ATLAS Tracking and Vertexing Performance

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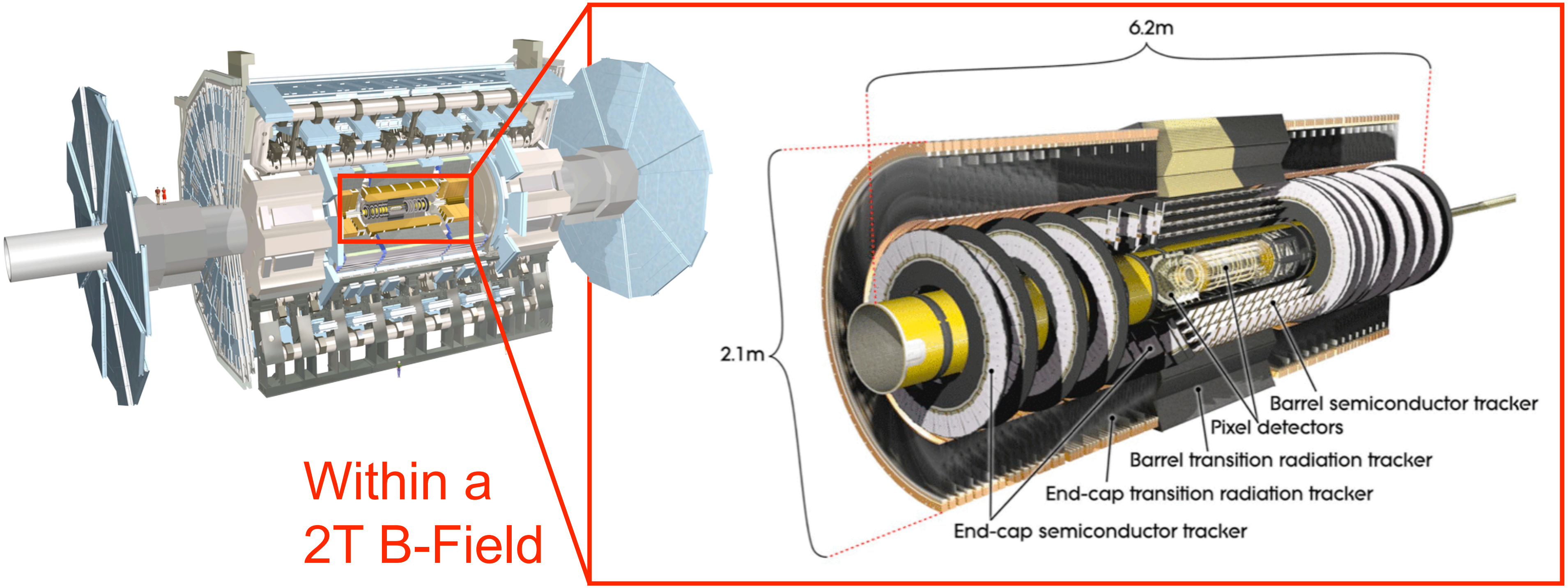
ATLAS EXPERIMENT
http://atlas.ch

The ATLAS Inner Detector



Within a
2T B-Field

	Pixel	**SCT**	**TRT**
Technology	Silicon pixels	Silicon strips	Drift tubes
Resolution	10μm ($R\phi$), 115μm (Z)	17μm ($R\phi$), 580μm (Z)	130μm ($R\phi$)
Number of Layers	3 Barrel, 2x3 Endcap	4 Barrel, 2x9 Endcap	3 Barrel, 2x40 Endcap
Number of Modules	1744	4088	176

Expected Performance

- Table below gives expected resolutions from simulation.
- Multiple scattering means that track parameter resolutions are dependent on p_T.

