

ATLAS Forward Proton detectors

First results

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Particle and Astroparticle Physics Division seminar
IFJ PAN, 20 October 2020



Introduction

Experimental techniques

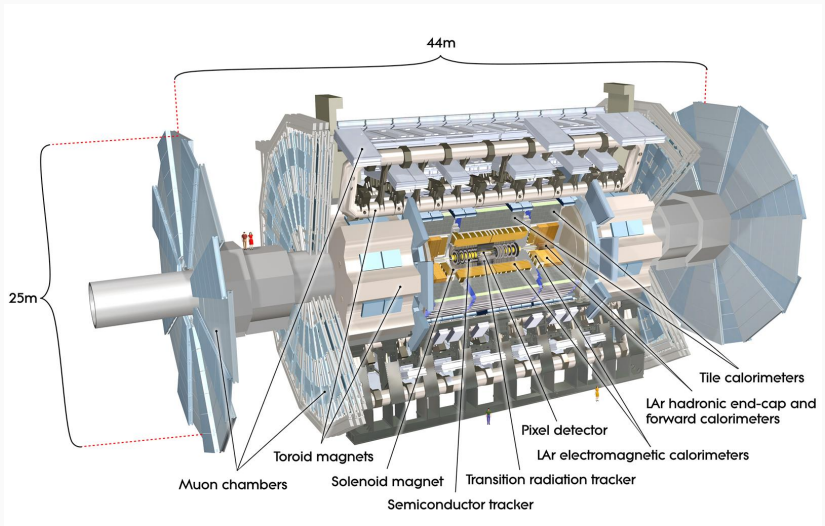
First results

Performance

Time-of-flight detector

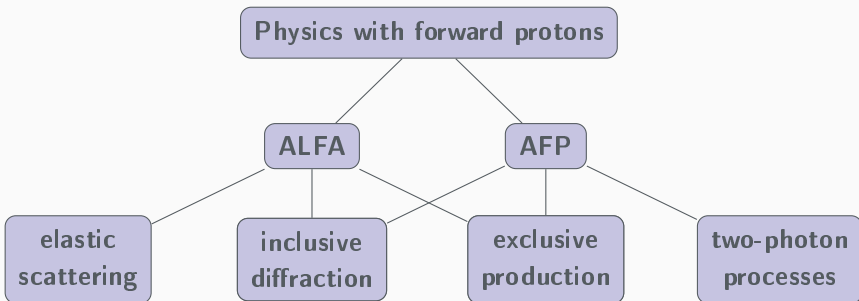
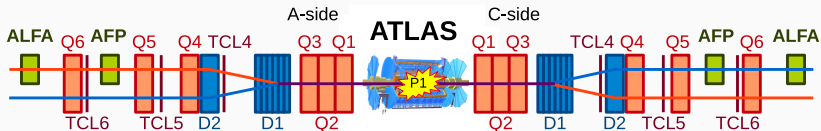
Conclusions

ATLAS Detector



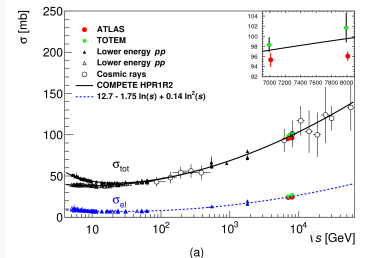
... but also **forward detectors**

Forward detectors and physics

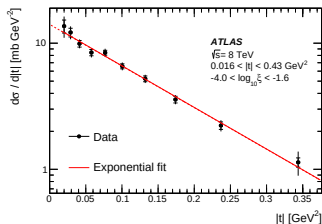


NOT in this talk

- elastic scattering
- total cross section
- ρ parameter
- odderon
- luminosity measurement
- ALFA detectors
- optical theorem
- pomeron structure
- single diffraction
- double pomeron exchange
- high- β^* optics
- special runs
- low pile-up (low μ)

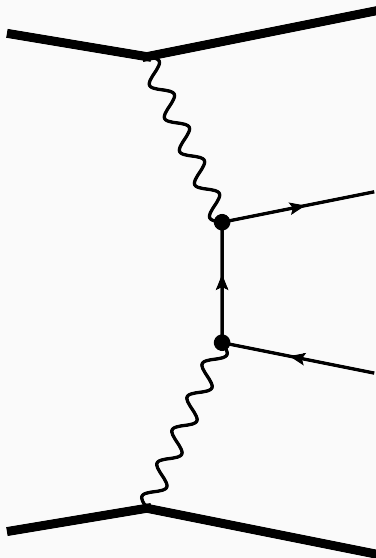


Phys. Lett. B (2016) 158



JHEP 02 (2020) 042

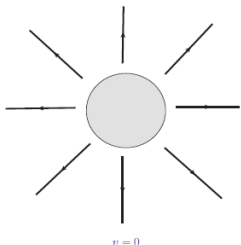
Two-photon processes



Equivalent photons



Consider a charged nucleus at rest. The associated electromagnetic field can be represented by:

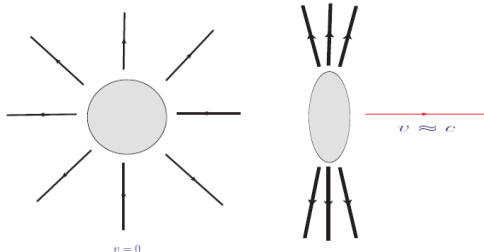


(slides borrowed from Victor Gonçalves)

Equivalent photons



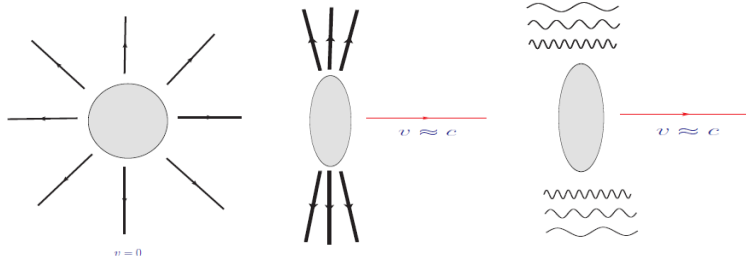
As a charged nucleus moves with nearly the speed of light, the electromagnetic field becomes transverse to its velocity.



(slides borrowed from Victor Gonçalves)

Equivalent photons

- Since the electric and magnetic field associated to the nucleus take on the same absolute value, this transverse electromagnetic field can be simulated by an equivalent swarm of photons ^a.

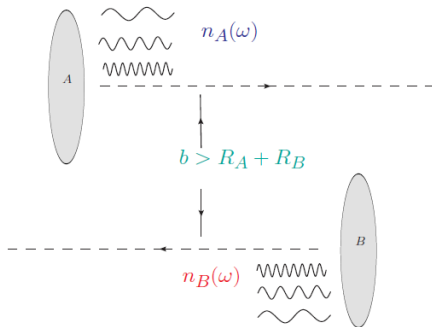


^aE. Fermi (1924), E. J. Williams (1933), C. F. Von Weizacker (1934)

(slides borrowed from Victor Gonçalves)

Equivalent photons

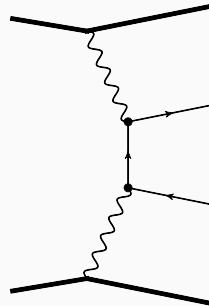
- Thus the collision of two charged nuclei at large impact parameter can be described as the collision of two equivalent swarms of photons.



