New for Diffraction and Low-x

First measurement of the photonuclear D^0 production in ultra-peripheral PbPb collisions with CMS

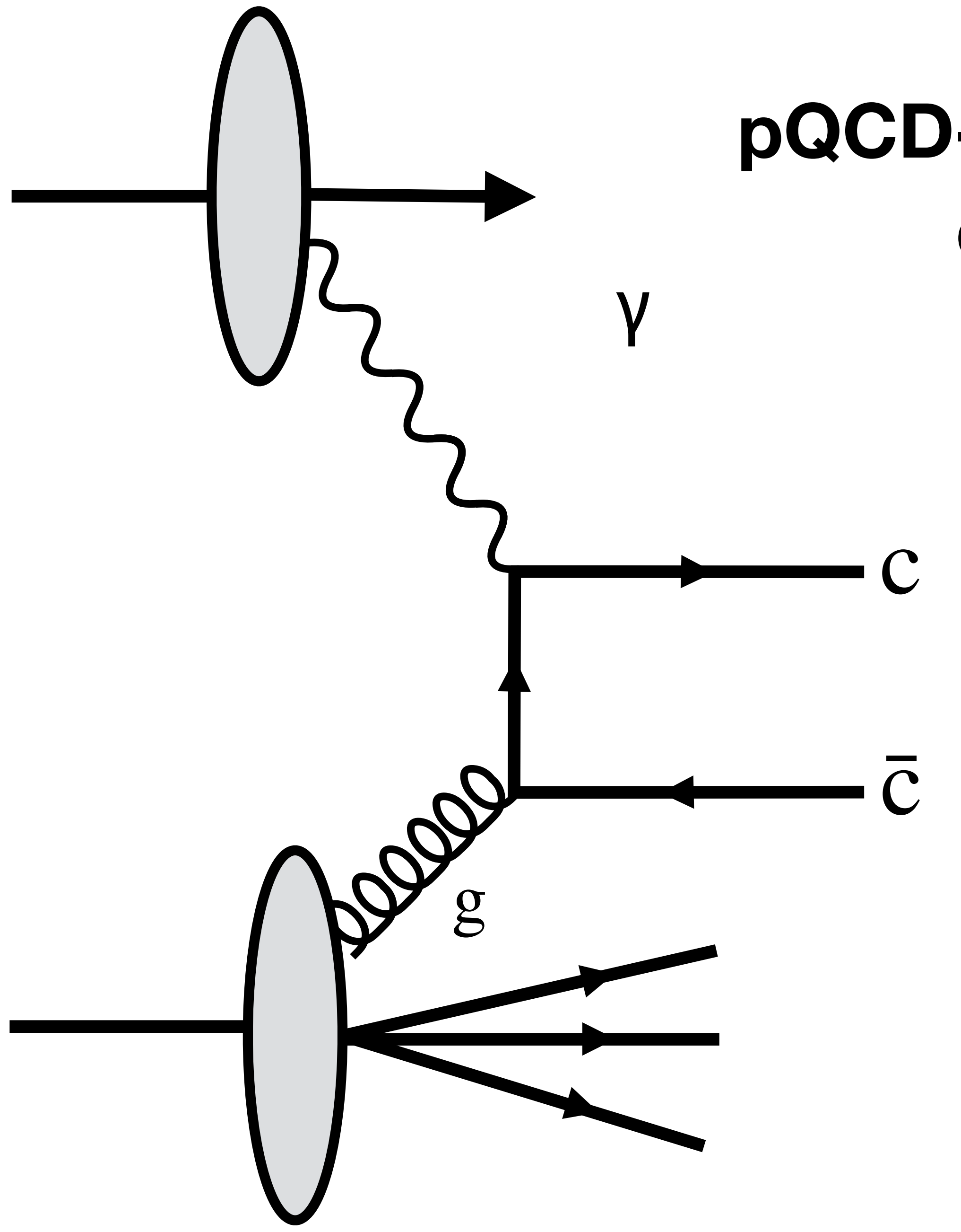
Diffraction and Low-x
Sep 8–14, 2024
Palermo (Italy)

Gian Michele Innocenti
Massachusetts Institute of Technology
on behalf of the CMS collaboration

Link to the PAS ***CMS-HIN-24-003***

“Open” heavy-flavor measurement in γN scatterings in UPCs

With a single probe, scan a large region of x and Q^2 (shadowing/saturation, anti-shadowing, and beyond)
→ “combine” the low-x, Q^2 reach of J/ψ exclusive measurements with the kinematic coverage of dijet measurements **(see Brian’s talk)**

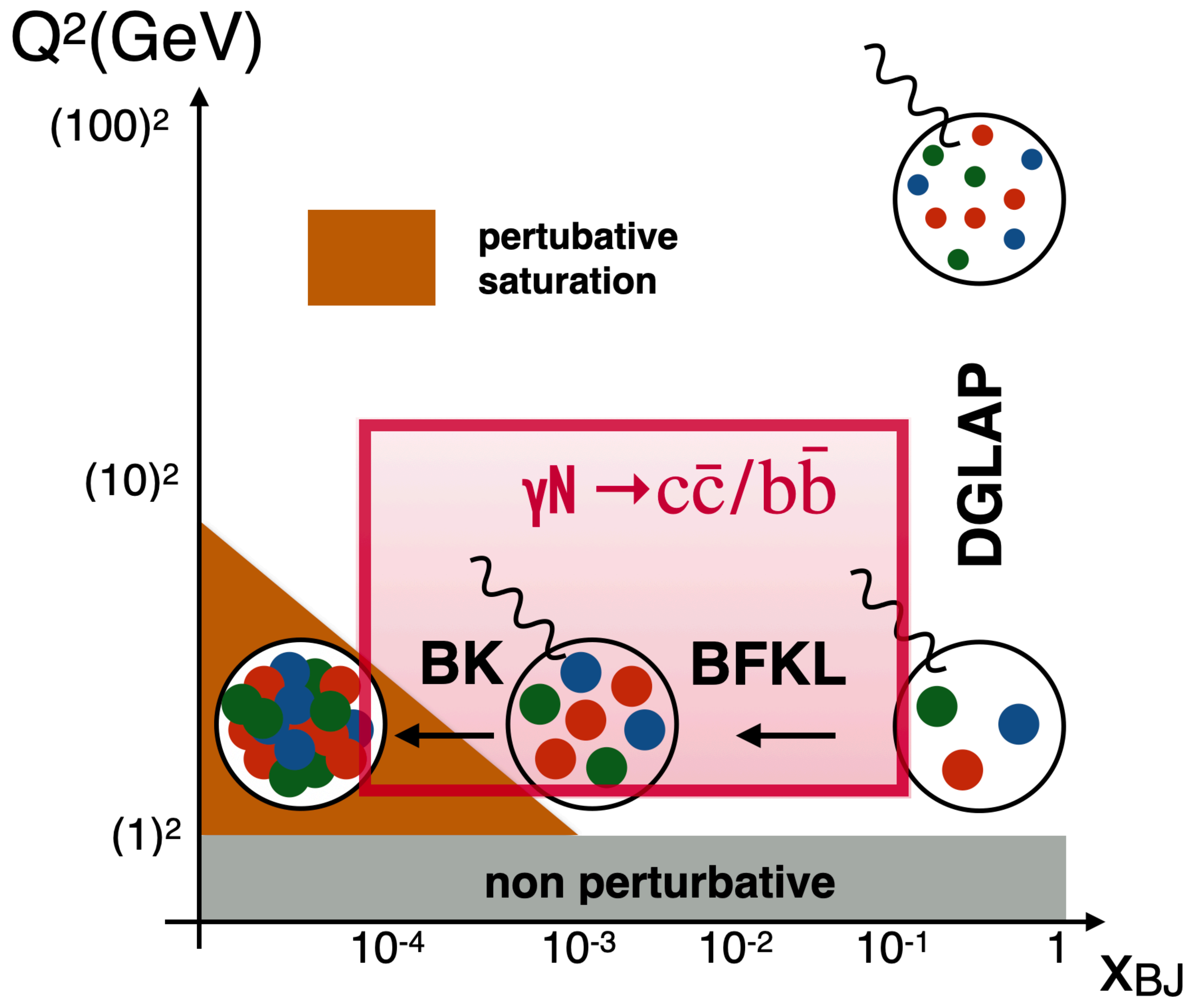


pQCD-based description
down to p_T=0

Good experimental control on the hadronic final states **from high to low p_T**

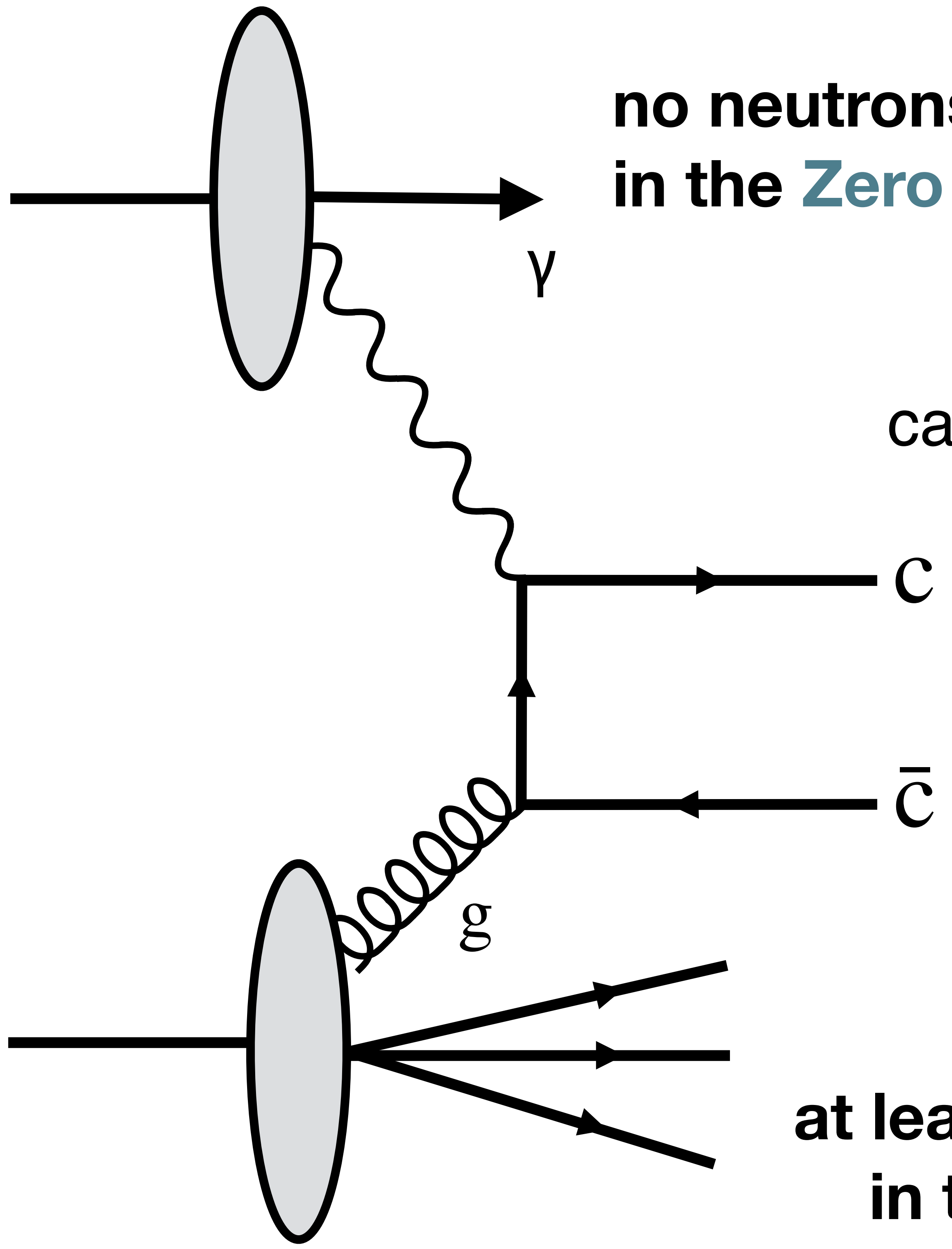
Clean experimental condition, limited final state effects (e.g. flow or beyond-vacuum hadronization)

No ambiguity of the incoming photon direction



ATLAS, ATLAS-CONF-2017-011
S. Klein, R. Vogt et al: Phys. Rev. C, v66, 2002

Experimental strategy and signal definition



no neutrons (0n)
in the Zero Degree Calorimeter (ZDC)

Rapidity gap in the hadronic forward calorimeter (HF) in the photon-going direction

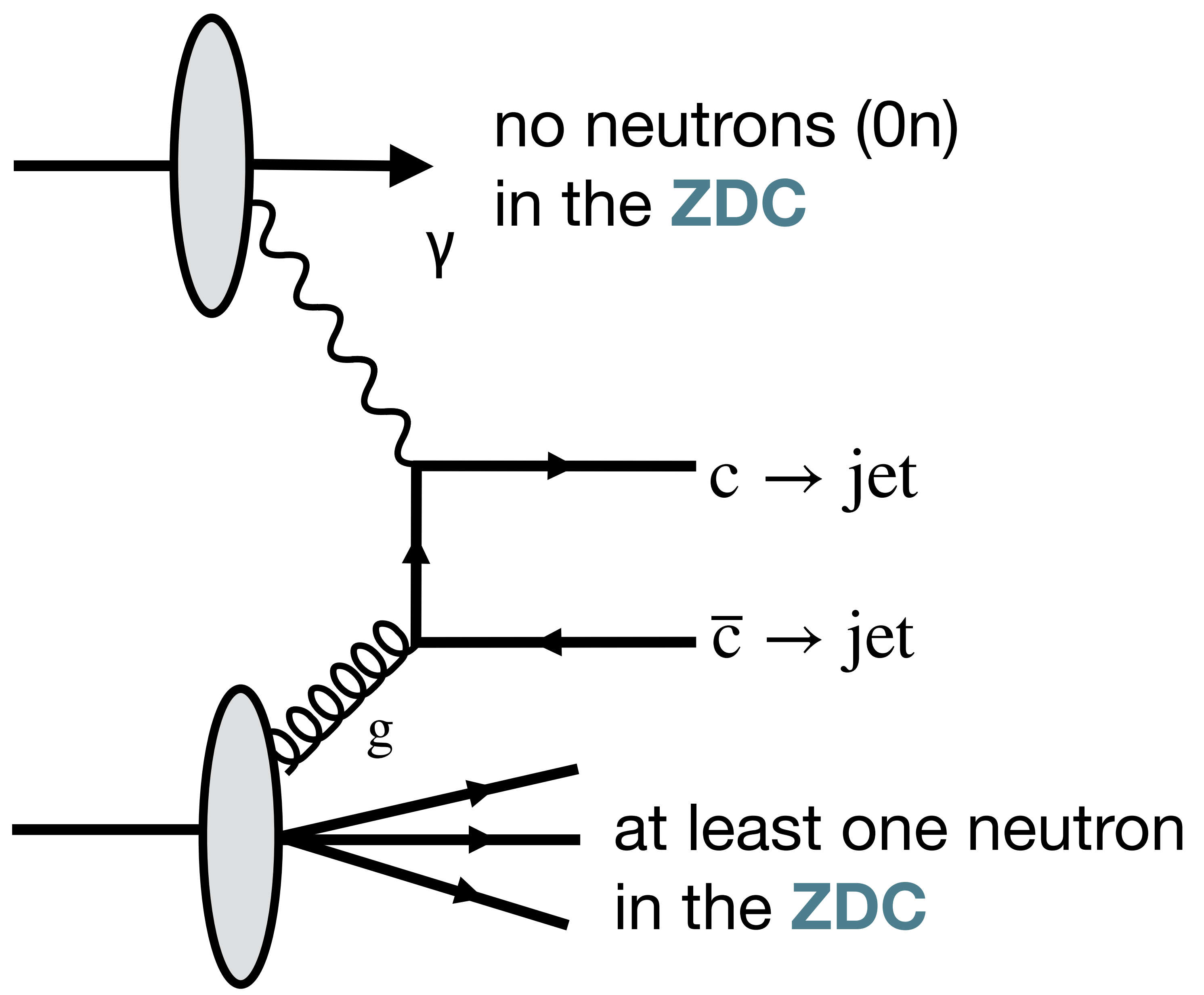
$D^0 \rightarrow K^-\pi^+$ with charged tracks in the tracker

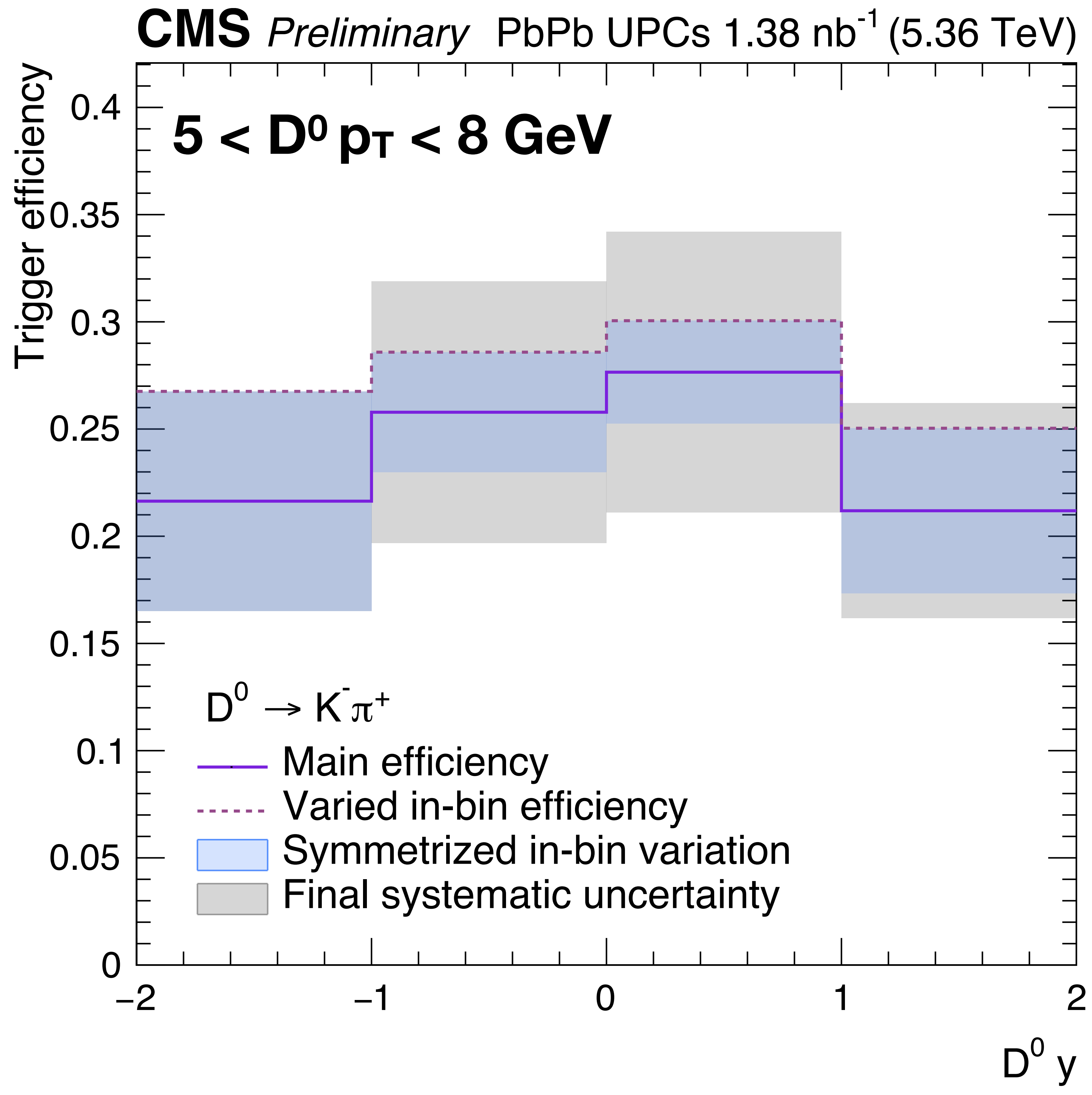
at least one neutron
in the ZDC (Xn)

"Semi-inclusive" photonuclear production in Xn0n with a large rapidity gap on the γ-going side
- **dominated by non-diffractive photoproduction** (due to the requirement on the broken nucleus)
- includes both direct and resolved-photon events, prompt ($c \rightarrow D^0$) and non-prompt ($c \rightarrow D^0$) contributions

New trigger strategy for heavy-quark photonuclear events

→ **signals from electromagnetic/hadronic calorimeters (HCAL/ECAL) combined with ZDC at Level-1 (hardware triggers)**
(ZDC for the first time used as L1-trigger detector in CMS)



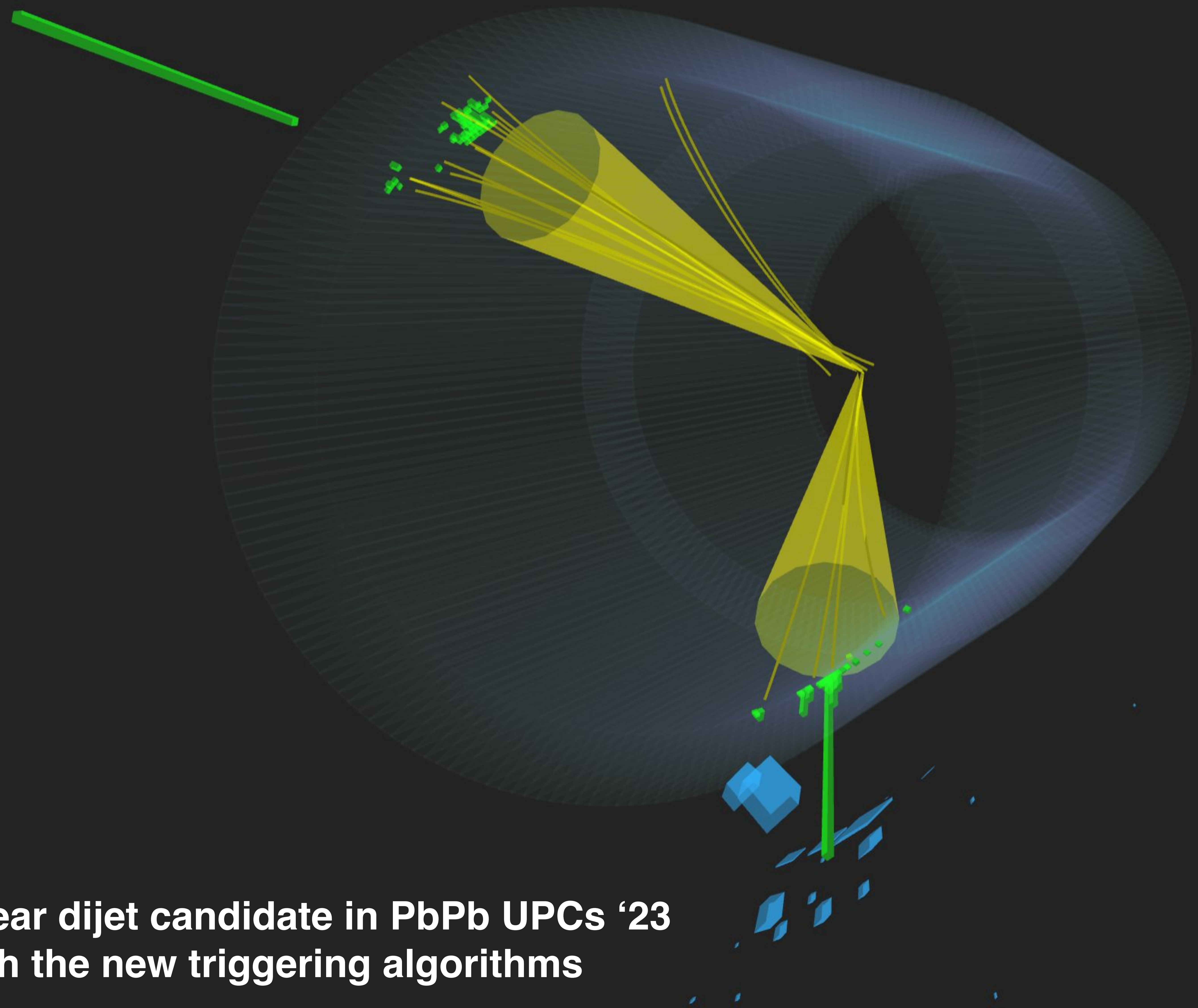


For low-p_T D^0 mesons (< 5 GeV)
→ at least one ZDC with >1n signal (**ZDCOR)**

For high-p_T D^0 mesons (> 5 GeV)
→ **ZDCOR in coincidence with a Level-1 jet** (E_{jet} > 8 GeV)

"Data-driven" trigger efficiency vs D^0 p_T and y
→ **Good control of the trigger efficiency**
also for low p_T D^0 mesons (p_T>5 GeV)

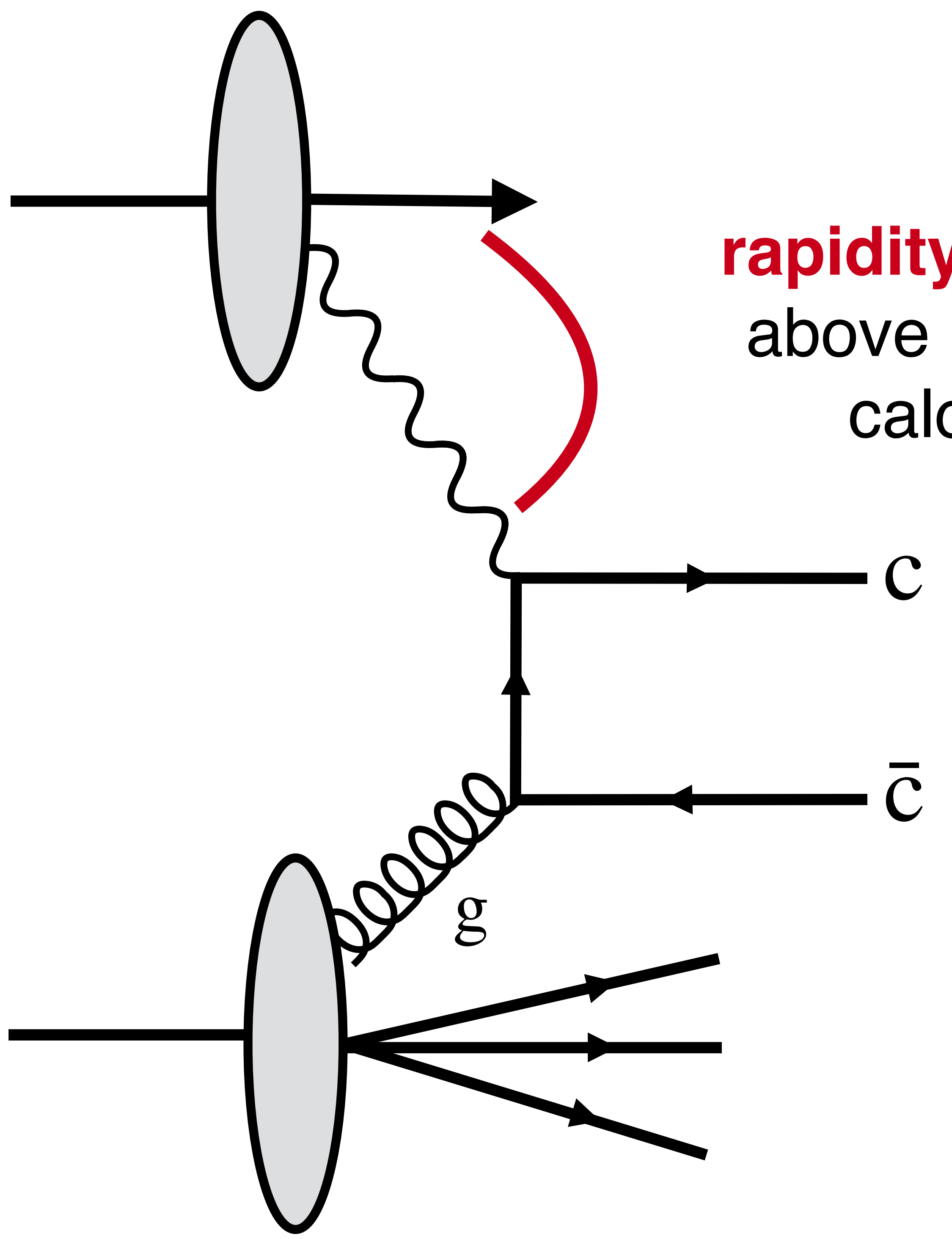
CMS Experiment at the LHC, CERN
Data recorded: 2023-Oct-10 05:24:04.000512 GMT
Run / Event / LS: 374925 / 591414336 / 646



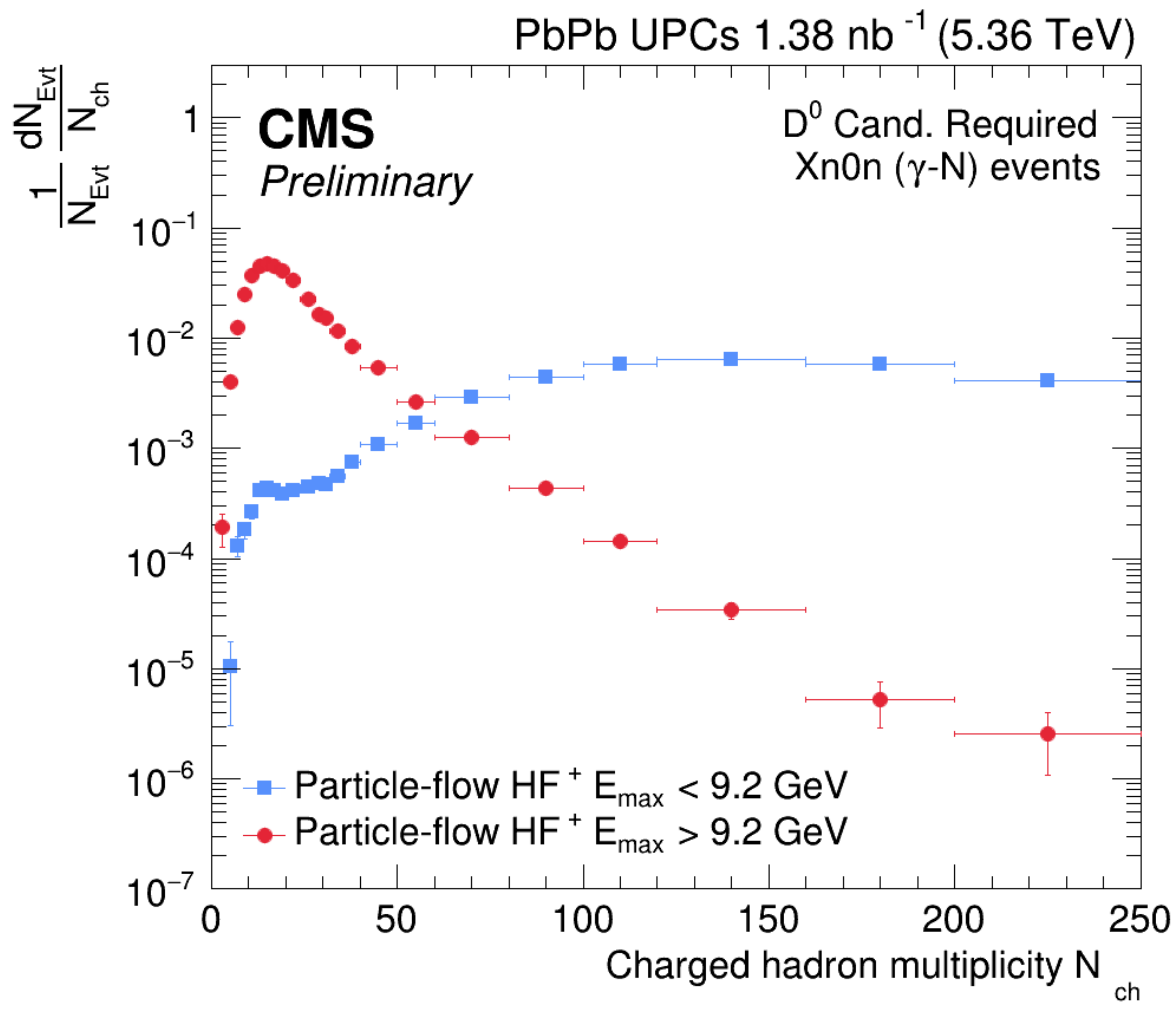
Clean dijets events with negligible underlying QCD background

A photonuclear dijet candidate in PbPb UPCs ‘23 collected with the new triggering algorithms

Rapidity gap selection



rapidity gap condition no deposit above E^{th} in the forward hadronic calorimeter (**3.0 < η < 5.2**)



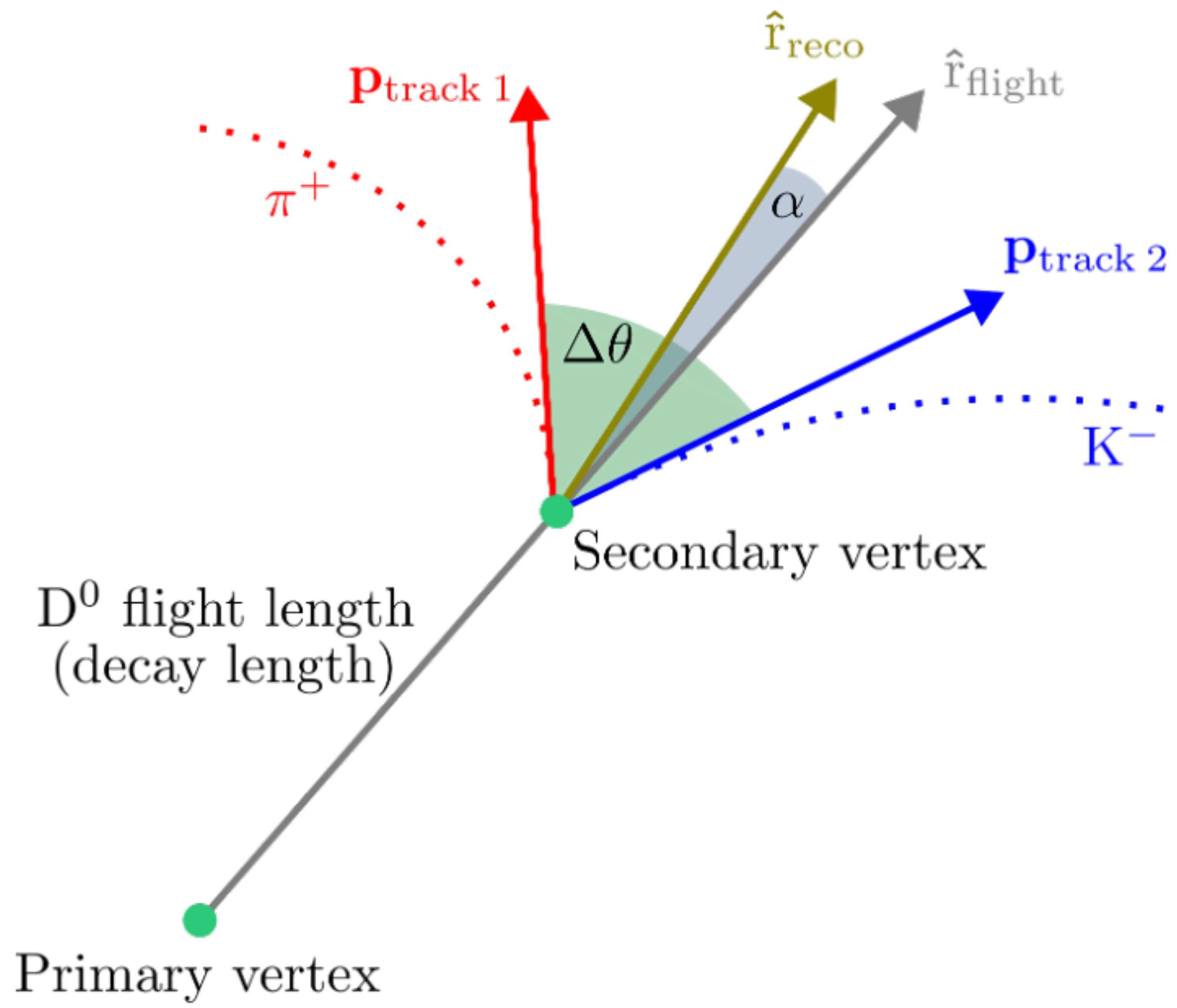
Events passing the rapidity gap condition
Events failing the rapidity gap condition (high N_{ch})
(mostly coming from "hadronic" PbPb collisions)

- **Event selection efficiency ε_{evt} > 98% for both direct-photon and resolved-photon events**
- With simultaneous requirements on ZDC Xn0n and rapidity gap
  → **negligible contamination from "hadronic" events**

D^0 reconstruction and yield-extraction

D^0 candidate reconstruction and selection:

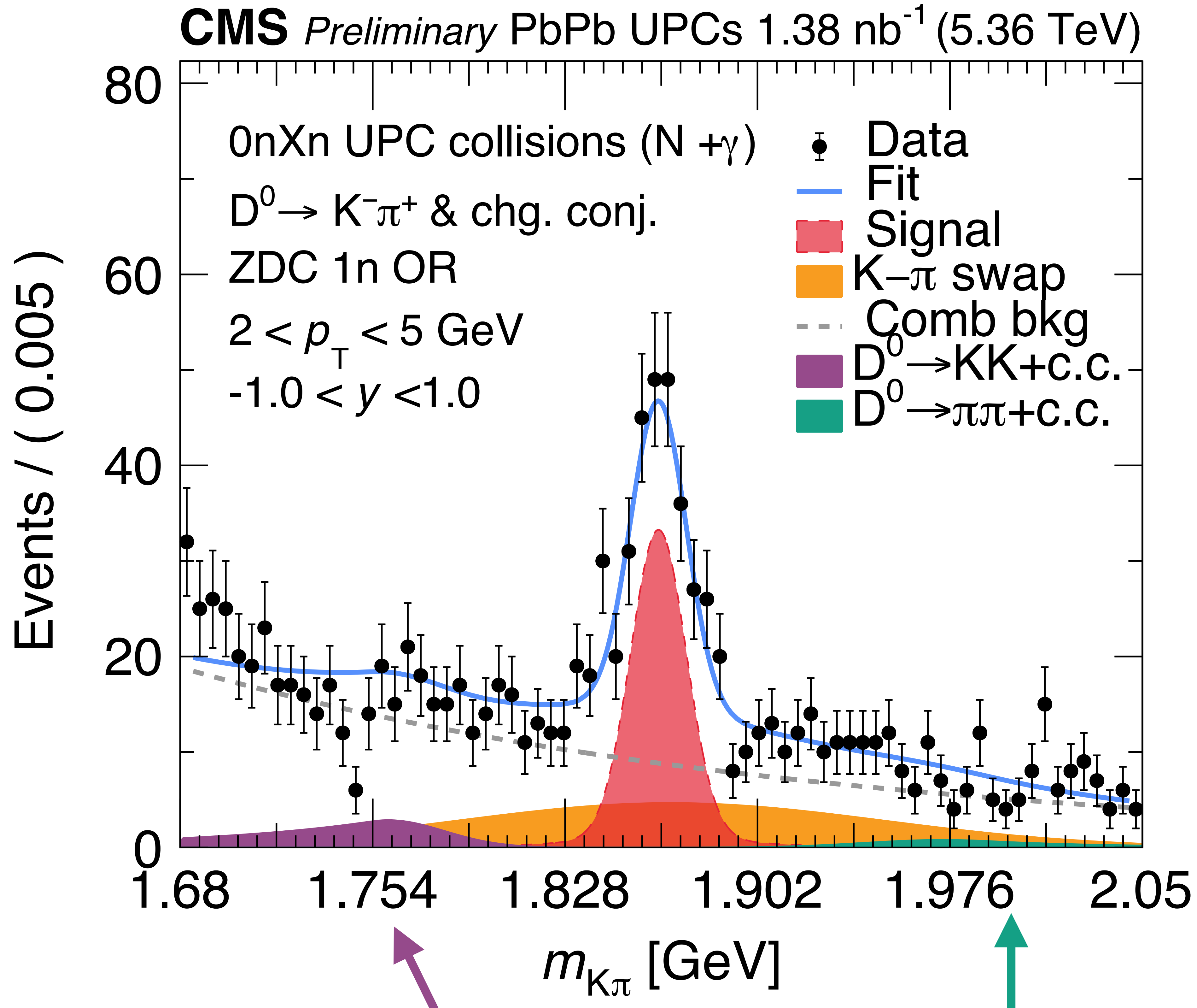
→ topological selection optimized in bins of D^0 p_T and rapidity



