Physics potential of a combined data taking of the LHCf and ATLAS Roman Pot detectors

Clara Leitgeb, Humboldt University Berlin
On behalf of ATLAS Forward Detectors

Low-x 2023 Workshop, Leros, 04.09.2023

HUMBOLDT-UNIVERSITÄT ZU BERLIN

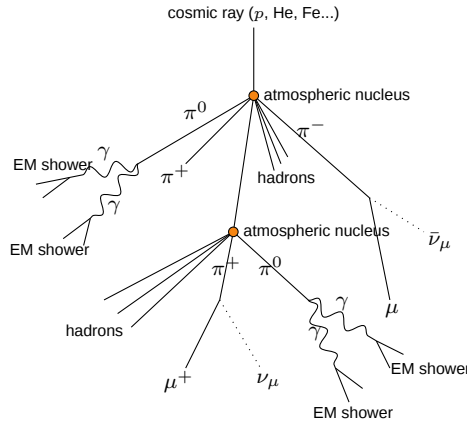
DESY.

ATLAS EXPERIMENT

Motivation

Soft QCD in Air Showers

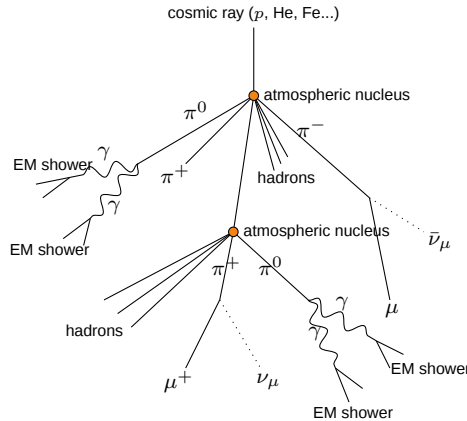
> Cosmic proton hits atmospheric nucleus
> $\rightarrow$ Particle shower



Motivation

Soft QCD in Air Showers

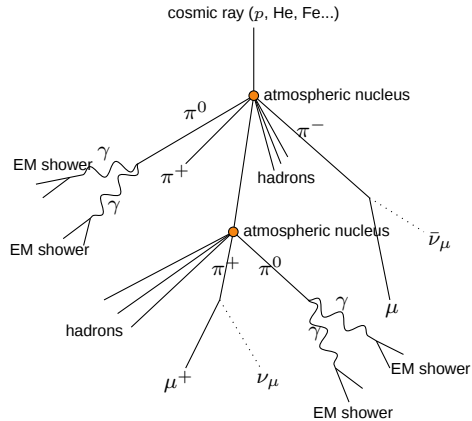
- Cosmic proton hits atmospheric nucleus $\rightarrow$ Particle shower
- Soft QCD: Hadronic interaction with low momentum transfer
- Non-perturbative $\rightarrow$ phenomenological models



Motivation

Soft QCD in Air Showers

- Cosmic proton hits atmospheric nucleus
  $\rightarrow$ Particle shower
- Soft QCD: Hadronic interaction with low momentum transfer
- Non-perturbative $\rightarrow$ phenomenological models
- Large differences in generator predictions:
  - Position of shower maximum
  - Particle multiplicities
- Identification of initial cosmic particle:
  Large uncertainties

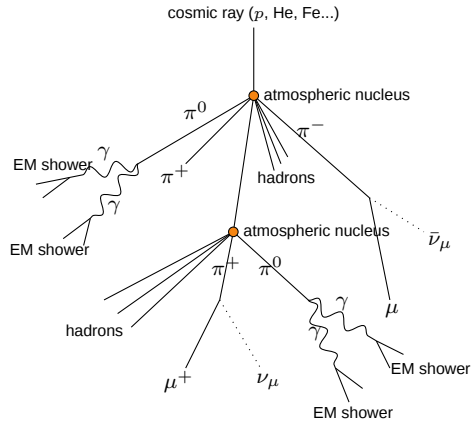


Motivation

Soft QCD in Air Showers

- Cosmic proton hits atmospheric nucleus
  $\rightarrow$ Particle shower
- Soft QCD: Hadronic interaction with low momentum transfer
- Non-perturbative $\rightarrow$ phenomenological models
- Large differences in generator predictions:
  - Position of shower maximum
  - Particle multiplicities
- Identification of initial cosmic particle: Large uncertainties

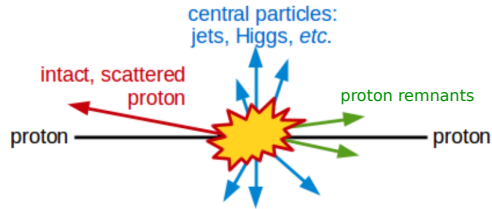
$\Rightarrow$ Tuning based on accelerator data



Motivation

Soft QCD at the LHC

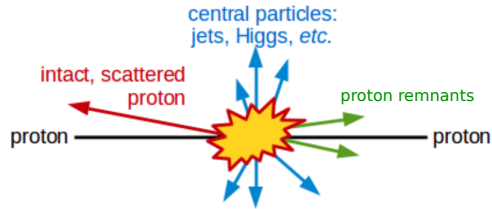
- Low momentum transfer scattering
  - → Particles in forward region
  - → Experiments at high $|\eta|$



Motivation

Soft QCD at the LHC

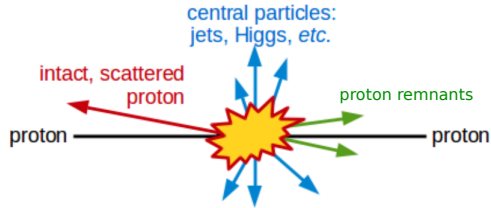
- Low momentum transfer scattering
  - → Particles in forward region
  - → Experiments at high $|\eta|$
- Large fraction of the total cross section
- High relevance for pileup modelling



Motivation

Soft QCD at the LHC

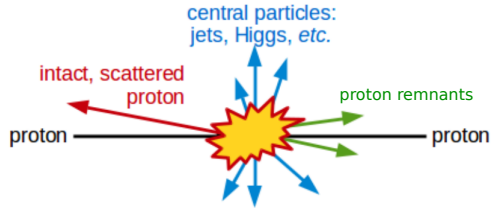
- Low momentum transfer scattering
  - → Particles in forward region
  - → Experiments at high $|\eta|$
- Large fraction of the total cross section
- High relevance for pileup modelling
- Measurements for CR modelling at LHC IP1:
  - Neutral forward particles (LHCf)
  - Neutral forward particles and central tracks (LHCf+ATLAS)
  - Forward protons (AFP, ALFA)



Motivation

Soft QCD at the LHC

- Low momentum transfer scattering
  - → Particles in forward region
  - → Experiments at high $|\eta|$
- Large fraction of the total cross section
- High relevance for pileup modelling
- Measurements for CR modelling at LHC IP1:
  - Neutral forward particles (LHCf)
  - Neutral forward particles and central tracks (LHCf+ATLAS)
  - Forward protons (AFP, ALFA)



New approach: Forward neutral particles + forward protons

Motivation

Original Questions:

Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

Motivation

Original Questions:

Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

> Useful for concrete physics cases?

Motivation

Original Questions:

Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

- Useful for concrete physics cases?
- Feasible in general and under which conditions?

Motivation

Original Questions:

Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

- Useful for concrete physics cases?
- Feasible in general and under which conditions?
- More feasible with AFP or with ALFA?

Motivation

Original Questions:

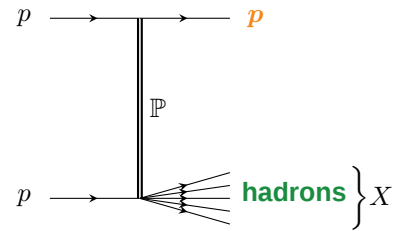
Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

- Useful for concrete physics cases?
- Feasible in general and under which conditions?
- More feasible with AFP or with ALFA?

Disclaimer:
Background estimates (especially combinatorics from pileup) will be done in the next months!

Soft QCD Target Processes

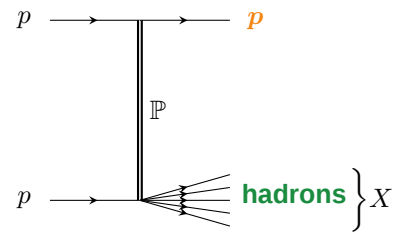
Single Diffraction



Soft QCD Target Processes

Single Diffraction

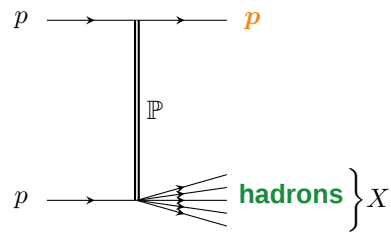
- Standalone Pythia 8.306 simulation
  - A3 tune (Tune for minbias and inelastic processes based on ATLAS Run 1 and early Run 2 data)
  - Generator level
- Cross section @13.6 TeV : 12.86 mb (Pythia)



Soft QCD Target Processes

Single Diffraction

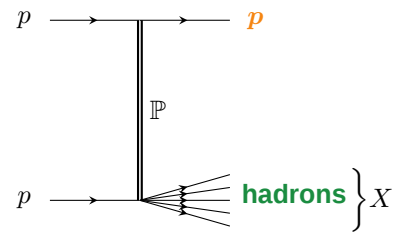
- Standalone Pythia 8.306 simulation
  - A3 tune (Tune for minbias and inelastic processes based on ATLAS Run 1 and early Run 2 data)
  - Generator level
- Cross section @13.6 TeV : 12.86 mb (Pythia)
- Important contribution to total inelastic cross section
- Simultaneous access to proton and X:
  - Better discrimination against other processes
  - Better kinematic reconstruction
    (can determine M_X via the proton)



Soft QCD Target Processes

Single Diffraction

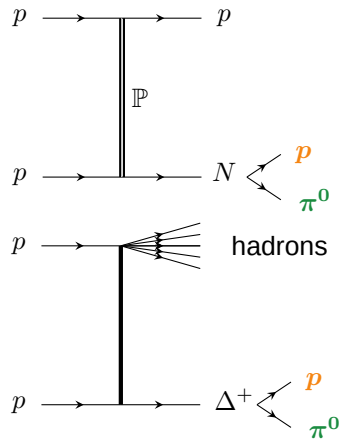
- Standalone Pythia 8.306 simulation
  - A3 tune (Tune for minbias and inelastic processes based on ATLAS Run 1 and early Run 2 data)
  - Generator level
- Cross section @13.6 TeV : 12.86 mb (Pythia)
- Important contribution to total inelastic cross section
- Simultaneous access to proton and X:
  - Better discrimination against other processes
  - Better kinematic reconstruction (can determine M_X via the proton)



Main physics target of these studies!

