AFP Acceptance Study

QT: The Study of the Potential for a Joint-Data Taking Between ATLAS, AFP, ZDC and LHCf Detectors

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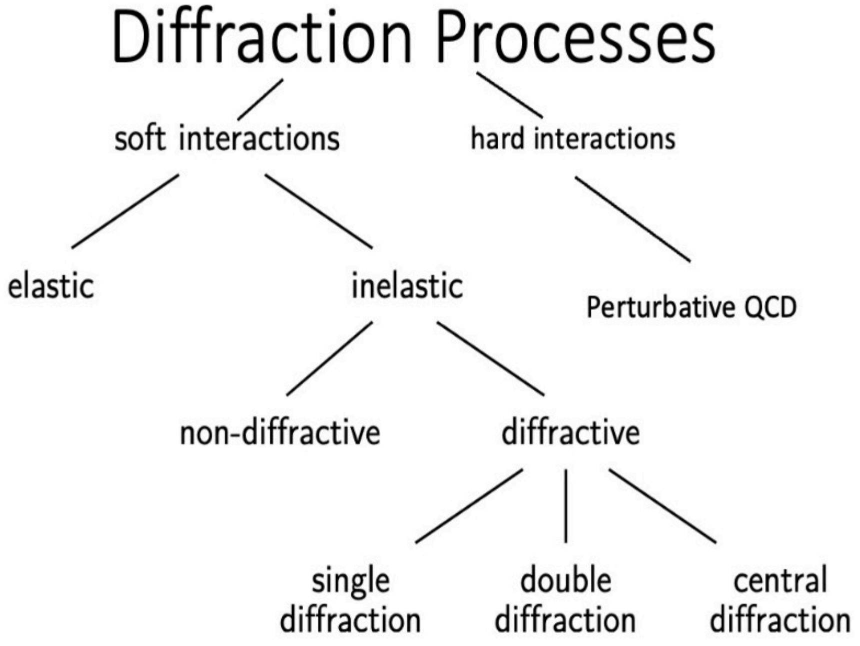
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

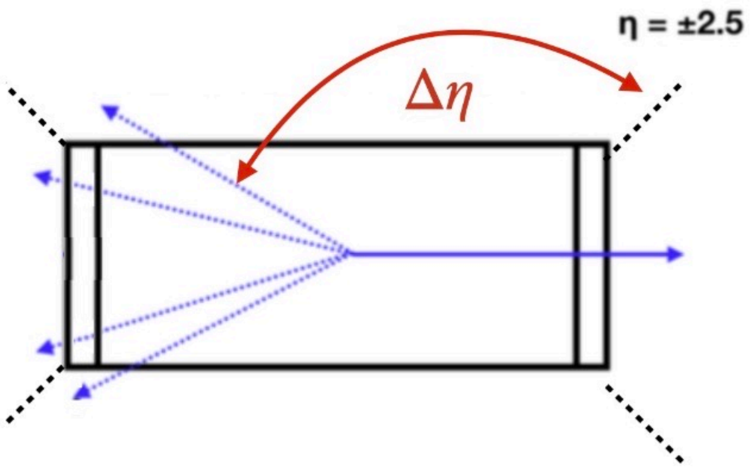
DESY.

Motivation

- Diffraction processes are poorly understood yet make up ~10% of total LHC cross-section.
- The forward studies at LHC aim to improve MC generators for cosmic ray air showers and pile-up modelling by studying these diffraction events.

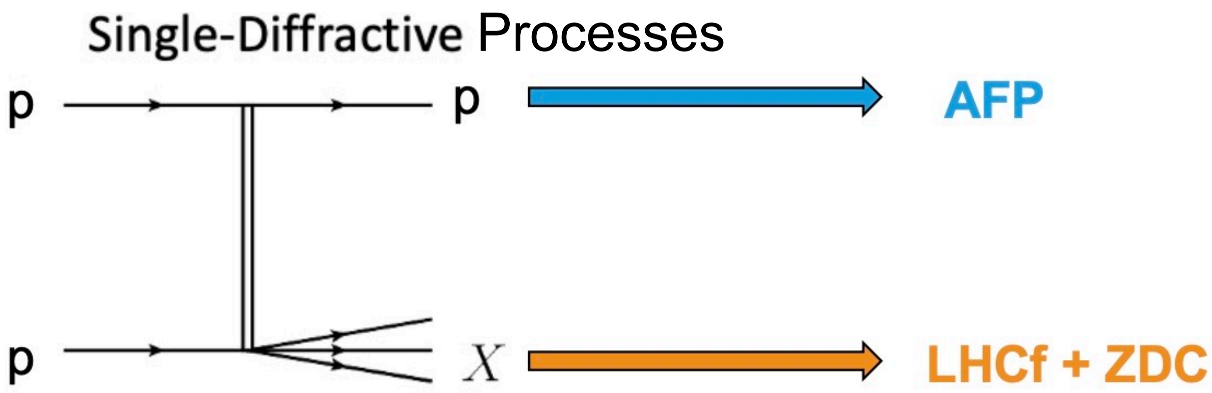


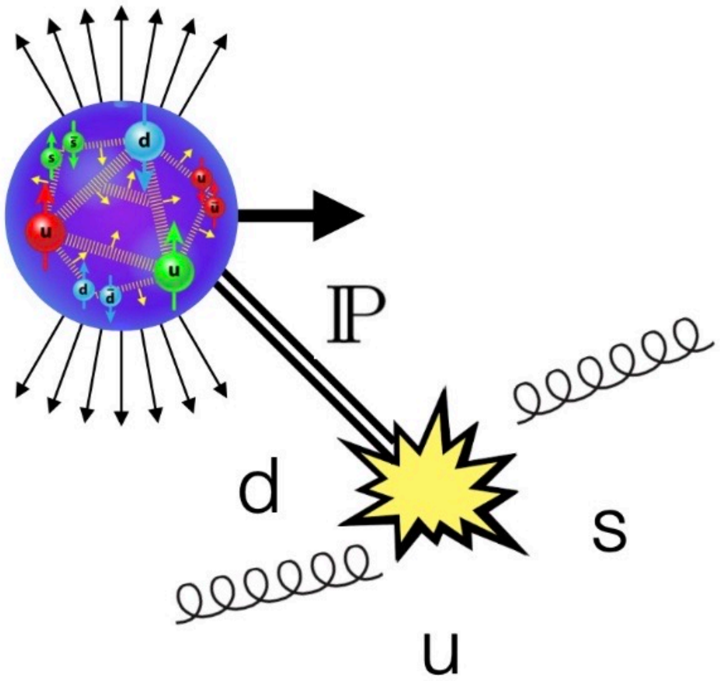
- Diffractive processes, in general, are identified by the large rapidity gaps at the final state.
- Single diffractive (SD) processes have one intact proton and one dissociated proton after a color singlet "Pomeron" exchange.



