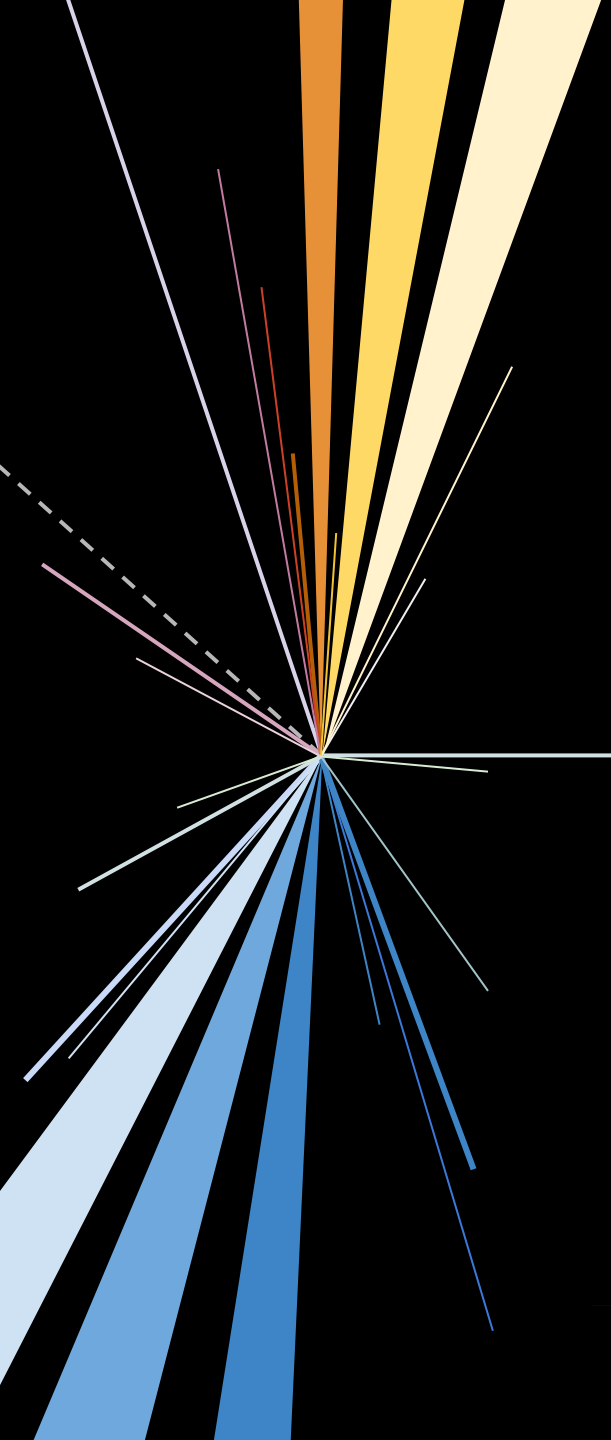


# The Alignment of the ATLAS Forward Proton Detectors

**40th International Conference on High Energy Physics**
*Session: Operation, Performance and Upgrade of Present Detectors*
30 July 2020

**Jesse Liu** (University of Chicago)
On behalf of *ATLAS Forward Detectors*

ATLAS EXPERIMENT

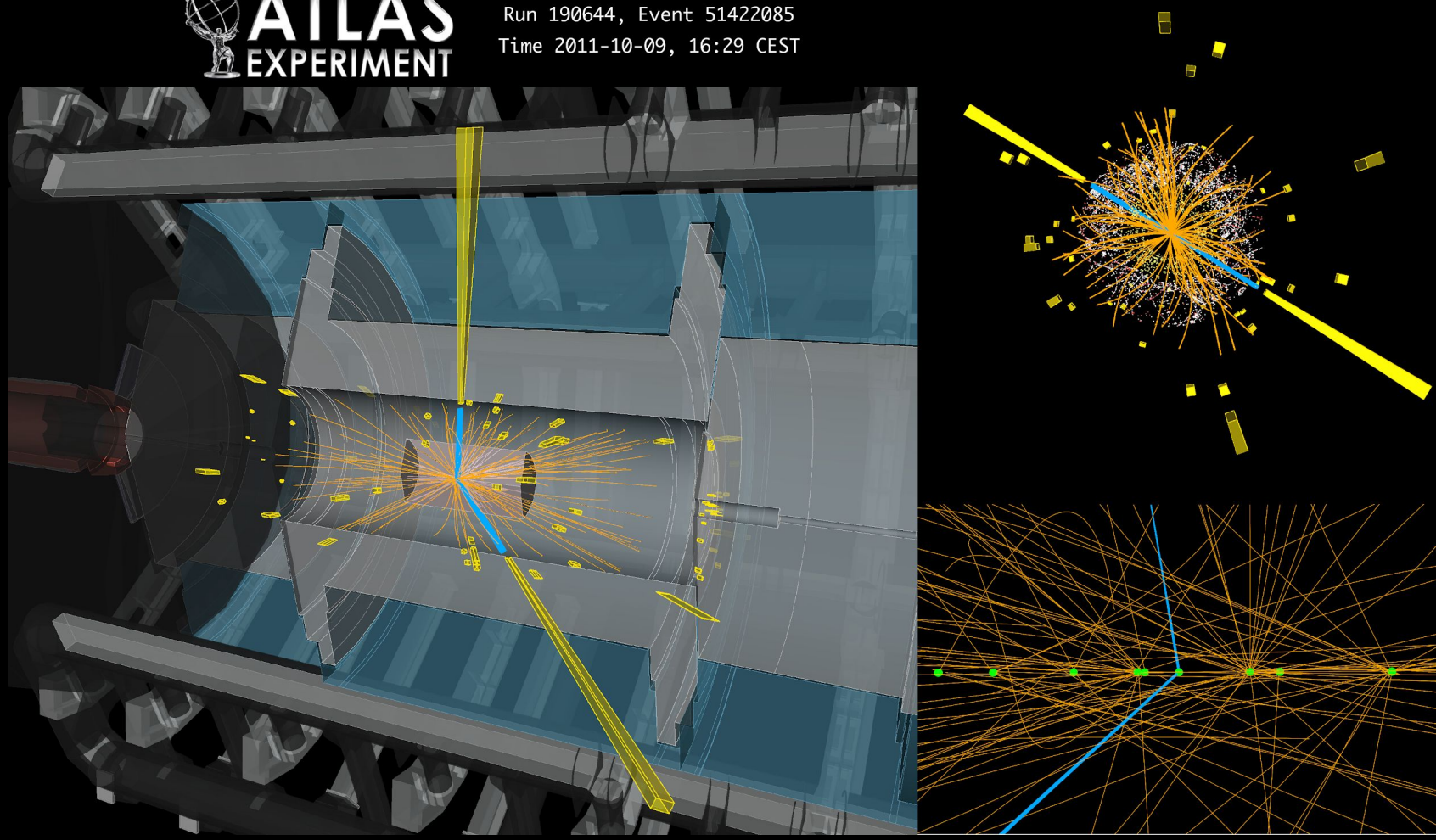
THE UNIVERSITY OF CHICAGO

# ATLAS Forward Proton

*It's not every day we install & operate a new class of LHC instrument*

**Today's talk: detector performance**

Overview of AFP spectrometer
Reconstruction of forward proton
Detector alignment methods
Data quality & efficiencies




γγ → ee @ 7 TeV event display [1506.07098]

