Roman Pots Lessons Learnt at the LHC
Technical Aspects

Maciej Trzebiński

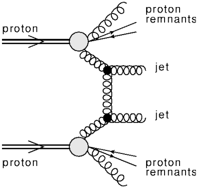
Institute of Nuclear Physics
Polish Academy of Sciences

EIC Workshop – Promoting Collaboration on the Electron-Ion Collider

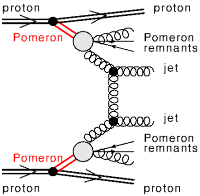
8th October 2020

Physics of Interest

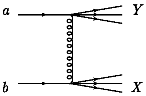
- **hard** – perturbative approach is valid; small cross-sections:
  - non-diffractive



  - diffractive

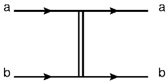


- **soft** – large cross-sections:
  - non-diffractive:

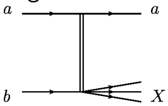


  - diffractive:

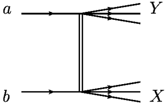
Elastic Scattering



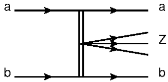
Single Diffraction



Double Diffraction



Central Diffraction



Diffraction:

- colour singlet exchanged,
- Pomeron (QCD = two gluons + ...).

Natural ways to seek for diffraction:

- rapidity gaps,
- **forward protons**.

Assumption: one would like to measure diffractive interactions at the LHC.

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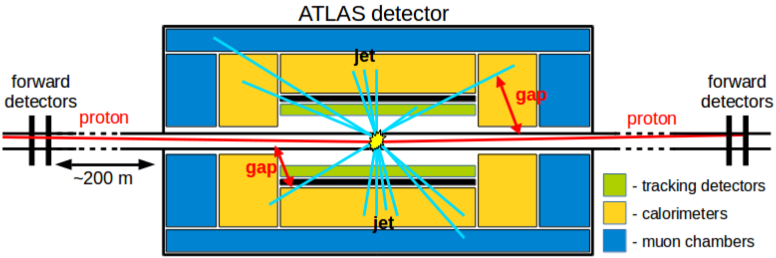
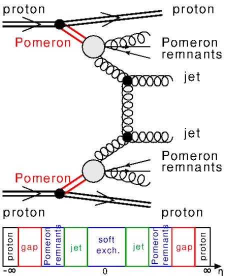
Typical diffractive topology: a gap in rapidity is present between proton(s) and central system and one or both interacting proton stay intact.





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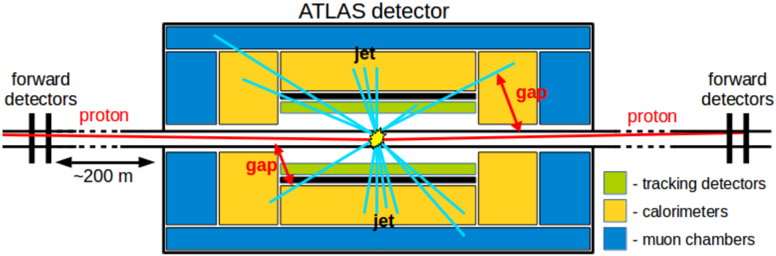

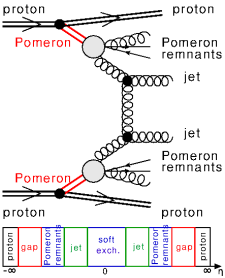

Method 1 (rapidity gap):

+ usual method of diffractive pattern recognition
+ no need to install additional detectors
− gap may be killed by *e.g.* particles from pile-up
− gap may be outside acceptance of central detector

Measurement Methods

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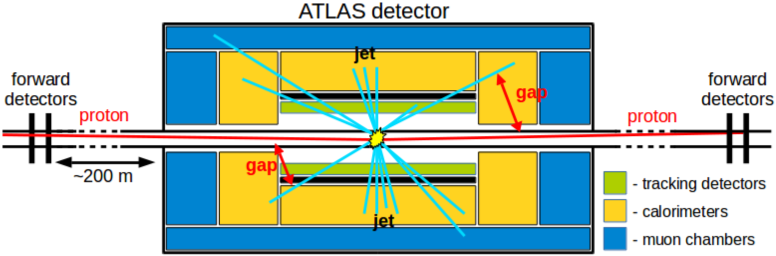

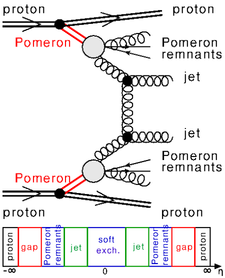

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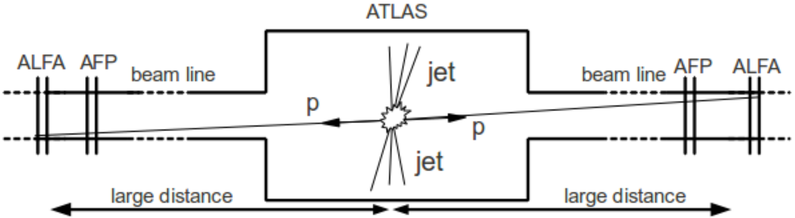
Method 2 (forward protons):

+ protons are directly measured
+ can be used in pile-up environment
− protons are scattered at small angles (few μrad)
− additional “forward” detectors are needed far away from the interaction point

Intact protons $\rightarrow$ natural diffractive signature $\rightarrow$ usually scattered at very small angles (μrad) $\rightarrow$ detectors must be located far from the Interaction Point.



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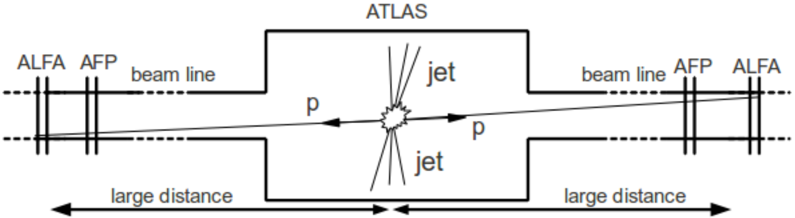

ALFA

- **A**bsolute **L**uminosity **F**or **A**TLAS
- 240 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- vertically inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = \sigma_y = 30\ \mu$m

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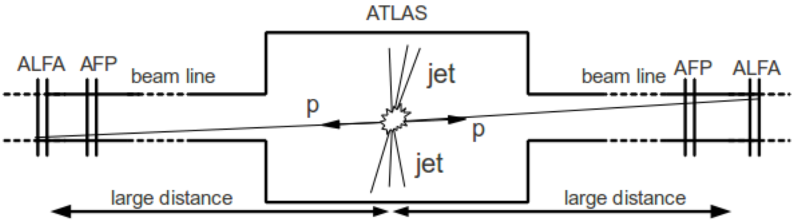

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AFP

- **A**TLAS **F**orward **P**roton
- 210 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- horizontally inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = 6\ \mu$m, $\sigma_y = 30\ \mu$m
- timing detectors, resolution: $\sigma_t \sim 25$ ps