Large rapidity gap

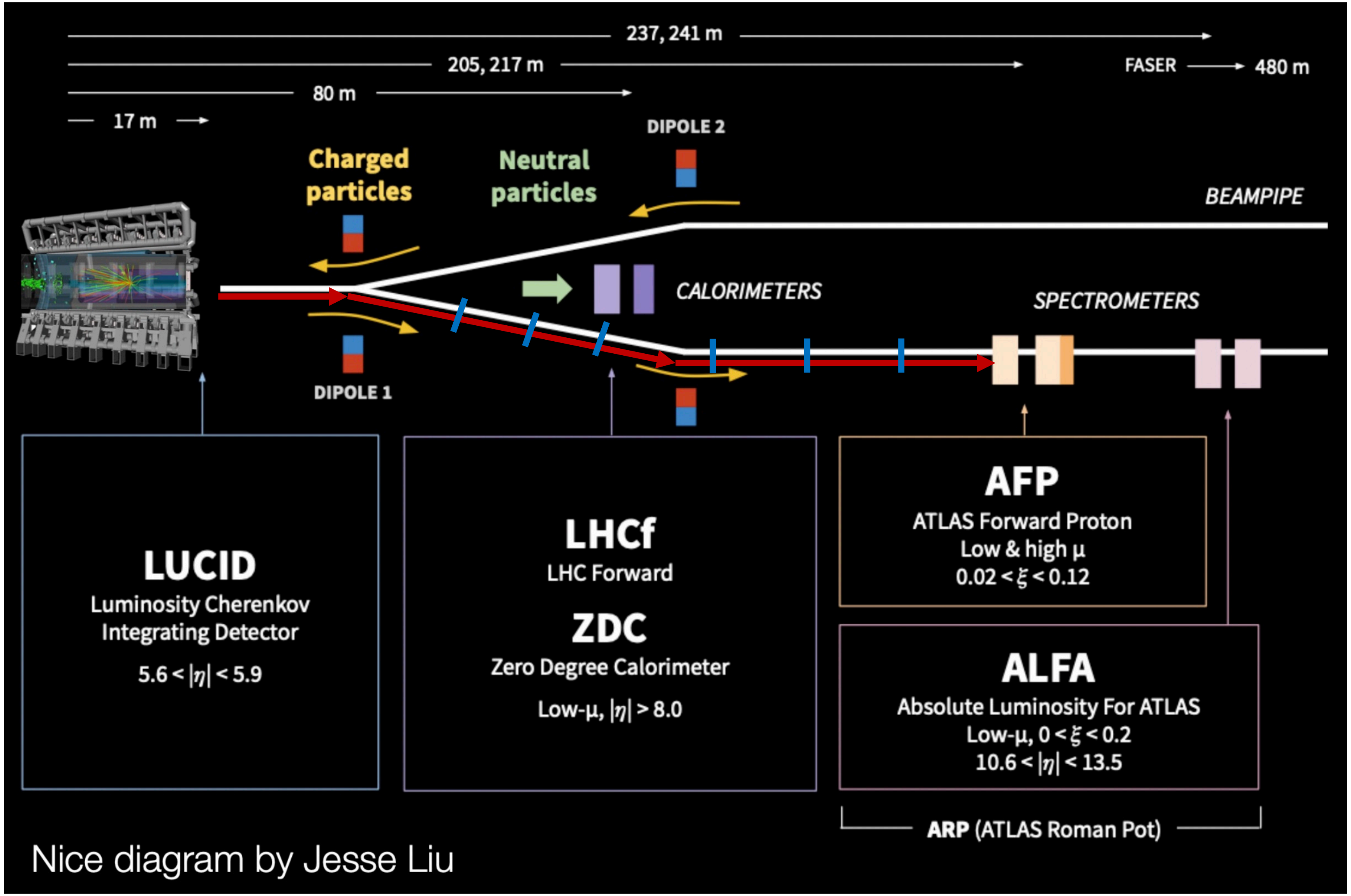
Motivation





- Single diffractive processes have been studied before with only neutral particle data coming from the LHCf or ZDC.
- A joint data-taking between LHCf, ZDC and AFP could improve the identification and kinematic reconstruction of single diffractive processes.
- The combination of LHCf and ZDC detectors also promises an improvement in the energy resolution of neutral particle detection.

ATLAS Forward Proton (AFP)



AFP is a proton detection system placed on one of the beam pipes on each side of the ATLAS.

The near station is placed at “205m, and the far station is at “217m”.

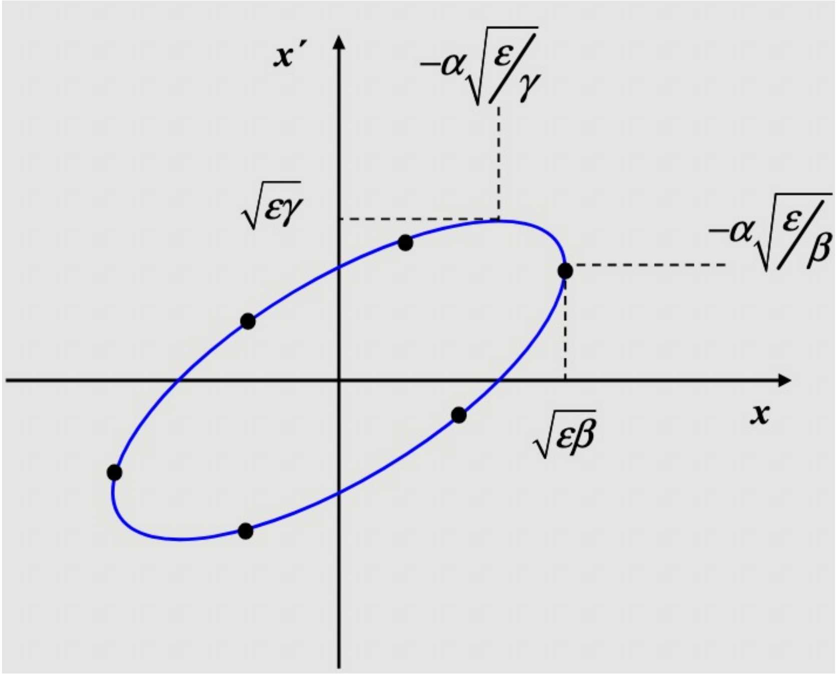
: protons

: collimators, dipoles, quadrapoles, kickers etc.

Analysis Code

- The code performs "a basic transportation" for protons from IP1 to AFP stations.

- The position of the protons are calculated by magnetic fields (dipoles, quadropoles etc.) acting as optical lenses stacked one after.
- "The transformation matrix elements" or "twiss parameters" for each magnetic interaction point are read from a "twiss file".



