Prospects of diffractive physics with the ATLAS forward detectors

I. López Paz on behalf of the ATLAS collaboration

17th Elastic and Diffractive scattering
Czech Republic, Prague
29th June 2017

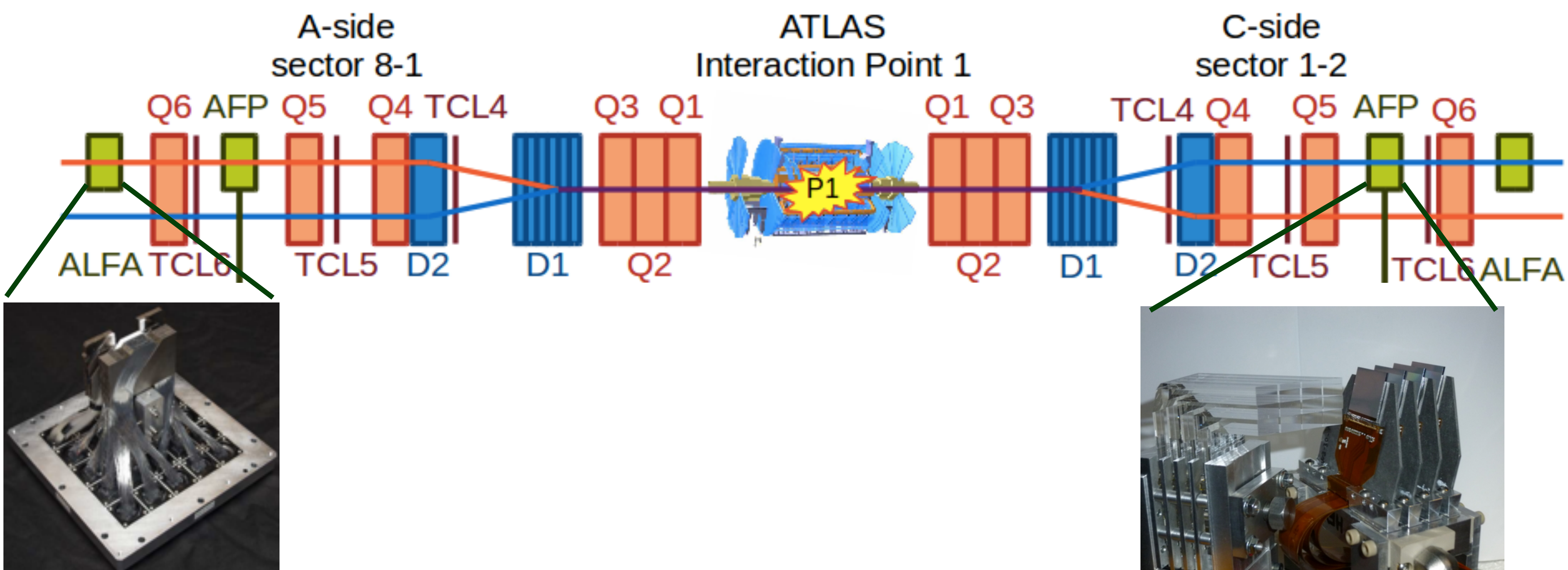
ATLAS Forward Detectors for Diffraction

In ATLAS it is possible to **identify diffractive events** by, e.g. large rapidity gaps

However, ATLAS is equipped with two forward detectors for **proton tagging**

- ALFA (Absolute Luminosity For ATLAS) vertical Roman Pots at $z = \pm 237$ and $z = \pm 245$ m for *elastic* and *diffractive* scattering measurements
- AFP (ATLAS Forward Proton) horizontal Roman Pots at $z = \pm 205$ and $z = \pm 217$ m for *diffractive* scattering measurements "NEW"

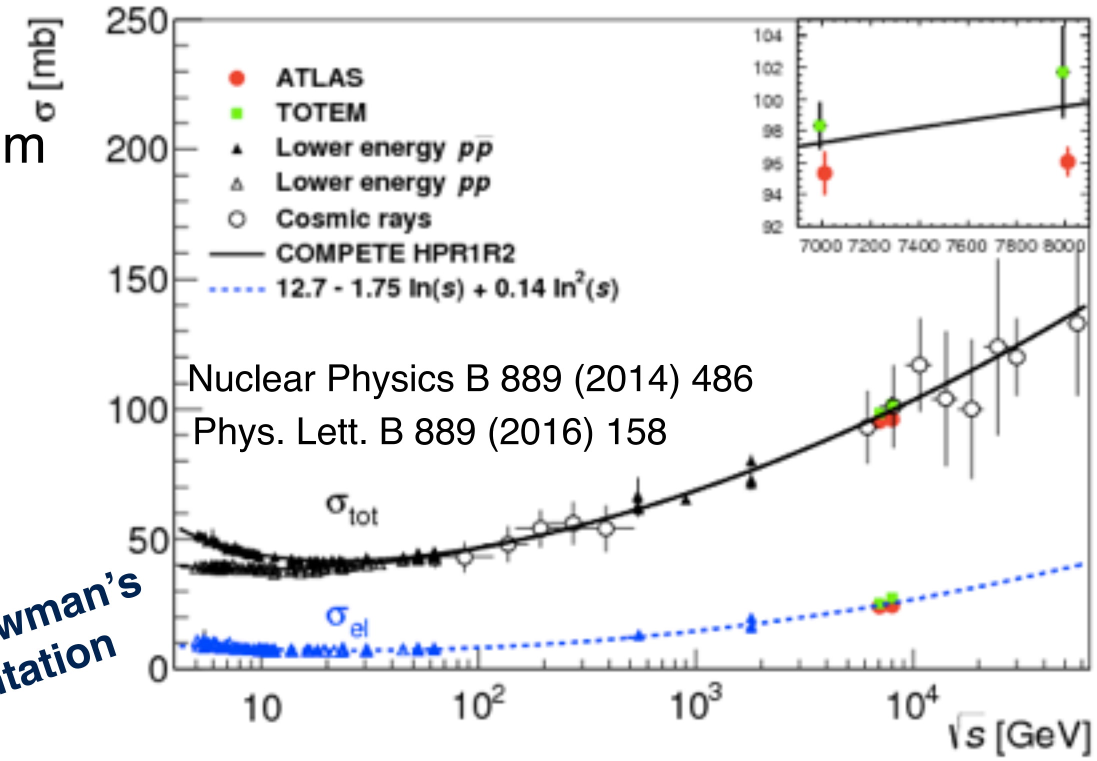
➡ Tag protons leaving intact the interaction point to **identify diffractive processes**



Proton tagging with ALFA (I)

ALFA (Absolute Luminosity For ATLAS)

- Scintillator fiber trackers in vertical Roman Pots at ± 237 m and ± 245 m from the ATLAS Interaction point

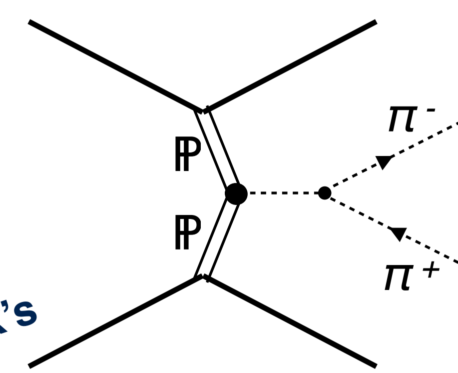


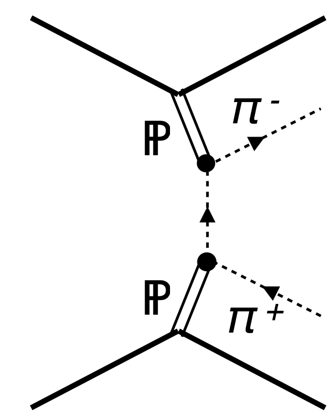
Total, elastic and inelastic *pp* cross-section with ALFA

- Measure elastic cross section at √s of 7 and 8 TeV and determine total cross section using the optical theorem
- Require special optics to access elastic scattering
- Analysis of 13 TeV data ongoing

See P. Newman's presentation

Exclusive π+π- production

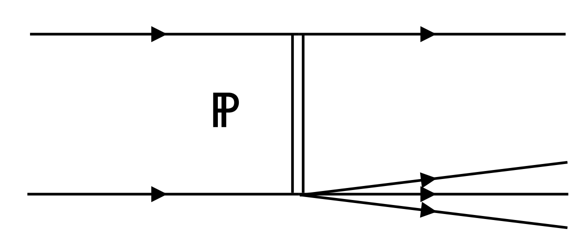




- Possible to measure with ALFA proton tags at special optics
- Analysis at √s of 7 and 8 TeV in well advanced, 13 TeV analysis in progress

See L. Adamczyk's presentation

Single diffraction



- Data taken with special optics
- Analysis advancing

Proton tagging with ALFA (II)

