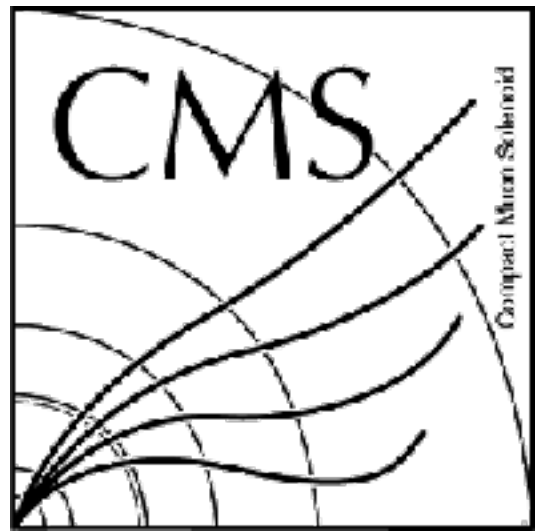




Observation of W, Z, and jet production with a tagged forward proton in proton-proton collisions at $\sqrt{s} = 13.6$ TeV

Elisabetta Manca (CERN)

for the CMS collaboration, QCD@LHC 2026, Oxford

Soft QCD effects with Hard scale consequences

In this talk:

- **New Result!** CMS-PAS-SMP-26-015 ([link](#)) “Observation of the production of high- p_T jets or electroweak bosons with an intact forward proton in pp collisions at 13.6 TeV”

First observation of TeV-scale jet production with an intact forward proton

First observation of Z production with an intact forward proton

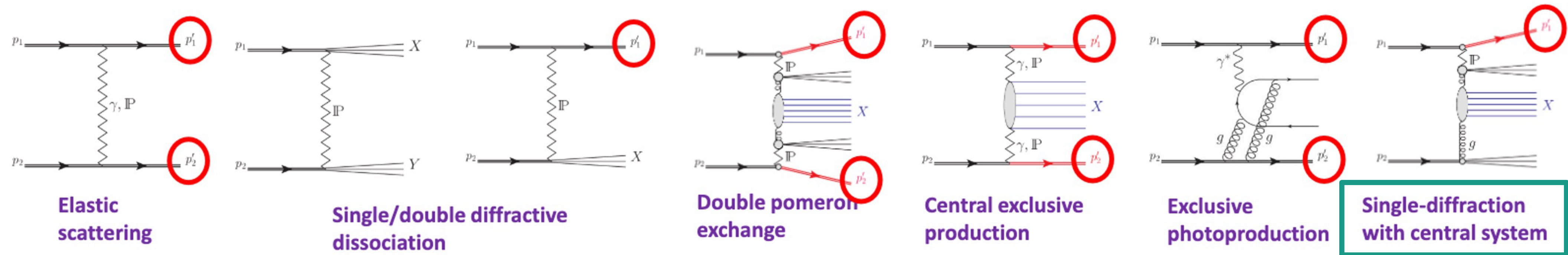
First observation at the LHC of W production with an intact forward proton

+ determination of in-fiducial signal fractions and forward-backward asymmetries
(inclusive and differential)

First CMS result with the 2026 low-PU data set (recorded in April)

- Signature is compatible with “Hard” Single Diffractive production

pp collisions with a forward intact proton



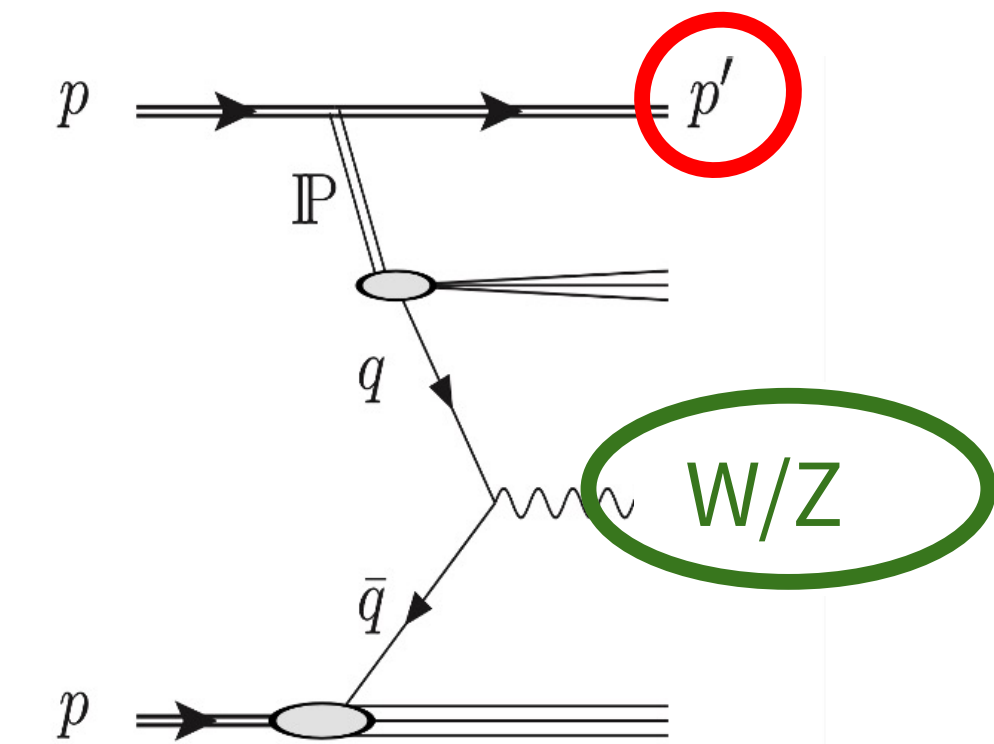
A t -channel exchange of color-neutral particles (QED, QCD)

- A rich physics programme for the LHC experiments, covering a wide range of energy scales and cross sections
- Often characterized by rapidity gaps, low track multiplicity, or by an **intact proton** in the final state, which can be tagged in a forward proton detector
- **Today:** focus on single diffraction signature, with central system X and an intact forward proton

W, Z, jets production with an intact proton

Search for 'hard scale' central events X with a tagged intact proton where $X = W, Z$, or high- p_T jets

- Expected rate of such events $O(1\%)$
- Relatively few measurements exist in this domain, often based on a rapidity gap signature in the central detector

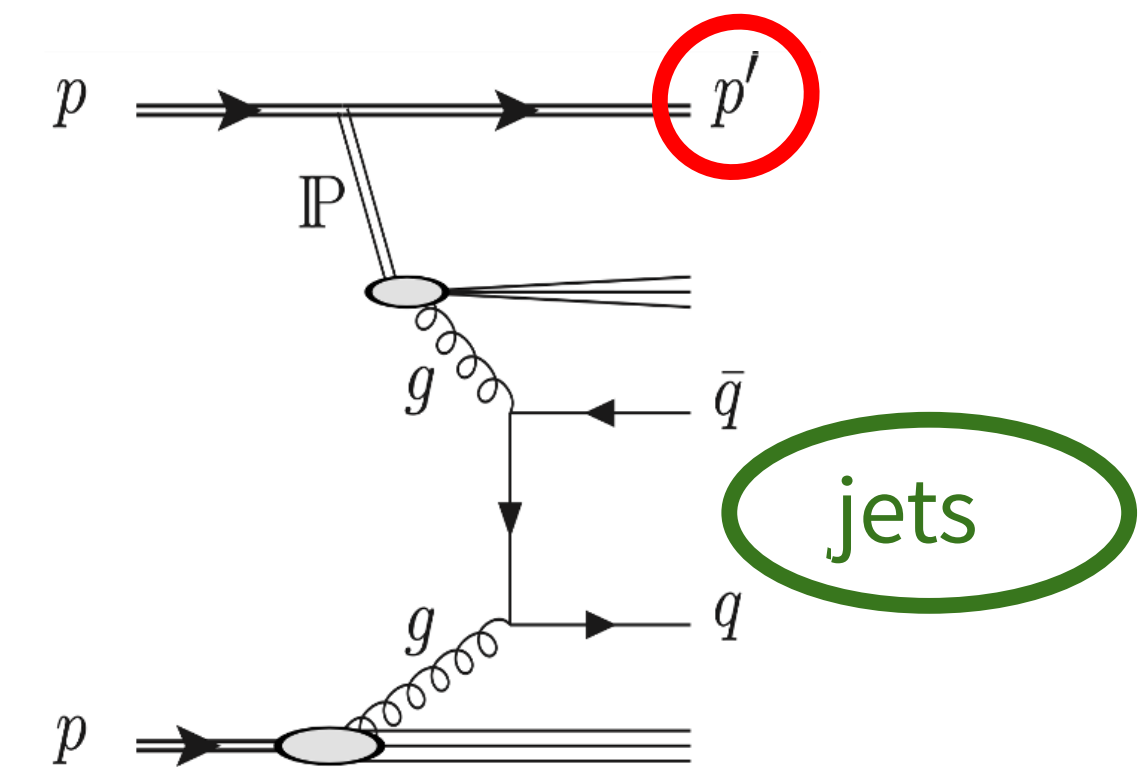


This analysis - no diffraction-specific requirements for central event:

