Studies of the LHC Optics at Point 1 and Hard Diffractive Program

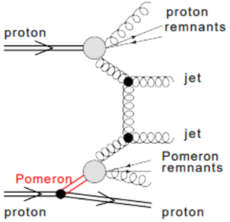
Sergio Javier Arbiol Val

Institute of Nuclear Physics
Polish Academy of Sciences

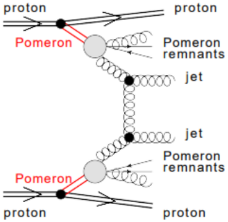
Diffractive physics

Hard Diffractive process: Protons are diffracted by a color singlet exchange. This process are mediated by either photons (QED) or pomerons (QCD). They have small cross-sections and are studied by perturbative QCD. Typical signatures are rapidity gaps and protons scattered at very small angles (μrad). Examples are:

Single Diffractive Jet Production.

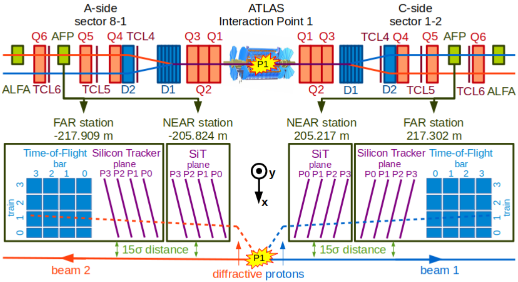


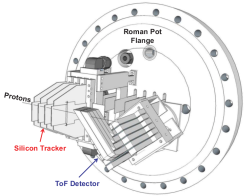
Double Pomeron Exchange Jet Production.



Rapidity gap is often destroyed by background → Need for detectors in forward region of ATLAS. The Atlas Forward Proton (AFP) is one such detector system.

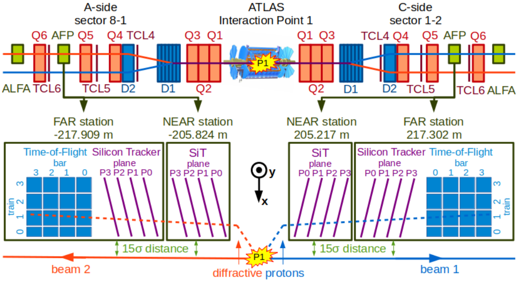
What is AFP?

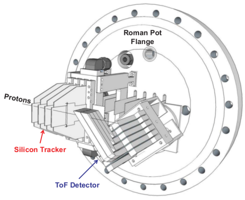




- Silicon Tracker (SiT): A set of four planes in each Roman Pot (RP) station.
  - 50 x 250 μm pixel size.
  - Planes tilted 14° to improve resolution.
  - Resolution: $\sigma_x = 5\mu m$, $\sigma_y = 30\mu m$.
- Time-of-flight (ToF): Designed to measure the primary vertex z-coordinate.
  - Installed only in the FAR stations.
  - Composed of a 4 x 4 matrix of quartz bars, L-shaped and rotated 48° with respect to the LHC beam.

What is AFP?





- Q = Quadrupole magnets. Focus the beam.
- D = Dipole magnets. Bend the beam to maintain orbit.
- TCL = Beam collimators. Protect the machine from escaping radiation.

Proton Trajectories

The proton trajectory depends on:

- The energy loss on the interaction $\xi = 1 - \frac{E_{proton}}{E_{beam}}$.
- The transverse momentum p_T at Interaction Point 1 (IP1).

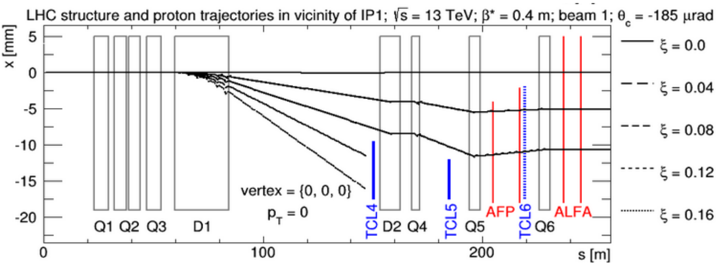


Figure: AFP measures displacement, which is related to mass of the central system.

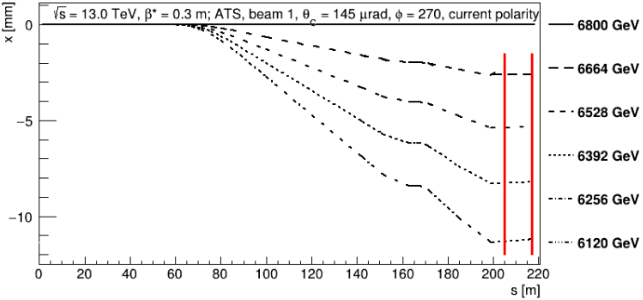
Acceptance of the detector limited by collimator apertures and beam-detector distance.

Optics run 3

In addition to the interaction, the protons trajectories are also influenced by accelerator optics parameters.

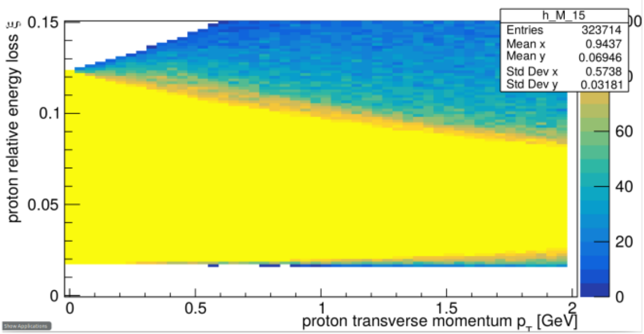
- β^*. The betatron function (at IP1) is a measure of the distance from a certain point to the one at which the beam is twice as wide.
- θ_C^*. Crossing angle of the beams at IP1.
- ϕ. Phase of the beams.

