AFP measurements and prospects for exclusive diffraction, BSM physics and Pomeron structure

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on behalf of the ATLAS Collaboration

7th International Conference on High Energy Physics in the LHC Era
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Outline

Diffraction at LHC

ATLAS Forward Proton (AFP) detector

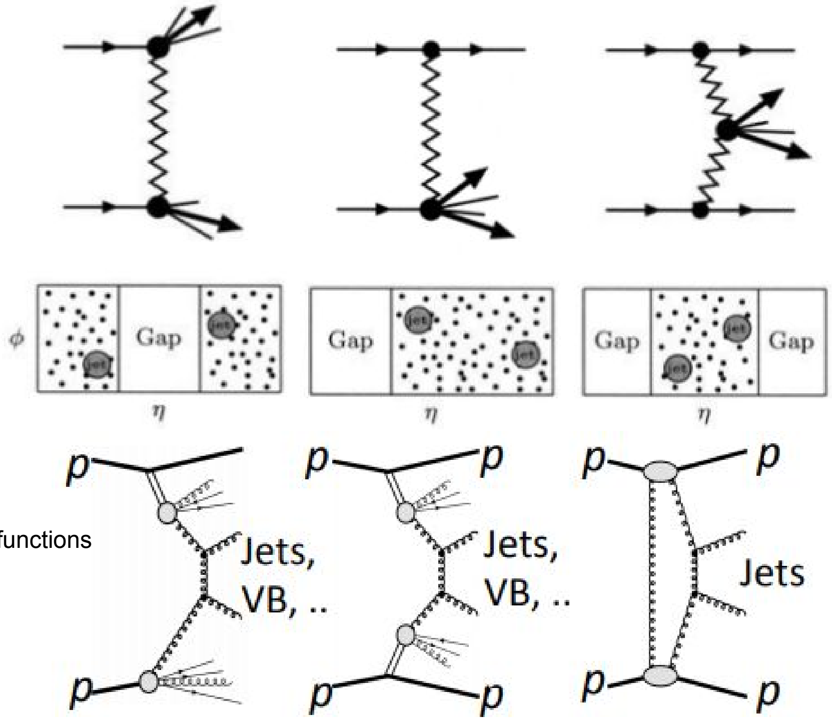
AFP measurements

- 2016 - single arm
- 2017 - two arms

Outlook

Summary

Diffraction at LHC



Exchange of vacuum quantum numbers

Soft diffraction - phenomenological models

Hard diffraction - pomeron structure, DPDF

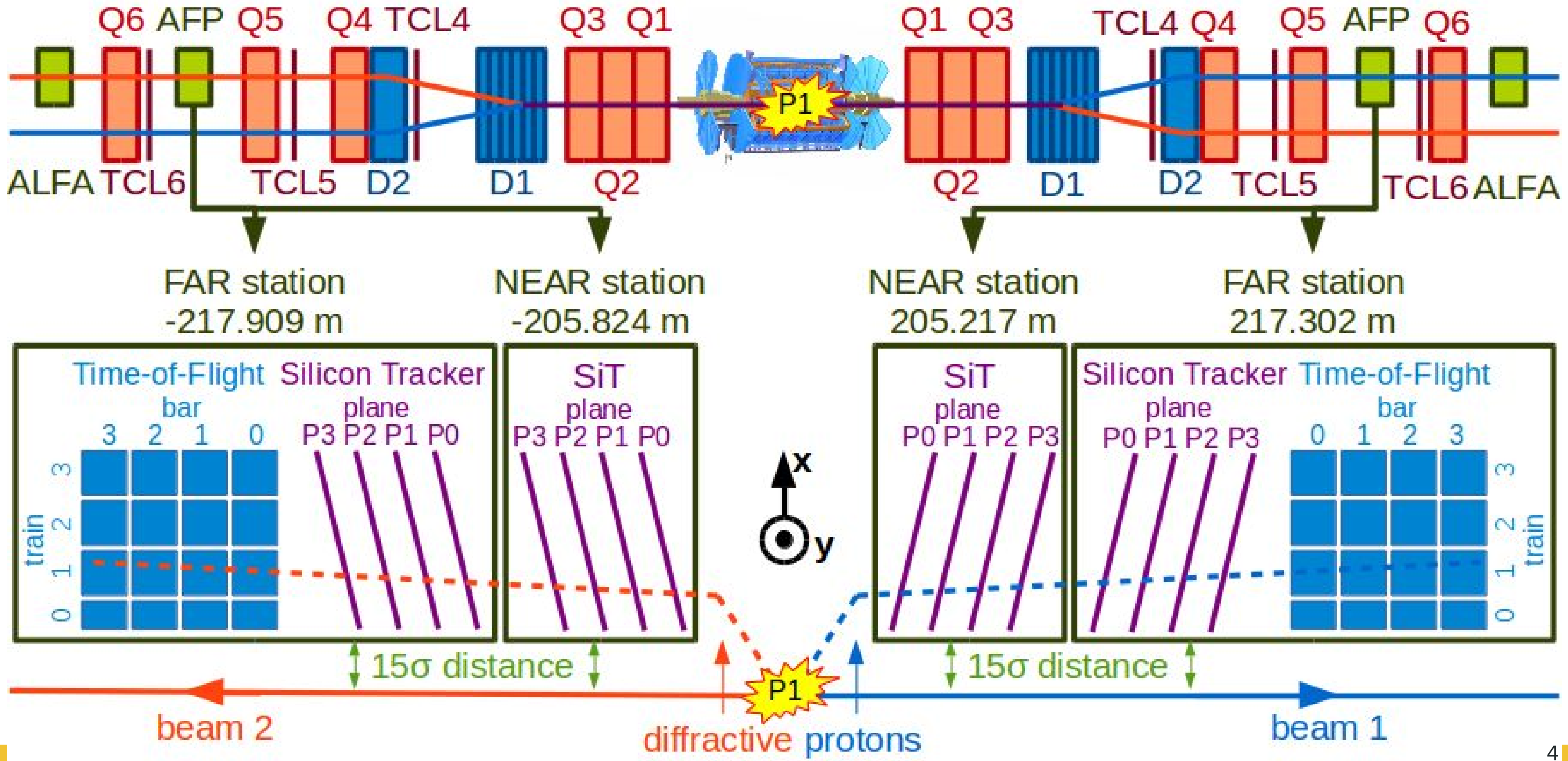
diffractive parton distribution functions

LHC running

- Small β^*, large μ - rare processes, diffraction only with pile-up rejection
- Smal β^*, small μ - inelastic pile-up modeling, underlying event, diffraction
- talk of T. Sýkora
- Large β^*, small μ - total cross section, B, ρ, soft diffraction + CEP (ALFA)

