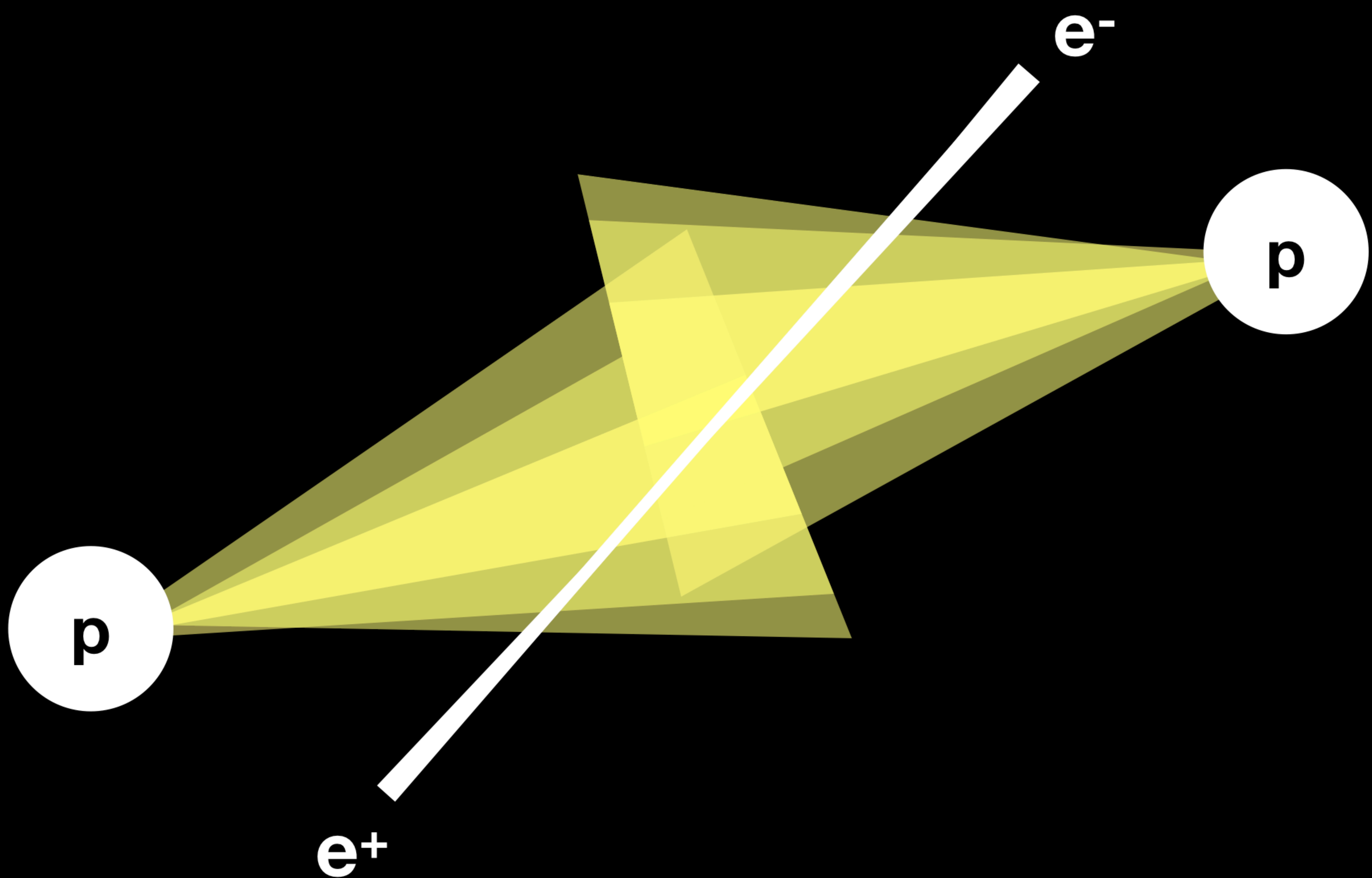


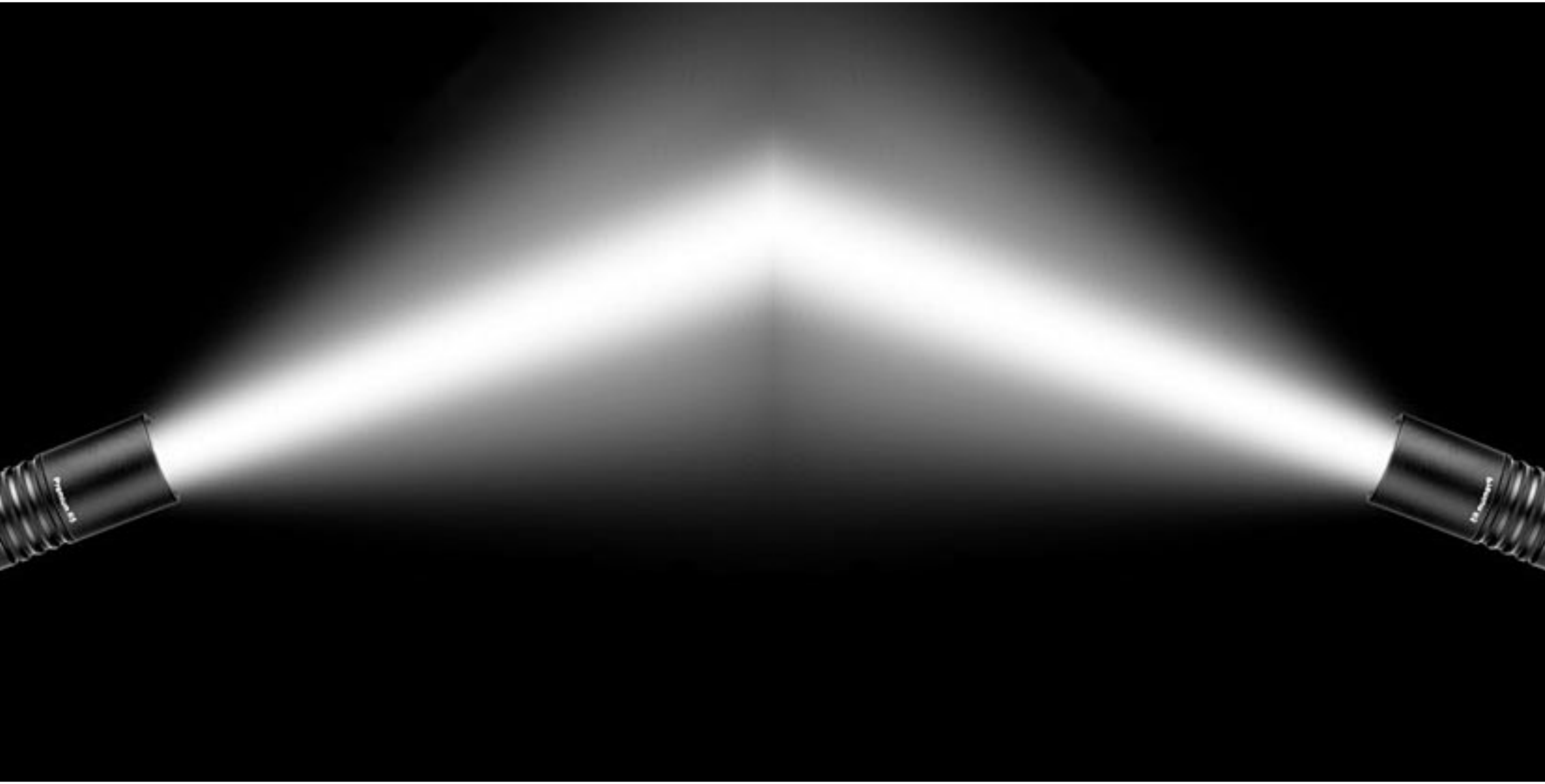
LHC photon collisions using forward detectors

Lydia Beresford

UNIVERSITY OF OXFORD

HighRR Seminar Heidelberg, 30/09/20

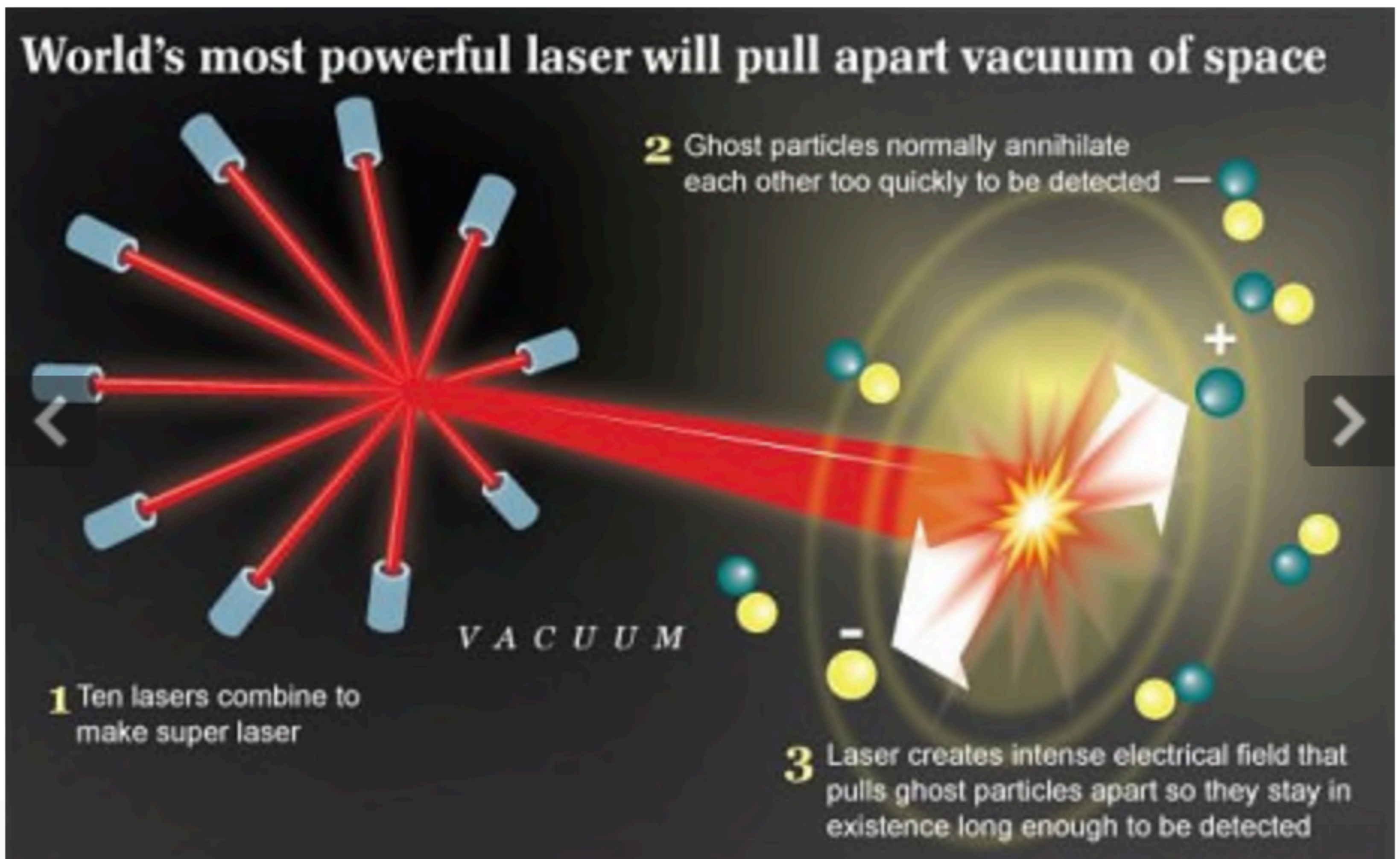
What happens when you collide photons?



HOME » NEWS » SCIENCE » SCIENCE NEWS

World's most powerful laser to tear apart the vacuum of space

A laser powerful enough to tear apart the fabric of space could be built in Britain as part major new scientific project that aims to answer some of the most fundamental questions about our universe.

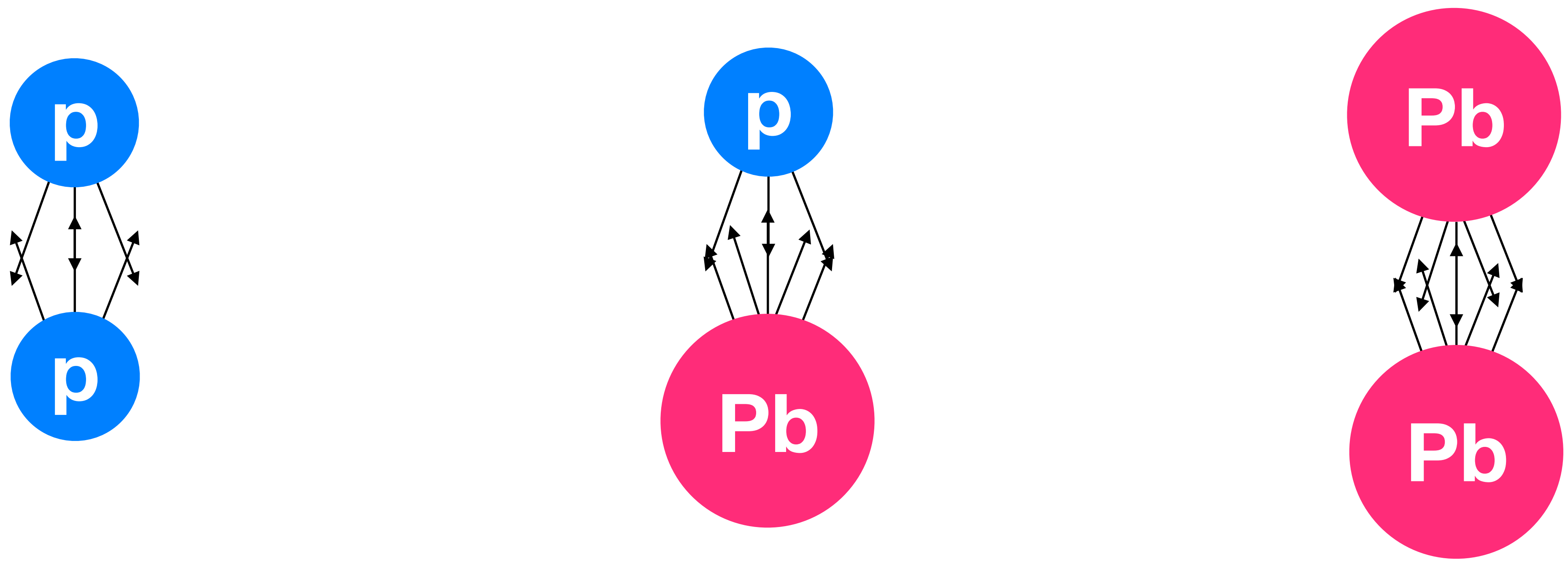


Print this article

Science News

News » Europe » UK News » Science » Richard Gray »

This already happens at the LHC!



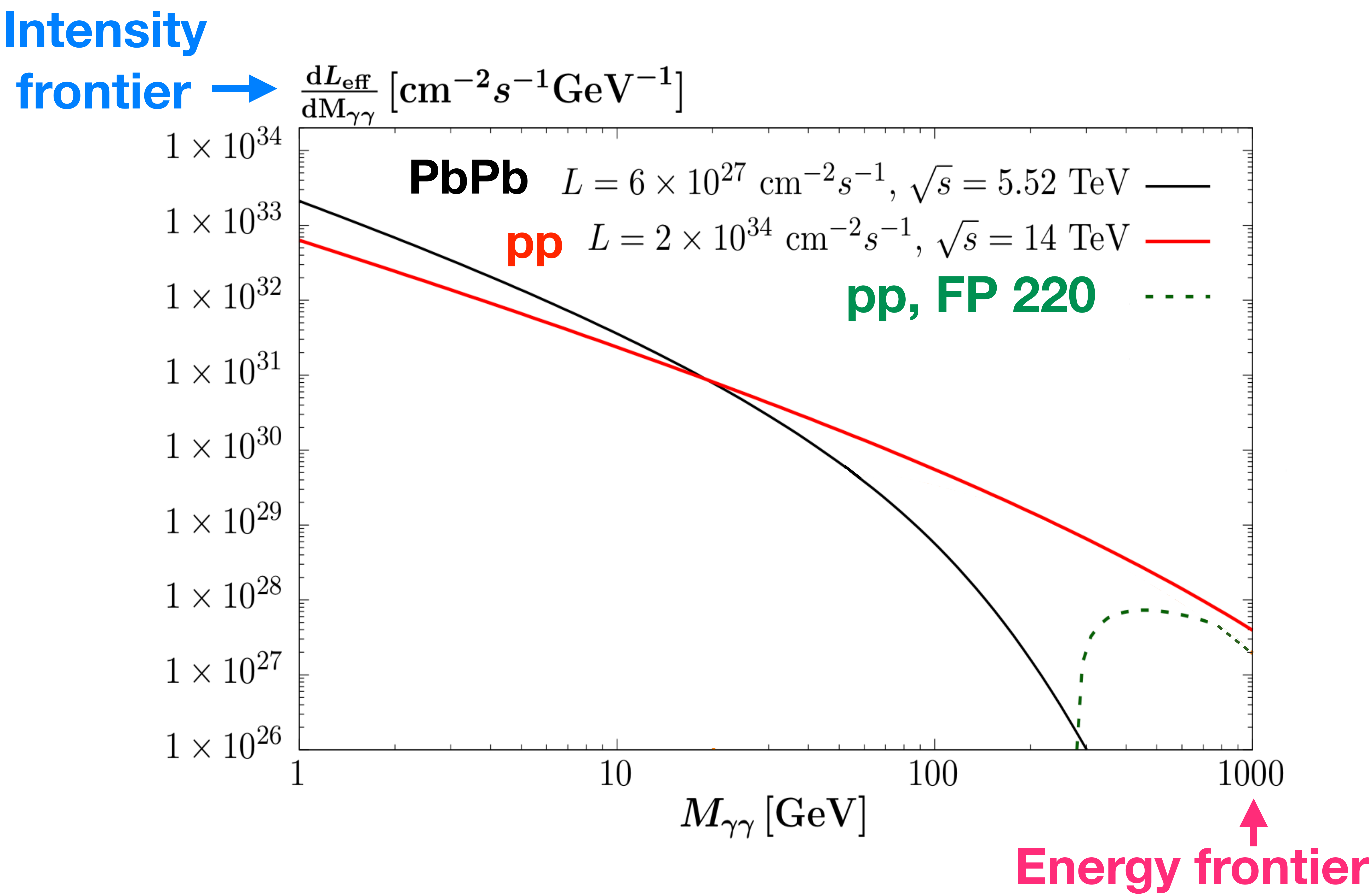
Strong electric fields around charged protons & lead ions

For lead ions electric field can be up to **10^{25} V m^{-1}**

Can turn photons into matter!

Broadband photon collider

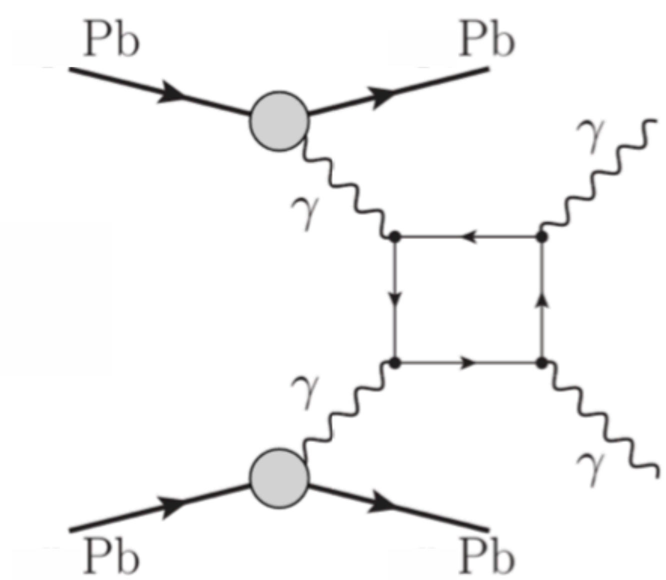
Bruce et al [1812.07688]



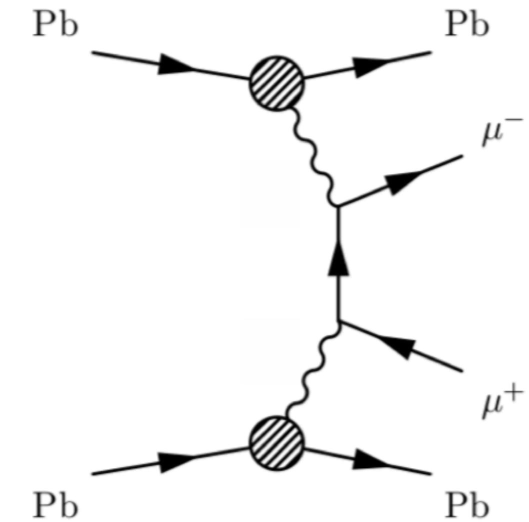
Motivation

* More motivation later on

PbPb

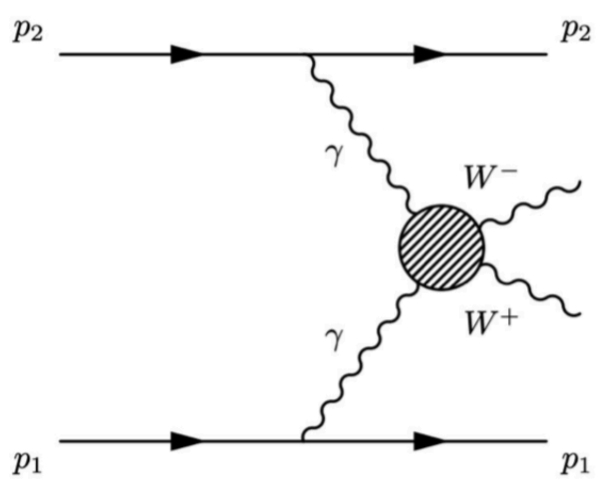


Light-by-light scattering

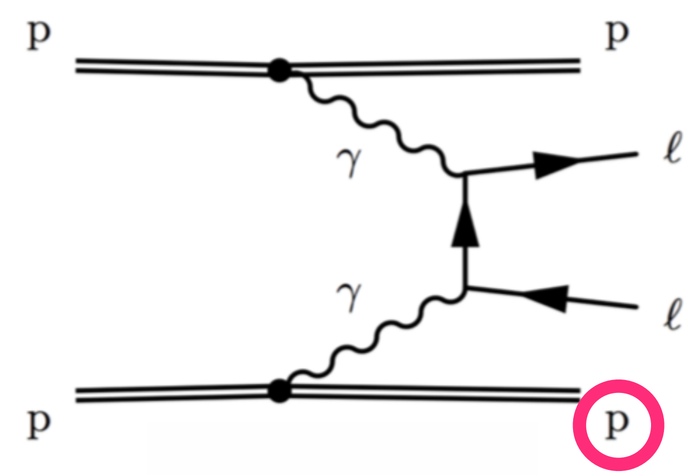


'Standard candle' constrains photon-flux

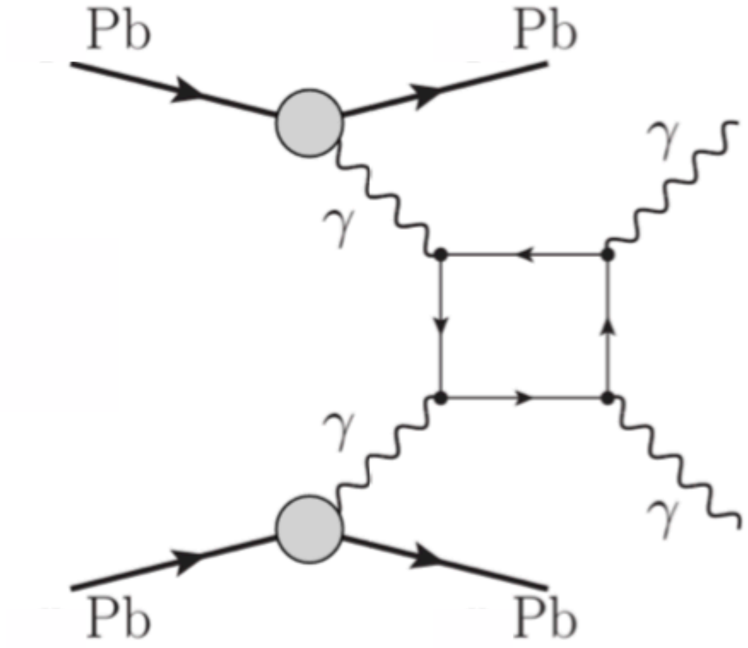
pp

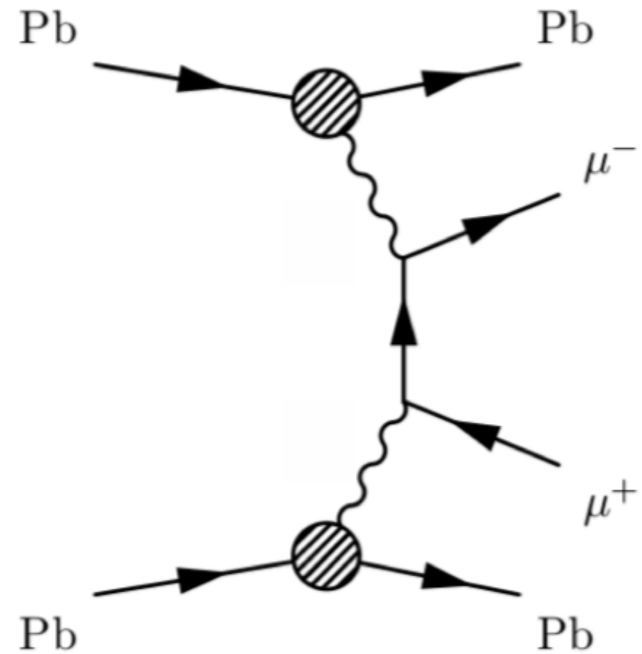


Sensitive to SM $\gamma\gamma$WW vertex anomalous quartic coupling?

