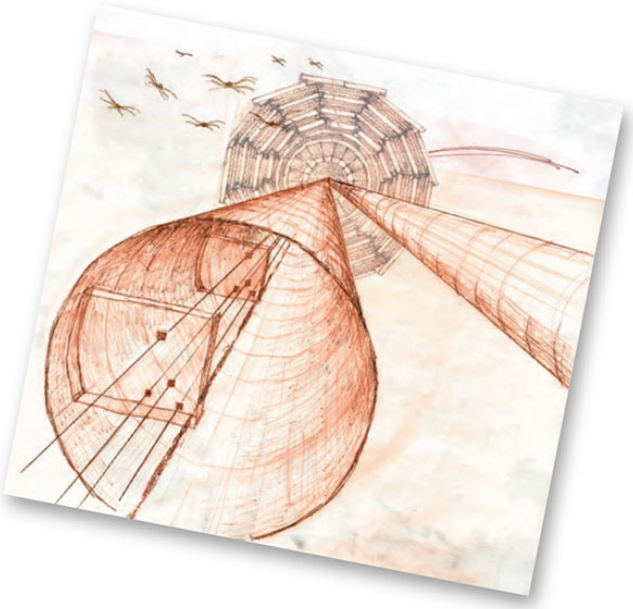
Anomalous Coupling Studies Using Proton Tagging at the LHC

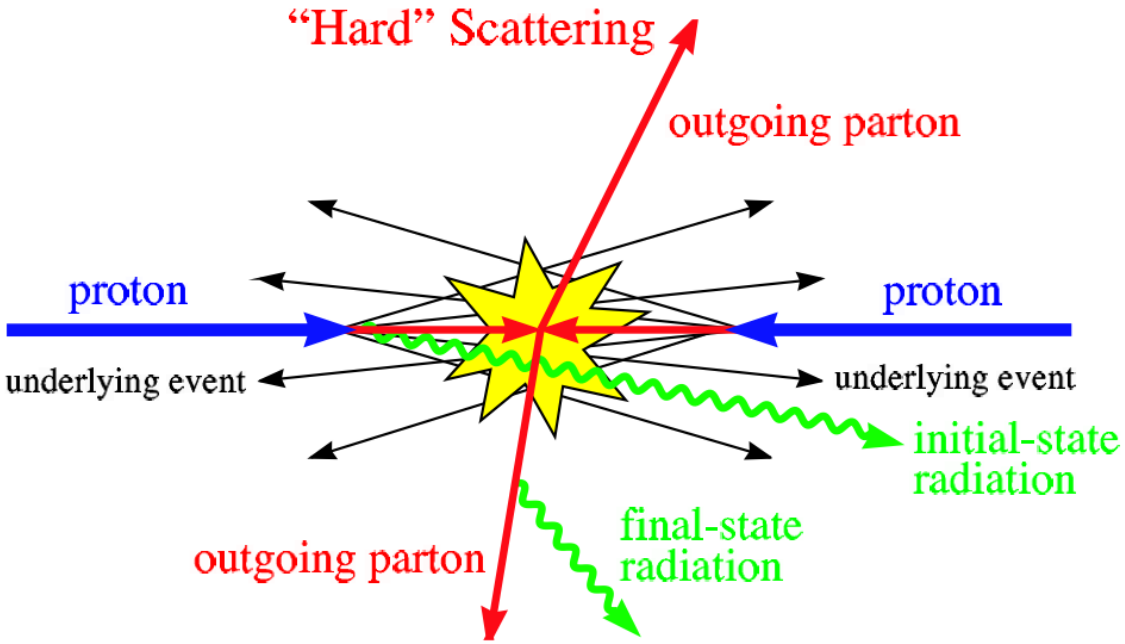
Justin Williams

The University Of Kansas



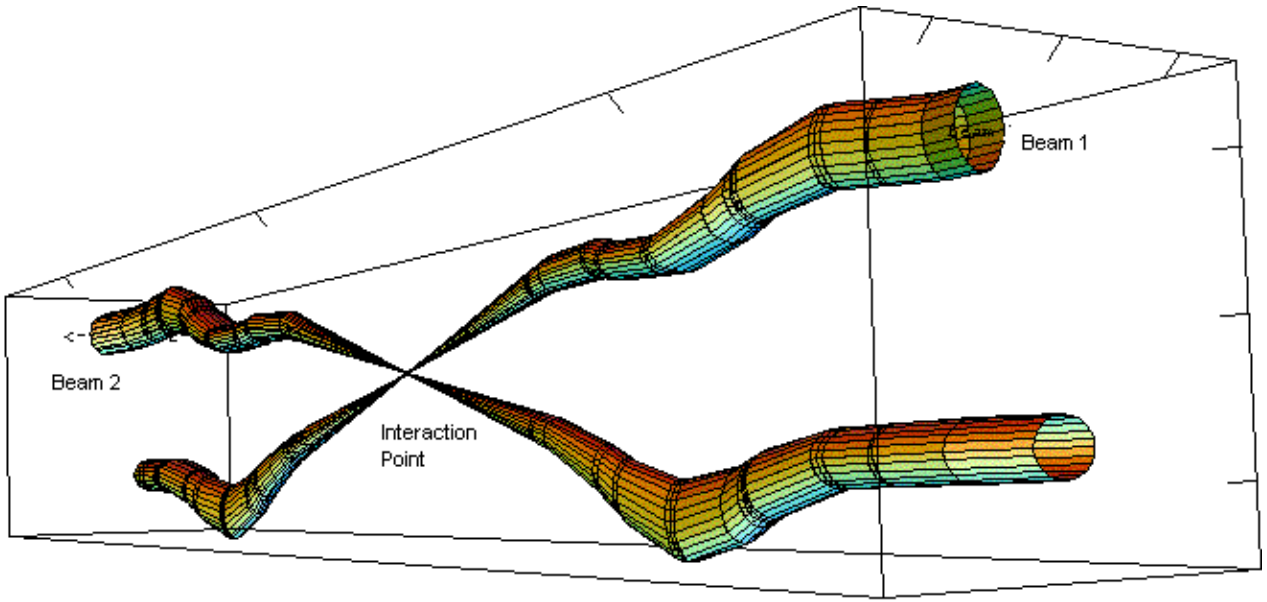
Setting The Scene

The typical collision at the LHC includes parton interactions



Setting The Scene

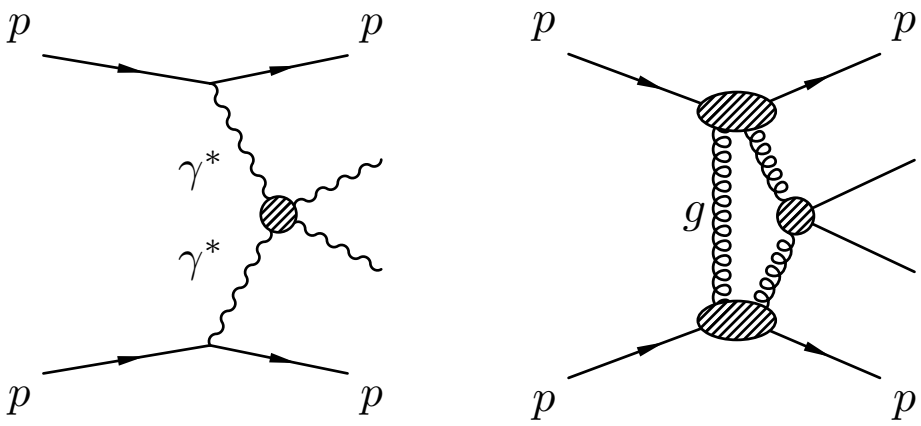
There's a significant number of collisions that leave protons intact



Relative beam sizes around IP1 (Atlas) in collision

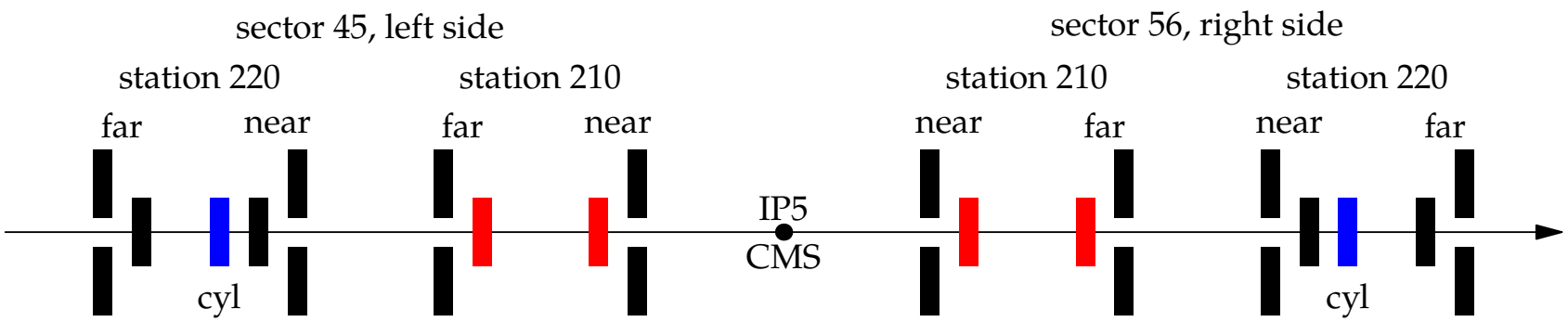
Physics Program

The physics program studies events giving intact protons in the forward regions



- The CMS Precision Proton Spectrometer (PPS) and ATLAS Forward Proton detectors (AFP) provides an opportunity for new searches and measurements
- Possibility of a very strong background suppression using intact protons
- Outline
  1. Description of proton detection technology
  2. Physics results
  3. Prospects: Anomalous Couplings, Axion-Like Particles, Dark Matter, etc.

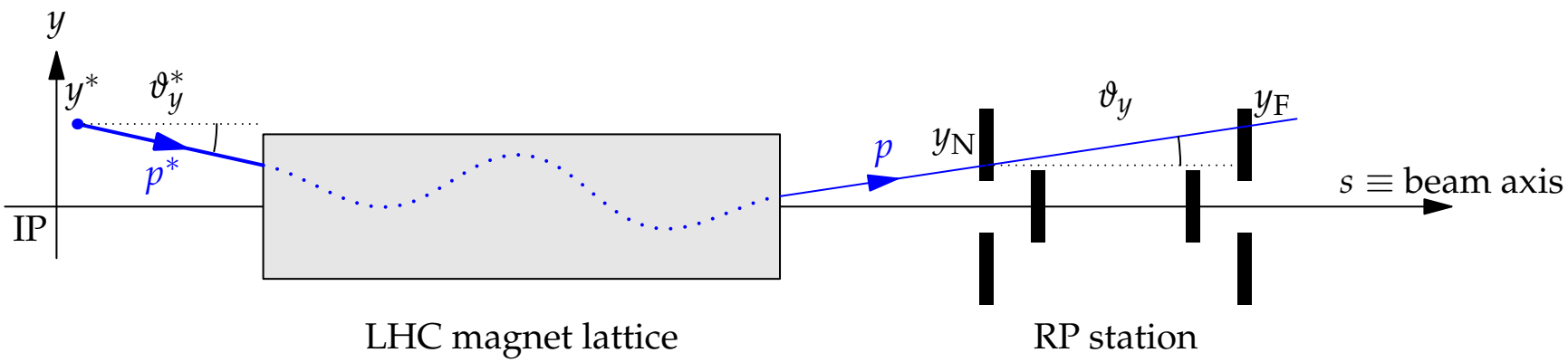
Proton Tagging at the LHC



One example of the experimental setup is CMS PPS

- Stations of detectors at $\pm$ 200 m from IP
- Multiple planes of detectors
- Measure x (and/or y) position $\rightarrow \xi$ of proton
- Timing detectors $\sim$ 40 ps

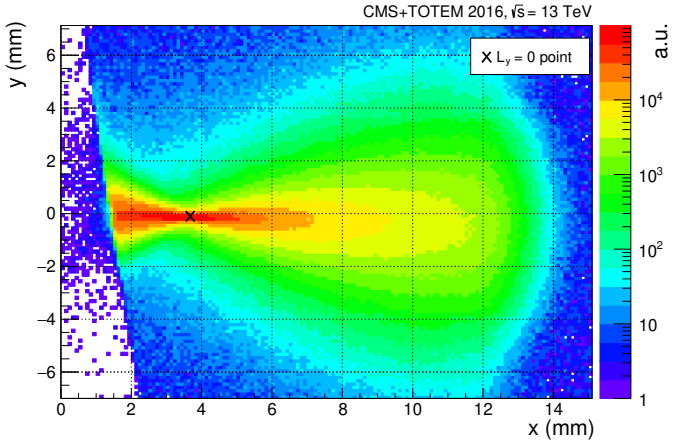
Optics



measured at RP

values at IP

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \xi \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & m_{13} & m_{14} & D_x \\ v'_x & L'_x & m_{23} & m_{24} & D'_x \\ m_{31} & m_{32} & v_y & L_y & D_y \\ m_{41} & m_{42} & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \xi^* \end{pmatrix}$$

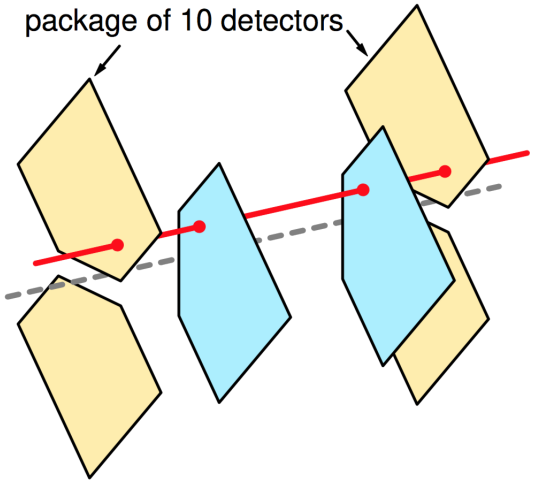


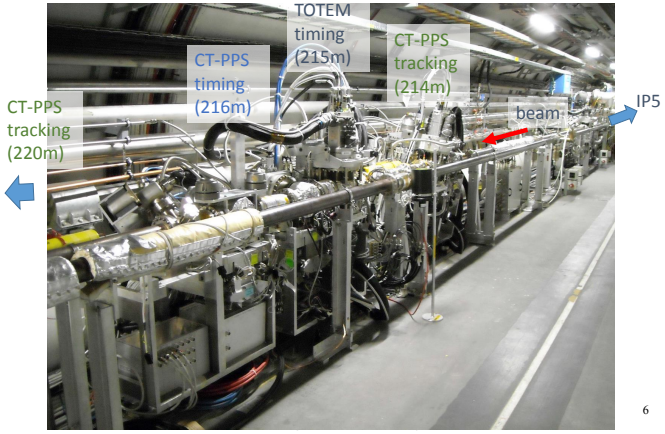
Roman Pot Technology

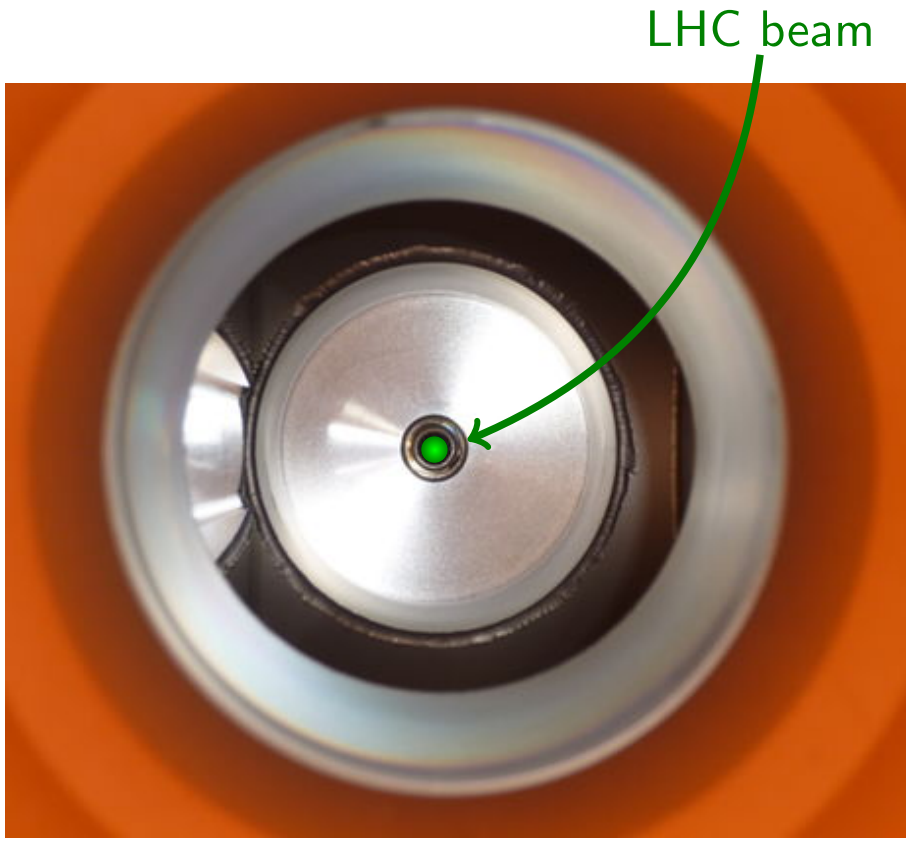
Roman Pots are the movable machinery that houses tracking detectors