central exclusive production

ATLAS Forward Proton



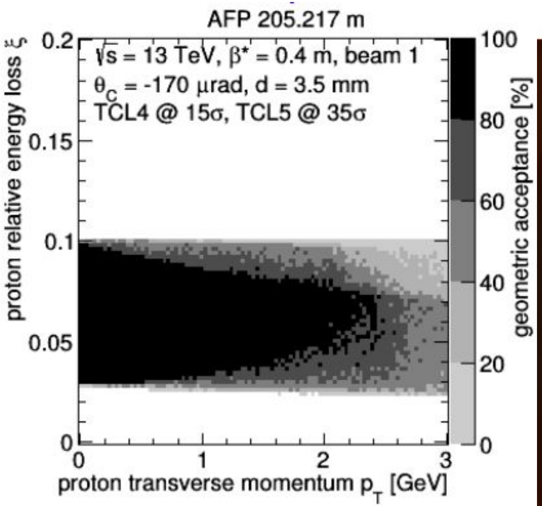
AFP tracker

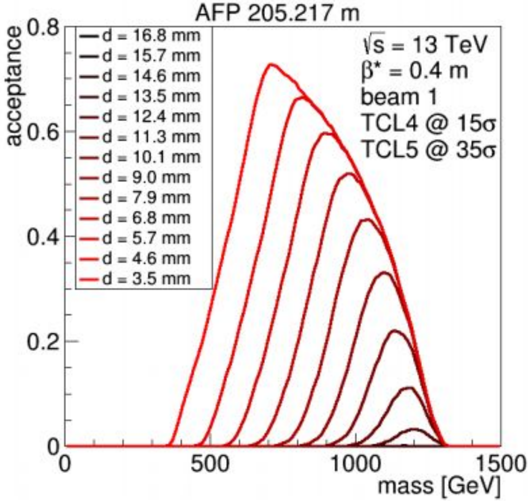
Requirements

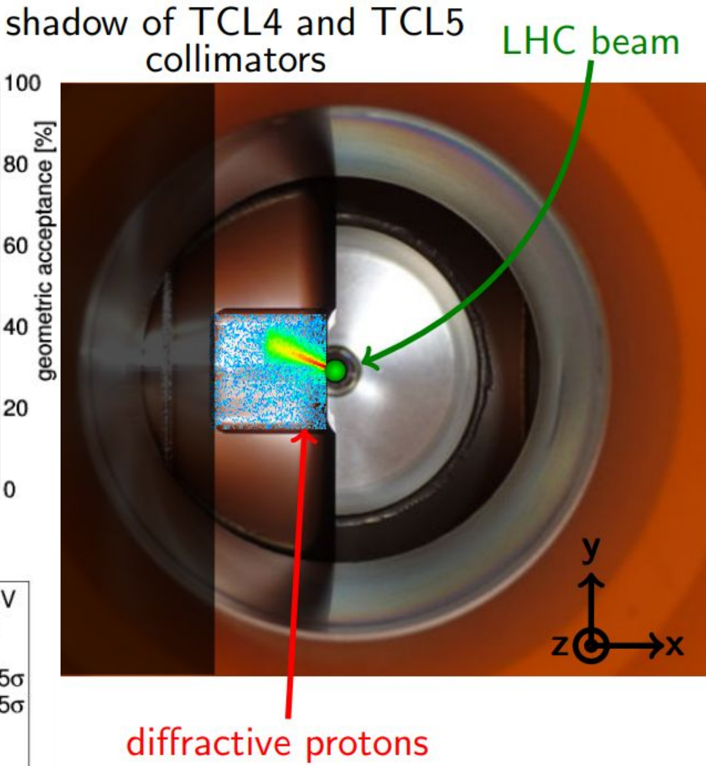
Minimal edge to measure low ξ

Radiation hard (3e15 cm^{-2} n_{eq} per 100 fb^{-1}), non-uniform irradiation

Resolution below 10 μm in x, 30 μm in y







ATLAS-TDR-024

AFP 3D Si tracker

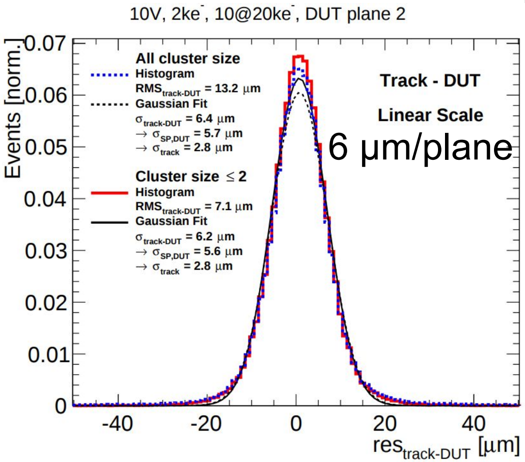
Almost edgeless 3D Si pixel sensors (dead material of 150 μm, ATLAS IBL)

4 planes with 16.8x20 mm^2 area, 50x250 μm^2 pixel size

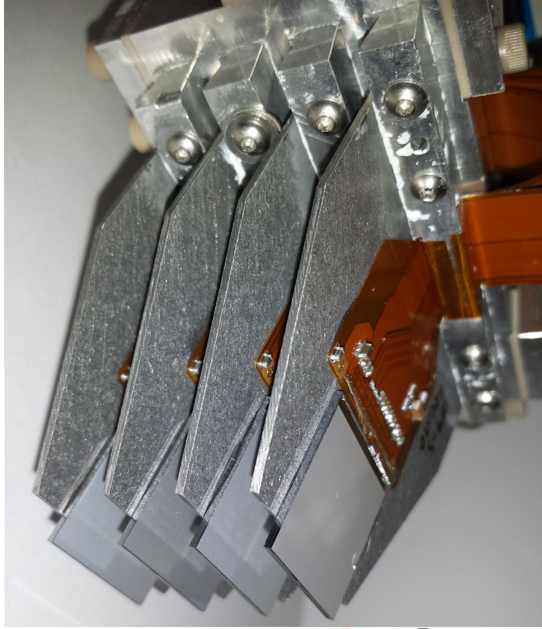
FE-I4 readout

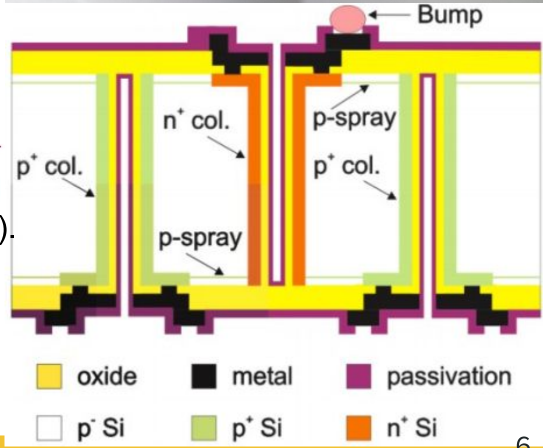
14° tilt in x, staggering in y

Spatial resolution 3 μm in x, 30 μm in y



J. Lange et al., JINST (2016).
arXiv:1608.01485





AFP Time-of-Flight

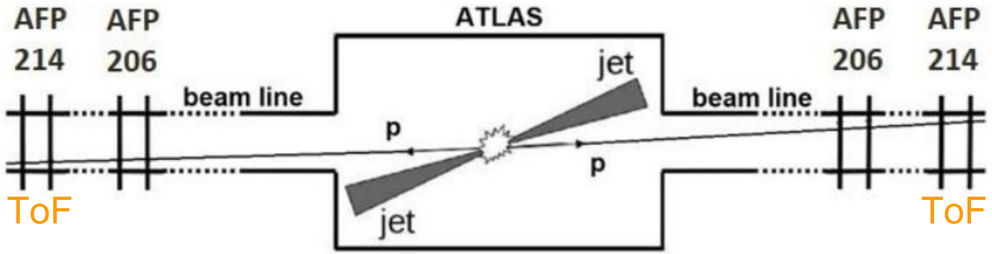
Requirements

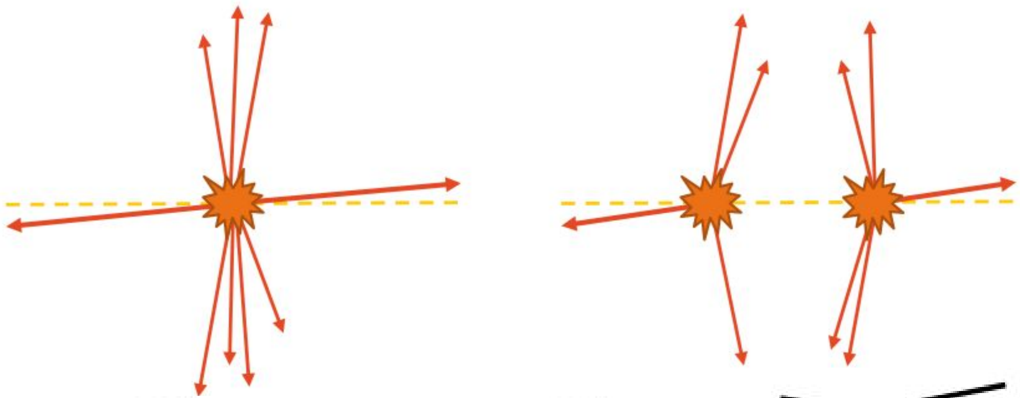
Interaction vertex through time difference

