Introduction to ultraperipheral collisions: UPC

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Outline

- Ultraperipheral collisions: photon induced reactions using relativistic heavy nuclei
- Examples of processes in UPC:
  - Photon-photon processes
  - Exclusive reactions
  - Inclusive processes:
    - ➤ Open charm photoproduction in UPC:
    - ➤ Theoretical predictions for D^0 production in UPC at LHC and comparison with CMS data

Work with **Gian-Michele Innocenti** and **Matteo Cacciari, arXiv:2506.09893**

UPC topical conference

UPC2025: The second international workshop on the physics of Ultra Peripheral Collisions

Jun 9 – 13, 2025
Saariselkä, Finland
Europe/Helsinki timezone

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- Call for Abstracts
- Timetable
- Contribution List
- Book of Abstracts
- Registration
- Participant List
- Important dates
- Financial support
- Travel and accommodation

UPC2025

The second international workshop on the physics of Ultra Peripheral Collisions will be organized in Finland in June 2025.

This is an in-person only event.

The following research topics will be discussed:

- Exclusive processes and small-x physics
- Monte Carlo event generators for UPCs and photon-mediated processes
- Inclusive and diffractive processes and photon, proton and nuclear structure
- Photon-photon physics, precision tests of SM and BSM
- New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities

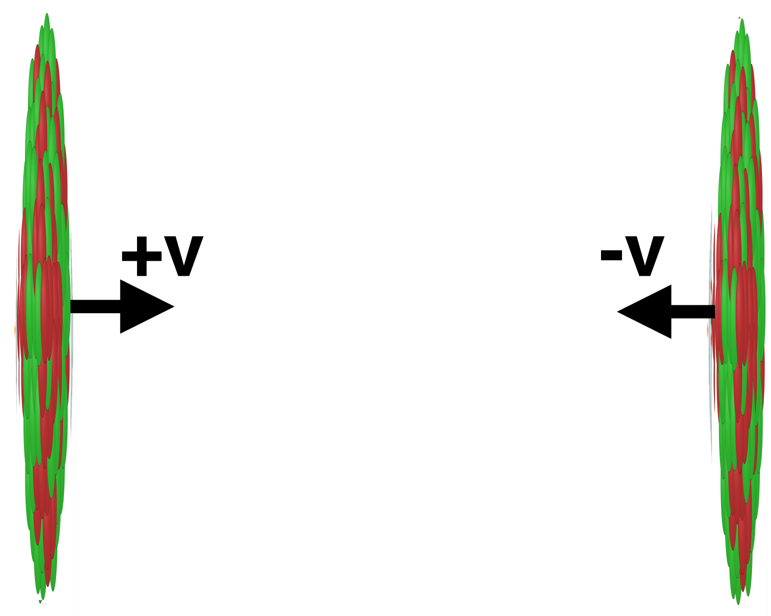
Discussing ultraperipheral collisions in ultraperipheral location…

Heavy ion collisions

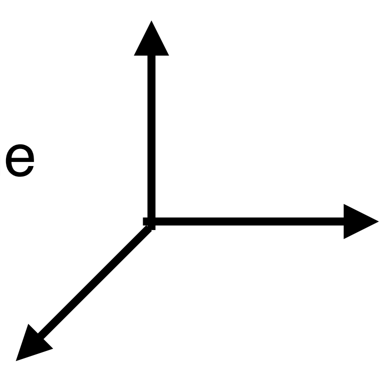
LHC :

$$\sqrt{s_{\mathrm{NN}}} = 5.36\,\mathrm{TeV}$$

Collisions of highly relativistic nuclei

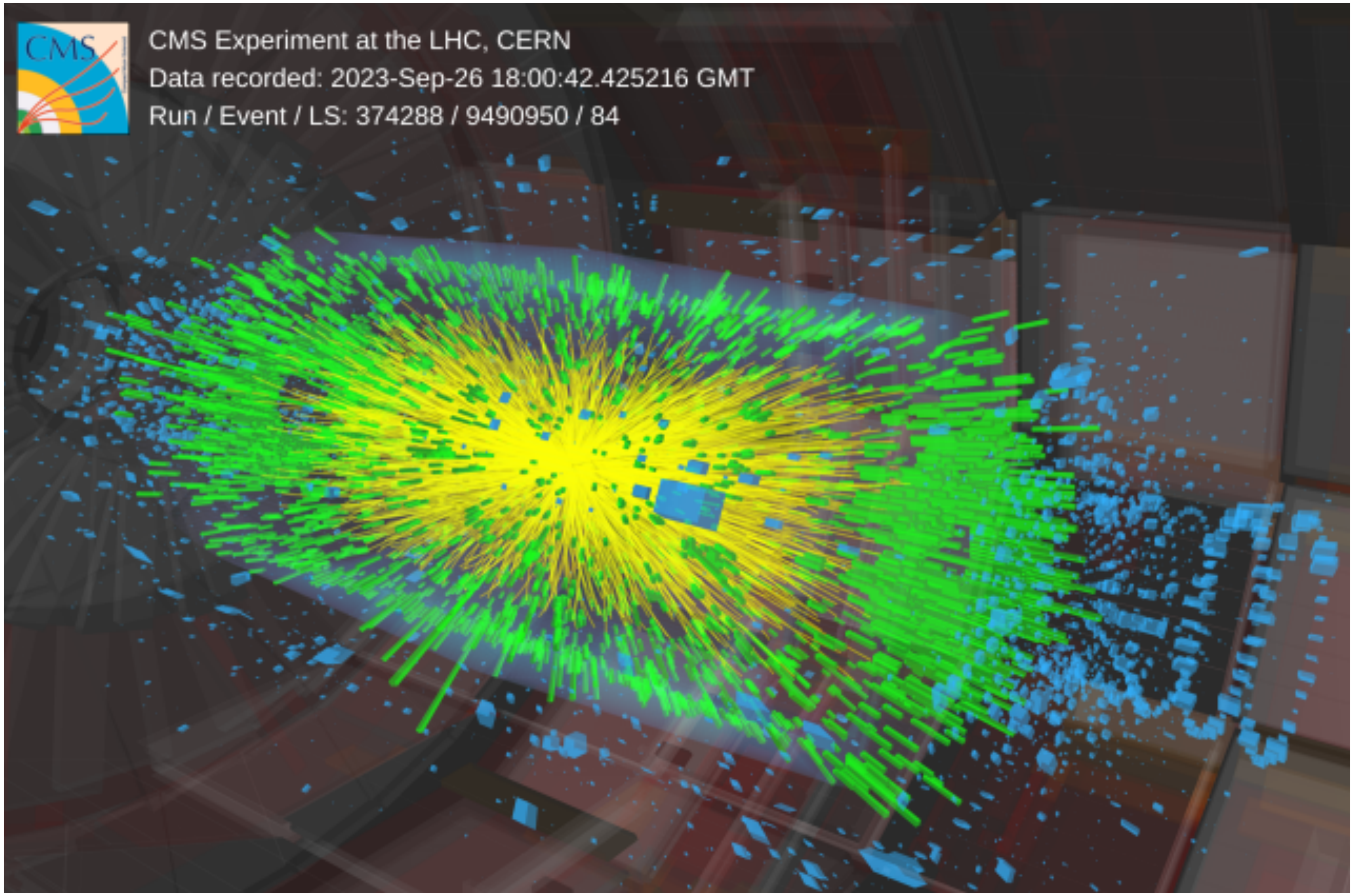


lab frame



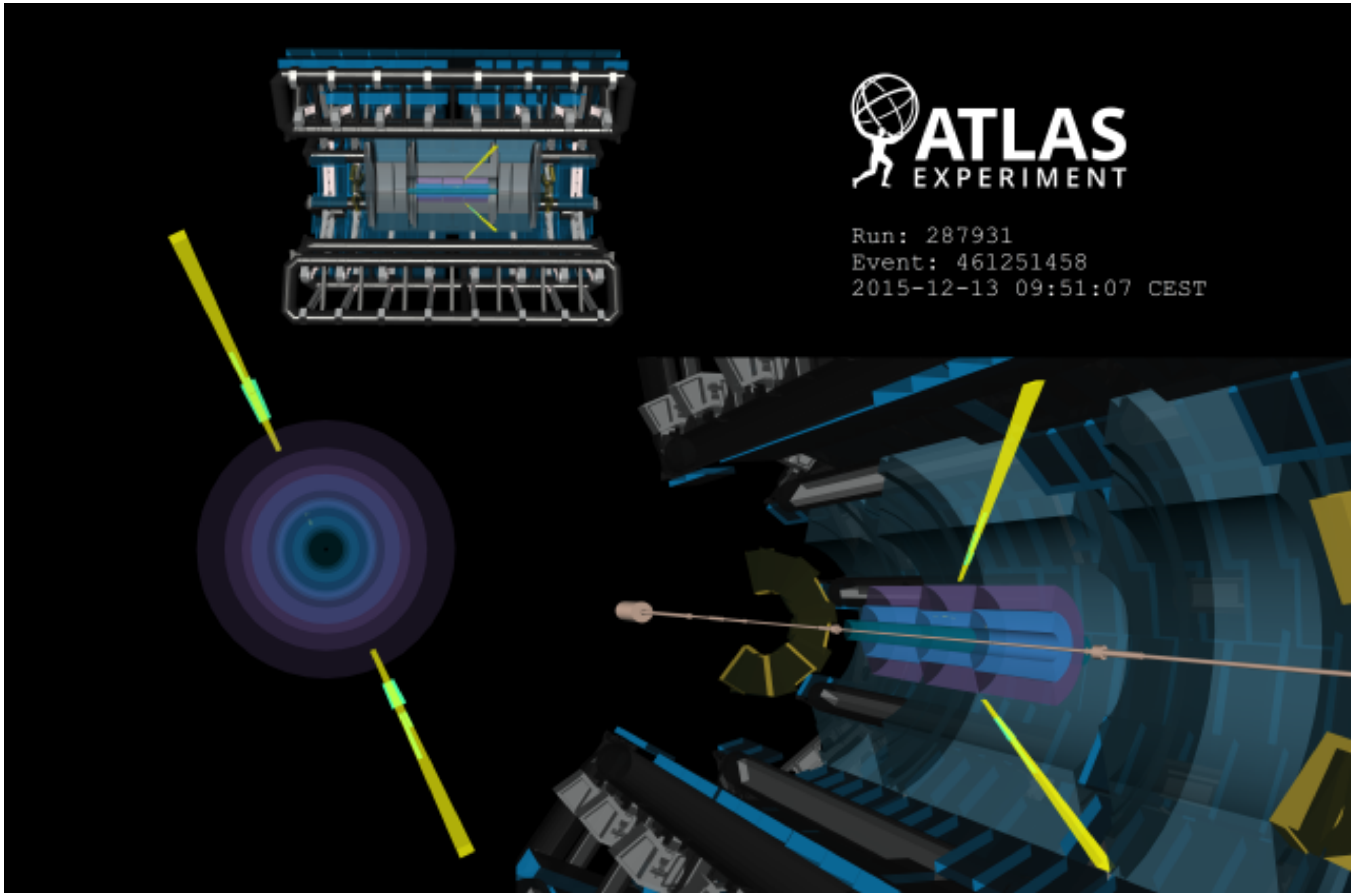
Lead (Pb) nuclei:
→ total 208 nucleus (A=208)
→ 82 protons (Z=82)
→ 126 neutrons

PbPb event at LHC



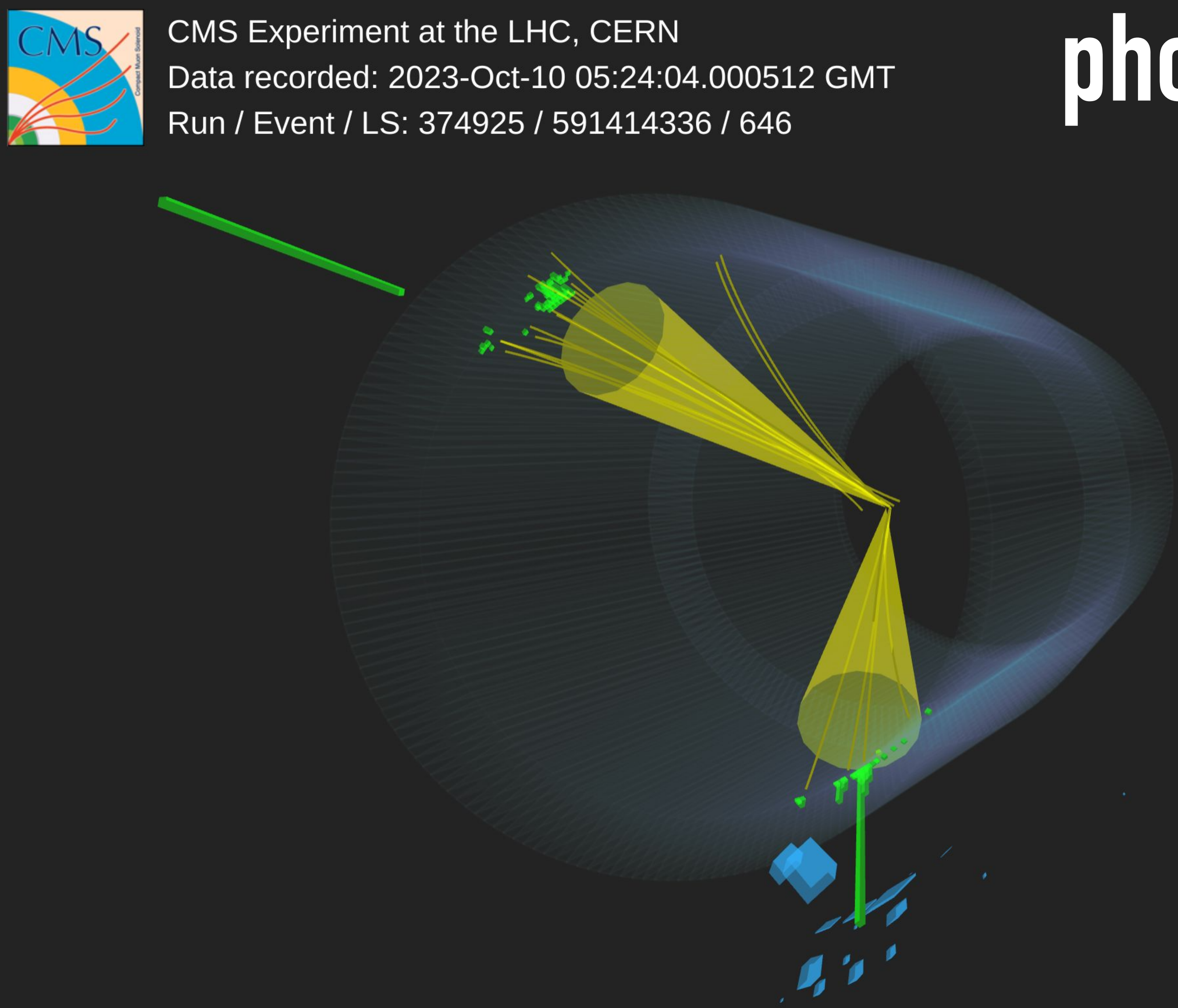
PbPb collision: large multiplicity of produced particles

UPC events: light by light scattering



light-by-light scattering in UPC PbPb collisions at 5.02 TeV
Two back-to-back photons with an invariant mass of 24 GeV with no additional activity in the detector are presented.

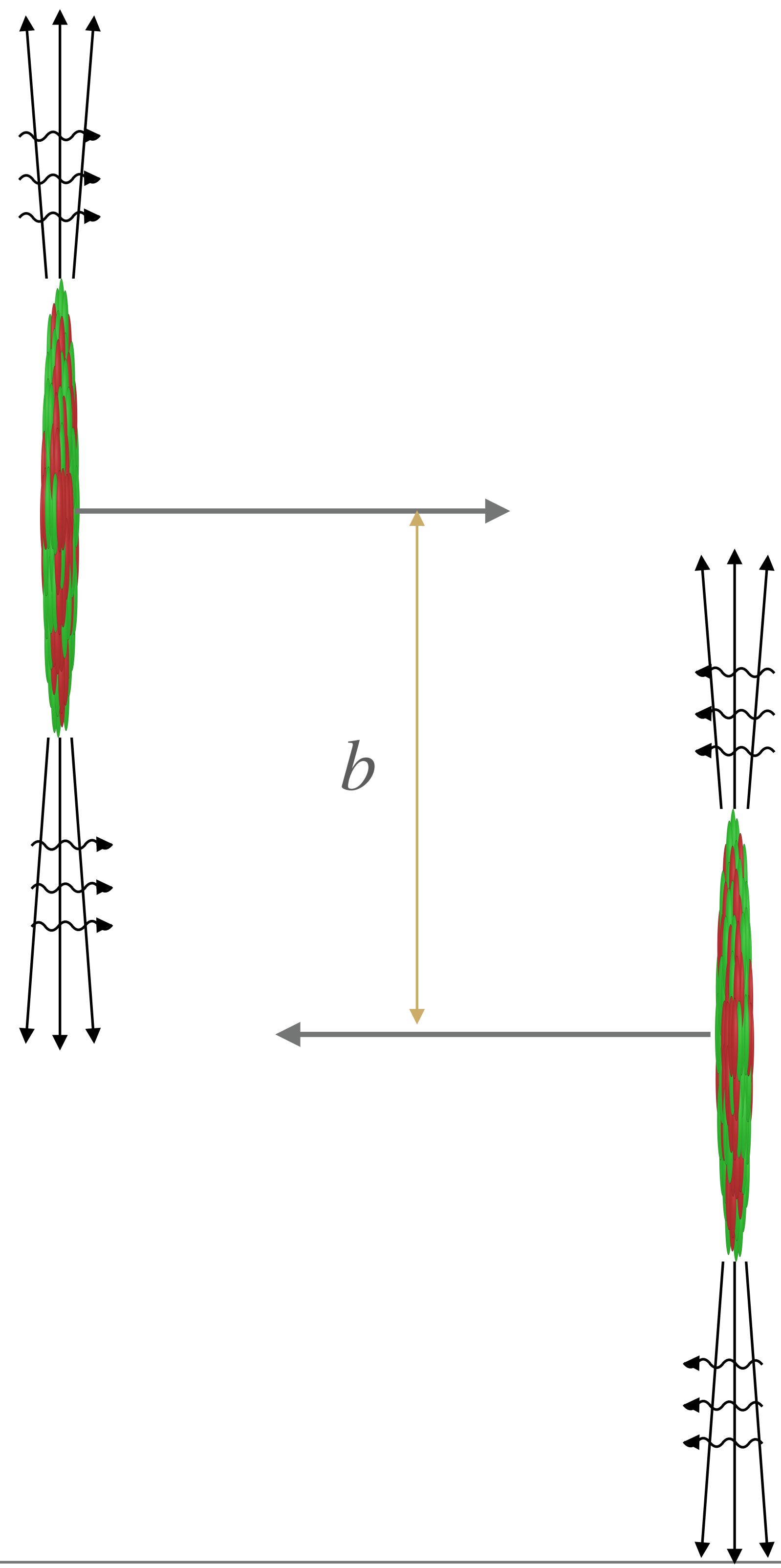
photonuclear events



Clean dijets events with negligible underlying QCD background

A photonuclear dijet candidate in PbPb UPCs ‘23

Ultraperipheral AA collisions



UPC: **ultraperipheral** AA collisions, $b > 2R_A$

Dominated by **electromagnetic** component

Cleaner environment than standard AA collisions

Equivalent photon approximation EPA

Photon flux **enhanced** by Z^2 of nucleus

Unique source of **high-energy photon-nucleus** collisions at a collision energy is much higher than in any electron-ion collider

LHC :

PbPb, Z=82, A=208

$\sqrt{s_{\rm NN}} = 5.36\,\rm TeV$

Equivalent photon approximation

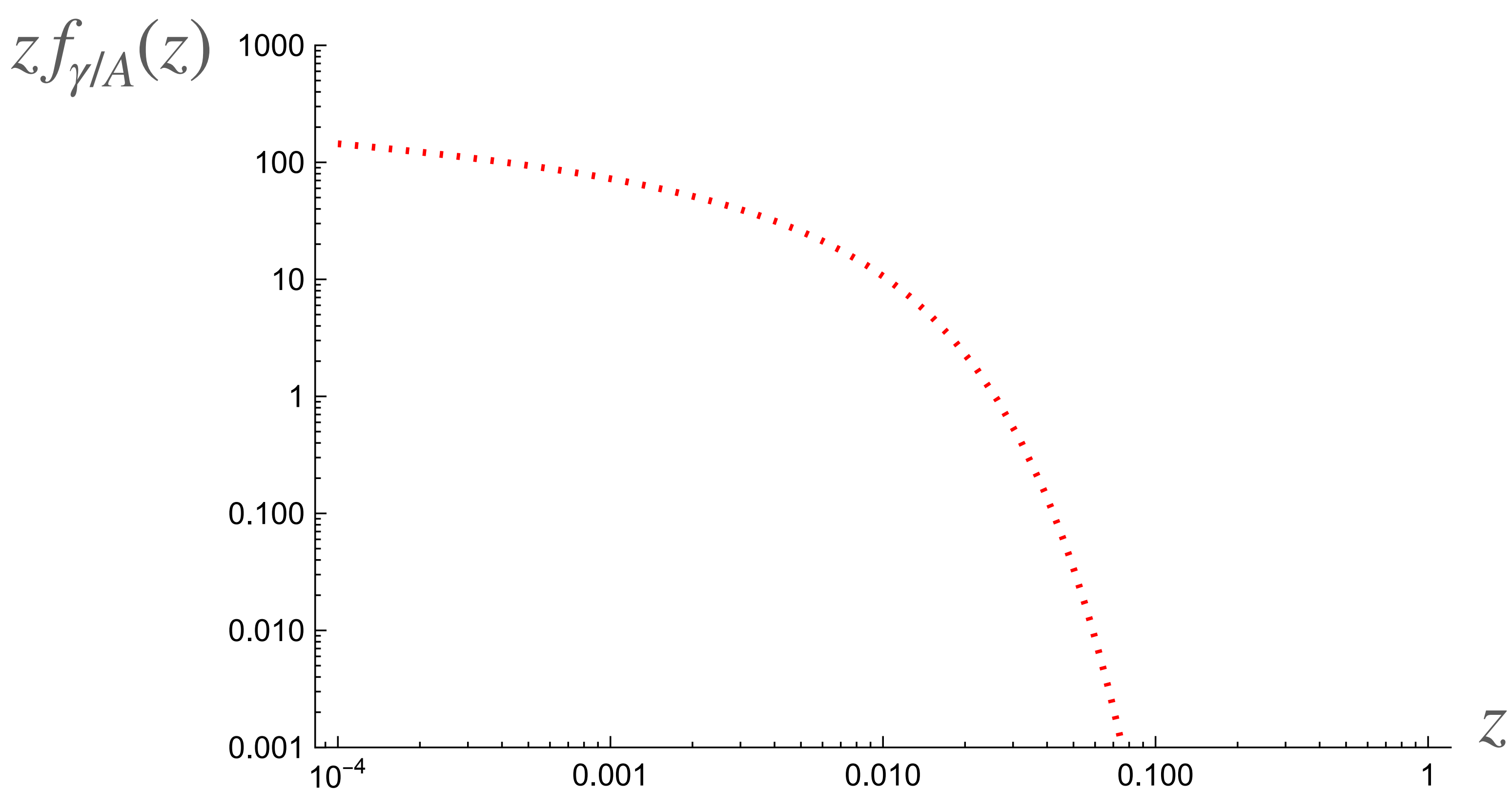
Fermi, Weizsaecker, Williams

Flux of photons from a highly relativistic projectile

$$f_{\gamma/A}(z) = \frac{2Z^2\alpha_{em}}{\pi z}\left[\eta K_0(\eta)K_1(\eta) - \frac{\eta^2}{2}(K_1(\eta)^2 - K_0(\eta)^2)\right]$$