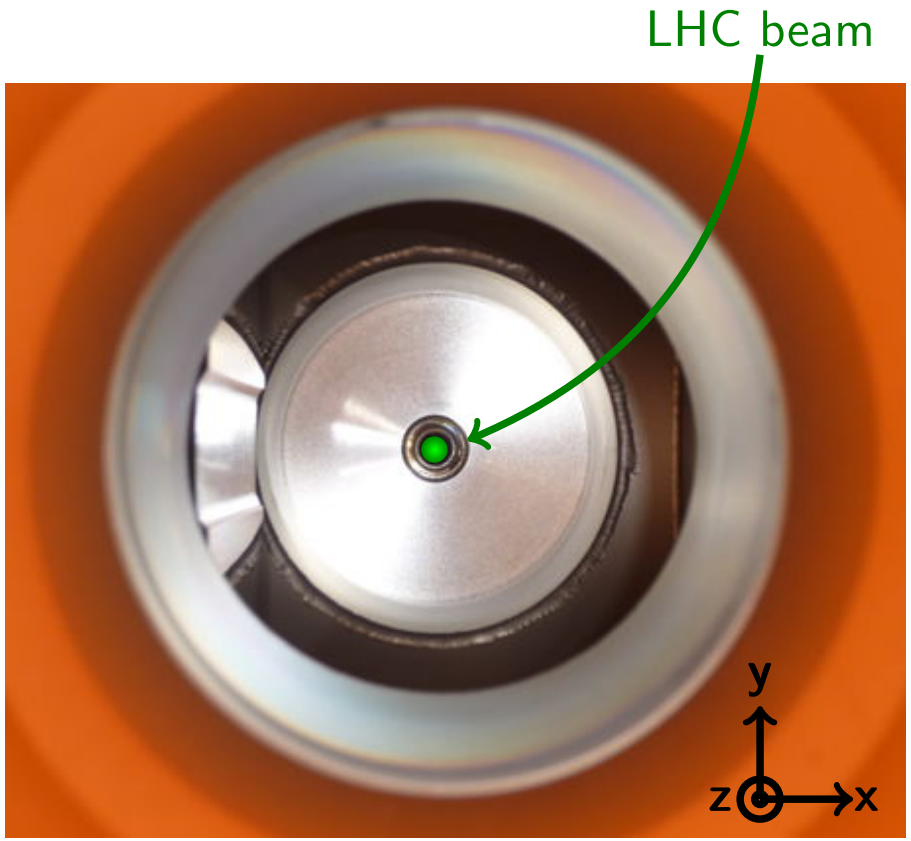
Roman Pots

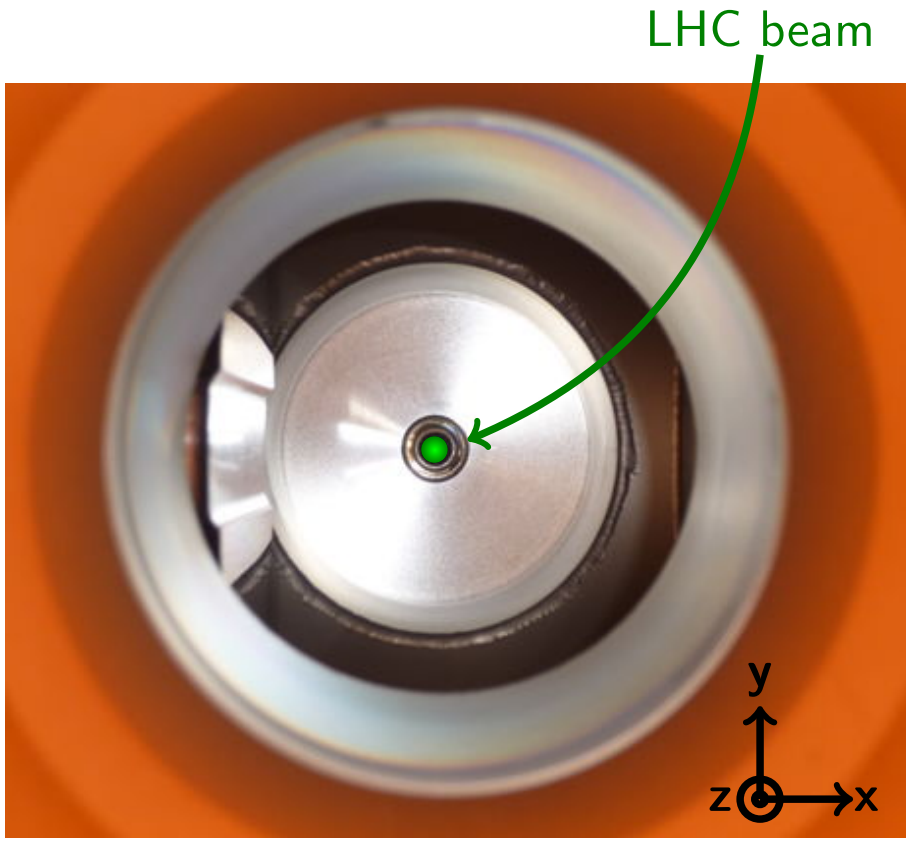
- Multiple planes of detectors
- Silicon or pixels
- Horizontal and vertical RPs
- Approach the beam at ~ 1 mm
- Designed to operate at standard running conditions

