Measuring Luminosity at the ATLAS Experiment

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Measuring Luminosity at ATLAS

Overview:

- Proton Proton Collisions at ATLAS
- Luminosity Measurement
- Counting Vertices with ATLAS Monte Carlo Simulated Data
- Corresponding Efficiencies and Fake Rates
- First Results with Real ATLAS data

ATLAS Monte Carlo simulated data:

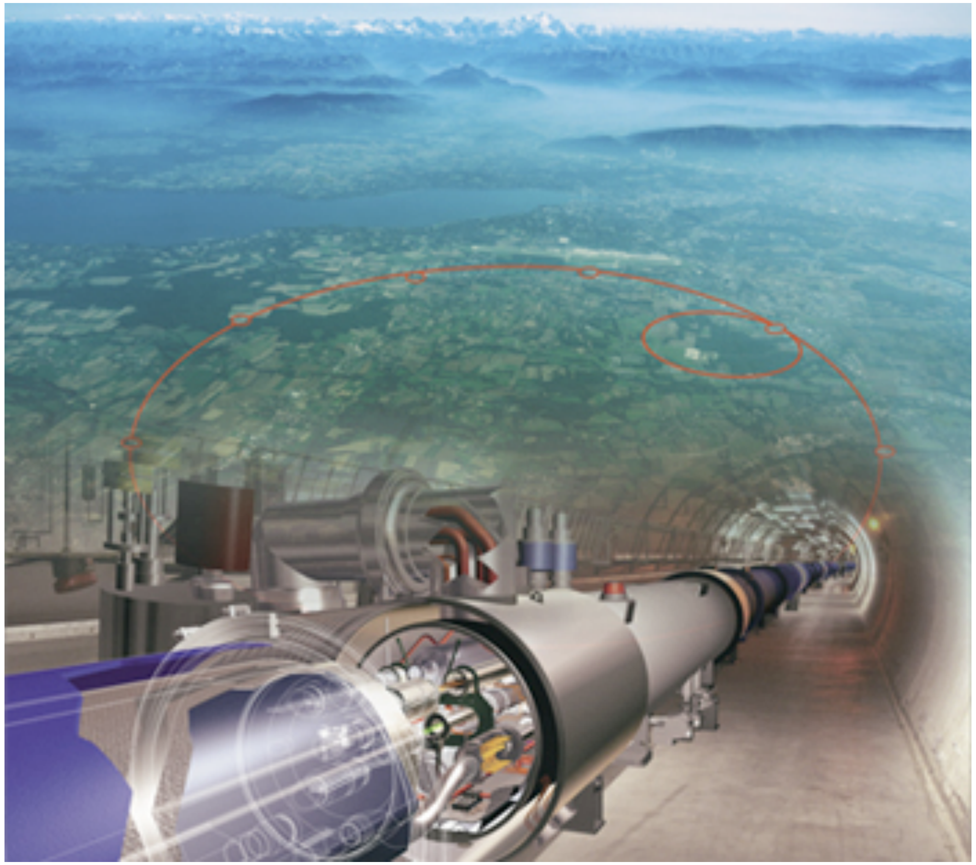
ttbar signal plus pile up data sample with $\lambda_{sim} = 7.88$

$E_{com} = 10$ TeV $L = 10^{33}$ cm^{-2} s^{-1} bunch crossing spacing = 75 ns

Real ATLAS Data:

900 GeV runs December 2009 $L < 10^{30}$ cm^{-2} s^{-1}

Proton Proton Collisions at ATLAS



Just outside Geneva, Switzerland

Large Hadron Collider (LHC)

- Particle accelerator 70-100m underground
- Collides proton bunches at a designed luminosity of 10^{34} cm^{-2} s^{-1} at center of mass energy of 14 TeV *
- Collides 2835 proton bunches every 25 ns at a frequency of revolution of 11.25 kHz.