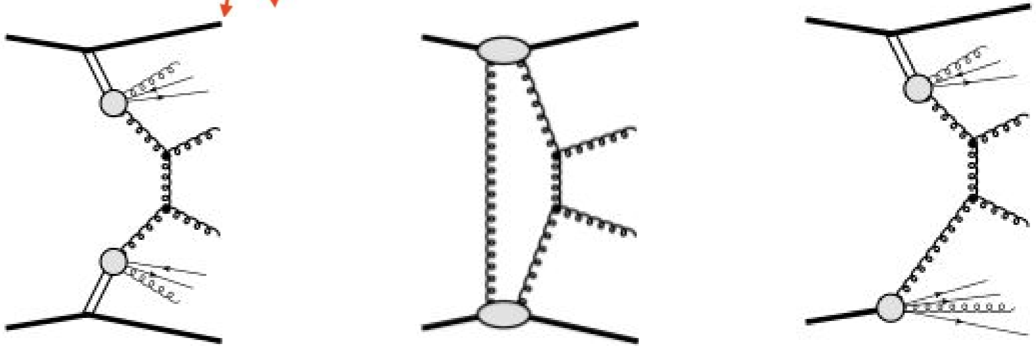
Detector time resolution below 30 ps

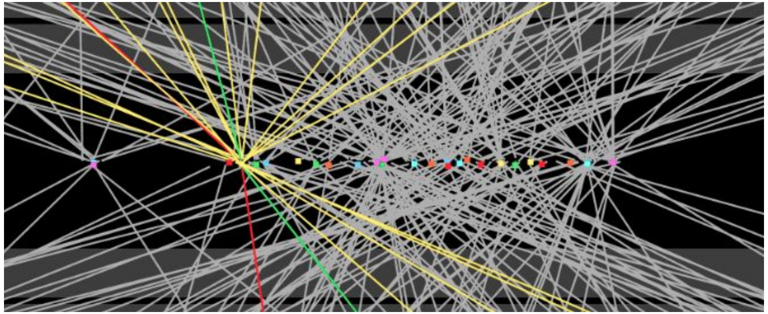
$z_{vtx} = c(t_L - t_R)/2$ - ~6 mm resolution

Background suppression by vertex matching









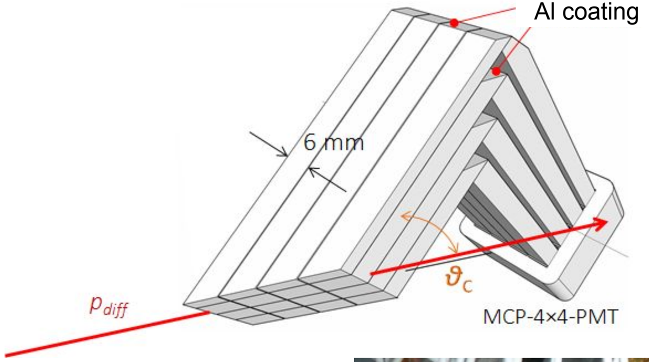
AFP ToF detector

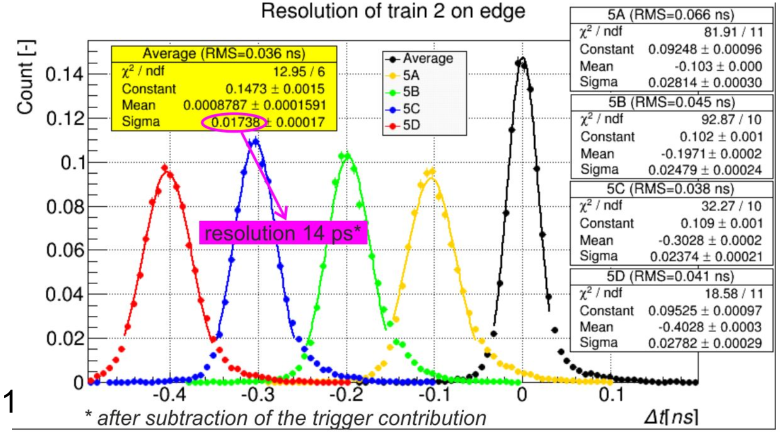
4x4 quartz Cerenkov radiating LQbars

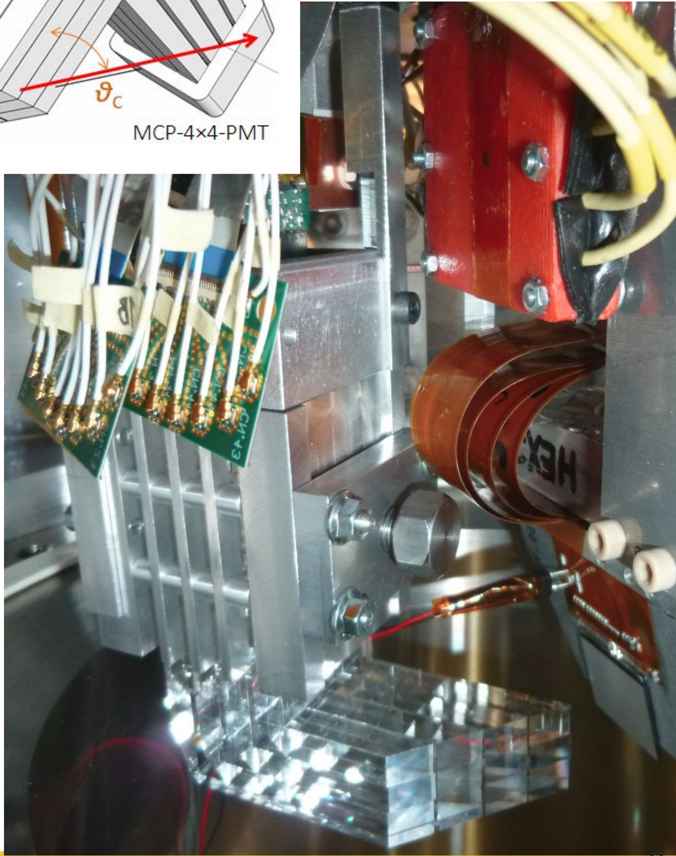
MCP-PMT (Photonis XPM85112)

Fast electronic readout (amplifiers, CFD, HPTDC)

Time resolution 20 ps (beam tests)







L. Nožka et al., Optics Express (2016).
DOI 10.1364/OE.24.027951

2016: AFP 0+2

Near and far station on C-side with SiT, no ToF

Commissioned during LHC intensity ramp up

Insertions at high pile-up up to $20\sigma_{beam}$ (~3 mm, ξ>0.035)