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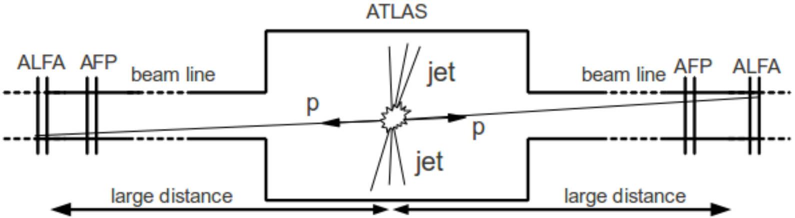

ALFA	**AFP**
Absolute **L**uminosity **F**or **A**TLAS	**A**TLAS **F**orward **P**roton
240 m from ATLAS IP	210 m from ATLAS IP
soft diffraction (elastic scattering)	hard diffraction
special runs (high β^* optics)	nominal runs (collision optics)
vertically inserted Roman Pots	horizontally inserted Roman Pots
tracking detectors, resolution: $\sigma_x = \sigma_y = 30$ μm	tracking detectors, resolution: $\sigma_x = 6$ μm, $\sigma_y = 30$ μm
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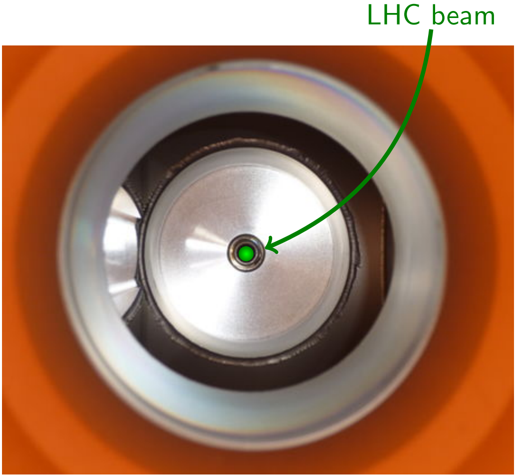
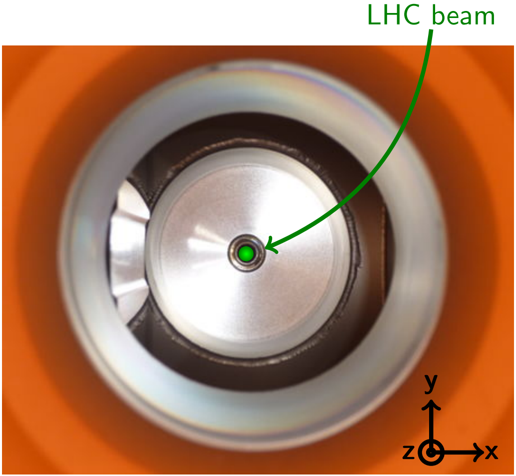
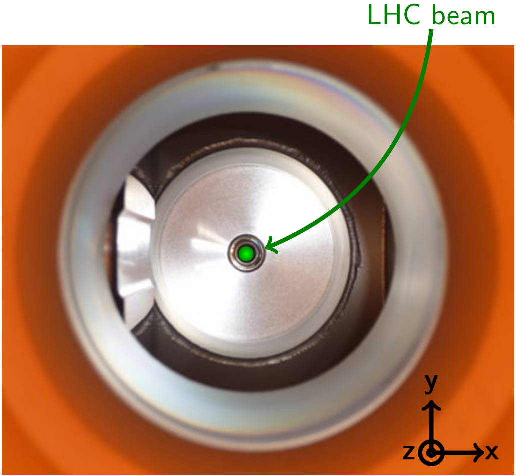
Similar devices @ IP5: CMS-TOTEM.


LHC beam


LHC beam
y
z
x


LHC beam
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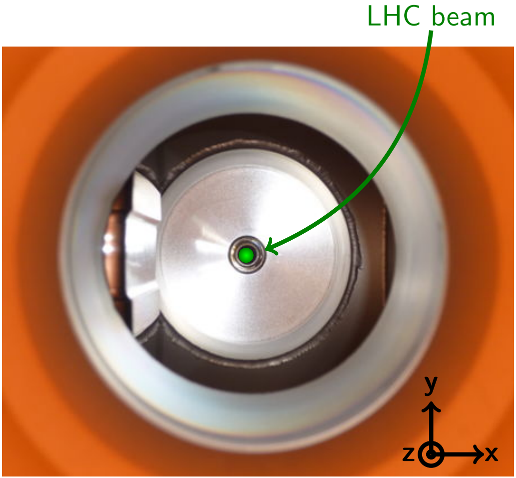
LHC beam
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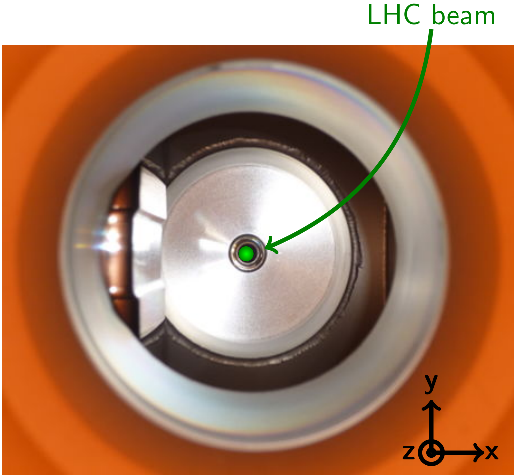
LHC beam
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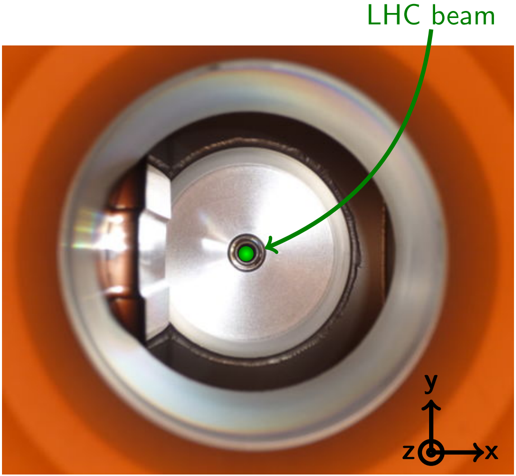
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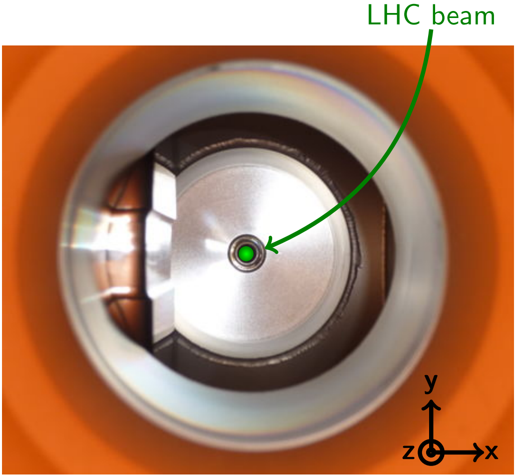
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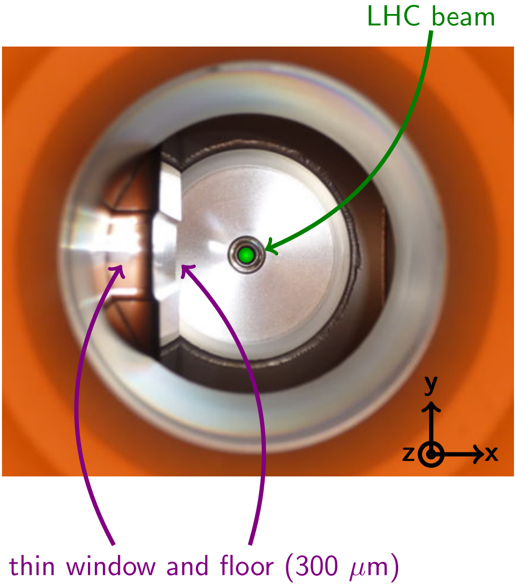
LHC beam
y
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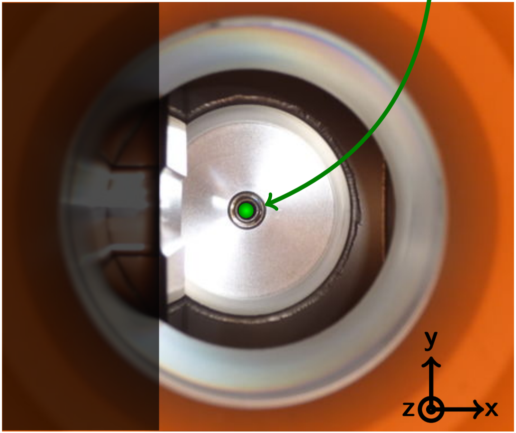
thin window and floor (300 μm)

