A study of the proton reconstruction efficiency with the ALFA detector using an overlay technique of Monte Carlo signal events with zero-bias collider data.

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Overlay technique

- Any cross section measurement requires a good understanding of the particle reconstruction efficiency. This task is particularly complicated in case of forward protons where actual beam conditions are important part of the working environment.
- So far in ATLAS Forward Detectors pile-up events have been simulated based on minimum bias MC, however, modelling of the very forward region in terms of primary particle flux and inactive material producing secondary particles is generally not precise.
- An overlay technique of signal Monte Carlo (MC) events with zero-bias collider data overcomes these difficulties and may provide better understanding of proton reconstruction efficiency and migration effects due to the actual experimental conditions.
- The scheme of the overlay with zero-bias data is shown in Figure 1.

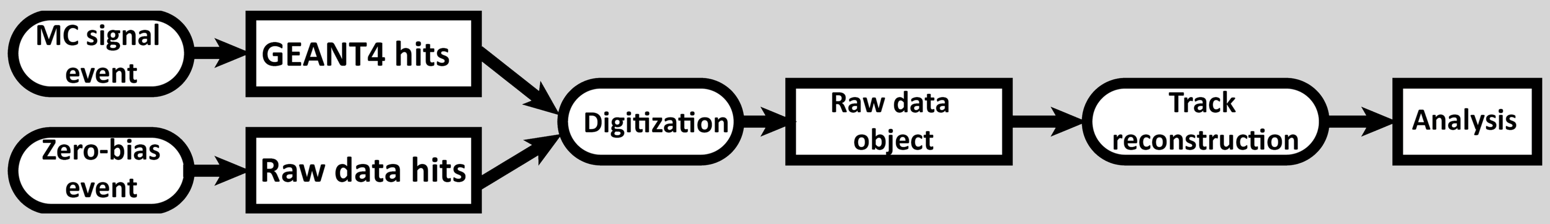

Figure 1 - A scheme of combining zero-bias collider data with MC signal events.

The ALFA detector

- part of ATLAS Roman Pot detectors
- designed to measure protons scattered at very small angles
- placed on both sides of ATLAS (~240 m from IP) [2] (the layout of the ALFA detectors is presented in Figure 2)
- this study has been performed using data collected in October 2015 at the special run with following parameters: β*=90m, μ=0.08, the distance of the inner ALFA station from the beam - 6.85 mm, exactly the same conditions have been used in simulations

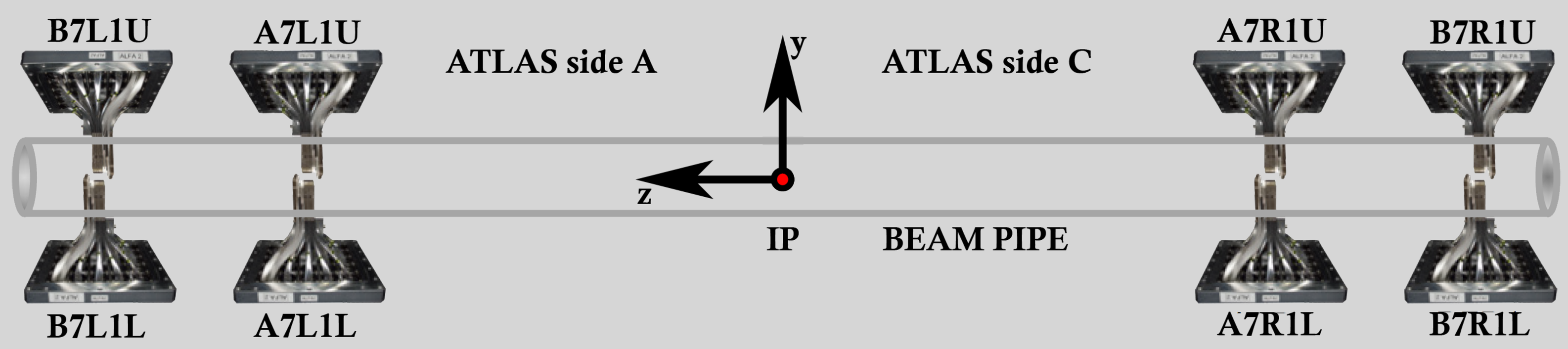

Figure 2 - Naming convention of the ALFA detectors. A letter indicates inner, B - outer, U - upper and L lower ALFA stations. [1]