AFP validated as a proton tagger for SD events

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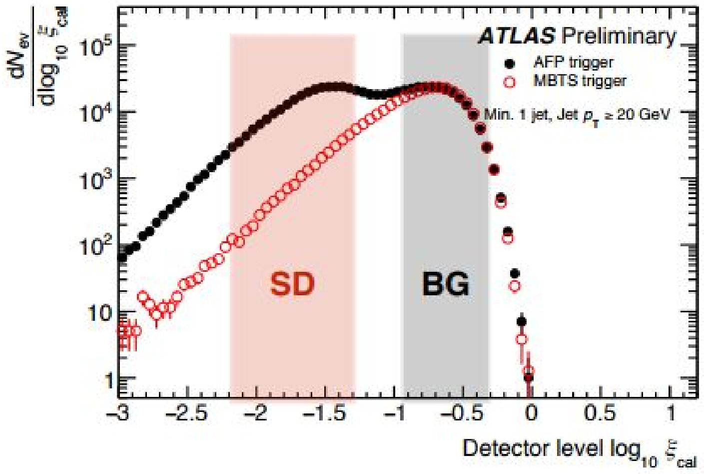
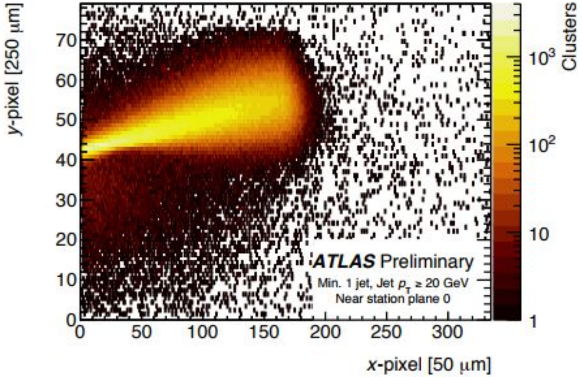
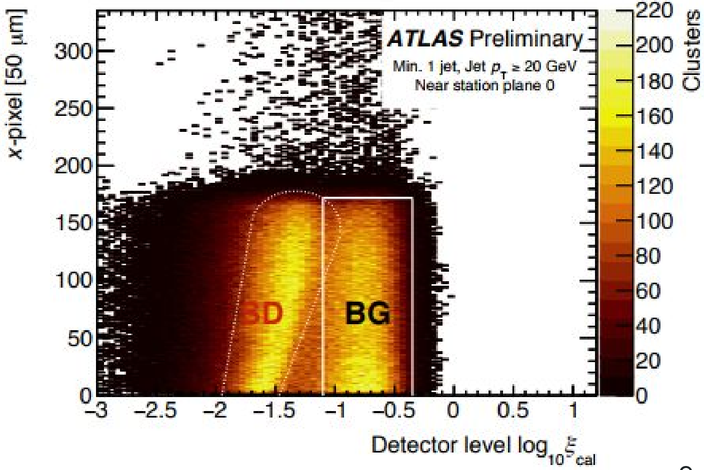






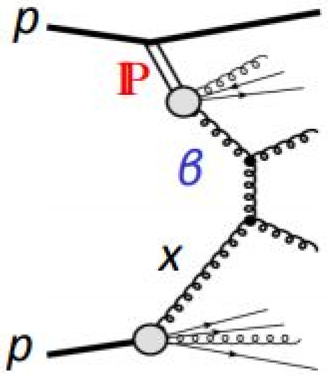
Physics prospects with AFP 0+2

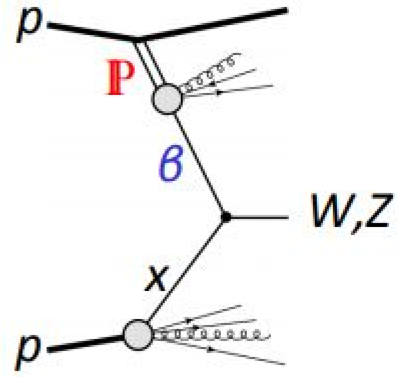
Two runs with small pile-up (μ = 0.03 and 0.3, L ≈ 0.5 pb^{-1})

Improve and extend ATLAS SD studies

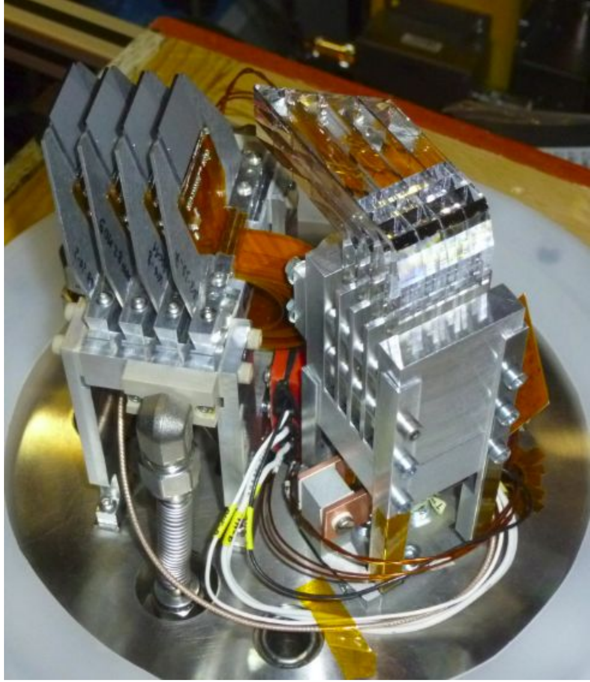
Soft diffraction, SD jet, jet-gap-jet, γ+jet, SD W and Z production

Pomeron flux, MC tuning, gap survival probability, Pomeron composition





2017: AFP 2+2



Near and far station on A-side

All detectors in: SiT+ToF

Qualified for insertions at $12\sigma_{beam}$ + 0.3 mm (~1.5-2.7 mm)

AFP inserted on regular basis

Trigger and readout timed in to correct BCID for both SiT and ToF

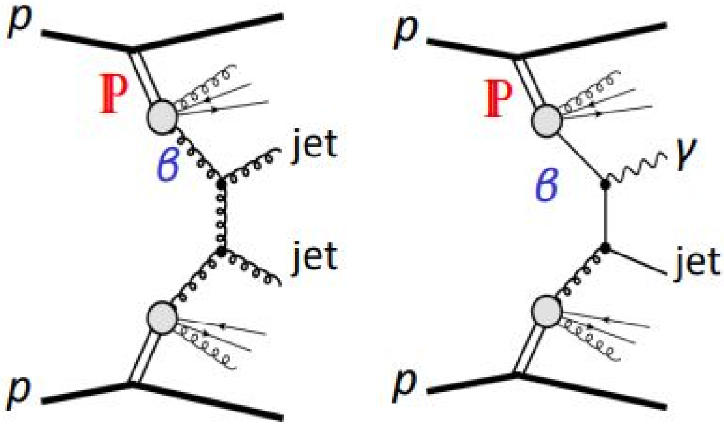
ToF performance under study (time resolution, cross-talk, efficiency)

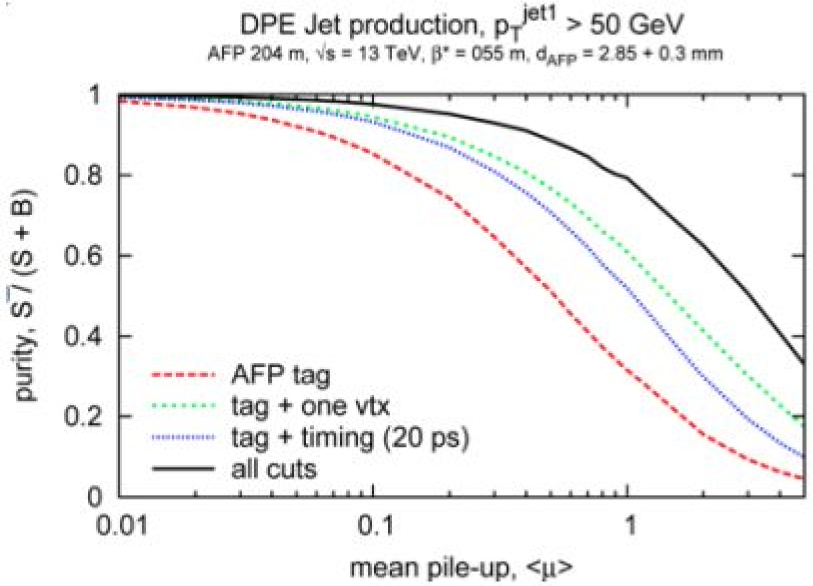
Physics prospects with AFP 2+2 - low μ

Three runs with μ ~ 0.05 (soft diffraction), 1 and 2 (jets, W, Z)

