

Winter School 2021
June 23, 2021

Diffractive vector meson photoproduction: a Swiss army knife for QCD

Guillermo Contreras

Czech Technical University in Prague



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Main focus on ALICE results ...
Many relevant results skipped ...

Diffractive vector meson photoproduction: a Swiss army knife for QCD

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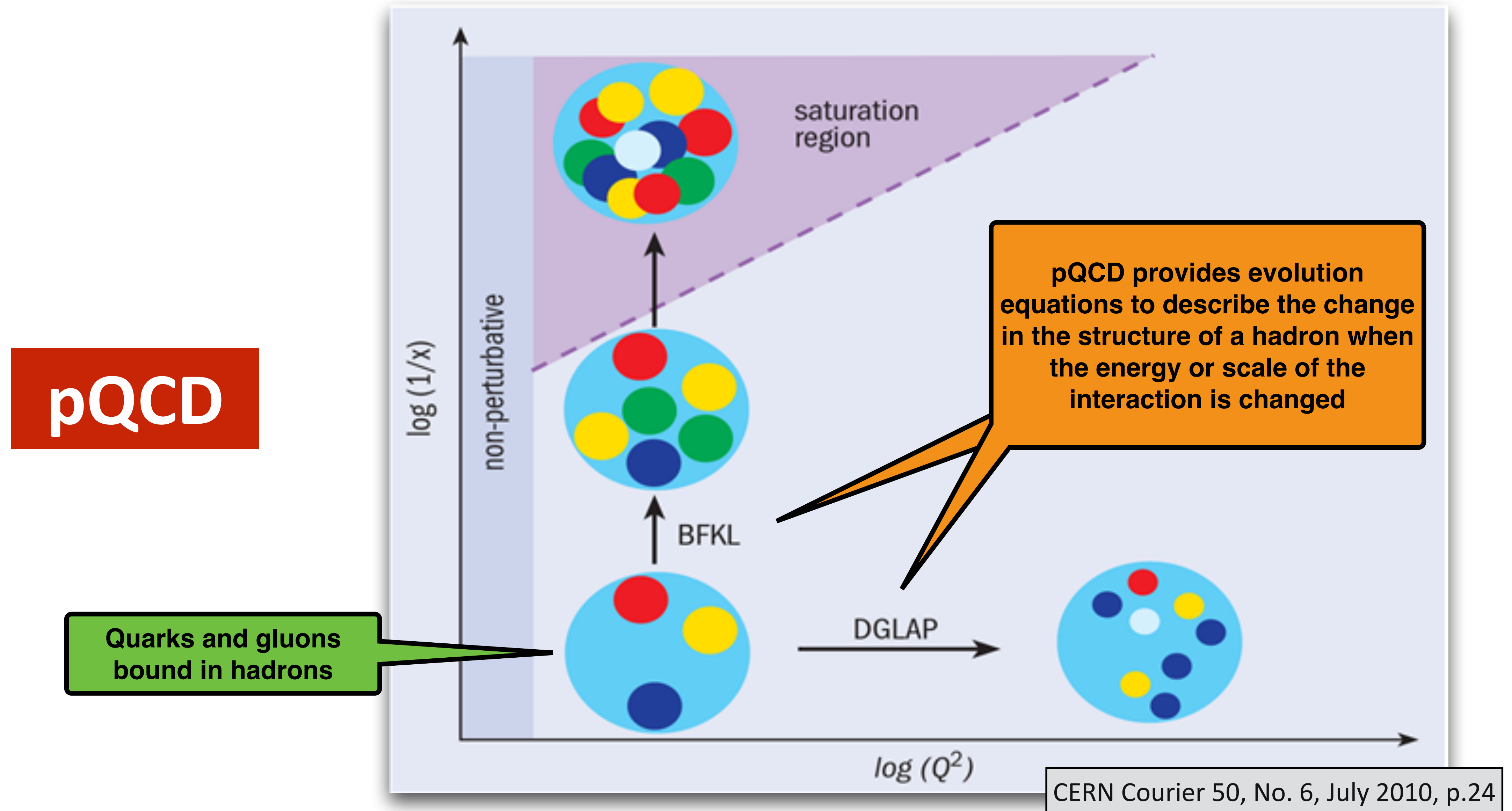
Skipped results from H1+ZEUS ...

H1 Topic	Journal	ZEUS Topic	Journal
<p>Exclusive $\pi^+\pi^-$ and ρ^0 in PHP</p> <p>Exclusive ρ^0 with Leading n in PHP</p> <p>Elastic and p-diss J/ψ in PHP</p> <p>Diffractive ρ^0 and ϕ in DIS</p> <p>Diffractive PHP of ρ^0 with large t</p> <p>Elastic J/ψ in PHP and DIS</p> <p>Diffractive PHP of J/ψ with large t</p> <p>Diffractive PHP of $\psi(2S)$</p> <p>Helicity structure of ρ^0 in DIS</p> <p>Elastic ϕ in DIS</p> <p>Elastic J/ψ and Υ in PHP</p> <p>Elastic ρ^0 in DIS</p> <p>Quasi-elastic ($z > 0.95$) $\psi(2S)$ in PHP</p> <p>P-diss. ρ^0 and Elastic ϕ in DIS</p> <p>Elastic and Inelastic J/ψ in PHP</p> <p>Elastic ρ^0 and J/ψ at large Q^2</p> <p>Elastic Rho0 in PHP</p>	<p>Eur.Phys.J.C80 (2020), 1189</p> <p>Eur.Phys.J.C76 (2016) 1, 41</p> <p>Eur.Phys.J.C73 (2013) 2466</p> <p>JHEP05 (2010) 032</p> <p>Phys.Lett.B 638 (2006) 422</p> <p>Eur.Phys.J.C46 (2006) 585</p> <p>Phys Lett B568 (2003) 205</p> <p>Phys.Lett.B541 (2002) 251</p> <p>Phys.Lett.B539 (2002) 25</p> <p>Phys.Lett.B483 (2000) 360</p> <p>Phys.Lett.B483 (2000) 23</p> <p>Eur.Phys.J.C13 (2000) 371</p> <p>Phys.Lett.B421 (1998) 385</p> <p>Z.Phys.C75 (1997) 607</p> <p>Nucl.Phys.B472 (1996) 3</p> <p>Nucl.Phys.B468 (1996) 3</p> <p>Nucl.Phys.B463 (1996) 3</p>	<p>$R(\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)})$ in DIS</p> <p>Exclusive Electroproduction of 2π</p> <p>$\Upsilon(1S)$ in PHP (t-dependence)</p> <p>P-dissociative J/ψ in PHP at large t</p> <p>Exclusive PHP of Υ Mesons</p> <p>Exclusive ρ^0 in DIS</p> <p>Exclusive ϕ in DIS</p> <p>Exclusive J/ψ in DIS</p> <p>P-dissociative VM in PHP at large t</p> <p>Exclusive PHP of J/ψ mesons</p> <p>Exclusive ω in DIS</p> <p>Diffractive PHP of VM at large t</p> <p>Spin-Density ME of Exclusive ρ^0 in DIS</p> <p>Exclusive ρ^0 and J/ψ in DIS</p> <p>Elastic Υ Photoproduction</p> <p>Elastic and p-Dissociative ρ^0 in PHP</p> <p>Elastic J/ψ in PHP</p> <p>Elastic ω in PHP</p> <p>$\gamma^*p \rightarrow \phi p$ in DIS</p> <p>Elastic ϕ in PHP</p> <p>Elastic ρ^0 in PHP</p> <p>Exclusive ρ^0 in DIS</p>	<p>Nucl. Phys. B 909 (2016) 934</p> <p>Eur.Phys.J. C 72 (2012) 1869</p> <p>Phys.Lett. B 708 (2012) 14</p> <p>JHEP 05 (2010) 085</p> <p>Phys. Lett. B 680 (2009) 4</p> <p>PMC Physics A 1, 6</p> <p>Nucl. Phys. B 718 (2005) 3</p> <p>Nucl. Phys. B 695 (2004) 3</p> <p>Eur. Phys. J. C 26 (2003) 389</p> <p>Eur. Phys. J. C 24 (2002) 345</p> <p>Phys. Lett. B 487 (2000) 273</p> <p>Eur. Phys. J. C 14 (2000) 213</p> <p>Eur. Phys. J. C 12 (2000) 393</p> <p>Eur. Phys. J. C 6 (1999) 603</p> <p>Phys. Lett. B 437 (1998) 432</p> <p>Eur. Phys. J. C 2 (1998) 247</p> <p>Z. Phys. C 75 (1997) 215</p> <p>Z. Phys. C 73 (1996) 73</p> <p>Phys. Lett. B 380 (1996) 220</p> <p>Phys. Lett. B 377 (1996) 259</p> <p>Z. Phys. C 69 (1995) 39</p> <p>Phys. Lett. B 356 (1995) 601</p>

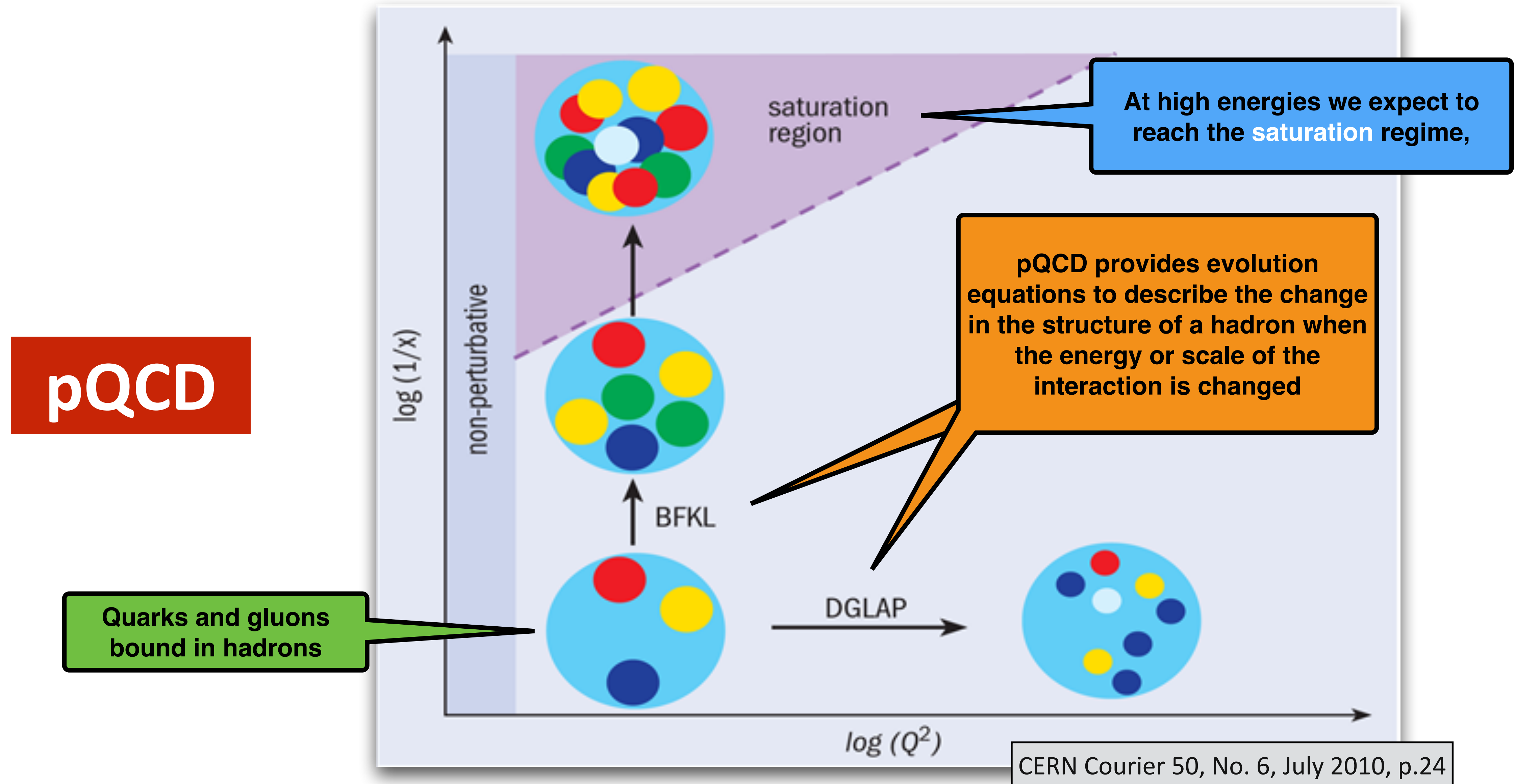
Slide from Sergey Levonian

<https://indico.bnl.gov/event/10155/contributions/46683/>

The physics we are interested in (in a nutshell)



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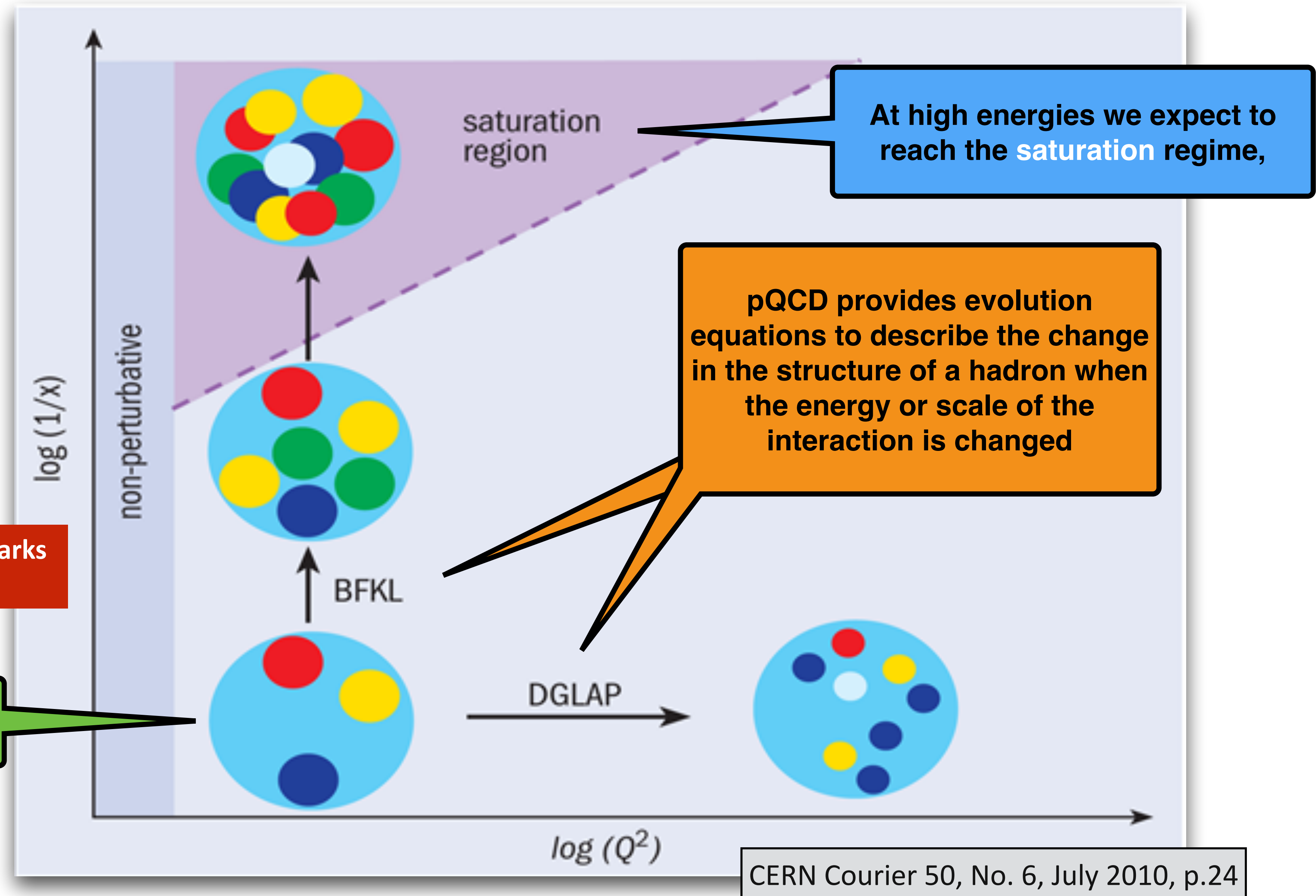