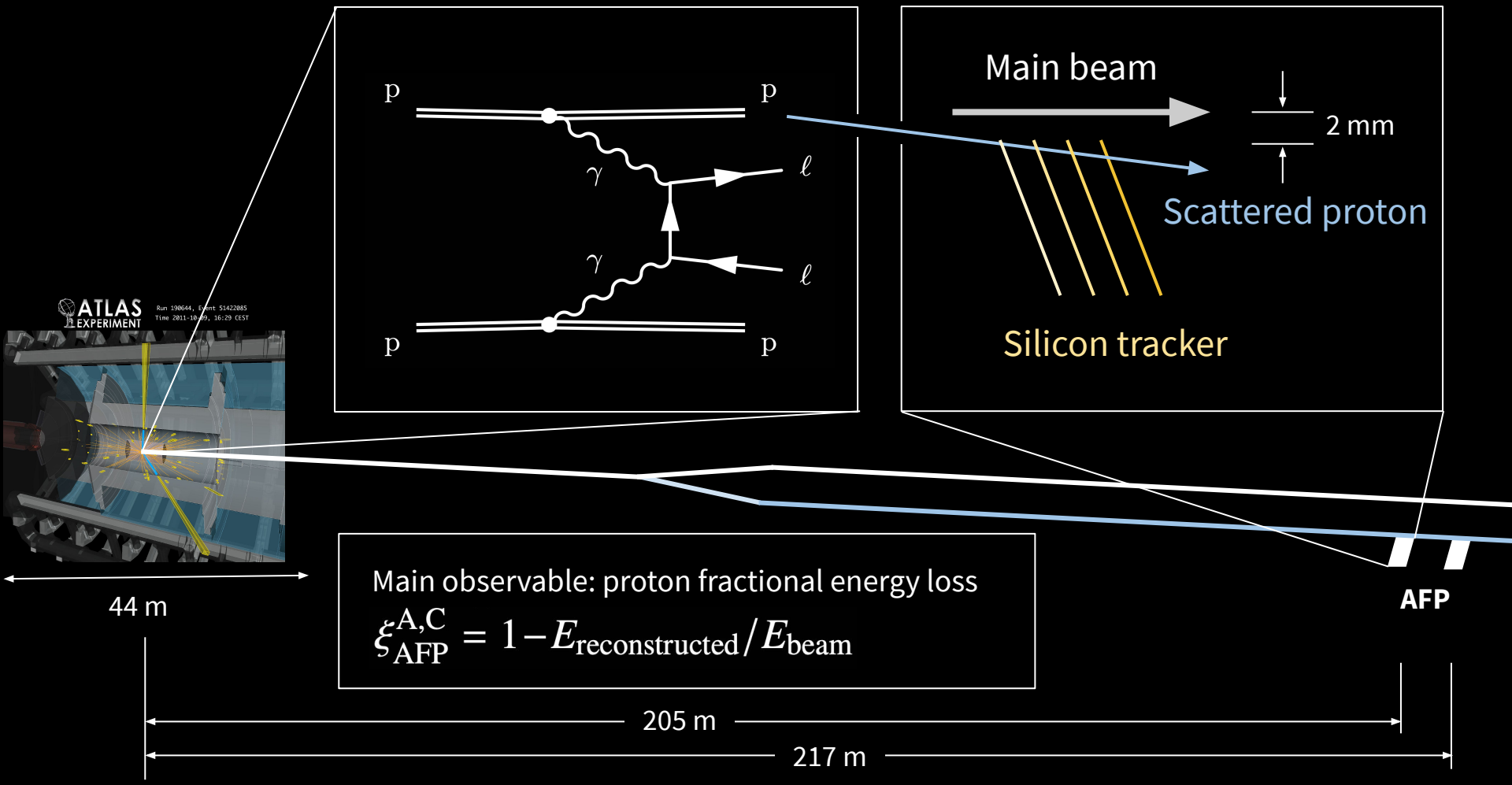
$$pp \to p + (\gamma\gamma \to ee/\mu\mu) + p$$

Without AFP can only see this

New: directly observe intact protons with AFP

# ATLAS Forward Proton

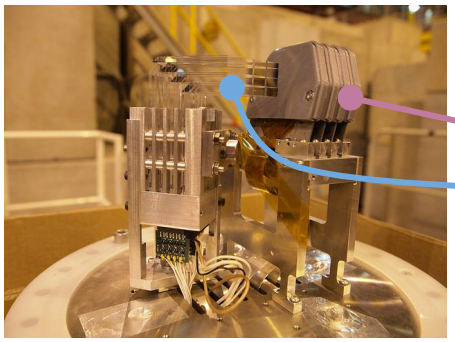
*Both arms installed in 2017 for standard high-luminosity LHC data-taking*
*New analysis object opening exciting program of diffractive & photon collision physics*