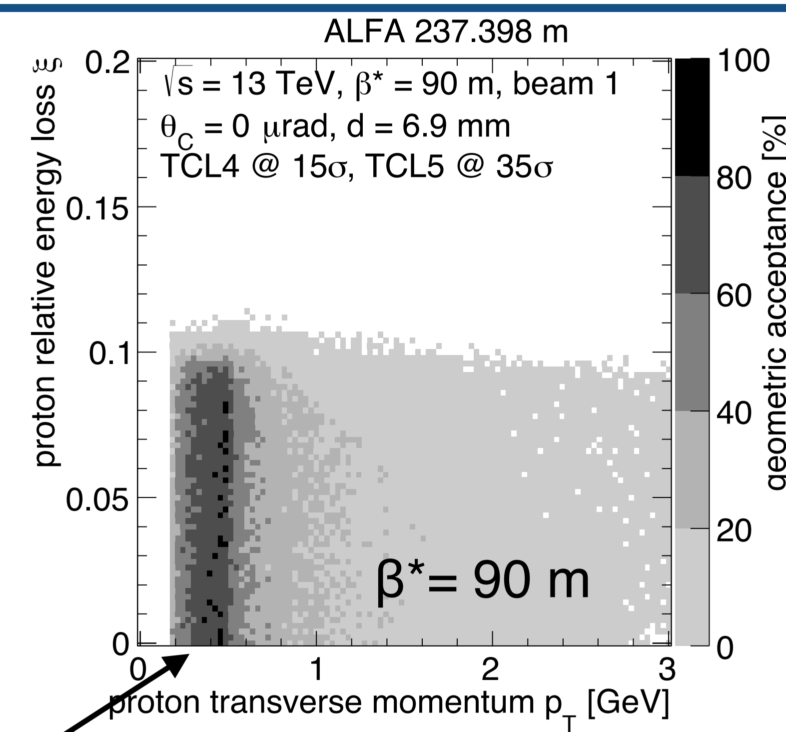
ALFA is optimized for elastic scattering and small momentum transfer

- Acceptance for protons with low relative energy loss (ξ~0) at special optics

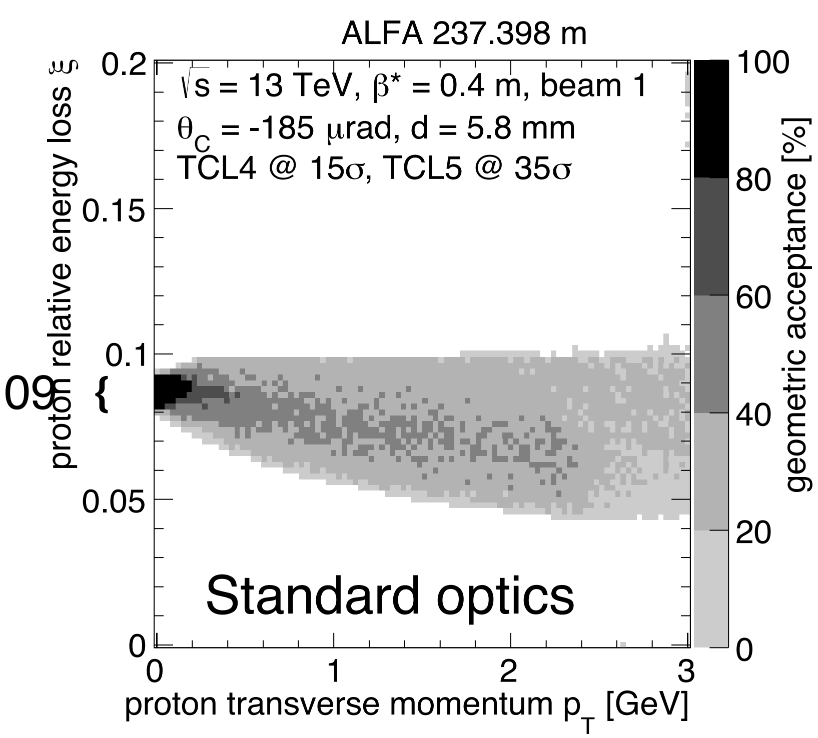
Not suitable for hard diffraction

- Little acceptance in ξ for hard diffraction at standard LHC optics

  ➡ New forward proton detector: **AFP**



ξ = 0 for elastic scattering with special optics



$0.08 < \xi < 0.09$ {

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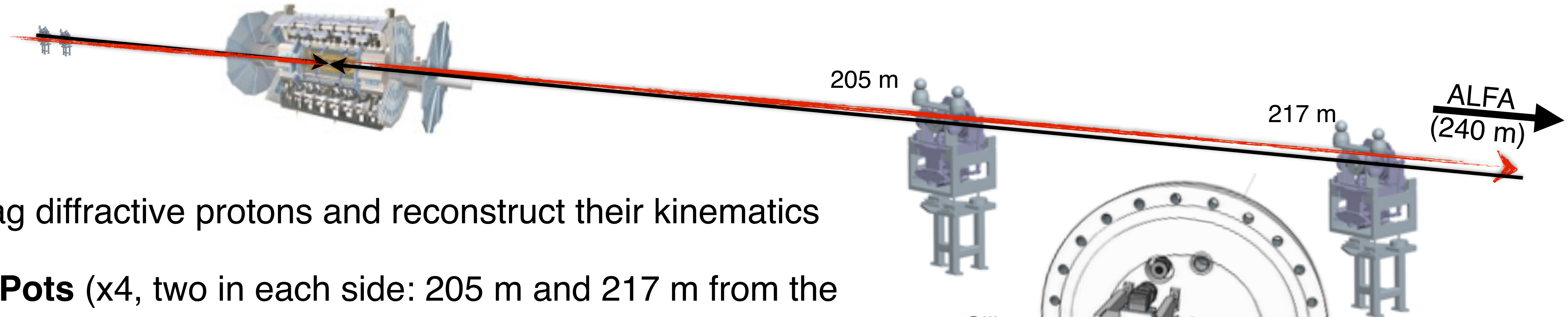
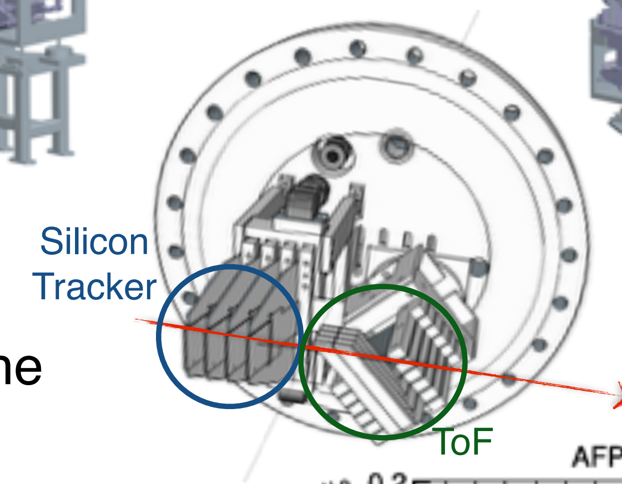
The ATLAS Forward Proton (AFP) detector



Goal: Tag diffractive protons and reconstruct their kinematics



Note: only 8 LQbars pictured

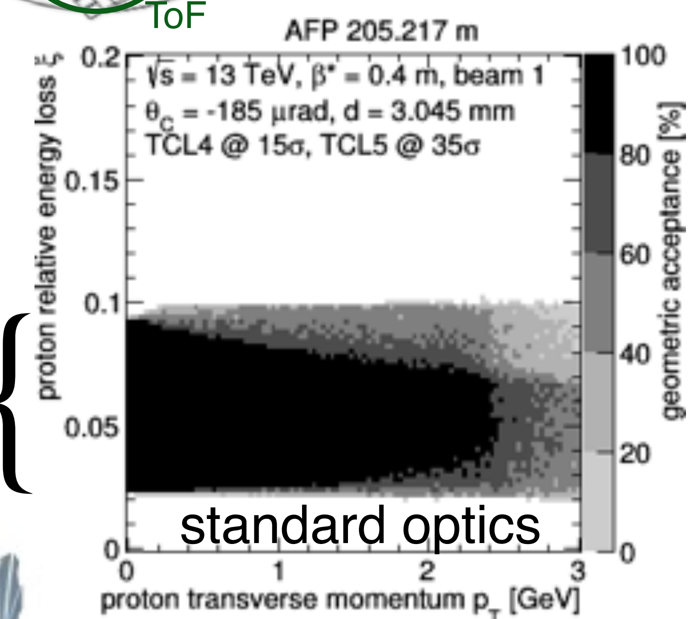
Roman Pots (x4, two in each side: 205 m and 217 m from the Interaction Point)

