# ATLAS FORWARD PROTONS (AFP) STATUS REPORT

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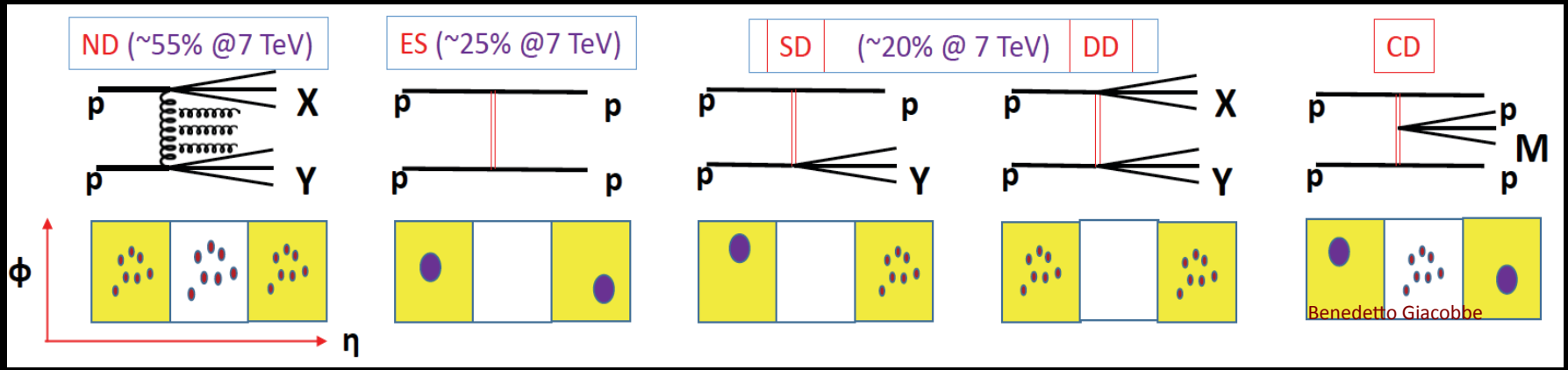
# MENU – A TASTE OF AFP

- Physics Case
- Why proton tagging?
- The AFP detector (0 + 2)
  - 2016: Single arm configuration
    - Physics Program
    - Gaining experience with the data
- Where we are now:
  - Double-arm configuration (2 + 2)
    - Present status of installation
    - Physics program

# Soft Diffraction (non-p QCD)

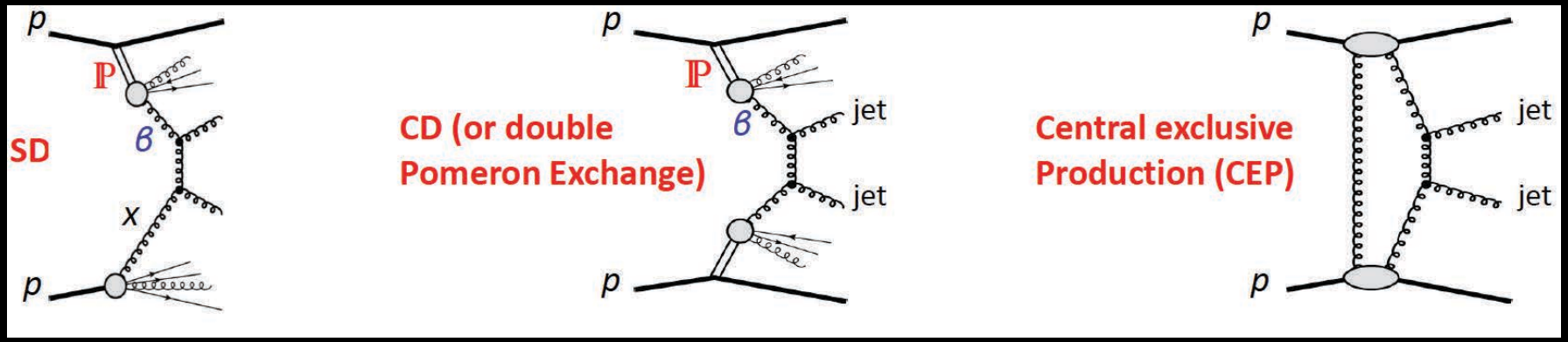
- *Mediated by strongly interacting colourless Pomerons*




- *Typical experimental signature for diffraction are rapidity gaps, but signal depends on purity, pile-up, gap-survival.*
- *Forward protons present in most of diffractive processes represent clear signature*

# Hard Diffraction (p-QCD)

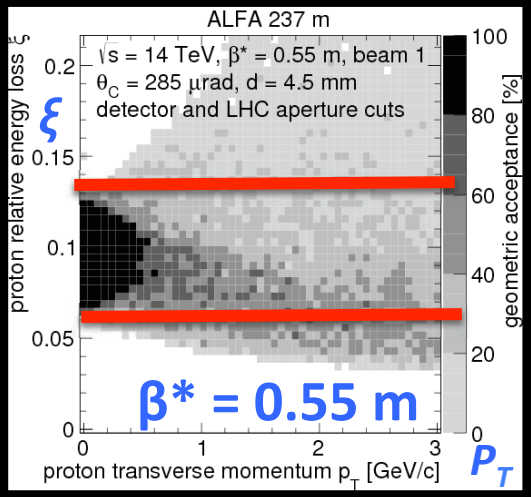
- *Diffractive processes can also be observed in events with a hard scale present i.e jets and/or W/Z bosons.*

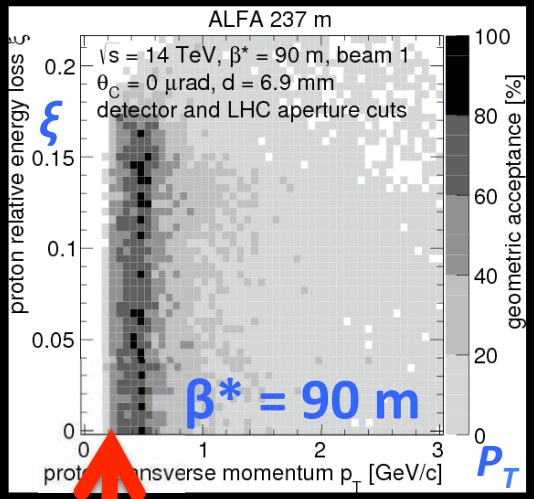


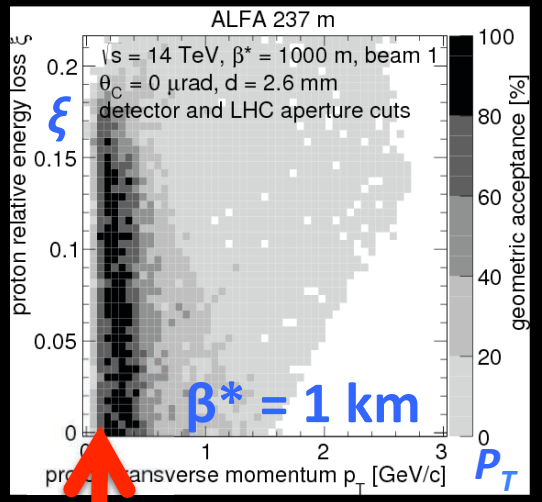

- *Rapidity gaps present but can be spoiled by additional soft interactions*
- *Proton tag crucial in addition to measurement in the central detector*

