Search for Axion-Like-Particle (ALP) with the ATLAS Forward Proton (AFP) Detector with Di-photons

arXiv:2304.10953

ALP with AFP

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(on behalf of the ATLAS Collaboration)
IEAP CTU in Prague

LHC Forward Physics meeting
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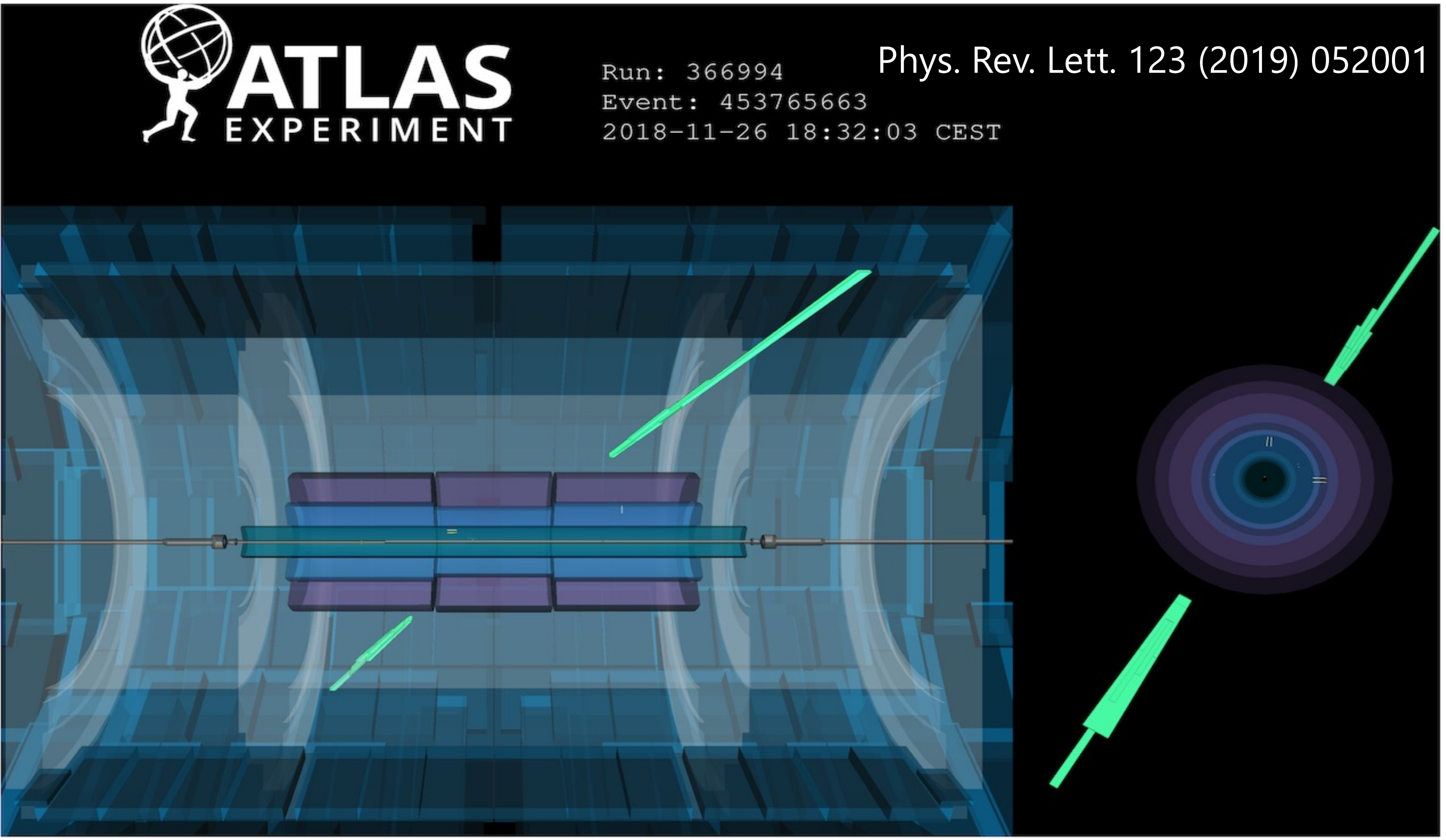
Light-by-light scattering at LHC

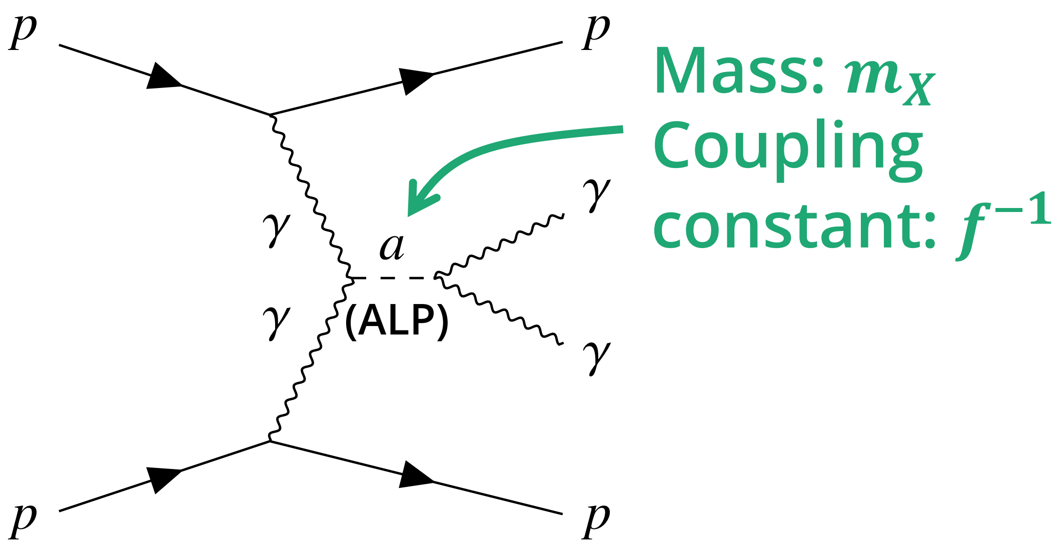
SM $\gamma\gamma \to \gamma\gamma$ observed in lead ion collisions



In pp collisions, SM $\gamma\gamma \to \gamma\gamma$ has small cross section...

But BSM can enhance it!

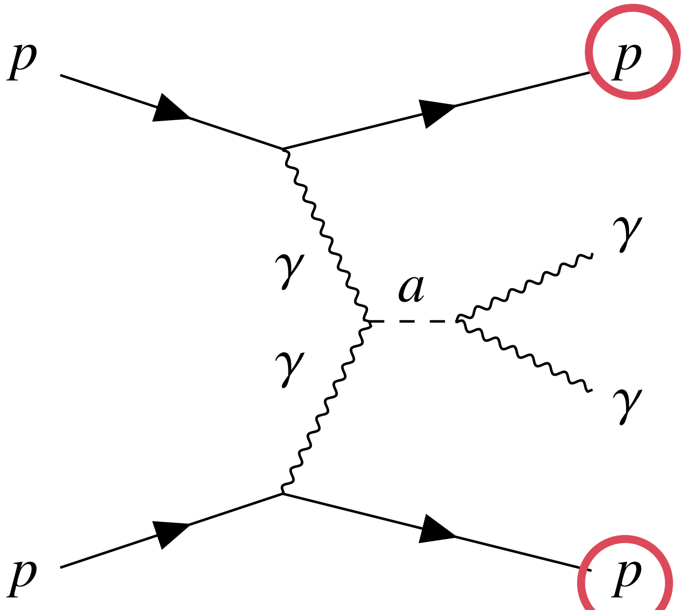
e.g. **Axion-like particle (ALP)** (assumed for signal modeling)



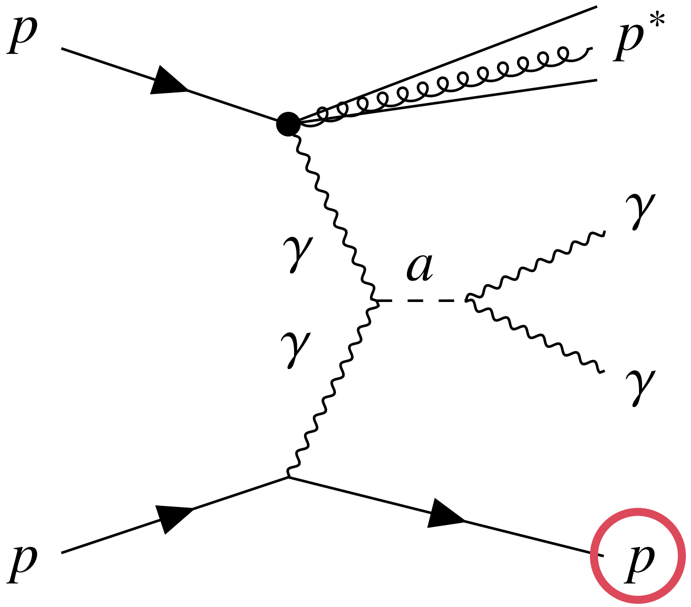
Signal models

In the $\gamma\gamma \rightarrow \gamma\gamma$ event, final state proton can be intact (not dissociative)