Standard selection of event in central CMS detector

+

- 1) correlation with the presence of a tagged forward proton
- 2) forward-backward asymmetry with respect to the tagged proton direction, due to the longitudinal boost

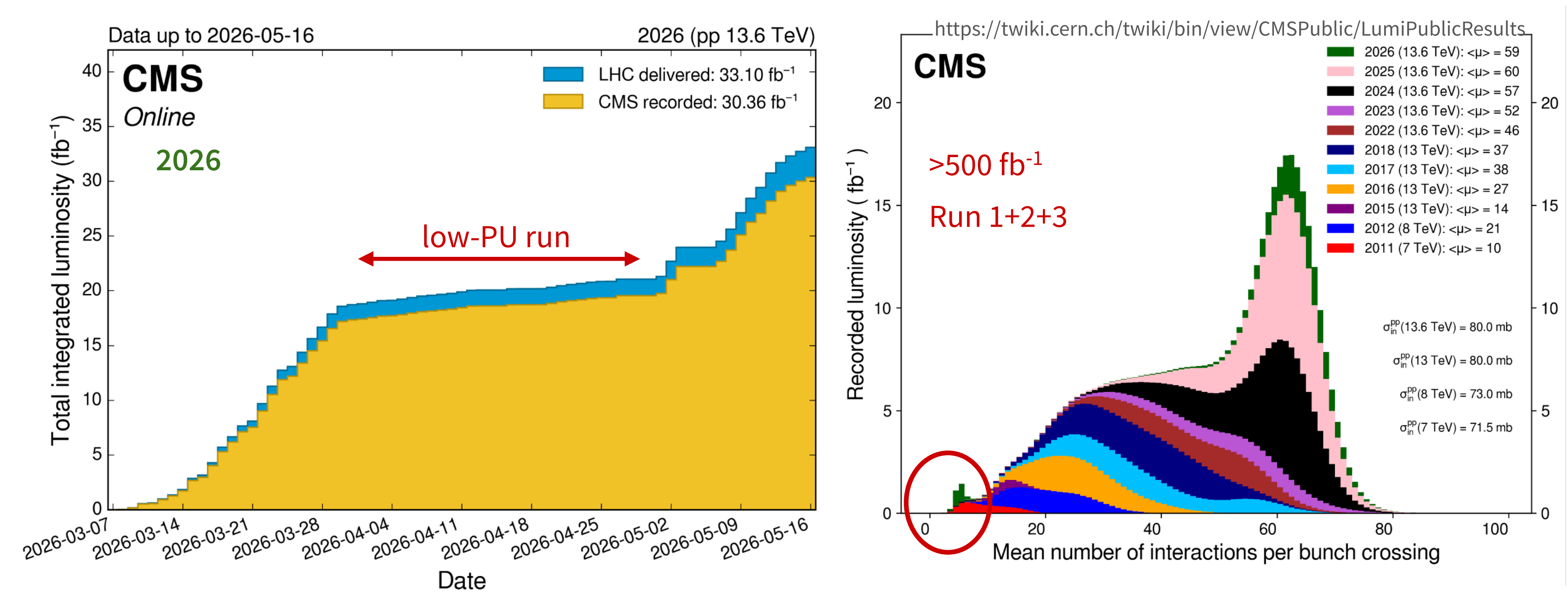


Data set used: the 2026 low-PU run

CMS low-PU run in April 2026

CMS dedicated 3 weeks of beam time to take data at low luminosities compared to the standard configuration ($\langle\mu\rangle=64$)

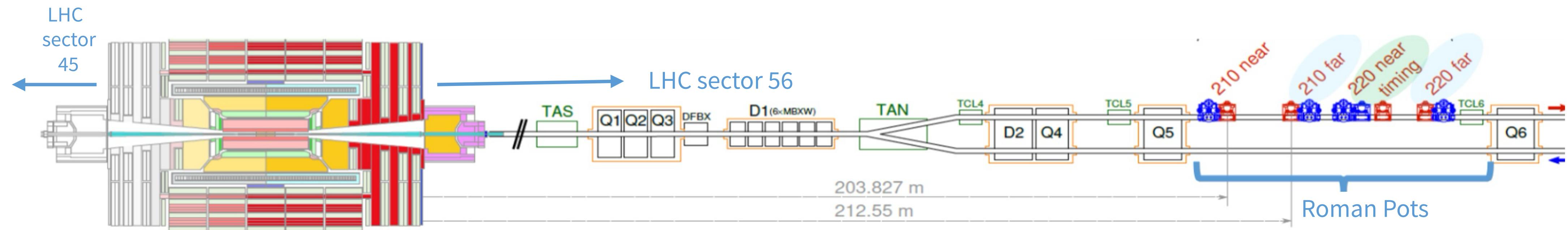
→ 2 fb⁻¹ of data recorded with $\langle\mu\rangle=5$



pp collisions with a forward intact proton

CMS Proton Precision Spectrometer (PPS) in Run 3

- Near-beam detectors located in Roman Pots (RPs) 200-220m away from the CMS detector
- On both sides of CMS



Event selection in W, Z and MultiJet channels

Standard MultiJet, W, or Z selection with muons in the central CMS detector:

MultiJet:

at least 2 jets
leading jet $p_T > 140$ GeV

W:

exactly 1 muon, no additional light leptons
W transverse mass $m_T > 50$ GeV

Z:

exactly 2 leptons with opposite charge
and $70 < m_{ll} < 110$ GeV

Channel	Events (10^6)	$R_{\text{tag}}^{z>0}$ (%)	$R_{\text{tag}}^{z<0}$ (%)	$R_{\text{tag}}^{\text{any}}$ (%)
Zero-bias / control	180.16	9.40	9.72	18.01
Multijet	733.04	9.70	10.02	18.55
W	17.50	9.94	10.27	19.00
Z	1.743	9.91	10.30	18.99

R_{tag} := fraction of the selected central events that
coincide with at least one tagged proton

+ require at least one proton in PPS (+z or -z)