Phase space of the beam

Twiss Parameters:

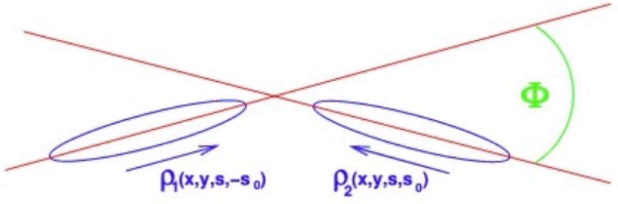
$$\alpha(s) = -\frac{1}{2}\beta'(s) \quad \text{, where} \quad \beta'(s) = \frac{d\beta}{ds}$$

$$\gamma(s) = \frac{1+\alpha^2(s)}{\beta(s)}$$

where "s" is the longitudinal displacement around the LHC and "ε" is emittance.

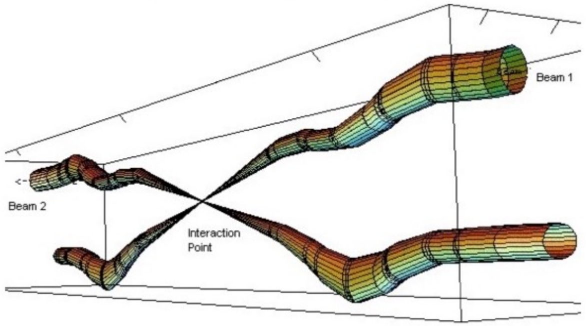
Crossing-Angle and Beta* Definitions

Crossing Angle

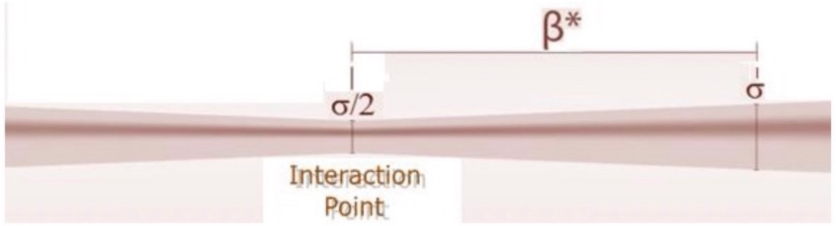


- The angle between two crossing bunches.
- Lower the angle higher the luminosity (collisions).
- For our study crossing-angle is chosen to be 290 μrad.

Beta Function



- The amplitude function, *β* , is determined by the accelerator magnet configuration and powering.
- If β is low, the beam is narrower, "squeezed". If β is high, the beam is wide and straight.
- Amplitude function at the interaction point is called *β**.
- For our study β* is chosen to be 19 m.



Sometimes β* is referred as the distance from the focus point that the beam width is twice as wide as the focus point.

Analysis Code

- By using transport matrices new coordinates are measured for each interaction point and passed to the next one.

- At the end, the protons arrived to the stations and the ones lost (collimators, magnets etc.) in the process are identified.

```
for (double e=5500.; e<=1.00001*6500.; e += 500.)
{
  for (double phi = 0.; phi < 2.*3.1415; phi += 2.*3.1415/15.)
  {
    for (double pT = 0.; pT < 3.; pT += 3./5.)
    {
```

→ Energy ranges from 5.5 TeV to 6.5 TeV

→ Phi ranges from 0 to 2pi

→ Pt ranges from 0 to 3

- The analysis code uses an uniform distribiton for starting proporties of the protons.

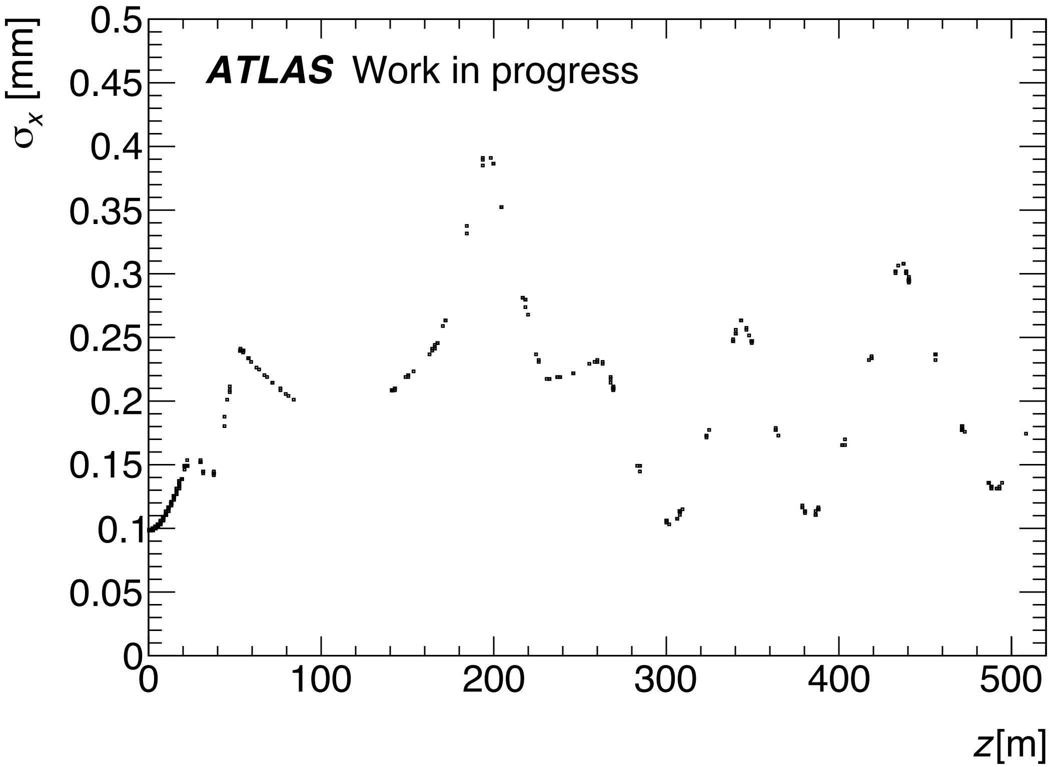
- The steps of the loops can be adjusted to create more or less data points.