$$\sigma_X(p_T) = \sigma_X(\infty)(1 \oplus p_X/p_T)$$

Intrinsic resolution

Value of p_T where intrinsic~MS

Barrel Slice

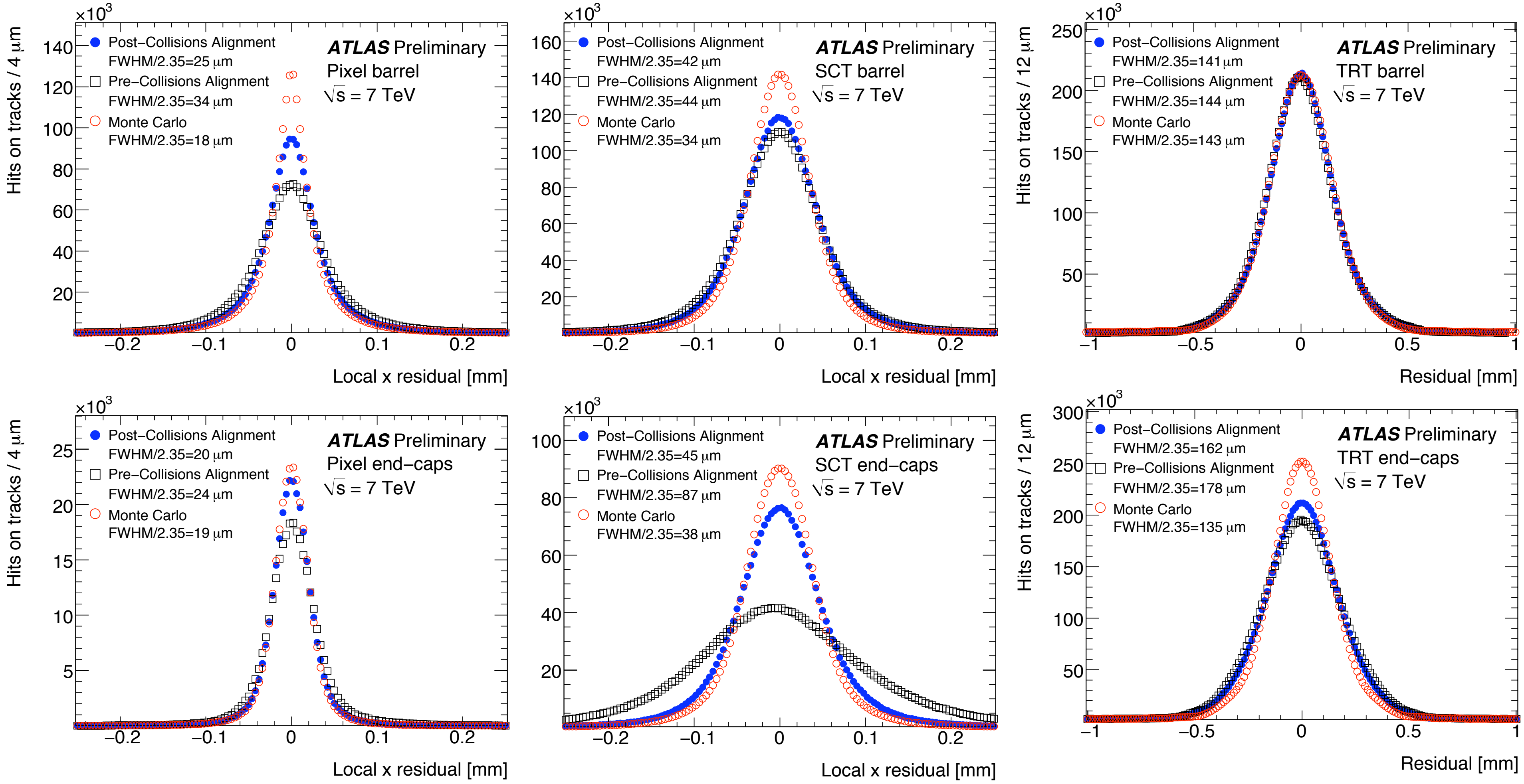
Endcap Slice

Track parameter	$0.25 < \|\eta\| < 0.50$		$1.50 < \|\eta\| < 1.75$	
	$\sigma_X(\infty)$	p_X (GeV)	$\sigma_X(\infty)$	p_X (GeV)
Inverse transverse momentum (q/p_T)	0.34 TeV^{-1}	44	0.41 TeV^{-1}	80
Azimuthal angle (ϕ)	70 μrad	39	92 μrad	49
Polar angle ($\cot\theta$)	0.7×10^{-3}	5.0	1.2×10^{-3}	10
Transverse impact parameter (d_0)	10 μm	14	12 μm	20
Longitudinal impact parameter ($z_0 \times \sin\theta$)	91 μm	2.3	71 μm	3.7

- How do we achieve this performance?
  - At high p_T:
    - ID Alignment: Determining the position/orientation of the ID modules.
    - Understanding the b-field mapping of the detector (already mapped to very high ~0.4 mT precision)
  - At low p_T:
    - Understanding the material distribution.

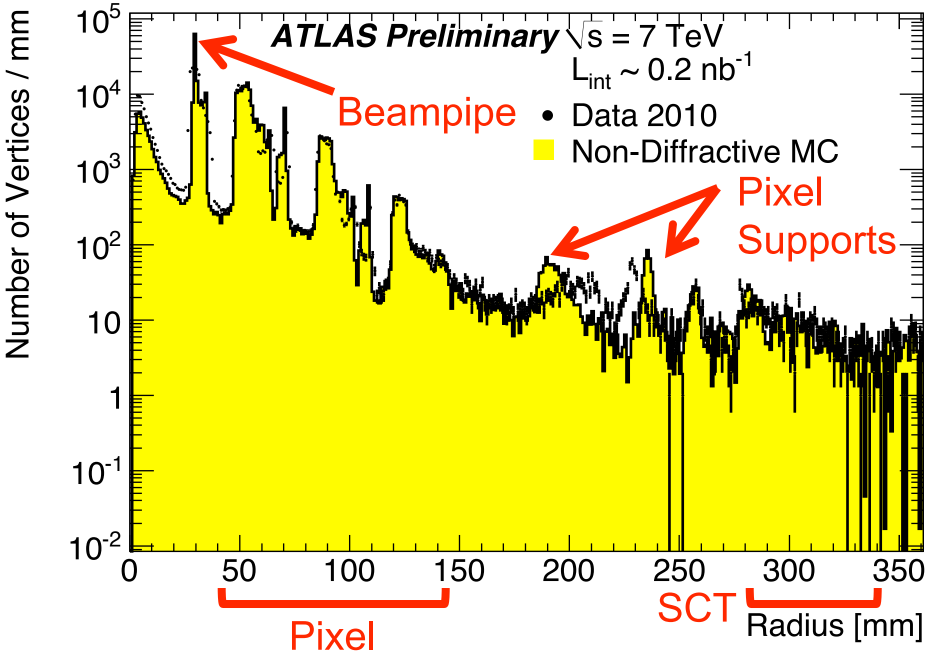
ID Alignment

- Alignment is crucial for resolutions (at high p_T) and momentum scale:
  - Require alignment to ~10μm precision in measurement plane.
- Alignment has been substantially improved using 900 GeV collisions data!
- Estimated residual misalignments ~17μm (Pixel barrel) ~25μm (SCT barrel).

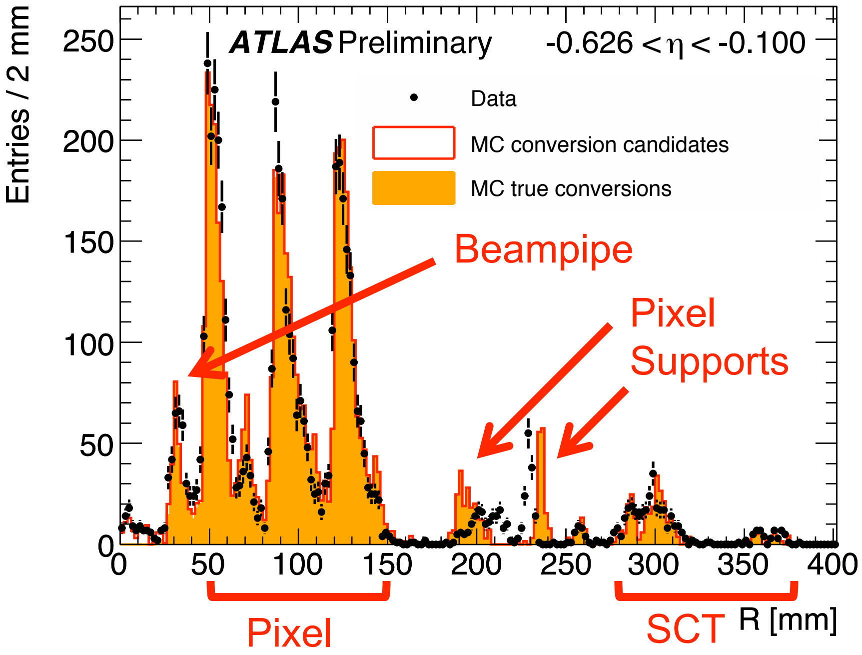


Material Description

- Understanding the ID material distribution is crucial for low p_T tracking:
  - To understand the contribution of multiple scattering (resolutions).
  - To correctly compensate for ionisation losses in the track fit (p_T scale).



