Physics prospects with the ALFA and AFP detectors at ATLAS

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on behalf of Forward Detector Group of ATLAS collaboration

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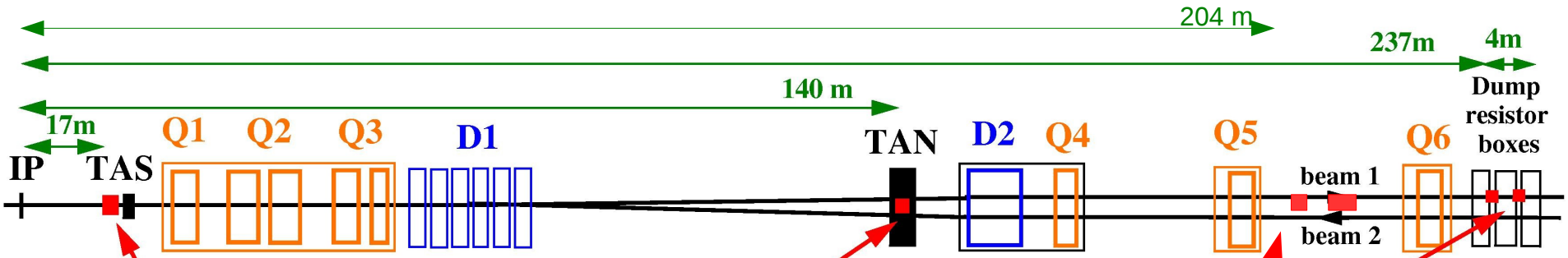
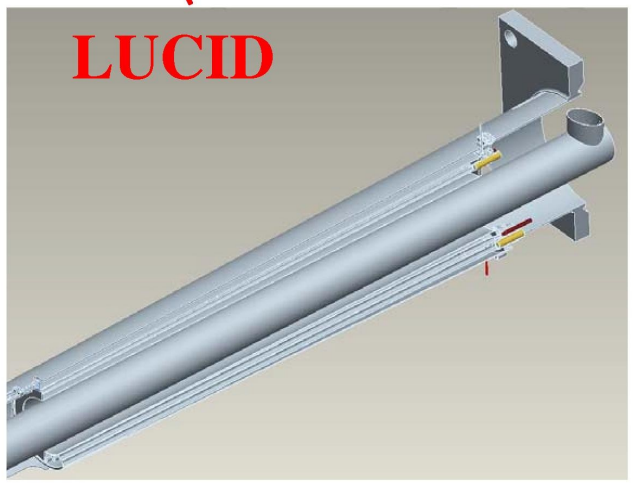
Outline

- ATLAS Forward Region
- ALFA
  - principles and aim
  - physics
  - data taking
- AFP
  - principles and aim
  - physics
- Summary & Future prospects

