



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

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André Sopczak
(on behalf of the ATLAS Collaboration)

ALP with AFP

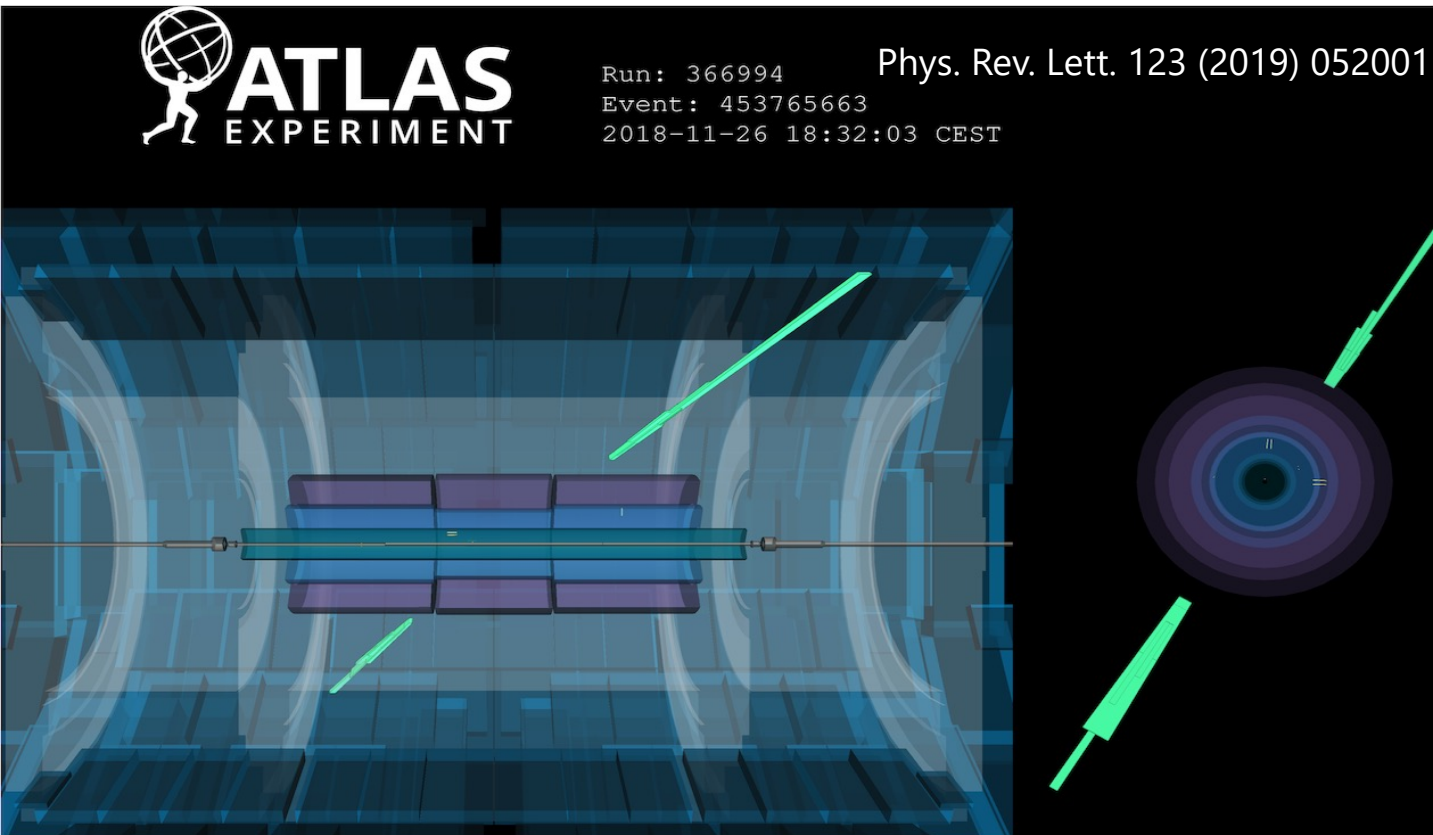
IEAP CTU in Prague

Visegrad Workshop, Budapest
12 March 2024



Light-by-light scattering at LHC

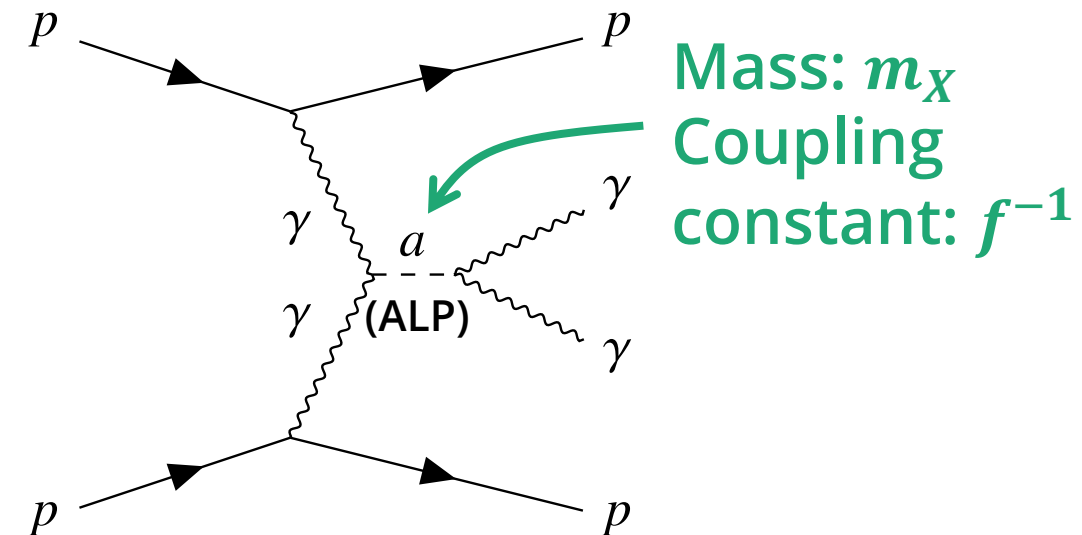
SM $\gamma\gamma \rightarrow \gamma\gamma$ observed in lead ion collisions



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

But BSM can enhance it!

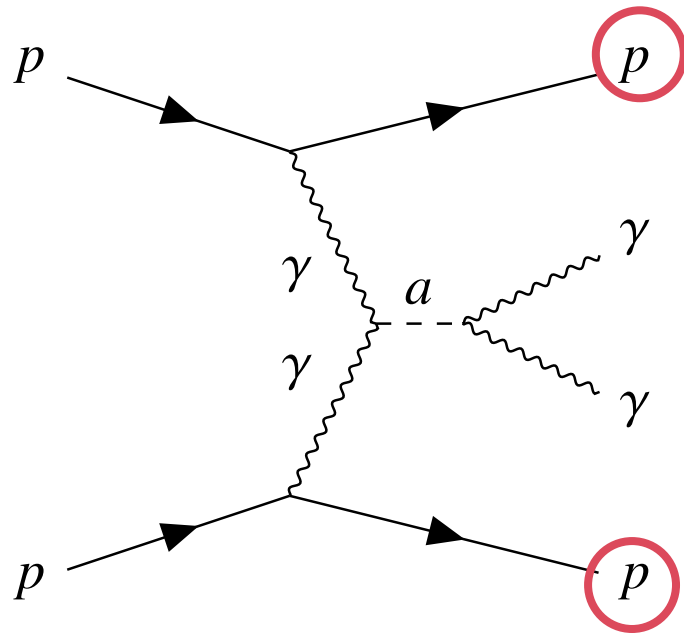
e.g. **Axion-like particle (ALP)**
 (assumed for signal modeling)



