Elastic scattering
and
total cross section in ATLAS

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On behalf of the ATLAS collaboration

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Outline

- Principle of the measurement
- The ALFA detector
- Luminosity and total cross section determination
- Precision of the measurement

Introduction

- The ALFA detector is designed to perform an absolute measurement of the luminosity at the interaction point of ATLAS and the total cross section with a precision of a few percent using elastic scattering

- This measurement will allow the calibration of all the detectors which response scales with the luminosity and especially the LUCID detector that will provide a bunch per bunch luminosity determination during the data taking of ATLAS

- Measuring the differential elastic cross section as a function of the 4-momentum transfer squared t will also provide a precise measurement of the nuclear slope B and the ratio of the real over the imaginary part of the forward elastic scattering amplitude ρ

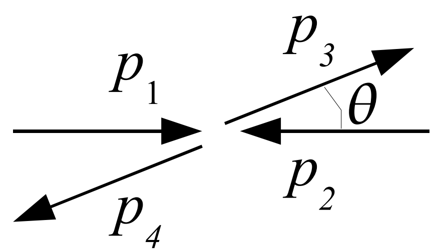
Principle of the measurement

• The rate of elastic scattering is linked to the total interaction rate through the optical theorem, which states that the total cross section is directly proportional to the imaginary part of the nuclear forward elastic scattering amplitude extrapolated to zero momentum transfer:

$$\sigma_{tot} = 4\pi \cdot \Im\left[F_{el}(t=0)\right]$$

where at small values of t:

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



The differential elastic cross section is linked to the luminosity through the number of event as a function of the t-value N_{el}:

$$\frac{dN_{el}}{dt} = \mathscr{L} \frac{d\sigma_{el}}{dt}$$

Principle of the measurement

- At small *t*-values the differential elastic cross section can be written as:

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

- Pure coulombian term:

$$\frac{d\sigma_c}{dt} = \frac{4\pi\alpha^2(\hbar c)^2 G(t)^4}{|t^2|}$$

with $G(t) = \left(1 + \frac{|t|}{0.71}\right)^{-2}$ Proton electromagnetic form factor

- Pure nuclear term:

$$\frac{d\sigma_n}{dt} = \frac{\sigma_{tot}^2(1+\rho)^2}{16\pi(\hbar c)^2}\exp(-B|t|)$$

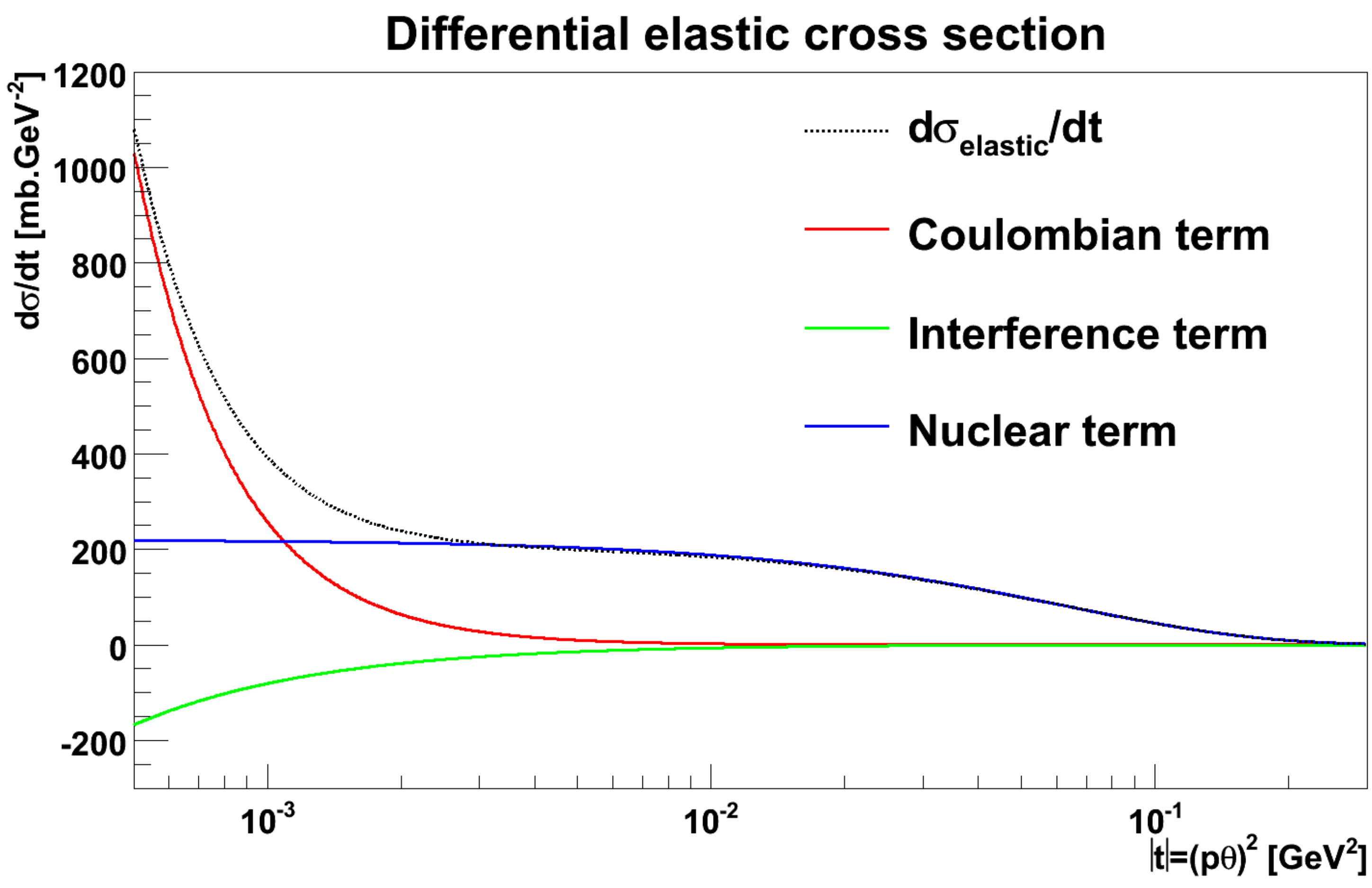
- Interference term:

$$\frac{d\sigma_{cn}}{dt} = -\frac{\sigma_{tot}\alpha(\rho - \alpha\phi(t))G(t)^2}{|t|}\exp(-B|t|/2)$$

with $\phi(t) = \ln\left(\frac{2}{B|t|}\right) - \gamma$ Phase of the Coulomb amplitude relative to the nuclear amplitude