(slides borrowed from Victor Gonçalves)

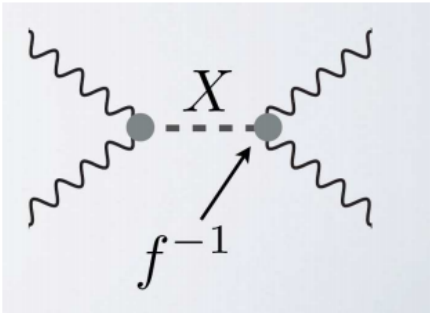
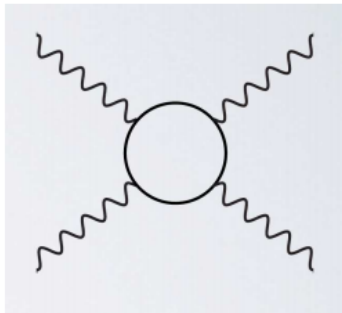
Two-photon processes

- Two-photon processes can be computed within QED
- Exclusive $\gamma\gamma \rightarrow ll$
 - Standard candle for photon-induced physics
 - Non-negligible background to Drell-Yan like reactions
- Test of SM γWW and $\gamma\gamma WW$ couplings

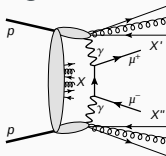
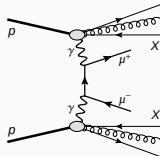
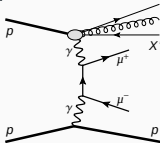
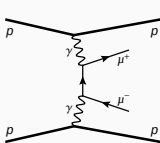


Complications (i.e. motivation)

BSM motivation – possible new particles:



QCD motivation – proton dissociation and additional exchanges:



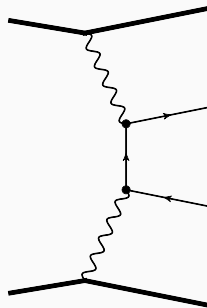
How to measure two-photon processes

Signatures of $\gamma\gamma \rightarrow l\bar{l}$ events:

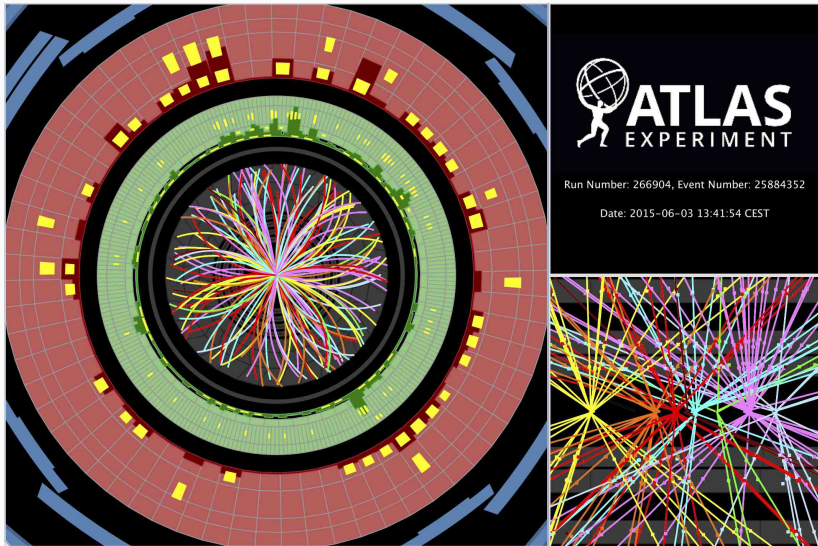
- clean final state
- low p_T of photons $\rightarrow$ low p_T of $l\bar{l}$ pair
 $\rightarrow$ low acoplanarity
- forward protons

Challenges:

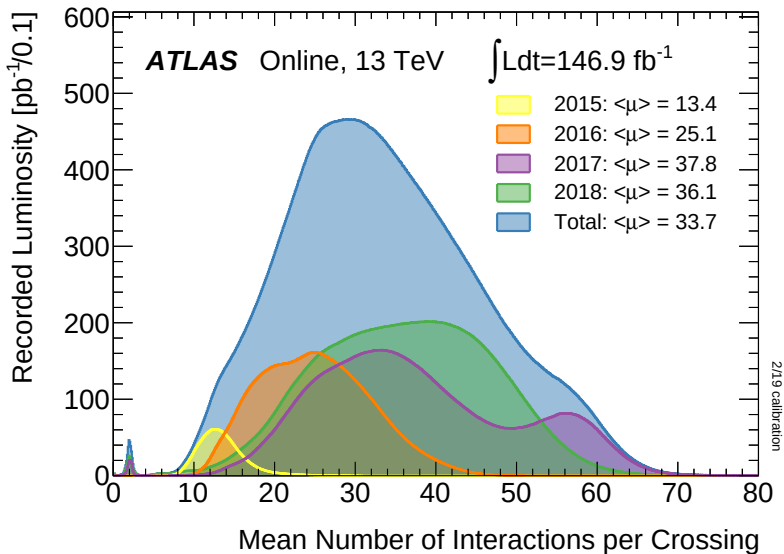
- small cross section
- trigger efficiency
- pile-up



Pile-up in pp LHC runs



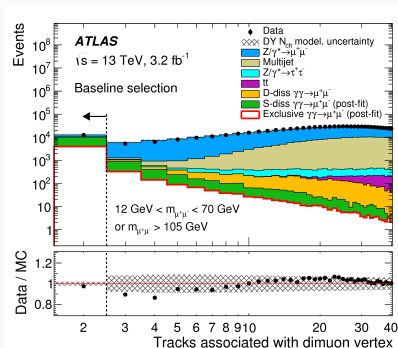
Pile-up in pp LHC runs



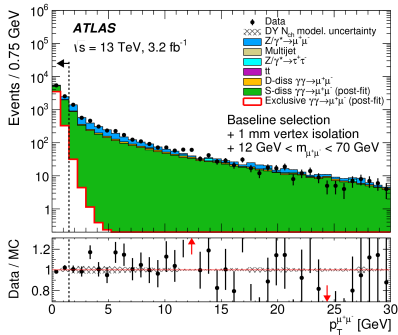
Analysis without forward protons

Exclusive selection:

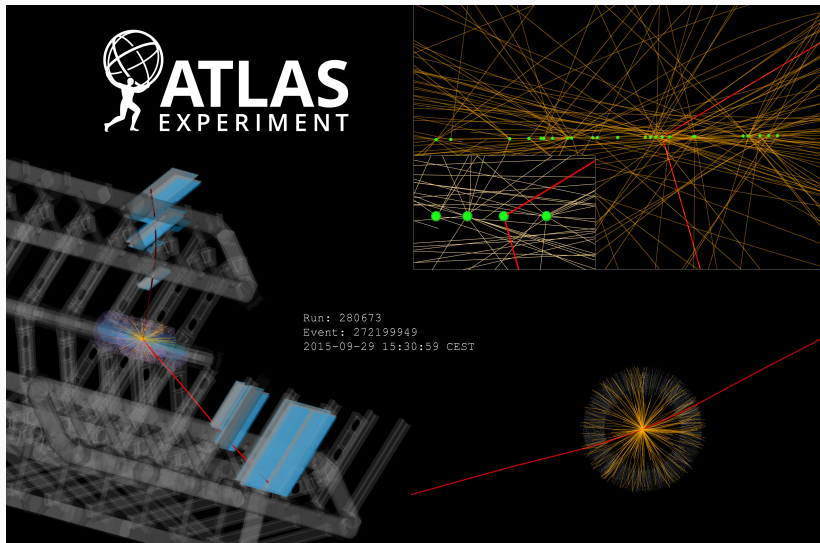
- vertex isolation



- low p_T of the $l\bar{l}$ pair

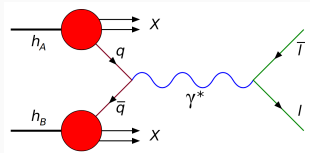


$\gamma\gamma \rightarrow \mu\mu$ in pp event candidate

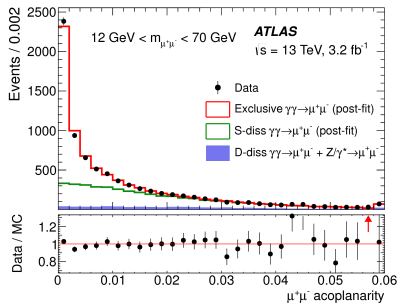
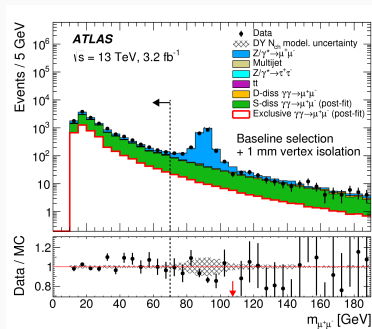
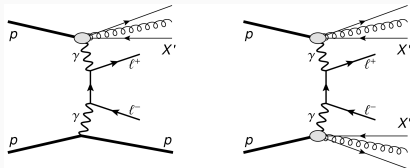