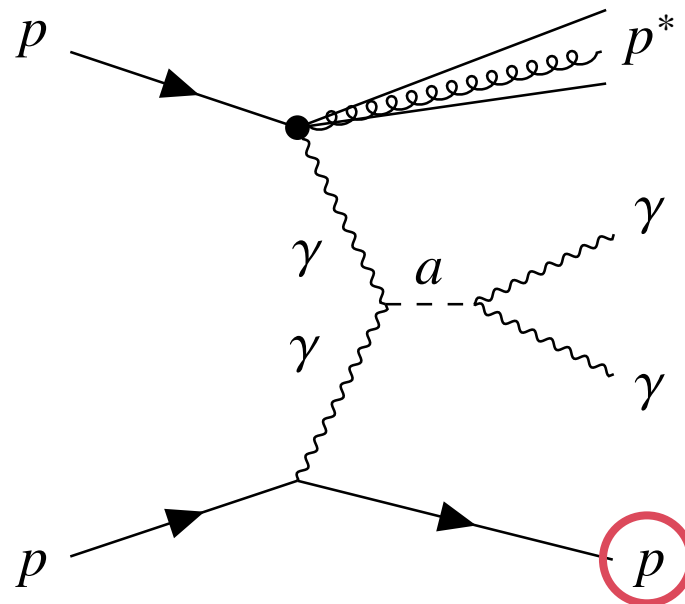
Signal models

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

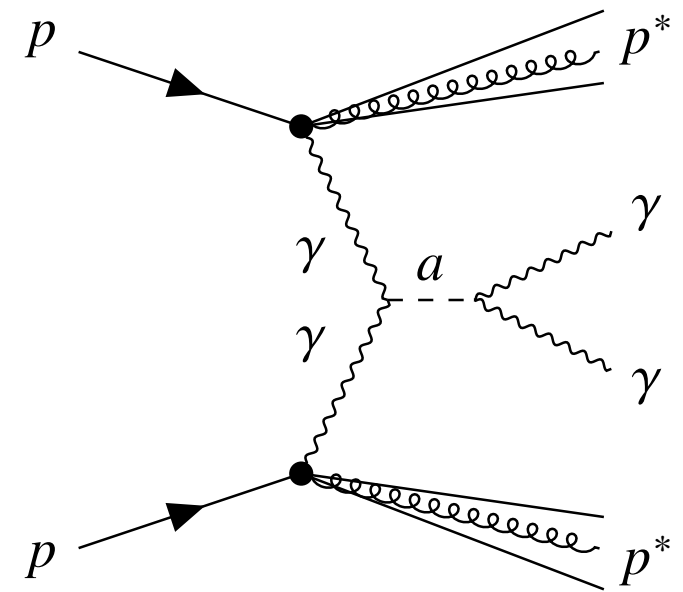
Exclusive event



Single-dissociative
(**SD**) event



Double-dissociative
(**DD**) event

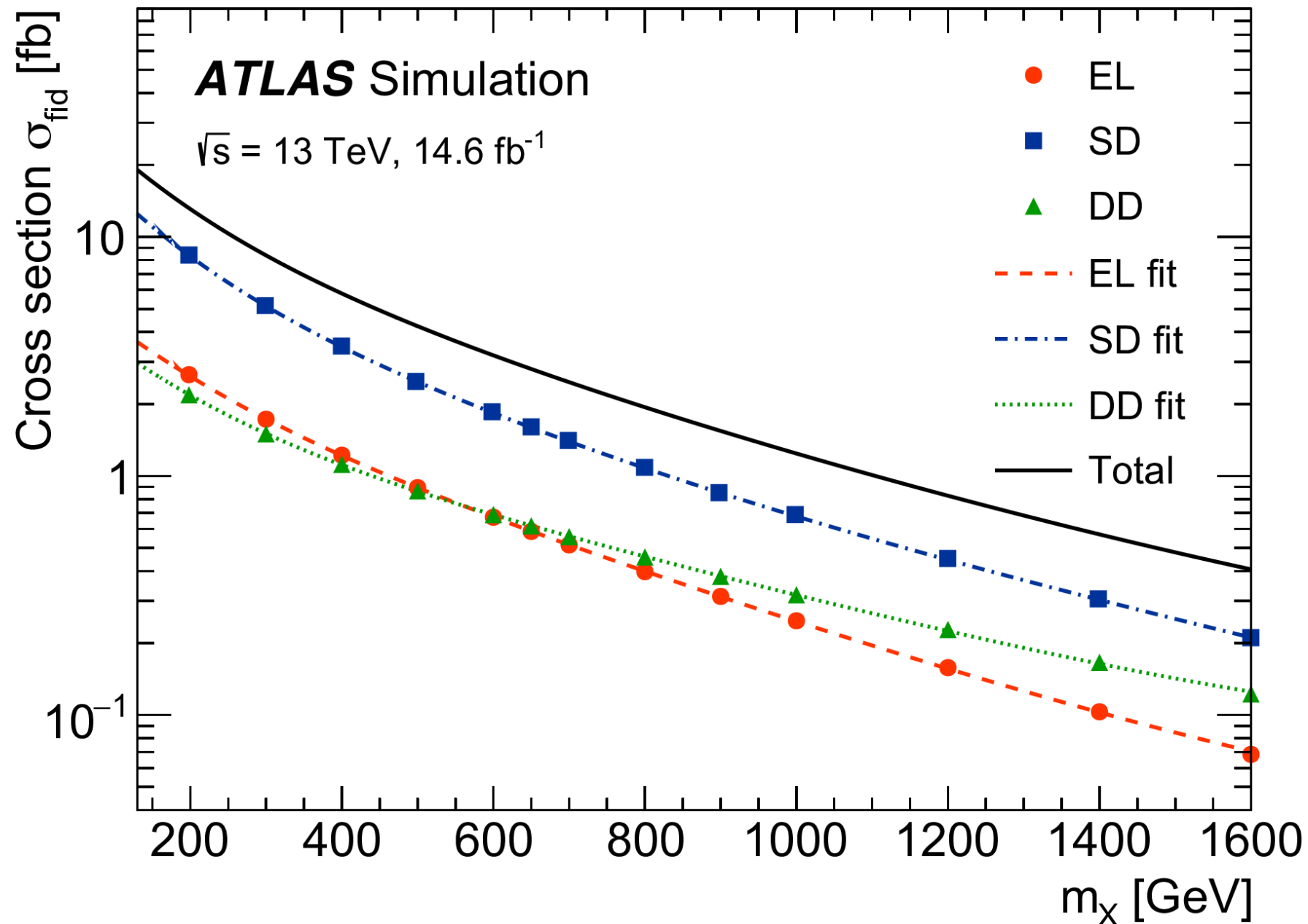


ALP Production Cross-section

Coupling constant
 $f^1 = 0.05 \text{ TeV}^{-1}$

SuperChic 4.02
 for EL

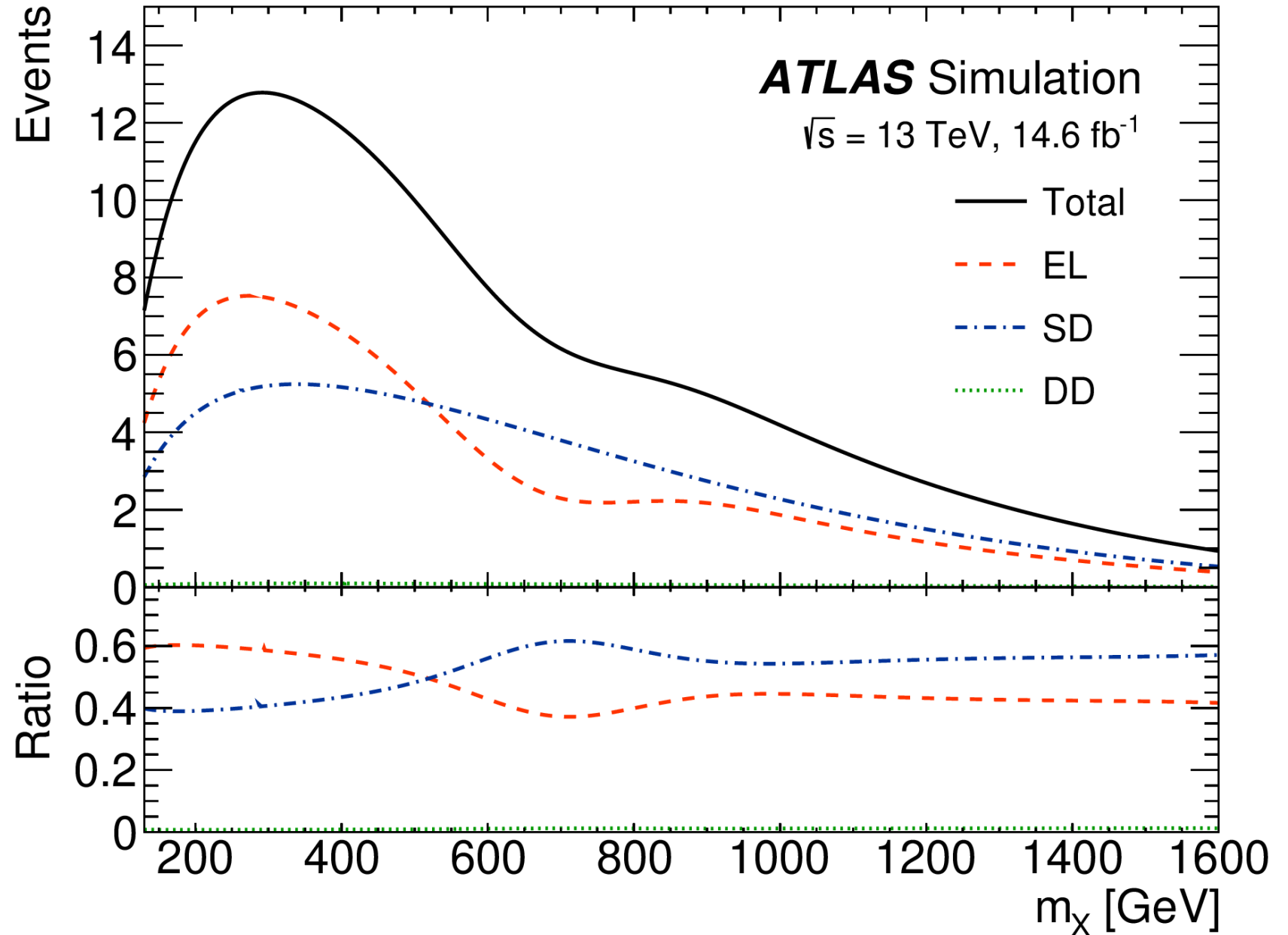
SuperChic 4.14
 for SD and DD



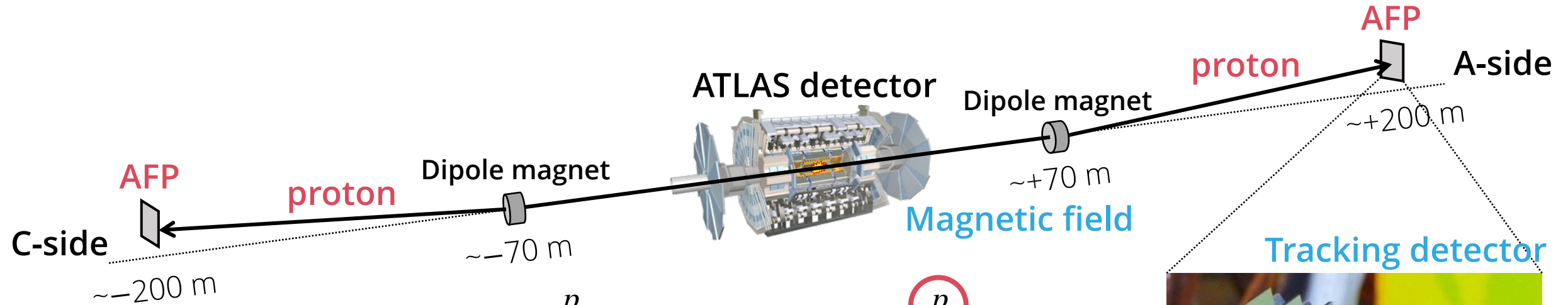
Signal Yields

Coupling constant
 $f^1 = 0.05 \text{ TeV}^{-1}$

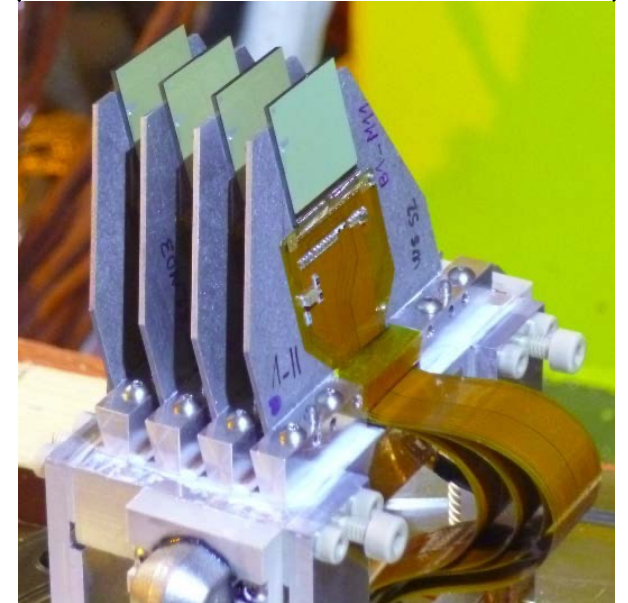
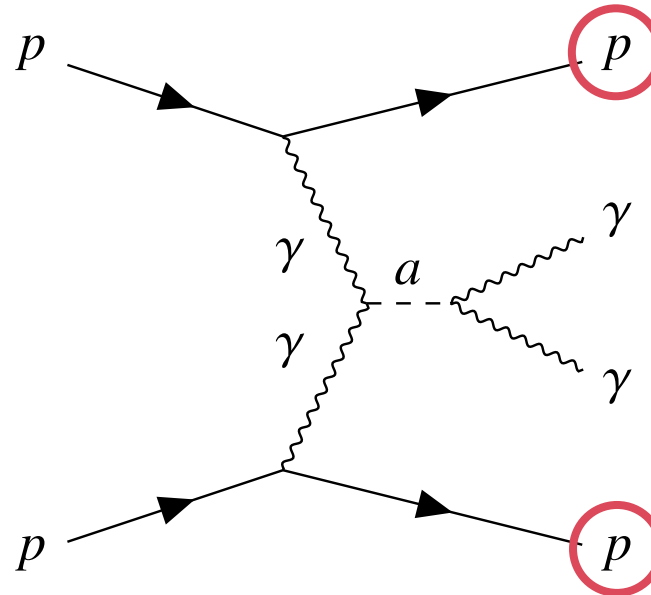
signal efficiency \times
 acceptance models \times
 cross-section \times
 luminosity