$\eta = z m_p b_{\min}/(\hbar c)$

$Z = 82,\ b_{\min} = 2R_A = 2\times 7.1$ fm



Flux is cutoff at:

$$z_{\max} \sim (\hbar c)/(m_p b_{\min})$$

For $E_N \simeq 2500$ GeV

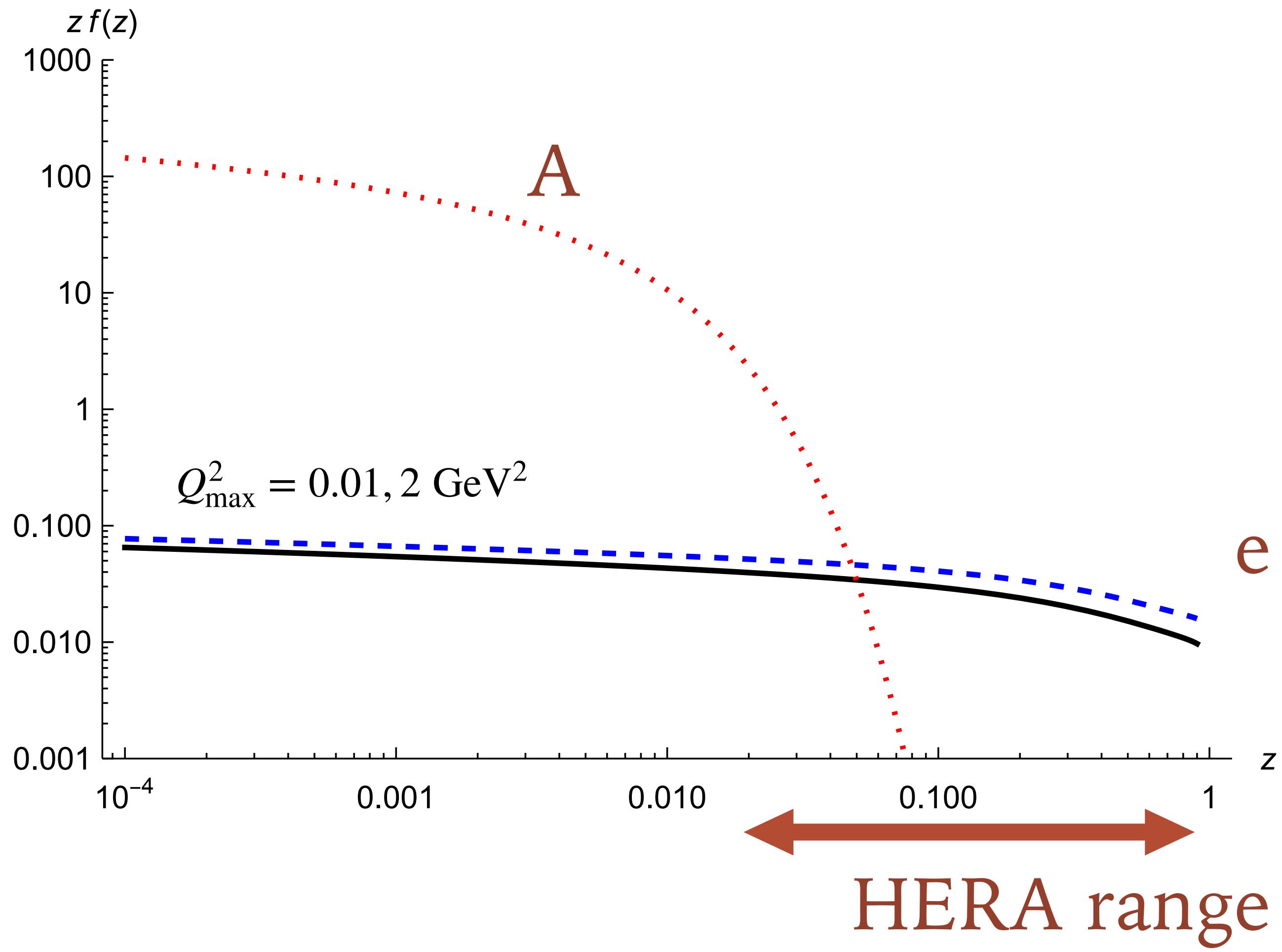
$$E_\gamma^{\max} \sim 100\,\mathrm{GeV}$$

(in the lab frame)

Small z

$$f_{\gamma/A}(z) \simeq \frac{2Z^2\alpha_{em}}{\pi z}\log(\frac{1}{\eta})$$

Photon fluxes for electron and nucleus



Comparison with **electron** flux

HERA (electron-proton) photon energy, extending to large fractions

UPC: flux steeply falling beyond z=0.01

Small z

electron

$$f_{\gamma/e}(z) = \frac{\alpha_{em}}{2\pi}\left[\frac{1+(1-z)^2}{z}\log\left(\frac{Q^2_{\max}(1-z)}{(m_e z)^2}\right)\right]$$

$$f_{\gamma/e}(z) \simeq \frac{\alpha_{em}}{\pi}\left[\frac{1}{z}\log\left(\frac{Q^2_{\max}}{(m_e z)^2}\right)\right]$$

nucleus

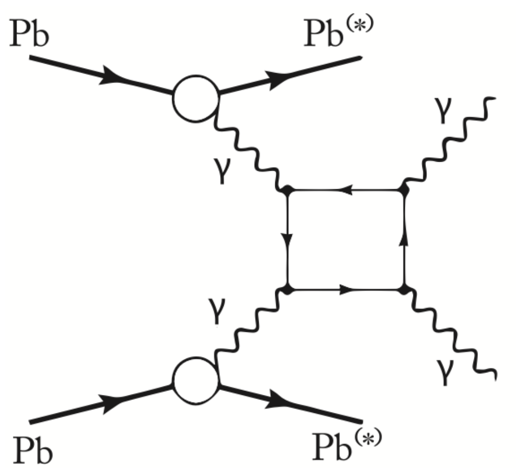
$$f_{\gamma/A}(z) = \frac{2Z^2\alpha_{em}}{\pi z}\left[\eta K_0(\eta)K_1(\eta) - \frac{\eta^2}{2}(K_1(\eta)^2 - K_0(\eta)^2)\right]$$

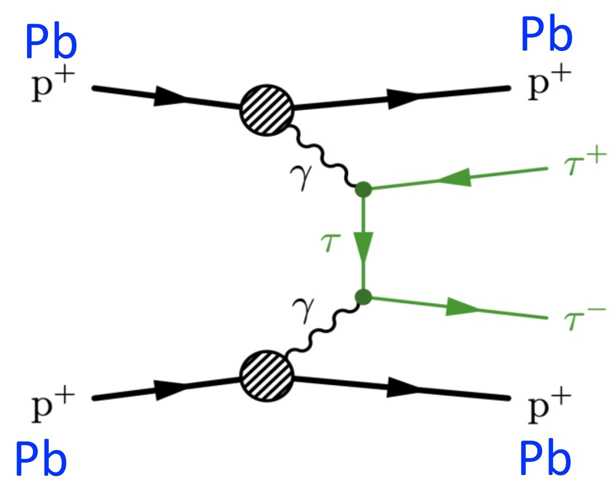
$$\eta = z m_p b_{\min}/(\hbar c)$$

$$Z = 82,\ b_{\min} = 2R_A = 2\times 7.1\ \mathrm{fm}$$

UPC physics

γγ physics



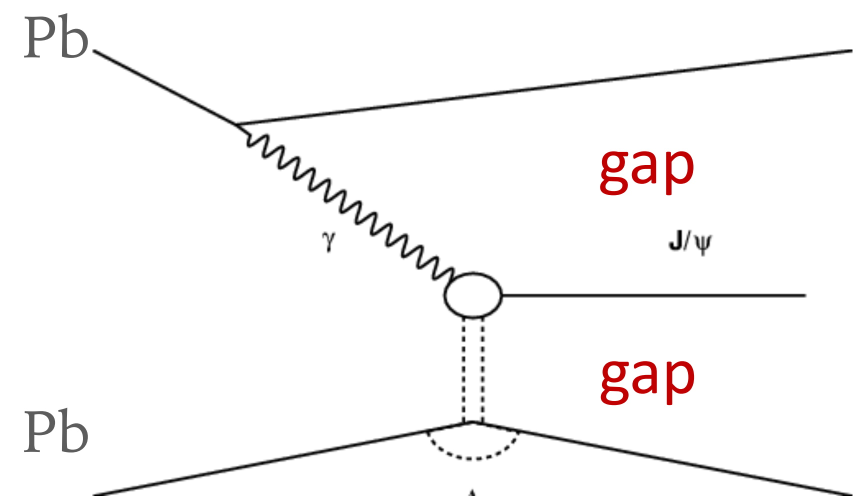


Testing QED

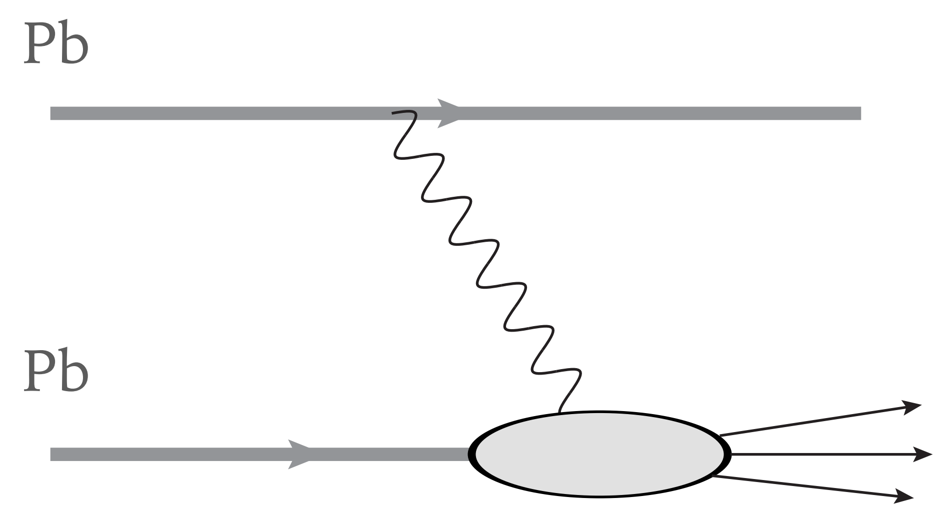
Testing SM in general

BSM and exotic searches

γA :photonuclear interactions

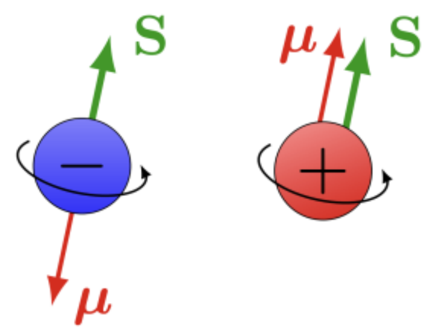


Exclusive production



Inclusive: dijet, heavy quark production

γγ physics: g−2

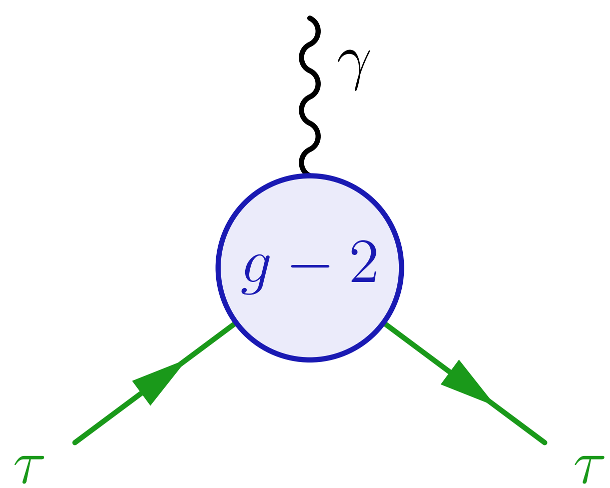


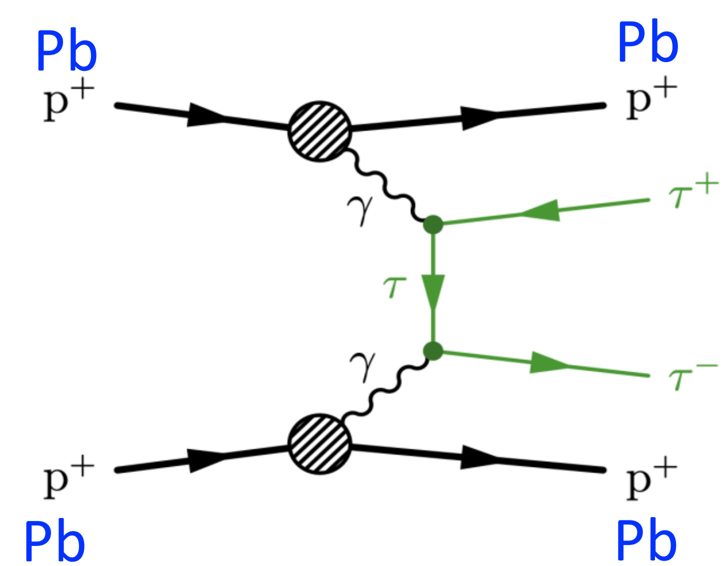
$$\boldsymbol{\mu} = g\frac{e}{2m}\mathbf{S} \longrightarrow \begin{cases} g = 1\text{: classical} \\ g = 2\text{: Dirac} \\ g \approx 2.002\text{: QED} \end{cases}$$

$$a_e^{(exp)} = 0.00115965218059(13)$$

$$a_\mu^{(exp)} = 0.001165920715(145)$$

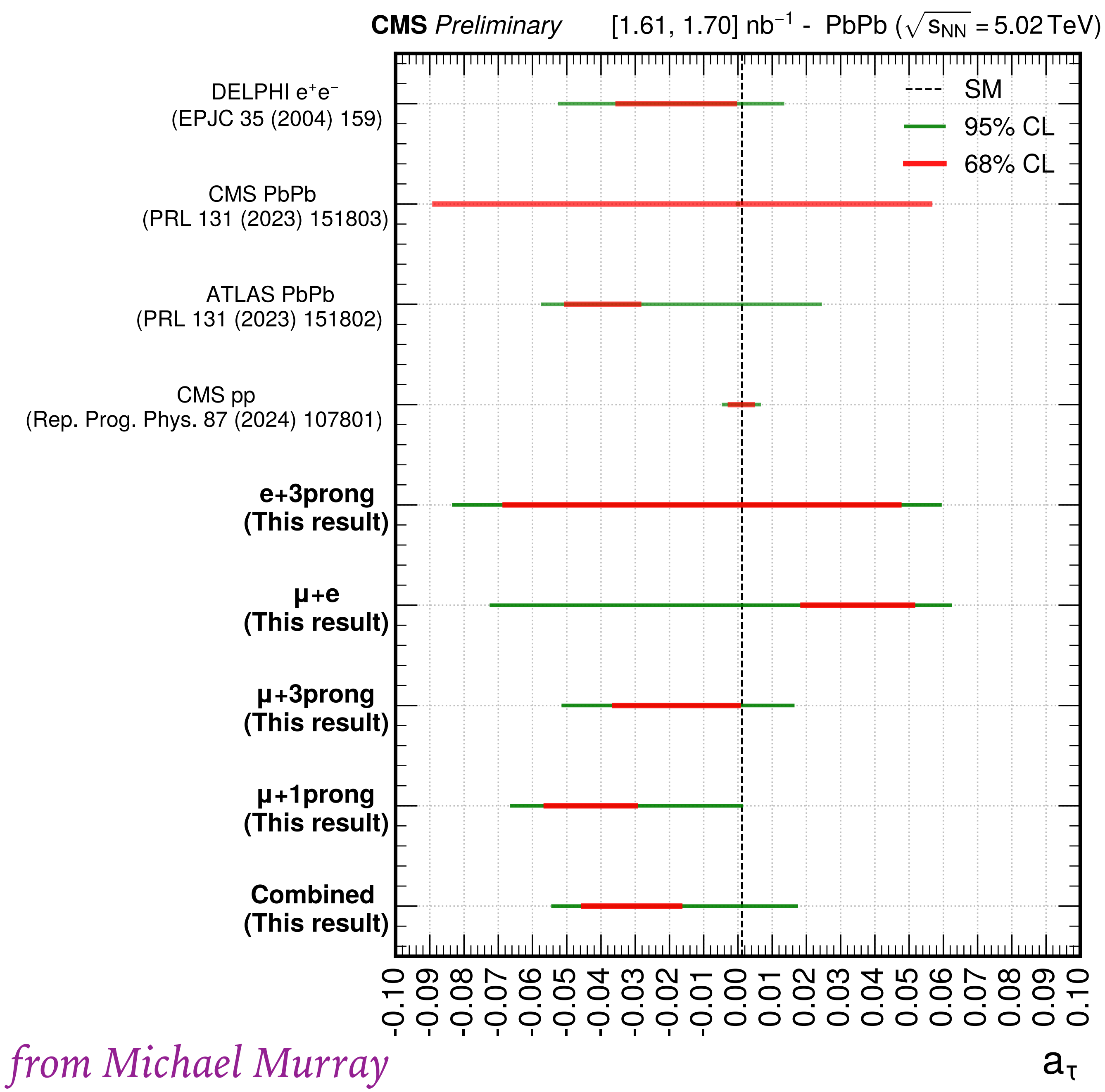
Latest FNAL+BNL combined





γγ physics: g-2

Constraints for g-2 from $\gamma\gamma \to \tau\tau$



plot from Michael Murray

PbPb measurement is in complementary phase space to pp measurement

From pp (most precise)

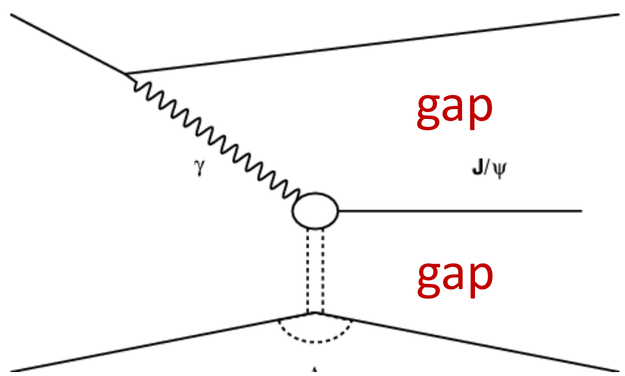
$$a_\tau^{(exp)} = 0.0009(+0.0032, -0.0031)$$

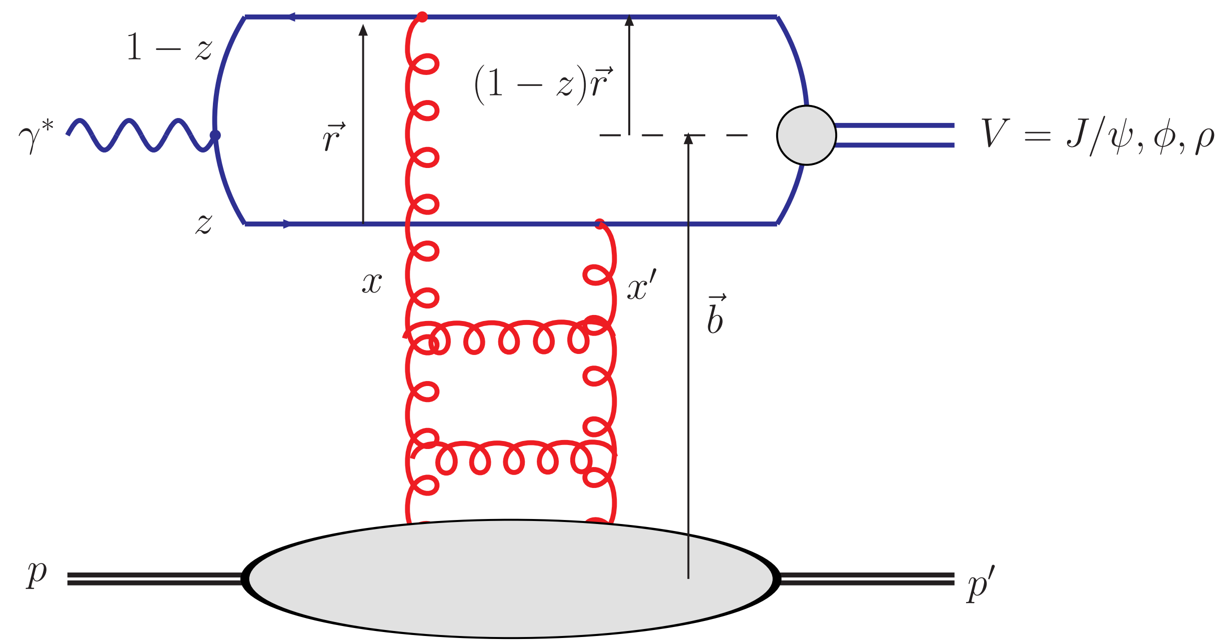
From PbPb

$$a_\tau^{(exp)} = -0.035(+0.018, -0.010)$$

Exclusive vector meson production

$\gamma p \to V p$





Exclusive (photo)production of vector mesons

Mass of the vector meson provides a hard scale

Process sensitive to **square of gluon density**

$$x = (Q^2 + M^2_{J/\psi})/(W^2 + M^2_{J/\psi})$$

$$\bar{Q}^2 = (Q^2 + M^2_{J/\psi})/4,$$

Lowest order formula (for electroproduction as well)

$$\frac{d\sigma}{dt}(\gamma^* p \to J/\psi\ p)\Big|_{t=0} = \frac{\Gamma_{ee} M^3_{J/\psi} \pi^3}{48\alpha} \boxed{\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} xg(x, \bar{Q}^2)\right]^2} \left(1 + \frac{Q^2}{M^2_{J/\psi}}\right)$$

Ryskin

Exclusive vector meson photoproduction

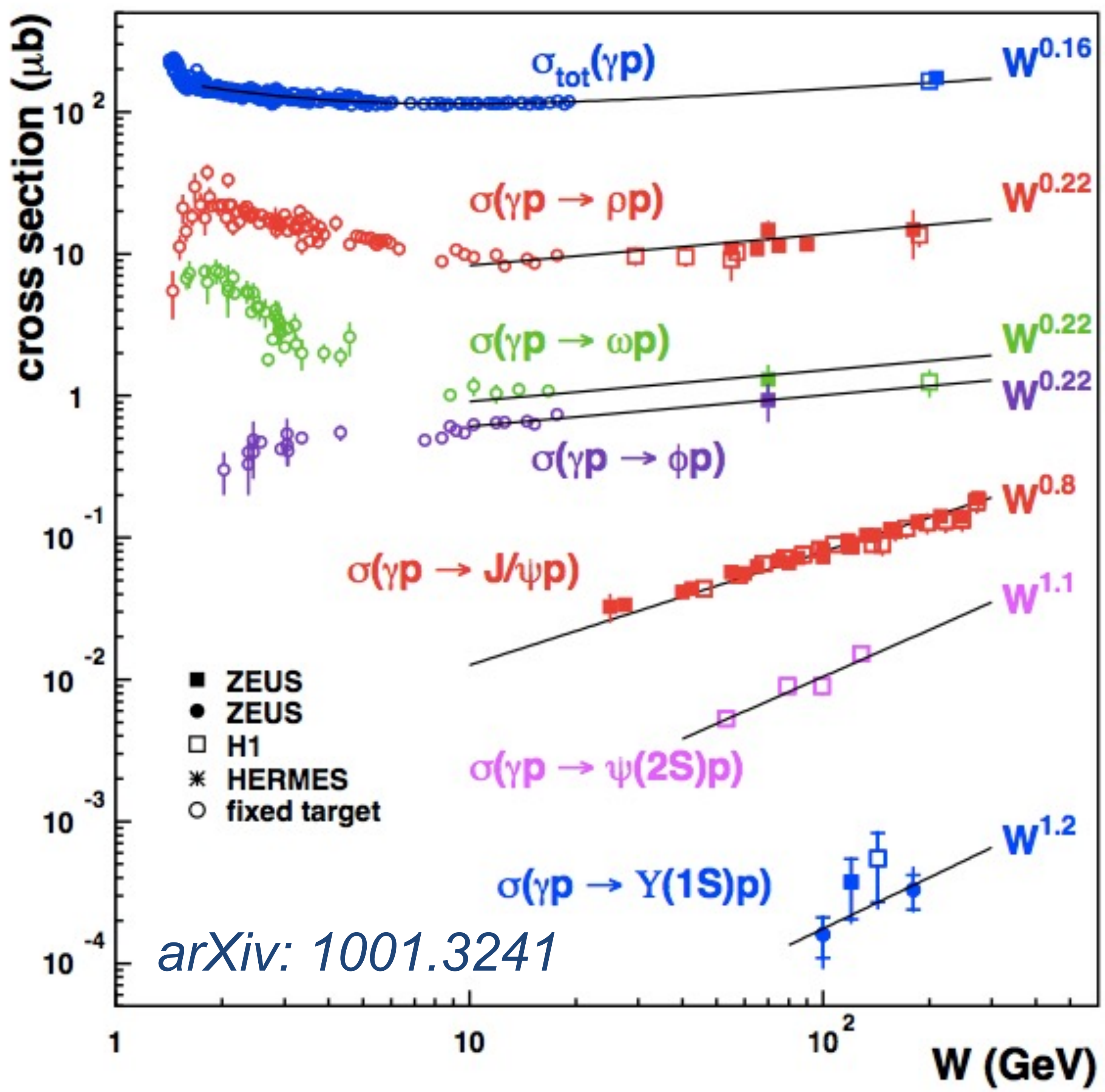
Measurements in ep

Rise in the slope of the energy
with the scale of the process

$$\sigma \sim W^{\delta}$$

$$\delta \sim 4(\alpha_p(t) - 1)$$

$$\alpha_p(t) = \alpha_p(0) + \alpha' t$$



VM photoproduction over range of energies

Can be measured in UPCs

Provides **large energy** range together with HERA measurements

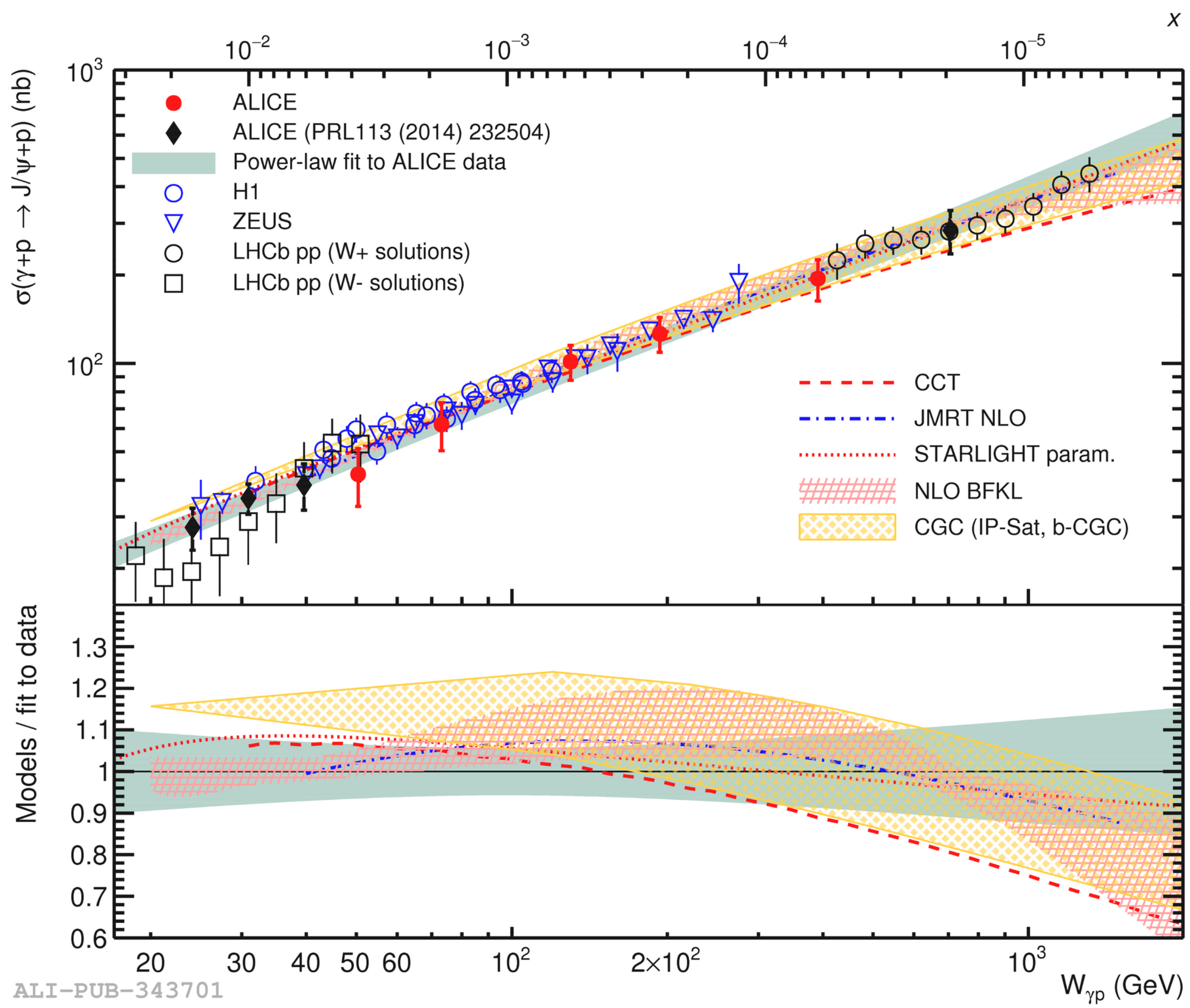
Can test **evolution** and **gluon density** at moderate scales