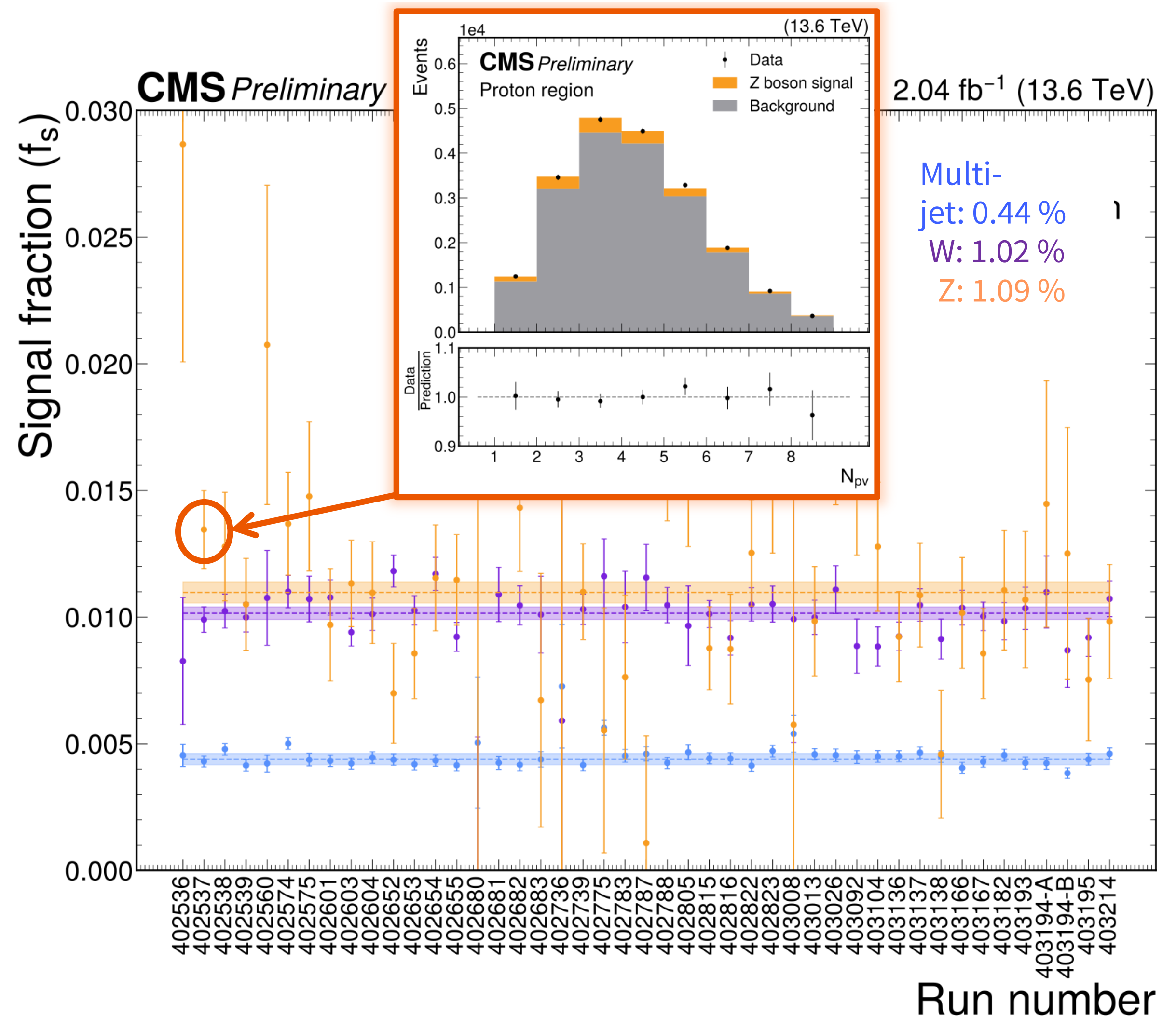
- employing simplified proton ID without full ξ reconstruction:
coincidence of proton hits in two RP stations in a given arm (+z or -z)
- no veto on proton activity in the other arm

1) Extract signal fraction directly from proton rates

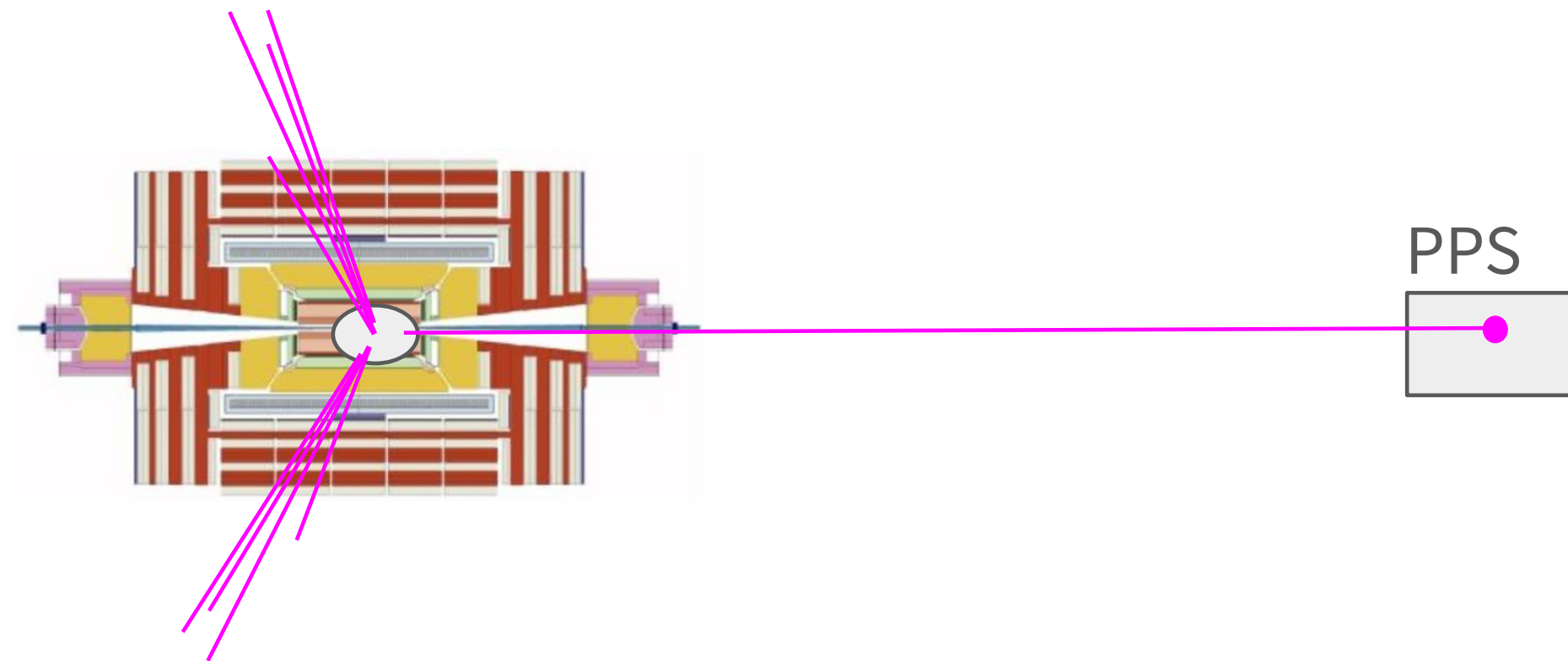
Most tagged protons are from PU interactions (even at $\langle\mu\rangle=5$)

- Use zero-bias triggered events to estimate the PU proton contribution
- Perform **fine-grained fit**: run-by-run, LHC bunch-by-bunch, with primary vertex counting

=> Extract fraction of the selected hard scatter events, f_s , with an intact forward proton in the final state, tagged in the PPS