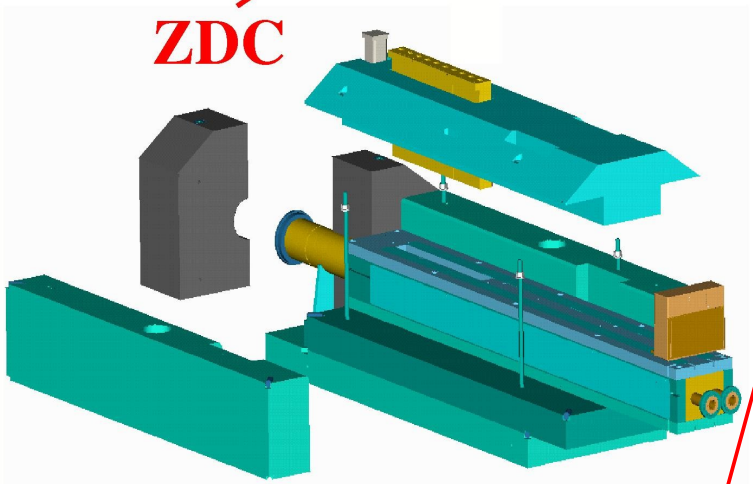
ATLAS Forward Region



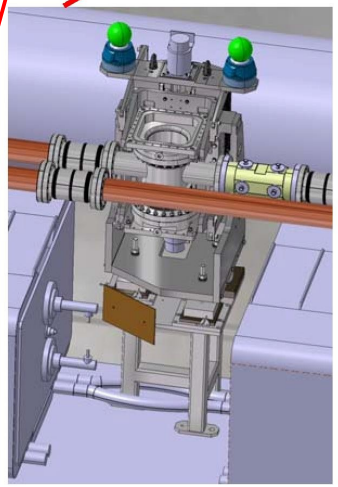
LUCID



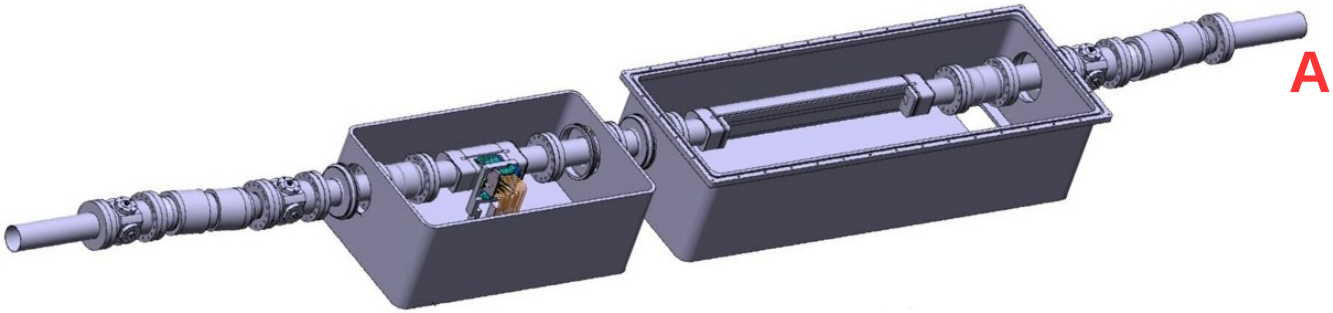
ZDC



ALFA



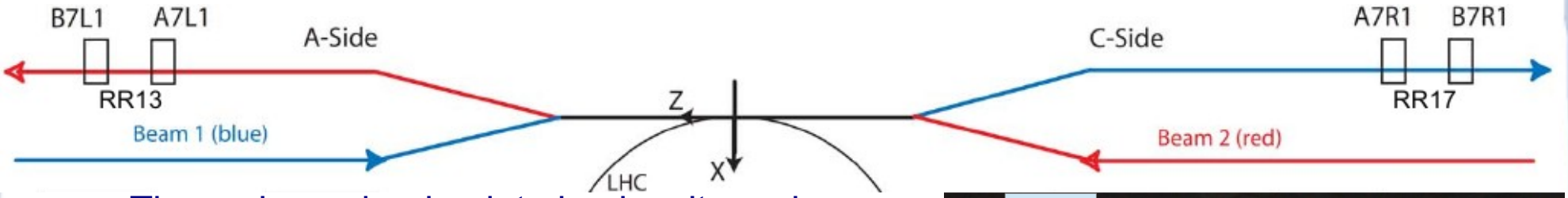
AFP



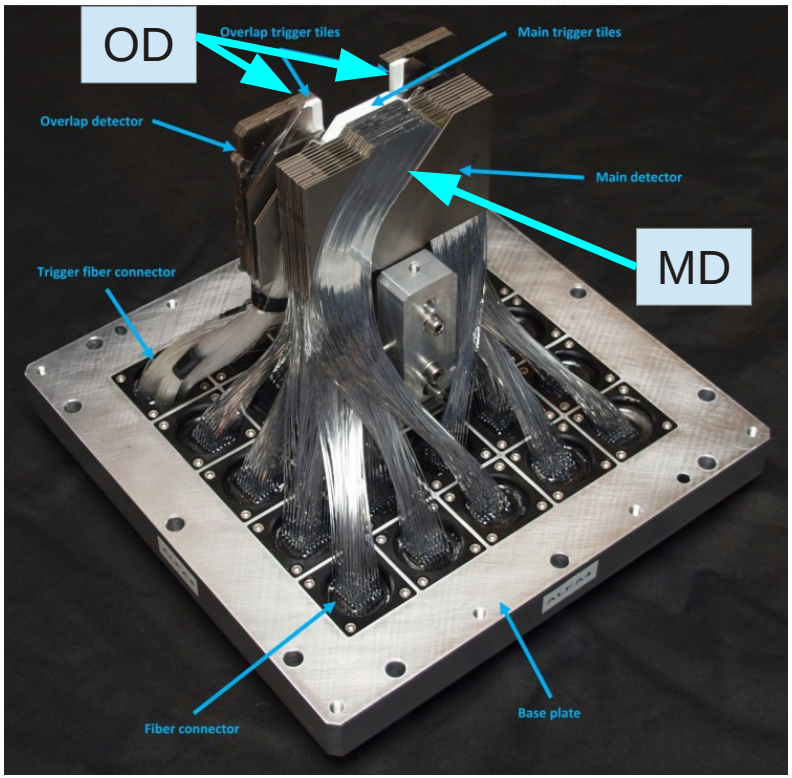
From http://atlas-project-lumi-fphys.web.cern.ch/atlas-project-lumi-fphys/images/forward_detectors.jpg (modified)

ALFA

ALFA – principals and aim



- The main goal - absolute luminosity and total cross section measurement
- Elastically scattered protons under a small angle (several micro radians)
- Main Detector (MD)
  - 10 plates (U and V layer)
  - 64 squared fibers (0.5x0.5 mm, staggering), coated by aluminium
  - spatial resolution ~30 μm
  - a scintillating fiber tracker technology
- Overlap Detectors (OD)
  - 3 plates of 30 squared fibers
  - relative alignment by optics: 10 μm in horizontal (x,z) plane
    5 μm in vertical (y,z) plane
- Roman Pots technology, vertical moving system



From “ATLAS TDR 18, CERN/LHCC/2008-004” and “ATLAS-LUM-PROC-2013-001”

ALFA – physics aim

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

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

- If *p* is the momentum of the scattered proton, then for small values of scattering angle (θ) is obtained

$$-t = (p\theta)^2$$

- The rate of elastic scattering events at small *t* values is written as

$$\left.\frac{dN}{dt}\right|_{t=0} = L\pi|f_C + f_N|^2 \approx \left|-\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)\exp\left(\frac{-B|t|}{2}\right)\right|^2$$

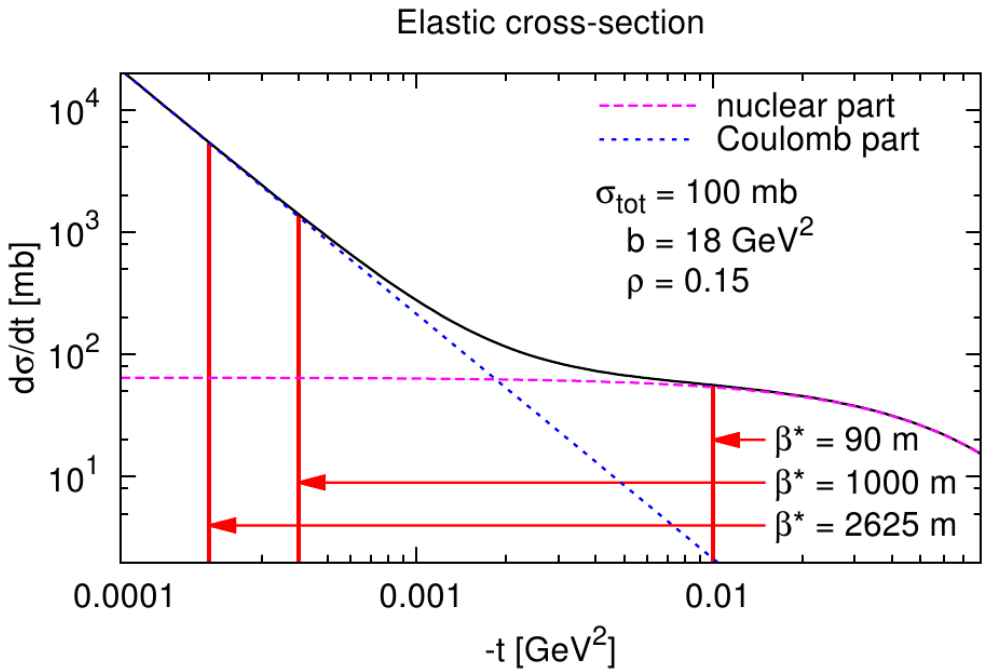
f_C corresponds to the Coulomb and f_N to the nuclear interaction amplitude, *b* ... nuclear slope, ρ … a ration of real to imaginary part of the elastic scattering amplitude

$$\rho = \left.\frac{\Re f_{el}}{\Im f_{el}}\right|_{t\to 0}$$

From “ATLAS TDR 18, CERN/LHCC/2008-004” and “ATLAS-LUM-PROC-2013-001”