Principle of the measurement

$$\sigma_{tot} = 100\ mb,\quad B = 18\ GeV^{-2},\quad \rho = 0.13$$

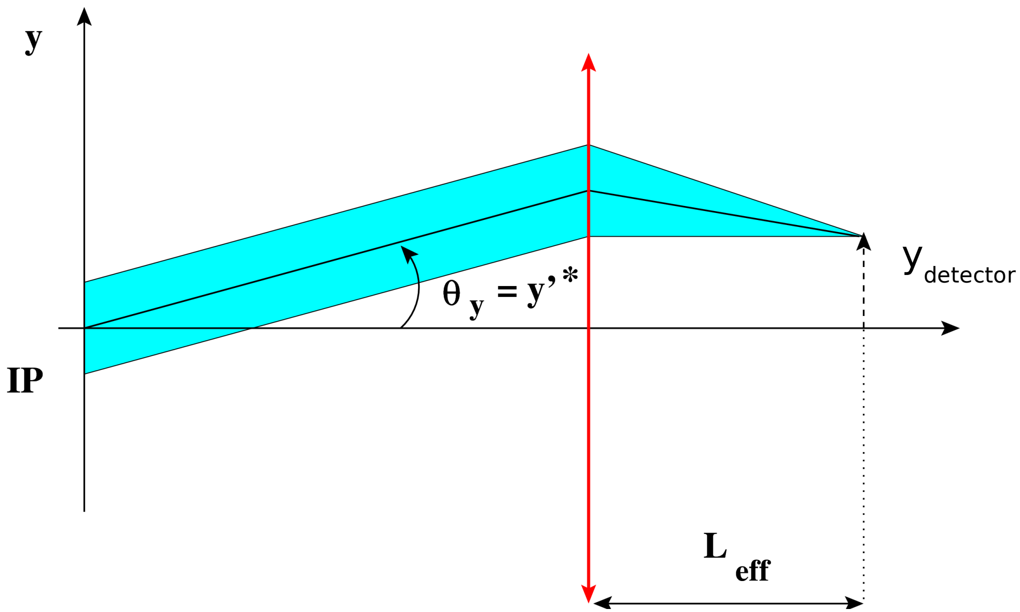


Principle of the measurement

- To obtain the 2-3 % absolute precision we must approach the coulombian region as close as possible which implies a dedicated run

- Low luminosity runs 10^{27} $cm^{-2}.s^{-1}$ (43 bunches of 10^{10} particles)

- Dedicated optics:
  - No crossing angle
  - High β^* of 2625 m to minimize the angular divergence
  - Parallel-to-point focusing with 90° phase advance in the vertical plane to focus particles with the same scattering angle at the same vertical position in the detector



Principle of the measurement

- The minimum t achievable is given by an unscattered particle in the horizontal plane and with the minimum scattering angle interceptable in the vertical one:

$$\theta_{IP,y} = \frac{y}{\sqrt{\beta \beta_{IP}}} \quad \Longrightarrow \quad -t_{min} = (p\,\theta_{min})^2 = \frac{p^2 y_{min}^2}{\beta \beta_{IP}}$$

With $y_{min} = n_{min}\sigma_y = n_{min}\sqrt{\epsilon \beta}$

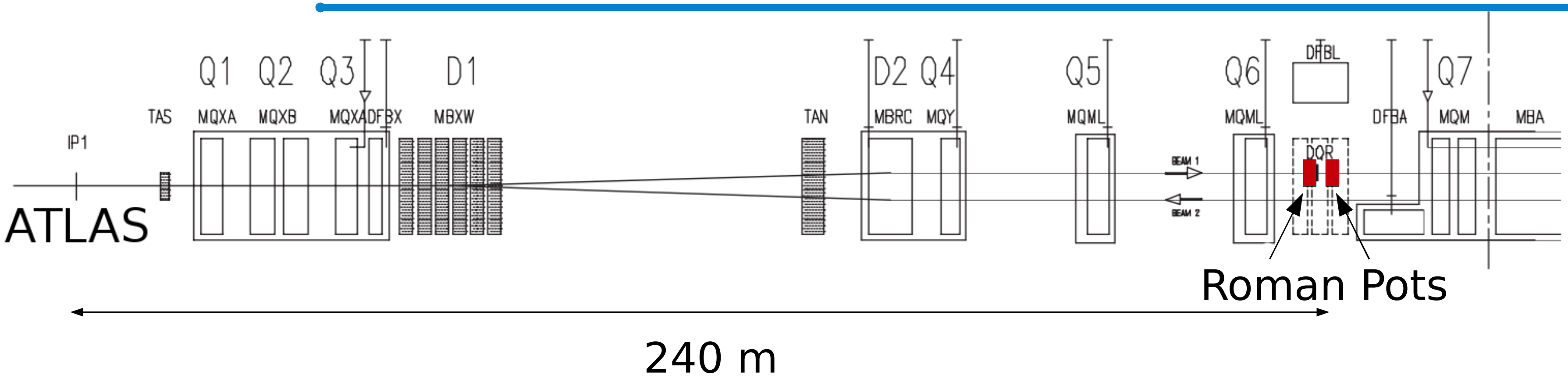
We obtain the following formula:

$$-t_{min} = p^2 n_{min}^2 \frac{\epsilon}{\beta_{IP}}$$

$$\left.\begin{array}{r} \epsilon_N = 1\ \mu\,mrad \\ n_{min} = 12 \\ p = 7\ TeV \end{array}\right\}$$

