



883. WE-HEREAUS FOLLOW UP SEMINAR

10 FEBRUARY 2026



THE HENRYK NIEWODNICZAŃSKI  
INSTITUTE OF NUCLEAR PHYSICS  
POLISH ACADEMY OF SCIENCES

# GAMMA-GAMMA TO LEPTON-LEPTON INTERACTIONS IN LHC

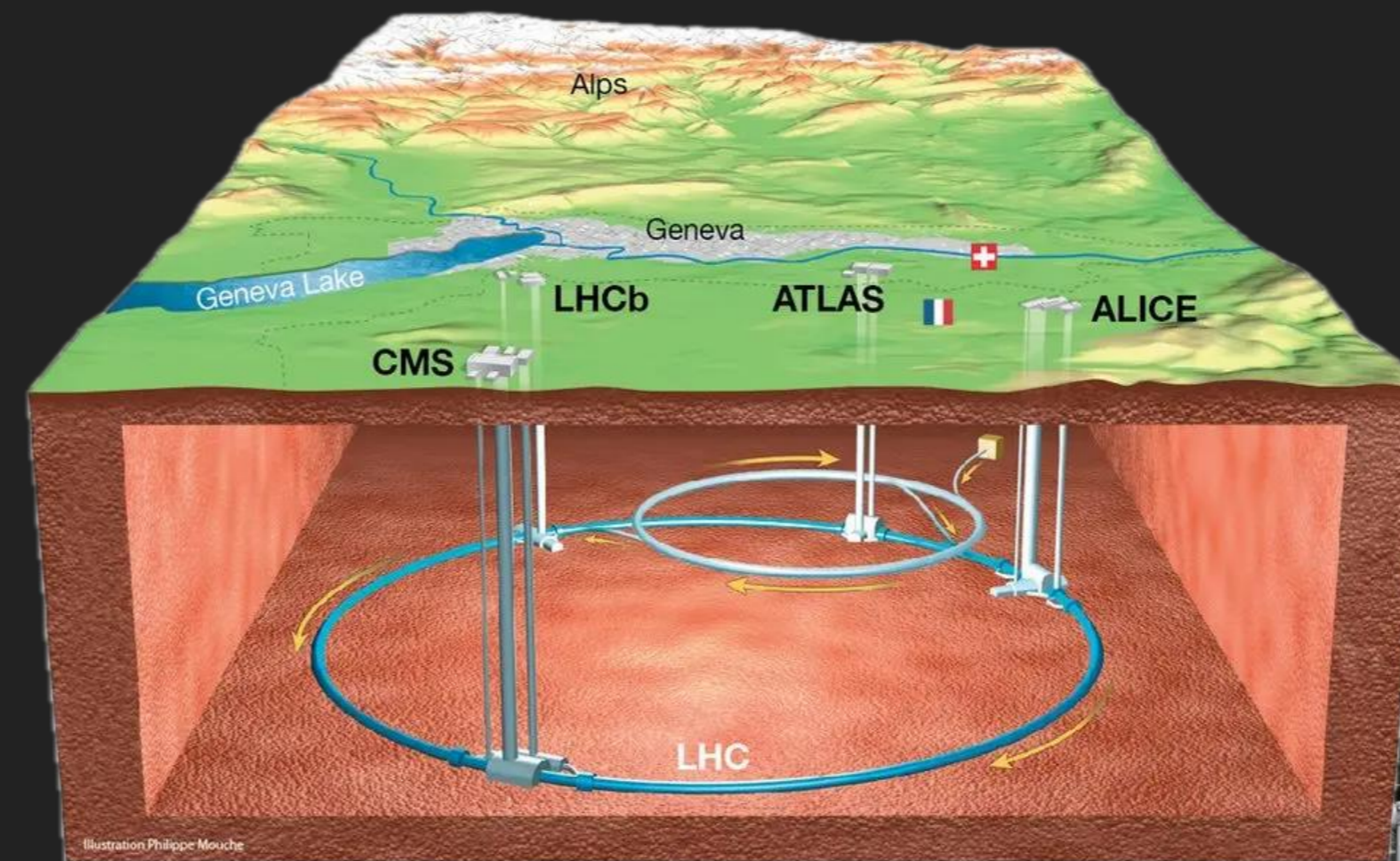
USING THE ATLAS FORWARD PROTON DETECTORS



TOMASZ MRÓZ

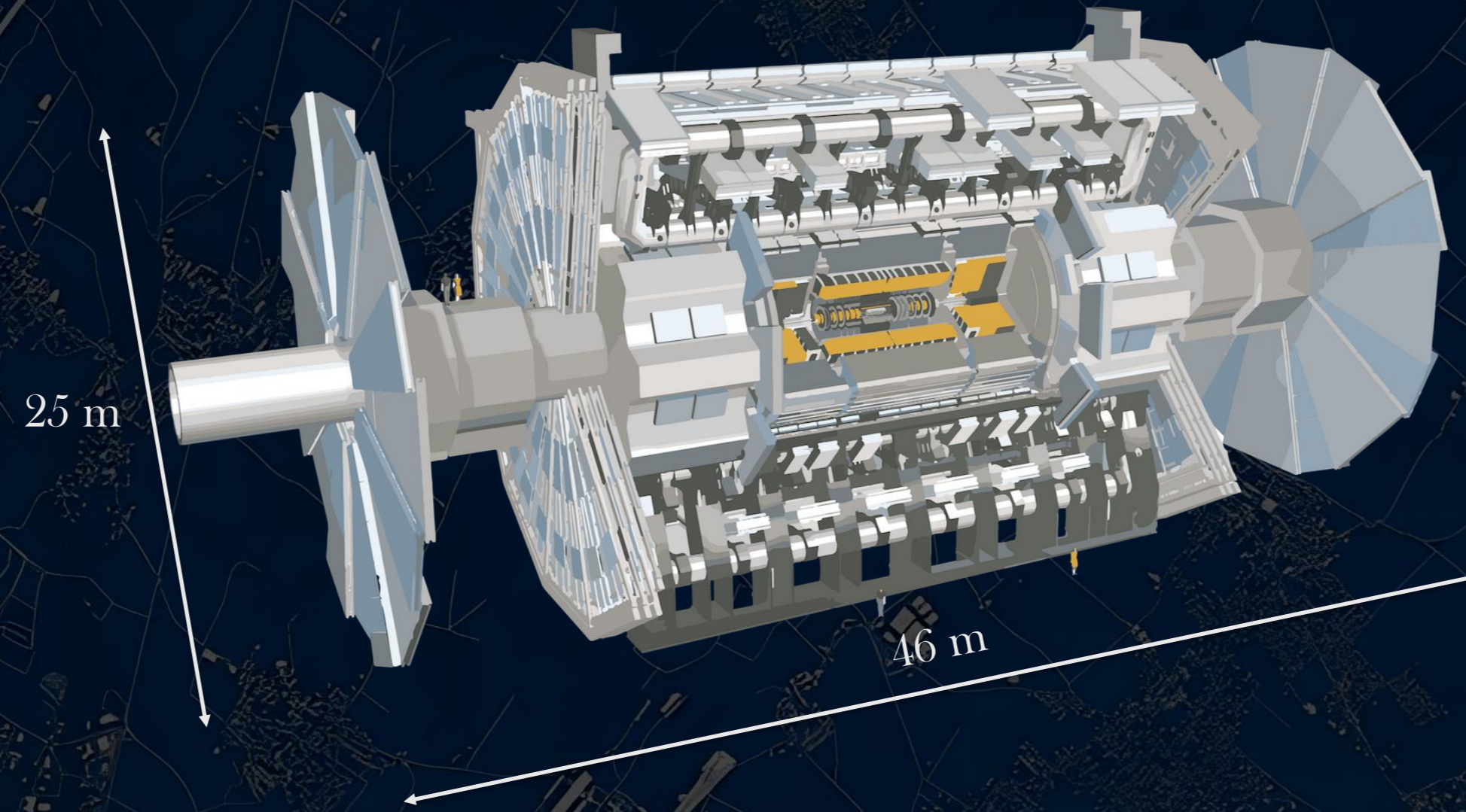
# LHC SUMMARY

- ▶ 100 m deep
- ▶ 27 km circumference
- ▶ 4 interaction points
- ▶ 2 proton/HI beams
- ▶ 13.6 TeV Collision Energy
- ▶ Collision rate 40MHz



# ATLAS SUMMARY

- ▶ General-purpose experiment
- ▶ Broad physics program: Standard Model tests, Higgs physics, and searches for new physics
- ▶ Largest detector in size ever built
- ▶ Key contribution to Higgs boson discovery (2012)



ATLAS Experiment



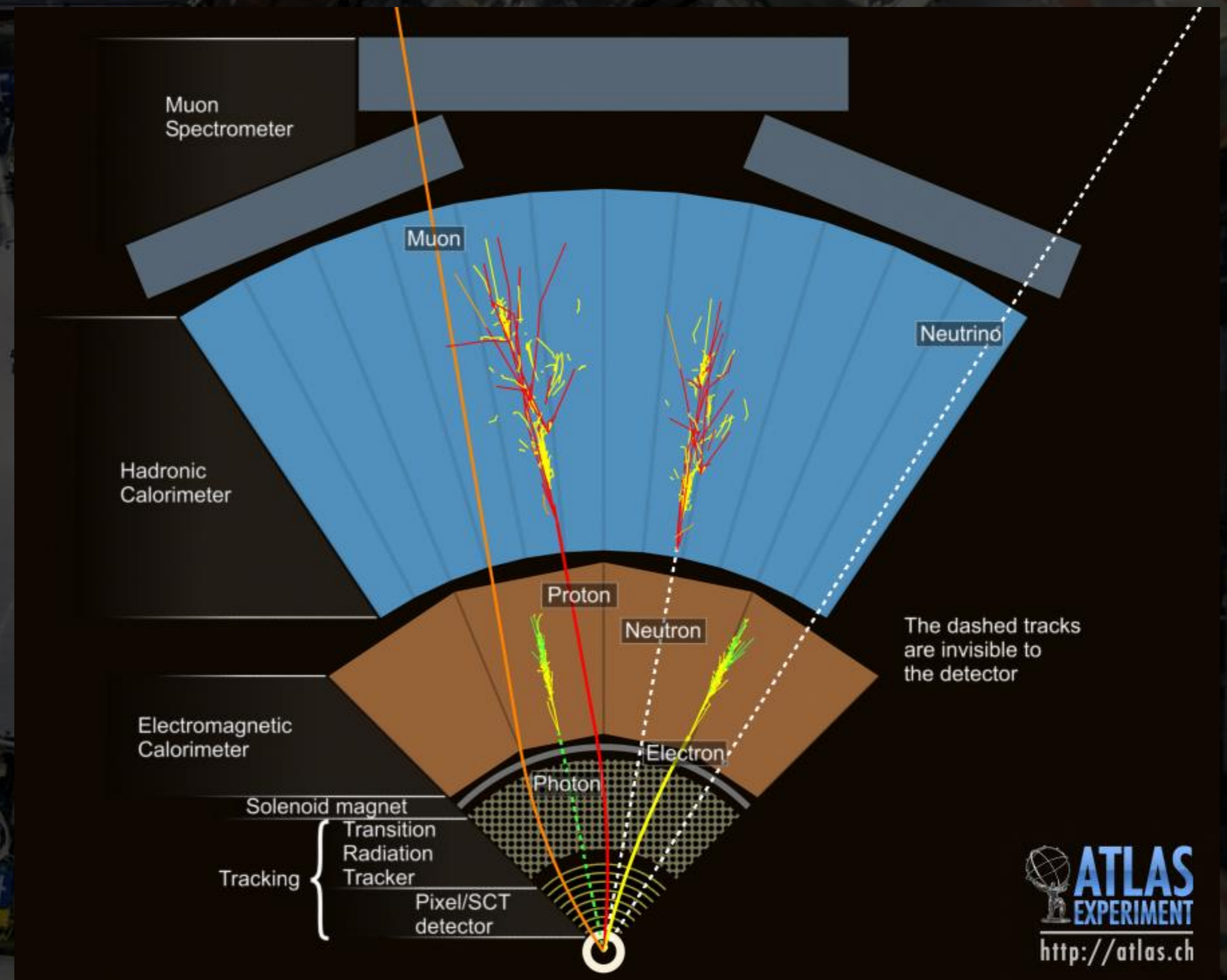
ALICE Experiment

LHCb Experiment

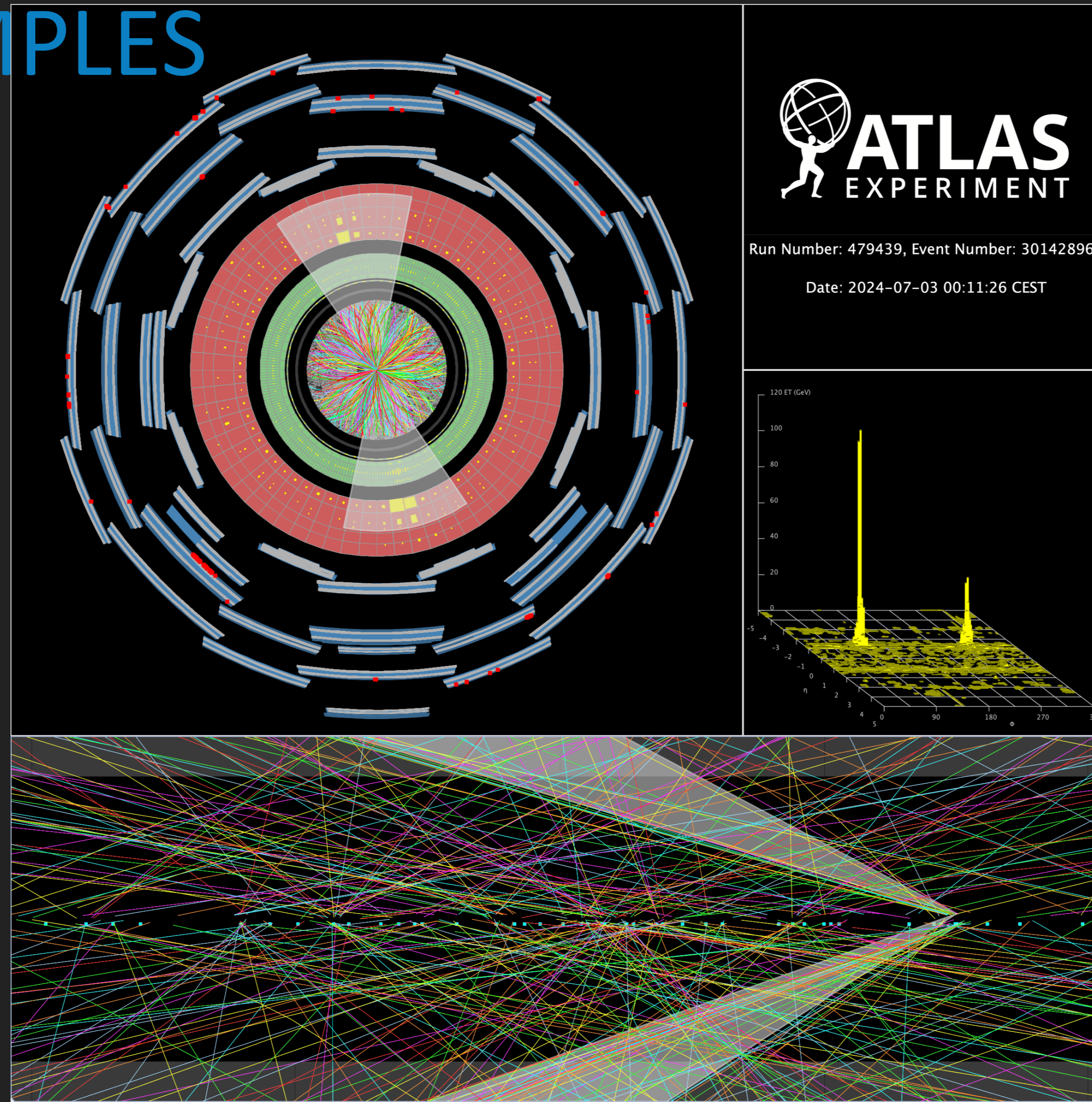


# INSIDE OF ATLAS

- ▶ Layered and cylindrical structure
- ▶ Concentric layers arranged radially around the interaction point (IP)
- ▶ Each layer has a distinct physics role