shadow of TCL4 and TCL5 collimators

LHC beam



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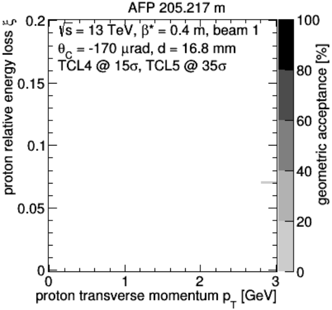
Geometric acceptance:



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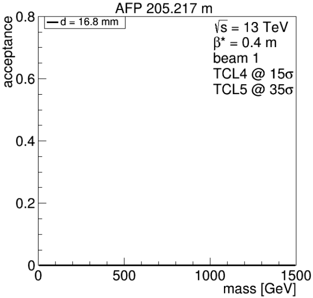

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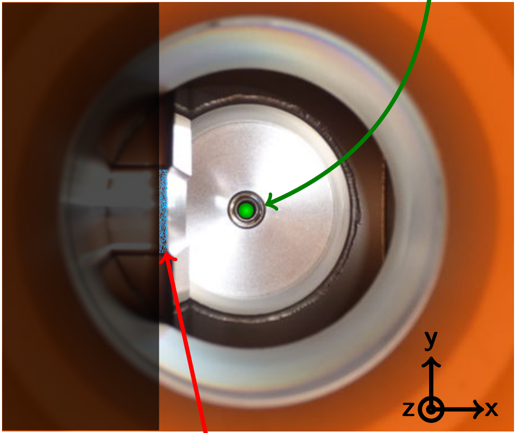

diffractive protons

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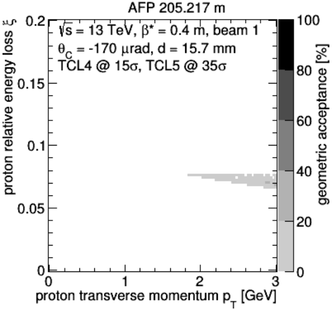

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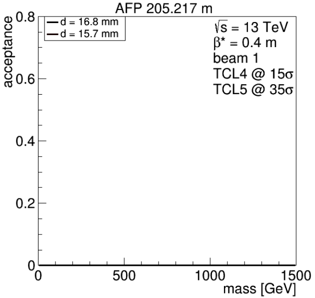

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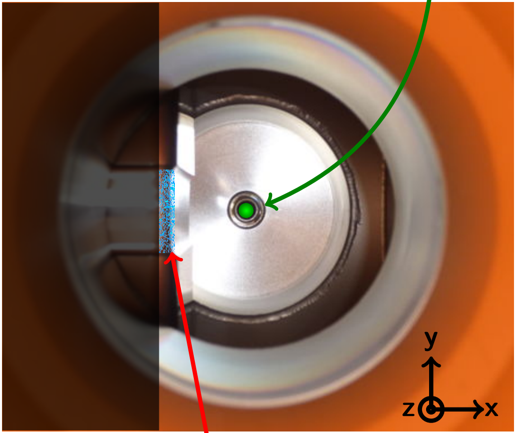

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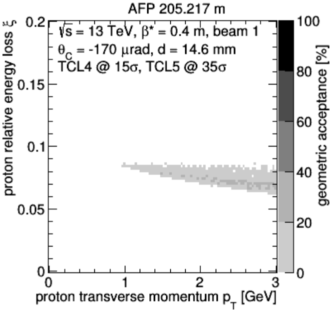

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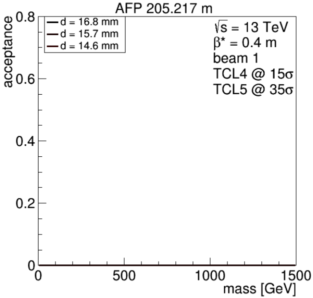

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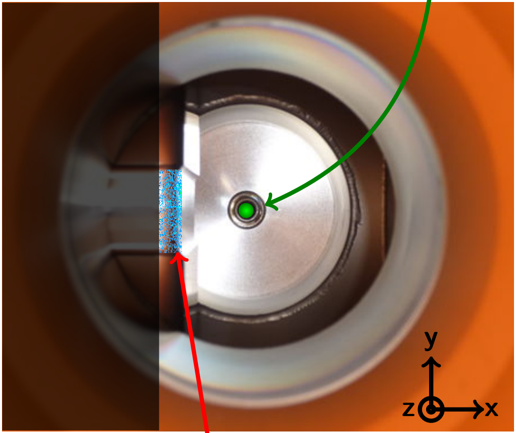

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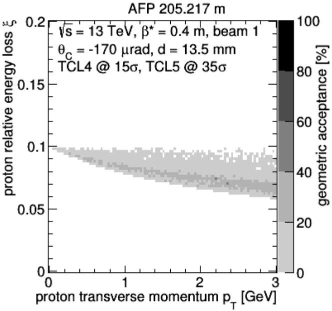

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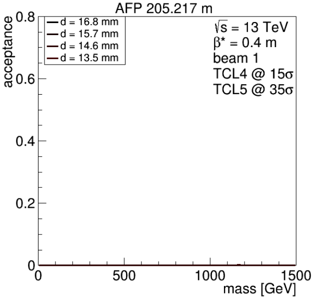

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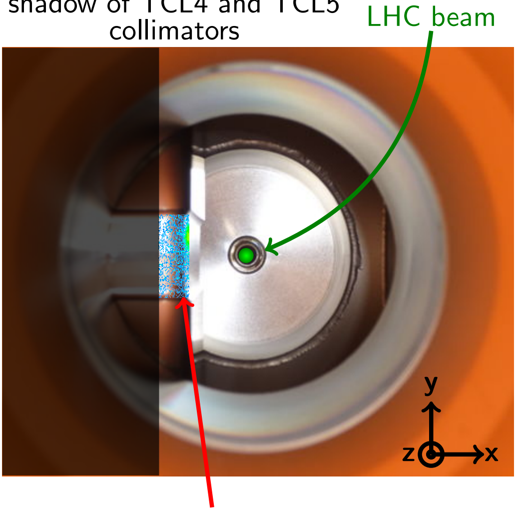