Soft QCD Target Processes

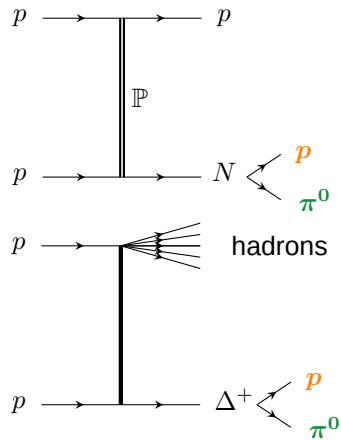
Proton Excitations



Soft QCD Target Processes

Proton Excitations

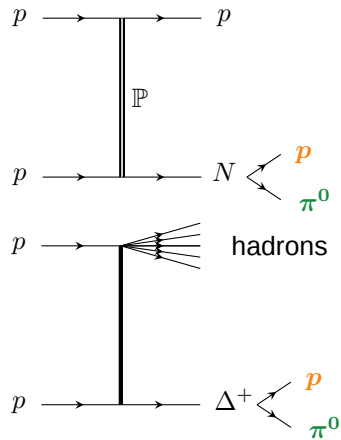
- Standalone Pythia 8.306 simulation
  - New low-energy QCD process class (UrQMD model)



Soft QCD Target Processes

Proton Excitations

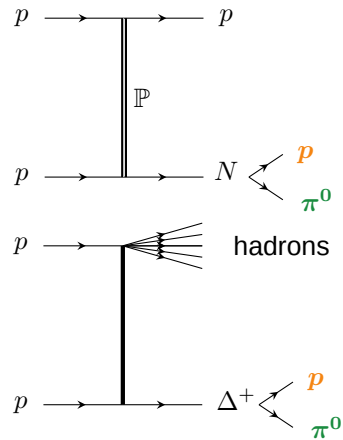
- Standalone Pythia 8.306 simulation
  - New low-energy QCD process class (UrQMD model)
- Never been measured at LHC before
- Diffraction at lowest mass range



Soft QCD Target Processes

Proton Excitations

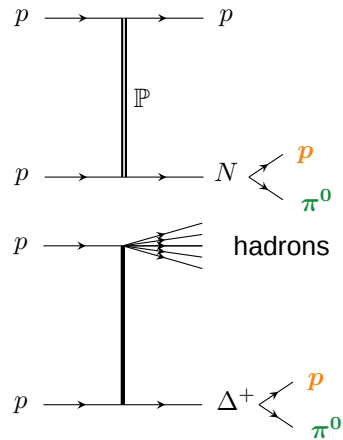
- Standalone Pythia 8.306 simulation
  - New low-energy QCD process class (UrQMD model)
- Never been measured at LHC before
- Diffraction at lowest mass range
- No available cross sections → estimation:
  (thanks to M. Ryskin)



Soft QCD Target Processes

Proton Excitations

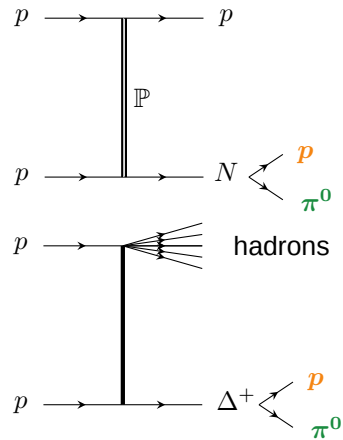
- Standalone Pythia 8.306 simulation
  - New low-energy QCD process class (UrQMD model)
- Never been measured at LHC before
- Diffraction at lowest mass range
- No available cross sections $\rightarrow$ estimation:
  (thanks to M. Ryskin)
  - N: Assumed $\sim 20\%$ of diffraction with $M_X < 3.4\,\text{GeV}$
    $\Rightarrow\ pp \rightarrow p + N(1440) \rightarrow p + p\pi^0$: $0.32\,\text{mb}$



Soft QCD Target Processes

Proton Excitations

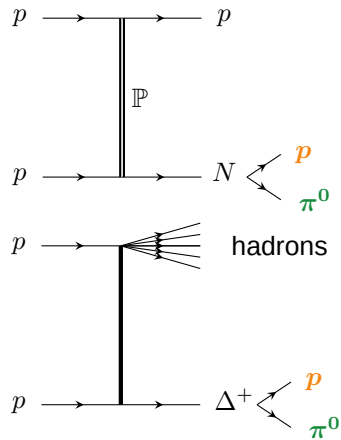
- Standalone Pythia 8.306 simulation
  - New low-energy QCD process class (UrQMD model)
- Never been measured at LHC before
- Diffraction at lowest mass range
- No available cross sections $\rightarrow$ estimation:
  (thanks to M. Ryskin)
  - N: Assumed $\sim 20\%$ of diffraction with $M_X < 3.4\,\text{GeV}$
    $\Rightarrow\ pp \rightarrow p + N(1440) \rightarrow p + p\pi^0$: $0.32\,\text{mb}$
  - Δ: Fixed target results at lower energies scaled by $1/s$
    $\Rightarrow\ pp \rightarrow X + \Delta^+(1232) \rightarrow X + p\pi^0$: $0.007\,\text{mb}$



Soft QCD Target Processes

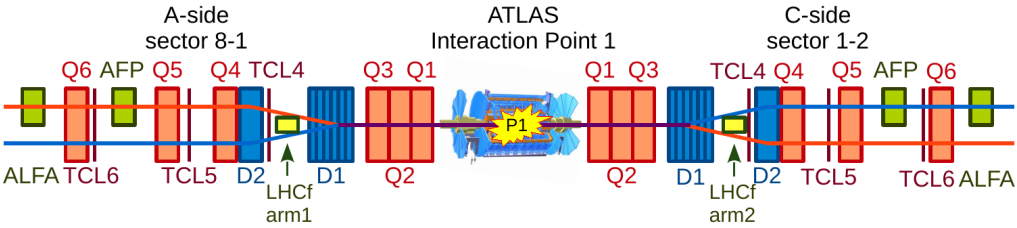
Proton Excitations

- Standalone Pythia 8.306 simulation
  - New low-energy QCD process class (UrQMD model)
- Never been measured at LHC before
- Diffraction at lowest mass range
- No available cross sections → estimation:
  (thanks to M. Ryskin)
  - N: Assumed $\sim 20\%$ of diffraction with $M_X < 3.4\,\text{GeV}$
    $\Rightarrow\ pp \to p + N(1440) \to p + p\pi^0$: $0.32\,\text{mb}$
  - Δ: Fixed target results at lower energies scaled by $1/s$
    $\Rightarrow\ pp \to X + \Delta^+(1232) \to X + p\pi^0$: $0.007\,\text{mb}$



Results to be treated with caution!

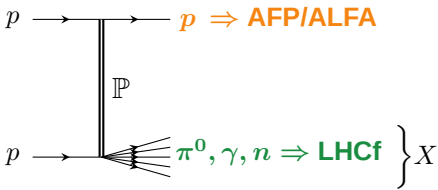
Forward Detectors



- LHCf Calorimeters: Neutral particles (γ, $\pi^0 \rightarrow \gamma\gamma$, n) at $|\eta| > 8.4$
- AFP Near & Far stations: Forward protons, low-μ and high-μ runs
- ALFA Near & Far stations: Forward protons, elastic and diffraction in high-β^* runs

Event Selection

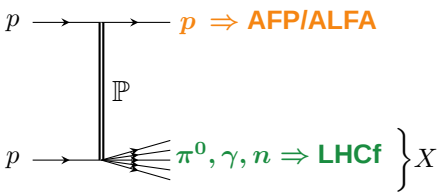
Single Diffraction



- $\geq 1\,\gamma$ or $= 1$ neutron in LHCf
- $E_{\gamma,n} > 200$ GeV (LHCf trigger)
- Proton in ARP (opposite side)

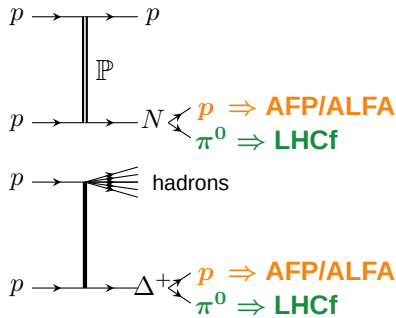
Event Selection

Single Diffraction



- $\geq 1\,\gamma$ or $= 1$ neutron in LHCf
- $E_{\gamma,n} > 200$ GeV (LHCf trigger)
- Proton in ARP (opposite side)

Proton Excitations



- $= 2\,\gamma$ in LHCf
- $E_\gamma > 200$ GeV (LHCf trigger)
- Proton in ARP (same side)

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Neutral Particle Acceptance

- Based on process simulation
- LHCf geometries
- LHCf trigger requirement
- Binned in associated proton ξ and p_{T}

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Neutral Particle Acceptance

- Based on process simulation
- LHCf geometries
- LHCf trigger requirement
- Binned in associated proton ξ and p_{T}

