Overview of ATLAS Roman Pot Detectors

Current Status and Future Perspectives

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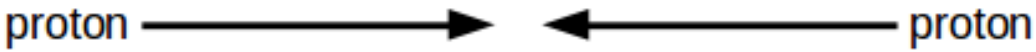
on behalf of ATLAS Forward Detectors

Institute of Nuclear Physics
Polish Academy of Sciences

WE-Heraeus-Seminar "Forward Physics and QCD at the LHC and EIC", Bad Honnef, Germany, 23 – 27 **October 2023**

Usual situation at the LHC:



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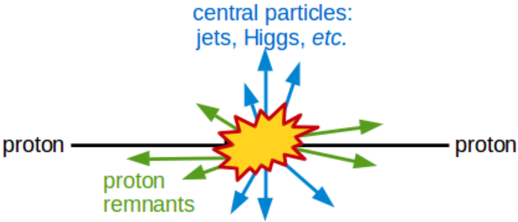

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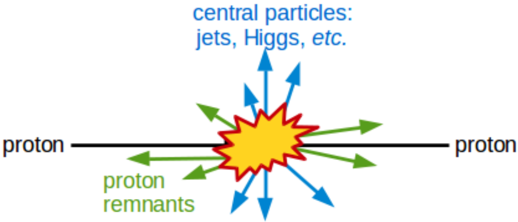

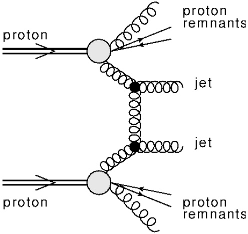

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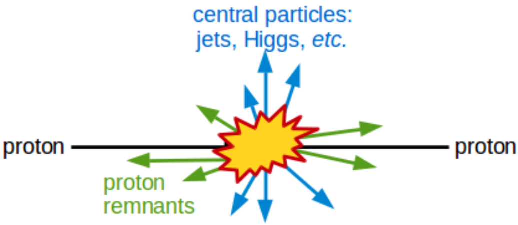

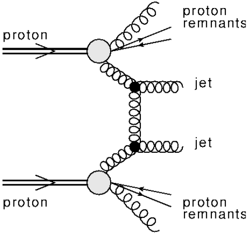

Can proton(s) remain intact?

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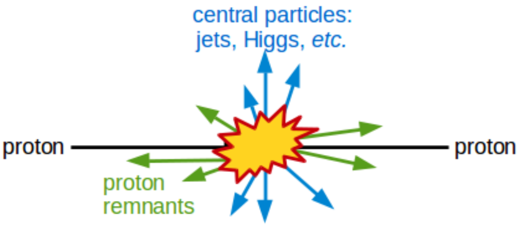

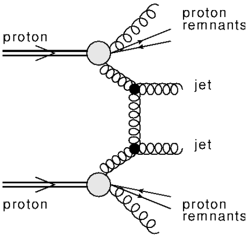

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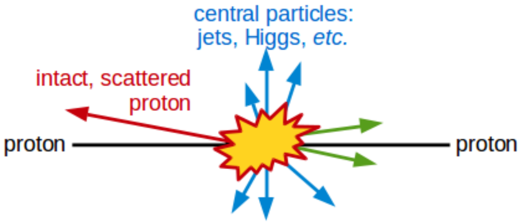

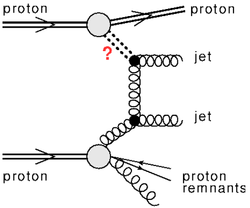

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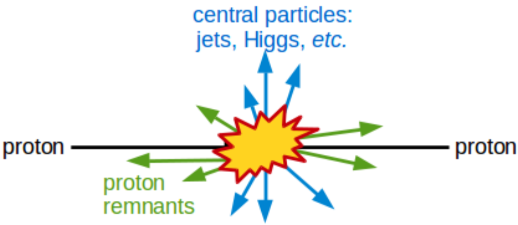

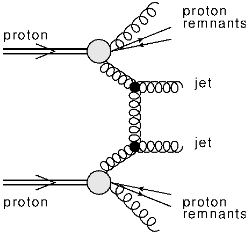

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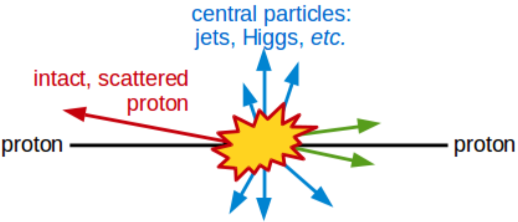
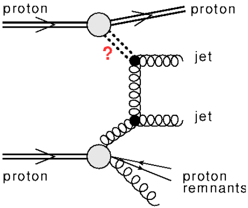


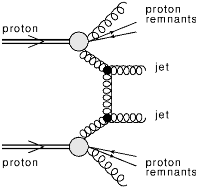


Yes! But exchanged object must not change quantum numbers of proton(s):

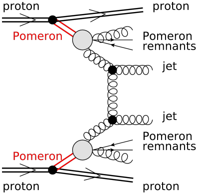
- electromagnetic force: photon,
- strong force: Pomeron (QCD = two gluons + h.o. terms).

Physics Processes

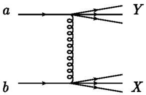
- **hard** – perturbative approach is valid; small cross-sections:
  - non-diffractive



  - diffractive

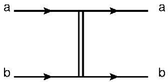


- **soft** – large cross-sections:
  - non-diffractive:

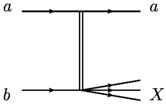


  - diffractive:

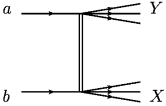
Elastic Scattering



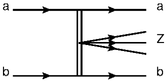
Single Diffraction



Double Diffraction



Central Diffraction



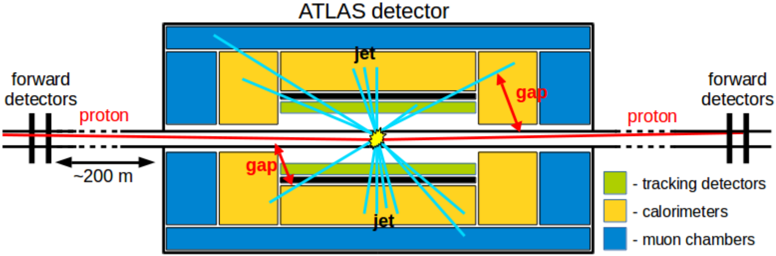
Diffraction:

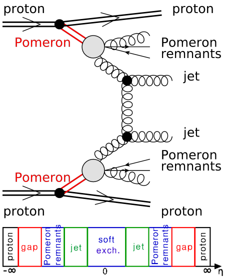
- colour singlet exchanged,
- Pomeron (QCD = two gluons + ...).