- pointing angle (α)
- decay length normalized to its error (d_0)
- D^0 vertex probability
- opening angle between the D^0 daughter prongs

Fitting strategy:

- exponential function to model the combinatorial background
- **double Gaussian to model the signal**
- **"wide" Gaussian shape** for candidates with the "swapped" mass hypothesis



Crystal Ball functions to model the contribution from $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ decays

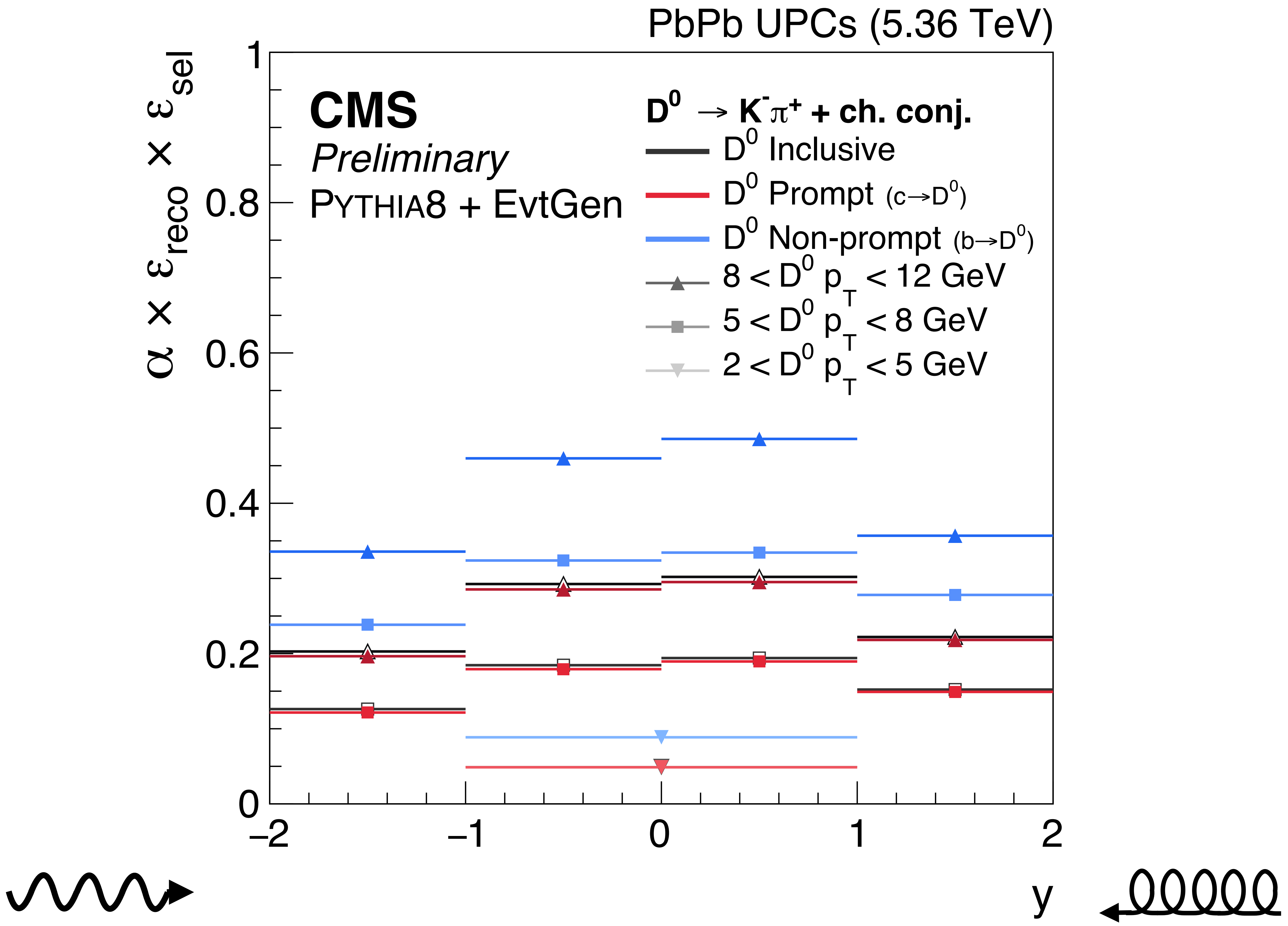
Invariant mass distributions in intervals of D^0 p_T and y

- $2 < p_T < 5$ GeV in the rapidity bin $-1 < y < 1$
- $5 < p_T < 8$ GeV with rapidity boundaries [-2, -1, 0, 1, 2]
- $8 < p_T < 12$ GeV with rapidity boundaries [-2, -1, 0, 1, 2]

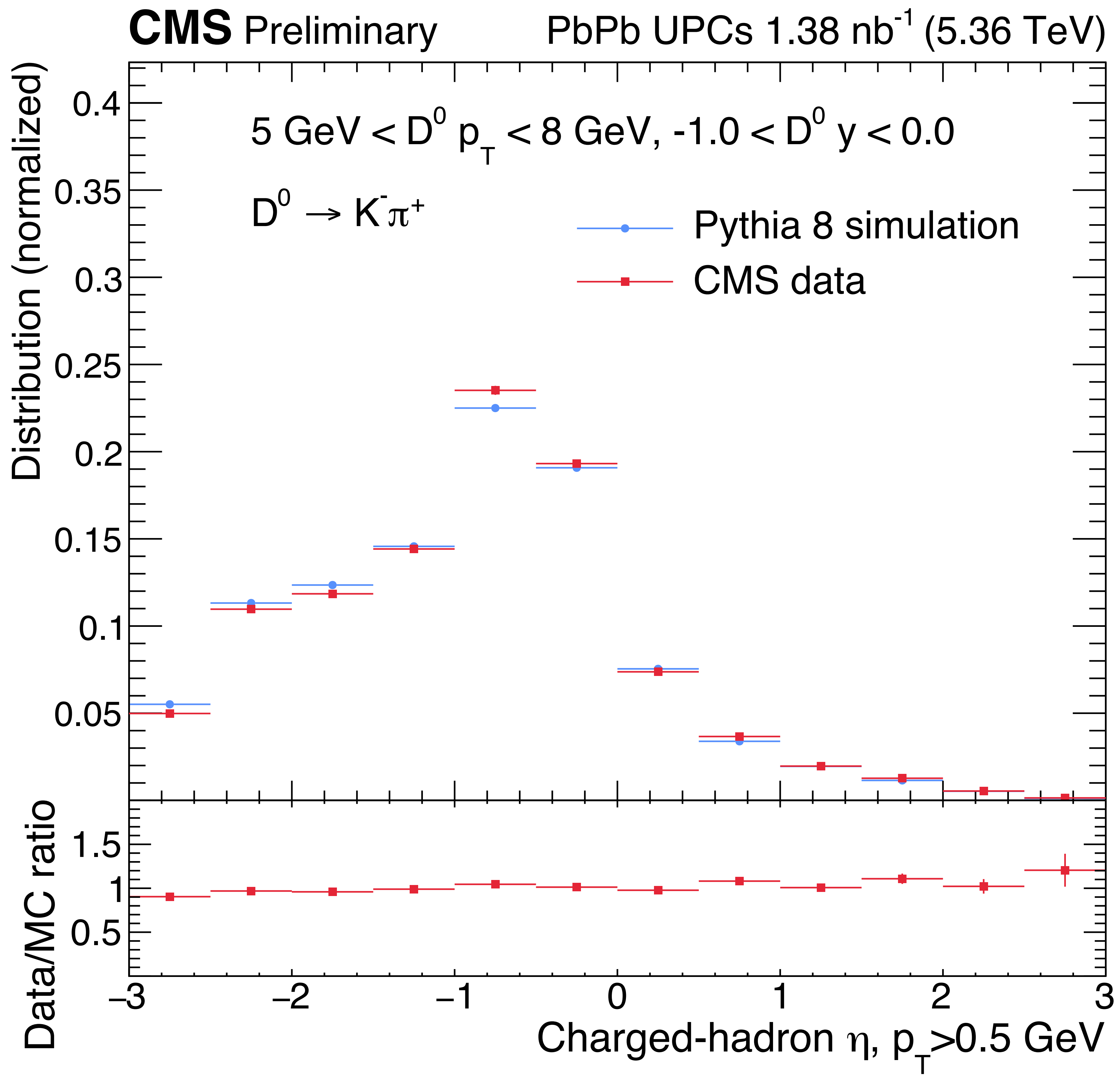
D^0 reconstruction and selection efficiencies

I. Helenius arXiv:1806.07326
K. J. Eskola et al.,, arXiv.2112.12462v2

Monte Carlo samples based on Pythia 8 + EvtGen γN events with EPPS21Pb nPDF parametrization



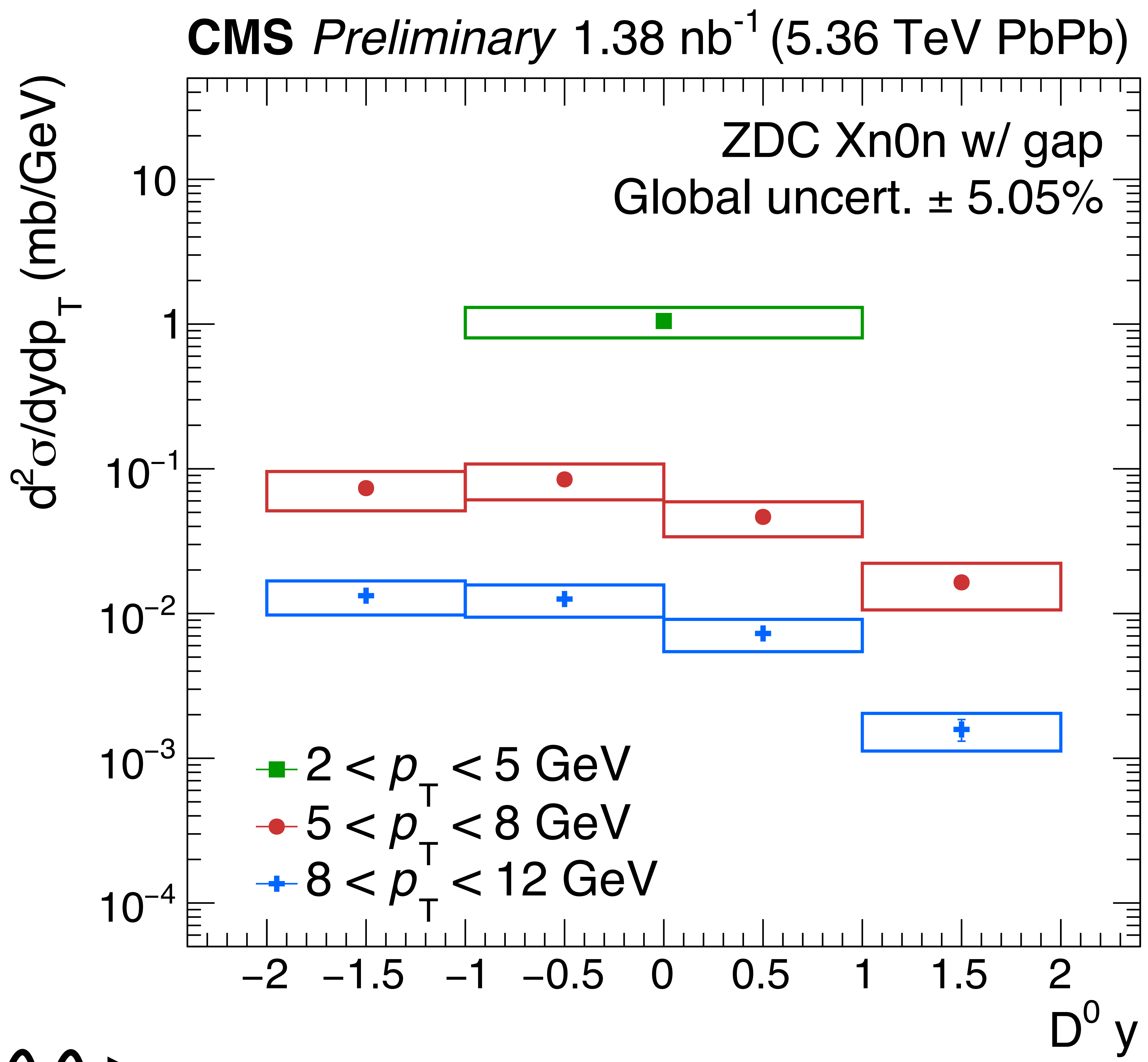
D^0 efficiencies strongly dependent on p_T and y:
due to acceptance, primary/secondary vertex resolution, topological selections



Pythia 8 γN simulations provides a very good description of the data distributions

$d\sigma/dp_T dy$ for photonuclear D^0 production in UPC collisions

New for Diffraction and Low-x

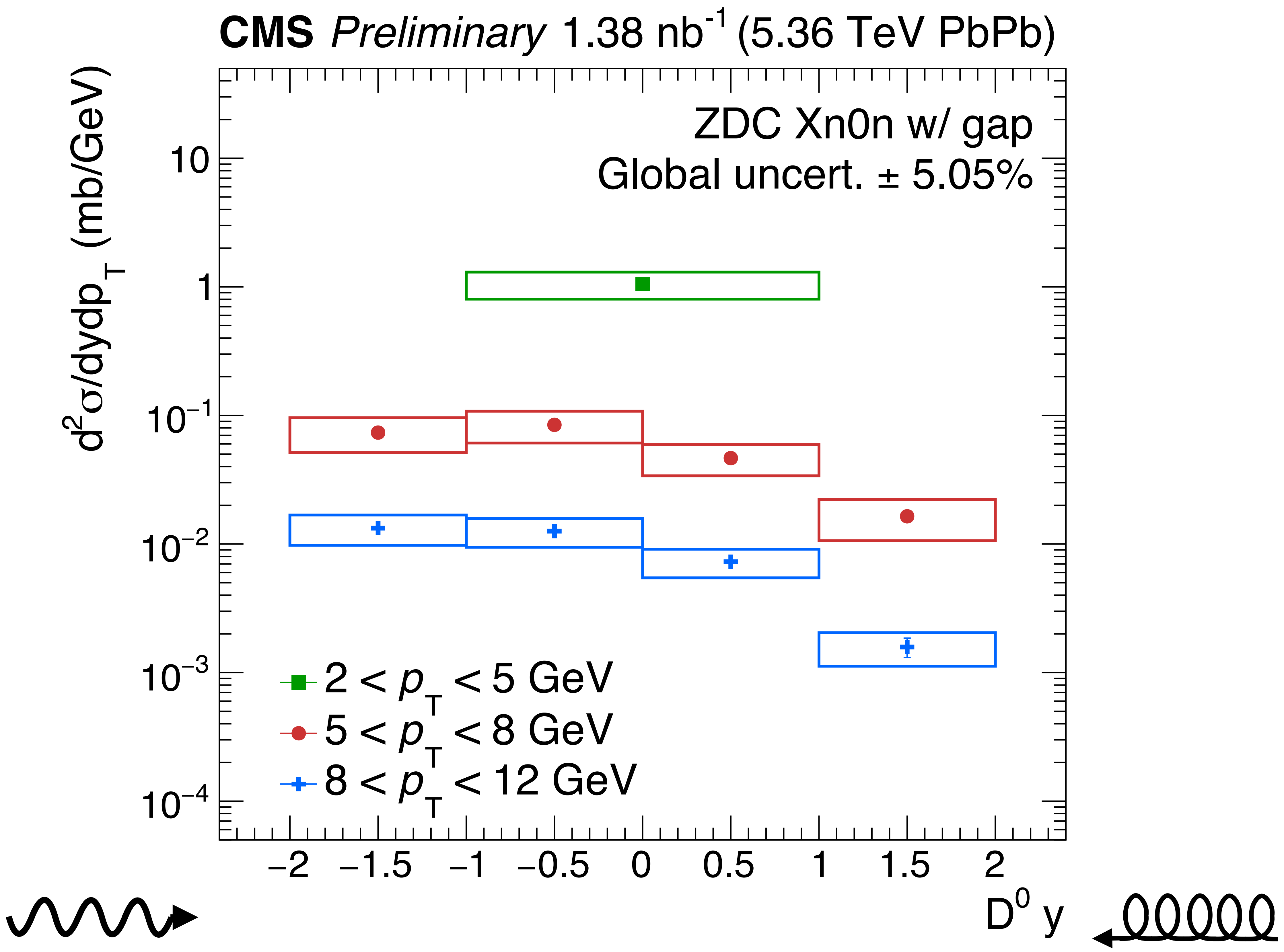


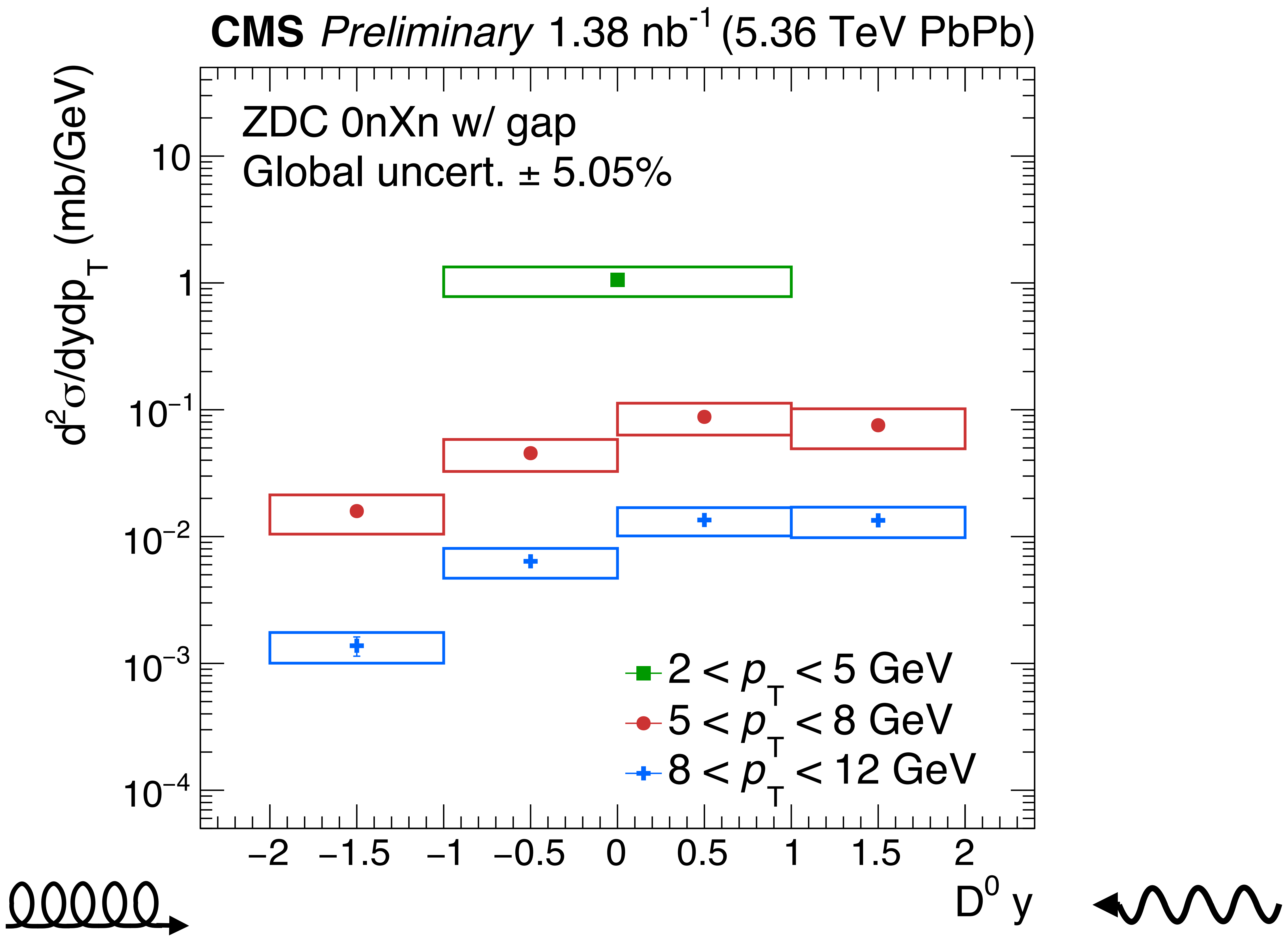
$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{2}\frac{1}{\mathscr{L}_{int}\ P_{\text{trig,presc}}\ BR^{D^0\to K^-\pi^+}}\frac{N^{\text{raw}}_{D^0+\bar{D}^0}}{\Delta p_T \Delta y}\frac{1}{\epsilon_{\text{evt}}\ \epsilon_{\text{trigger}}\ \epsilon^{tot}_{D^0}\ \epsilon_{EMpileup}}$$

Main sources of systematic uncertainties:

- **trigger correction** (for p_T> 5 GeV)
- **rapidity-gap condition**
- **D^0-selection efficiency, mostly driven by MC-data differences in:**
  - distributions of selection variables
  - multiplicity, p_T/y shape,
  - fraction of prompt/non prompt D^0, resolved vs direct photon events
- **Yield-extraction and modeling of the peaking backgrounds**

$d\sigma/dp_T dy$ for photonuclear D^0 production in UPC collisions





Xn0n and 0nXn cross section are first measured separately

→ clear rapidity dependence of the D^0 cross-section with respect to the incoming photon direction

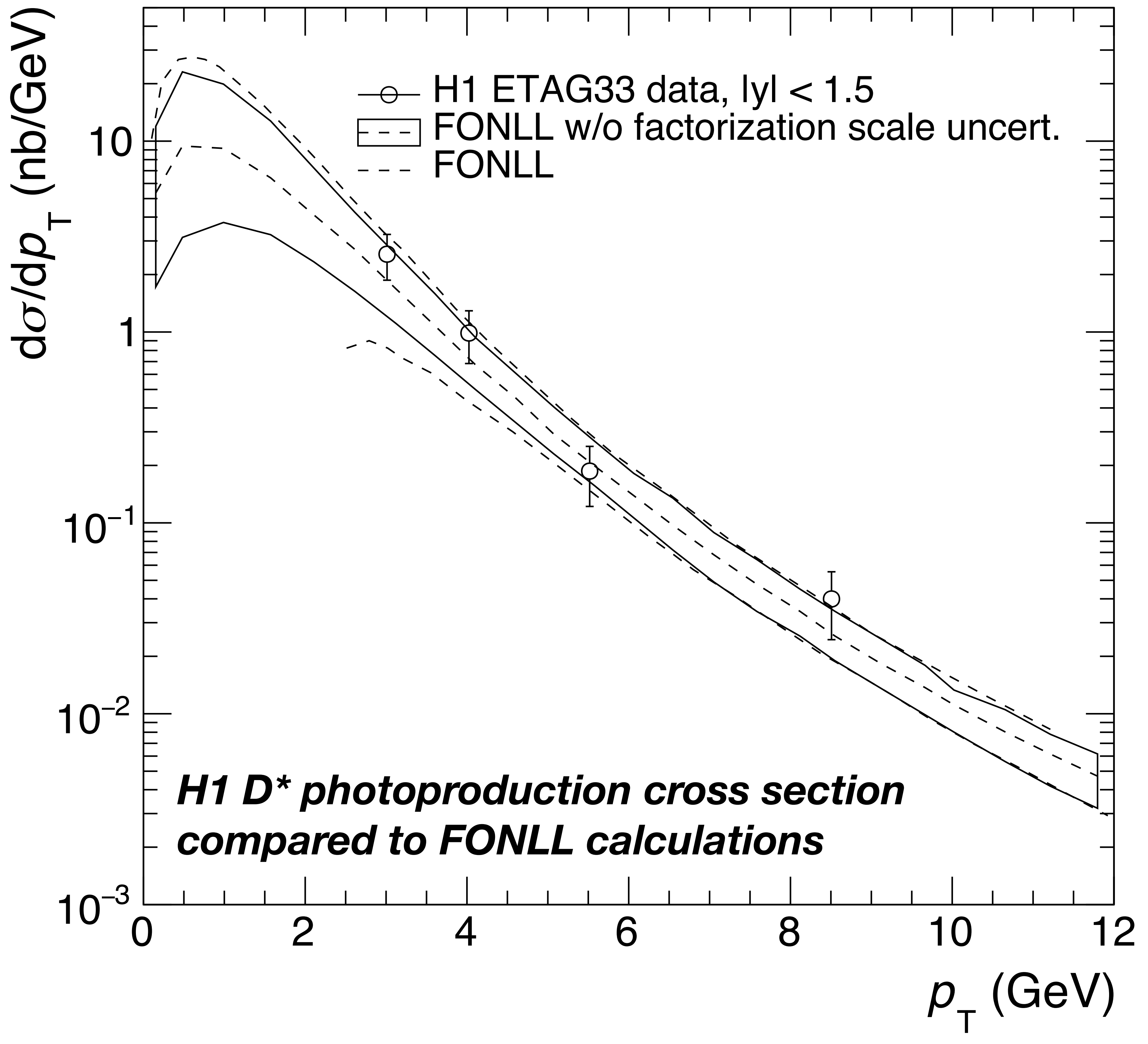
and then combined by symmetrizing the 0nXn measurement

$$\frac{d^2\sigma}{dp_T dy}_{\text{Xn0n tot}} = \frac{d^2\sigma}{dp_T dy}_{\text{Xn0n}} + \frac{d^2\sigma}{dp_T dy}_{\text{0nXn}} (y \rightarrow -y)$$

“Building” FONLL-based predictions for D^0 in UPCs at the LHC

FONLL for prompt inclusive charm photoproduction
→ *full agreement with existing predictions for ZEUS/H1*

*FONLL predictions developed with **Anna Maria Stasto**, based on the original code for photonuclear heavy-flavor production*
(paper in preparation)



S. Frixione, P. Nason, JHEP 0203 (2002) 053
M. Cacciari, M.Greco and P. Nason, JHEP 9805:007,1998

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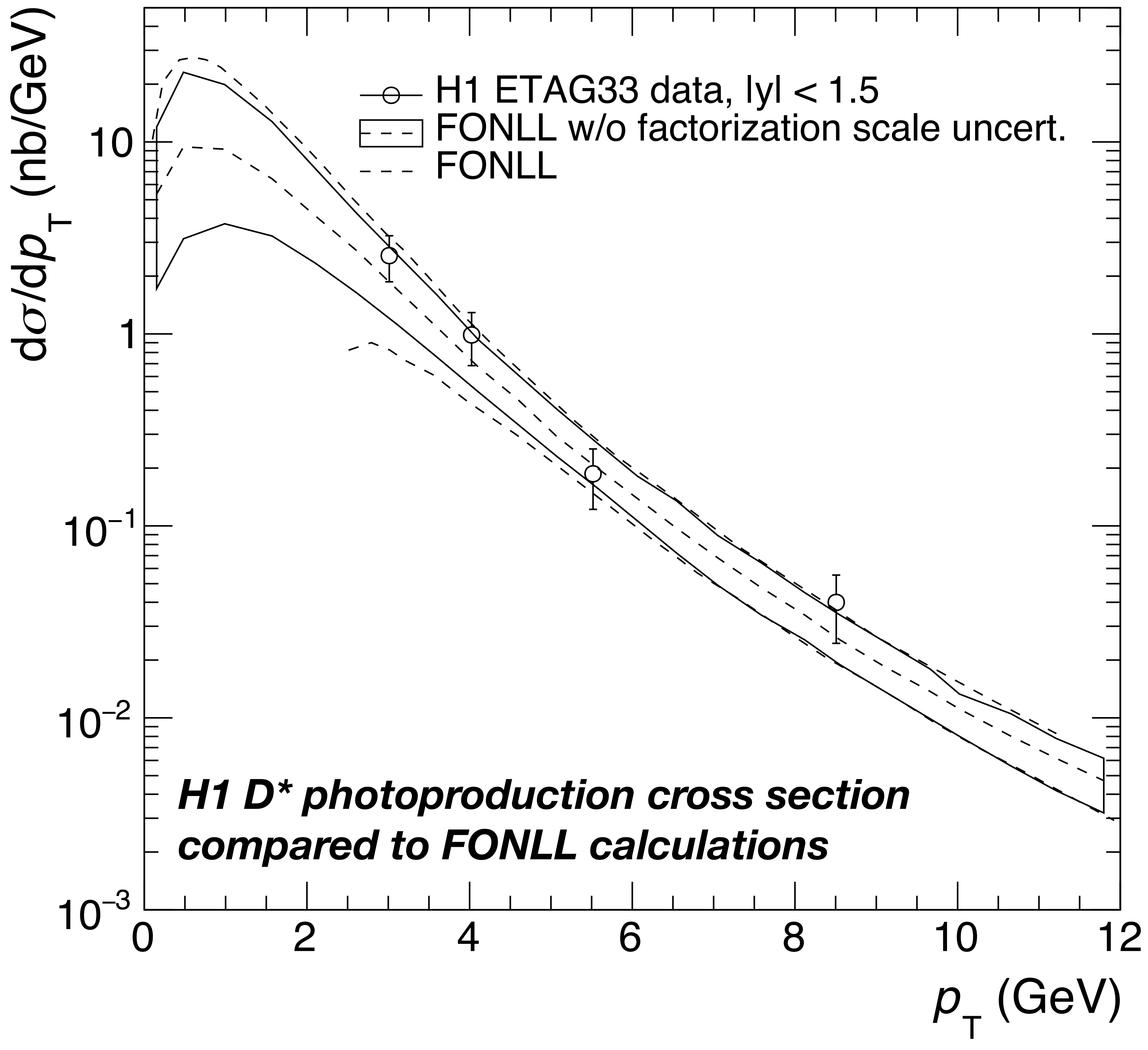
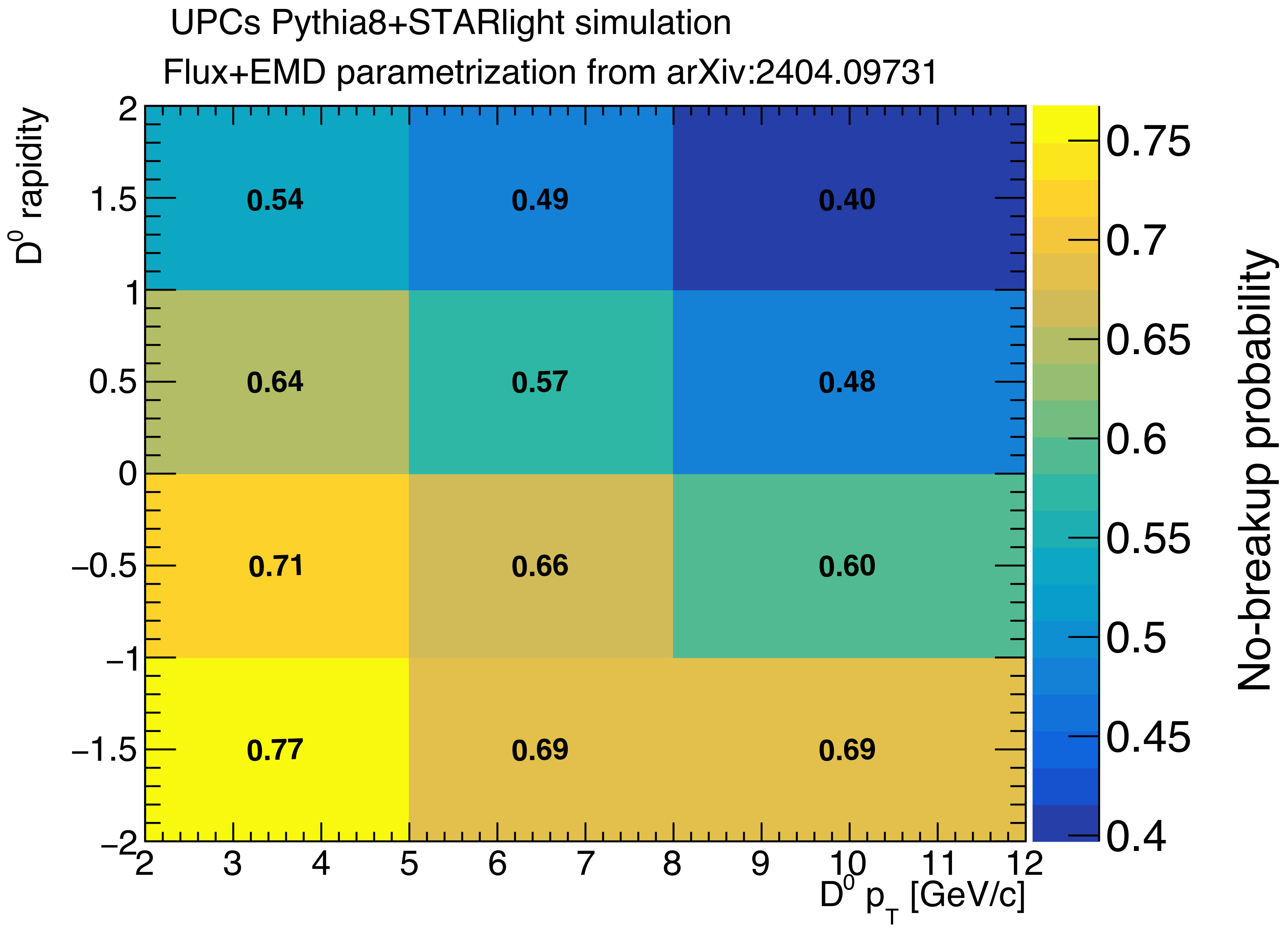


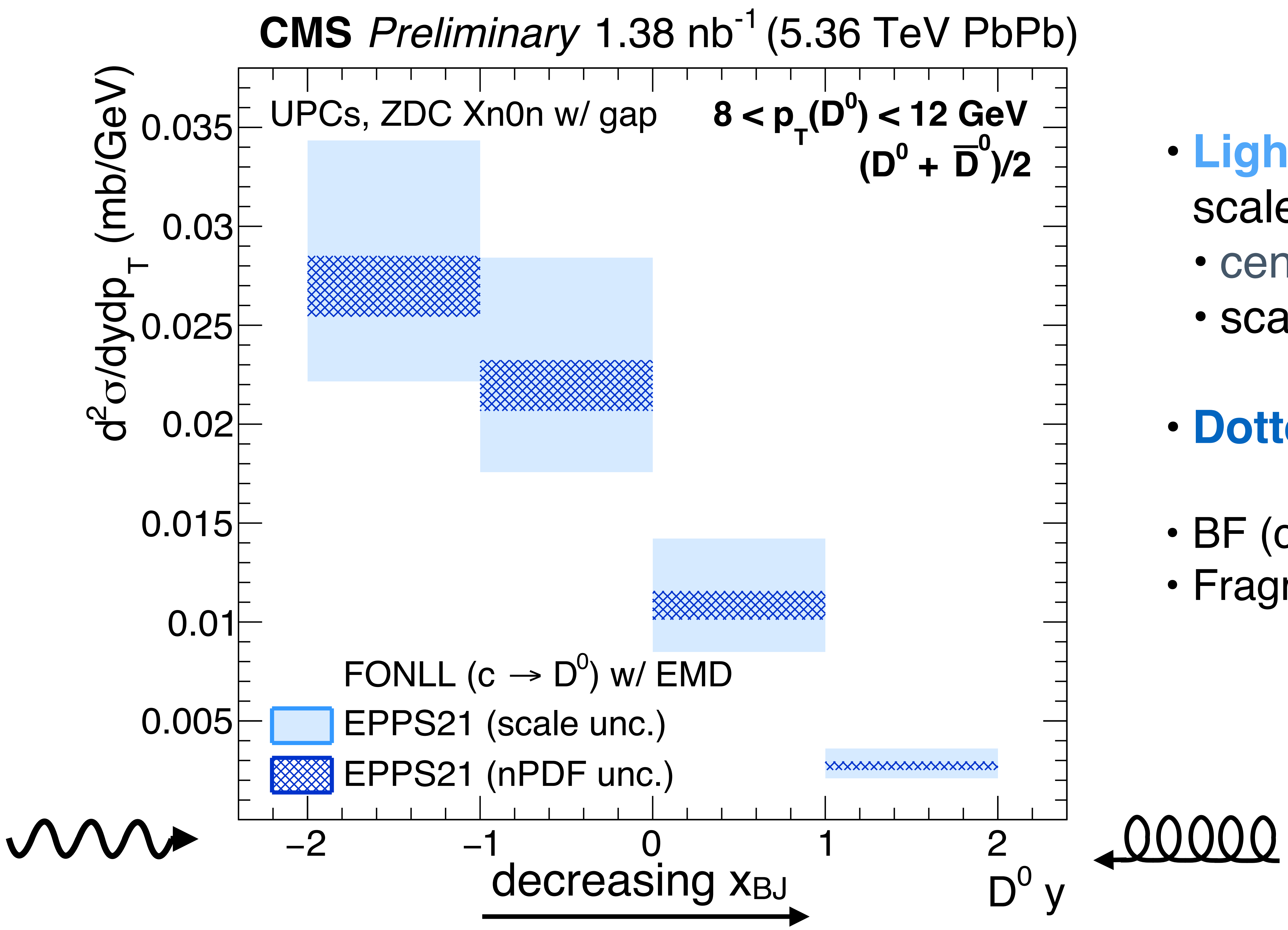
Reweight photon flux to match those expected in UPCs