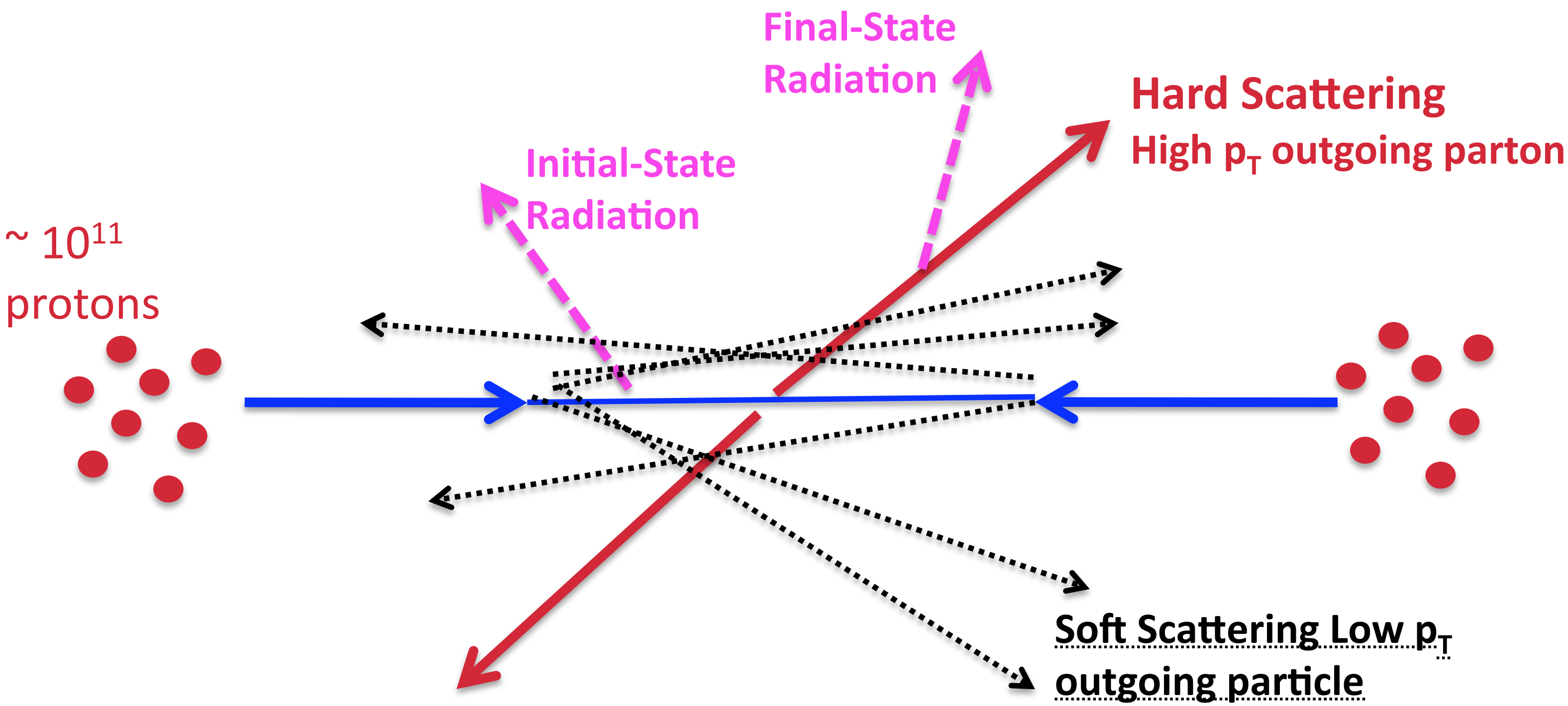
Parton Model - hadrons are made of quarks and gluons collectively called partons
The proton - 3 valance quarks (uud) gluons and a sea of quark-antiquark pairs
LHC beam – describes by structure function

$$dn_i/dp$$

n_i = number parton type, p = momentum

*Also collides lead nuclei up to 5.5 TeV per nucleon with design luminosity 10^{27} cm^{-2} s^{-1}.

Hadronic scatter



Hadronic scattering process:

- Hard subprocess
  - Two high p_T partons interact
  - Leads to initial and final state radiation (ISR/FSR)
  - High p_T particles produces
- Soft component
  - Underlying event containing processes of remaining partons – **pile-up**
  - Produces low momentum particles in final state

Measuring Luminosity at ATLAS

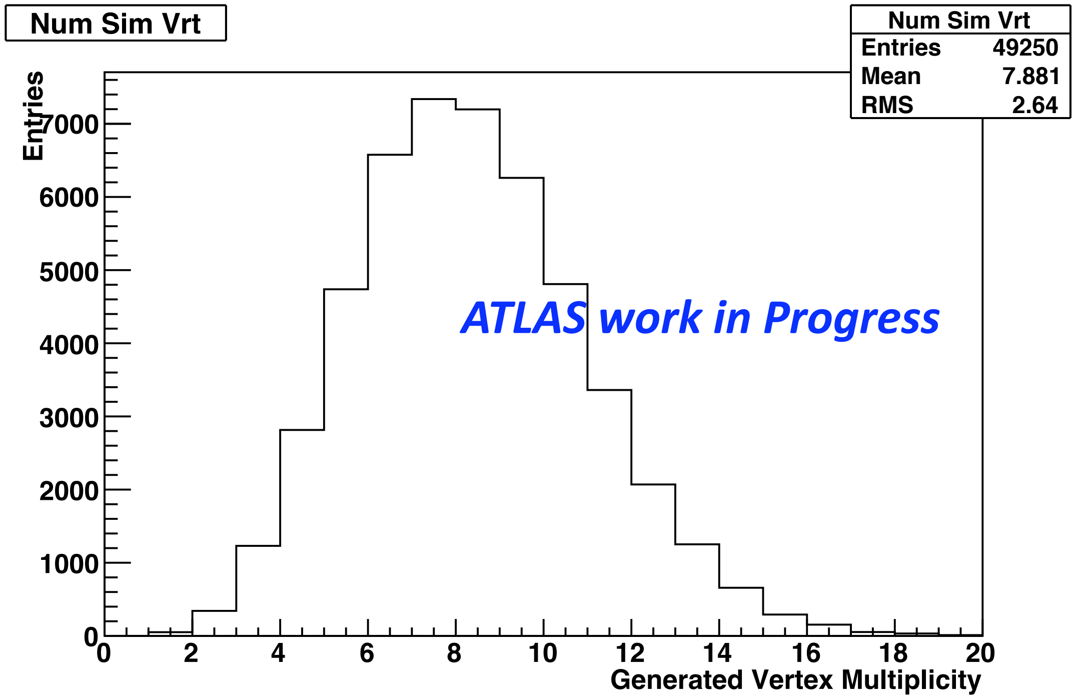
non-diffractive parton parton interactions per bunch crossing.