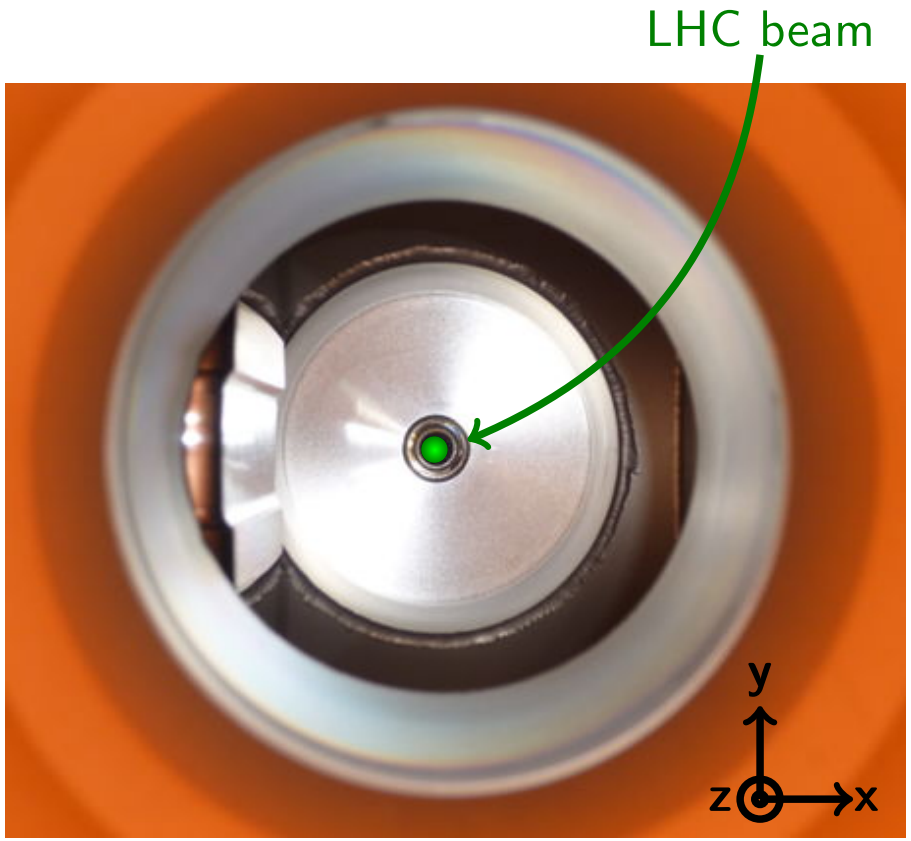


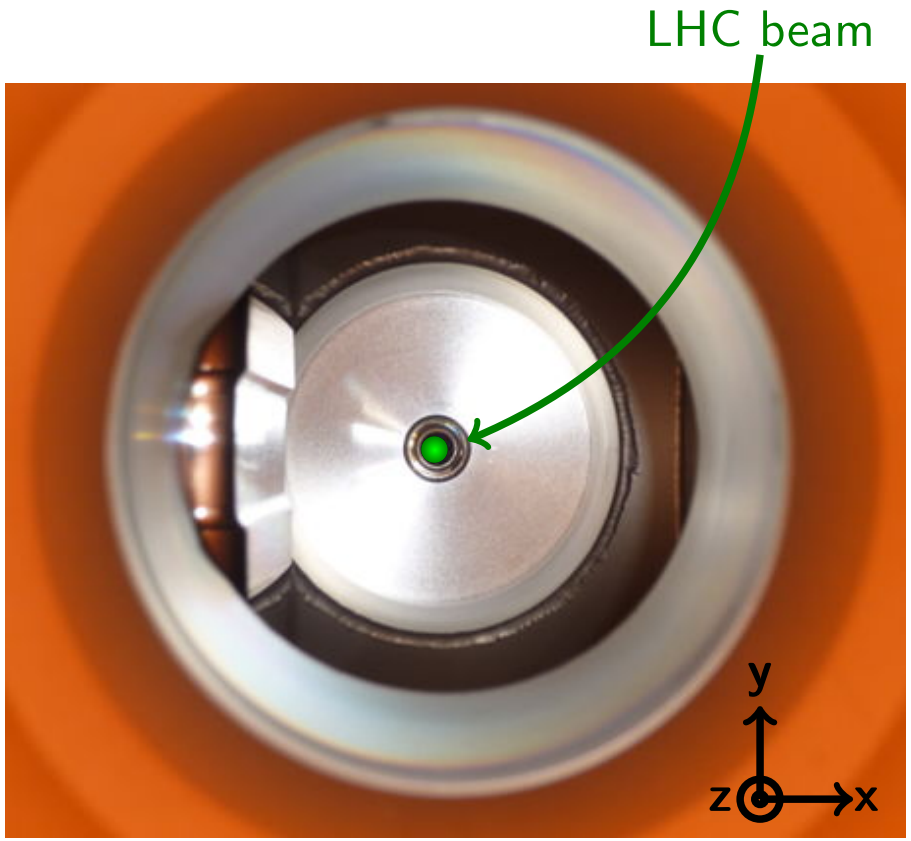


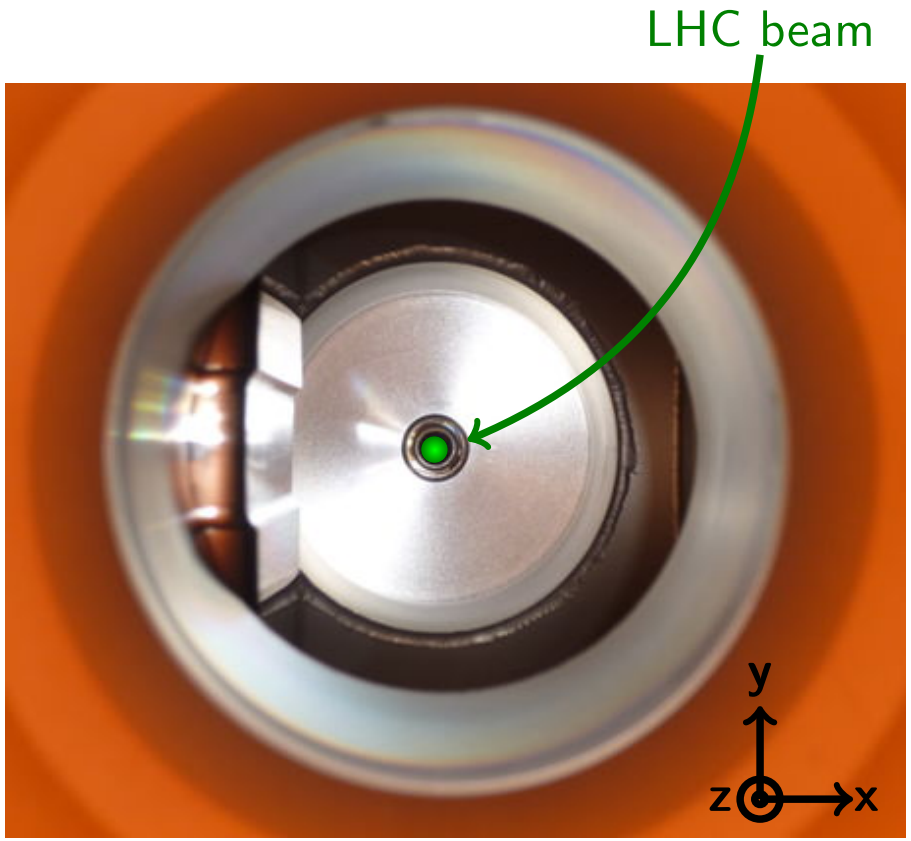

LHC beam

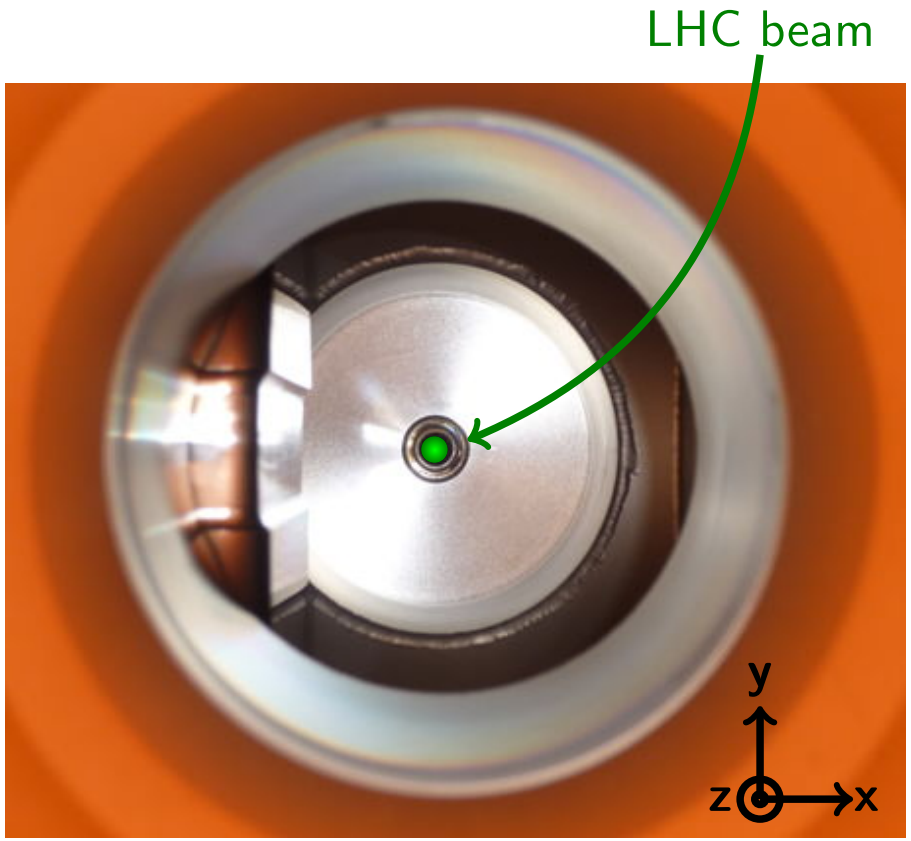

LHC beam
y
z
x

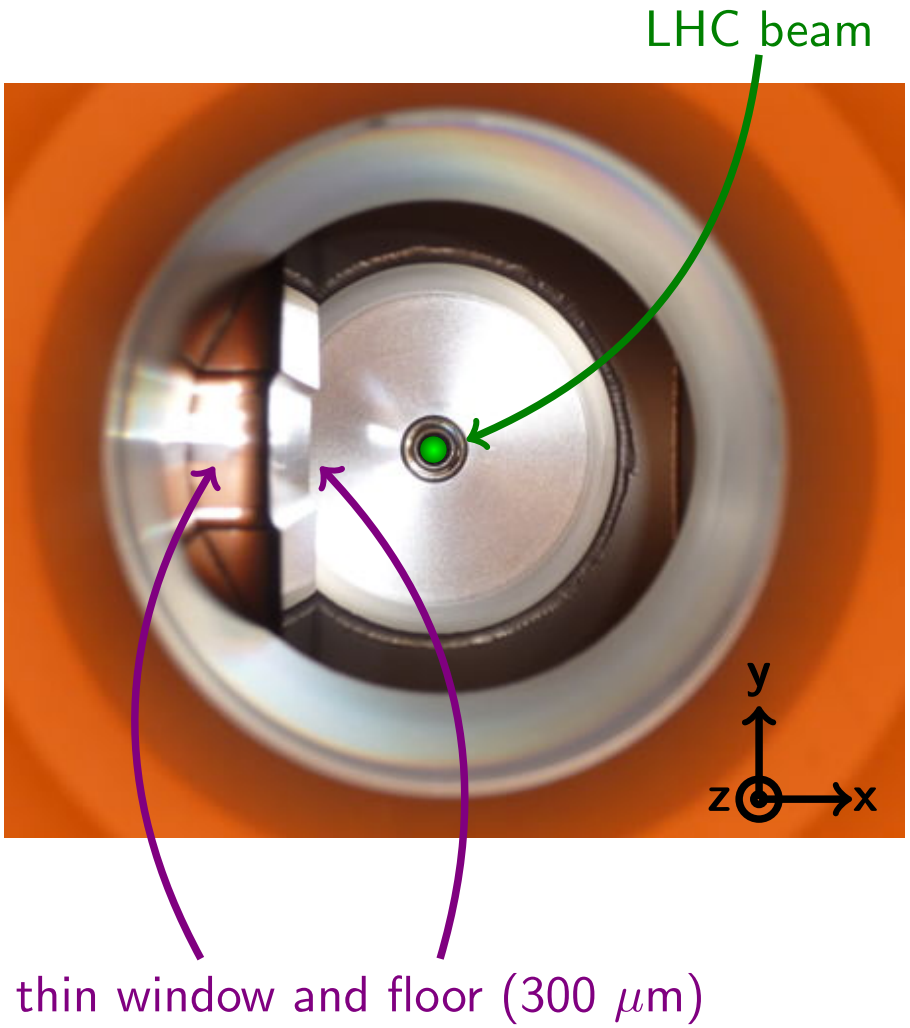

LHC beam
y
z
x


LHC beam
y
z
x


LHC beam
y
z
x

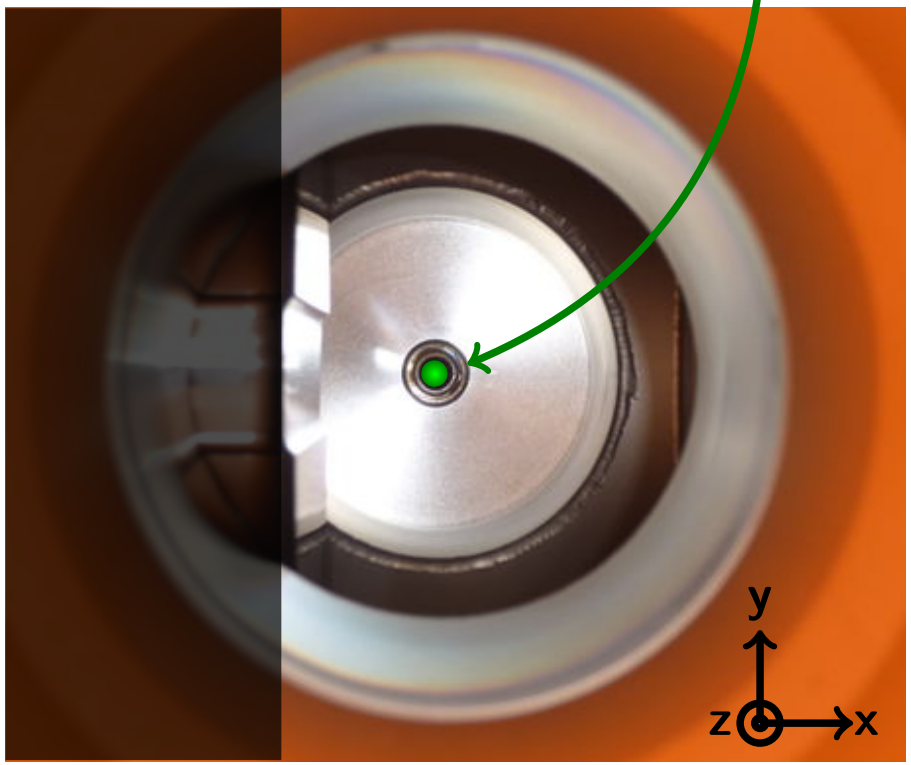

LHC beam
y
z
x


LHC beam
y
z
x


LHC beam
y
z
x
thin window and floor (300 μm)

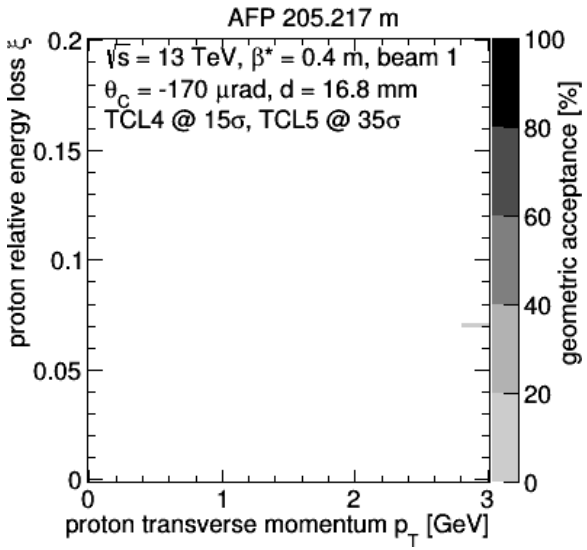
shadow of TCL4 and TCL5 collimators

LHC beam

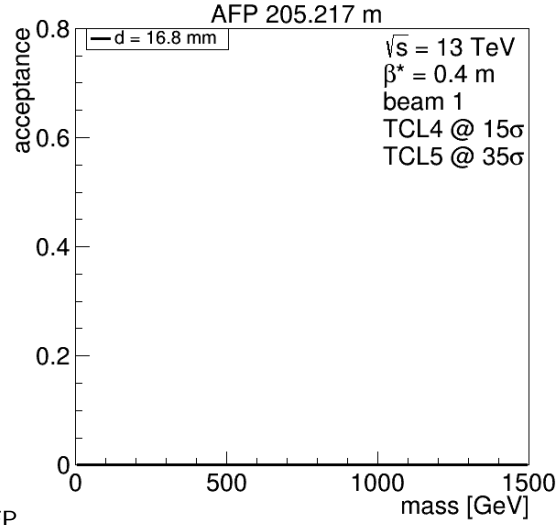


thin window and floor (300 μm)

Geometric acceptance:



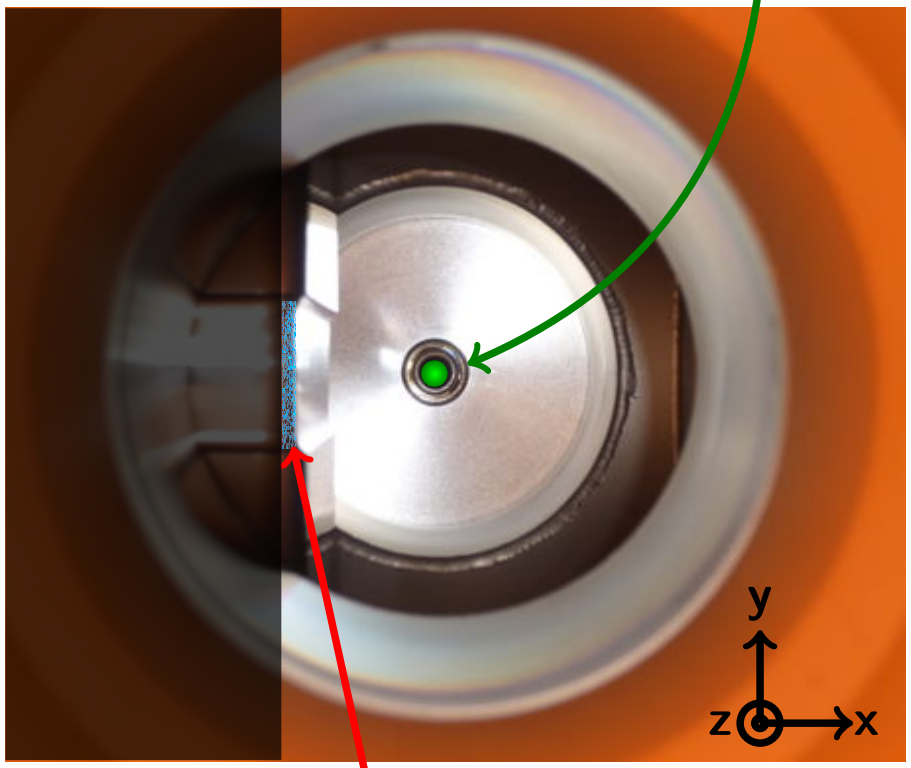
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

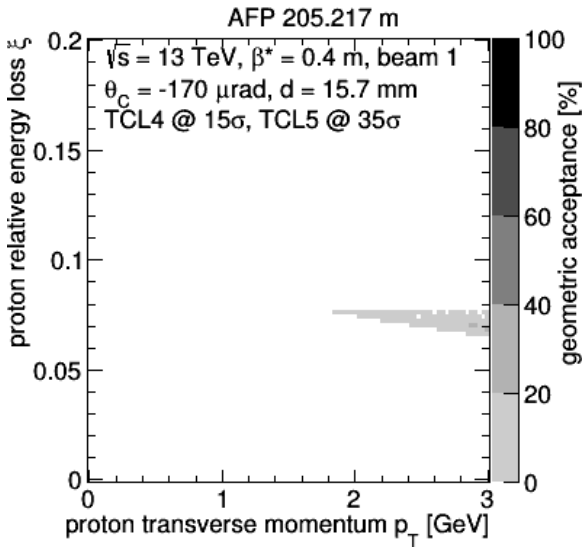
LHC beam



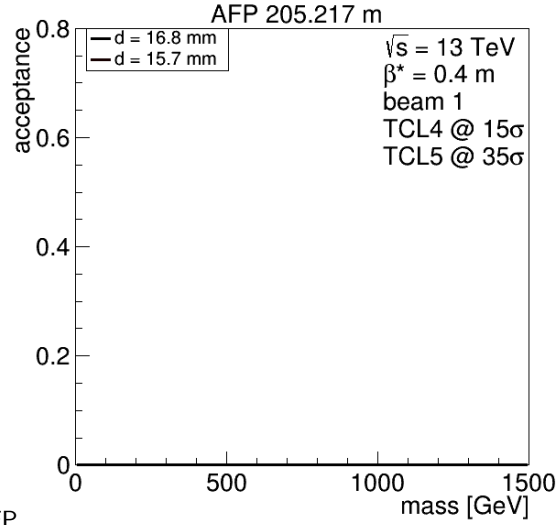
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



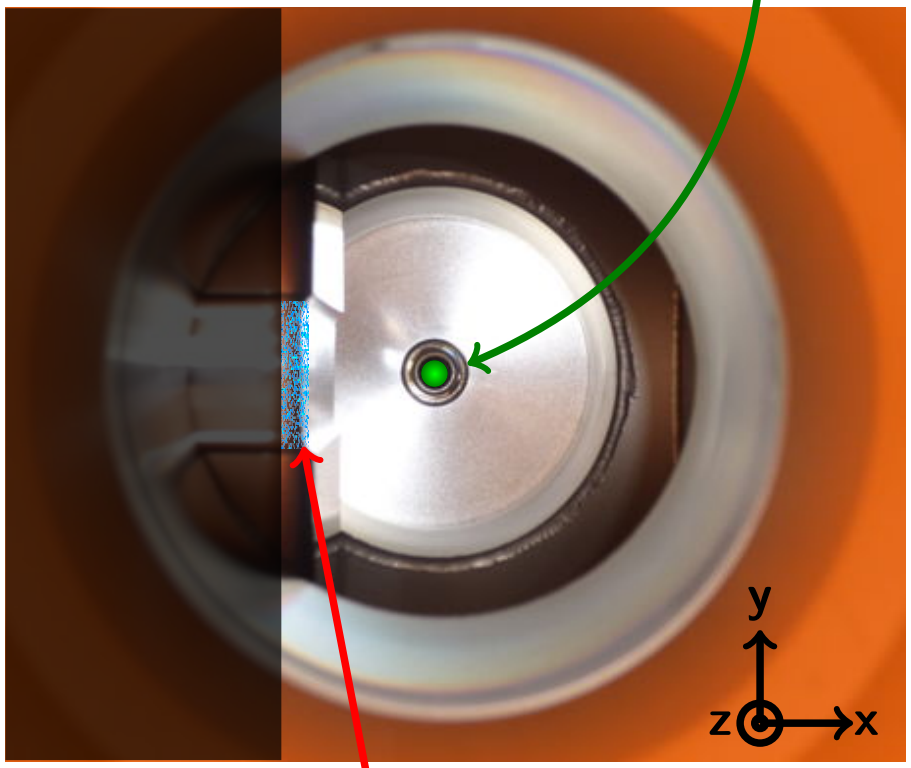
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