NLO collinear

NLO BFKL

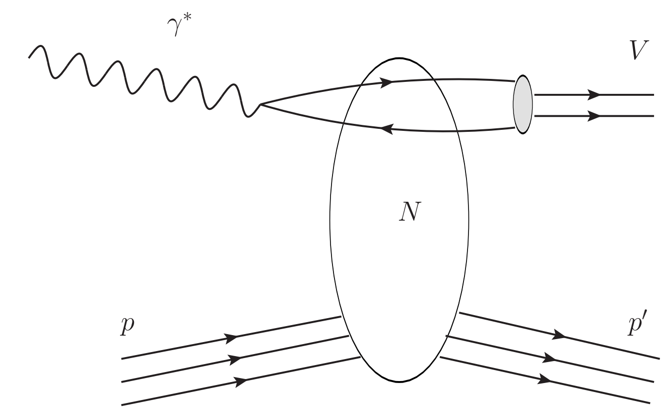
Nonlinear BK evolution with parton saturation

$$\gamma p \to J/\psi\, p$$



VM production: dipole approach at high energy

At high energy: **photon fluctuates** into quark-antiquark pair and interacts with the target



Differential cross section

$$\frac{d\sigma}{dt} = \frac{1}{16\pi}|A(x,\Delta,Q)|^2$$

Amplitude

$$A(x,\Delta,Q) = \sum_{h,\bar{h}} \int d^2\mathbf{r} \int dz\, \Psi_{h,h^*}(\mathbf{r},z,Q^2)\, \mathcal{N}(x,\mathbf{r},\Delta,z)\, \Psi^V_{h,h^*}(\mathbf{r},z)$$

$$\mathcal{N}(x,\mathbf{r},\Delta,z) = 2\int d^2\mathbf{b}\, N(x,\mathbf{r},\mathbf{b})\, e^{i\Delta\cdot(\mathbf{b}-(1-z)\mathbf{r})}$$

Dipole amplitude

$$N(x,\mathbf{r},\mathbf{b})$$

$\mathbf{r}$ dipole size

$\mathbf{b}$ impact parameter

VM production in the dipole picture

BK nonlinear equation for dipole amplitude at small x

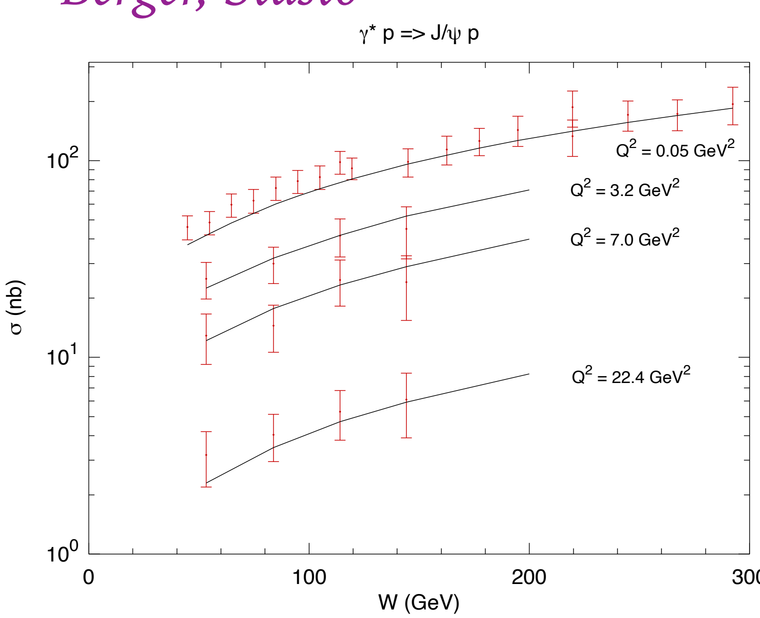
Balitsky; Kovchegov

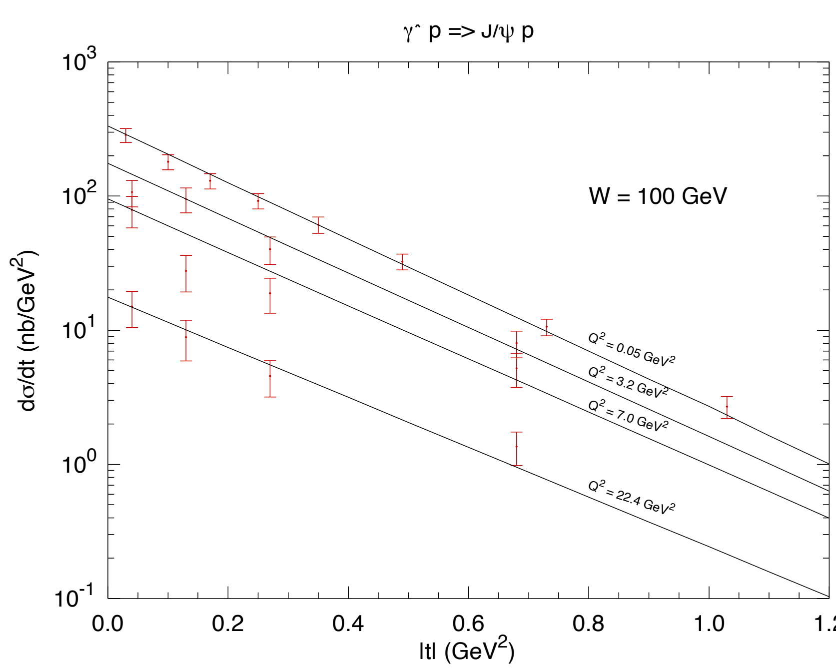
$$\frac{\partial N_{\mathbf{x}_0\mathbf{x}_1}}{\partial Y} = \int \frac{d^2\mathbf{x}_2}{2\pi}\,\mathcal{K}(x_{01},x_{12},x_{02};\alpha_s,m)\,[N_{\mathbf{x}_0\mathbf{x}_2}+N_{\mathbf{x}_2\mathbf{x}_1}-N_{\mathbf{x}_0\mathbf{x}_1}-N_{\mathbf{x}_0\mathbf{x}_2}N_{\mathbf{x}_2\mathbf{x}_1}]$$

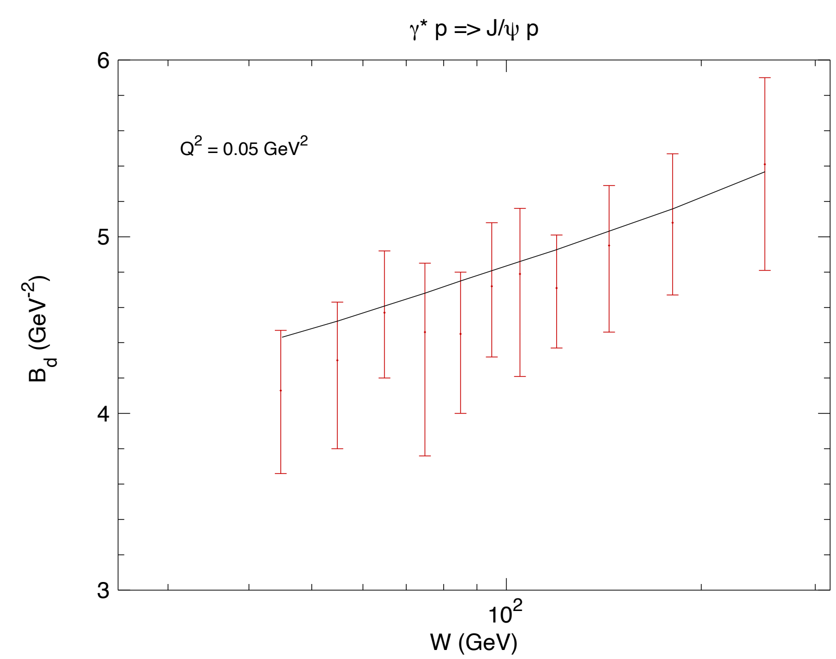
Can obtain good description of various features of the data on VM elastic photo- and electroproduction in electron - proton using impact parameter dependent BK

HERA data

Berger, Stasto



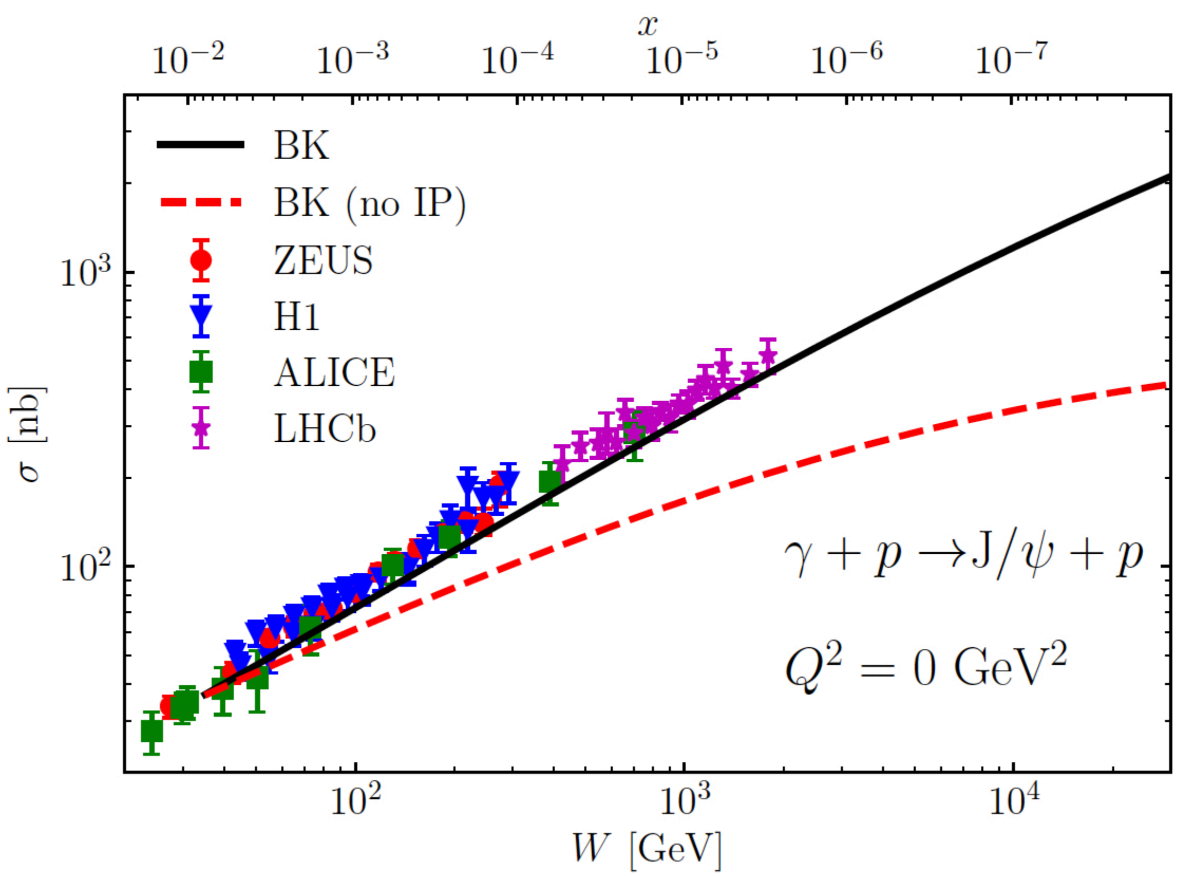


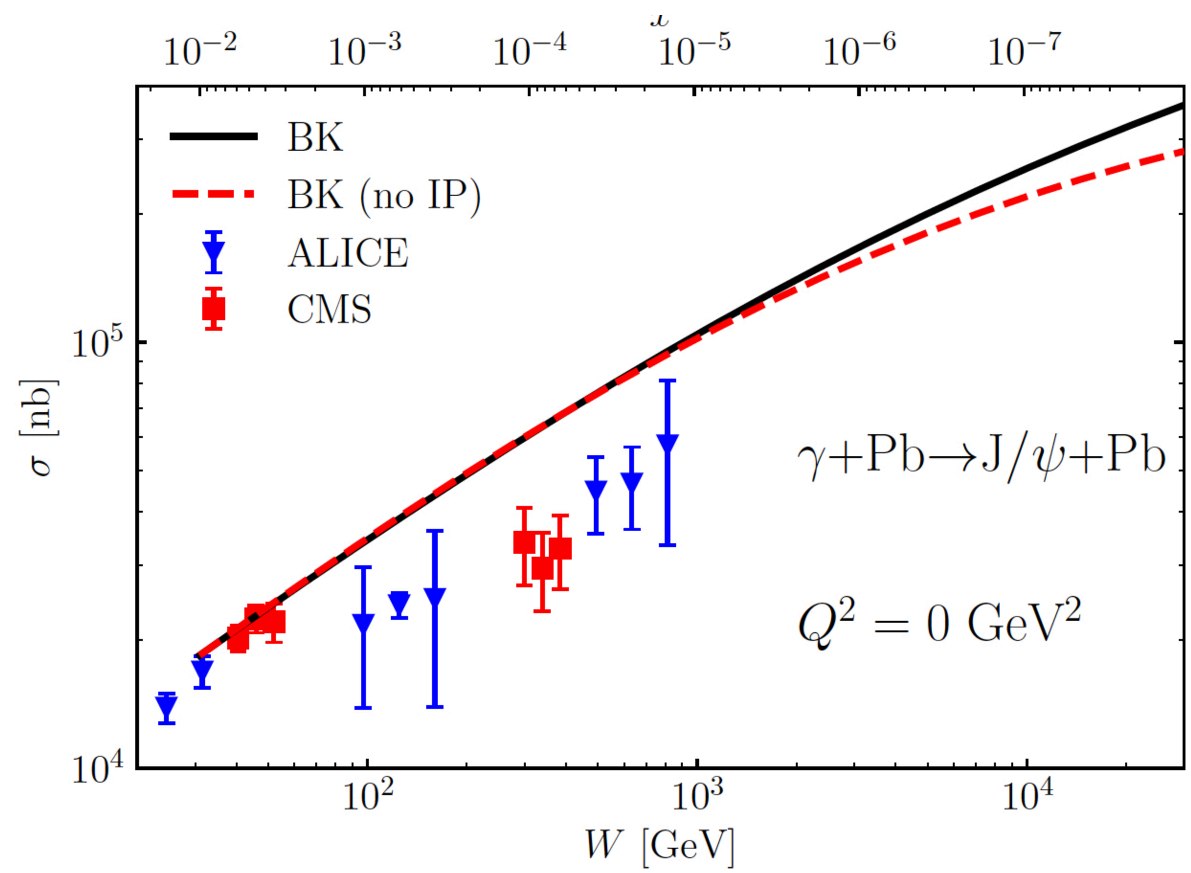


energy dependence **t dependence** **energy dependence of the slope**

VM production in UPC on proton and nuclei

plots from J.Penttala





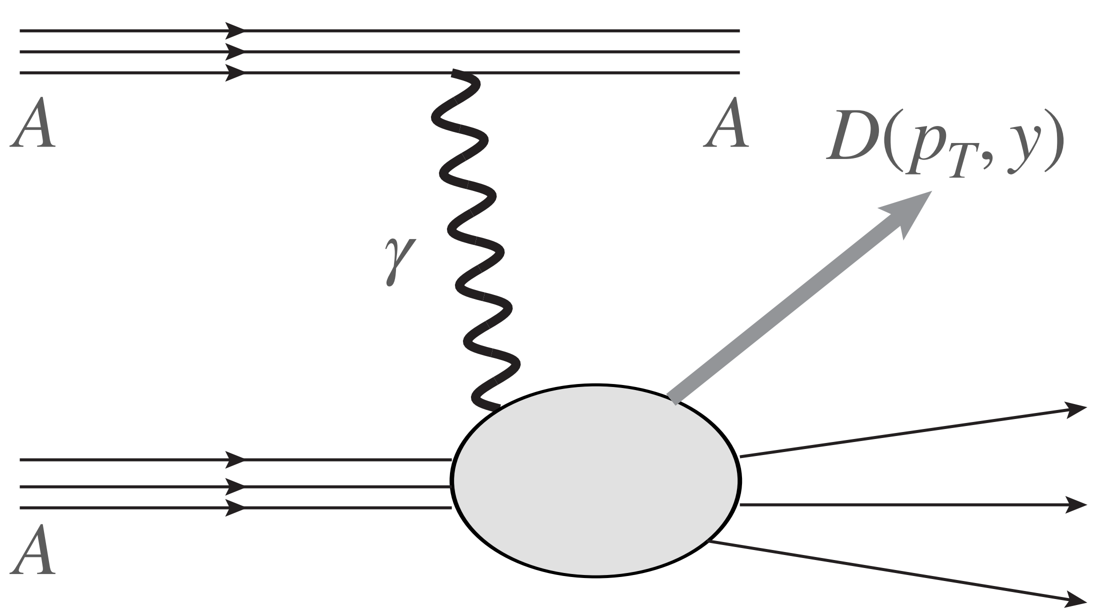
VM in UPC PbPb: can test nuclear effects of the gluon density
BK equation (with impact parameter dependence) can provide reasonable description of the data
Pb data point to stronger suppression

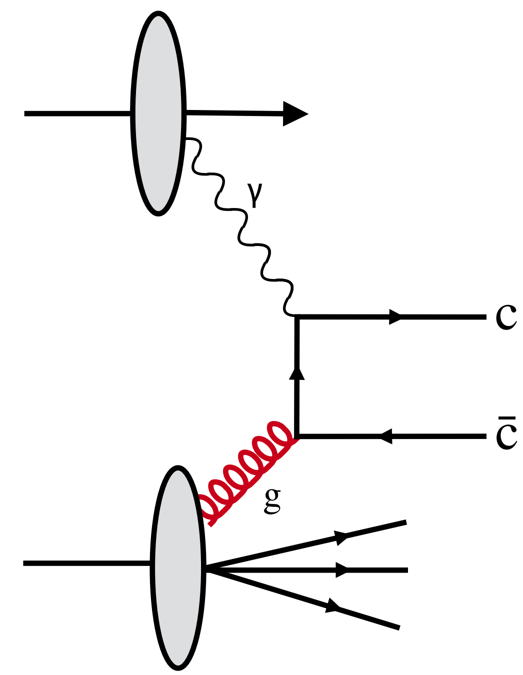
see lecture by Christophe Royon

UPC with hard scale: open charm production

$$A\,A \to A\,D\,X$$

Klein, Nystrand, Vogt;
Adeluyi, Bertulani;
Adeluyi, Bertulani, Murray;
Gonçalves, Bertulani



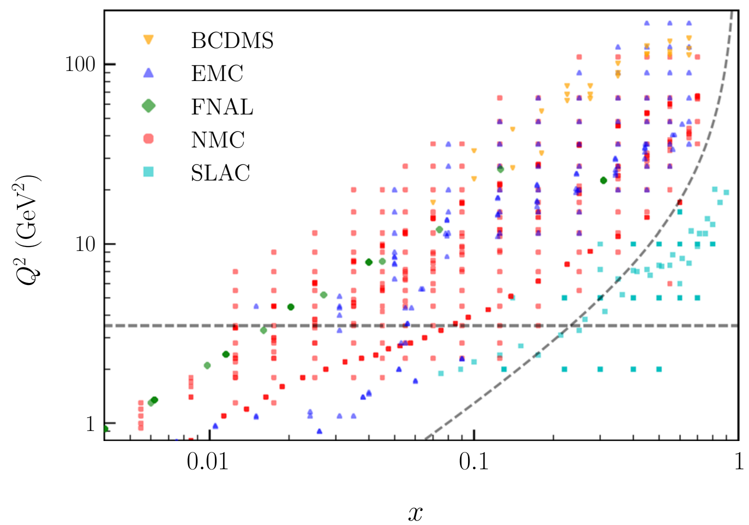


- Advantage: access to **wide range of scales** : $m_T = \sqrt{p_T^2 + m_c^2}$
- Inclusive$^{(*)}$ process: test of **factorization** and **universality** of PDFs
- **Charm** produced mainly in γg **fusion**
- Sensitive to the **nuclear gluon density: nuclear modification**
- Tests of parton evolution: **DGLAP** vs **BFKL** vs **CGC ...**

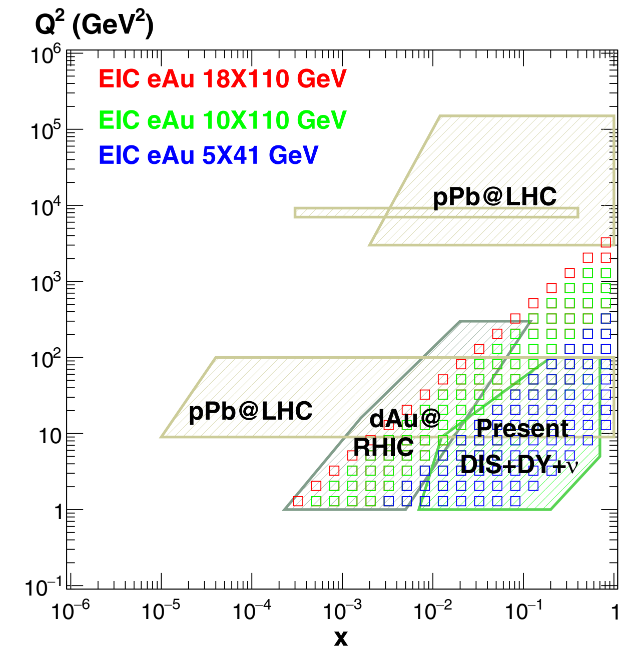
(x, Q^2) kinematic space in nuclear DIS

- Probing **nuclear structure**
- Limited to fixed target DIS so far, moderate to large x
- **Electron Ion Collider** will open new kinematics