Limitations of analysis without forward protons

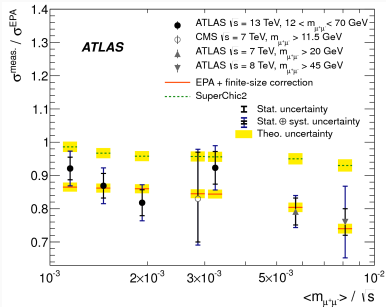
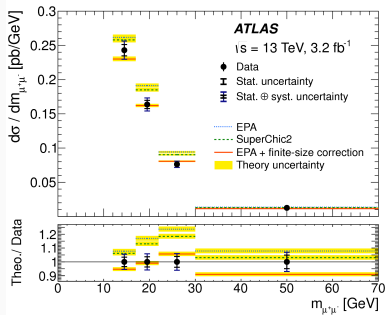
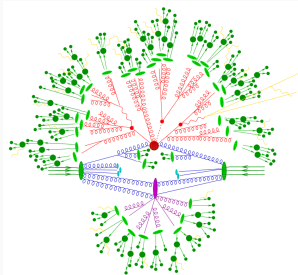
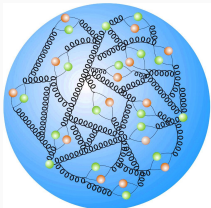
DY background



Processes with dissociation



Absorptive corrections



Introduction

Experimental techniques

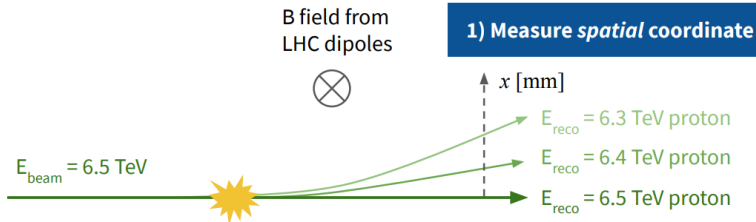
First results

Performance

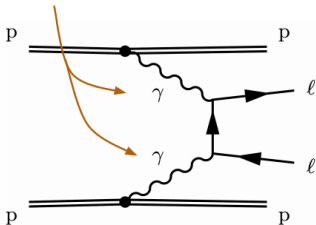
Time-of-flight detector

Conclusions

Forward proton spectrometer



$$\xi_{\text{AFP}}^{\text{A,C}} = 1 - E_{\text{reconstructed}} / E_{\text{beam}}$$



1) Measure *spatial* coordinate

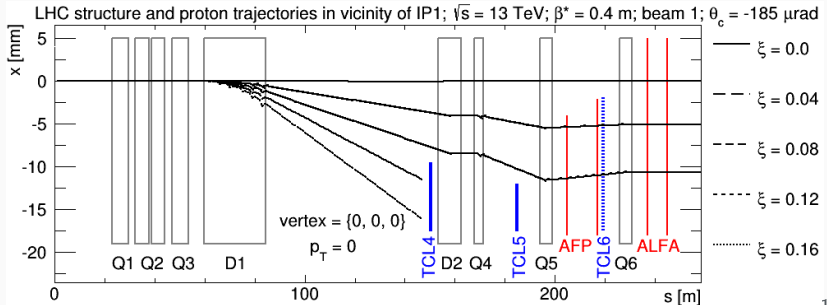
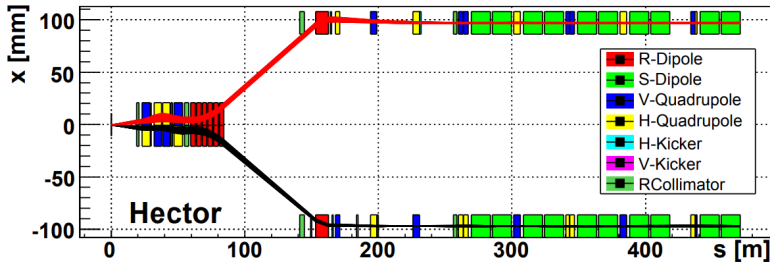
2) Infer *energy* lost by proton

3) Know *initial* photon energy

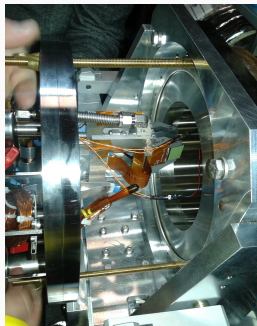
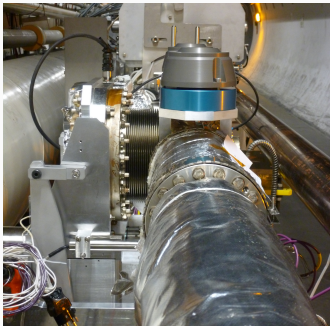
Novelty: reconstruct $\gamma\gamma$ system
without central ATLAS detectors

(drawing from Jesse Liu)

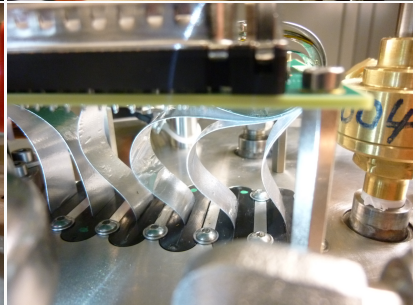
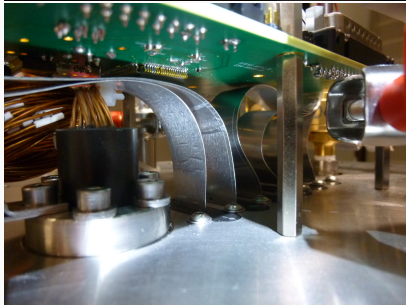
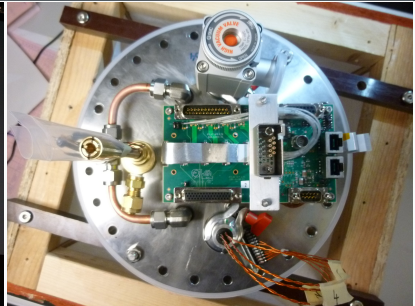
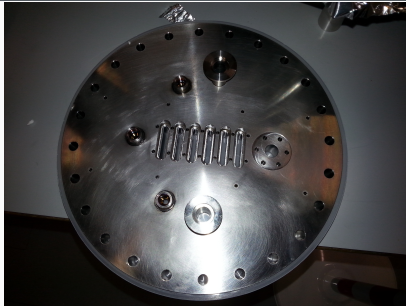
Trajectories of forward protons



