Interesting Physics with Forward Proton Detectors at the LHC

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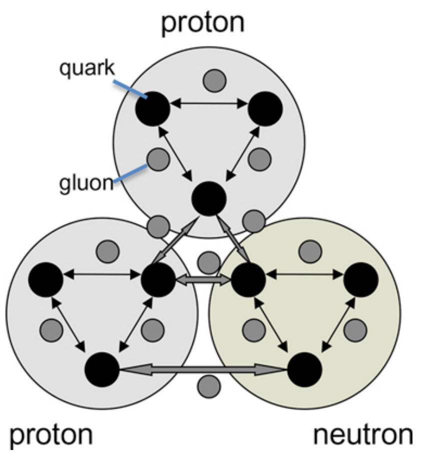
Outline

1. Diffractive Physics
2. γγ collider and Forward Protons (tagging)
3. ATLAS Forward Proton detector
4. Current status
5. The future

Diffractive Physics

The majority of interactions involving hadrons is ruled by strong interactions

- In Quantum Chromo-Dynamics (**QCD**), the theory of strong interactions described by a color field and their quanta - gluons.



- Processes in which no quantum numbers are exchanged between the interacting particles are called diffractive ones.

Diffractive interactions can be experimentally recognized by two features:

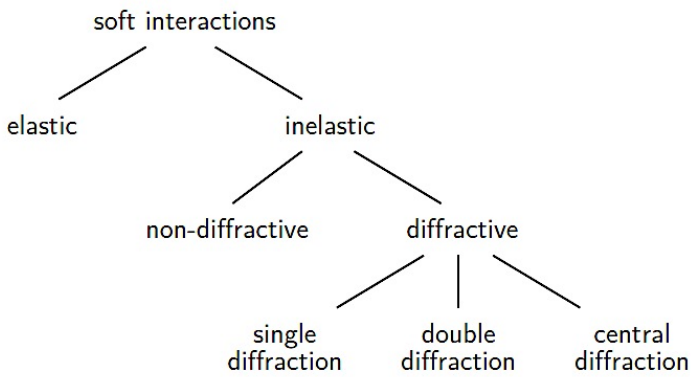
- **Large rapidity gaps** – there is no color exchange in the diffractive interactions, therefore radiation between the interacting particles is suppressed.

- **Intact protons** – when only vacuum quantum numbers are exchanged it is possible that the interacting hadron (proton, at the LHC) is not destroyed, but remains intact.

Diffractive Physics

The Classification

1. **Soft Diffraction**
2. **Hard Diffraction**
3. **Exclusive Production**



In QCD the coupling increases with increasing distance

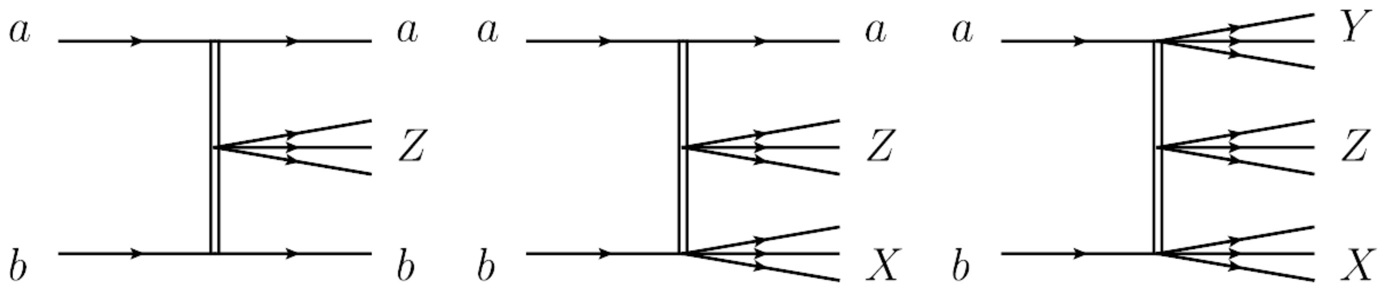
- At large distances the coupling is large, which leads to the confinement effect.
- When the distance is very small the coupling is small enough:
  I. Then **perturbative** calculations are possible → **Hard interaction**
  II. Otherwise, the interaction is **non-perturbative** → **Soft interaction**

A great majority of hadron collisions is soft

- In fact only a very tiny fraction of events is hard, and this fraction decreases with increasing momentum scale.
- When considering the total cross section for hadron interactions only soft processes have a significant contribution.

Diffractive Physics

Central diffraction (Double Pomeron Exchange) processes



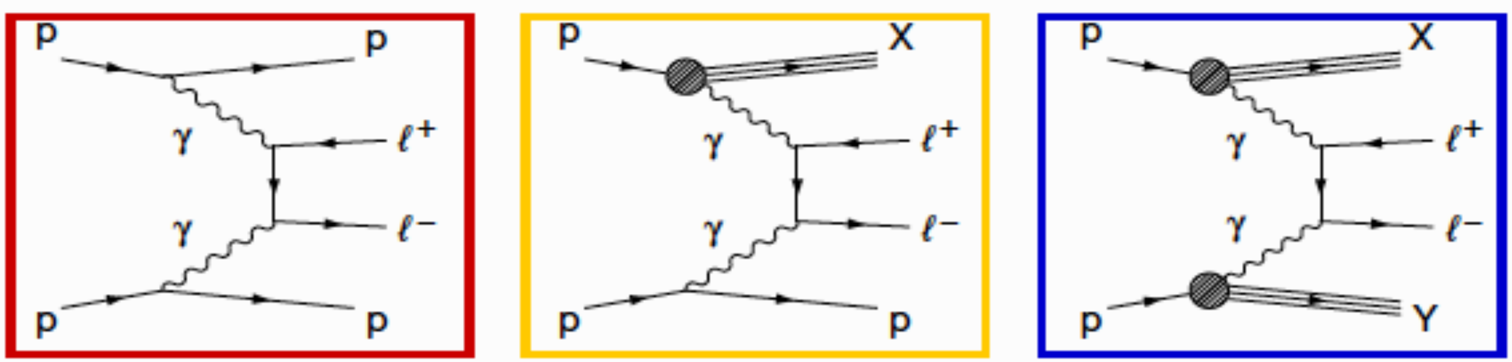
Feynman diagrams of central diffraction processes. Different possibilities of proton states:

Left – Both protons stay intact

Centre – One proton stays intact and the other one gets dissociated

Right – Both protons dissociate

QED processes or Photon-Photon interactions

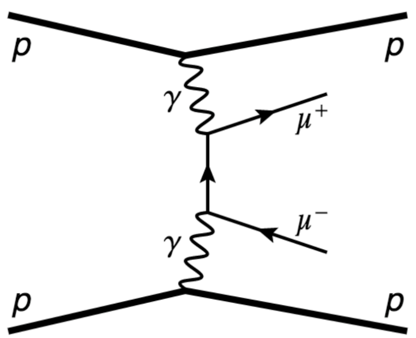


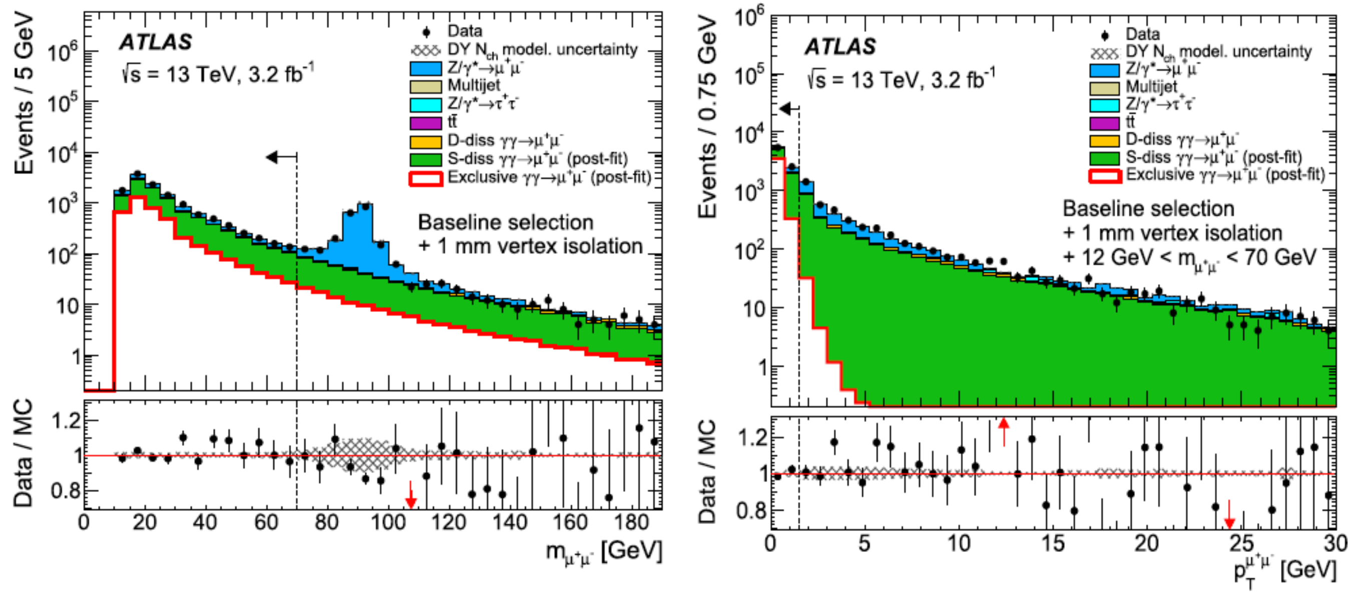
Elastic - Exclusive **SP - Dissociation** **DP - Dissociation**

γγ collider and Forward Protons (tagging)

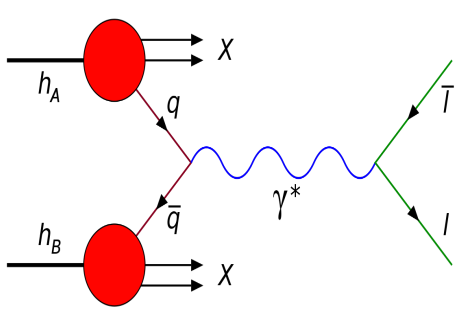
- **LHC** can be treated as a **high energy γγ collider** using the photons produced by the protons EM fields as a quasi-real beam of photons with small virtuality of: $Q^2 < 0.1$ GeV^2

(Equivalent Photon Approximation - EPA)





Main background:
Drell–Yann process



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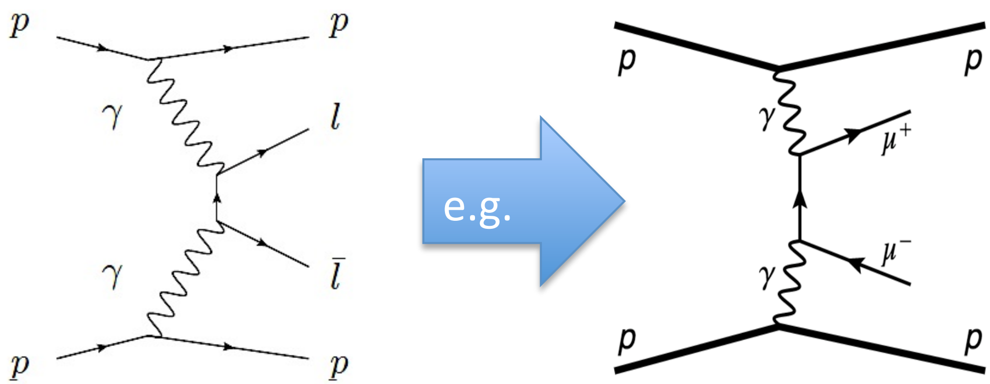
The EM field of colliding protons acts as a photon beam

γγ collider and Forward Protons (tagging)

QED processes exclusive di-eptons (e.g muons)

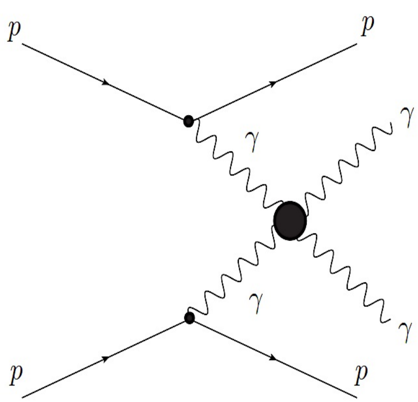
$pp(\gamma\gamma) \longrightarrow p\,\mu^+\mu^-\,p$



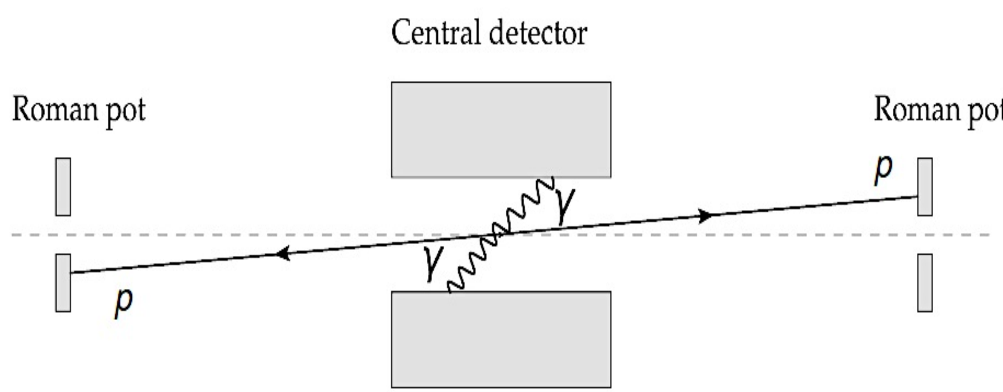
Fractional Momentum Loss:
(Longitudinal for intact protons)

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

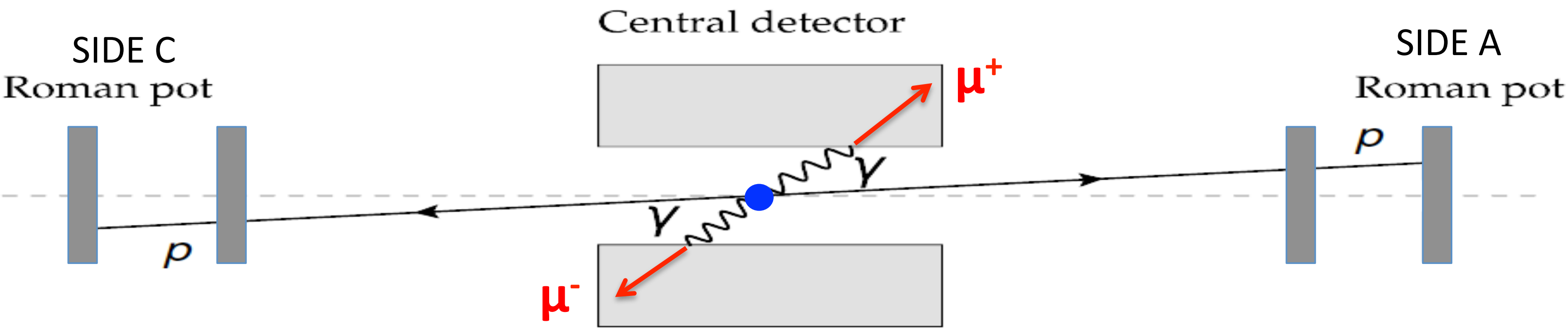
QED processes exclusive photons
(1925 Fermi-Weizsacker) $pp(\gamma\gamma) \longrightarrow p\,\gamma\gamma\,p$