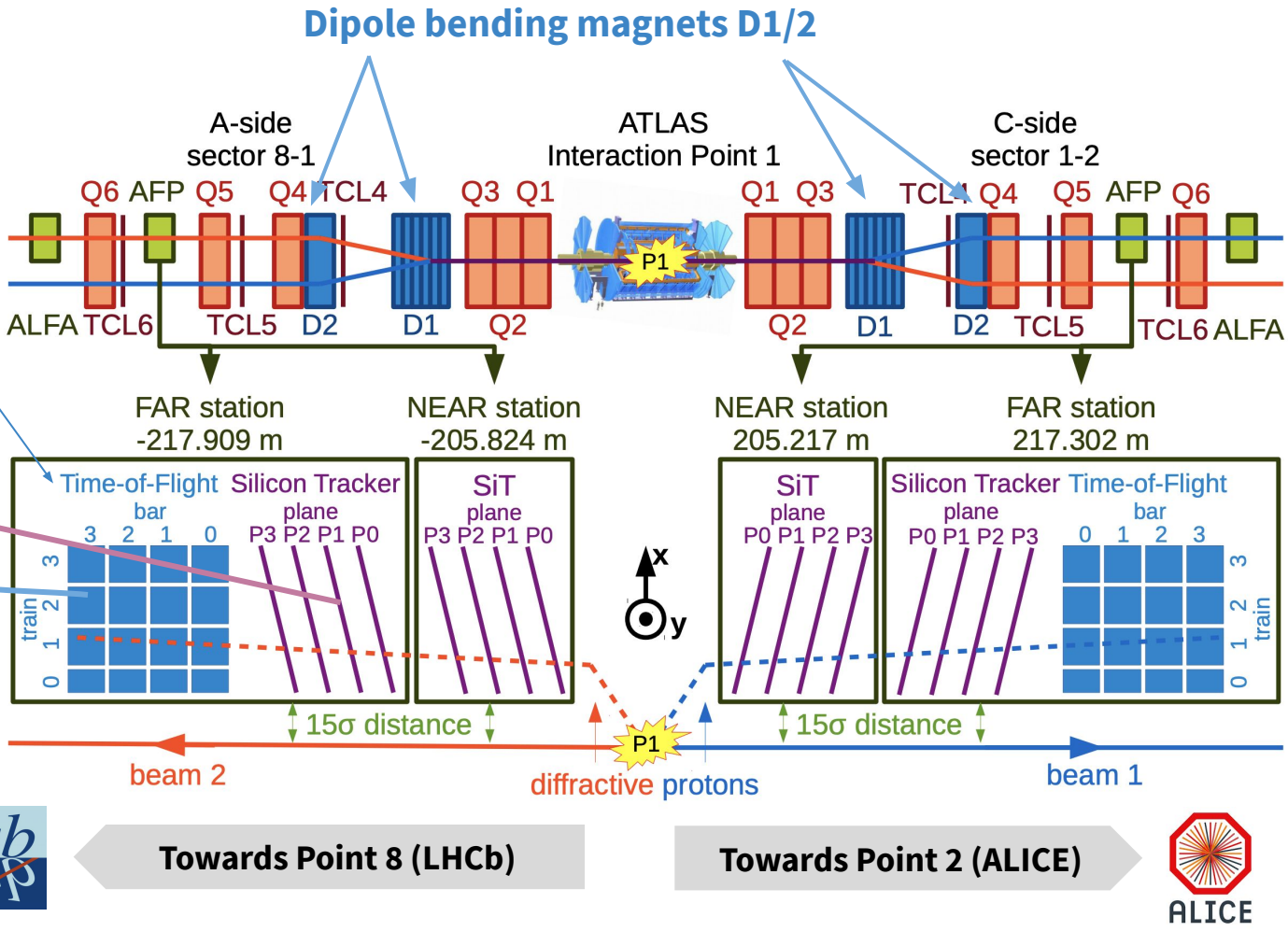



Main observable: proton fractional energy loss

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

# ATLAS Forward Proton system: full diagram



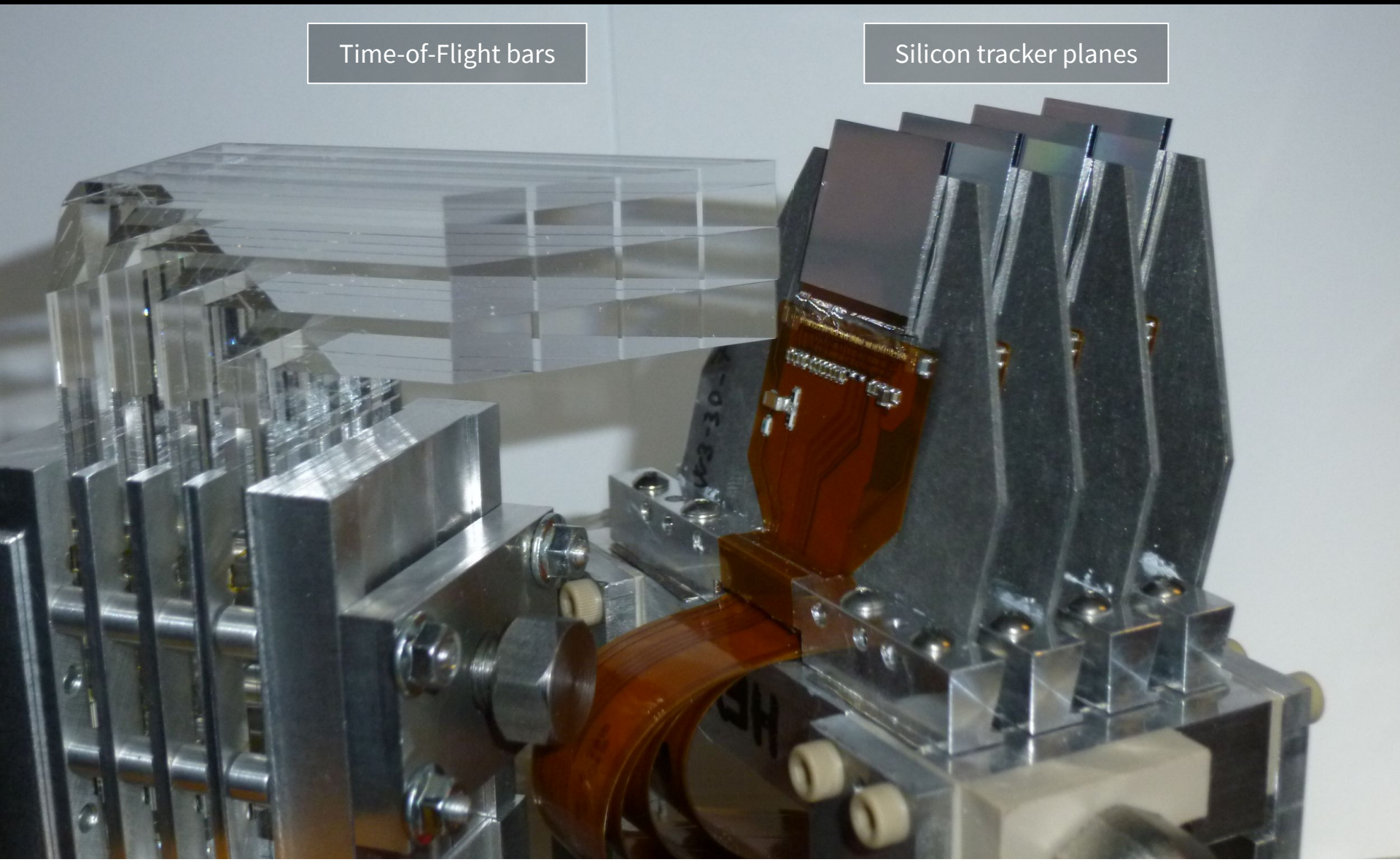



Towards Point 8 (LHCb)

Towards Point 2 (ALICE)

2016: Installed one arm for diffractive jets [PHYS-PUB-2017-012]
2017: installed both arms for first high-luminosity physics

# Close-up: AFP Silicon Tracker and Time-of-Flight detectors



# The idea of a TeV proton spectrometer

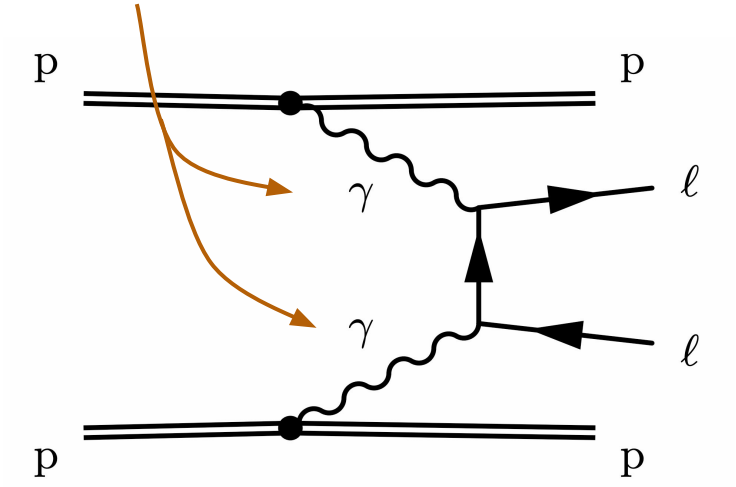
B field from LHC dipoles

**1) Measure *spatial* coordinate**




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

**2) Infer *energy* lost by proton**



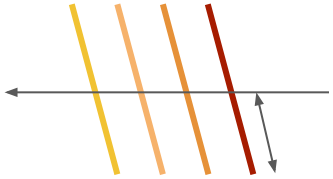

**3) Know initial photon energy**

Novelty: reconstruct γγ system without central ATLAS detectors

# Local interplane alignment

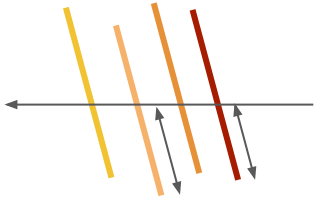
**Proton leaves clusters measured at *x* position relative to plane edge**