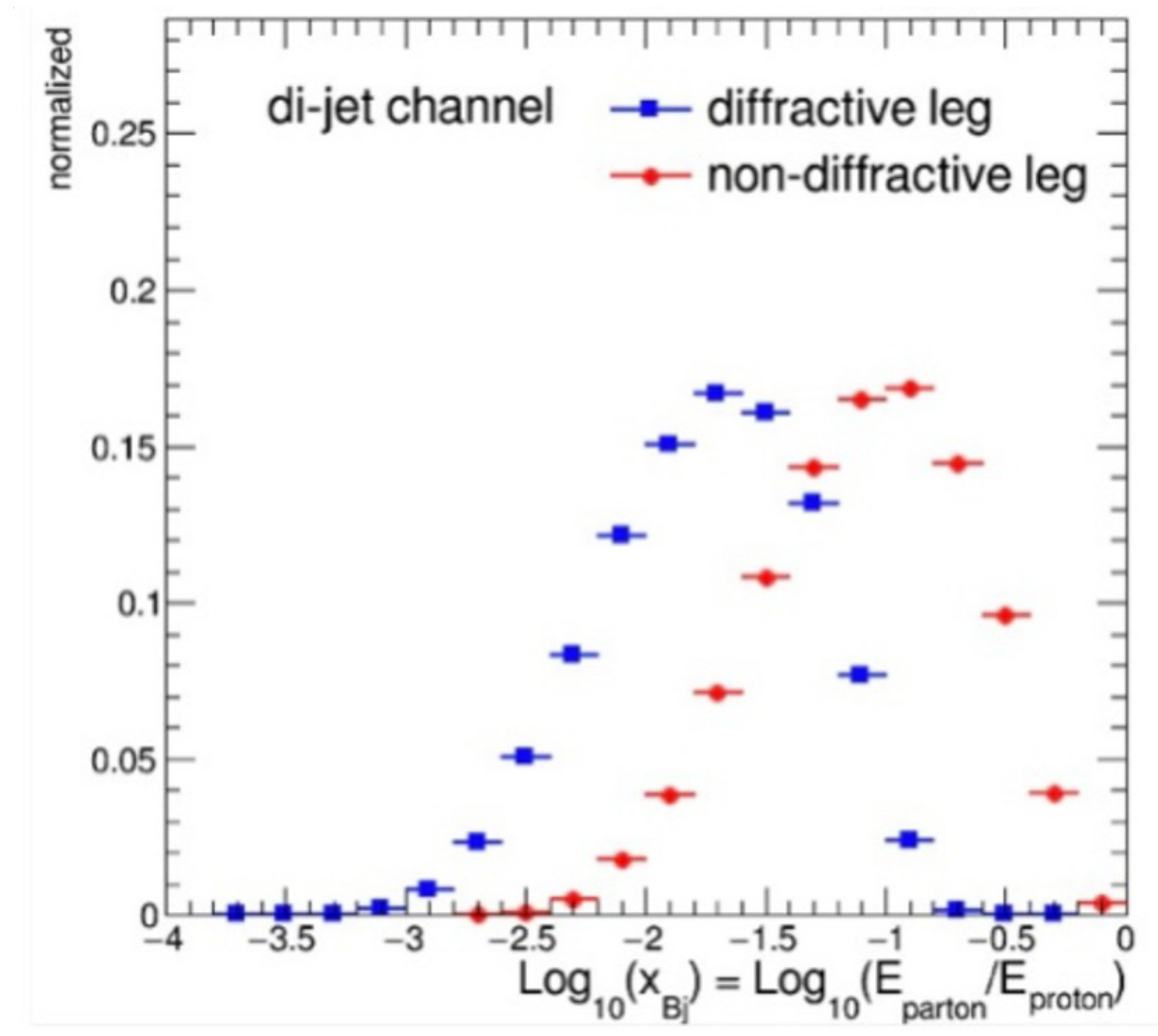
2) Longitudinal Boost Asymmetry method



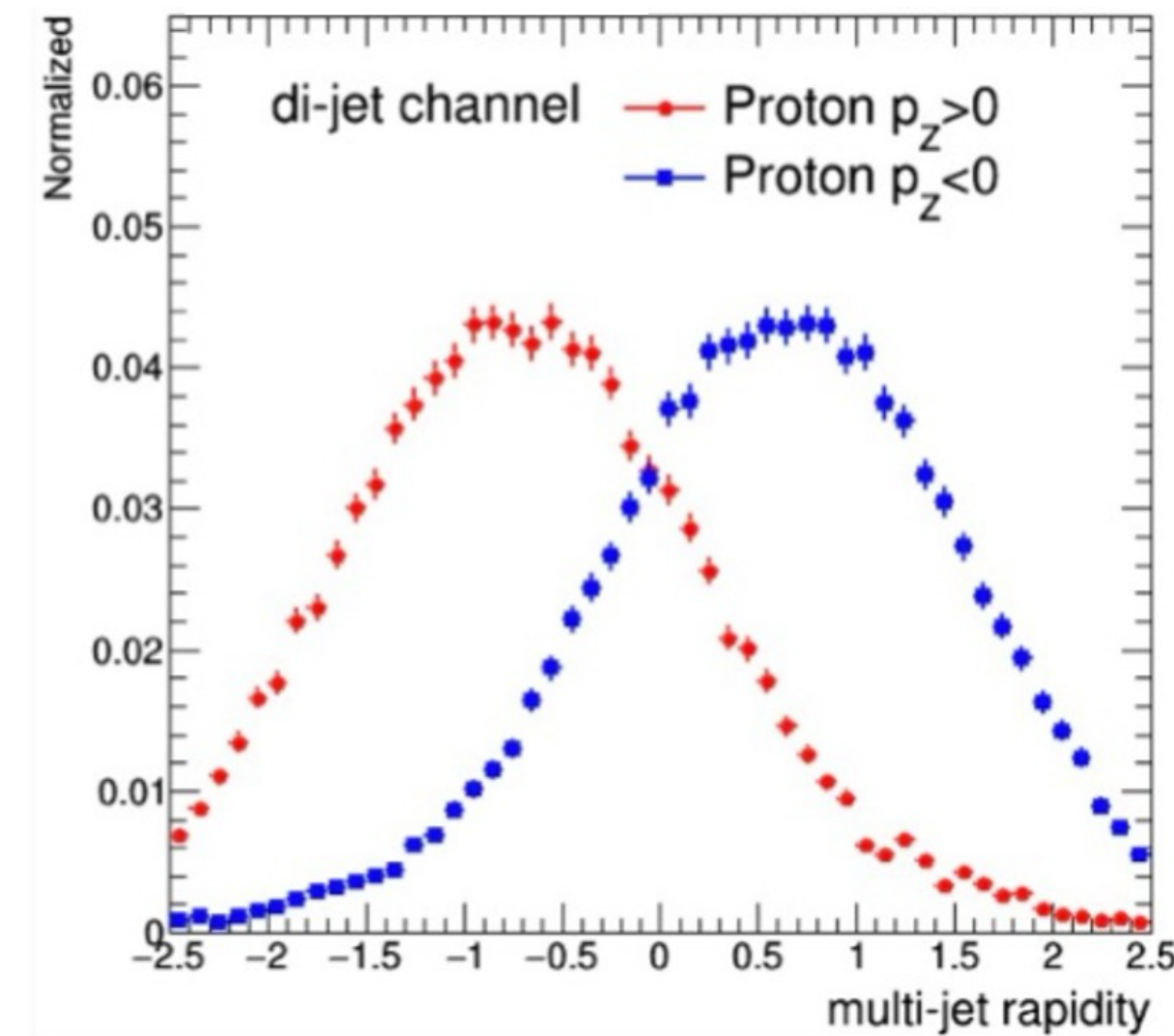
Look for longitudinal momentum (p_z) imbalance:

- Intact proton in PPS lost **approx 3-13%** of long. momentum relative to beam energy
- Björken x from 'normal' proton PDF on the other side
- Causes longitudinal boost of central system