Combined Acceptance

- Based on neutral particle acceptance (LHCf tag)
- Multiply proton acceptance from map according to (ξ,p_{T}) bin

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Neutral Particle Acceptance

- Based on process simulation
- LHCf geometries
- LHCf trigger requirement
- Binned in associated proton ξ and p_{T}

Combined Acceptance

- Based on neutral particle acceptance (LHCf tag)
- Multiply proton acceptance from map according to (ξ,p_{T}) bin

Estimated Event Rates

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Neutral Particle Acceptance

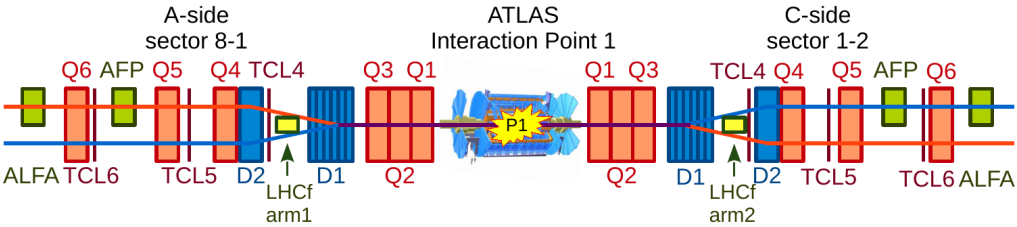
- Based on process simulation
- LHCf geometries
- LHCf trigger requirement
- Binned in associated proton ξ and p_{T}

Combined Acceptance

- Based on neutral particle acceptance (LHCf tag)
- Multiply proton acceptance from map according to (ξ,p_{T}) bin

Estimated Event Rates

Proton Transportation Framework



- LHC elements $\hat{=}$ Transformations on proton coordinates
- MAD-X input: Beam parameters, idealized LHC setting
- Protons simulated in equidistant steps in E, p_{T} and ϕ at IP1
- Output: For specific z-positions...
  - Proton xy-coordinates
  - Beam position (at $(0, 0, 0)$ in idealized LHC setting)
  - Beam width σ_{beam}

Assumed Conditions for LHCf Special Run

- Center of mass energy $= 13.6$ TeV
- $\beta^* = 19.2$ m, full crossing angle $= -290\,\mu$rad in vertical plane
- All collimators open (requested according to studies, see backup)
- ARP detector-beam distance $= 11.5\sigma_{\text{beam}}$ + dead material width + safety margin
  - → Actual value determined in beam-based alignment before run
  - → Can differ by ~ 1 mm in real conditions

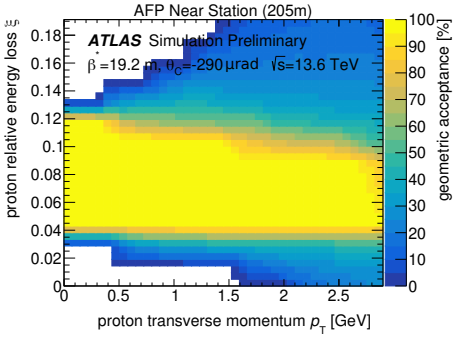
Station	σ_{beam} [mm]	$\delta_{\text{detector-beam}}$ [mm]
AFP near station	0.379	5.157
AFP far station	0.314	4.413
ALFA near station	0.266	3.859
ALFA far station	0.234	3.493

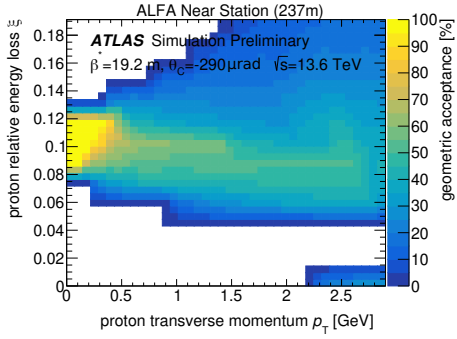
ARP Proton Acceptance

$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$

ARP Proton Acceptance

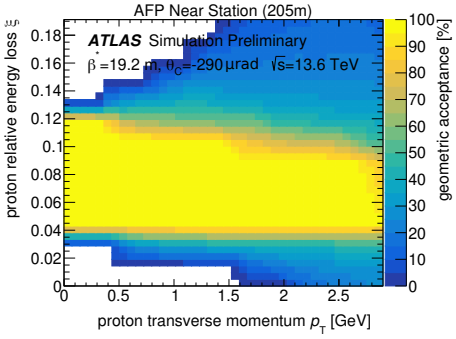
$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$

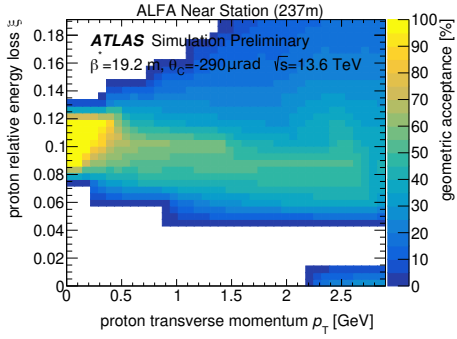




ARP Proton Acceptance

$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$





- AFP acceptance region at $0.04 < \xi < 0.12$
- ALFA acceptance region much smaller and at higher ξ ($0.09 < \xi < 0.12$)

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Neutral Particle Acceptance

- Based on process simulation
- LHCf geometries
- LHCf trigger requirement
- Binned in associated proton ξ and p_{T}

Combined Acceptance

- Based on neutral particle acceptance (LHCf tag)
- Multiply proton acceptance from map according to (ξ,p_{T}) bin

Estimated Event Rates

LHCf Acceptance

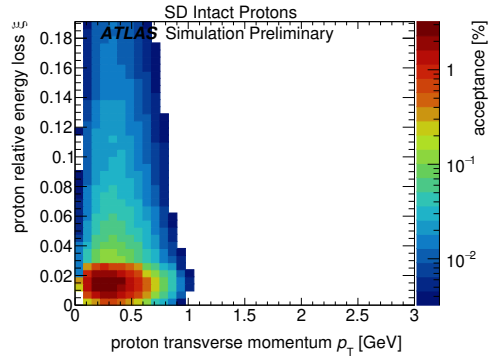
Single Diffraction

$$\text{LHCf acceptance}(p_T, \xi) = \frac{N(\text{events passing LHCf cuts \& a proton passing side criteria})(p_T, \xi)}{N_{\text{total}}(\text{events})}$$

LHCf Acceptance

Single Diffraction

$$\text{LHCf acceptance}(p_T, \xi) = \frac{N(\text{events passing LHCf cuts \& a proton passing side criteria})(p_T, \xi)}{N_{\text{total}}(\text{events})}$$

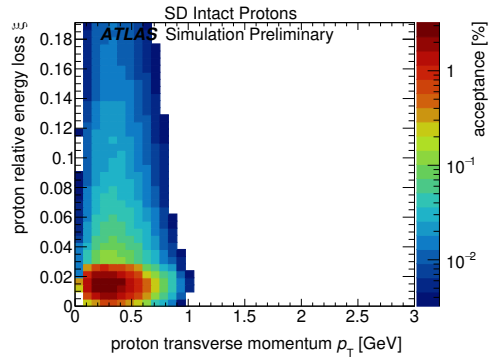


LHCf Acceptance

Single Diffraction

$$\text{LHCf acceptance}(p_T, \xi) = \frac{N(\text{events passing LHCf cuts \& a proton passing side criteria})(p_T, \xi)}{N_{\text{total}}(\text{events})}$$

- Falling spectrum with ξ clearly visible
- High acceptance at very low proton ξ and low proton p_T
- Best acceptance values of all considered physics cases

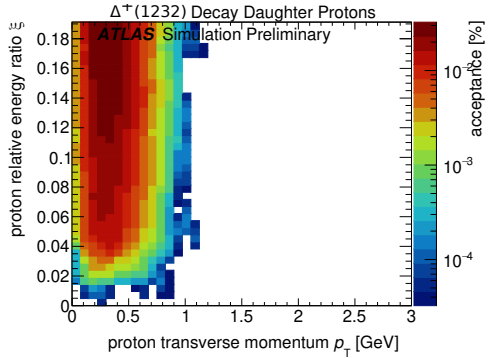


LHCf Acceptance

Δ^+ Production

$$\text{LHCf acceptance}(p_T, \xi) = \frac{N(\text{events passing LHCf cuts \& a proton passing side criteria})(p_T, \xi)}{N_{\text{total}}(\text{events})}$$

- Distribution according to Pythia low-energy QCD simulation
- Acceptance region reaching towards higher proton ξ values
- High acceptances at low proton p_T values

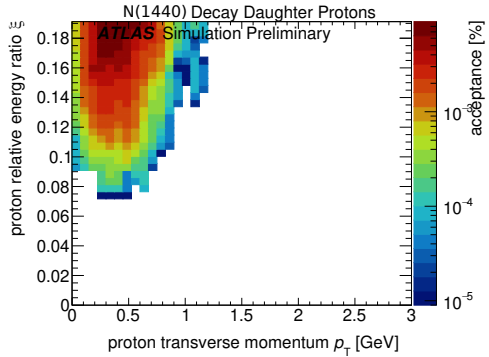


LHCf Acceptance

$N(1440)$ Production

$$\text{LHCf acceptance}(p_T, \xi) = \frac{N(\text{events passing LHCf cuts \& a proton passing side criteria})(p_T, \xi)}{N_{\text{total}}(\text{events})}$$

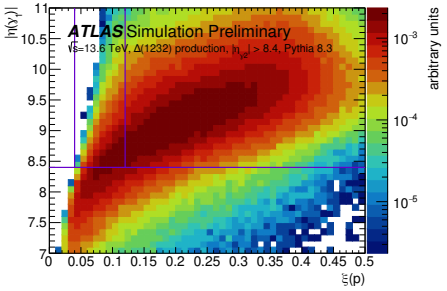
- Distribution according to Pythia low-energy QCD simulation
- Acceptance region starting at higher ξ values than for $\Delta^+(1232)$ case
  - $\rightarrow$ Lower acceptance than for $\Delta^+(1232)$
- High acceptances at low proton p_T values



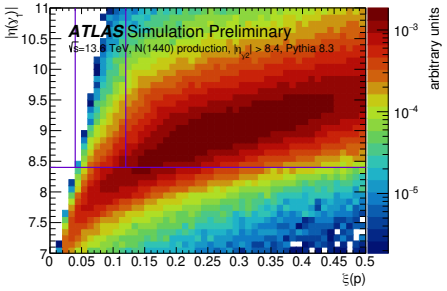
Proton Excitation Acceptance

Where do the differences come from?