**Ideal alignment**

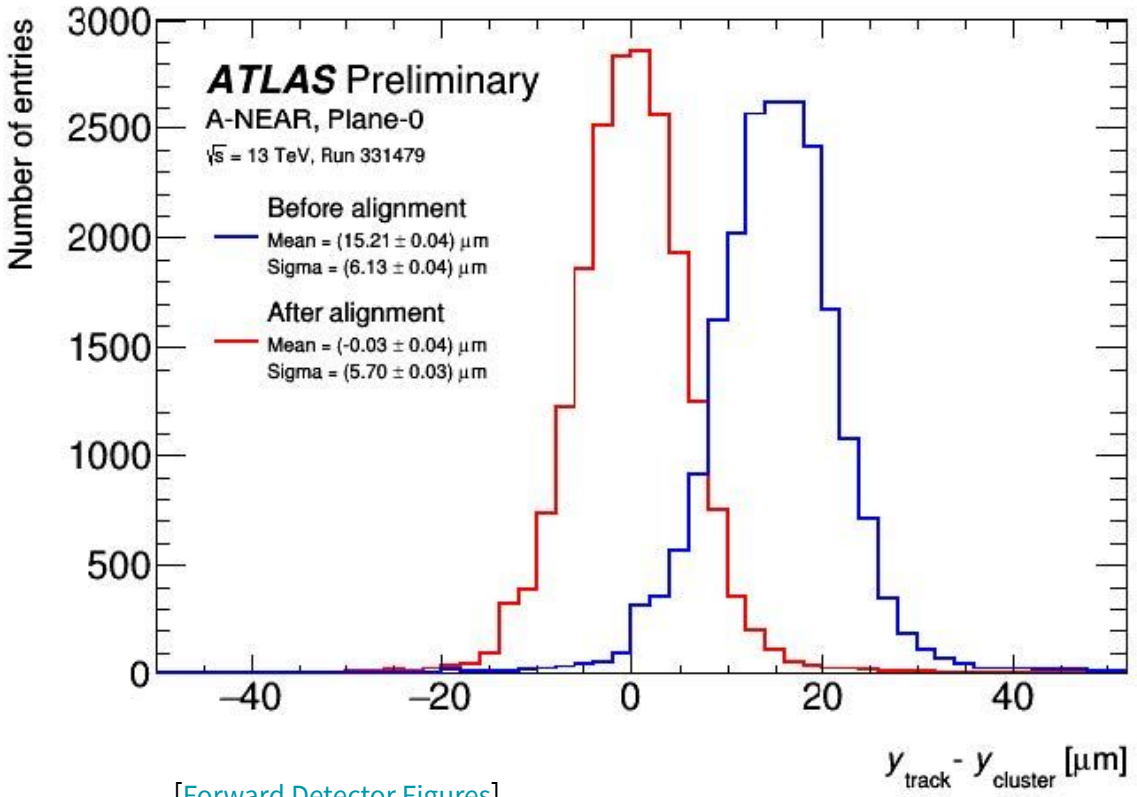


Cluster to edge distance is the same for all planes

**In reality**



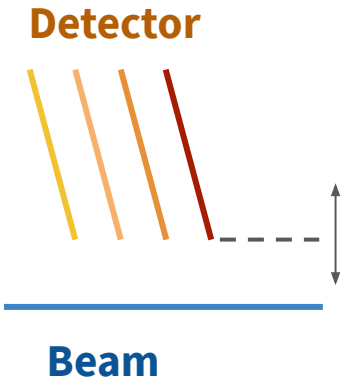
Cluster positions relative to plane edge can be different before interplane alignment




[Forward Detector Figures]

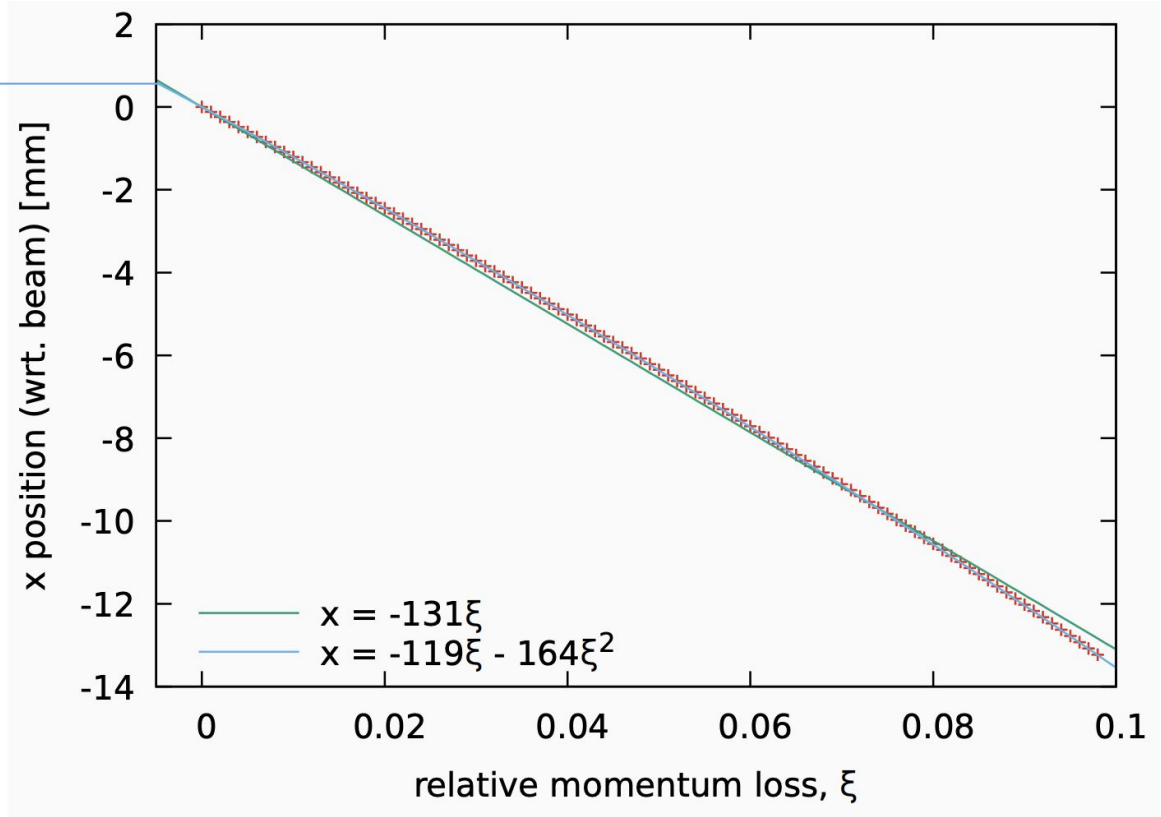
# Global alignment: motivation & idea

**Global absolute offset**




**Spectrometer:**
Instrument turning ***spatial measurements*** into ***energy measurements***

**MAD-X beam propagation simulation**




**Directly impacts reconstructed fractional proton energy loss ξ**

# Beam based alignment: the principle

**"What is the absolute position (& transverse size) of the beam?"**

**The idea:**
Collimators probe beam & Beam Loss Monitors (BLM) monitor impact

https://journals.aps.org/prab/pdf/10.1103/PhysRevSTAB.15.051002

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **15**, 051002 (2012)

**Semiautomatic beam-based LHC collimator alignment**

Gianluca Valentino,[1,2,*] Ralph Aßmann,[1] Roderik Bruce,[1] Stefano Redaelli,[1] Adriana Rossi,[1] Nicholas Sammut,[1,2] and Daniel Wollmann[1]
[1]*CERN, Geneva, Switzerland*
[2]*University of Malta, Msida, Malta*
(Received 27 January 2012; published 8 May 2012)

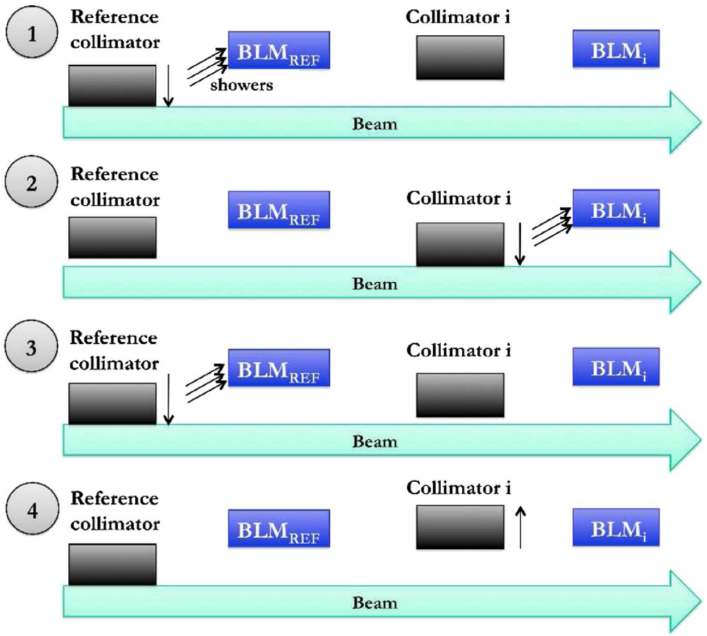
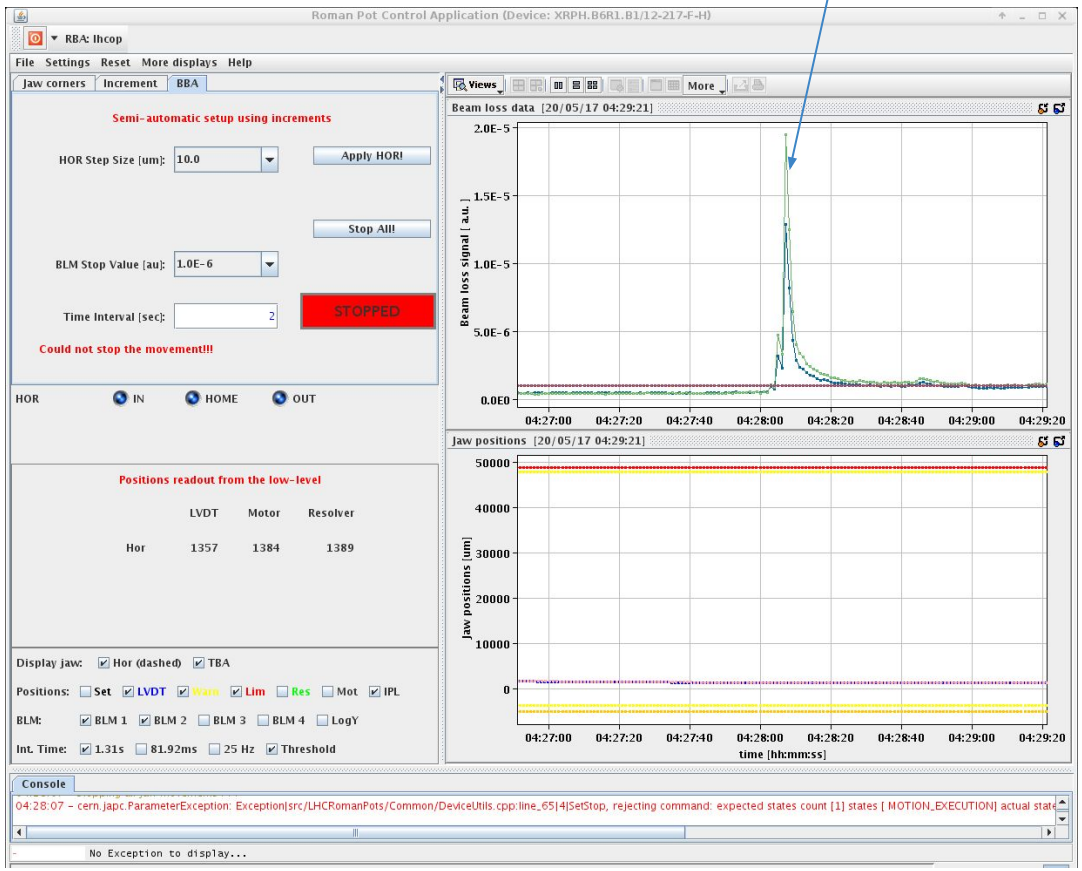