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

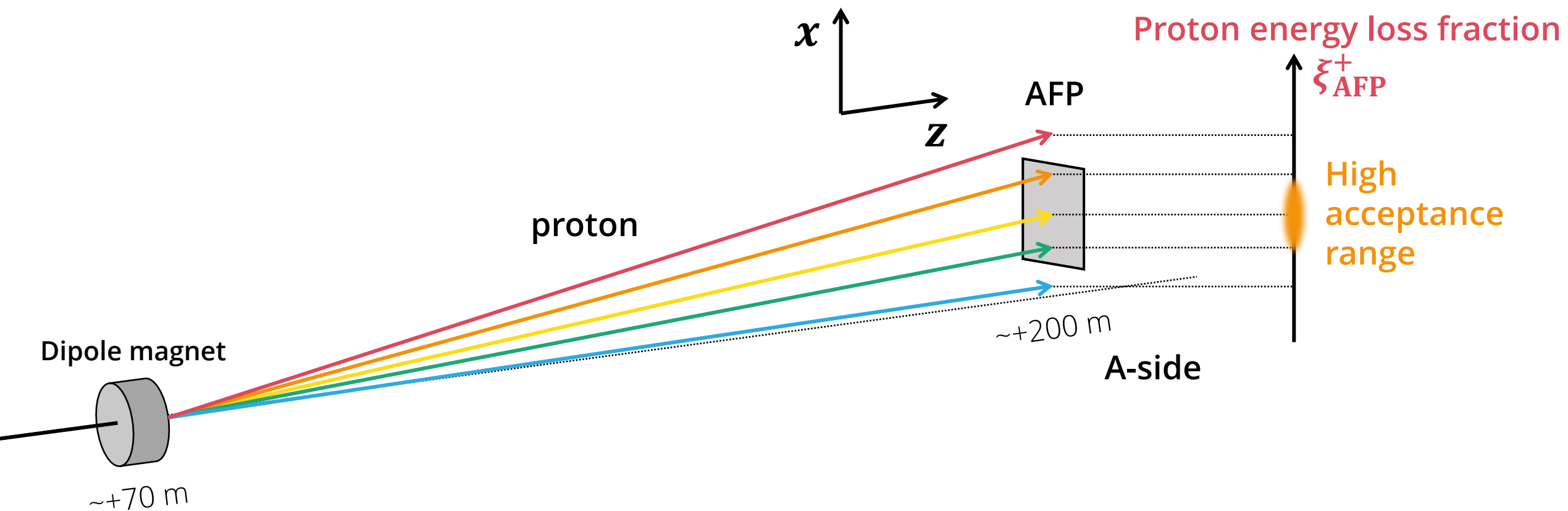


Example:
 Register protons
 from light-by-light
 scattering



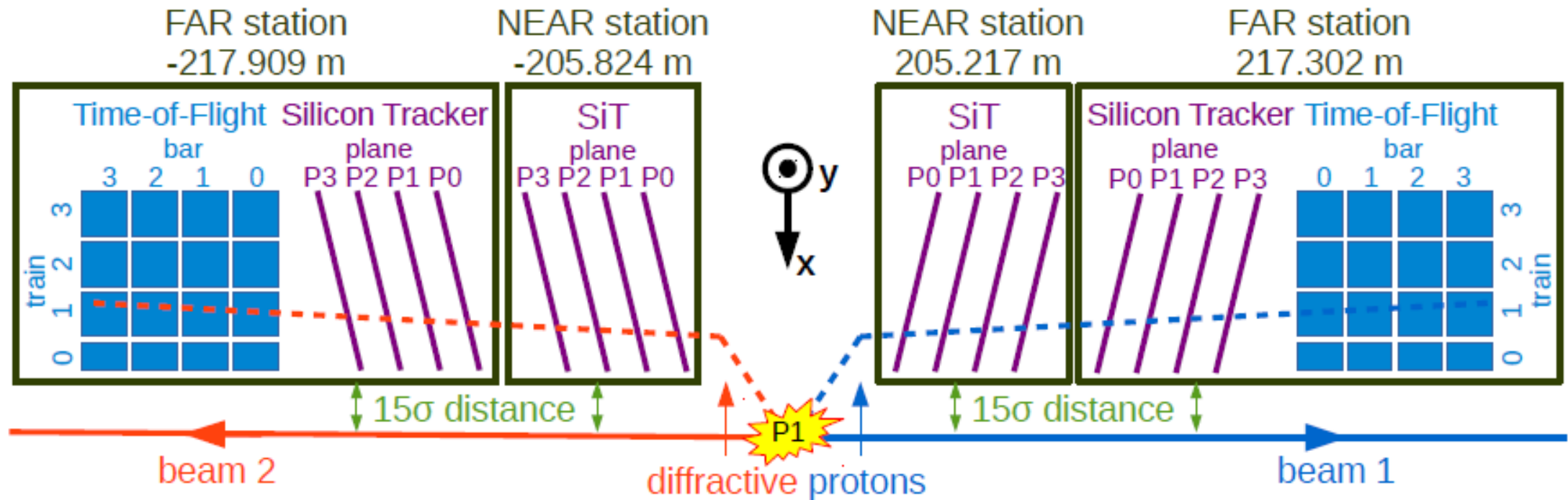
AFP detector

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



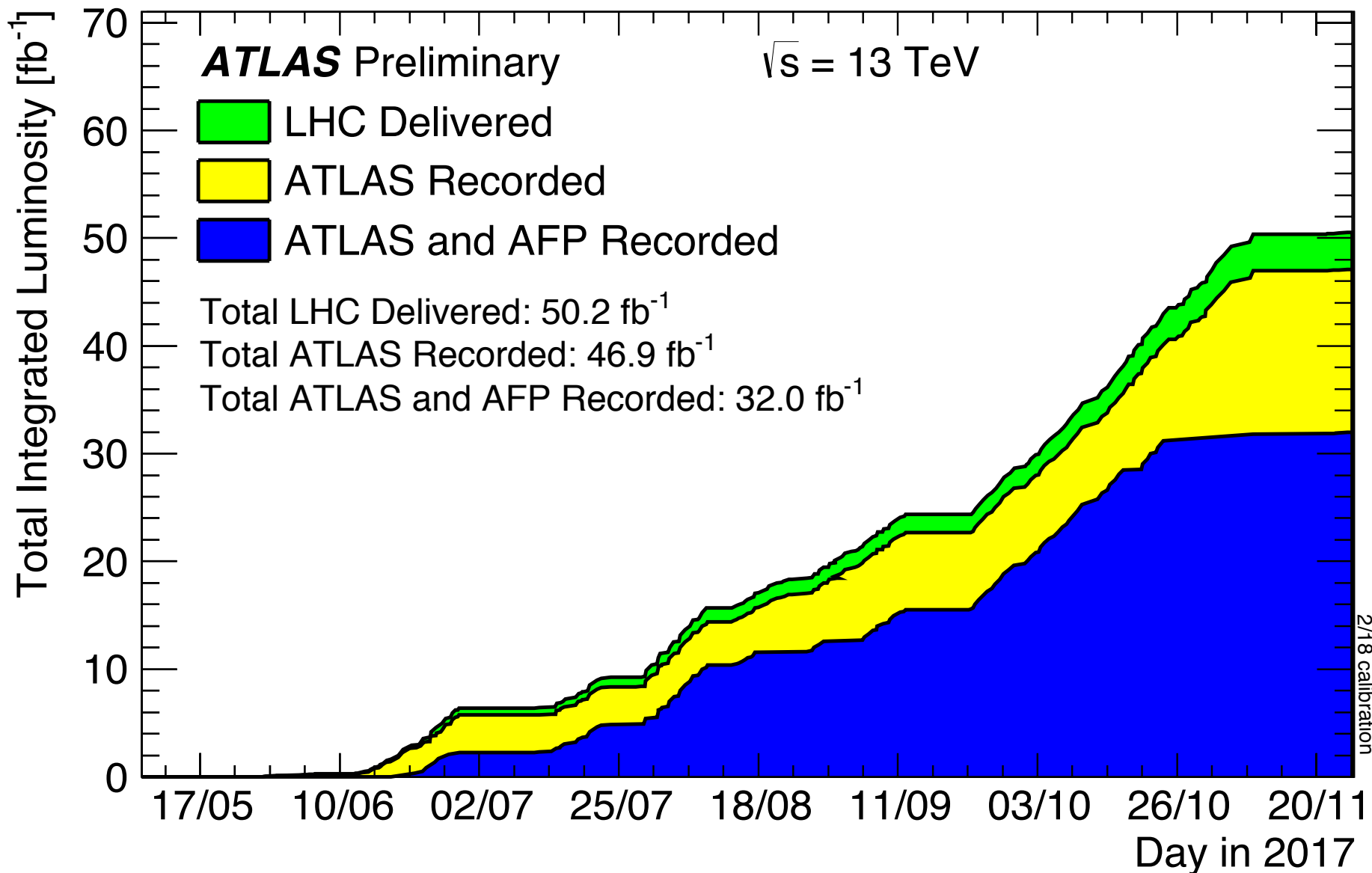
AFP detector

- 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>

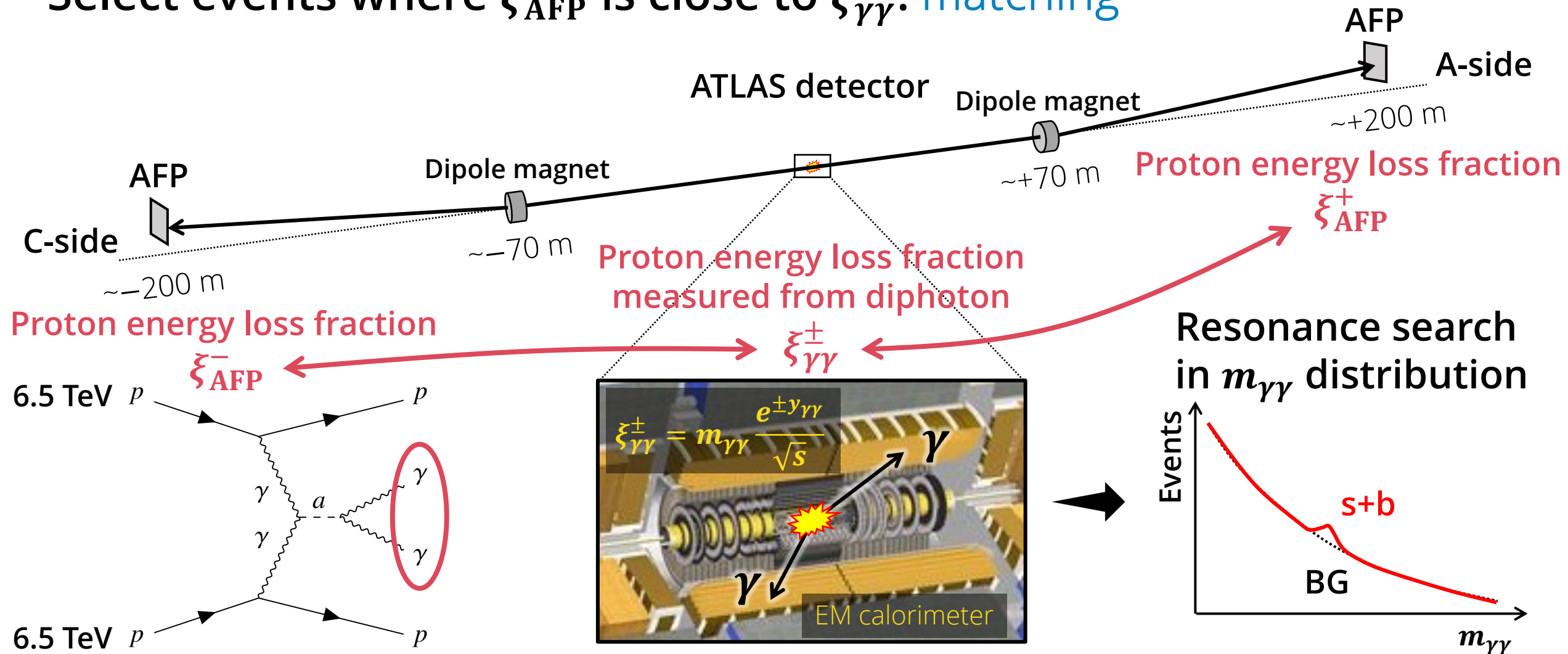


Used for
this analysis
14.6 fb⁻¹

Purpose and main strategy

Diphoton resonance search using AFP

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



Event selection

1. Require diphoton to be back-to-back

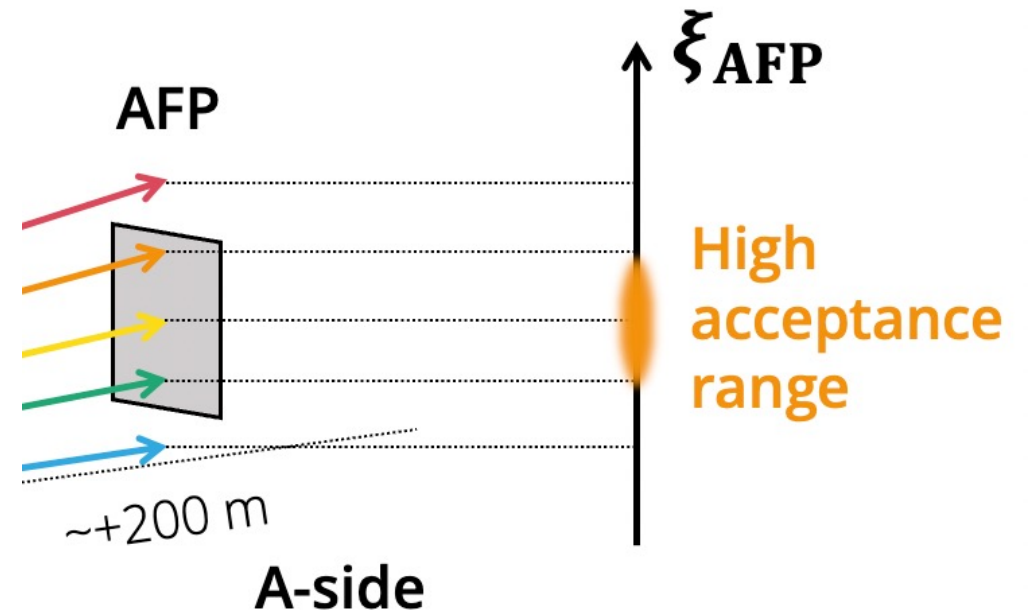
$$\text{Acoplanarity } A_{\phi}^{\gamma\gamma} \equiv 1 - \frac{|\Delta\phi|}{\pi} < 0.01$$