for illustration



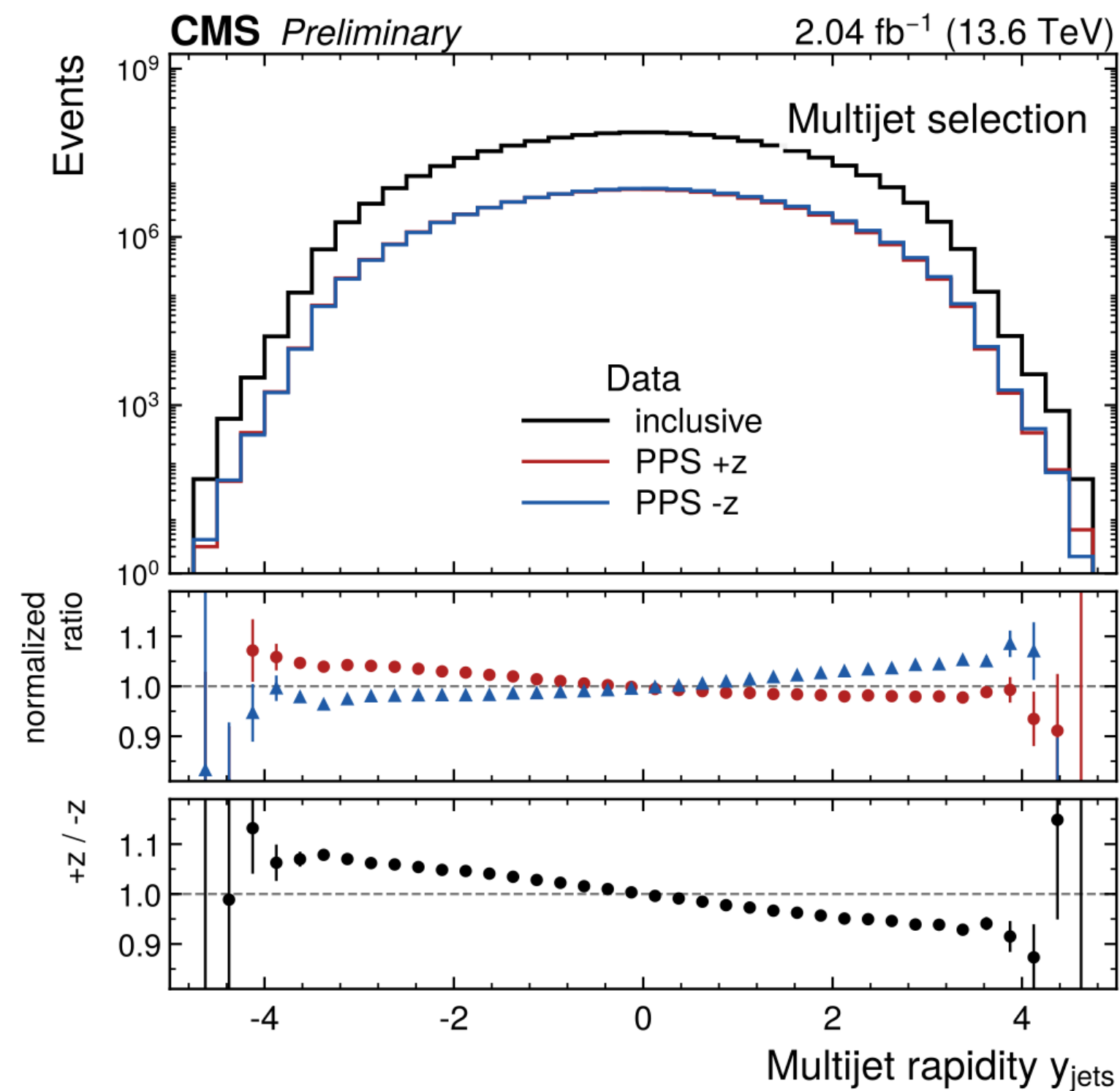
for illustration



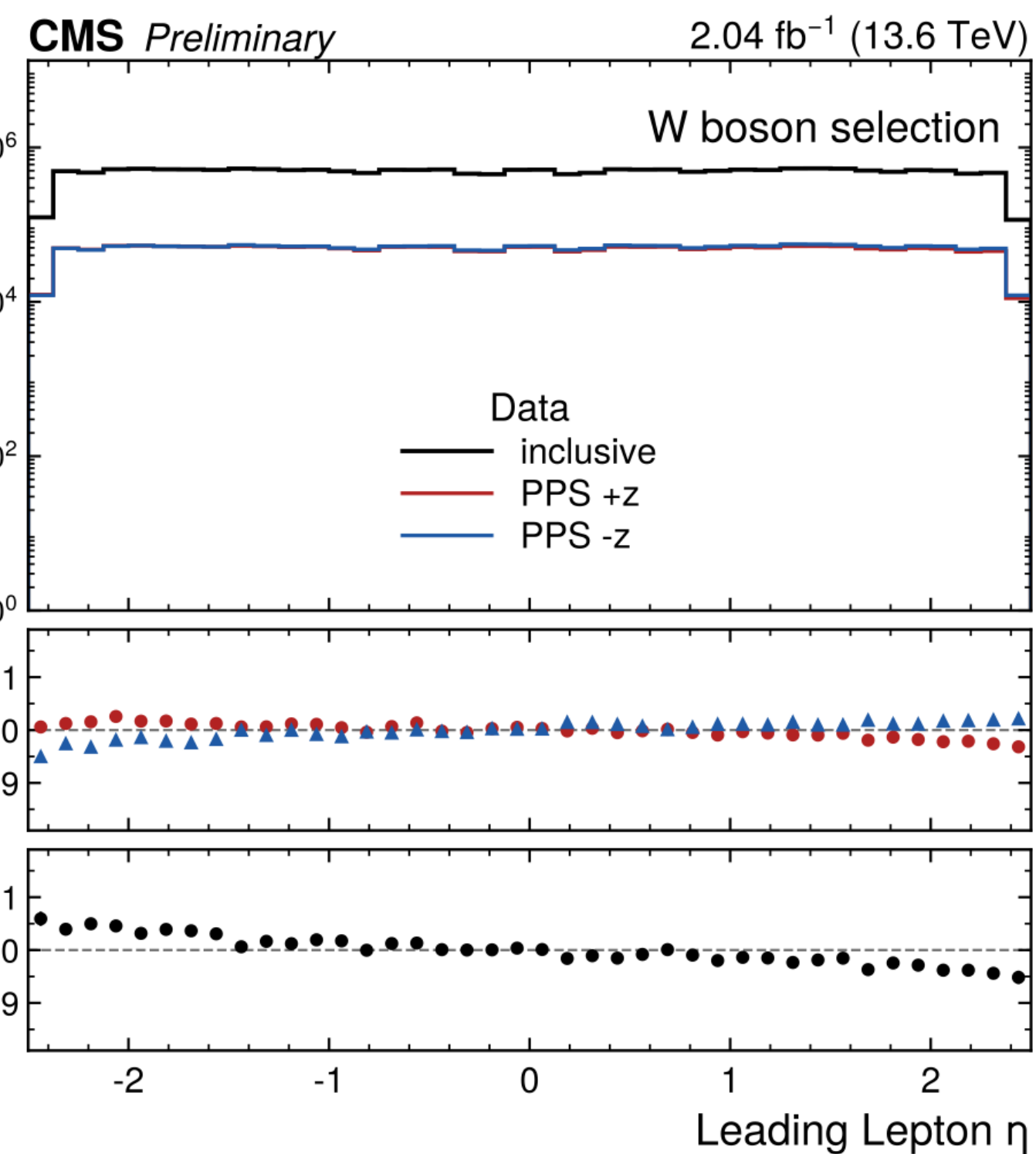
Boost ratio asymmetry in W, Z and jets channels

Take normalized ratio wrt inclusive selection, for a rapidity-like observable $\Rightarrow$ non-zero slope is observed