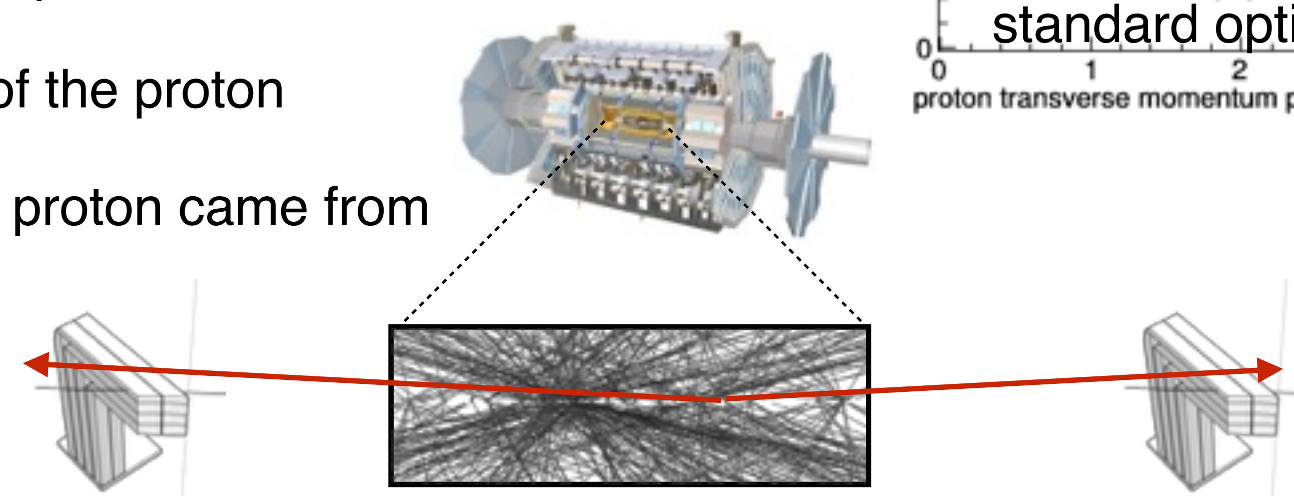
- House the detectors and move them up to few millimeters from the LHC proton beam

Detectors in AFP

- **Silicon Tracker:** 4 planes per station in all stations
    - Reconstruct transverse momentum and proton energy loss
- **Time-Of-Flight:** 16 Cherenkov Quartz bars per side in FAR station
    - Determine position of primary vertex of the proton
    - ➡ Distinguish from which interaction the proton came from (pile-up removal)

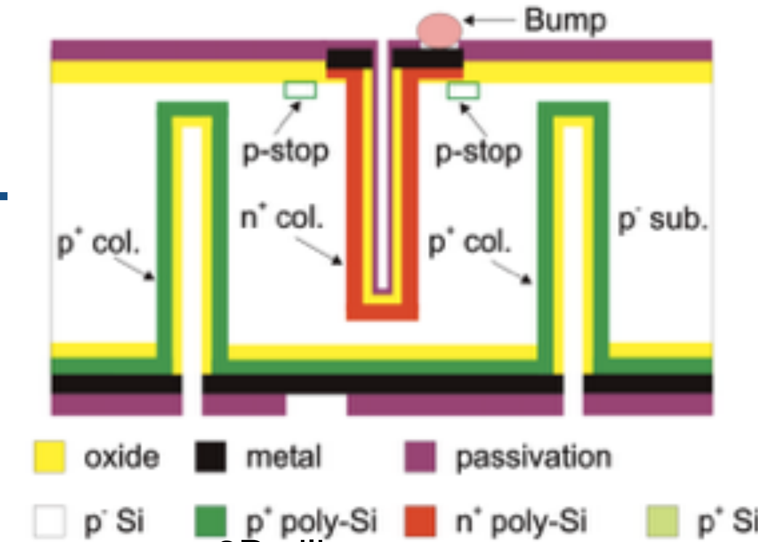
Larger acceptance than ALFA



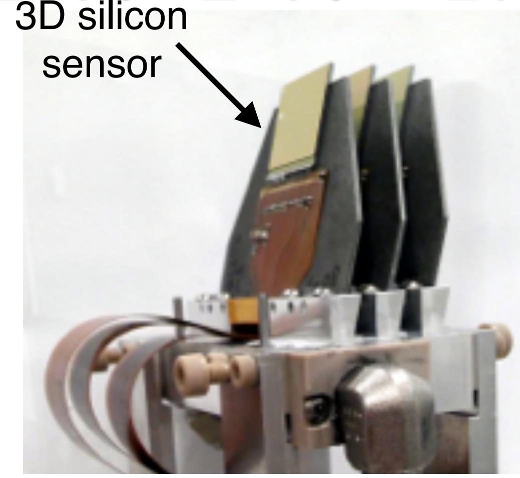


EXCELENCIA SEVERO OCHOA

AFP Silicon Tracker



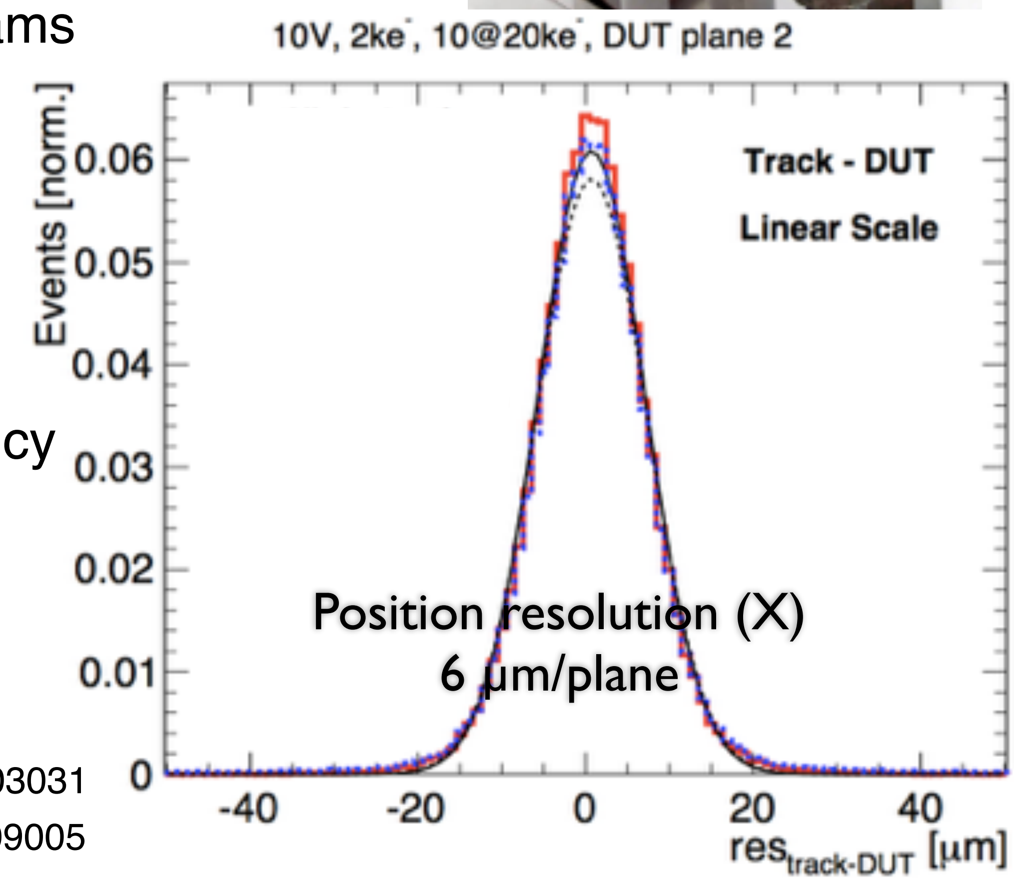
Silicon tracker technology: 3D pixel sensors



- **Column-like electrodes:** Inter-electrode distance (~67 μm) de-coupled from detector thickness (230 μm)
  - ➡ **Low voltage** for full depletion (~10 V) before irradiation
  - ➡ Shorter drift distance -> Lower trapping probability -> **Radiation hard**
- Use its trigger signal in AFP0+2
- 336x80 pixels with 50x250 μm^2 area each

Tracker qualification: Performance evaluated in various test-beams

- Measured ~6 μm/plane resolution in short pixel direction
- Able to sustain non-uniform radiation of up to 5×10^{15} n_{eq}/cm^2 (expected in AFP life-span)
- Dead area can be cut down to <150 μm without losing efficiency
  - ➡ Active area as close as possible to the Roman Pot wall

