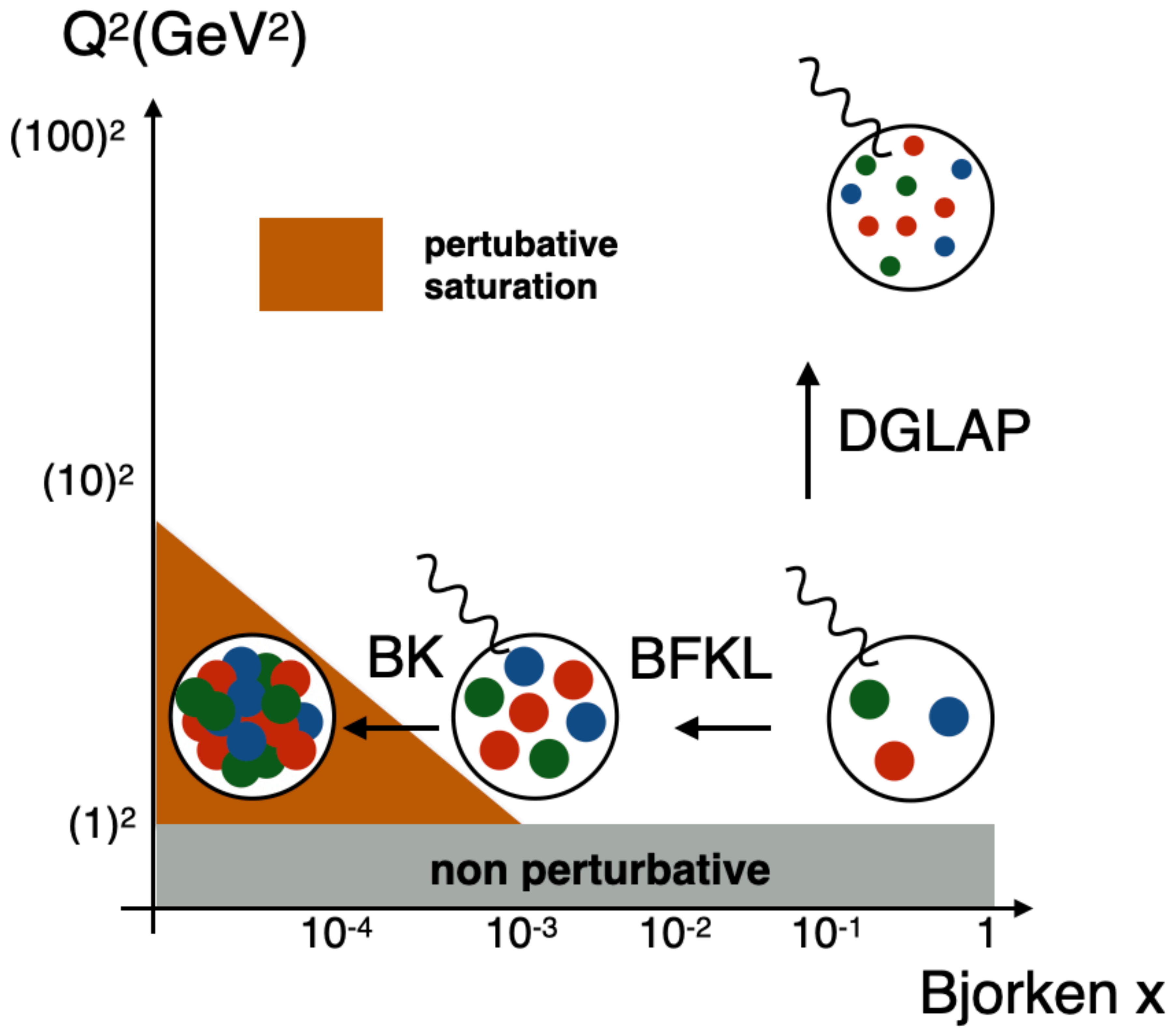
Nuclear parton structure in heavy-ion collisions with CMS (towards the EIC)

Heavy Ion Physics in the EIC Era
August 19-24, 2024, INT (Seattle)

Gian Michele Innocenti
Massachusetts Institute of Technology

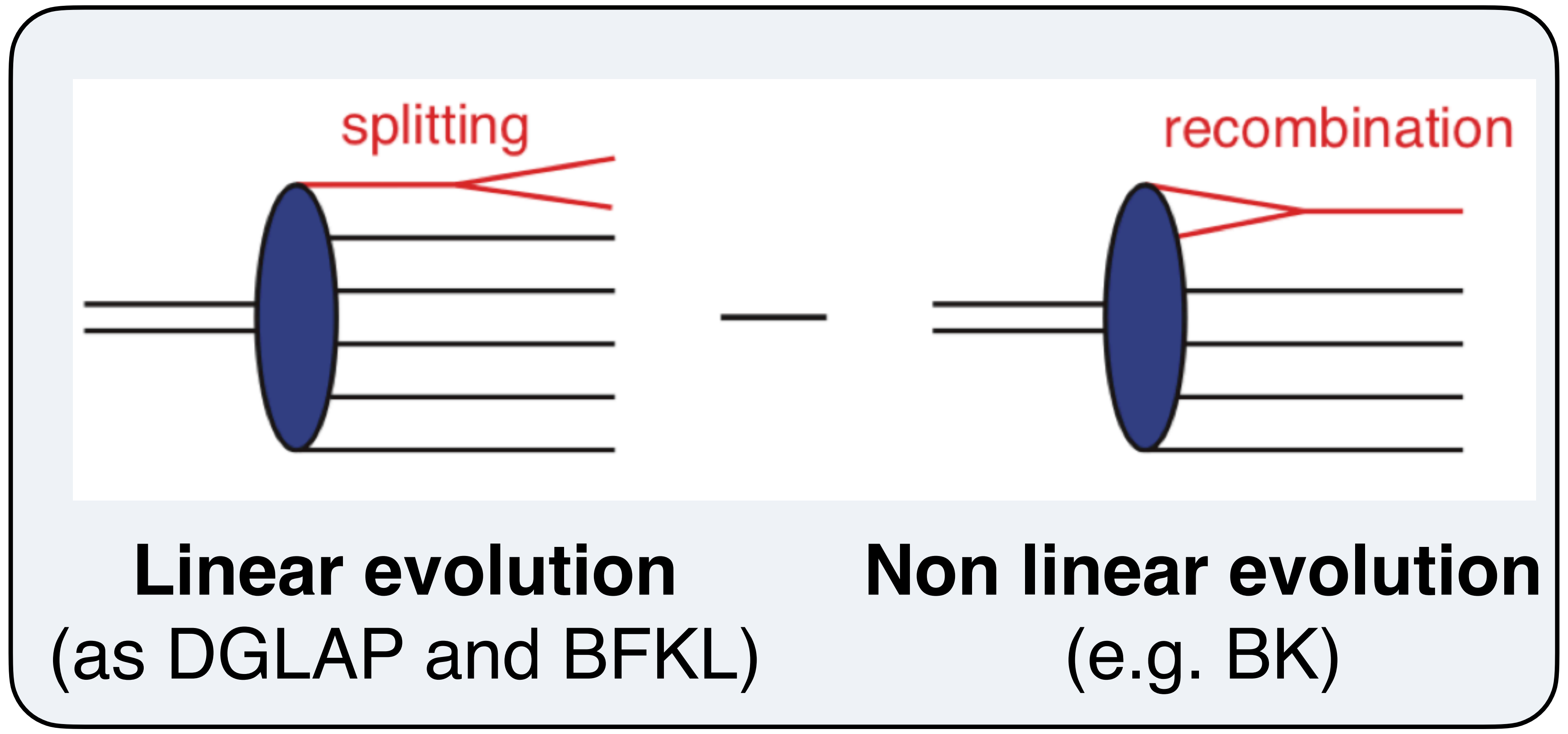
Constraining parton dynamics in nuclei in (x, Q^2)

Exploit the advantages of heavy-ion collisions to study parton dynamics in the widest region of x and Q^2
In nuclei, high-density effects are expected at higher x-values



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

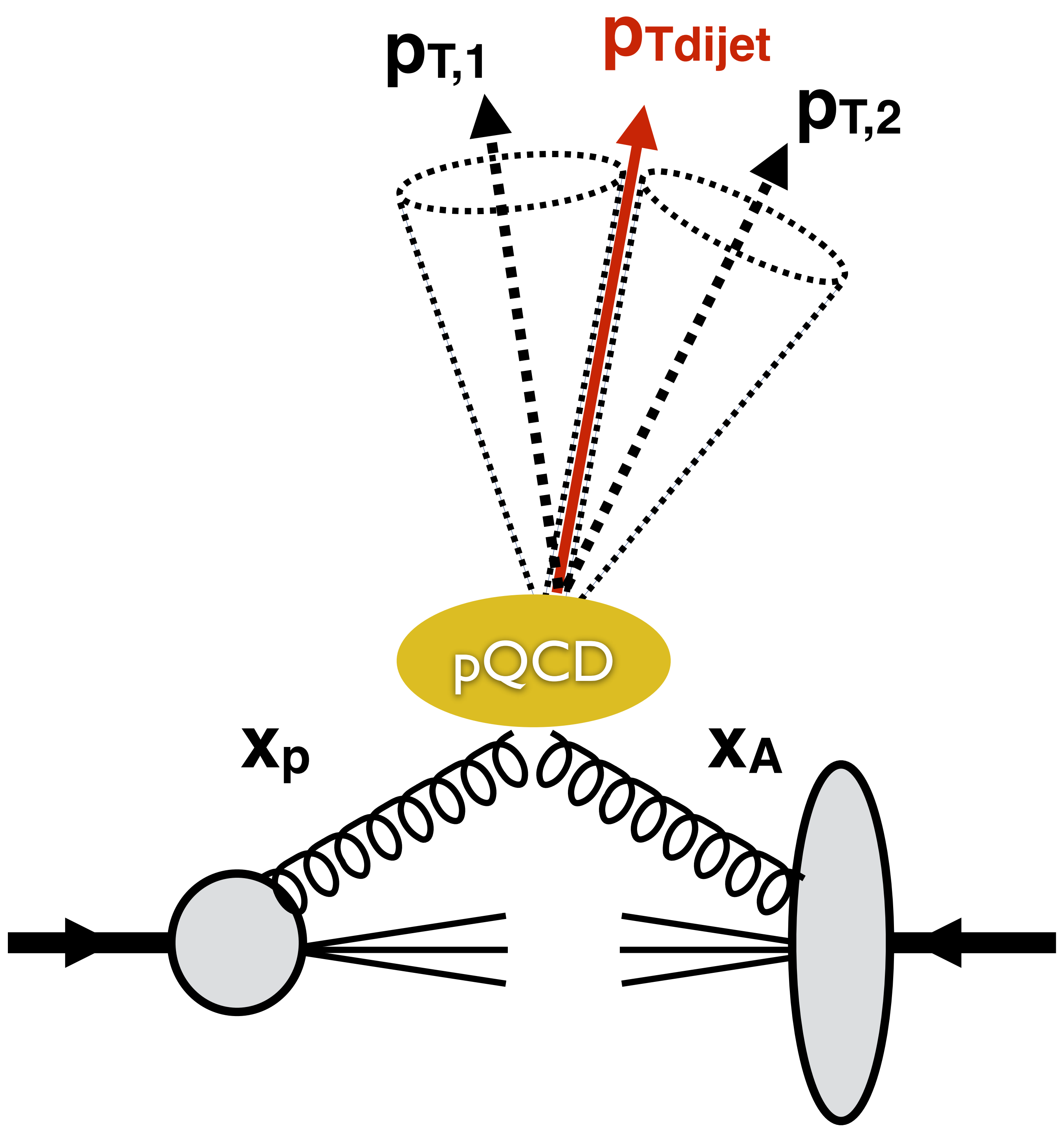
Searches for non-linear evolution equations



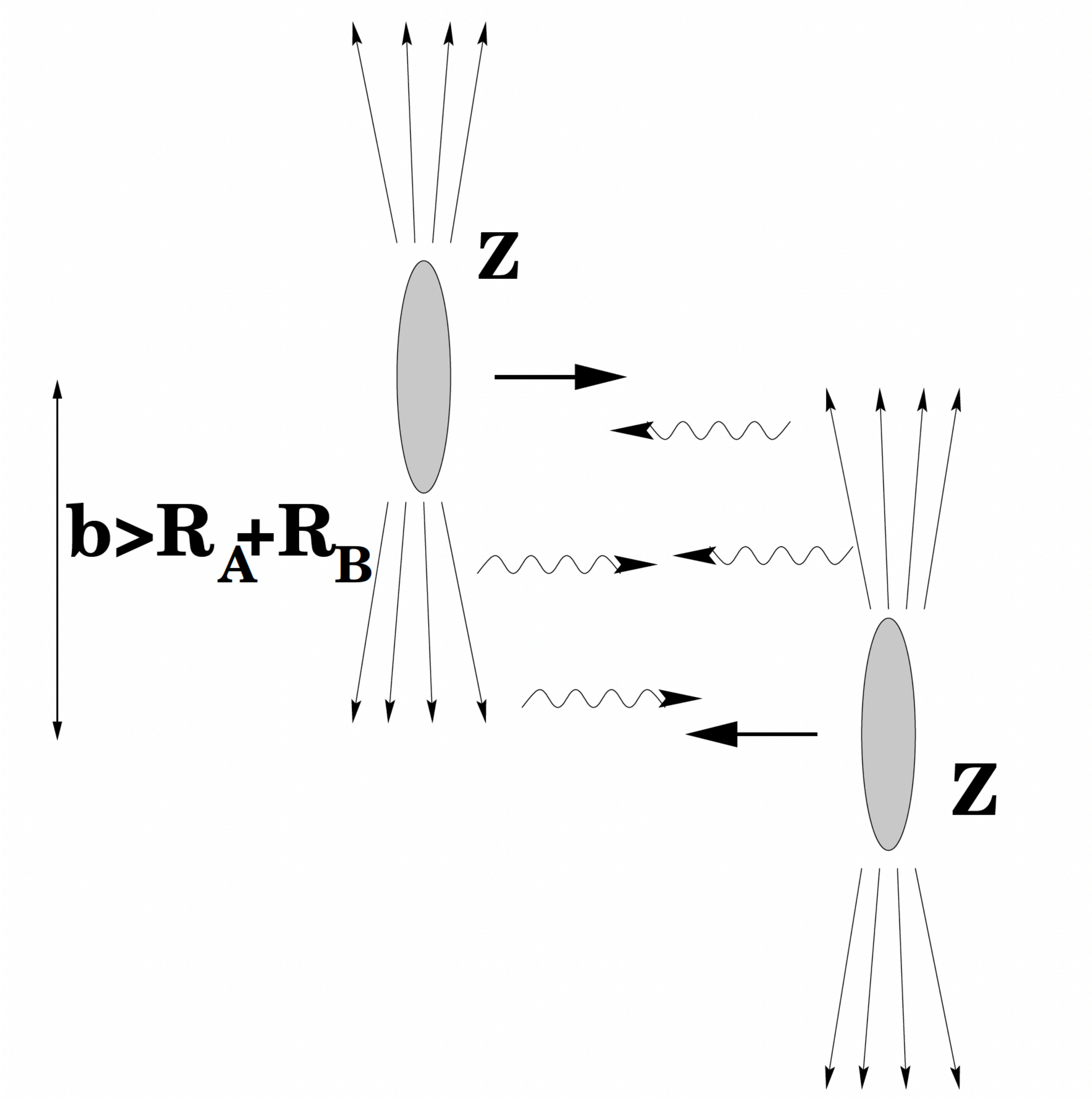
- do we see saturation?
- what is its shape in (x, Q^2)?
- what is the dependence on A?
- **can we characterize the transition across the different regimes?**

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

Our toolbox: hadronic and UPC collisions



proton-nucleus hadronic collisions (e.g. pPb pr pO)

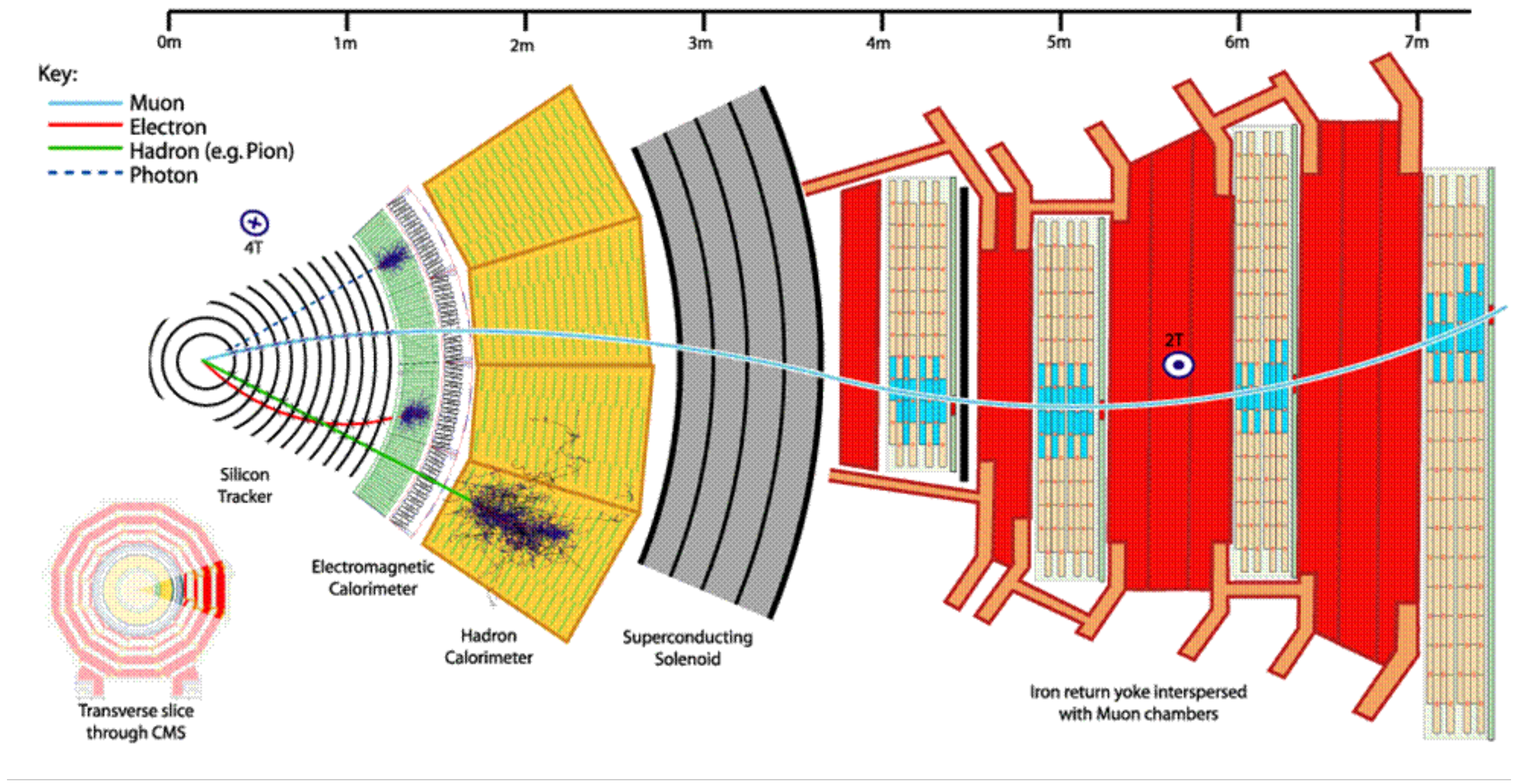


ultra-peripheral heavy-ion collisions

Wide set of experimental observables in the largest region of p_T and pseudorapidity:
→ sensitivity to gluon and quark nPDFs
→ large region of (x,Q^2)

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

CMS as a broad-spectrum high-density QCD experiment



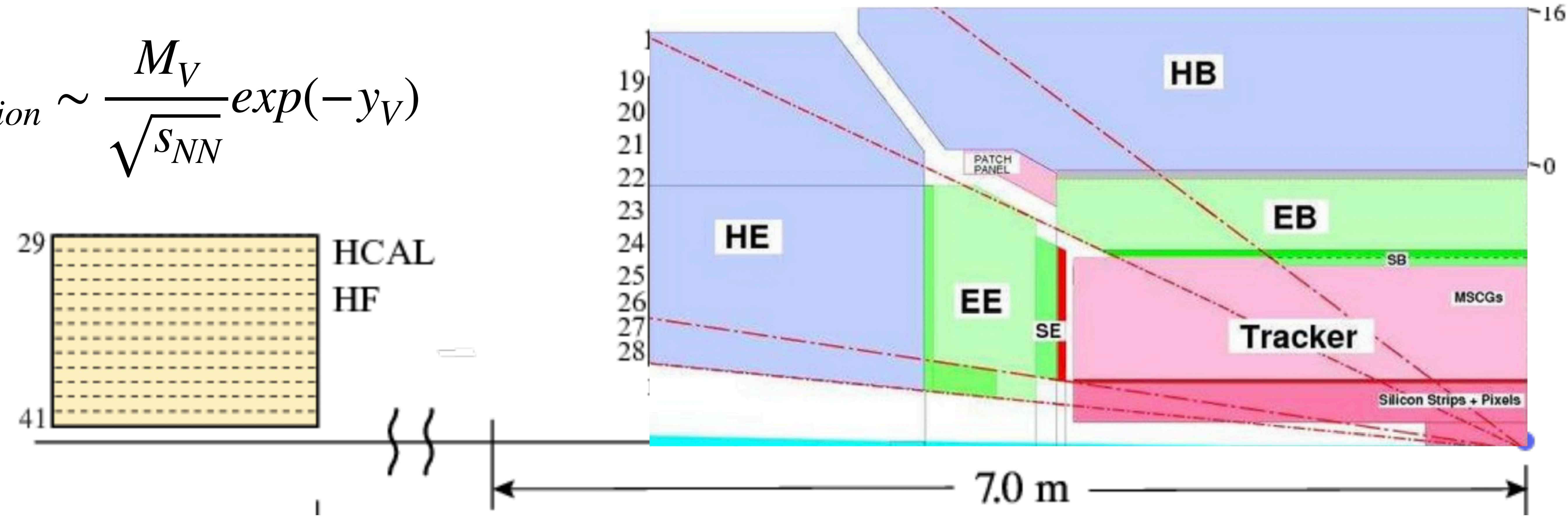
<u>Large-coverage high-rate</u> detector for hadronic and EM probes

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

Wide pseudorapidity coverage, from high to low p_T:

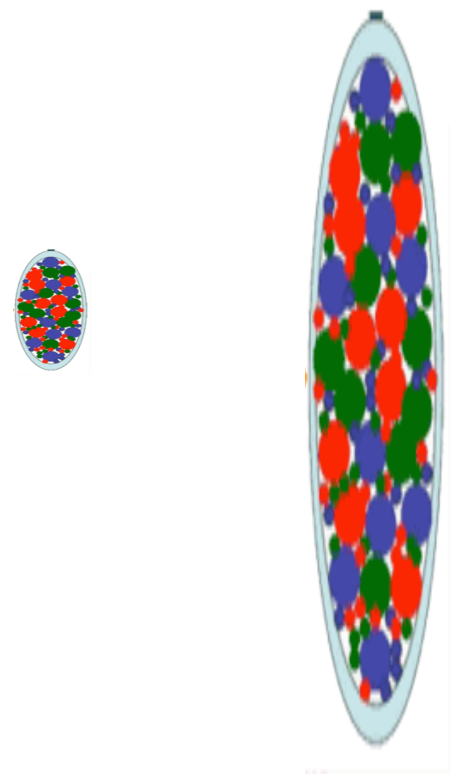
- Charged tracks in $|\eta_{tracks}| \leq 3$
- Calorimetry (ECAL/HCAL) in $|\eta_{cal}| \leq 5.2$
- Muon detectors in $|\eta_{muon}| \leq 3.0$
- ZDC + PPS detectors

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



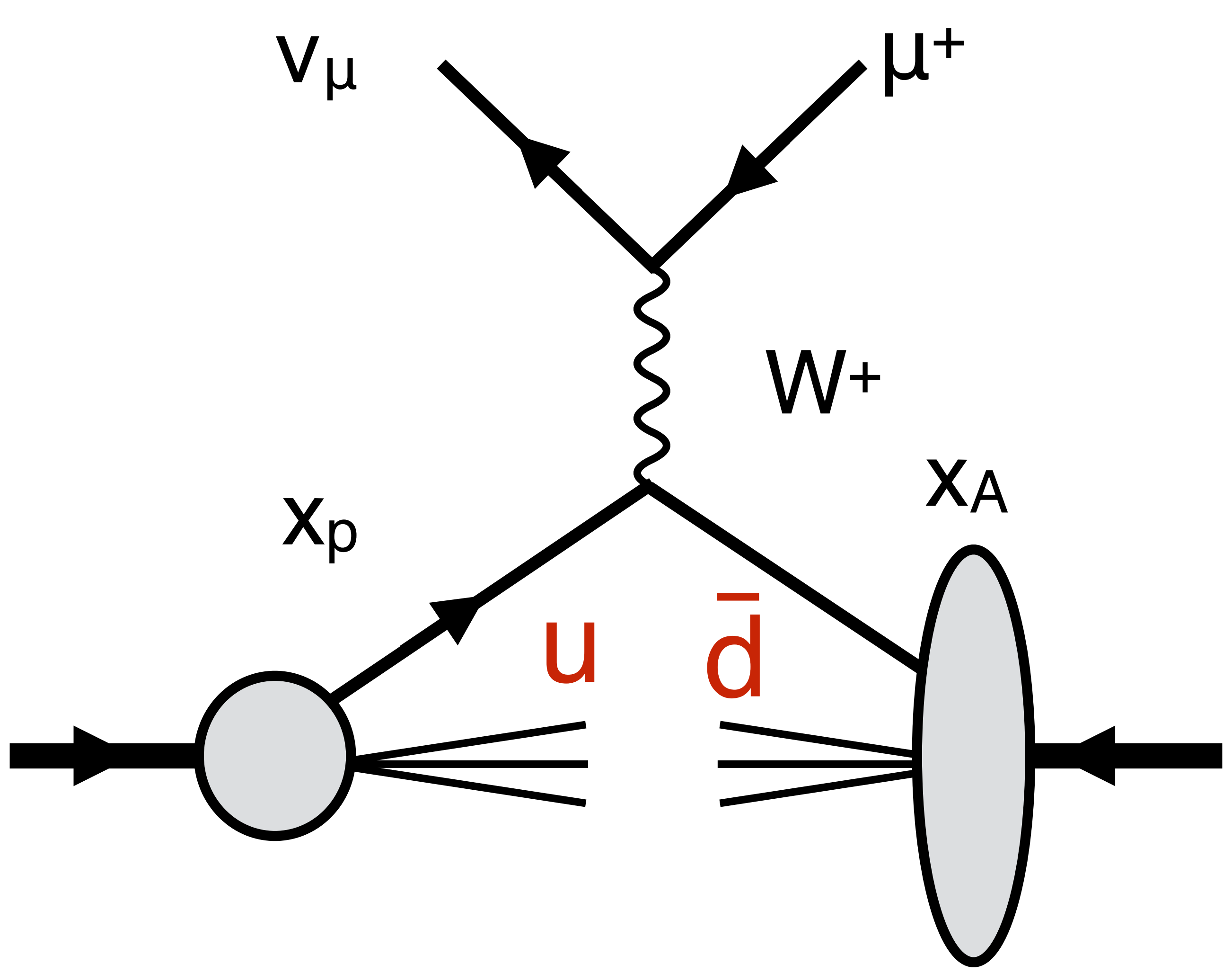
→ With even stronger capabilities after HL-LHC upgrades

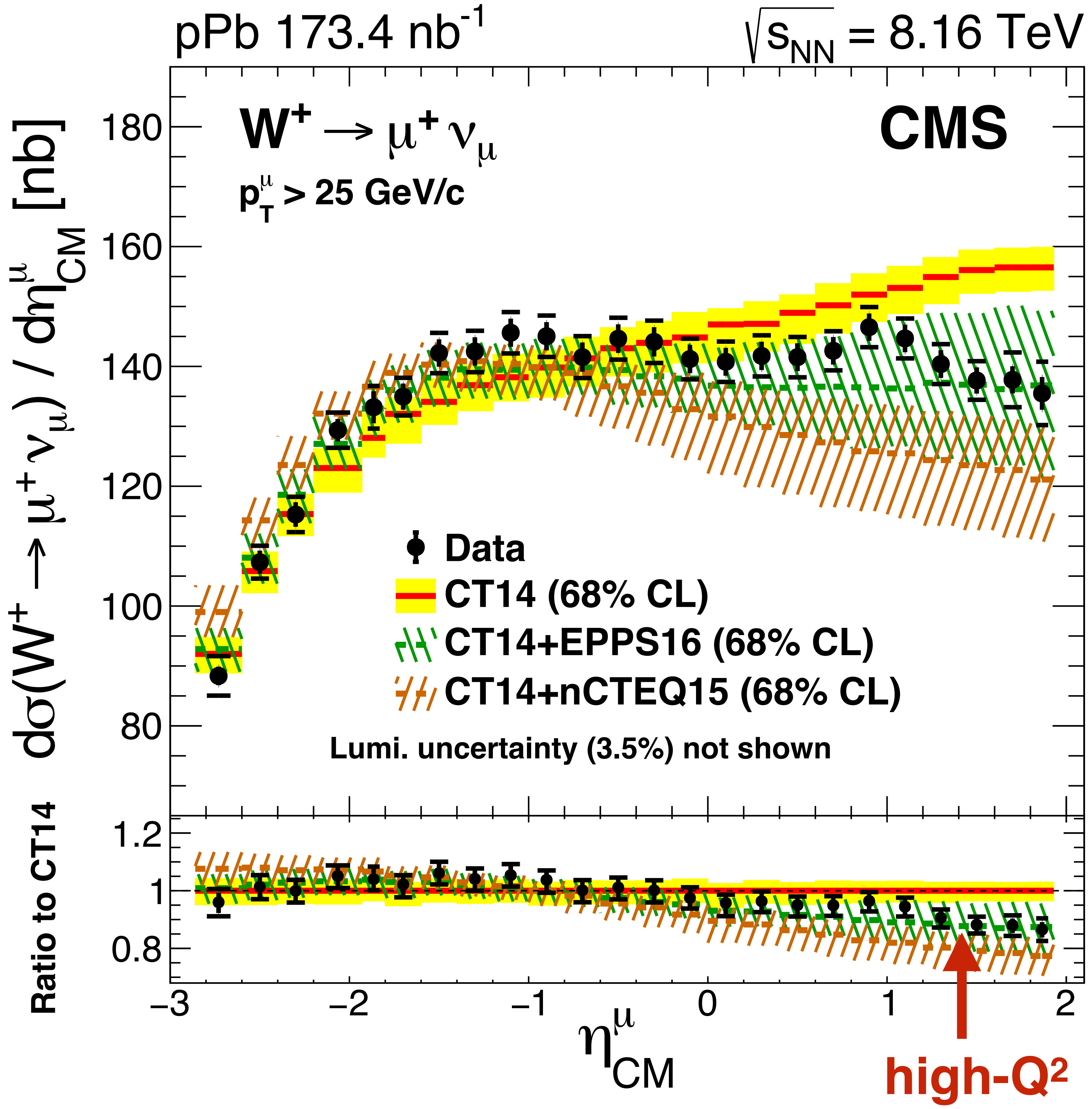
Constraining nuclear PDFs at the LHC with "hadronic" collisions



W+- measurements in pPb with CMS

$Q^2 \sim M^2_W$, (anti)shadowing
valence/sea light quarks
mid-rapidity





backward
higher x_A

forward
low x_A

high-Q^2 shadowing

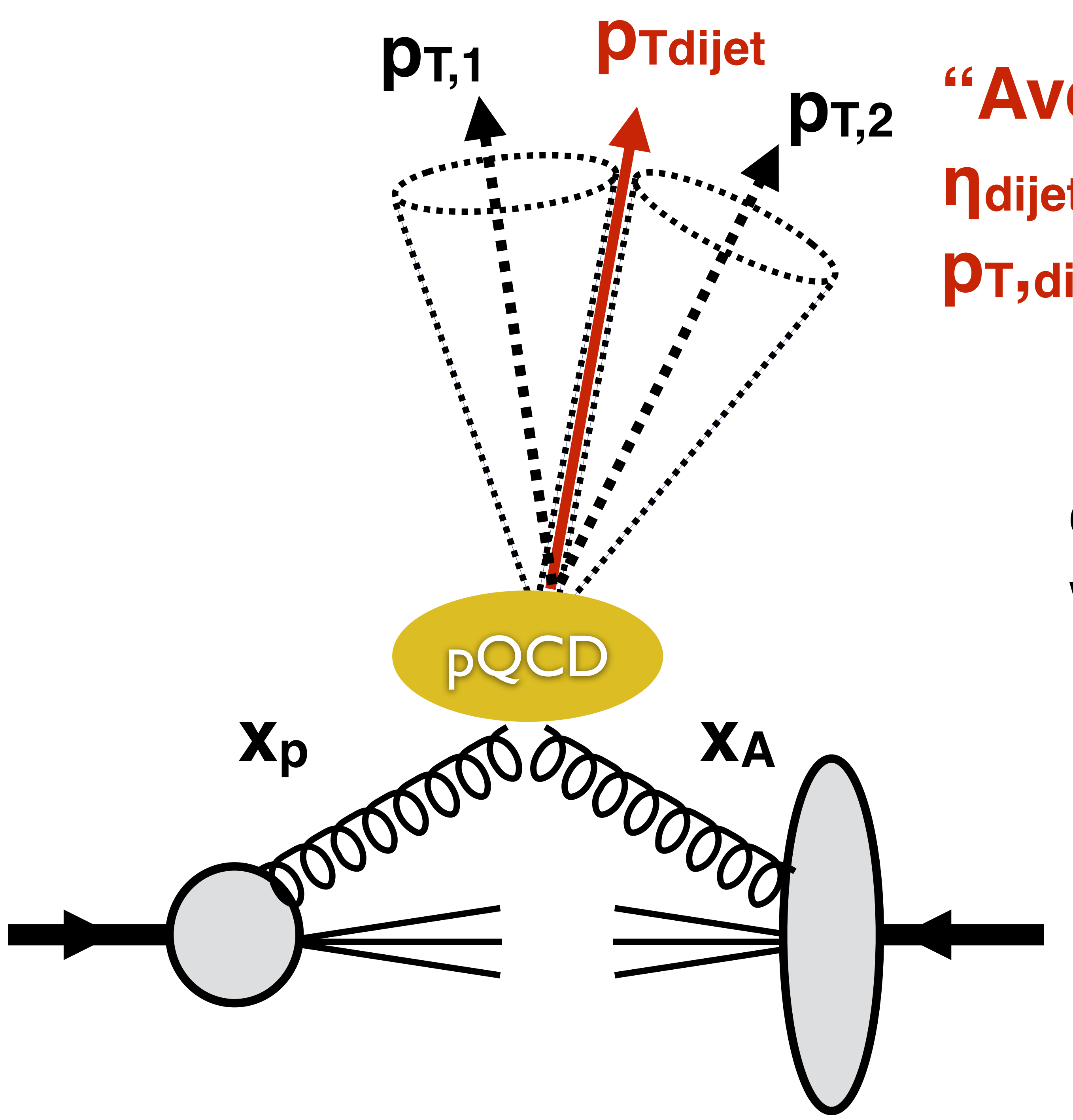
W+- and W asymmetry vs η measured at mid-rapidity
- experimental uncertainty < calculation uncertainties

→**sizeable constraints on nPDF** (starting from EPPS16)

CMS: PLB 800 (2020) 135048

Dijets in hadronic pPb collisions

CMS: Phys. Rev. Lett. 121.062002
Eskola et al. arXiv.1812.05438

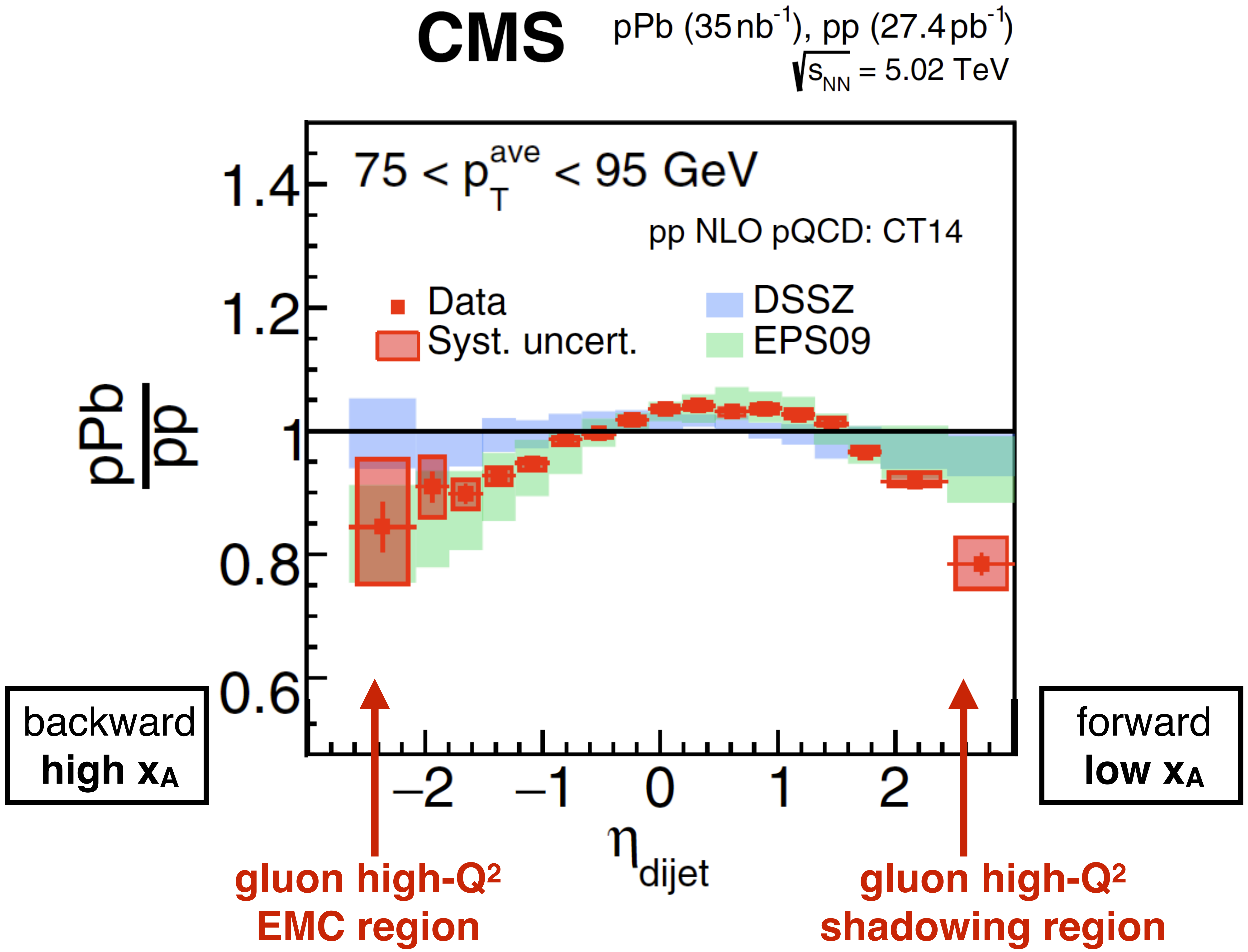


"Averaged" dijet

η_{dijet} = ½ (η_1+η_2)