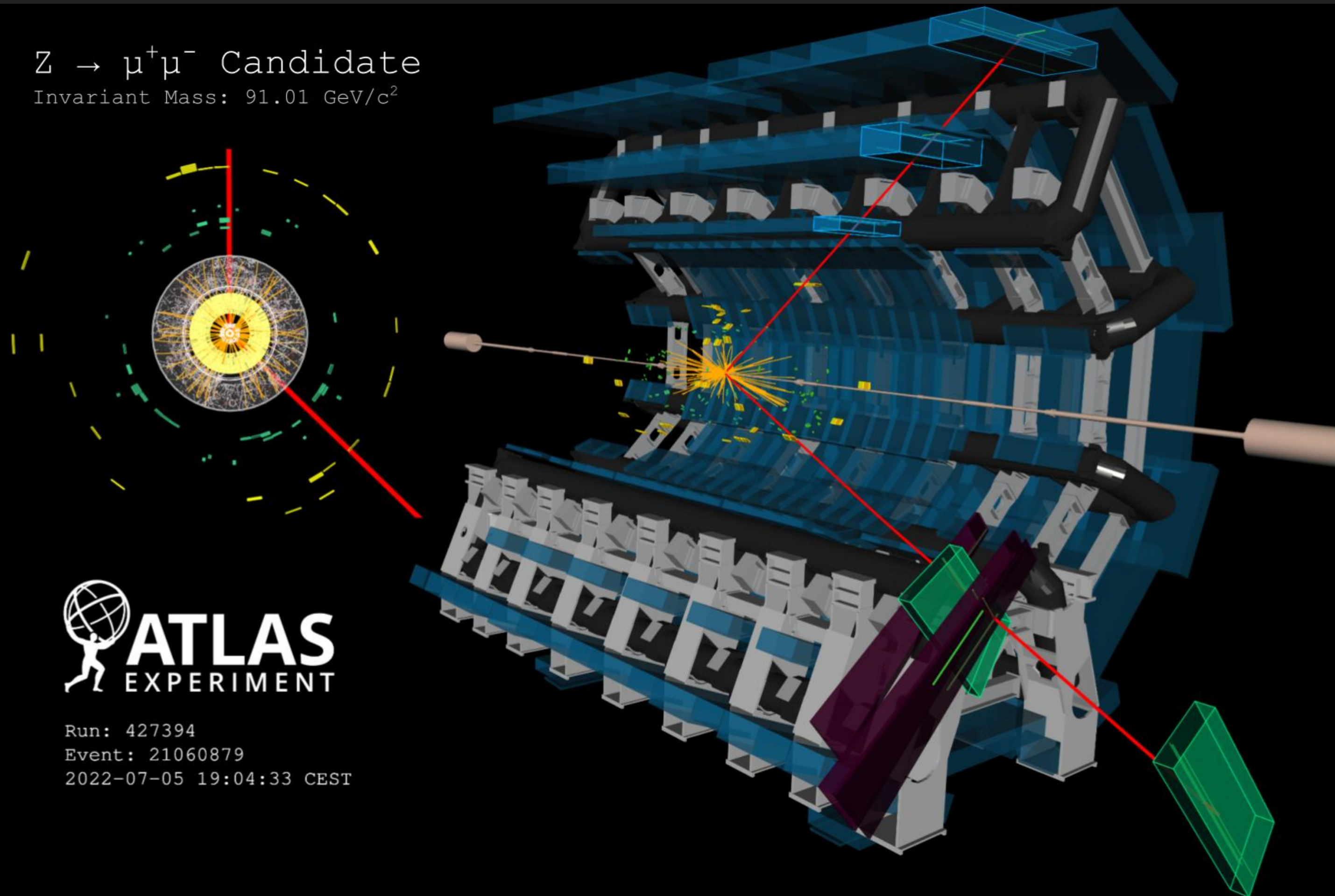
# EVENT DISPLAY EXAMPLES



# EVENT DISPLAY

E

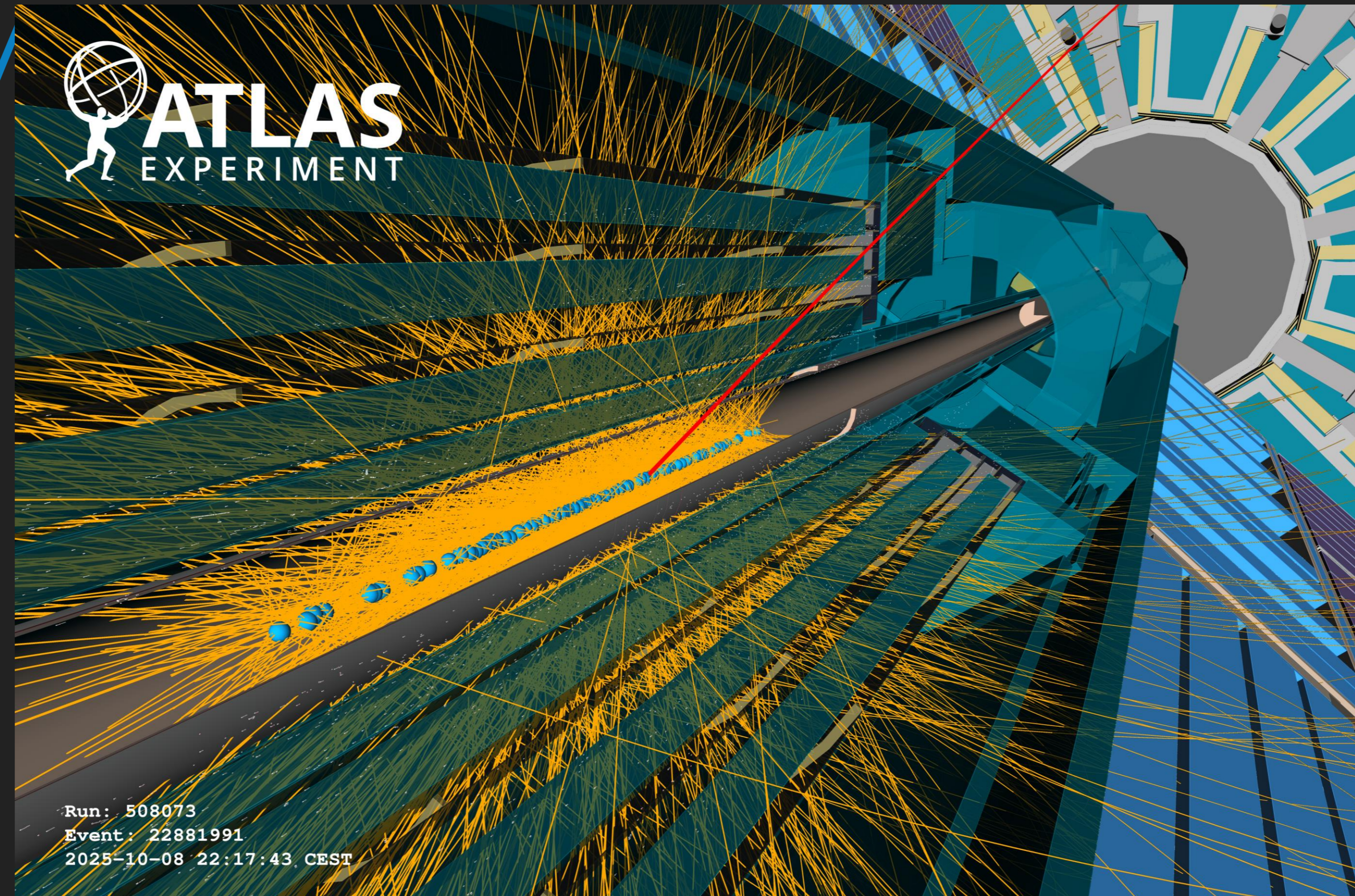
$Z \rightarrow \mu^+\mu^-$  Candidate  
Invariant Mass: 91.01 GeV/c<sup>2</sup>



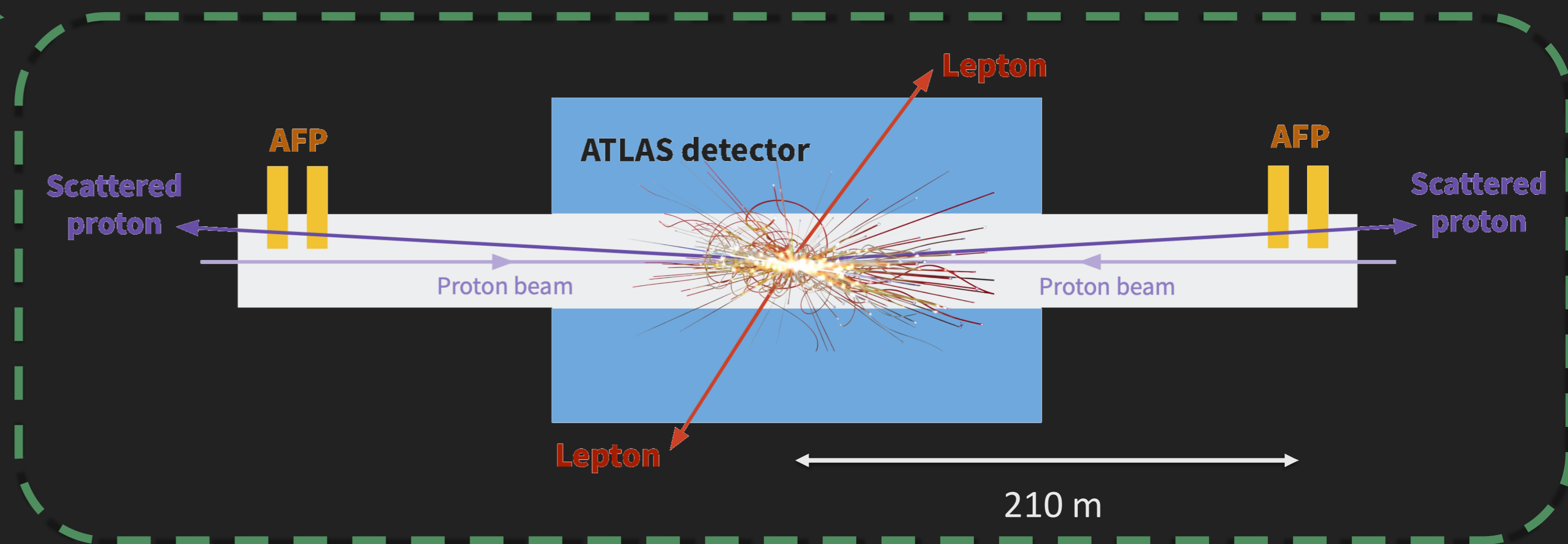
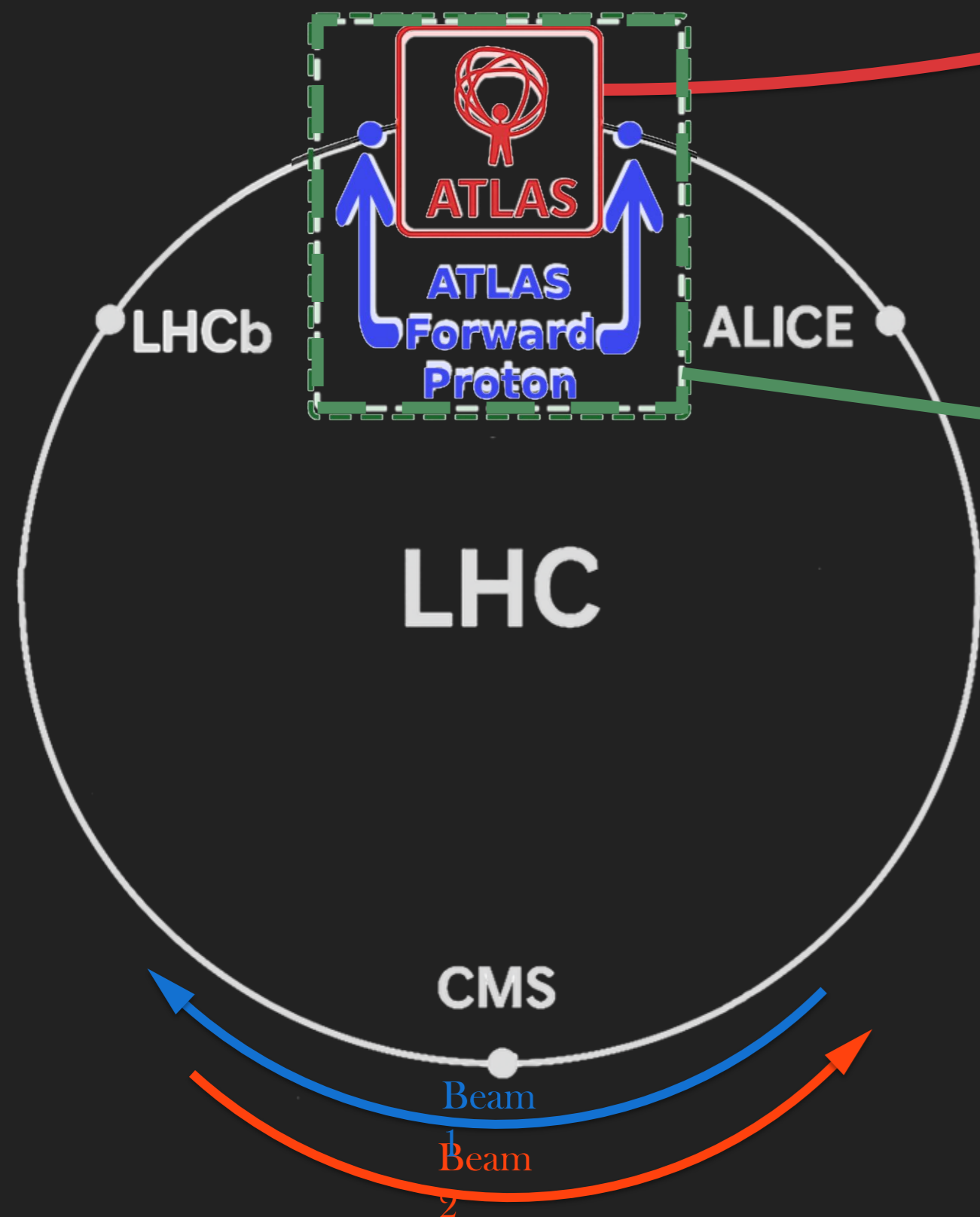
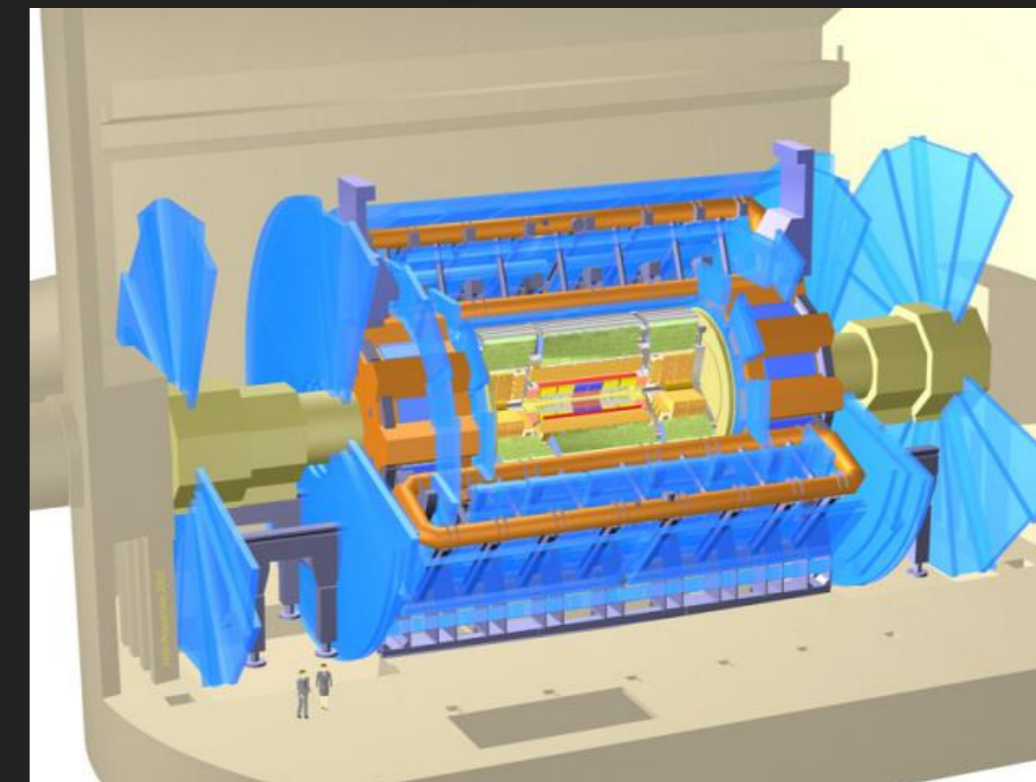
 **ATLAS**  
EXPERIMENT