$$t_{min} = 3.7\,10^{-4}\,GeV^2 \equiv \theta_{IP,y} = 3\,\mu\,rad$$

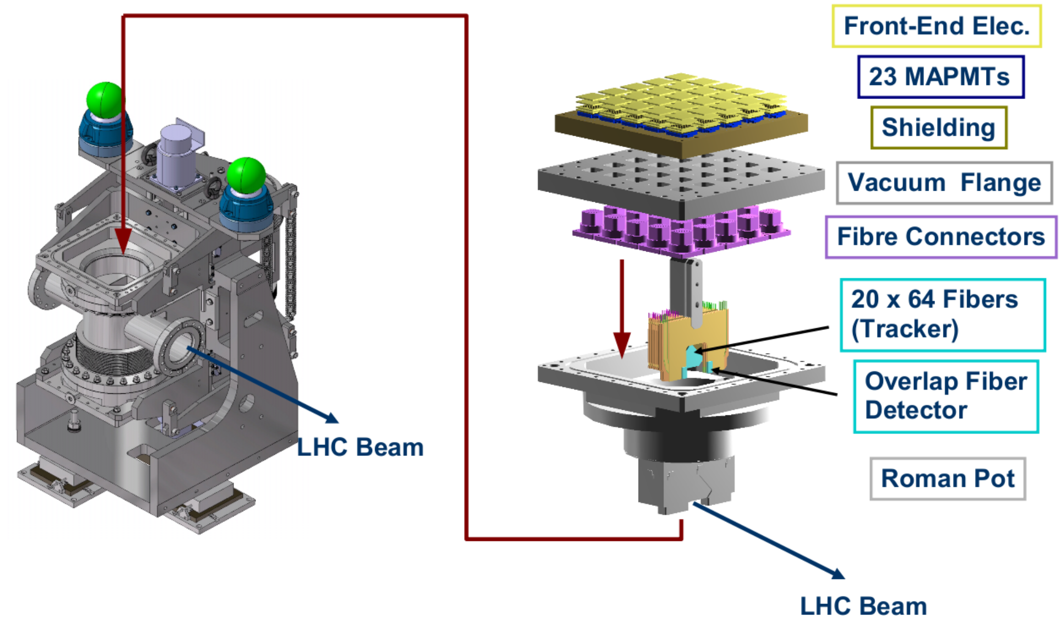
The ALFA Detector



- **ALFA** ≡ **A**bsolute **L**uminosity **F**or **A**TLAS

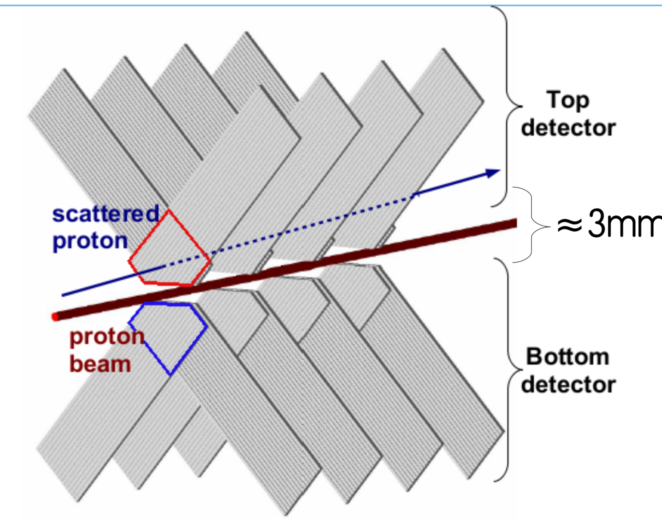
- Two roman pot stations in the forward direction on each side of the interaction point of ATLAS. Each station contains an upper and a lower detector.

- Each detector is made of a 20x64 scintillating fibers tracker readout by a 64 channels MAPMT. The compact front end electronics is mounted on top of the MAPMT.

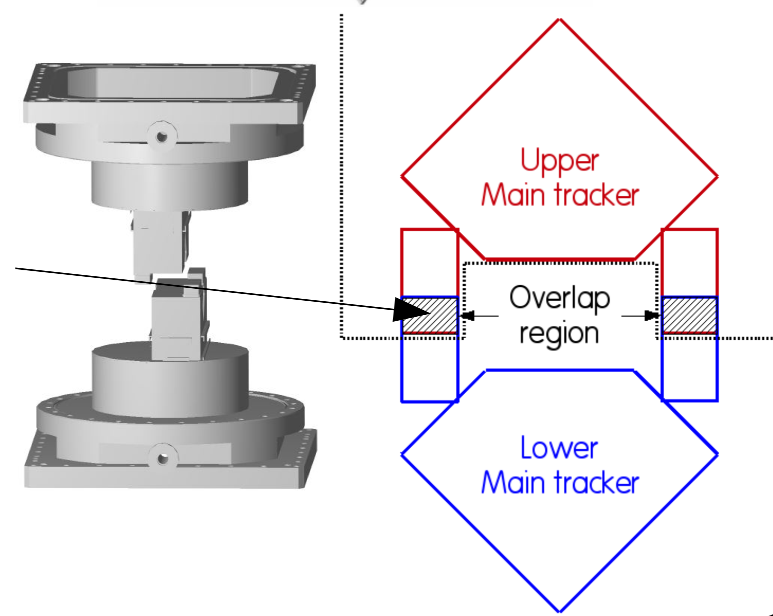


The ALFA Detector

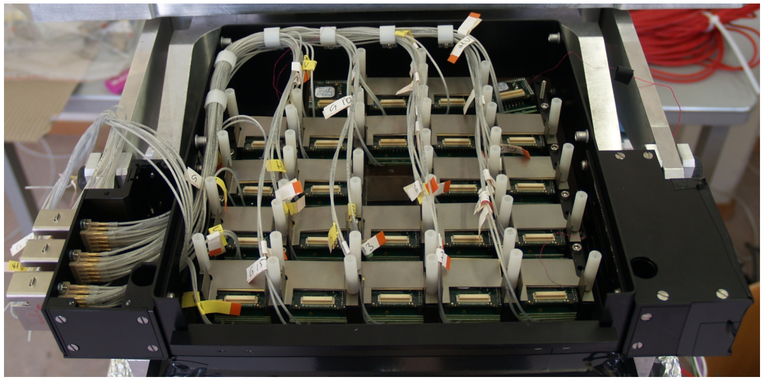
- The tracker:
  - 500 µm width squared scintillating fibers
  - 70 µm staggering between consecutive layers
    → 30 µm resolution in x and y



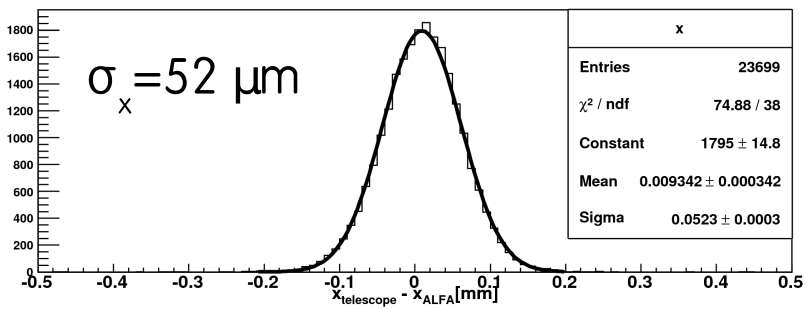
- The overlap detectors:
  - In order to determine the *t*-scale, we must know very precisely the relative position between the lower and the upper detectors
  - The overlap detectors are meant to measure this distance with a precision up to 10 µm
  - Mecanically fixed to the main tracker these detectors (3x30 horizontal scintillating fiber tracker) overlap when the lower and the upper parts are brought to data taking position