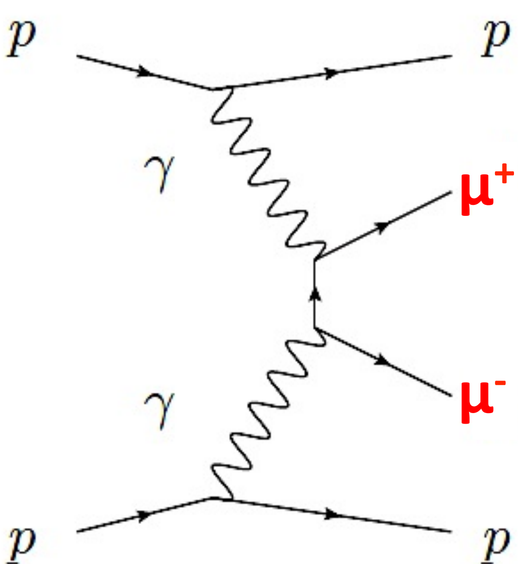
The main idea for Tagging Forward Protons



γγ collider and Forward Protons (tagging)



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



Fractional Momentum Loss:
(Longitudinal for intact protons)

$$\xi_{\mu\mu} = \frac{m_{\mu\mu}}{\sqrt{s}} e^{\mp Y_{\mu\mu}}$$

muon pair invariant mass:

$$m_{\mu\mu} = \sqrt{\xi^{A}_{\mu\mu} \xi^{C}_{\mu\mu}} \sqrt{s}$$

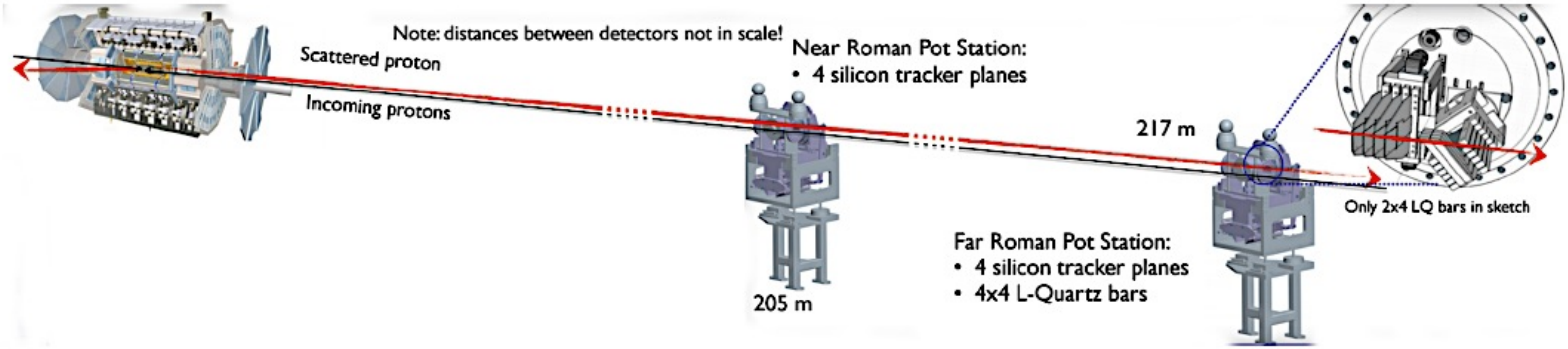
muon pair rapidity:

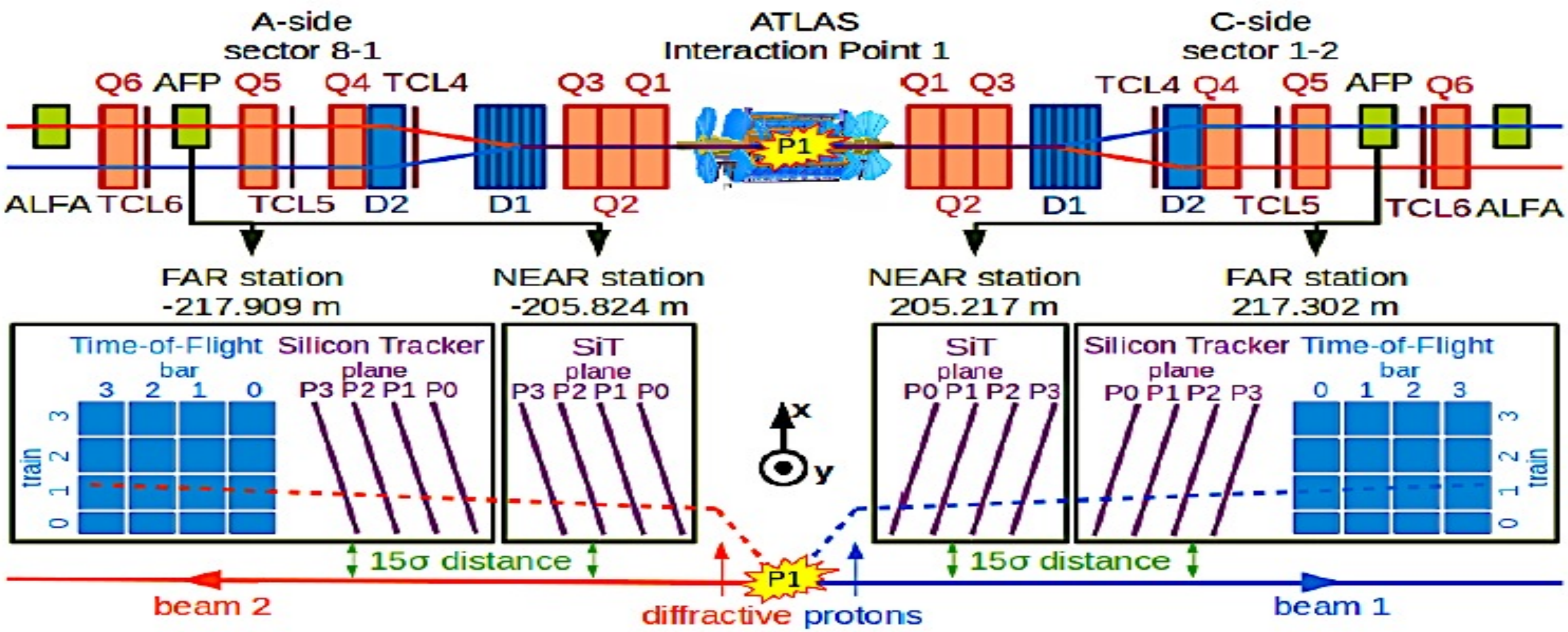
$$Y_{\mu\mu} = \frac{1}{2} \log \sqrt{\frac{\xi^{A}_{\mu\mu}}{\xi^{C}_{\mu\mu}}}$$

tagging condition:

$$\xi_{\mu\mu} = \xi$$

ATLAS Forward Proton detector

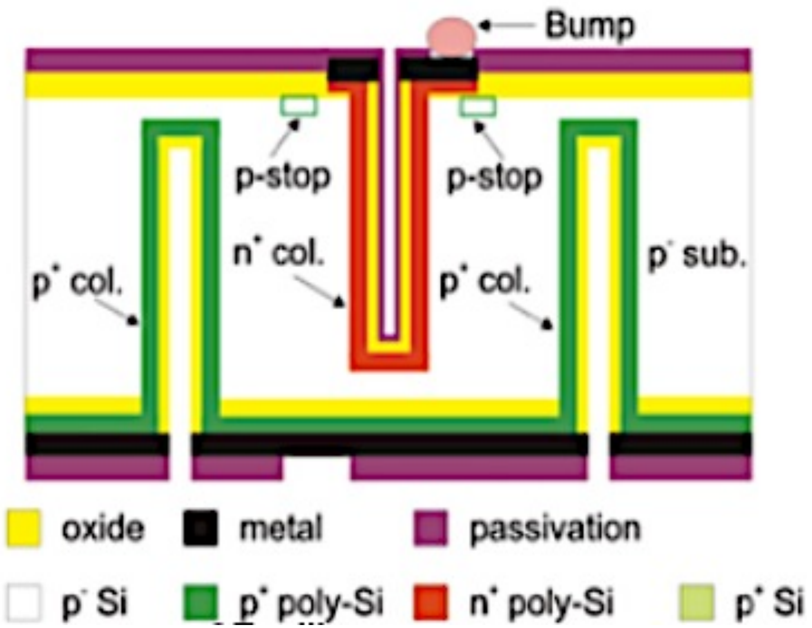


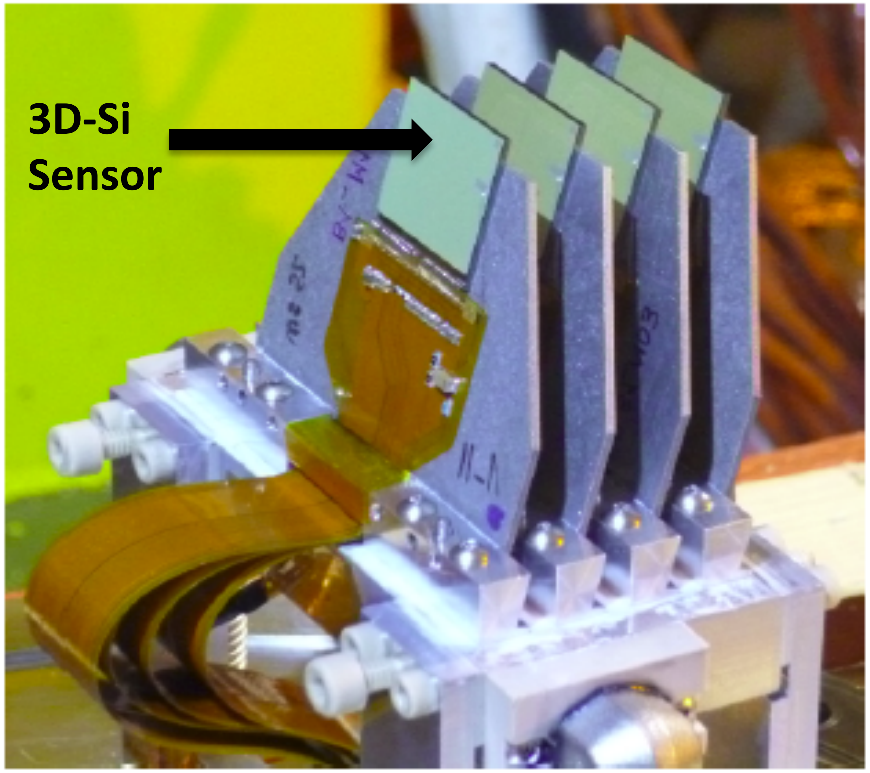


ATLAS Forward Proton detector

AFP Silicon Tracker Technology: 3D pixel sensors

- **Column-like:** Inter-electrode distance (~67 µm) de-coupled from detector thickness (230 µm)
- **Low Voltage:** for full depletion (~10 Volt) before irradiation
- **Use its Trigger signal in AFP0 + 2**
- **336 x 80 pixels with 50 x 250 µm² area each**



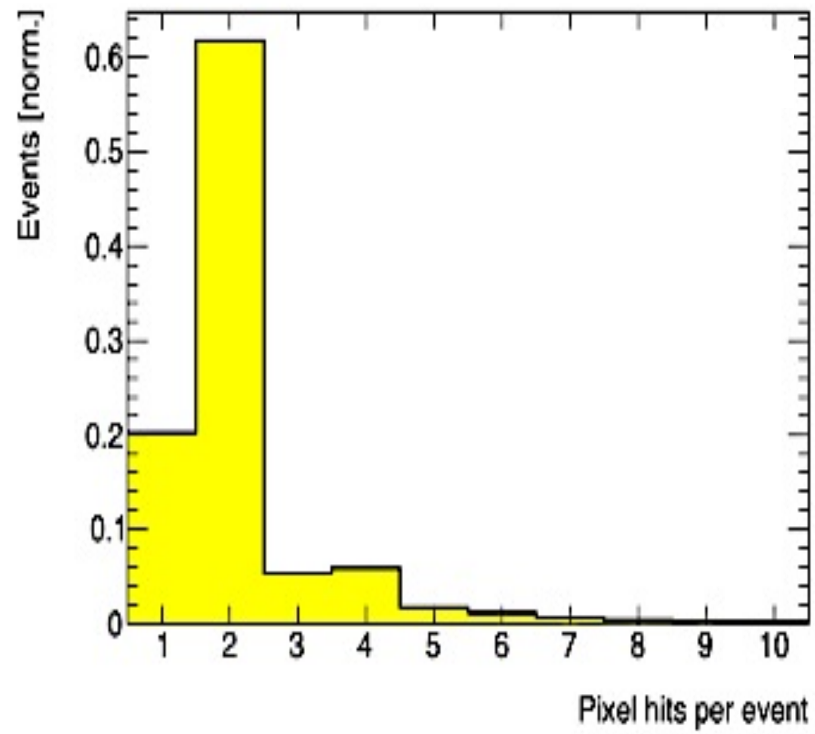


ATLAS Forward Proton detector

AFP Silicon Tracker Technology: 3D pixel sensors

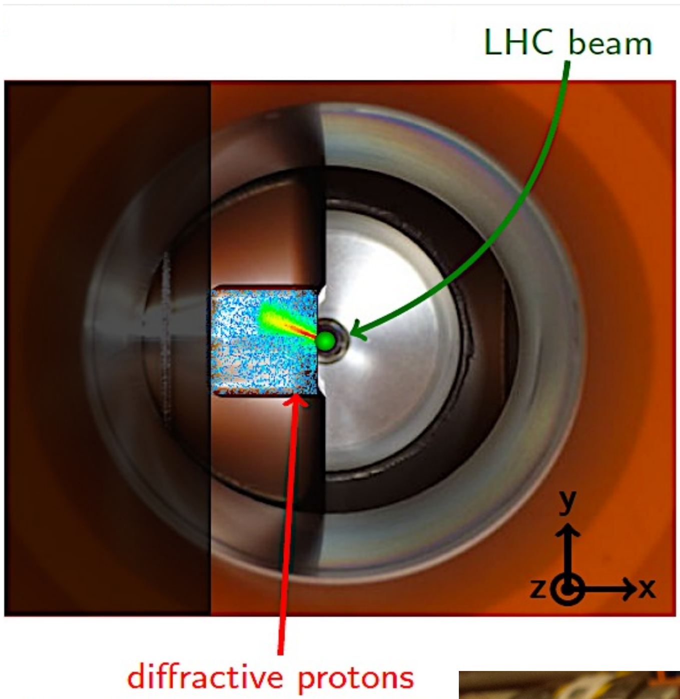
Tracker Qualifications: Performance evaluated in various test-beams

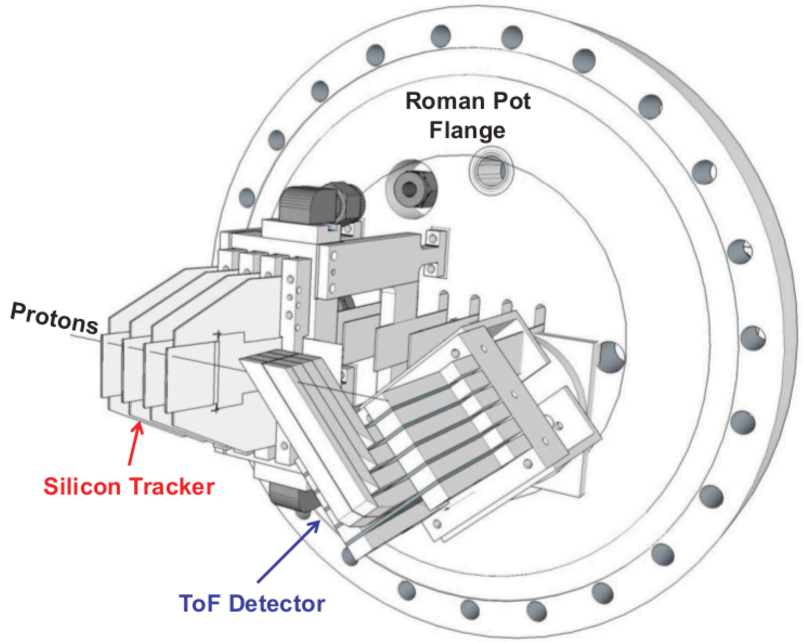
1. **4 detectors in each station (16 planes in total)**
2. **Resolution σ_x= 6 μm and σ_y= 30 μm**
3. **Tilted 14^0 to improve resolution in x**
4. **Able to sustain non-uniform radiation of up to $5x10^{15}$ n_{eq}/cm^2**
5. **Dead area can be cut down to less than 150 μm without loosing efficiency**
6. **Active area as close as possible to the RP's (Roman Pots)**