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

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

3. At least one matching proton

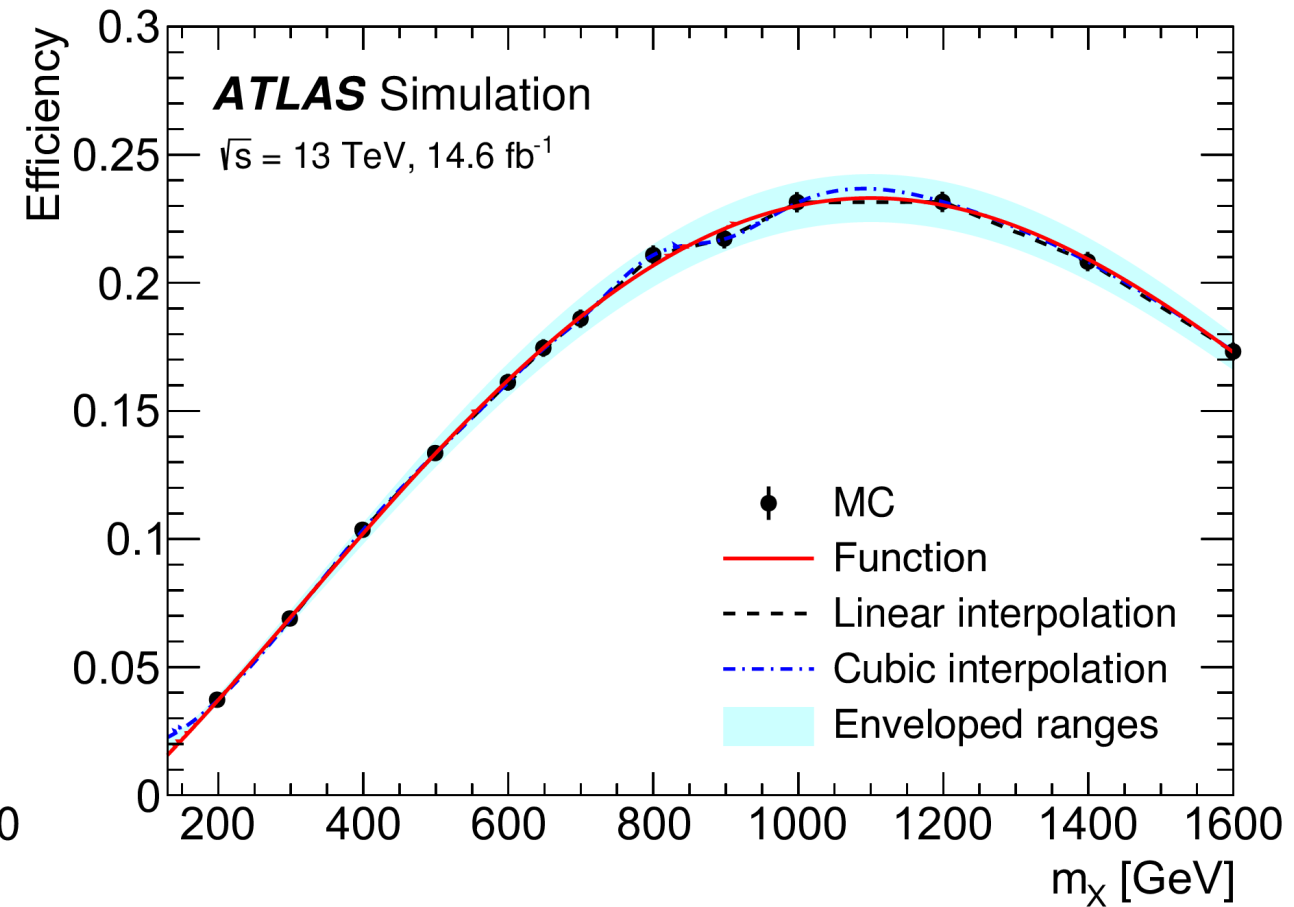
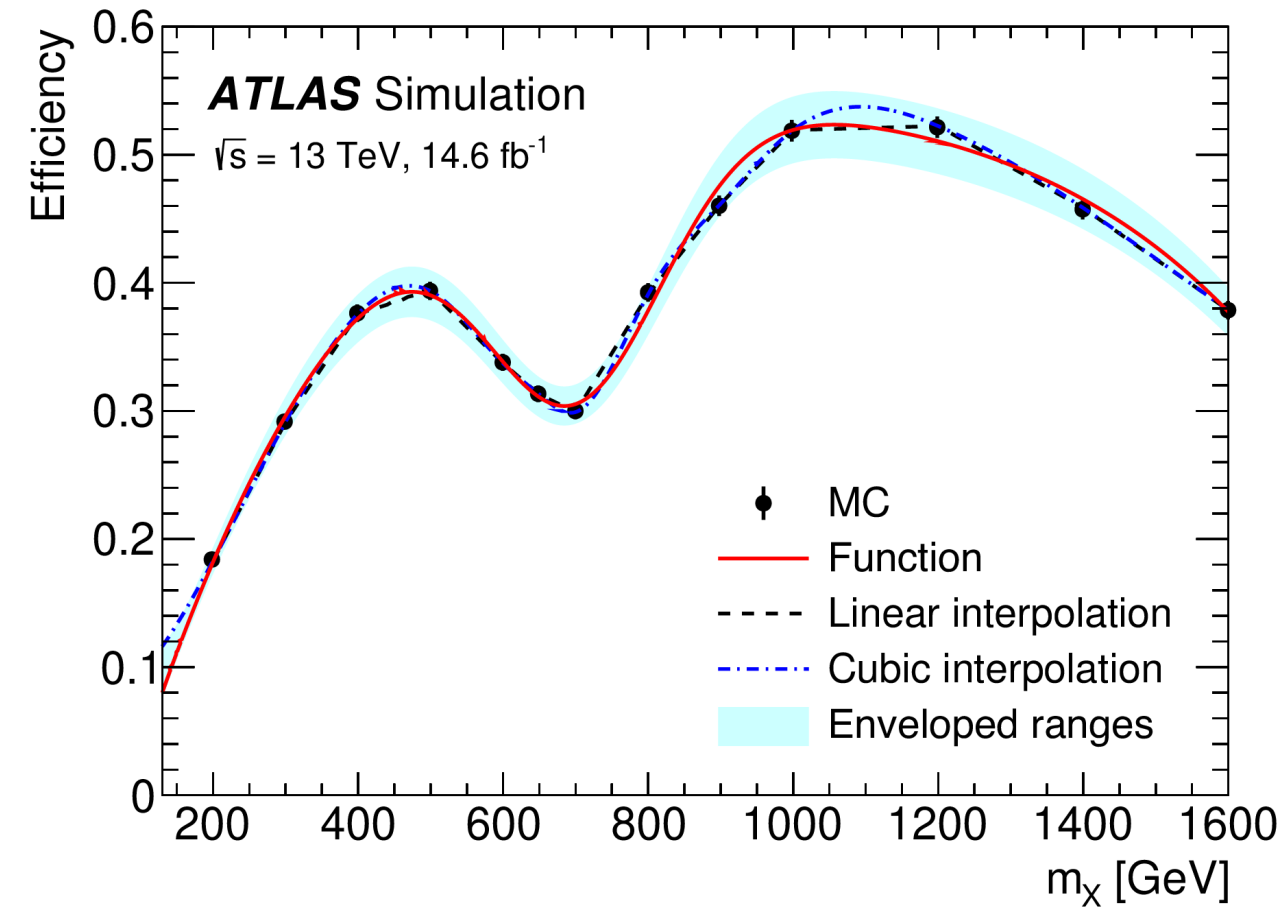
$$|\Delta\xi| \equiv |\xi_{\text{AFP}} - \xi_{\gamma\gamma}| < 0.004 + 0.1\xi_{\gamma\gamma}$$



