Performances of the ATLAS/ALFA Roman Pots system

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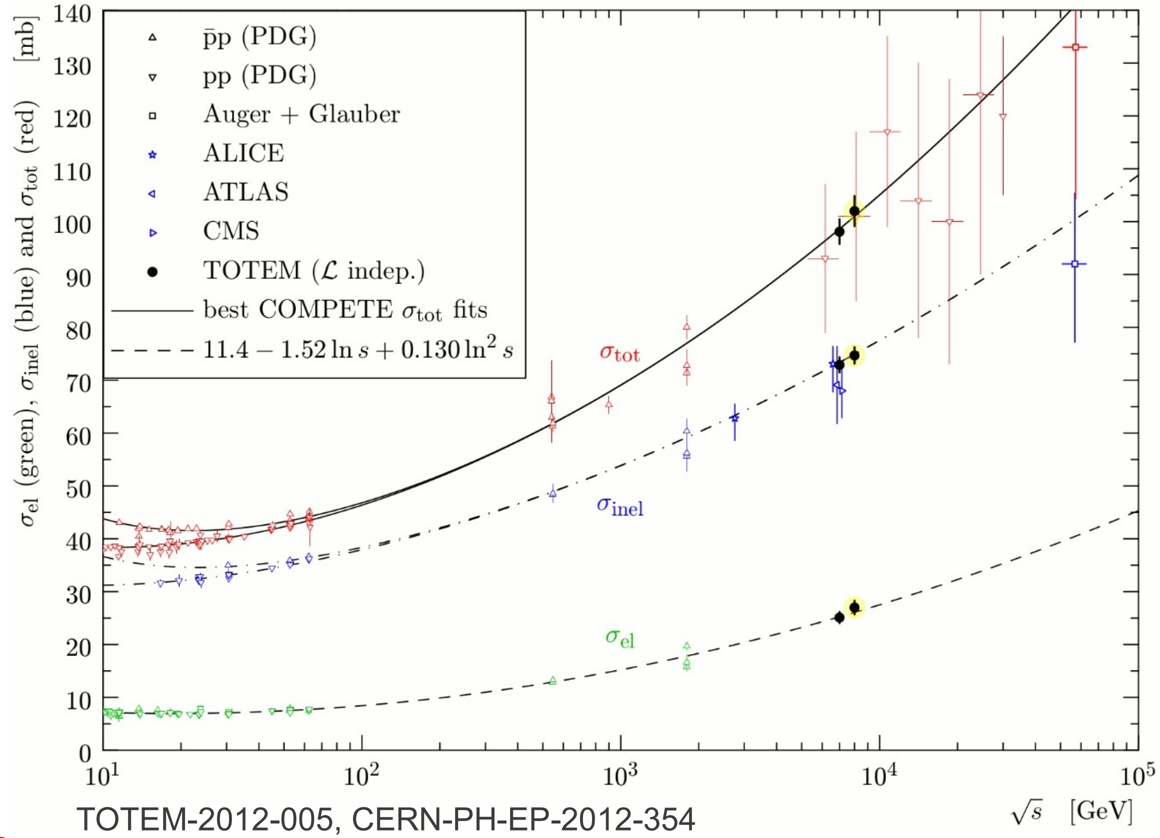
Presentation plan

- Overview on the ALFA physics program
- Optics requirements
- ALFA setups
- Data taking status
- Optics fine tunning
- Summary and outlook

ALFA main goals:

- Measurement of the total proton-proton cross section σ_{tot}
- Measurement of the absolute luminosity for the ATLAS experiment

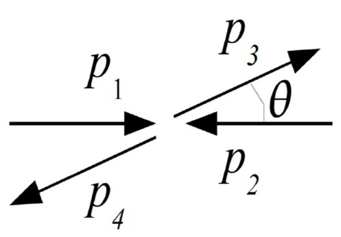


TOTEM-2012-005, CERN-PH-EP-2012-354

ALFA strategy & analysis key points:

- Detect elastic protons scattered from the interaction point
- Measure momentum transfer spectrum (*t-spectrum)* which can be written at small θ as:

$$t = (p_1 - p_3)^2 \approx -(p\theta)^2$$



- The rate of elastic scattering is linked to the total interaction rate through the optical theorem

$$\sigma_{tot} = 4\pi \Im(F_n(t \to 0))$$

Luminosity measurement strategy

The rate of elastic scattering at small t-values can be written as

$$\frac{dN_{el}}{dt} = \mathcal{L}\frac{d\sigma_{el}}{dt} = \mathcal{L}\left|F_c + F_n\right|^2 = \mathcal{L}\left(\frac{d\sigma_c}{dt} + \frac{d\sigma_{cn}}{dt} + \frac{d\sigma_n}{dt}\right)$$

Instantaneous luminosity

Elastic cross section

Coulomb interaction amplitude

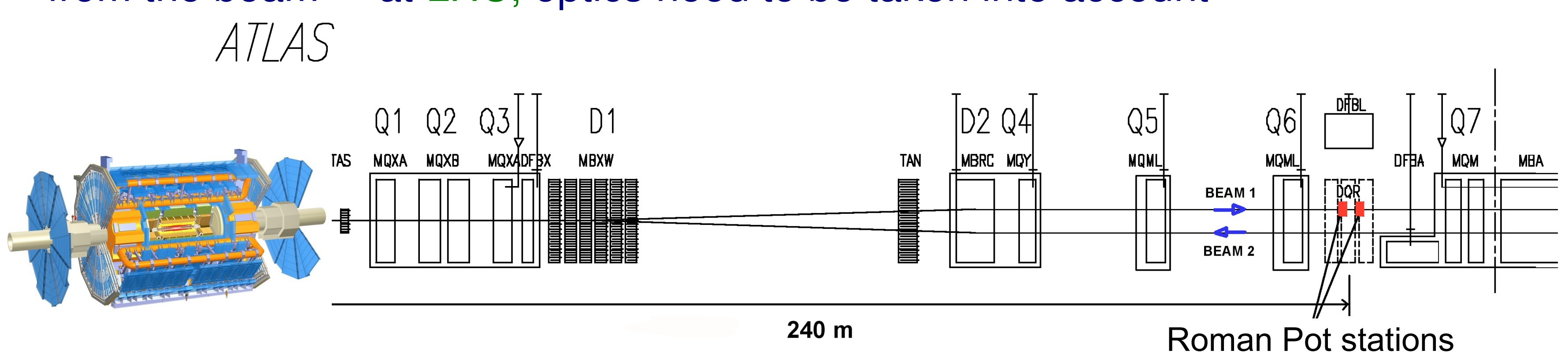
Nuclear interaction amplitude

Nuclear term $\propto \sigma_{tot}^2 \exp(|-t|)$

Interference term $\propto \sigma_{tot} \frac{\exp(|-t|)}{|t|}$

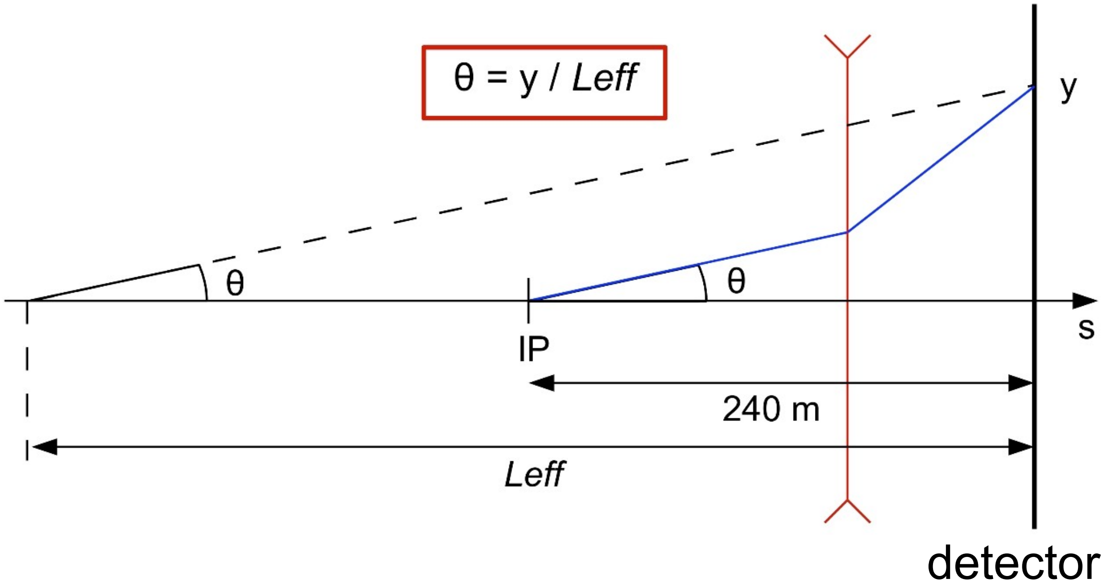
Coulomb term $\propto \frac{1}{t^2}$

- Ultimate ALFA goal: reach the Coulomb Nuclear Interference region (CNI) → small $|t|$ values ($<10^{-3}$ GeV^2) → precise determination of the absolute luminosity
- Main requirement: movable tracker system which can go close to the beam to detect protons in the CNI region
- Practical case: put detectors far away from the IP where the elastic will be separated from the beam → at LHC, optics need to be taken into account



Why special (high beta*) optics?