$p_{T,dijet}$ = ½ ($p_{T,1}$+$p_{T,1}$) ~ Q

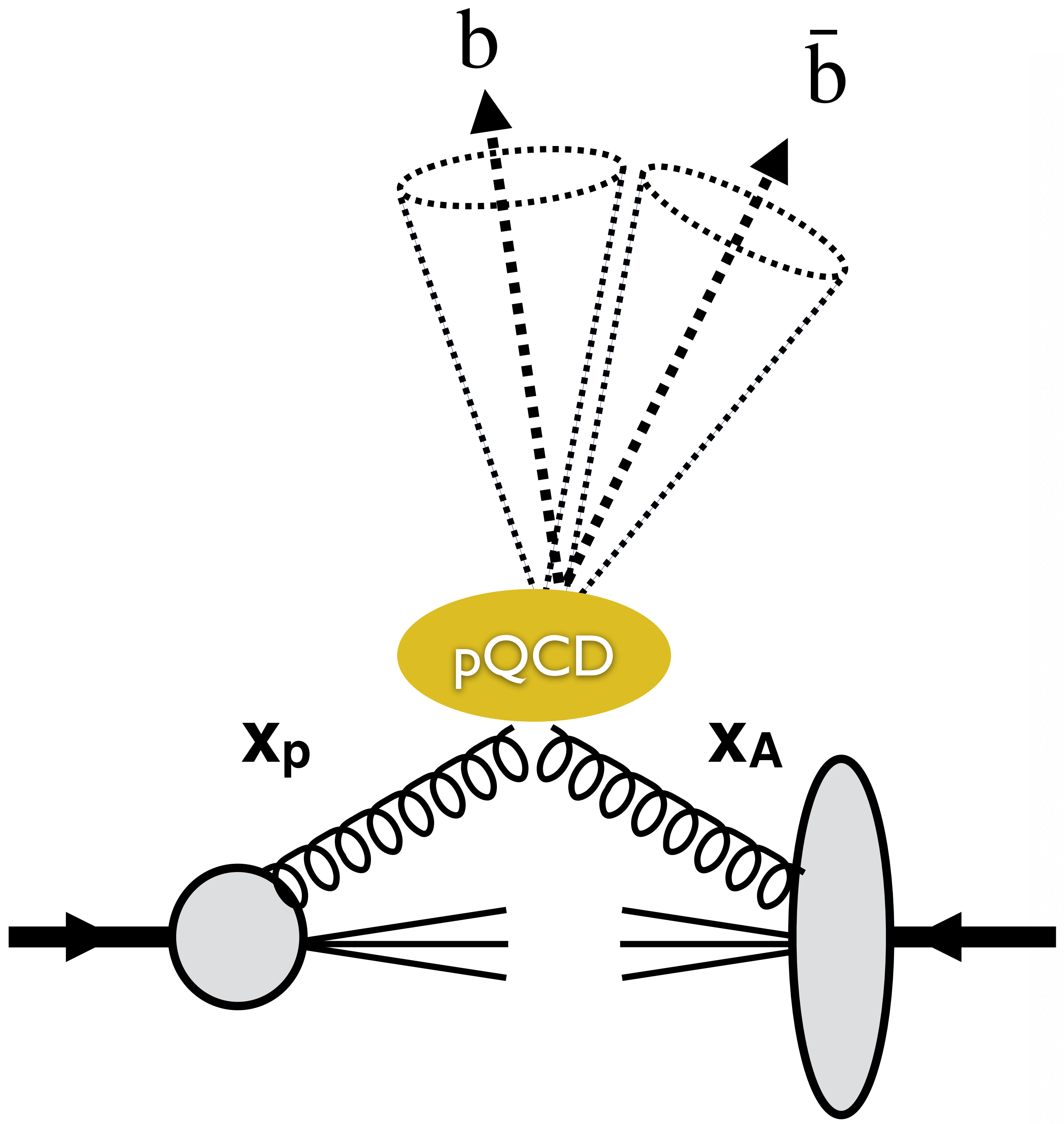
maximize correlation with x, Q^2

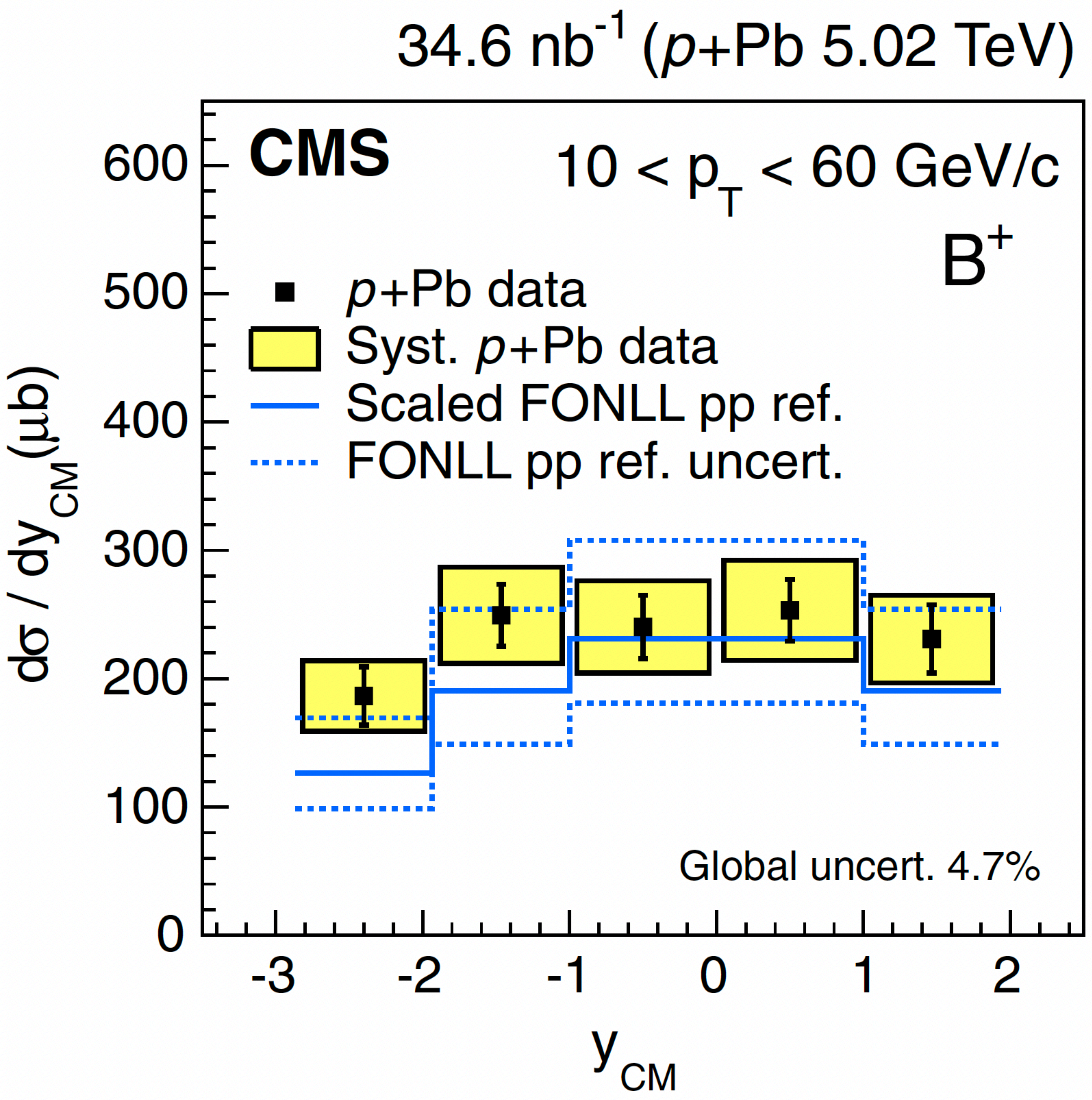


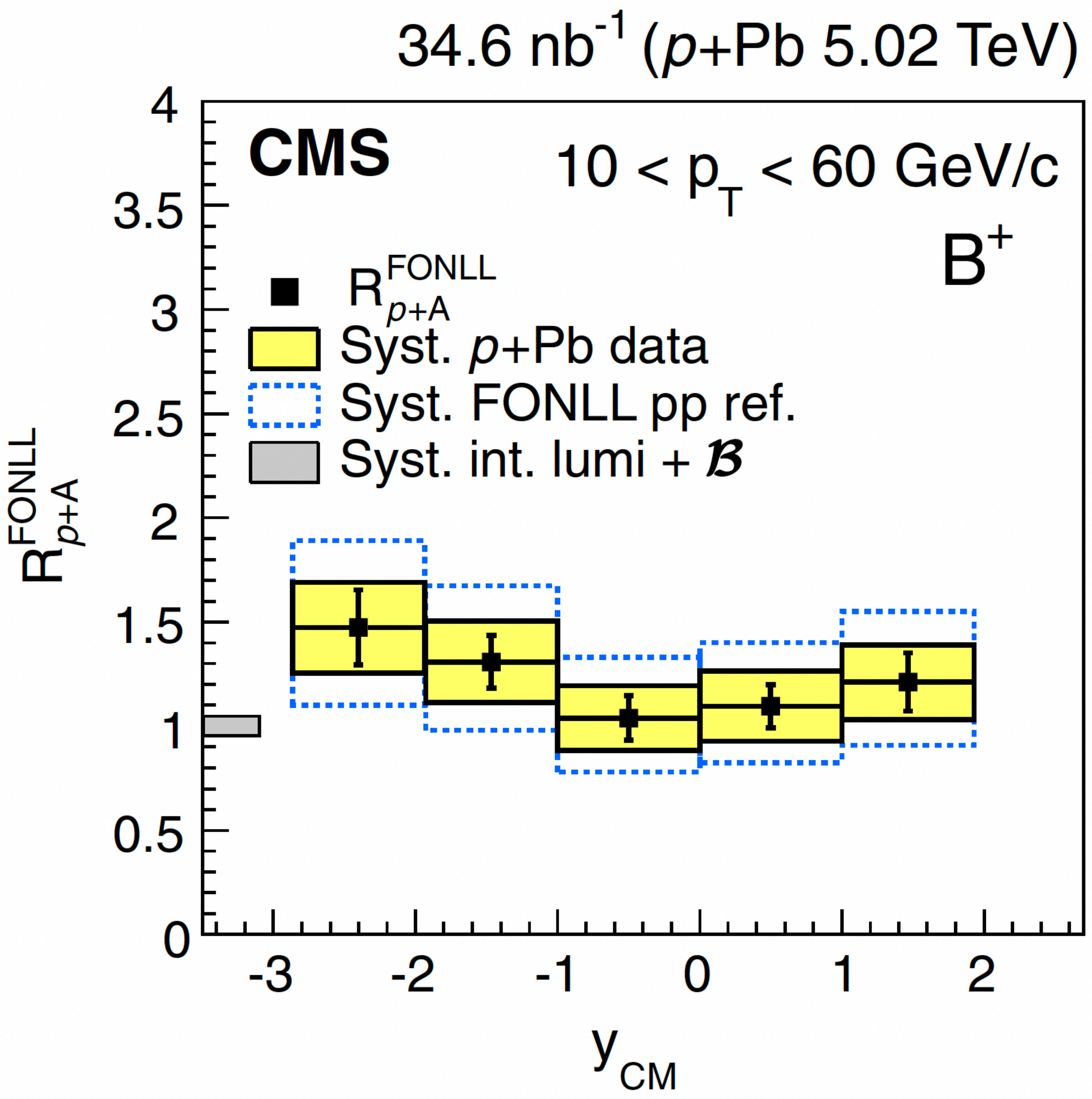
→ Sensitivity to gluon nPDF for $55^2 < Q^2 < 400^2$ GeV, **$0.005 < x_A <\sim 0.8$ (EMC)**

→ **Strong constraints since Run1 on nPDF of gluons (EPPS21 and NNPF3.0)**

B-meson production in pPb collisions at 5.02 TeV



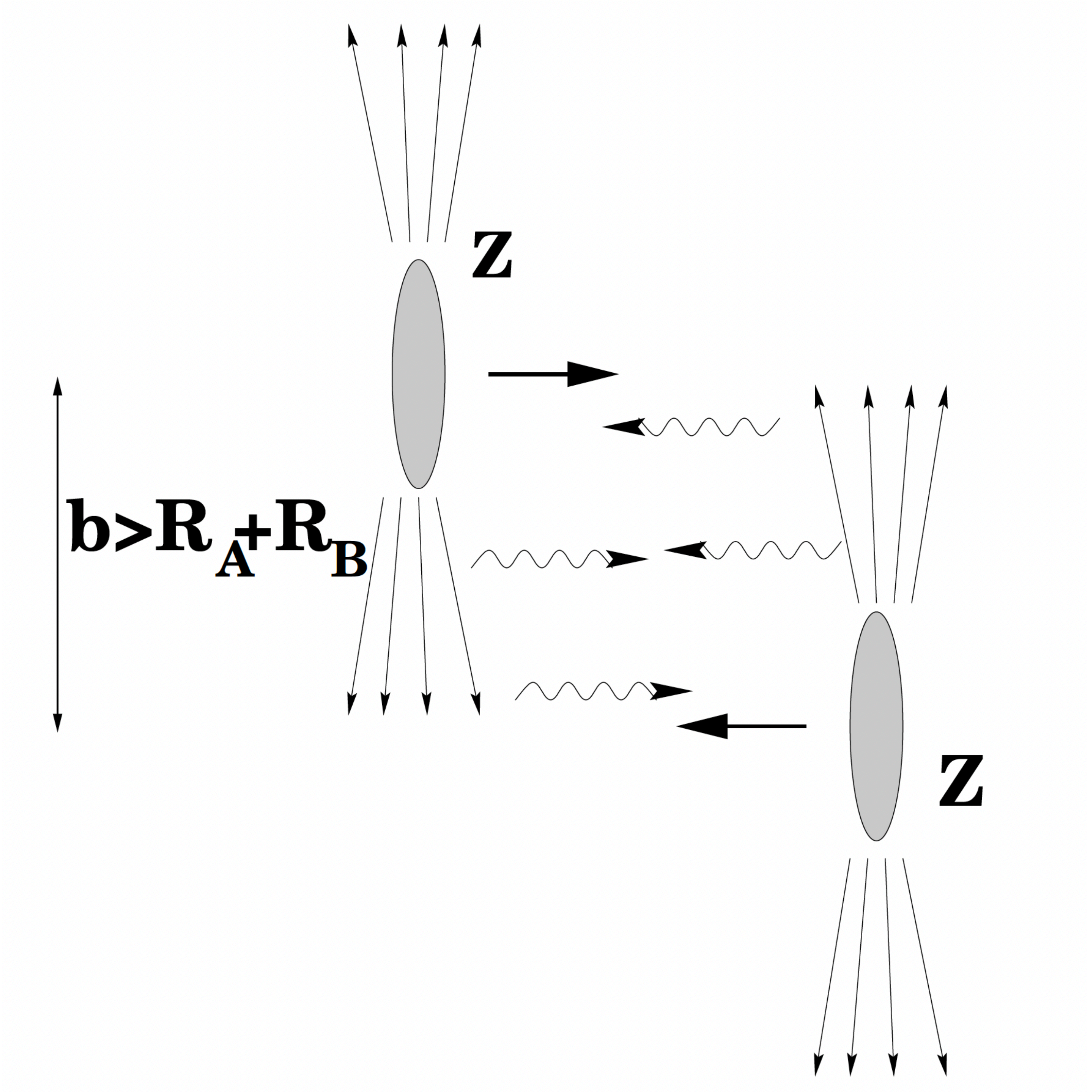




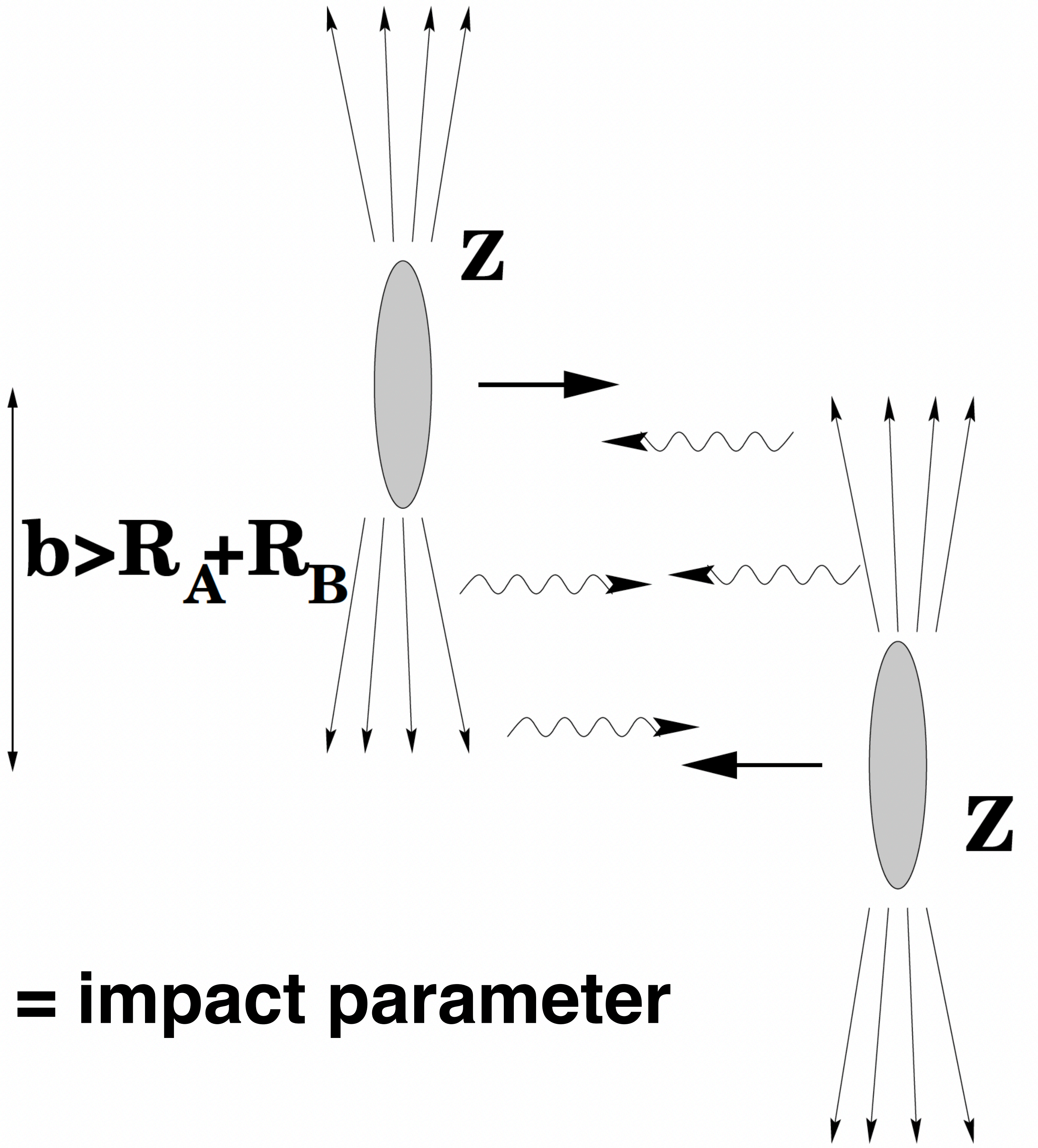
First attempt to use beauty quarks to study nPDF modifications of gluons (limited experimental accuracy)

- lack of proton-proton reference (R_{pA} built w.r.t. to FONLL predictions)
- **rely on larger pPb statistics in Run 4 (or Run 3?)** and beyond to improve the uncertainties of these measurements

Constraining nuclear PDFs at the LHC in UPCs



UPC collisions: LHC as a photon-nucleus collider



b = impact parameter

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.

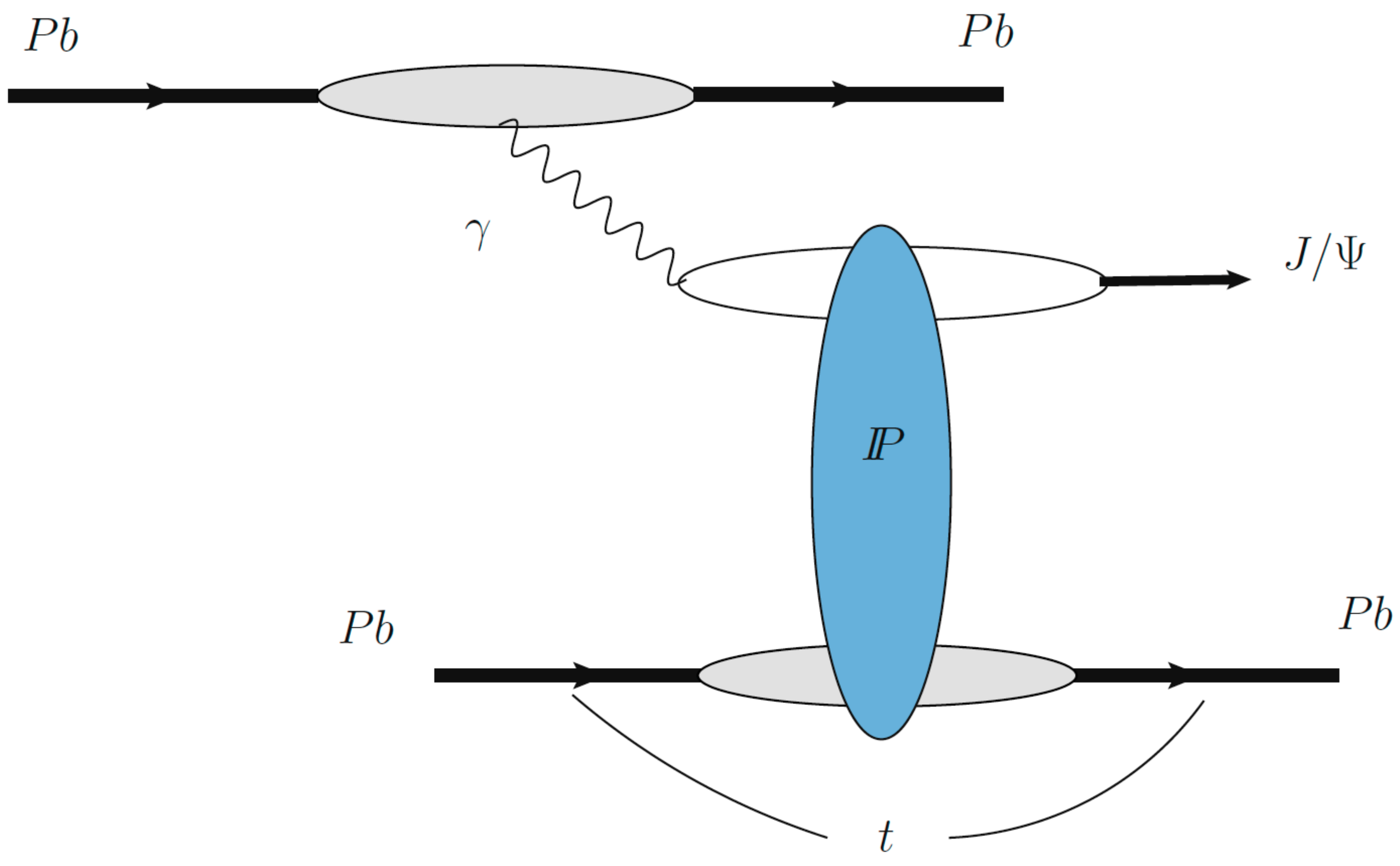
K. Hencken, M. Strikman, R. Vogt, P. Yepes, Phys. Rept. 458:1-171, 2008

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)

M. Strikman et al, Phys. Lett. B 640 (2006) 162-169

J/ψ production in coherent γPb collisions

Heavy quarkonia in γN collisions are produced via coupling to small x gluon fields
→ allow to test small dipole interactions with small-x gluon fields
→ heavy-quark mass guarantees a perturbative description

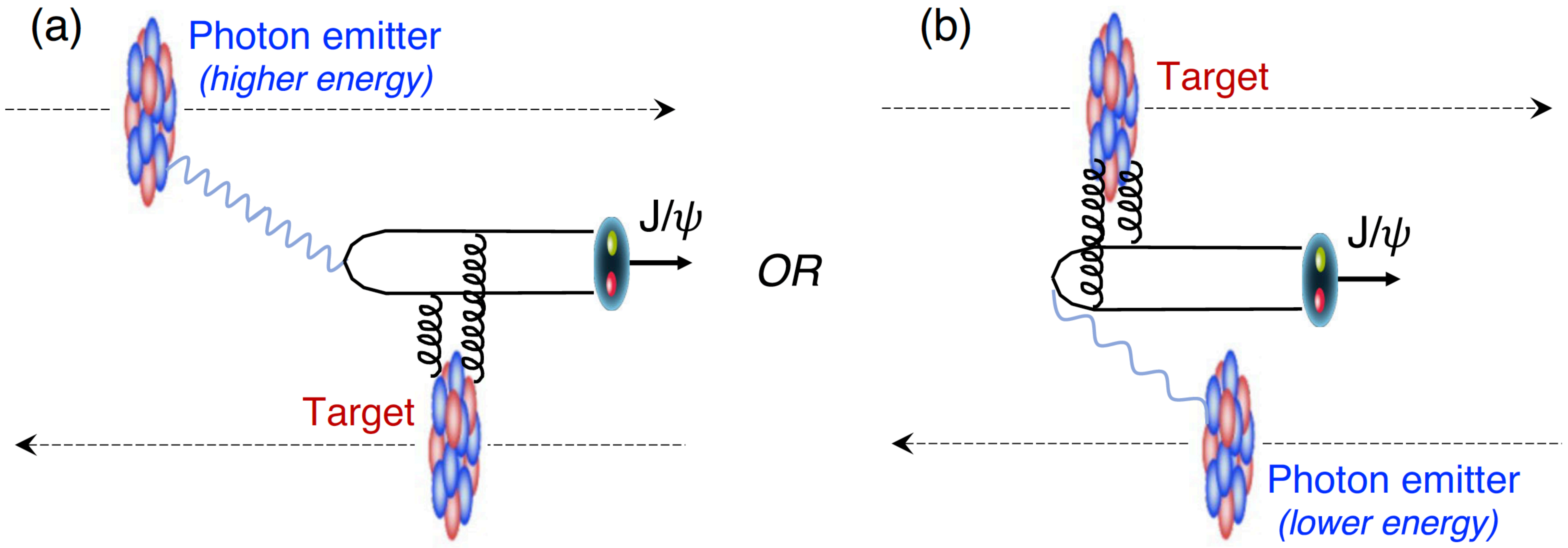


Properties of coherent production:
• γA → γAμμ with no nuclear breakup
→$\sigma_{coherent}$ ~ g(x, Q_2)
→Gluon properties with x<<10^{-3} , Q_2 ~ 2.5-4.0 GeV^2

Two-way ambiguity in coherent γPb collisions

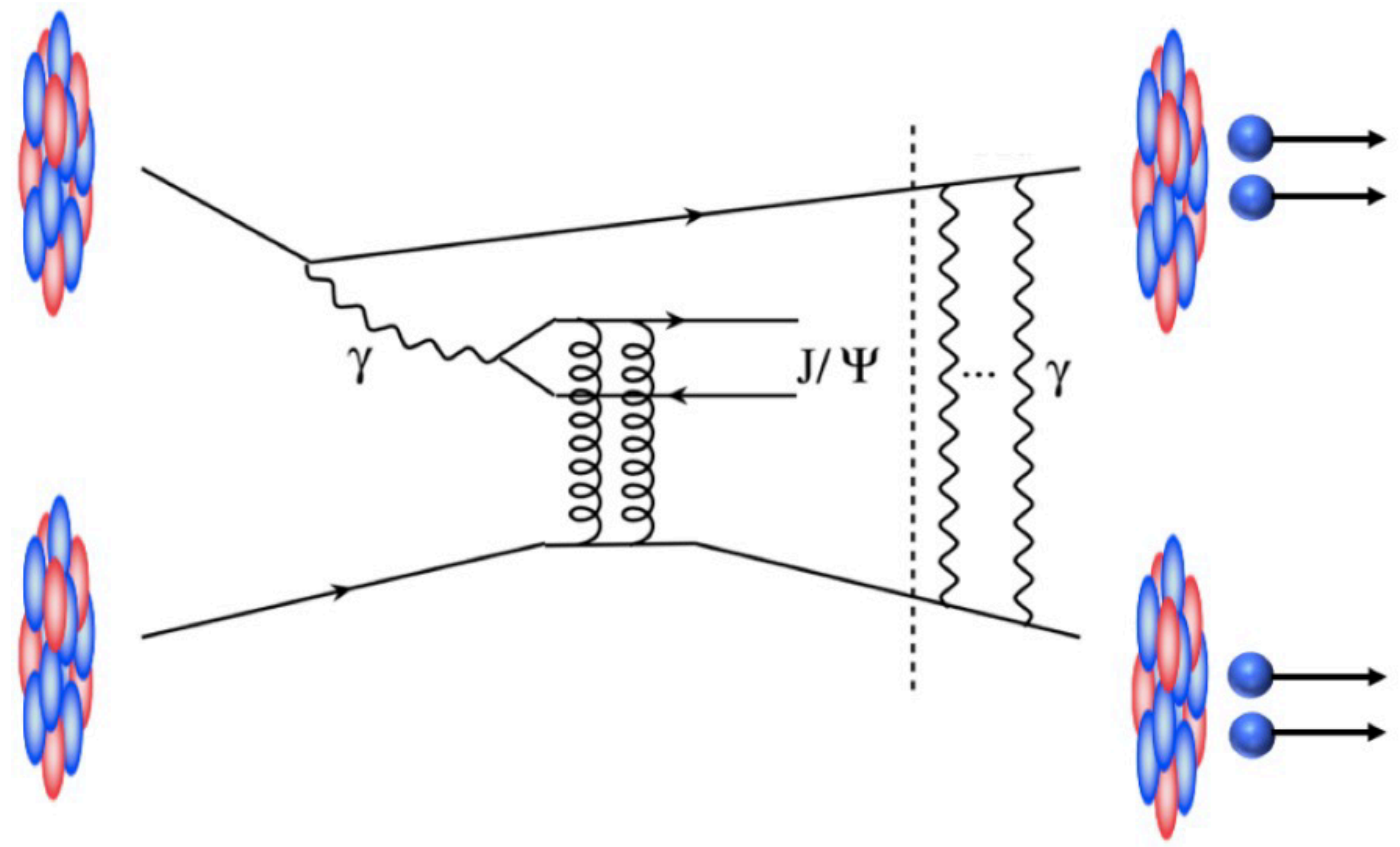
- The initial direction of the photon is not fully defined
- at $y_{J/\psi}$, a mixture of low-x and higher-x events

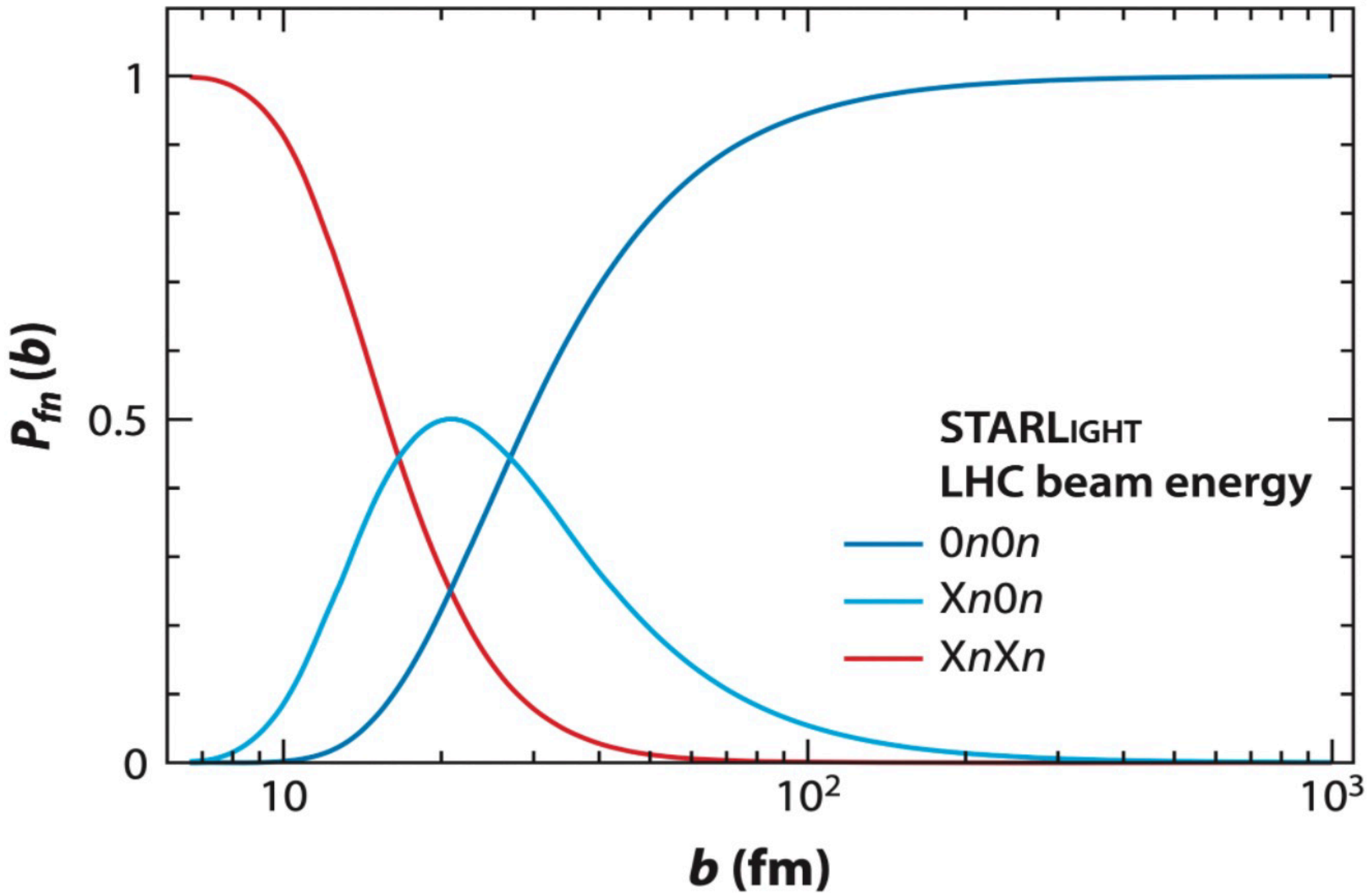
→ limit the constraining power due to uncertainty on the value of x



Solving the photon ambiguity with neutron information from ZDC

Exploit the properties of electromagnetic dissociation (EMD) to distinguish between the two event classes





EMD = neutron emission due to soft-photon exchanges

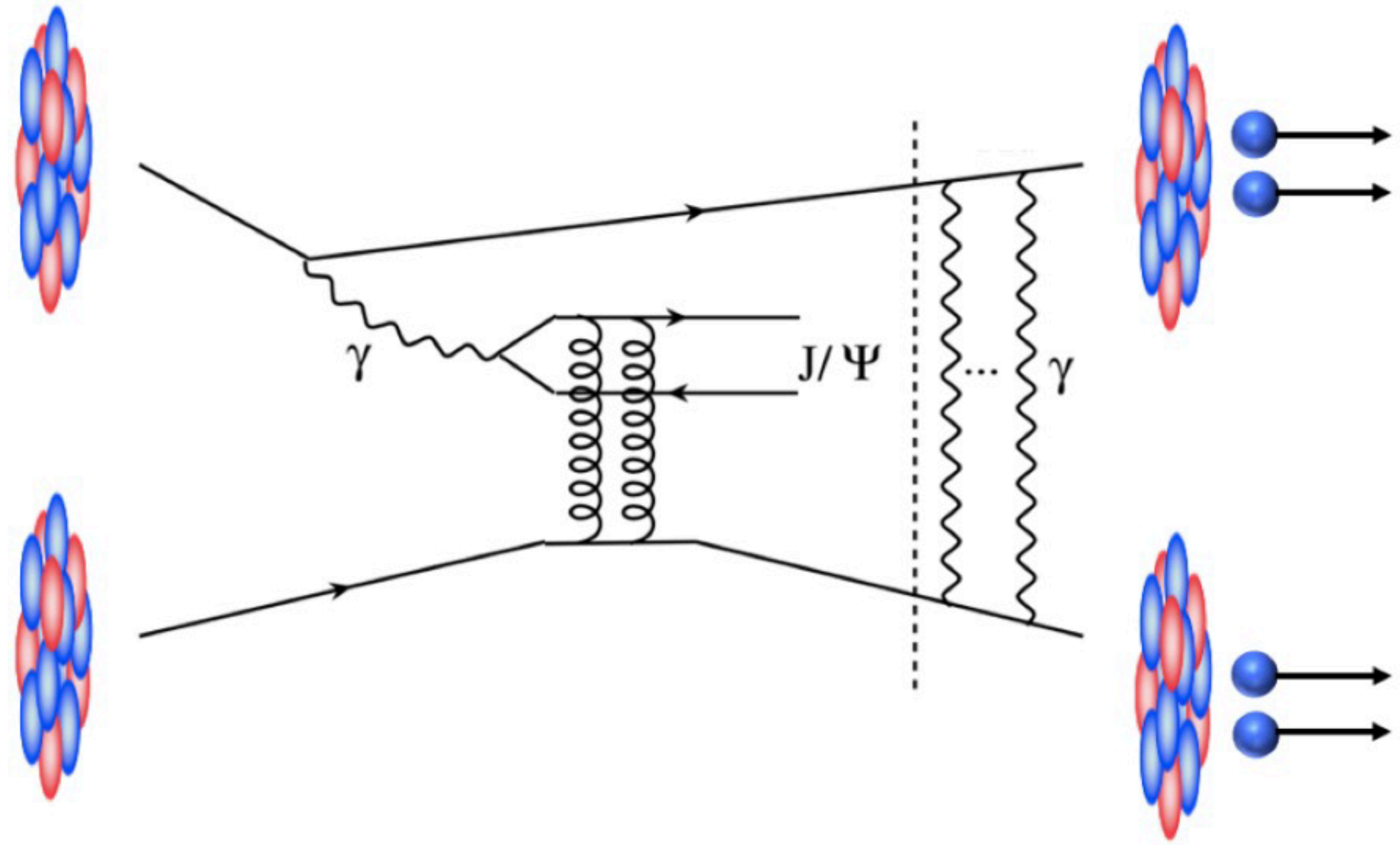
→ **EMD is larger for collisions at small impact parameters**

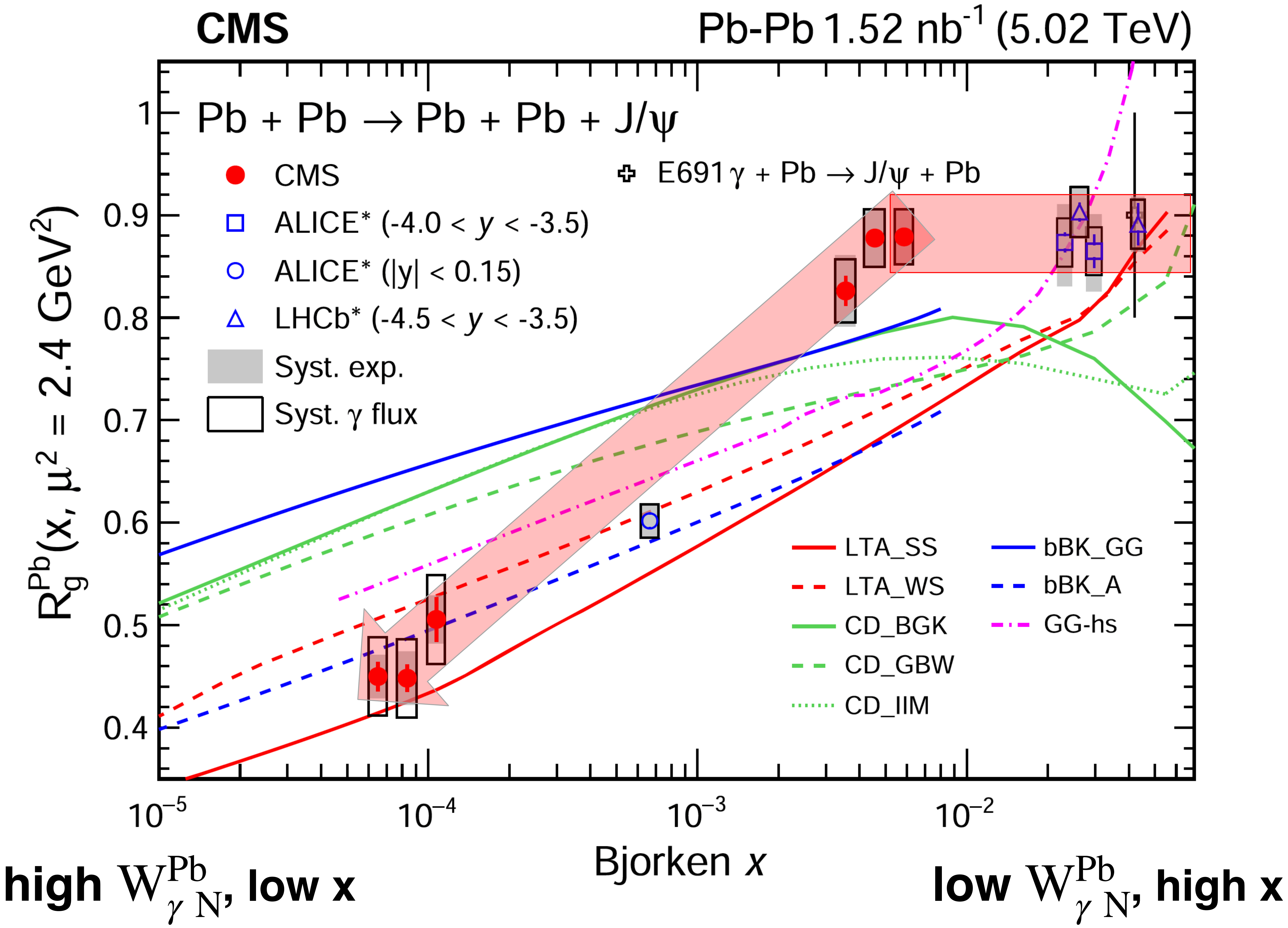
By selecting events with at least one neutron on the same "side" of the J/ψ