# Why AFP?

- *ALFA is optimized for elastic scattering measurement at very low momentum transfer*
  - *Needs to measure small proton fractional momentum (ξ) and $P_T$*



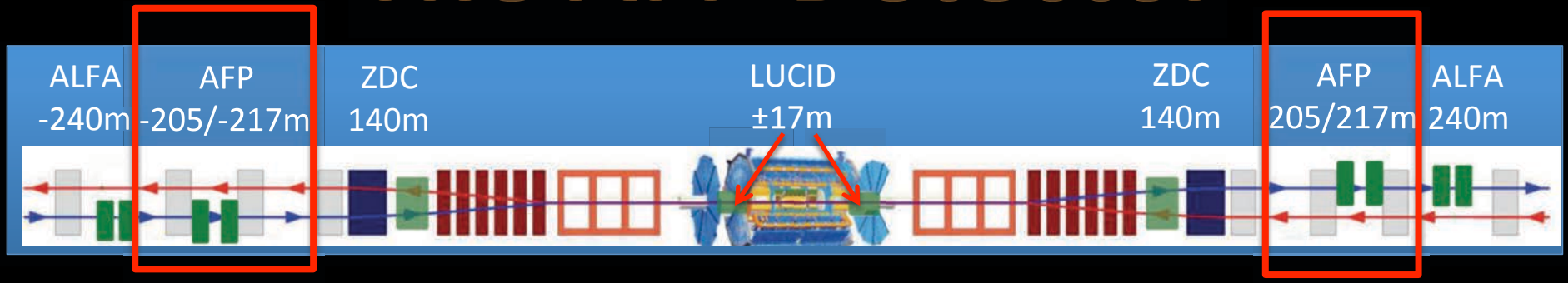




***LHC nom. 0.06 < ξ < 0.12***

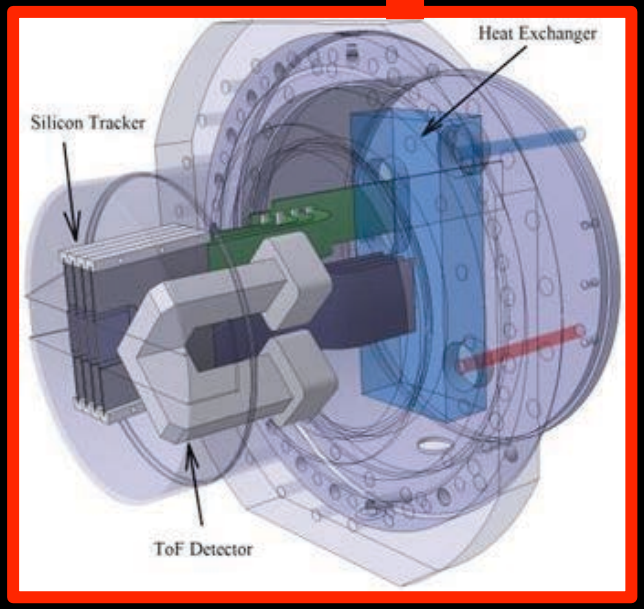
***Low-t RoI for elastic scattering & $\sigma_{tot}$ measurement***

- *Acceptance depends on LHC optics: ξ ~ 0 reached in high-β* (low focusing) mode.*
  - *Using standard optics acceptance is not optimal for diffractive studies to access lower ξ - need new forward proton detectors*

# The AFP Detector



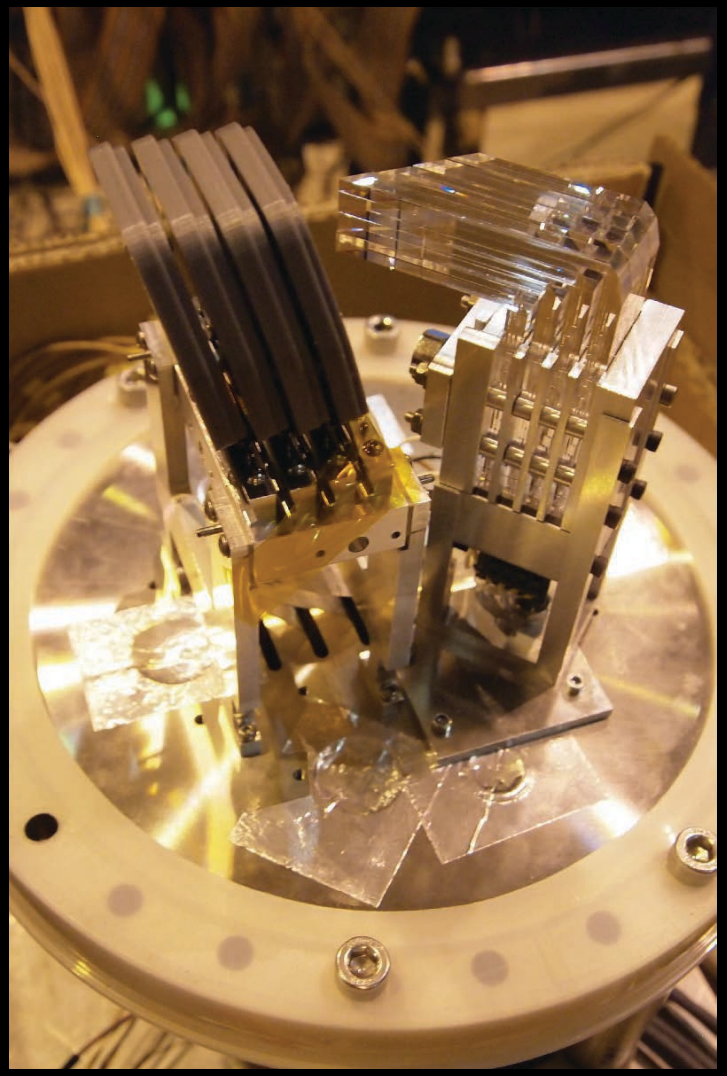

- *2 stations at ±205 & ±217 m from IP*
- *Housed in horizontal Roman Pots*
  - *Near stations house 3D pixel tracking detectors*
  - *Far stations also have ToF counters*
- *Pixels tag and measure momentum & emission angle of forward protons*
- *Time of flight to identify origin of protons in longitudinal direction*
  - *$\Delta z$ ~ 2mm if time resolution of ToF is 10ps)*