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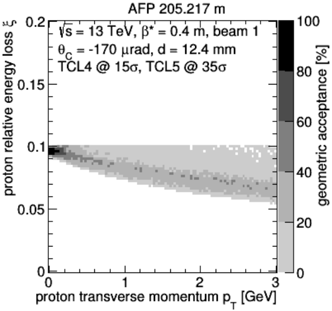

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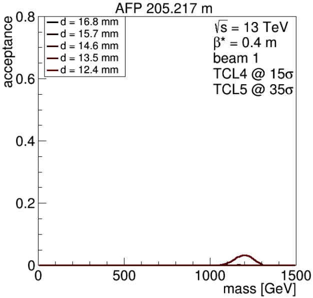

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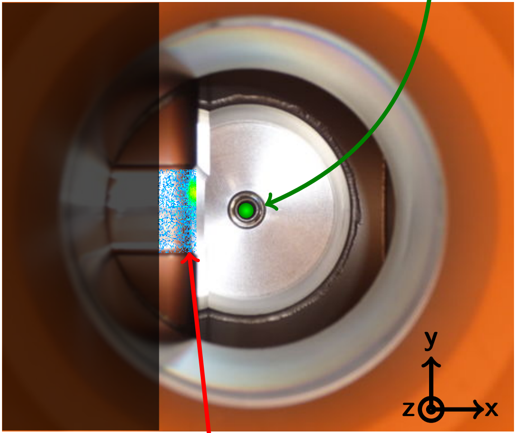

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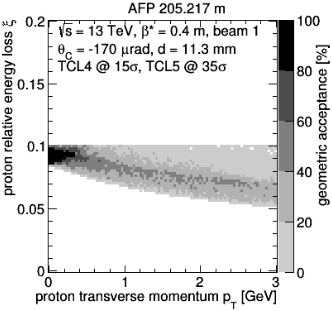

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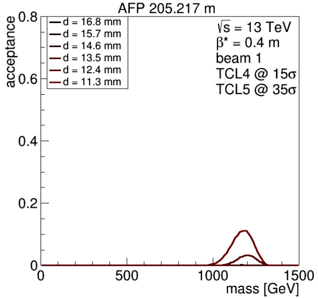

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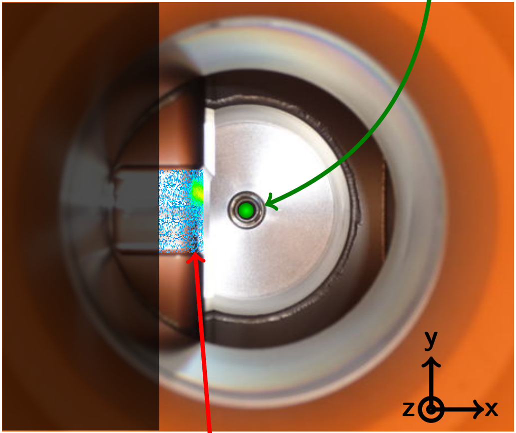

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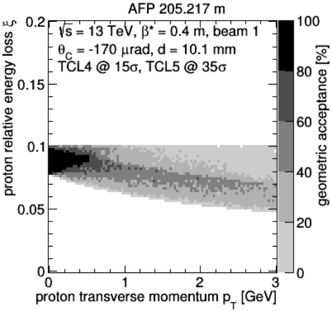

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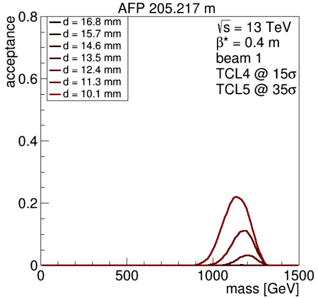

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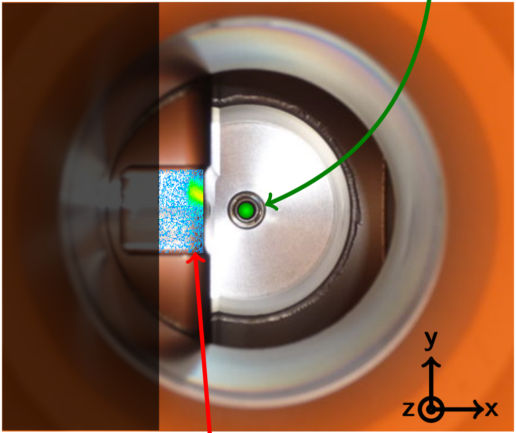

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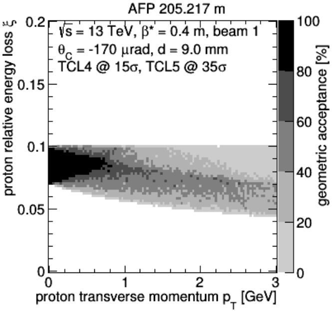

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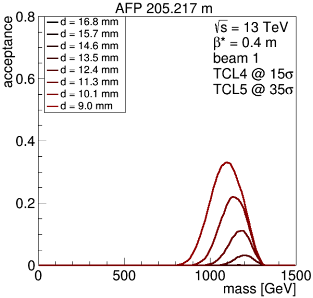

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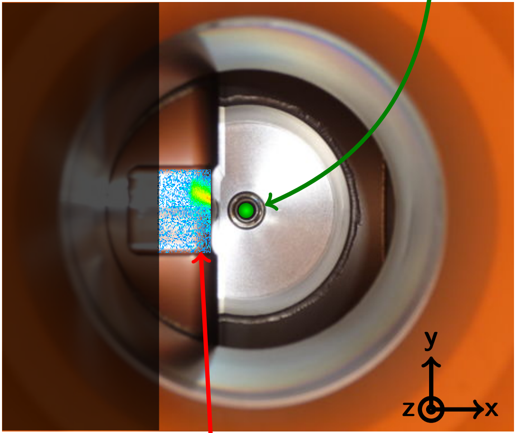

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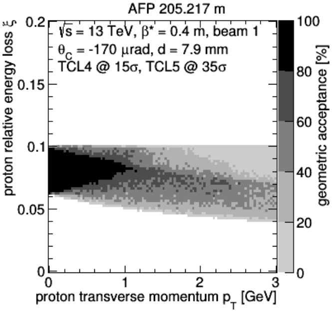

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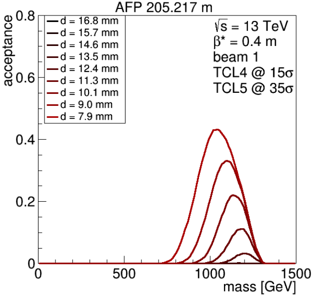

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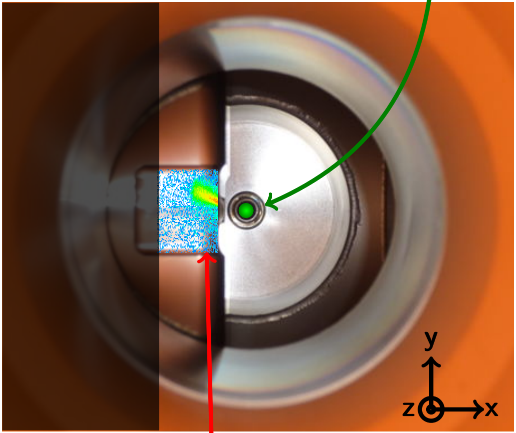