SD + DD, DPE jet and γ+jet

Very clean samples for model testing, DPDF and Pomeron quark/gluon content





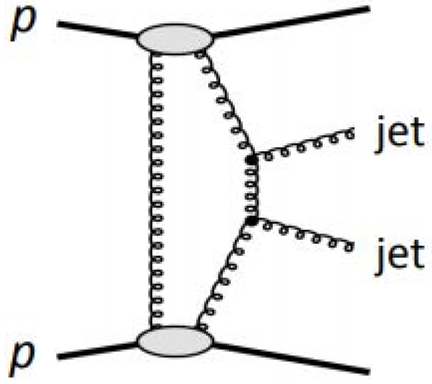
Physics prospects with AFP 2+2 - high μ

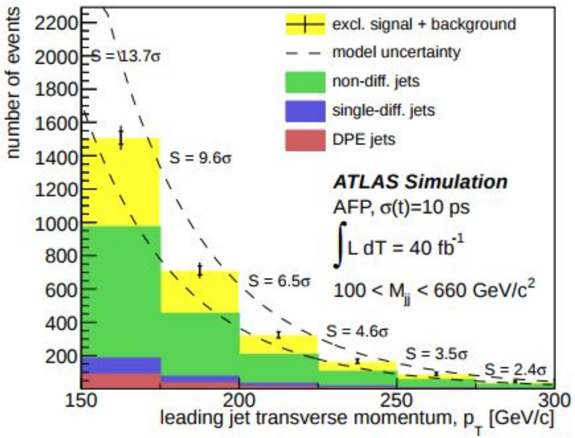
139 AFP physics insertions in 2017 (29.6 fb^{-1})

Prospects with good ToF performance:

Central exclusive production

- Low cross section
- Double tag + ToF to reduce BG
- Pomeron structure

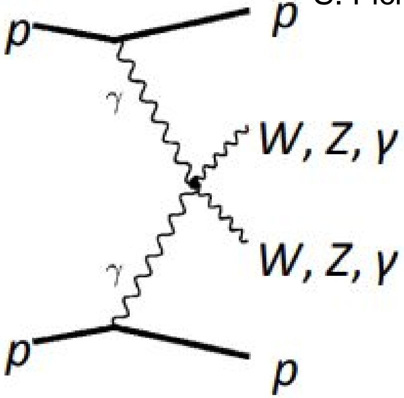


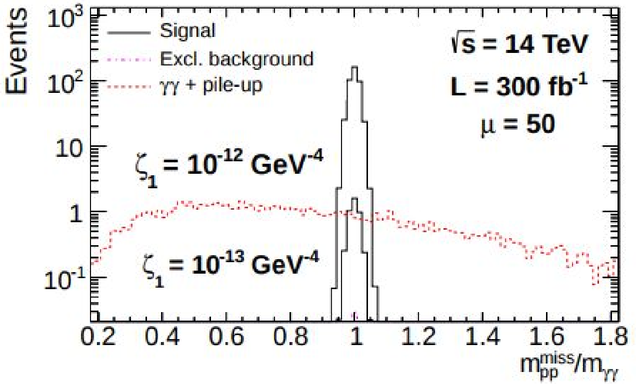


ATL-COM-PHYS-2012-775

Physics prospects for BSM

S. Fichet et al., Phys. Rev. D (2014). arXiv:1312.5153



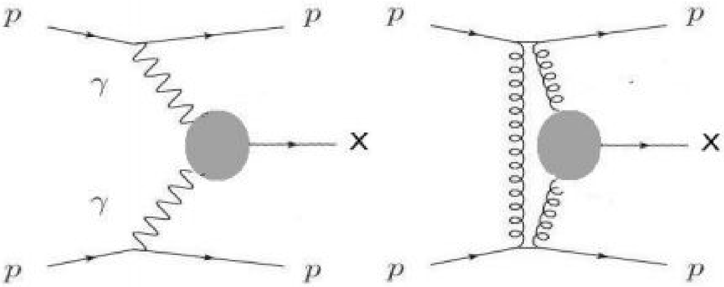


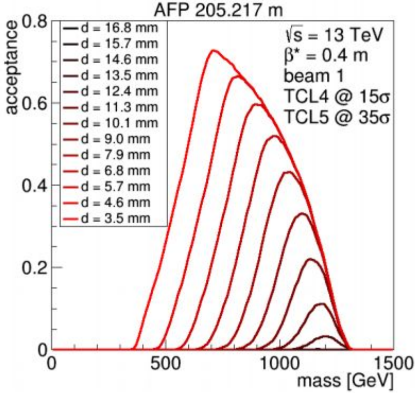
γγ -> γγ/WW/ZZ

- Sensitive to anomalous quartic gauge couplings

New particles

- Missing mass signature for invisible particles
- Additional background suppression





A. De Roeck et al., Eur. Phys. J. (2012). arXiv:1112.2999

Outlook

Future AFP program depending on measured high-μ backgrounds in Run 2

Run 3 (2020-2022) - possibly improved ToF detector, running with higher luminosity

HL-LHC (2025+)

- Ongoing investigation of perspectives and potential upgrades
- High mass resonances
- Stations at 420 m (for lower missing mass, e.g. exclusive Higgs) ?

Summary

AFP installed in the ATLAS forward region to tag forward protons

AFP taking data with ATLAS, qualified for insertion at $12\sigma_{beam} + 0.3$ mm (~1.5-2.7 mm)

Rich physics program - precision measurements, pomeron structure, BSM

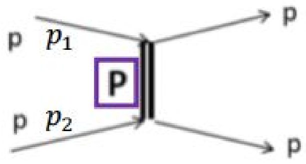
Running during Run 3 and beyond under investigation

Thank you for your attention

Author gratefully acknowledges support from projects MŠMT no. LM 2015058, no. LTT17018; and IGA_PrF_2017_005 of the Palacky University.