Natural ways to seek for diffraction:

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

Assumption: one would like to measure diffractive interactions at the LHC.
Typical diffractive topology: a gap in rapidity is present between proton(s) and central system and one or both interacting proton stay intact.





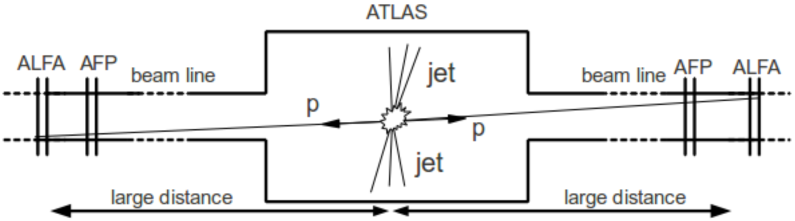
Method 1 (rapidity gap):

+ 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

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 → natural diffractive signature → usually scattered at very small angles (μrad) → detectors must be located far from the Interaction Point.

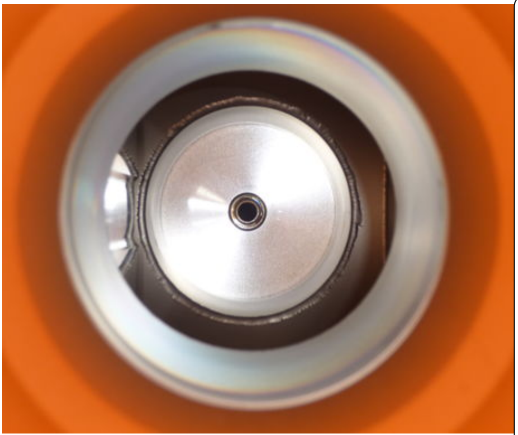


ALFA

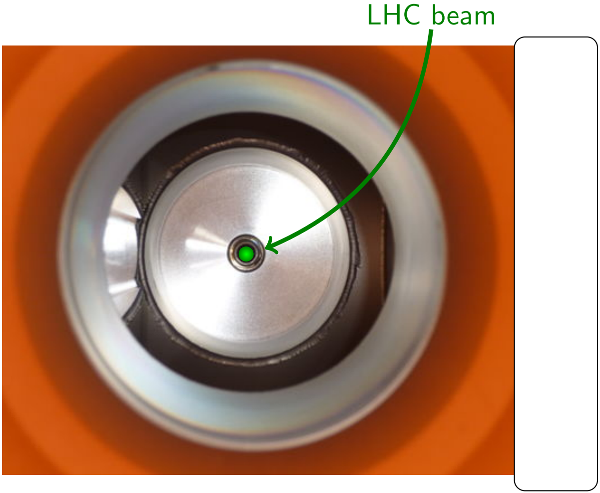
- **A**bsolute **L**uminosity **F**or **A**TLAS
- 240 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- vertically inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = \sigma_y = 30\ \mu$m

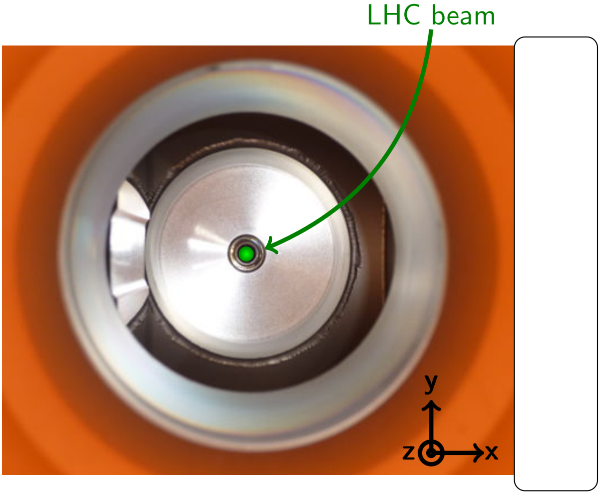
AFP

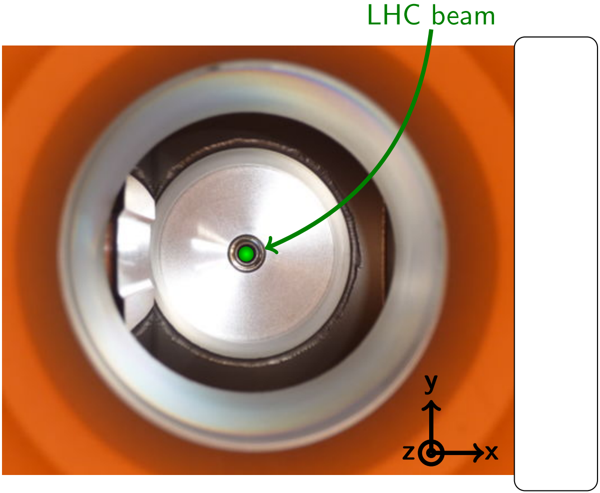
- **A**TLAS **F**orward **P**roton
- 210 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- horizontally inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = 6\ \mu$m, $\sigma_y = 30\ \mu$m
- timing detectors, resolution: $\sigma_t \sim 25$ ps



Advantages of Roman Pot Technology




LHC beam
y
z
x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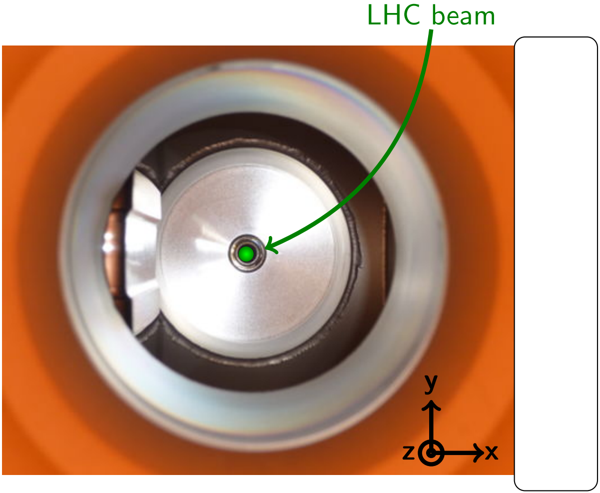