→ select events corresponding to a high-energy photon (low-x gluon)

V. Guzey, M. Strikman, M. Zhalov, EPJC (2014) 72 2942

Coherent J/ψ in PbPb UPCs with forward-neutron tag with CMS





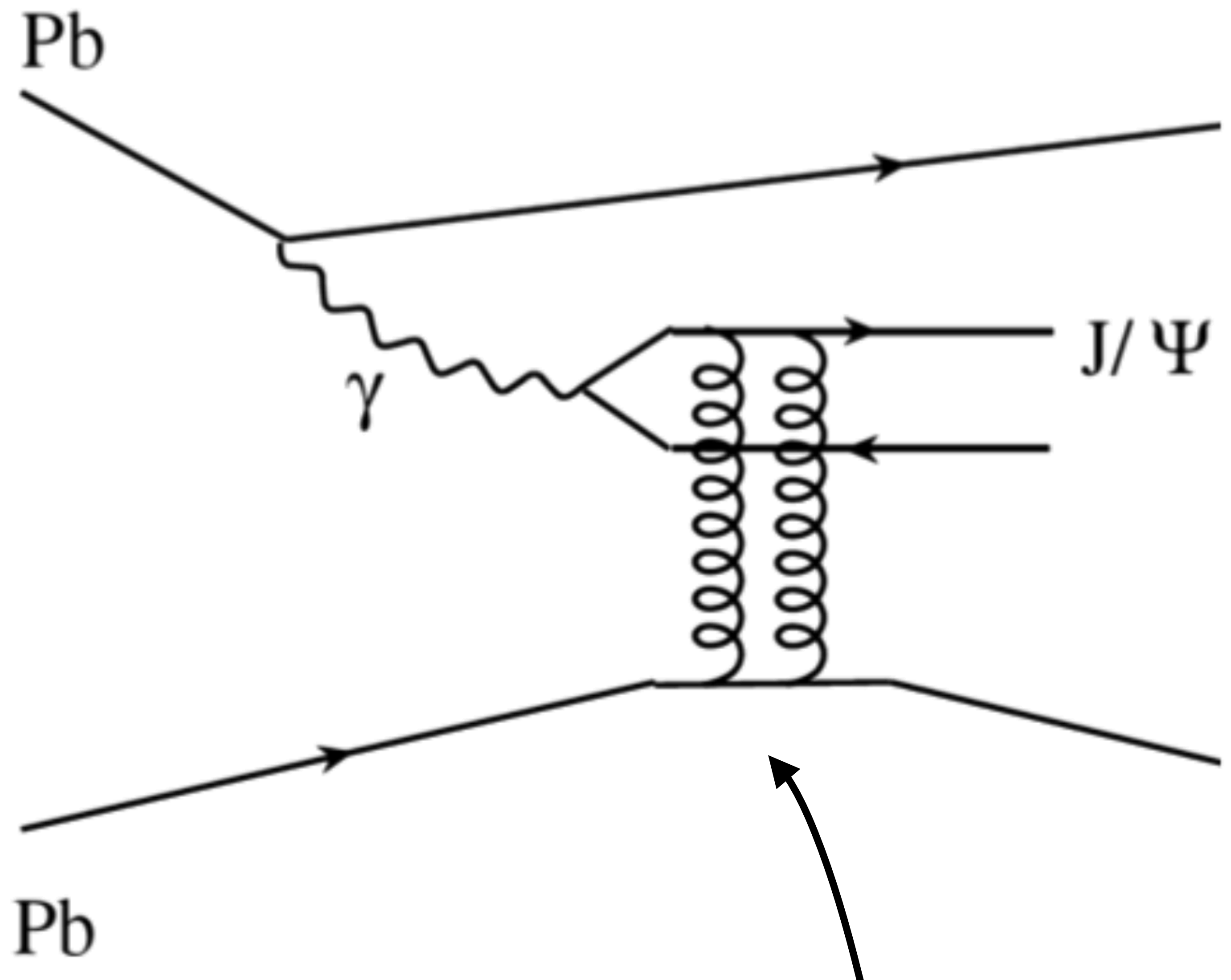
Increased sensitivity to low-x effects without “low/high energy“ ambiguities

- strong experimental constraints on theory for $x_{BJ} < 10^{-4}$ at low Q^2
- non trivial dependence of R^{Pb}_g vs x, currently not fully captured by theoretical calculations

CMS, Phys. Rev. Lett. 131 (2023) 262301

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

Coherent J/ψ in PbPb UPCs



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

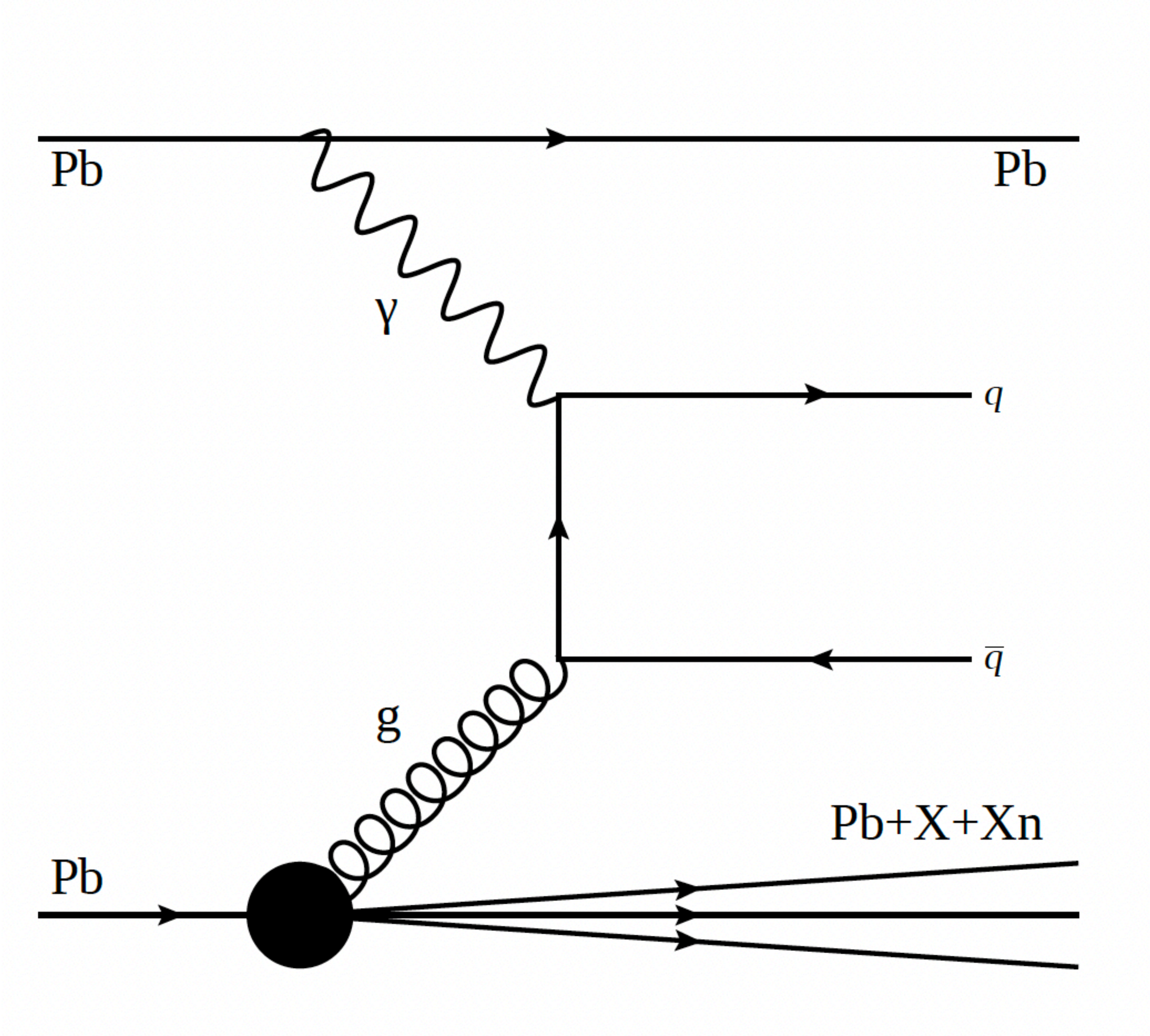
Constraints on a "fixed" region of Q^2

Complex theoretical description

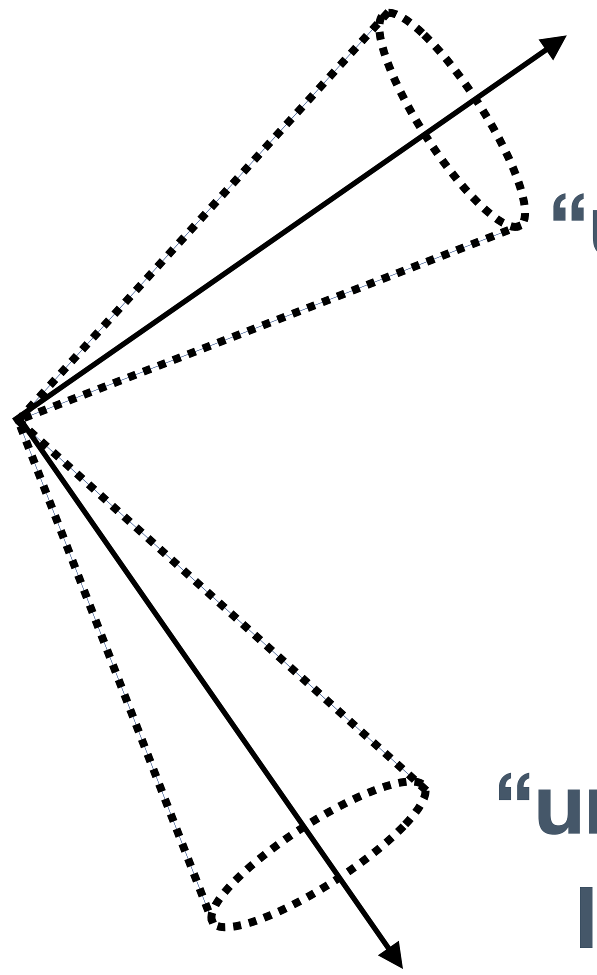
- J/ψ production at low p_T and NLO calculations are challenging

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



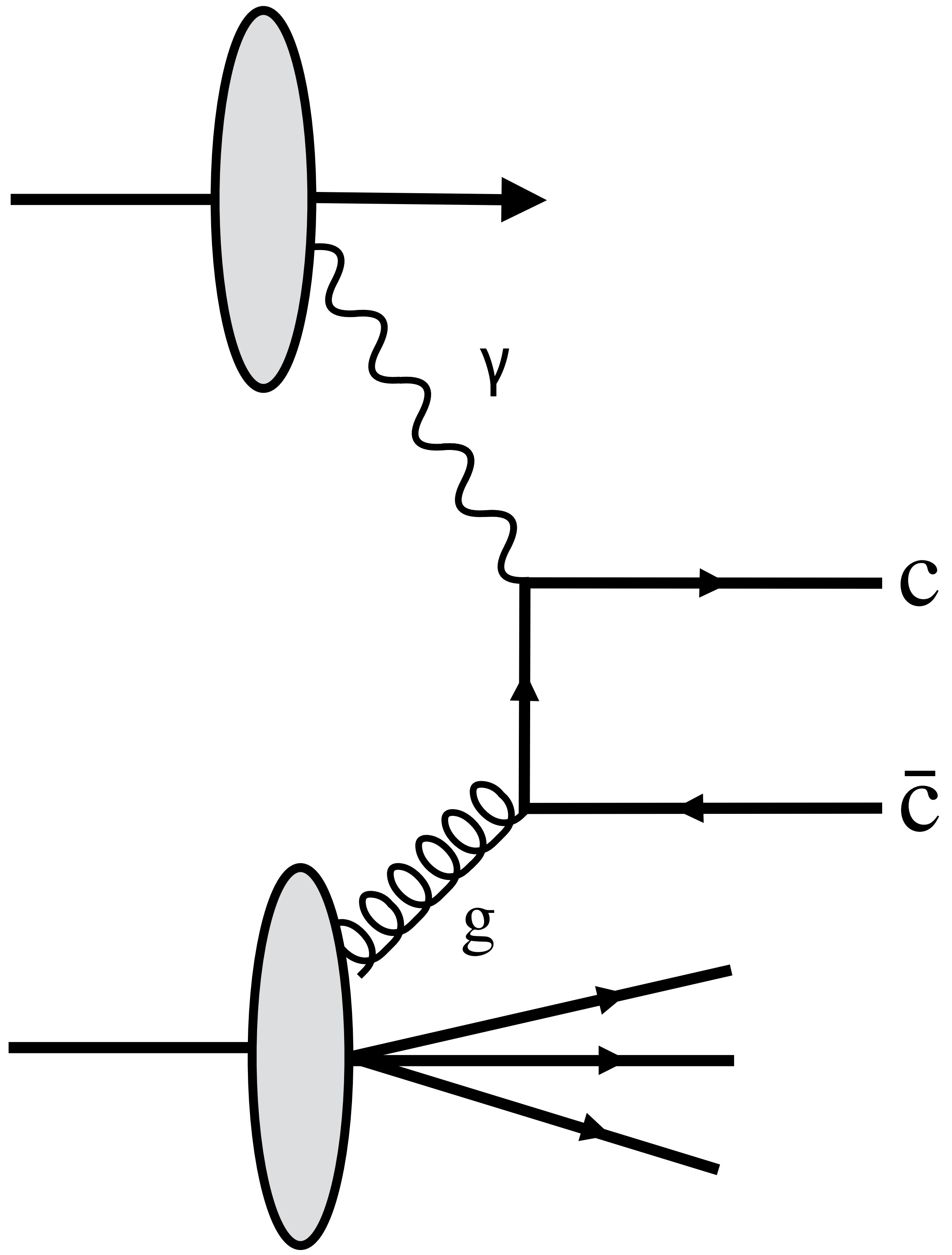
“untagged” light jet

Limited access to low x and low Q^2
→ jets limited to p_T >10-15 GeV/c

“untagged” light jet

ATLAS, ATLAS-CONF-2017-011

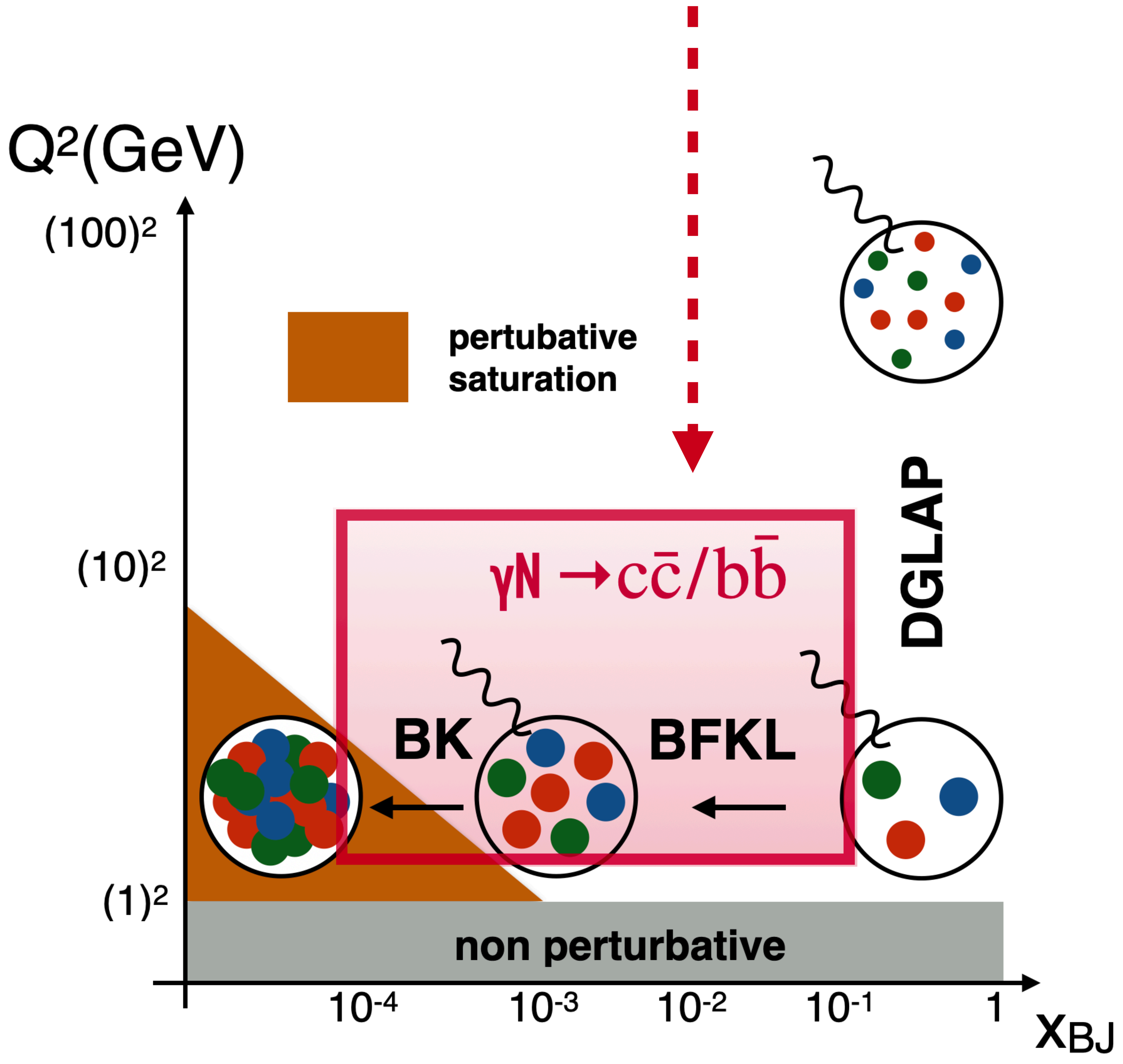
“Open” heavy-flavor and HF-jet photoproduction in UPCs



- Simple pQCD description down to p_T=0
- dynamical access to a wide region of x, Q^2 region down to low x_{BJ}

→ fill the gap between the high and low p_T regime

→ scan the region where high-density effects should emerge with a perturbatively-produced probe

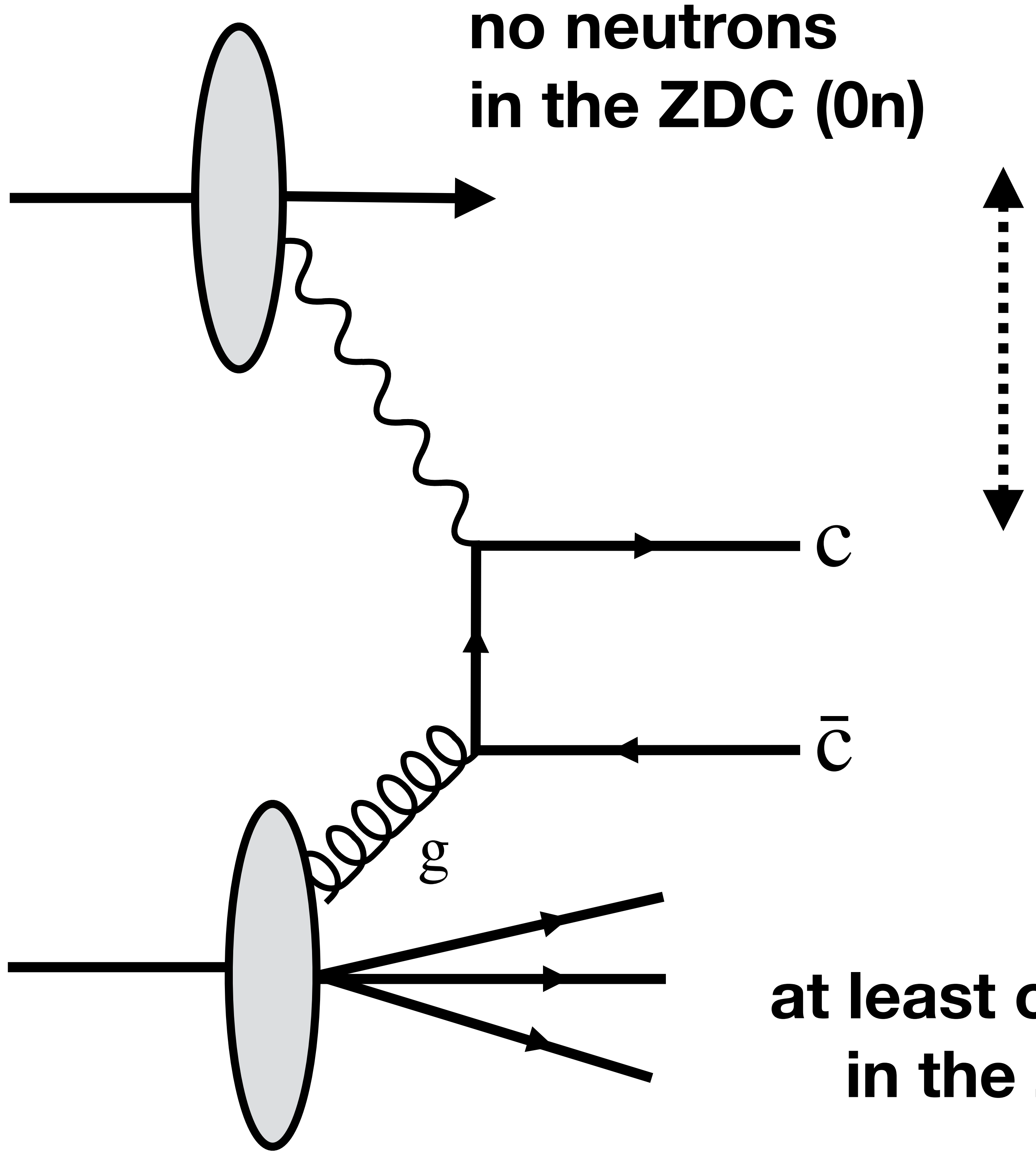


- $x_{min} \approx 10^{-4}$ with low p_T, forward probes (LHC)
- $Q^2_{min} \approx m^2_{c\bar{c}}$

Spencer Klein, **R. Vogt et al**: Phys. Rev. C, v66, 2002

Experimental strategy for "hard" inclusive photoproduction

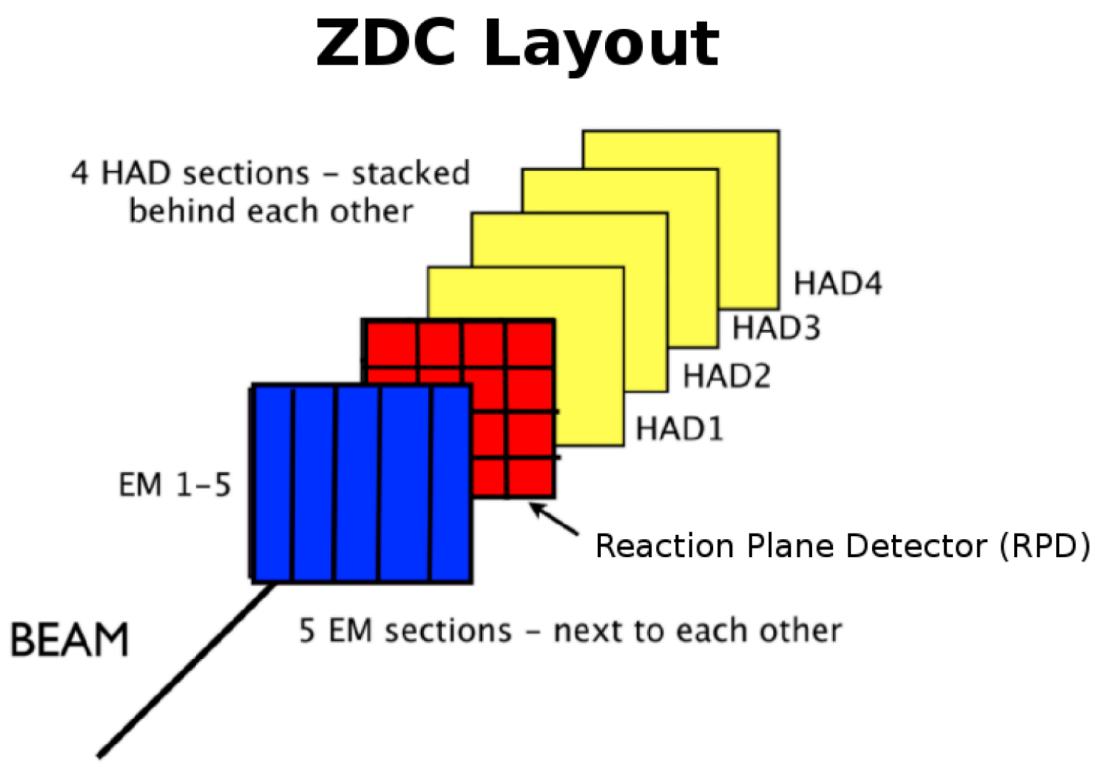
no neutrons in the ZDC (0n)



Rapidity gap in the direction of outgoing photon

Jets and heavy-quark-tagged jets:
→ high-statistics up to high p_T
Fully-reconstructed heavy flavor
→ Trace charm quark down to low p_T

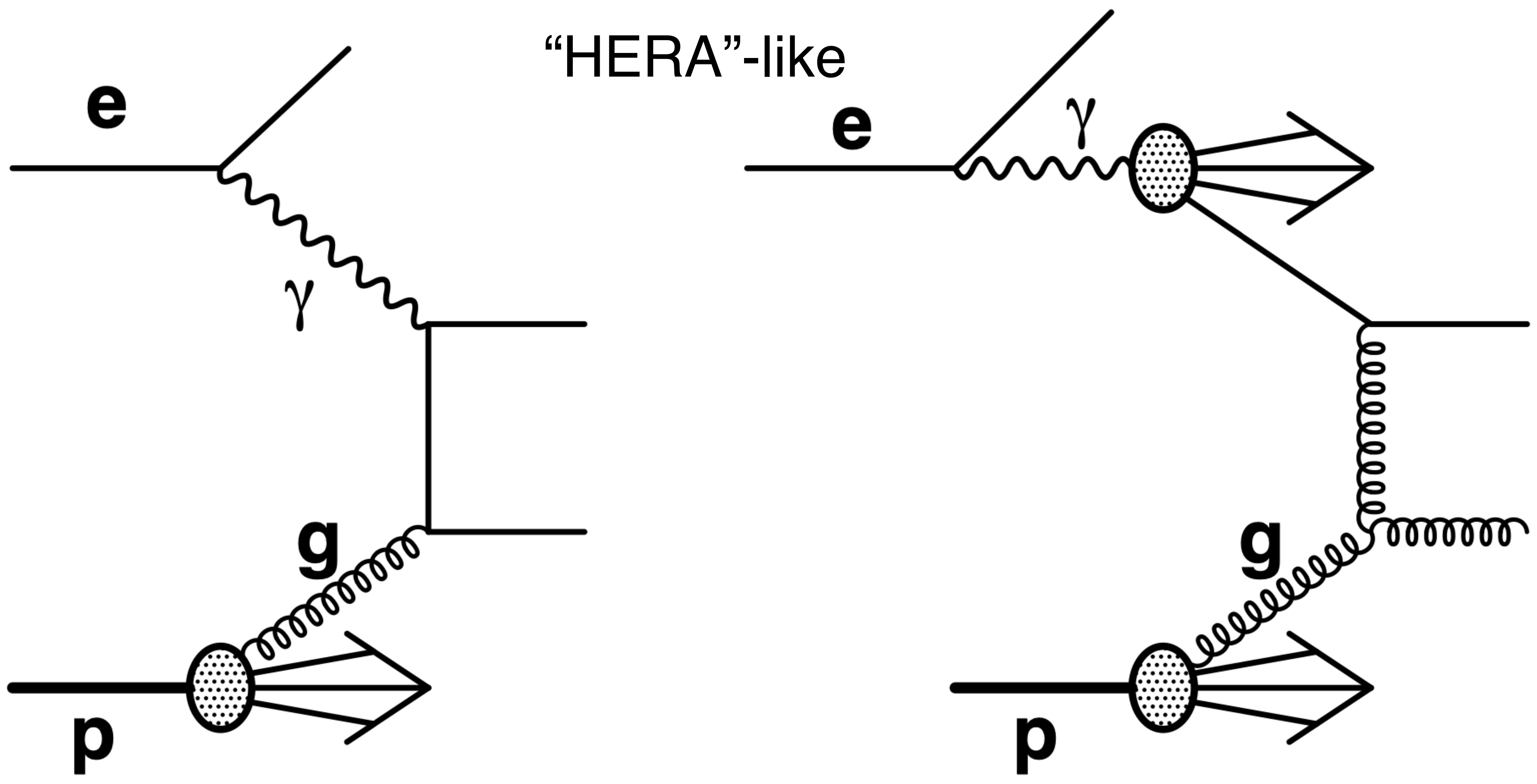
at least one neutron in the ZDC (Xn)

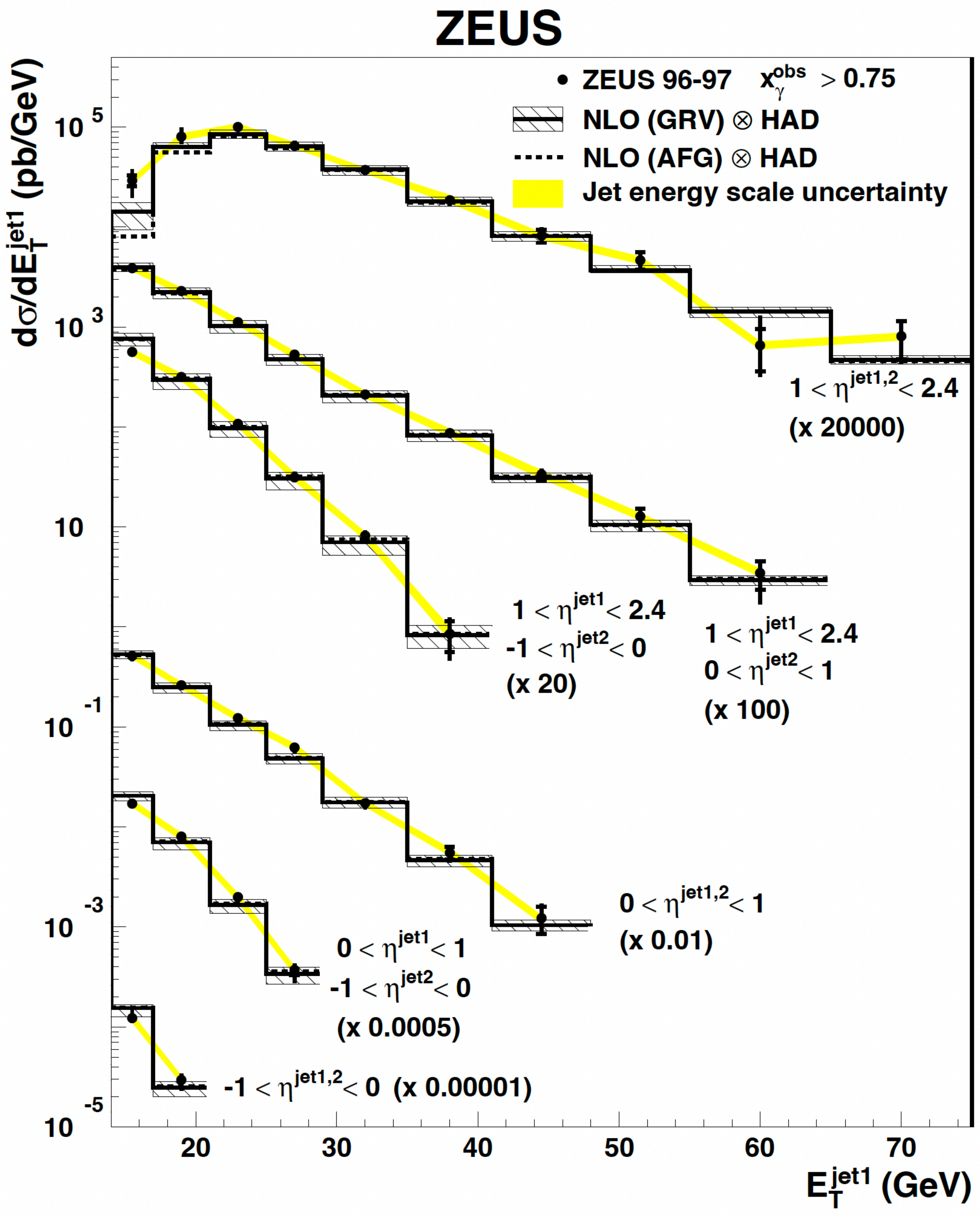


Nontrivial questions about signal "definition" and theoretical challenges:
→ inclusive? semi-inclusive due to requirement on the Xn0n?
→ how to improve the control of the photon-flux and on EM dissociation?