Luminosity	Pile up events
$L = 10^{34}\ cm^{-2}\ s^{-1}$	18
$L = 10^{33}\ cm^{-2}\ s^{-1}$	6.9
$< L = 10^{30}\ cm^{-2}\ s^{-1}$	< 1

Number of proton proton interactions per bunch crossing will vary according to Poisson Statistics with a mean λ.

$$L_b = \lambda \times \sigma_{nd}$$

$$L = L_b \times f \times n_{bunches}$$

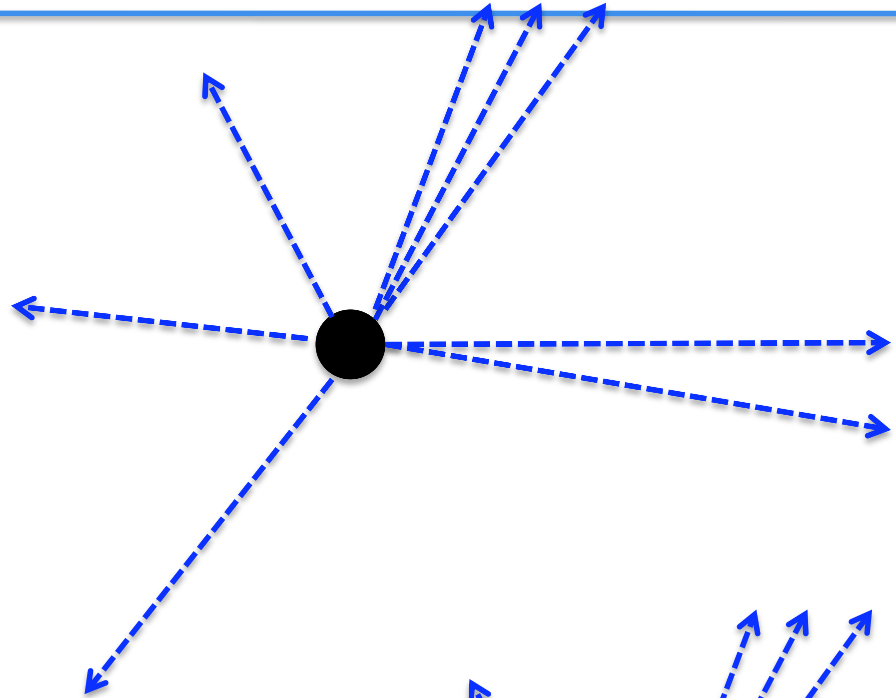


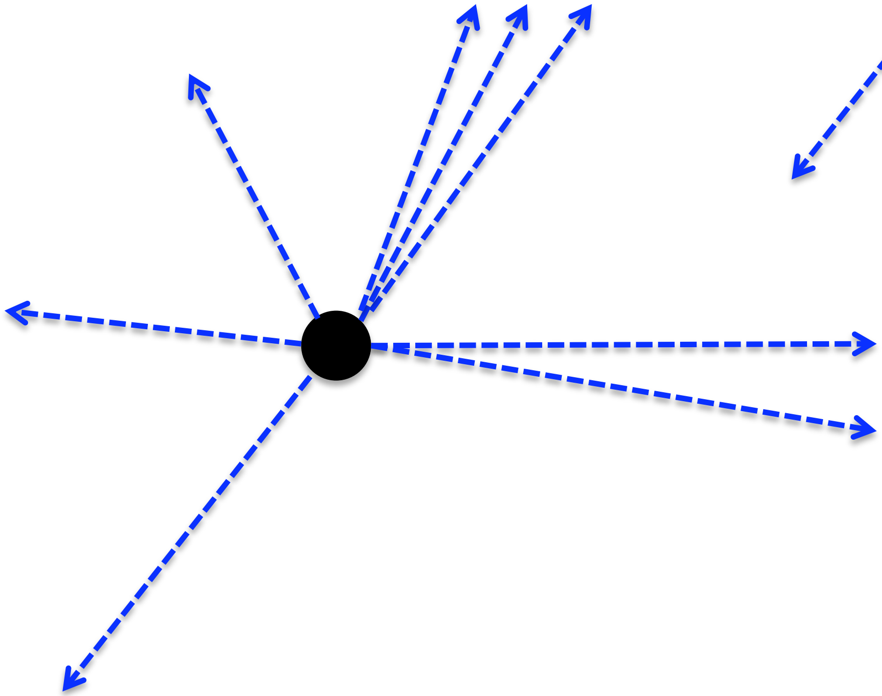
ATLAS generated ttbar + pile up sample
λ = 6.9 pile up collisions + 1 ttbar signal interaction