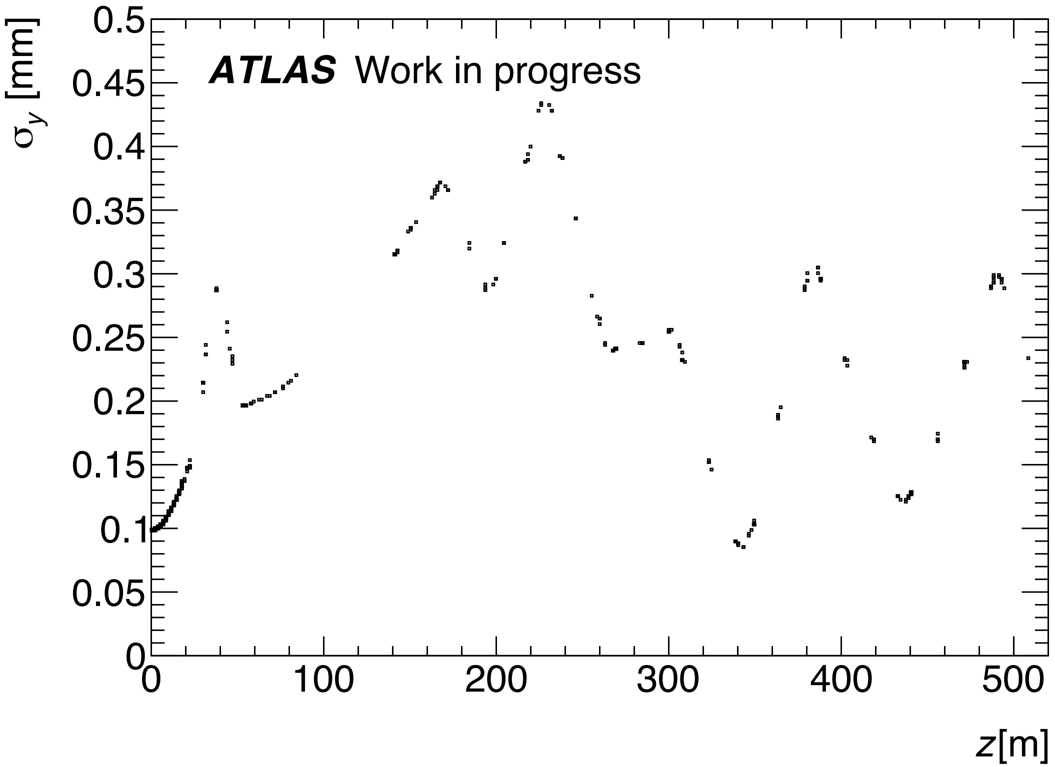
- The beam represented from its center as the proton having E=6.5 TeV [1] and Pt=0.

[1] The forseen Run 3 beam energy is 6.8 TeV. Therefore, creating a new twiss file for this energy will be next.

Beam Width Plots

The x-axis of the plots are in the same order as the protons path followed in the LHC, taking “0” as IP1.





Calculation:

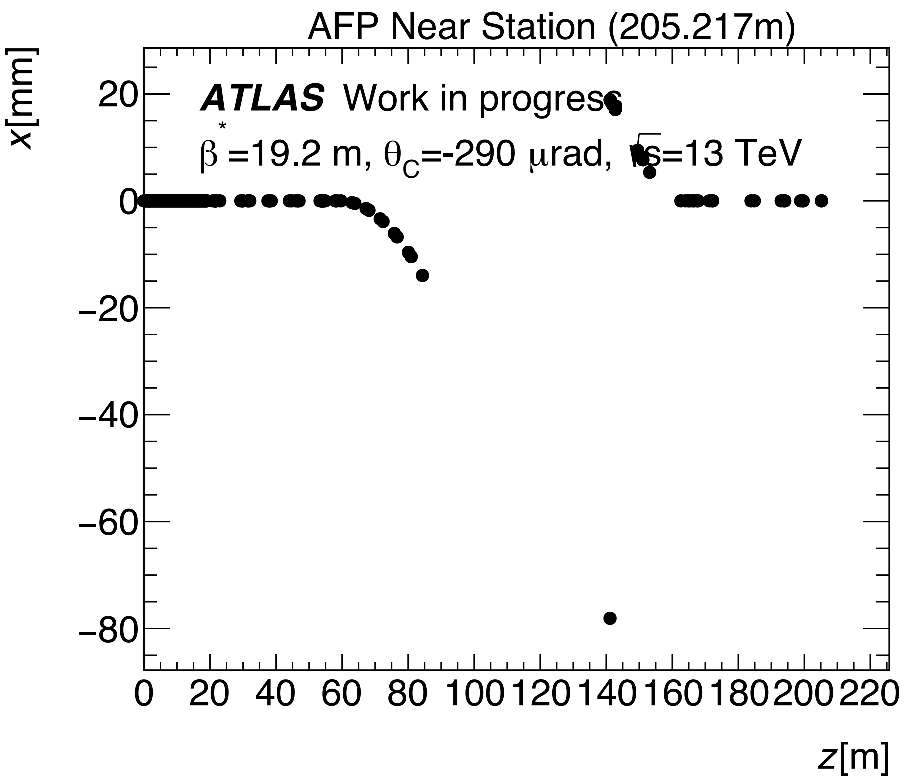
$$\sigma_{x,y} = \sqrt{\frac{\beta_{x,y}.\epsilon}{\gamma}}$$

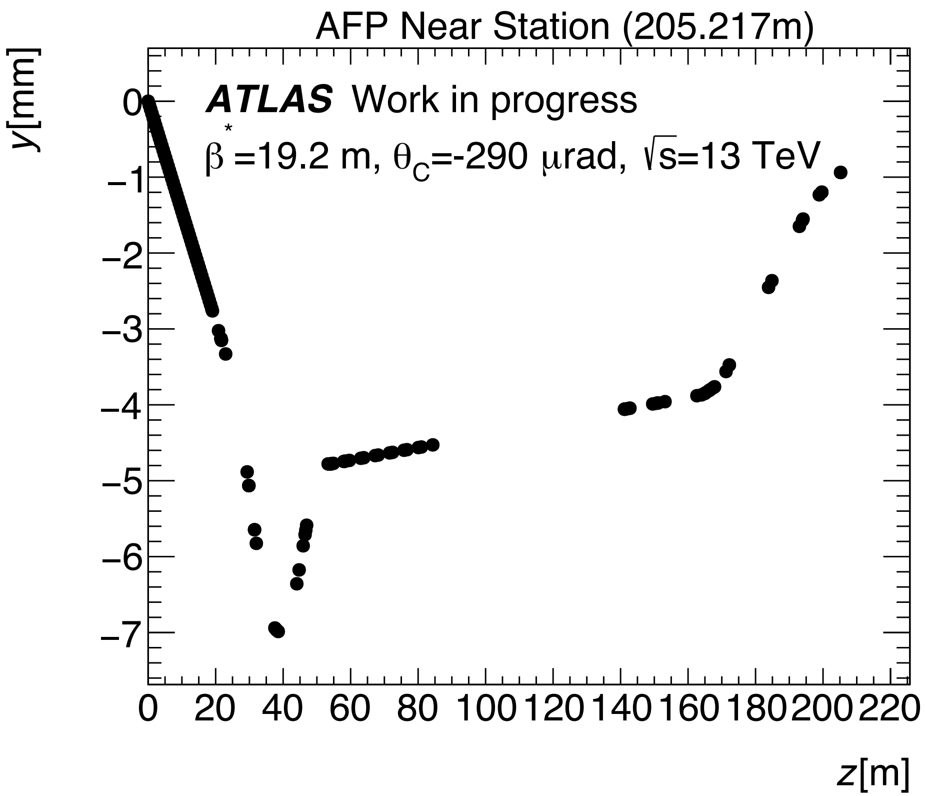
$$\gamma = \frac{E_{Beam}}{m_p} = \frac{6.5 \text{ x } 10^{12}}{938 \text{ x } 10^{6}}$$, c=1, $\epsilon=3.5\text{x}10^{-6}$

Beam Trajectory Plots

Near Station Plots

The plots show the trajectory of the proton in the beam center in “x” and “y” separately.