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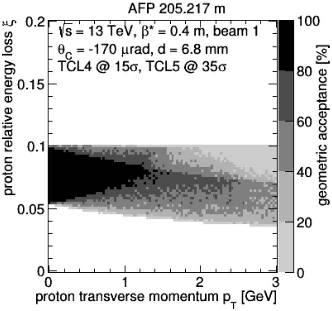

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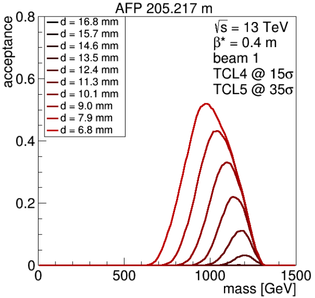

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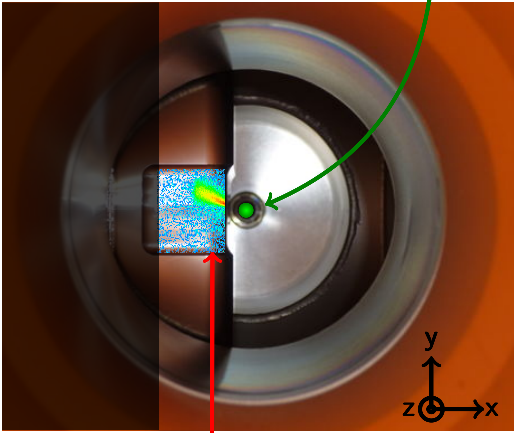

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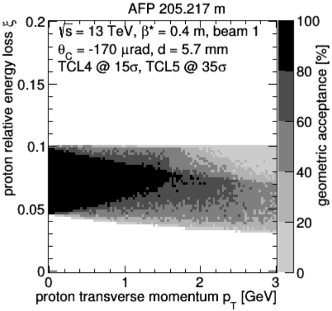

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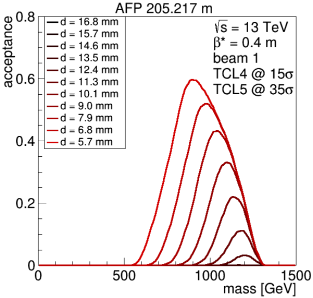

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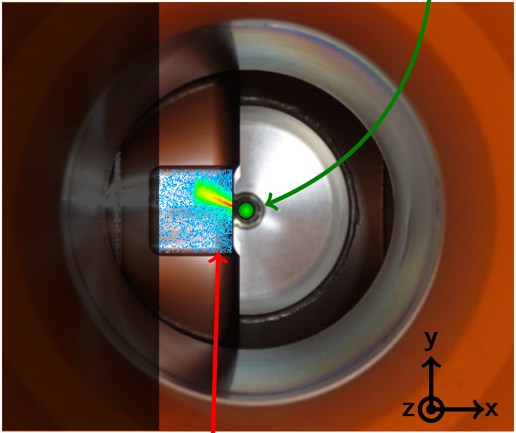

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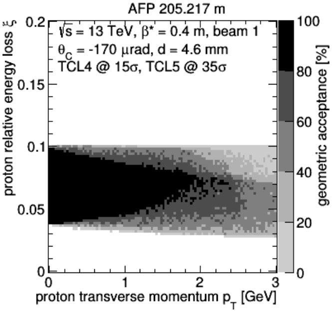

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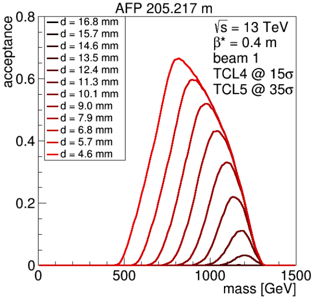
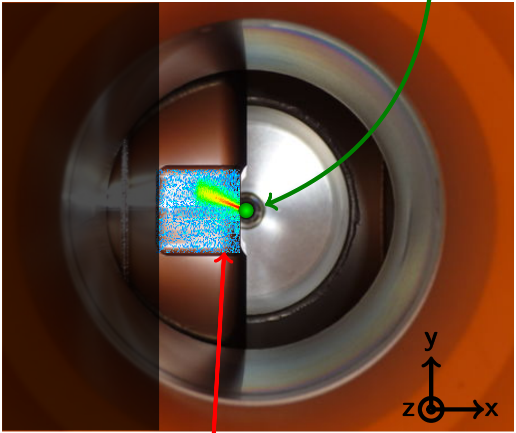


shadow of TCL4 and TCL5 collimators

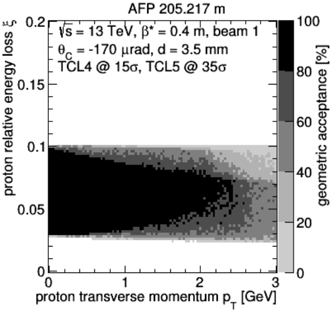
LHC beam



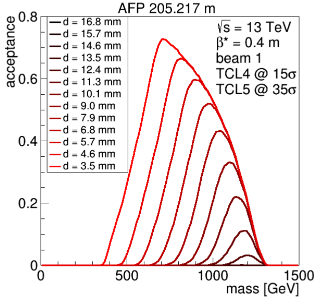
diffractive protons

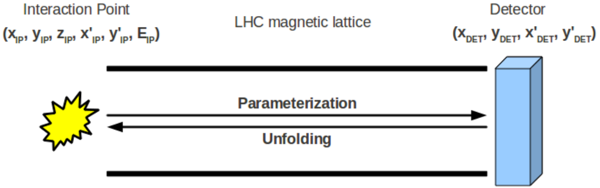
thin window and floor (300 μm)

Geometric acceptance:

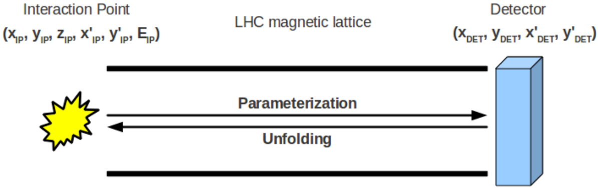


Mass acceptance:

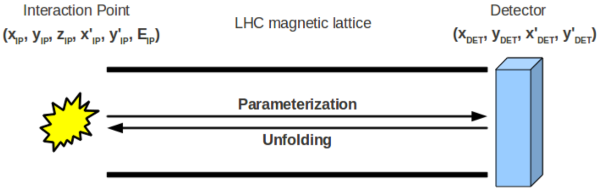




- At the interaction point proton (IP) is fully described by six variables: position (x_{IP}, y_{IP}, z_{IP}), angles (x'_{IP}, y'_{IP}) and energy (E_{IP}).



- At the interaction point proton (IP) is fully described by six variables: position (x_{IP}, y_{IP}, z_{IP}), angles (x'_{IP}, y'_{IP}) and energy (E_{IP}).
- They translate to unique position at the forward detector (x_{DET}, y_{DET}, x'_{DET}, y'_{DET}).