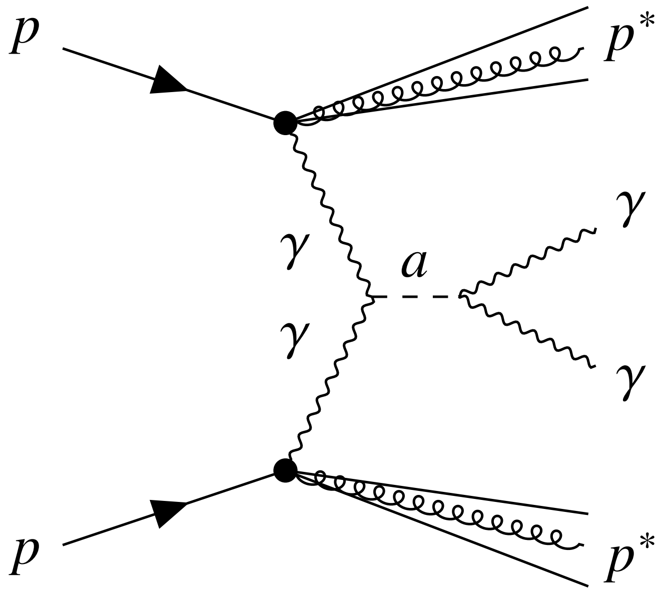
Exclusive event



Single-dissociative (**SD**) event



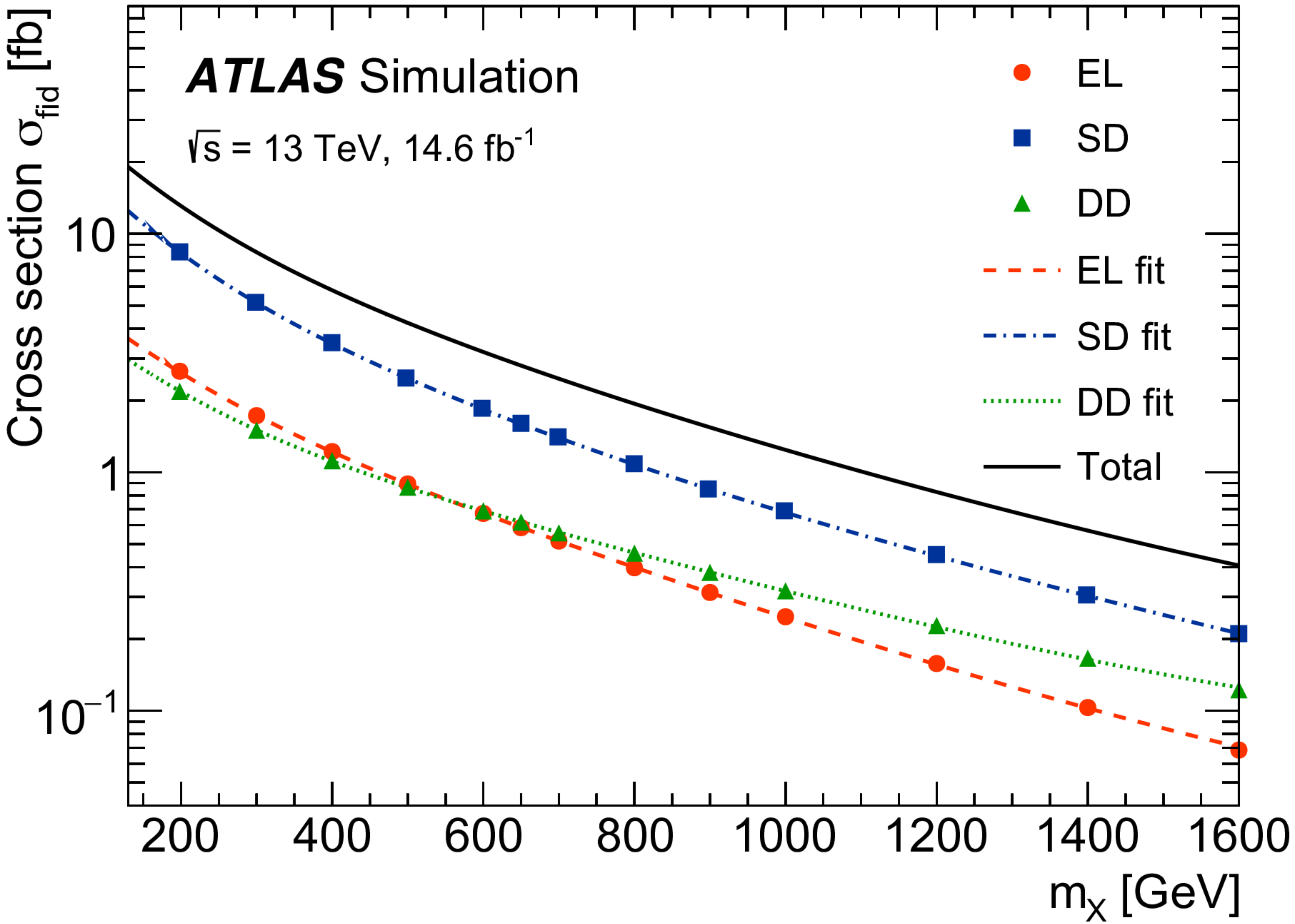
Double-dissociative (**DD**) event



ALP Production Cross-section

Coupling constant
f^{-1}=0.05 TeV^{-1}

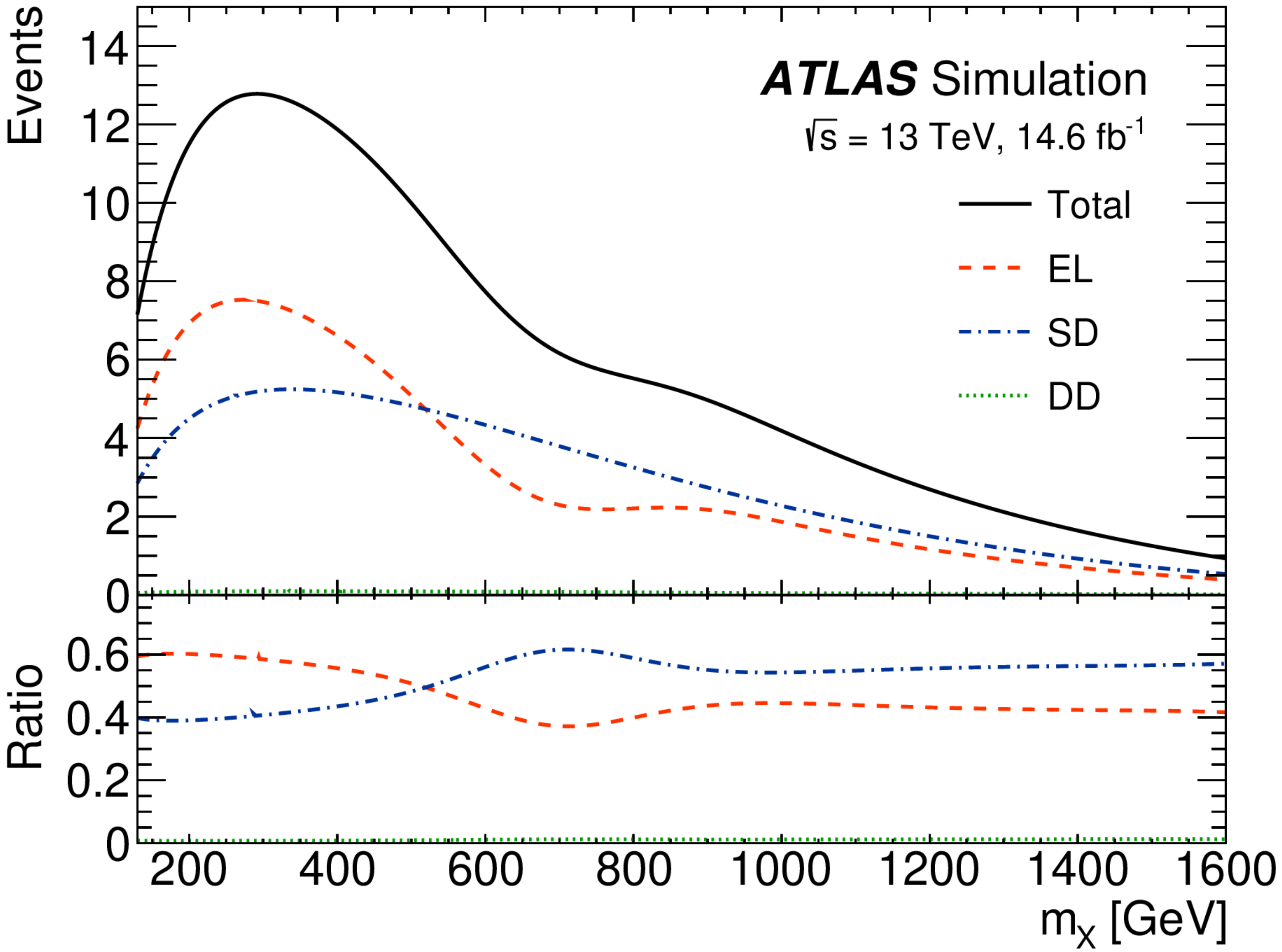
SuperChic 4.02
for EL
SuperChic 4.14
for SD and DD