Run: 427394  
Event: 21060879  
2022-07-05 19:04:33 CEST

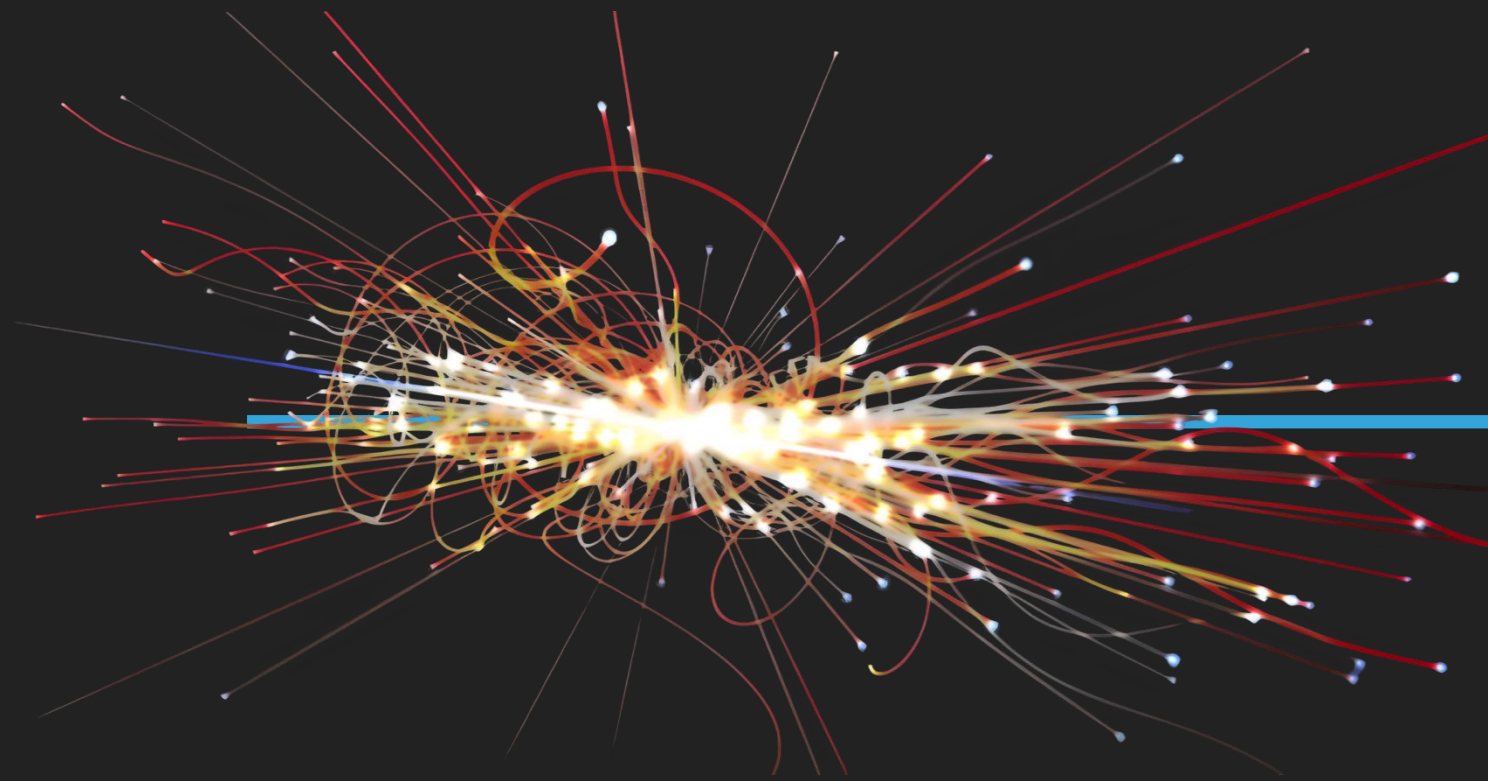
# EVENT DISPLAY EXAM



# ATLAS & AFP

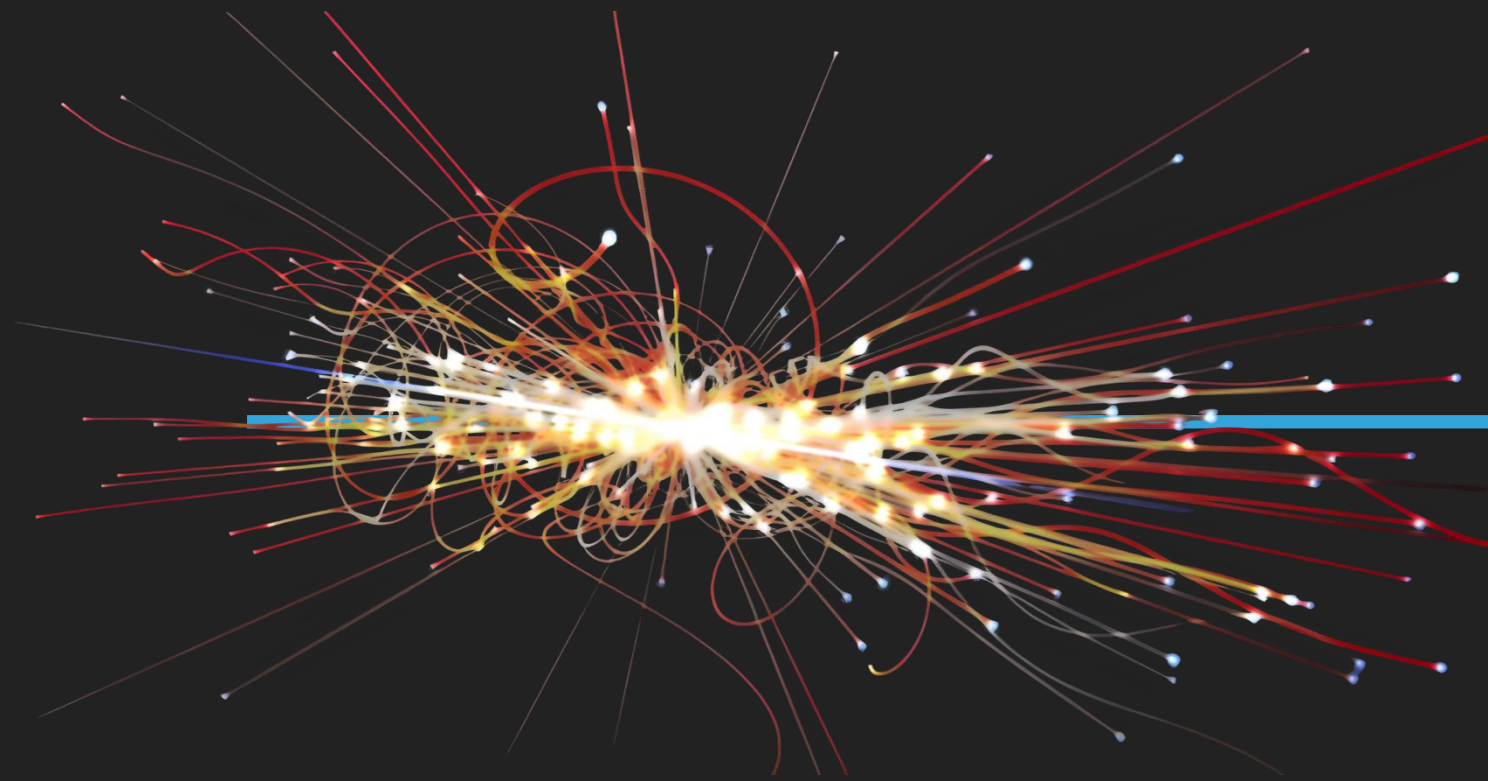


# WHAT IS FORWARD PHYSICS ?



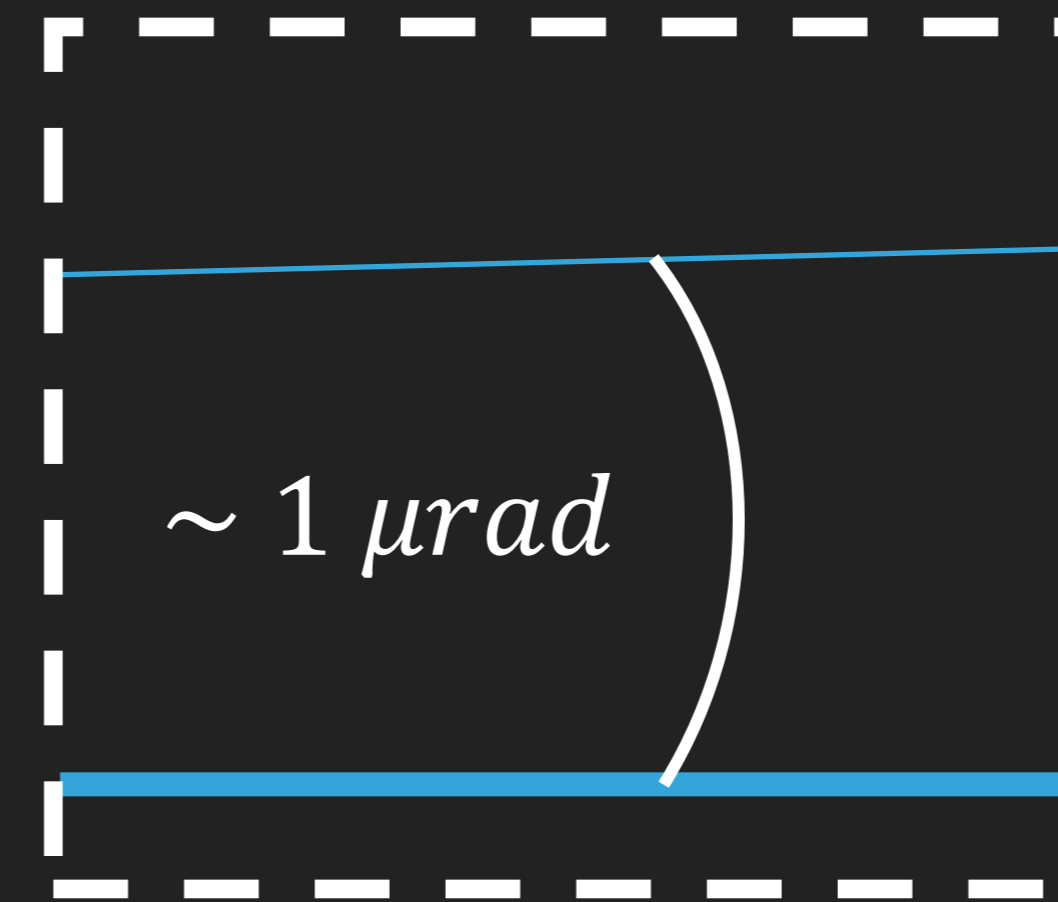
# WHAT IS FORWARD PHYSICS ?

PROTON SCATTERED AT A VERY SMALL ANGLE FROM THE BEAM



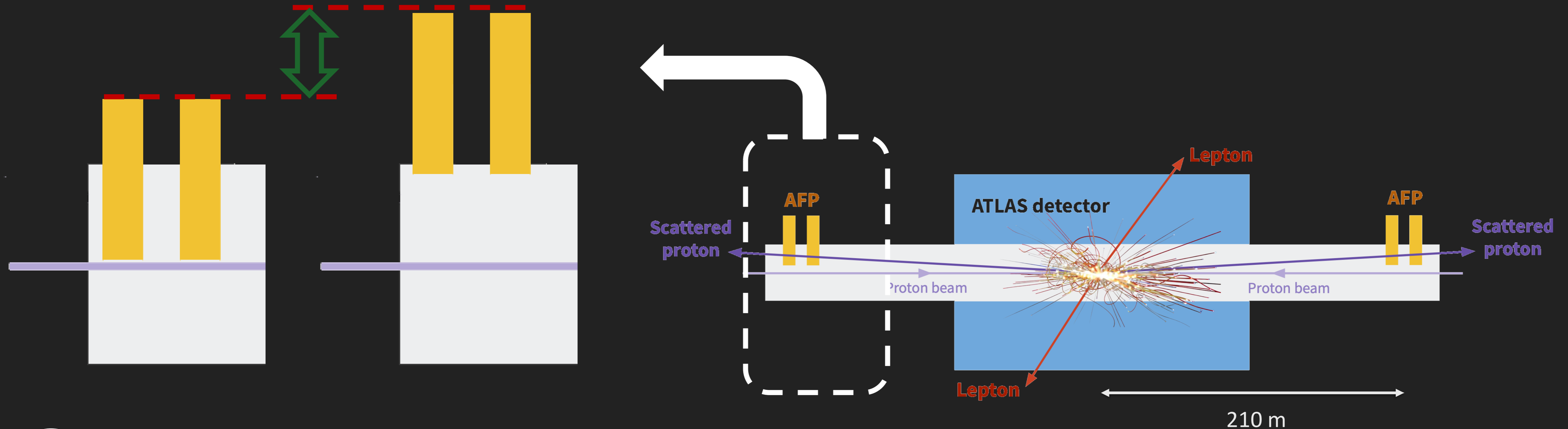
PROTON BEAM

- DIFFRACTIVE
- PHOTON INDUCED

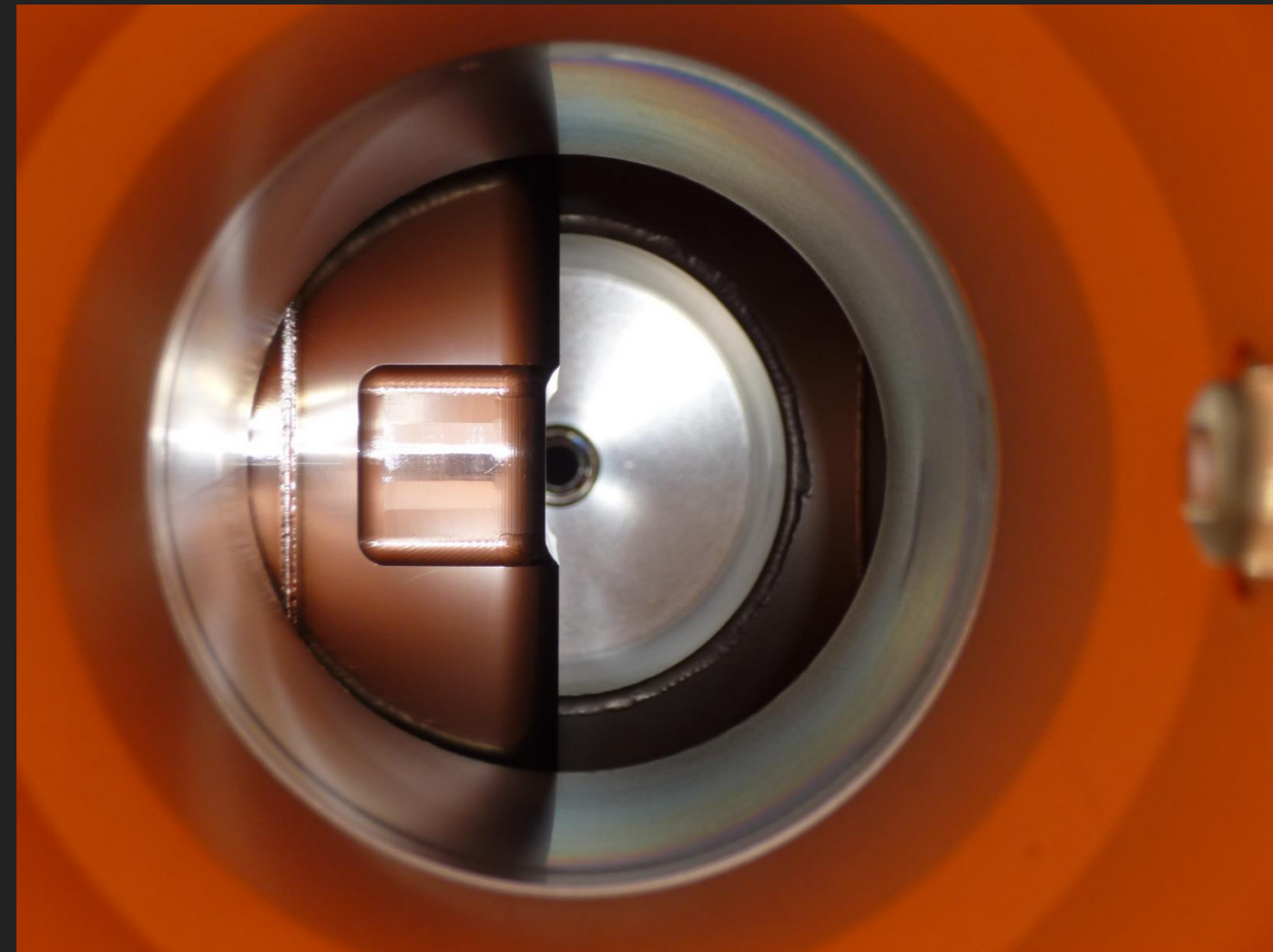


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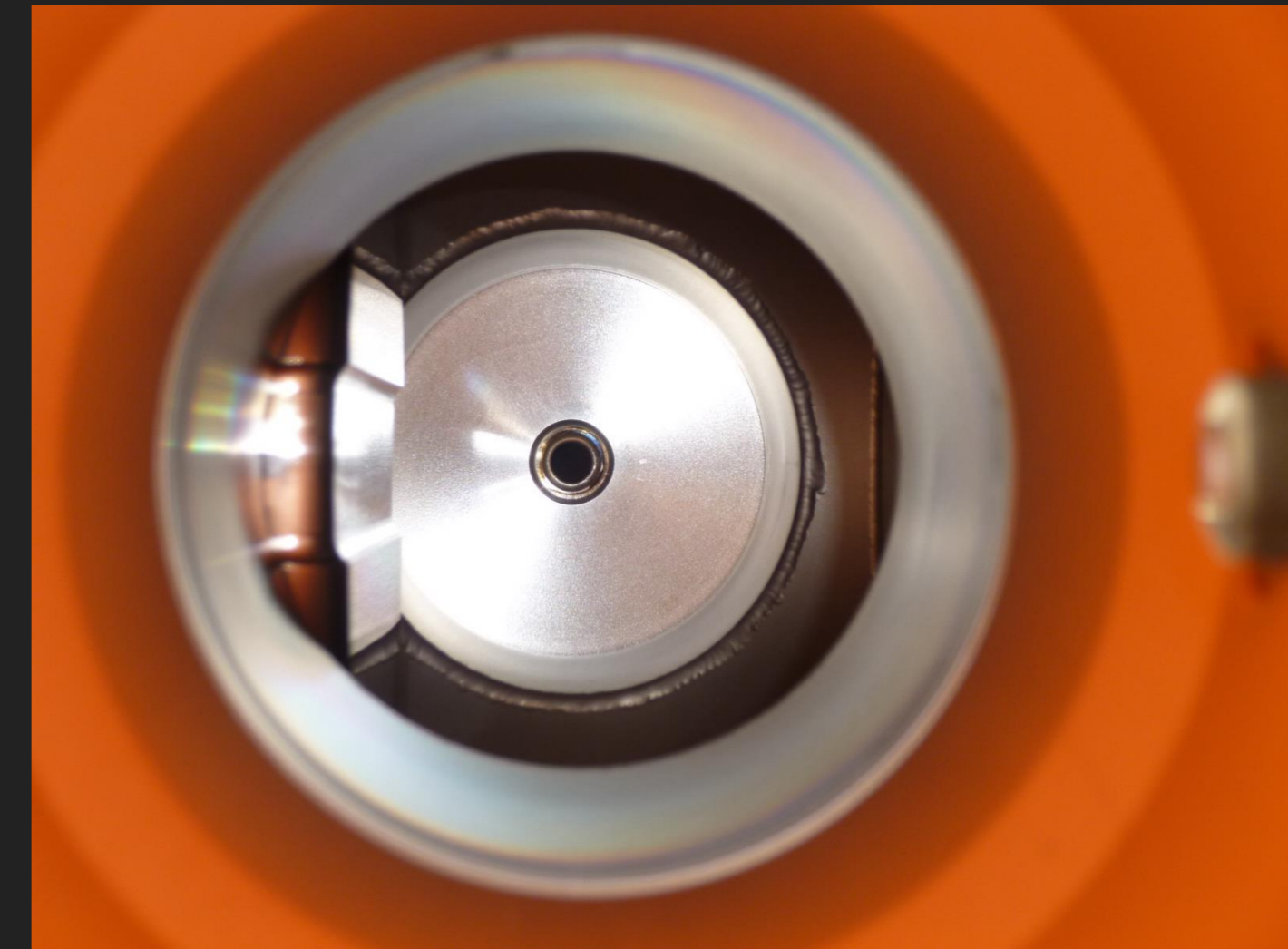
# MOVED IN AND OUT OF THE BEAM PIPE