Proton reconstruction

Ten fibre modules with two layers of 64 orthogonally arranged fibres are used in each of eight ALFA stations to measure transverse positions of the forward protons. A hit pattern of a proton trajectory in ten layers of one fibre orientation is shown in Figure 3.
Two track reconstruction methods have been used in this study to investigate proton reconstruction efficiency and migration effects:

1. a multi track selection where the longest track with at least 4 associated active fibres in each orientation in the given station is taken as a proton candidate
2. a single track selection where the longest track is required to have at least 5 associated active fibres in each orientation in the given station is taken as a proton candidate, no additional such tracks are present in the given station

Figure 4 shows a comparison of the active fibre multiplicity between PYTHIA 8 elastic MC pure GEANT4 simulation and MC simulation with overlay zero-bias collider data taken with relatively small pileup value of μ=0.08. A distribution obtained with overlay shows a small shift towards larger values of multiplicities and a clear peak around 40 from events with two overlaid protons.

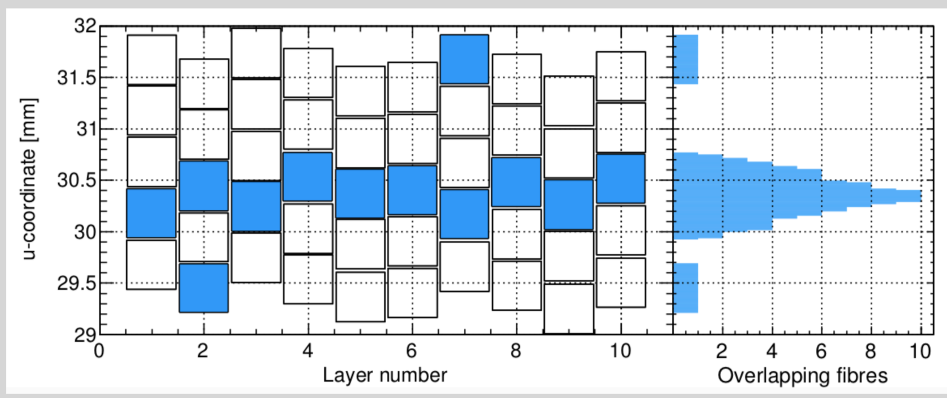

Figure 3 - A hit pattern of a proton trajectory in ten layers of one fibre orientation. The superposition of active fibres attributed to a track is shown in the histogram. The position of maximum overlap is used to determine the track position. [3]

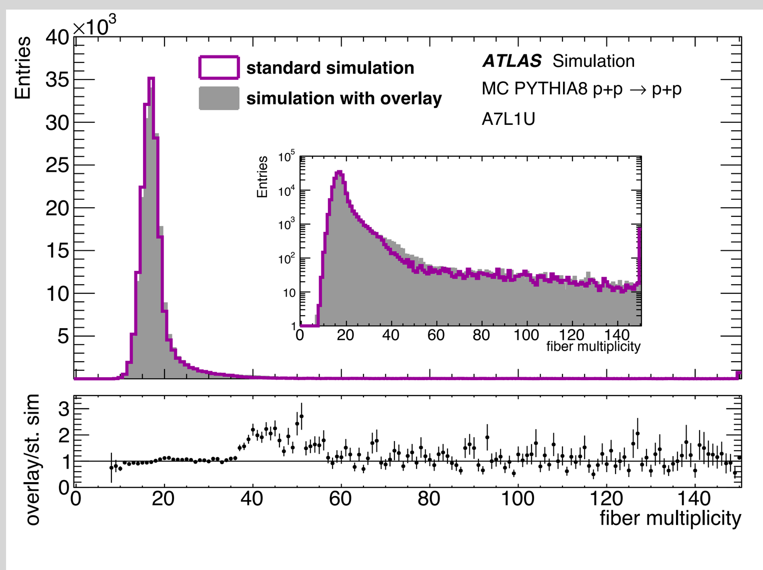

Figure 4 - Distribution of active fibre multiplicity for A7L1U inner station for events with at least 5 active fibres.

Performance of the proton reconstruction

Elastic events have been used to confront simulations with real data. The elastic events have been selected first by a requirement of the correlation between the proton candidates hit positions in inner and outer stations (armlet) on the same ATLAS side expected for beam energy protons. Next the proton candidates from opposite ATLAS sides (arm) have been required to show the back-to-back topology anticipated for elastic scattering. Reconstruction inefficiencies in simulation and data are studied based on events with a missing proton candidate in one or two stations using the subset of elastic event selection cuts, which is still possible to apply [3]. The ratios of the number of events where no track was reconstructed in one station (case 3/4) and where no track was reconstructed in two stations from the same armlet (case 2/4) to the fully reconstructed elastic event (case 4/4) are presented in Figures 5 and 6 respectively. The reconstruction efficiency (probability that proton(s) expected in given armlet (arm) was(were) reconstructed there) and a fraction of tracks reconstructed 3.5 of detector resolution away from the expected proton position are shown in Figures 7 and 8.