- β* = the beam focusing parameter at the interaction point
- t_{min} α 1/β* → increasing β* is important to reach CNI
- Dedicated optics ensures that scattered angle at the IP translates into vertical position at the detector (90° vertical phase advance)



Ultimate ALFA optics conditions & plans:

- β* > 2000 m with detectors edge as close as possible to the beam (~5 σ_y)
  → Machine development
- Reaching the CNI → constraint the absolute luminosity, the total cross section and the rho (phase of the nuclear scattering amplitude)

What can ALFA do with intermediate optics?

Actual ALFA optics condition:

- β^*= 90 m, detectors edge at ~6.5 σ_y → only nuclear region → 5 h runs with:
  - 2011 (7 TeV), L ~ 80 μb^{-1},
  - 2012 (8 TeV)

  → σ_{tot} measured using ATLAS luminosity

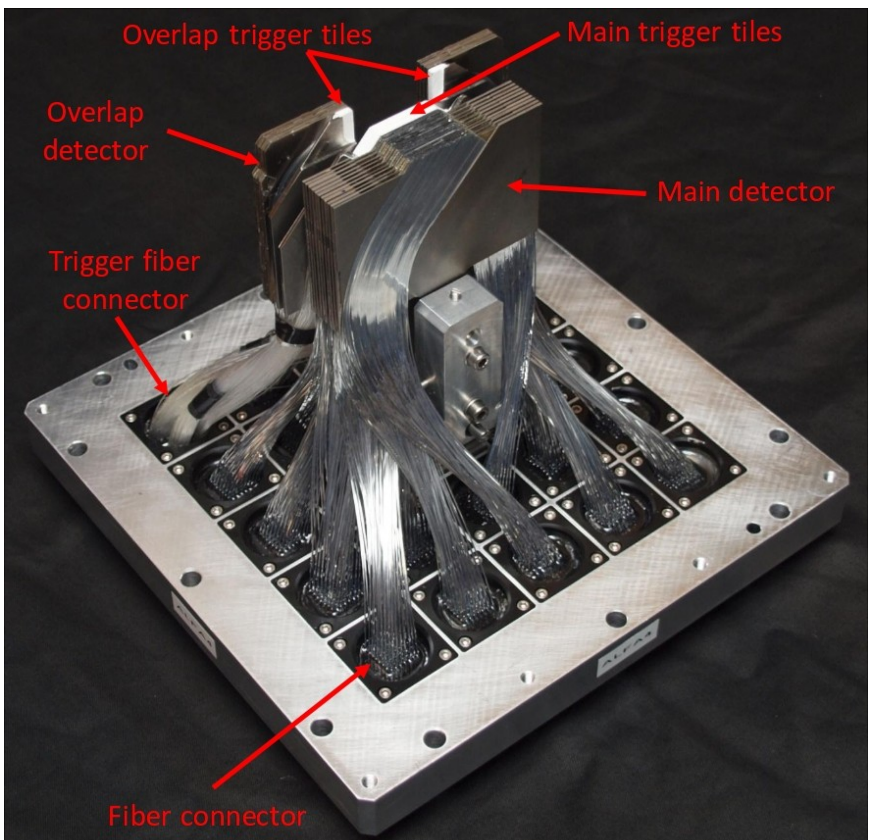
- β^*= 1000 m with detectors edge at ~3 σ_y from the beam (2012) → analysis ongoing

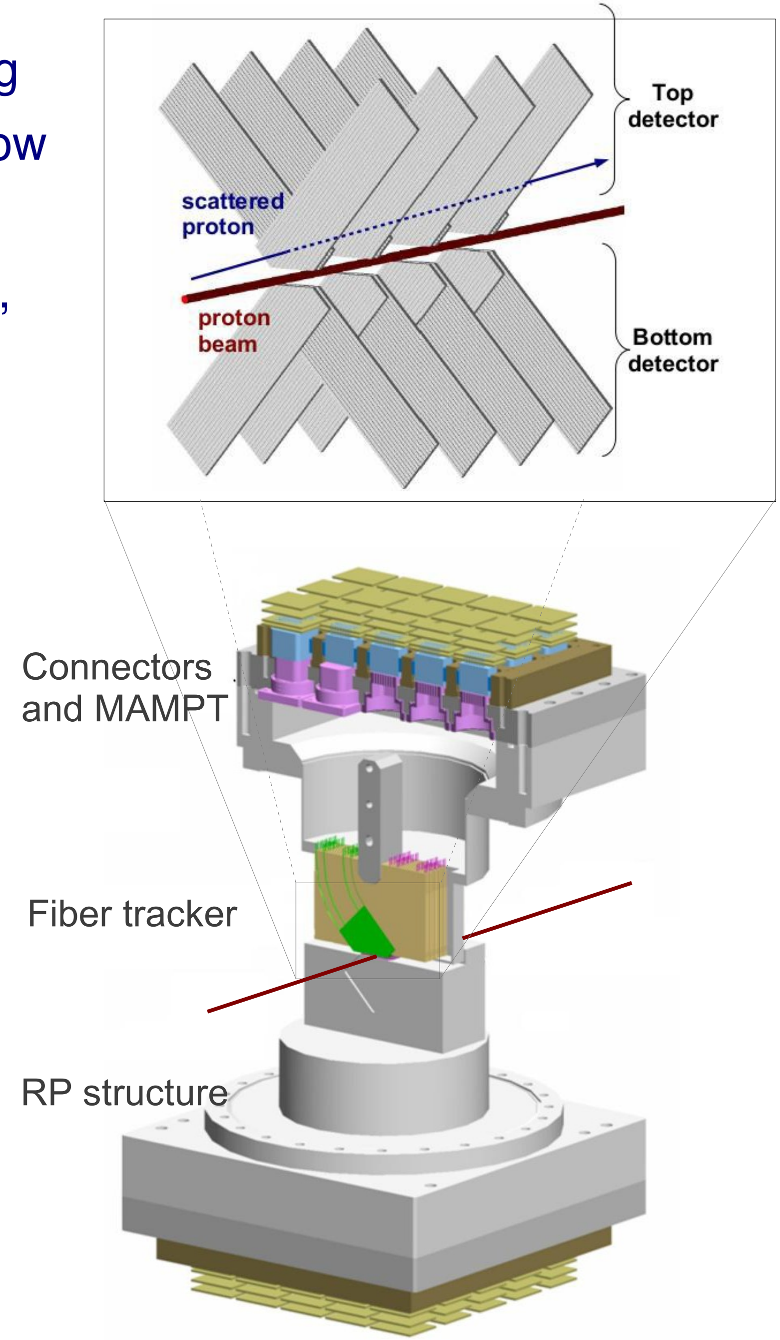
Knowing the absolute luminosity (machine parameters + VdM scans), one can measure the total cross section from the elastic cross section extrapolated to the forward direction, i.e t→0

$$\frac{dN_{el}}{dt} \xrightarrow{L} \frac{d\sigma_{el}}{dt} = \left.\frac{d\sigma_{el}}{dt}\right|_{t=0} e^{-B|t|} \xrightarrow{\rho} \sigma^2_{tot} = \frac{16\pi(\hbar c)^2}{1+\rho^2} \left.\frac{\sigma_{el}}{dt}\right|_{t=0}$$

ALFA detector

- ALFA detector is a tracking system based on scintillating fibres and will be located in Roman Pots above and below the LHC beam axis
- Main components: fibres tracker, 64 channels MAPMTs, front-end electronics



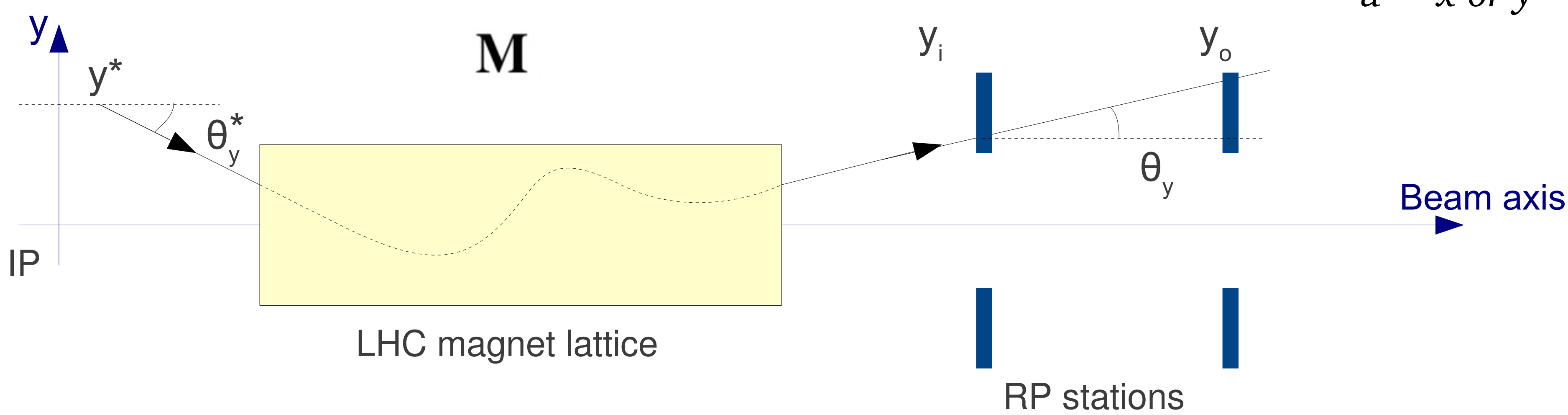


From the RPs to the IP

- The knowledge of the magnetic elements setting $\mathbf{M}$ (transport matrix) between the IP and the RPs allows to measure the scattering angle at the interaction point

$$\begin{pmatrix} u(s) \\ u'(s) \\ \Delta p(s)/p \end{pmatrix} = \mathbf{M} \begin{pmatrix} u^* \\ u^{*\prime} \\ \Delta p^*/p \end{pmatrix}$$