Selection efficiency as a function of ALP mass¹²

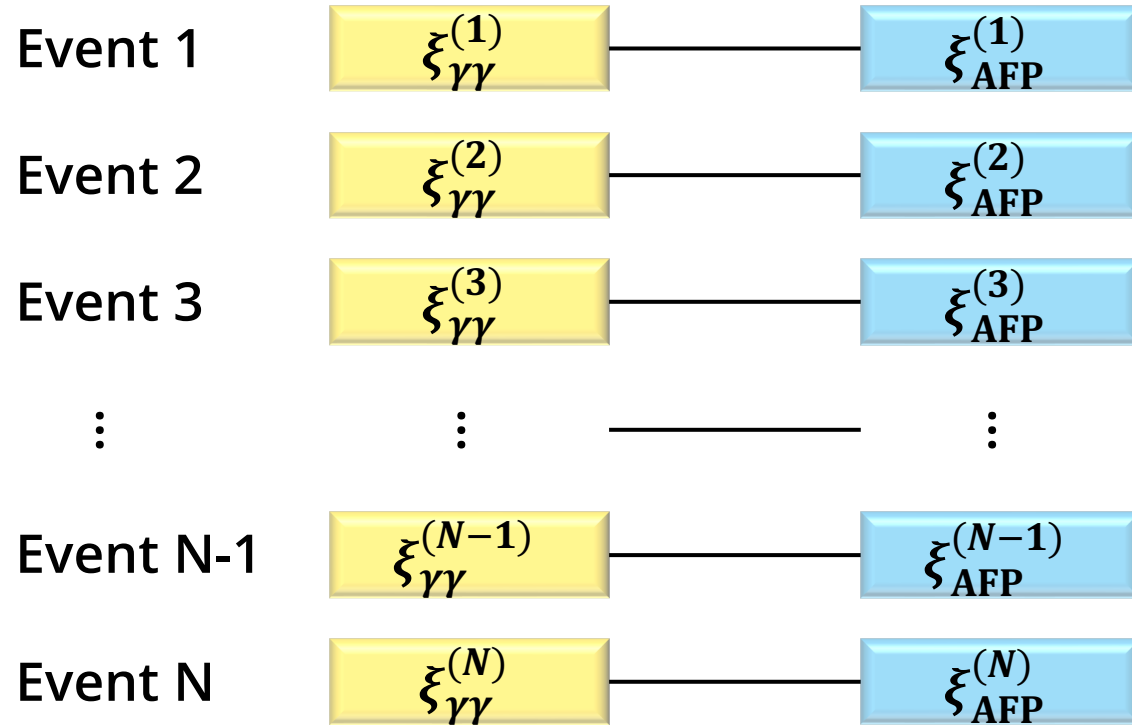
Exclusive event

Single-dissociative
(SD) event



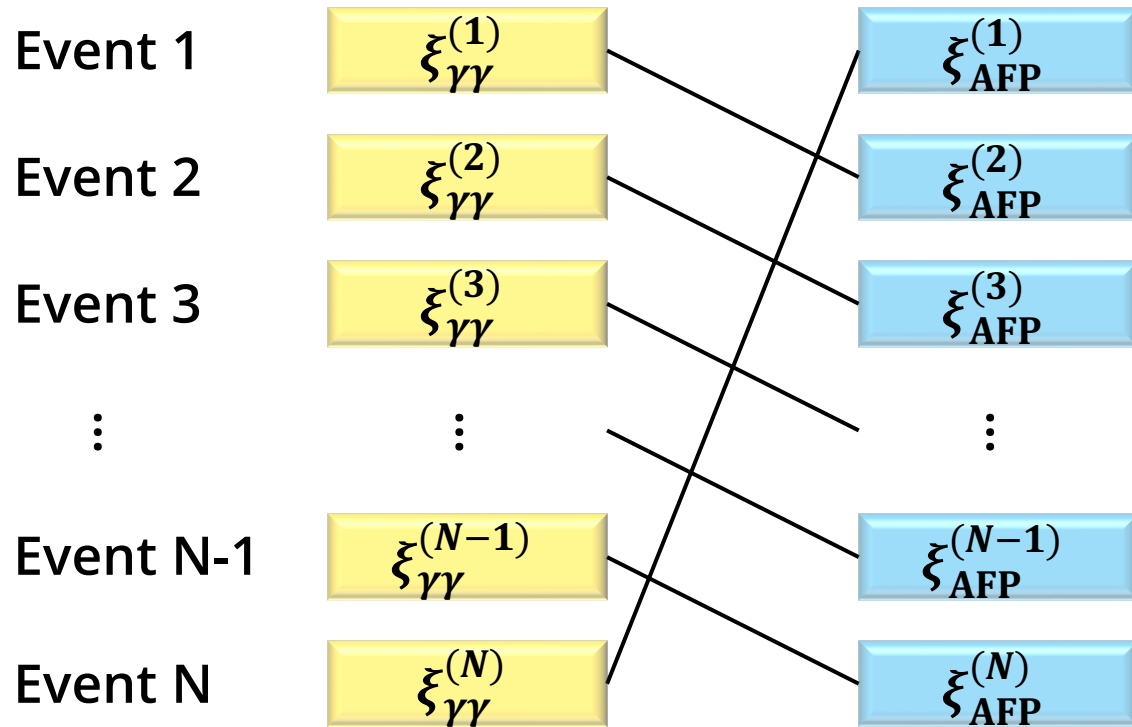
Background sample generation

Photons and protons are recorded for each event



Background sample generation

Photons and protons are recorded for each event



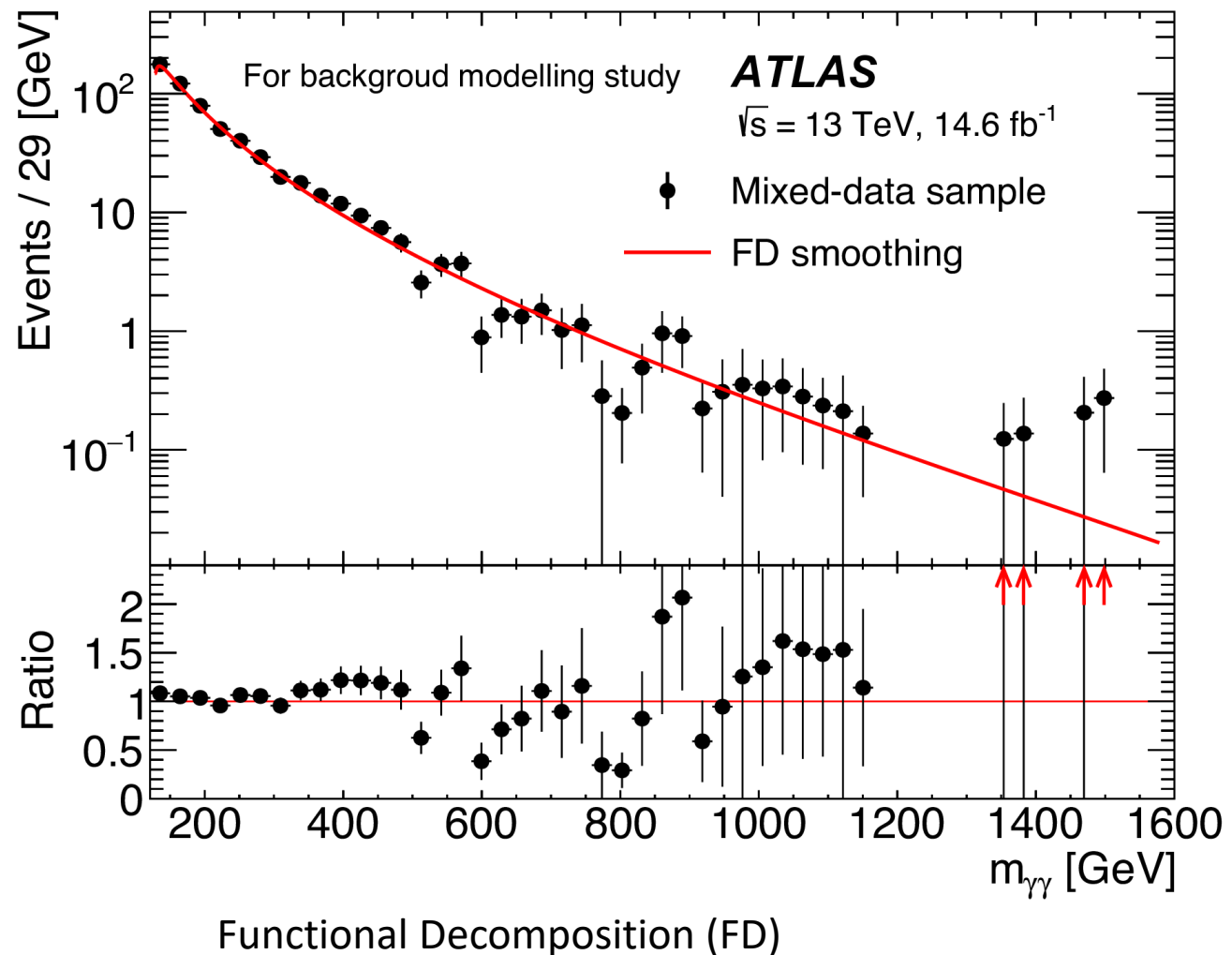
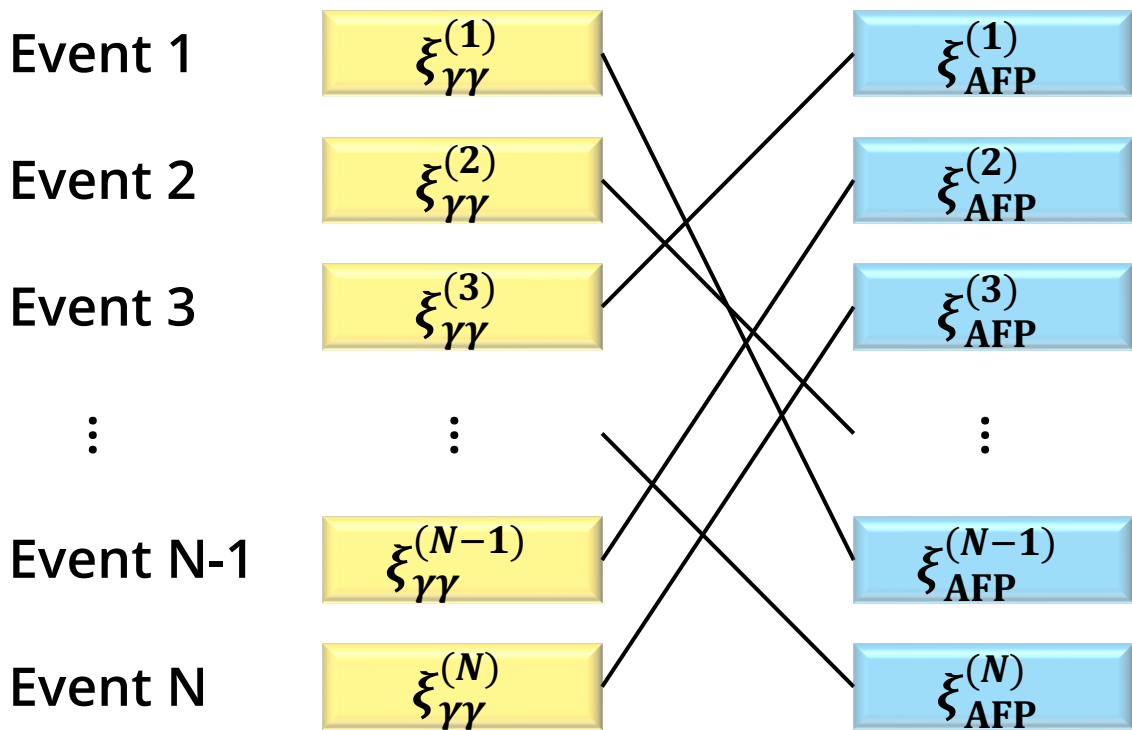
Reassignment of
protons to diphotons