FIG. 4. The four-stage beam-based alignment procedure for collimator *i*. The reference collimator is aligned to form a reference cut in the beam halo (1). Collimator *i* is aligned (2), followed by a realignment of the reference collimator (3). Finally, collimator *i* is opened to its position in the hierarchy (4).

# Beam based alignment: the practice

**Sharp signal spike in BLM when beam is probed**




LHC operations: 20 May 2017

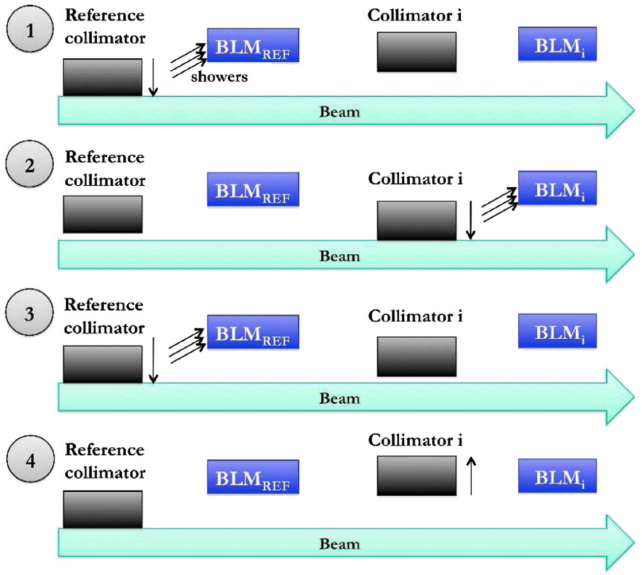
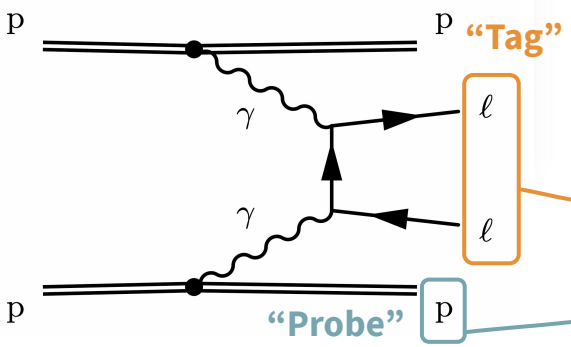
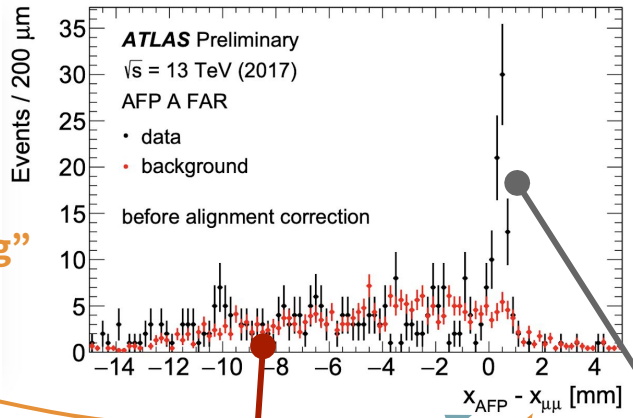


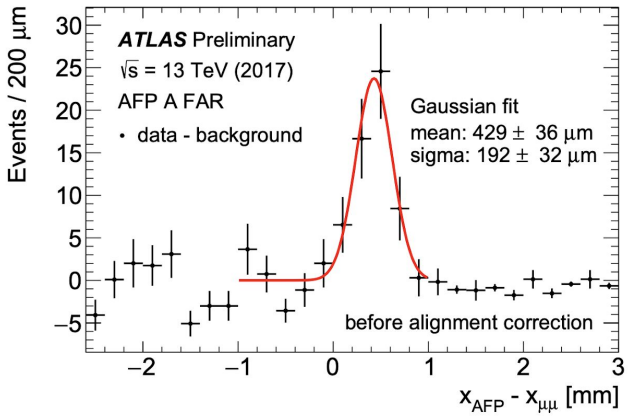

FIG. 4. The four-stage beam-based alignment procedure for collimator *i*. The reference collimator is aligned to form a reference cut in the beam halo (1). Collimator *i* is aligned (2), followed by a realignment of the reference collimator (3). Finally, collimator *i* is opened to its position in the hierarchy (4).

# Innovative technique: in situ dimuon calibration

**Use (γγ → μμ)+p signal as standard candle: "The J/ψ of AFP"**



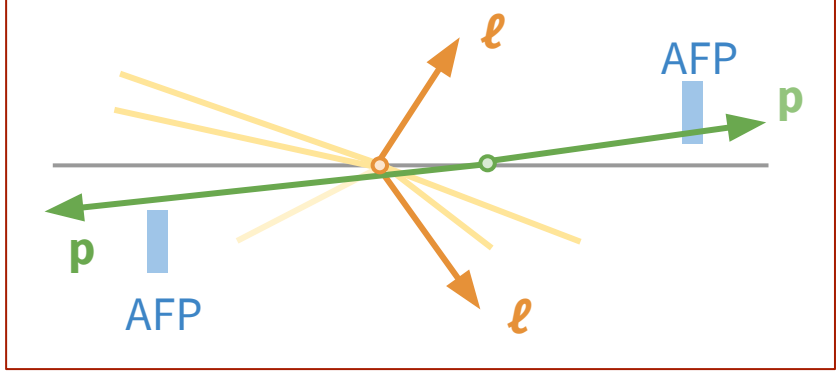



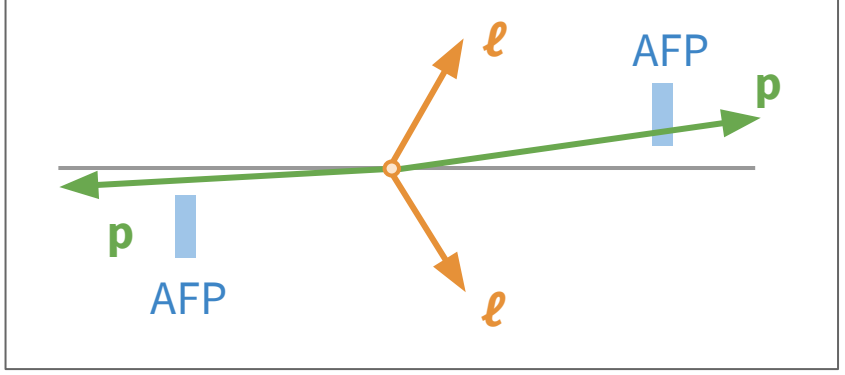

$$\xi^{\pm}_{\ell\ell} = (m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}}$$