Backup

σ_{tot}, B, ρ



$$\boxed{\sigma_{\text{tot}} \approx s^{\alpha(0)-1}}$$

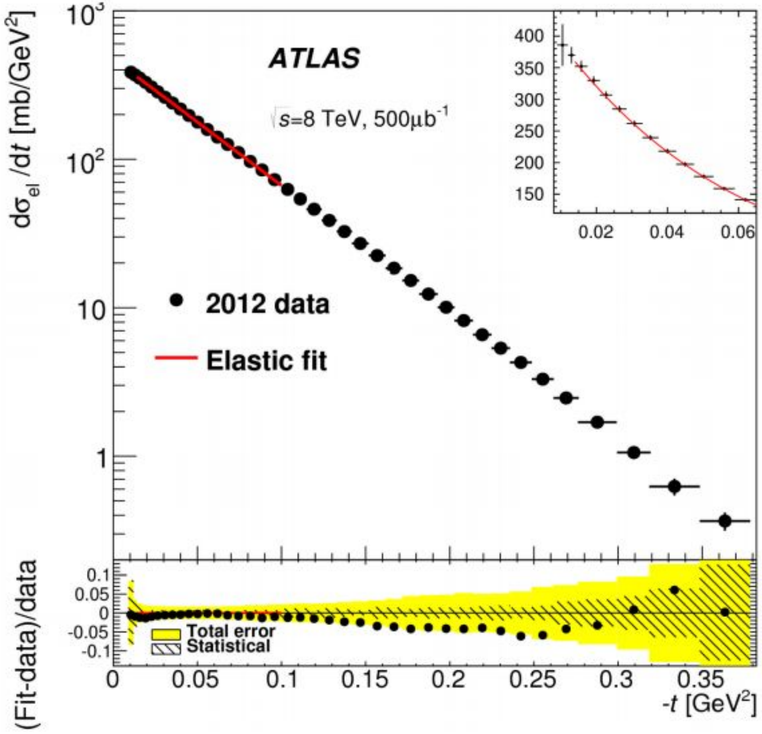
$$s = (p_1 + p_2)^2$$

$$\boxed{\frac{d\sigma_{\text{el}}}{dt} \approx s^{2(\alpha(0)-1)} e^{-B|t|}}$$

$$B = B_0 + 2\alpha' \ln s$$

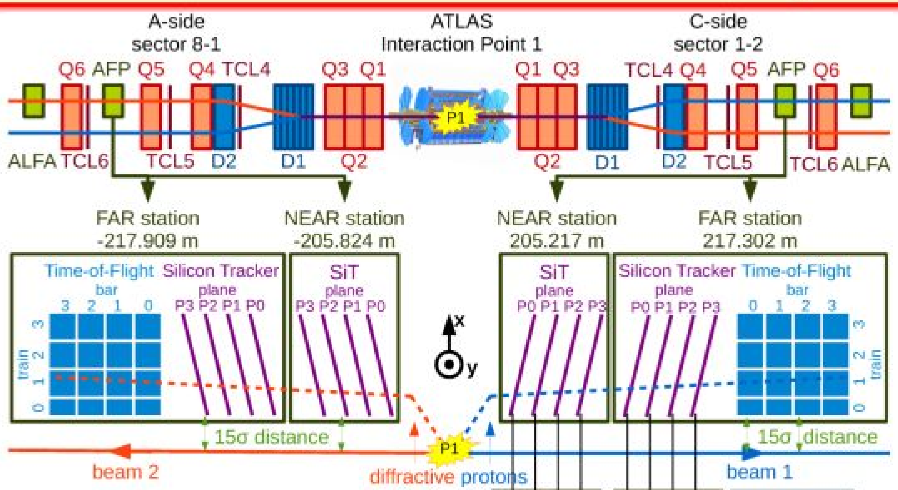
$$\sigma_{\text{tot}}^2 = \frac{16\pi}{1+\rho^2} \frac{1}{\mathcal{L}} \left. \frac{dN}{dt} \right|_{t \to 0}$$

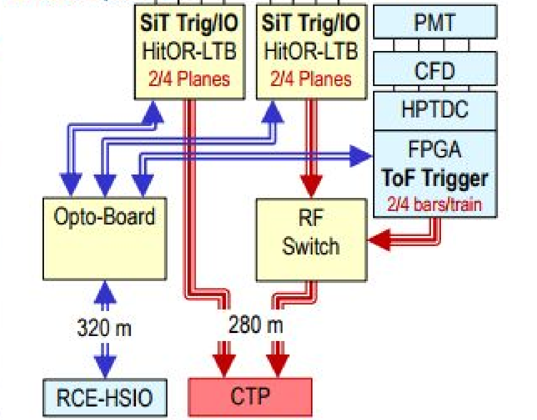
$$\rho = \left. \frac{\operatorname{Re} f_{\text{el}(t)}}{\operatorname{Im} f_{\text{el}(t)}} \right|_{t \to 0}$$

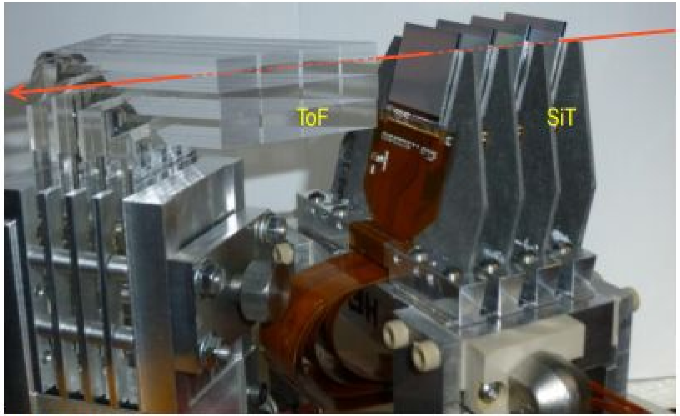


Detector and TDAQ (2017)

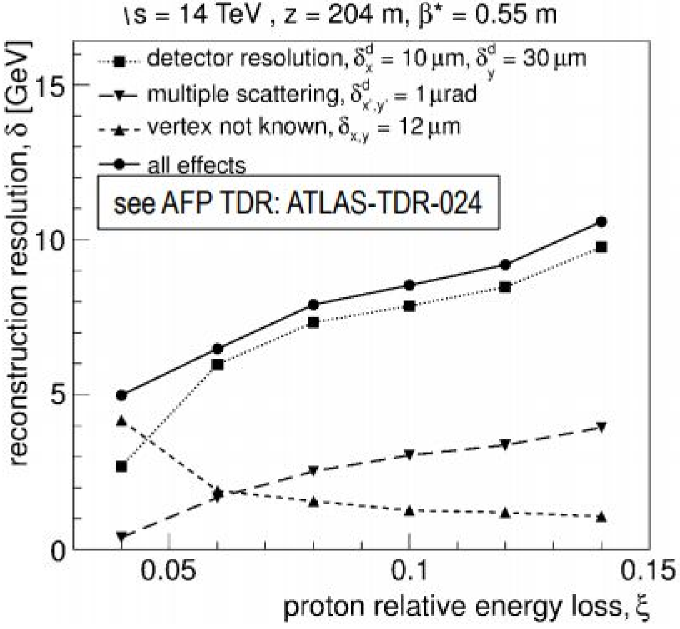
- Layout:







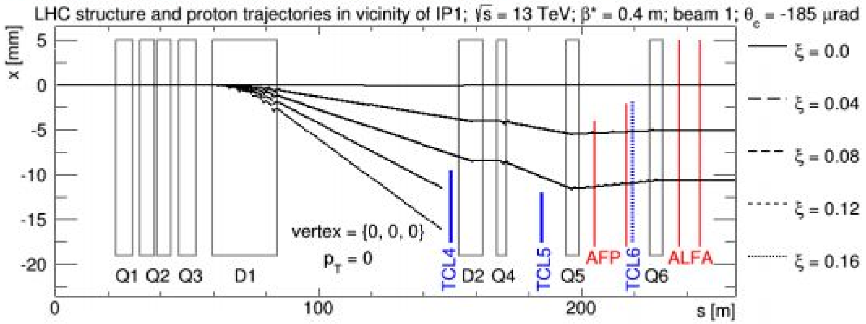
LHC optics: use Mad-X simulations to derive transformation between $(x, y, z, \theta_x, \theta_y, \xi)^*$ at IP and $(x, y, \theta_x, \theta_y)^{\mathrm{Det}}$ at the detector.