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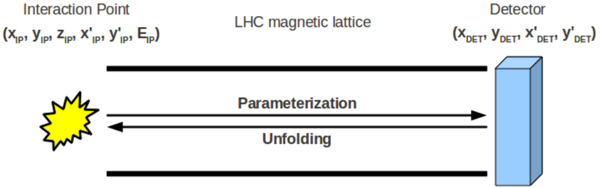
- Idea: get information about proton kinematics at the IP from their position in the AFP detector.



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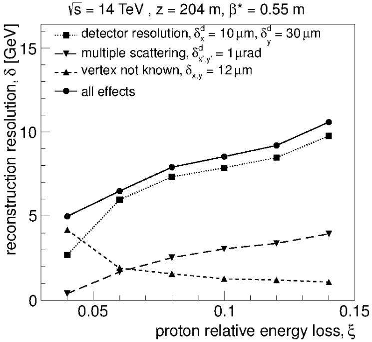
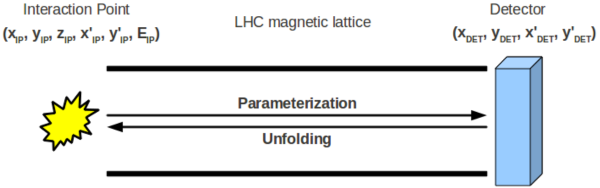
- Exclusivity: kinematics of scattered protons is strictly connected to kinematics of central system.



From ISRN High Energy Physics (2012) 491460; ATLAS-TDR-024



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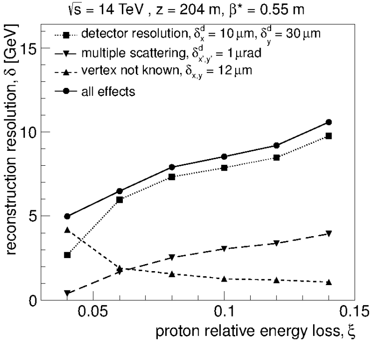
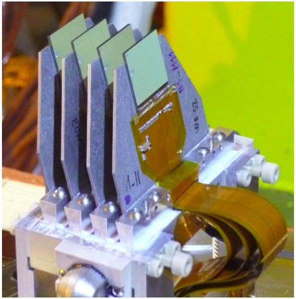
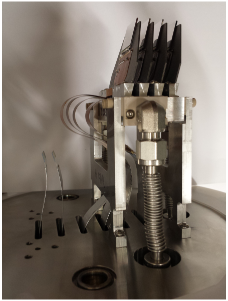
- Idea: get information about proton kinematics at the IP from their position in the AFP detector.
- Exclusivity: kinematics of scattered protons is strictly connected to kinematics of central system.
- Detector resolution play important role in precision of such method.

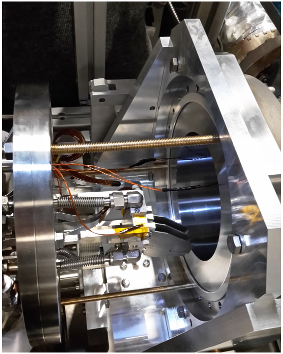


From ISRN High Energy Physics (2012) 491460; ATLAS-TDR-024

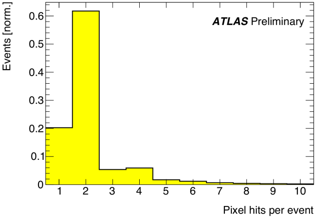
AFP: Silicon Trackers (SiT)



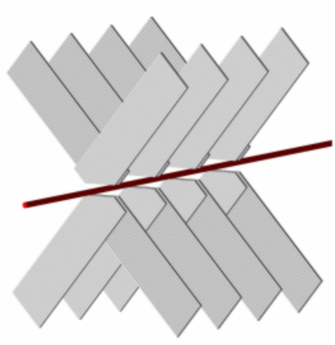


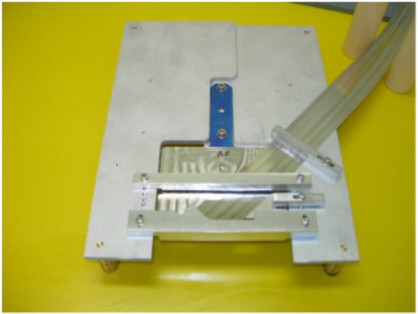


- Four detectors in each station.
- Technology: slim-edge 3D ATLAS IBL pixel sensors bonded with FE-I4 readout chips.
- Pixel size: $50 x 250\ \mu m^2$.
- Tilted by 14^0 to improve resolution in x.
- Resolution: $\sim 6\ \mu m$ in x and $\sim 30\ \mu m$ in y.
- Trigger: majority vote (2 out of 3; two chips in FAR station are paired and vote as one).



From JINST **11** (2016) P09005; JINST **12** (2017) C01086



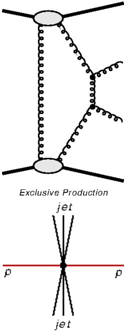


- Near stations: 237 m from ATLAS Interaction Point (IP).
- Far stations: till 2014 – 241 m, after 2014 – 245 m from ATLAS IP.
- Each station contains:
  - four outer detectors (OD) for precise alignment,
  - two main detectors (MD):
    - 10 + 10 layers of 64 fibres,
    - UV geometry,
    - trigger.
- More details in: JINST **11** (2016) P11013.

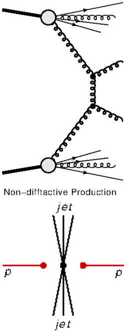
How to Reduce Physics Background?

Pile-up – multiple collisions during one bunch crossing (mostly min-bias).

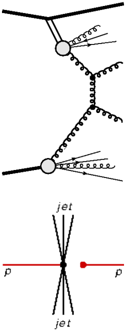
signal



background



background



Pile-up – multiple collisions during one bunch crossing (mostly min-bias).

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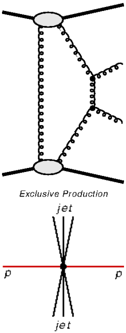
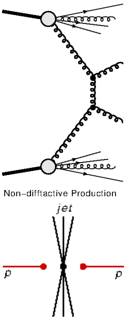
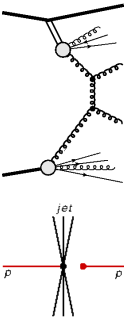


background

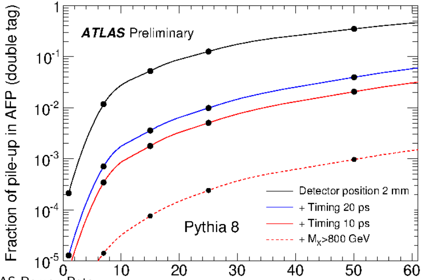


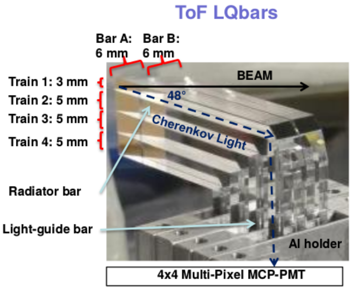
background

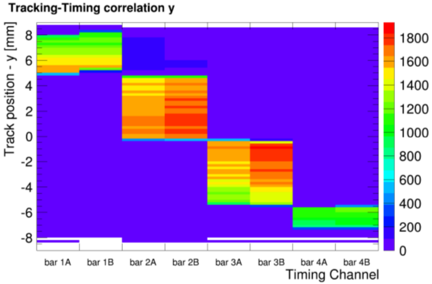


Idea:

- measure difference of time of flight of scattered protons, $(t_A - t_C)/2$
- compare to vertex reconstructed by ATLAS, $(t_A - t_C) \cdot c/2 - z_{ATLAS}$

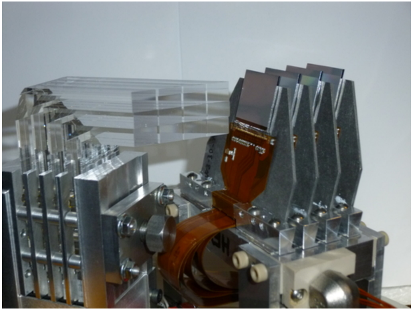






Setup and performance shown above are from testbeam (Opt. Express **24** (2016) 27951, JINST **11** (2016) P09005).