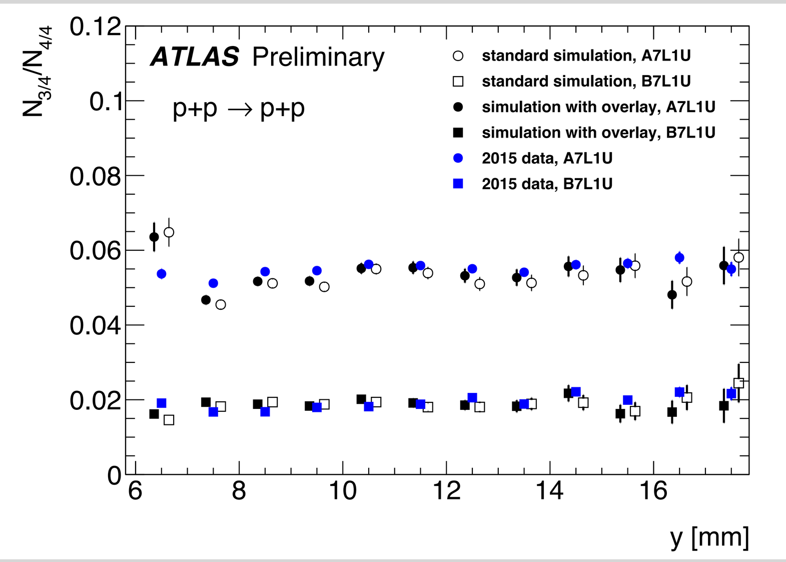

Figure 5 - The ratio of a position distribution in y of case 3/4 for A7L1U station where no track was reconstructed in station B7L1U (circles) and for B7L1U station where no track was reconstructed in station A7L1U (squares) to the fully reconstructed elastic case 4/4 in arm B7L1U-A7L1U- A7R1L-B7R1L.

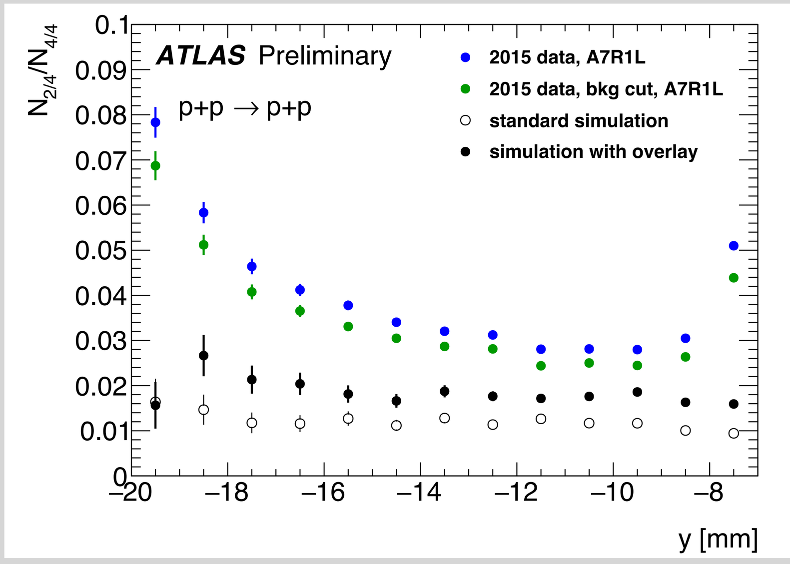

Figure 6 - The ratio of a position distribution in y of case 2/4 for A7R1L station where no track was reconstructed in armlet B7L1U - A7L1U to the fully reconstructed elastic case 4/4 in arm B7L1U-A7L1U-A7R1L-B7R1L.