ALFA – physics

- High β^* optic allow us to access low t values for elastically scattered protons
- The elastic cross section as a function of t spectrum for a possible set of parameters at LHC energies. An estimate of the expected t value reachable at a given β^* is plotted.

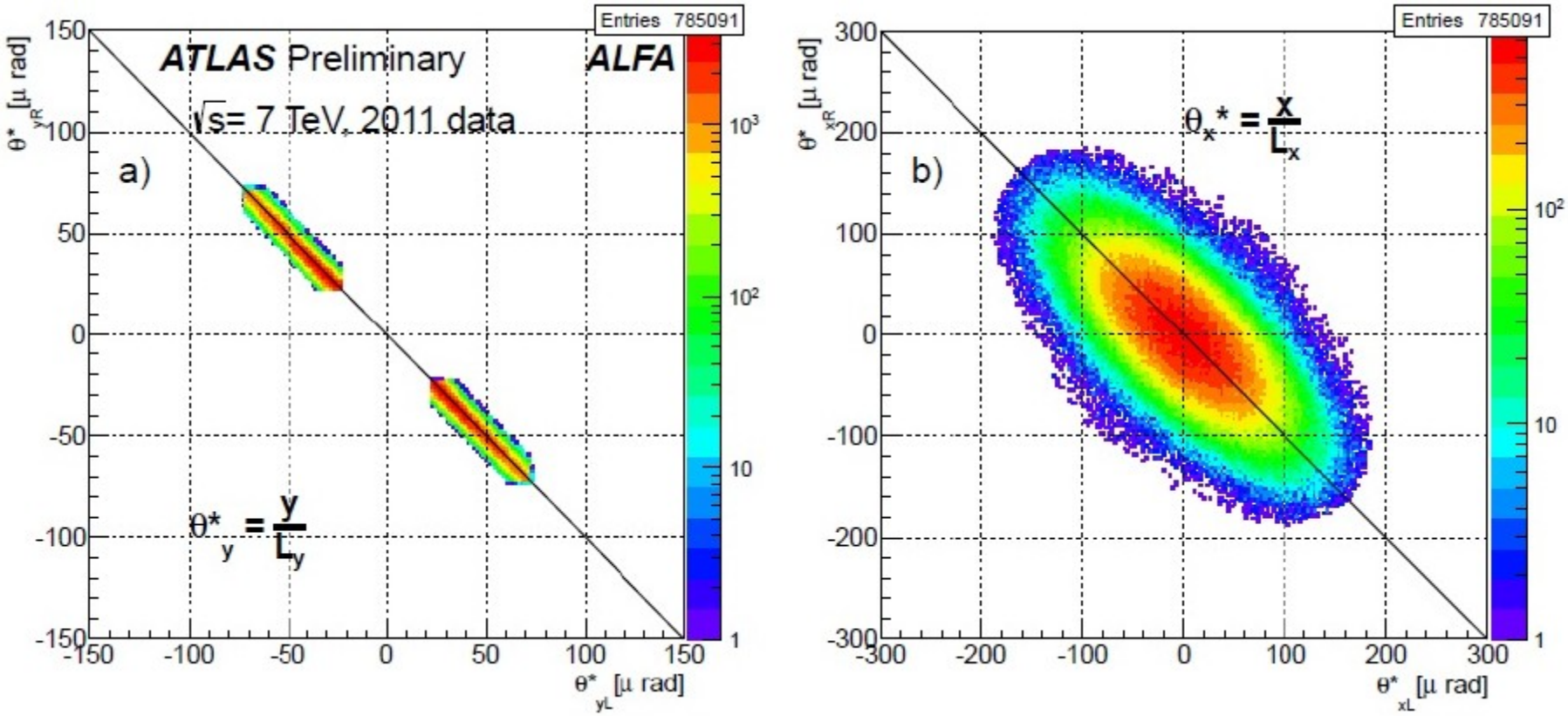


- To achieve highest β^* ~ 2625 m optics (and fulfill ALFA physics programme) additional cables in the tunnel are needed; scheduled for the winter break 2015/16

Towards a Total Cross Section Measurement with the ALFA Detector at ATLAS, ATLAS-LUM-PROC-2013-001

ALFA – physics

- Reconstructed scattering angle correlation between left (θ^*_{xL}, θ^*_{yL}) and right side (θ^*_{xR}, θ^*_{yR}) for elastic candidates after background rejection cuts in the vertical (left plot) and in the horizontal plane (right plot)



- Data taking from October 20th 2011, √s = 7 TeV, β^* = 90 m
- Beam intensities ~2.1E11 ppb, RP position at 6.5 σ (~1.8 mm)
- About 800.000 clean elastic events

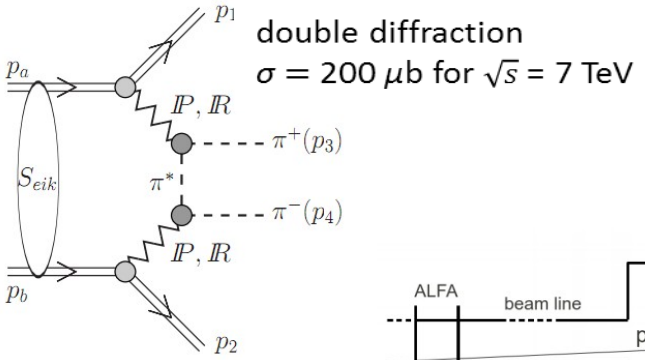
From ATLAS Detector public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