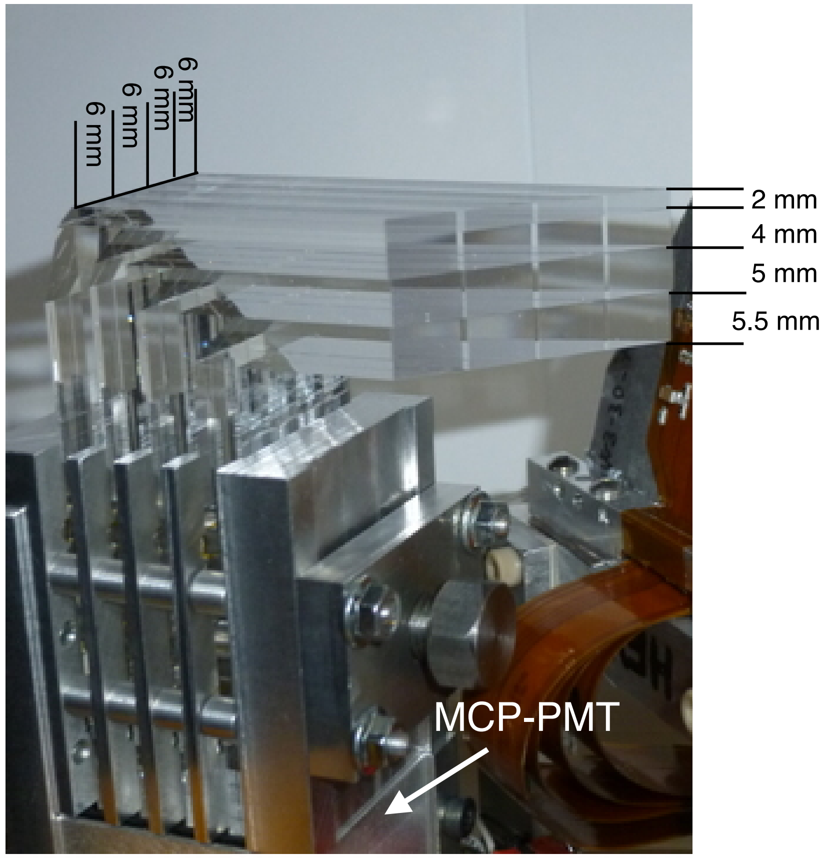


JINST 10 (2015) C03031
JINST 11 (2016) P09005

AFP Time-of-Flight detectors

Cherenkov Quartz bars

- At Cherenkov angle (48°) with respect to proton direction to maximize photon collection
- Photons collected in a Micro-Channel-Plate Photomultiplier (MCP-PMT) at the end of the bars
- Finer segmentation at lower ξ for triggering
- L-shaped due to space constrains (ToF shares Roman Pot station with SiT)

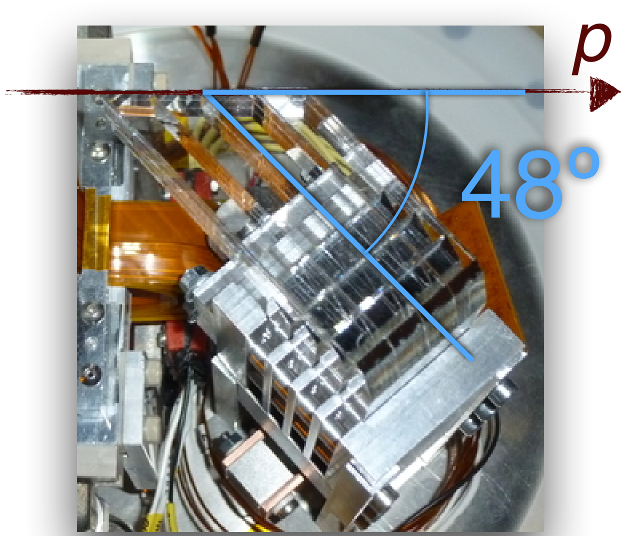


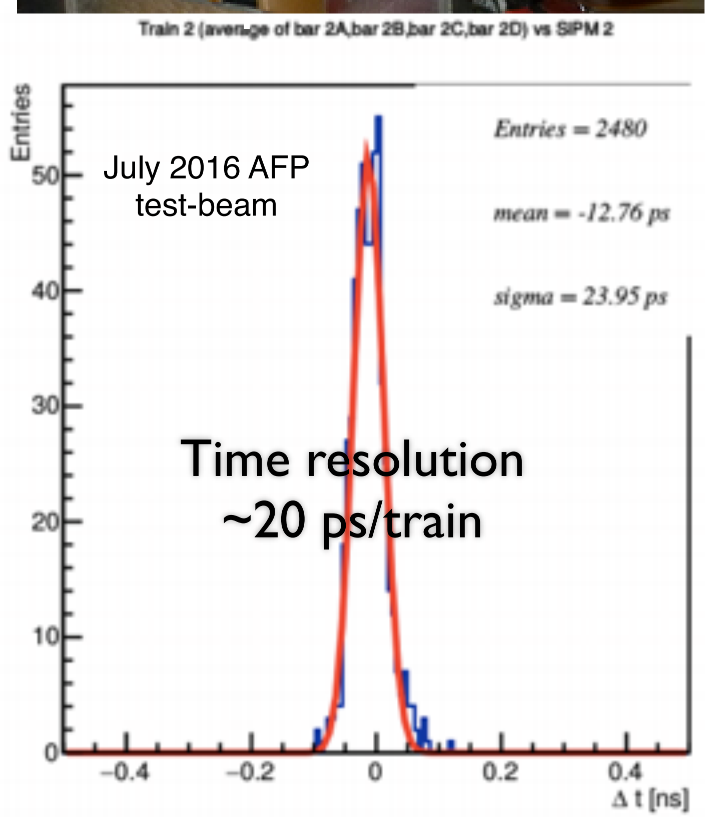
ToF qualification: Performance evaluated in various test-beams

- Full train (4 bars) time resolution: ~20 ps

Opt Express. 2016 Nov 28;24(24):27951-27960

➡ ~ 4 mm *z*-resolution of the primary vertex in the central detector

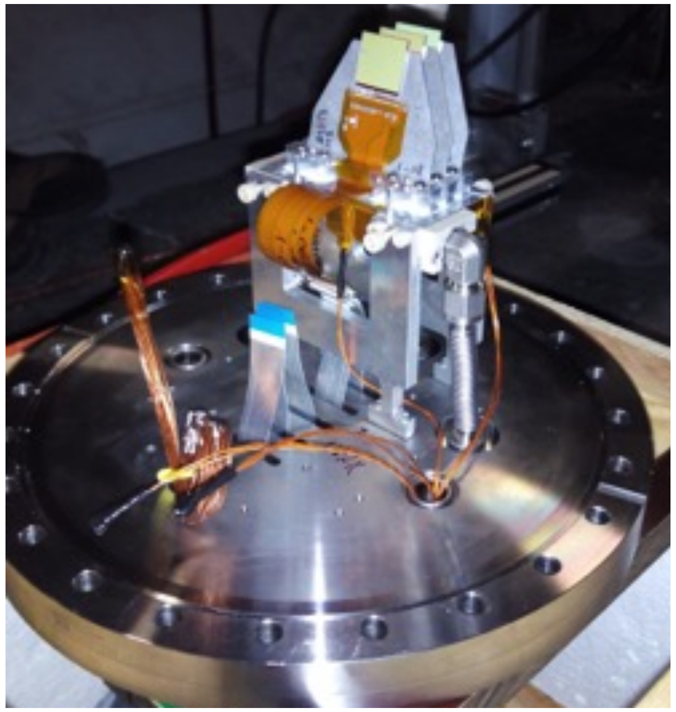


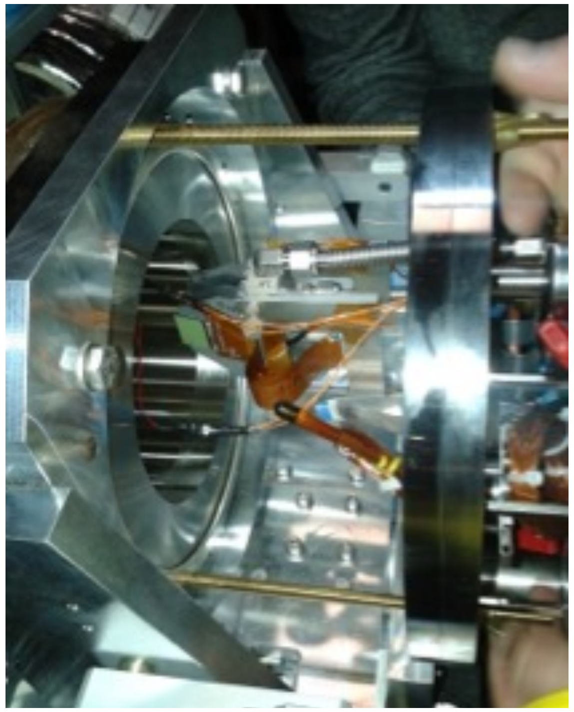


AFP installation in 2016

One-Arm installation successful in February 2016:

- **2 stations in one side of ATLAS**
  - ➡ Allow for single diffractive studies
  - ➡ Silicon tracker only: 3 (4) in Near (Far) station
  - ➡ No Time-of-flight detector available for installation
- **Trigger from silicon sensors**
  - ➡ ~50-250 ns trigger dead time*: only useful for low-μ conditions





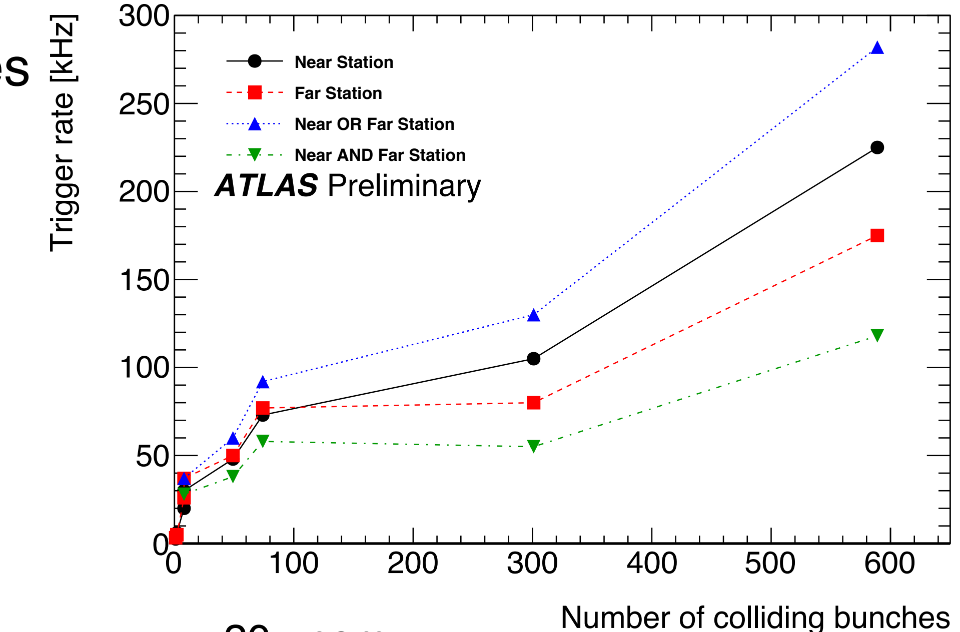
Successful tracker installation!

*Trigger dead time depends on charge collection. Can take data with 25 ns spacing.

AFP operation in 2016

Standard pile-up: AFP was inserted in beam position during intensity ramp-up in each intensity step up to 600 colliding bunches

- Study detector performance and alignment
- Understand beam background and AFP trigger
- Time-in detector to read-out 1BC and to send triggers inside ATLAS Latency

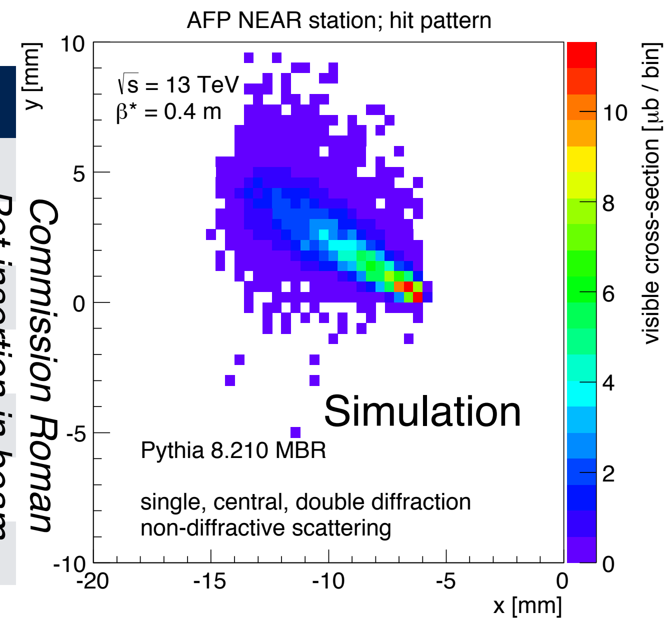


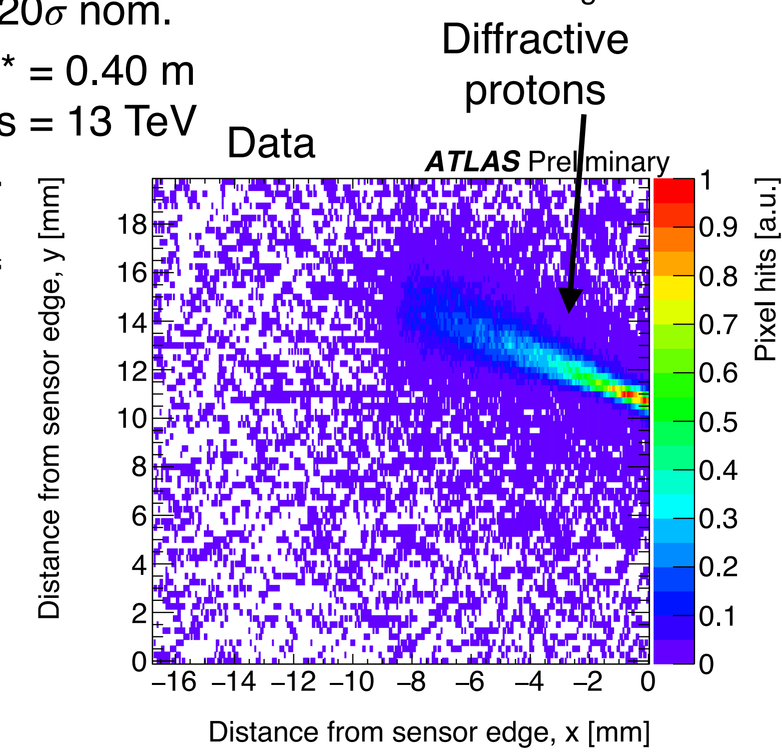
Low pile-up: PHYSICS

20σ nom.
β^* = 0.40 m
$\sqrt{s}$ = 13 TeV

Date (2016)	Fills with AFP inserted	TDAQ Mode
19-22 April	Alignment and Loss Maps	AFP only
23 April	3 bunches	AFP only
24-25 April	12 bunches	AFP only
29 April – 5 May	LHC power cut -> TDAQ integration	
7 May	49/86 bunches	with ATLAS
9 May	300 bunches	with ATLAS
13 May	600 bunches	with ATLAS
31 July	**600 b. low-μ physics run**	**with ATLAS**
21 September	2nd Align. and Loss Maps	with ATLAS
8 October	**600 b. low-μ physics run**	**with ATLAS**
14 October	100 bunches	with ATLAS

Pot insertion in beam
Commission Roman





AFP working as intended in 2016!

AFP data from 2016

One-arm AFP

- ➡ One proton tag: Single diffraction physics processes
- ➡ No pile-up removal (low luminosity only): high cross-section processes

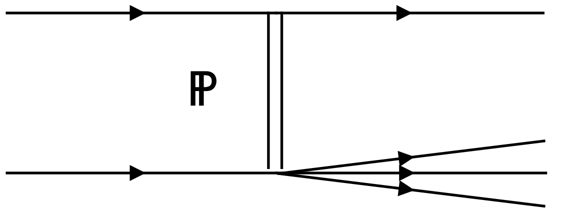
Several standard luminosity runs for commissioning

- ➡ Inter-plane and global alignment
- ➡ Background studies
- ➡ Gain experience with the new detector's data

Two physics runs at low pile-up in 2016

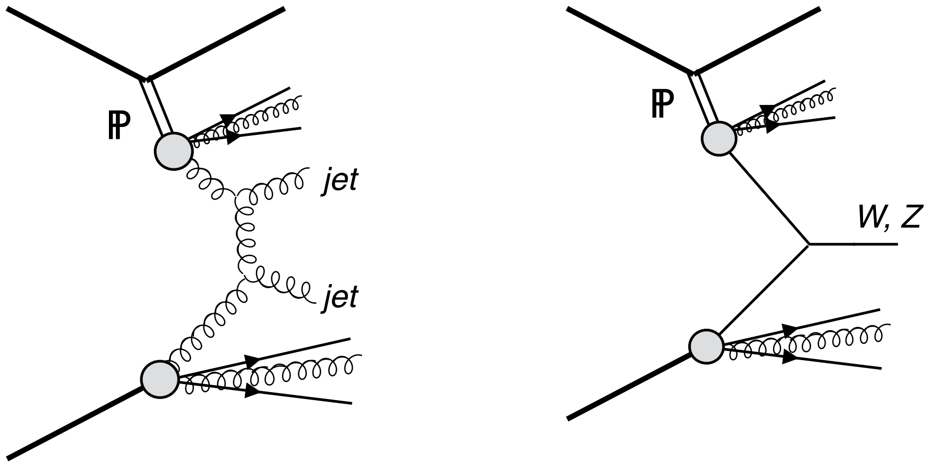
- Roman pots at 20σ from proton beam
- Standard LHC optics (β* = 0.44 m)
- Reduced pile-up by beam separation:
  - **<μ> ~ 0.03**, L ~ 0.04 pb^{-1} in data taking conditions
  - **<μ> ~ 0.3**, L ~ 0.5 pb^{-1} in data taking conditions

Soft (single) diffraction



Hard (single) diffraction

e.g.