Multiply for the predicted Xn0n "survival" probability in the presence of EM dissociation (EMD)
- estimated by reweighting gen-level Pythia events by the EMD-corrected photon flux for 0nXn topologies

ATLAS, ATLAS-CONF-2017-011
K. J. Eskola et al., https://arxiv.org/pdf/2404.09731

FONLL with EPPS21 nPDFs



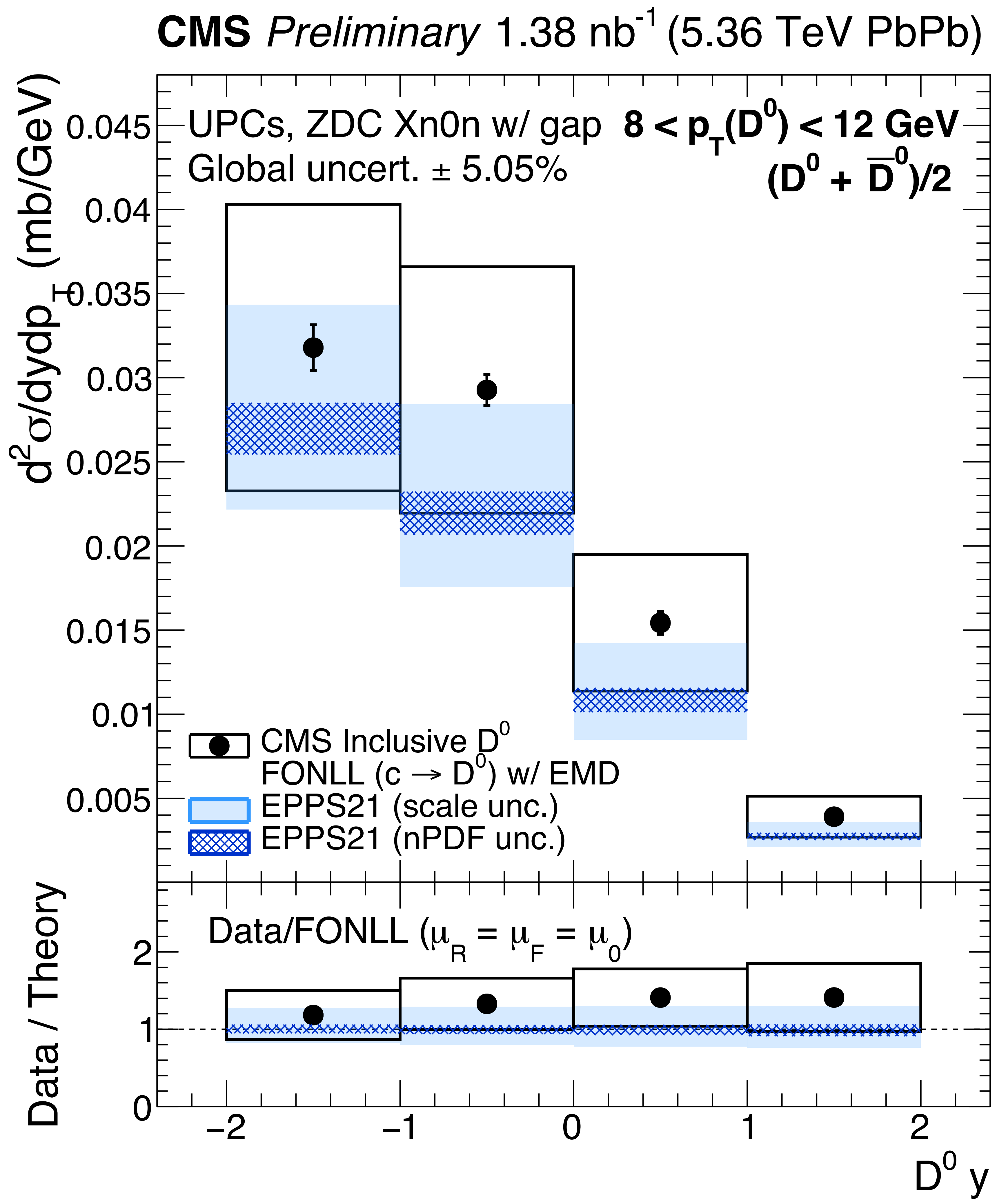
- **Light blue band**: prompt FONLL predictions for inclusive photoproduction with scale variations
  - central values: μ_R/μ_0=1 μ_F/μ_0=1, $\mu_0 \sim m_T$
  - scale variation only ($0.5 < \mu_R/\mu_0 < 2.0$, $0.5 < \mu_F/\mu_0 < 2.0$)

- **Dotted blue band**: EPPS21Pb nPDF uncertainty only

- BF ($c \rightarrow D^0$) = 0.577 as measured in ep, ee data.
- Fragmentation function based on BFCY01 r=0.1 parametrization

K. J. Eskola et al.,, arXiv.2112.12462v2
A.M. Stasto et al., paper in preparation

Comparison with FONLL with EPPS21 nPDFs



- **CMS D^0 ($c \rightarrow D^0$ and $b \rightarrow D^0$) Xn0n with rapidity gap**

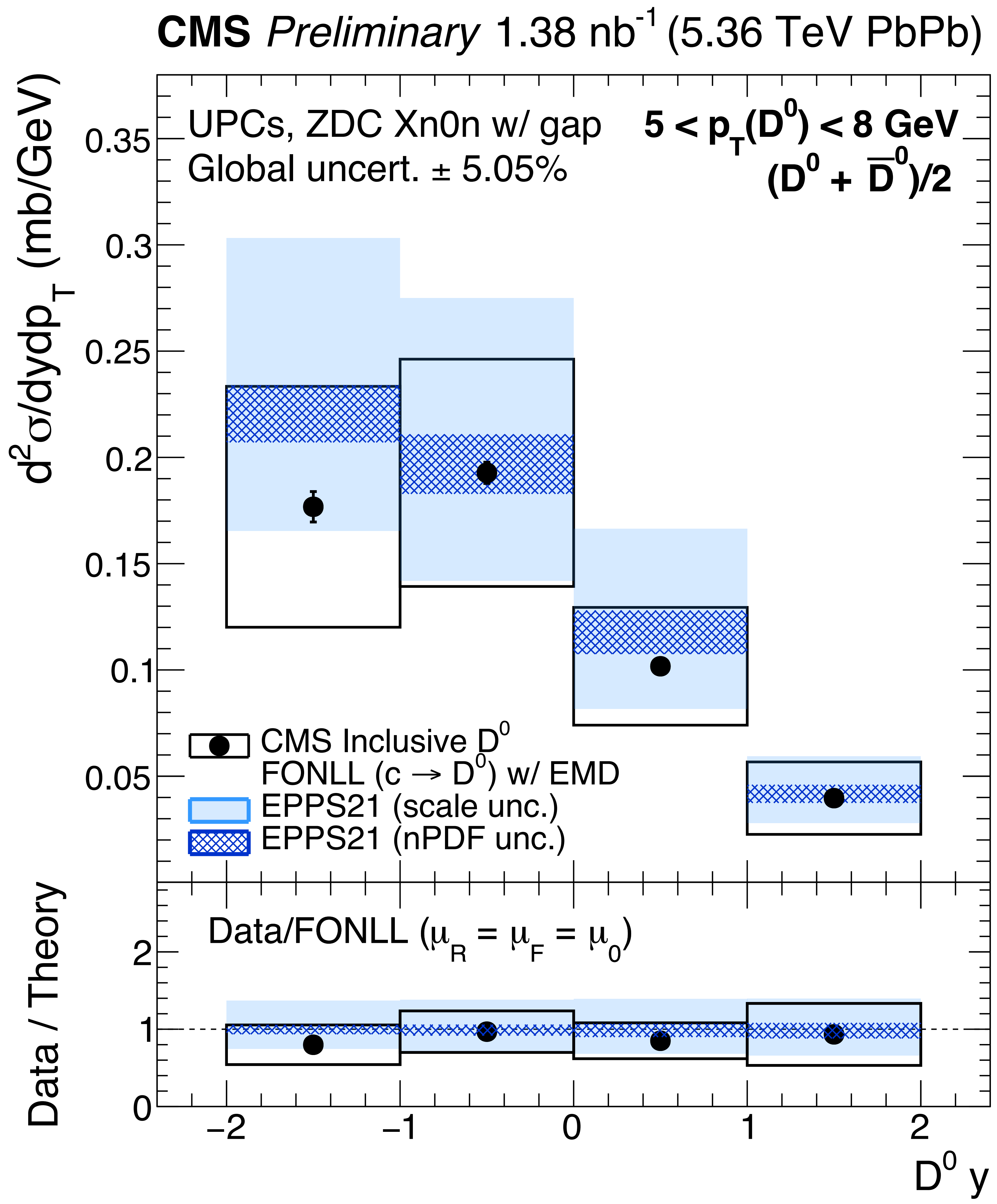
- Light blue band: **prompt FONLL predictions with scale variations**
- **Dotted blue band**: EPPS21Pb nPDF uncertainty only
- FONLL+EPPS21nPb scaled for the probability of no-breakup (EMD)

D^0 $8 < p_T < 12$ GeV:
→at higher p_T, data are overall above the central values of the predictions

A.M. Stasto et al., paper in preparation

Comparison with FONLL with EPPS21 nPDFs

New for Diffraction and Low-x



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- Light blue band: **prompt FONLL predictions with scale variations**
- **Dotted blue band**: EPPS21Pb nPDF uncertainty only
- FONLL+EPPS21nPb scaled for the probability of no-breakup (EMD)

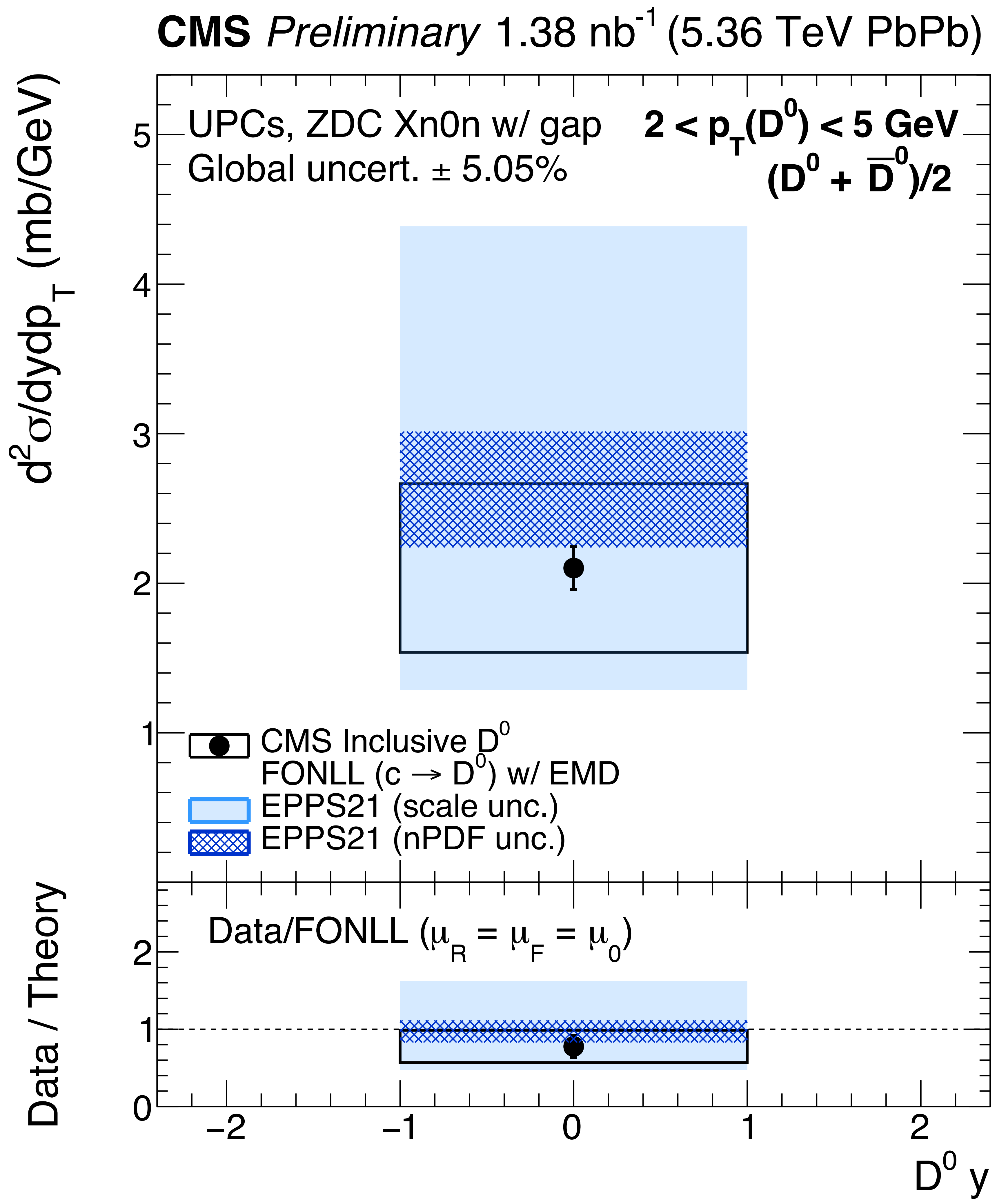
D^0 5 < p_T < 8 GeV:

- $x_{BJ} \approx 0.001 \div 0.03$ **

→data consistent with central values of the FONLL-based predictions

** based on Pythia 8 photo-nuclear simulations

Comparison with FONLL with EPPS21 nPDFs



D^0 2 < p_T < 5 GeV:

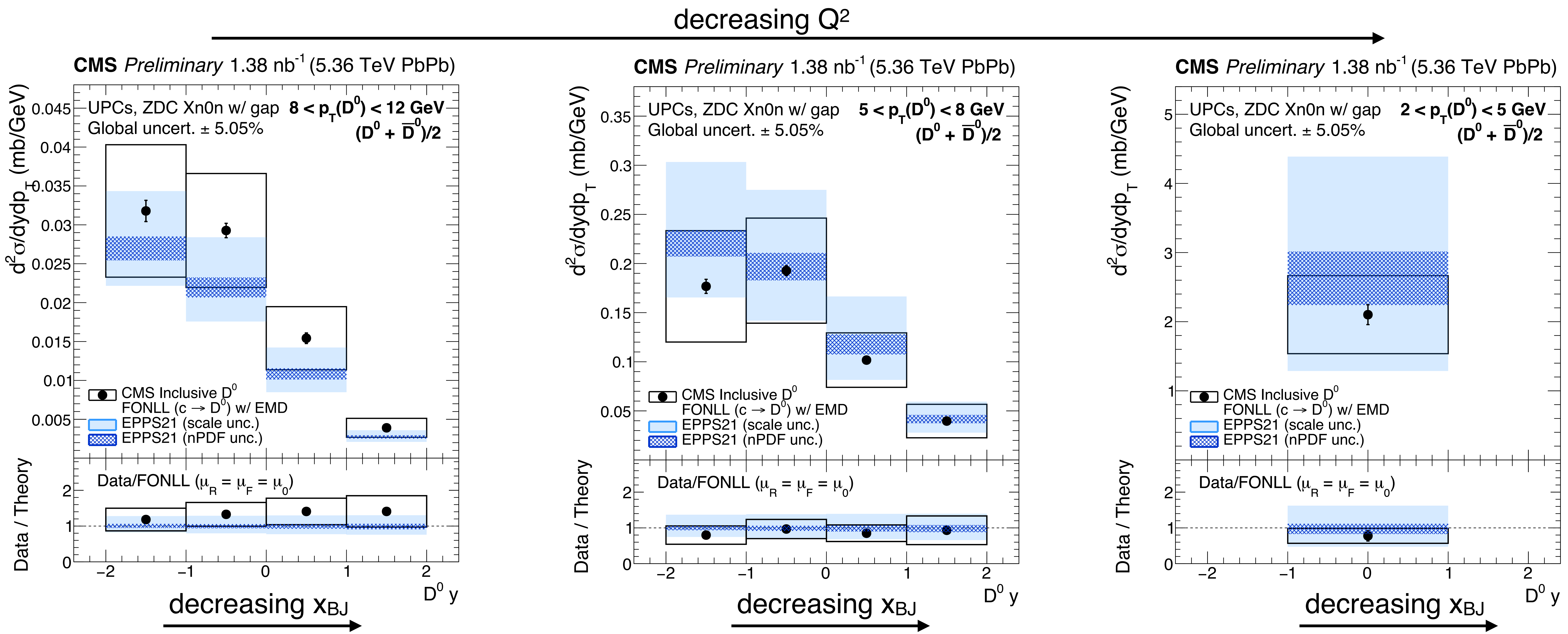
- x_{BJ} down to 5-8 * 10^{-3} **
- Q^2 down to ≈ 20 GeV^2

→ Constraints in the saturation region at low Q^2
→ At low p_T, the data/FONLL ratio is below unity.

** based on Pythia 8 photo-nuclear simulations

Comparison with FONLL with EPPS21 nPDFs

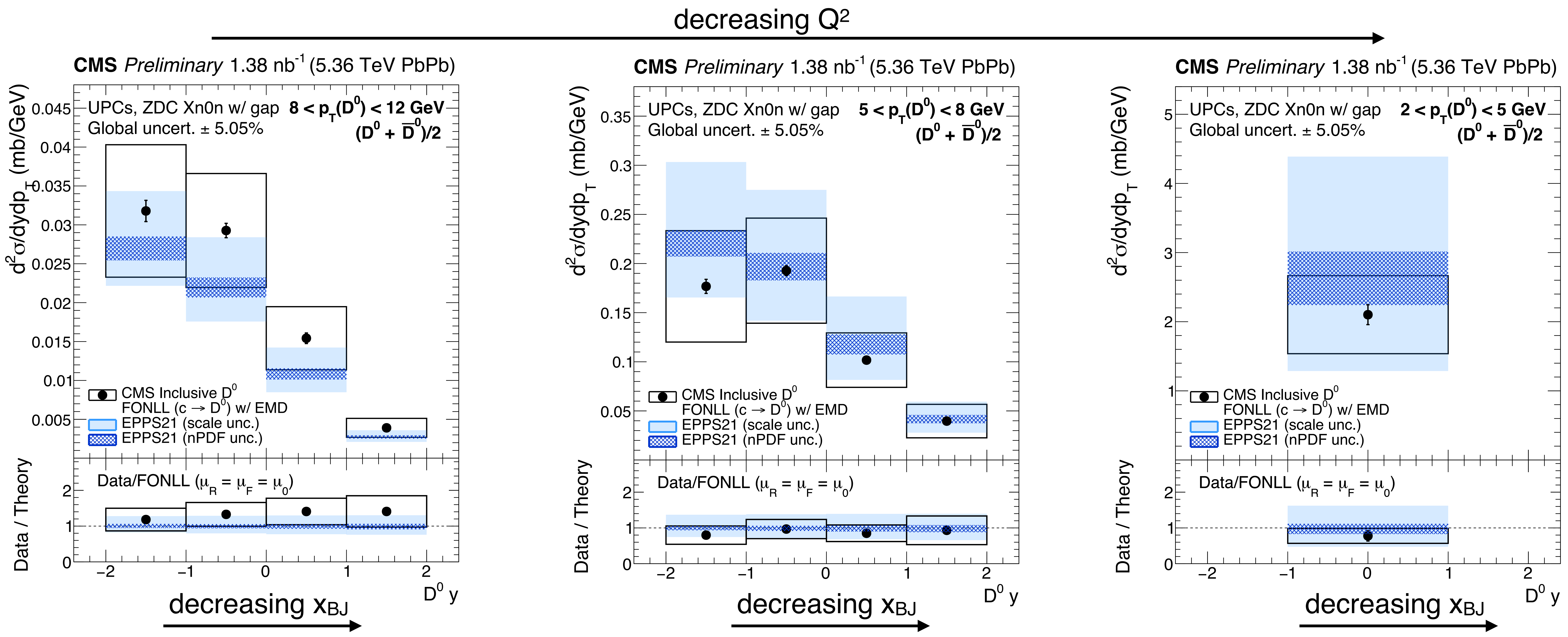
New for Diffraction and Low-x



p_T dependence of the data/FONLL comparison:

- **"new" constraints coming from charm γN collisions (in the absence of final state effects)?**
- "overall" poor description of the D^0 p_T dependence in FONLL photonuclear events?(hints already in HERA data vs FONLL)
- p_T dependence induced by the "missing" diffractive component?
- EMD correction?

Comparison with FONLL with EPPS21 nPDFs

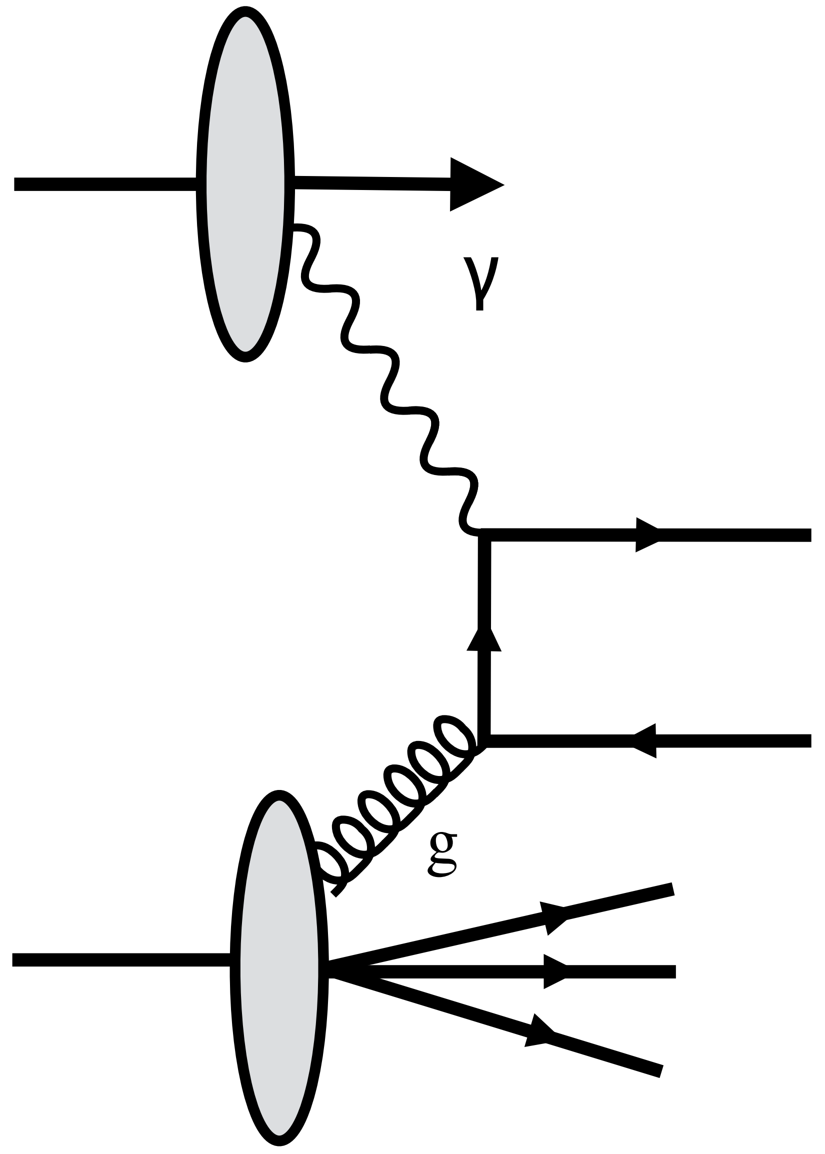


Main caveats affecting data and theory predictions:

- **Theory includes only c→D⁰**, while CMS data includes a (small) contribution of b→D⁰
- **Predictions based on inclusive nPDF.** Data are dominated by non-diffractive production due the requirement (Xn) on the broken nucleus

(Selected) Prospects for Run 3 data

→ Open the way for a broad heavy-flavor program in **inclusive, semi-inclusive, diffractive (and γγ) UPC events**

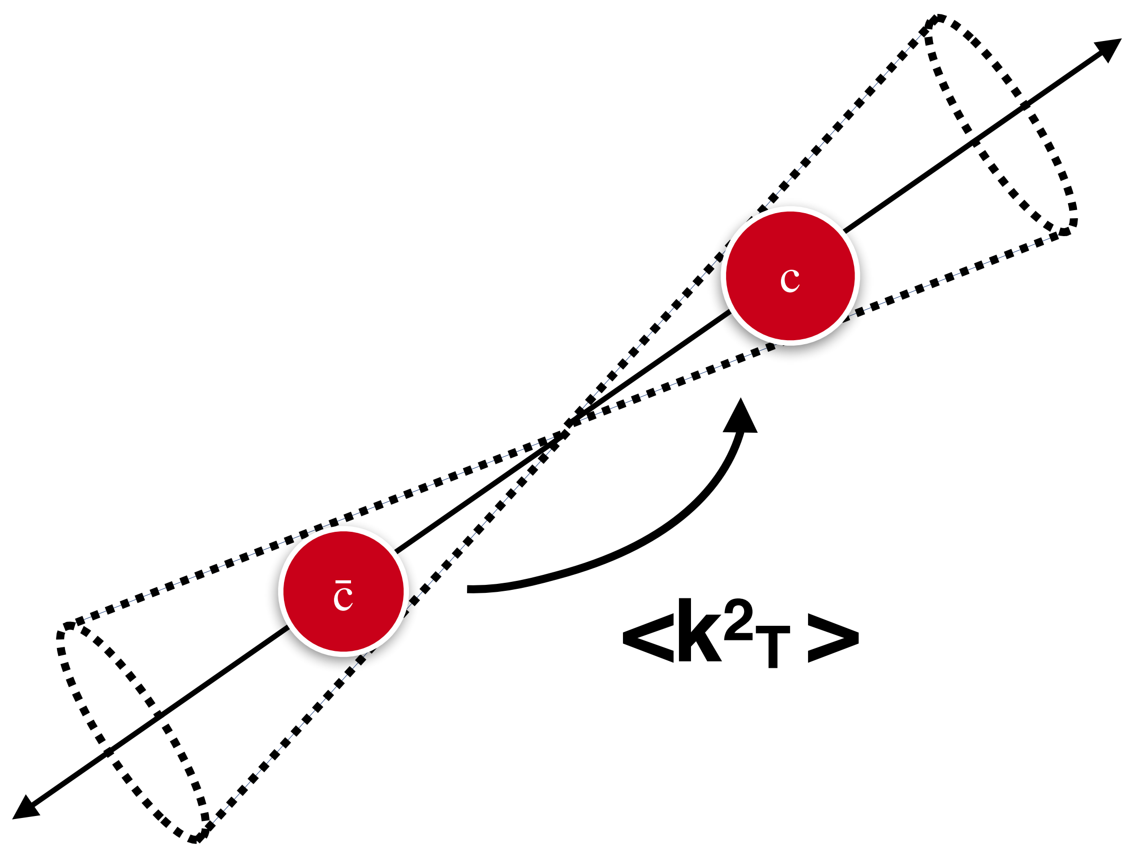


HQ-tagged jets
or HF hadron

$d\sigma/dp_T dy$ of heavy-flavor mesons and baryons in γPb (PbPb) and γp (pPb)
- prompt and non prompt D^0, D^+, Λ_c with improved low-p_T and y reach

→ lowest x, Q^2 regime
→ benchmark for the description of hadronization in γp and γN

→ work in progress to improve the low-p_T kinematic reach with 2023 data and with higher-statistics data from 2024 and 2025
→ **reduce systematic uncertainties**



Heavy-quark (di) jets and correlation measurements measurements:
→ strongest kinematic constraints on (x,Q^2)
→ sensitivity to the Q_s scale via $\langle k^2_T \rangle$ broadening

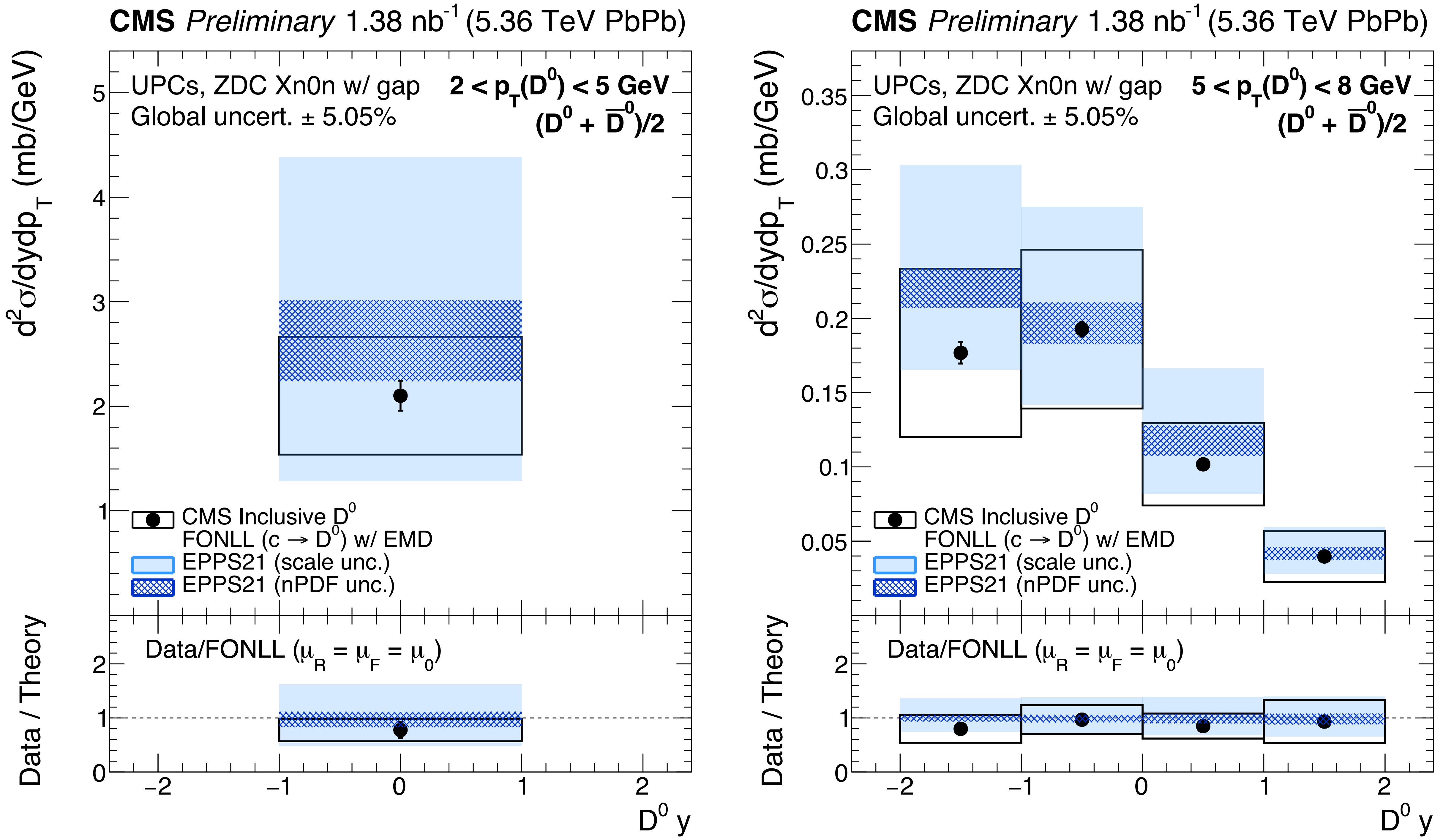
→ **In Run 4 (2029-2032), improved accuracy and kinematic reach** thanks to the extended pseudorapidity coverage of the tracker ($|\eta|<4.0$) and the new PID capabilities (see backup)

Summary and conclusions

First measurement of the D^0 photonuclear production in Xn0n UPC collisions with 2023 PbPb data at $\sqrt{s_{NN}}$= 5.36 TeV

→ dynamic constraints on PDFs with clean “perturbative” probes in a large regime of (x,Q^2) with limited final-state interactions

→ first step toward a broad program of heavy-flavor hadrons, jets and correlations in UPCs



Inputs needed from theory (e.g.):

- predictions for charmed meson cross-sections based on different theoretical approaches (nPDFs, dynamic description of shadowing/saturation)
- predictions for heavy-flavor dijet production and heavy-flavor correlations (e.g. k_T broadening)
- theoretical constraints on nuclear diffraction (MC/calculations) uncertainties of the photo-flux parametrization

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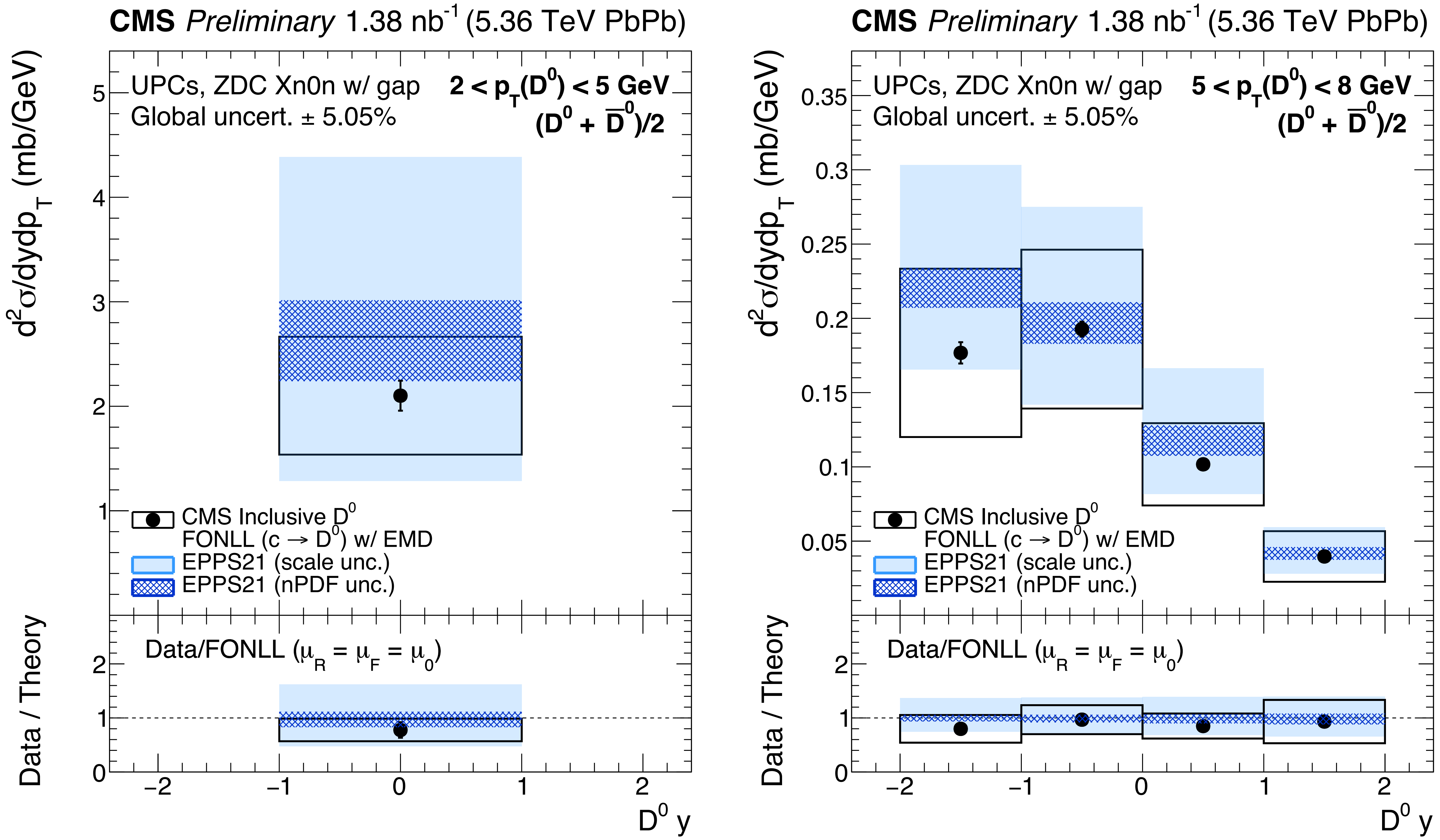

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Thank you for your attention!