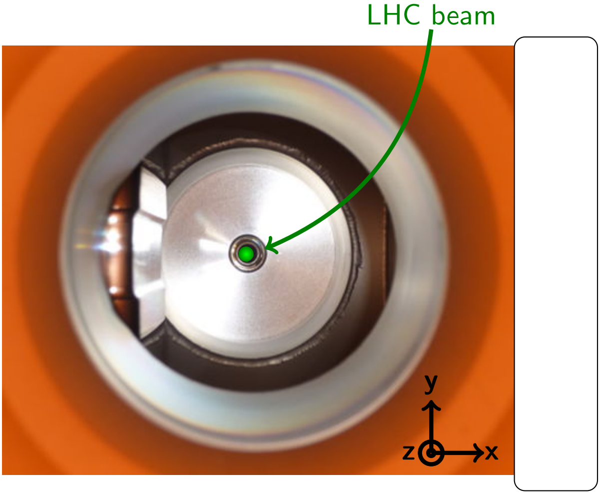
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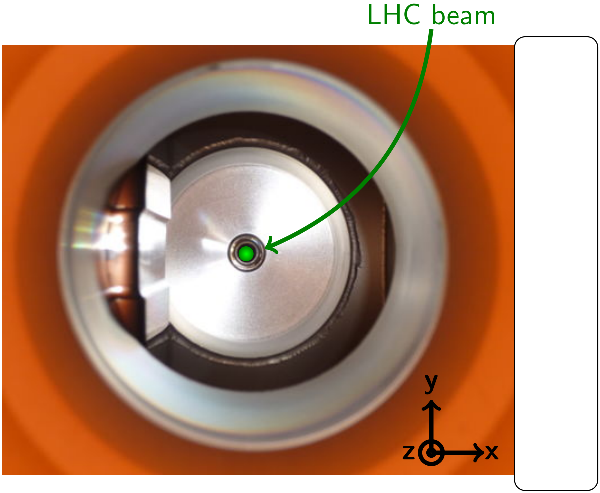
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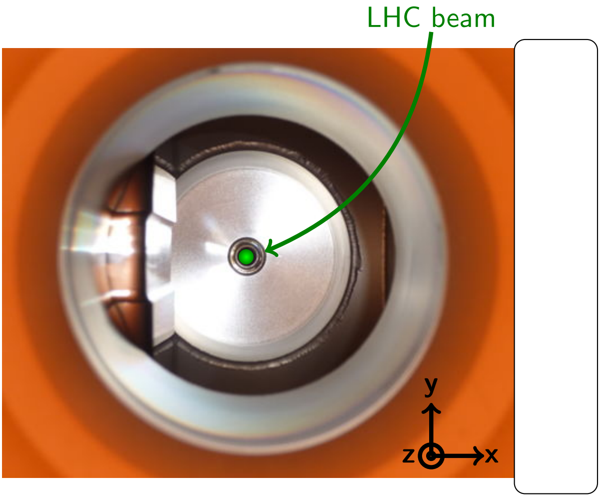
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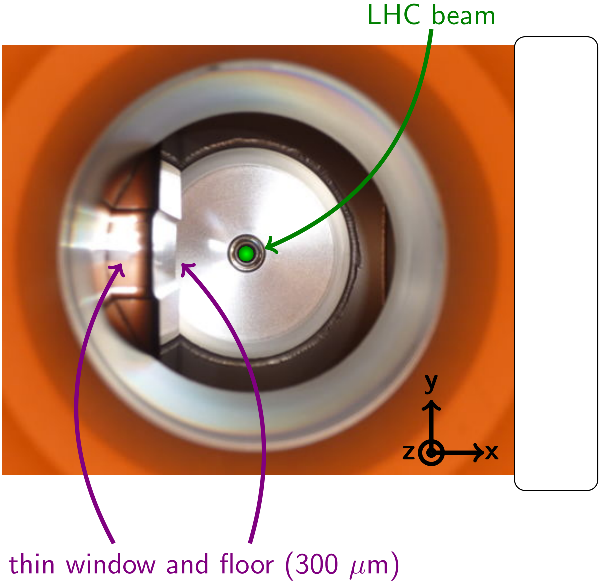
LHC beam
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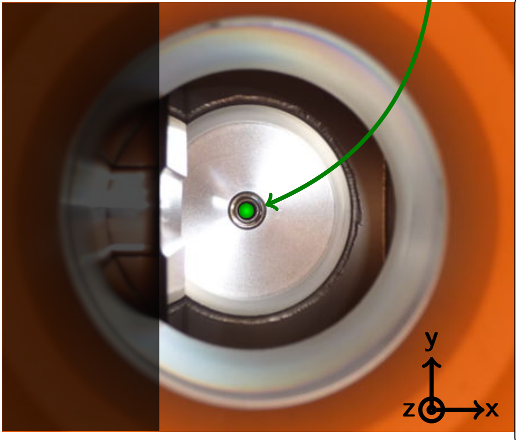
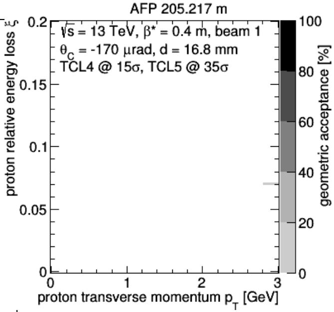
thin window and floor (300 μm)

shadow of TCL4 and TCL5 collimators

LHC beam



Geometric acceptance:



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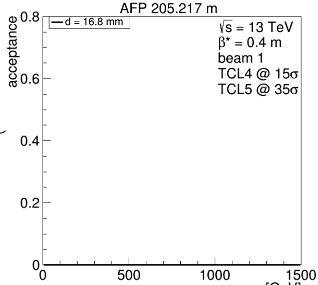

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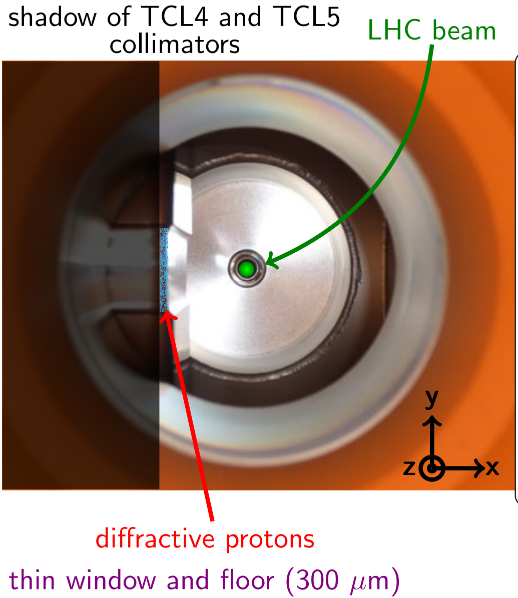

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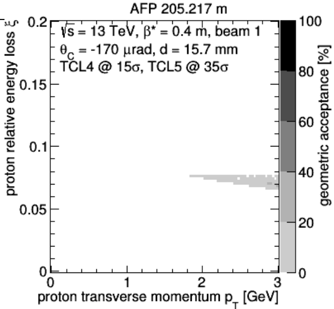