- 4x4 quartz bars oriented at the Cherenkov angle with respect to the beam trajectory.
- Light is directed to Photonis MCP-PMT.
- Expected resolution: $\sim$25 ps.
- Installed in both FAR stations.



(some) Lessons Learnt at the LHC

- Pots are installed far away from collision point – latency is a serious factor to be considered during design.
- These devices are small, but complete particle detectors:
  - connection/access to parts/services must be carefully considered due to very confined space,
  - variety of sub-groups which must cooperate makes coordination challenging.
- There is no such thing as 'too much spares'.
- As they are installed in the accelerator tunnel, access is more constraint than in case of main detector.
- Roman pots are special devices as they 'belong' to experiment and accelerator:
  - cooperation with various accelerator groups (optics, machine protection, collimators, etc.) is a must,
  - (some) failures during the operation may impact not only data taking, but can interlock accelerator,
  - an 'on site' expert is a must during data-taking.
- Accelerator settings (like optics) may be, to great extent, tweaked in order to enhance data-taking possibilities.
- Automatization of precesses (like pot insertion and extraction) is a huge manpower- and time-saver.
- There is not such thing as too much metrology – be ready for surprises such as pot rotation during insertion!
- A well defined share of responsibilities and a long-term support defined *e.g.* in Memorandum of Understanding is important.
- Core experts should be employed on long-term contracts. Students, PhDs or post-docs are of great help, but building full teams based on them creates issues related to knowledge transfer.

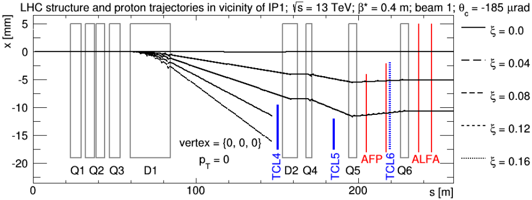
Backup

Proton trajectory is determined by the LHC magnetic field.

Proton trajectory is determined by the LHC magnetic field.

collision optics, **ALFA** and **AFP**: trajectory due to ξ

$\xi = 1 - E_{proton}/E_{beam}$



Proton trajectory is determined by the LHC magnetic field.

collision optics, **ALFA** and **AFP**: trajectory due to ξ

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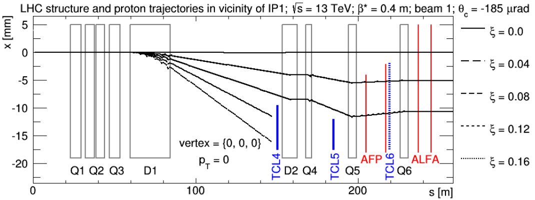
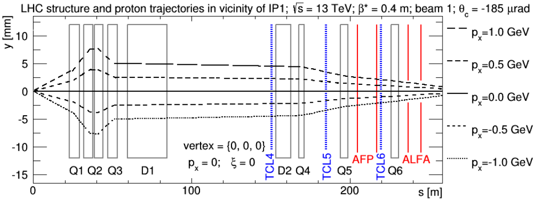


collision optics, **ALFA** and **AFP**: trajectory due to p_y

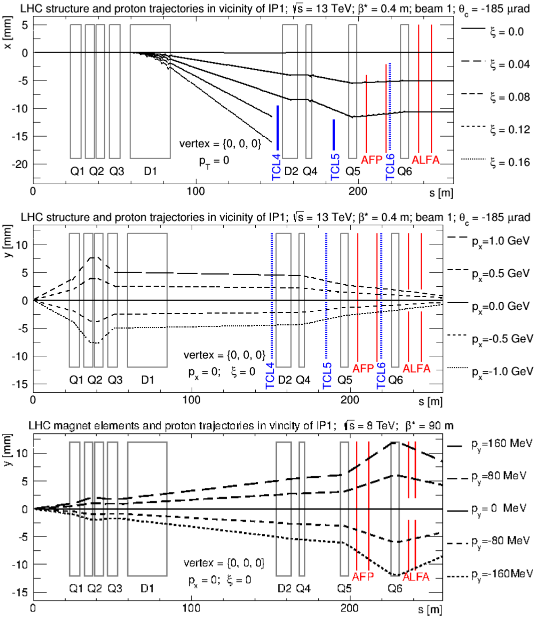


Proton trajectory is determined by the LHC magnetic field.

collision optics, **ALFA** and **AFP**:
trajectory due to ξ
$\xi = 1 - E_{proton}/E_{beam}$

collision optics, **ALFA** and **AFP**:
trajectory due to p_y

special high-β^* optics, **ALFA**:
improve acceptance in
$p_T = \sqrt{px^2 + py^2}$

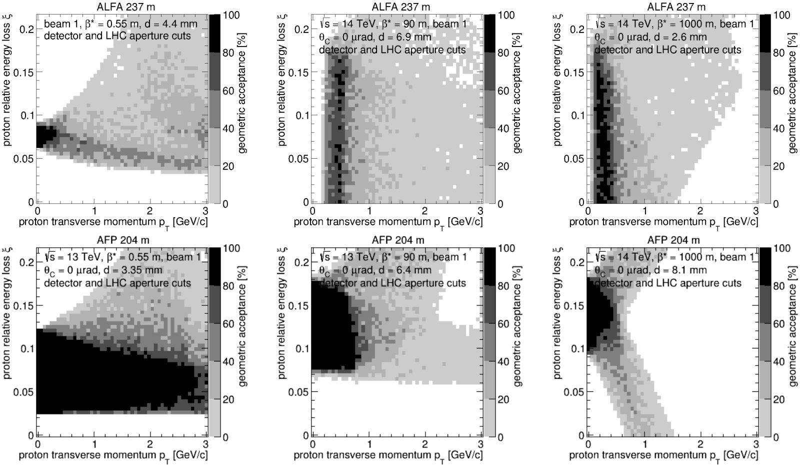


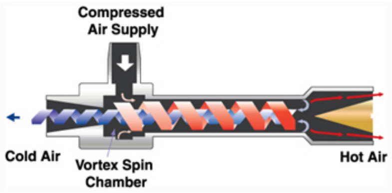
From SPIE 9290 (2014) 929026, arXiv:1408.1836

Ratio of the number of protons with a given relative energy loss (ξ) and transverse momentum (p_T) that crossed the active detector area to the total number of the scattered protons having ξ and p_T.