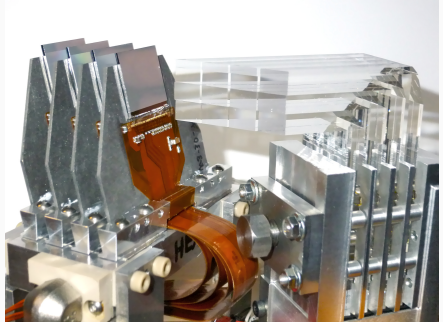
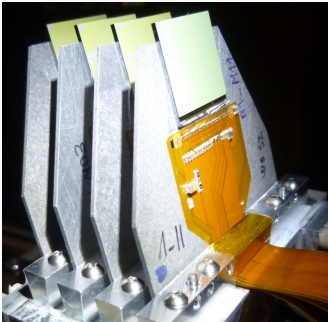
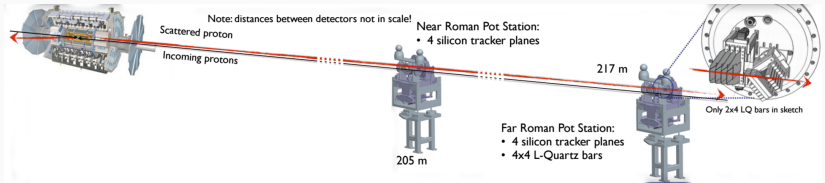
Roman pots



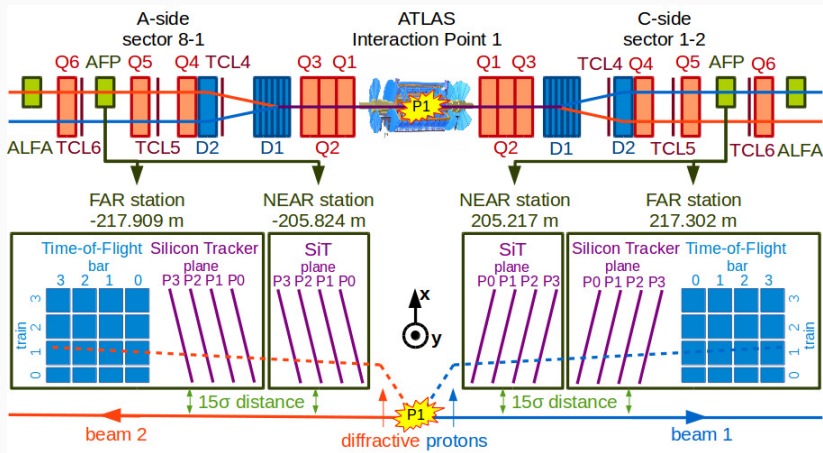
Feedthrough flange



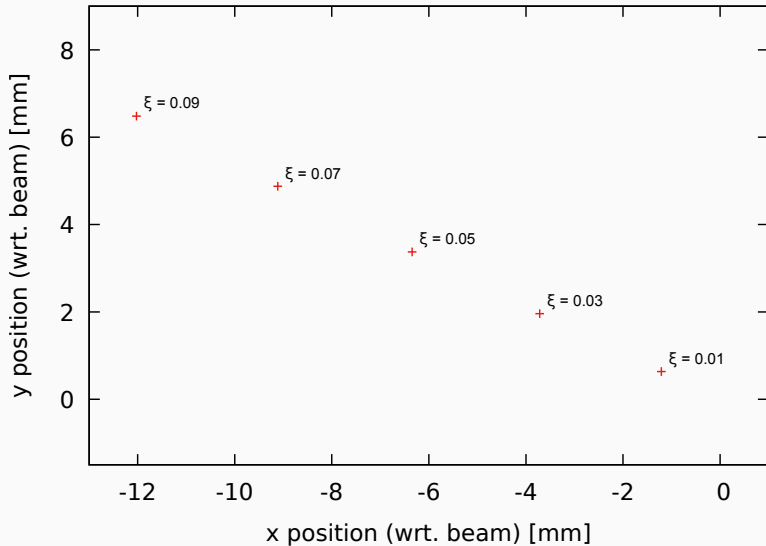
ATLAS Forward Proton detectors – one arm



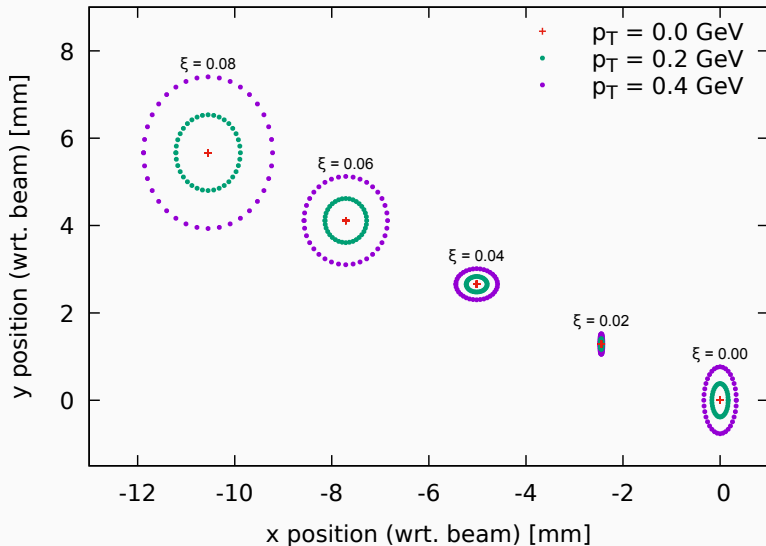
ATLAS Forward Proton detectors – full system