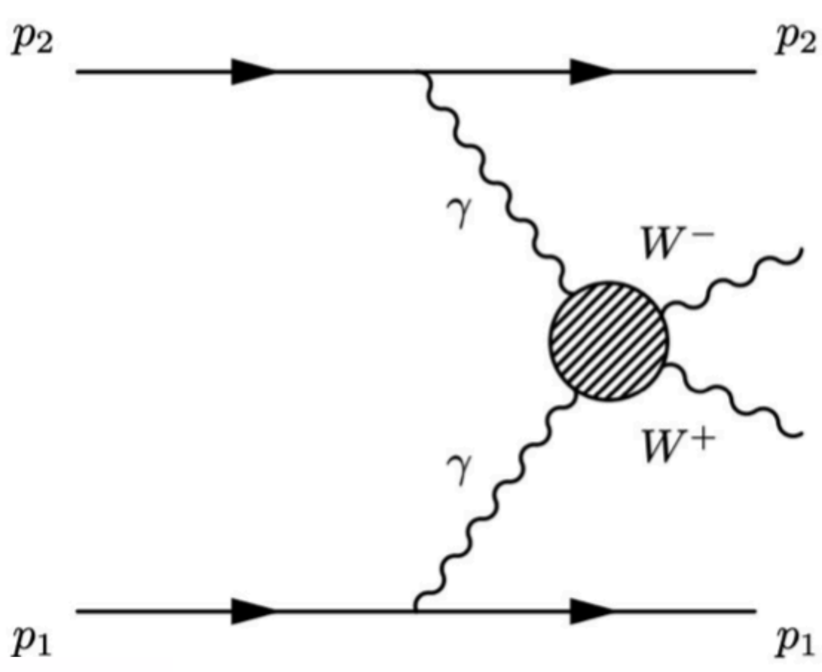


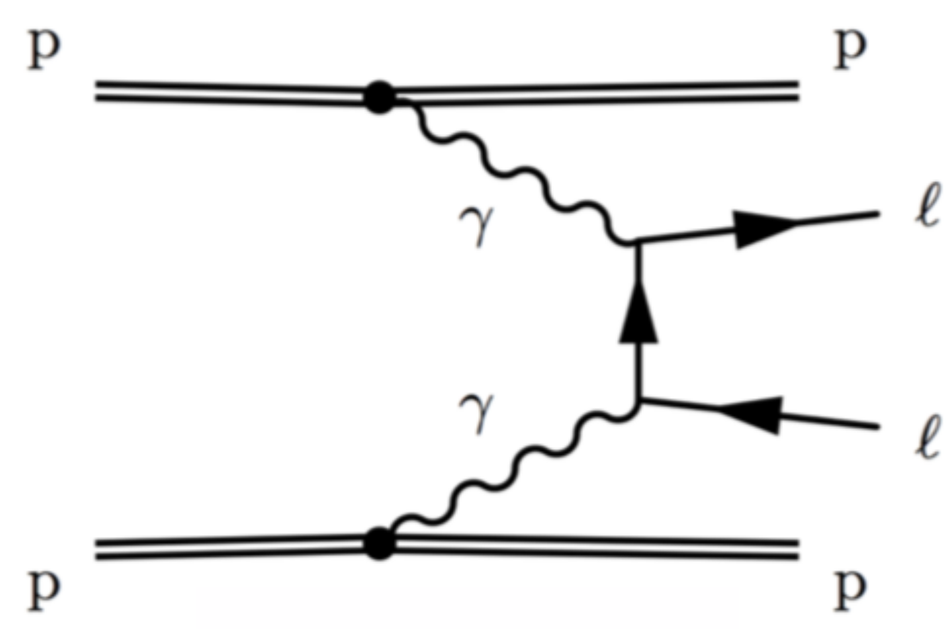
Constrains proton survival probabilities.



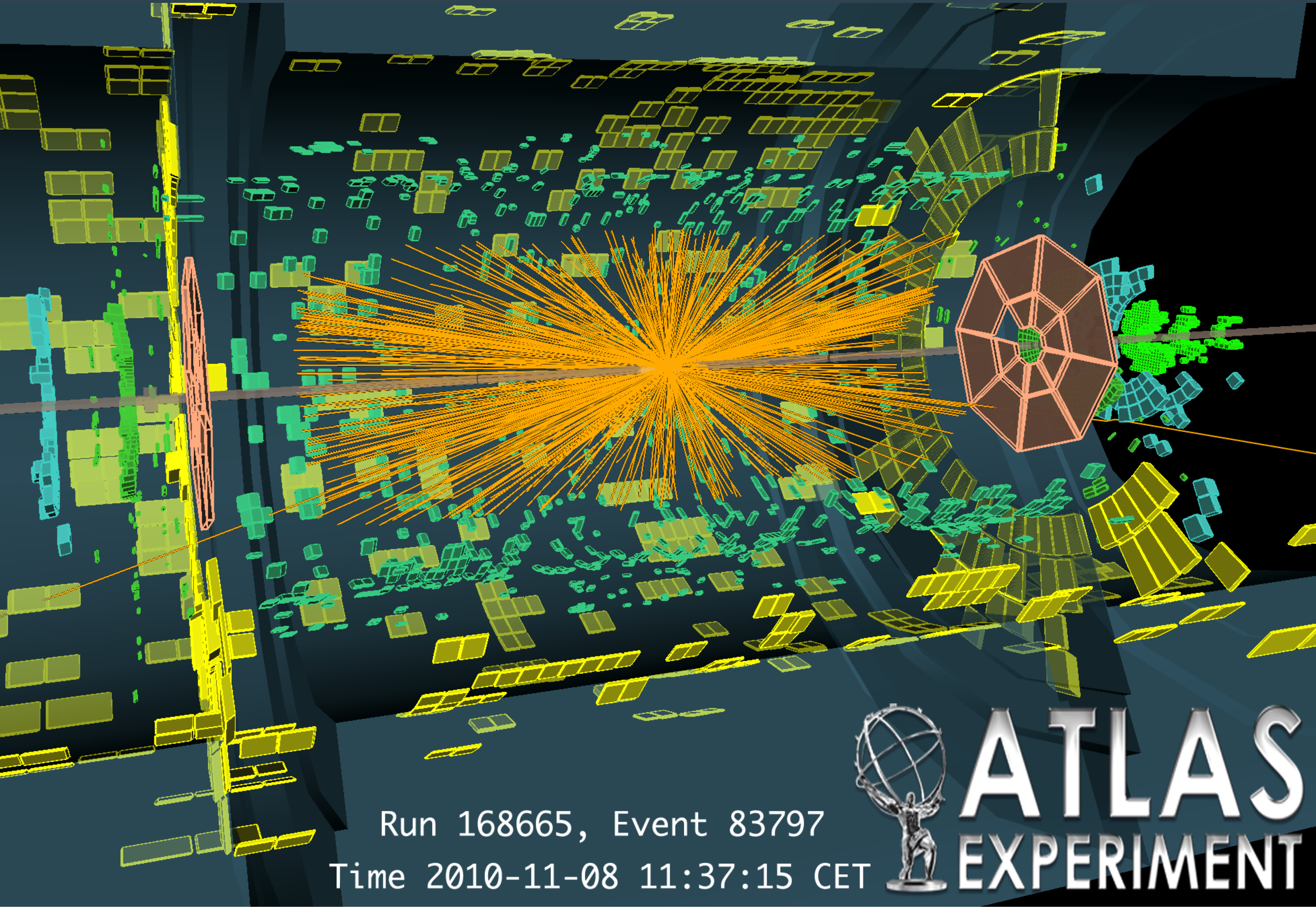


How to find photon collisions?

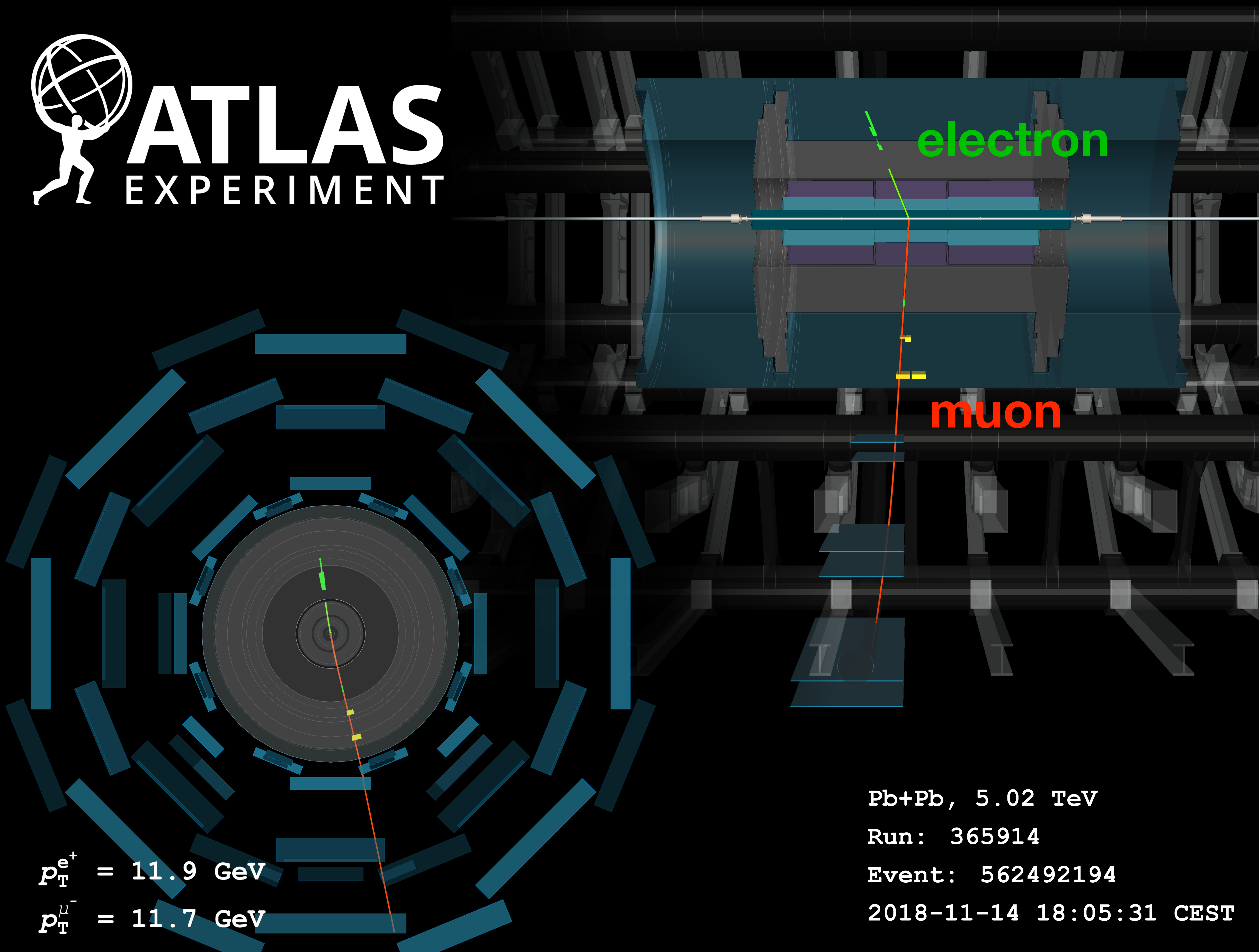




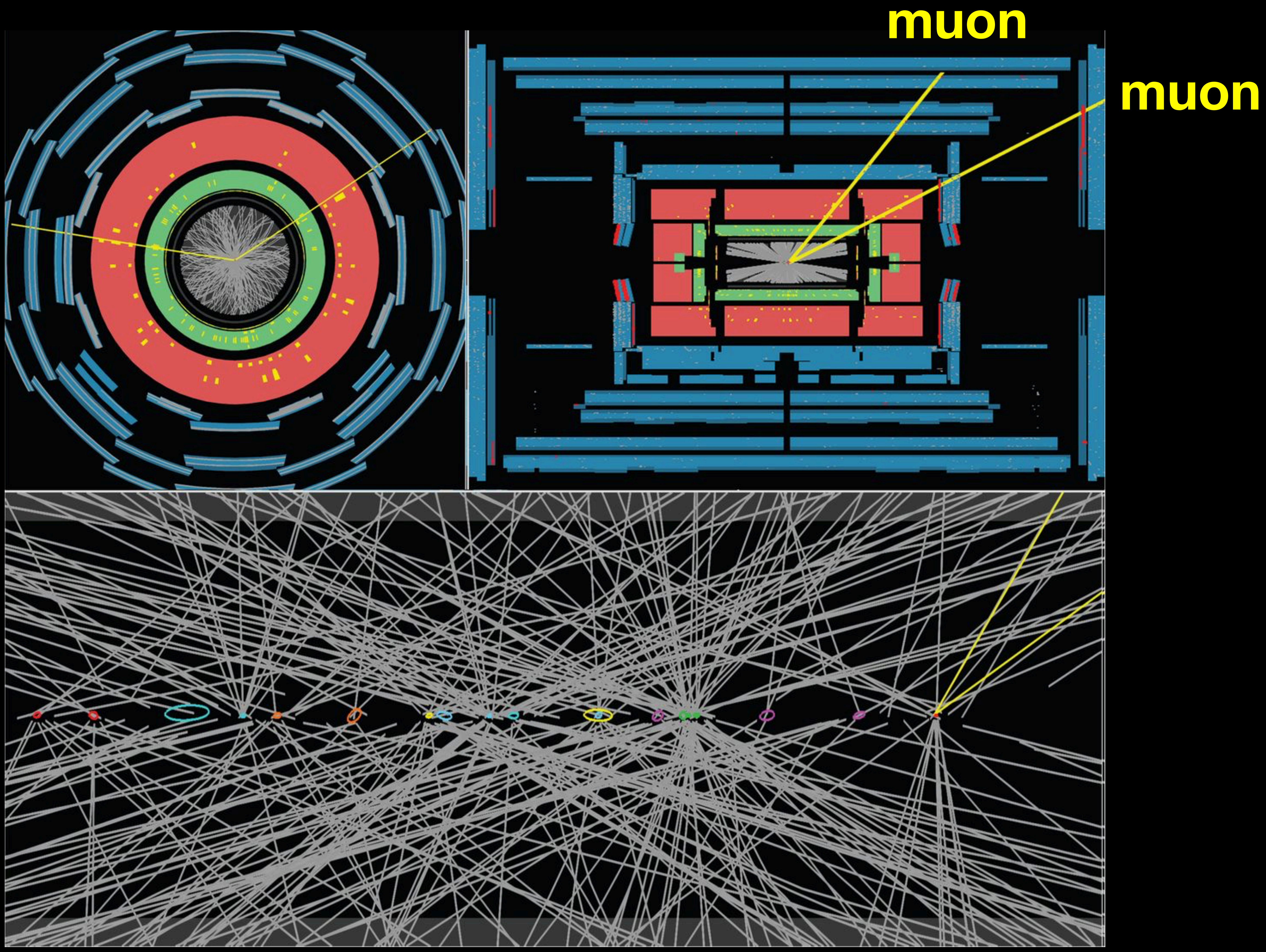
PbPb head-on collision



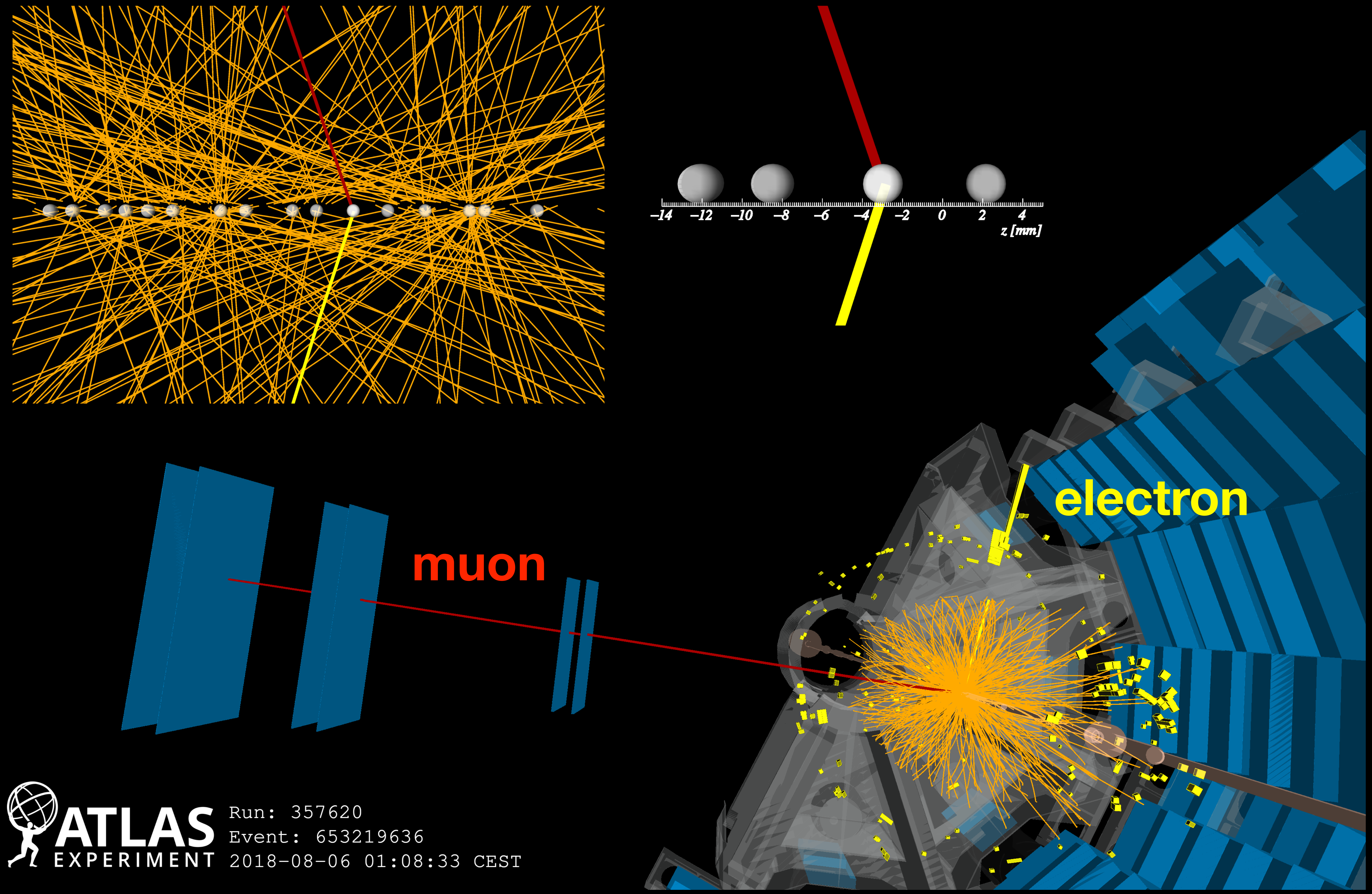
PbPb photon collision



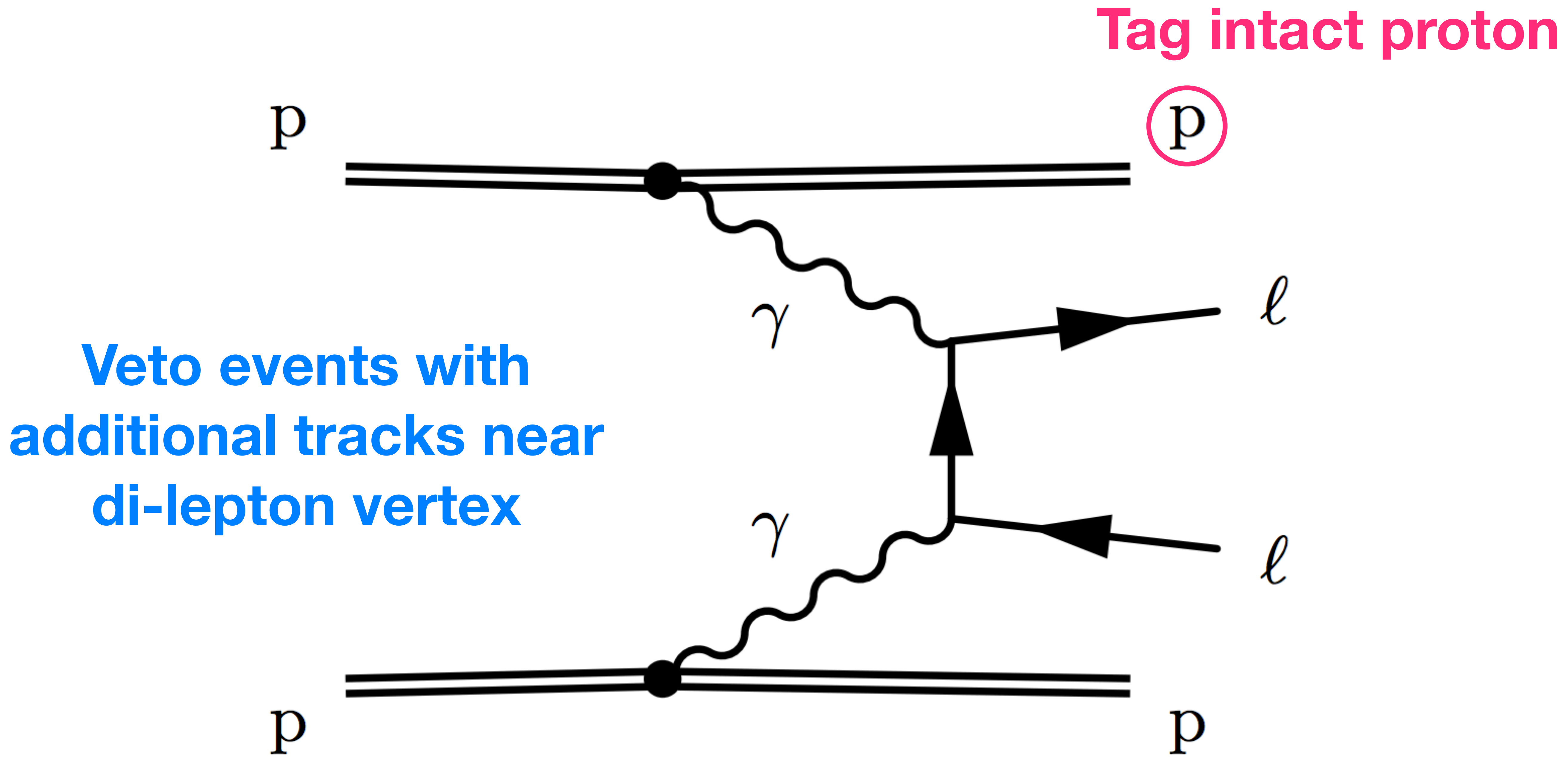
pp head-on collision



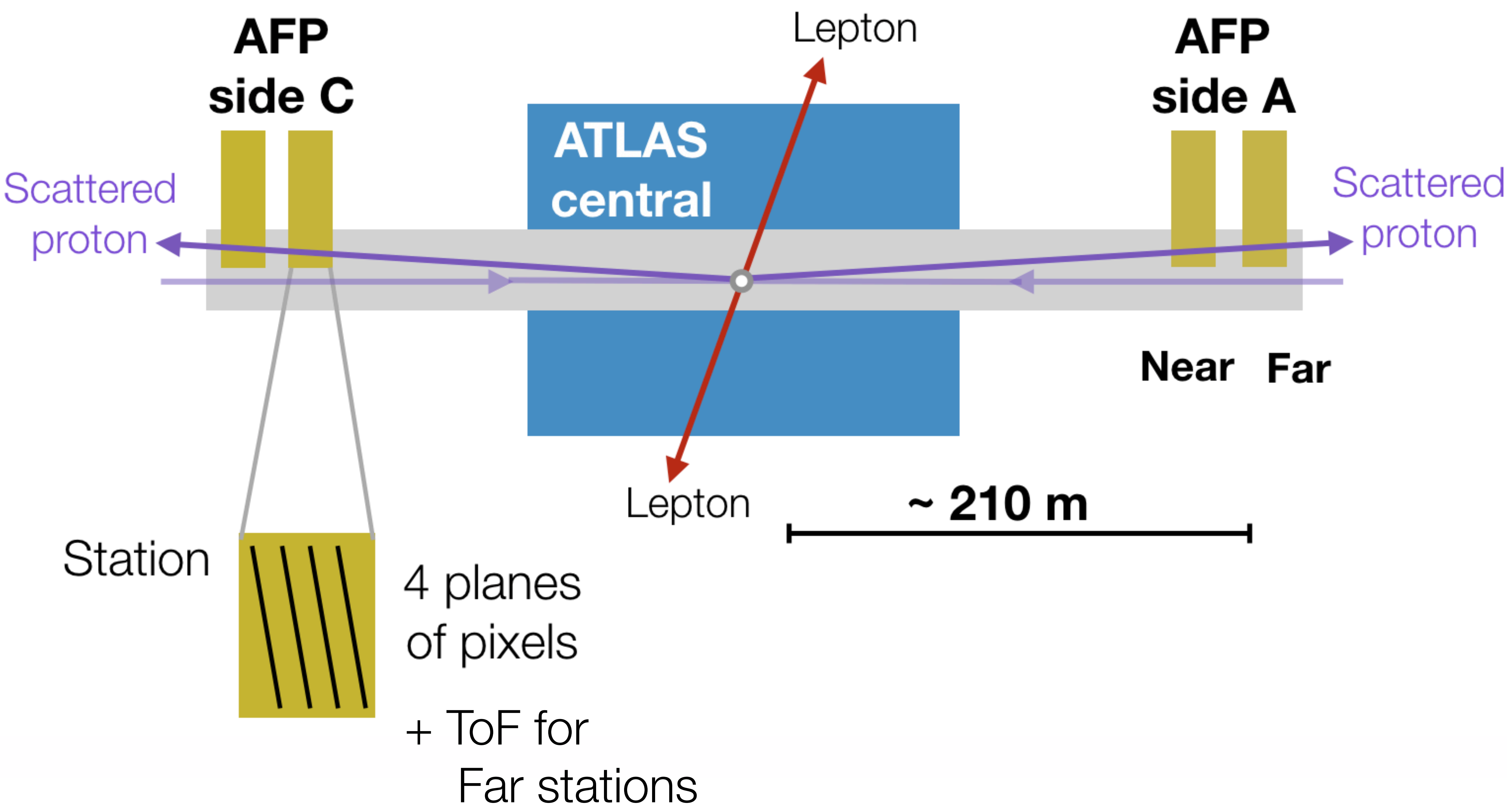
pp photon collision



Tracking detectors are key!