The physics we are interested in (in a nutshell)

pQCD

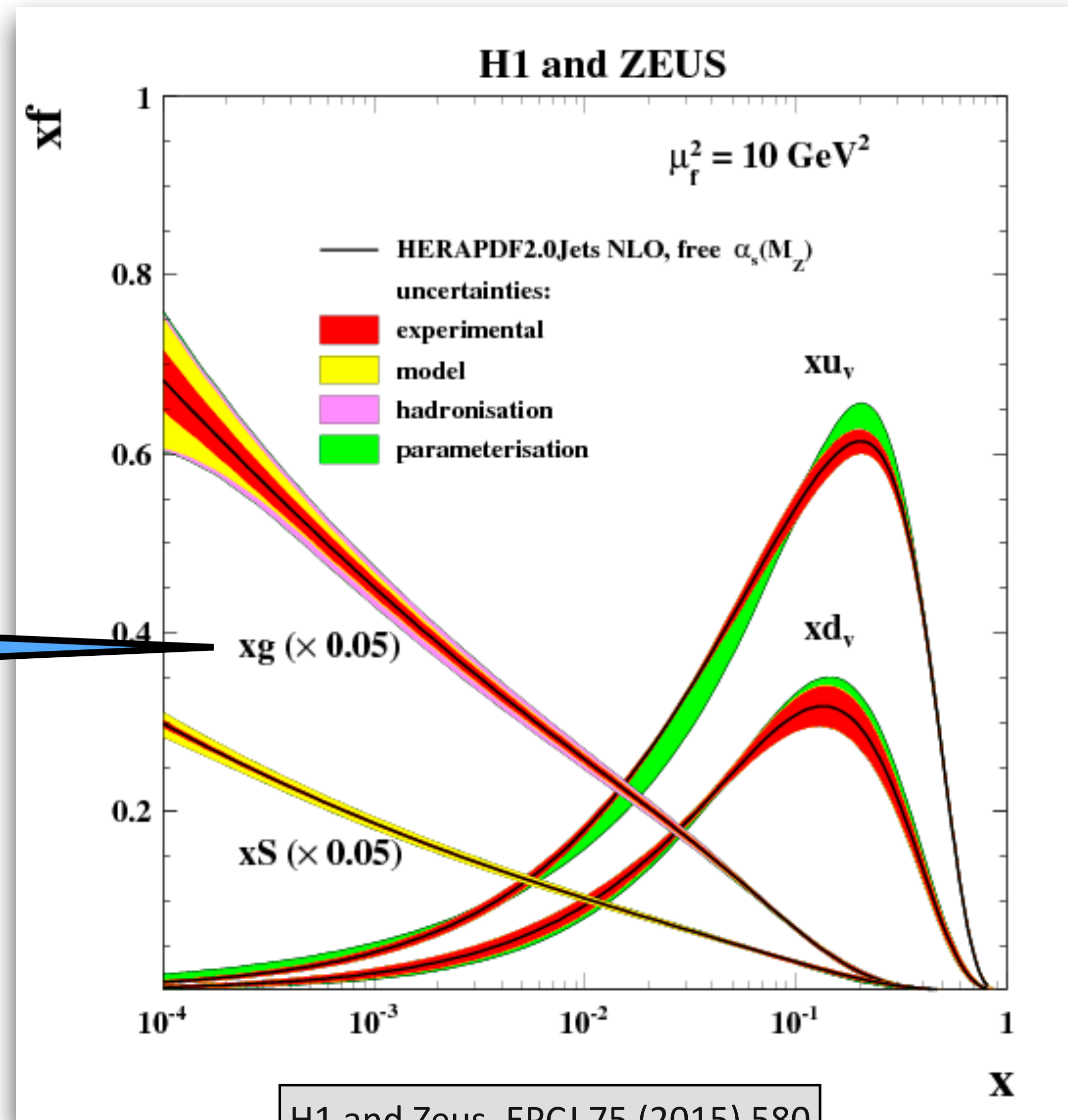
Measure the structure of hadrons in terms of quarks and gluons at different scales and energies

Quarks and gluons bound in hadrons



What do we know about the physics we are interested in ? (In a nutshell)

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

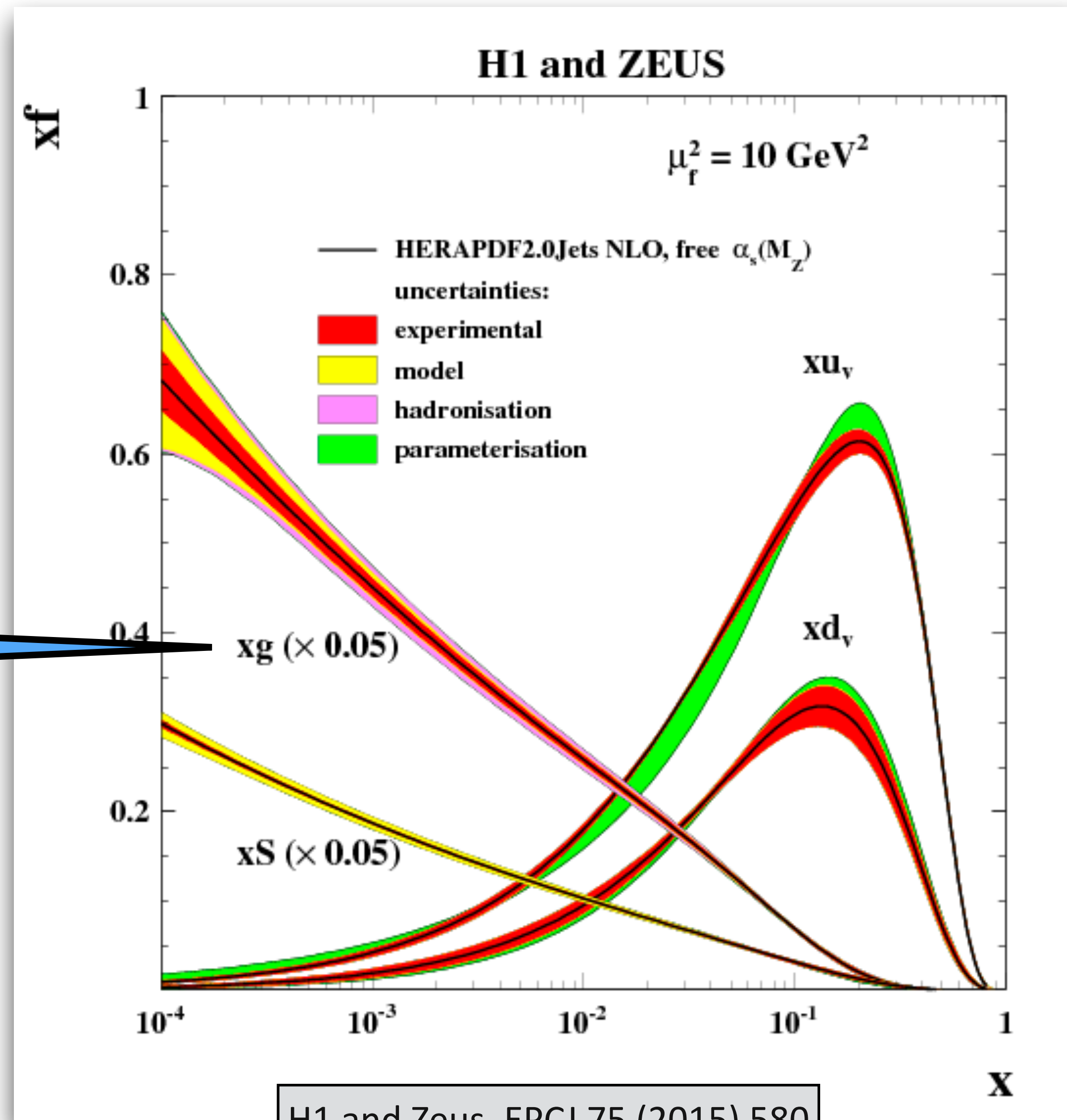


H1 and Zeus, EPCJ 75 (2015) 580

What do we know about the physics we are interested in ? (In a nutshell)

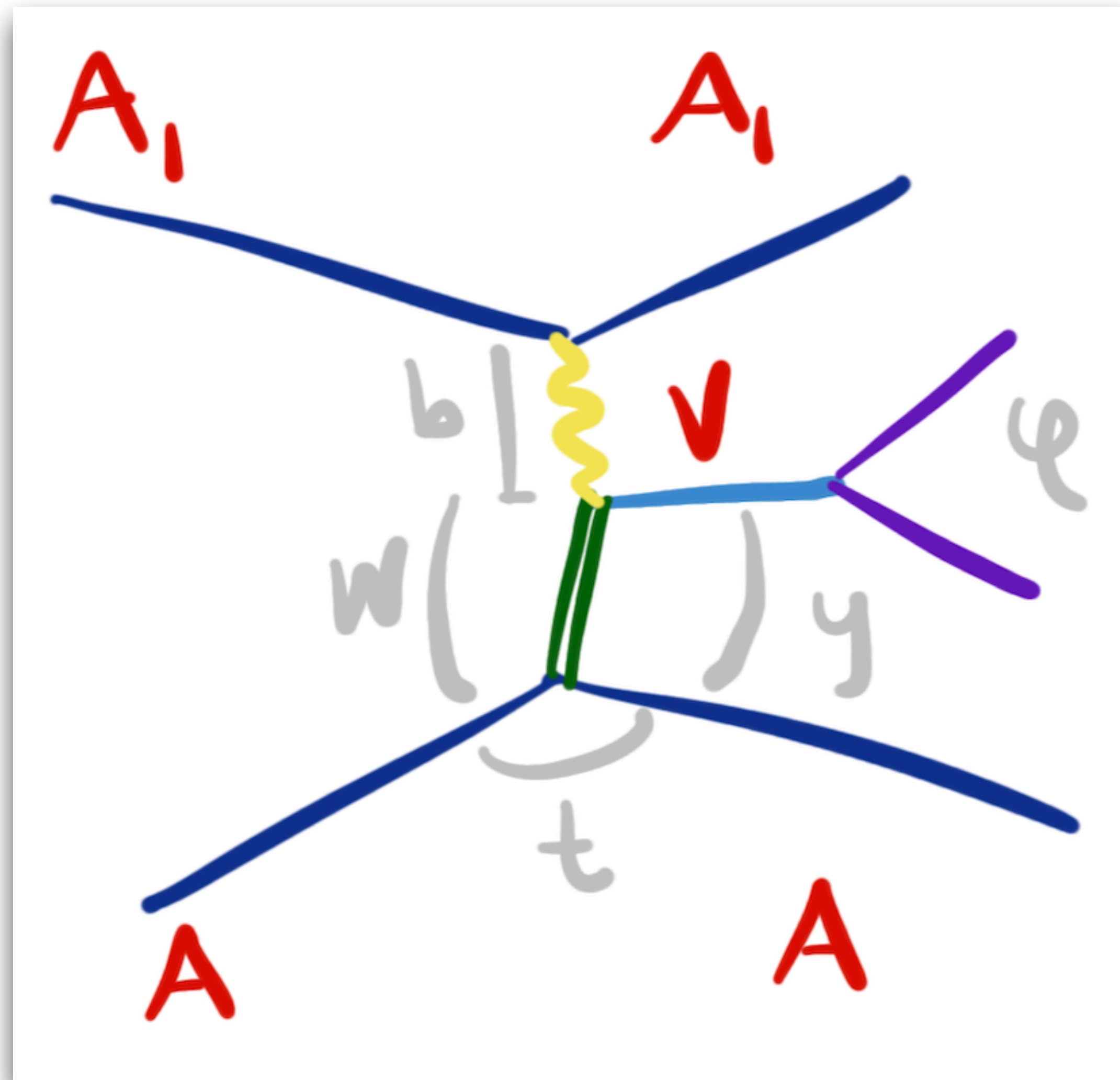
The gluon distribution in the proton **dominates** for decreasing x where it grows as a **power law**