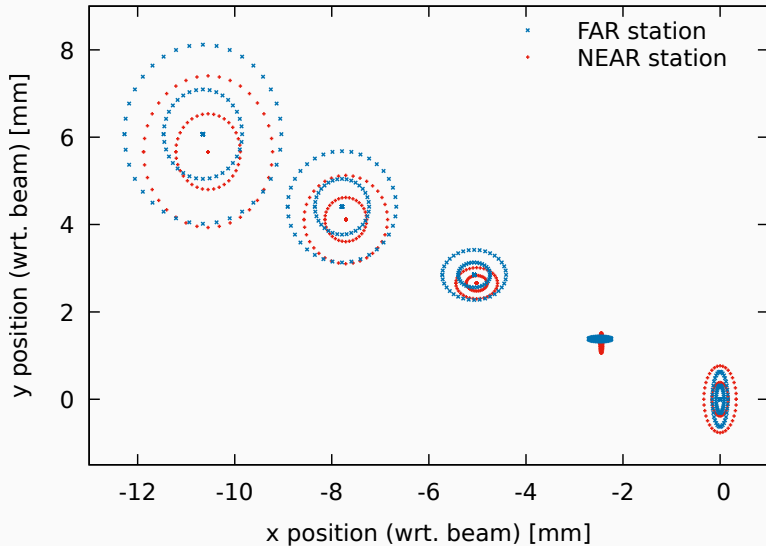
Reconstruction of proton kinematics



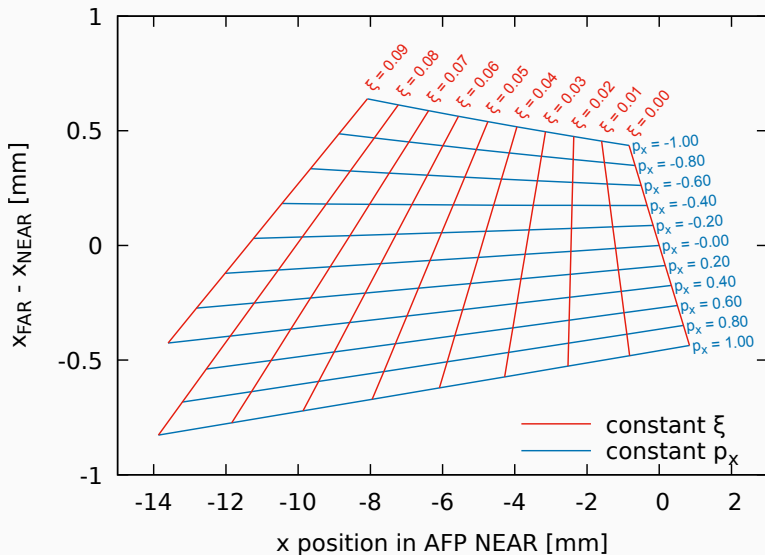
Reconstruction of proton kinematics



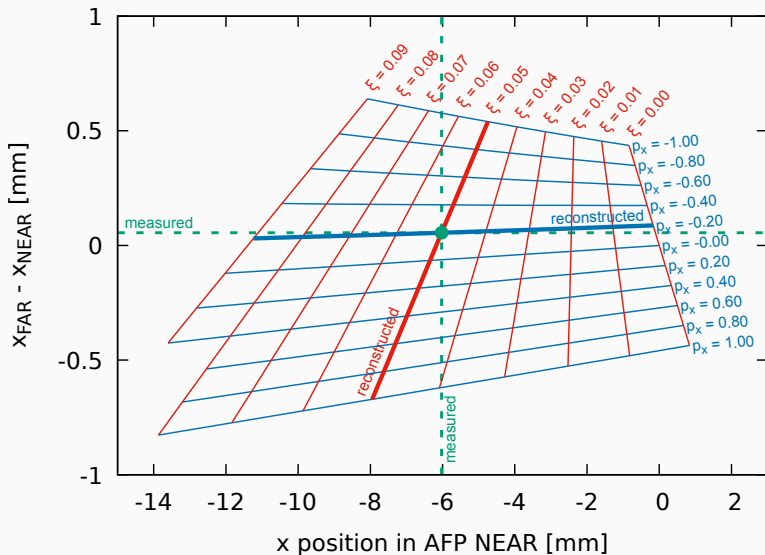
Reconstruction of proton kinematics



Reconstruction of proton kinematics



Reconstruction of proton kinematics



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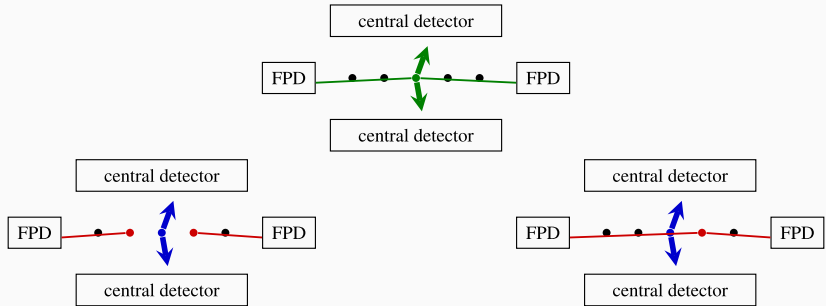
First results

Performance

Time-of-flight detector

Conclusions

Analysis strategy



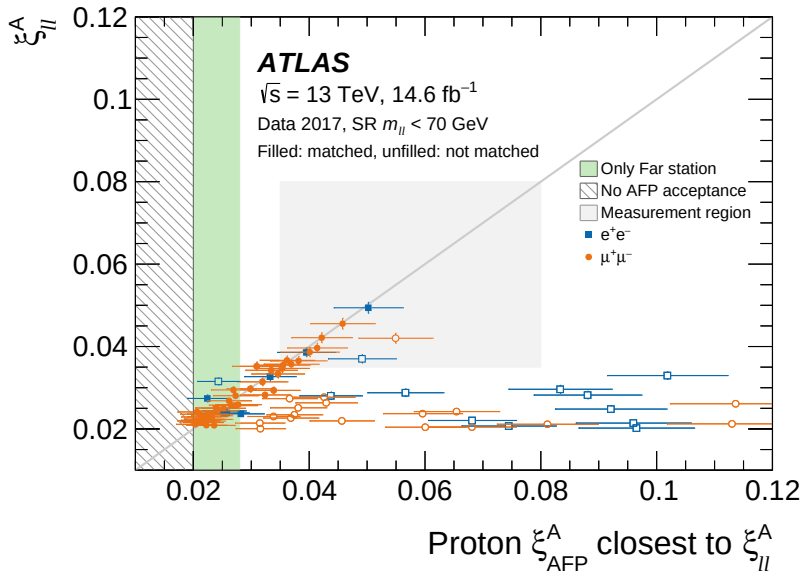
- ξ – fraction of proton energy carried by the photon
- approximations: neglecting proton mass and transverse momentum
- ξ from proton measurement

$$\xi = 1 - E_p/E_{\text{beam}}$$

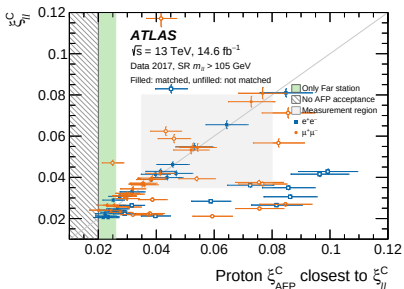
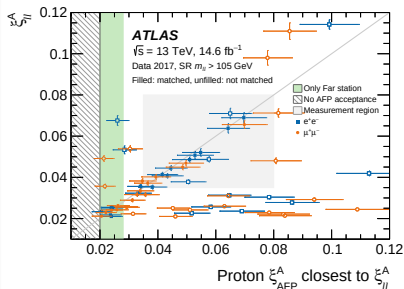
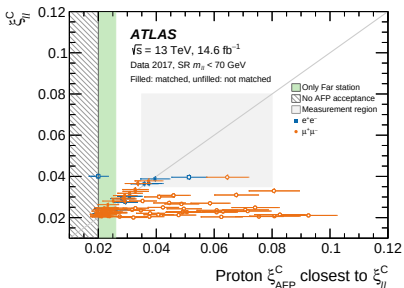
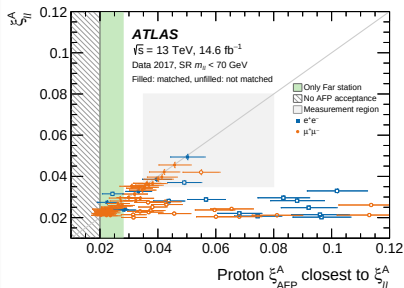
- ξ from $l\bar{l}$ system