In 2022 and 2023 running this parameters were: $\sqrt{s} = 13.7$ TeV, $\beta^* = 0.3$ m, $\theta_C^* = 145\ \mu rad$, $\phi = 270°$.



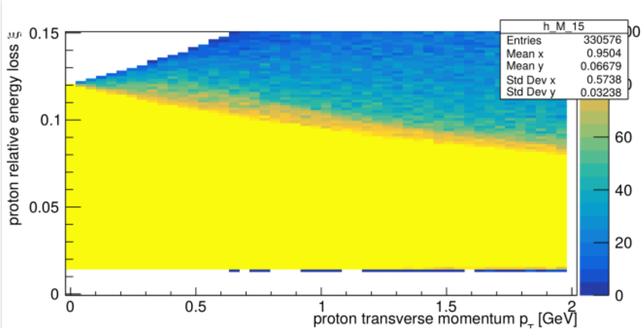
Optics run 3: 2022

- The geometric acceptance is in the range $0.02 < \xi < 0.12$.
- The corresponding mass acceptance is in the range $260 < M_{central} < 1560$ GeV.
- The distance to the beam is 2.3<d<2.8 mm for NEAR stations and 1.5<d<2.3 mm for FAR stations.



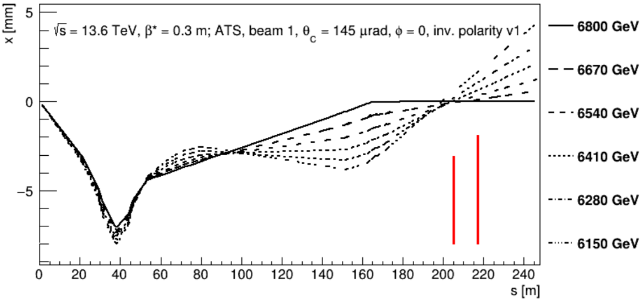
Optics run 3: 2023-2025

- The geometric acceptance is in the range $0.015 < \xi < 0.12$.
- The corresponding mass acceptance is in the range $195 < M_{central} < 1560$ GeV.
- The distance to the beam is $1.7 < d < 2.3$ mm for NEAR stations and $1.5 < d < 2.3$ mm for FAR stations.



Future Optics: Inner triplet polarity inversion

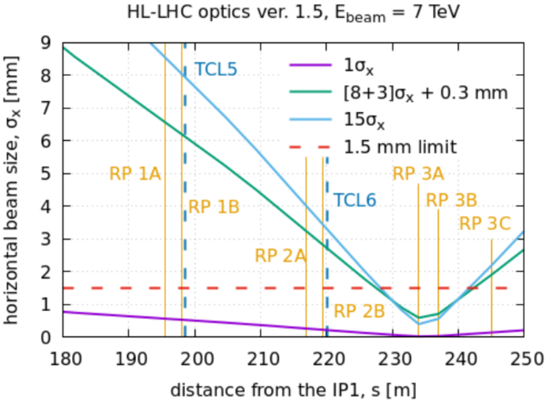
An inversion of the inner triplet polarity was proposed for 2024 running. However, it has been postponed.



The proposed change leaves AFP without acceptance → End of AFP high-μ program. AFP will only take data on special runs.

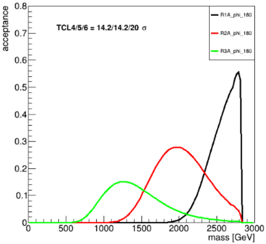
Future Optics: HL-LHC

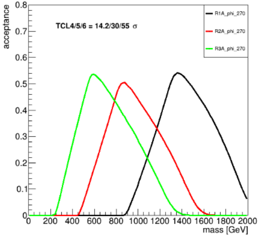
- For the HL-LHC we expect optics: $\sqrt{s} = 14$ TeV, $\beta^* = 15$ cm, $\theta_C^* = 250\ \mu rad$, 4 different phases $\phi = 0°$ (+x), $\phi = 90°$ (+y), $\phi = 180°$ (-x) and $\phi = 270°$ (-y.).
- Location is not yet decided, but options are limited. Further constrained by the effects of collimators on acceptance.

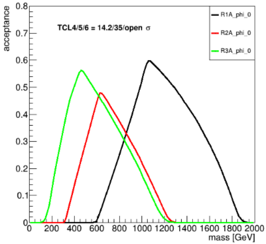


Future Optics: HL-LHC Optics

- Default settings of the collimators leave us with almost no acceptance → need more open settings.
- Acceptance is shifted towards bigger masses.
- Physics case depends on the exact collimator settings used but is mainly focused on photon-induced process $\gamma\gamma \to \mathrm{WW}/\mathrm{ZZ}/t\bar{t}$ and BSM searches (ALP/DM).







Summary

- Optics in 2022 and 2023 running gives us good acceptance and proton separation. Due to some improvements of the detector, we have better acceptance for 2023.
- The inversion of the inner triplet polarity will leave us without acceptance in AFP. Postponed to 2025.
- Acceptance in HL-LHC depends greatly on collimator aperture, which conditions the physics case. With the default settings, we only have acceptance for high central mass.