Method:

Collection of each step data of “x” and “y” positions for a proton with E = 6500 GeV and pT=0.

Acceptance Calculation

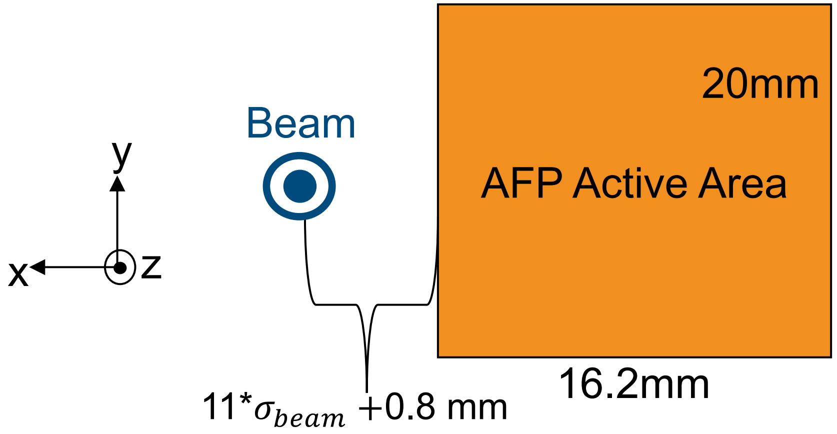
$$acceptance = \frac{\#proton_{reached}}{\#proton_{total}}$$ for the protons sharing the same ξ and pT, where $$\xi = \frac{E_{beam} - E_{proton}}{E_{beam}}$$

E_{beam} = 6.5TeV, E_{proton} = Scattered proton (energy assigned from the "*for loop*")

To consider the detector-beam distance and the detector active area in the LHC machine:

Cut on "y position" to consider the detector active area in the vertical:

-10 mm < Y < +10 mm



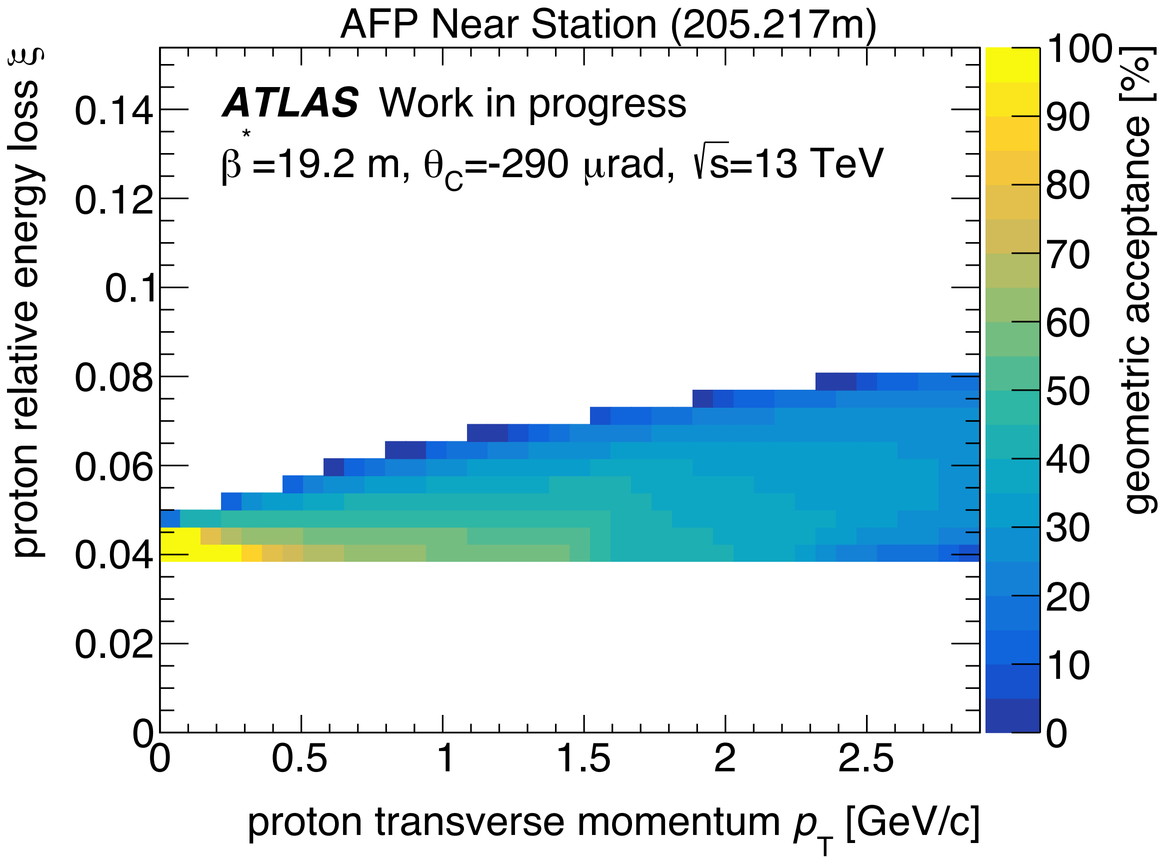
Cut on "x position" for reached protons in the "negative x" only:

X_{beam} - 11*σ_{beam} - 0.8 mm (safety measure) – 16.2 mm (detector area) < X < X_{beam} - 11*σ_{beam} - 0.8 mm