$$\xi_{\pm} = \frac{M_{l\bar{l}}}{\sqrt{s}} \cdot e^{\pm y_{l\bar{l}}}$$

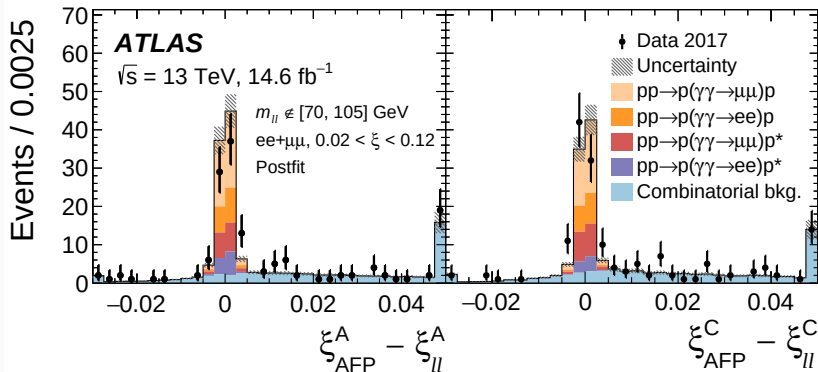
Kinematic matching



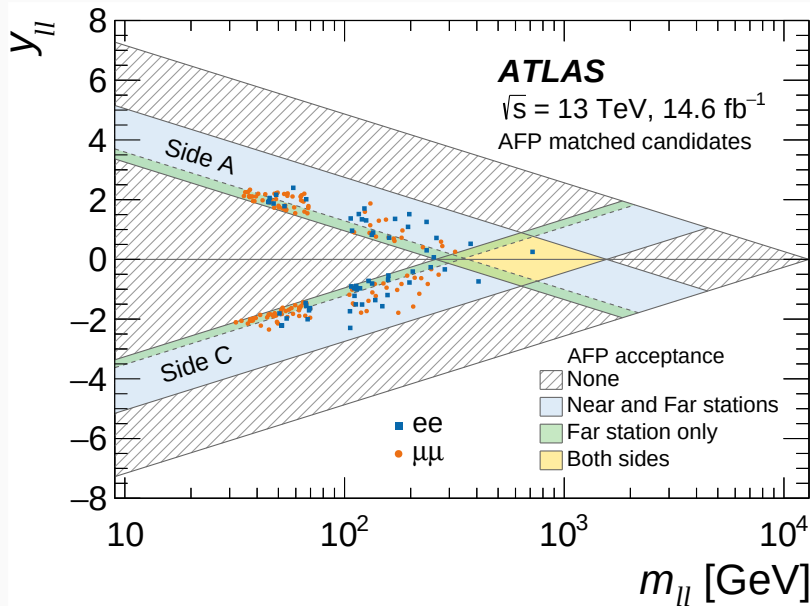
Kinematic matching – all channels



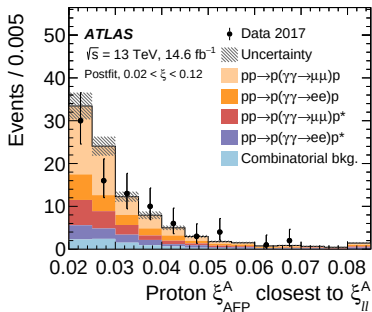
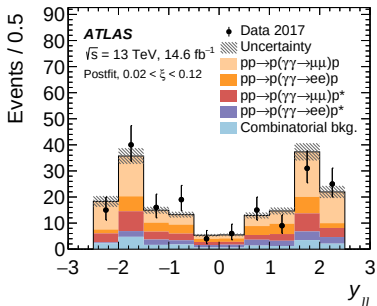
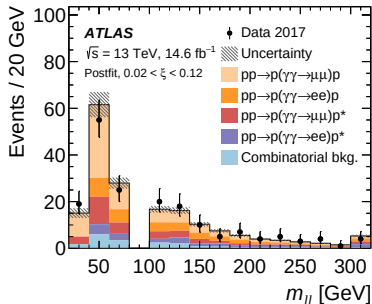
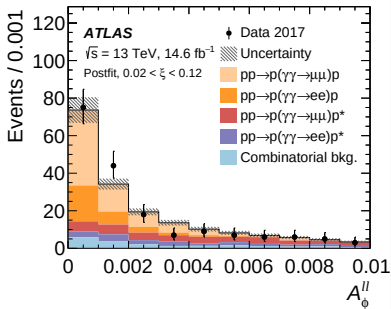
Signal evidence



Signal candidates



Distributions



Uncertainties

$$\sigma_{ee+p} = 11.0 \pm 2.6(\text{stat.}) \pm 1.2(\text{syst.}) \pm 0.3(\text{lumi.}) \text{ fb}$$

$$\sigma_{\mu\mu+p} = 7.2 \pm 1.6(\text{stat.}) \pm 0.9(\text{syst.}) \pm 0.2(\text{lumi.}) \text{ fb}$$

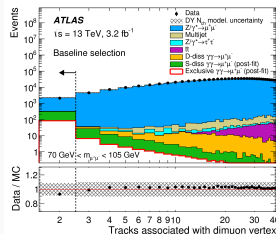
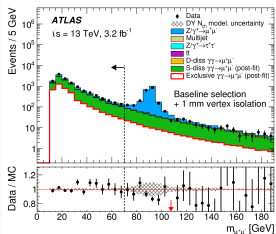
Source of systematic uncertainty	Impact
Forward detector	
Global alignment	6%
Beam optics	5%
Resolution and kinematic matching	3–5%
Track reconstruction efficiency	3%
Alignment rotation	1%
Clustering and track-finding procedure	< 1%
Central detector	
Track veto efficiency	5%
Pileup modeling	2–3%
Muon scale and resolution	3%
Muon trigger, isolation, reconstruction efficiencies	1%
Electron trigger, isolation, reconstruction efficiencies	1%
Electron scale and resolution	1%
Background modeling	2%
Luminosity	2%

Experiment vs theory

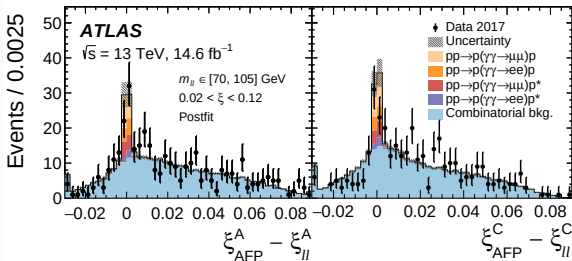
	$\sigma_{ee+p}^{\text{fid.}} \text{ [fb]}$	$\sigma_{\mu\mu+p}^{\text{fid.}} \text{ [fb]}$
Measurement	11.0 ± 2.9	7.2 ± 1.8
Predictions		
$S_{\text{surv}} = 1$		
HERWIG+LPAIR	15.5 ± 1.2	13.5 ± 1.1
HERWIG	9.3 ± 0.7	8.0 ± 0.6
LPAIR	6.2 ± 1.1	5.5 ± 0.9
S_{surv} using Refs. [31,30]		
HERWIG+LPAIR	10.9 ± 0.8	9.2 ± 0.7
HERWIG	7.0 ± 0.5	5.9 ± 0.4
LPAIR	3.9 ± 0.7	3.4 ± 0.6
SUPERCHIC 4 [94]		
Exclusive + single-dissociative	12.2 ± 0.9	10.4 ± 0.7
Exclusive	8.6 ± 0.6	7.3 ± 0.5
Single-dissociative	3.6 ± 0.6	3.1 ± 0.5

To tag or not to tag

$\gamma\gamma \rightarrow l\bar{l}$ in Z mass window **without** forward proton tagging:

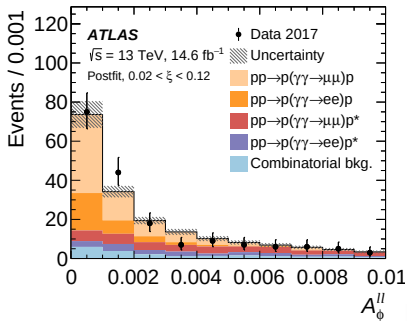


$\gamma\gamma \rightarrow l\bar{l}$ in Z mass window **with** forward proton tagging:

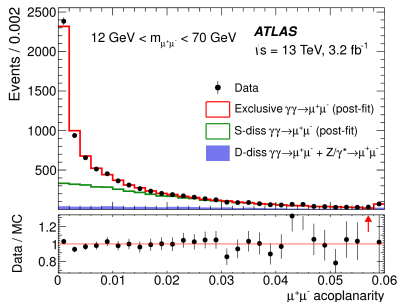


To tag or not to tag

With forward proton tagging



Without forward proton tagging



- Different sensitivity to processes with dissociation
- Double-tag measurement would provide more information