*Special thanks to **Anna Maria Stasto, Mark Strikman, Ilkka Helenius, Petja Paakkinen, Vadim Guzey** and all the theorists that supported this effort with discussions, calculations, and simulations*

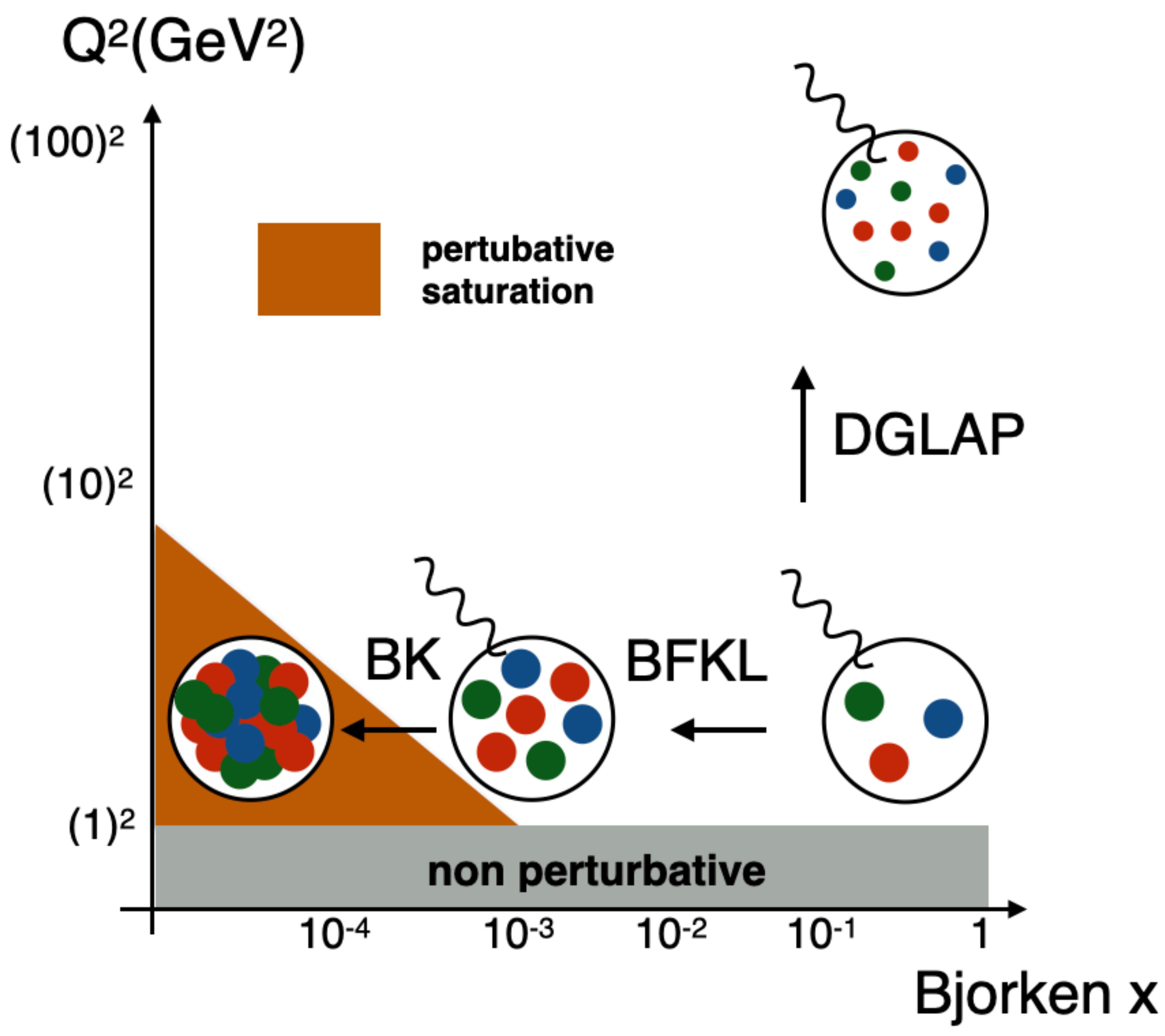
BACKUP

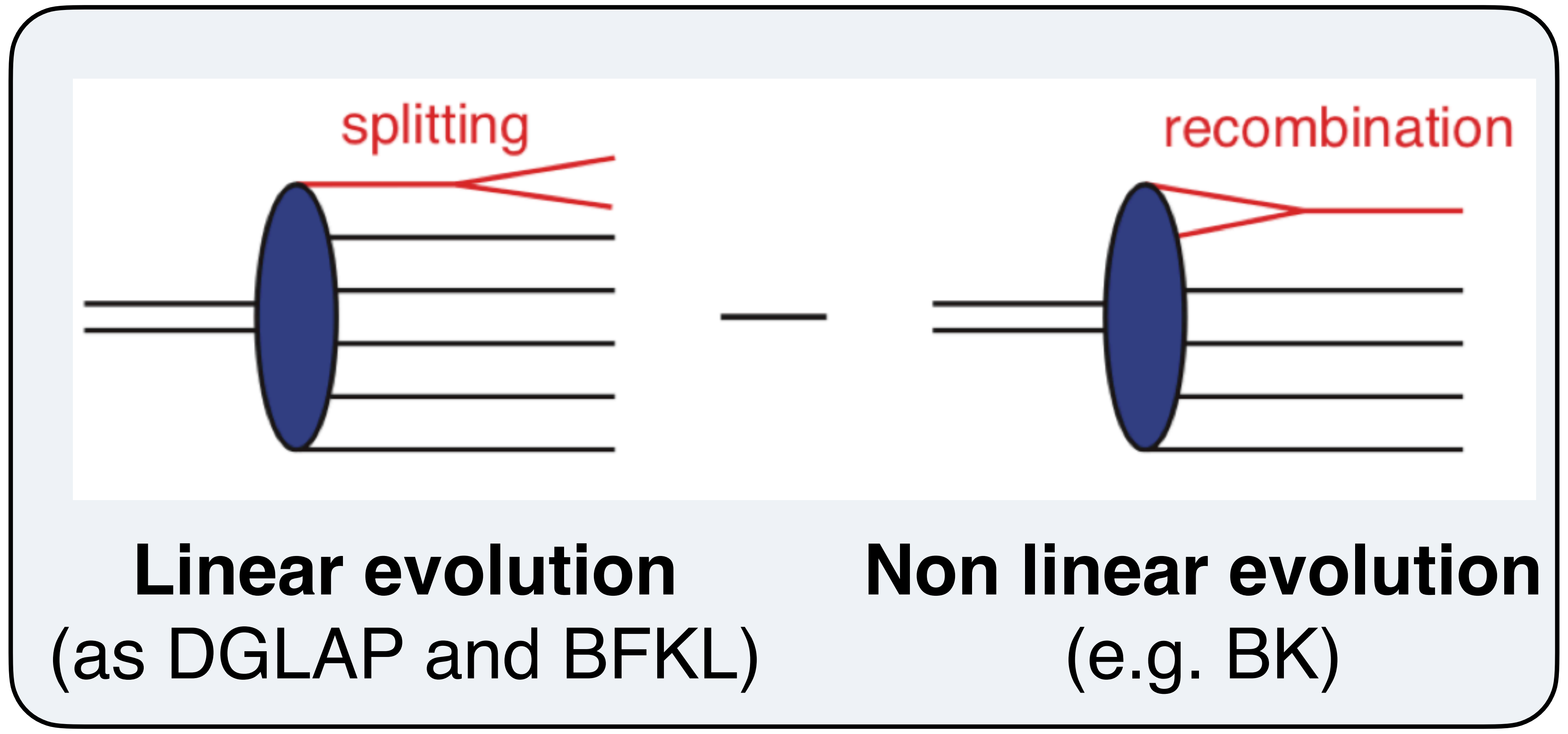
BACKUP: UPCs and heavy flavors in UPCs

Constraining parton dynamics in nuclei

Constrain parton dynamics from high to low-x, from high to low Q^2 and the transition across the different regimes

In nuclei, high-density effects are expected at higher x-values



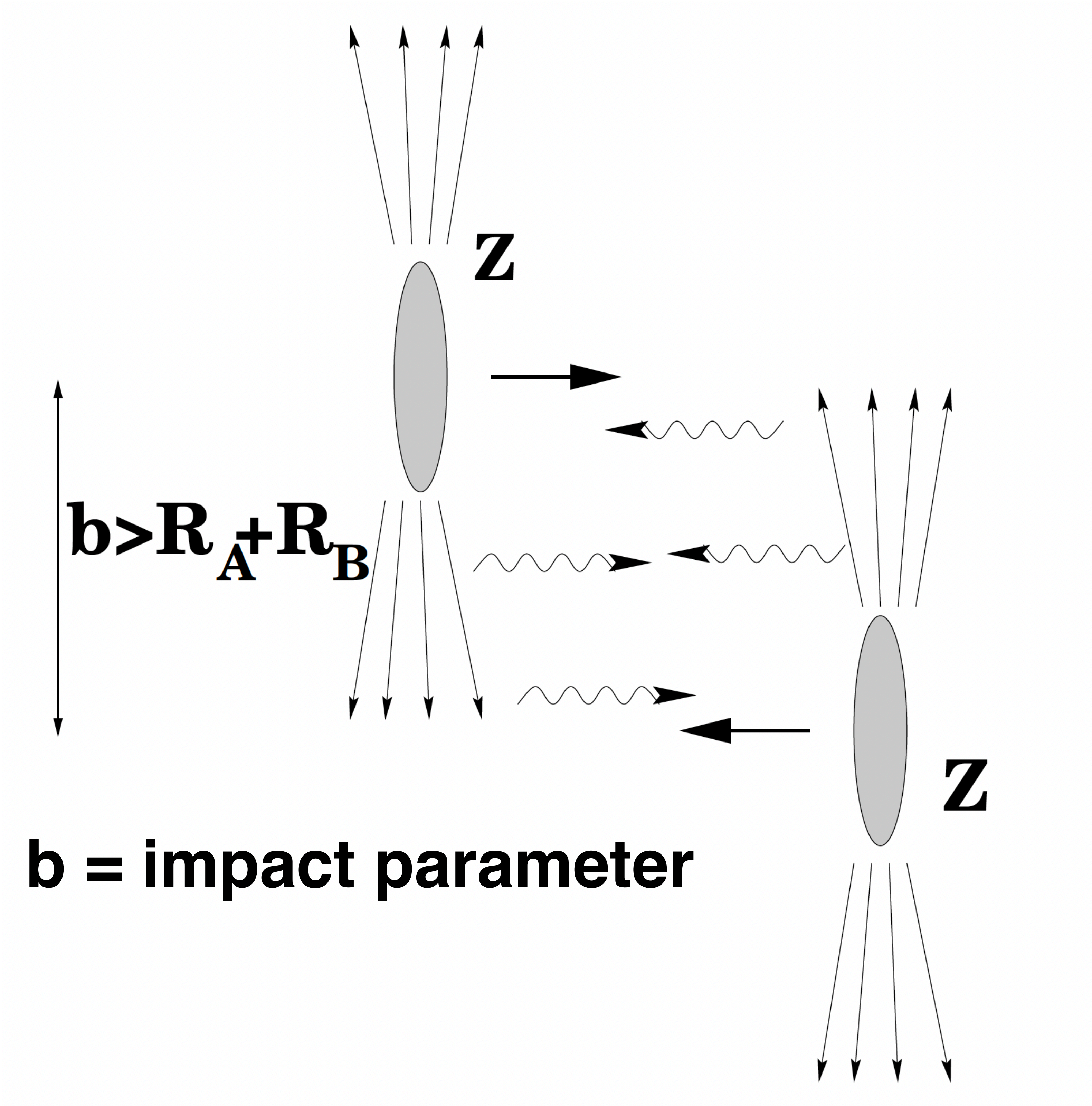


- **Emergence of gluon saturation**
  → properties of saturation as a function of x, Q^2
  → dependence on the atomic number A

K. Hencken, M. Strikman et al. Phys.Rept.458 1-171, 2008

K. Hencken, M. Strikman et al. Phys.Rept.458 1-171, 2008

UPC collisions: LHC as a photon-nucleus collider



Ultra-peripheral collisions (impact parameter b > R_A+R_b)
• the flux of quasi-real photons is proportional to Z^2

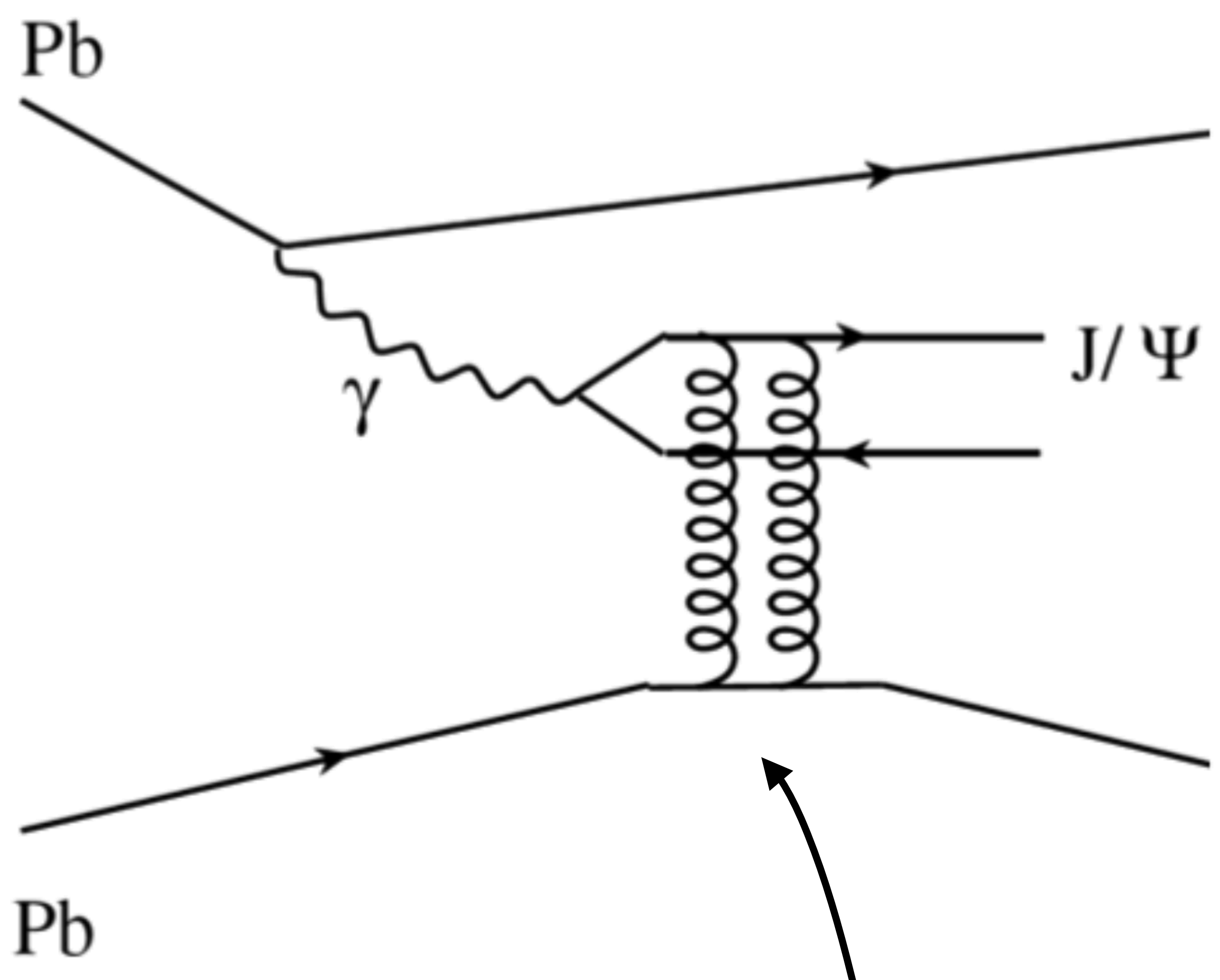
• **Photon kinematics**:
  • $p_T < \hbar/R_A \sim 30$ MeV
  • $E_{max} \sim O(100)$ GeV at LHC.

Access to photo-nuclear collisions to test nuclear matter:
• **at the highest γN center-of-mass energies** experimentally reachable
• **in the absence of significant final-state interactions** (as in hadronic pPb collisions)

K. Hencken, M. Strikman, R. Vogt, P. Yepes, Phys. Rept. 458:1-171, 2008

Coherent J/ψ in PbPb UPCs

gluons with $x<10^{-4}$, Q^2 ~ 2.5-4.0 GeV^2



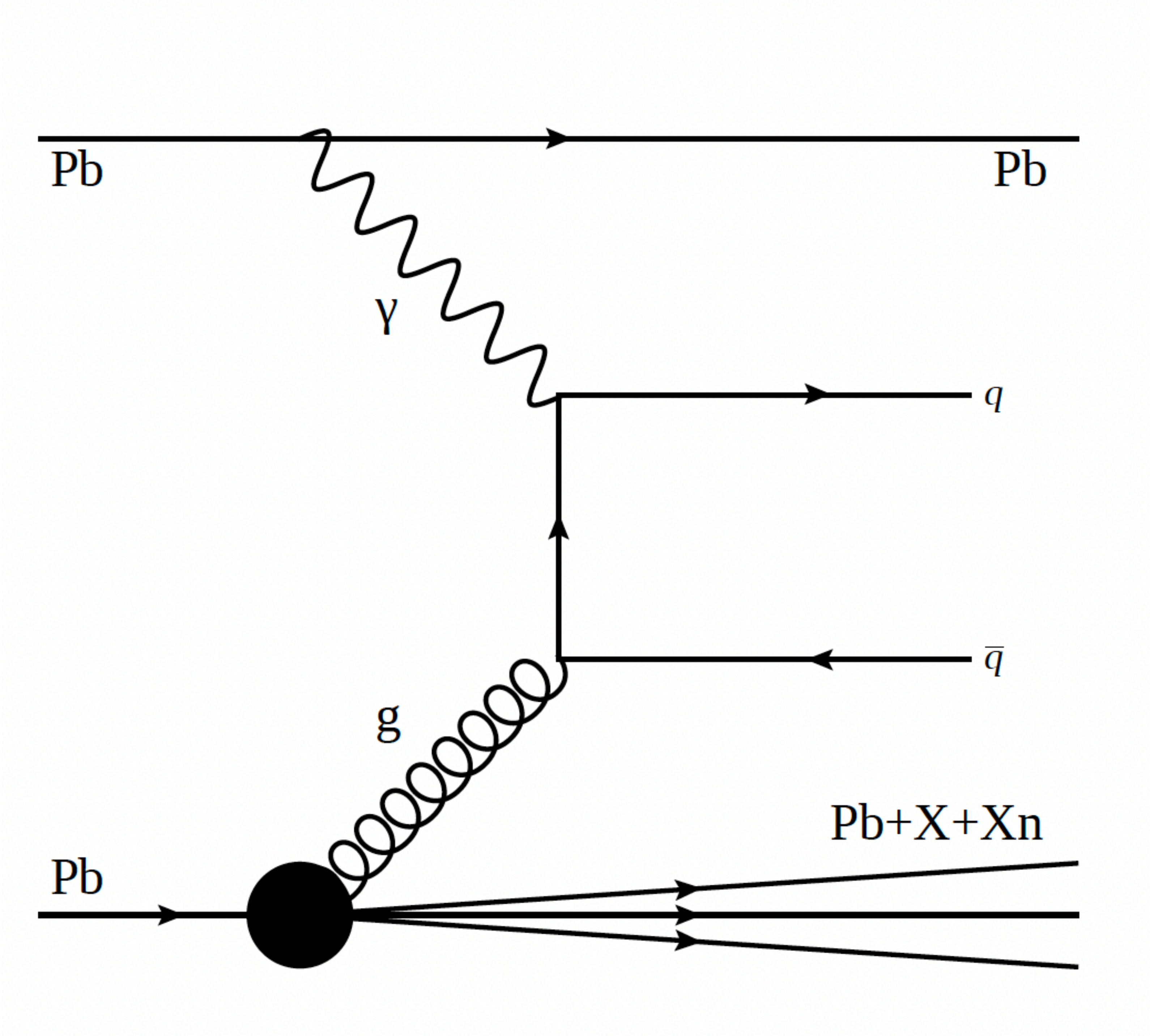
Constraints on a "fixed" region of Q^2

Complex theoretical description

- J/ψ production at low p_T and NLO calculations are challenging

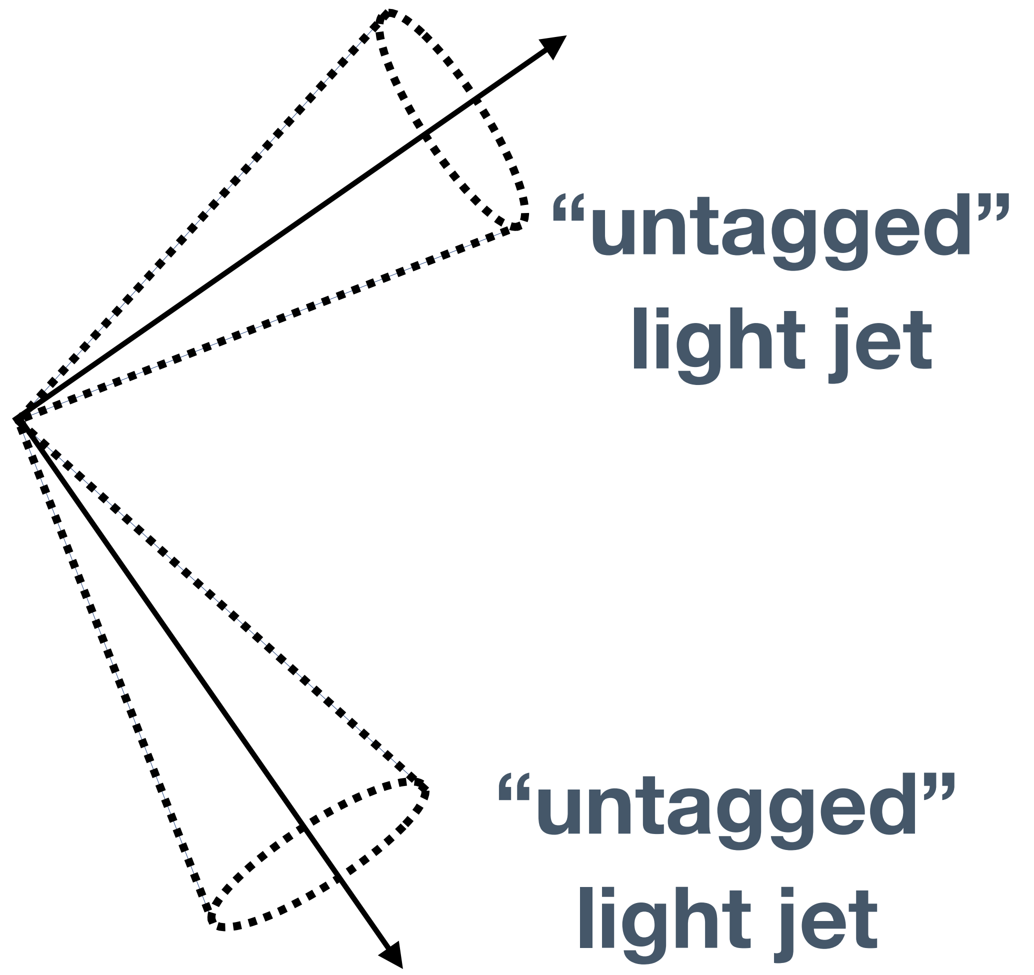
ALICE, JHEP 10 (2023) 119
CMS, Phys. Rev. Lett. 131 (2023) 262301

Untagged di-jets in γN scatterings



Dynamic constraints on (x, Q^2)

by varying dijet kinematics



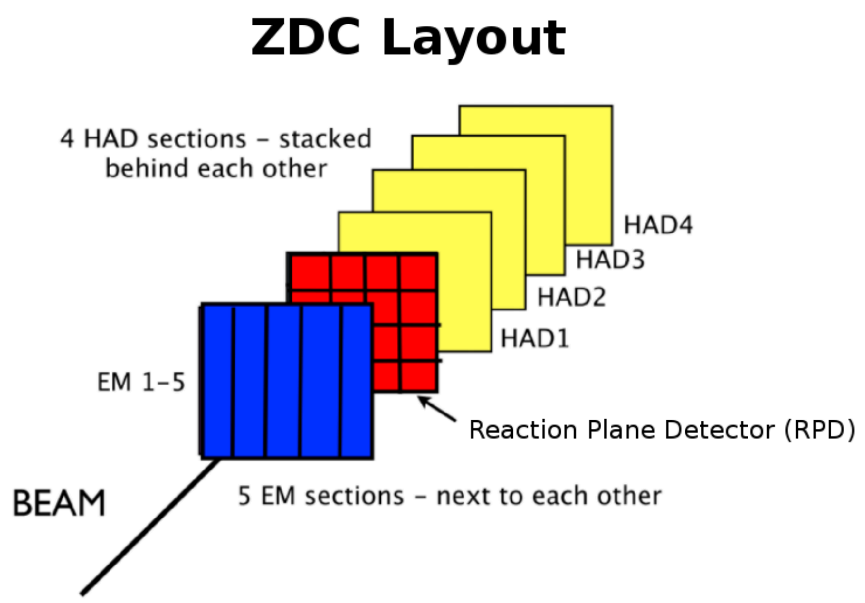
Limited access to low x and low Q^2

→ jets limited to p_T >10-15 GeV/c

ATLAS, ATLAS-CONF-2017-011

BACKUP: D^0 measurement

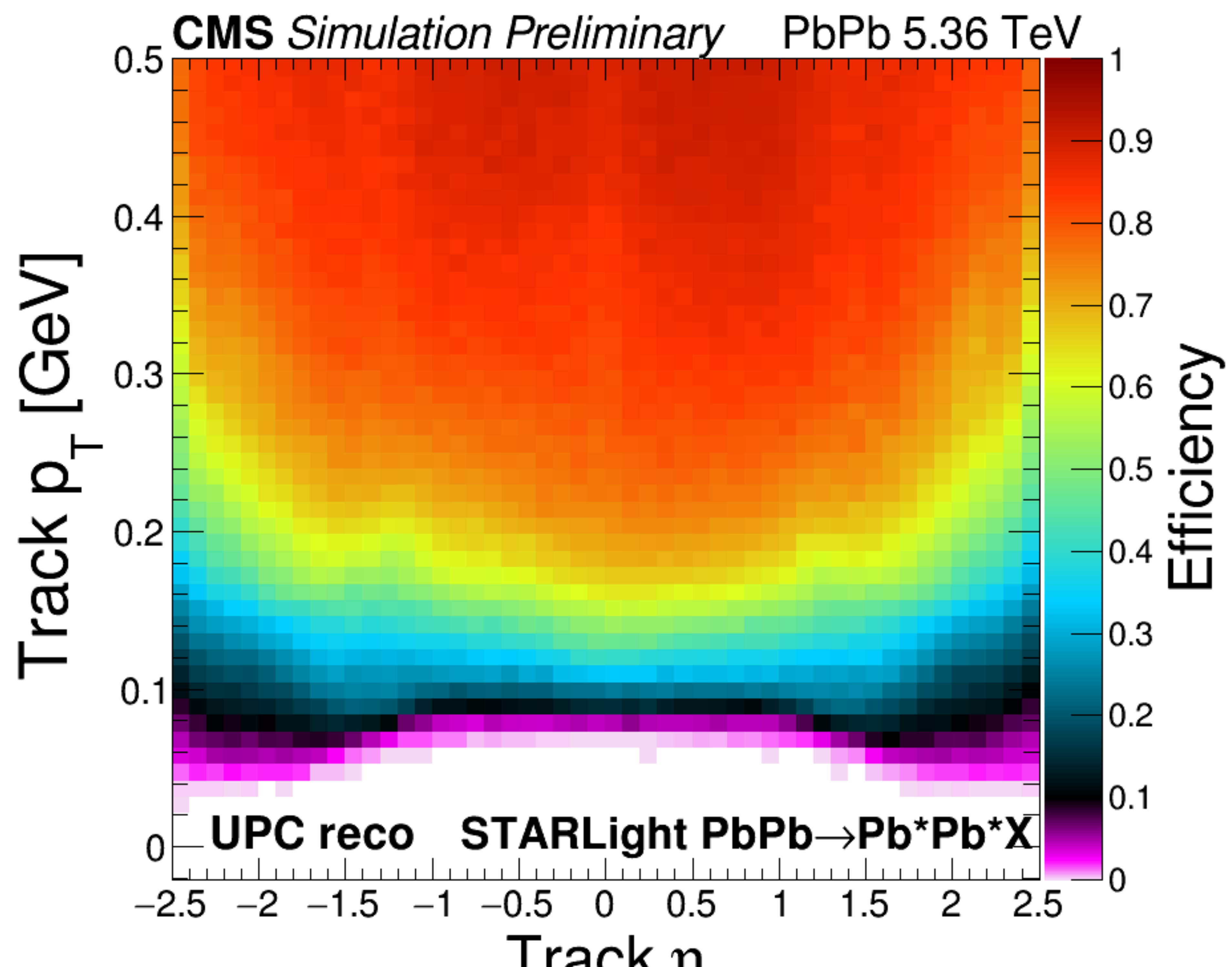
Converting CMS into a γγ, γN detector for the “LHγC”



Zero-Degree Calorimeter (ZDC) as a trigger detector for the first time in CMS
→ integrate ZDC in the Level-1 (hardware) trigger-emulation chain
→ develop a strategy for fast online calibration

New trigger algorithms for γγ and γN “hard” events
→ **photonuclear high-Q^2 triggers** (ZDCOR with L1 jets)
→ **photonuclear low-Q^2 triggers** (ZDCOR)
→ **γγ and diffractive triggers** (no HF coincidence)

Improved low-p_T tracking and vertexing performance



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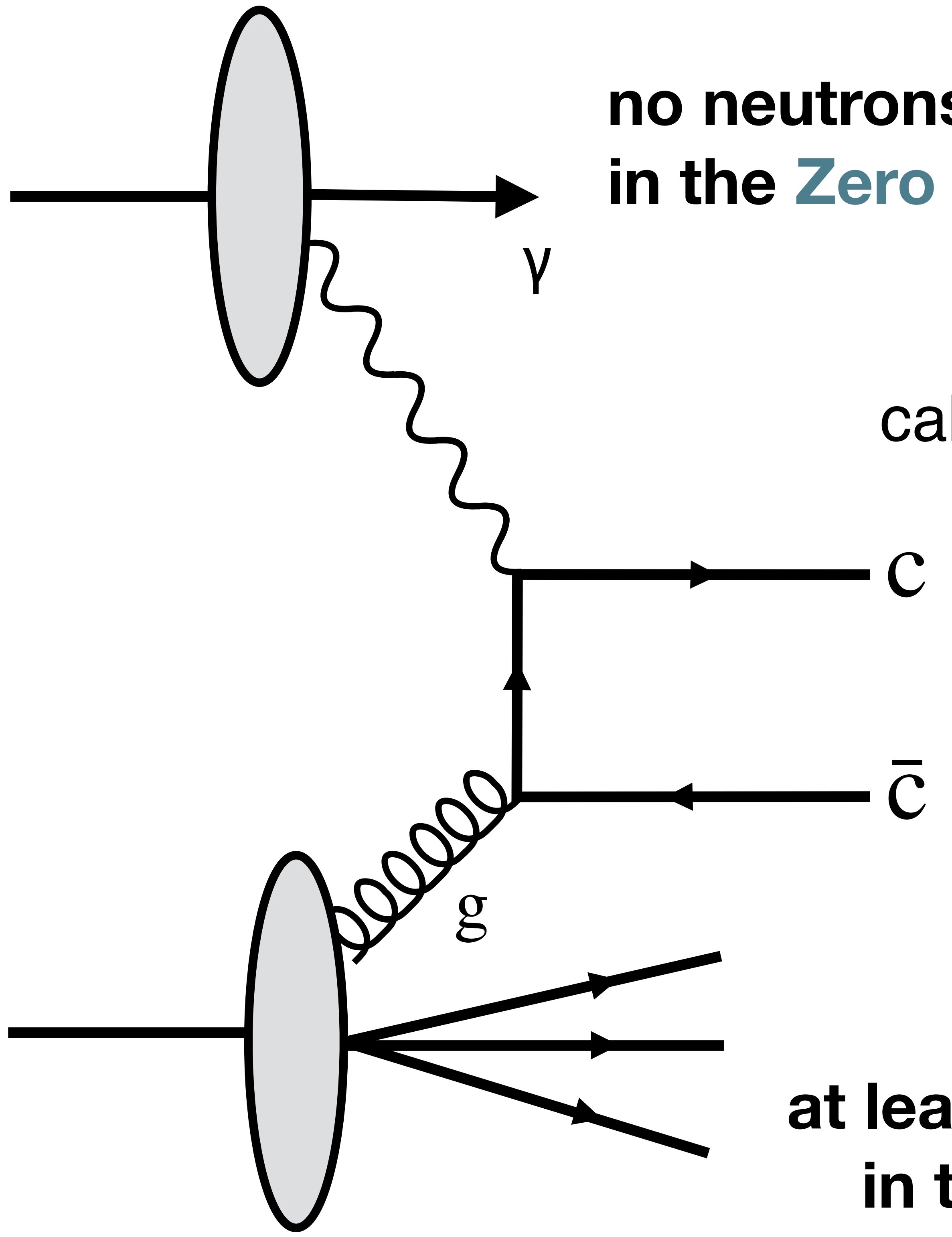
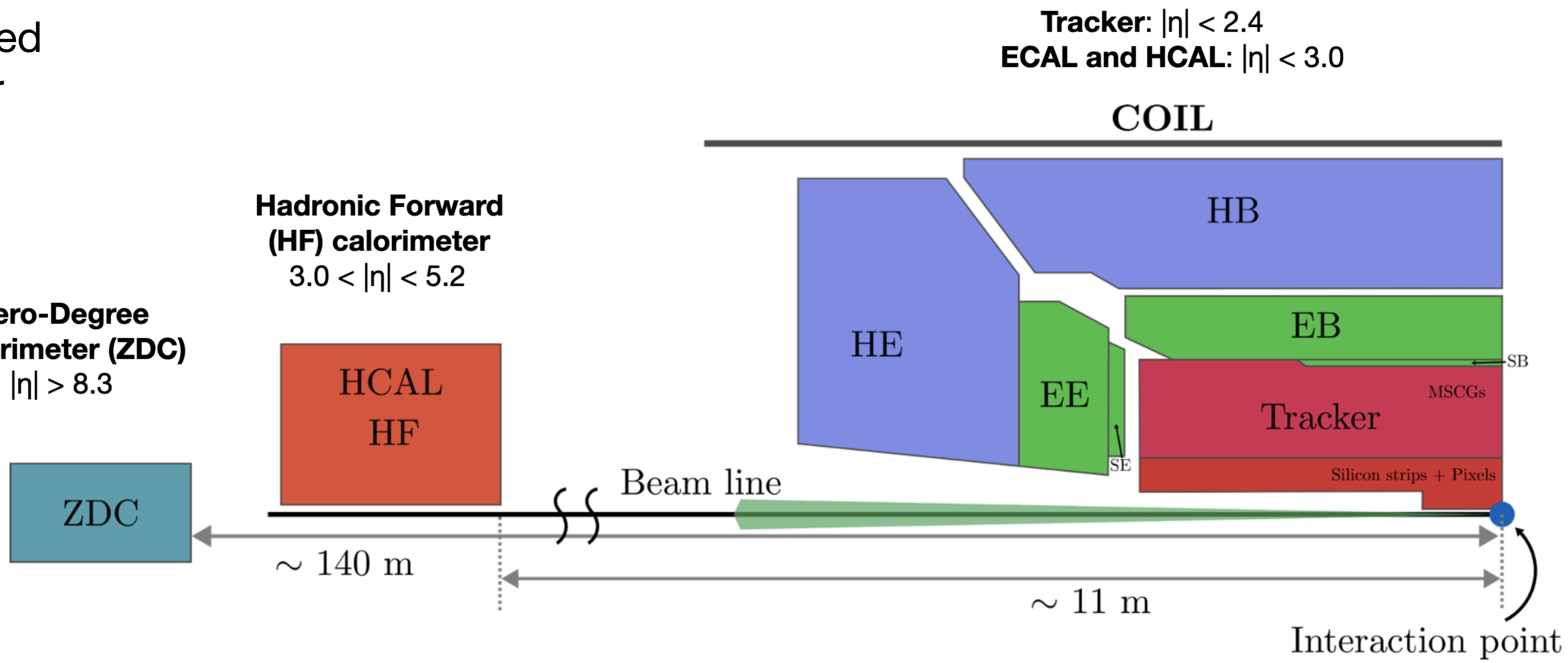


no neutrons (0n)
in the Zero Degree Calorimeter (ZDC)

Rapidity gap in the hadronic forward calorimeter (HF) in the photon-going direction

$D^0 \rightarrow K^-\pi^+$ with charged tracks in the tracker

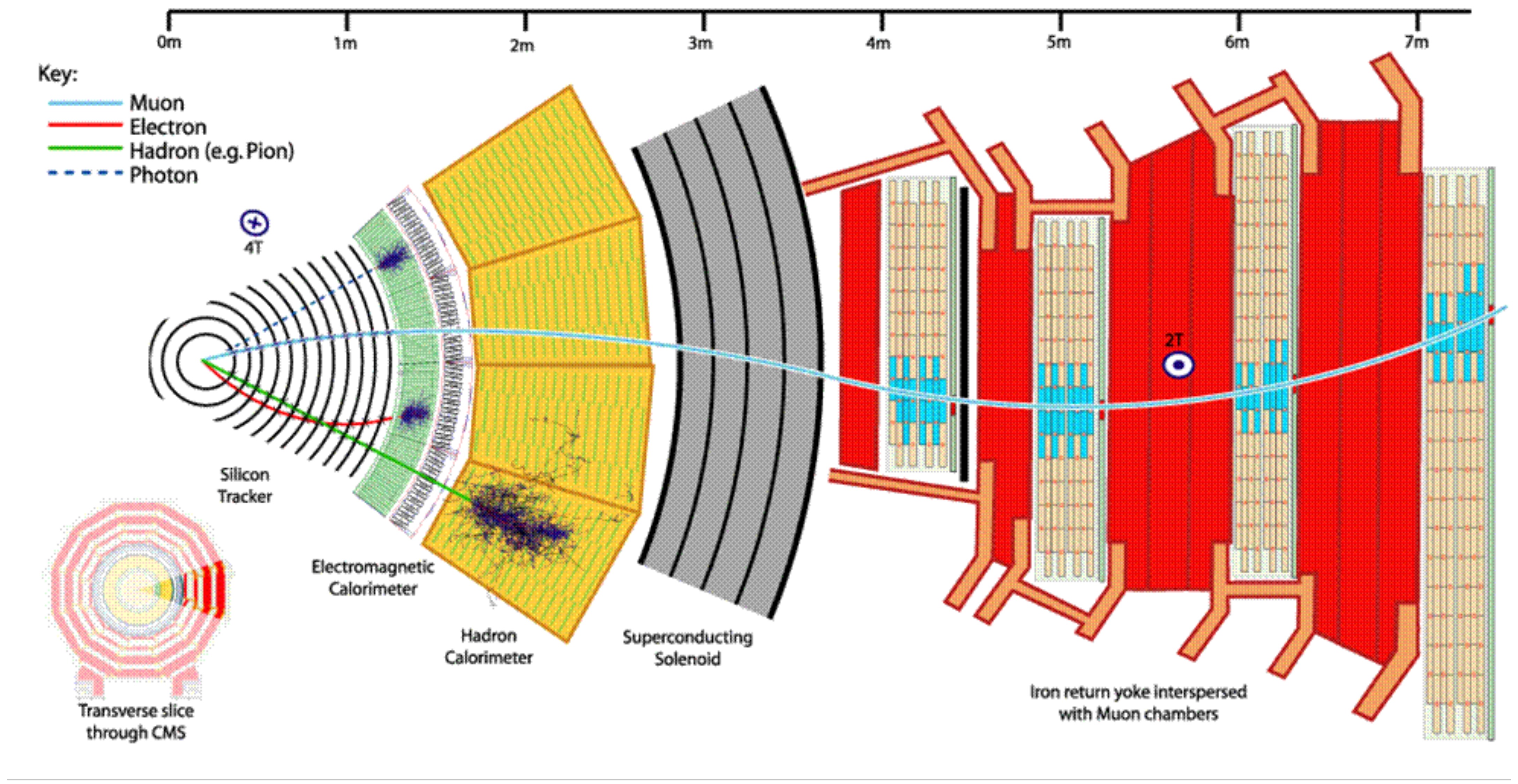
at least one neutron in the ZDC (Xn)



"Semi-inclusive" photonuclear production in Xn0n with a large rapidity gap on the γ-going side

- **dominated by non-diffractive photoproduction** (due to the requirement on the broken nucleus)
- includes both direct and resolved-photon events, prompt ($c \rightarrow D^0$) and non-prompt ($c \rightarrow D^0$) contributions