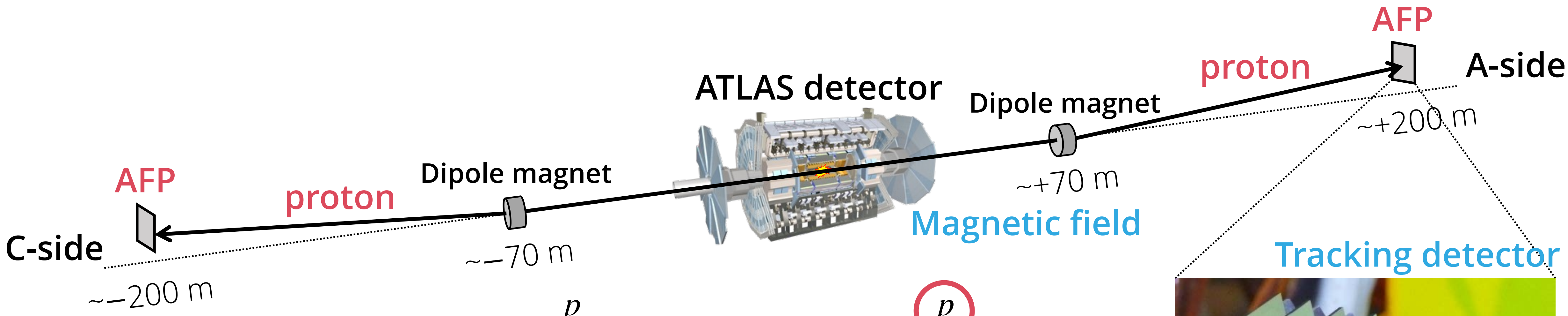
Signal Yields

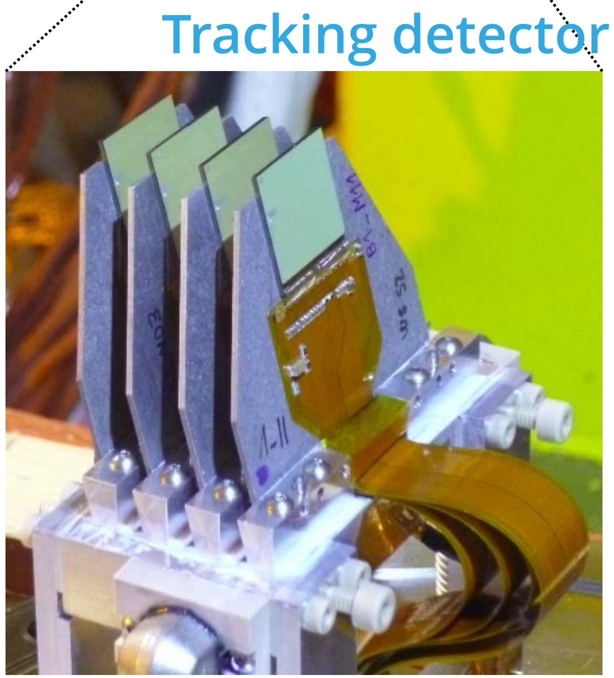
Coupling constant
f^{-1}=0.05 TeV^{-1}

signal efficiency ×
acceptance models ×
cross-section ×
luminosity

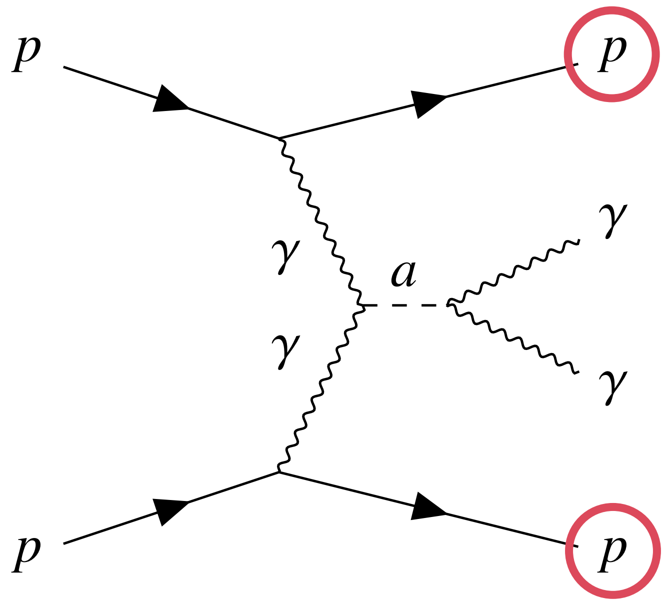


AFP detectors at -200m and +200m from IP



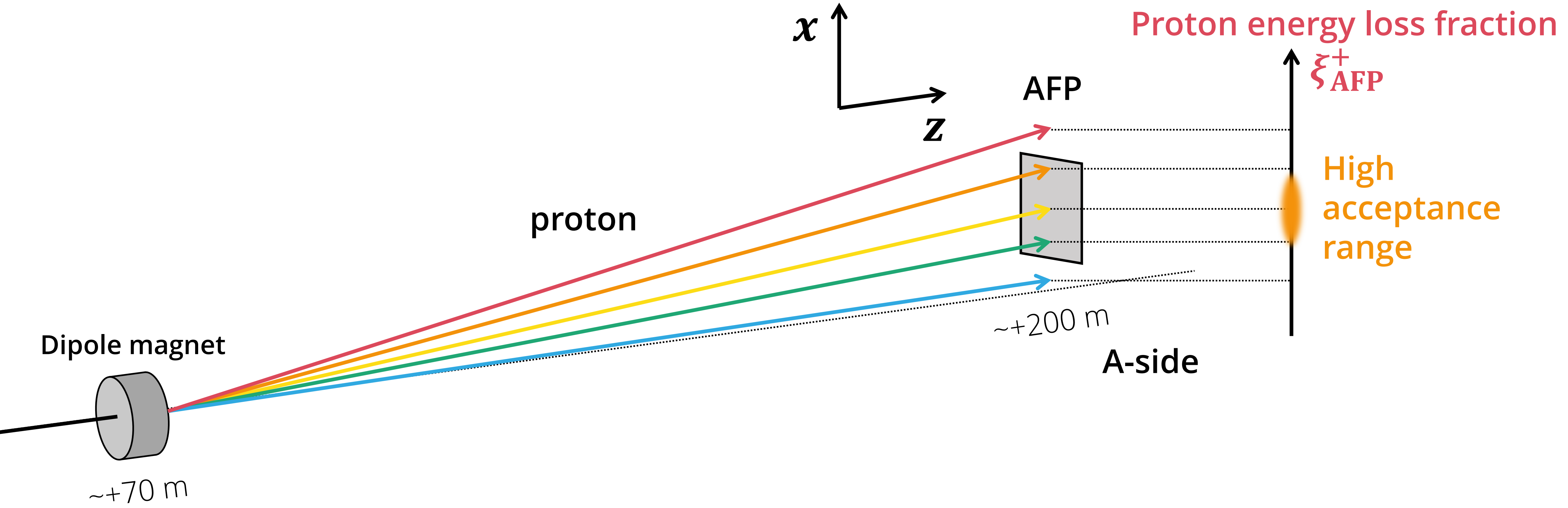


Example:
Register protons from light-by-light scattering



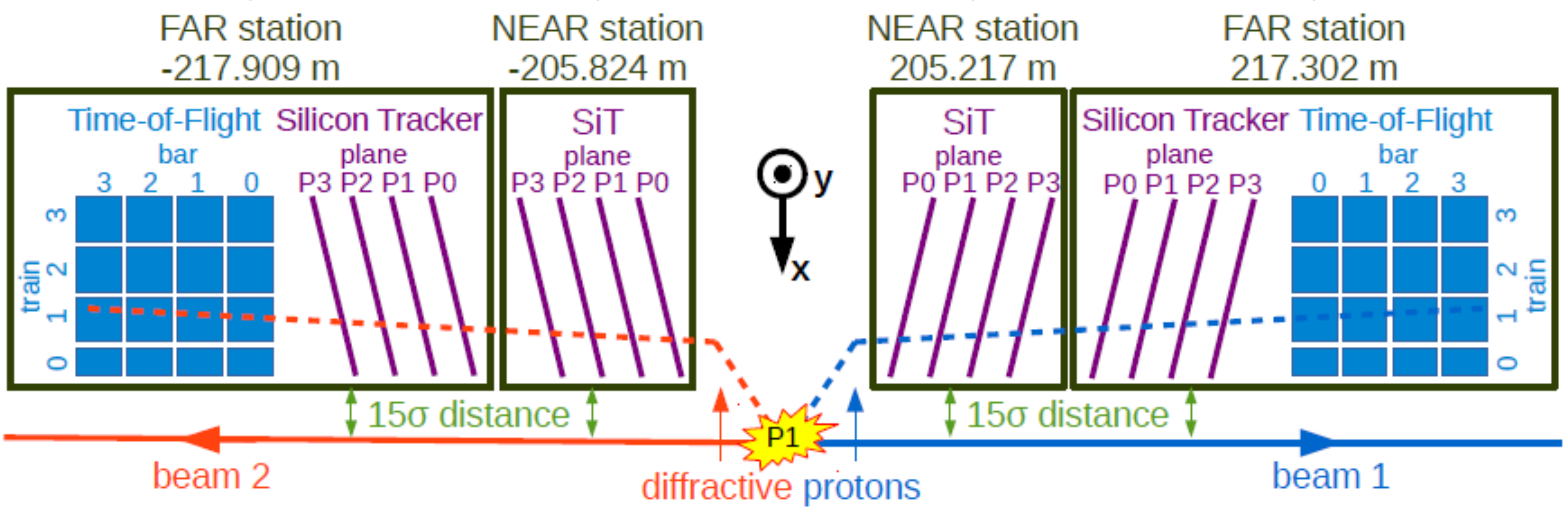
AFP detector

In $\gamma\gamma \rightarrow \gamma\gamma$ events, final state proton can be intact, record ATLAS forward proton (AFP) detectors



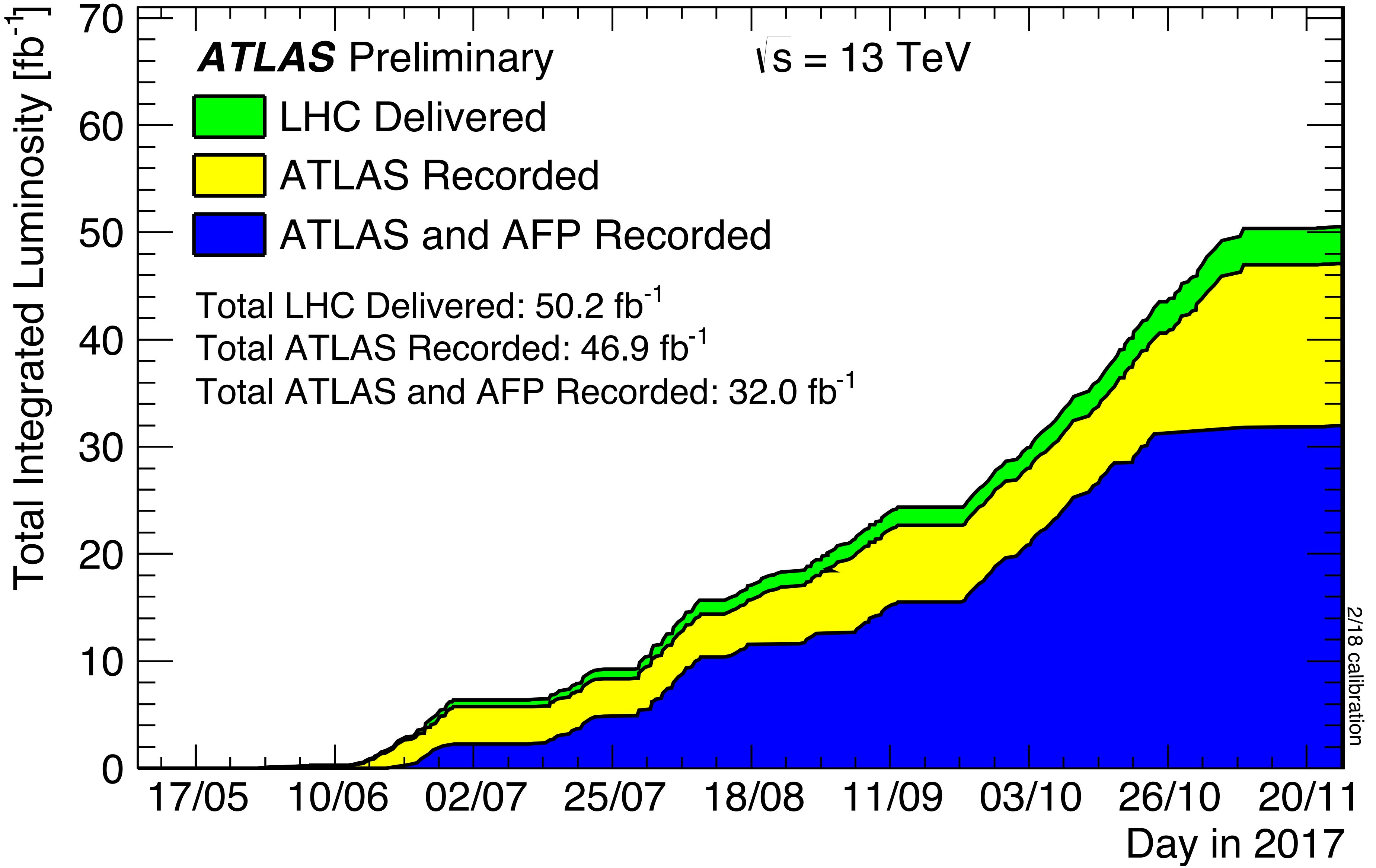
AFP detector

- Each side of the AFP systems is referred to as an arm.
- For tracking the Silicon Tracker (SiT) is used, which consists of four layers of silicon pixel detectors.
- Only FAR stations equipped with the Time-of-Flight (ToF) detectors.