$\Delta^+(1232)$ production



$N(1440)$ production



Correlation of η_γ and ξ_{proton}

- Correlation of η and E of decay products according to Pythia 8.3 low-energy QCD simulation
- Slight differences visible between $\Delta^+(1232)$ and $N(1440)$ case (spin, angular momenta)
- Most populated region for $\Delta^+(1232)$ coincides better with acceptance region ($\sim$ violet lines) than for $N(1440)$

Strategy Overview

Proton Acceptance

- Independent of process
- Dependent on run conditions
- Only ARP detector geometries
- Binned in proton energy loss $\xi = \frac{E_{\text{beam}} - E}{E_{\text{beam}}}$ and p_{T}

Neutral Particle Acceptance

- Based on process simulation
- LHCf geometries
- LHCf trigger requirement
- Binned in associated proton ξ and p_{T}

Combined Acceptance

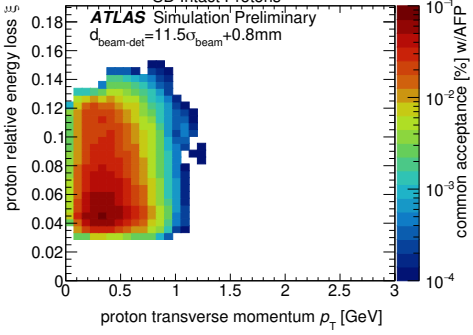
- Based on neutral particle acceptance (LHCf tag)
- Multiply proton acceptance from map according to (ξ,p_{T}) bin

Estimated Event Rates

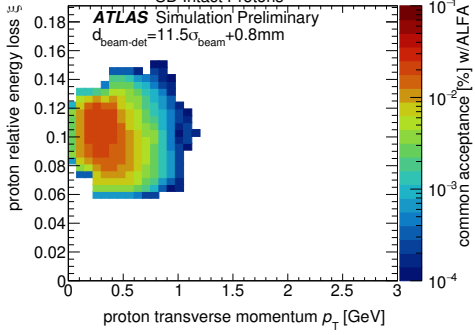
ARP+LHCf Acceptance Combination

Single Diffraction

AFP near station:



ALFA near station:

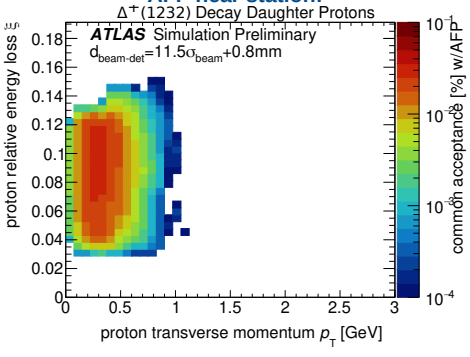


- AFP shows more promising acceptance than ALFA
- Same conclusion for far stations (see backup)

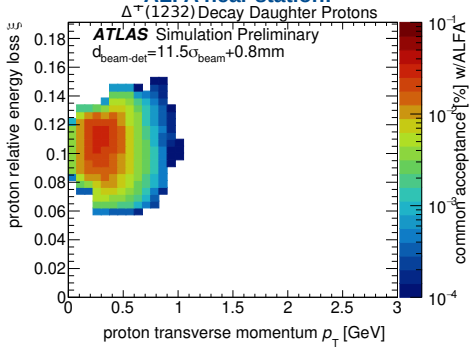
ARP+LHCf Acceptance Combination

$\Delta^+(1232)$ Production

AFP near station:



ALFA near station:

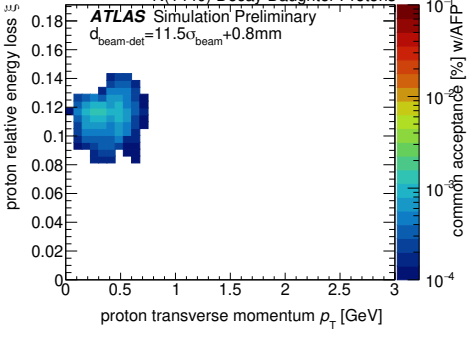


- Distribution according to Pythia low-energy QCD simulation
- AFP shows more promising acceptance than ALFA
- Same conclusion for far stations (see backup)

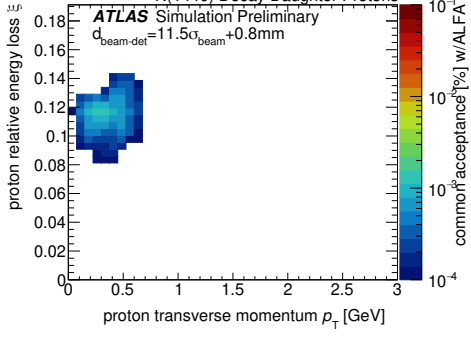
ARP+LHCf Acceptance Combination

$N(1440)$ Production

AFP near station:



ALFA near station:



- Distribution according to Pythia low-energy QCD simulation
- Similar acceptance for AFP and for ALFA
- Same conclusion for far stations (see backup)

Event Rate Expectations

Single Diffraction

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T, \xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

Event Rate Expectations

Single Diffraction

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

- Assumed $\langle \mu \rangle = 0.02$
- $\sigma_{\text{process}} = 12.86\,\text{mb}$

Event Rate Expectations

Single Diffraction

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

- Assumed $\langle \mu \rangle = 0.02$
- $\sigma_{\text{process}} = 12.86\,\text{mb}$

	event rate [Hz]	event count (2 days)
AFP near	66.1 ± 1.7	11.4 ± 0.3 million
AFP far	66.1 ± 1.7	11.4 ± 0.3 million
ALFA near	19.2 ± 0.7	3.3 ± 0.2 million
ALFA far	16.2 ± 0.6	2.8 ± 0.1 million

Event Rate Expectations

Single Diffraction

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

- Assumed $\langle \mu \rangle = 0.02$
- $\sigma_{\text{process}} = 12.86\,\text{mb}$
- Same result for AFP near and far stations
- Expected rates much lower for ALFA than for AFP
- Maximum expected rate at $66\,\text{Hz}$

	event rate [Hz]	event count (2 days)
AFP near	66.1 ± 1.7	11.4 ± 0.3 million
AFP far	66.1 ± 1.7	11.4 ± 0.3 million
ALFA near	19.2 ± 0.7	3.3 ± 0.2 million
ALFA far	16.2 ± 0.6	2.8 ± 0.1 million

Event Rate Expectations

Single Diffraction

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

- Assumed $\langle \mu \rangle = 0.02$
- $\sigma_{\text{process}} = 12.86\,\text{mb}$
- Same result for AFP near and far stations
- Expected rates much lower for ALFA than for AFP
- Maximum expected rate at $66\,\text{Hz}$

	event rate [Hz]	event count (2 days)
AFP near	66.1 ± 1.7	11.4 ± 0.3 million
AFP far	66.1 ± 1.7	11.4 ± 0.3 million
ALFA near	19.2 ± 0.7	3.3 ± 0.2 million
ALFA far	16.2 ± 0.6	2.8 ± 0.1 million

→ Very promising for cross section measurements

Event Rate Expectations

$\Delta^+(1232)$ Production

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

- $\sigma_{\text{process}} = 0.007$ mb
- Expected rates lower for ALFA than for AFP
- Maximum expected rate at 20 mHz

	event rate [mHz]	event count (2 days)
AFP near	19.9 ± 0.6	3440 ± 100
AFP far	19.9 ± 0.6	3440 ± 100
ALFA near	10.1 ± 0.4	1740 ± 70
ALFA far	8.5 ± 0.4	1470 ± 60

→ Cross section measurement possible
- Given background can be sufficiently controlled
- Assuming cross section estimate and simulation not too far from the truth

Event Rate Expectations

$N(1440)$ Production

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

- $\sigma_{\text{process}} = 0.32\,\text{mb}$
- Maximum expected rate at $14\,\text{mHz}$
- Rates lower than for $\Delta^+(1232)$ because of lower acceptance
  (despite larger cross section for $N(1440)$)

	event rate [mHz]	event count (2 days)
AFP near	13.6 ± 1.3	2350 ± 220
AFP far	13.6 ± 1.3	2350 ± 220
ALFA near	11.7 ± 1.1	2020 ± 200
ALFA far	10.2 ± 1.0	1770 ± 180

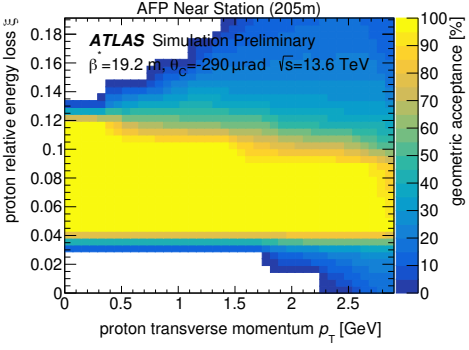
→ Cross section measurement possible

- Given background can be sufficiently controlled
- Assuming cross section estimate and simulation not too far from the truth