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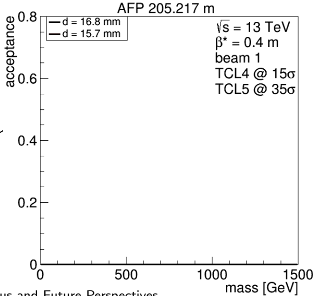

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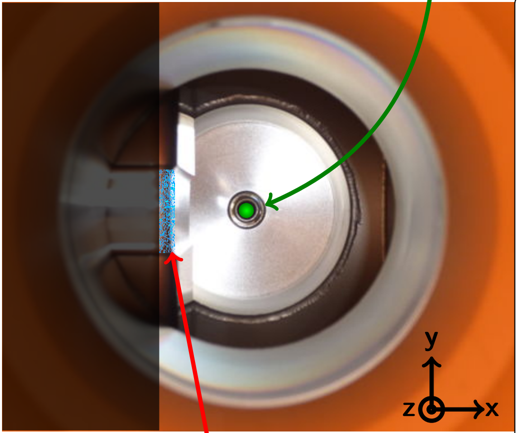

diffractive protons

thin window and floor (300 μm)

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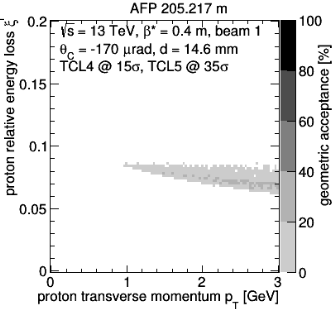

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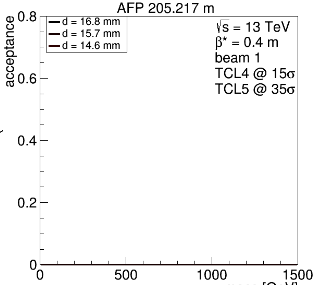

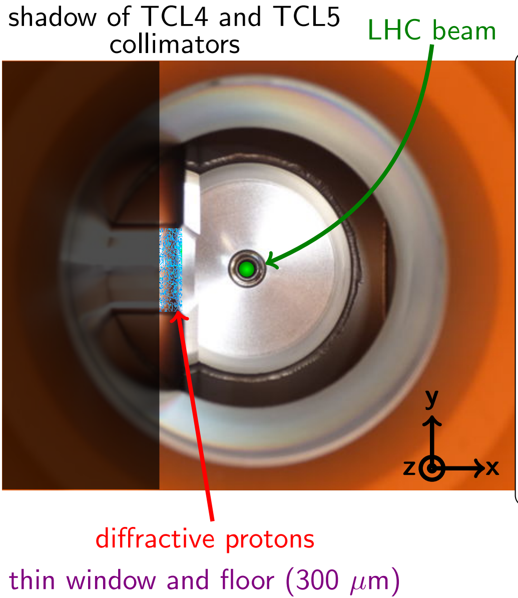

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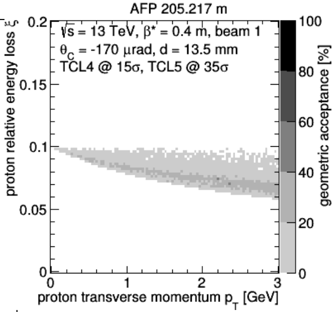

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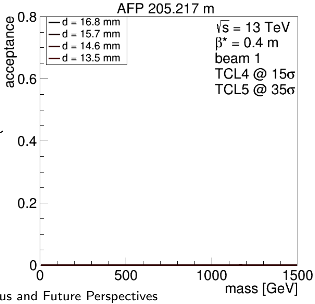

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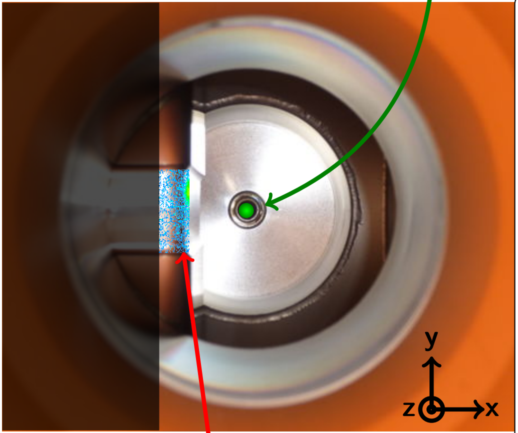

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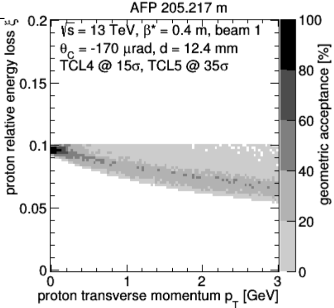

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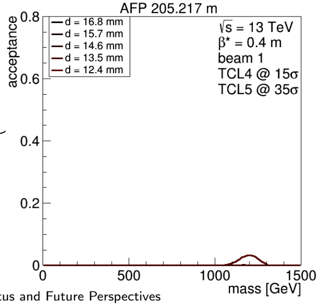

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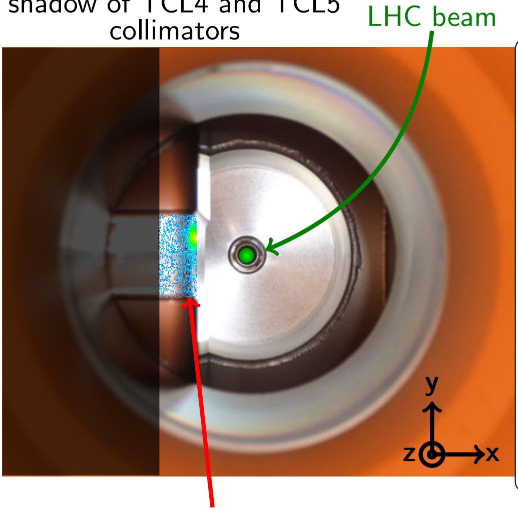

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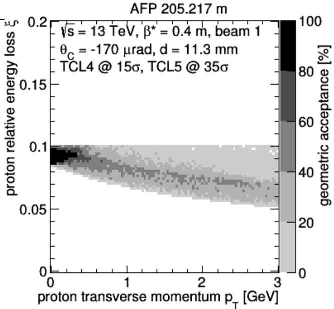