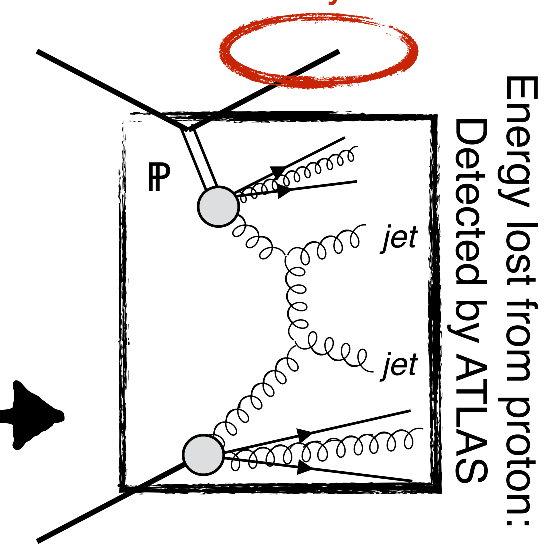


First look at the data: Proton tagged SD+jets

Validate AFP proton tagging

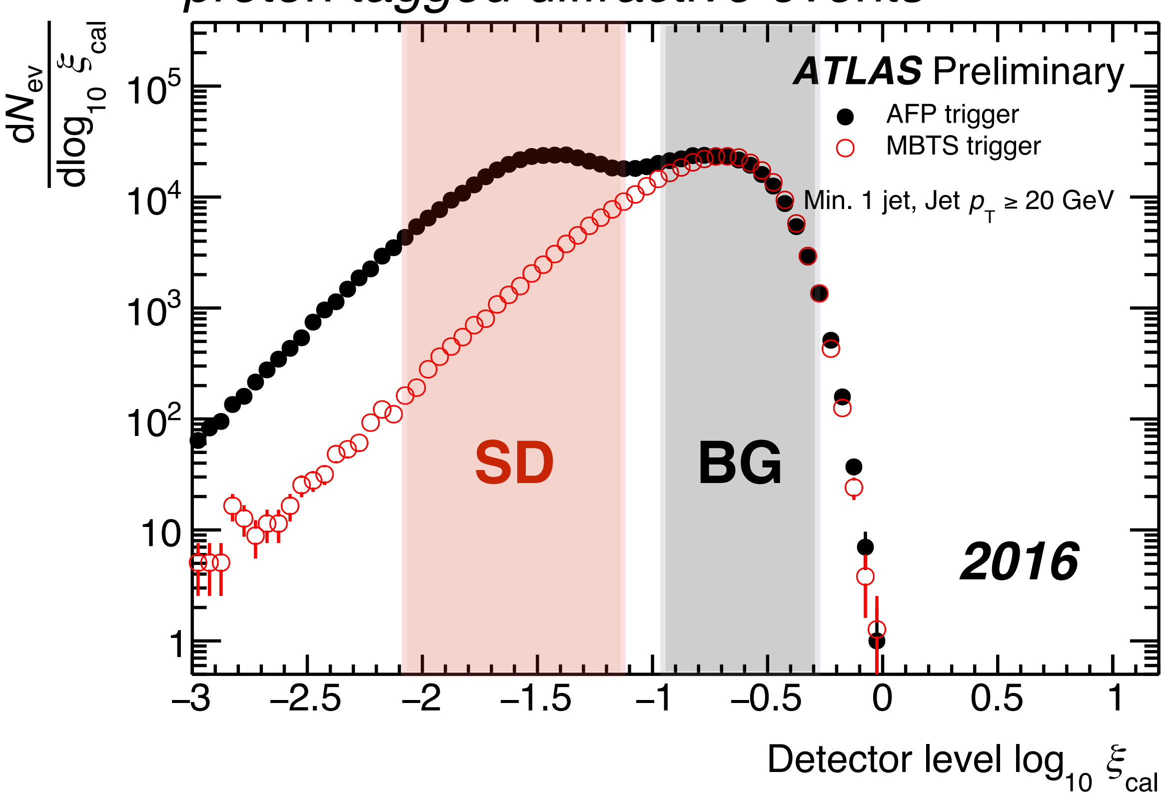
- Tag protons to select single diffractive events with jets in the final state
- Proton kinematic reconstruction not yet available
  - ➡ Correlate AFP triggered events to ξ measured at the calorimeter

$$\xi^{CAL} = \frac{1}{\sqrt{s}} \sum_{CalClus} p_T e^{-\eta}$$

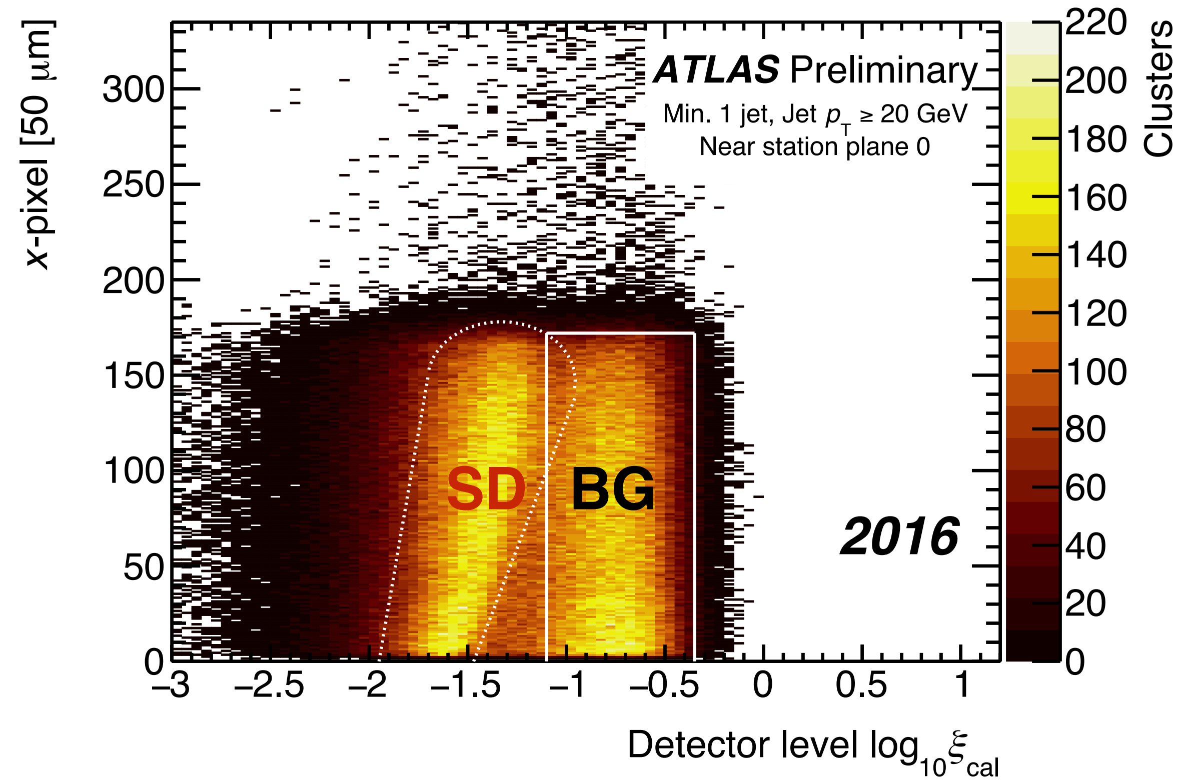


Single Diffractive (SD) Event

Excess in low ξ indicates presence of proton tagged diffractive events



Low ξ excess correlated to position measured at AFP (trajectory of diffractive proton in LHC magnetic fields depends on its energy)