Data-MC comparison of rate of secondary hadronic interaction vertices as a function of radius in barrel.



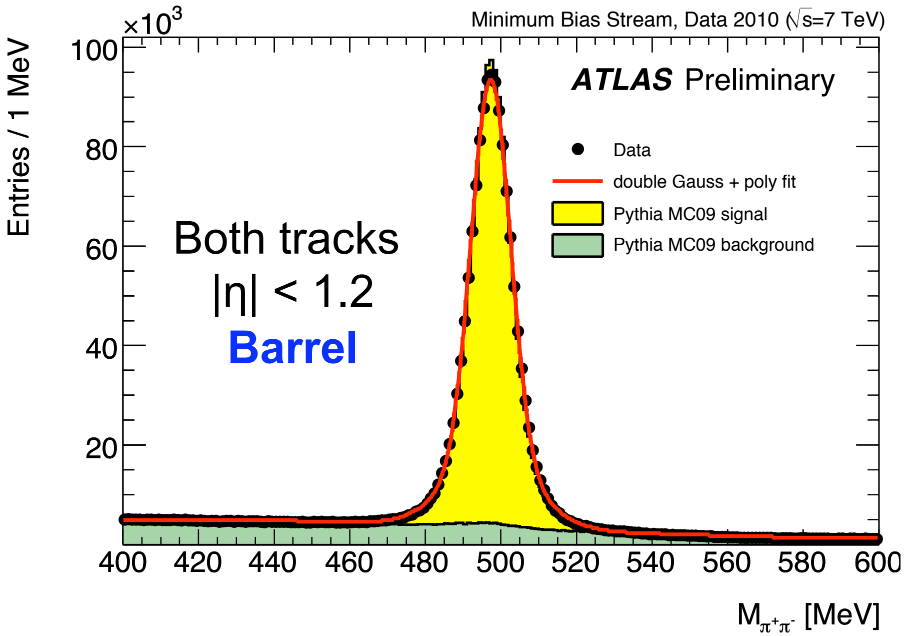
Data-MC comparison of rate of photon conversions in barrel as a function of radius in the barrel.

Direct probes of material map show that it is generally very good – discrepancy in Pixel support structure already understood.

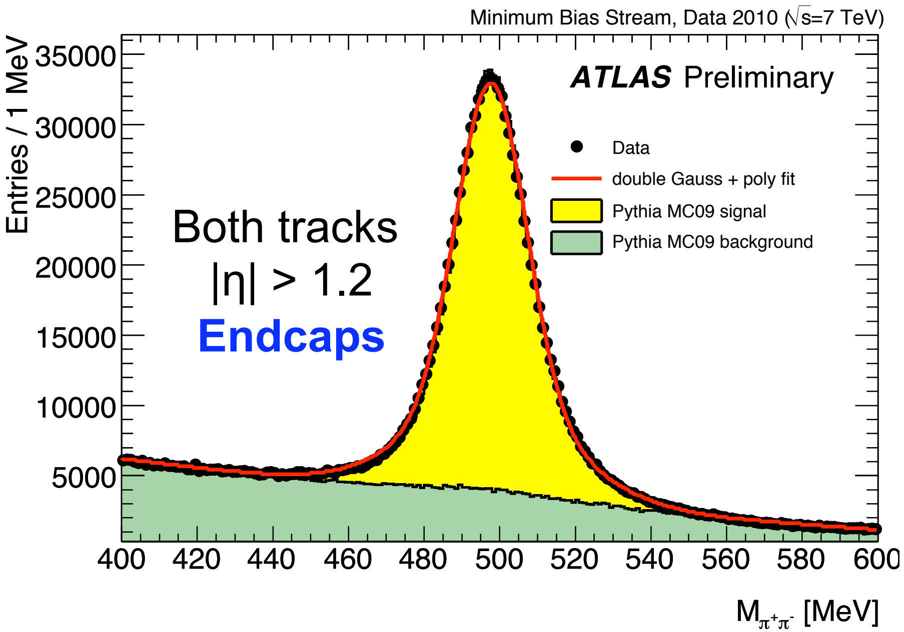
$K^0_s \rightarrow \pi^+\pi^-$ Reconstruction

- K_s reconstruction probes quality of low p_T track reconstruction (< 1 GeV):
  - Mainly sensitive to material description
- Fitted mass and width compatible with MC simulation (and PDG mass):
  - Validation of track momentum scale at low p_T

PDG mass = 497.614 ± 0.024 MeV



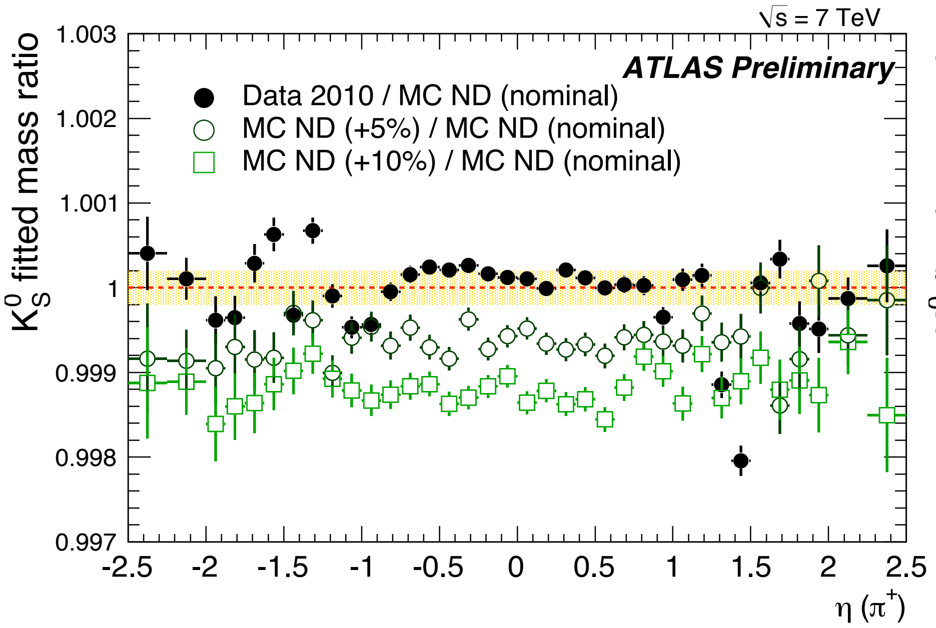
	μ (MeV)	σ (MeV)
Data	497.427±0.006 (stat.)	5.60
MC	497.329±0.006 (stat.)	5.42