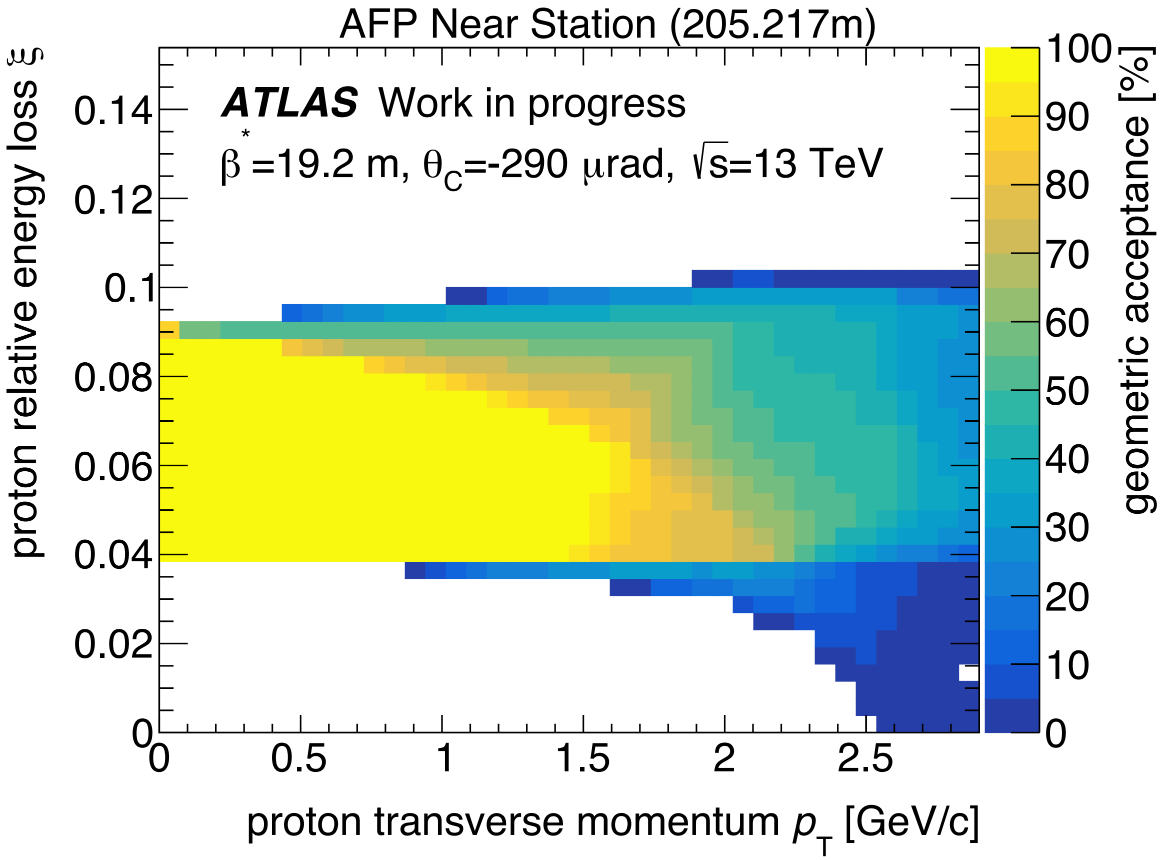
Acceptance Plots

Beam settings for the Twiss file: “beta* = 19.2 m” and “crossing-angle=-290 µrad”.

Collimator settings: TCL4 at 20 σ_{beam} , TCL5 at 40 σ_{beam}



TCL4 at 40 σ_{beam} , TCL5 at 80 σ_{beam}

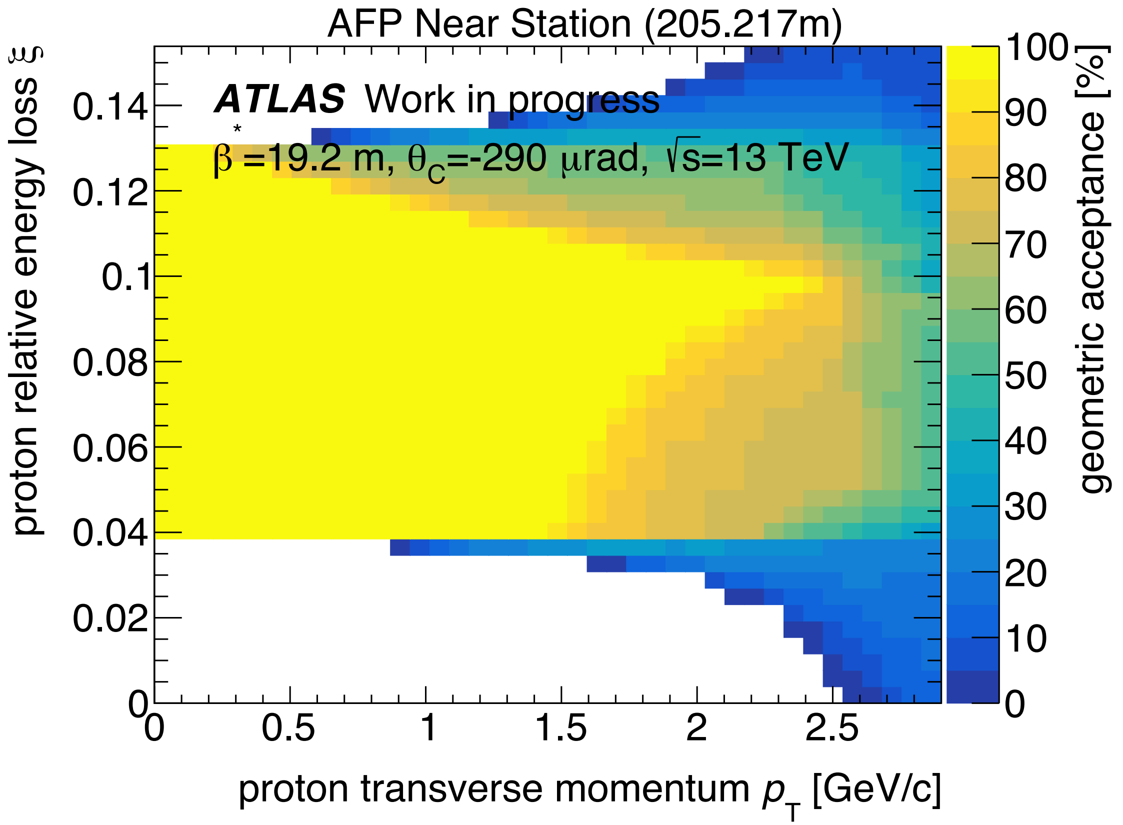


- Changing collimator settings changes acceptances dramatically.