CMS as a broad-spectrum high-density QCD experiment



<u>Large-coverage high-rate</u> detector for hadronic and EM probes

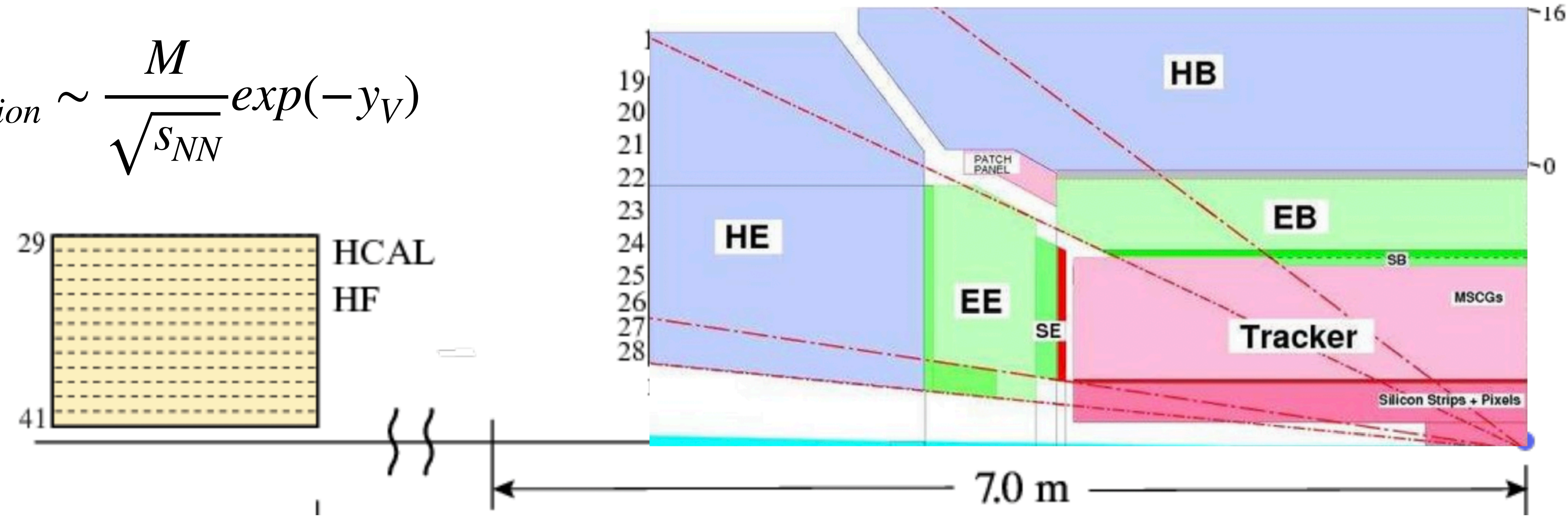
- charged hadrons
- jets, heavy-flavour hadrons
- isolated photons, Z/W bosons

Wide pseudorapidity coverage, from high to low p_T:

- Charged tracks in $|\eta_{tracks}| \leq 3$
- Calorimetry (ECAL/HCAL) in $|\eta_{cal}| \leq 5.2$
- Muon detectors in $|\eta_{muon}| \leq 3.0$
- ZDC + PPS detectors

→ With even stronger capabilities after HL-LHC upgrades

$$x_{ion} \sim \frac{M}{\sqrt{s_{NN}}} exp(-y_V)$$

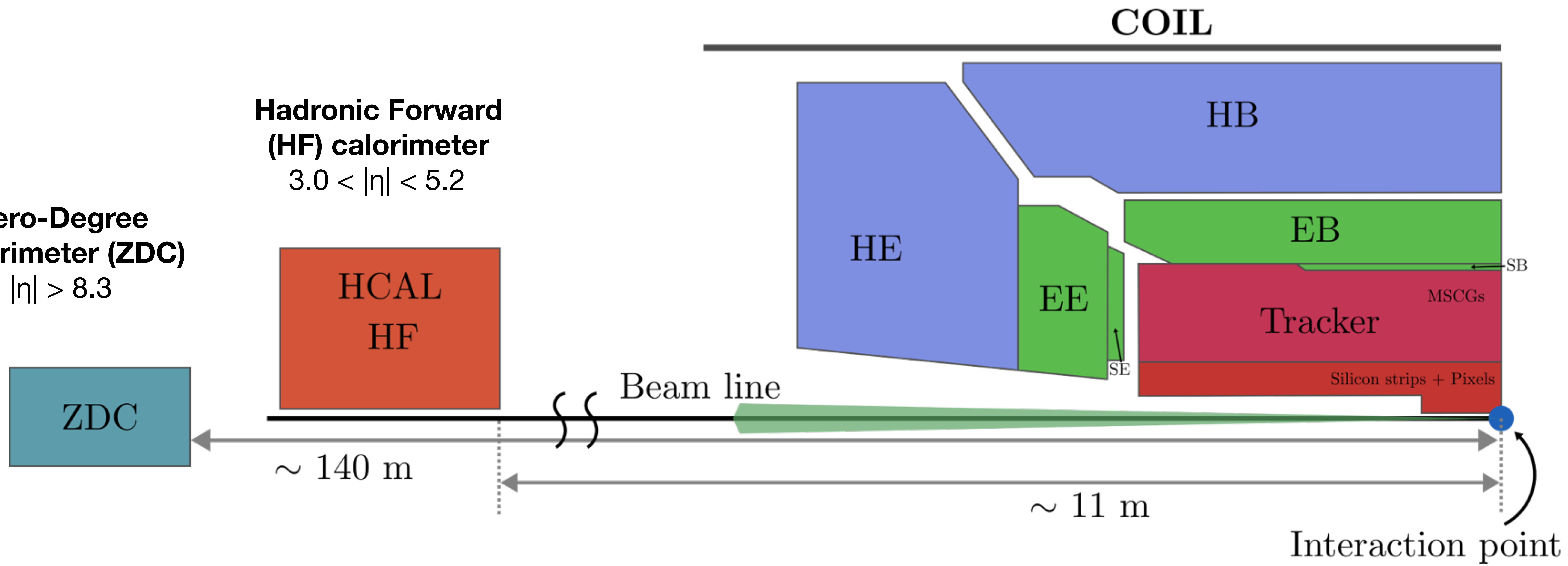


CMS (half) detector

Tracker: $|\eta| < 2.4$
ECAL and HCAL: $|\eta| < 3.0$

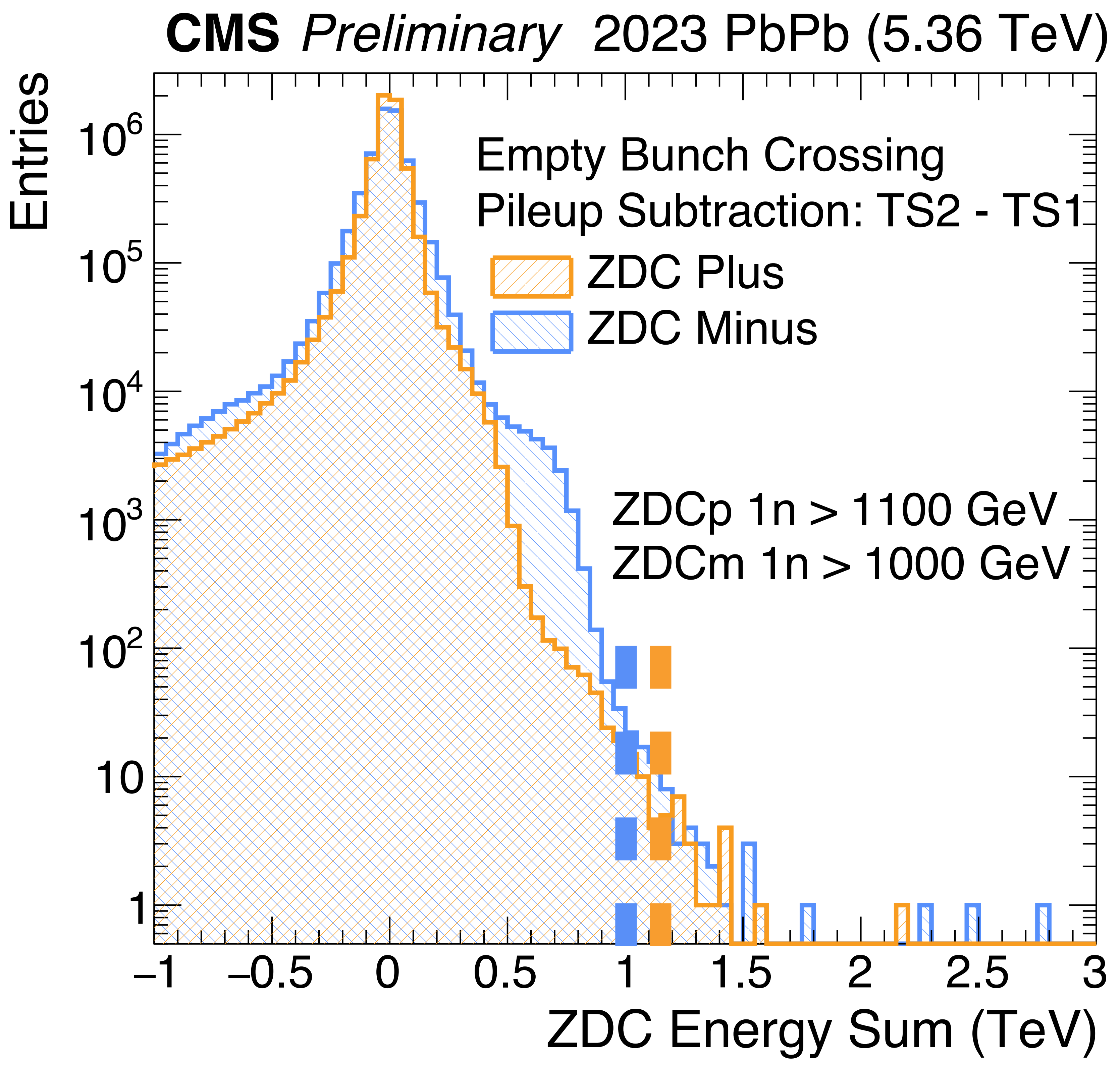
Hadronic Forward (HF) calorimeter
$3.0 < |\eta| < 5.2$

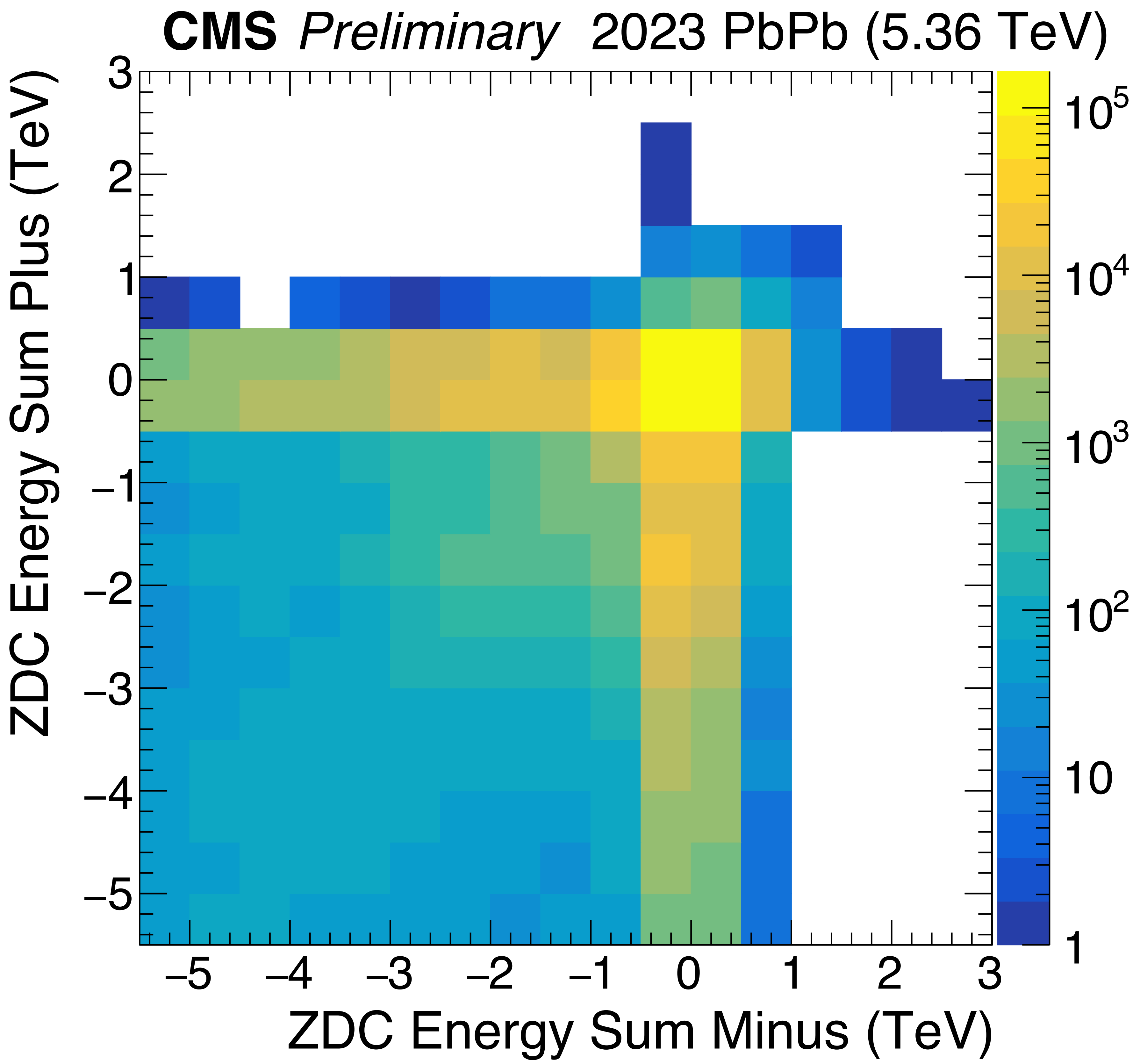
Zero-Degree Calorimeter (ZDC)
$|\eta| > 8.3$



ZDC noise distributions with empty-BX data

To test the hypothesis of negligible ZDC noise, we performed a study in empty-BX events in 2023 data, where we do not expect the presence of any signal events (or EMD processes)



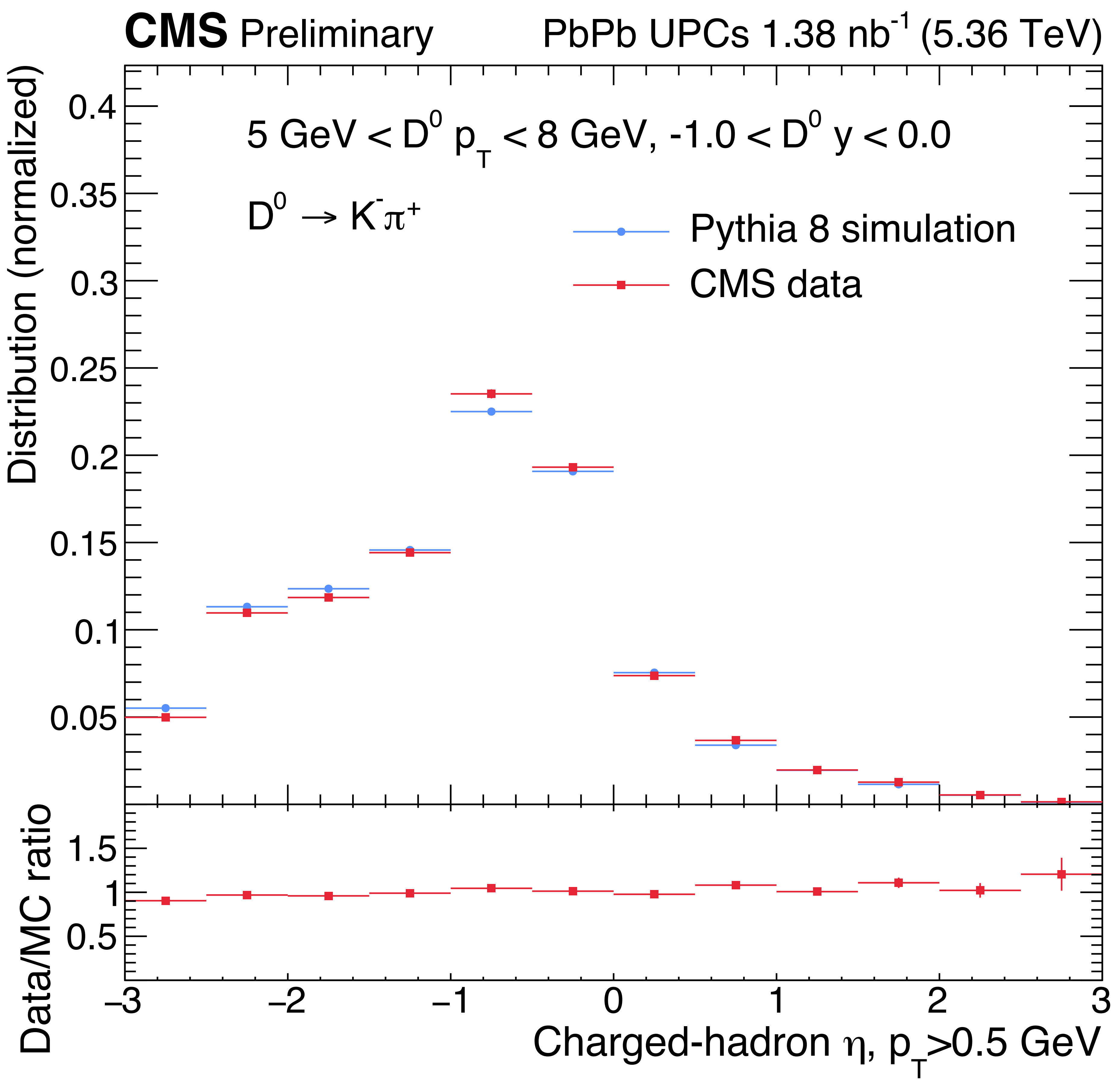


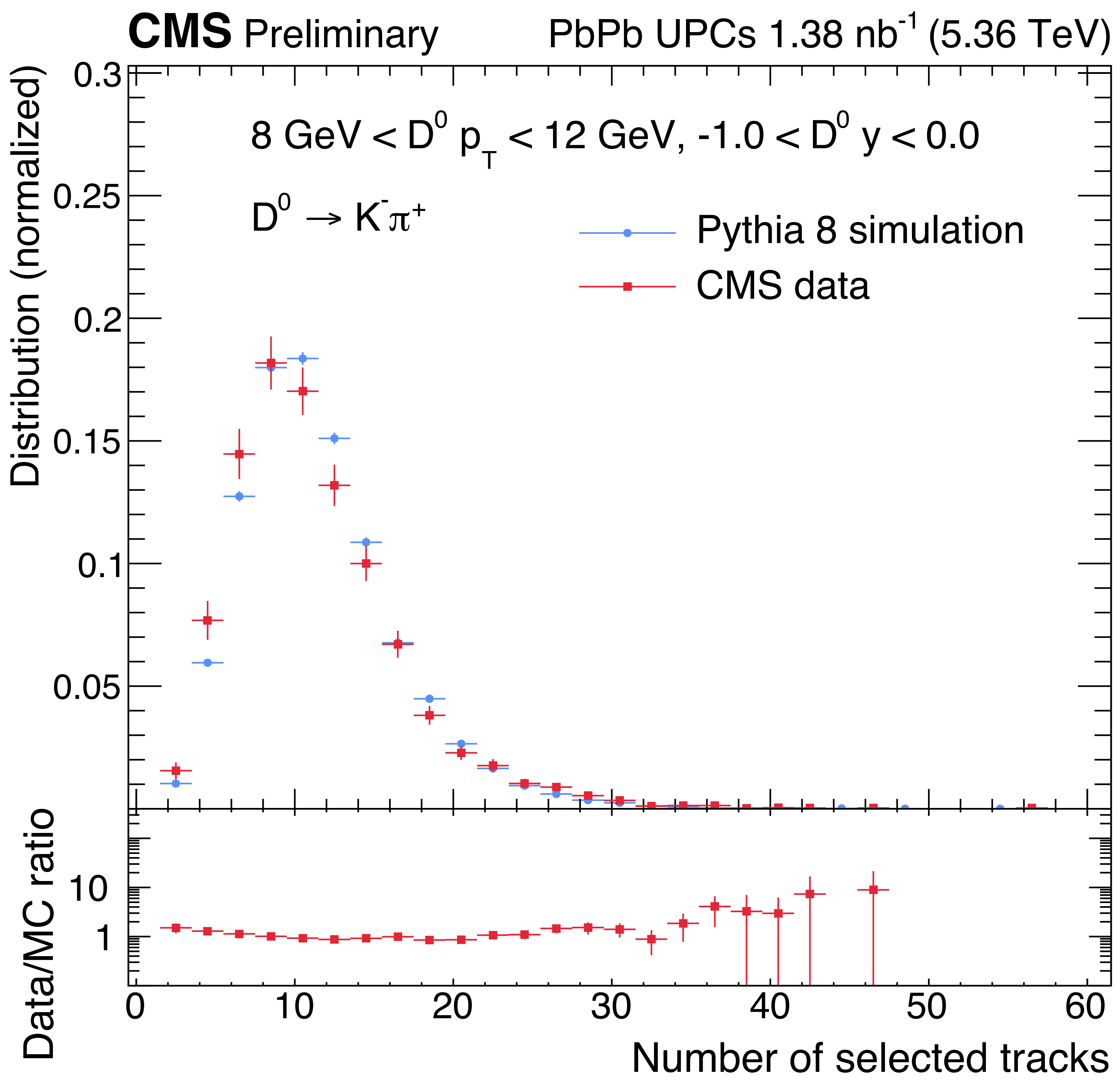
- Negligible ZDC noise above the 1n threshold due to the strict Out-Of-Time Pileup subtraction (TS2-TS1) (which acts as a noise/pedestal subtraction)

MC-data validation

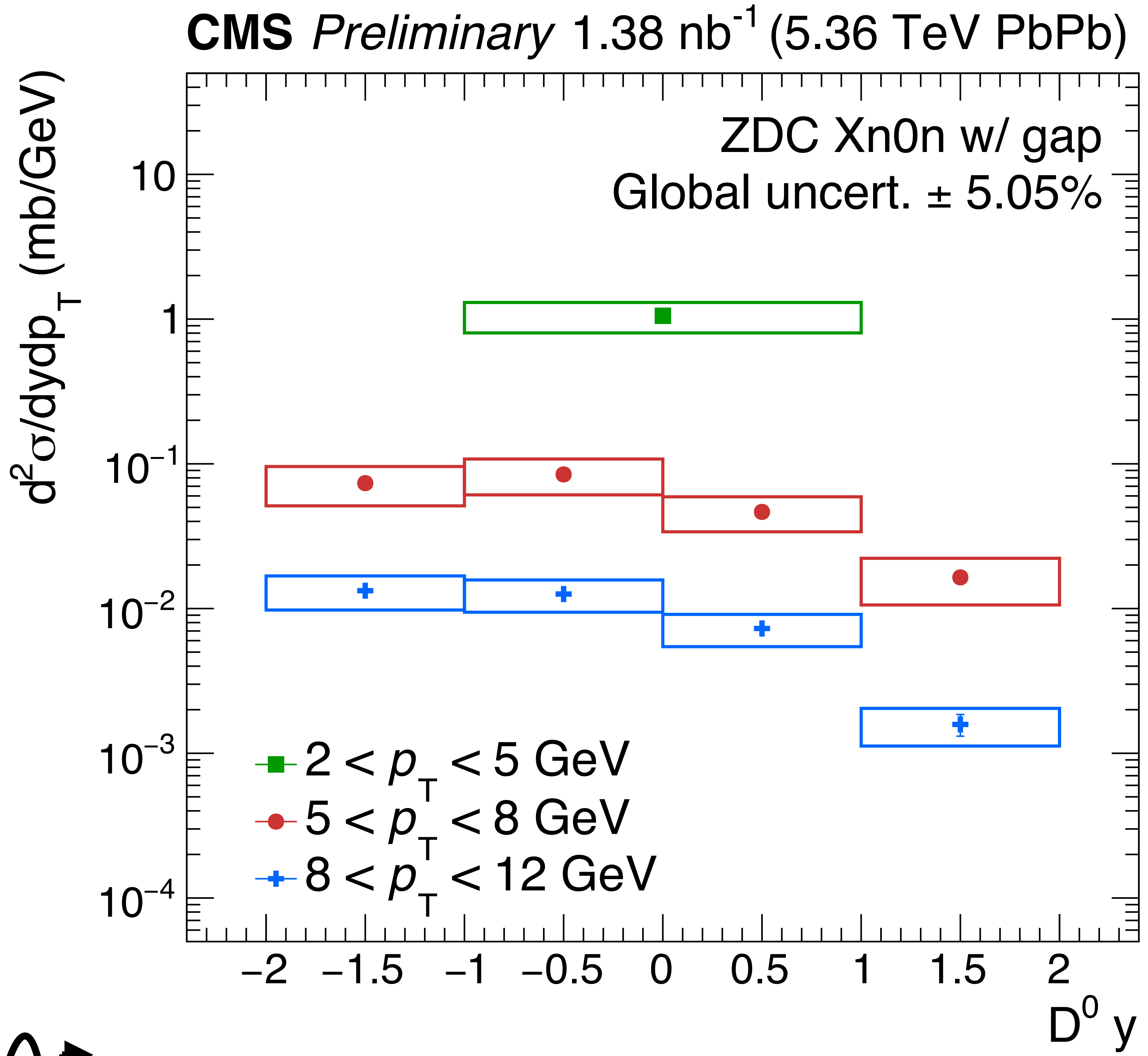
Monte Carlo samples based on Pythia 8 + EvtGen simulations for photonuclear events with EPPS21Pb nPDF:

- Both resolved and direct-photon events, prompt and non-prompt D^0





dσ/dp$_T$dy for photonuclear D^0 production in UPC collisions



$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{2}\frac{1}{\mathscr{L}_{int}\, P_{\text{trig,presc}}\, BR^{D^0\to K^-\pi^+}}\frac{N^{\text{raw}}_{D^0+\bar{D}^0}}{\Delta p_T \Delta y}\frac{1}{\epsilon_{\text{evt}}\,\epsilon_{\text{trigger}}\,\epsilon^{tot}_{D^0}\,\epsilon_{EMpileup}}$$

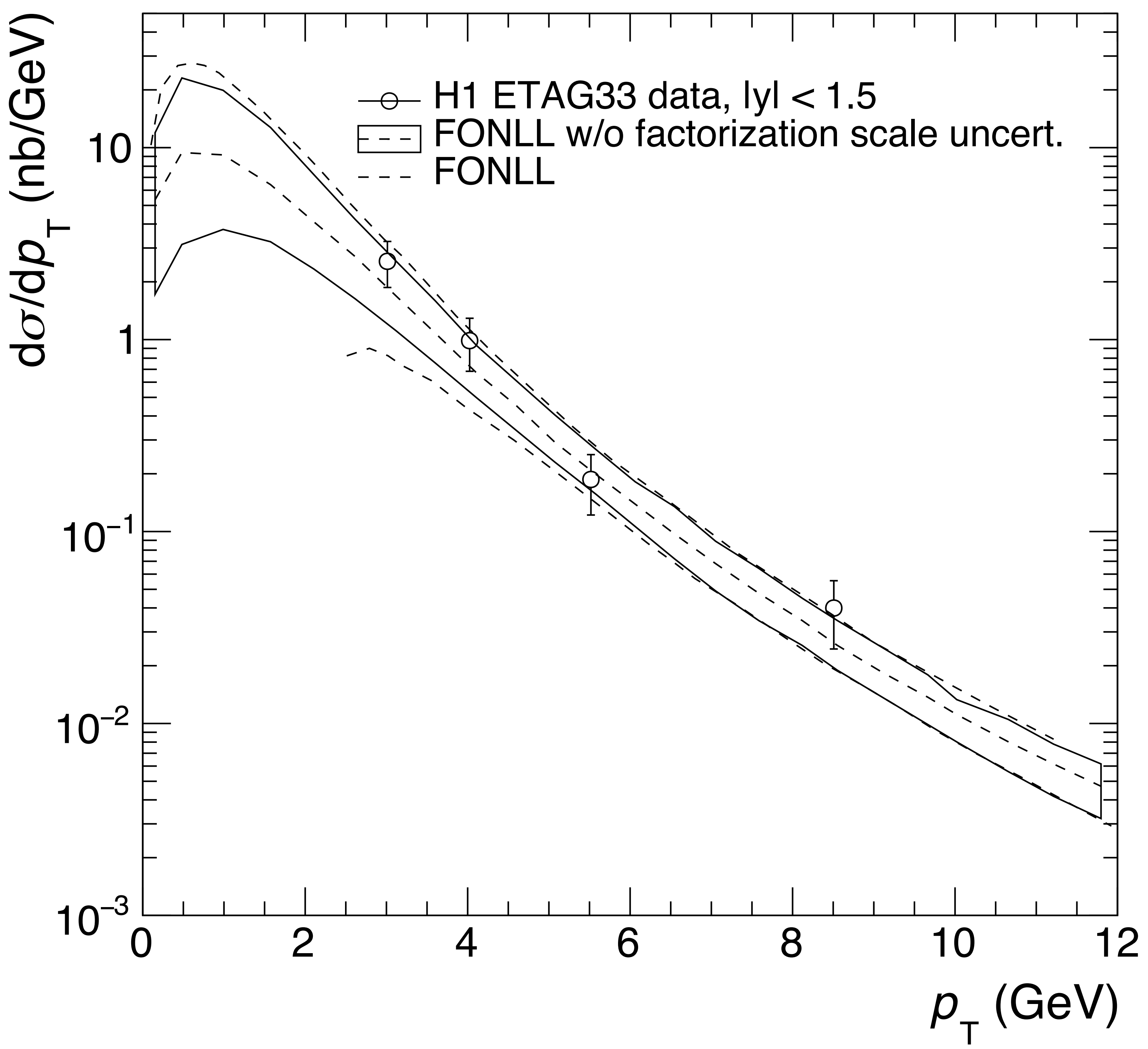
- $\mathscr{L}_{int}$ integrated luminosity
- **ε_{evt}**: event-selection efficiency
- **ε_{D}** : D^0-selection efficiency
- **$P_{\text{trig,presc}}$**: average prescale of each trigger algorithm
- **$\varepsilon_{\text{trig}}$** : trigger efficiency evaluated in intervals of D^0 p$_T$ and y (only for triggered sample)
- **$\varepsilon_{\text{EMpileup}}$**
  → account for the probability that electromagnetic dissociation affecting an independent PbPb collision would lead to a neutron in 0n side of the analysis

"Building" FONLL-based predictions for D^0 in UPCs at the LHC

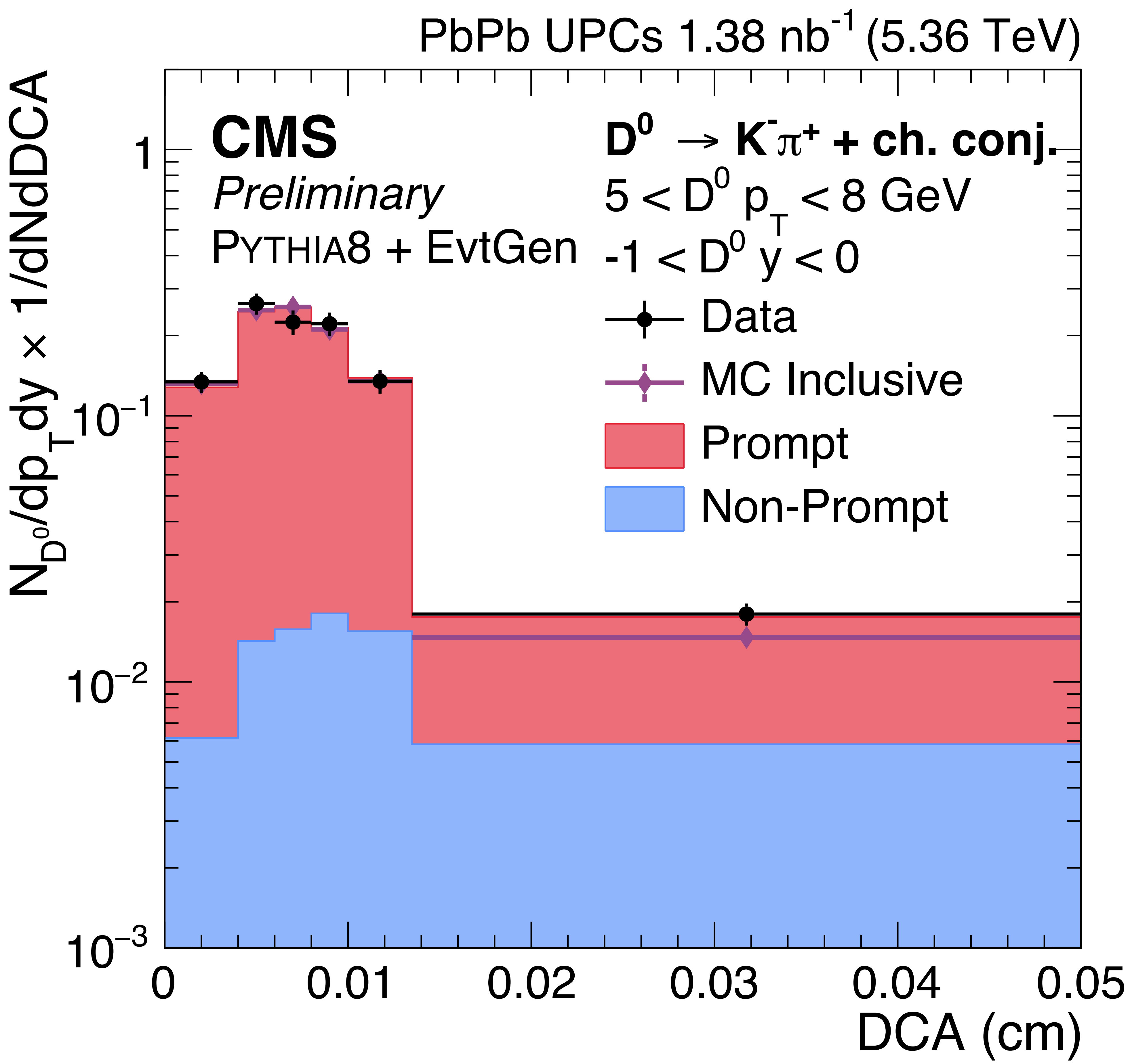
FONLL code for prompt charm photo-production (used for HERA prediction)

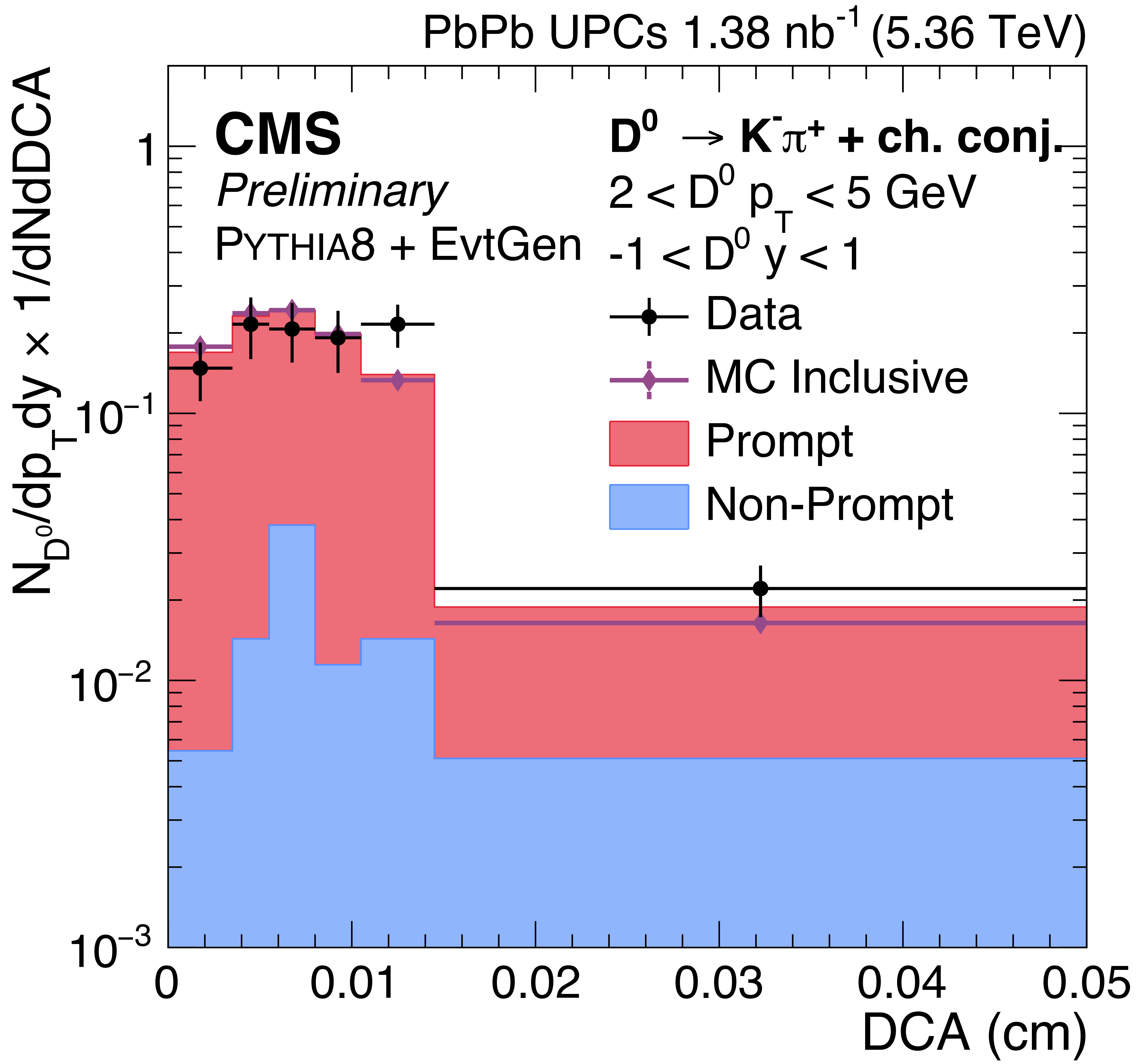
- **Photon PDF** based on GRV parametrization
- **D^0 fragmentation function (**Peterson, BFCY01)
- **Fragmentation fraction** (FF) set to 0.577
- **Factorization and renormalization scale** $\mu_R/\mu_0 = 1$, $\mu_F/\mu_0 = 1$ ("central" values)
- **FONLL pQCD uncertainties**: $0.5 < \mu_R/\mu_0 < 2$ and $0.5 < \mu_F/\mu_0 < 2$, independently.