$u = x \text{ or } y$



- Scattering angle measurements:
  - Using reconstructed transverse positions from opposite detectors → back to back topology

$$\theta^* = (u_L - u_R)/2.M_{12}$$

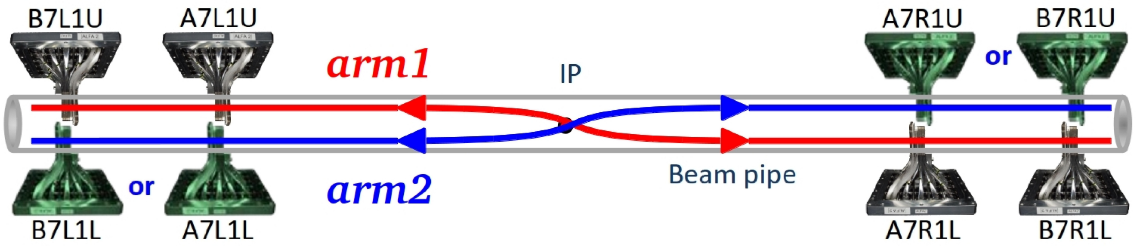
  - Using the locale reconstructed angle reconstruction from opposite detector (see figure)

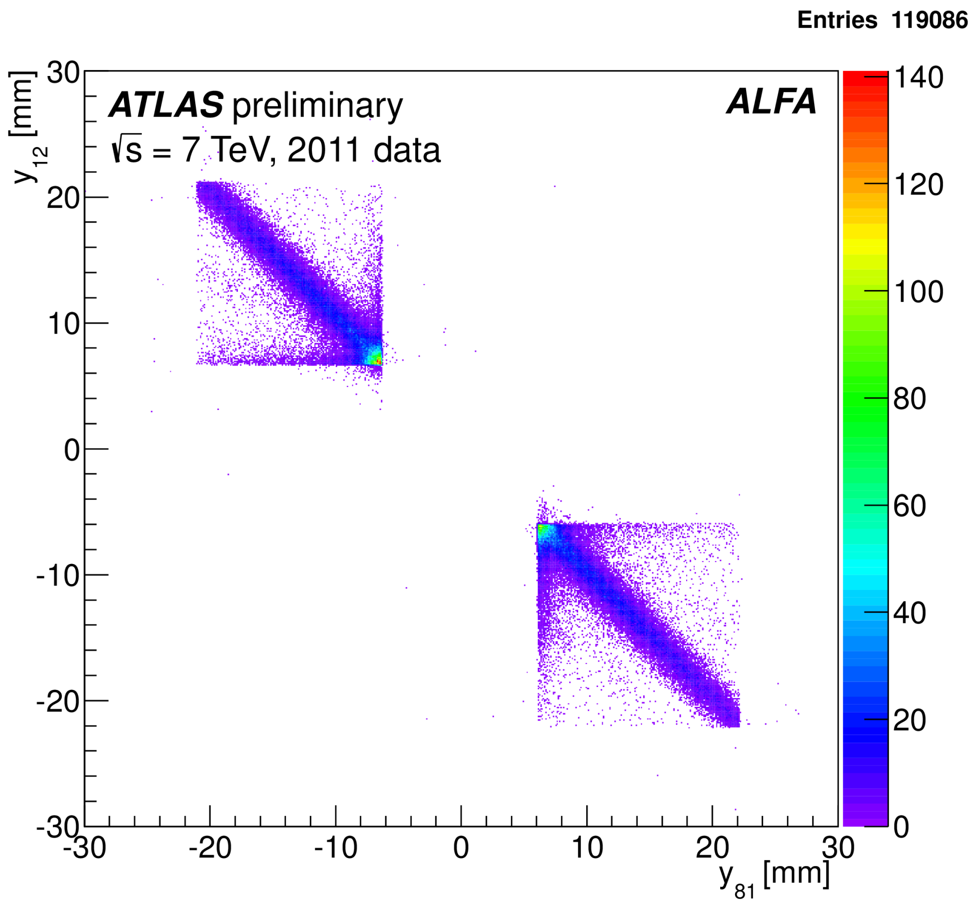
$$\theta^* = (\theta_L - \theta_R)/2.M_{22}$$

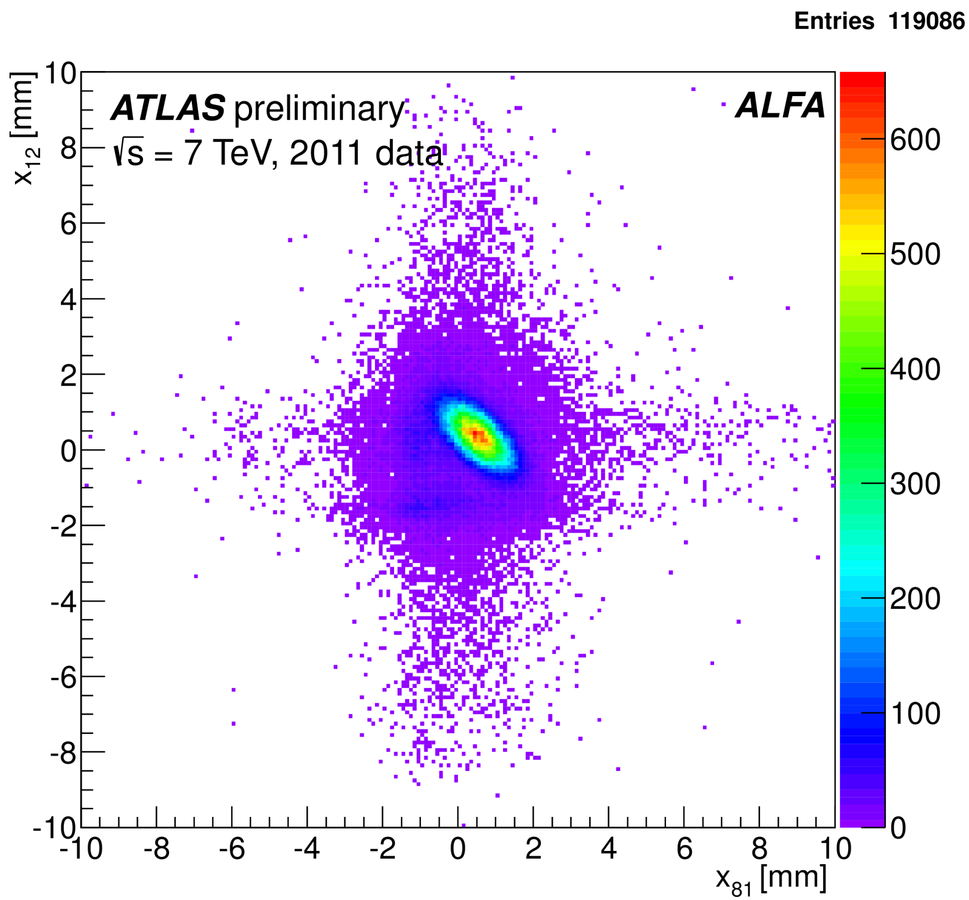
- Precise optics knowledge is a key for ALFA

First data taking at 90 m beta* optics

- *Goal:* determine total cross section
- Roman Pots at 6.5 σ_y
- 2 colliding bunches of 7.10^{10} protons