**Expected proton energy loss constrained by dimuon system**

**Background: no correlation (pileup)**

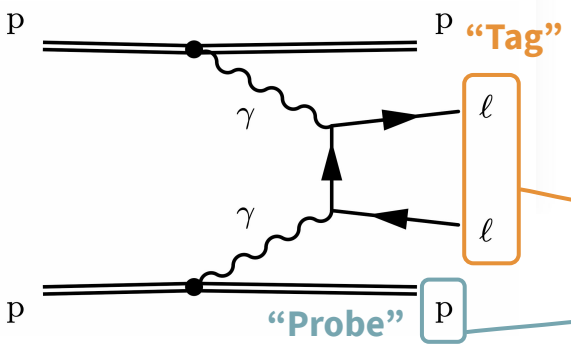


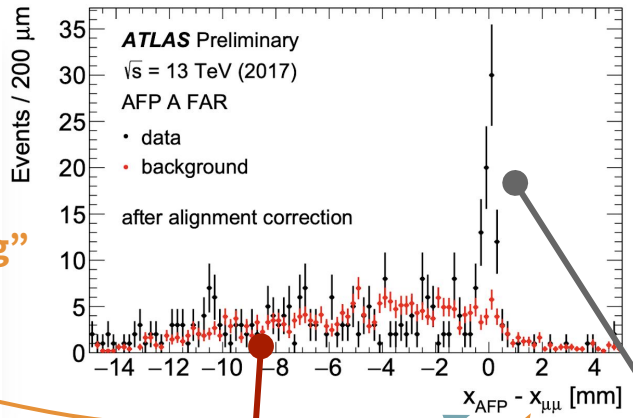

**Signal: if $x_{AFP} = x_{\ell\ell}$ ⇒ aligned & calibrated**

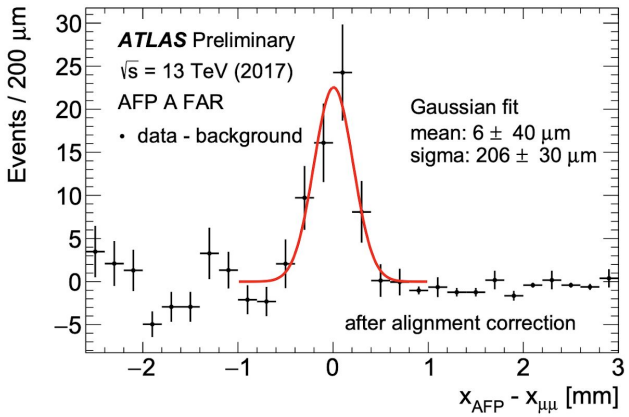


# In situ dimuon calibration: fit & shift residuals

**Use (γγ → μμ)+p signal as standard candle: "The J/ψ of AFP"**



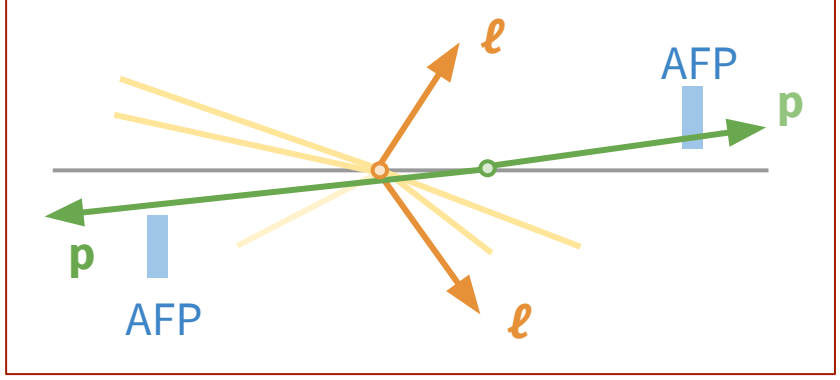



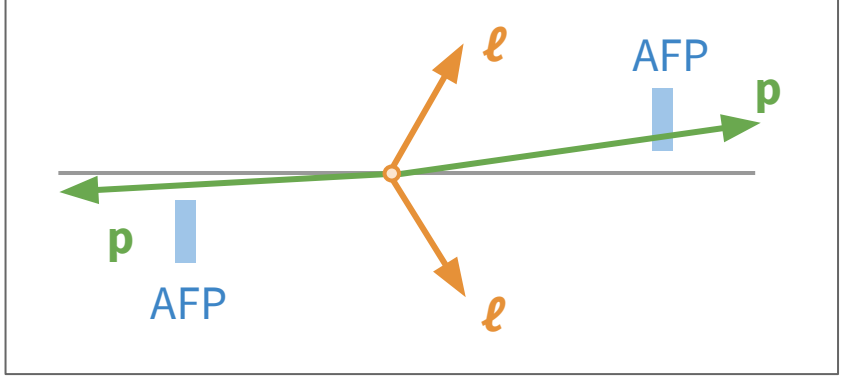

$$\xi^{\pm}_{\ell\ell} = (m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}}$$