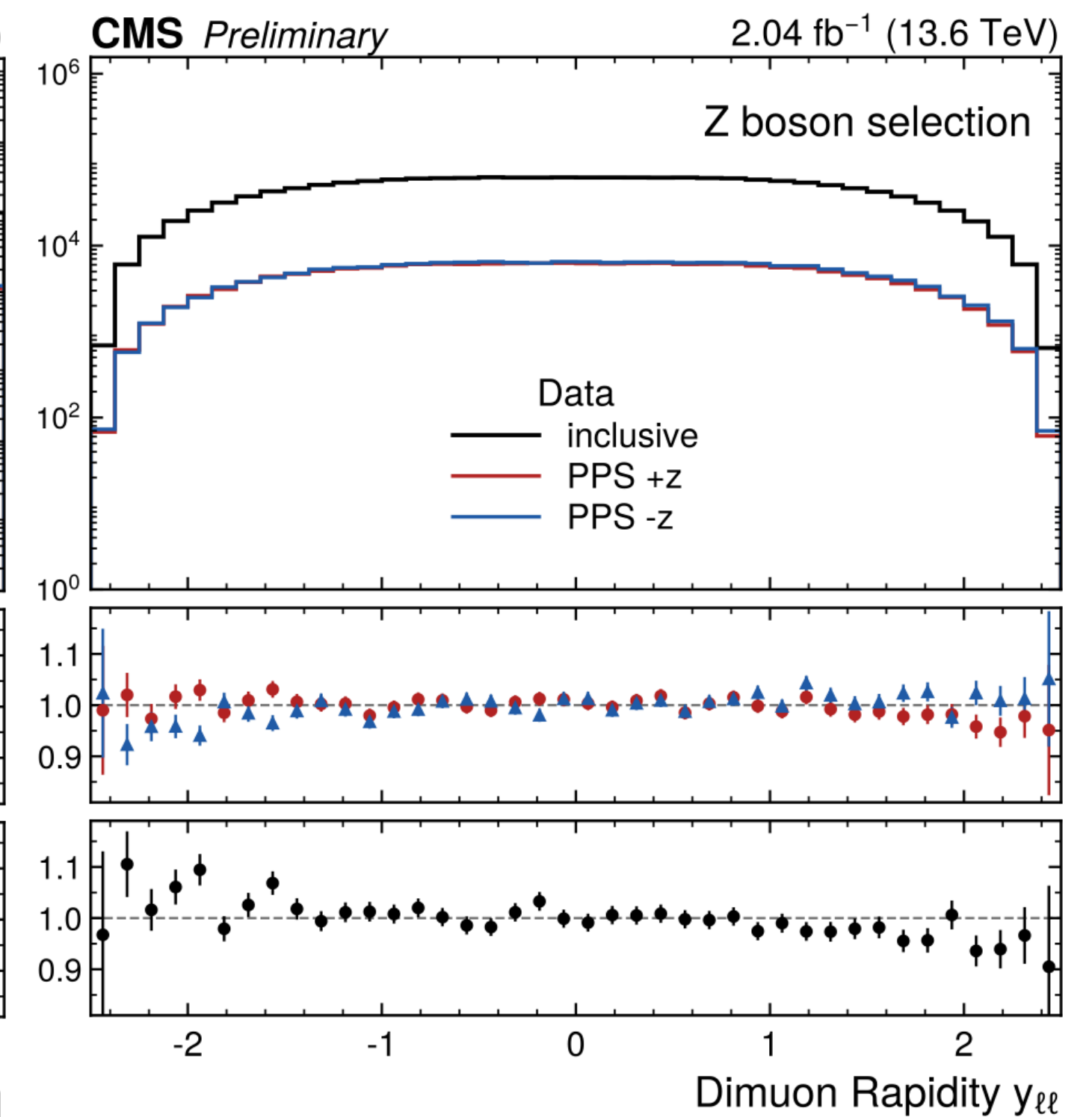
Multijet channel



W channel



Z channel



Inclusive Results

Use estimated **signal fraction** to correct the **observed Asymmetry** for the dilution from PU protons

Channel	f_S (%)	A_{obs}	A_S
Multijet	0.44 ± 0.02	-0.01190 ± 0.00006	-0.585 ± 0.030
W	1.02 ± 0.03	-0.0100 ± 0.0004	-0.218 ± 0.010
Z	1.09 ± 0.04	-0.006 ± 0.001	-0.127 ± 0.025

$$A_S = \frac{N_S^+ - N_S^-}{N_S^+ + N_S^-} = A_{\text{obs}} \frac{R_{\text{tag}}^{\text{incl}}}{f_S C_m}$$

>5 sigma observation in each channel, from

- non-zero signal fraction f_S
- and
- non-zero value of A_{obs}

main sources of uncertainty:

- statistical uncertainty
- available calibrations for jet energy scale, proton ξ acceptance, (minor) background fit model approximations

f_S := fraction of the inclusive hard scatter central events that have an intact proton in the final state inside the acceptance of the PPS. $C_m \sim 0.91$ corrects for ‘mixed’ events with a signal proton in one arm and PU proton on the other side

based on nominal PPS alignment and LHC beam optics during the 2026 lowPU run, the estimated ξ acceptance is $3\% < \xi < 13\%$

caveat: the currently quoted values of f_S contain the proton tagging efficiency ($< 100\%$) which is likely non-constant within the acceptance window

Differential results

In bins of:

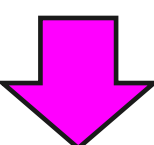
- N_{jet}
- W boson charge
- Multijet mass

>5 sigma observation from

- non-zero signal fraction f_S and/or
- non-zero value of A_{obs}

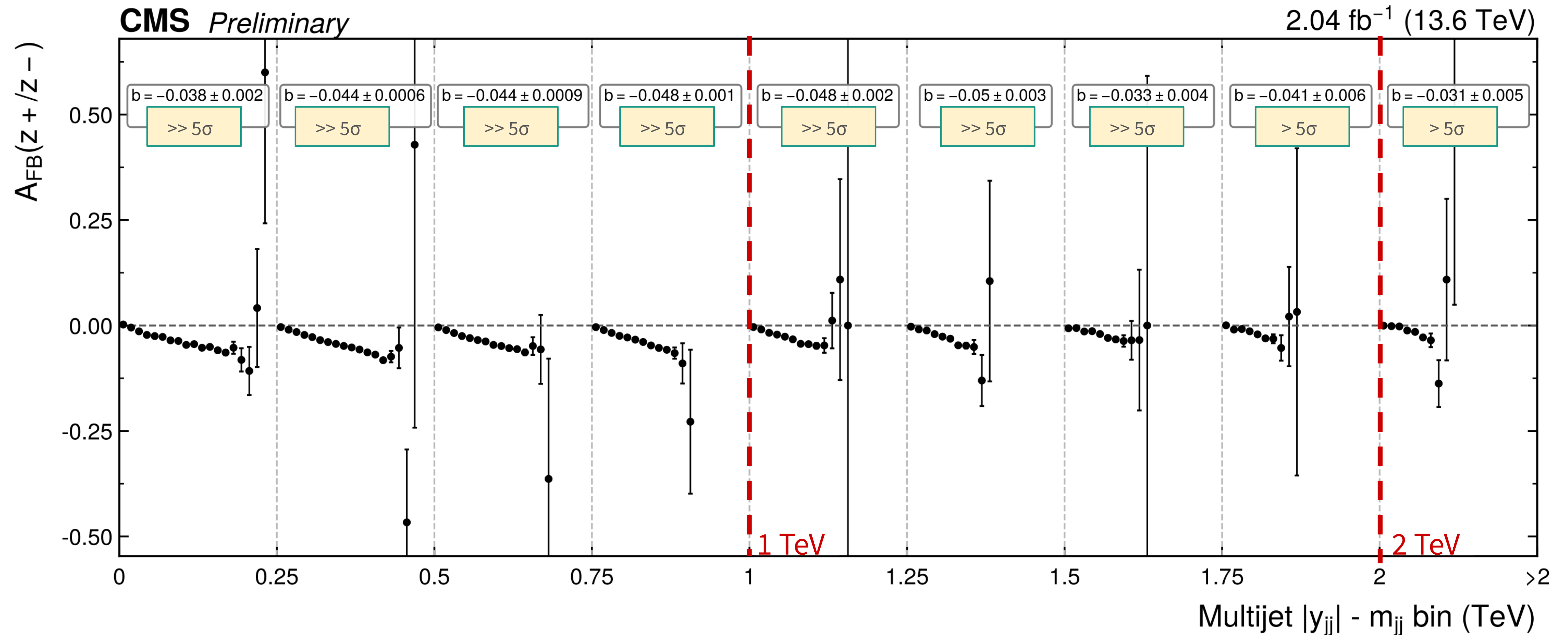
f_S is equal for W^+ and W^- but A_S differs by about 4σ

Clear evidence of kinematic effects on f_S and A_S

				
Channel	Category	f_S (%)	A_{obs}	A_S
Jet multiplicity				
Multijet	$N_{\text{jet}} = 2$	0.58 ± 0.02	-0.01443 ± 0.00010	-0.536 ± 0.021
Multijet	$N_{\text{jet}} = 3$	0.47 ± 0.02	-0.01242 ± 0.00009	-0.571 ± 0.027
Multijet	$N_{\text{jet}} \geq 4$	0.31 ± 0.02	-0.00958 ± 0.00009	-0.673 ± 0.049
W	$N_{\text{jet}} = 0$	1.13 ± 0.03	-0.01124 ± 0.00041	-0.221 ± 0.010
W	$N_{\text{jet}} = 1$	0.72 ± 0.04	-0.00640 ± 0.00091	-0.196 ± 0.030
W	$N_{\text{jet}} \geq 2$	0.41 ± 0.05	-0.00436 ± 0.00136	-0.229 ± 0.076
W boson charge				
W	W^+	1.03 ± 0.03	-0.01153 ± 0.00048	-0.248 ± 0.012
W	W^-	1.00 ± 0.03	-0.00805 ± 0.00054	-0.178 ± 0.013
Multijet invariant mass				
Multijet	$0.25 < m_{\text{MJ}} < 0.5 \text{ TeV}$	0.56 ± 0.02	-0.01381 ± 0.00008	-0.534 ± 0.021
Multijet	$0.5 < m_{\text{MJ}} < 1.0 \text{ TeV}$	0.42 ± 0.02	-0.01194 ± 0.00008	-0.612 ± 0.033
Multijet	$1.0 < m_{\text{MJ}} < 1.5 \text{ TeV}$	0.25 ± 0.02	-0.00905 ± 0.00016	-0.764 ± 0.069
Multijet	$1.5 < m_{\text{MJ}} < 2.0 \text{ TeV}$	0.13 ± 0.02	-0.00583 ± 0.00026	-0.981 ± 0.185
Multijet	$m_{\text{MJ}} > 2.0 \text{ TeV}$	0.01 ± 0.02	-0.00187 ± 0.00028	-3.779 ± 8.472

Asymmetry observed in the (multi-)TeV region

Negative slope = boost away from the tagged proton direction → observed up to $m(\text{multijet}) = 2 \text{ TeV}$!