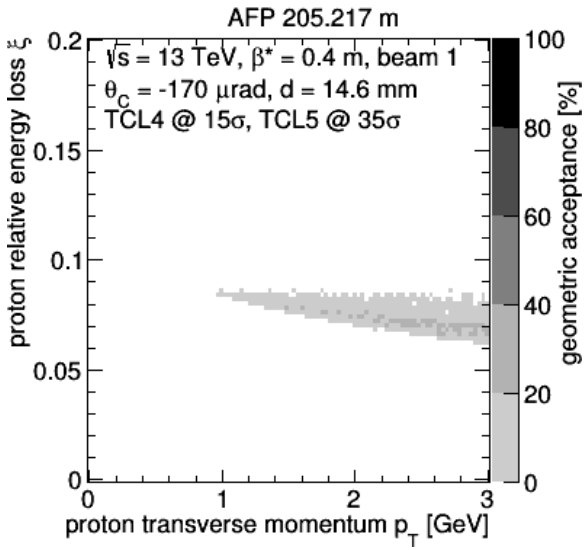
LHC beam



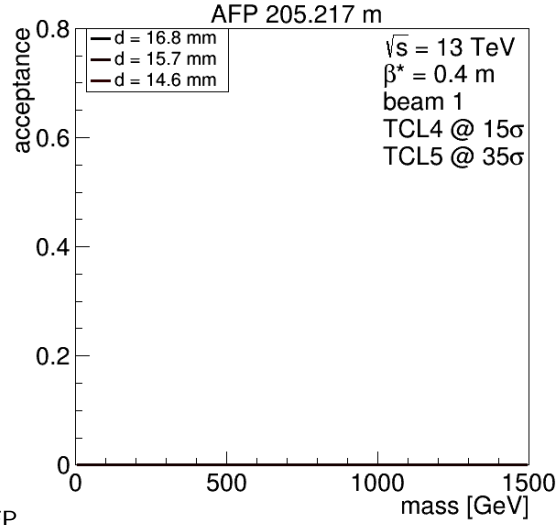
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



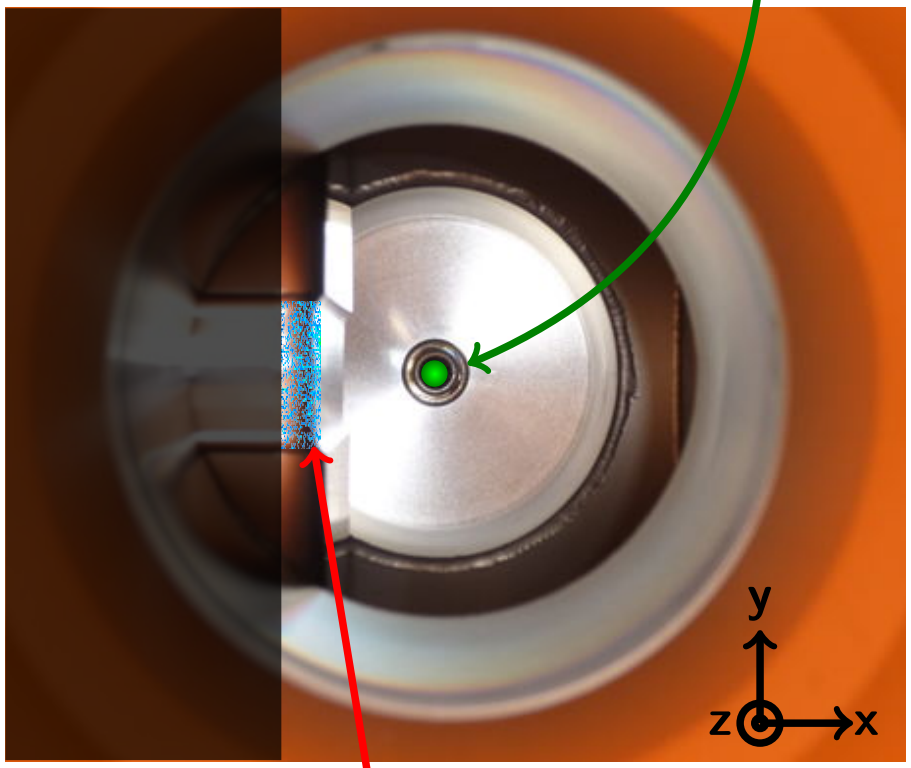
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

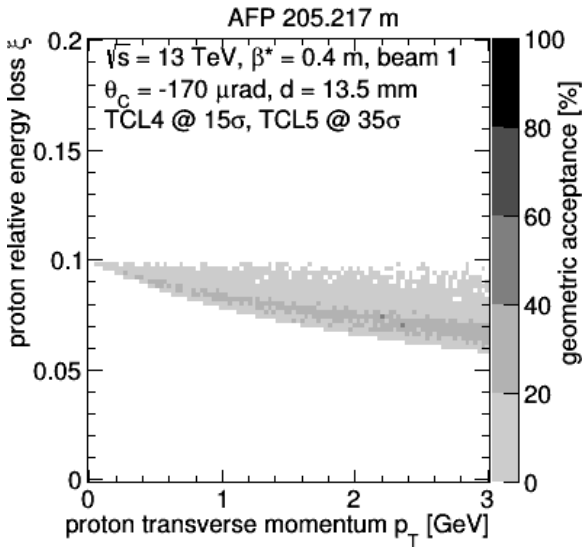
LHC beam



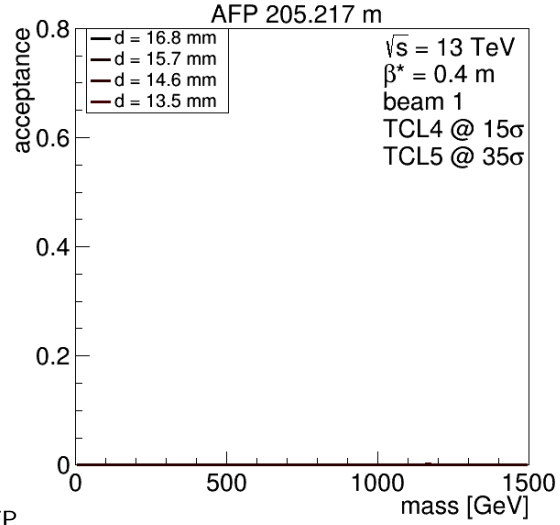
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



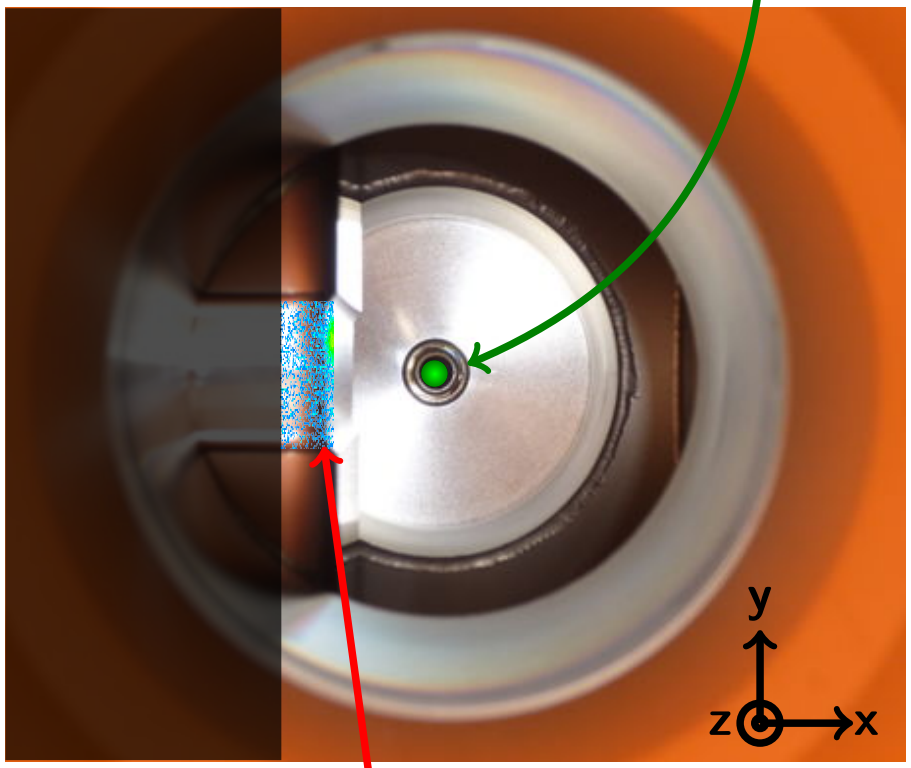
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

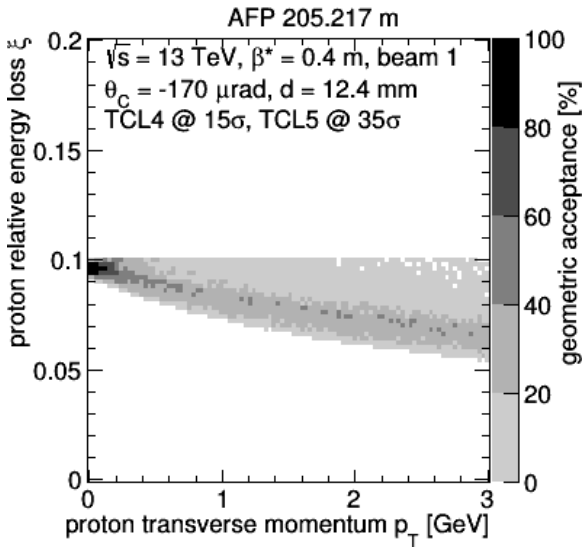
LHC beam



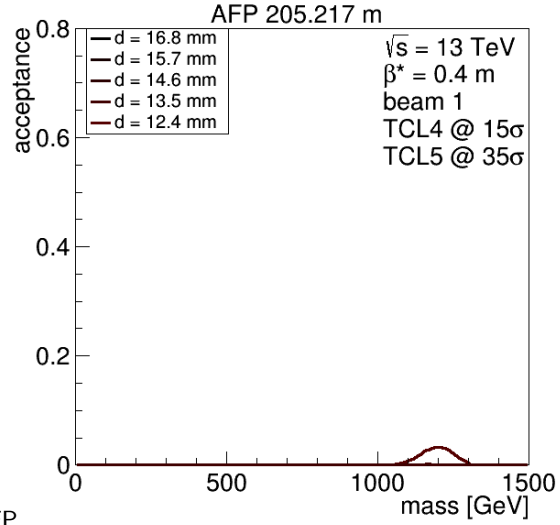
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



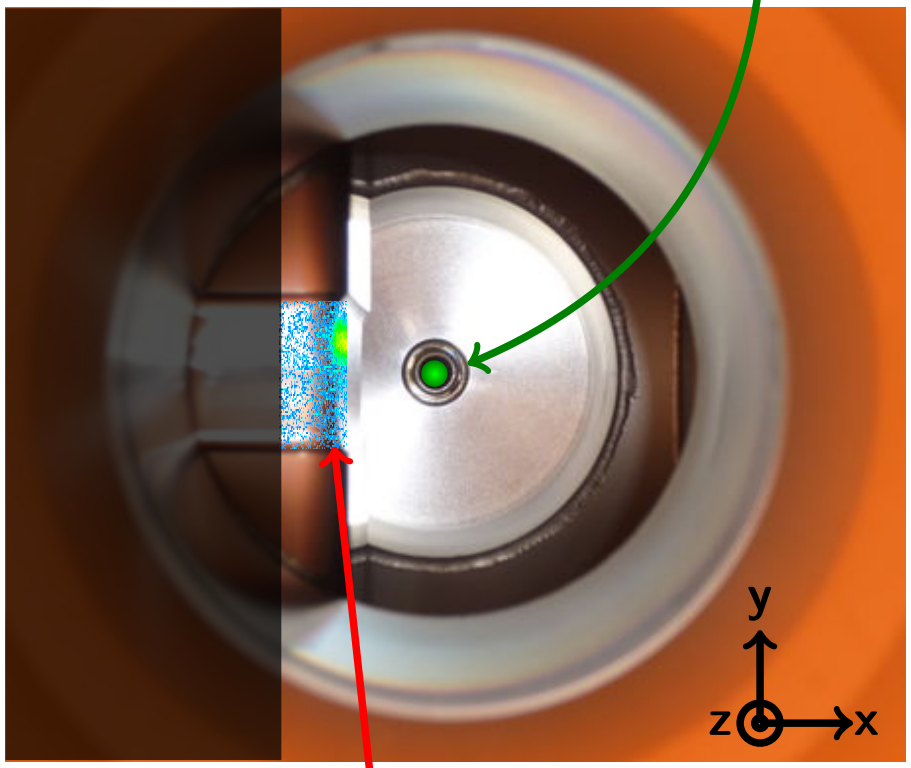
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

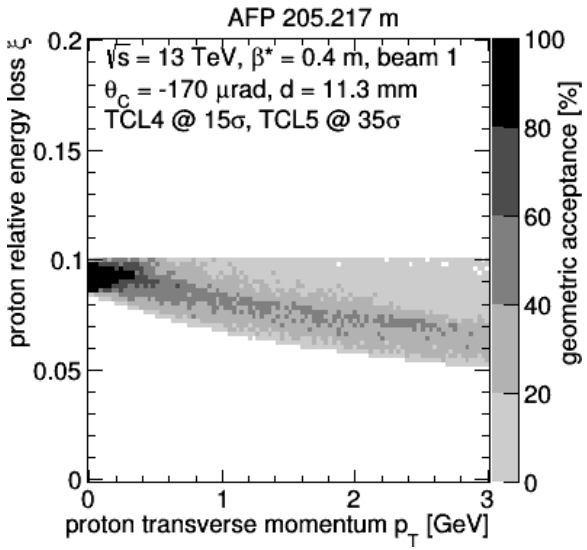
LHC beam



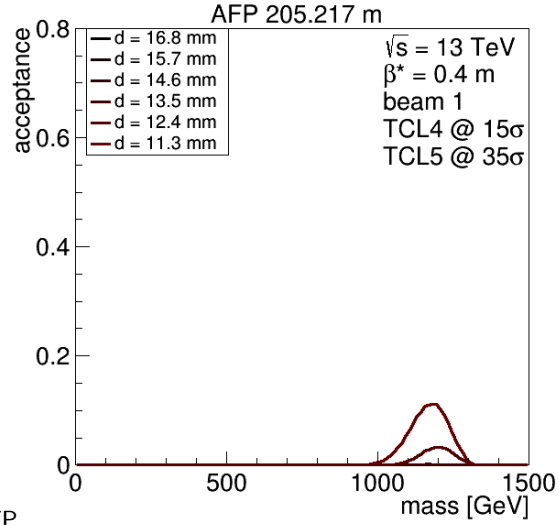
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