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

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



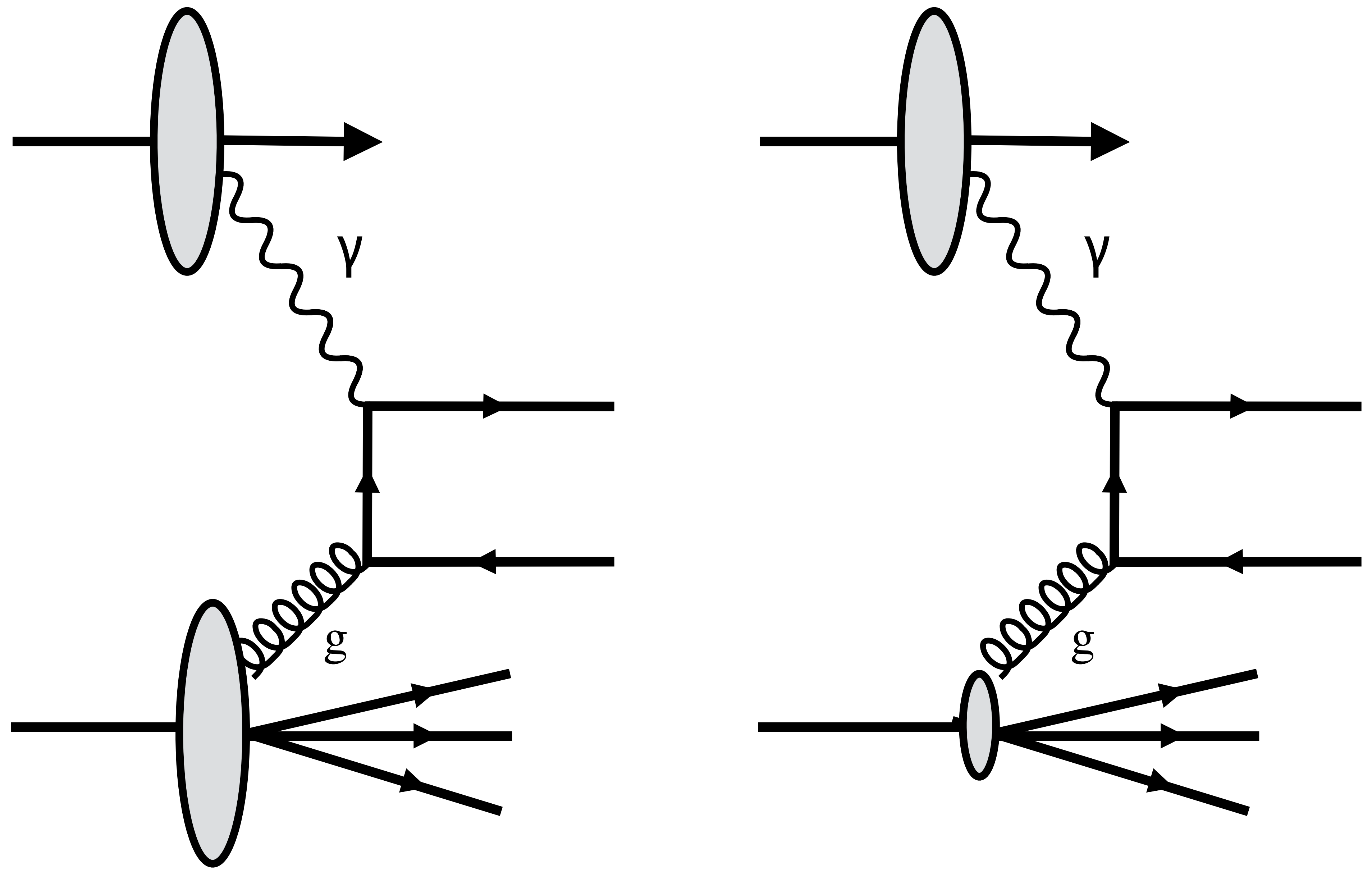


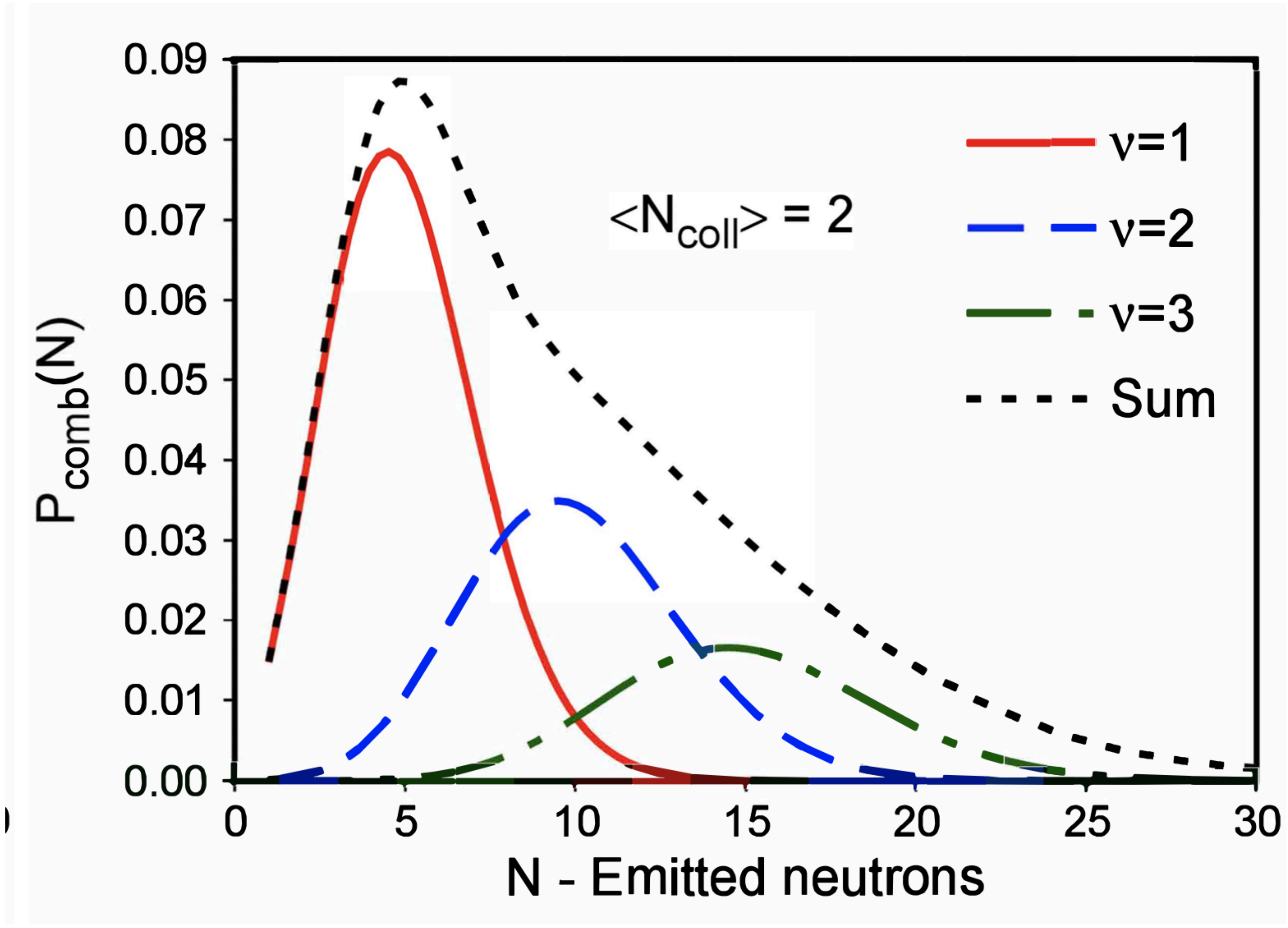
ZEUS, Eur.Phys.J.C23:615-631,2002

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

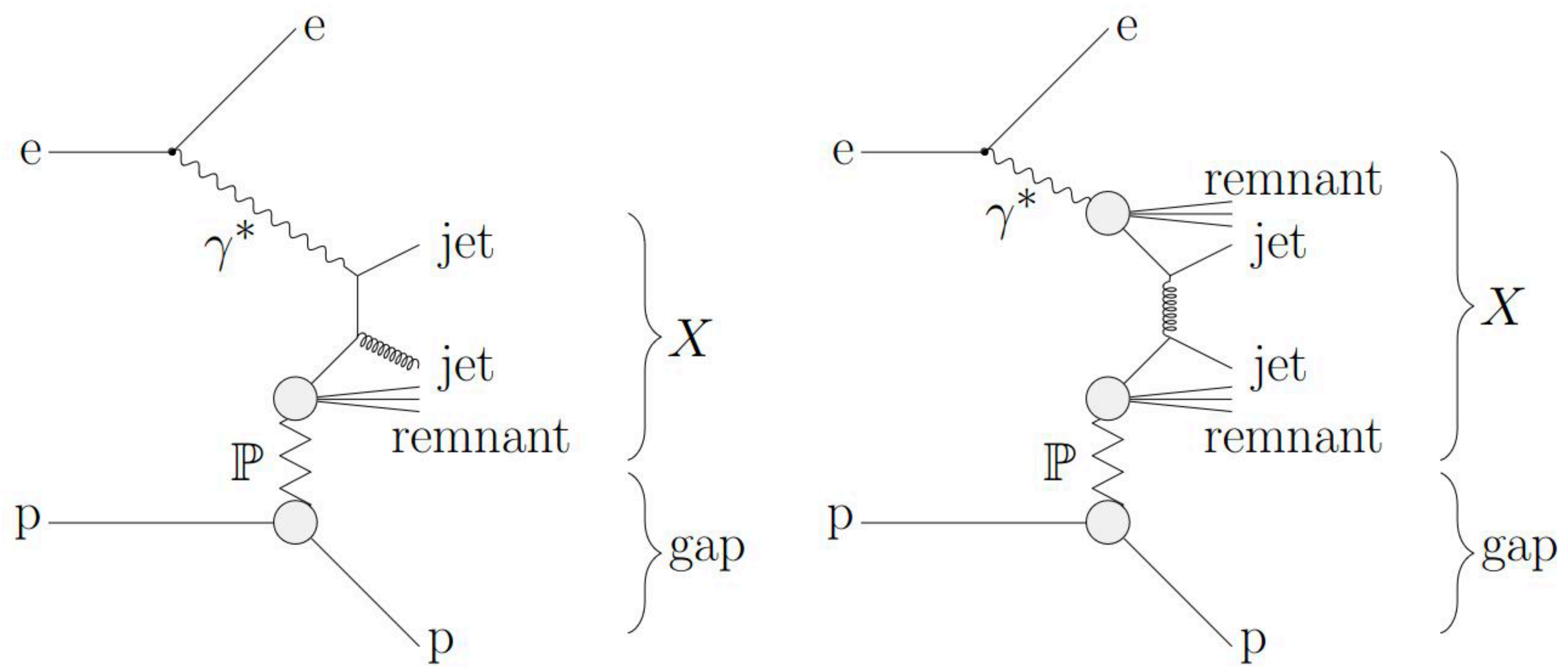


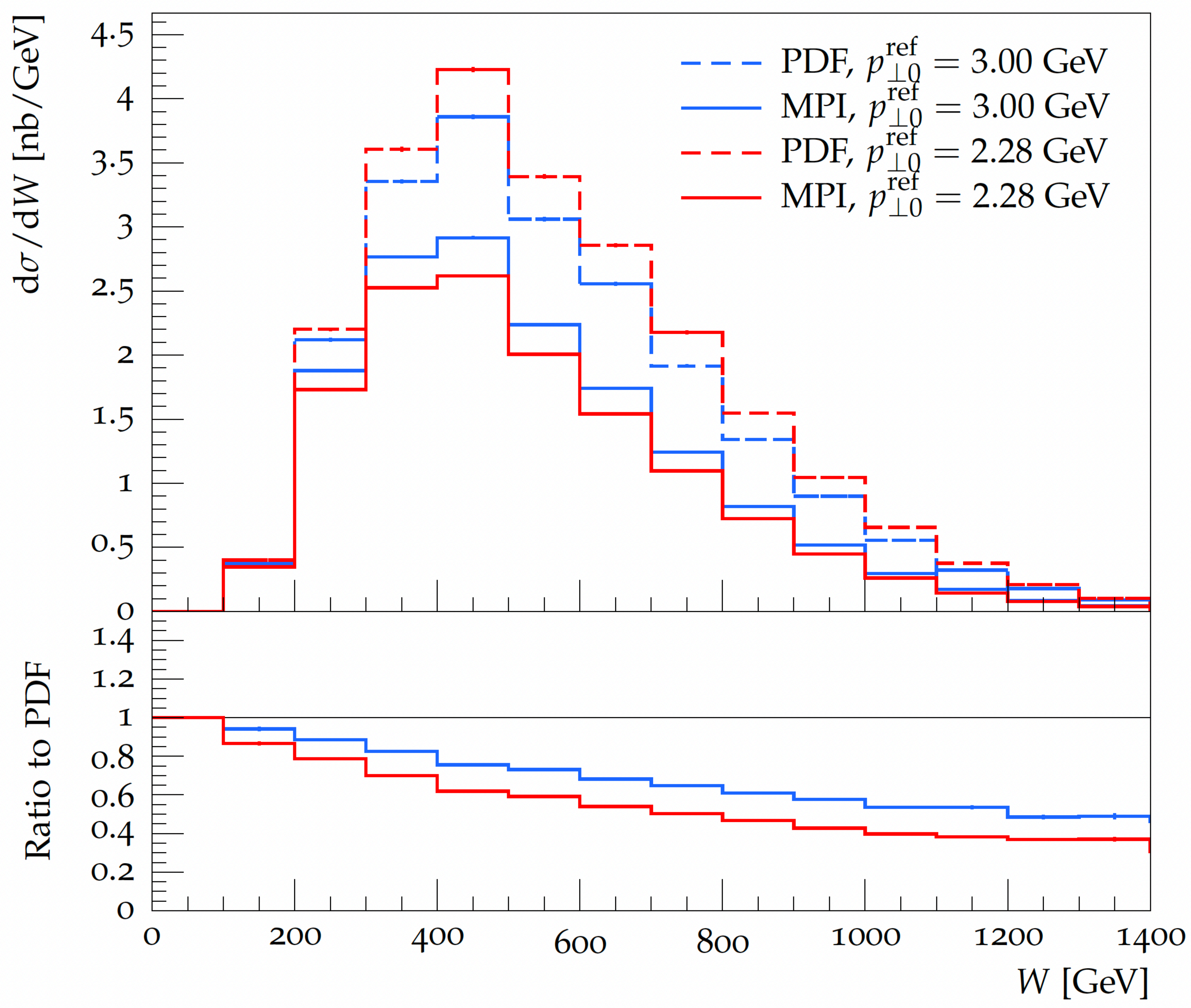


Hard-scattering production at central rapidities with information on the number of neutrons in ZDC:
→ stronger discrimination power on low-x nuclear matter
→ **new experimental challenges for ZDC reconstruction and calibration**

Diffractive production of jets and heavy quarks

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



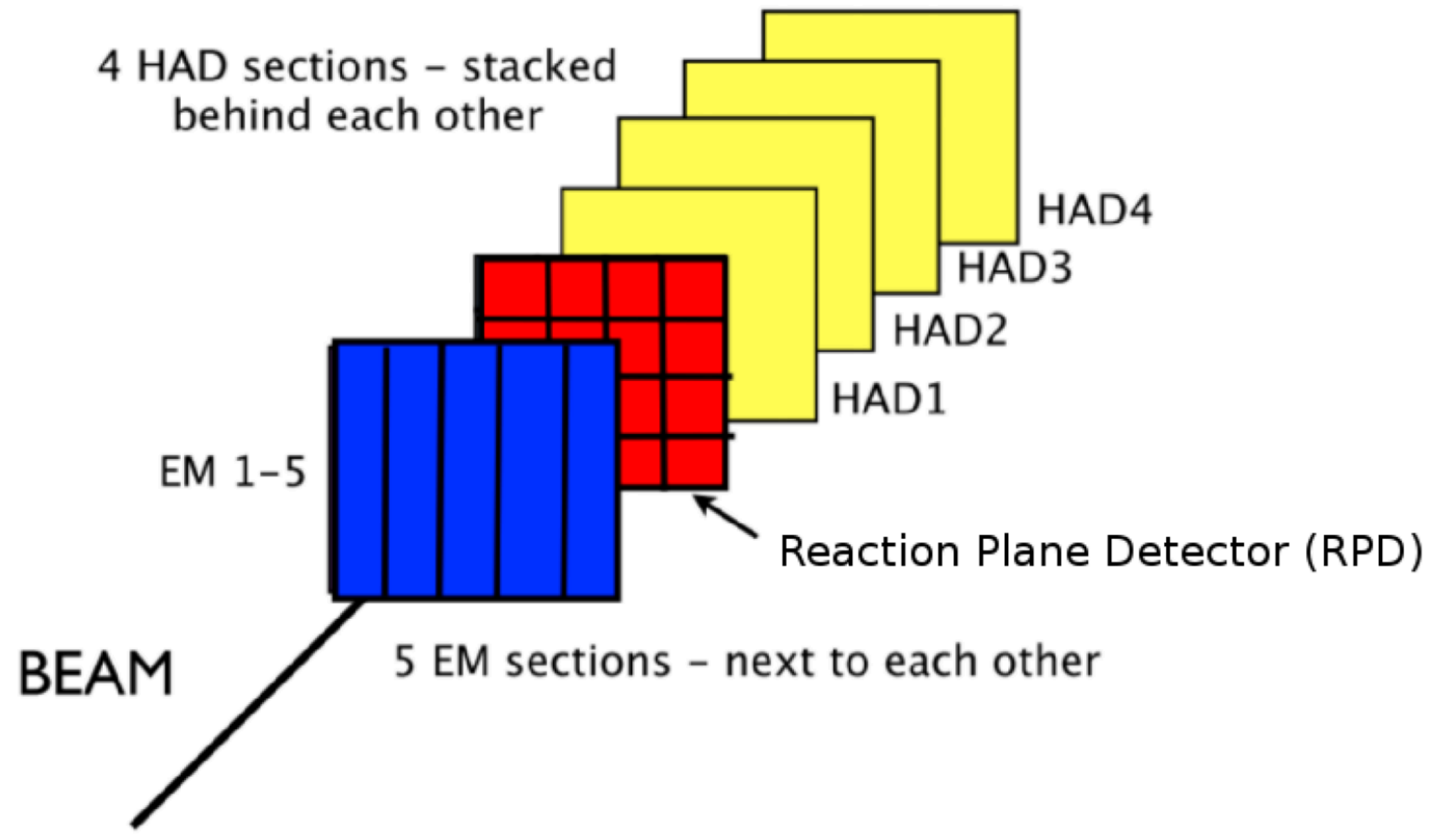


→ **test for factorization**: diffractive PDFs ⊗ partonic coefficient functions
→ benchmark for PbPb measurements

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

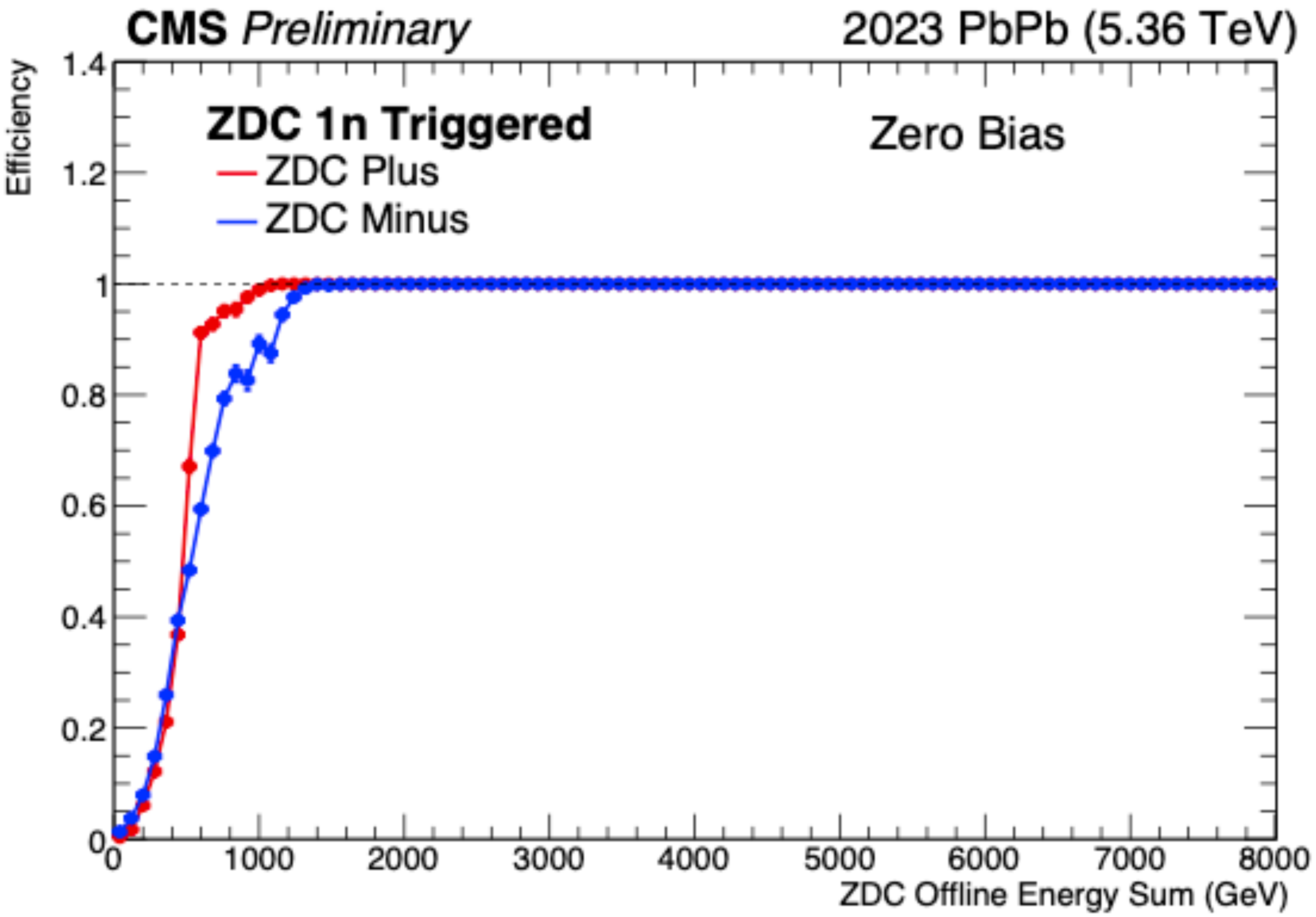
Converting CMS into a γγ, γN detector for the "LHγC"

ZDC Layout



Zero-degree calorimeter (ZDC) as a trigger detector
→ integrate ZDC in the Level-1 (hardware) trigger-emulation chain
→ develop a strategy for fast online calibration

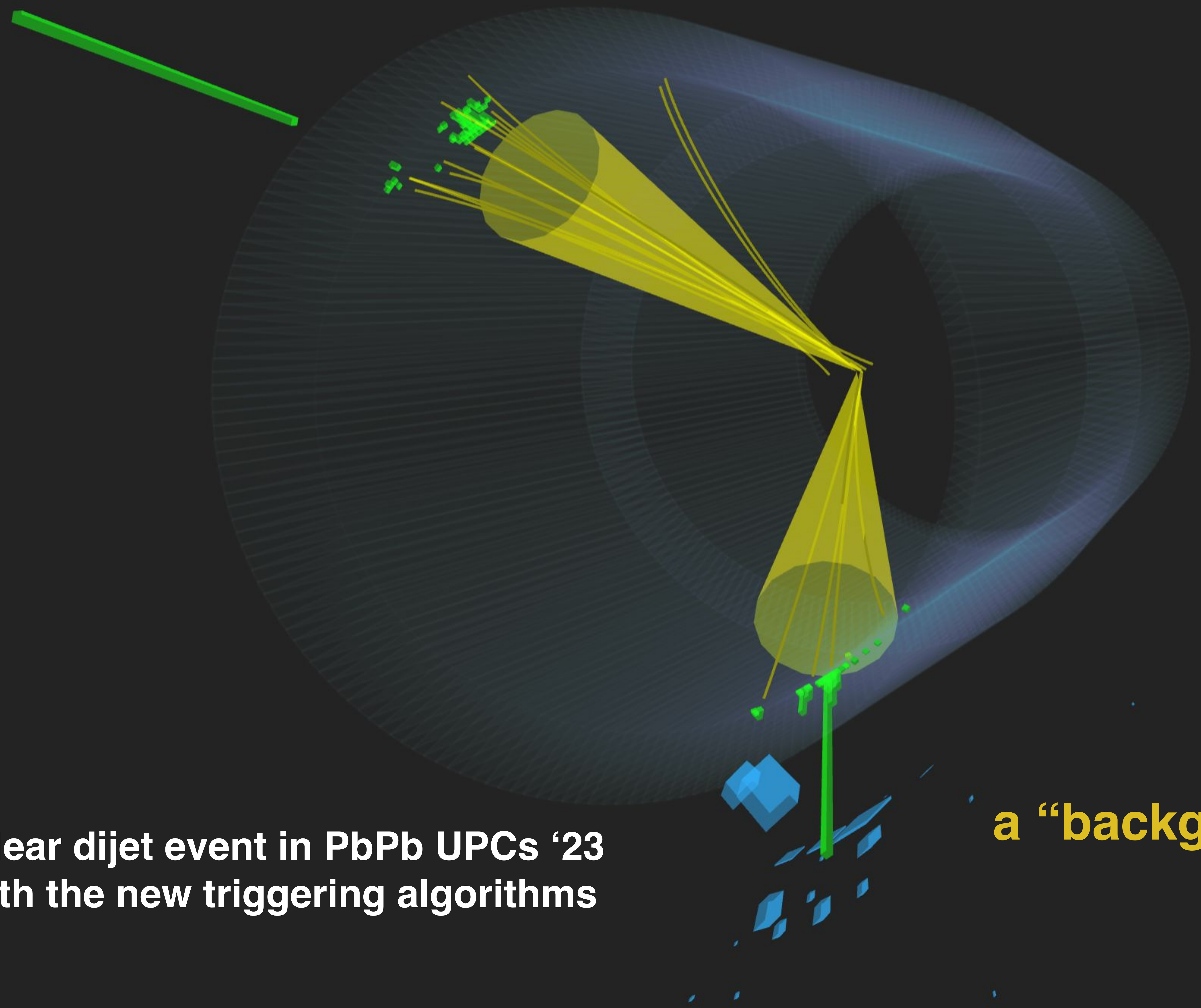
L1 trigger efficiency vs D^0 p_T (2023 data)



New trigger algorithms deployed for the 2023 run
(100-1000 more data than in Run 2)
→ **photonuclear high-Q^2 triggers** (ZDCXOR && L1 jet)
→ **photonuclear low-Q^2 triggers** (ZDCXOR)
→ **γγ and diffractive triggers**

Improved algorithms being optimized for the 2024 data-taking period

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

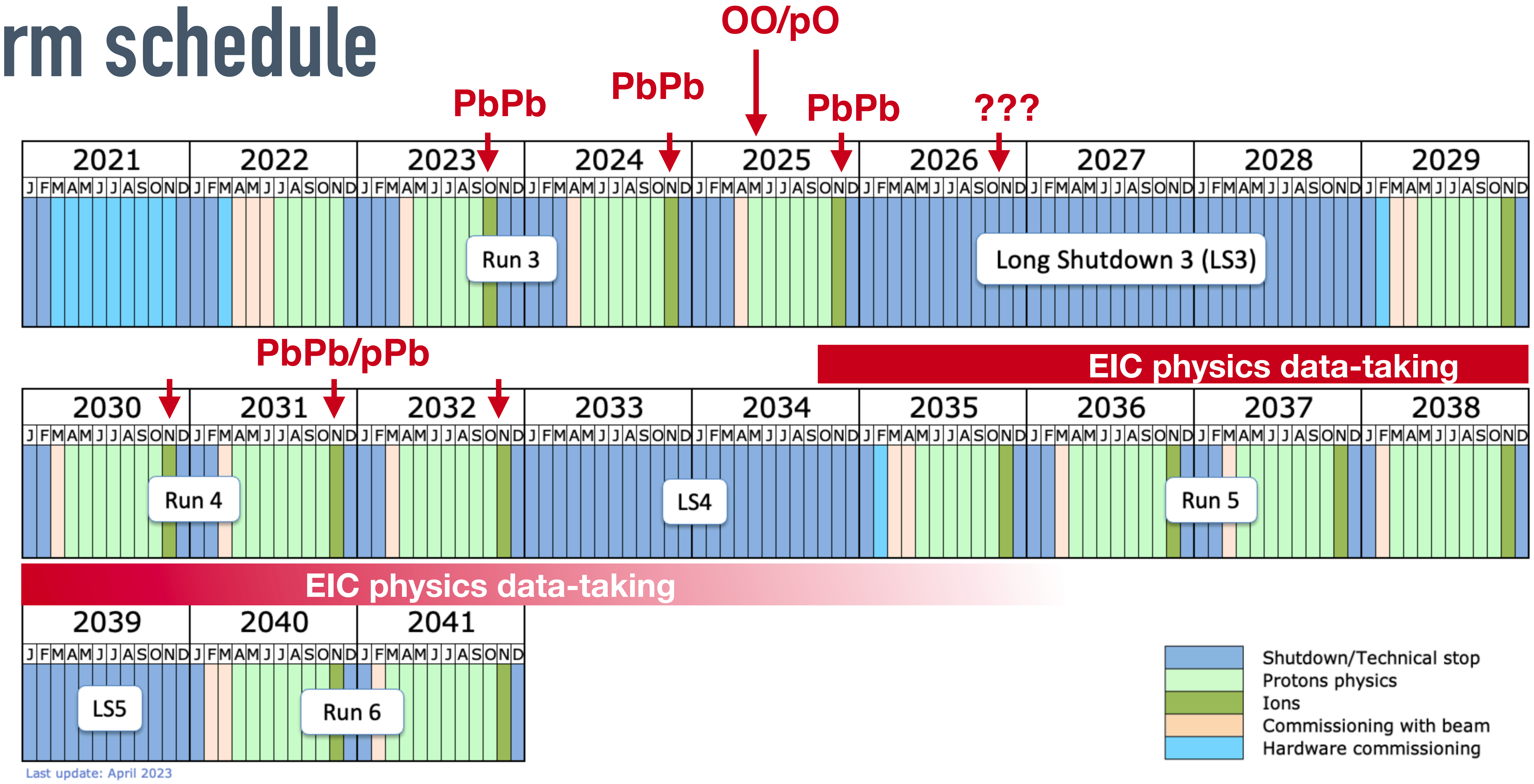


A photonuclear dijet event in PbPb UPCs ‘23 collected with the new triggering algorithms

a “background-less” forward dijet event

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

LHC long-term schedule

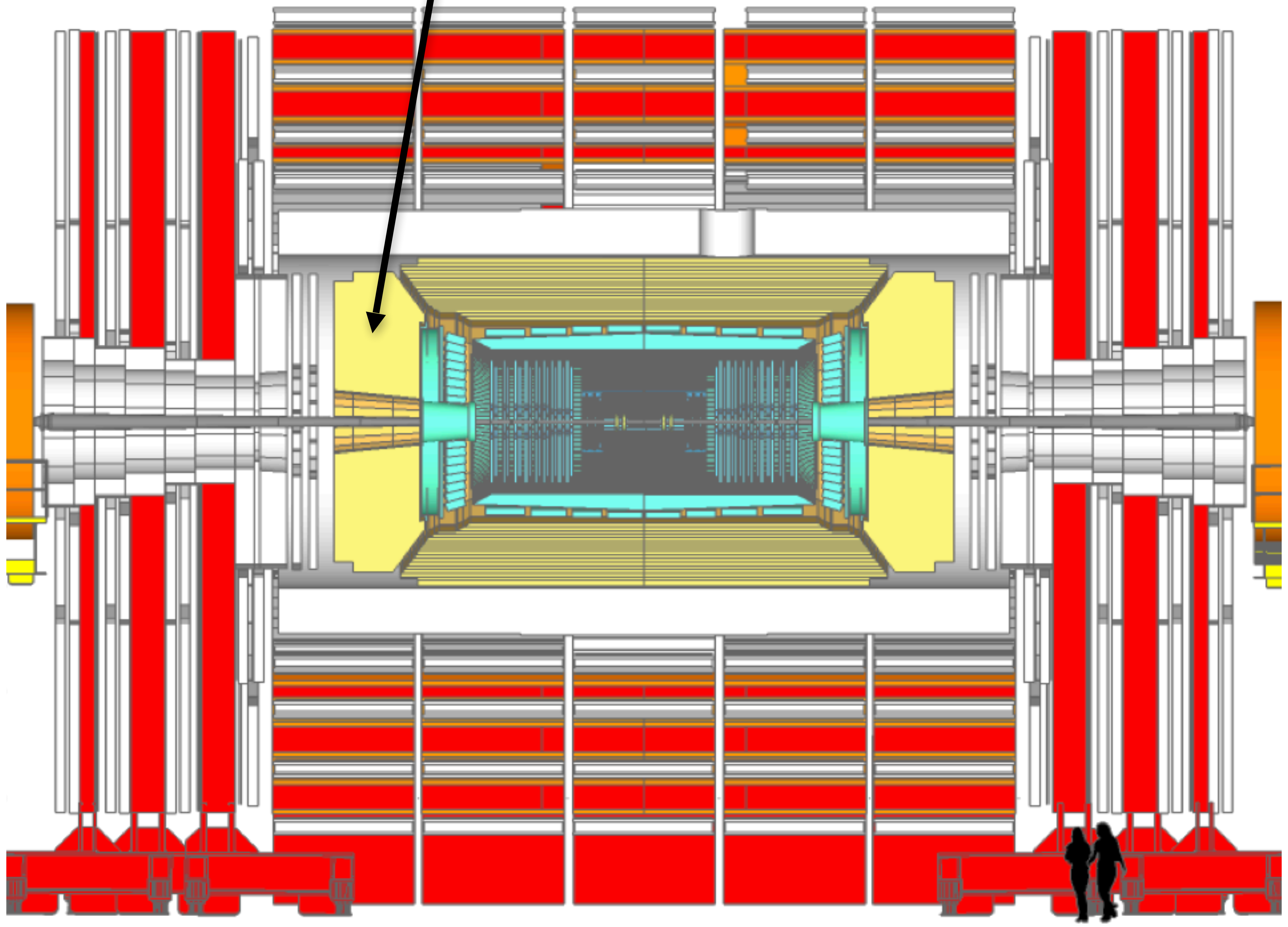


- **About a week of OO/pO in 2025:** statistics is enough for very soft-probe measurements, assessing quenching in small systems
  → we would need a few weeks of data to constrain nPDFs with EM probes or high-accuracy heavy-quark probes
- **Additional run in Run 3? pPb in Run 4?**
- **Inputs for Run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

The upgraded CMS detector for Run 4 (Phase II)

Trigger / HLT / DAQ
- L1/HLT rate x7.5
- DAQ: 6 → 60 GB/s
- **tracking capabilities at Level-1**
  → possibility of sampling the entire delivered luminosity of UPCs with negligible trigger biases

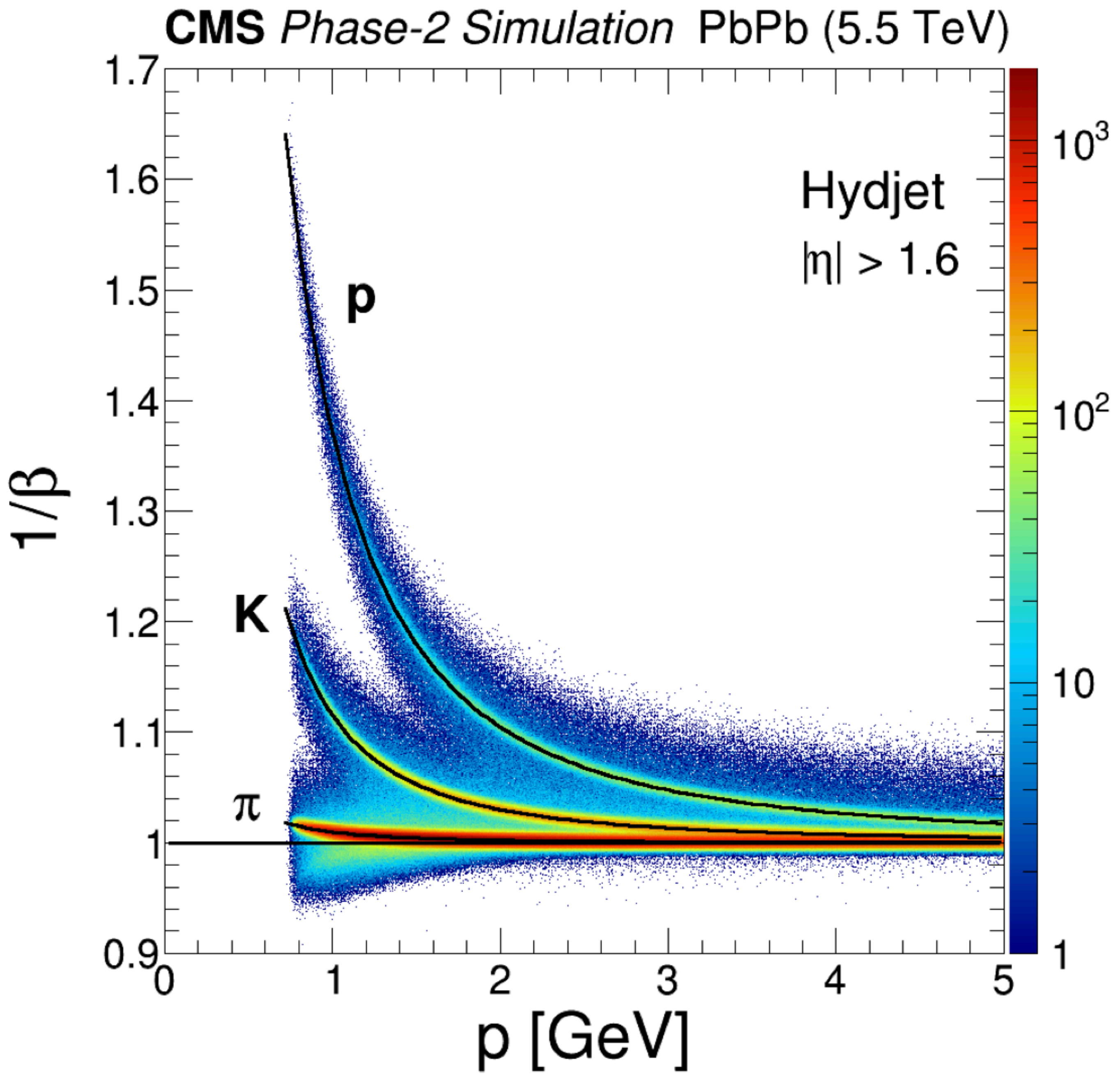
New endcap calorimeters (HGCal)
Unprecedented granularity $|\eta| < 3$

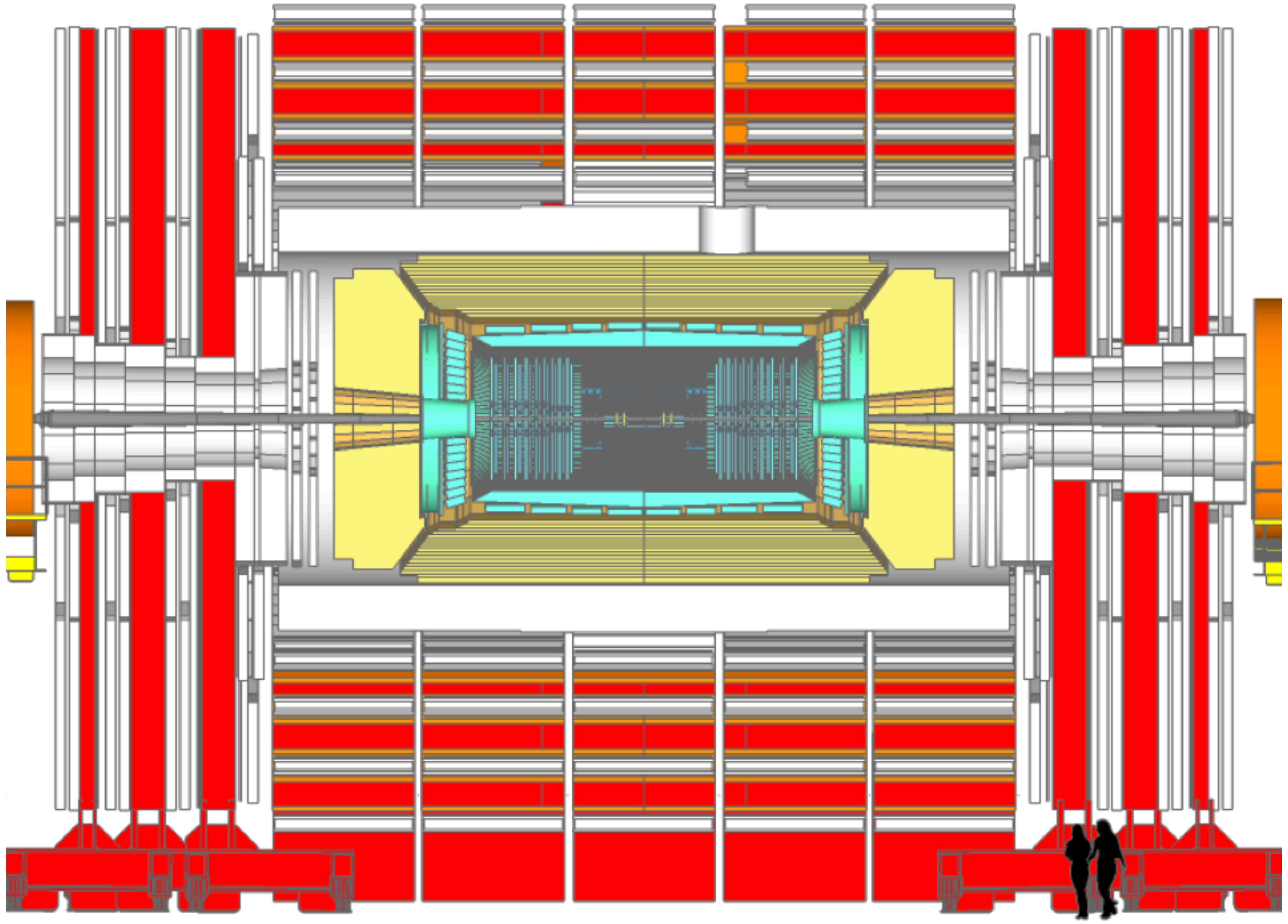


CMS, CERN-LHCC-2019-003
CMS, CMS-TDR-014

The upgraded CMS detector for Run 4 (Phase II)

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



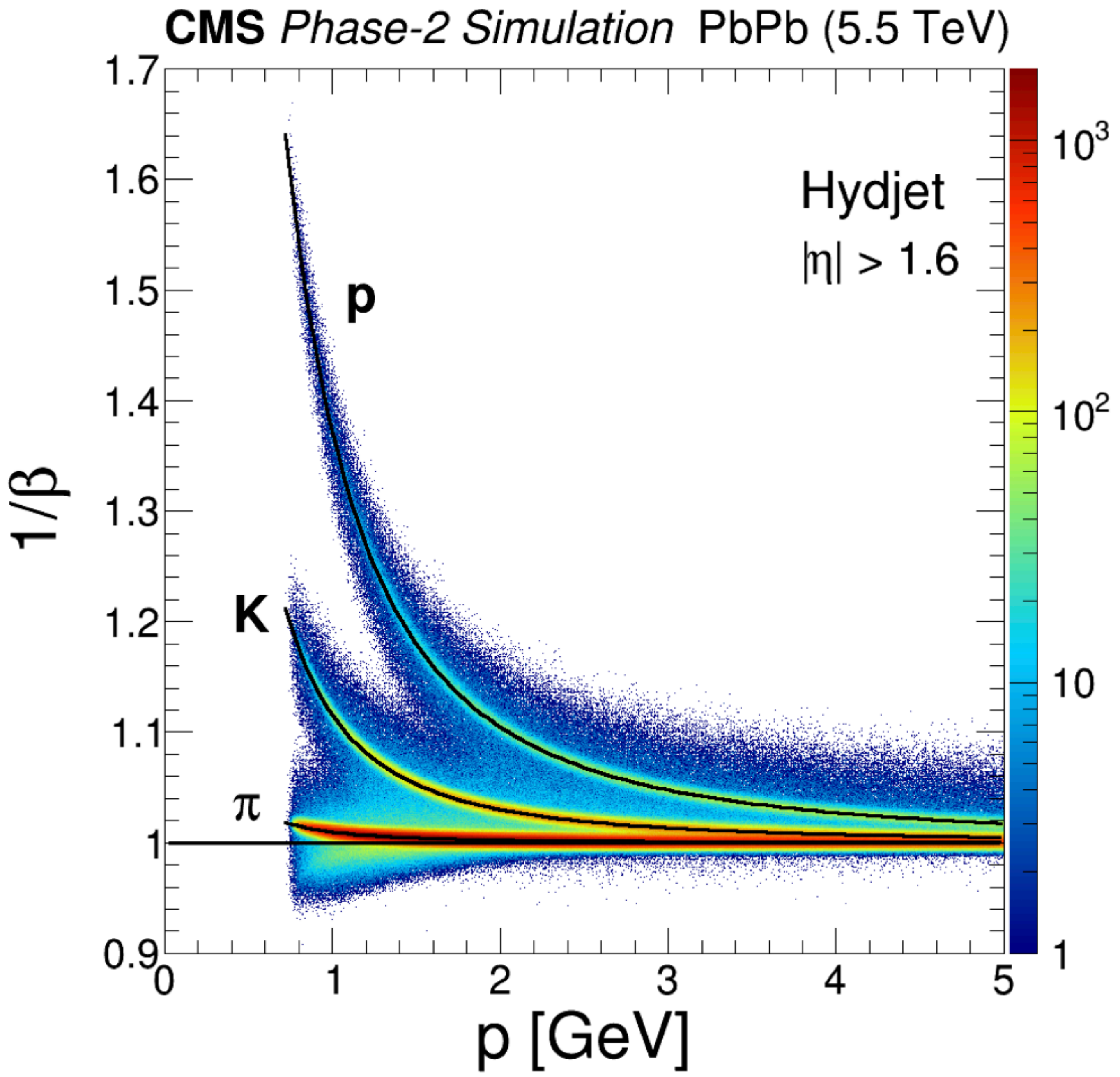


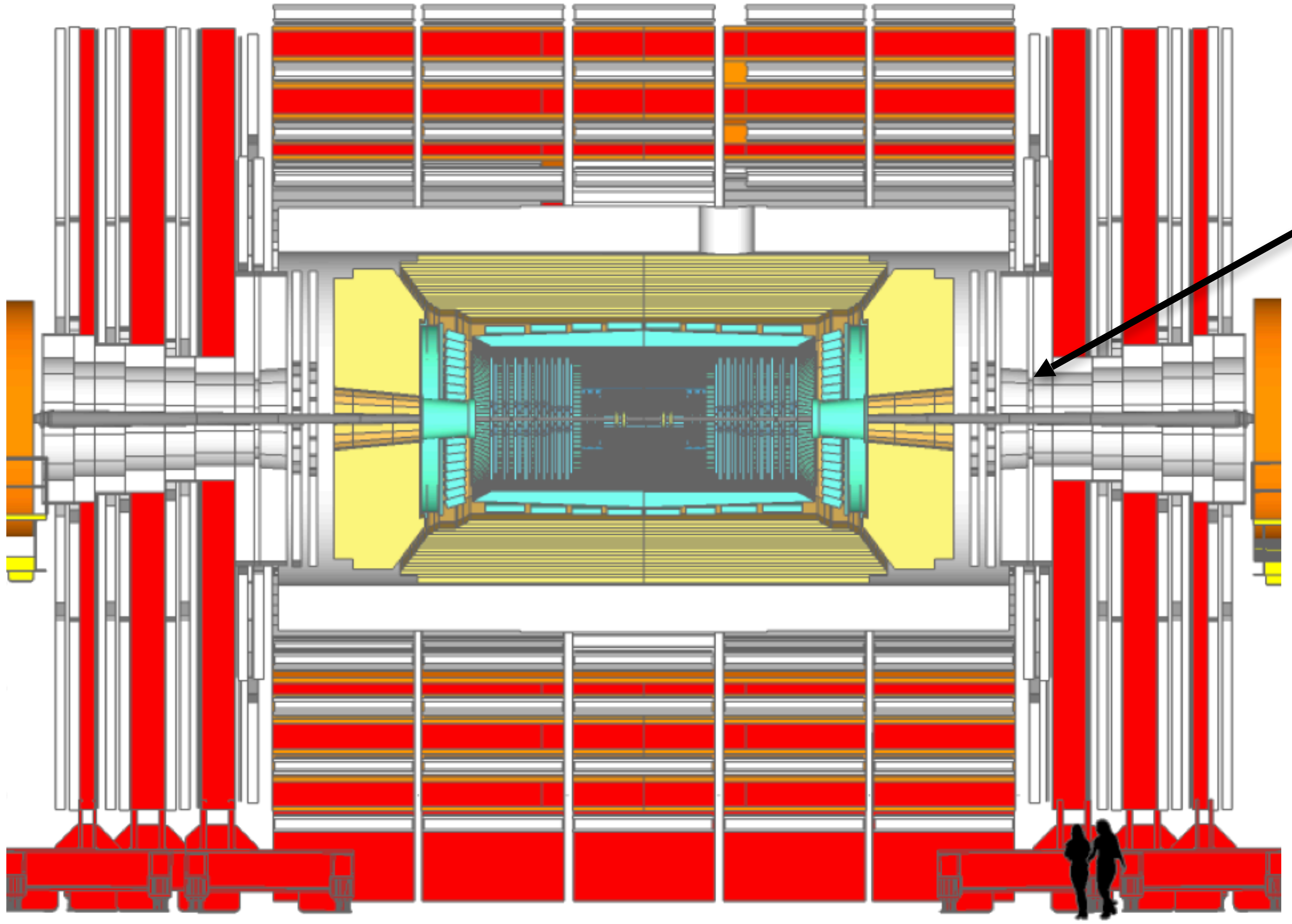
CMS, CERN-LHCC-2019-003
CMS, CMS-TDR-014

