EMMI Workshop: New vistas in photon physics in heavy-ion collisions
September 19-22, 2022, Cracow

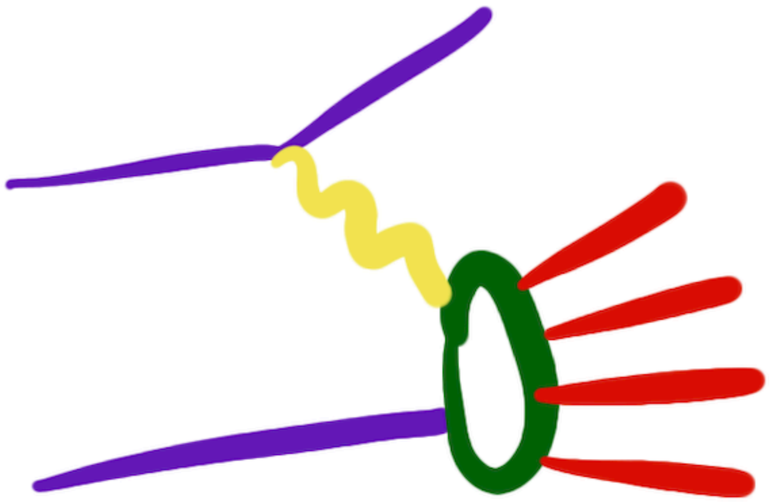
Recent ALICE measurements of photon-induced processes

Guillermo Contreras

Czech Technical University in Prague

Photon-induced processes at the LHC

Photon flux from the highly boosted electromagnetic field of the beam particles at the LHC
Flux particularly intense from Pb ions thanks to the Z^2 dependence



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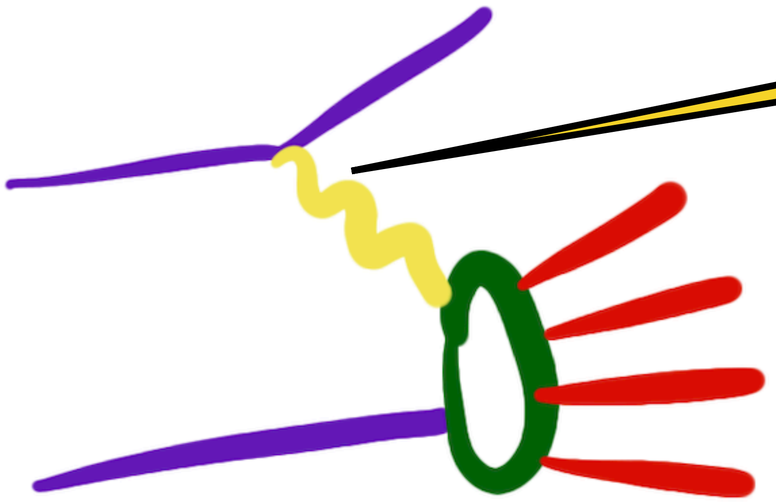

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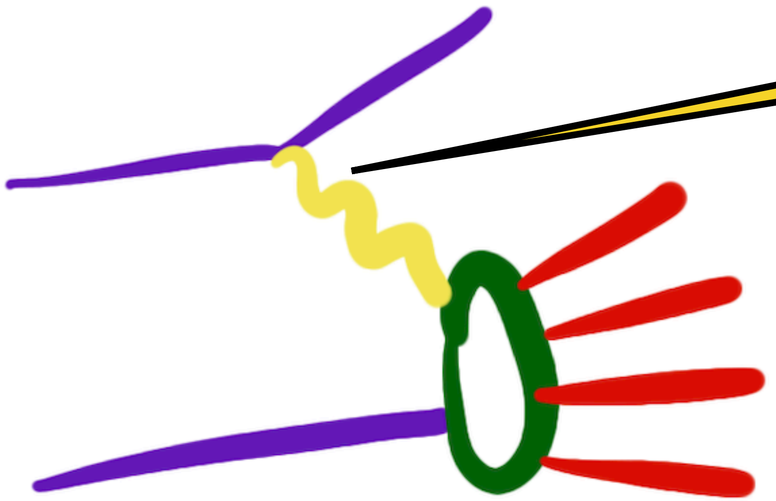

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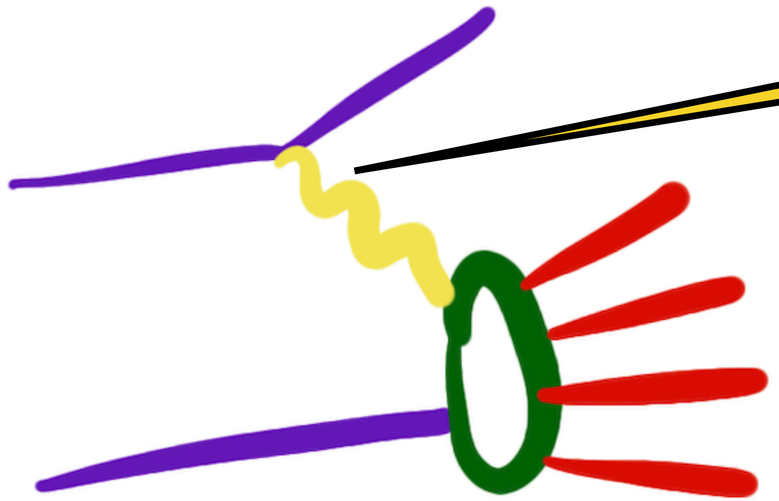

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Oxygen beams planned for next year :)

ALICE-PUBLIC-2021-004,https://cds.cern.ch/record/2765973

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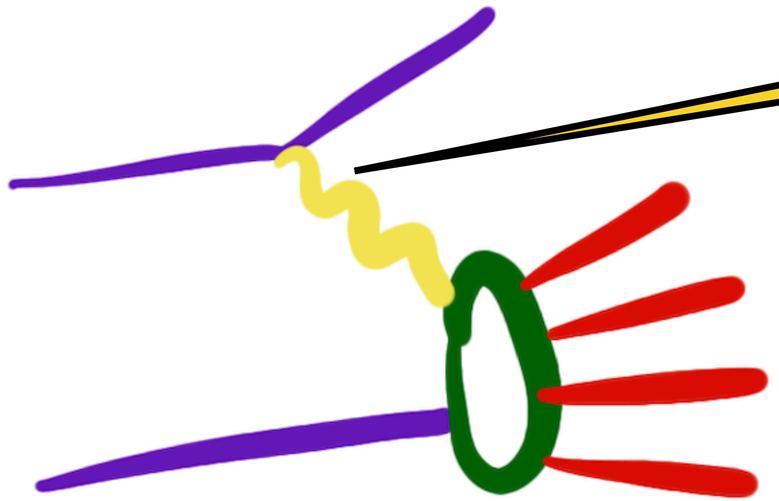

Different final states can be studied, e.g.: diffractive photoproduction, photon-photon interactions ...

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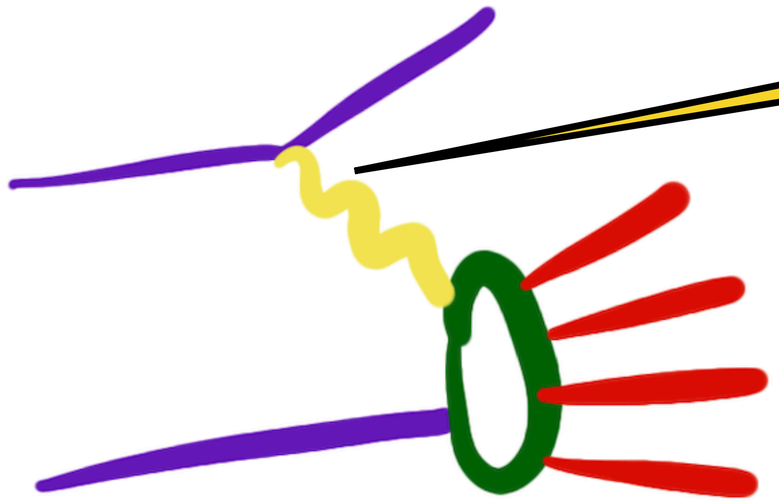

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Here I will only mention some results from photon-photon and diffractive photoproduction of vector mesons from ALICE
Many other results available from LHC and RHIC

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Photon-photon dilepton production

The Breit-Wheeler process

DECEMBER 15, 1934 PHYSICAL REVIEW VOLUME 46

Production of matter from light!

Collision of Two Light Quanta

G. BREIT* AND JOHN A. WHEELER,** *Department of Physics, New York University*

(Received October 23, 1934)

The recombination of free electrons and free positrons and its connection with the Compton effect have been treated by Dirac before the experimental discovery of the positron. In the present note are given analogous calculations for the production of positron electron pairs as a result of the collision of two light quanta. The angular distribution of the ejected pairs is calculated for different

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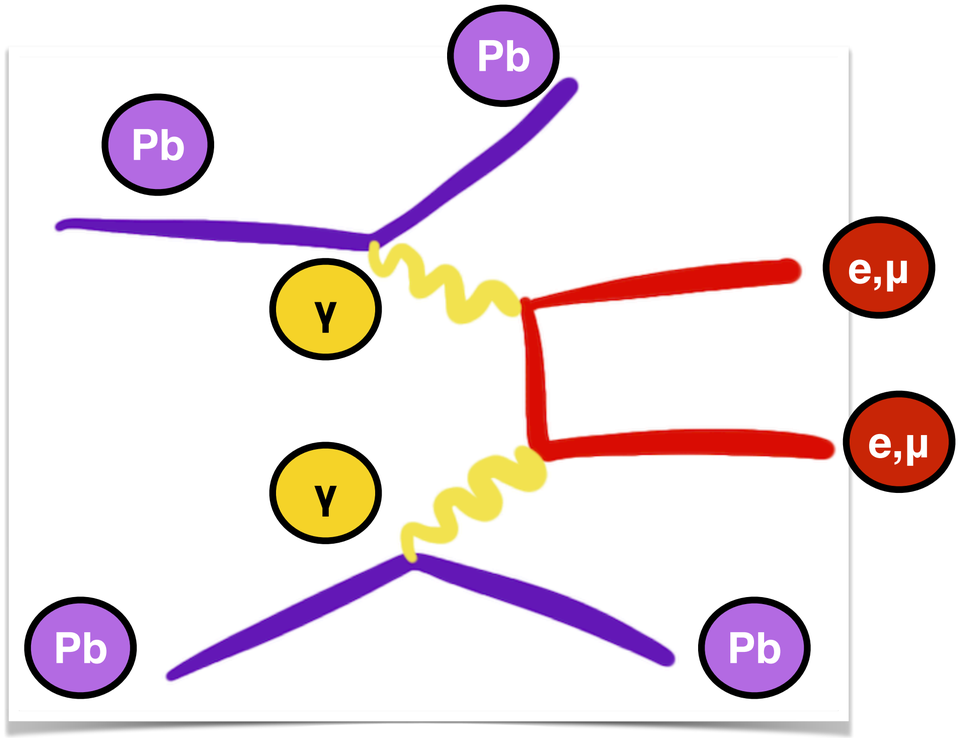

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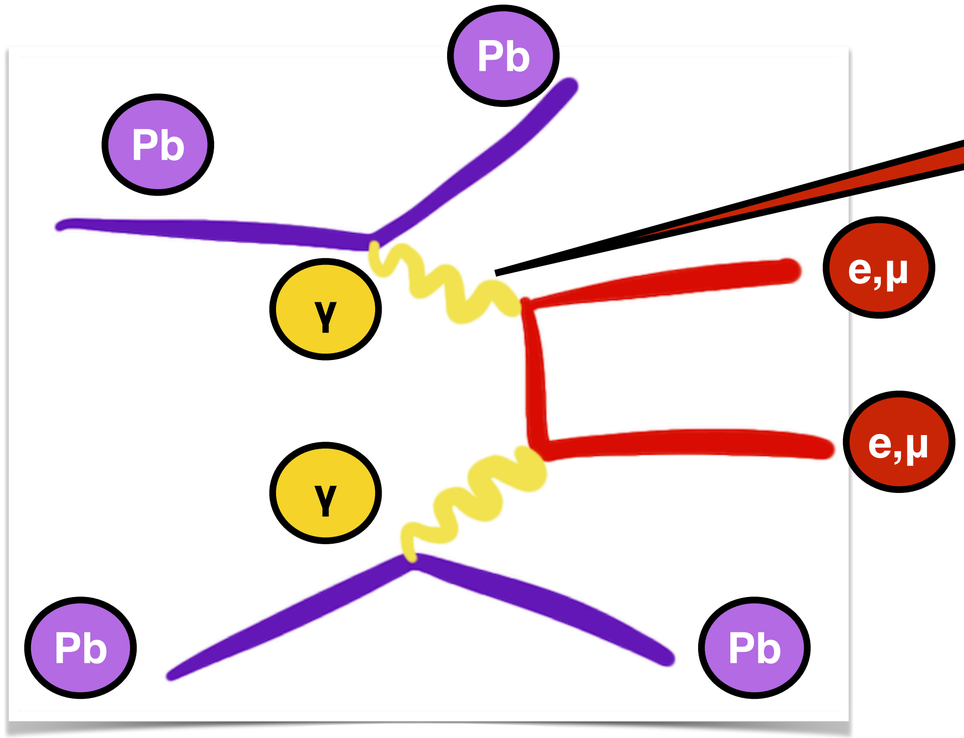

Open question: How well do we model the photon flux?

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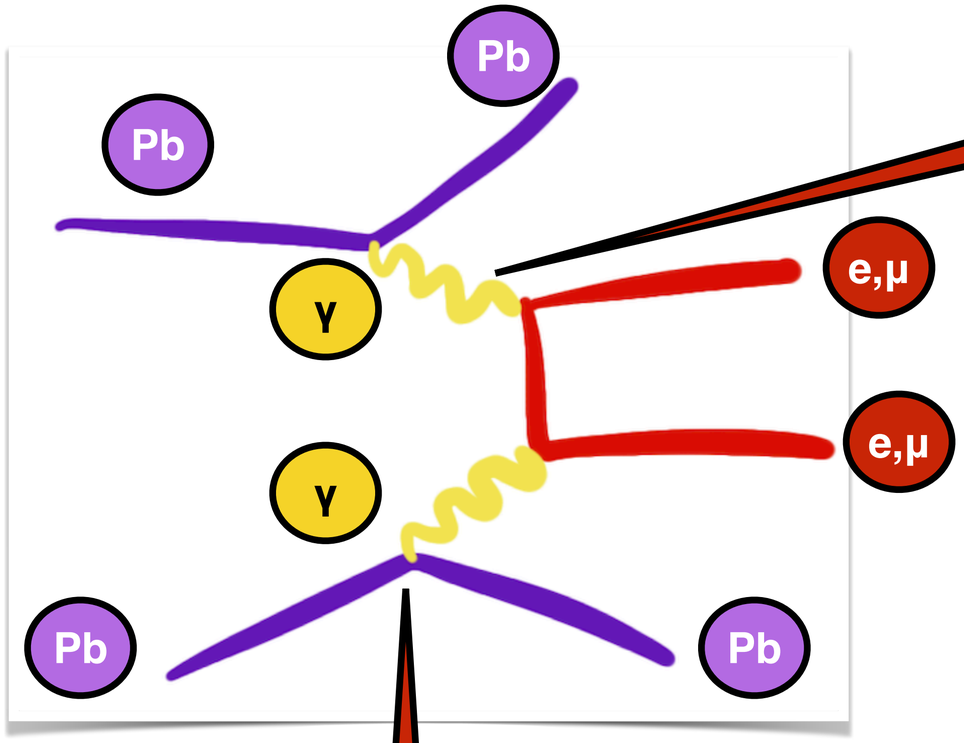

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Open question: Coupling at the vertex is large: Zα≈0.6. Are NLO corrections important?

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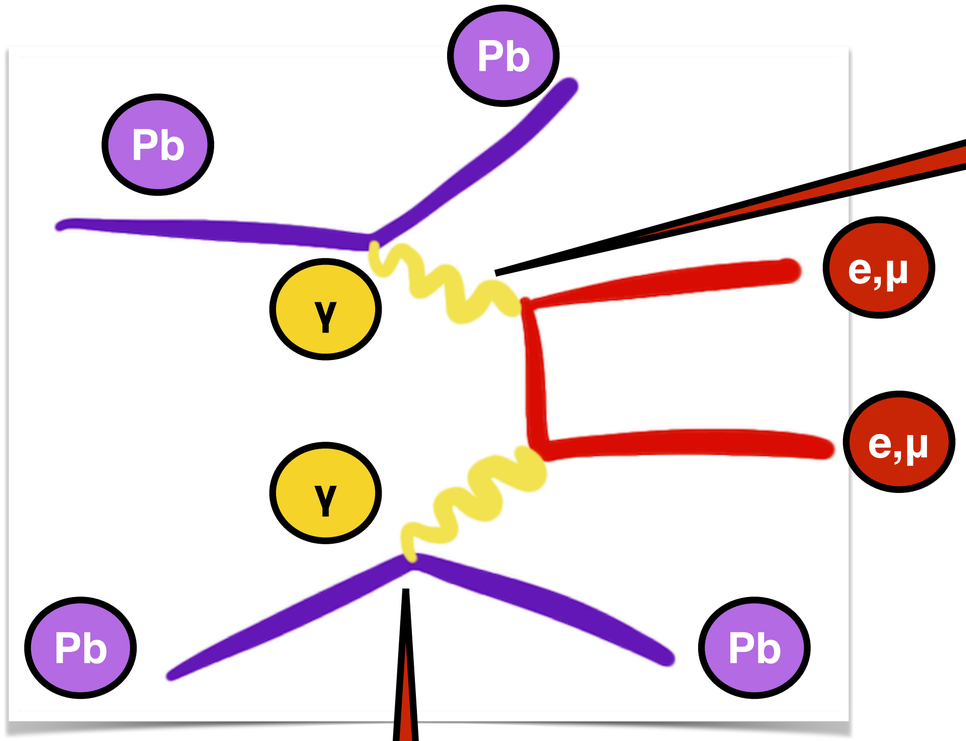
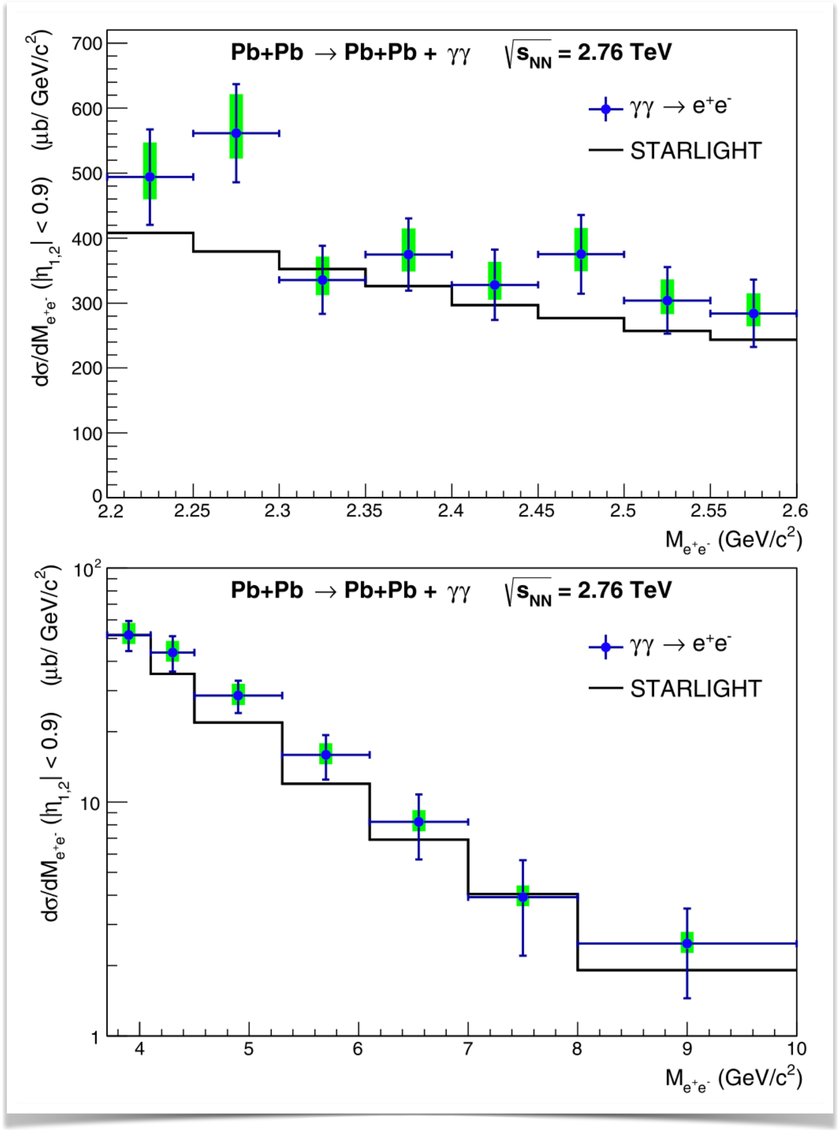


Open question: How well do we model the photon flux?

Handles: perform measurements at
different dilepton masses, energies (rapidities),
different impact parameter of the collisions
different systems ...

Open question: Coupling at the vertex is large: Zα≈0.6.
Are NLO corrections important?

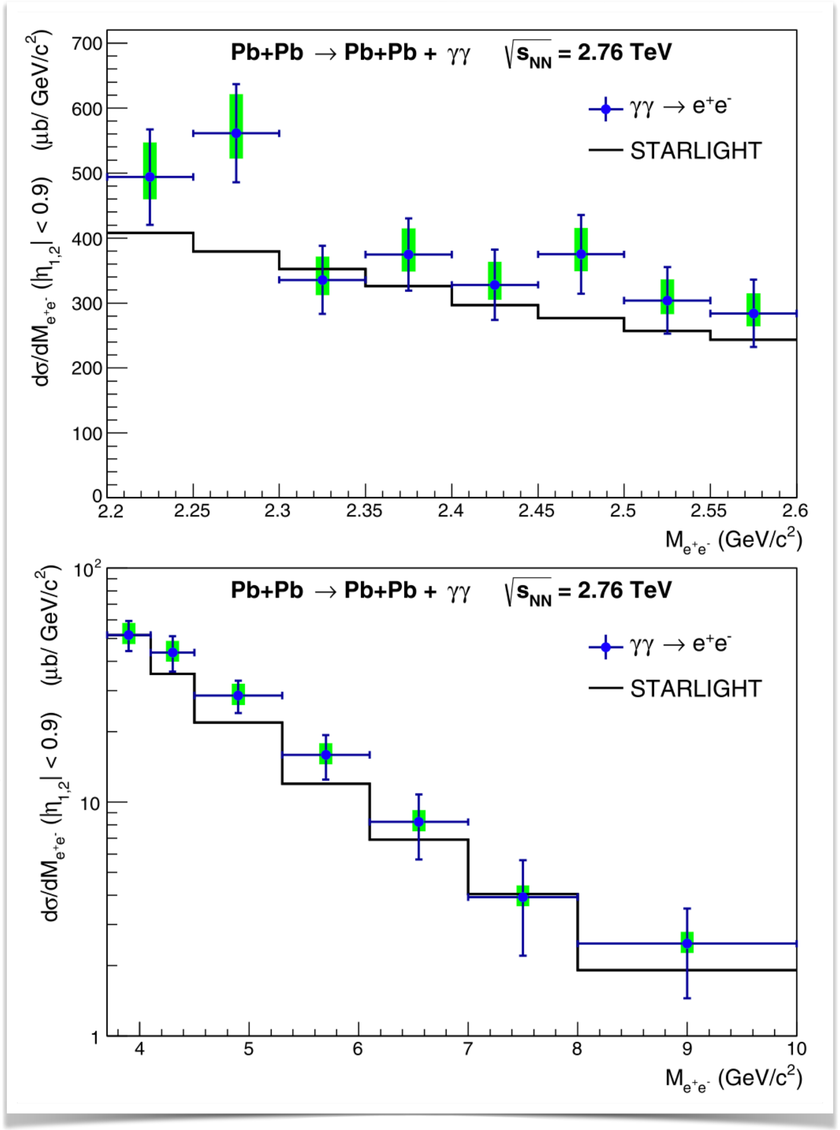
Photon-photon dilepton production: mass dependence



ALICE, EPJC73 (2013) 2617

Photon-photon dilepton production: mass dependence

Measurement at midrapidity



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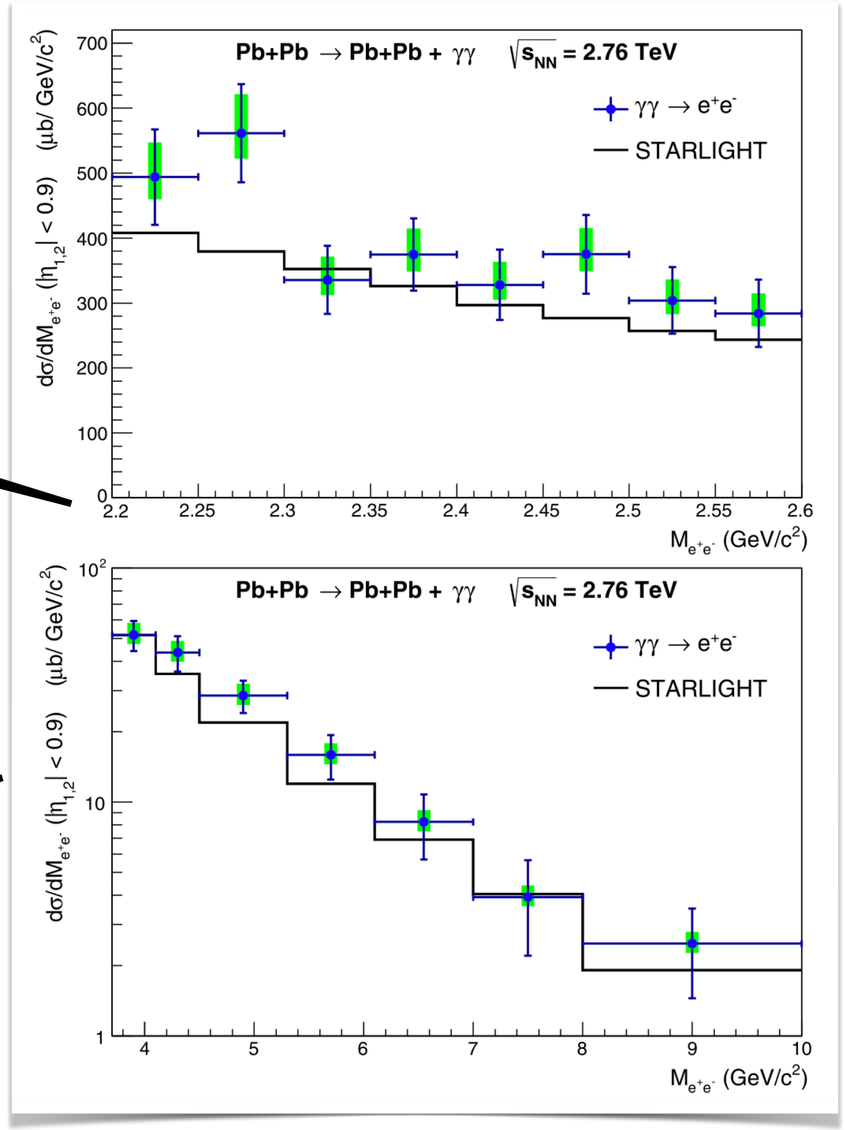
Photon-photon dilepton production: mass dependence

Measurement at very low invariant masses

Measurement at midrapidity



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Photon-photon dilepton production: mass dependence

Complementary to ATLAS measurements

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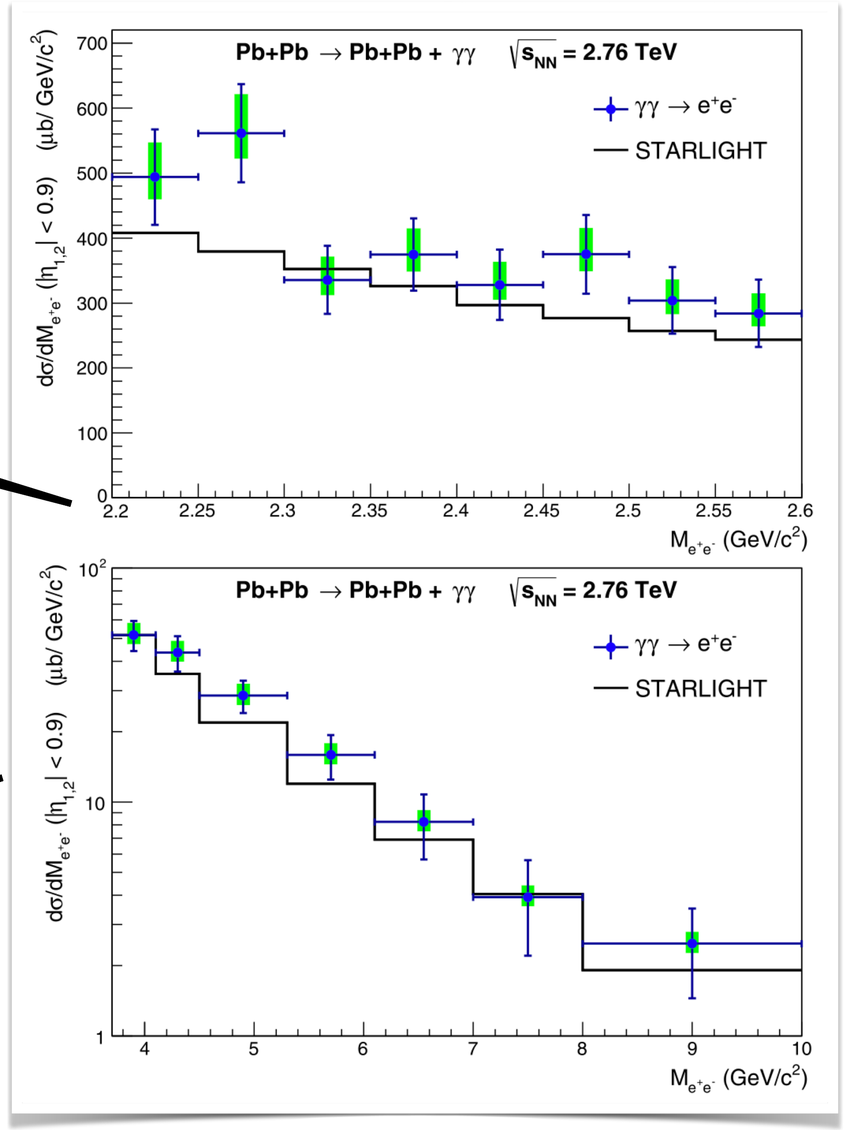

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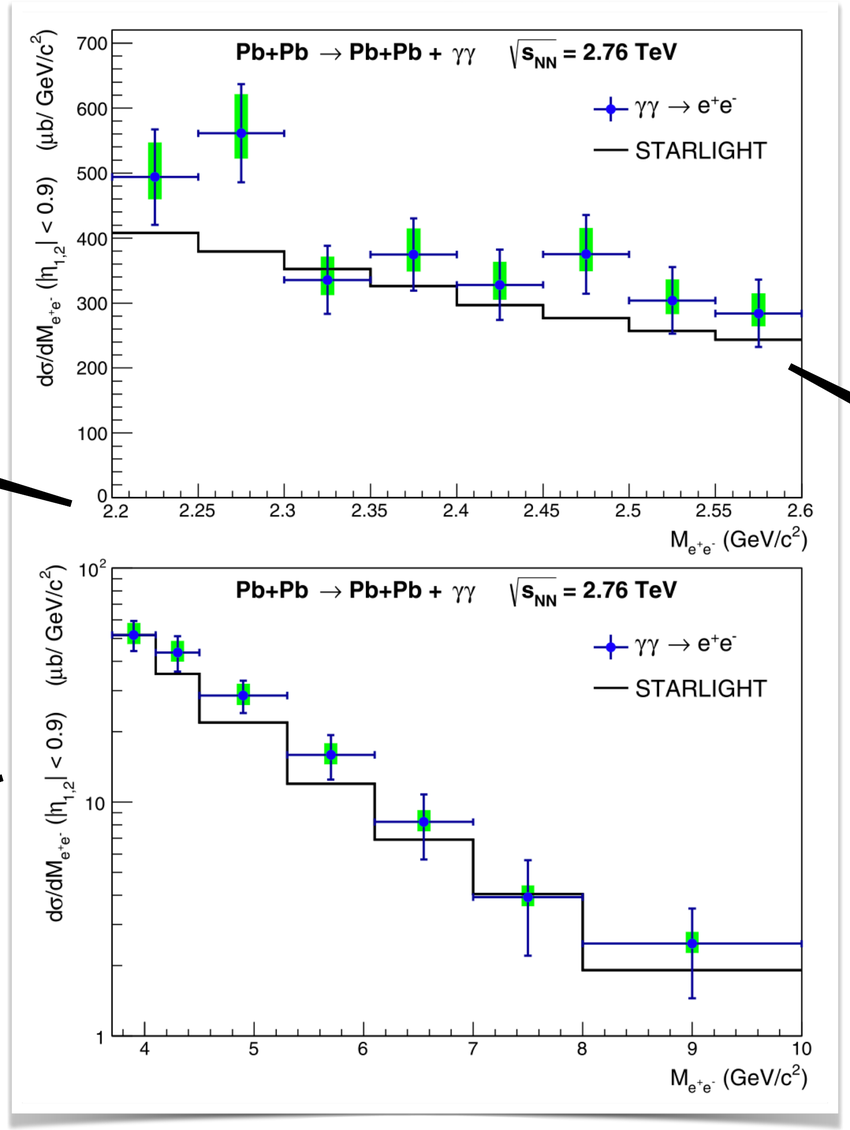

Starlight: LO Monte Carlo

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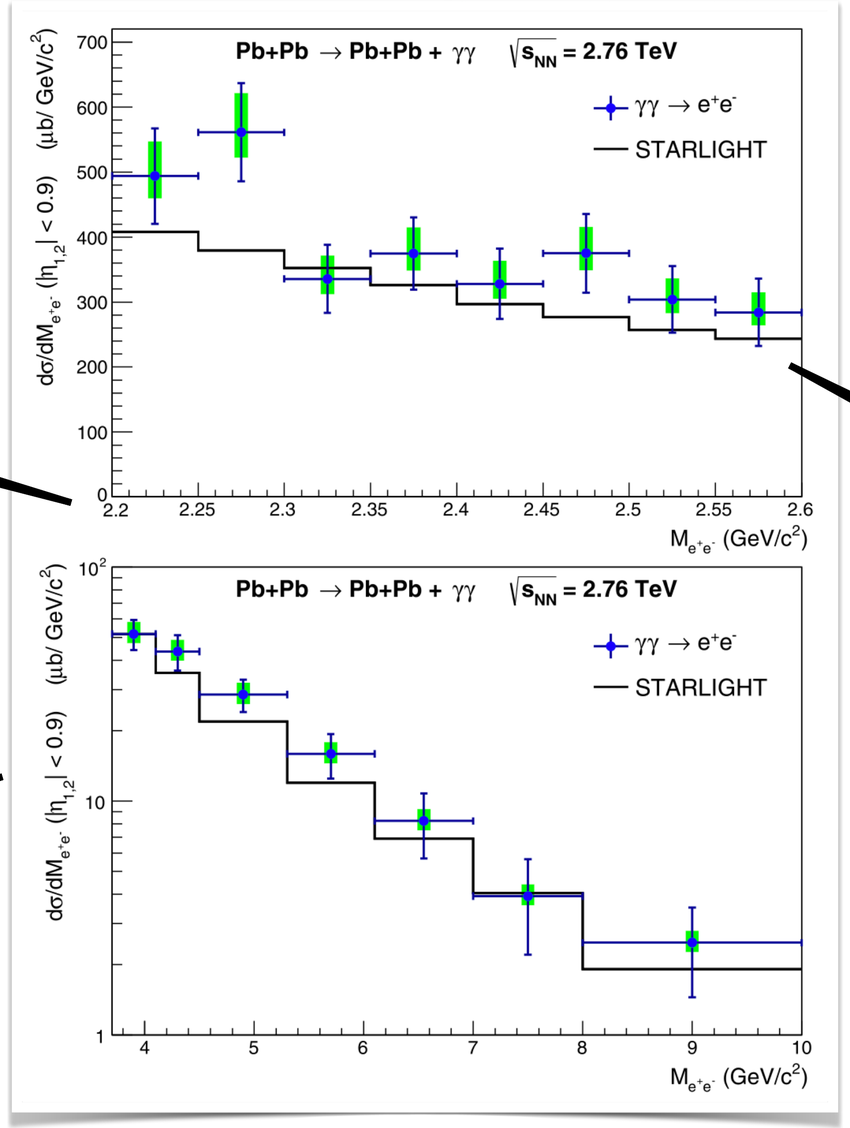

Starlight: LO Monte Carlo

Does a good job, but seems to be systematically lower than data

Measurement at midrapidity

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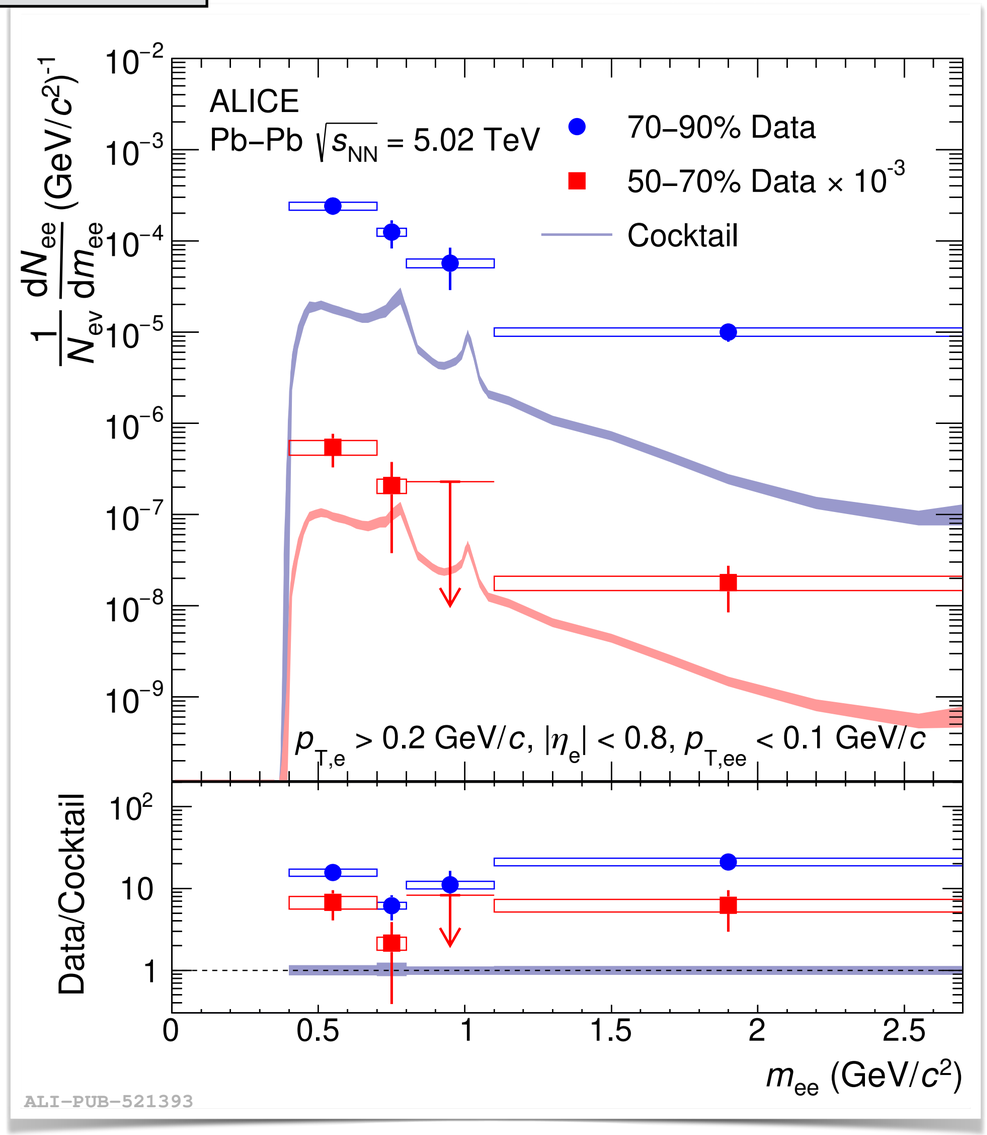
Photon-photon dilepton production: peripheral collisions (1/2)

ALICE: 2204.11732



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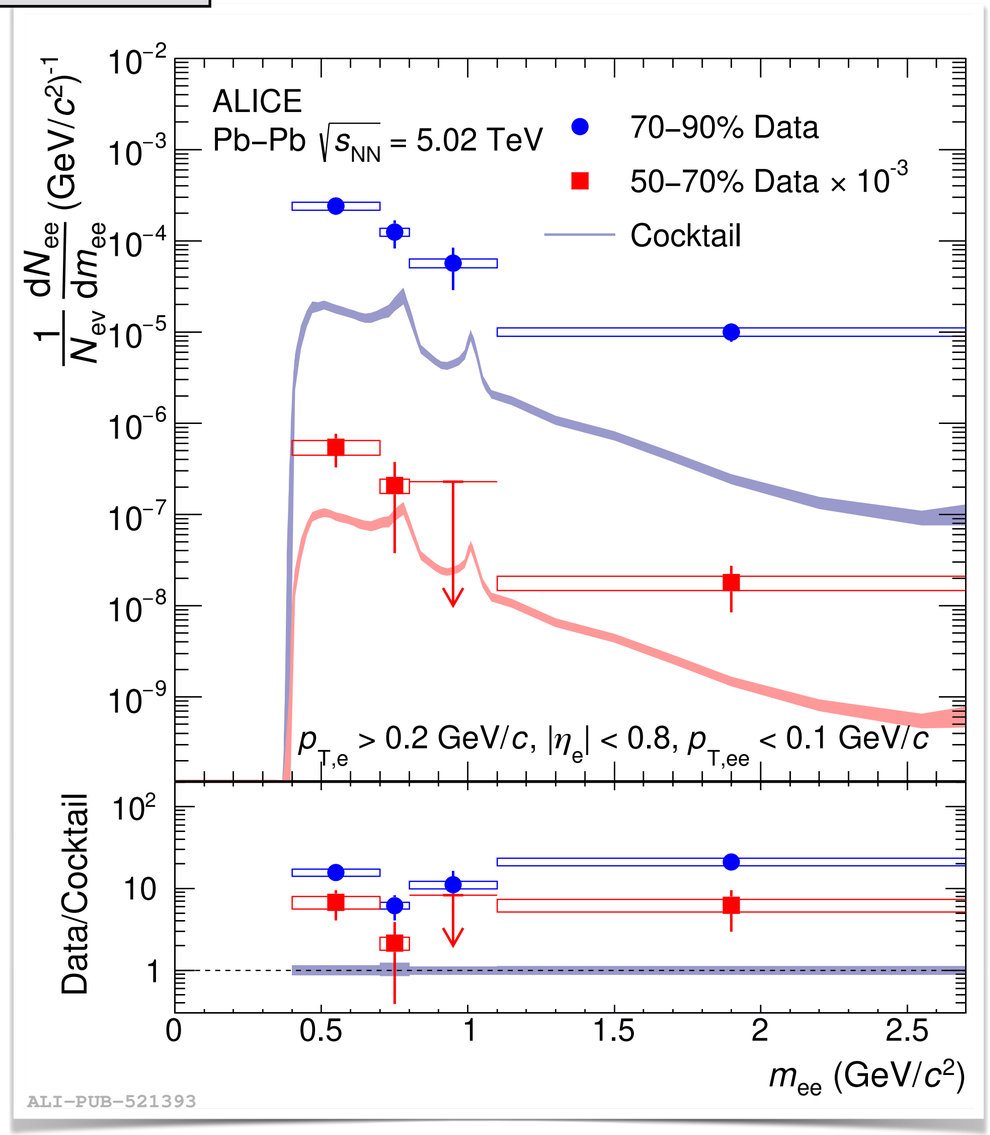

Midrapidity, low pair pT

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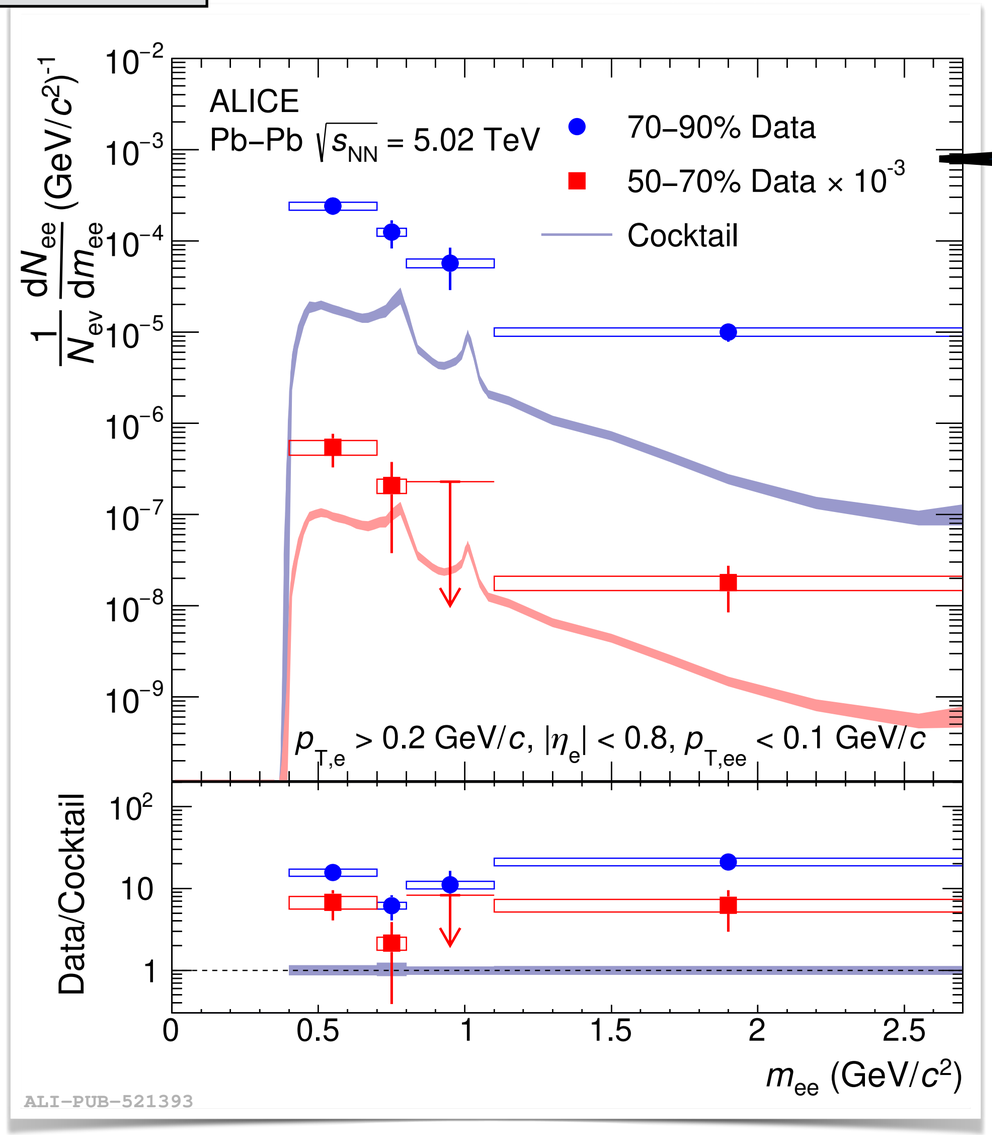

Centralities

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Very low invariant masses of the lepton pair

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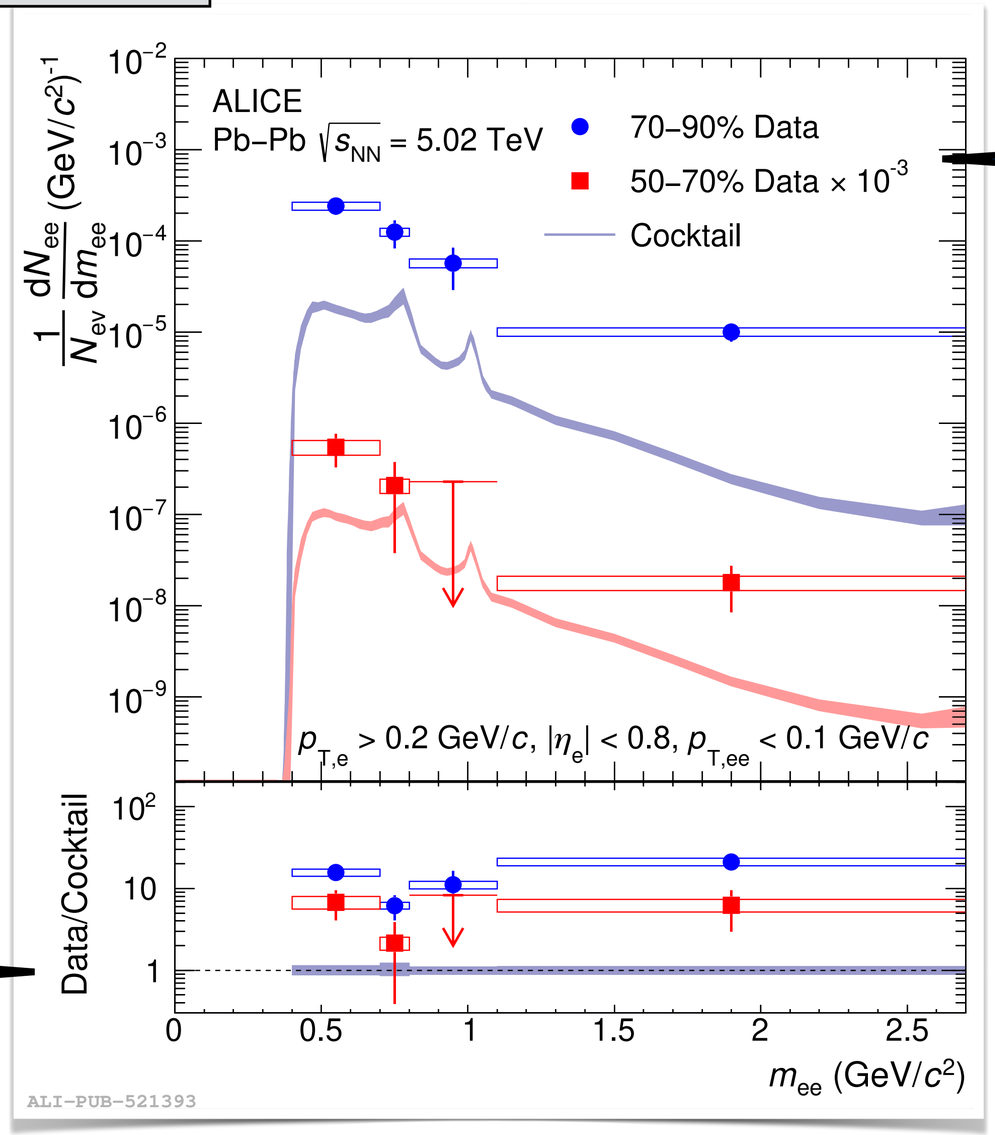

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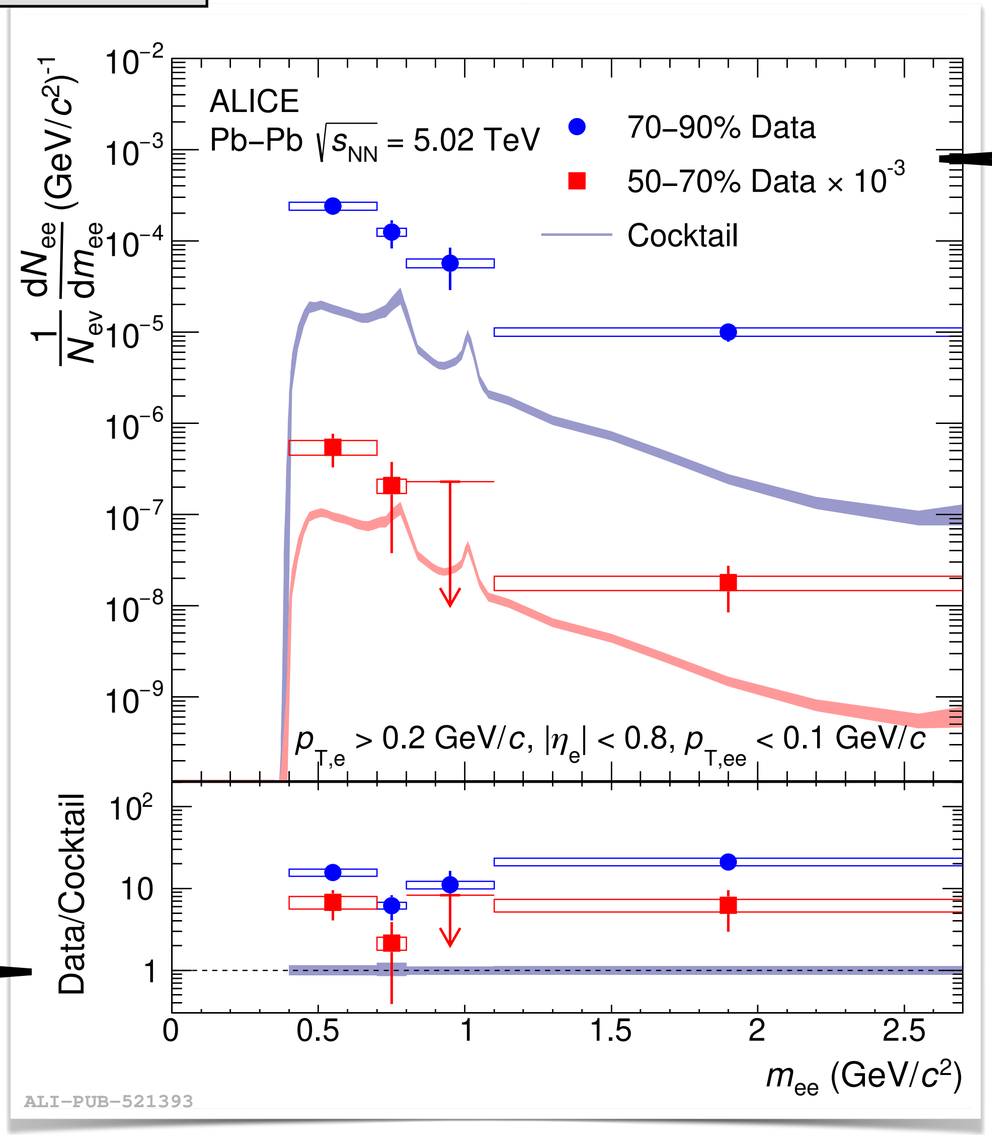


Centralities

Excess interpreted as photon-induced interactions

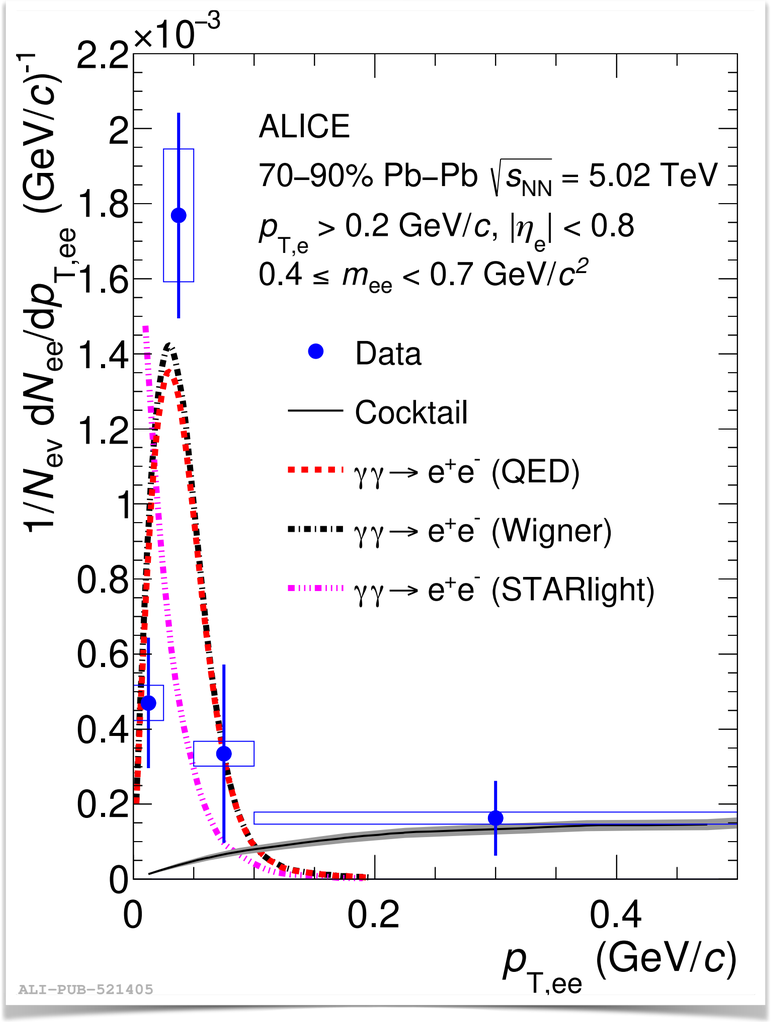
Midrapidity, low pair pT

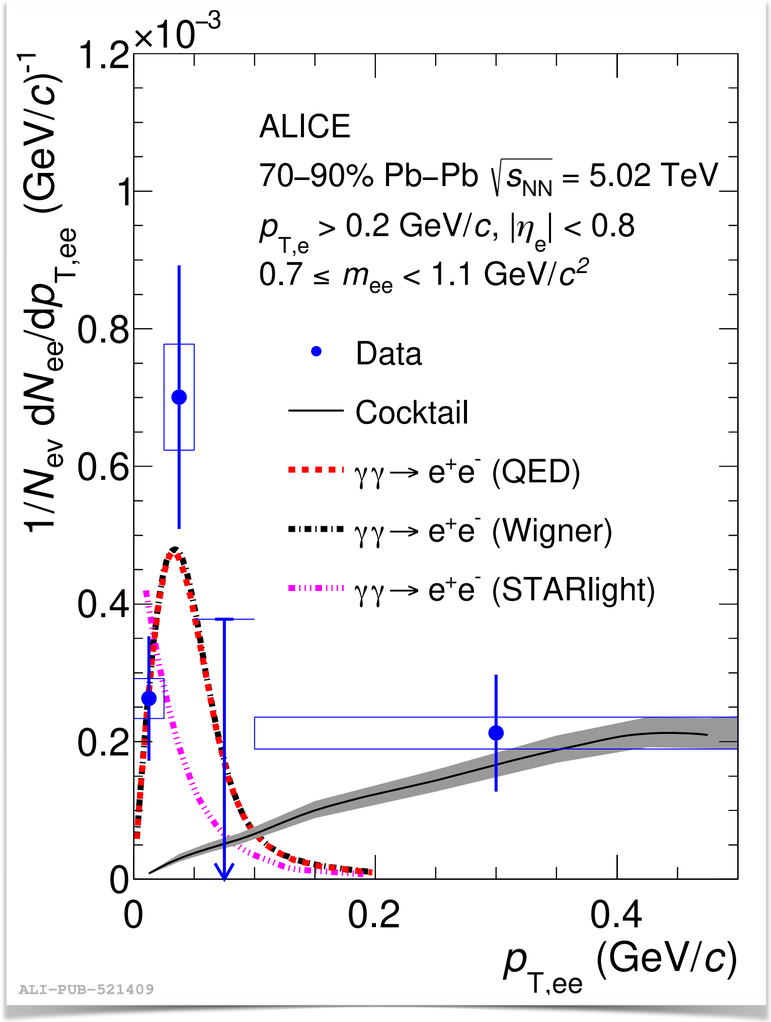
Clear excess over hadronic expectations

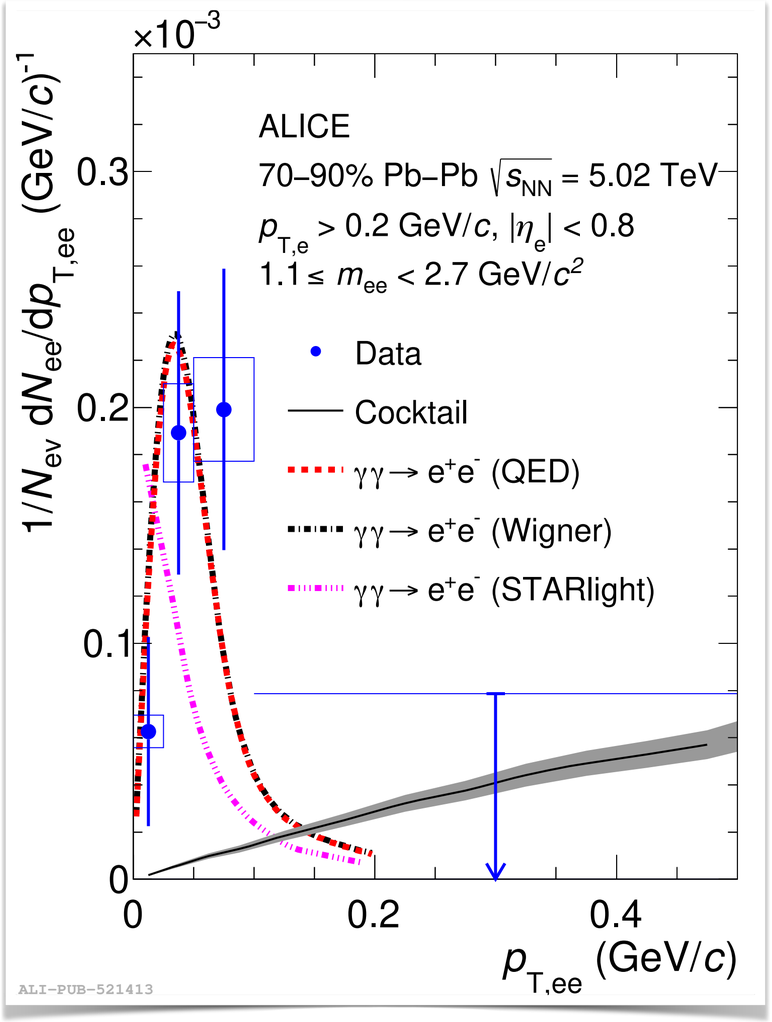
Very low invariant masses of the lepton pair

Photon-photon dilepton production: peripheral collisions (2/2)

ALICE: 2204.11732







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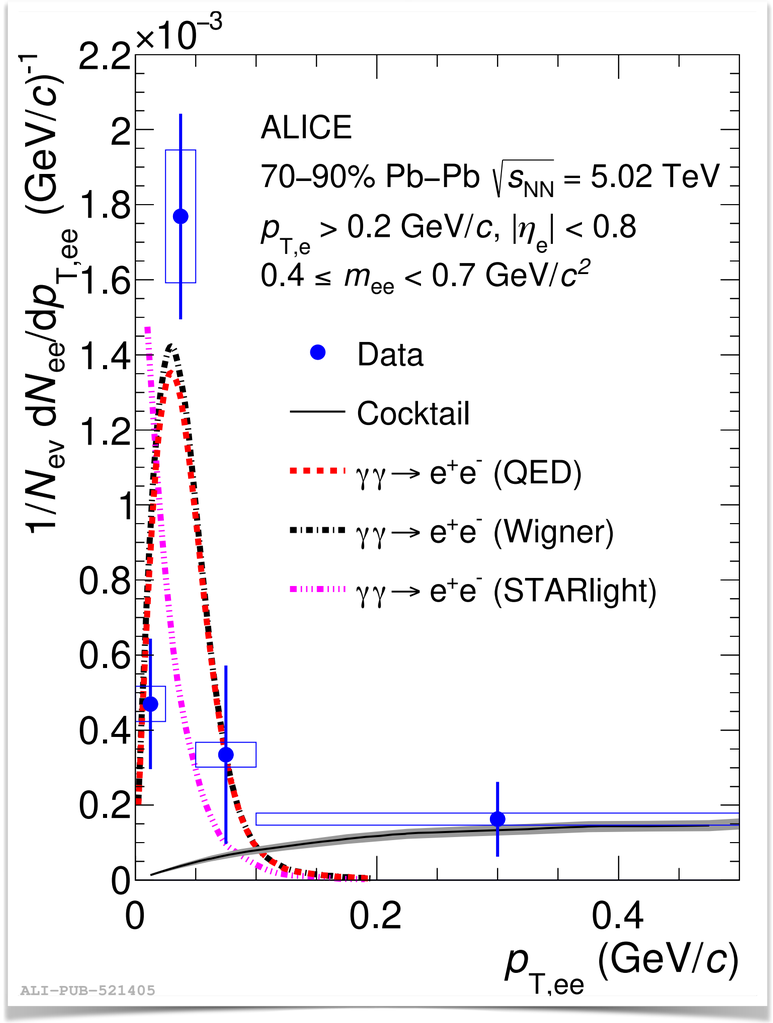

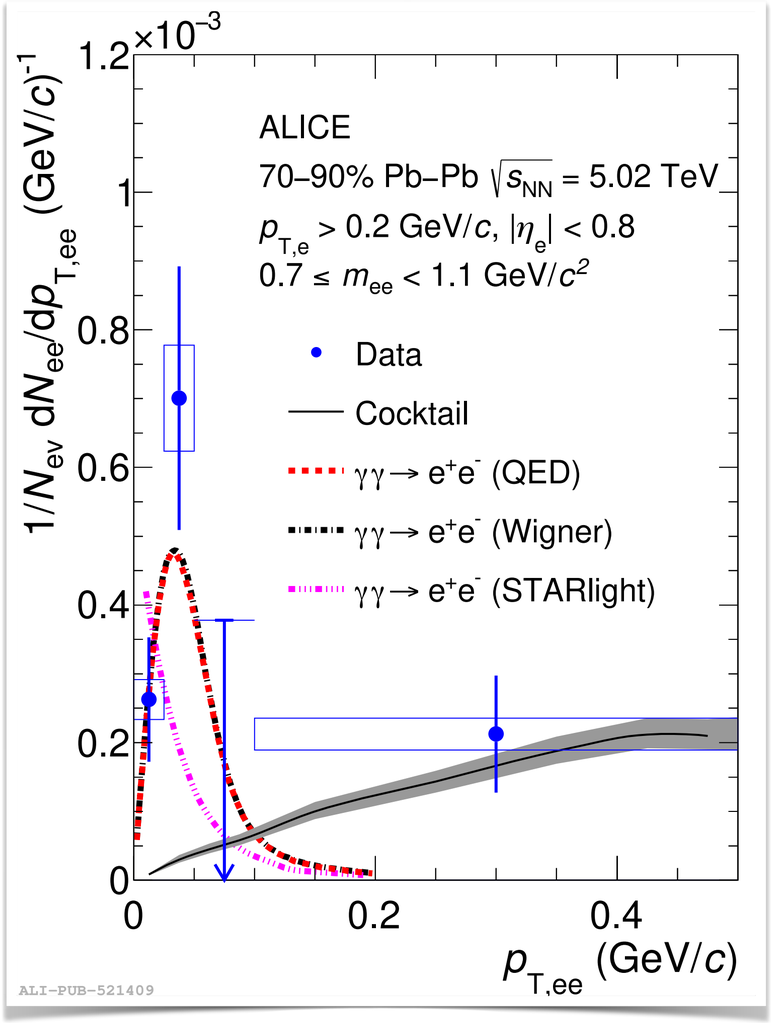

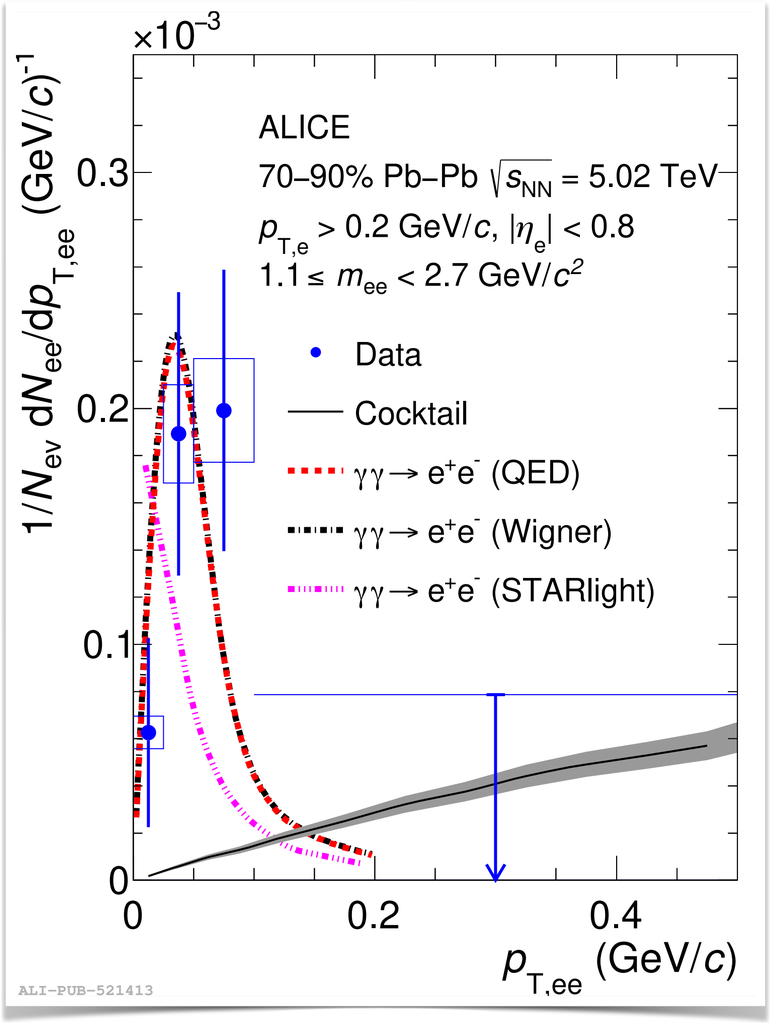

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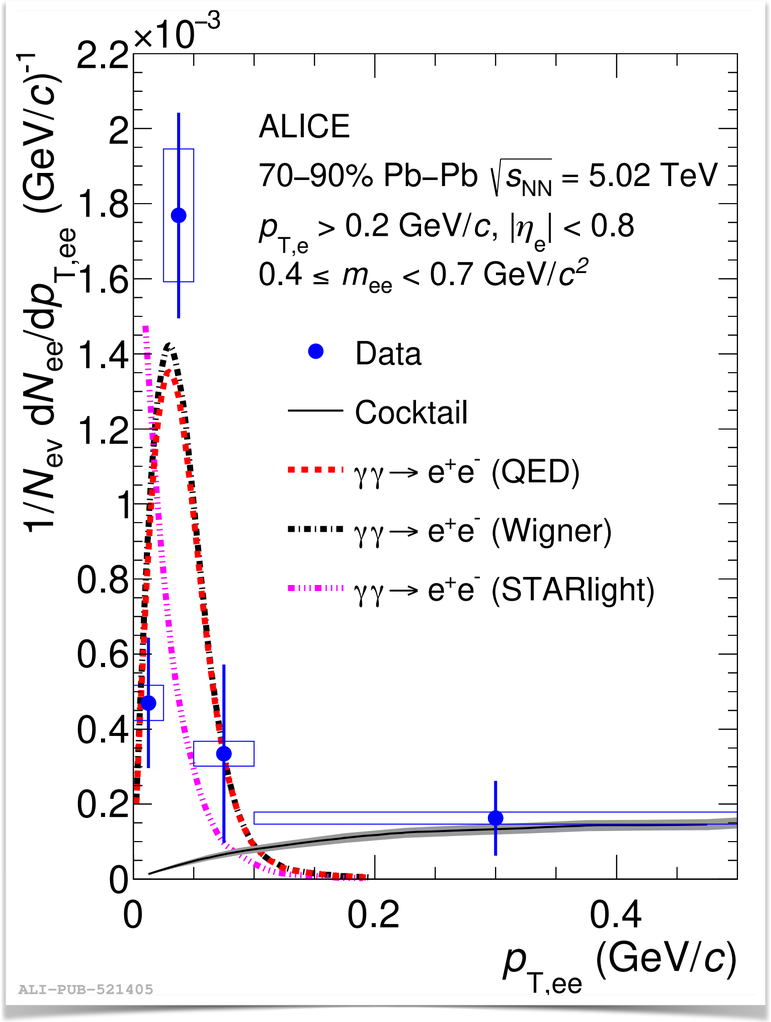

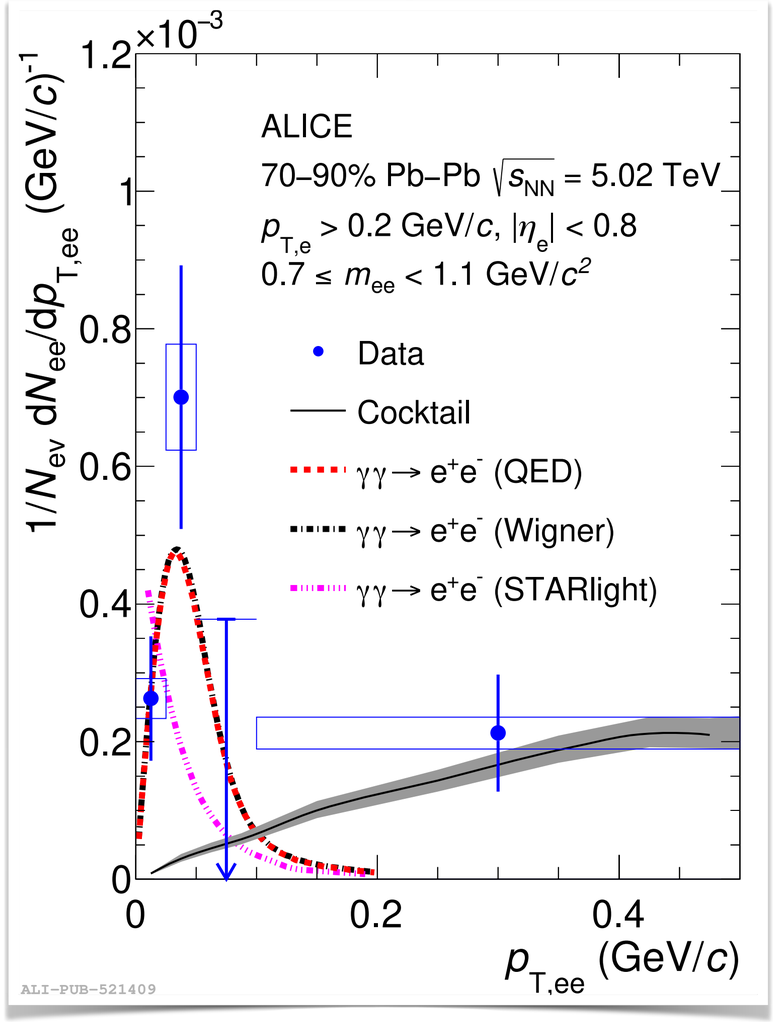

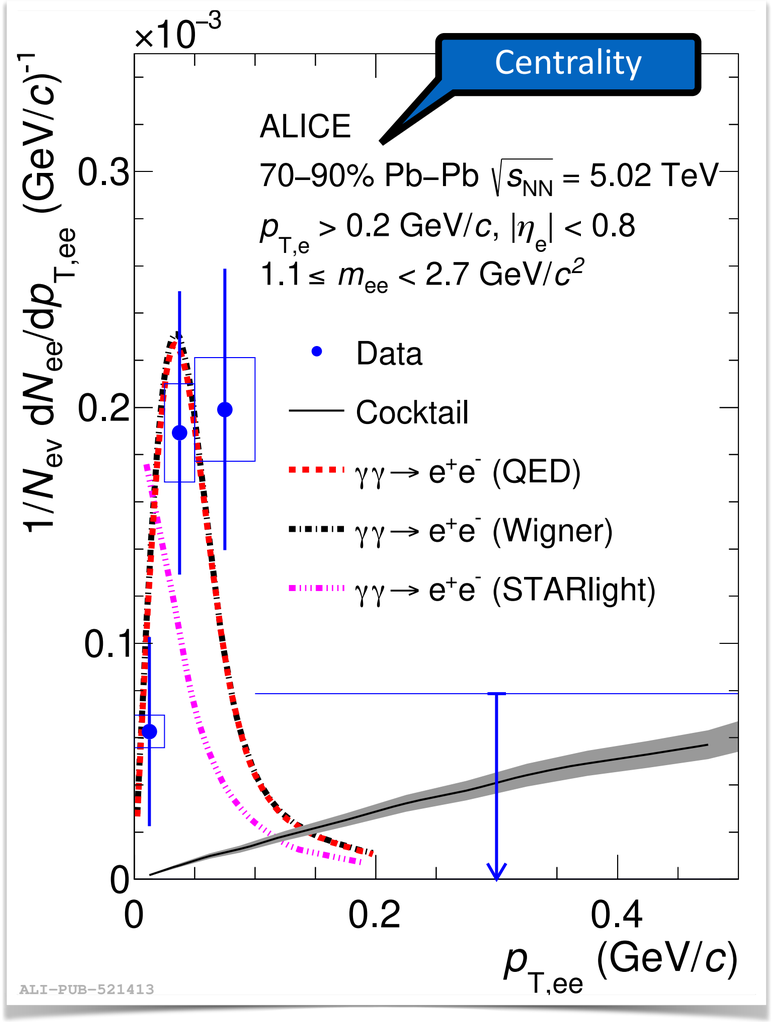

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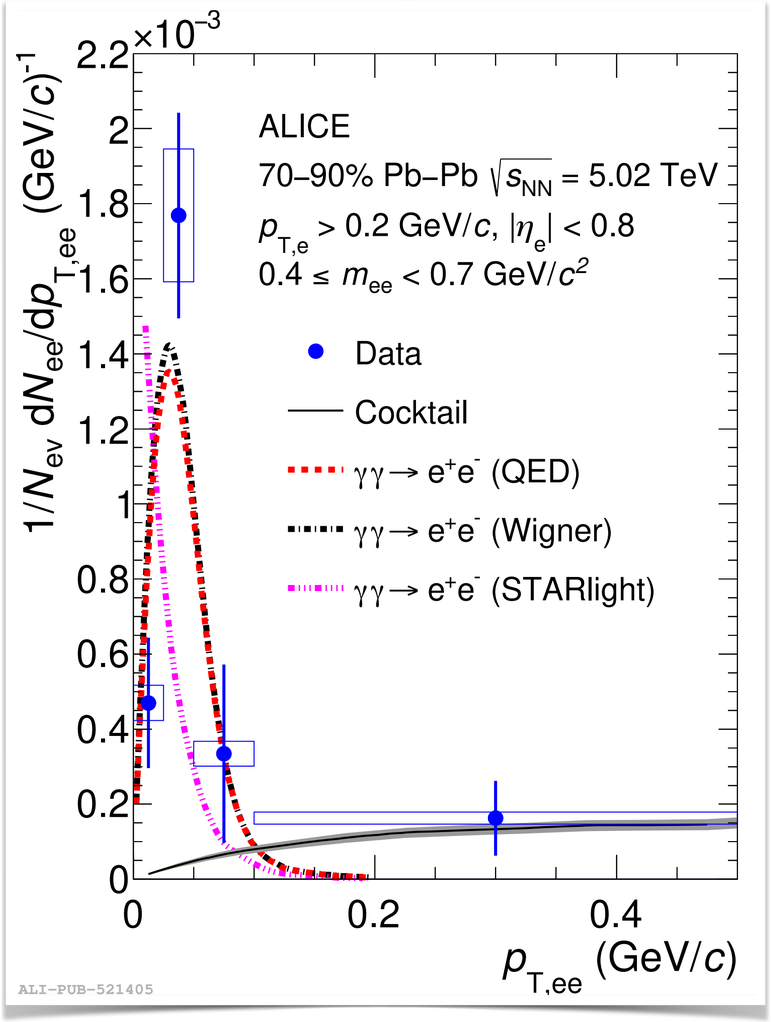
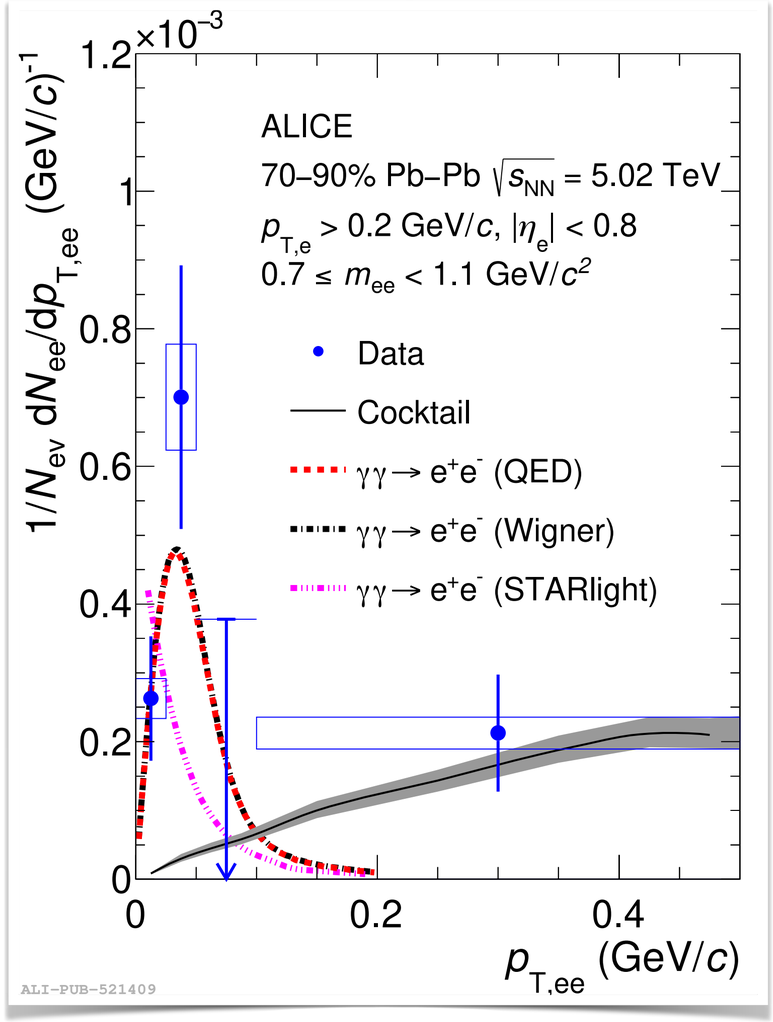
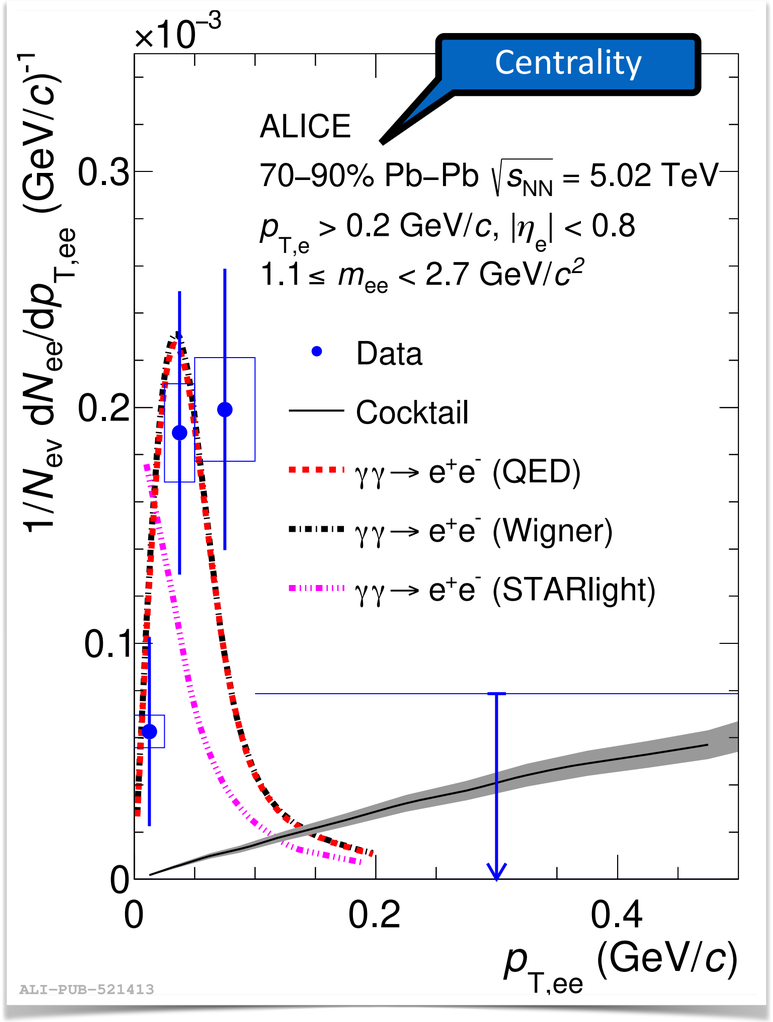
Dilepton invariant mass increasing in this direction





Centrality



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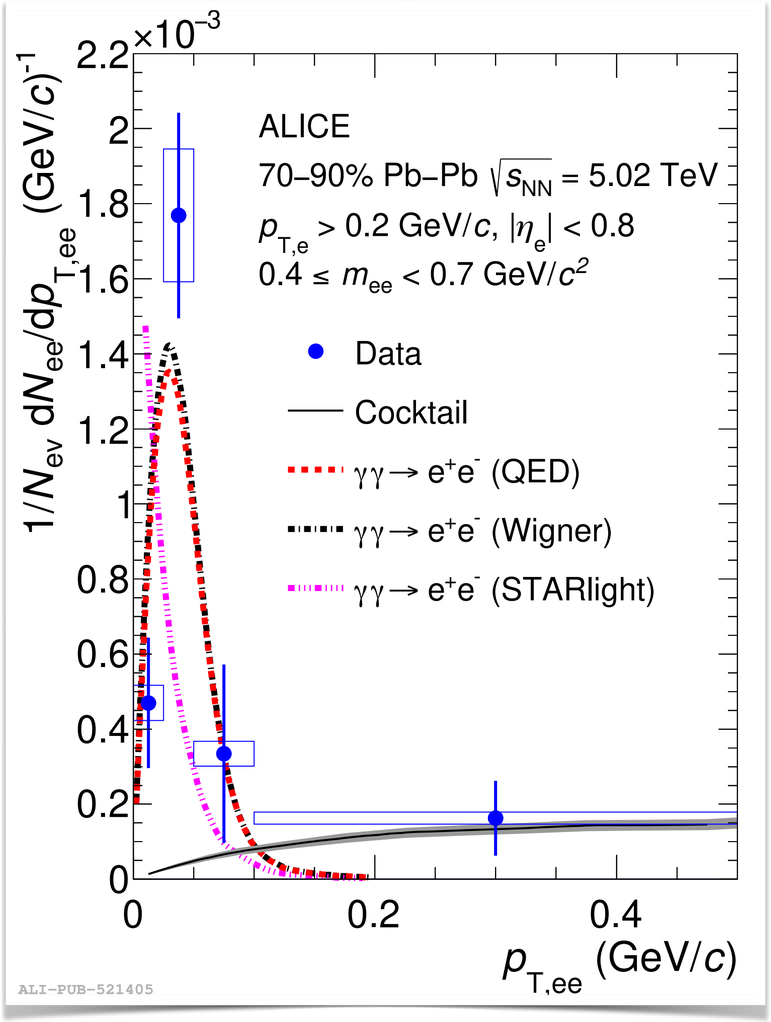

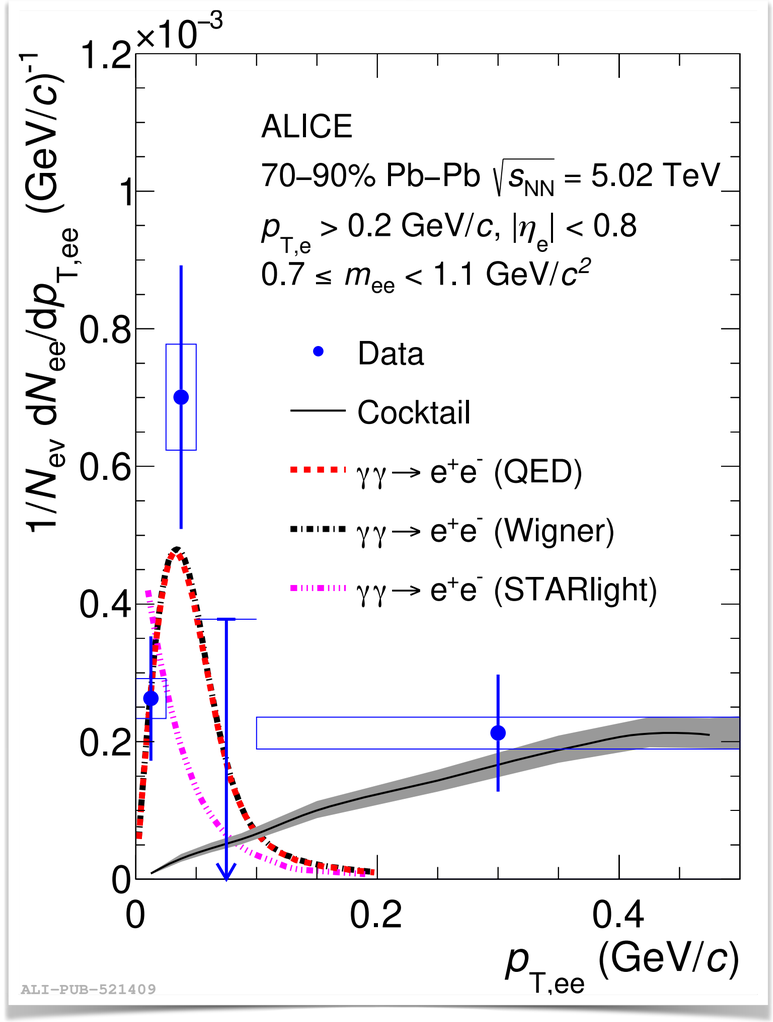

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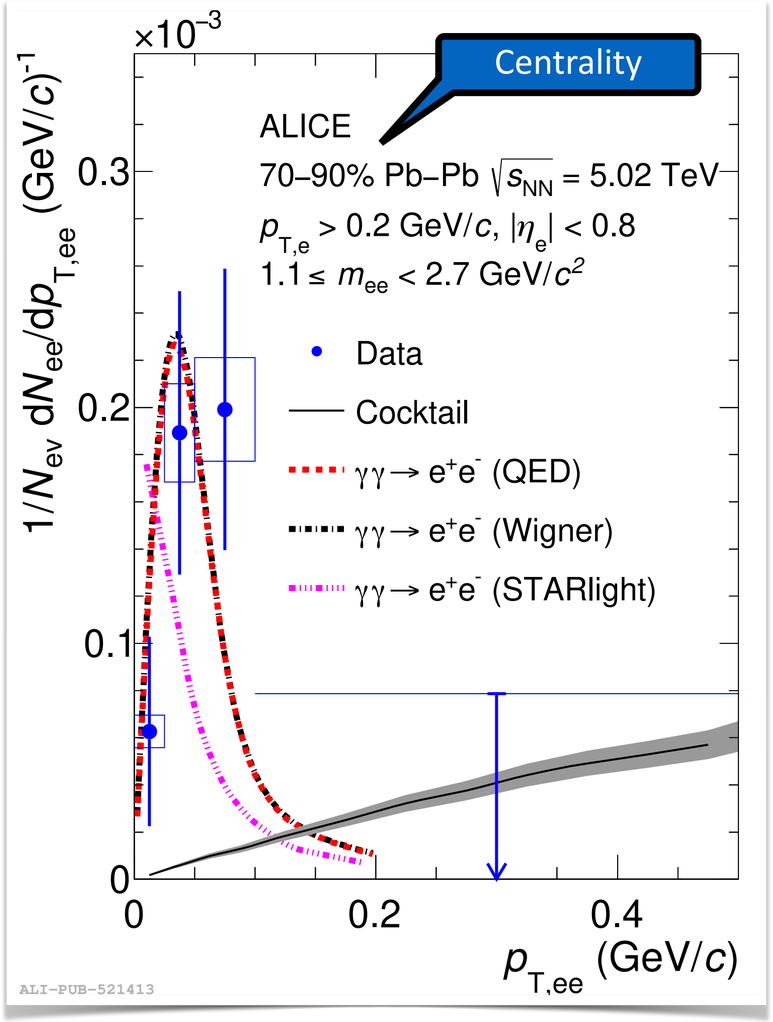
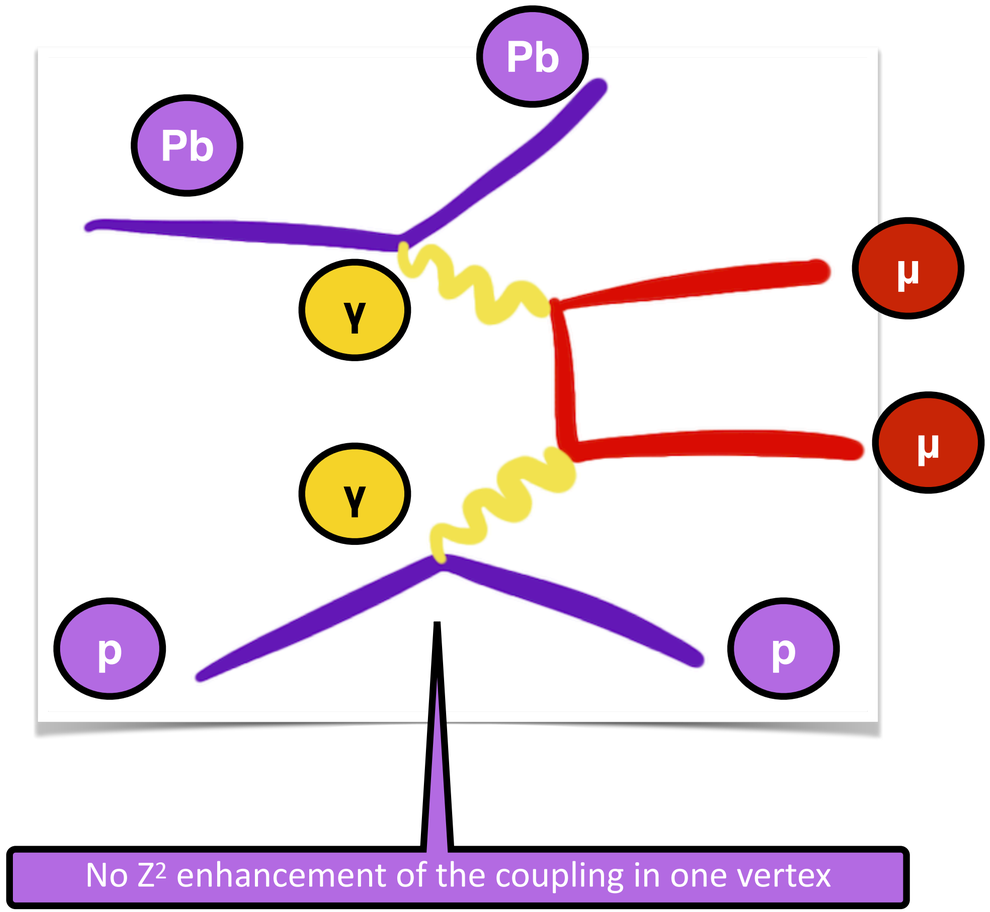


Dilepton pT

Model w/o impact-parameter dependence (STARlight) disfavoured by data, model with such dependence describe data

Photon-photon dilepton production: p-Pb



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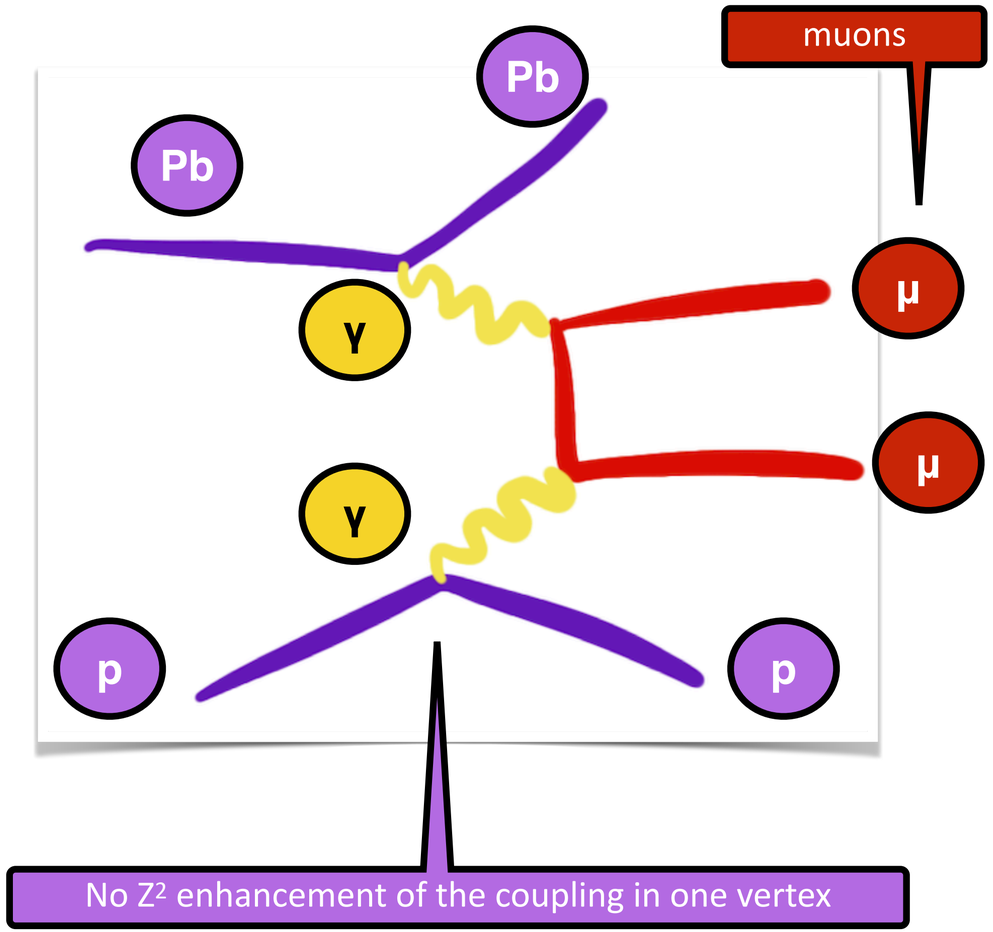

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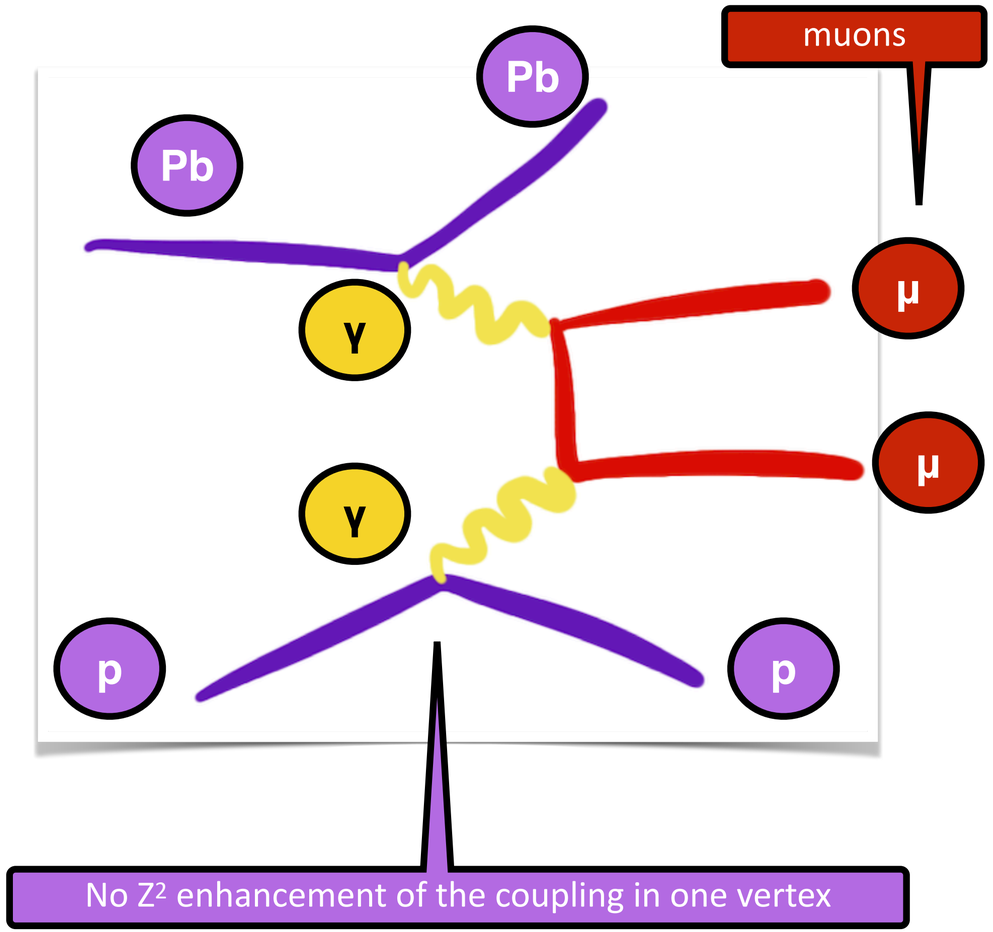

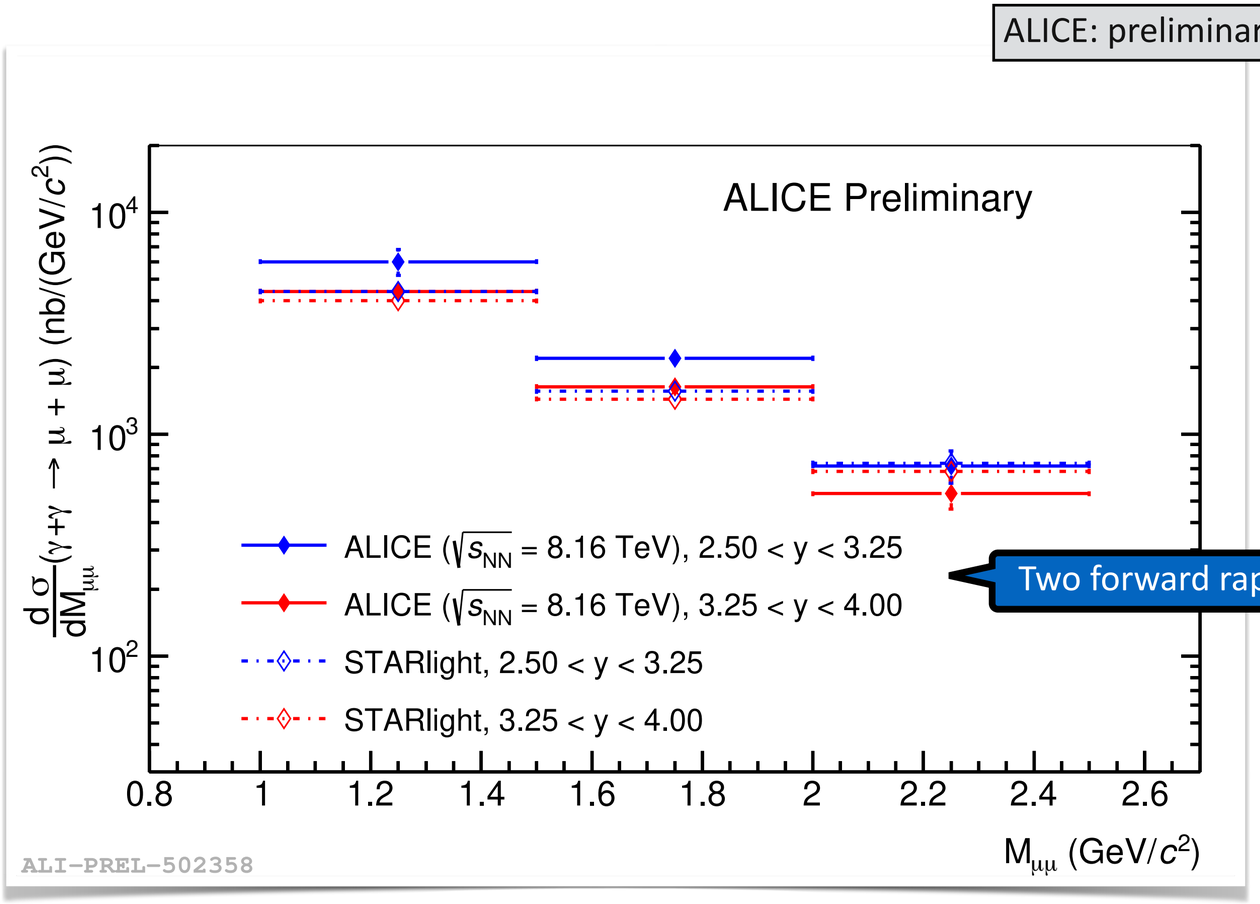

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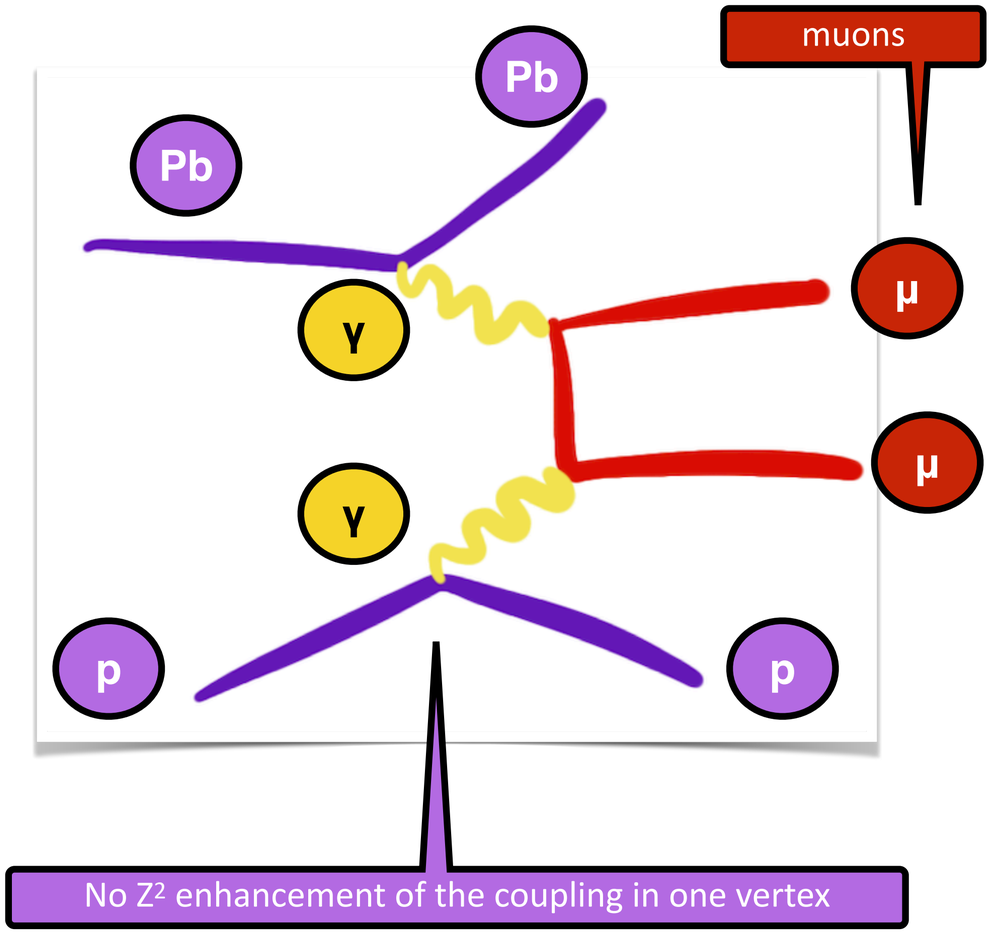

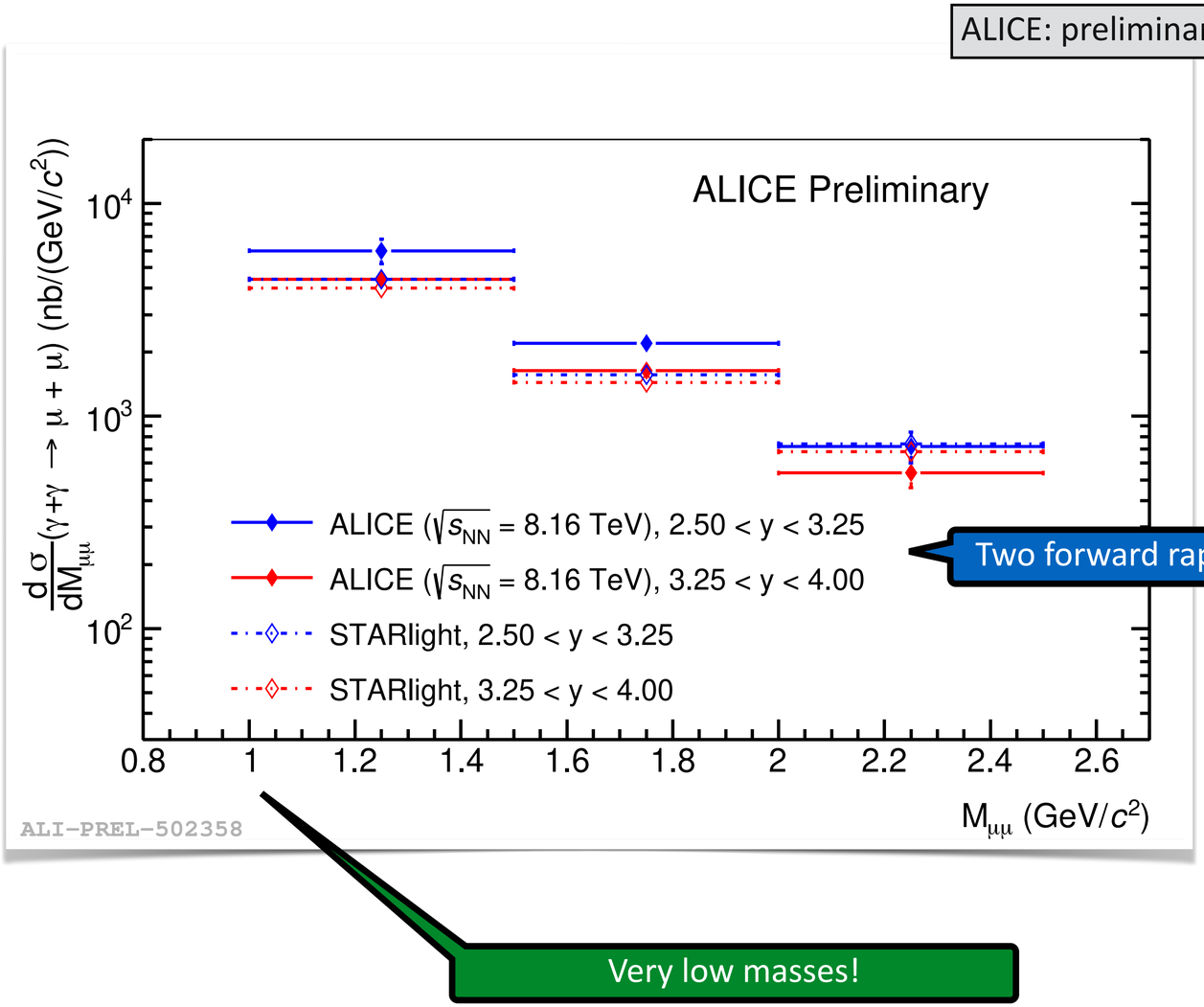

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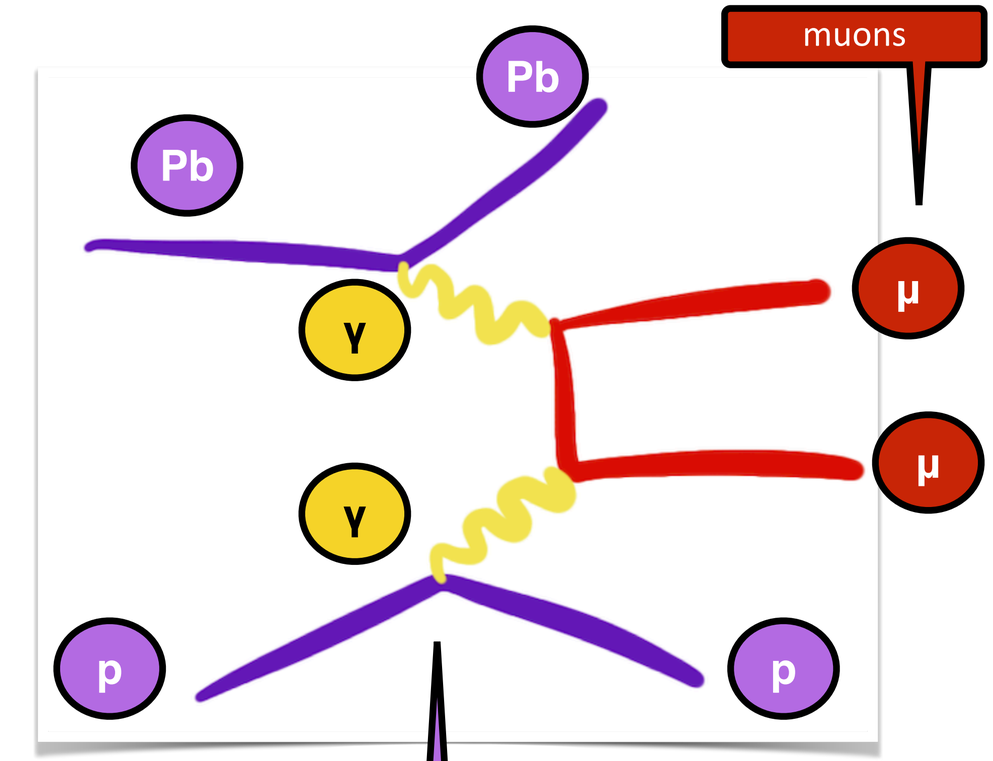
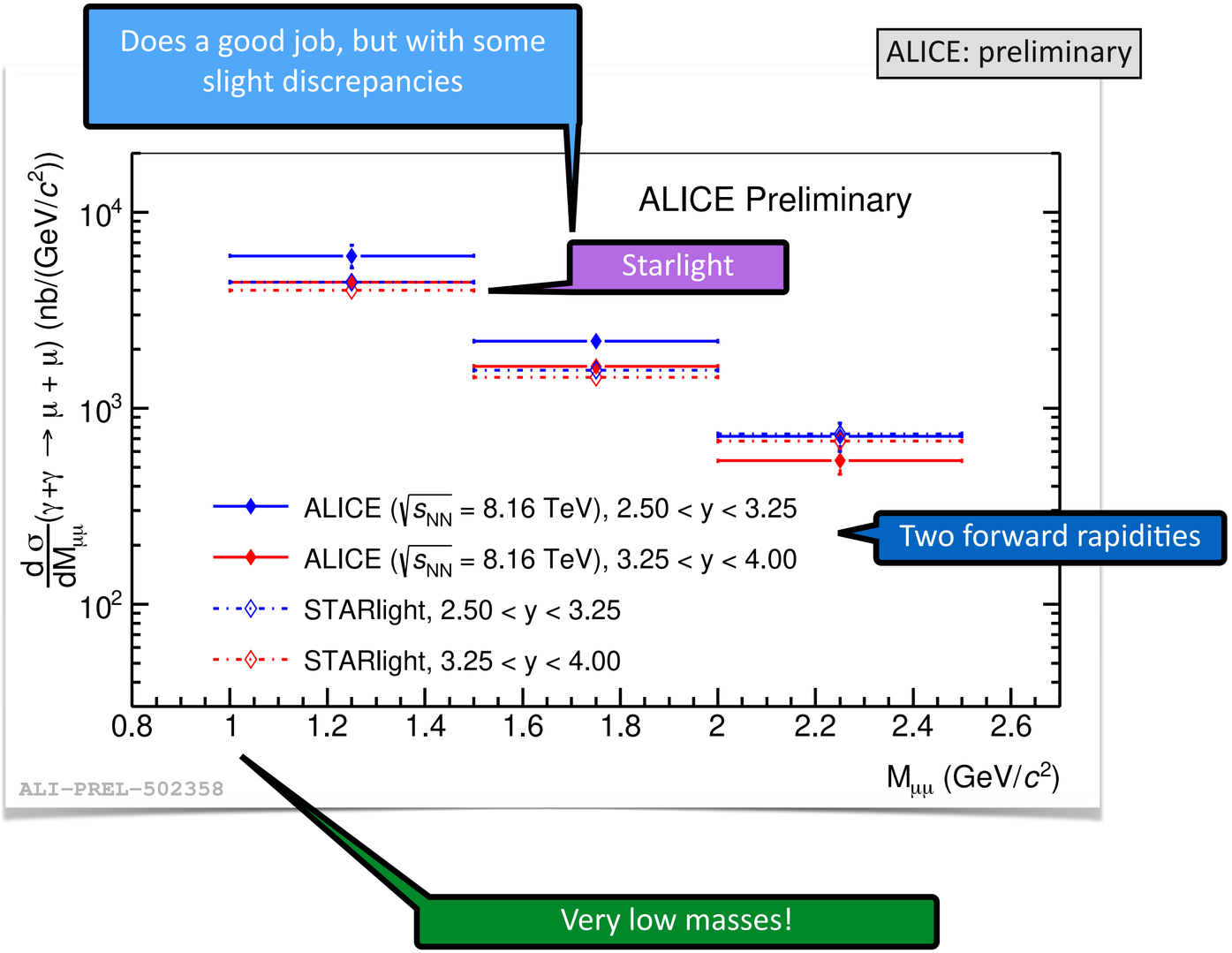
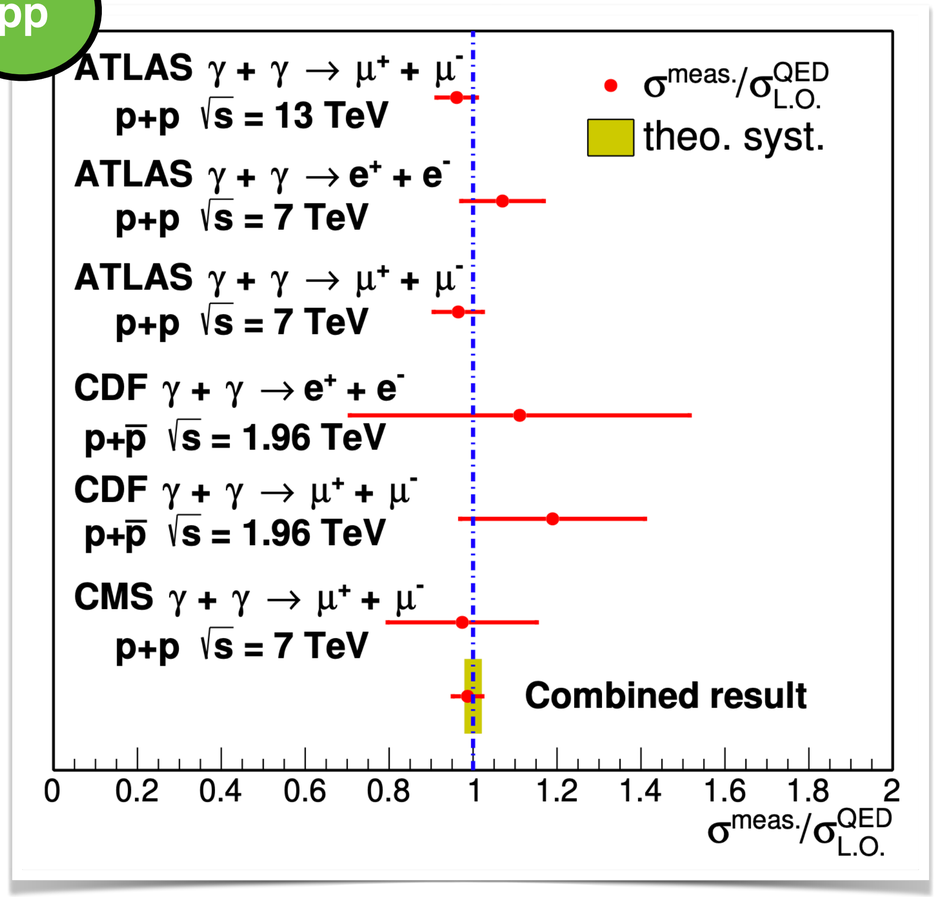


No Z^2 enhancement of the coupling in one vertex



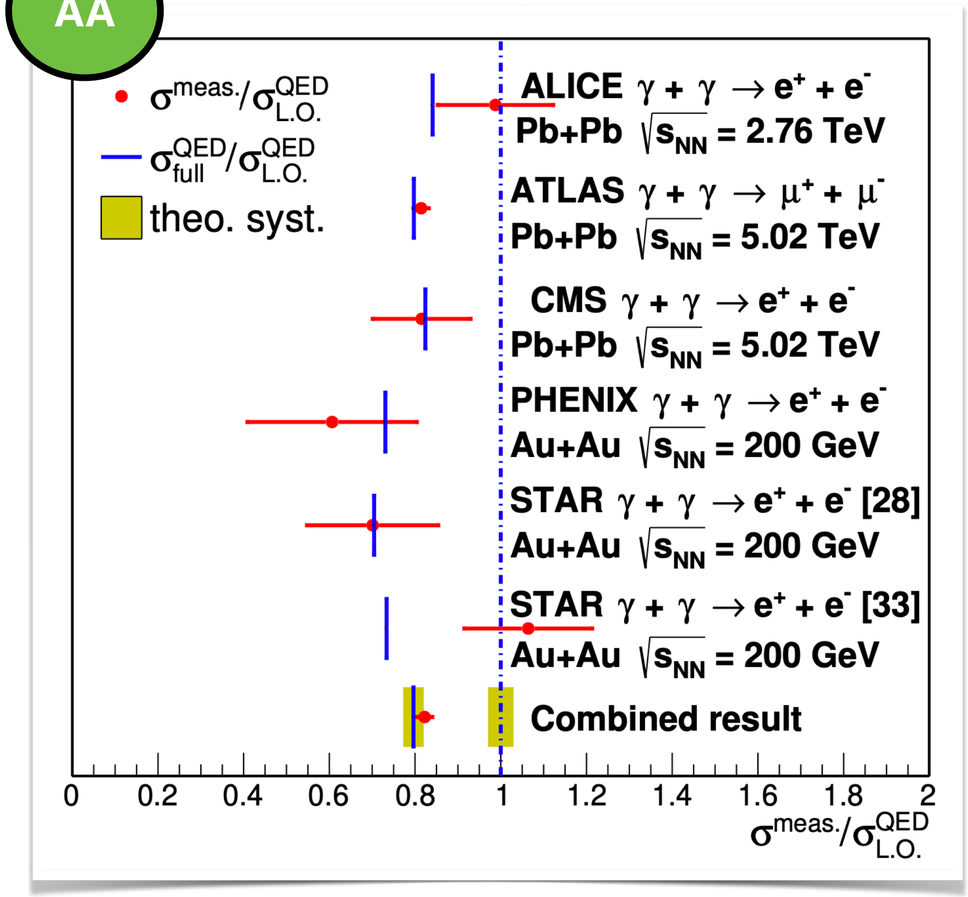
Photon-photon dilepton production: higher orders?

pp



AA

Zha, Tang, JHEP 08 (2021) 083



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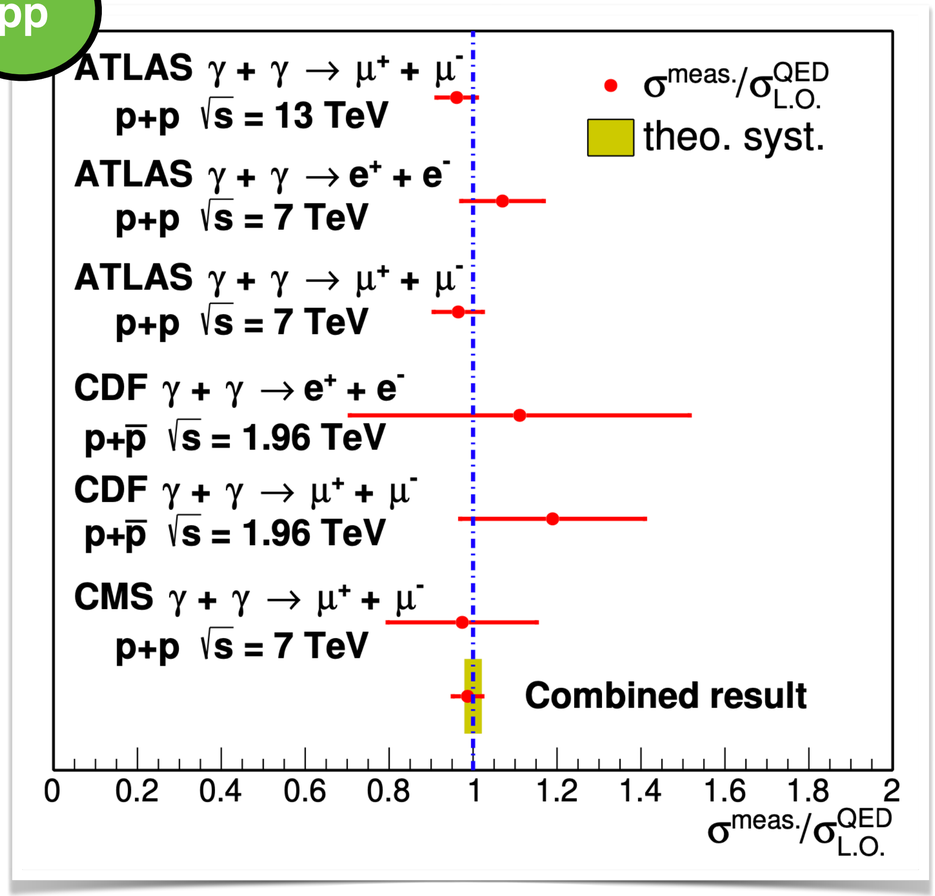

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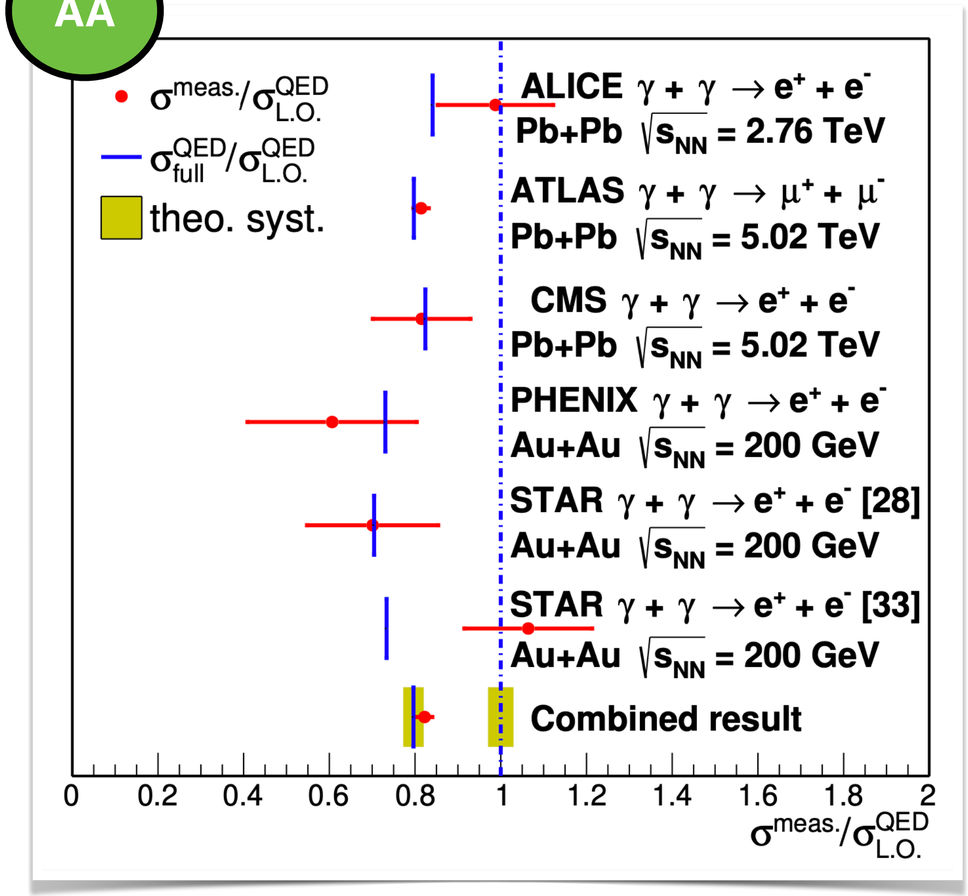

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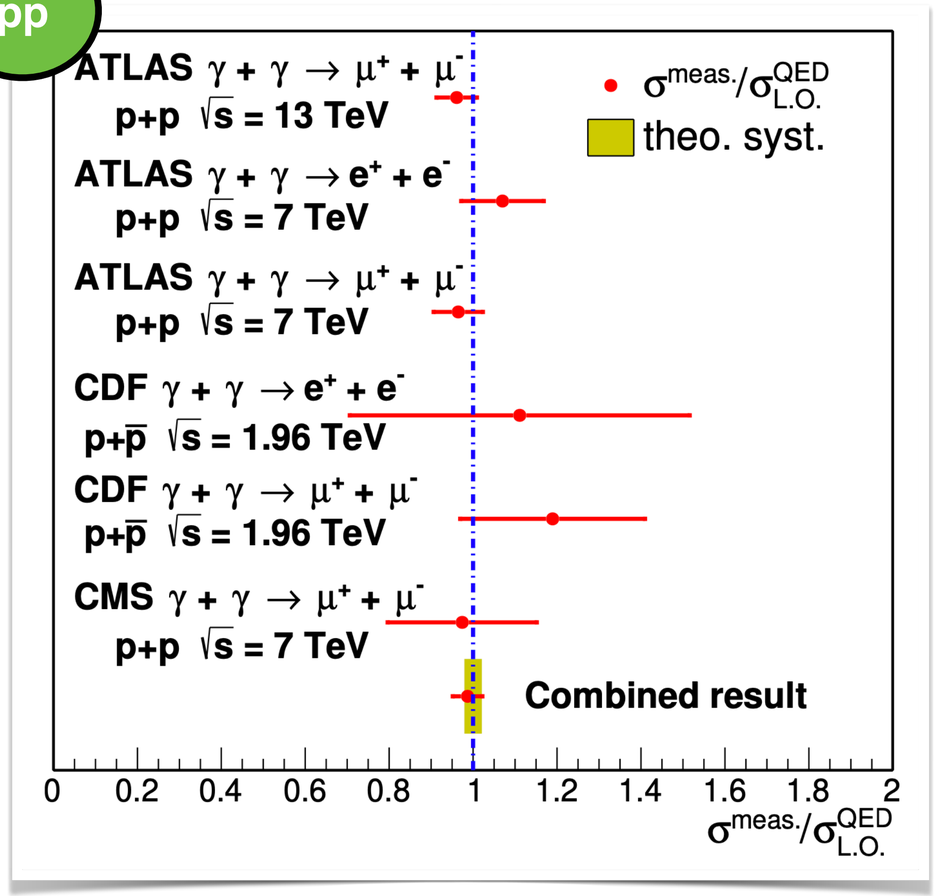

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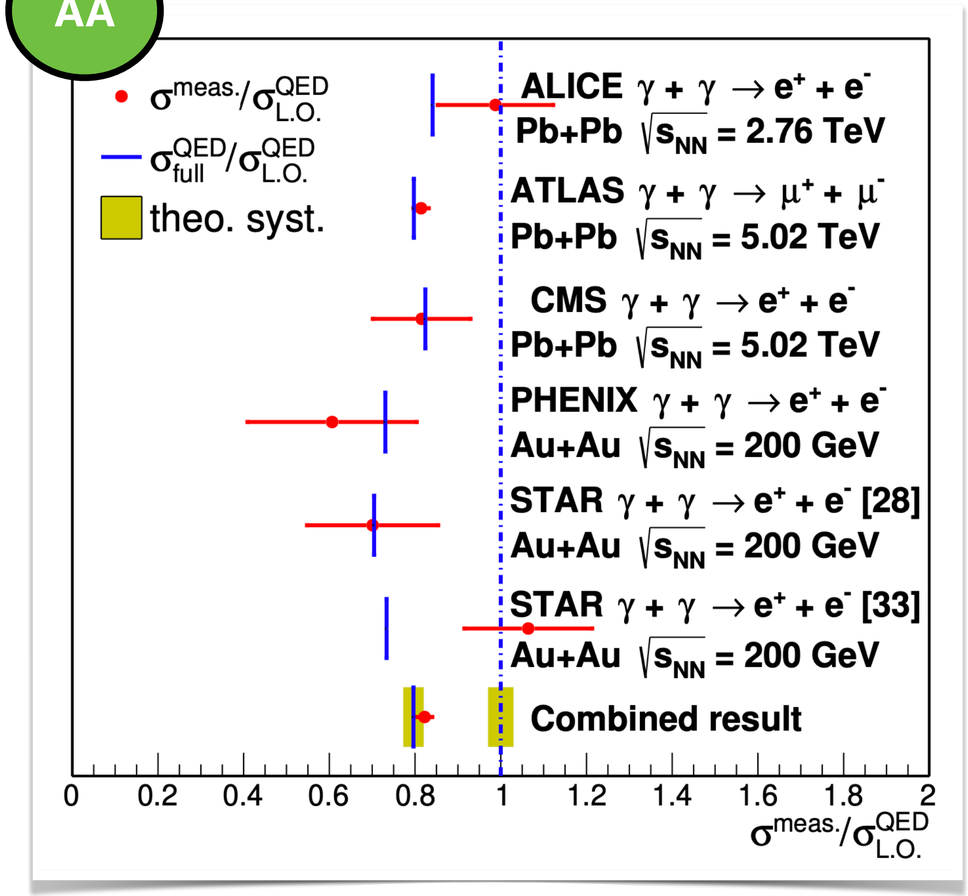

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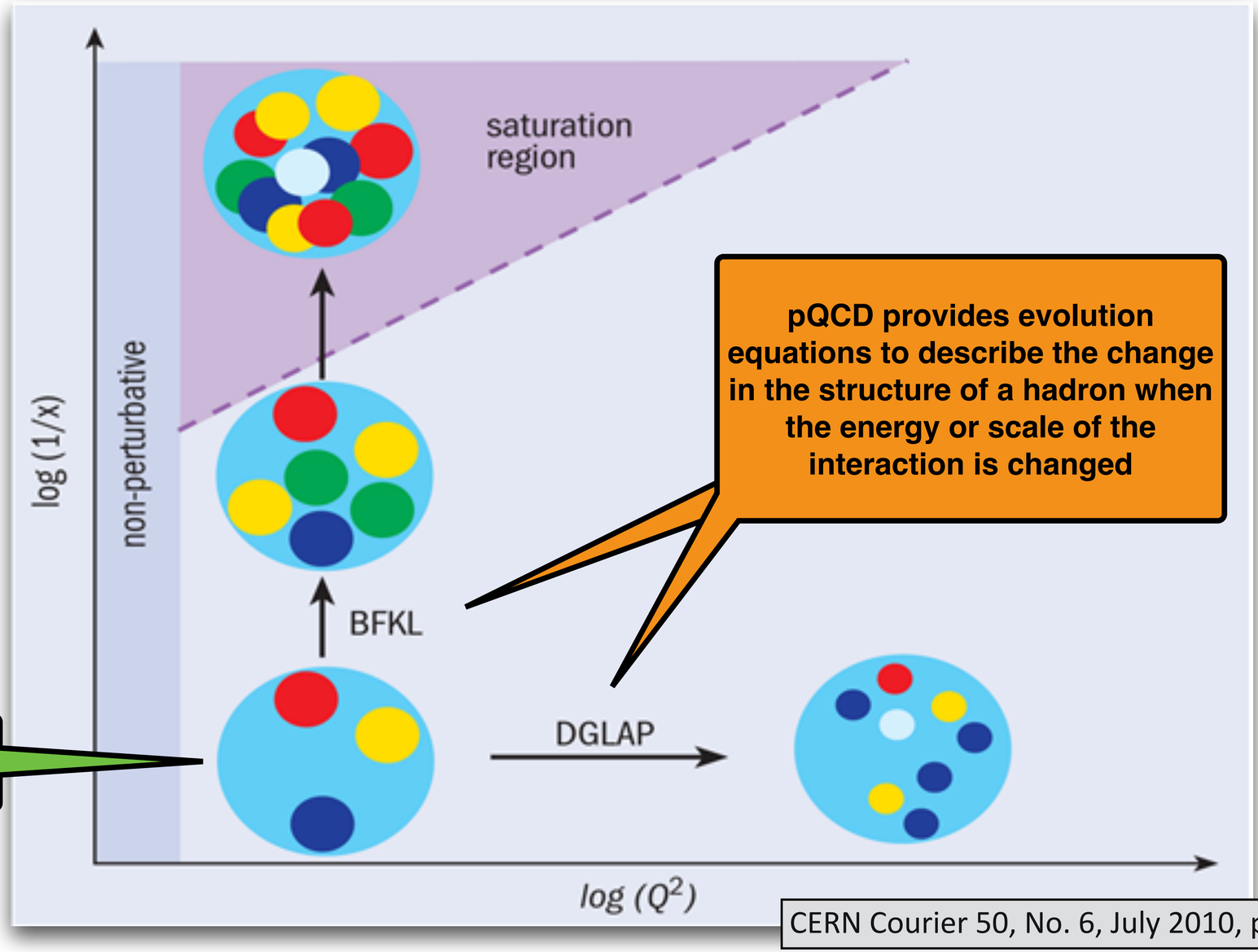
Many experimental handles available at the LHC
A large increase in the size of the data sample for Run 3

Diffractive vector-meson photoproduction
Introduction

The physics we are interested in (in a nutshell)

pQCD



CERN Courier 50, No. 6, July 2010, p.24

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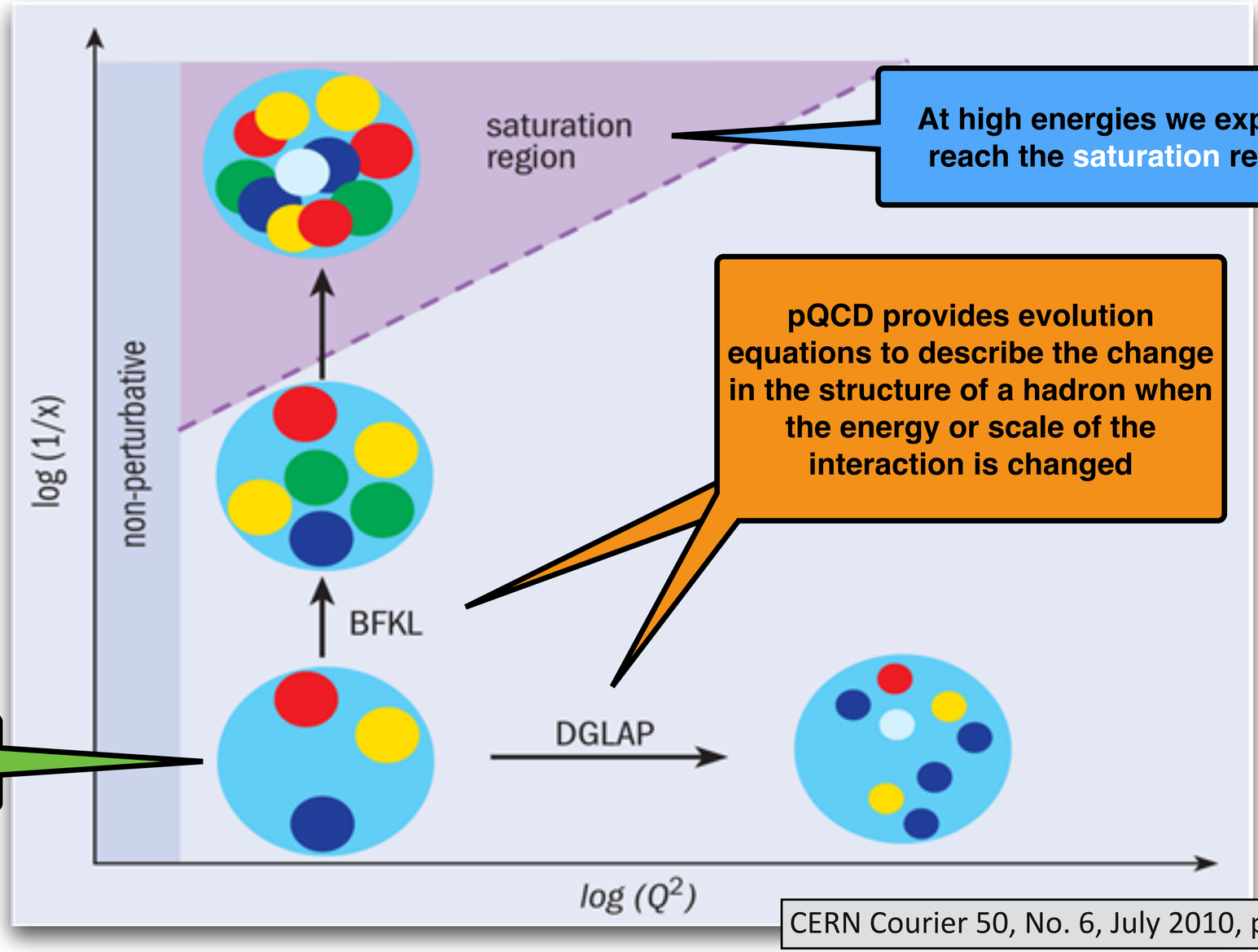


At high energies we expect to reach the saturation regime,

pQCD provides evolution equations to describe the change in the structure of a hadron when the energy or scale of the interaction is changed

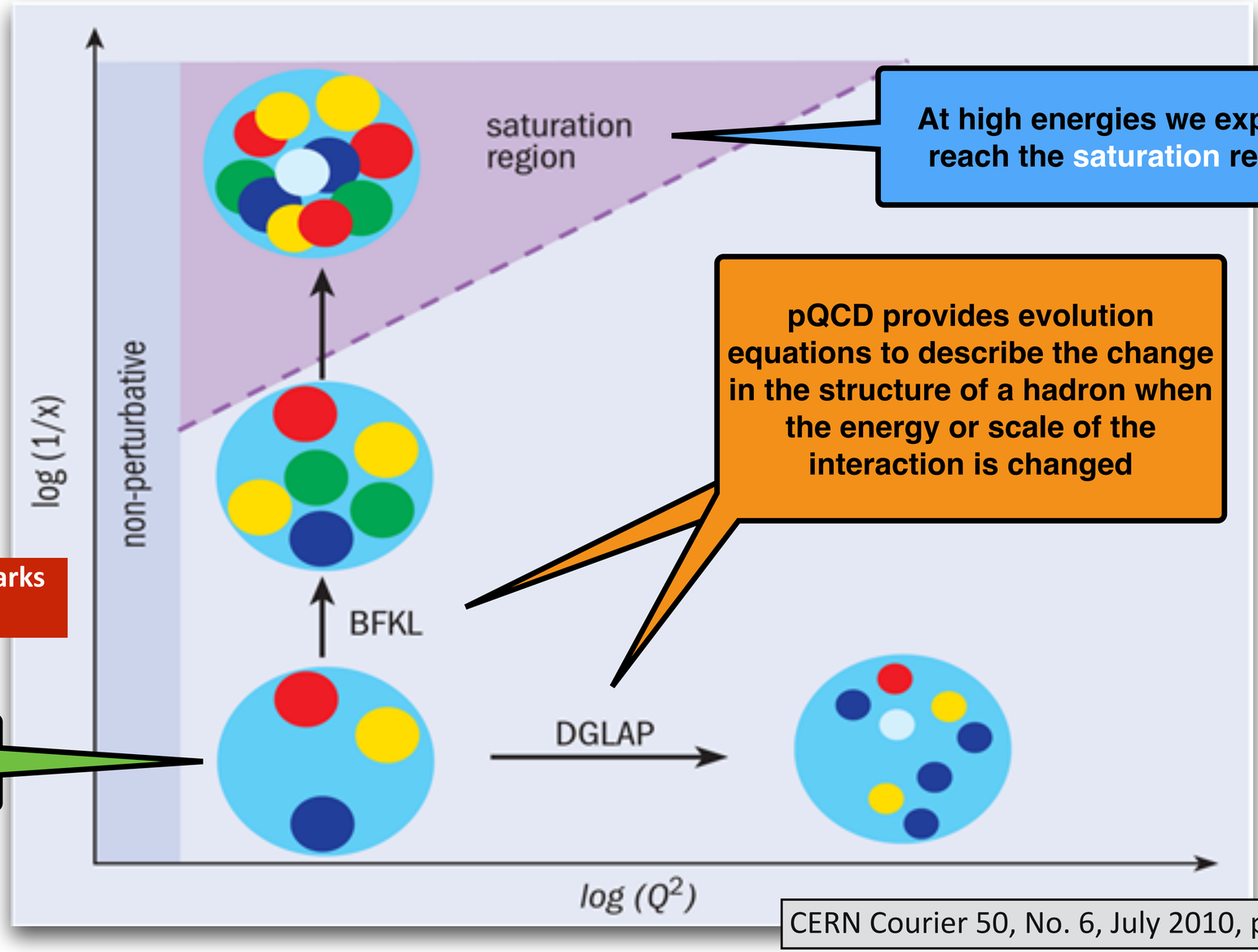
Quarks and gluons bound in hadrons

CERN Courier 50, No. 6, July 2010, p.24

The physics we are interested in (in a nutshell)

pQCD

Measure the structure of hadrons in terms of quarks and gluons at different scales and energies



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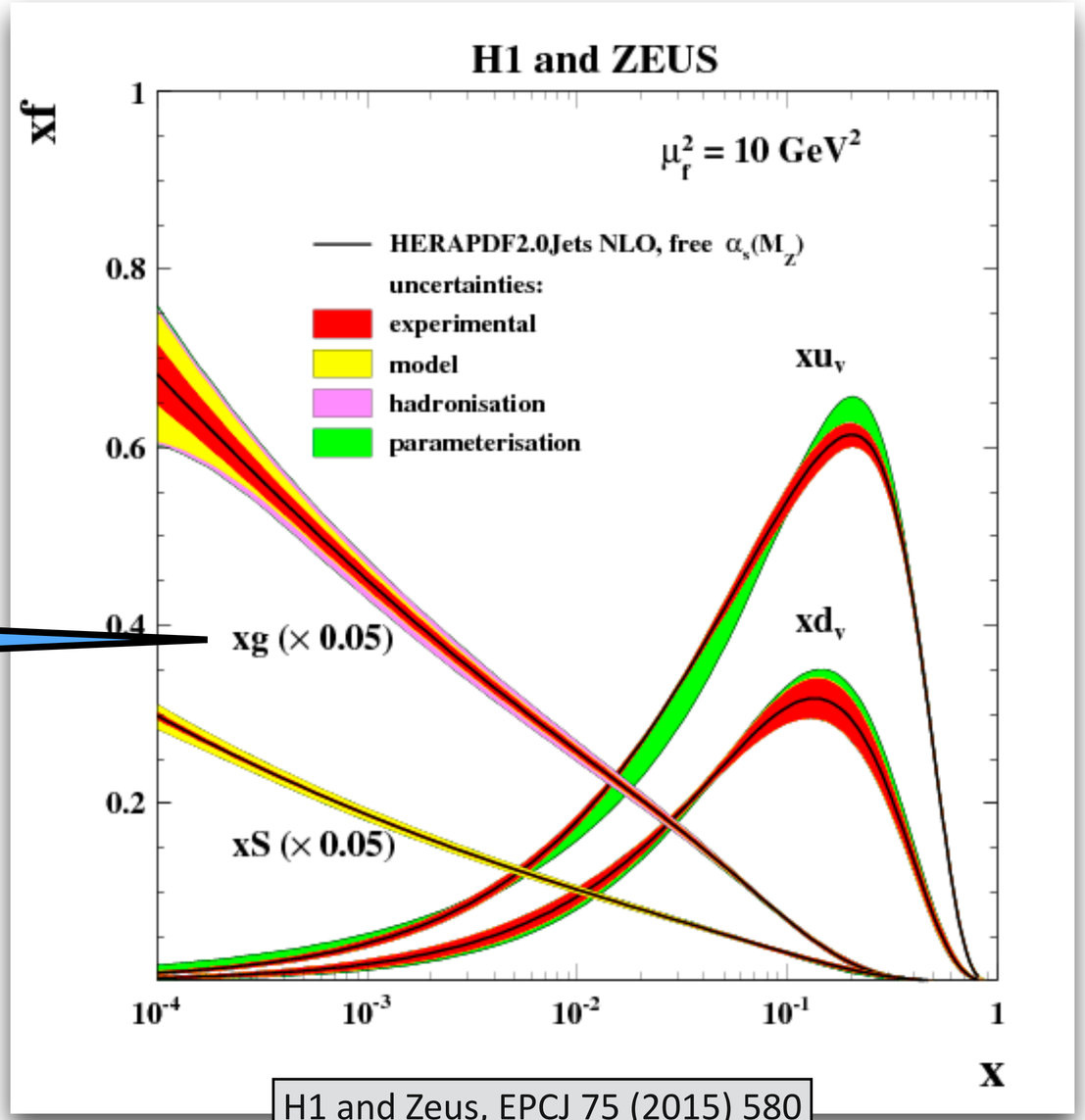
The gluon distribution in the proton dominates for decreasing x where it grows as a power law



H1 and Zeus, EPCJ 75 (2015) 580

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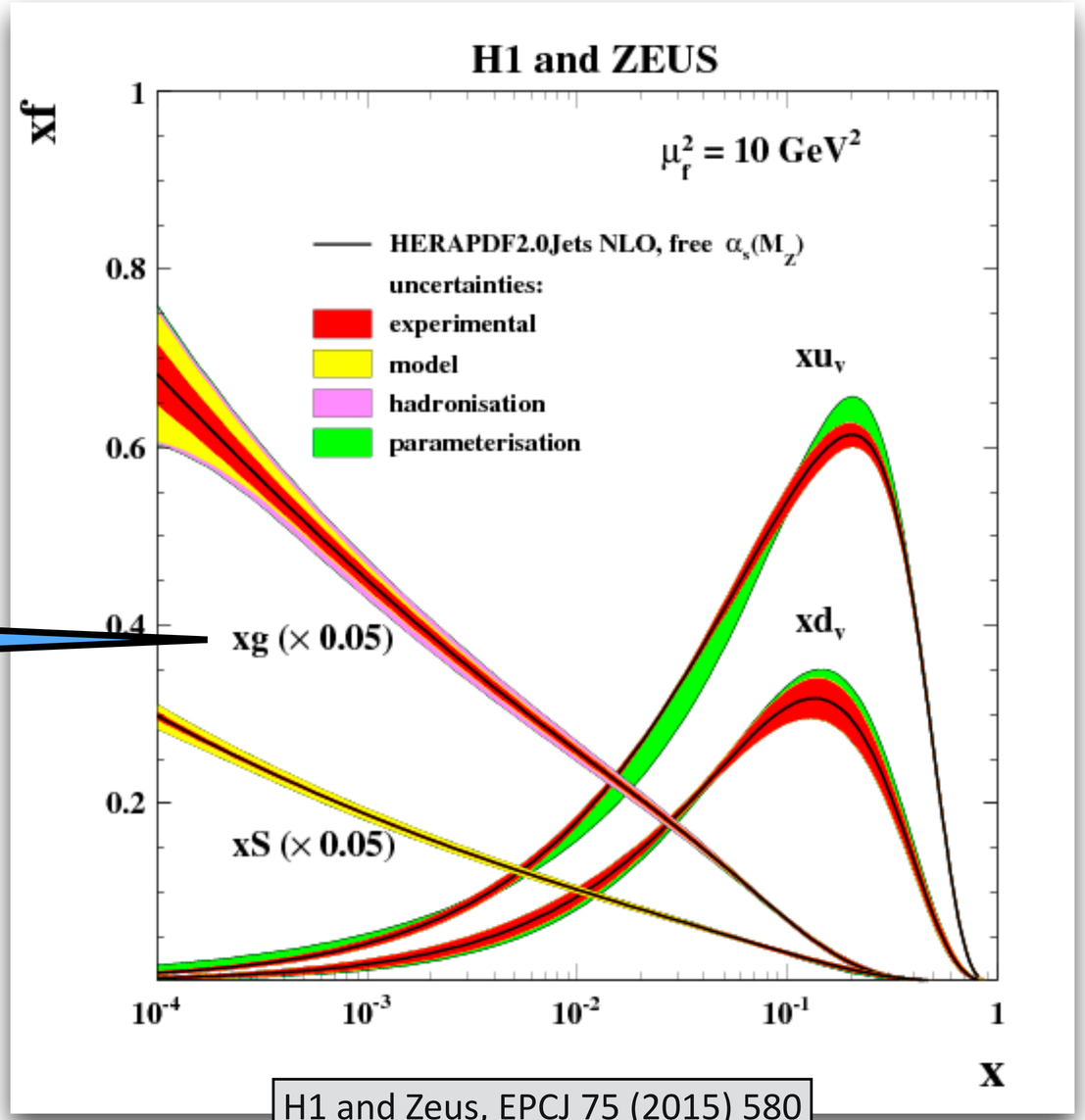
Concentrate on processes highly sensitive to the gluon content in hadrons



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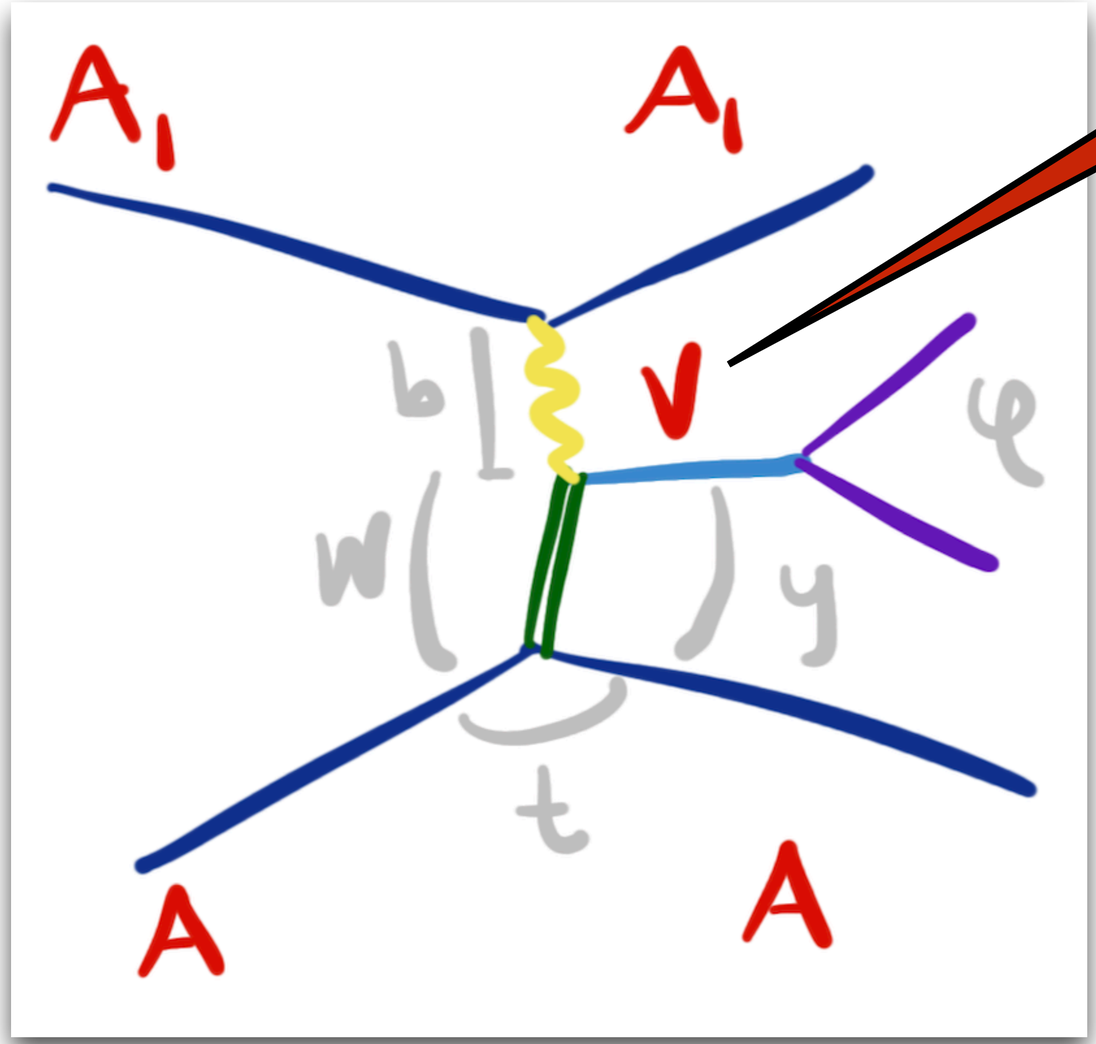
The process we are interested in



Diffractive photoproduction of vector mesons is very sensitive to the gluon distribution

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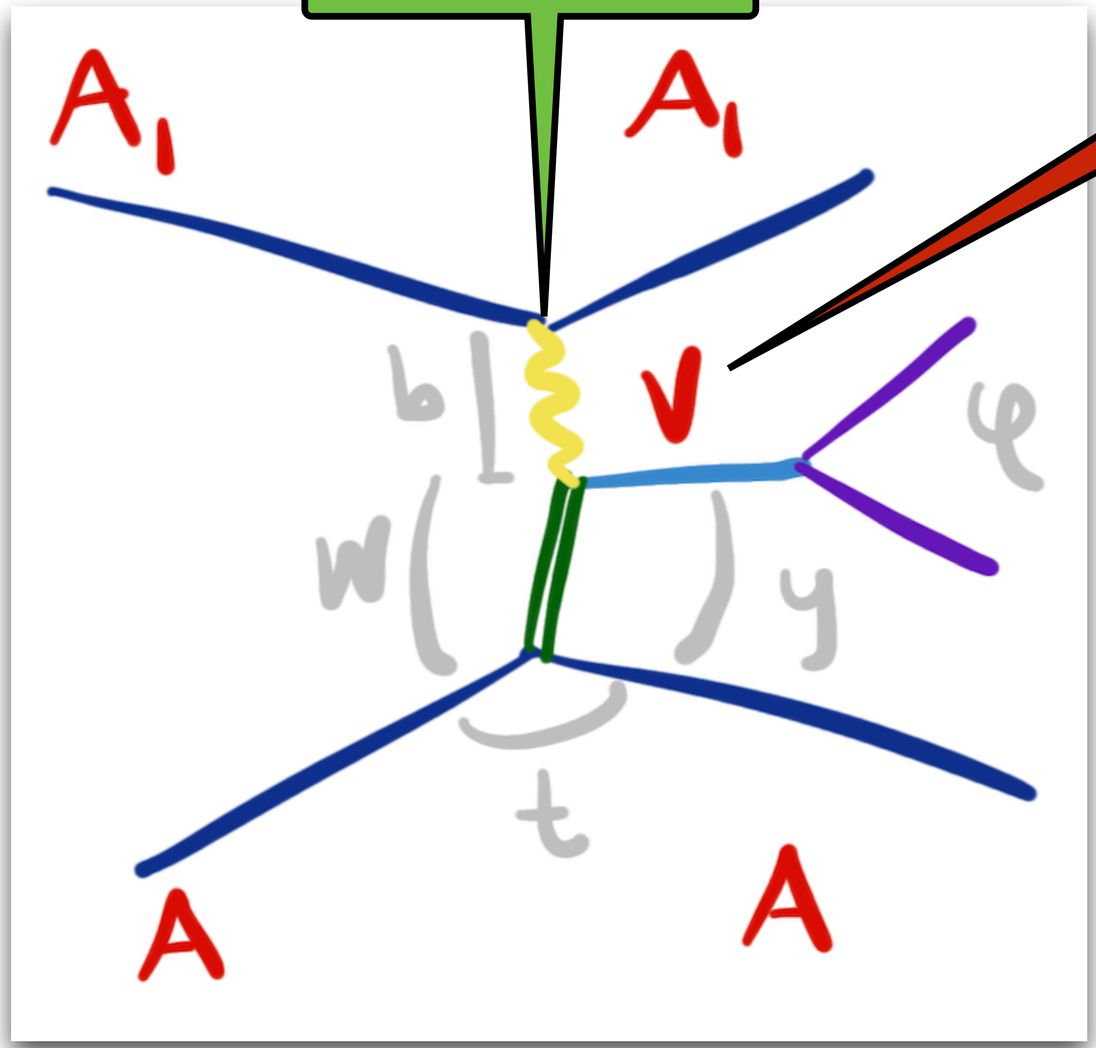

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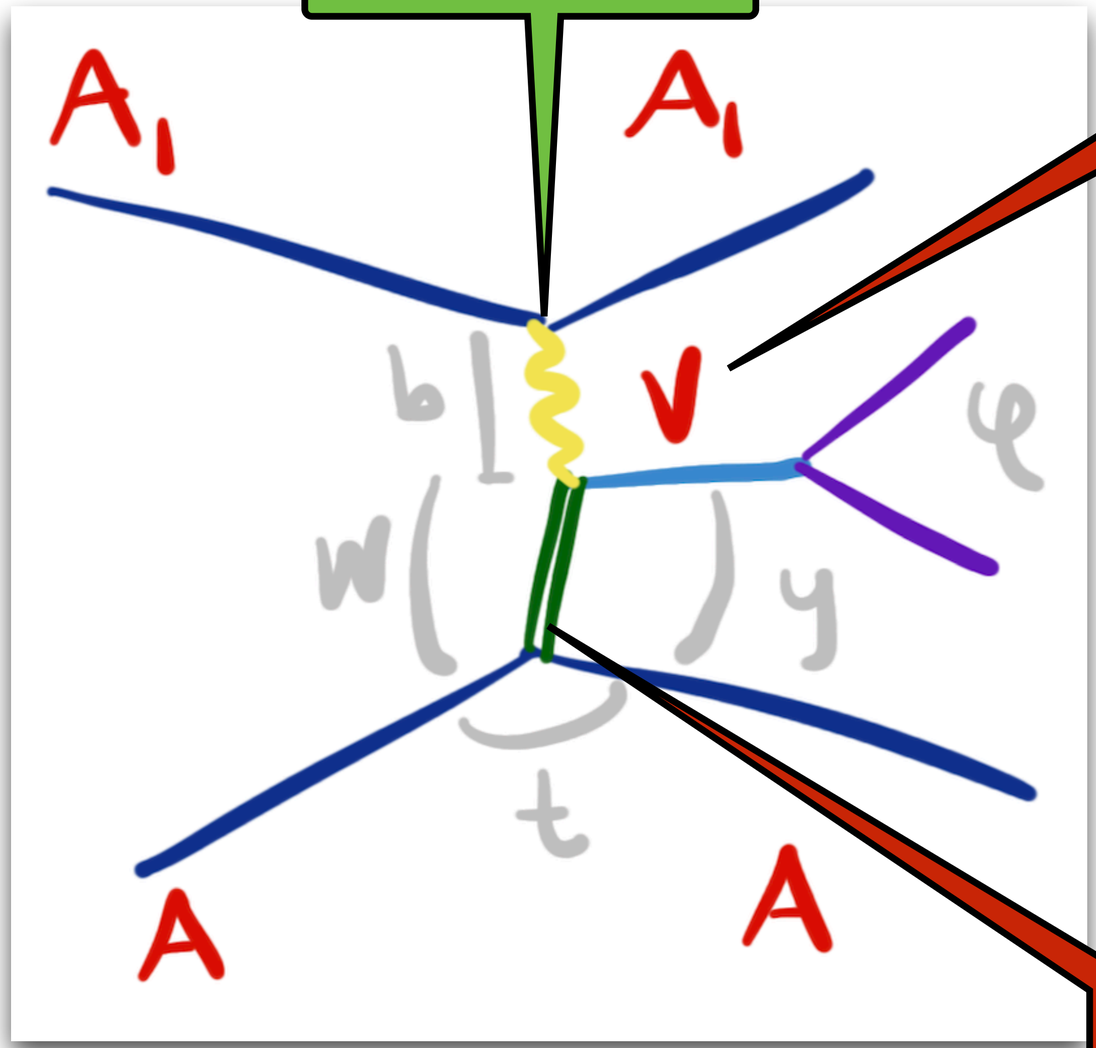

QED is in here

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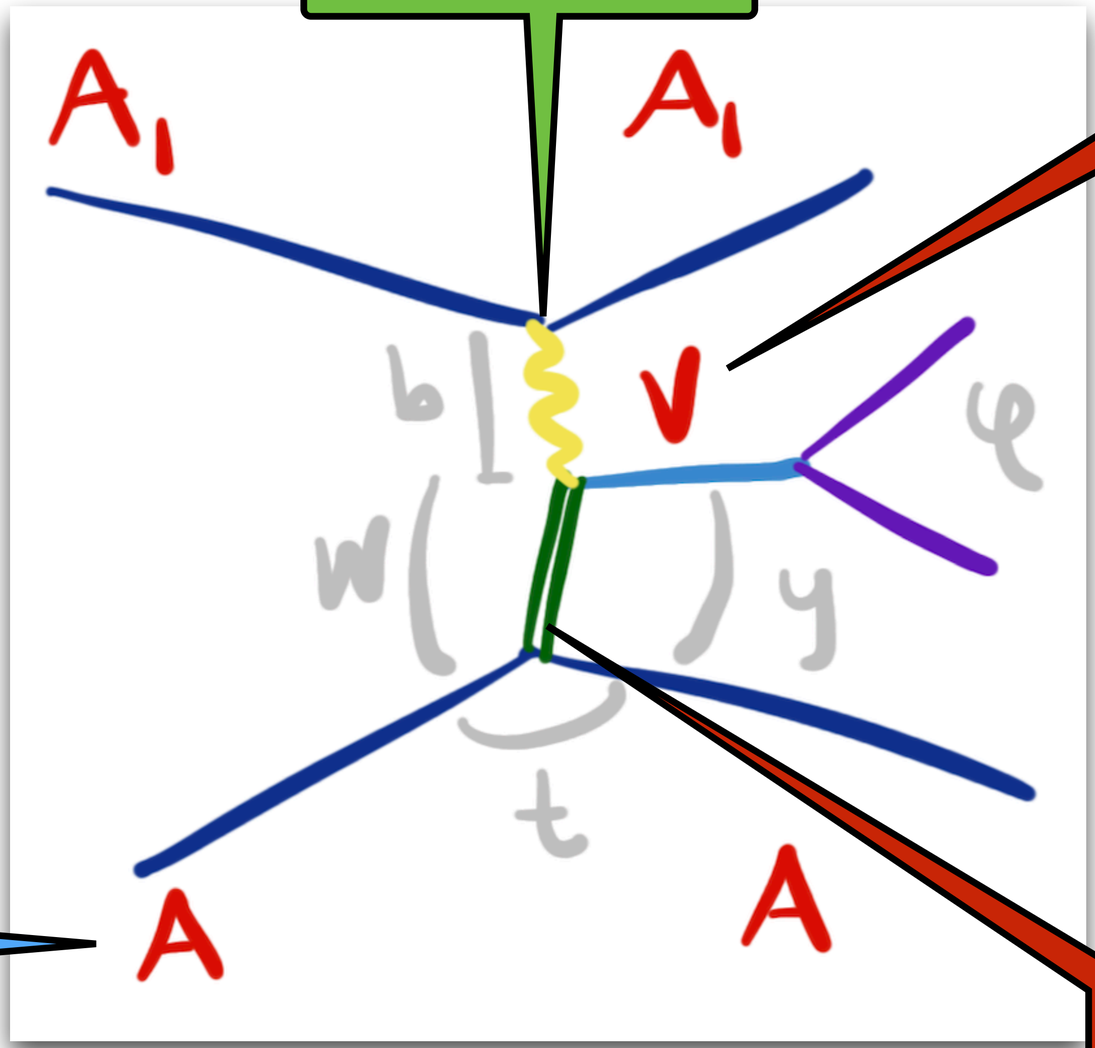

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At the LHC A=p, Pb or Xe

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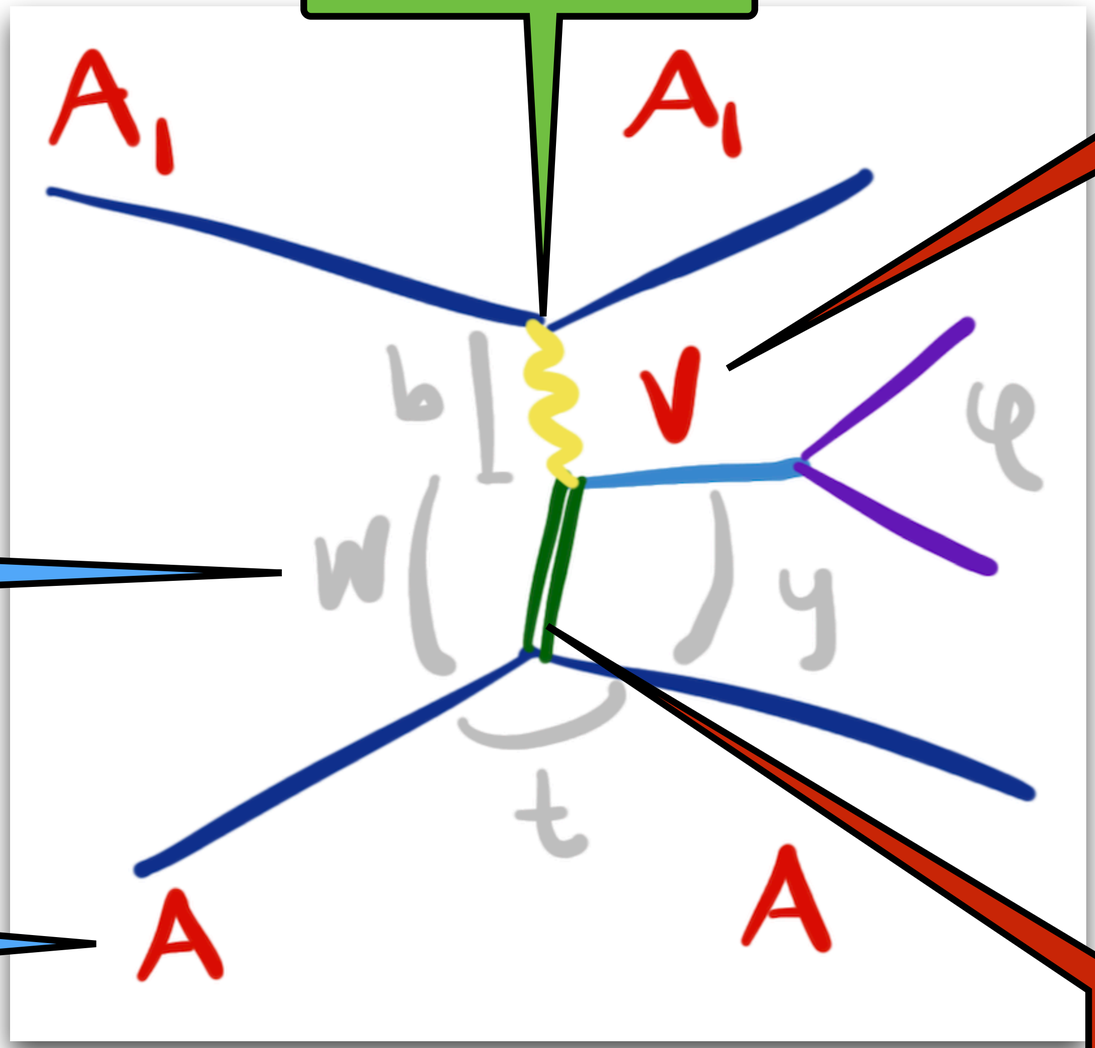

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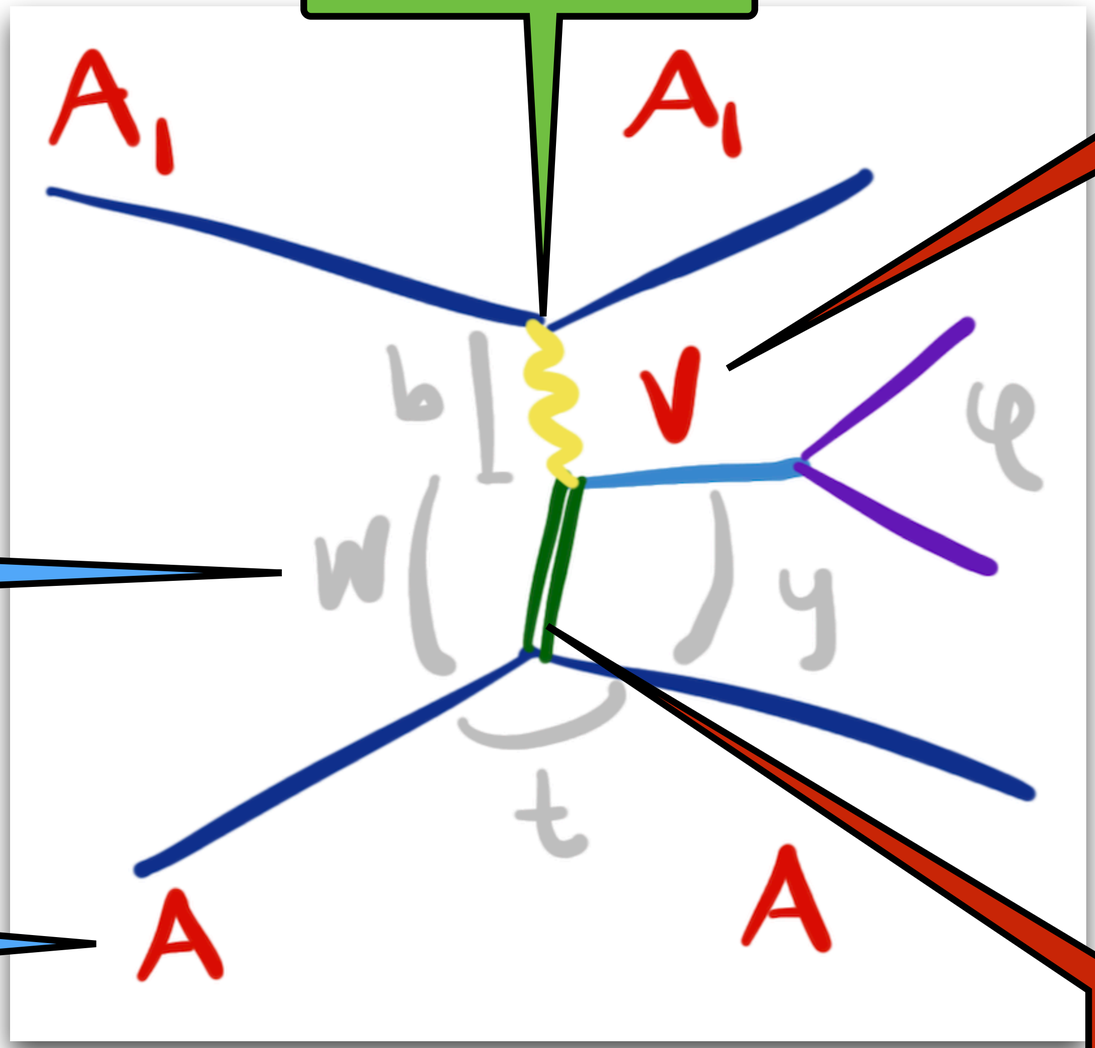

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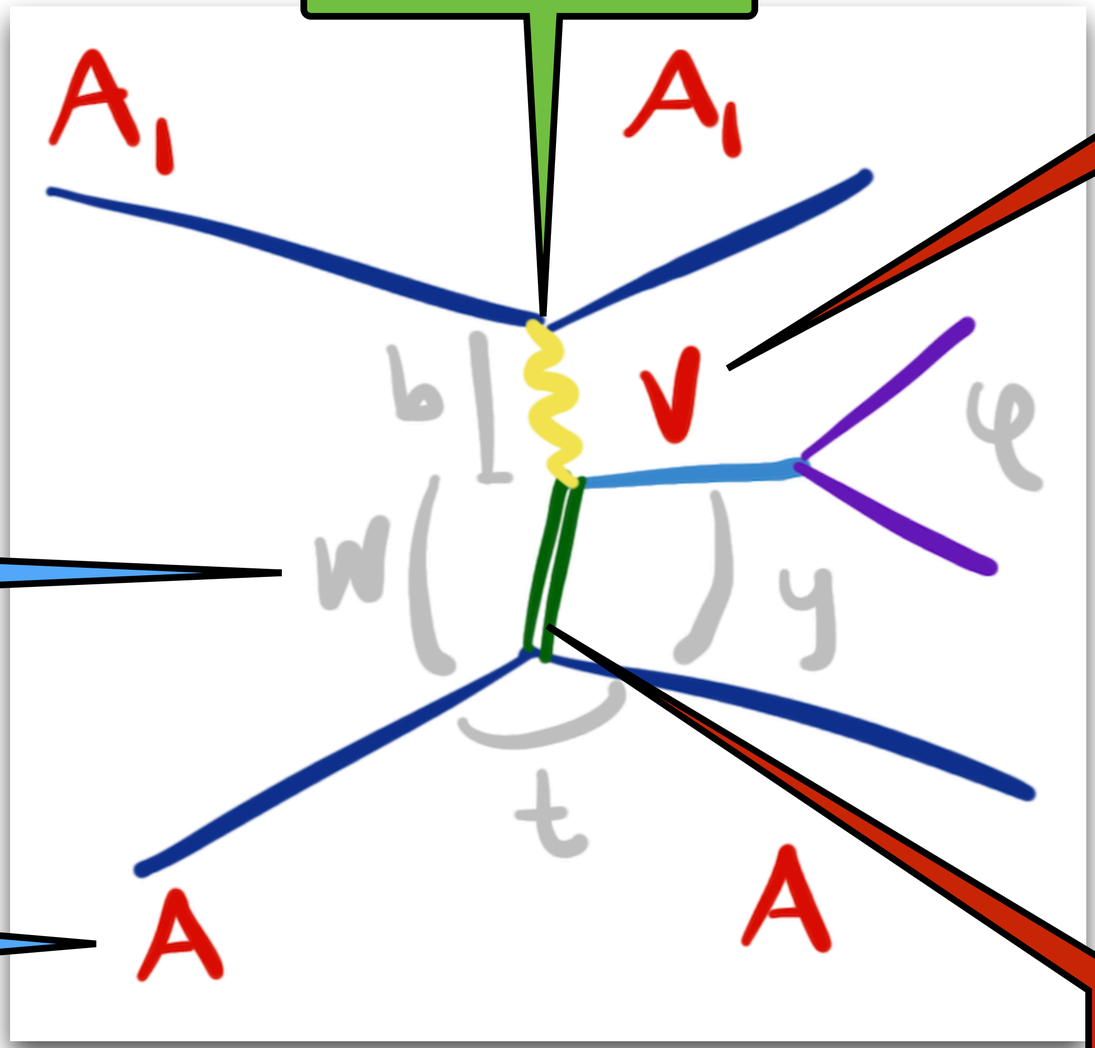

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Run 3+4

Hundred thousands of events expected In Run 3+4

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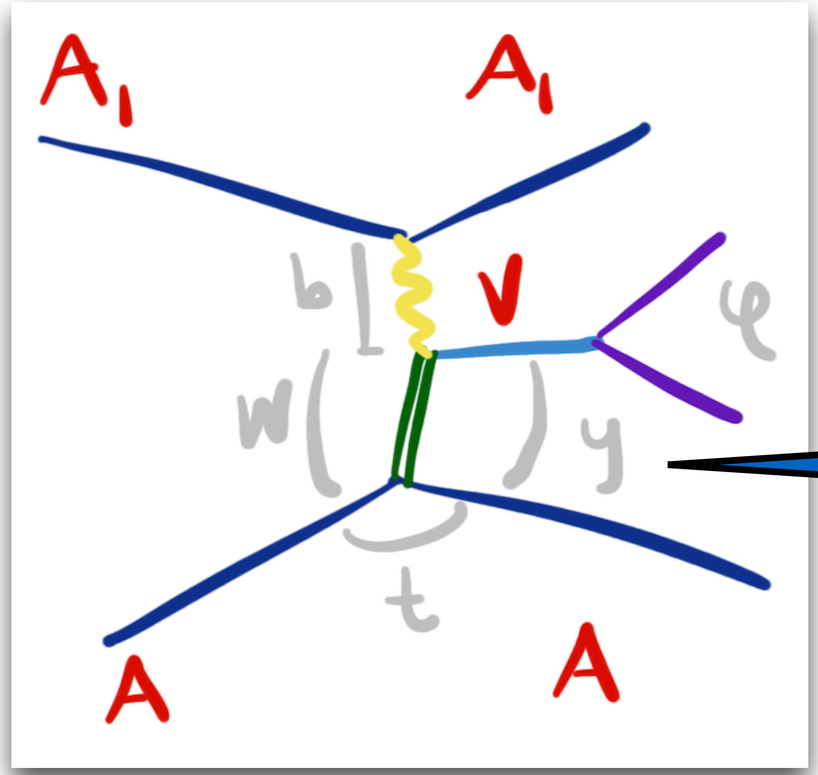
Diffractive vector-meson photoproduction
Results from p-Pb

Diffractive vector-meson photoproduction: Rapidity dependence



Rapidity dependence
⇨ x evolution

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

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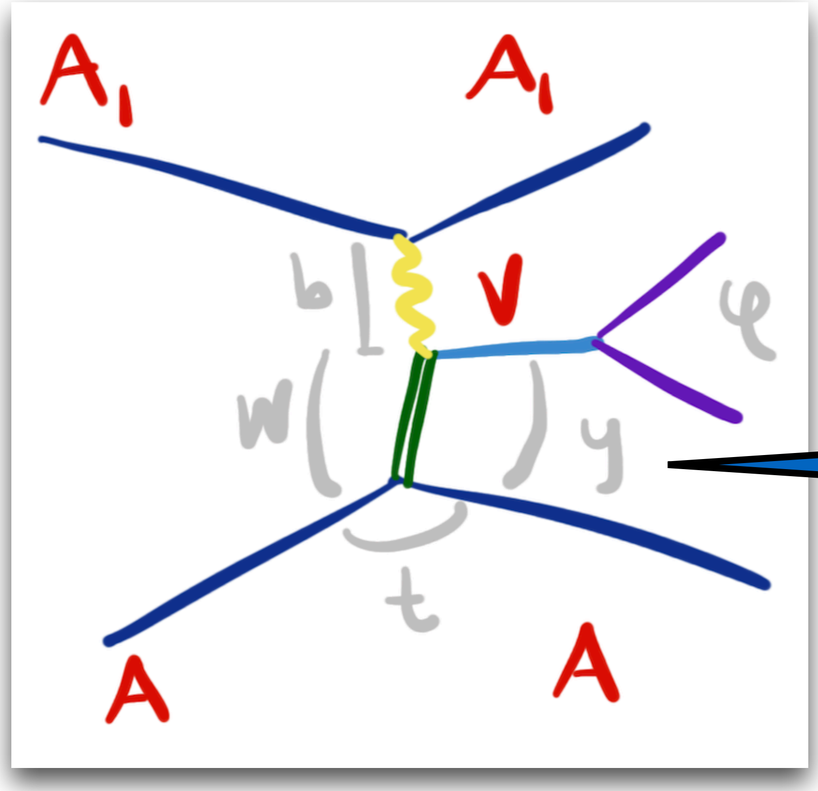


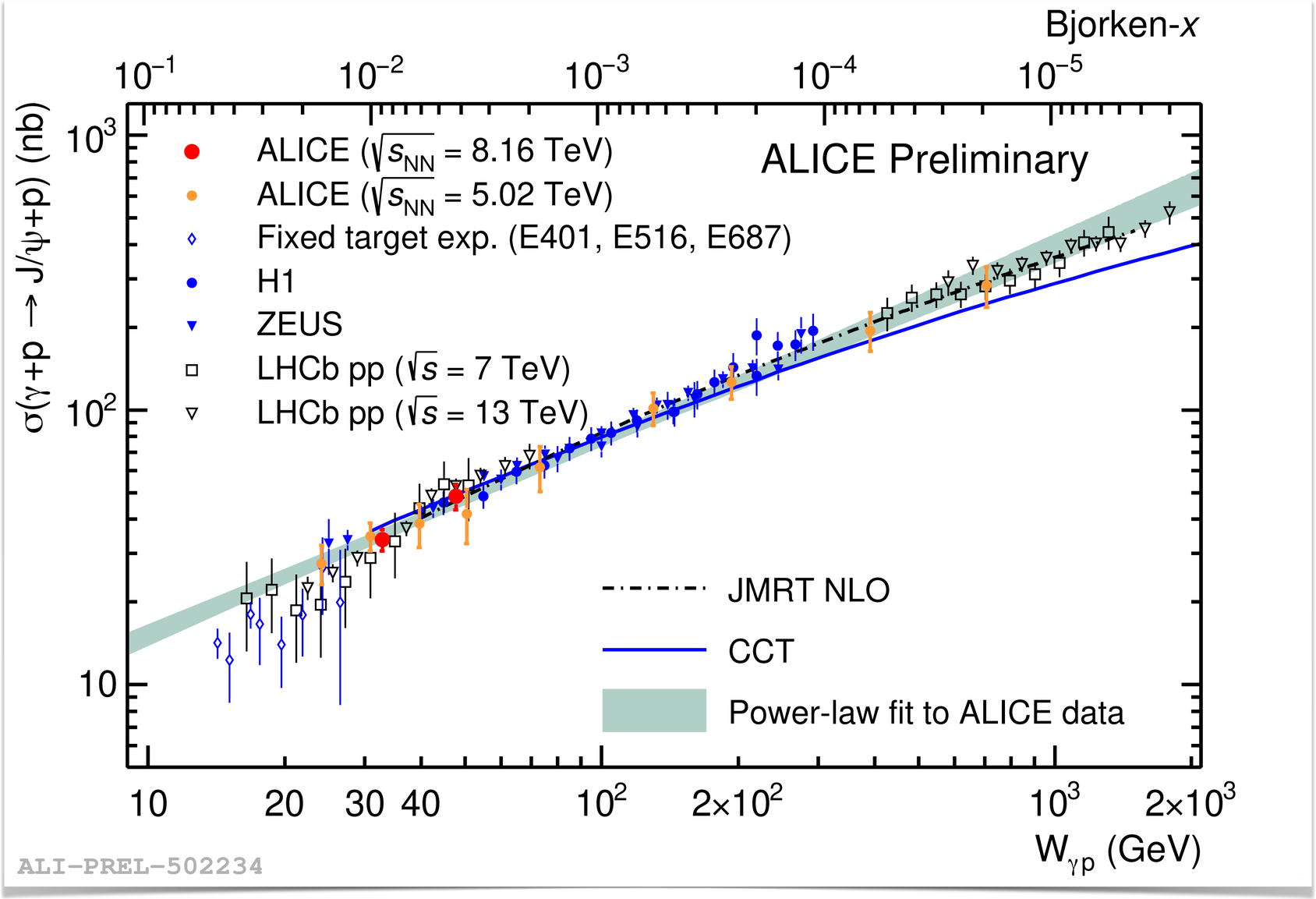
Expectations:
The gluon distribution raises as a power law with decreasing x
⇨
The cross section raises as a power law until it saturates

Rapidity dependence
⇨ x evolution

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

J/ψ

Energy dependence of dissociative production: p-Pb results from ALICE



ALICE, EPJ C79 (2019) 402

ALICE,Preliminary

J/ψ

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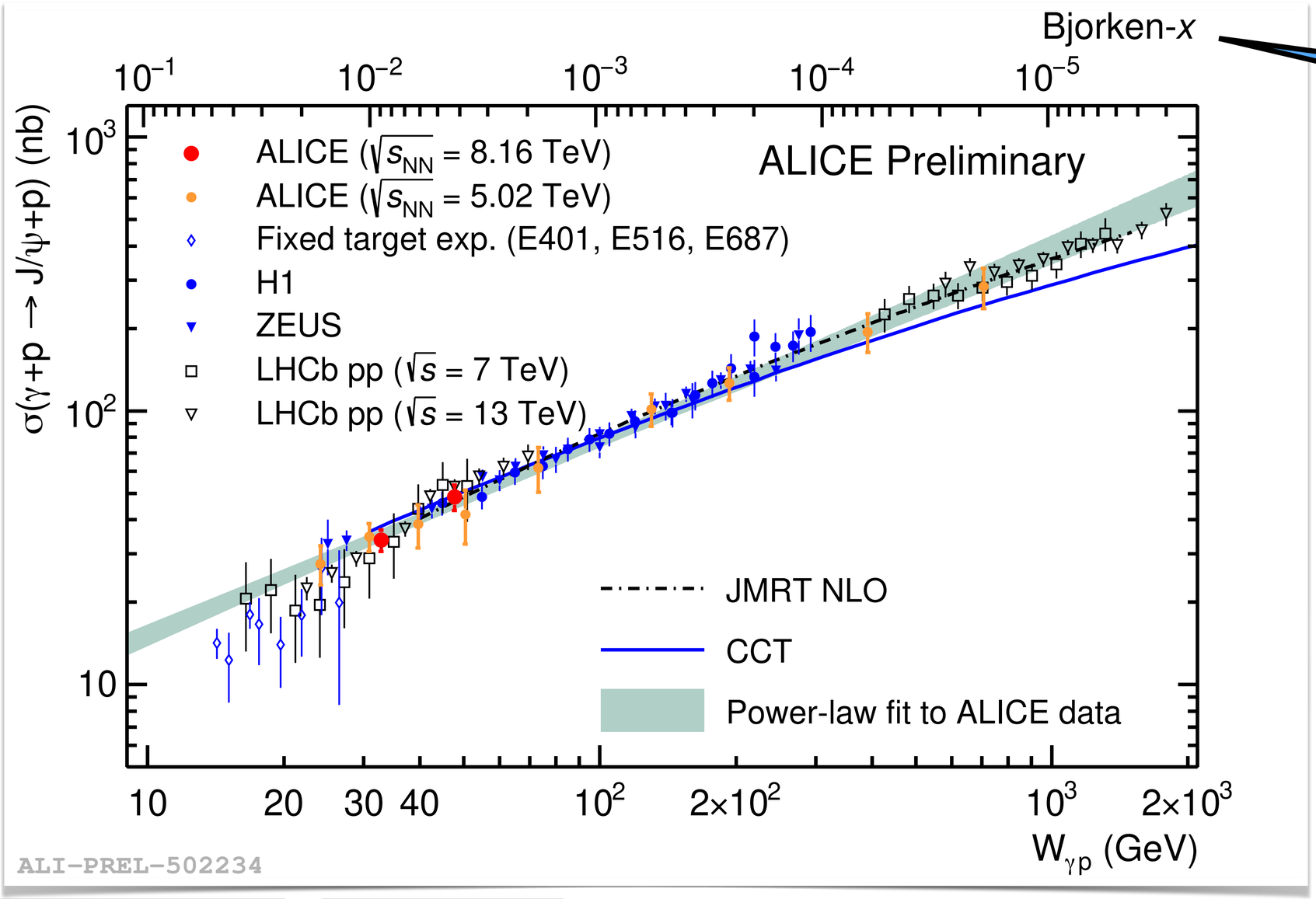

3 orders of magnitude in x are covered with one detector!

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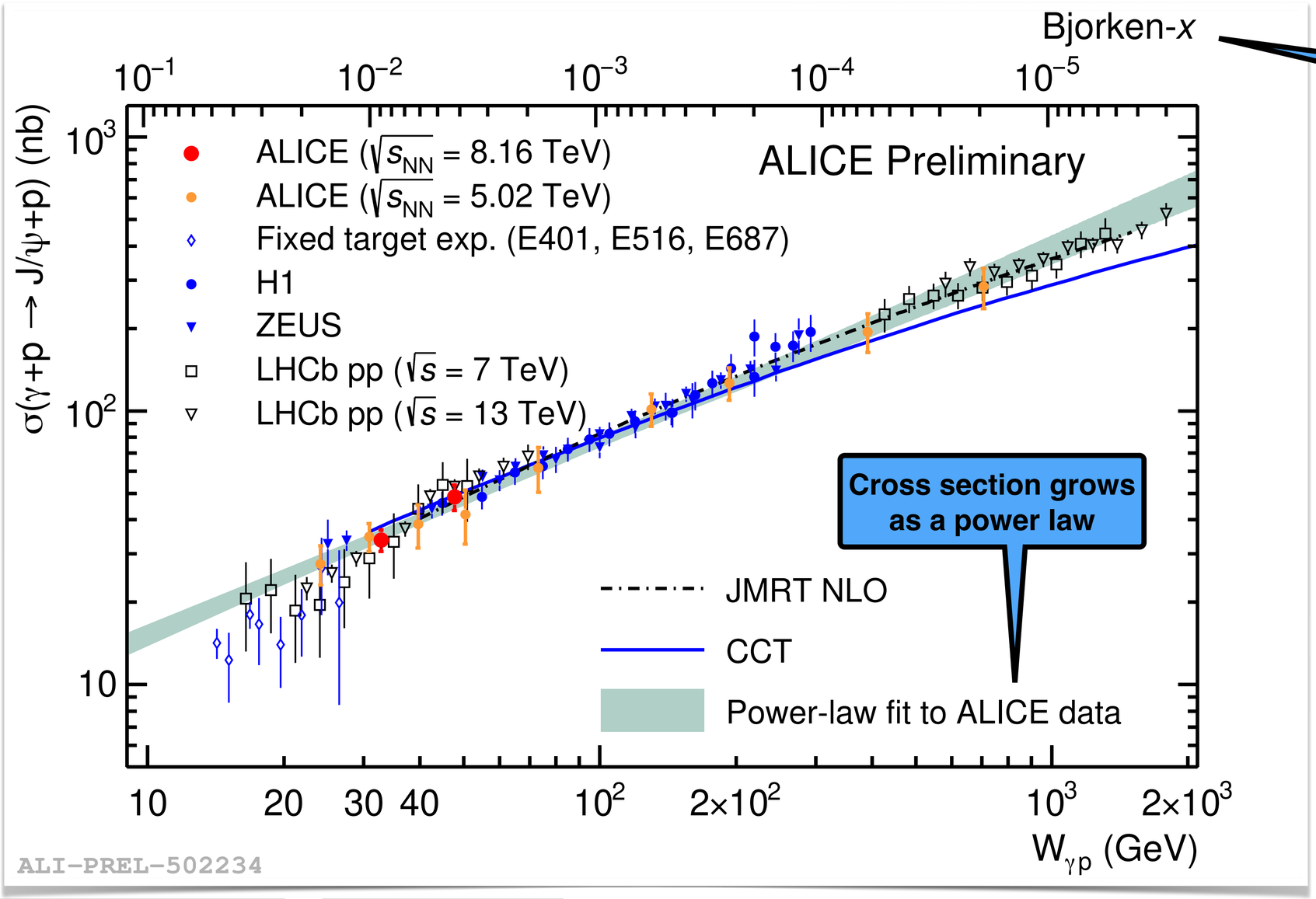

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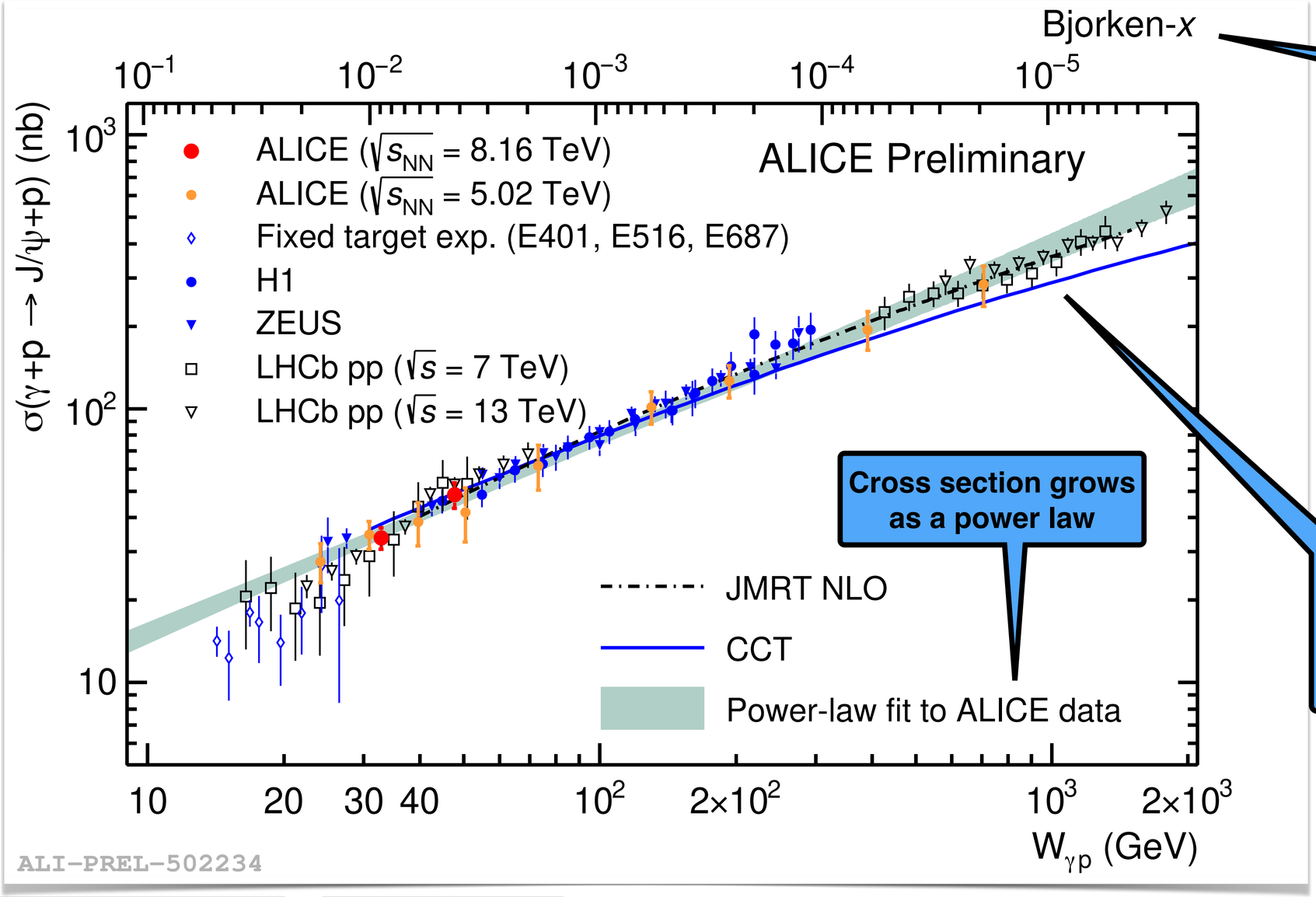

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All types of models describe data: VDM, DGLAP, BFKL, CCG … (here only DGLAP and colour dipole shown)

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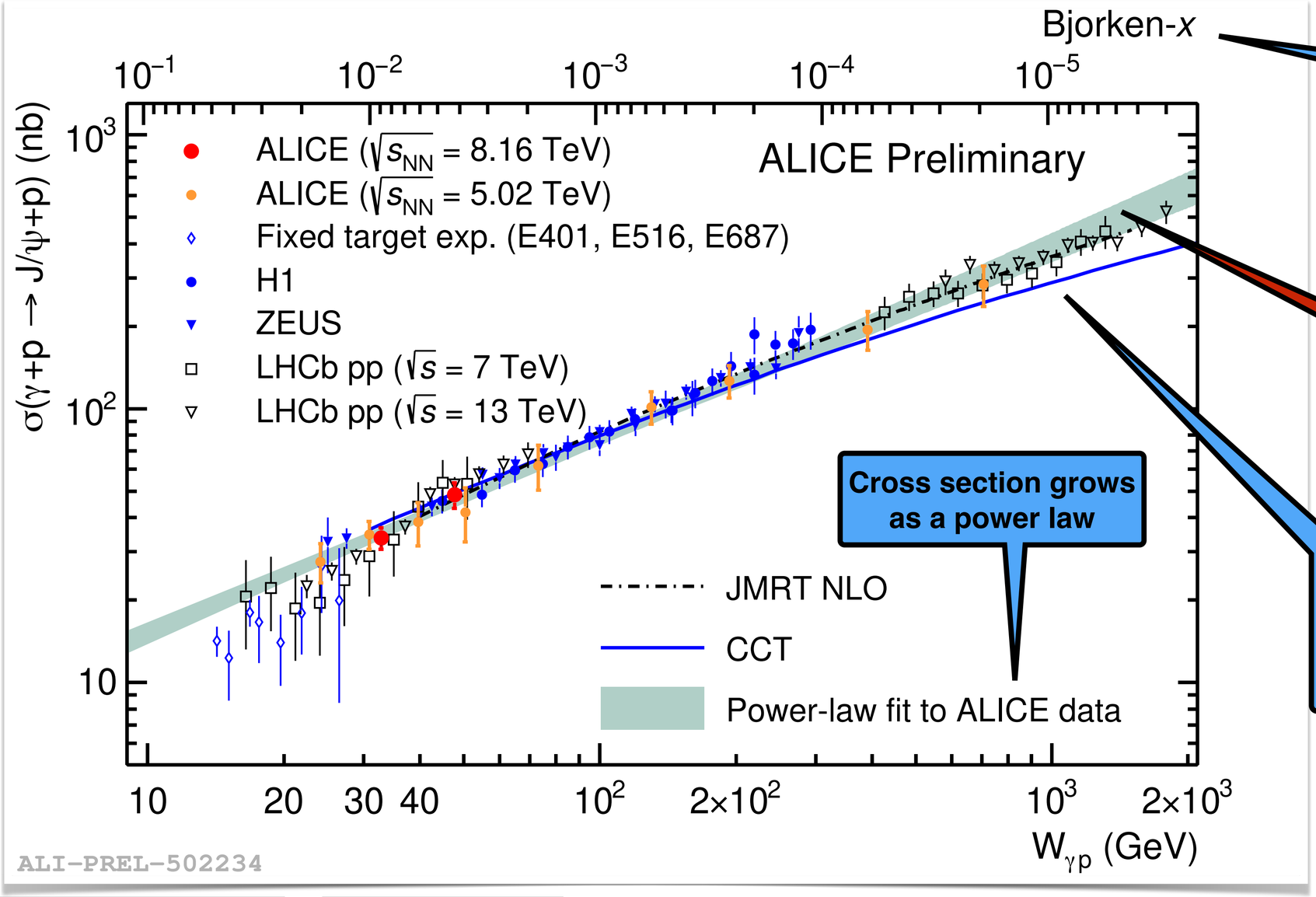

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Open question: Where is saturation?

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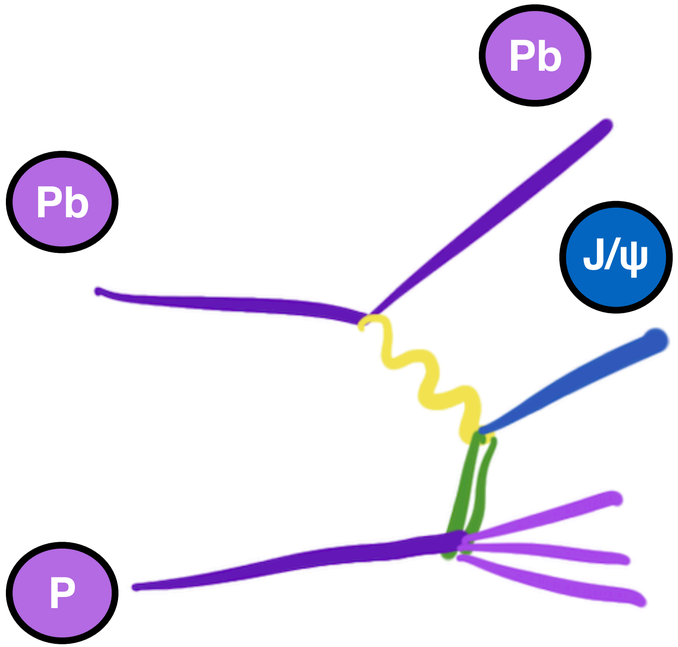

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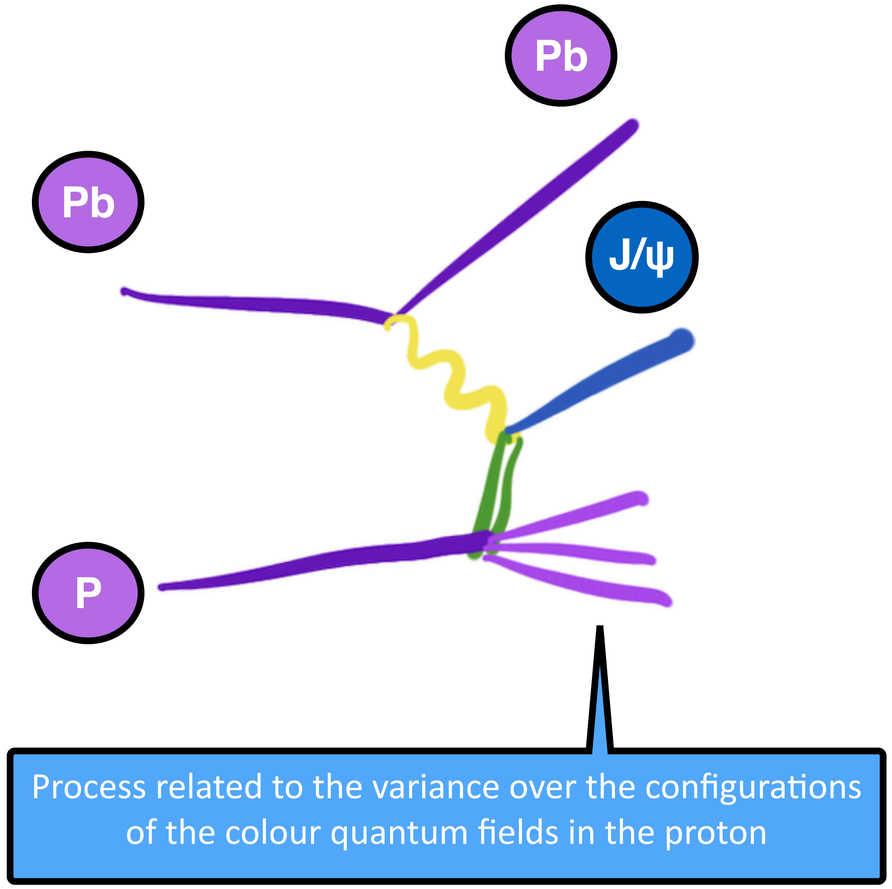

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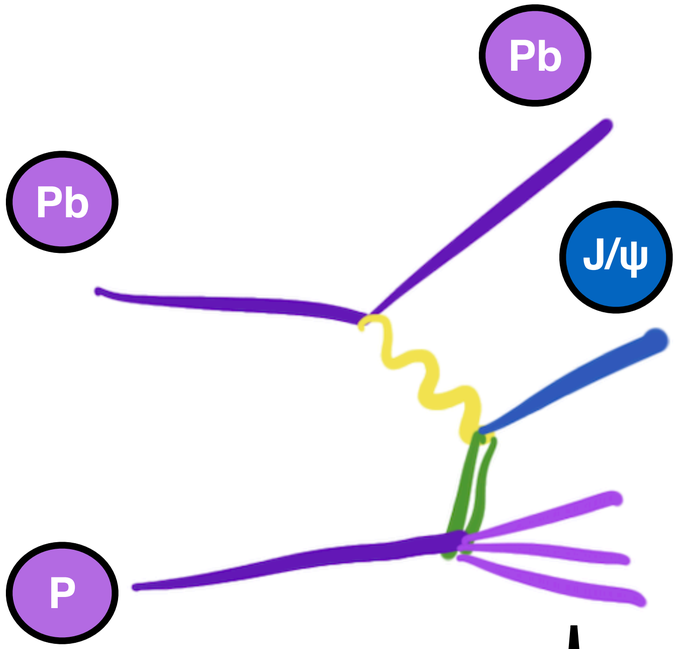

Process related to the variance over the configurations of the colour quantum fields in the proton

When saturated all configurations look the same, thus variance goes to zero: new signature of saturation!

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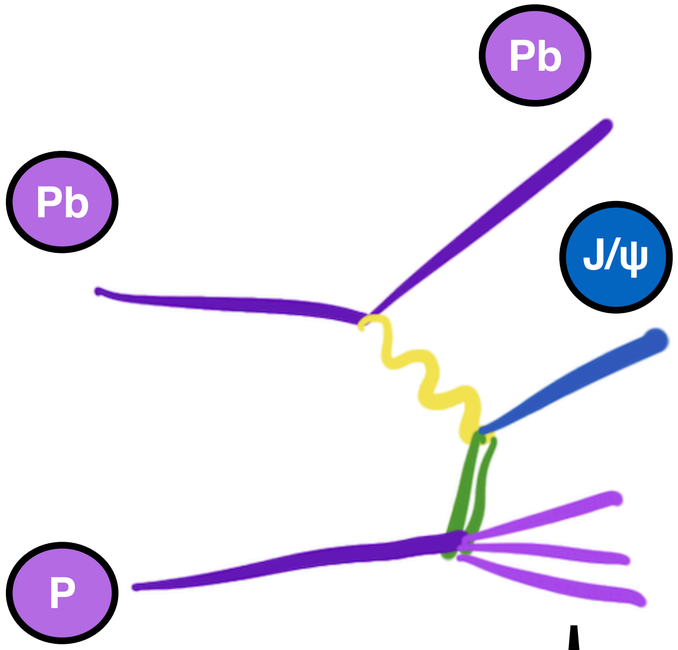

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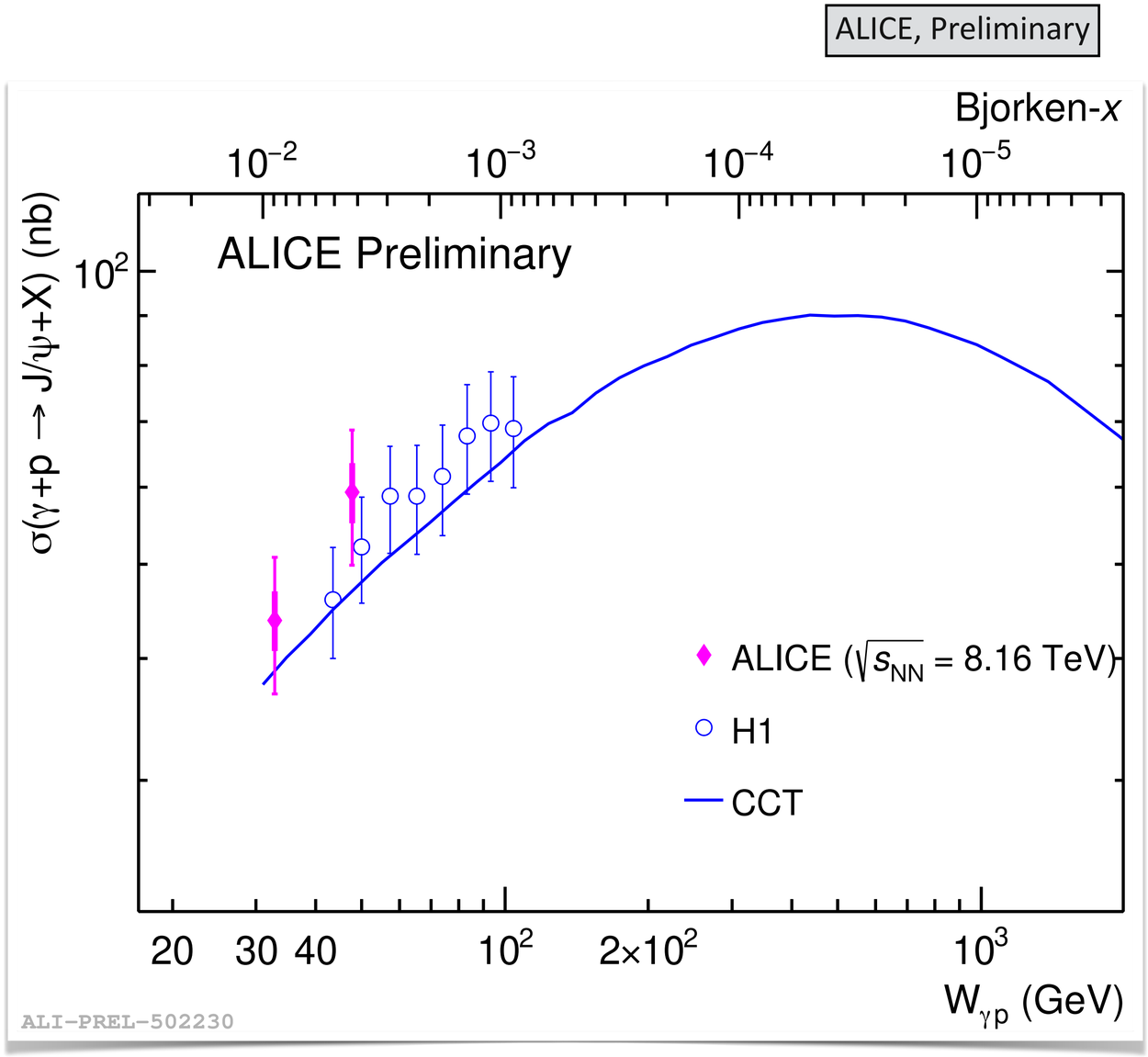

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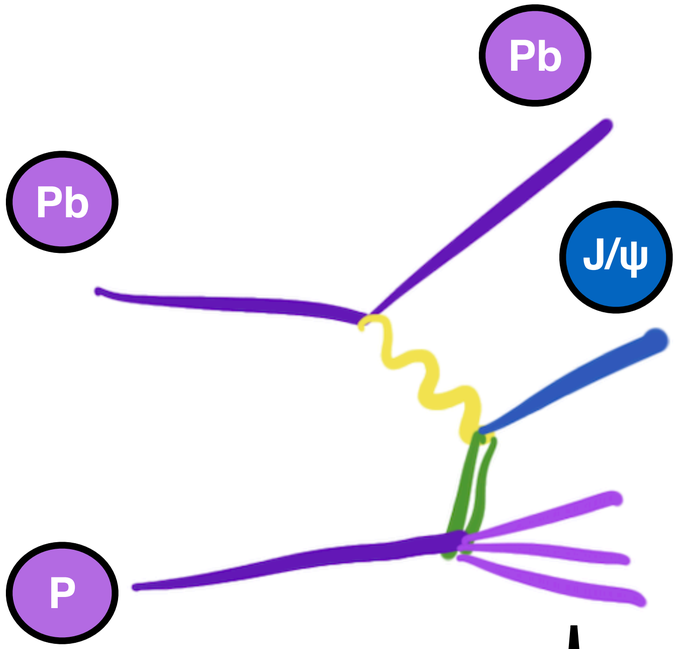
First measurement of dissociative photoproduction of vector mesons at the LHC



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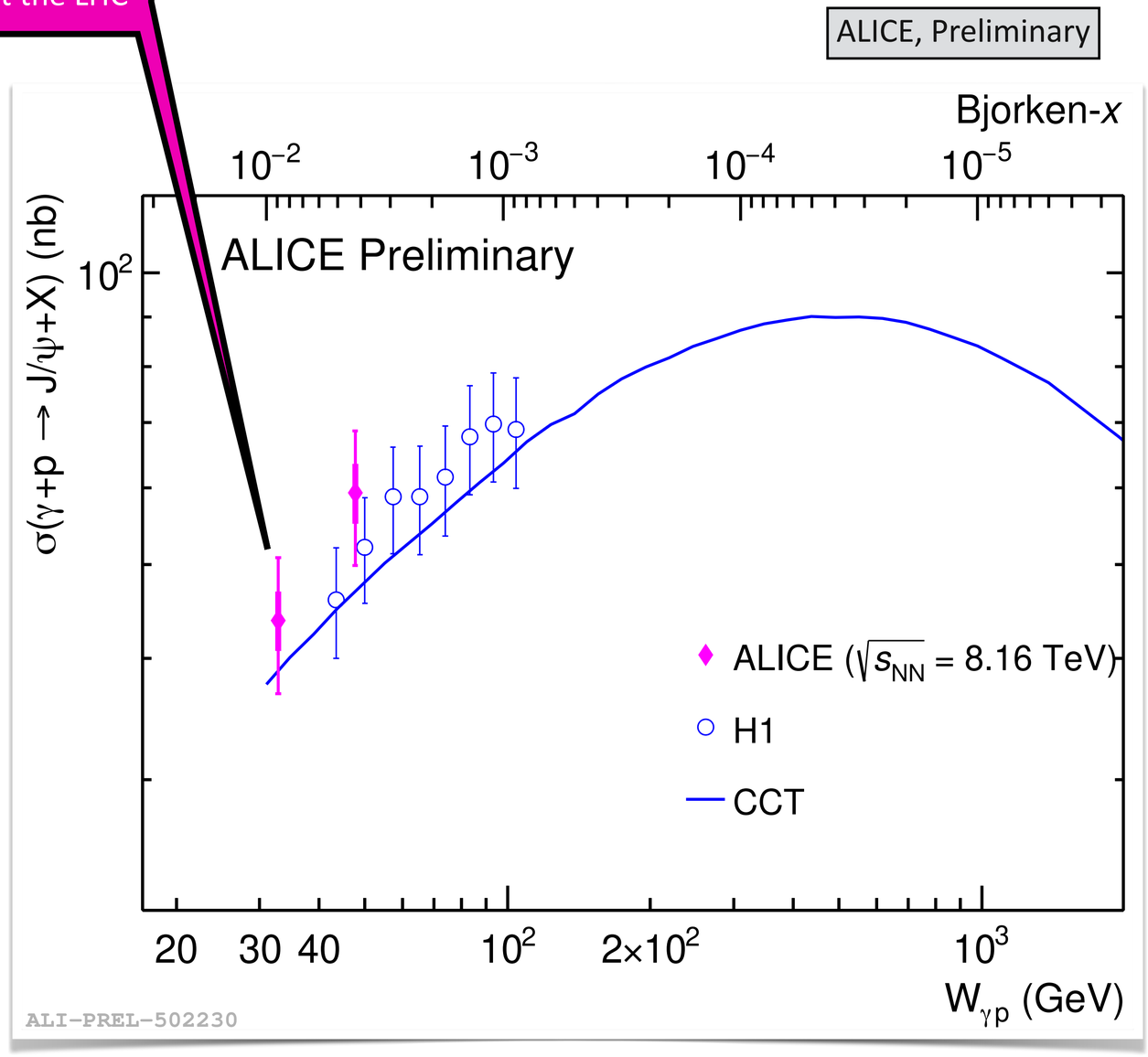

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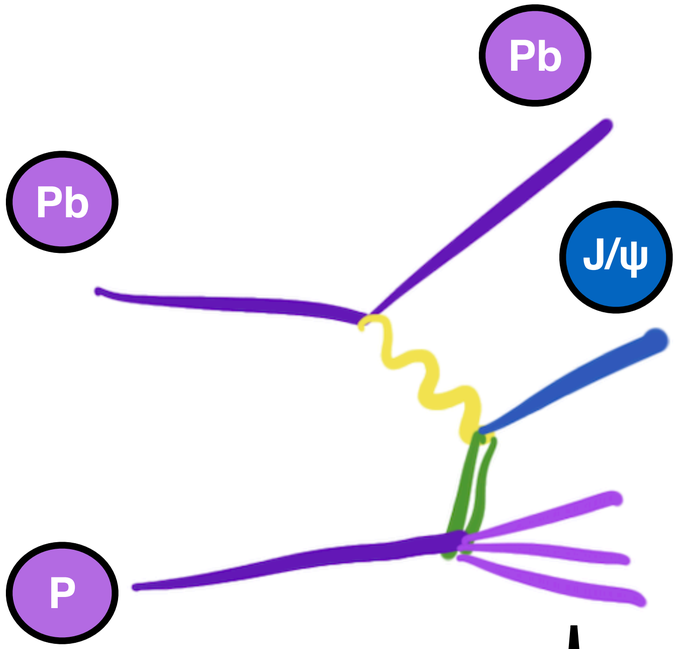

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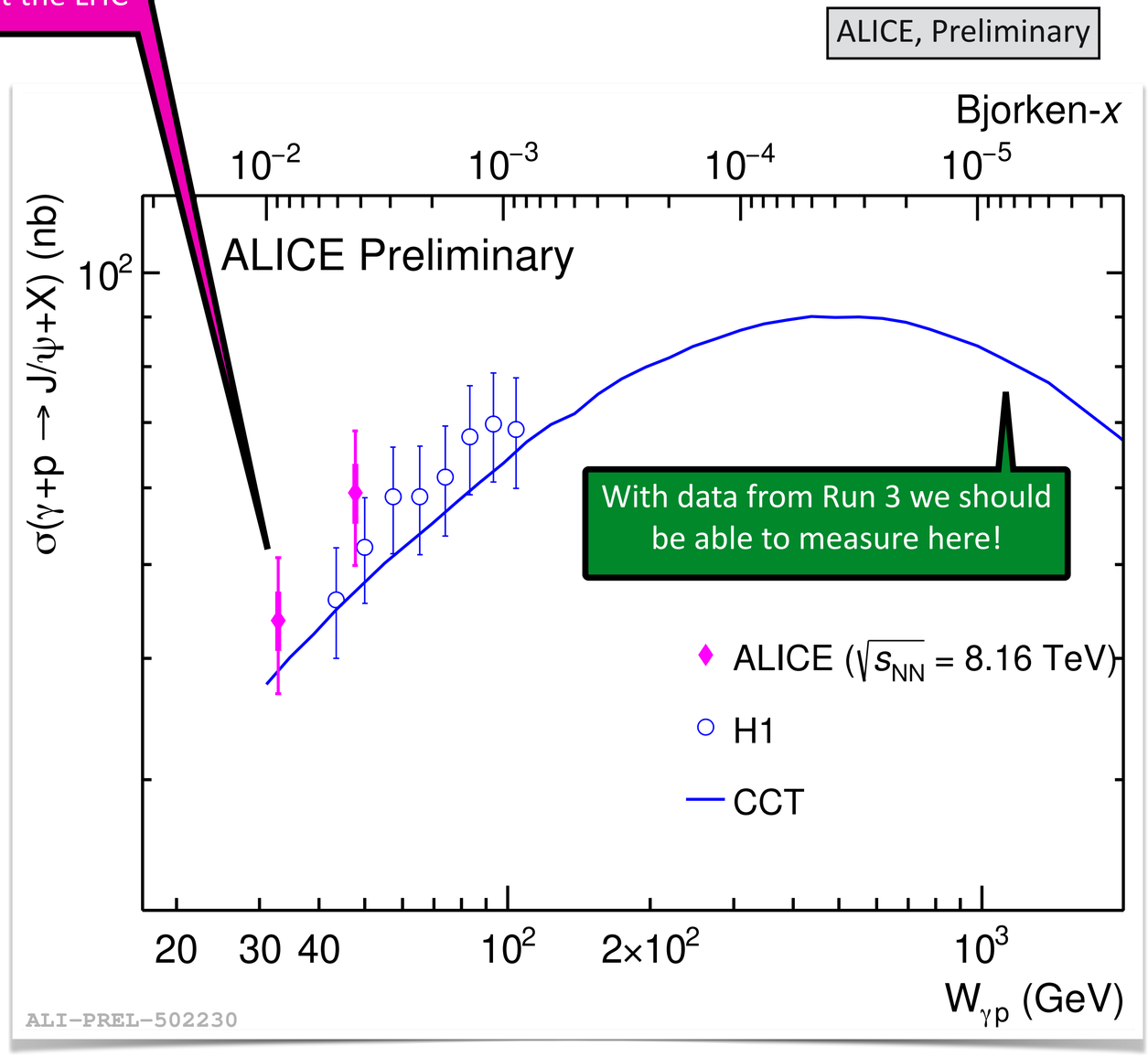
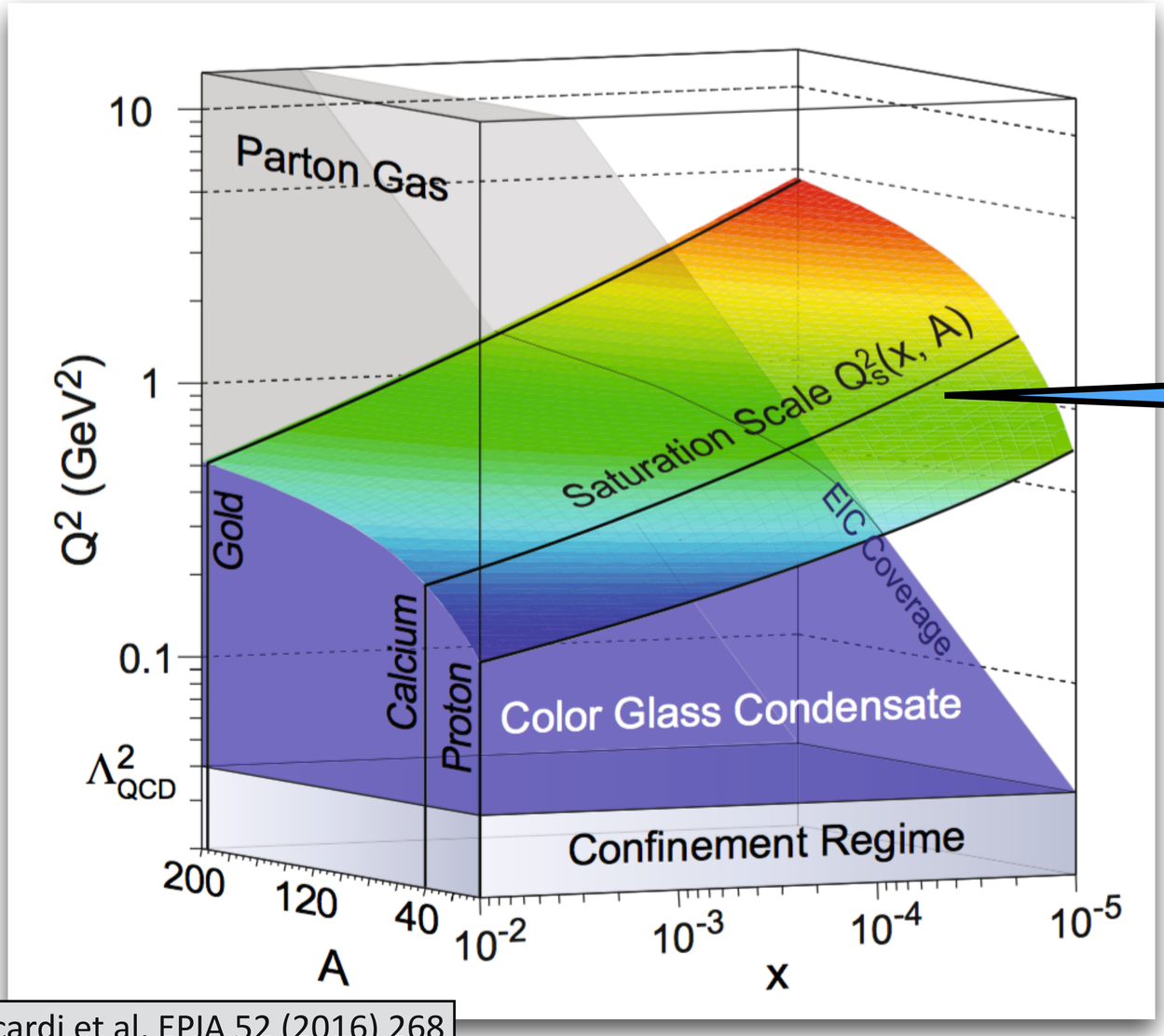


Diffractive vector-meson photoproduction
Results from AA

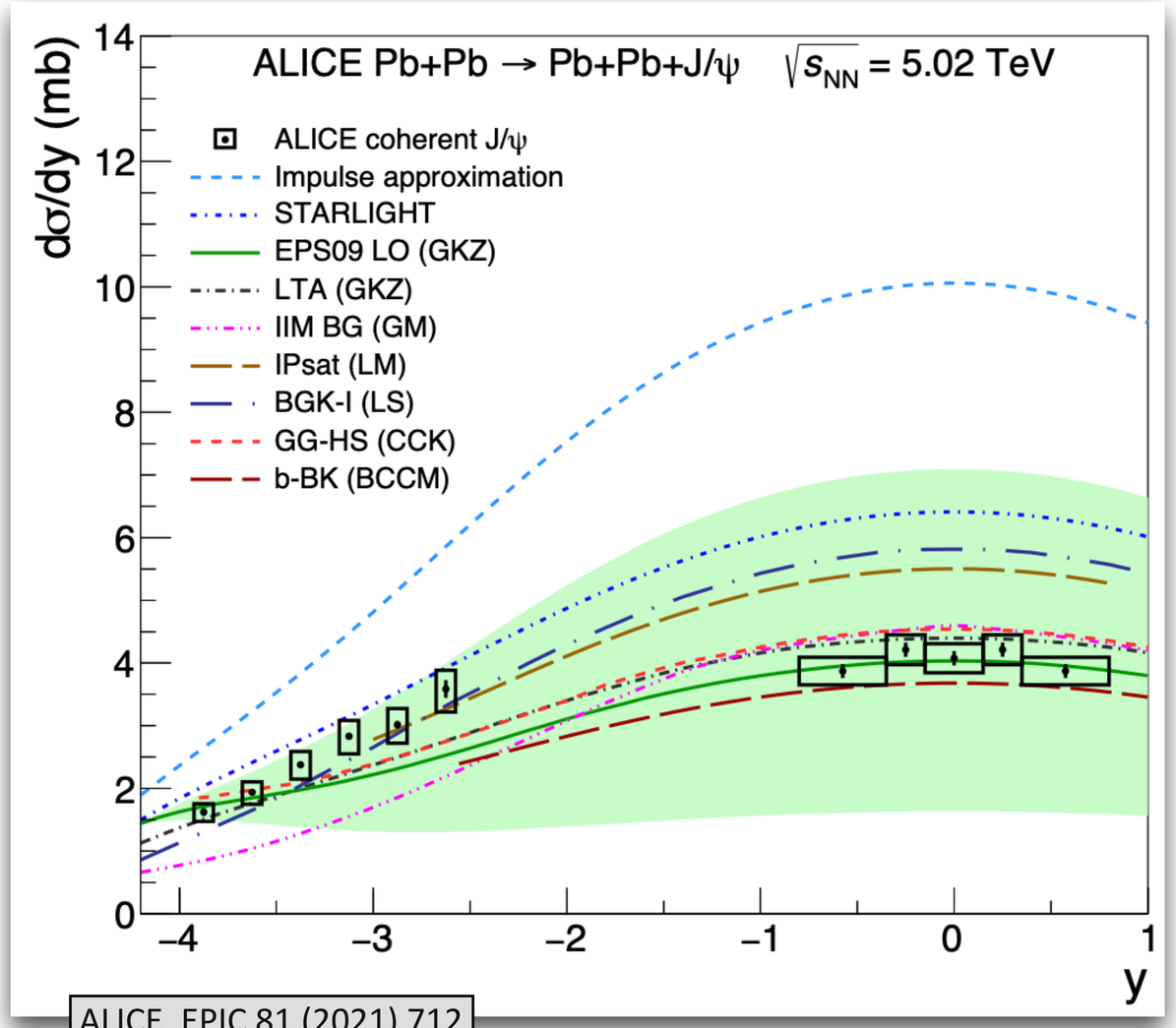
Searching for saturation: the case for nuclei



Accardi et al, EPJA 52 (2016) 268

Saturation is expected to set in earlier in heavier nuclei

Rapidity dependence: ALICE results in Pb-Pb



ALICE, EPJC 81 (2021) 712

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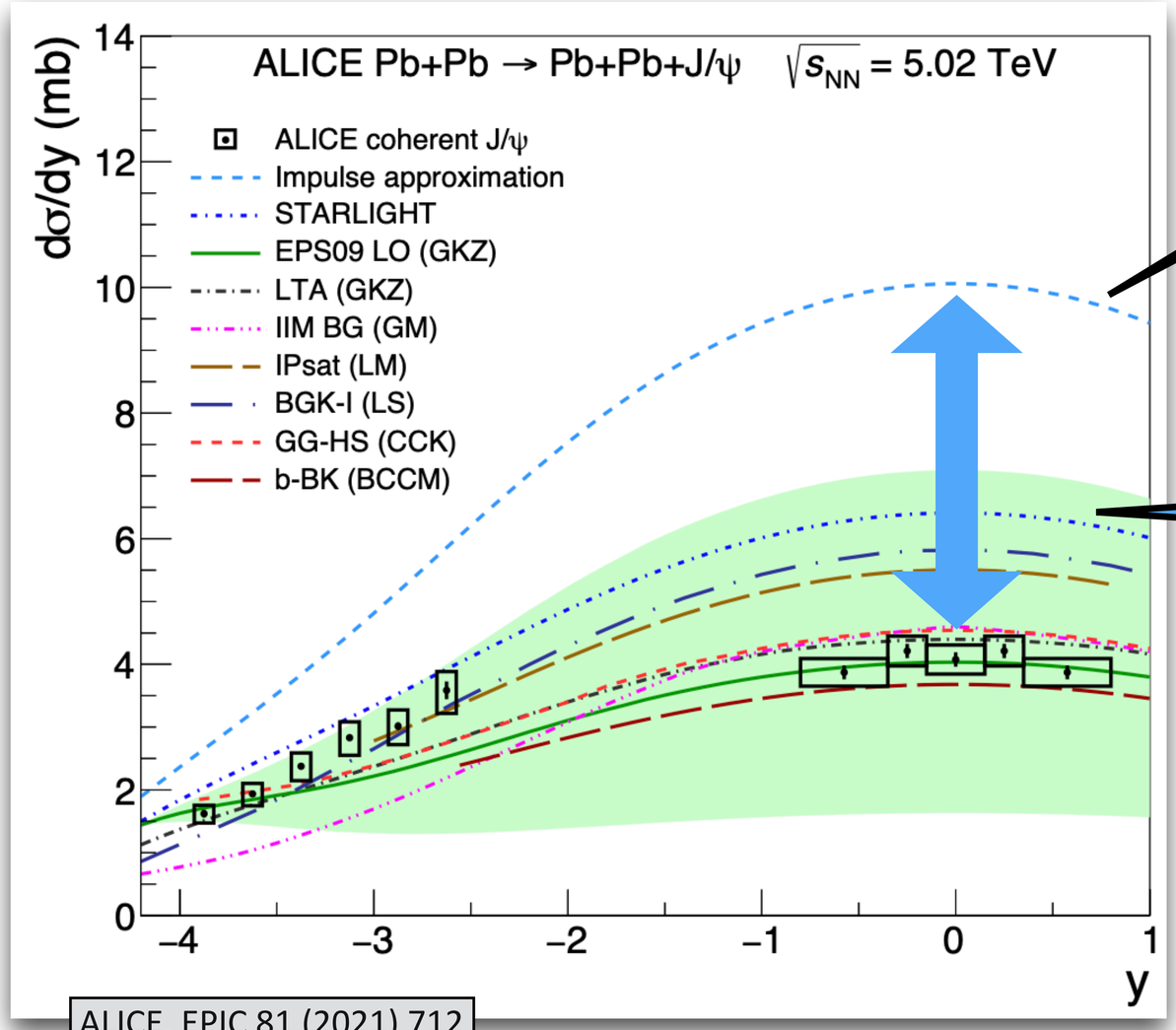

ALICE, EPJC 81 (2021) 712

Impulse approximation

Nuclear suppression factor for $x \sim 10^{-3}$ is 0.65±0.03

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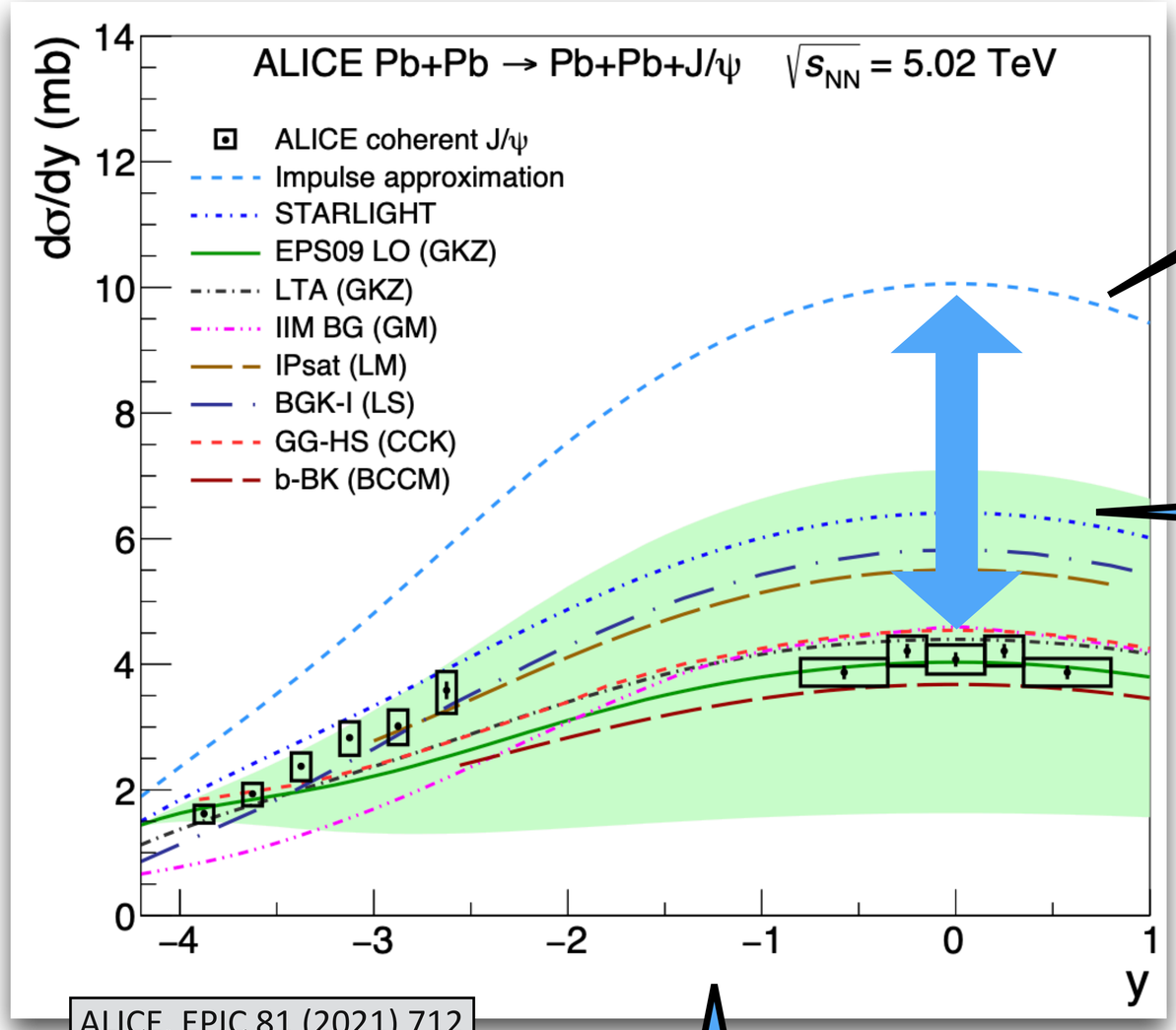

ALICE, EPJC 81 (2021) 712

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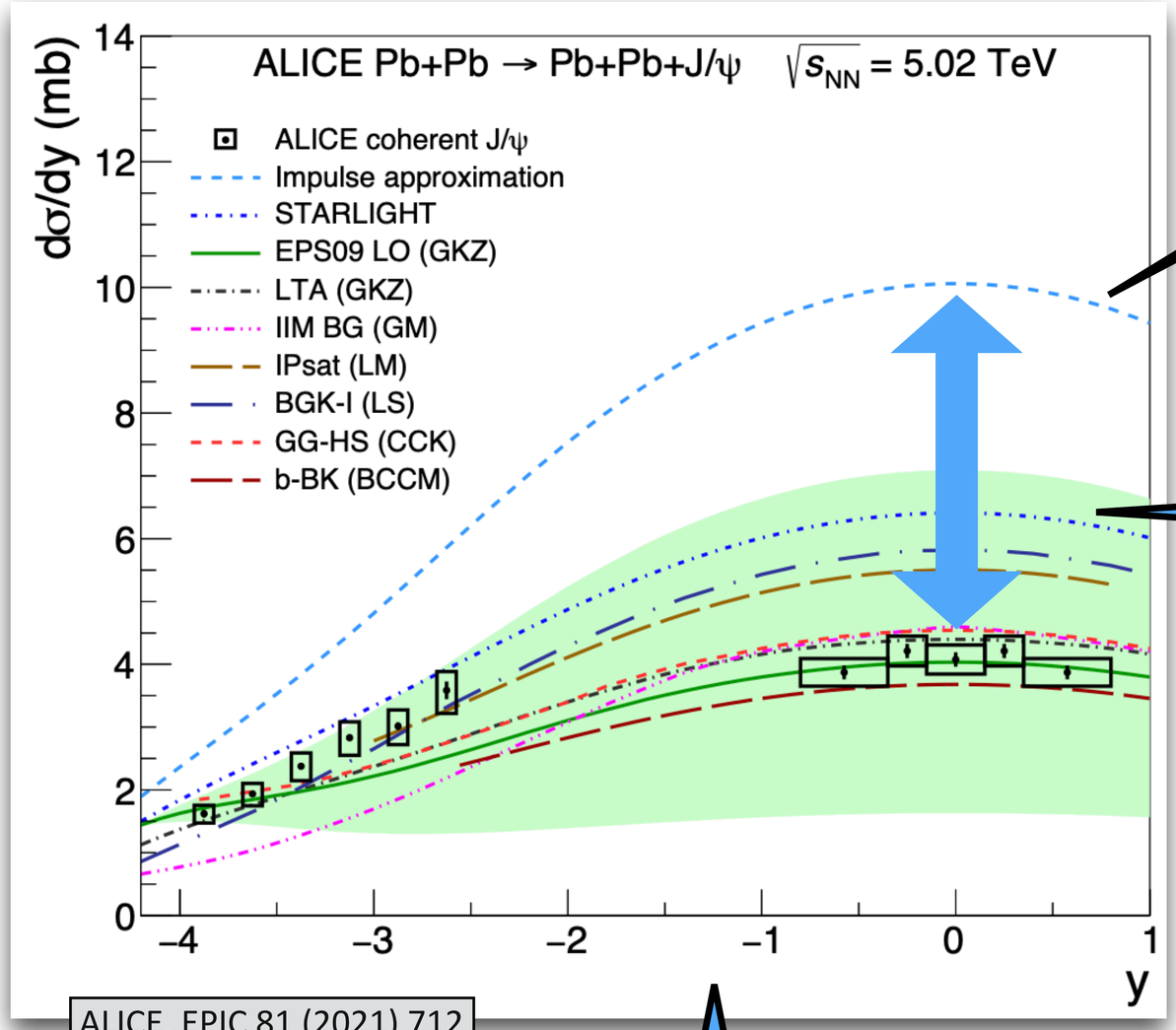

ALICE, EPJC 81 (2021) 712

Impulse approximation

Open question:
How much of shadowing is saturation?

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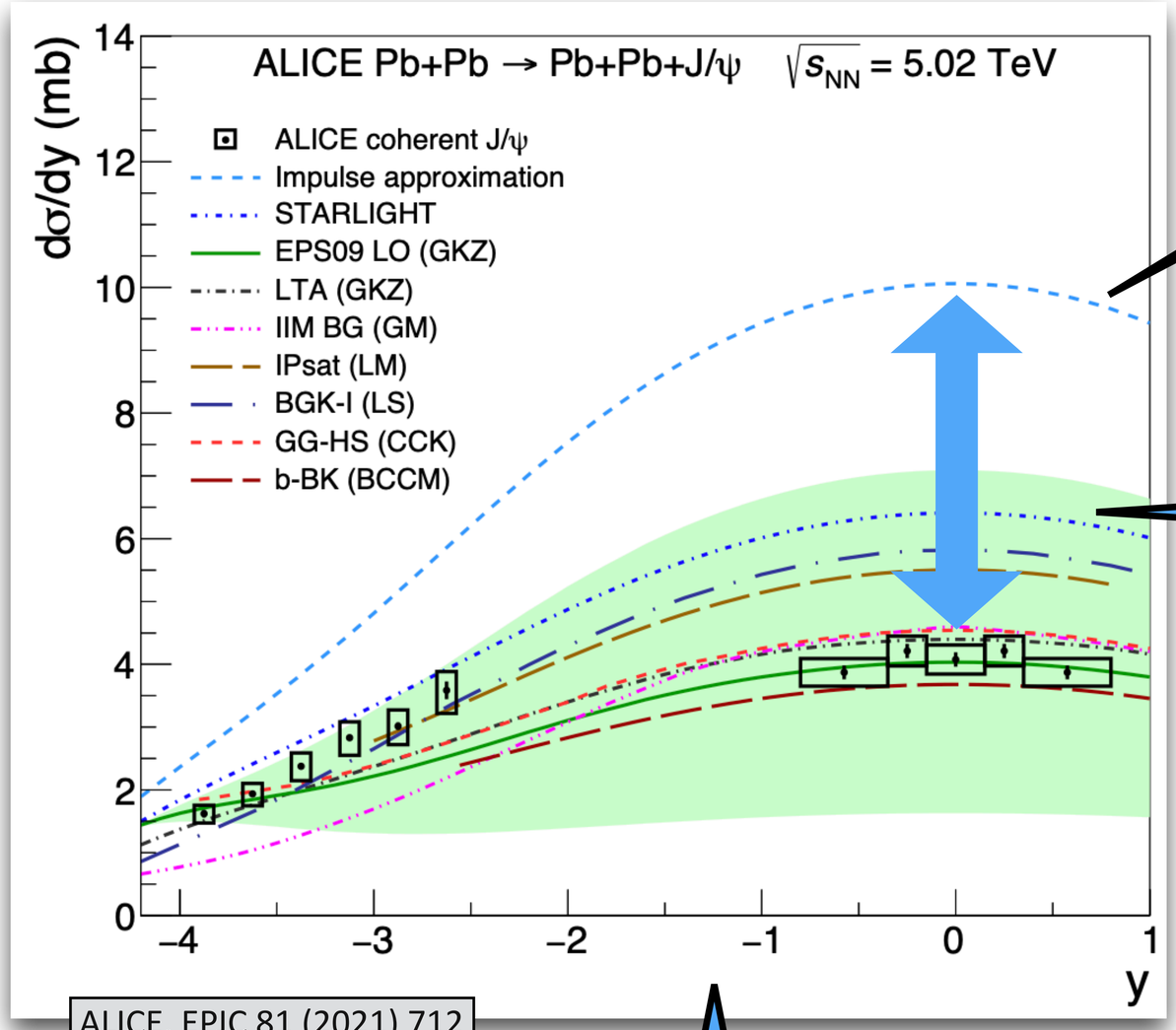

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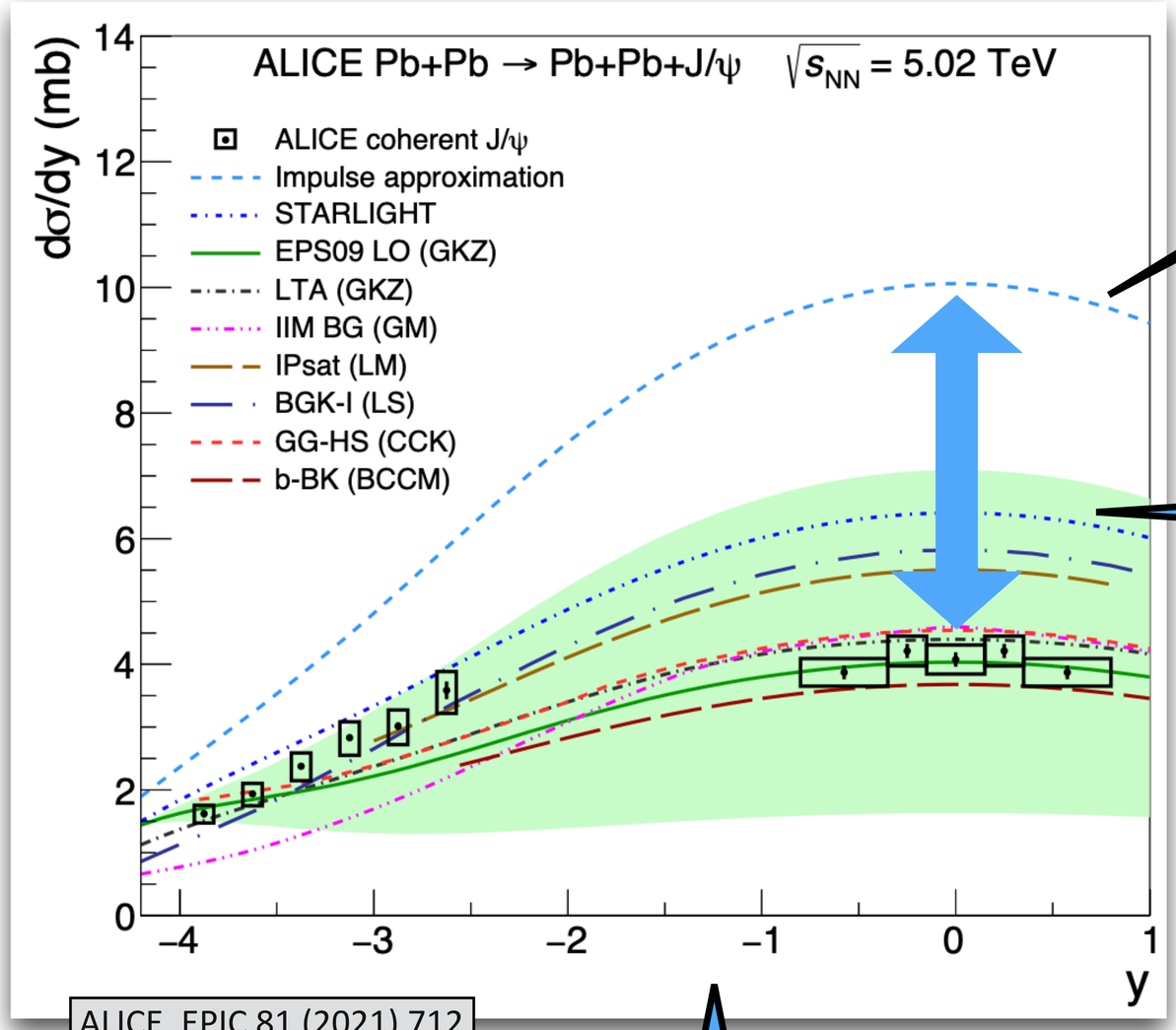

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Try to plot vs x?

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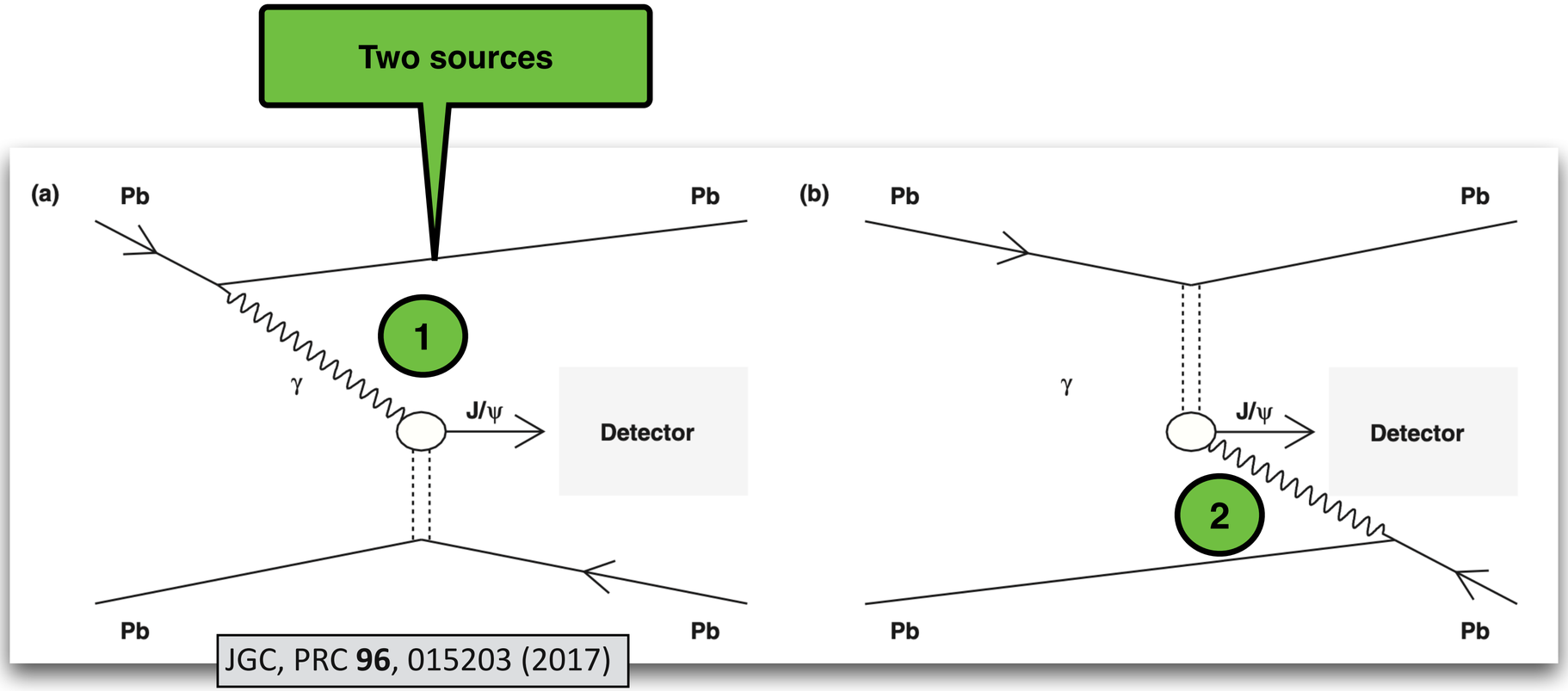
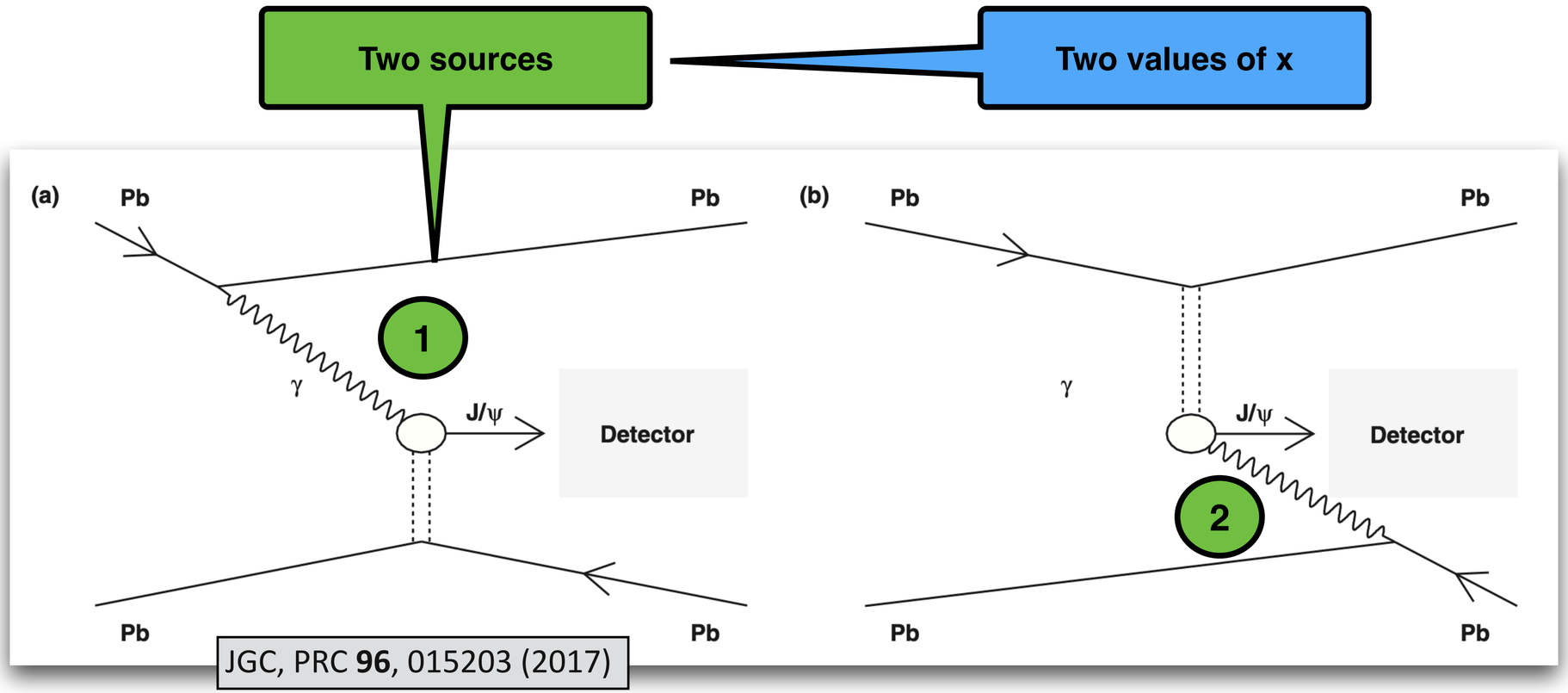
Rapidity dependence: ambiguity problem



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

Rapidity dependence: ambiguity problem



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

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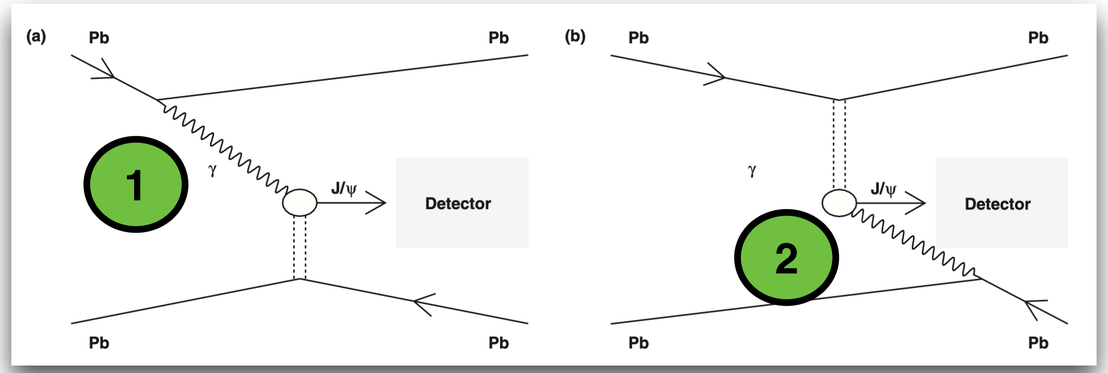
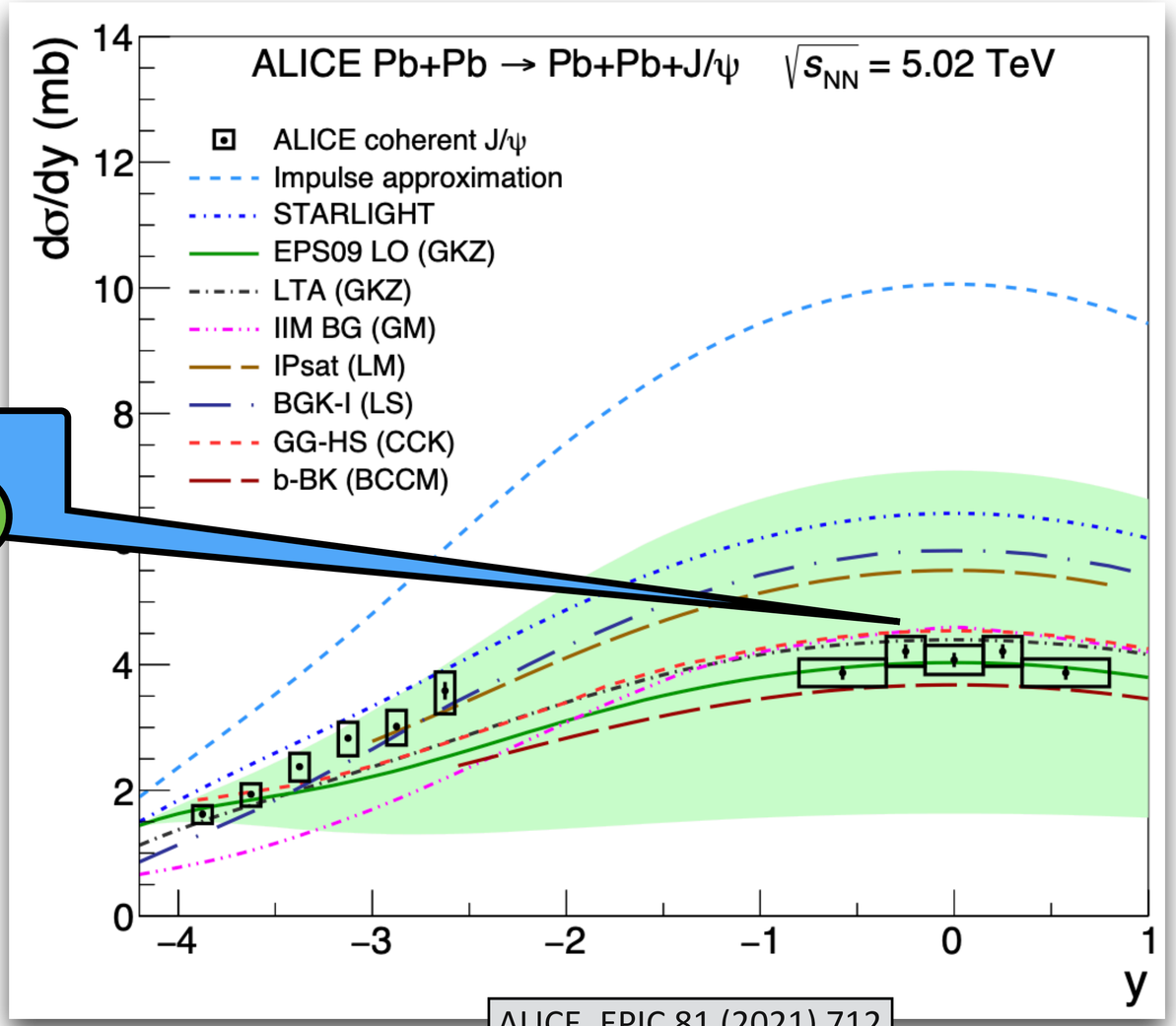


2

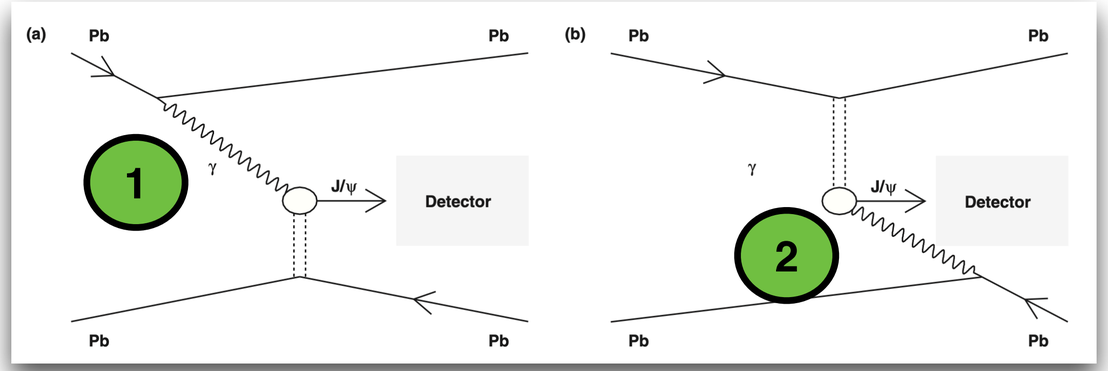
50% each x~1. 10^{-3}

1



ALICE, EPJC 81 (2021) 712

Rapidity dependence: ambiguity problem



2

50% each x~1. 10^{-3}

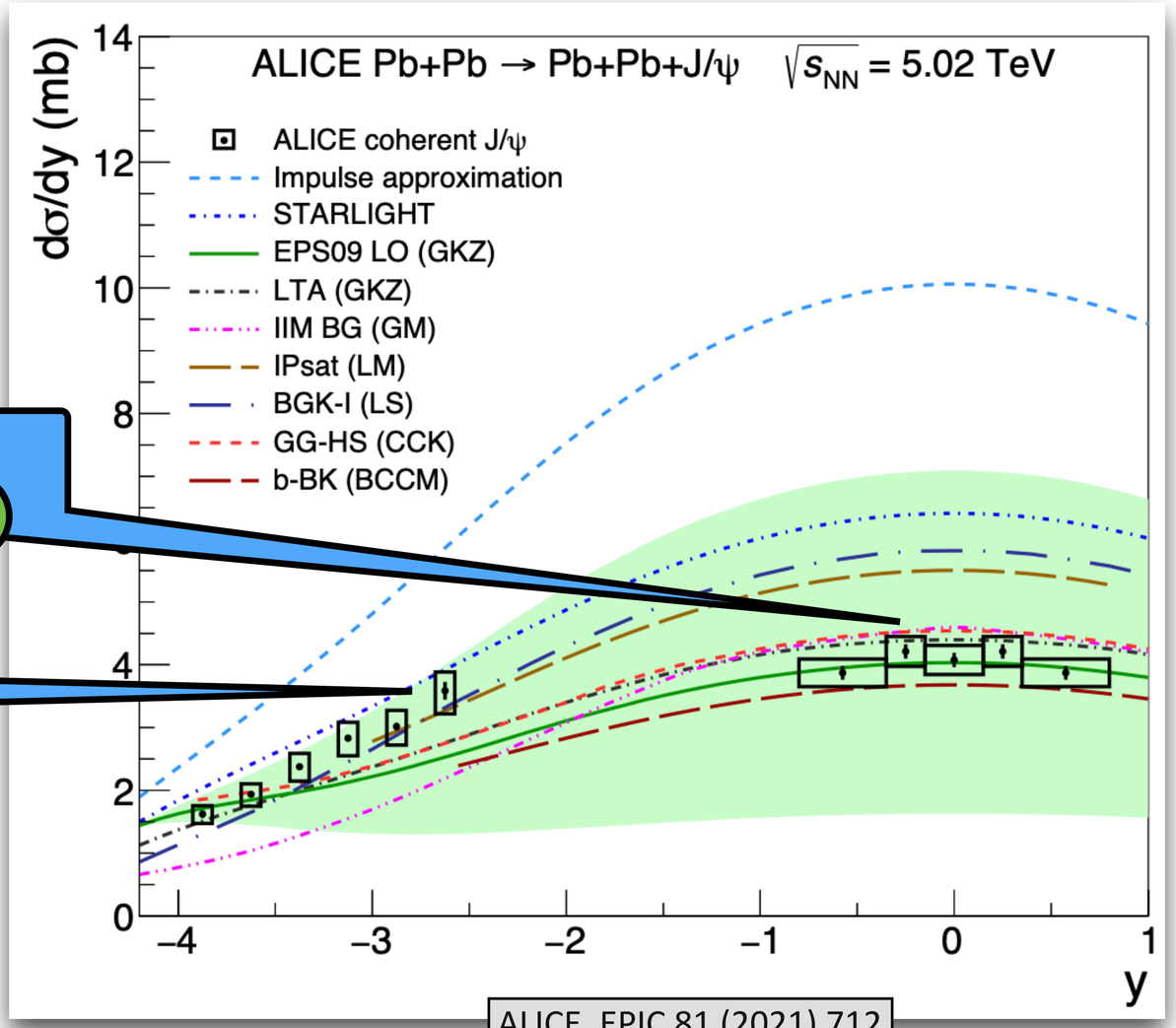
1

2

60% x~0.7 10^{-2}

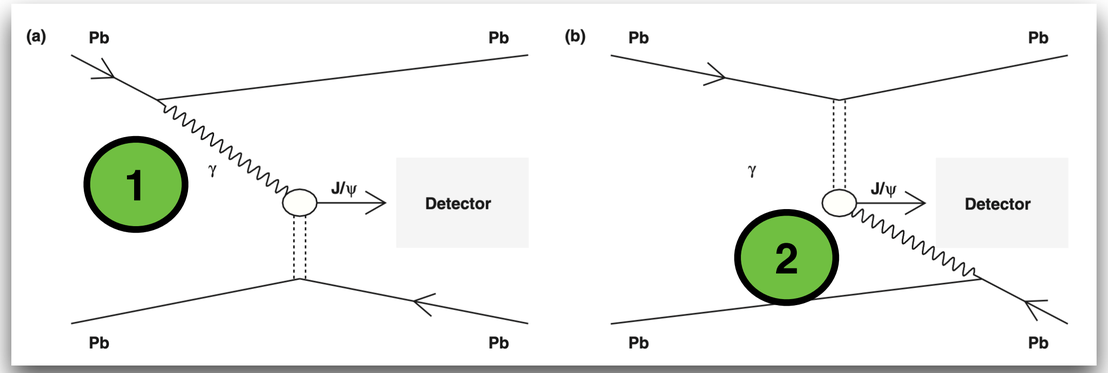
40% x~5.1 10^{-5}

1



ALICE, EPJC 81 (2021) 712

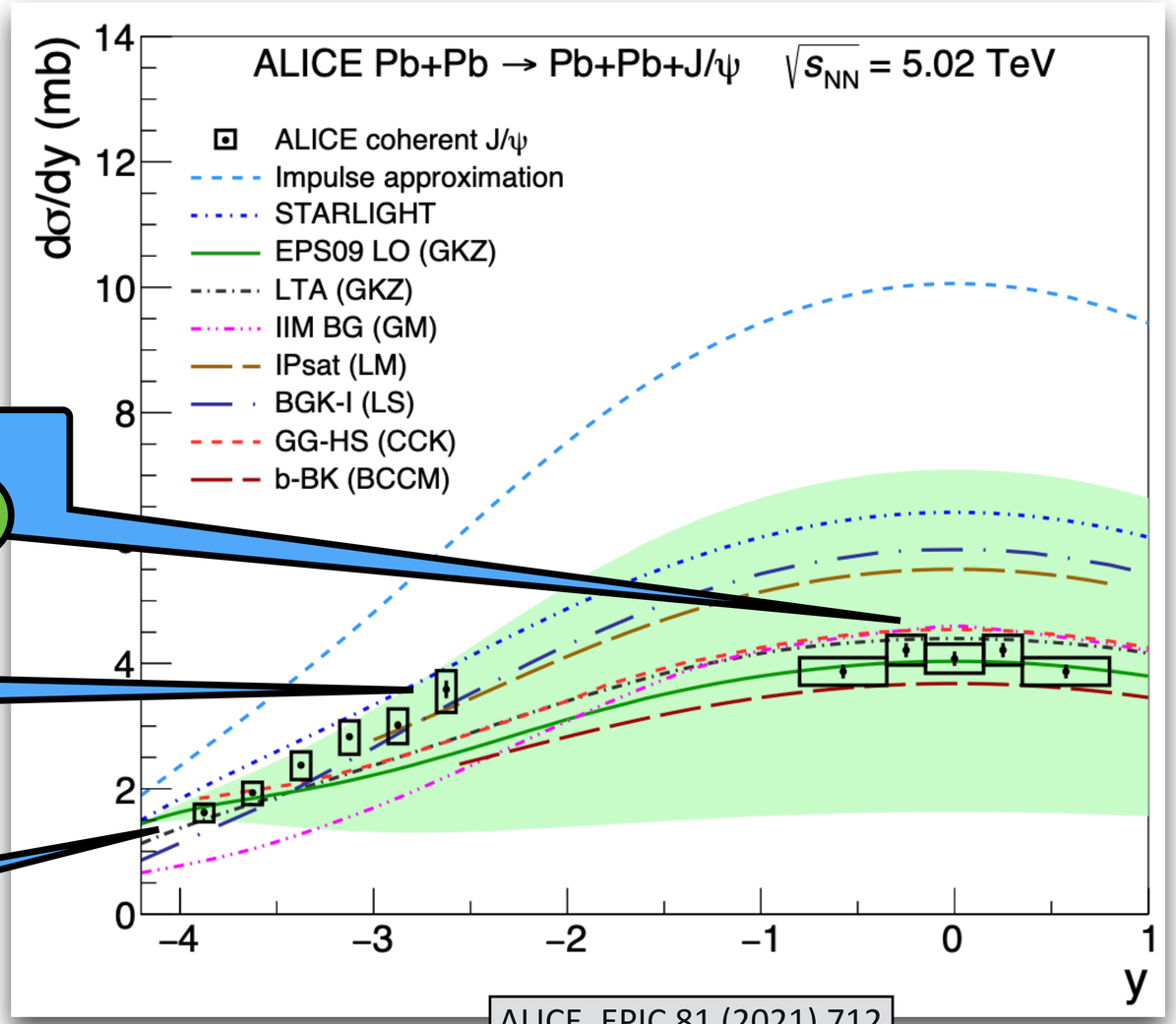
Rapidity dependence: ambiguity problem



2
50% each x~1. 10^{-3}
1

2
60% x~0.7 10^{-2}
40% x~5.1 10^{-5}
1

2
95% x~3.3 10^{-2}
5% x~1.1 10^{-5}
1

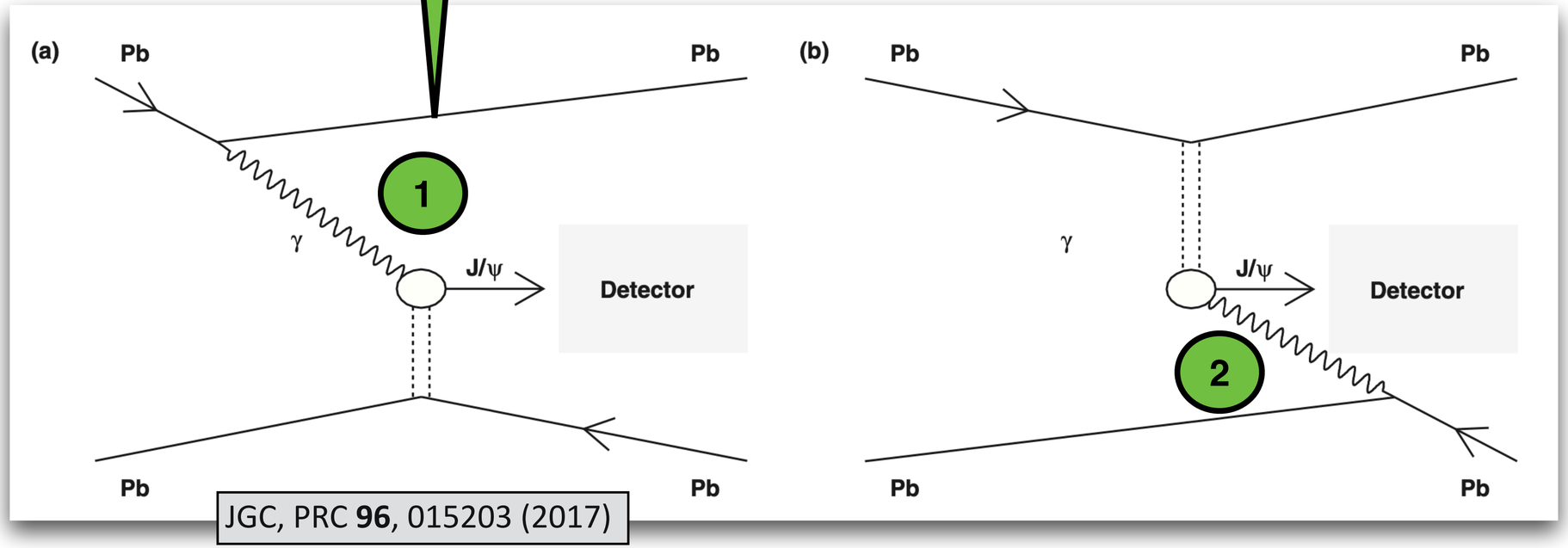


ALICE, EPJC 81 (2021) 712

Rapidity dependence: ambiguity problem

Open question: how to disentangle both contributions?

Two sources



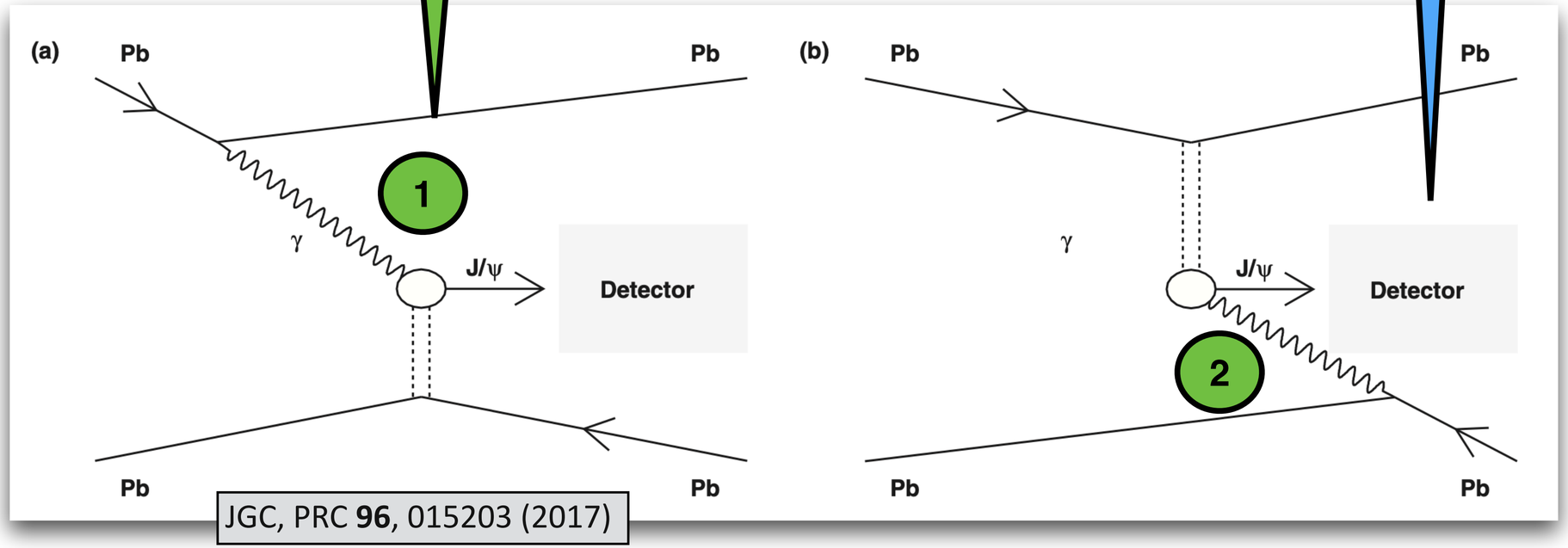
JGC, PRC **96**, 015203 (2017)

Rapidity dependence: ambiguity problem

Open question: how to disentangle both contributions?

Two sources

Another independent measurement needed at the same rapidity

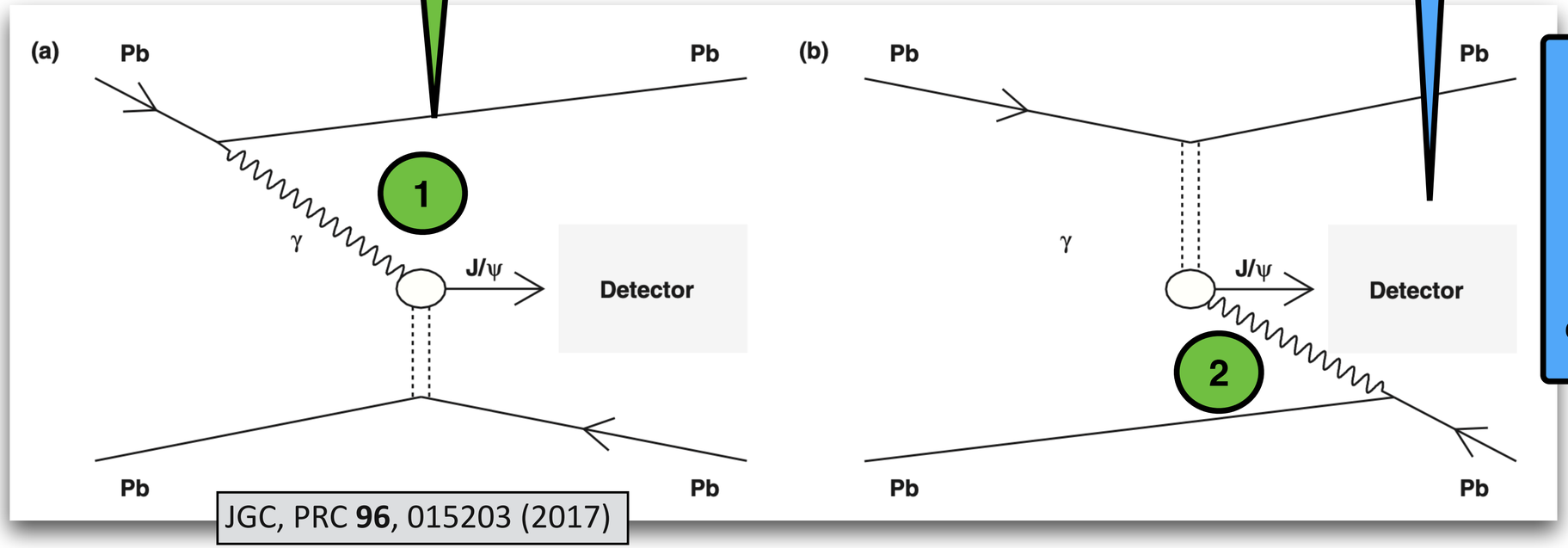


JGC, PRC **96**, 015203 (2017)

Rapidity dependence: ambiguity problem

Open question: how to disentangle both contributions?

Two sources



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

Another independent measurement needed at the same rapidity

Up to now, two options:

Measure the same process in peripheral collisions

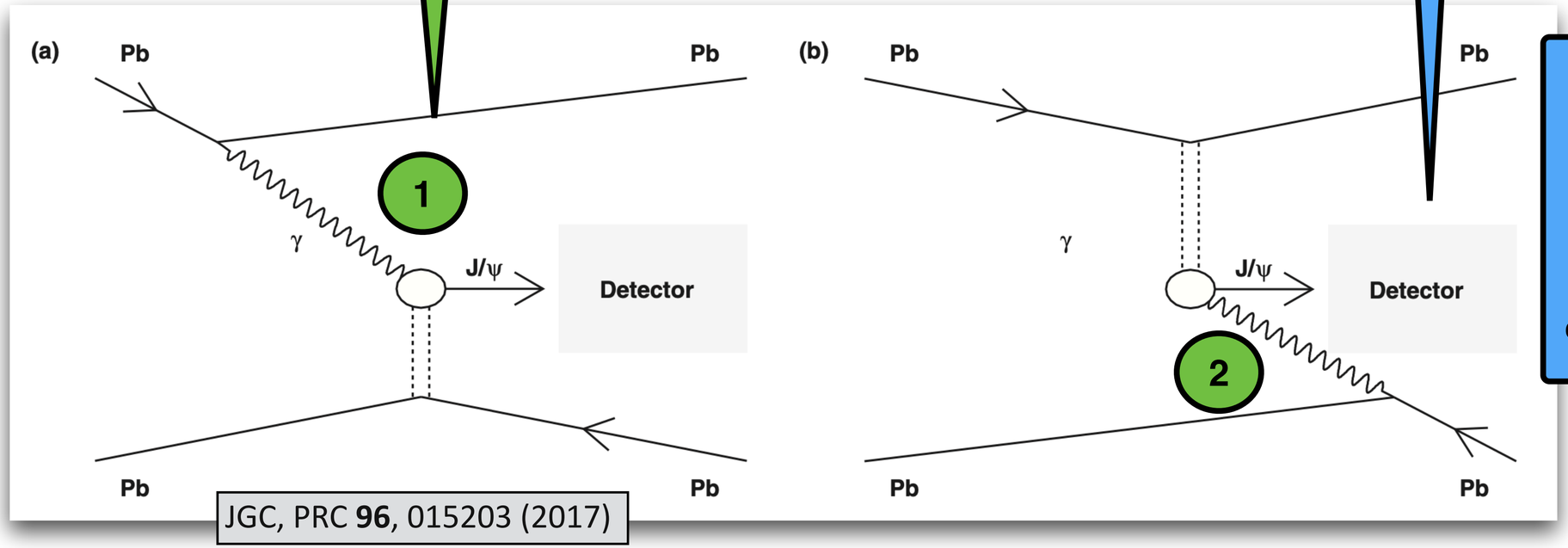
Measure the same process with electromagnetic dissociation (EMD)

Both options select different regions of the impact parameter

Rapidity dependence: ambiguity problem

Open question: how to disentangle both contributions?

Two sources



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

Another independent measurement needed at the same rapidity

We are not there yet, but let's have a look at this one

Up to now, two options:

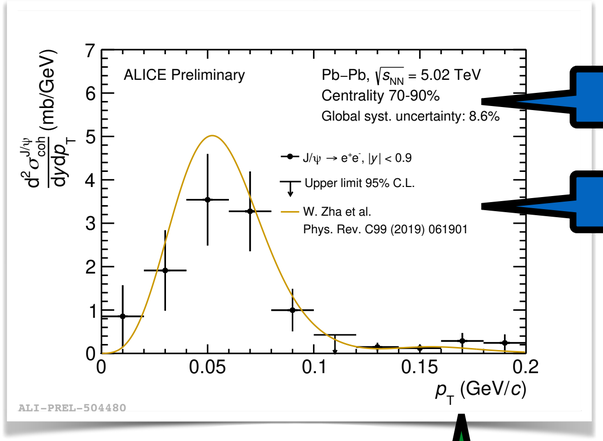
Measure the same process in peripheral collisions

Measure the same process with electromagnetic dissociation (EMD)

Both options select different regions of the impact parameter

J/ψ photoproduction in Pb-Pb peripheral collisions (1/2)

ALICE, Preliminary



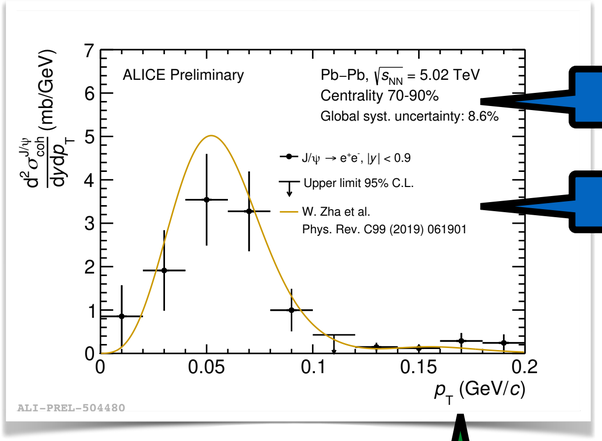
Centrality

Midrapidity

pT of dilepton pair

J/ψ photoproduction in Pb-Pb peripheral collisions (1/2)

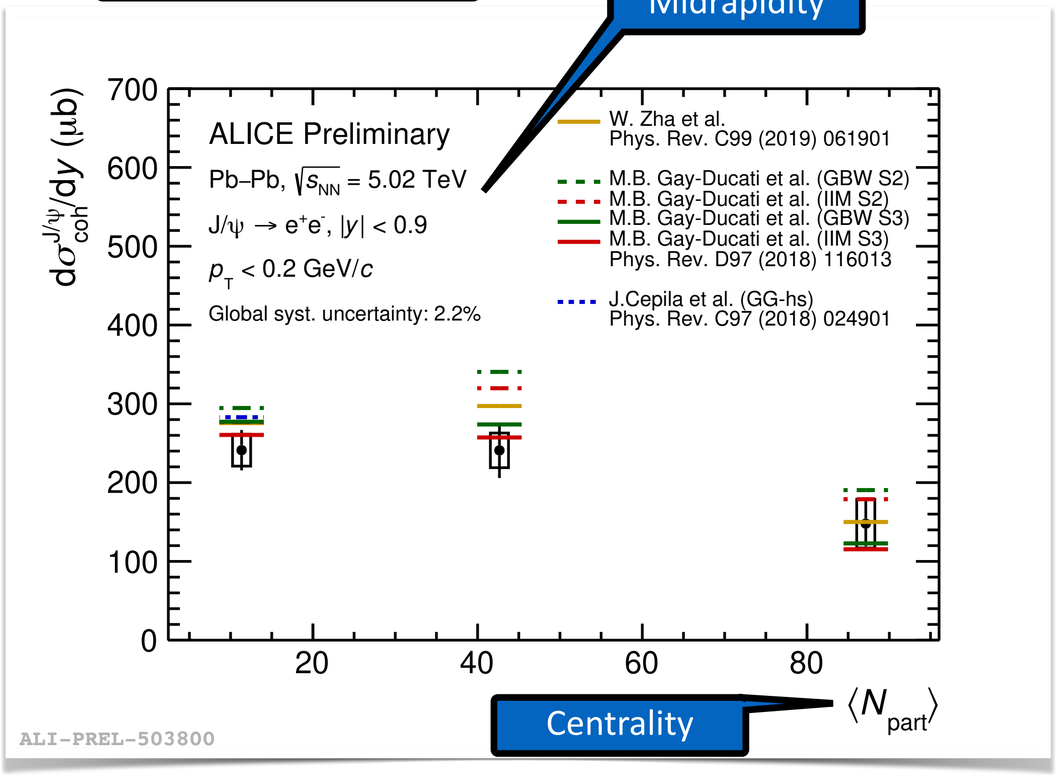
ALICE, Preliminary



Centrality

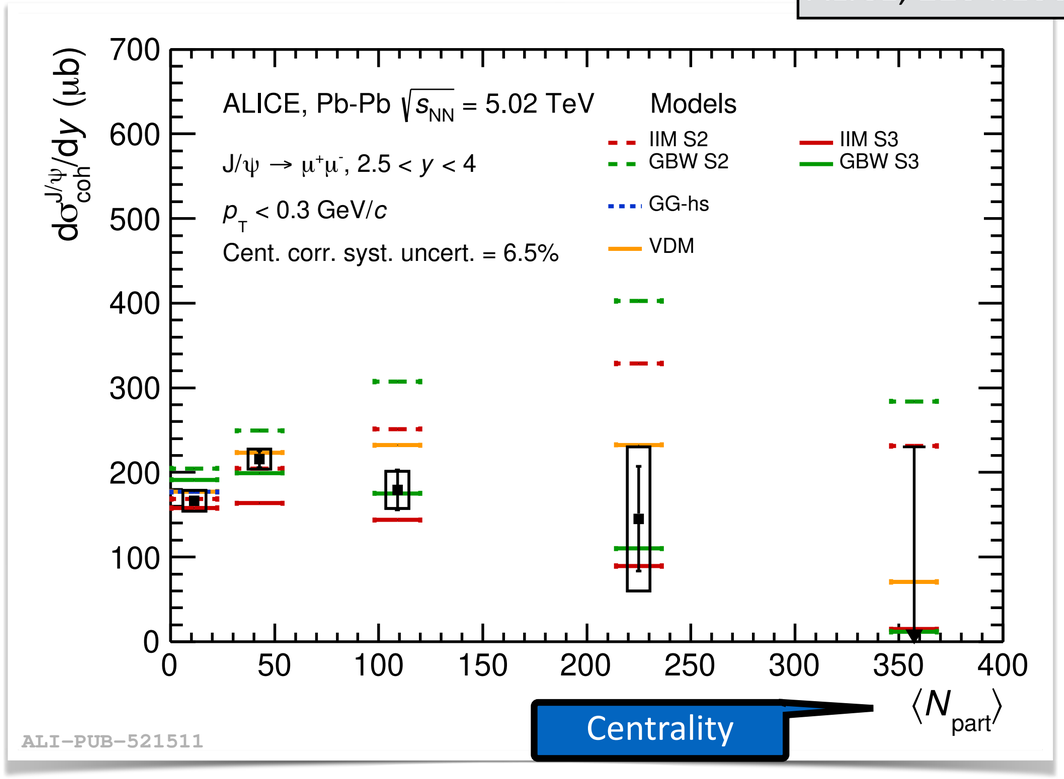
Midrapidity

pT of dilepton pair



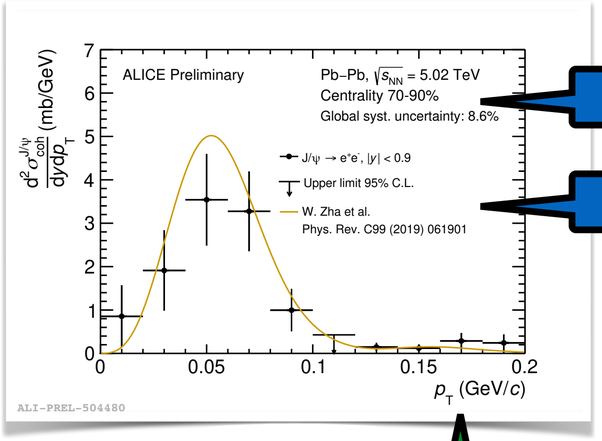
Fwd rapidity

ALICE, 2204.10684



J/ψ photoproduction in Pb-Pb peripheral collisions (1/2)

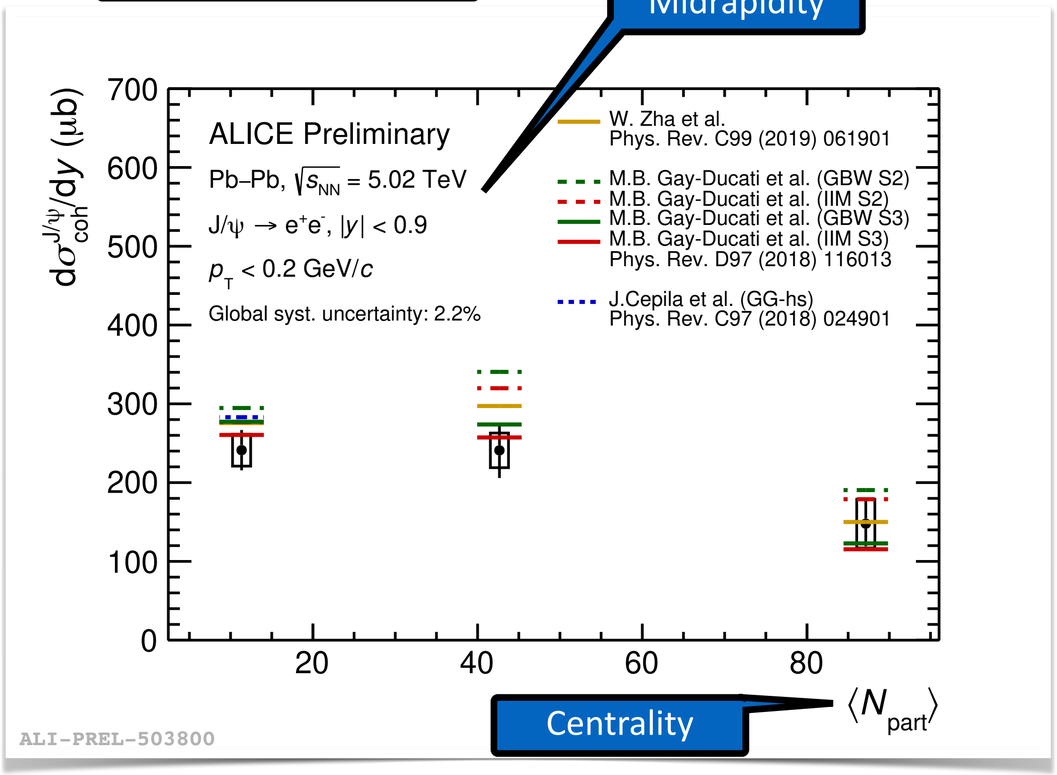
ALICE, Preliminary



Centrality

Midrapidity

pT of dilepton pair

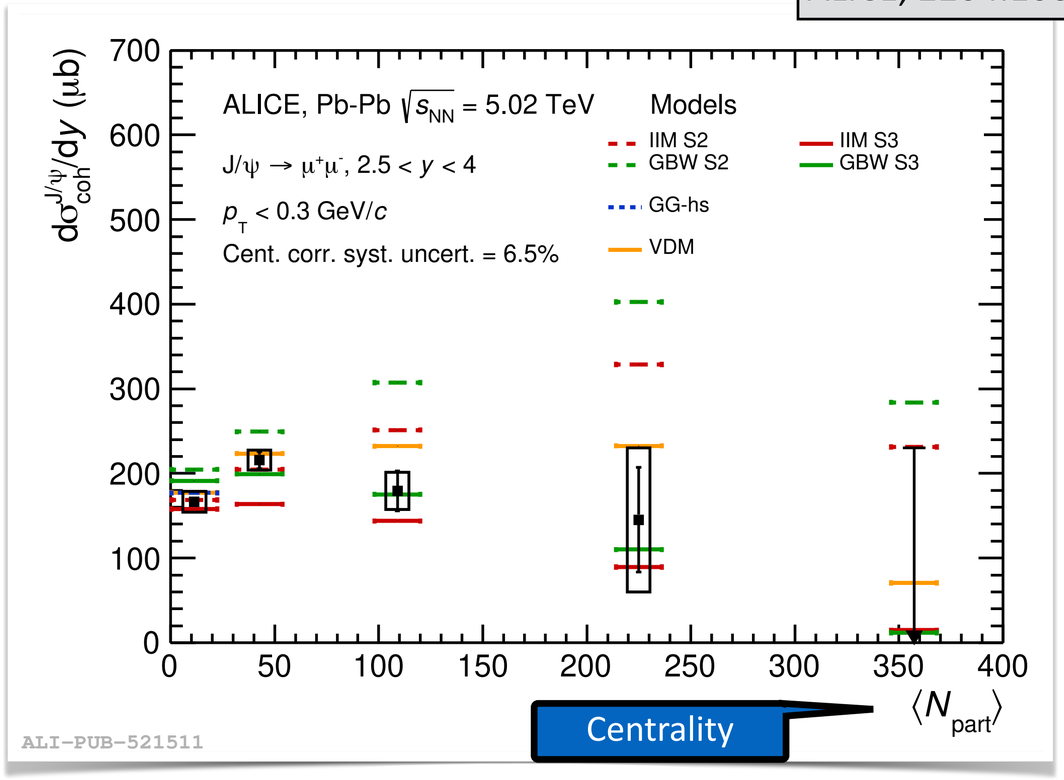


Midrapidity

Centrality

Fwd rapidity

ALICE, 2204.10684

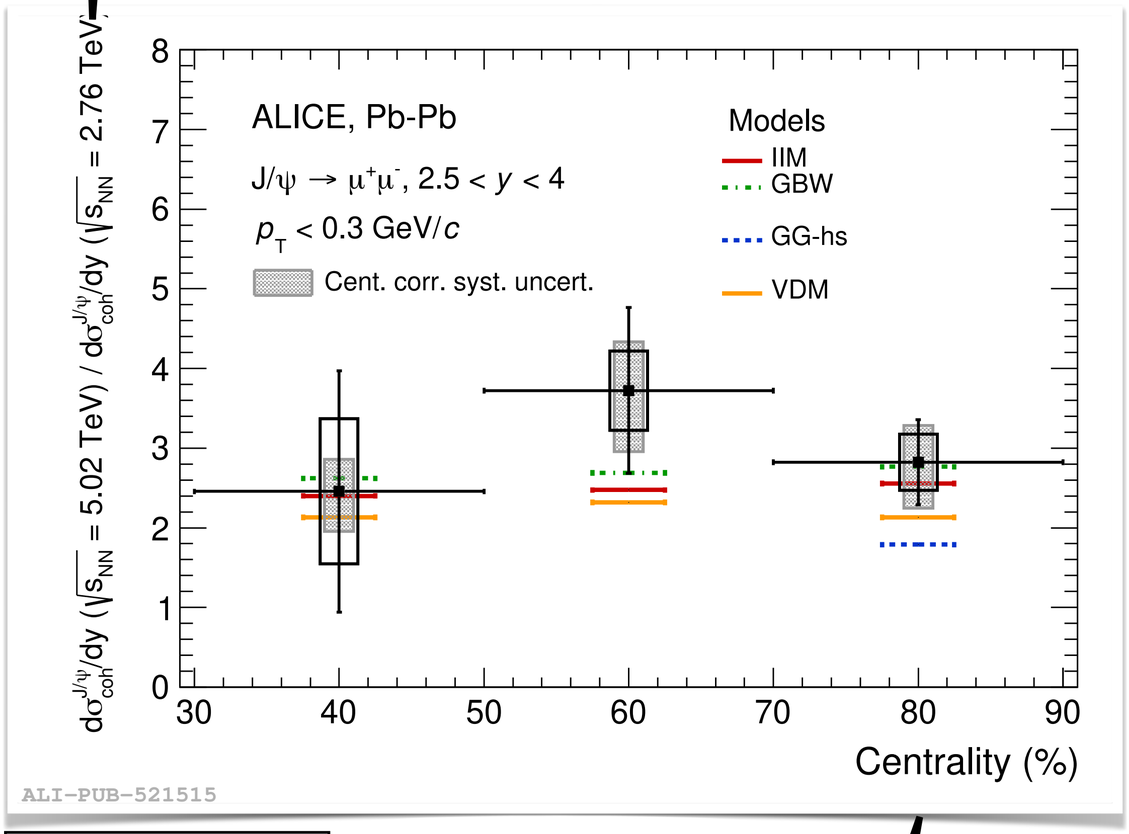


Centrality

Models with different treatments of the flux and also different implementations of the QCD part of the interaction:
VDM: modified flux
IMM S3: modified flux and cross section

J/ψ photoproduction in Pb-Pb peripheral collisions (2/2)

Ratio of peripheral cross sections at different energies

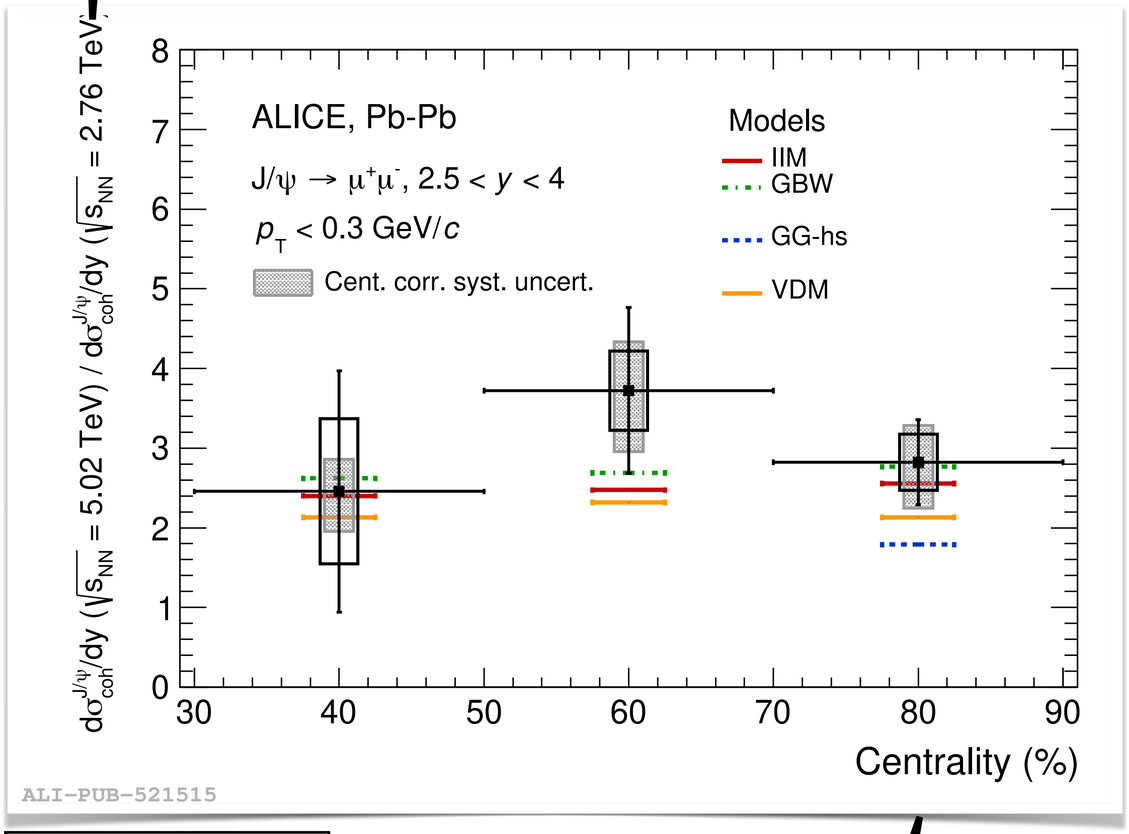


ALICE, 2204.10684

Centrality

J/ψ photoproduction in Pb-Pb peripheral collisions (2/2)

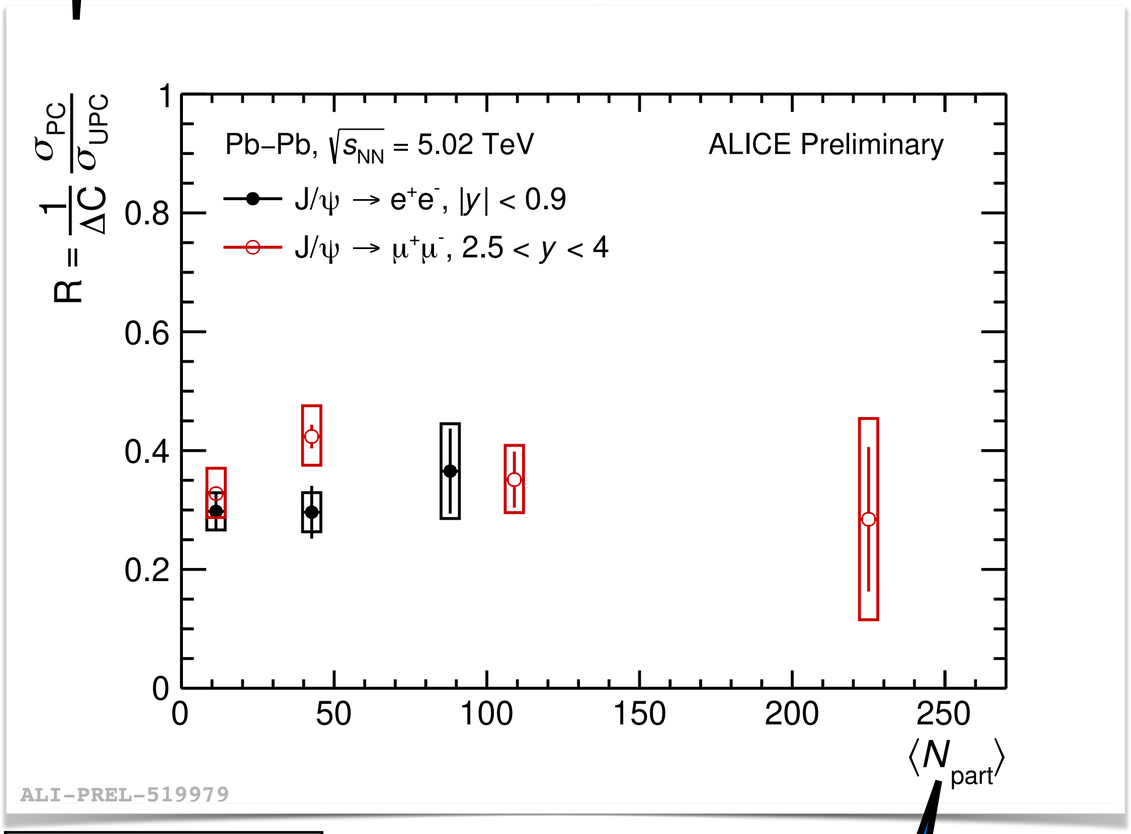
Ratio of peripheral cross sections at different energies



ALICE, 2204.10684

Centrality

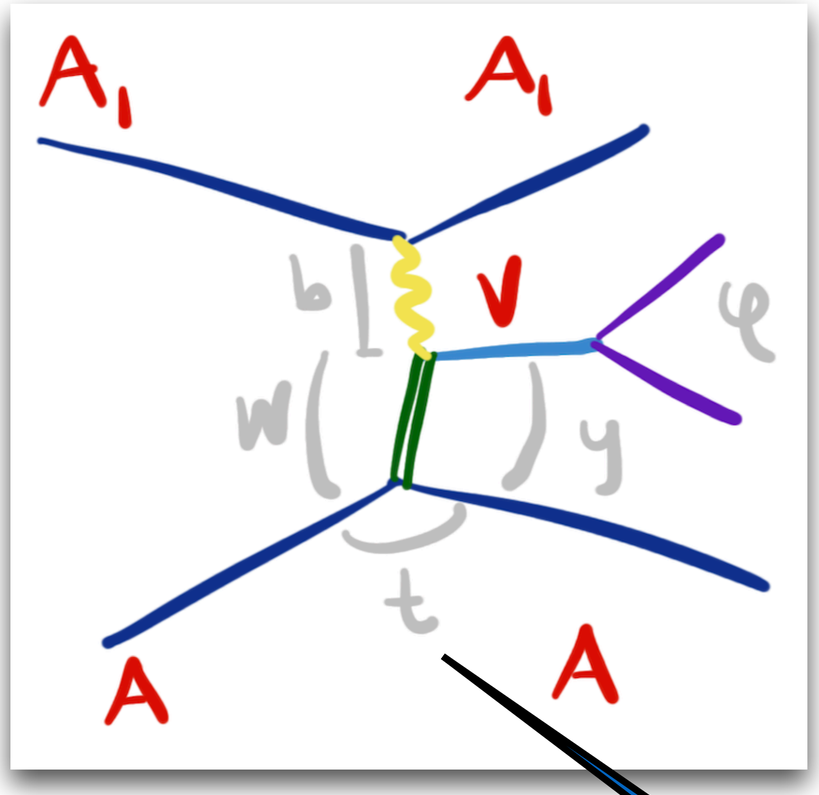
Ratio of peripheral to UPC cross section at 5.02 TeV



ALICE, Preliminary

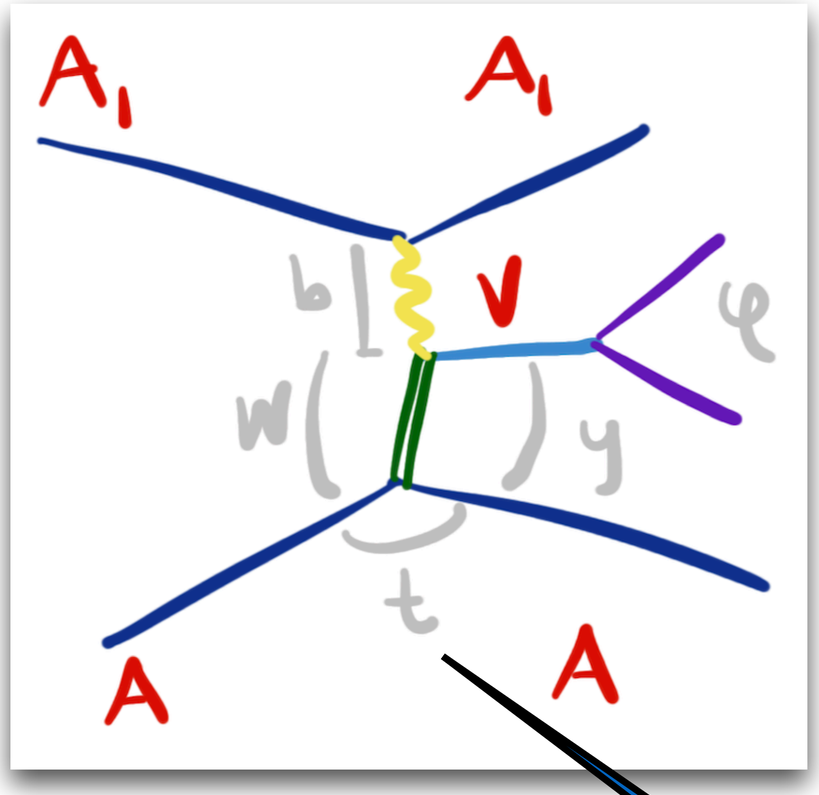
Centrality

|t| Momentum transferred at the target vertex



|t| dependence
⇨
A window to transverse structure

|t| Momentum transferred at the target vertex

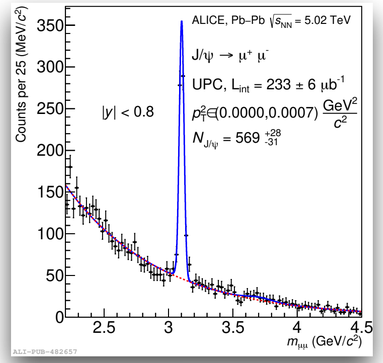


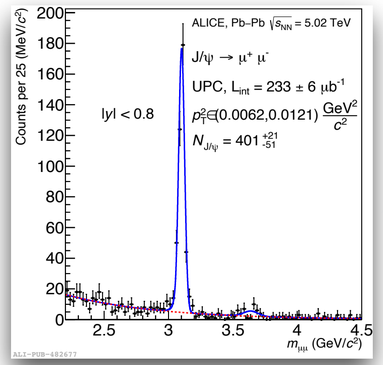
Expectations:
The distribution of gluons in the transverse plane is sensitive to saturation effects

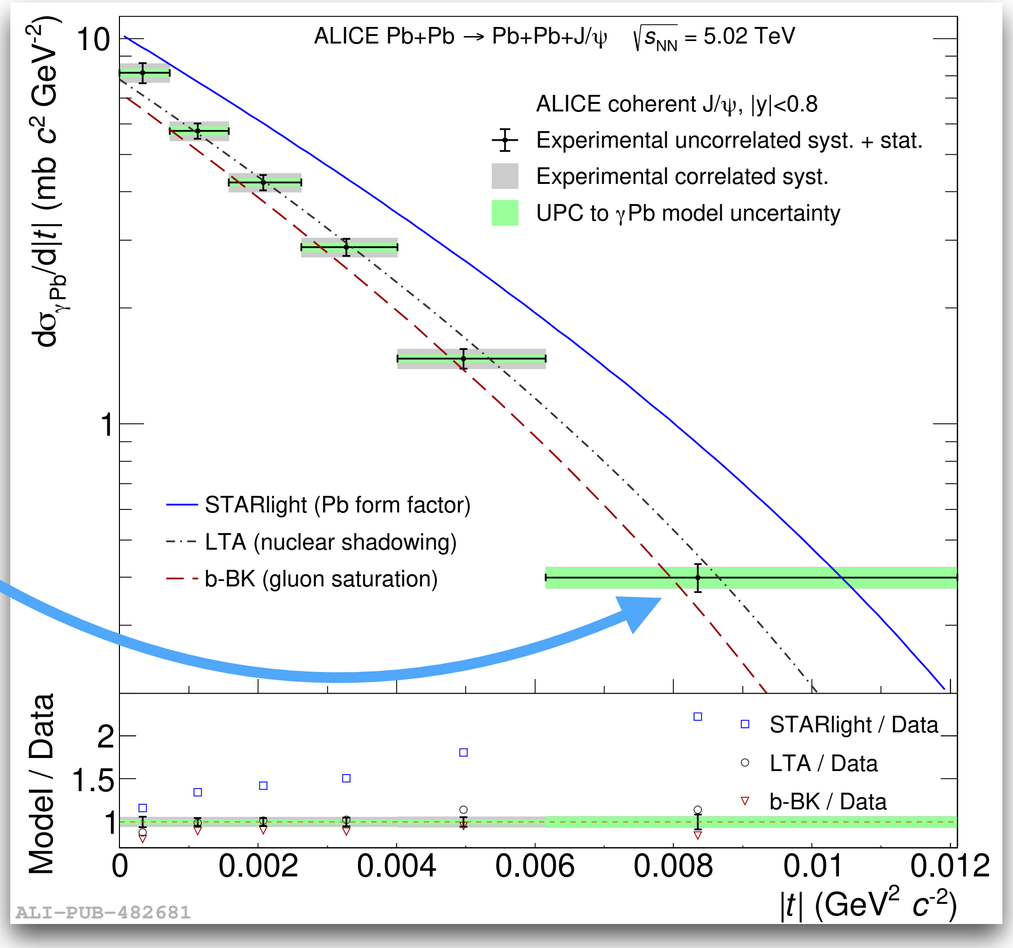
|t| dependence
⇨
A window to transverse structure

J/ψ

J/ψ in Pb-Pb UPC at midrapidity as seen by ALICE





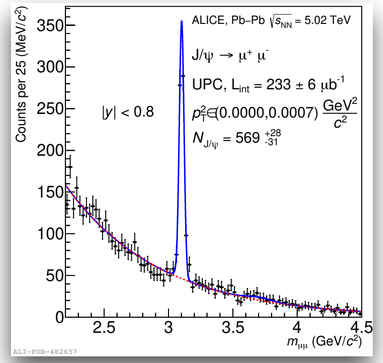


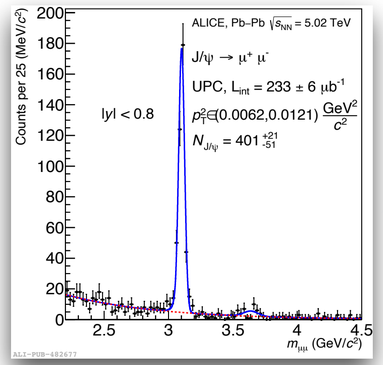
Very clear signals

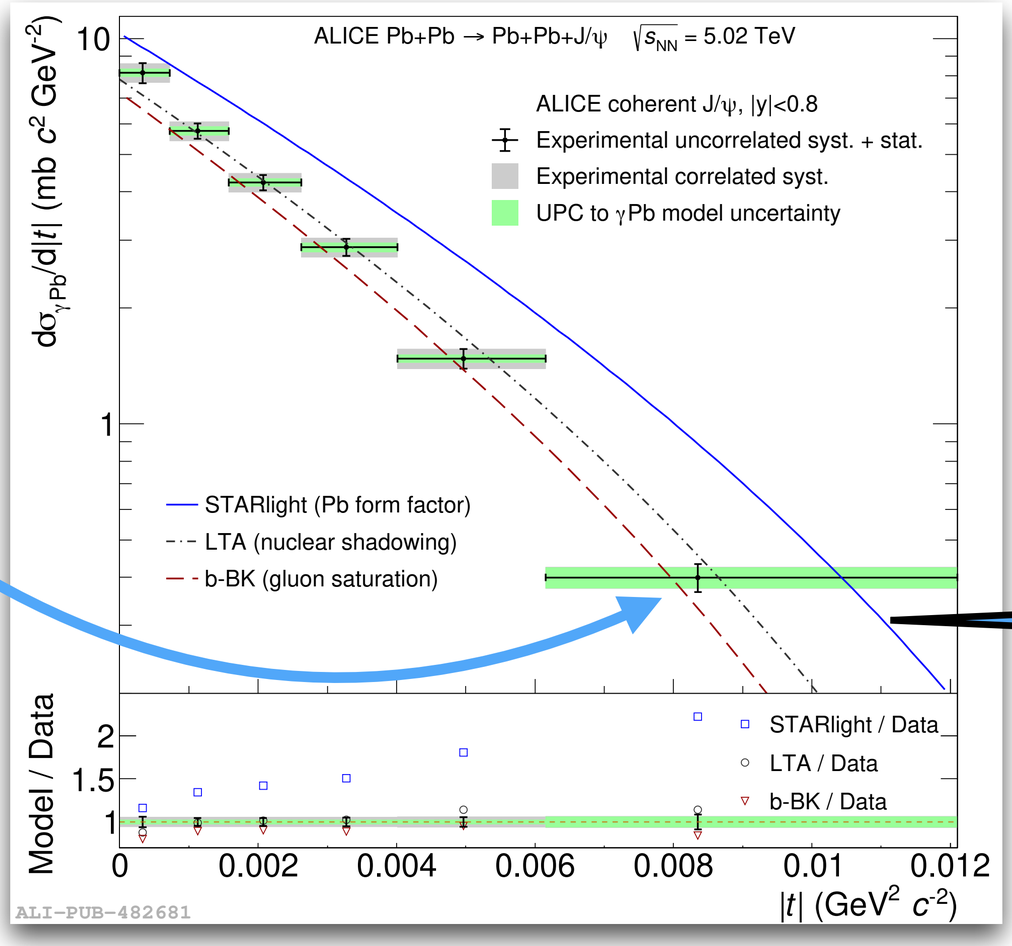
ALICE, PLB 817(2021) 136280

J/ψ

J/ψ in Pb-Pb UPC at midrapidity as seen by ALICE







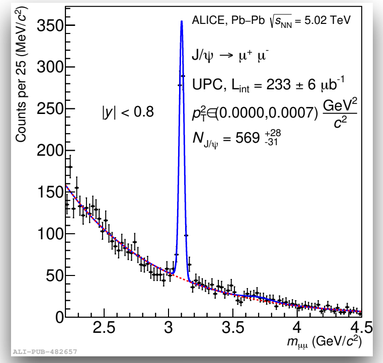
Very clear signals

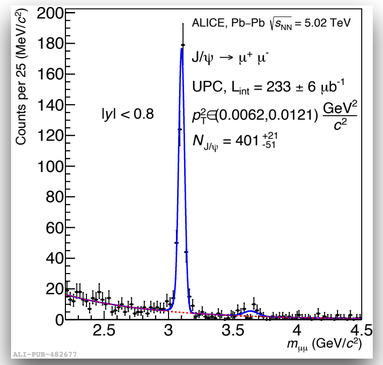
A model based on the form factor does not describe data

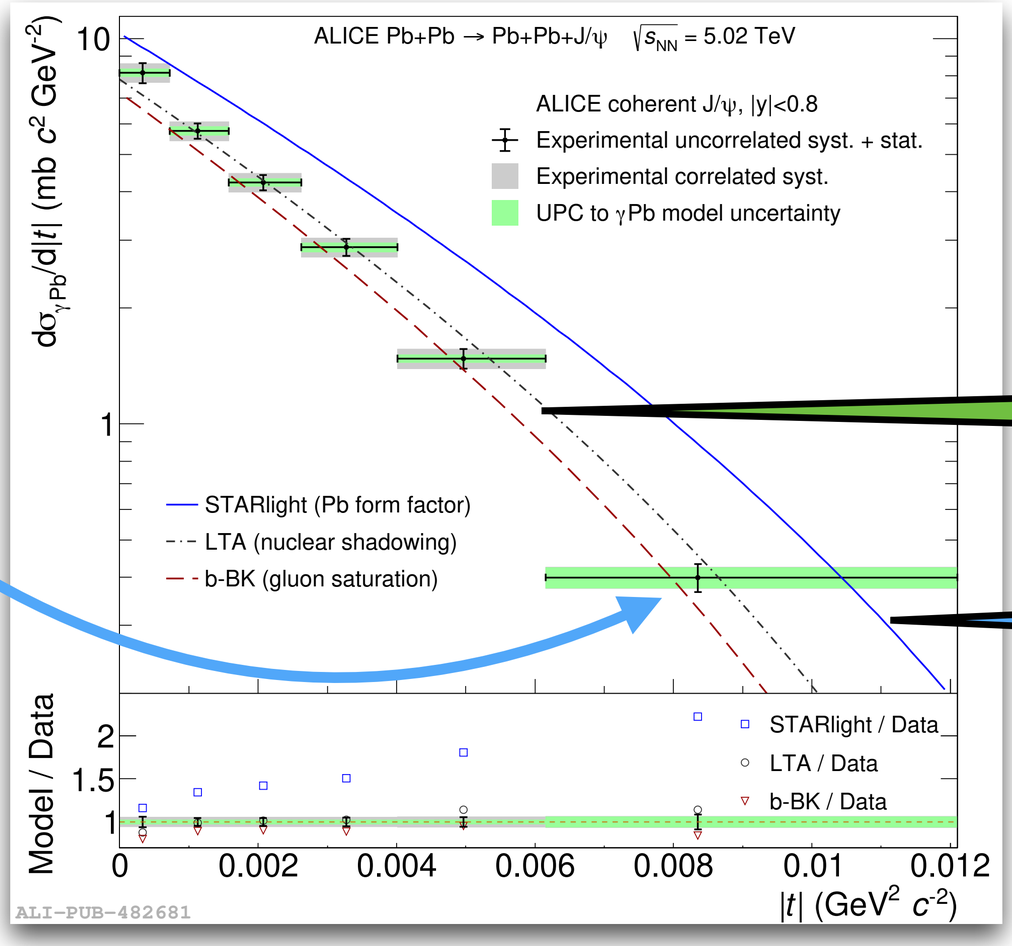
ALICE, PLB 817(2021) 136280

J/ψ

J/ψ in Pb-Pb UPC at midrapidity as seen by ALICE







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

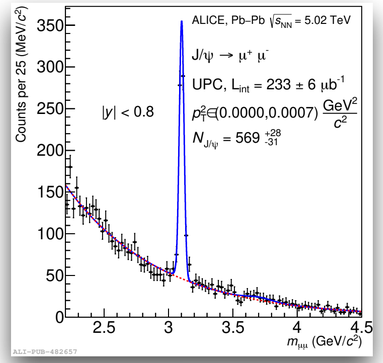
A model based on the form factor does not describe data

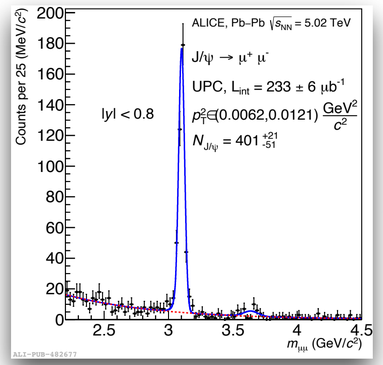
Very clear signals

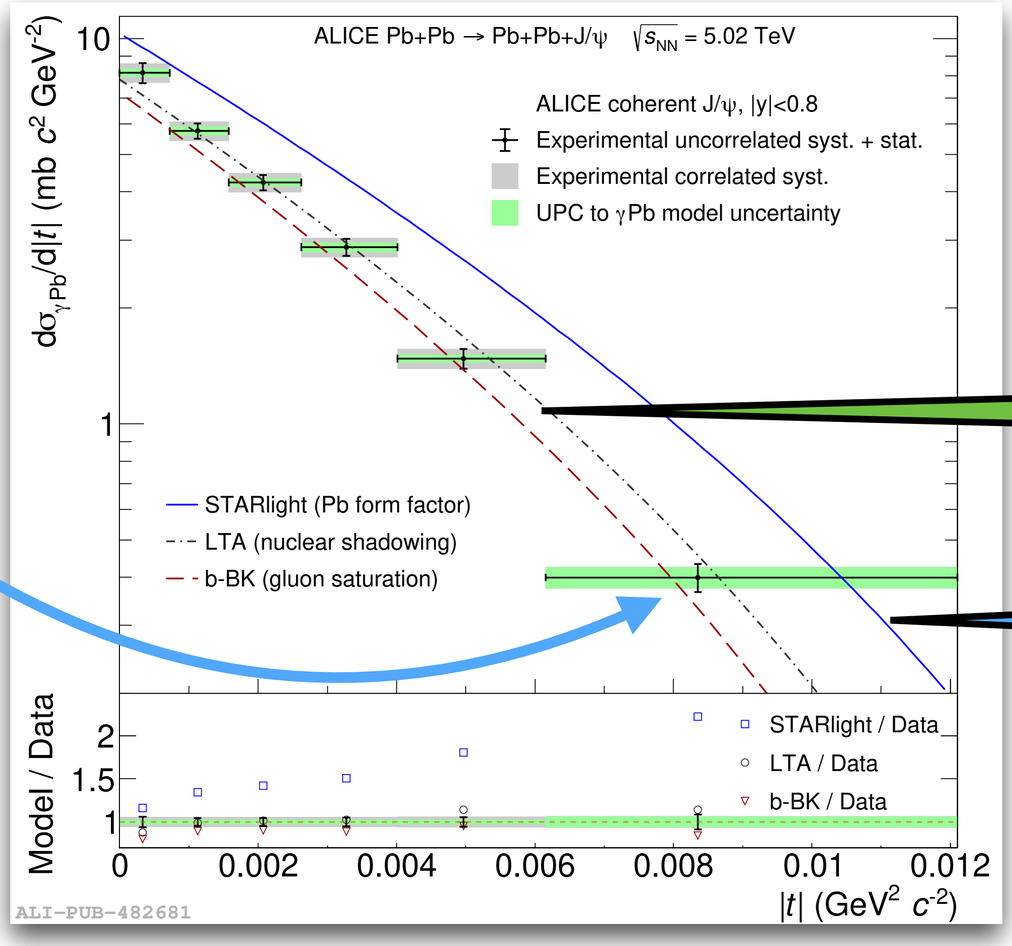
ALICE, PLB 817(2021) 136280

J/ψ

J/ψ in Pb-Pb UPC at midrapidity as seen by ALICE







Open question:
How much of shadowing is saturation?
Does the answer depend on |t|?

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

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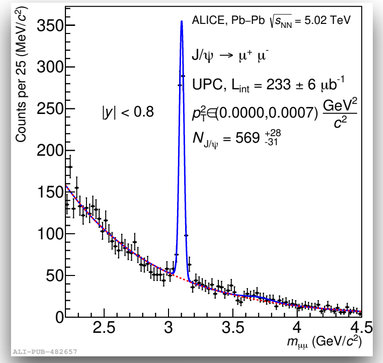
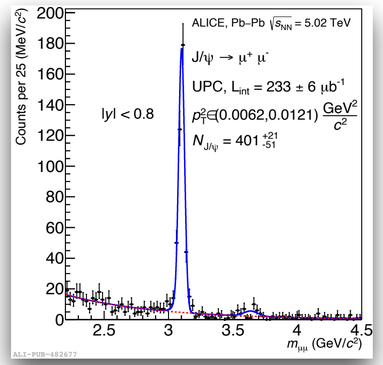
Very clear signals

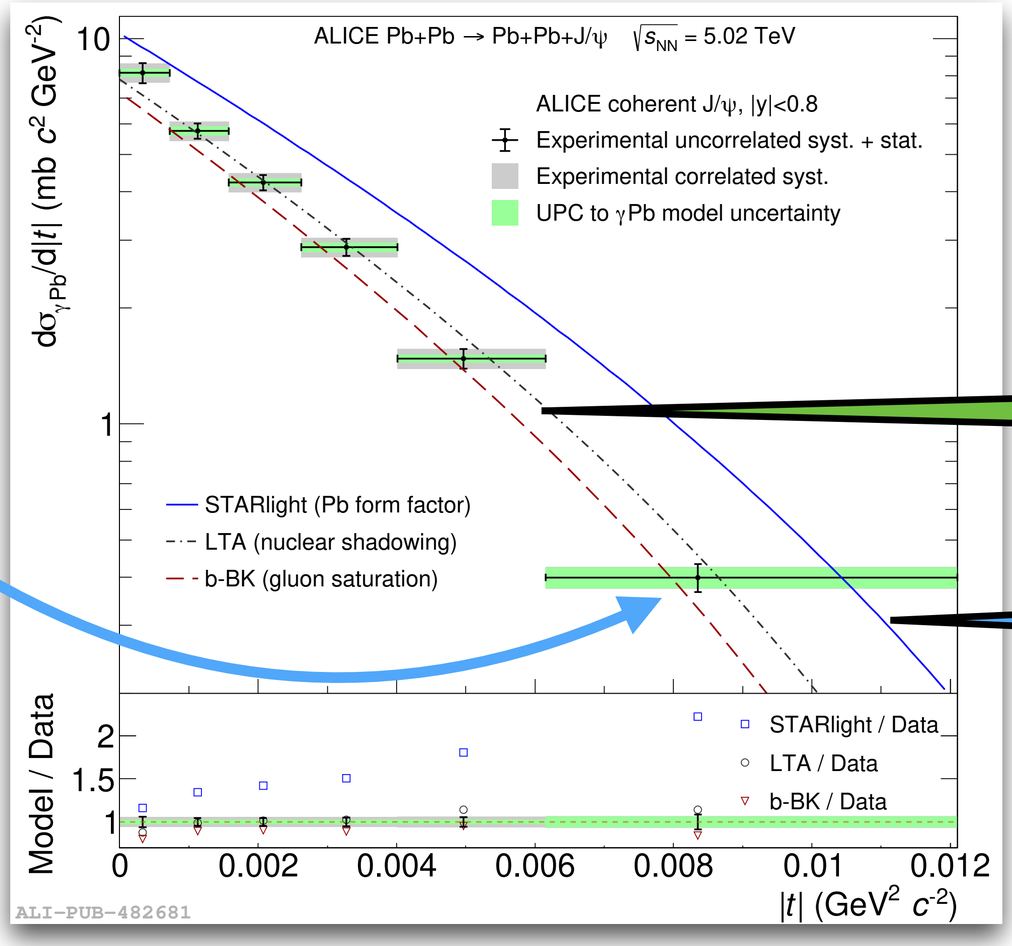
ALICE, PLB 817(2021) 136280

J/ψ

J/ψ in Pb-Pb UPC at midrapidity as seen by ALICE







ALICE, PLB 817(2021) 136280

Open question:
How much of shadowing is saturation?
Does the answer depend on ltl?

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

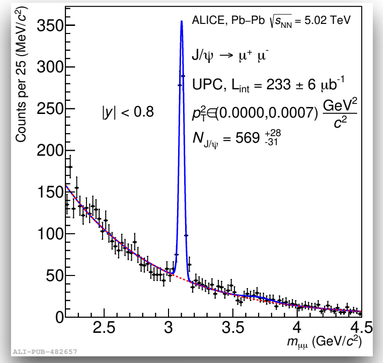
A model based on the form factor does not describe data

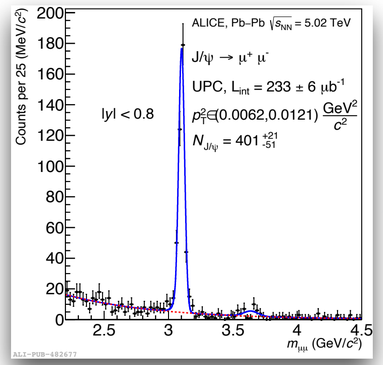
Open question:
How to measure at large ltl in the presence of incoherent background?

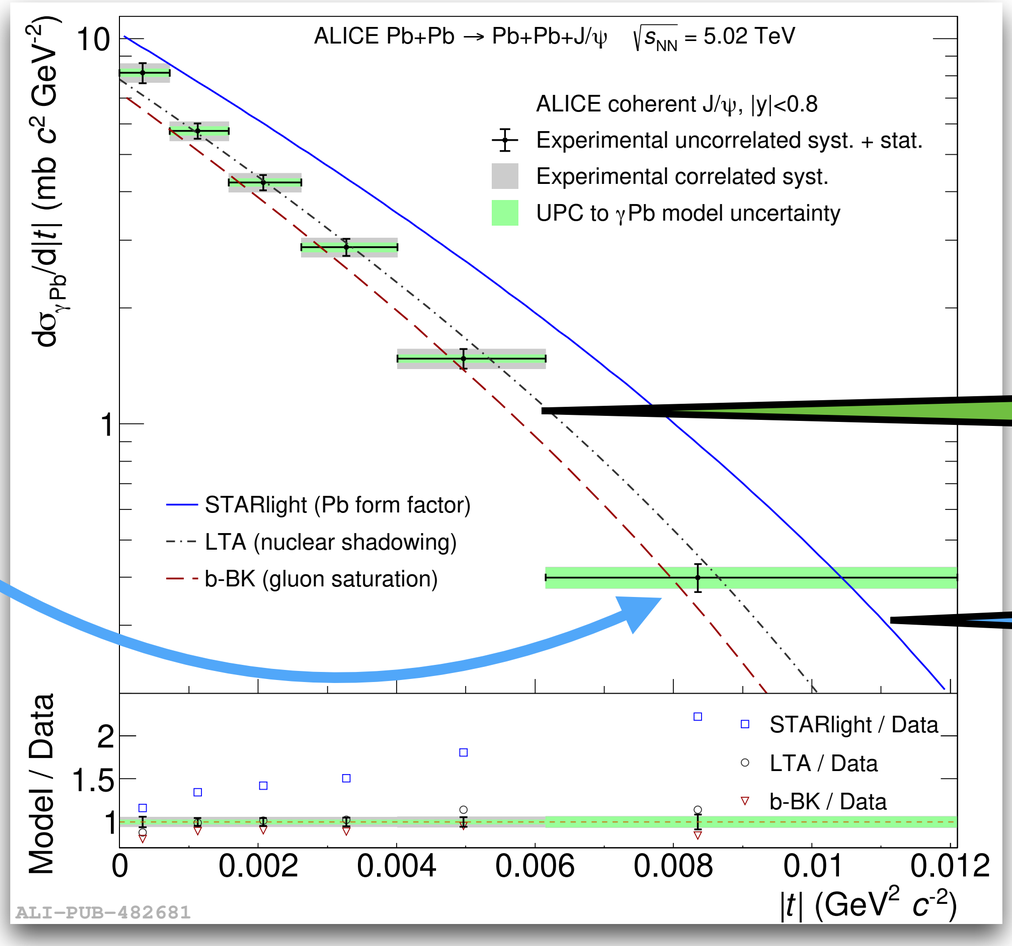
Very clear signals

J/ψ

J/ψ in Pb-Pb UPC at midrapidity as seen by ALICE







ALICE, PLB 817(2021) 136280

Very clear signals

Open question:
How much of shadowing is saturation?
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A shadowing based, and a saturation-based computation with impact-parameter dependence, close to data

A model based on the form factor does not describe data

Open question:
How to measure at large ltl in the presence of incoherent background?

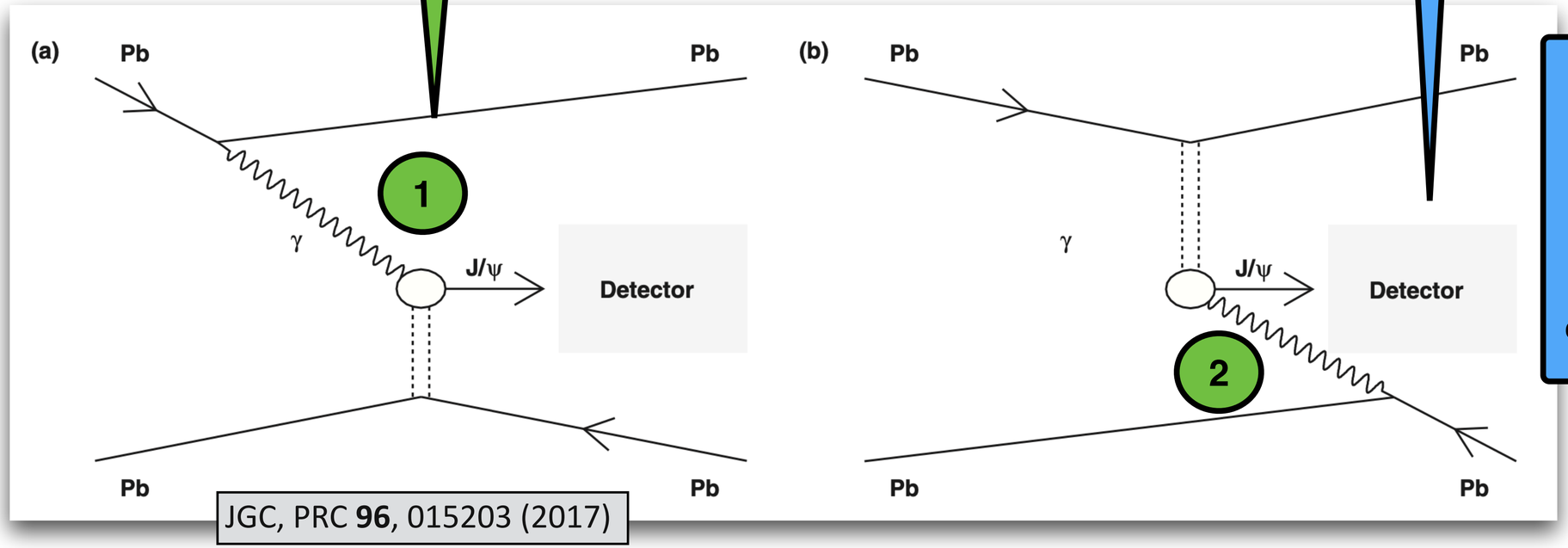
Use 0n0n events to suppress incoherent production

Diffractive vector-meson photoproduction
Results from AA

Rapidity dependence: ambiguity problem

Open question: how to disentangle both contributions?

Two sources



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

Another independent measurement needed at the same rapidity

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Rapidity dependence: ambiguity problem

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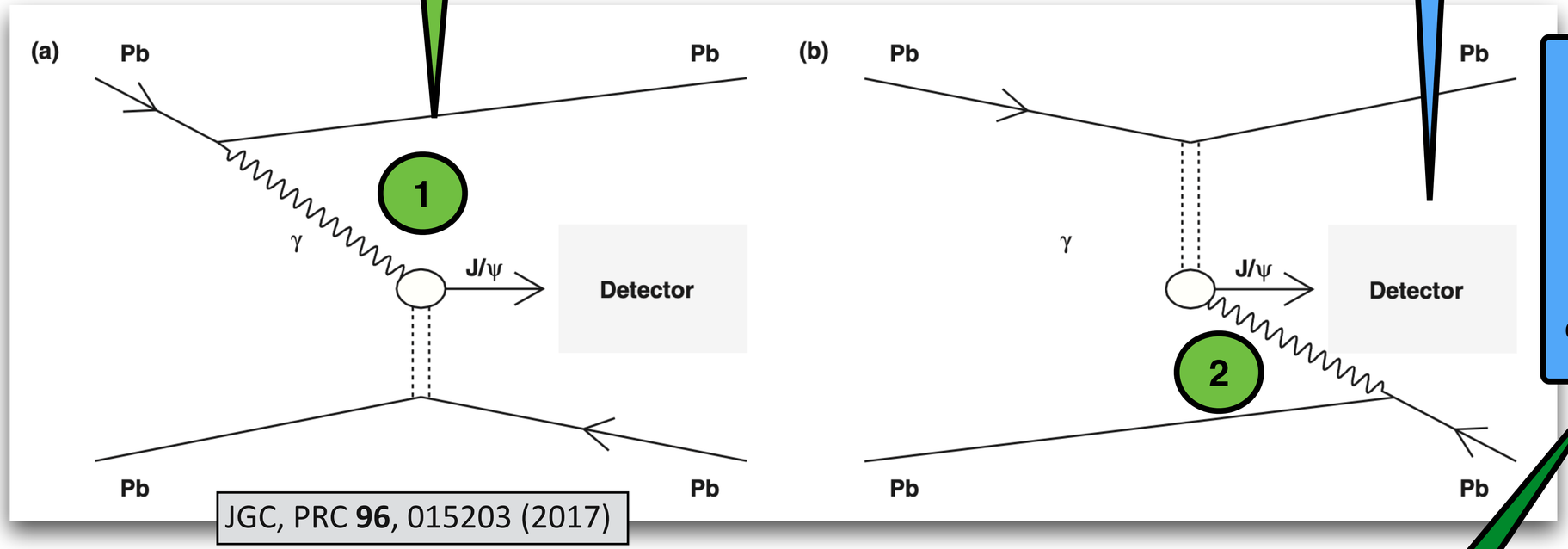


JGC, PRC **96**, 015203 (2017)

Another independent measurement needed at the same rapidity

Up to now, two options:

Measure the same process in peripheral collisions

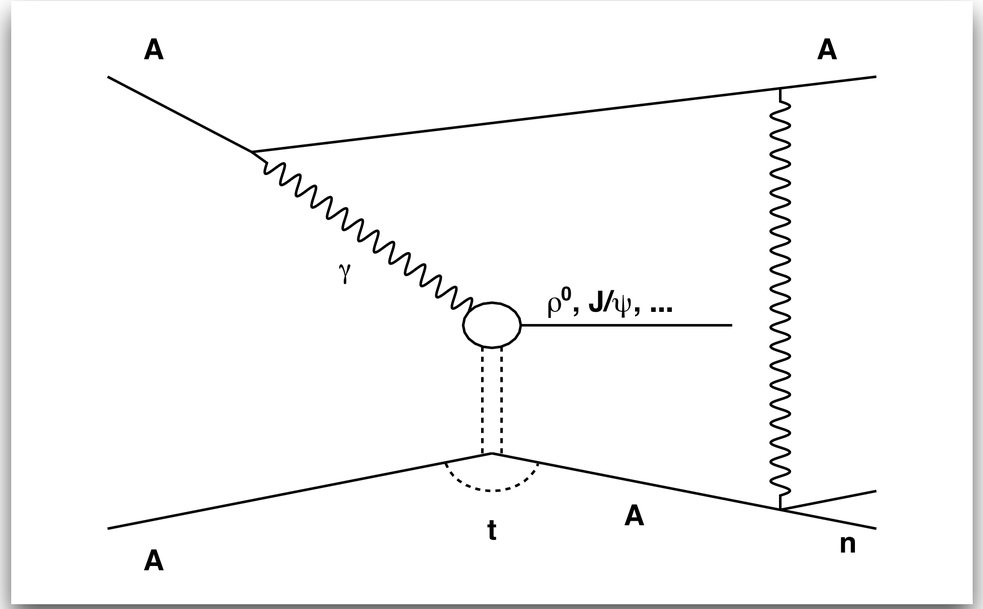
Measure the same process with electromagnetic dissociation (EMD)

Both options select different regions of the impact parameter

Now, let's look at this one

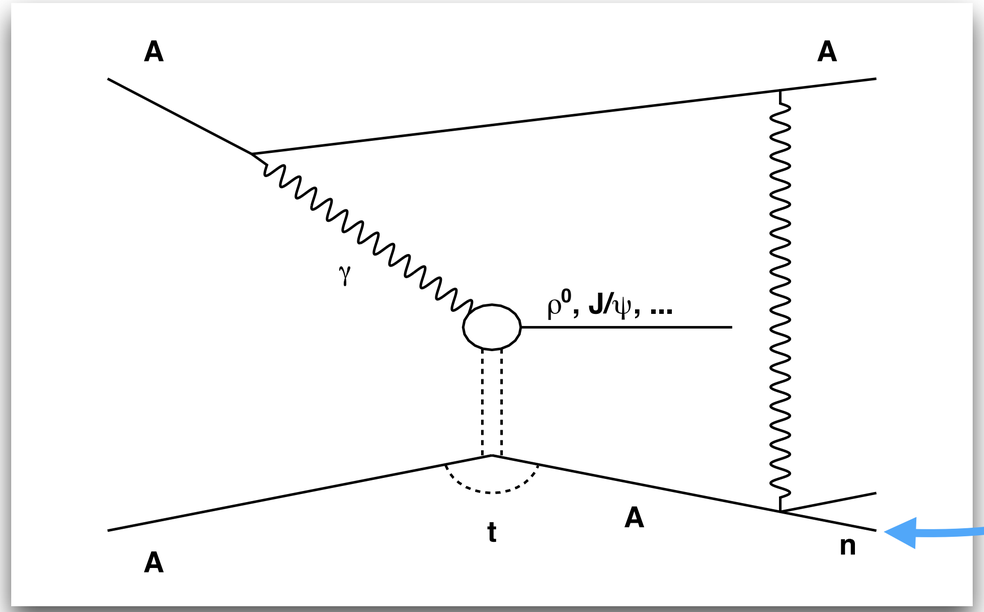
Rapidity dependence: Using EMD

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

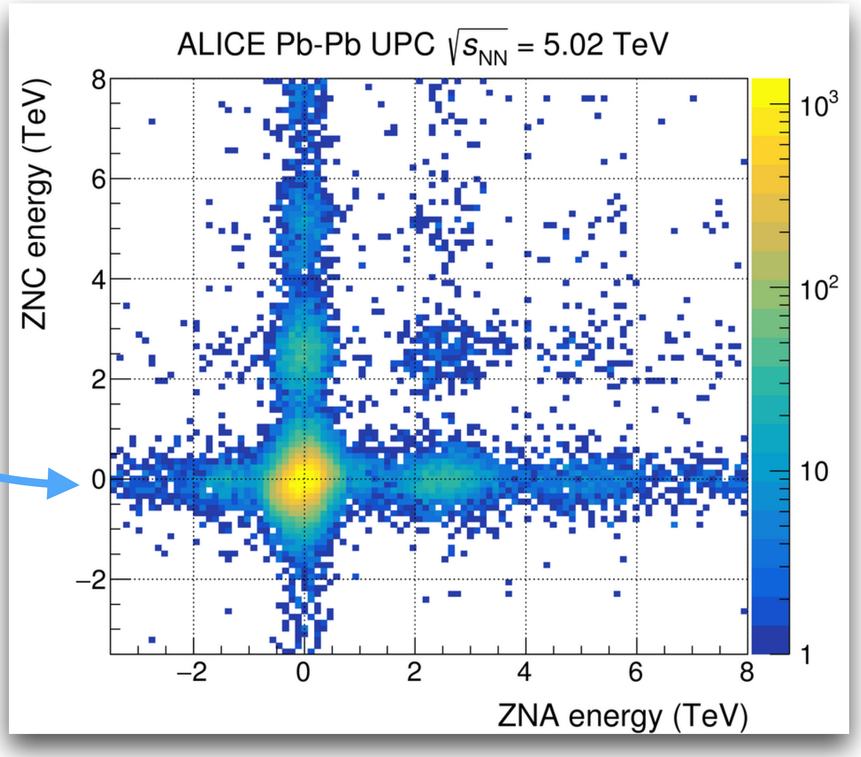


Rapidity dependence: Using EMD

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



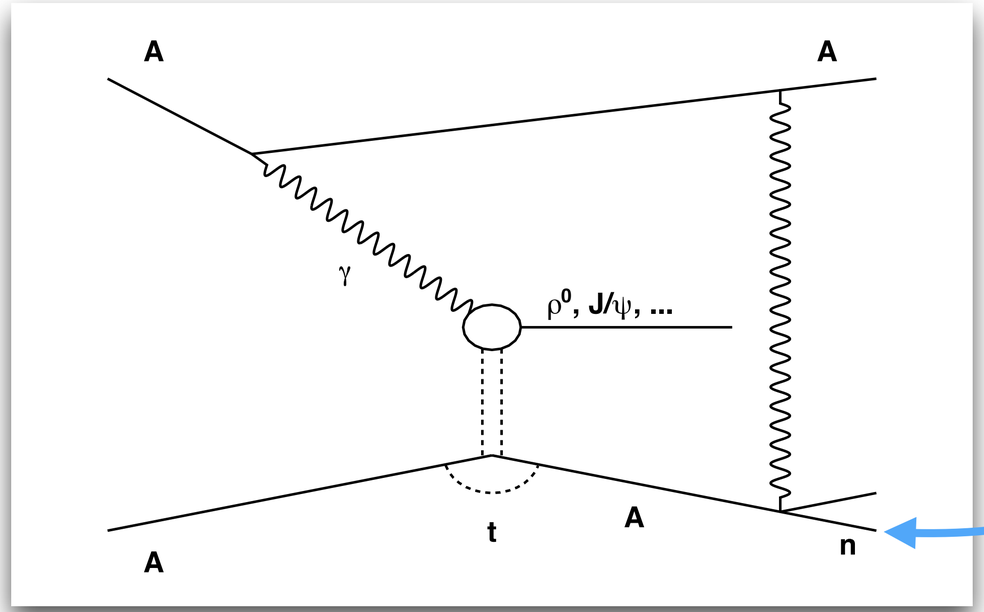
ZDC



ALICE, JHEP 06 (2020) 035

Rapidity dependence: Using EMD

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



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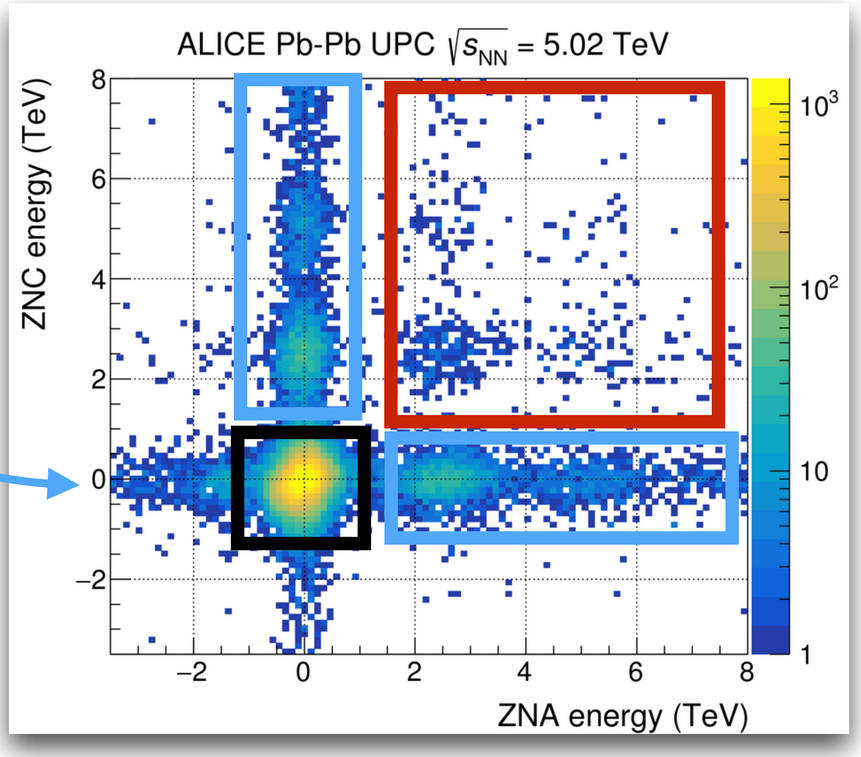
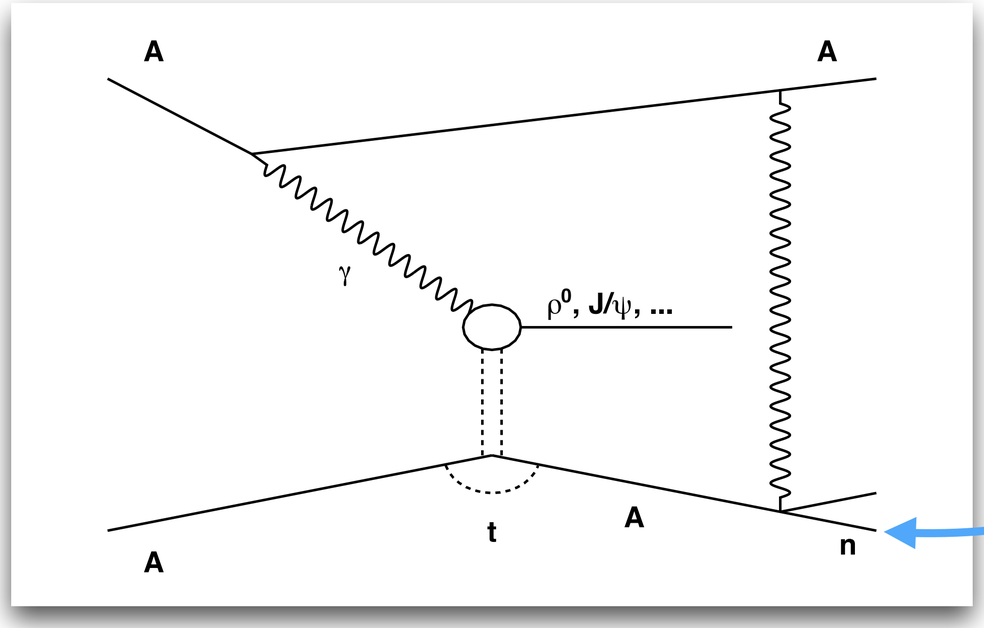


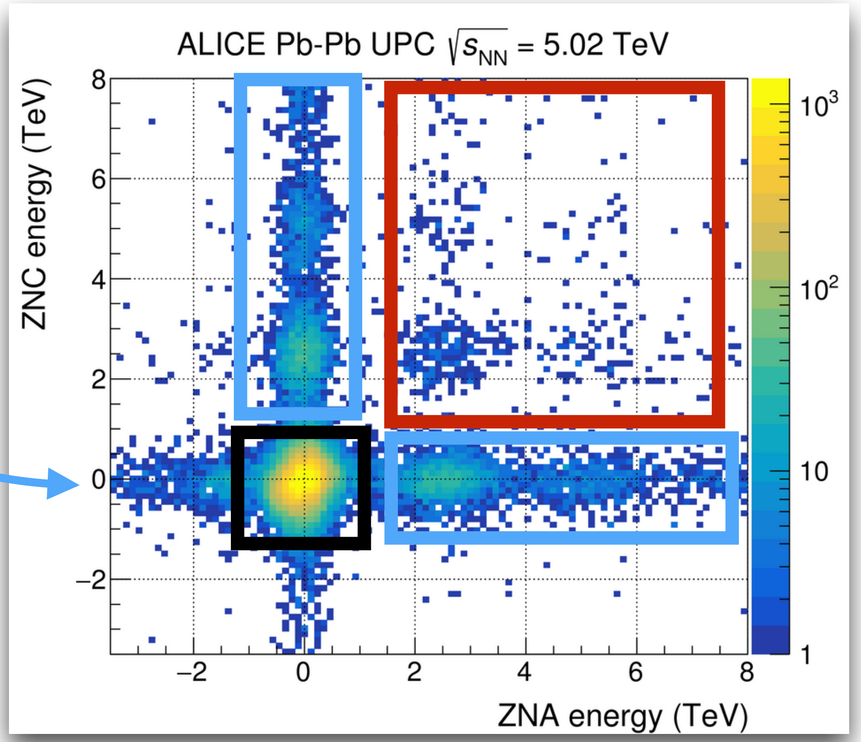
ALICE, JHEP 06 (2020) 035

Rapidity dependence: Using EMD

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

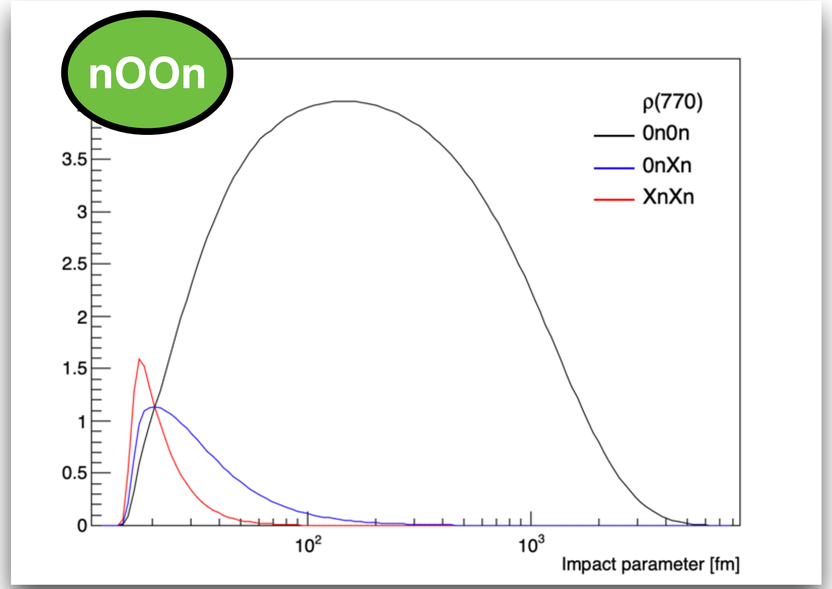


ZDC



ALICE, JHEP 06 (2020) 035

nOOn



Broz et al., CPC 235 (2020) 107181

0n0n: large impact parameters
0nXn: smaller impact parameters
XnXn: smallest impact parameters

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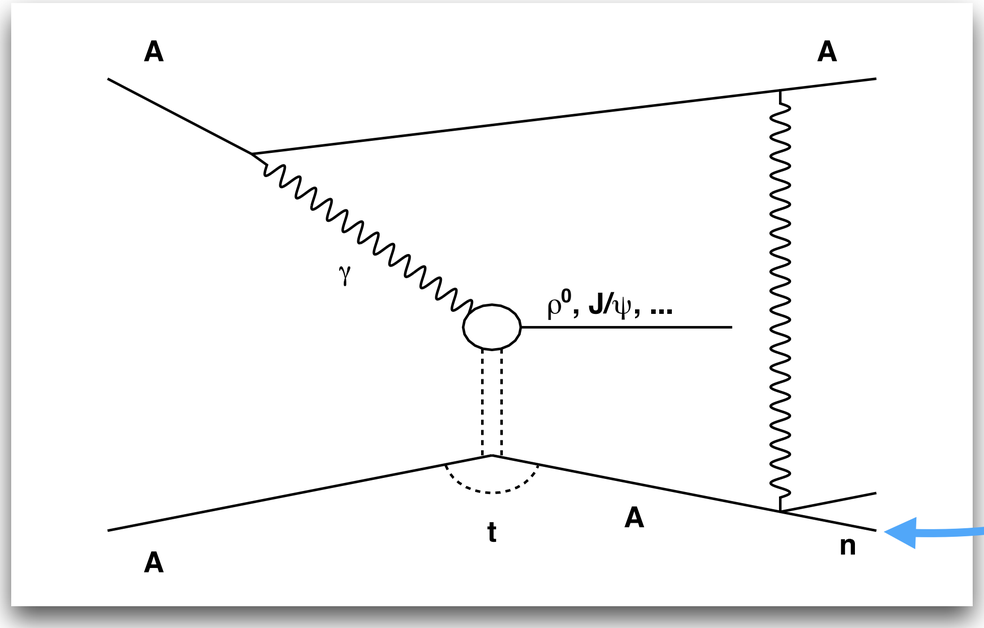

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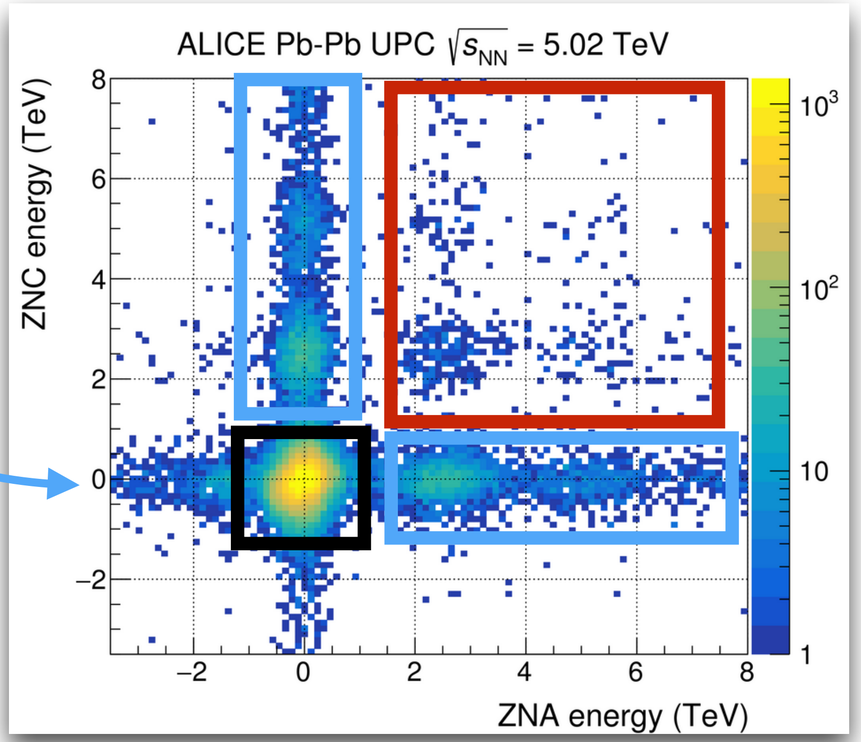

ALICE, JHEP 06 (2020) 035

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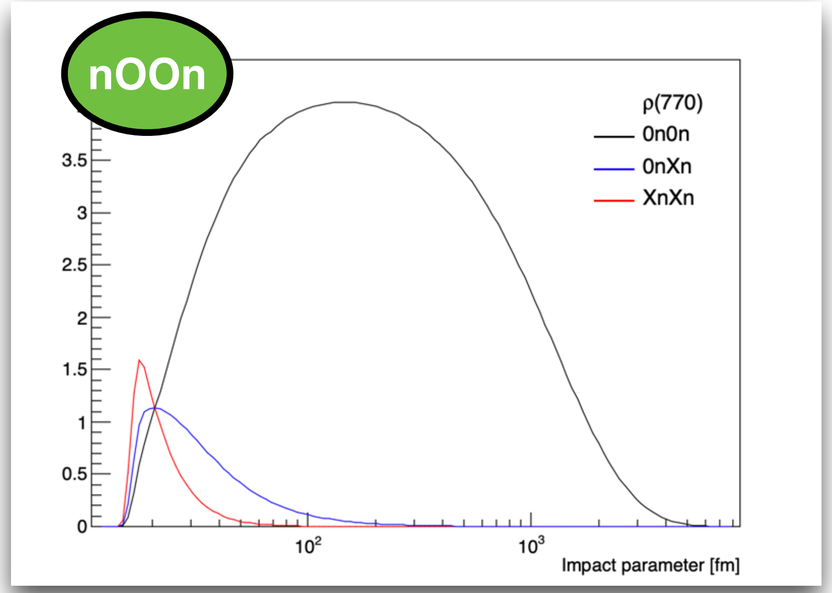

Broz et al., CPC 235 (2020) 107181

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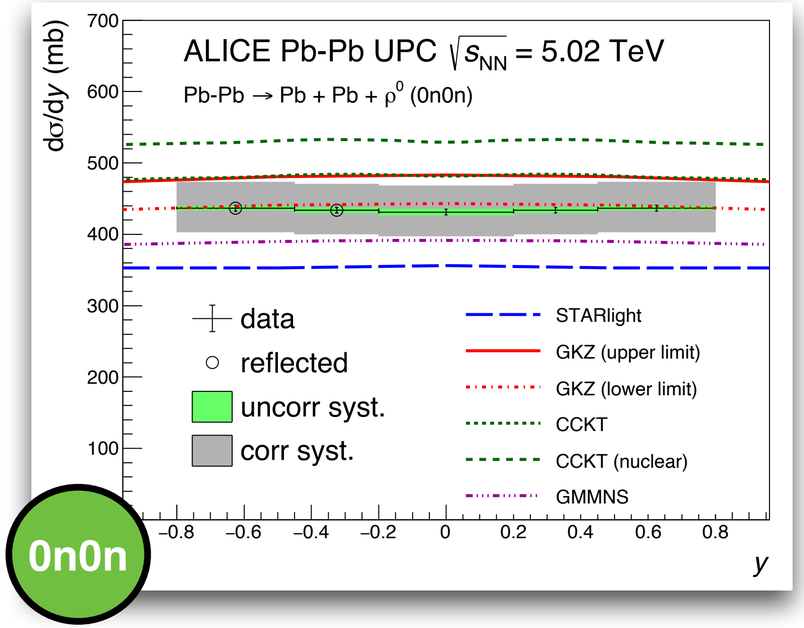
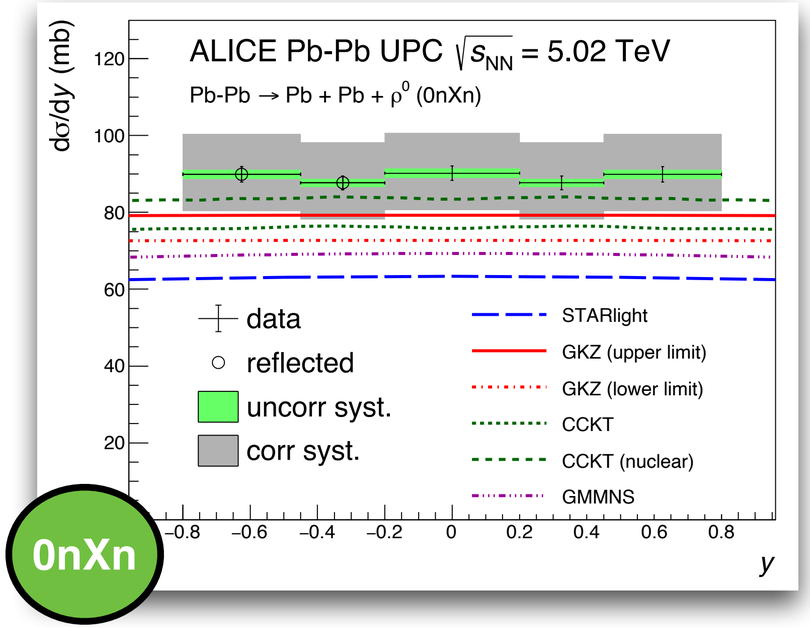
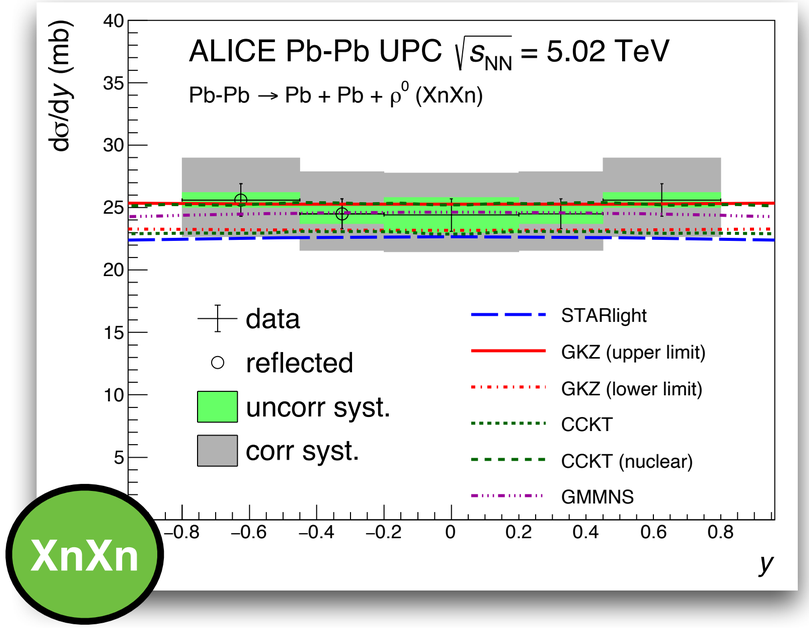
Few events in XnXn wrt 0n0n

ρ(770) in Pb-Pb as seen by ALICE

Testing the EMD method at midrapidity







ALICE, JHEP 06 (2020) 035

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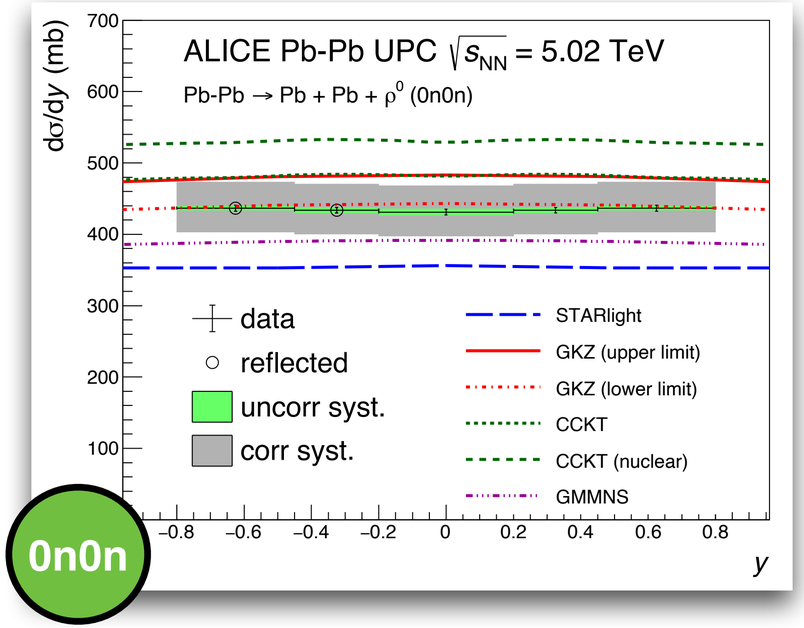

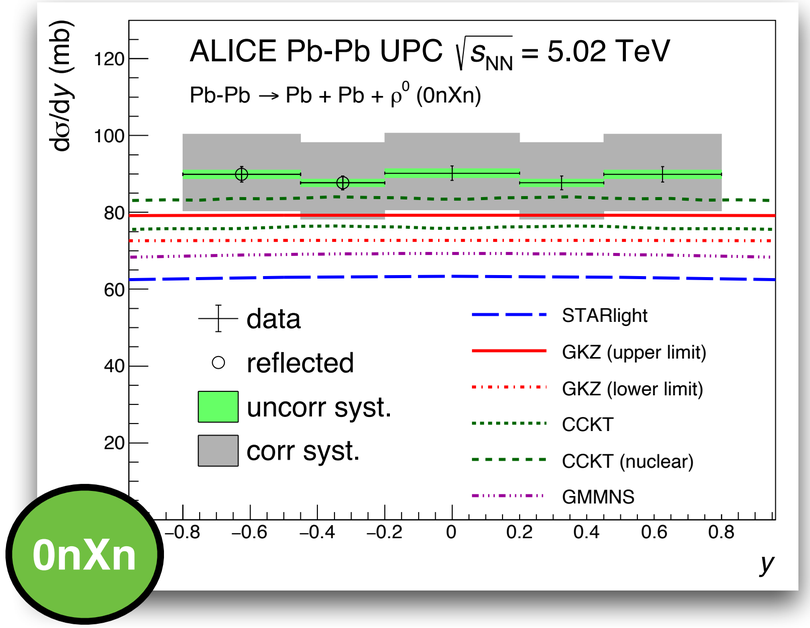

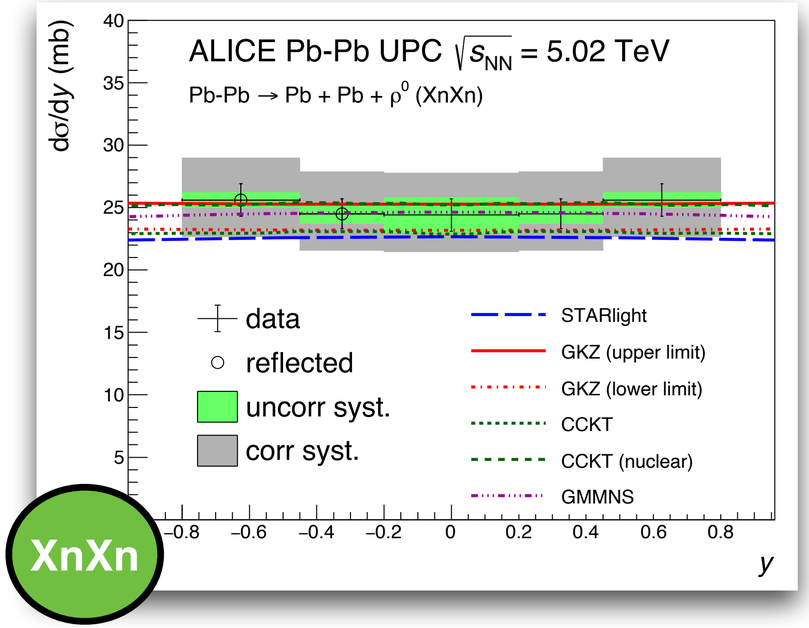

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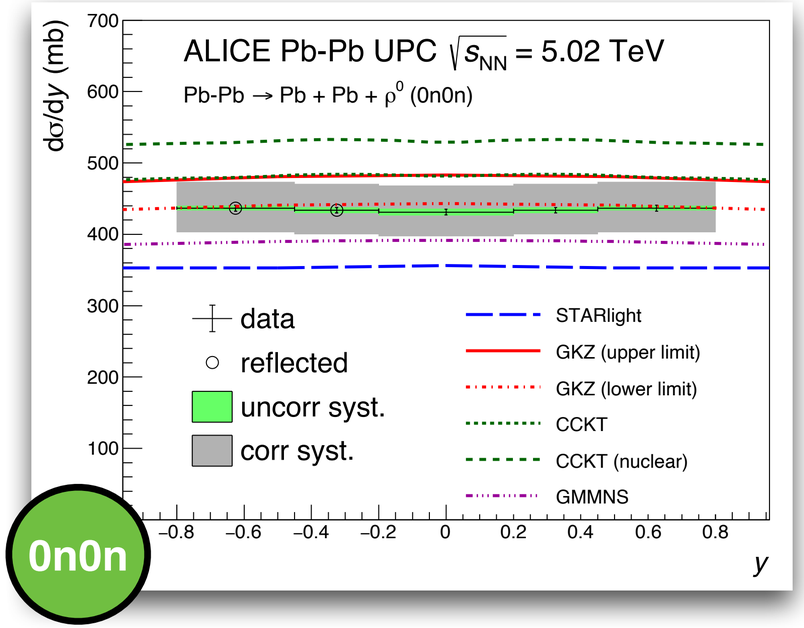

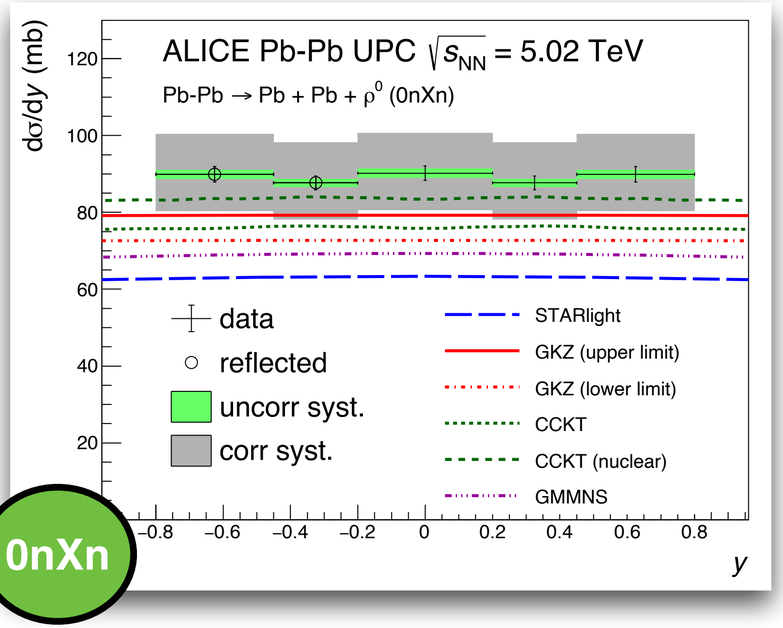

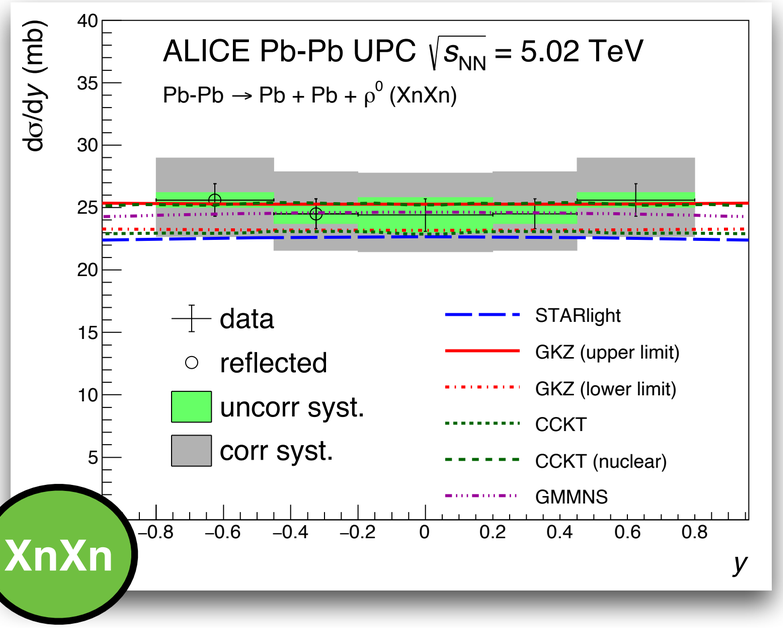

ALICE, JHEP 06 (2020) 035

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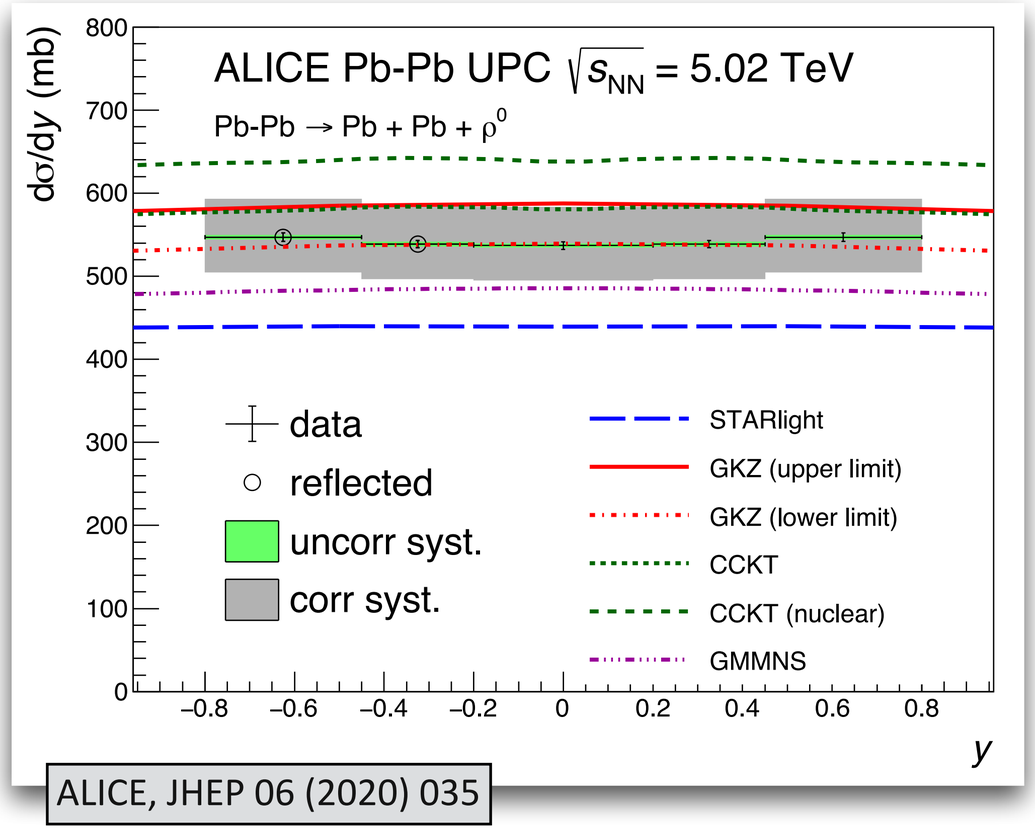
Run 2

ALICE work in progress: method to be applied to J/ψ data at mid and fwd rapidities

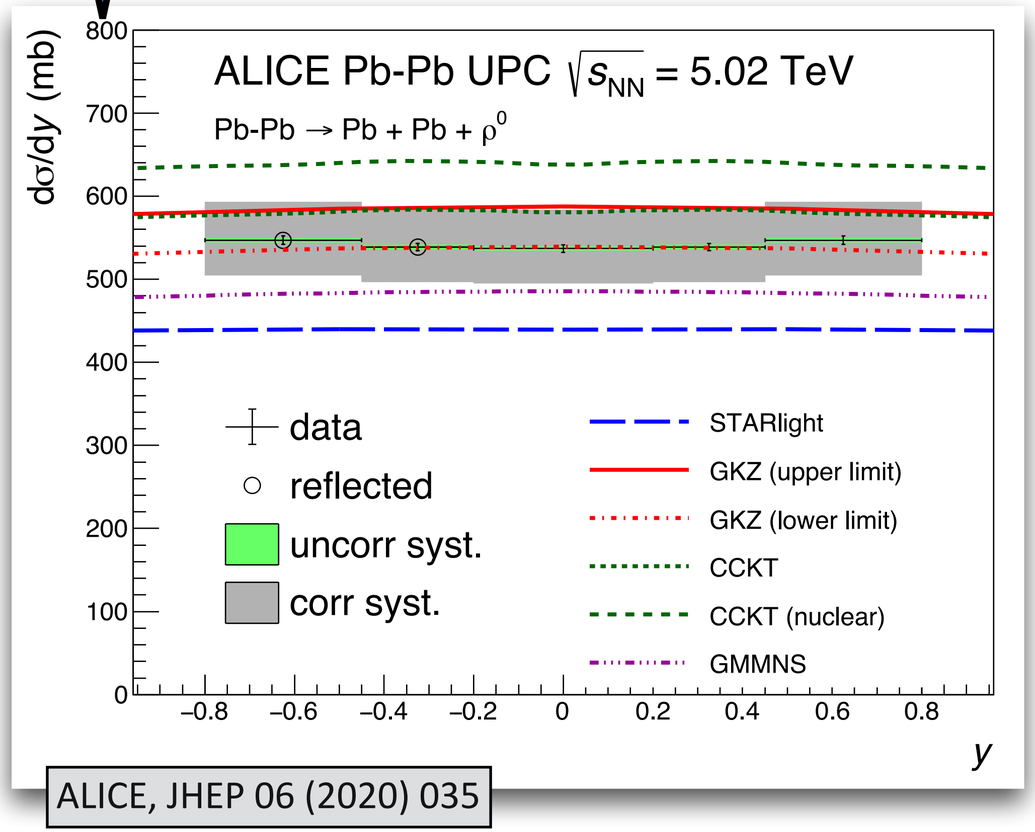
ρ(770) as seen by many experiments



ALICE, JHEP 06 (2020) 035

ρ(770) as seen by many experiments

Huge cross section!



ALICE, JHEP 06 (2020) 035

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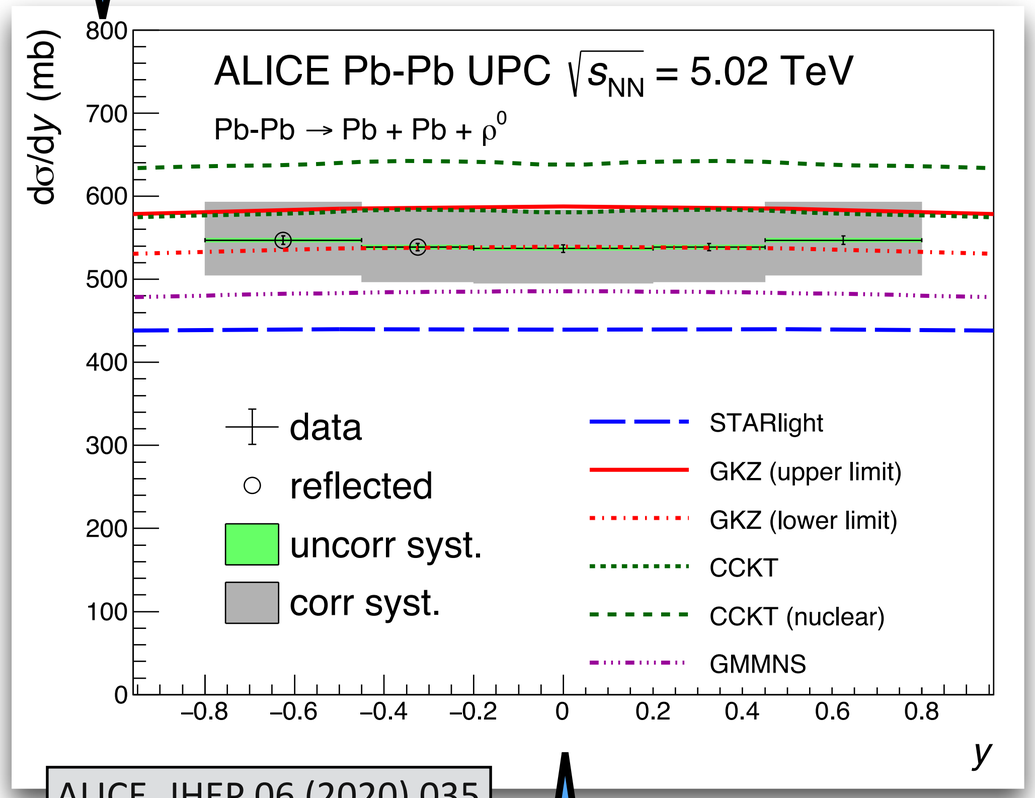

ALICE, JHEP 06 (2020) 035

Measurement at y=0
⇨ no ambiguity

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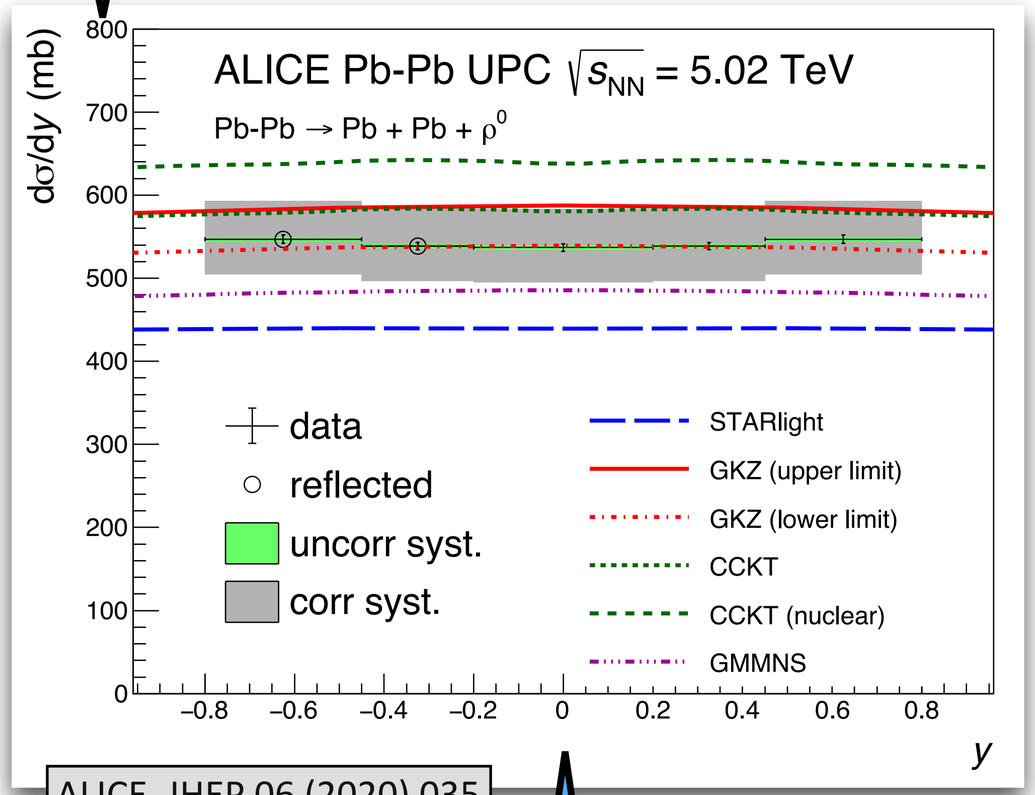

ALICE, JHEP 06 (2020) 035

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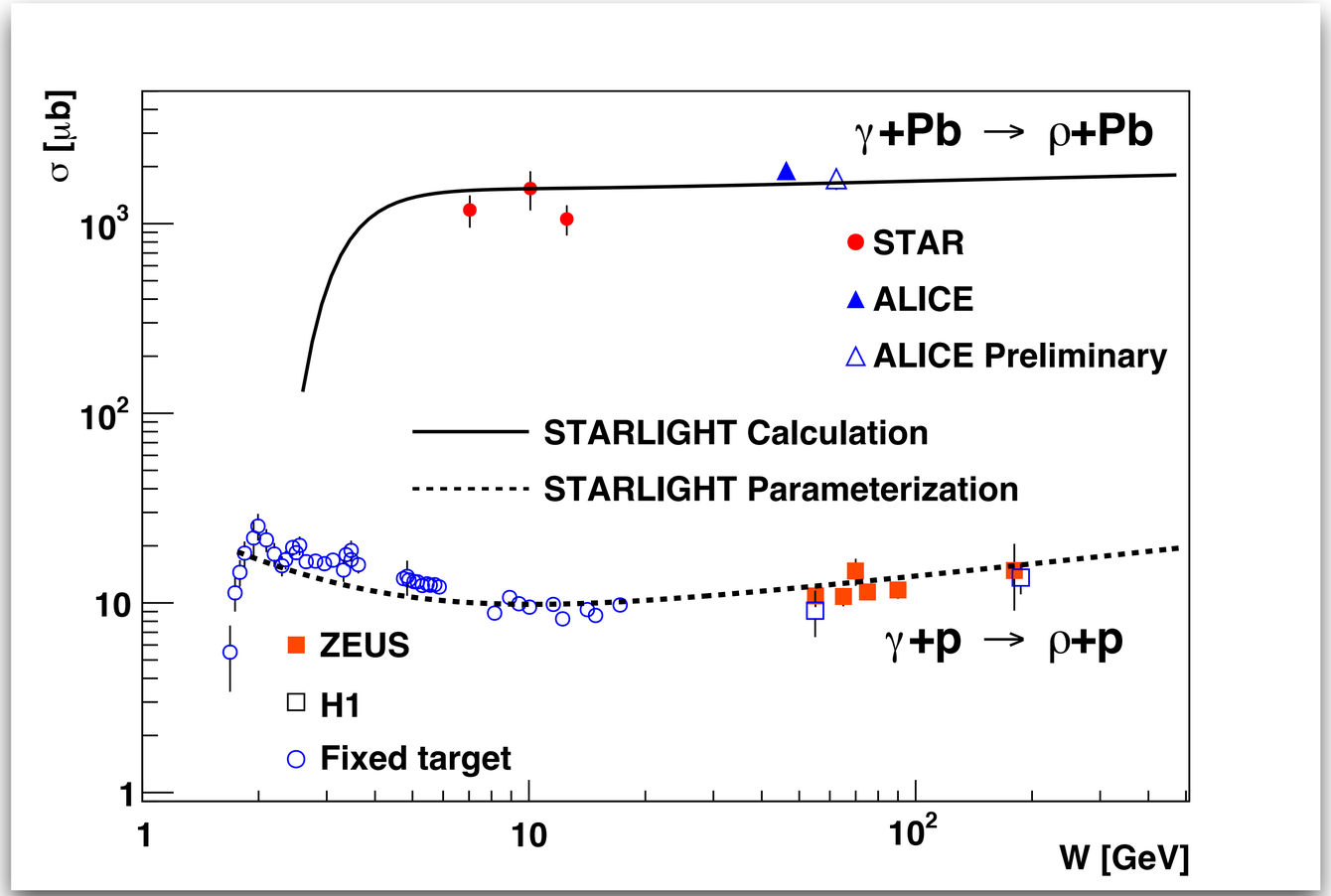

Plot produced by **Joakim Nystrand**
(personal communication, 2018)

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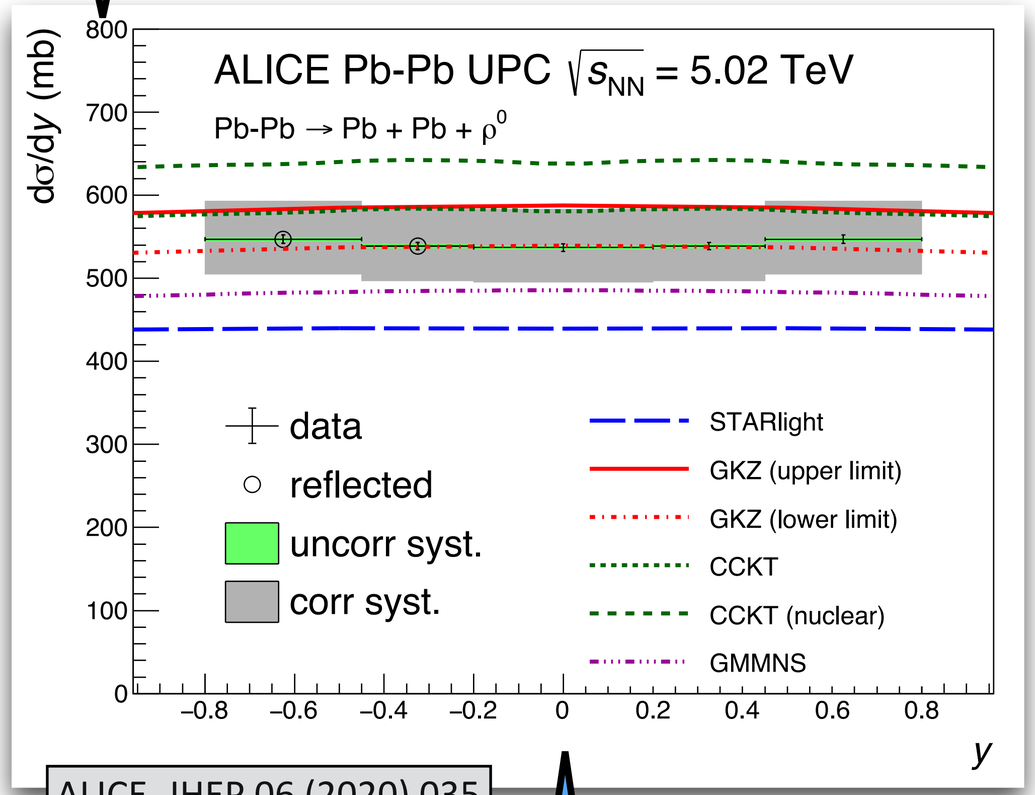

ALICE, JHEP 06 (2020) 035

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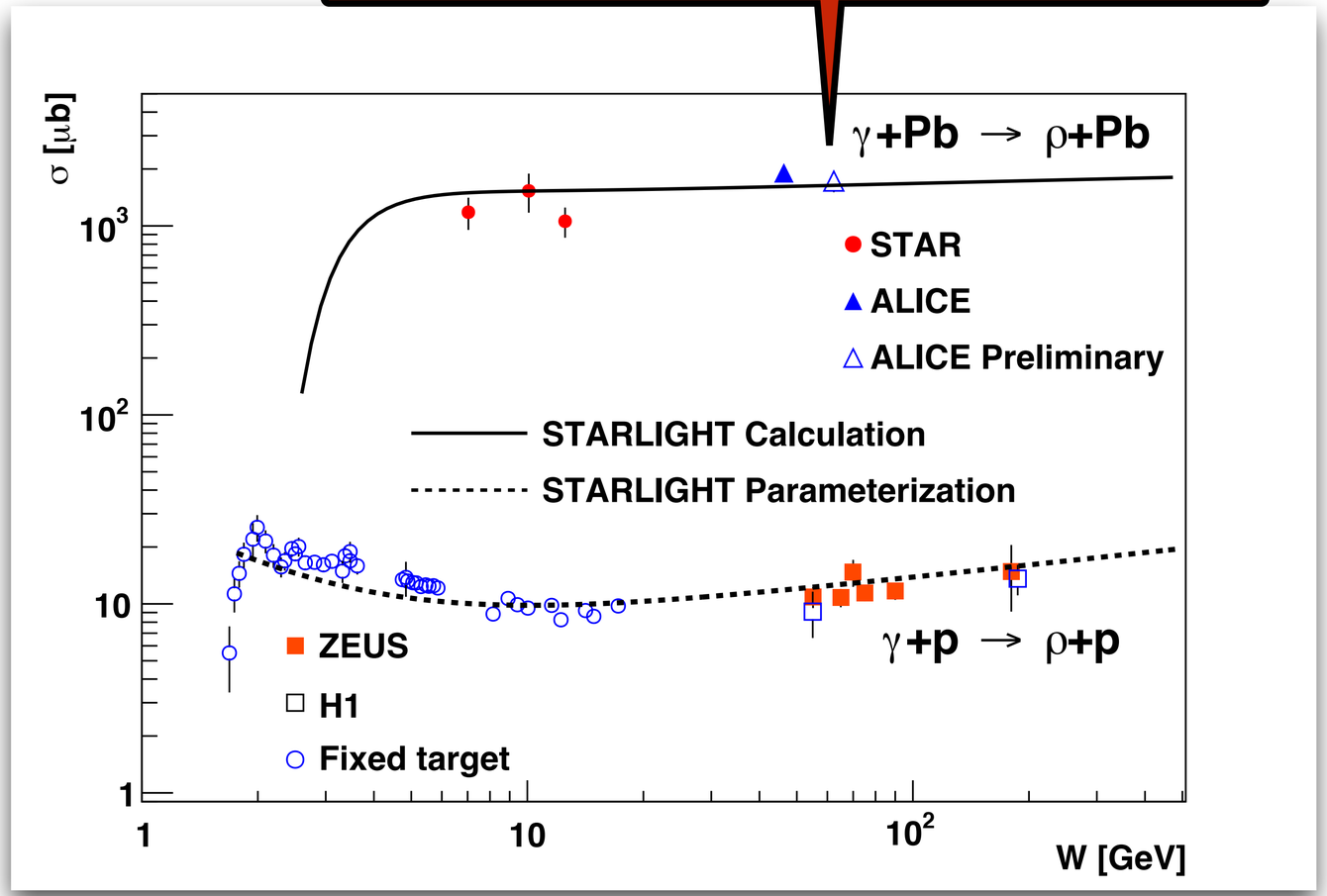
Open question:
Have we reached the black-disc limit?



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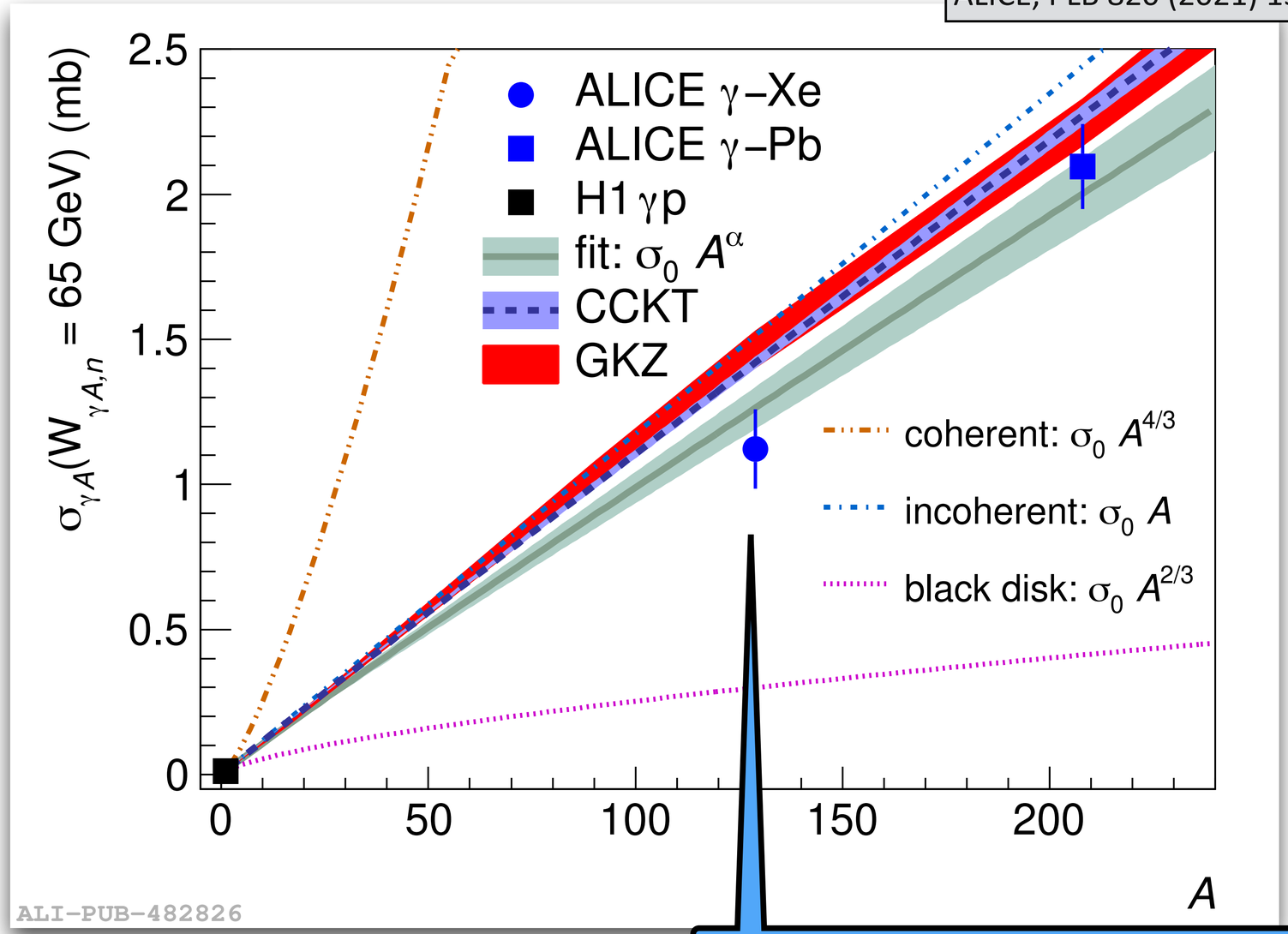
A dependence of coherent ρ(770) photoproduction by ALICE

ALICE, PLB 820 (2021) 136481



New measurement at y=0: Xe-Xe UPC

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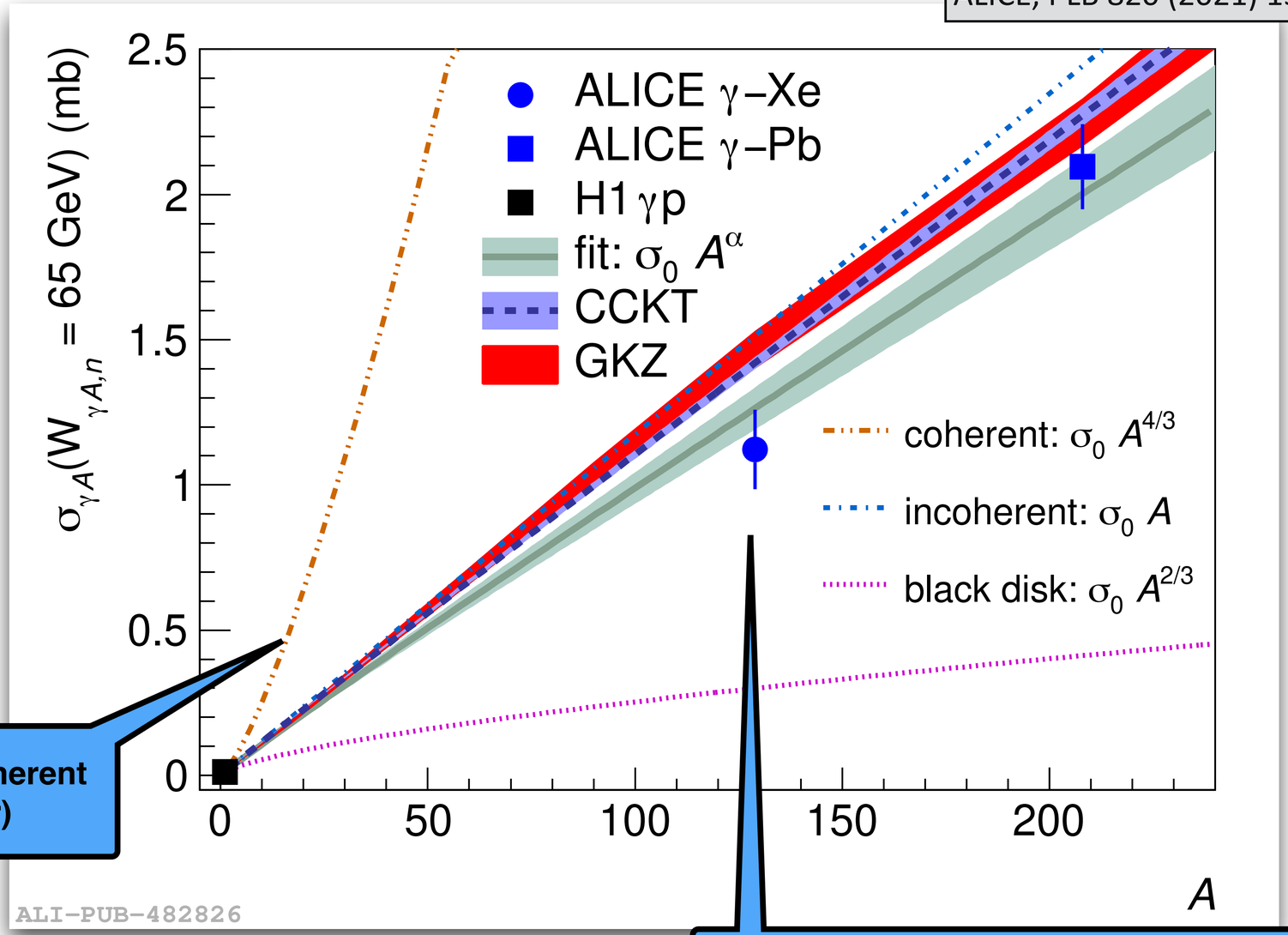

Expectation from coherent (just form factor)

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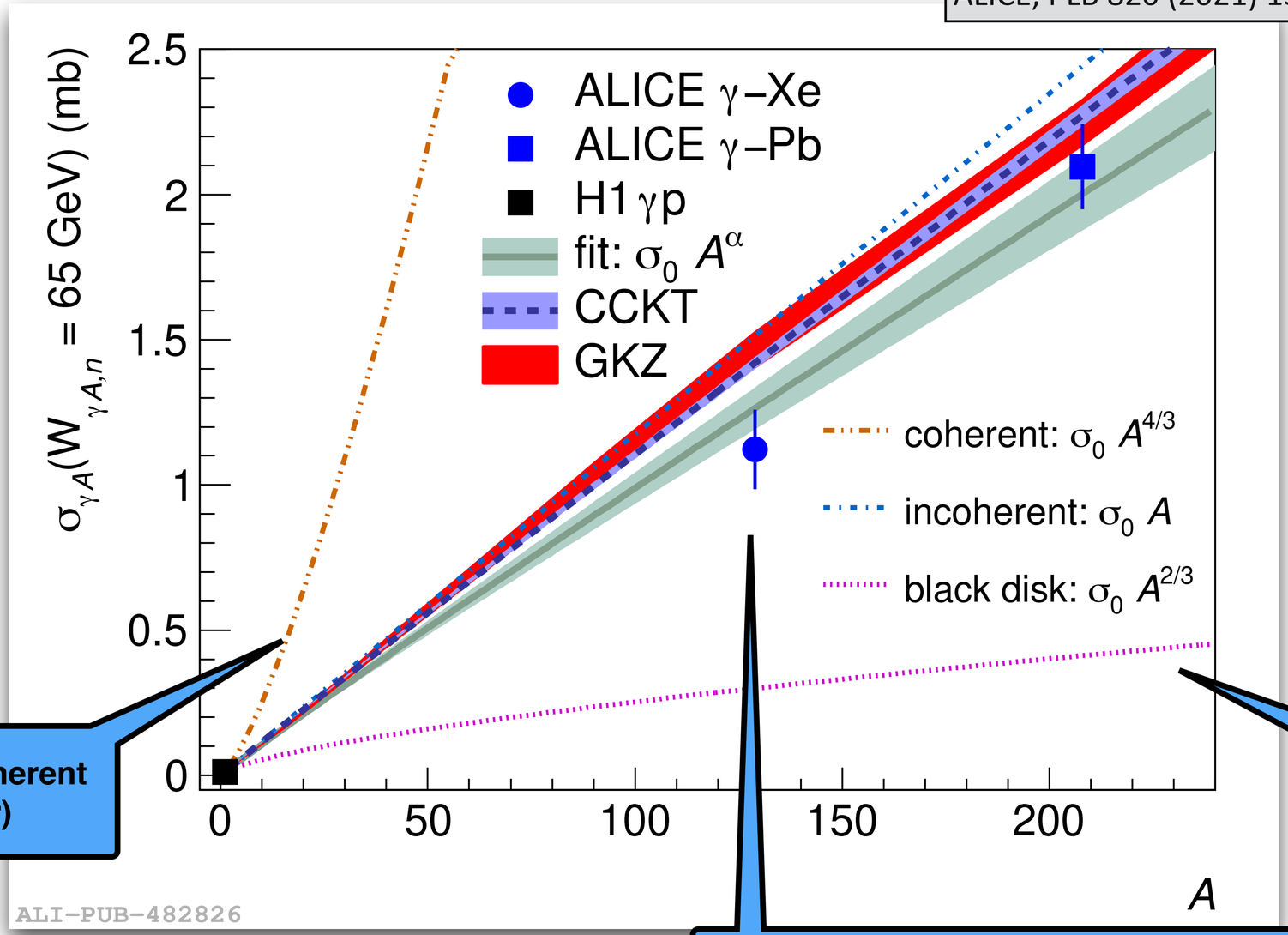

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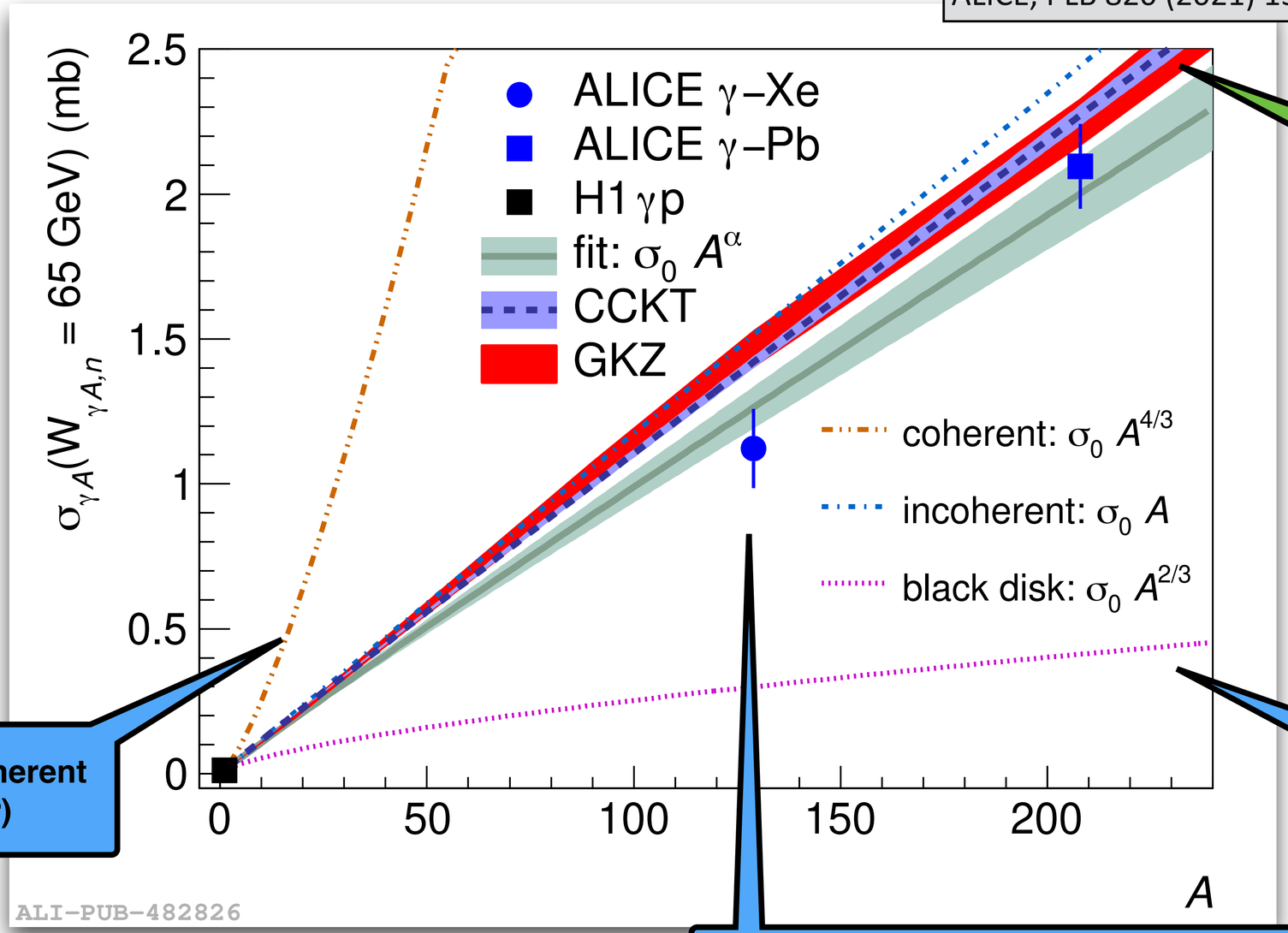

A shadowing based, and a colour dipole model with saturation and hot spots, close to data

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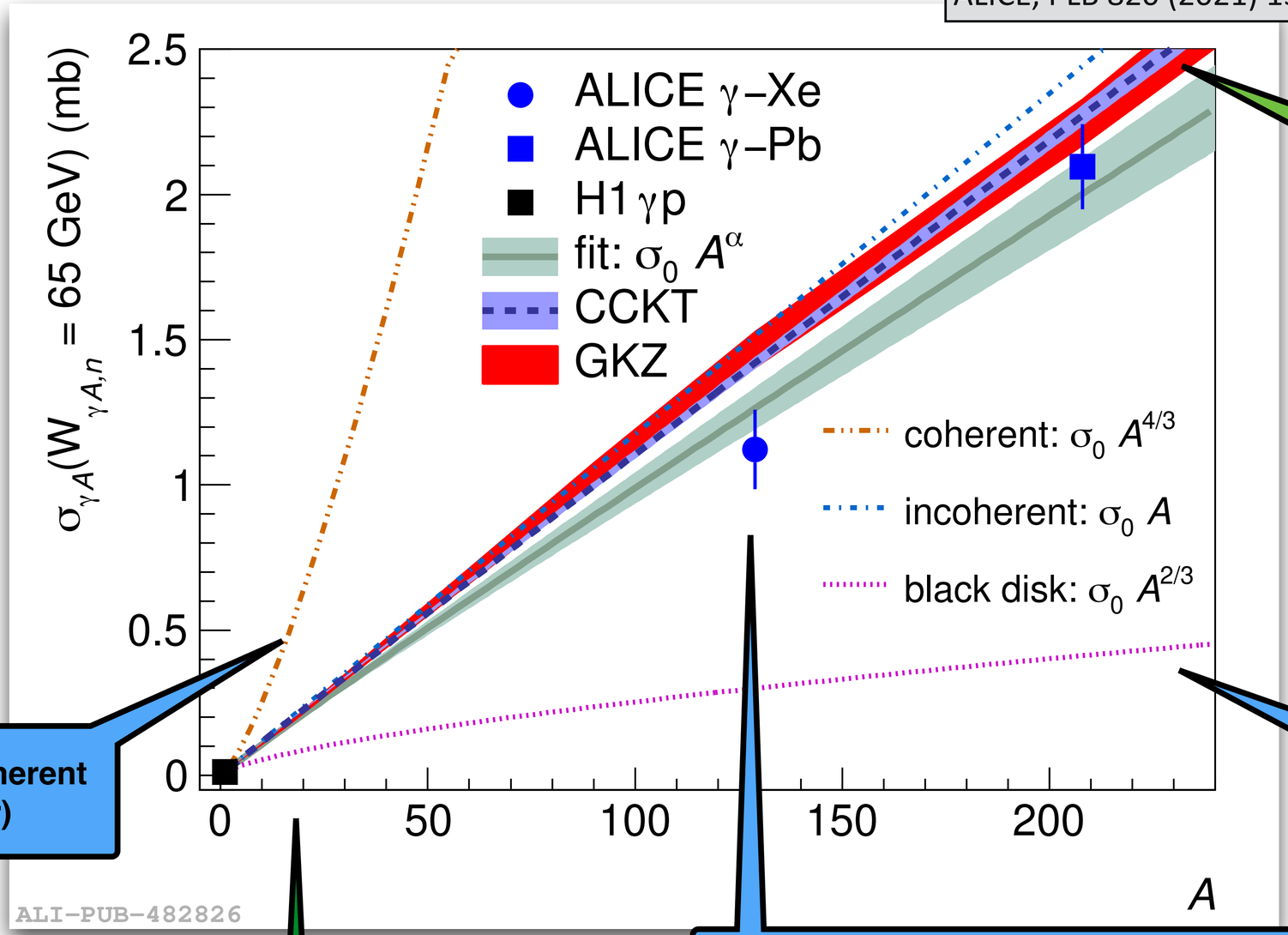

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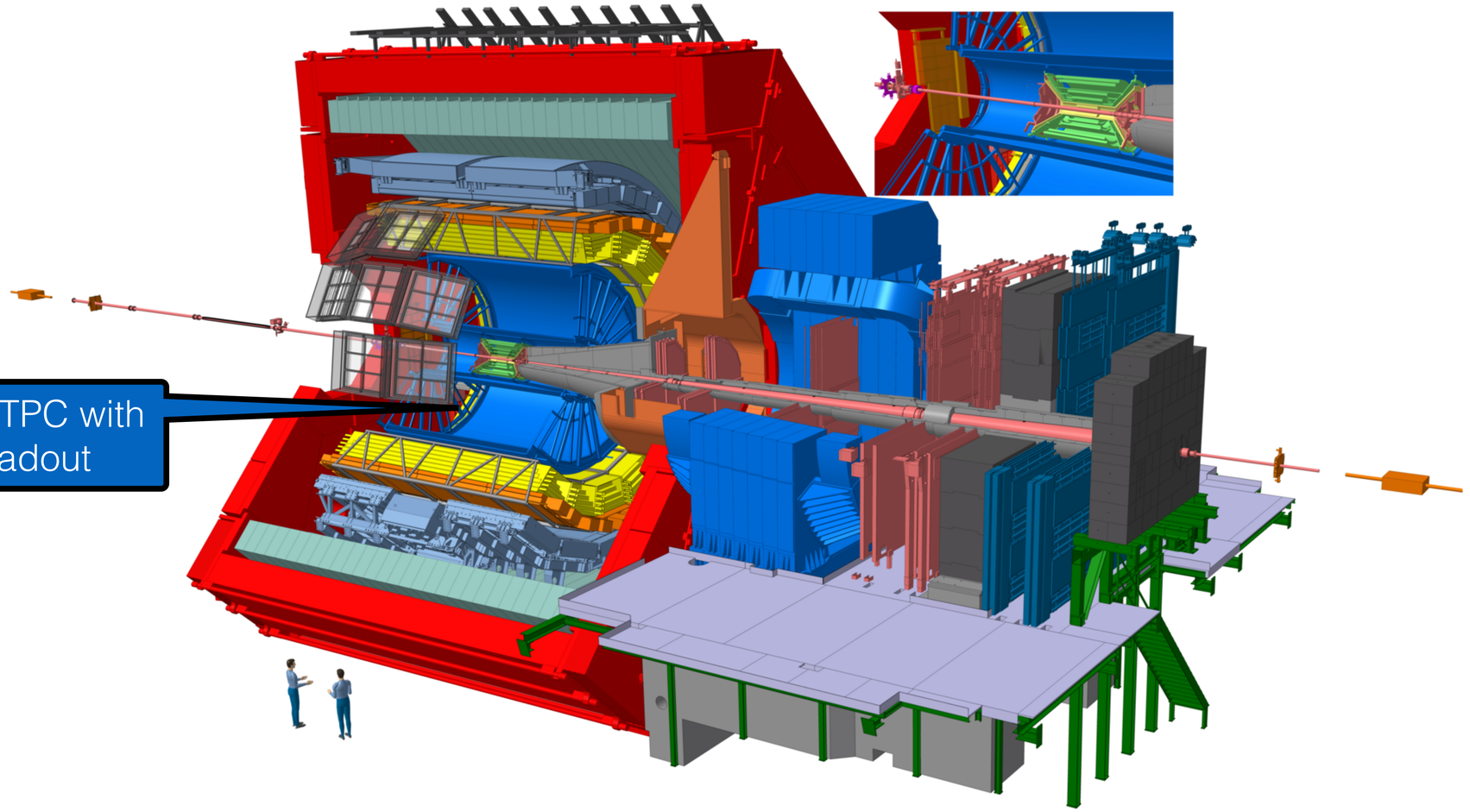
Expectation from the black-disc limit

In Run 3 we expect to have O-O collisions!

New measurement at y=0: Xe-Xe UPC

Expectations for Run 3 and 4

The new ALICE: main detector improvments for UPC physics



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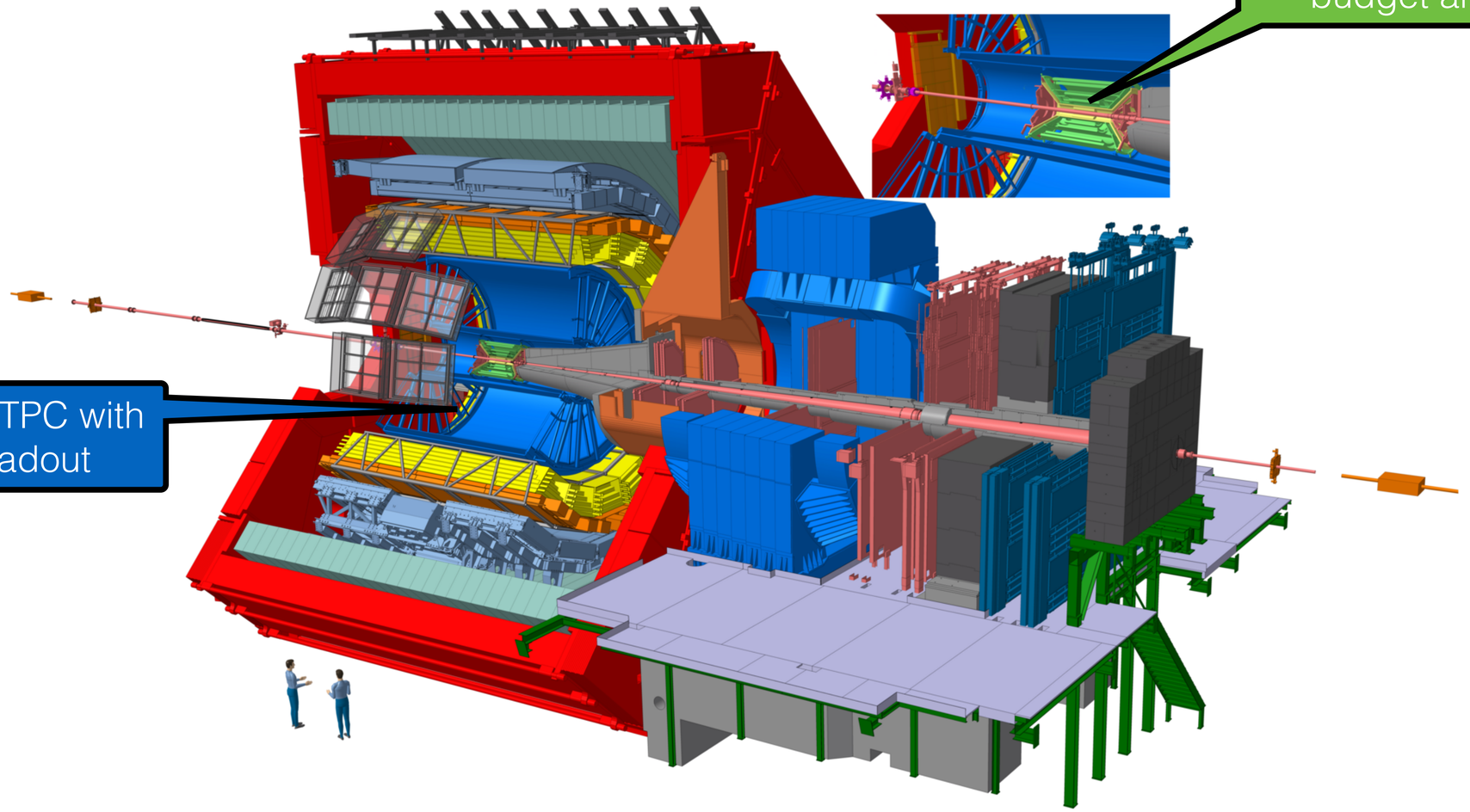

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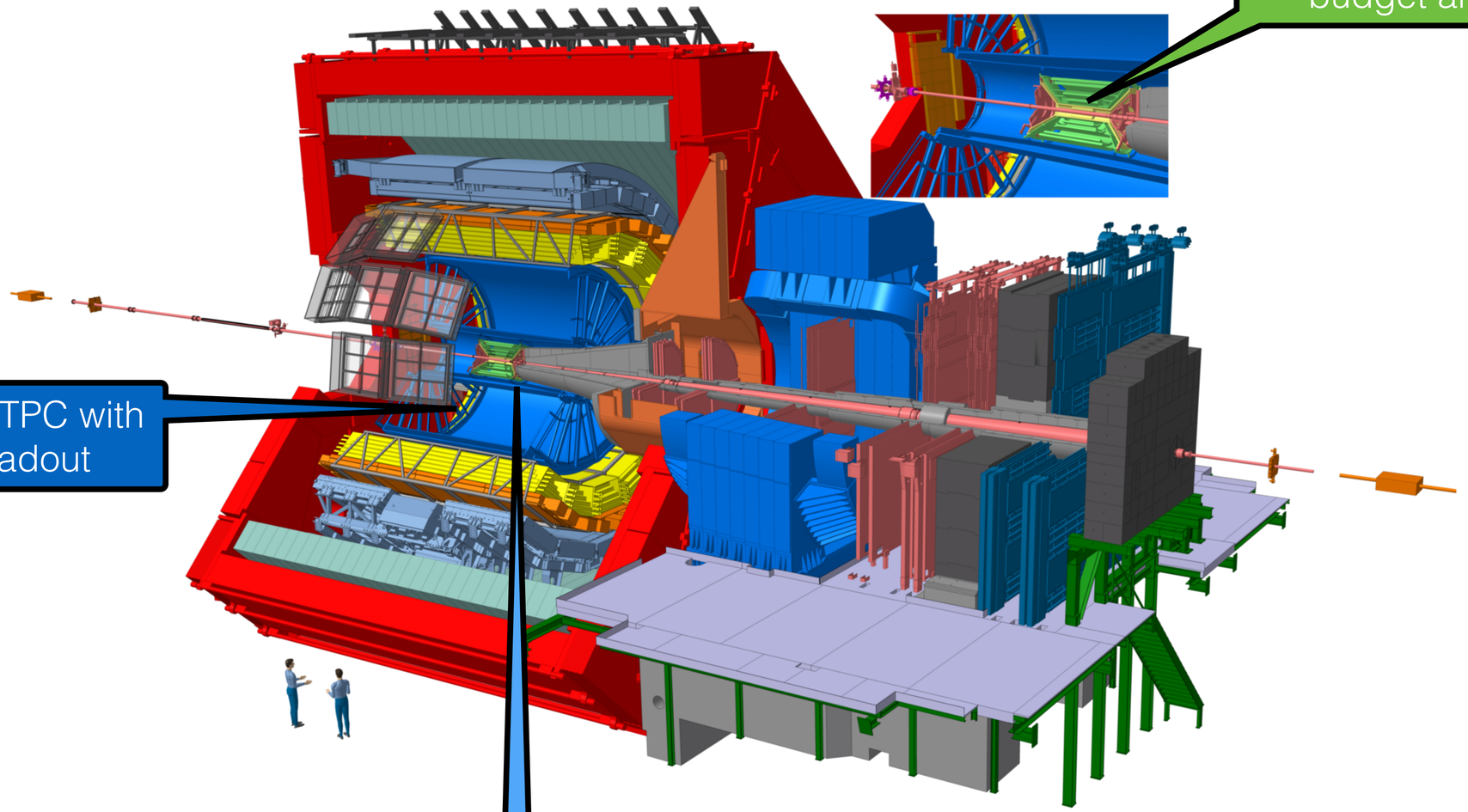

New ITS with a lower material budget and better resolution

Upgraded TPC with GEM readout

New muon forward tracker (MFT) vertex tracker at forward rapidity

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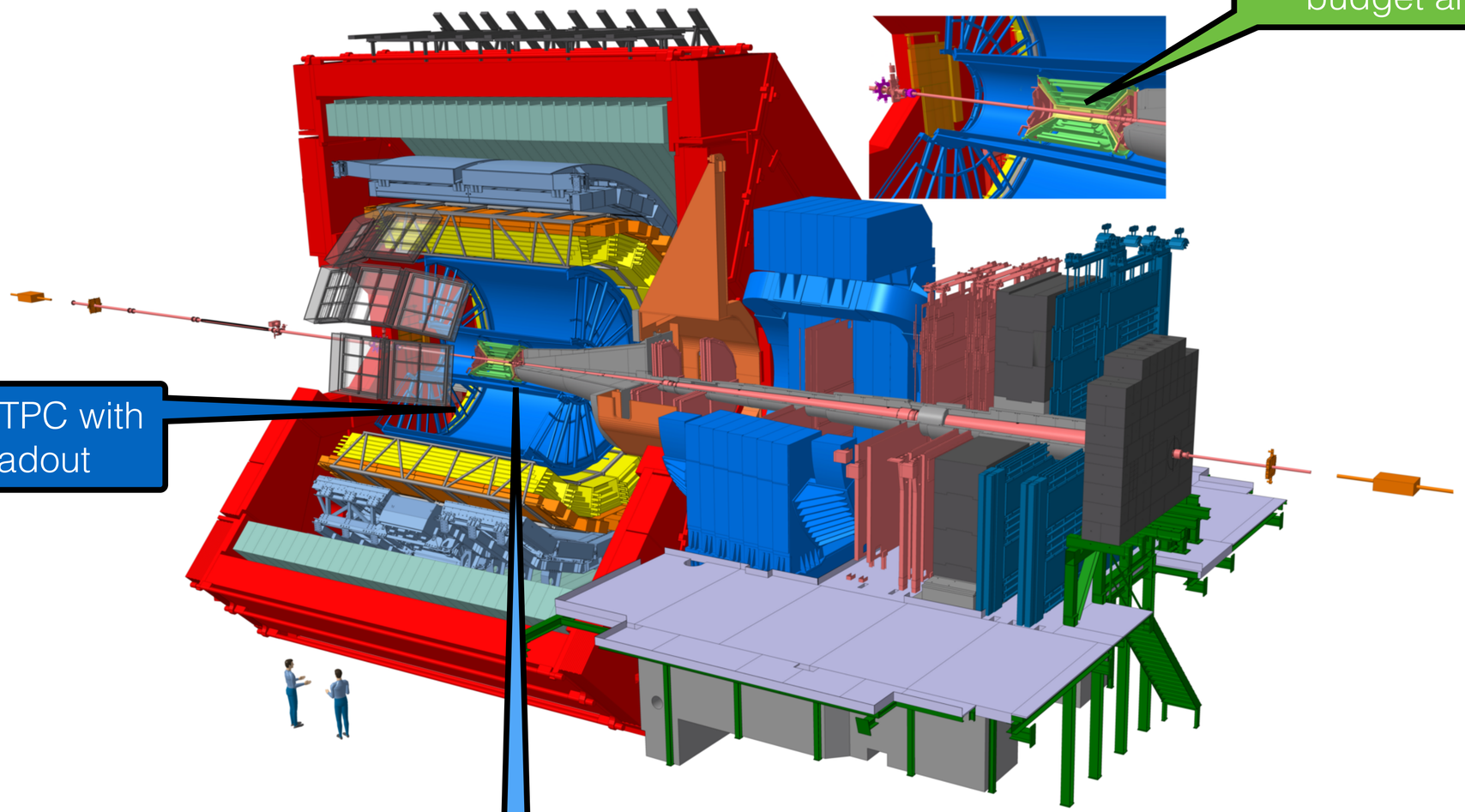

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New data acquisition and reconstruction framework allowing for **continuous readout**

Expectations for UPC in ALICE

Pb-Pb

2.7/nb
... this November?!

Details in arXiv:1812.06772 and https://cds.cern.ch/record/2765973

Expectations for UPC in ALICE

Pb-Pb

Chanel	midrapidity	fwd rapidity
ρ→π+π-	1.1 B	1 B
ρ'→π+π-π+π-	44 M	39 M
J/ψ→μ+μ-	230 K	125 K
Υ→μ+μ-	580	180

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γp

p-Pb

0.6/pb
Run 3+4

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Chanel	midrapidity	fwd/bkwd rapidity
ρ→π+π-	1.2 B	600 M/ 300 M
J/ψ→μ+μ-	300 K	80 K/ 55 K
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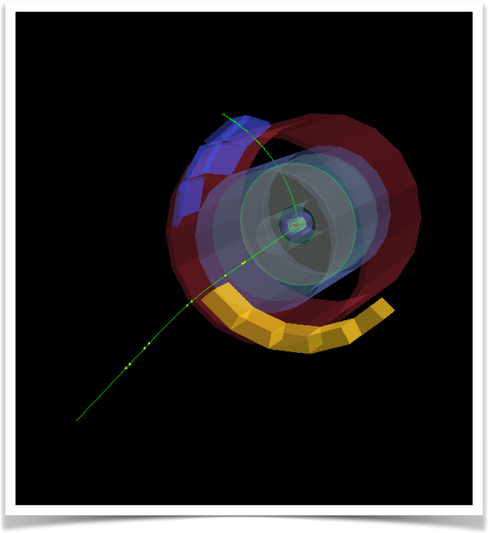
Also semi-central topologies



ALICE, EPJ C79 (2019) 402

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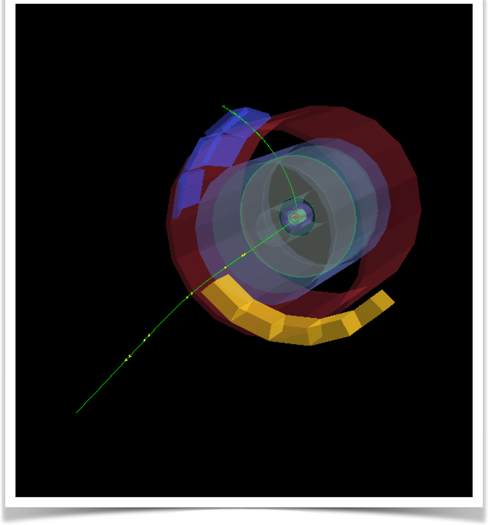

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0.6/pb
Run 3+4

In addition: p-O and O-O program

Details in arXiv:1812.06772 and https://cds.cern.ch/record/2765973

Summary

A rich program of photon-induced physics has been carried out with the ALICE detector

The performed measurements allow us to address fundamental questions on QED and QCD

The ALICE detector has been upgraded to fully profit from the large increase of data that the LHC Run 3 and 4 offer