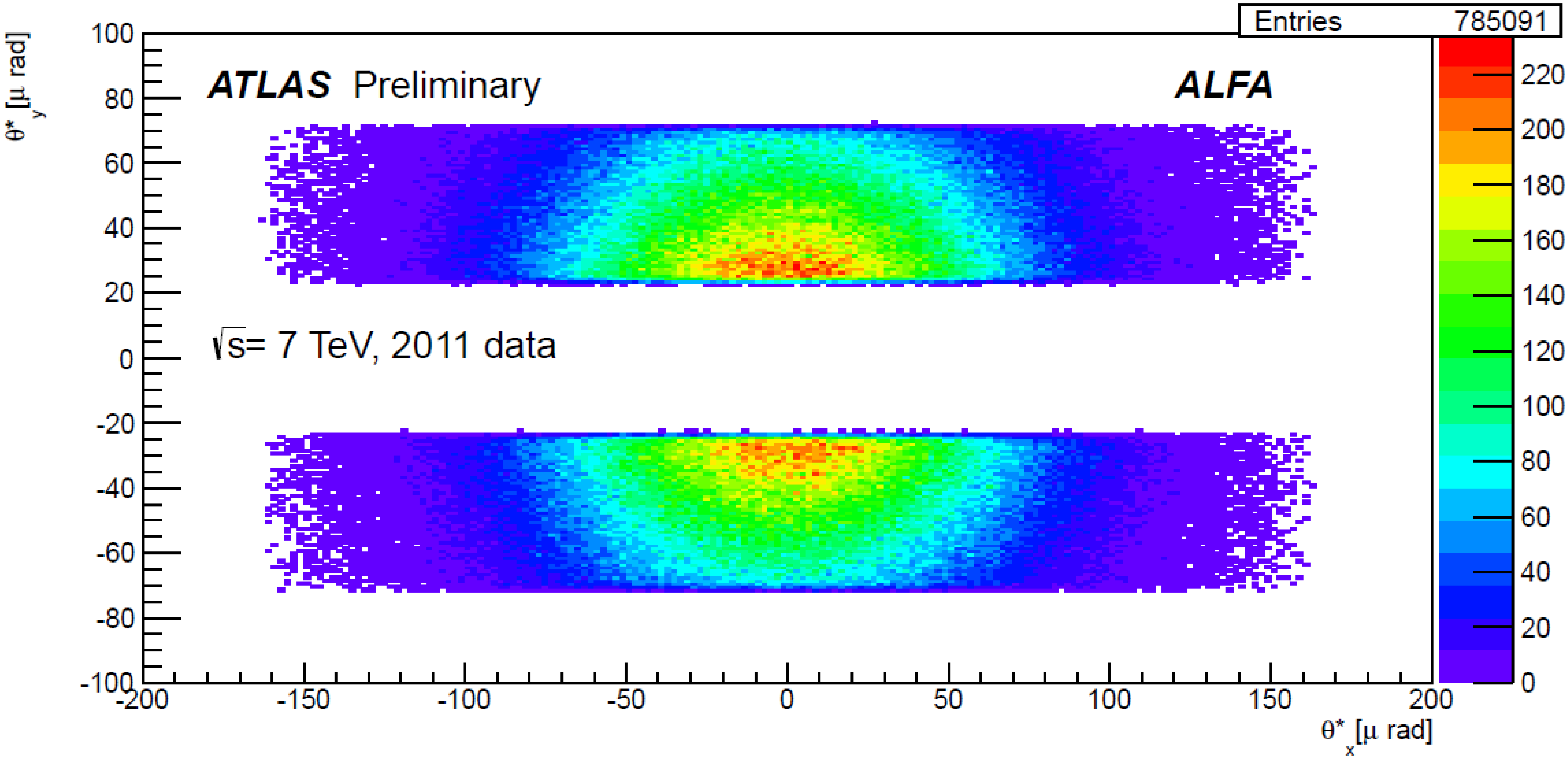




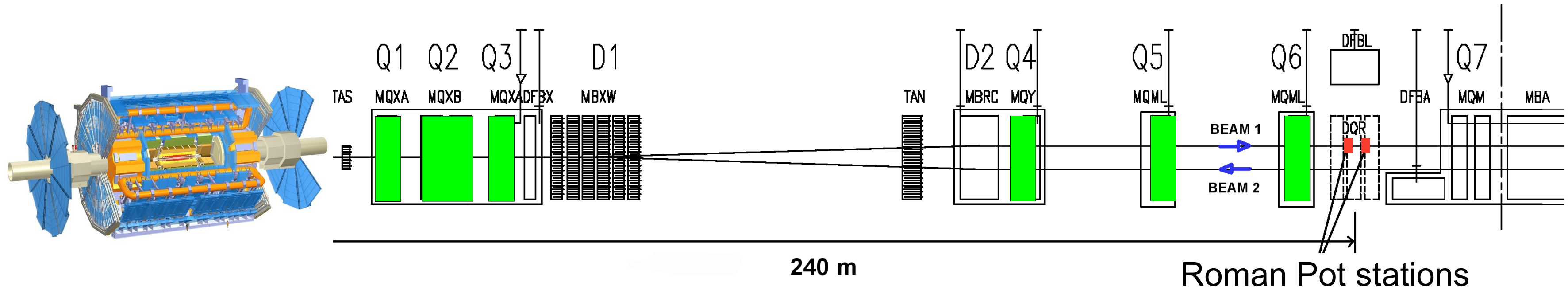


The view at the interaction point

Reconstructed scattering angle distribution between vertical and horizontal planes combining both arms of ALFA, after background rejection cuts.



The way to precise optics



- Constrain the optics using the measurement of its parameters with ALFA and machine
- Fit the quadrupole strength within acceptable deviations

  <u>What we have?</u>

- There are 6 quadrupoles → 6 (strength) for both beams

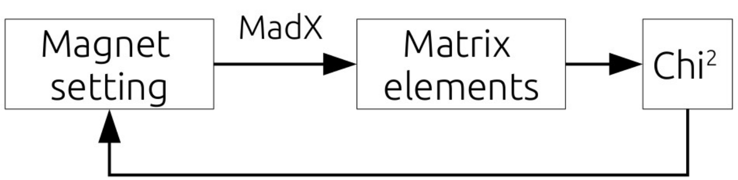
  → 12 free parameters in total

- ALFA observables (tracks position) are used to constraint the optics; opposed and same side detectors provide matrix elements ratios → ratios can be used as constraints

  → 14 constraints in total (some of them are not independent)

  <u>Phase space limits?</u>

- Discussions with experts indicate that relative error on quadrupole fields should not exceed 10^{-3} though in some few cases 2-3 10^{-3} might be possible



Selected optics candidates → effective optics fixed
→ analysis comes to an end

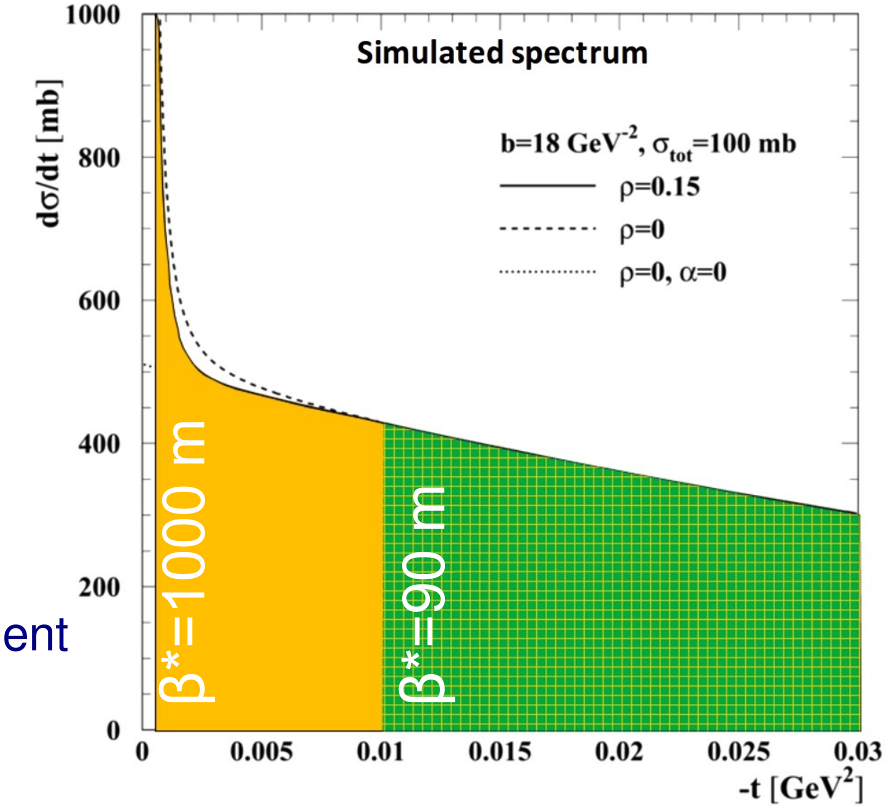
Summary and outlook

- Intermediate optics allowed the measurement of the total cross section, luminosity provided by ATLAS → publication in preparation

- ALFA is dedicated to get the absolute luminosity for ATLAS. This will be done with ultimate optics conditions

- A lot of achievements was done in last 2 years:
  - Installation in the tunnel
  - Successful combined running with ATLAS
  - First physics run to measure the σ_{tot} value
  - Development the physics analysis chain
  - Understanding and fine tuning of the optics

- Future plan:
  - RF/heat protection
  - Total cross sections for different LHC energies
  - Development of higher beta* optics → independent luminosity measurement and rho measurement