AFP Run-2 data-taking in 2017: 32 fb^{-1} at 13 TeV

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3

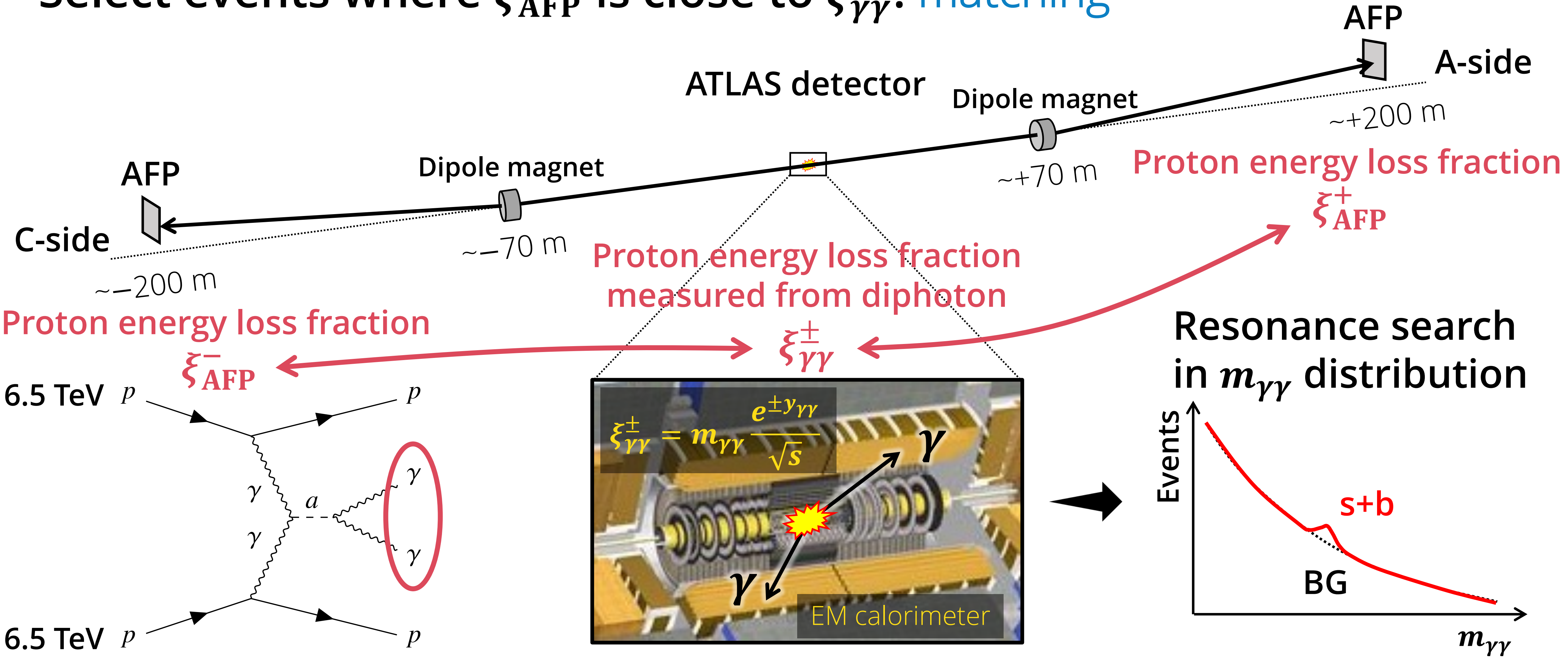


Used for this analysis 14.6 fb^{-1}

Purpose and main strategy

Diphoton resonance search using AFP

Select events where $\xi_{\mathbf{AFP}}$ is close to $\xi_{\gamma\gamma}$: matching



Event selection

1. Require diphoton to be back-to-back

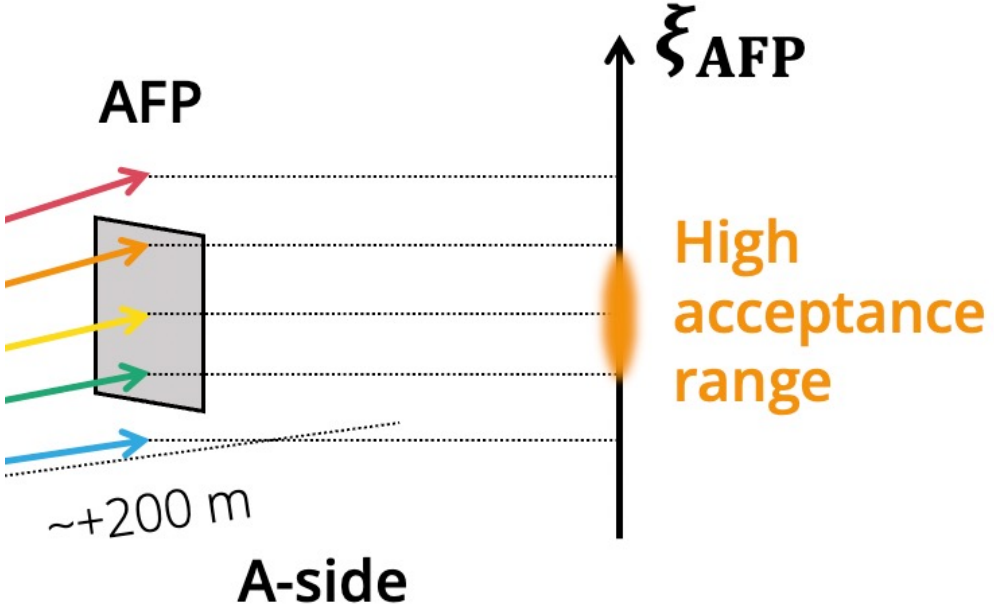
   Acoplanarity $A_{\phi}^{\gamma\gamma} \equiv 1 - \frac{|\Delta\phi|}{\pi} < 0.01$

2. Require ξ_{AFP} in the high acceptance range

   $0.035 < \xi_{\mathrm{AFP}} < 0.08 \rightarrow \xi_{\gamma\gamma}$ range is also limited

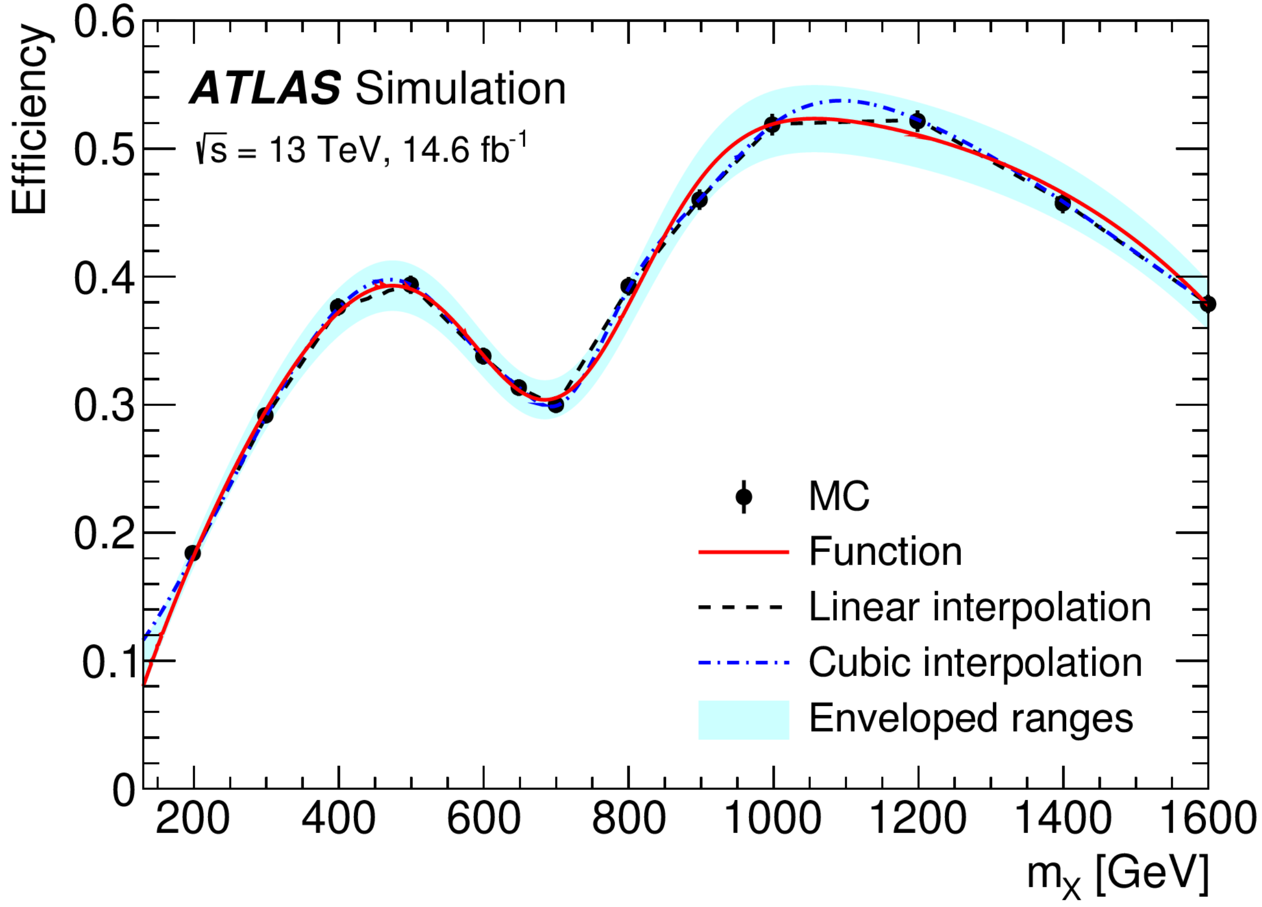
3. At least one matching proton

   $|\Delta\xi| \equiv |\xi_{\mathrm{AFP}} - \xi_{\gamma\gamma}| < 0.004 + 0.1\xi_{\gamma\gamma}$