Detector-Beam Distances During Run

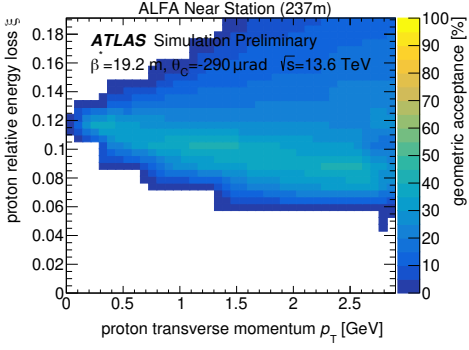
Beam-based alignment: Detector positions determination before actual run

AFP near station: $5.2\,\text{mm} \rightarrow 6.5\,\text{mm}$



$\rightarrow$ Acceptance loss for low ξ region

ALFA near station: $3.9\,\text{mm} \rightarrow 6.1\,\text{mm}$

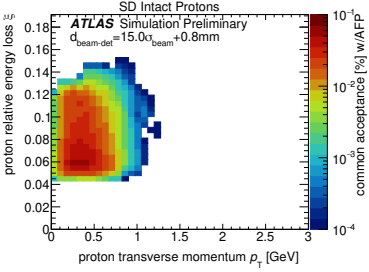


$\rightarrow$ Loss of 100% acceptance region

Results with Updated Detector-Beam Distances

LHCf+AFP

Single diffraction

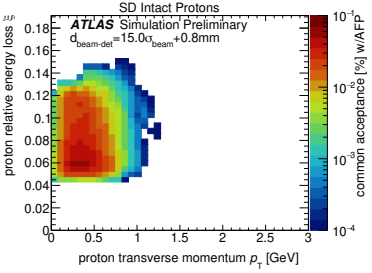


event rate [Hz]	# events (2 d)
46.5 ± 1.3	8.0 ± 0.3 million

Results with Updated Detector-Beam Distances

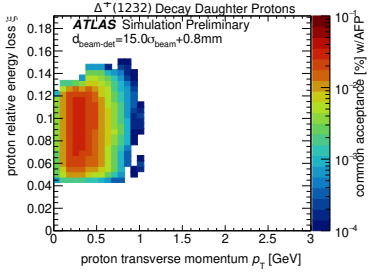
LHCf+AFP

Single diffraction



event rate [Hz]	# events (2 d)
46.5 ± 1.3	8.0 ± 0.3 million

$\Delta^+(1232)$ production

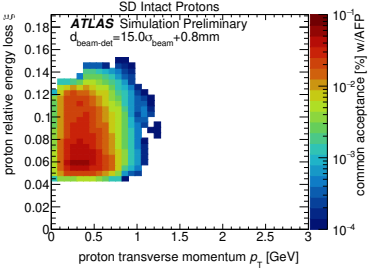


event rate [mHz]	# events (2 d)
17.7 ± 0.6	3050 ± 100

Results with Updated Detector-Beam Distances

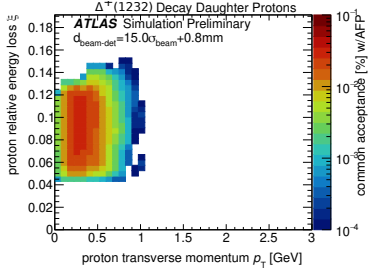
LHCf+AFP

Single diffraction



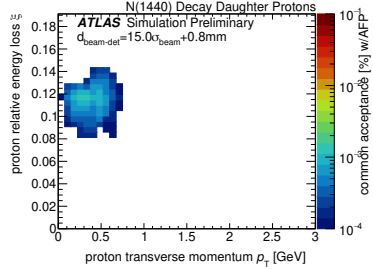
event rate [Hz]	# events (2 d)
46.5 ± 1.3	8.0 ± 0.3 million

$\Delta^+(1232)$ production



event rate [mHz]	# events (2 d)
17.7 ± 0.6	3050 ± 100

$N(1440)$ production

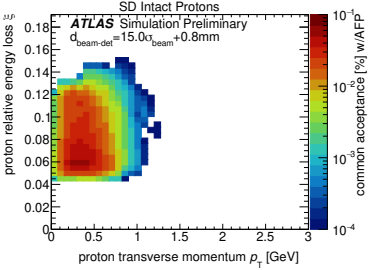


event rate [mHz]	# events (2 d)
13.6 ± 1.3	2350 ± 220

Results with Updated Detector-Beam Distances

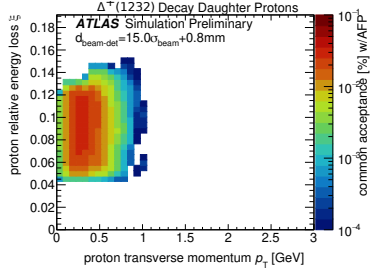
LHCf+AFP

Single diffraction



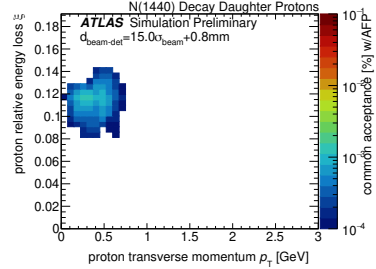
event rate [Hz]	# events (2 d)
46.5 ± 1.3	8.0 ± 0.3 million

$\Delta^+(1232)$ production



event rate [mHz]	# events (2 d)
17.7 ± 0.6	3050 ± 100

$N(1440)$ production



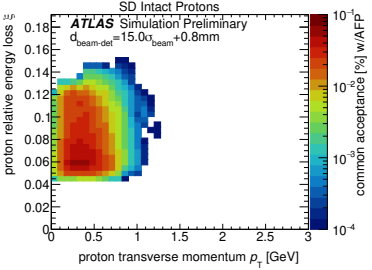
event rate [mHz]	# events (2 d)
13.6 ± 1.3	2350 ± 220

> Event rates still promising for all three cases

Results with Updated Detector-Beam Distances

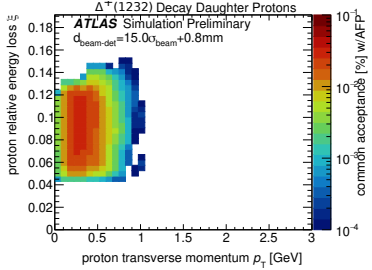
LHCf+AFP

Single diffraction



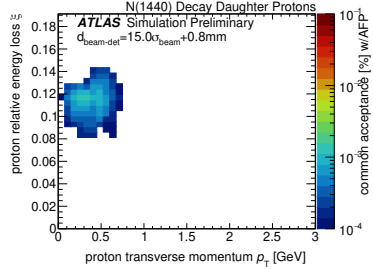
event rate [Hz]	# events (2 d)
46.5 ± 1.3	8.0 ± 0.3 million

$\Delta^+(1232)$ production



event rate [mHz]	# events (2 d)
17.7 ± 0.6	3050 ± 100

$N(1440)$ production



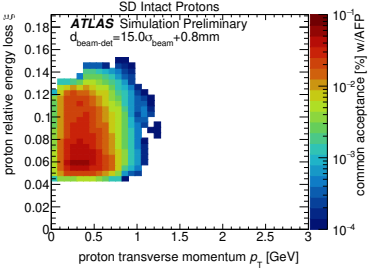
event rate [mHz]	# events (2 d)
13.6 ± 1.3	2350 ± 220

- Event rates still promising for all three cases
- Rates for LHCf+ALFA extremely low in comparison (see backup)

Results with Updated Detector-Beam Distances

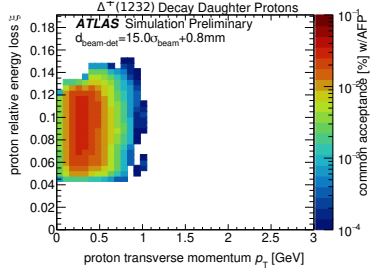
LHCf+AFP

Single diffraction



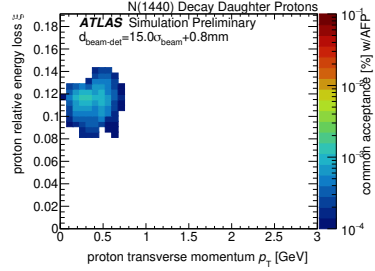
event rate [Hz]	# events (2 d)
46.5 ± 1.3	8.0 ± 0.3 million

$\Delta^+(1232)$ production



event rate [mHz]	# events (2 d)
17.7 ± 0.6	3050 ± 100

$N(1440)$ production



event rate [mHz]	# events (2 d)
13.6 ± 1.3	2350 ± 220

- Event rates still promising for all three cases
- Rates for LHCf+ALFA extremely low in comparison (see backup)
- Caveats: Background estimation pending, untested simulation & cross sections for excitations

Conclusion

Original Questions:

Would a combined data taking of LHCf and
one of the ATLAS Roman Pot (ARP) detectors be...

✓ Useful for concrete physics cases?

✓ Feasible in general and under which conditions?

✓ More feasible with AFP or with ALFA?

Conclusion

Original Questions:

Would a combined data taking of LHCf and
one of the ATLAS Roman Pot (ARP) detectors be...

✓ Useful for concrete physics cases?

→ All investigated physics cases showed promising expected event rates

✓ Feasible in general and under which conditions?

✓ More feasible with AFP or with ALFA?

Conclusion

Original Questions:

Would a combined data taking of LHCf and
one of the ATLAS Roman Pot (ARP) detectors be...

✓ Useful for concrete physics cases?

→ All investigated physics cases showed promising expected event rates
→ Simulations and cross sections for excitation scenarios to be taken with great care!

✓ Feasible in general and under which conditions?

✓ More feasible with AFP or with ALFA?

Conclusion

Original Questions:

Would a combined data taking of LHCf and
one of the ATLAS Roman Pot (ARP) detectors be...