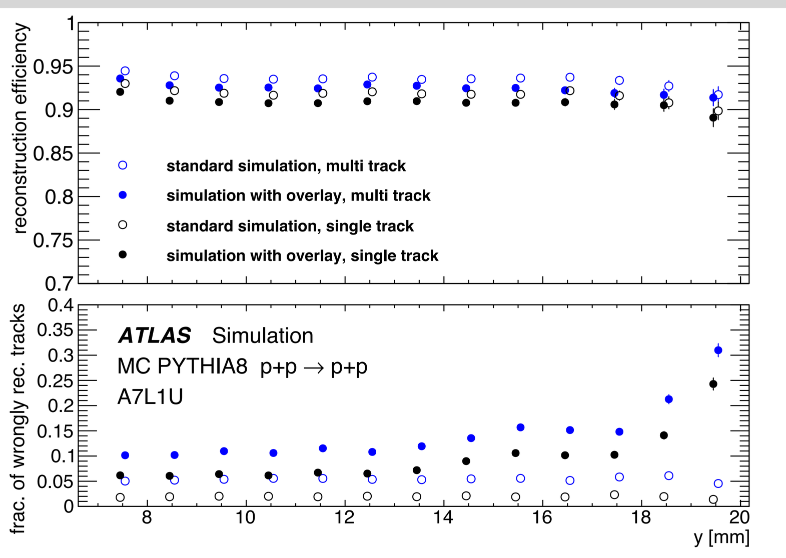

Figure 7 - Reconstruction efficiency and fraction of wrongly reconstruction tracks for armlet A7L1U-B7L1U.

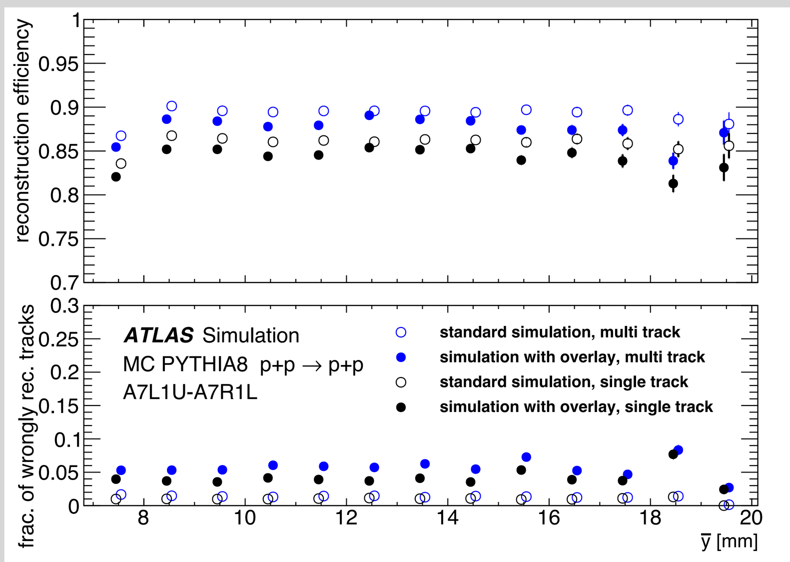

Figure 8 - Reconstruction efficiency and fraction of wrongly reconstruction tracks for elastic arm B7L1U-A7L1U-A7R1L-B7R1L.

Summary

- The number of events with one failed reconstruction (case 3/4) makes up about three fourth of the total number of failed elastic events. In most of these cases, an outer detector has failed to reconstruct, because a shower was started in the inner detector. This fraction is well described by MC simulation with and without overlay.
- The number of events where both detectors on one side of the IP in a given arm do not contain a proton candidate (case 2/4) makes up about one fourth of the total number of failed elastic events. Such events are found mainly because of the formation of showers before or in the inner detector on one side. It results in the inability to reconstruct tracks in either one or two detectors. This fraction is not described by elastic MC simulation but simulation with overlay is closer to the data. It is expected that data contain significant contribution of inelastic background.
- MC simulation with overlay predicts 2% smaller elastic event reconstruction efficiency and 5% higher fraction of wrongly reconstructed events compared to pure GEANT4 simulation.

- **The overlay technique of signal Monte Carlo events with zero-bias collider data shows visible effects on proton reconstruction efficiency and migration effects due to the actual experimental conditions even at relatively small event pileup of μ=0.08. It is a promising analysis technique of data taken with much larger pileup achieved in LHC Run 2 and expected in Run 3.**

References:

[1] Commissioning of the Absolute Luminosity For ATLAS detector at the LHC - Jakobsen, Sune CERN-THESIS-2013-230

[2] ATLAS Collab., ATLAS Forward Detectors for Measurement of Elastic Scattering and Luminosity, Technical Design Report, ATLAS TDR 018, CERN/LHCC 2008-04

[3] Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector - ATLAS Collaboration (Aaboud, Morad et al.) Phys.Lett. B761 (2016) 158-178 arXiv:1607.06605 [hep-ex] CERN-EP-2016-158

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