Expected proton energy loss constrained by dimuon system

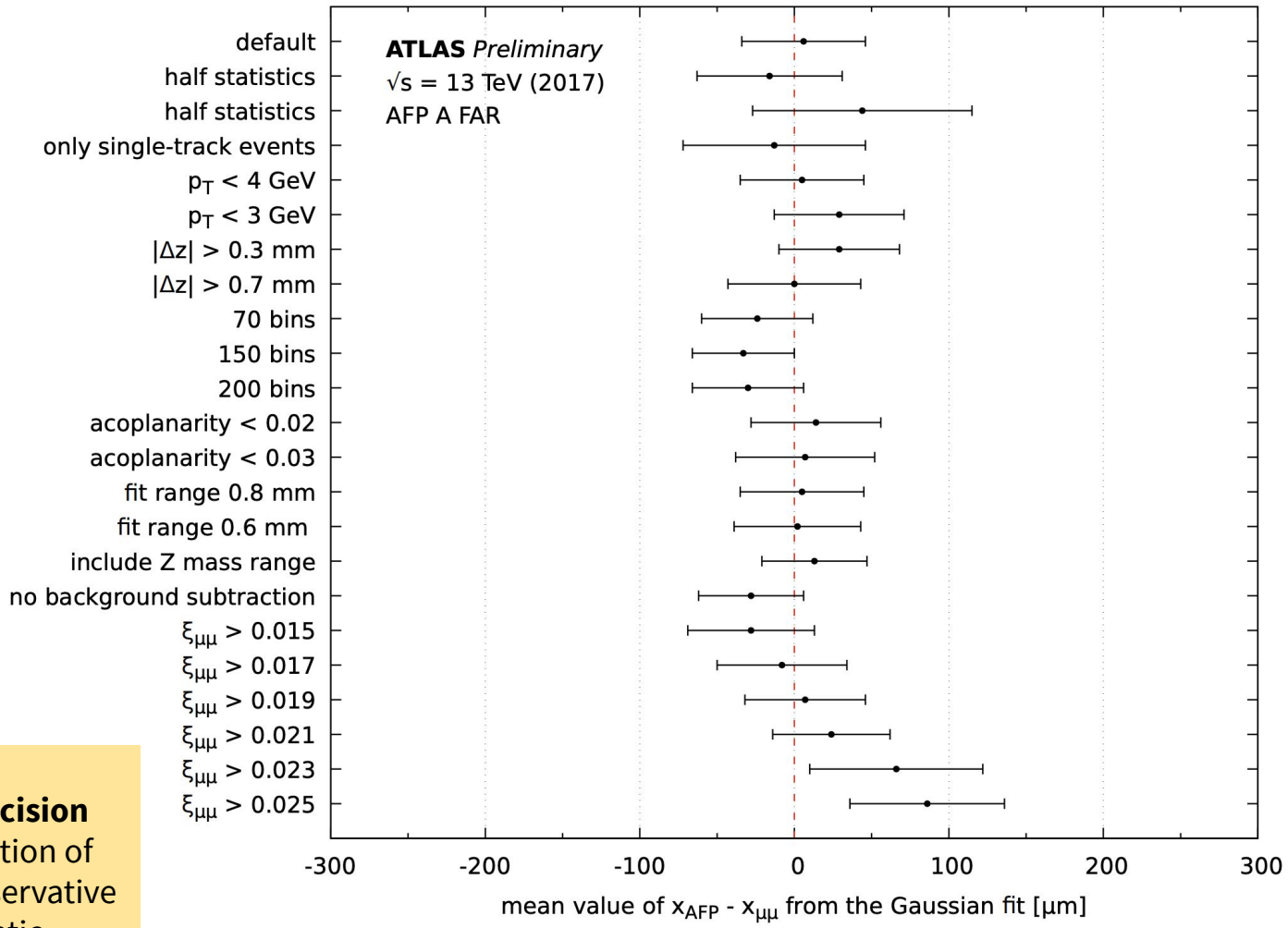
**Background: no correlation (pileup)**




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

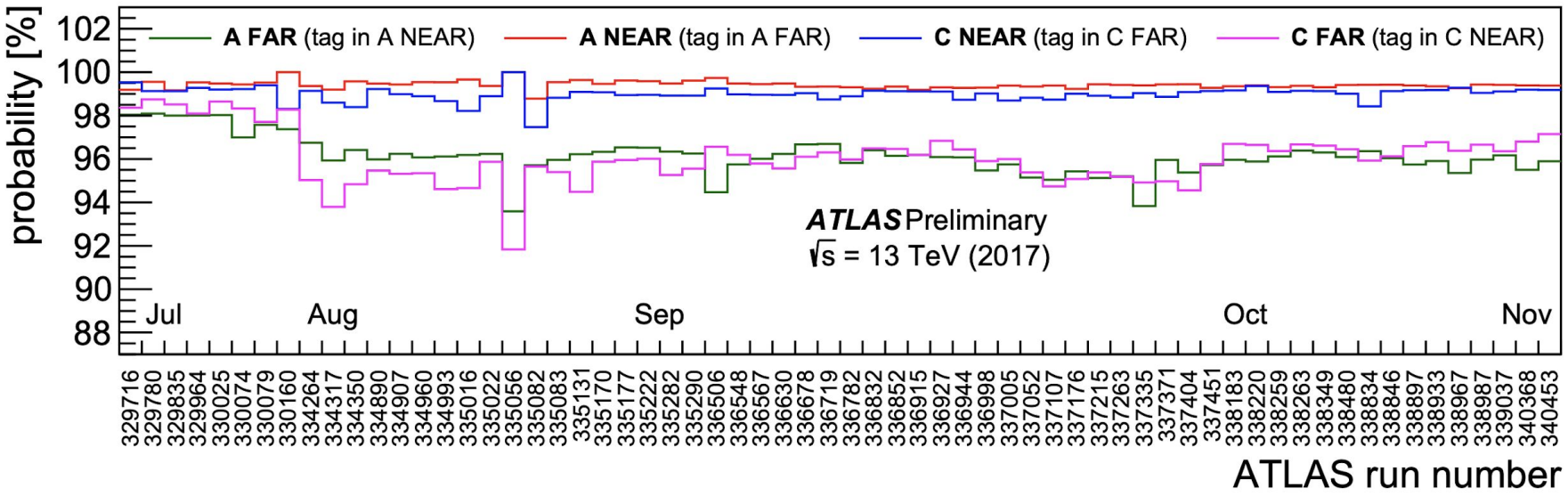


# In situ dimuon calibration: systematic uncertainties



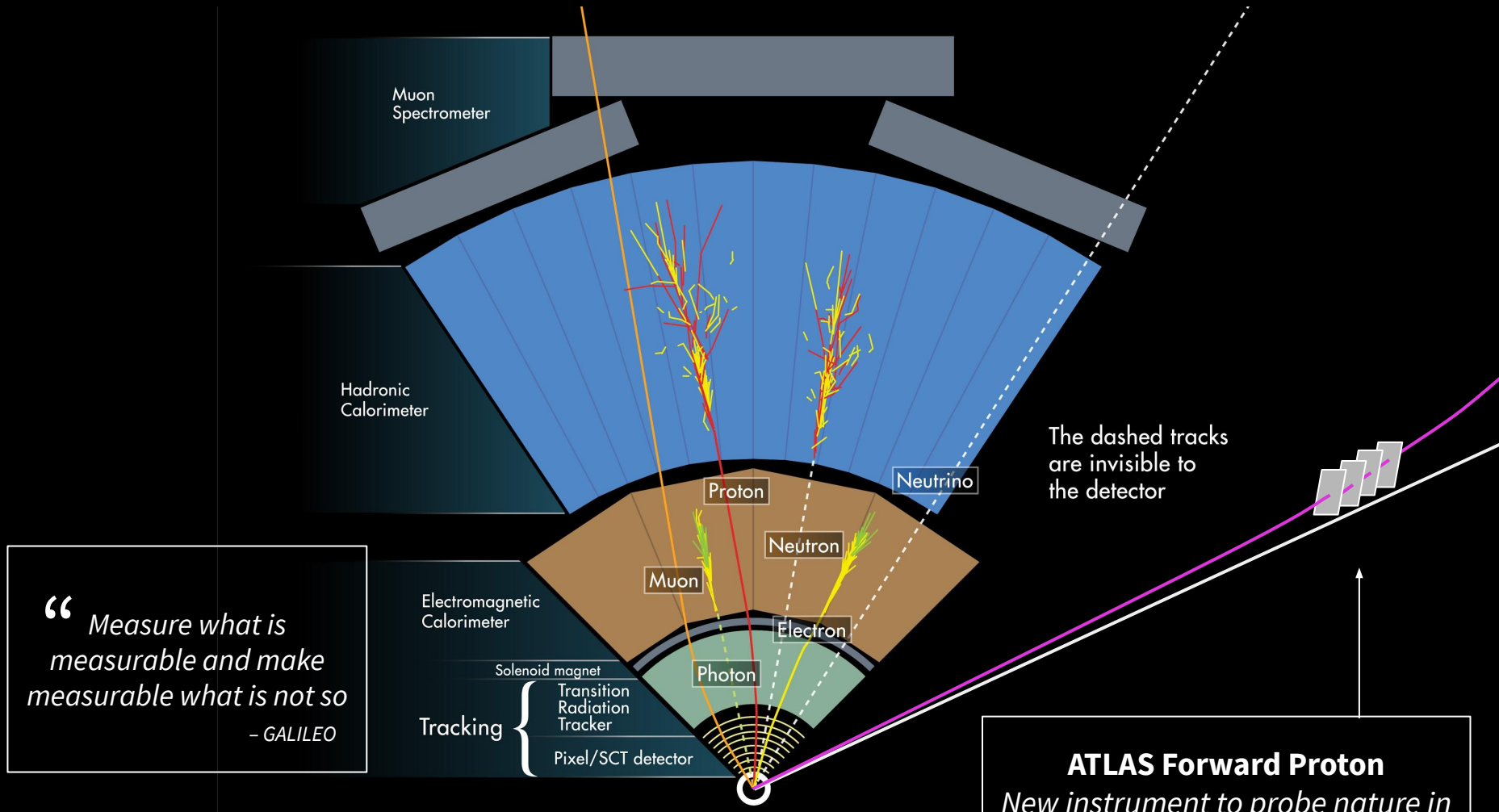

**The road towards precision**
Comprehensive evaluation of variations for initial conservative 300 micron systematic

# Track reconstruction efficiency & data quality




**Efficiencies**: crucial to correct (unfold) AFP detector effects – first time evaluated for AFP
Tag a track in one station, probe fraction of events with track matched $|x_{Near} - x_{Far}| < 2$ mm
Far stations have systematically lower efficiency than Near due to showering
**Data quality**: diagnostic to check runs with problematic detector – vetoed in Good Runs List