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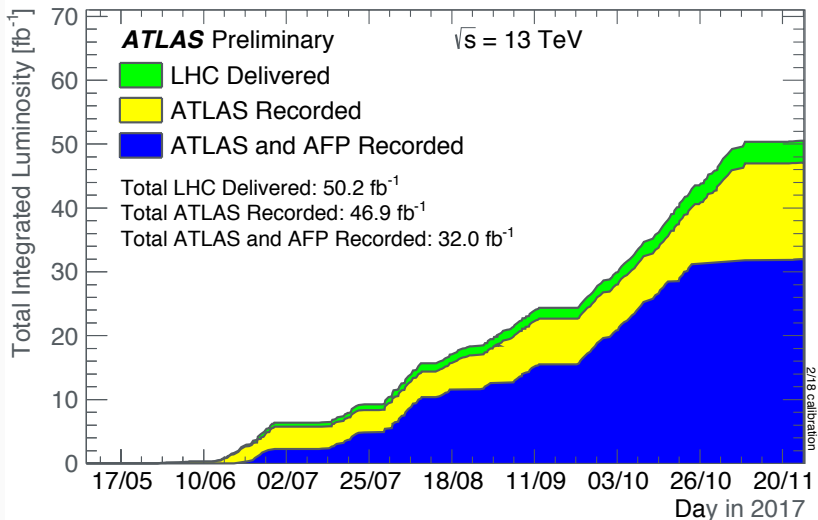
First results

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Time-of-flight detector

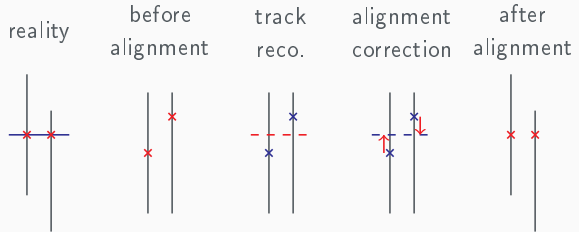
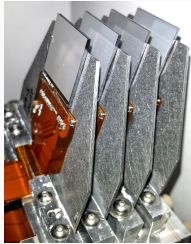
Conclusions

Luminosity in 2017

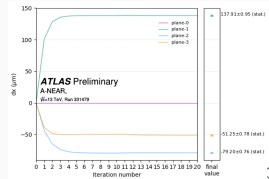
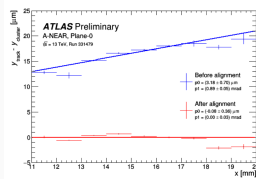
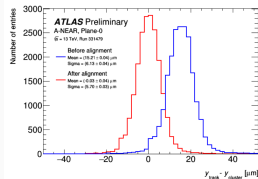


AFP inter-plane alignment

Inter-plane alignment – relative positioning of Si layers within one AFP station



- Three degrees of freedom aligned: x and y offsets, rotations around z
- First plane in every station fixed; other planes aligned relative to the first one



Beam-based alignment

Sharp signal spike in BLM when beam is probed

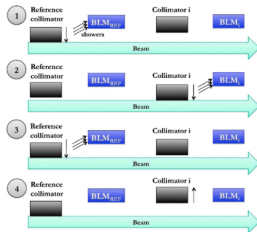
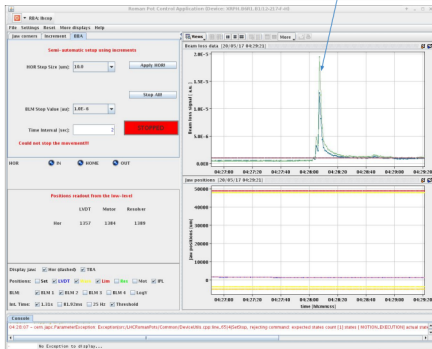
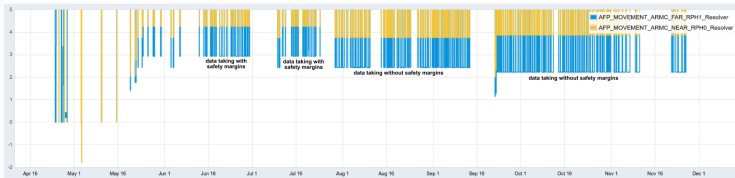


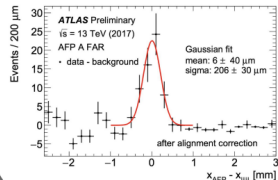
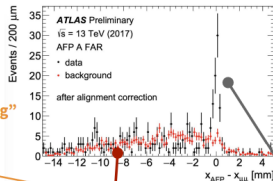
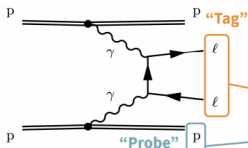
FIG. 4. The four-stage beam-based alignment procedure for collimator i . The reference collimator is aligned to form a reference cut in the beam halo (1). Collimator i is aligned (2), followed by a realignment of the reference collimator (3). Finally, collimator i is opened to its position in the hierarchy (4).

LHC operations: 20 May 2017



Data-driven alignment

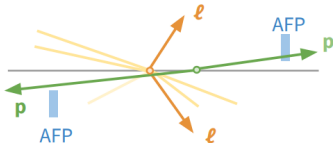
Use $(\gamma\gamma \rightarrow \mu\mu)+p$ signal
as standard candle:
“The J/ψ of AFP”



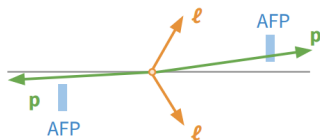
$$\xi_{\ell\ell}^{\pm} = (m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}}$$

Expected proton energy loss
constrained by dimuon system

Background: no correlation (pileup)

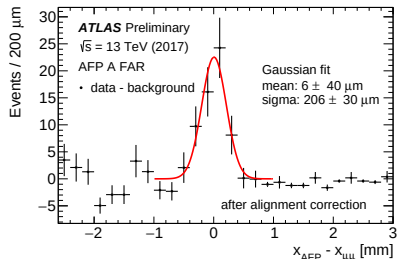
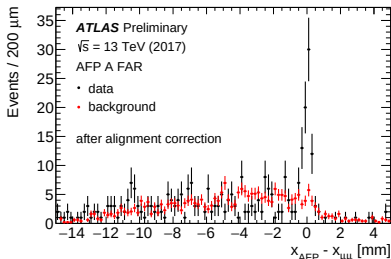
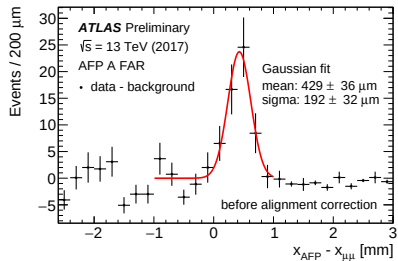
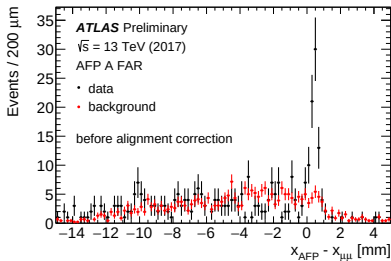


Signal: if $x_{\text{AFP}} = x_{\ell\ell} \Rightarrow$ aligned & calibrated

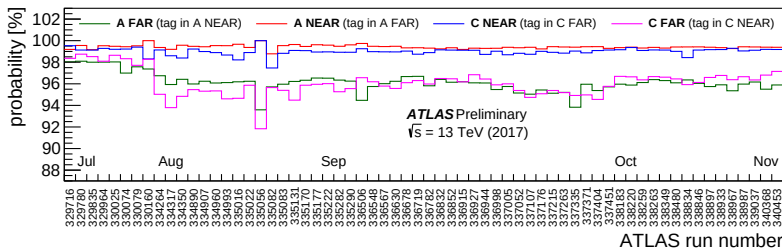
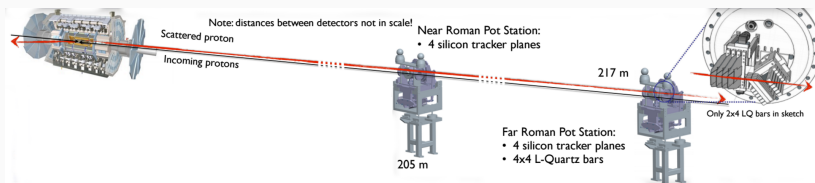