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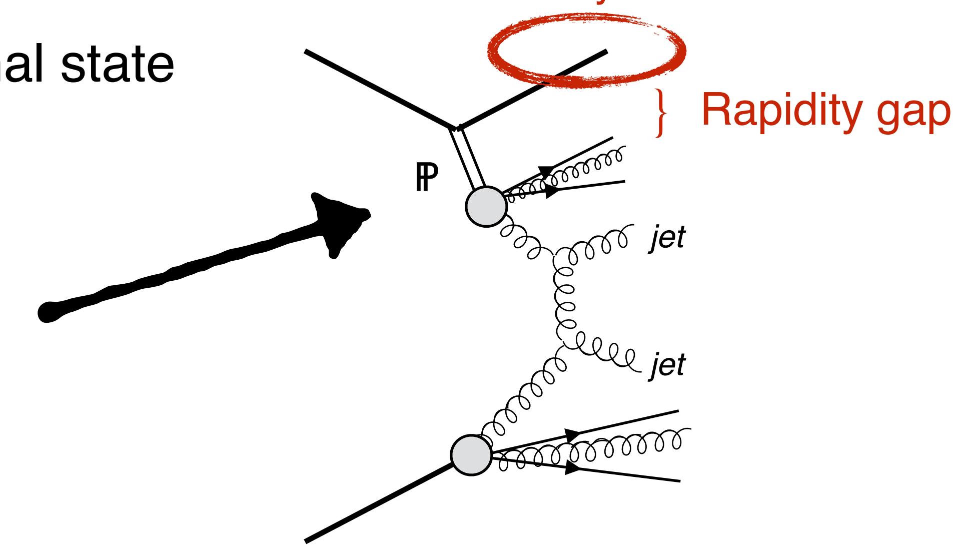
First look at the data: Proton tagged SD+jets

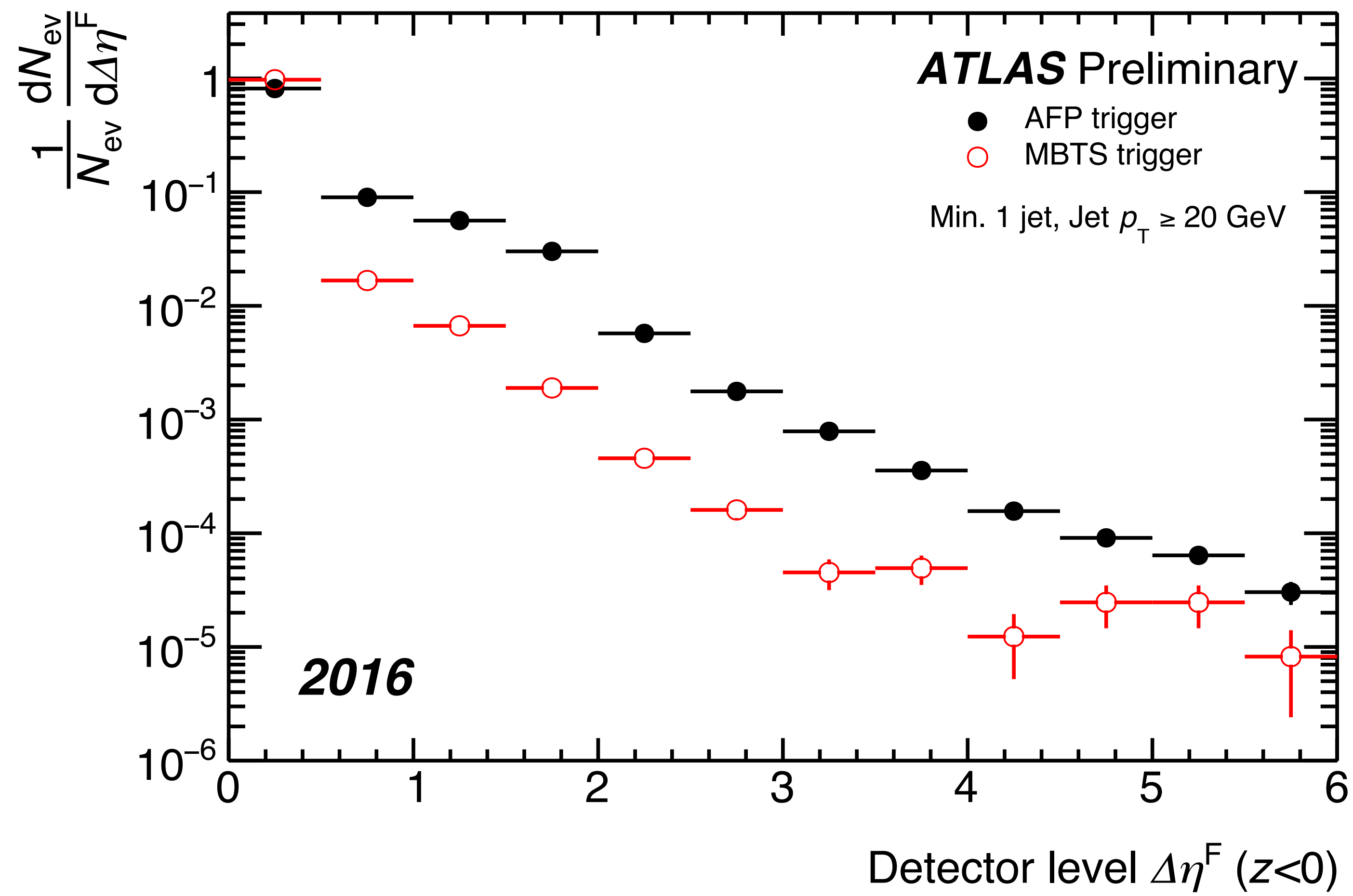
Validate AFP proton tagging

- Tag protons to select single diffractive events with jets in the final state
- Proton kinematic reconstruction not yet available
  - ➡ Correlate AFP triggered events with forward rapidity gaps



Single Diffractive (SD) Event

AFP triggered data has larger rapidity gaps
-> Rich in diffractive events



AFP is able to tag on diffractive events!

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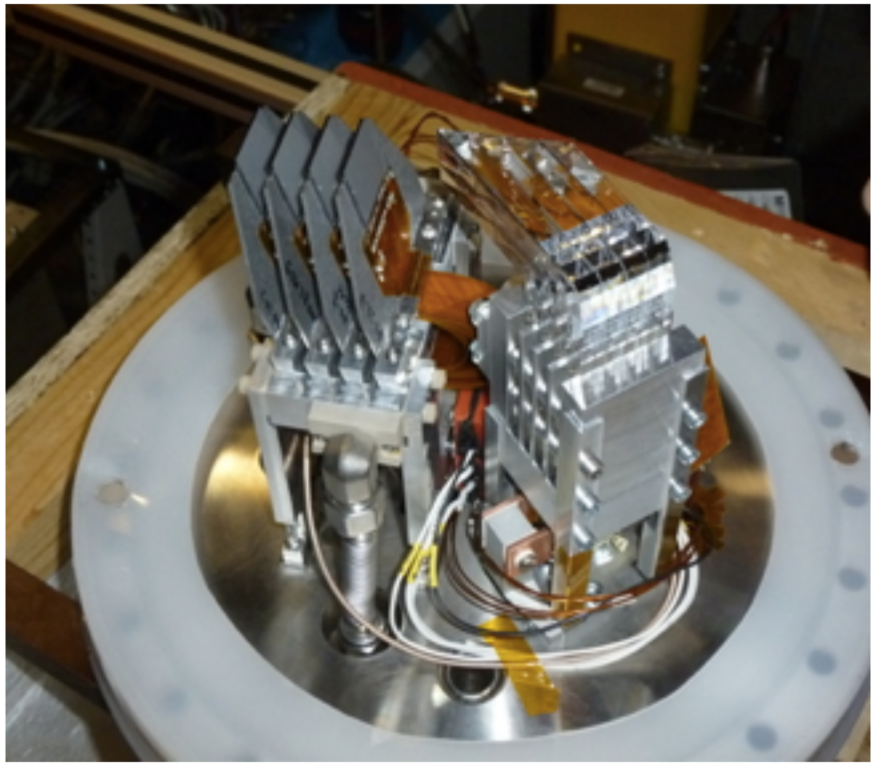
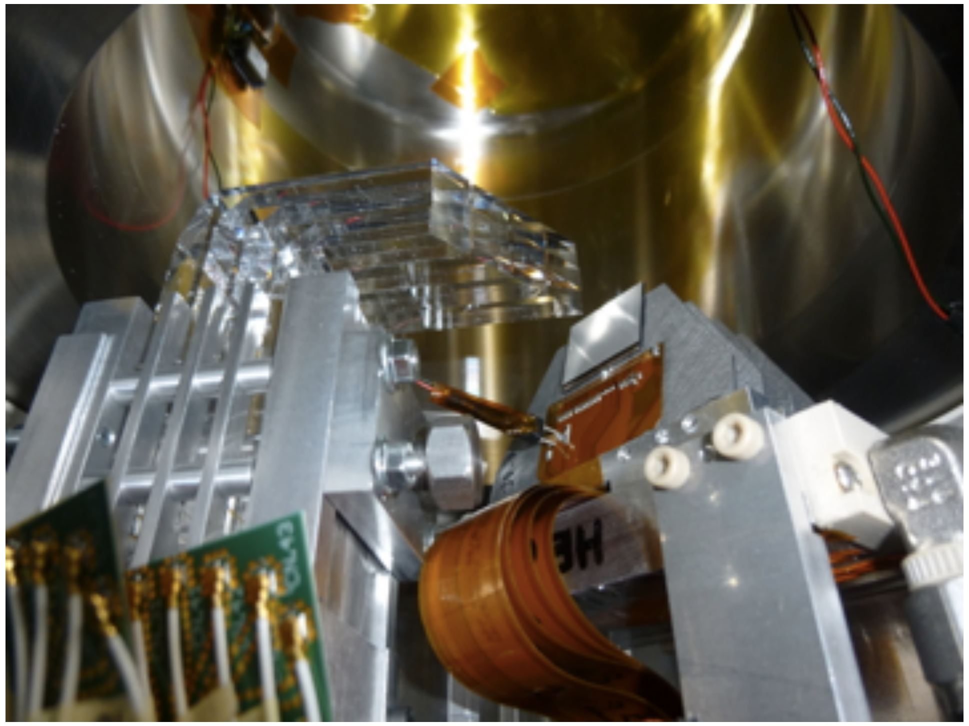
AFP Installation in 2017