*CERN-LHCC-2015-009 + ATLAS-TDR-024*

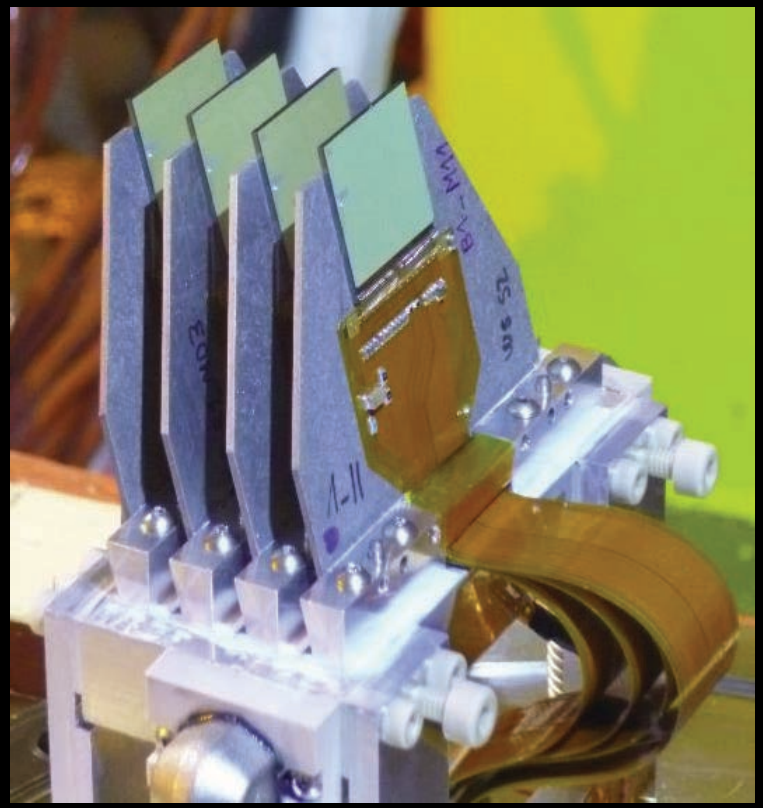
# AFP Status

- *AFP 0+2 in 2016*
  - *installation of 2 trackers on one side.*
  - *Data collected in special low-μ runs (L = 500 nb-1) for studies of single diffraction*
  - *Data analyses are already in progress*
- *AFP 2+2 in winter 2016/2017*
  - *installation of the other arm with ToF detectors on both sides*
  - *Data acquisition in standard runs with high pile-up as well as dedicated runs*
  - *Studies focused on central diffraction*



# The Tracking Detectors

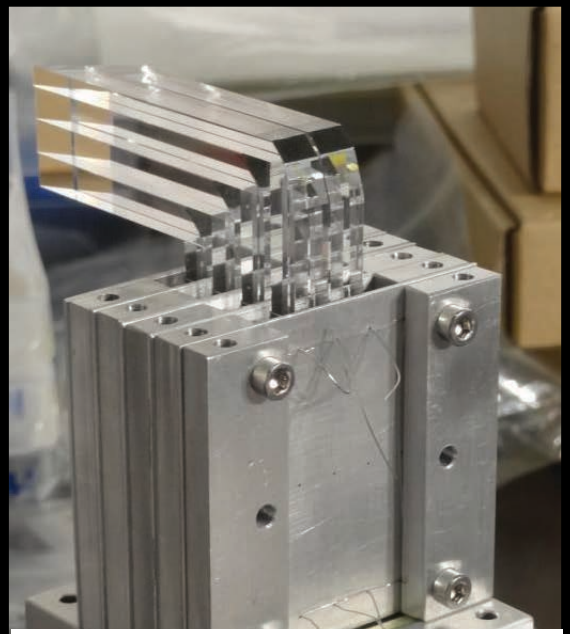
- *Together with LHC magnets measure momentum of forward scattered protons*
  - *Resolution of 15 µm needed*
  - *Radiation hardness crucial – $5x10^{15}p/cm^2/100\ fb^{-1}$*
- *To maximize approach to the beam (2-3 mm) inactive edge < 200 µm*
  - *In each station 4 pixel layers 336 x 80 pixels (50 x 250 $\mu m^2$)*
  - *3D pixel sensors derived from ATLAS IBL (rad-hard)*