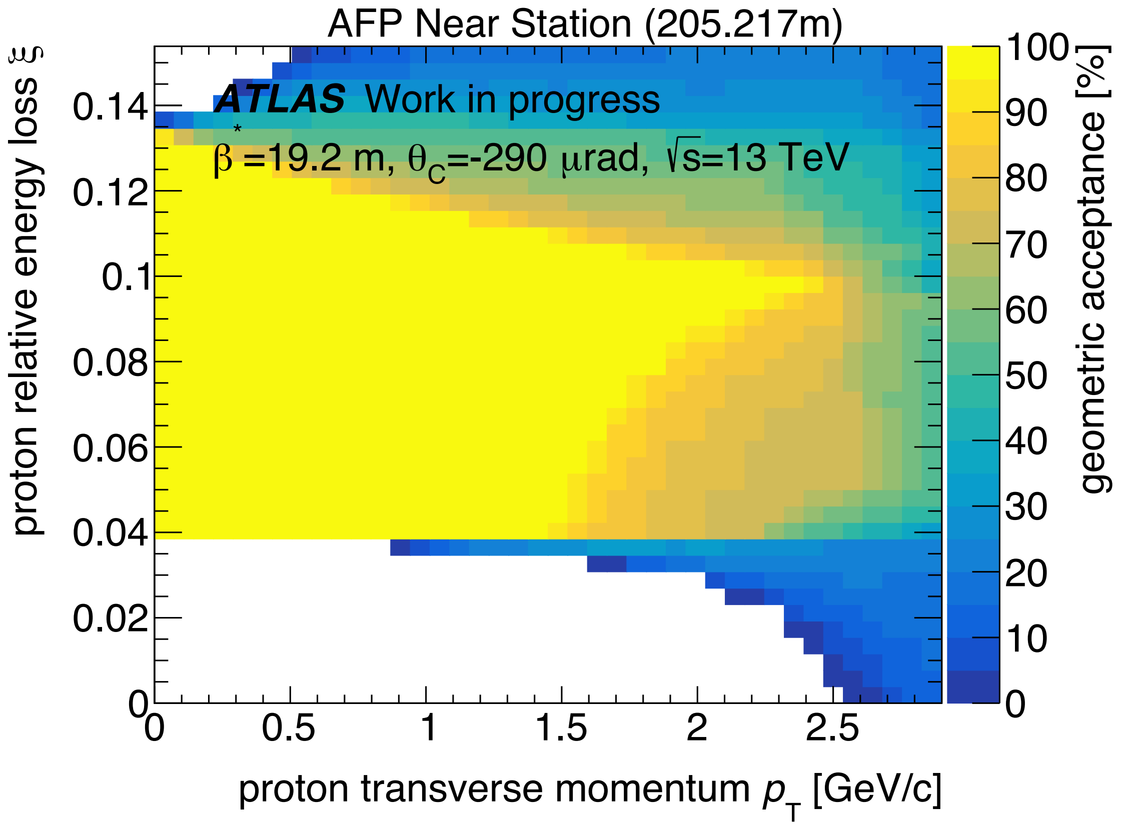
Acceptance Plots

Beam settings for the Twiss file: “beta* = 19.2 m” and “crossing-angle=-290 μrad”.

Collimator settings : TCL4 at 60 σ_{beam} , TCL5 at 120 σ_{beam}



TCL4 at 80 σ_{beam} , TCL5 at 160 σ_{beam}



- Yet, the dramatic change stops at some point and then the change itself. Above the 80 σ_{beam} for TCL4 acceptances stay the same (see backup slide).
- Which suggests there is an optimum point for the collimator settings.

Next

For AFP studies:

- The creation of new Twiss files for different energy, beta*, and crossing-angles for optimization within reasonable[2] values.
- Investigation of the best collimator settings within the allowed values.

For ZDC/LHCf studies:

- Either creation or rescale of the existing MC simulation data.
- Analysis of common acceptances for ZDC and LHCf detectors with the consideration of AFP acceptances.

- The re-do of the studies for the planned proton-Oxygen run.

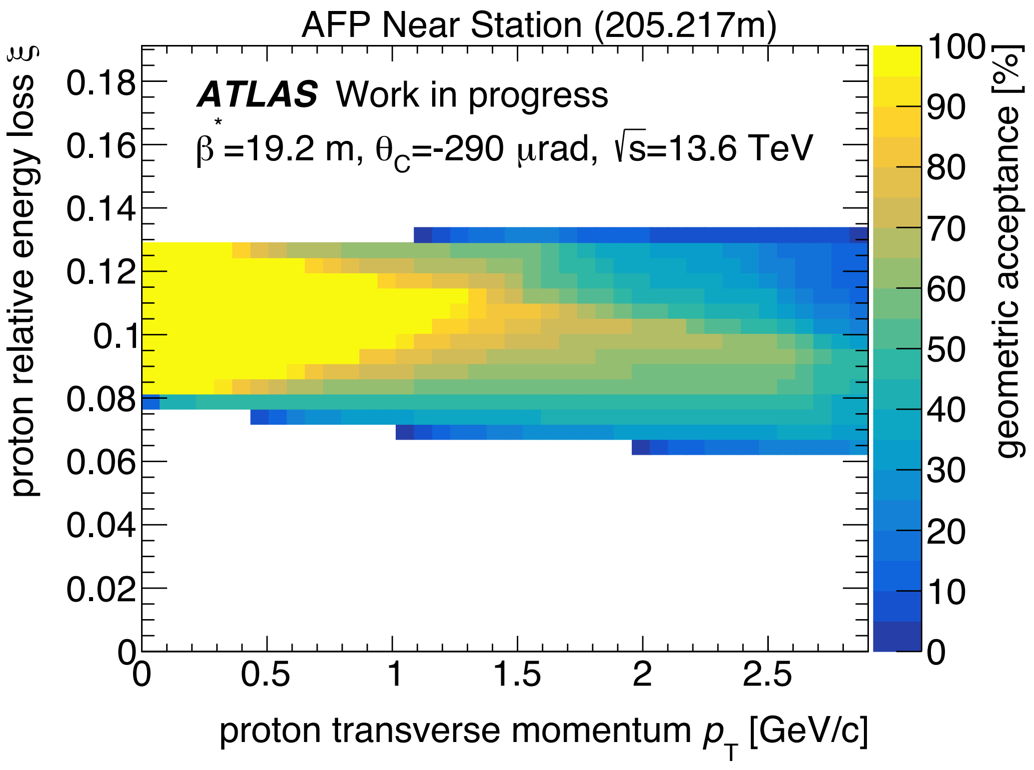
[2]Reasonable in terms of allowance from the LHC machine and accordingly to the analysis of ZDC/LHCf detectors will show.

