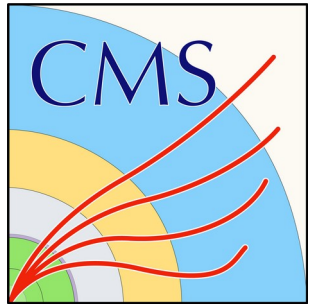
Constraining gluon nPDFs with open heavy-flavor production in ultraperipheral heavy ion collisions with CMS

Balazs Kovacs (MIT)
on behalf of the CMS Collaboration

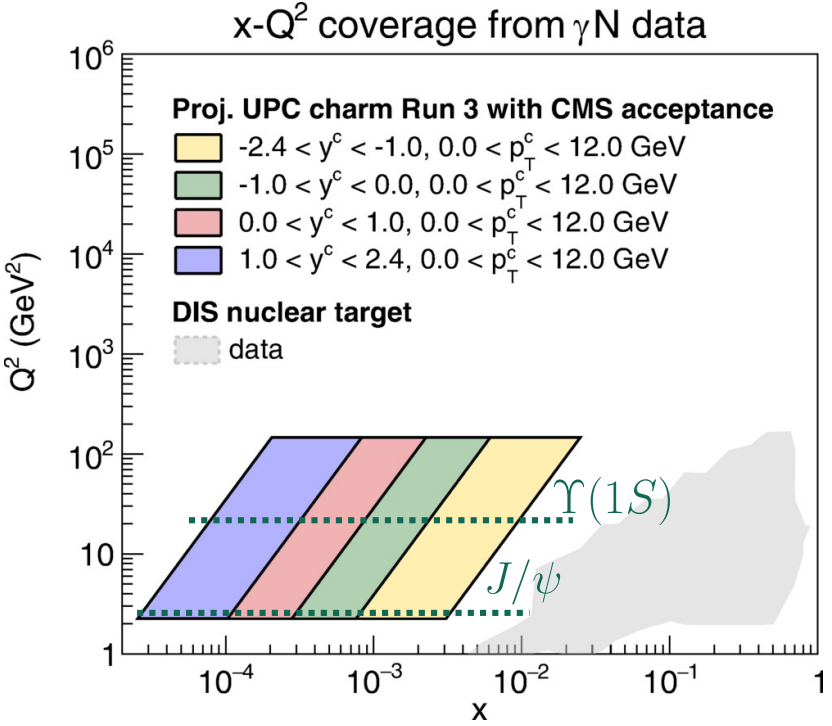
MITHIG's work is supported by the US DOE-NP



Talk overview

- Physics motivation: Understanding low-x nuclear matter
- Introduction to ultraperipheral collisions (UPCs)
- UPC D^0 meson cross section measurement
- First results and prospects for the future

Probing nPDFs with charm quarks

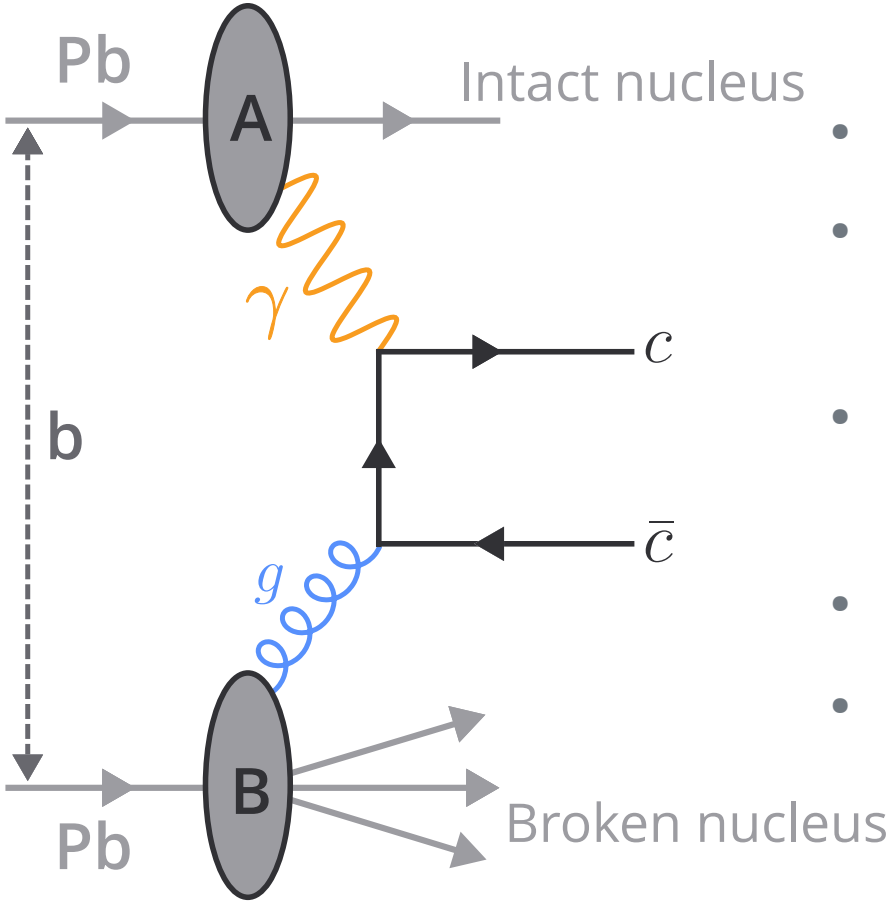


*Parametric estimate

- Constraining nPDFs down to low-x
- $m_c > \Lambda_{QCD}$
  → pQCD description at any p_T
- Open charm measurement:
  Control over charm kinematics
  ↓
  Phase space scan in (x, Q^2)

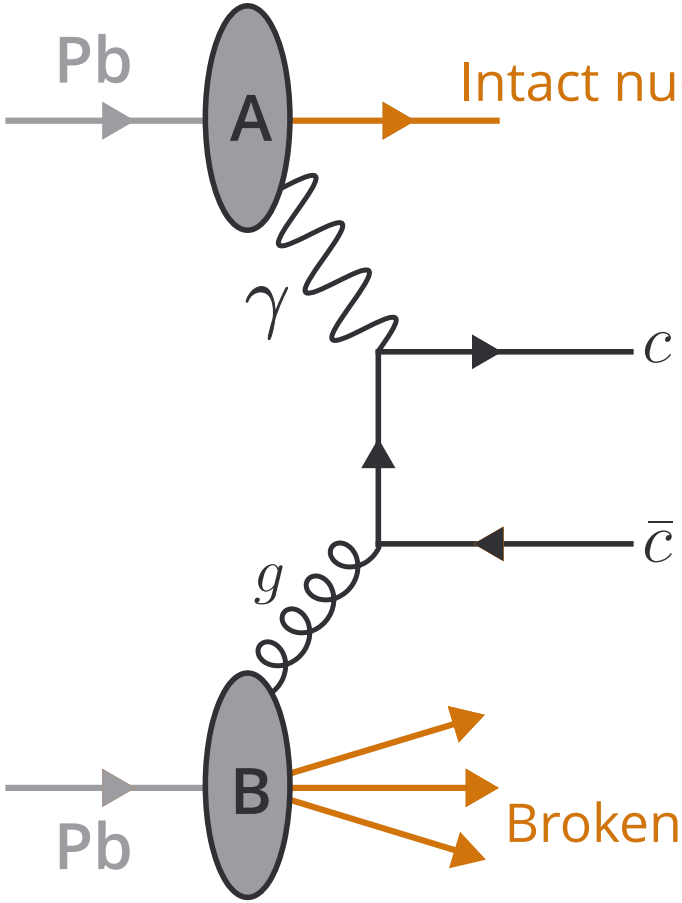
$$Q^2 \approx m_T^2 = p_T^2 + m_c^2 \qquad x \approx \frac{m_T}{\sqrt{s_{NN}}} e^{-y_c}$$

Ultraperipheral collisions (UPCs)



- Impact parameter: b > ~(R_A+R_B)
- Strong EM field around relativistic nuclei ⟶ source of quasi-real photons
- Hard scattering between a quasi-real photon and a parton
- Clean experimental environment
- Negligible final state effects