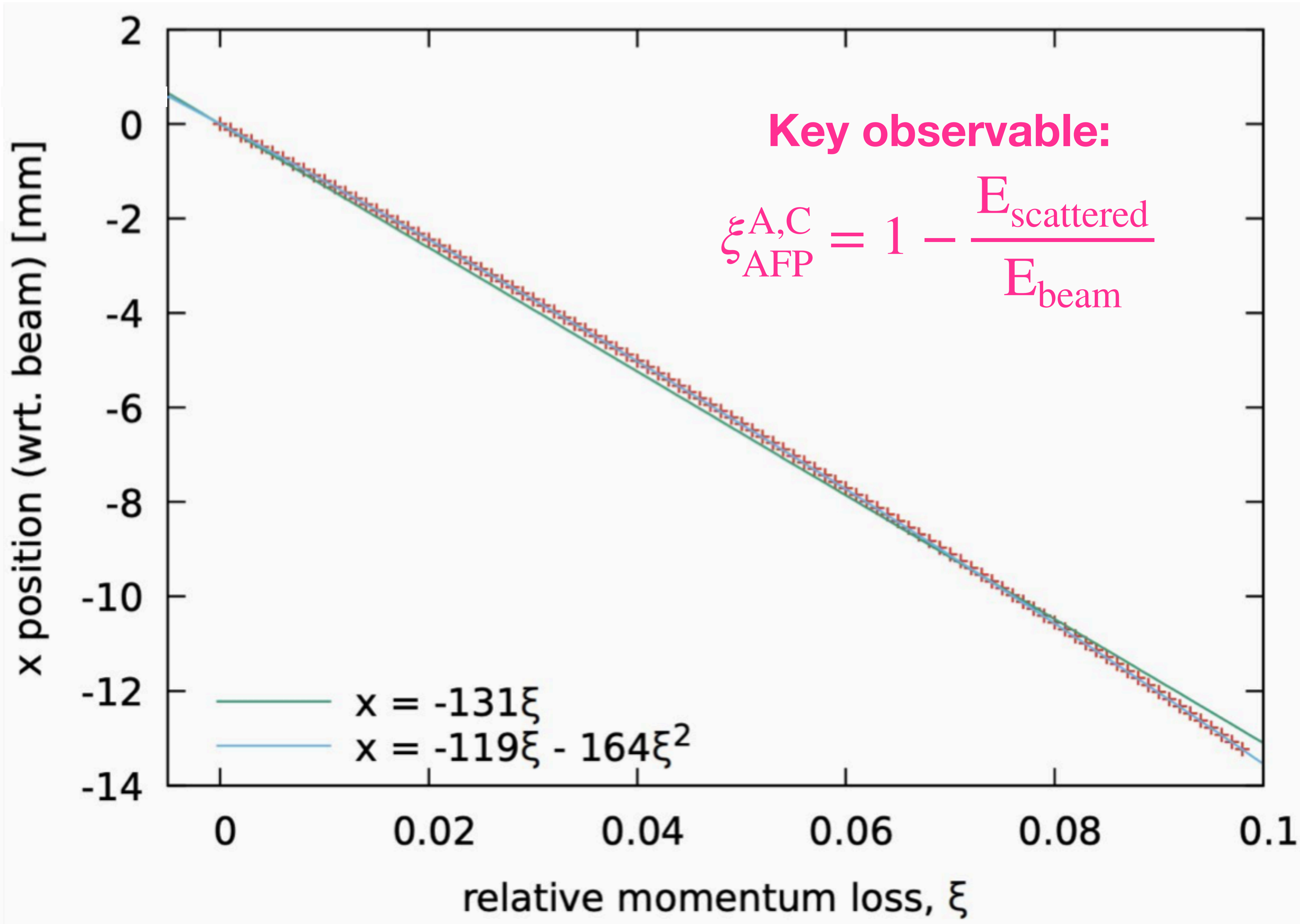
Tracking detectors are key!



Pixel hits → Pixel clusters → Tracks (station) → Proton

Mapping between position and energy loss

MAD-X beam propagation simulation



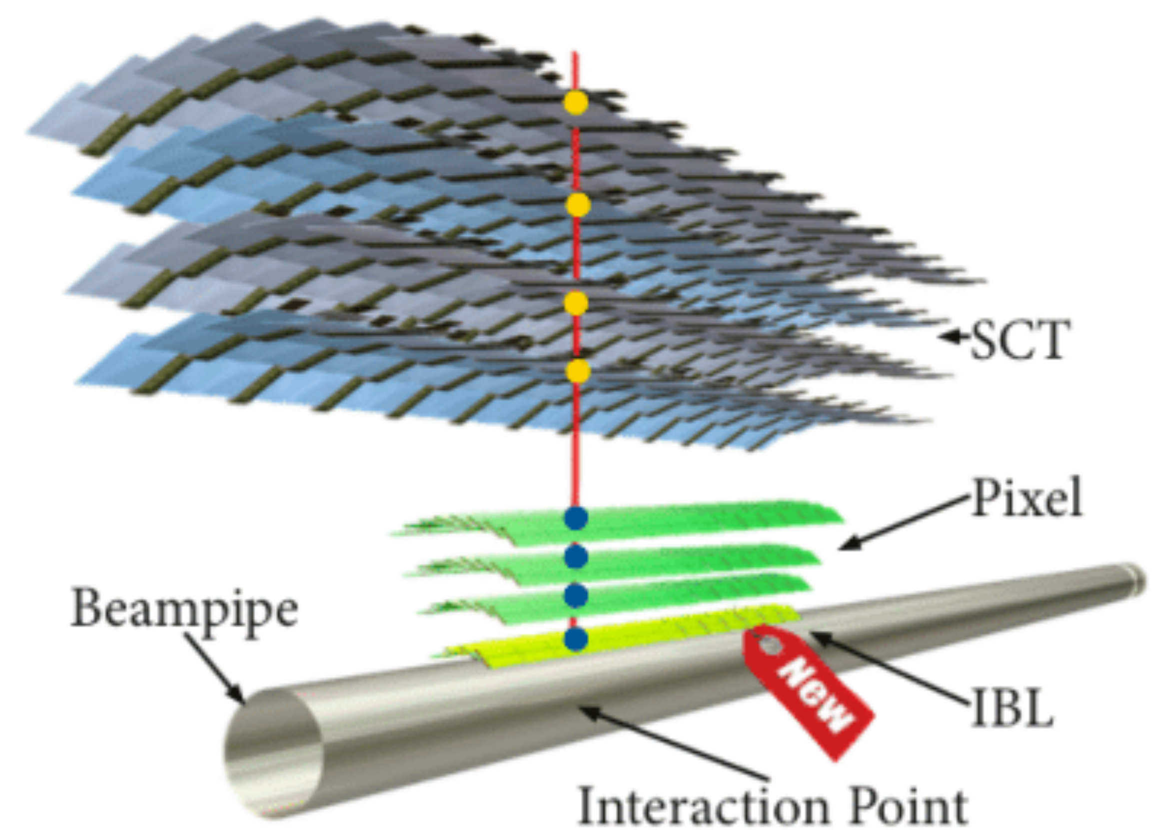
Key observable:

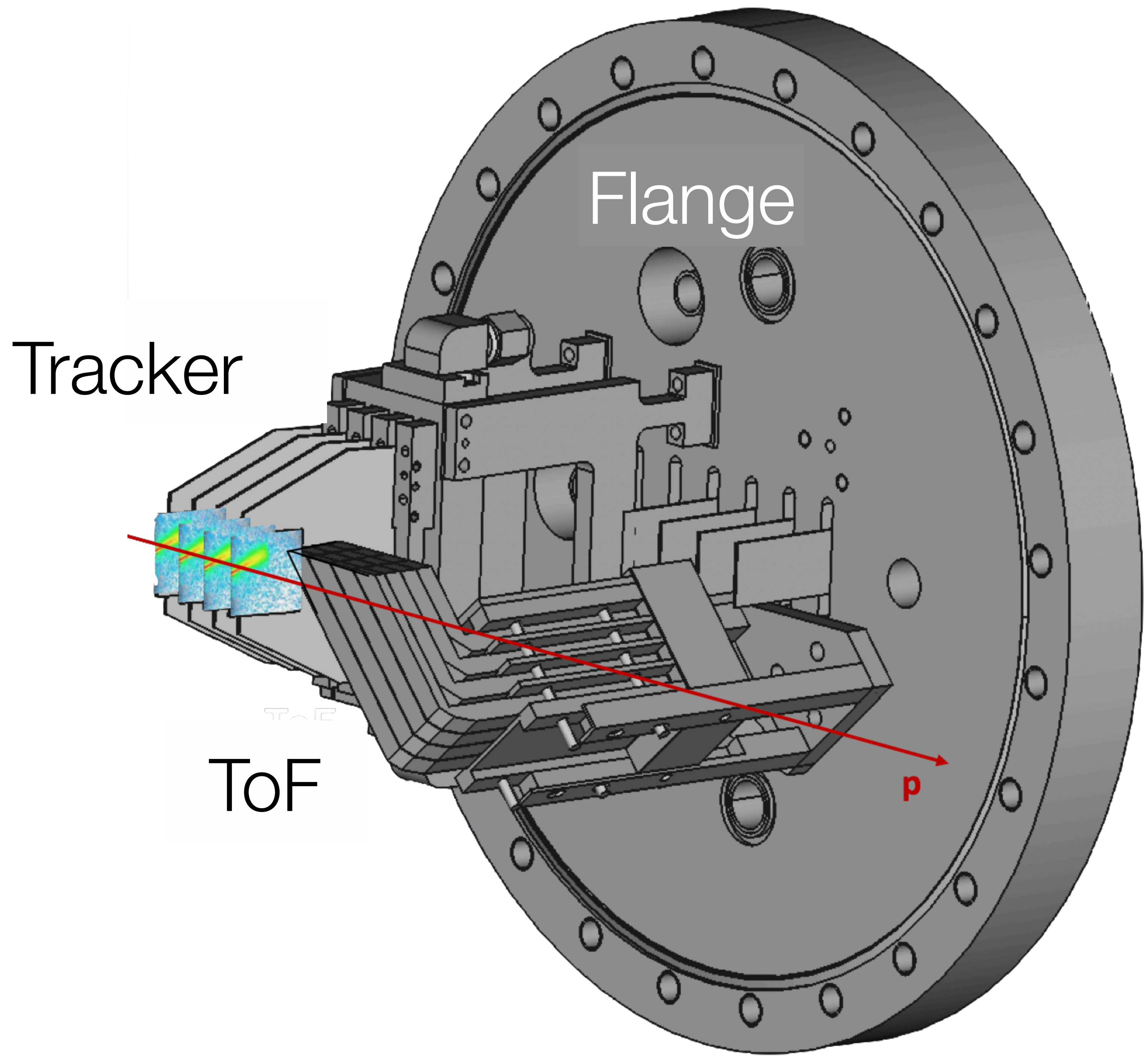
$$\xi_{\mathrm{AFP}}^{\mathrm{A,C}} = 1 - \frac{E_{\mathrm{scattered}}}{E_{\mathrm{beam}}}$$

ATLAS Forward Proton detectors

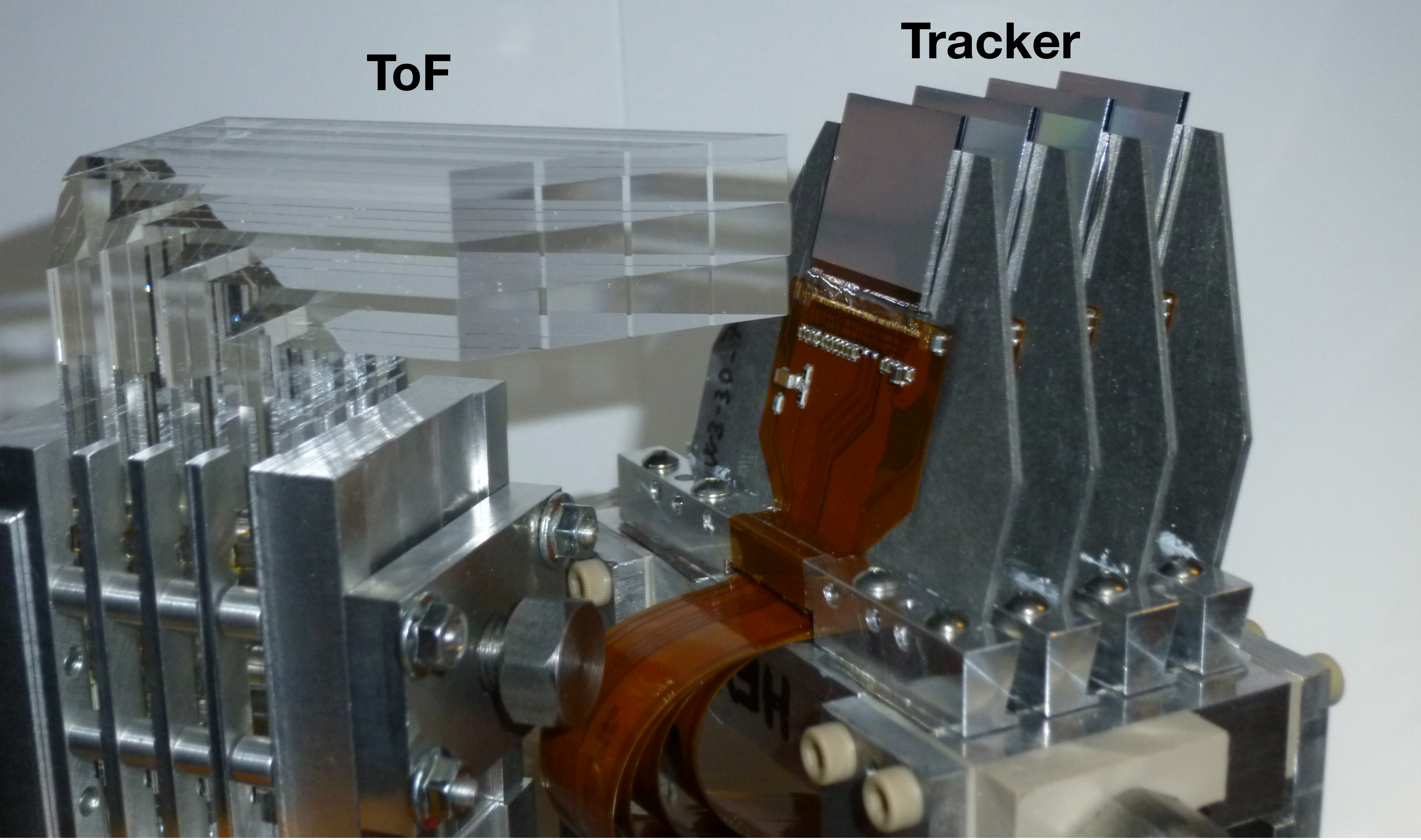
Silicon Tracker

- Within ~2 mm of beam
- ‘slim-edge’ ~100 μm
- Non-uniform irradiation





→ Use 3D silicon pixels a la the ATLAS insertable B-layer (IBL)



Cherenkov detector
L-shaped quartz bars
Microchannel Plate PMT
~ 30 ps timing resolution

Each plane = 336×80 pixels
Pixel size of 50×250 μm^2
Thickness of 230 μm
Active area 1.68 x 2 cm^2

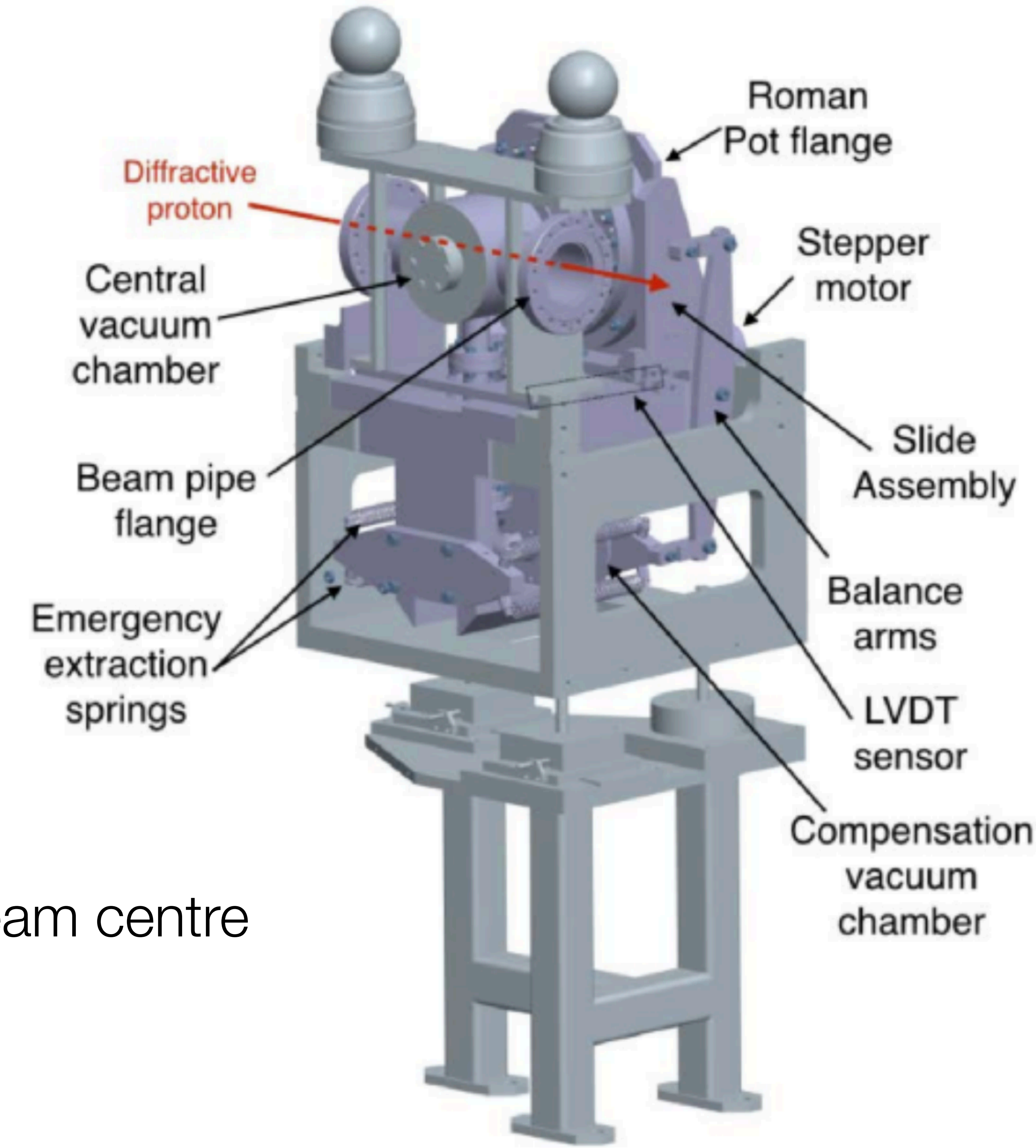
Roman pot

Beam size & position depends on LHC settings

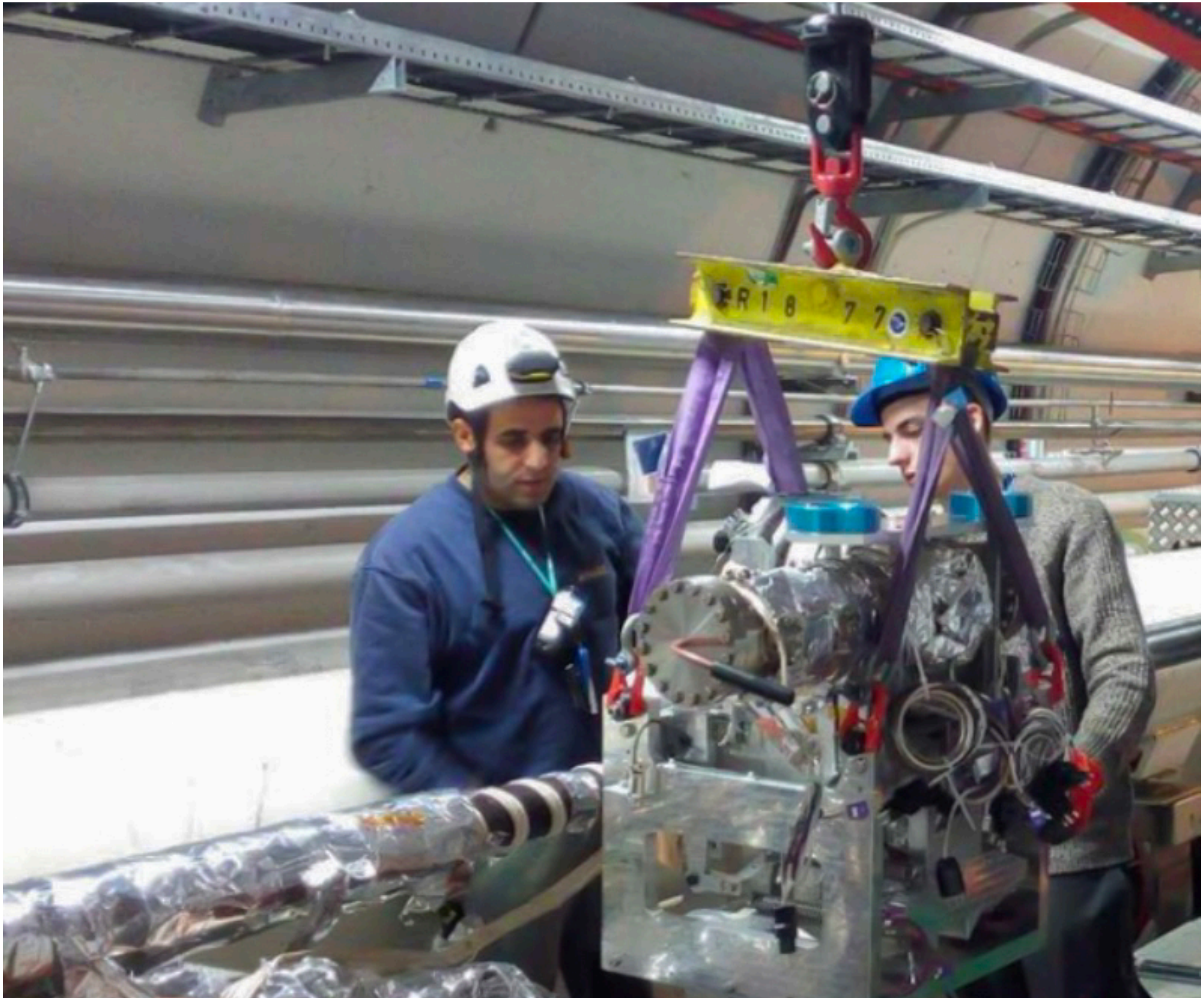
Moveable detectors

Unstable beams:
Detectors 'in garage'
40 mm away

Stable beams:
Detectors ~2 mm from beam centre



Installed in 2016 + 2017



Hot off the press

Information | Discussion (0) | Files

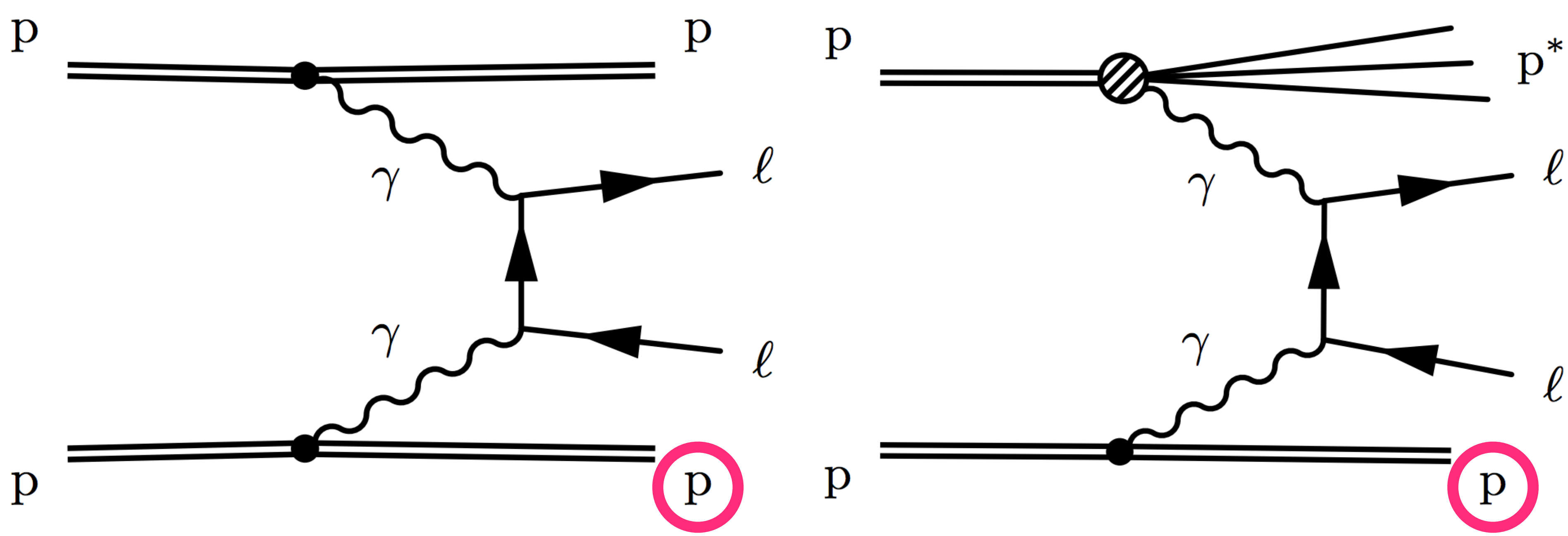
Preprint

Report number	CERN-EP-2020-167
Title	**Observation and measurement of forward proton scattering in association with lepton pairs produced via the photon fusion mechanism at ATLAS**
Related	supersedes: ATLAS-CONF-2020-041
Corporate author(s)	ATLAS Collaboration
Collaboration	ATLAS Collaboration
Imprint	29 Sep 2020
Subject category	Particle Physics - Experiment
Accelerator/Facility, Experiment	CERN LHC ; ATLAS

First measurement using AFP

Observe $(\gamma\gamma \rightarrow \ell^+\ell^-) + p$ & measure cross-section

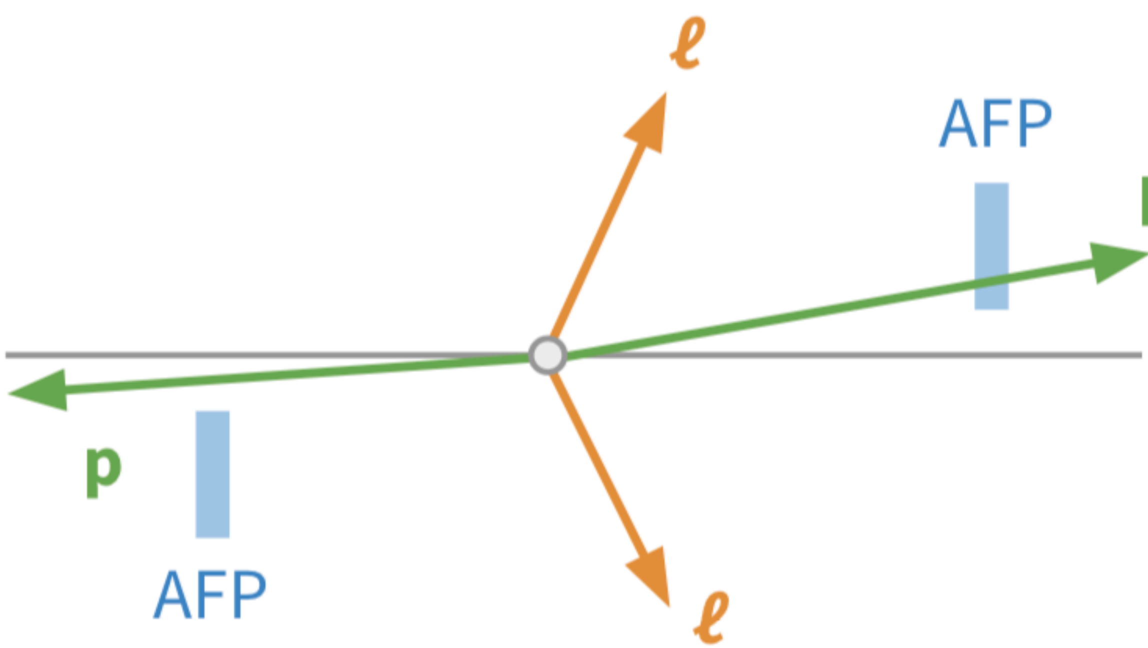
Previous ATLAS measurements don't tag a proton!