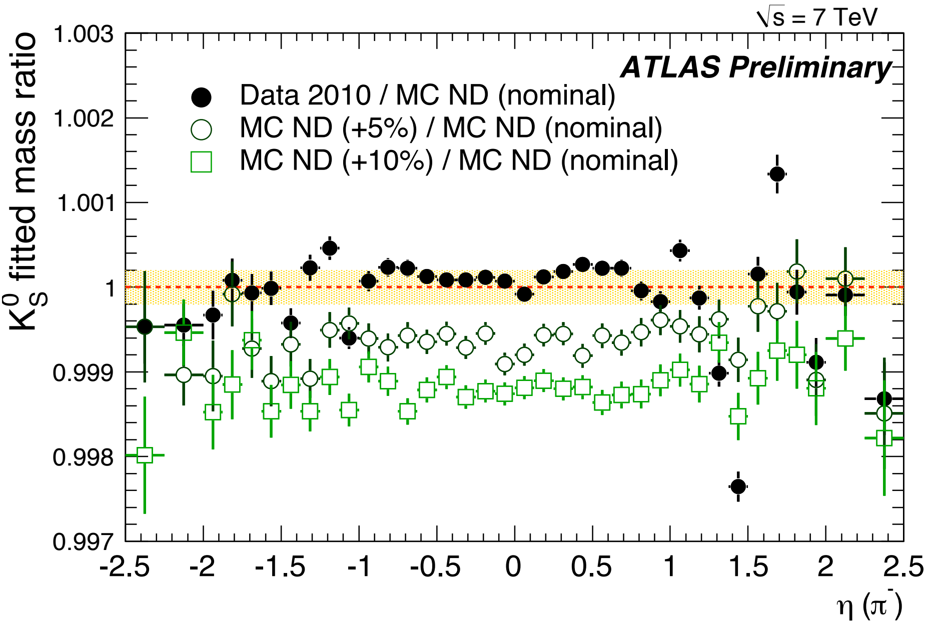


	μ (MeV)	σ (MeV)
Data	497.797±0.016 (stat.)	10.45
MC	497.868±0.016 (stat.)	10.14

Probing Material Map with K^0_S

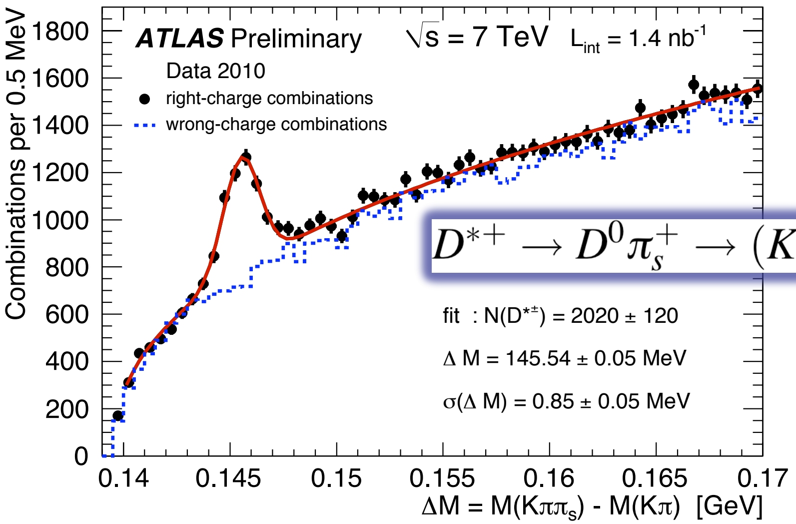
- Incorrect material budget will bias track momenta and hence $K_S \rightarrow \pi^+\pi^-$ reconstructed mass.
- Compare reconstructed K_S mass over a large rapidity range with special MC minbias simulation samples with additional material.
- No evidence for additional material in the barrel.
- Evidence for ~10% material uncertainty in endcaps.



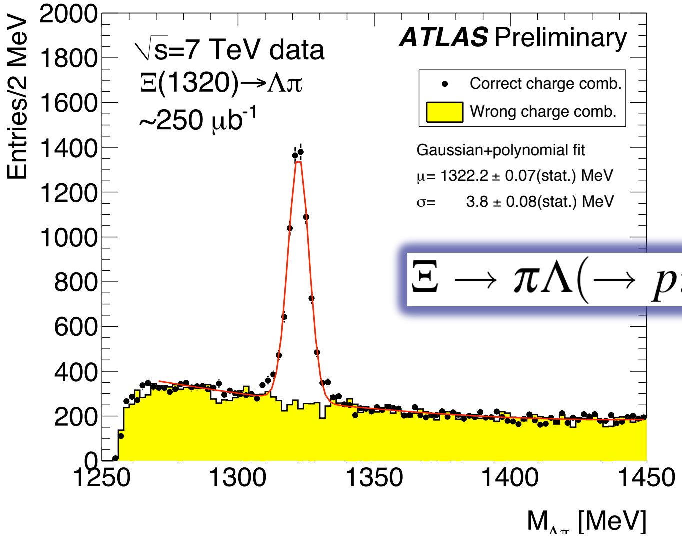


Reconstruction of Cascade Decays

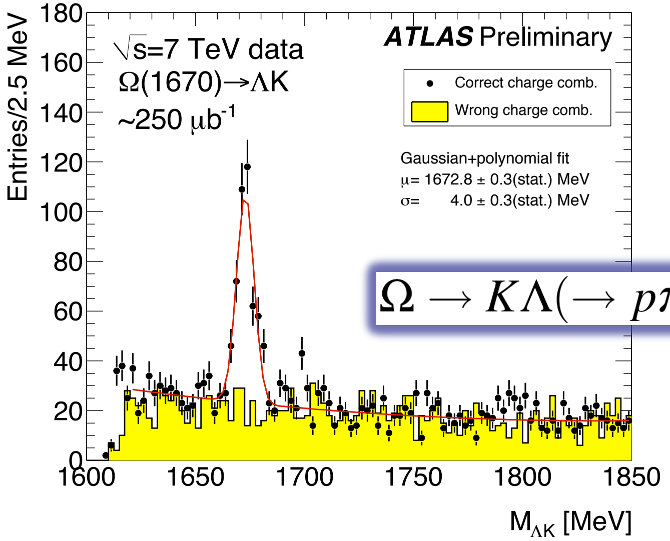
- All measured resonance masses in agreement with PDG values.
- All measured resonance widths in agreement with simulation expectations.