Selecting open charm in UPCs



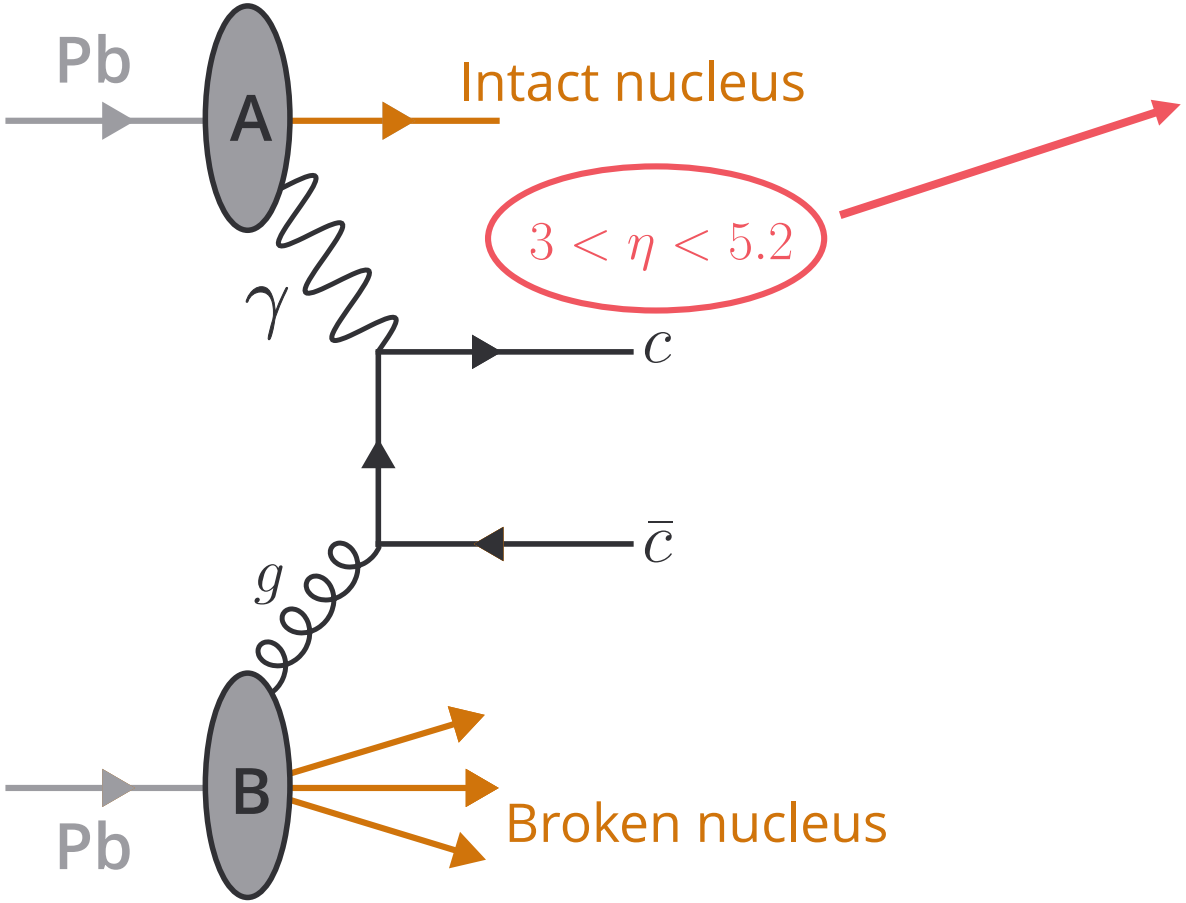
No neutrons → 0n condition on ZDC

ZDC: Zero Degree Calorimeter

Neutron emission → Xn condition on ZDC

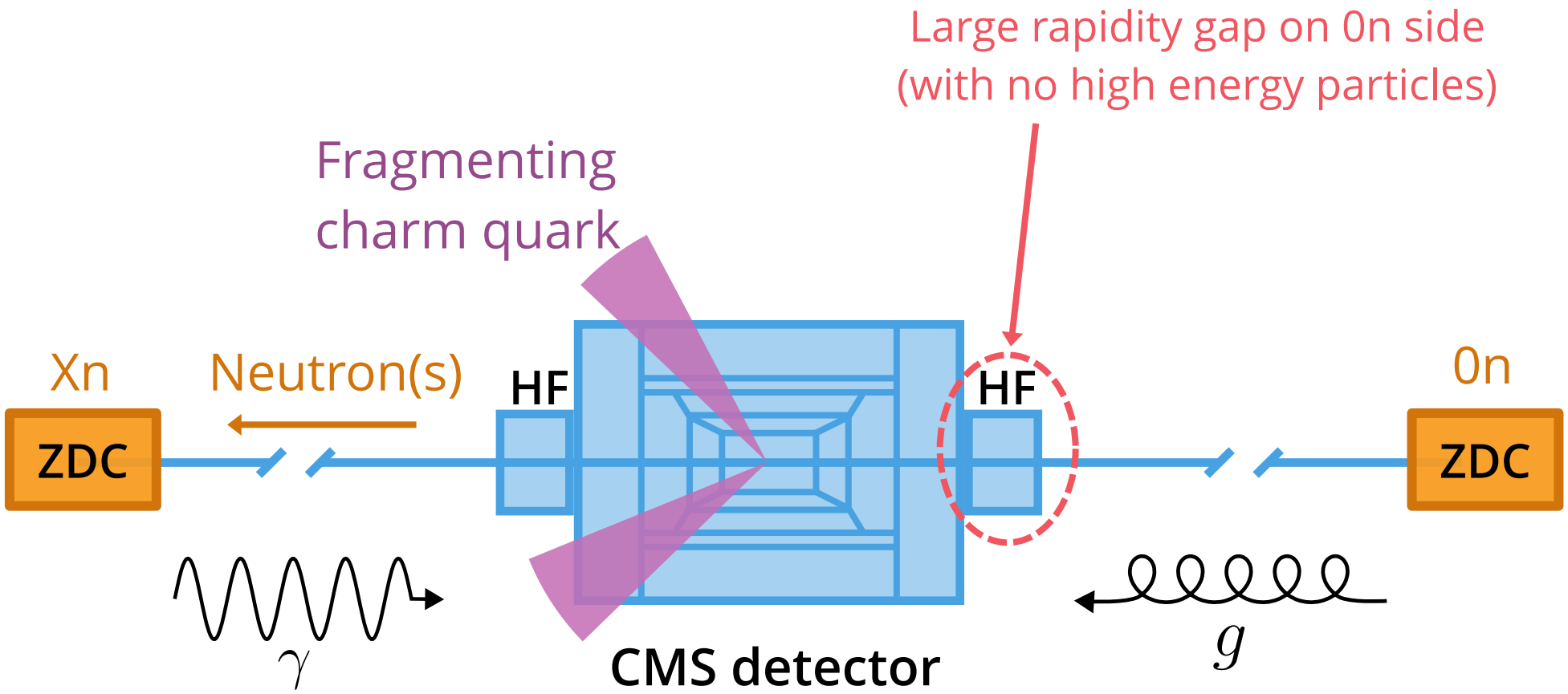
*Xn requirement suppresses coherent diffraction

Selecting open charm in UPCs

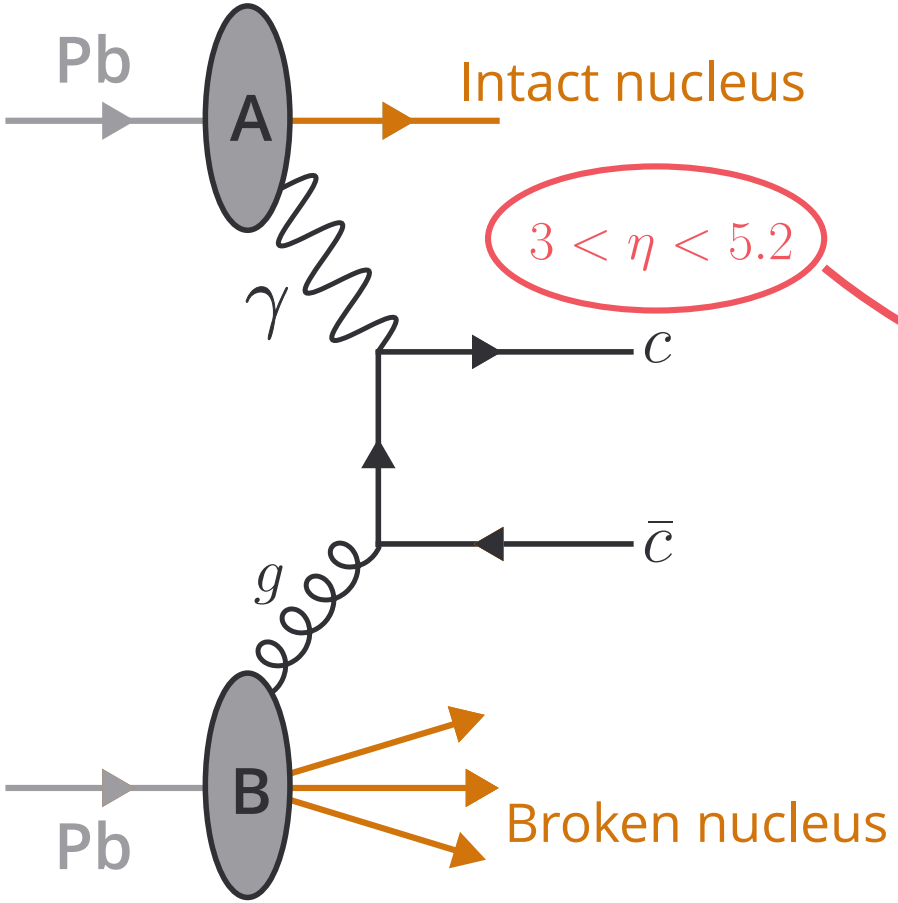


Large rapidity gap on 0n side
(with no high energy particles)

Selecting open charm in UPCs



Effect of rapidity gap selection



Large rapidity gap on 0n side
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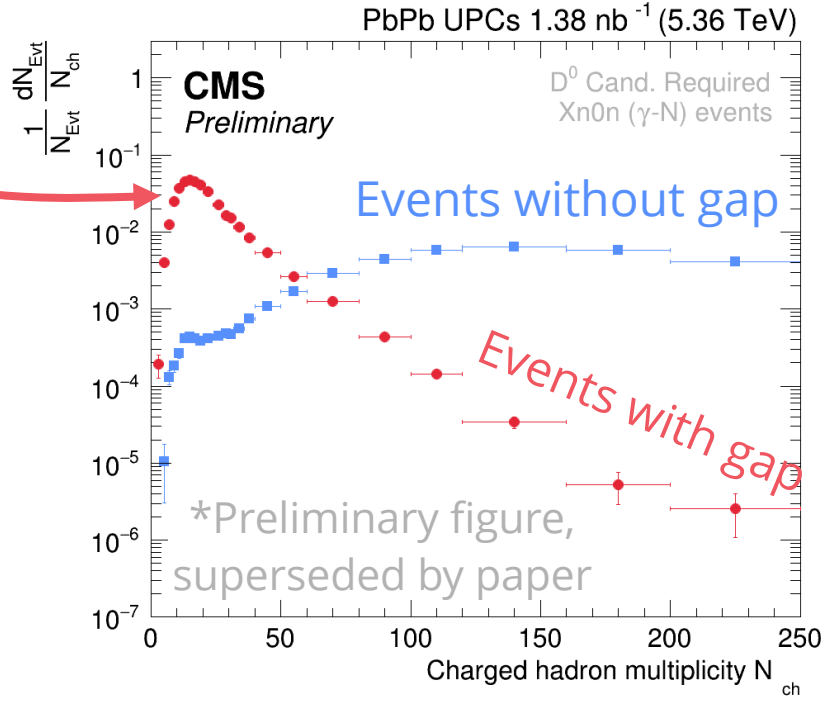
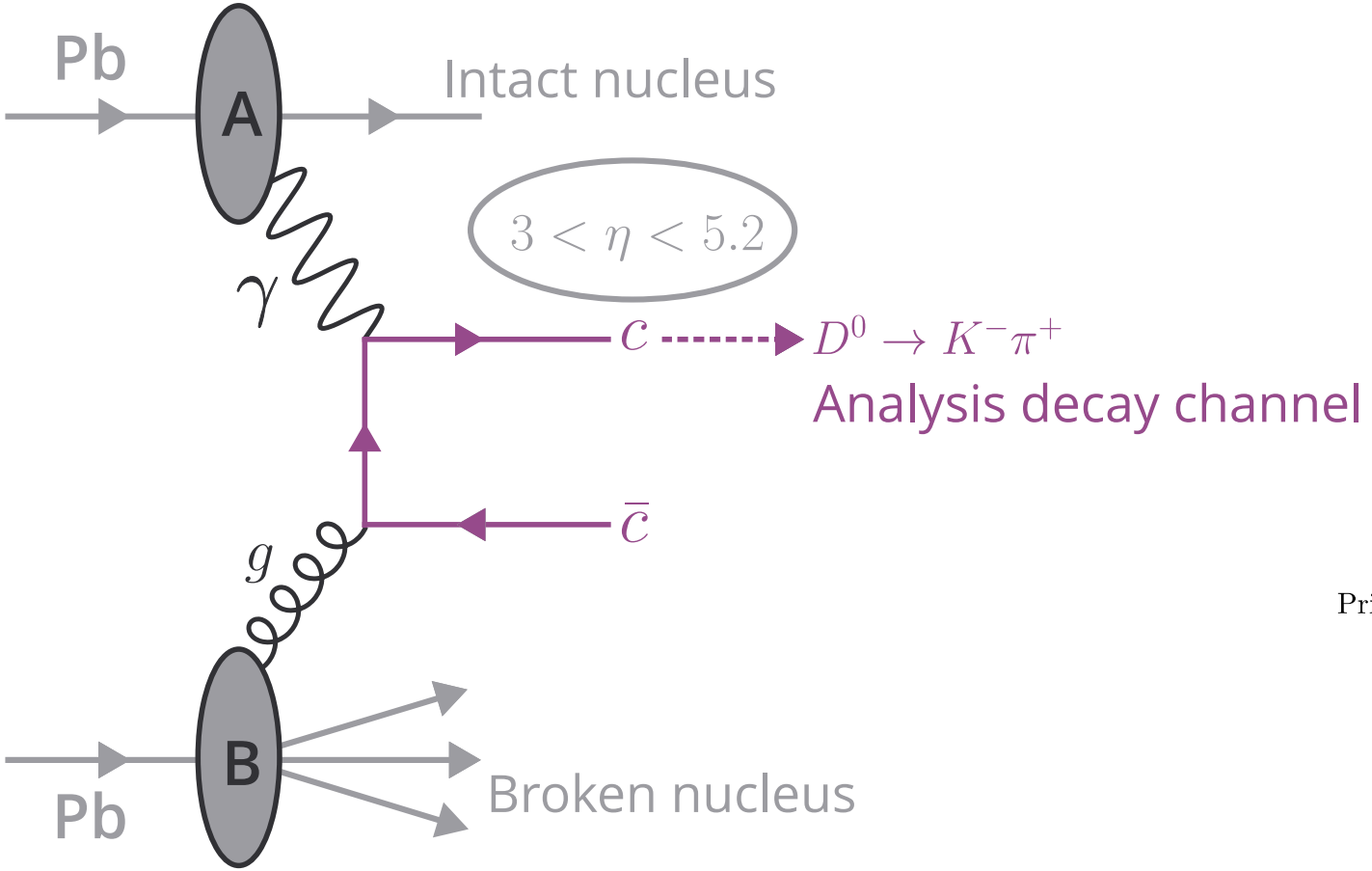
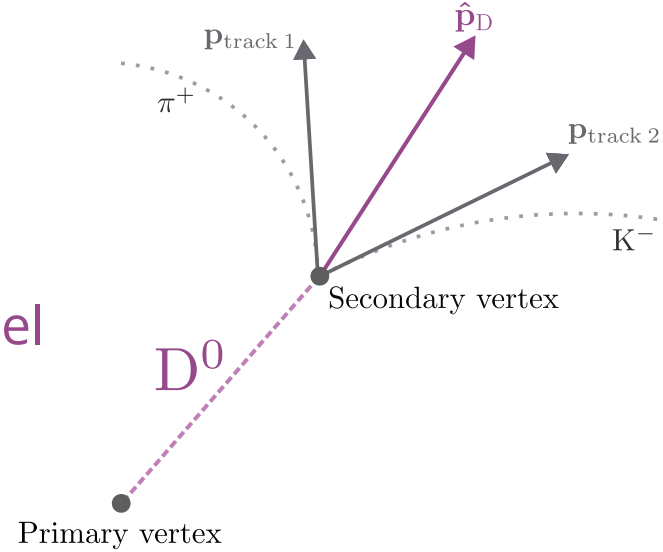
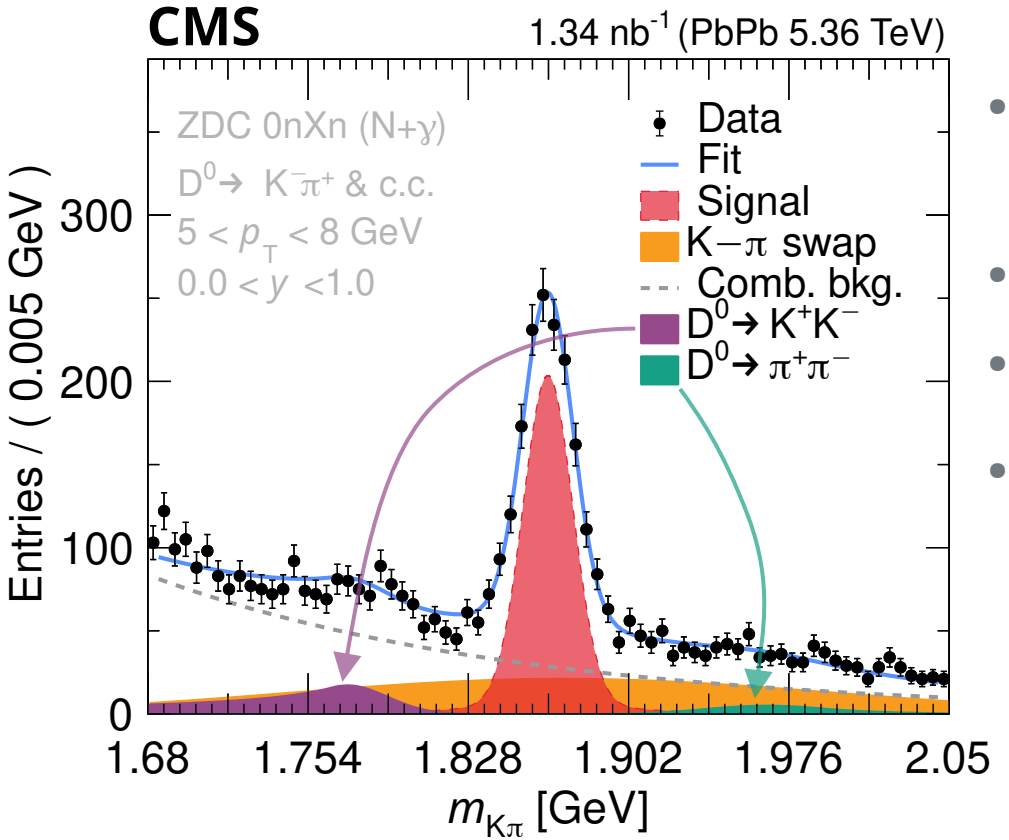