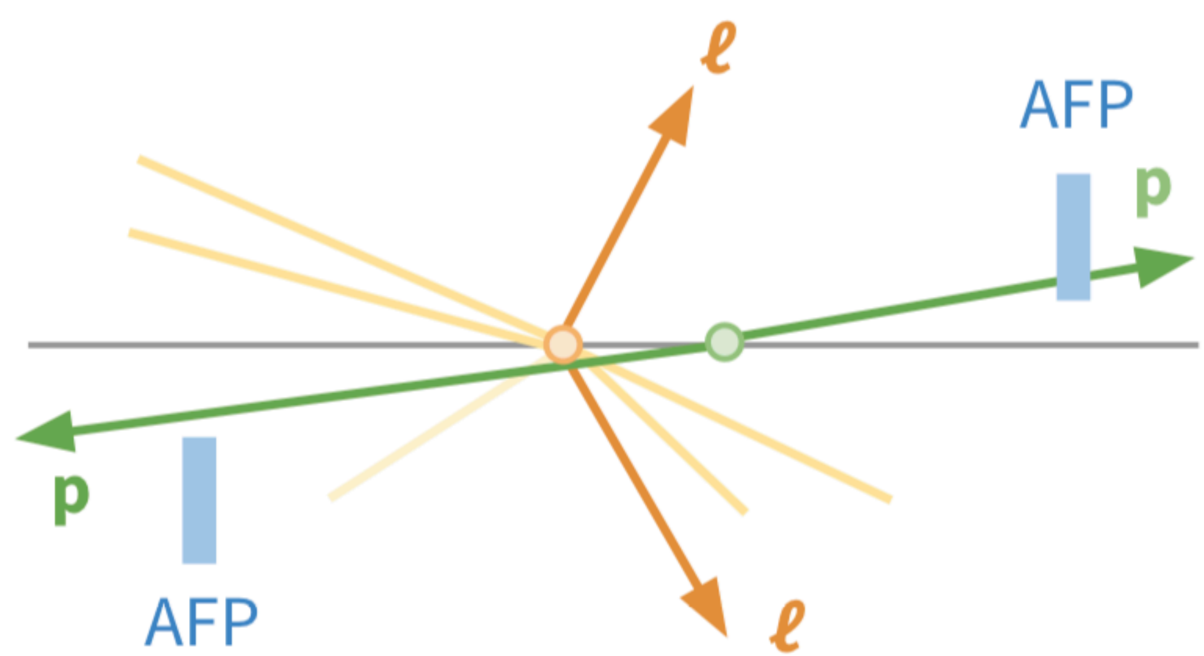
Turning light into matter :)

Kinematic correlation

Signal



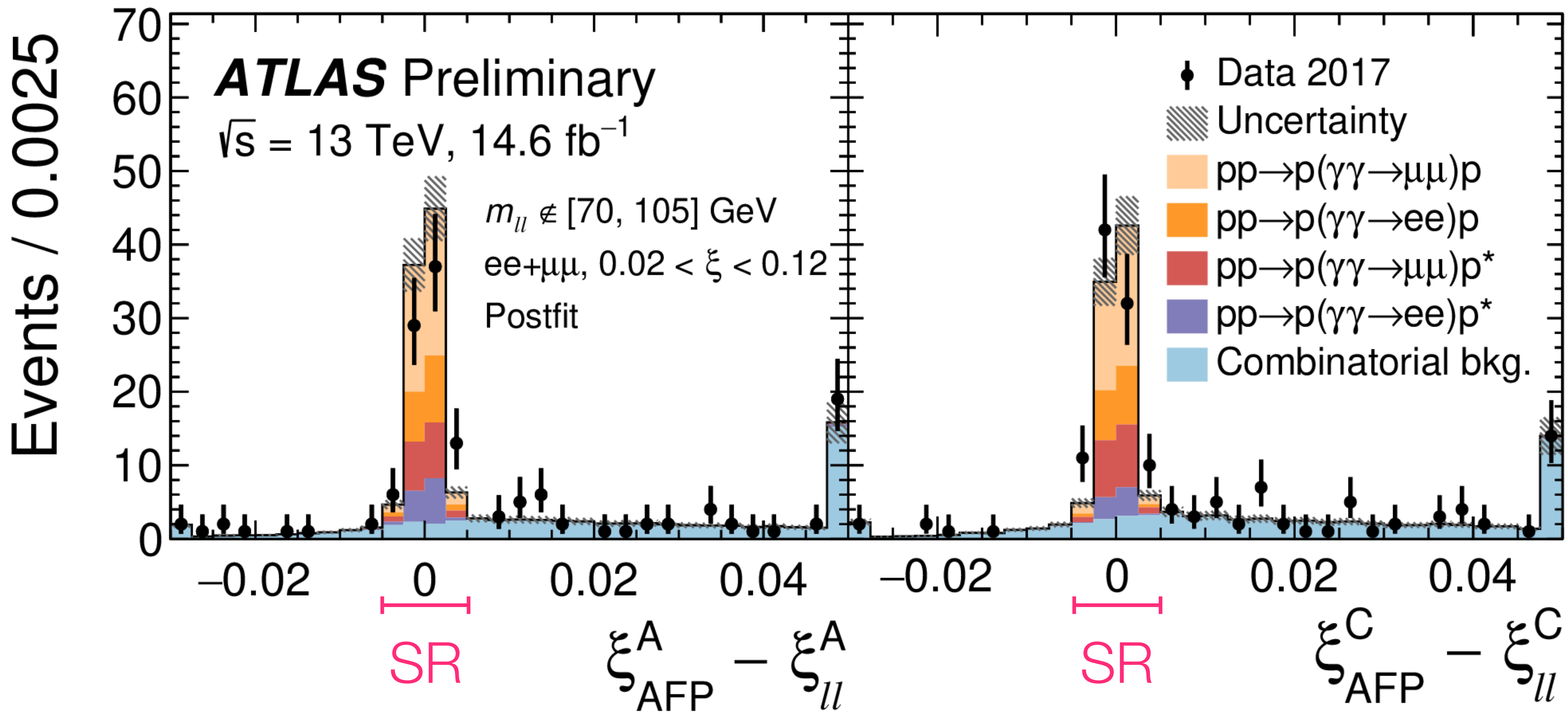
Background



Kinematic correlation

Fully data-driven bkg estimate!

Observe ee+p and $\mu\mu$+p cf CMS-TOTEM 2.6σ, 4.3σ



Measured with AFP

$$\xi^{A,C}_{AFP} = 1 - E_{forward}/E_{beam}$$

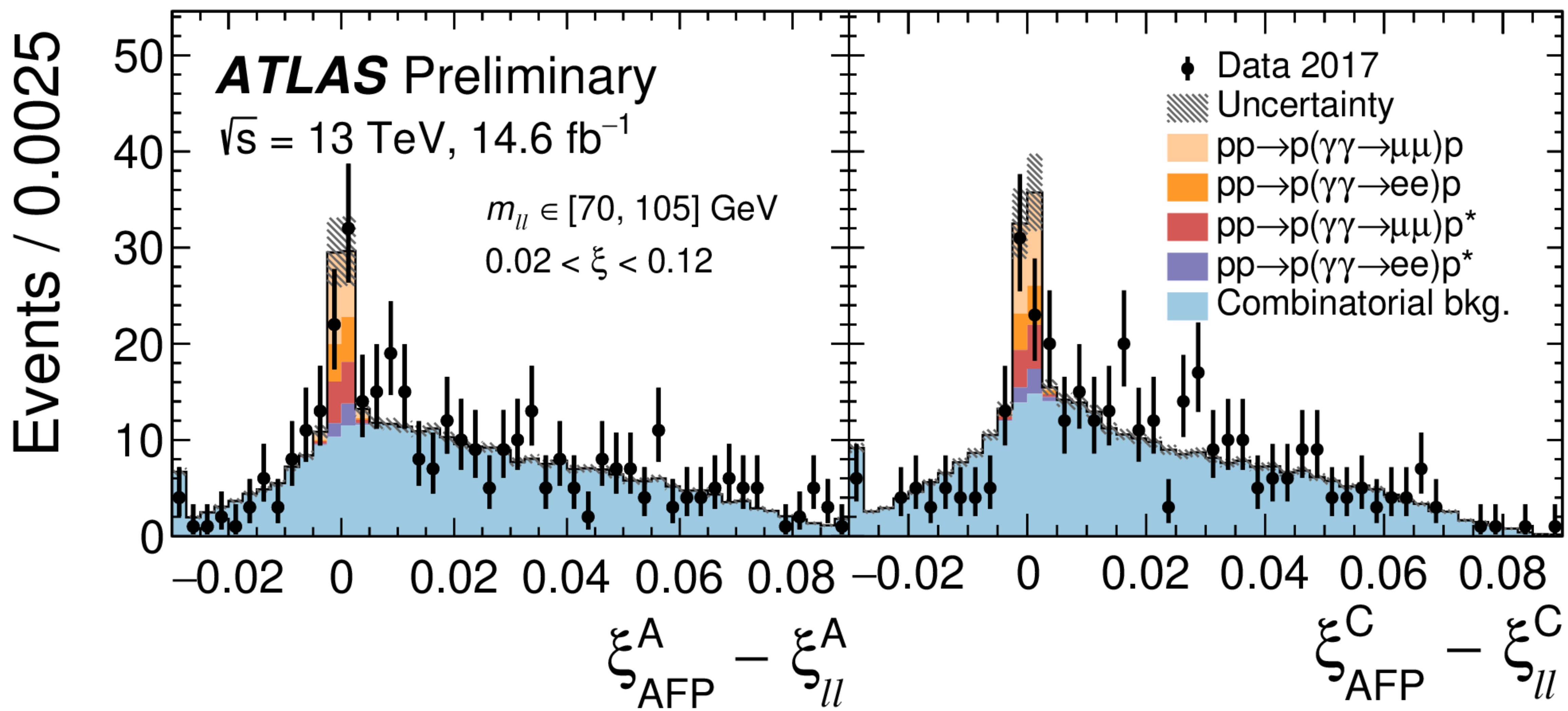
Measured with ATLAS

$$\xi^{\pm}_{ll} = \frac{m_{ll}}{\sqrt{s}} e^{\pm y_{ll}}$$

Background rejection

Powerful background suppression

Can see photo-production of di-leptons above Drell-Yan background :)

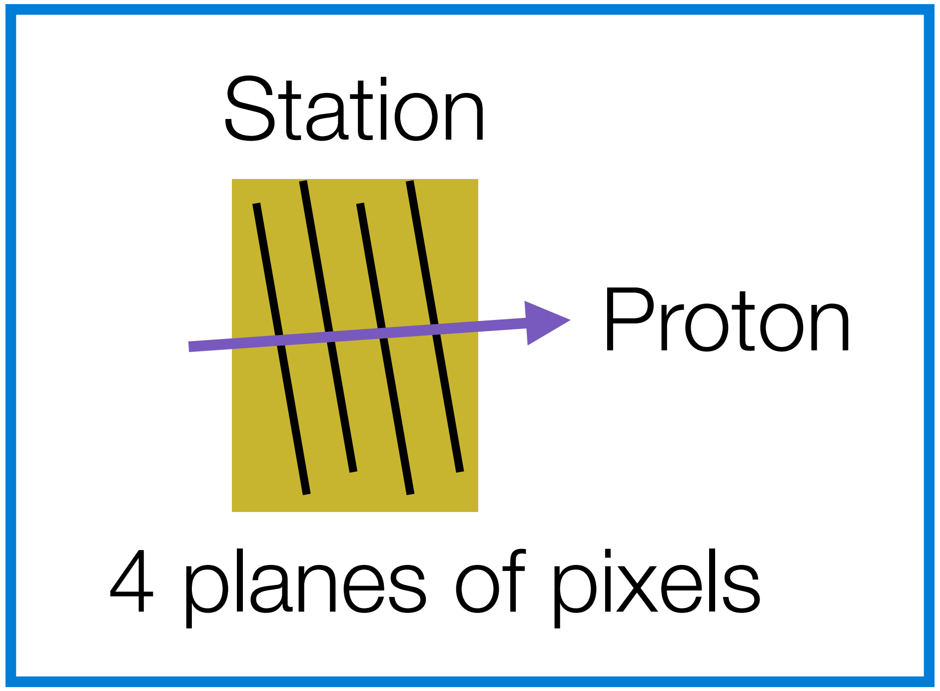


Run 3: Time-of-flight detector will further suppress

AFP Alignment

Inter-plane:

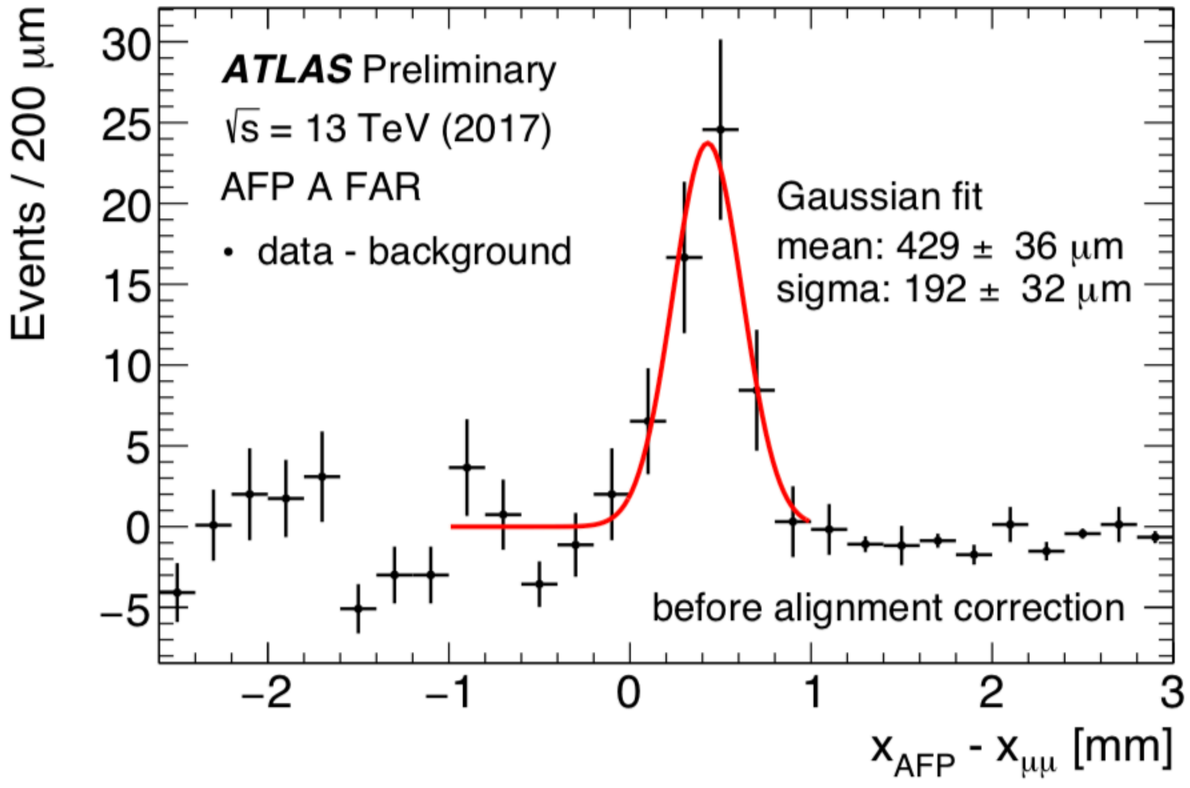
Use differences in track & hit positions to correct for mis-alignments



Global:

Measurements of tracker, beam & roman pot position used

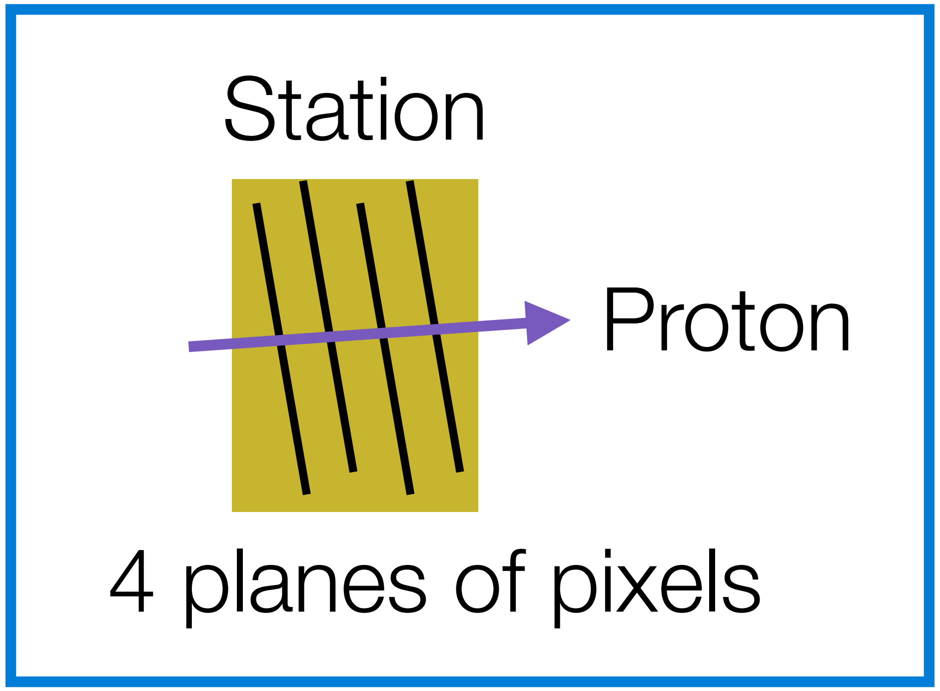
+ di-muon in situ correction →



AFP Alignment

Inter-plane:

Use differences in track & hit positions to correct for mis-alignments



Global:

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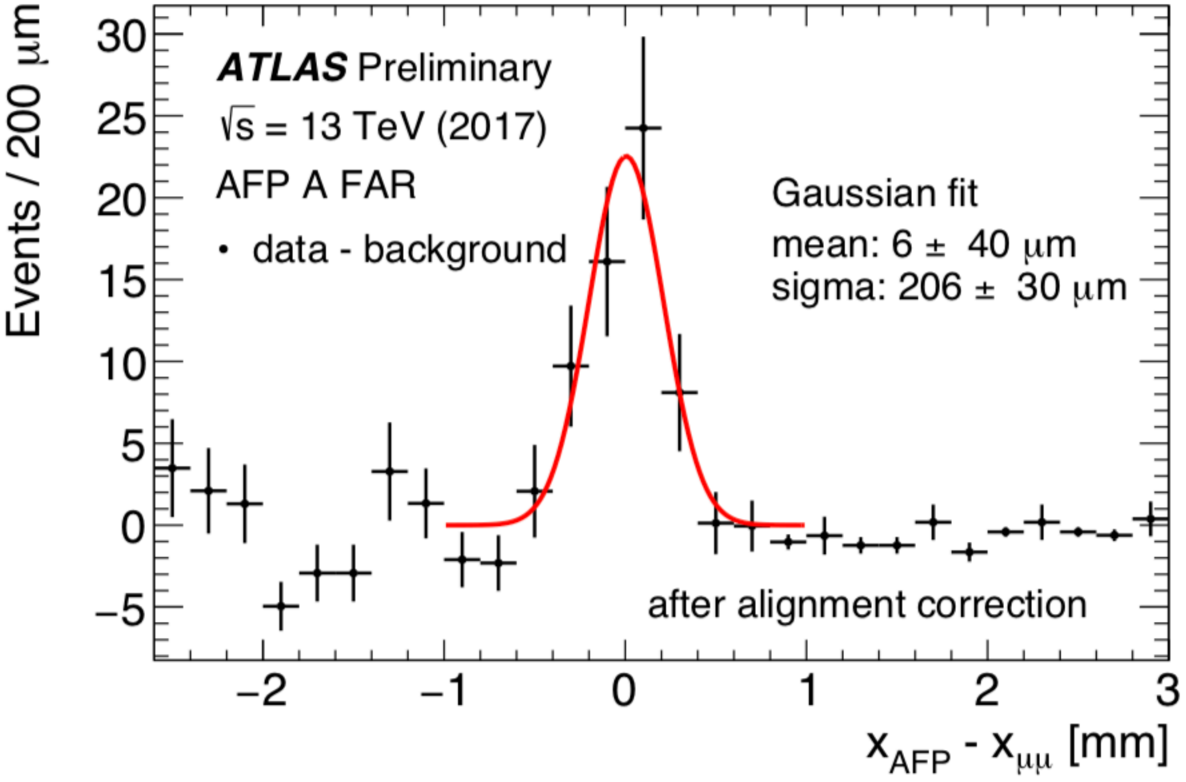
+ di-muon in situ correction →



AFP Efficiency

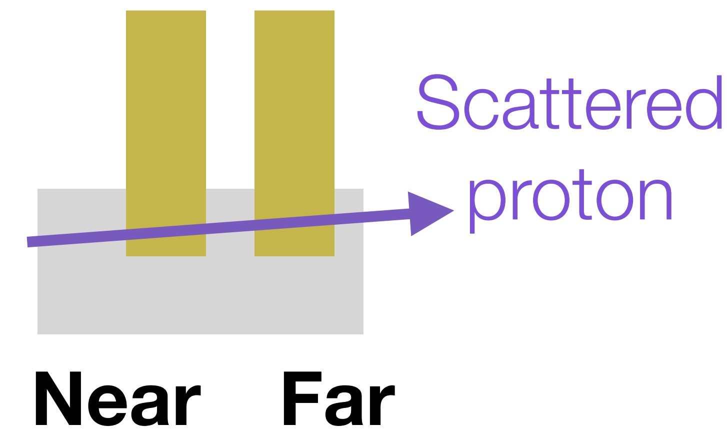
Needed to correct for detector effects

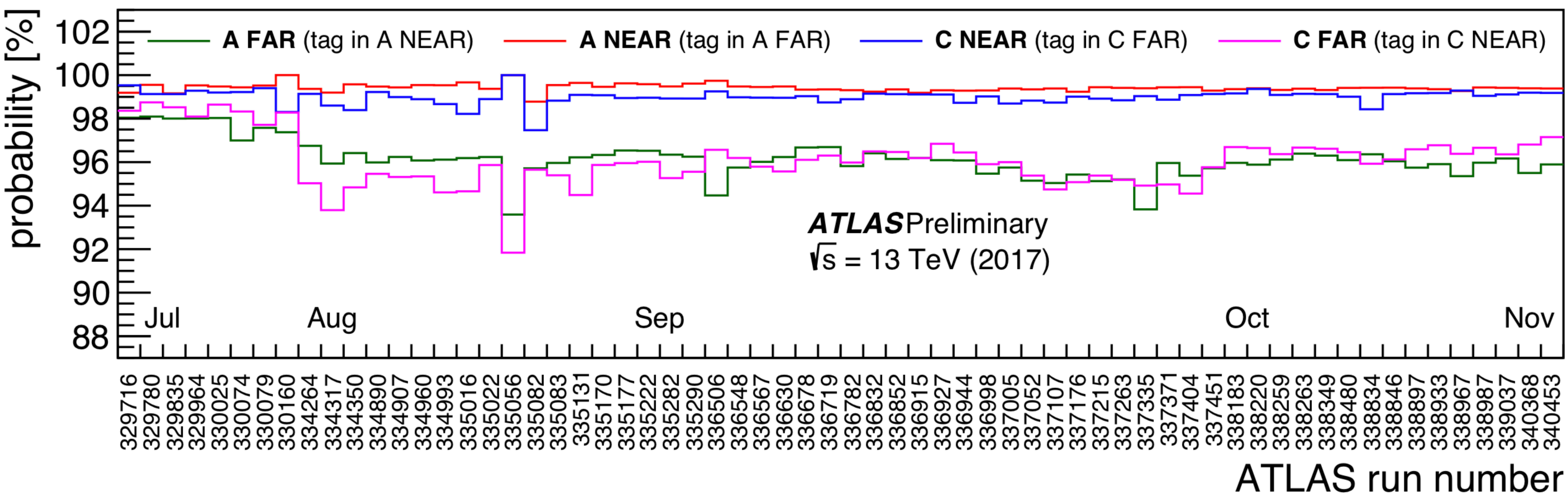
Station tag and probe:

- 'Tag' track in near station (require exactly 1)
- Check if track in far (within $|x_{near}-x_{far}| < 2$ mm)

& vice versa

AFP side A





Lower efficiency in far station due to showers

Results

1st LHC cross-section measurements for this process

$\sigma_{\text{HERWIG+LPAIR}} \times S_{\text{surv}}$	$\sigma^{\text{fid.}}_{ee+p}$ [fb]	$\sigma^{\text{fid.}}_{\mu\mu+p}$ [fb]
$S_{\text{surv}} = 1$	15.5 ± 1.2	13.5 ± 1.1
S_{surv} using Refs. [30, 31]	10.9 ± 0.8	9.4 ± 0.7
SuperChic 4 [94]	12.2 ± 0.9	10.4 ± 0.7
Measurement	11.0 ± 2.9	7.2 ± 1.8

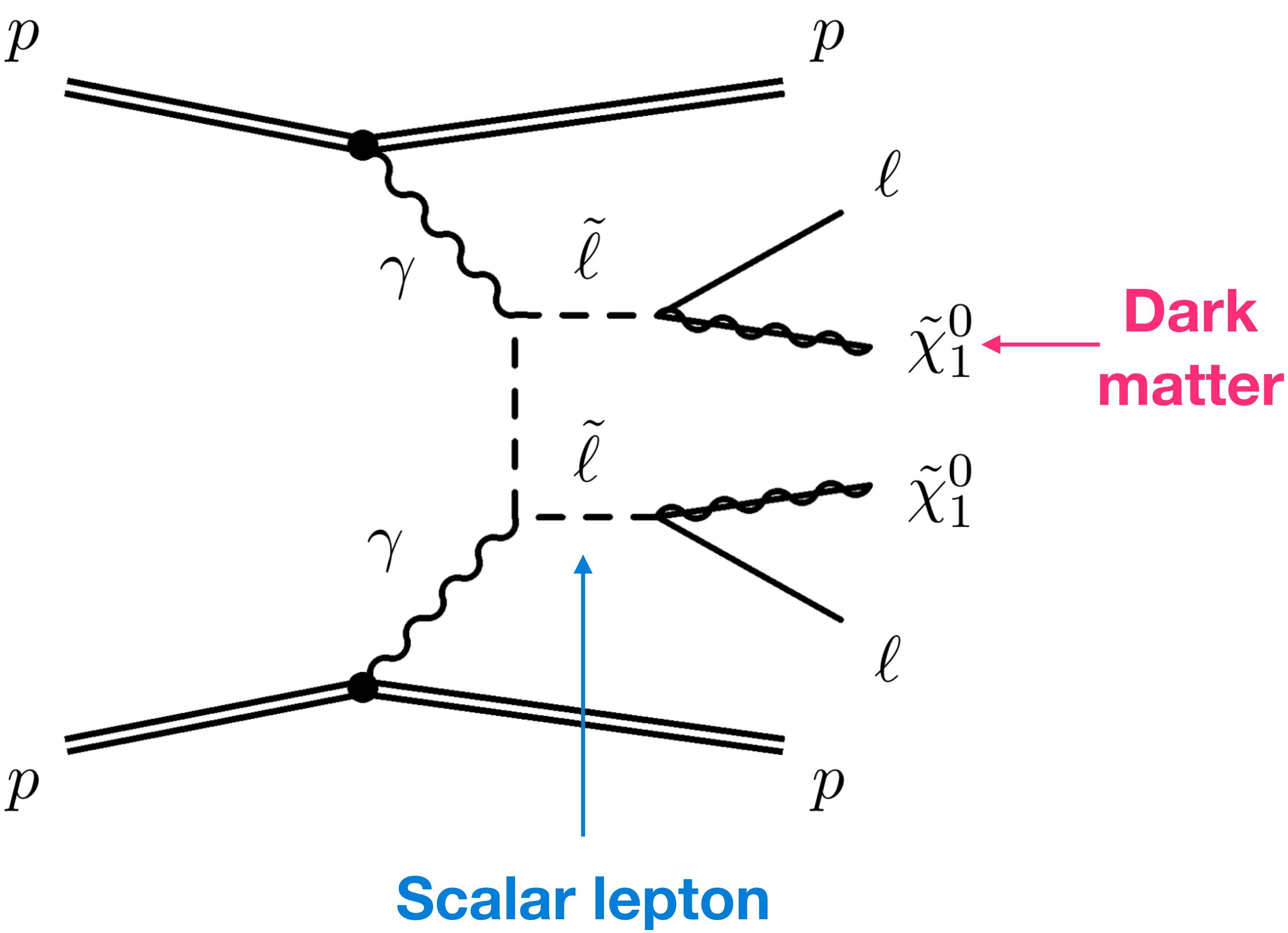
Fiducial cross-sections $\xi \in [0.035, 0.08]$ compared to proton soft survival models

[30] Eur. 314 Phys. J. C 76 (2016) 9
[31] Phys. Lett. B 741 (2015) 66
[94] arXiv: 2007.12704

First step towards diverse program exploiting AFP

What next for photon collisions?

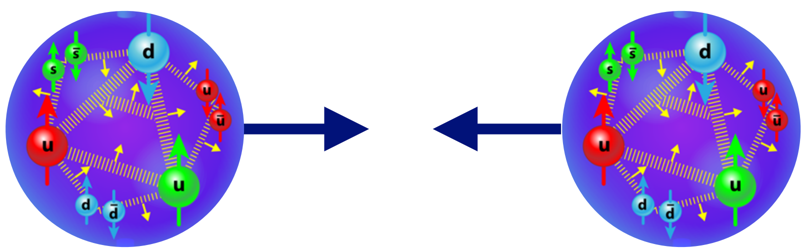
Turning light into dark matter?



The holy grail

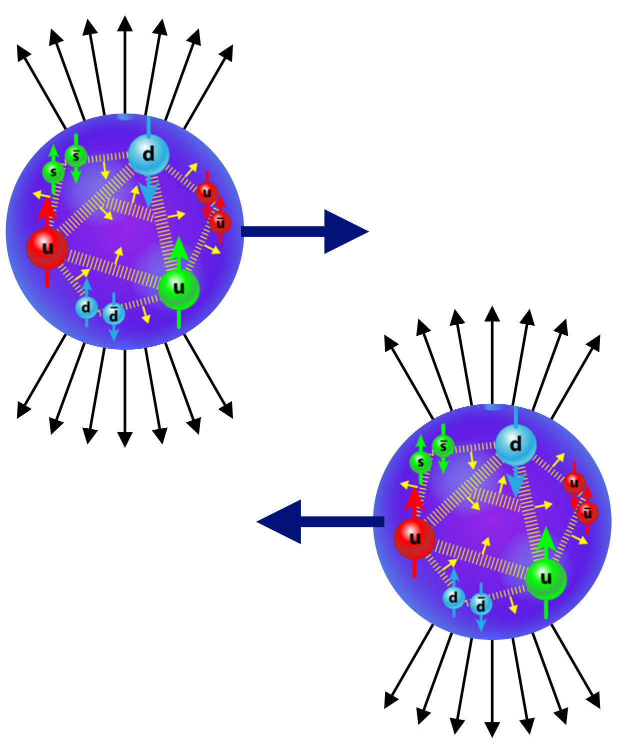
Dark matter is invisible
to our detectors

Fundamental hadron collider problem



Don't know the parton momentum
in direction of the beam

→ Use **missing transverse momentum**

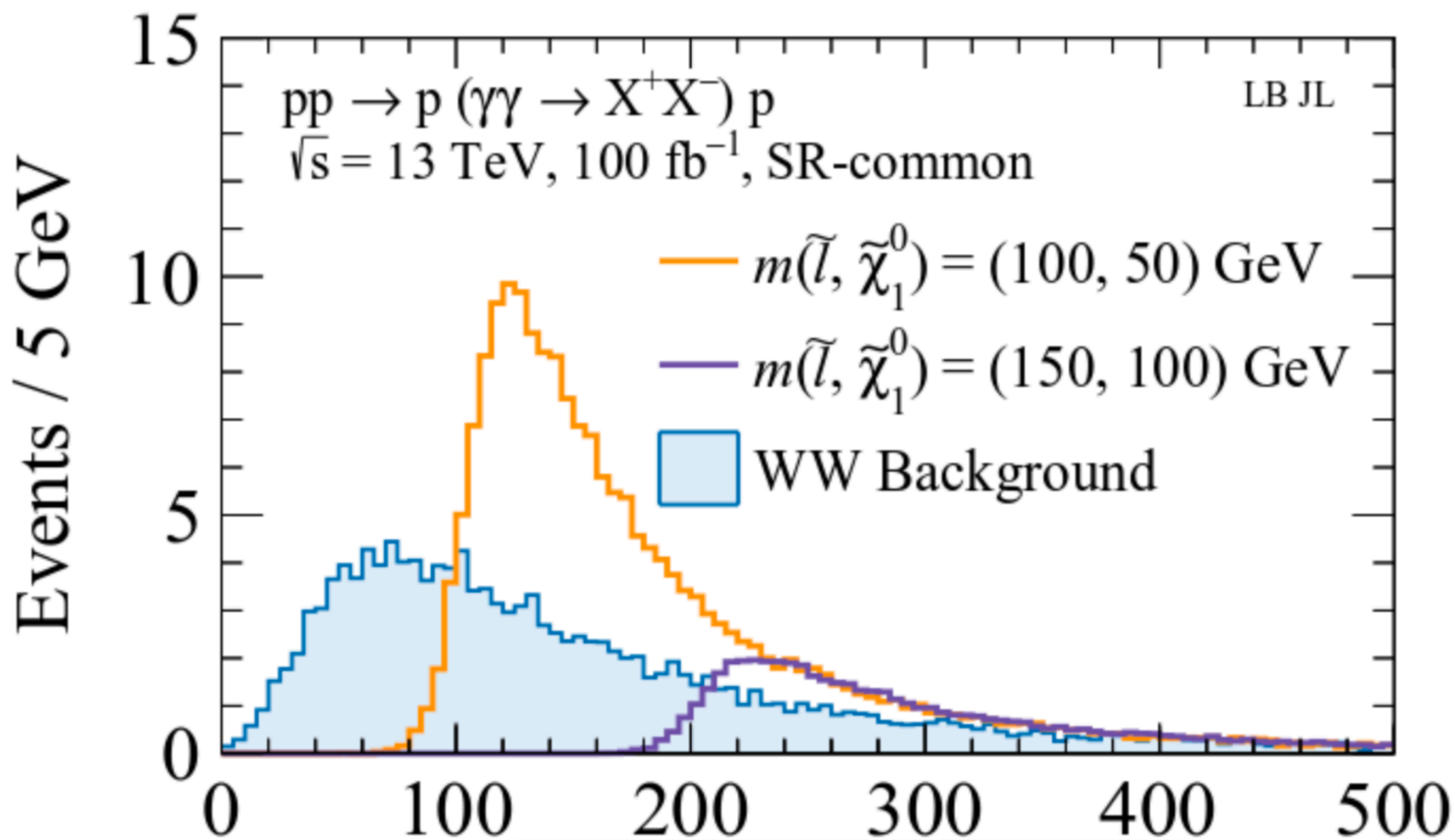


Initial proton E is known (6.5 TeV)
Measure scattered proton E using **AFP/CT-PPS**

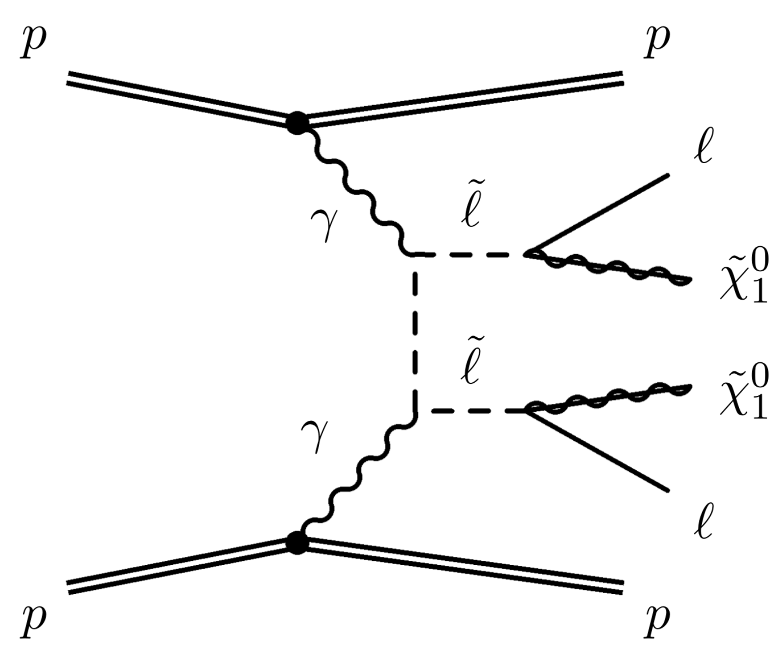
→ Initial state kinematics known
Can calculate **total missing momentum!**

→ Measure DM mass

min(W_{miss}) = 2 x m_{DM}



$$W_{miss} = \sqrt{(p_1^\gamma + p_2^\gamma - p_1^l - p_2^l)^2} \text{ [GeV]}$$



Powerful observable for dark matter searches

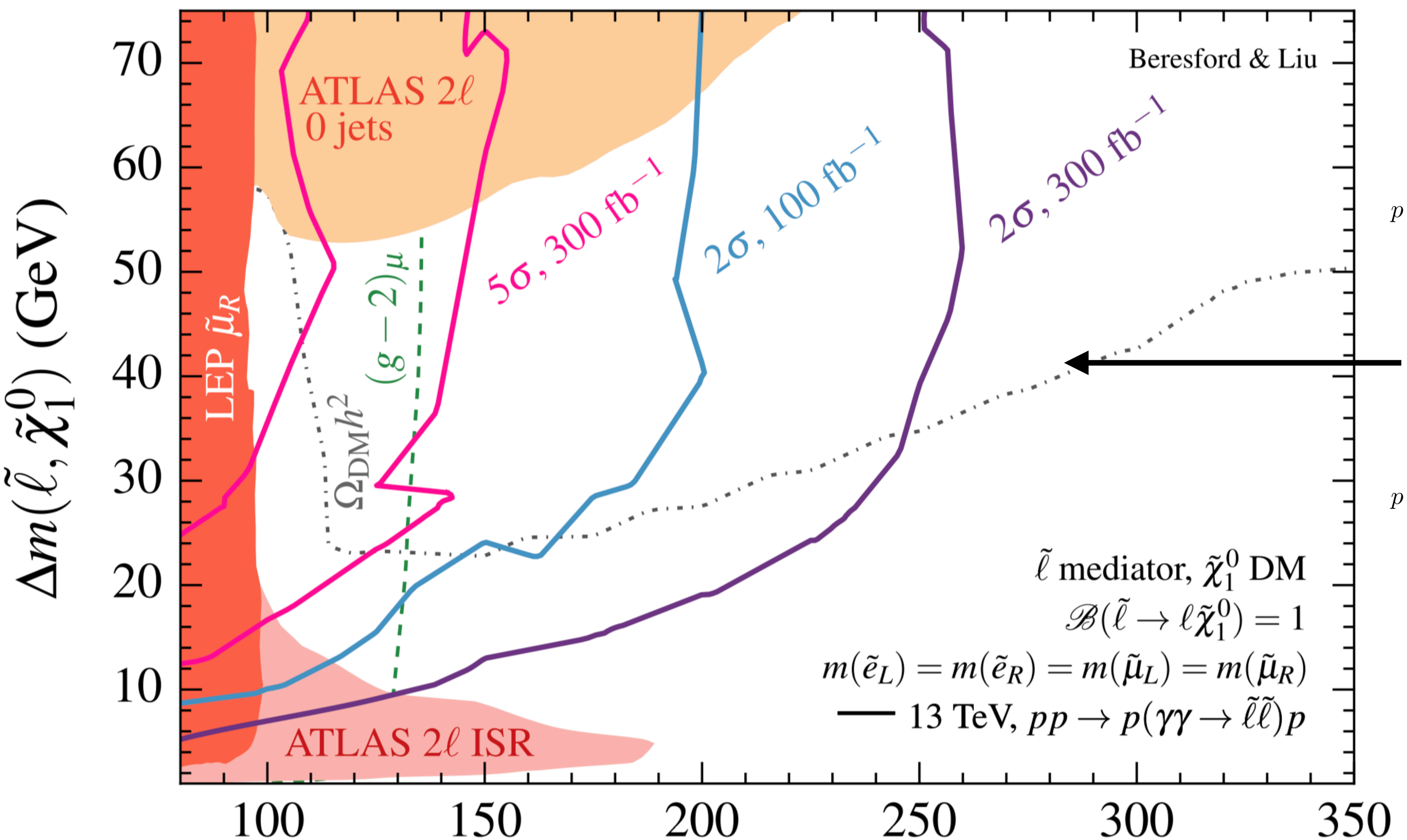
Illustrative plot: Efficiencies & FD acceptance not applied, only resolution smearing

Powerful potential

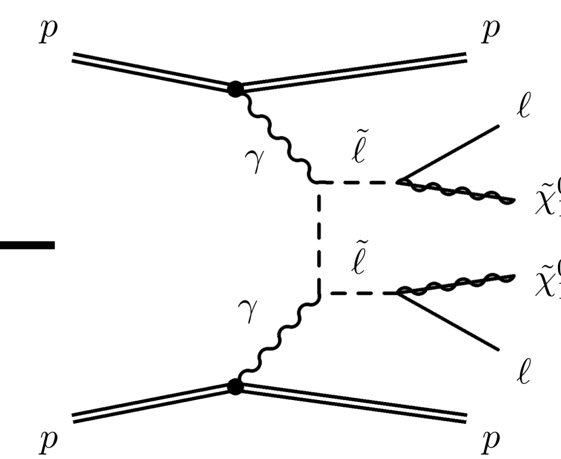
Beresford, Liu [PRL (2019)]

Potential to probe well motivated ATLAS blind spot!

Mass difference (mediator,DM)



Mediator $m(\tilde{\ell}_{L,R})$ (GeV)



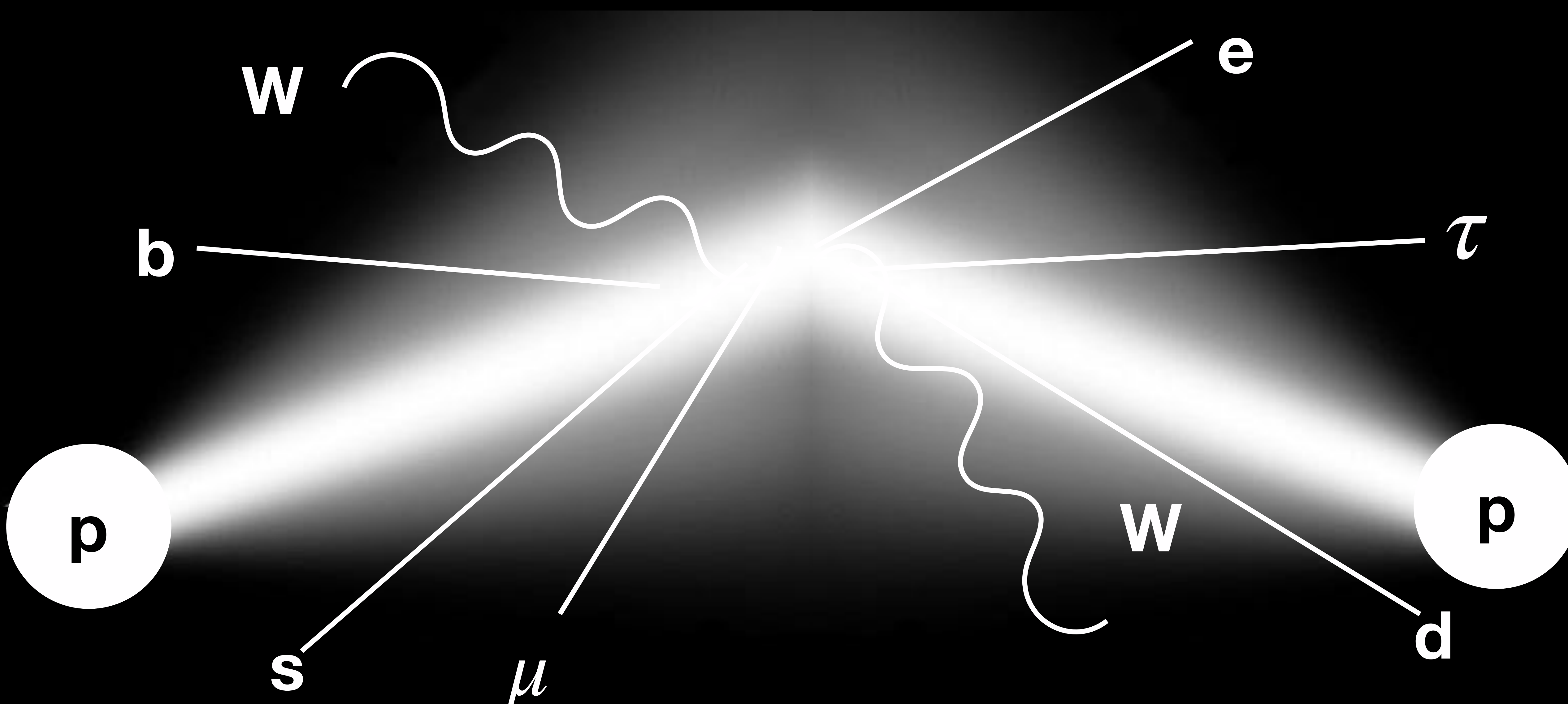
NB most recent ATLAS results:
[1911.12606] [1908.08215]

Summary

Rich ATLAS photon collision program

Enabled by tracking detectors!

Only the beginning …



Backup

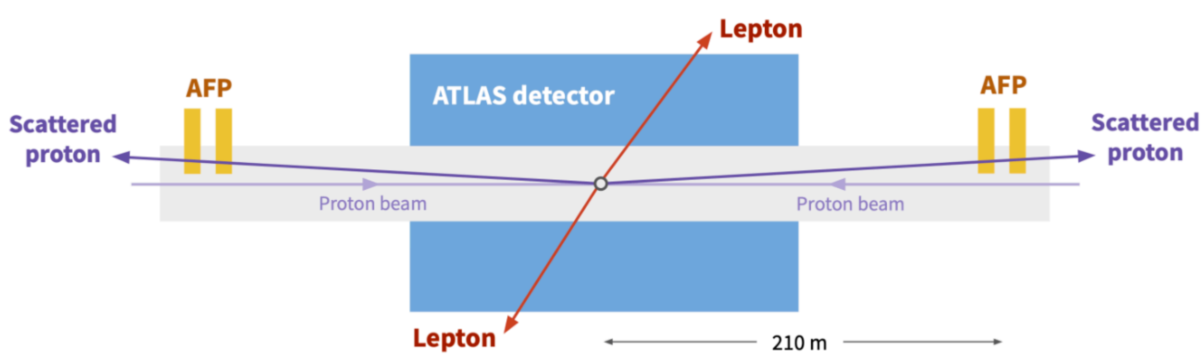
More?

Physics briefing

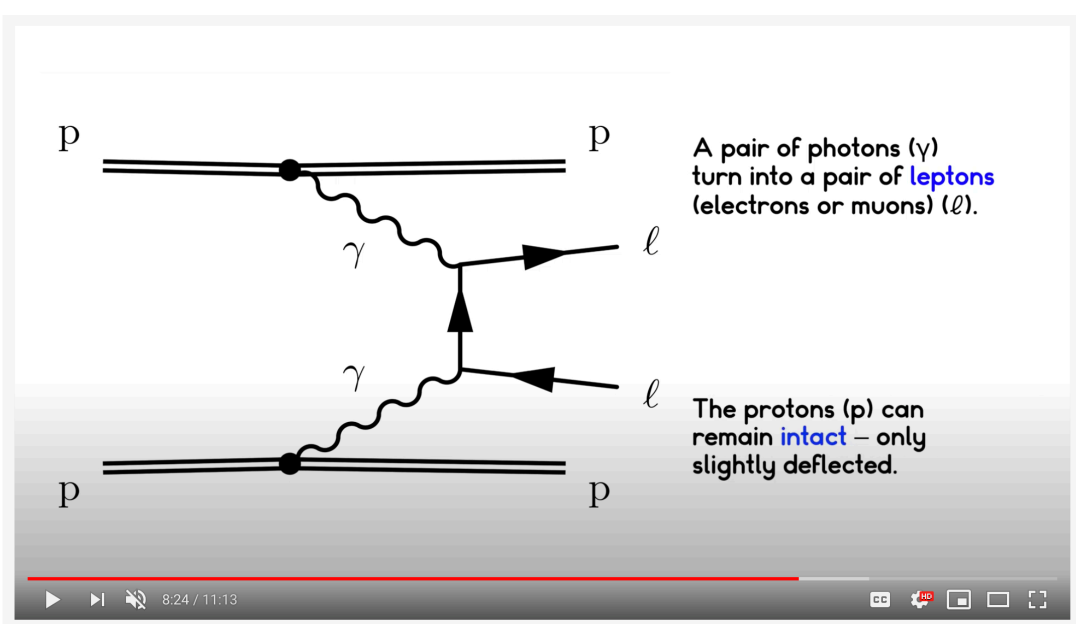
Looking forward: ATLAS measures proton scattering when light turns into matter

By ATLAS Collaboration, 30th July 2020

Today, at the International Conference for High Energy Physics (ICHEP 2020), the ATLAS Collaboration announced first results using the ATLAS Forward Proton (AFP) spectrometer (Figure 1). With this instrument, physicists directly observed and measured the long sought-after prediction of proton scattering when particles of light turn into matter.