The upgraded CMS detector for Run 4 (Phase II)

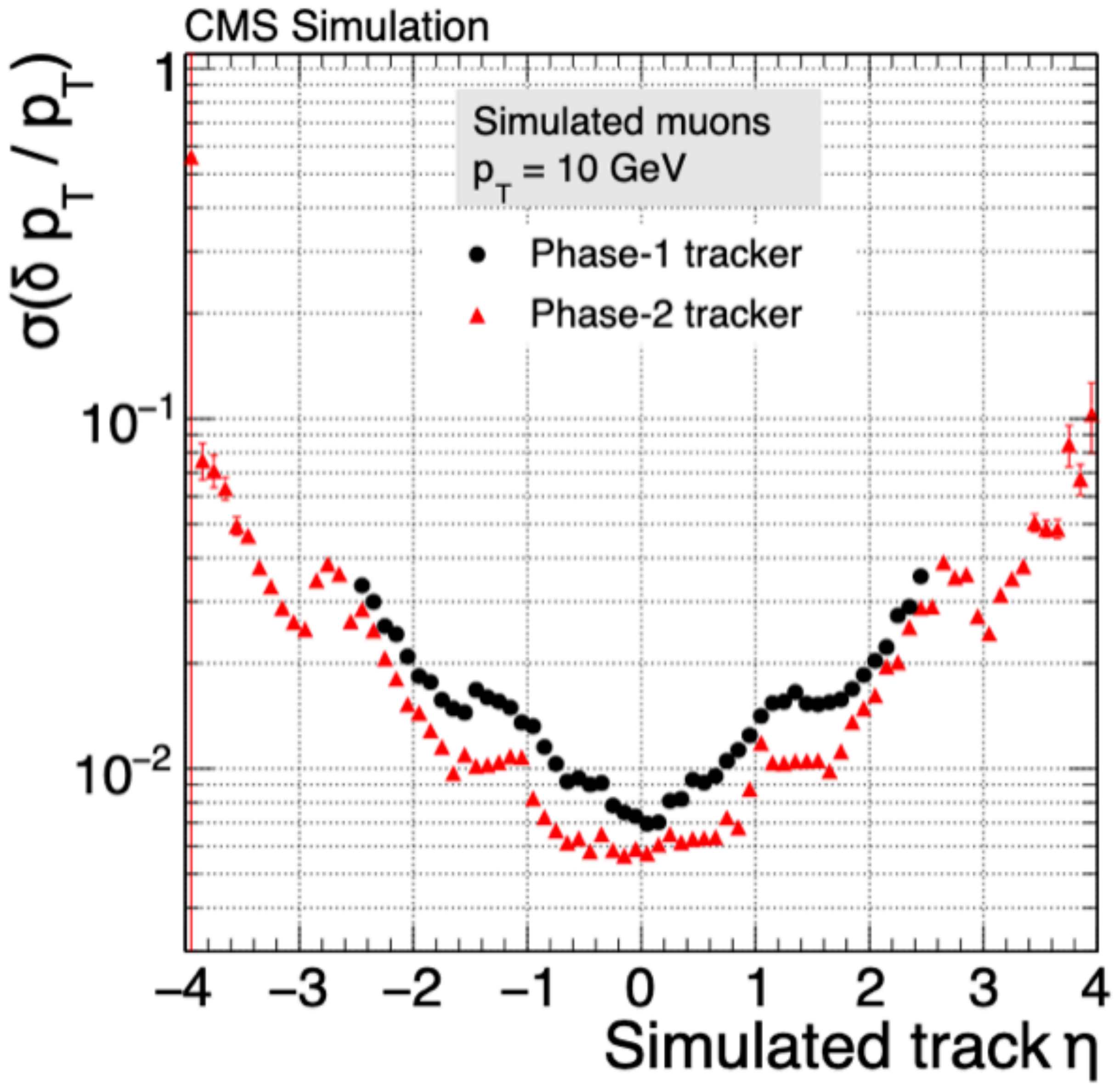
CMS, CERN-LHCC-2019-003
CMS, CMS-TDR-014

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



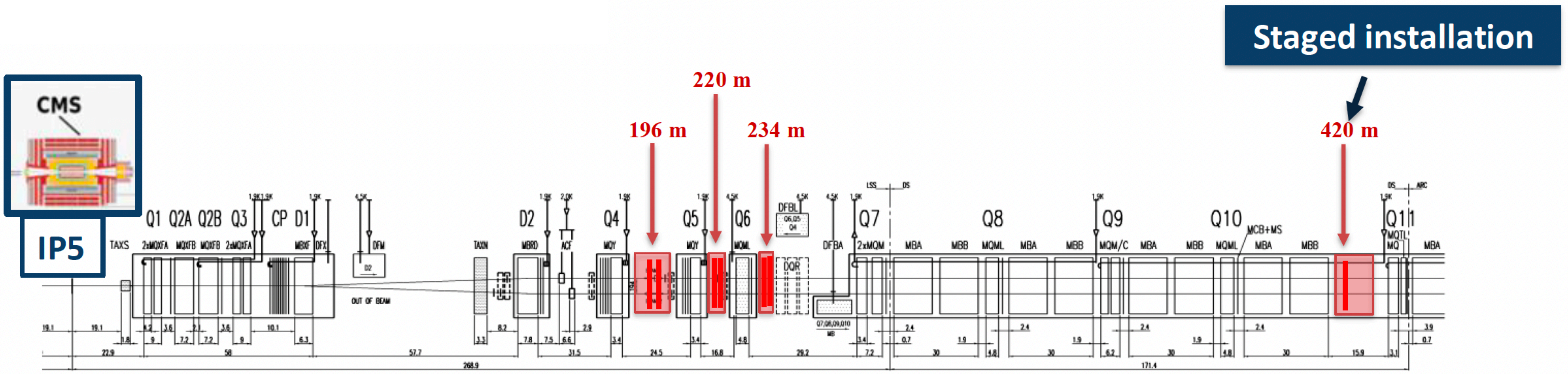


New silicon tracker
Improved granularity
Lighter material budget
$|\eta| < 2.4$ → **$|\eta| < 4$**



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 $\xi = \Delta p/p$**

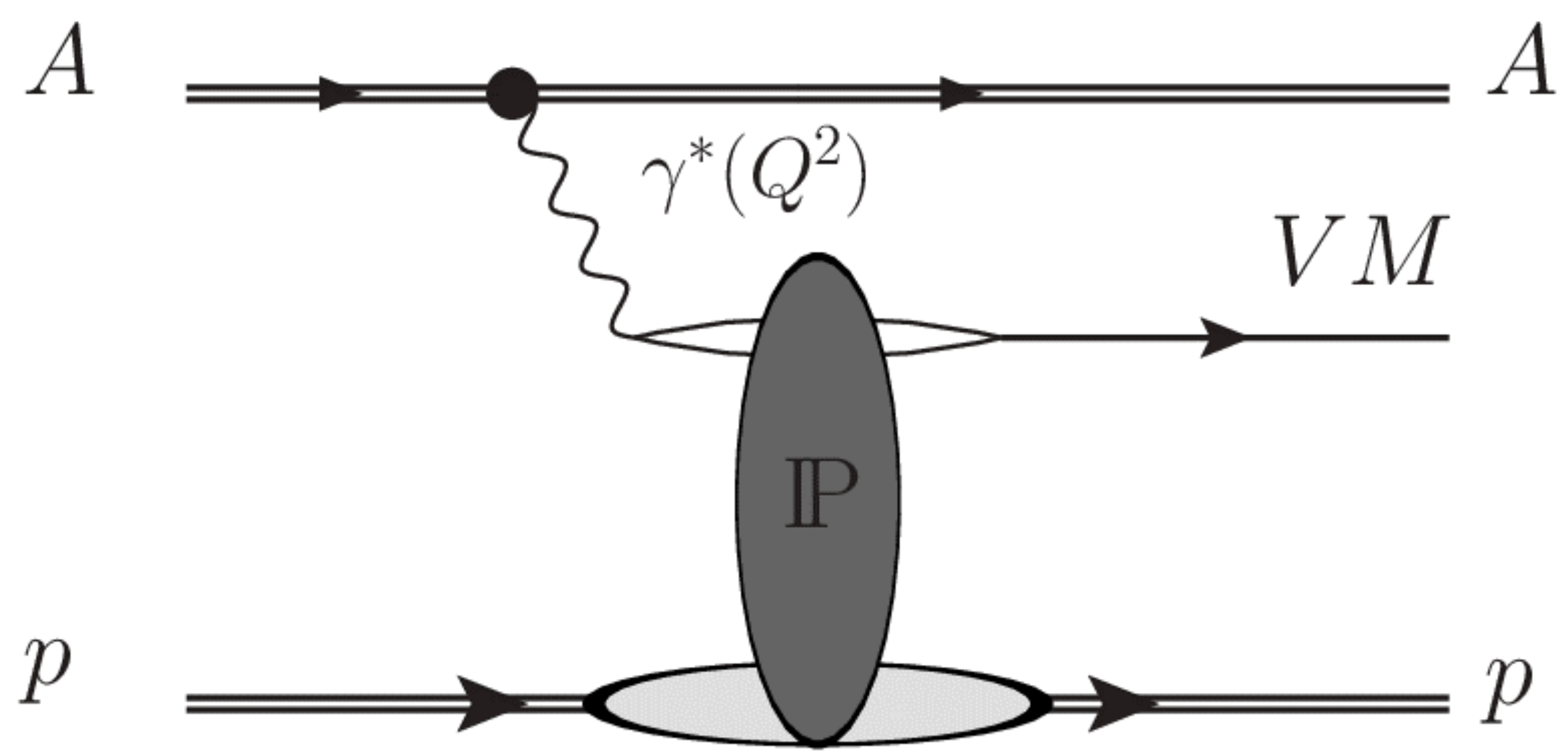


PPS upgrade will further extend the ξ acceptance of the existing PPS (already operational in Run 3)

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

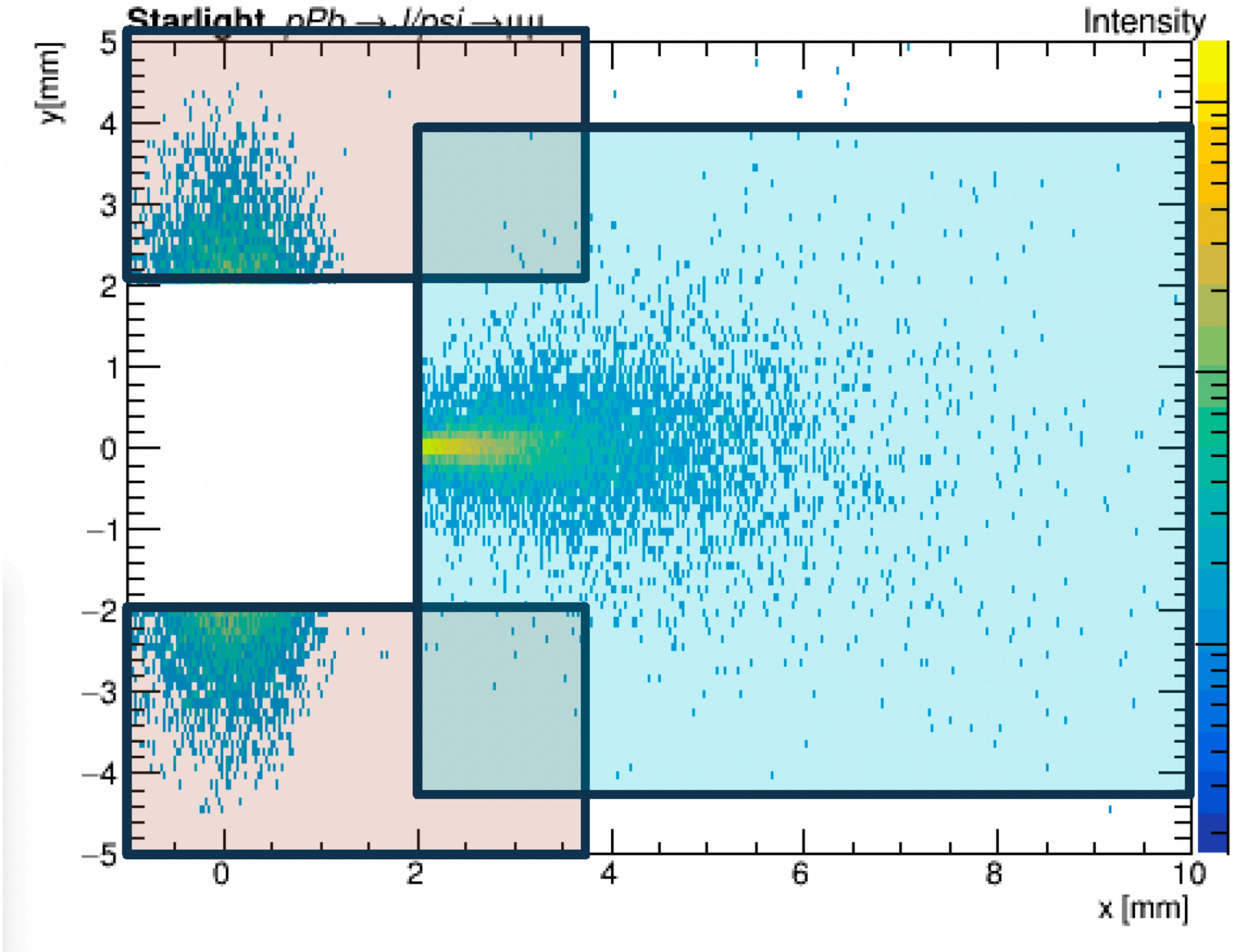
CMS NOTE -2020/008

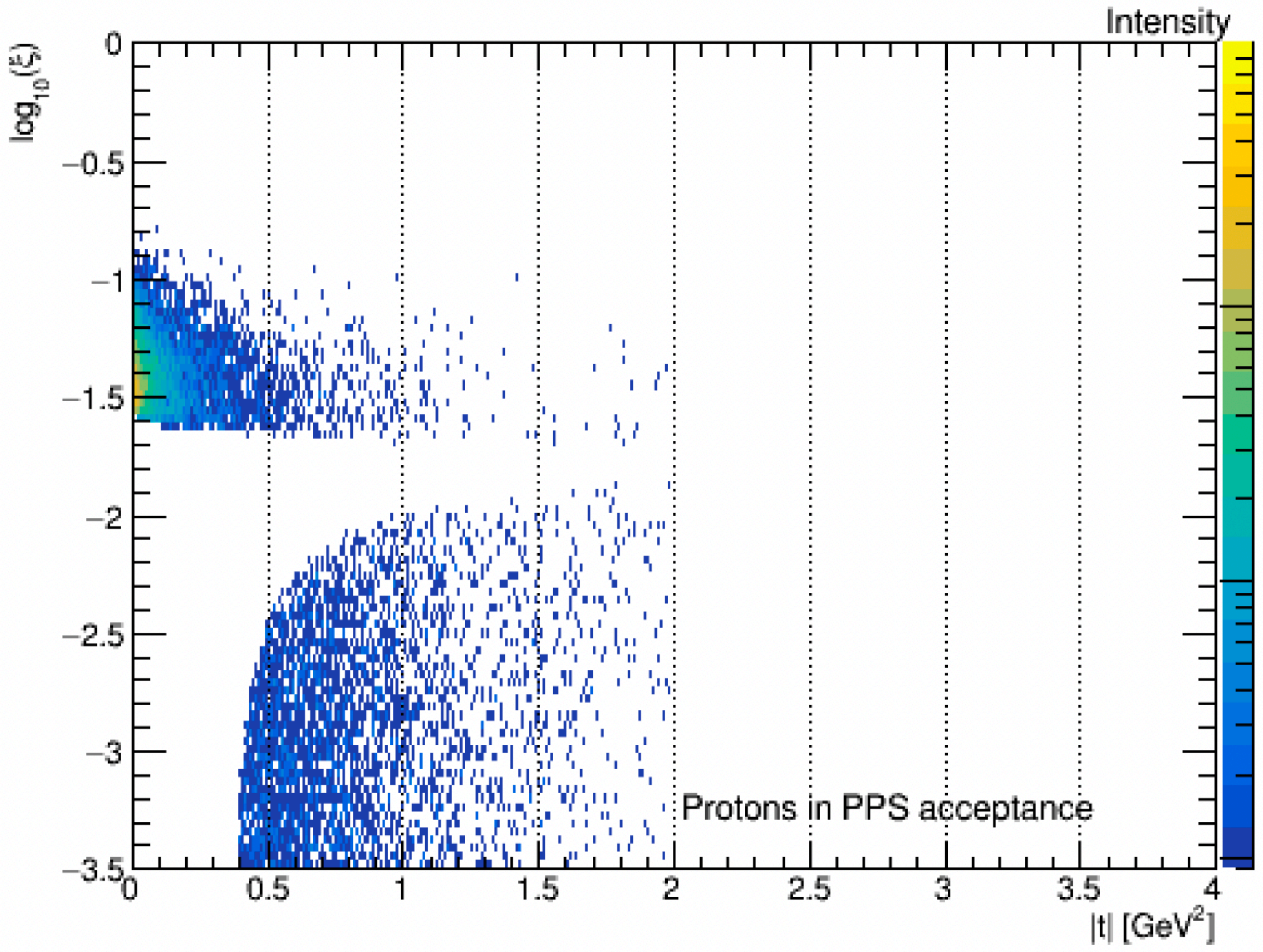
Highlight: exclusive vector-meson production in pA

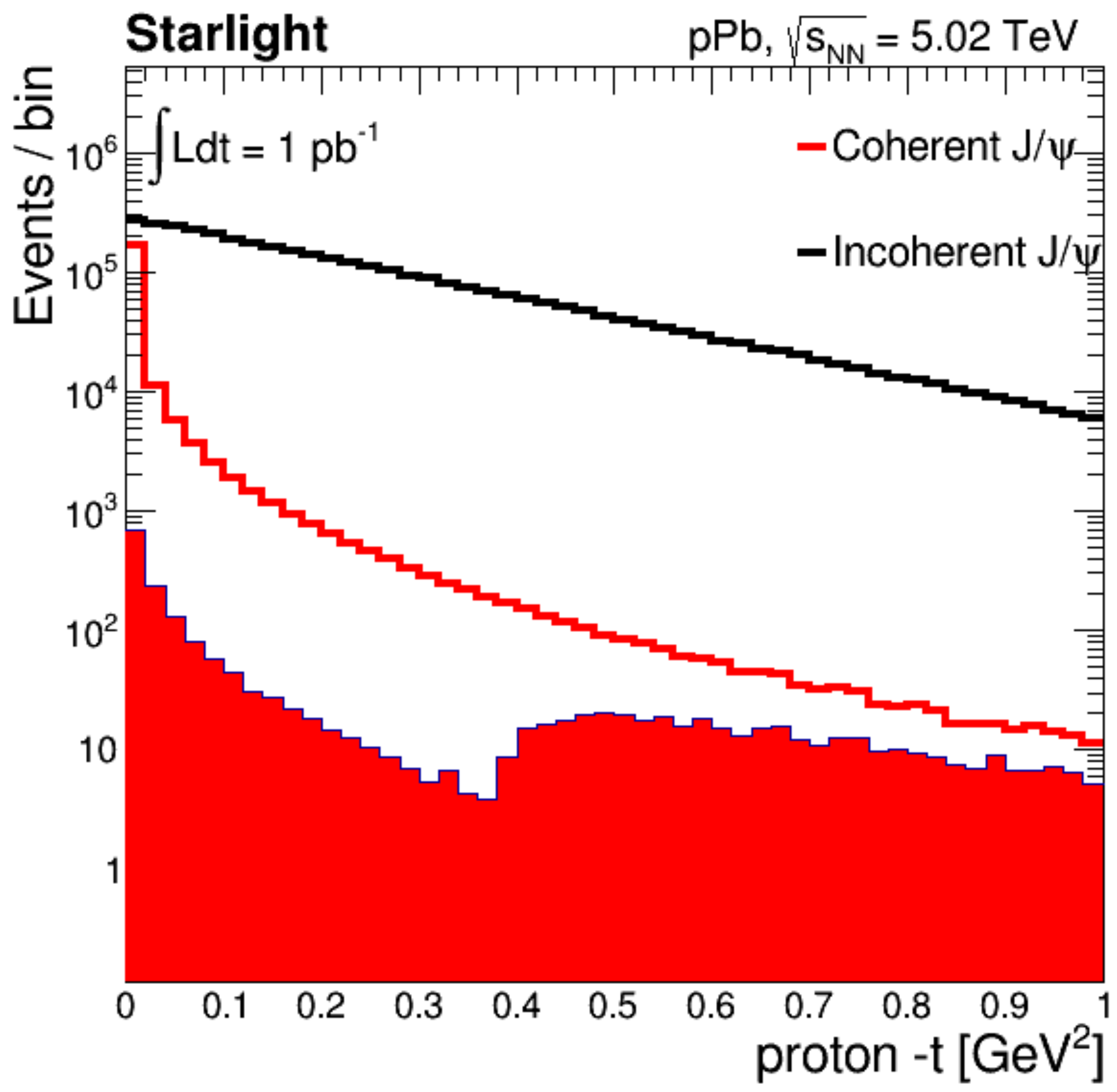


- Vector mesons (Spin 1) are produced in $\gamma - I\!P$ interactions
- Ions emit a photon at $Q^2 \sim 0$
- **In coherent production, the proton remains intact**

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

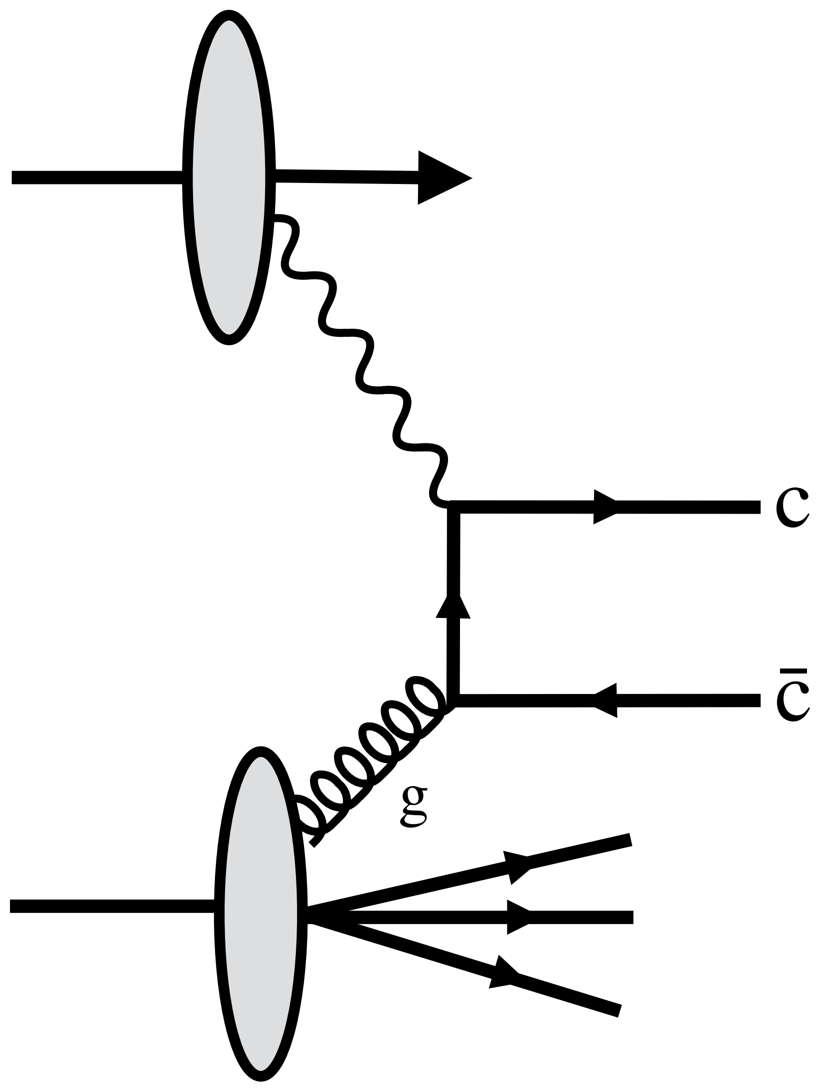




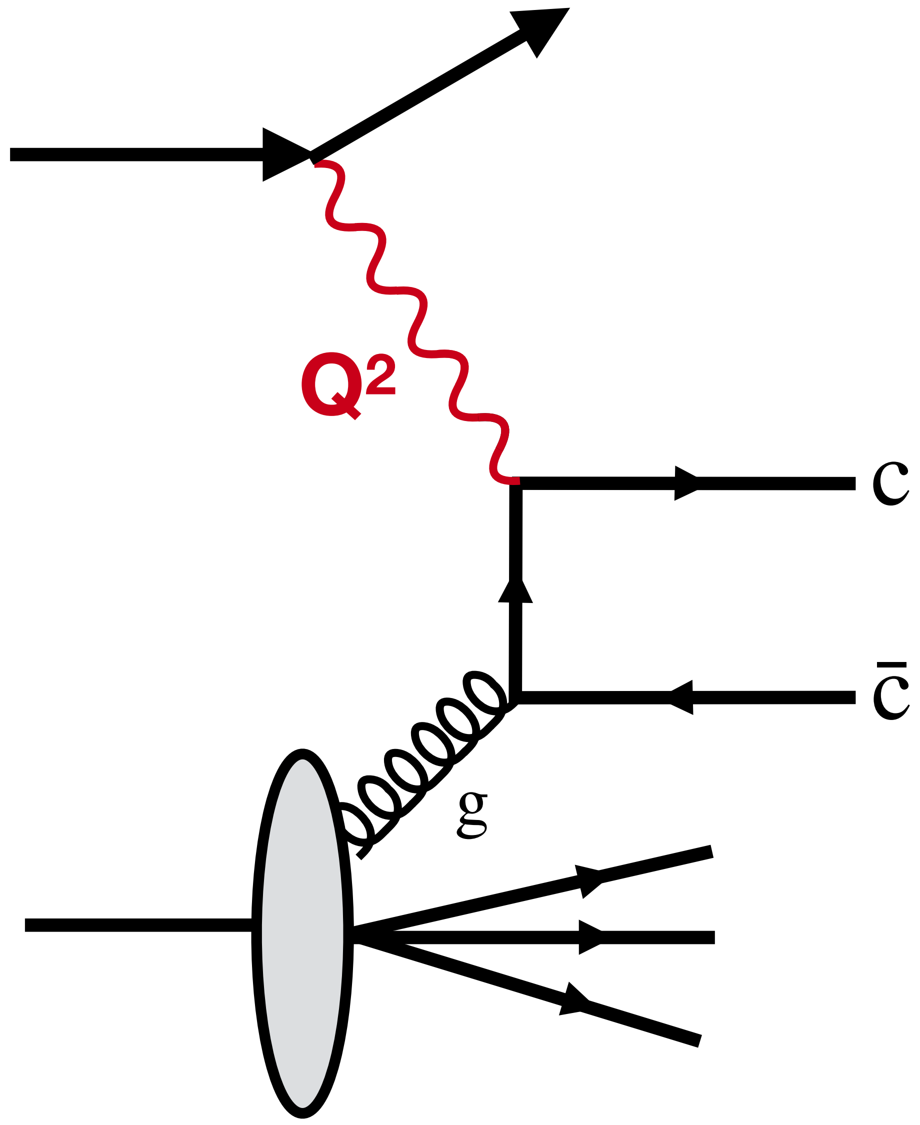


→ Proof of principle for proton (and ion) tagging with the upcoming pO/OO run (scheduled for 2025)

Synergies and complementarities with the EIC program



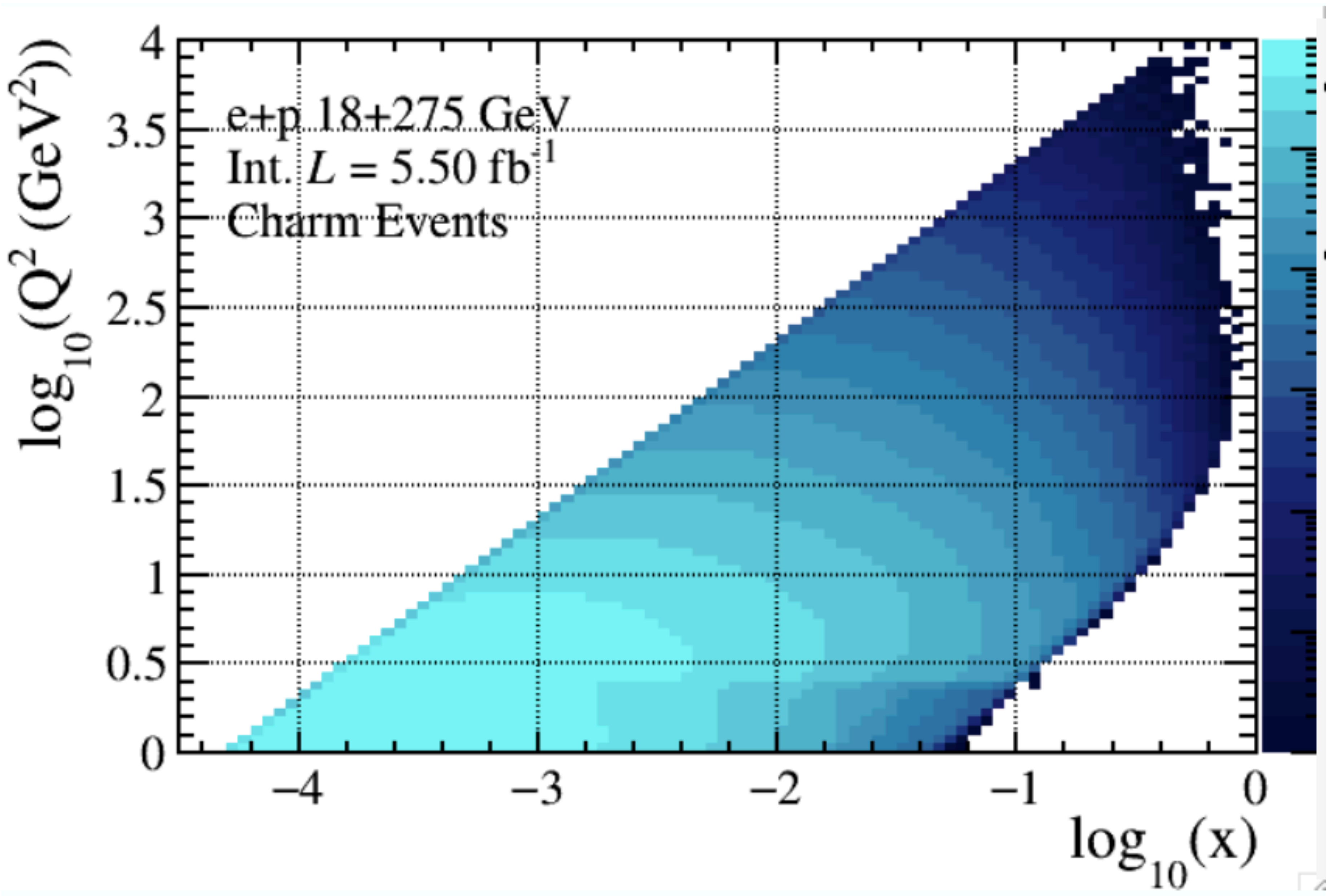
UPC at the LHC
→ very low x reach

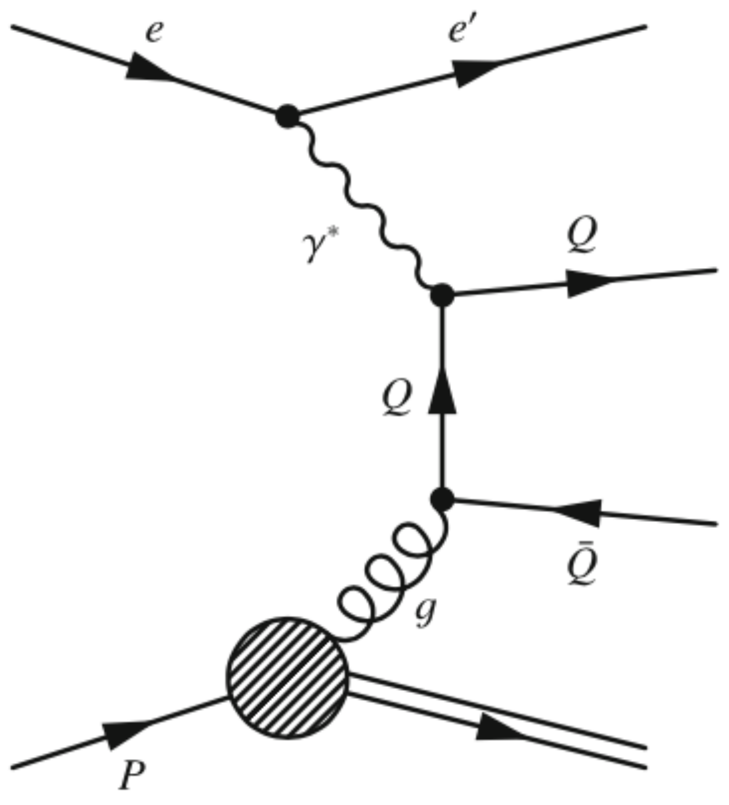


EIC → control on the photon virtuality (Q^2) and the scale of the interaction

Heavy-flavor and jets at the Electron-Ion Collider

B.S. Page et al. Phys. Rev. D 101, 072003
H. T. Li and I. Vitev, Phys. Rev. Lett. 126, 252001
EIC , BNL-98815-2012, arXiv:1212.1701





Inclusive heavy-flavor measurements in ep/eA collisions (J/ψ, open charm, and beauty jets)

→ gluon (n)PDFs down to moderate/low x_{BJ}

→ **evolution equations beyond DGLAP?**

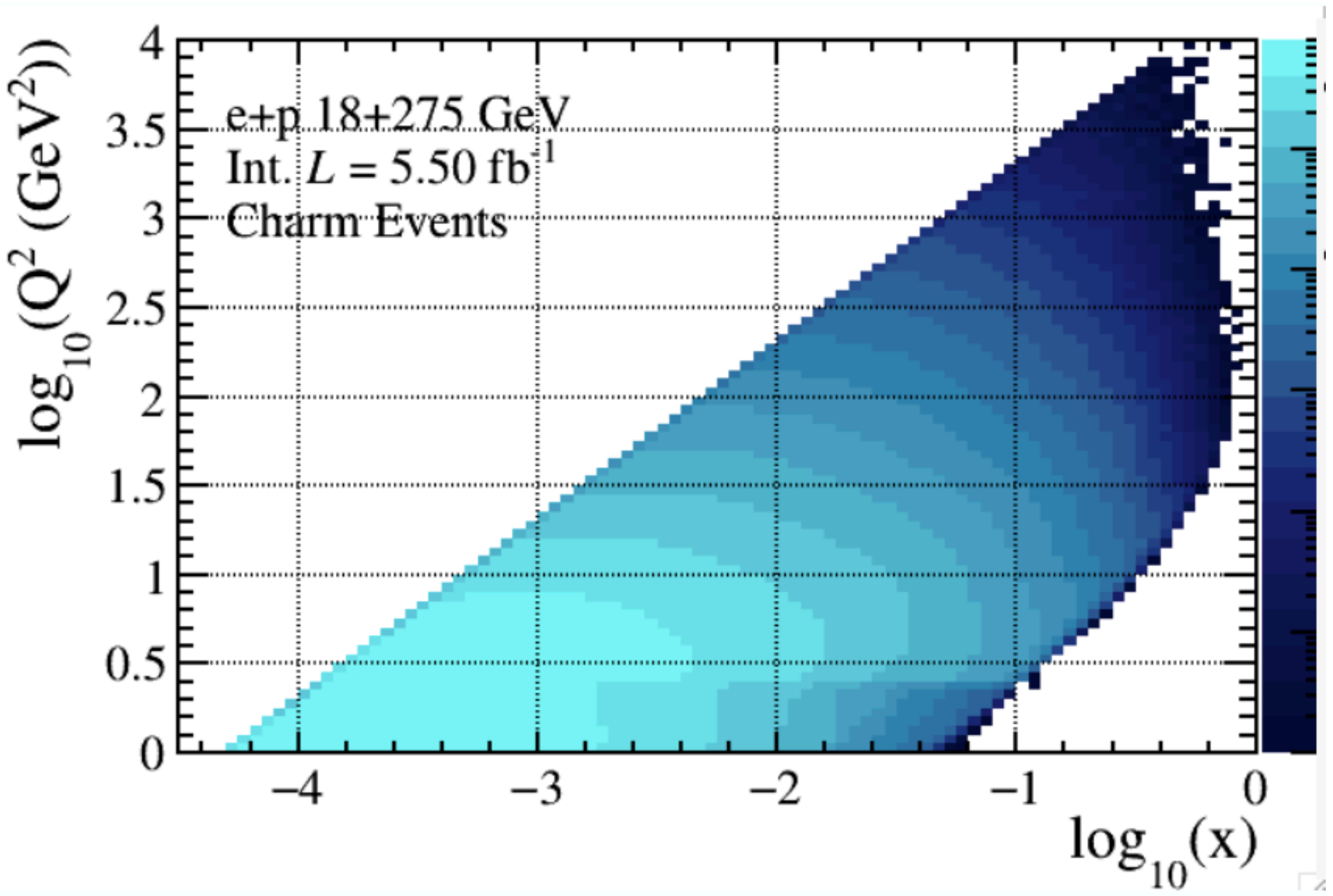
$D\bar{D}$ correlations:

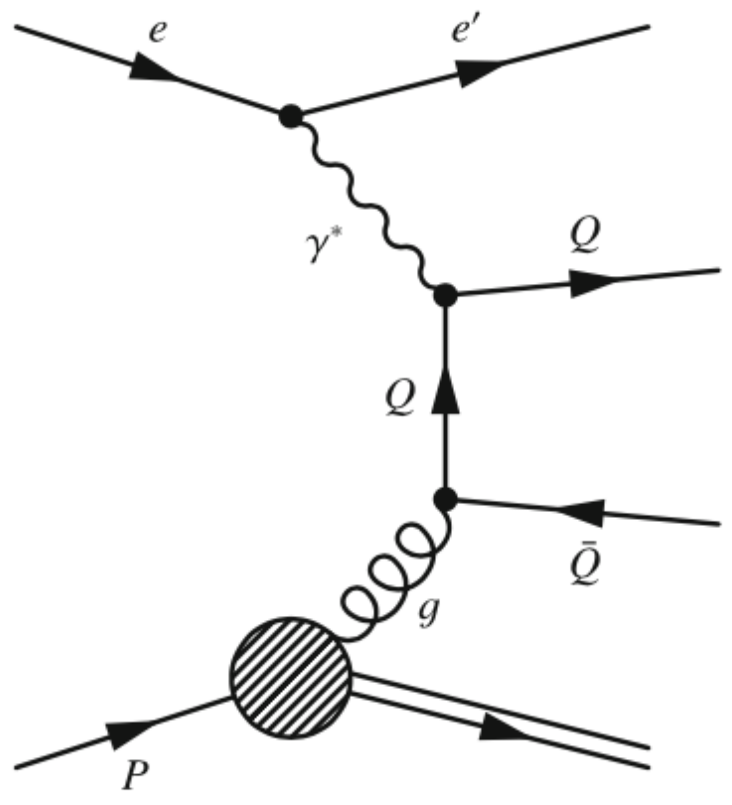
→ access to gluon TMDs

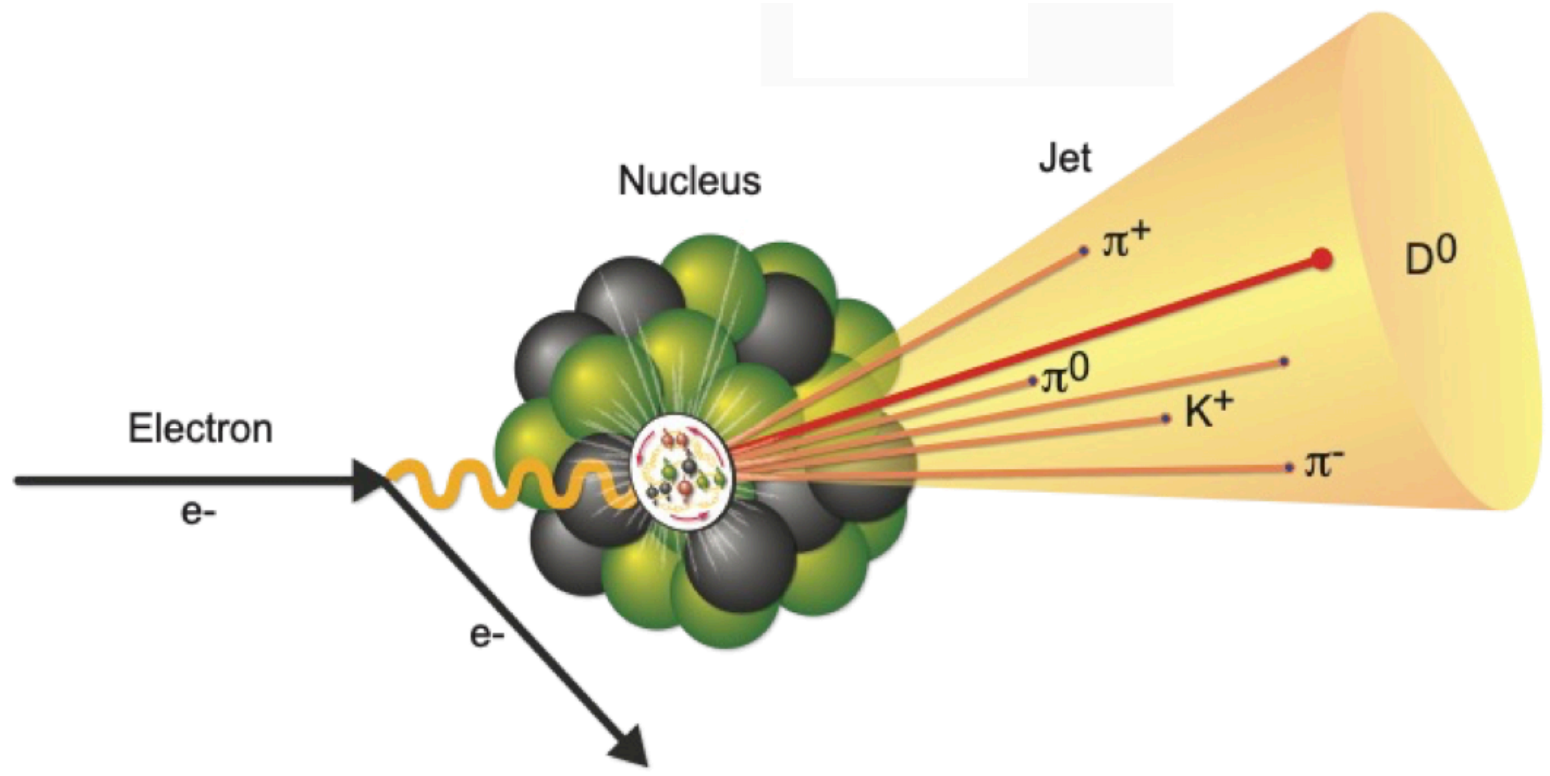
→ **nuclear structure beyond the collinear limit**

Heavy-flavor and jets at the Electron-Ion Collider

B.S. Page et al. Phys. Rev. D 101, 072003
H. T. Li and I. Vitev, Phys. Rev. Lett. 126, 252001
EIC , BNL-98815-2012, arXiv:1212.1701







Inclusive heavy-flavor measurements in ep/eA collisions (J/ψ, open charm and beauty, jets)

→ gluon (n)PDFs down to moderate/low x_{BJ}

→ evolution equations beyond DGLAP?

$D\bar{D}$ correlations:

→ access to gluon TMDs

→ nuclear structure beyond the collinear limit

Heavy-quark jet production and substructure in ep/eA:

→ parton-propagation inside the "cold" nuclear matter

→ parton-shower evolution in a vacuum-like environment

Heavy-flavor hadrochemistry and collectivity:

→ hadronization modification in cold-nuclear matter

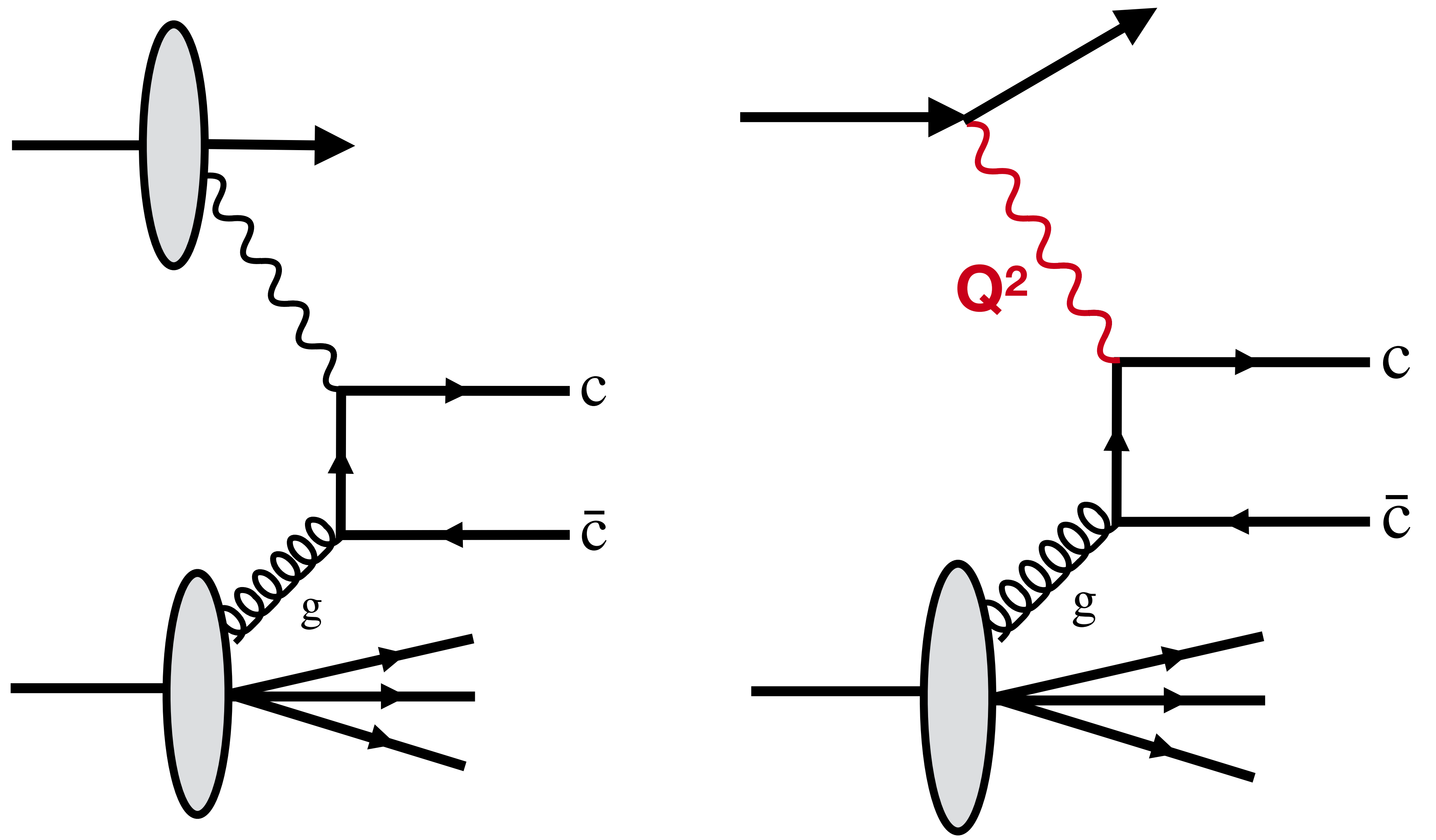
→ what is the time scale of hadronization?

HL-LHC and EIC for a multi-scale exploration of nuclear matter

CMS has a solid program for exploit pPb and PbPb to study nuclear matter down to low x in protons and nuclei with Run 3 data and with future heavy-ion runs at the HL-LHC.

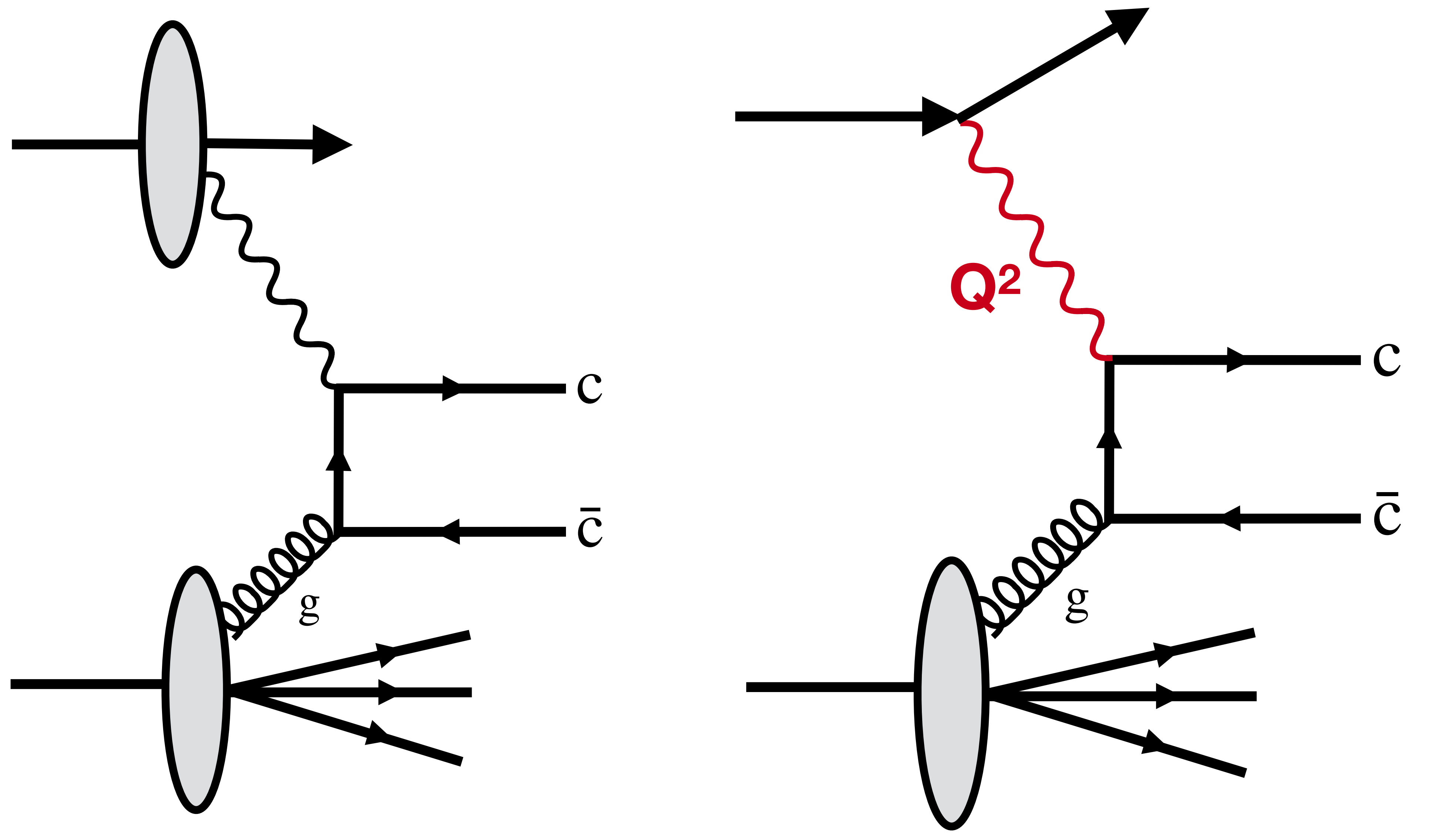
LHC + RHIC + EIC → comprehensive understanding of QCD phenomena

- complementary kinematic regions (x,Q^2)
- different experimental/theoretical advantages



HL-LHC and EIC for a multi-scale exploration of nuclear matter

CMS has a strong program to exploit pPb and PbPb to study nuclear matter down to low x in protons and nucleus with Run 3 data and with future heavy-ion runs at the HL-LHC



LHC + RHIC + EIC → comprehensive understanding of QCD phenomena
- complementary kinematic regions (x, Q^2)
- different experimental/theoretical advantages

With the LHC heavy-ion programs, and in particular with UPC collisions:
- building and supporting the development of the experimental and theoretical tools for EIC
- **we need theory support to develop this program and to solve some of the existing theoretical questions/limitations**

2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038

CMS at the LHC

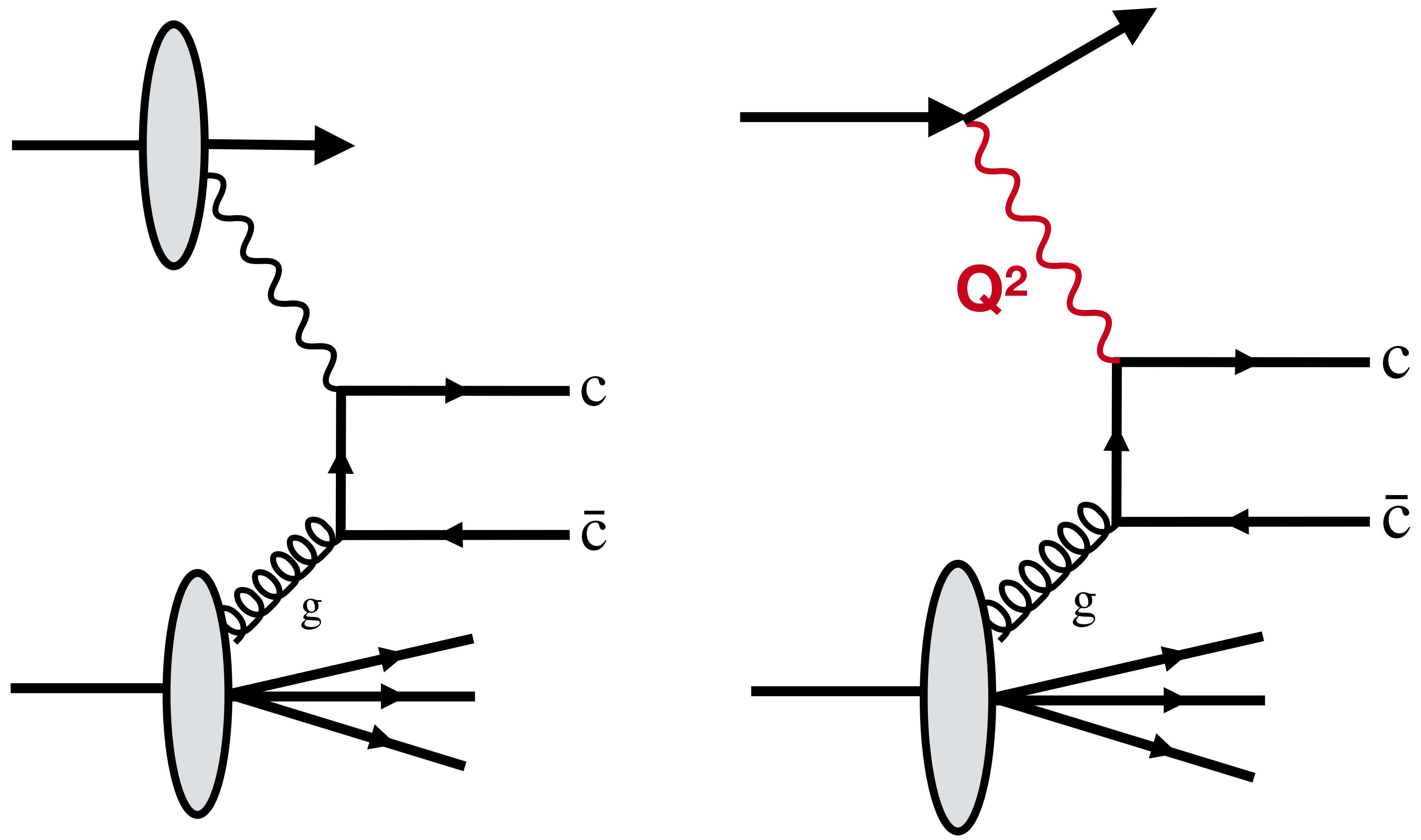
Upgraded CMS at the LHC ($|\eta|$ up to 4 + PID with MTD)

Run 5 and 6 at the LHC

EIC physics data-taking

HL-LHC and EIC for a multi-scale exploration of nuclear matter

CMS has a strong program to exploit pPb and PbPb to study nuclear matter down to low x in protons and nucleus with Run 3 data and with future heavy-ion runs at the HL-LHC



LHC + RHIC + EIC → comprehensive understanding of QCD phenomena
- complementary kinematic regions (x,Q^2)
- different experimental/theoretical advantages

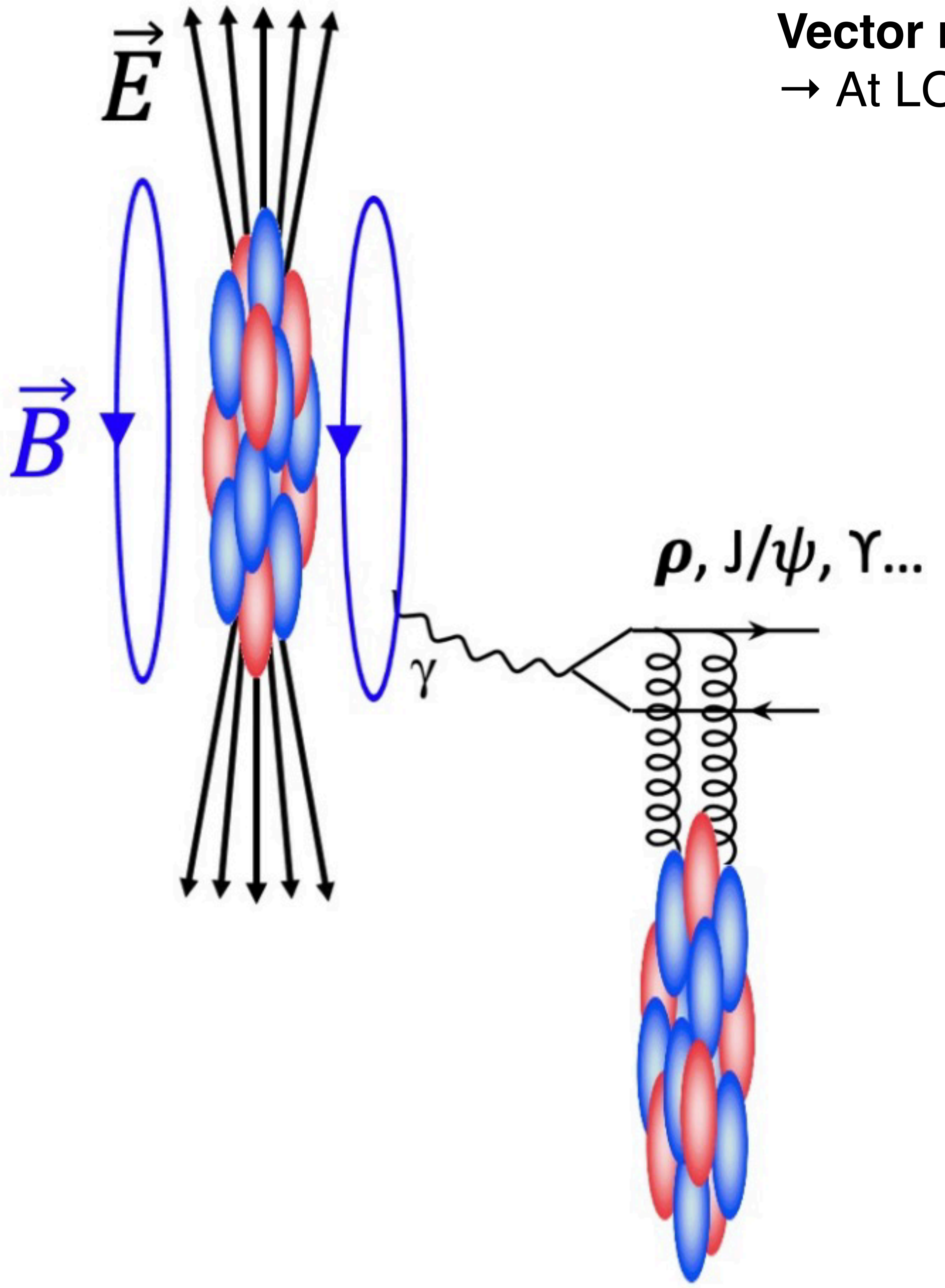
With the LHC heavy-ion programs, and in particular with UPC collisions:
- building and supporting the development of the experimental and theoretical tools for EIC
- **we need theory support to develop this program and to solve some of the existing theoretical questions/limitations**

Thank you for your attention!

BACKUP

BACKUP: J/ψ

Vector-meson photoproduction in UPC



Vector mesons (VM) probe gluonic structure of nucleus and nucleon.
→ At LO in pQCD, cross section ~ photon flux ⊗ [xG(x)]2

Coherent production ($\langle p_T \rangle \sim 50$ MeV)
- Photon fluctuated dipole couples coherently to entire nucleus
- Target nucleus remains intact
- VM $\langle p_T \rangle \sim 50$ MeV
- Probing the averaged gluon density

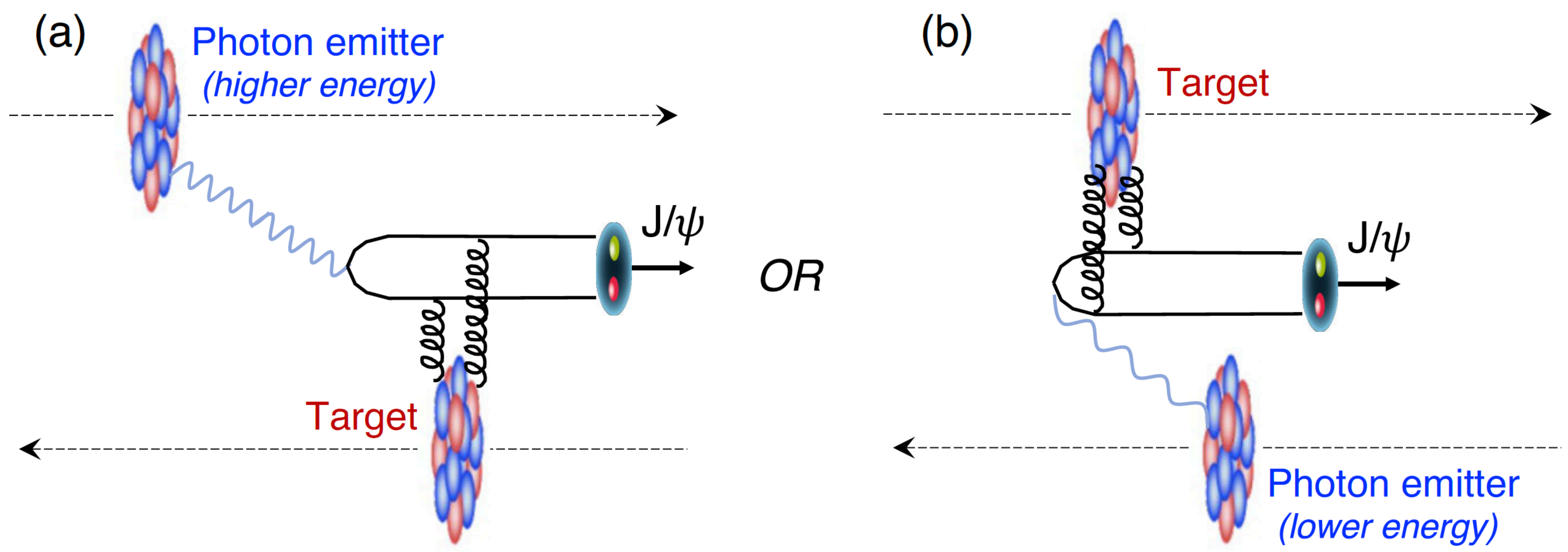
Incoherent production VM ($\langle p_T \rangle \sim 500$ MeV)
- Photon fluctuated dipole couples to individual nucleons
- Target nucleus usually breaks
- Probing the local gluon density fluctuation

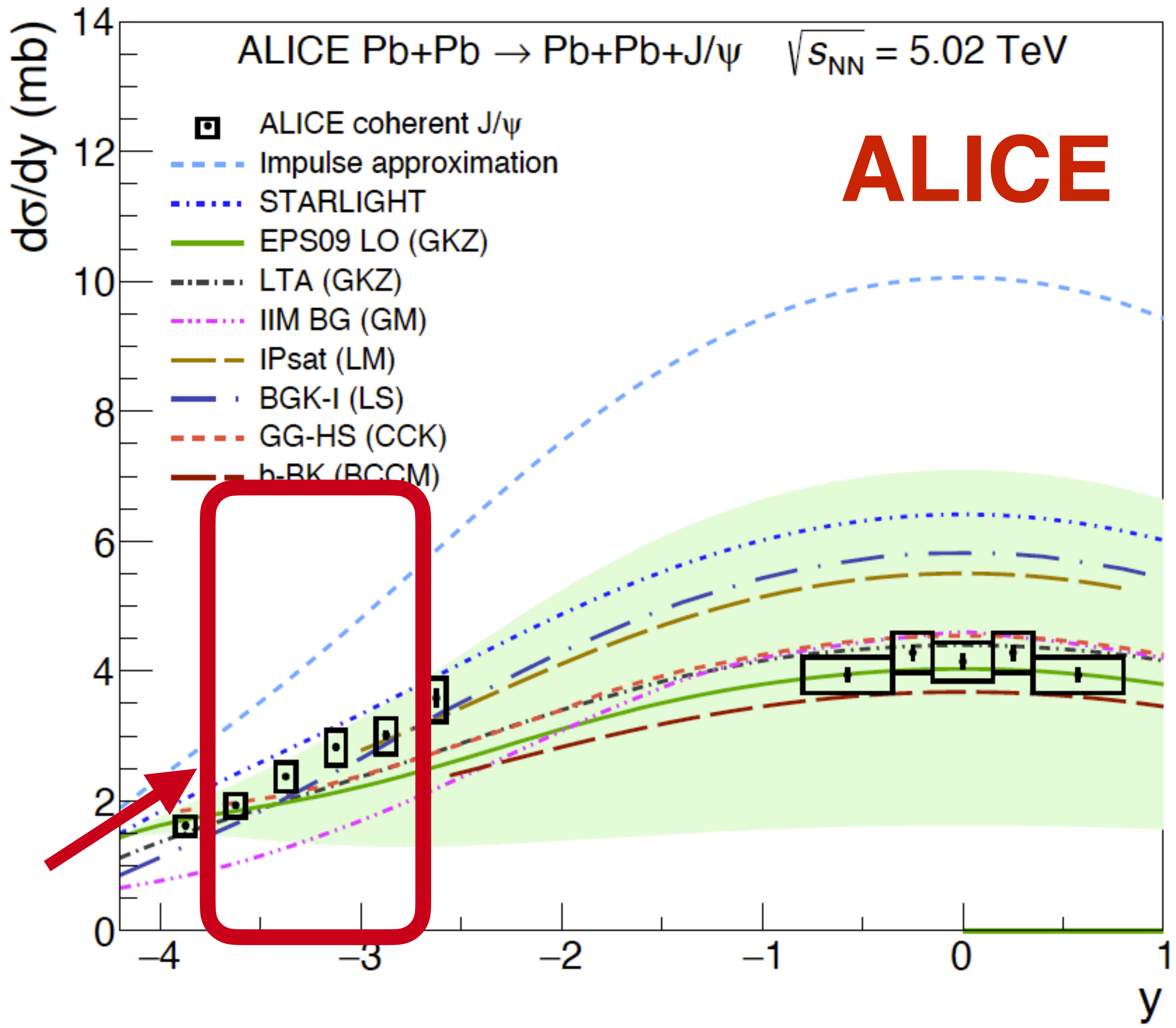
*Sketches from **Zaochen Ye's** talk at GHP2023*

Coherent J/ψ photoproduction in UPC PbPb collisions

$Q^2 \sim M^2_{cc}$ GeV, x_A ~shadowing
(gluon PDFs)^2
- 4.0< y*< -2.5 (forward)

→ access to gluon PDF in **absence of hadronic interactions**





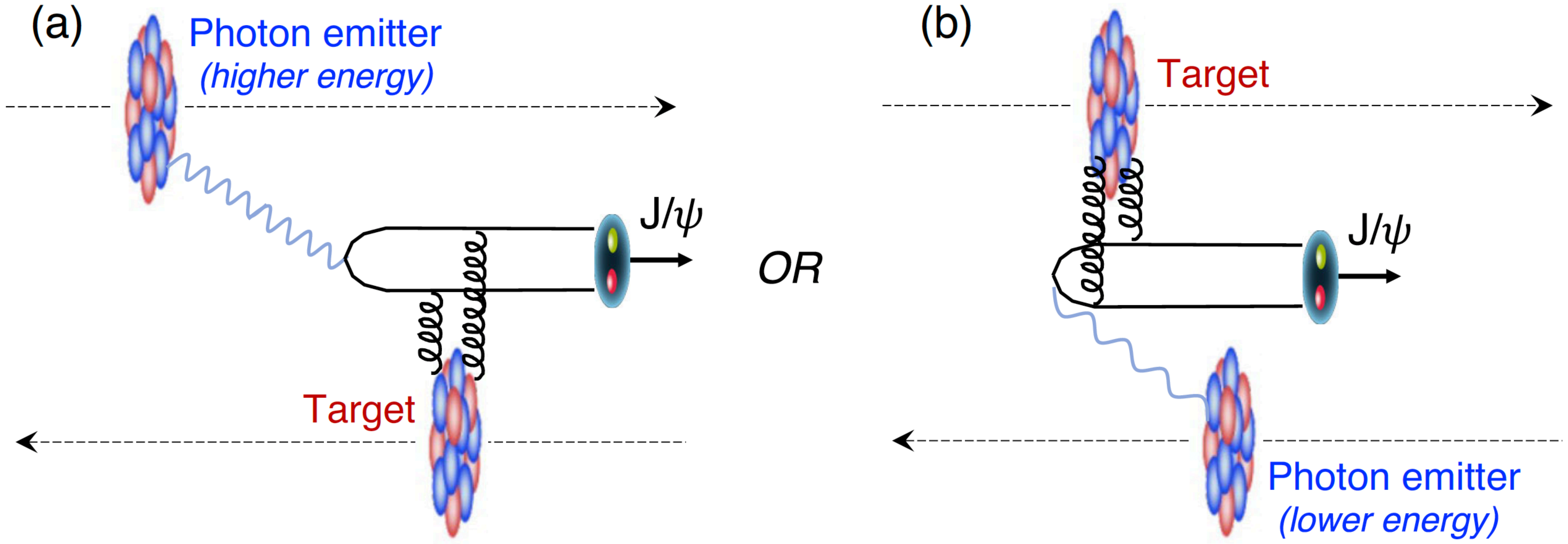
At fixed y, contributions from different x regions (higher and lower)

Two-way ambiguity can limit the constraining power due to large uncertainty on the determination of x!