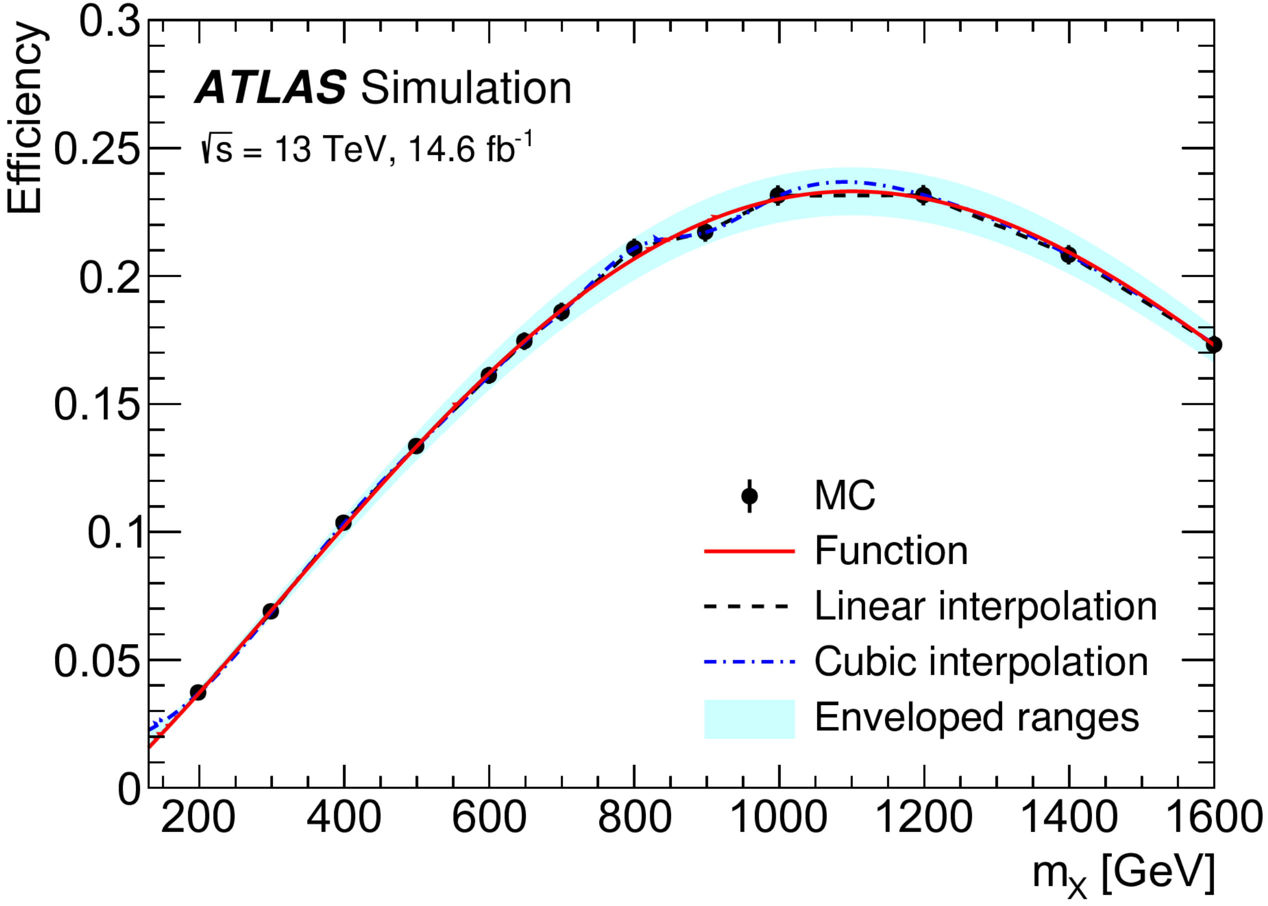


Selection efficiency as a function of ALP mass

Exclusive event



Single-dissociative (**SD**) event



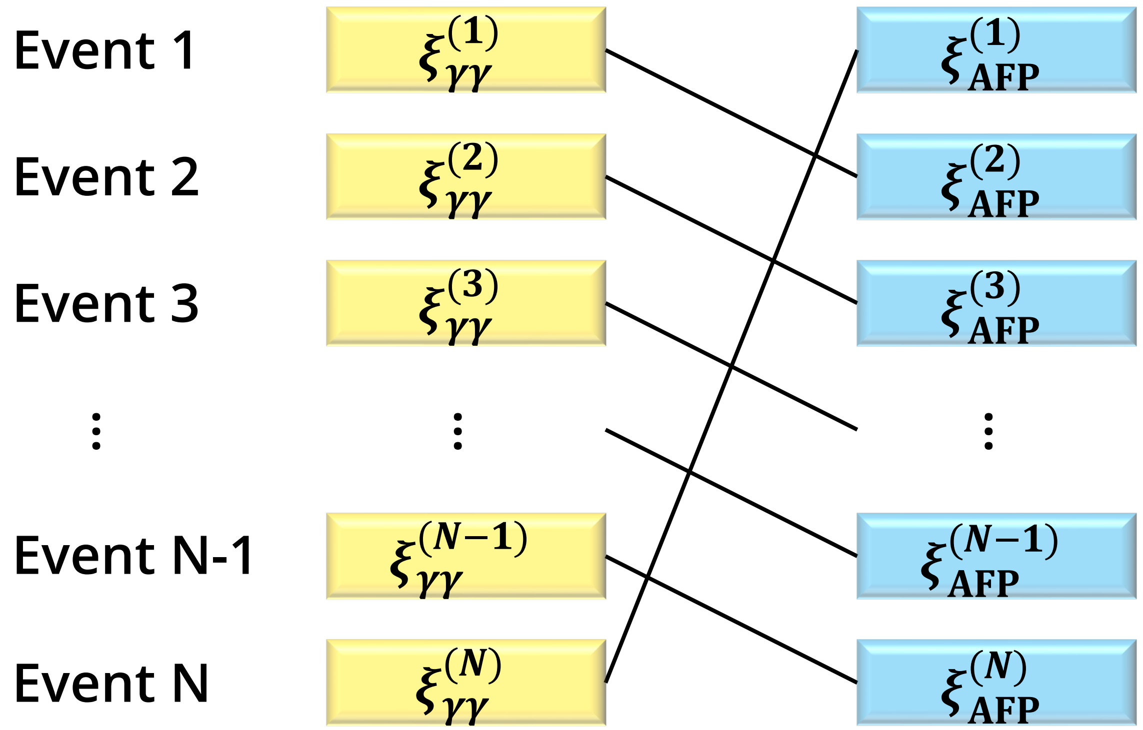
Background sample generation

Photons and protons are recorded for each event

Event 1	$\xi_{\gamma\gamma}^{(1)}$	$\xi_{\mathrm{AFP}}^{(1)}$
Event 2	$\xi_{\gamma\gamma}^{(2)}$	$\xi_{\mathrm{AFP}}^{(2)}$
Event 3	$\xi_{\gamma\gamma}^{(3)}$	$\xi_{\mathrm{AFP}}^{(3)}$
⋮	⋮	⋮
Event N-1	$\xi_{\gamma\gamma}^{(N-1)}$	$\xi_{\mathrm{AFP}}^{(N-1)}$
Event N	$\xi_{\gamma\gamma}^{(N)}$	$\xi_{\mathrm{AFP}}^{(N)}$