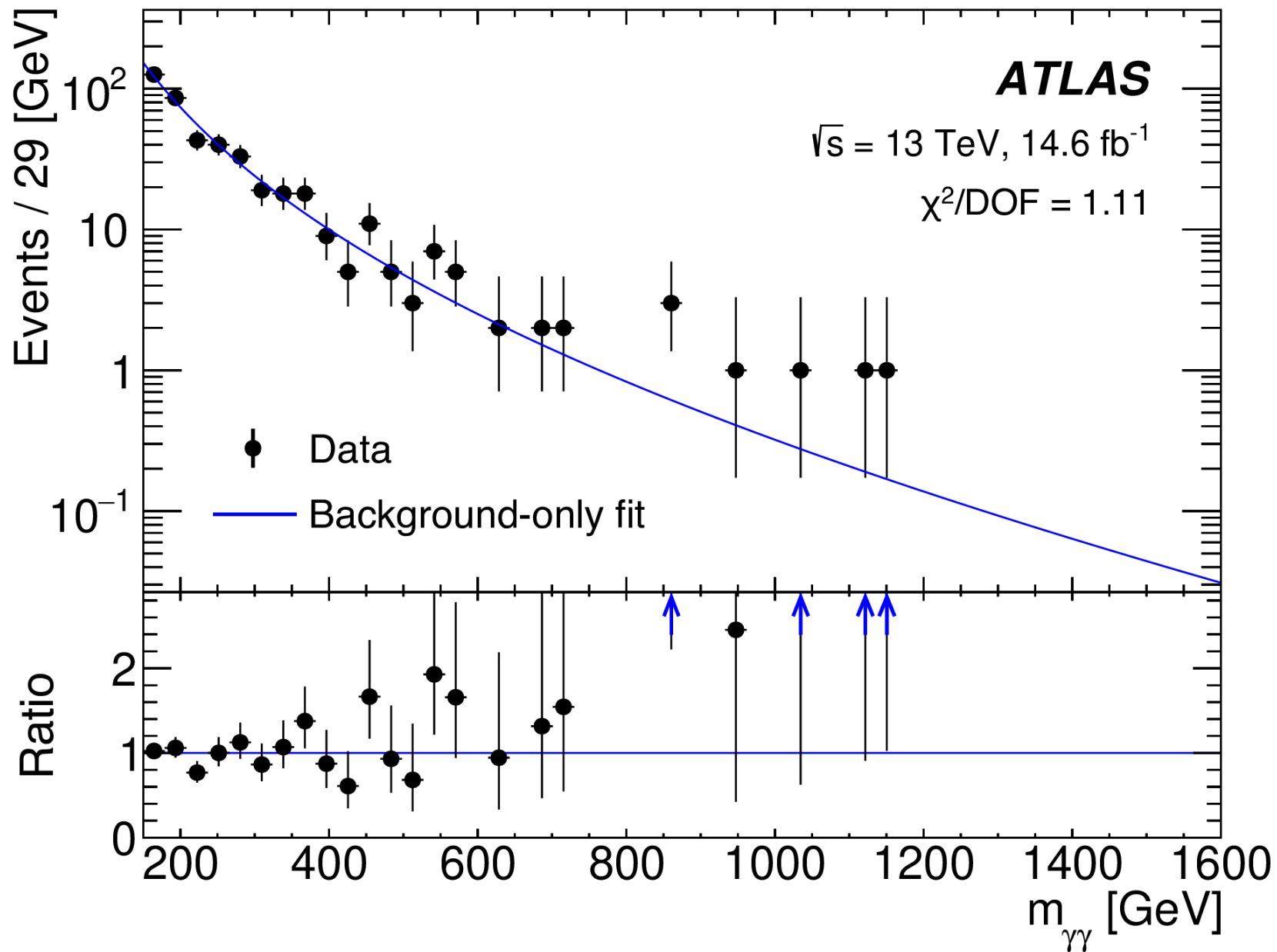
→ Pure combinatorial BG sample

Background sample generation

All other combination of the reassignment

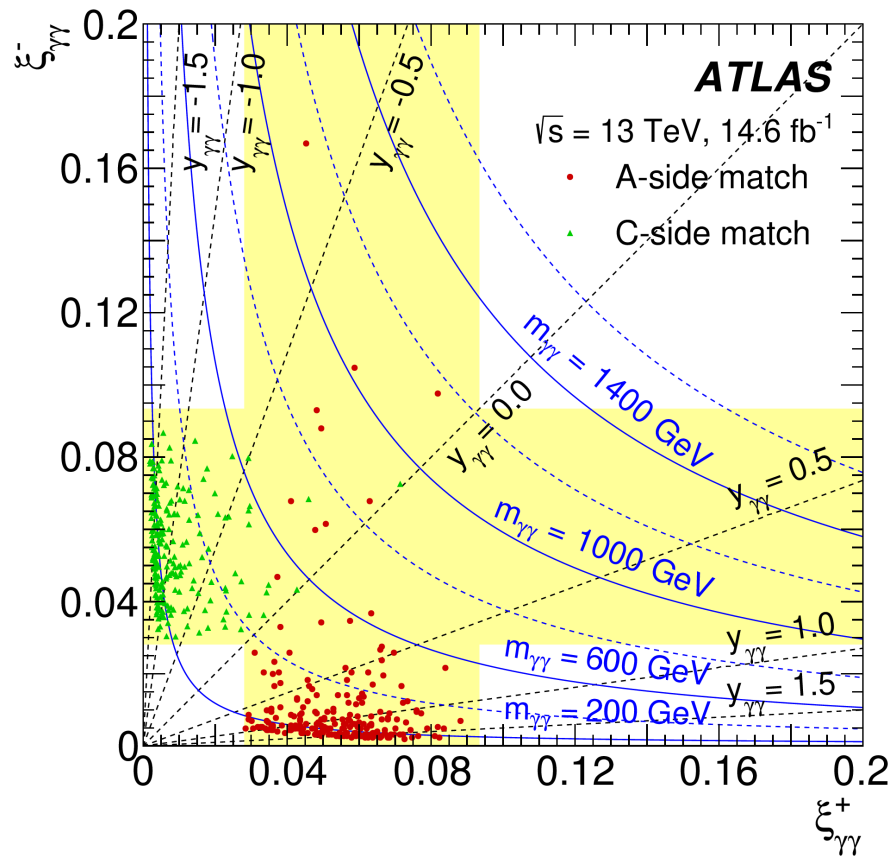


Data and background-only fit

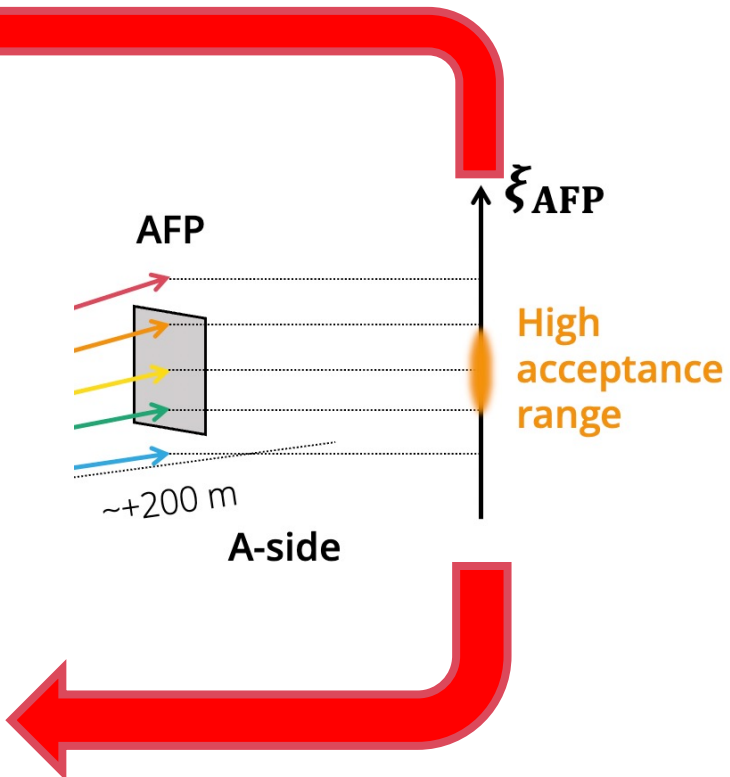