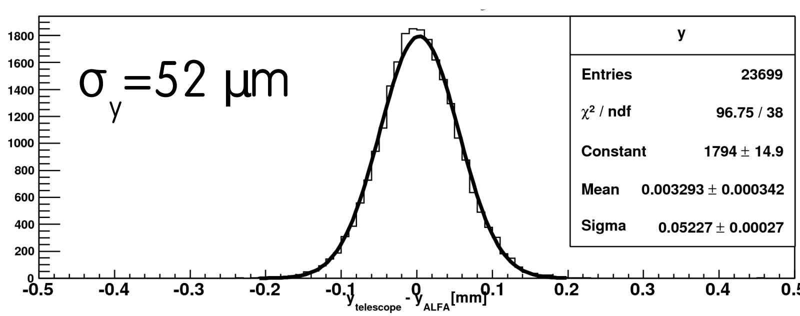


The ALFA Detector



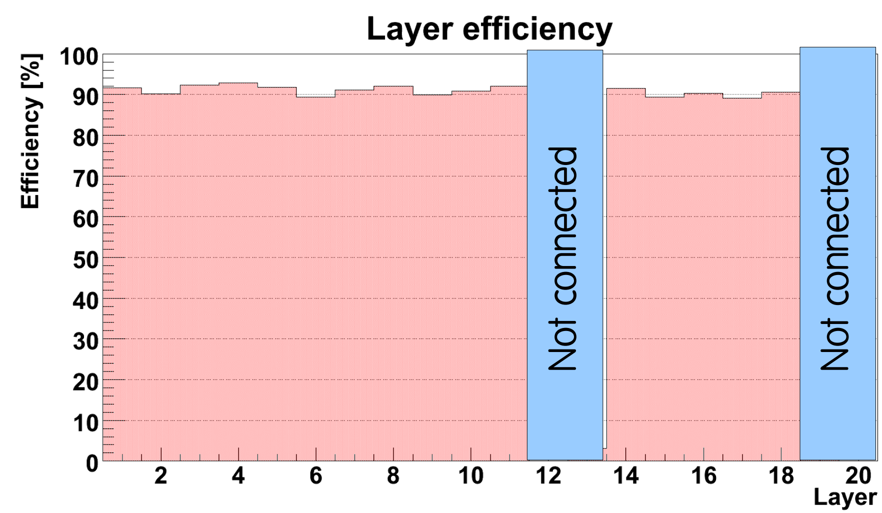
Resolution for half a detector





August 2008
Test-Beam results

180 GeV Pions



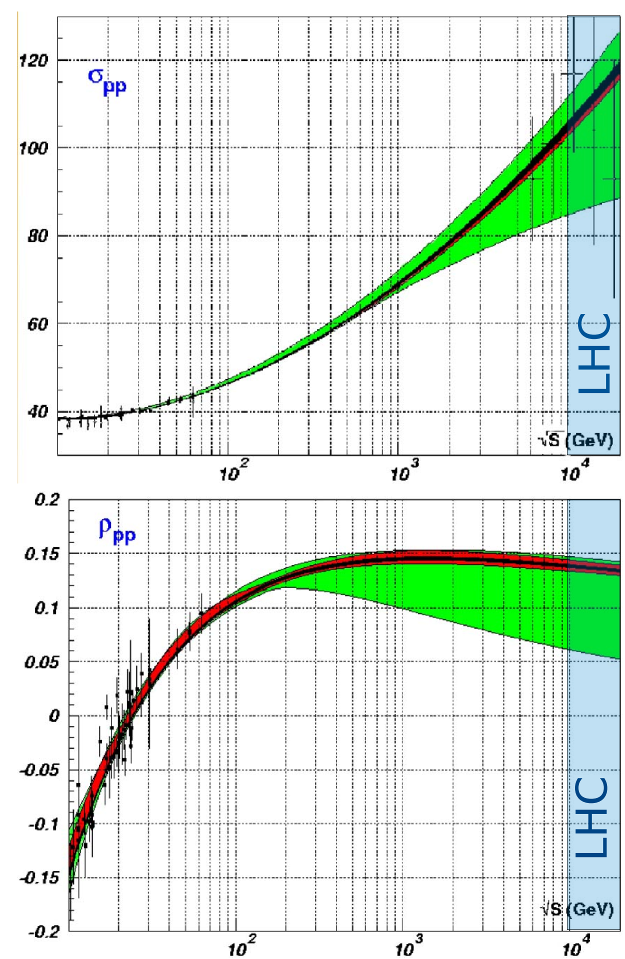
Measurement procedure

- The overall acceptance (optics and detector) cannot be determined empirically. It has to be done using a full simulation.

- We use a three steps simulation:
  - Generation using Pythia 6.4 or 8.1
    - Generation range: $4\ 10^{-5} \leq -t \leq 0.3\ \mathrm{GeV}^2$
    - $\sigma_{tot} = 100$ mb, $\rho = 0.13$ (From COMPETE[1]) and $B = 18\ \mathrm{GeV}^{-2}$
  - Transport using MAD-X thintrack
  - Reconstruction of the t-spectrum

- This will allow to correct the detected spectrum including all systematic effects.