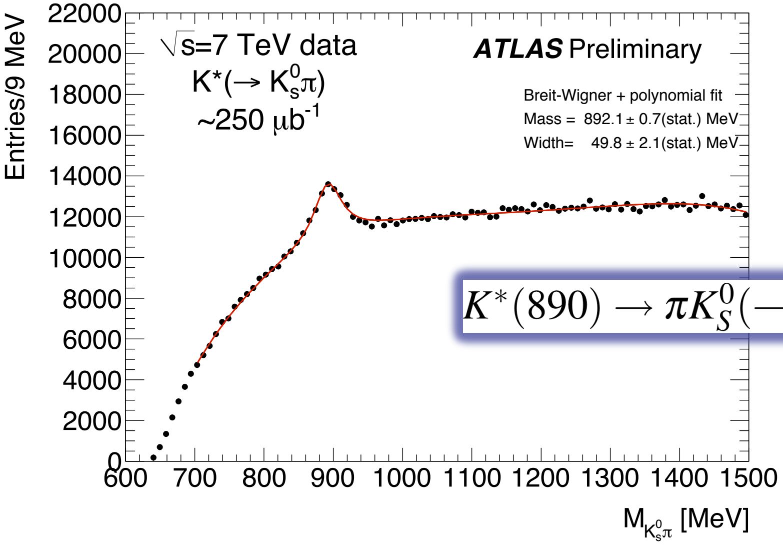
$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$



$\Xi \to \pi\Lambda(\to p\pi)$



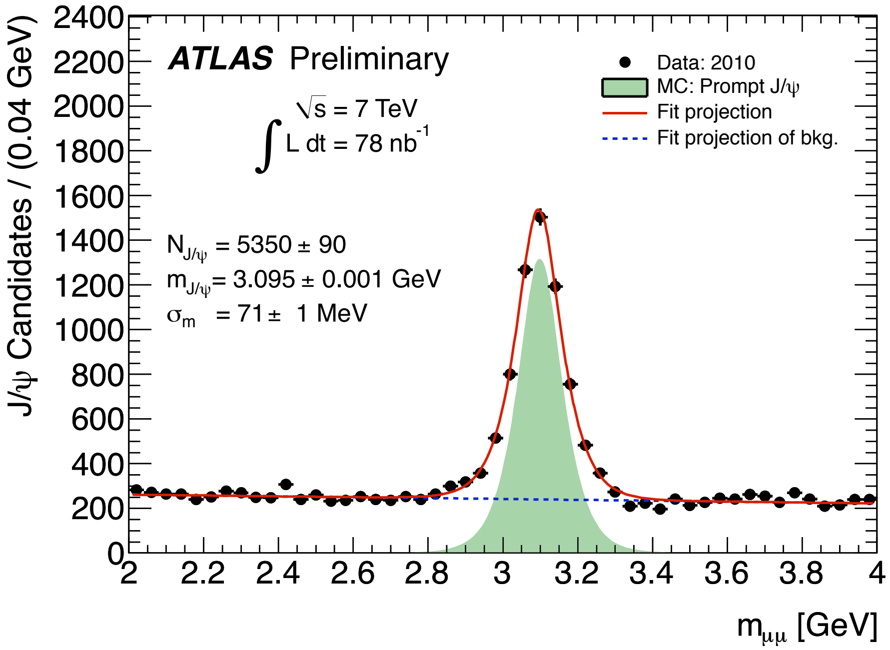
$\Omega \to K\Lambda(\to p\pi)$

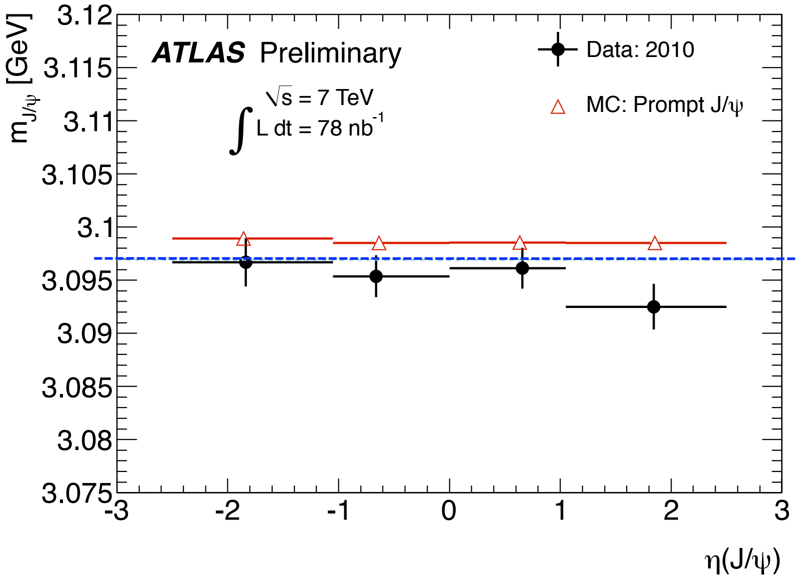


$K^*(890) \to \pi K_S^0(\to \pi\pi)$

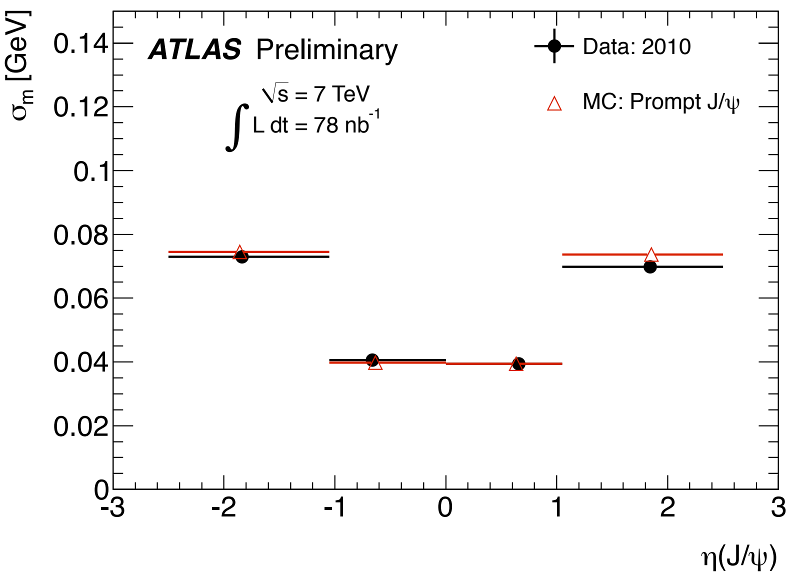
J/ψ→μμ Reconstruction

- Muons identified from combined ID and muon spectrometer track, but $m_{\mu\mu}$ formed from ID-tracks only.
- No deviation larger than 0.2 ± 0.1% in mean of reconstructed mass vs PDG.
  - Validation of momentum scale for average muon p_T ~ 4 GeV.
- Across all rapidity ranges width of signal peak in agreement with MC simulation.