Concentrate on processes highly sensitive to the gluon content in hadrons



H1 and Zeus, EPCJ 75 (2015) 580

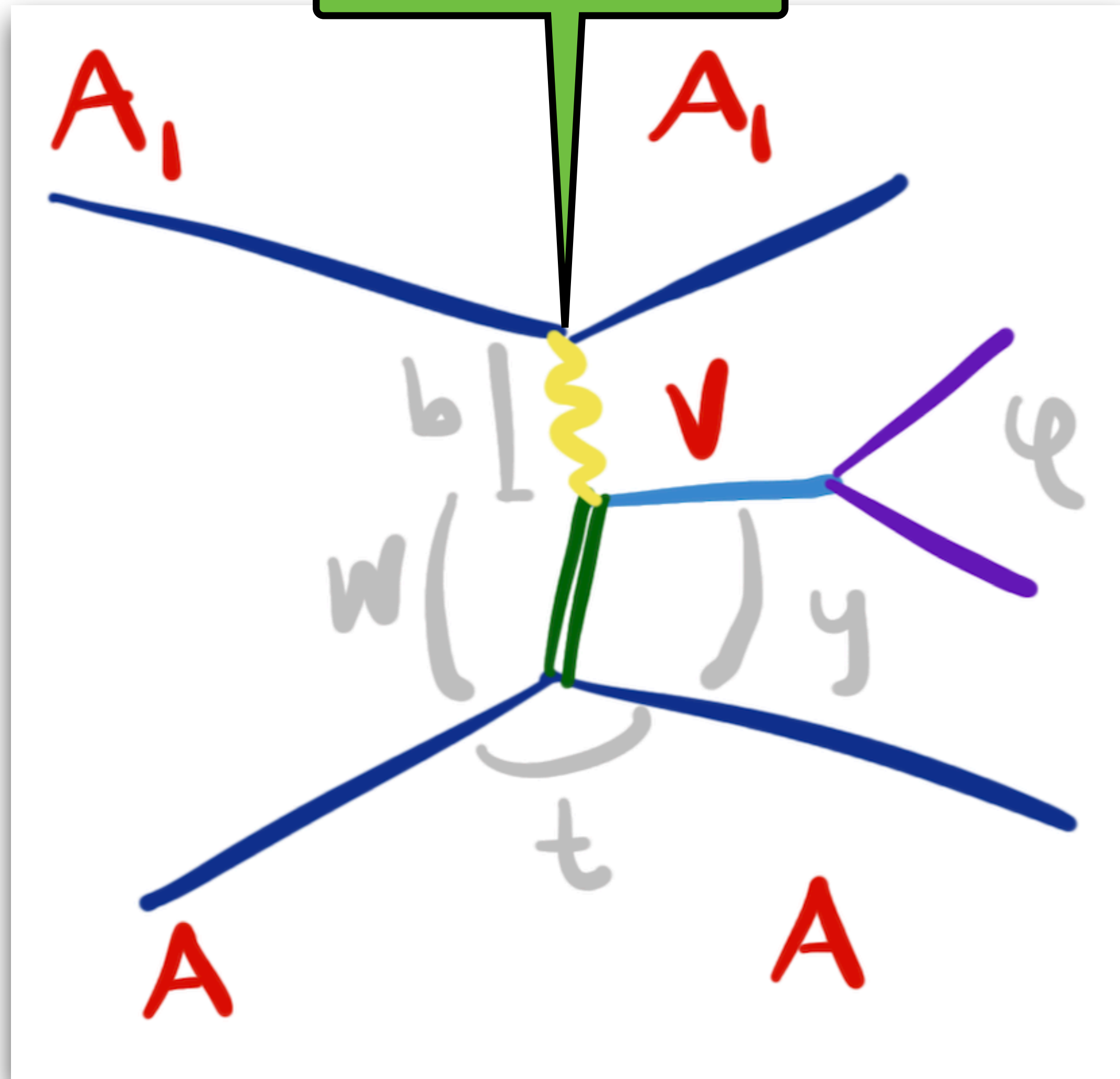
The process we are interested in



The process we are interested in

Interesting recent developments not covered here

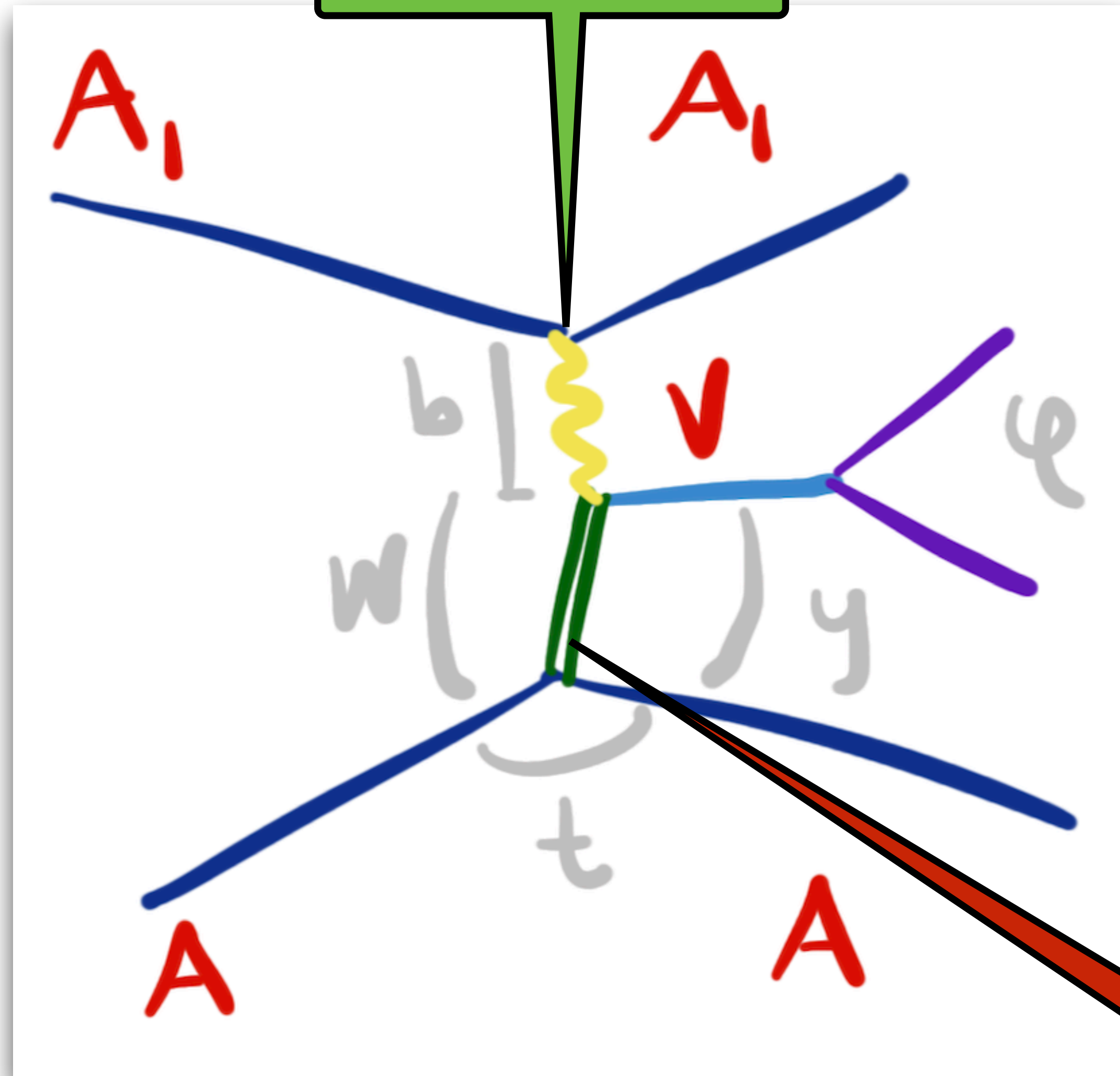
QED is in here



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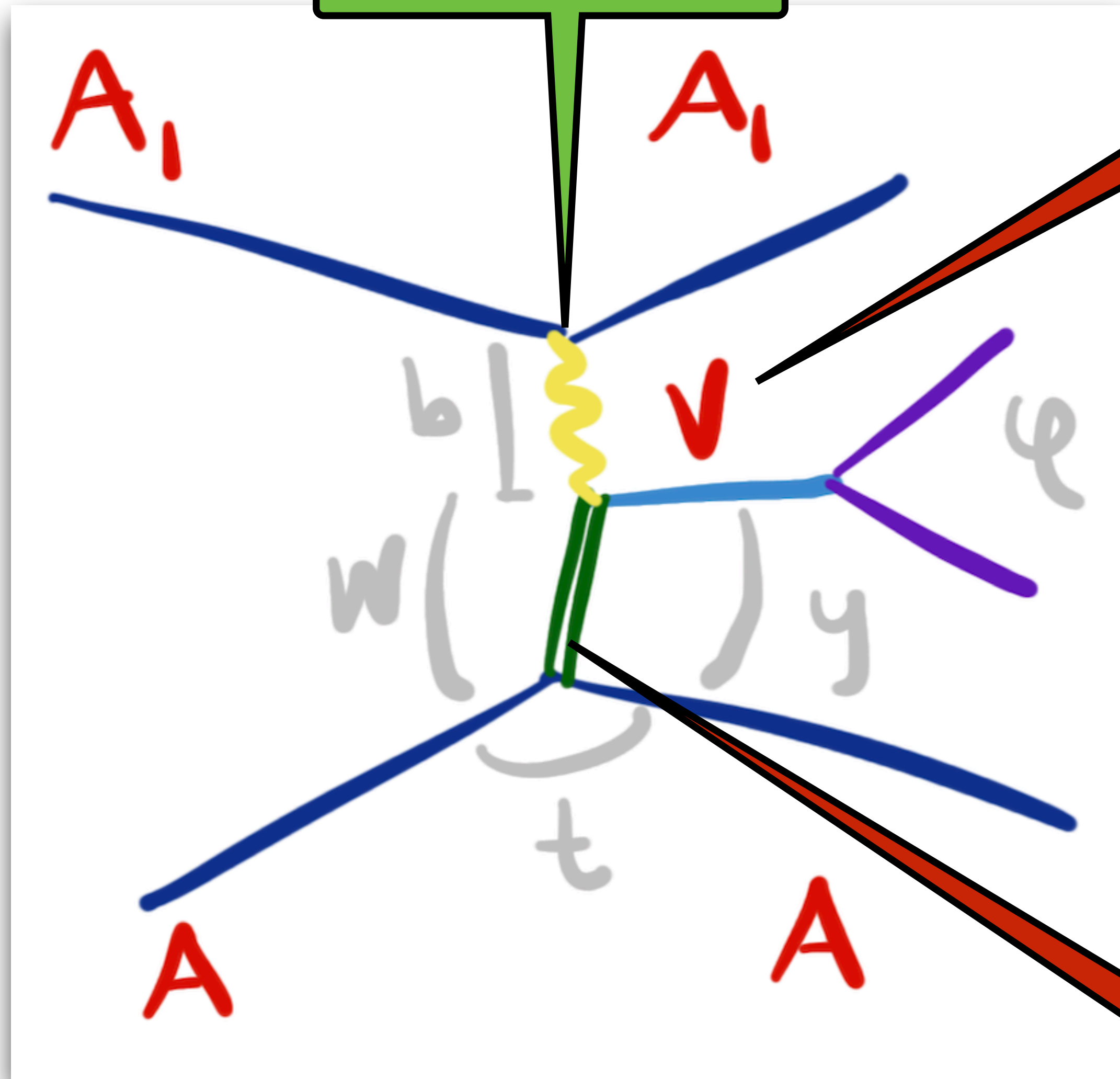
pQCD is in here

The process we are interested in

Interesting recent developments not covered here

QED is in here

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



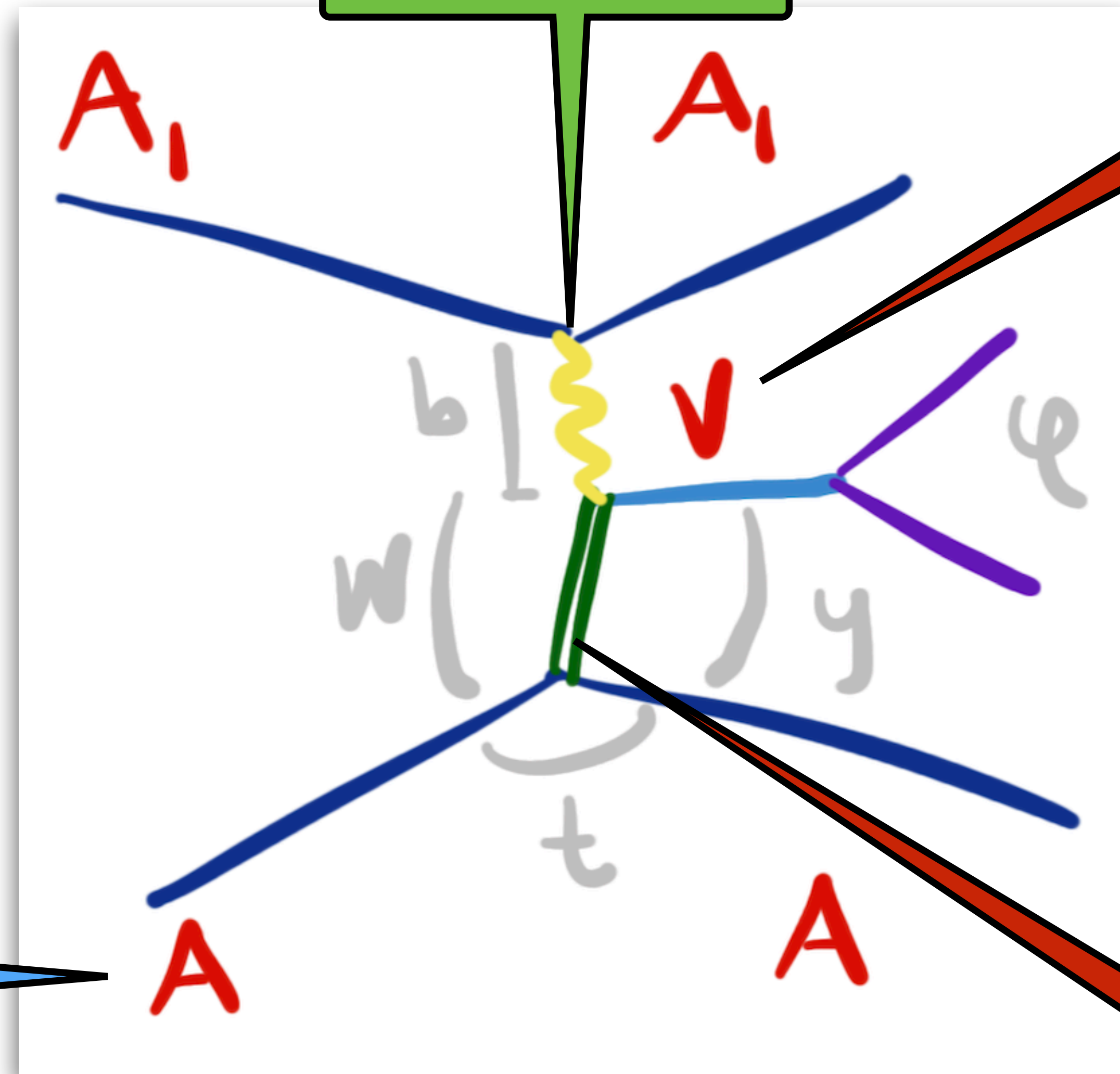
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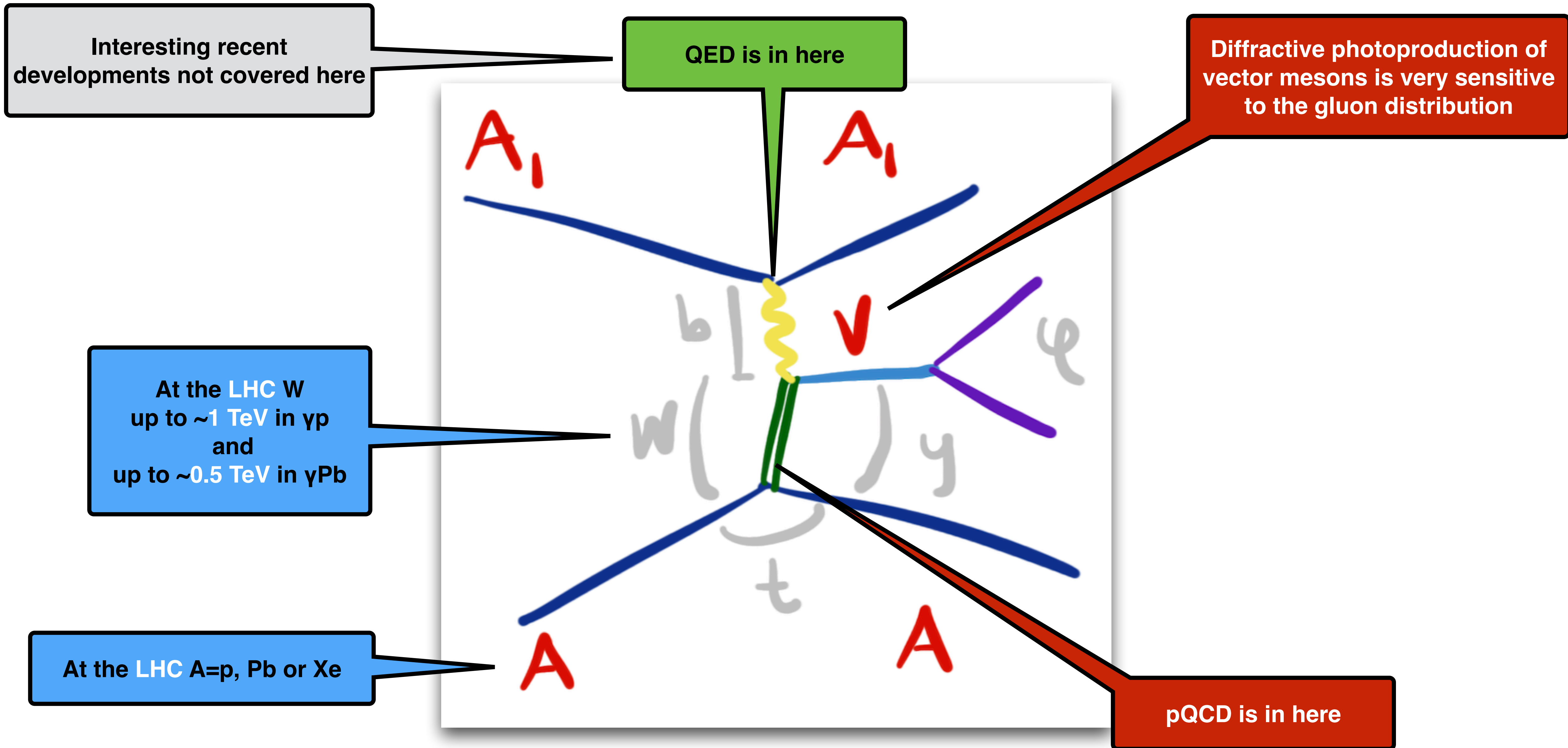
Diffractive photoproduction of vector mesons is very sensitive to the gluon distribution