NNPDF, EPJC 79, 471, 2019

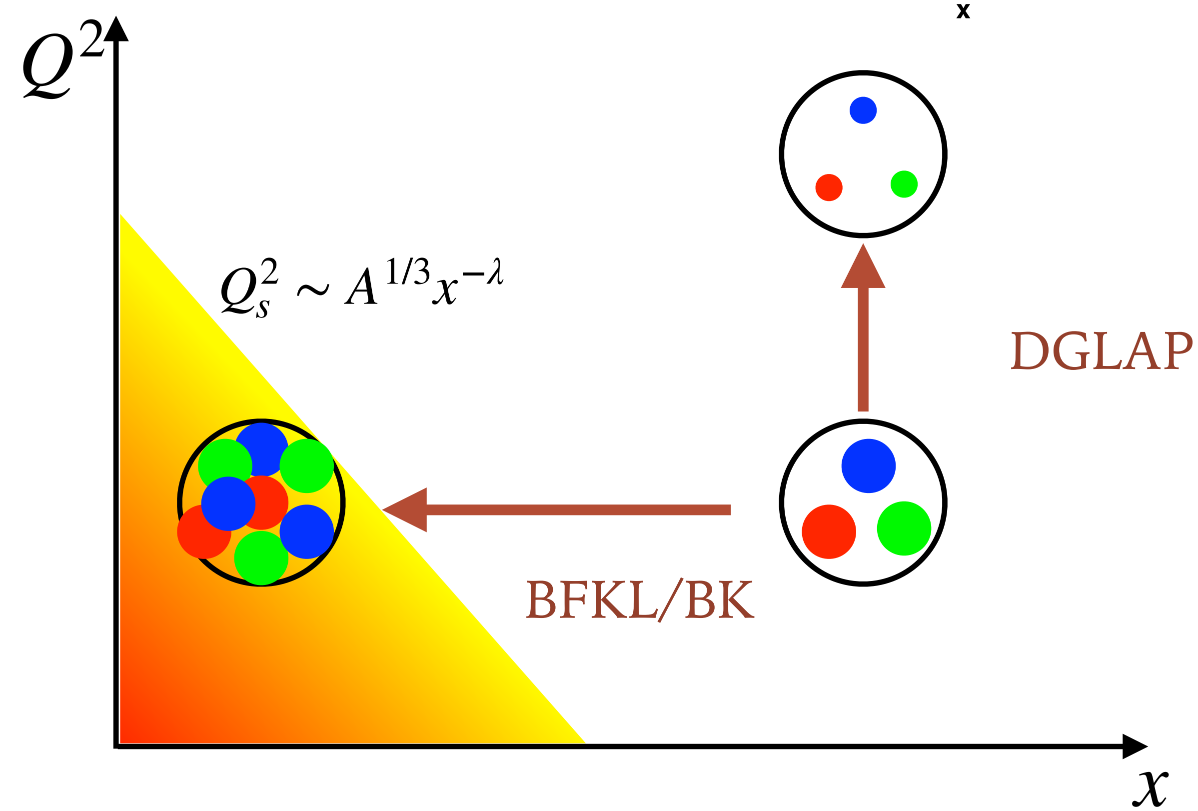


Armesto, Cridge, Giuli, Harland-Lang, Newman, Schmookler, Thorne, Wichmann

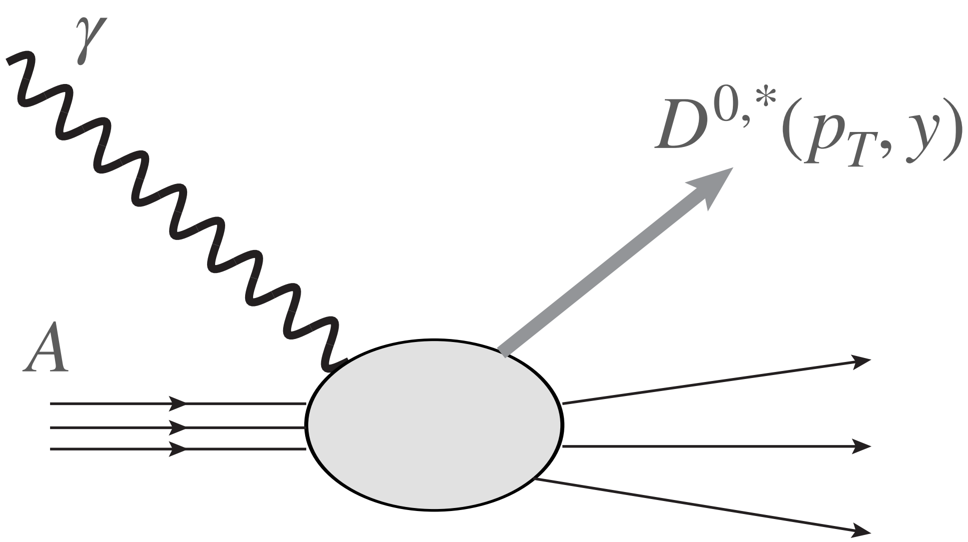


Charm photoproduction

- Charm produced mainly in γg **fusion**
- Sensitive to the **nuclear gluon density in UPC**
- Can test low x evolution: **DGLAP vs BFKL vs BK**



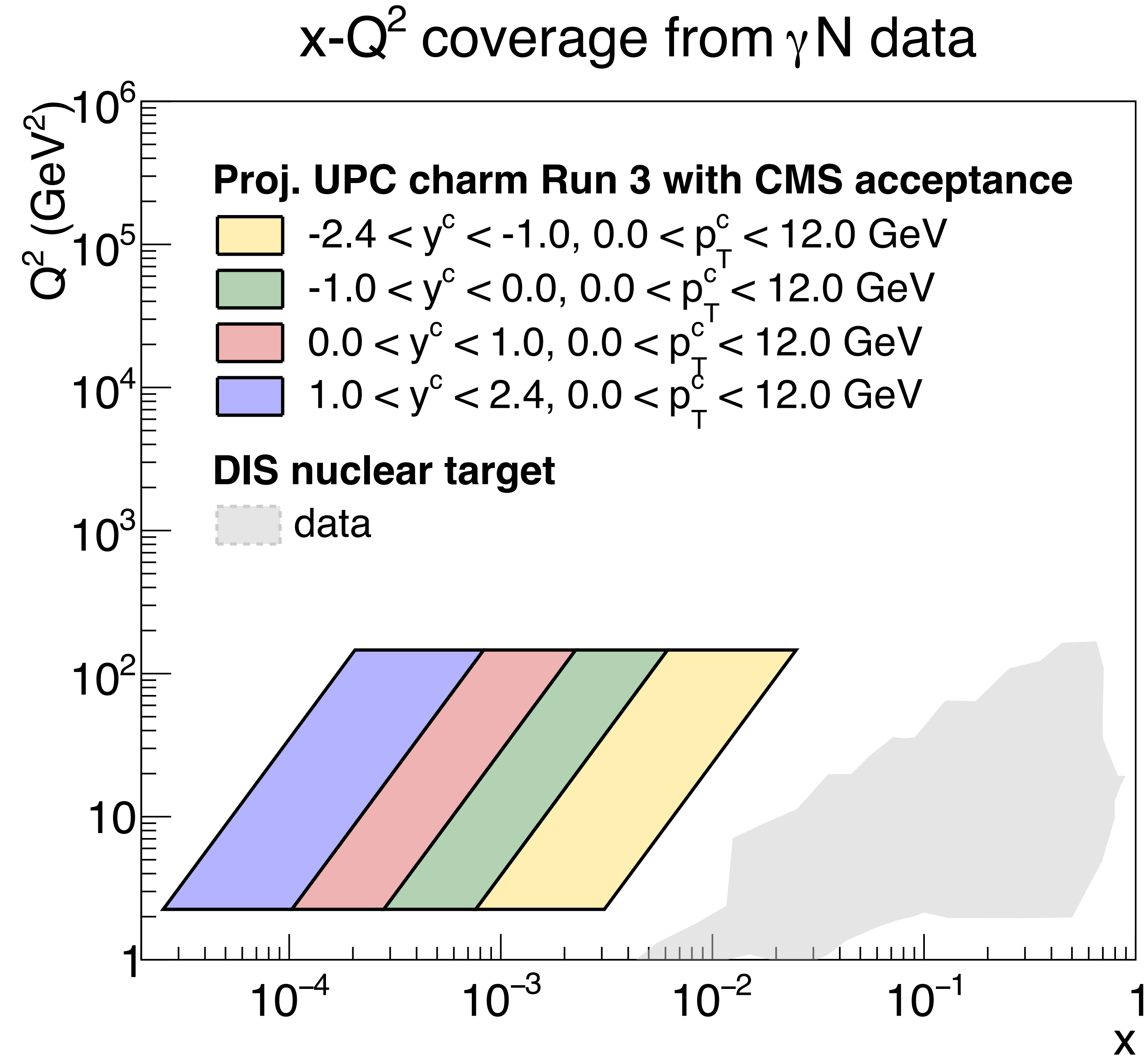
(x, Q^2) kinematic space in UPC with nuclei



LO kinematics crude estimate

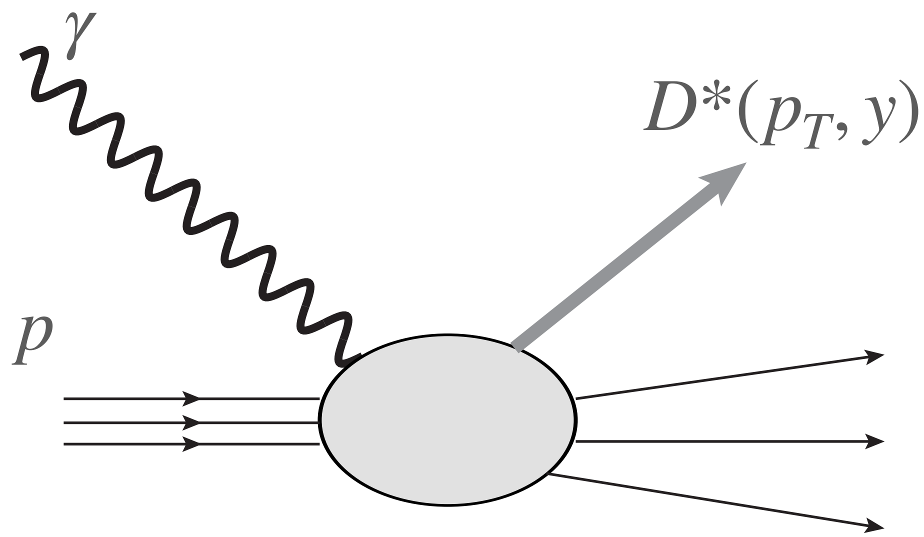
$$x \sim \frac{m_T}{\sqrt{s_{NN}}} e^{-y}$$

Need $p_T < 2\,\mathrm{GeV}, y > 1$ to probe small x and Q^2 region

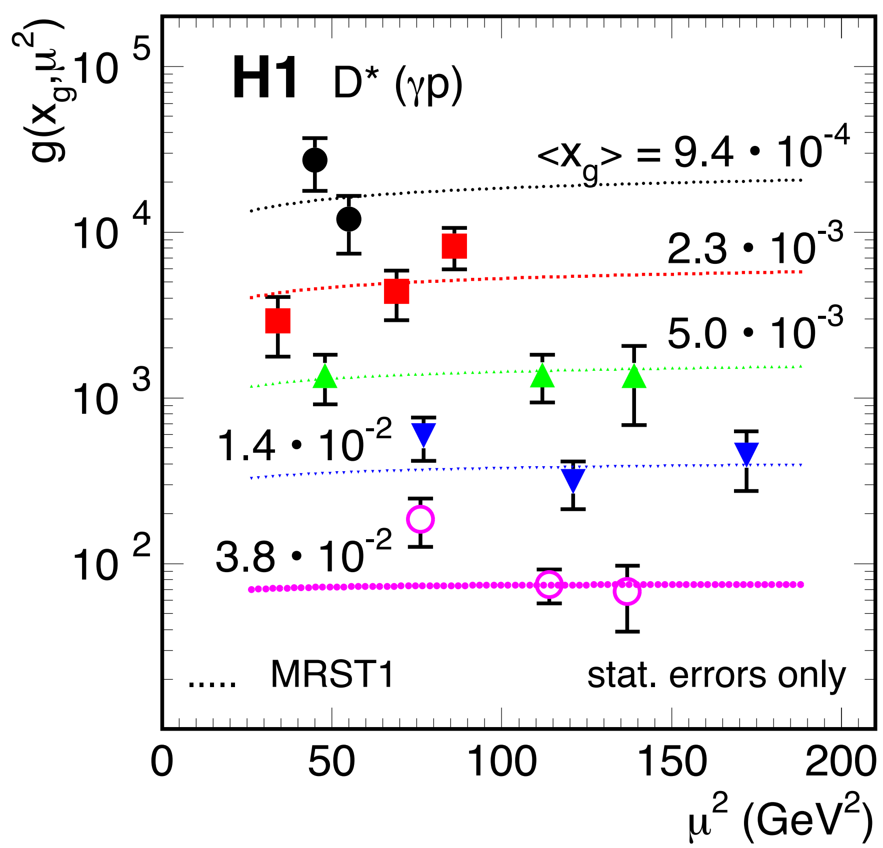


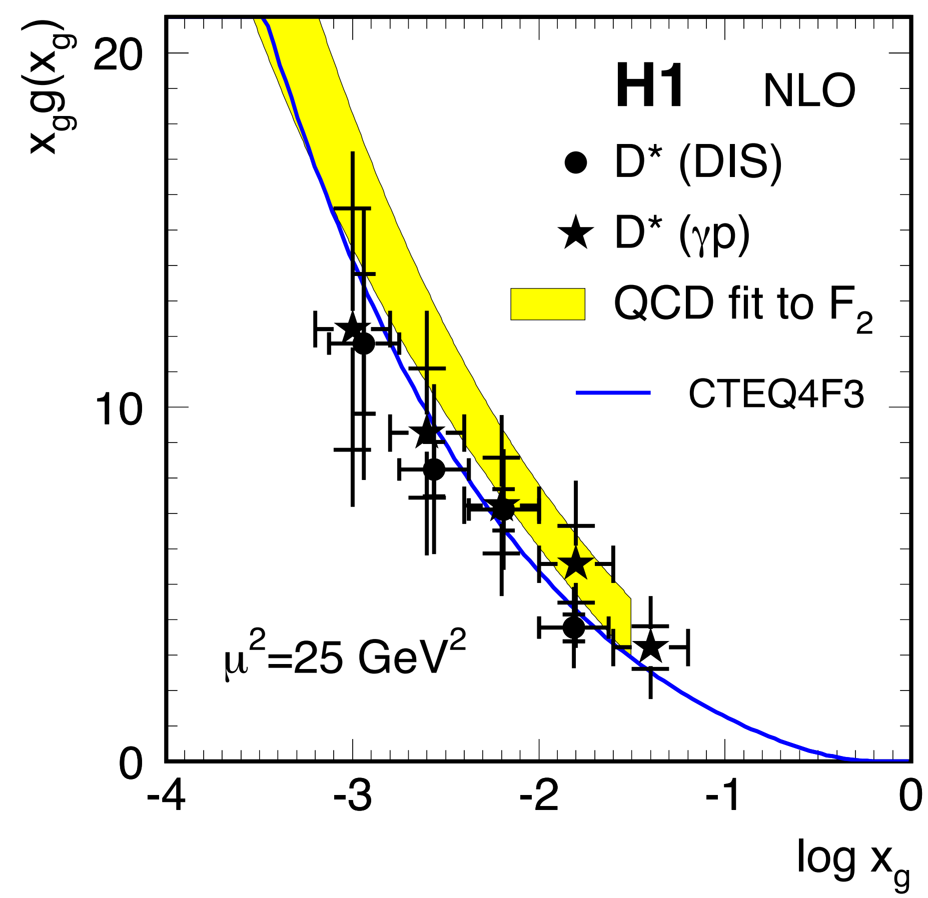
Charm level estimate, fragmentation shifts the estimates to higher Q^2

Example: probing low x gluon using charm at HERA



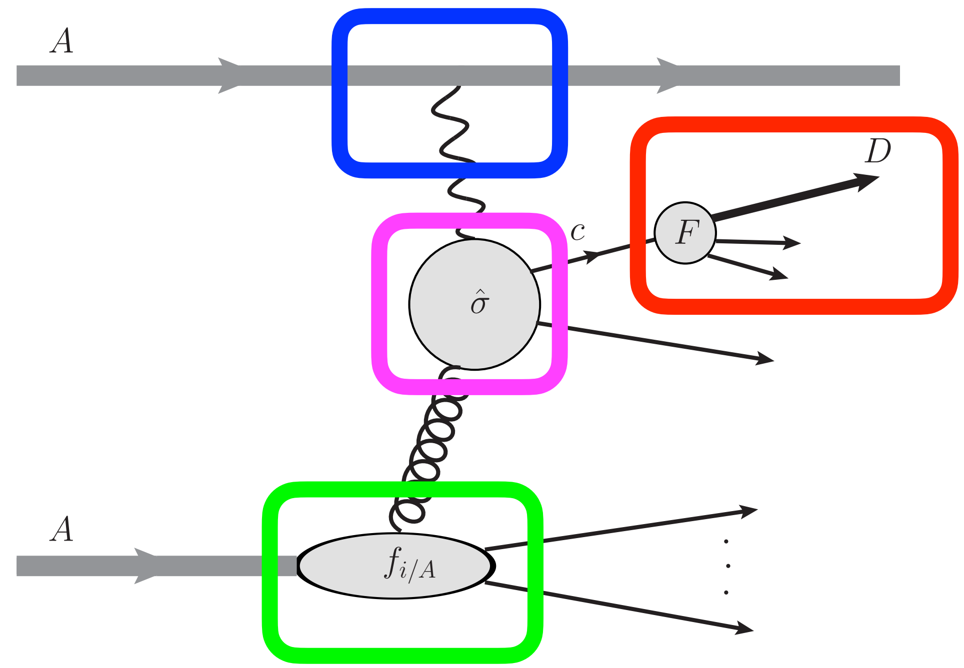
Using photoproduction D* data H1 extracted gluon density; using estimator of the longitudinal momentum fraction of proton carried by the gluon





Sensitive to gluon at small x !

Cross section for charm production in ep and UPC



Applying collinear factorization

$$\frac{d\sigma^{AA}}{dy d^2 p_T} = \int dx_\gamma \, f_{\gamma/A}(x_\gamma) \, \frac{d\sigma^{\gamma A}}{dy d^2 p_T}$$

photon flux

$$\frac{d\sigma^{\gamma A}}{dy d^2 p_T} = \int \frac{dz}{z^2} D_{h/c}(z) \, \frac{d\sigma^{\gamma A}}{dy_c d^2 p_{Tc}}$$

fragmentation function

partonic cross section

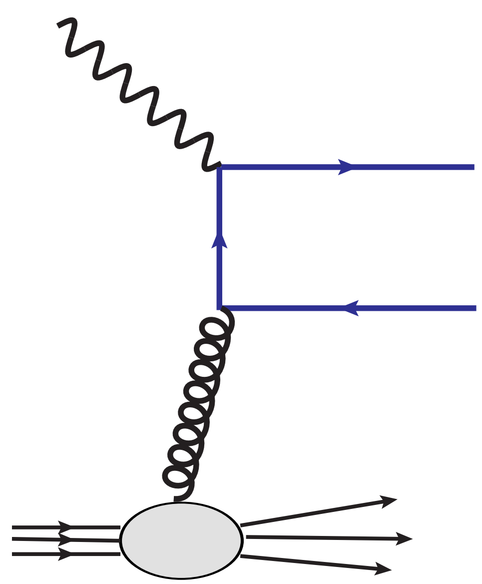
PDF

$$\frac{d\sigma^{\gamma A}}{dy_c d^2 p_{Tc}} = \sum_j \int dx_A \, f_{j/A}(x_A, \mu_F) \, \frac{d\hat{\sigma}^{\gamma j}}{dy_c d^2 p_{Tc}}(P_\gamma, x_A P_A, \mu_R, \mu_F)$$

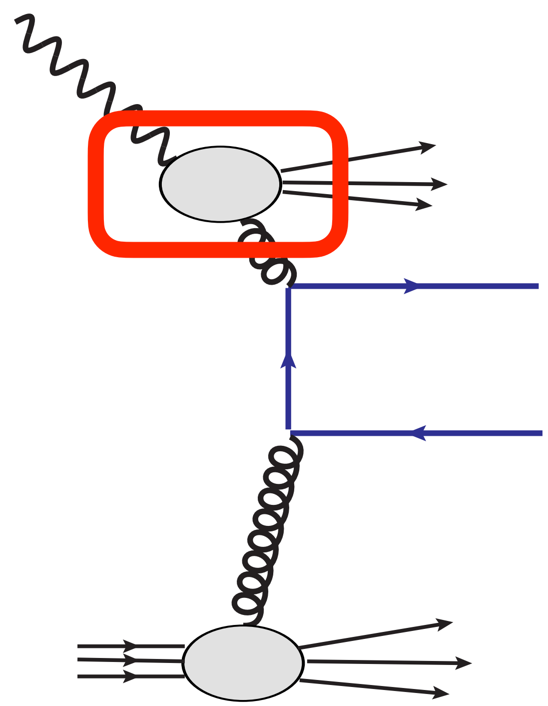
Direct and resolved contribution

In addition to direct process, need to take into account the contribution when the photon fluctuations and the parton from the photon interacts with parton from the nucleus to produce ccbar pair.

direct



resolved



Both related beyond LO

Only sum is observable

$$\frac{d\sigma^{\gamma A}}{dy_c d^2 p_{Tc}} = \sum_{jk} \int dx_A \int dx_k f_{j/A}(x_A, \mu_F) f_{k/\gamma}(x_k, \mu_F) \frac{d\hat{\sigma}^{kj}}{dy_c d^2 p_{Tc}}(x_k P_\gamma, x_A P_A, \mu_R, \mu_F)$$

Cross section for charm photoproduction in FONLL

FONLL: collinear framework for **heavy flavor photoproduction and hadroproduction**

Cacciari, Frixione, Nason; Cacciari, Greco, Nason

Connects **small transverse momenta** with mass effects to the **large transverse momentum** region with logarithmically enhanced terms $\ln p_T/m$

Accurate up to NLO: $\alpha_{\rm em}\alpha_s$, $\alpha_{\rm em}\alpha_s^2$ terms exact

Includes terms up to NLL: $\alpha_{\rm em}\alpha_s(\alpha_s \ln p_T/m)^k$, $\alpha_{\rm em}\alpha_s^2(\alpha_s \ln p_T/m)^k$

Fixed order NLO

$$\frac{d\sigma}{dy dp_T} = A(m)\alpha_{\rm em}\alpha_s + B(m)\alpha_{\rm em}\alpha_s^2 +$$

Resummed NLL

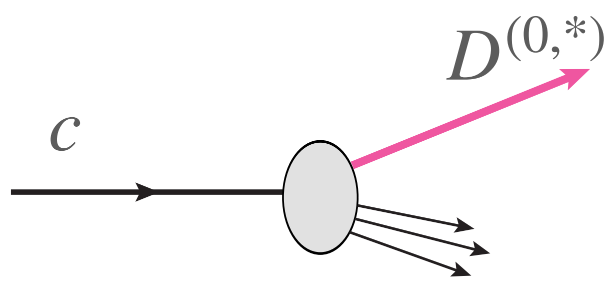
$$+\left(\alpha_{\rm em}\alpha_s \sum_{i=2}^{\infty} a_i(\alpha_s \log(p_T/m))^i + \alpha_{\rm em}\alpha_s^2 \sum_{i=1}^{\infty} b_i(\alpha_s \log(p_T/m))^i\right) \times G(m, p_T)$$

$$+\mathcal{O}(\alpha_{\rm em}{\alpha_s}^3(\alpha_s \log(p_T/m))^i) + \mathcal{O}(\alpha_{\rm em}{\alpha_s}^3 \times \mathrm{PST})$$

PST: power suppressed terms

$G(m, p_T)$ is regularizing function, vanishing at $p_T \to 0$, and approaching unity at large p_T

Fragmentation functions: from c to D



D⁰ in UPC and D* at HERA

Braaten-Cheung-Fleming-Yuan (BCFY) fragmentation function

Direct decays $c \to D^0$ and decays from D* states

Parameter choice: $r = 0.1$

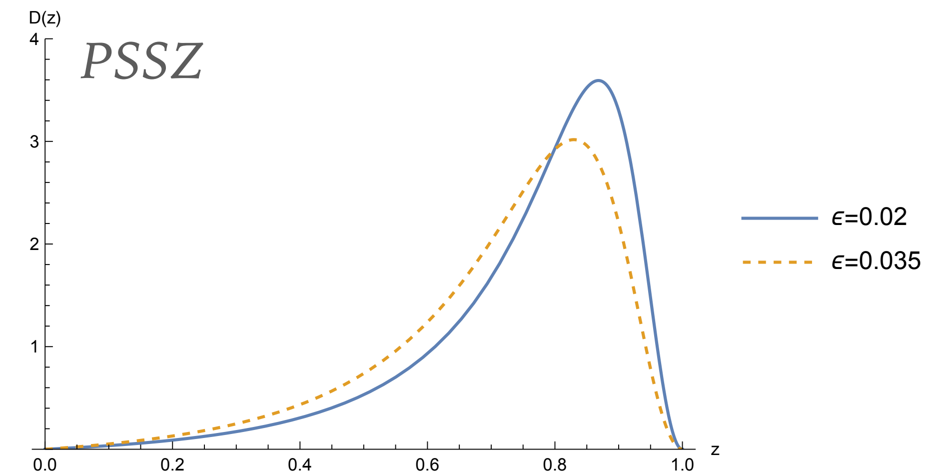
Cacciari, Nason ; Cacciari, Frixione, Houdeau, Mangano, Nason, Ridolfi

Use **Peterson-Schlatter-Schmitt-Zerwas (PSSZ)** function:

$$D(z) = \mathcal{N} \frac{1}{z} \left(1 - \frac{1}{z} - \frac{\varepsilon}{1-z}\right)^{-2}$$

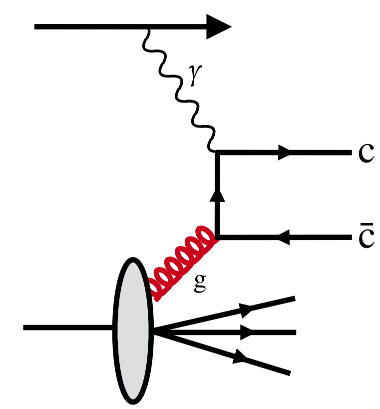
Parameter choice: $\varepsilon = 0.02, 0.035$

Frixione, Nason



Comparison with HERA data on D*

Update FONLL results by *Frixione & Nason* with **recent** PDFs
Compute both FONLL and fixed order FO at NLO; direct+resolved



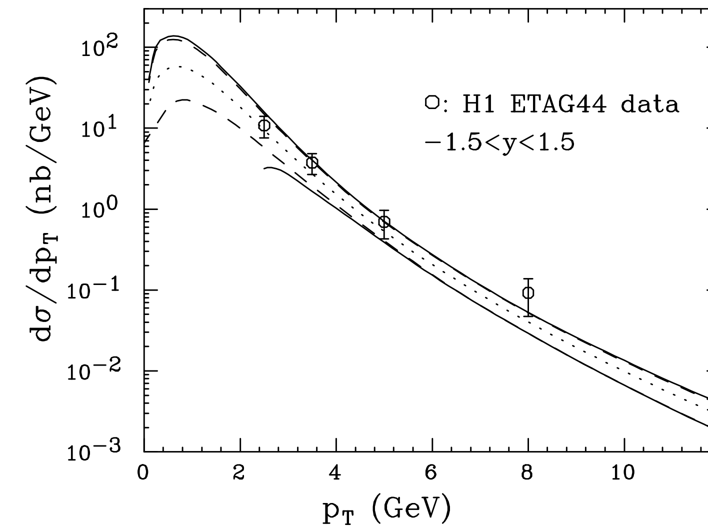
Proton PDF sets: CT18ANLO, HERAPDF2.0, nNNPDF3.0_p

Photon PDF sets: GRV, AFG

Fragmentation:

PSSZ with $\varepsilon = 0.02{,}0.035$, Frag. frac. for D^{*+} : 0.235

BCFY with r=0.1, r=0.06



Frixione&Nason

Scale variation:

$$\mu_r = 0.5 \div 2.0\,\mu_0\ ,\ \ \mu_f = 0.5 \div 2.0\,\mu_0\,, \mu_0 = \sqrt{m_c^2 + p_T^2}$$

Ratio of photon energy to incoming electron (usually denoted by y)

Charm mass: 1.3-1.5 GeV

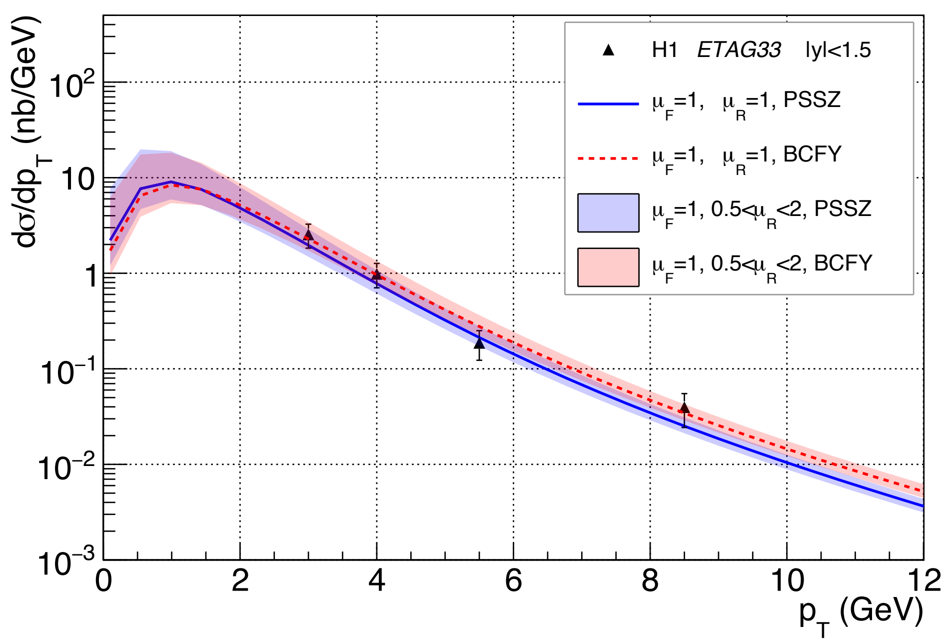
Data set	$Q^2_{\max}$	z_{min}	z_{max}	p_T	(pseudo)rapidity
H1 ETAG44	0.009	0.02	0.32	$p_T > 2\,\text{GeV}$	$\lvert y\rvert < 1.5$
H1 ETAG33	0.01	0.29	0.62	$p_T > 2\,\text{GeV}$	$\lvert y\rvert < 1.5$
ZEUS	1	0.187	0.869	$p_T > 2\,\text{GeV}$	$\lvert\eta\rvert < 1.5$
H1 2012	2	0.09	0.8	$p_T > 1.8\,\text{GeV}$	$\lvert\eta\rvert < 1.5$

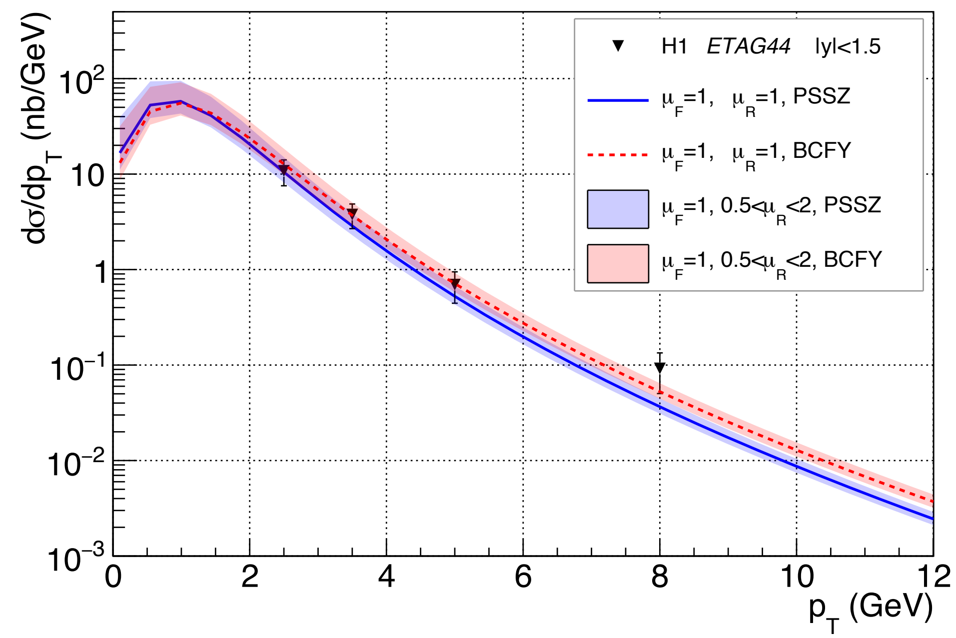
H1 NPB 545 (1999) 21

ZEUS EPJC 6 (1999) 67

H1 EPJC 72 (2012) 1995

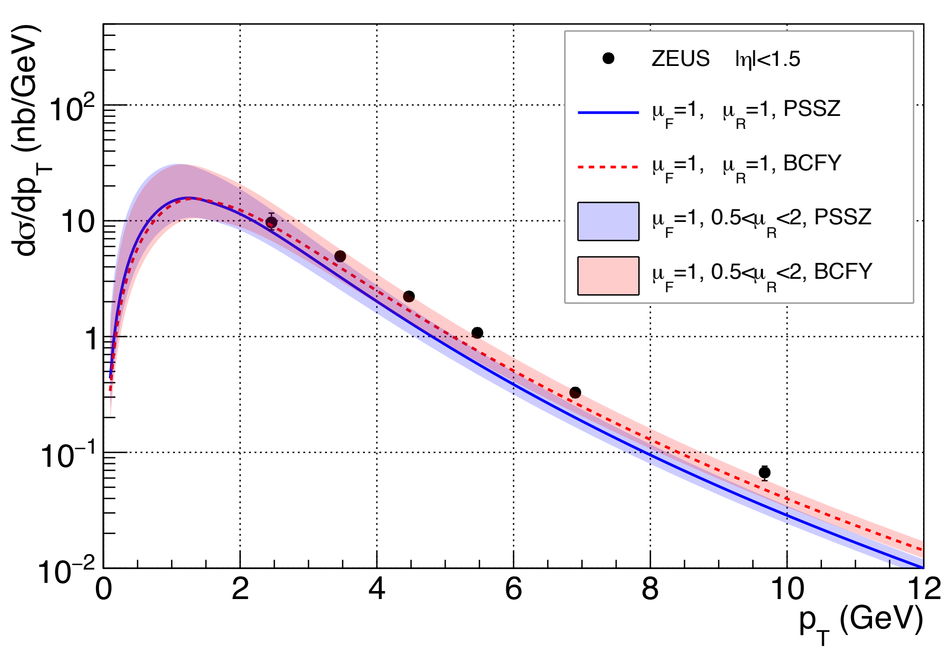
Comparison with HERA: p_T distributions for D*

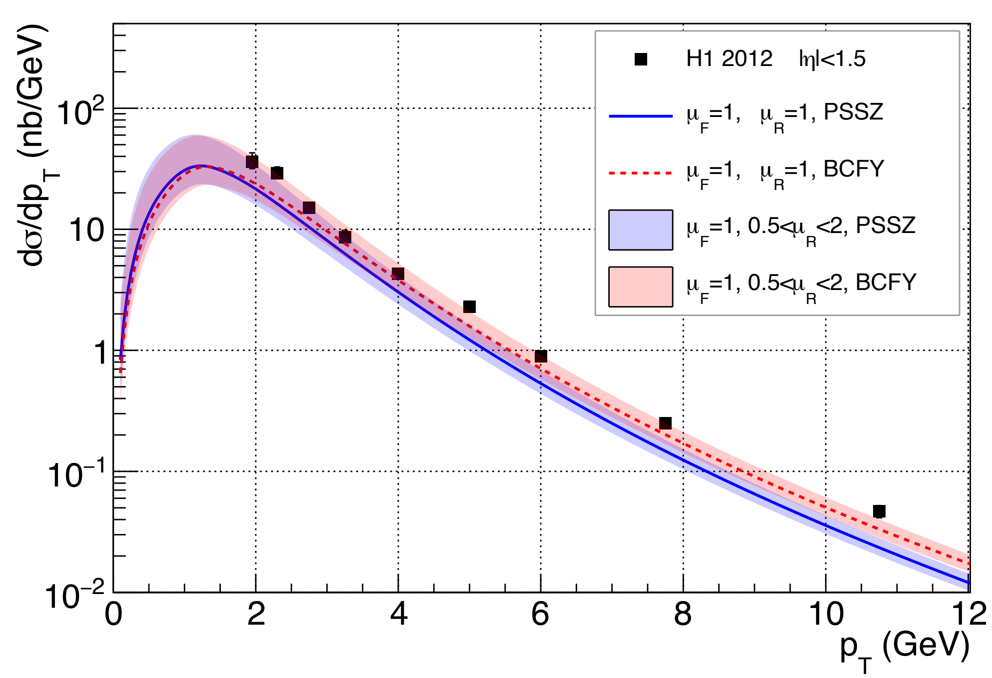




Note: these are ep cross sections

$m(D^*) = 2010\,\mathrm{MeV}$





Fragmentation:

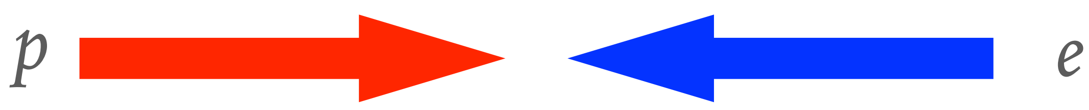
Red: BCFY

Blue: PSSZ

Reproducing *Frixione&Nason* calculations, results with CT18ANLO consistent with previous ones

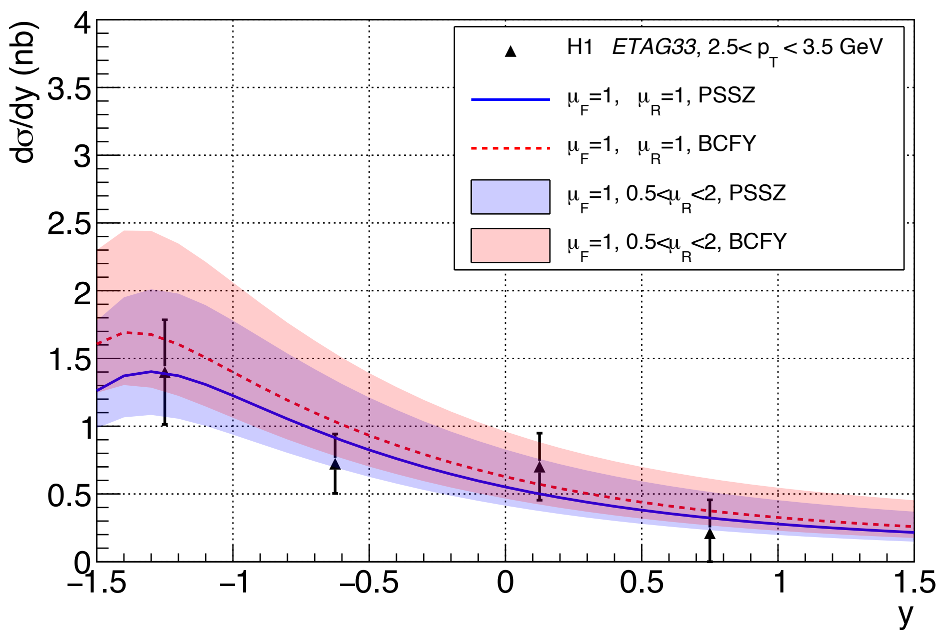
Fragmentation dependence: calculation with **BCFY closer** to the data than PSSZ

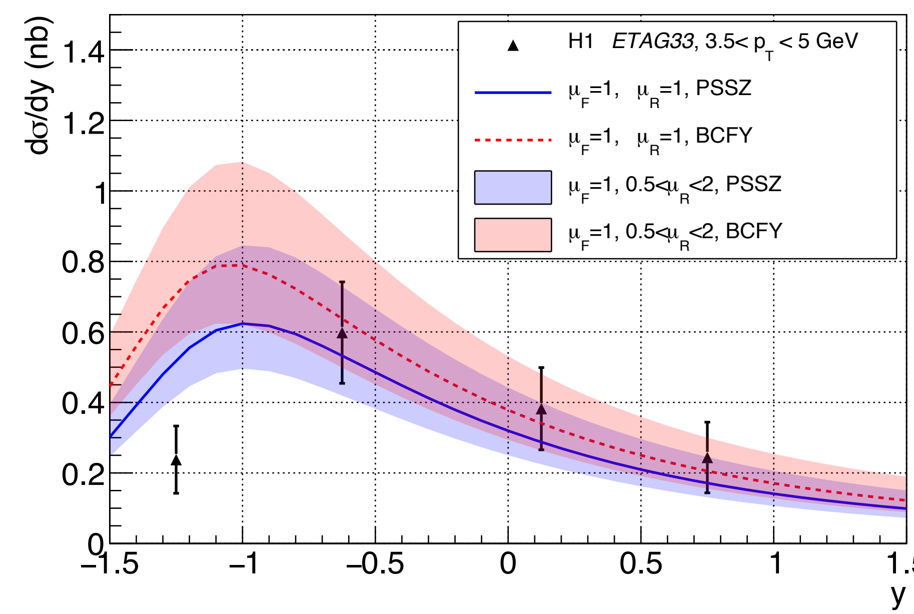
Comparison with H1 (ETAG44, ETAG33) data: rapidity distributions D*

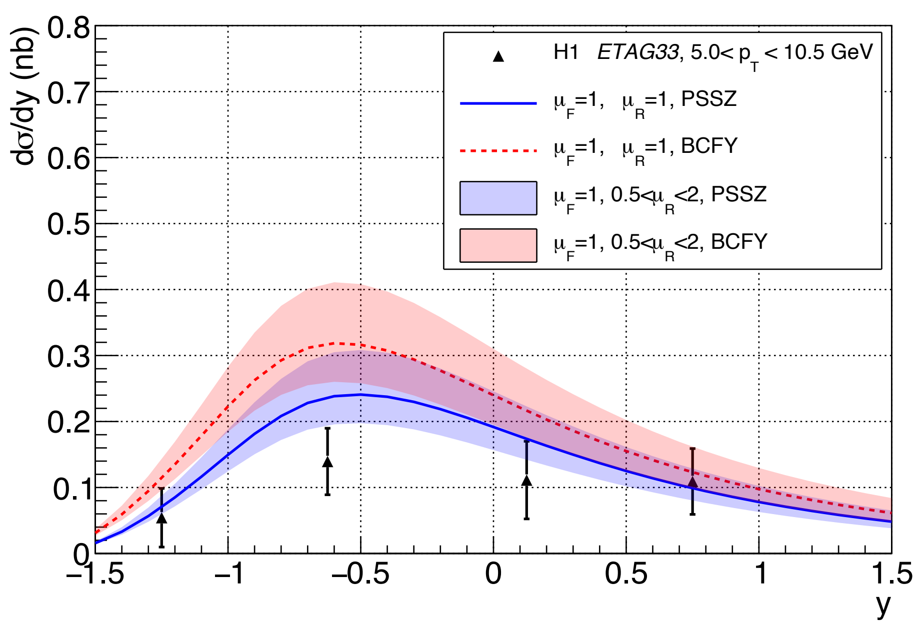


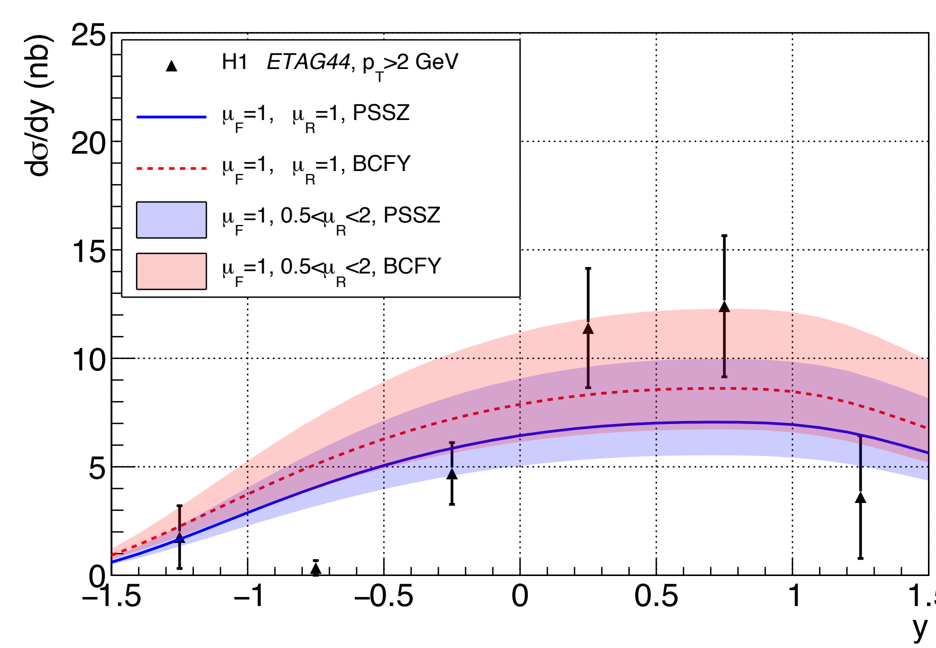
z: frac. of e energy carried by γ

Data set	$Q^2_{\max}$	z_{min}	z_{max}
H1 ETAG44	0.009	0.02	0.32
H1 ETAG33	0.01	0.29	0.62
ZEUS	1	0.187	0.869
H1 2012	2	0.09	0.8

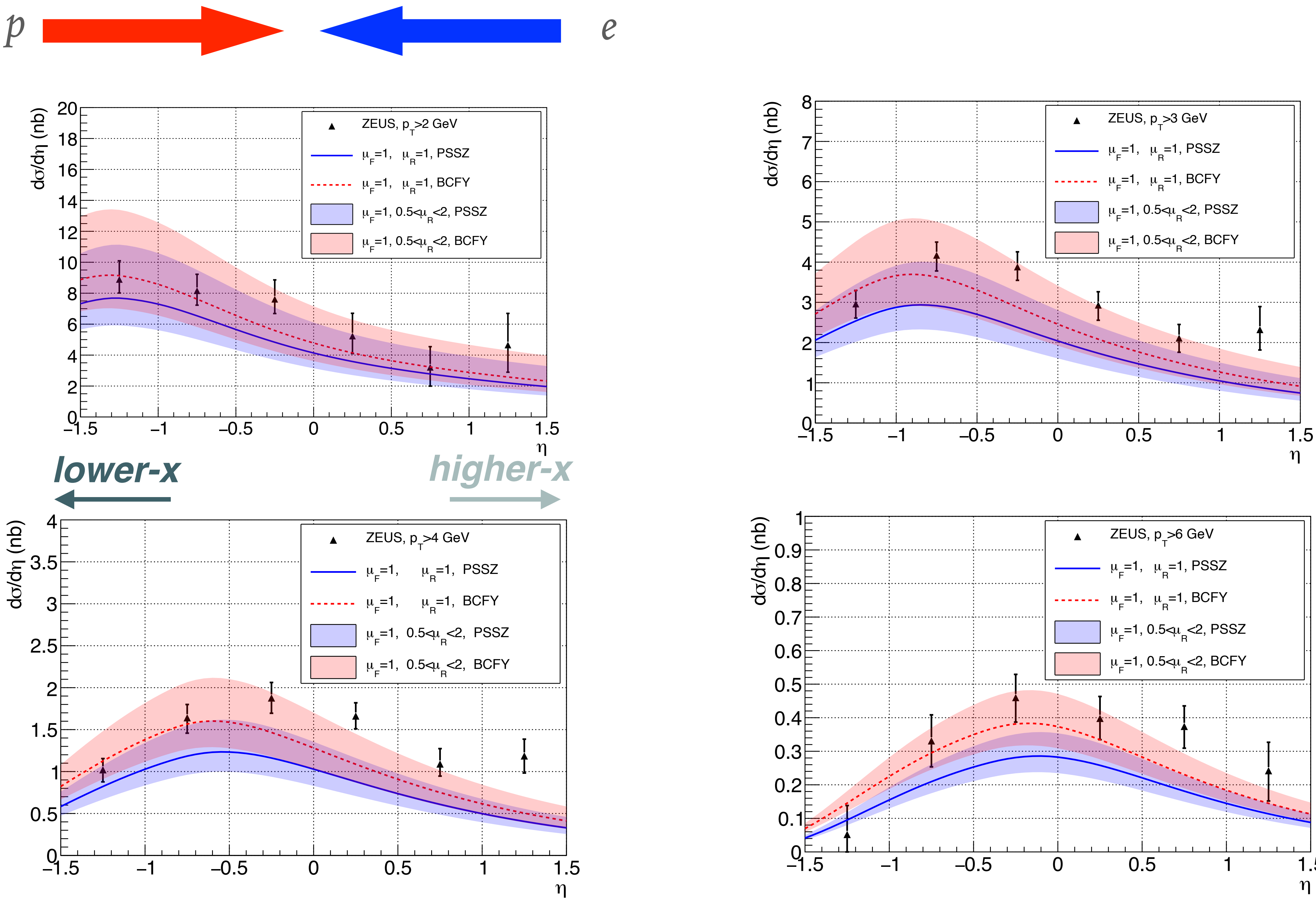




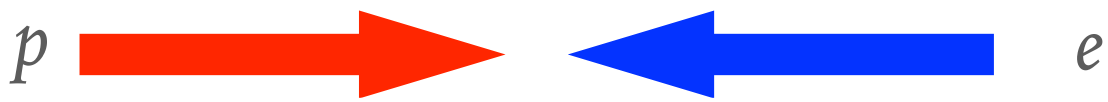


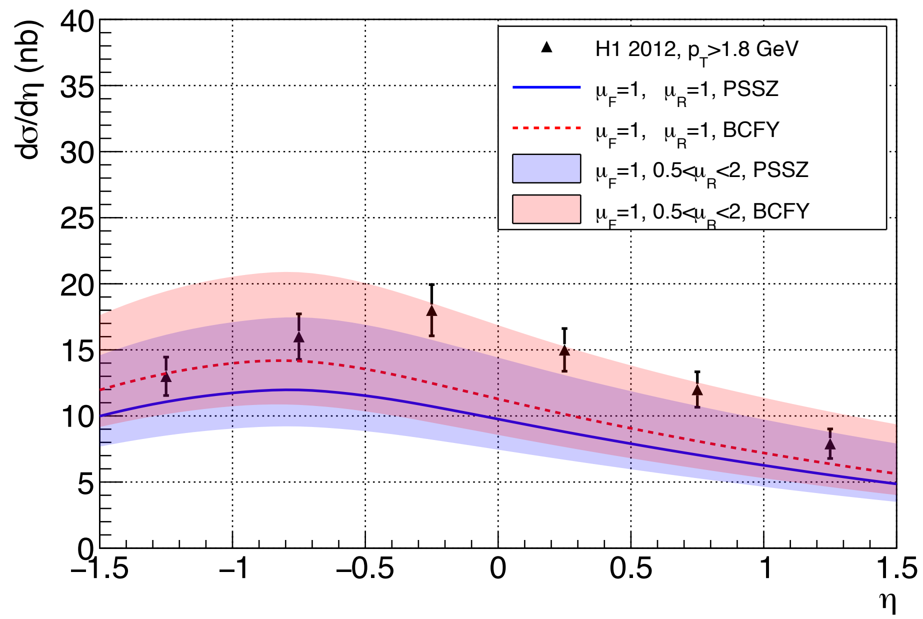


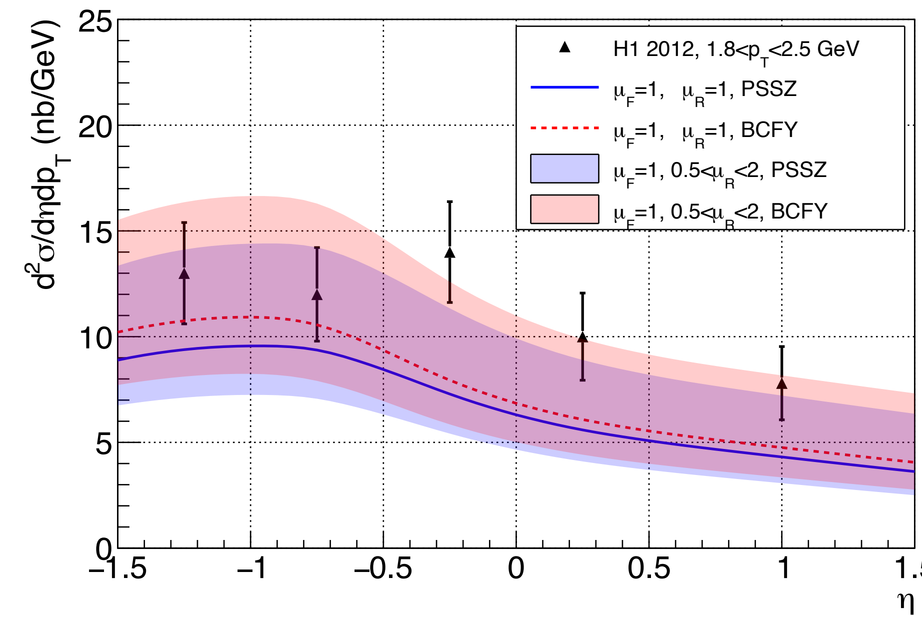
Comparison with ZEUS data: pseudorapidity distributions D*



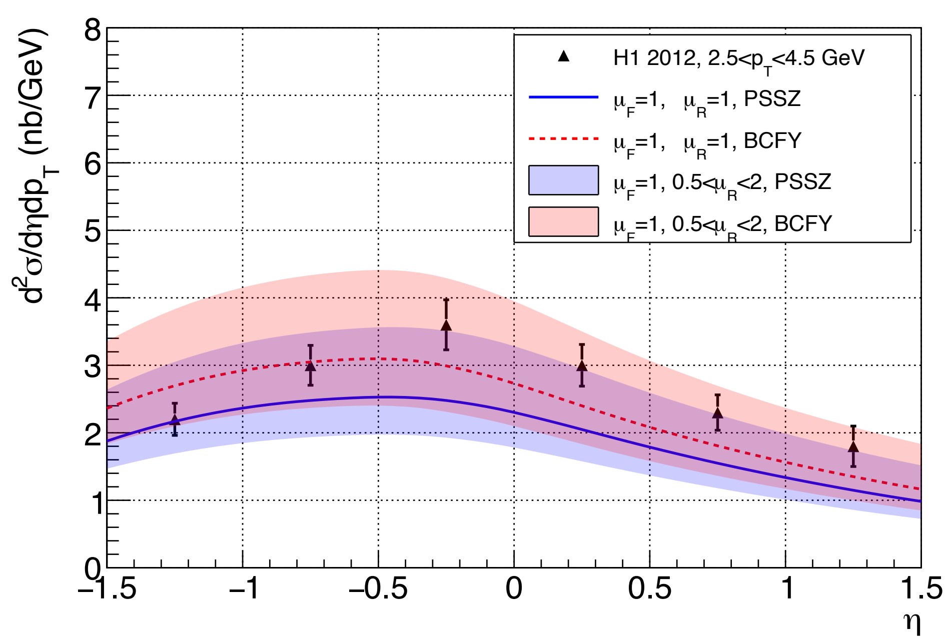
Comparison with H1 2012 data: pseudorapidity distributions D*

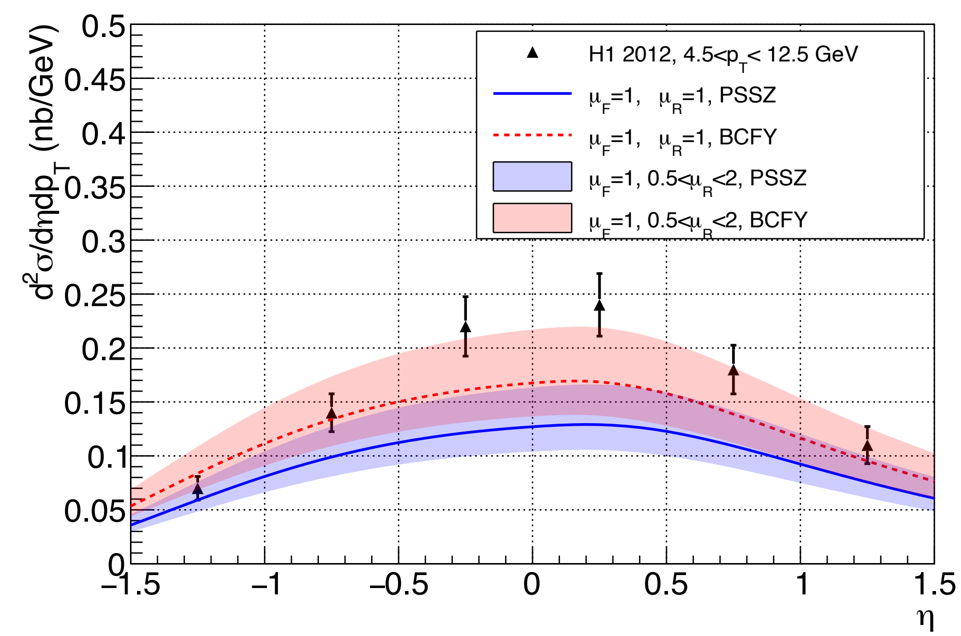






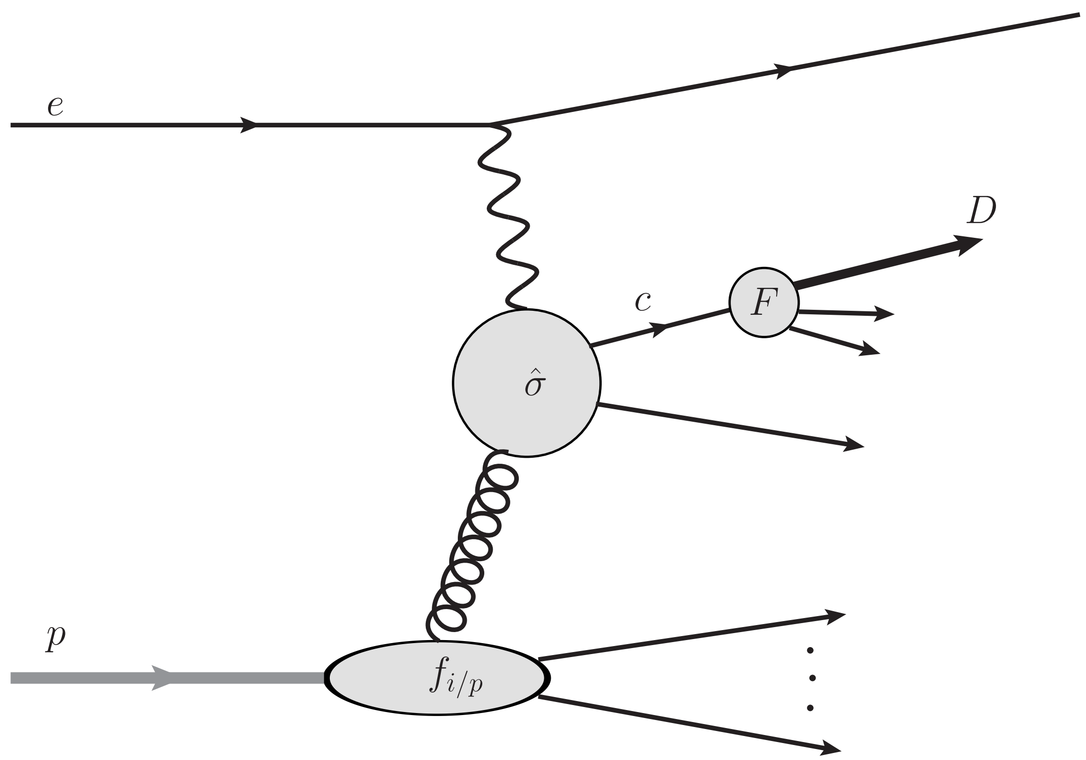
lower-x ← → ***higher-x***

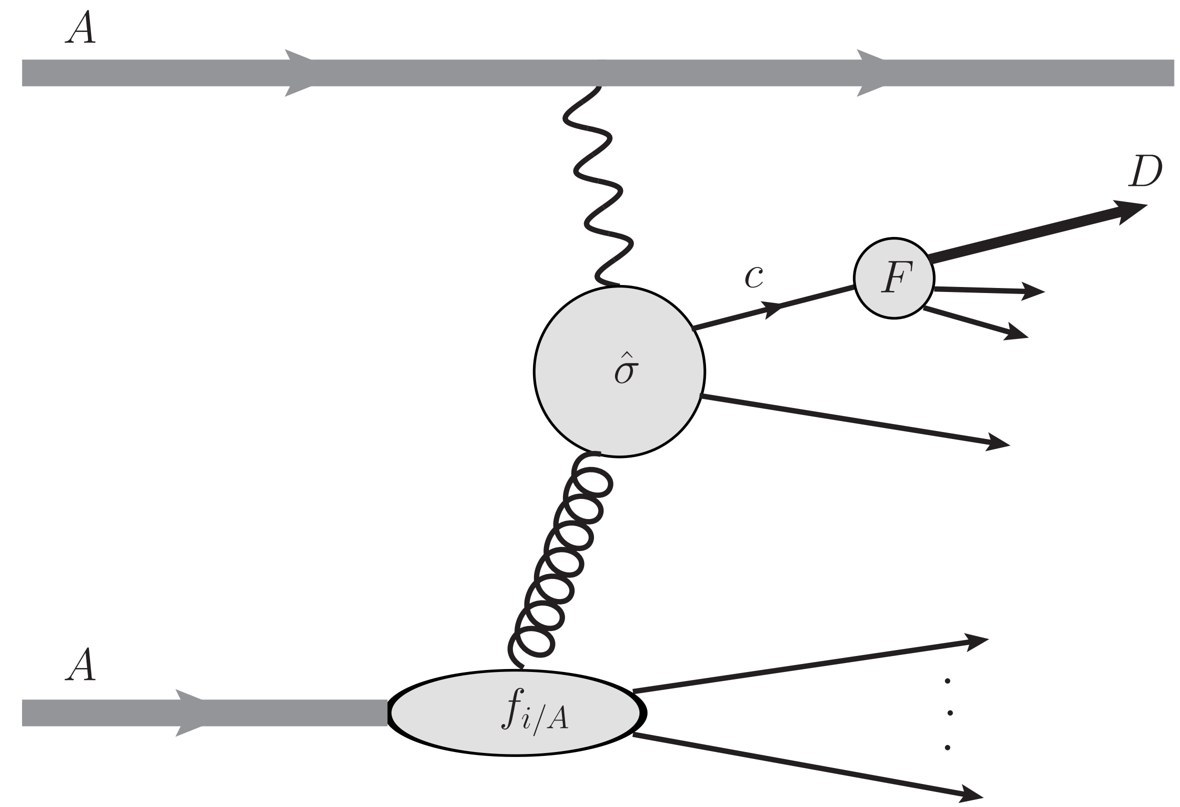




HERA ep vs LHC UPC AA

Differences between ep and UPC AA

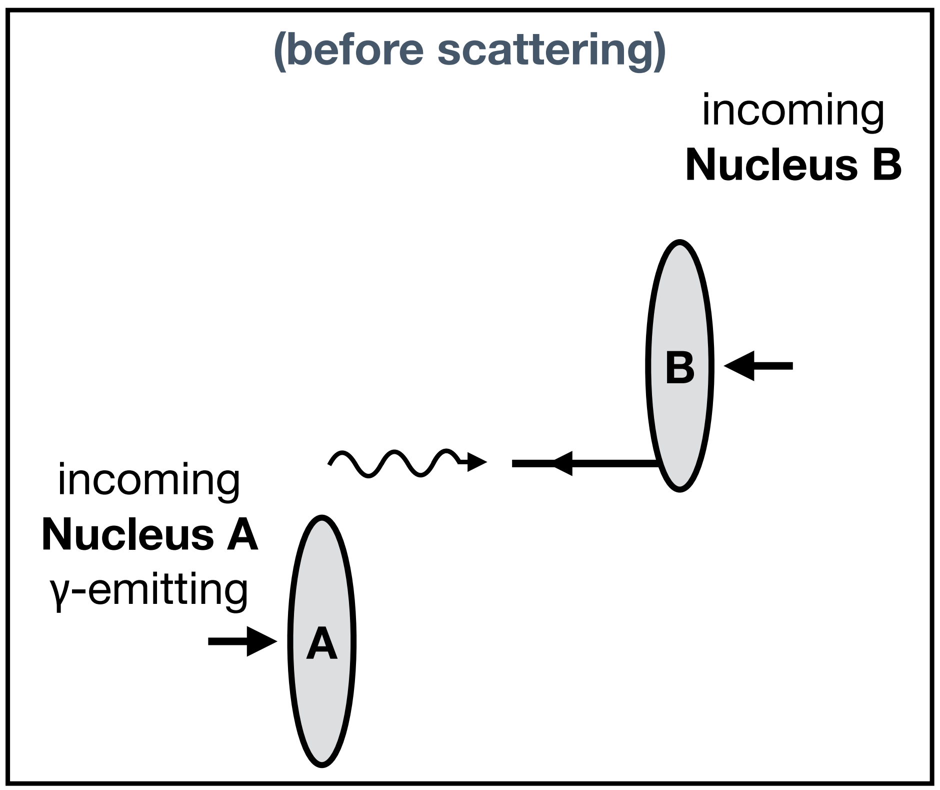


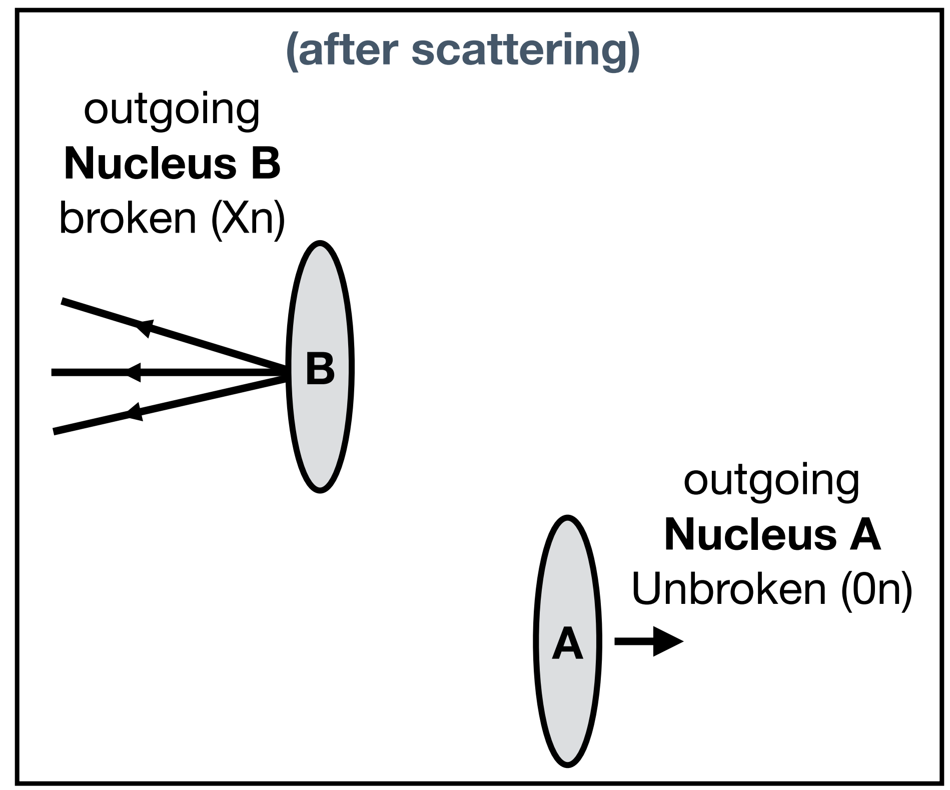


- **Electron** vs **nucleus** photon flux: different behavior
- In ep: some data sets have larger range of $Q^2(\sim 2\,\mathrm{GeV}^2)$
- **Proton** vs **nuclear** target: **nuclear modification** expected

UPC event selection

AA UPC: CMS selection of UPC events with **0nXn** (zero neutrons in one ZDC, at least one neutron in opposite ZDC), requires accounting for **survival probability** factor for nucleus due to possibility of **electromagnetic dissociation (EMD)**





In UPC **0nXn** selection means (part of) **coherent diffraction** is rejected.
In theoretical calculation it is included: **inclusive** process
Estimate from Frankfurt-Guzey-Strikman model: $\sim 10\,\%$

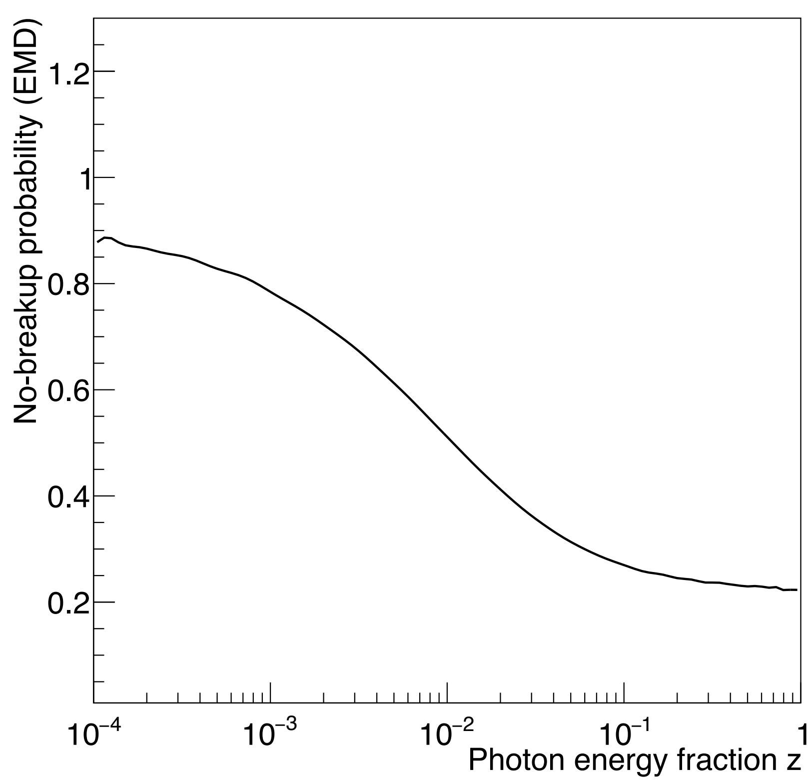
Electromagnetic dissociation in UPC

- **0nXn** requirement means photon-emitting nucleus left unbroken
- Additional EM interactions can lead to break-up of nucleus
- Effective flux: fold the survival probability, assuming factorization of hard interaction and soft-excitation probability

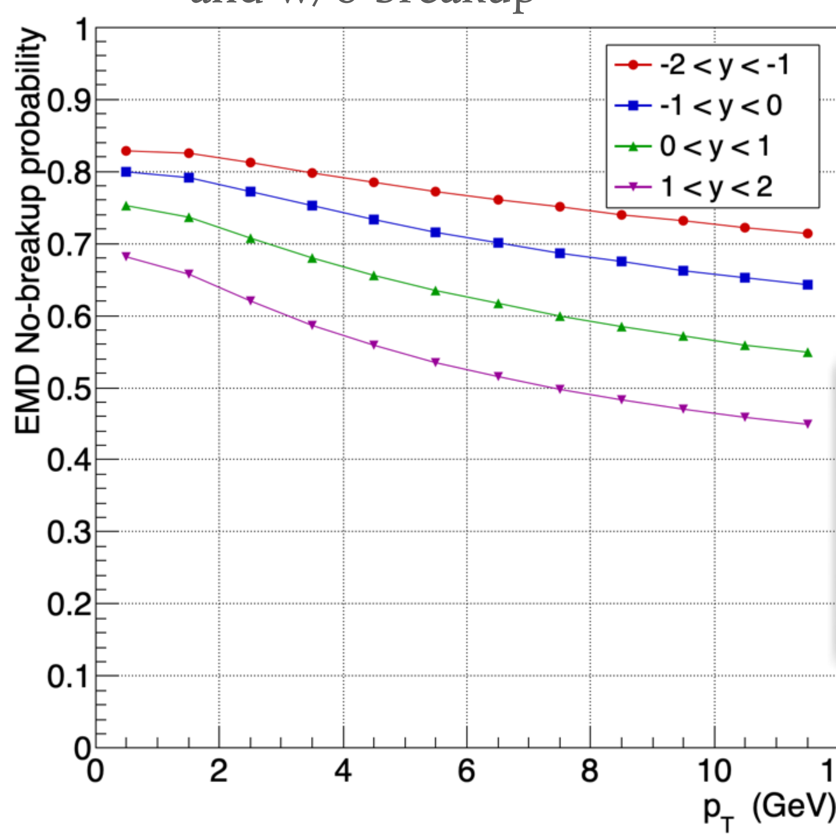
STARLIGHT

$$f^{\mathrm{eff}}_{\gamma/A}(z) \;=\; \int d^2\mathbf{b}\, P_{\mathrm{no\ EM}}(\mathbf{b})\; \tilde{f}_{\gamma/A}(z,\mathbf{b})\; \theta(|\mathbf{b}|-b_{\min})$$

Ratio of effective photon flux to no-break up photon flux



Ratio of D0 cross section with and w/o breakup



EPPS21 PDF
BCFY FF
$m_c = 1.3$ GeV

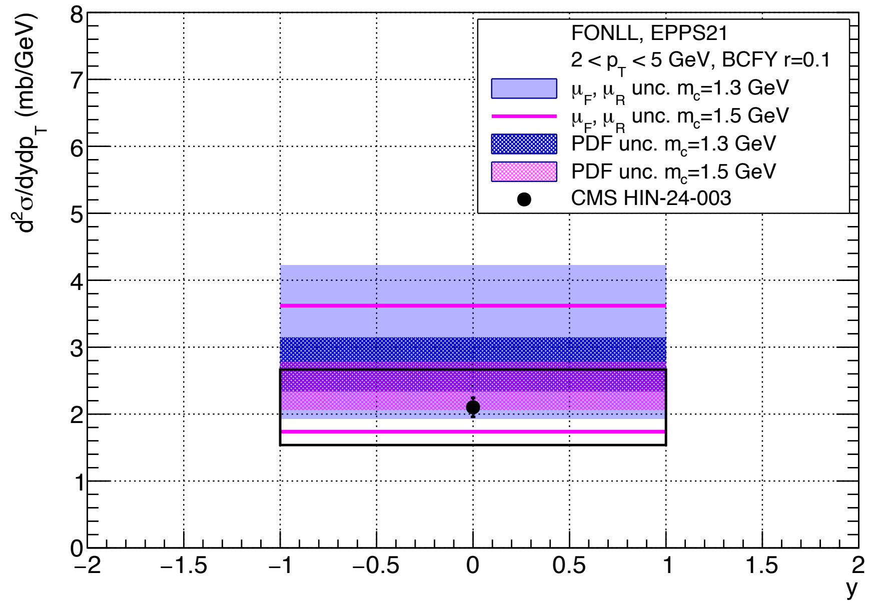
Eskola, Guzey, Helenius, Paakkinen, Paukkunen

Large reduction: 0.8 to 0.4

Comparison of FONLL with preliminary CMS data on D^0

$Pb(\gamma) \longrightarrow \quad \longleftarrow Pb(g)$

Preliminary CMS data extracted from CMS PAS HIN-24-003

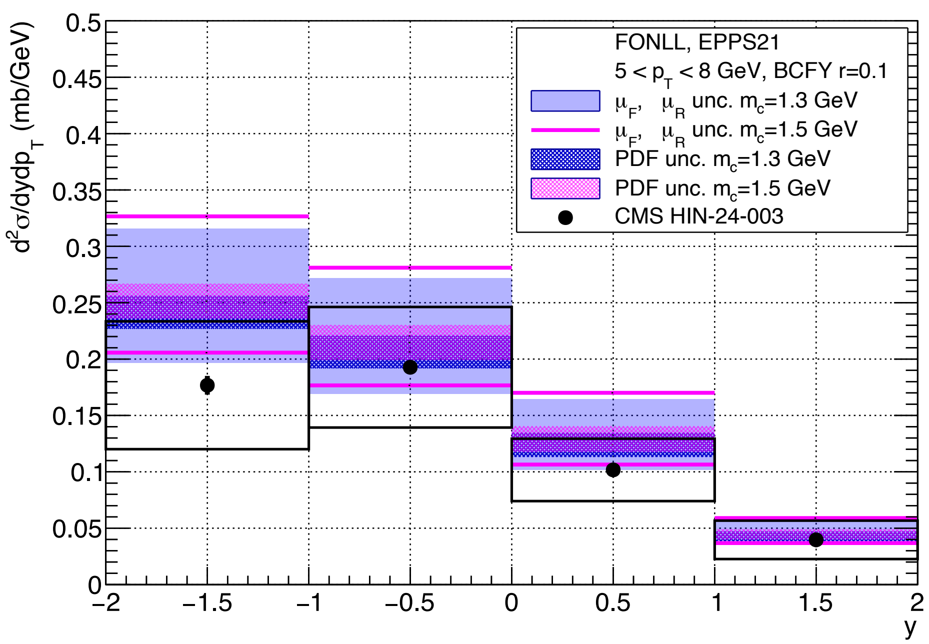


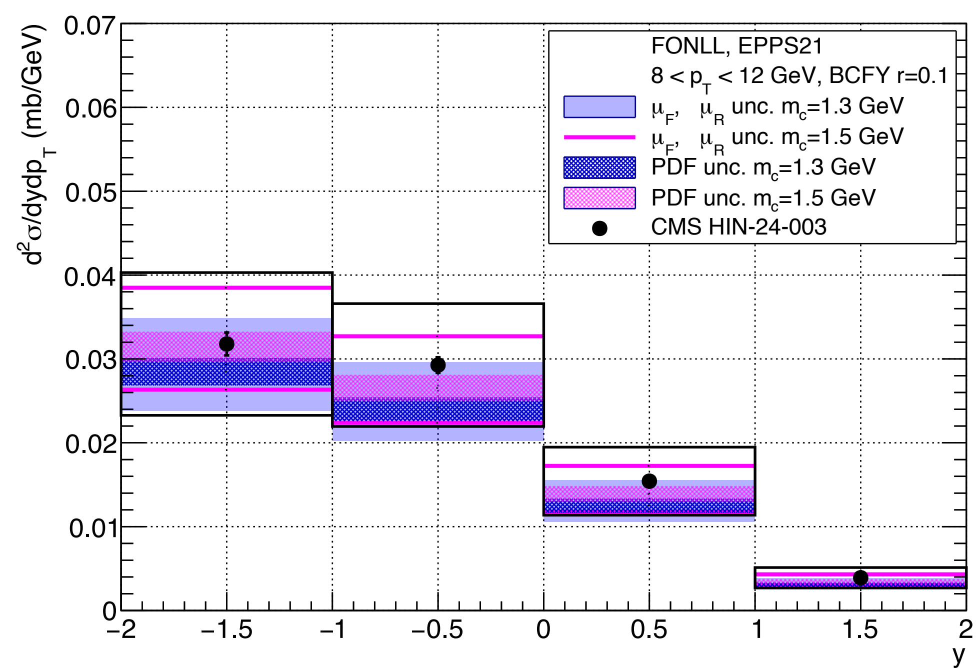
Cross section: FONLL
nPDF: EPPS21
Photon flux: EMD included
Fragmentation: BCFY, r=0.1
Lighter bands/lines :

Scale variation: μ_f/m_T, $\mu_r/m_T(0.5,1,2)$, $\frac{1}{2} \leq \mu_f/\mu_r \leq 2$

Darker/smaller bands: PDF uncertainty
$m_c = 1.3, 1.5$ GeV

$m(D^0) = 1865\,\mathrm{MeV}$



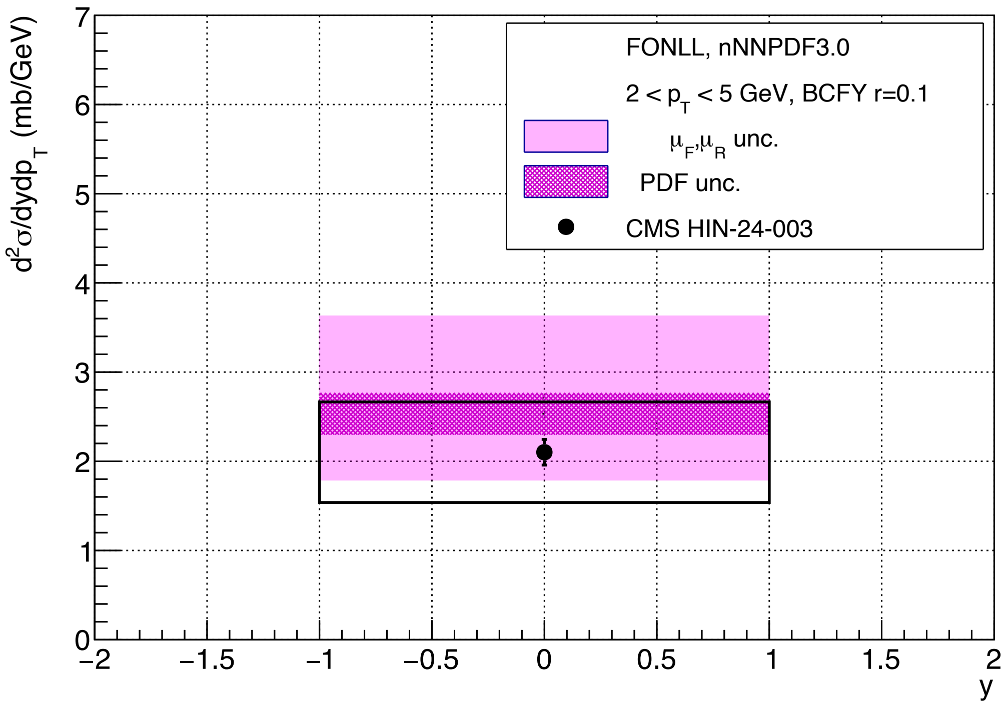


Comparison of FONLL with CMS data

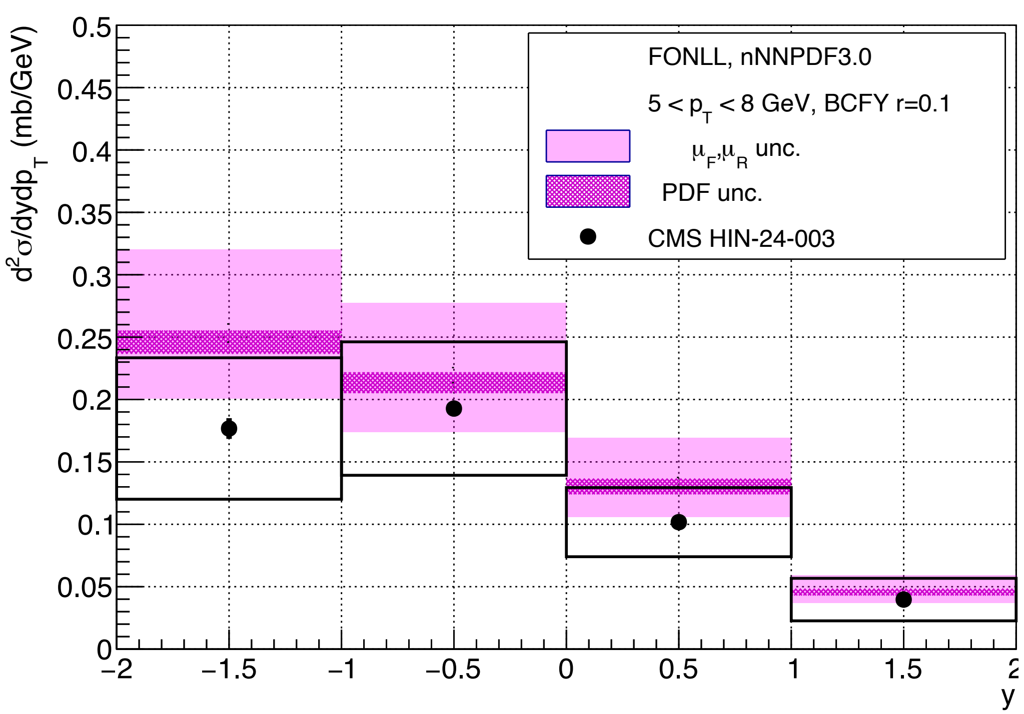
Reasonable agreement within the theoretical/experimental uncertainties

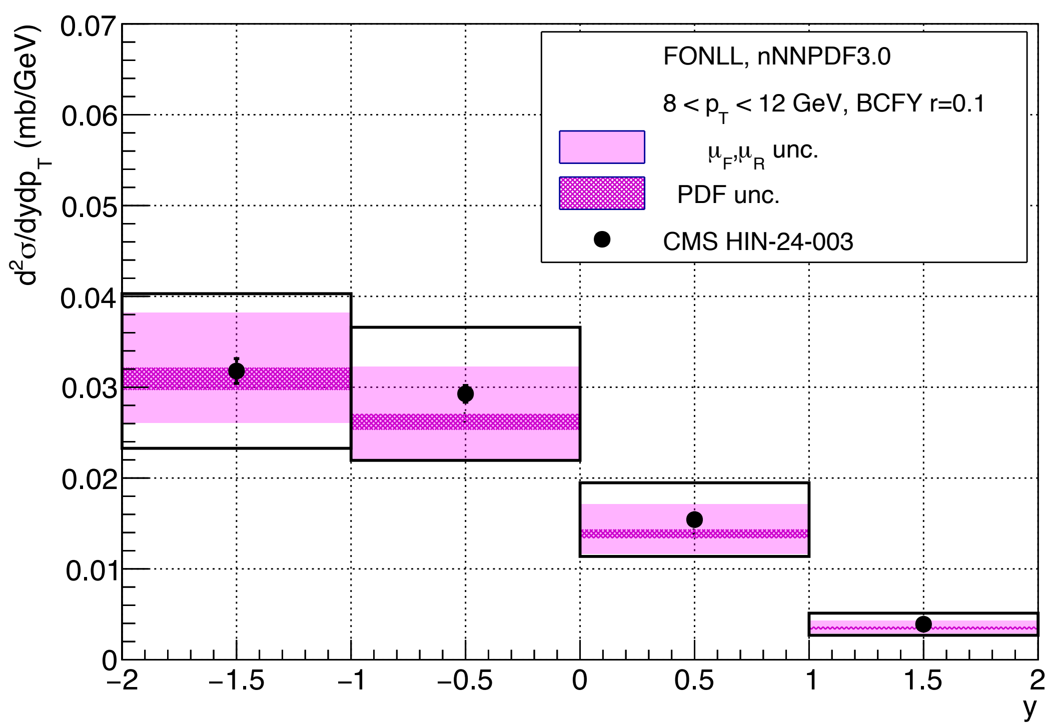
Cacciari, Innocenti, AS, arXiv:2506.09893

Comparison of FONLL with preliminary CMS data on D⁰



Cross section: FONLL
nPDF: nNNPDF
Fragmentation: BCFY, r=0.1
Lighter bands/lines
Scale variation: μ_f/m_T, $\mu_r/m_T(0.5,1,2)$, $\frac{1}{2} \leq \mu_f/\mu_r \leq 2$
Darker/smaller bands: PDF uncertainty
$m_c = 1.5$ GeV

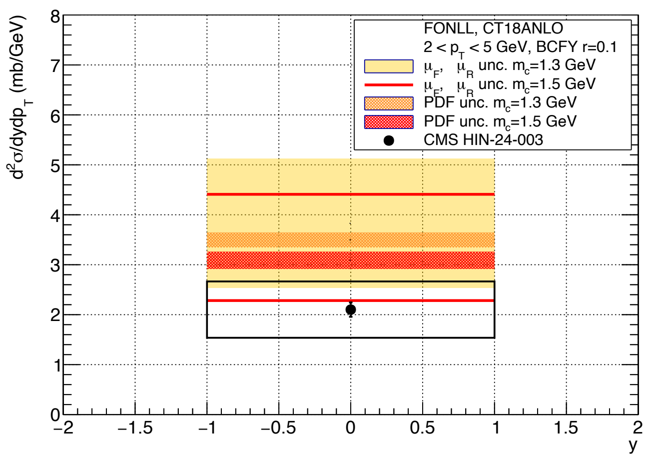


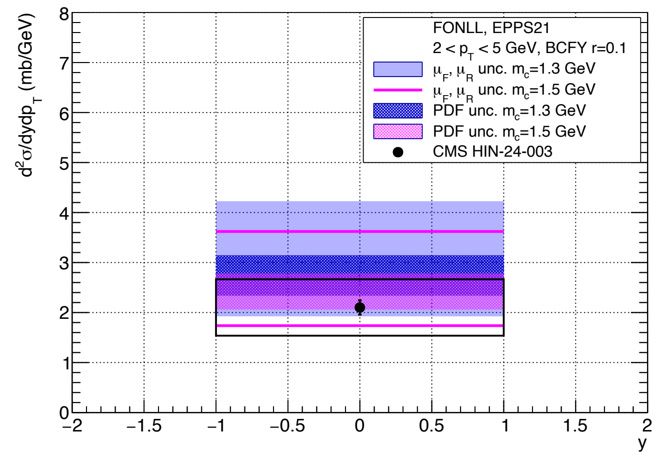


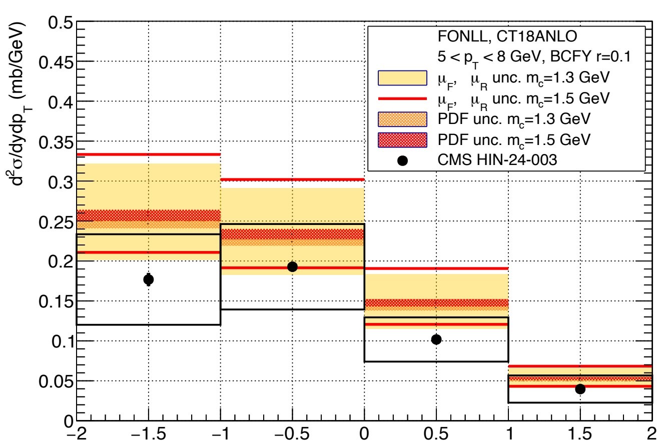
Quality of description similar to EPPS21 with $m_c = 1.5$ GeV

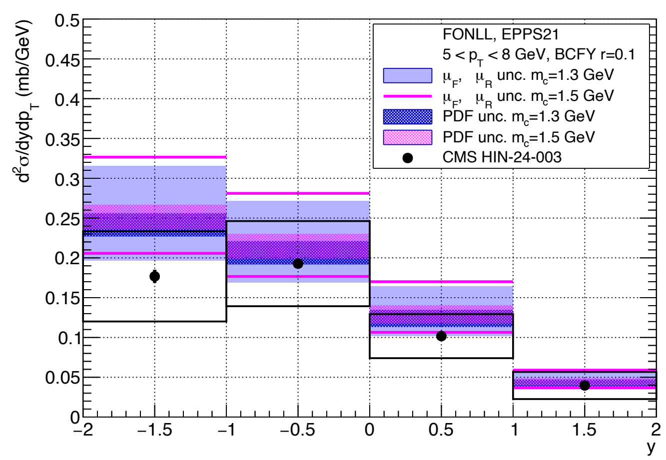
Comparison of FONLL with preliminary CMS data on D^0

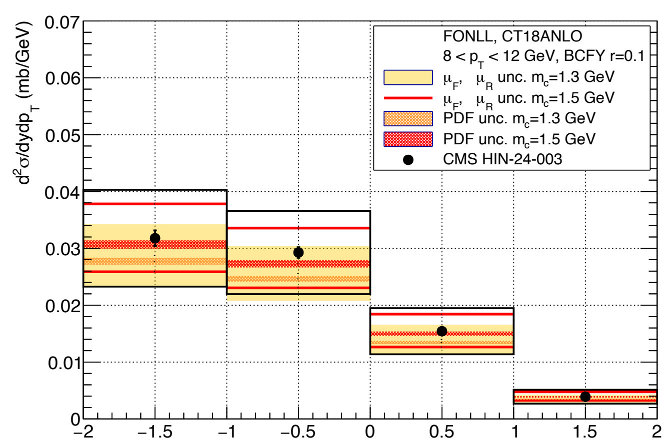
proton **PDF** *lead* **PDF**

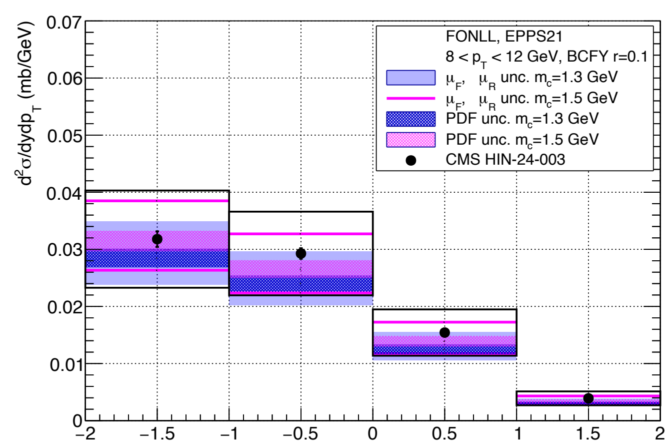












Testing nuclear effects:

***proton* vs *lead* PDF**

Comparison of proton vs nuclear PDF

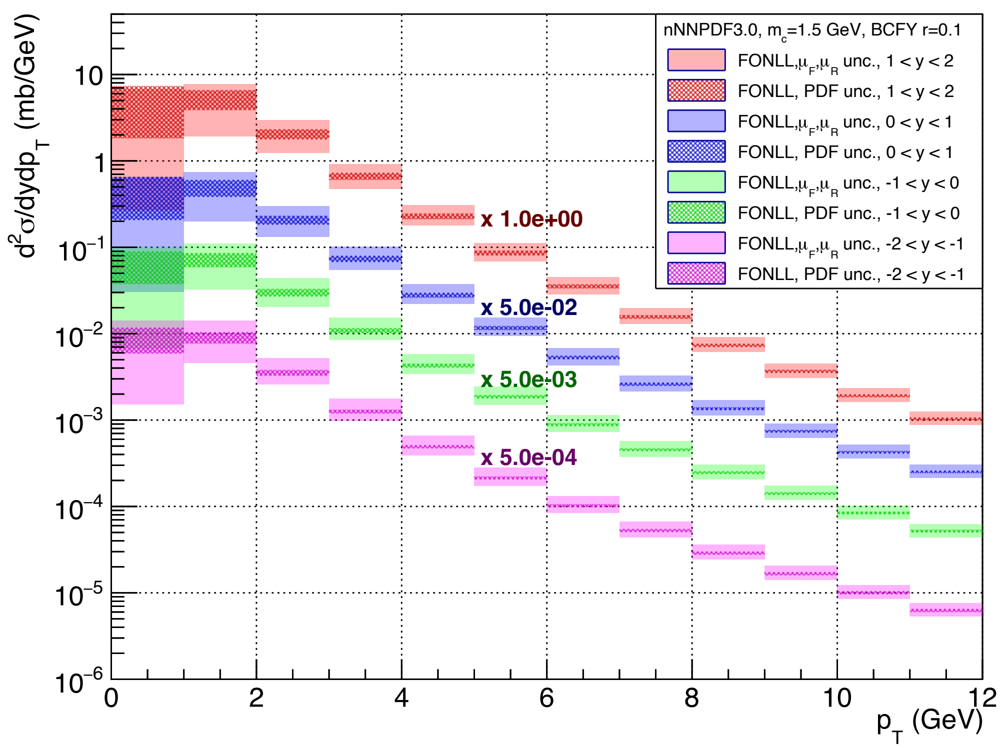
CT18ANLO vs EPPS21 Pb

Nuclear modification largest for

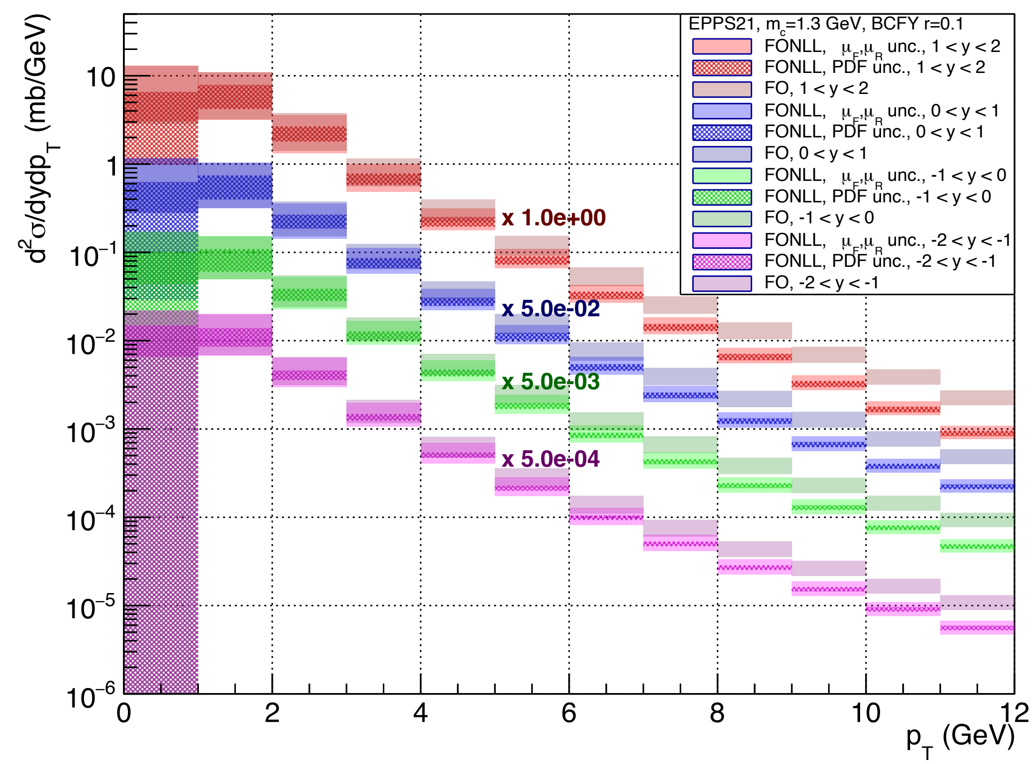
$2 < p_T < 5$ GeV

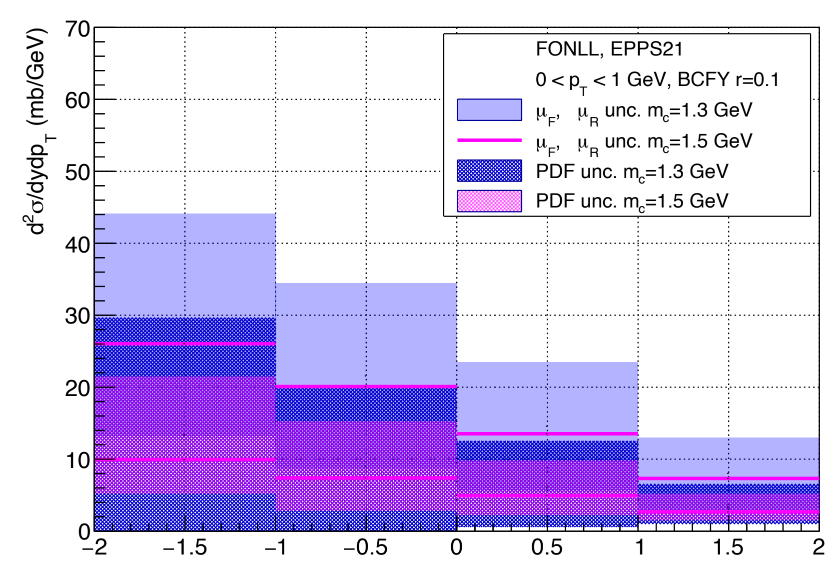
Low p_T and transverse momentum distributions

nNNPDF3.0



EPPS21



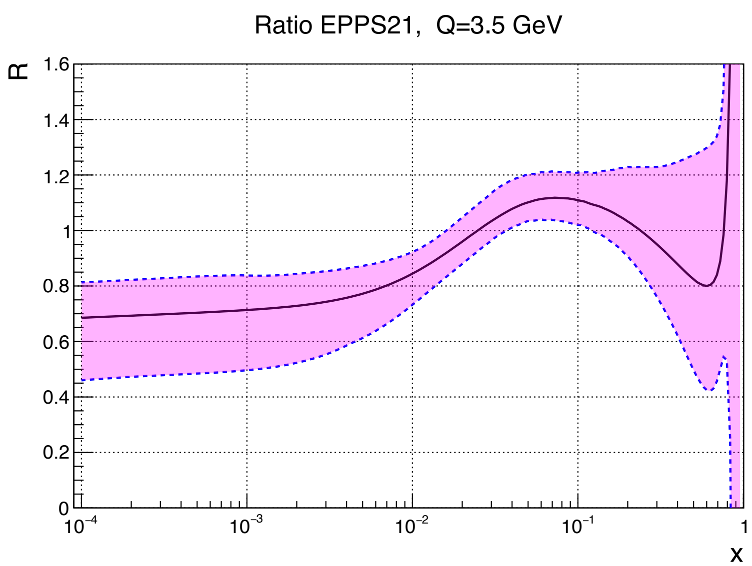


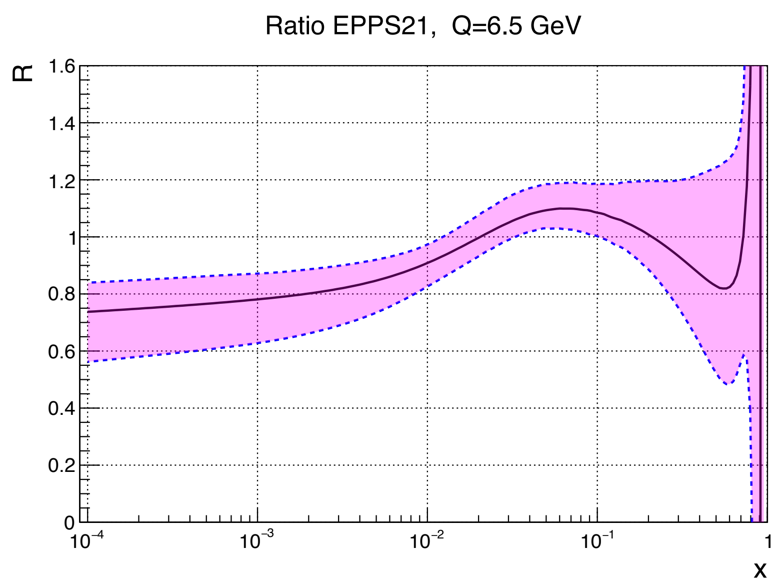
Very large scale and PDF uncertainties for low transverse momentum region
Opportunity for measurements to put strong constraints on nPDFs at very low scales

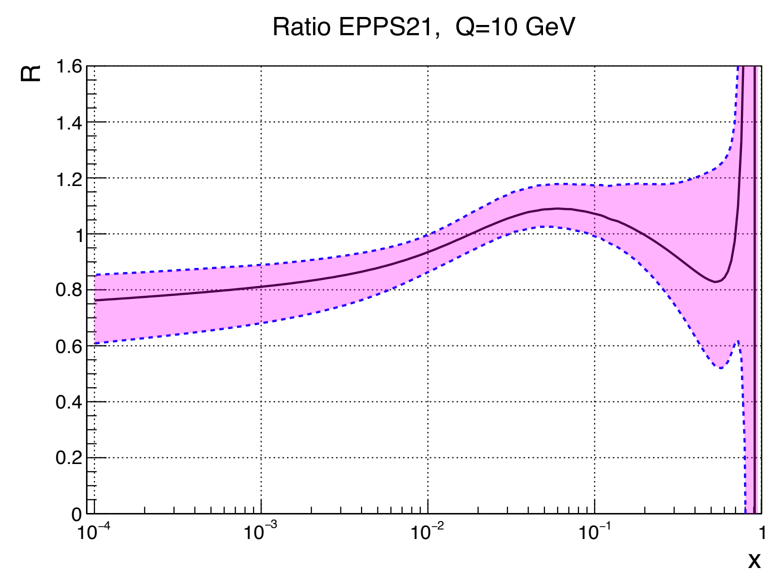
Nuclear gluon distribution: shadowing effects

Nuclear ratios for gluon EPPS21 evaluated at the middle of the pT bins

(2,5), (5,8), (8,12)

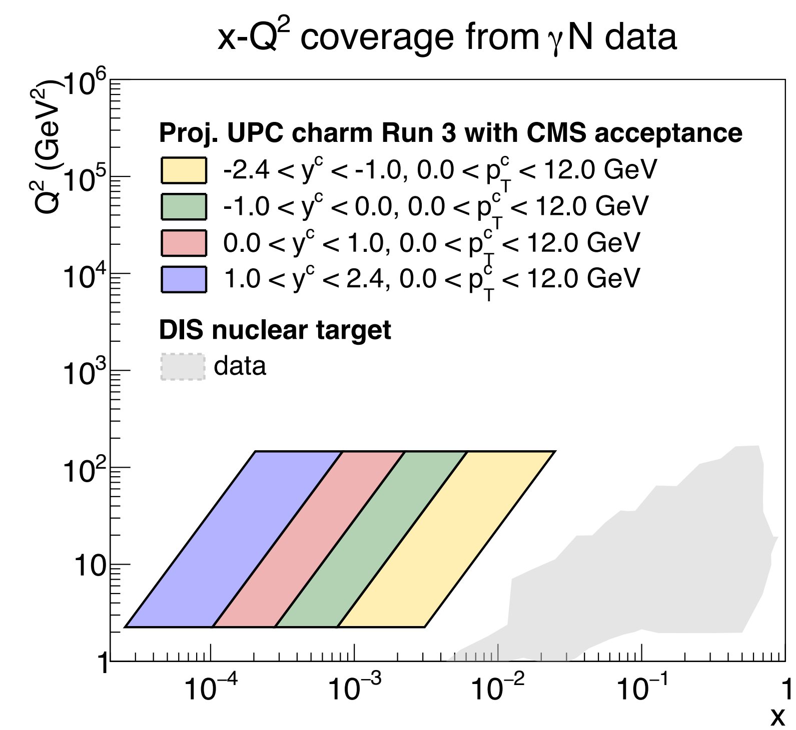






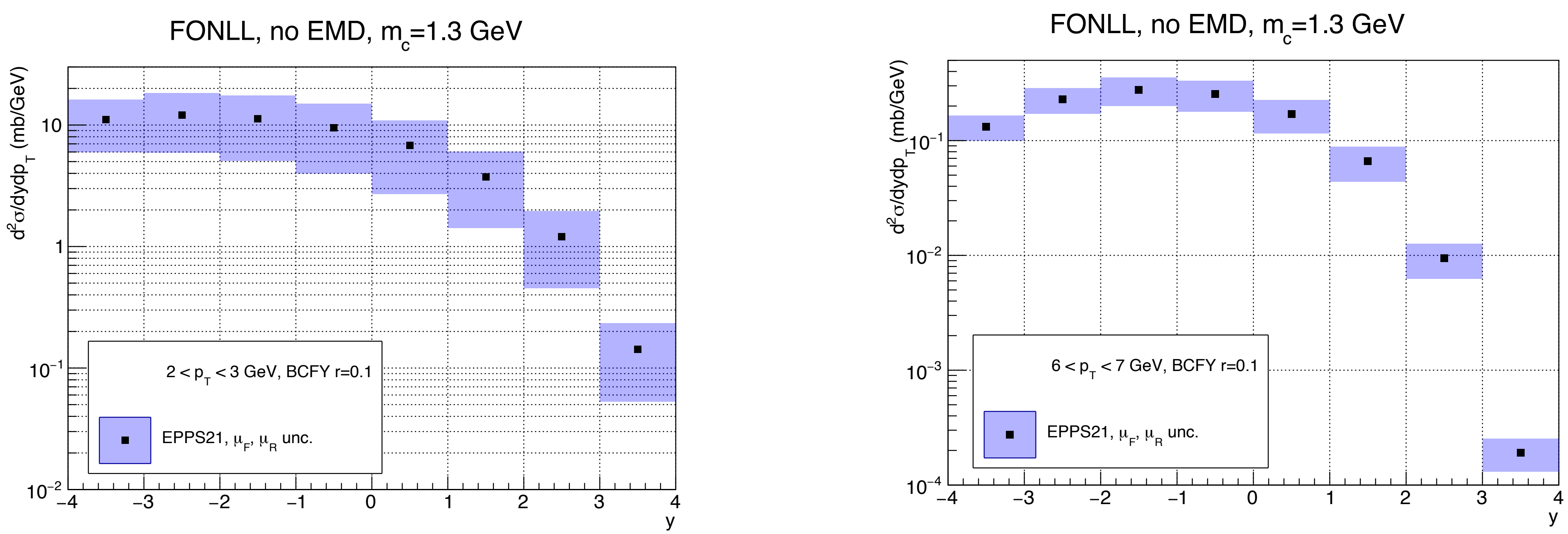
Shadowing ratio at about 70% for lowest p_T bin and low x, evaluated at the gluon(parton) level

Indeed, a reduction visible in lowest bin in CMS measurement, seems stronger than the nPDFs

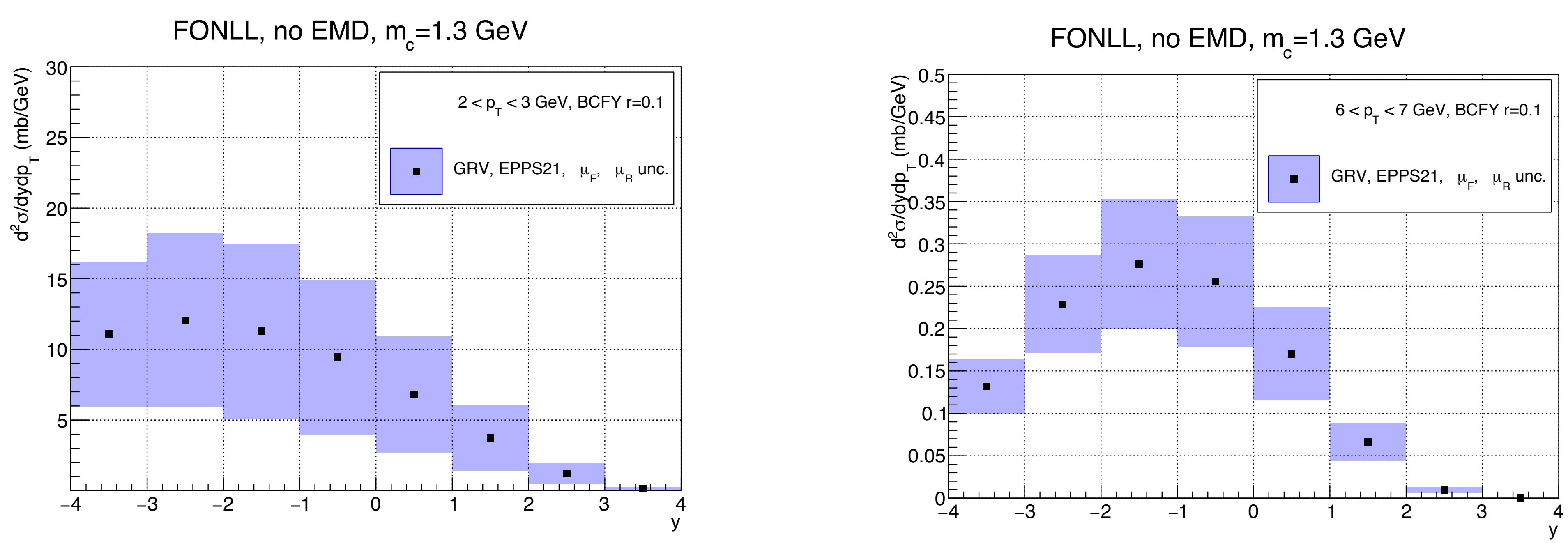


Wider range of rapidity: −4<y<4

log scale

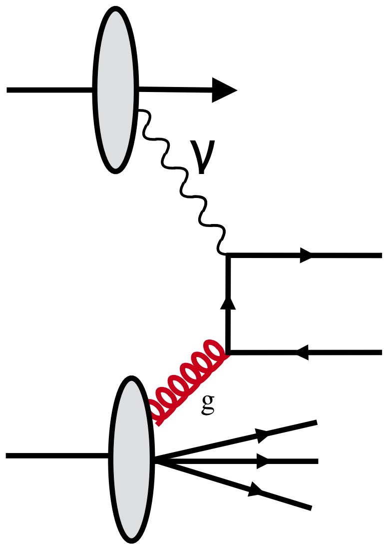


lin scale

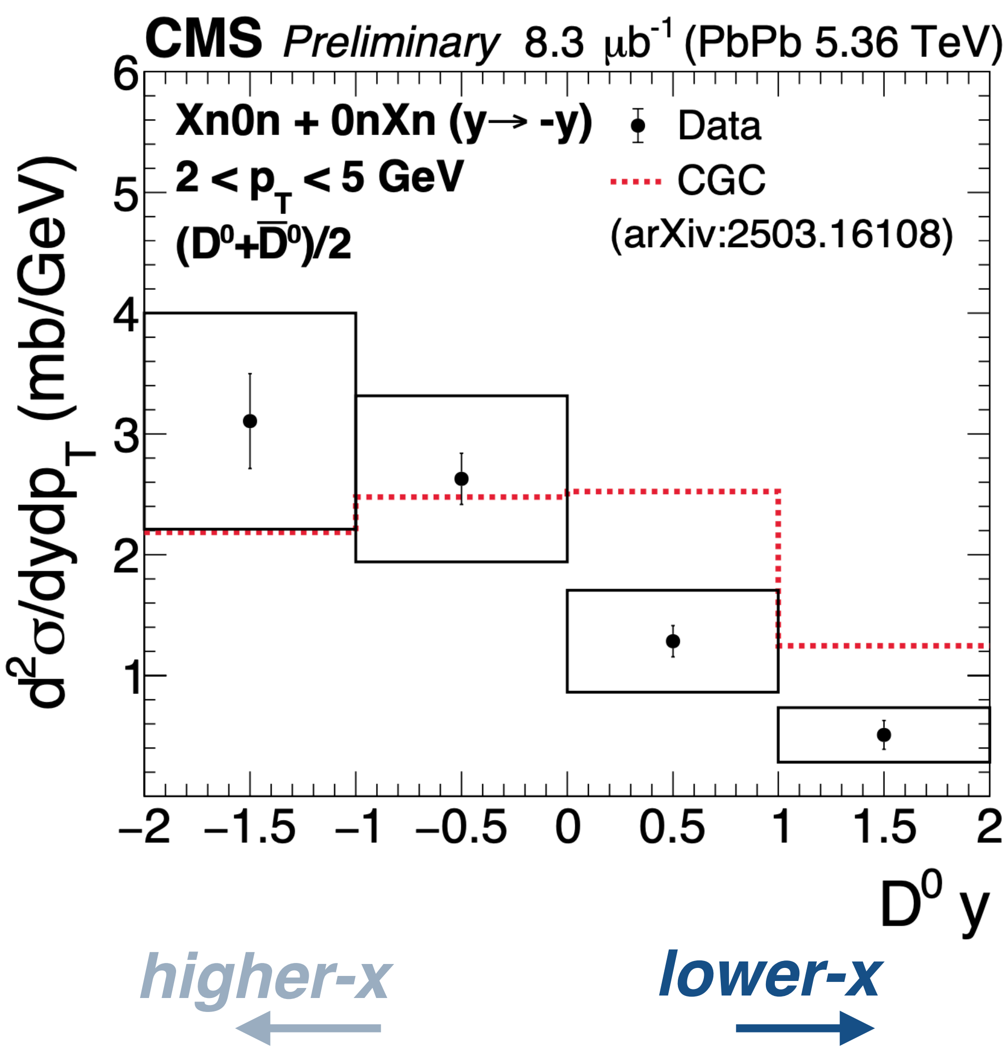


Cross section large down to y=-4: large x in nucleus, more photon PDF sensitivity
Cross section still non-negligible for low p_T up to y=3: small x region

y-differential measurement of D^0 UPC production

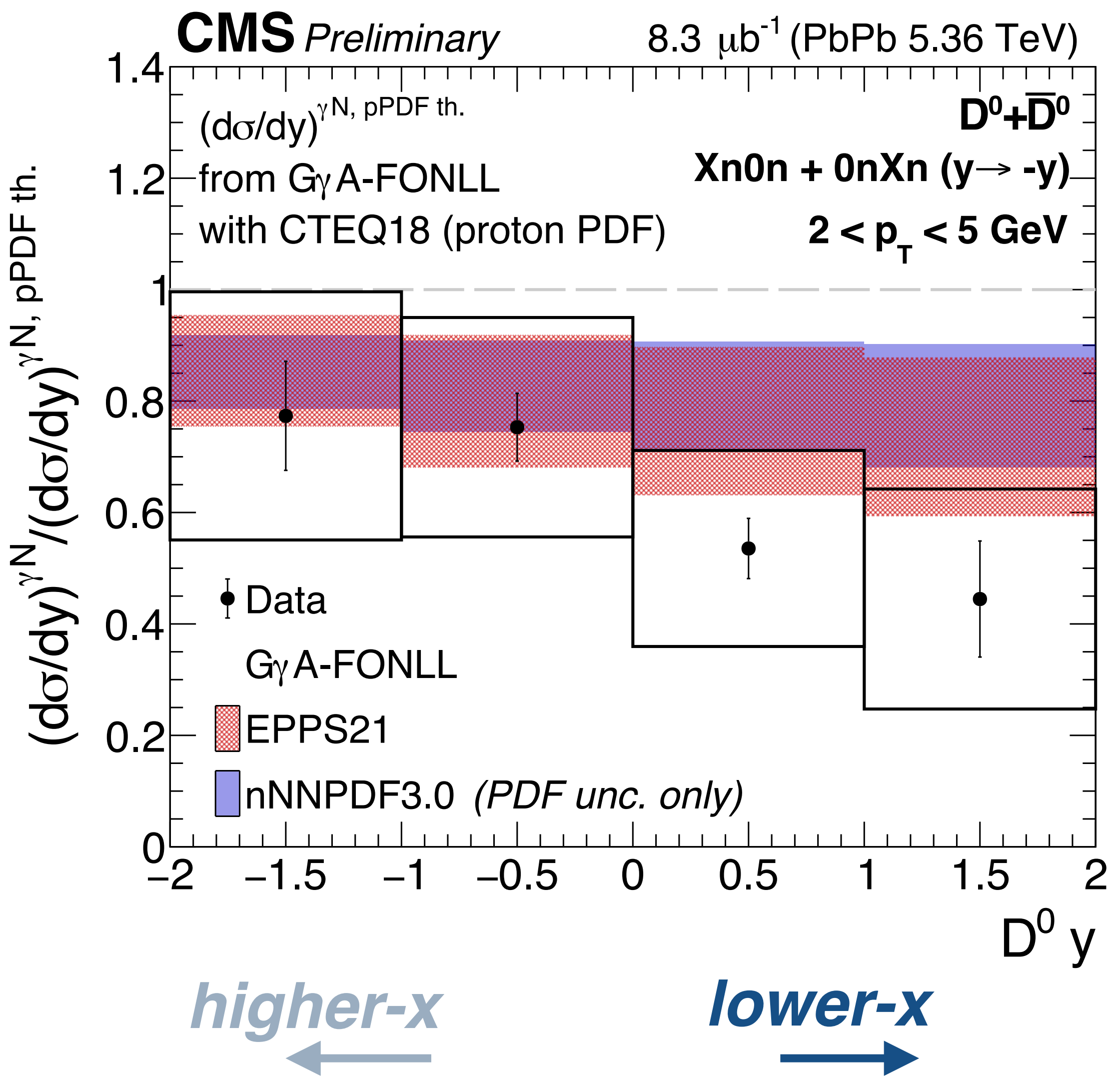


p_T (2-12 GeV)
y (-2 to 2)



P. Gimeno-Estivill, T. Lappi, H. Mäntysaari, arXiv:2503.16108

Ratio to GγA-FONLL with proton PDFs



Sensitivity to nPDF down to ~ 10^{-4} at low Q^2

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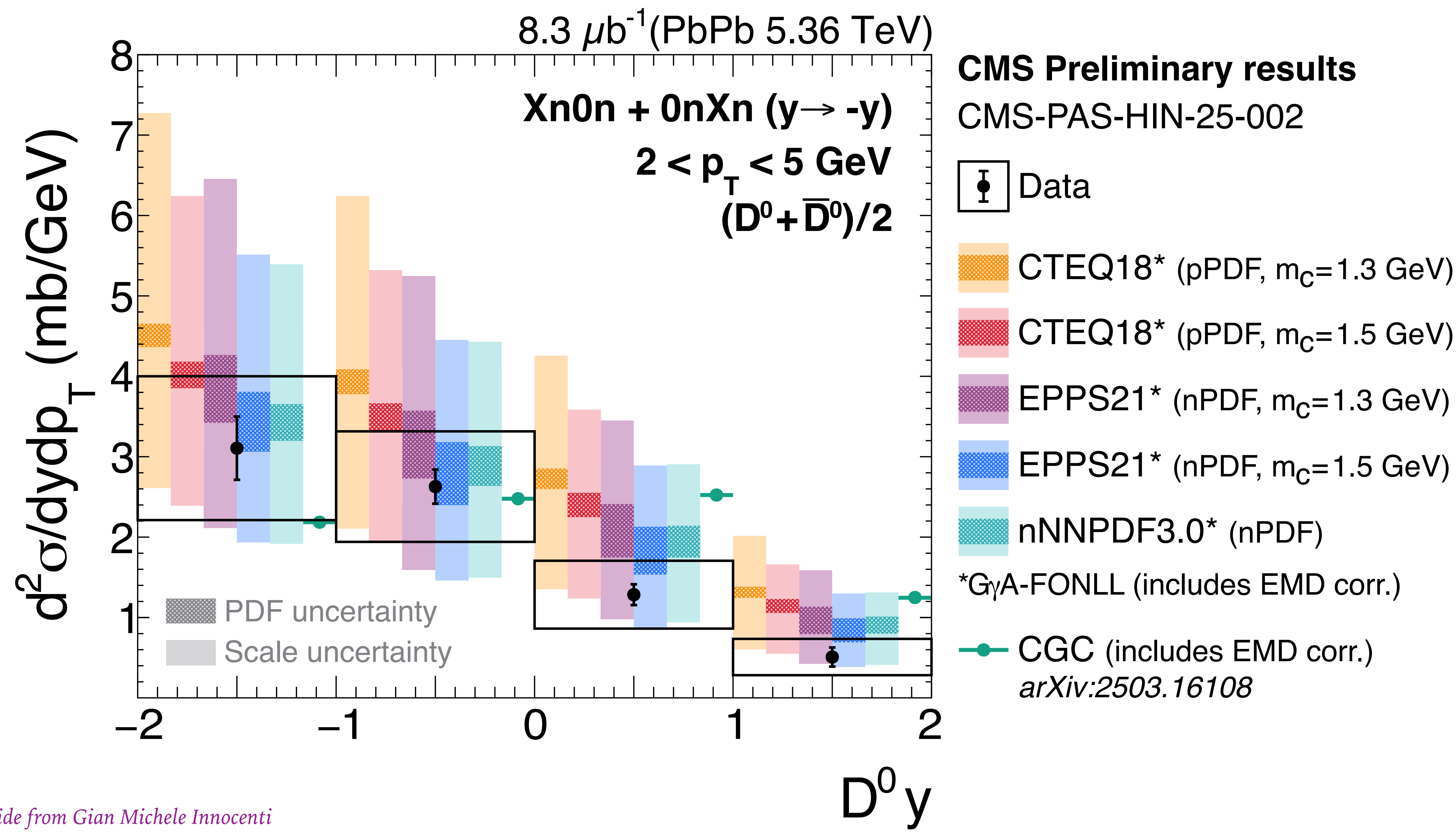
Slide from Gian Michele Innocenti

CMS data vs theoretical calculations



Slide from Gian Michele Innocenti

Summary and outlook

- UPCs offer ample opportunities to test **SM and nuclear structure**
- Many new measurements at RHIC and LHC
- Recently: CMS measurement on the **open charm photoproduction in PbPb UPC at LHC** $\sqrt{s_{\mathrm{NN}}} = 5.36\,\mathrm{TeV}$
- **Reasonable agreement** between theory and data on **D^0 production from CMS**, within theoretical and experimental uncertainties
- Effects of **nuclear modification visible** in the CMS kinematics, at low p_T
  - CMS data at **low p_T** (differential in rapidity) may point to **stronger nuclear** modification than currently encoded in the nPDFs, however more detailed studies needed to disentangle various effects