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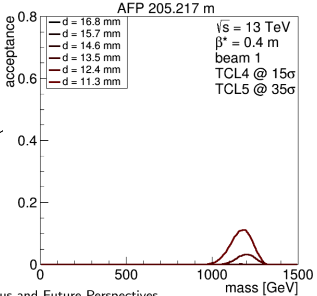

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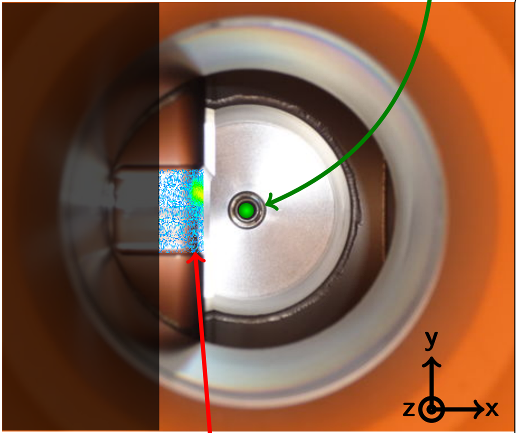

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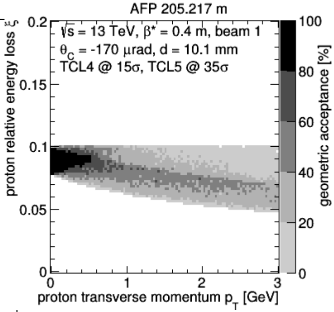

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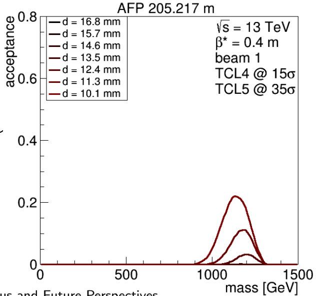

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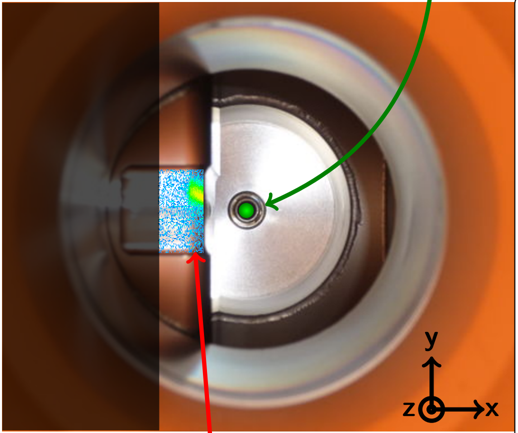

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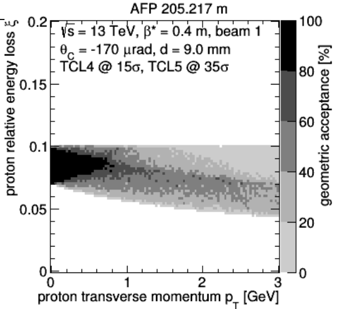

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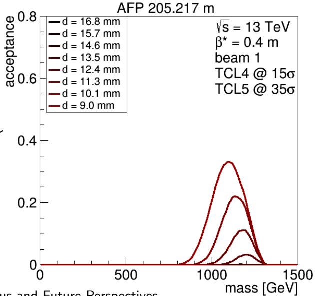

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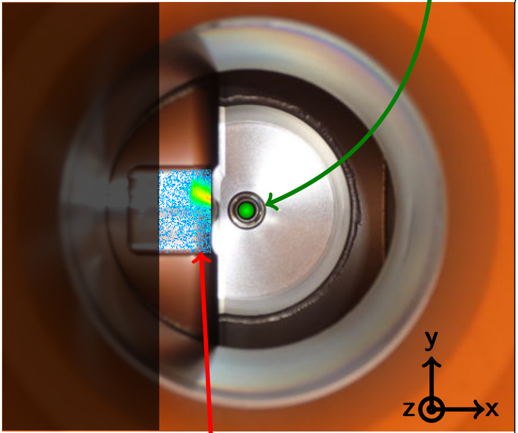

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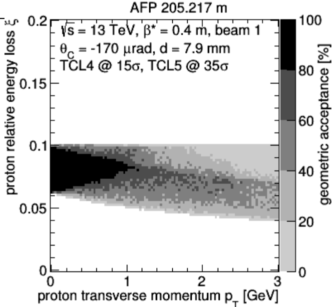

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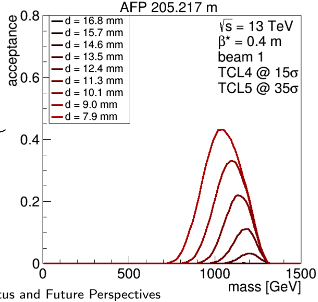

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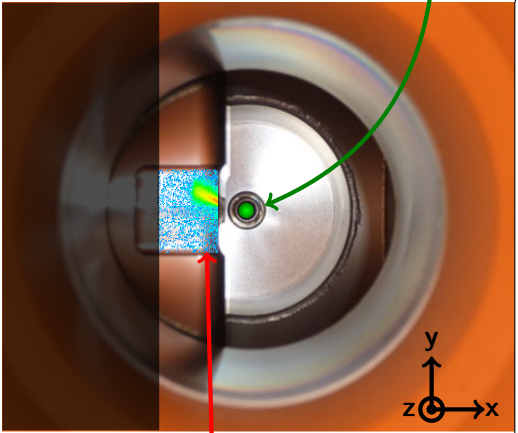

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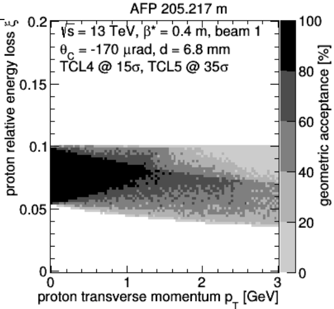

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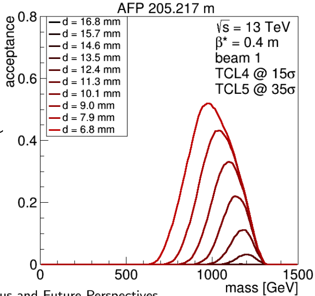

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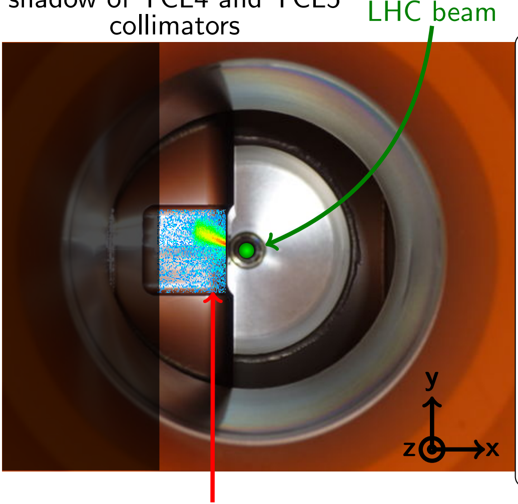