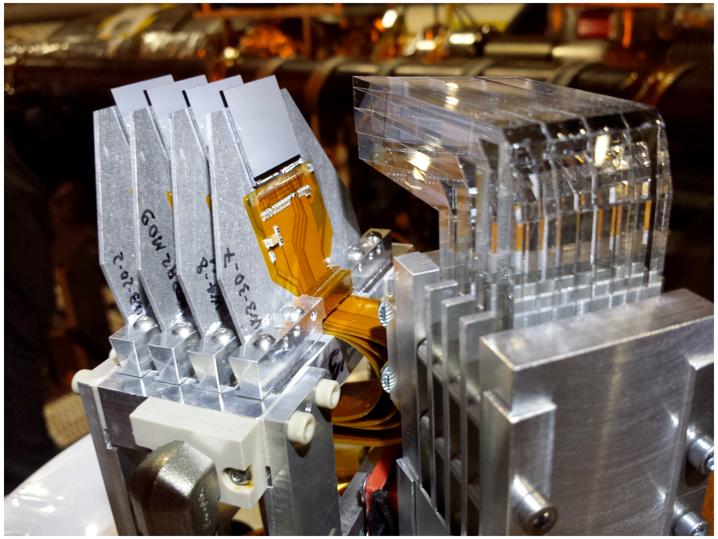


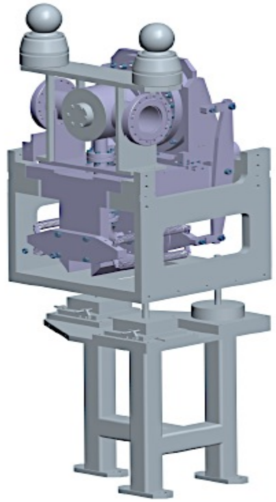
JINST 10 (2015) C03031
JINST 11 (2016) P09005