Search results

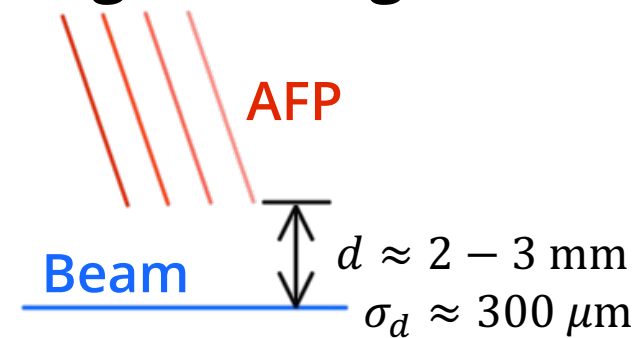
441 events observed



No double matching



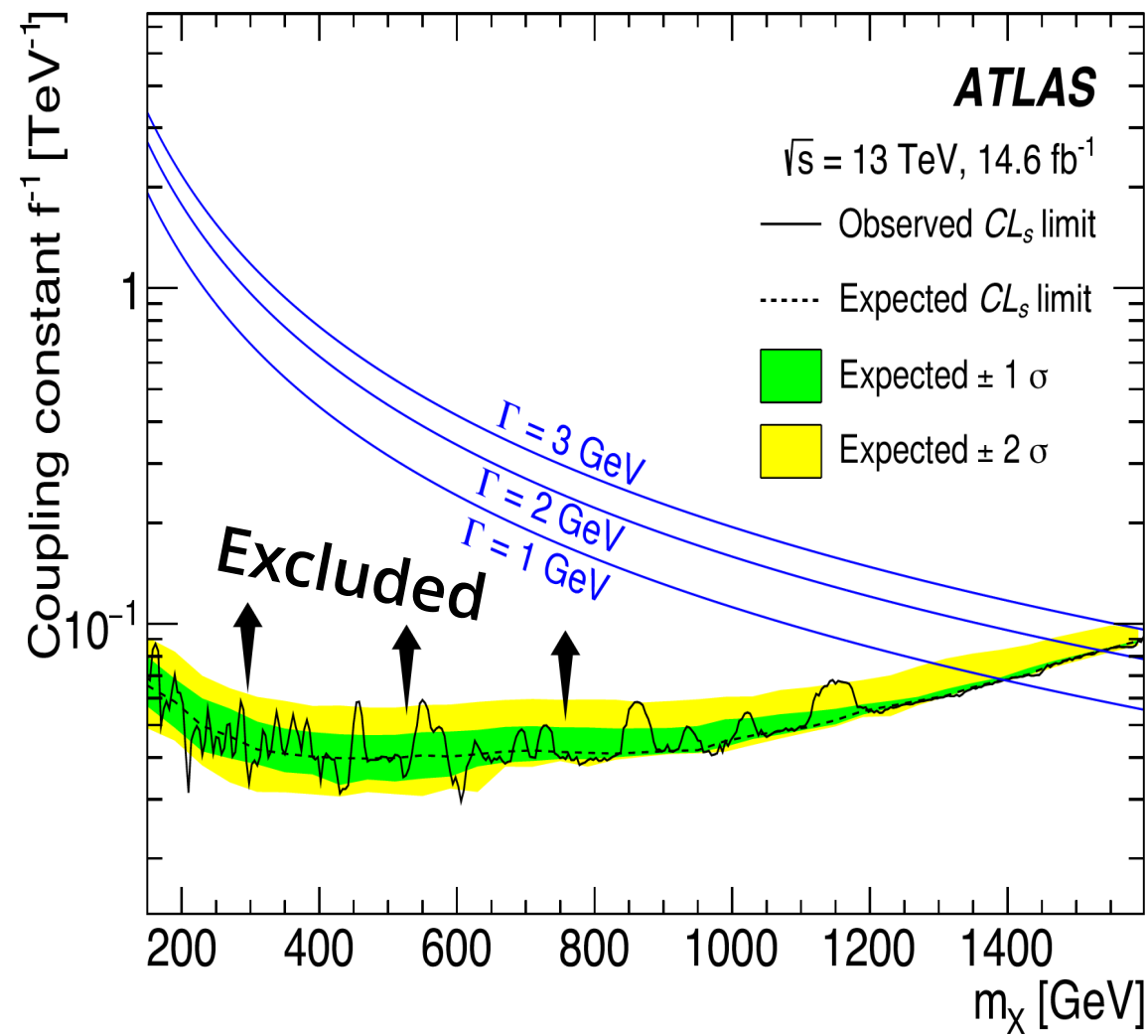
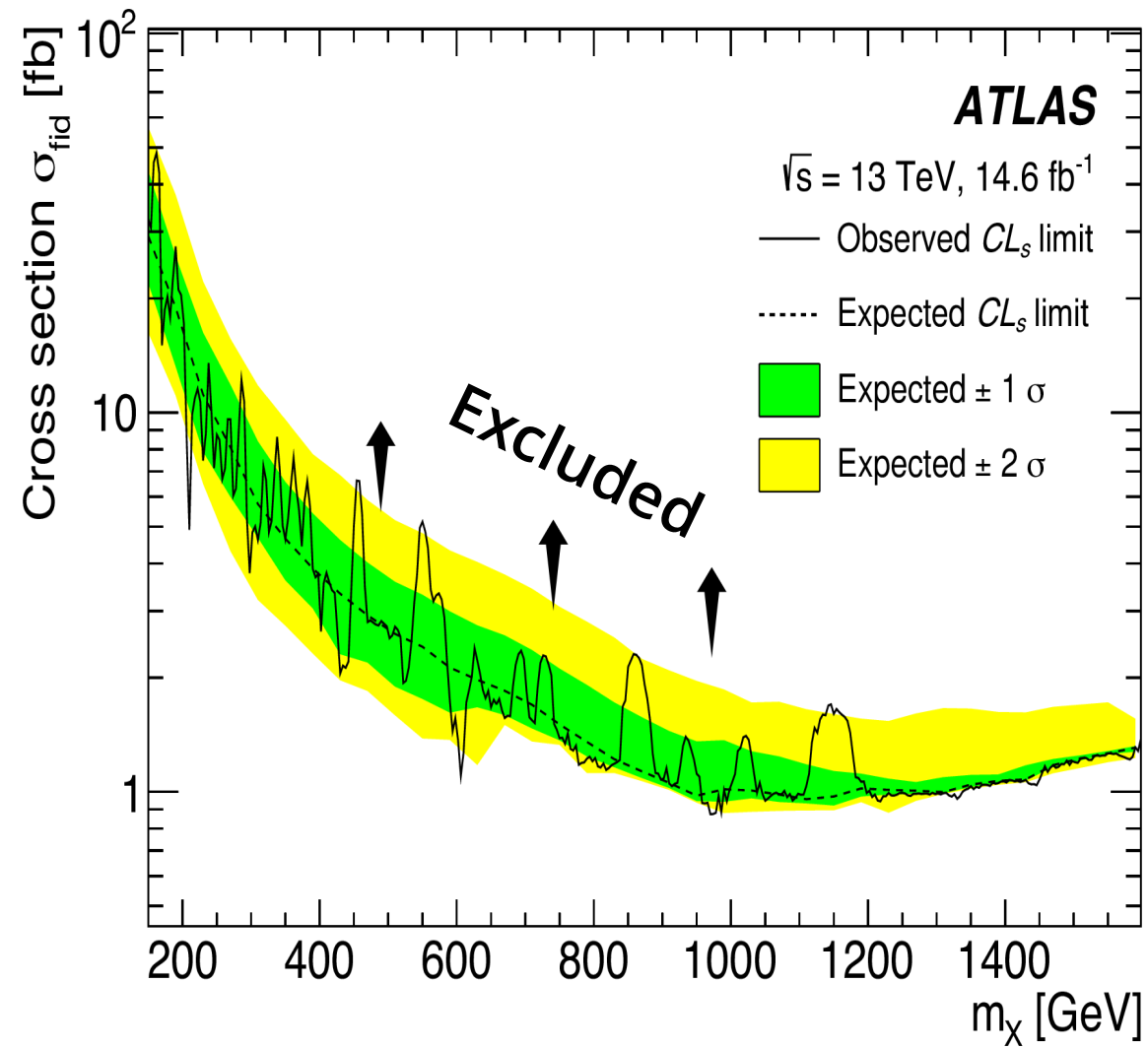
Dominant systematic uncertainty:
 AFP global alignment