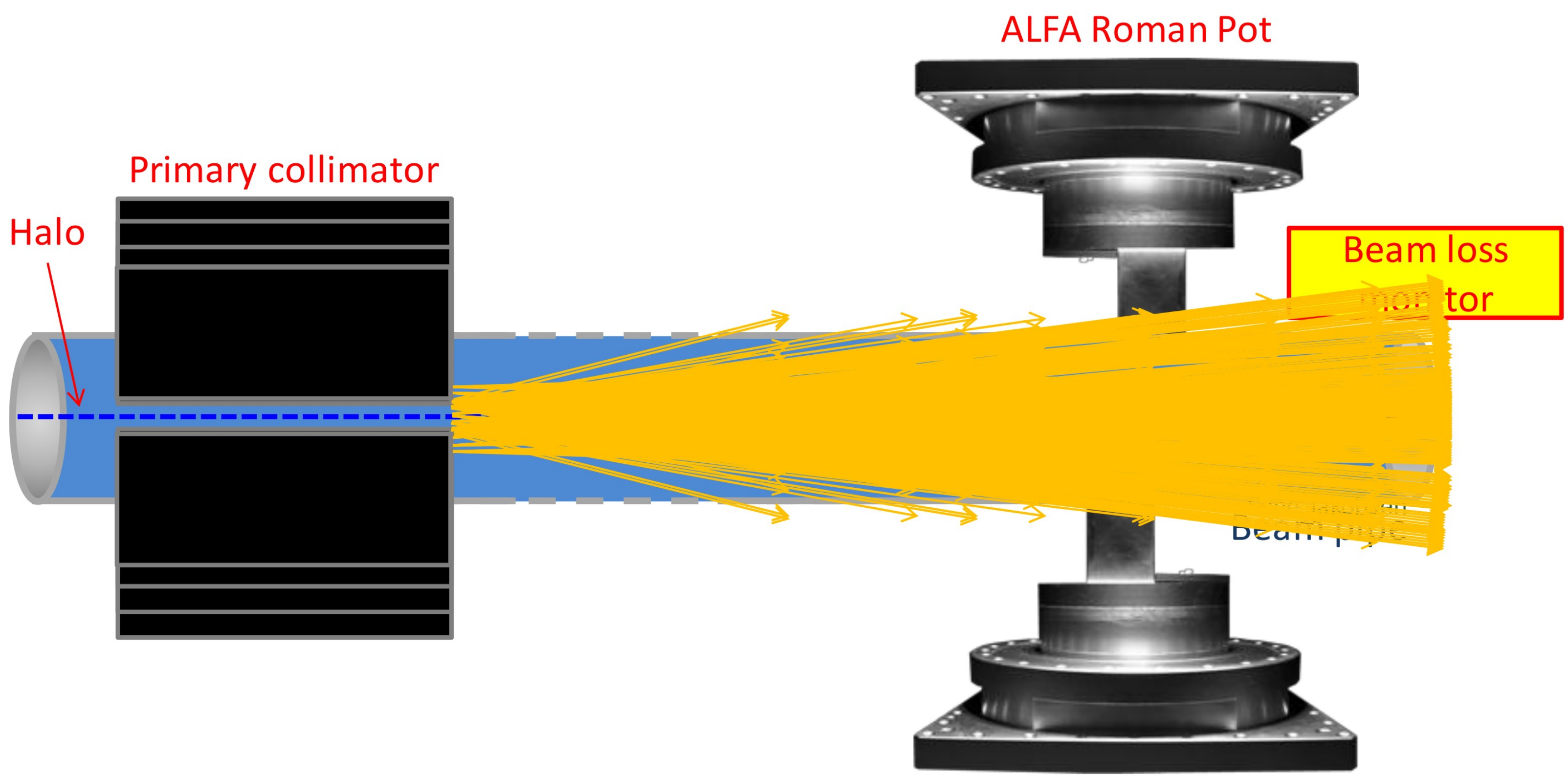
Backup

2012 β*=1000 m run

Goal: Data taking with Roman Pots at 3.0 σ without being dominated by background

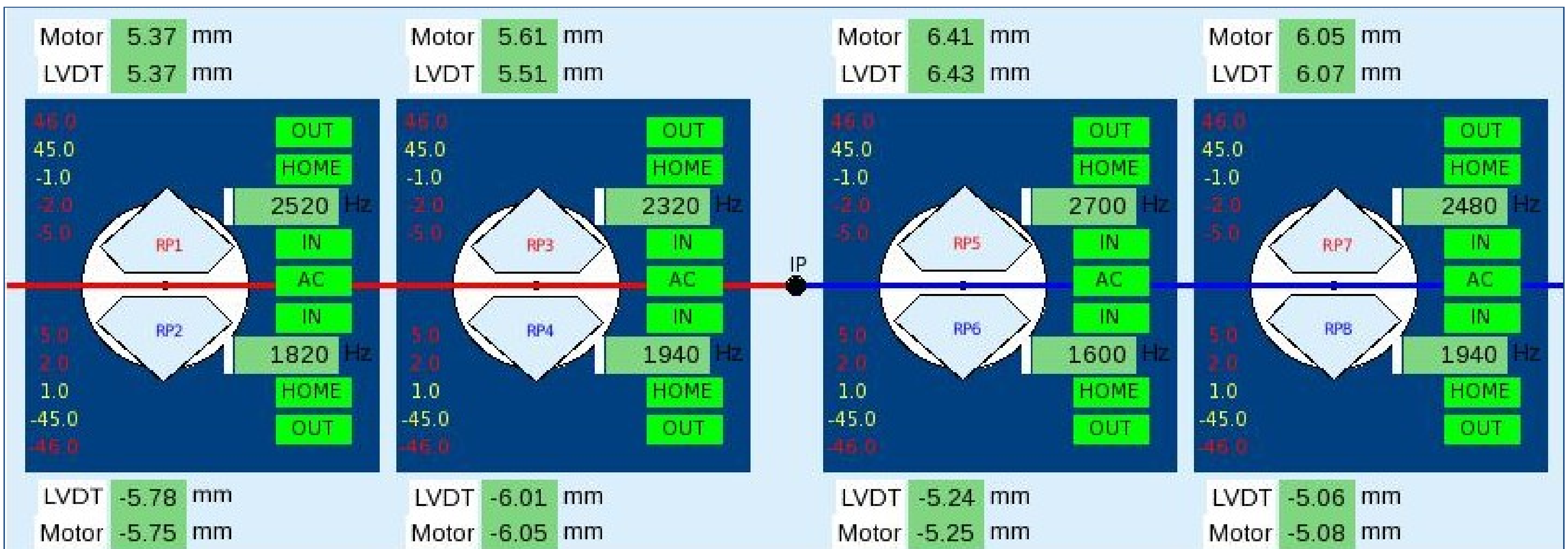
Method of background cleaning for data taking:

- Scrap down the beam with the TCPs (Primary collimator) to 2.0 σ
- Position Roman Pots at 3.0 σ → very large background from TCP spray observed
- Move TCPs out to 2.5 σ → data taking with greatly reduced background
- Re-population of the gab and background returning → Repeat last 3 steps (7 times)

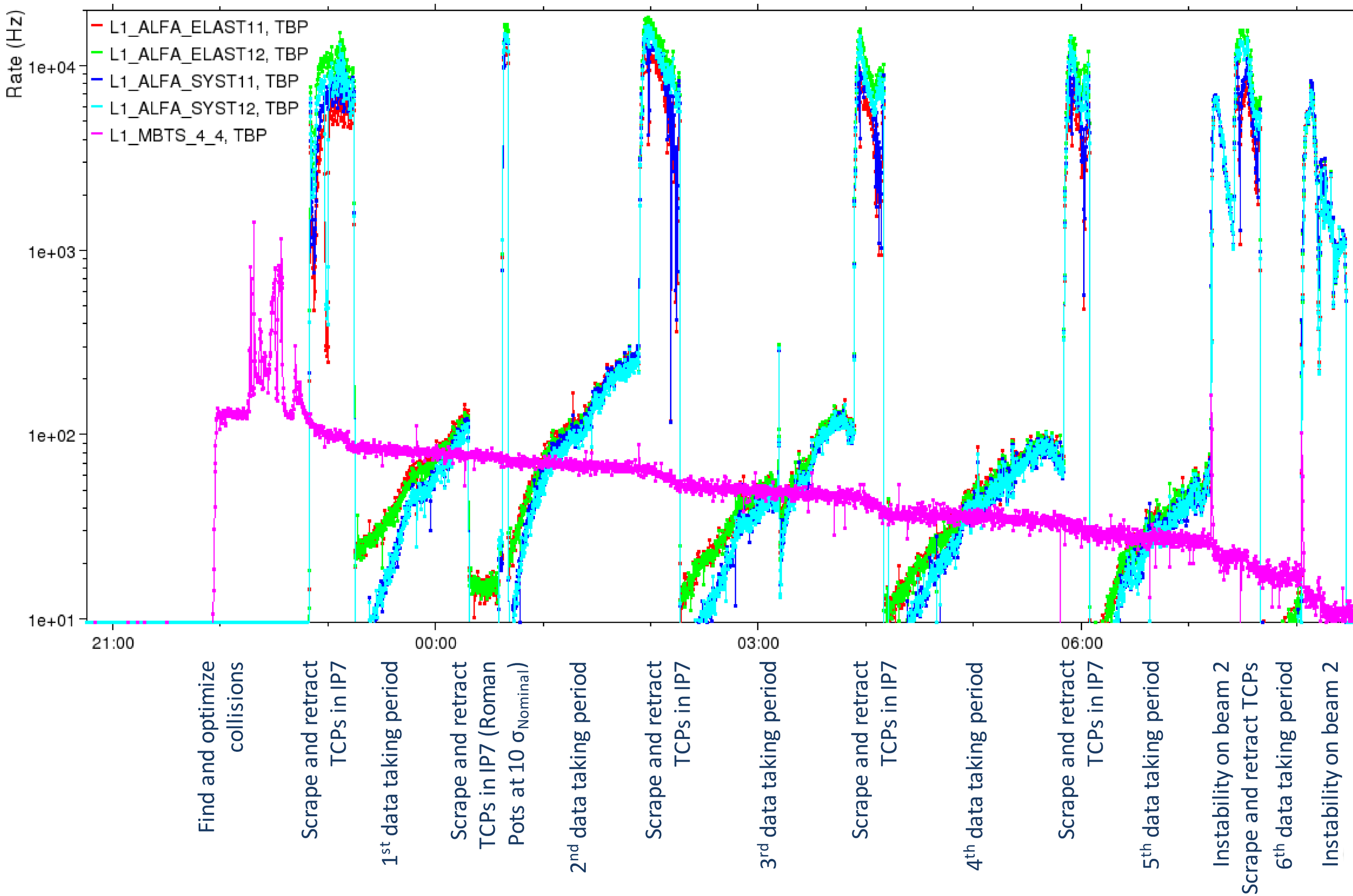


Historical view of the ALFA experiment

- ALFA subdetector was approved in January 2008
- 7 institutes and 25 members
- January 2011 all detectors were installed in the tunnel
- 20th of September, ALFA made a successful physics run with the special LHC optic β^*=90m (remind you that the nominal LHC β^*~1-2m)
- In this run detector edges go to 5mm from the beam center for the first time