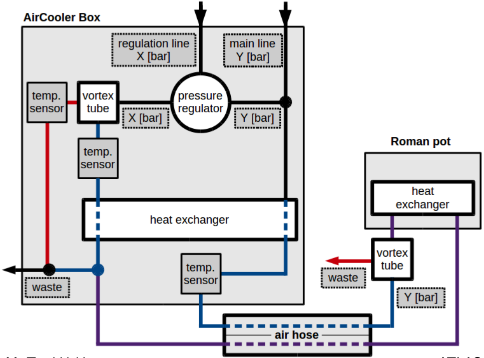
optics

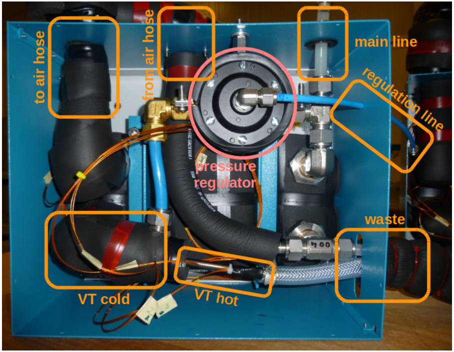
	$\beta^* = 0.55$ m nominal (*collision*)	$\beta^* = 90$ m special (*high-β^**)	$\beta^* = 1000$ m special (*high-β^**)
ALFA			
AFP			



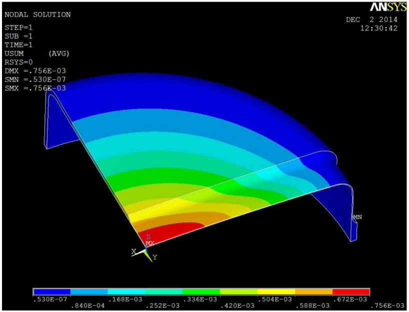


- Technology: Vortex Tube.
- Staged approach:
  - precooling of input air in AirCooler box,
  - cooling with Vortex tube installed on RP.
- Efficient cooling: temp. down to -30 ^{0}C with detectors powered on.
- Operational requirements: -10 ^{0}C.
- Online temperature regulation with PID algorithm.

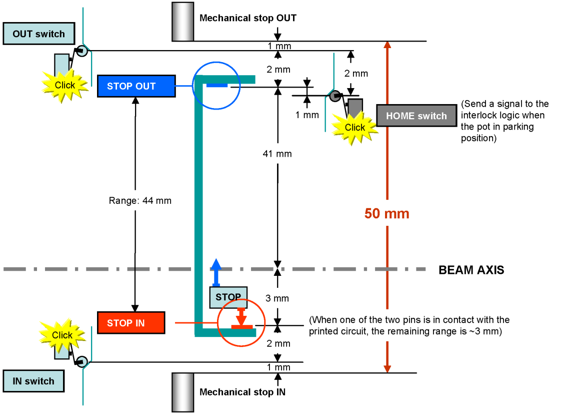


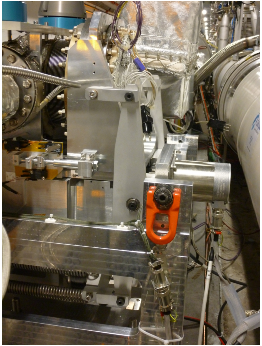


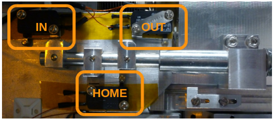
- Each RP is kept under secondary vacuum:
    - reduce stress and limit "bulge" of thin window,
    - allows cooling below 0 deg. (prevents icing of detectors).
- Two vacuum pumps (P1, P2) are located in alcoves on both sides (RR13 and RR17).
- Four operating modes:
    - mode 1: alternating between P1 and P2,
    - mode 2: use P1, if problem switch to P2,
    - mode 3: use P2, if problem switch to P1,
    - mode 4: use both pumps.
- Overall leak rate below 0.3 mbar / min.

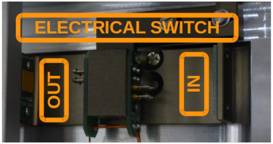


Pot Motion and Controls









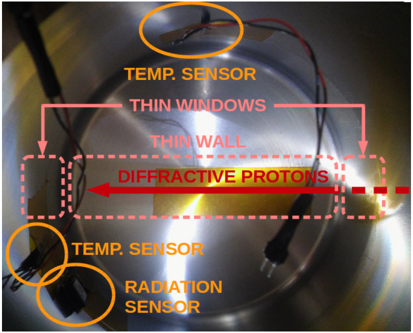
- Positions of IN, OUT, and HOME switch and Electrical Stop were set according to the laser measurements.
- Pot position is precisely calibrated (few μm) before every insertion w.r.t. electrical switch.
- In case of emergency (*i.e.* loss of power) – retraction with springs to the HOME position.
- Mechanical stops installed to prevent damage of fragile electrical stop.

Temperature sensors (NTC):

- each station:
  - each SiT detector (on flex),
  - ToF (on amplifiers),
  - heat exchanger (NTC + PT1000),
  - pot wall (up + under second thin window),
  - flange (cold output of Vortex tube + HV for ToF),
  - LTB.
- VReg. crate.
- AirCooler box:
  - hot output of VT,
  - cold output of VT,
  - output of box.

Radiation sensors:

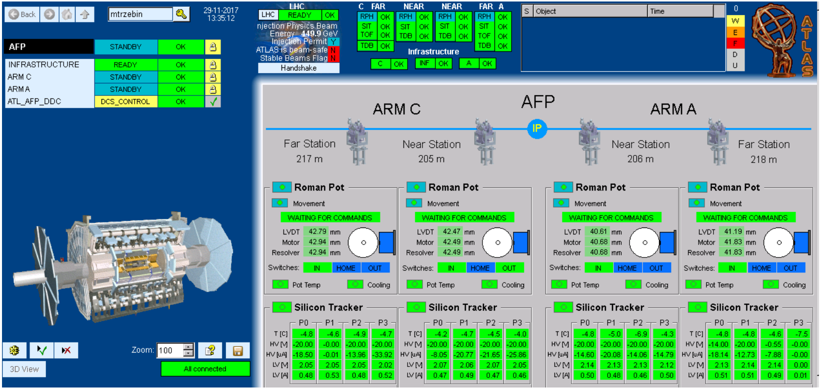
- bottom of each pot,
- VReg. crate,
- far station LTB,
- RR17 alcove.



DCS is responsible for coherent and safe operation of the detector:

- provides tools for bringing the detector into desired operational state, monitors its parameters, signals any abnormal behaviour and performs actions,
- defined subset of detector parameters is stored in data bases for later inspections,
- graphical user interfaces allow overall detector operation and visualisation.

AFP is fully integrated with ATLAS DCS system.



Architecture of AFP TDAQ:

- High Speed Input Output board (HSIO): DAQ board with many high-speed and low-speed I/O channels, Xilinx Artix 200 FPGA, mezzanines with ATLAS TTC and RCE (Reconfigurable Cluster Element),
- frontends are configured at 40 Mbps, the data are readout at 160 Mbps.

AFP is fully integrated with ATLAS TDAQ system:

- AFP trigger signals are generated, combined (OR, AND, majority vote logics), synchronized with LHC clock and send to ATLAS Central Trigger Processor,
- trigger signals are sent via fast air-core cables and reach CTP within the standard ATLAS latency (85 BCXs).