ATLAS Forward Proton detector

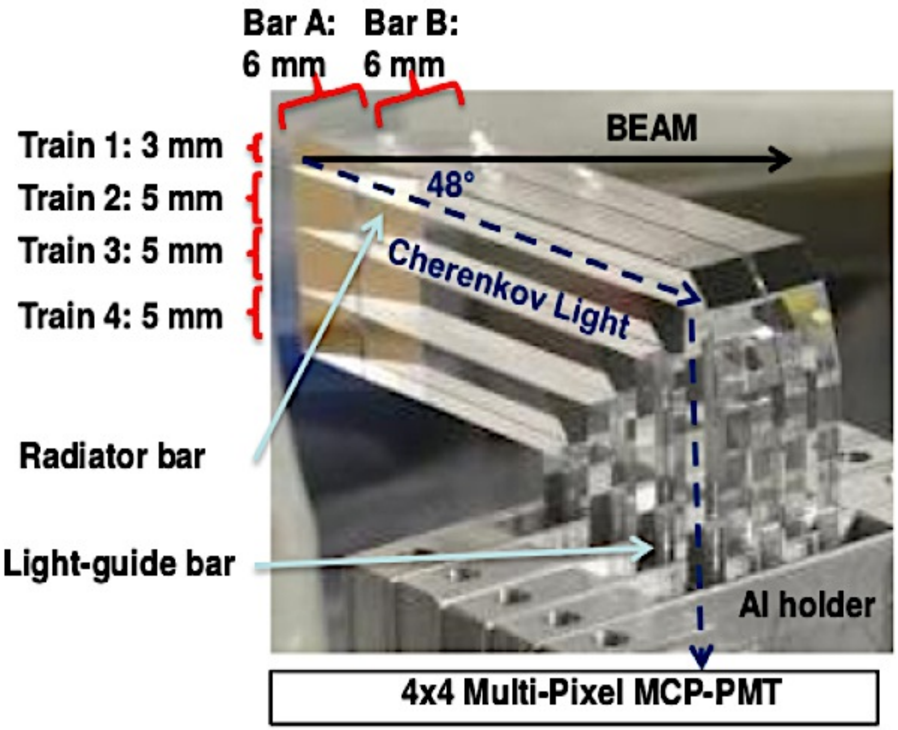


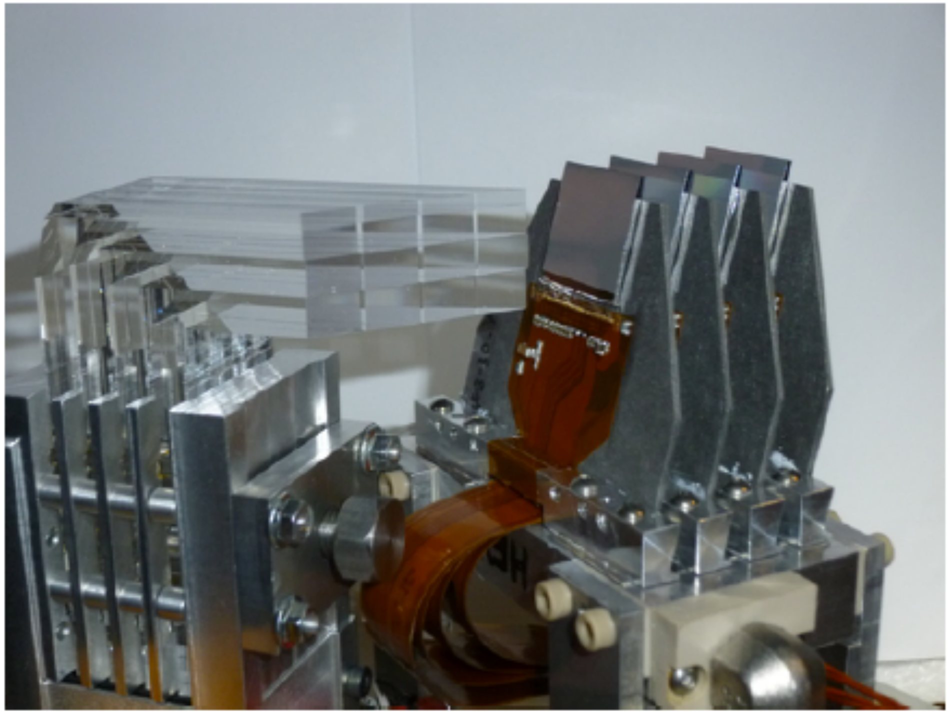






ATLAS Forward Proton detector

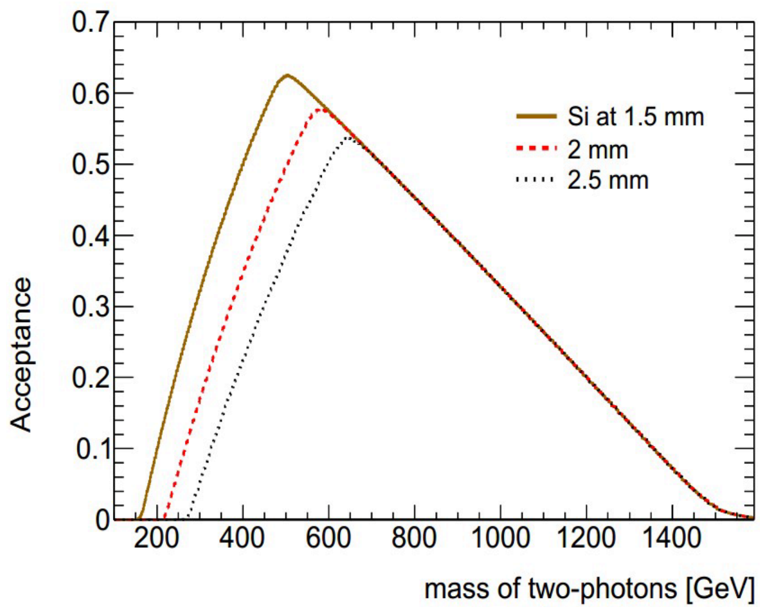


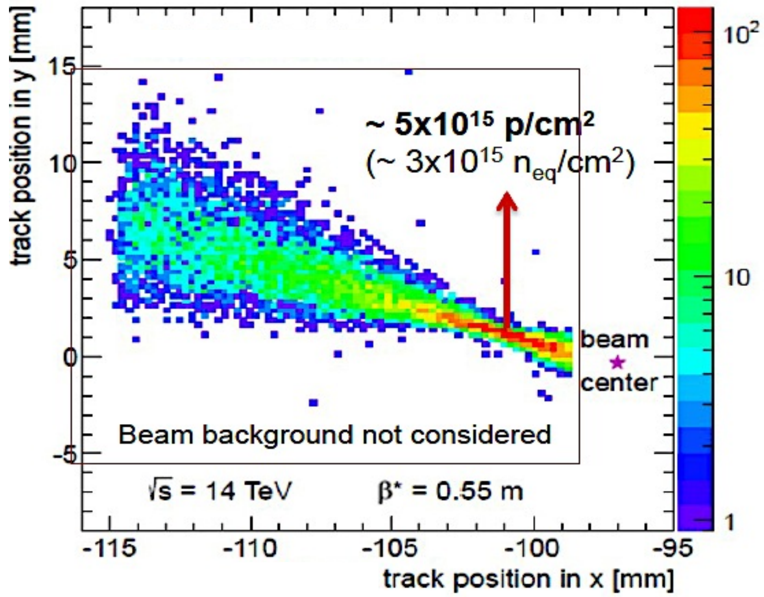


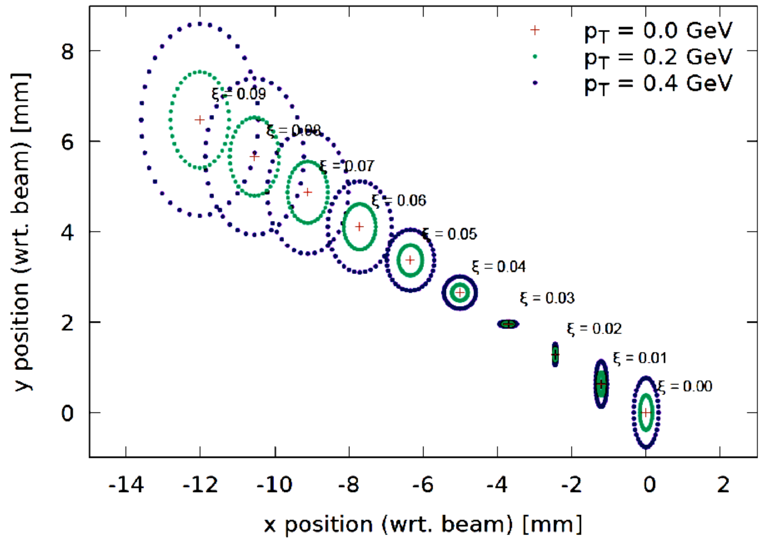
ToF LQBars

- **4x4 Quartz Bars oriented at the Cherenkov angle with respect to the beam trajectory**
- **Expected Resolution: σ = 25 ps**

ATLAS Forward Proton detector

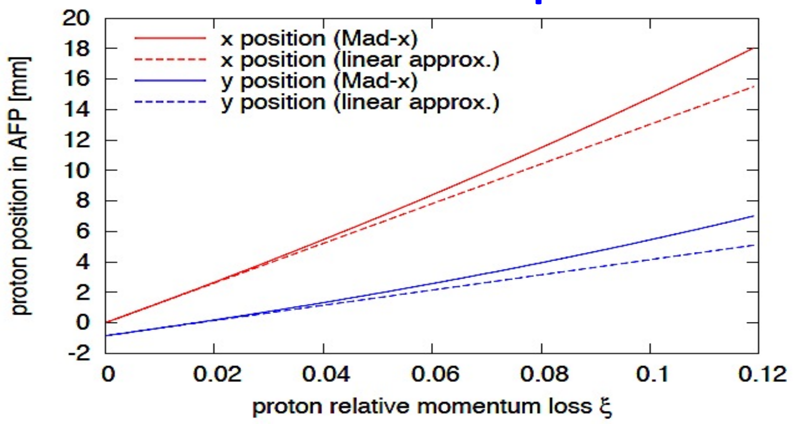






$0.02 < \xi < 0.1$

AFP detectors acceptance



Current Status

- **Start processing and analyzing the 2017 and 2018 data for exclusion dimuon production and AFP tagging using the AFP detector.**
- **Running Monte Carlo simulation for comparison and fiducial cross section estimation.**
- **Developing a new analysis code for the next step which is the Light–by–Light scattering.**
- **Looking for physics beyond the Standard Model (like:** **a**nomalous **Q**uartic **G**auge **C**ouplings and search for Axion Like Particles or new ideas ????**).**


The future

anomalous Quartic Gauge Couplings

Dimension 6(WWγγ and ZZγγ) and 8(γγγγ) operators parameterized with 4 (2) different parameters

$$L_6^0 = -\frac{e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^- - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

$$L_6^C = -\frac{e^2}{8}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}\frac{1}{2}\left(W^{+\alpha}W_\beta^- + W^{-\alpha}W_\beta^+\right) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

$$\mathcal{L}_{\gamma\gamma\gamma\gamma} = \zeta_1^\gamma F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \zeta_2^\gamma F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu}$$

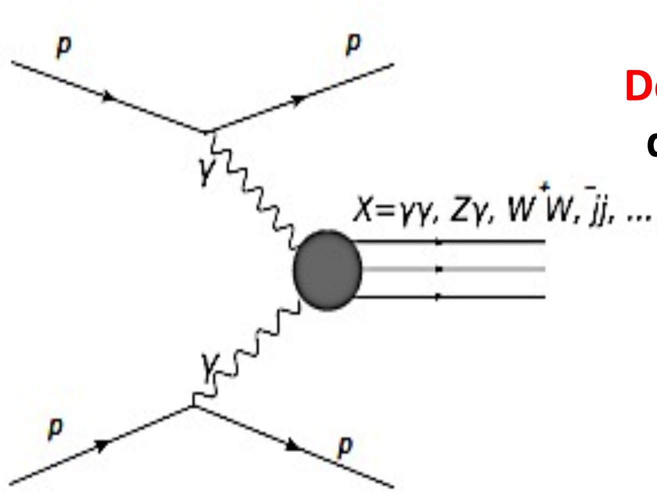
$$\zeta_1, \zeta_2 < (10^{-12} - 10^{-11})\mathrm{GeV}^{-4}$$

The future

pp ⟶ pXp

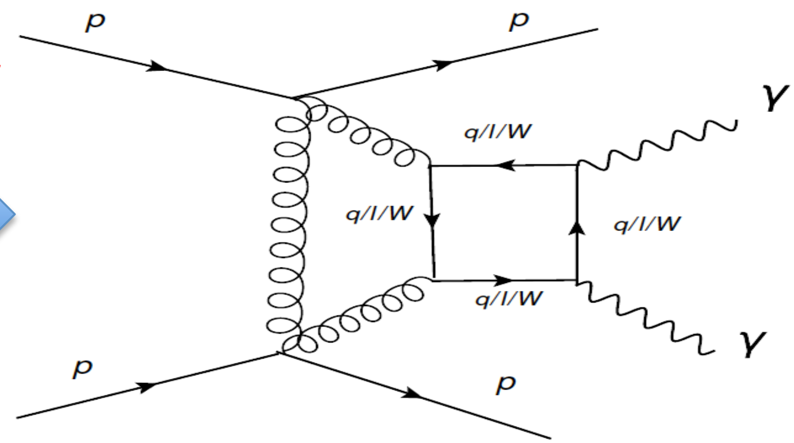
Central Exclusive channel

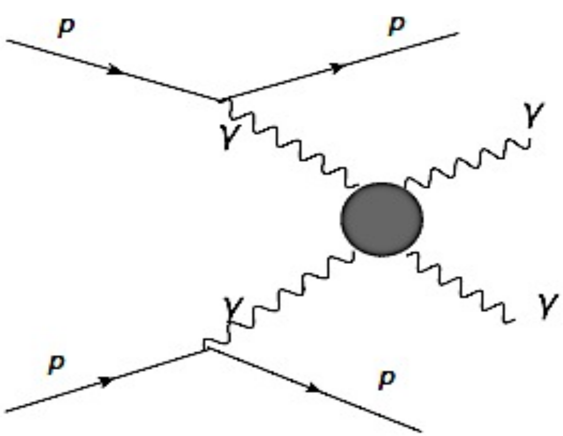
$$\Lambda_{New\ Physics} \gg \sqrt{s_{\gamma\gamma}}$$