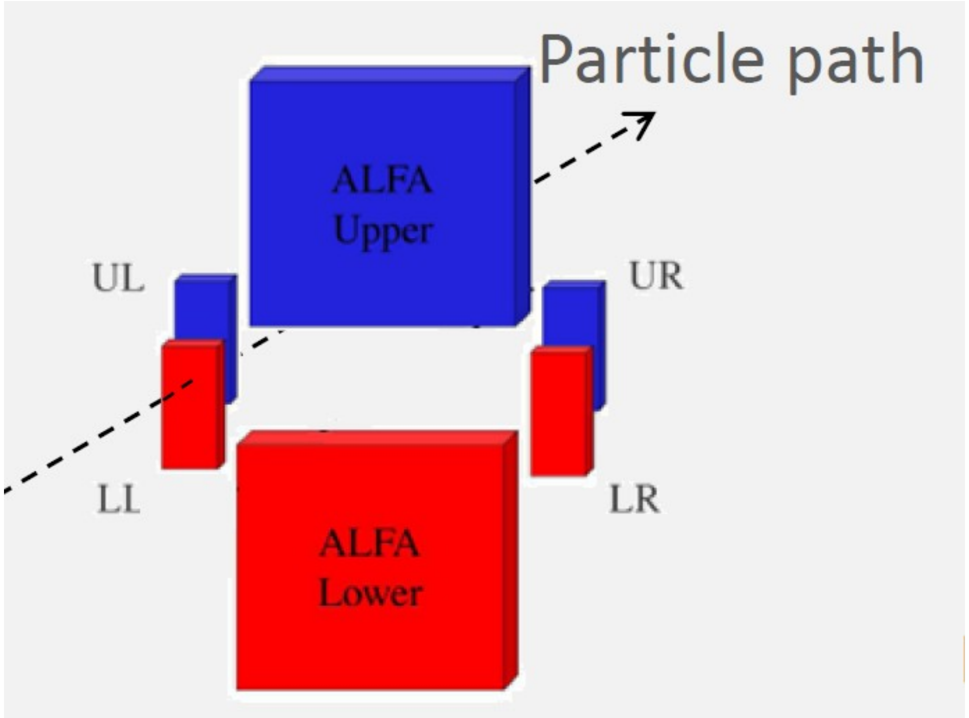


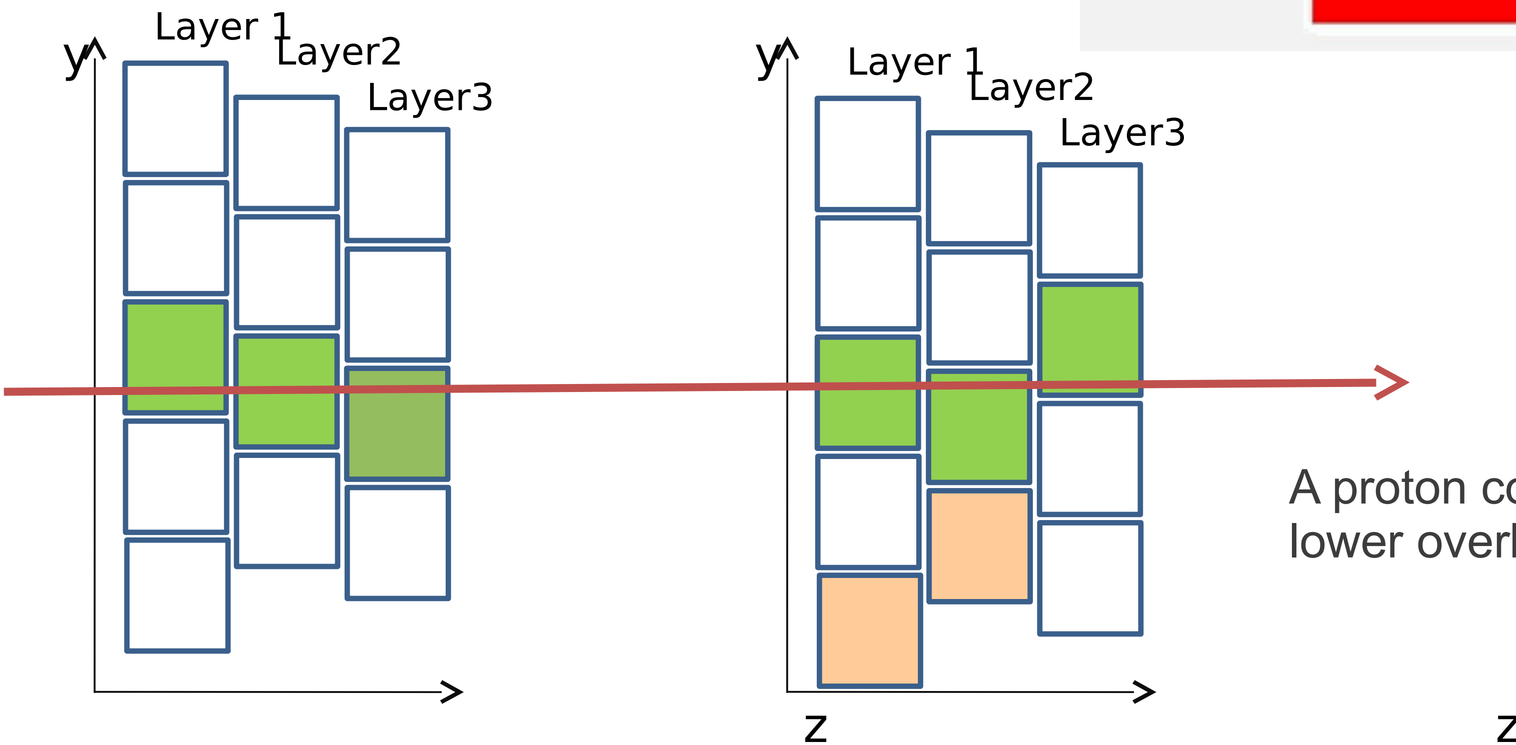
2012 β*=1000 m run



ALFA detector and stations

2 overlap detectors are dedicated to the distance measurement between upper and lower station and the local rotation angle





A proton comes through upper and lower overlap in one side

ALFA detector and stations

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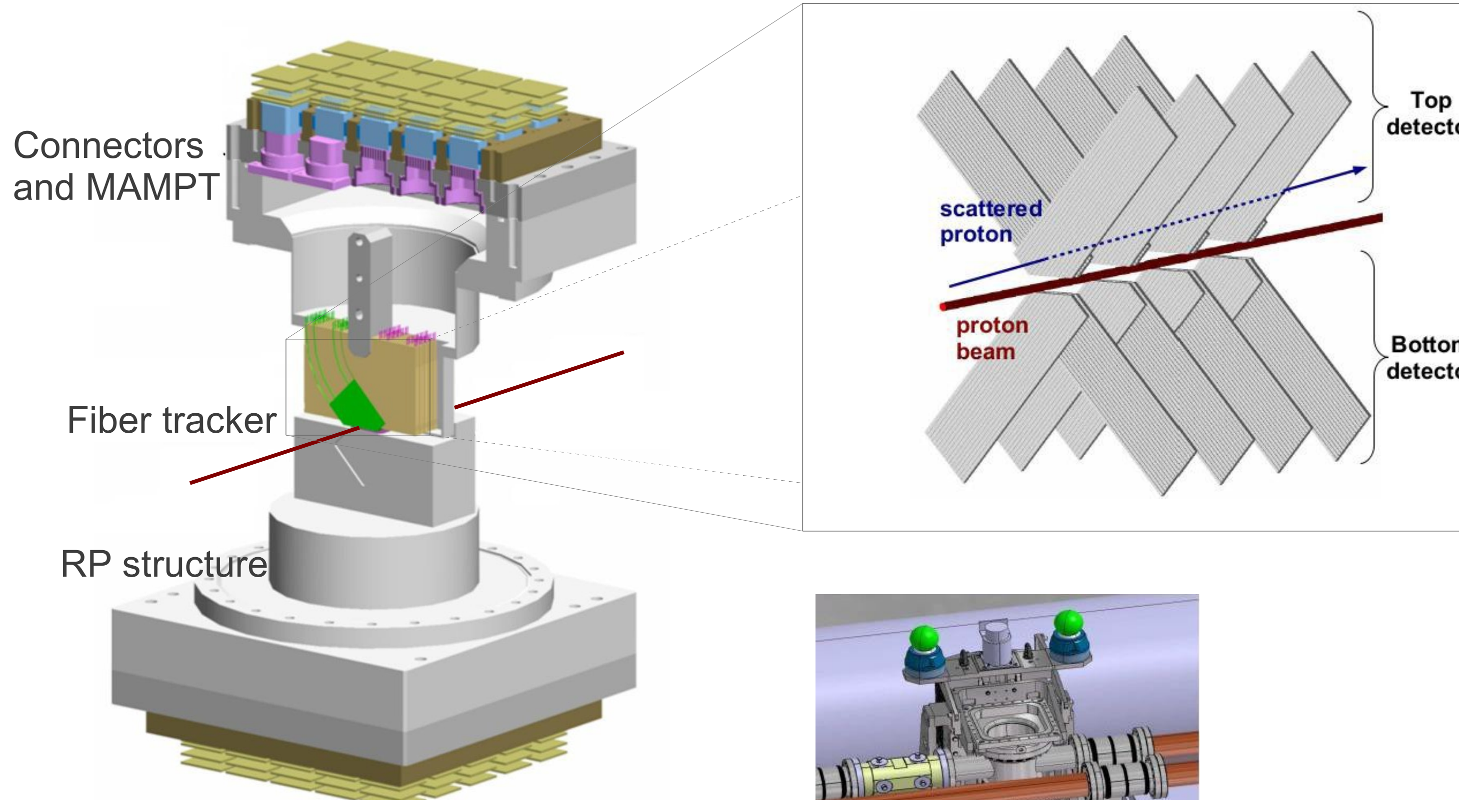
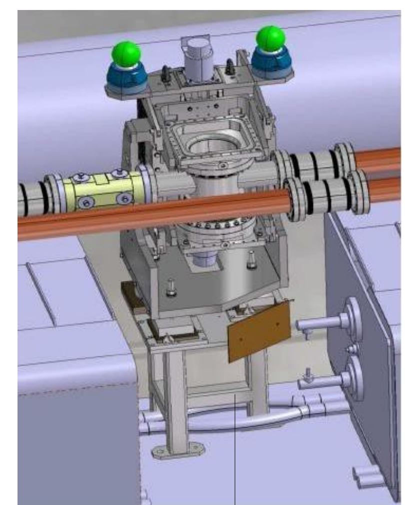
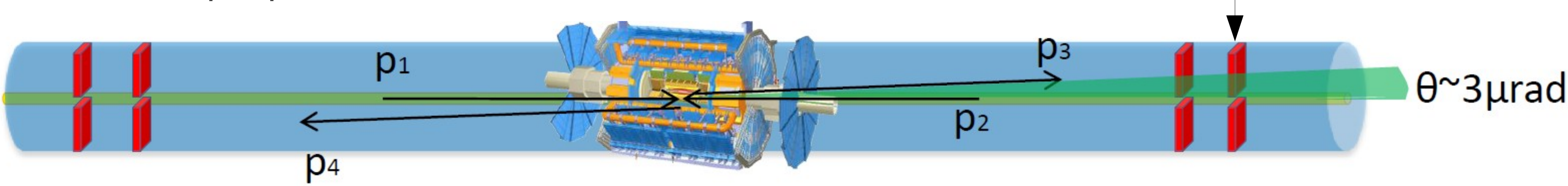