# AFP expands our repertoire to probe the microcosm




> *"Measure what is measurable and make measurable what is not so*
> *– GALILEO*

**ATLAS Forward Proton**
*New instrument to probe nature in ways we have never done before*

CERN [https://cds.cern.ch/record/1505342]

# Summary

## This talk

We are pioneering strategies for AFP detector alignment & performance characterisation critical for opening a novel program of ATLAS analyses

## See more proton tagging in ATLAS @ ICHEP

**“The ATLAS Forward Proton Time-of-Flight Detector System”**
By Karel Cerny
Thu 30 Jul 09:15am [direct sequel to this talk]

**“Measurements of soft-QCD and diffractive processes with ATLAS”**
By Rafał Staszewski
Thu 30 Jul 10:40am [Strong interactions and hadron physics]

**“Measurements of photon-photon fusion at ATLAS”**
By Mateusz Dyndal
Thu 30 Jul 10:50am [Top quark and electroweak physics]

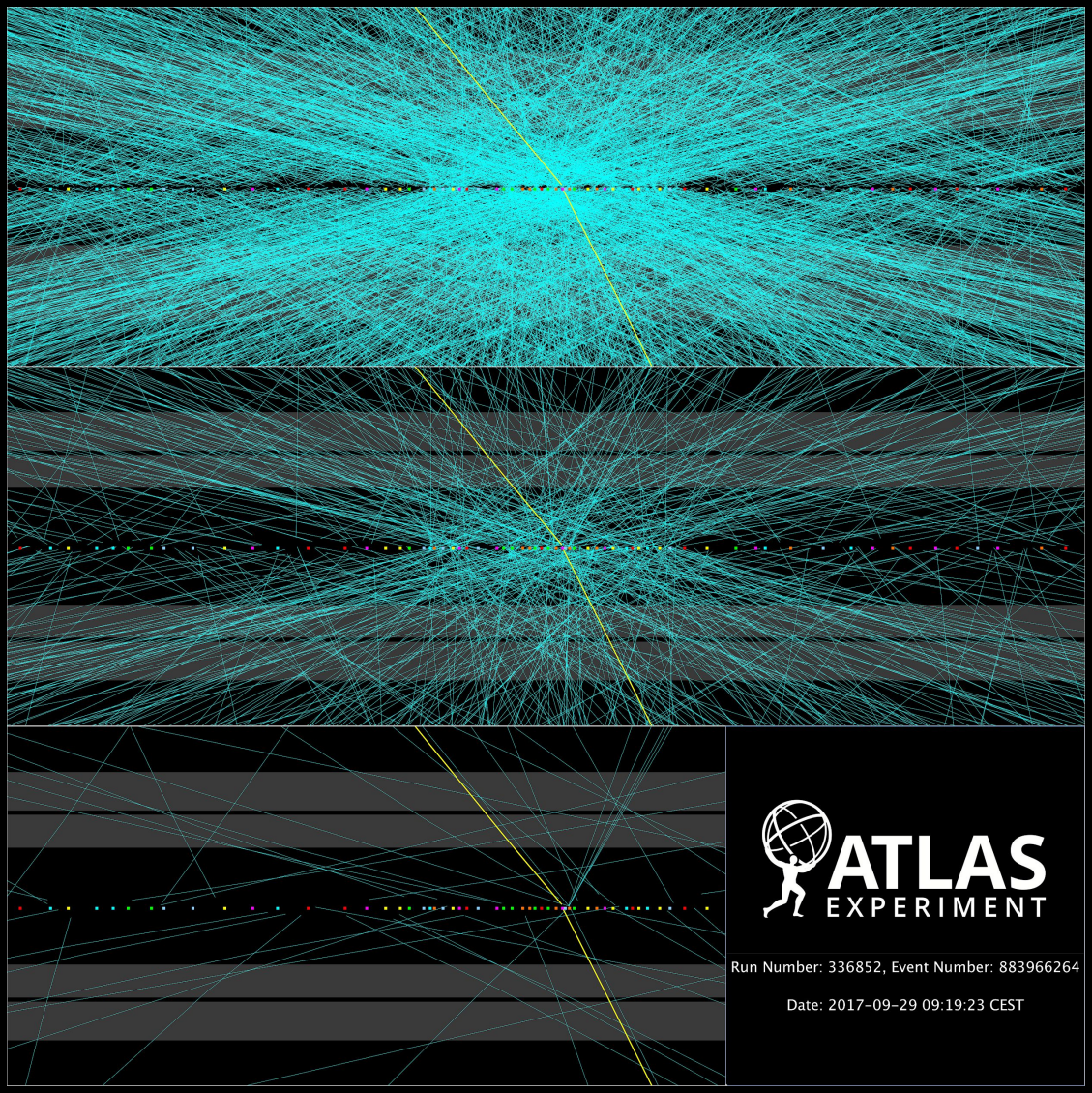
# EXTRAS

[ATLAS Run 2 Event Displays]

$p_T$ > 100 MeV tracks

$p_T$ > 1 GeV tracks

$p_T$ > 5 GeV tracks

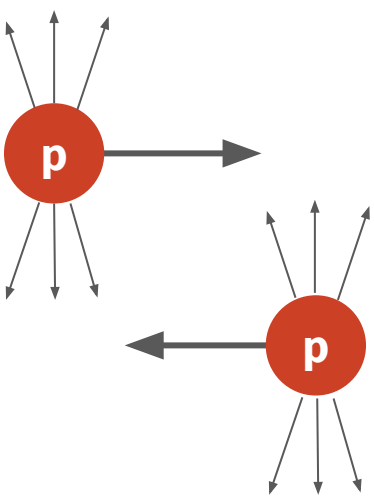



# Key challenges

Track modelling from soft QCD very challenging

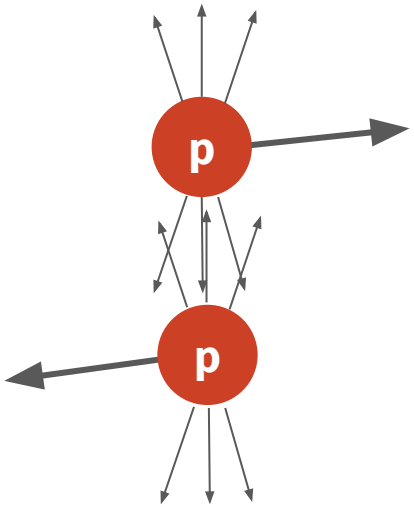
*"The Z boson candidate is reconstructed in a beam crossing with 65 additionally reconstructed vertices from minimum bias interactions…The invariant mass of the two muons is 87 GeV."*

# LHC as photon collider is laboratory for extreme QED



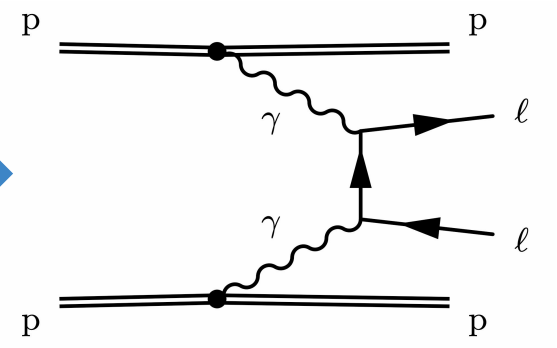

Protons effectively source intense beam of photons

Weizsäcker (1934)
Williams (1934)




Protons stay intact and can be tagged

ATLAS Forward Proton
CMS–TOTEM PPS




Collision of Two Light Quanta

G. Breit and John A. Wheeler
Phys. Rev. **46**, 1087 – Published 15 December 1934

Phys Rev (1934)
Schwinger (1952)

Schwinger 1952: particle production from vacuum if $B \gtrsim 10^9$ T, $E \gtrsim 10^{18}$ V/m
**Hadron colliders**: $B \gg 10^{14}$ T, $E \gg 10^{23}$ V/m, **Magnetar neutron stars**: $B \sim 10^{11}$ T
**Test QED with new probes at extreme regimes ⇒ '*who ordered that*' surprises?**