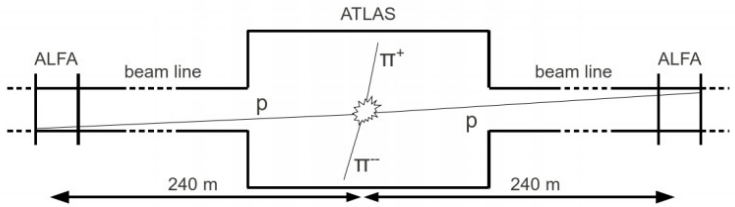
ALFA – physics

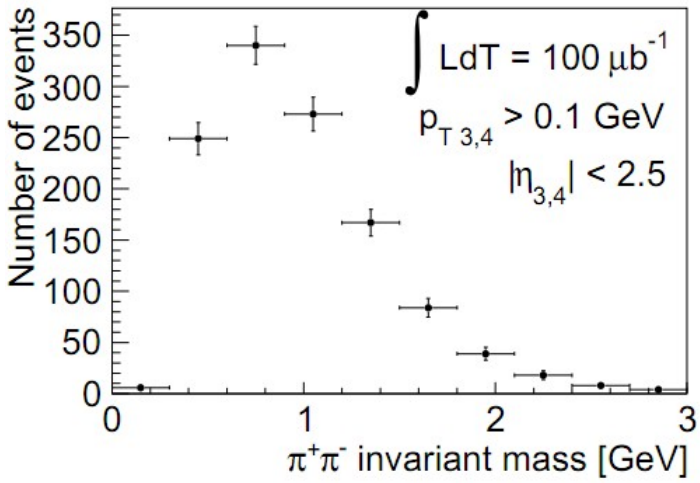
- Study of exclusive production in ATLAS
  - pp->pp $\pi^+\pi^-$ measurement possible, expected ~2000 events for L = 10^{27} $cm^{-2}s^{-1}$, 30 hour
  - it requires ALFA elastic AND trigger + low-pT tracking
  - so far only measurements were performed at = 62 & 63 GeV by ABCDHW Collaboration, ISR
  - other processes such as K+K- or p+p- can be studied

More theoretical studies in:

- Exclusive pp → pp π+π- reaction: from the treshold to LHC P. Lebiedowicz, A. Szczurek, Phys. Rev. D81 (2010) 0360
- R. Staszewski, P. Lebiedowicz, M. Trzebinski, J. Chwastowski and A. Szczurek, Acta Physica Polonica B vol. 42 (2011) 1861





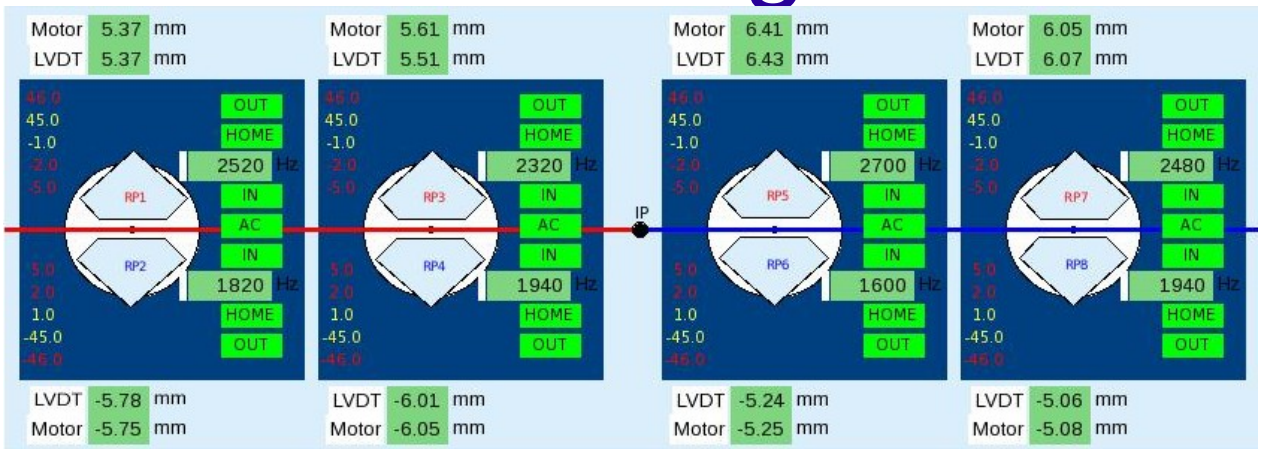


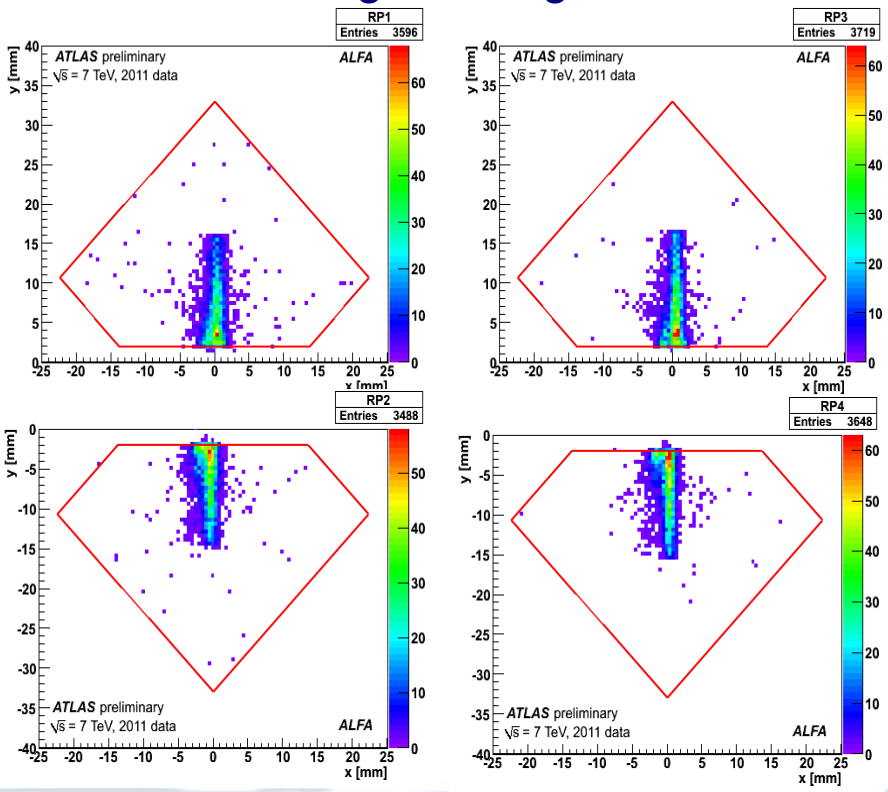
From ALFA detector and prospects for measurements, T. Sýkora, Results and prospects of FP at LHC, 12.02.2012