D^0 reconstruction





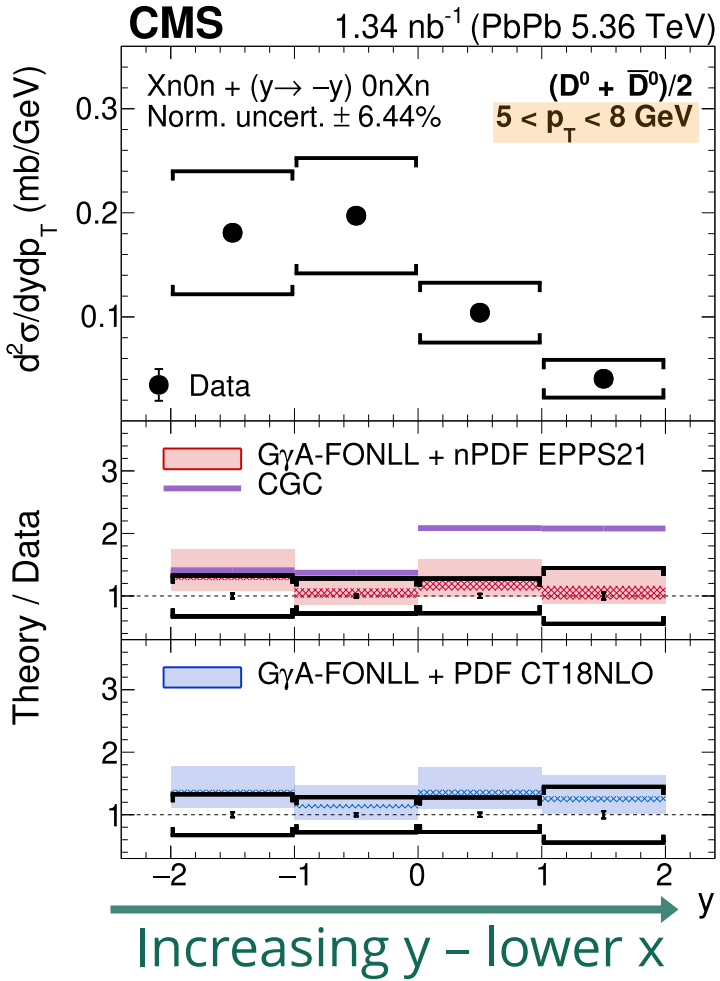
D^0 yield extraction



- Invariant mass fits in bins of D^0 p_T and rapidity
- Multi-component fit
- Low combinatorial background
- Yield: number of D^0 and $\bar{D}^0$ mesons

Results

- GγA-FONLL NLO and CGC LO predictions available
- Important to consider EMD effects in theory
- Caveat: Measurement is semi-inclusive (**Xn**0n), theory is inclusive

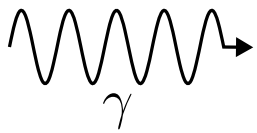


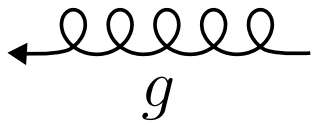
Recently published!

CMS, PRL 136 (2026) 122303

$$Q^2 \approx m_{\mathrm{T}}^2 = p_{\mathrm{T}}^2 + m_{\mathrm{c}}^2$$

$$x \approx \frac{m_{\mathrm{T}}}{\sqrt{s_{\mathrm{NN}}}}\, e^{-y_{\mathrm{c}}}$$





Results

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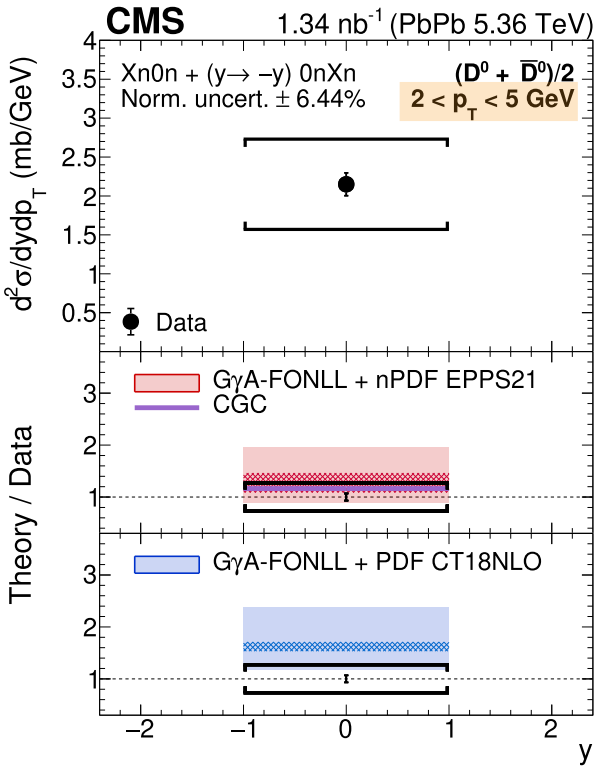
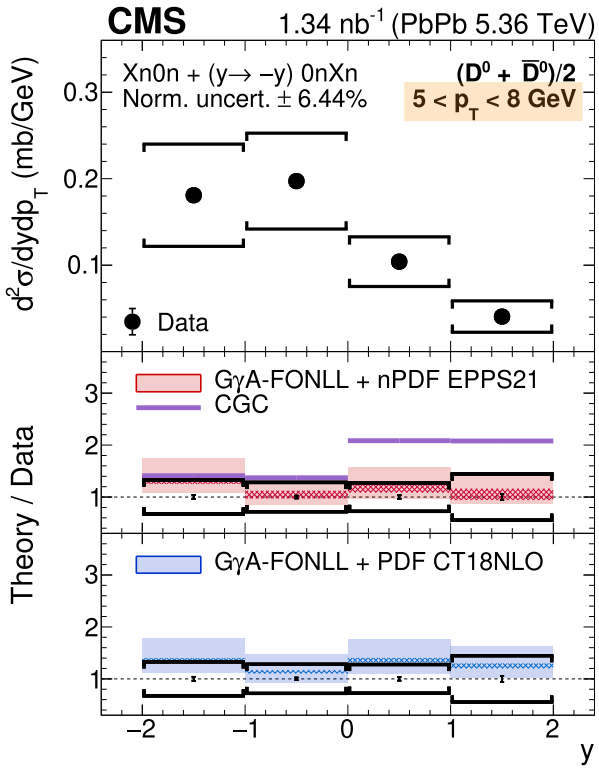
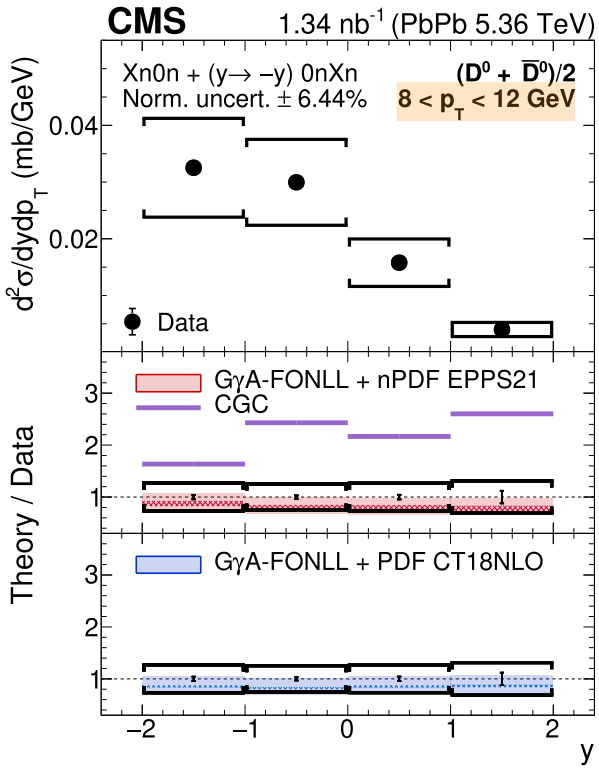
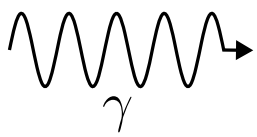
Increasing D^0 p_T – larger Q^2 and x



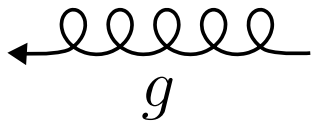






Increasing y – lower x

$$x \approx \frac{m_T}{\sqrt{s_{NN}}} e^{-y_c}$$



Results

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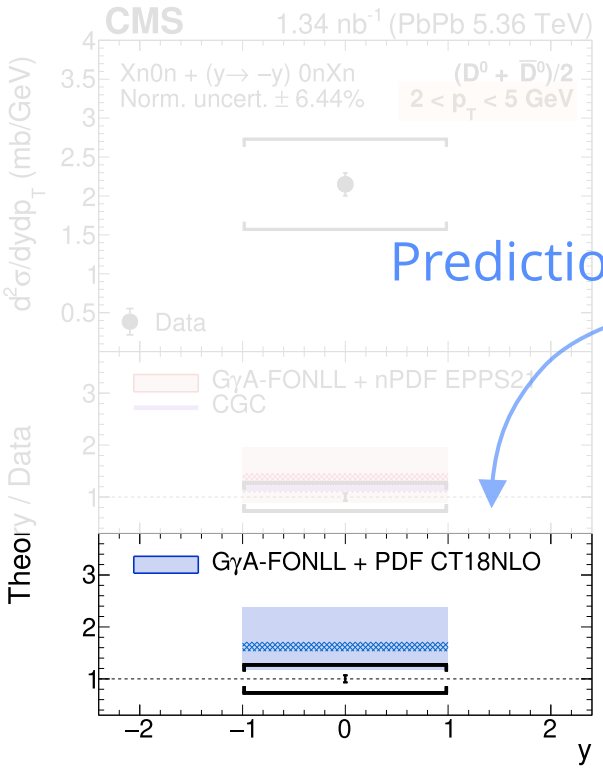
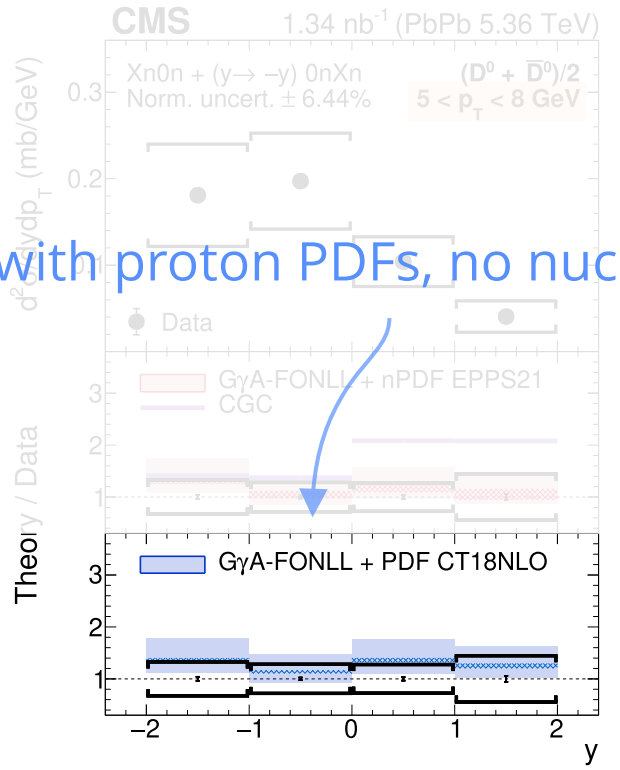
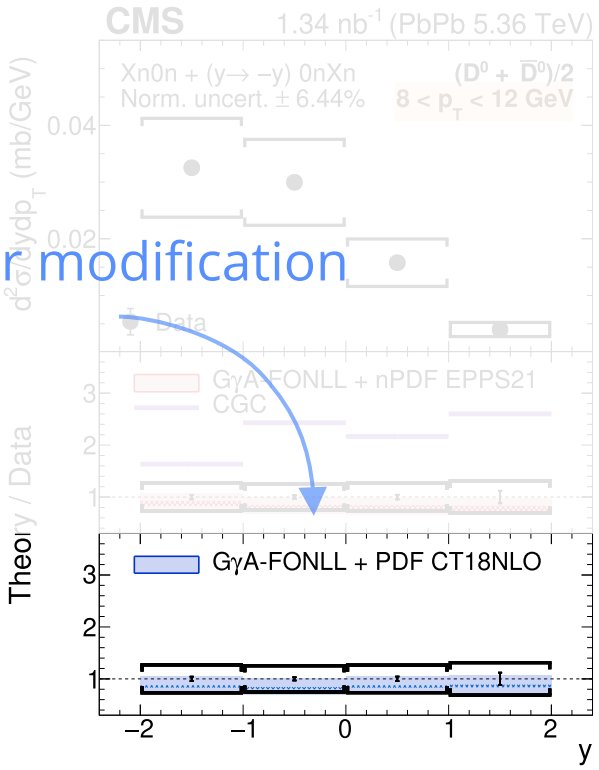
Increasing D^0 p_T – larger Q^2 and x