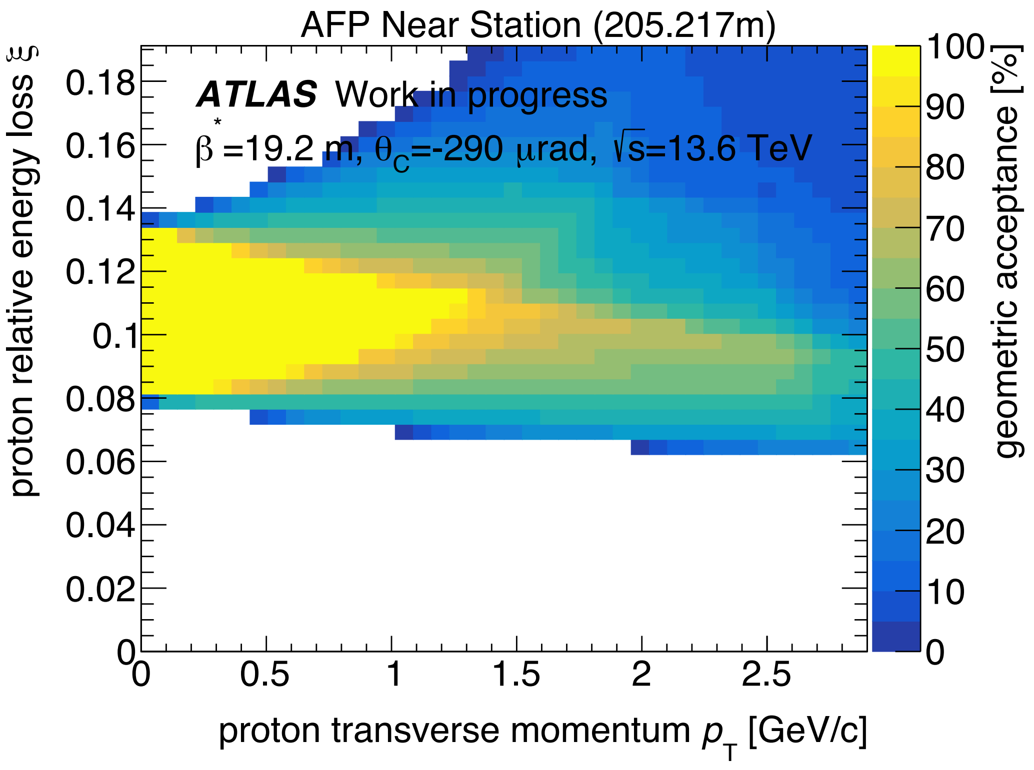
Back Up

Acceptance Plots

Beam settings for the Twiss file: “beta* = 19.2 m” and “crossing-angle=-290 µrad”.

<u>Collimator settings</u> : TCL4 at 60 σ_{beam} , TCL5 at 120 σ_{beam} TCL4 at 80 σ_{beam} , TCL5 at 160 σ_{beam}





- Energy is changed to 6800 GeV as proposed value for Run 3.
- However, since the beta (twiss) values are stayed the same, the results might not represents the real values.
    - For that new twiss files are needed to be created with the new energy.

Analysis Code

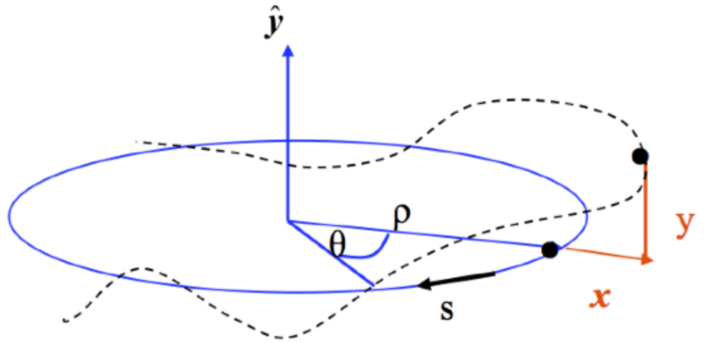
- The code performs “a basic transportation” for protons from IP1 to AFP stations.

- The position of the protons are calculated by magnetic fields (dipoles, quadropoles etc.) acting as optical lenses stacked one after.
- “The transformation matrix elements” or “twiss parameters” for each magnetic interaction point are read from a “twiss file”.

Hill’s Equation: $$x'' + K(s)x = 0$$ (equation of motion), where “s” is the beam direction.

Solution to Hill’s equation: $$x(s) = \sqrt{\varepsilon}\sqrt{\beta(s)}cos(\varphi(s) + \varphi_0)$$

where $$\varphi(s) = \int_0^s \frac{ds}{\beta(s)}$$



Analysis Code

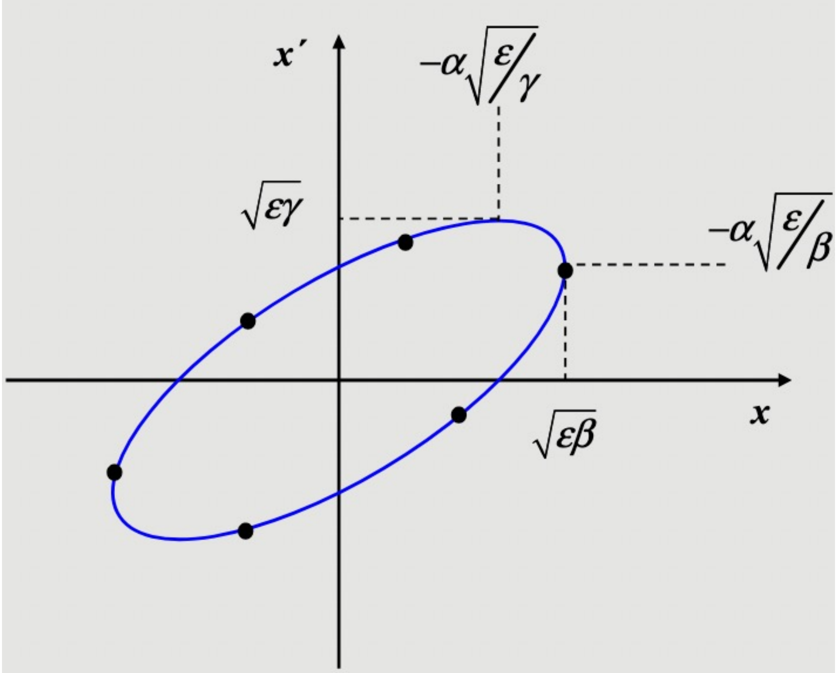
Twiss Parameters:

$$\alpha(s) = -\frac{1}{2}\beta'(s) \quad \text{, where} \quad \beta'(s) = \frac{d\beta}{ds}$$

$$\gamma(s) = \frac{1+\alpha^2(s)}{\beta(s)}$$

Emittance:

$$\varepsilon = \gamma(s)\, x^2(s) + 2\alpha(s)x(s)x'(s) + \beta(s)\, x'^2(s)$$



Phase space of the beam

Liouville's theorem: Under the influence of conservative forces the particle density in phase space is constant.

Transportation Matrix:

$$\begin{pmatrix} x(s) \\ x'(s) \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{\beta_s}{\beta_0}}[\cos\varphi_s + \alpha_0 sin\varphi_s] & \sqrt{\beta_s\beta_0}\, sin\varphi_s \\ \frac{1}{\sqrt{\beta_s\beta_0}}[(\alpha_0-\alpha_s)\cos\varphi_s - (1+\alpha_0\alpha_s)sin\varphi_s] & \sqrt{\frac{\beta_s}{\beta_0}}[cos\varphi_s - \alpha_s\, sin\varphi_s]x'_0 \end{pmatrix} \cdot \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

By knowing Twiss parameters in two points, one can calculate the new position without knowing elements in between.