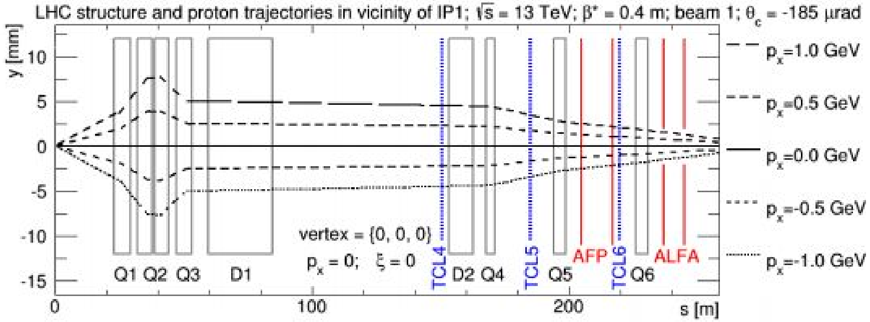
Proton trajectory is determined by the LHC magnetic field.

collision optics, **ALFA** and **AFP**: trajectory due to ξ

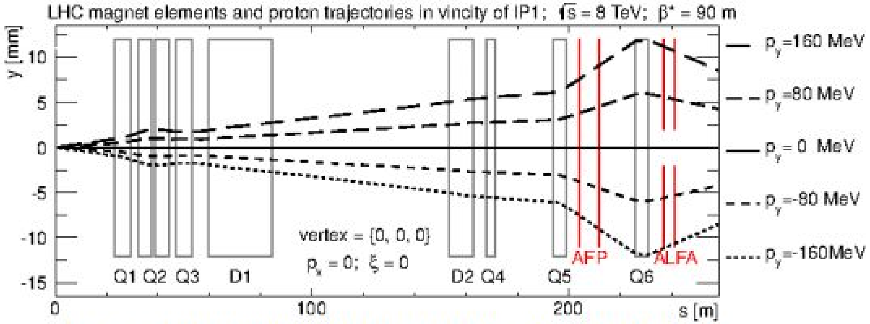
$\xi = 1 - E_{proton}/E_{beam}$



collision optics, **ALFA** and **AFP**: trajectory due to p_y

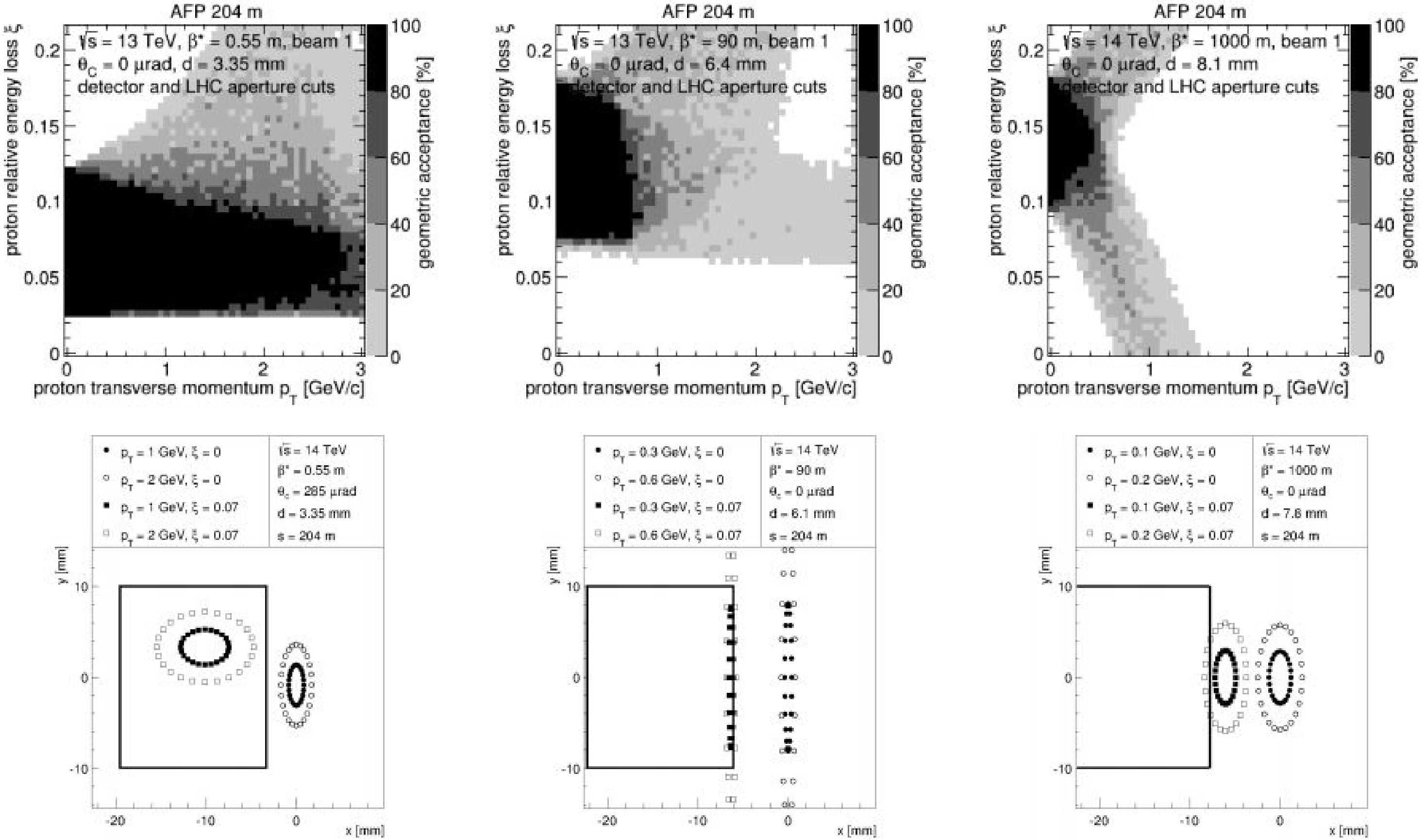


special high-β^* optics, **ALFA**: improve acceptance in $p_T = \sqrt{px^2 + py^2}$



From SPIE 9290 (2014) 929026, arXiv:1408.1836

$\beta^* = 0.55$ m nominal (*collision*) | $\beta^* = 90$ m special (*high-β^**) | $\beta^* = 1000$ m special (*high-β^**)



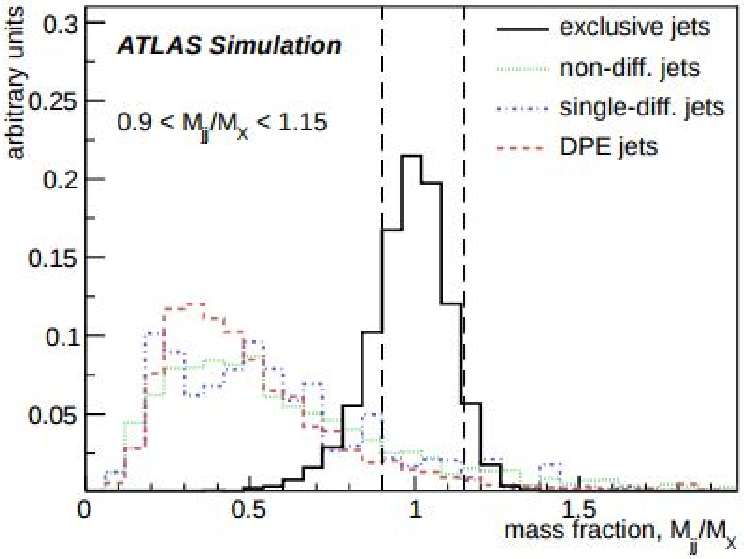
Simulation: distance from the beam was set to 10σ ($\beta^* = 0.55$ m) or 15σ ($\beta^* = 90$ and 1000 m).