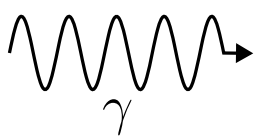


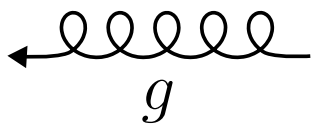


Predictions with proton PDFs, no nuclear modification

Increasing y – lower x

$$x \approx \frac{m_T}{\sqrt{s_{NN}}} e^{-y_c}$$





Results

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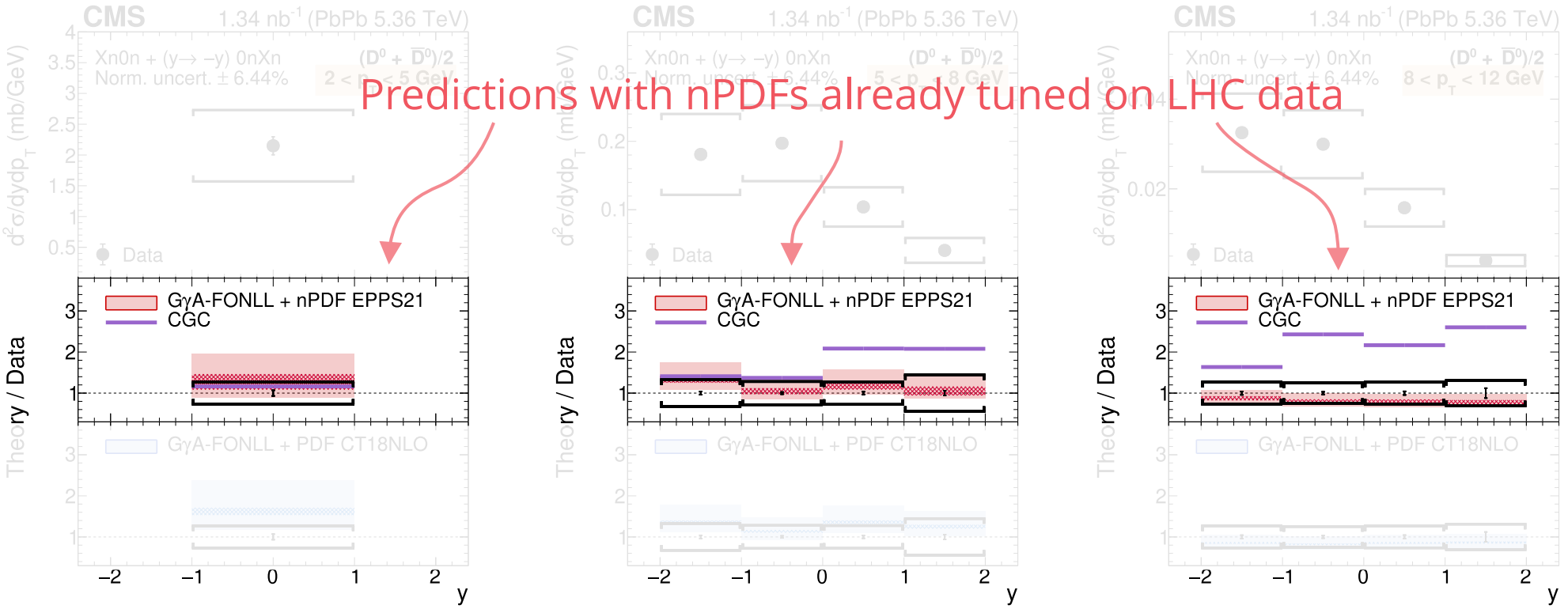
Increasing D^0 p_T – larger Q^2 and x

Predictions with nPDFs already tuned on LHC data



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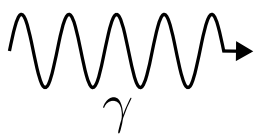

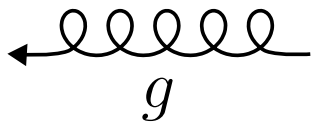

Results

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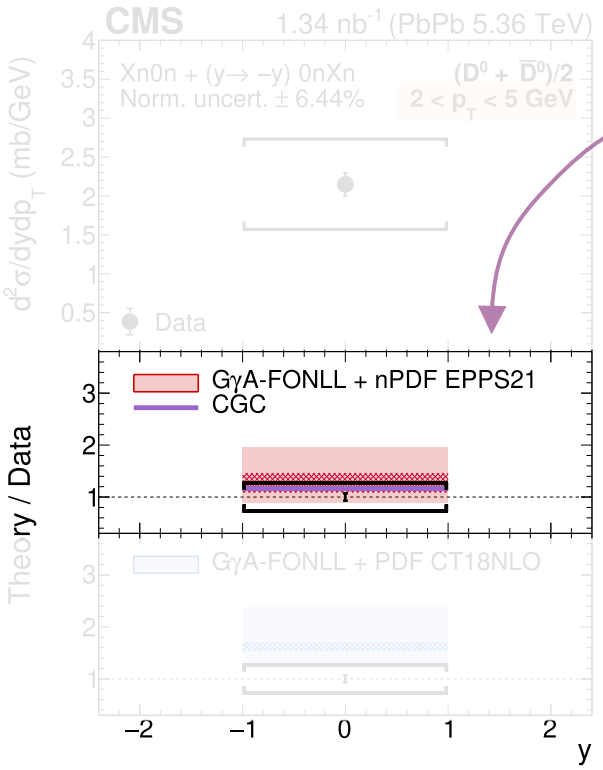
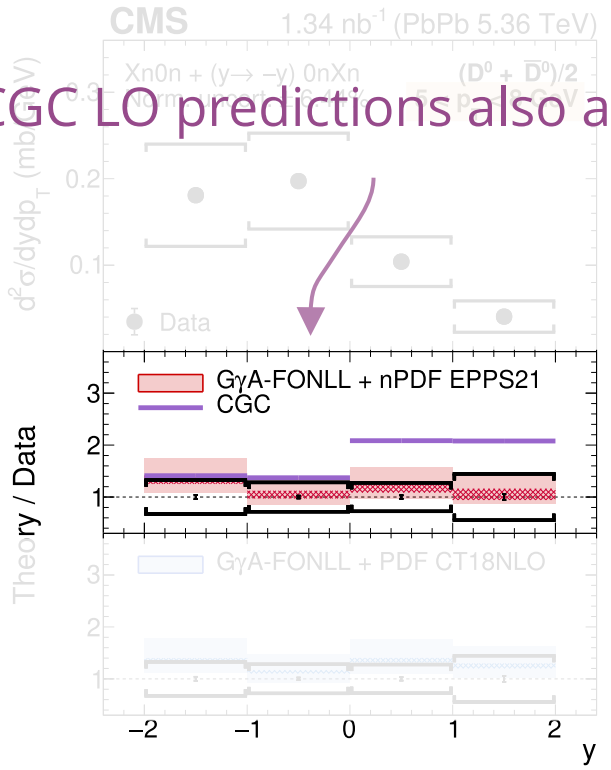
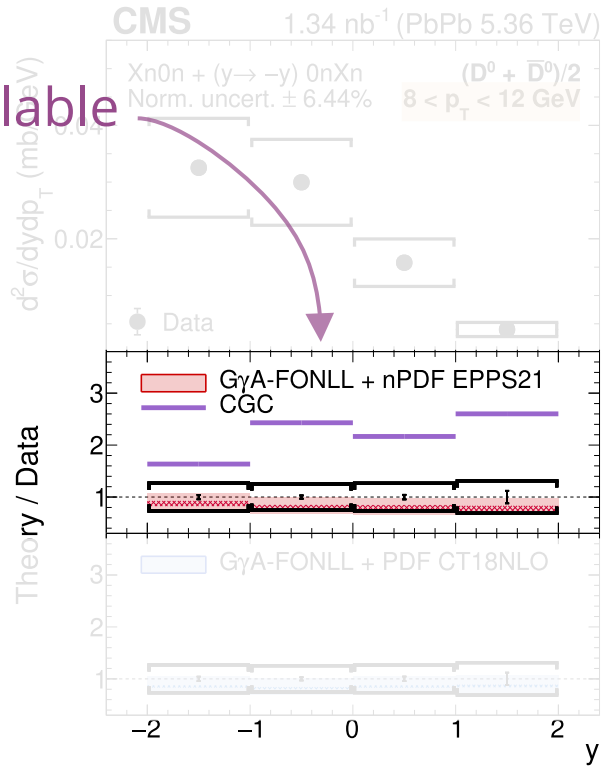
Increasing D^0 p_T – larger Q^2 and x