Full AFP installation successful in April 2017:

- **4 stations, 2 in each side**
  - ➡ Allow for single diffractive **and central diffraction/double pomeron exchange** studies
- **Silicon tracker AND Time-of-flight detector available for installation**
  - ➡ Silicon trackers: 4 in each station
  - ➡ Time-of-Flight: possibility of pile-up removal
- **Trigger from silicon sensors AND ToF detectors**
  - ➡ Flexibility to chose between two types of triggers while ToF is commissioned (lower dead time)





Full AFP detector installed!

AFP operation in 2017

Standard pile-up: AFP is being inserted in beam position during intensity ramp-up in each intensity step

- Study detector performance and alignment
- Understand beam background and new ToF-based AFP trigger
- Time-in detector to read-out 1BC and to send triggers inside ATLAS Latency
- ToF detector commissioning

Planned low and high (standard) pile-up PHYSICS runs

- Physics runs after commissioning Triggers, DAQ and Roman Pots

AFP detector commissioning ongoing…

Date (2017)	Fills with AFP inserted
19-20 May	Alignment and Loss Maps
21-22 May	3 bunches
25-26 May	12 bunches
27 May	72 bunches
30 May - 3 June	300 bunches
5-12 June	600 bunches
14-15 June	900 bunches
15-16 June	1200 bunches
…	…

Commission Roman Pot insertion in beam

AFP program for 2017 and beyond

Two arm AFP with ToF detector

➡ Double proton tag: Both single and central diffraction physics

➡ Running in std. and special (low-medium pile-up) conditions: lower cross-section processes available

Plan to take data in standard luminosity runs by default:

➡ Central Exclusive Jet Production

➡ Di-muon production $\gamma\gamma \rightarrow \mu\mu$

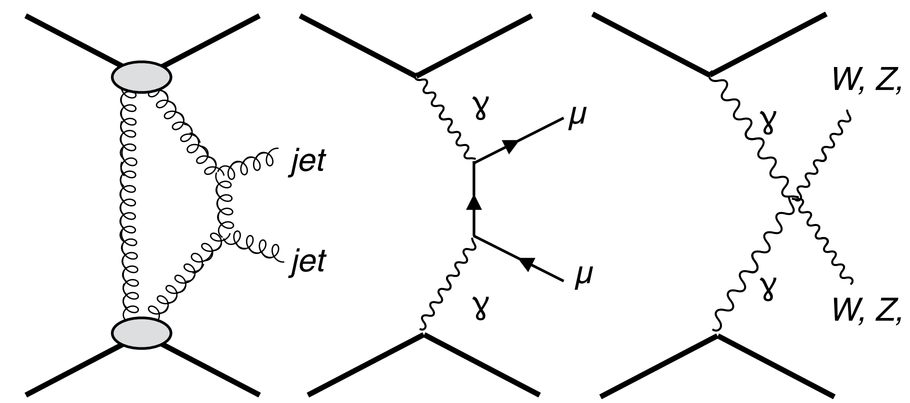
➡ Processes sensitive to aQGC, e.g. $\gamma\gamma \rightarrow W^+W^-$

Special low (μ~0.01 pile-up) and medium (μ~1 pile-up) luminosity runs:

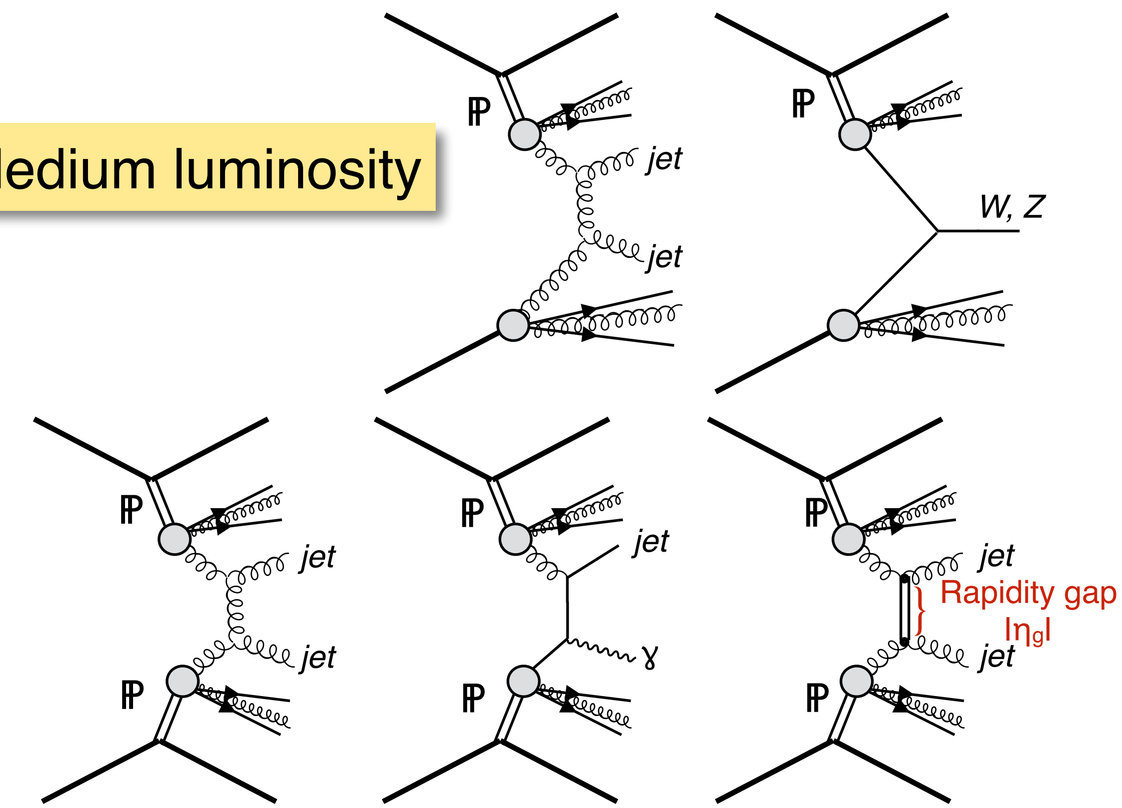
➡ Soft and hard single diffraction (continue 2016 physics program)

➡ Double Pomeron Exchange: Jet production, photon+jet, jet-gap-jet

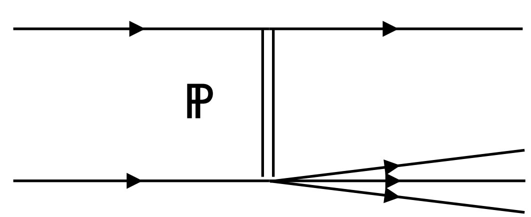
Standard luminosity



Medium luminosity



Low luminosity



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Conclusions

The ATLAS Forward Proton (AFP) detector was installed in two phases in 2016 and 2017

2016: 2x Roman Pot stations with Silicon trackers in one side ($z<0$) of ATLAS

- Commissioned and took data for physics analyses
- **Single** proton tag and **low luminosity** (no ToF -> no pileup removal)
  - ➡ **Physics program (2016):** High cross section single diffraction processes
    - Proved that AFP is able to tag diffractive events

2017: 4x Roman Pot stations, 2 in each side of ATLAS, with Silicon trackers and Time-of-Flight detectors in the farthest Roman Pots

- Commissioning of detector ongoing…
- **Double** proton tag and **low** to **high luminosity** (ToF available for pile-up removal)
  - ➡ **Physics program (2017+):** Single and double diffractive processes with lower cross section, CEP, anomalous quartic couplings, …

Looking forward to get more data in 2017!

Back-up