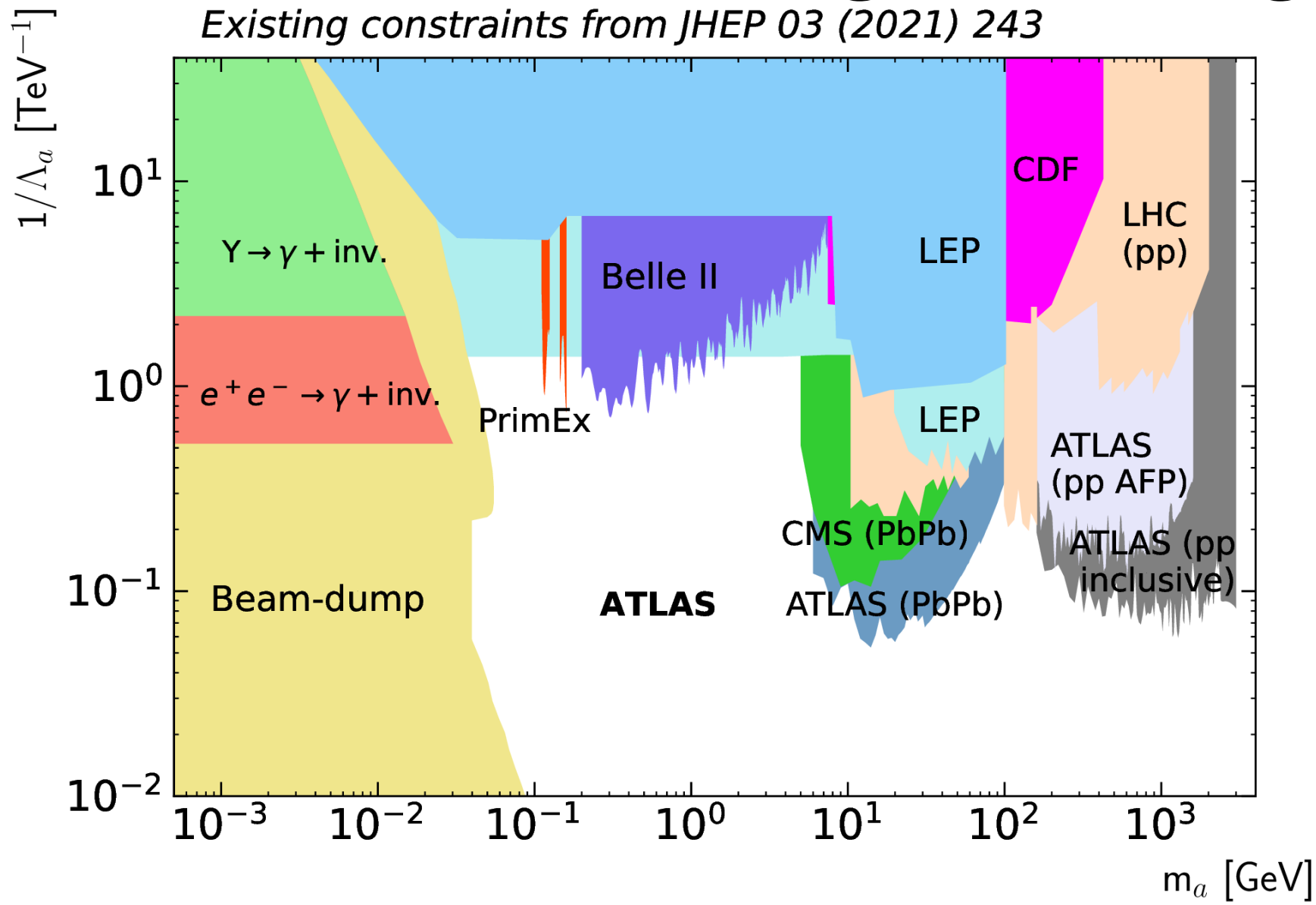
Systematics

Source	Uncertainty
Signal yield uncertainty	
Pile-up reweighting	+2.7% -2.6
Luminosity	±2.4%
Photon identification efficiency	+1.6% -1.5
Photon isolation efficiency	±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)	±(0.02–0.7) events
Signal modelling	
Photon energy resolution	+14.1% -4.8
Photon energy scale	±(0.5–1.0)%
Signal cross-section uncertainty	
Soft survival factor (exclusive process)	±2%
Soft survival factor (single-dissociative process)	±10%
Soft survival factor (double-dissociative process)	±50%

Exclusion limits



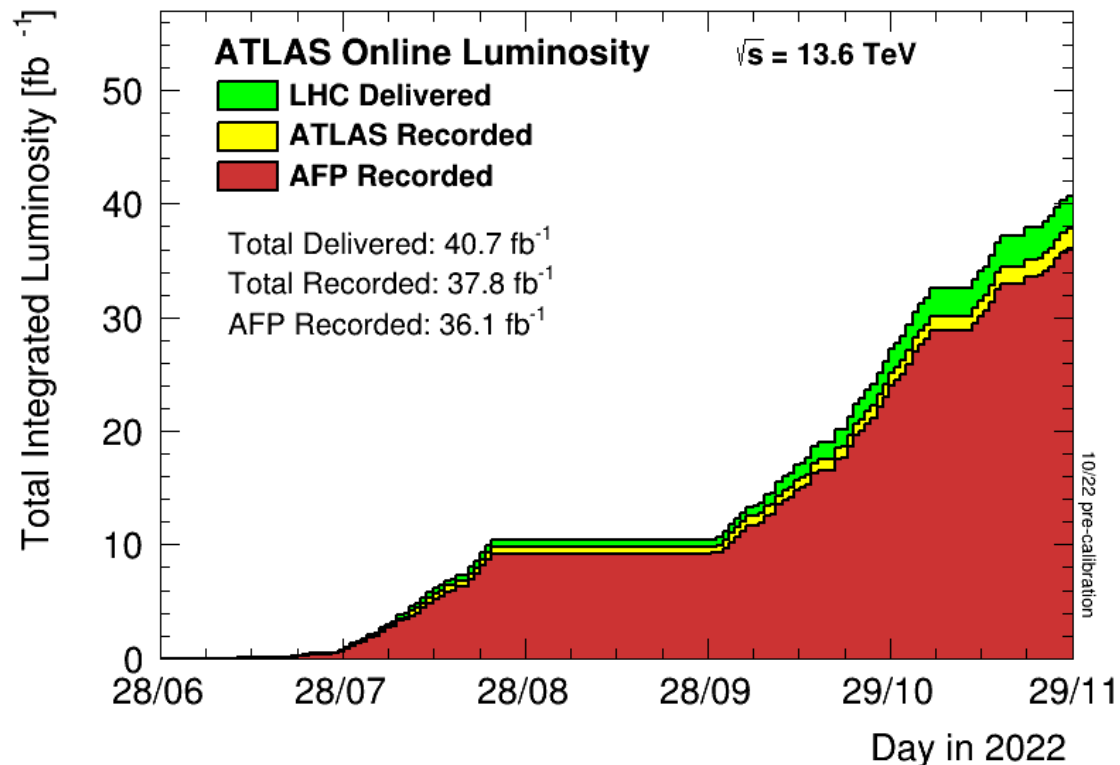
This analysis extends previous limits, JHEP 03 (2021) 243, in high mass region



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/bin/view/AtlasPublic/ForwardDetPublicResults>



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

- 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 $\sqrt{s}=13 \text{ TeV}$, [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, [CERN-THESIS-2023-075](#)
- Haritina Sakova (CERN 2023 summer student), Study of sensitivities for Axion-Like-Particles using the ATLAS Forward Proton (AFP) detector, [CERN-STUDENTS-Note-2024-005](#)

Conclusions

- Run-2 data analysed (data taken in 2017, 14.6 fb⁻¹)
- Matching between $\gamma\gamma$ and proton measurements with AFP
- No indication of Light-by-Light scattering via an ALP
- Limits set on production cross-section and coupling
- Outlook: LHC Run-3 analysis