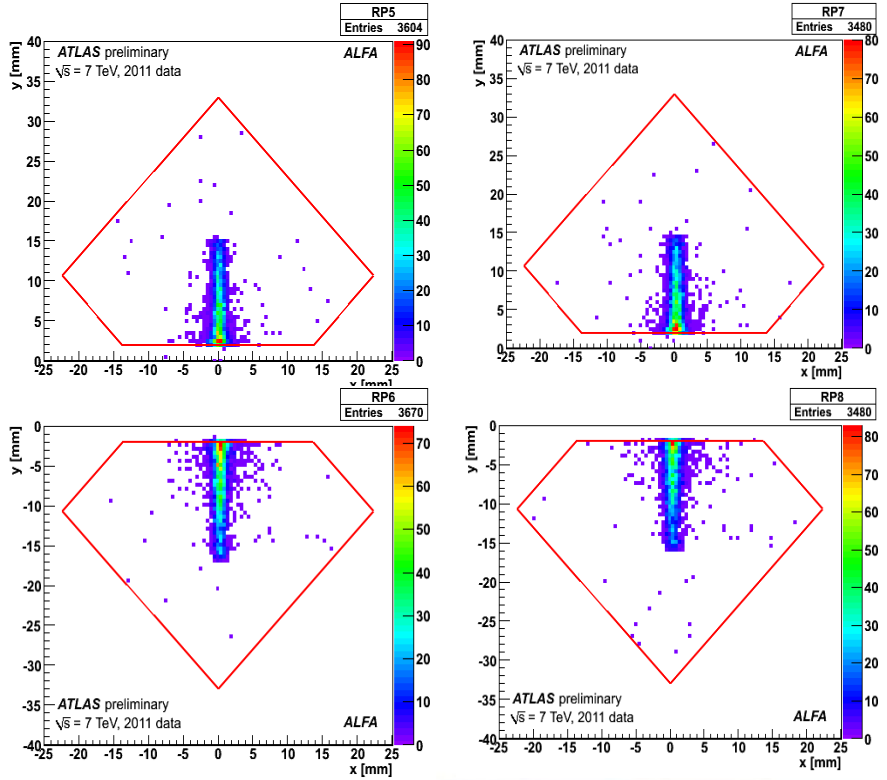
ALFA – data taking

- ATLAS Control Room

- Elastic track pattern in the detectors online histogramming







ALFA – data taking

run#1: β* = 90 m, √s = 7 TeV, October 18-20, 2011

- 2 bunches of 7E10 ppb plus 12 pilots
- data taking at 6.5 σ (~1.8 mm)
- optics measurements and data taking for distance calibration, background studies
- about 1.4 M elastic and 2 M diffractive triggers; 800.000 clean elastic events

run#2: β* = 90 m, √s = 8 TeV, July 7, 2012

- low intensity run with 3 bunches 1E+11 ppb, scraping at 4 σ (~ 2 hours)
- data taking at 6, 8, 9.5 σ
- about 3.6/65 million elastic/minimum bias triggers

run#3, β* = 90 m, √s = 8 TeV, July 14, 2012

- high intensity run with 108 bunches of 0.9E+11 ppb
- data taking at 9.5 σ
- elastic triggers from 3 bunches only (3 hours), diffractive triggers from all bunches (5 hours)
- about 6.5/284/12 millions of elastic/minimum bias/diffractive triggers useful

run#4: β* = 1 km, √s = 8 TeV, October 24-25, 2012

- data taking at 3 σ (bellow 1 mm, ~6 hours)
- total of 33M elastic and many diffractive triggers
- about 300k events for elastic and total cross section