I  
N



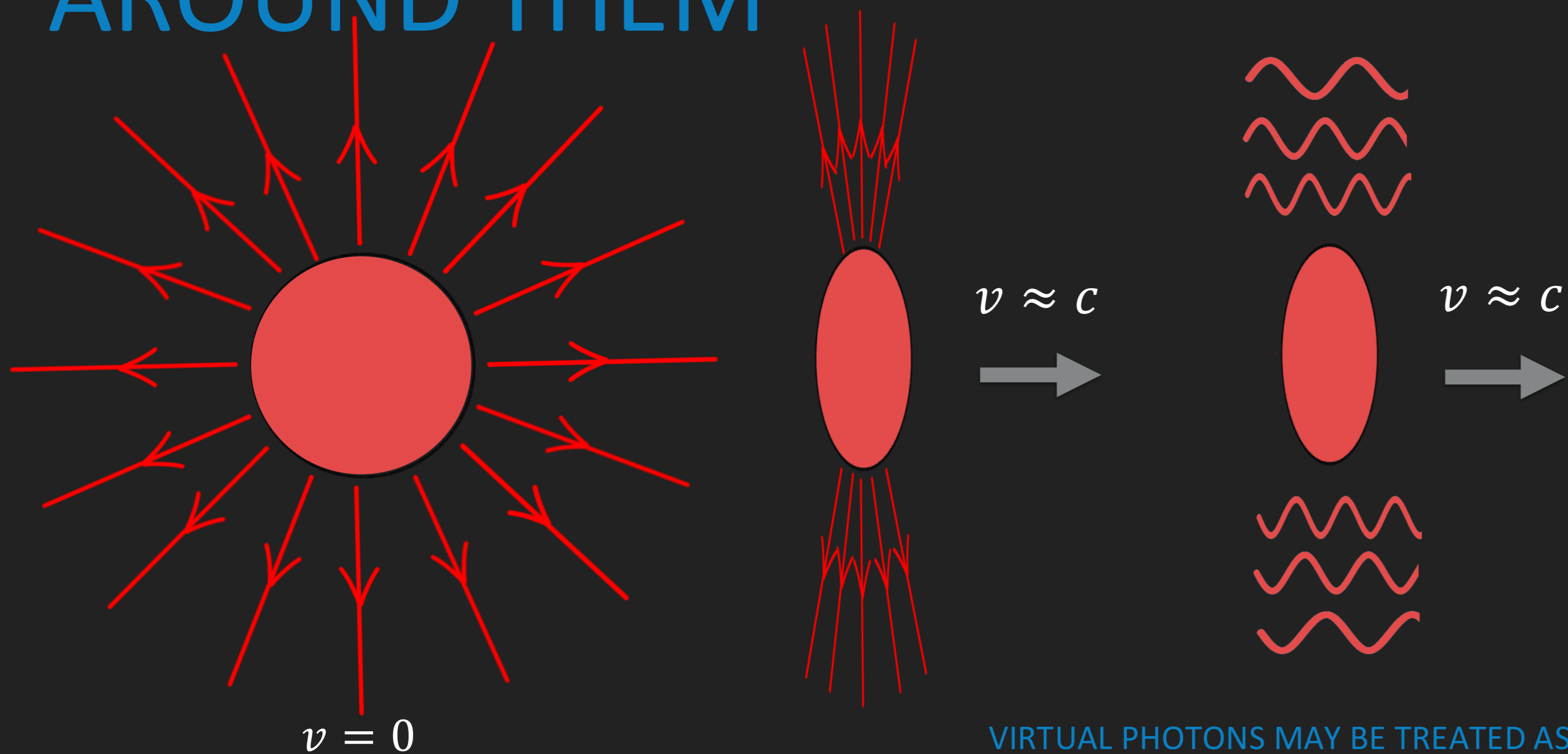
O  
U  
T



# INSIDE THE ROMAN POT

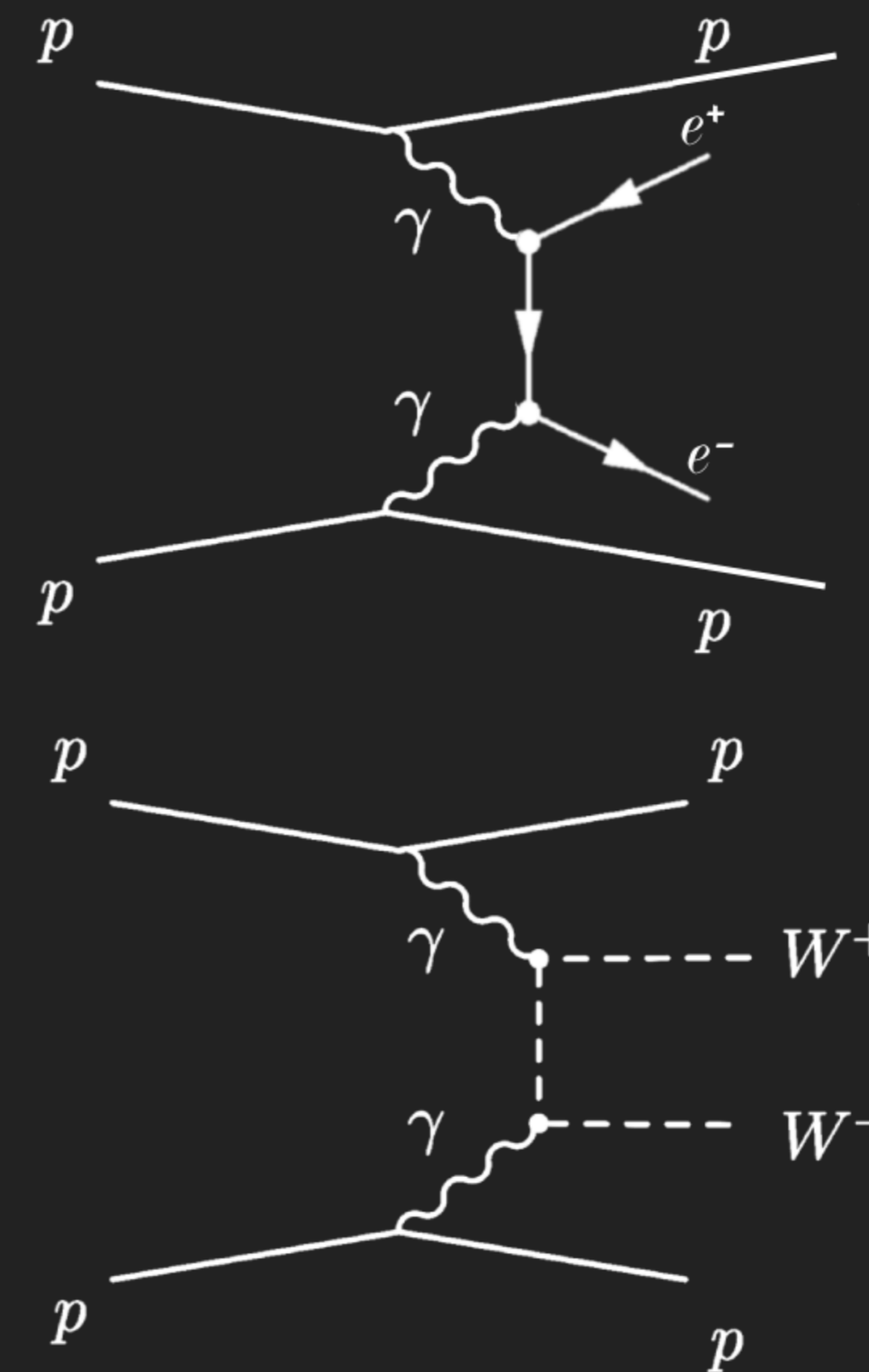


# RELATIVISTIC PROTONS AND ELECTROMAGNETIC FIELD AROUND THEM



VIRTUAL PHOTONS MAY BE TREATED AS REAL

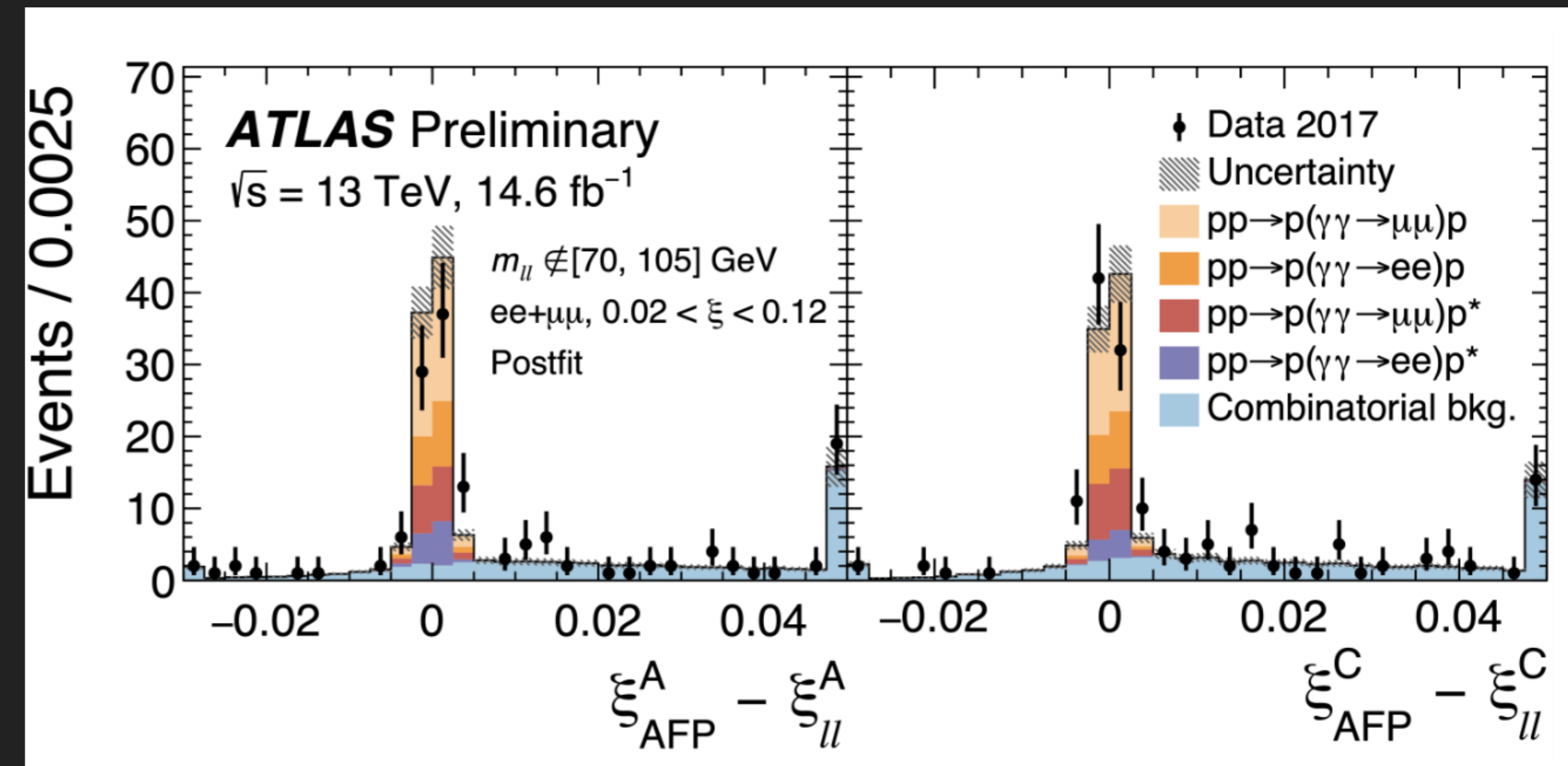
- ▶ Photon virtuality is small
- ▶ Proton remains intact or weakly excited
- ▶ Proton is ultra-relativistic
- ▶ Photon transverse momentum is small
- ▶ Process is dominated by QED interactions



# FRACTIONAL ENERGY LOSS $\xi$

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

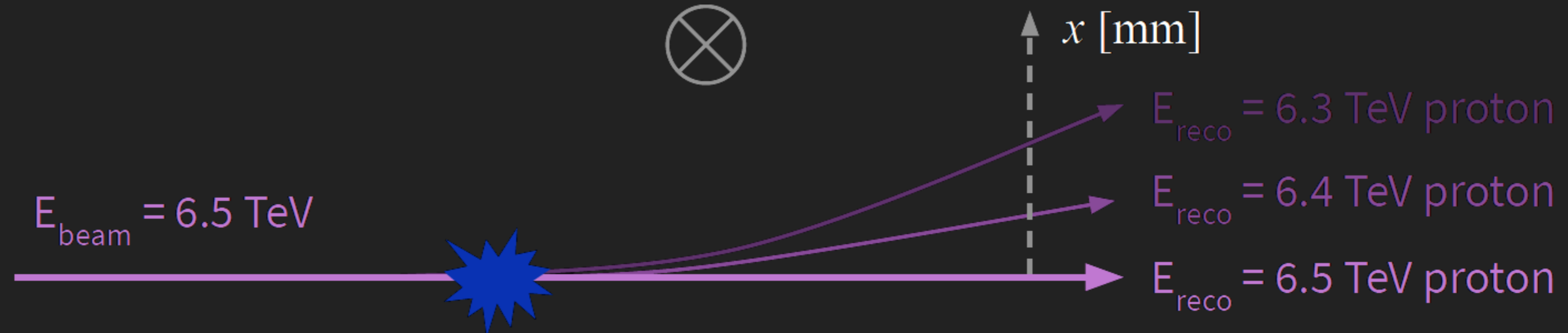
$$\xi_{ll}^{\pm} = \frac{m_{ll}}{\sqrt{s}} e^{\pm y_{ll}}$$