Dominant in Low diphoton mass

QCD

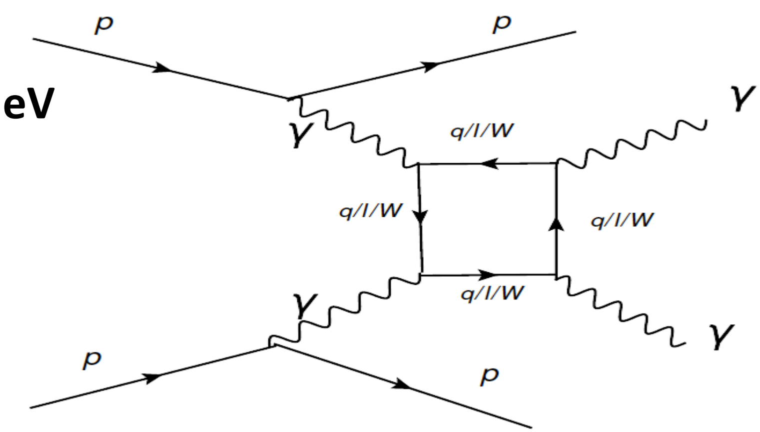




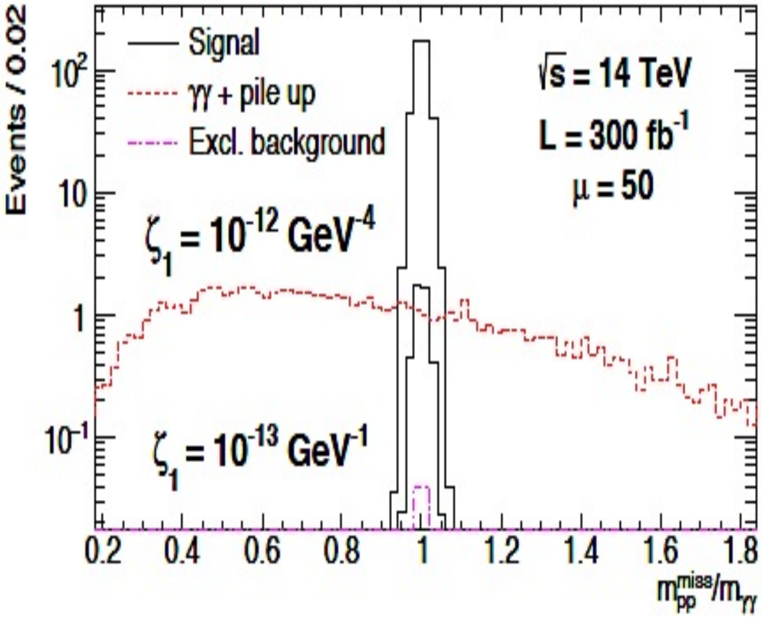
Dominant in High diphoton mass >750 GeV

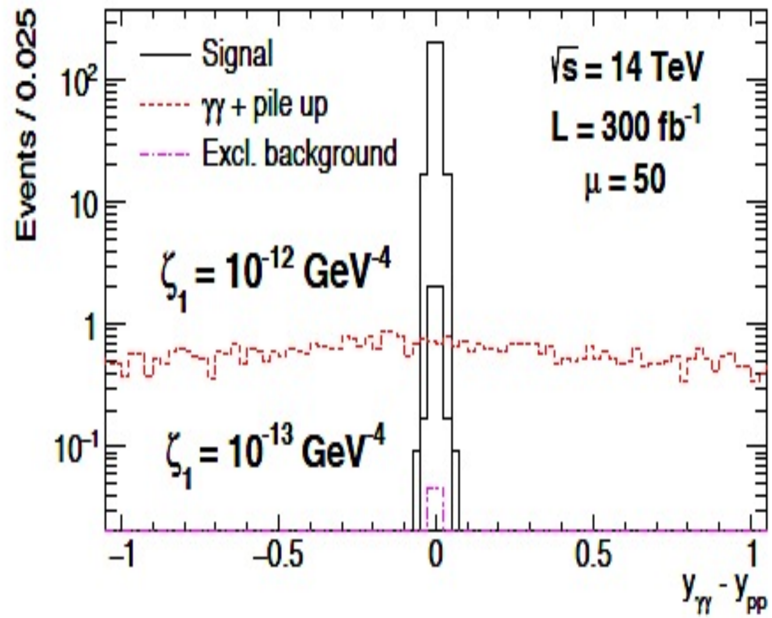
QED

Light – by –Light Scattering

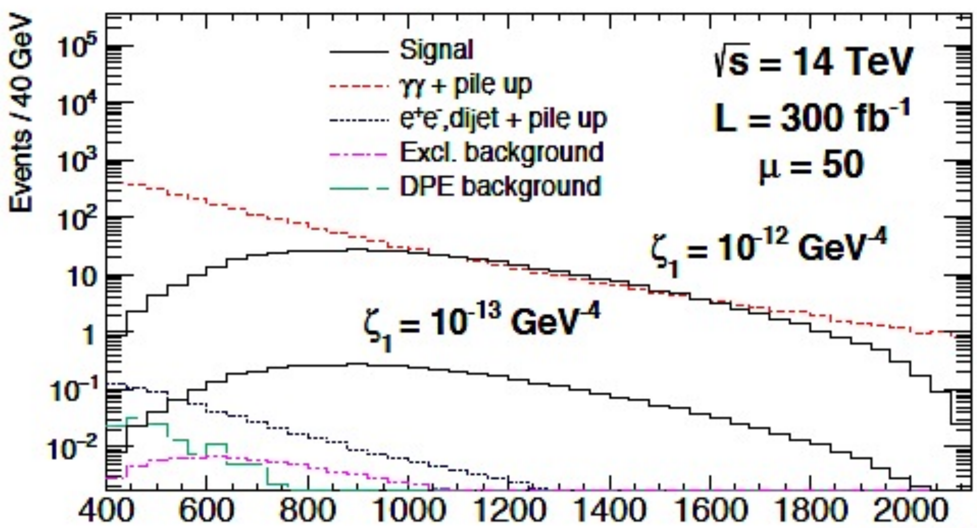


The future





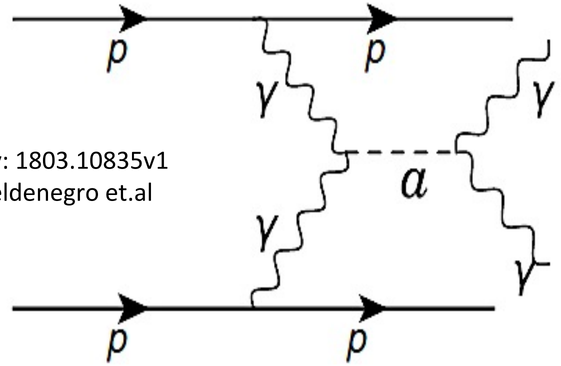
arXiv: 1606.07675v1
C. Royon



The future

Searching for **A**xion **L**ike **P**articles (**ALP**)