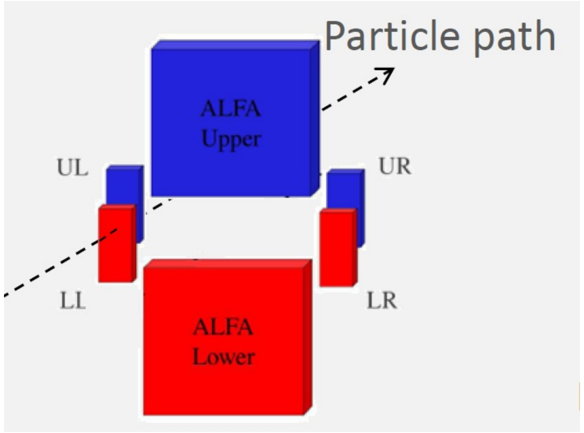
Station in the tunnel

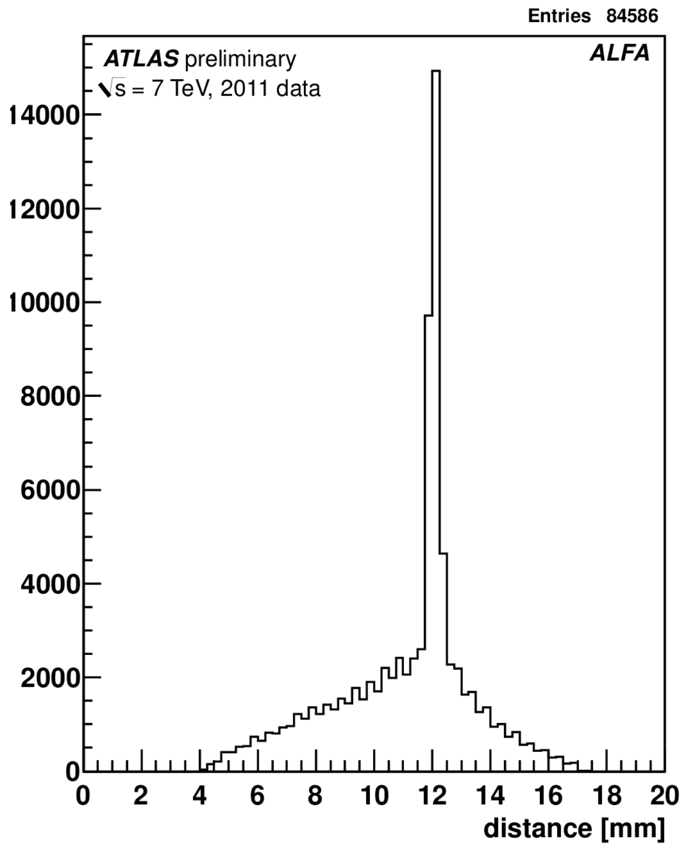
- Fibers have a good radiation hardness.
- 20 layers of fibers ensure the 30 μm of resolution
- Fibers have been cut with 45° for to reduce the dead space at the edge.
- An overlap system between upper and lower detector to reach 10 μm precision on the distance

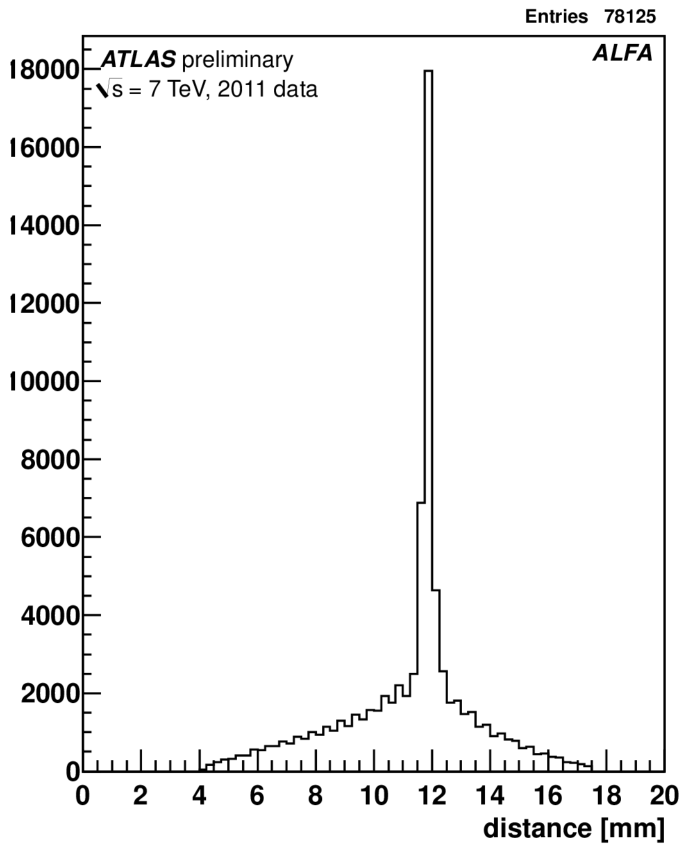


Overlap detector data

Overlap data distribution shows a distance peak which can be used to determine the distance between upper and lower detector







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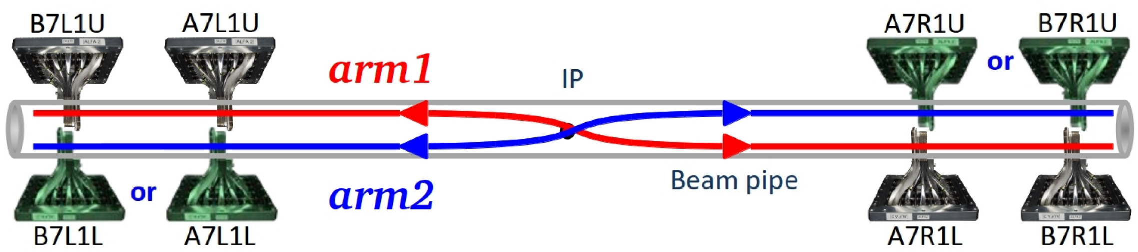
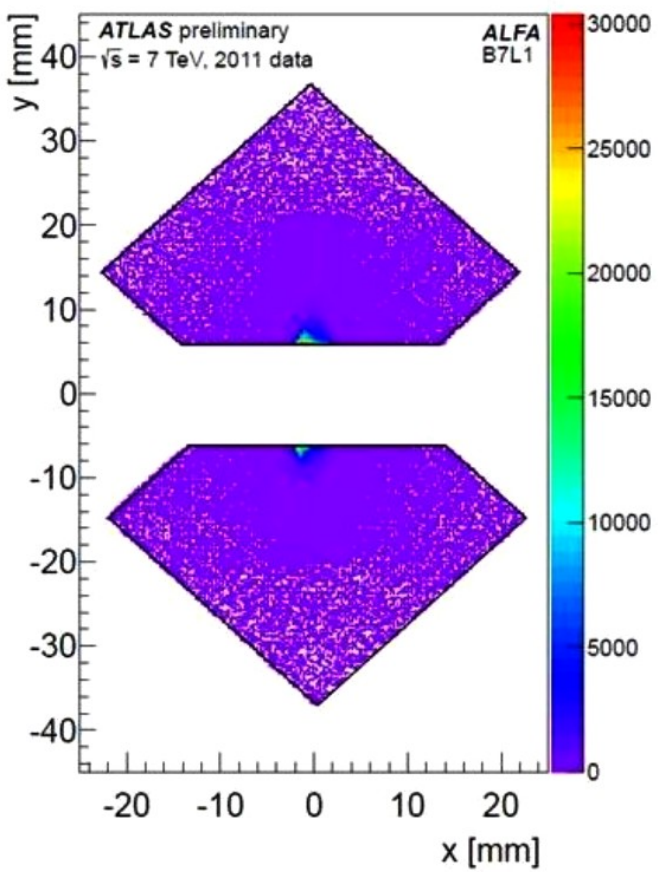
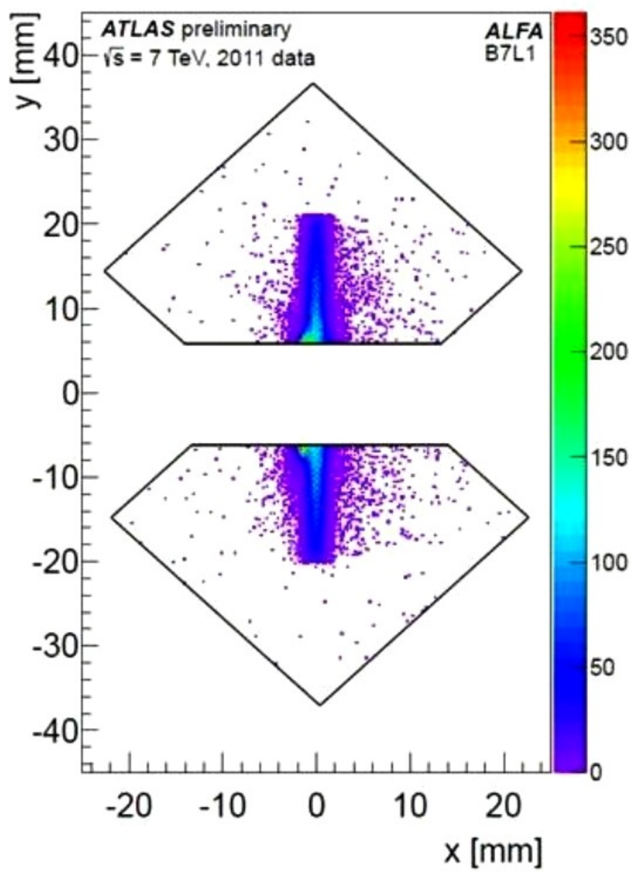