ATLAS ICHEP highlights



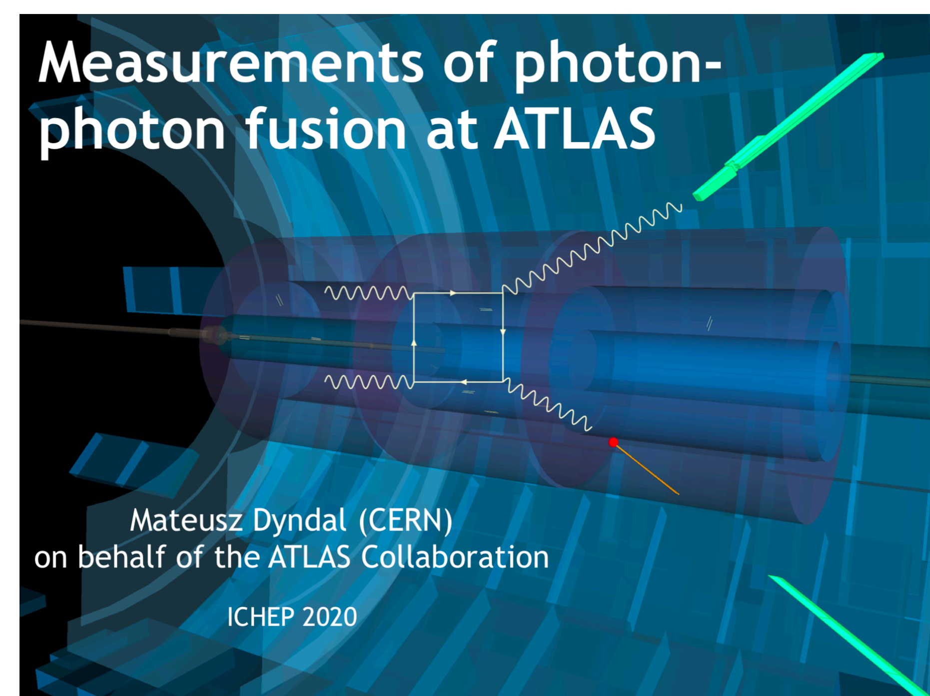
CERN
Explained | New ATLAS results from ICHEP 2020 conference [CC]

ATLAS ICHEP highlights

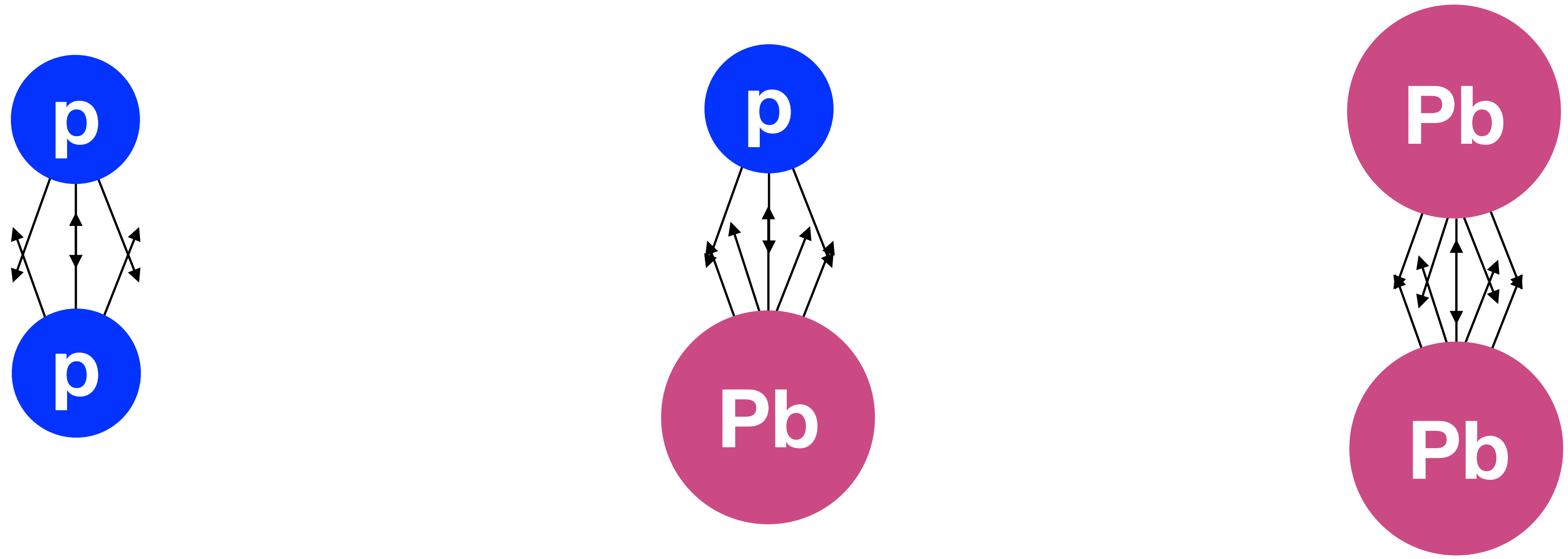
Two-photon production

Two highlights this year concern photon production in proton–proton collisions. In "normal" collisions at the LHC, a quark or a gluon from one proton interacts with a quark or a gluon from a proton in the opposing beam, breaking the two protons apart. However, in the rare cases where the protons pass close by each other instead of colliding head-on, each proton can radiate a photon which can then collide while the proton stays intact. This results in events where, except for the particles stemming from the photon–photon interaction, the ATLAS detector sees no other particles originating from the primary interaction vertex.

ICHEP Talk & interview



The LHC is a photon collider

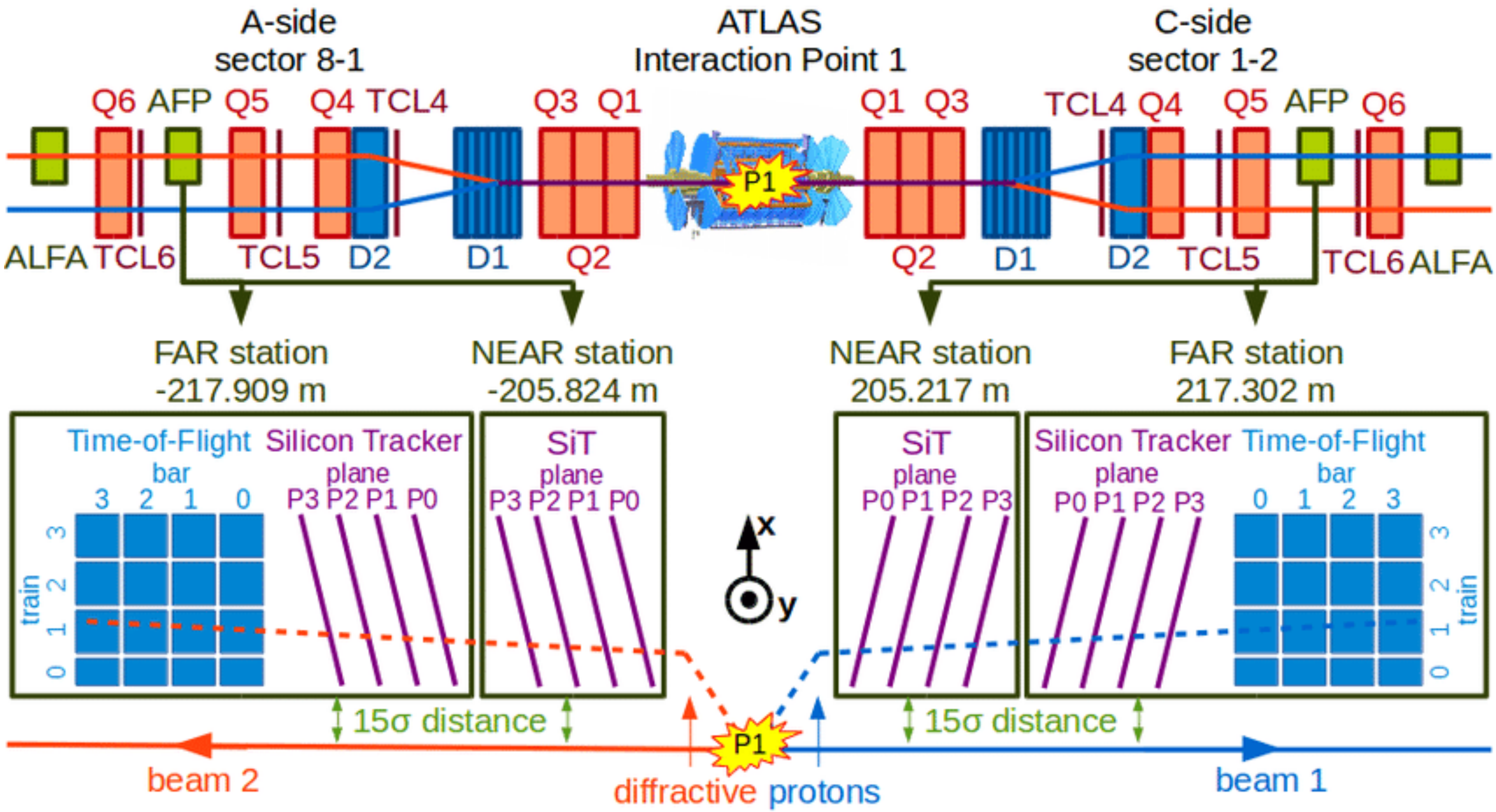


ATLAS

$\sqrt{s}$	13 TeV	8.16 TeV	5.02 TeV
$\mathscr{L}$	~140 fb^{-1}	~170 nb^{-1}	~2 nb^{-1}
σ	-	$\propto Z^2$	$\propto Z^4$

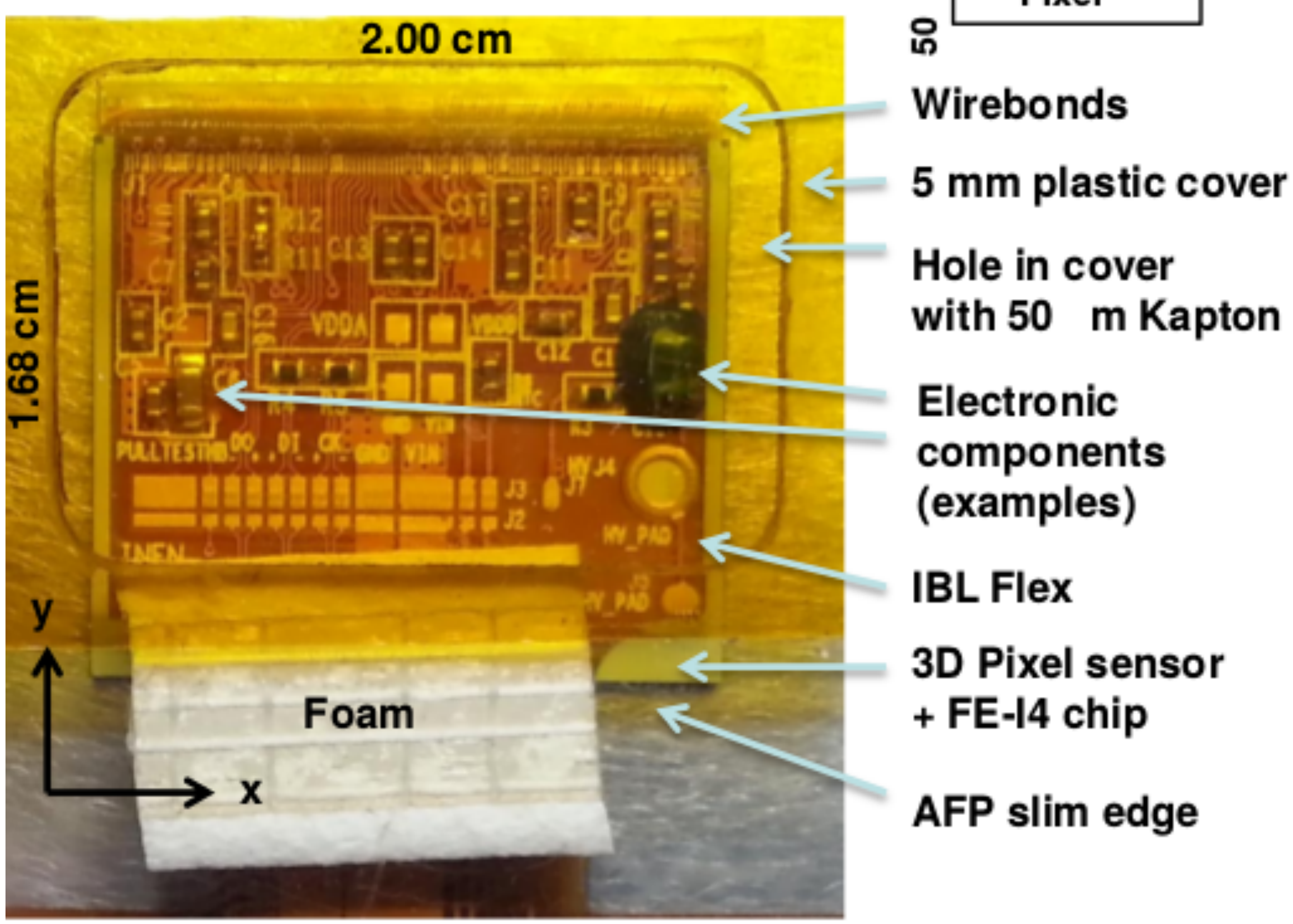
Z = 82 for Pb

ATLAS Forward Detectors

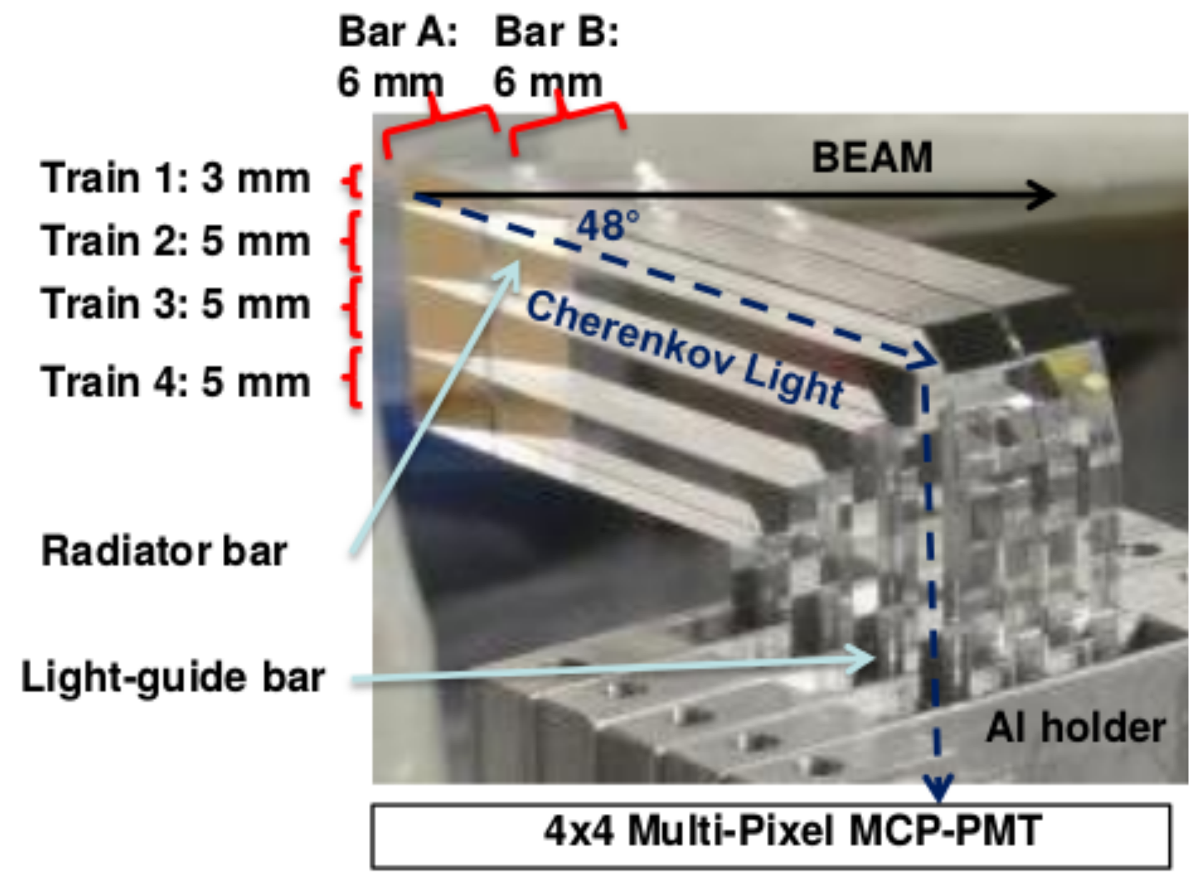


AFP detectors

3D FE-I4 Pixel Module

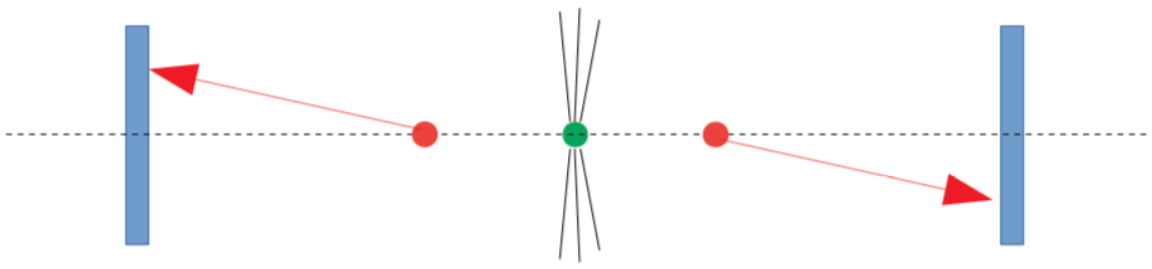


ToF LQbars



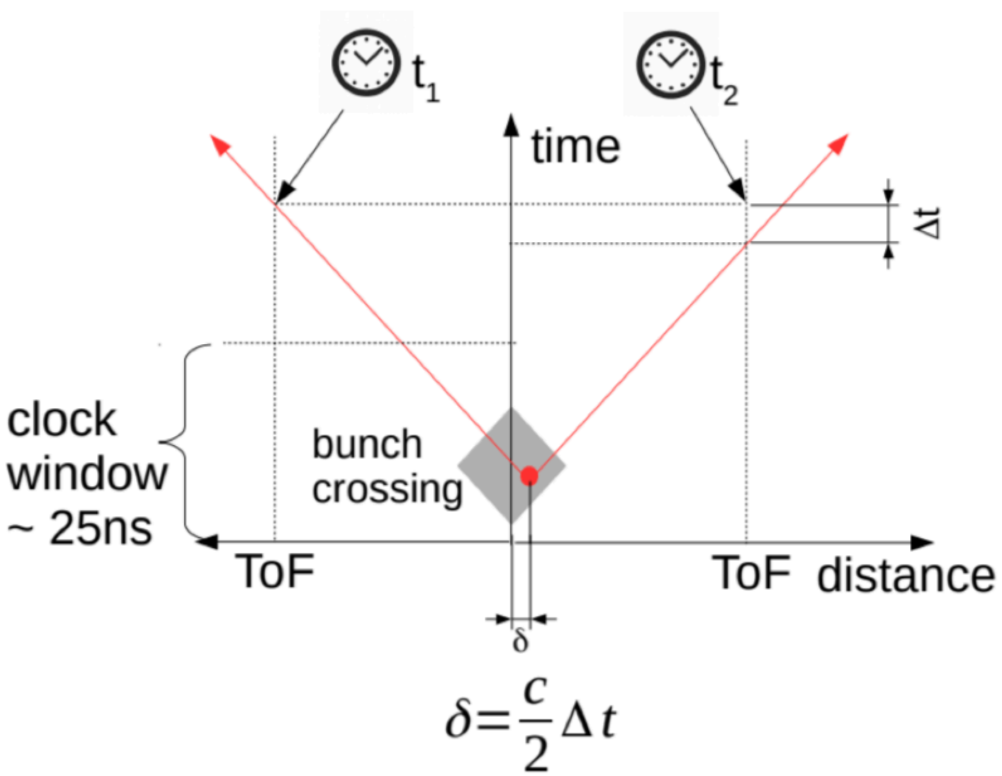
Time-of-Flight method

Diffractive interactions from pile-up can mimic the signal in AFP.



Comparison of arrival times on both sides provides z-position of the pp → pXp interaction.

The two outermost AFP stations are equipped with Cherenkov **T**ime-**o**f-**F**light (ToF) detectors

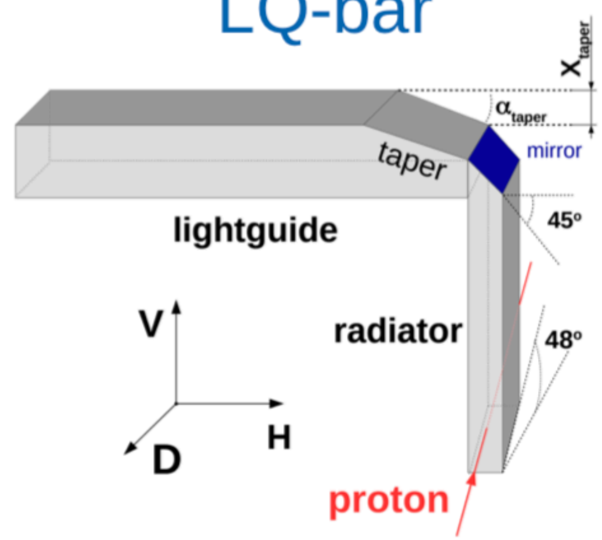


Karel Černý, AFP/ToF performance, ICHEP 2020

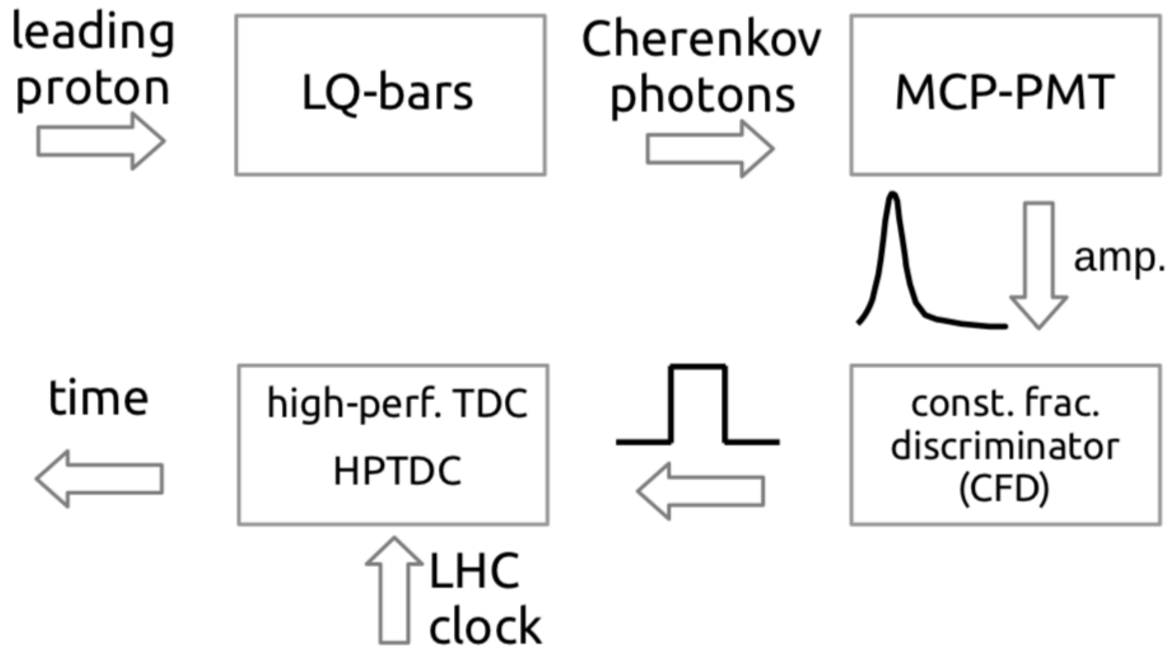
Time-of-Flight detectors

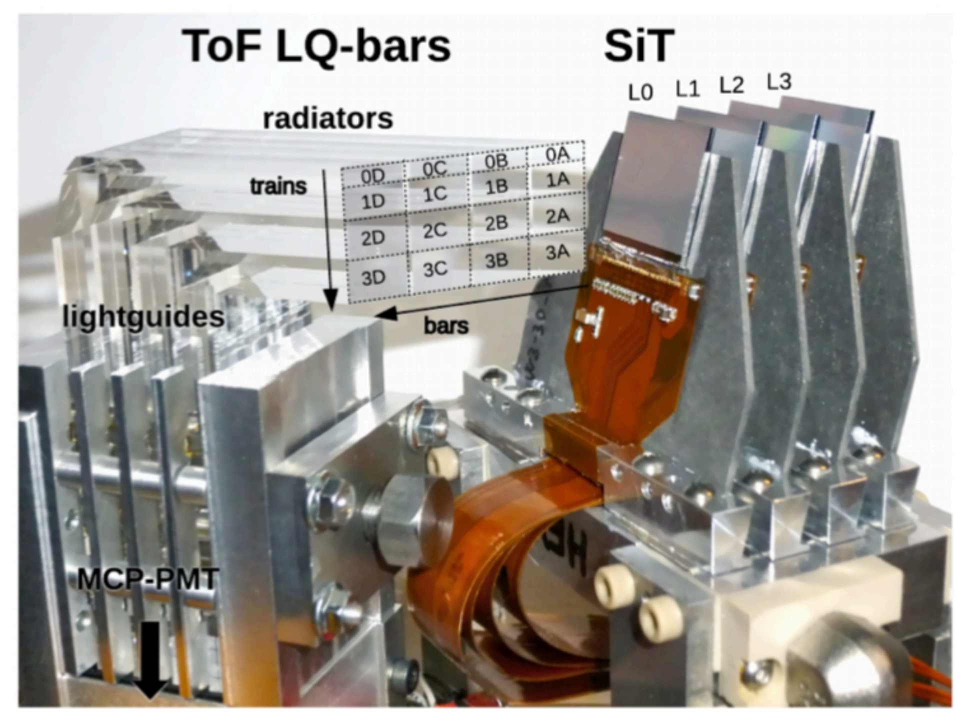
Function of the detectors is based on collection of Cherenkov photons in L-shaped Quartz bars (LQ-bars).