CGC LO predictions also available

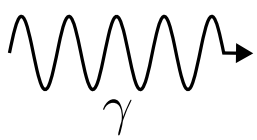


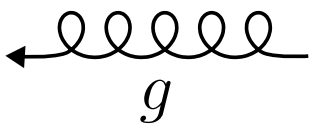




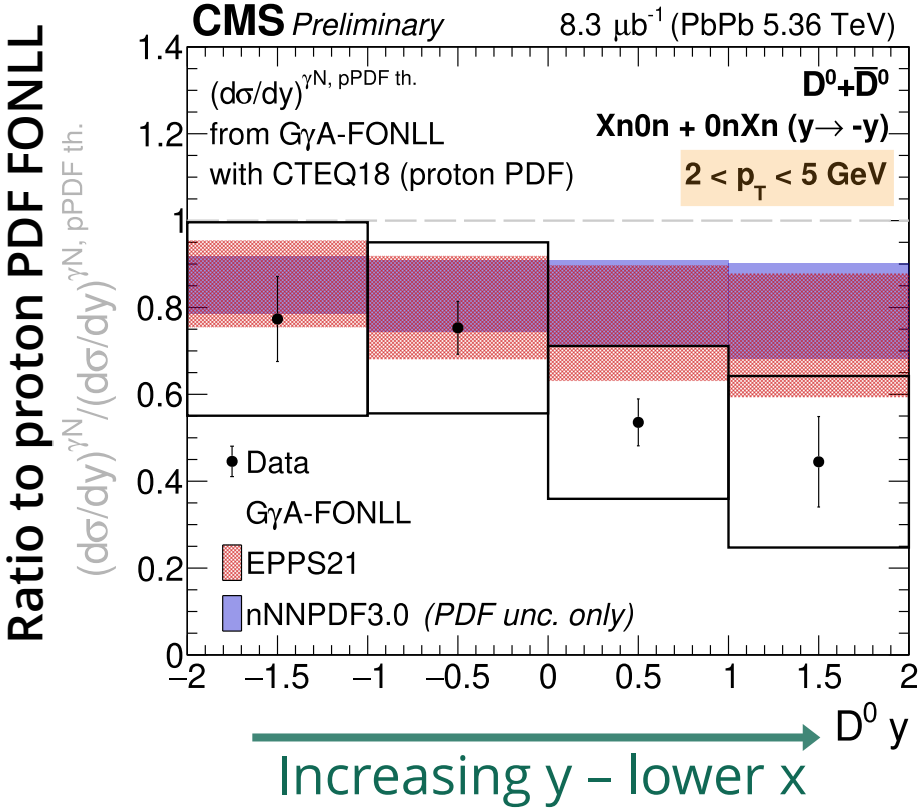
Increasing y – lower x

$$x \approx \frac{m_T}{\sqrt{s_{NN}}} e^{-y_c}$$





Increasing low-x reach



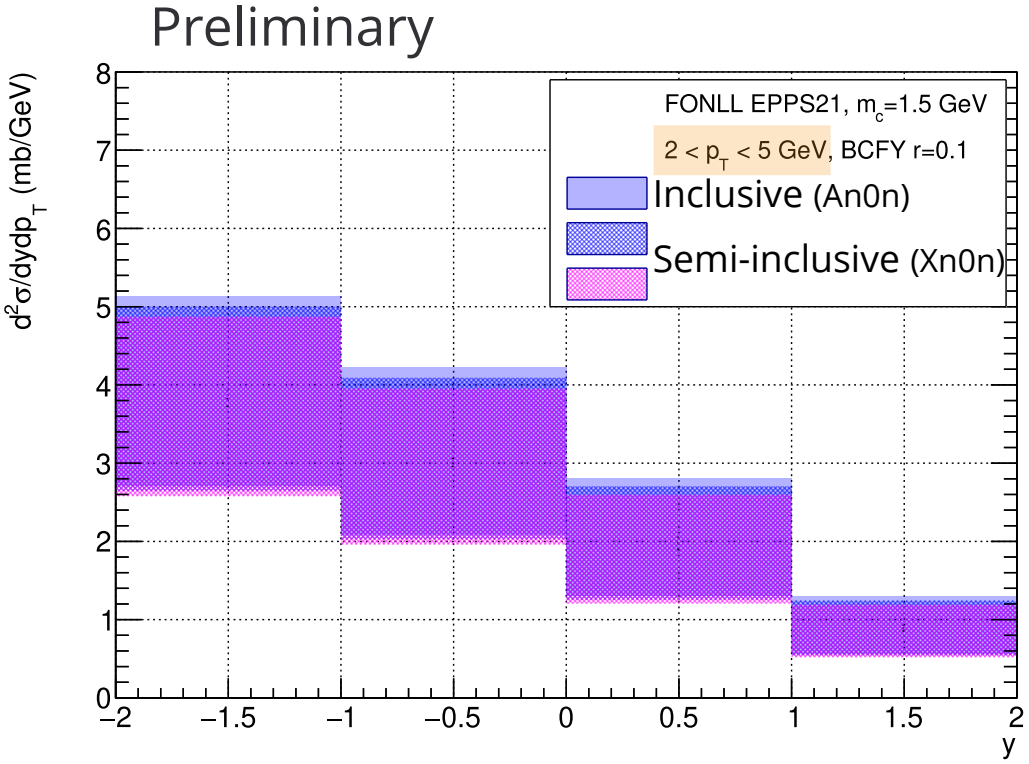
- Preliminary result extending rapidity coverage at low-p_{T}
- Uses 2023 data only!
  Even larger datasets available from 2024, 2025

Caveats:

- Comparison between data and theory
- Not only nuclear modification difference
- Nγ photon flux in denominator

→ Need for a UPC pγ (pPb) reference!

UPC diffractive component

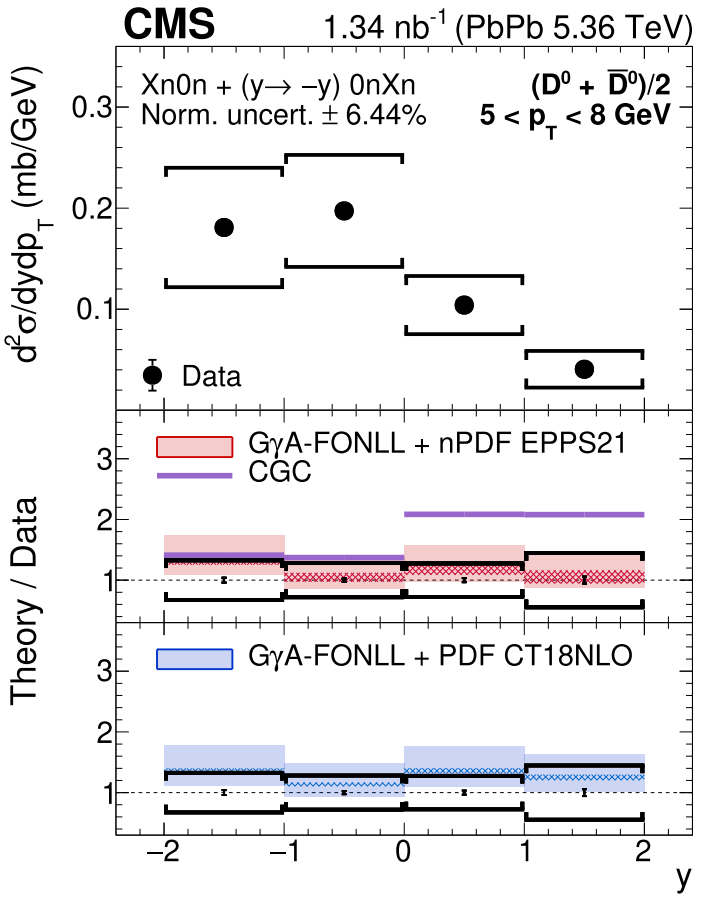


- **First UPC nuclear diffractive prediction in FONLL framework:**
  Anna Stasto's talk (WG1, 15:50)
- Effect of 0n0n ⟶ Xn0n migration included (from EMD)
- Only small difference between semi-inclusive vs inclusive prediction
- Need for experimental measurement of diffractive cross section

Conclusions and outlook

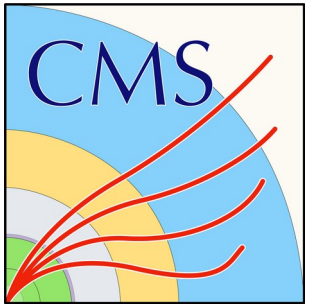
Recently published!
CMS, PRL 136 (2026) 122303

- **First UPC open-heavy flavor measurement**
- Approaching sensitivity to constrain theory
  ⟶ future focus on precision
- Kinematic reach: $x \approx 10^{-4} - 10^{-2}$,
  $Q^2 \approx 10^{1} - 10^{2}\,\mathrm{GeV}^2$
- Full Run 3 dataset should be analysed
  (~15x more data than 2023)



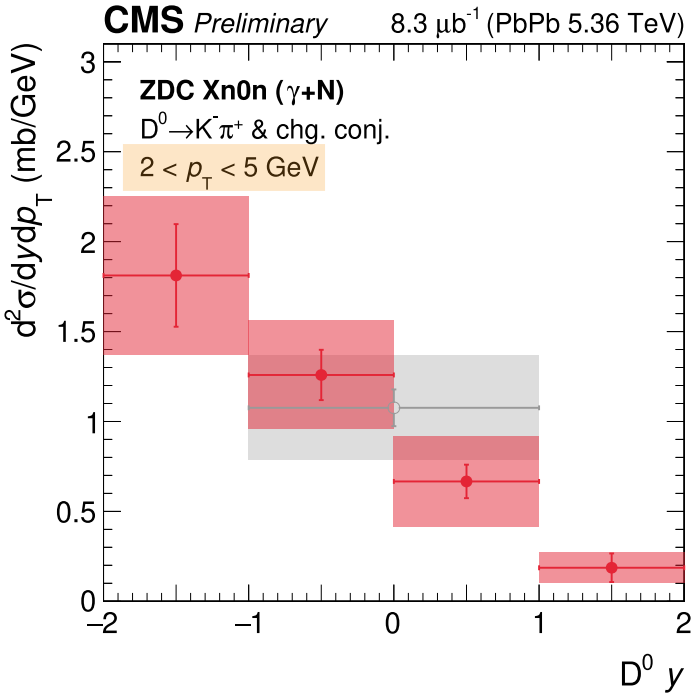
Thank you for your attention!

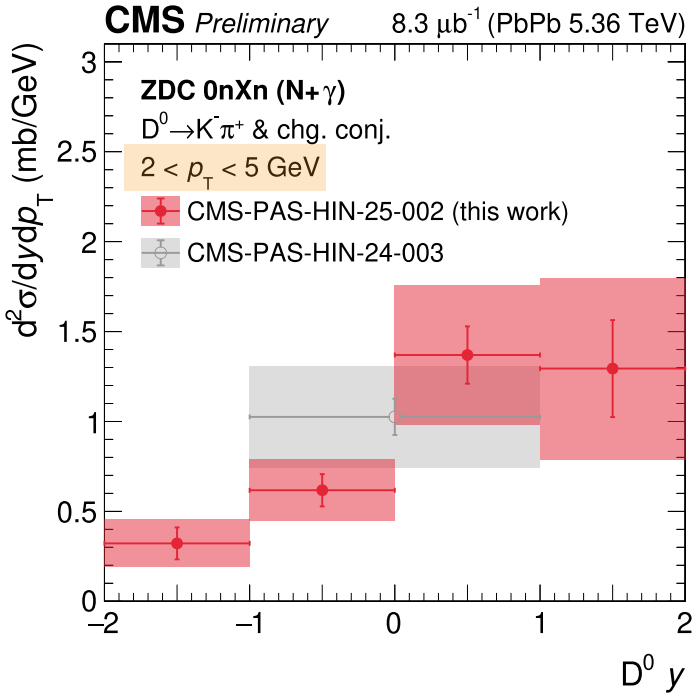
Questions?



Backup slides

Increasing low-x reach



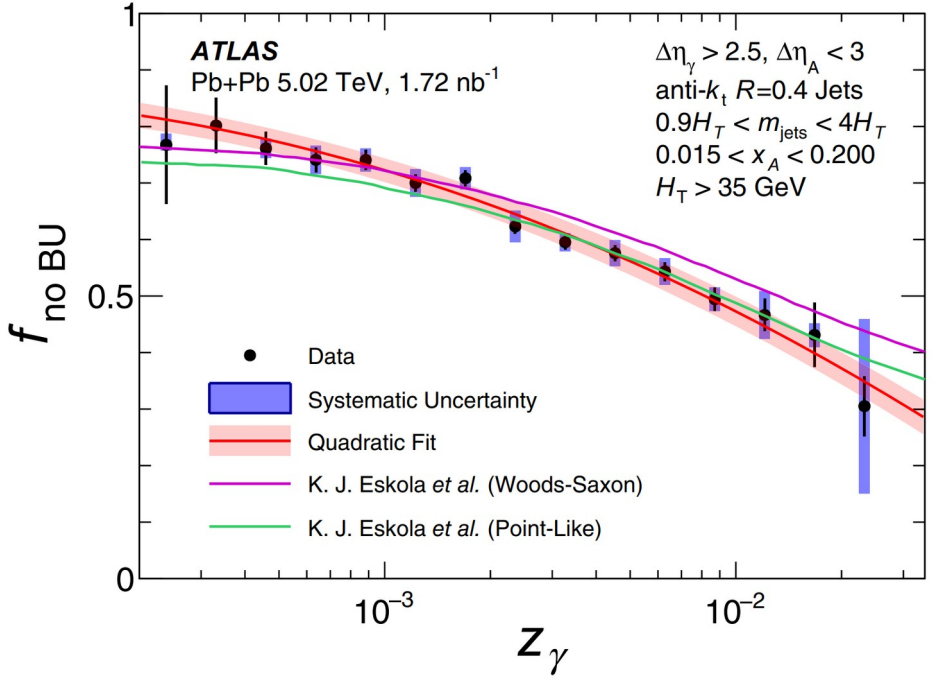


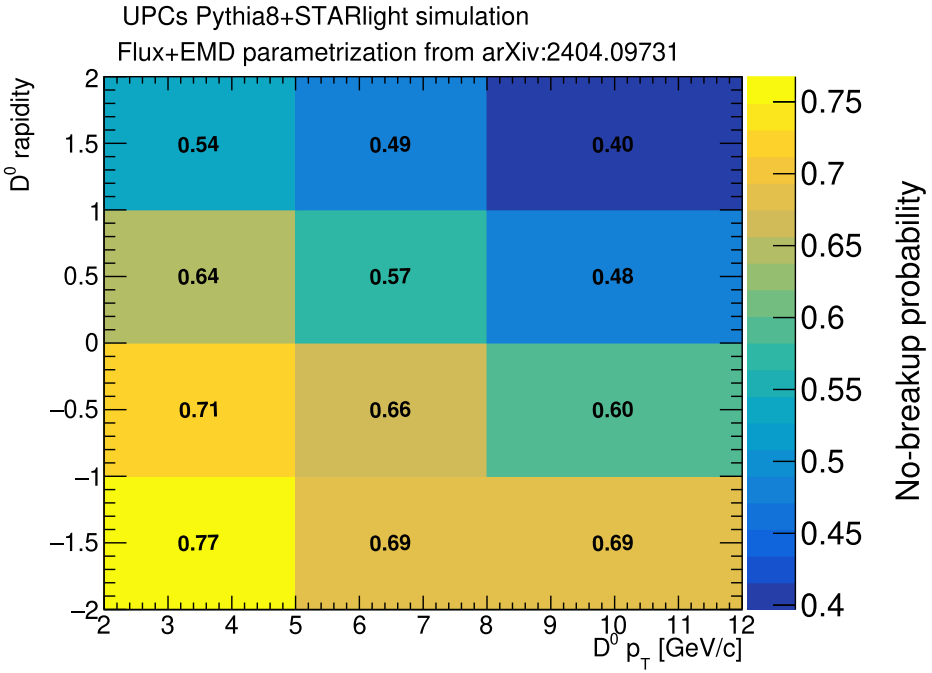
Increasing y – lower x

Electromagnetic dissociation (EMD)

