mu}$**,** $\mathbf{p_{mask}}$**)** parameterises the vertex merging, taking into account:

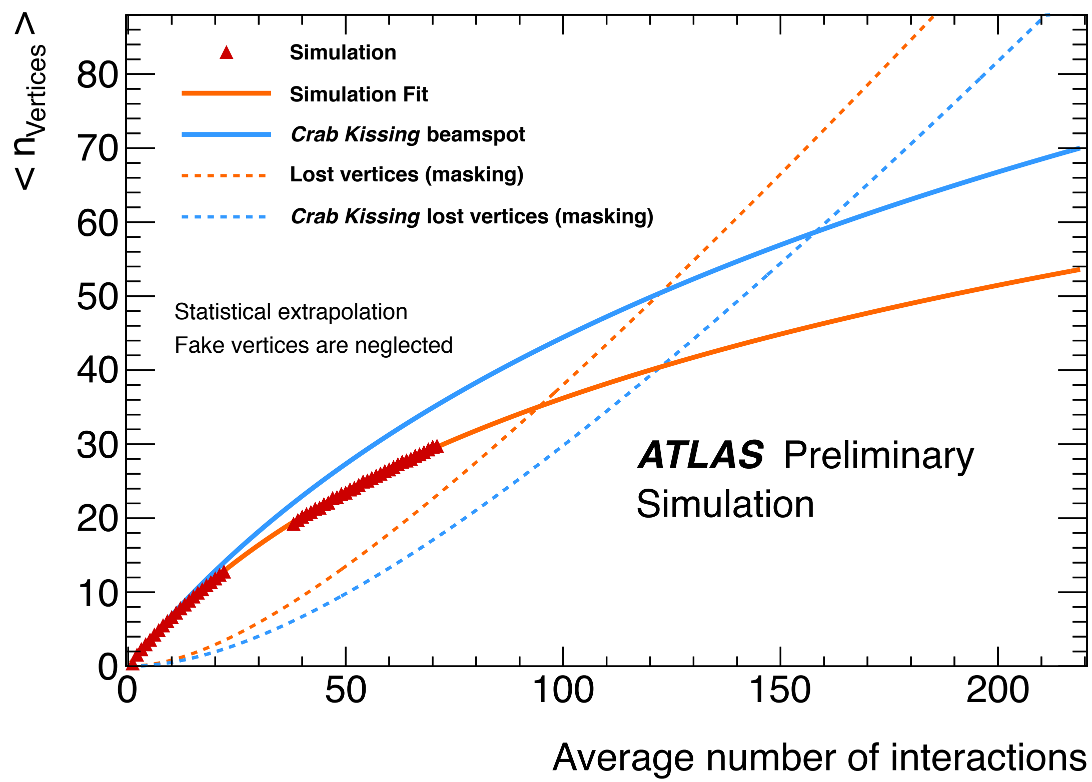
- the poissonian distribution of the number of reconstructed vertices
- the probability of two to multiple vertex merging

p_{mask} can be independently computed from data

Extrapolation to different scenarios: the HL-LHC

The parameterisation allows to evaluate the expected performance in different:

- Environments (beam profiles)
- Detectors (ATLAS ITK)
- Tracking selections
- Vertex reconstruction algorithms



Conclusions

The ATLAS vertex reconstruction has been performing robustly during the LHC run 2.