At the LHC $A=p$, Pb or Xe

pQCD is in here

The process we are interested in



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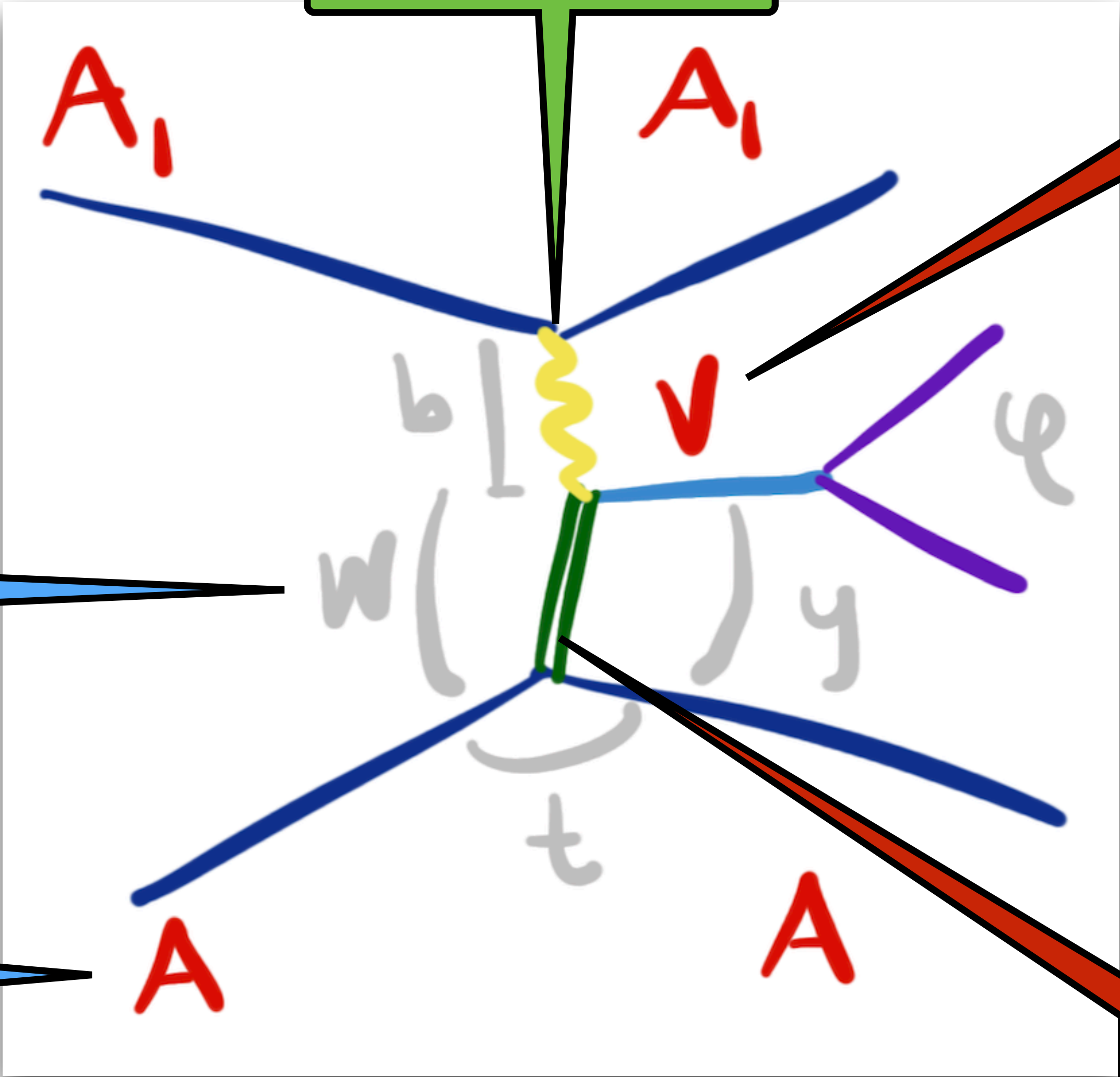
Diffraction photoproduction of vector mesons is very sensitive to the gluon distribution

**Current measurements
based in a few hundreds to
few thousand events.**

pQCD is in here

**At the LHC W
up to ~ 1 TeV in γp
and
up to ~ 0.5 TeV in γPb**

At the LHC $A=p, \text{Pb or Xe}$



Expectations for Run 3+4 at the LHC

Pb-Pb

PbPb						
Meson	σ	All Total	Central 1 Total	Central 2 Total	Forward 1 Total 1	Forward 2 Total
$\rho \rightarrow \pi^+ \pi^-$	5.2b	68 B	5.5 B	21B	4.9 B	13 B
$\rho' \rightarrow \pi^+ \pi^- \pi^+ \pi^-$	730 mb	9.5 B	210 M	2.5 B	190 M	1.2 B
$\phi \rightarrow K^+ K^-$	0.22b	2.9 B	82 M	490 M	15 M	330 M
$J/\psi \rightarrow \mu^+ \mu^-$	1.0 mb	14 M	1.1 M	5.7 M	600 K	1.6 M
$\psi(2S) \rightarrow \mu^+ \mu^-$	$30\mu\text{b}$	400 K	35 K	180 K	19 K	47 K
$Y(1S) \rightarrow \mu^+ \mu^-$	$2.0\mu\text{b}$	26 K	2.8 K	14 K	880	2.0 K

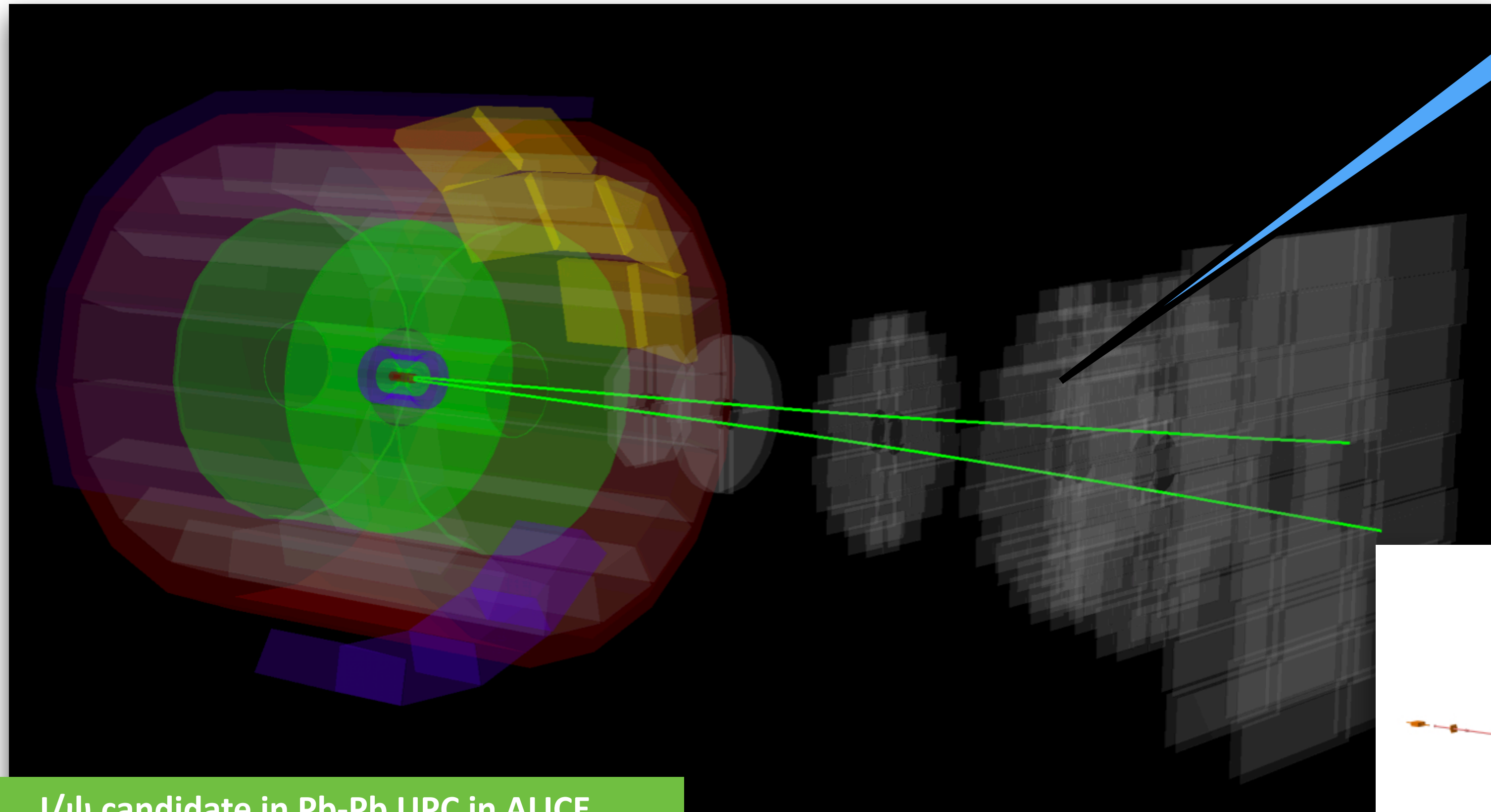
Acceptances

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

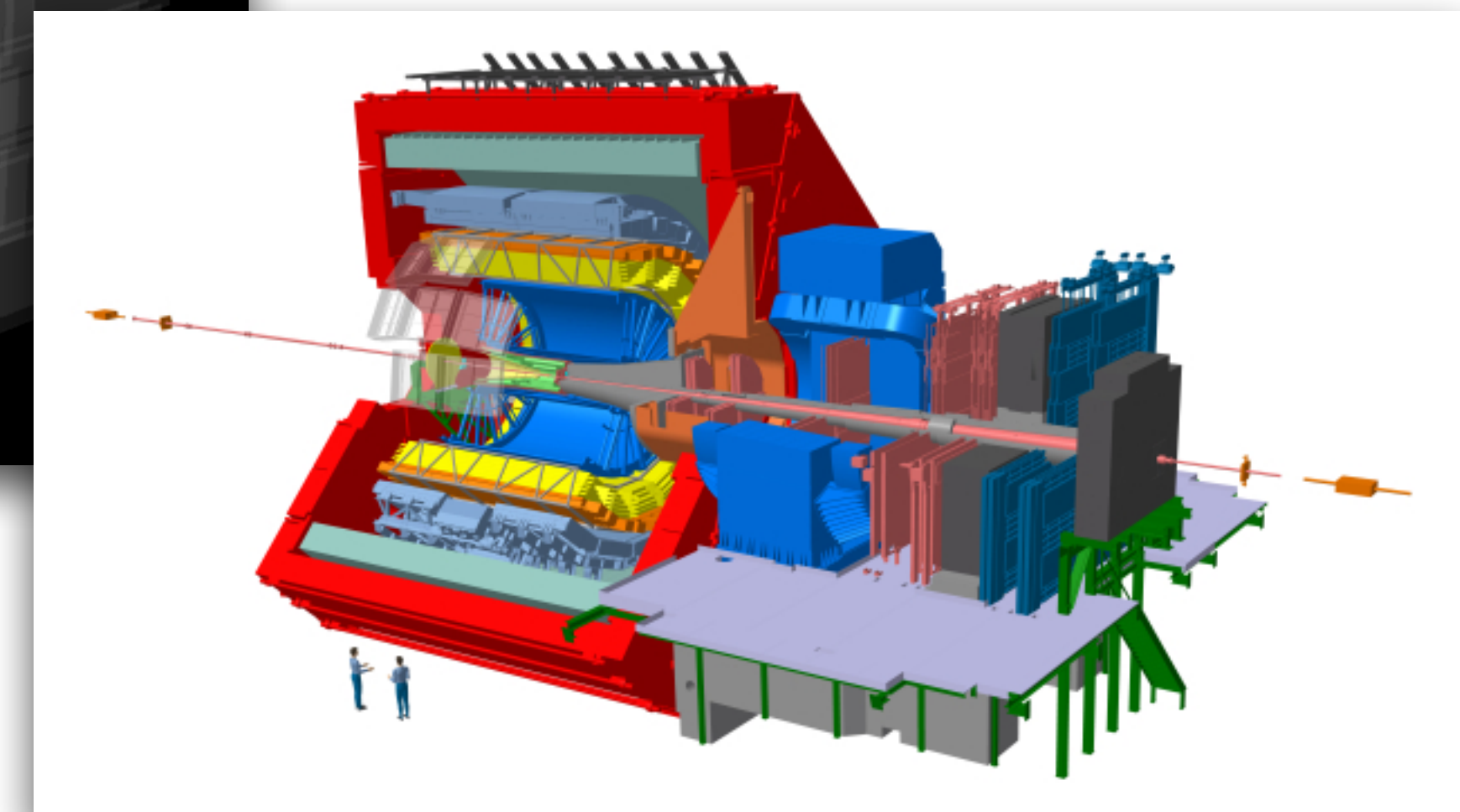
Run 3+4
Millions or even billions
events expected In Run 3+4

How does this process looks like in reality?