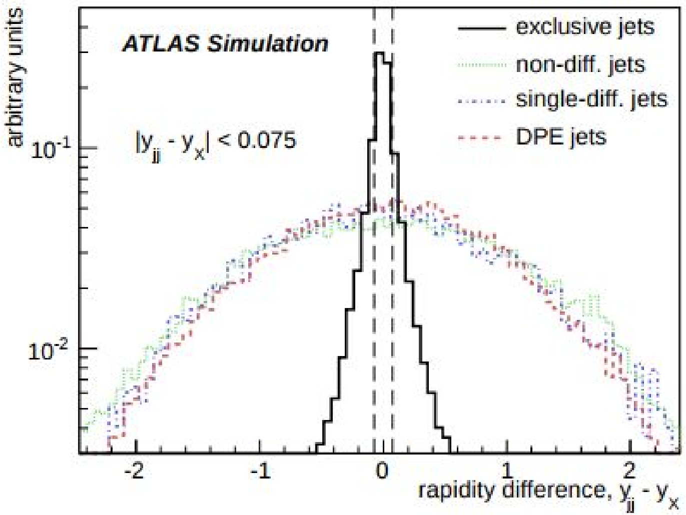
From SPIE 9290 (2014) 929026, arXiv:1408.1836

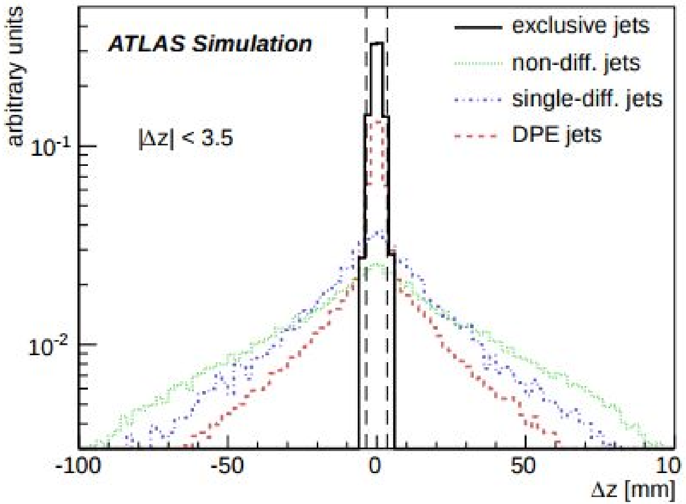
Analysis	Motivation	$\int Ldt$ [pb^{-1}]	Optimal μ
Soft Single Diffraction with AFP0+2			
$d\sigma/dt$, $d\sigma/d\xi$, t-Slope vs. ξ, $dN^{\pm}/dp_T$ vs. t and ξ	Saturation, MC tuning, Cosmic Ray physics	1	$\mu \sim 0.01$
Single Diffractive jet Production [26]			
σ, rapidity gap, Jet structure and p_T, event shape (MPI [26]); vs. t, ξ, and β	gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive jet-gap-jet Production [27, 28, 29]			
σ, central gap distribution, Jet p_T; vs. t, ξ, and β	observation of a new process, test of BFKL dynamics	1 – 100	$\mu \sim 1$
Single Diffractive Production of γ + jet [30]			
σ, rapidity gap, Jet structure and p_T, Photon p_T, event shape (MPI); vs. t, ξ, and β	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, ξ, and β	gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive W Production			
σ, rapidity gap; vs. t, ξ, and β	gap survival probability, Pomeron structure and flavor composition	10 – 100	$\mu \sim 1$

Analysis	Motivation	$\int Ldt$ [pb^{-1}]	Optimal μ
Soft Central Diffraction with AFP2+2			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, t-Slope vs. ξ, Mass M and y of the central diffractive system, ϕ_1 vs. ϕ_2, $dN^{\pm}/dp_T$; vs. $t_{1,2}$, $\xi_{1,2}$, M.	general understanding of DPE processes	1	$\mu \sim 0.1$
Central Diffractive jet Production (DPEjj) [33]; see also Sect. A			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, t-Slope vs. ξ, $d\sigma/dp_T^{jet}$, Mass M and y of the central dijet system, ϕ_1 vs. ϕ_2	gap survival probability for DPE processes, Pomeron structure, general understanding of DPE processes	$10-100$	$\mu \sim 1$
Jet-gap-jet Production [27, 29]			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, $d\sigma/dM_{jj}$, central gap distribution, $d\sigma/dp_T^{jet}$, ϕ_1 vs. ϕ_2	observation of a new process, test of BFKL dynamics	$10-100$	$\mu \sim 1$
γ + jet Production			
σ, rapidity gap(s), Jet structure and p_T, Photon p_T; vs. $t_{1,2}$, $\xi_{1,2}$, and M_{jj}	observation of a new process, mechanism of hard diffraction, gap survival probability, Pomeron structure	$10-100$	$\mu \sim 1$

Exclusive jets







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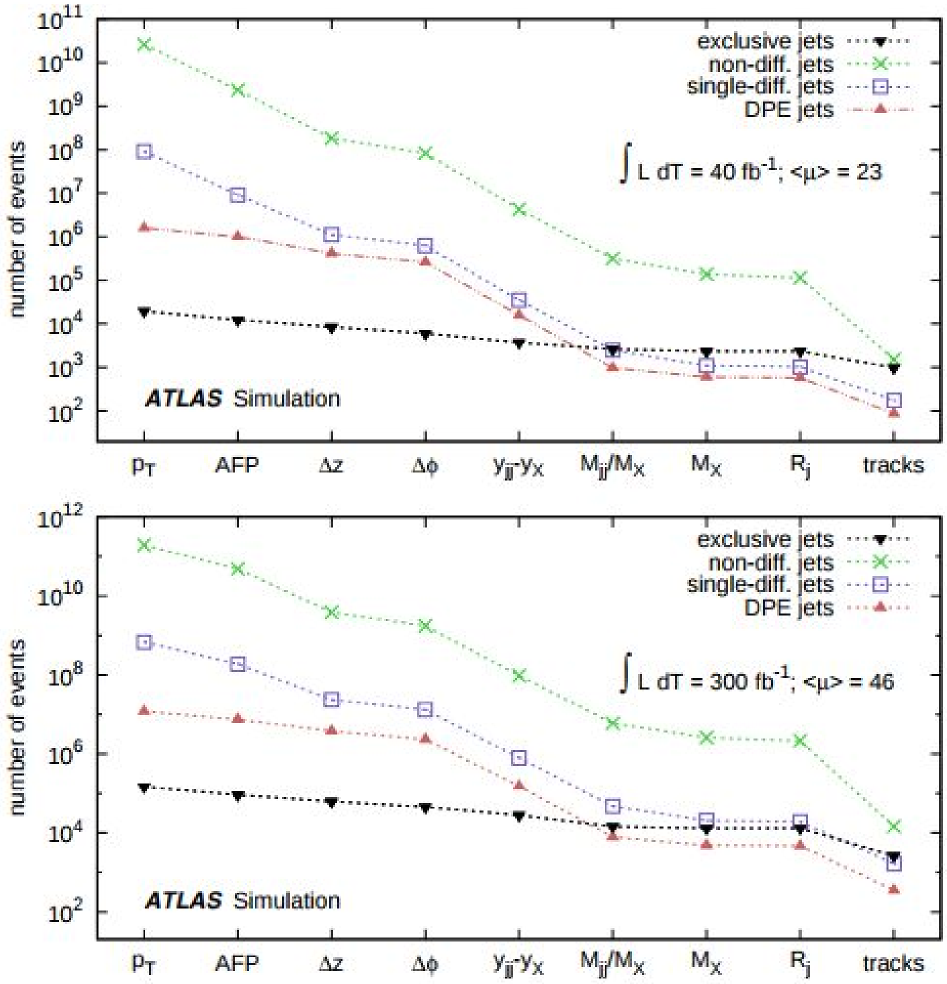
Exclusive jets

Cutflow:



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Anomalous quartic coupling

$\zeta_1 = 10^{-13}$ GeV^{-4}

Cut / Process	Signal	Excl.	DPE	e^+e^-, dijet + pile-up	$\gamma\gamma$ + pile-up
$0.015 < \xi < 0.15$, $p_{T1,2} > 50$ GeV	20.8	3.7	48.2	$2.8 \cdot 10^4$	$1.0 \cdot 10^5$
$p_{T1} > 200$GeV, $p_{T2} > 100$ GeV	17.6	0.2	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	16.6	0.1	0	0.2	1023
$p_{T2}/p_{T1} > 0.95$, $\lvert\Delta\phi\rvert > \pi - 0.01$	16.2	0.1	0	0	80.2
$\sqrt{\xi_1 \xi_2 s} = m_{\gamma\gamma} \pm 3\%$	15.7	0.1	0	0	2.8
$\lvert y_{\gamma\gamma} - y_{pp}\rvert < 0.03$	15.1	0.1	0	0	0