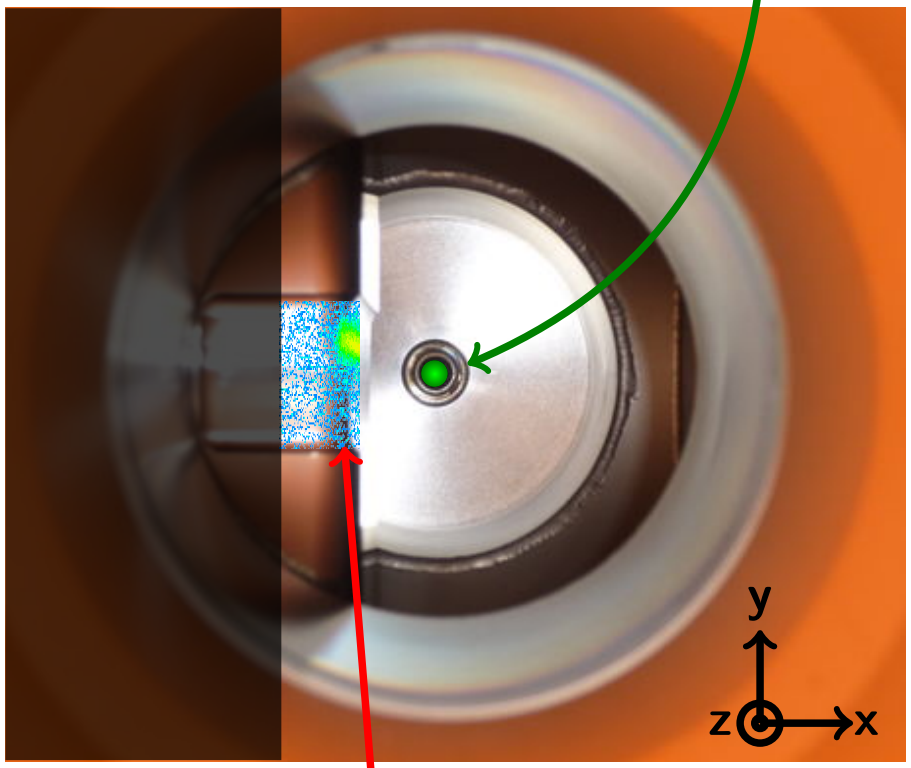
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

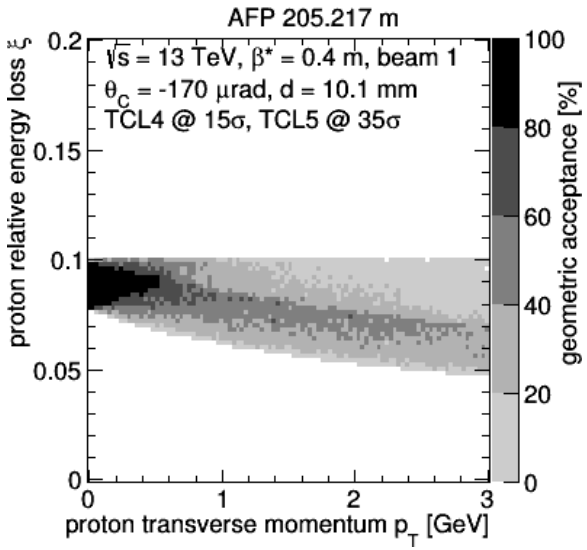
LHC beam



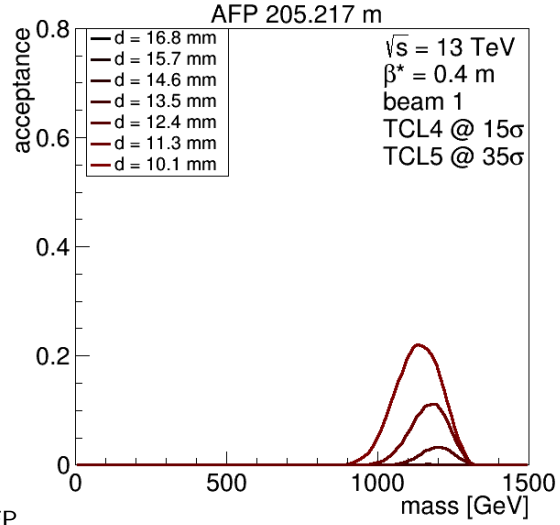
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



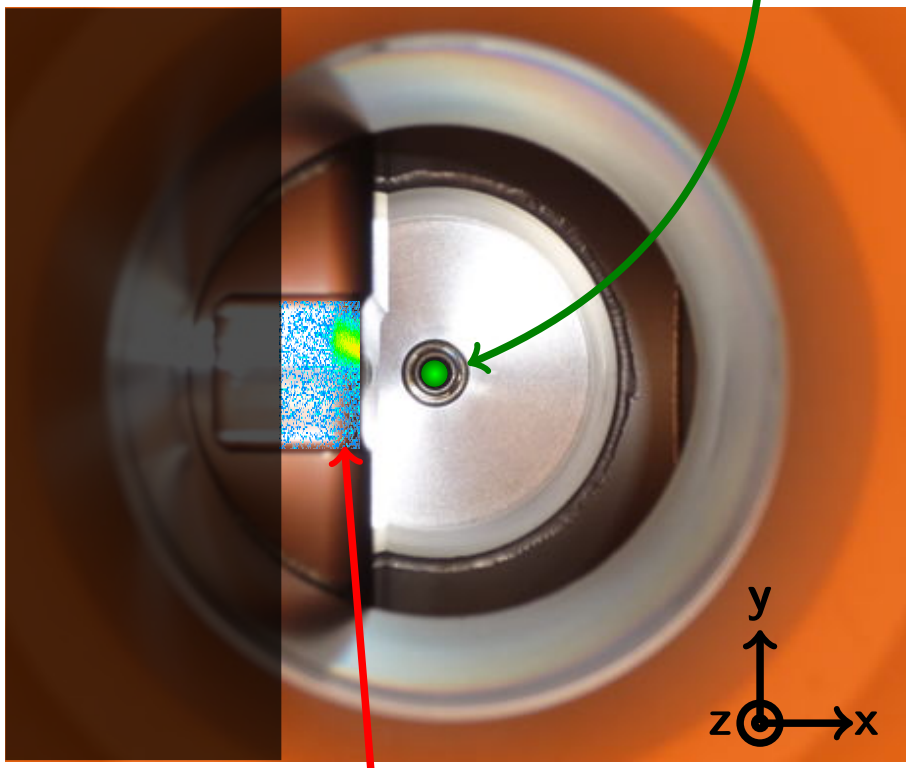
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

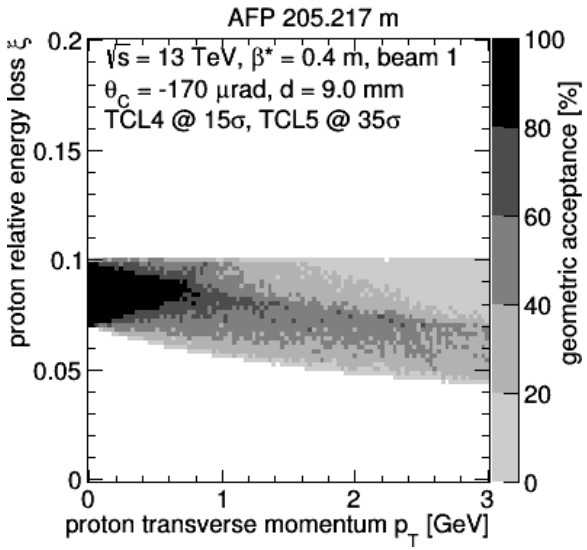
LHC beam



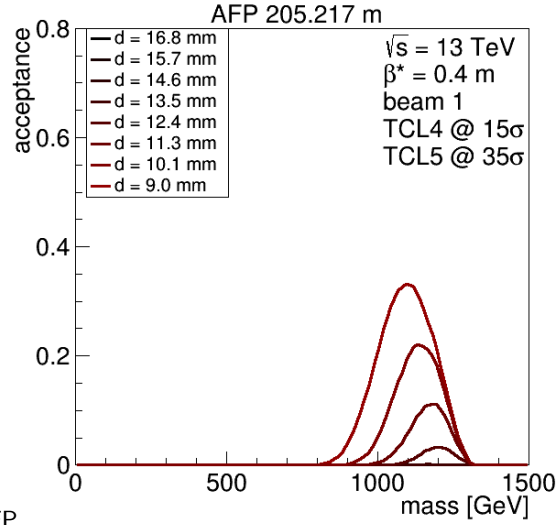
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



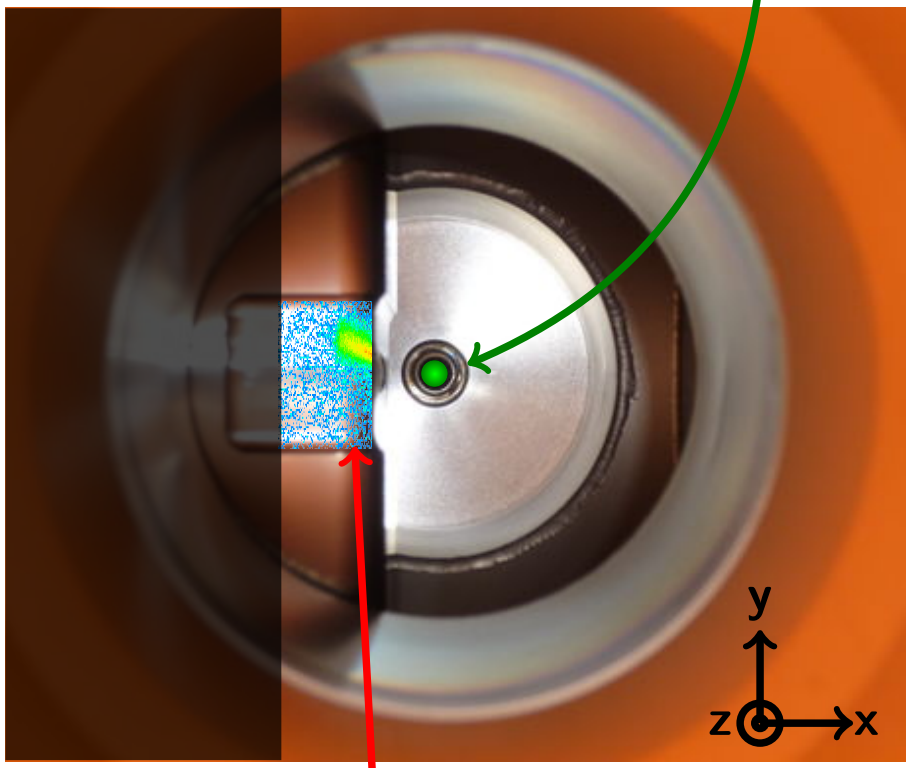
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

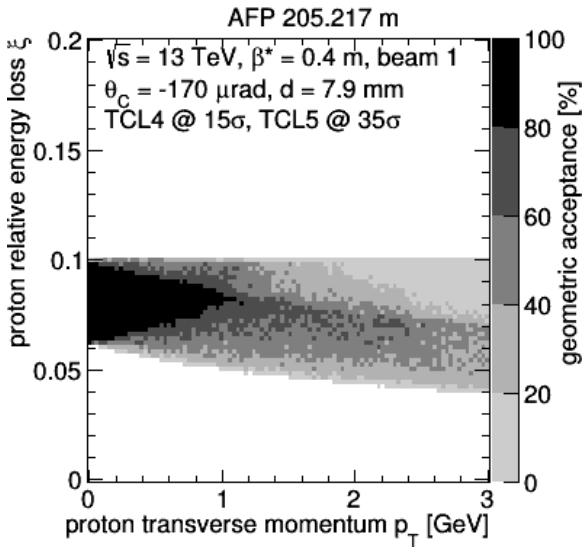
LHC beam



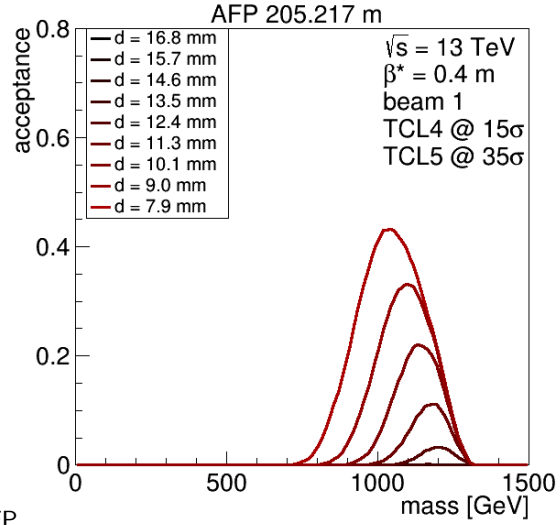
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



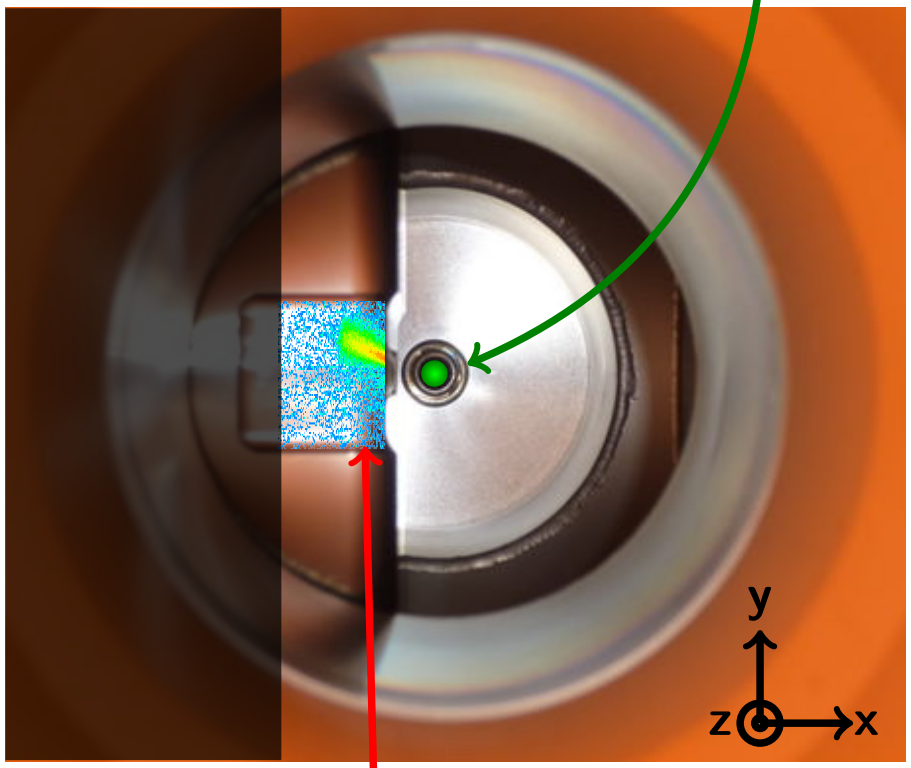
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

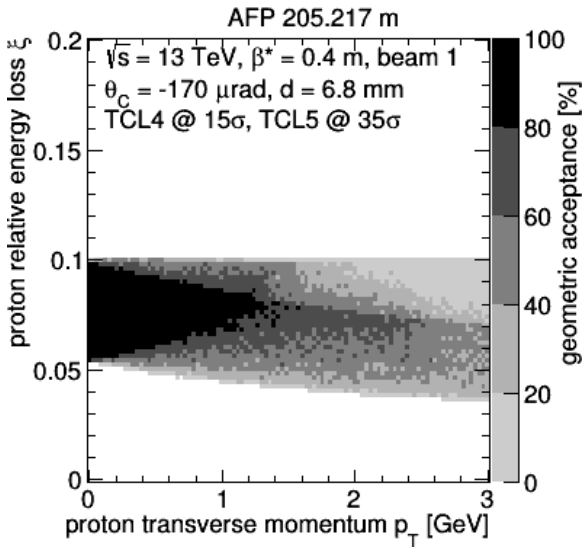
LHC beam



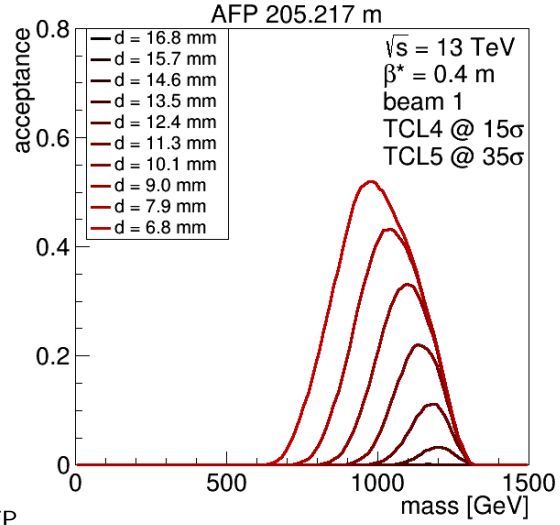
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