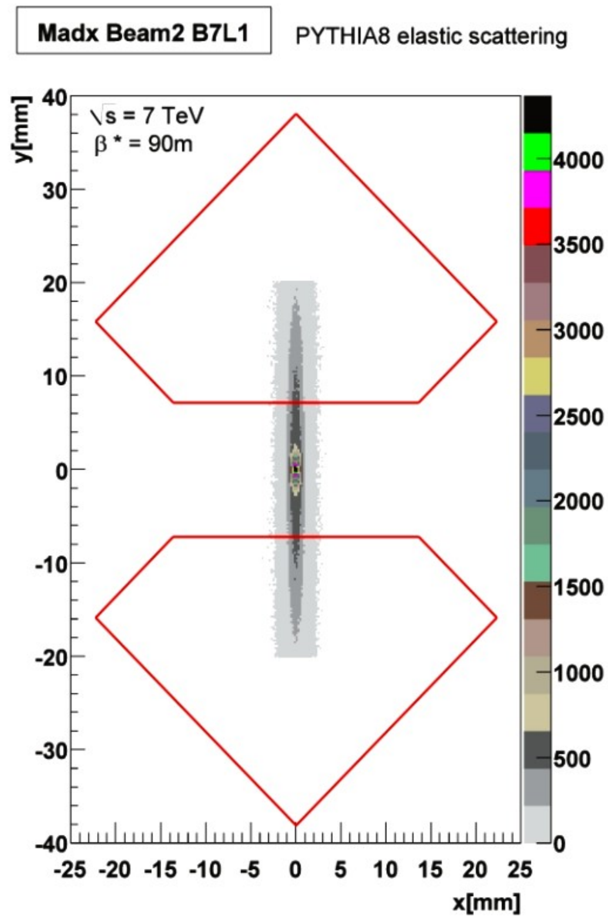
Track pattern before cuts



Track pattern for only elastic candidates

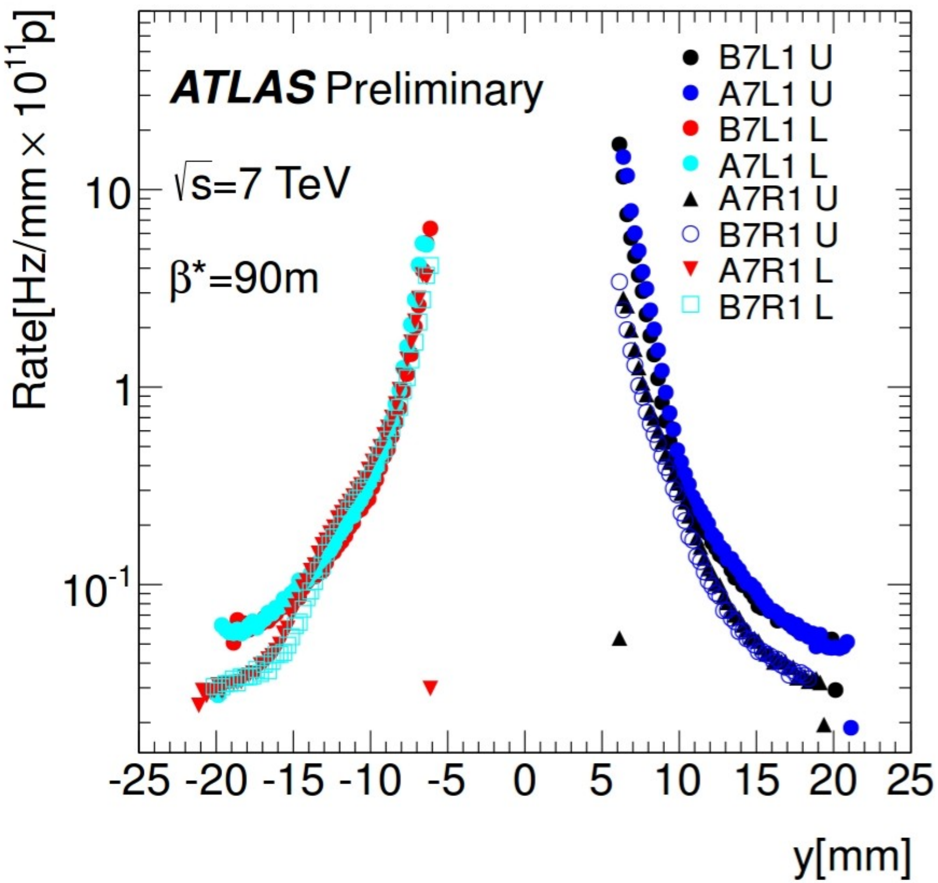


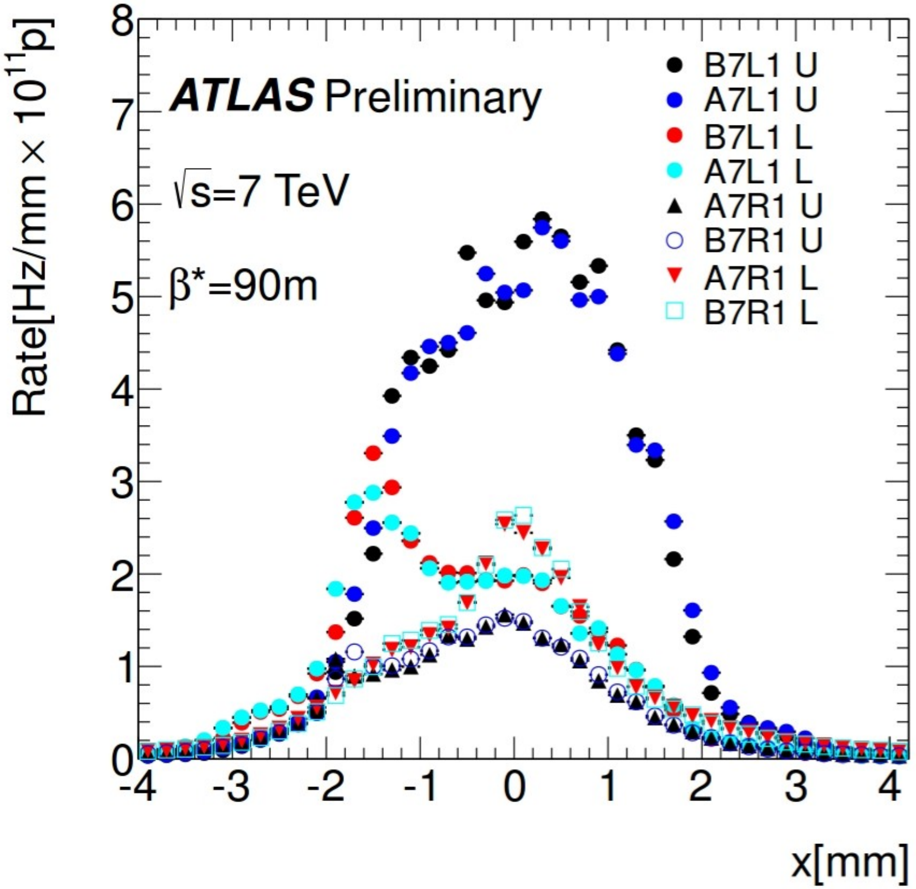
Simulated track pattern for elastic



LHC beam halo background rates

The background rate density is normalized to the current in each bunch group per beam. The detectors were placed at a distance of about 5.5mm from the beam centre. The detectors B7L1 are located at the A-side of ATLAS at a distance of 241m from IP1, the detectors A7L1 at 237m, the detectors A7R1 resp. B7R1 are at the C-side at distances of 237m resp. 241m, and labels U resp. L denote the upper and lower detectors.





ALFA performance plots at β*= 90m

Reconstructed scattering angle correlation between left and right side for elastic candidates after background rejection cuts a) in the vertical and b) in the horizontal plane.