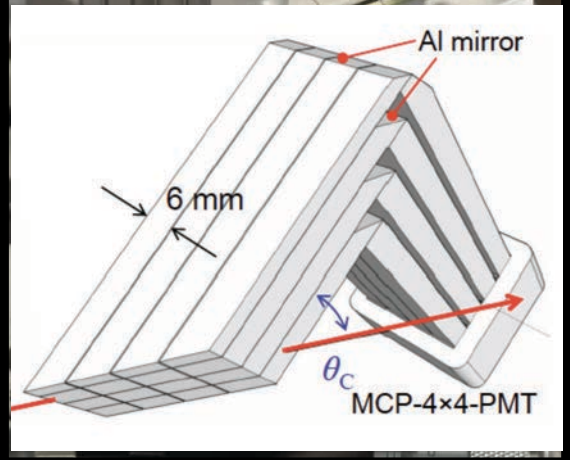


*JINST 11 (2016) P09005*

# The ToF Counters

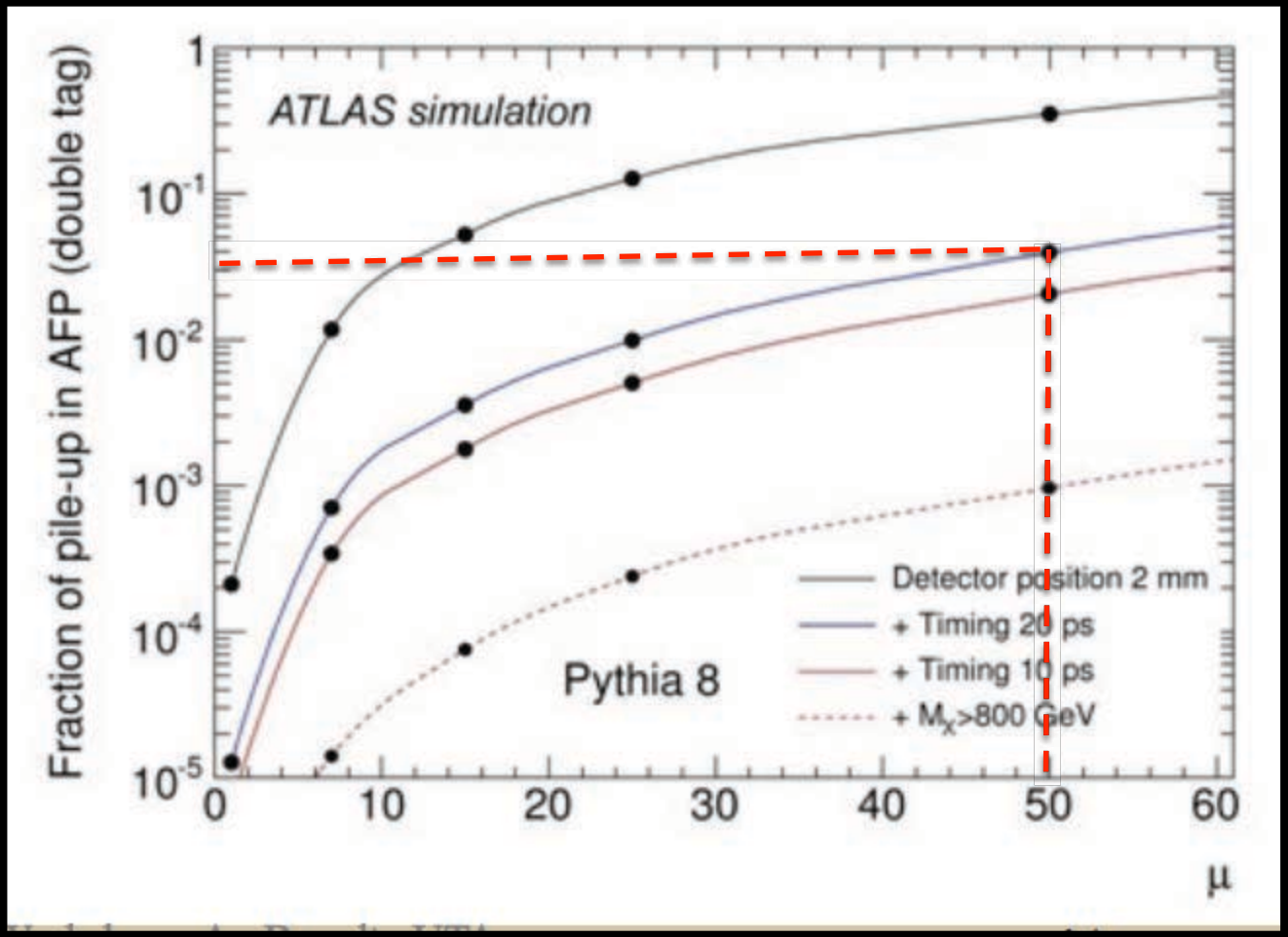
- *ToF Detector for pileup background reduction e.g. $\sigma_t$= 10 ps => $\sigma_z$= 2.1 mm*
  - *High resolution: $\sigma_t \leq$ 15 ps*
  - *High rate: ≤ 5 MHz*
  - *Radiation hard (100-300 $fb^{-1}$)*
  - *Long life, high rate MCP-PMT readout*
  - *Segmentation in x*
- *L1 Trigger capability*
- *Low mass: 1.8%λint/bar*
- *ToF Cerenkov Radiator Design: "Lqbar"*
  - *Each bar σt ≤ 30 ps - Tests so far: 25-30 ps*
  - *(4X) 4 independent bars: ≤ 15 ps*
  - *Eff. > 90%, high granularity for multiple p's*