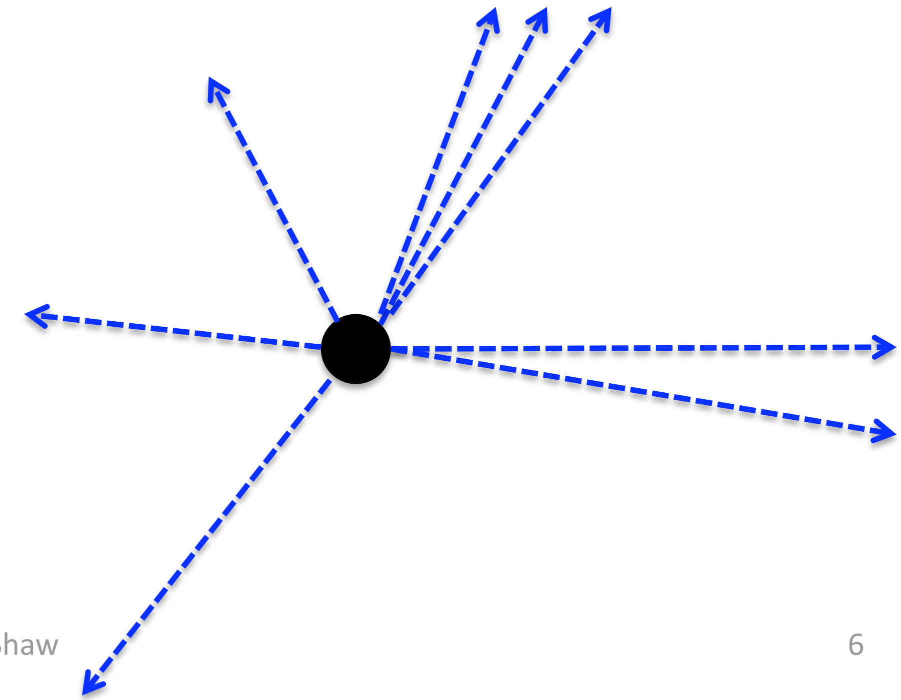
Counting Vertices i

Vertex – represents a pp interaction

Trajectory of a charged particle





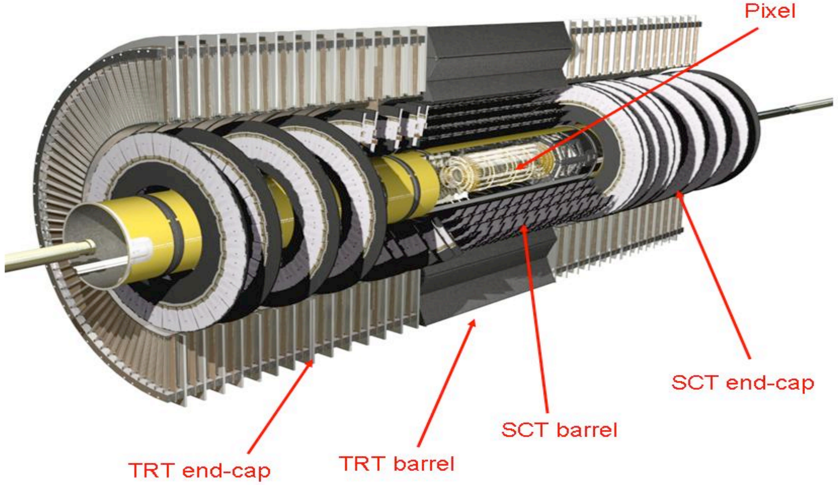


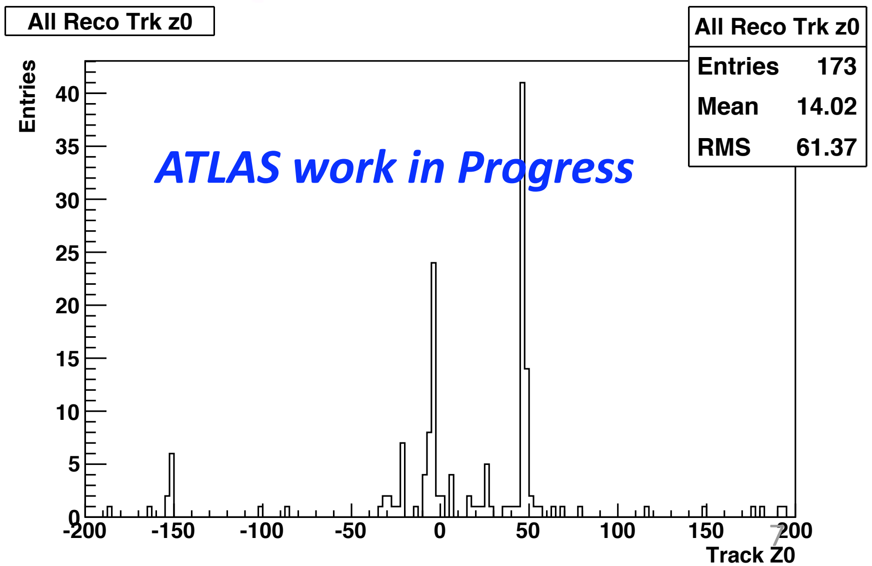
Counting Vertices ii

To measure λ we count the number of pp interactions per bunch crossing

i. Detect and reconstruct tracks from charged particles originating from collision and find their originating position in the plane of the beam axis (*z*-plane).

- ATLAS Inner Detector – silicon pixel and silicon strip detector and in the outer radii Transition Radiation Tracker (TRT)
- ATLAS offline track reconstruction software used to reconstruct tracks that follow the trajectory of the charged particle.
- Extrapolate the track to the interaction region and determine the tracks initial position in the *z*-plane.





Counting Vertices iii

ii. Using different clustering methods cluster tracks together to form candidate vertices.
- Four methods developed to count candidate vertices
  - Sliding Window Method
  - Histogramming Method
  - Divisive Method
  - Peak Counting Method

	λ_{reco}	$\lambda_{sim} - \lambda_{reco}$	accuracy
Sliding Window	8.44 ± 0.01	-0.56	93 %
Histogramming Method	7.29 ± 0.01	0.59	93 %
Divisive Method	7.53 ± 0.01	0.35	96 %
Peak Counting	7.98 ± 0.01	-0.10	99 %

For ATLAS Monte Carlo simulated data
ttbar signal plus pile up sample with $\lambda_{sim} = 7.88$
E_{com} = 10 TeV L = 10^{33} cm^{-2} s^{-1} bunch crossing spacing = 75 ns