- The initial direction of the photon is not fully defined

Solving the photon ambiguity with neutron information from ZDC

V. Guzey, M. Strikman, M. Zhalov, EPJC (2014) 72 2942

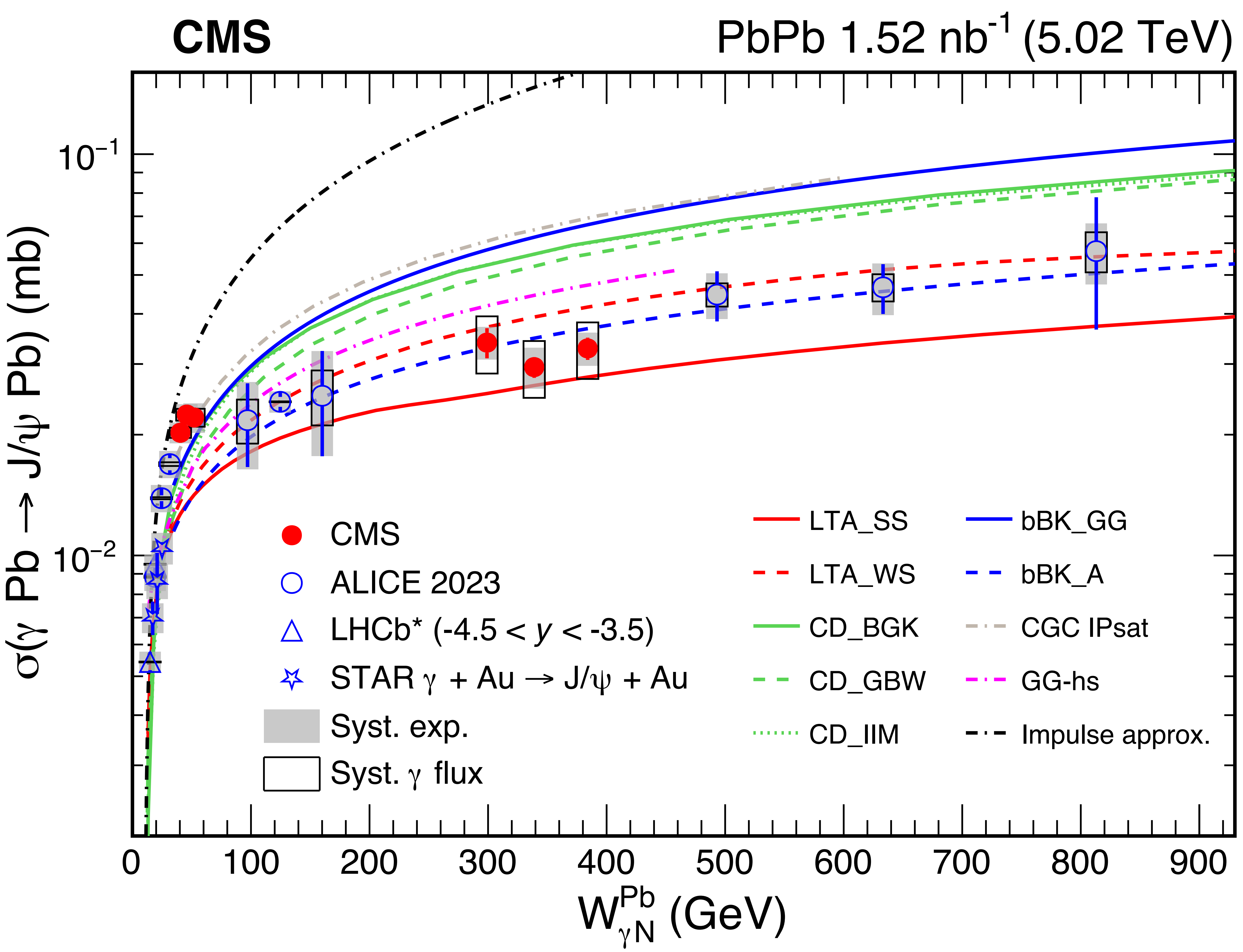


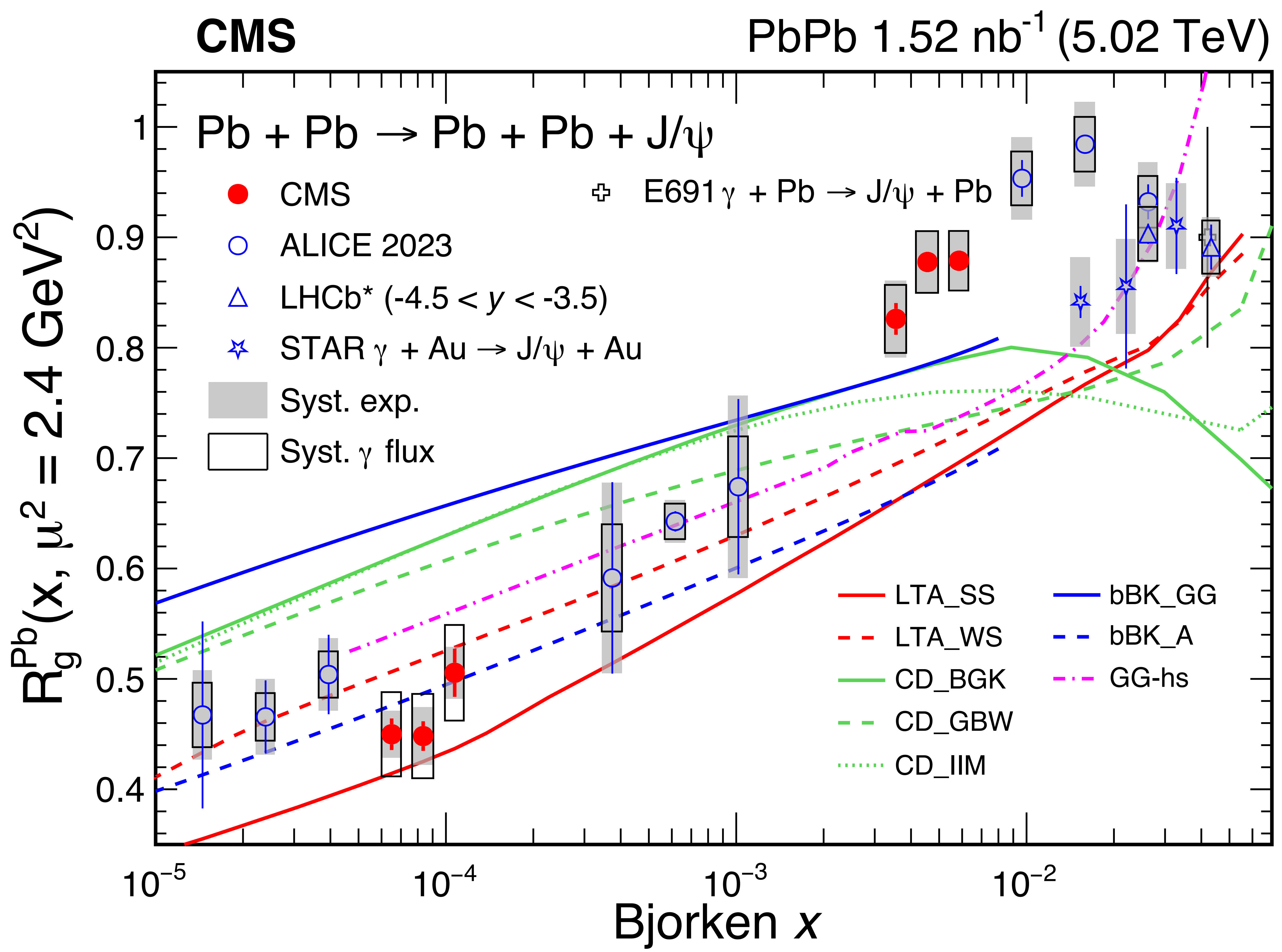
$$\frac{d\sigma^{in\,jn}_{J/\psi}(y)}{dy} = n^{in\,jn}_{\gamma A}(\omega_1)\,\sigma_{J/\psi}(\omega_1) + n^{in\,jn}_{\gamma A}(\omega_2)\,\sigma_{J/\psi}(\omega_2)$$

- *i*n *j*n = (0n0n, 0nXn, XnXn)
- $\omega_{1,2} = \omega_{1,2}(y)$ are the two possible photon energies
- $n_{\gamma A}(\omega)$ is the photon flux (from theory)
- $\sigma_{J/\psi}(\omega)$ is the coherent photoproduction cross section for a single γA interaction, averaged over a range of y

Coherent J/ψ in PbPb UPCs: CMS vs ALICE

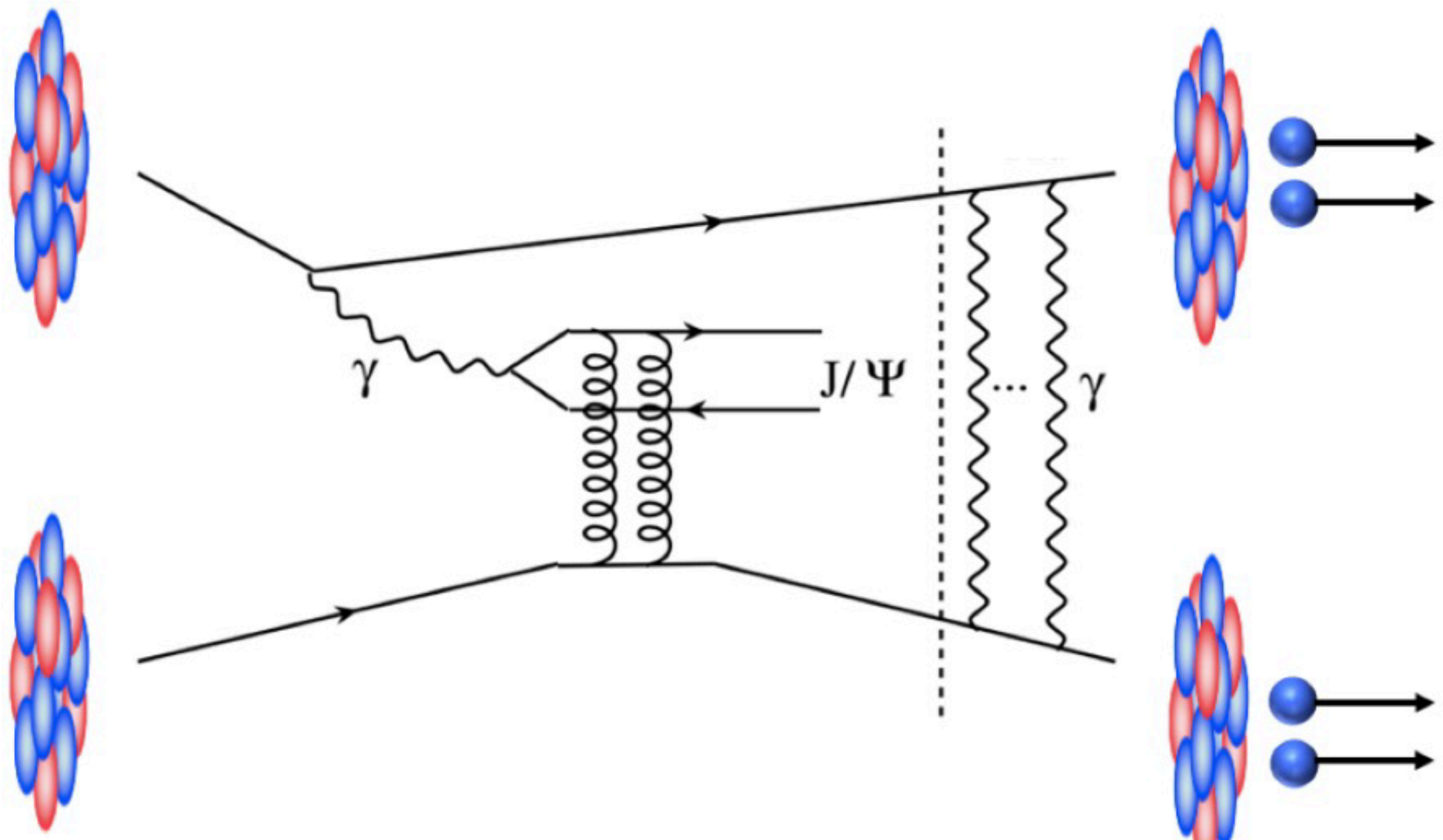
ALICE, JHEP 10 (2023) 119
CMS, Phys. Rev. Lett. 131 (2023) 262301



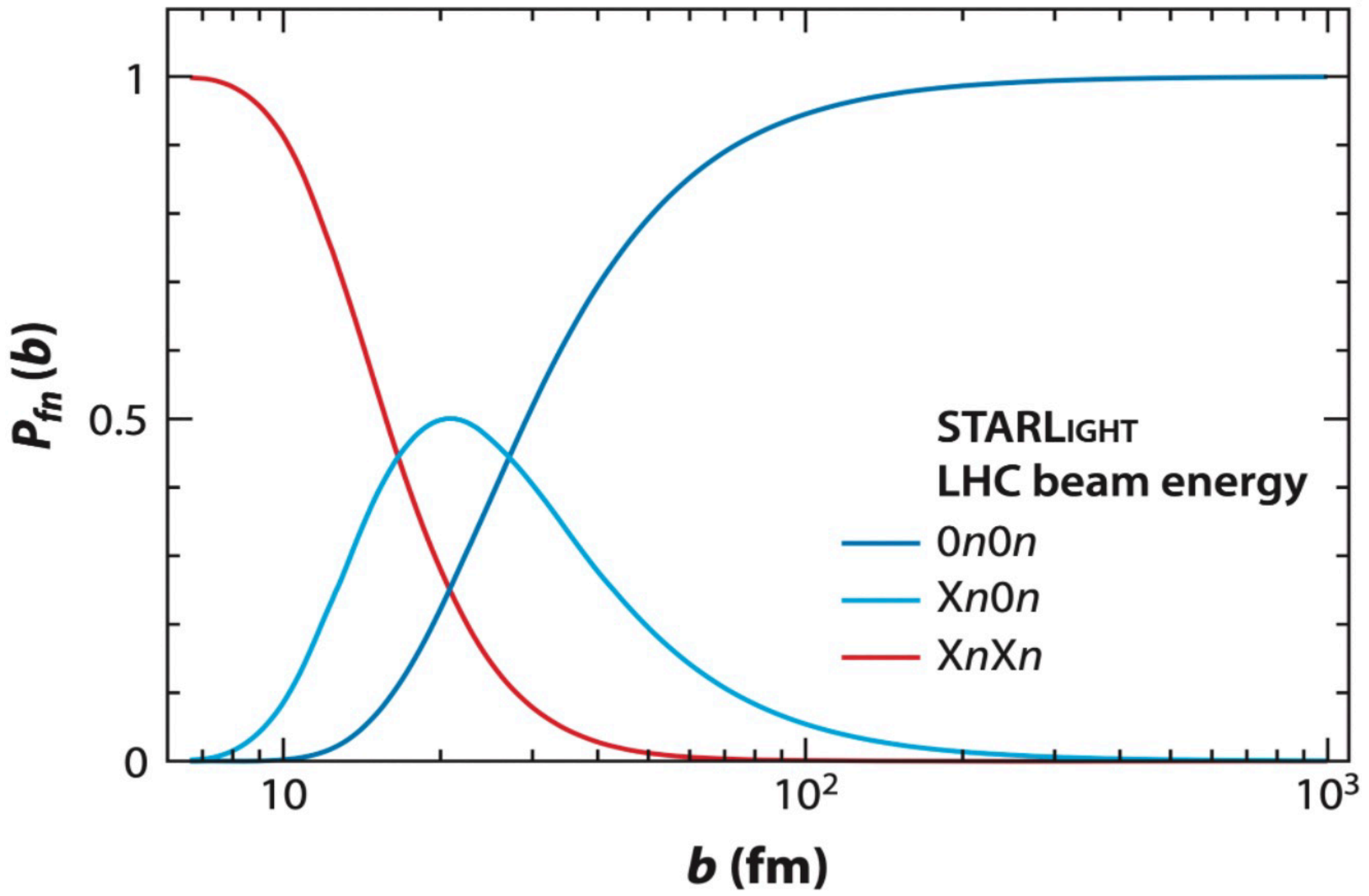


Solving the photon ambiguity with neutron information from ZDC

Method in a nutshell (V. Guzey, M. Strikman, M. Zhalov, EPJC (2014) 72 2942)
- Rate of high energy photon flux is larger at smaller impact parameter
- impact parameter of the collision can be estimated by considering the magnitude of EM dissociation



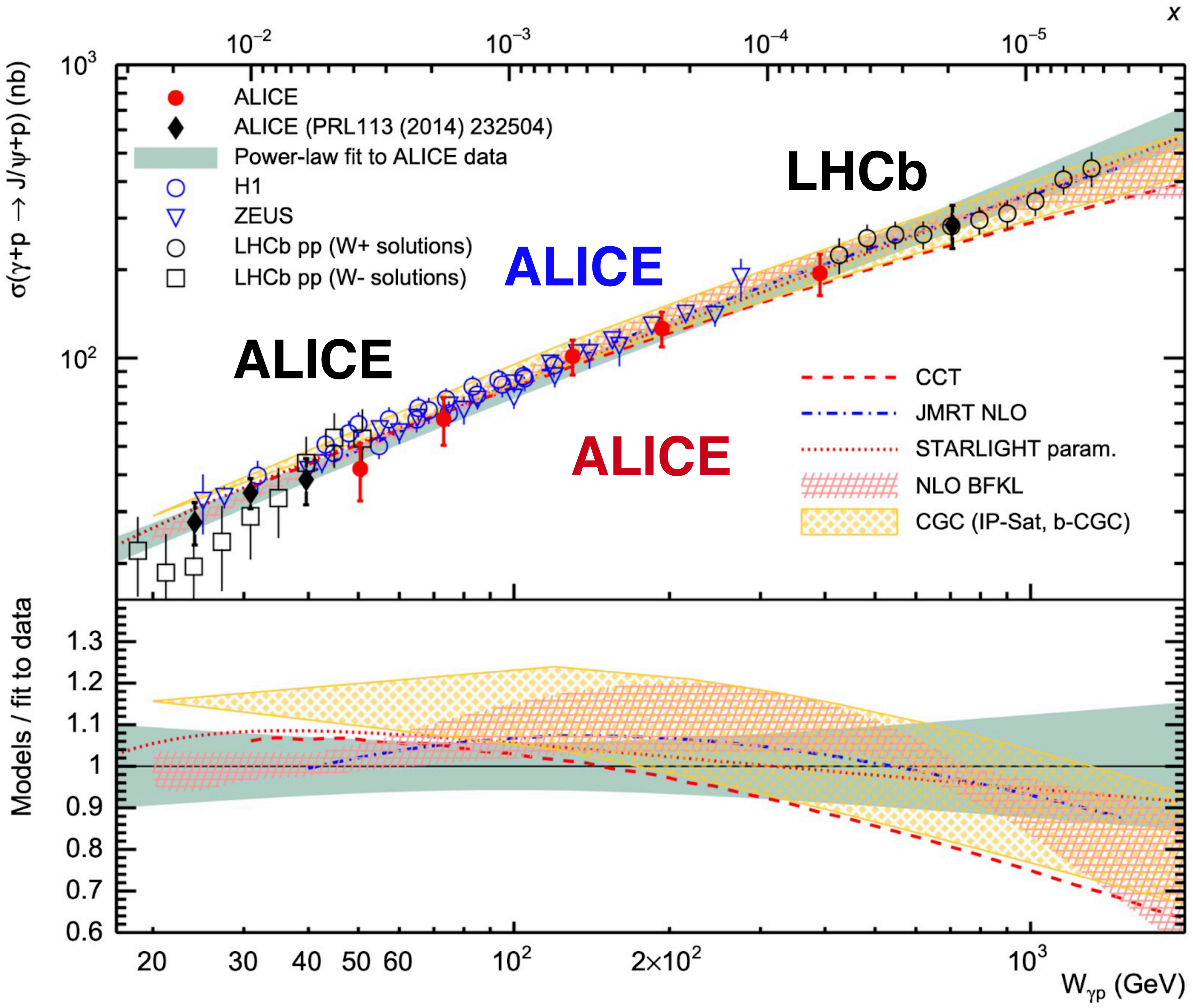
EM dissociation (EMD) leads to neutron emission with additional photon exchange
- Independent of interested physics process
- Large cross section ~200 b (single EMD)



Probability of EMD is strongly correlated with the impact parameter of the collision **b**

Exclusive and inclusive quarkonium photoproduction

γ+p→J/ψ p collisions:



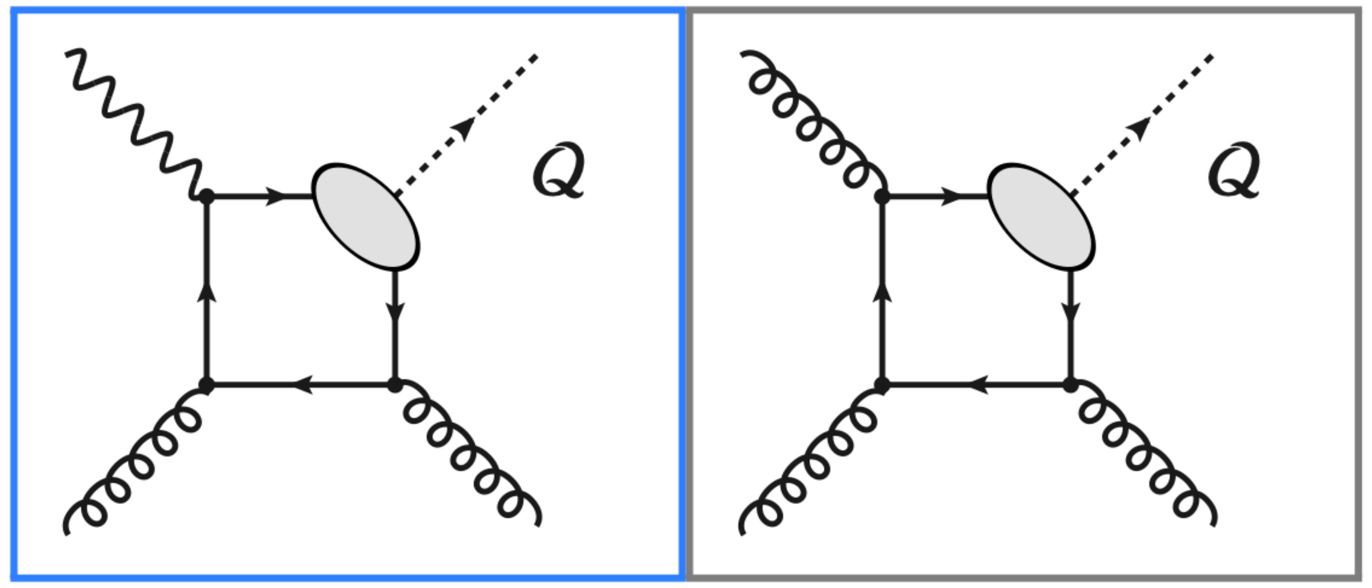
$$W_{\gamma p} = 2\sqrt{\omega \cdot E_{beam}}$$

Sensitive to the proton structure at high-gluon densities

(So far, no indication of gluon saturation, even down to x~10^{-5} in a free nucleon)

From Kate Lynch's talk Jean-Philippe Lansberg (IJCLab), Charlotte Van Hulse (UAH), Ronan McNulty (UCD)

- Anticipate sizeable photoproduction yield
- Large hadronic background must be shown to be suppressed



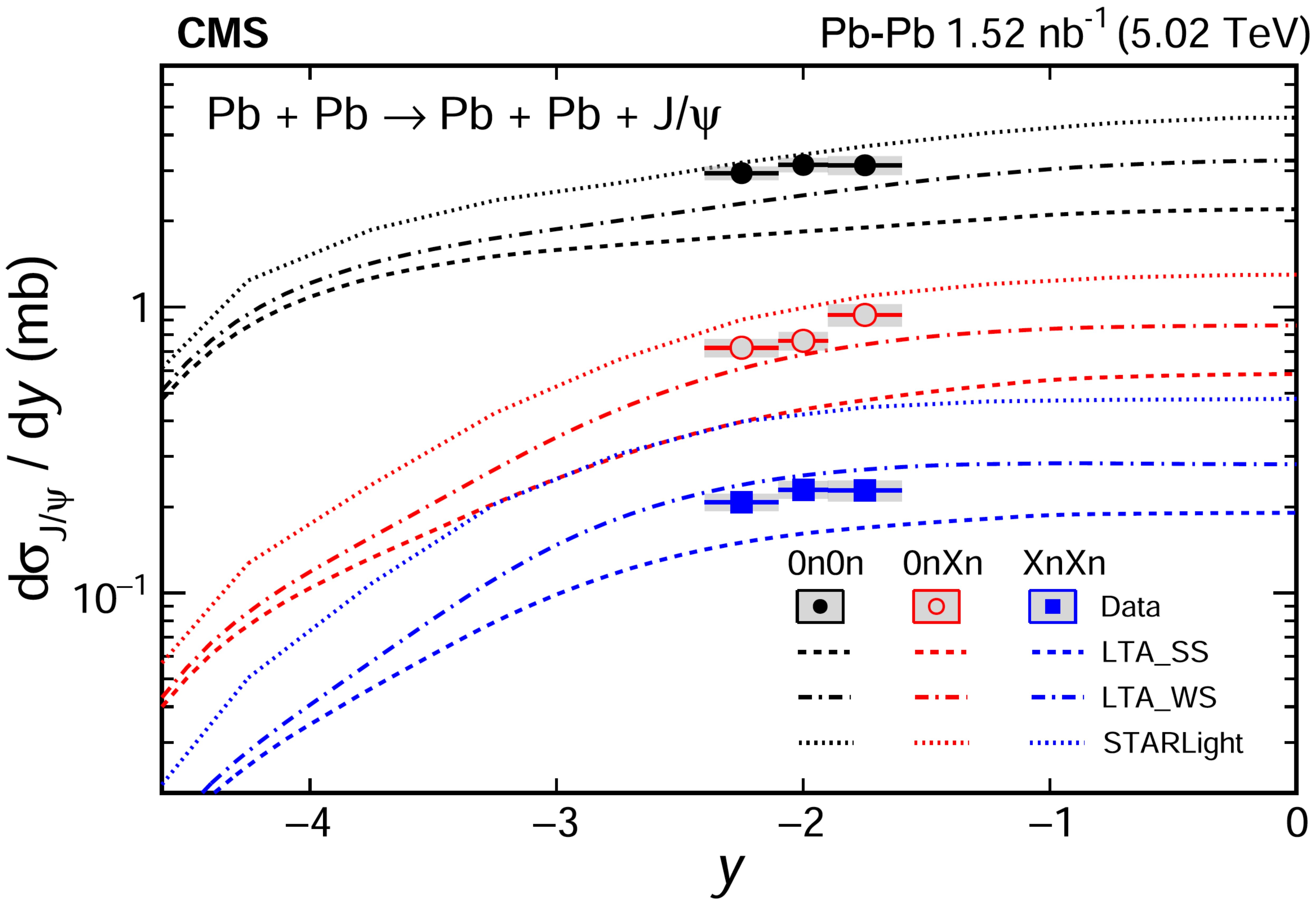
Proton-lead is the ideal collision system

- No ambiguity as to the photon emitter
- Enhanced photon flux w.r.t. *pp* $\propto Z^2$
- Less pileup than *pp*

Coherent J/ψ in PbPb UPCs with forward-neutron tag with CMS

CMS, Phys. Rev. Lett. 131 (2023) 262301

First coherent measurement in different neutron classes → ***inputs to disentangle low from high energy γN events***



$$\frac{d\sigma^{in\,jn}_{J/\psi}(y)}{dy} = n^{in\,jn}_{\gamma A}(\omega_1)\,\sigma_{J/\psi}(\omega_1) + n^{in\,jn}_{\gamma A}(\omega_2)\,\sigma_{J/\psi}(\omega_2)$$

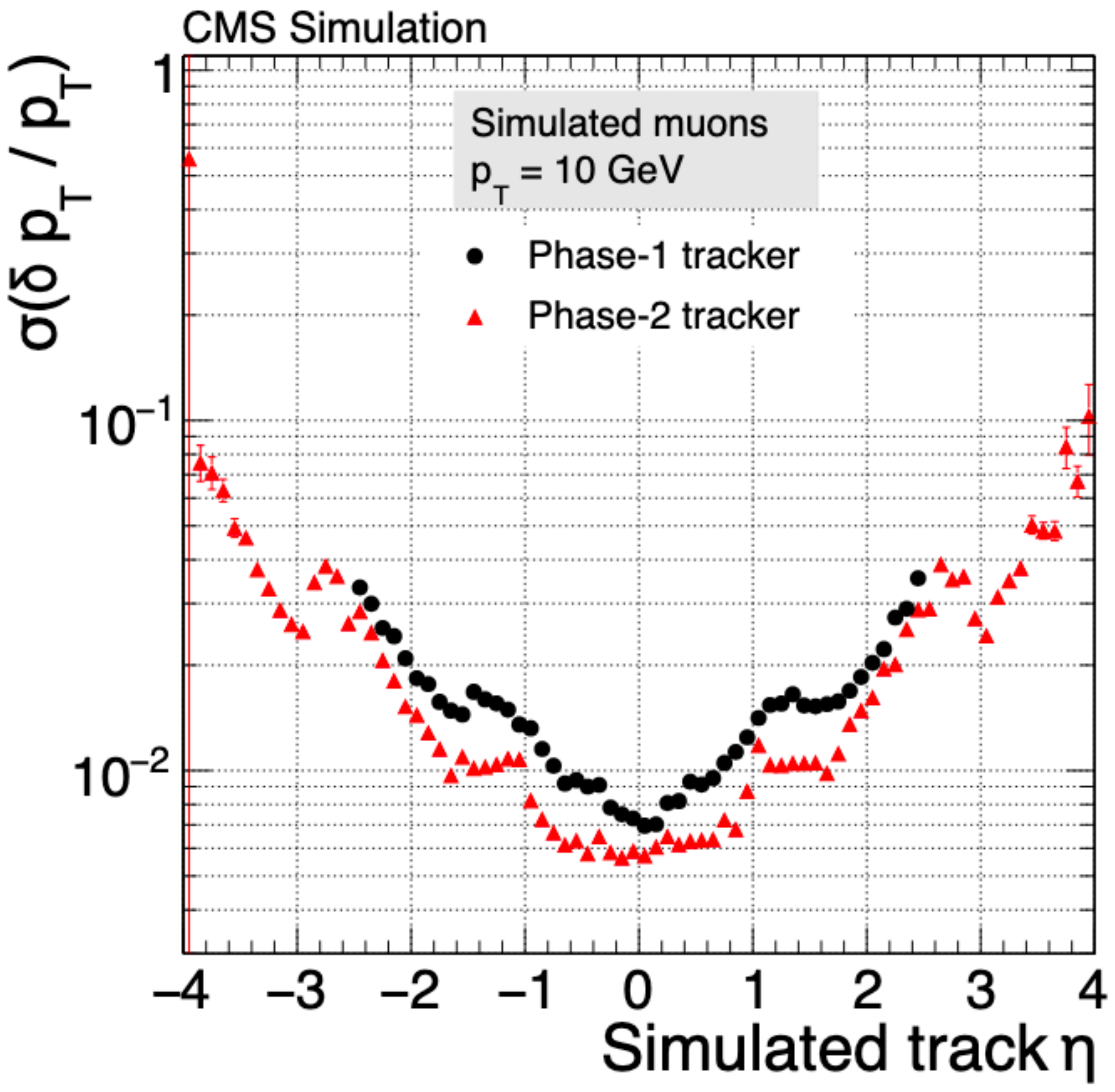
- *i*n *j*n = (0n0n, 0nXn, XnXn)
- $\omega_{1,2} = \omega_{1,2}(y)$ two possible photon energies
- $n_{\gamma A}(\omega)$ is the photon flux (from theory)
- $\sigma_{J/\psi}(\omega)$ the coherent photoproduction cross section for a single γA interaction, averaged over a range of y

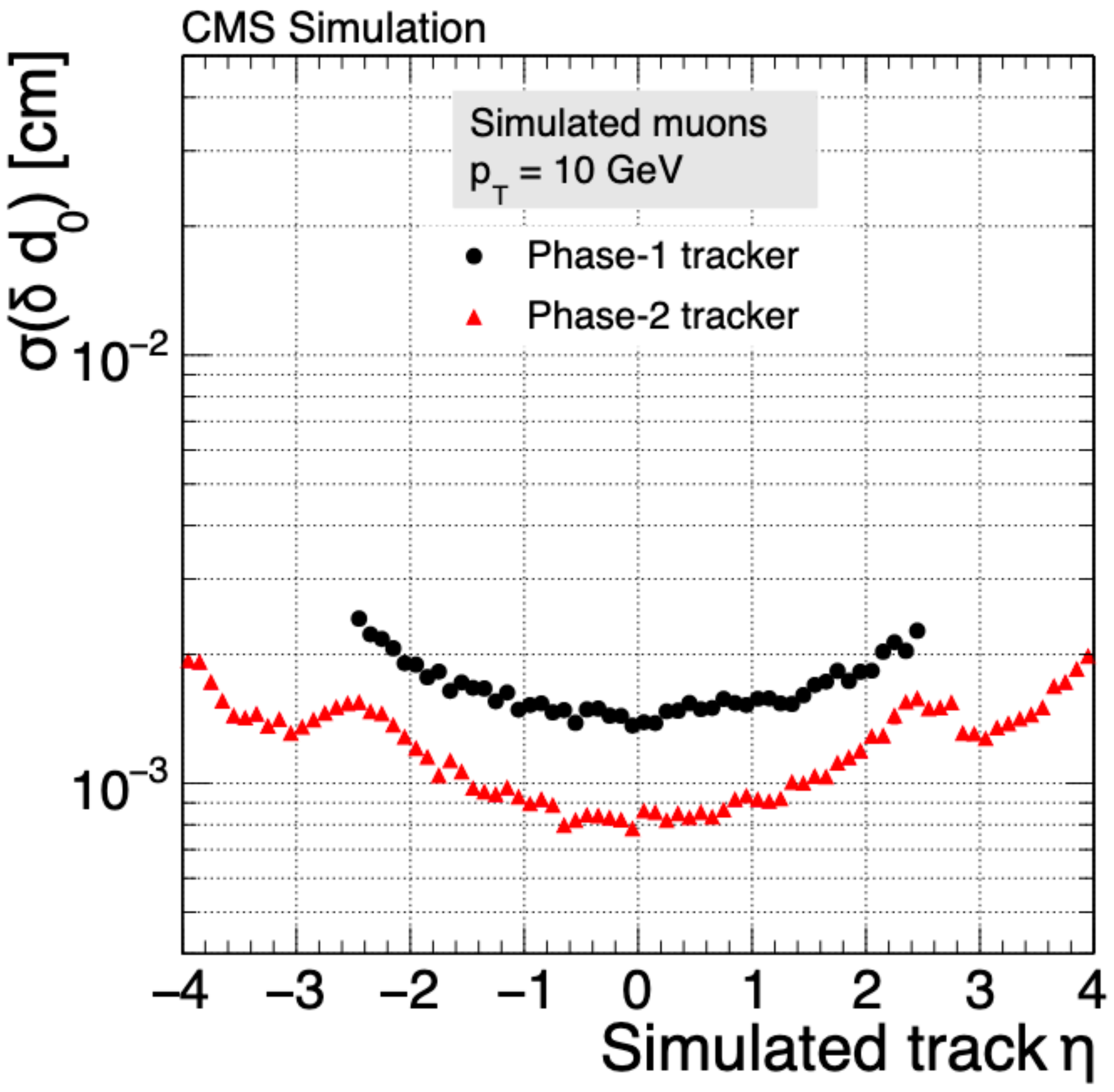
BACKUP: CMS Run4

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





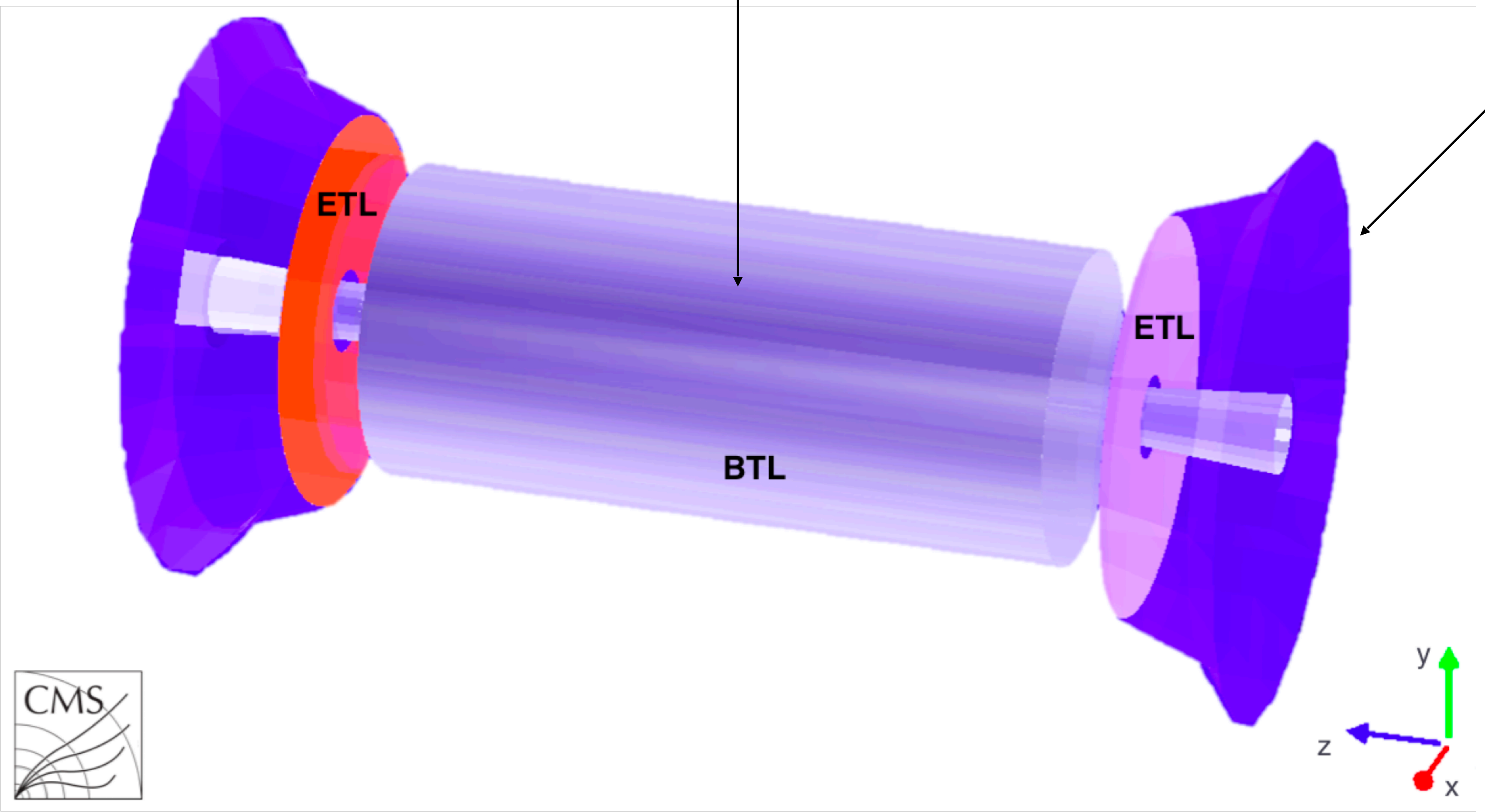
Improved p_T resolution by about 25%
- Improved mass resolution for resonances

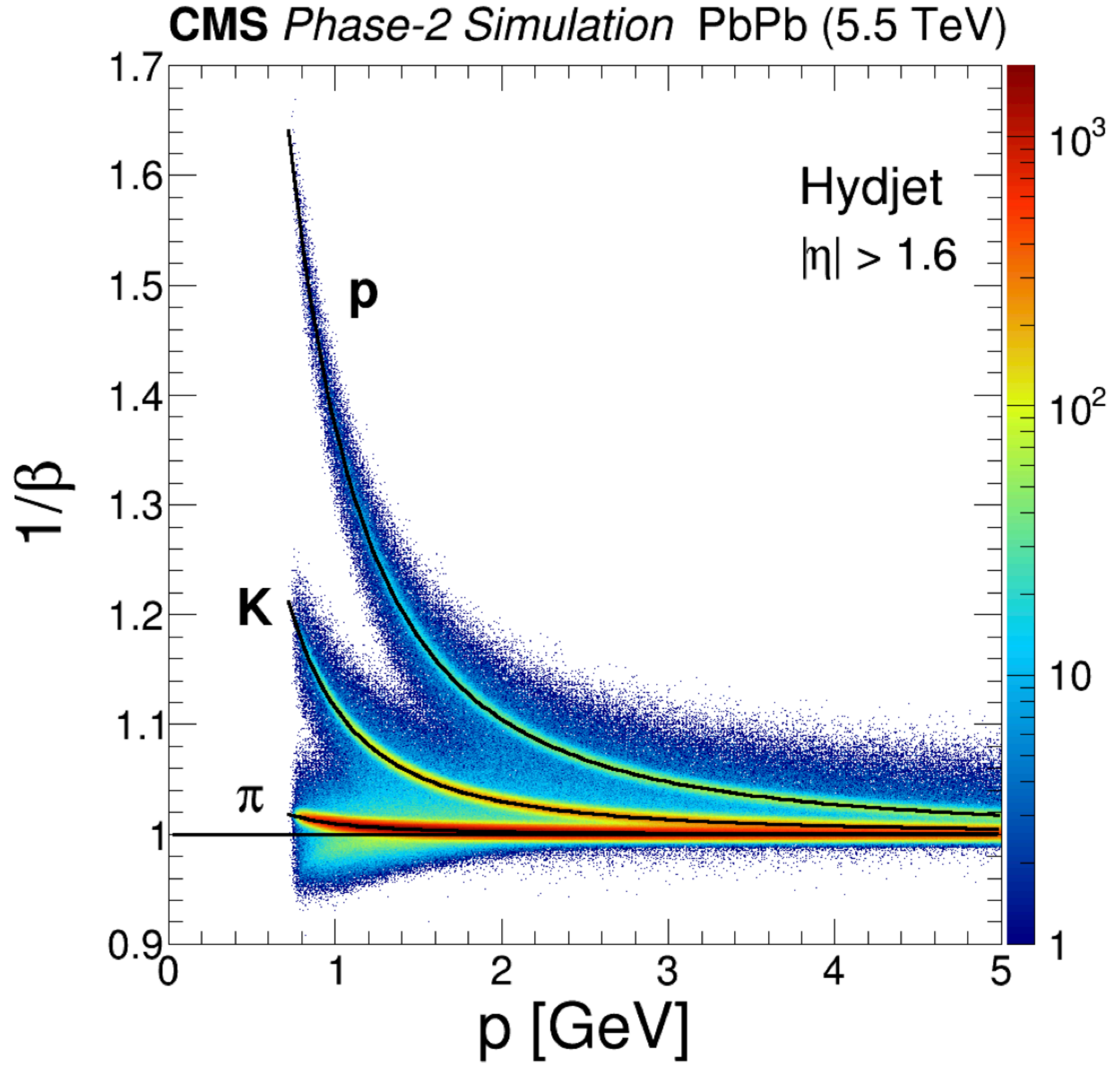
Impact parameter resolution improved by 40%
- Improved heavy flavor measurements (B/D hadrons & b/c-jet tagging)

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)