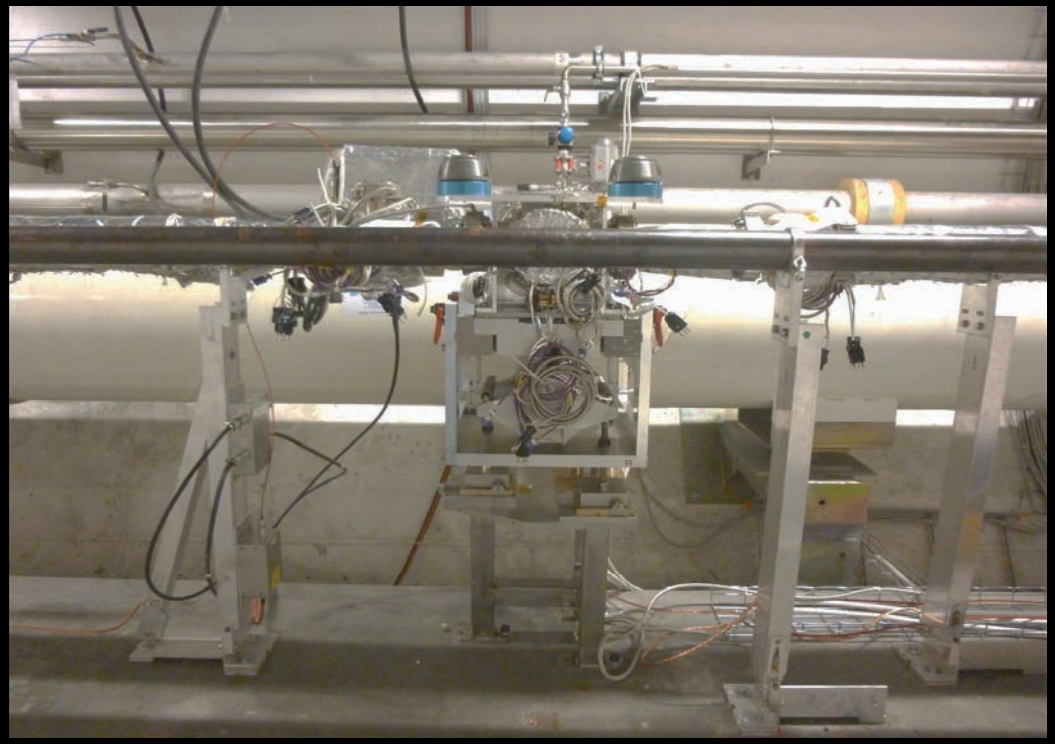



*Opt Express. 2016 Nov 28;24(24) 27951*

# Estimate of Pileup Background Reduction

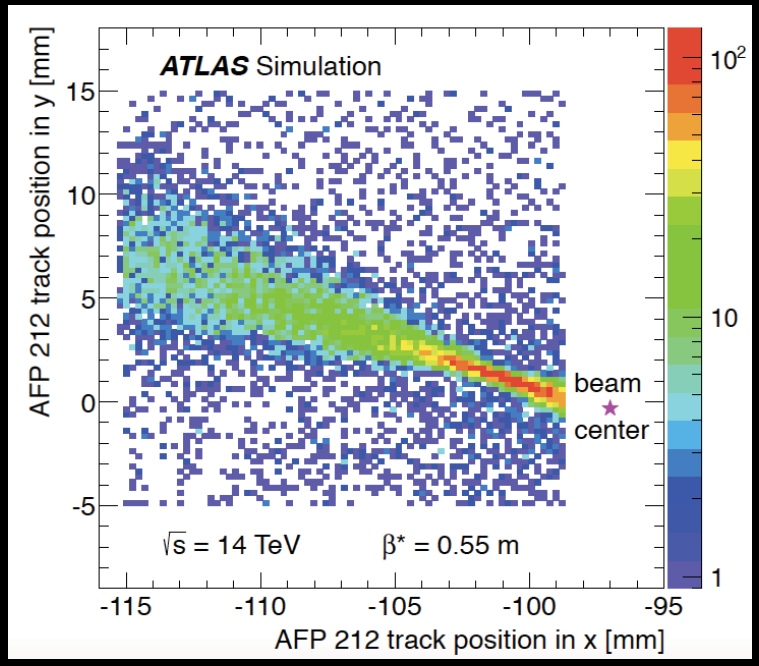


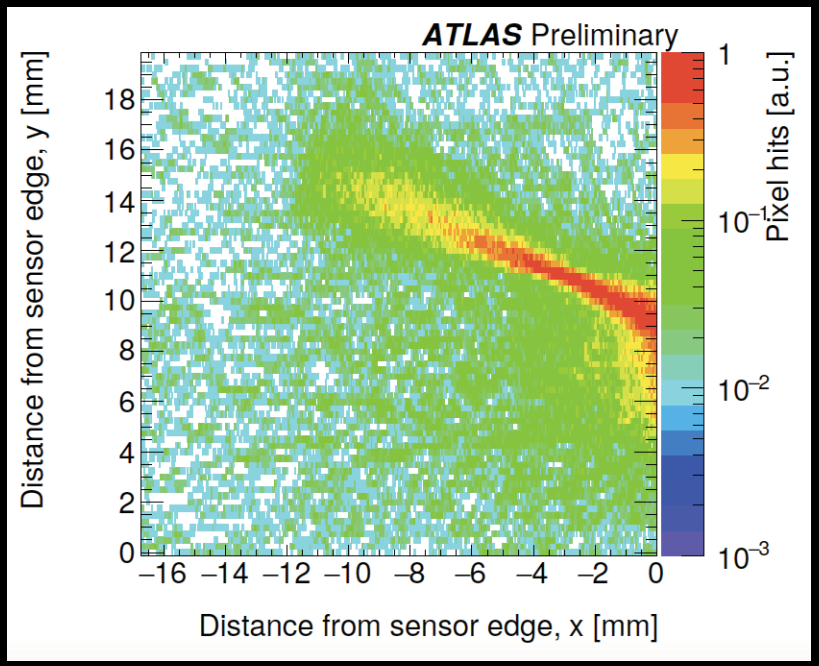
# AFP (0+2) Installation in 2016



- *Two stations installed on one side ATLAS tracking detectors installed in the stations but no ToF*
- *Passed LHC qualication DAQ system integrated with ATLAS trigger system integrated with ATLAS*

# Data Taking in 2016



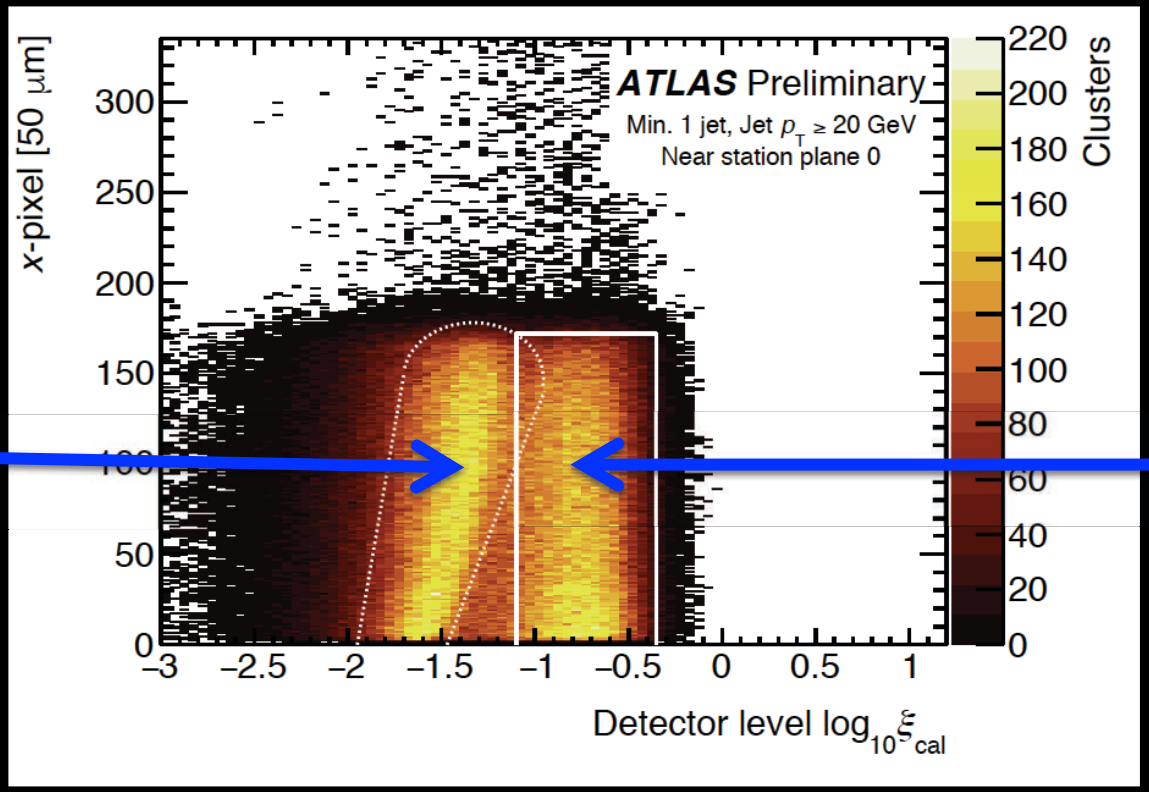




- *Commissioning runs with various detector positions:*
  - *~10 h acquisition (L~0.5 pb $^{-1}$) at low pile-up (μ< 0.3) – Physics run*
  - *~15 h acquisition (L~2 pb $^{-1}$) at high luminosity (max μ~35 & 3->600 bunches) – study background and beam conditions*
- *Data analysis is ongoing……*