p+Pb runs: January/February 2013

- data taking at 20 σ (~4.5 mm) on the proton side

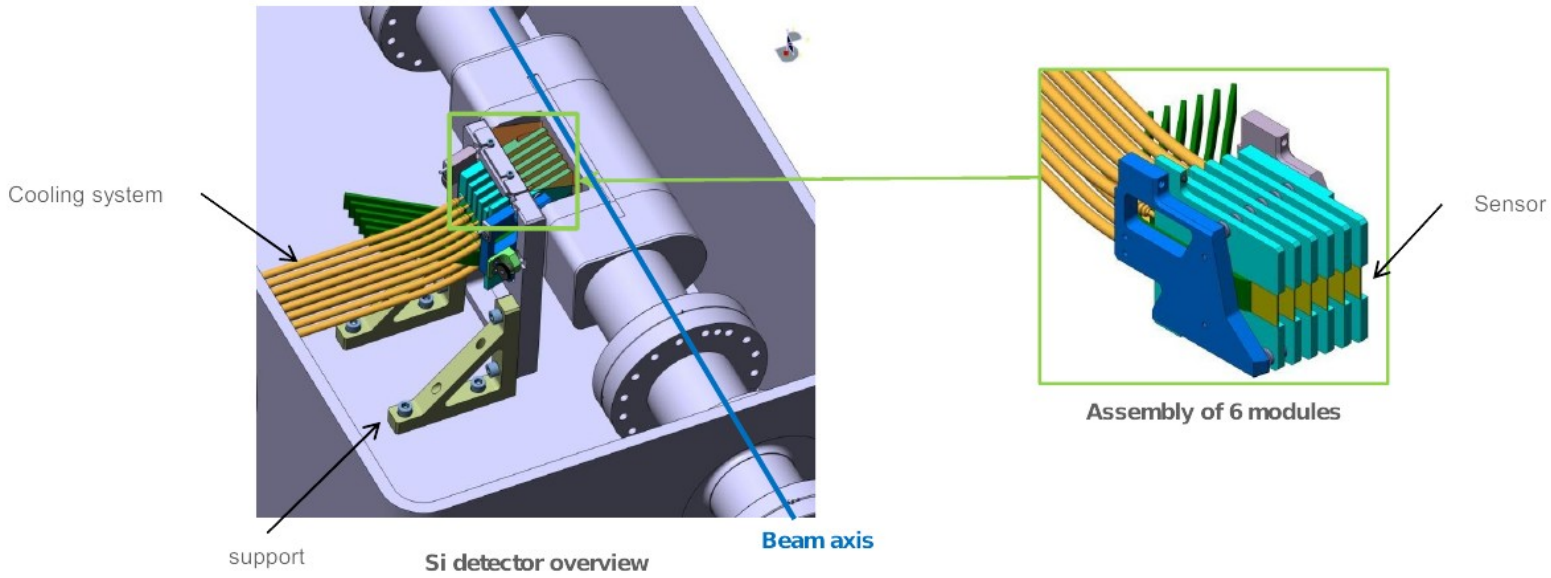
AFP

AFP – principals and aim

- A successor of ALFA and foreseen for forward / diffractive physics at highest LHC intensities
- The goal of the AFP (**A**TLAS **F**orward **P**roton) - to measure exclusive physics processes and anomalous coupling
- To detect intact protons from hard interaction, scattered at very small angles
- Position: ±204 m and ±212 m from the ATLAS IP
- Designed to operate with high pile up
- Allows to run with standard high luminosity runs, contrary to ALFA

AFP – Tracking Detectors

- The main purpose: a measurement of the trajectory of beam collision deflected protons coming from the ATLAS IP
- 3D Si pixel detector - a technology also used for IBL
- Two stations: ±204 m, ±212 m
- Current status: a spatial resolution ~10 μm in horizontal plane, ~30 μm in vertical plane, ~1 μrad angular



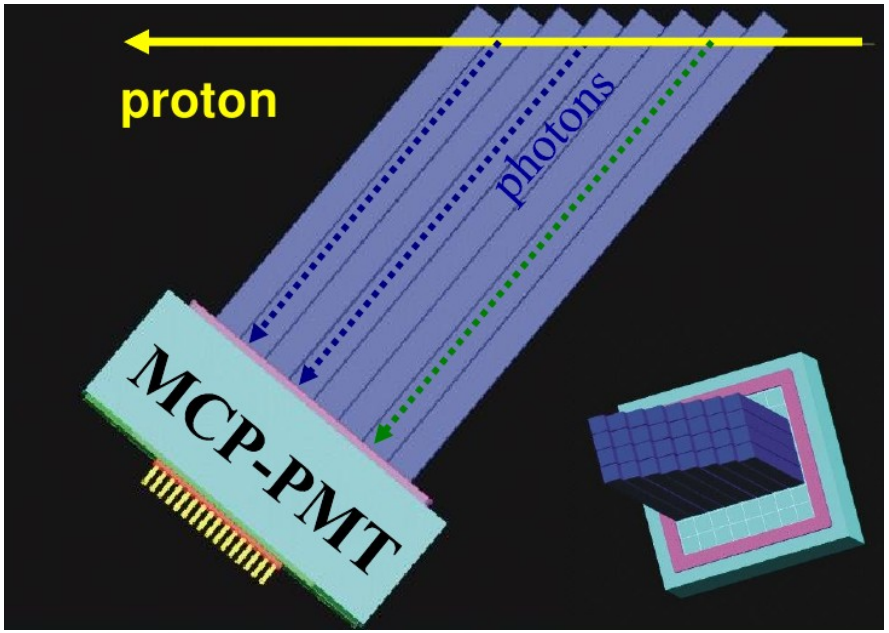
ATLAS Letter of Intent Phase-I Upgrade (CERN LHCC-2011-012, LHCC-I-020)
AFP - Si Detector Mechanical Design, Nathalie Grouas, AFP Technical Review, 17.9.2012 (modified)

AFP – Timing Detector

- Precise time of flight measurement using Quartic timing detector
- Purpose - pileup background rejection / signal confirmation
- 10 ps or better resolution for nominal luminosity and μ ~50 interactions

- To achieve required time resolution:
  - 4x8 (6x6 mm^2) quartz bars, 8-12 cm long → 8 measurements per detector with 30-40 ps resolution each

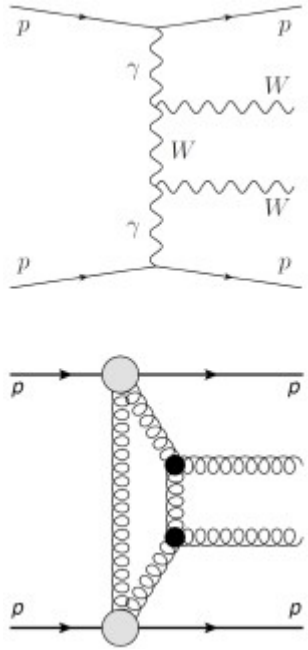
- Another solution: diamond timing detector (in RND)



Picture from The Timing Detector, Andrew Gerhart Brandt, ATLAS Week Parallel Session #4 – AFP, 2.10.2012