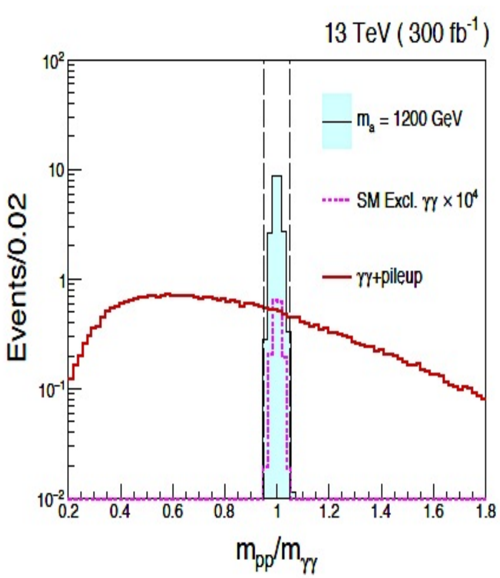
arXiv: 1803.10835v1
C. Beldenegro et.al

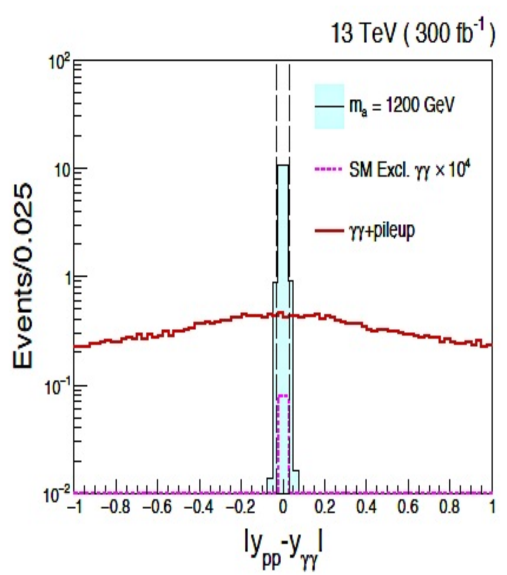


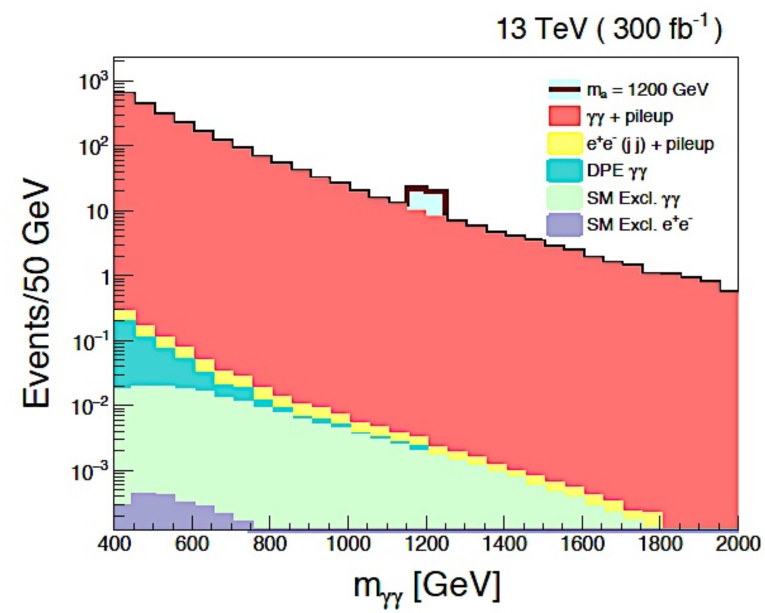
These particles might address the longstanding question of why QCD seems to not break the CP symmetry.

- Is a possible component of Dark Matter
- **A CP-odd scalar** appear in the string theory landscape
- **A CP-even scalar** appear in extra dimensions models

m_α = 0.6 to 2 TeV



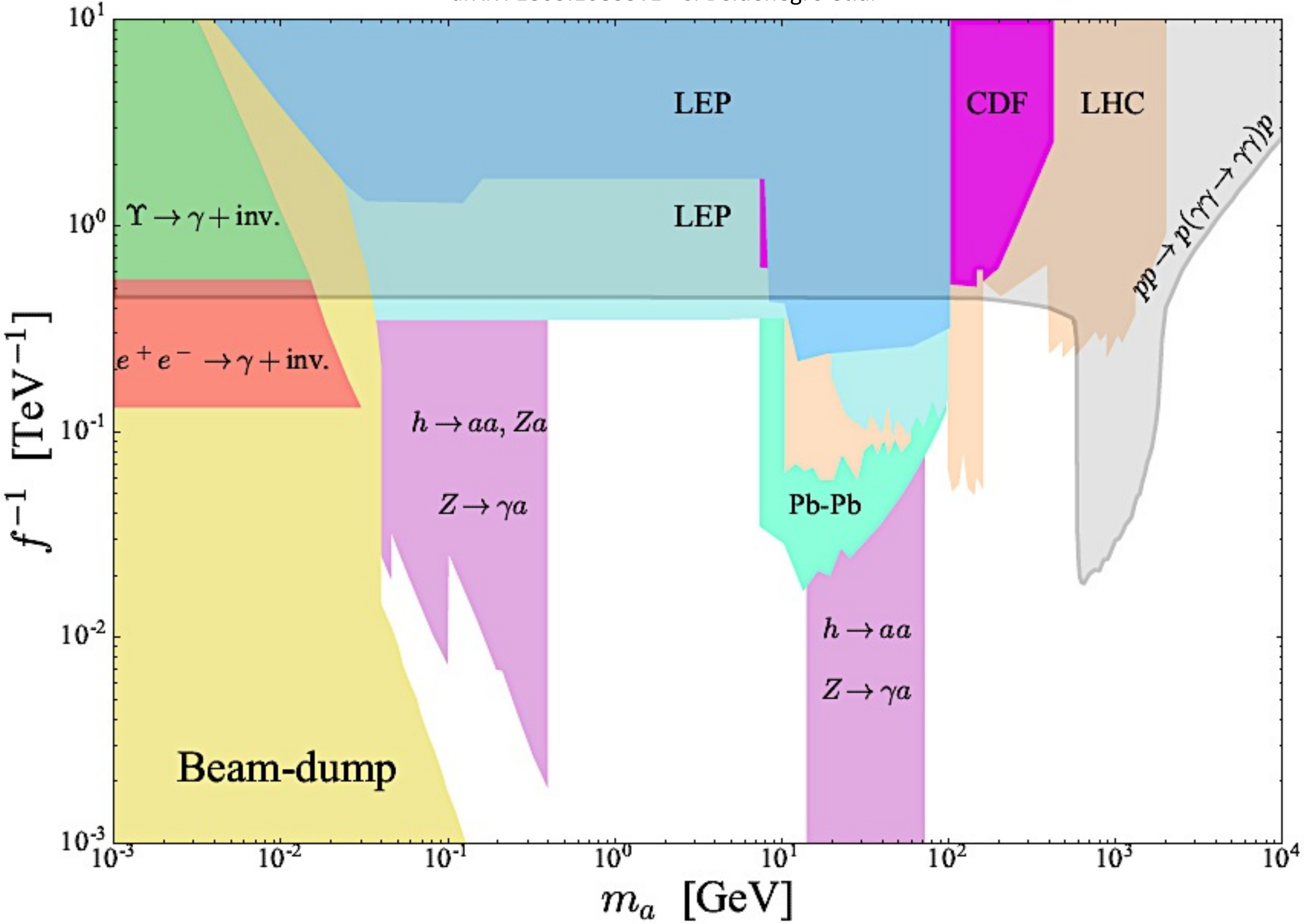




The future

Exclusion regions on the ALP photon coupling f^{-1} and mass of the ALP m_α plane.

arXiv: 1803.10835v1 C. Beldenegro et.al



$$\Gamma(a \to \gamma\gamma) = \frac{m_a^3}{4\pi f^2}$$

$$\sigma_{\gamma\gamma \to a \to \gamma\gamma} \propto f^{-2} \mathcal{B}_{a \to \gamma\gamma}$$

Thank you
for your attention