# Hot of the Press

## We are Observing Diffractive Physics

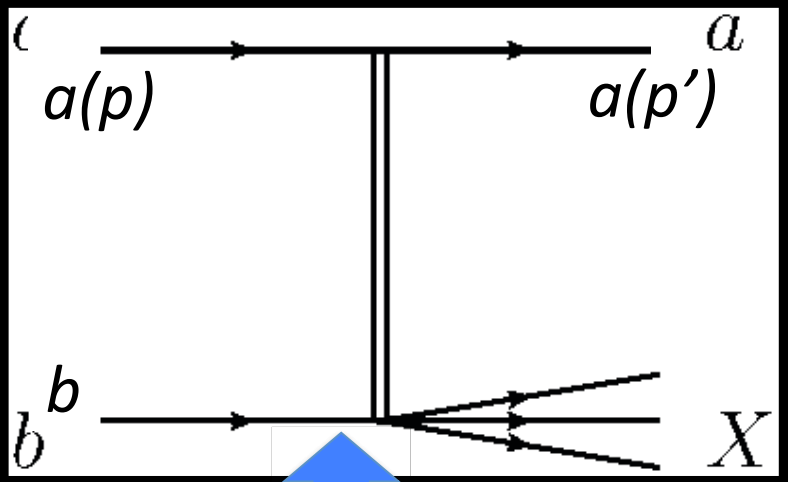
Diffractive events

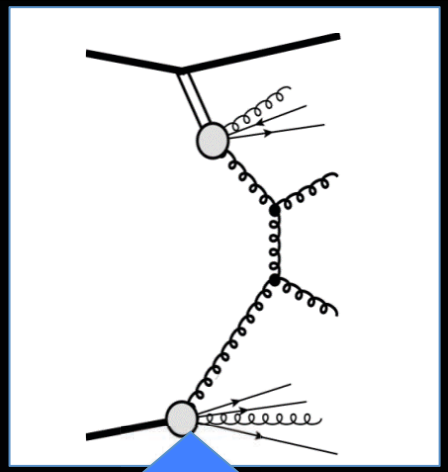


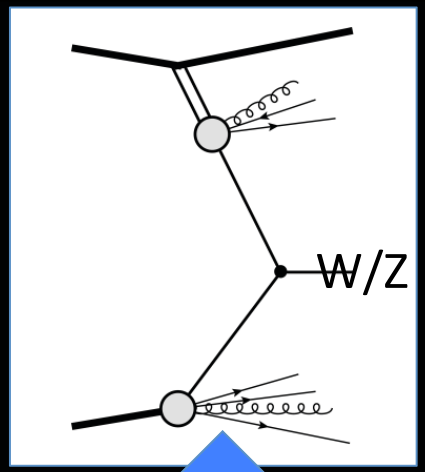

Diffractive events

- *$\xi_{cal}$ is the fraction of the proton mom. participating in the hard interaction estimated using the calorimetry*
- *X is the deflection of the AFP proton into the AFP detector*

# What can be Studied with (0+2)





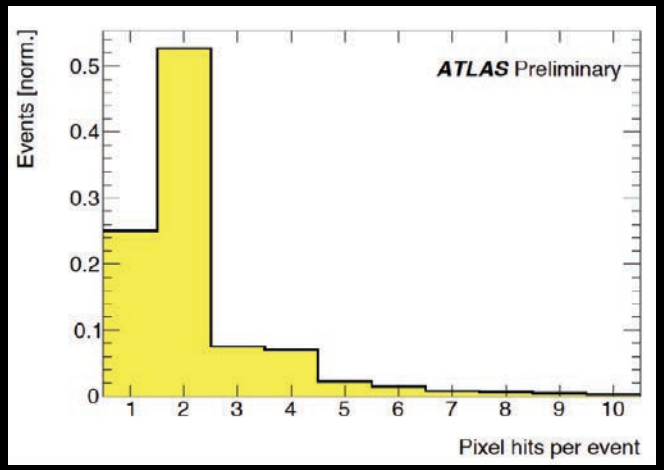

- *PRESENTLY STUDIED BY ATLAS*
- *Inclusive single diffraction*
- *Diffractive di-jet production*

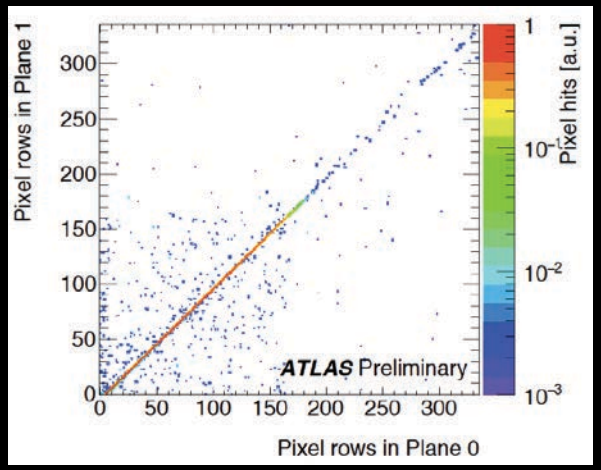
*Single diffraction of W/Z to be studied by AFP*