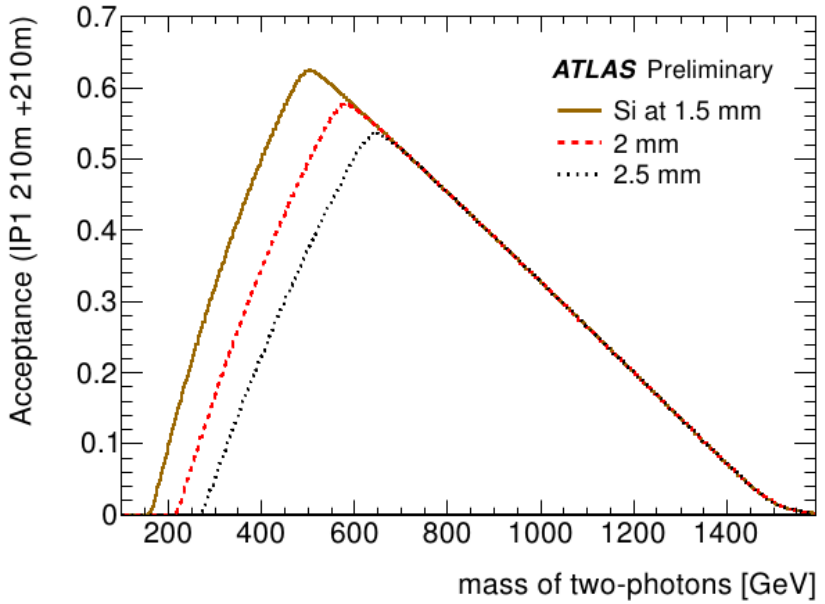
AFP – physics

- Studies:
  - exclusive physics processes – (eg. jets, *γγ*, W/Z)
  - Anomalous gauge coupling studies (*γγWW*, *γγZZ*, *γγγγ*)
  - SUSY; magnetic monopoles
  - Any production of new objects (with mass up to 2 TeV) via photon or gluon exchanges: Kaluza-Klein resonances, black holes, etc.



More details in:

- ATLAS Letter of Intent Phase-I Upgrade (CERN LHCC-2011-012, LHCC-I-020)
- Physics Cases within the AFP project (ATL-COM-PHYS-2012-775)
- AFP physics topics (ATL-COM-PHYS-2013-390)



Picture from AFP Physics Programme, Maciej Trzebinski, ATLAS Week Parallel Session #4 – AFP, 2.10.2012

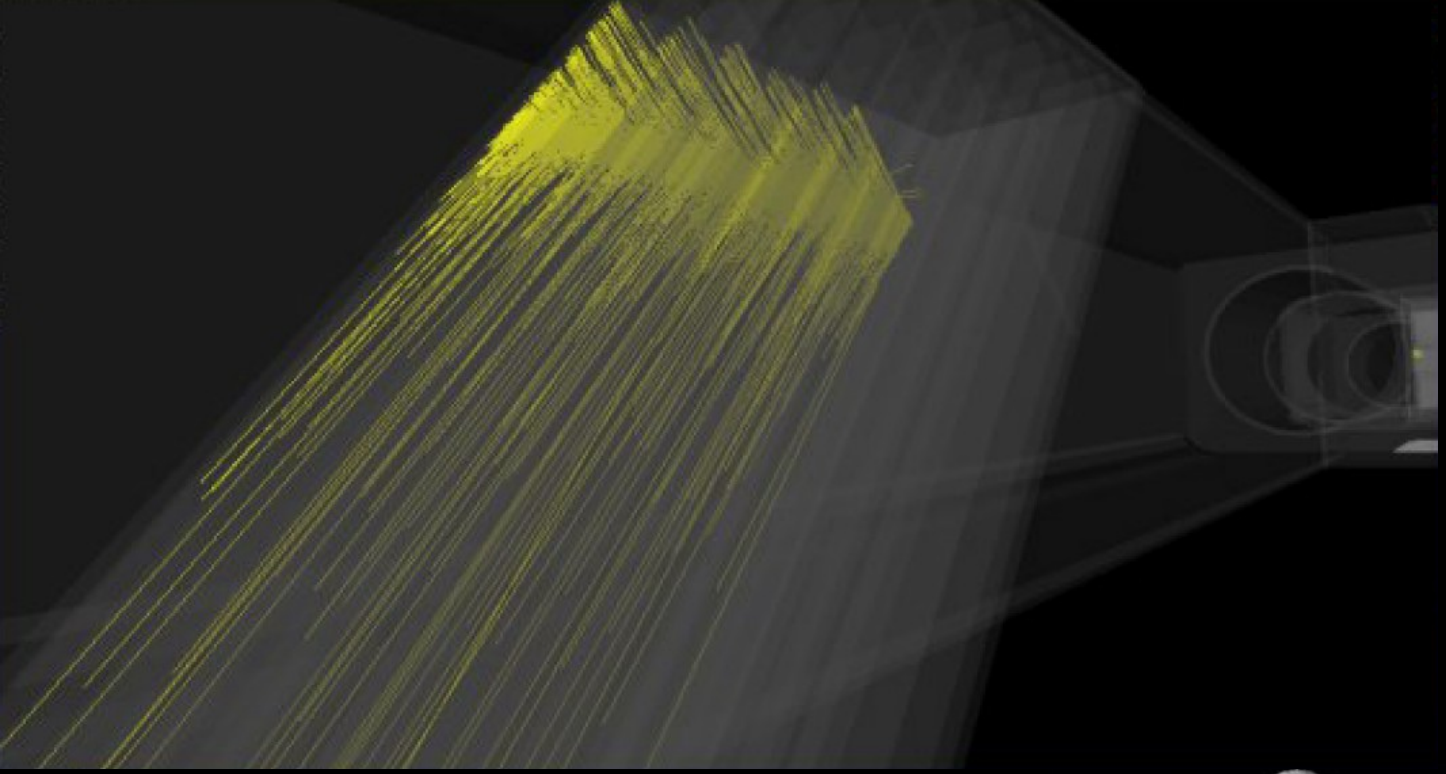
Summary & Future prospects

ALFA

- successful data taking with β^* = 90m and β^* = 1km optics
- promising results from β^* = 90m data taking, analysis with β^* = 1km ongoing
- better understanding of the LHC optics for special high β^* runs still in process
  increase the distance between neighboring stations for better angular resolution
- to achieve highest β^* ~ 2625 m optics (and fulfill ALFA physics programme) additional cables in the tunnel are needed; scheduled for the winter break 2015/16