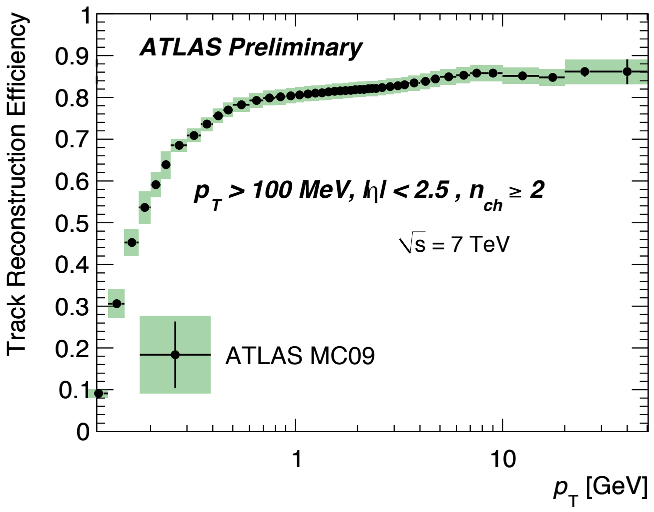


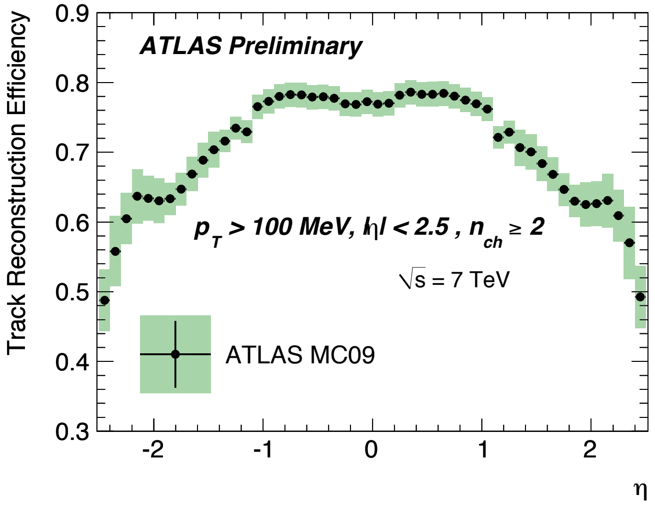


PDG value

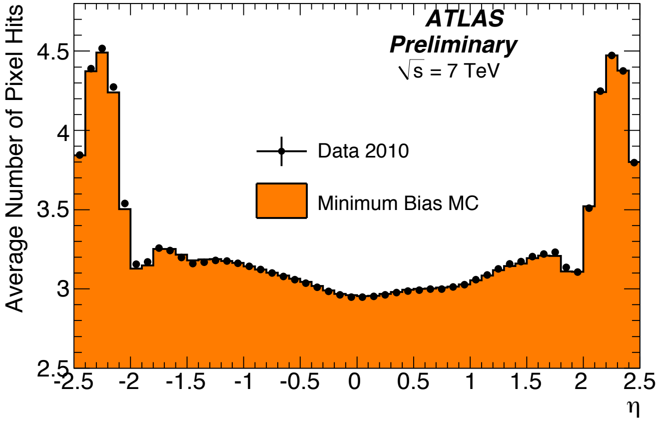


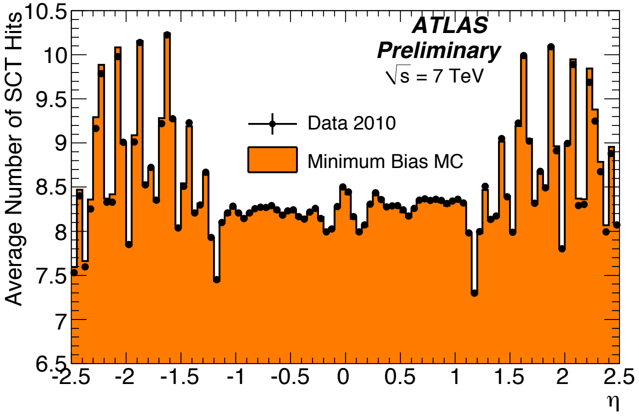
Tracking Efficiencies





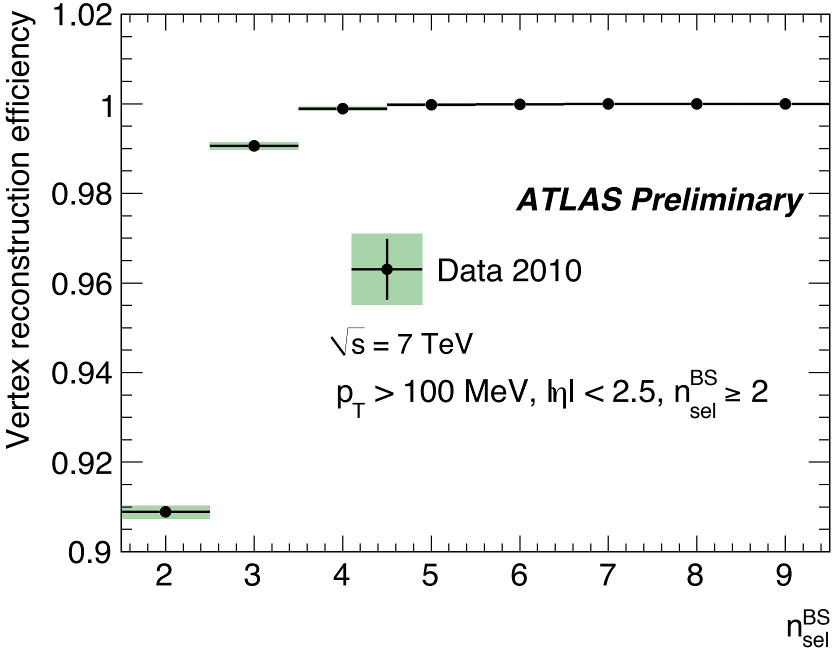
- Tracking efficiencies are thus far determined from MC simulation.
- Main systematic is from uncertainty in material budget.
- We can do this since (after much work) the simulation models the tracks seen in data extremely well:





Primary Vertex Reconstruction

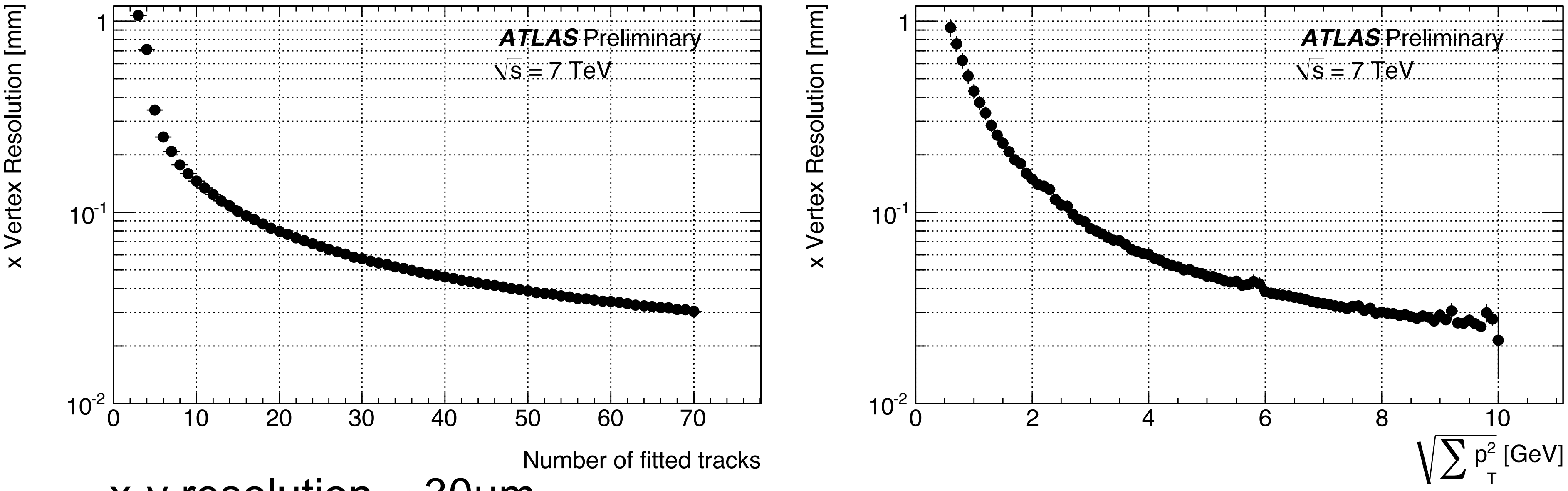
- Iterative vertex finding algorithm:
  - Uses all tracks not significantly different from beamspot with p_T > 100 MeV and minimum number of hits in silicon detectors.
  - Fits these to a single vertex, with progressive downweighting of outlier tracks.
  - Tracks incompatible with vertex are used to seed a new one.
  - Repeats until no tracks left or no new seed created.
- In case of multiple vertices – primary vertex chosen as that with highest $\sum p_{\mathrm{T}}^2$



- Primary vertex reconstruction efficiency as a function of number of tracks.
- Turn on due to looser definition of tracks in the analysis.
- Vertex efficiency is 100% provided there are enough tracks of reasonable quality.

Primary Vertex Resolution

- Data-driven single-vertex resolution determination:
  - Split single vertices randomly into two and refit independently.
  - Width of the resultant vertex separation distribution gives intrinsic resolution.
- Resolution dependent on number and p_T of tracks used to fit vertex:
  - Can look significantly better for high p_T analyses.