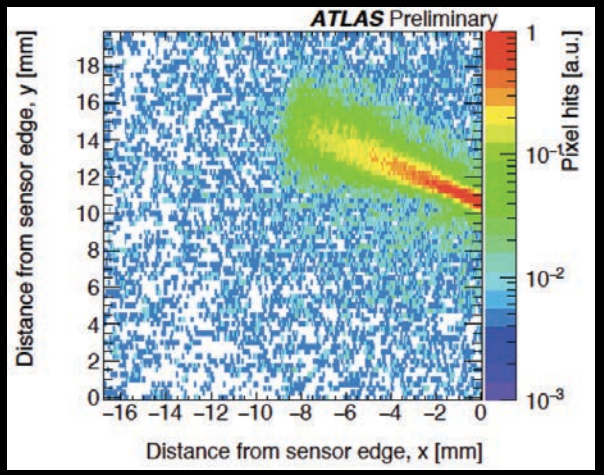
- *Relatively high x-section single proton detectable in AFP (need 10-100 $pb^{-1}$ of integrated luminoisty*
  - *We need to run with $\mu$ =~1 for this physics*
  - *AFP provides access to so far non-measurable quantities like:*

$$\xi = (E - E')/E \quad \text{and} \quad t = (p - p')^2$$

# 1st Experience with High μ<26 Data



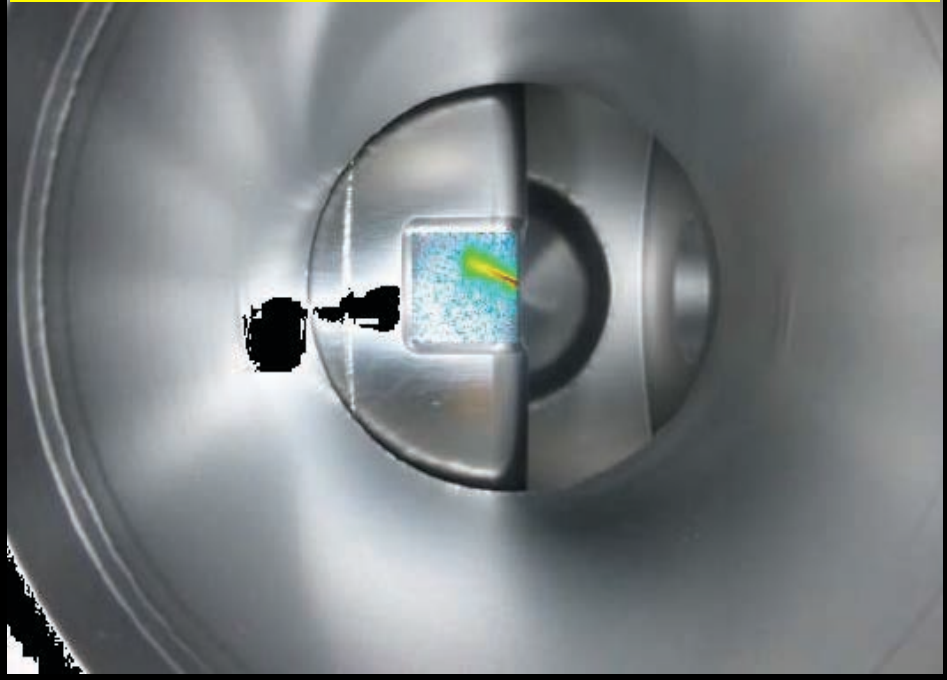




- *Data-taking at high pile-up (μ <26), 300 bunches and AFP distance 20σ (~2mm) from the beam: background, AFP performance, trigger rate*
- *~2 hits/track observed as expected due to 14° tilt of sensors*
- *Trigger rates compatible with simulation in wide pile-up range*

# 2016-17 AFP (2+2)

Far station with Time-of-Flight & tracker

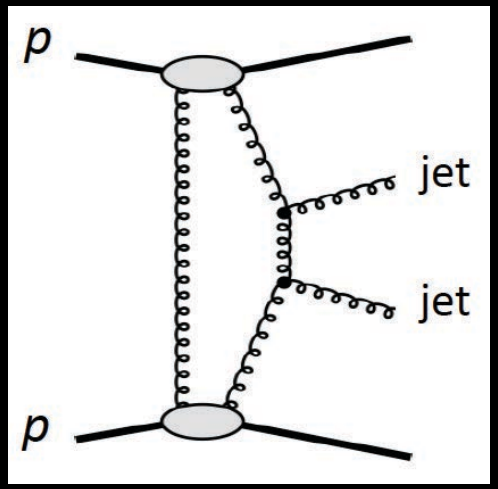
Roman-pot seen from inside the Beam-pipe



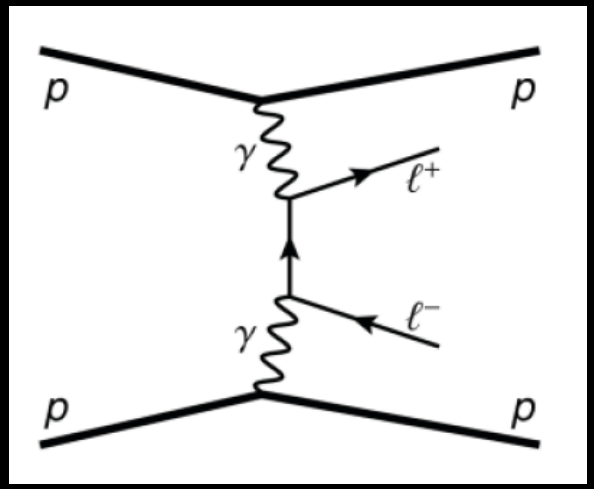
- *Both arms now installed*
  - *All stations with 4 layers of silicon sensors*
  - *Far stations also include ToF counters*
  - *All detectors operational*
  - *Beam-based alignment done*
  - *Ready to take data (both in special and normal runs) !*

# AFP (2+2) Physics

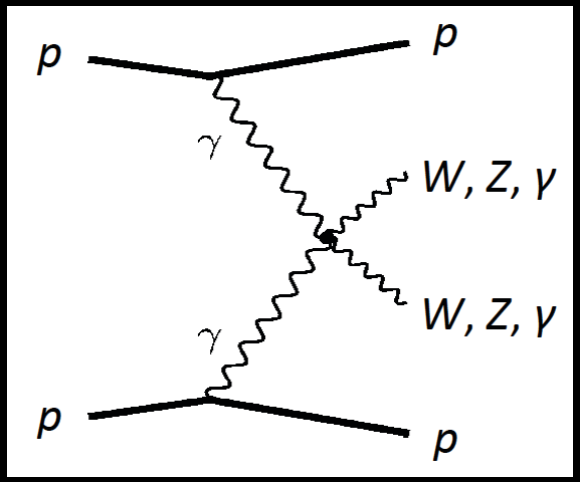
- *Low pile-up runs for studies of high cross-section processes*
  - *Standard runs for small cross-section processes studies*
  - *Double proton tag allows direct observation of central diffraction - access to full event kinematics*
- *Key new physics channel - anomalous quartic couplings (x100 reduction in "standard" LHC analysis method) PRD*