→ ***full agreement with original FONLL predictions for H1 and ZEUS D* measurement at HERA***

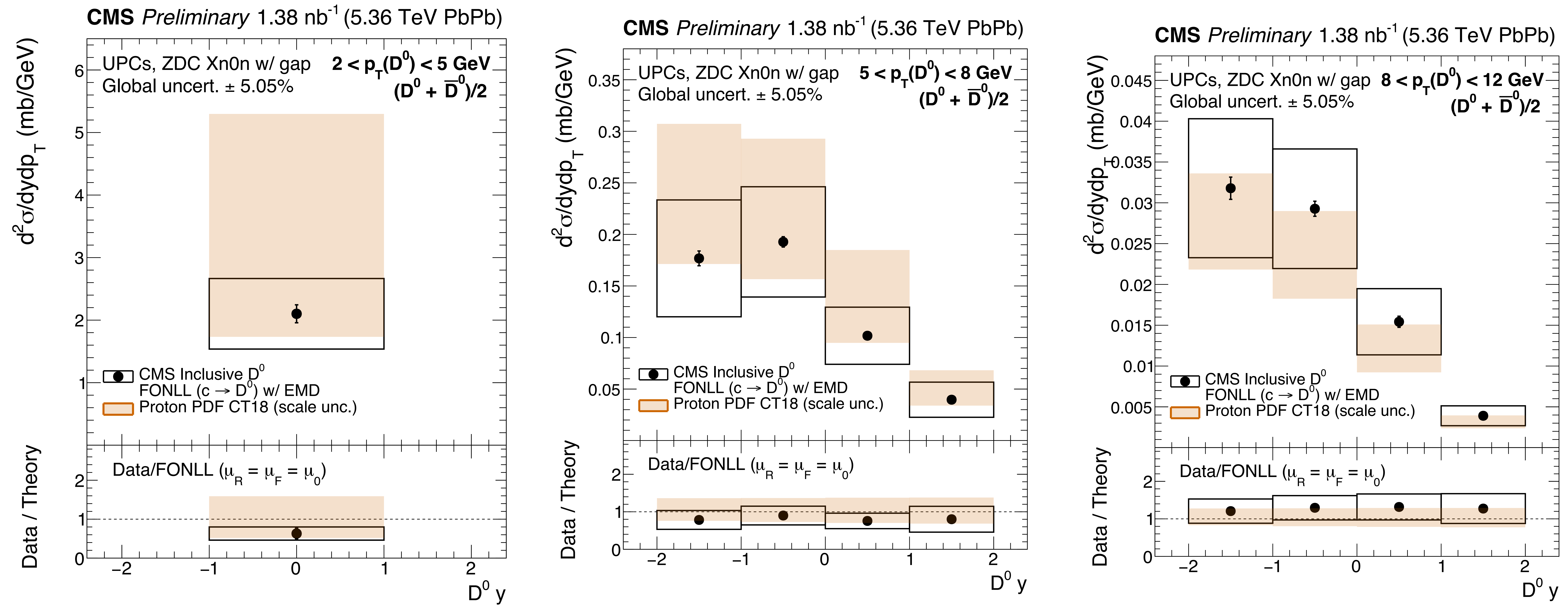


f_{prompt} template fits in data





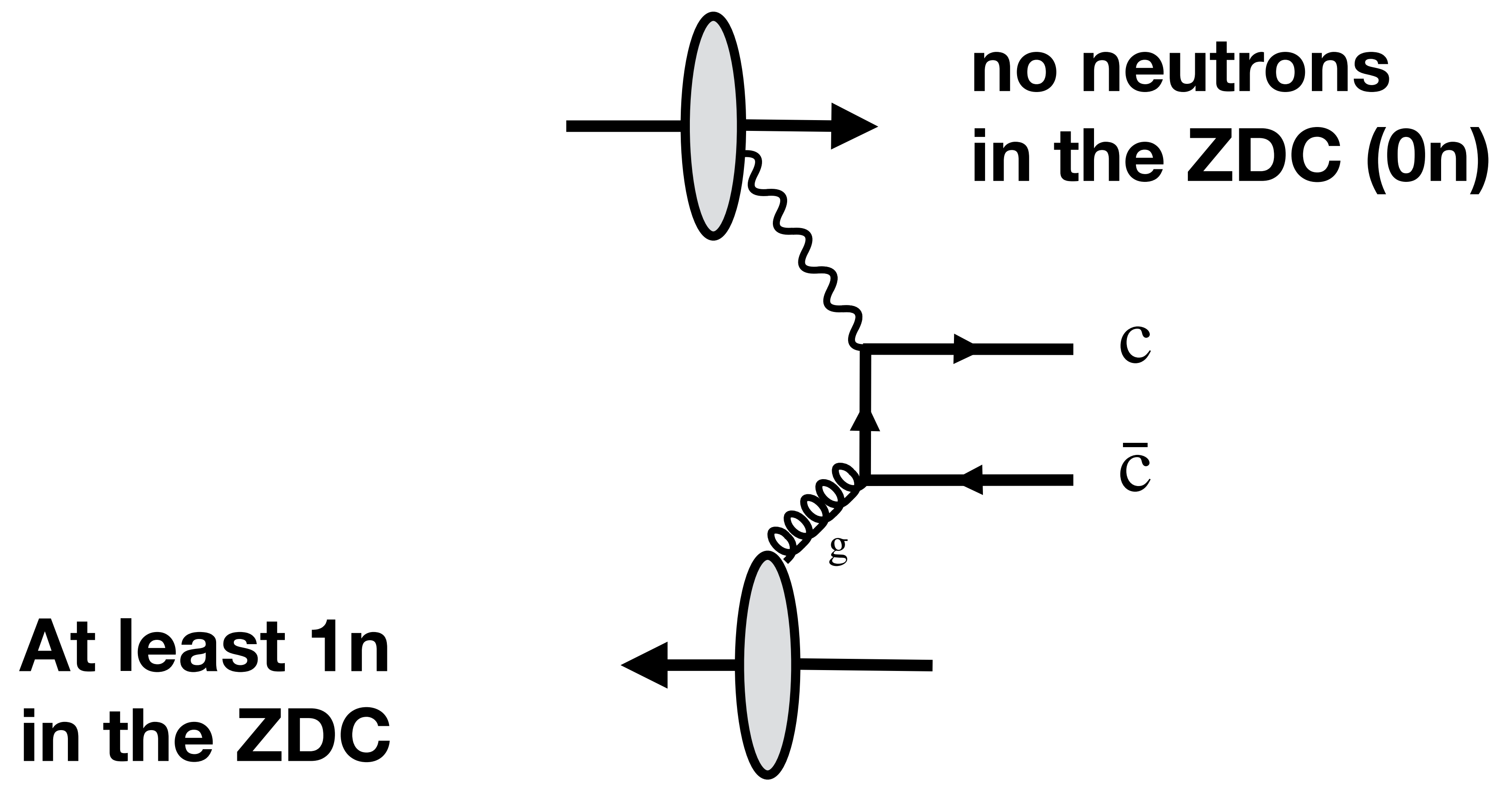
Comparison with FONLL with CT18



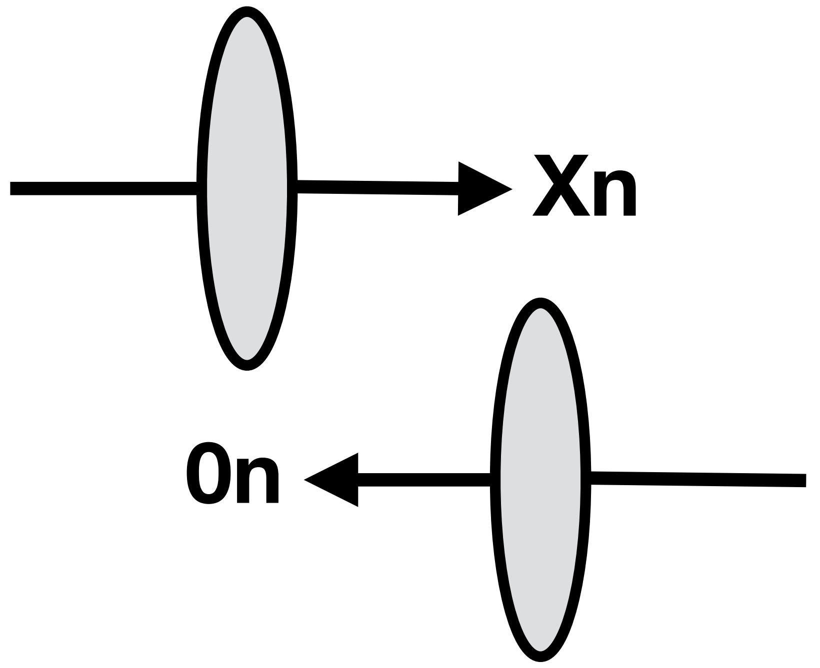
M. Yan et al., Phys. Rev.D 107 (2023) 11, 116001

BACKUP: theory predictions

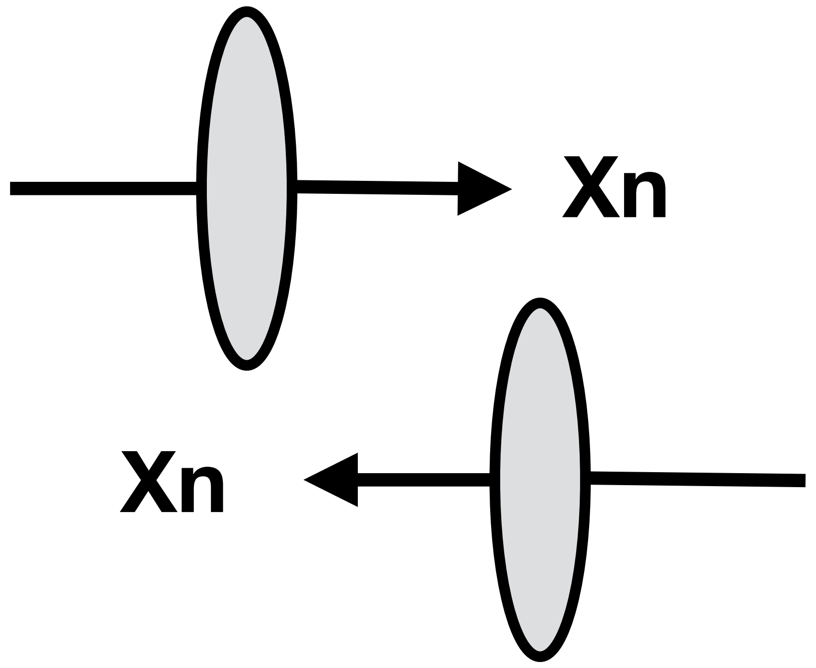
Electromagnetic pileup



In overlap with another independent PbPb collision (in the same bunch crossing) that leads to one or more neutron in the ZDC corresponding to the 0n side of the charm event.



Single EM dissociation with Xn on the the side of the 0n of the charm event



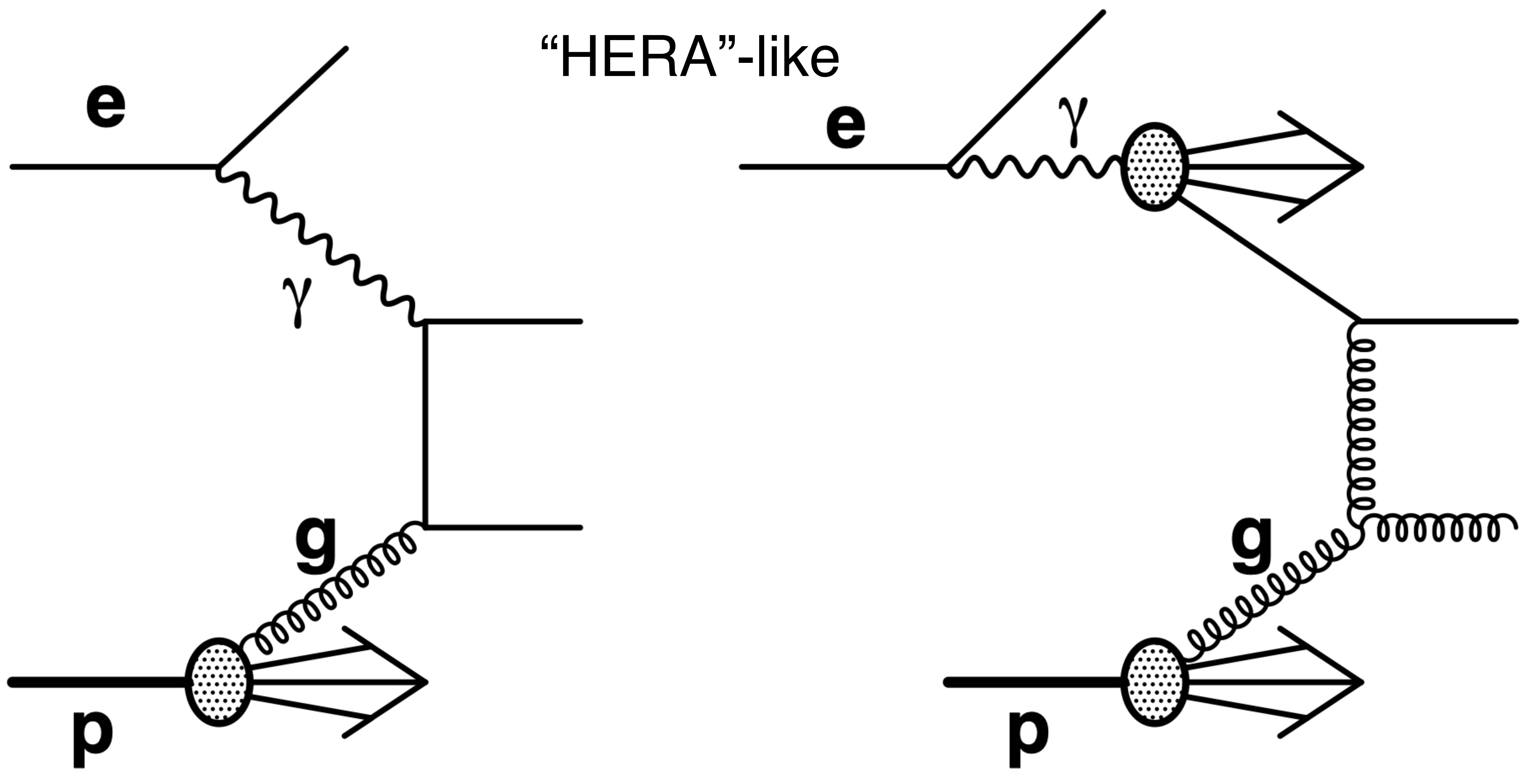
Mutual EM dissociation with Xn on the the side of the 0n of the charm event

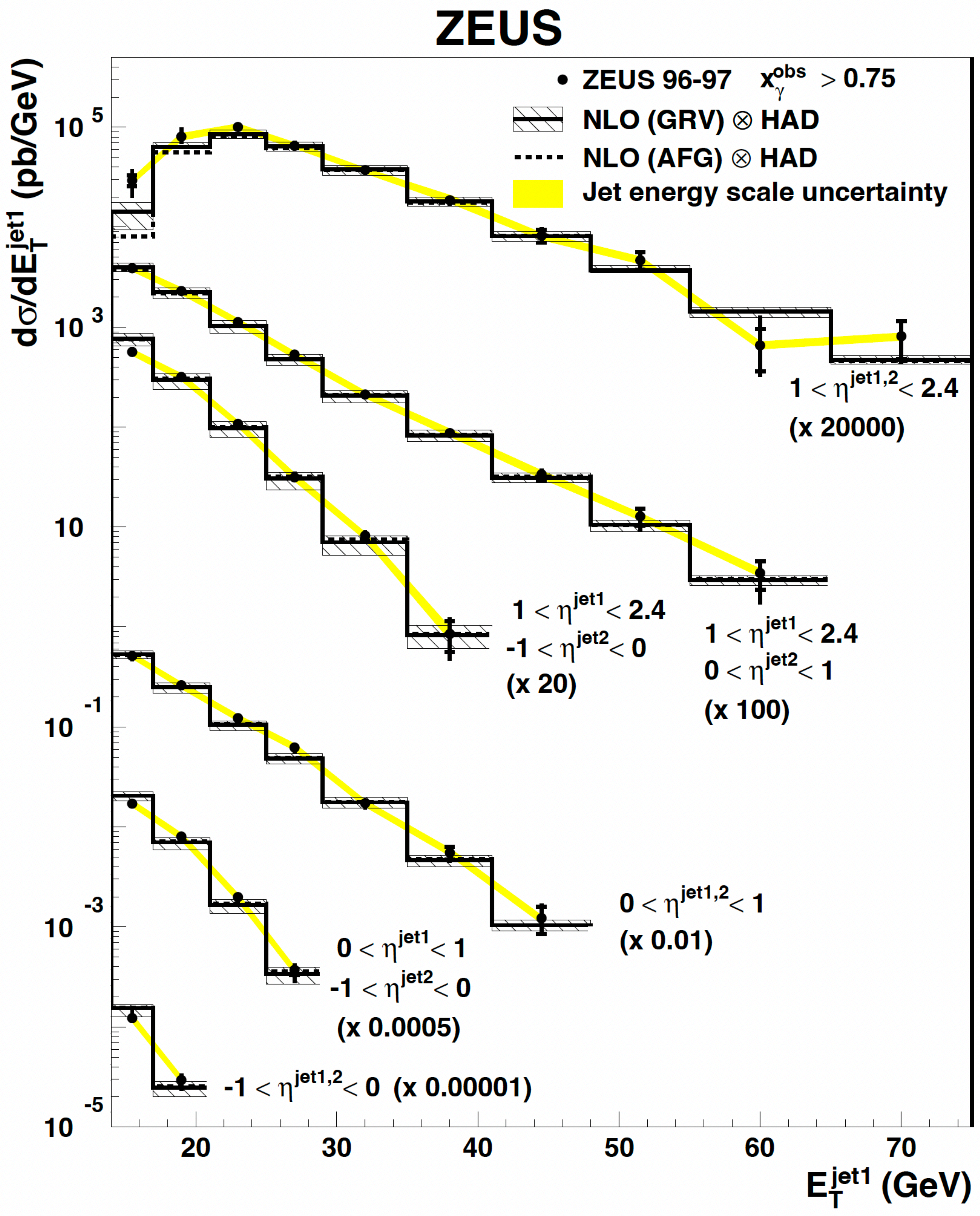
- **We have estimated a survival probability of 0.96 with a systematic uncertainty of 0.04**

Hard-processes in UPCs:
to test the transition towards low-x

Jets and open heavy-quarks in γp scatterings in pPb collisions

→ γp scatterings in pPb collisions as the baseline for γPb measurements





ZEUS, Eur.Phys.J.C23:615-631,2002

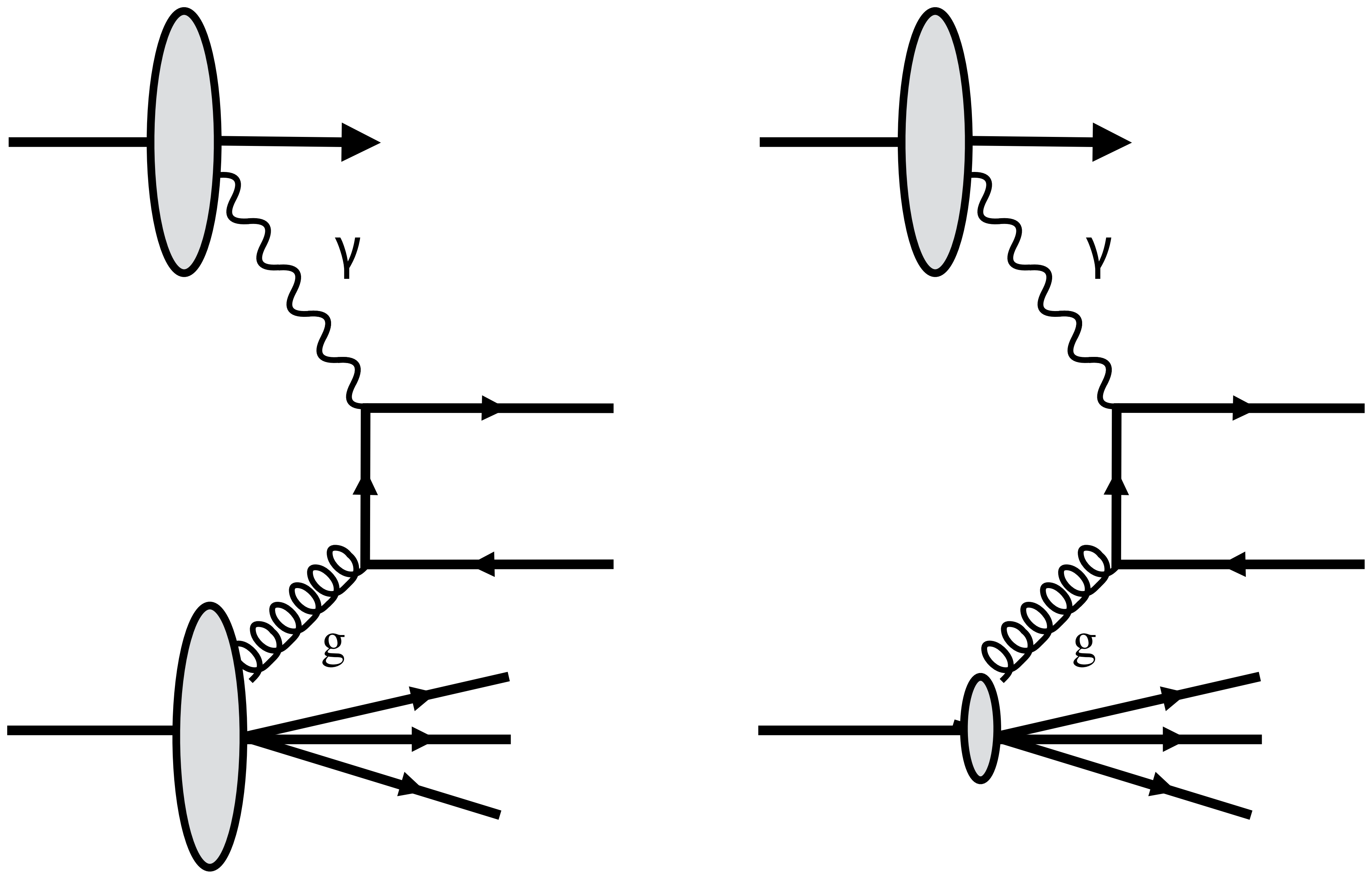
In combination with HERA and EIC measurements:

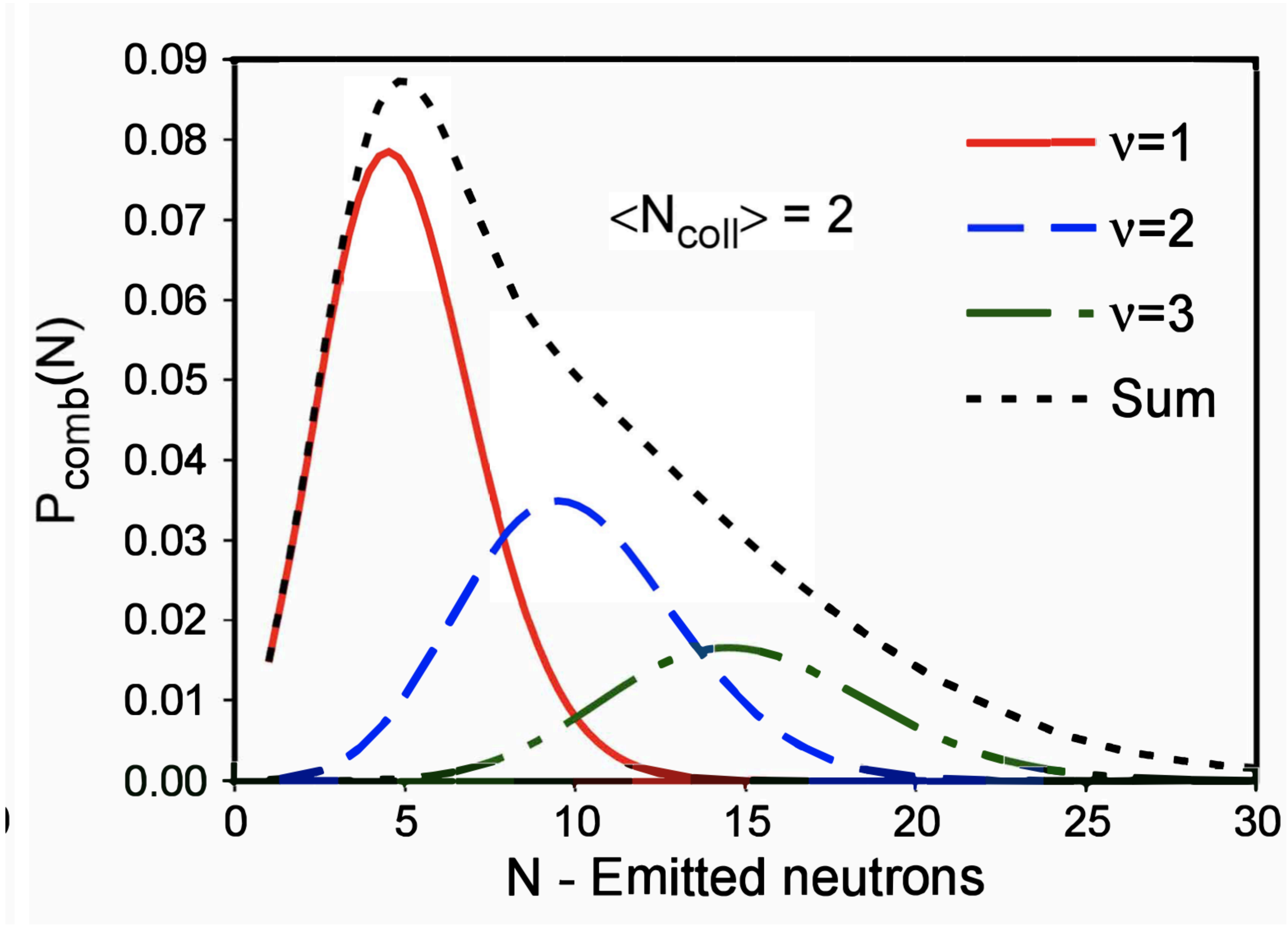
→New constraints on proton nPDFs, GDF, TMD at the highest γp center of mass energies available

New observables in γp/γPb collisions

Basic concept: “over-constraining” low-x models by measuring both barrel and very forward observables

M. Strikman, V. Guzey et al., arXiv.2402.19060





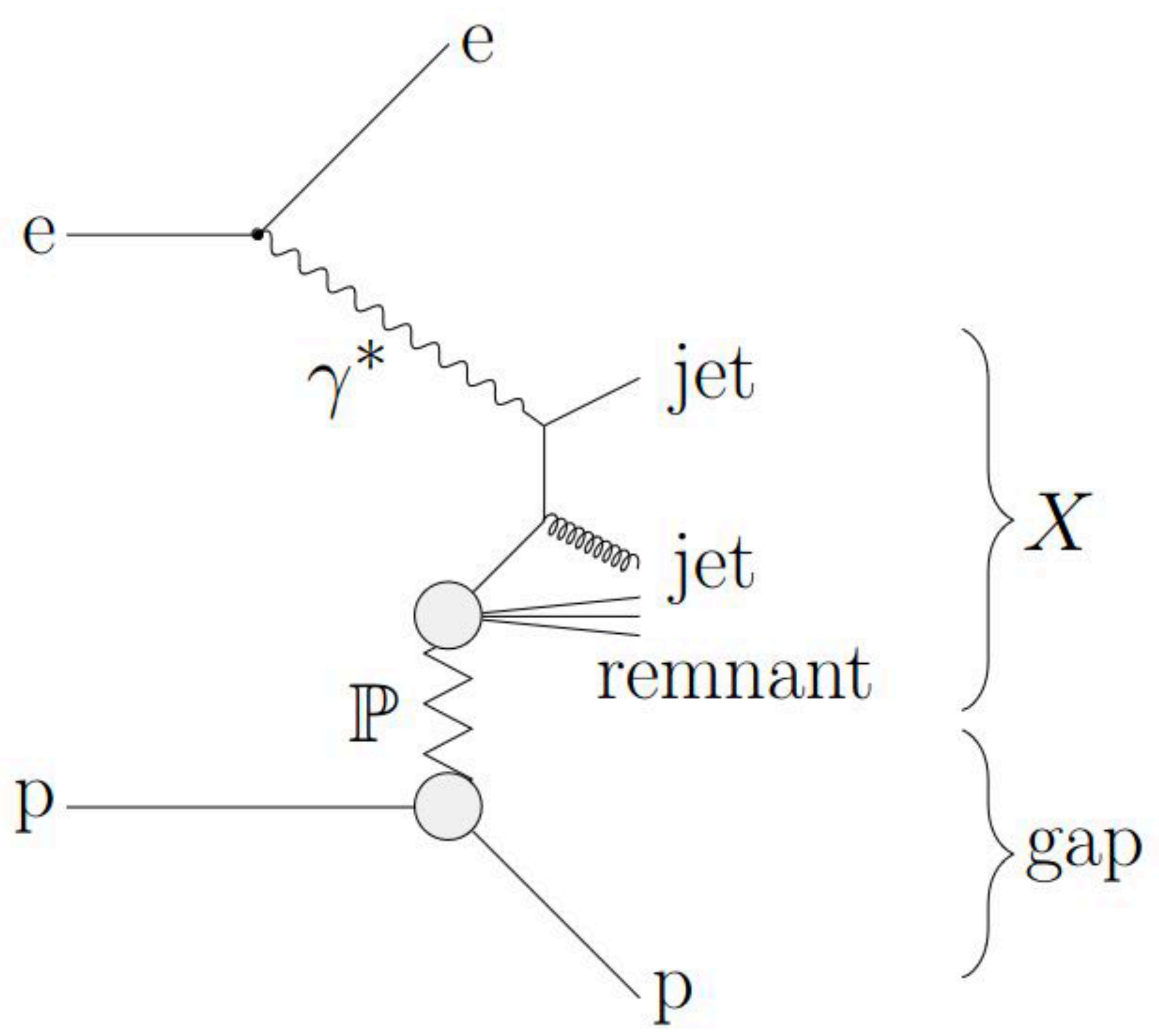
Hard-scattering production at central rapidities with information on the number of neutrons in ZDC:

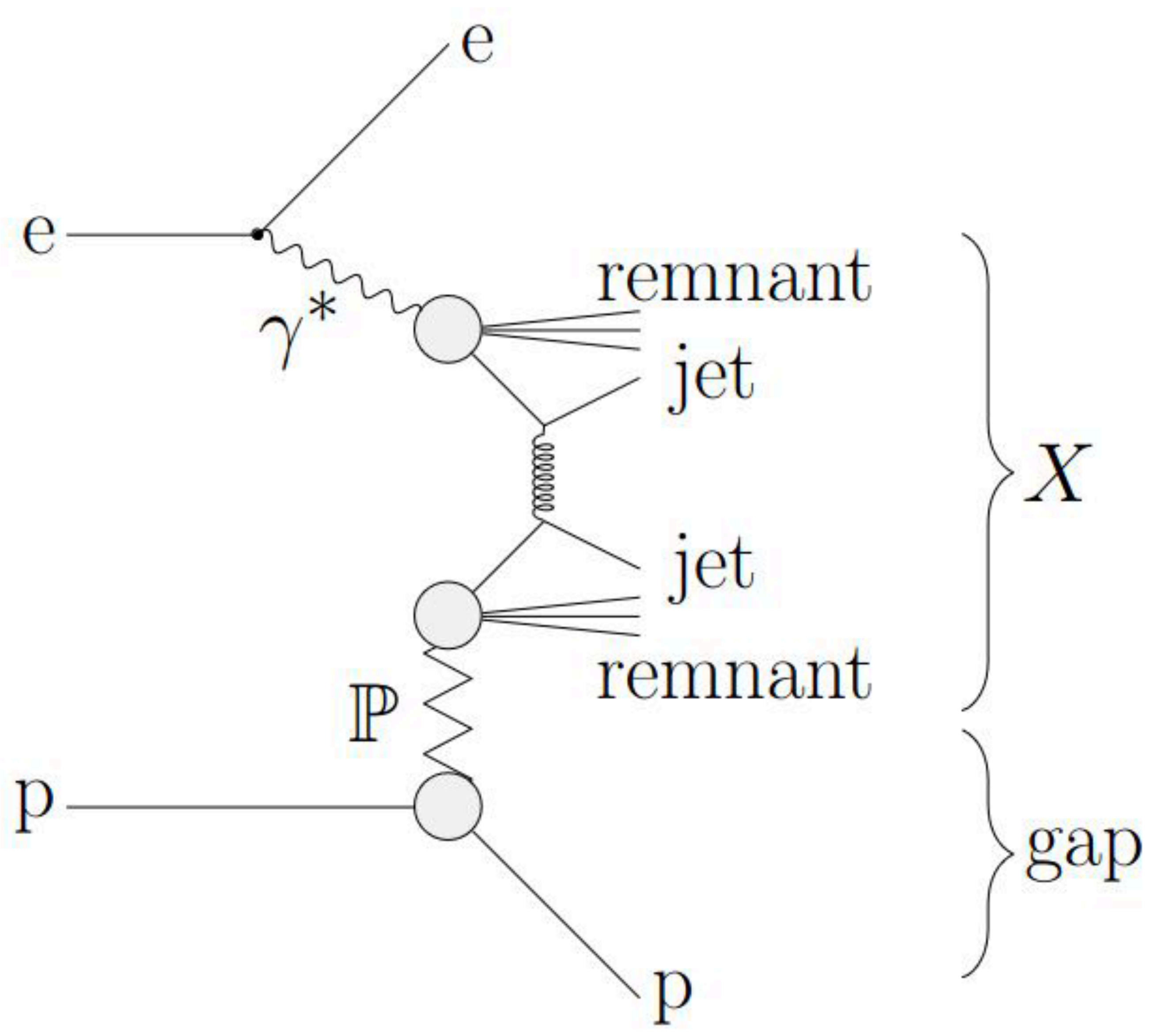
→ stronger discrimination power on low-x nuclear matter

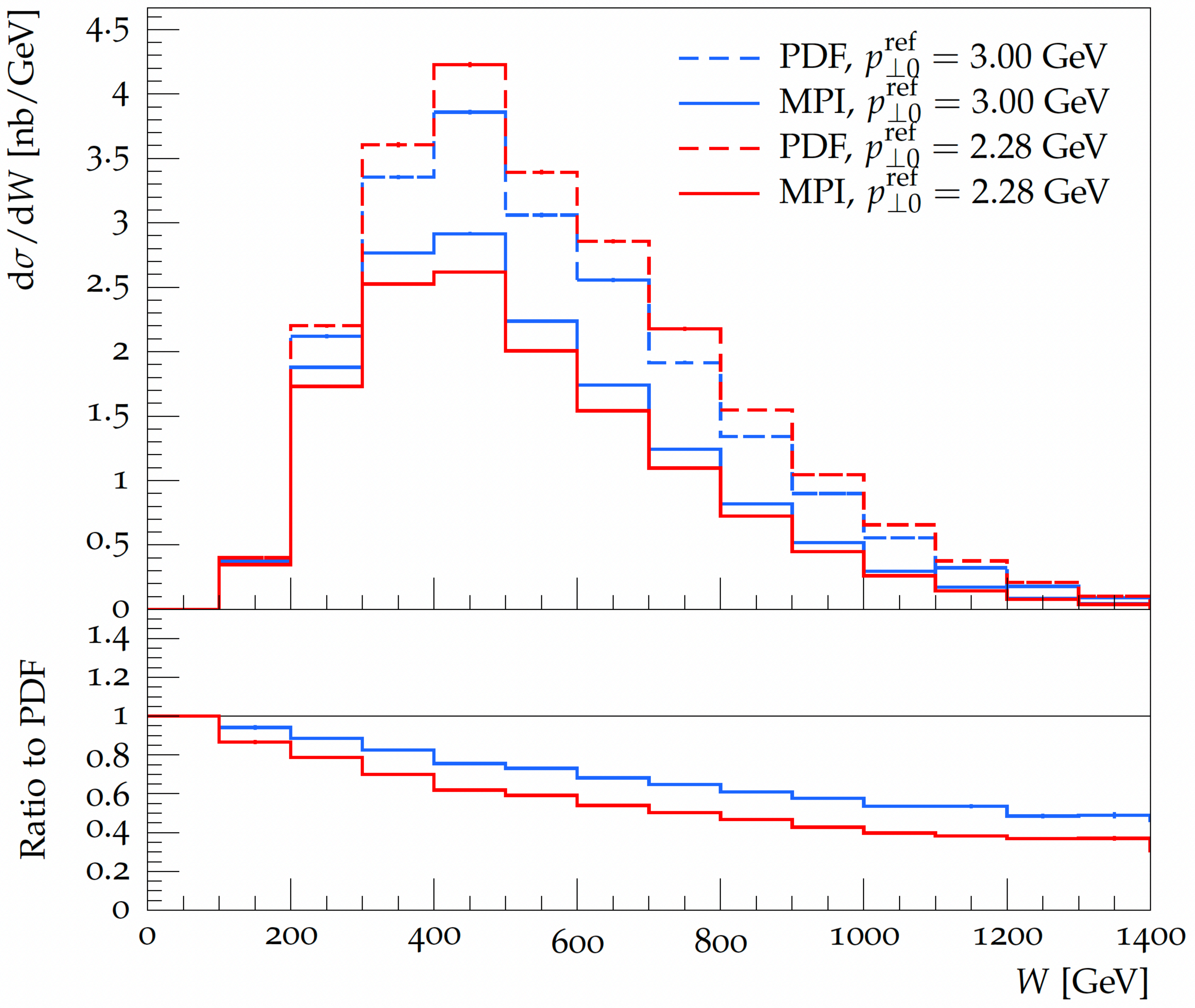
→ **new experimental challenges for ZDC reconstruction and calibration**

Diffractive production of jets and heavy quarks

Ilkka Helenius, arXiv:2107.07389
C. Marquet, C. Rayon et al. arXiv.1306.4901





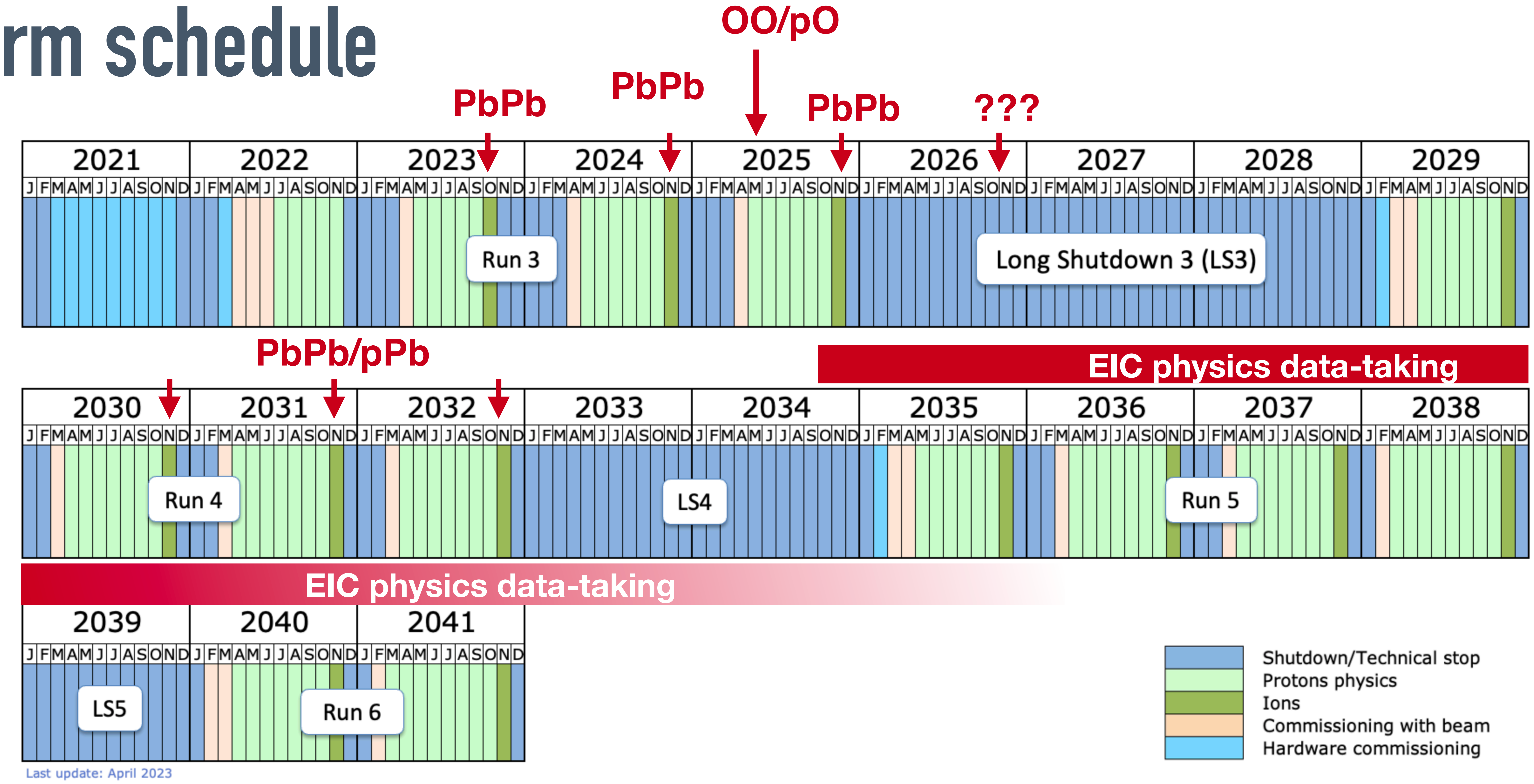


→ **test for factorization**: diffractive PDFs ⊗ partonic coefficient functions
→ benchmark for PbPb measurements

Need for theoretical calculations and MC simulations for diffractive events in both γp and γPb collisions!