# AFP MEASUREMENT PRINCIPLE

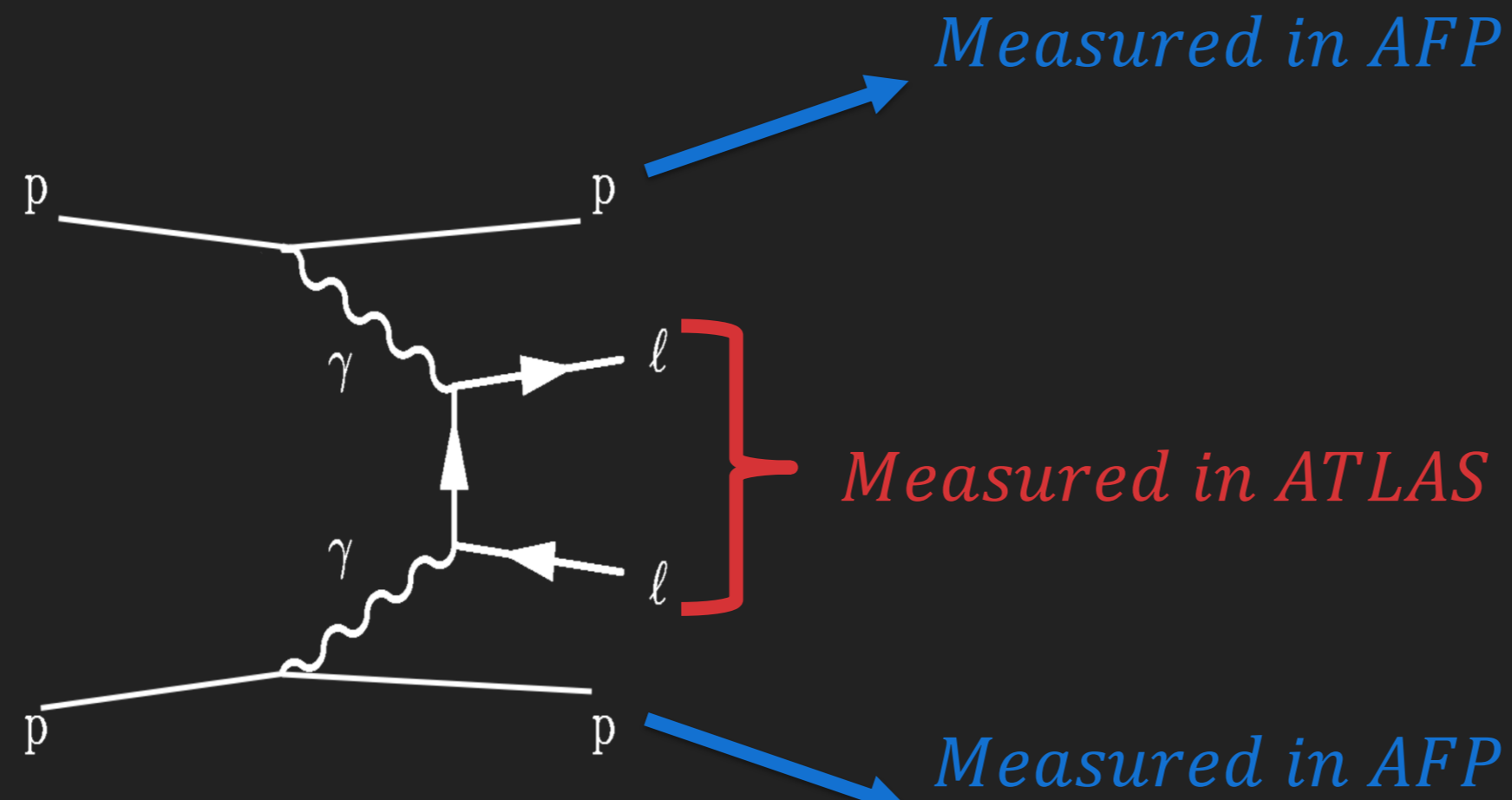
B field from LHC dipoles

1) Measure *spatial coordinate*



$$\xi_{AFP}^{A,C} = 1 - E_{reconstructed} / E_{beam}$$

2) Infer *energy lost by proton*



3) Know *initial photon energy*

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



# MY ANALYSIS

## ▶ GOALS

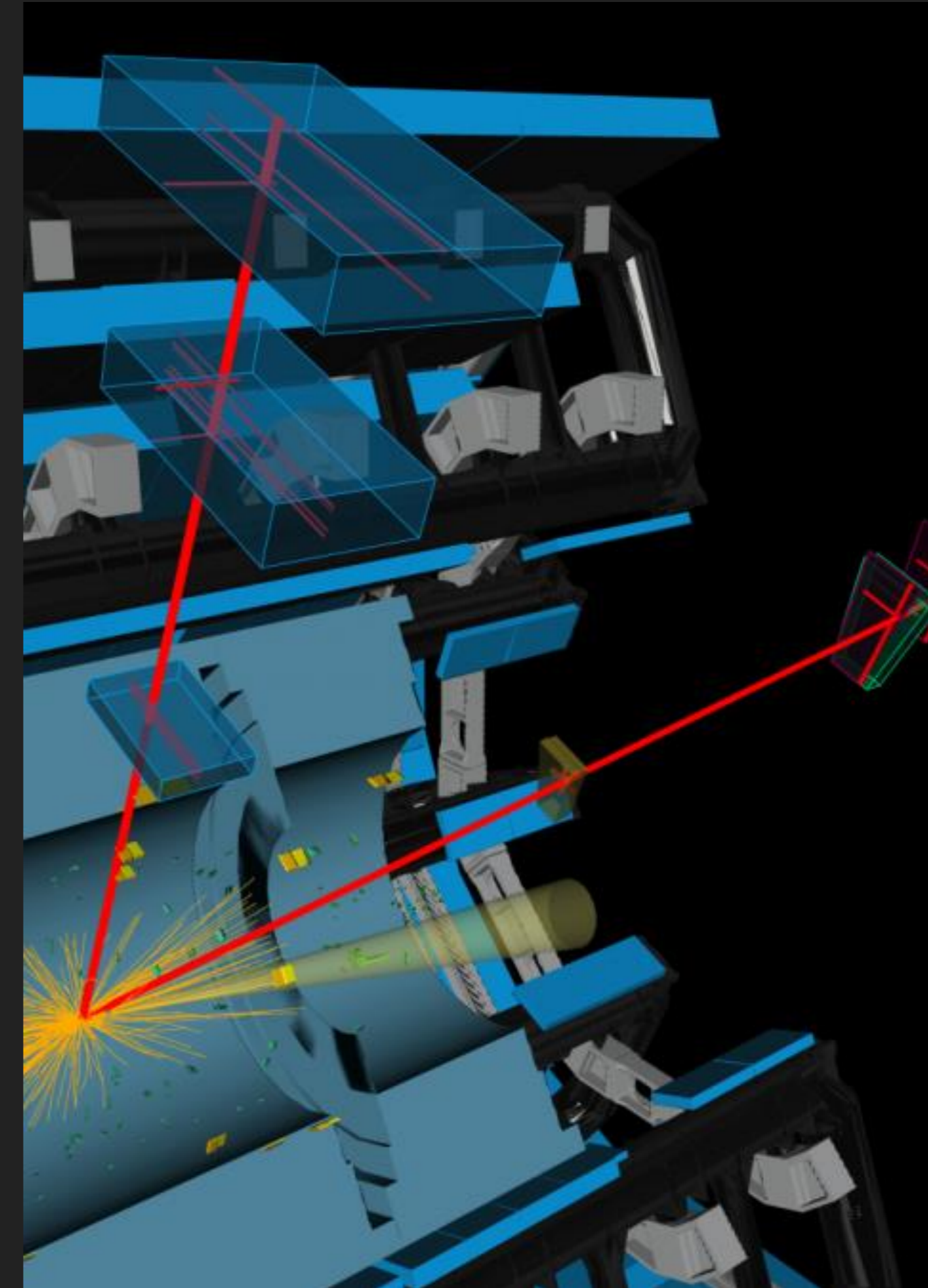
- ▶ Observation and measurement of proton-tagged di-lepton production

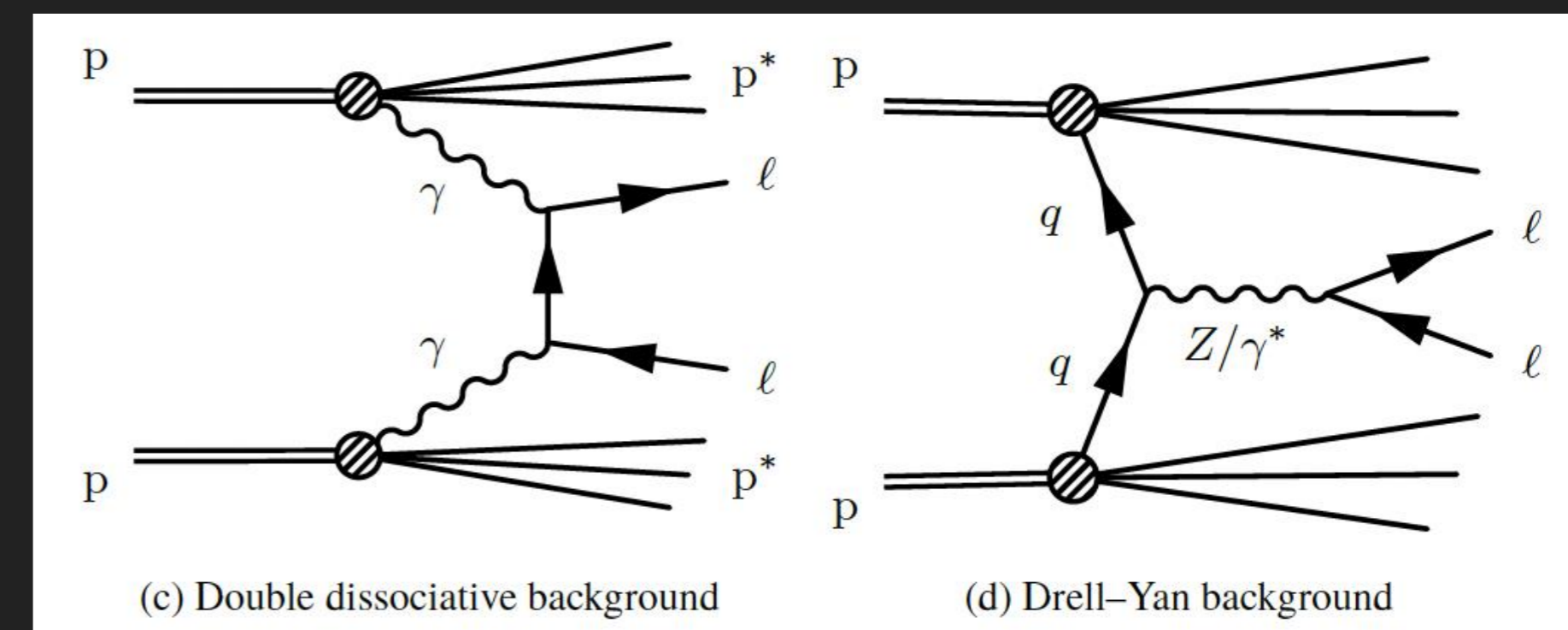
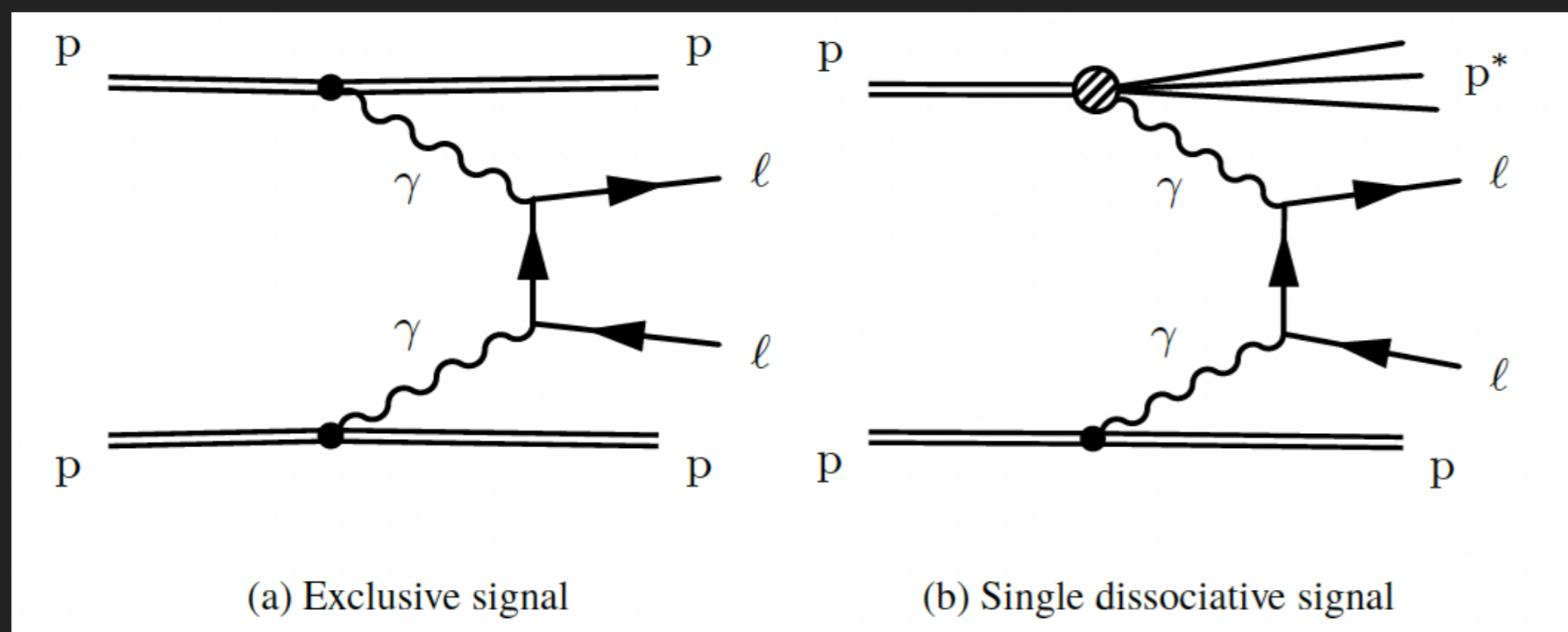
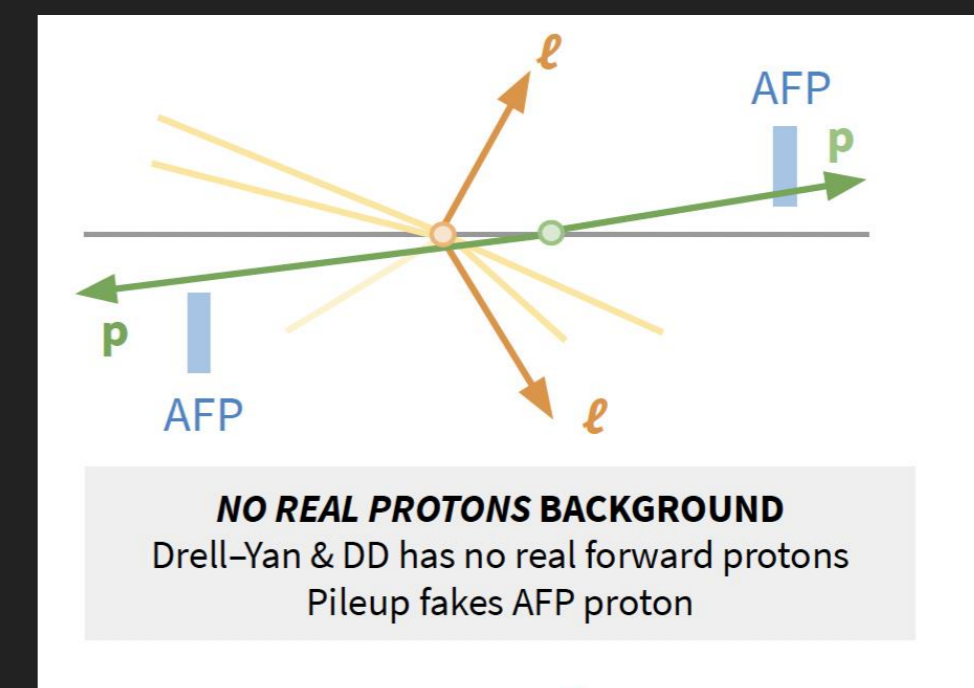
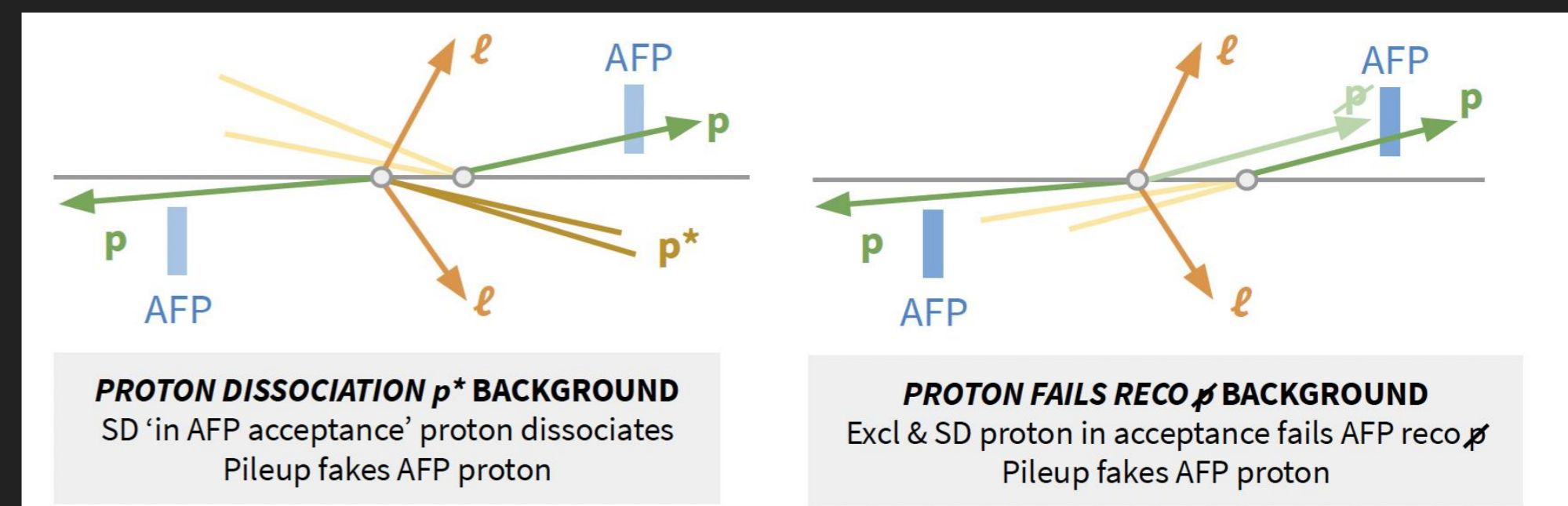
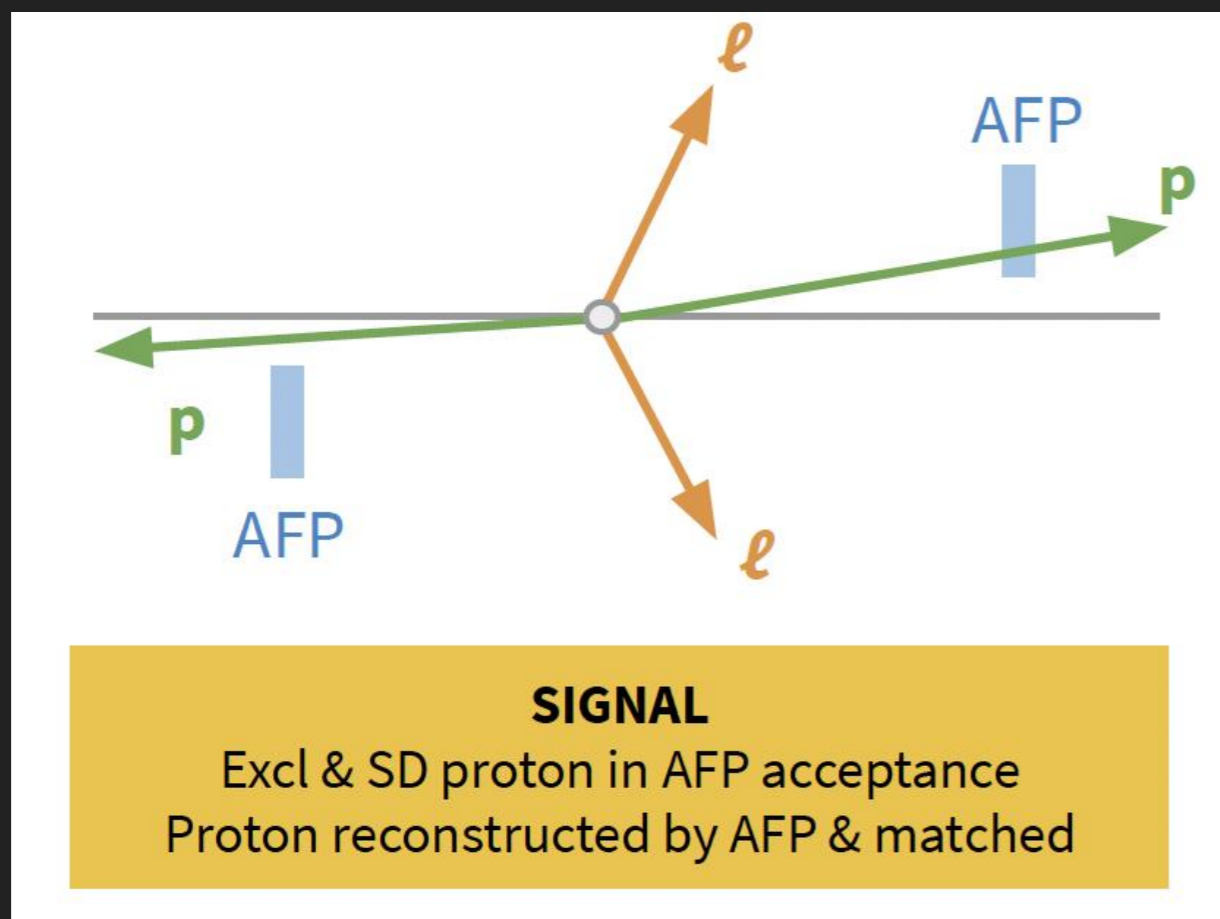
- ▶  $pp \rightarrow p(\gamma\gamma \rightarrow ee)p^{(*)}$