Background sample generation

Photons and protons are recorded for each event



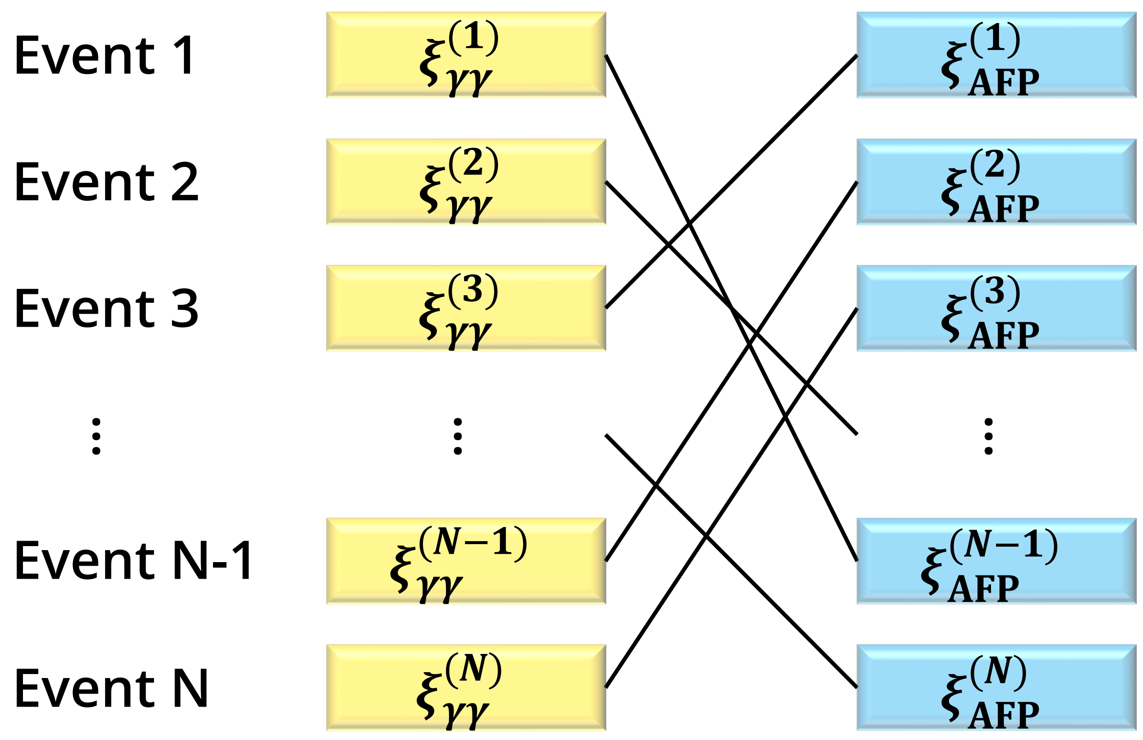
Reassignment of protons to diphotons

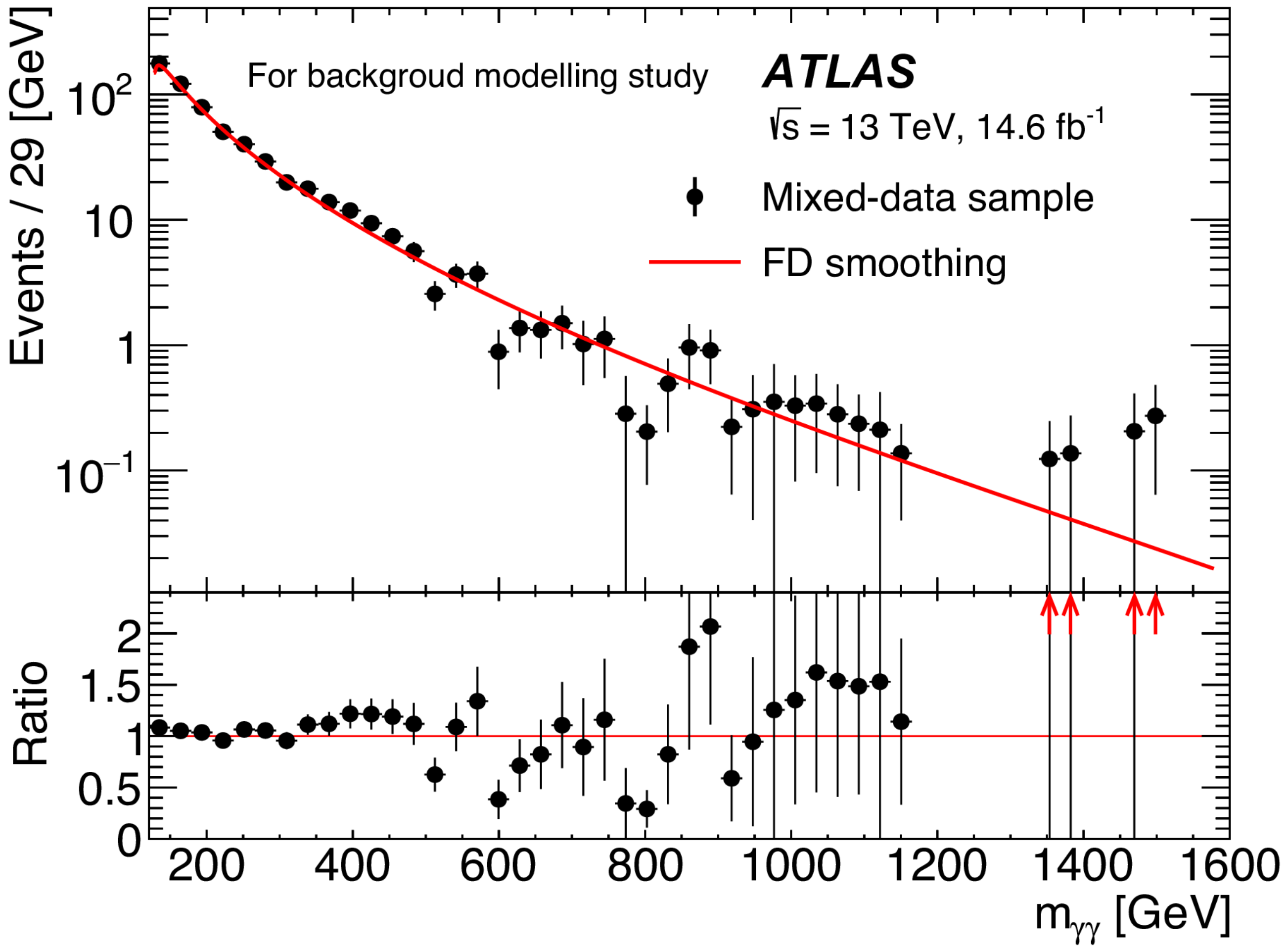
↓

→ Pure combinatorial BG sample

Background sample generation

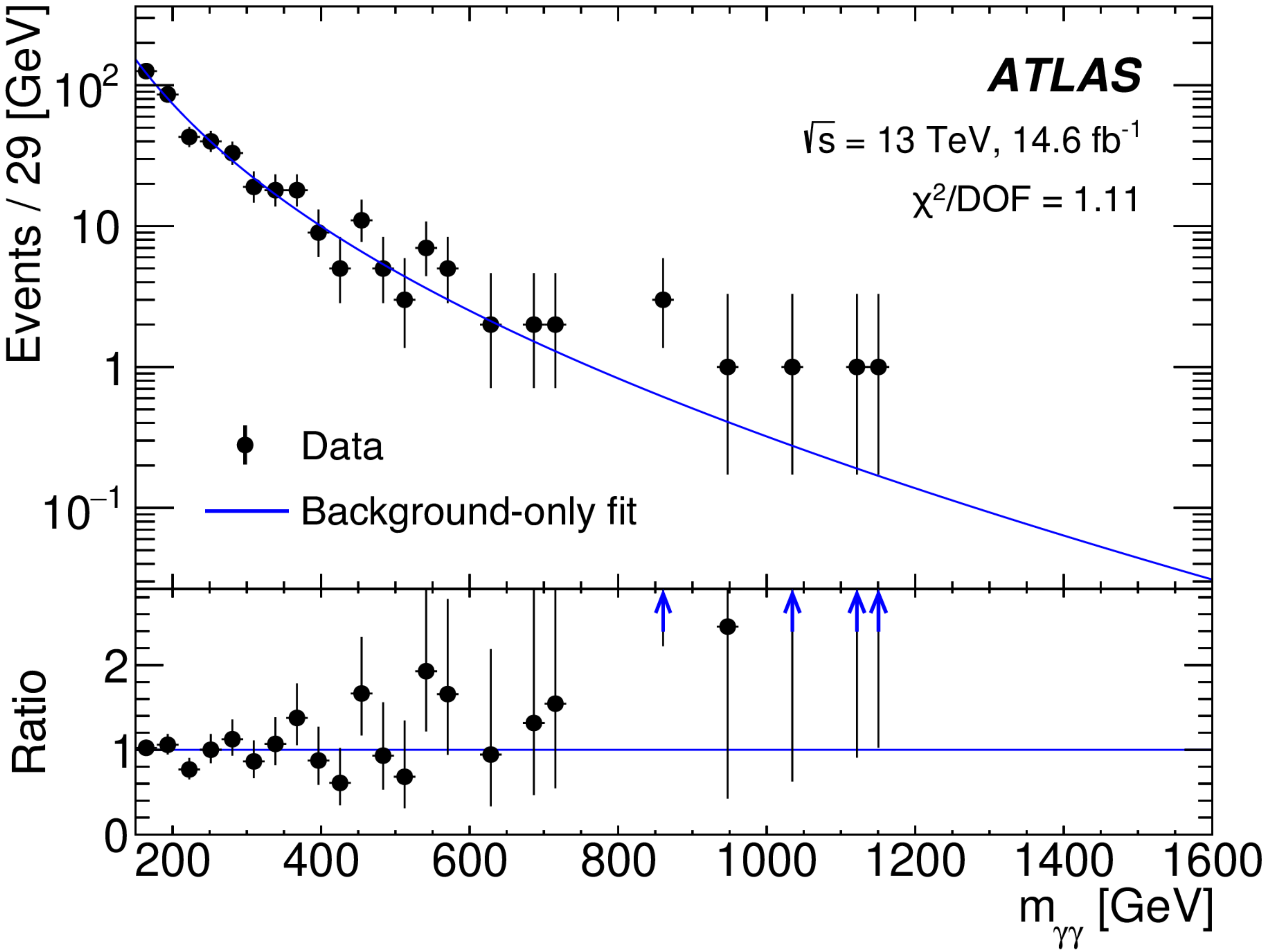
All other combination of the reassignment





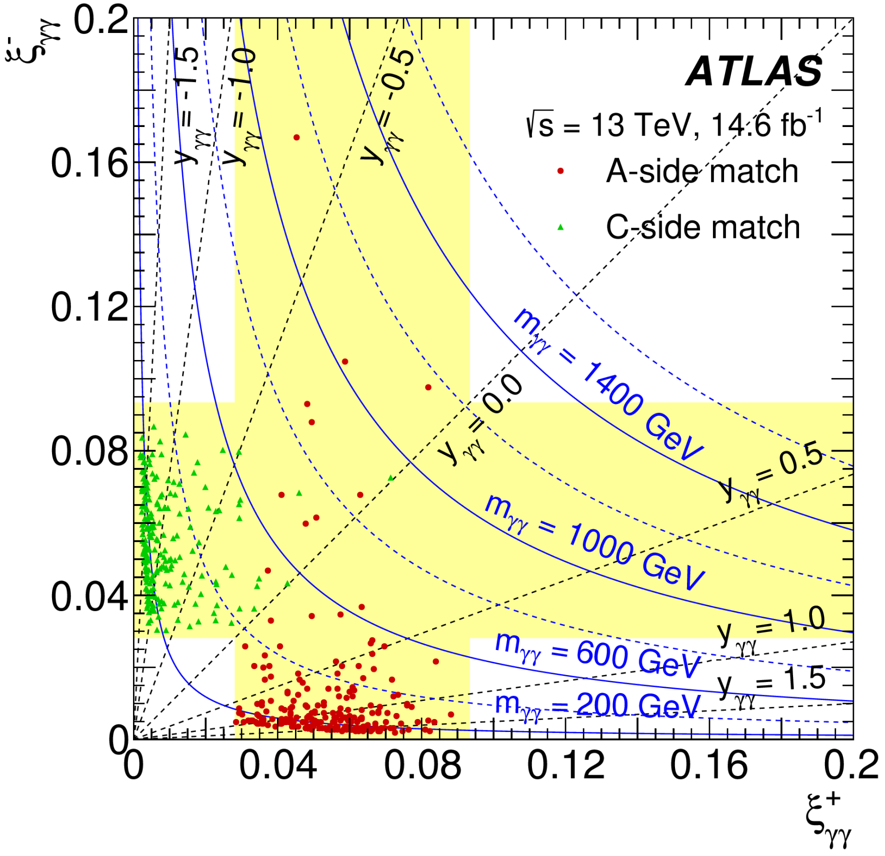
Functional Decomposition (FD)