Clustering Method

1. Z_0 of all reconstructed tracks in event

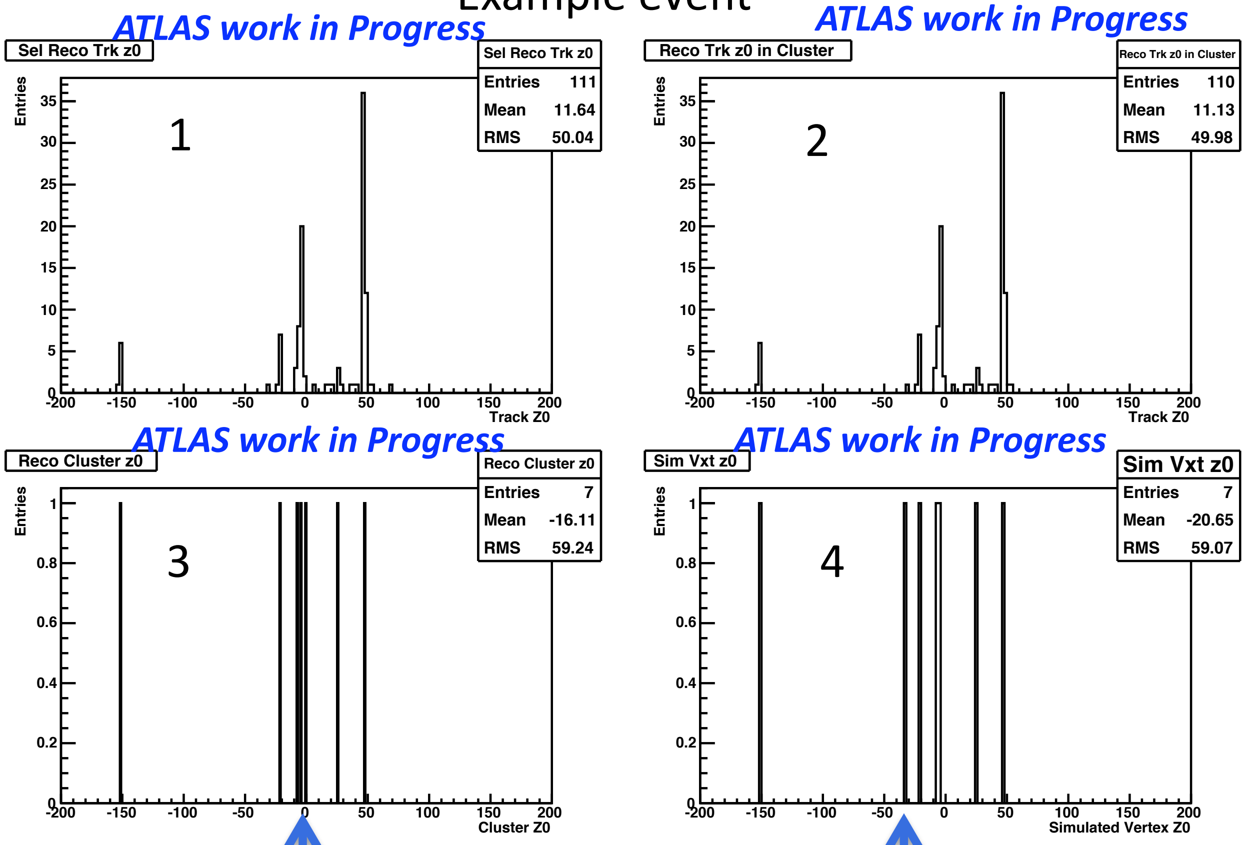
2. Z_0 of reconstructed tracks after selection cuts (including pT > 0.5 GeV)

3. Reconstructed cluster z0 position ($z_{0(clu)}$)

4. Comparison with simulated vertices from Monte Carlo data sample.

$$z_{0(clu)} = \frac{\sum(z_{0i(trk)} \setminus \sigma_{i(trk)})}{\sum(1 \setminus \sigma_{i(trk)})}$$

Example event



7 reconstructed clusters, 7 simulated vertices

One reconstructed vertex is a fake z = 0.6 mm

One simulated vertex not reconstructed z = -32.5 mm

Fake Rates and Efficiencies i

Match = A simulated vertex and associated reconstructed cluster
Fake = reconstructed cluster that has no associated simulated vertex
NoReco = a simulated vertex that has no associated reconstructed vertex
Overlap = When two simulated vertices are matched to the same reconstructed cluster

Efficiency (ε) = fraction of simulated vertices that are matched to a reconstructed cluster
Fake Rate (*fr*) = fraction of reconstructed clusters that are fakes

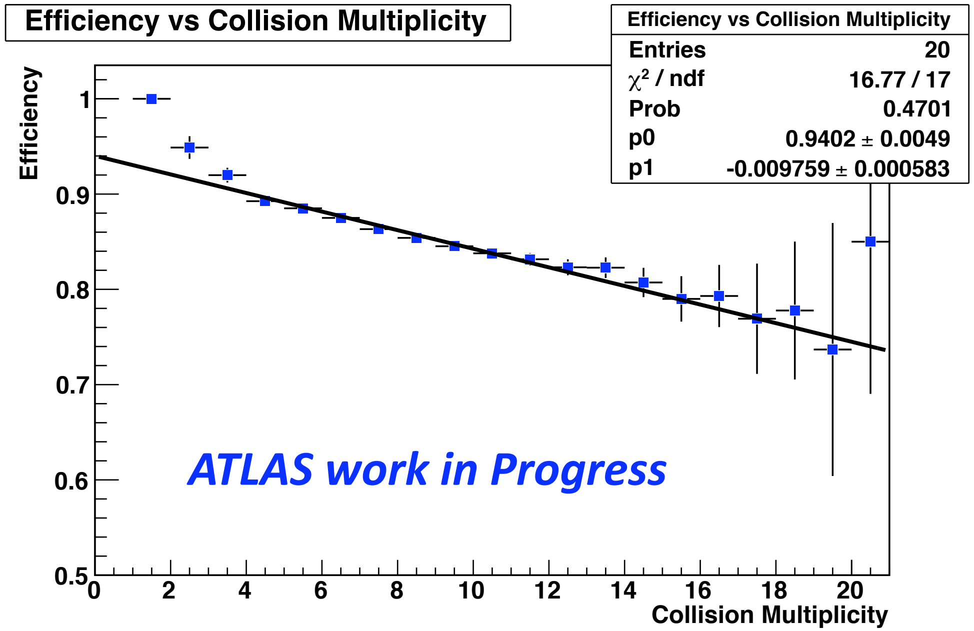
$$\varepsilon = N_{match} / N_{sim\_vxt}$$
$$\underline{Fr} = N_{fake} / N_{reco\_clu}$$