x-y resolution ~ 30µm

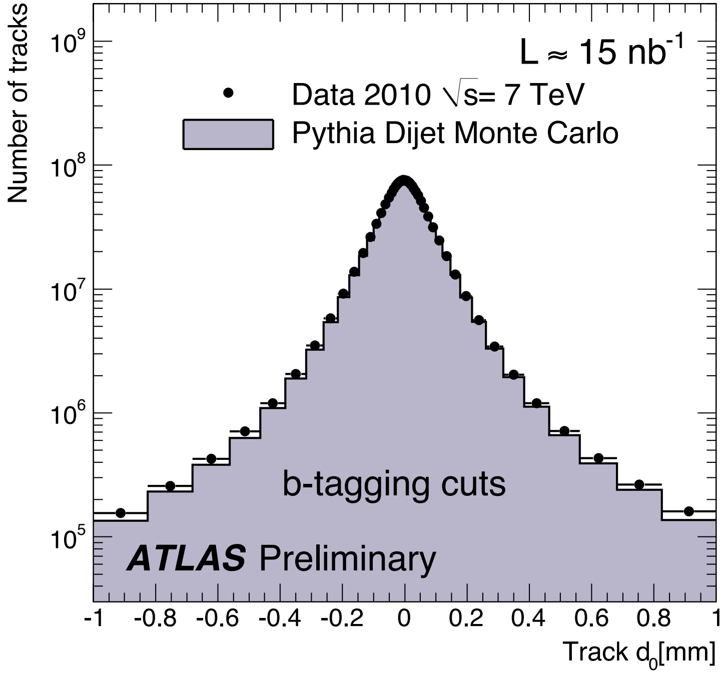
z resolution ~ 50µm for N_{trks} = 70

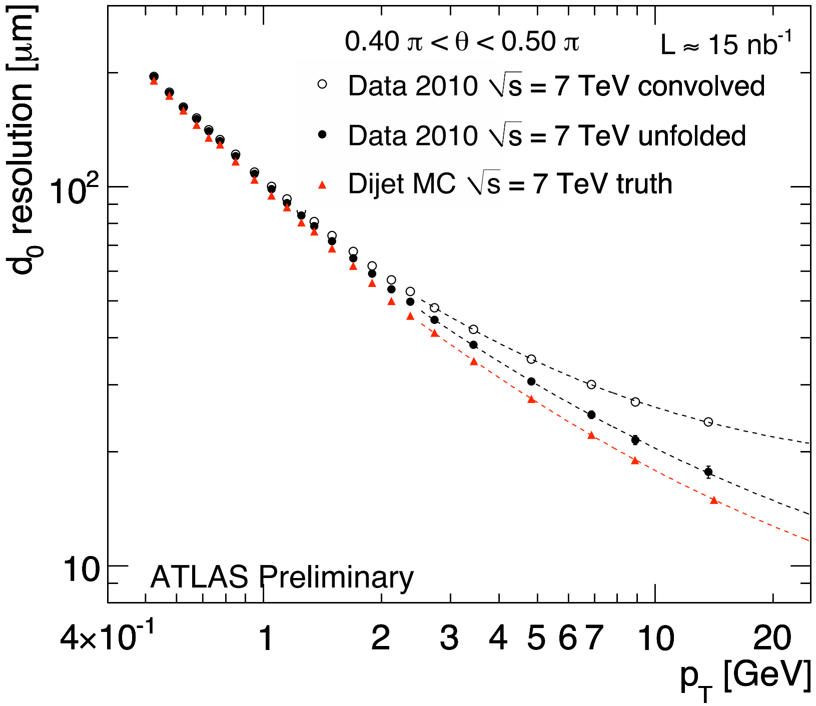
Impact Parameter Resolution

- B-tagging relies on successful identification of tracks/vertices displaced from the primary interaction:
  - Understanding of transverse impact parameter (d_0) resolution is crucial.

Width of d_0 distribution is a convolution of d_0 resolution $\sigma_{d0,trk}$ and primary vtx resolution $\sigma_{d0,PV}$:

$$R_{\text{meas}}(d_0) = \int \exp\left[-\frac{1}{2}\frac{d_0^2}{\sigma^2_{d_0,\text{trk}} + \sigma^2_{d_0,\text{PV}}}\right] P\left(\sigma_{d_0,\text{PV}}\right) \mathrm{d}\sigma_{d_0,\text{PV}}$$





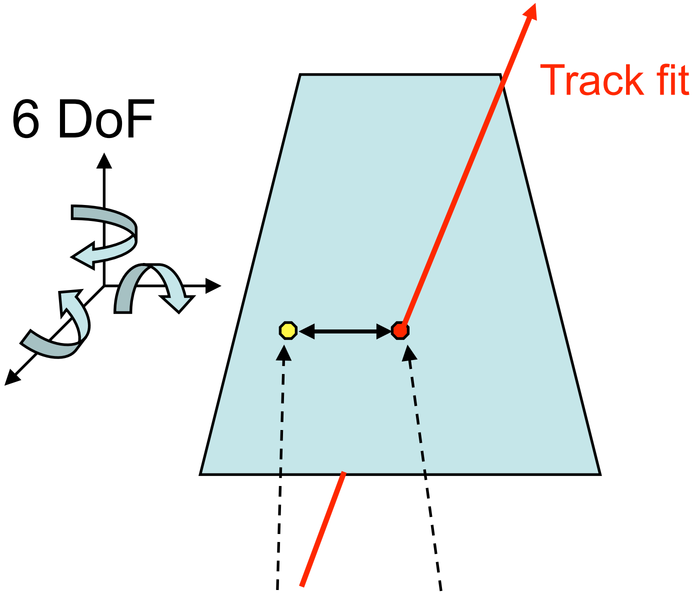
- Iterative procedure is applied to deconvolve $\sigma_{d0,trk}$ from $\sigma_{d0,PV}$.
- Good agreement with MC at low p_T
- Deviations at high p_T potentially due to residual misalignment

Summary & Conclusions

- Detailed comparisons between track reconstruction in data and simulation demonstrate that tracking at ATLAS is already very well understood.
- “Successful” reconstruction of low mass resonances demonstrates the accuracy of the momentum determination at low p_T
  - The material description is already very good and can be improved further.
  - Work ongoing to assess the reconstruction of higher mass resonances such as Z bosons (more sensitive to alignment and B-field mapping).
- Primary vertex reconstruction is working well and data-driven methods can be used to determine the vertex resolution and efficiency.
- Data-driven determination of impact parameter resolutions and comparison to simulation demonstrates that this is also generally well understood – rapid commissioning of b-taggers should be possible.

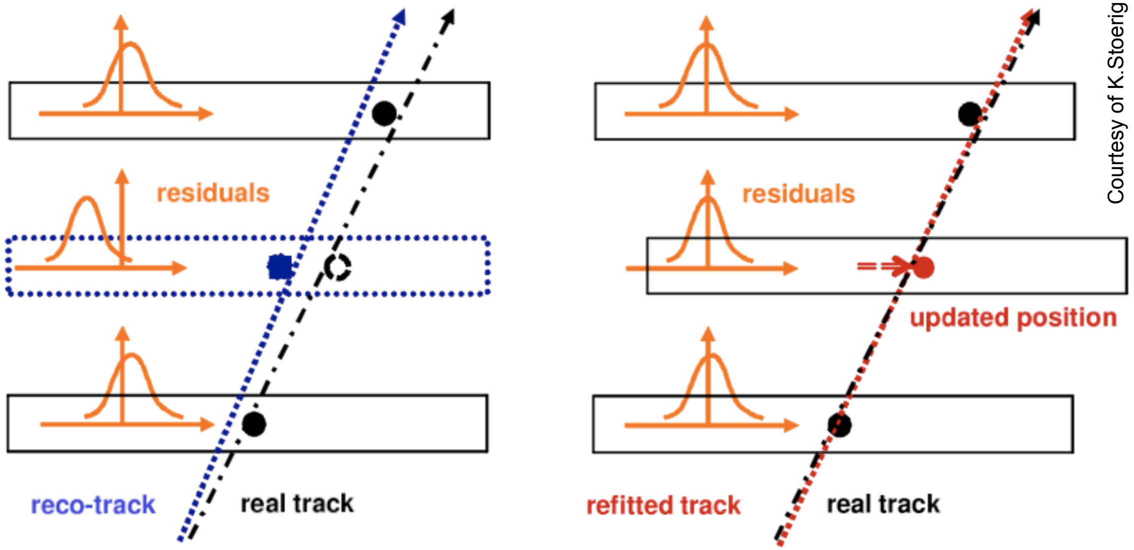
Backup Slides

Track-Based Alignment Algorithms



$$\vec{r}_i \equiv \vec{m}_i - \vec{e}_i(\pi, a)$$

$$\boxed{\chi^2 = \sum_{tracks} r^T V^{-1} r}$$



Courtesy of K.Stoerig

- Use module residual distributions to determine alignment constants a.
- **Global χ^2 Algorithm** (Pixel & SCT):
  - full minimisation of χ^2 w.r.t track parameters π and a.
  - Requires 6N x 6N matrix inversion (N=5832)! Numerically challenging!
  - Iterative procedure needed.
  - Baseline algorithm for Si alignment.