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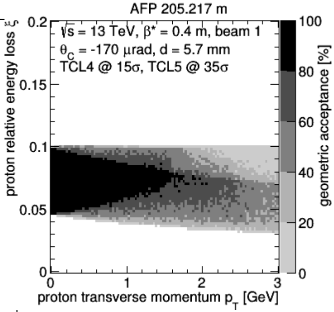

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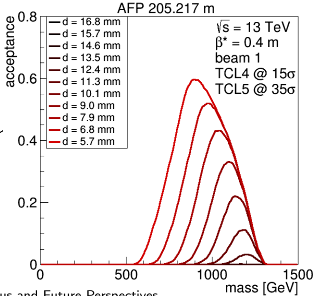

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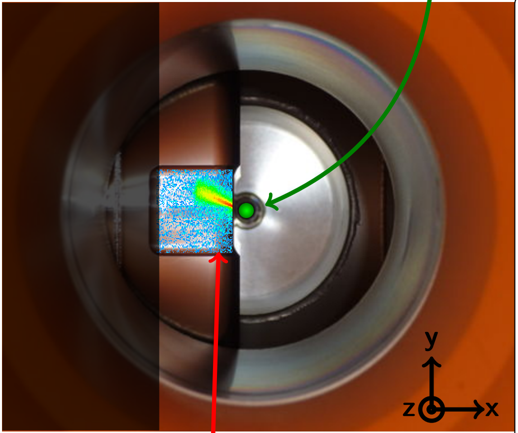
shadow of TCL4 and TCL5 collimators

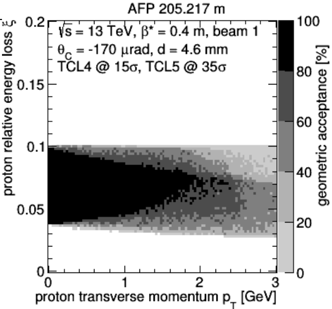
LHC beam



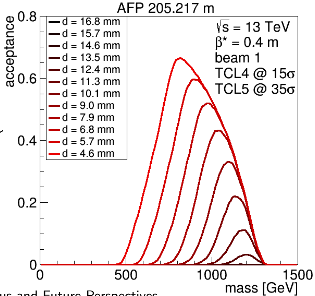
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:

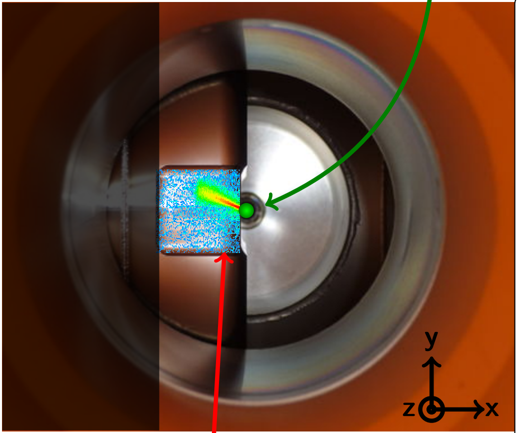


Mass acceptance:



shadow of TCL4 and TCL5 collimators

LHC beam



diffractive protons

thin window and floor (300 μm)

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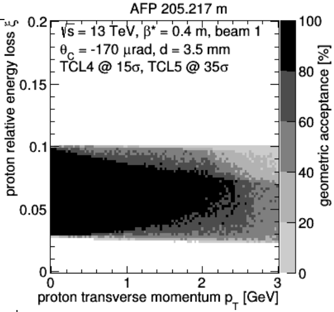
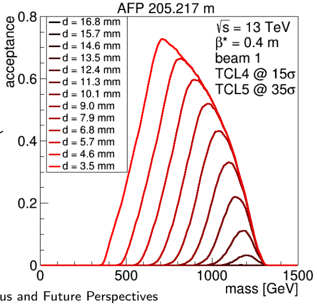
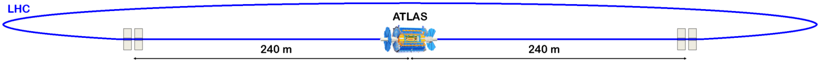
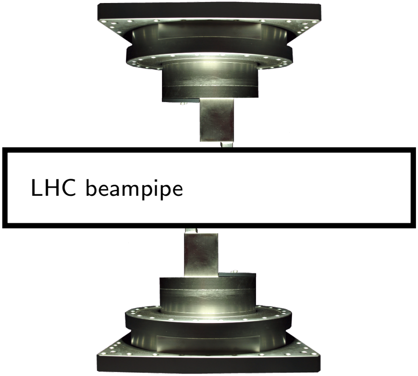


Mass acceptance:

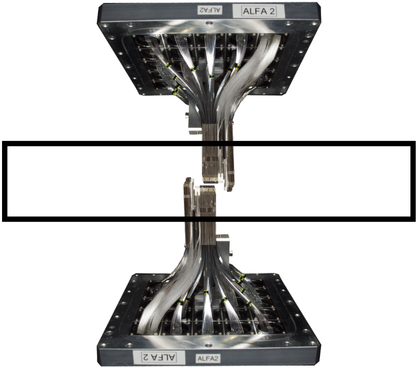


- Two stations at each ATLAS side, 240 m far from the IP1.
- Scintillating fibres – position measurement with precision of $\sim 30\mu$m,
- *Roman Pot* technology – detectors can move in vertical (y) direction.