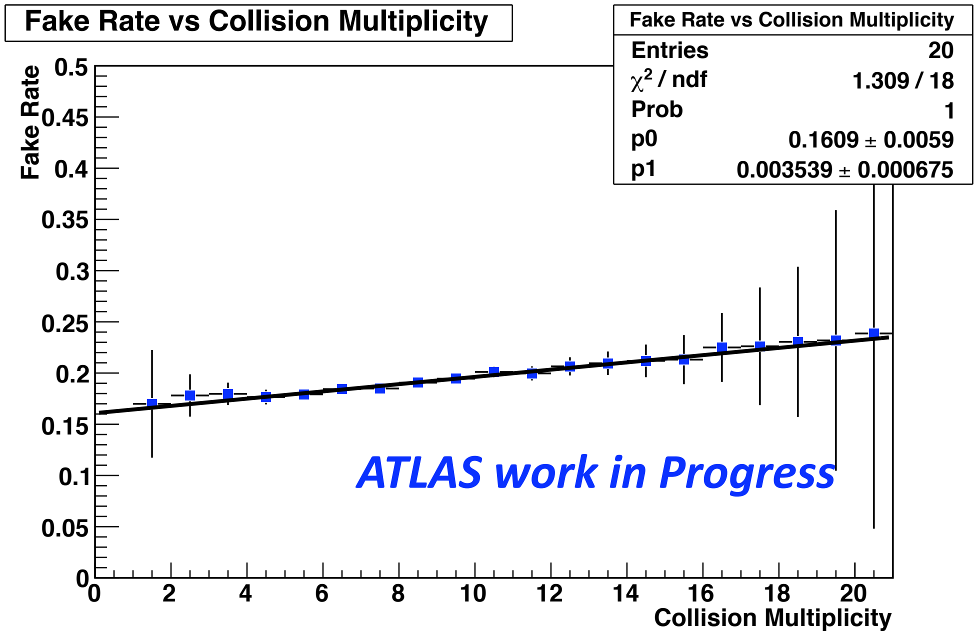
Algorithm	Efficiency	Fake Rate	$\text{Overlap}_{initial}$	Overlap_{final}
Sliding Window	85.74 ± 0.06 %	20.30 ± 0.06 %	8.89 %	7.82 %
Histogramming Method	81.13 ± 0.06 %	12.34 ± 0.05 %	9.17 %	9.07%
Divisive Method	82.93 ± 0.06 %	13.20 ± 0.06 %	8.86 %	8.22 %
Peak Counting Method	82.86 ± 0.06 %	18.41 ± 0.06 %	6.21 %	4.89 %

Fake Rates and Efficiencies ii

Efficiency decreases with collision multiplicity

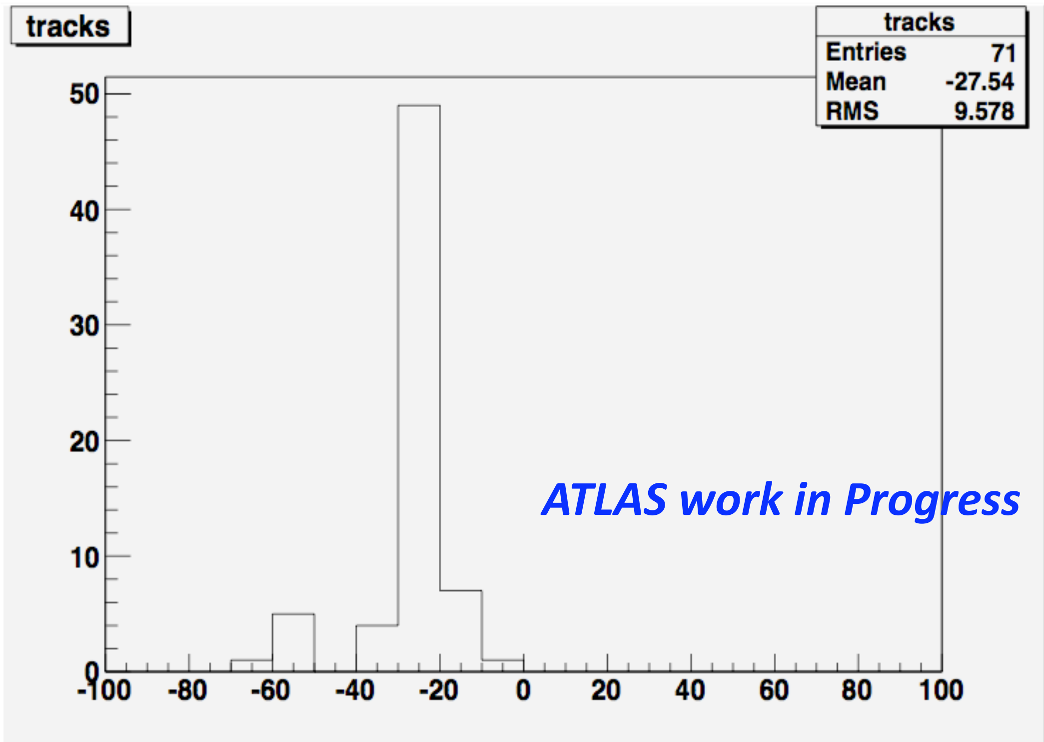
Fake rate increases with collision multiplicity