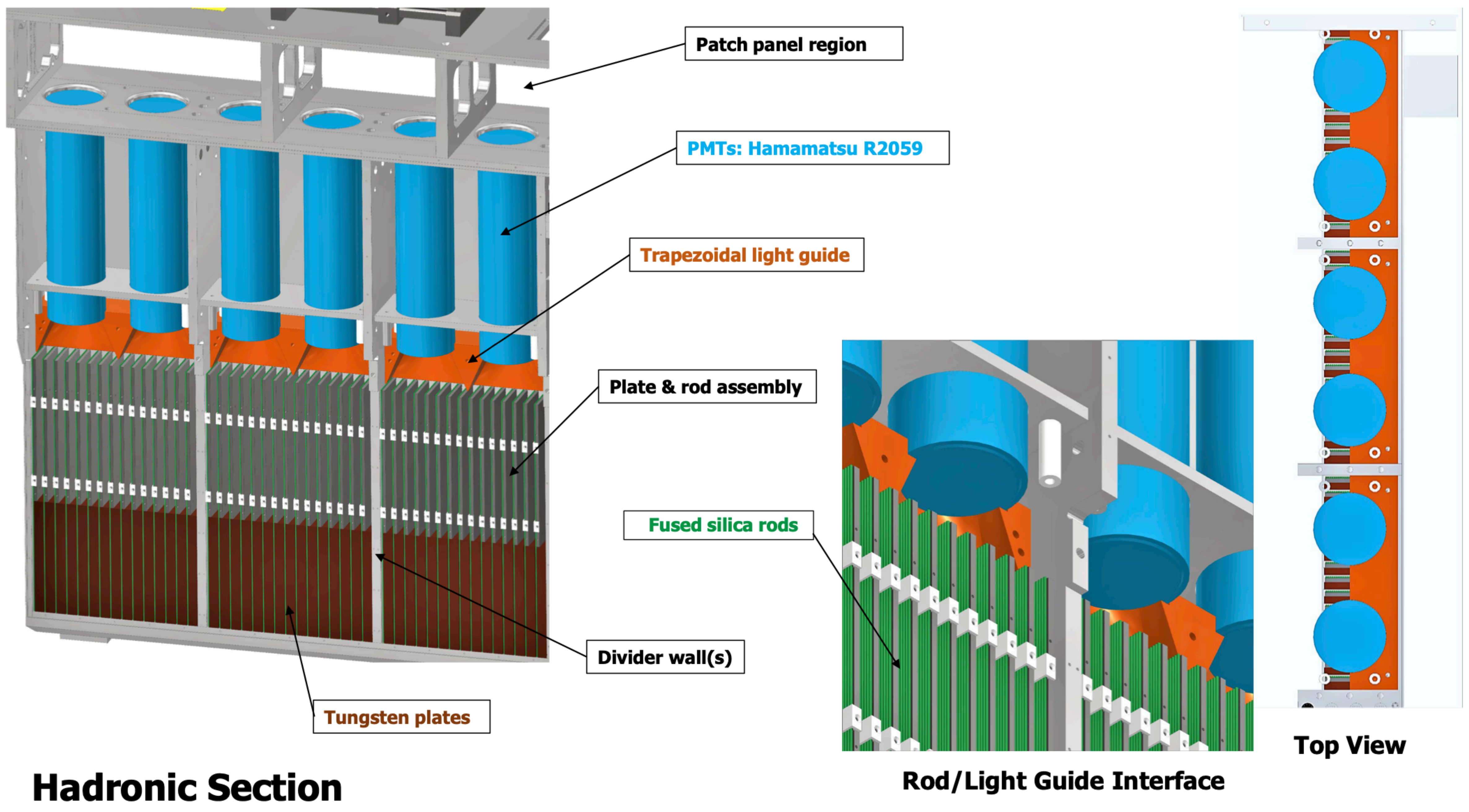




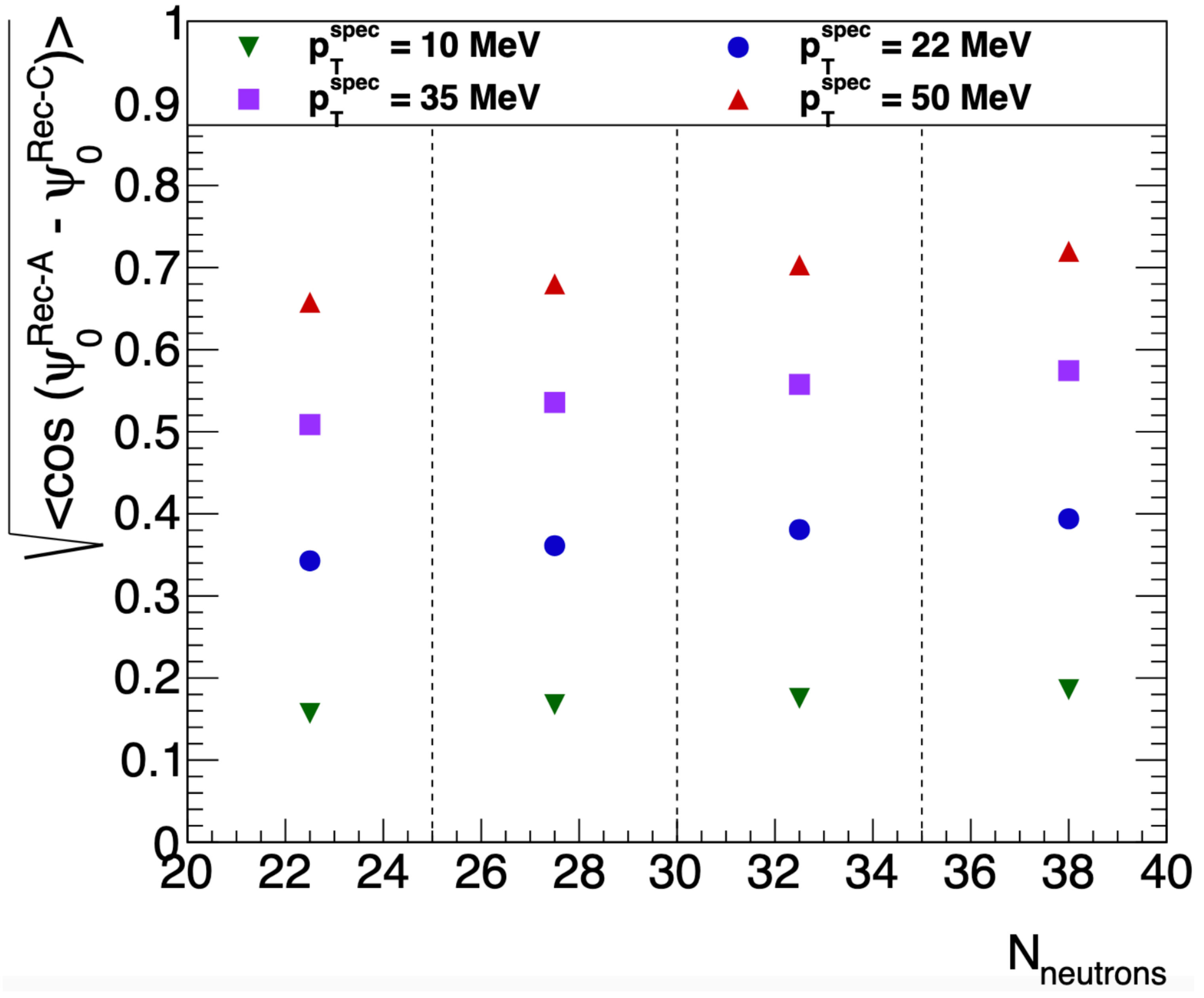
Unlock a wide set of semi-inclusive "DIS-like" measurements with identified hadrons with CMS

CERN-LHCC-2019-003

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)

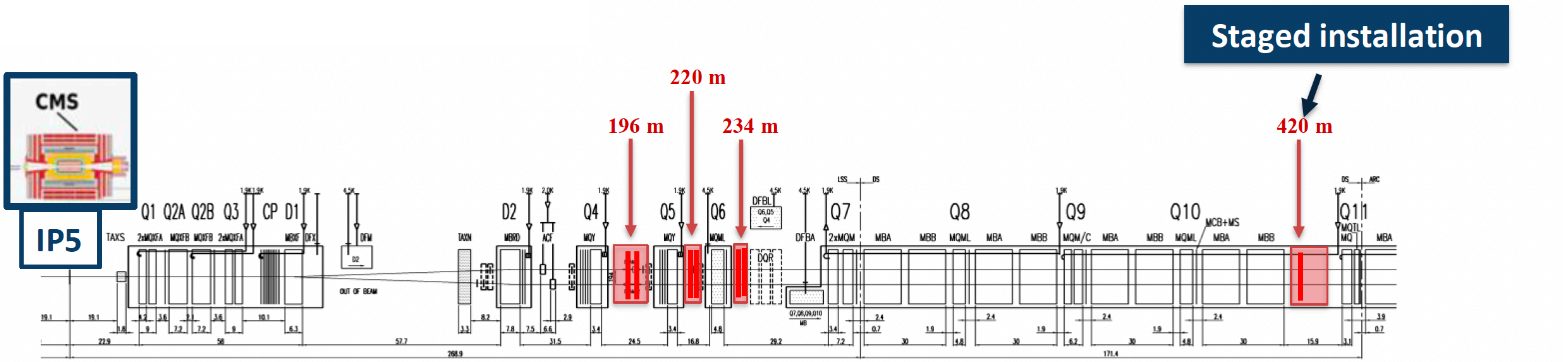


CMS-TDR-024

Upgraded Precision Proton Spectrometer (Run 4 and 5)

See Michael Pitt's talk

Basic working principle:
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 legacy PPS:

- $1.42 < \xi < 20$ % for the first 3 stations (from Run 4)
- $0.33 < \xi < 20$ % for the first 3 stations (from Run 5)

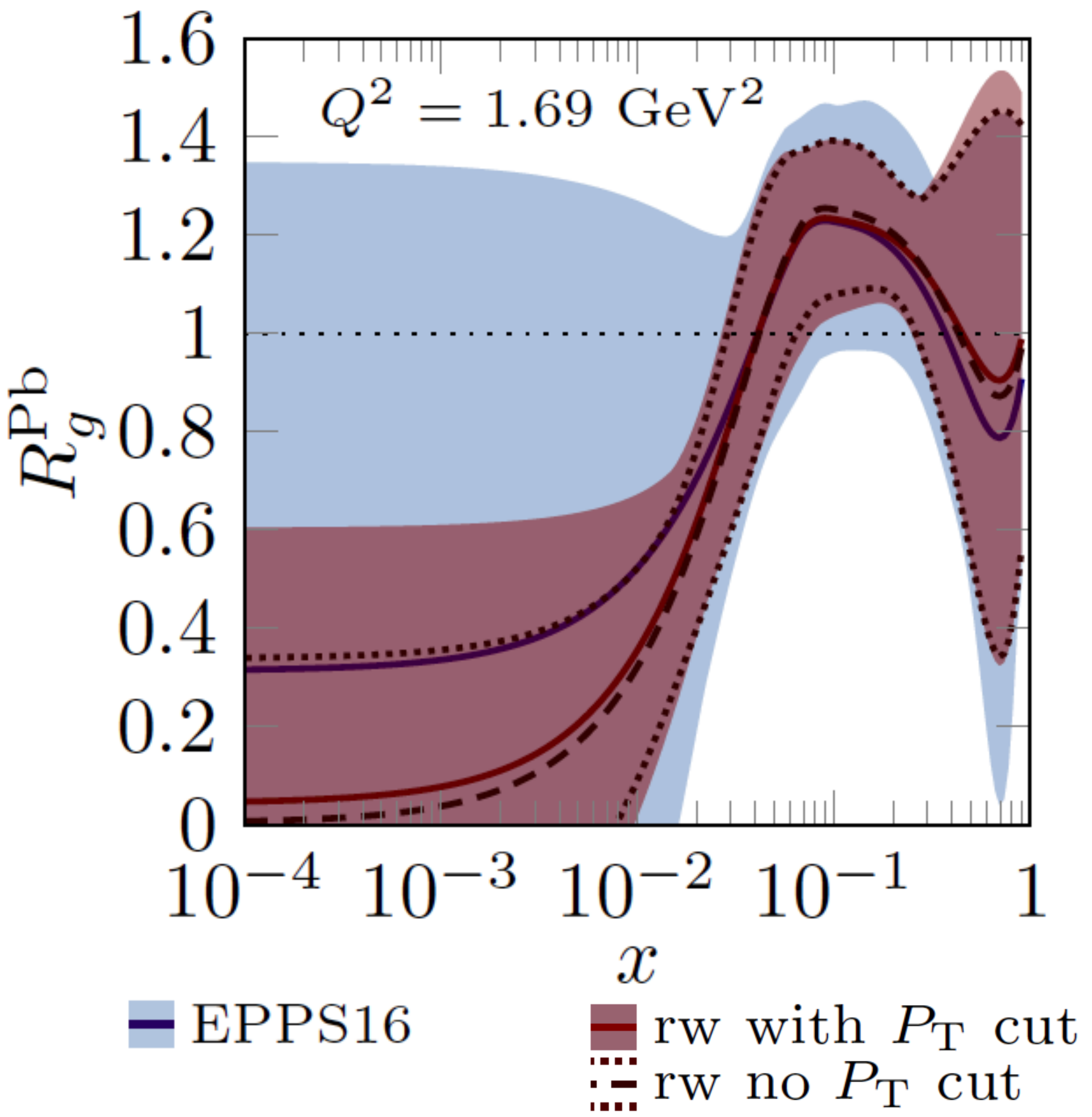
CMS NOTE -2020/008

BACKUP: CMS pPb measurements

From measurements to nPDF constraints

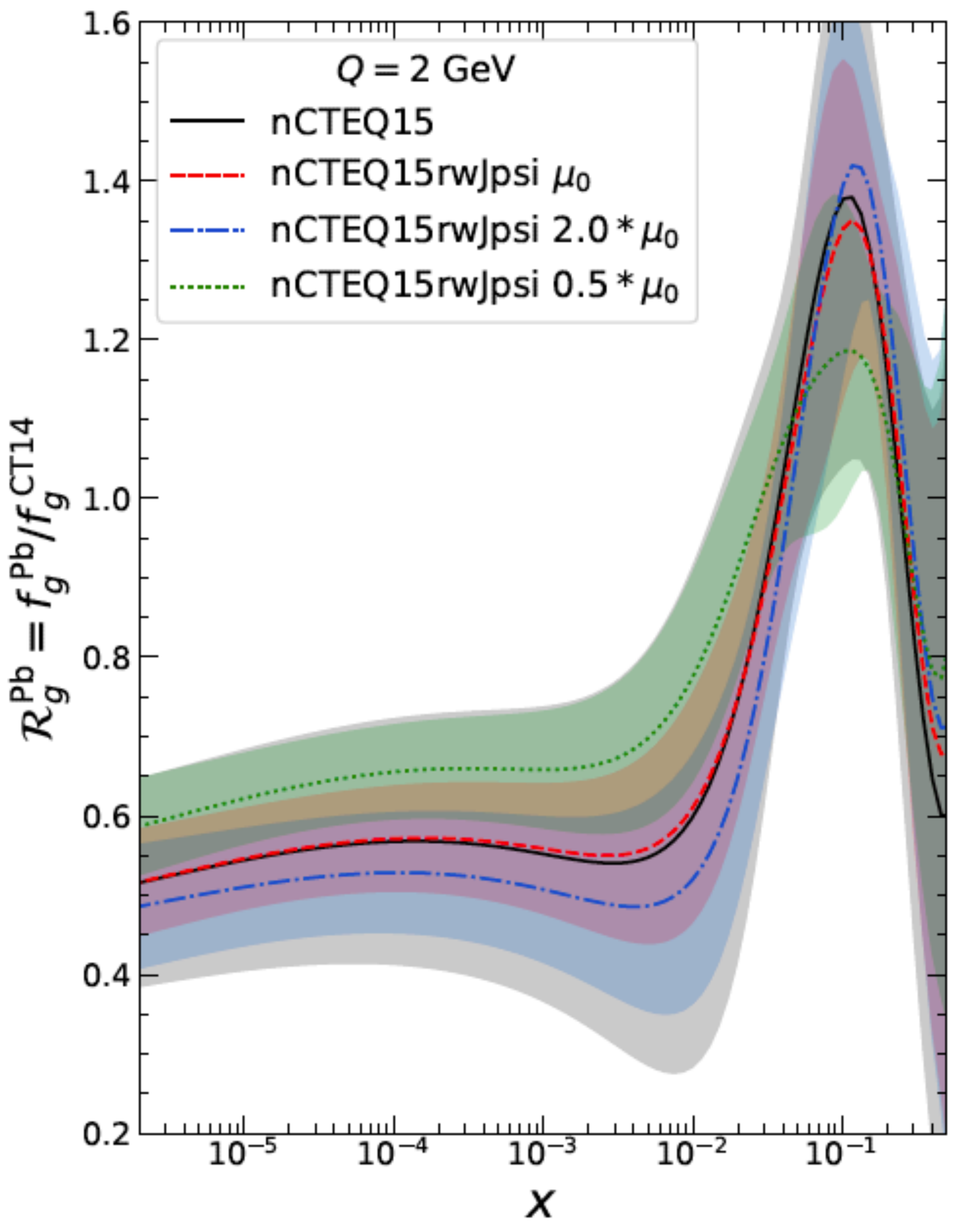
→**Using a non-quadratic Hessian PDF reweighting**, K. J. Eskola et al., EPJC 79, 511 (2019)

K. J. Eskola et al., JHEP 2020 37 (2020)
With D meson LHCb data at 5.02 TeV

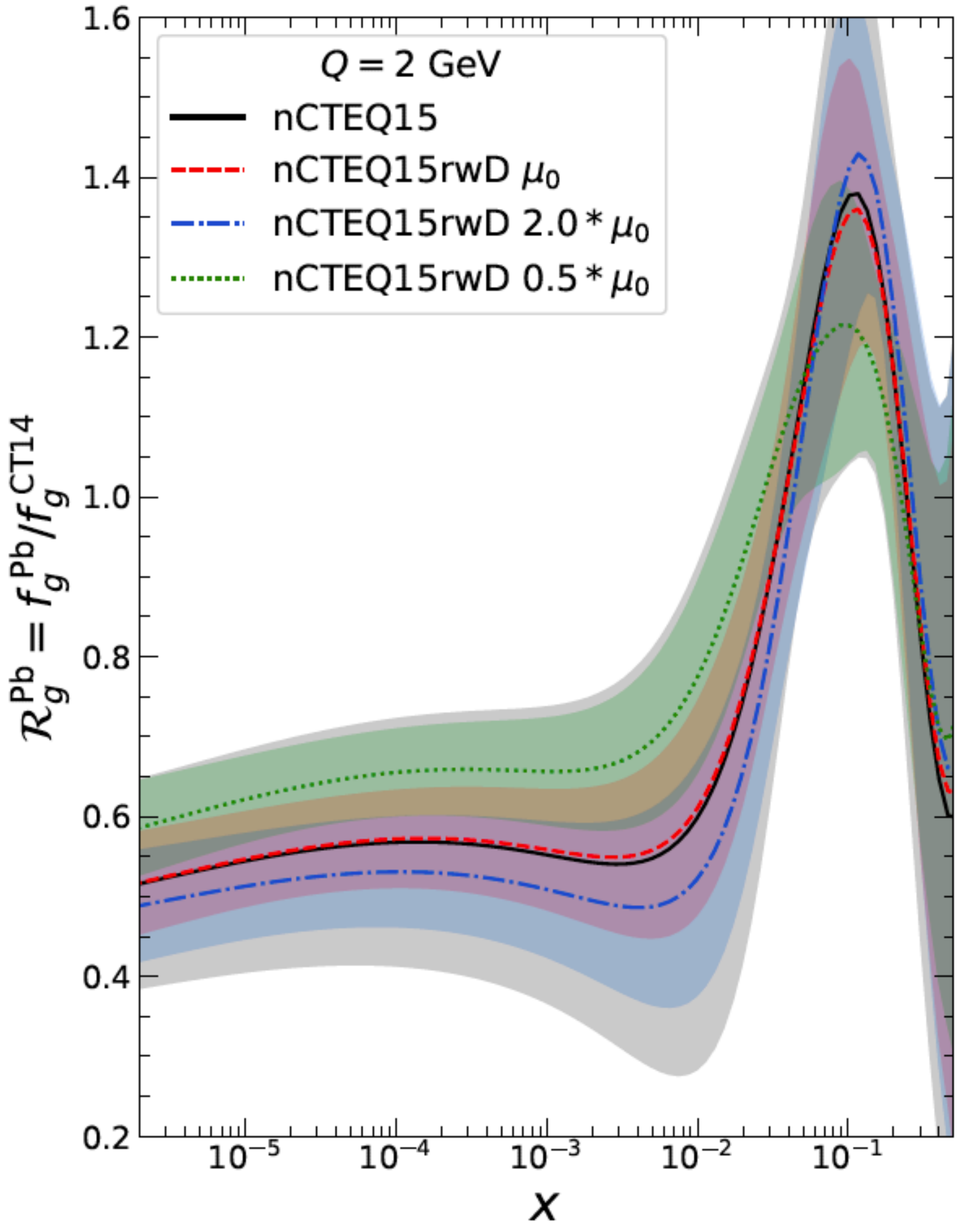


A. Kusina et al. arXIv.2012.11462

ALICE+LHCb D mesons in pPb



ALICE+LHCb J/ψ mesons in pPb



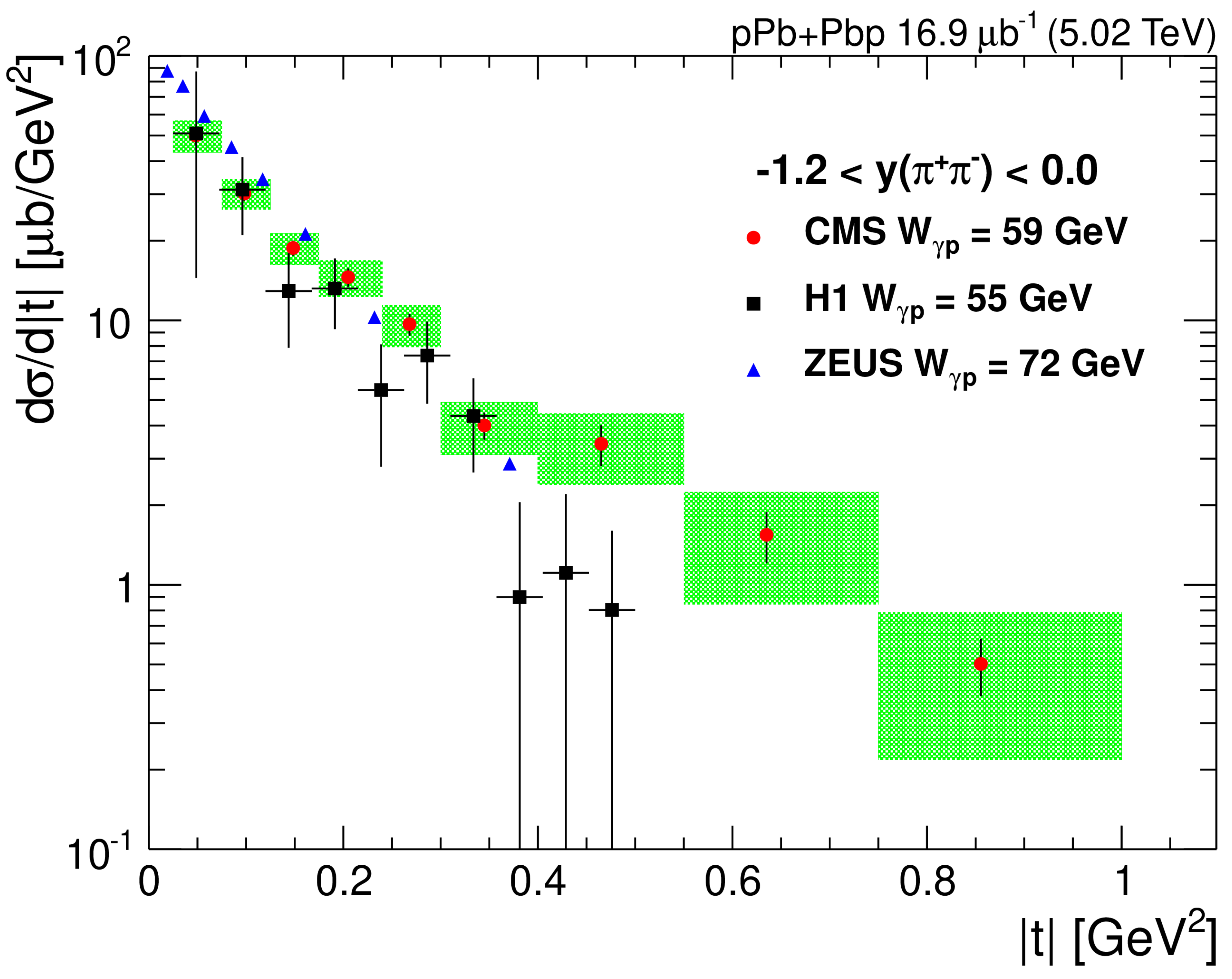
Significant constraints from inclusion of charm data from the LHC. Some caveats:

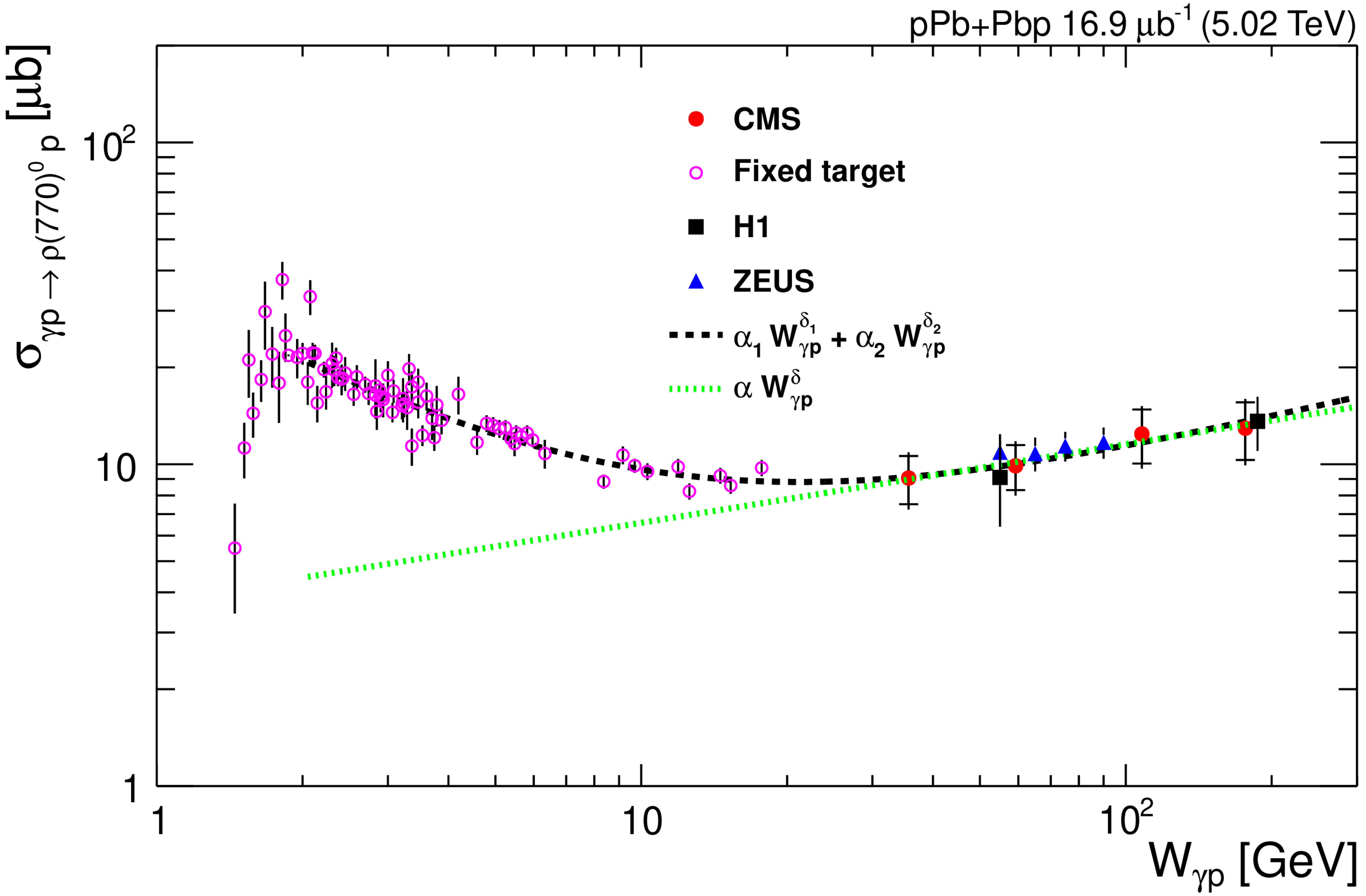
- **what is the influence of final state effects (e.g. D meson flow or hadronization)?**
- **can we account for them in the nPDF fits?**

BACKUP:

Recent UPC measurements in pPb collisions: a few highlights

$\rho_0(770)$ photoproduction in pPb UPC collisions at 5.02 TeV





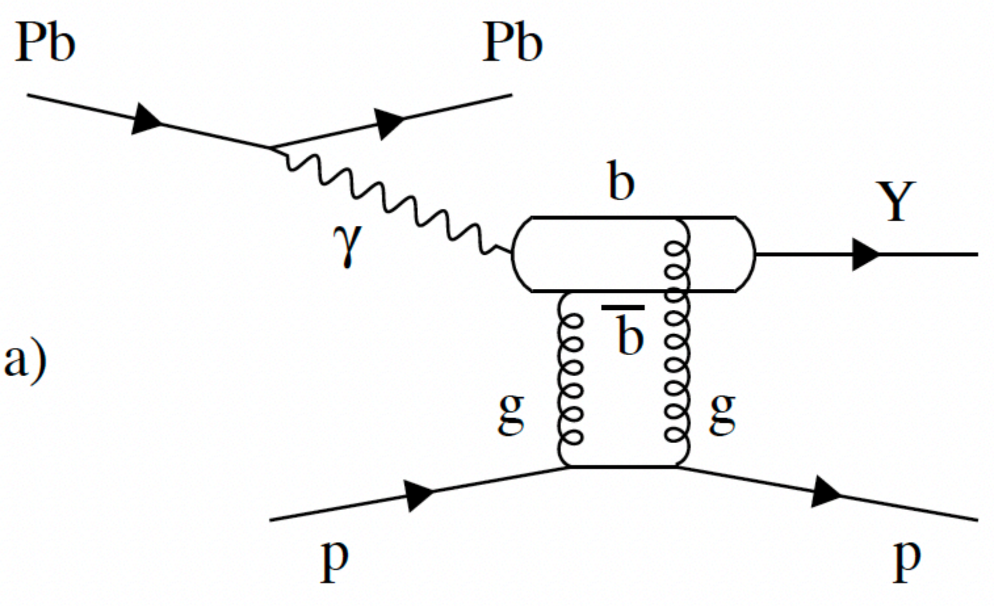
Results are consistent with those of the H1 and ZEUS Collaborations at HERA

→ **ion–proton collisions can be used in the same way as electron–proton ones, with ions acting as a source of quasi-real photons.**

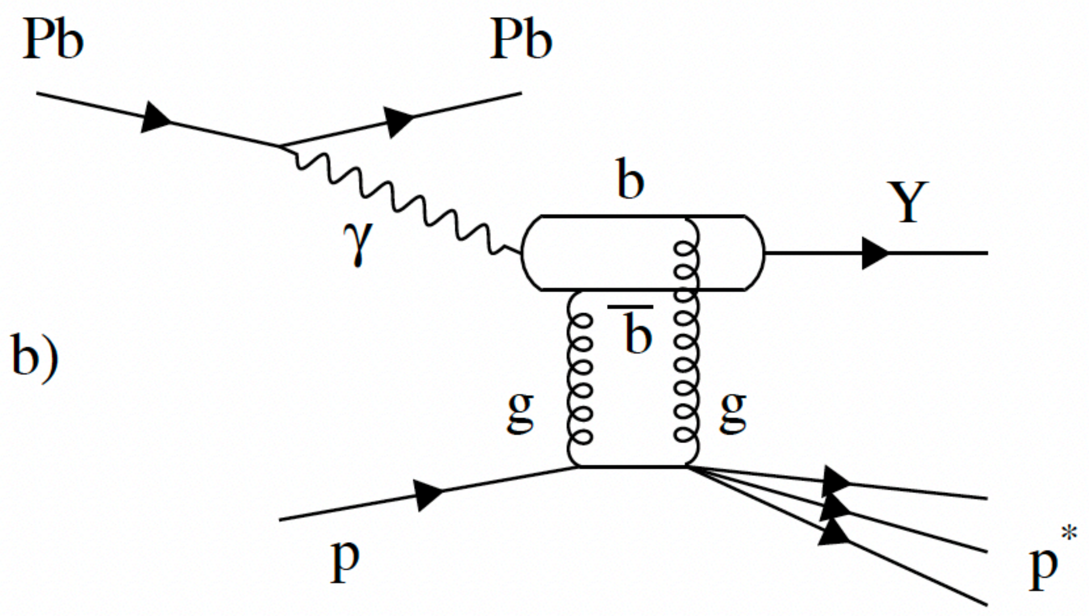
CMS, Eur. Phys. J. C 79 (2019) 702, CMS-FSQ-16-007

Upsilon production in exclusive photonuclear pPb events

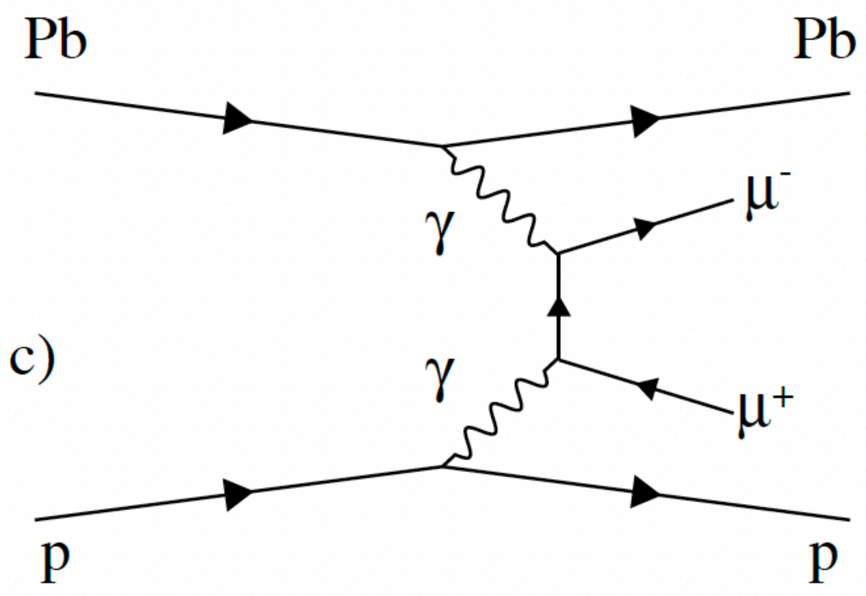
→ **sensitive to generalized parton distributions (GPDs) in the proton for $10^{-4} < x < 10^{-2}$**



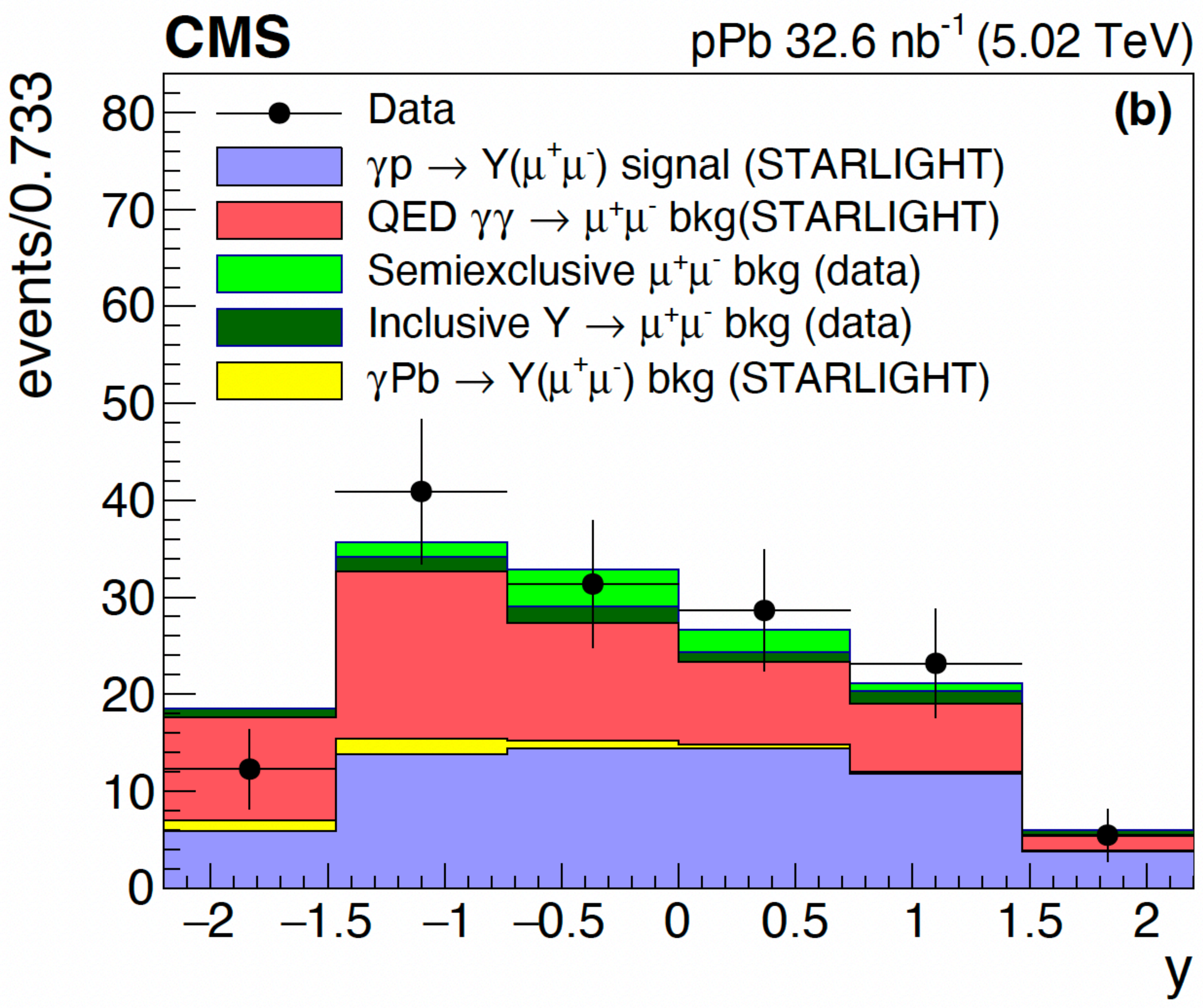
exclusive photoproduction

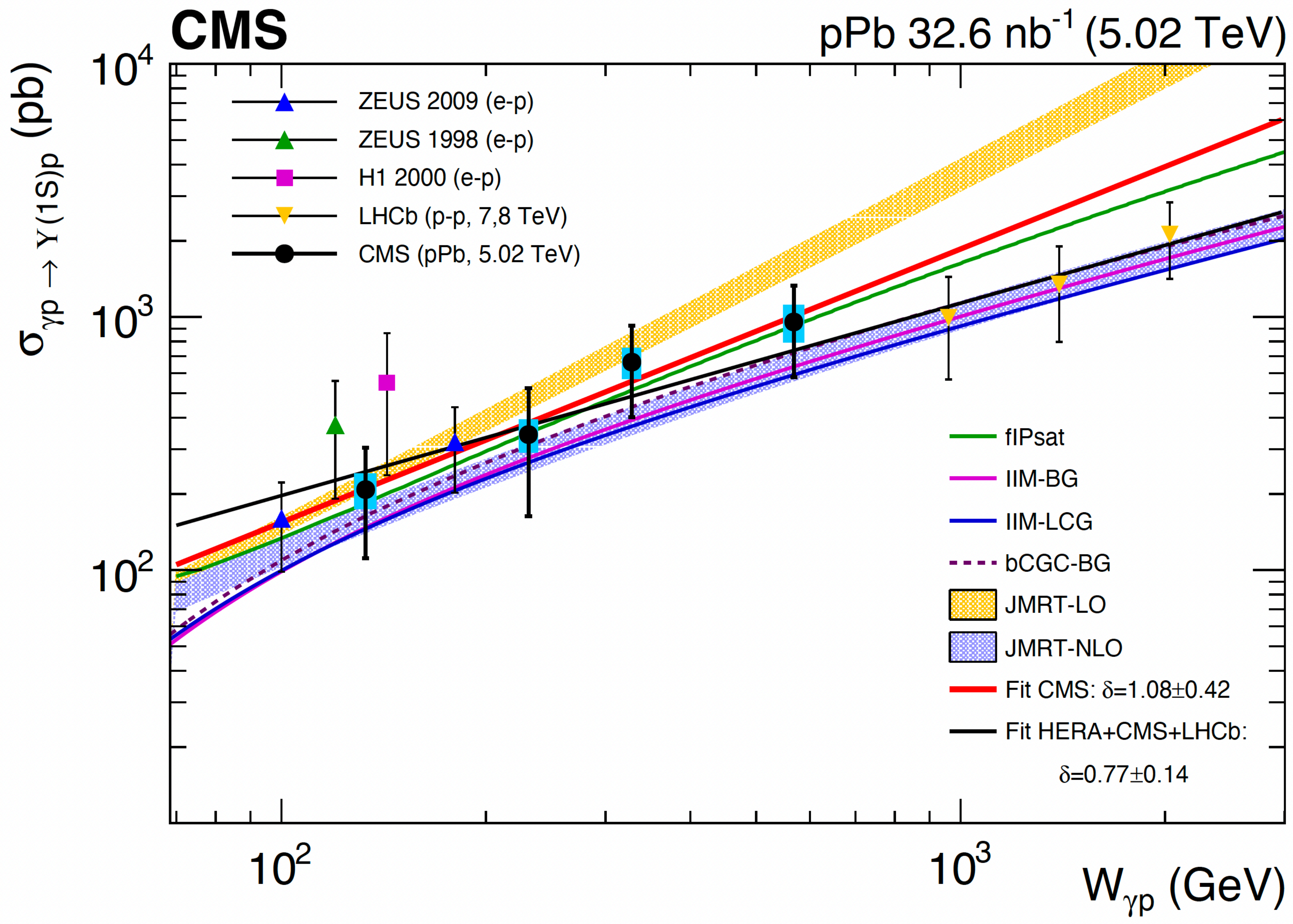


semiexclusive photoproduction



exclusive dimuon QED continuum





CMS, Eur. Phys. J. C 79 (2019) 277