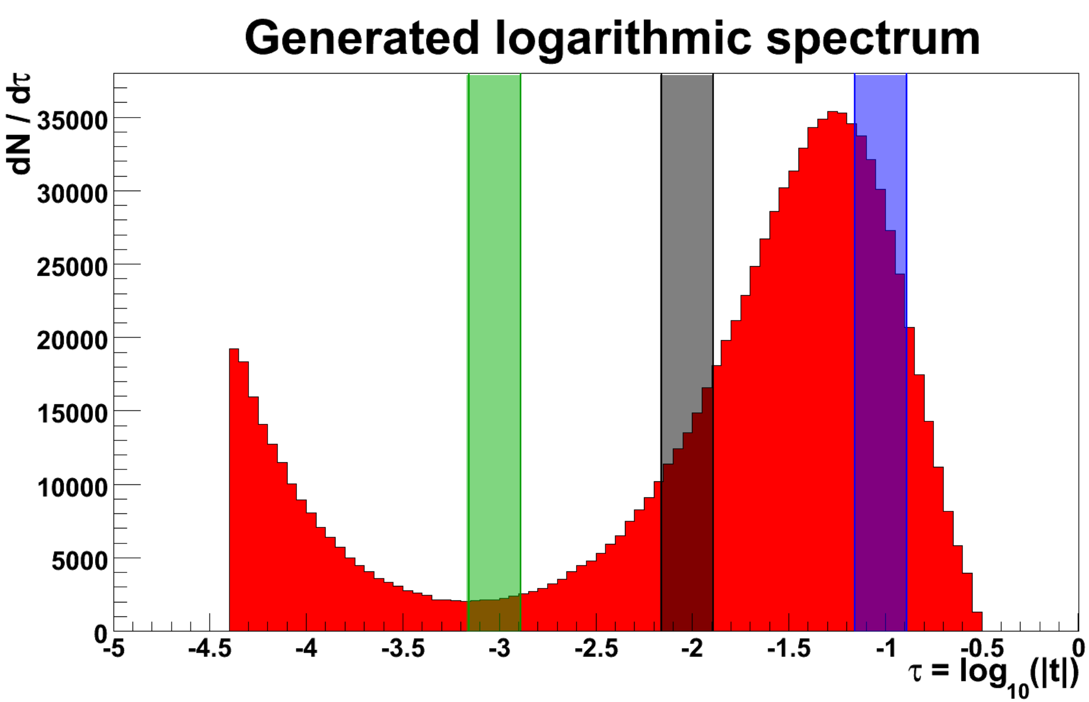
COMPETE



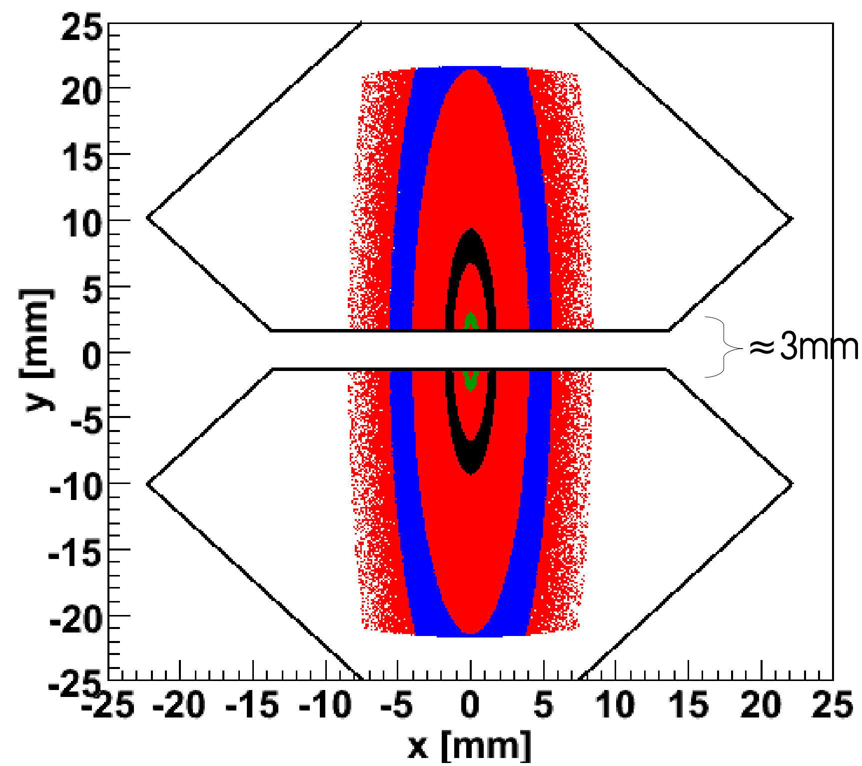
[1] Cudell JR, Ezhela VV, Gauron P, Kang K, Kuyanov YV, Lugovsky SB, et al. Benchmarks for the forward observables at RHIC, the Tevatron-run II, and the LHC. Physical review letters. 2002 Nov