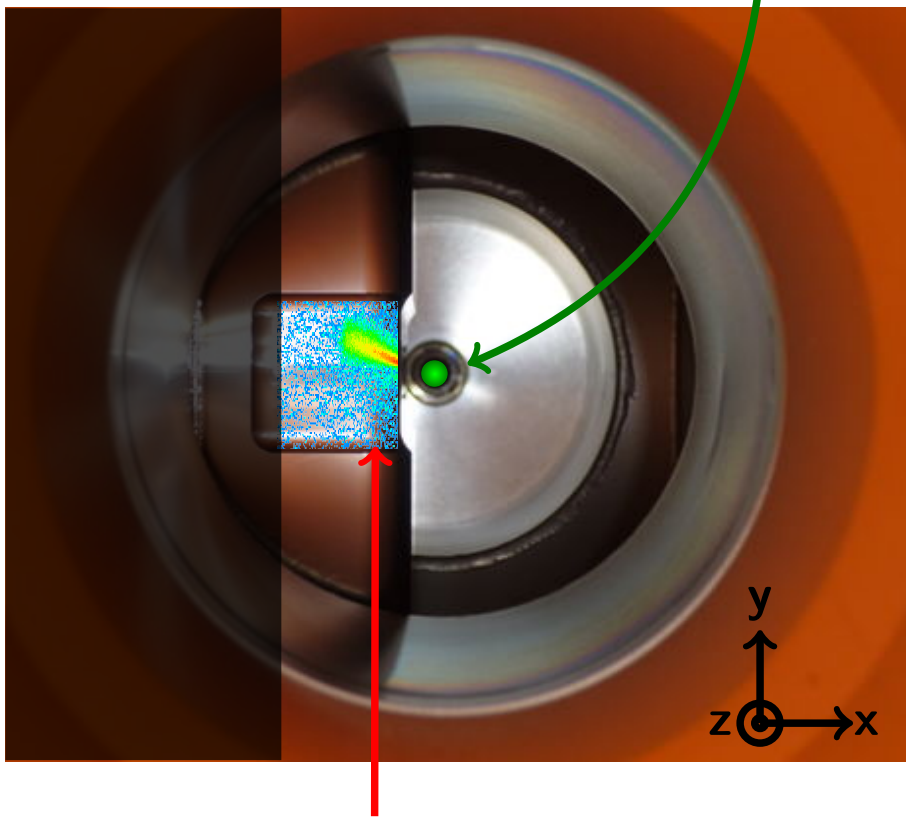
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

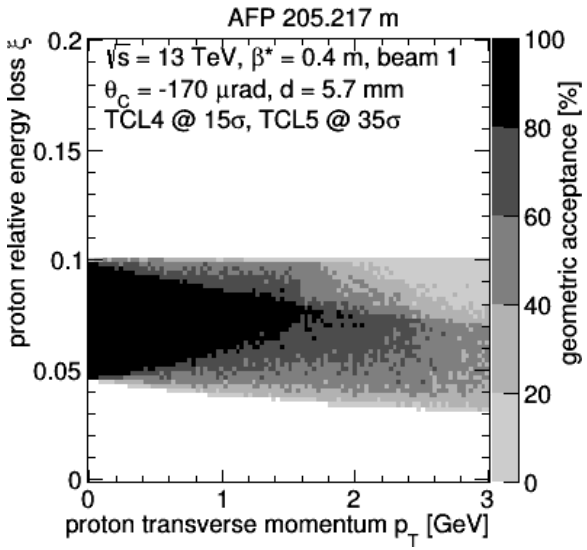
LHC beam



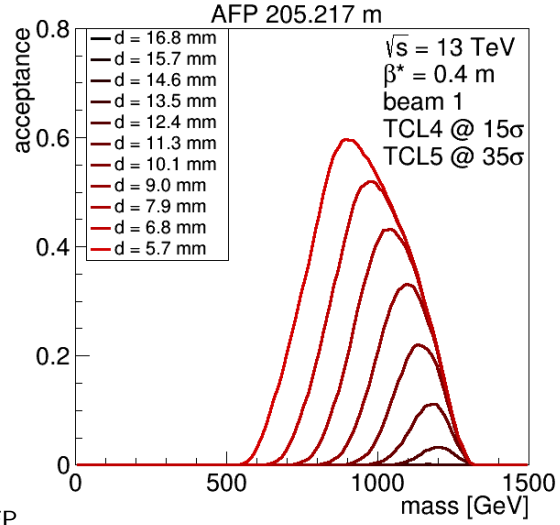
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



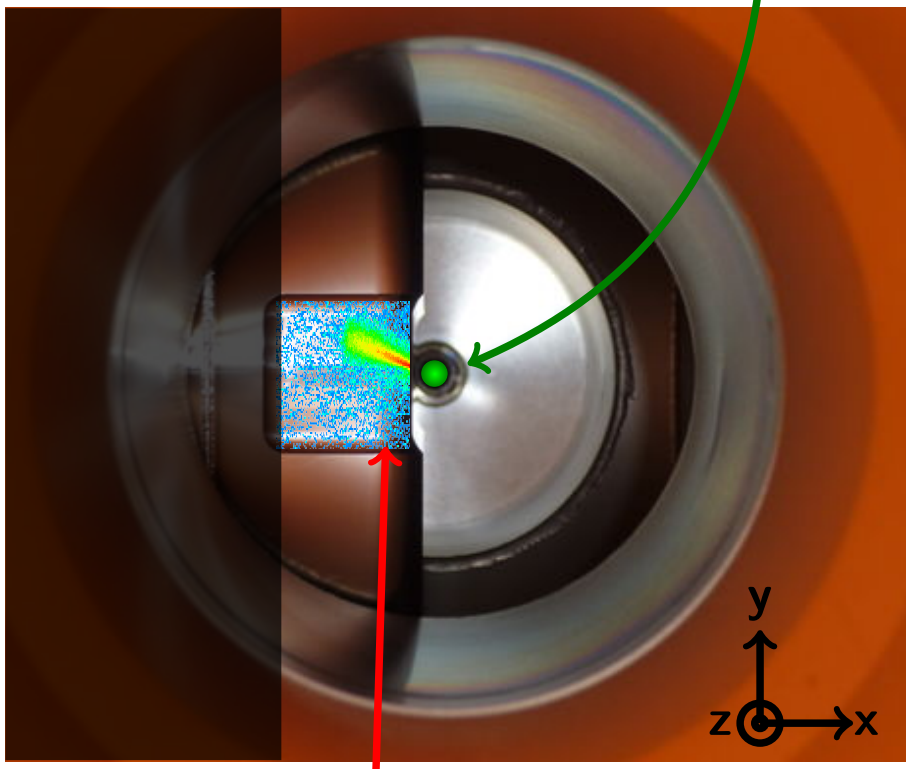
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

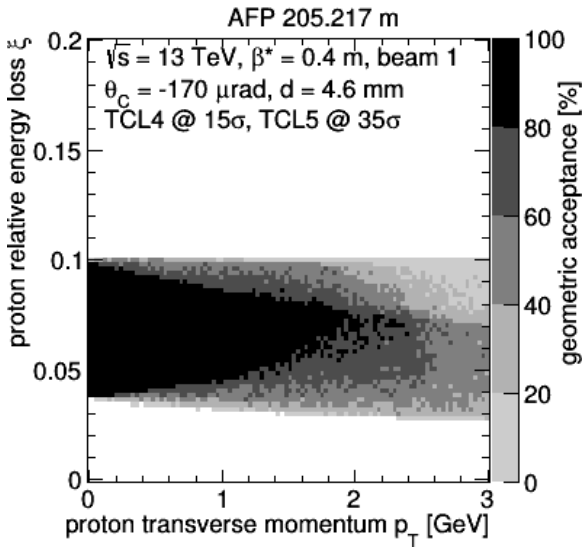
LHC beam



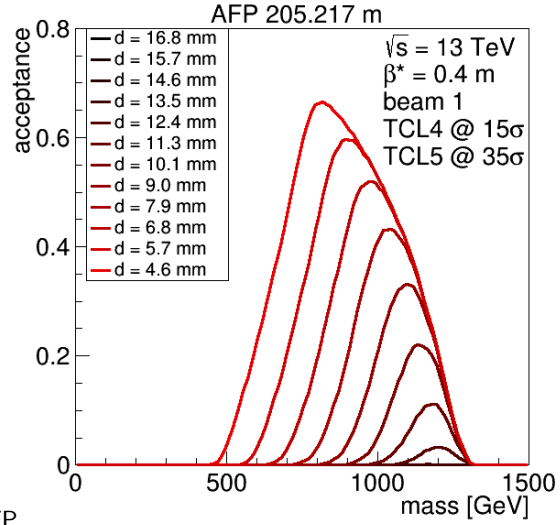
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



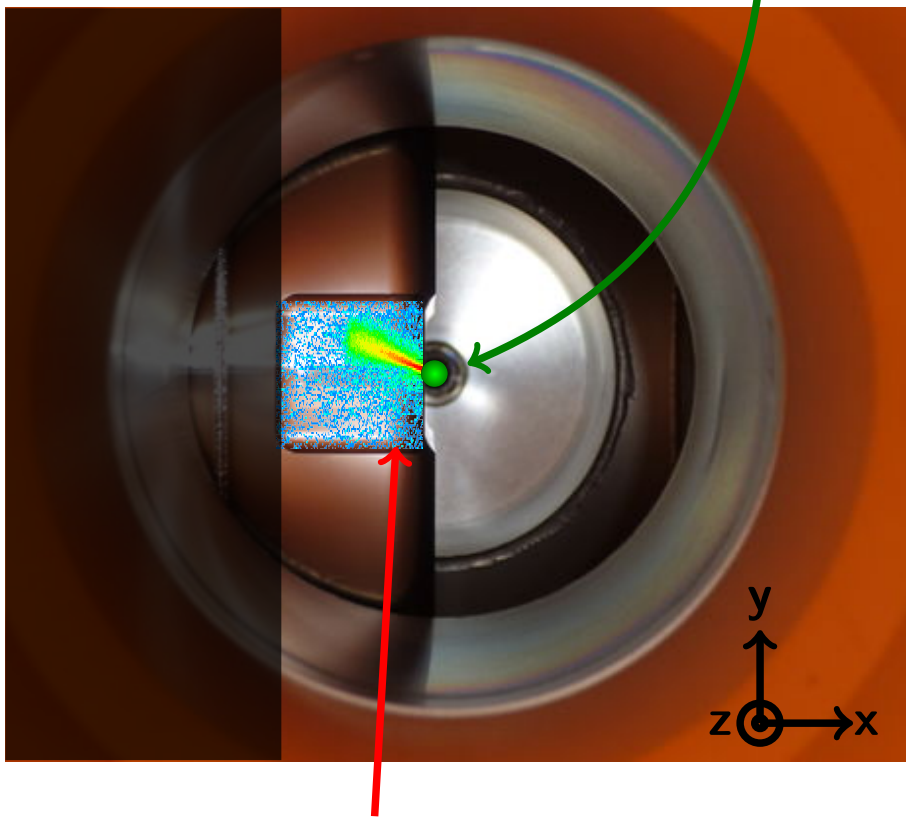
Mass acceptance:



M. Trzebiński Photon-Photon @ ATLAS/AFP

shadow of TCL4 and TCL5 collimators

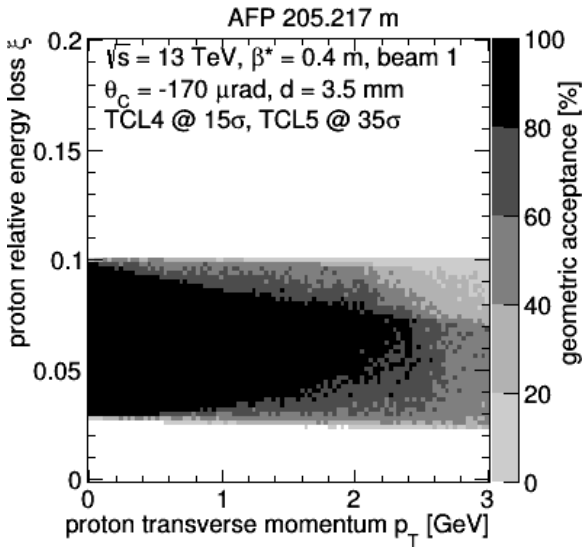
LHC beam



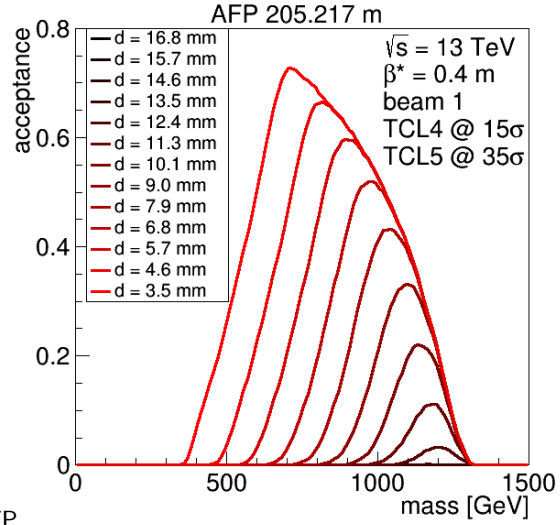
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:

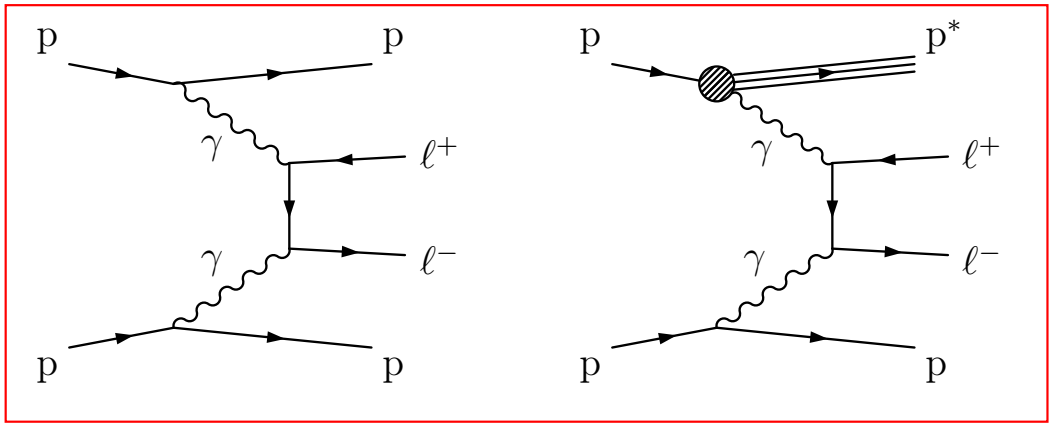


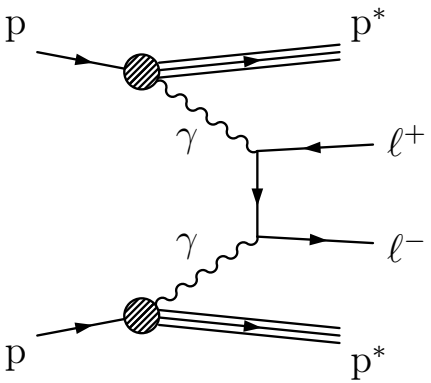
Mass acceptance:



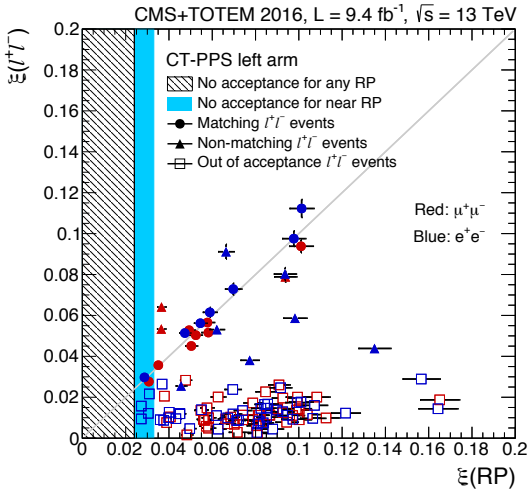
M. Trzebiński Photon-Photon @ ATLAS/AFP

Physics Results (PPS)



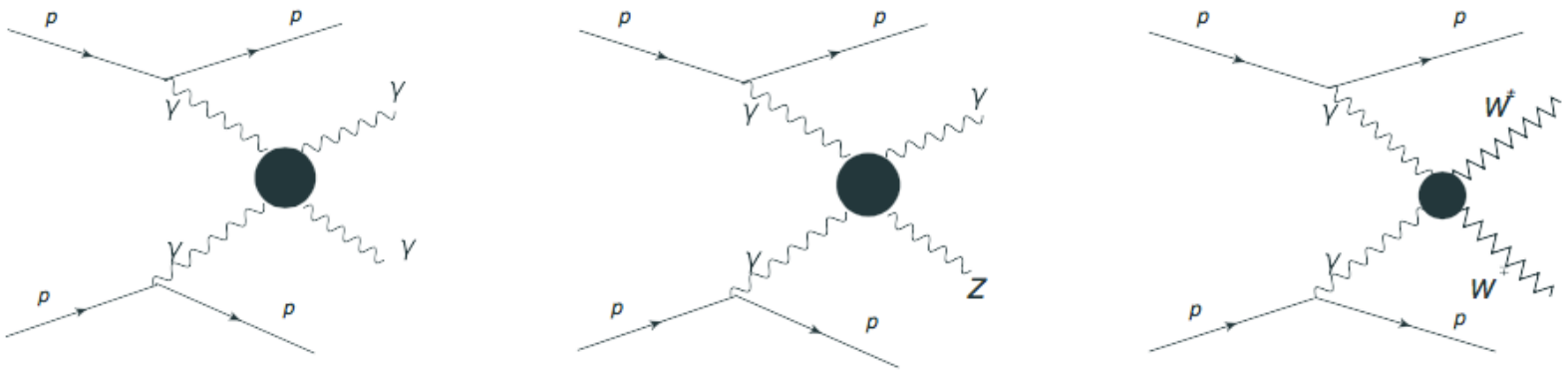


- First observation of the process at high mass using intact protons
- Observed 13 signal events (5.1σ) consistent with the SM expectation
- Performed at normal optics and pileup conditions
- Proof that the alignment, optics, trigger, proton tagging, etc are working



JHEP 1807 (2018) 153

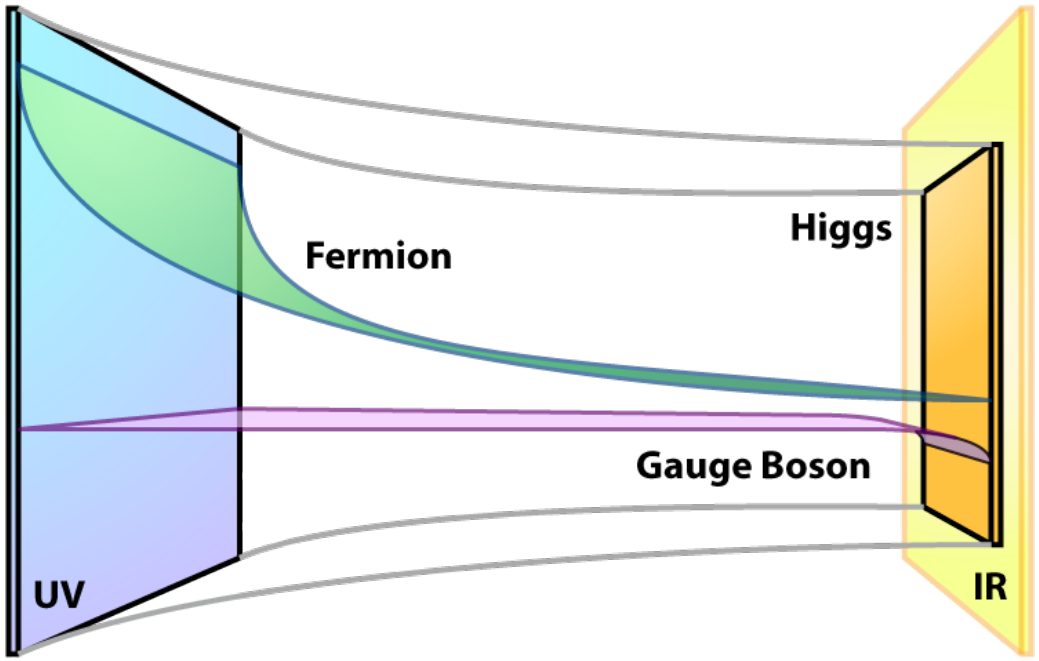
Anomalous Quartic Guage Couplings



- Photon induced processes with intact protons in forward regions
- Exclusive processes with a very clean signal
- Proton tagging provides the best sensitivity to anomalous couplings

Motivations

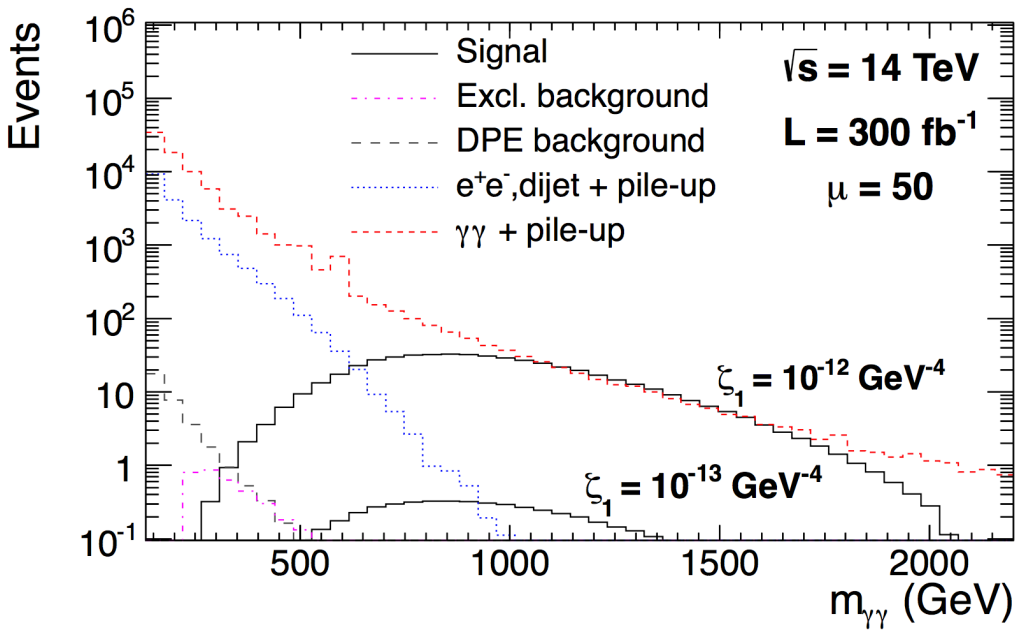
- Warped Extra Dimensions solve hierarchy problem of the SM
- Predicted by Composite Higgs, Kaluza Klein, Extra Dimensional models
- Couplings can be probed independently of models
- Effective 4-photon couplings $\zeta_i \sim 10^{-14}$ - 10^{-13} GeV^{-4} possible



JHEP 1403 (2014) 102

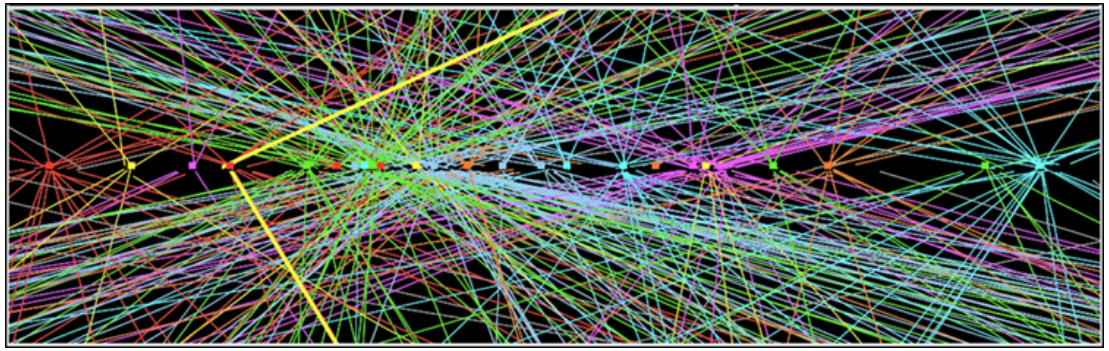
Backgrounds

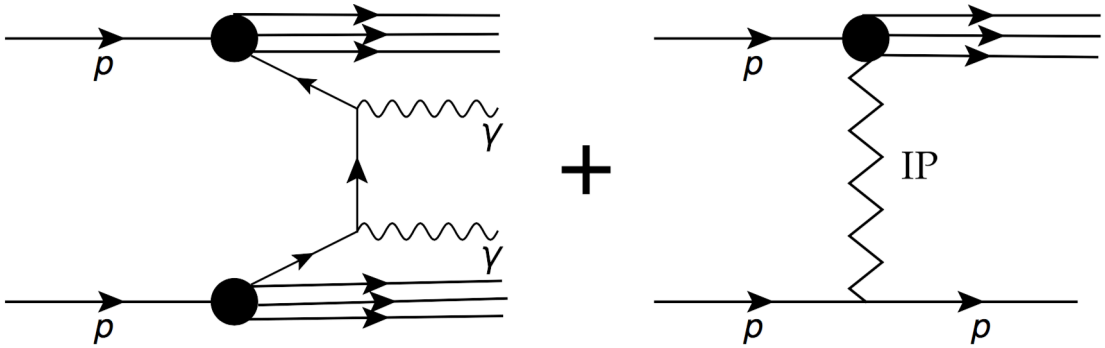
- Requesting two protons identified in forward detectors + two converted photons in central detector
- All backgrounds considered (DPE diphoton production, H→ $\gamma\gamma$, exclusive $\gamma\gamma$ production, dilepton + dijet misidentification, PU, Drell-Yan, ...)
- Pileup is the main source of background



JHEP 02, 165 (2015)

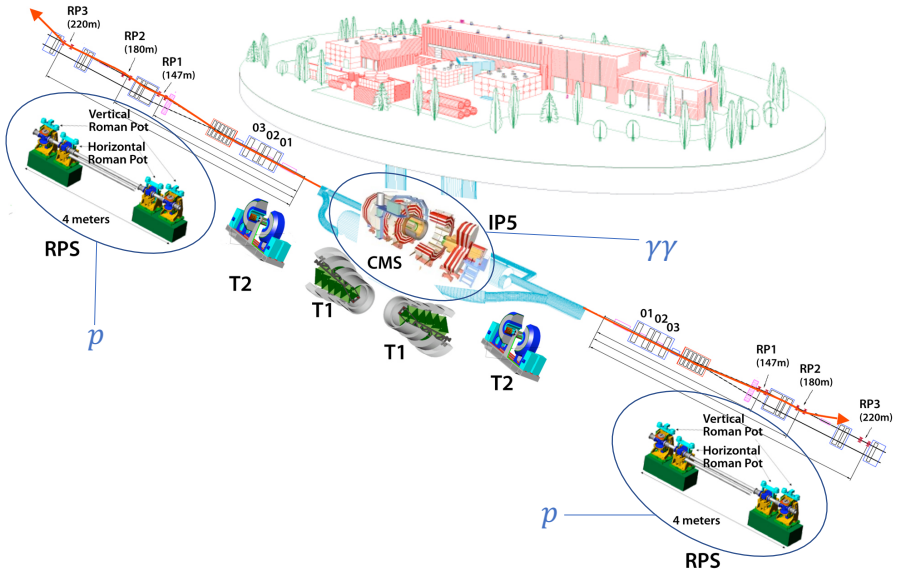
Pile Up

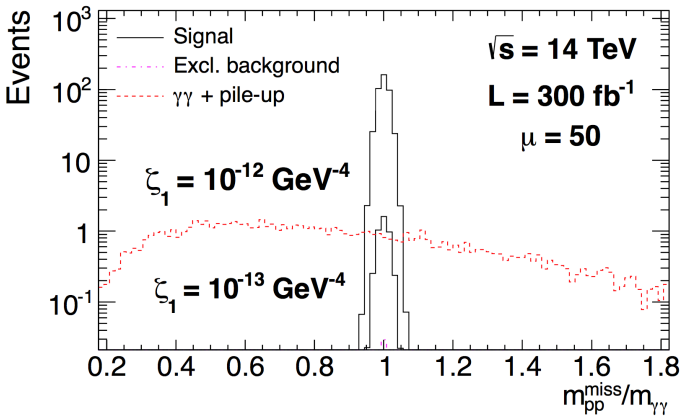


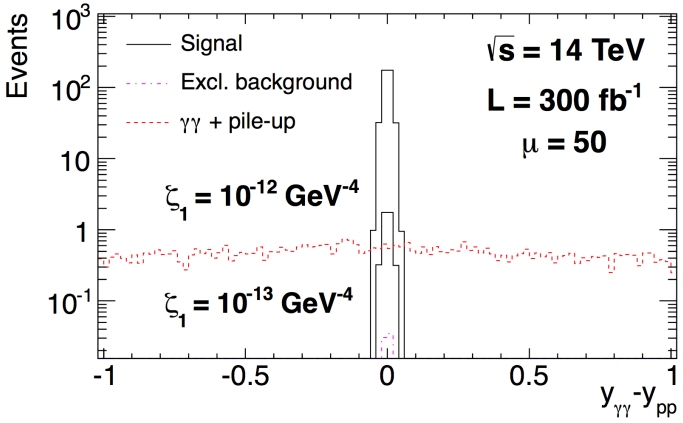


- The LHC collides packets of protons
- PU causes background from particles generated at unrelated vertices
- For conditions of the LHC in 2016, can have up to 60 PU vertices

Dealing With Pile Up







JHEP 02, 165 (2015)