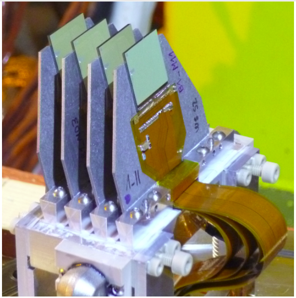


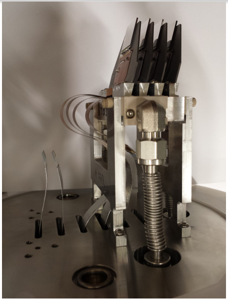
open

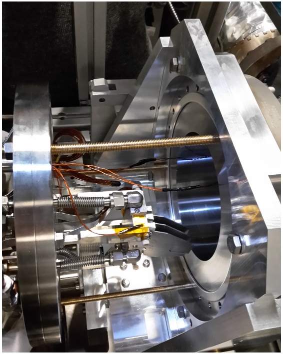


closed

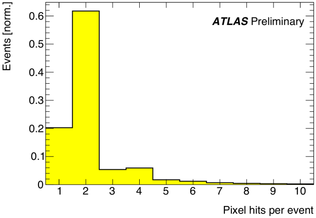
AFP: Silicon Trackers (SiT)



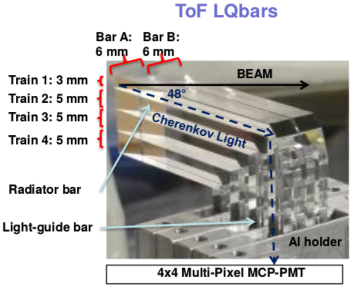


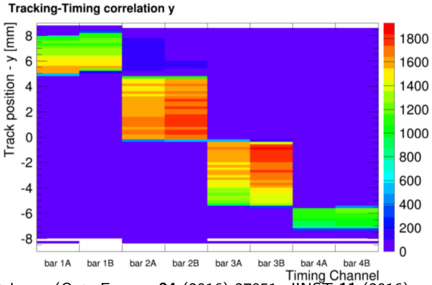


- Four detectors in each station.
- Technology: slim-edge 3D ATLAS IBL pixel sensors bonded with FE-I4 readout chips.
- Pixel size: 50x250 μm^2.
- Tilted by 14^0 to improve resolution in x.
- Resolution: $\sim$6 μm in x and $\sim$30 μm in y.
- Trigger: majority vote (2 out of 3; two chips in FAR station are paired and vote as one).
- **No major changes between Run 2 and Run 3 detector setups.**



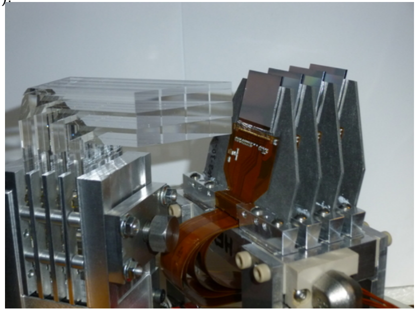
From JINST **11** (2016) P09005; JINST **12** (2017) C01086





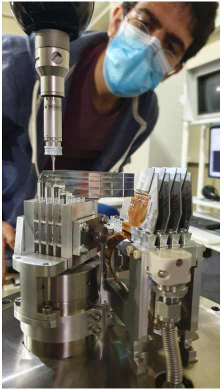
Setup and performance shown above are from test-beam (Opt. Express **24** (2016) 27951, JINST **11** (2016) P09005).

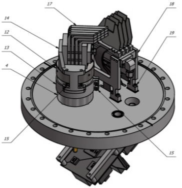
- 4x4 quartz bars oriented at the Cherenkov angle with respect to the beam trajectory.
- Light is directed to Photonis MCP-PMT.
- Expected resolution: ∼25 ps.
- Installed in both FAR stations.

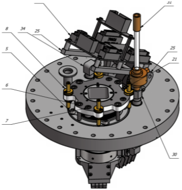


AFP upgrades for Run 3

- Improvement in silicon detector cooling (new heat exchangers).
- Production of new tracking modules.
- New design of detector flange: Out-of-Vacuum solution for ToF detectors
- New trigger module: possibility to trigger on single train.
- New photo-multipliers: address inefficiency issues from Run2 data-taking.
- AFP regularly takes data during LHC Run 3. In addition, few special low-μ datasets were collected.

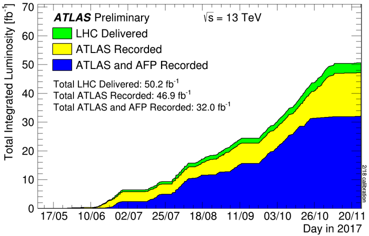


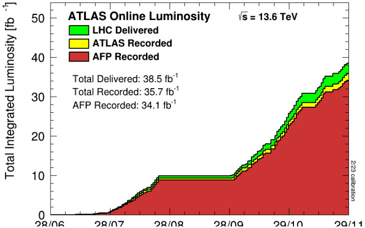


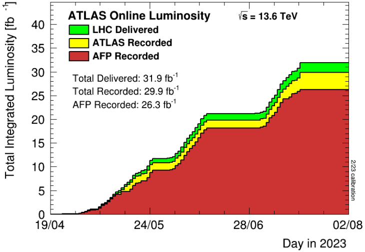


More upgrades planned for coming LHC Year End Technical Stop:

- design, production and installation of pot heat-sink to address issues with overheating at highest beam intensities,
- production of picoTDC for ToF,
- installation of new Local Trigger Boards,
- all upgrades will be followed by laser survey (positioning wrt. LHC).







Data recorder so far by AFP:

- $32.0\ \text{fb}^{-1}$ in 2017 (left),
- $34.1\ \text{fb}^{-1}$ in 2022 (top right),
- $26.3\ \text{fb}^{-1}$ in 2023 (bottom right),
- **in total: $92.4\ \text{fb}^{-1}$.**

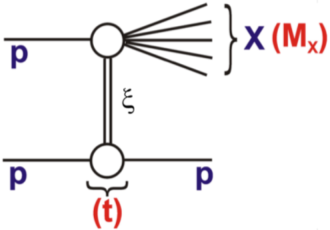
ALFA: $\beta^* = 3/6$ km campaign in 2023 + various Run 1 and Run 2 high-β^* datasets.

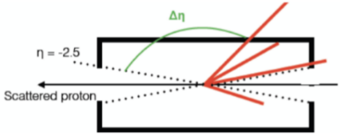
With successful $\beta^* = 3.6$ km campaign, ALFA finished its unexpectedly long data-taking story.

AFP took good data in Run 3 and is eagerly waiting for continuation.

Backup

Kinematic Variables



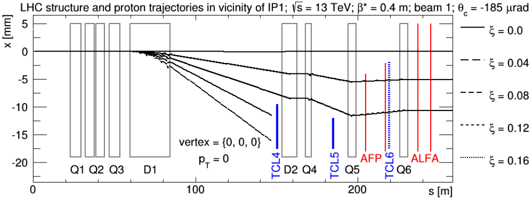


- t – squared four-momentum transferred from the proton:
$$t \approx -p_T^2$$
- p_T – proton transverse momentum
- ξ – momentum fraction of the proton carried by the Pomeron:
$$\xi = 1 - E/E_{beam}$$
$$\xi \approx \sum_i (E^i \pm p_z^i)/\sqrt{s}$$
- $\Delta\eta$ – pseudorapidity gap – space in which no particles are produced / detected

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

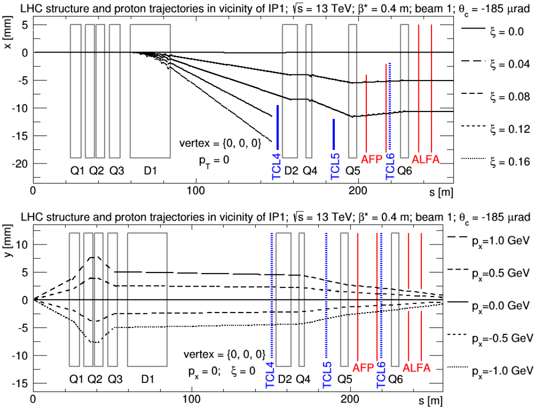


Proton trajectory is determined by the LHC magnetic field.