LQ-bar



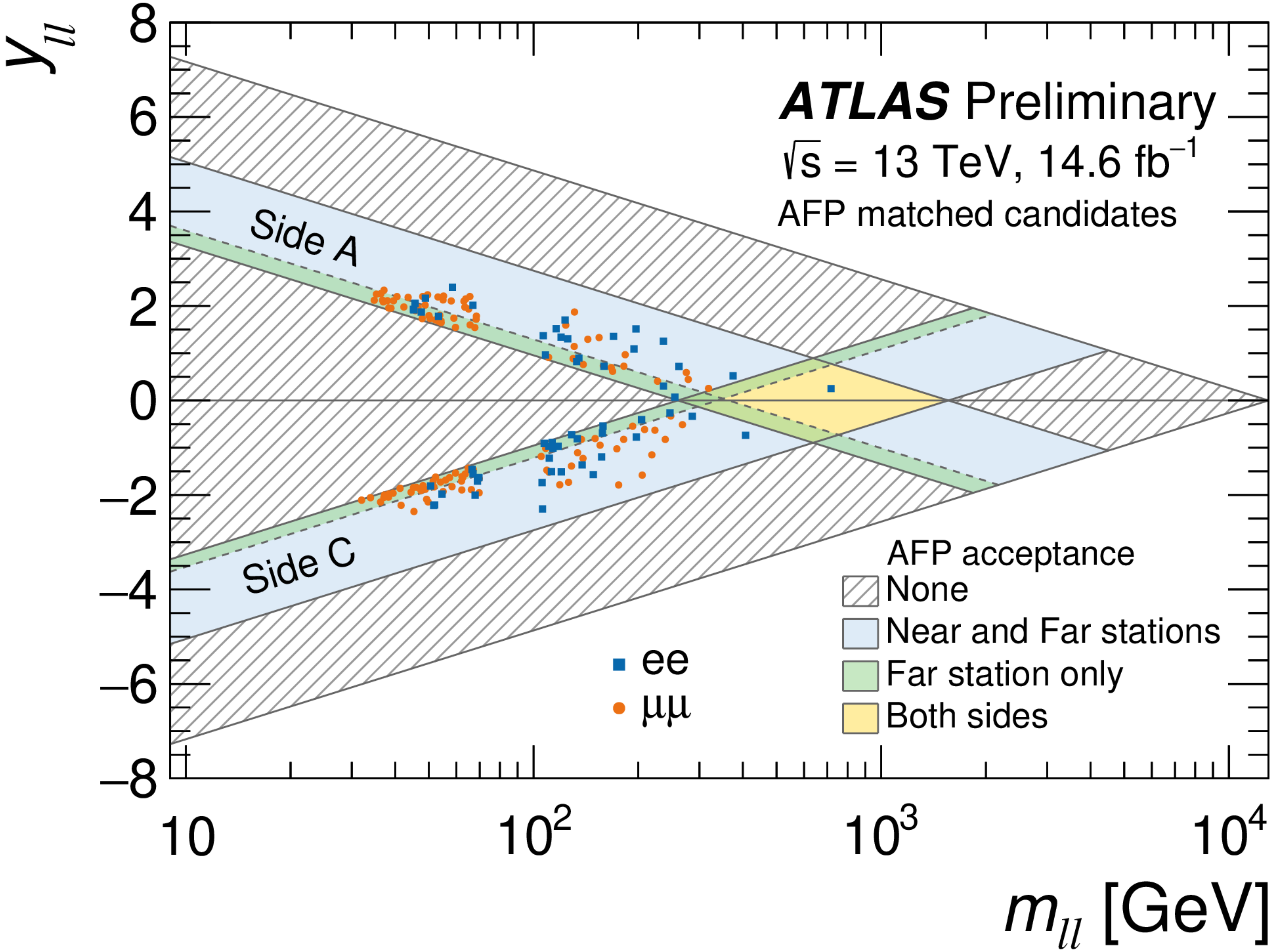
Stacked in a 4x4 (train x channel) matrix mounted to a multi-anode microchannel-plate photomultiplier (MCP-PMT).





Karel Černý, AFP/ToF performance, ICHEP 2020

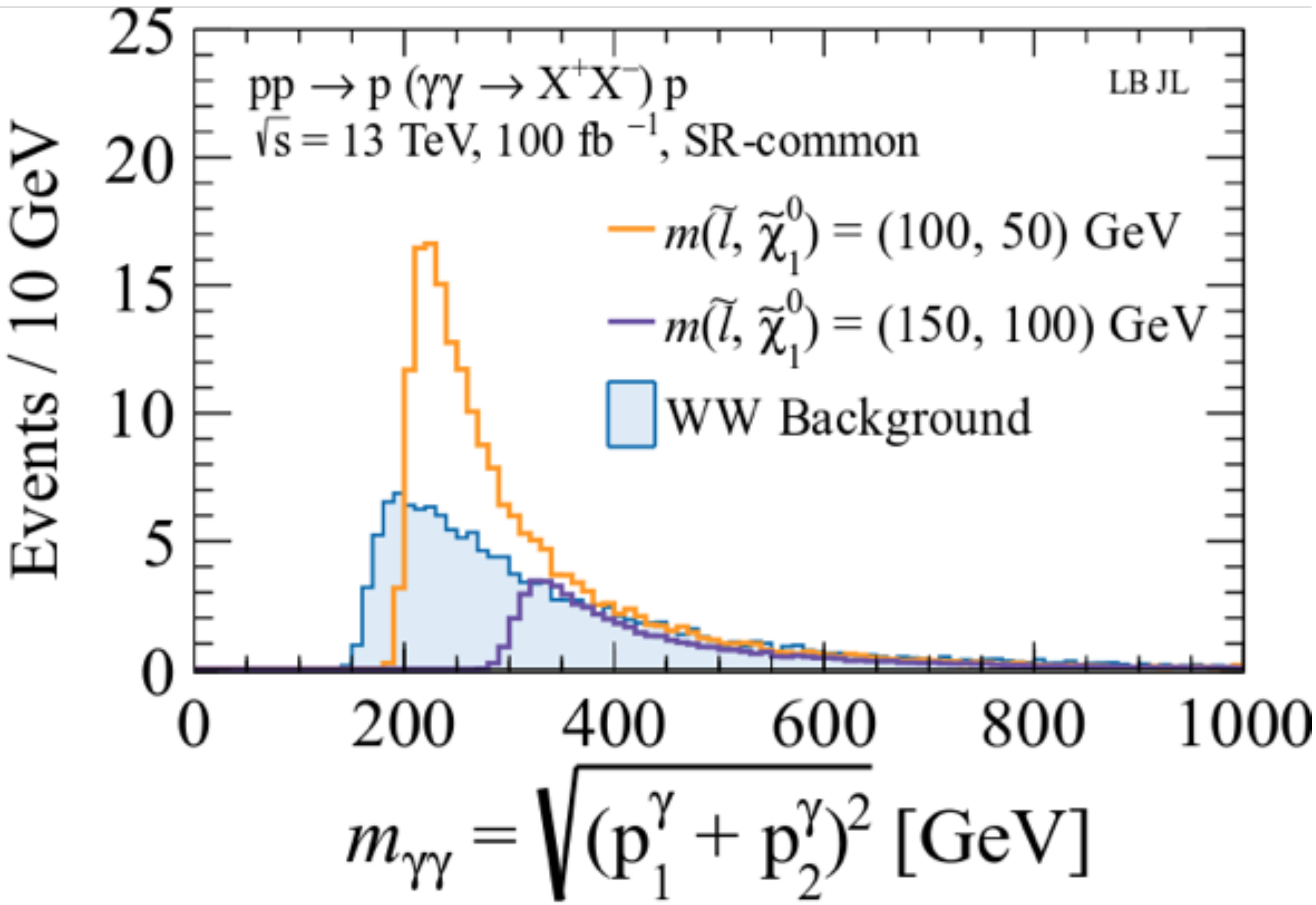
Results

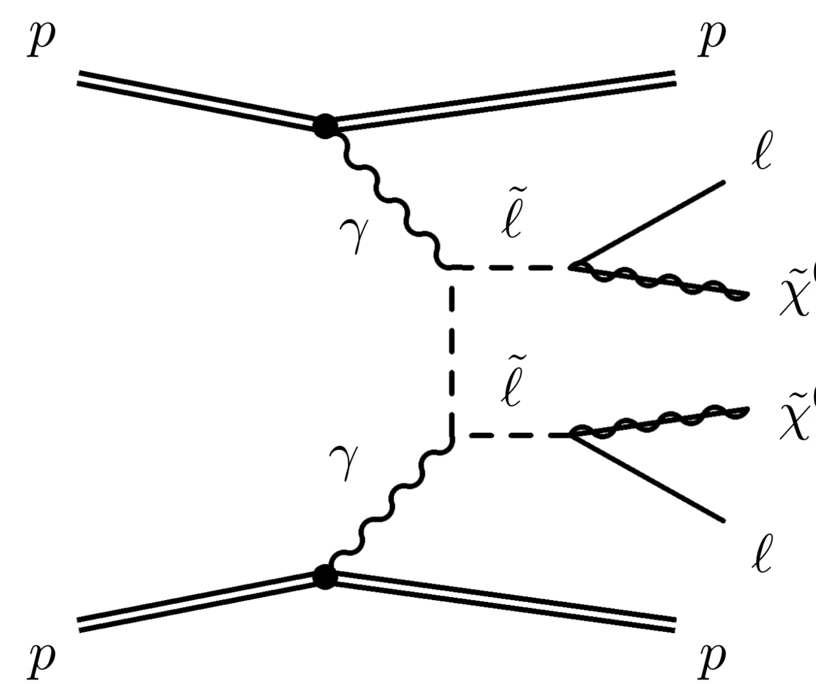


Probing masses up to ∼ 700 GeV

→ Search for production threshold

min($m_{\gamma\gamma}$) = 2 x $m_{\tilde{l}}$

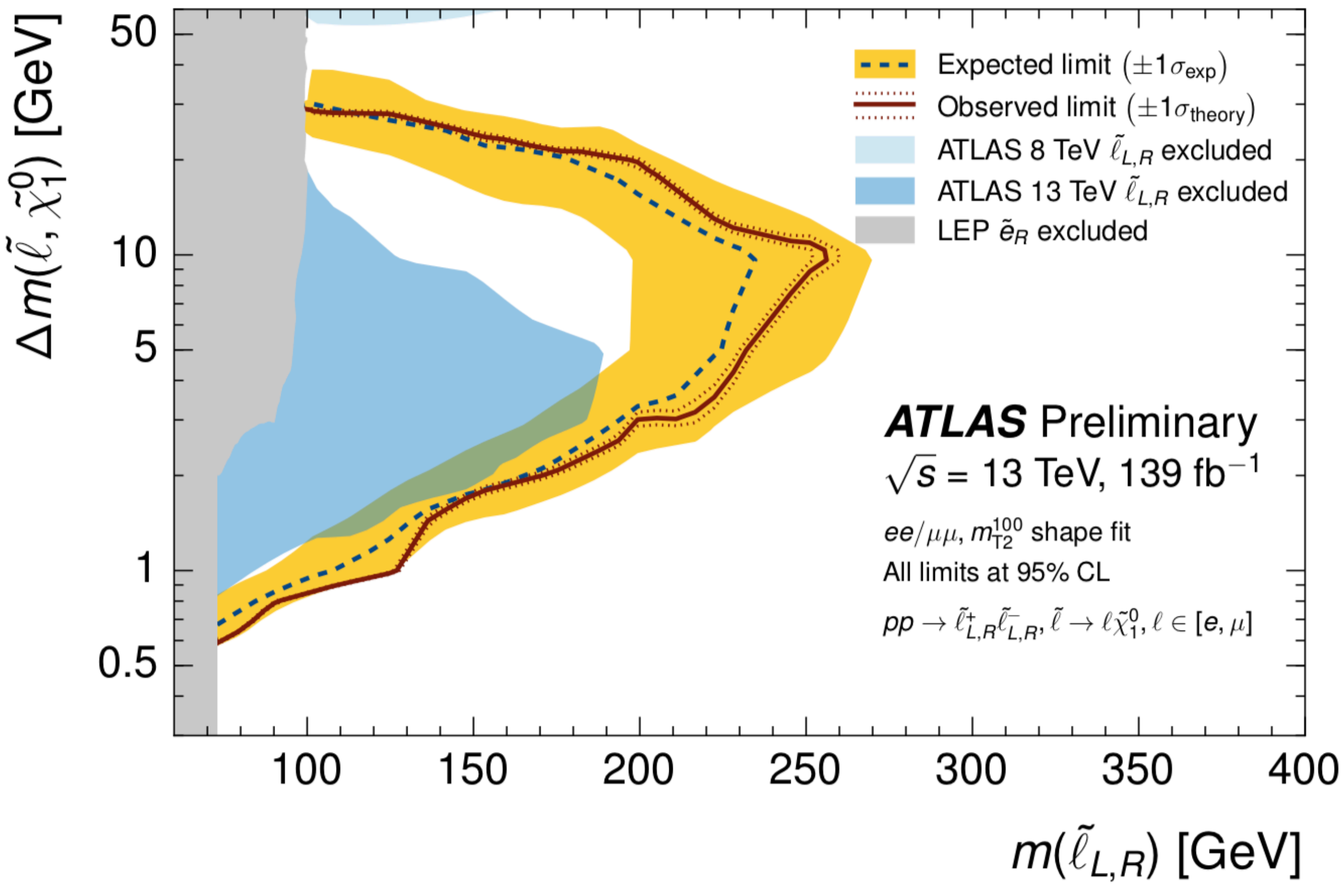


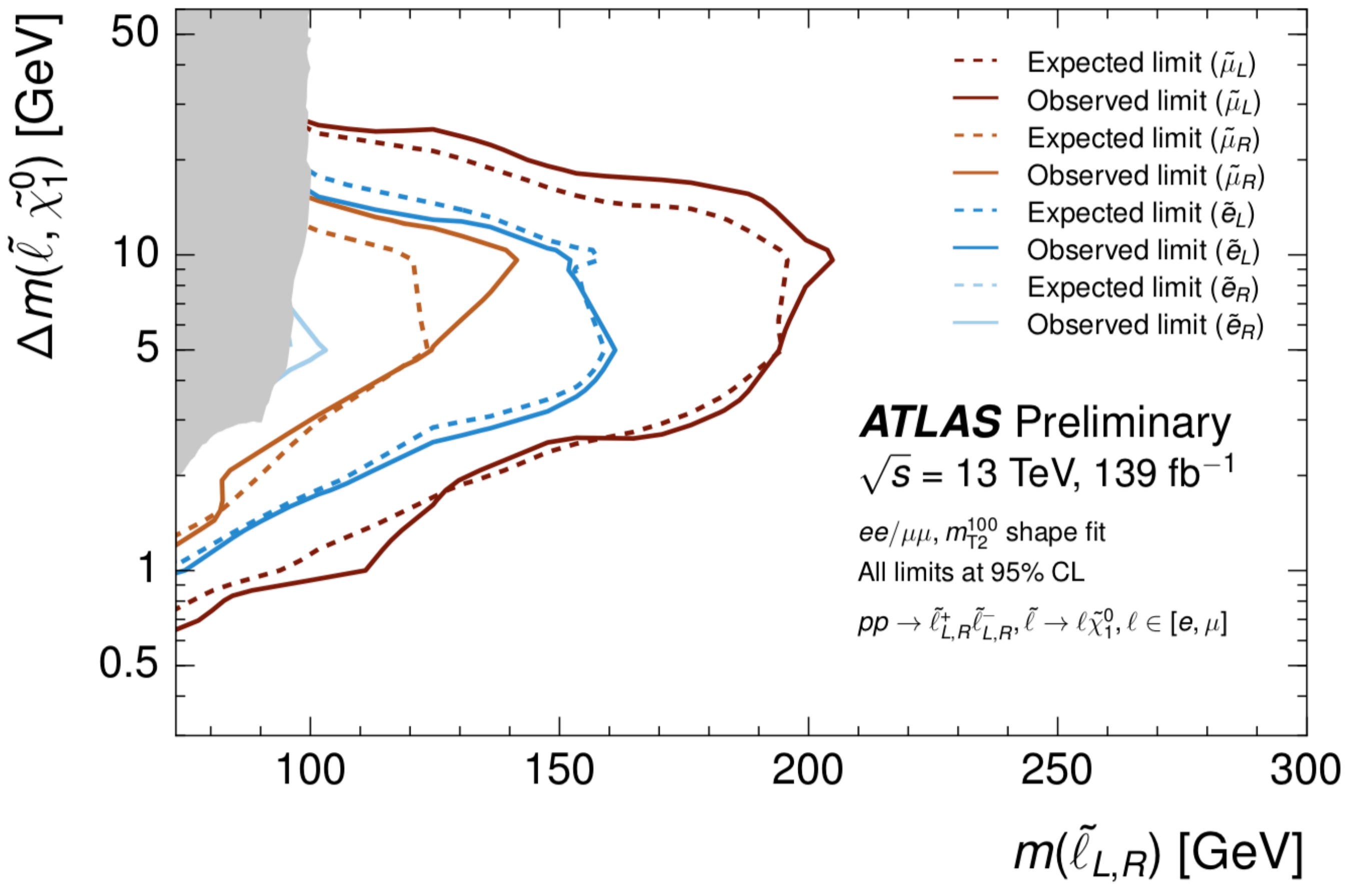


Calculated from proton energy loss

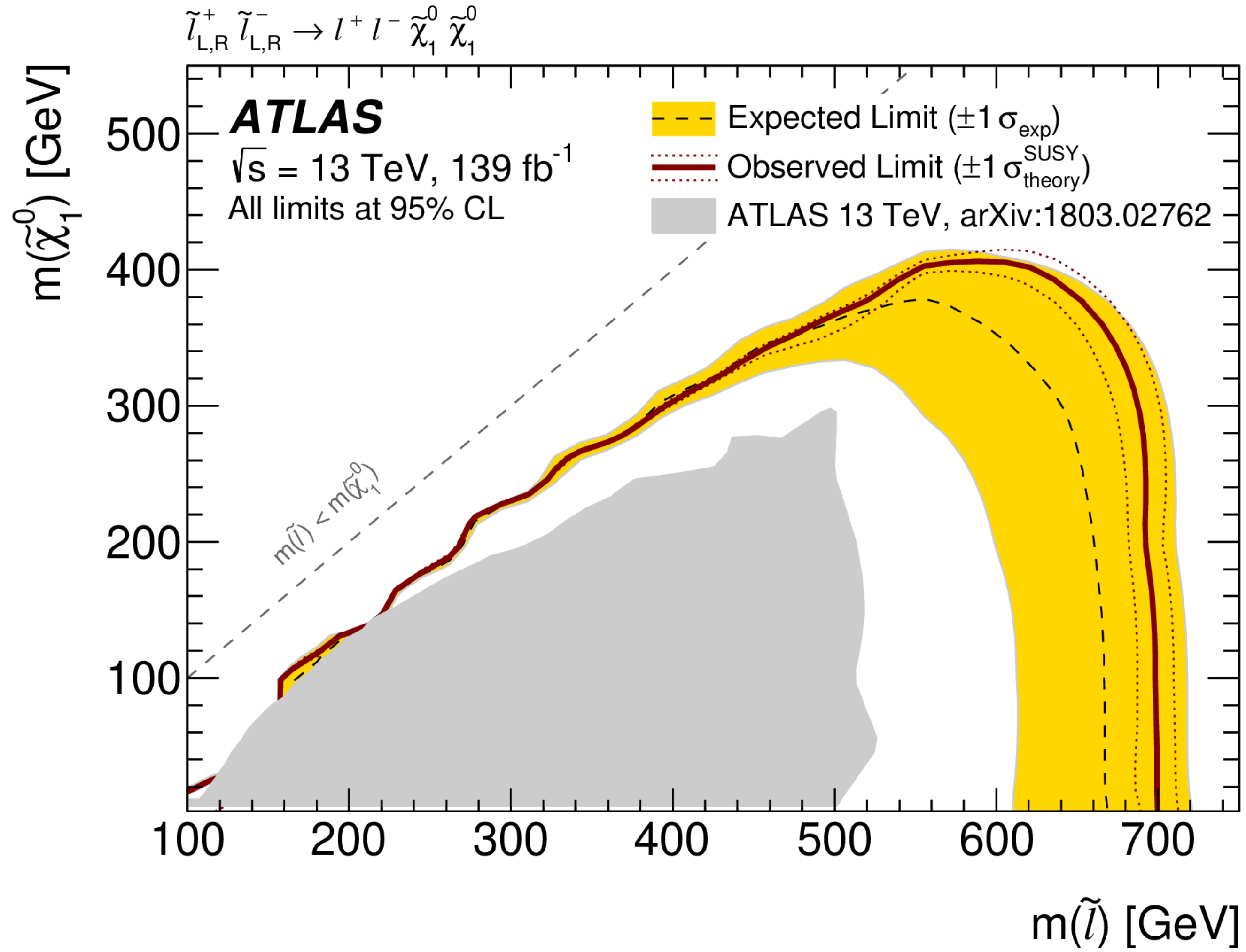
Illustrative plot: Efficiencies & FD acceptance not applied, only resolution smearing