- ✓ Useful for concrete physics cases?
  - → All investigated physics cases showed promising expected event rates
  - → Simulations and cross sections for excitation scenarios to be taken with great care!
- ✓ Feasible in general and under which conditions?
  - → Yes, if the collimators are maximally open and the ARP detectors can be operated close enough to the beam
- ✓ More feasible with AFP or with ALFA?

Conclusion

Original Questions:

Would a combined data taking of LHCf and
one of the ATLAS Roman Pot (ARP) detectors be...

- ✓ Useful for concrete physics cases?
  - → All investigated physics cases showed promising expected event rates
  - → Simulations and cross sections for excitation scenarios to be taken with great care!
- ✓ Feasible in general and under which conditions?
  - → Yes, if the collimators are maximally open and the ARP detectors can be operated close enough to the beam
- ✓ More feasible with AFP or with ALFA?
  - → AFP showed better acceptance under the run conditions

Conclusion

LHCf Special Run

- 23^{rd} – 26^{th} September 2022
- ~ 2.5 days of physics data taking
- ATLAS recorded: $\sim 0.14\,\text{pb}^{-1}$
- LHCf recorded: ~ 380 million events

Original Questions:

Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

✓ Useful for concrete physics cases?

→ All investigated physics cases showed promising expected event rates

→ Simulations and cross sections for excitation scenarios to be taken with great care!

✓ Feasible in general and under which conditions?

→ Yes, if the collimators are maximally open and the ARP detectors can be operated close enough to the beam

✓ More feasible with AFP or with ALFA?

→ AFP showed better acceptance under the run conditions

Conclusion

LHCf Special Run

- 23^{rd} – 26^{th} September 2022
- ~ 2.5 days of physics data taking
- ATLAS recorded: $\sim 0.14\,\text{pb}^{-1}$
- LHCf recorded: ~ 380 million events

Original Questions:

Would a combined data taking of LHCf and one of the ATLAS Roman Pot (ARP) detectors be...

✓ Useful for concrete physics cases?

→ All investigated physics cases showed promising expected event rates

→ Simulations and cross sections for excitation scenarios to be taken with great care!

✓ Feasible in general and under which conditions?

→ Yes, if the collimators are maximally open and the ARP detectors can be operated close enough to the beam

✓ More feasible with AFP or with ALFA?

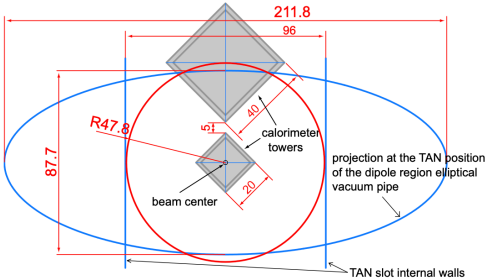
→ AFP showed better acceptance under the run conditions

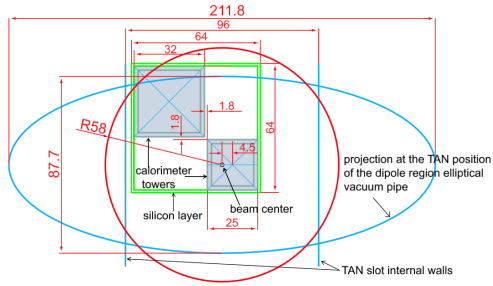
Stay tuned for the analysis of this dataset!

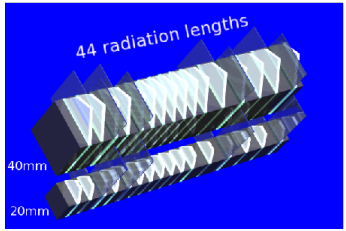
Backup

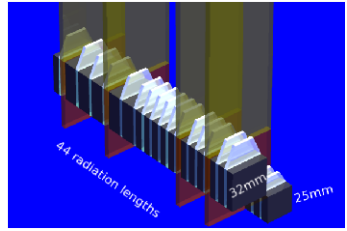
Detector Geometries

LHCf



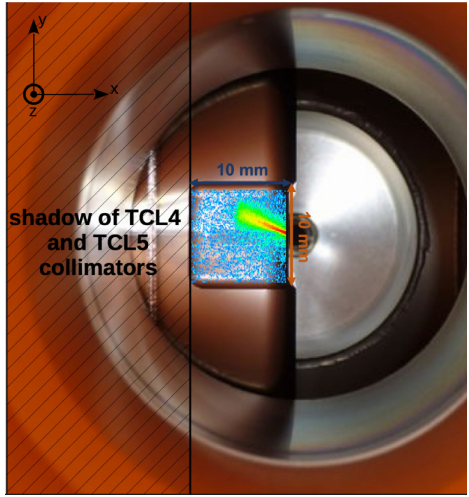






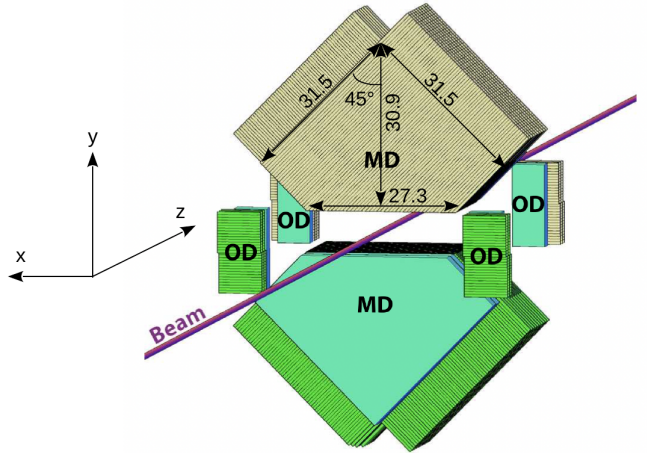
Detector Geometries

AFP



Detector Geometries

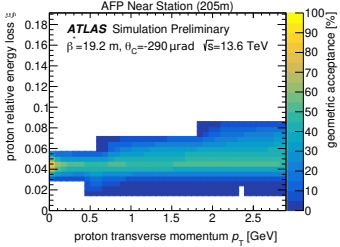
ALFA



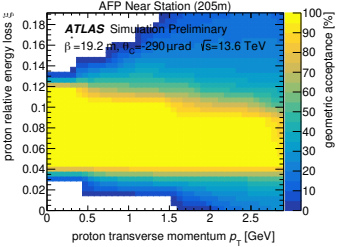
Collimator Opening Studies

AFP

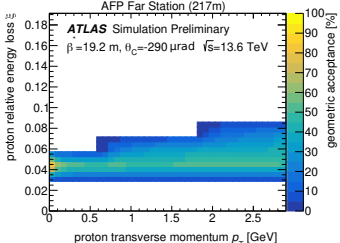
Near station, TCLs at $20\sigma_{\text{beam}}$:



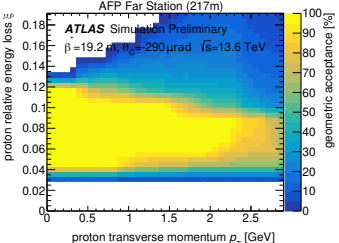
Near station, TCLs at $80\sigma_{\text{beam}}$:



Far station, TCLs at $20\sigma_{\text{beam}}$:



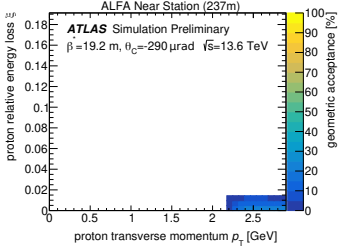
Far station, TCLs at $80\sigma_{\text{beam}}$:



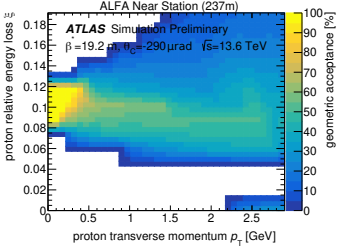
Collimator Opening Studies

ALFA

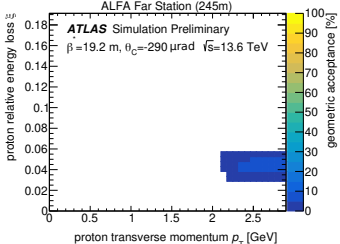
Near station, TCLs at $20\sigma_{\text{beam}}$:



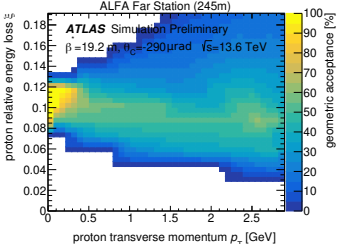
Near station, TCLs at $80\sigma_{\text{beam}}$:



Far station, TCLs at $20\sigma_{\text{beam}}$:



Far station, TCLs at $80\sigma_{\text{beam}}$:

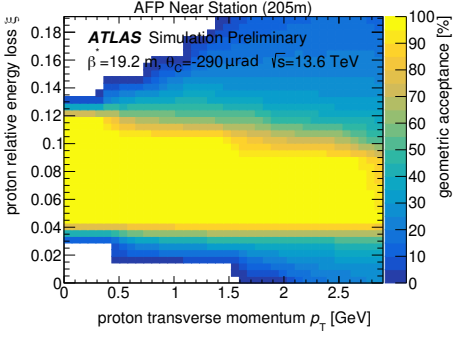


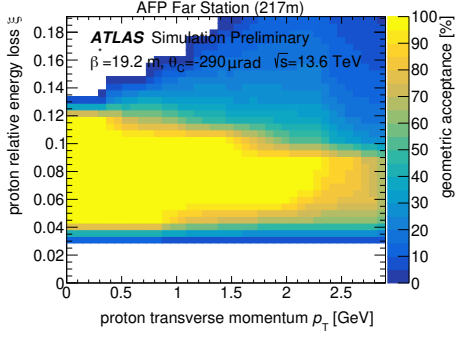
AFP Proton Acceptance

$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$

AFP Proton Acceptance

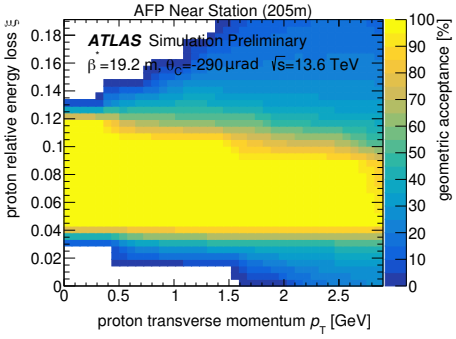
$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$