Two muons from the decay of the J/ψ and nothing else

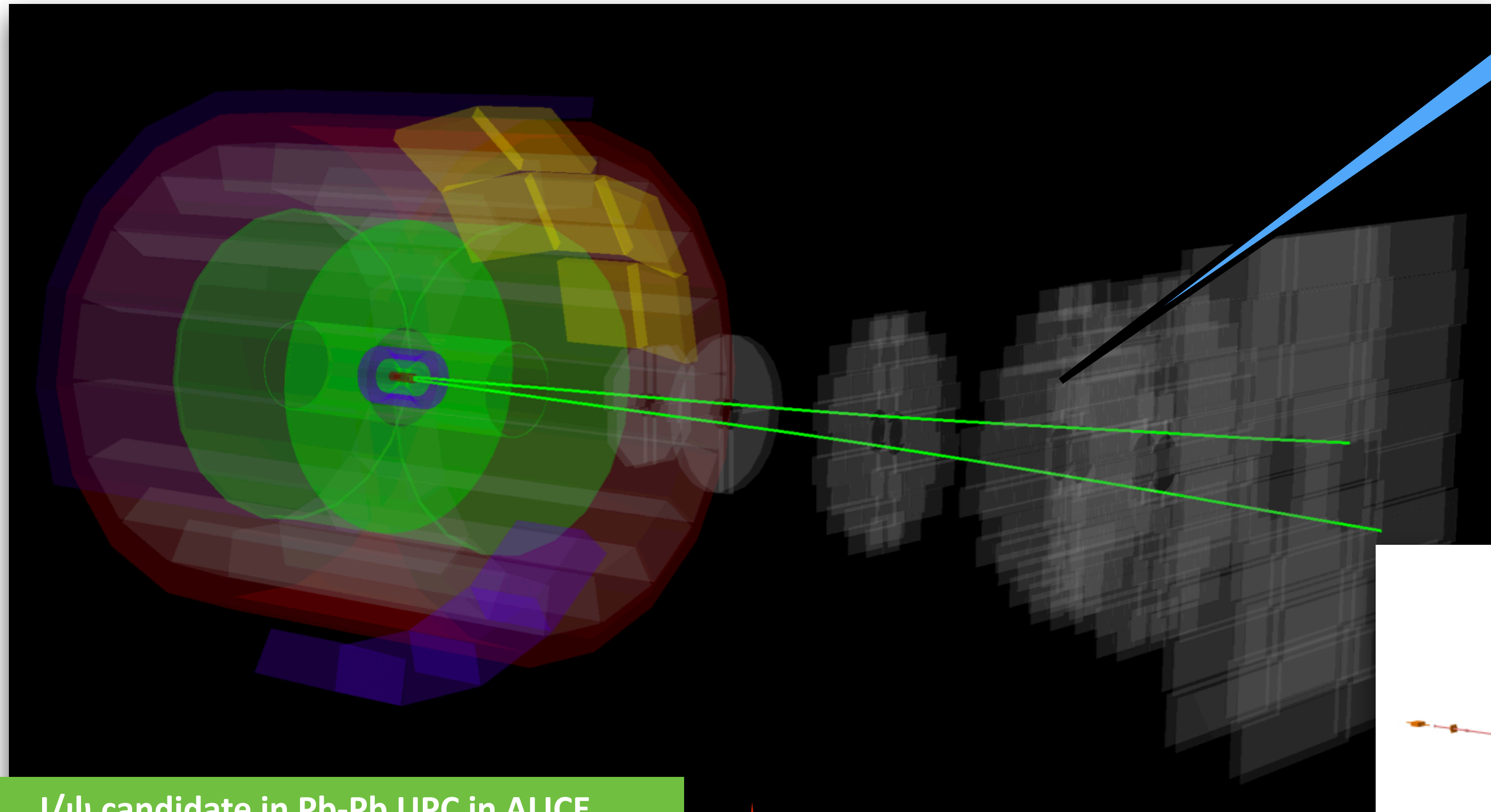


J/ψ candidate in Pb-Pb UPC in ALICE



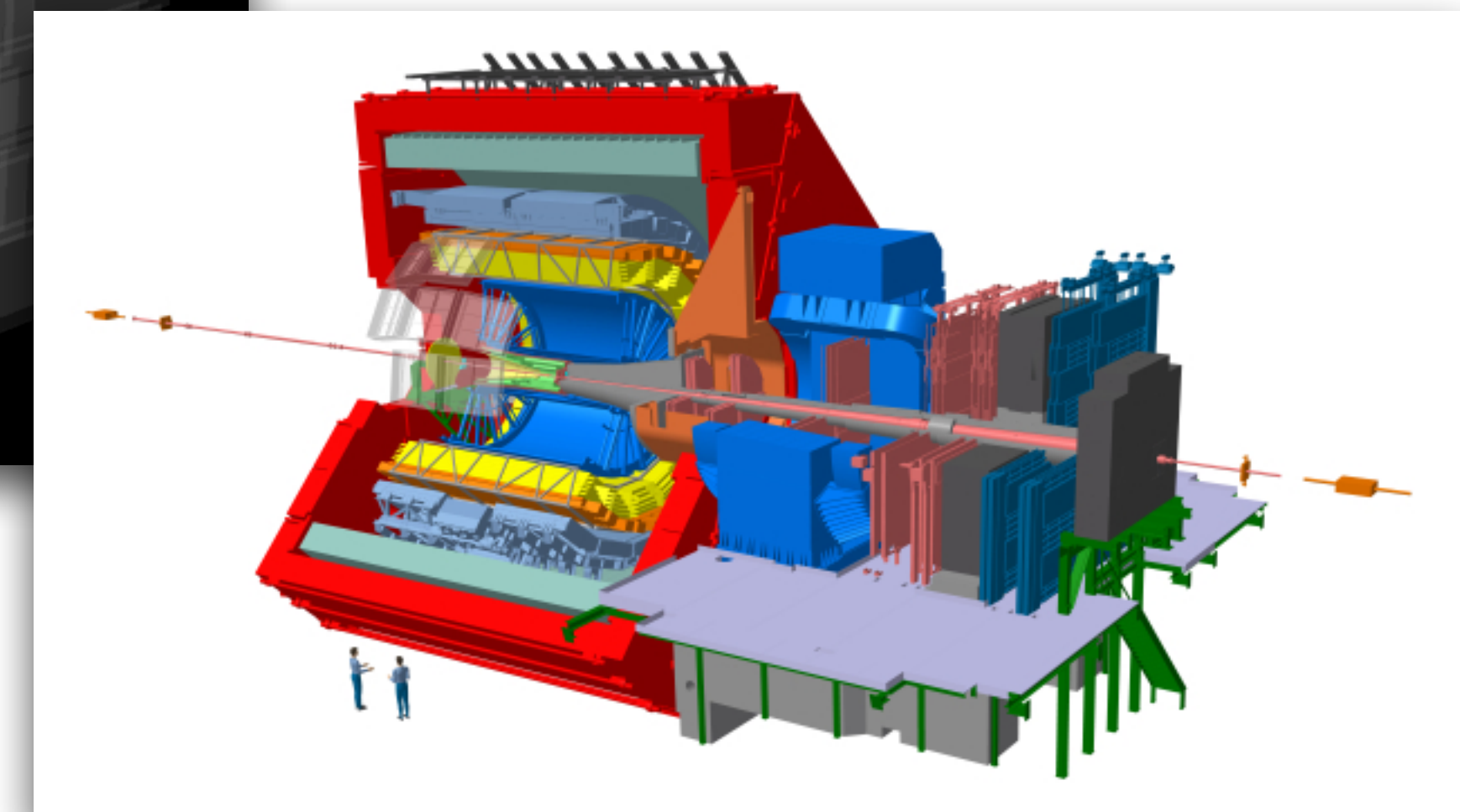
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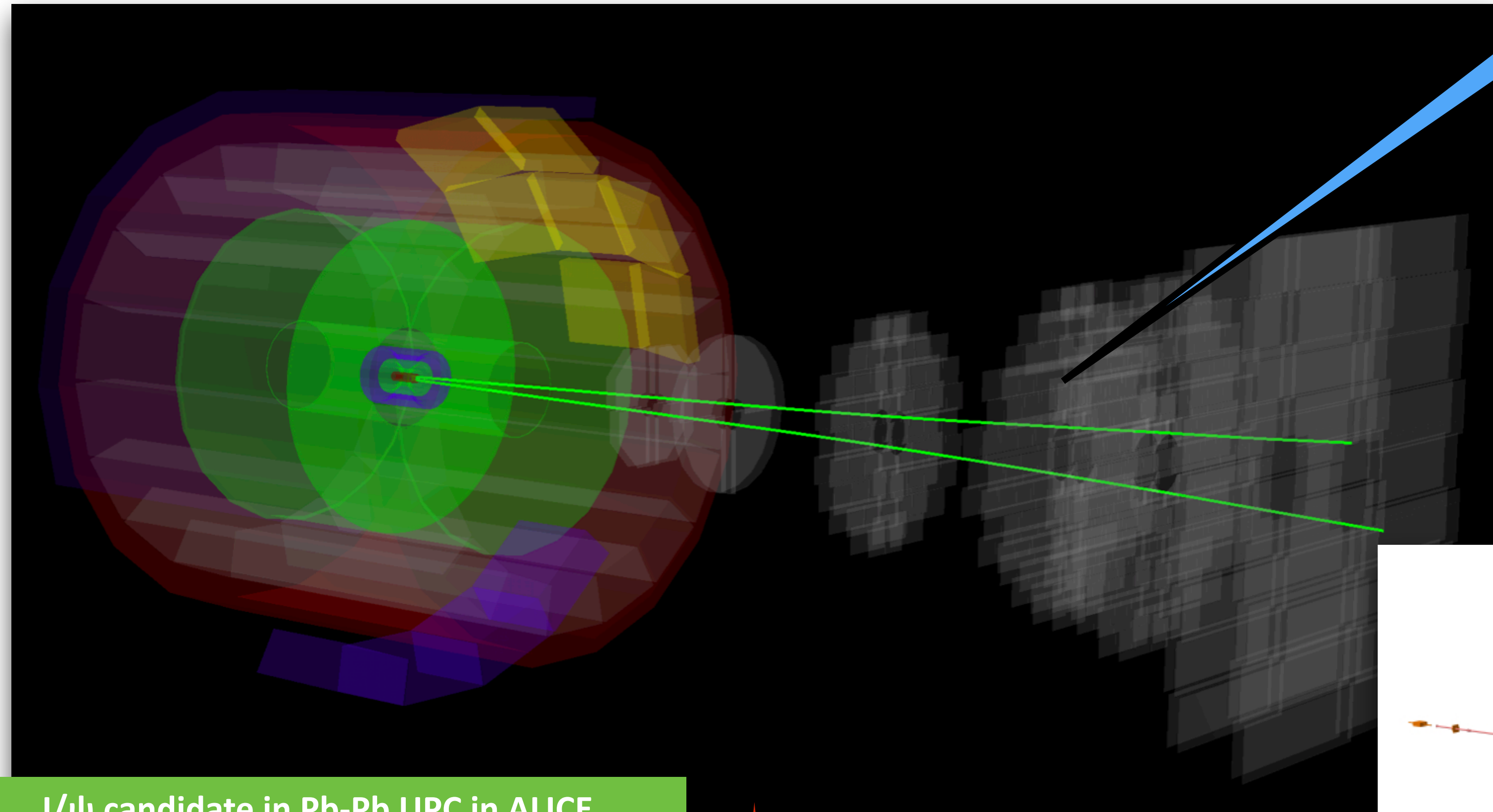


J/ψ candidate in Pb-Pb UPC in ALICE

Open question:
How to trigger/select these events?



How does this process looks like in reality?

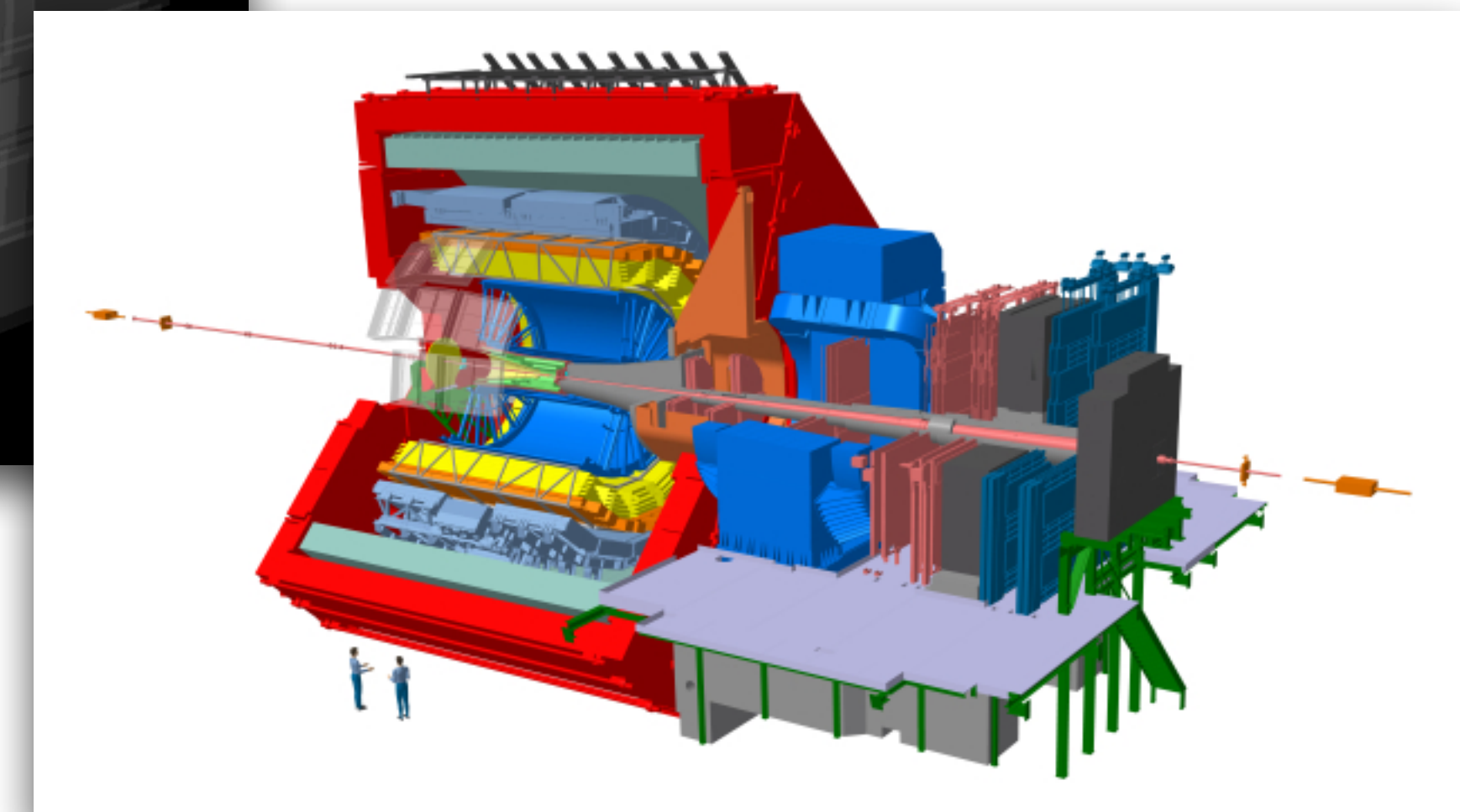


Two muons from the decay of the J/ψ and nothing else

Open question:
How to ensure 'nothing else'?

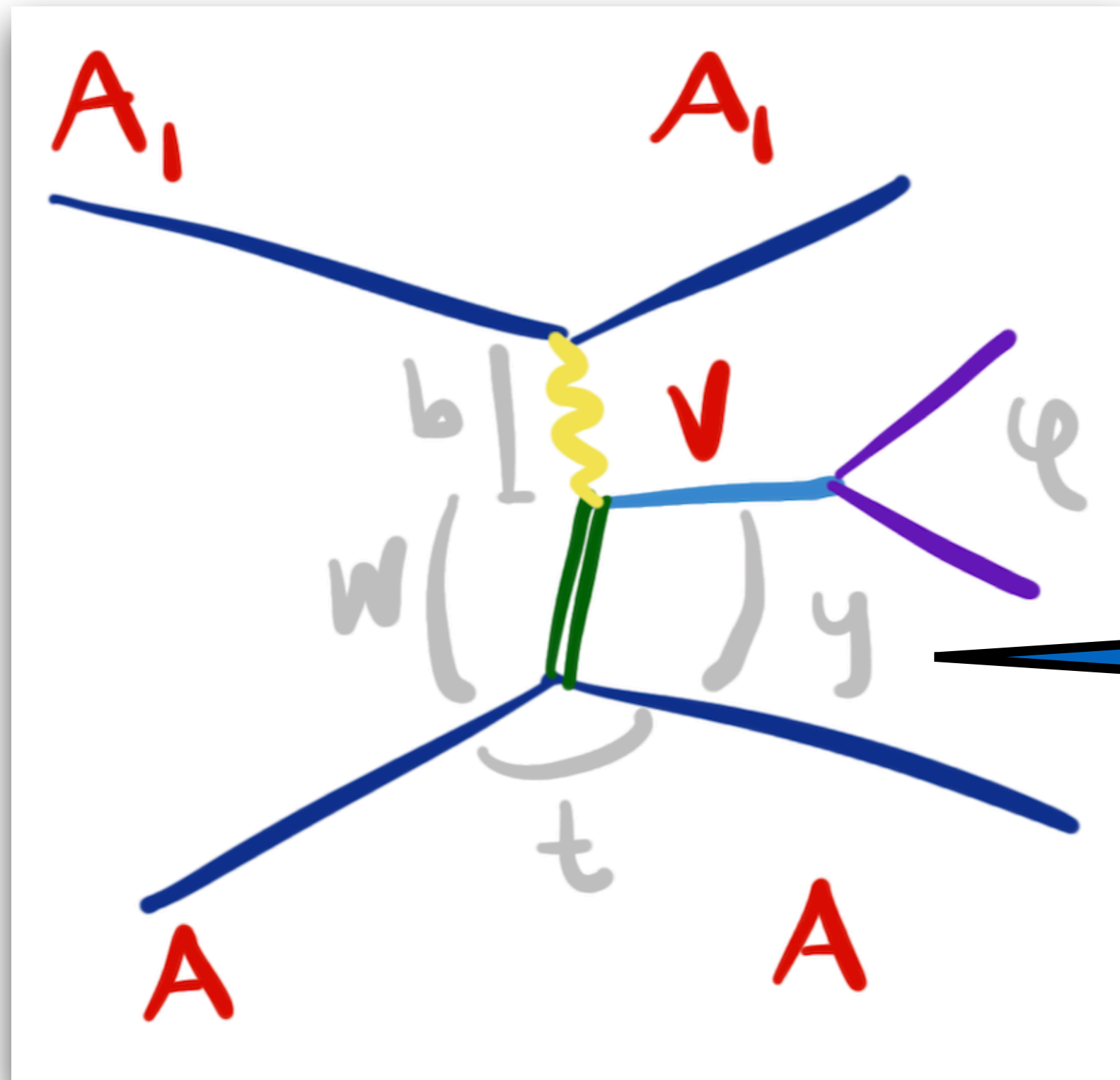
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y