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

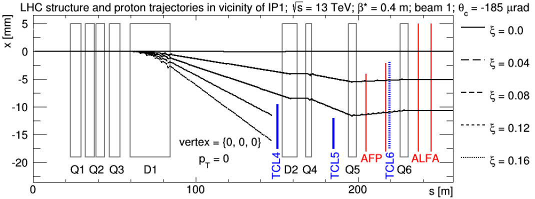
$\xi = 1 - E_{proton}/E_{beam}$

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

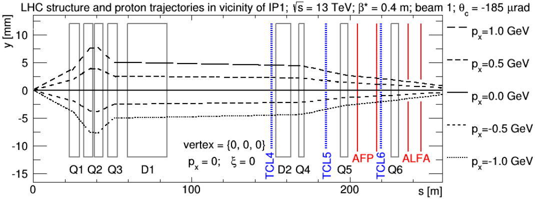


Proton trajectory is determined by the LHC magnetic field.

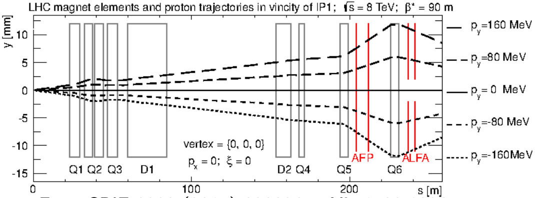
collision optics,
ALFA and **AFP**:
trajectory due to ξ
$\xi = 1 - E_{proton}/E_{beam}$



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



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



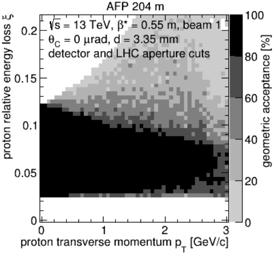
From SPIE 9290 (2014) 929026, arXiv:1408.1836

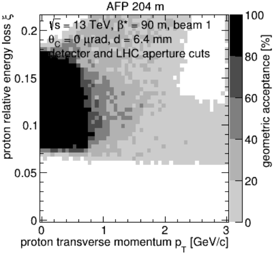
Ratio of the number of protons with a given relative energy loss (ξ) and transverse momentum (p_T) that crossed the active detector area to the total number of the scattered protons having ξ and p_T.

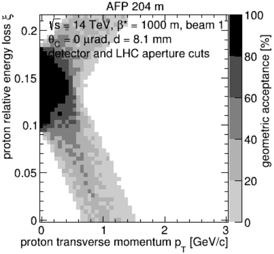
$\beta^* = 0.55$ m
nominal (*collision*)

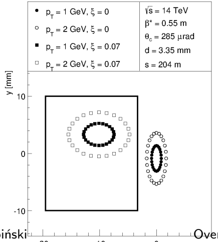
$\beta^* = 90$ m
special (*high-β^**)

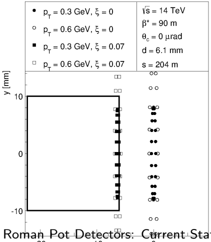
$\beta^* = 1000$ m
special (*high-β^**)

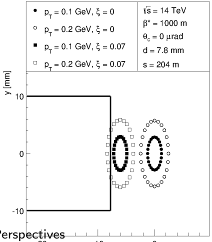


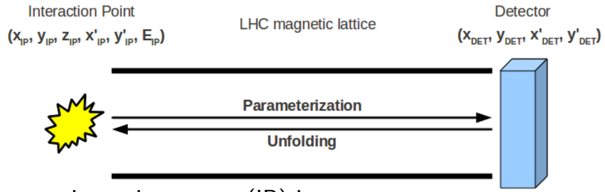




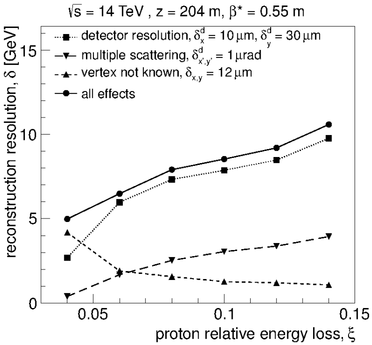




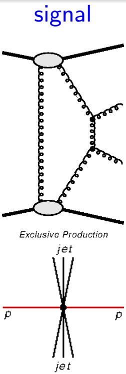


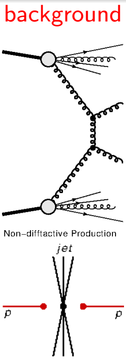


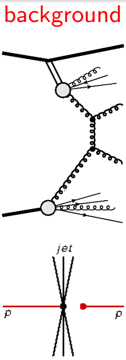
- At the interaction point proton (IP) is fully described by six variables: position (x_{IP}, y_{IP}, z_{IP}), angles (x'_{IP}, y'_{IP}) and energy (E_{IP}).
- They translate to unique position at the forward detector (x_{DET}, y_{DET}, x'_{DET}, y'_{DET}).
- Idea: get information about proton kinematics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

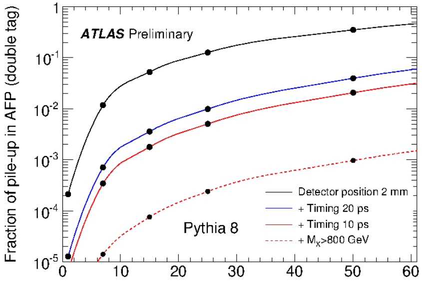






Idea:

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



- Performance analysis based on 2017 data (taken with $\mu \approx 2$): ATL-FWD-PUB-2021-002.
- Poor efficiency of few percent due to fast PMT degradation; effect not expected during Run 3 due to new PMTs.
- Very good timing resolution: 20 – 50 ps for single bar.
- Overall time resolution of each ToF detector:
  - 20 ± 4 ps for side A,
  - 26 ± 5 ps for side C,
  - note: systematic uncertainties dominate.