- ▶  $pp \rightarrow p(\gamma\gamma \rightarrow \mu\mu)p^{(*)}$

## ▶ MOTIVATION

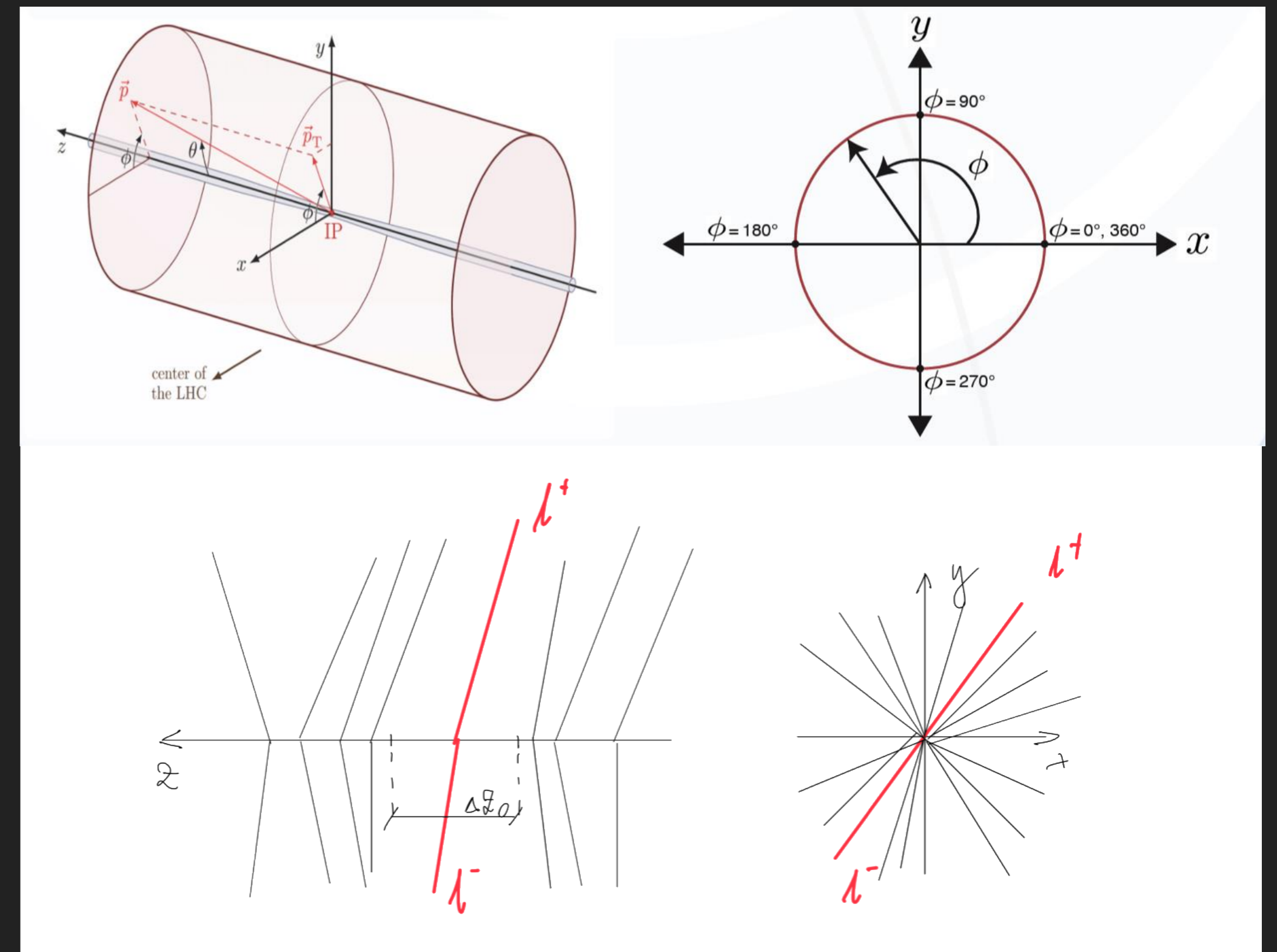
- ▶ Proton dissociation
- ▶ Soft survival effect factor
- ▶ QED testing (Schwinger limit exceeded – electromagnetic fields surrounding protons are sufficiently intense to allow spontaneous lepton pair creation)
- ▶ Photon collision physics: higgs production, supersymmetry, dark matter searches, axion-like particles etc.



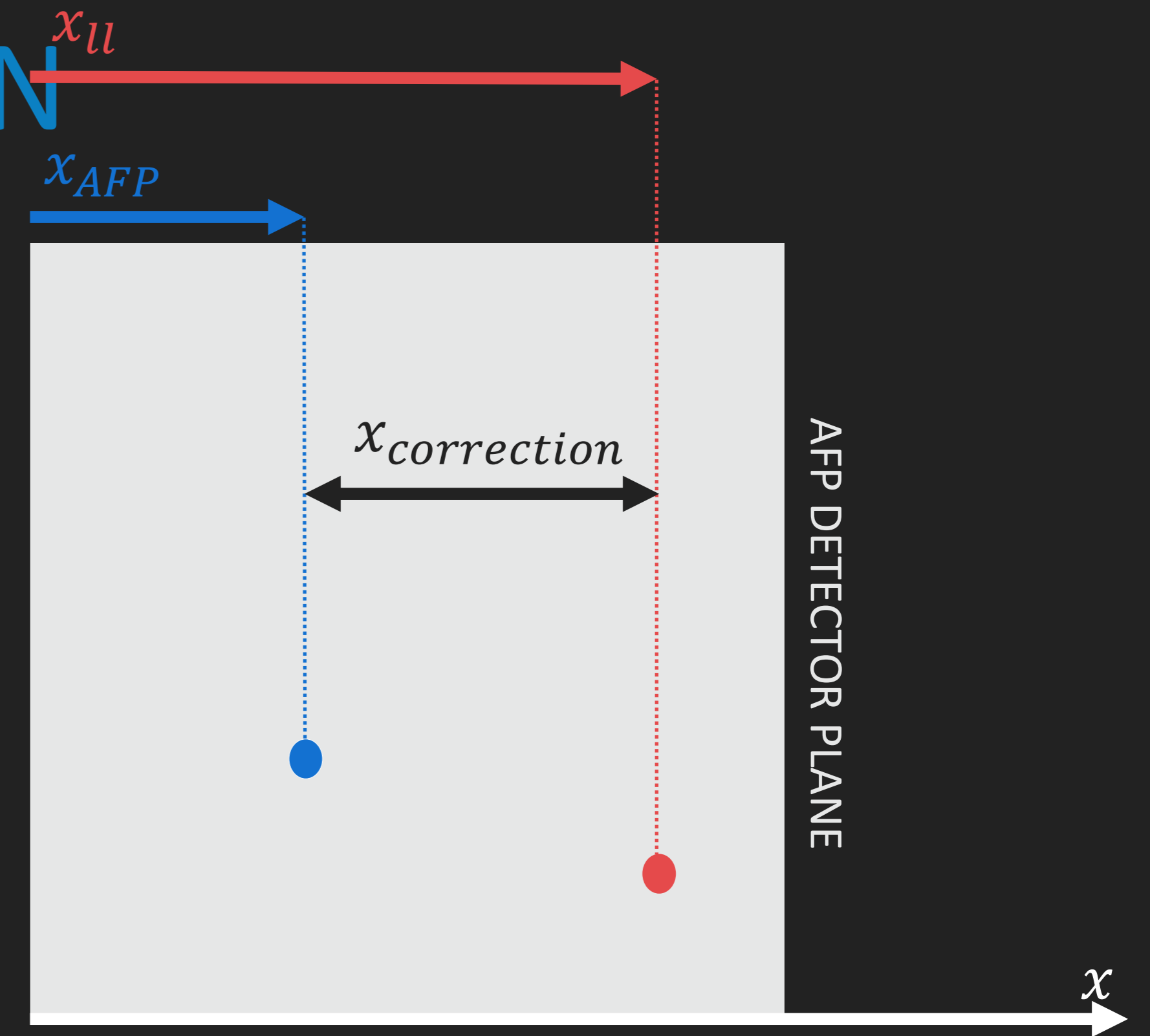
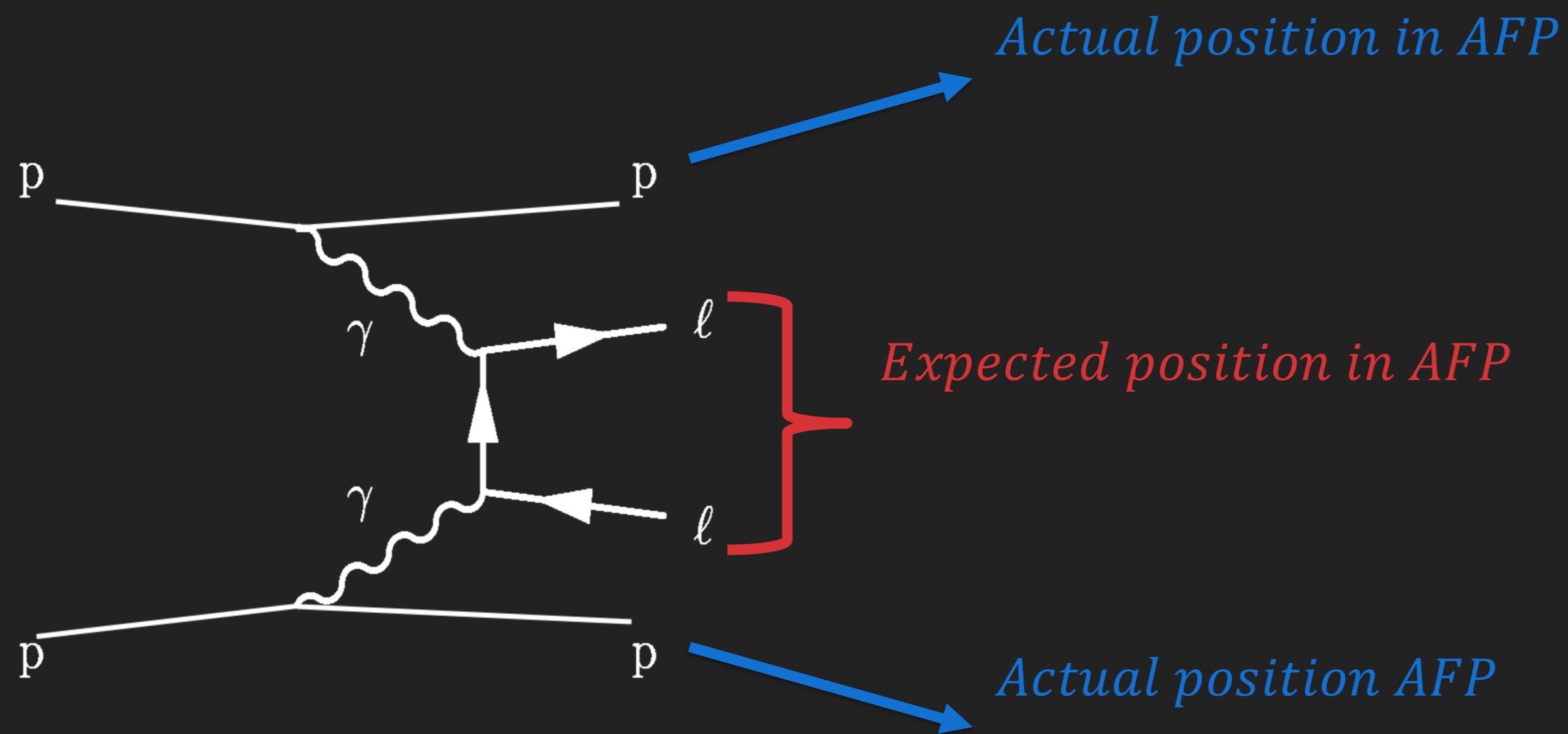