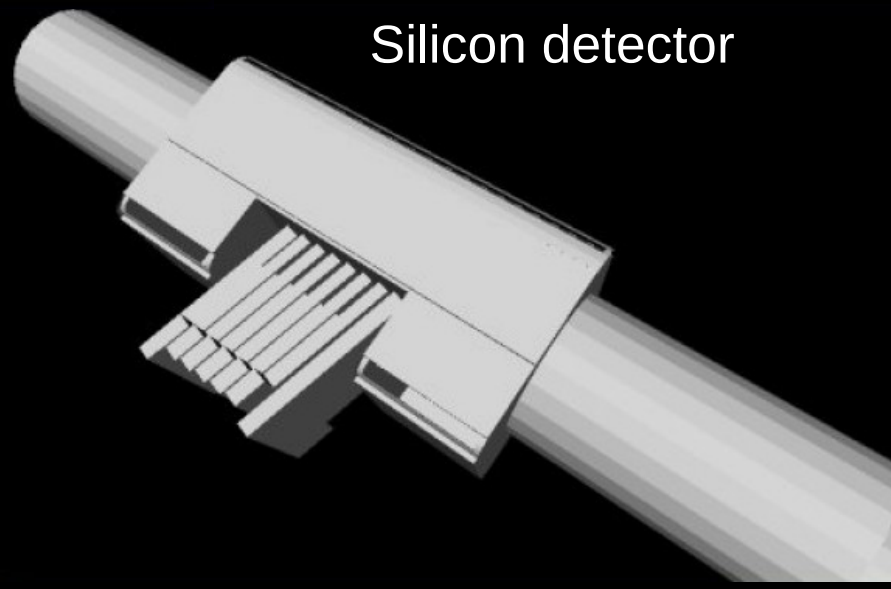
AFP

- 3D Si Tracking Detector – a technology coming from IBL
- Timing Detector
  - 10 ps Quartic TD development is ongoing
  - Diamond TD in RND
- Full simulation and integration is ongoing

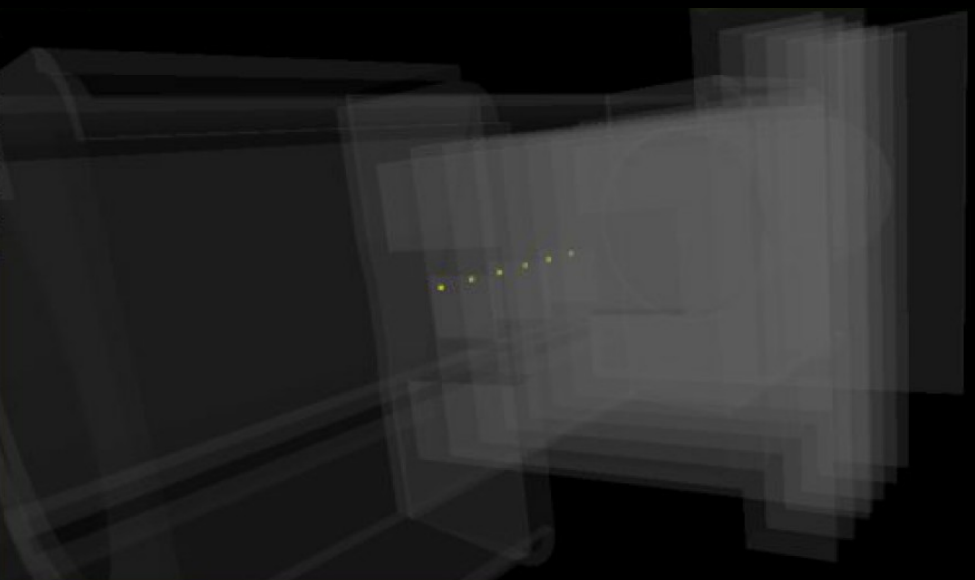


Timing Detector
with simulated
photon tracks
(yellow lines)

Silicon detector



Silicon detector with simulated hits
(yellow dots)



back up

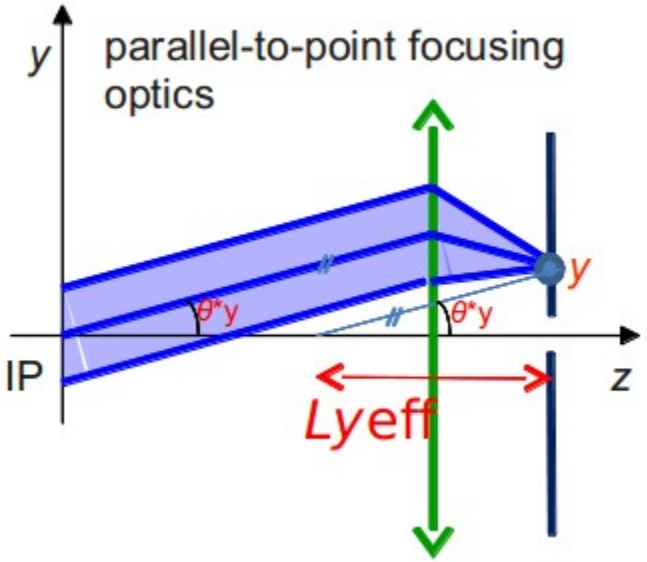
ALFA – optics

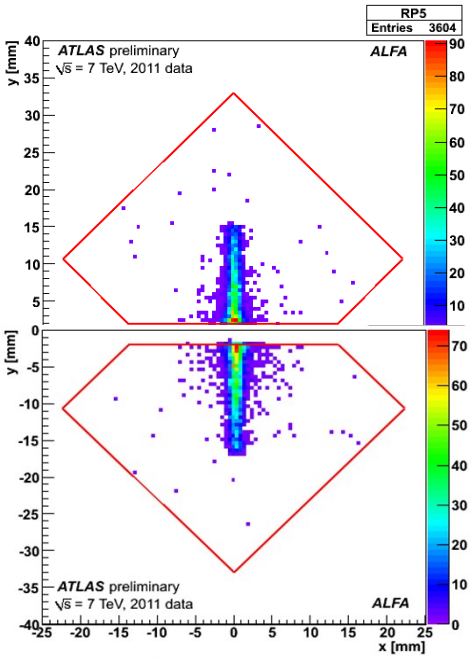
- The ALFA aim is to determine θ^* angle at ATLAS IP via the optics

$$\theta_y^* = \frac{y}{L_{y_{eff}}}$$

where $L_{yeff} = L_{yeff}(\beta, \beta^*, \psi)$ is effective arm in y axis, β is betatron function, ψ is phase

- parallel-to-point focusing – all protons with the same p_y are focused in one point at ALFA station (y)
  - phase advance $\psi = \pi/2$
- t-spectrum can be described by superposition of nuclear and Coulomb scattering ($t \equiv -(p\text{-}p')^2$ – Mandelstam variable)





From "ATLAS TDR 18, CERN/LHCC/2008-004"