Measurement procedure

Example with 1M events



Scattering picture at the roman pot

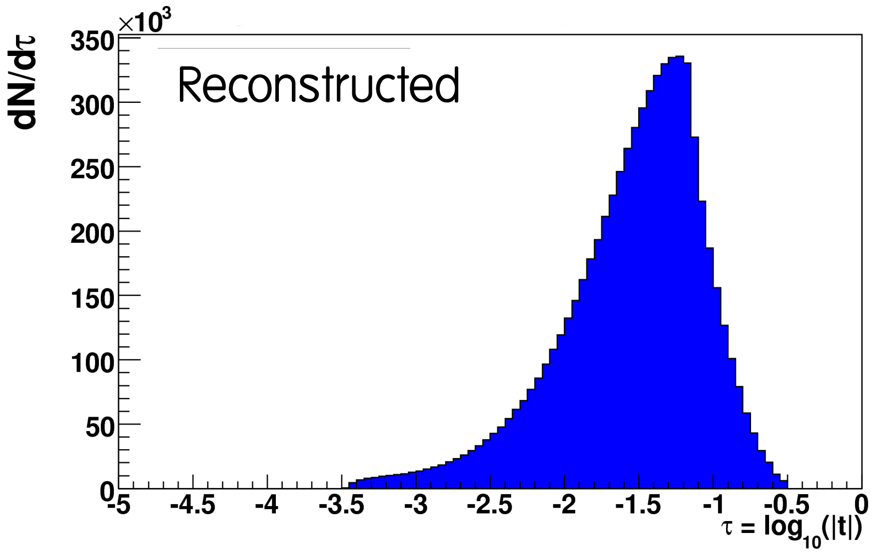


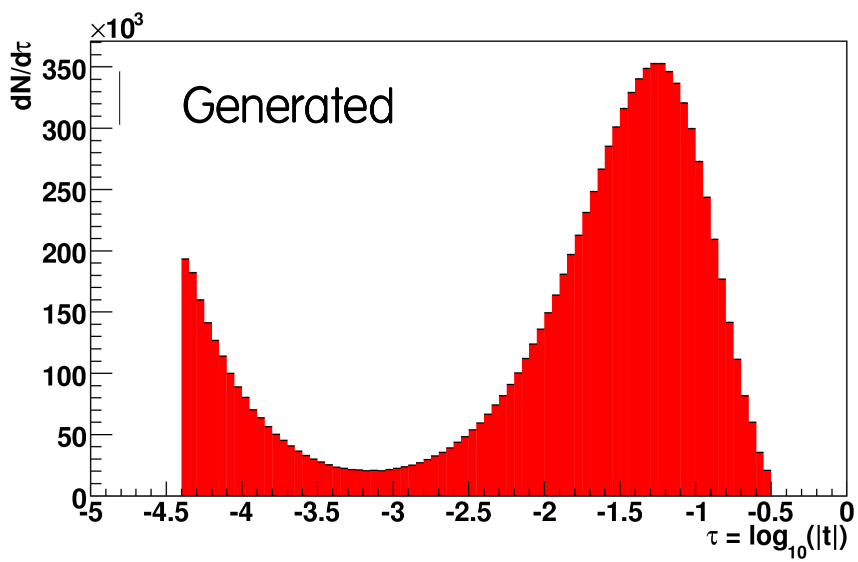
$0.0007 < -t < 0.0013$ GeV^2

$0.007 < -t < 0.013$ GeV^2

$0.07 < -t < 0.13$ GeV^2

Measurement procedure





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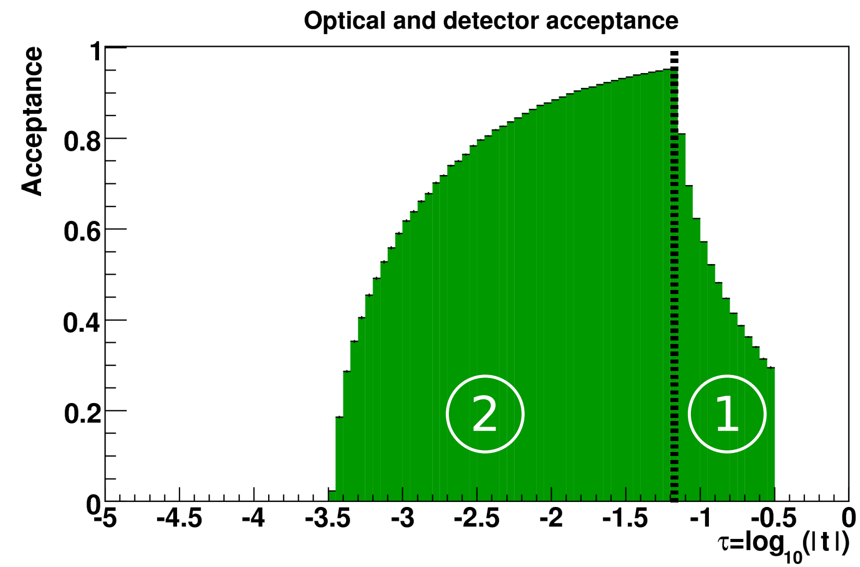
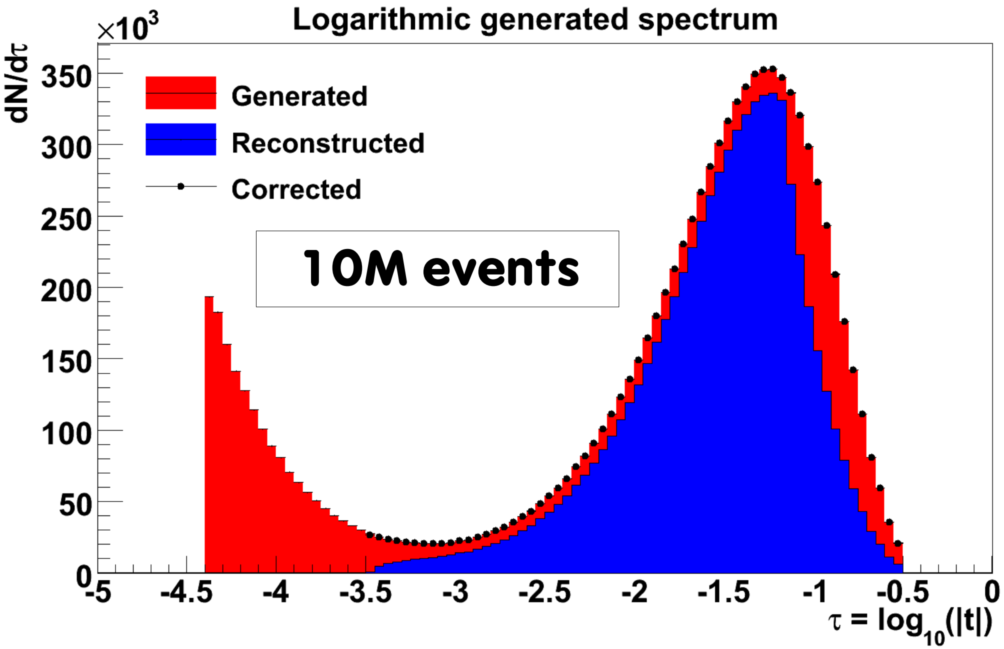
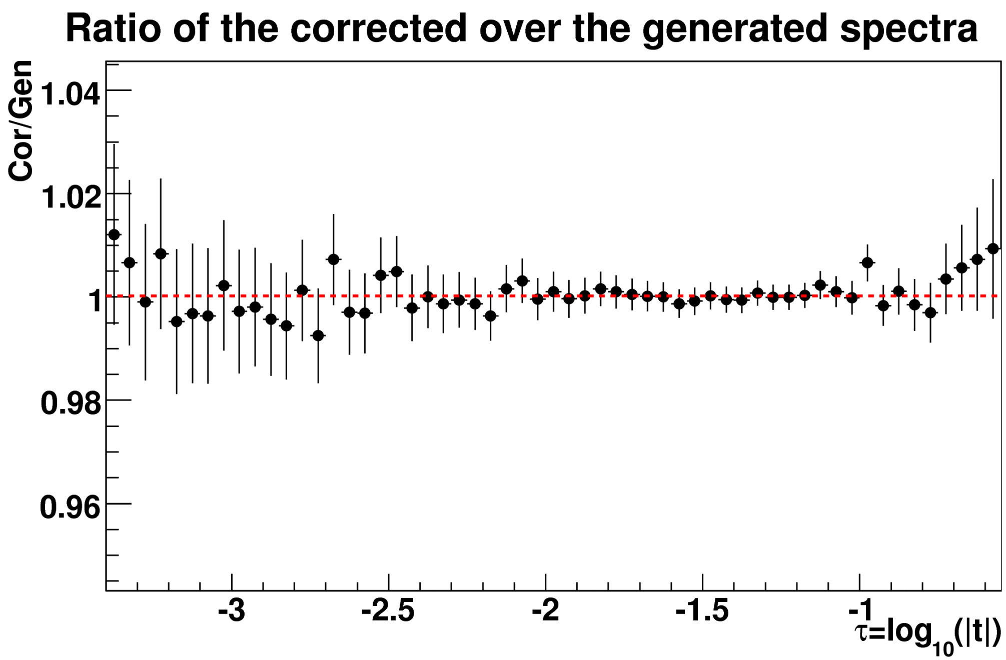
Example with 10M events
Acceptance = 67 %



1- Losses due to accelerator acceptance (Magnet aperture)
2- Losses due to detector acceptance (Effect of the distance to the beam center)

Measurement procedure





The luminosity, the total cross section, *B* and *ρ* are determined by fitting the corrected spectrum represented by the black dots on the left plot. Beeing at 12σ from the center of the beam does not allow to measure the pure coulomb contribution.