Real ATLAS Data - 900 GeV Collisions

First ATLAS collisions run at E_{com} = 900 GeV
Expect < 1 pp interaction per bunch crossing
Used clustering methods to search for events with > 1 pp interaction



Using Run = 142156

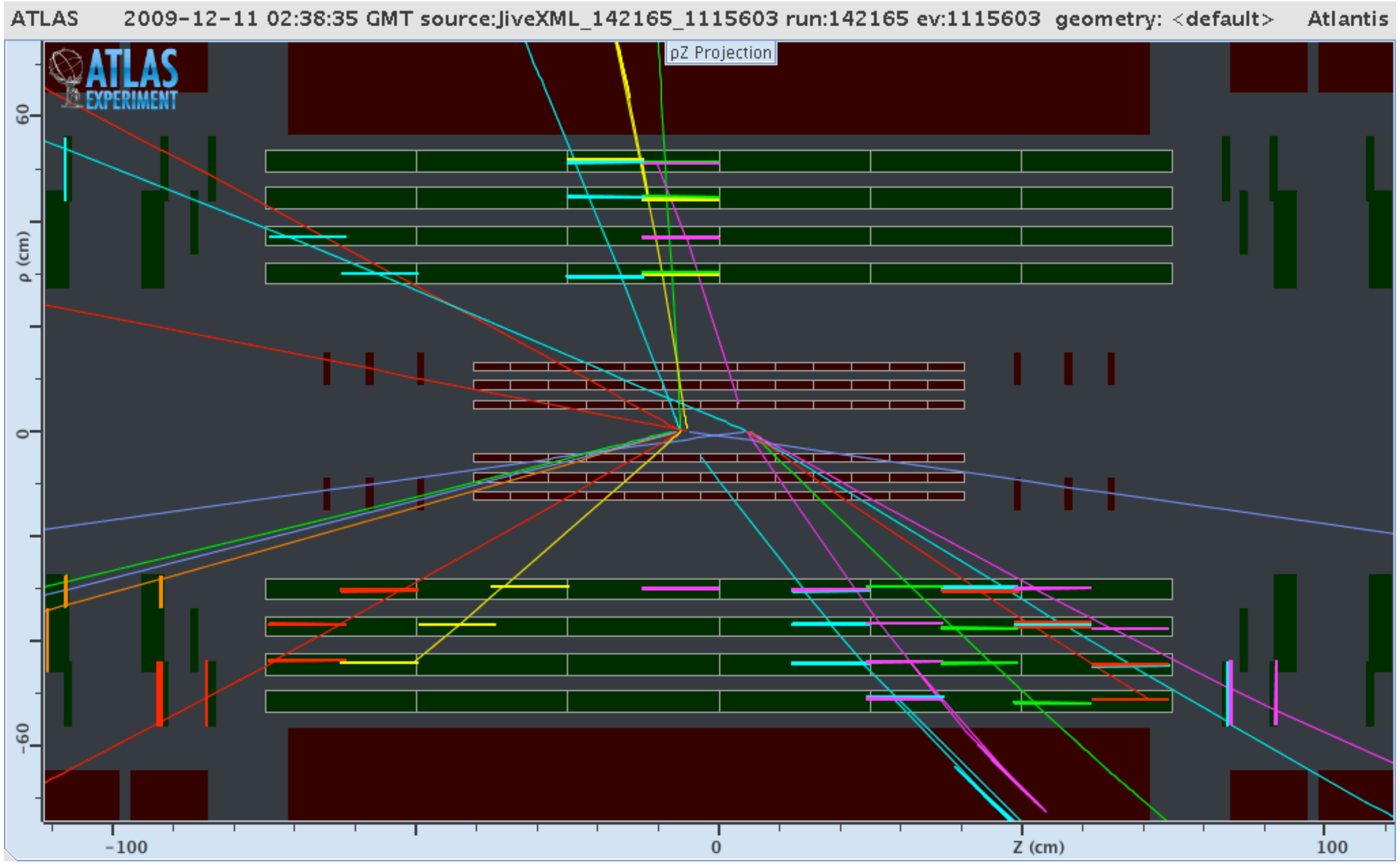
So far found one event with > 1 collision

Event number = 1115603

Real ATLAS Data - 900 GeV Collisions

ATLANTIS event display of event with two collisions

ATLAS work in Progress



Conclusions

- ❑Want to measure the Luminosity per bunch crossing and ultimately the absolute Luminosity
- ❑Developed a method to count the number of pp interactions (vertices) per bunch crossing
- ❑Efficiencies and fakes with Monte Carlo simulated data are acceptable for low luminosities
- ❑Method has been applied to real data
- ❑Need more data!!