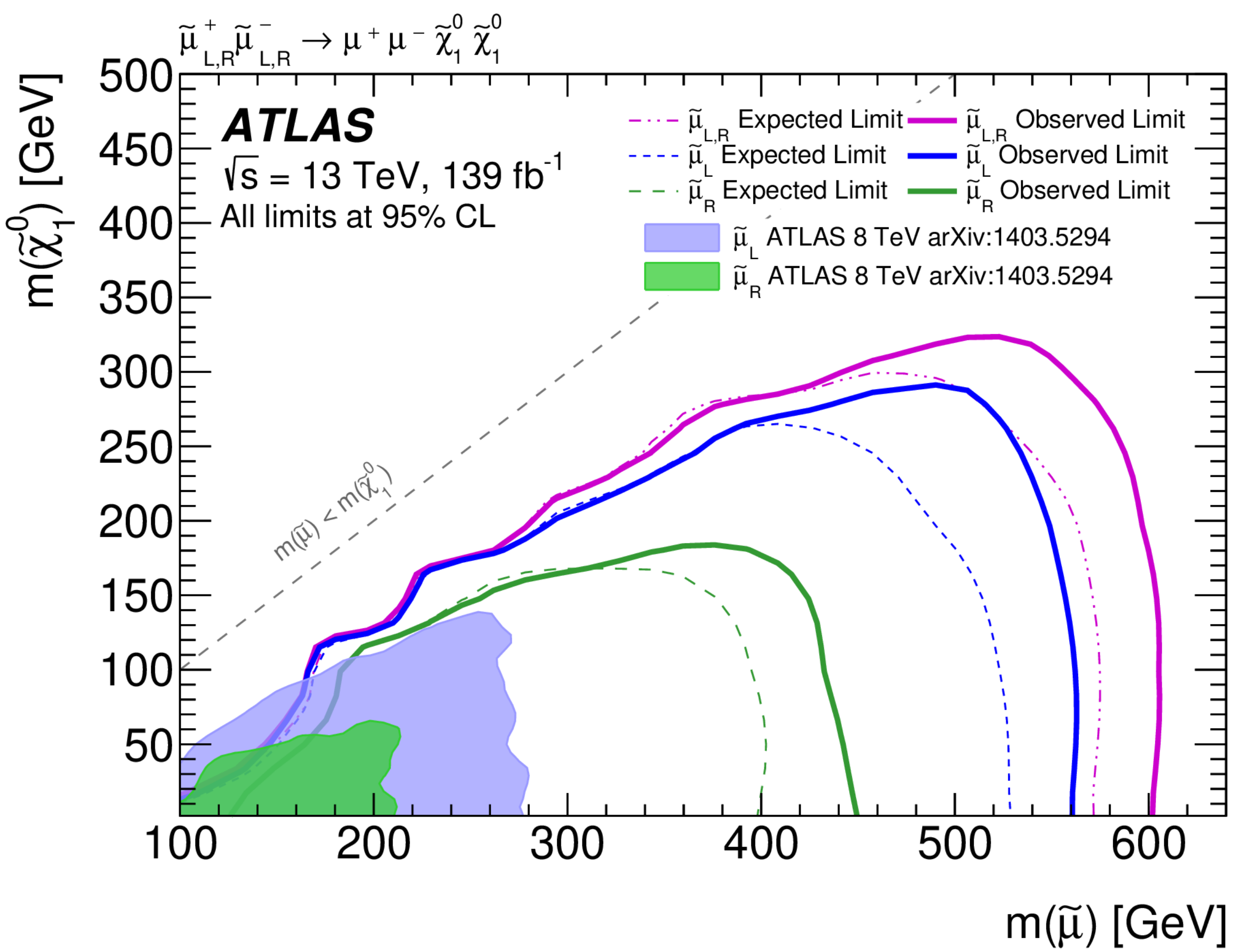
ATLAS latest - 2L ISR

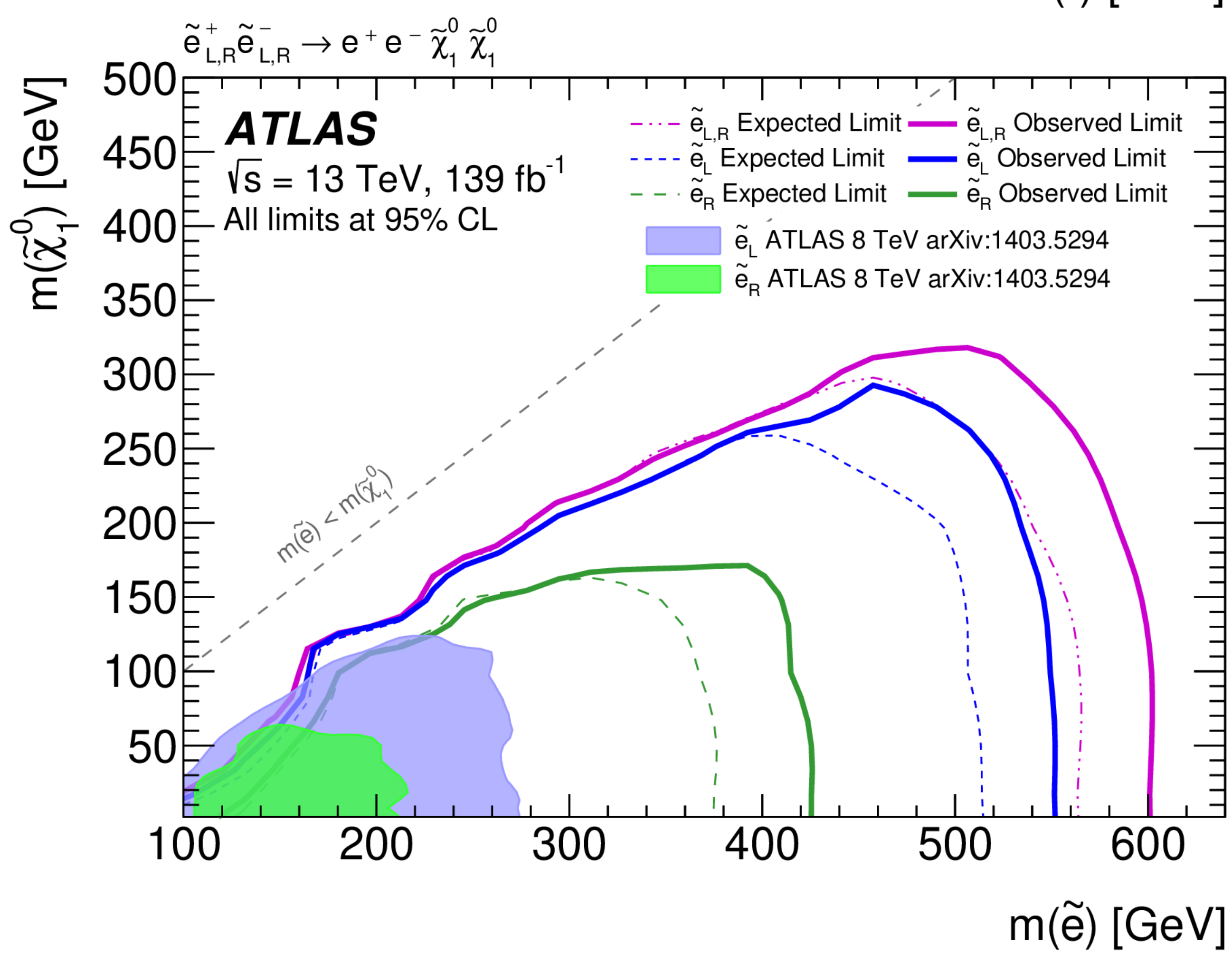




ATLAS latest
- 2L 0 jets







What next for photon collisions?

Beresford, Liu [1908.05180]

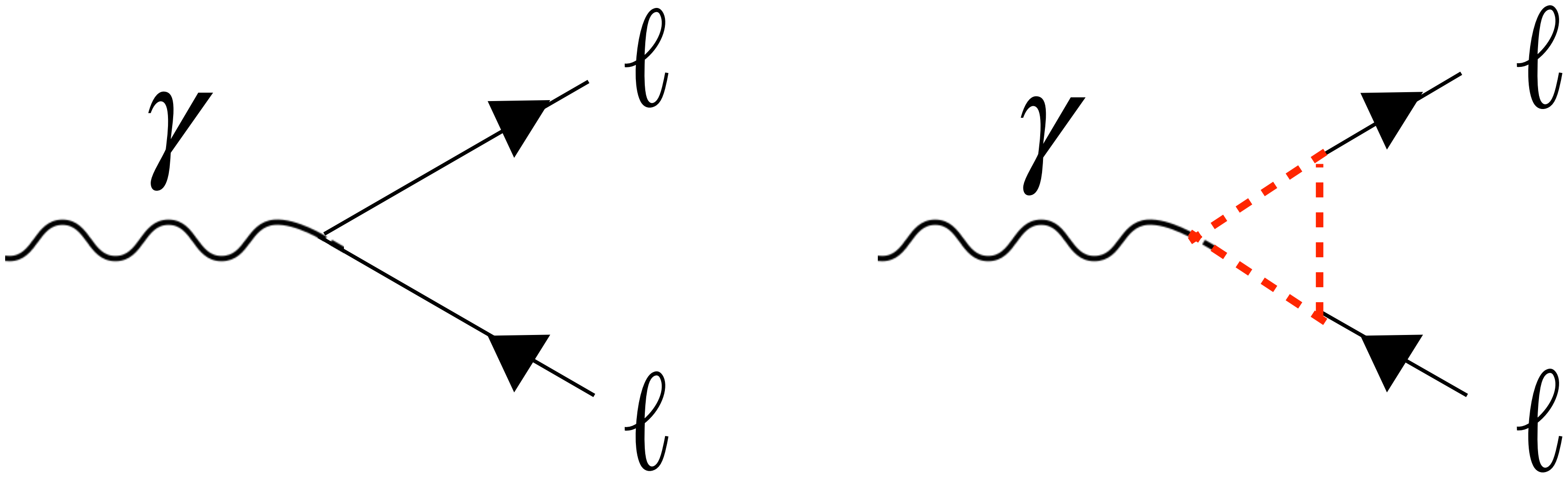
How particles interact with light

Tau g-2

Particles can have intrinsic **magnetic moment**

For spin 1/2 particles: $\boldsymbol{\mu} = g\frac{q}{2m}\mathbf{S}$

$\boldsymbol{\mu} \, . \, \mathbf{B}$



g = 2 + loop corrections

Dirac, 1928

What is g-2?

Anomalous magnetic moment

$$a = \frac{(g-2)}{2}$$

Why is it interesting?

Does light couple to all lepton generations in the same way?

Fundamental test of QED

Electron g-2: 10^{-8} precision **-2.5σ tension**

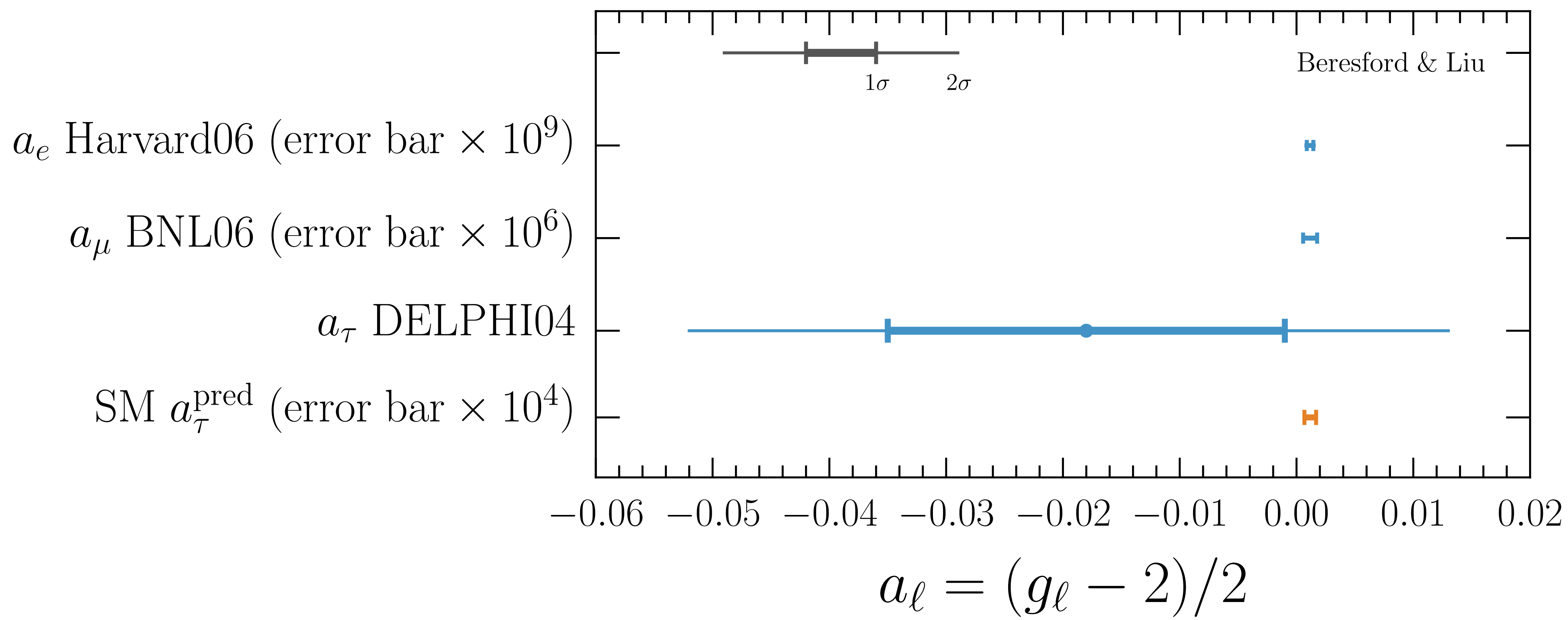
Muon g-2: 10^{-7} precision **$3\text{-}4\sigma$ tension**

Electron: Odom et at PRL (2006) Bouchendira et al PRL (2011) Aoyama et al 1205.5368 Parker et al Science (2018)

Muon: BNL E821 hep-ex/0602035 J-PARC 1901.03047 Davier et al 1908.00921
Keshavarzi, Nomura and Teubner 1802.02995

Sibling Rivalry

Tensions seen for electron & muon, what about the tau?



PDG value doesn't test 1-loop QED

$$a_\tau^{\rm exp} = -\,0.018\ (17)$$

Delphi EPJC (2004)

Constraints also set by L3 and OPAL

$$a_\tau^{\rm theory} = 0.00117721\ (5)$$

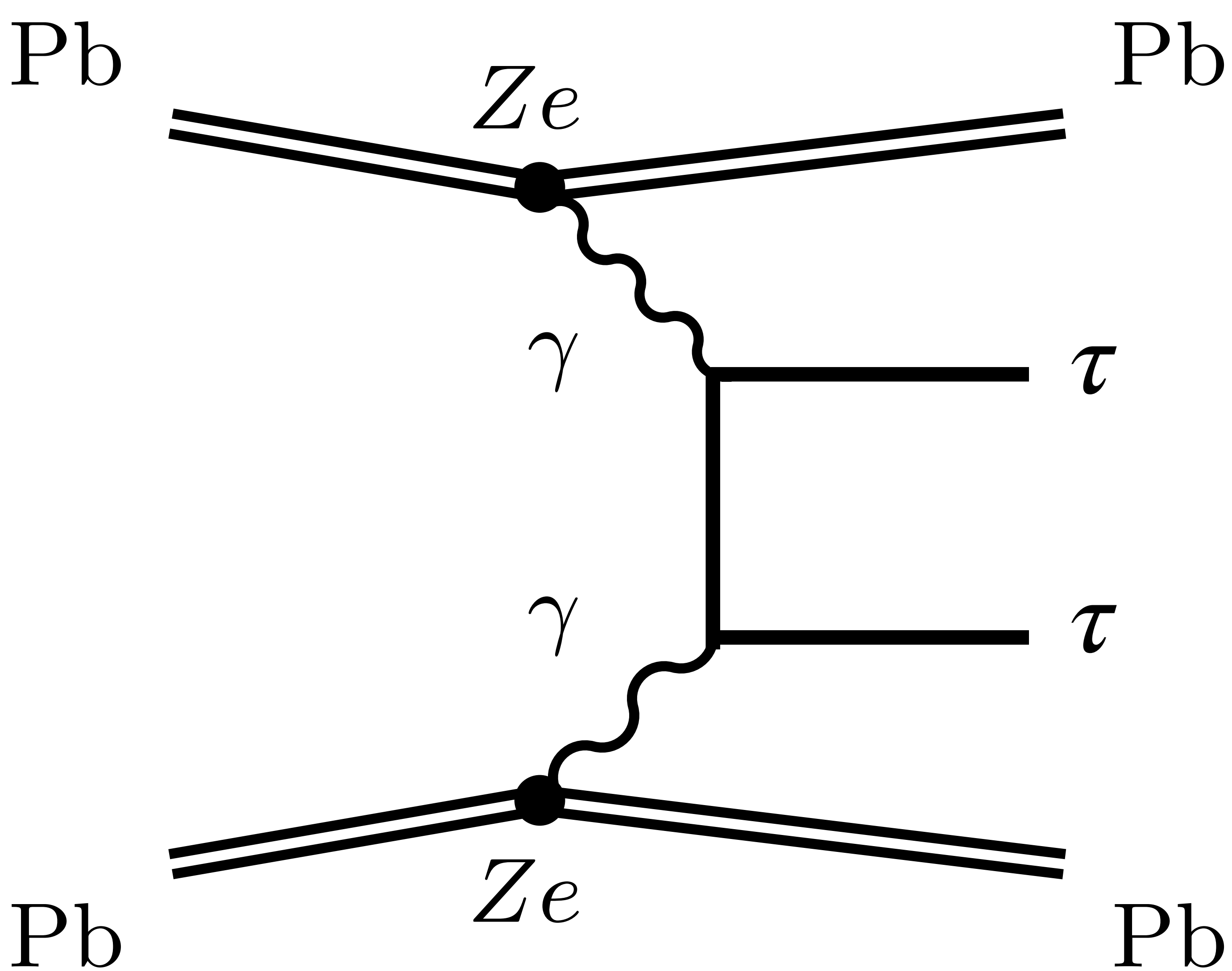
1-loop, Schwinger $a = \alpha/2\pi$ = 0.0012

Eidelman, Passera hep-ph/0701260

Di-tau Production

Aguila, Cornet and Illana PLB (1991)
Beresford, Liu 1908.05180
Dyndal et al 2002.05503

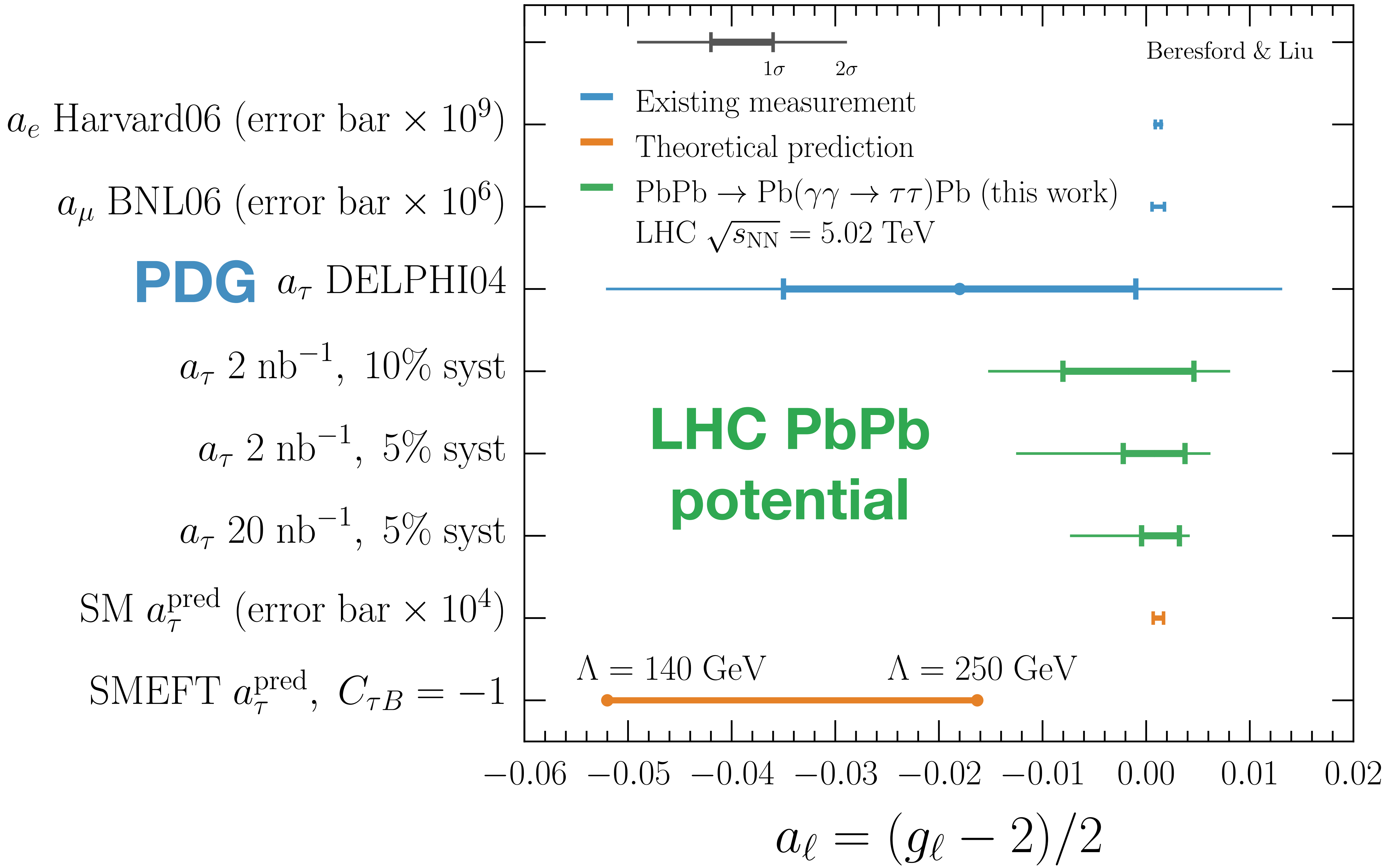
Photo production of tau pairs



Cross section
sensitive to **g-2**

Promising prospects

Beresford, Liu [1908.05180](https://arxiv.org/abs/1908.05180)



Surpass PDG value … or discover tension!

Ultra Peripheral PbPb collisions

Super clean with ~ 0 pile-up

One month to gather dataset

Low trigger thresholds → Trigger on soft taus!

→ Quantify potential using MC

MG with modified photon flux + Pythia + Delphes (ATLAS)

Also sensitive to tau EDM

How objects interact with an ***electric*** *field*

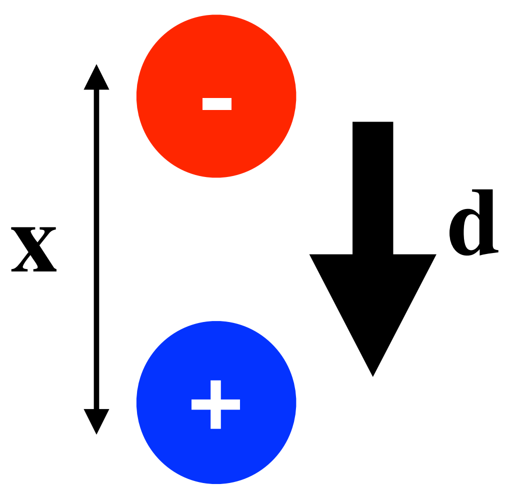
EDM = Electric Dipole Moment

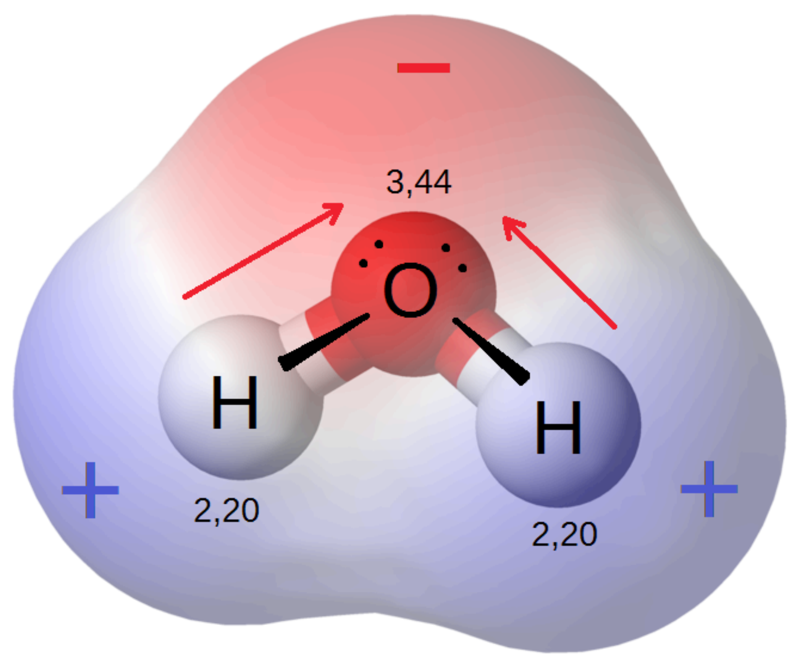
$$\boldsymbol{\tau} = \boldsymbol{d} \times \mathbf{E}$$

torque — electric dipole moment

Possessed by e.g. water (polarised molecule)

$$\mathbf{d} = q\mathbf{x}$$





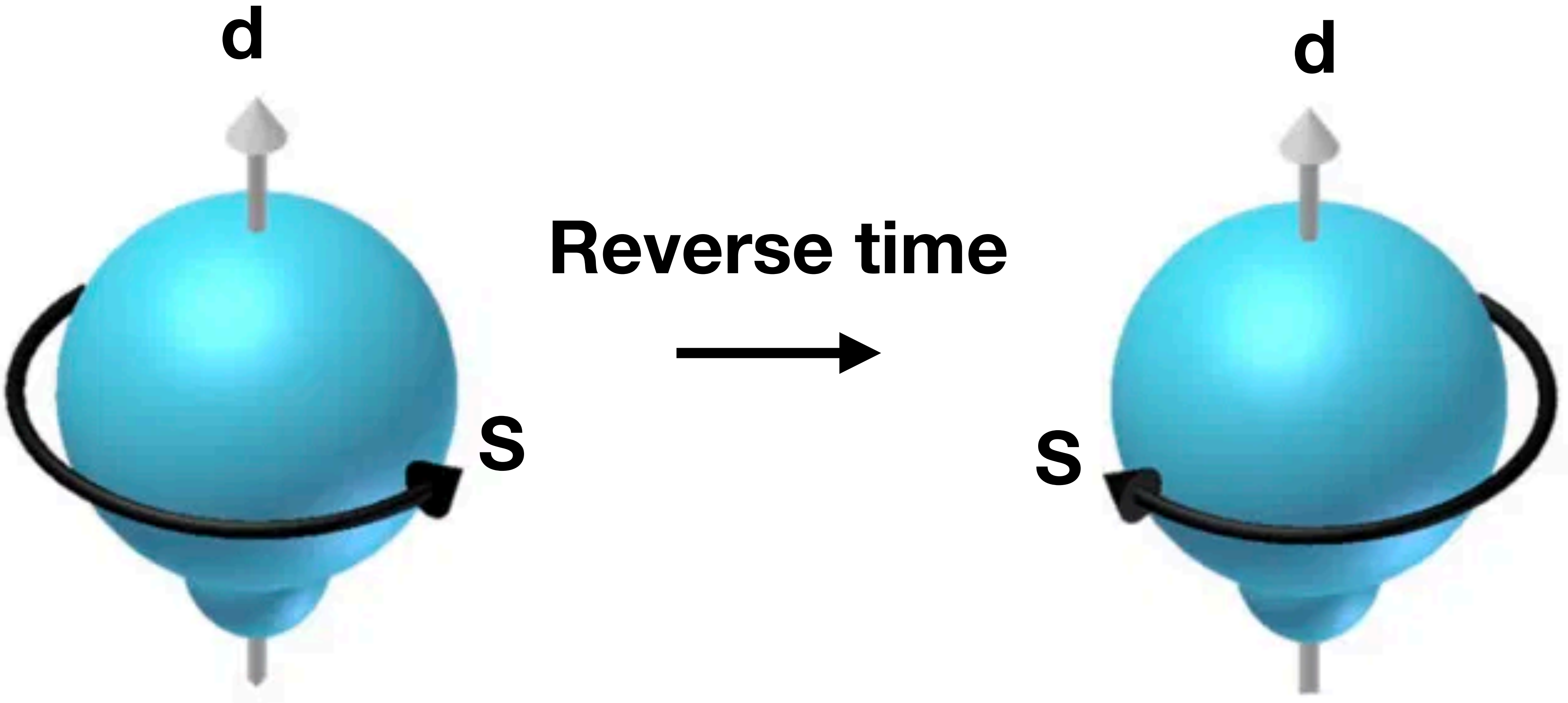
EDM tells us about charge distribution

Why are EDMs interesting?

Further details

Non-zero EDM → CP violation!

assuming CPT conserved



EDM tiny in SM, observation = New Physics!

What next for photon collisions?

Searching for axion-like particles