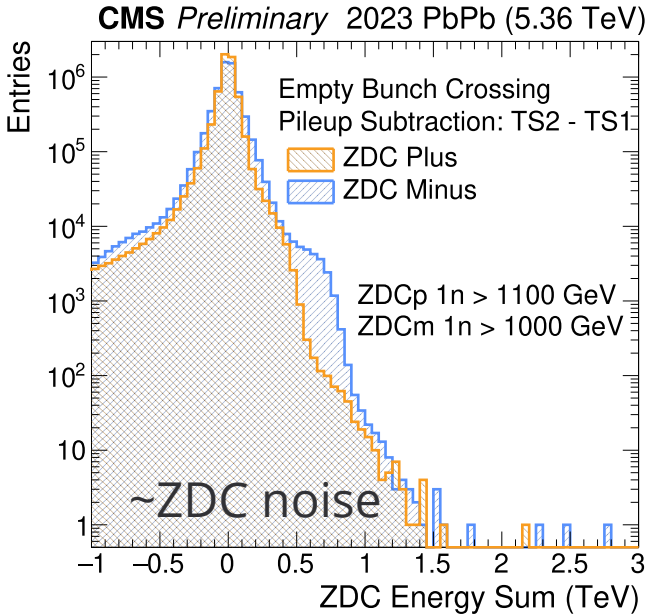
- 0n break-up survival probability folded into the photon flux used for FONLL
- Strong dependence on photon energy

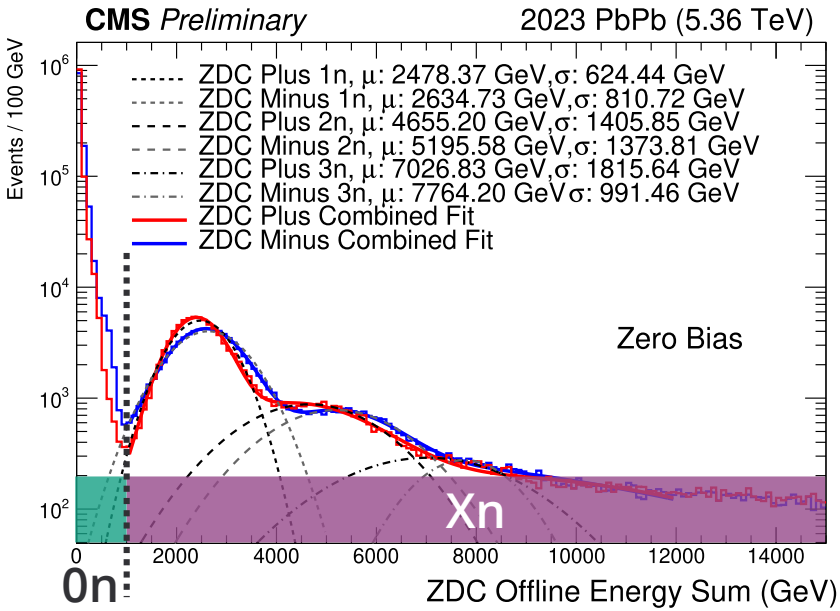
$$f_{\gamma/A}^{(0\mathrm{nAn})}(z) = \int d^2\mathbf{b}\, f_{\gamma/A}(z,\mathbf{b})\, \Gamma_{AA}(\mathbf{b})\, P_{\text{no-EM}}(\mathbf{b})$$

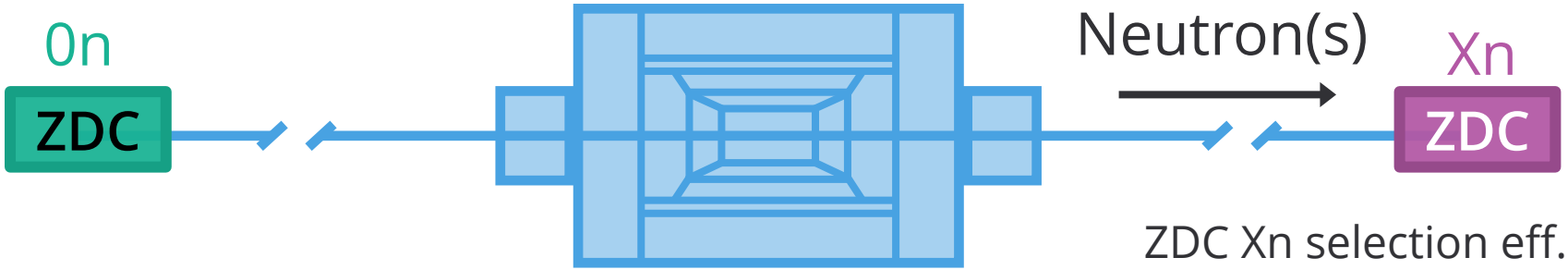




0nXn selection

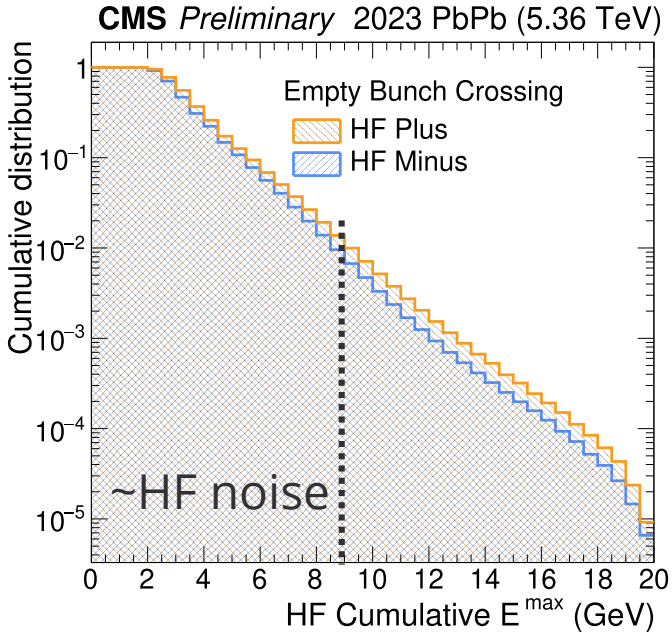




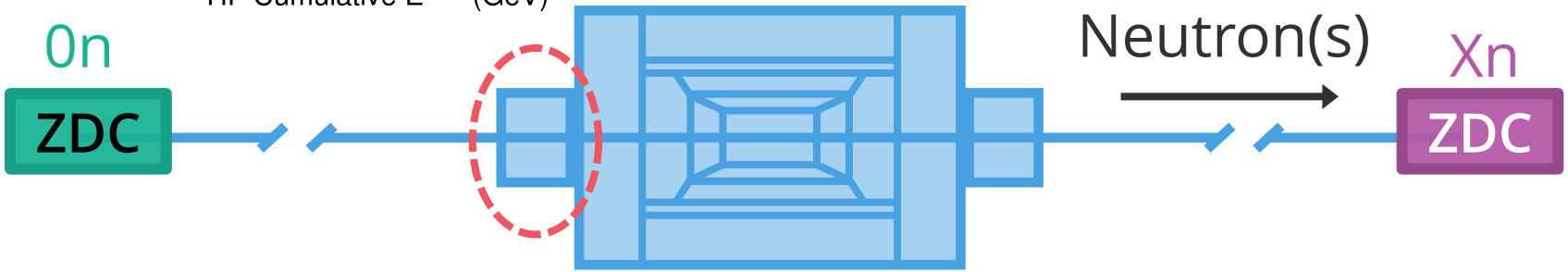


ZDC Xn selection eff. ≥99%

Rapidity gap selection

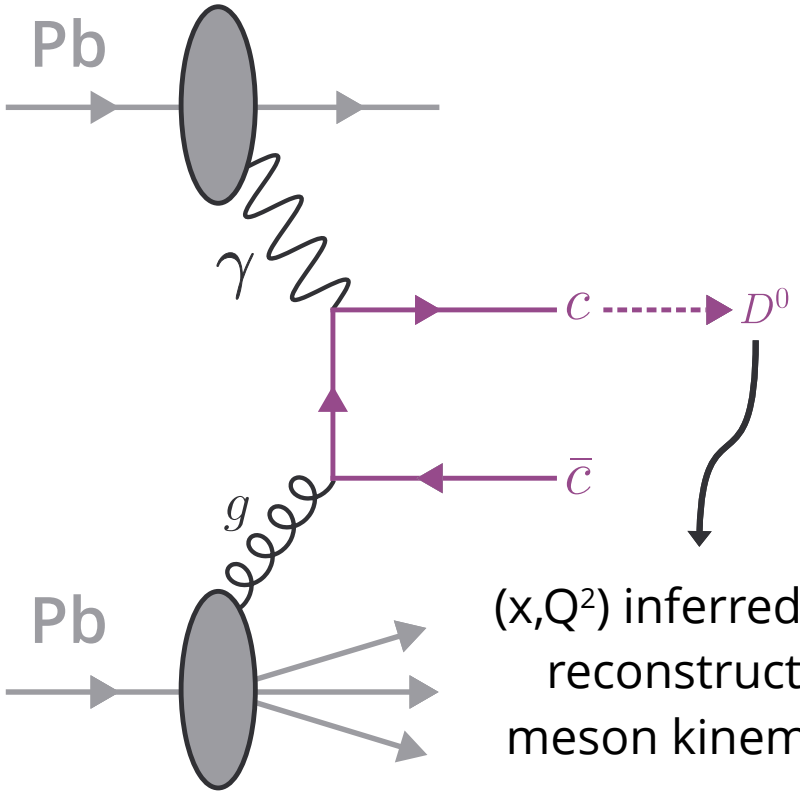


- Threshold above noise level of both Data and MC
- Minimize efficiency difference between direct/resolved events
- Minimize hadronic contamination
- HF energy cuts: HF+: 9.2 GeV, HF-: 8.6 GeV
- ~10% syst. uncertainty



UPCs vs e-p measurements

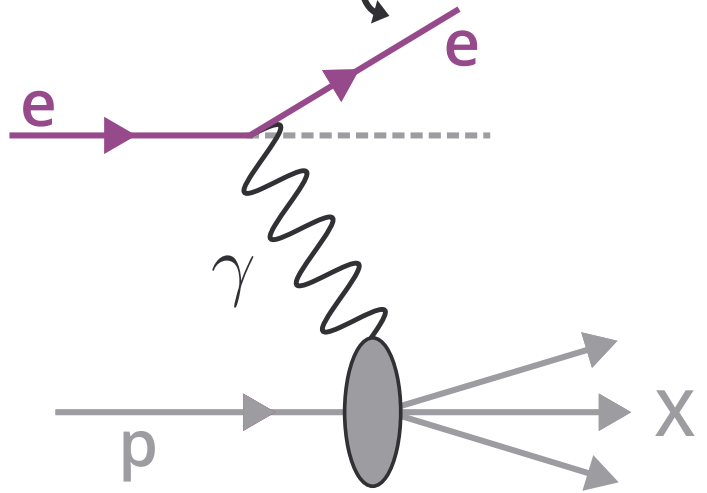
UPC



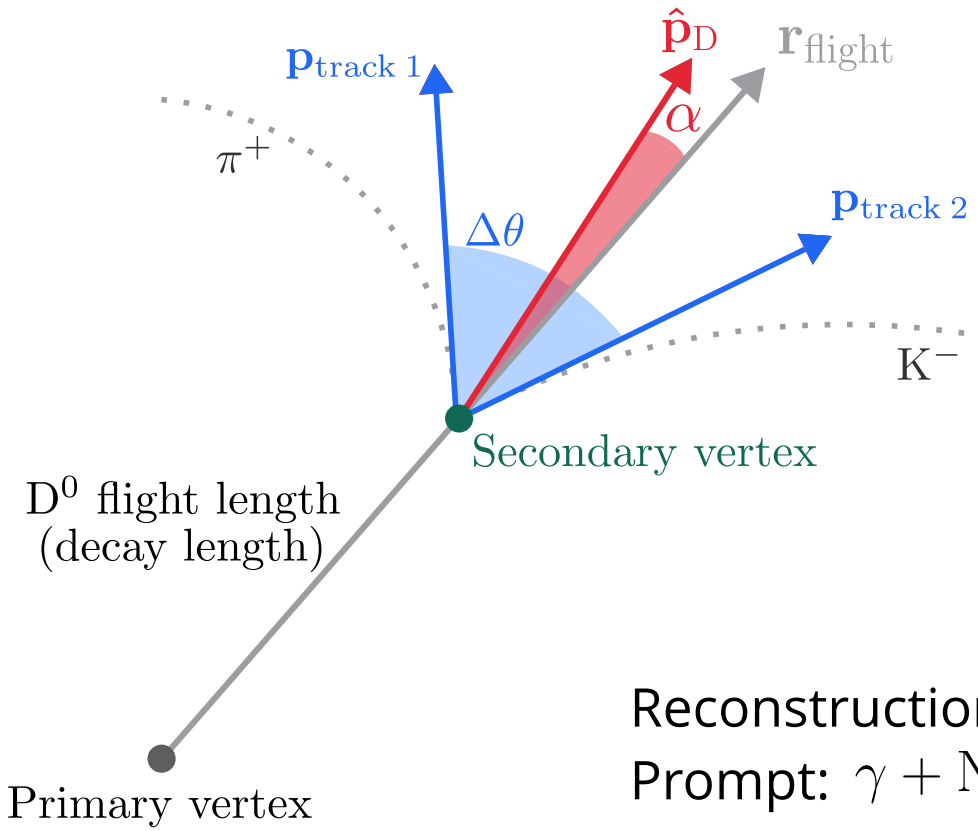
(x,Q²) inferred from reconstructed meson kinematics

e-p scattering

(x,Q²) inferred from scattered electron kinematics



D^0 meson reconstruction and selection



Topological cuts:

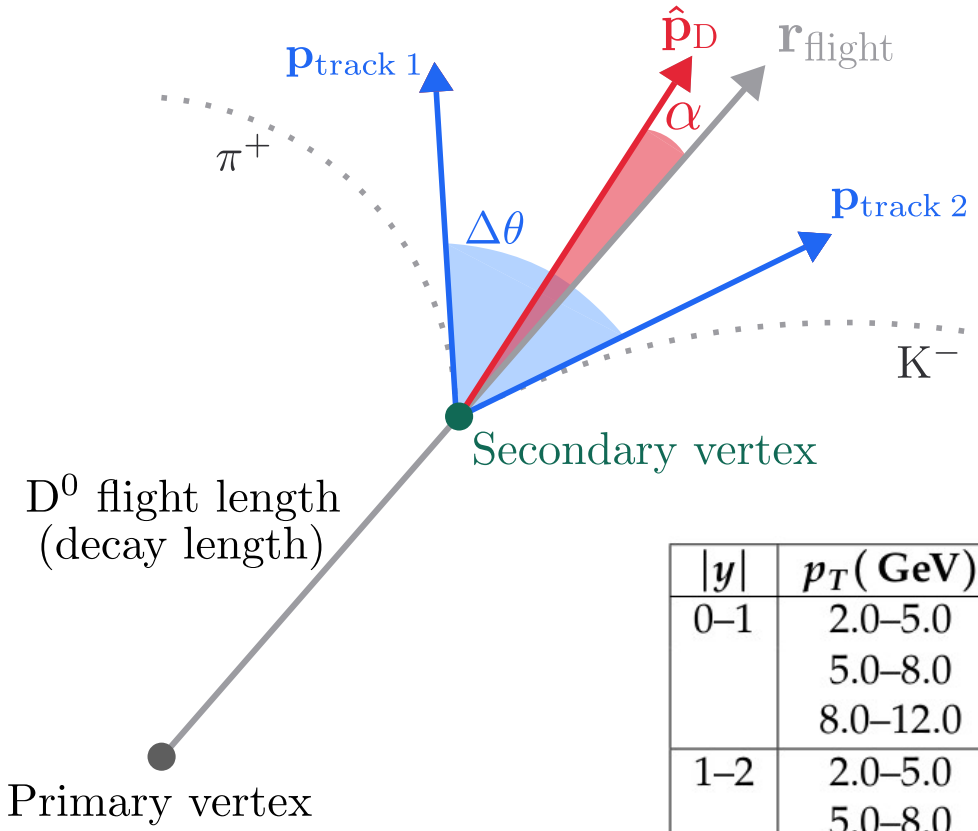
- Pointing angle (α)
- Opening angle (Δθ)
- Secondary vertex reconstruction quality (χ^2)
- Decay length significance

Reconstruction inclusive over:

Prompt: $\gamma + \text{N} \rightarrow c + \ldots \rightarrow D^0$

Non-prompt: $\gamma + \text{N} \rightarrow b + \ldots \rightarrow B \rightarrow D^0$

D^0 meson reconstruction and selection



Topological cuts:

- Pointing angle (α)
- Opening angle (Δθ)
- Secondary vertex reconstruction quality (χ^2)
- Decay length significance

$\lvert y\rvert$	p_T (GeV)	α	$d_0/\sigma(d_0)$	Vertex Probability	$\Delta\theta$
0–1	2.0–5.0	< 0.4	> 2.5	> 0.1	< 0.5
	5.0–8.0	< 0.35	> 3.5	> 0.1	< 0.3
	8.0–12.0	< 0.4	>3.5	> 0.1	< 0.3
1–2	2.0–5.0	< 0.2	> 2.5	> 0.1	< 0.3
	5.0–8.0	< 0.25	> 3.5	> 0.1	< 0.3
	8.0–12.0	< 0.25	> 3.5	> 0.1	< 0.3

Computing the cross section

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} = \frac{1}{\mathcal{L}_\mathrm{int}\, P_\mathrm{presc.}\, \varepsilon_\mathrm{trigger}\, f_\mathrm{EMD\ PU}} \cdot \frac{1}{\varepsilon_\mathrm{evt.}} \cdot \frac{1}{\mathcal{B}(D^0 \to K^-\pi^+)\,(\alpha\varepsilon)_{D^0}} \frac{1}{2} \frac{N_\mathrm{raw}^{D^0+\bar{D}^0}}{\Delta y \Delta p_\mathrm{T}}$$

- Luminosity normalization
- Trigger efficiency
- Electromagnetic pile-up correction
- Event selection efficiency

- Branching ratio of the decay channel
- D^0 acceptance, reconstruction and selection efficiency
- D^0 yield from fitting

Systematic uncertainties

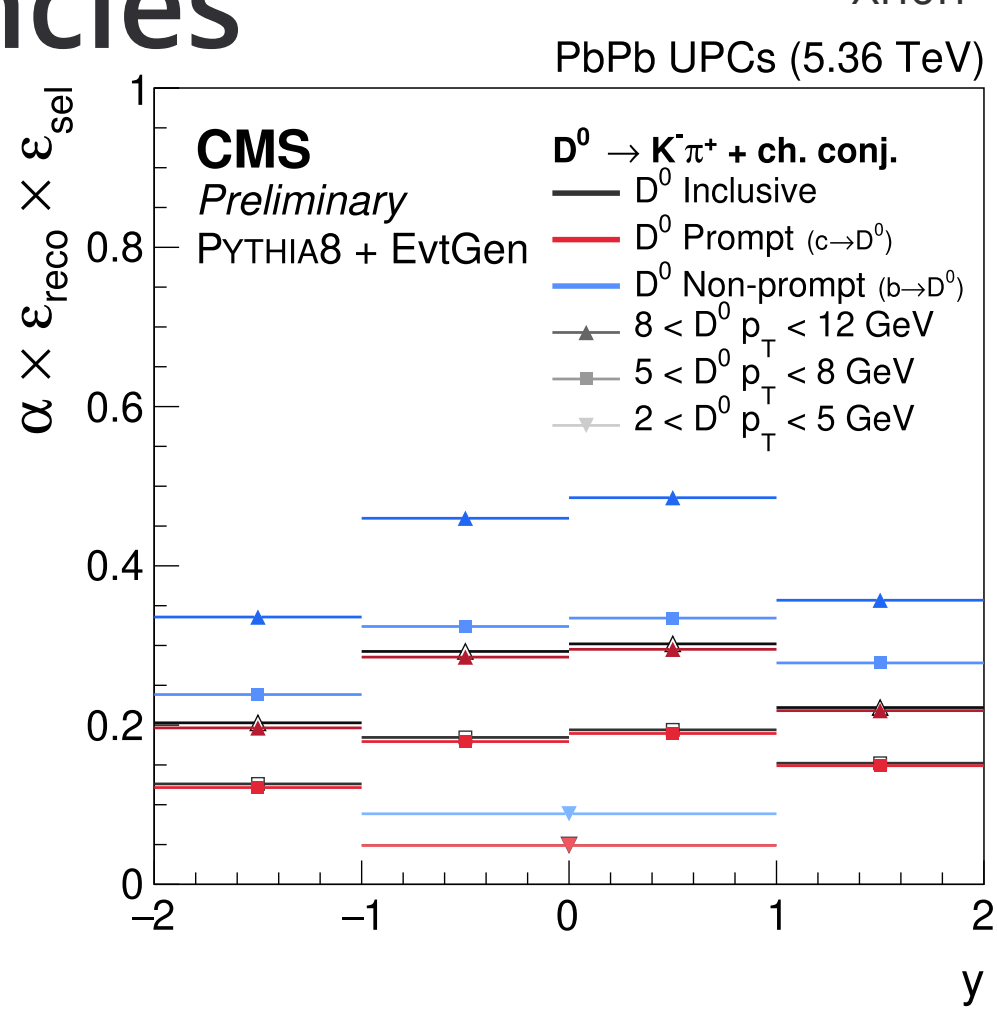
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} = \frac{1}{\mathcal{L}_\mathrm{int}\, P_\mathrm{presc.}\, \varepsilon_\mathrm{trigger}\, f_\mathrm{EMD\ PU}} \cdot \frac{1}{\varepsilon_\mathrm{evt.}} \cdot \frac{1}{\mathcal{B}(D^0 \to K^-\pi^+)\,(\alpha\varepsilon)_{D^0}} \frac{1}{2} \frac{N_\mathrm{raw}^{D^0+\bar{D}^0}}{\Delta y \Delta p_\mathrm{T}}$$

- Global luminosity unc.
- Trigger efficiency and EMD PU unc.
- Rapidity gap selection unc.

- Branching fraction unc.
- Prompt/non-prompt and direct/resolved MC-Data differences
- D^0 selection and fit unc.
- D^0 MC reweighting

D^0 related efficiencies

- Extracted from MC simulation
- Strong increase with p_T
- Lower at large rapidity
- Overall efficiency dominated by prompt production