*Central diffractive jets & γ+jets production*

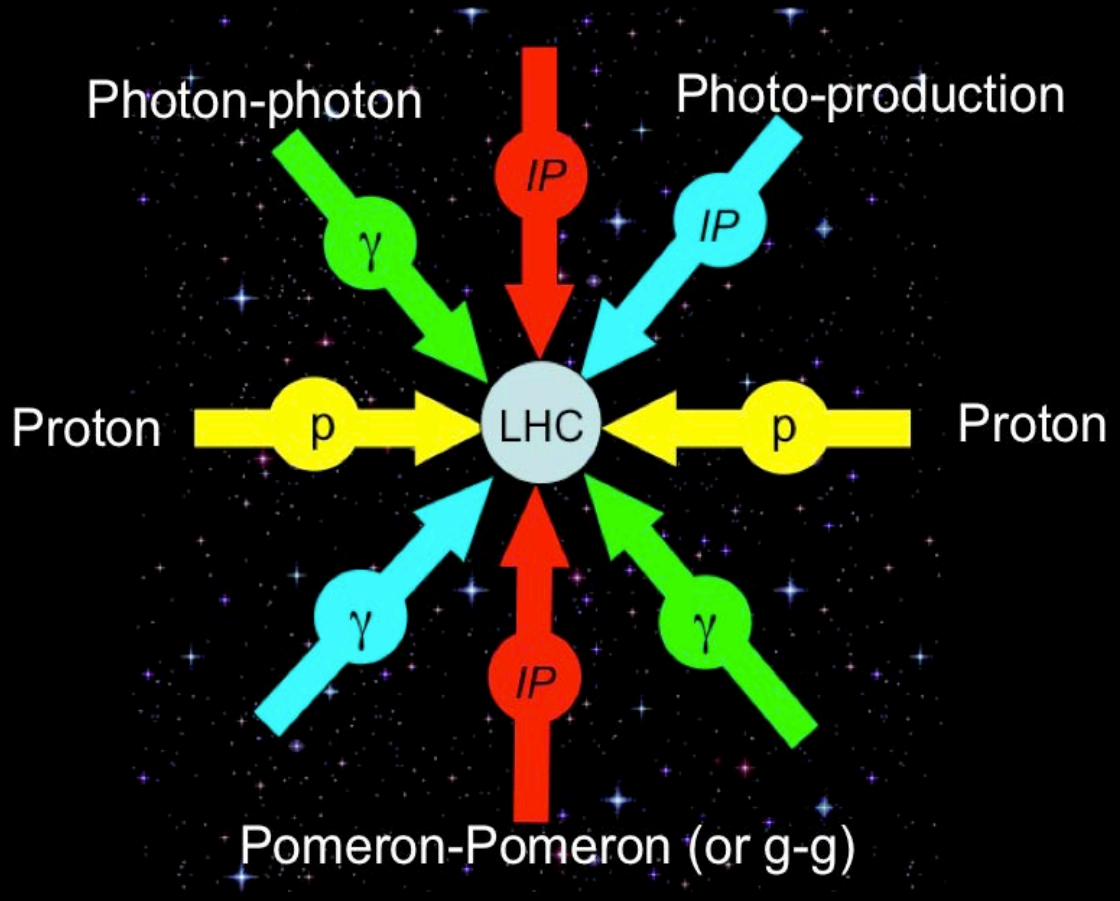



*Two photon production and photoproduction*




*Quartic couplings – access to new physics*

# Final Words

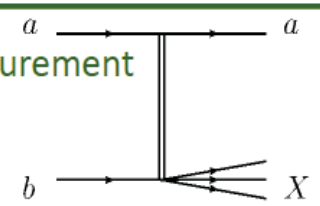



- *When AFP starts up the LHC for ATLAS will not only be a p-p collider but also a IP-IP, a γ-IP and a γ–γ collider!*

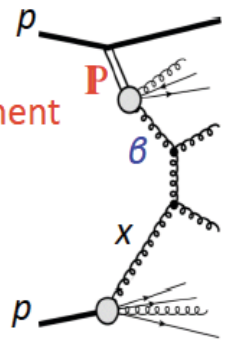
# EXTRA SLIDES

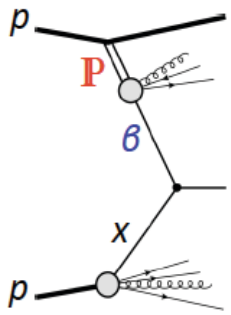
# What can be Studied with (0+2)

So far ATLAS measurement with rap gap and no p-tag




So far ATLAS measurement with rap gap and no p-tag




| Analysis | Motivation | $\int Ldt$ [pb$^{-1}$] | Optimal μ |
|---|---|---|---|
| Soft Single Diffraction with AFP0+2 | | | |
| $d\sigma/dt$, $d\sigma/d\xi$, $t$-Slope vs. $\xi$, $dN^{\pm}/dp_T$ vs. $t$ and $\xi$ | Saturation, MC tuning, Cosmic Ray physics | 1 | $\mu \sim 0.01$ |
| Single Diffractive jet Production [21] | | | |
| σ, rapidity gap, Jet structure and $p_T$, event shape (MPI [21]); vs. $t$, $\xi$, and $\beta$ | gap survival probability, Pomeron structure | 10 – 100 | $\mu \sim 1$ |
| Single Diffractive jet-gap-jet Production [22, 23, 24] | | | |
| σ, central gap distribution, Jet $p_T$; vs. $t$, $\xi$, and $\beta$ | observation of a new process, test of BFKL dynamics | 1 – 100 | $\mu \sim 1$ |
| Single Diffractive Production of $\gamma$ + jet [25] | | | |
| σ, rapidity gap, Jet structure and $p_T$, Photon $p_T$, event shape (MPI); vs. $t$, $\xi$, and $\beta$ | observation of a new process, mechanism of hard diffraction, gap survival probability, Pomeron structure | 10 – 100 | $\mu \sim 1$ |
| Single Diffractive $Z$ Production | | | |
| σ, rapidity gap, charge-asymmetry; vs. $t$, $\xi$, and $\beta$ | gap survival probability, Pomeron structure | 10 – 100 | $\mu \sim 1$ |
| Single Diffractive $W$ Production | | | |
| σ, rapidity gap; vs. $t$, $\xi$, and $\beta$ | gap survival probability, Pomeron structure and flavor composition | 10 – 100 | $\mu \sim 1$ |