Short and long-term prospects with CMS at the LHC and HL-LHC

LHC long-term schedule



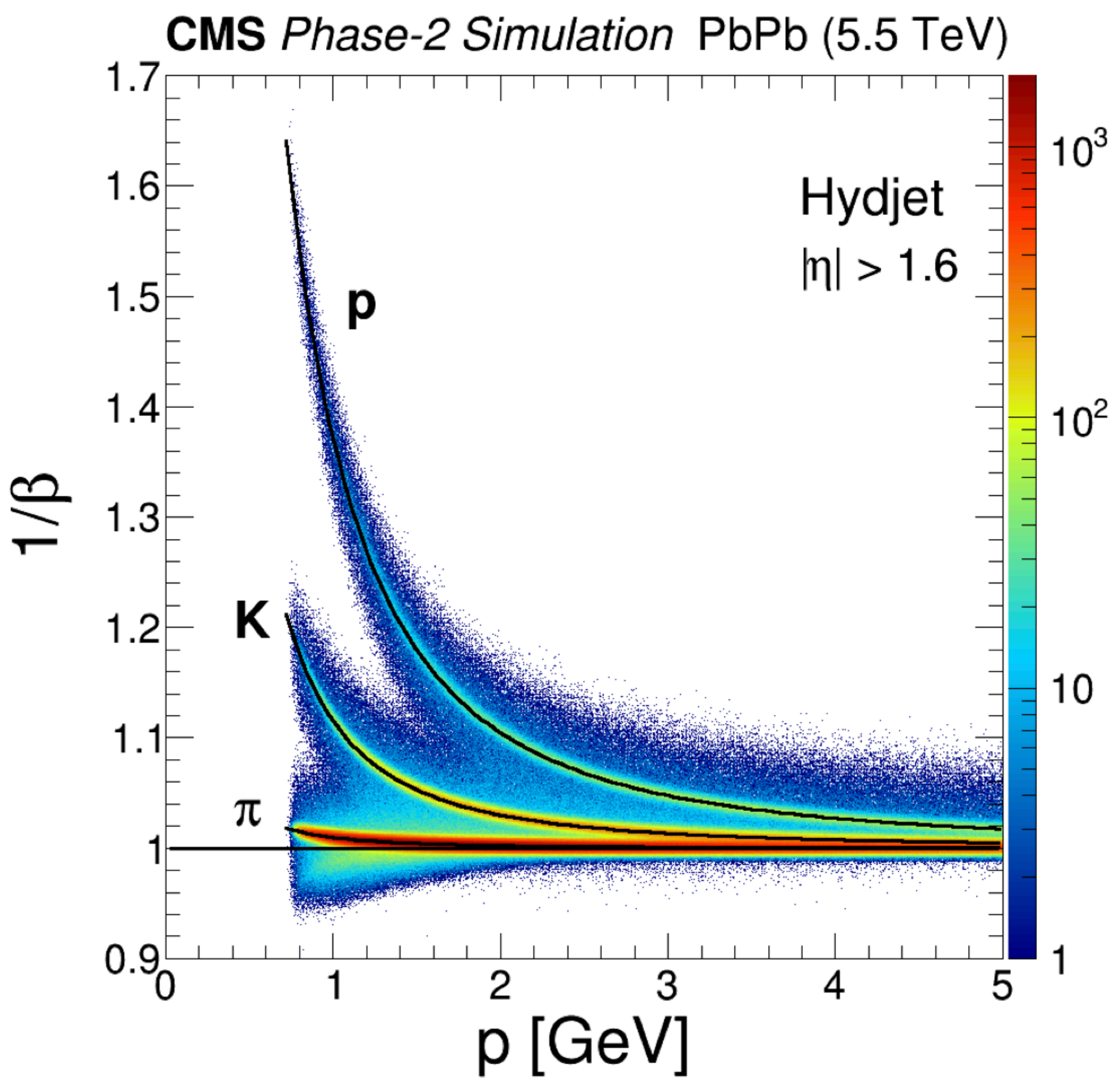
- **About a week of OO/pO in 2025:** statistics is enough for very soft-probe measurements, assessing quenching in small systems
  → we would need a few weeks of data to constrain nPDFs with EM probes or high-accuracy heavy-quark probes
- **Additional run in Run 3? pPb in Run 4?**
- **Inputs for Run 5/6 from the “parton-structure” community?**

The upgraded CMS detector for Run 4 (Phase II)

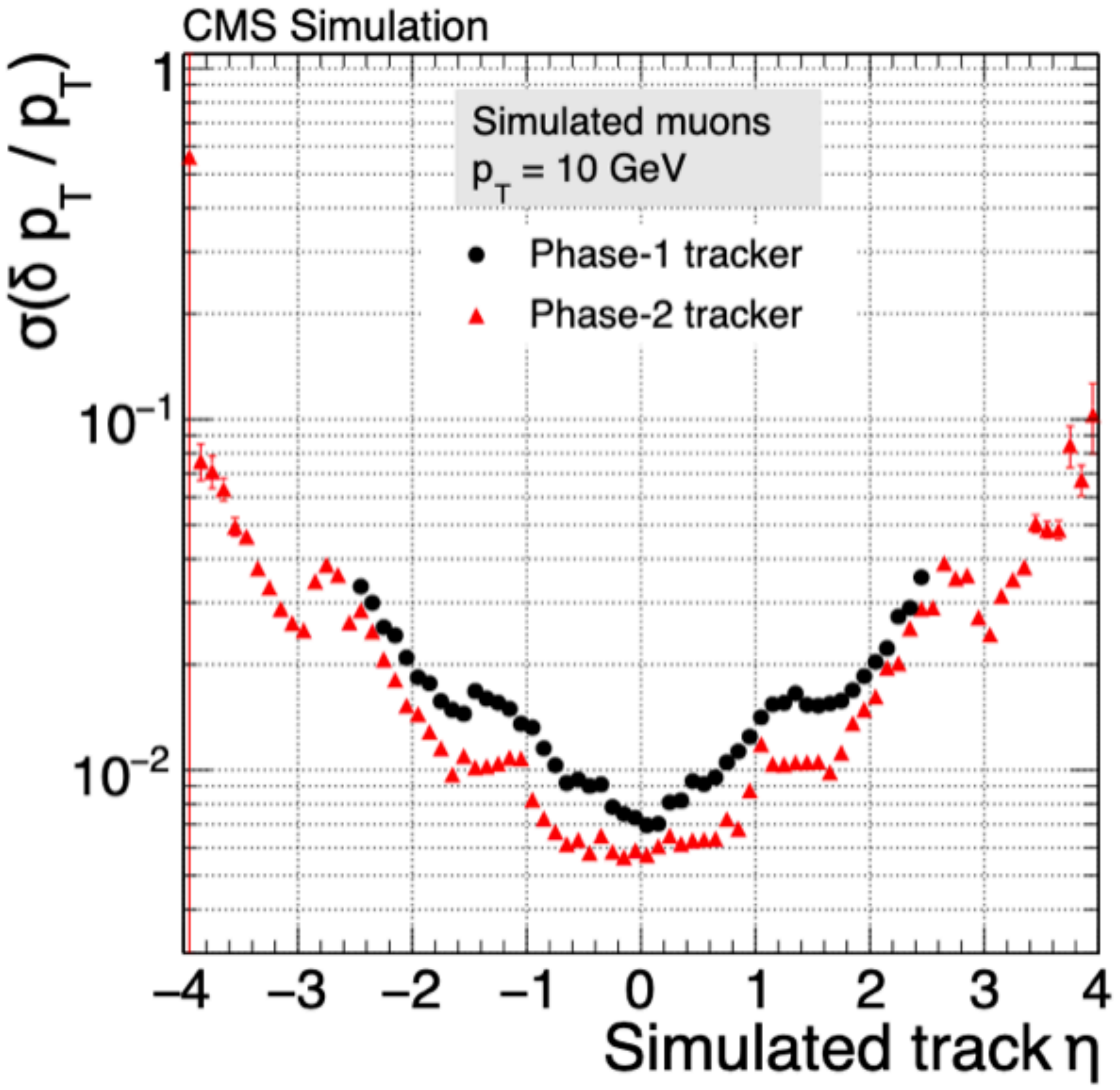
CMS, CERN-LHCC-2019-003
CMS, CMS-TDR-014

Track-based triggers at Level-1 to sample the entire cross section of photon-induced collisions in both pPb and PbPb events

Particle Identification over (MTD) in |η| < 3



New high resolution silicon tracker with ~ factor 2 larger coverage from **$|\eta_{tracks}|$< 2.4 to** from **$|\eta_{tracks}|$< 4.0**



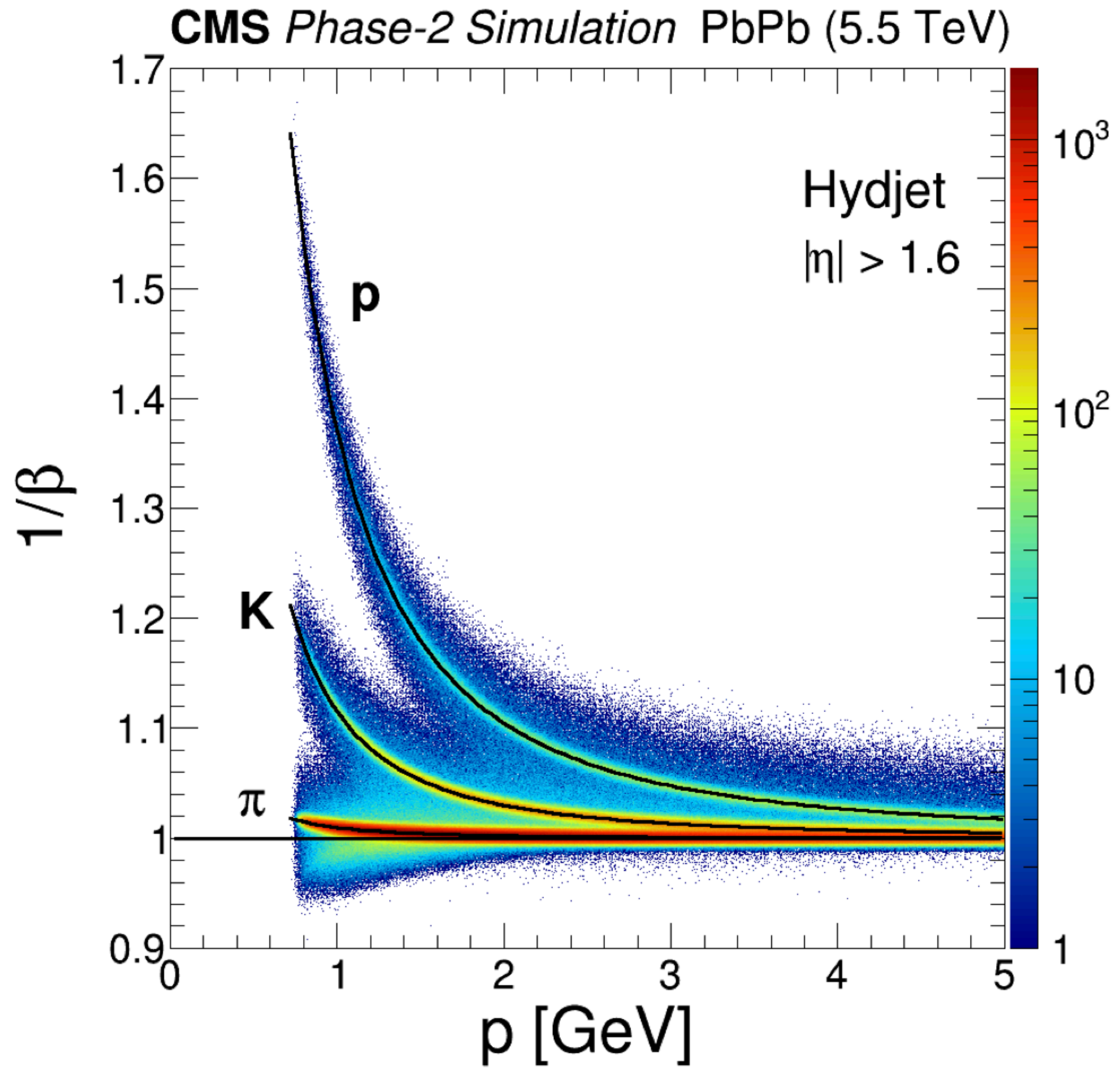
$$x_{ion} \approx \frac{M}{\sqrt{s_{NN}}} e^{-y}$$

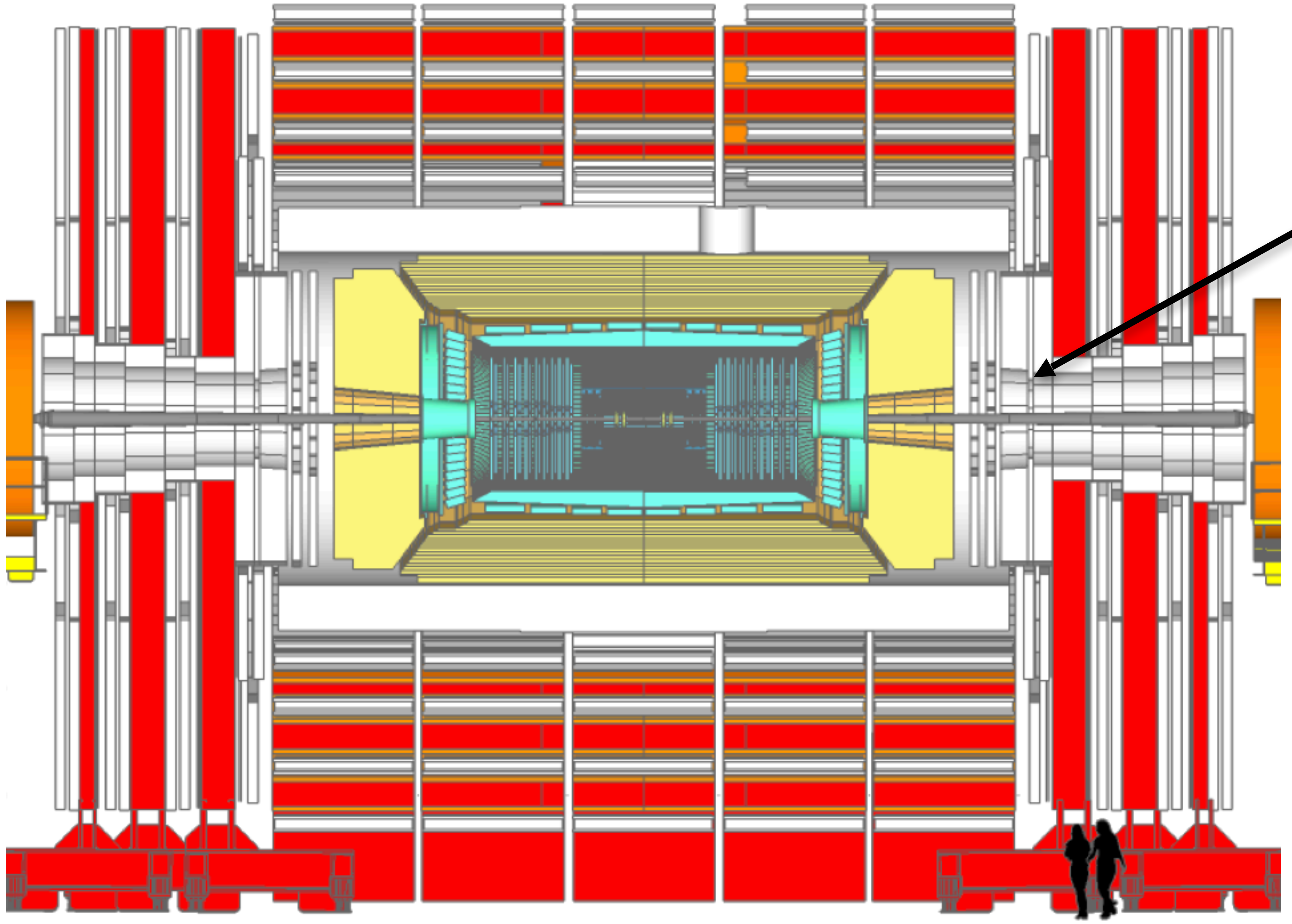
Big jump in the x_{BJ} coverage of future Run-4 analyses

The upgraded CMS detector for Run 4 (Phase II)

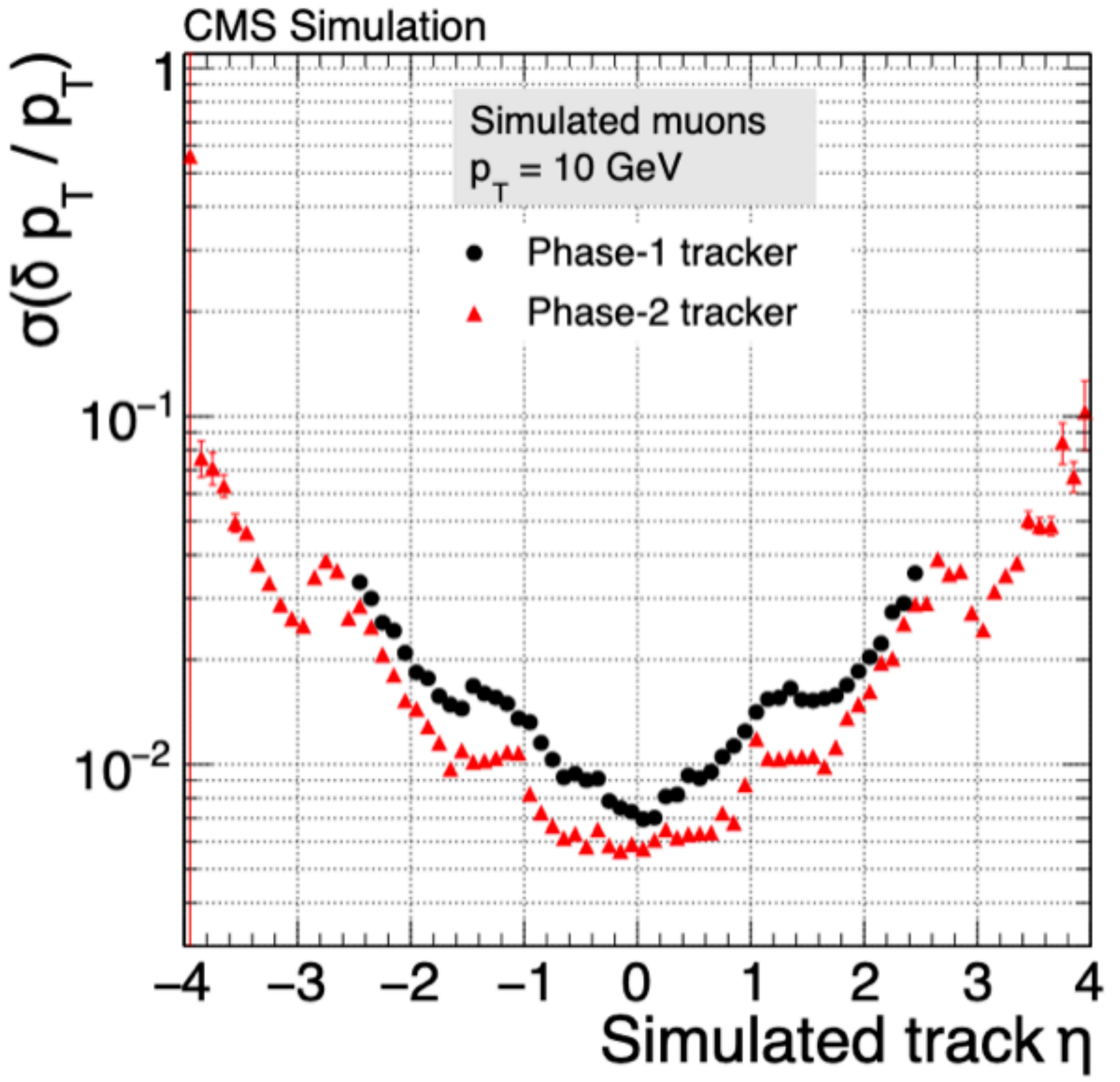
CMS, CERN-LHCC-2019-003
CMS, CMS-TDR-014

New MIP Timing Detector (MTD)
Precision timing $|\eta| < 3$
Particle Identification over several units of η!



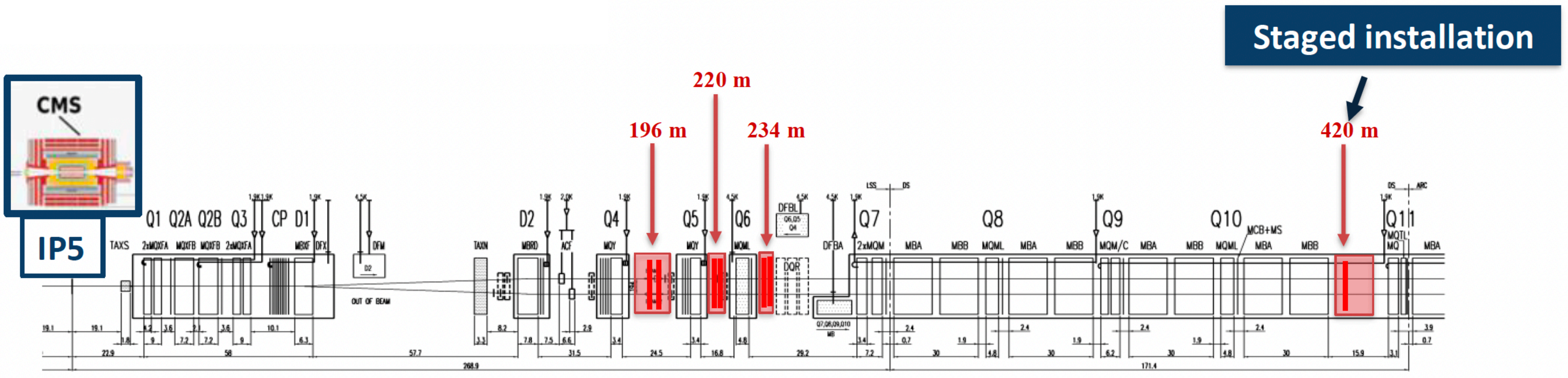


New silicon tracker
Improved granularity
Lighter material budget
$|\eta| < 2.4 \rightarrow |\eta| < 4$



Upgraded Precision Proton Spectrometer (Run 4 and 5)

Basic working principle of the PPS: Protons which lose a fraction of momentum at the interaction point ($\xi = \Delta p/p$) are deflected away from the beam and measured by PPS → **direct measure of the $\xi = \Delta p/p$**

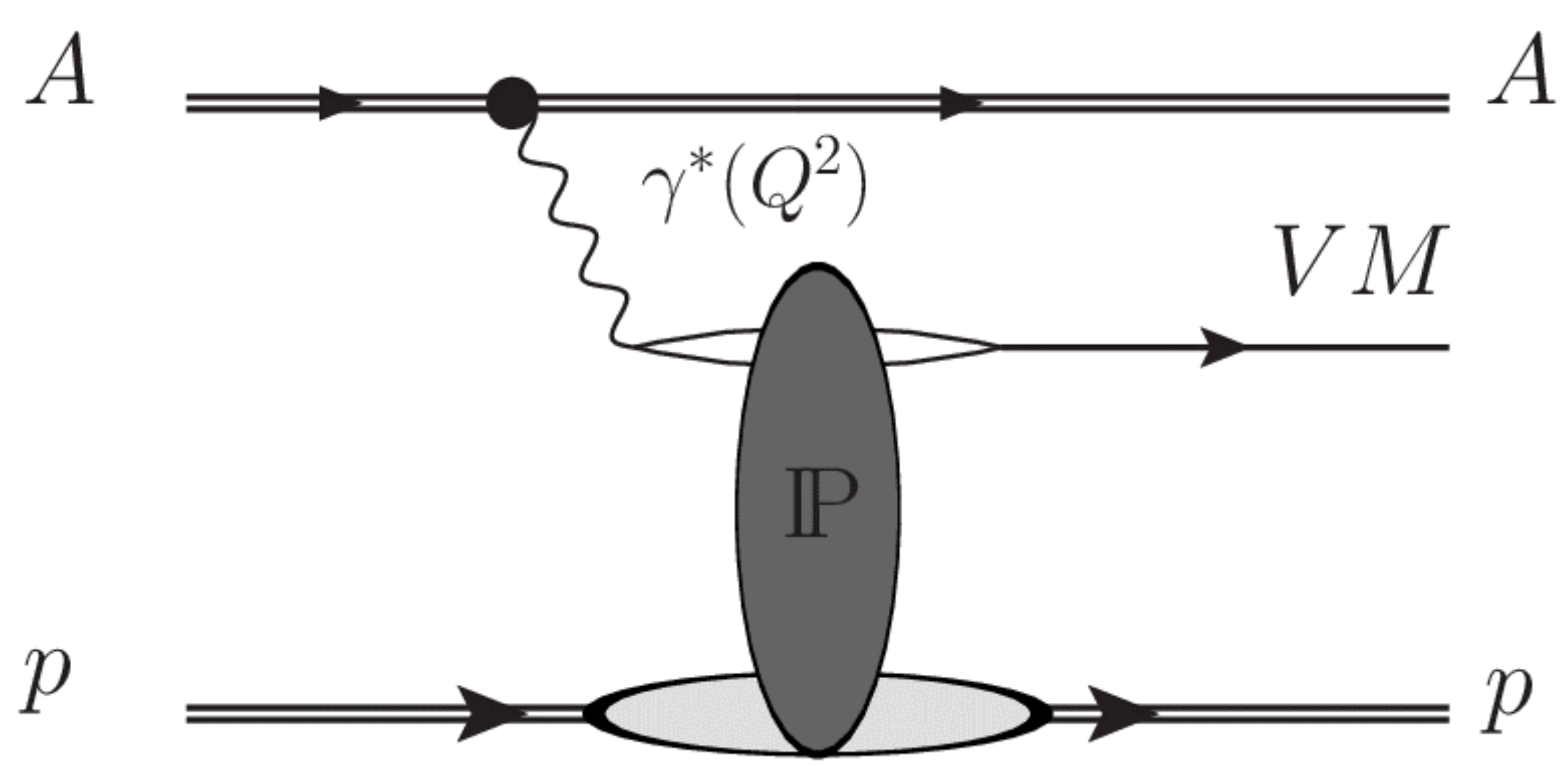


PPS upgrade will further extend the ξ acceptance of the existing PPS (already operational in Run 3)

- $1.42 < \xi < 20$ % for the first three stations (from Run 4)
- $0.33 < \xi < 20$ % for the first three stations (from Run 5)

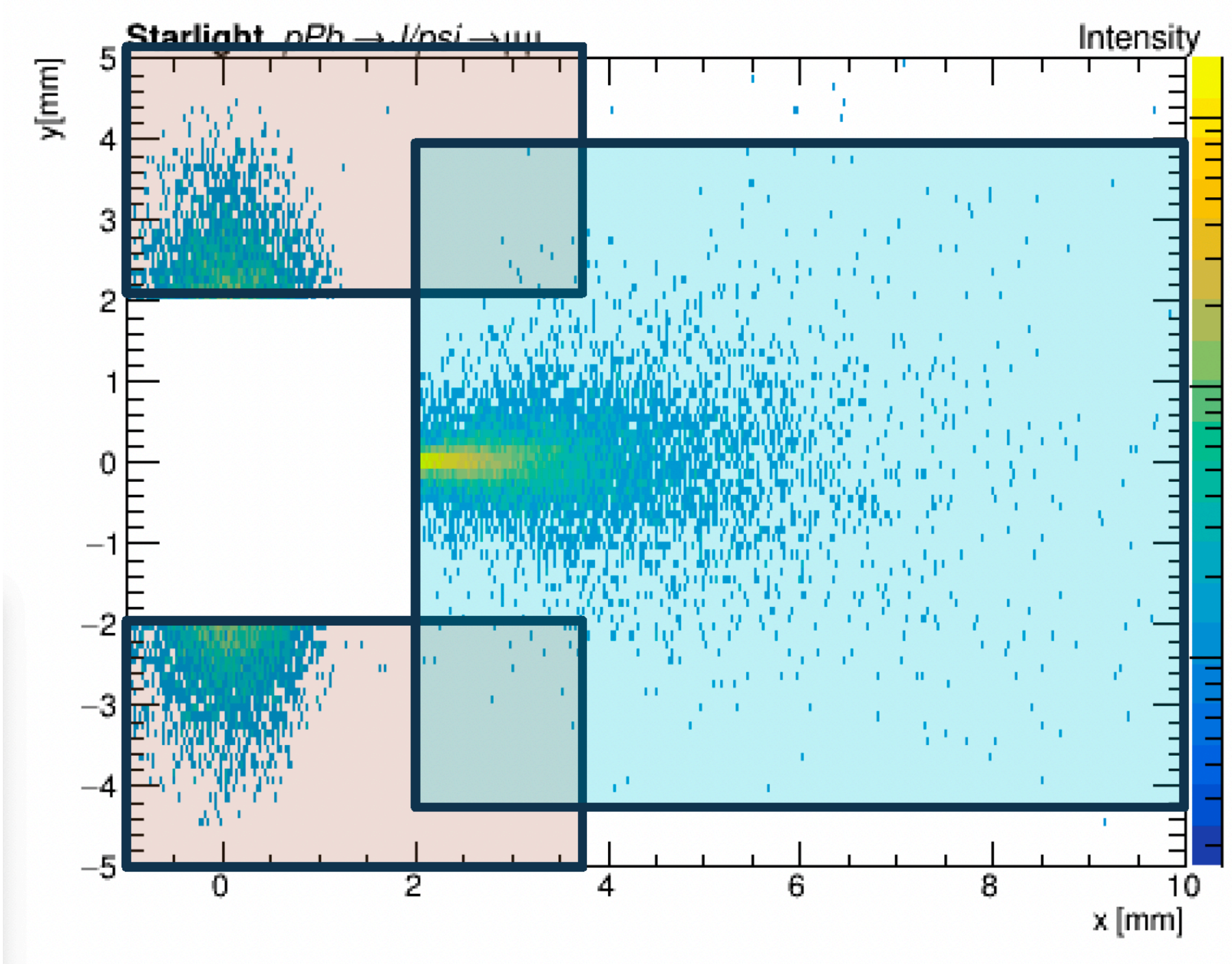
CMS NOTE -2020/008

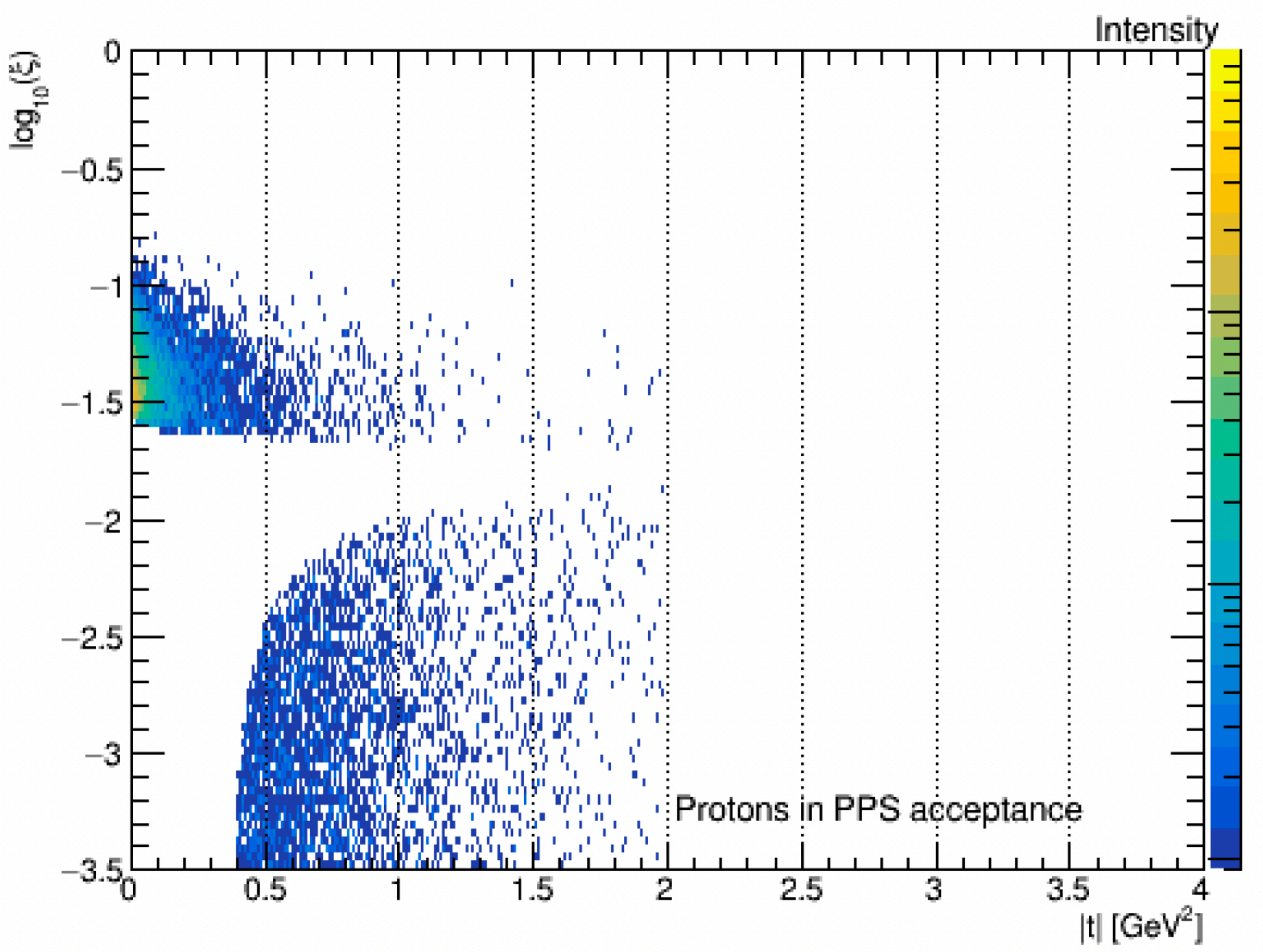
Highlight: exclusive vector-meson production in pA