(drawing from Jesse Liu)

Data-driven alignment



Reconstruction efficiency



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Experimental techniques

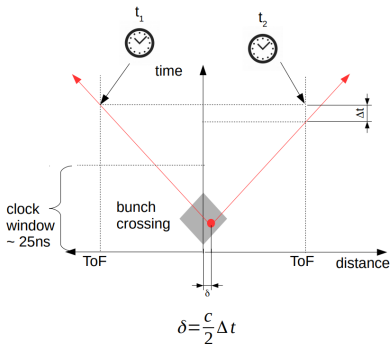
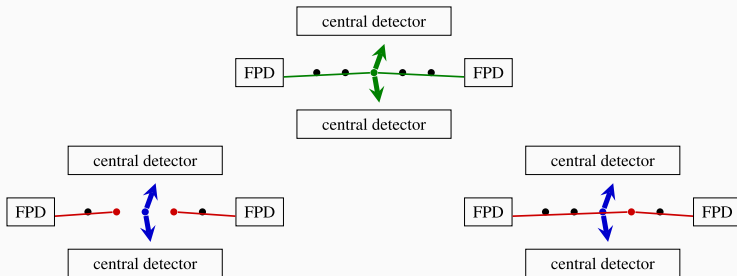
First results

Performance

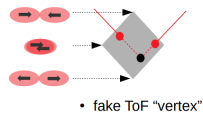
Time-of-flight detector

Conclusions

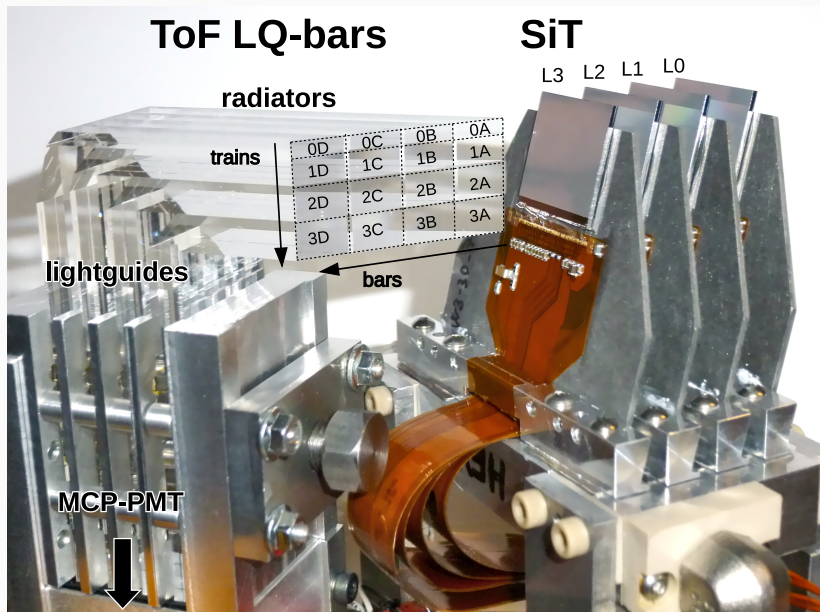
Combinatorial backgrounds



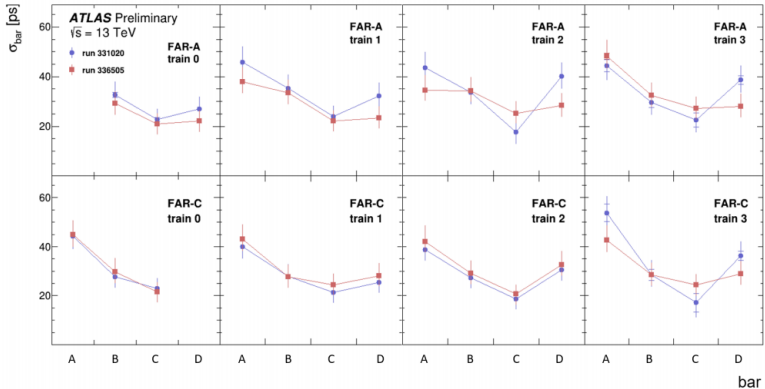
pile-up background



Time-of-Flight detector

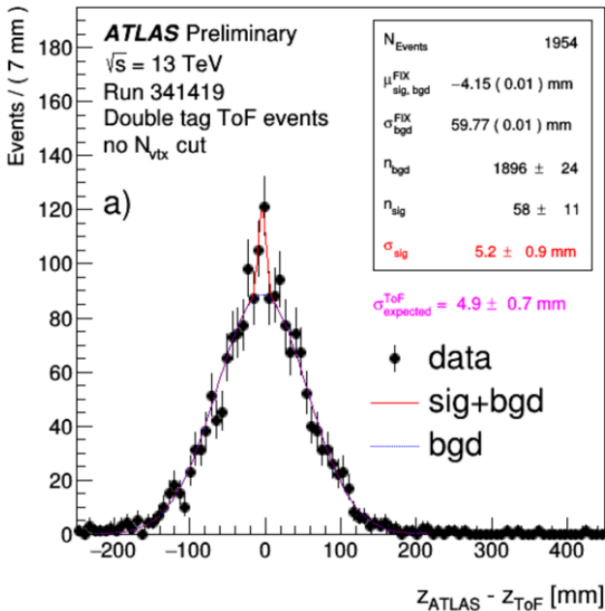


ToF resolutions



- 30 ps $\leftrightarrow$ 9 mm (at speed of light)
- More bars – better combined resolution

ToF-vertex matching



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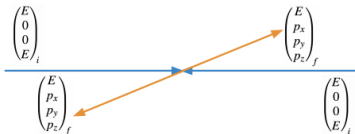
Time-of-flight detector

Conclusions

AFP → new physics object

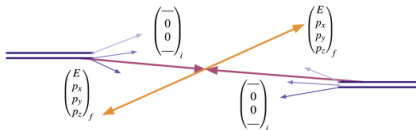
Lepton collider

All initial & visible final state
4-vectors measurable



Hadron collider: no AFP

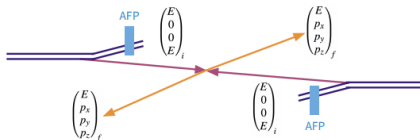
Initial state 4-vectors of
partons immeasurable in event
We cannot use what we cannot measure!



Hadron collider: with AFP

Measure energy lost by protons
⇒ measure initial state 4-vectors

New event kinematic information!

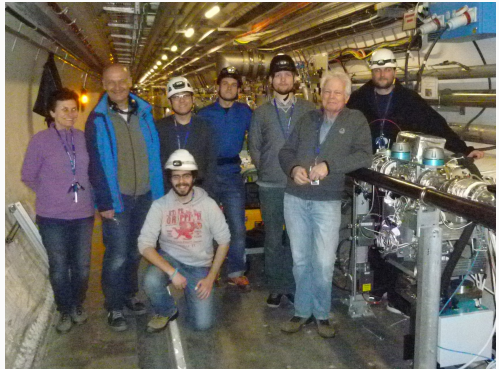


(drawing from Jesse Liu)

Involvement of Cracow groups in AFP

Crucial involvement (leading role in several activities) of IFJ PAN and AGH-UST teams:

- physics programme
- beam tests
- construction
- commissioning
- slow control
- trigger
- data acquisition
- operation
- detector simulation
- data preparation
- reconstruction software
- performance studies
- physics analyses



Installation of first arm in 2016