# KINEMATIC CUTS

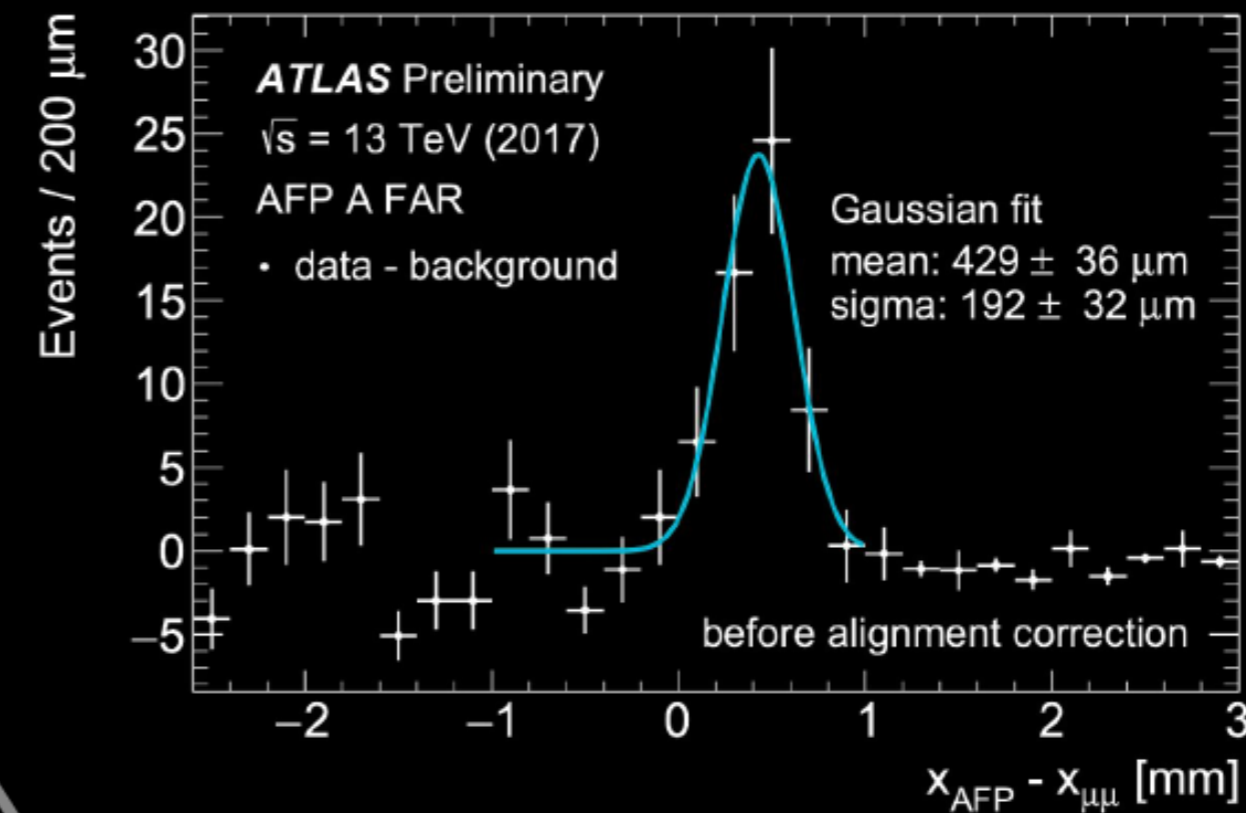
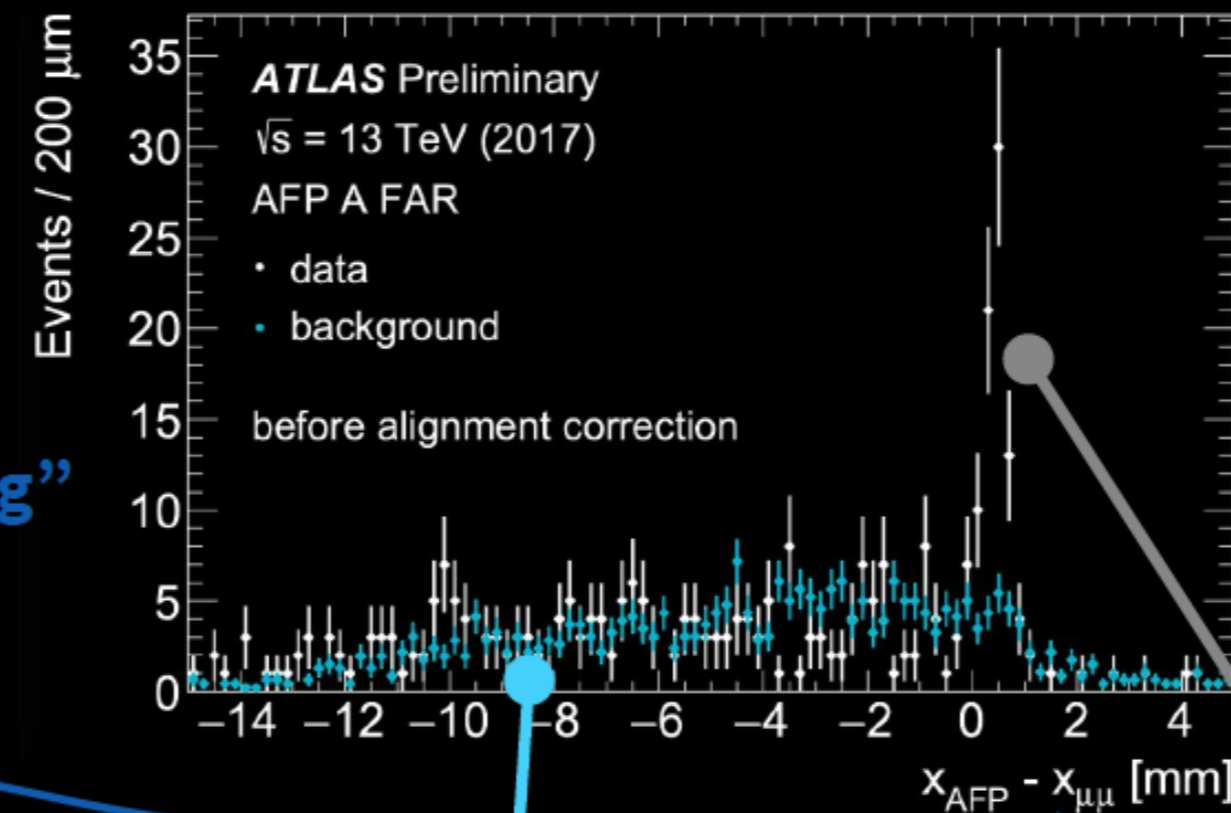
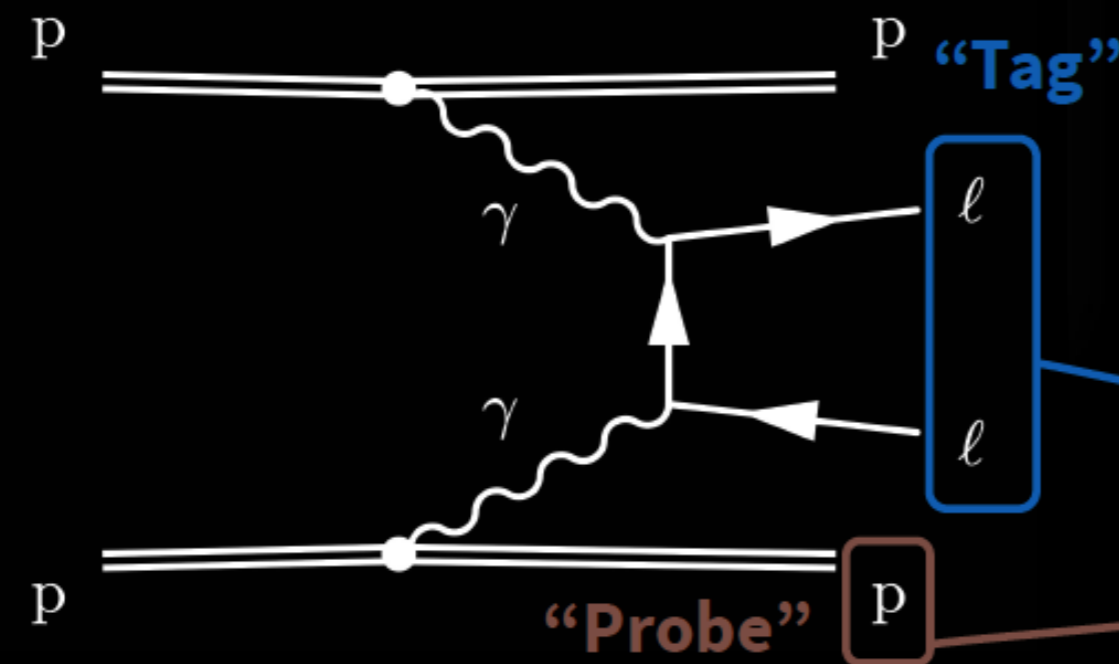
- ▶ Low dilepton  $p_T^{ll} < 5 \text{ GeV}$
- ▶ Low dilepton acoplanarity  $A_\phi^{ll} = 1 - \frac{|\Delta\phi_{ll}|}{\pi} < 0.01$
- ▶ Tracks nearby vertex veto  $N_{tracks}^{0.5 \text{ mm}} = 0$ 
  - ▶  $z_0^{ll} = \frac{z_0^{l1} + z_0^{l2}}{2}$
  - ▶  $\Delta R(track, l) > 0.01$  – overlap removal
  - ▶ Z veto – excluding  $m_{ll} \in [70, 105] \text{ GeV}$
  - ▶ Fractional energy loss  $\xi_{ll} > 0.03$



# PHYSICS GUIDED MISALIGNMENT CORRECTION



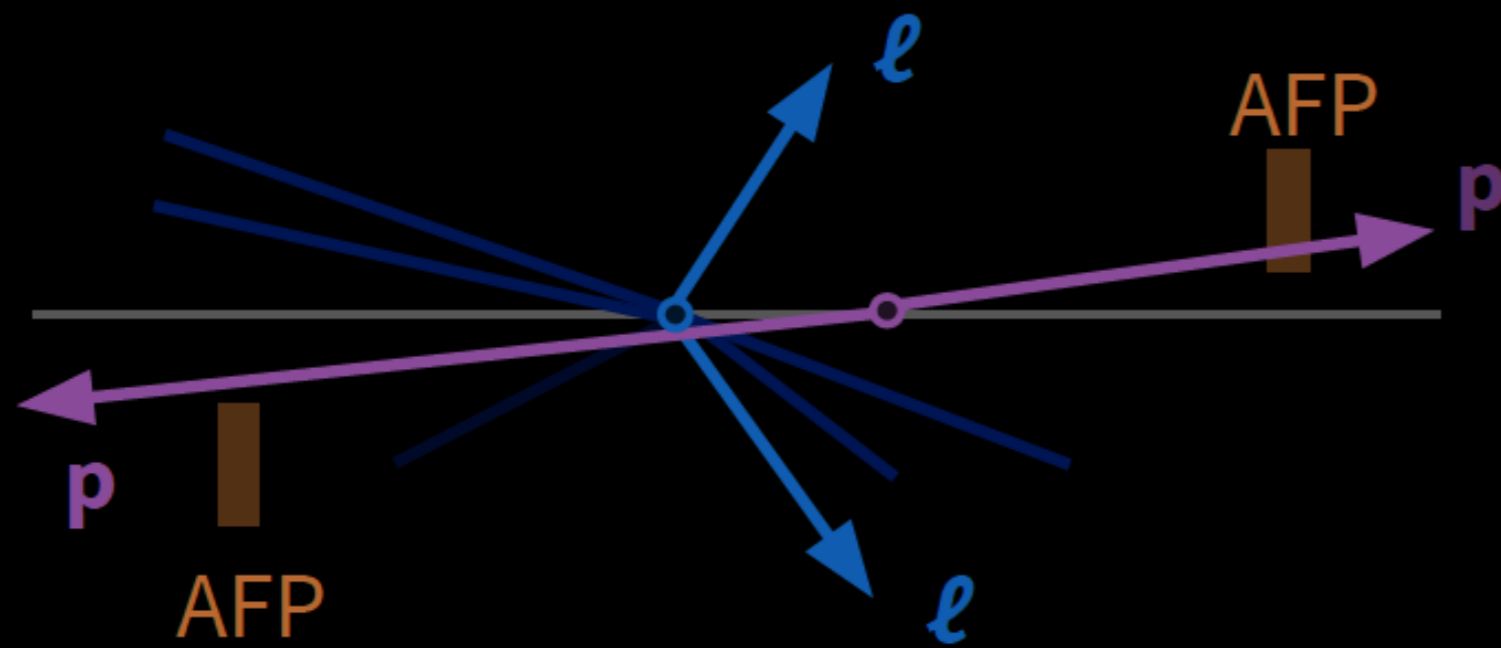
Use  $(\gamma\gamma \rightarrow \mu\mu)+p$  signal as standard candle



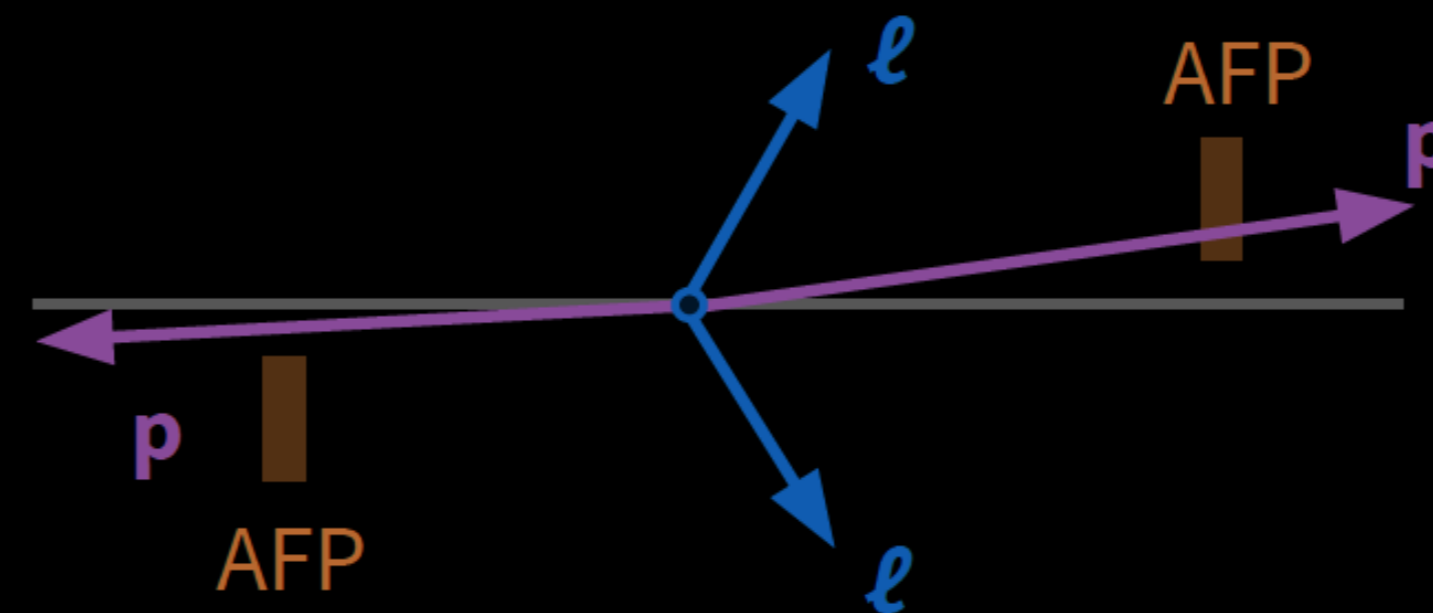
$$\xi_{\ell\ell}^{\pm} = (m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}}$$