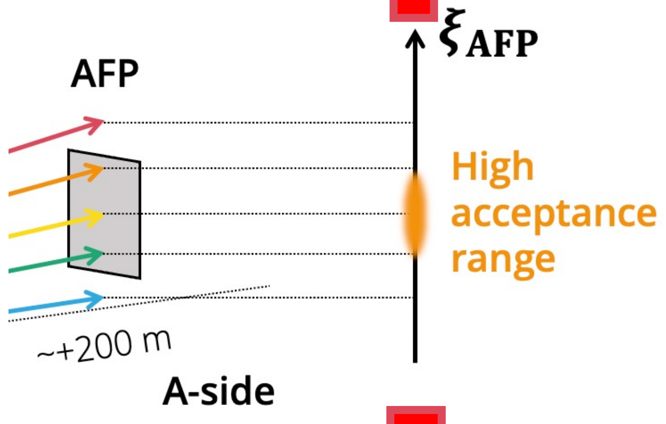
Data and background-only fit



Search results

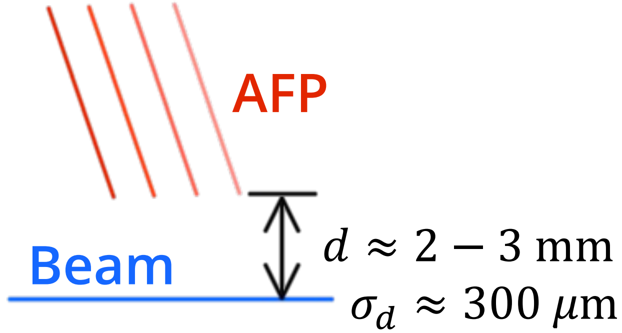
441 events observed





No double matching

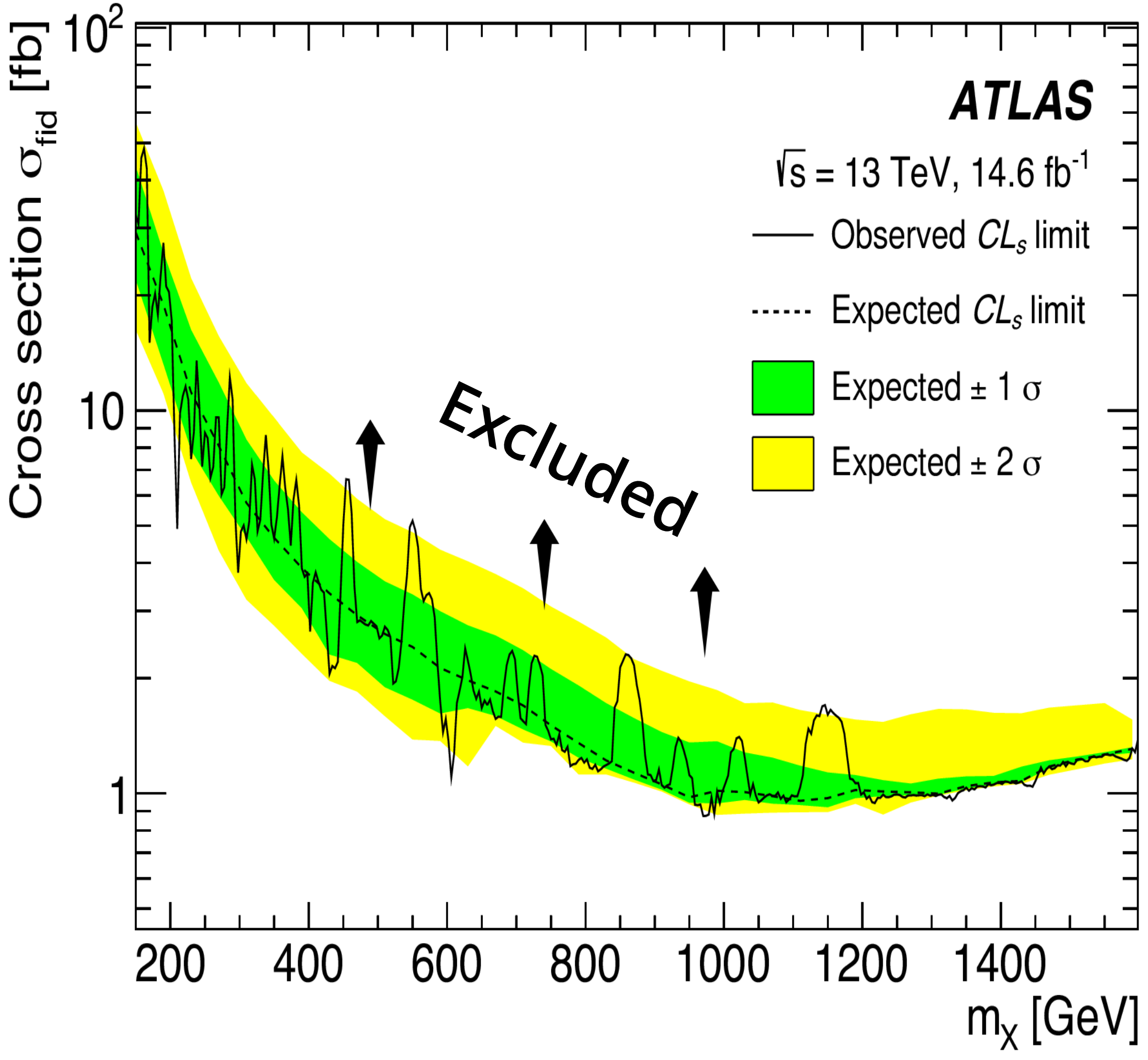
Dominant systematic uncertainty:
AFP global alignment

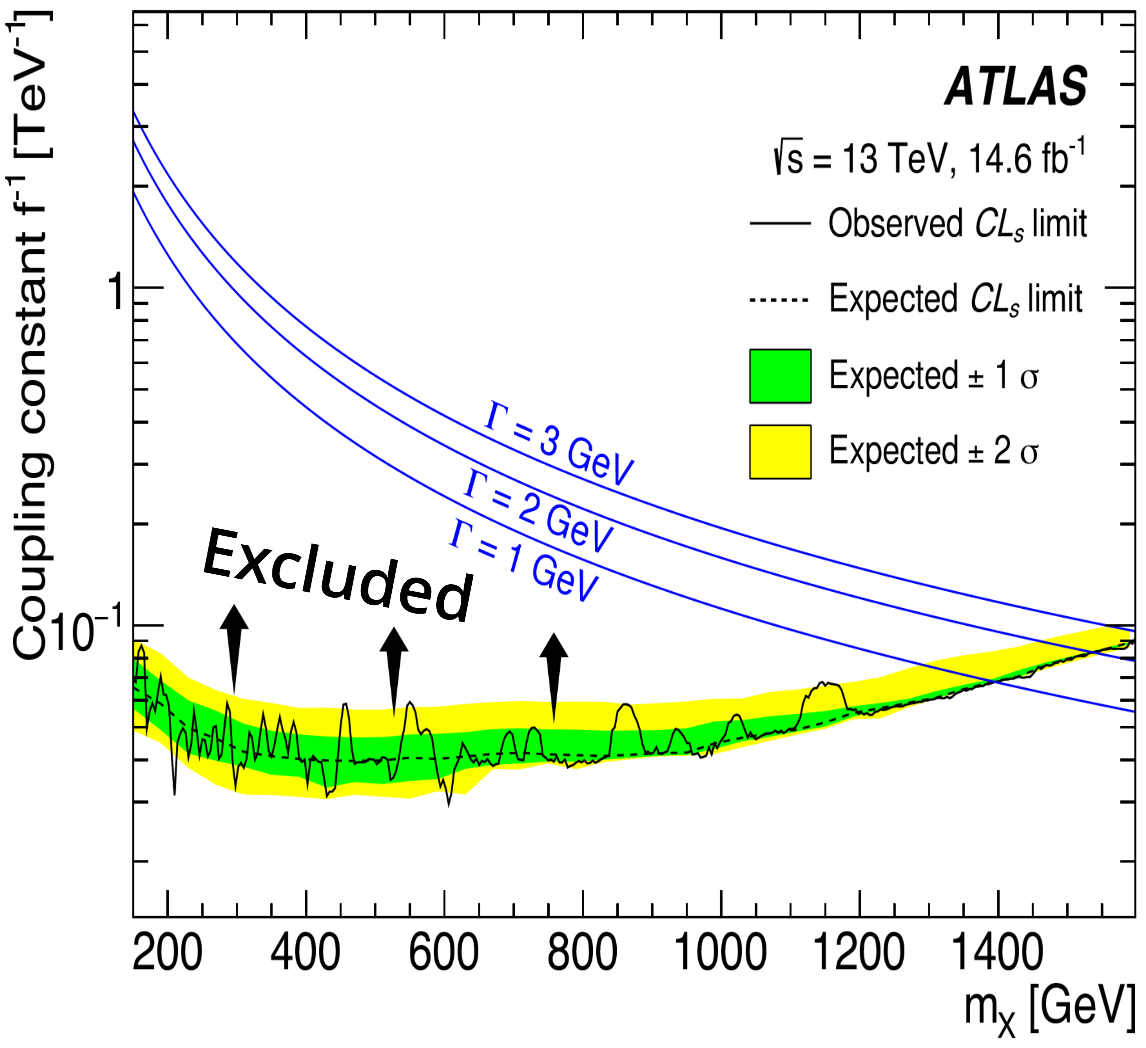


Systematics

Source	Uncertainty
Signal yield uncertainty	
Pile-up reweighting	$^{+2.7}_{-2.6}\%$
Luminosity	$\pm 2.4\%$
Photon identification efficiency	$^{+1.6}_{-1.5}\%$
Photon isolation efficiency	$\pm 1.9\%$
Beam optics between ATLAS central and AFP detectors	$^{+0.8}_{-3.4}\%$
AFP global alignment	$^{+10.0}_{-8.6}\%$
Proton reconstruction efficiency	$^{+3.0}_{-2.2}\%$
Showering in the AFP	$^{+0.0}_{-6.6}\%$
Background modelling (mass-dependent)	$\pm$(0.02–0.7) events
Signal modelling	
Photon energy resolution	$^{+14.1}_{-4.8}\%$
Photon energy scale	$\pm$(0.5–1.0)%
Signal cross-section uncertainty	
Soft survival factor (exclusive process)	$\pm 2\%$
Soft survival factor (single-dissociative process)	$\pm 10\%$
Soft survival factor (double-dissociative process)	$\pm 50\%$