Backup slides

Distinguishing vertices

To distinguish separate pp collisions in a bunch crossing:

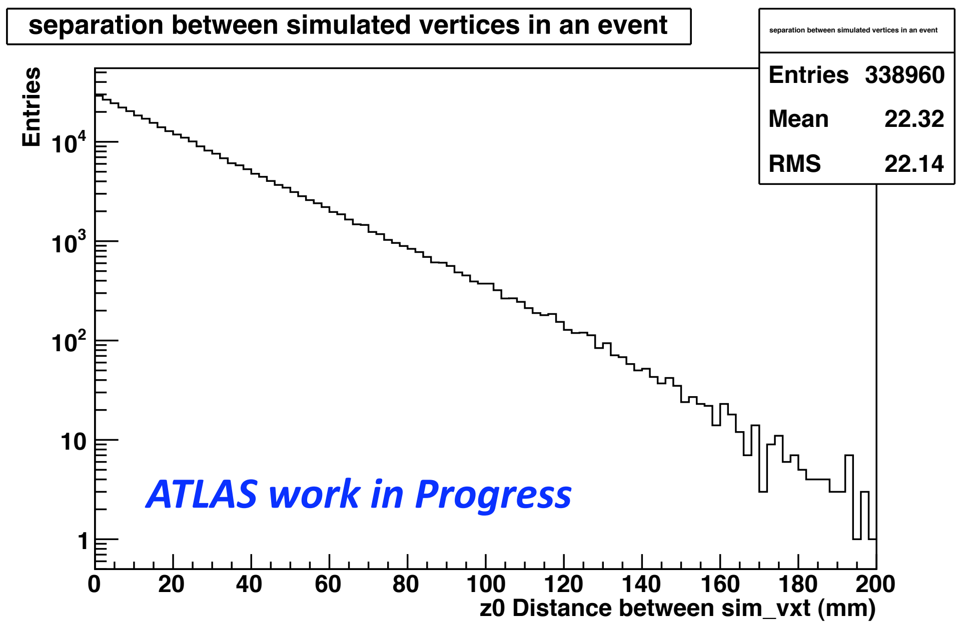
Separation distance between neighbouring vertices (x_{vxt_sep}) must be greater than the reconstructed track resolution in the z-plane ($\sigma_{trk,\ z0}$).

$$x_{vxt\_sep} > \sigma_{trk,\ z0}$$

Probability of finding two collisions within 0.5 mm of one another < 2%

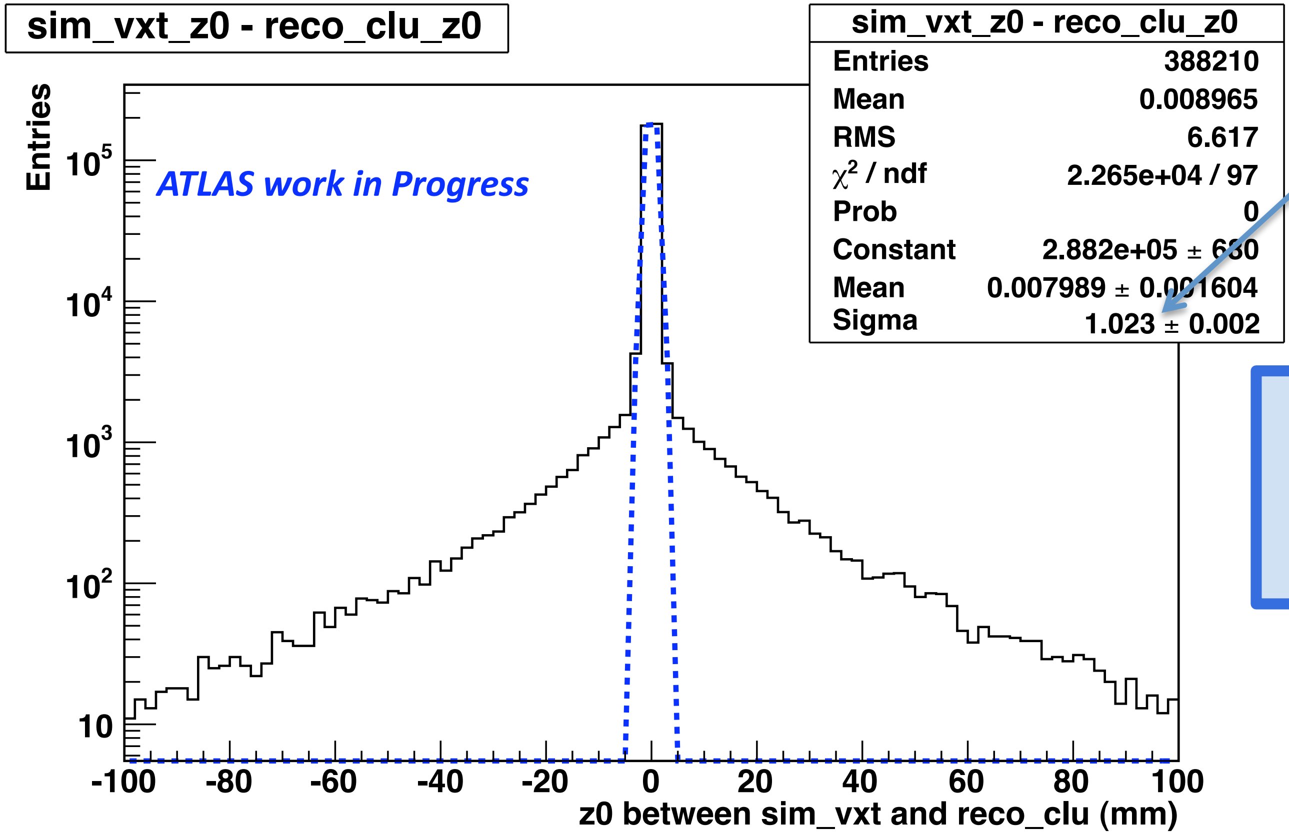
Resolution on the z_0 impact parameter for reconstructed tracks with p_T = 0.5 GeV
$\sigma_{trk,\ z0}$ ~ 0.2 mm

Thus it should be possible to associate reconstructed tracks to their production vertices



Match Definition

Plot of separation distance in the z-plane between simulated vertices and their nearest reconstructed vertex



σ = standard deviation of Gaussian distribution

If :

Sim_vxt_z0 – reco_clu_z0 < 3σ

Match!