Precision of the measurement

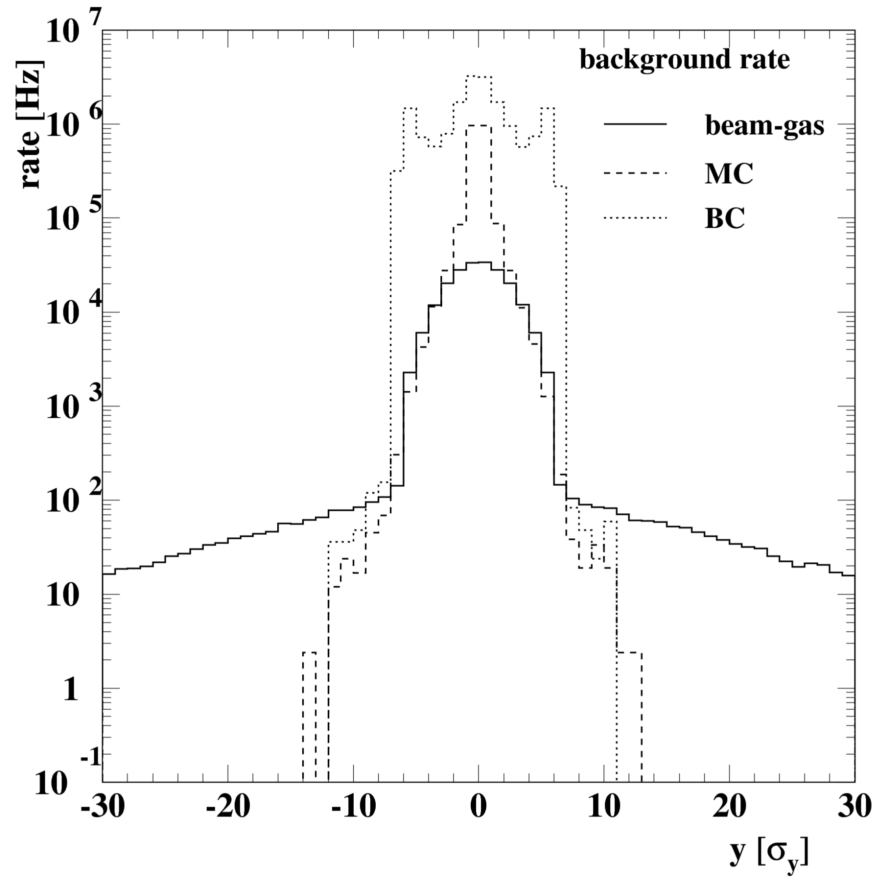
All figures in brackets are the systematic uncertainties obtained on the luminosity for 10M events

- Beam properties
  - Nominal energy measurement (0.2 %)
  - Angular divergence (0.3 %)
  - Energy dispersion (< 1‰)
  - Beam spread (< 1‰)
  - Measurement of the optical parameters (β^*, phase advance...) (1.2 %)
- Detector properties
  - Resolution (0.3 %)
  - Detector alignment (1.3 %)
  - Geometrical detector acceptance (0.5 %)

Precision of the measurement

Background

- Main sources:
    - Non elastic processes (e.g. Single Diffraction)
    - Halo events
        - Beam-gas
        - Momentum and betatron cleaning
- Tagging and substraction:
    - Back to back topology
    - Acollinearity
    - Vertex reconstruction



Precision of the measurement

Summary

Nominal result for $\int_{100h} \mathscr{L} = 3.6\ 10^{32}\ cm^{-2}$

	[%]
Beam properties	1.2
Detector properties	1.4
Backgroud substraction	1.1
Total uncertainty	2.1
Statistical error	1.8
Total	2.8

Conclusion

- All beam tests done so far have confirmed the detector behaviour and main parameters (layer efficiency, spatial resolution...)

- As a consequence, the final production and assembling is on going and all detectors should be calibrated and ready for next summer

- Extremely challenging measurement

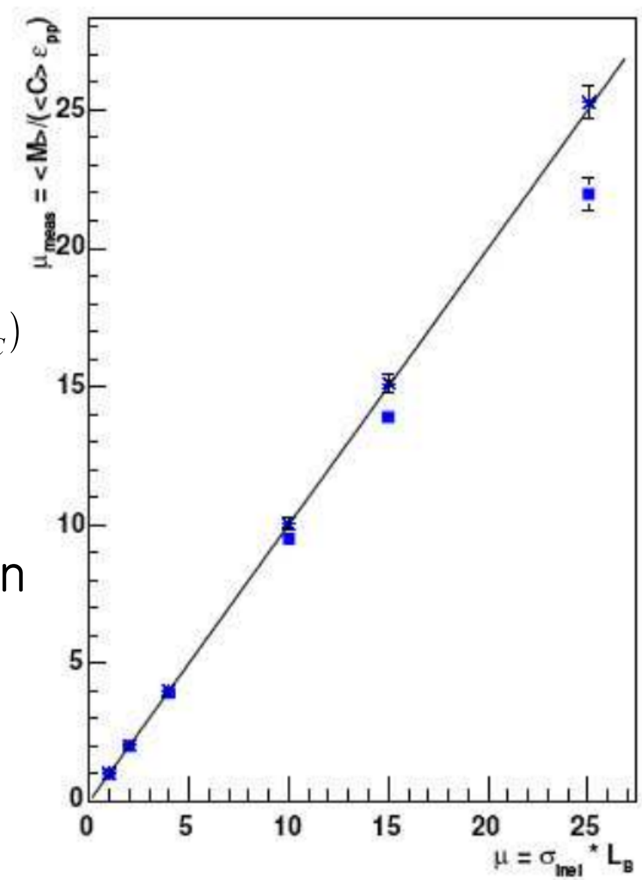
Thanks for your attention

Backup

- <u>LUCID (Luminosity measurement using Cerenkov Integrating Detector)</u>
  - Inelastic events intercepted for $5.5 \leq \eta \leq 6.1$
  - Rate of detected charged particle a luminosity
- <u>Extrapolation of the low luminosity measurement thanks to a perfect linearity:</u>