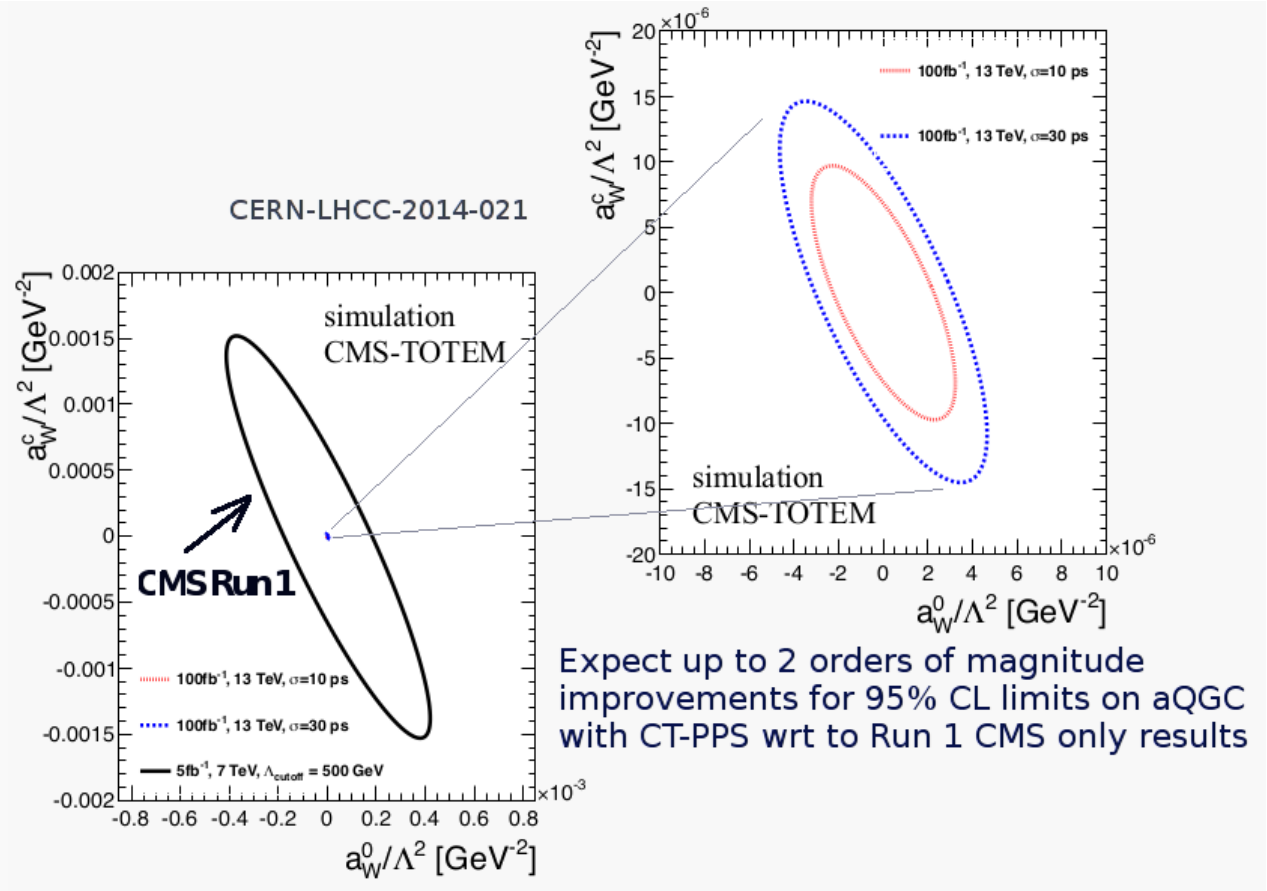
Dealing With Pile Up

Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15,$ $p_{T1,(2)} > 200, (100)$ GeV$]$	65	18 (187)	0.13	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	64	17 (186)	0.10	0	0.2	1023
$[p_{T2}/p_{T1} > 0.95,$ $\lvert\Delta\phi\rvert > \pi - 0.01]$	64	17 (186)	0.10	0	0	80.2
$\sqrt{\xi_1\xi_2 s} = m_{\gamma\gamma} \pm 3\%$	61	16 (175)	0.09	0	0	2.8
$\lvert y_{\gamma\gamma} - y_{pp}\rvert < 0.03$	60	12 (169)	0.09	0	0	0

Virtually no background after selection cuts [1]

[1] JHEP 02, 165 (2015)

Comparison Of Limits

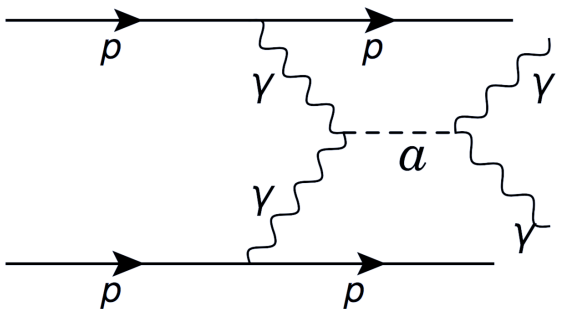


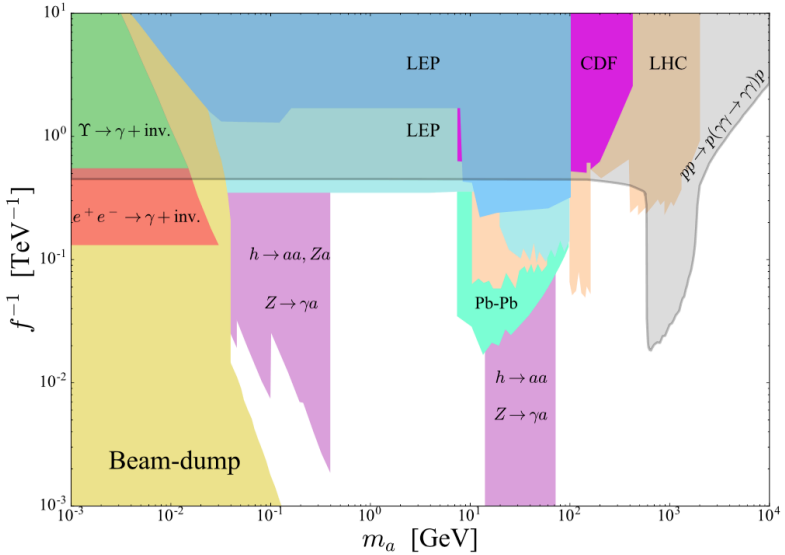
Expect up to 2 orders of magnitude improvements for 95% CL limits on aQGC with CT-PPS wrt to Run 1 CMS only results

Search For Axion-Like Particles

We can study the production of ALPs via photon exchange with intact protons

- Study the production of ALPs via photon exchange with intact protons
- Sensitivity is enhanced since ALP production rate increases with $m_{\gamma\gamma}$
- Proton tagging provides sensitivity that is competitive and complementary to other collider searches above 600 GeV
- Existing limits on ALP production[2]





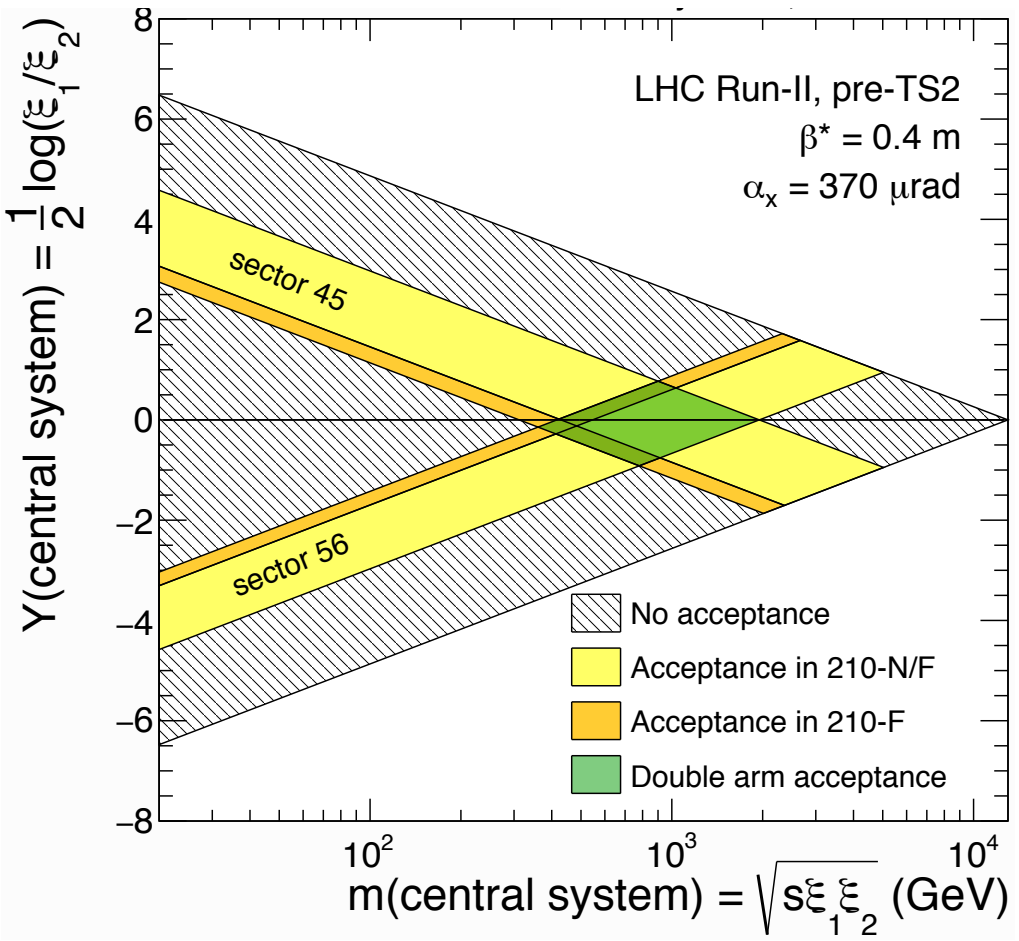
[2] JHEP 1806 (2018) 131

Summary

- Proton tagging provides a broad physics program, from the study of proton structure to BSM physics
- Proton tagging provides the best sensitivity to anomalous couplings
- Measuring all final state particles gives a closed kinematic system
- PPS and AFP have taken data during the LHC Run 2 that are currently being analyzed

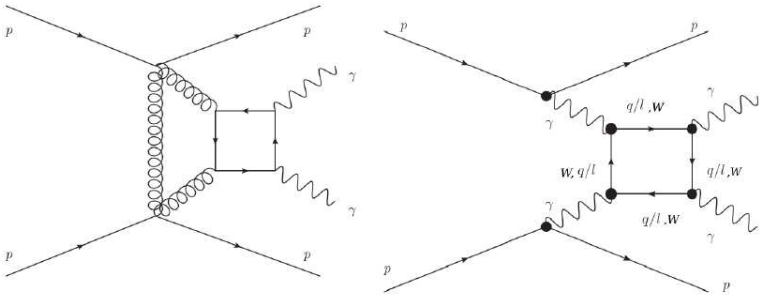
Questions?

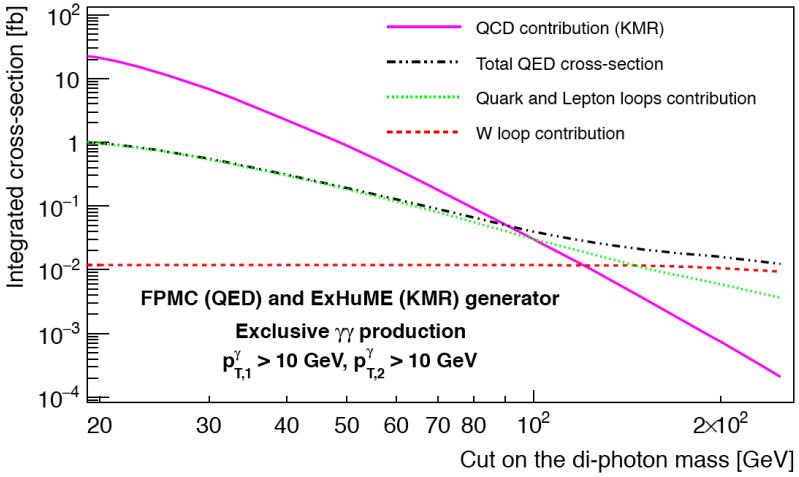
Available Phase Space



Standard Model $\gamma\gamma$ Exclusive Production

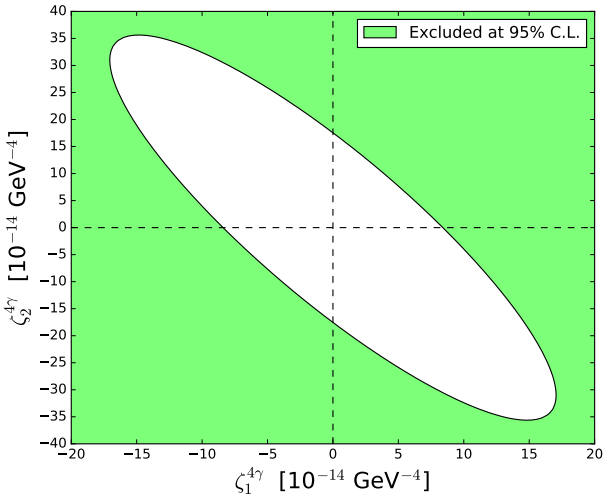
- QED process dominates at high $m_{\gamma\gamma}$
- Cross section is well known
- W boson loop is the most significant at high $m_{\gamma\gamma}$





JHEP 02, 165 (2015)

Potential For Limits



Cross section scales as a function of the coupling values ζ_1,ζ_2

$$\frac{d\sigma}{d\Omega} = \frac{1}{16\pi^2 s}\left(s^2 + t^2 + st\right)^2 \left[48\left(\zeta_1\right)^2 + 40\zeta_1\zeta_2 + 11\left(\zeta_2\right)^2\right]$$

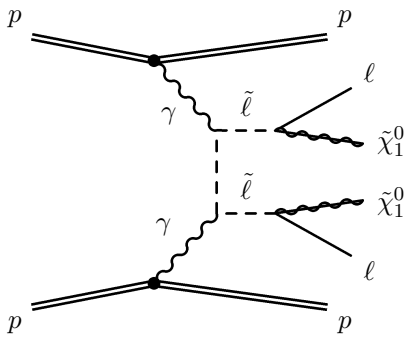
- Based on 9.41 fb^{-1} of data from 2016
- Assume signal and background obey a Poisson distribution
- Assume expected background is 0 and observed events is 0

$$\sqrt{48\zeta_1^2 + 40\zeta_1\zeta_2 + 11\zeta_2^2} \geq 5.8 \times 10^{-13}\text{GeV}^{-4}$$

Compressed SUSY Searches With Intact Protons

See talk by L. A. Hardland-Lang at PHOTON2019

- Cross section for ~ 100 GeV slepton pair CEP ~ fb $\Rightarrow$ essential to take data during **nominal high-luminosity** LHC running.
- Question discussed in recent study: what are **challenges/backgrounds** in searching for such a signal via CEP?



IPPP/18/103

LHC Searches for Dark Matter in Compressed Mass Scenarios: Challenges in the Forward Proton Mode

L.A. Harland-Lang[1*], V.A. Khoze[2,3†], M.G. Ryskin[3‡] and M. Tasevsky[4§]

[1]Rudolf Peierls Centre, Beecroft Building, Parks Road, Oxford, OX1 3PU, UK

[2]IPPP, Department of Physics, University of Durham, Durham, DH1 3LE, UK

[3]Petersburg Nuclear Physics Institute, NRC "Kurchatov Institute", Gatchina, St. Petersburg, 188300, Russia

[4]Institute of Physics, Czech Academy of Sciences, CS-18221 Prague 8, Czech Republic

Abstract

We analyze in detail the LHC prospects at the center-of-mass enery of $\sqrt{s} = 14$ TeV for charged electroweakino searches, decaying to leptons, in compressed supersymmetry scenarios, via exclusive photon-initiated pair production. This provides a potentially increased

LHL, V.A. Khoze, M.G. Ryskin, M. Tasevsky, JHEP 1904 (2019) 010

JHEP 04 (2019) 010