Expected proton energy loss constrained by dimuon system

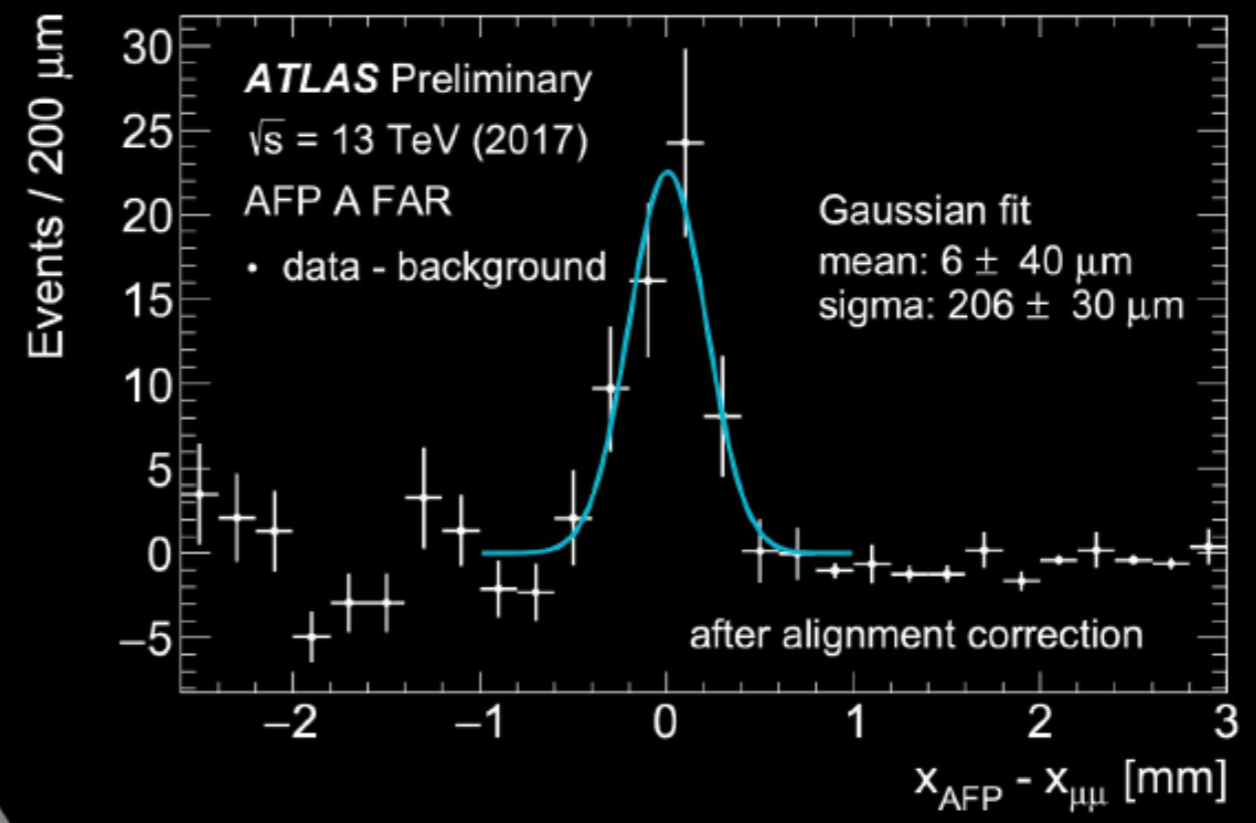
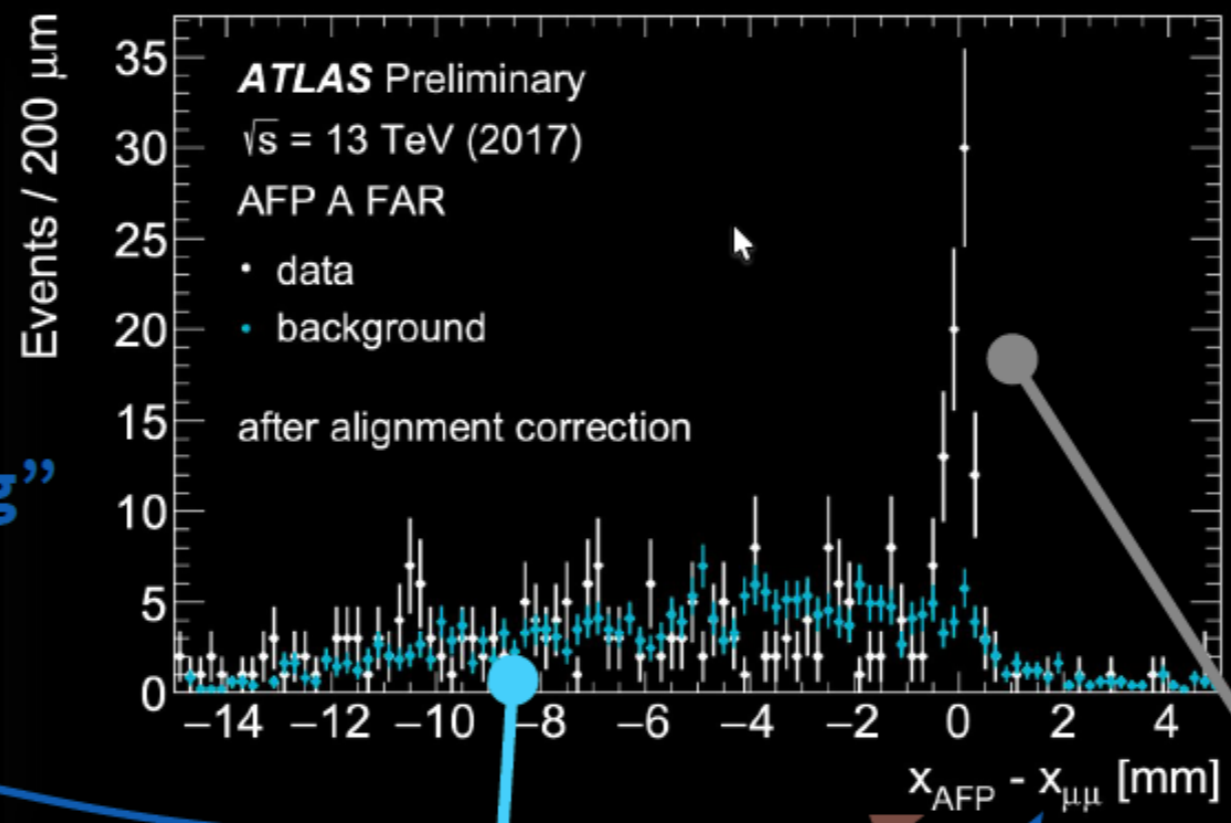
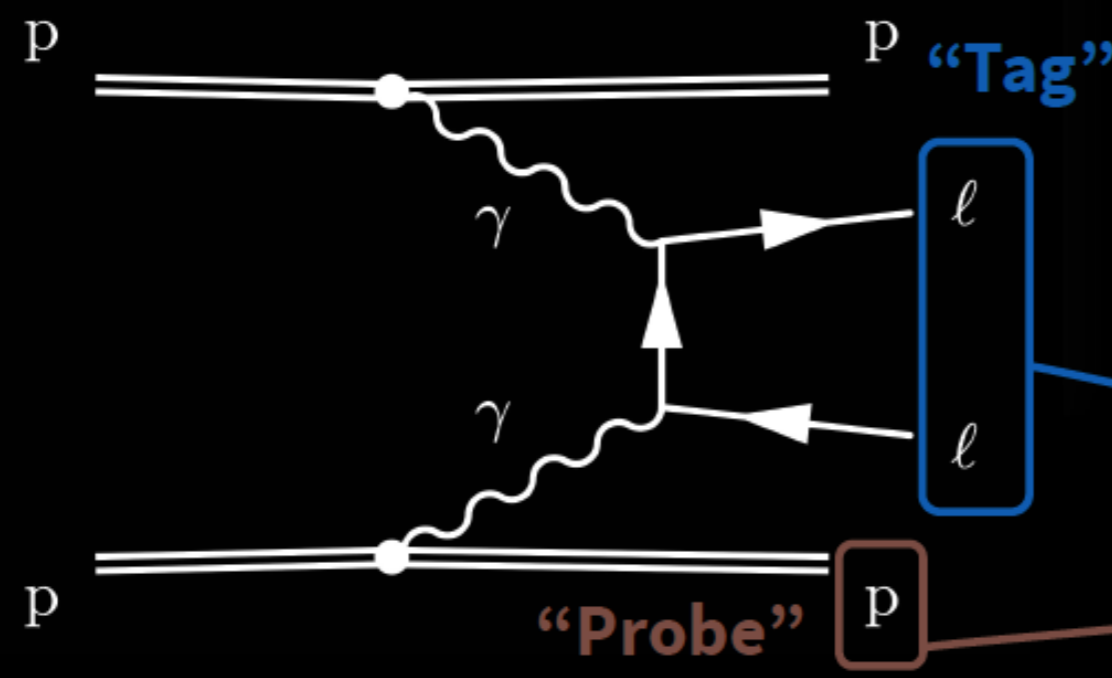
Background: no correlation (pileup)



Signal: if  $x_{AFP} = x_{\ell\ell} \Rightarrow$  aligned & calibrated



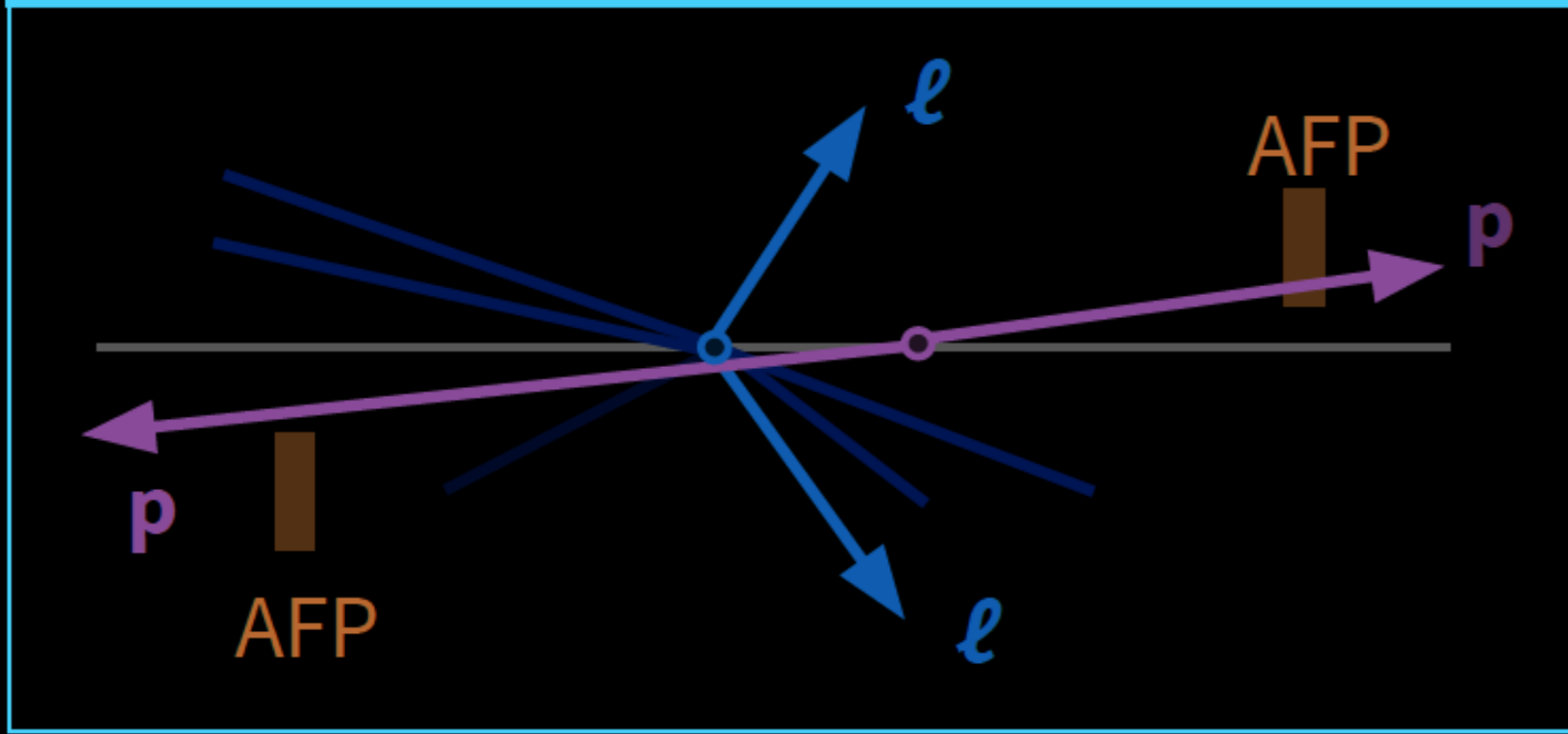
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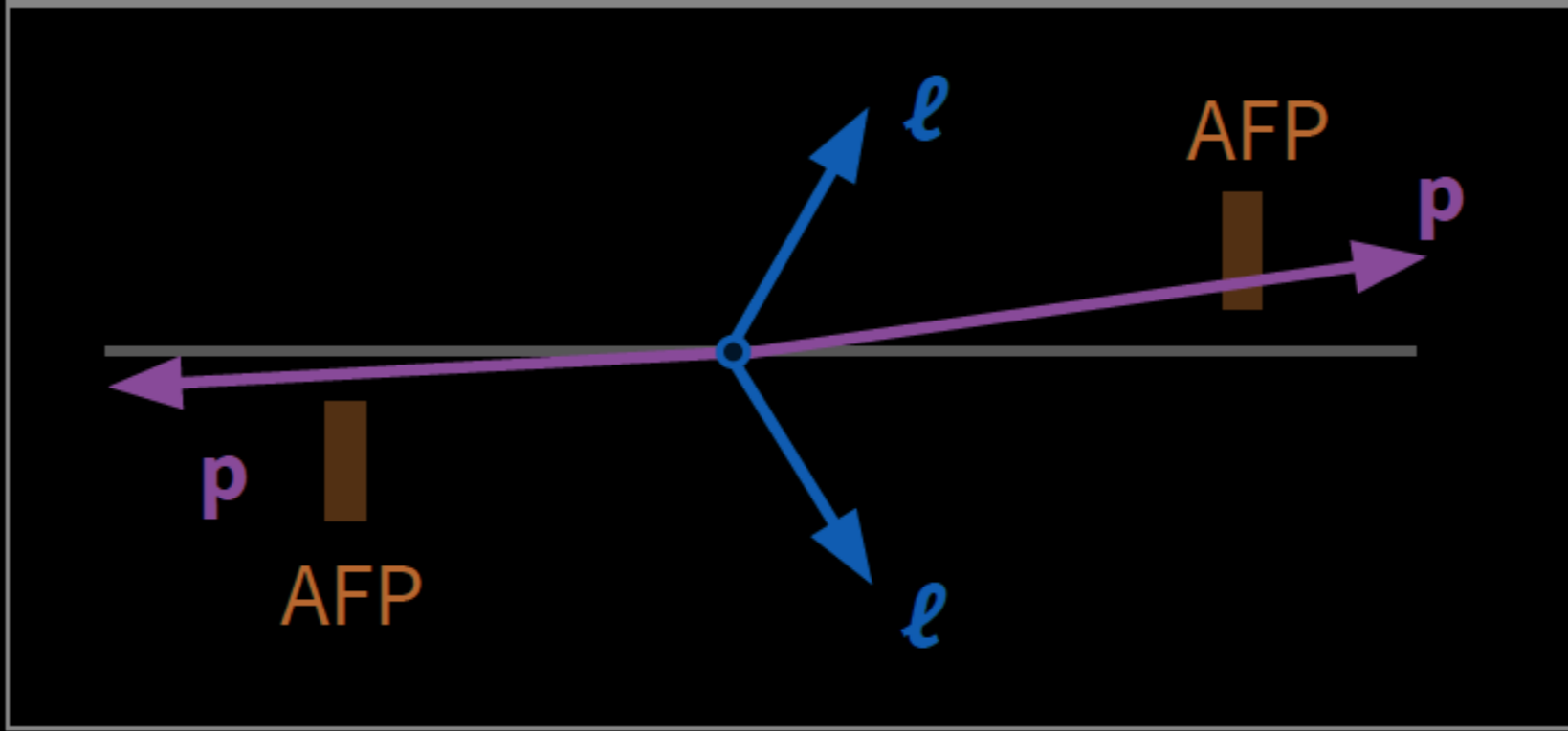
$$\xi_{\ell\ell}^{\pm} = (m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}}$$

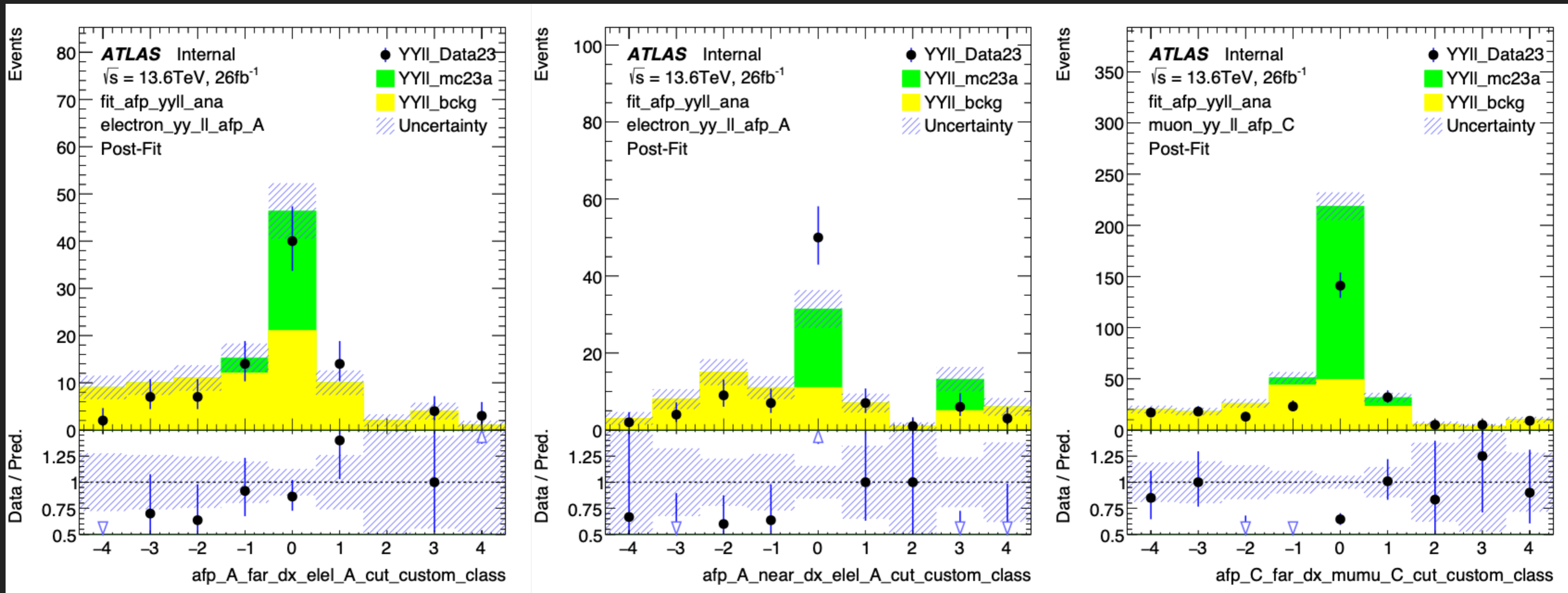
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Background: no correlation (pileup)



Signal: if  $x_{AFP} = x_{\ell\ell} \Rightarrow$  aligned & calibrated





THANKS FOR ATTENTION

Q&A