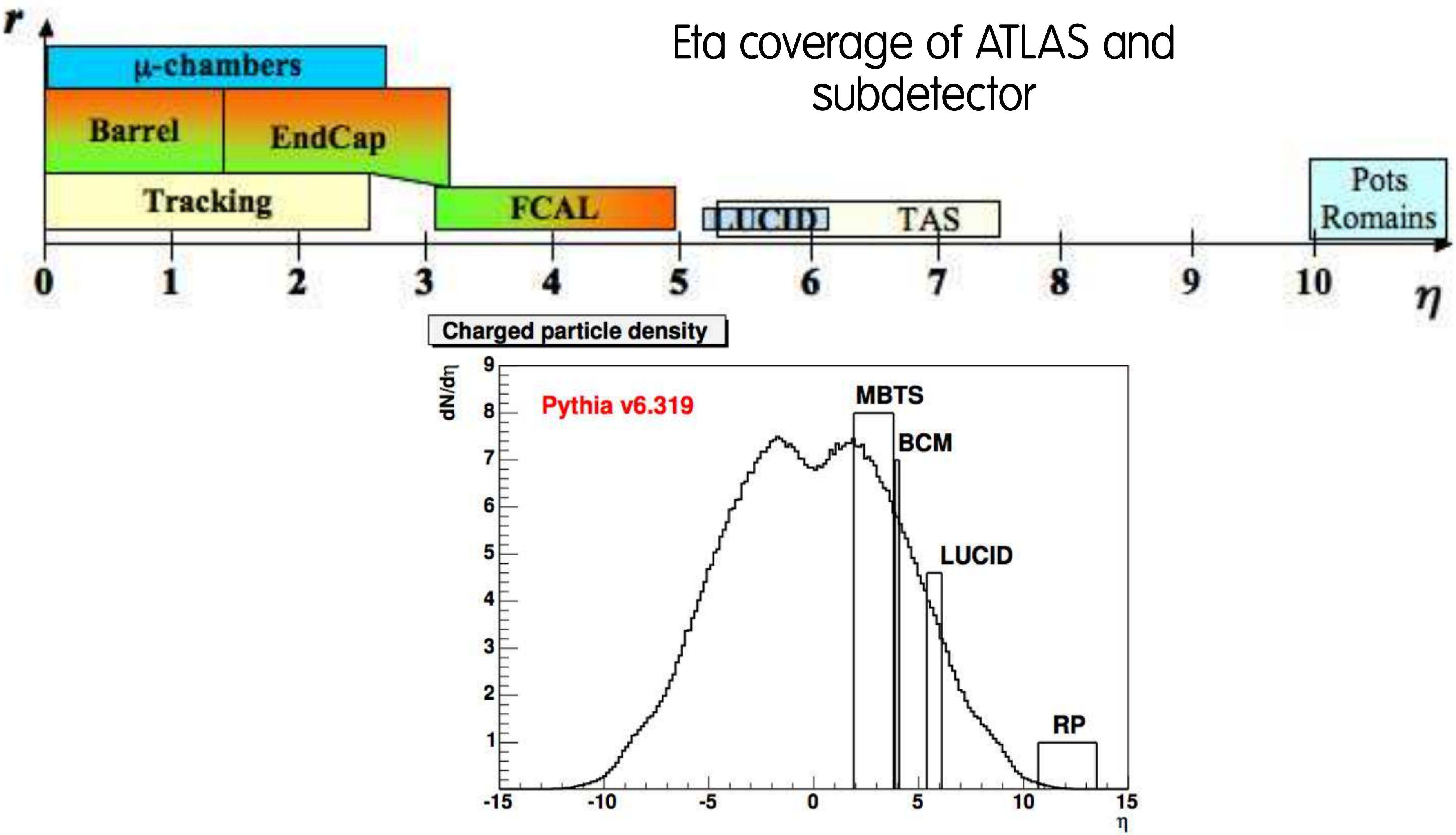
$$\dot{N} = (Nb\ pp\ interaction\ detected\ per\ bunch\ crossing\ \mu_{LUCID}) \times (Filling\ factor\ f_{BC})$$

- μ_{LUCID} must be determined at each luminosity:
  - Low: Nb of bunch crossing without detection / with detection
  - Medium: Nb of tubes recording some signal
  - High: Nb of charged particle detected



Backup

Eta coverage of ATLAS and subdetector



Backup

- Reconstruction method:

$$u = \sqrt{\beta/\beta^*}\,(\cos\phi + \alpha^* \sin\phi))\, u^* + \sqrt{\beta\beta^*}$$

$$u_L - u_R = 2\sqrt{\beta\beta^*}\sin\phi \cdot \theta_u^*$$

$$\theta_u^* = \frac{u_L - u_R}{2L_{eff,u}} \quad \text{with} \quad L_{eff,u} = \sqrt{(\beta\beta^*)}\sin\phi$$

If we consider the four RPs for the reconstruction it gives for the y axis:

$$\theta_{RP_{1,y}} = \frac{\frac{y_{RP_1}}{L_{eff_{1,y}}} - \frac{y_{RP_3}}{L_{eff_{3,y}}}}{2} \qquad \theta_{RP_{2,y}} = \frac{\frac{y_{RP_2}}{L_{eff_{2,y}}} - \frac{y_{RP_4}}{L_{eff_{4,y}}}}{2}$$

And finally :

$$t_{reconstructed} = \frac{(\theta_x^2 + \theta_y^2) \times (7\ TeV)^2}{4}$$

Backup

- Beam momentum calibration[1]:
  - Measurement of the central frequency

$$P = \frac{Ze}{2\pi} \oint B(s)\, ds = P_{dipole} + P_{quadrupole} + P_{other}$$

$$P_{dipole} = \frac{e}{2\pi} (BL)_d$$

$$P_{quadrupole} = -\frac{1}{\alpha} \frac{C - C_c}{C}$$

$$C_c = \frac{h \beta c}{f^c_{RF}}$$

α : momentum compaction factor
C: Actual orbit length
C_c: Central orbit length

  - Magnetic calibrations (Derive from magnetic calibration curves of the dipole)

  - Energy calibration with ion beams

[1] J. Wenninger , Beam momentum calibration at the LHC, LHC project note 334 2004, Jan

Backup

Ratio of the differential elastic cross section without the CNI contribution over the one with the CNI