Rapidity dependence

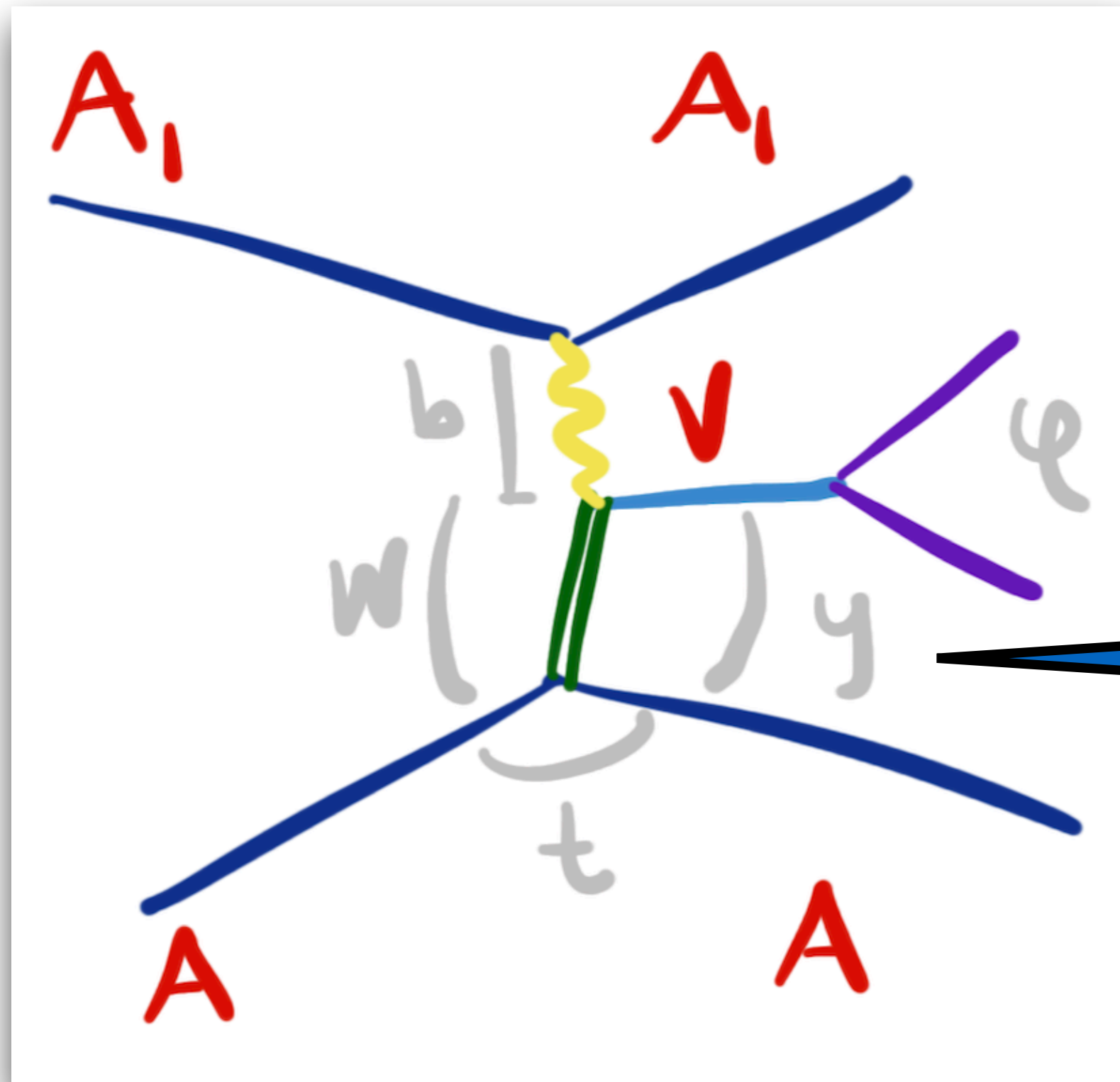


Rapidity dependence
 \Rightarrow x evolution

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

y

Rapidity dependence



Expectations:

The gluon distribution raises as a power law with decreasing x

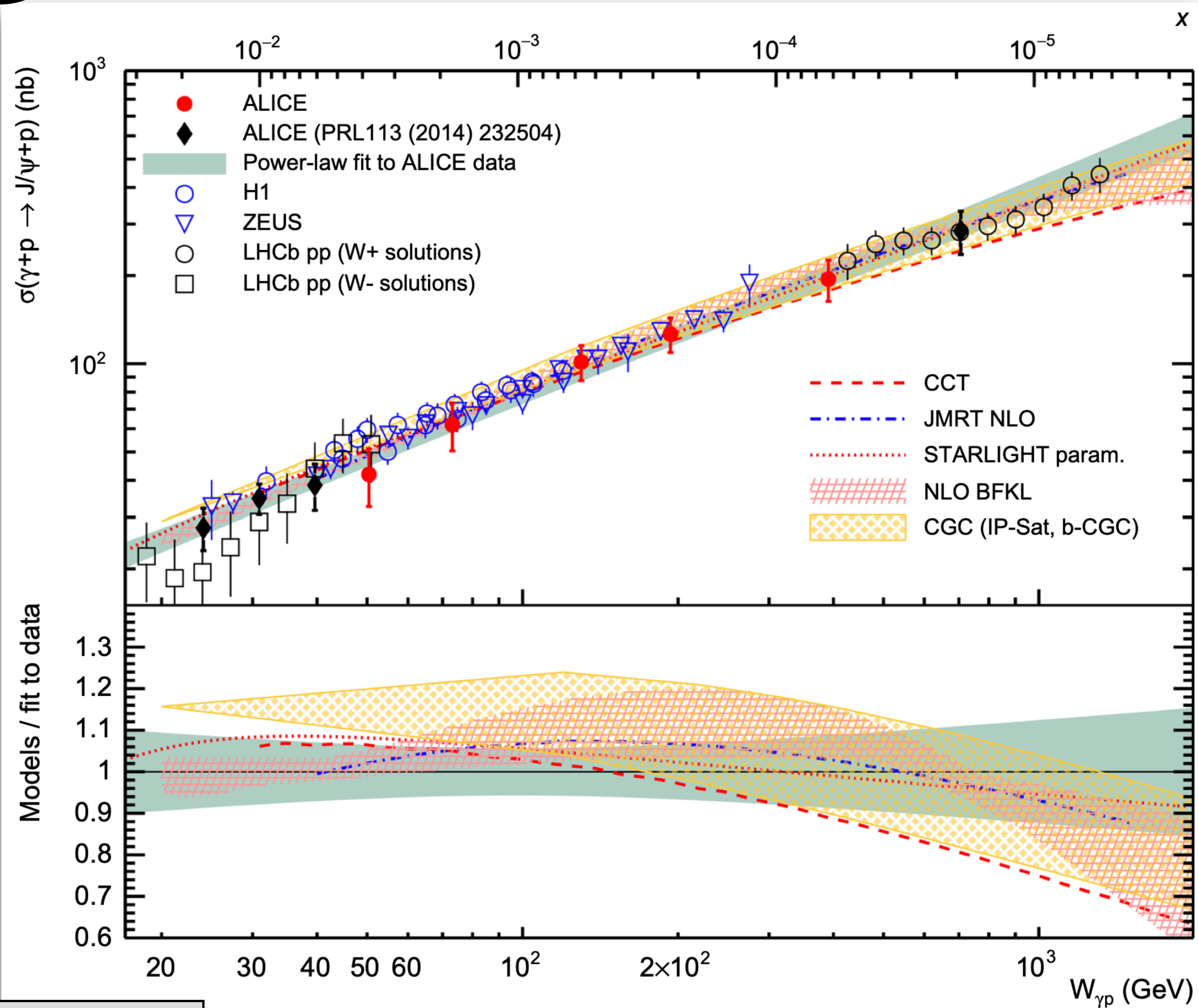


The cross section raises as a power law until it saturates

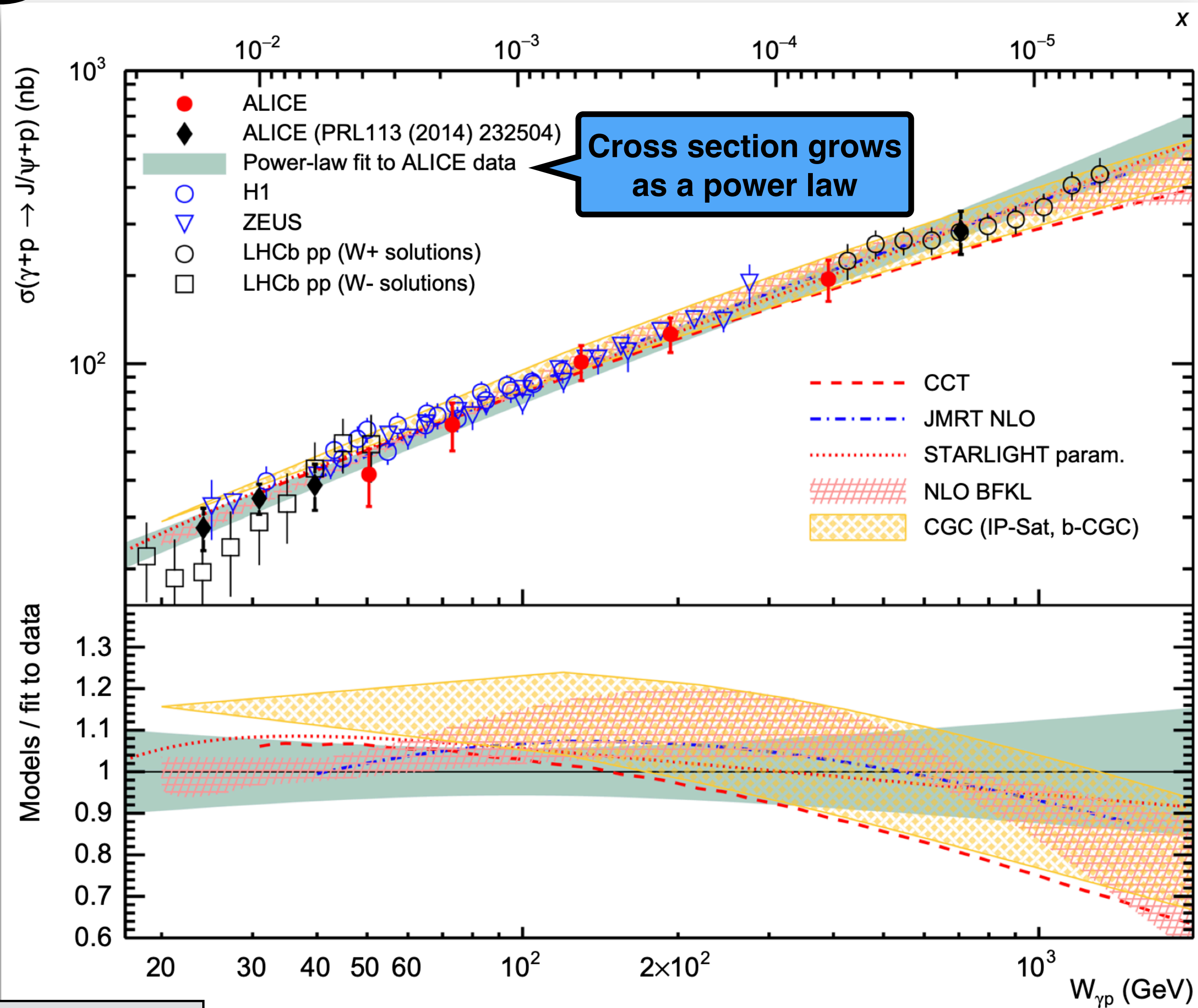
Rapidity dependence

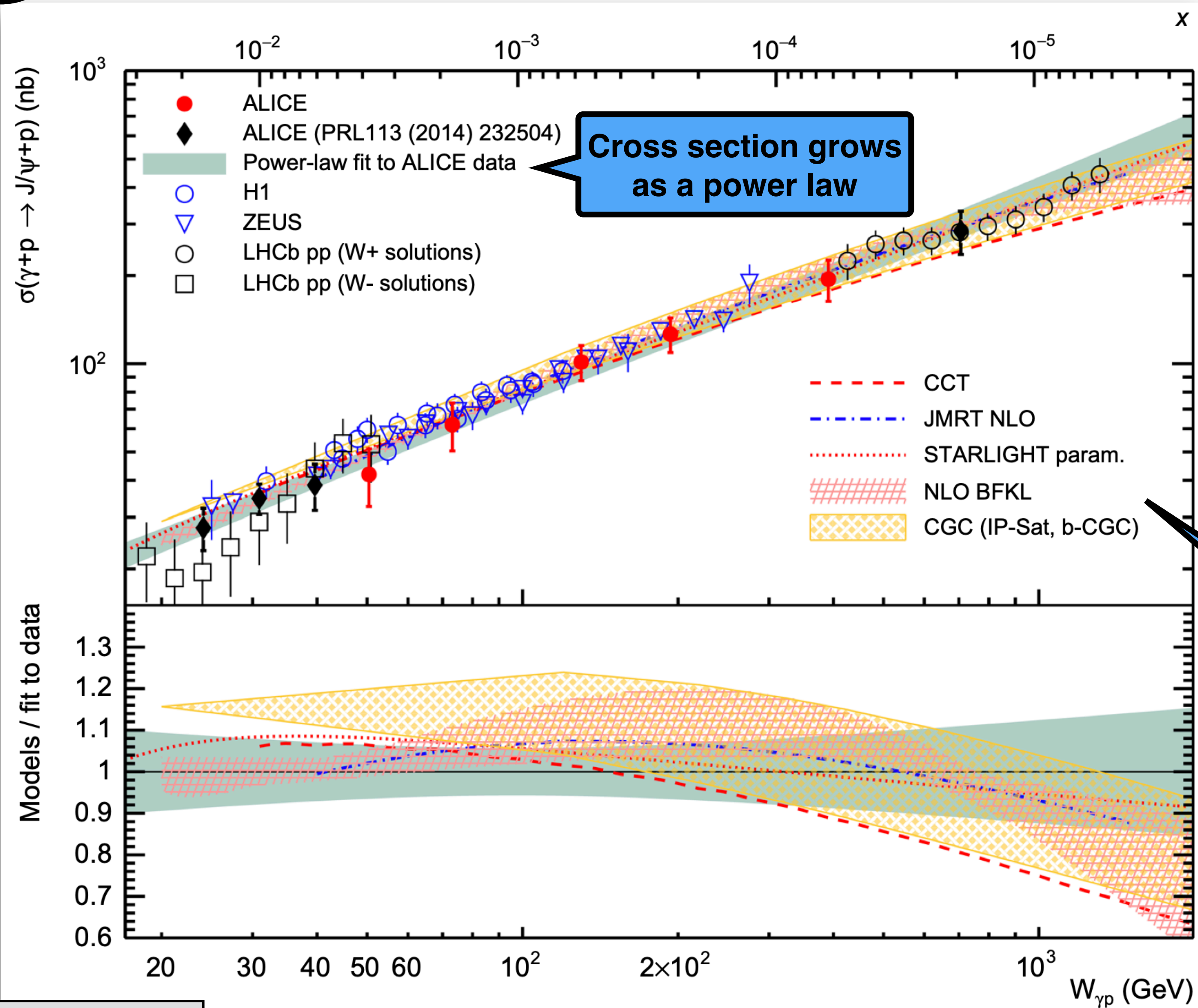
⇒ x evolution

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



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

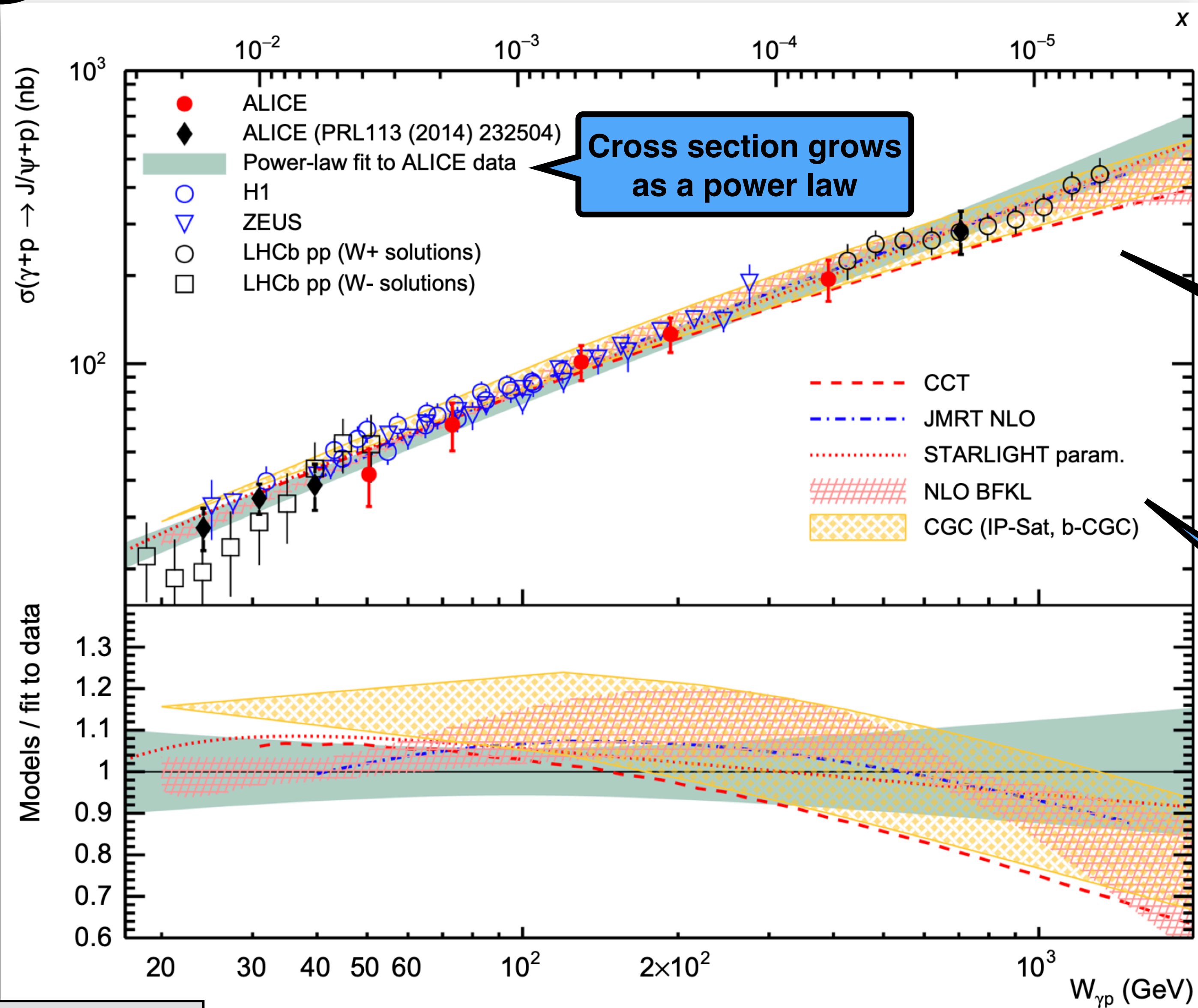




Cross section grows as a power law

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

All types of models describe data: VDM, DGLAP, BFKL, CCG ...



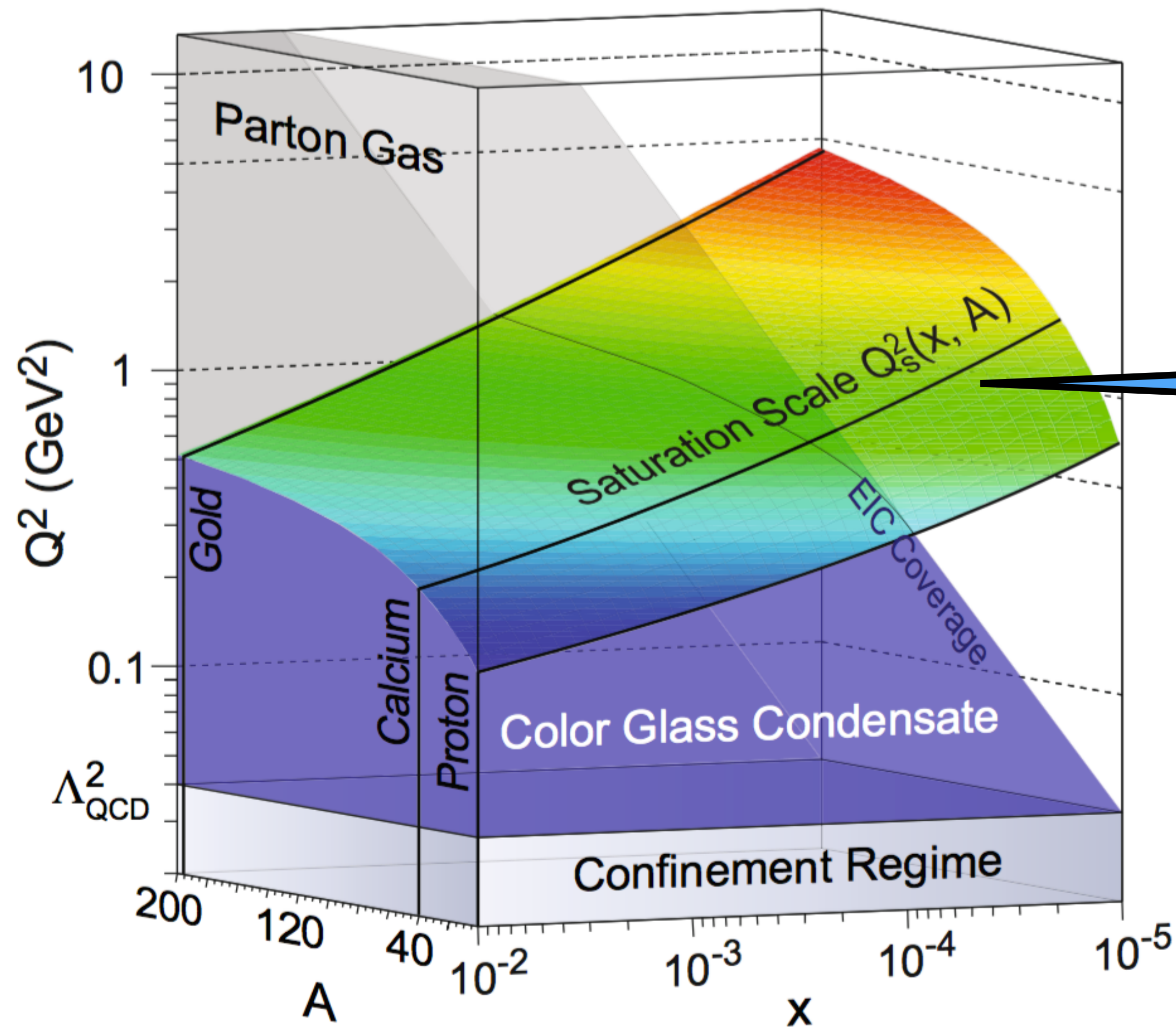
Cross section grows as a power law

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Open question: Where is saturation?

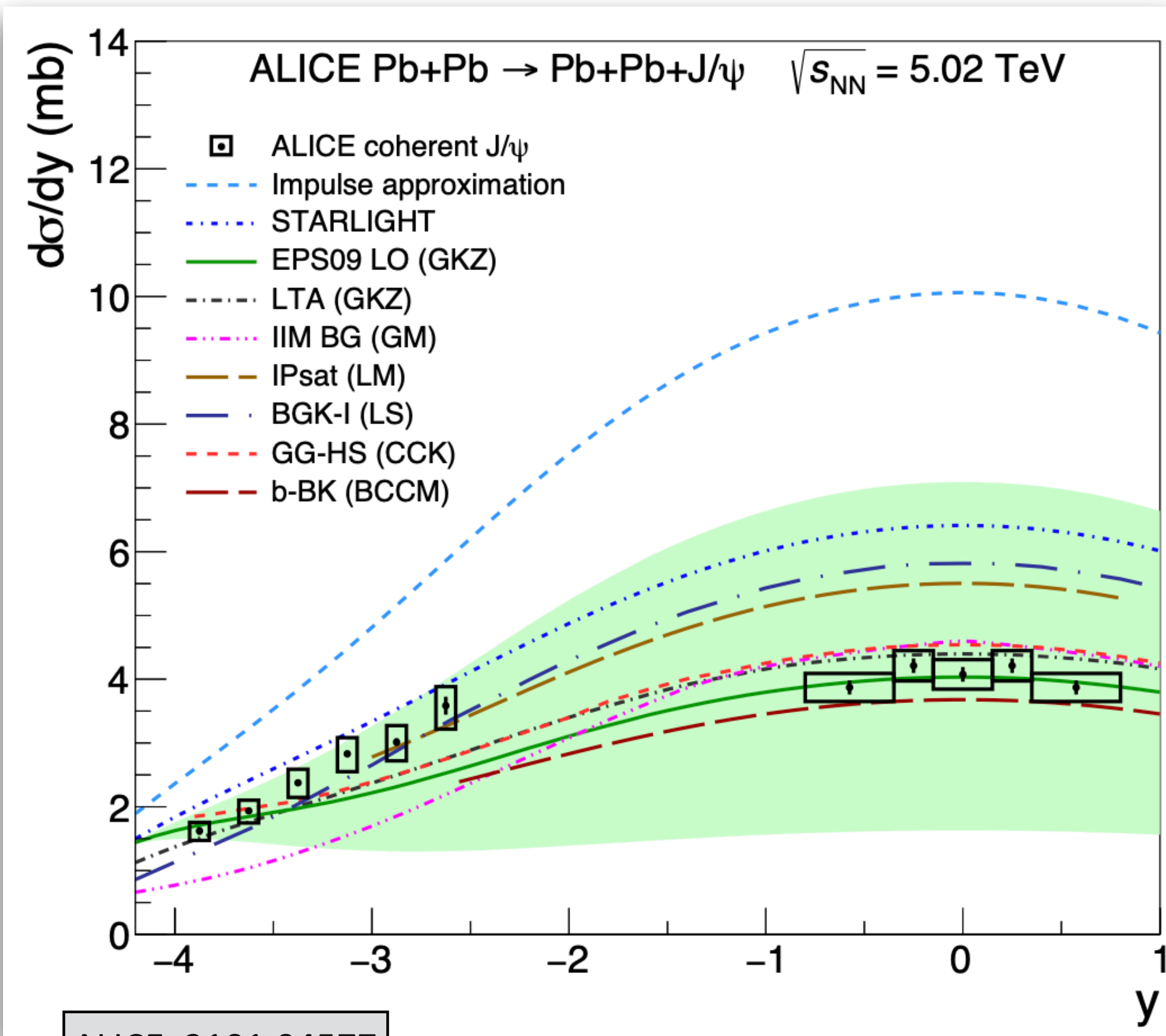
All types of models describe data: VDM, DGLAP, BFKL, CCG ...