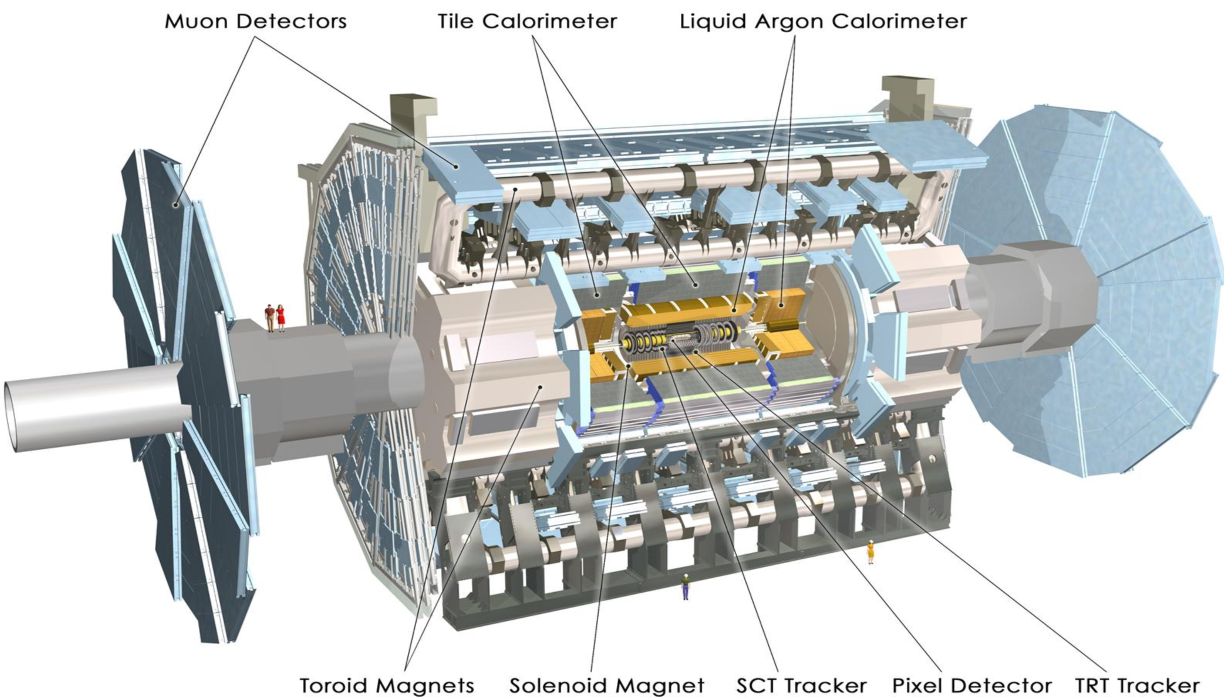
- High reconstruction efficiency
- Data and simulation in good agreement

ATLAS is now focusing on improving these performances and preparing for even higher luminosities.

THANKS FOR YOUR ATTENTION!

BACKUP

A Toroidal Lhc ApparatuS



ATLAS is a multi-purpose detector composed by:

- **Inner Detector**
  - Track reconstruction for charged particles
  - Primary and secondary vertex reconstruction
- **Calorimeters**
  - Measurement of electron, γ and jet energies
  - Hermeticity for E_T^{miss} reconstruction
- **Muon spectrometer**
  - Muon identification and reconstruction

The split vertex method

- The tracks used in the vertex fit are assumed to originate from a single interaction.
- This set of tracks can then be split into two groups of approximately the same Σp_T and two independent vertices can be reconstructed. No beam-spot constraint is used during the vertex fit.
- The separation between the two daughter vertices gives an estimate for their combined intrinsic resolution. The scale factor is then the standard deviation of a Gaussian fit to the pull distribution given by normalizing this separation to the respective error:

$$\mathrm{Pull}_x = \frac{x_{1,PV} - x_{2,PV}}{\sqrt{\sigma^2_{x_1,\mathrm{fit}} + \sigma^2_{x_2,\mathrm{fit}}}},$$

Beamspot reconstruction

The beam-spot reconstruction is based on an unbinned maximum likelihood fit to the spatial distribution of primary vertices collected from many events.

- These primary vertices are reconstructed without beam-spot constraint from a representative subset of the data during the detector calibration
- In each event only the primary vertex with the highest sum of squares of transverse momenta of contributing tracks
- In order to be used in the beam-spot fit, this vertex must include at least 5 tracks and must have a probability of the χ^2 of the vertex fit greater than 0.1%.
- The requirement of at least 5 tracks ensures that most vertices have a transverse vertex resolution better than 50 μm with a most probable value of about 15 μm that is comparable to the transverse beam-spot size.
- At least 100 selected vertices are required to perform a beam-spot fit
- The fit extracts the centroid position of the beam spot