Conclusion and Outlook

New Result! CMS-PAS-SMP-26-015 ([link](#))

First observation of TeV-scale jet production with an intact forward proton

First observation of Z production with an intact forward proton

First observation at the LHC of W production with an intact forward proton

+ determination of in-fiducial signal fractions and forward-backward asymmetries
(inclusive and differential) = *first measurement of this signature at 13.6 TeV,
probing previously unexplored phase space, extending to TeV-scale central systems*

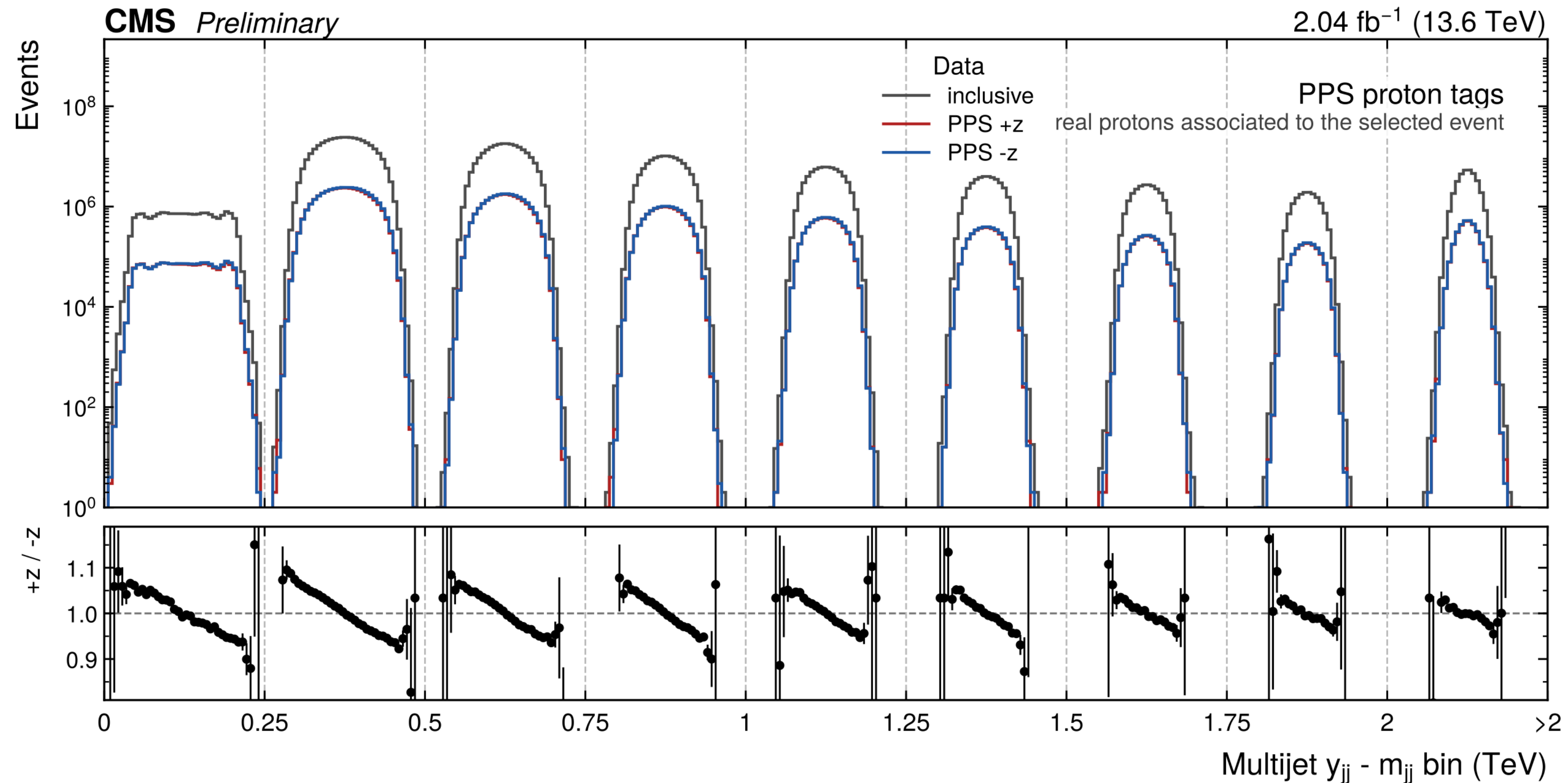
- First CMS result with the low-PU data set recorded in April 2026
- Quick result with fully data-based, model-independent methods, without requiring “diffraction-specific” signatures in the centrally reconstructed hard scatter event
>> opportunities for more detailed (soft QCD) follow-up studies, comparisons to model predictions, extension to other final states, etc

Stay tuned for other exciting results from the CMS 2026 low-PU data set !

Backup Slides

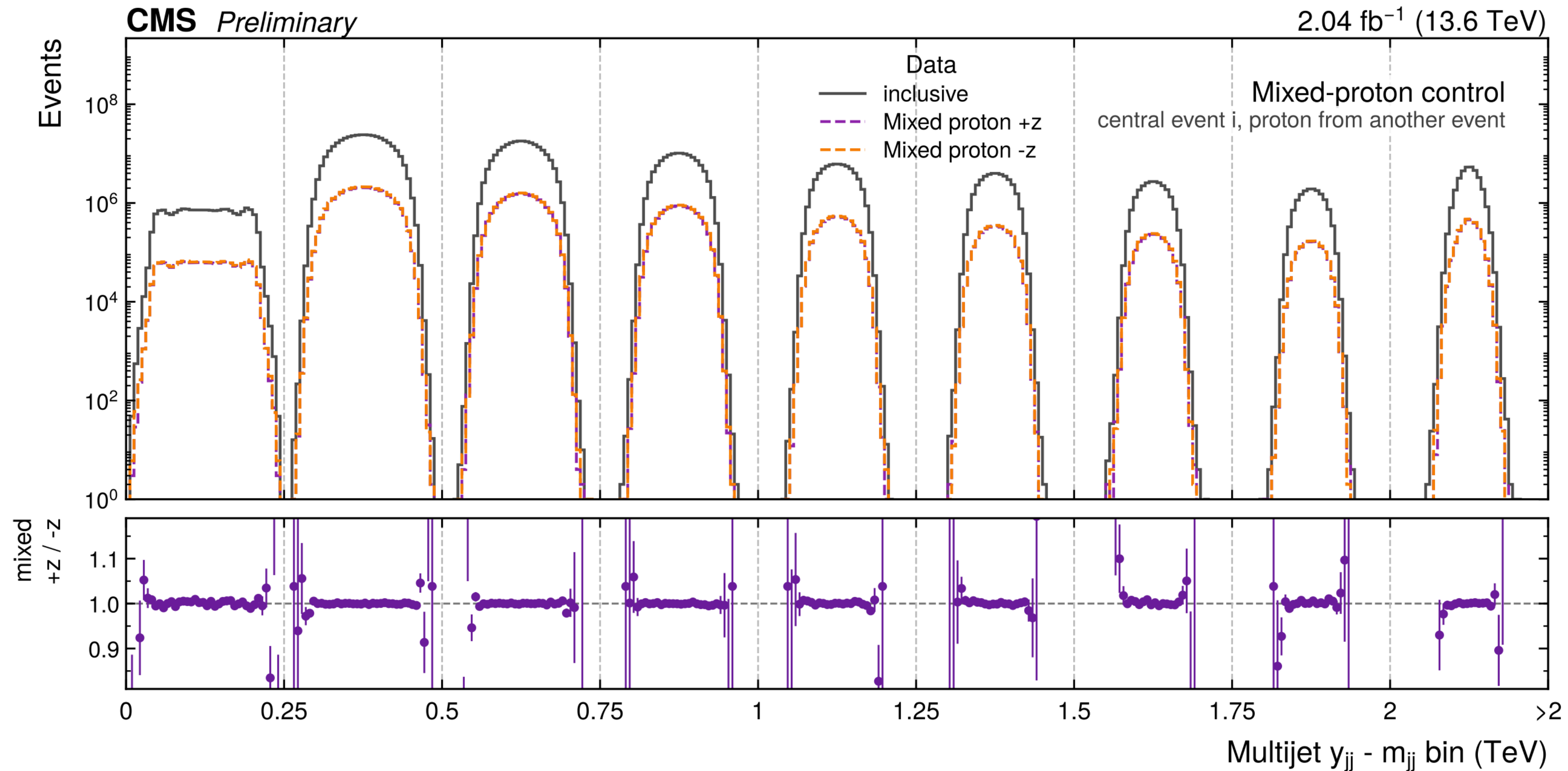
Asymmetry slope vs m(jets)