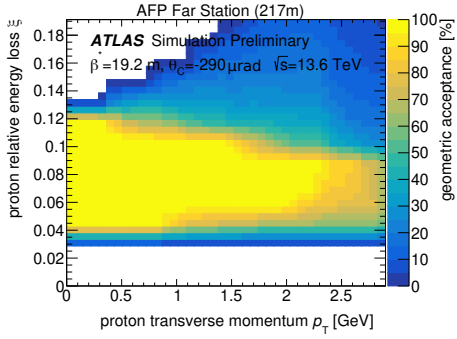




AFP Proton Acceptance

$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$

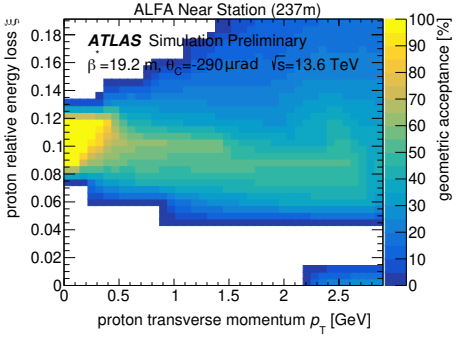


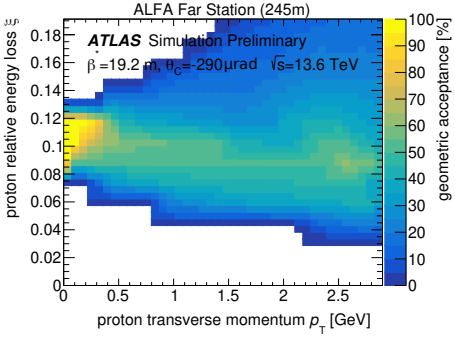


- Acceptance region $0.04 < \xi < 0.12$ for both stations
- Near station acceptance extends to higher p_T than for far station

ALFA Proton Acceptance

$$\text{acceptance}(p_T, \xi) = \frac{N(\text{protons in sensitive detector area})(p_T, \xi)}{N_{\text{total}}(\text{protons})(p_T, \xi)}$$

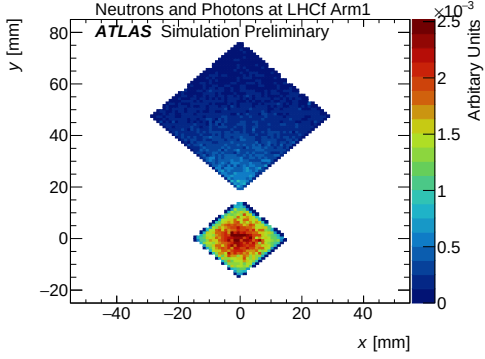




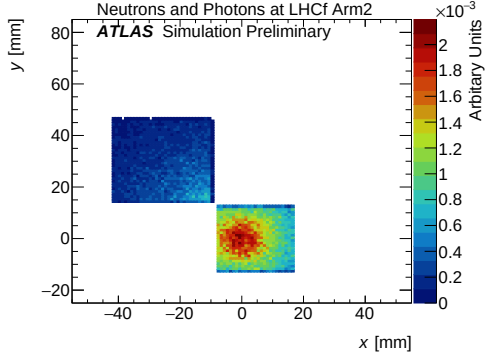
> Acceptance region much smaller than for AFP and at higher ξ ($0.09 < \xi < 0.12$)

LHCf Acceptance

LHCf arm 1



LHCf arm2

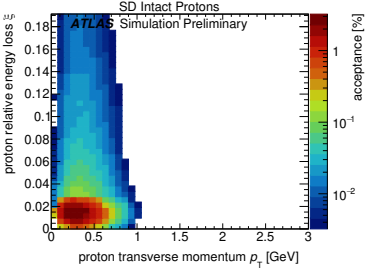


- Use particles from simulation at generator level
- Calculate xy-coordinates at LHCf detector z-position
- Assuming 100% sensitivity in active areas

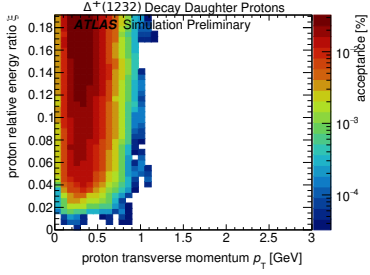
LHCf Acceptance Summary

$$\text{LHCf acceptance}(p_T, \xi) = \frac{N(\text{events passing LHCf cuts \& a proton passing side criteria})(p_T, \xi)}{N_{\text{total}}(\text{events})}$$

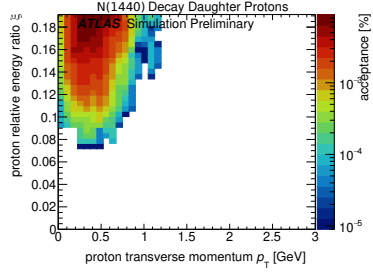
Single diffraction:



Δ^+ production:



$N(1440)$ production:

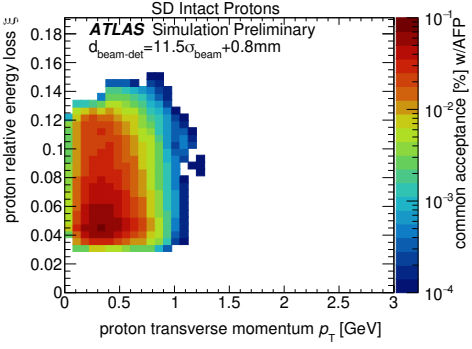


- LHCf acceptance is best for single diffraction simulation
- Larger acceptance region for proton excitation to Δ than to N
- LHCf acceptance for N only starts at higher ξ values

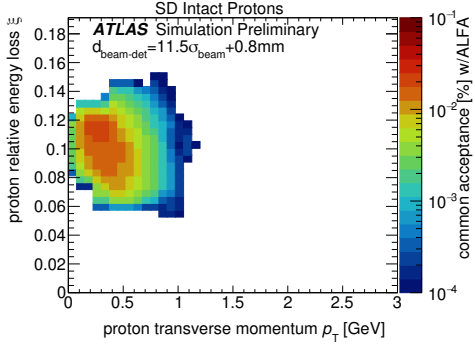
ARP+LHCf Acceptance Combination

Single diffraction

AFP far station:



ALFA far station:

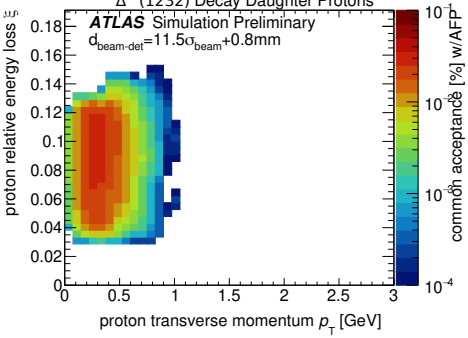


> AFP shows more promising acceptance than ALFA

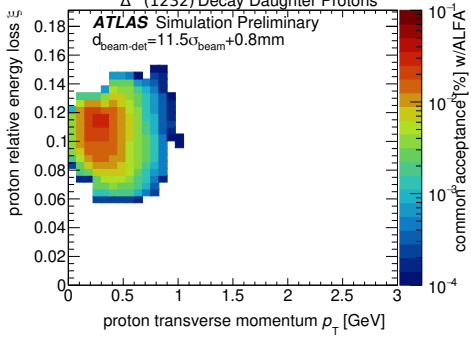
ARP+LHCf Acceptance Combination

$\Delta^+(1232)$ production

AFP far station:



ALFA far station:

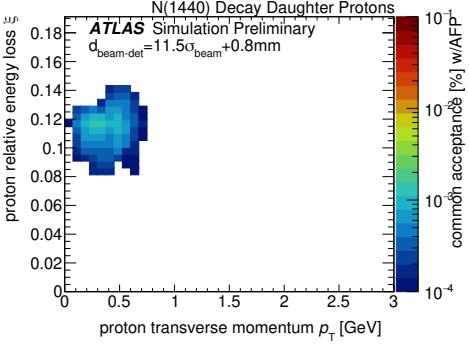


> AFP shows more promising acceptance than ALFA

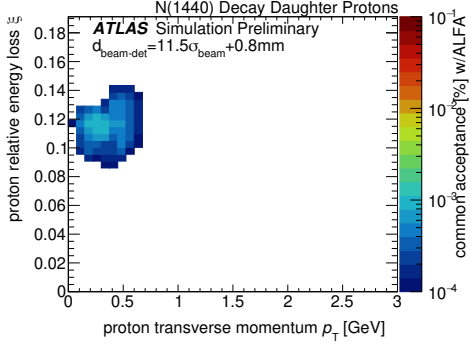
ARP+LHCf Acceptance Combination

$N(1440)$ production

AFP far station:



ALFA far station:



> Similar acceptance for AFP and for ALFA

Event Rate Estimation

Calculation

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

$$\text{Collision rate} = \text{Number of bunches} \times \langle \mu \rangle \times \text{revolution rate} \times \text{LHCf trigger efficiency}$$