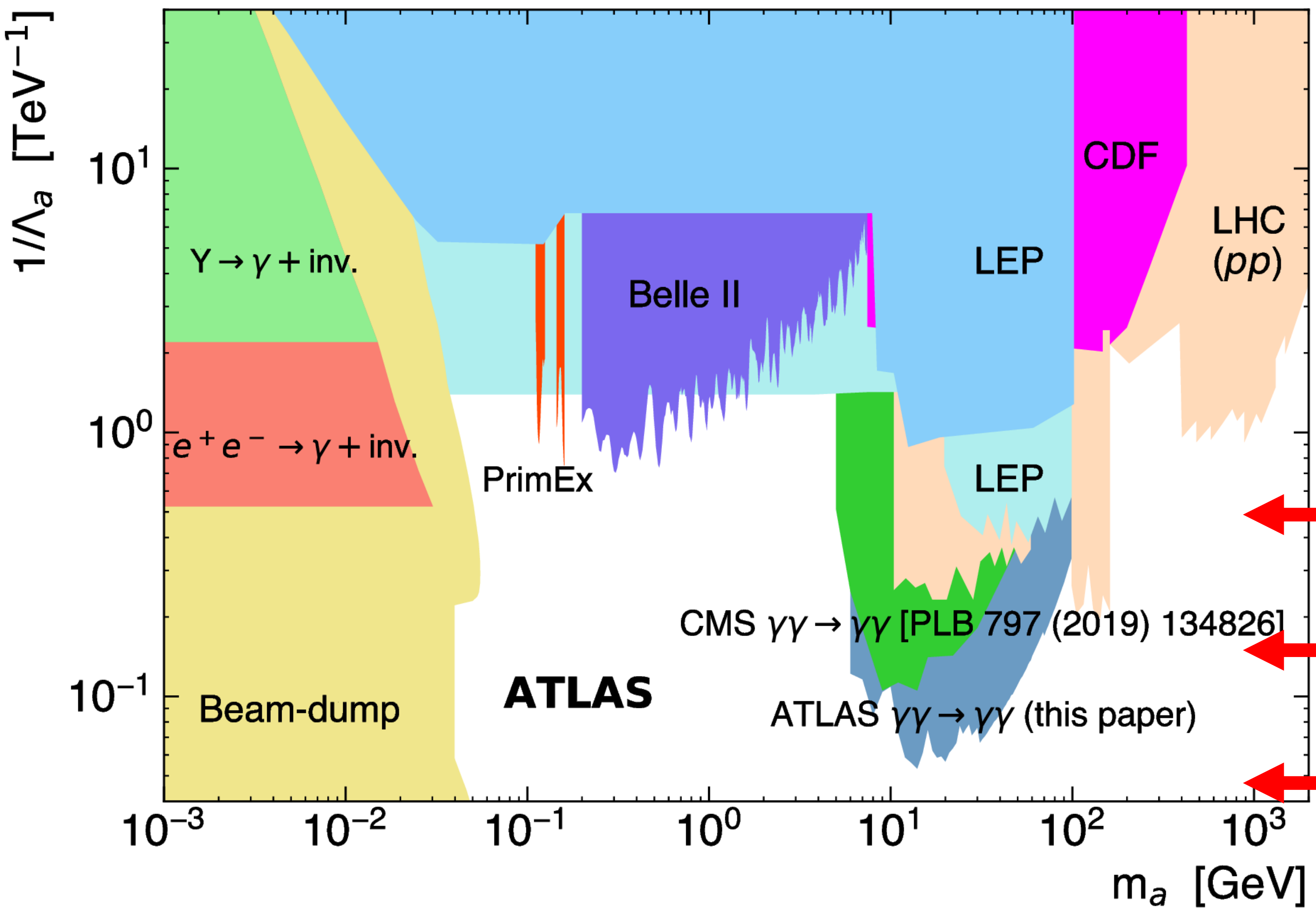
Exclusion limits

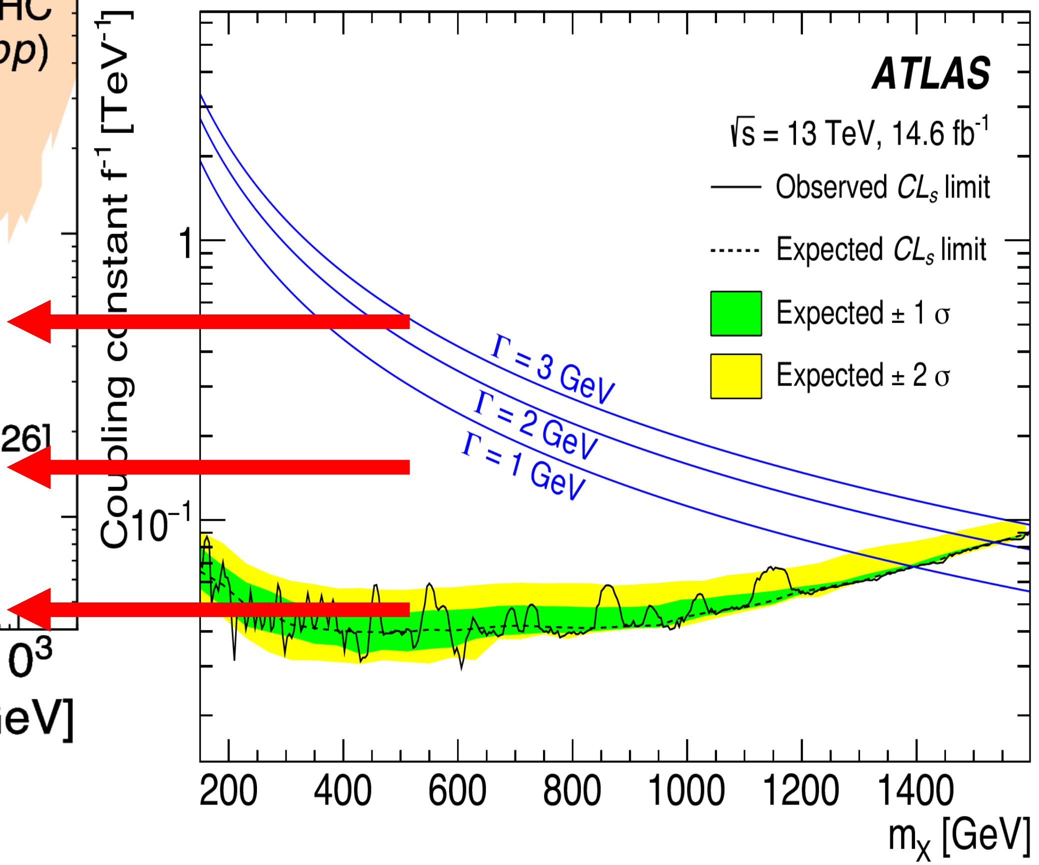




This analysis extends previous limits, JHEP 03 (2021) 243, in high mass region

Existing constraints from JHEP 12 (2017) 044





Further reading

- Initial Discussion: LHC Working Group on Forward Physics and Diffraction, CERN, 7–8 Dec 2017
- Patrick Odagiu, Searching for ALPs in light-by-light scattering in pp collisions using AFP proton tagging with the ATLAS detector, CERN-STUDENTS-Note-2019-225
- Tomas Chobola, Study of light-by-light scattering with the ATLAS Forward Proton (AFP) Detector at CERN, CERN-THESIS-2020-058
- Petr Dostal: Optimization of the Matching Criteria Between the ATLAS and AFP Detectors at CERN, CERN-THESIS-2020-106
- Hussain Kitagawa, Optimization of diphoton acoplanarity for an Axion-Like Particle in Light-by-Light scattering with the ATLAS detector at CERN, CERN-STUDENTS-Note-2020-029
- Hussain Kitagawa, Study of jet multiplicity for an Axion-Like Particle search in Light-by-Light scattering with the ATLAS central detector and the ATLAS Forward Proton detector, CERN-STUDENTS-Note-2021-237
- Gen Tateno, Search for resonances in light-by-light scattering in 14.6 fb^{-1} of pp collisions at $\sqrt{s}$=13 TeV, CERN-THESIS-2023-006, PhD
- Ondrej Matousek, Axion-Like-Particle Search Using Machine Learning for the Signal Sensitivity Optimization with Run-2 LHC Data Recoded by the ATLAS Experiment, defense date 14 June 2023

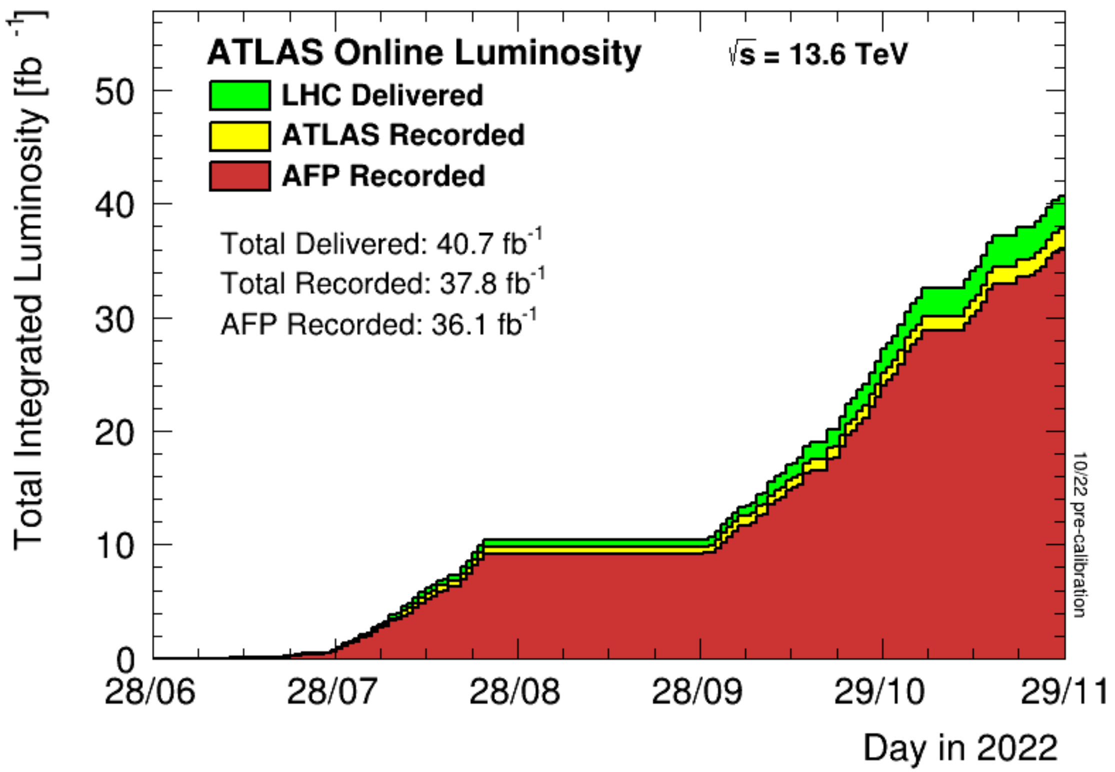
Conclusions

- Run-2 data analysed (data taken in 2017)
- Matching between $\gamma\gamma$ and proton measurements with AFP
- No indiction of Light-by-Light scattering via an ALP
- Limits set on production cross-section and coupling

Plans for the future

- Much increased statistics with Run-3 data
- Time-of-Flight (ToF) detector for background reduction
- Using machine learning for signal and background separation

https://twiki.cern.ch/twiki/pub/AtlasPublic/ForwardDetPublicResults



AFP Run-3 data-taking in 2022: 36.1 fb^{-1} at 13.6 TeV