Multijet rapidity – ratio for events with proton $z>0$ / proton $z<0$



Asymmetry slope vs $m(\text{jets})$ – null test

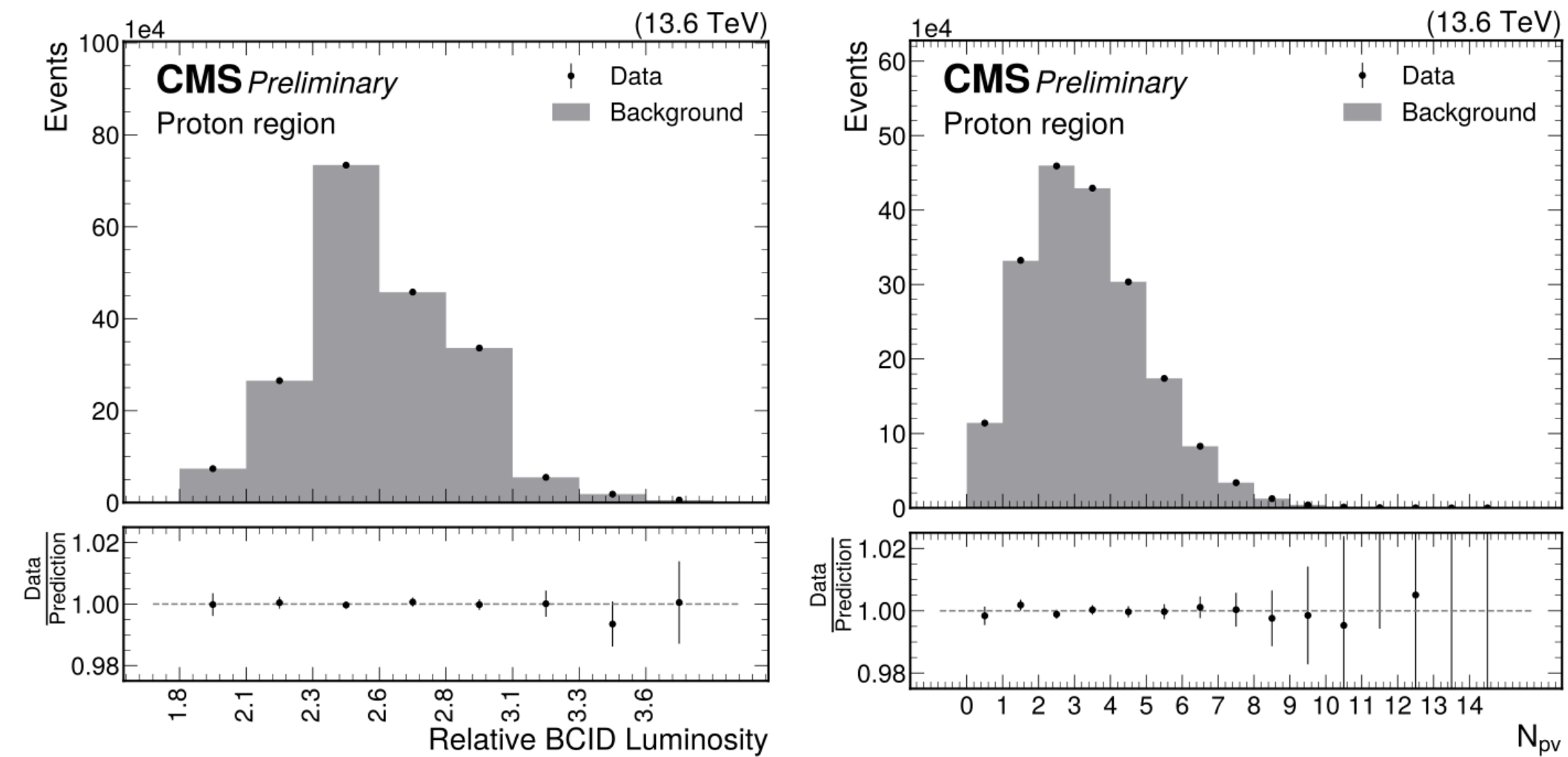
Multijet rapidity – ratio for events with proton $z>0$ / proton $z<0$ – **protons taken from different event**



Example signal fraction fits (run 402537)

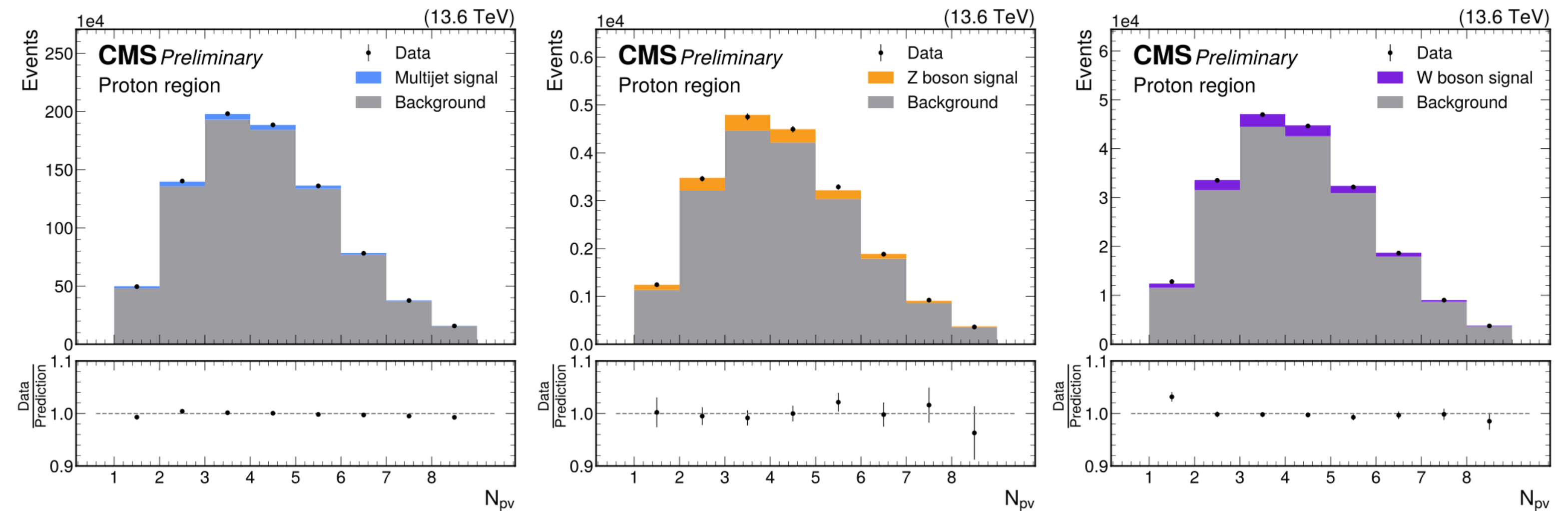
Fit with zero-bias data ----->

- To fix unknown model parameters



Fit in signal region ----->

- With background fixed
- To fit signal fraction



Asymmetry slope vs m(jets)

Predicted A_{obs} for multijet channel post-fit,
compared to data,
as a function of the estimated signal purity
in the proton-tagged sample:

- All runs included
- Good agreement is observed