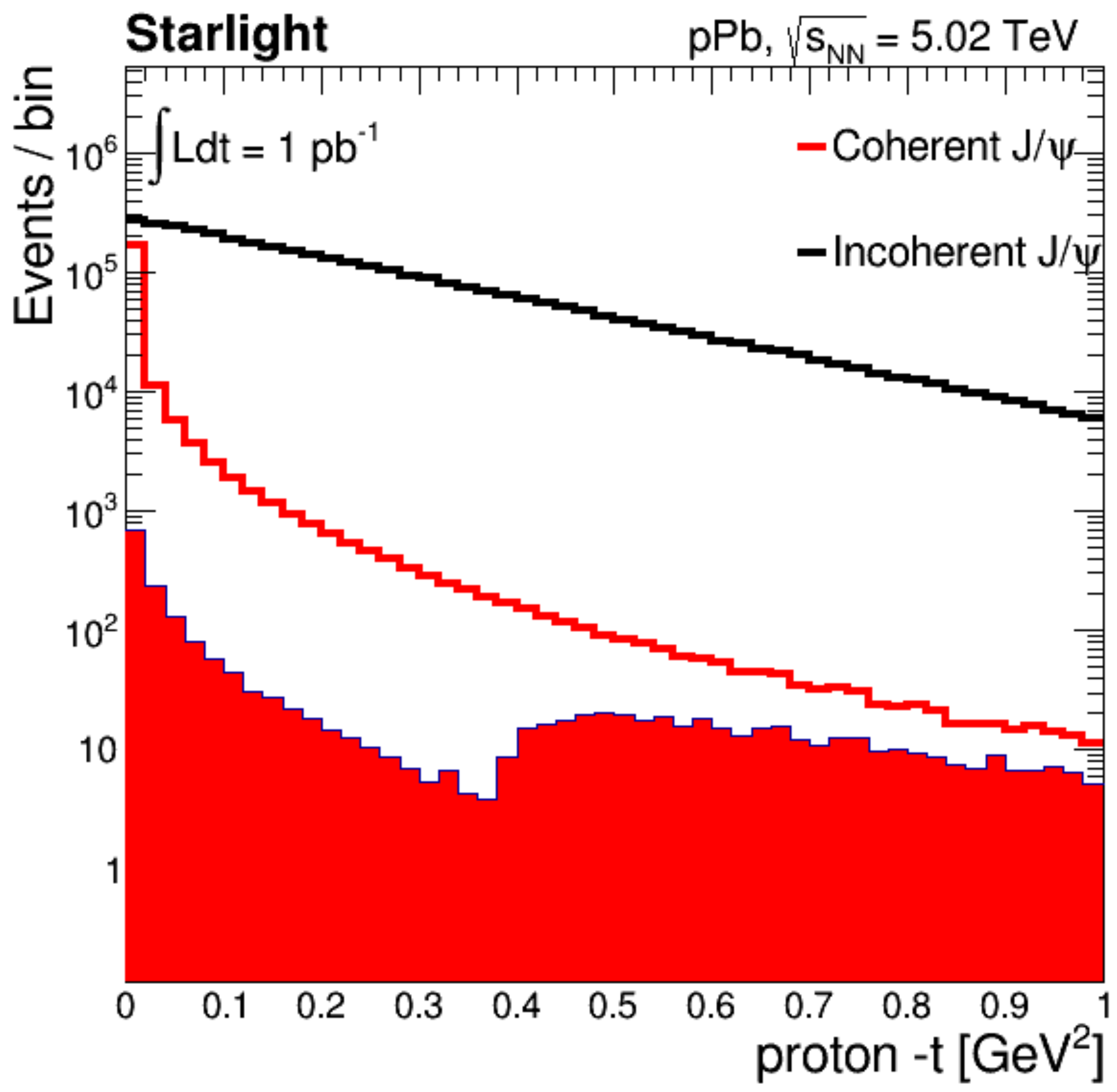


- Vector mesons (Spin 1) are produced in $\gamma - IP$ interactions
- Ions emit a photon at Q^2~0
- **In coherent production, the proton remains intact**

→ PPS would provide high-accuracy tagging of coherent processes
→ Similar technique applicable to exclusive dijet production







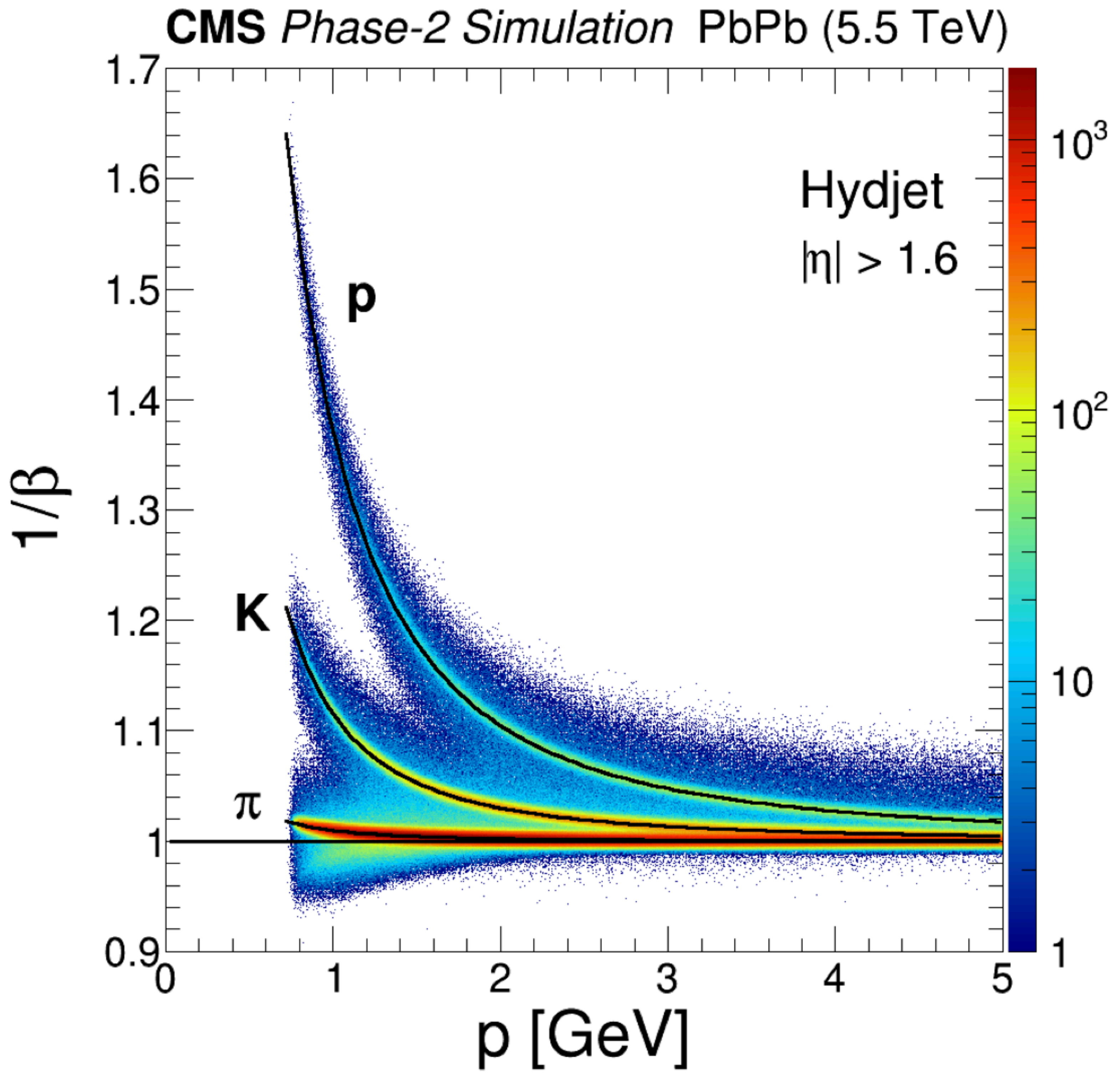
→ Proof of principle for proton (and ion) tagging with the upcoming pO/OO run (scheduled for 2025)

The upgraded CMS detector for Run 4 (Phase II)

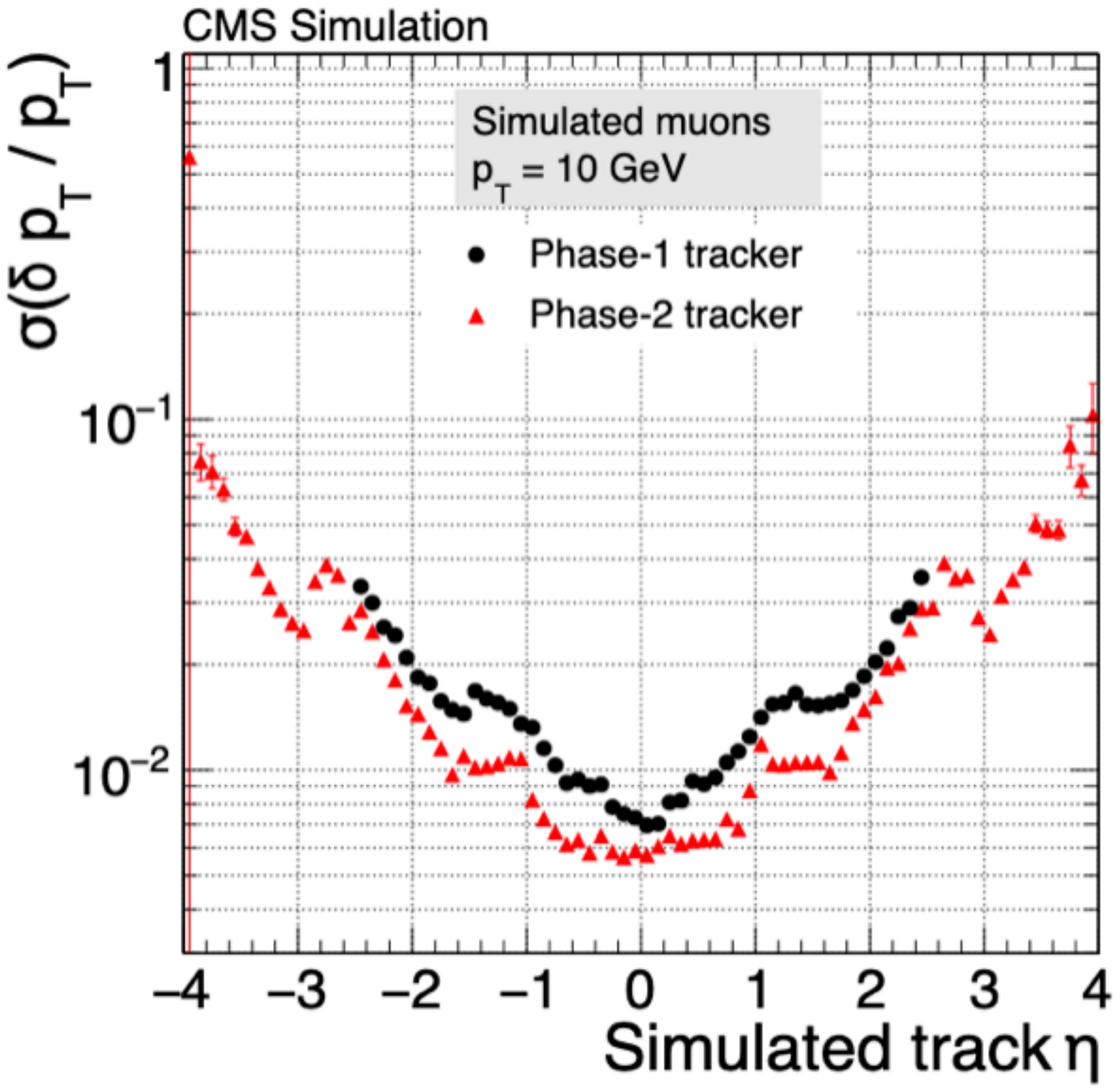
CMS, CERN-LHCC-2019-003
CMS, CMS-TDR-014

Track-based triggers at Level-1 to sample the entire cross section of photon-induced collisions in both pPb and PbPb events

Particle Identification over (MTD) in $|\eta| < 3$



New high resolution silicon tracker with ~ factor 2 larger coverage from $|\eta_{tracks}| < 2.4$ **to from** $|\eta_{tracks}| < 4.0$



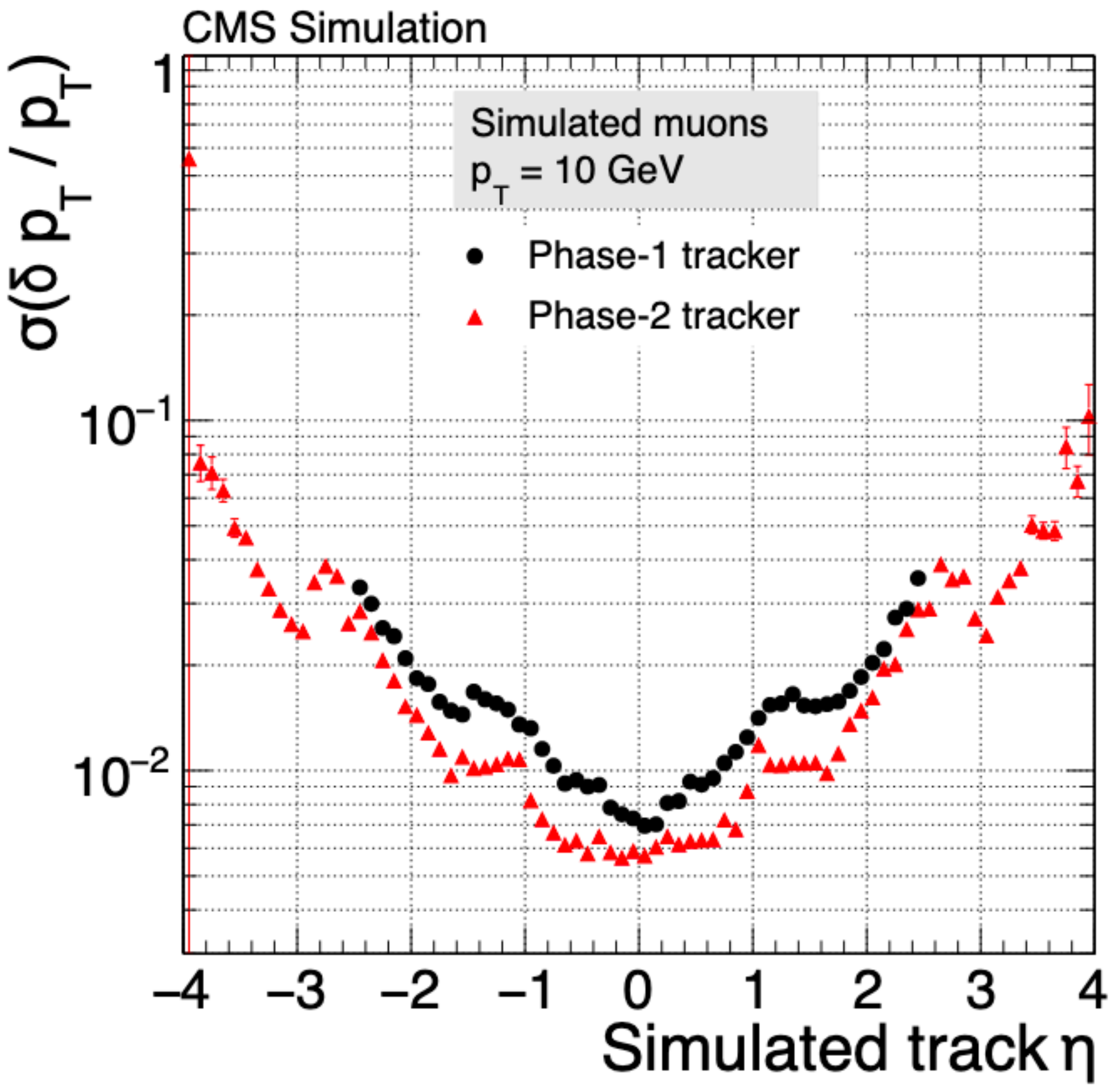
$$x_{ion} \approx \frac{M}{\sqrt{s_{NN}}} e^{-y}$$

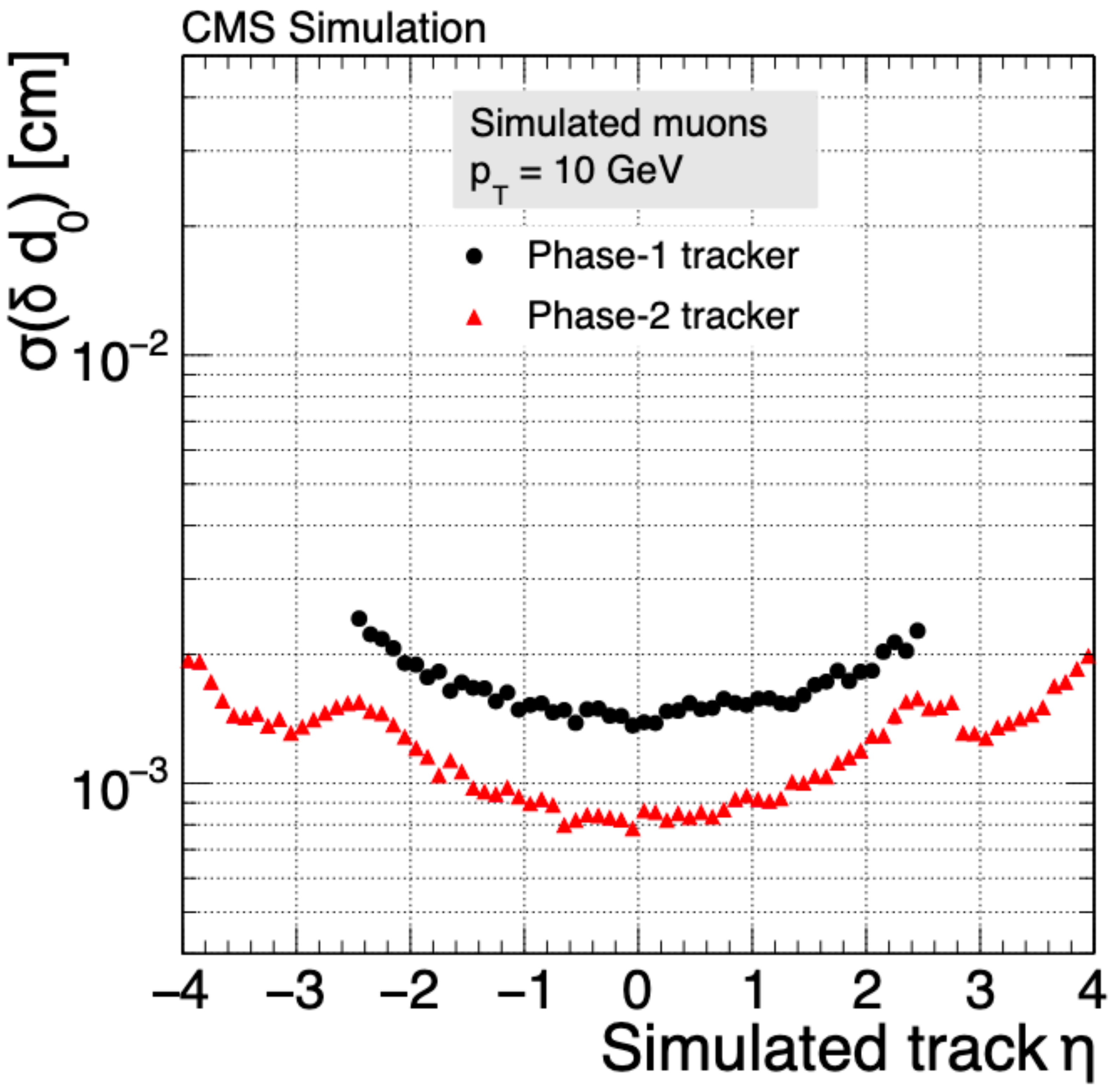
Big jump in the x_{BJ} coverage of future Run-4 analyses

High-resolution, large acceptance silicon tracker (|η| < 4)

from 100 x 150 to 50 x 50 μm^2 pixel size
Tracking out to |η| < 4 !!
Reduced material budget by up to 2x

CMS, CMS-TDR-014





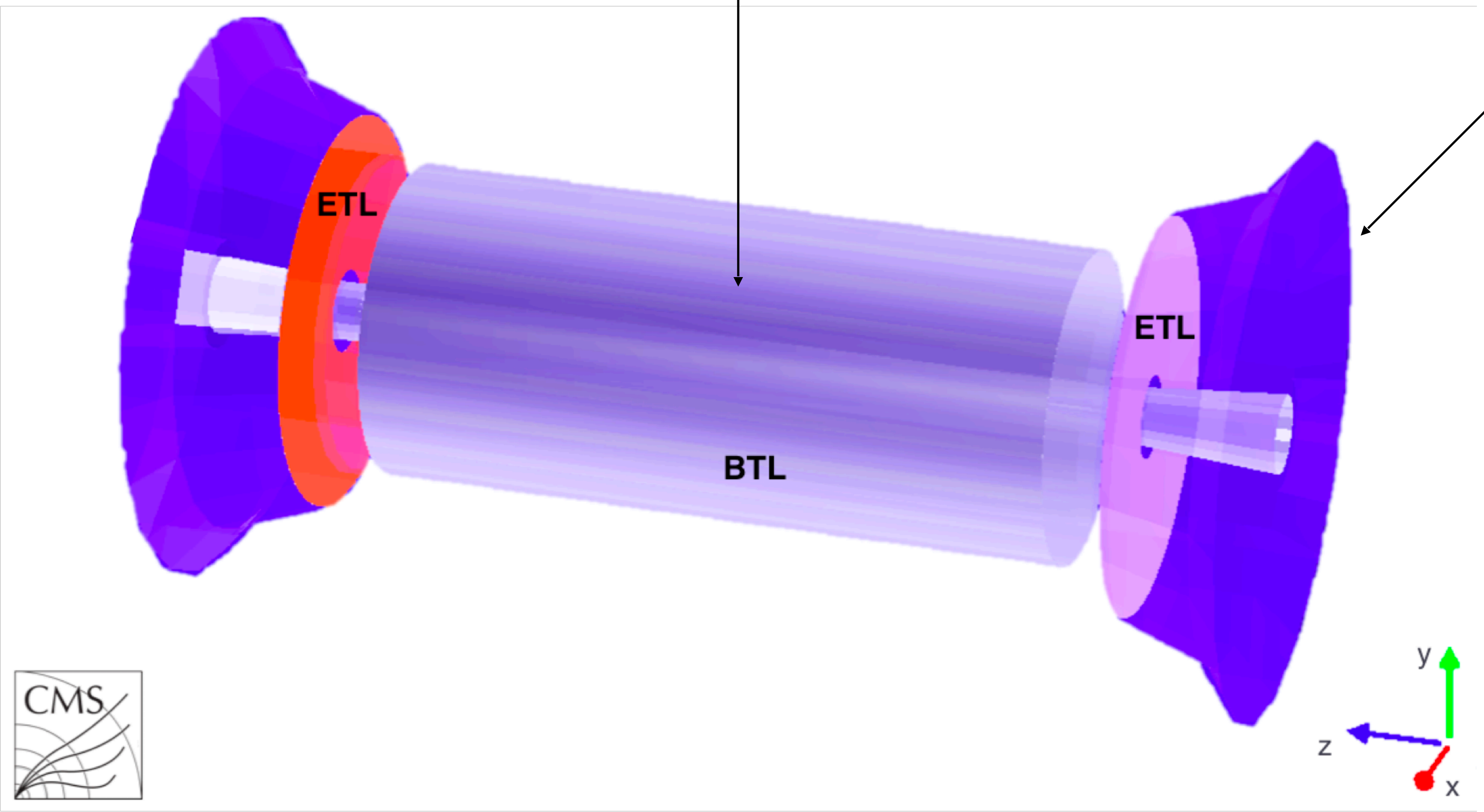
Improved p_T resolution by about 25%
- Improved mass resolution for resonances

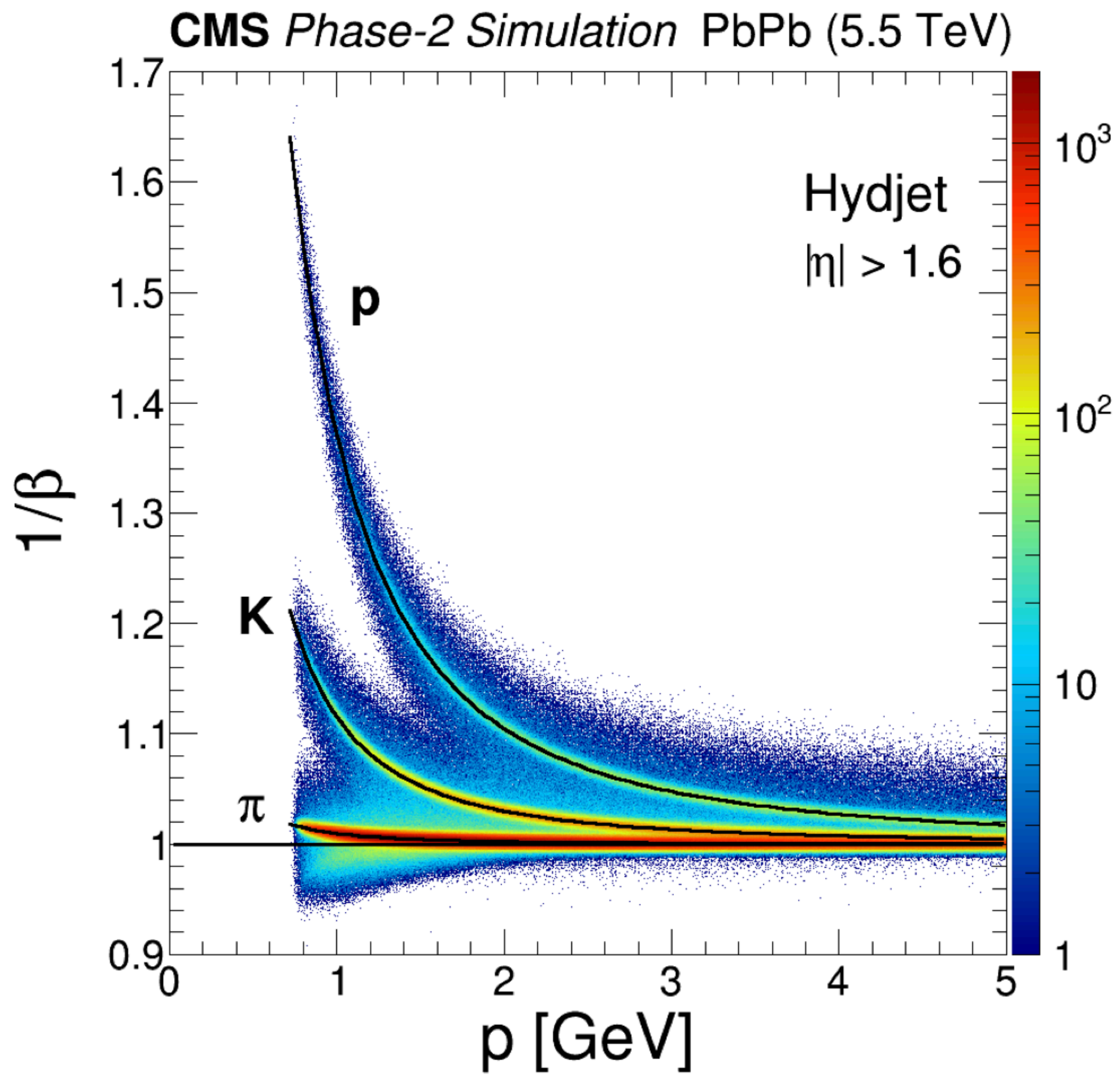
Impact parameter resolution improved by 40%
- Improved heavy flavor measurements (B/D hadrons & b/c-jet tagging)

MIP timing detector (MTD)

Barrel Timing Layer (BTL)
- Coverage: $|\eta| < 1.45$, $p_T > 0.7$ GeV
- Timing resolution: ~ 30 ps
- Tech: Scintillator + Si photo-multiplier

Endcap timing layer (ETL)
- Coverage: $1.6 < |\eta| < 3.0$, $p > 0.7$ GeV
- Timing resolution: ~ 30 – 40 ps
- Tech: Silicon w/ internal gain (LGAD)





Unlock a wide set of semi-inclusive "DIS-like" measurements with identified hadrons with CMS

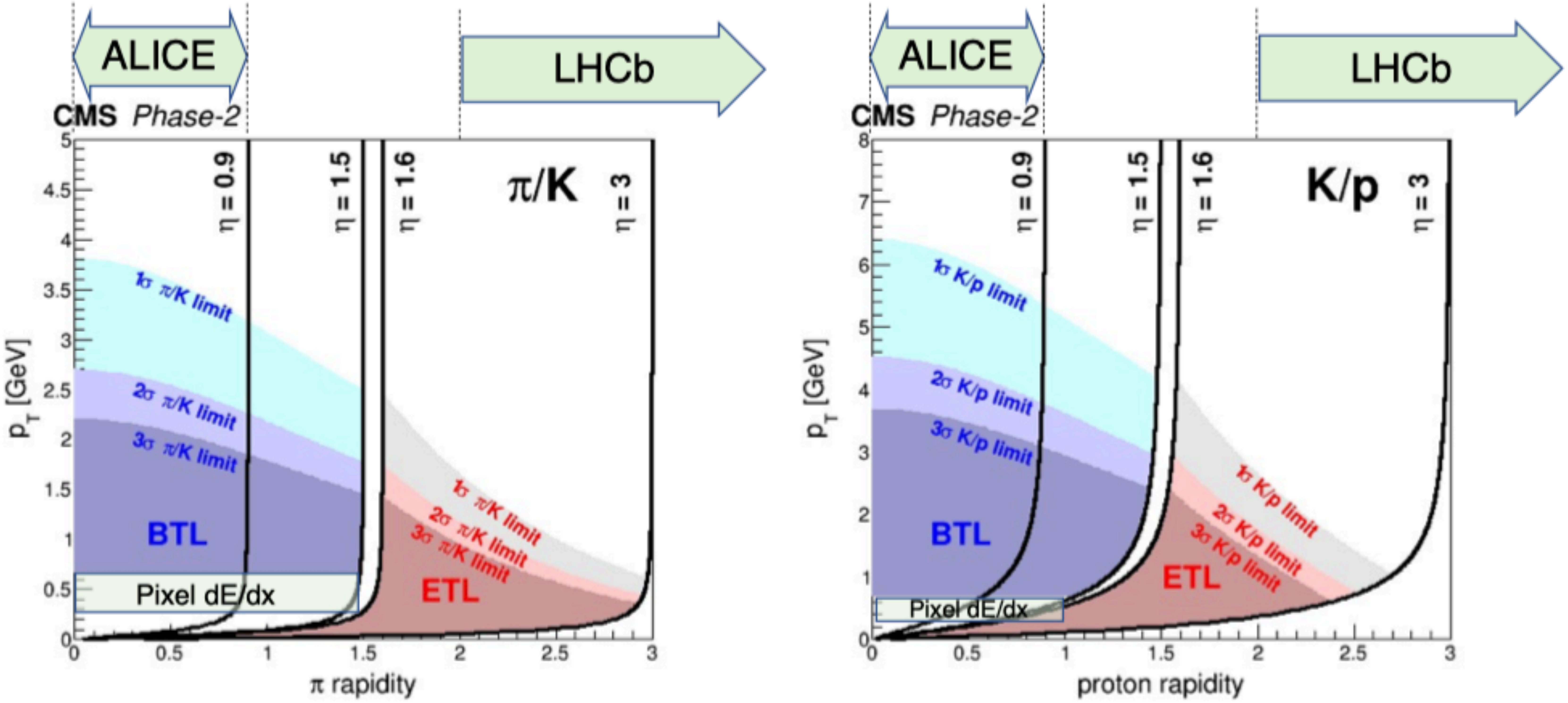
CERN-LHCC-2019-003

Future CMS PID coverage

Large acceptance PID: $|\eta| < 3$
Complementary w/ ALICE & LHCb

Experiment	η coverage	r (m)	σ_T (ps)	r/σ_T (x100)
CMS	$\|\eta\| < 3.0$	1.16	30	3.87
ALICE	$\|\eta\| < 0.9$	3.7	56	6.6
STAR	$\|\eta\| < 0.9$	2.2	80	2.75

π/K separation
up to p ≈ 2.5 GeV

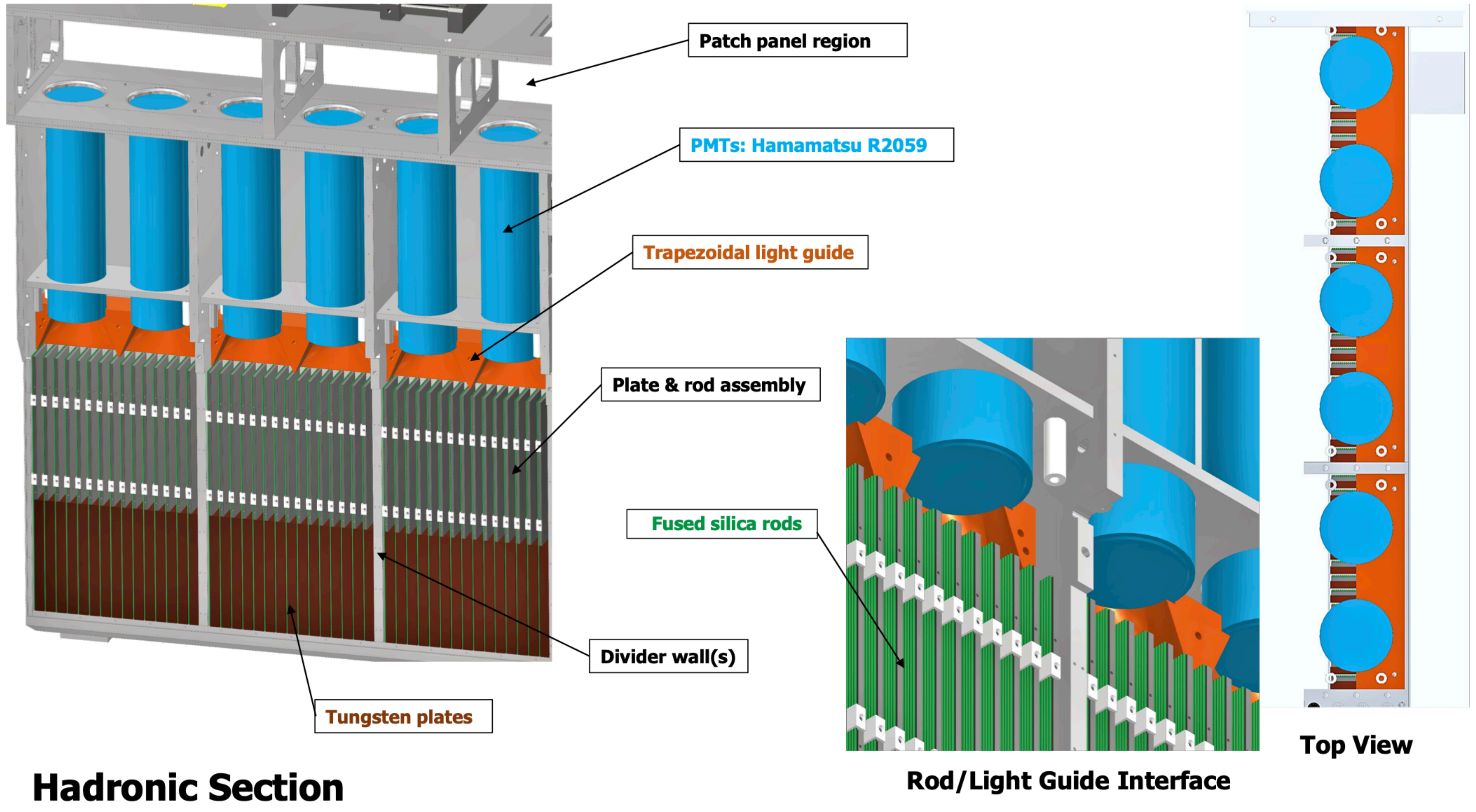


/p separation
ɔ to p ≈ 5 GeV

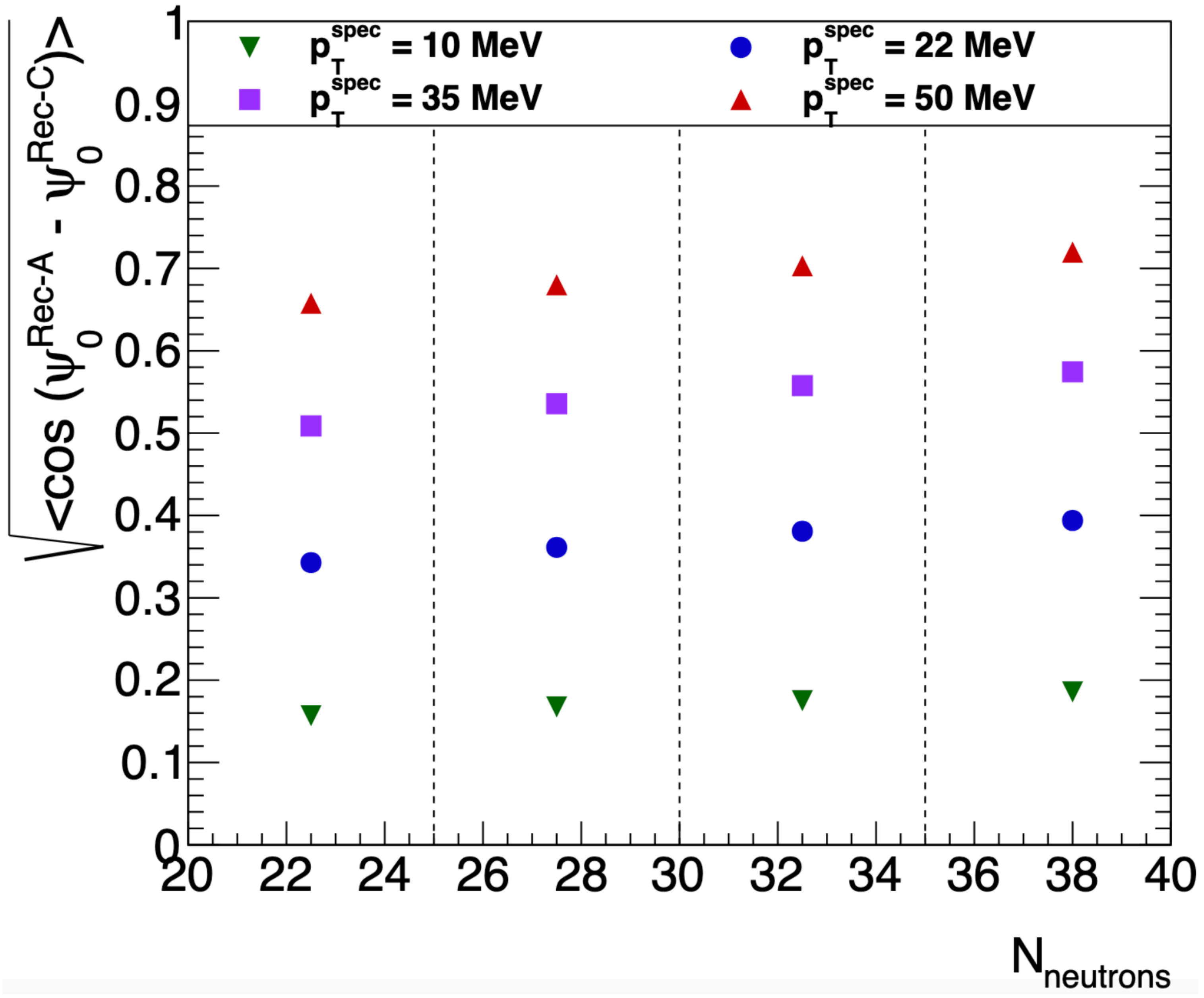
-LHCC-2019-003

Combined with dE/dx from pixel detector, **π/K/p coverage down p_T = 300 MeV**!

A new ZDC CMS detector



- **Joint ATLAS & CMS effort: radiation-hard ZDCs for Run 4**
- Crucial part of heavy-ion min. bias trigger from Run 3 onwards
  - Used to identify & characterize ultra-peripheral collisions
  - Bias estimation for centrality, especially in small systems
  - Exclusively HI detector (removed for high-lumi pp)



CMS-TDR-024