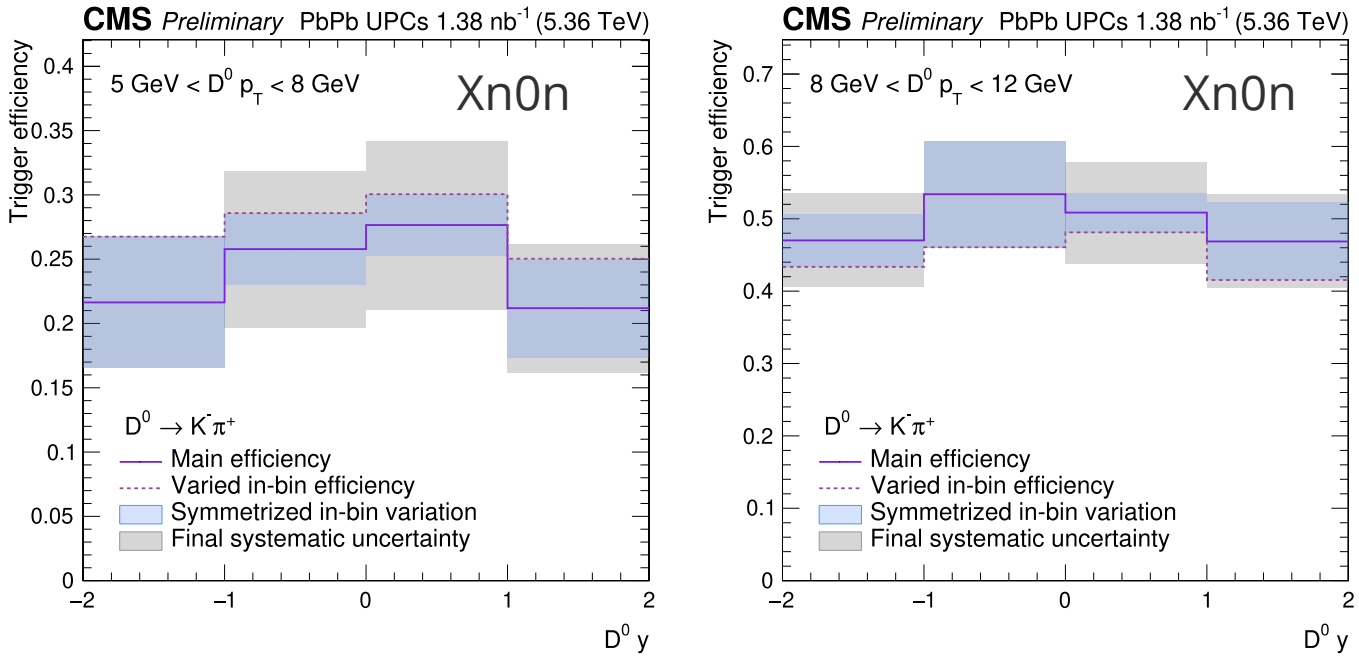


Trigger efficiency

$2 < p_T < 5$ GeV: ZDCOR trigger – offline selection is strictly tighter

$5 < p_T < 12$ GeV: ZDCXOR+Jet8 trigger – needs correction for jet trigger part

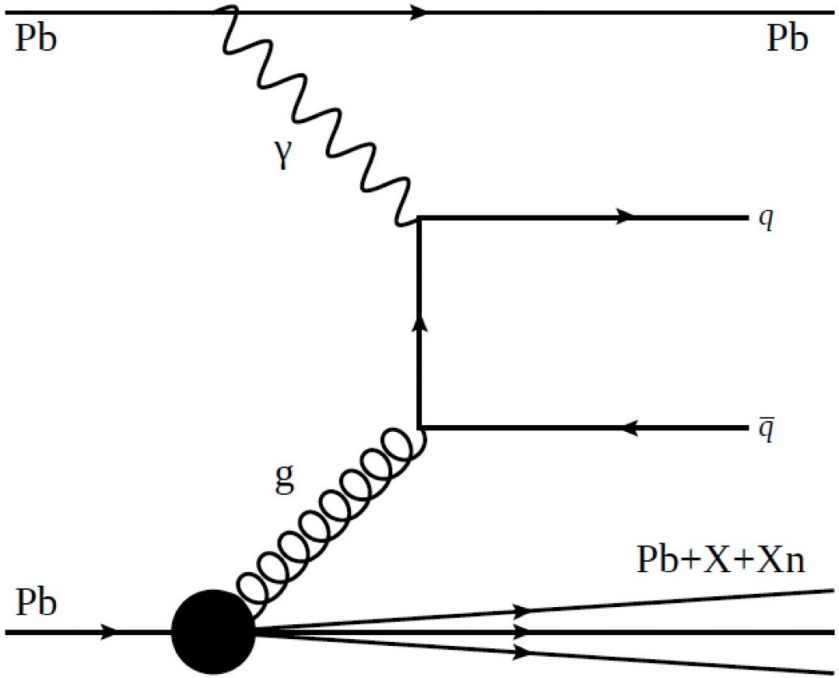
→ large systematic unc.



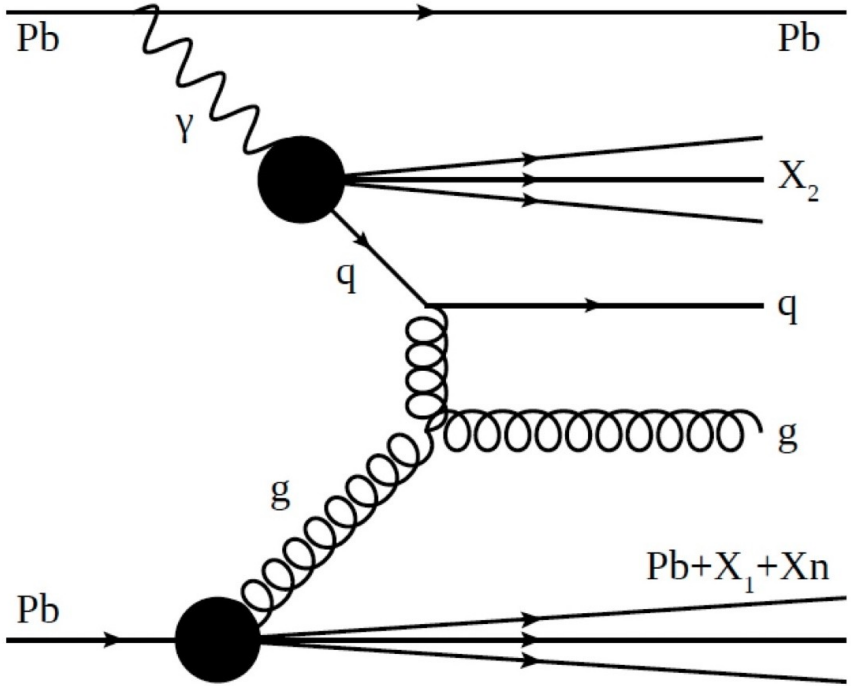
Direct vs resolved events

Our measurement contains both processes

Systematic considered for possible selection efficiency difference

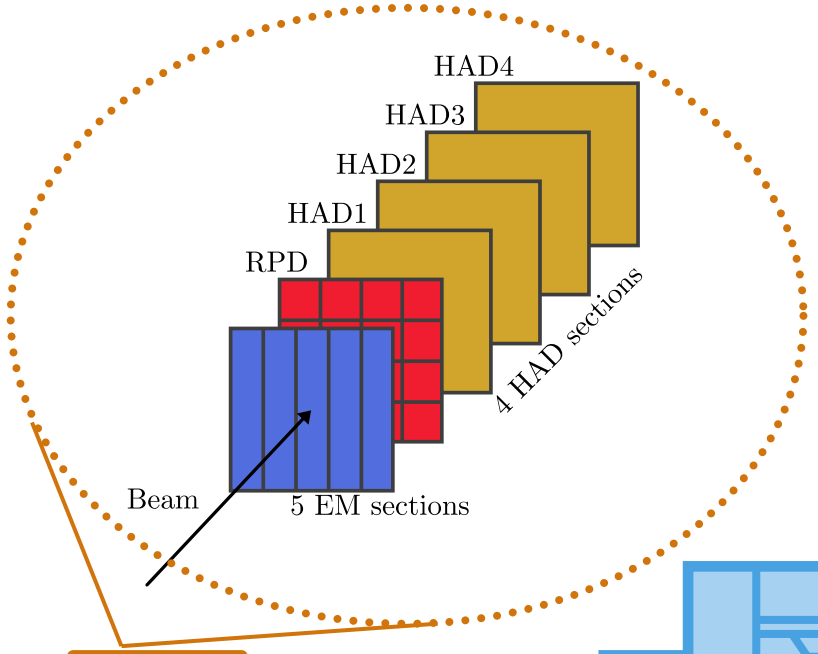


Direct production

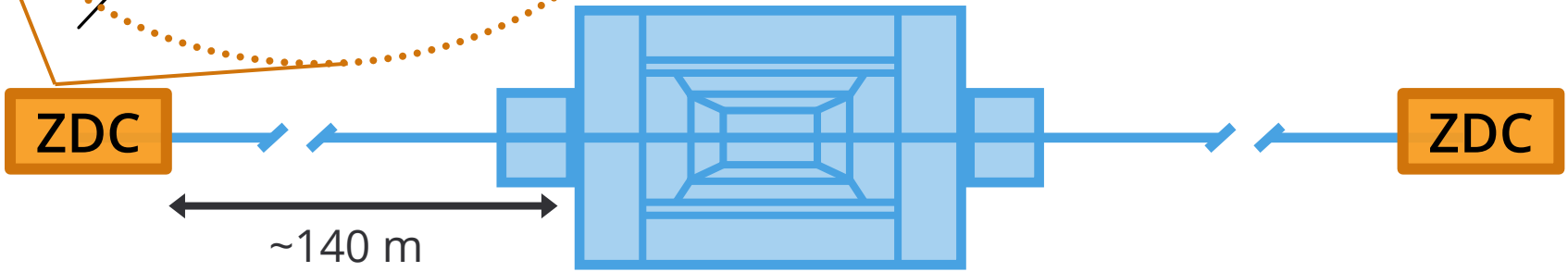


Resolved production

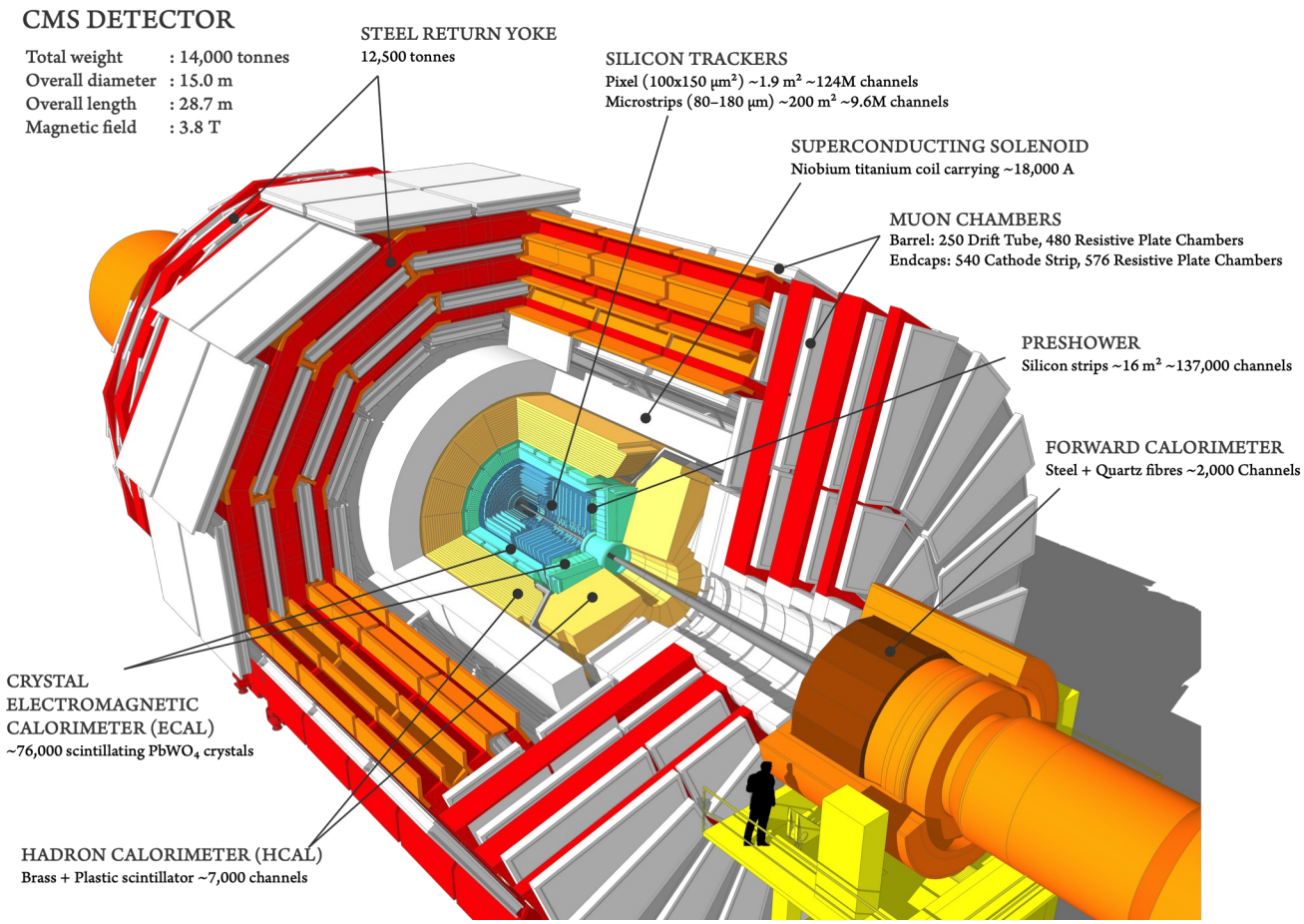
Zero Degree Calorimeters

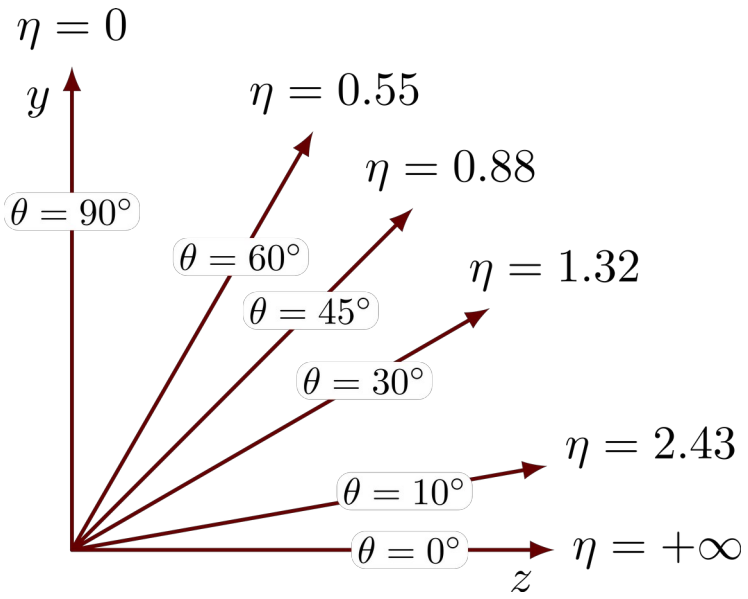


ZDC signal built by a weighted sum of electromagnetic and hadronic calorimeter signals



The CMS detector





$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$