- $\sigma_{\text{single diffraction}} = 12.86\,\text{mb}$
- $\sigma_{\Delta^+(1232)\text{ production}} = 0.007\,\text{mb}$
- $\sigma_{N(1440)\text{ production}} = 0.32\,\text{mb}$
- $\sigma_{\text{total inelastic}} = 80\,\text{mb}$

- number of bunches $= 150$
- revolution rate $= 11.2\,\text{kHz}$
- $\langle \mu \rangle = 0.02$
- LHCf trigger efficiency $= 100\%$
- collision rate $= 33.6\,\text{kHz}$

Event Rate Expectations Summary

Estimated Event Rates

$$\text{Event rate} = \left(\sum_{(p_T,\xi)} \text{combined acceptance} \right) \times \sigma_{\text{process}} \times \frac{\text{collision rate}}{\sigma_{\text{total inelastic}}}$$

Single diffraction

	event rate [Hz]	event count (2 days)
AFP near	66.1 ± 1.7	11.4 ± 0.3 million
AFP far	66.1 ± 1.7	11.4 ± 0.3 million
ALFA near	19.2 ± 0.7	3.3 ± 0.2 million
ALFA far	16.2 ± 0.6	2.8 ± 0.1 million

$\Delta^+(1232)$ production

	event rate [mHz]	event count (2 days)
AFP near	19.9 ± 0.6	3440 ± 100
AFP far	19.9 ± 0.6	3440 ± 100
ALFA near	10.1 ± 0.4	1740 ± 70
ALFA far	8.5 ± 0.4	1470 ± 60

$N(1440)$ production

	event rate [mHz]	event count (2 days)
AFP near	13.6 ± 1.3	2350 ± 220
AFP far	13.6 ± 1.3	2350 ± 220
ALFA near	11.7 ± 1.1	2020 ± 200
ALFA far	10.2 ± 1.0	1770 ± 180

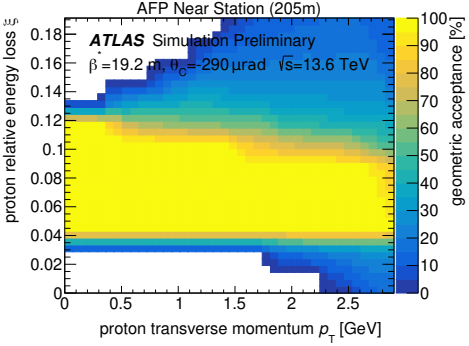
$\rightarrow$ Results clearly favour AFP for the combination with LHCf

Detector-Beam Distances During Run

AFP

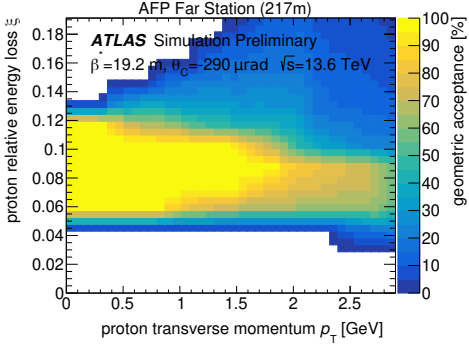
Beam-based alignment: Detector positions determination before actual run

AFP near station: $5.2\,\text{mm} \rightarrow 6.5\,\text{mm}$



$\rightarrow$ acceptance loss for low ξ region

AFP far station: $4.4\,\text{mm} \rightarrow 5.5\,\text{mm}$



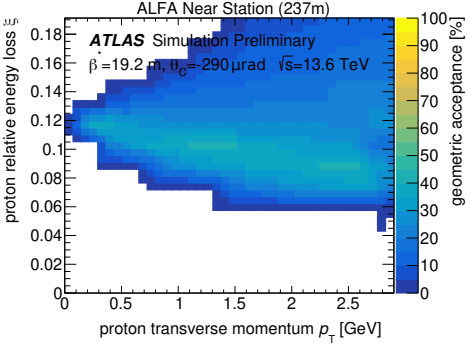
$\rightarrow$ acceptance loss for low ξ & high p_T region

Detector-Beam Distances During Run

ALFA

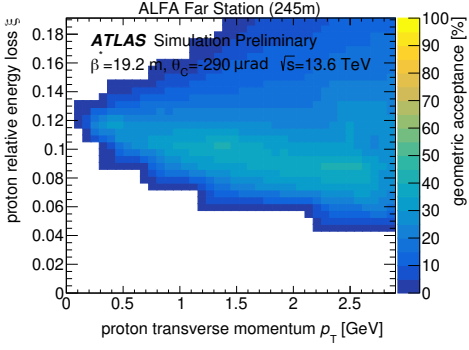
Beam-based alignment: Detector positions determination before actual run

ALFA near station: $3.9\,\text{mm} \rightarrow 6.1\,\text{mm}$



$\rightarrow$ loss of 100% acceptance region

ALFA far station: $3.5\,\text{mm} \rightarrow 5.5\,\text{mm}$

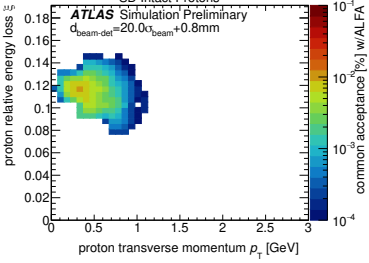


$\rightarrow$ loss of 100% acceptance region

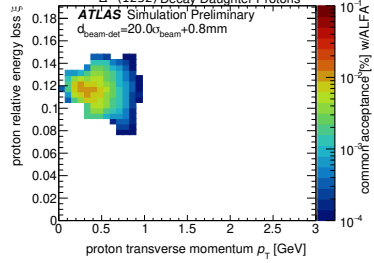
Results with Updated Detector-Beam Distances

LHCf+ALFA

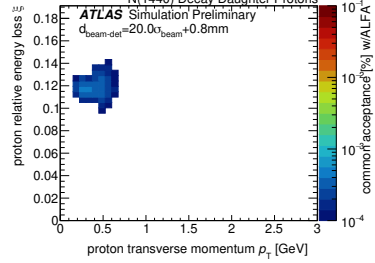
Single diffraction



$\Delta^+(1232)$ production



$N(1440)$ production



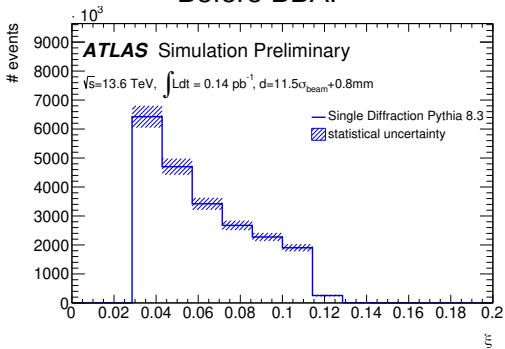
	Single diffraction		$\Delta^+(1232)$ production		$N(1440)$ production	
	event rate [Hz]	# events (2 d)	event rate [mHz]	# events (2 d)	event rate [mHz]	# events (2 d)
Near	3.8 ± 0.2	0.7 ± 0.1 million	2.2 ± 0.2	380 ± 30	4.2 ± 0.5	730 ± 90
Far	2.8 ± 0.2	0.5 ± 0.1 million	1.6 ± 0.2	270 ± 30	3.2 ± 0.4	550 ± 70

- Reduced rates for all three cases
- Recommendation for LHCf+AFP data taking confirmed

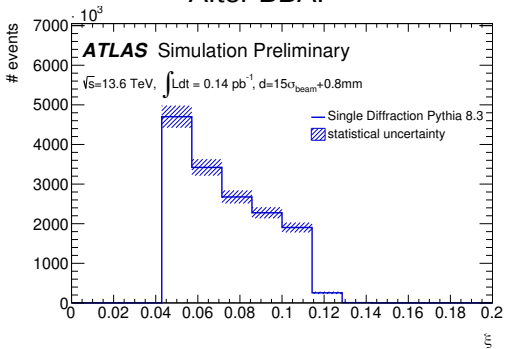
Kinematic Distributions with LHCf+AFP Selection

Single Diffraction

Before BBA:



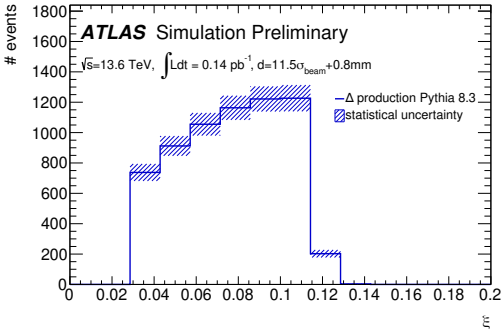
After BBA:



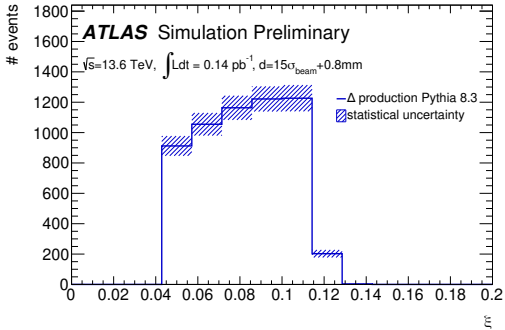
Kinematic Distributions with LHCf+AFP Selection

$\Delta^+(1232)$ Production

Before BBA:



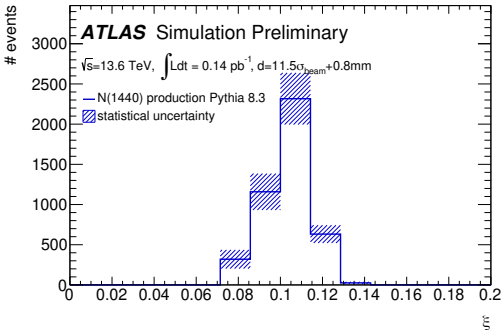
After BBA:



Kinematic Distributions with LHCf+AFP Selection

$N(1440)$ Production

Before BBA:



After BBA: