LHCPhysics
Belgrade, 22 - 26 May 2023

Probing gluons in nuclei using UPC

Guillermo Contreras
Czech Technical University in Prague

On behalf of

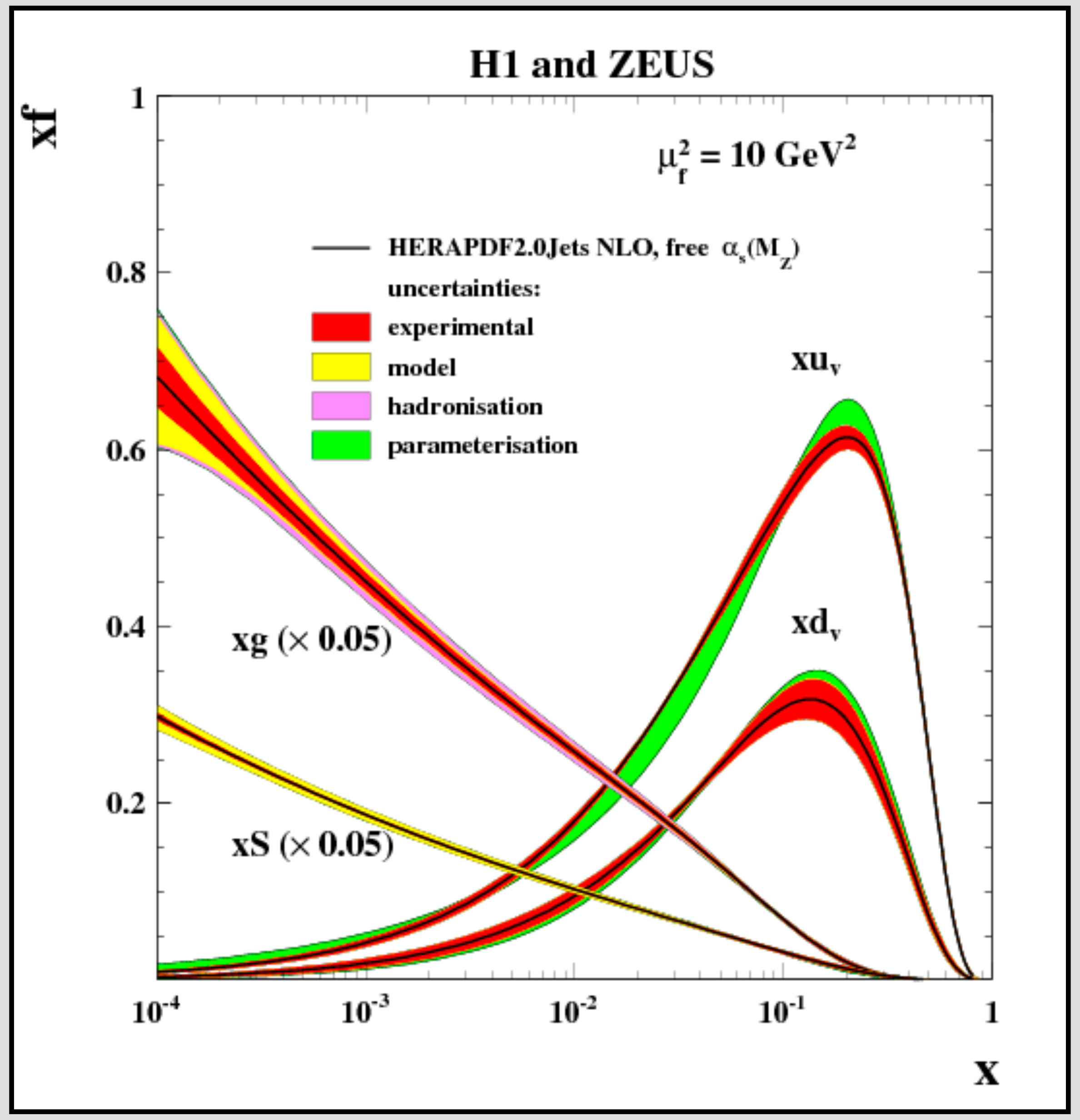
ALICE ATLAS EXPERIMENT CMS

Key questions we are interested in

What can we learn about the structure of hadrons at high energies with the LHC?

Key questions we are interested in

Measurements at HERA imply that, when seen with a high-energy probe, nucleons are made mainly of gluons

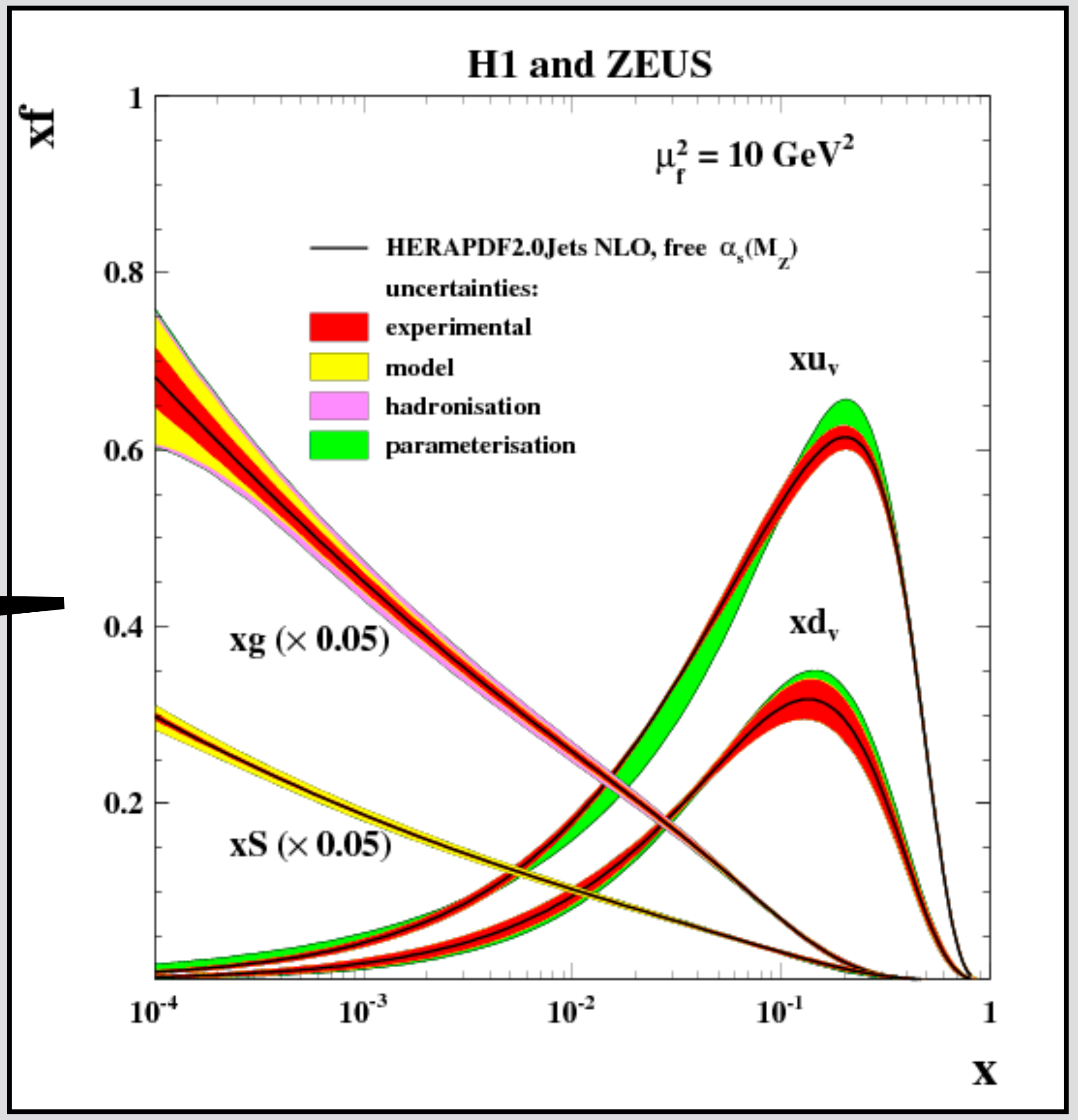


H1 and Zeus, EPCJ 75 (2015) 580

What can we learn about the structure of hadrons at high energies with the LHC?

Key questions we are interested in

Measurements at HERA imply that, when seen with a high-energy probe, nucleons are made mainly of gluons



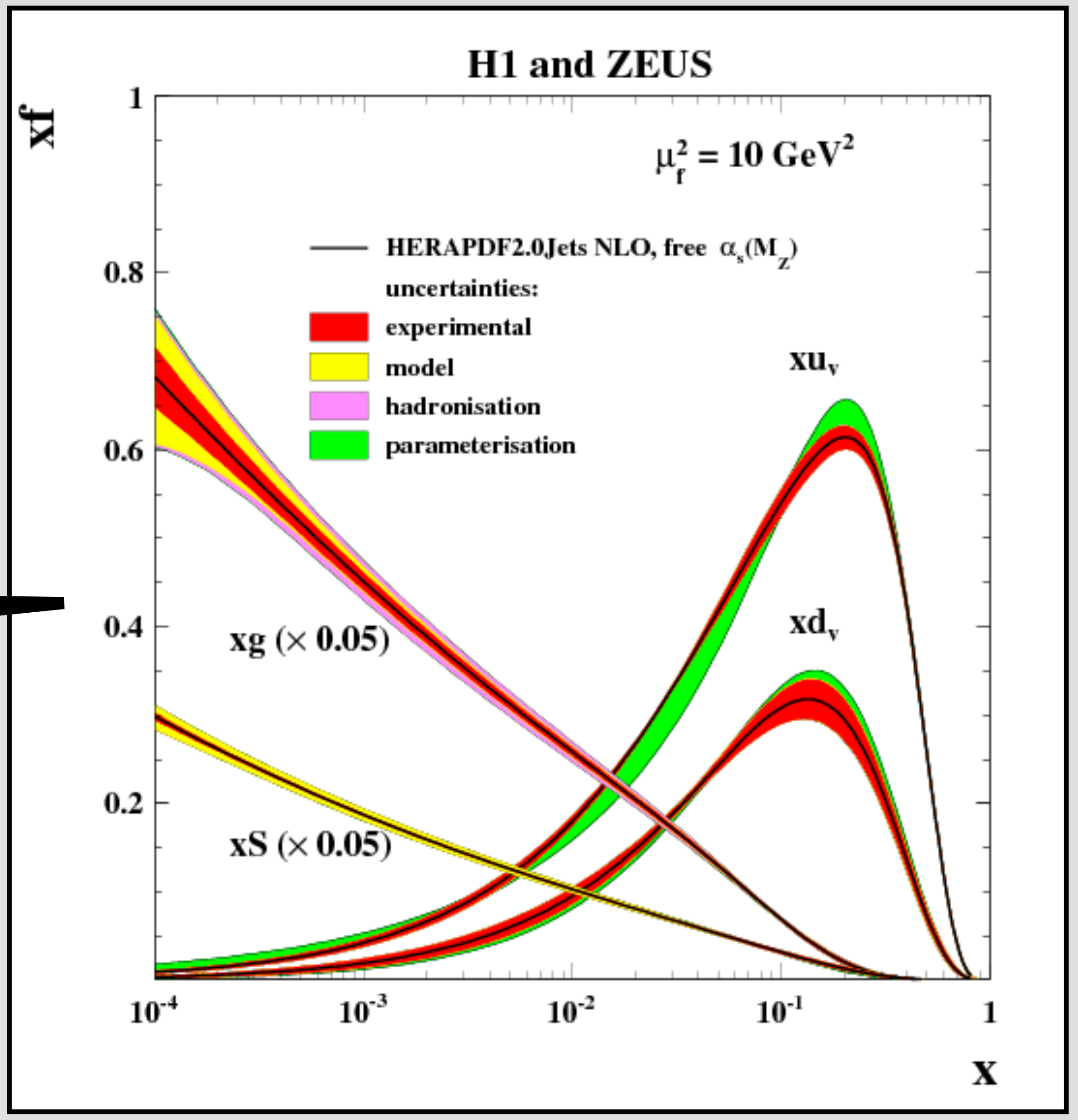
H1 and Zeus, EPCJ 75 (2015) 580

How does the gluon structure of nucleons change with energy at high energies?

What can we learn about the structure of hadrons at high energies with the LHC?

Key questions we are interested in

Measurements at HERA imply that, when seen with a high-energy probe, nucleons are made mainly of gluons



H1 and Zeus, EPCJ 75 (2015) 580

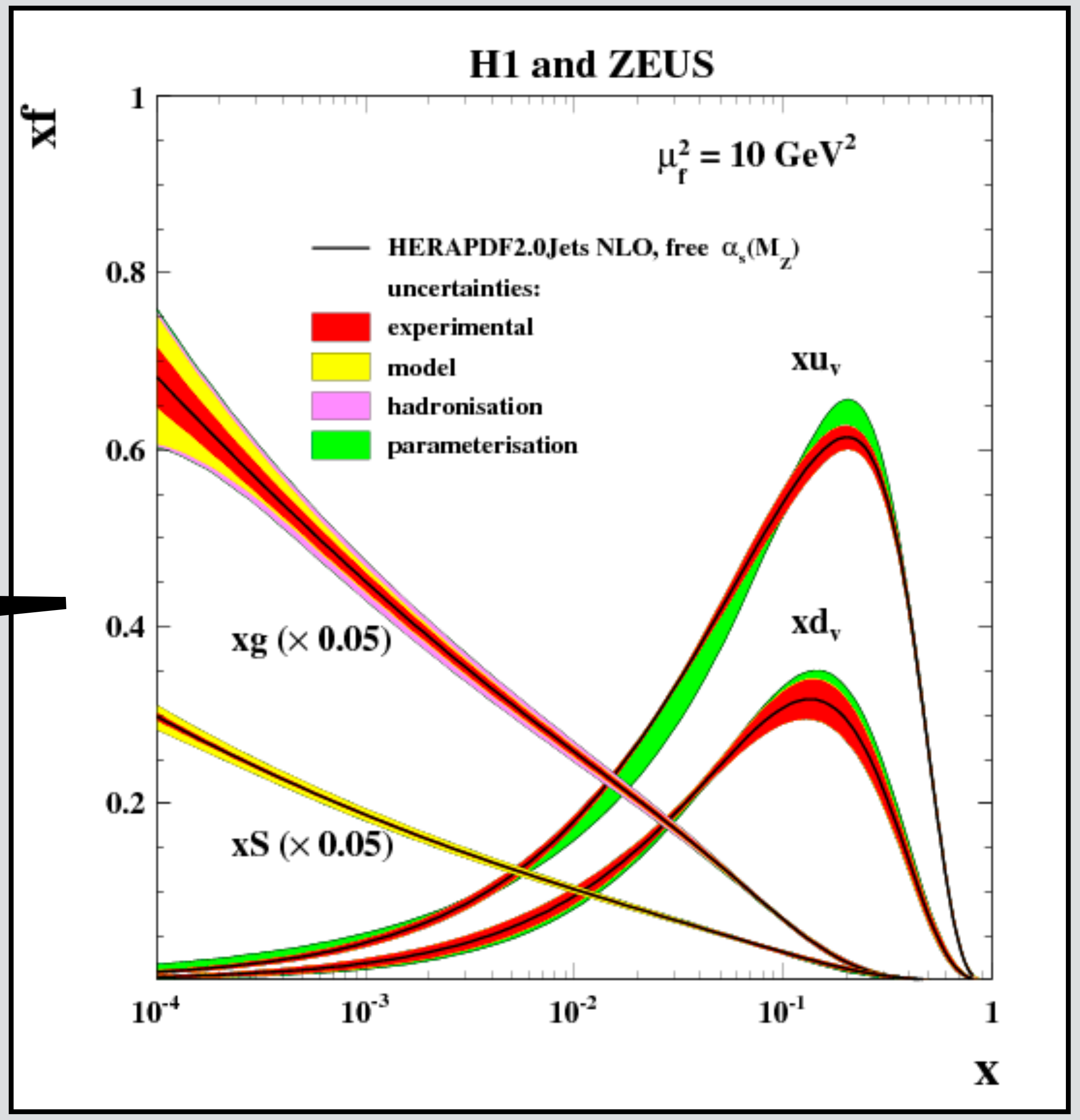
How does the gluon structure of nucleons change with energy at high energies?

Key question: have we reached the saturation regime?

What can we learn about the structure of hadrons at high energies with the LHC?

Key questions we are interested in

Measurements at HERA imply that, when seen with a high-energy probe, nucleons are made mainly of gluons



H1 and Zeus, EPCJ 75 (2015) 580

How does this structure change when the nucleon is embedded in a nucleus?

How does the gluon structure of nucleons change with energy at high energies?

Key question: have we reached the saturation regime?

What can we learn about the structure of hadrons at high energies with the LHC?

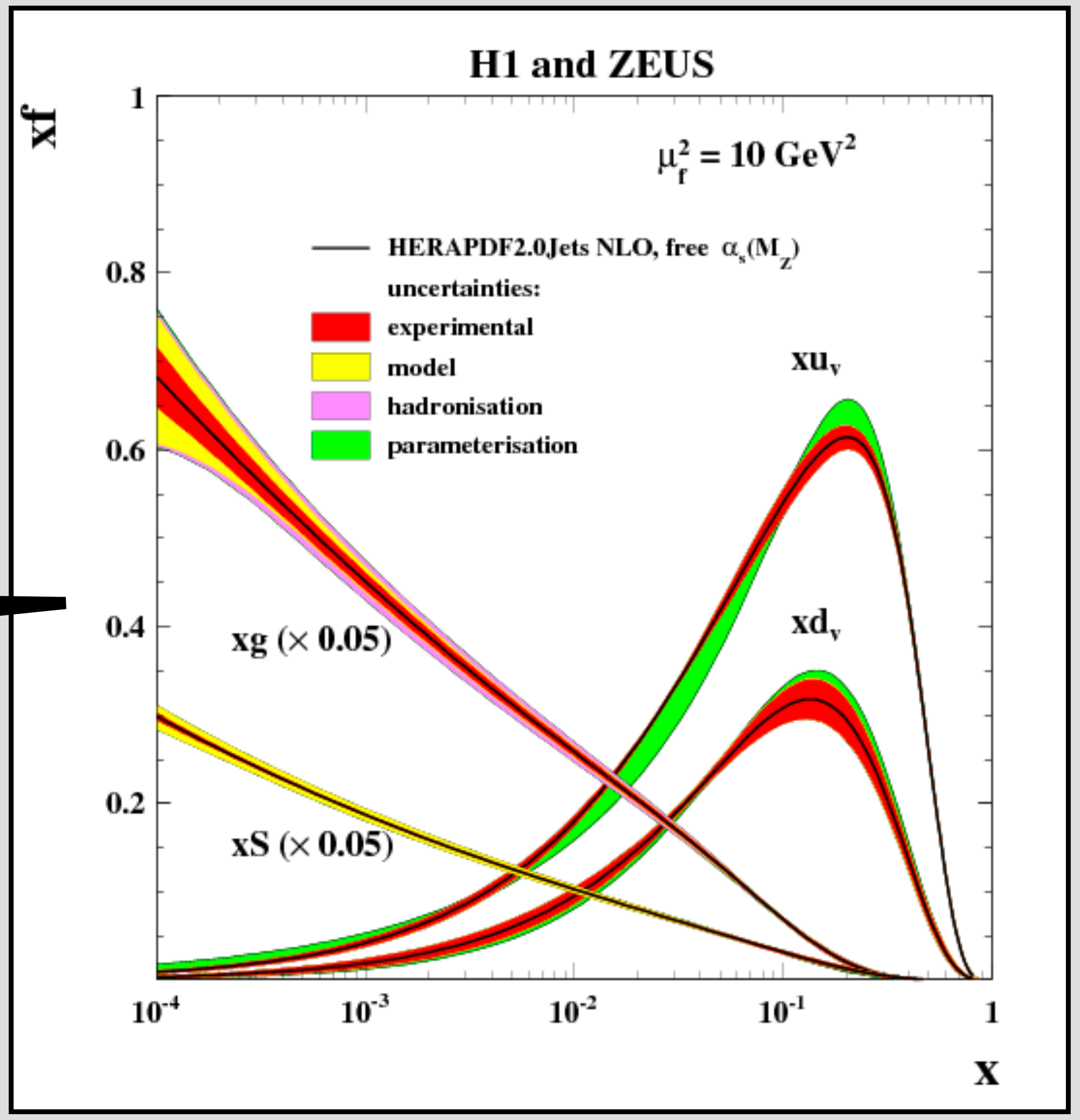
Key question: what is the origin of shadowing at high energies?

How does this structure change when the nucleon is embedded in a nucleus?

How does the gluon structure of nucleons change with energy at high energies?

Key question: have we reached the saturation regime?

Measurements at HERA imply that, when seen with a high-energy probe, nucleons are made mainly of gluons

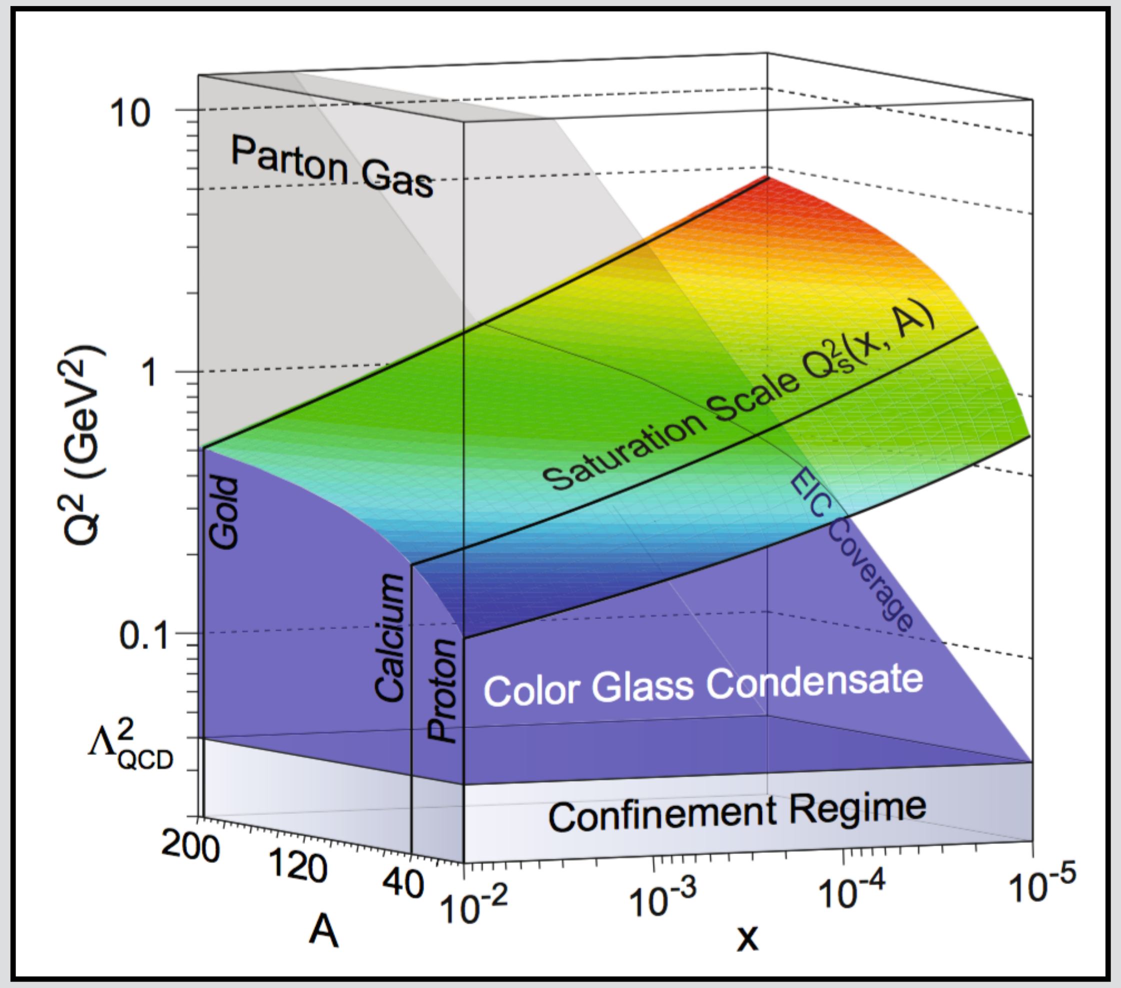


H1 and Zeus, EPCJ 75 (2015) 580

What can we learn about the structure of hadrons at high energies with the LHC?

Key questions we are interested in

Saturation is expected to set at higher x in heavy nuclei



Accardi et al, EPJA 52 (2016) 268

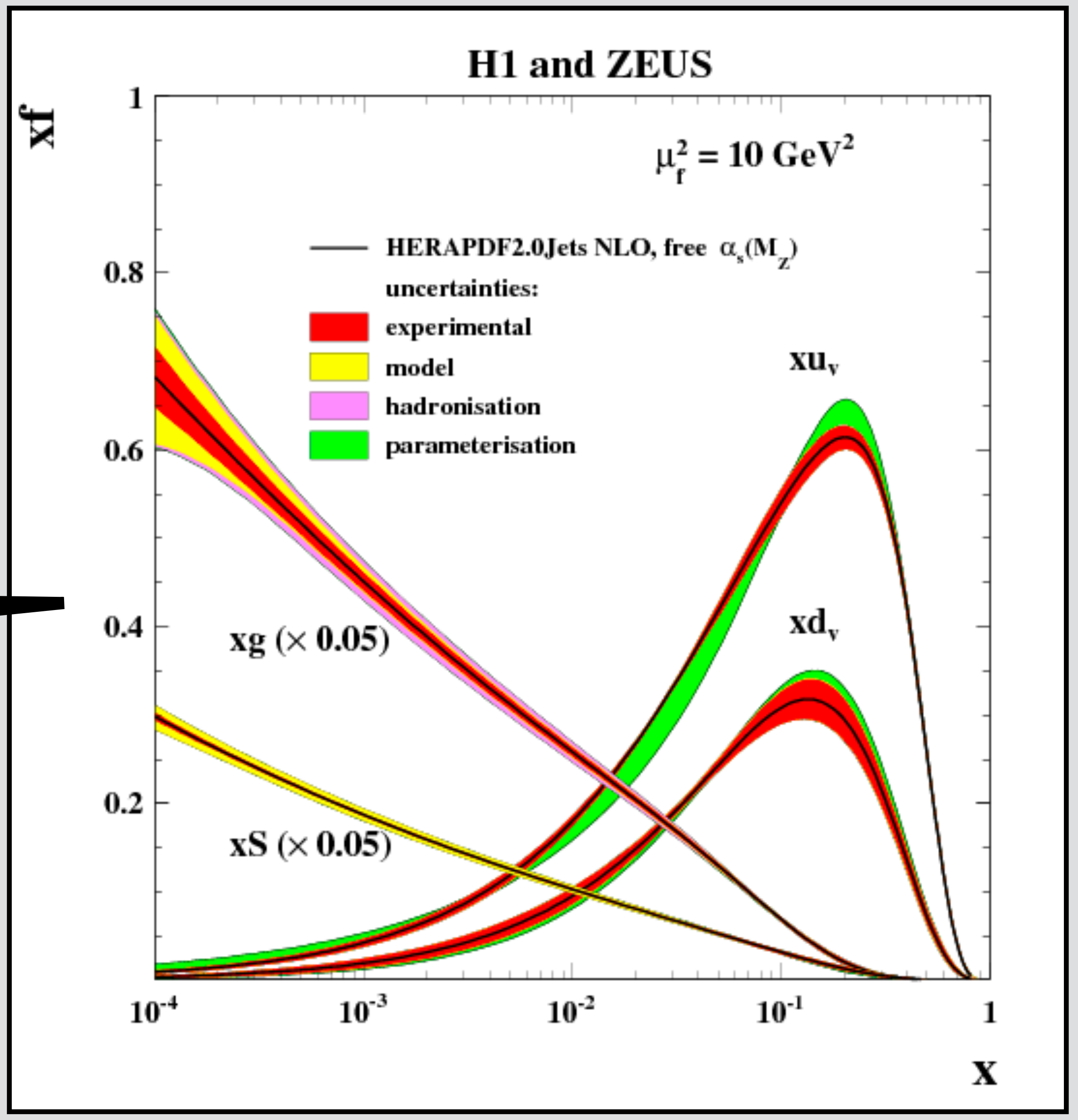
Key question: have we reached the saturation regime?

Key question: what is the origin of shadowing at high energies?

How does this structure change when the nucleon is embedded in a nucleus?

How does the gluon structure of nucleons change with energy at high energies?

Measurements at HERA imply that, when seen with a high-energy probe, nucleons are made mainly of gluons

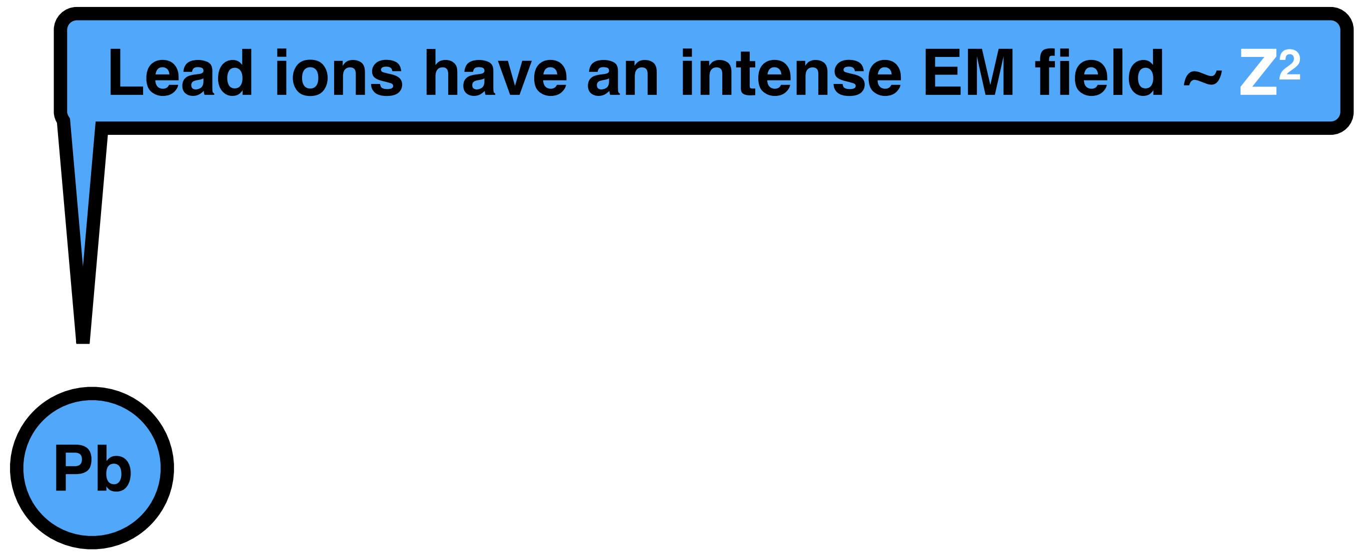


H1 and Zeus, EPCJ 75 (2015) 580

What can we learn about the structure of hadrons at high energies with the LHC?

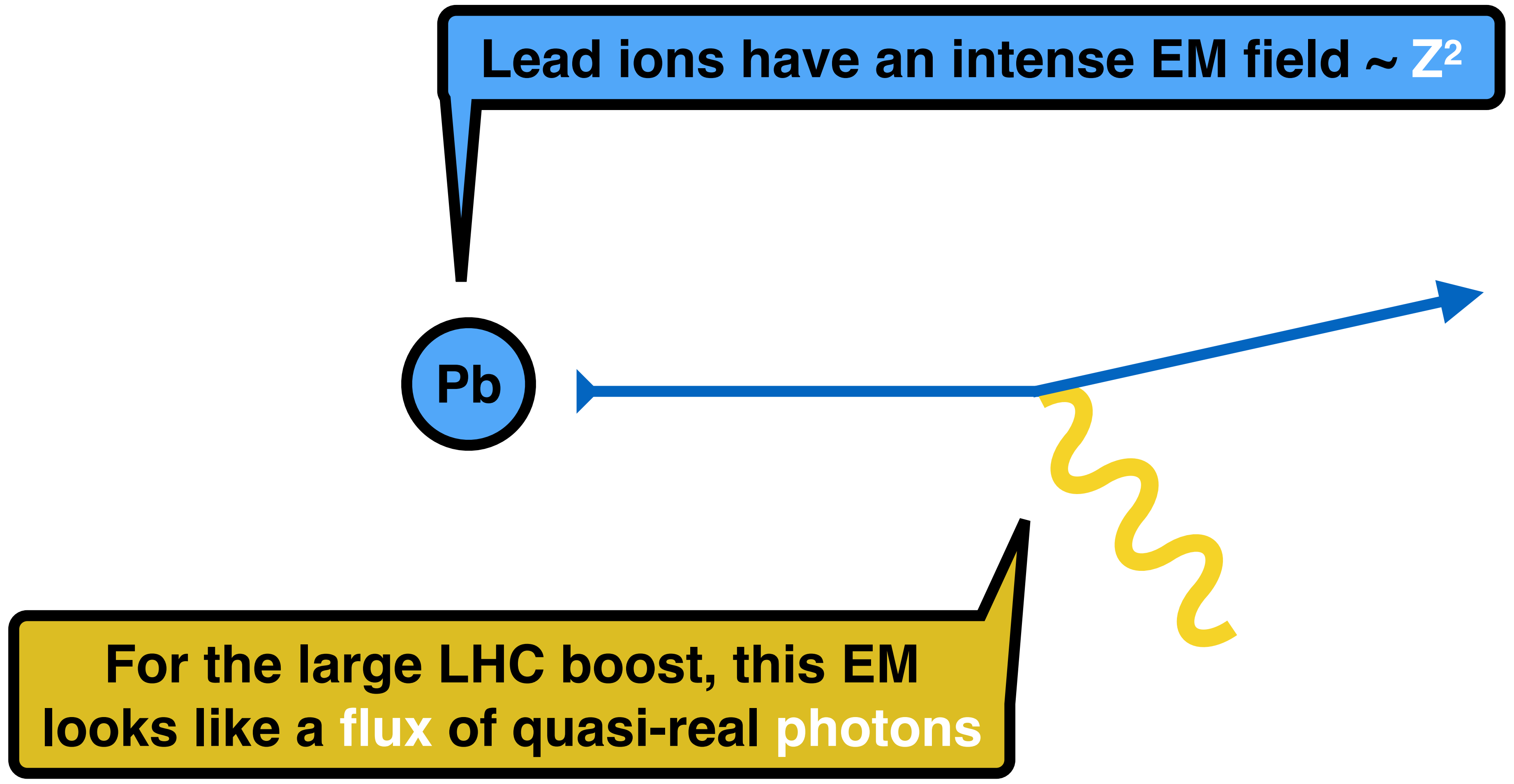
Guillermo Contreras, CTU in Prague

Photons at the LHC to understand QCD

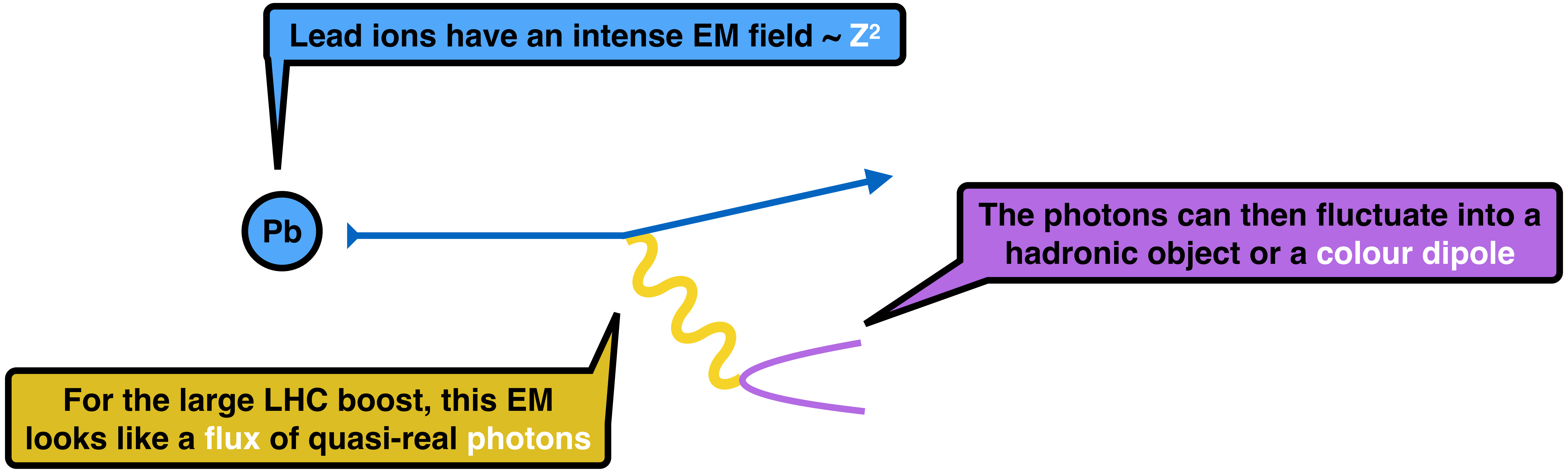


Guillermo Contreras, CTU in Prague

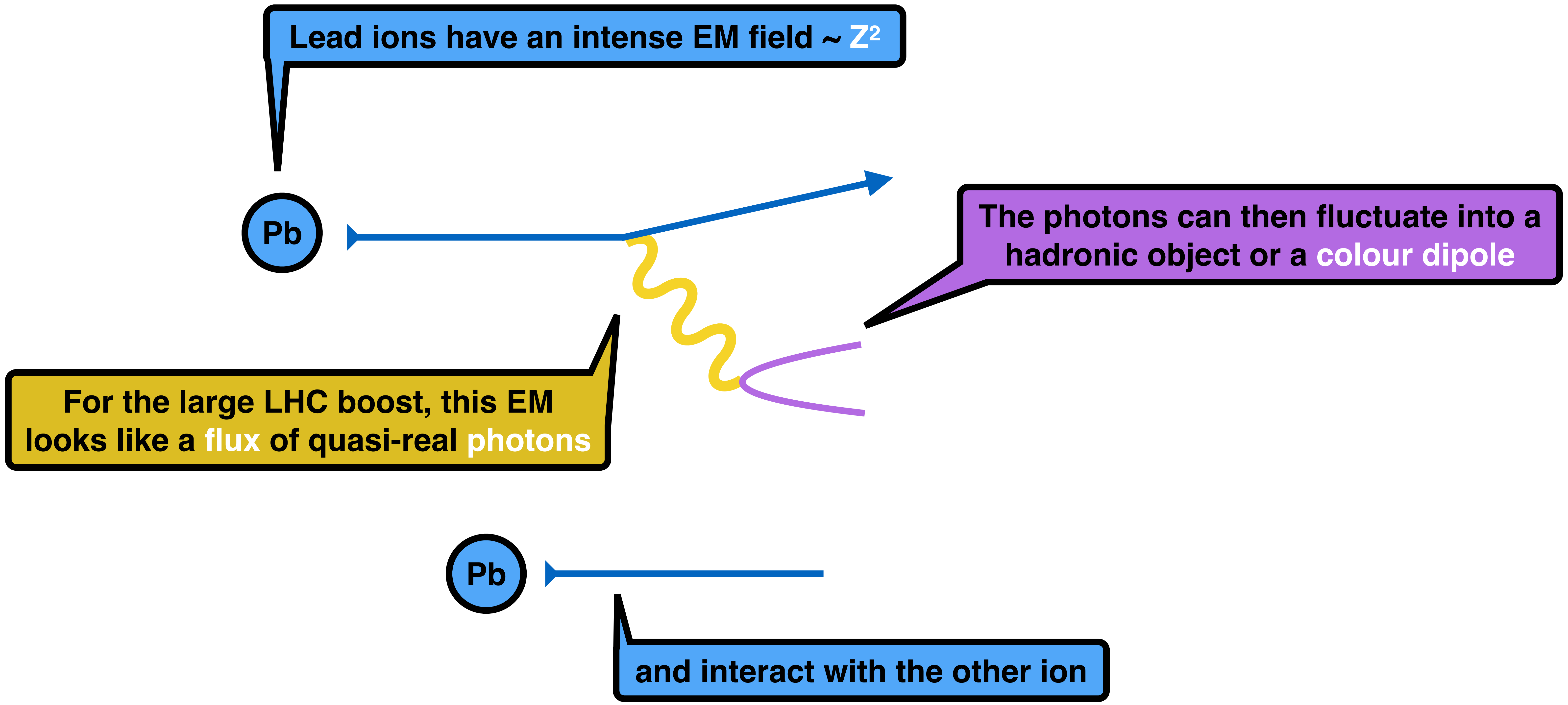
Photons at the LHC to understand QCD



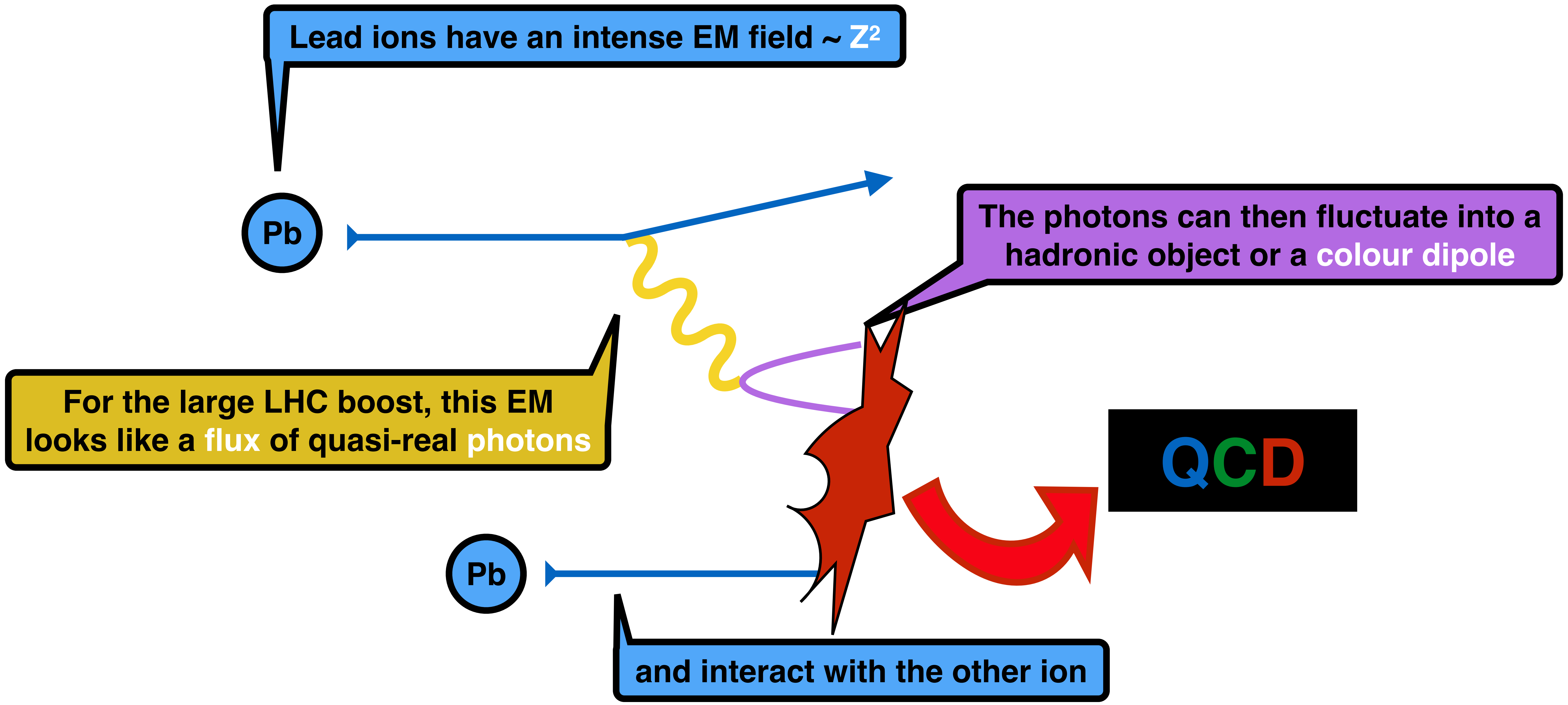
Photons at the LHC to understand QCD



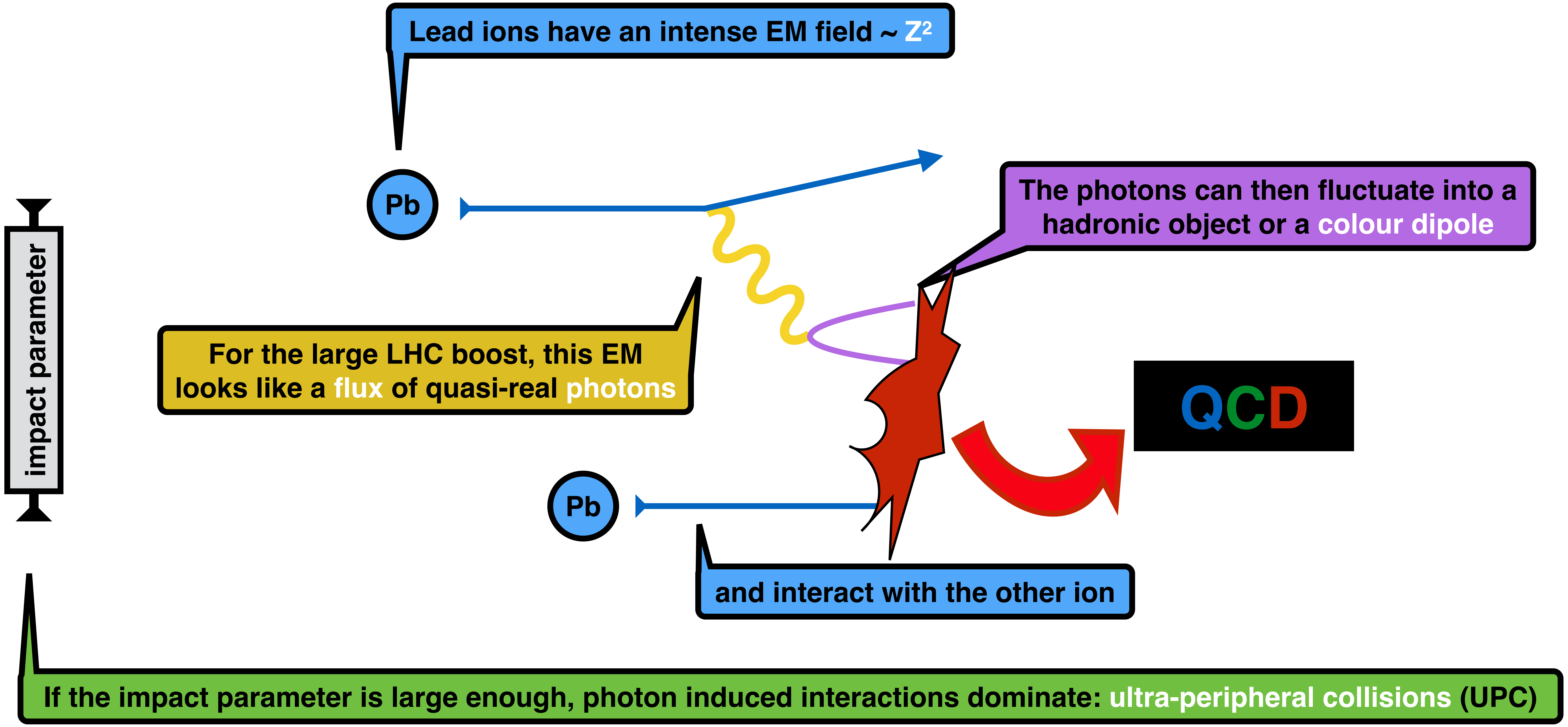
Photons at the LHC to understand QCD



Photons at the LHC to understand QCD

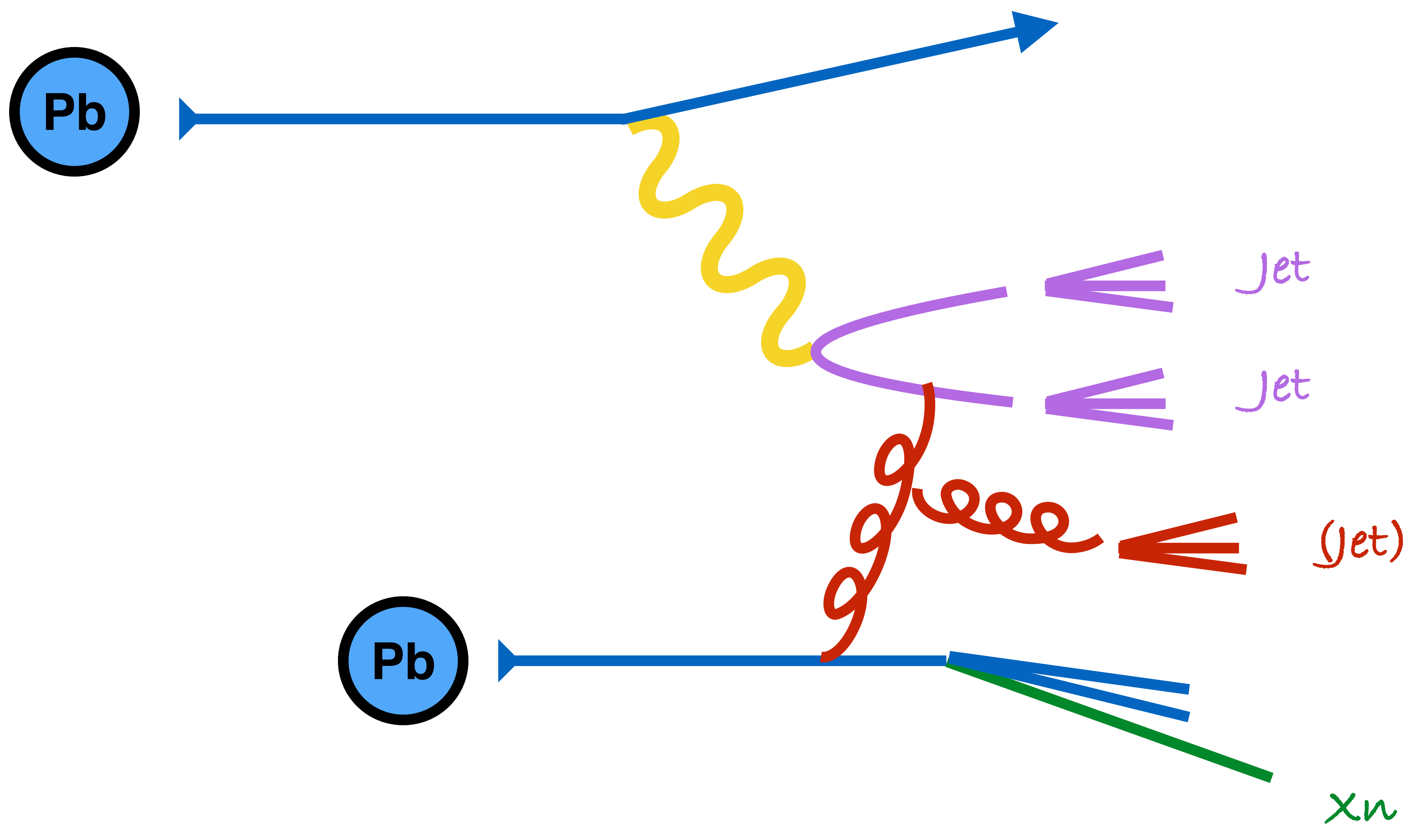


Photons at the LHC to understand QCD



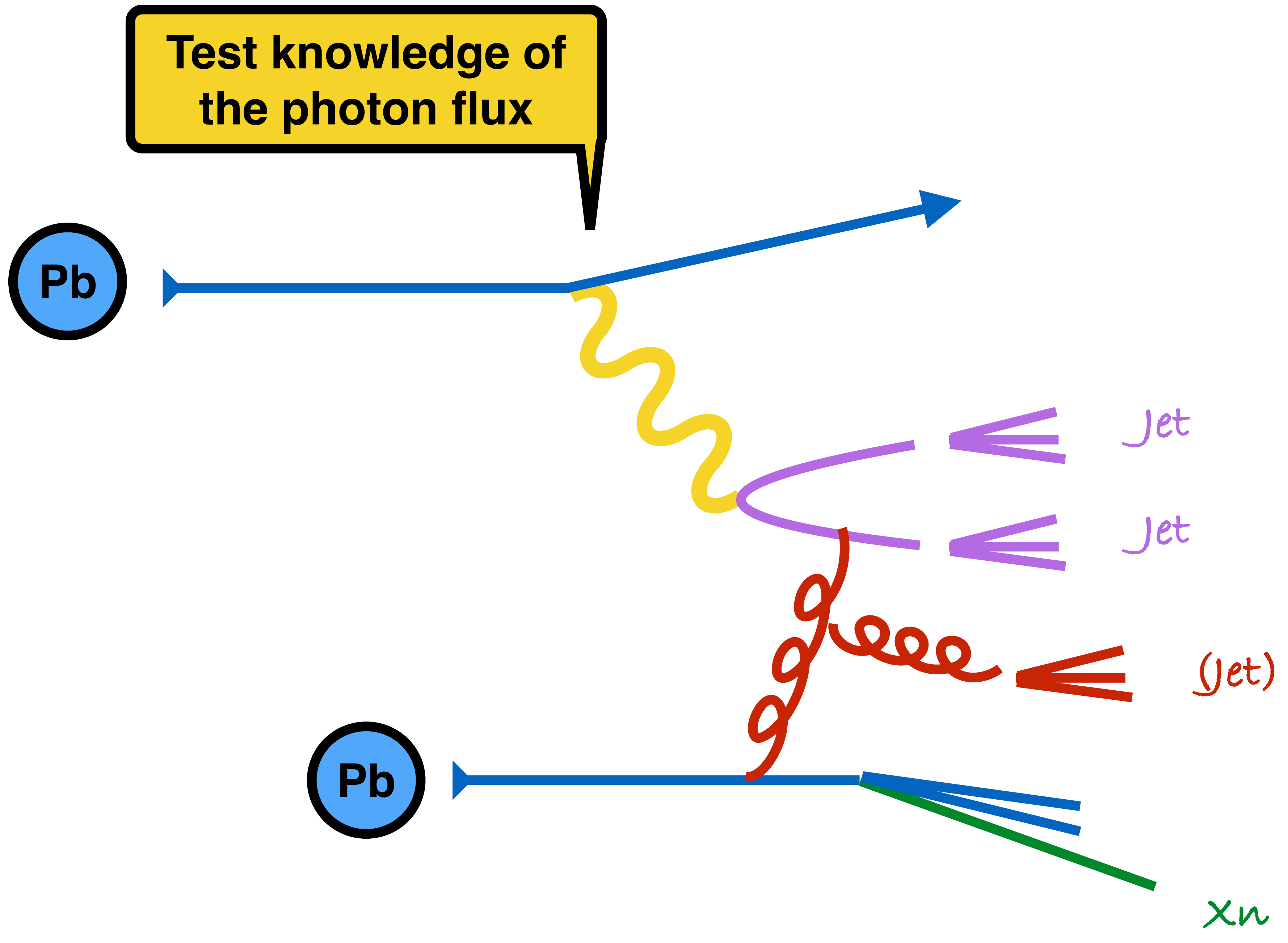
Jet production in Pb-Pb UPC

The process:



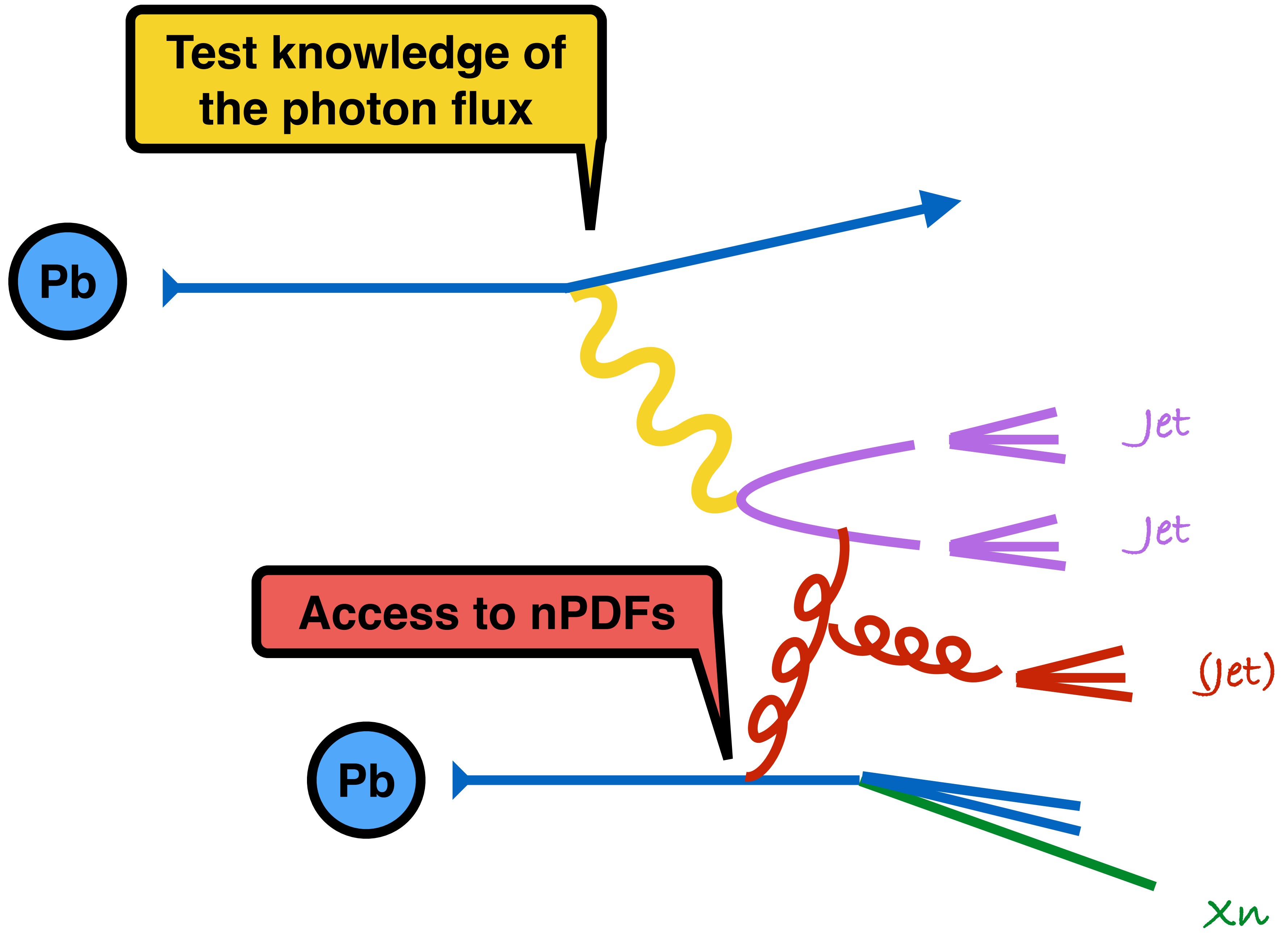
Guillermo Contreras, CTU in Prague

The process:



Photonuclear jet production: the process

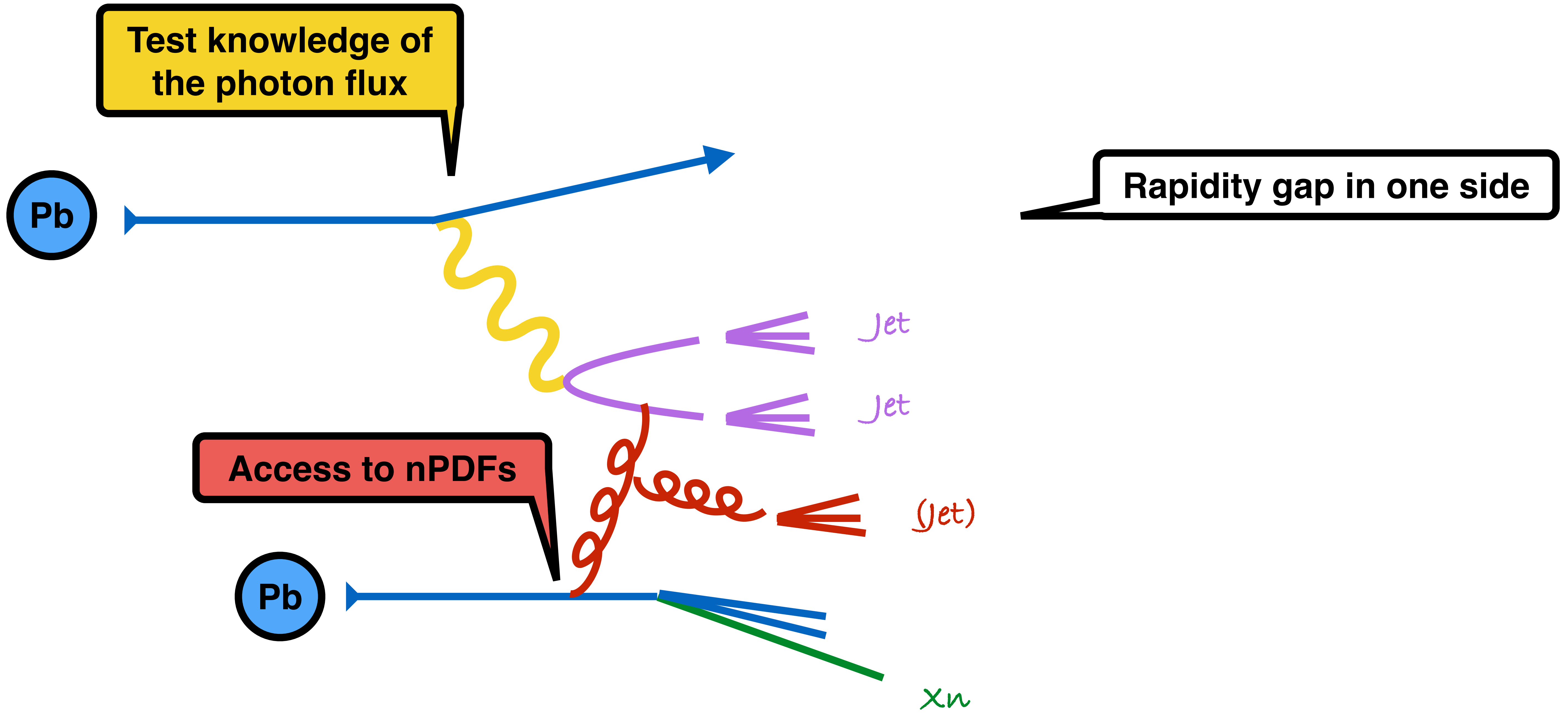
The process:



Photonuclear jet production: the process

The process:

Selection:



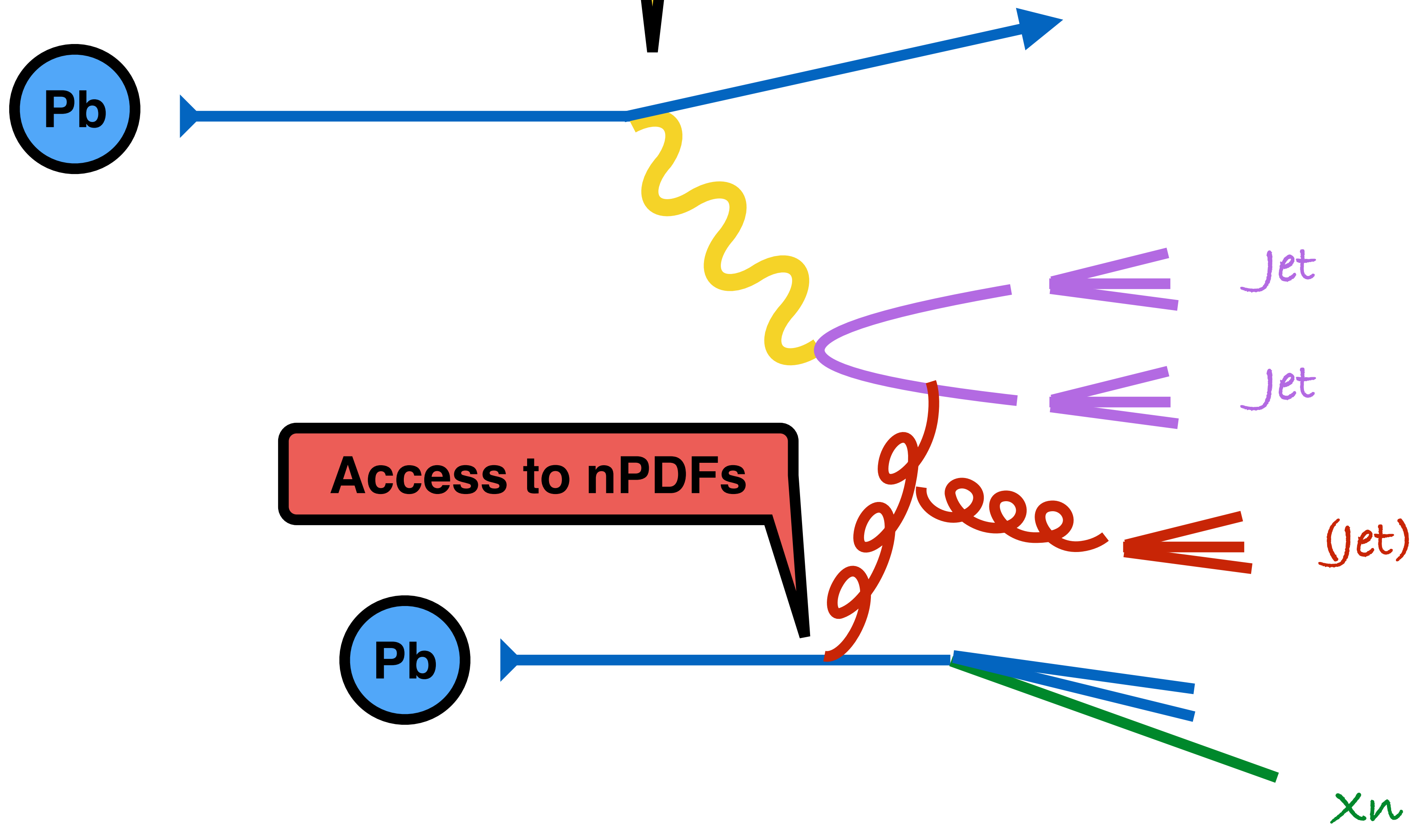
Guillermo Contreras, CTU in Prague

Photonuclear jet production: the process

The process:

Selection:

Test knowledge of the photon flux



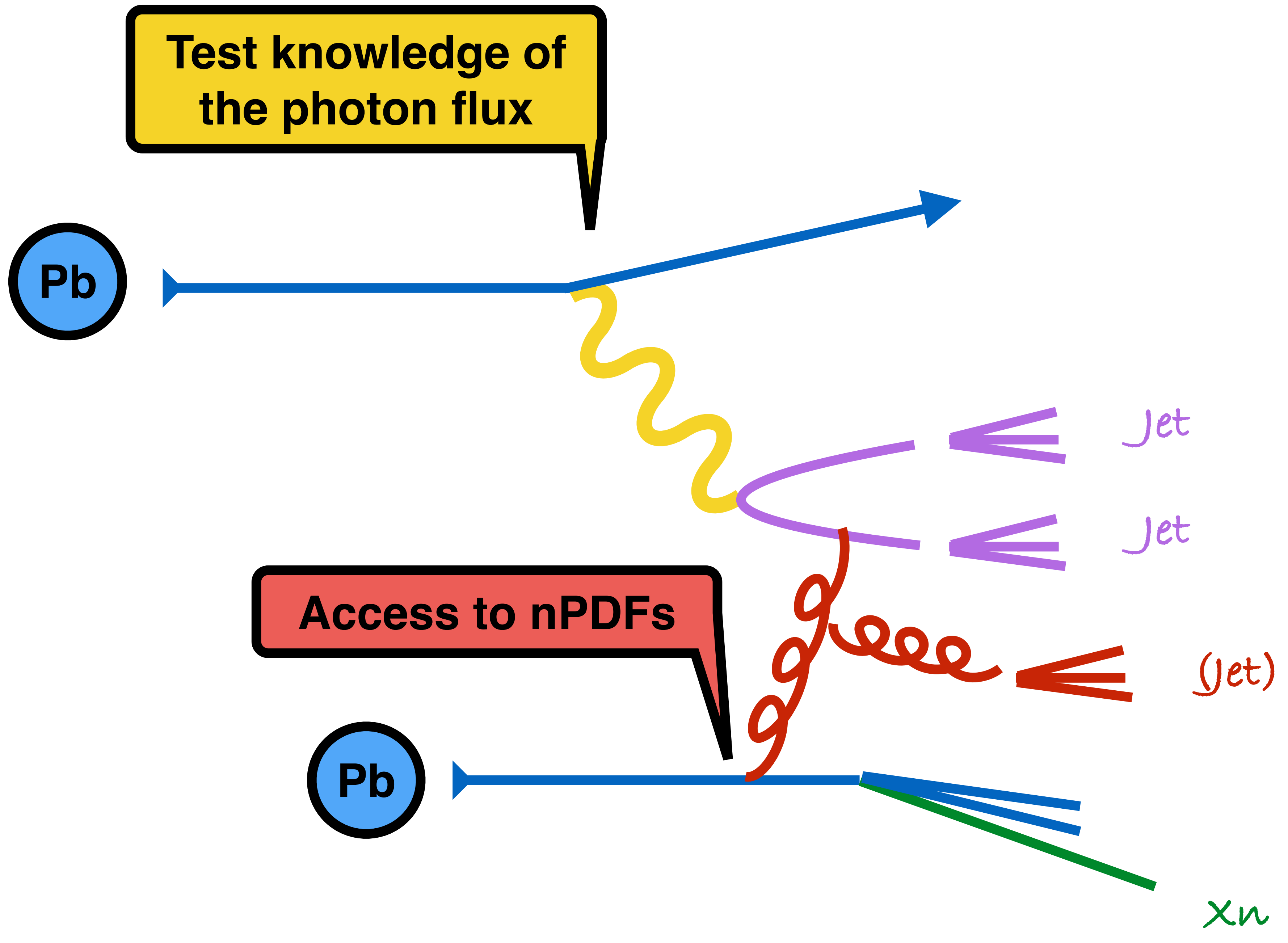
Access to nPDFs

Rapidity gap in one side

At least one zero-degree neutron in the other side

Photonuclear jet production: the process

The process:



Selection:

Rapidity gap in one side

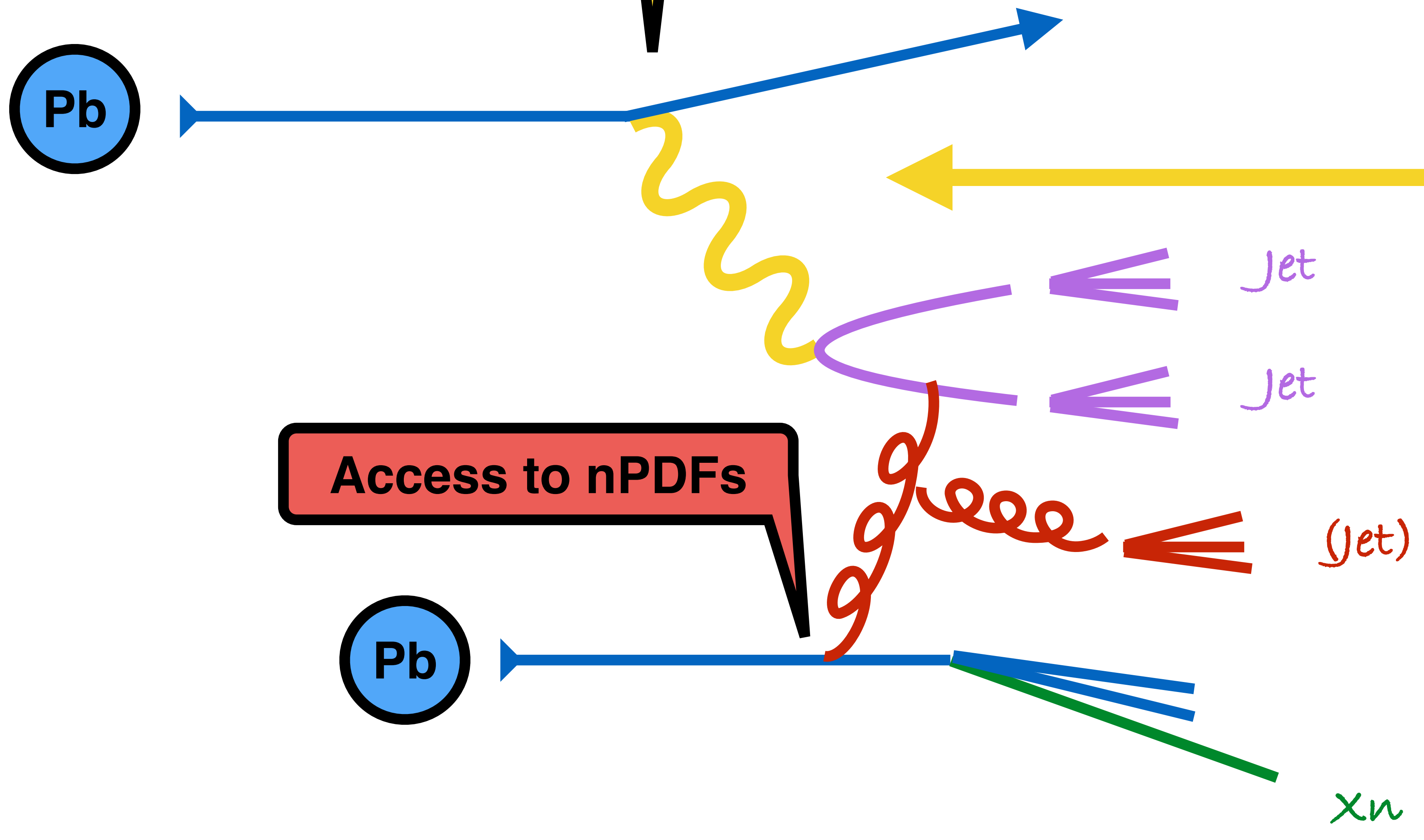
Two or more jets (Anti-k_T, R=0.4)

At least one zero-degree neutron in the other side

Photonuclear jet production: the process

The process:

Test knowledge of the photon flux



Access to nPDFs

Selection:

Rapidity gap in one side

Two or more jets (Anti-k_T, R=0.4)

At least one zero-degree neutron in the other side

Kinematics:

Photon energy

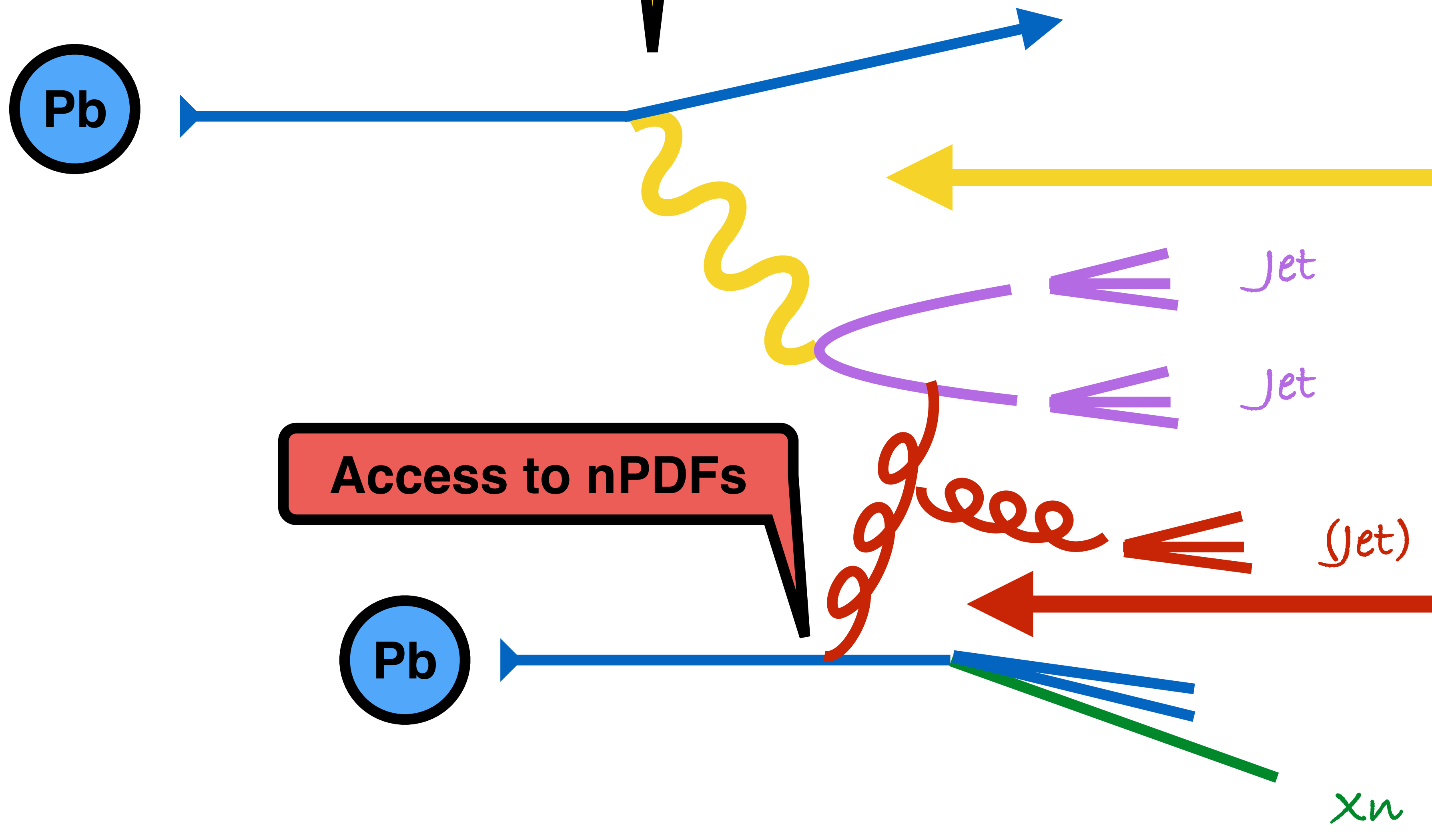
$$z_\gamma \equiv \frac{M_{\text{jets}}}{\sqrt{s_{\text{NN}}}} e^{+y_{\text{jets}}}$$

Photonuclear jet production: the process

The process:

Test knowledge of the photon flux

Access to nPDFs



Selection:

Rapidity gap in one side

Two or more jets (Anti-k_T, R=0.4)

At least one zero-degree neutron in the other side

Kinematics:

Photon energy

$$z_\gamma \equiv \frac{M_{\text{jets}}}{\sqrt{s_{\text{NN}}}} e^{+y_{\text{jets}}}$$

nPDF: 'Bjorken-x'

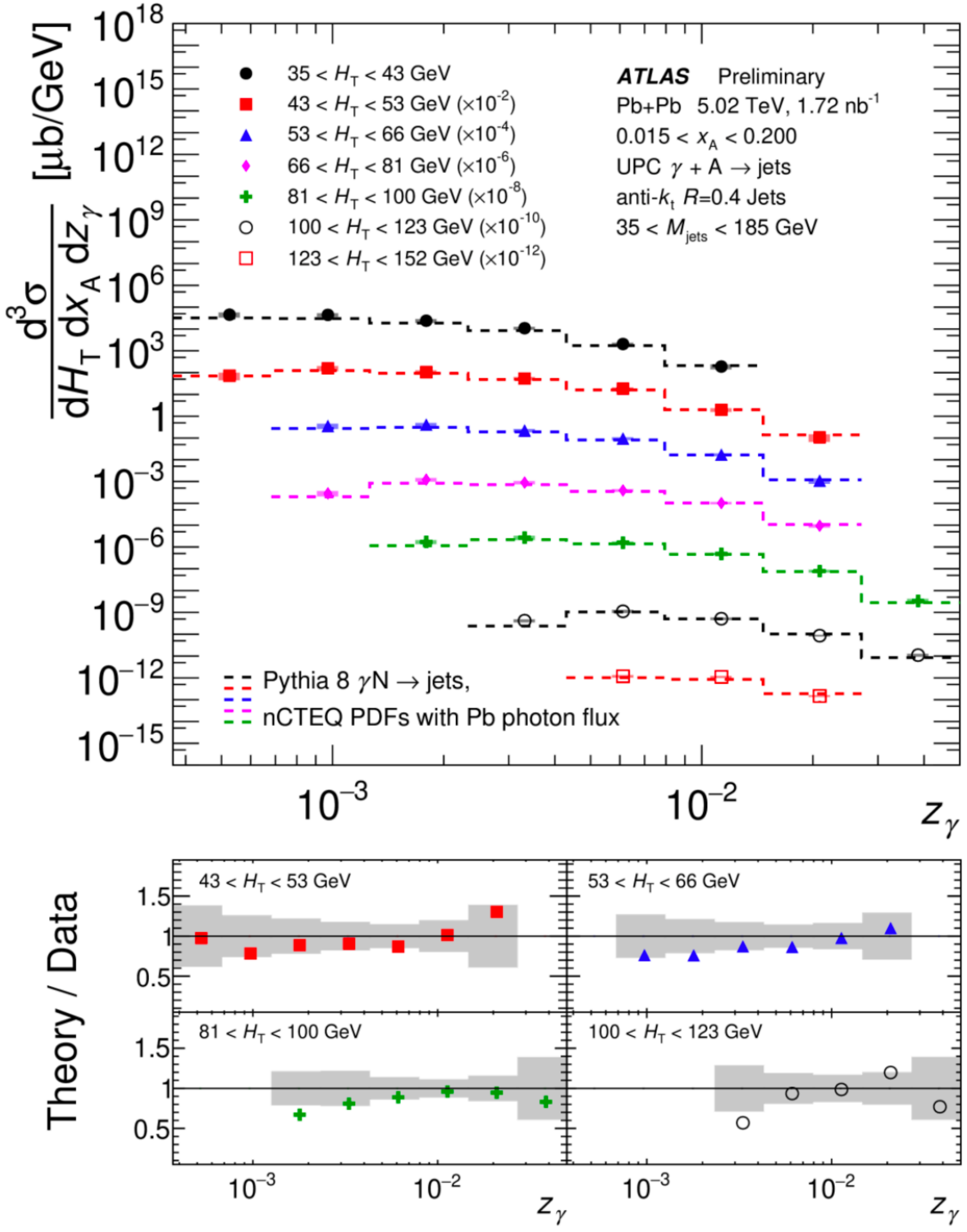
$$x_A \equiv \frac{M_{\text{jets}}}{\sqrt{s_{\text{NN}}}} e^{-y_{\text{jets}}}$$

nPDF: Scale

$$H_T \equiv \sum_i p_{T\,i}$$

Photonuclear jet production: photon energy

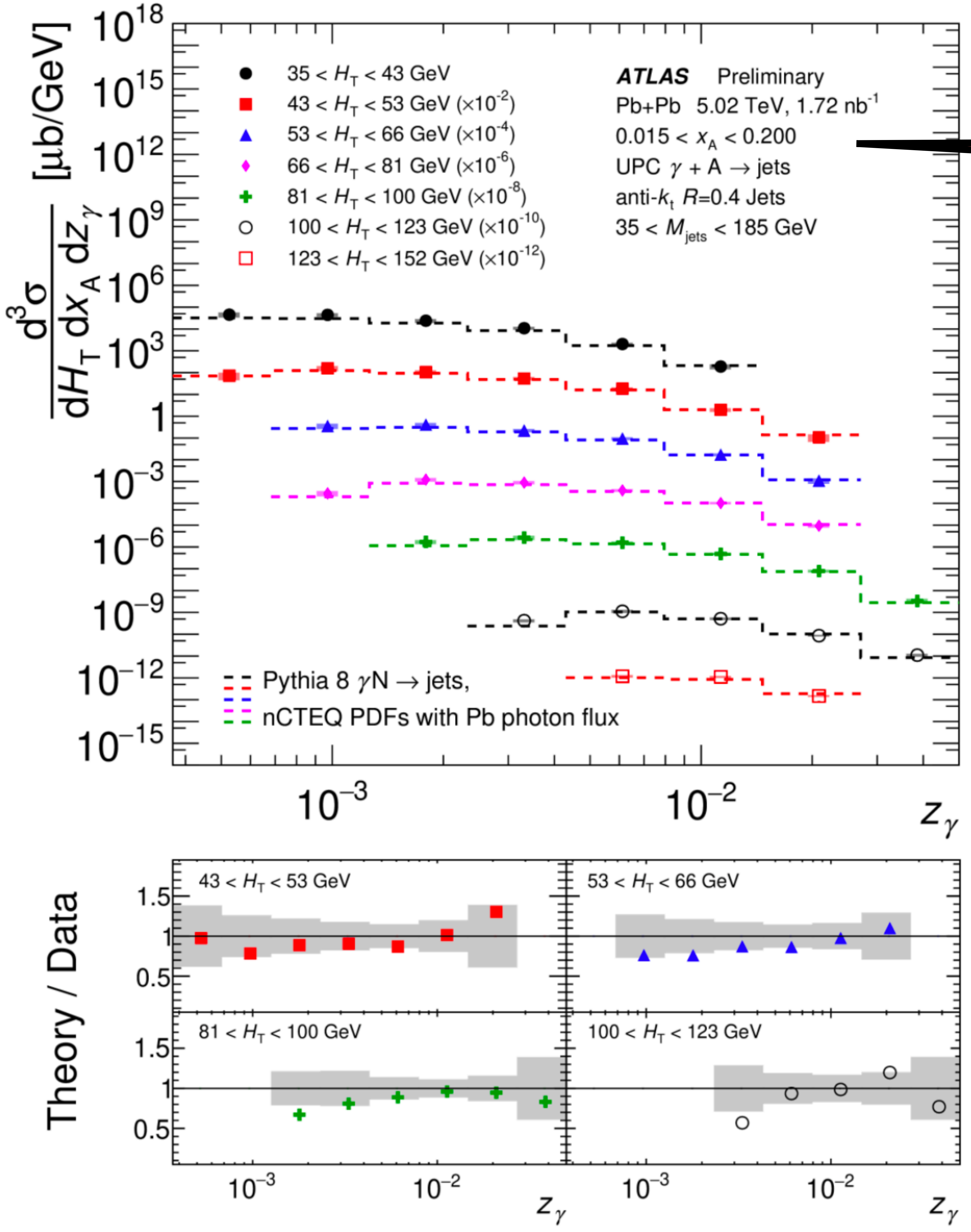
Triple differential cross section



Photon energy

ATLAS-CONF-2022-021

Photonuclear jet production: photon energy



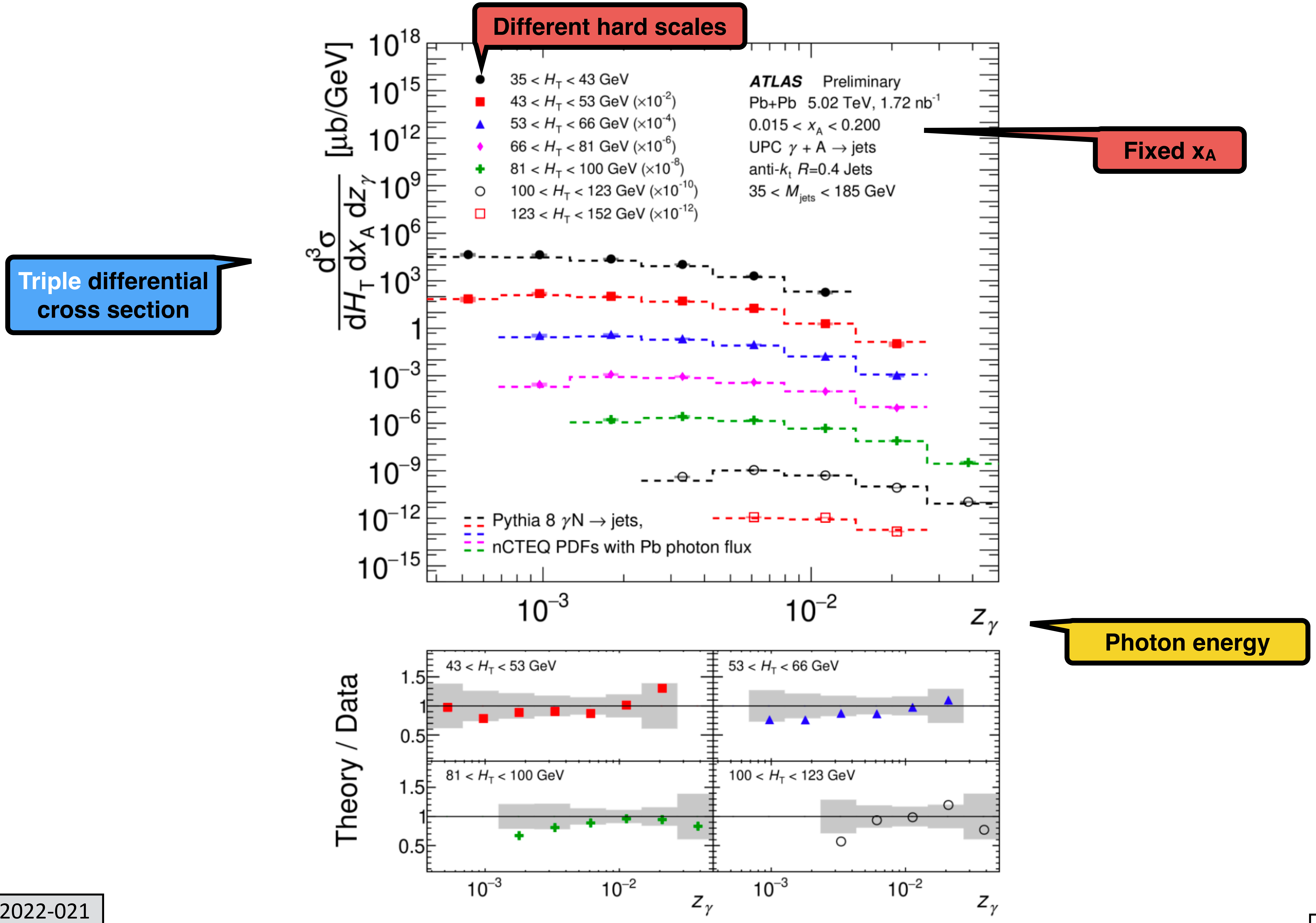
Fixed x_A

Triple differential cross section

Photon energy

ATLAS-CONF-2022-021

Photonuclear jet production: photon energy



ATLAS-CONF-2022-021

Guillermo Contreras, CTU in Prague

Photonuclear jet production: photon energy

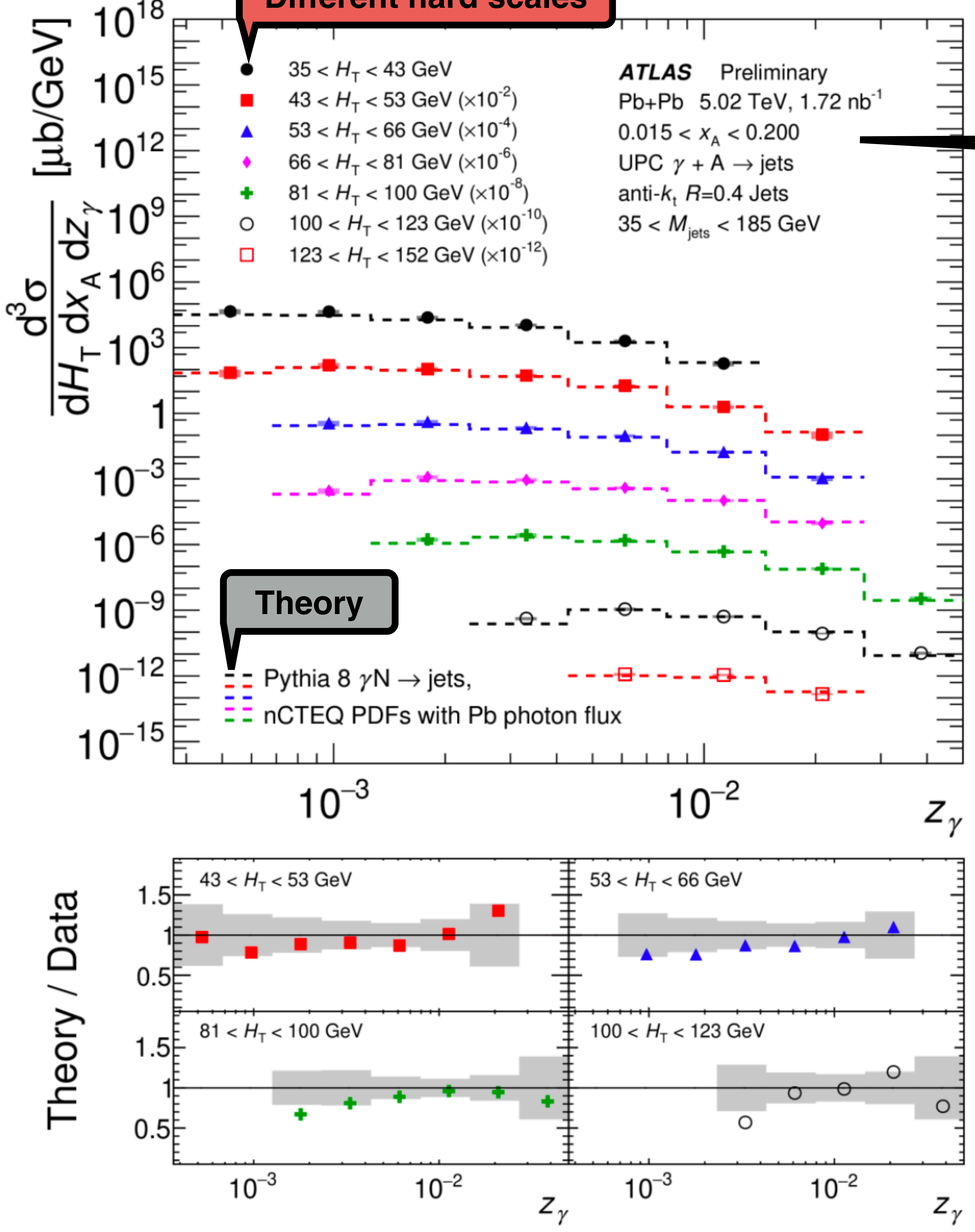
Different hard scales

Fixed x_A

Triple differential cross section

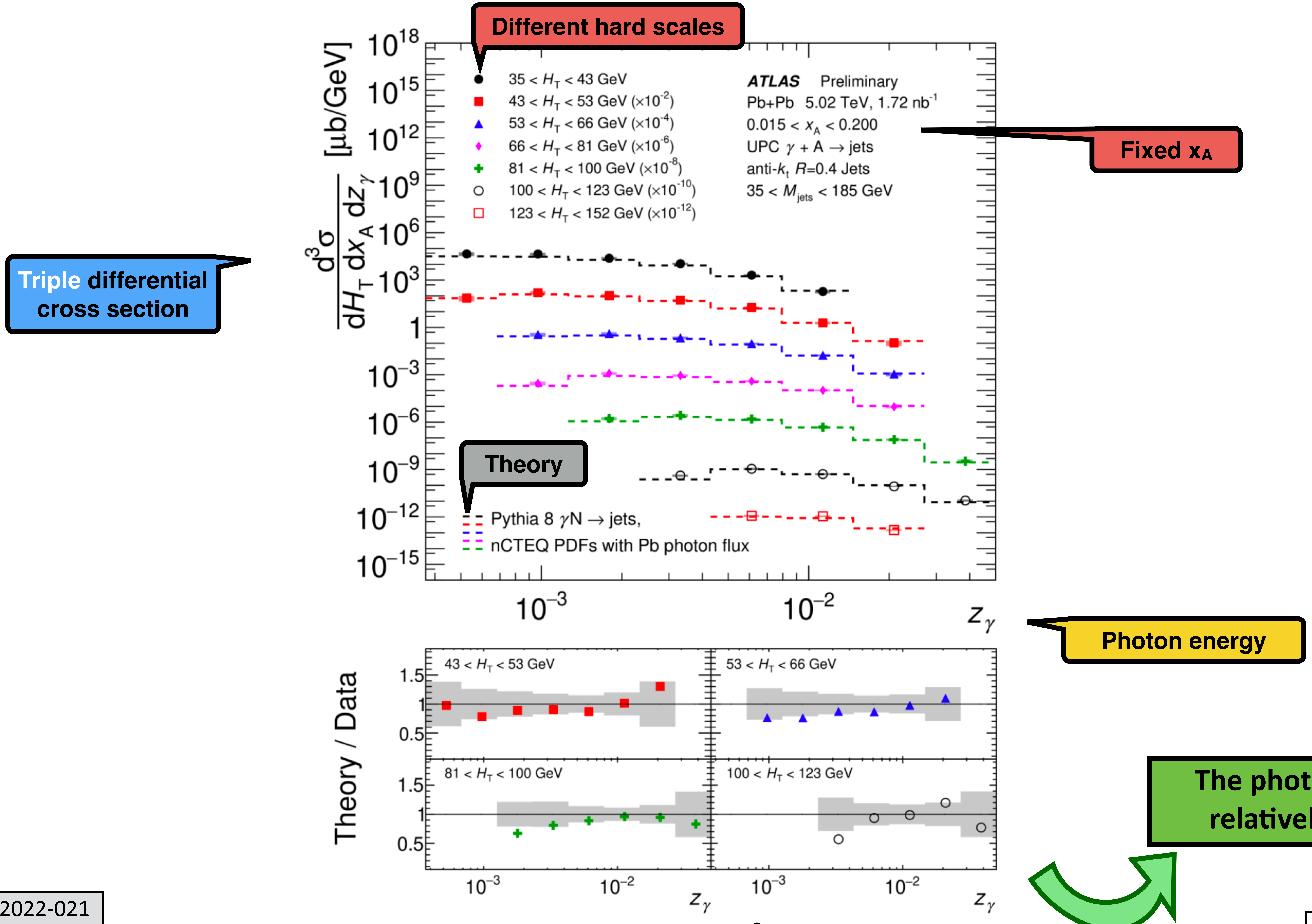
Theory

Photon energy



ATLAS-CONF-2022-021

Photonuclear jet production: photon energy

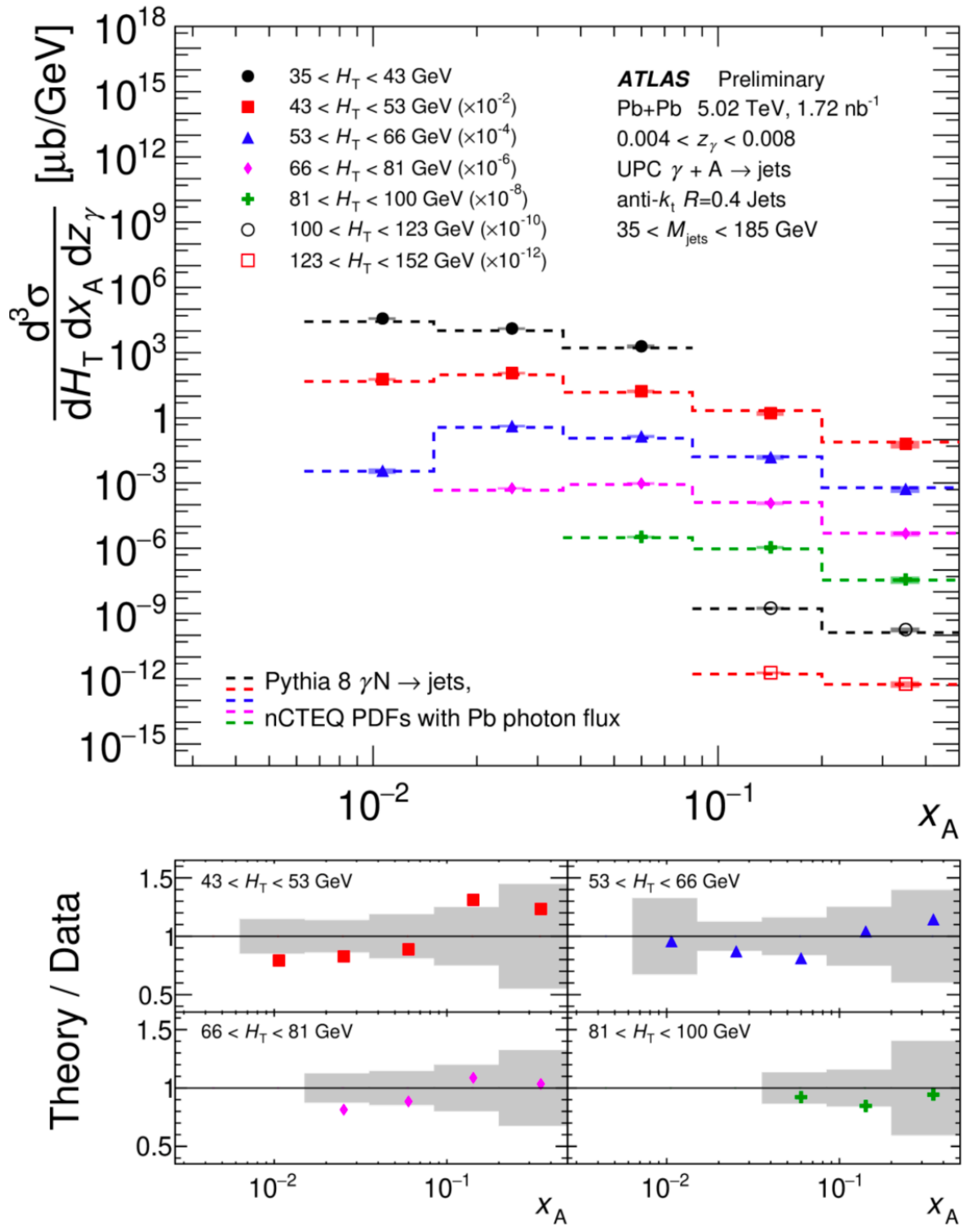


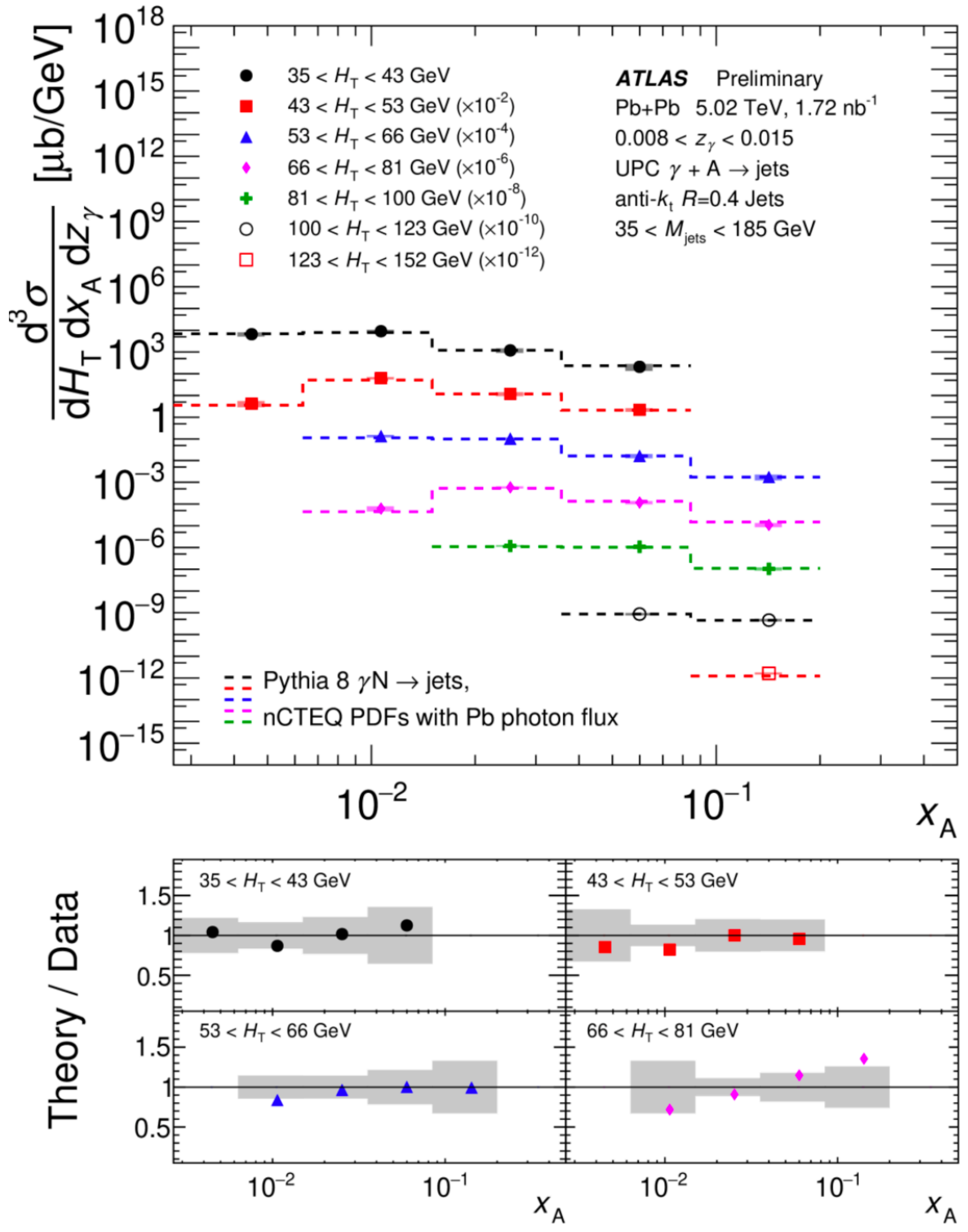
The photon flux seems to be relatively well understood

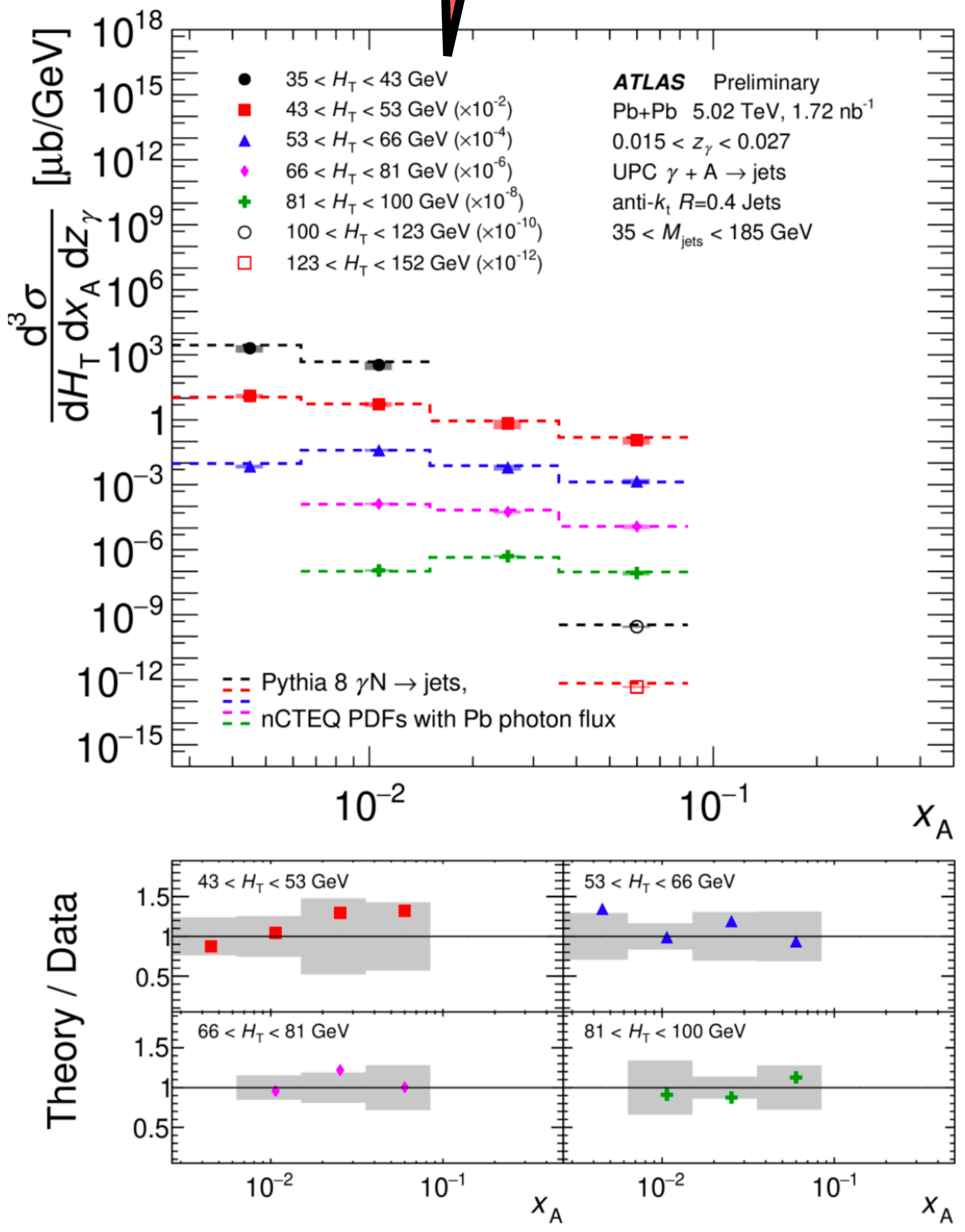
ATLAS-CONF-2022-021

Photonuclear jet production: xA dependence

Different hard scales





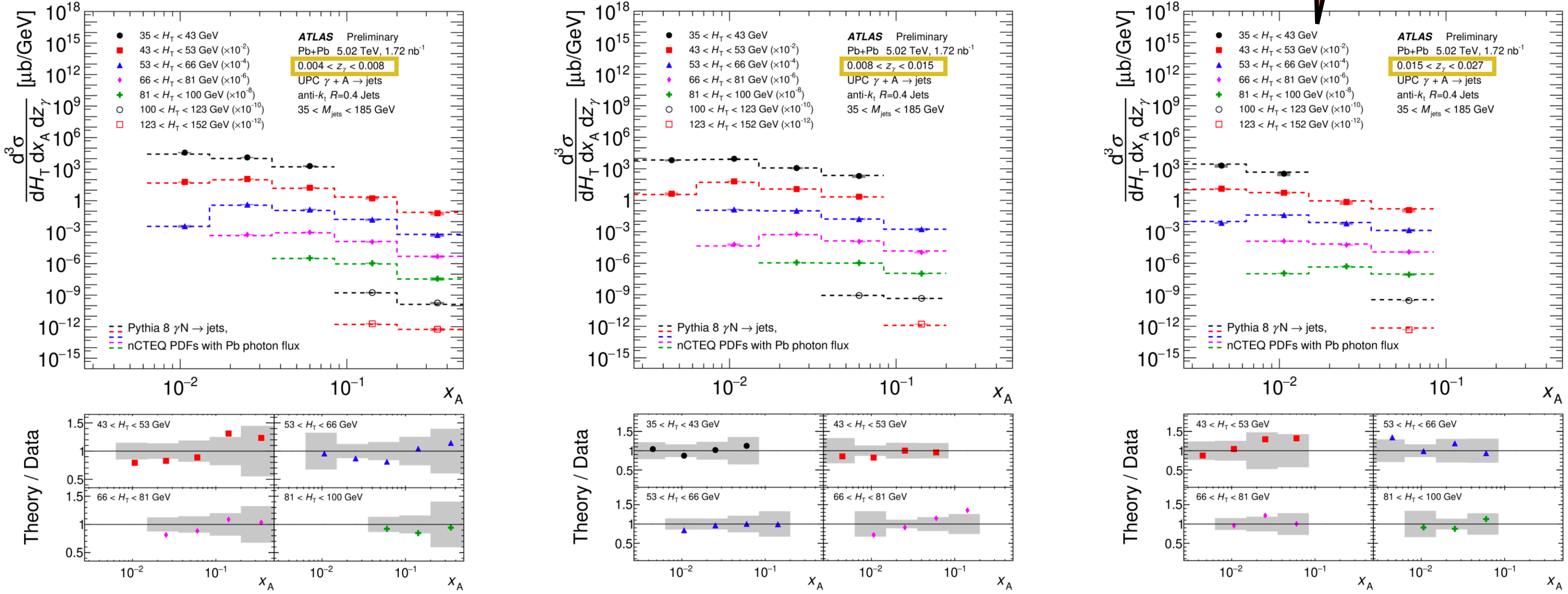


x_A

Photonuclear jet production: xA dependence

Increasing photon energy →

Different hard scales



x_A

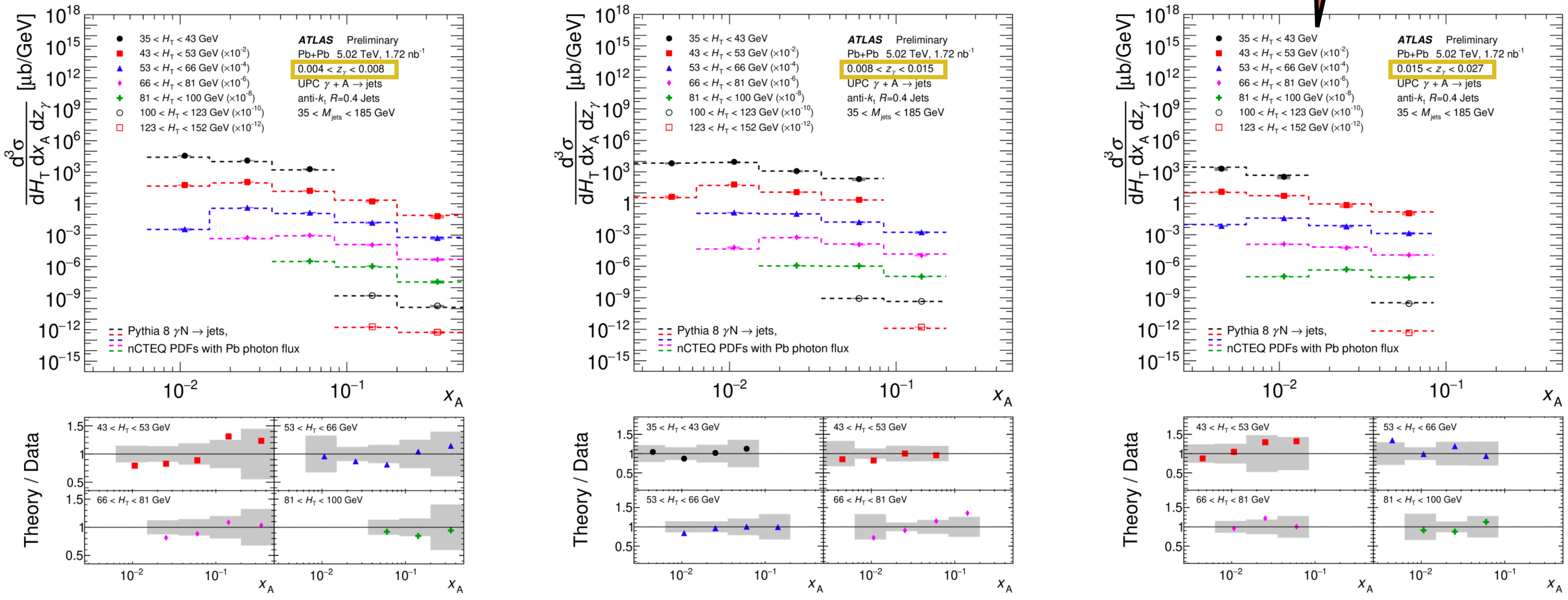
ATLAS-CONF-2022-021

Guillermo Contreras, CTU in Prague

Photonuclear jet production: xA dependence

Increasing photon energy →

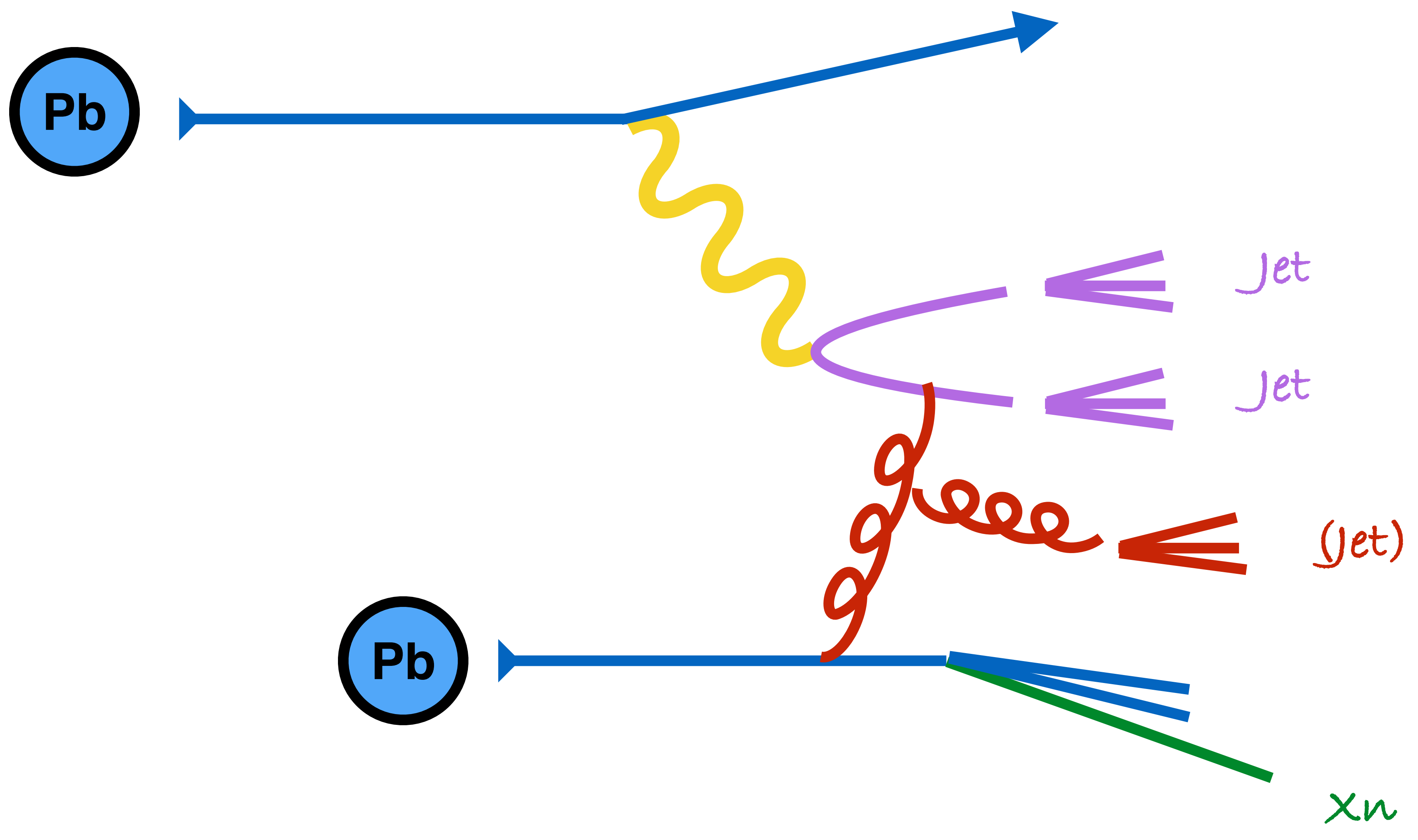
Different hard scales



Evolution in x_A for a fixed hard scale, relatively well understood down to a few times 10^{-3}

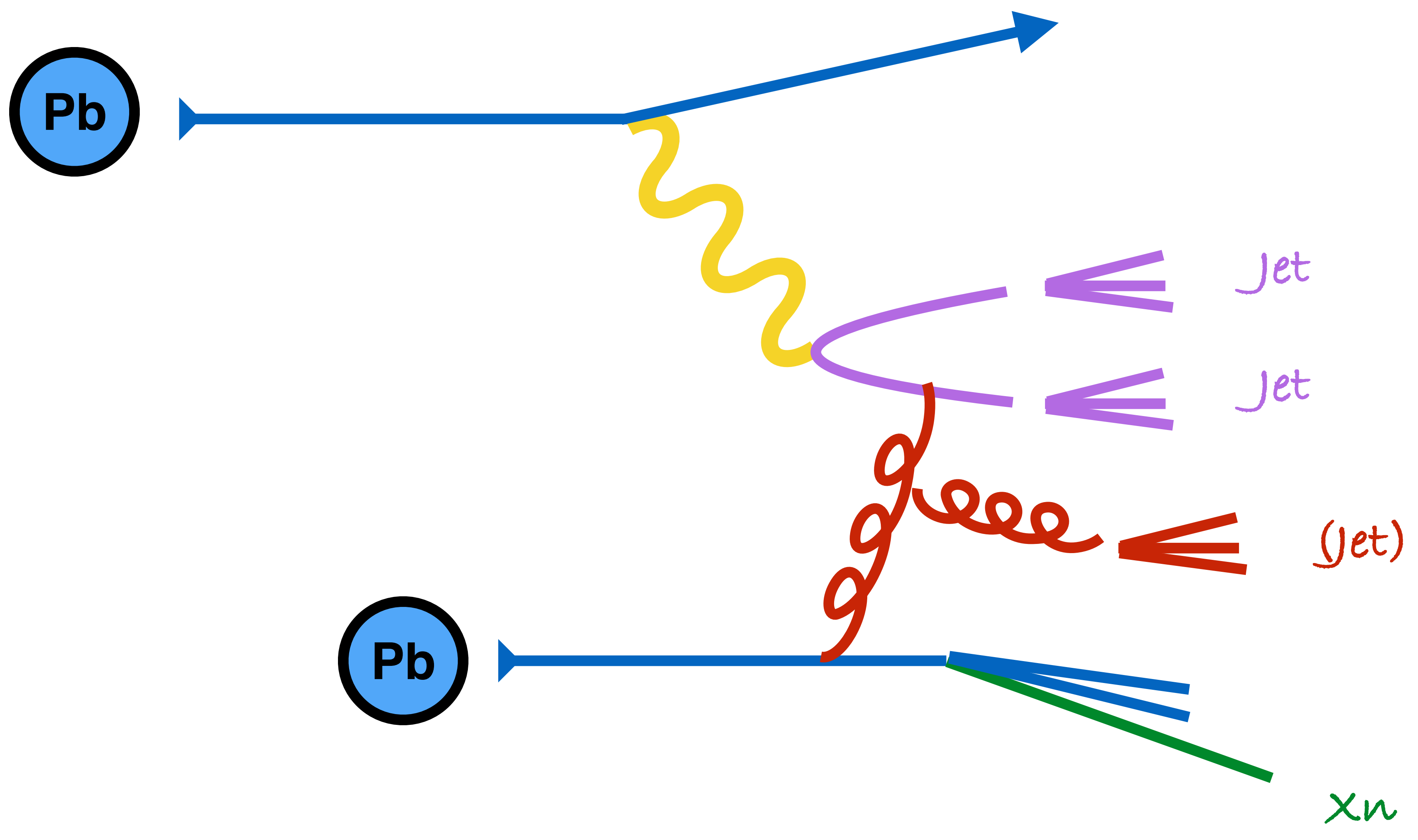
x_A

What else can we do?



The process I have discussed until now, is sensitive to the gluon distribution in hadrons. Can we do something different/complementary?

What else can we do?

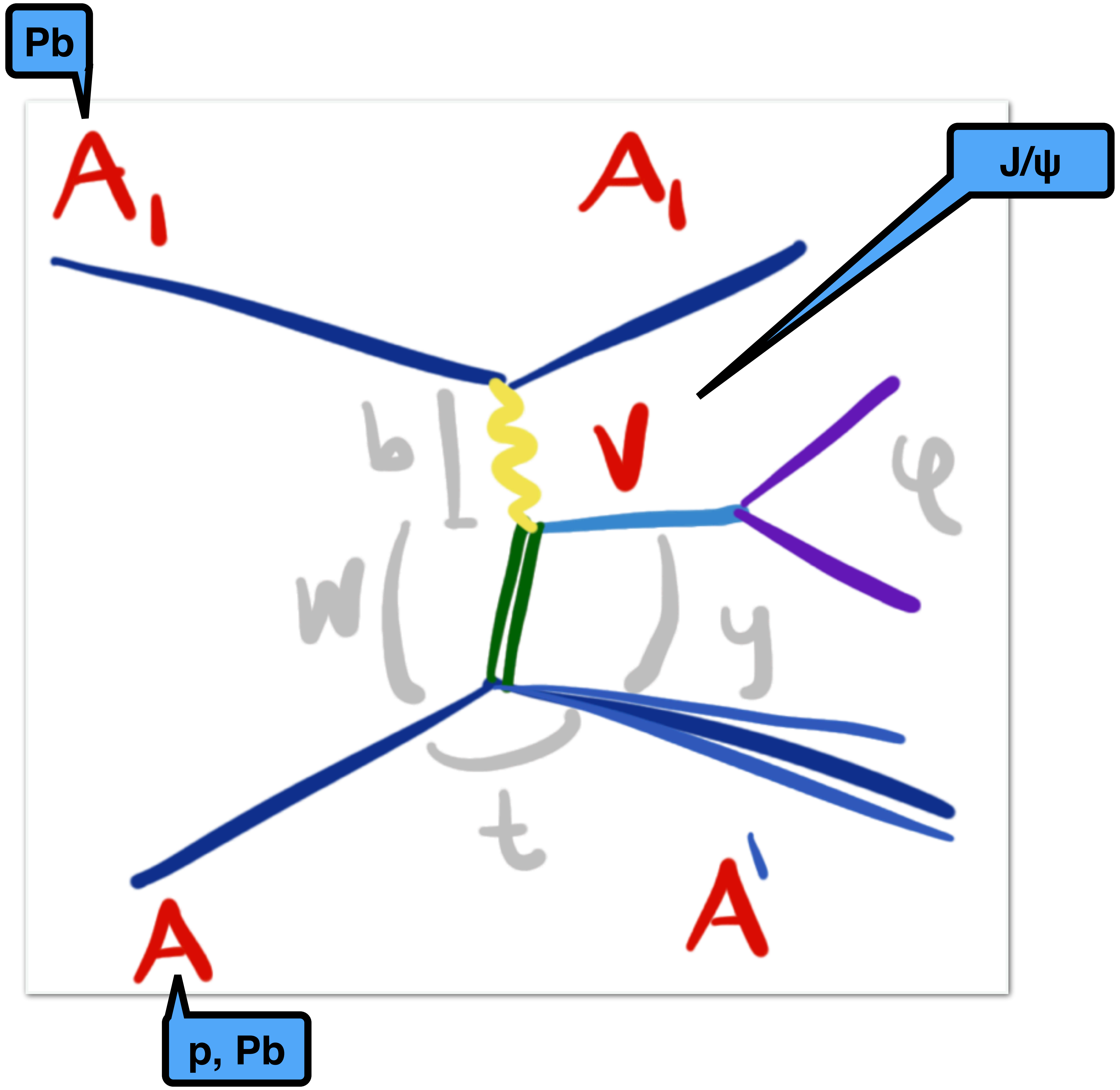


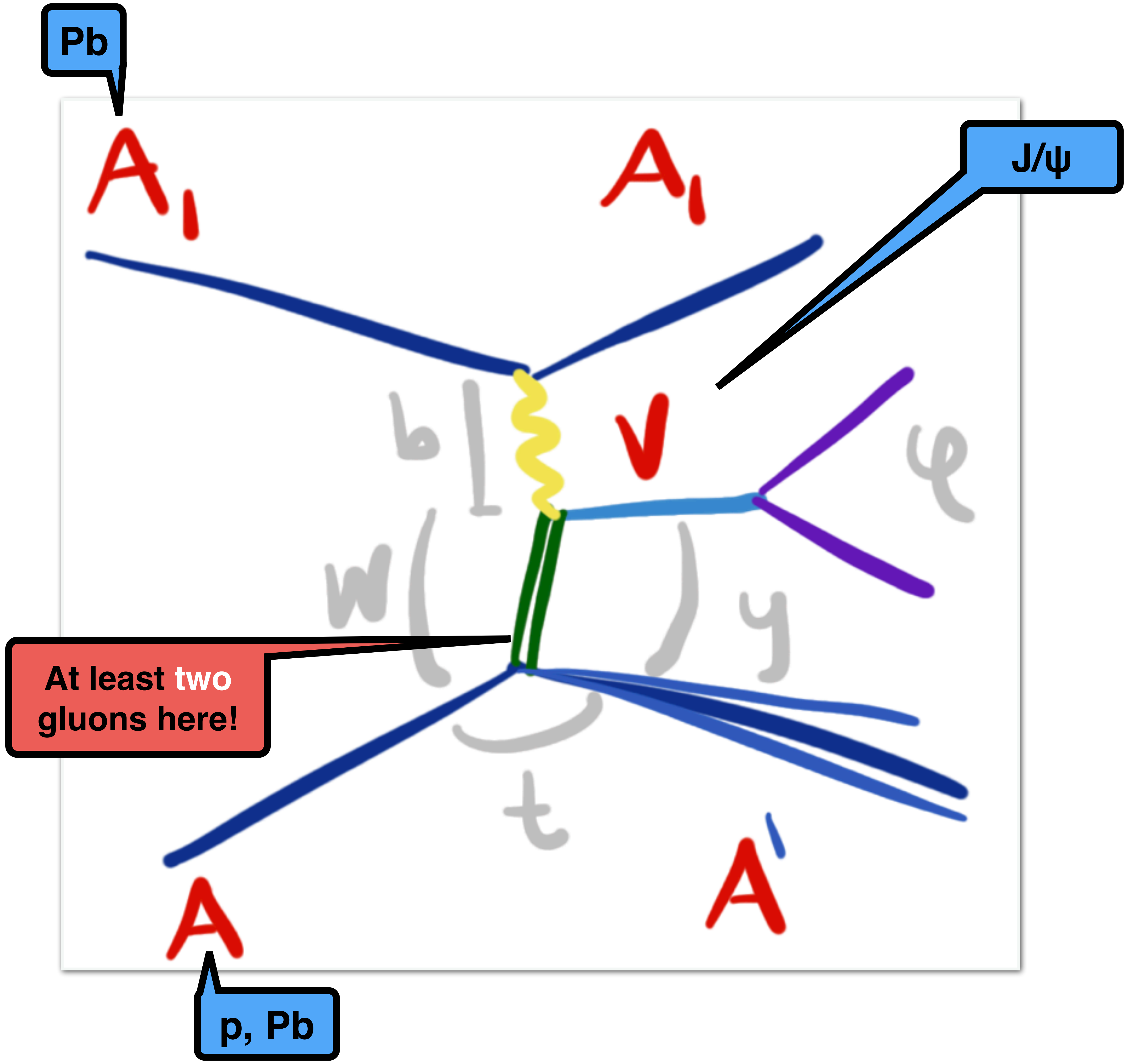
The process I have discussed until now, is sensitive to the gluon distribution in hadrons. **Can we do something different/complementary?**

Let's look at a process that depends at leading order on the **square** of the gluon distribution in hadrons

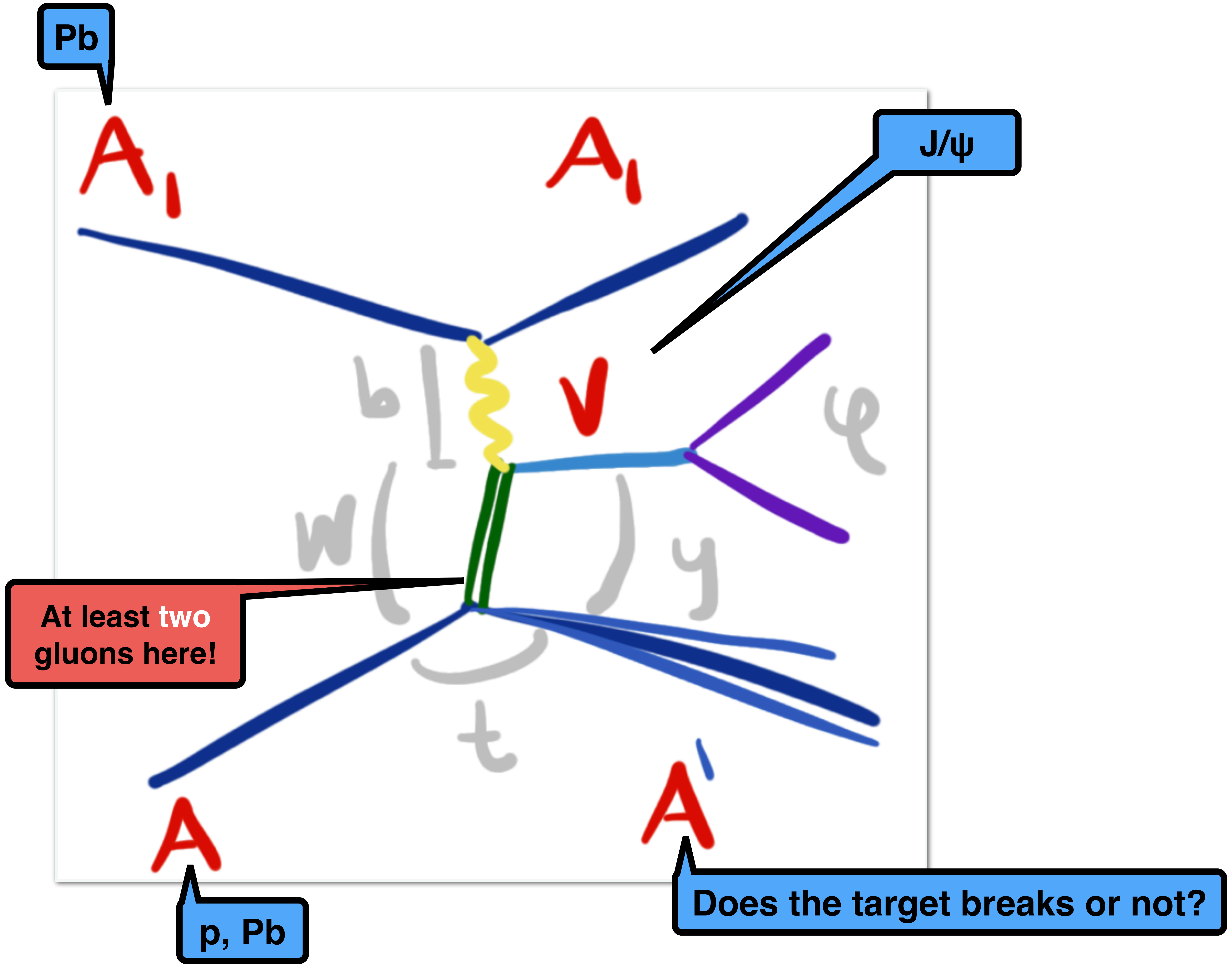
Coherent J/ψ production in Pb-Pb UPC
Bjorken-*x* dependence

Diffractive J/ψ photoproduction in UPC

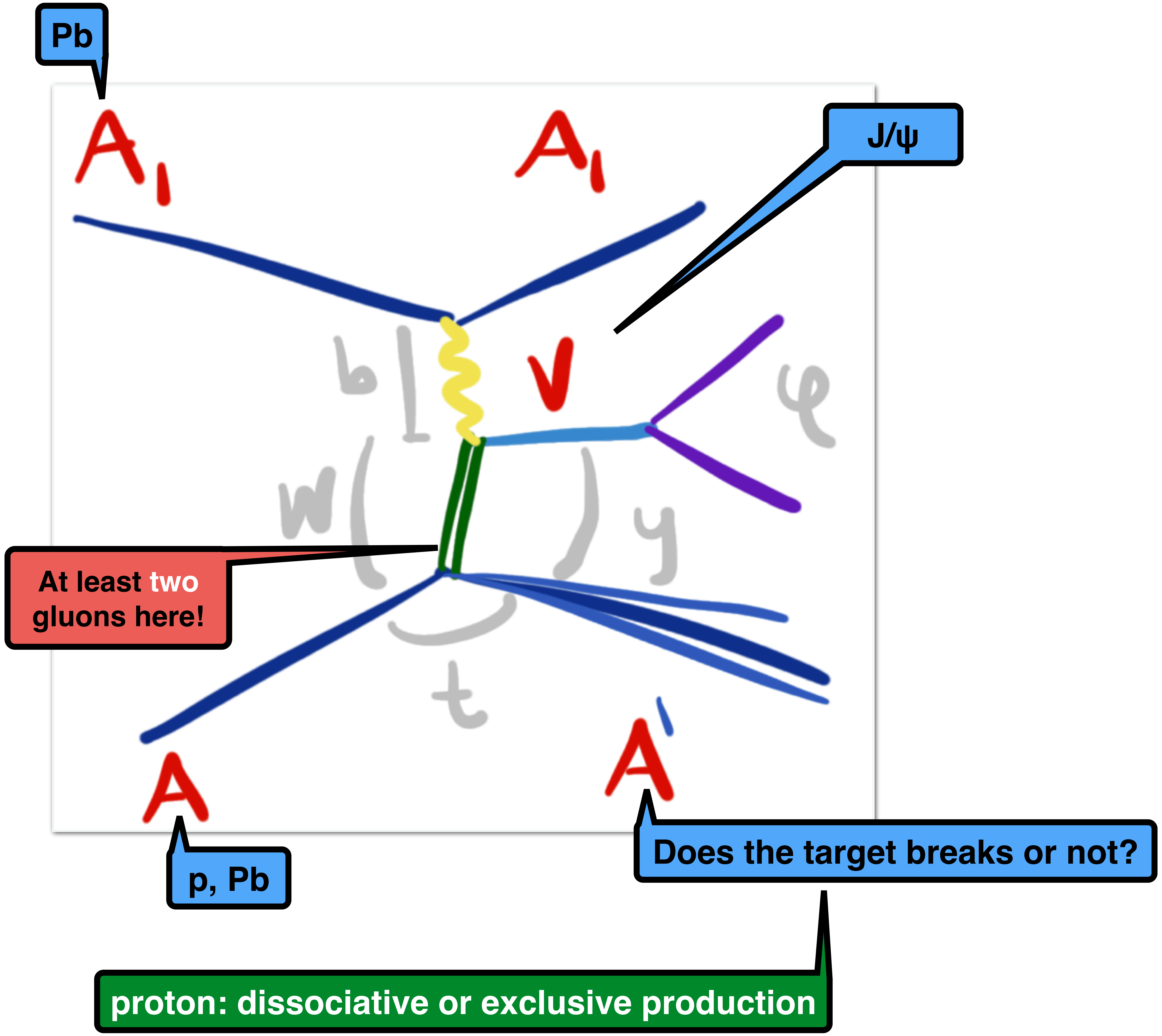



Pb
A1
A1
J/ψ
b
V
ℓ
W
y
At least two gluons here!
t
A
A'
p, Pb

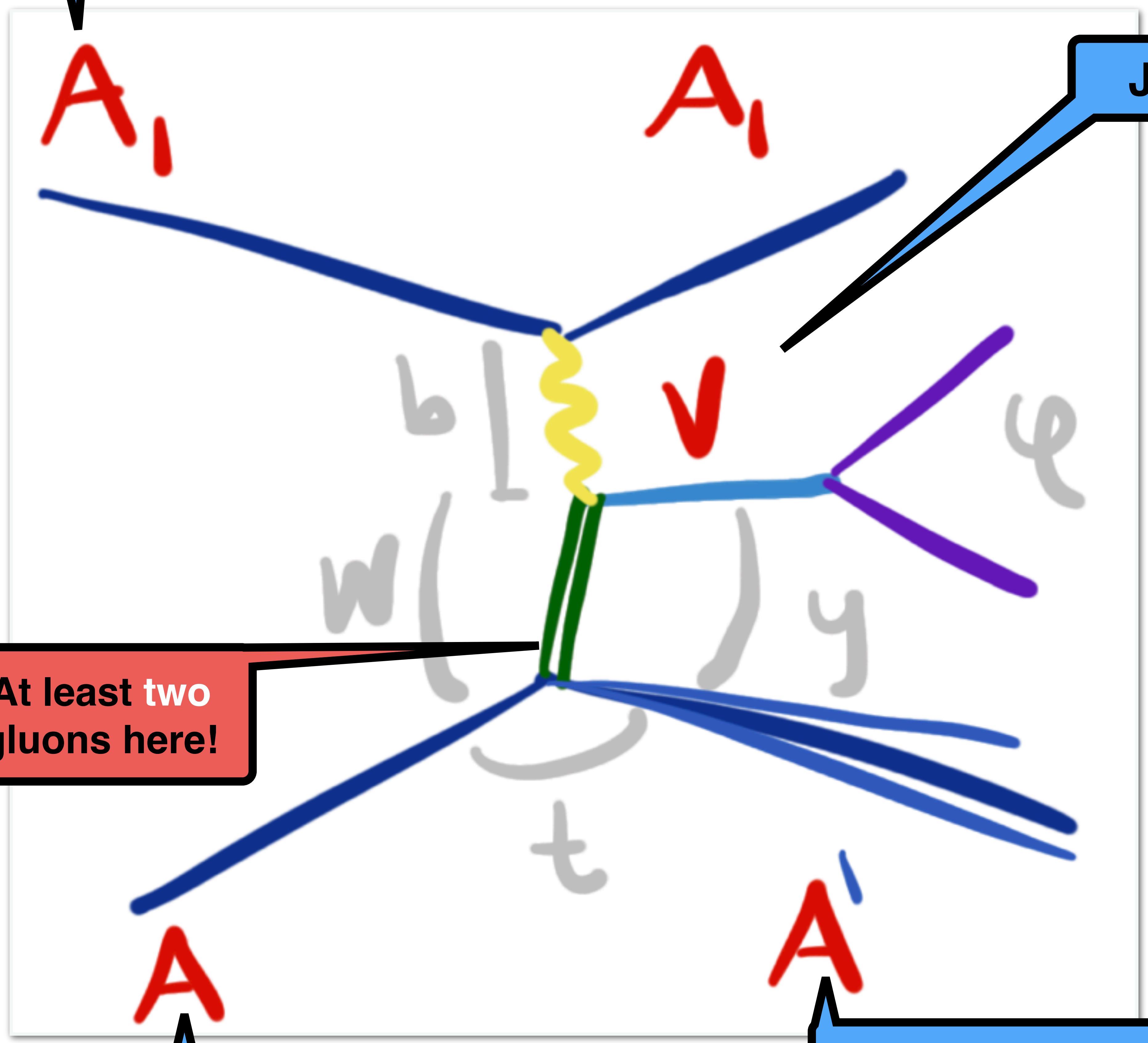
Diffractive J/ψ photoproduction in UPC



Diffractive J/ψ photoproduction in UPC



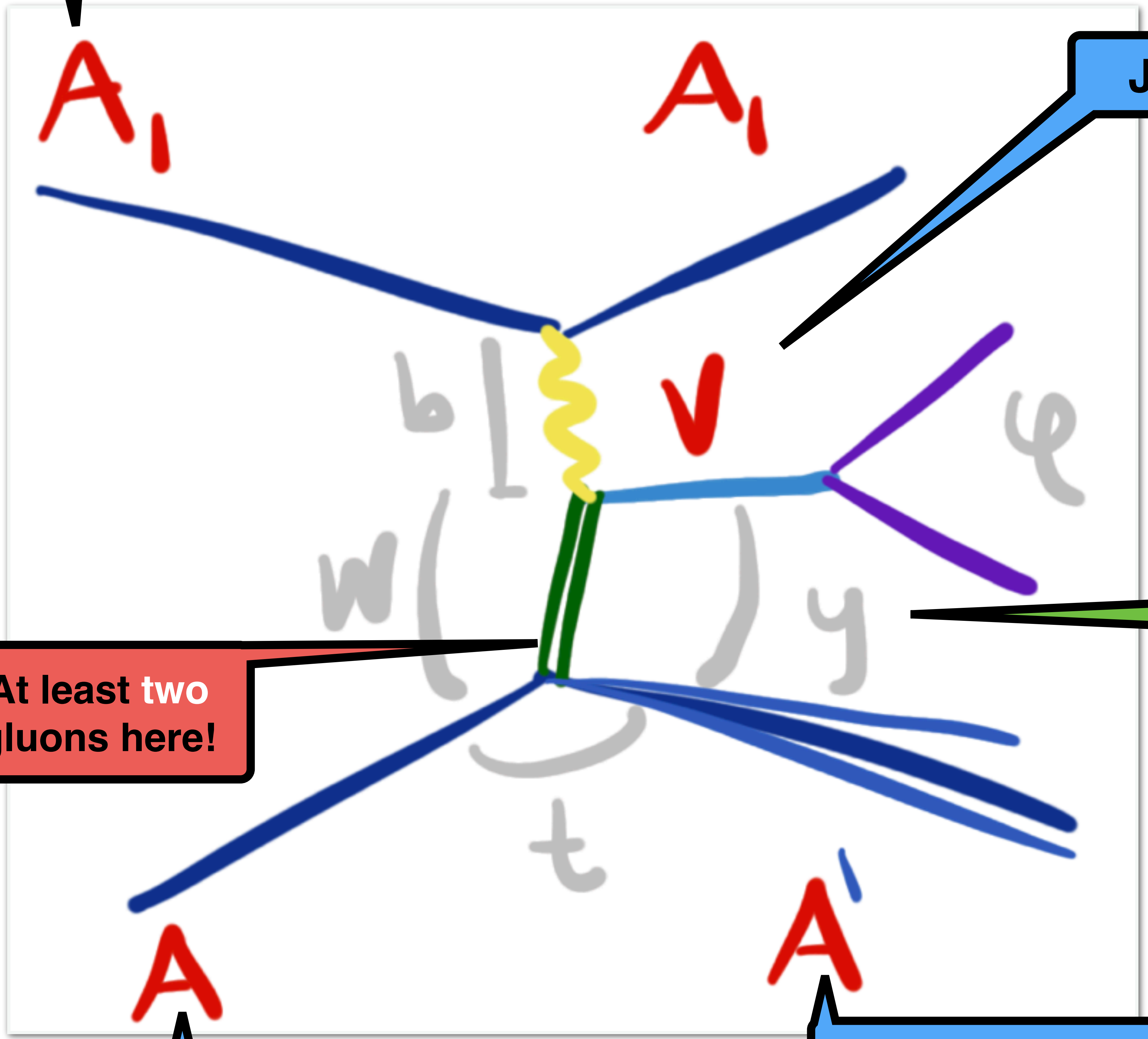
Diffractive J/ψ photoproduction in UPC



Diffractive J/ψ photoproduction in UPC

Pb

J/ψ



At least two gluons here!

p, Pb

$$x = \frac{m}{\sqrt{s}} e^{-y} = \frac{m^2}{W^2}$$

Kinematics: vector meson rapidity => energy (Bjorken-x) evolution

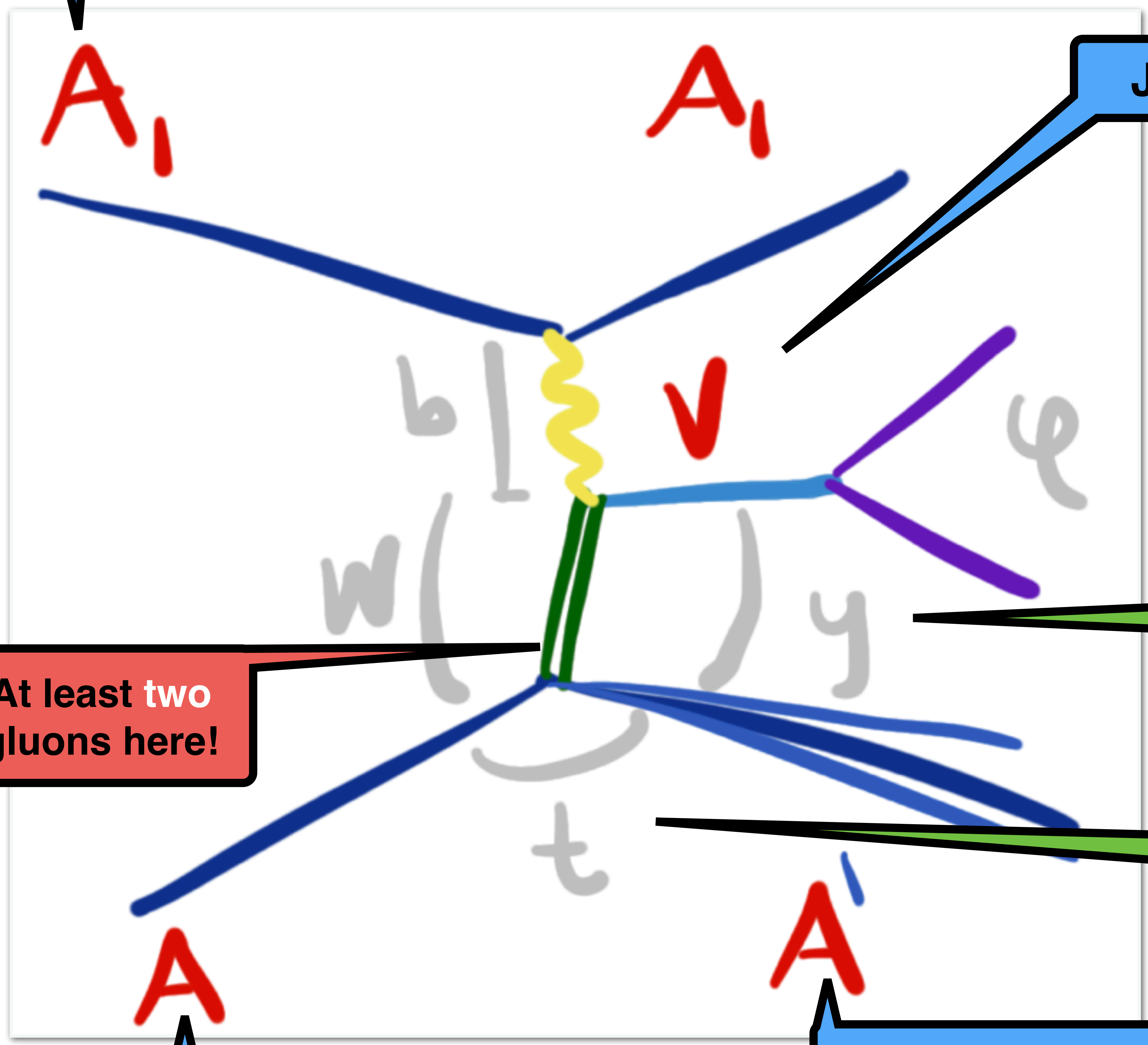
Does the target breaks or not?

proton: dissociative or exclusive production

nucleus: incoherent or coherent production

Diffractive J/ψ photoproduction in UPC

Pb



J/ψ

$$x = \frac{m}{\sqrt{s}} e^{-y} = \frac{m^2}{W^2}$$

Kinematics: vector meson rapidity => energy (Bjorken-x) evolution

At least two gluons here!

Kinematics: Mandelstam t => transverse structure of the target

p, Pb

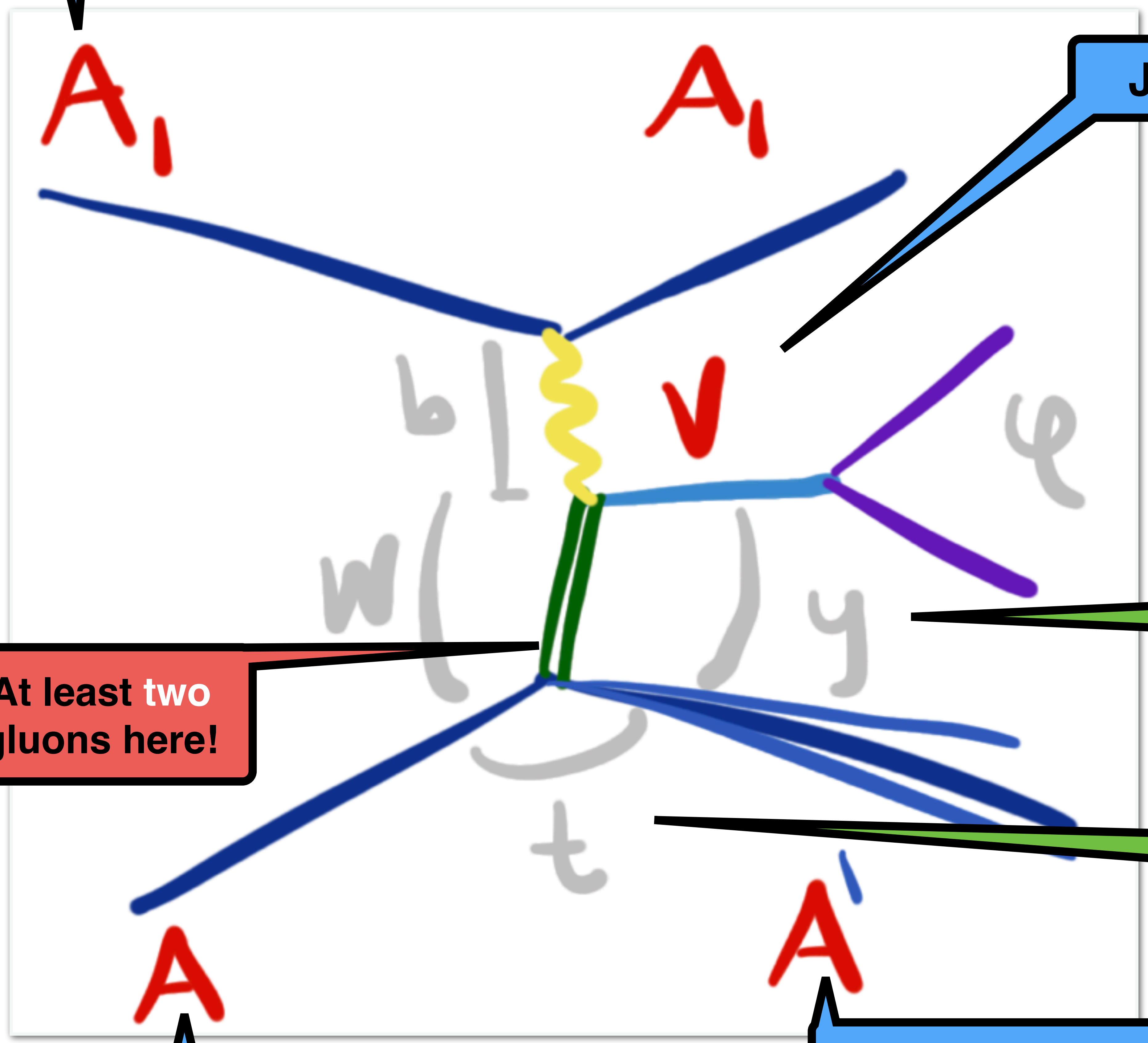
Does the target breaks or not?

proton: dissociative or exclusive production

nucleus: incoherent or coherent production

Diffractive J/ψ photoproduction in UPC

Pb



J/ψ

At least **two** gluons here!

p, Pb

$$x = \frac{m}{\sqrt{s}} e^{-y} = \frac{m^2}{W^2}$$

Kinematics: vector meson rapidity => energy (Bjorken-x) evolution

Kinematics: Mandelstam t => transverse structure of the target

$|t| \approx p_{\perp}^2$

Transverse momentum of the vector meson

Does the target breaks or not?

proton: dissociative or exclusive production

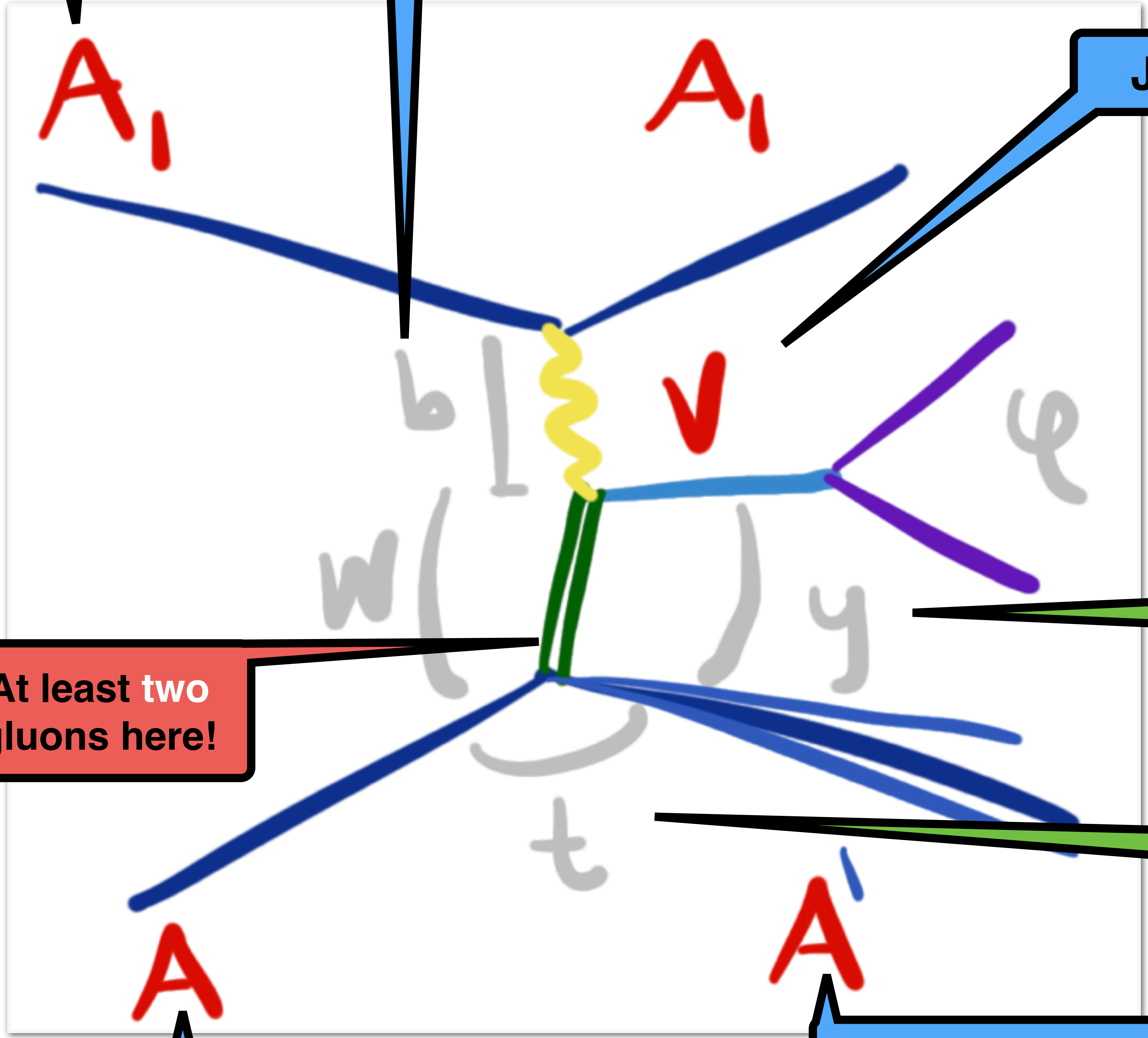
nucleus: incoherent or coherent production

Diffractive J/ψ photoproduction in UPC

Pb

For coherent production, different impact parameters (for the photon emission): peripheral, several ultra-peripheral ranges

J/ψ



$$x = \frac{m}{\sqrt{s}} e^{-y} = \frac{m^2}{W^2}$$

Kinematics: vector meson rapidity => energy (Bjorken-x) evolution

At least two gluons here!

Kinematics: Mandelstam t => transverse structure of the target

$|t| \approx p_{\perp}^2$

p, Pb

Does the target breaks or not?

Transverse momentum of the vector meson

proton: dissociative or exclusive production

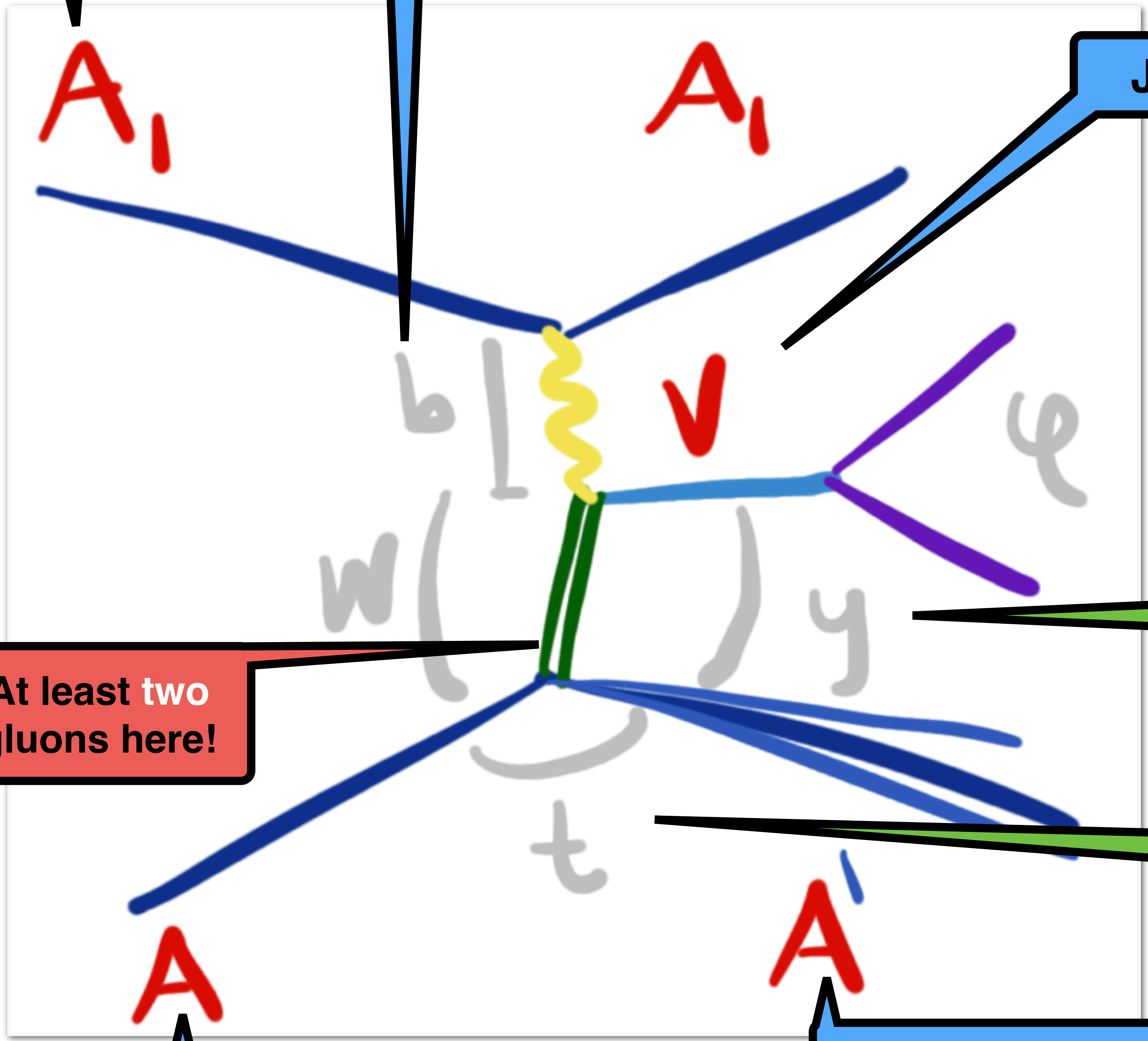
nucleus: incoherent or coherent production

Diffractive J/ψ photoproduction in UPC

Pb

For coherent production, different impact parameters (for the photon emission): peripheral, several ultra-peripheral ranges

J/ψ



We need to know the rapidity (wrt the direction of the target)

$$x = \frac{m}{\sqrt{s}} e^{-y} = \frac{m^2}{W^2}$$

Kinematics: vector meson rapidity => energy (Bjorken-x) evolution

At least **two** gluons here!

Kinematics: Mandelstam t => transverse structure of the target

$$|t| \approx p_{\perp}^2$$

Transverse momentum of the vector meson

p, Pb

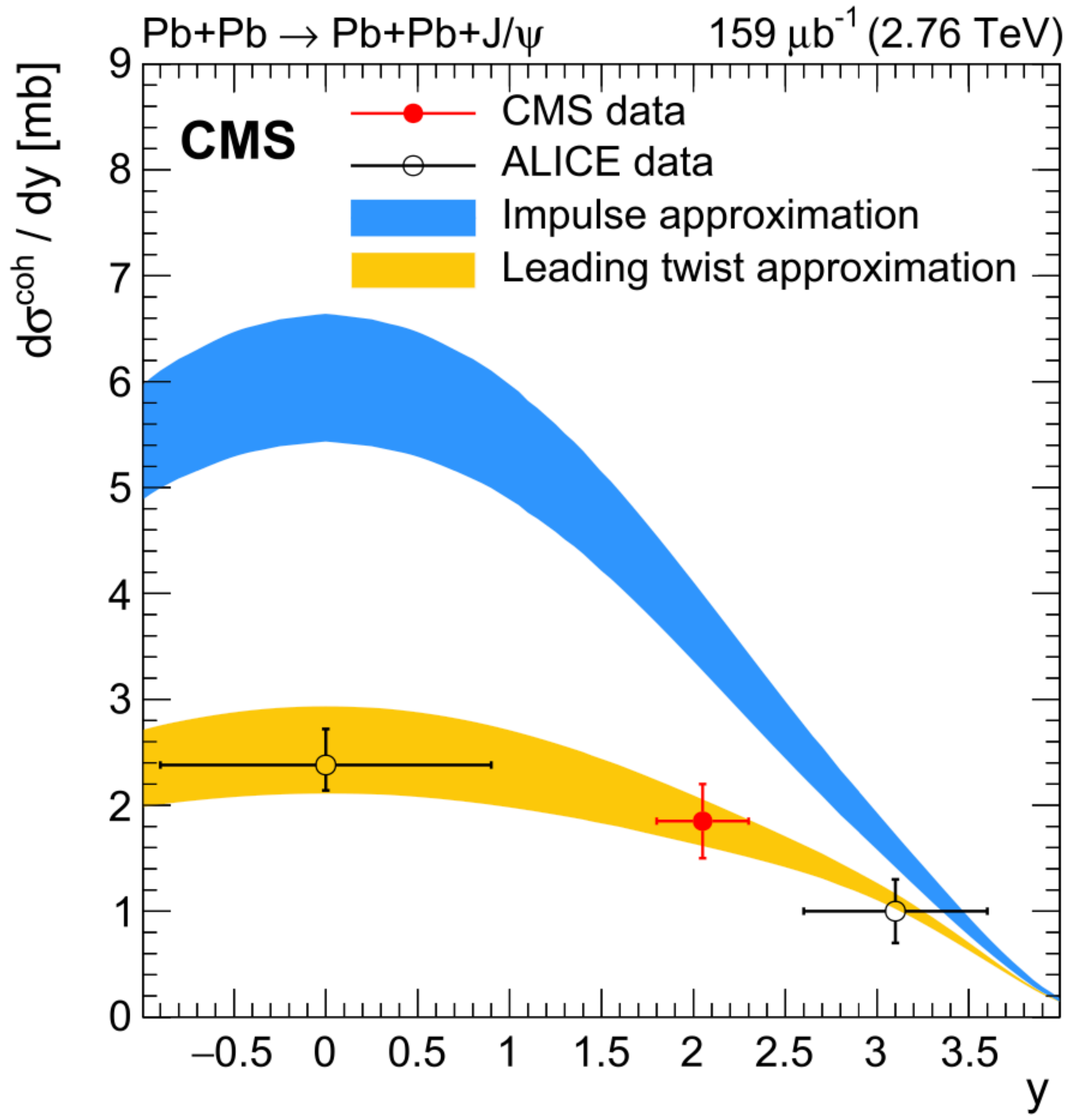
Does the target breaks or not?

proton: dissociative or exclusive production

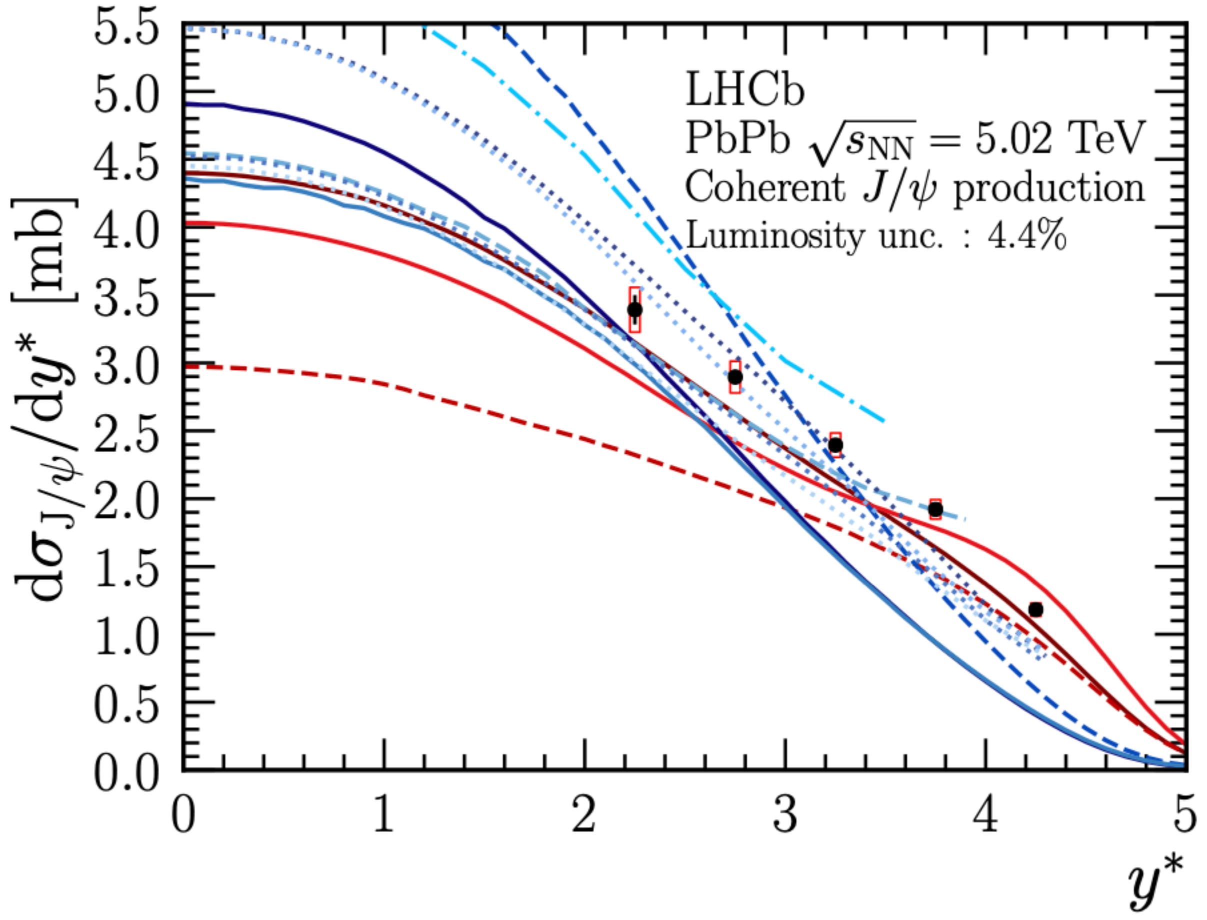
nucleus: incoherent or coherent production

Rapidity dependence

CMS,PLB772 (2017) 489

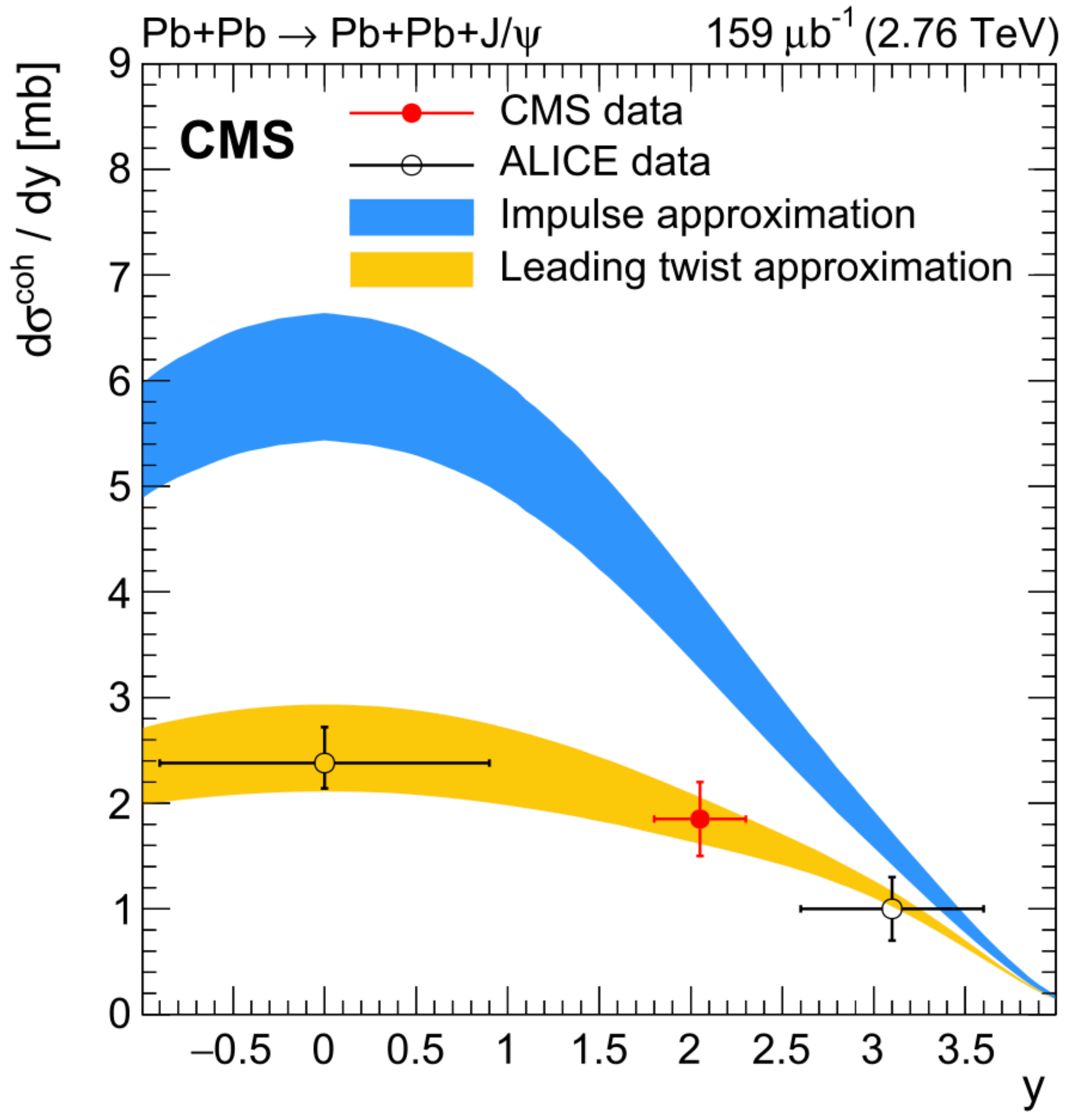


LHCb, 2206.08221

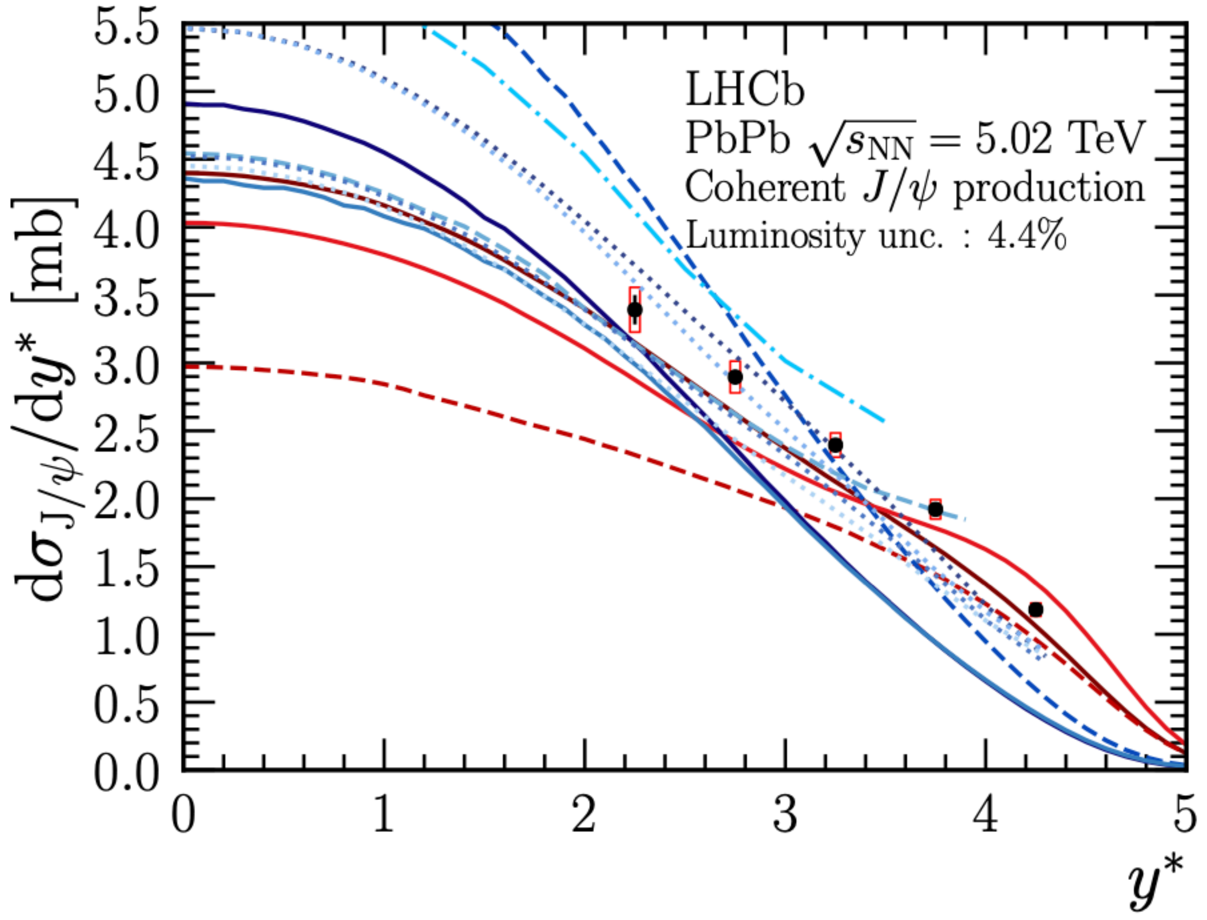


Rapidity dependence

CMS,PLB772 (2017) 489

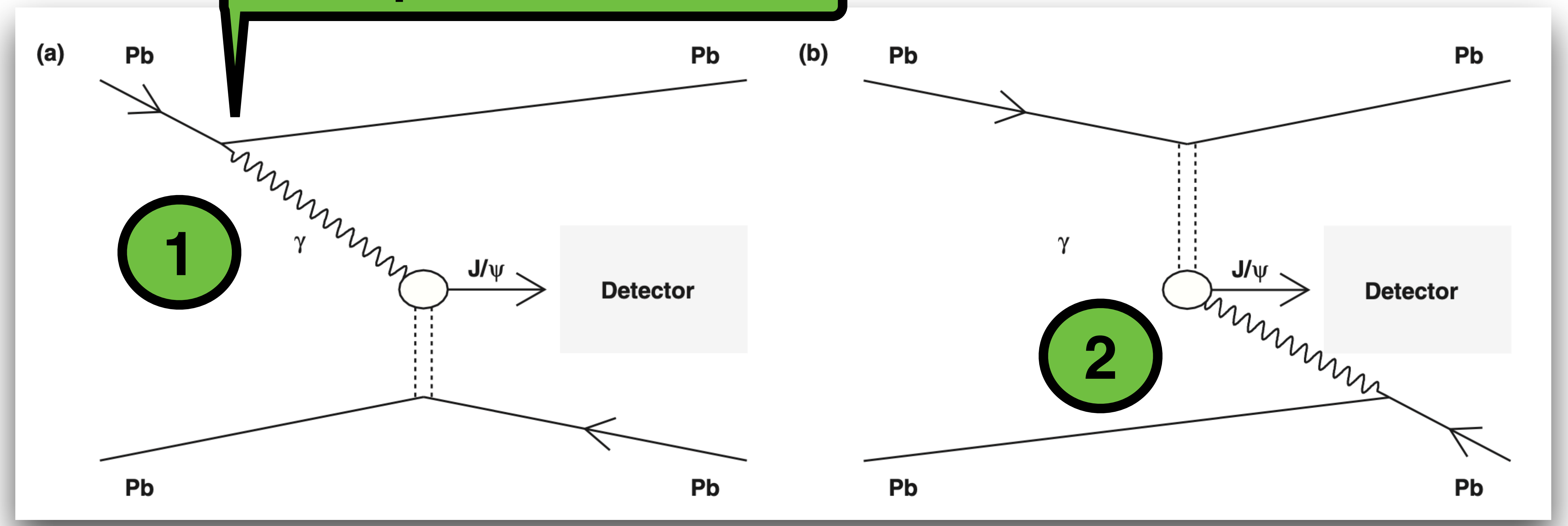


LHCb, 2206.08221



We need to know the rapidity (wrt the direction of the target)

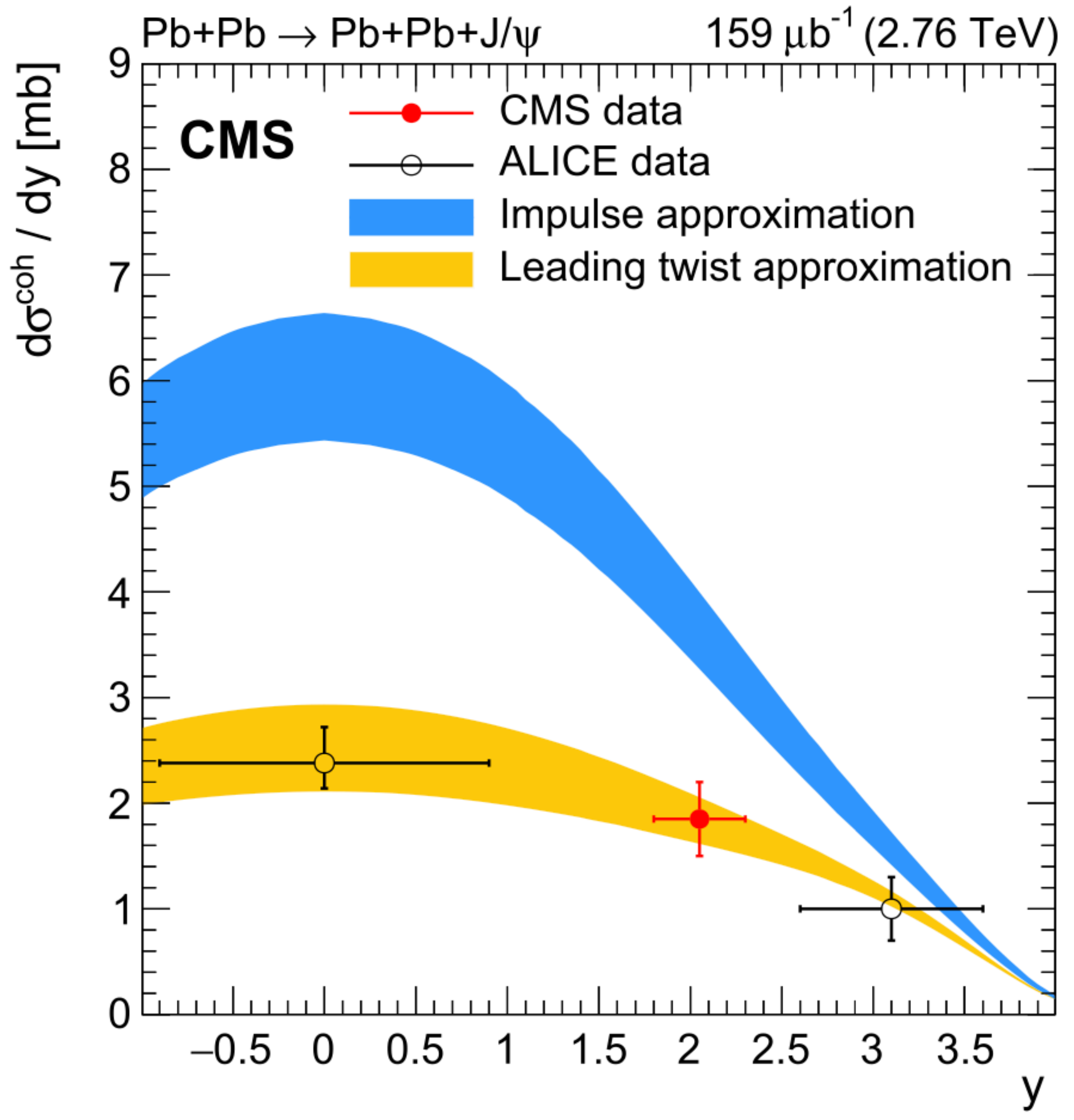
Two photon sources



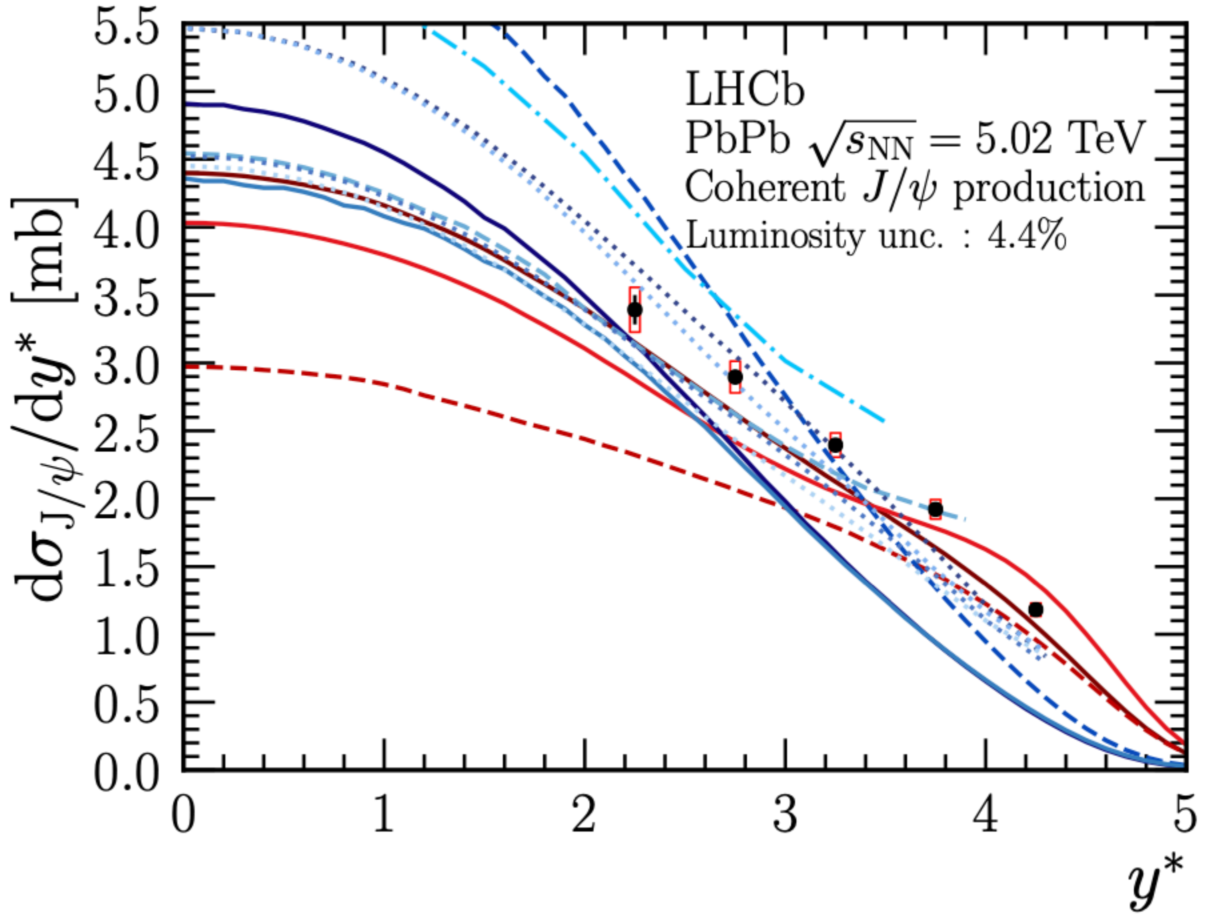
Guillermo Contreras, CTU in Prague

Rapidity dependence

CMS,PLB772 (2017) 489

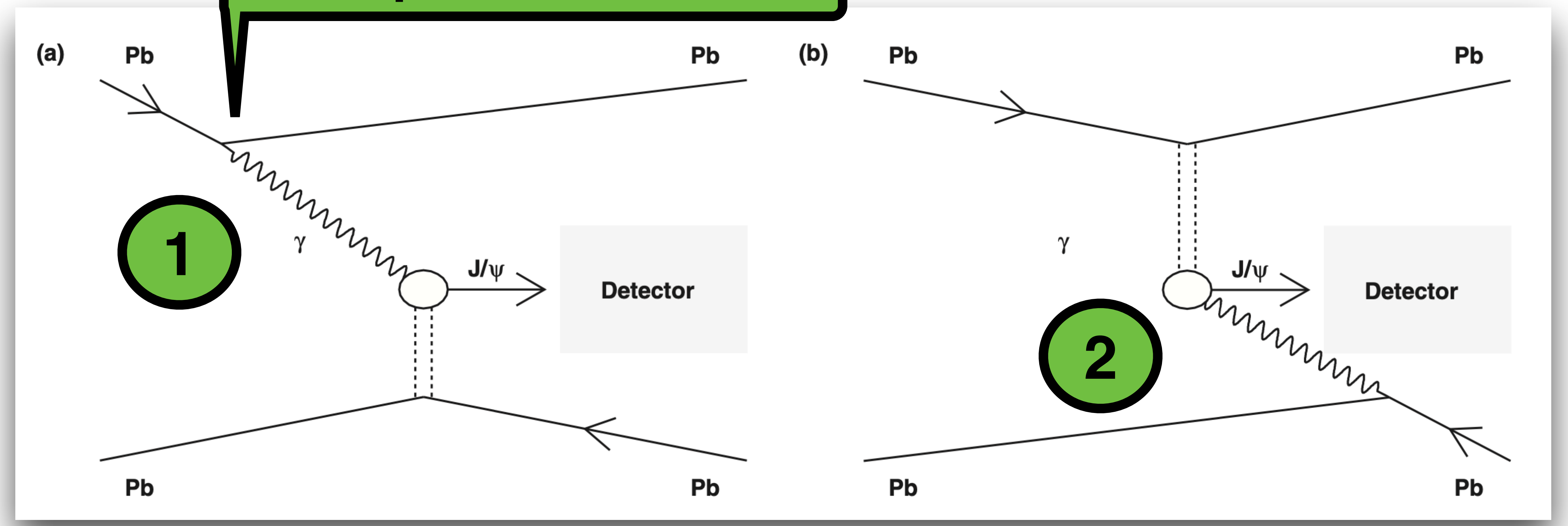


LHCb, 2206.08221



We need to know the rapidity (wrt the direction of the target)

Two photon sources



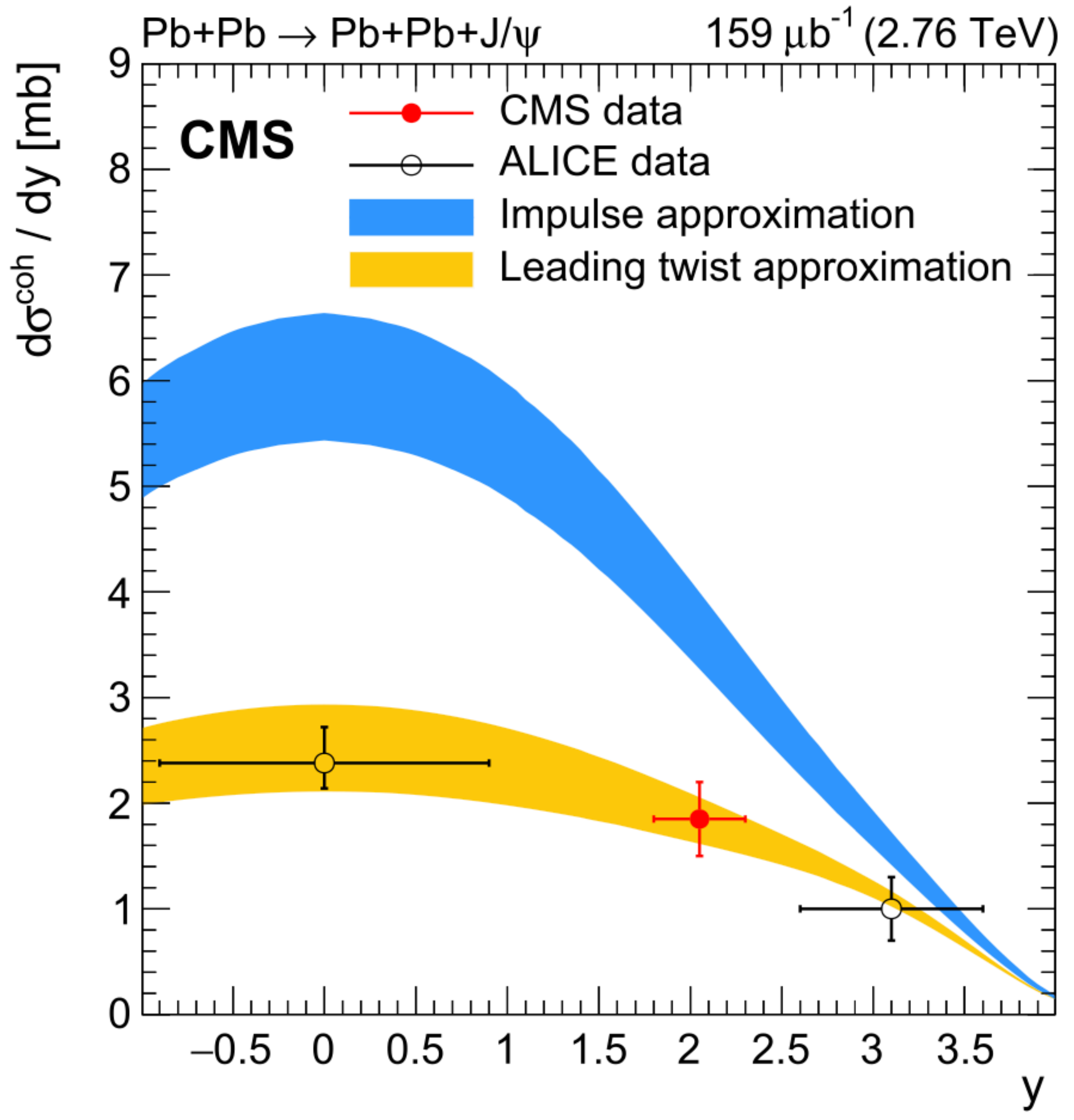
What we measure — What we want (1) — What we want (2)

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_\gamma(y;\{b\})\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\})\sigma_{\gamma\mathrm{Pb}}(-y)$$

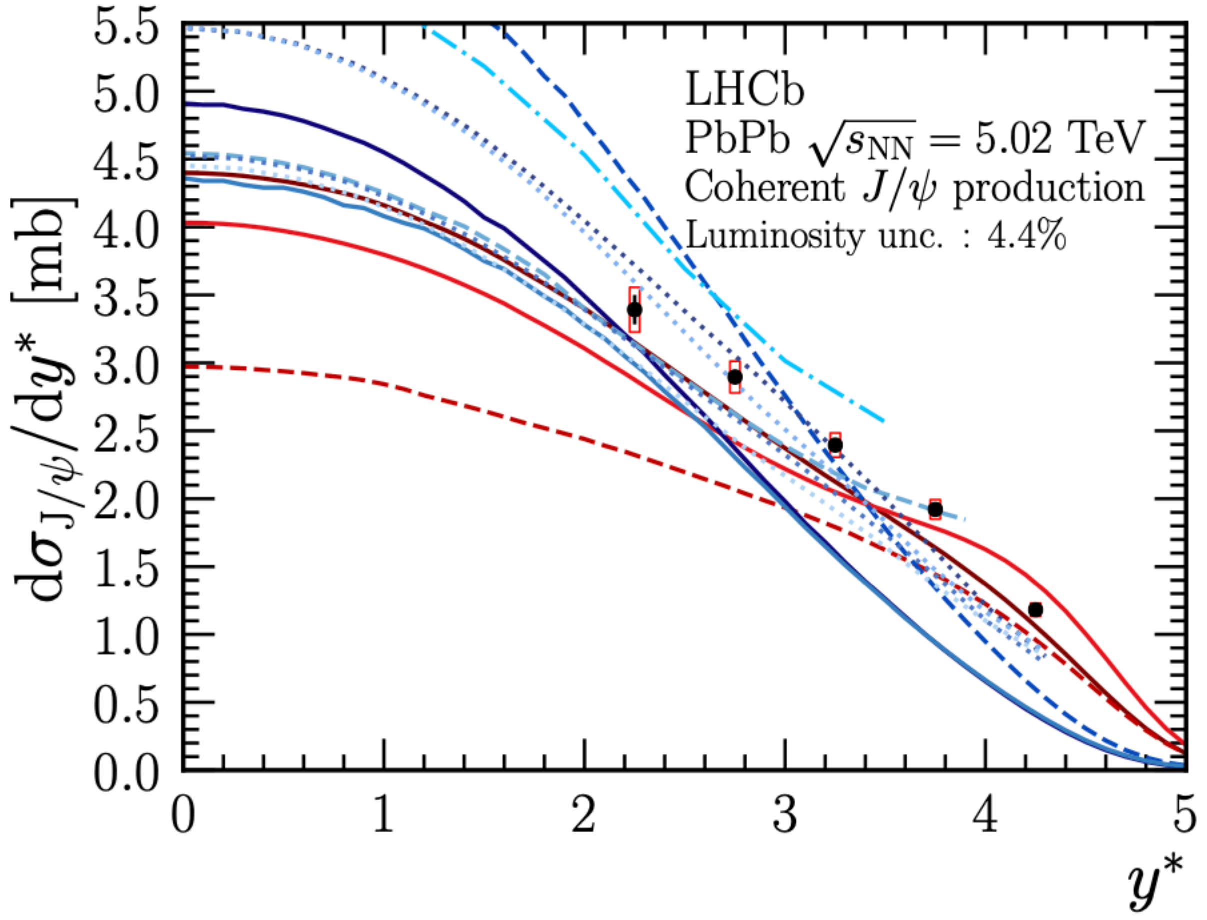
Photonuclear cross sections at two rapidities, i.e. Bjorken-x

Rapidity dependence

CMS,PLB772 (2017) 489

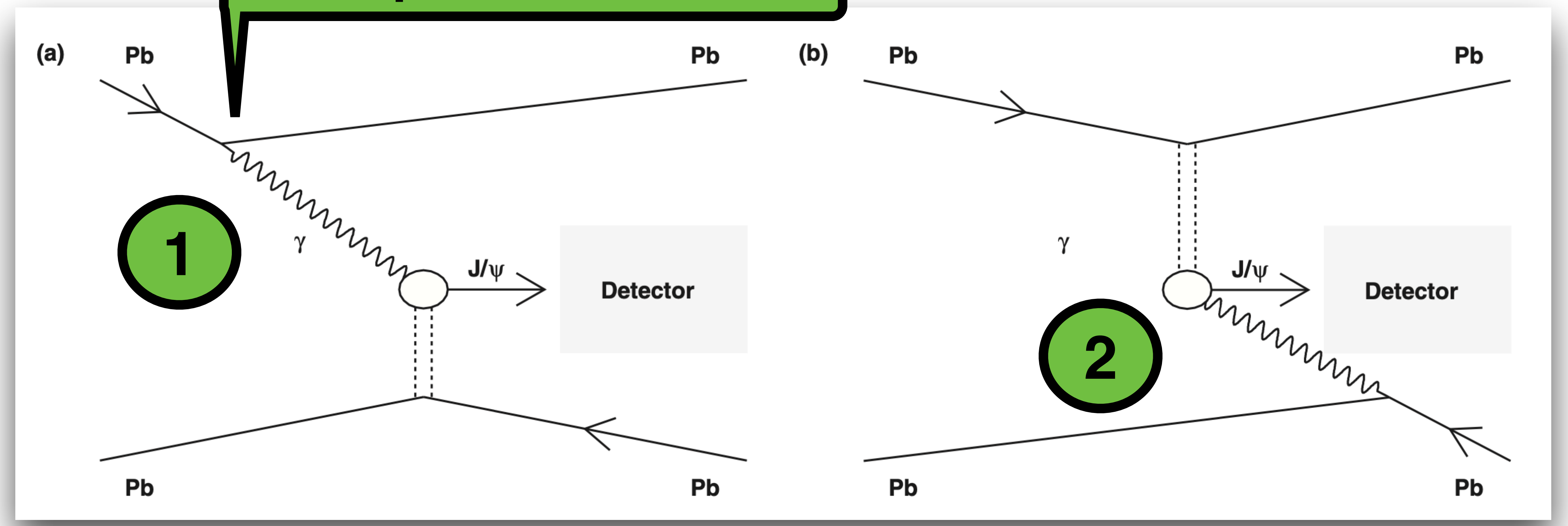


LHCb, 2206.08221



We need to know the rapidity (wrt the direction of the target)

Two photon sources



What we measure

What we want (1)

What we want (2)

$$\frac{d\sigma_{PbPb}}{dy} = n_\gamma(y;\{b\})\sigma_{\gamma Pb}(y) + n_\gamma(-y;\{b\})\sigma_{\gamma Pb}(-y)$$

Photonuclear cross sections at two rapidities, i.e. Bjorken-x

How to **extract** the photonuclear cross section if the photon fluxes are known?

Guillermo Contreras, CTU in Prague

Ambiguity problem: first solutions applied to LHC Run 1 data

At midrapidity both contributions are equal, no problem

What we measure

What we want

What we want

1

2

$$\frac{d\sigma_{\text{PbPb}}}{dy} = n_{\gamma}(y;\{b\})\sigma_{\gamma\text{Pb}}(y) + n_{\gamma}(-y;\{b\})\sigma_{\gamma\text{Pb}}(-y)$$

Photonuclear cross sections at two rapidities, i.e. Bjorken-x

How to extract the photonuclear cross section if the photon fluxes are known?

Ambiguity problem: first solutions applied to LHC Run 1 data

At forward rapidities (2) dominates (95% of the cross section)

Guzey et al, Phys.Lett. B726 (2013) 290-295

At midrapidity both contributions are equal, no problem

What we measure — **(1)** **What we want** — **(2)** **What we want**

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_{\gamma}(y;\{b\})\sigma_{\gamma\mathrm{Pb}}(y) + n_{\gamma}(-y;\{b\})\sigma_{\gamma\mathrm{Pb}}(-y)$$

Photonuclear cross sections at two rapidities, i.e. Bjorken-x

How to extract the photonuclear cross section if the photon fluxes are known?

Ambiguity problem: first solutions applied to LHC Run 1 data

At forward rapidities (2) dominates (95% of the cross section)

Guzey et al, Phys.Lett. B726 (2013) 290-295

At midrapidity both contributions are equal, no problem

What we measure — **What we want** (1) — **What we want** (2)

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_\gamma(y;\{b\})\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\})\sigma_{\gamma\mathrm{Pb}}(-y)$$

Photonuclear cross sections at two rapidities, i.e. Bjorken-x

How to extract the photonuclear cross section if the photon fluxes are known?

Perform two independent measurements at the same rapidity, but different impact parameter, then solve the equations.

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_A = n_\gamma(y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(-y)$$

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_B = n_\gamma(y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(-y)$$

Guillermo Contreras, CTU in Prague

Ambiguity problem: first solutions applied to LHC Run 1 data

At forward rapidities (2) dominates (95% of the cross section)

Guzey et al, Phys.Lett. B726 (2013) 290-295

At midrapidity both contributions are equal, no problem

What we measure

What we want

What we want

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_\gamma(y;\{b\})\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\})\sigma_{\gamma\mathrm{Pb}}(-y)$$

(1) (2)

Photonuclear cross sections at two rapidities, i.e. Bjorken-x

How to extract the photonuclear cross section if the photon fluxes are known?

Perform two independent measurements at the same rapidity, but different impact parameter, then solve the equations.

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_A = n_\gamma(y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(-y)$$

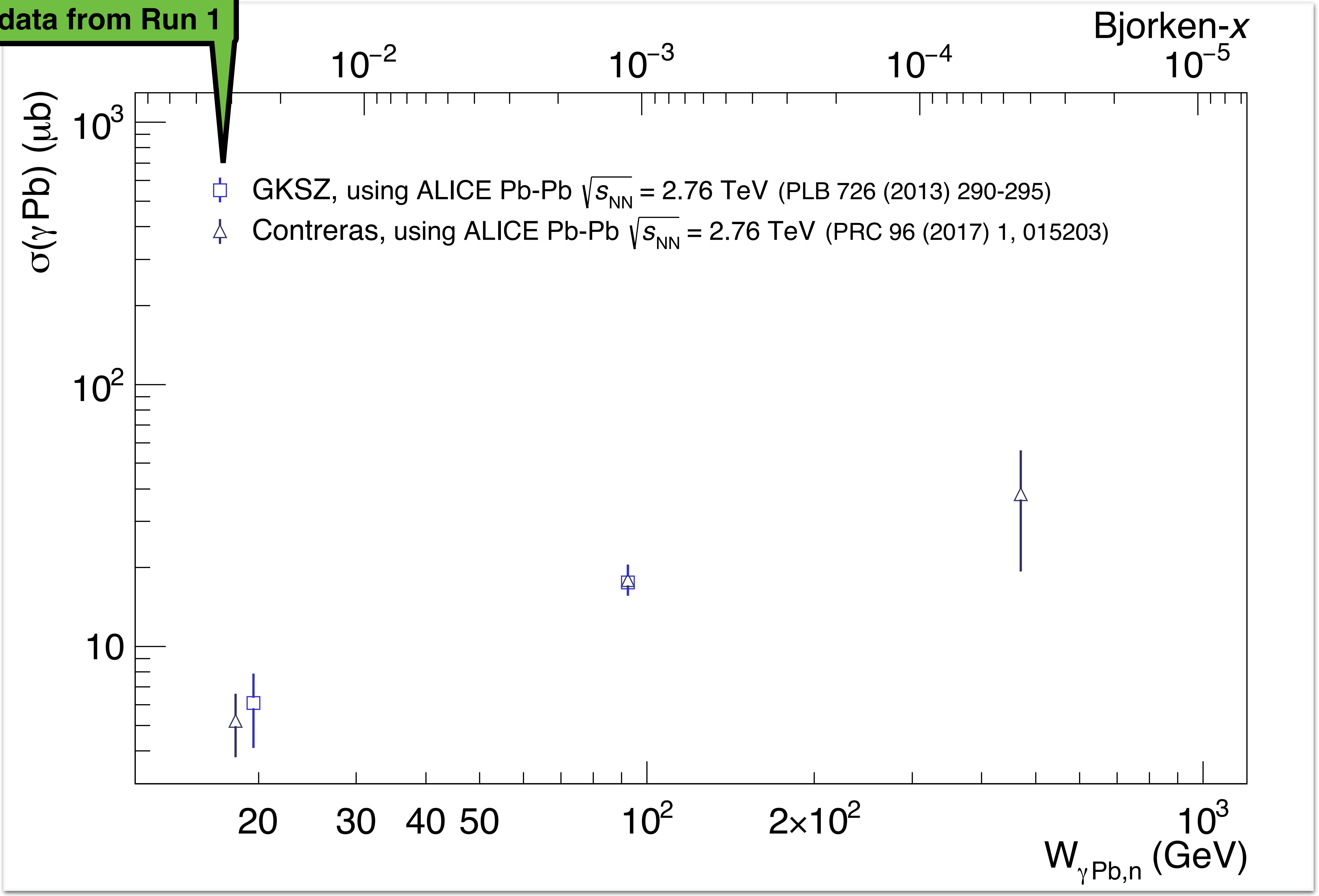
$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_B = n_\gamma(y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(-y)$$

For example, use peripheral and ultra-peripheral collisions

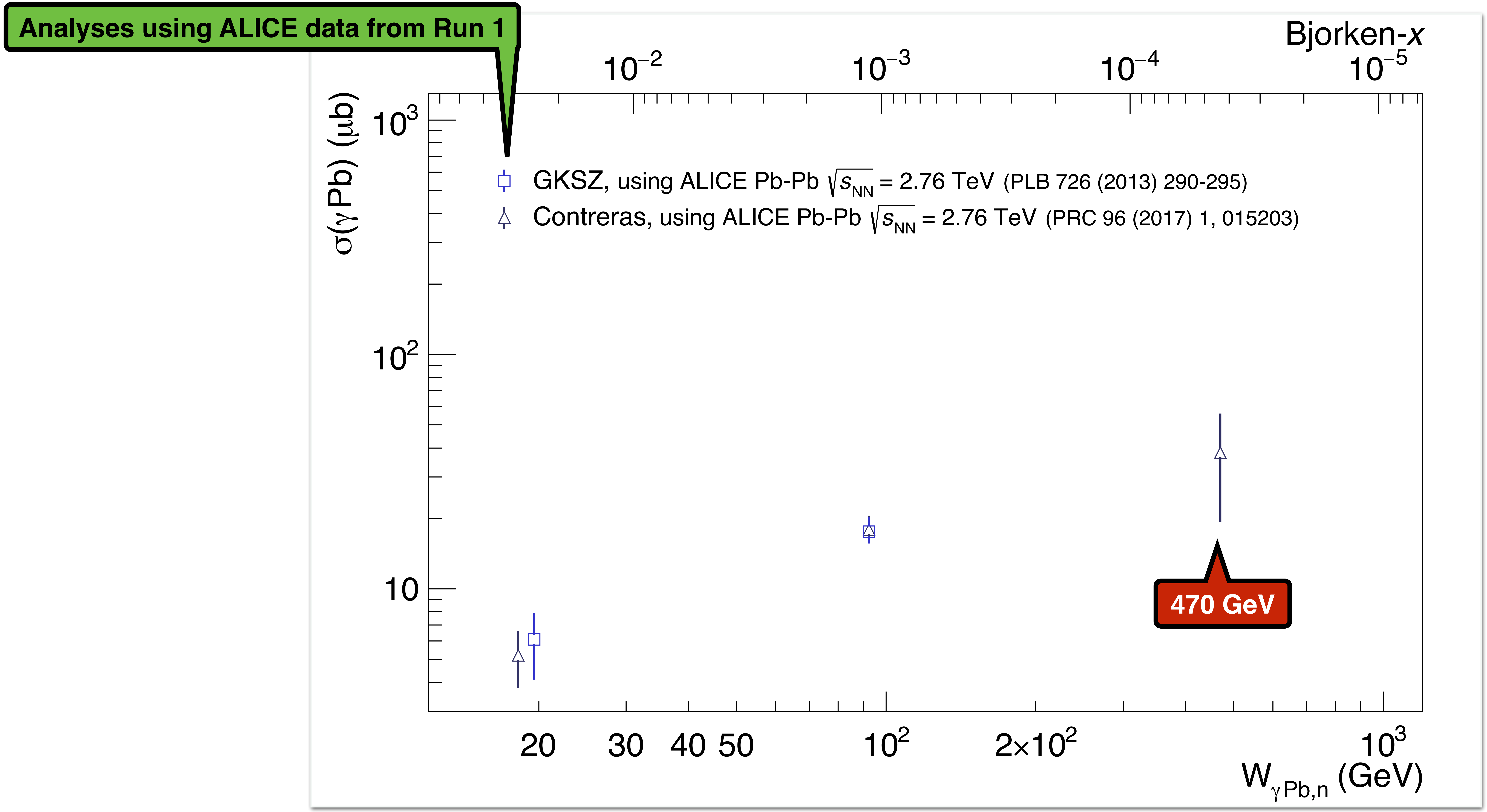
JGC, PRC **96**, 015203 (2017)

Energy/Bjorken-x dependence of coherent production from Run 1

Analyses using ALICE data from Run 1



Energy/Bjorken-x dependence of coherent production from Run 1

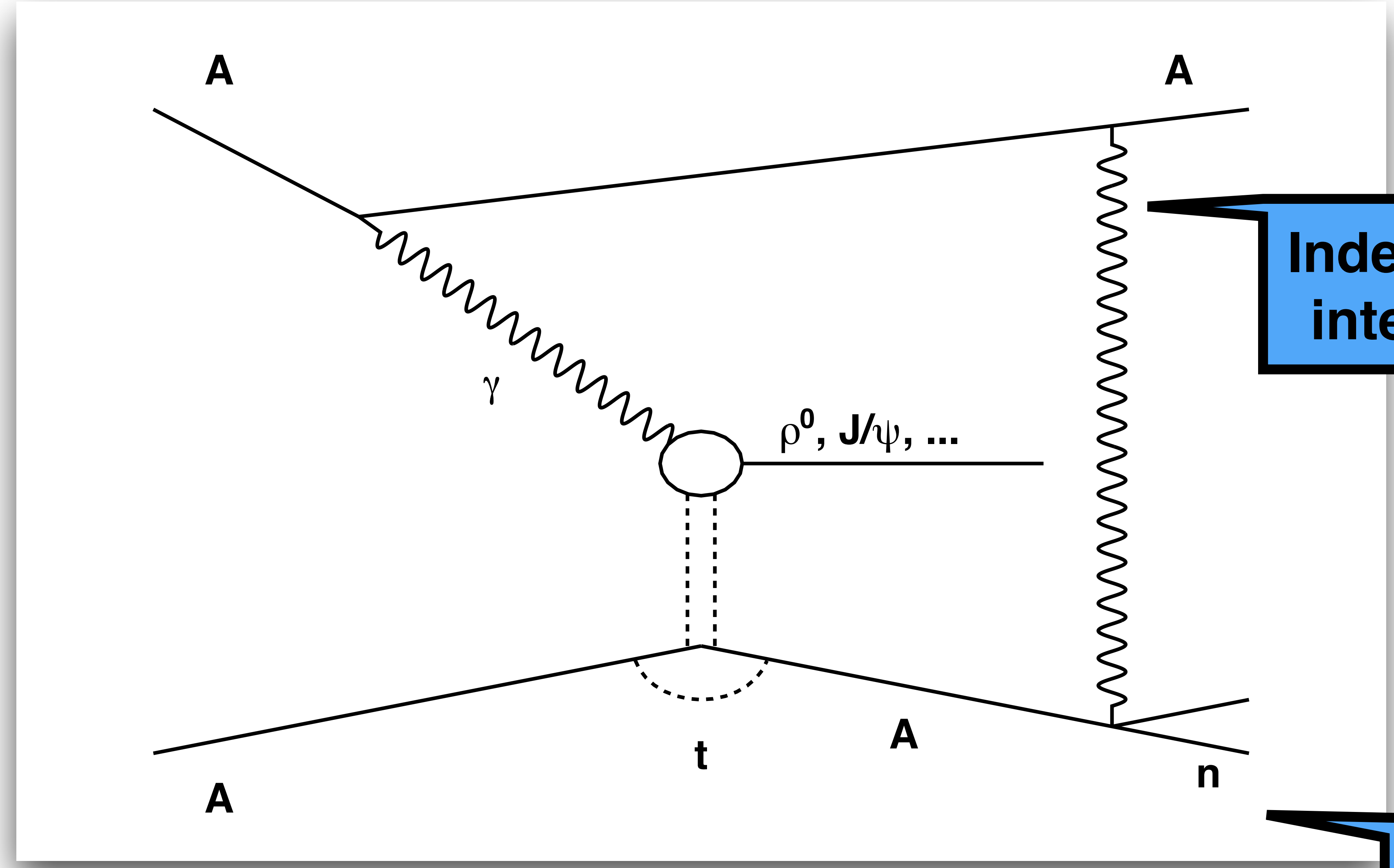


Guillermo Contreras, CTU in Prague

Ambiguity problem: use EMD

Guzey, Strikman, Zhalov, EPJ C74 (2014) 2942

Electromagnetic dissociation of nuclei

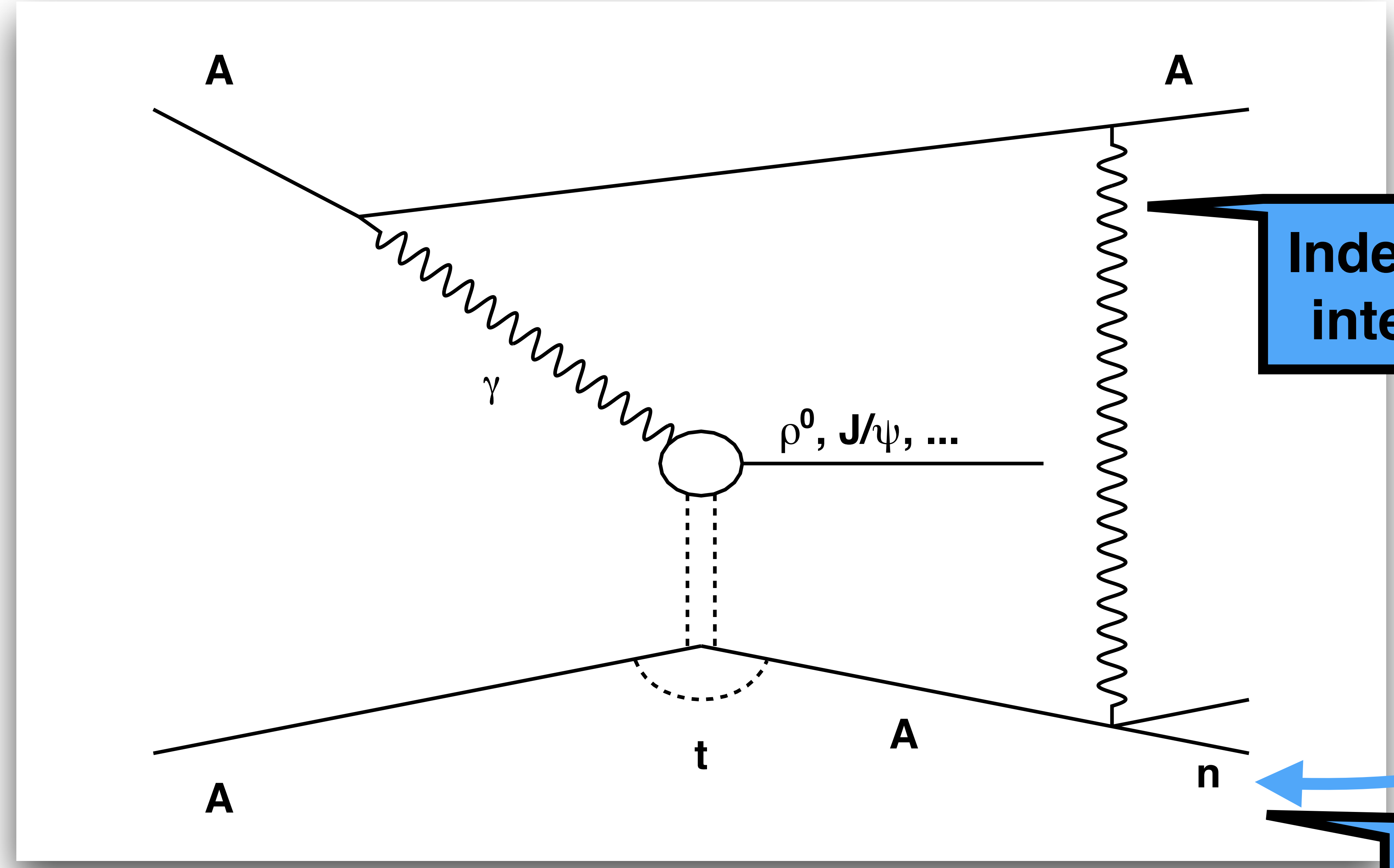


Independent interaction

neutrons are emitted along the beamline

Ambiguity problem: use EMD

Guzey, Strikman, Zhalov, EPJ C74 (2014) 2942

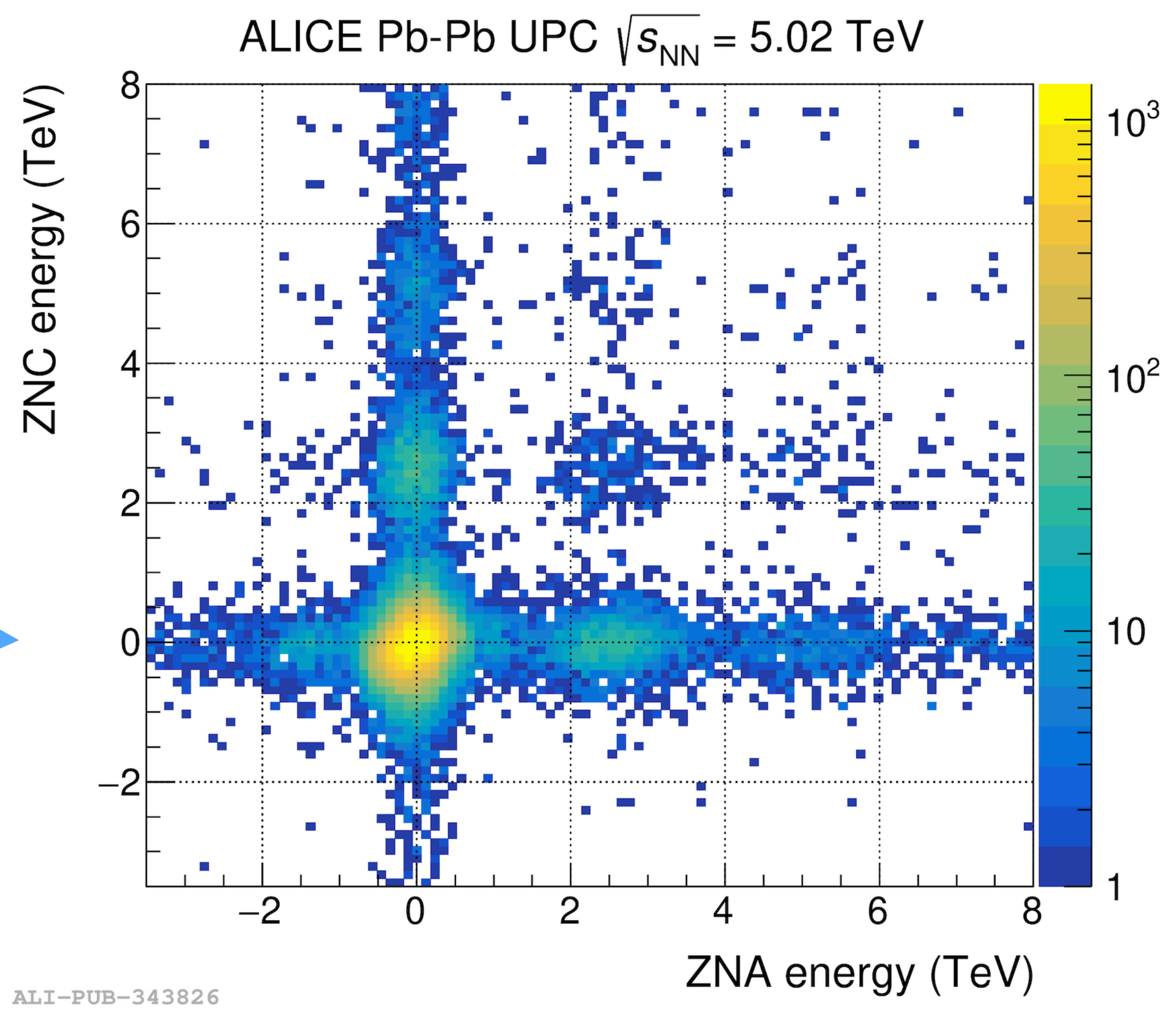


Independent interaction

neutrons are emitted along the beamline

ZDC

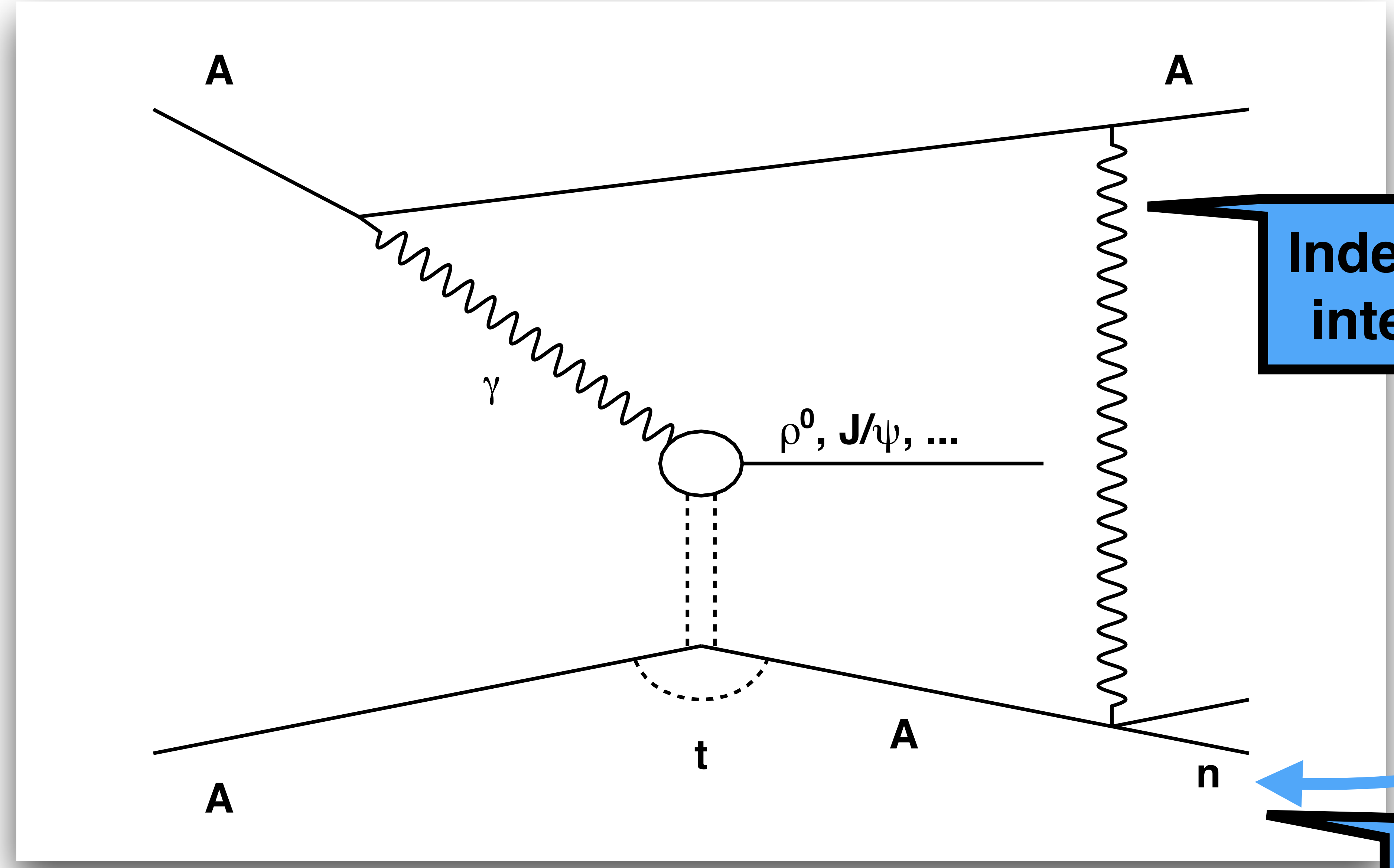
Electromagnetic dissociation of nuclei



ALICE, JHEP 06 (2020) 035

Ambiguity problem: use EMD

Guzey, Strikman, Zhalov, EPJ C74 (2014) 2942

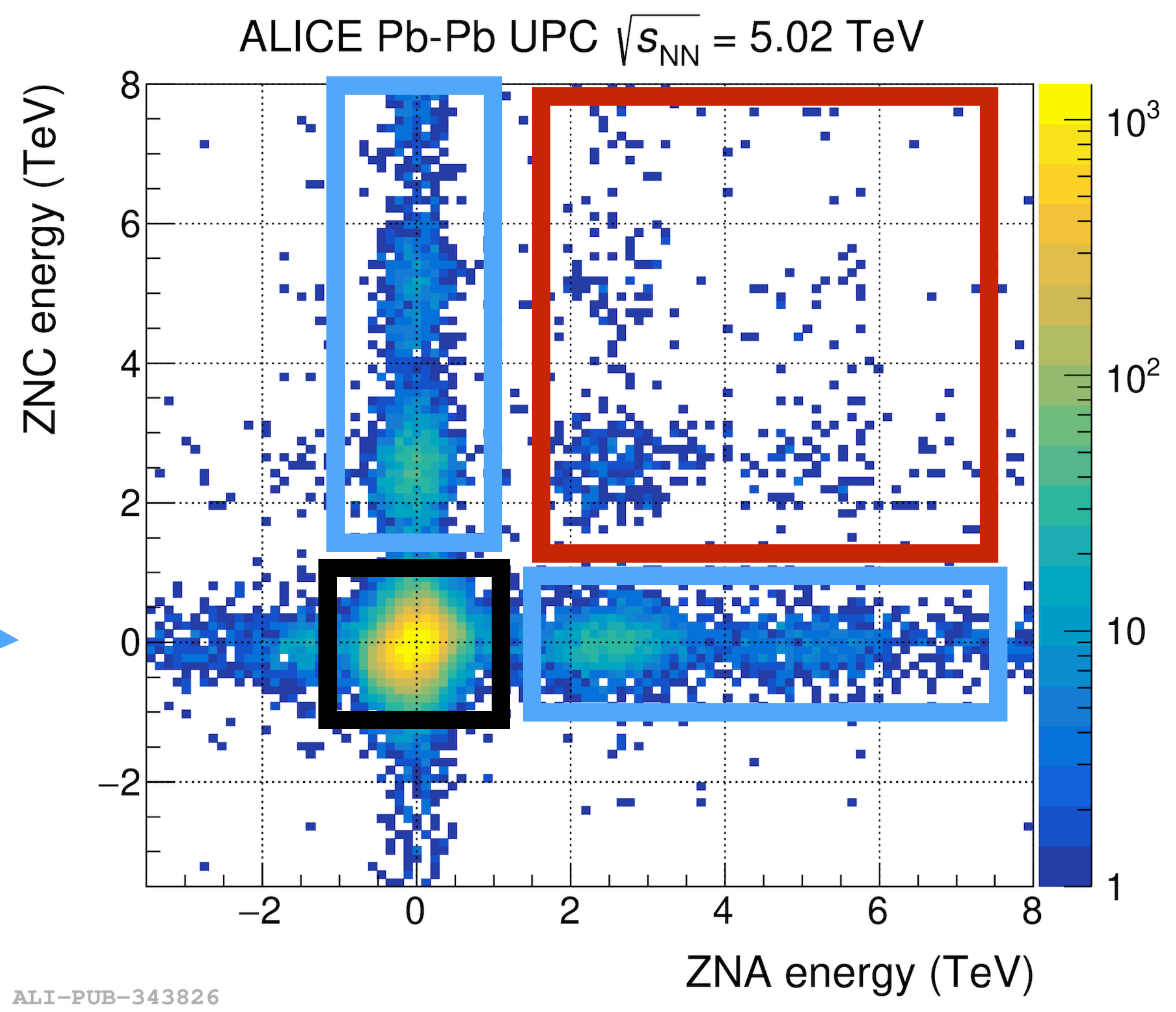


Independent interaction

ZDC

neutrons are emitted along the beamline

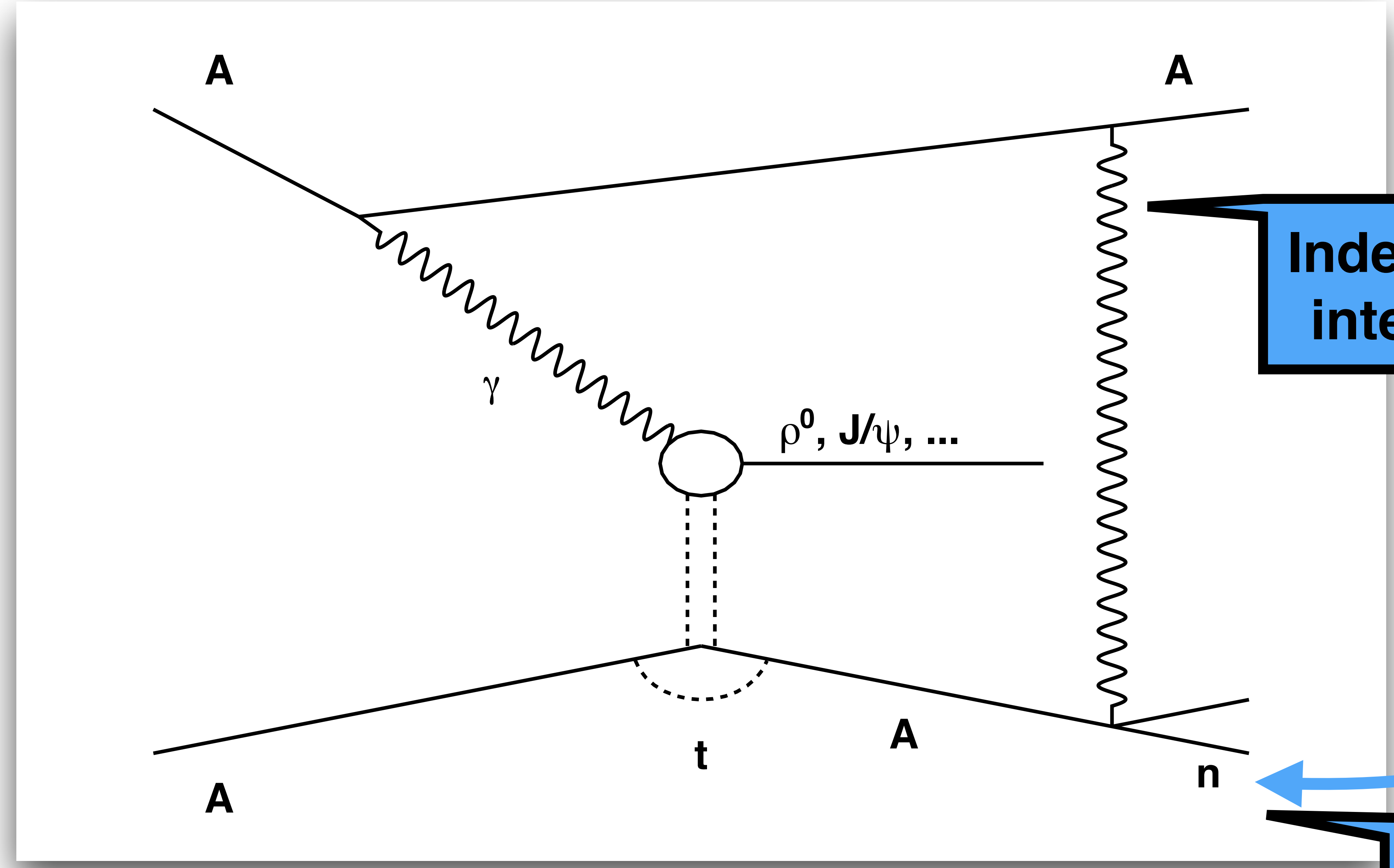
Electromagnetic dissociation of nuclei



ALICE, JHEP 06 (2020) 035

Ambiguity problem: use EMD

Guzey, Strikman, Zhalov, EPJ C74 (2014) 2942

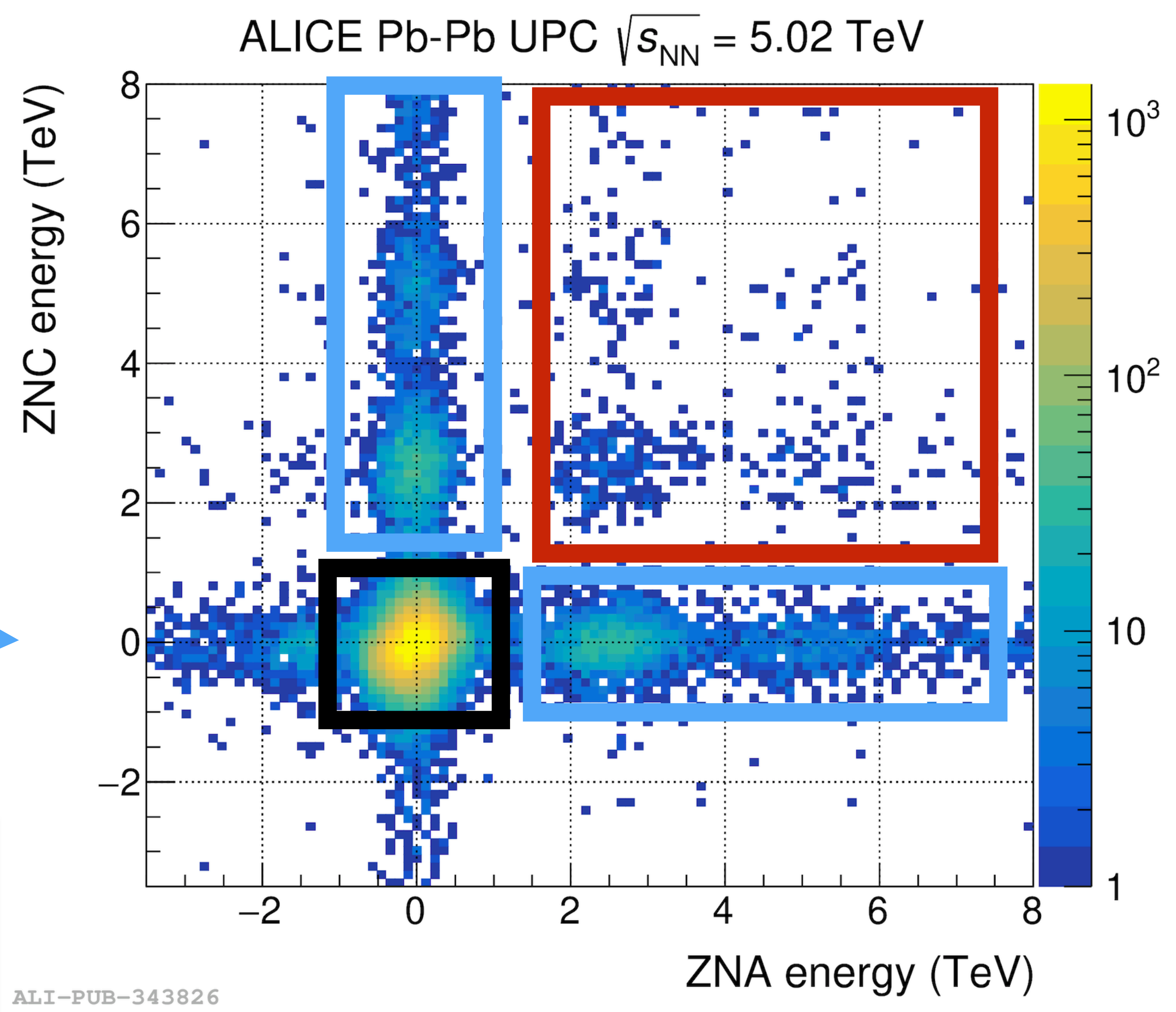


Independent interaction

neutrons are emitted along the beamline

ZDC

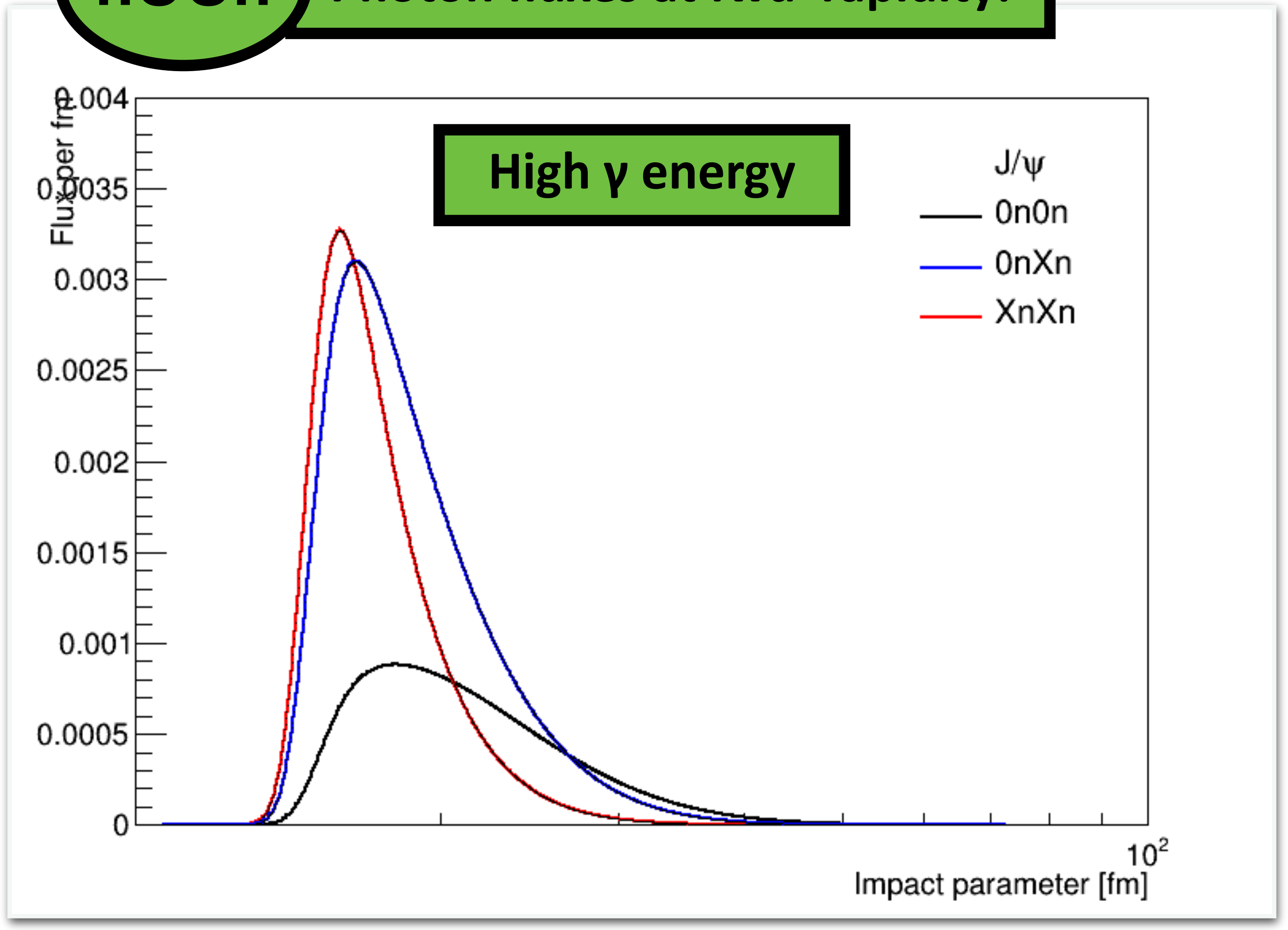
Electromagnetic dissociation of nuclei

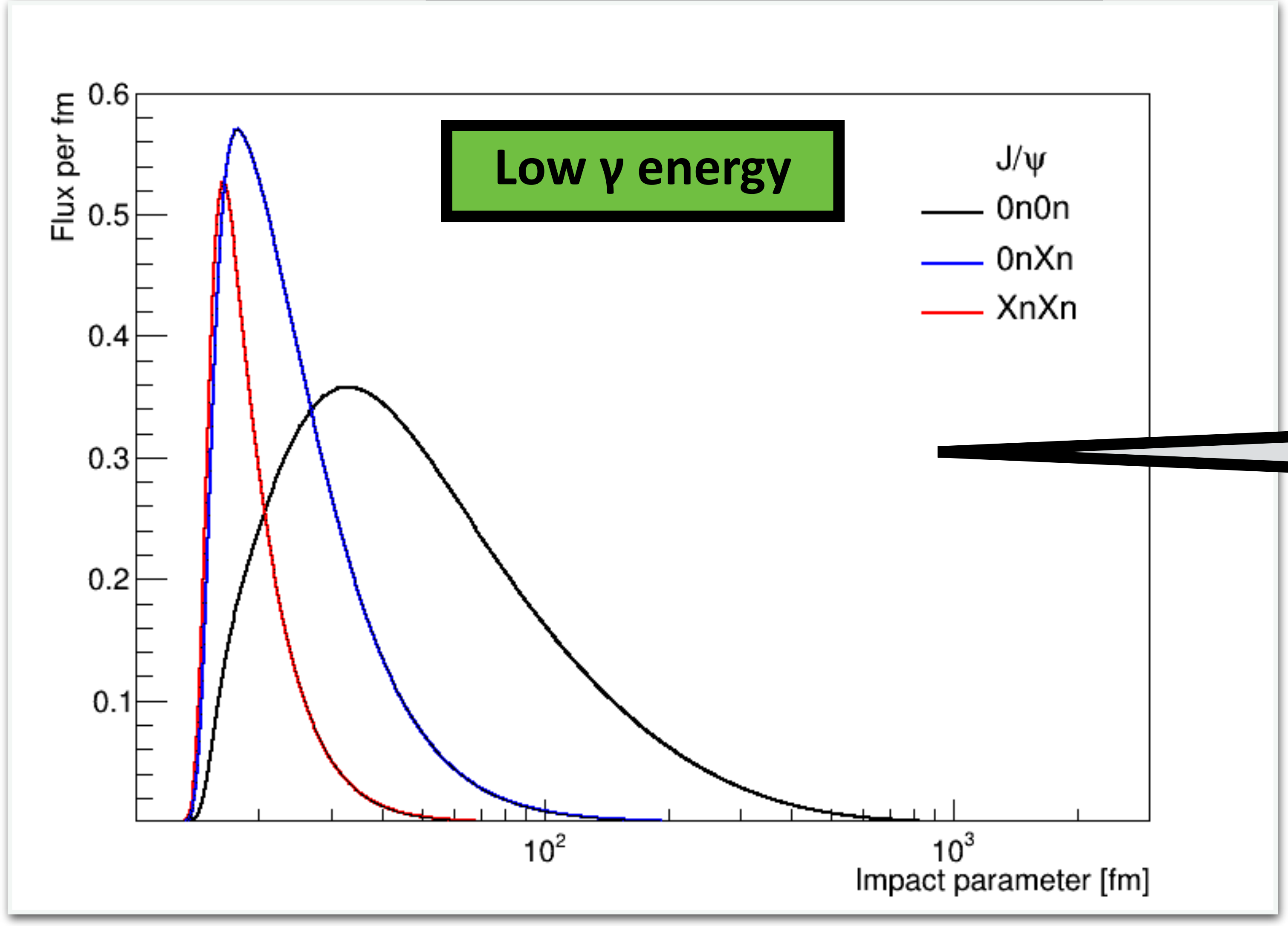


ALICE, JHEP 06 (2020) 035

0n0n: no EMD neutron (large b)
0nXn: single EMD (medium b)
XnXn: mutual EMD (smaller b)

nOOn **Photon fluxes at fwd rapidity:**

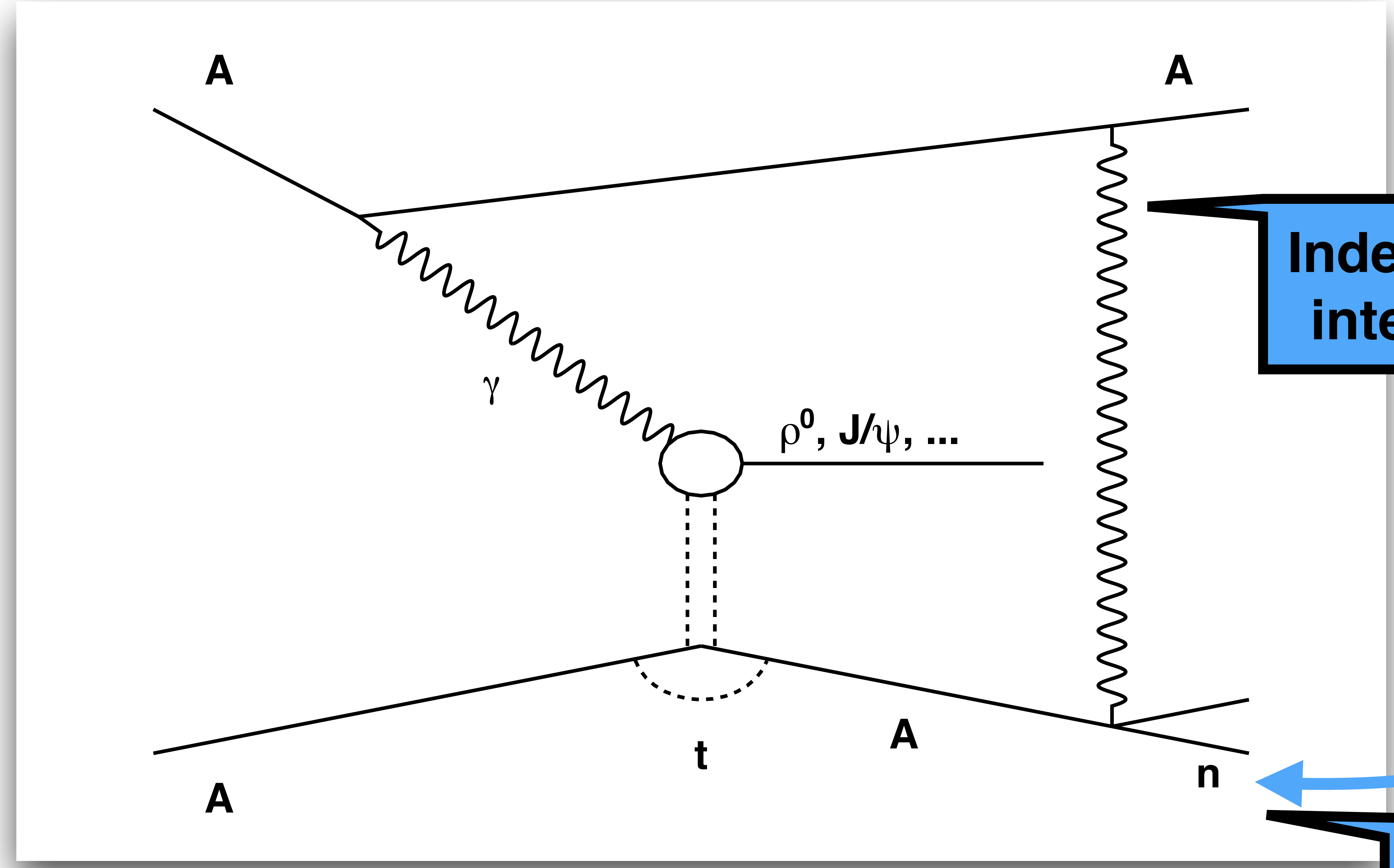




Broz et al., CPC 235 (2020) 107181

Ambiguity problem: use EMD

Guzey, Strikman, Zhalov, EPJ C74 (2014) 2942

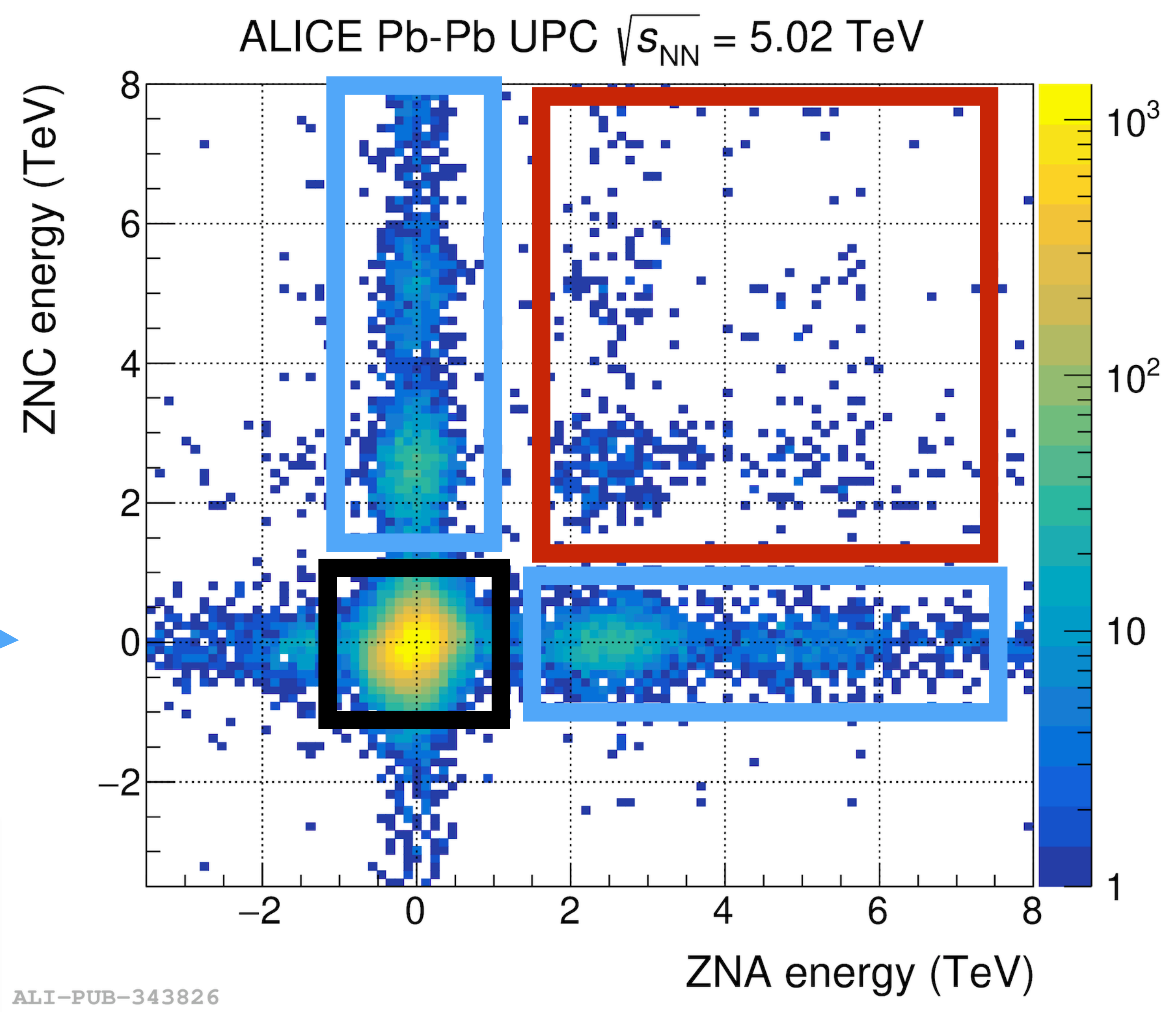


Independent interaction

ZDC

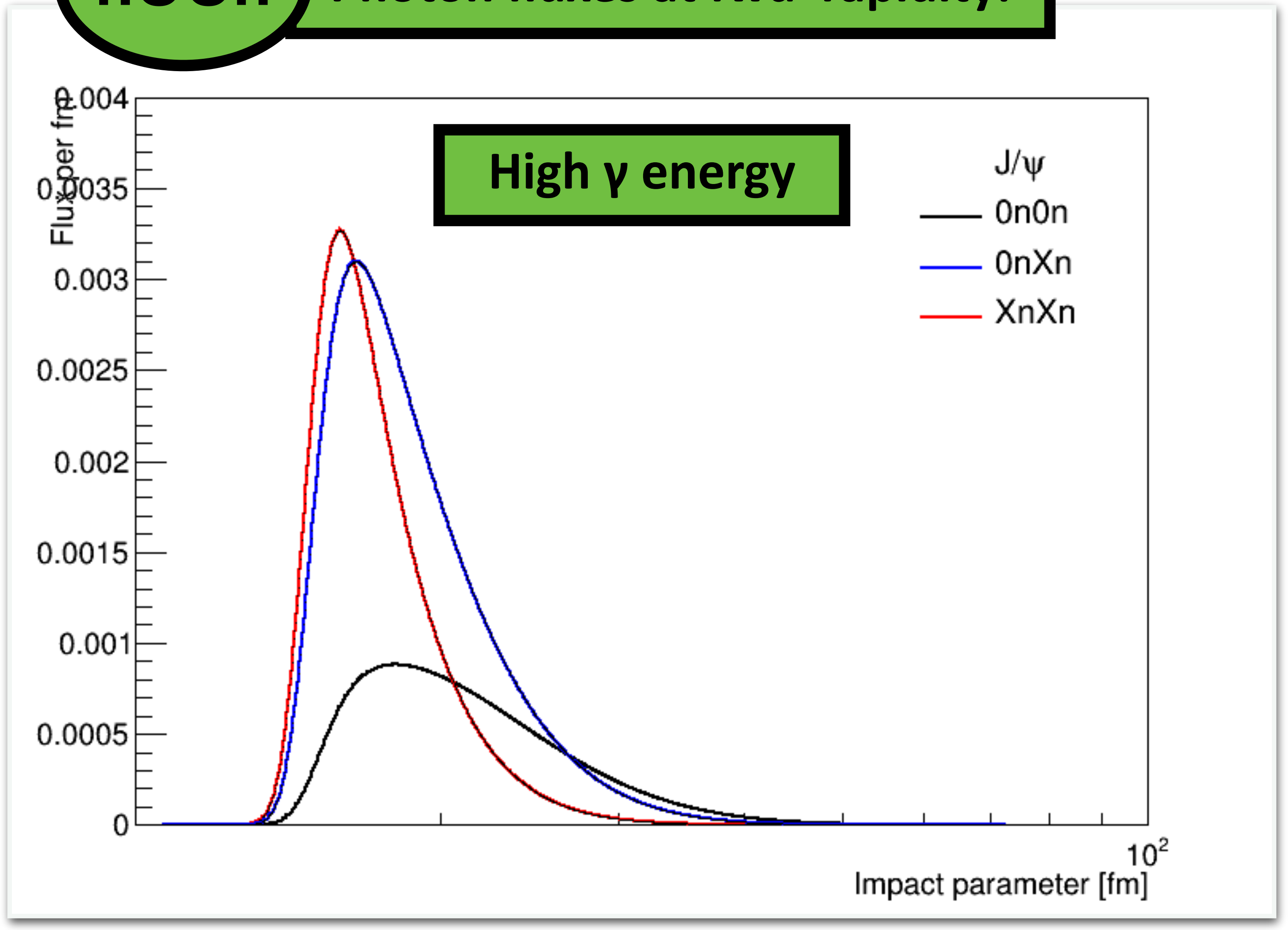
neutrons are emitted along the beamline

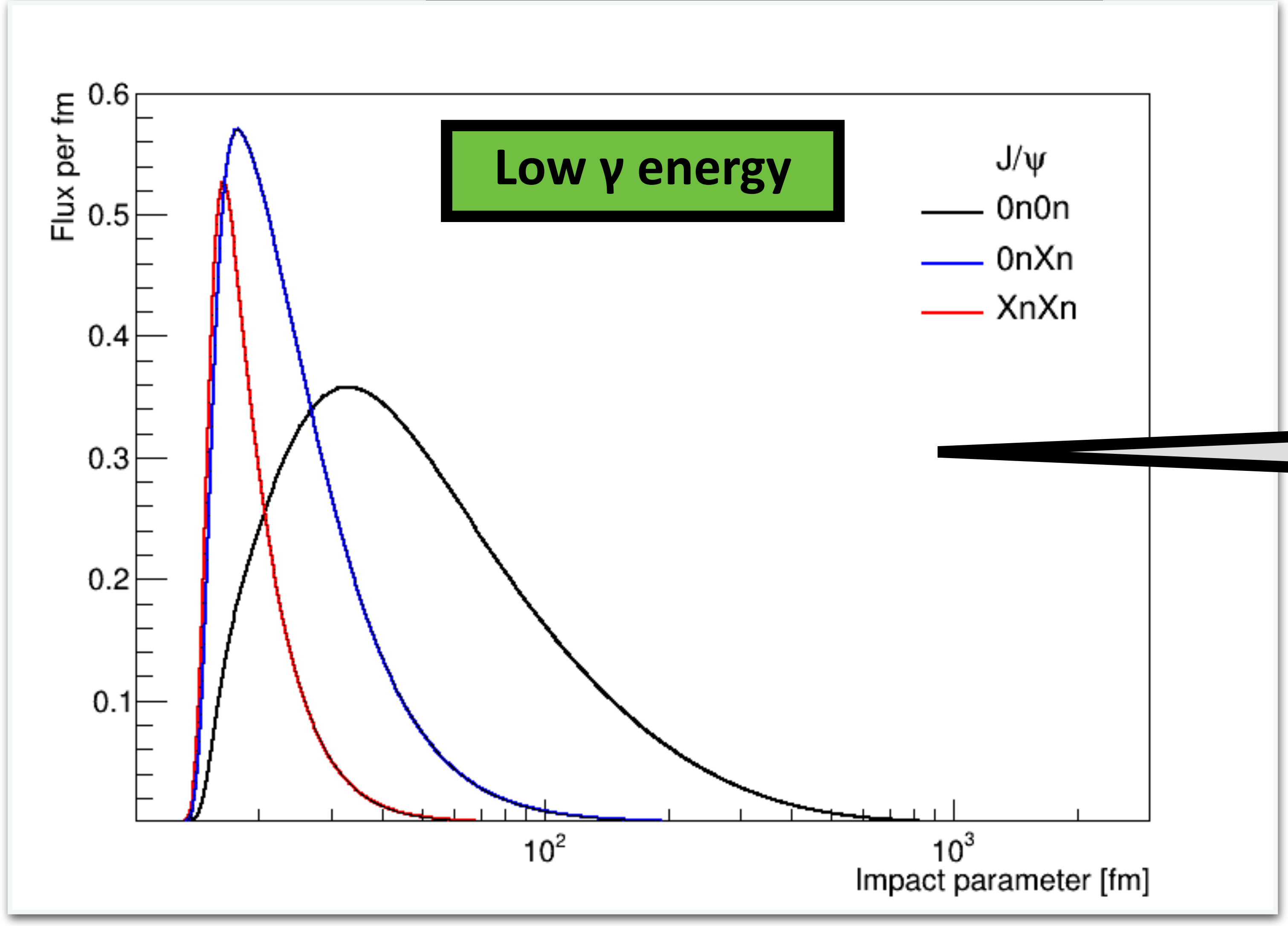
Electromagnetic dissociation of nuclei



ALICE, JHEP 06 (2020) 035

nOOn **Photon fluxes at fwd rapidity:**





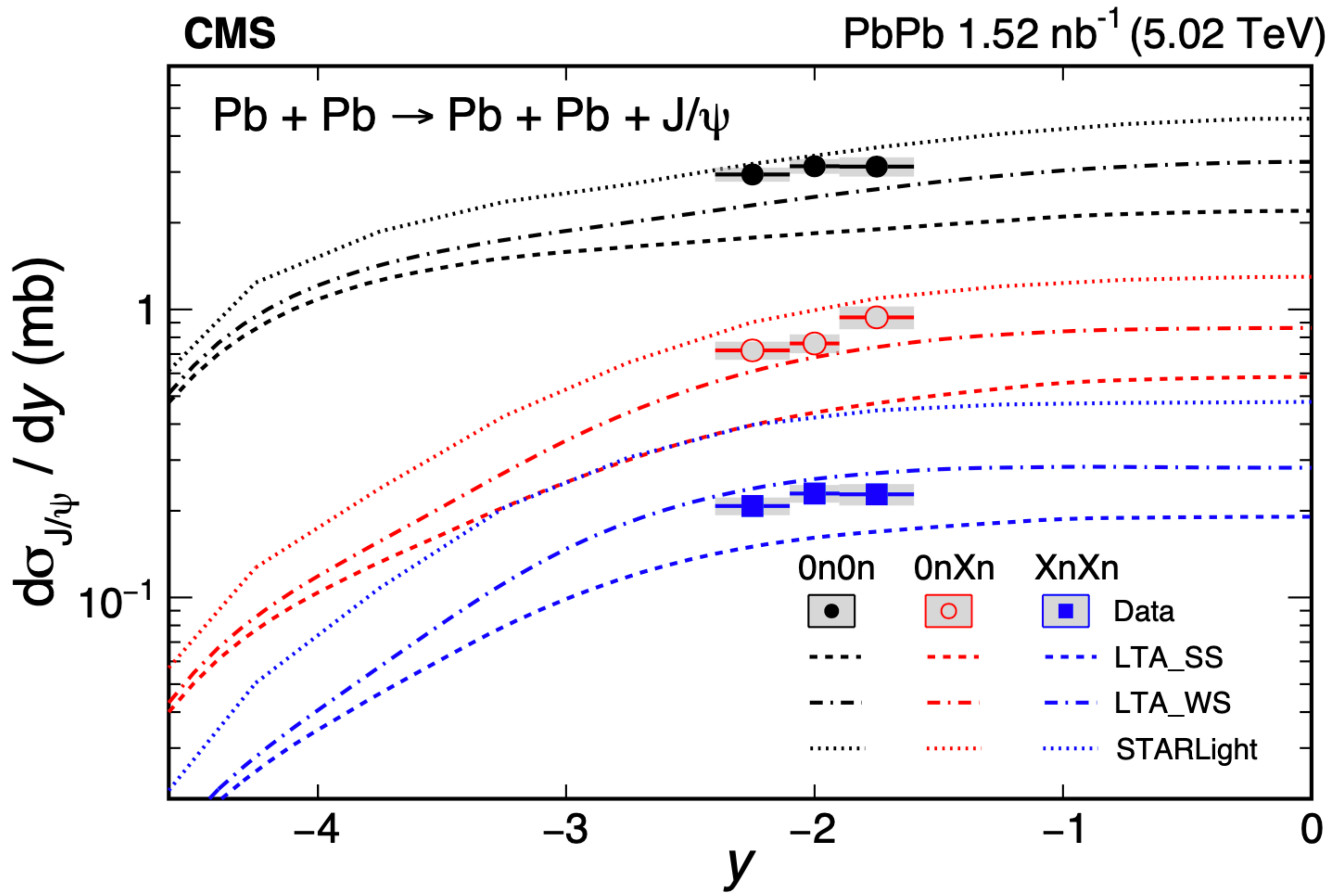
0n0n: no EMD neutron (large b)
0nXn: single EMD (medium b)
XnXn: mutual EMD (smaller b)

Three independent measurements at the same rapidity, but different impact parameters

Broz et al., CPC 235 (2020) 107181

Run 2: rapidity dependence of J/ψ coherent production in EMD classes

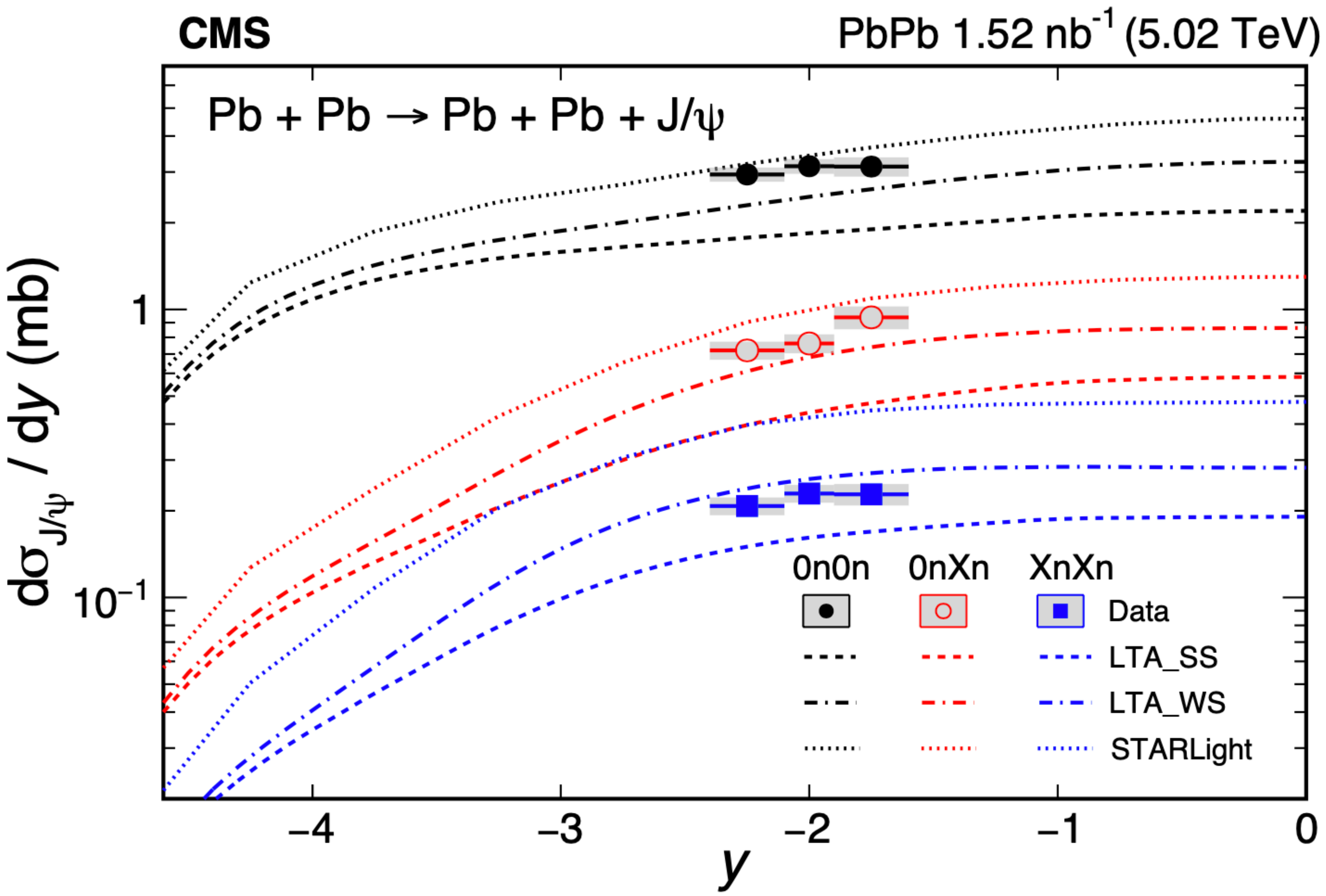
CMS



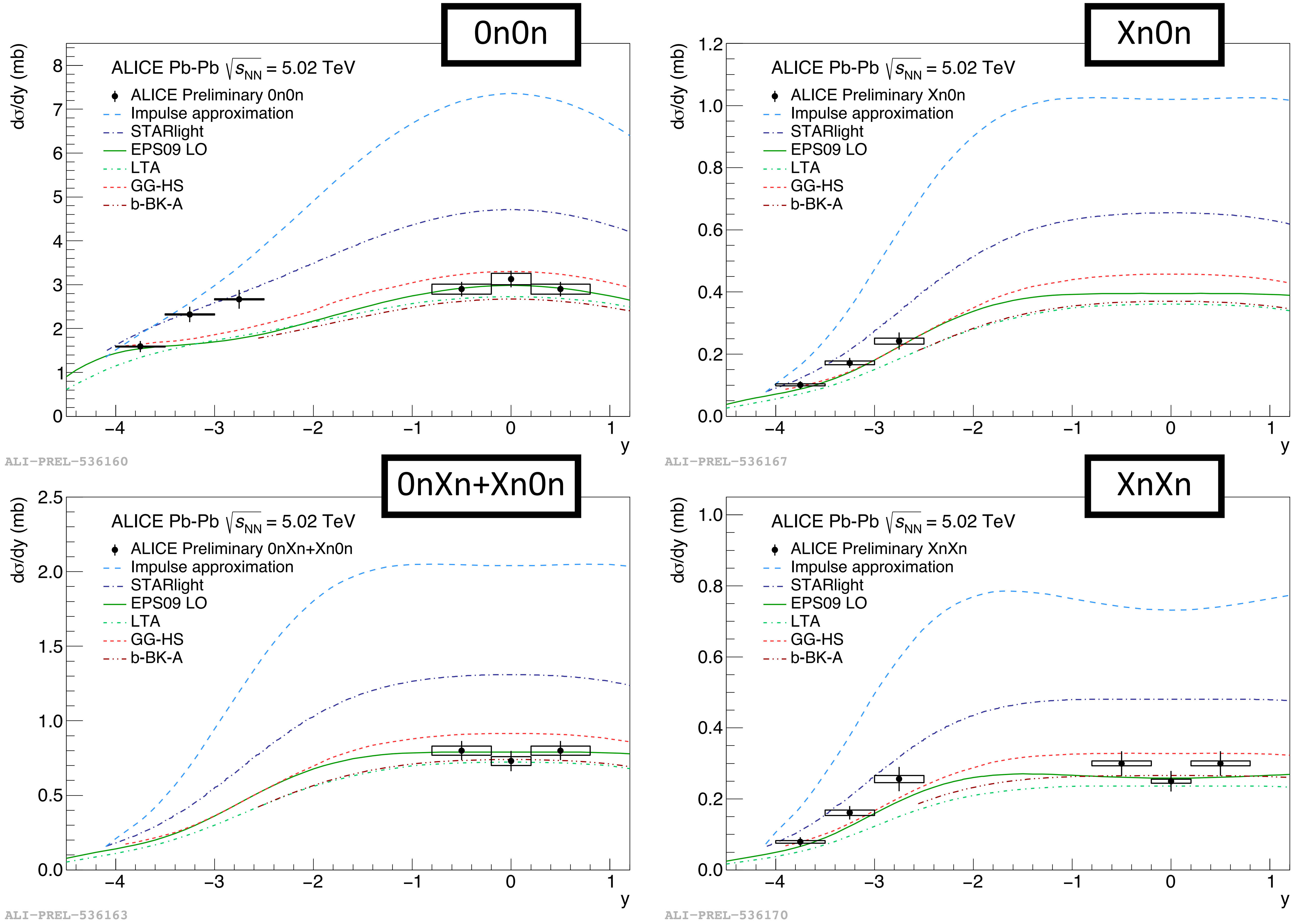
CMS, arXiv 2303.16984

Run 2: rapidity dependence of J/ψ coherent production in EMD classes

CMS



ALICE

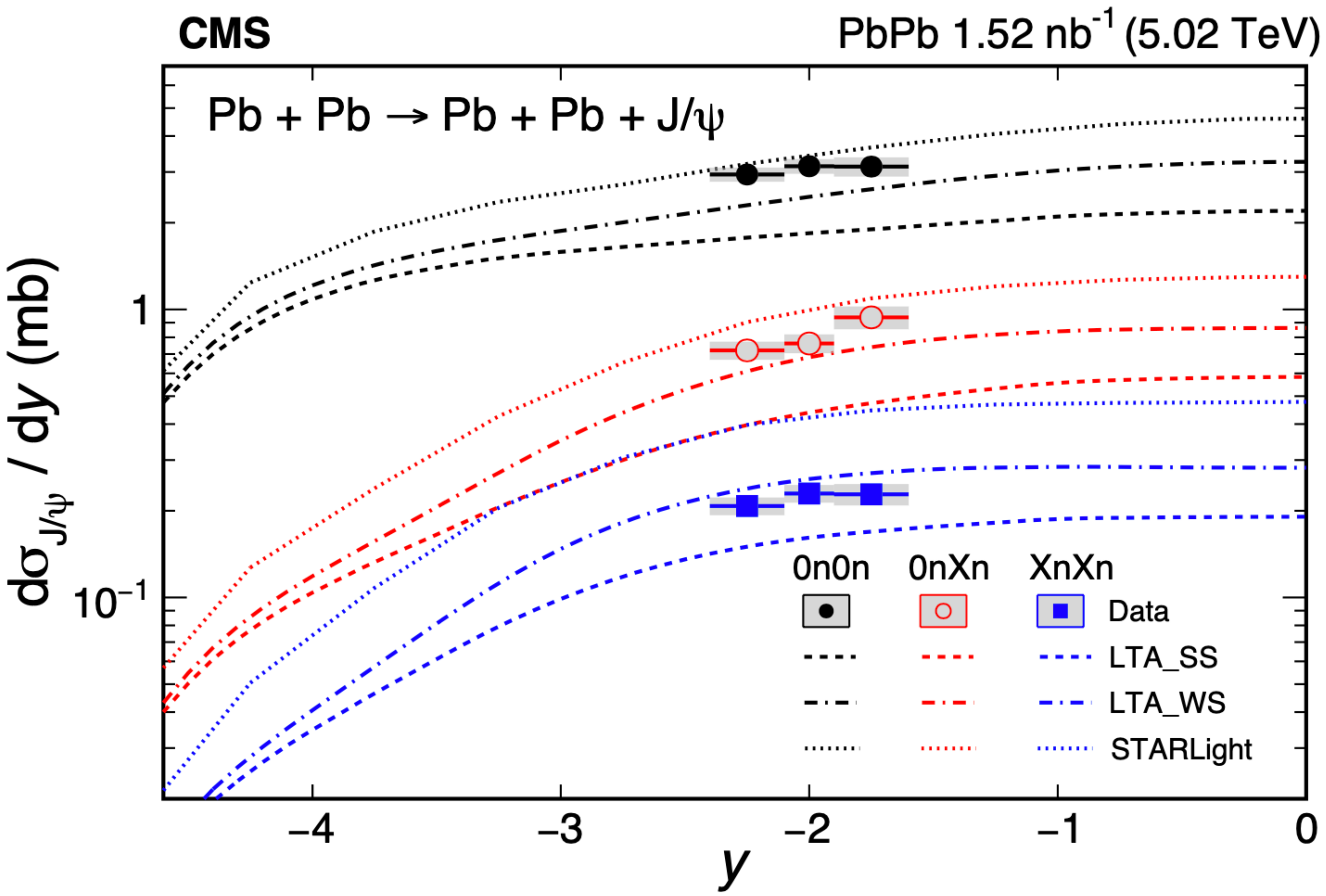


CMS, arXiv 2303.16984

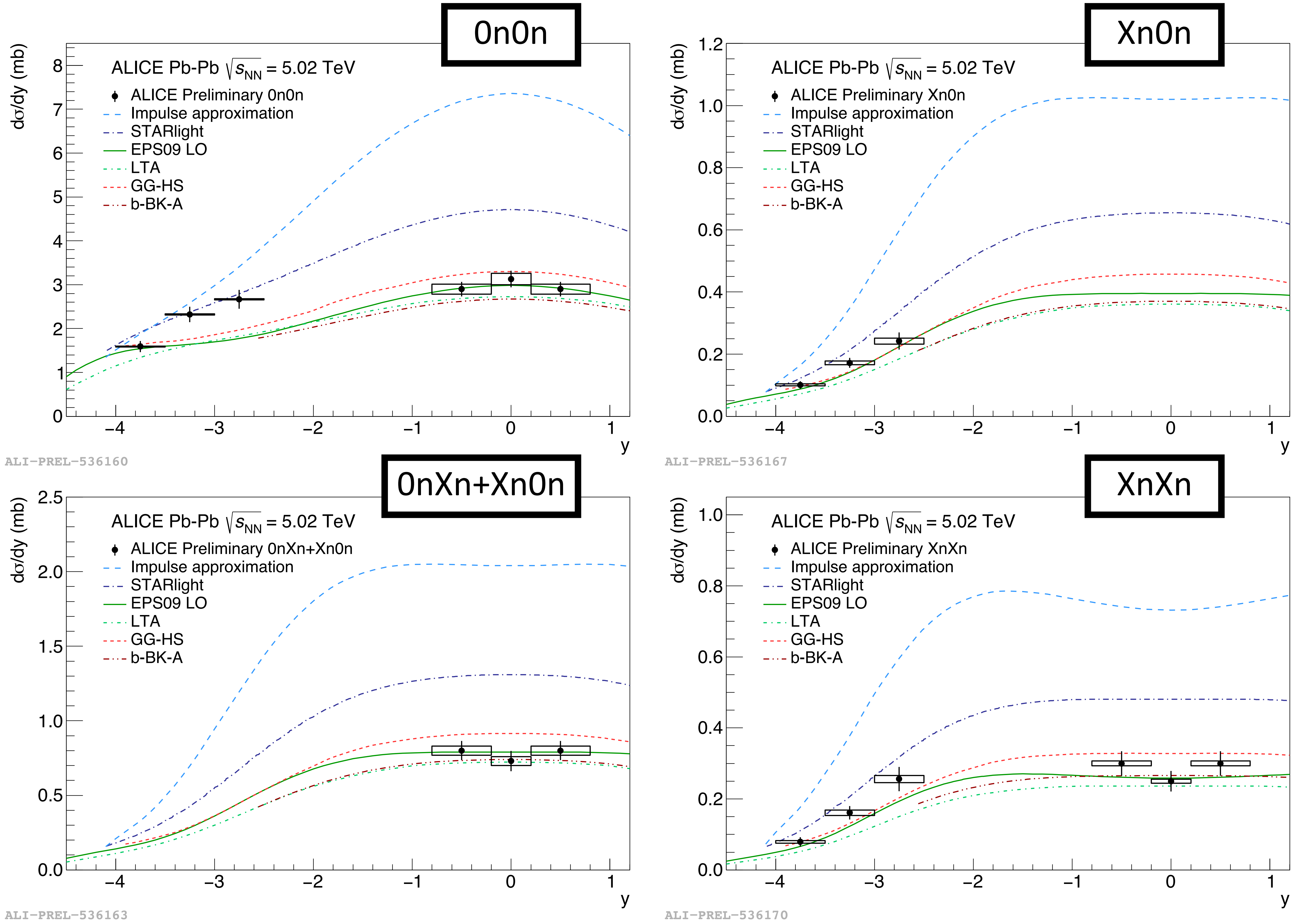
ALICE, CERN-EP-2023-100

Run 2: rapidity dependence of J/ψ coherent production in EMD classes

CMS



ALICE



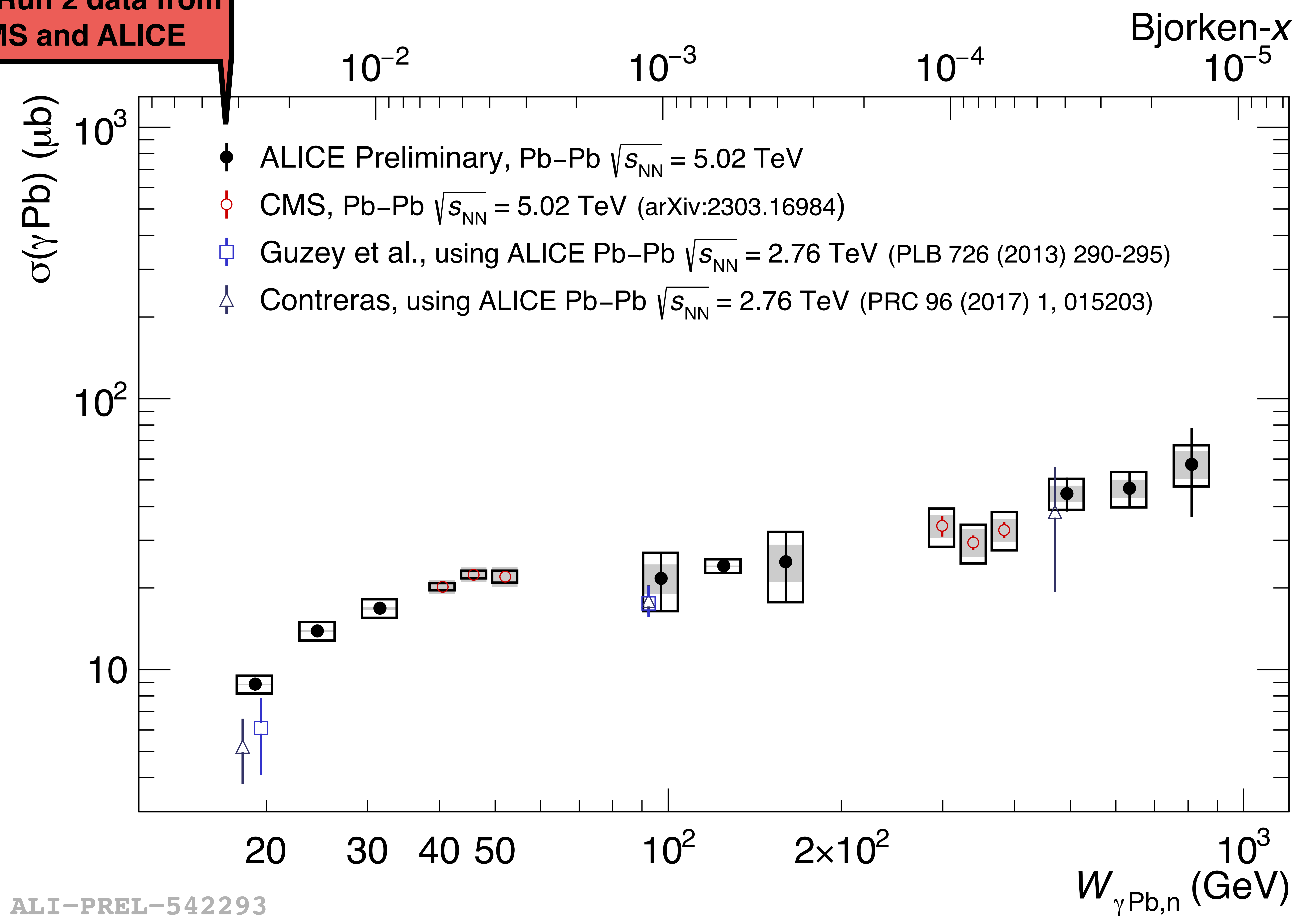
Several UPC measurements for each rapidity range → We can extract the photonuclear cross sections!

CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2

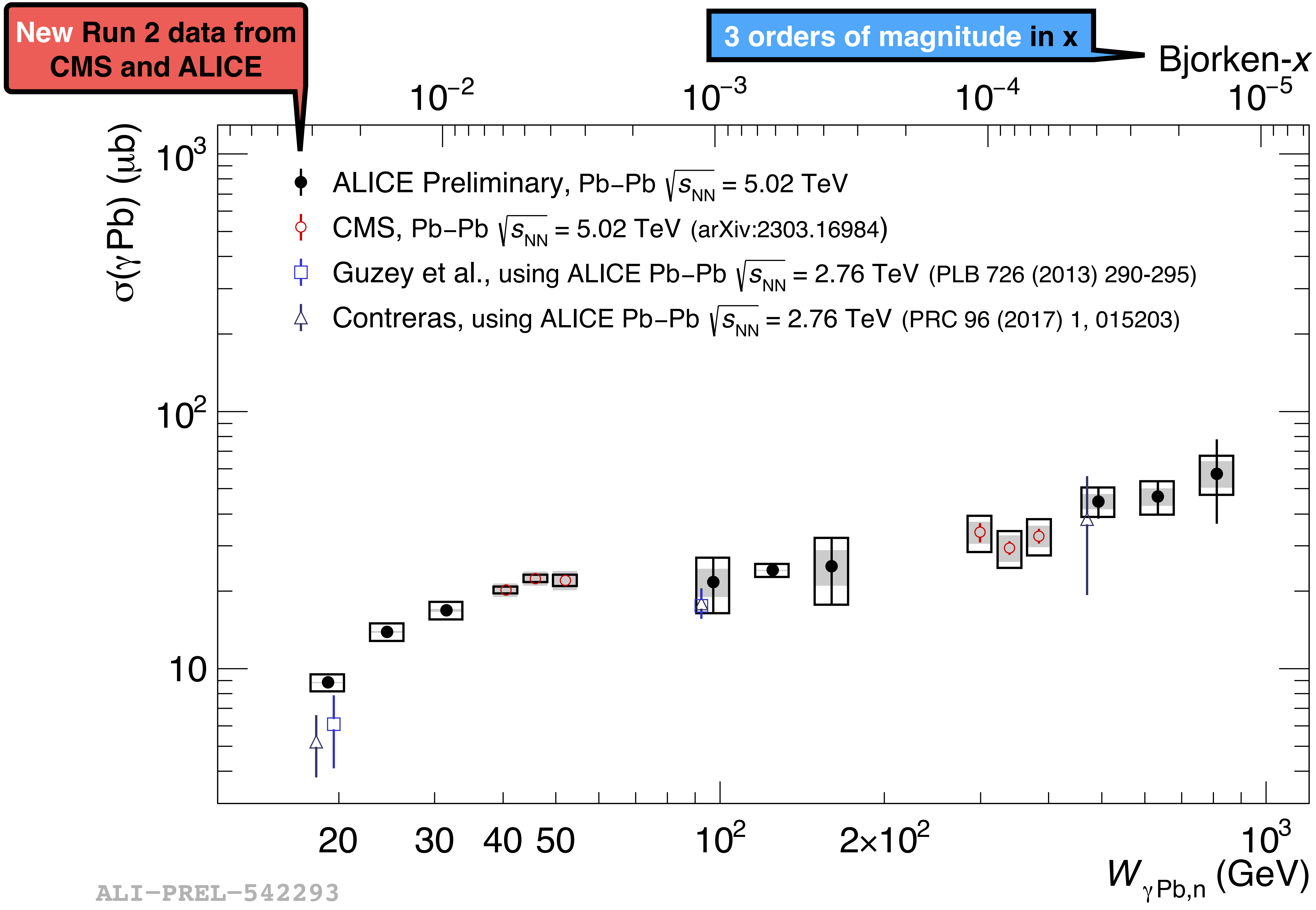
New Run 2 data from CMS and ALICE



CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2

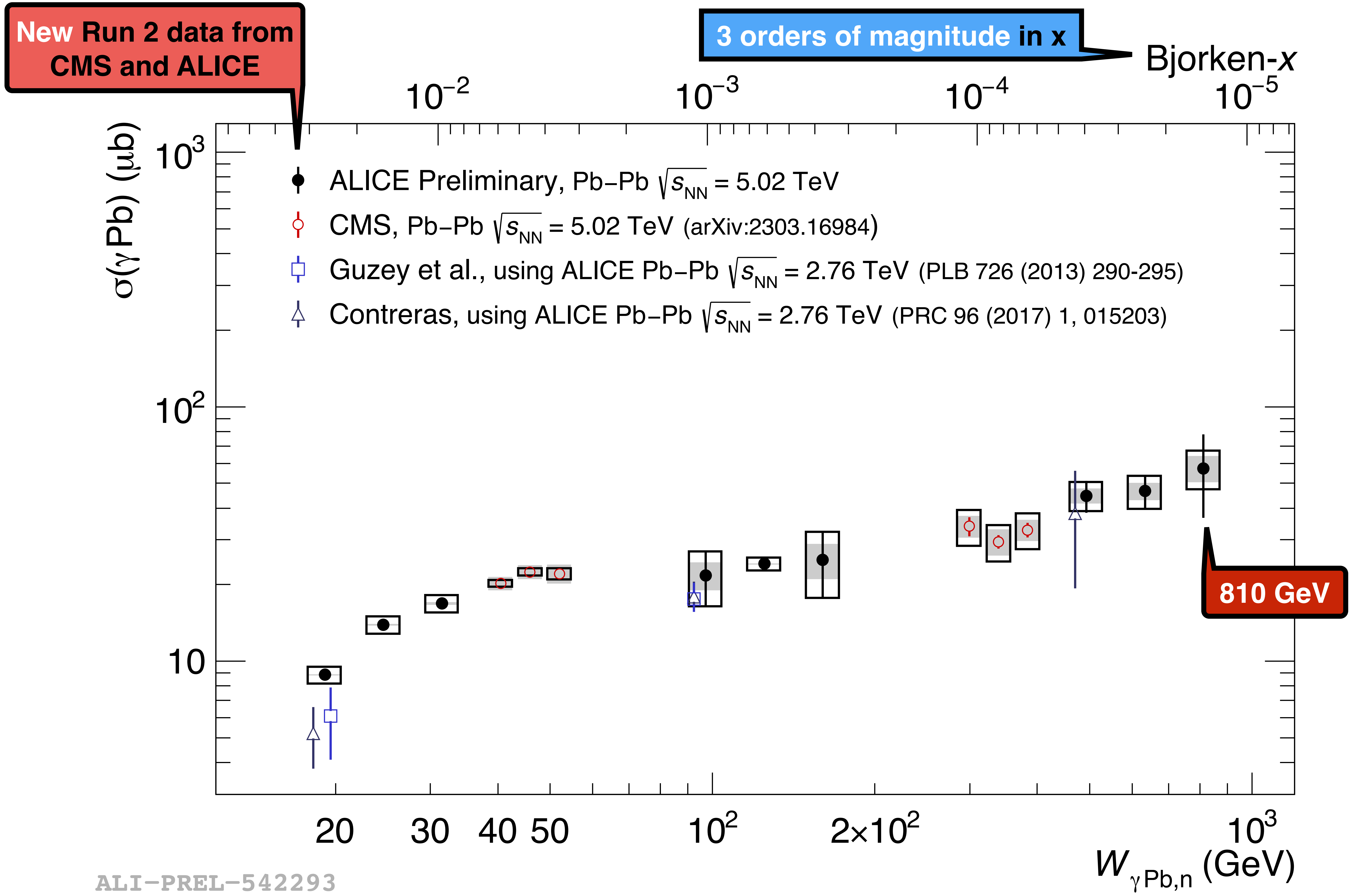


CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

Guillermo Contreras, CTU in Prague

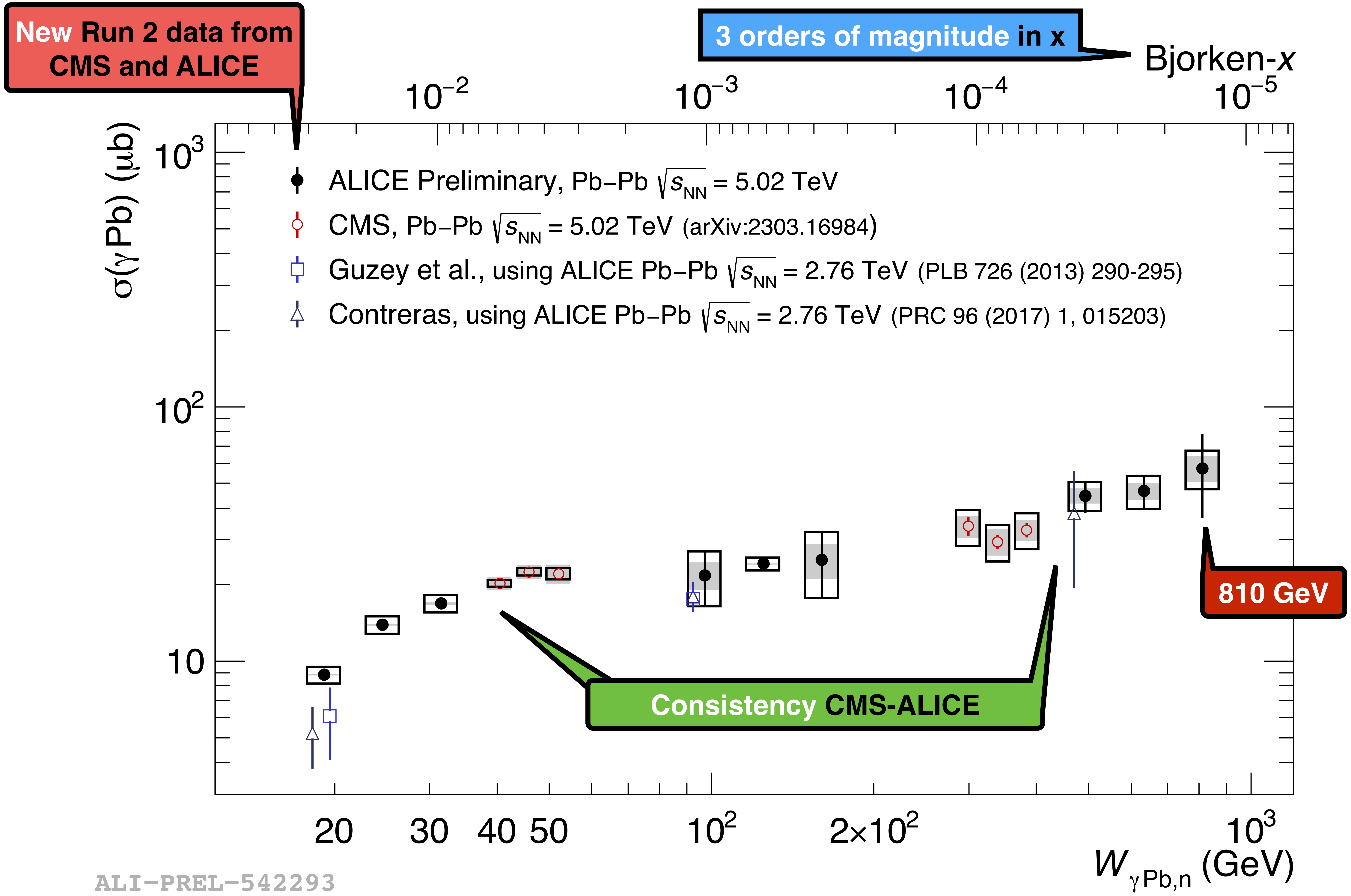
Energy/Bjorken-x dependence of coherent production from Run 2



CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

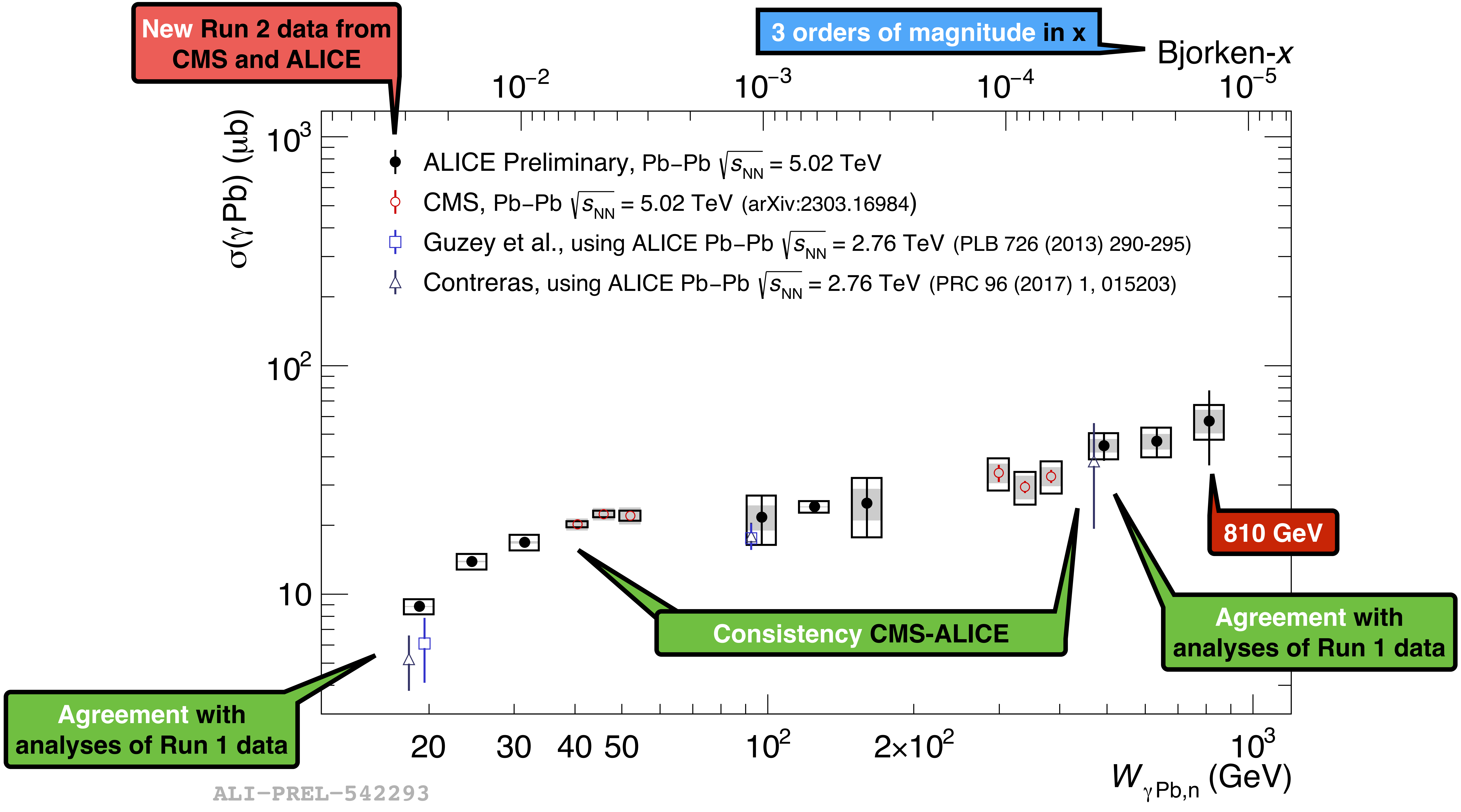
Energy/Bjorken-x dependence of coherent production from Run 2



CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

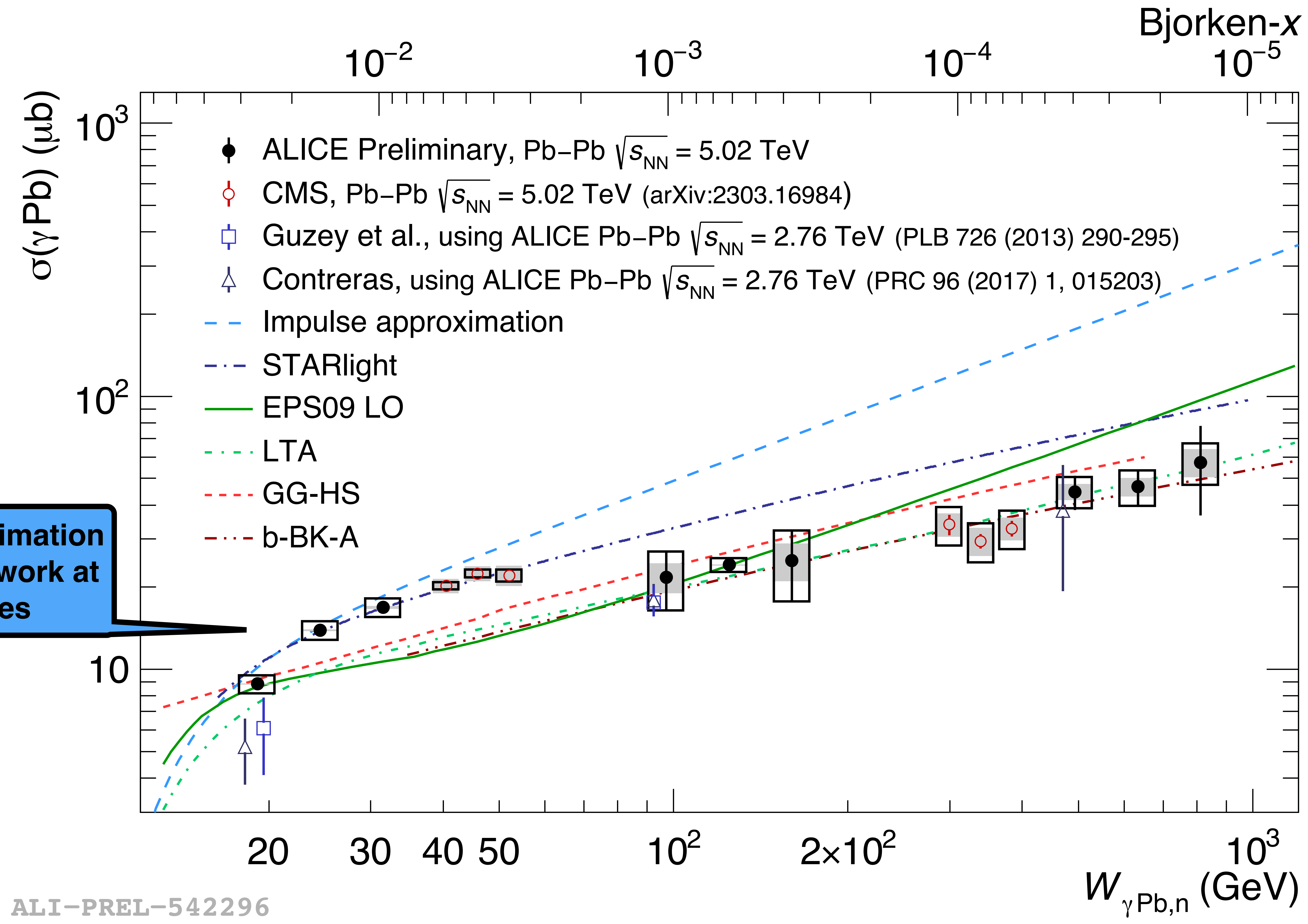
Energy/Bjorken-x dependence of coherent production from Run 2



CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2: Models



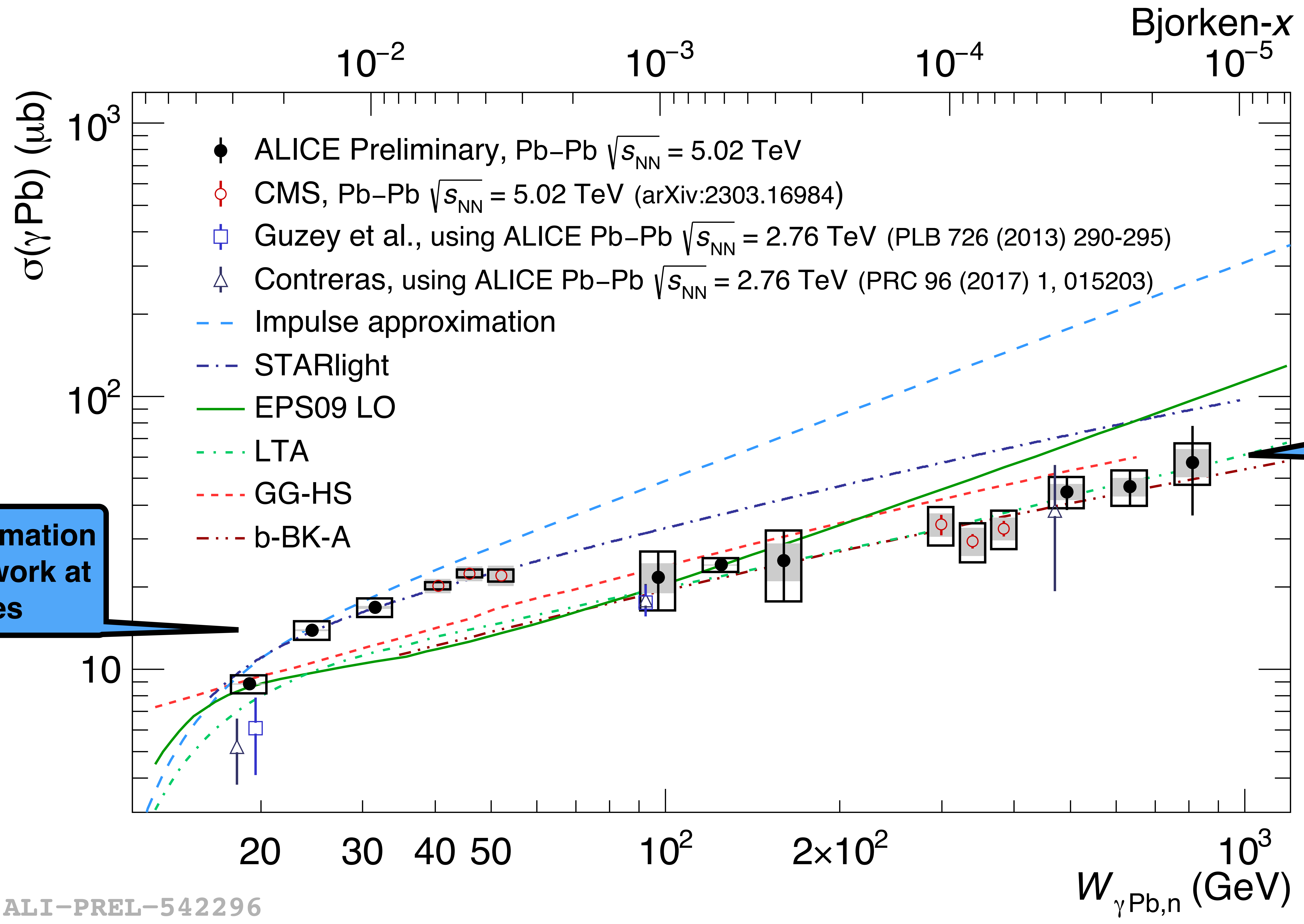
Impulse approximation and STARlight work at low energies

CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

Guillermo Contreras, CTU in Prague

Energy/Bjorken-x dependence of coherent production from Run 2: Models



Impulse approximation and STARlight work at low energies

LTA and colour dipole based models (b-BK-A, GG-HS) work at high energies

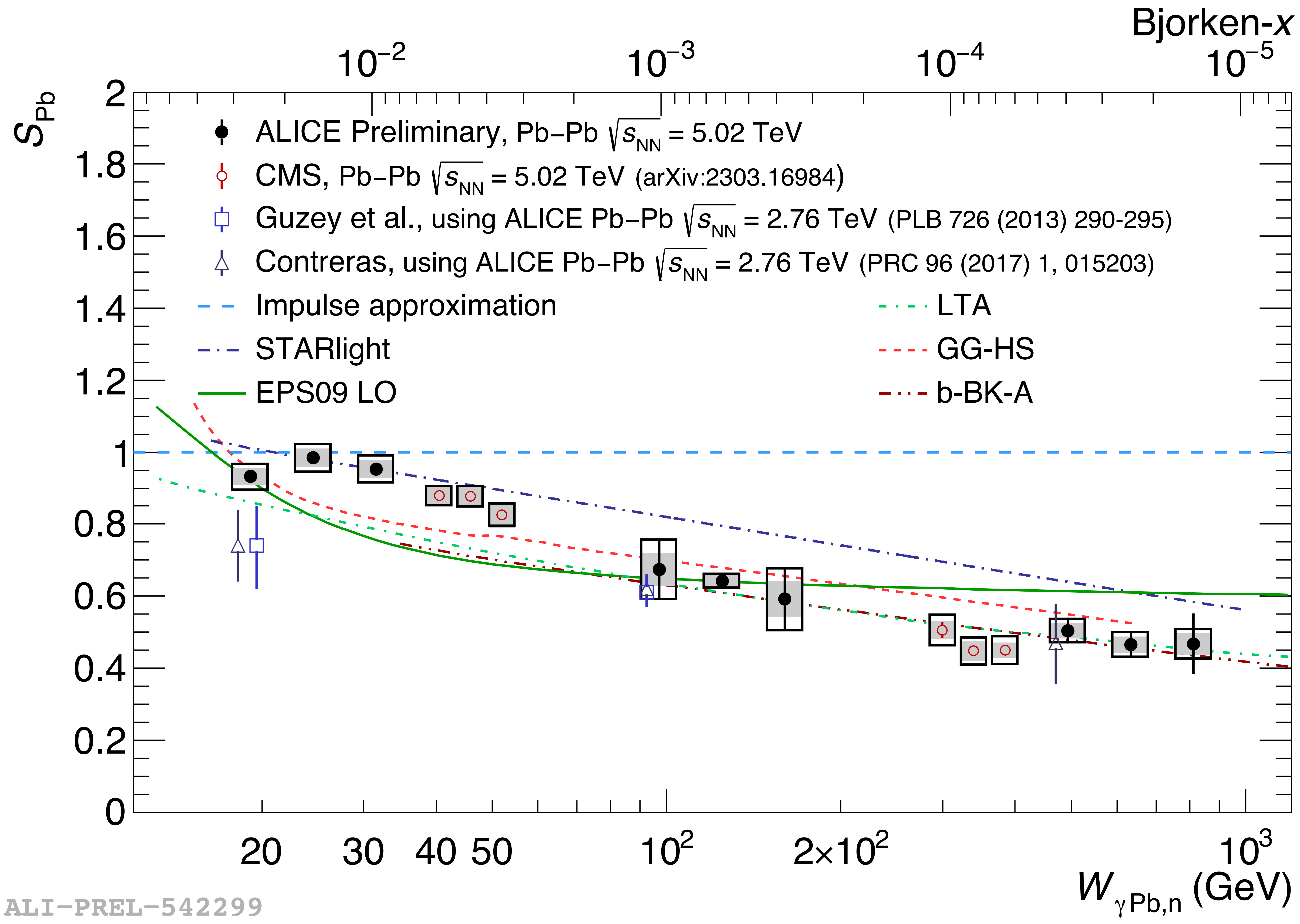
CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2: Shadowing

Nuclear suppression factor (shadowing)

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}_{\gamma Pb}}}$$



CMS, arXiv 2303.16984

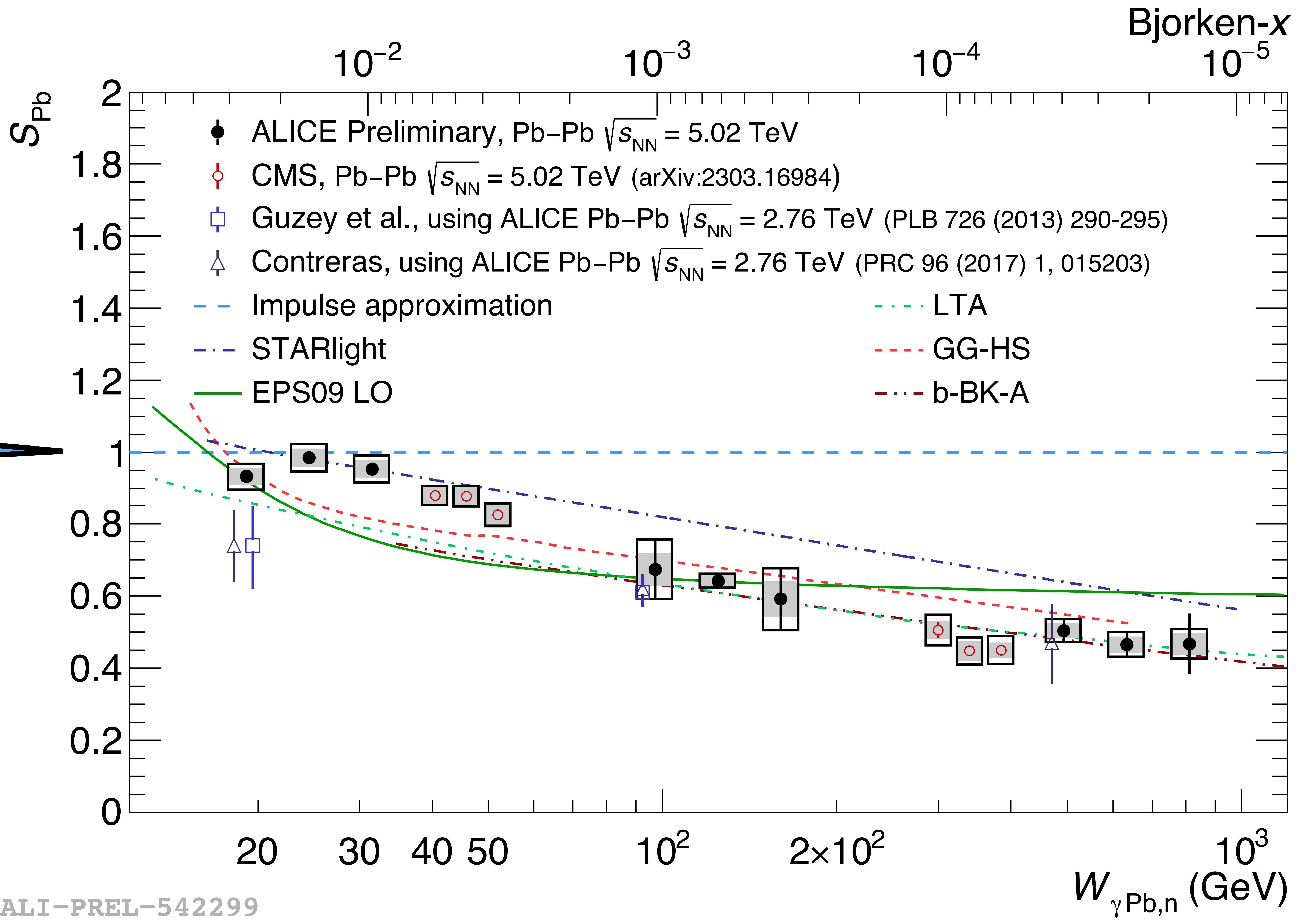
ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2: Shadowing

Nuclear suppression factor (shadowing)

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}_{\gamma Pb}}}$$

No suppression at low energies?



CMS, arXiv 2303.16984

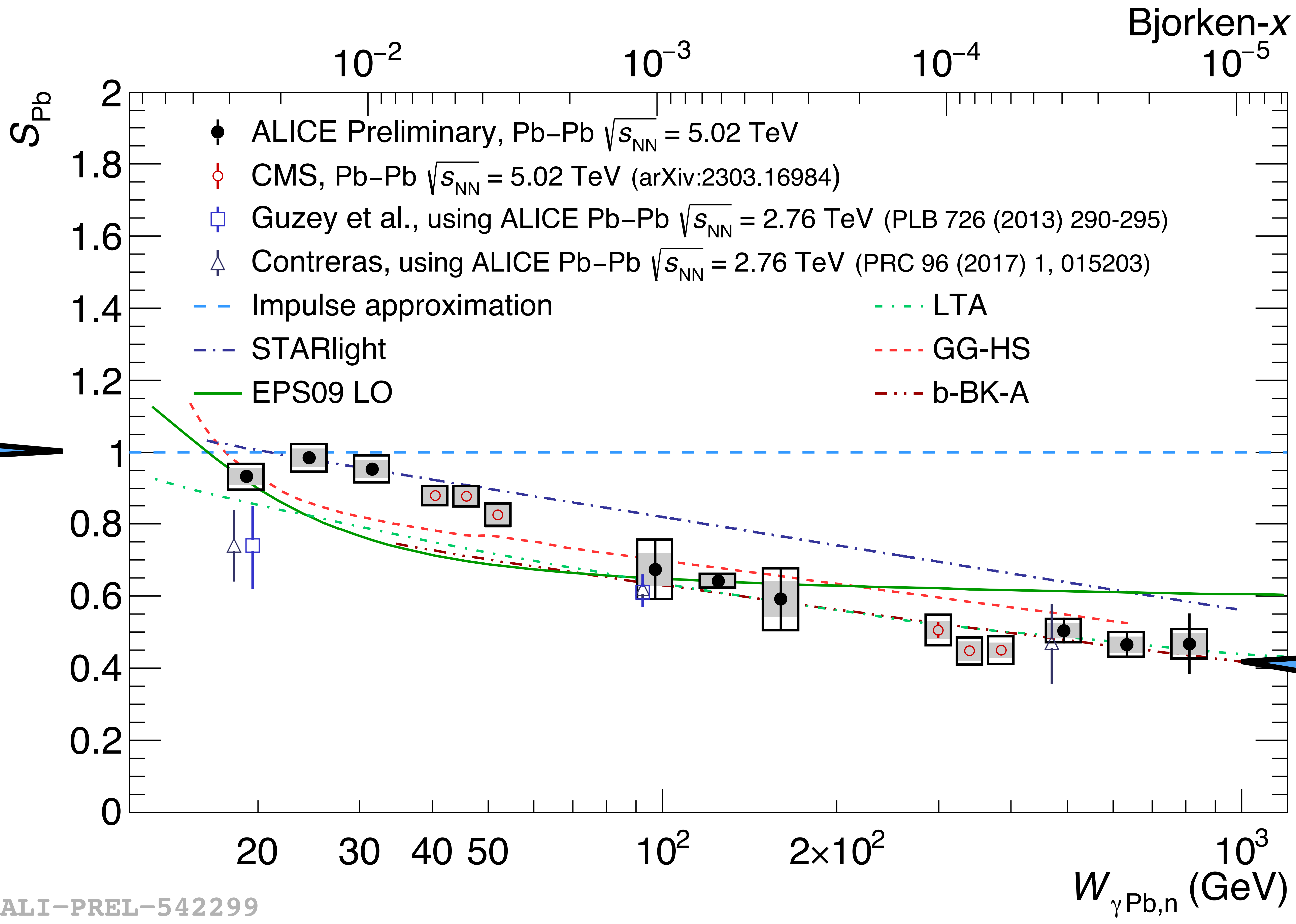
ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2: Shadowing

Nuclear suppression factor (shadowing)

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}_{\gamma Pb}}}$$

No suppression at low energies?



Flattening of suppression at high energies?

CMS, arXiv 2303.16984

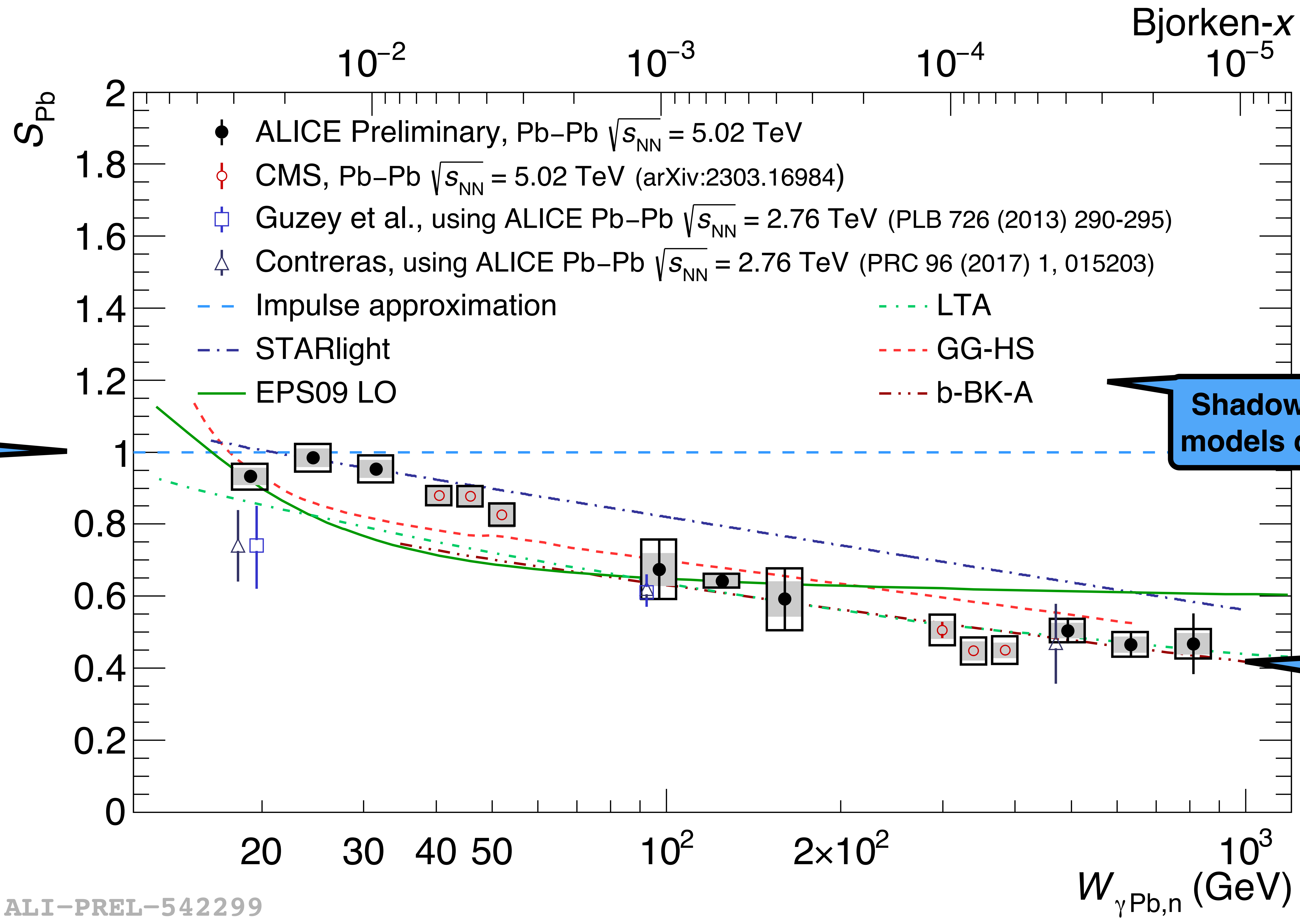
ALICE, CERN-EP-2023-100

Energy/Bjorken-x dependence of coherent production from Run 2: Shadowing

Nuclear suppression factor (shadowing)

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}_{\gamma Pb}}}$$

No suppression at low energies?



Shadowing and saturation based models describe data equally well.

Flattening of suppression at high energies?

CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

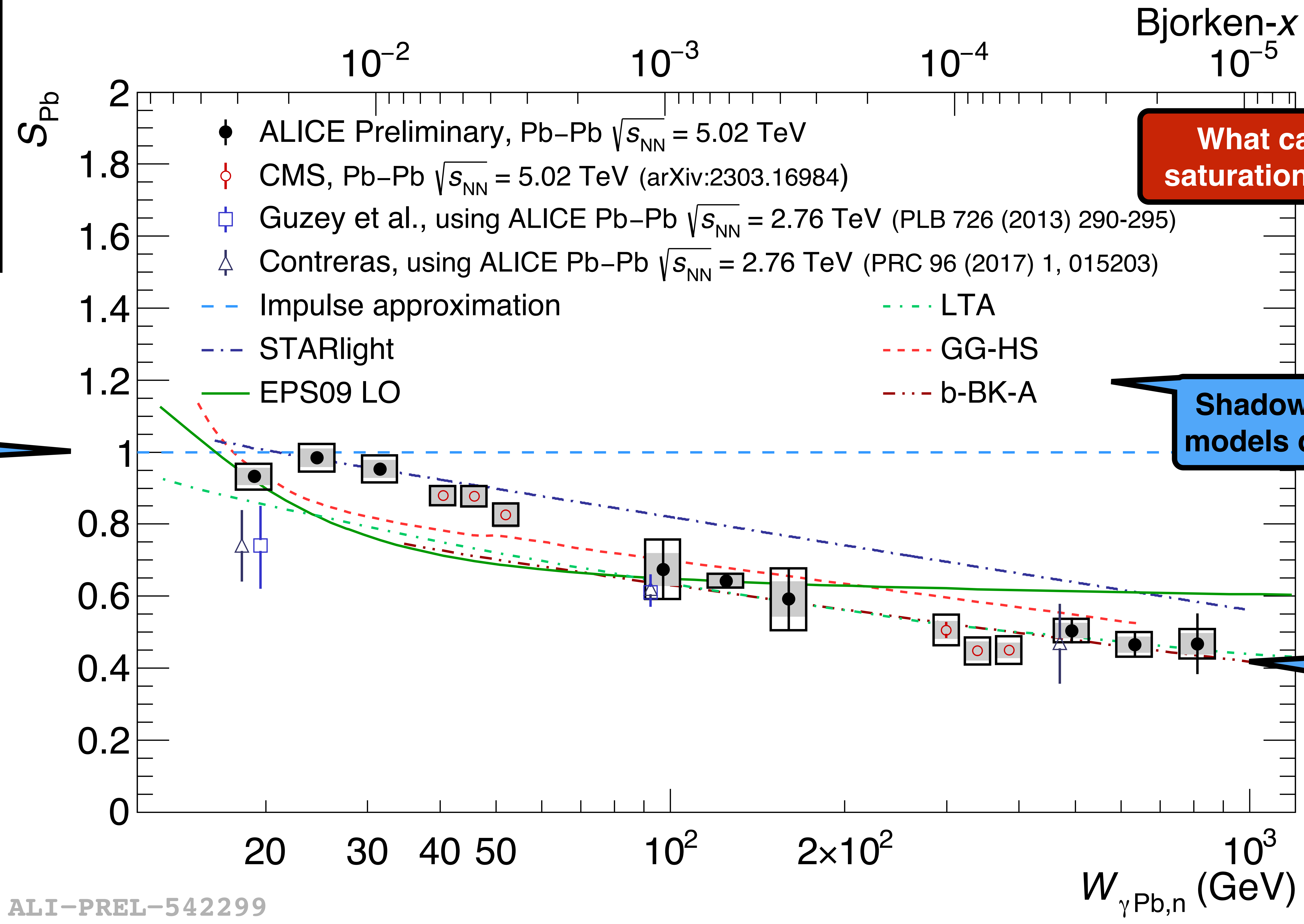
Guillermo Contreras, CTU in Prague

Energy/Bjorken-x dependence of coherent production from Run 2: Shadowing

Nuclear suppression factor (shadowing)

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}_{\gamma Pb}}}$$

No suppression at low energies?



What can we do to disentangle saturation and shadowing models?

Shadowing and saturation based models describe data equally well.

Flattening of suppression at high energies?

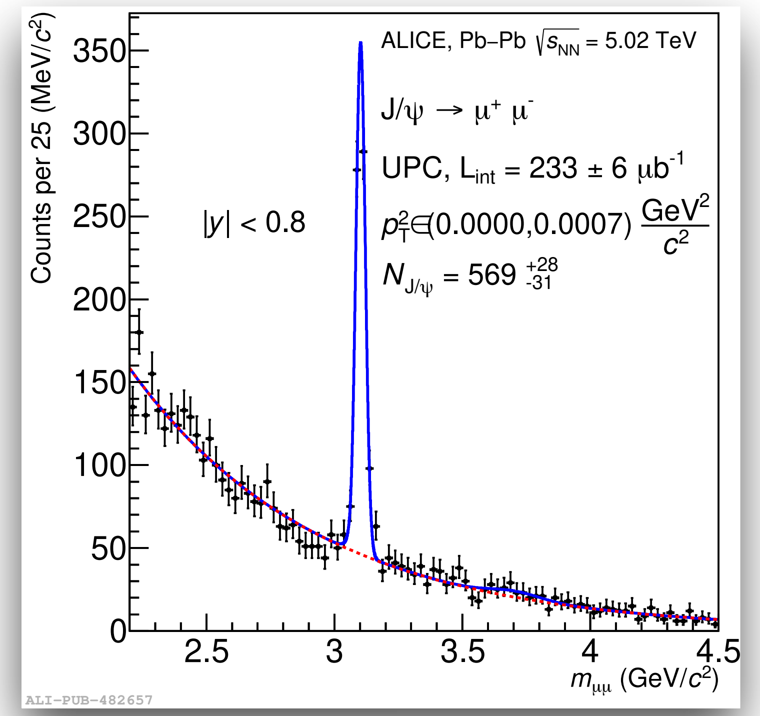
CMS, arXiv 2303.16984

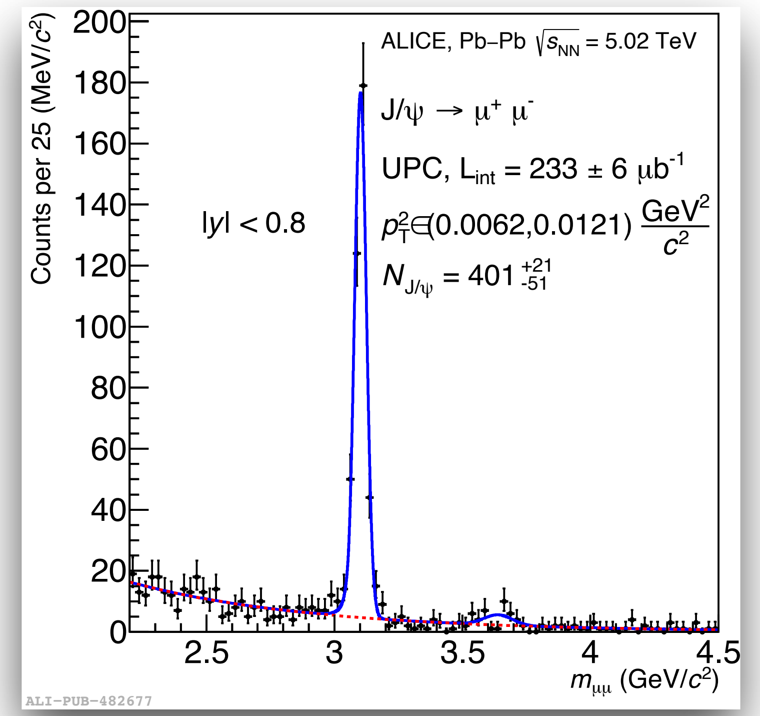
ALICE, CERN-EP-2023-100

J/ψ photonuclear production in Pb-Pb UPC
Mandelstam-*t* dependence

γPb collisions: Mandelstam-t dependence of coherent production

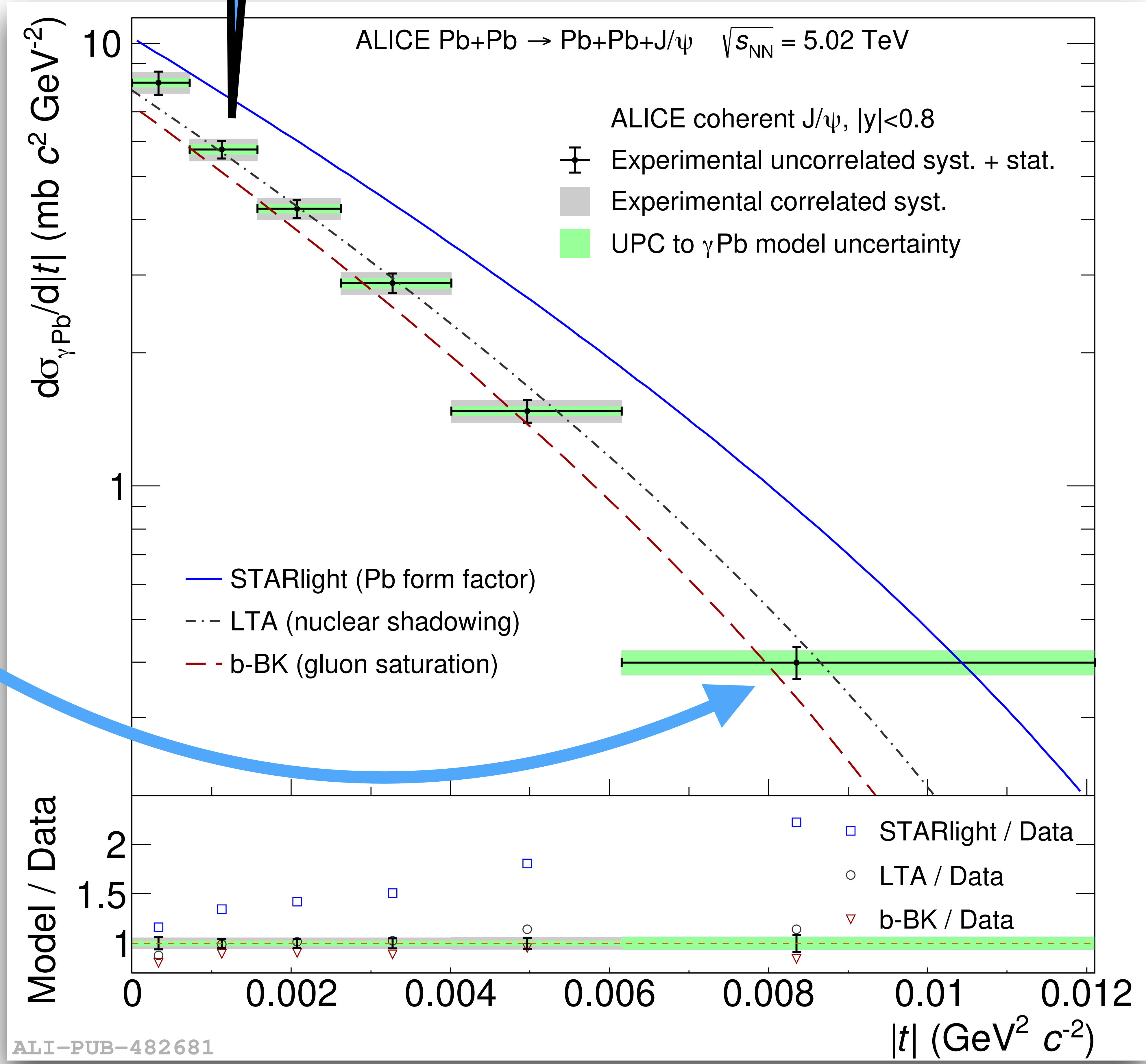
ALICE, PLB 817(2021) 136280





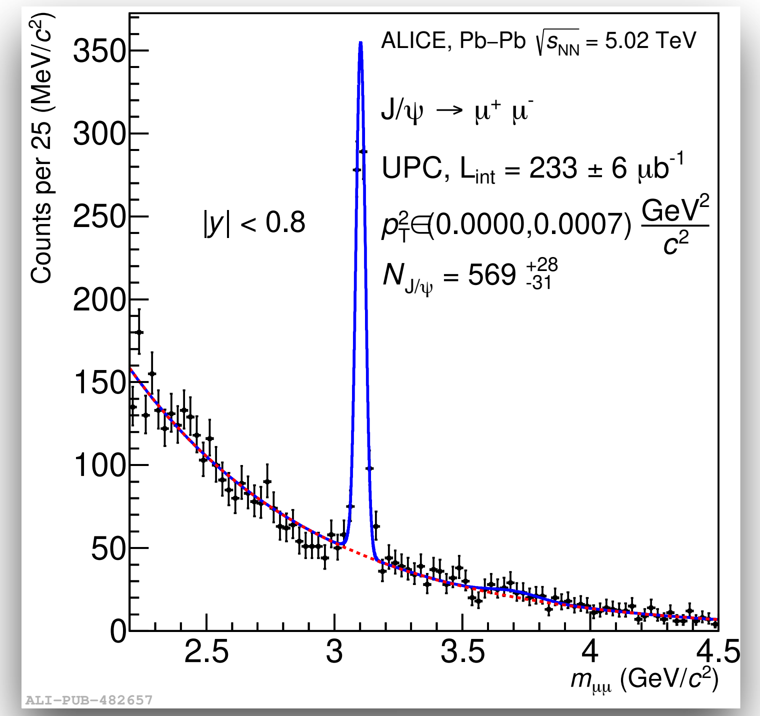
Very clear signals

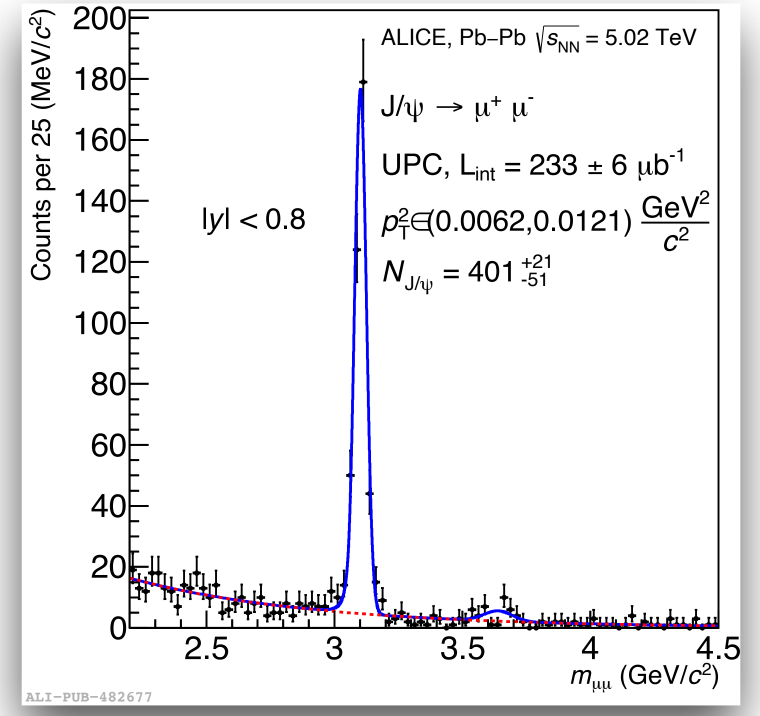
HERA-like precision!



γPb collisions: Mandelstam-t dependence of coherent production

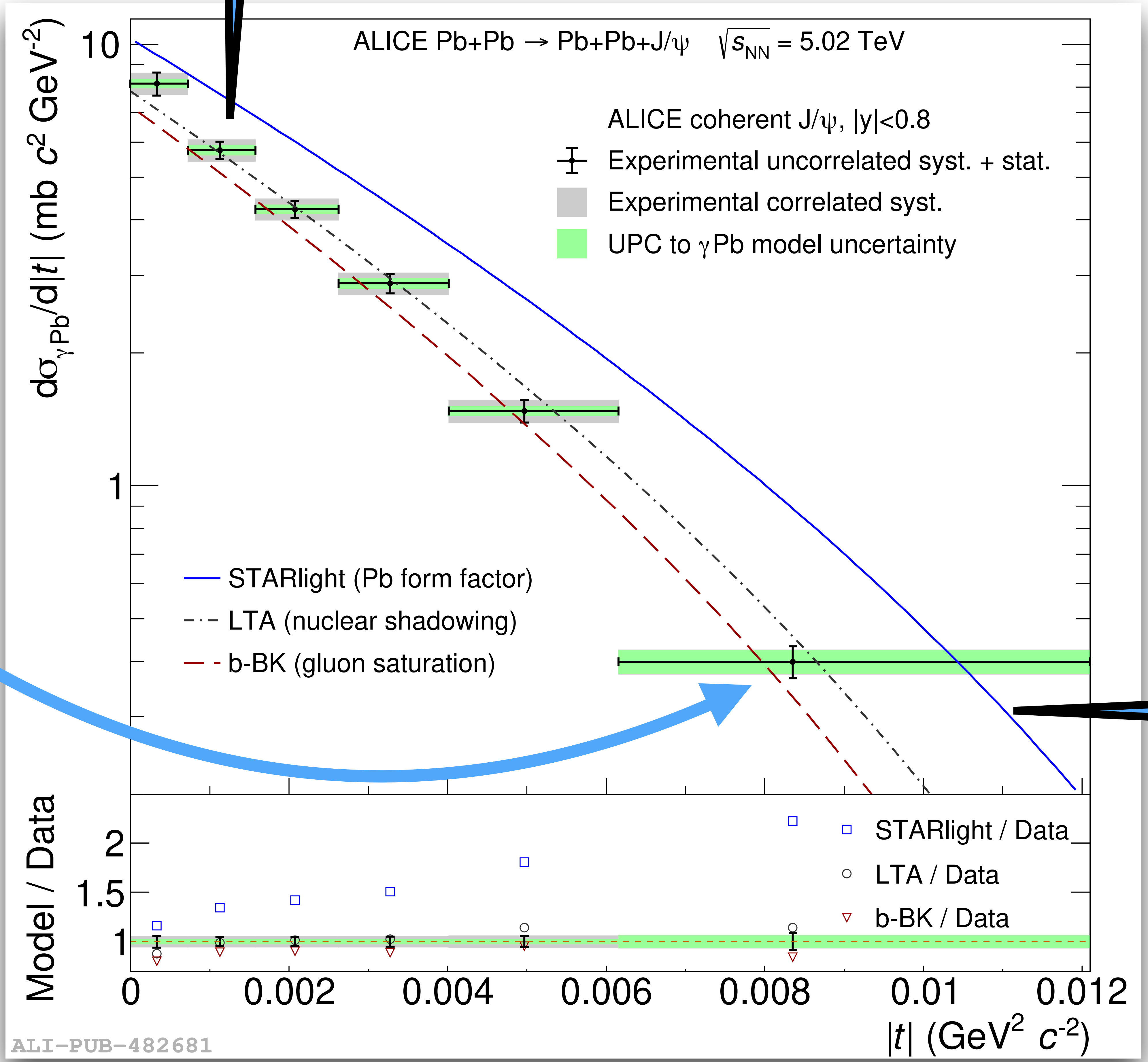
ALICE, PLB 817(2021) 136280





Very clear signals

HERA-like precision!

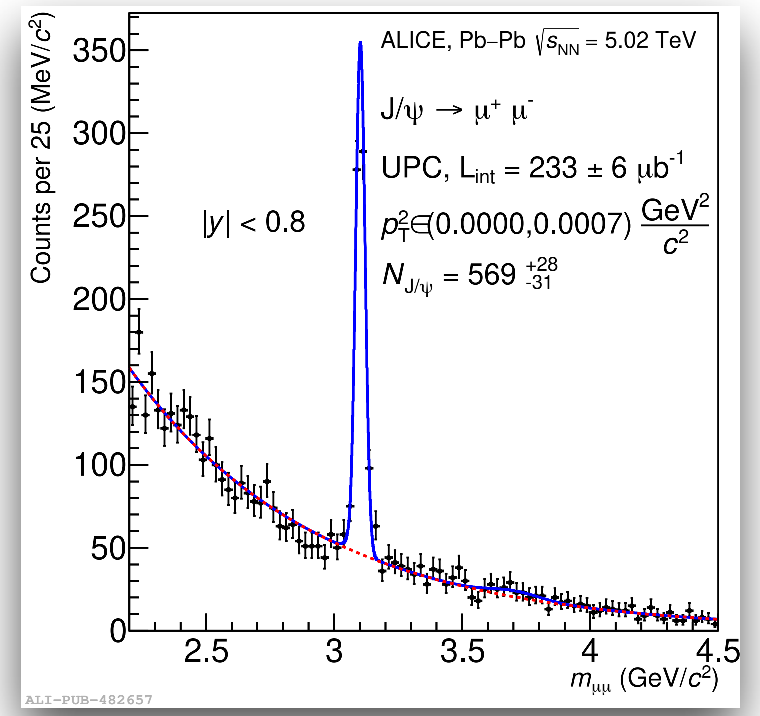


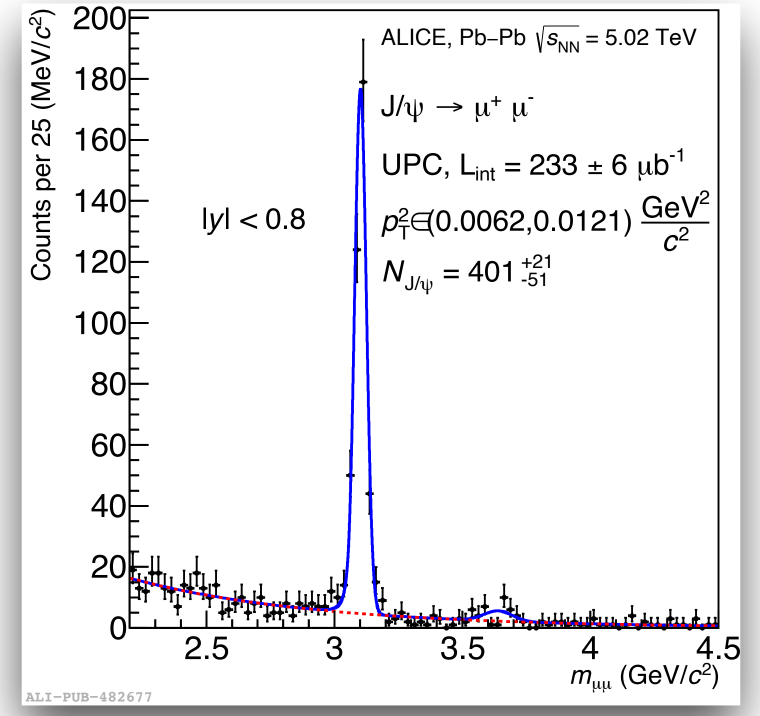
A model based on the form factor does not describe data

Guillermo Contreras, CTU in Prague

γPb collisions: Mandelstam-t dependence of coherent production

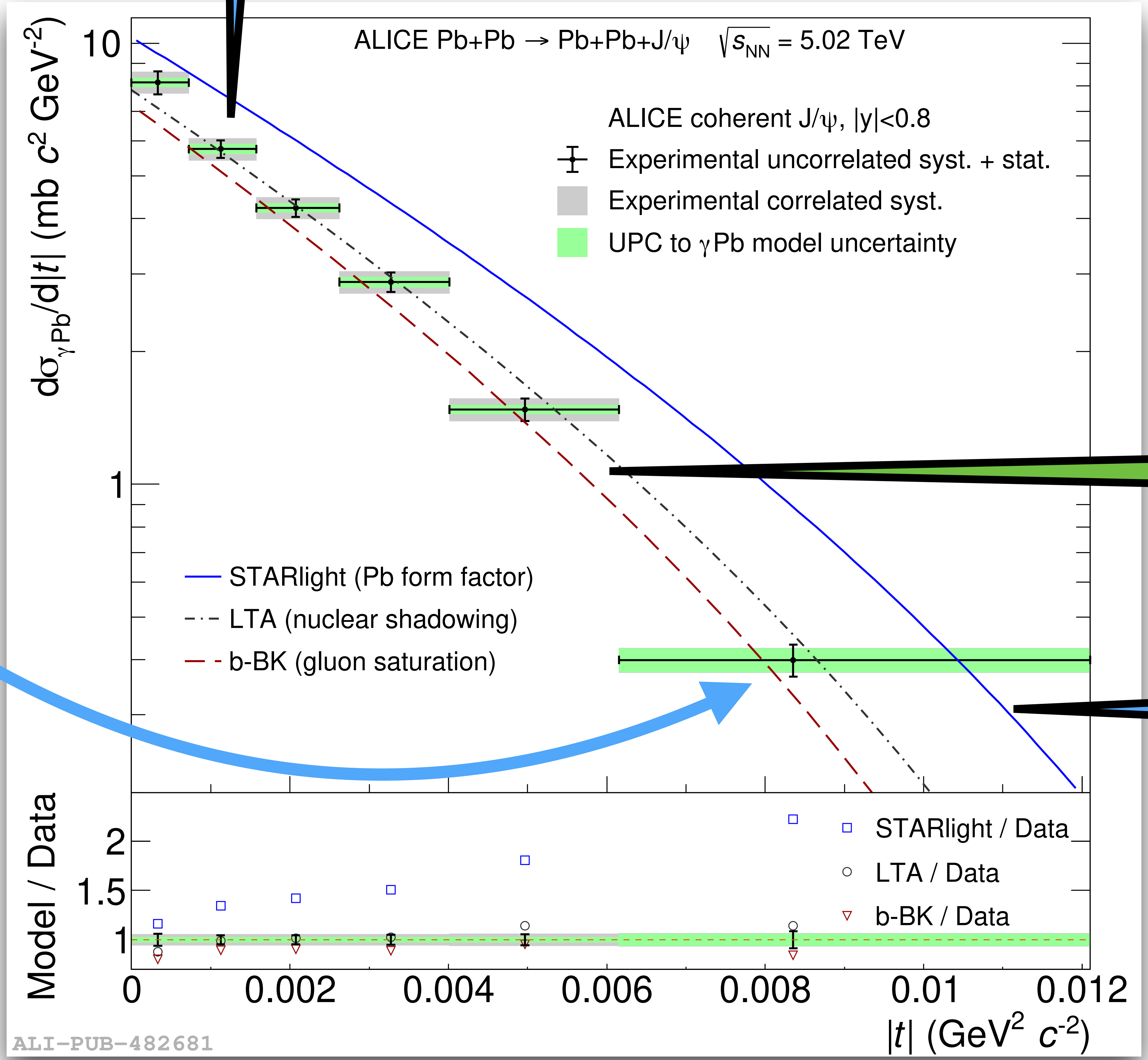
ALICE, PLB 817(2021) 136280





Very clear signals

HERA-like precision!

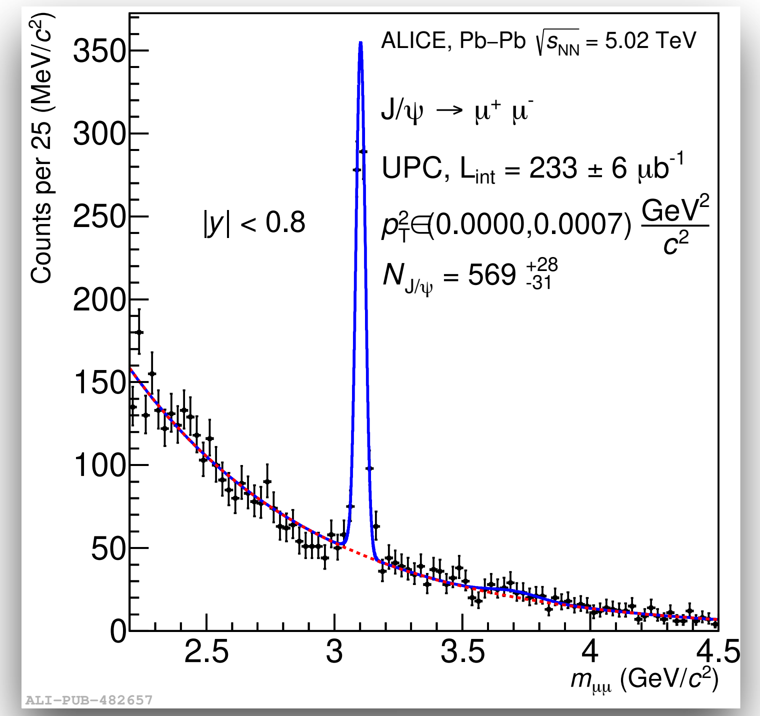


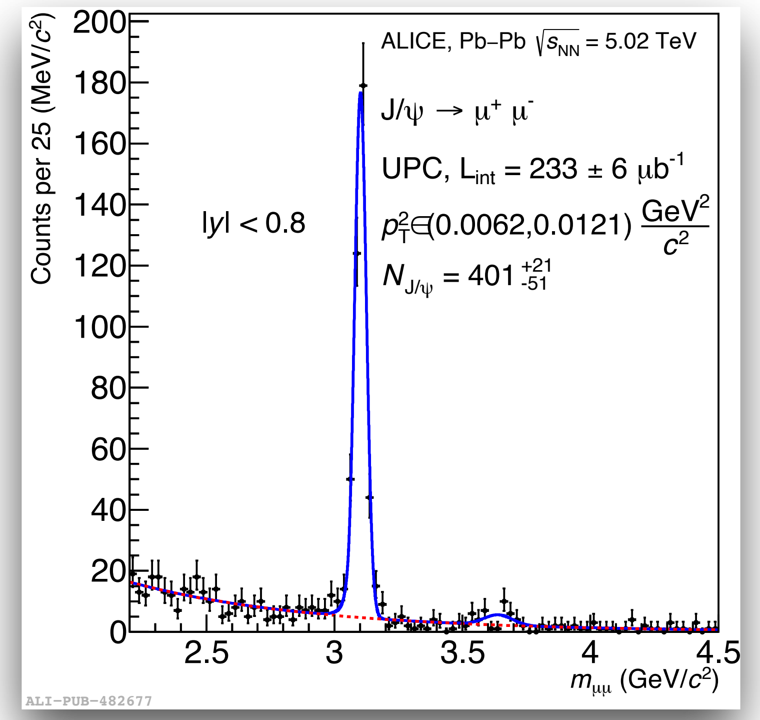
A shadowing based, and a BK computation with impact-parameter dependence, close to data

A model based on the form factor does not describe data

γPb collisions: Mandelstam-t dependence of coherent production

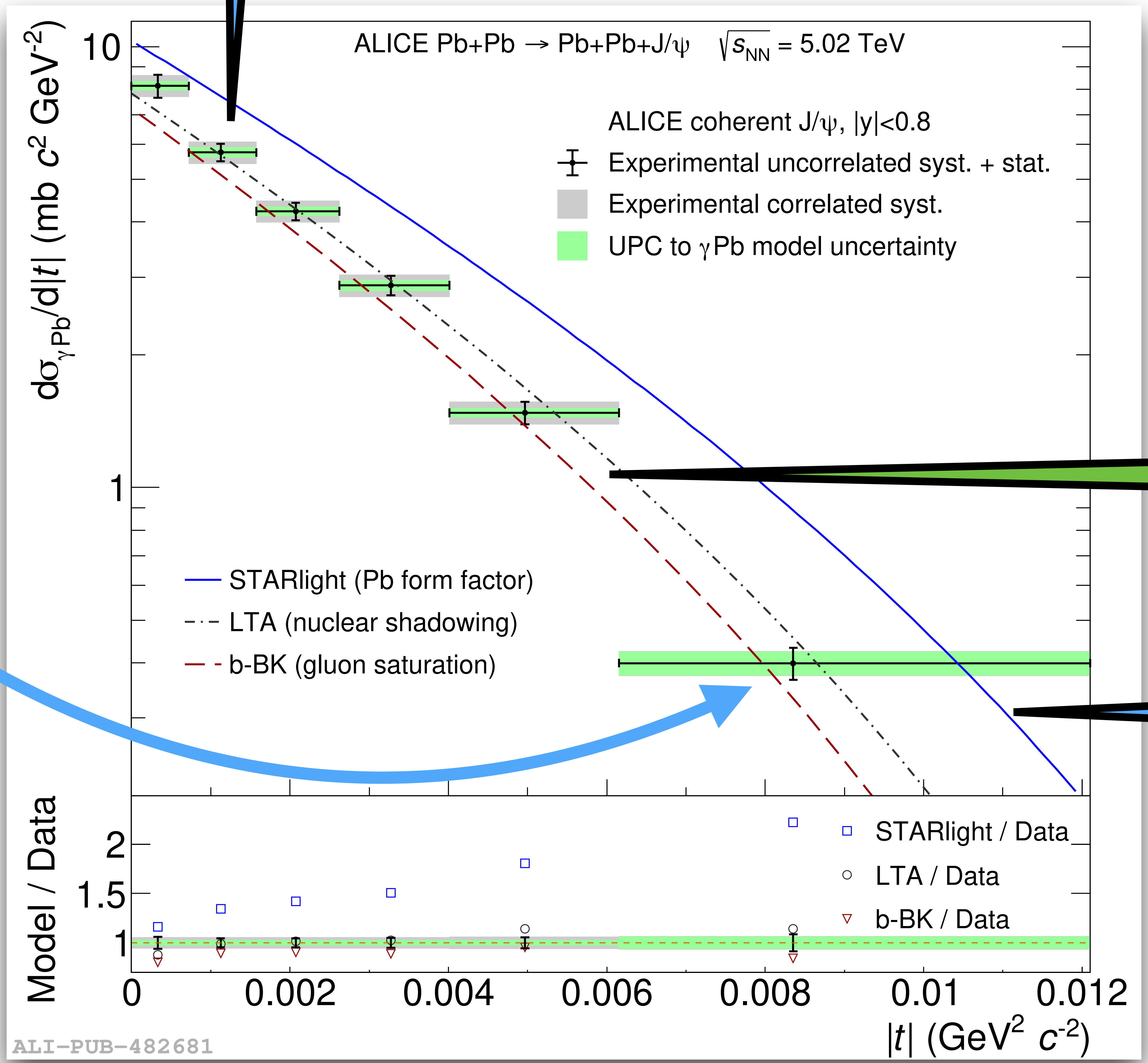
ALICE, PLB 817(2021) 136280





Very clear signals

HERA-like precision!



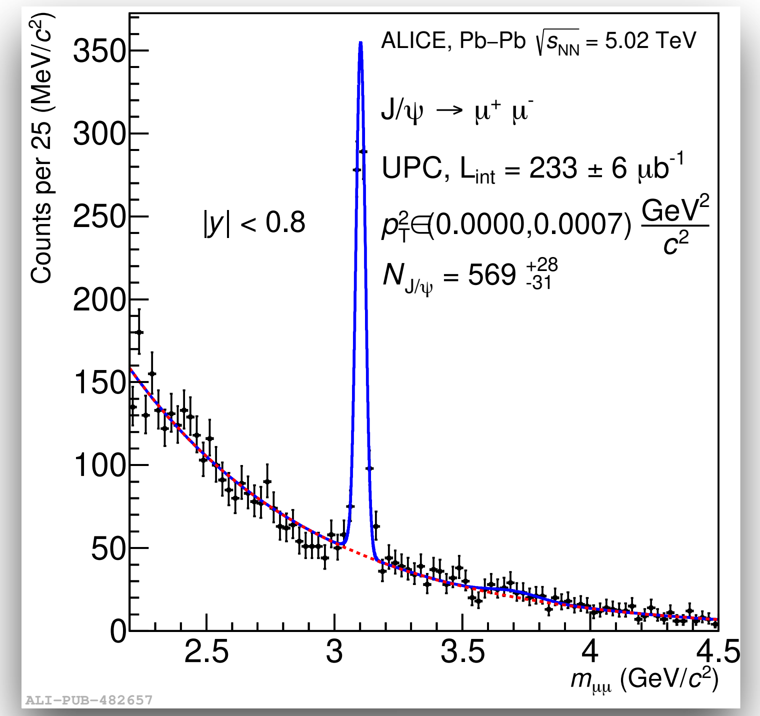
A shadowing based, and a BK computation with impact-parameter dependence, close to data

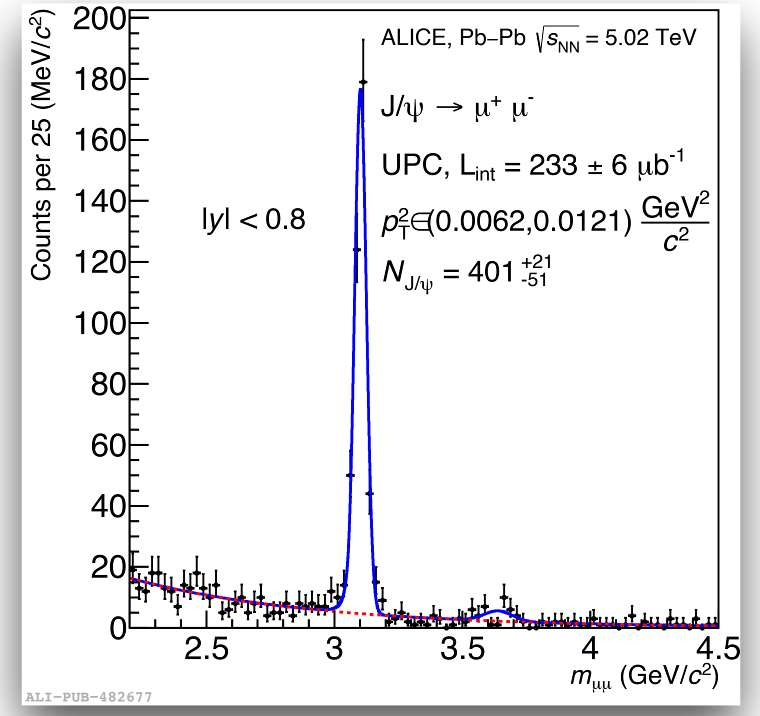
A model based on the form factor does not describe data

|t| related to the transverse size of the target (b and p_T are Fourier conjugates)

γPb collisions: Mandelstam-t dependence of coherent production

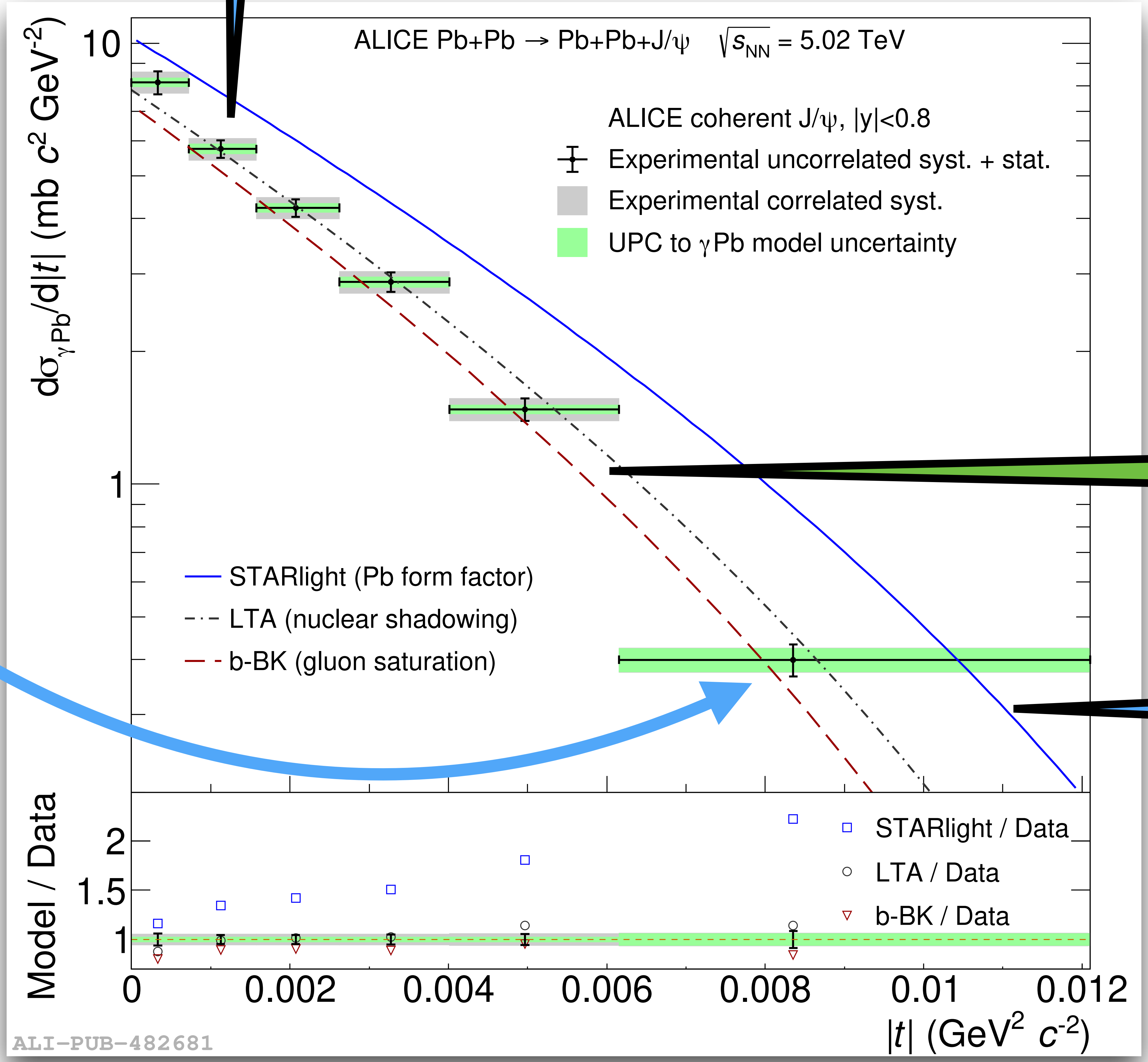
ALICE, PLB 817(2021) 136280





Very clear signals

HERA-like precision!



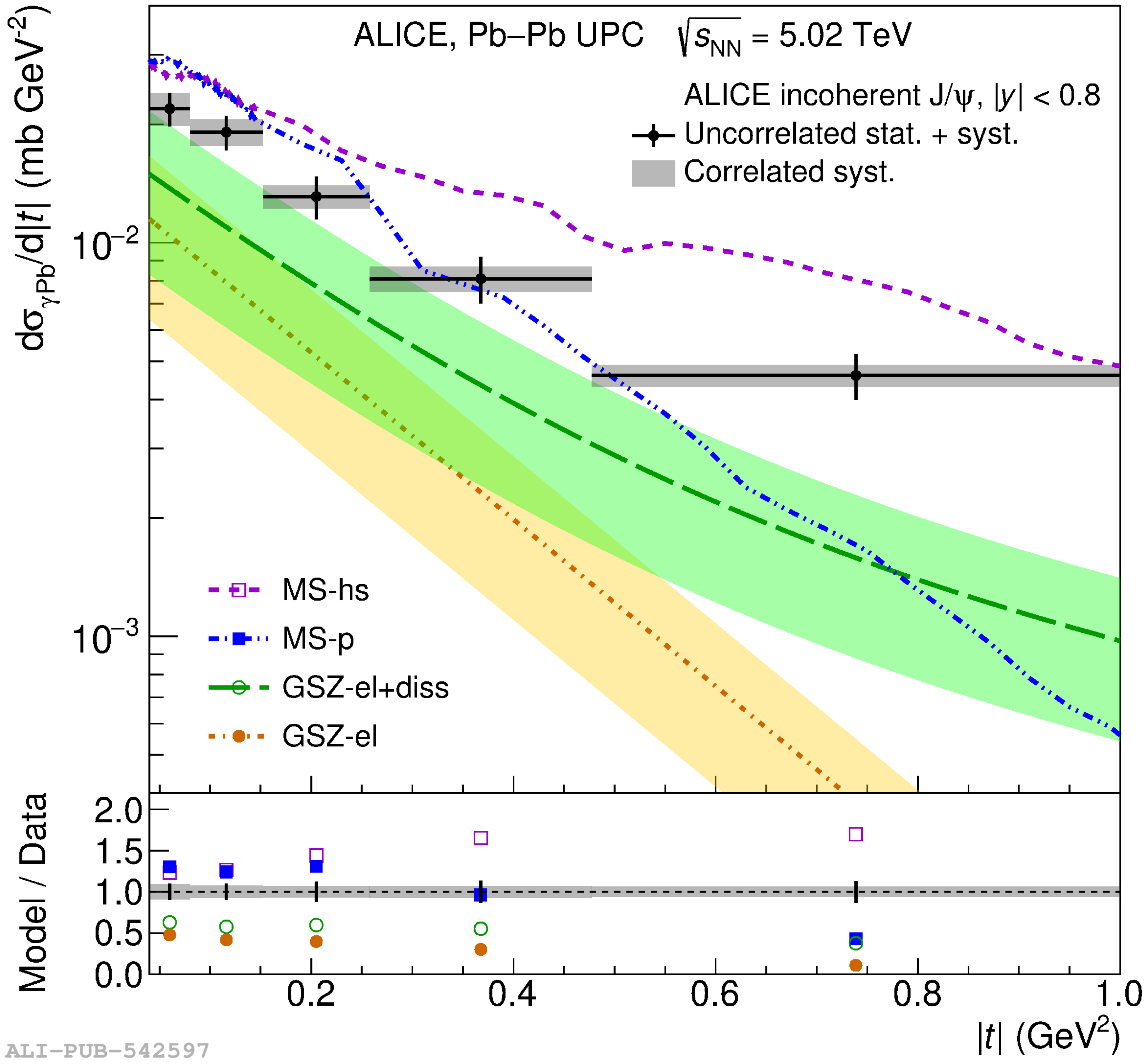
A shadowing based, and a BK computation with impact-parameter dependence, close to data

A model based on the form factor does not describe data

|t| related to the transverse size of the target (b and p_T are Fourier conjugates)

Dynamic QCD effects seem to make the t-distribution steeper ... do nuclei grow with energy?

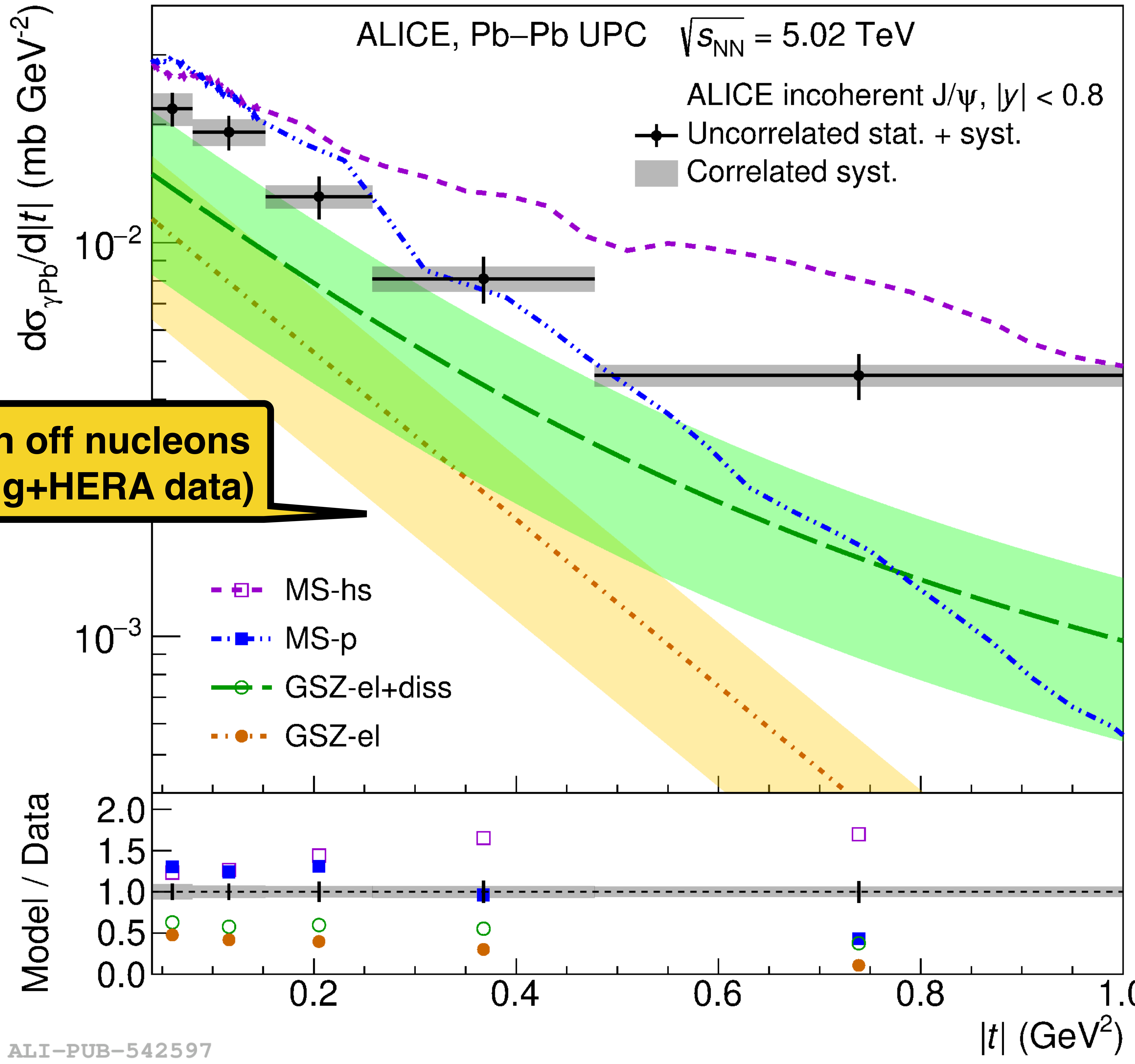
γPb collisions: Mandelstam-t dependence of incoherent production



|t| related to the size of the target: effect of smaller structures appears at lager |t|

ALICE, arXiv 2305.06169

γPb collisions: Mandelstam-t dependence of incoherent production



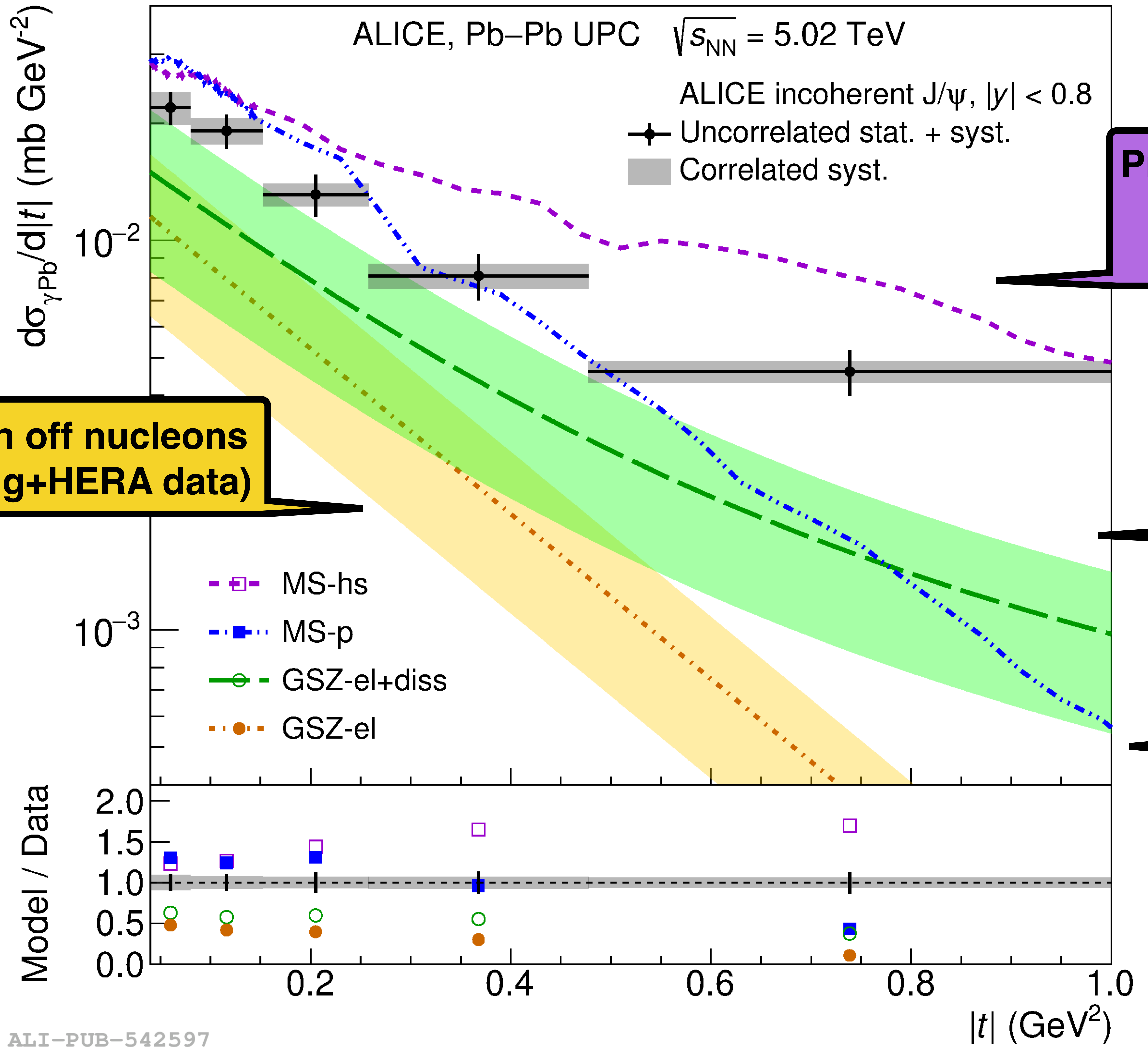
Production off nucleons (Shadowing+HERA data)

Production off nucleons (CGC approach)

|t| related to the size of the target: effect of smaller structures appears at lager |t|

ALICE, arXiv 2305.06169

γPb collisions: Mandelstam-t dependence of incoherent production



Production off nucleons including hot spots (CGC approach)

Production off nucleons (Shadowing+HERA data)

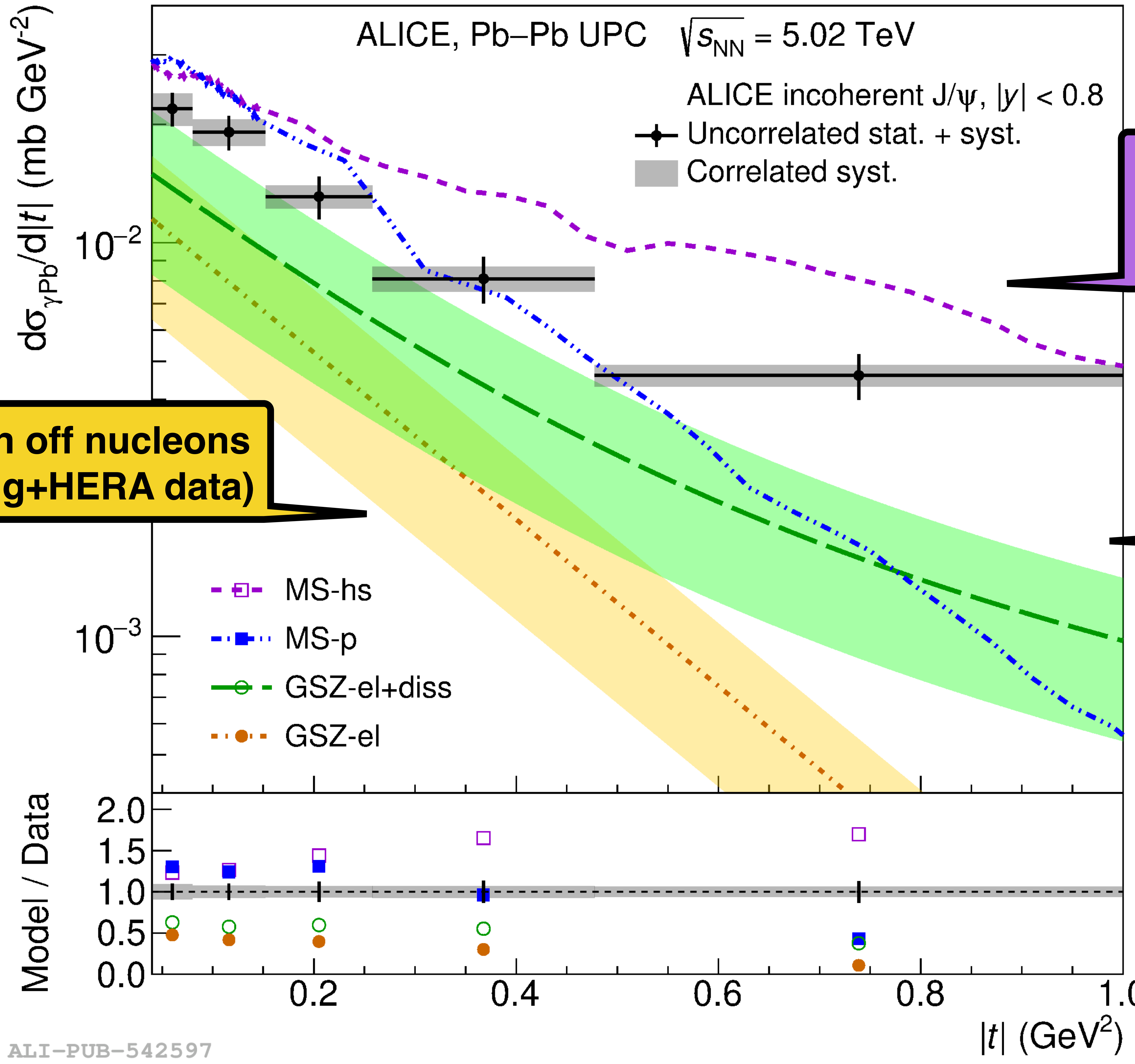
Production off nucleons including dissociation (Shadowing+HERA data)

Production off nucleons (CGC approach)

Itl related to the size of the target: effect of smaller structures appears at lager Itl

ALICE, arXiv 2305.06169

γPb collisions: Mandelstam-t dependence of incoherent production



Production off nucleons including hot spots (CGC approach)

Production off nucleons (Shadowing+HERA data)

Production off nucleons including dissociation (Shadowing+HERA data)

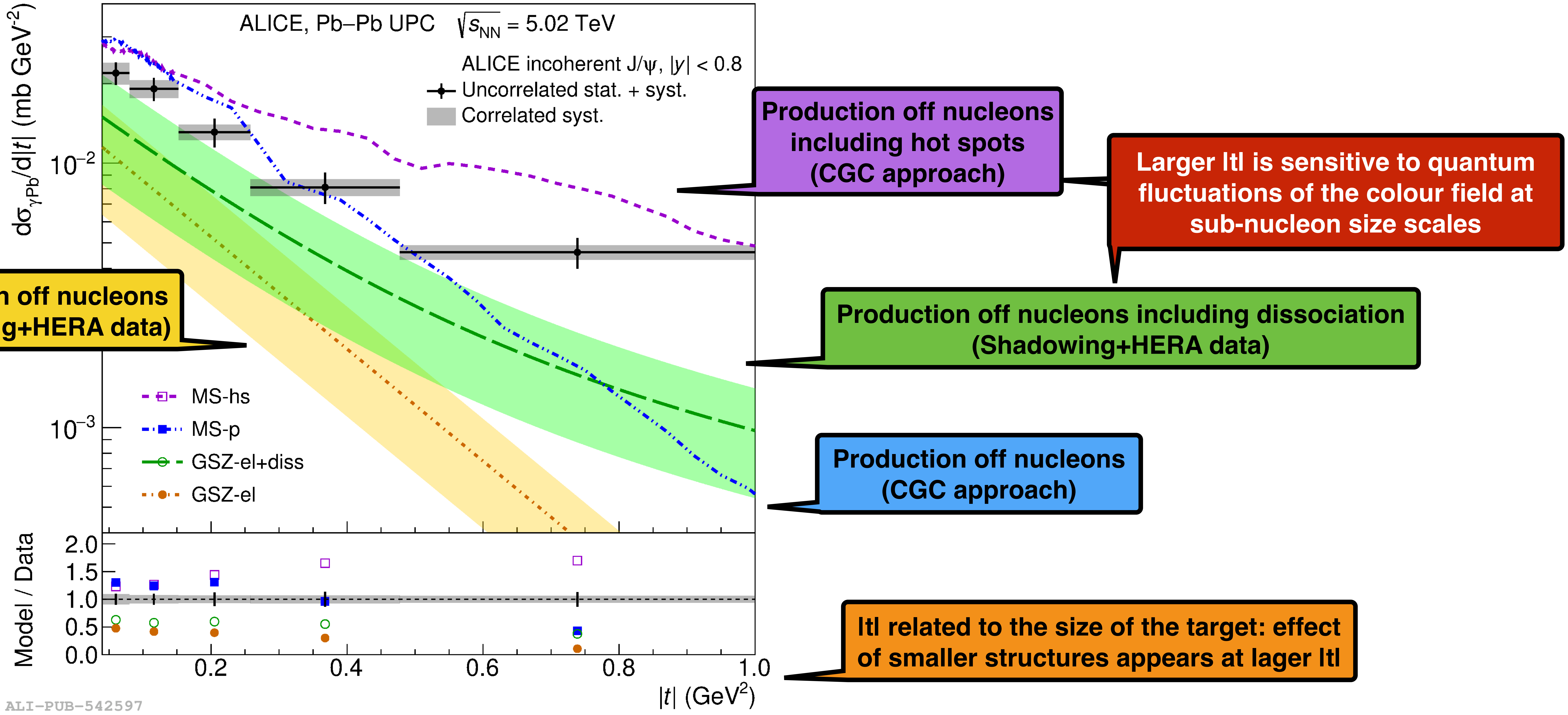
Production off nucleons (CGC approach)

|t| related to the size of the target: effect of smaller structures appears at lager |t|

Models including hot spots or dissociation agree better with the slope of data

ALICE, arXiv 2305.06169

γPb collisions: Mandelstam-t dependence of incoherent production



Models including hot spots or dissociation agree better with the slope of data

A brief look at the future

Expectations for Run 3+4 at the LHC

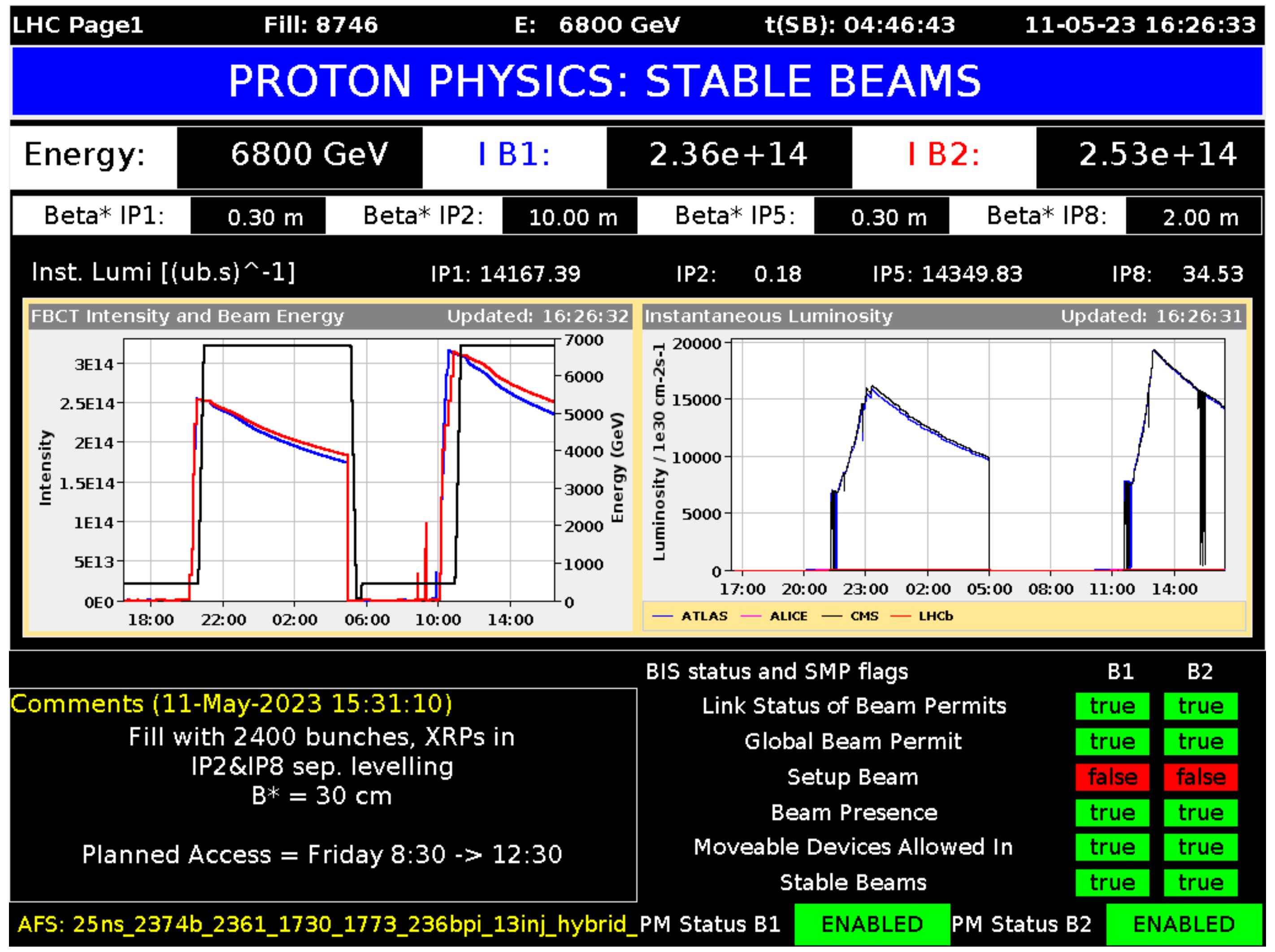
Current measurements were done with few thousand of J/ψ candidates from LHC Run 2 data

Guillermo Contreras, CTU in Prague

Expectations for Run 3+4 at the LHC

Current measurements were done with few thousand of J/ψ candidates from LHC Run 2 data

The LHC Run 3 is ongoing and new data are being recorded!

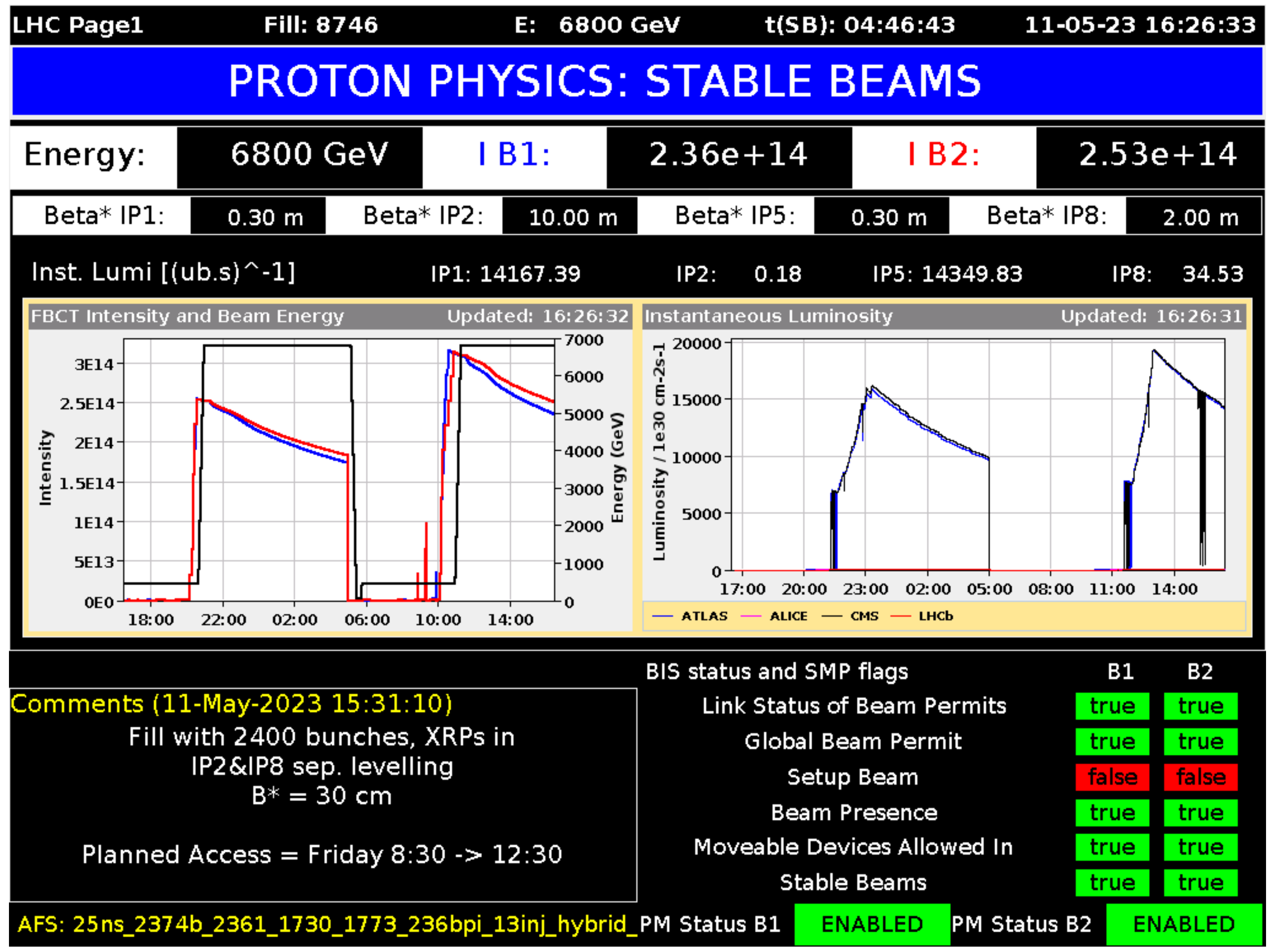


Guillermo Contreras, CTU in Prague

Expectations for Run 3+4 at the LHC

Current measurements were done with few thousand of J/ψ candidates from LHC Run 2 data

The LHC Run 3 is ongoing and new data are being recorded!



Pb-Pb UPCs: projections for 13 1/nb in the LHC Run 3 and 4

Acceptances

		PbPb				
	σ	All	|y|<0.9	|y|<2.4	2.5<|y|<4	2<|y|<5
Meson		Total	Total	Total	Total 1	Total
$\rho \to \pi^+\pi^-$	5.2b	68 B	5.5 B	21B	4.9 B	13 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	9.5 B	210 M	2.5 B	190 M	1.2 B
$\phi \to K^+K^-$	0.22b	2.9 B	82 M	490 M	15 M	330 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	14 M	1.1 M	5.7 M	600 K	1.6 M
$\psi(2S) \to \mu^+\mu^-$	30μb	400 K	35 K	180 K	19 K	47 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	26 K	2.8 K	14 K	880	2.0 K

Millions of J/ψ expected In Run 3+4

Citron et al, CERN Yellow Rep.Monogr. 7 (2019) 1159-1410

Summary and outlook

Summary

The LHC keeps producing new photoproduction measurements, which allow us to understand better the nuclear structure at high energies (small Bjorken-x)

Summary and outlook

Many of the measurements from photon-induced processes not shown today: polarisation, flow, exclusive dijet production, A-dependence of ρ^0, exclusive and dissociative vector meson production off protons, ...

See partial list of results in the backup

Summary

The LHC keeps producing new photoproduction measurements, which allow us to understand better the nuclear structure at high energies (small Bjorken-x)

Summary and outlook

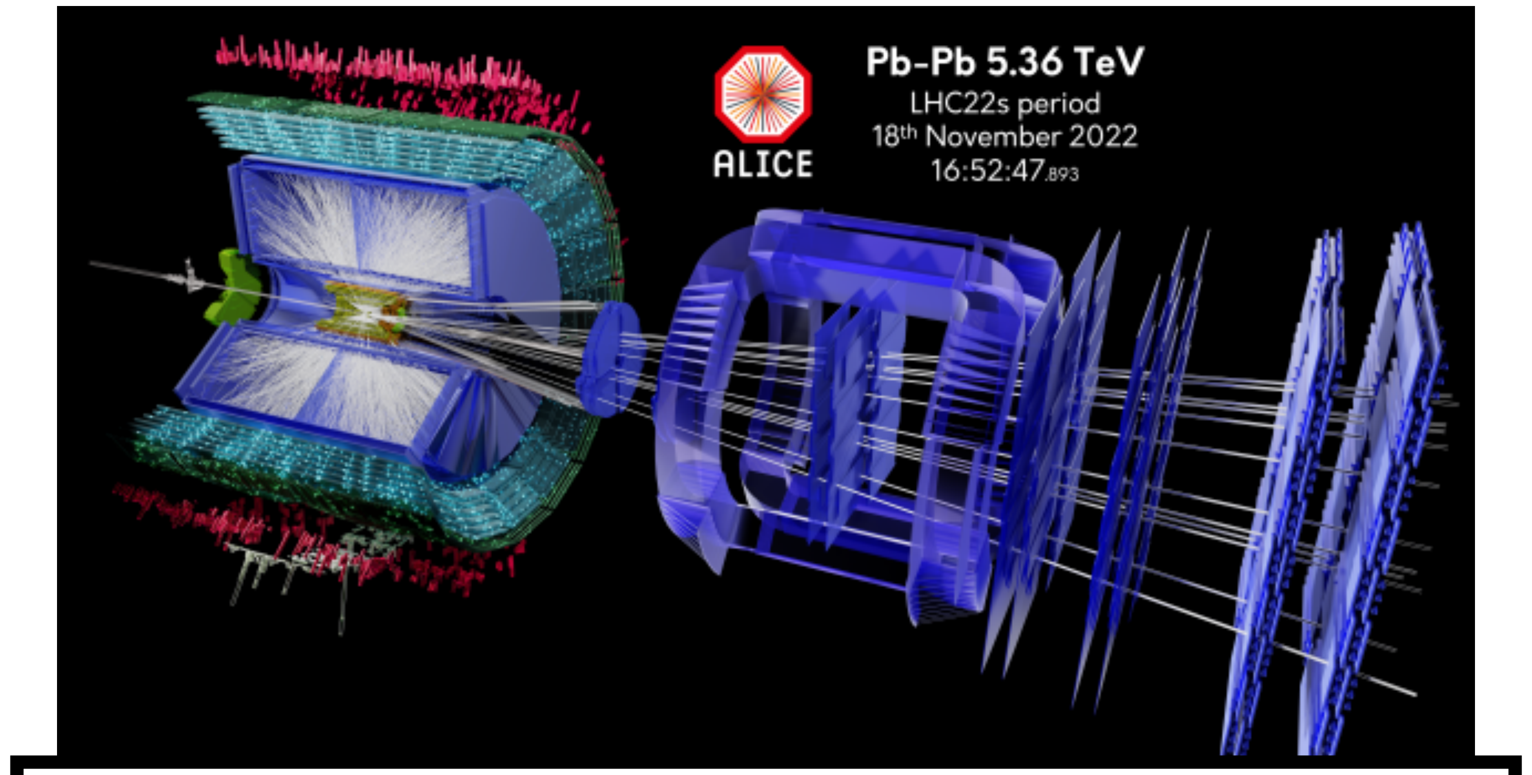
Many of the measurements from photon-induced processes not shown today: polarisation, flow, exclusive dijet production, A-dependence of ρ^0, exclusive and dissociative vector meson production off protons, ...

See partial list of results in the backup

Summary

The LHC keeps producing new photoproduction measurements, which allow us to understand better the nuclear structure at high energies (small Bjorken-x)

The LHC Run 3 has started!
Large Pb-Pb data sample this year
Oxygen-Oxygen and proton-Oxygen collisions for 2024
Later on p-Pb (γp) collisions
....



Event from the 2022 data taking period

Summary and outlook

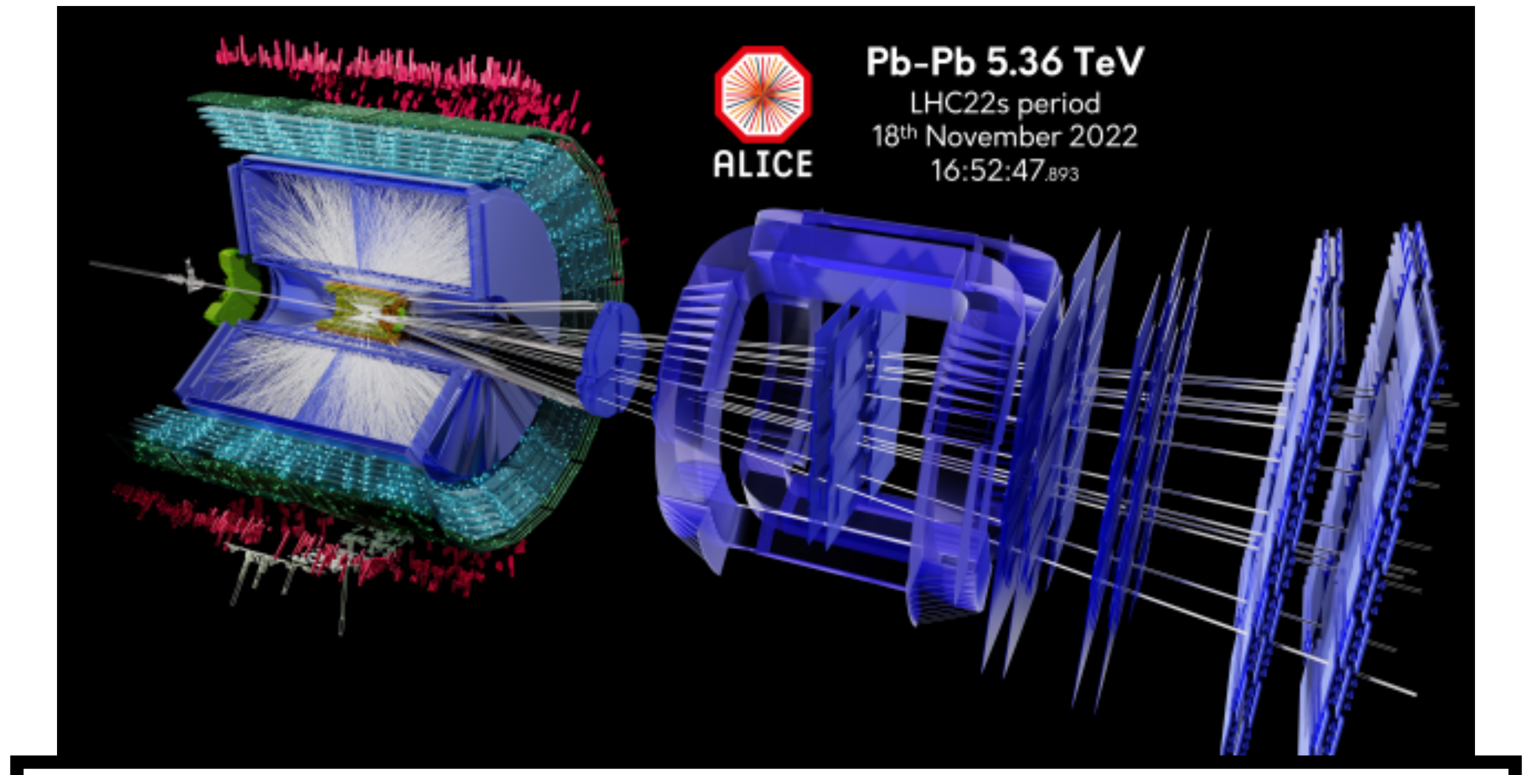
Many of the measurements from photon-induced processes not shown today: polarisation, flow, exclusive dijet production, A-dependence of ρ^0, exclusive and dissociative vector meson production off protons, ...

See partial list of results in the backup

Summary

The LHC keeps producing new photoproduction measurements, which allow us to understand better the nuclear structure at high energies (small Bjorken-x)

The LHC Run 3 has started!
Large Pb-Pb data sample this year
Oxygen-Oxygen and proton-Oxygen collisions for 2024
Later on p-Pb (γp) collisions
....



Event from the 2022 data taking period

Outlook

A bright future for photoproduction studies at the LHC with Run 3+4 data!

Partial list of LHC results on photon-induced interactions

[1] **ALICE** Collaboration, B. Abelev *et al.*, "Measurement of the Cross Section for Electromagnetic Dissociation with Neutron Emission in Pb-Pb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV", *Phys. Rev. Lett.* **109** (2012) 252302, arXiv:1203.2436 [nucl-ex].

[2] **ALICE** Collaboration, B. Abelev *et al.*, "Coherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Lett. B* **718** (2013) 1273–1283, arXiv:1209.3715 [nucl-ex].

[3] **ALICE** Collaboration, E. Abbas *et al.*, "Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV", *Eur. Phys. J. C* **73** (2013) 2617, arXiv:1305.1467 [nucl-ex].

[4] **ALICE** Collaboration, J. Adam *et al.*, "Coherent ρ^0 photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *JHEP* **09** (2015) 095, arXiv:1503.09177 [nucl-ex].

[5] **ALICE** Collaboration, J. Adam *et al.*, "Measurement of an excess in the yield of J/ψ at very low $p_{\rm T}$ in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Rev. Lett.* **116** (2016) 222301, arXiv:1509.08802 [nucl-ex].

[6] **CMS** Collaboration, V. Khachatryan *et al.*, "Coherent J/ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the CMS experiment", *Phys. Lett. B* **772** (2017) 489–511, arXiv:1605.06966 [nucl-ex].

[7] **CMS** Collaboration, V. Khachatryan *et al.*, "Coherent J/ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV with the CMS experiment", *Phys. Lett. B* **772** (2017) 489–511, arXiv:1605.06966 [nucl-ex].

[8] **ATLAS** Collaboration, M. Aaboud *et al.*, "Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC", *Nature Phys.* **13** no. 9, (2017) 852–858, arXiv:1702.01625 [hep-ex].

[9] **ALICE** Collaboration, S. Acharya *et al.*, "Energy dependence of exclusive J/ψ photoproduction off protons in ultra-peripheral p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV", *Eur. Phys. J. C* **79** (2019) 402, arXiv:1809.03235 [nucl-ex].

[10] **CMS** Collaboration, A. M. Sirunyan *et al.*, "Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV", *Phys. Lett. B* **797** (2019) 134826, arXiv:1810.04602 [hep-ex].

[11] **CMS** Collaboration, A. M. Sirunyan *et al.*, "Measurement of exclusive Υ photoproduction from protons in pPb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV", *Eur. Phys. J. C* **79** no. 3, (2019) 277, arXiv:1809.11080 [hep-ex]. [Erratum: Eur.Phys.J.C 82, 343 (2022)].

Partial list of LHC results on photon-induced interactions

[12] **ATLAS** Collaboration, G. Aad *et al.*, "Observation of light-by-light scattering in ultraperipheral Pb+Pb collisions with the ATLAS detector", *Phys. Rev. Lett.* **123** no. 5, (2019) 052001, arXiv:1904.03536 [hep-ex].

[13] **ALICE** Collaboration, S. Acharya *et al.*, "Coherent J/ψ photoproduction at forward rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", *Phys. Lett. B* **798** (2019) 134926, arXiv:1904.06272 [nucl-ex].

[14] **CMS** Collaboration, A. M. Sirunyan *et al.*, "Measurement of exclusive $\rho(770)^0$ photoproduction in ultraperipheral pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", *Eur. Phys. J. C* **79** no. 8, (2019) 702, arXiv:1902.01339 [hep-ex].

[15] **CMS** Collaboration, A. M. Sirunyan *et al.*, "Observation of Forward Neutron Multiplicity Dependence of Dimuon Acoplanarity in Ultraperipheral Pb-Pb Collisions at $\sqrt{s_{NN}}$=5.02 TeV", *Phys. Rev. Lett.* **127** (2021) 122001, arXiv:2011.05239 [hep-ex].

[16] **ALICE** Collaboration, S. Acharya *et al.*, "Coherent photoproduction of ρ^0 vector mesons in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", *JHEP* **06** (2020) 035, arXiv:2002.10897 [nucl-ex].

[17] **ATLAS** Collaboration, G. Aad *et al.*, "Exclusive dimuon production in ultraperipheral Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV with ATLAS", *Phys. Rev. C* **104** (2021) 024906, arXiv:2011.12211 [nucl-ex].

[18] **ATLAS** Collaboration, G. Aad *et al.*, "Measurement of light-by-light scattering and search for axion-like particles with 2.2 nb^{-1} of Pb+Pb data with the ATLAS detector", *JHEP* **03** (2021) 243, arXiv:2008.05355 [hep-ex]. [Erratum: JHEP 11, 050 (2021)].

[19] **LHCb** Collaboration, R. Aaij *et al.*, "Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{\rm NN}} = 5$ TeV", *JHEP* **07** (2022) 117, arXiv:2107.03223 [hep-ex].

[20] **ALICE** Collaboration, S. Acharya *et al.*, "First measurement of coherent $\rho 0$ photoproduction in ultra-peripheral Xe–Xe collisions at $\sqrt{s_{\rm NN}} = 5.44$ TeV", *Phys. Lett. B* **820** (2021) 136481, arXiv:2101.02581 [nucl-ex].

[21] **ALICE** Collaboration, S. Acharya *et al.*, "First measurement of the $|t|$-dependence of coherent J/ψ photonuclear production", *Phys. Lett. B* **817** (2021) 136280, arXiv:2101.04623 [nucl-ex].

[22] **ALICE** Collaboration, S. Acharya *et al.*, "Coherent J/ψ and ψ' photoproduction at midrapidity in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV", *Eur. Phys. J. C* **81** (2021) 712, arXiv:2101.04577 [nucl-ex].

[23] **LHCb** Collaboration, R. Aaij *et al.*, "J/ψ photoproduction in Pb-Pb peripheral collisions at $\sqrt{s_{NN}}$= 5 TeV", *Phys. Rev. C* **105** (2022) L032201, arXiv:2108.02681 [hep-ex].

Partial list of LHC results on photon-induced interactions

[24] **ATLAS** Collaboration, G. Aad *et al.*, "Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at 5.02 TeV with ATLAS", *Phys. Rev. C* **104** no. 1, (2021) 014903, `arXiv:2101.10771 [nucl-ex]`.

[25] **ALICE** Collaboration, "Photoproduction of low-$p_{\rm T}$ J/ψ from peripheral to central Pb−Pb collisions at 5.02 TeV", `arXiv:2204.10684 [nucl-ex]`.

[26] **ATLAS** Collaboration, G. Aad *et al.*, "Measurement of muon pairs produced via $\gamma\gamma$ scattering in nonultraperipheral Pb+Pb collisions at sNN=5.02 TeV with the ATLAS detector", *Phys. Rev. C* **107** no. 5, (2023) 054907, `arXiv:2206.12594 [nucl-ex]`.

[27] **ATLAS** Collaboration, "Exclusive dielectron production in ultraperipheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ATLAS", `arXiv:2207.12781 [nucl-ex]`.

[28] **CMS** Collaboration, "Observation of τ lepton pair production in ultraperipheral lead-lead collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", `arXiv:2206.05192 [nucl-ex]`.

[29] **ALICE** Collaboration, "Neutron emission in ultraperipheral Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", `arXiv:2209.04250 [nucl-ex]`.

[30] **CMS** Collaboration, A. Tumasyan *et al.*, "Probing small Bjorken-x nuclear gluonic structure via coherent J/ψ photoproduction ir ultraperipheral PbPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", `arXiv:2303.16984 [nucl-ex]`.

[31] **ALICE** Collaboration, "Exclusive and dissociative J/ψ photoproduction, and exclusive dimuon production, in p−Pb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV", `arXiv:2304.12403 [nucl-ex]`.

[32] **ALICE** Collaboration, S. Acharya *et al.*, "First measurement of the $|t|$-dependence of incoherent J/ψ photonuclear production", `arXiv:2305.06169 [nucl-ex]`.