Rapidity dependence: the case for nuclei

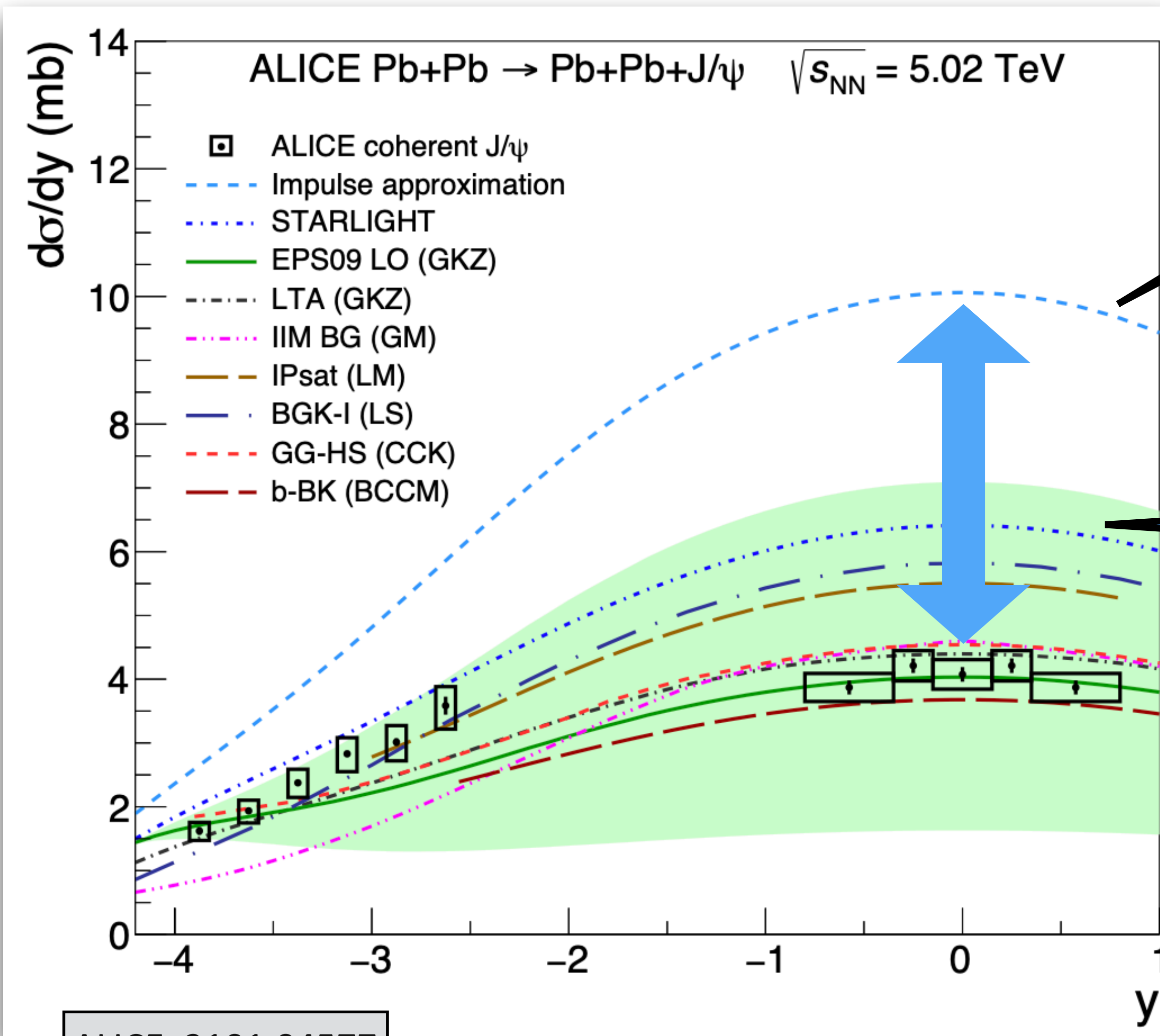


Saturation is expected to set in earlier in heavier nuclei

Accardi et al, EPJA 52 (2016) 268



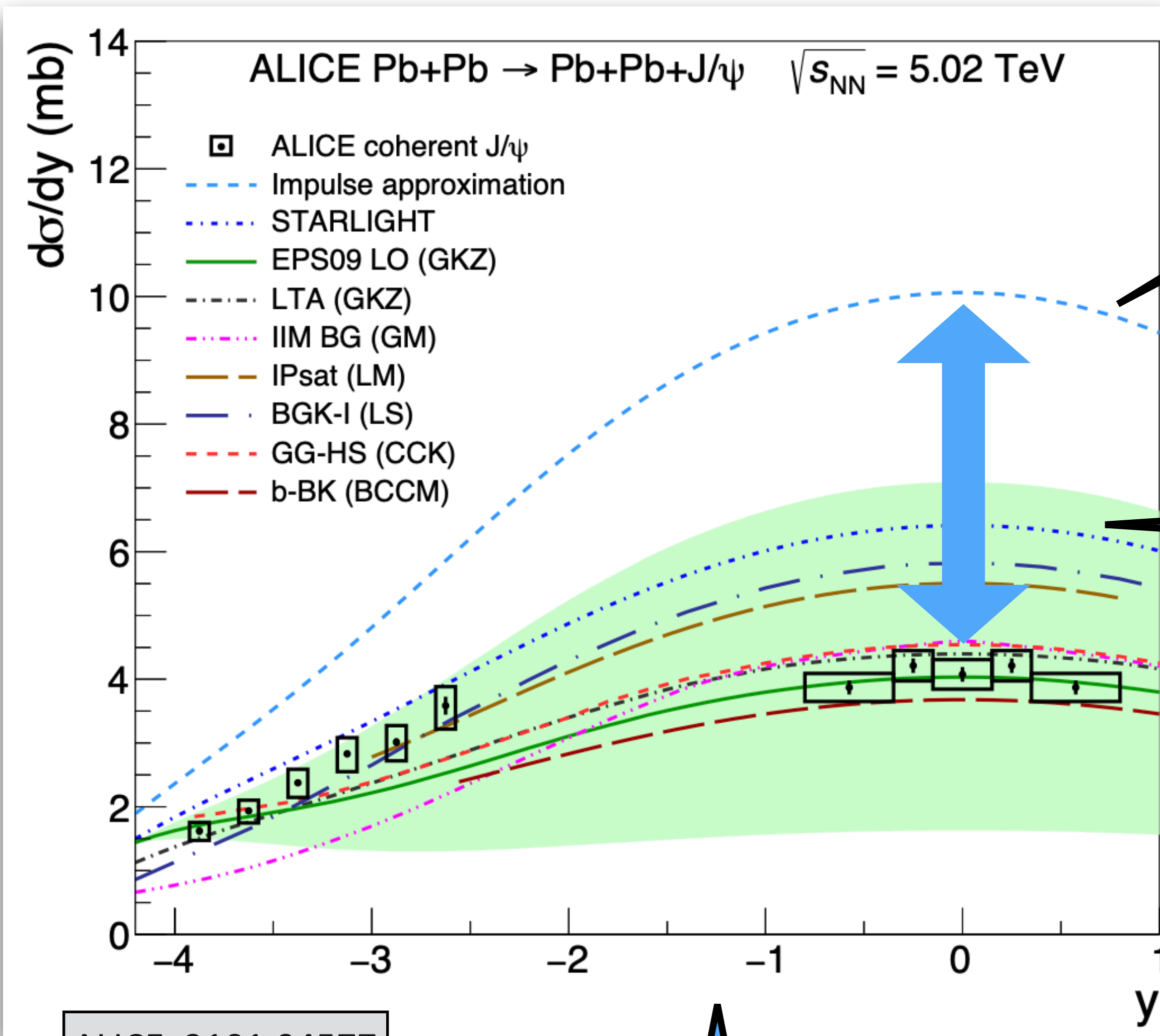
ALICE, 2101.04577



Impulse approximation

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

ALICE, 2101.04577

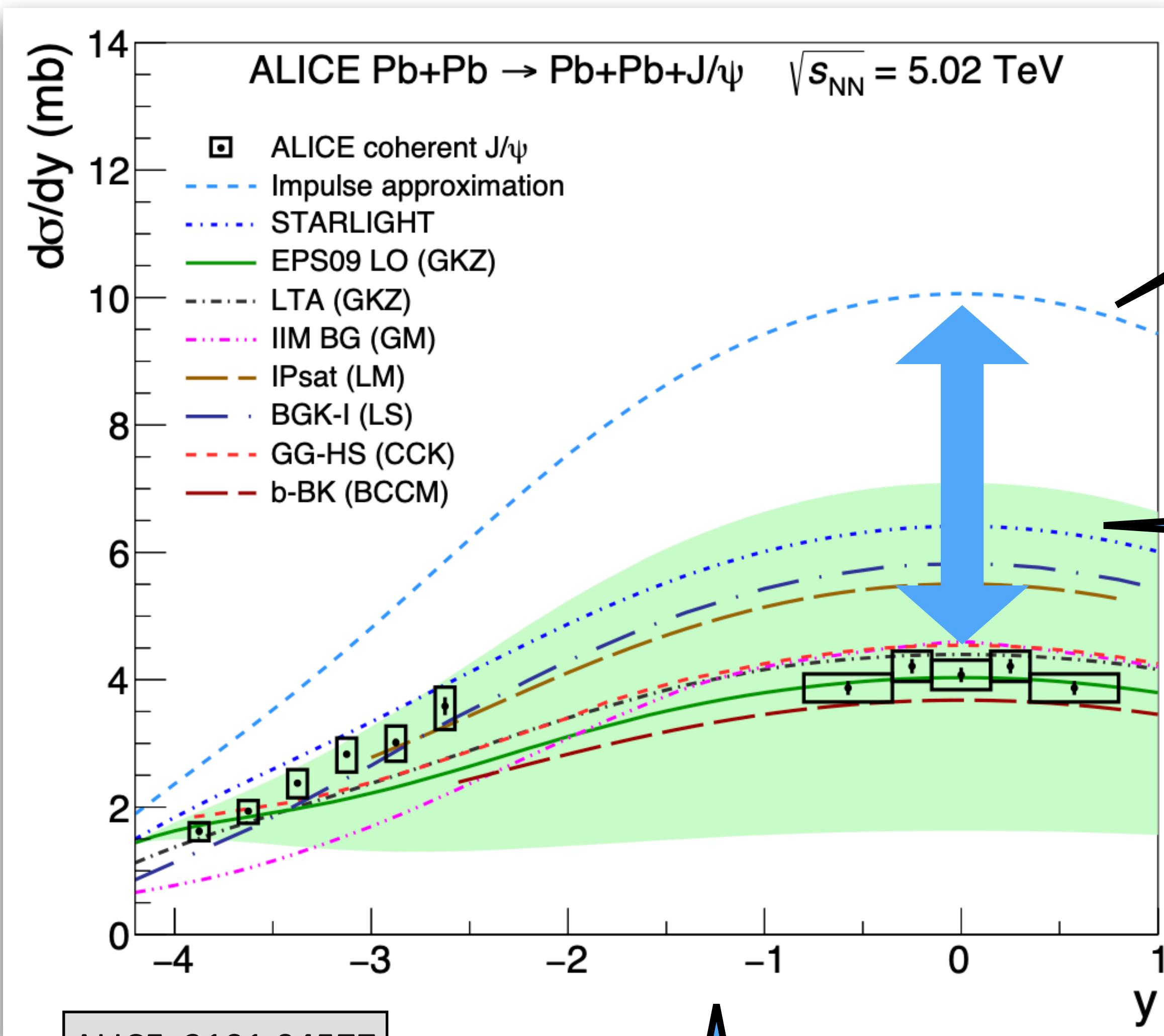


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No model describes all data



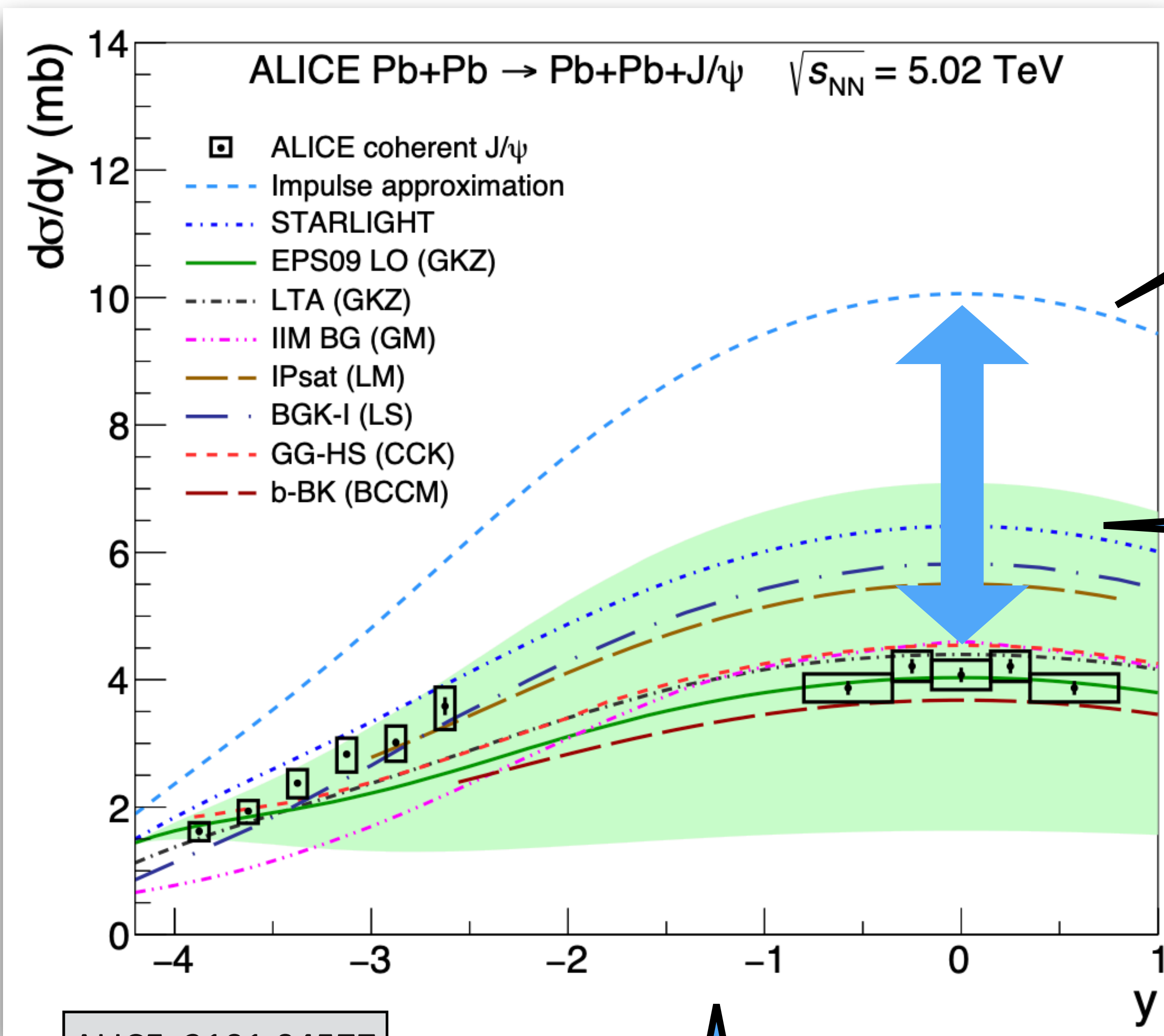
Impulse approximation

Open question:
How much of shadowing is saturation?

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ALICE, 2101.04577

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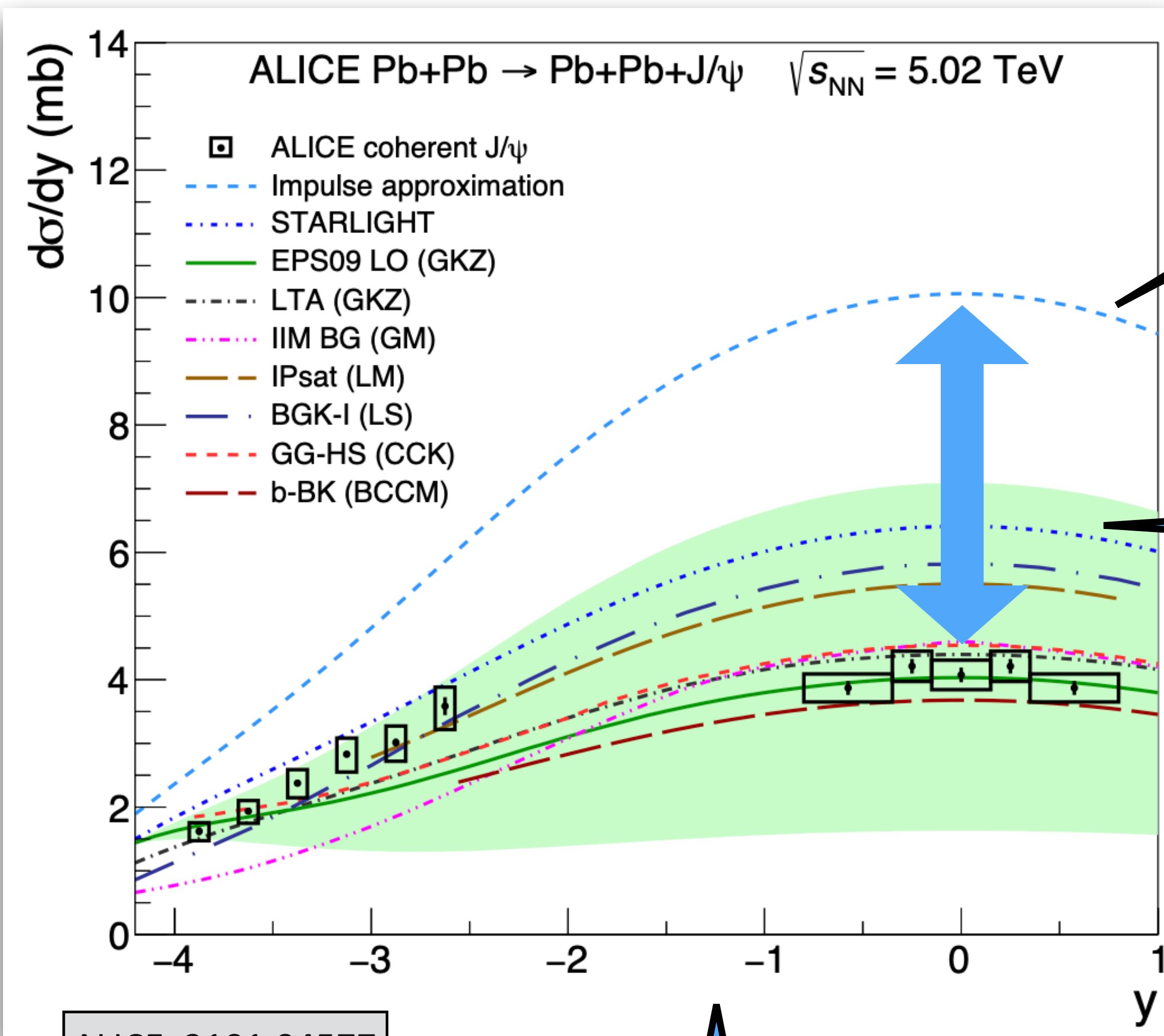
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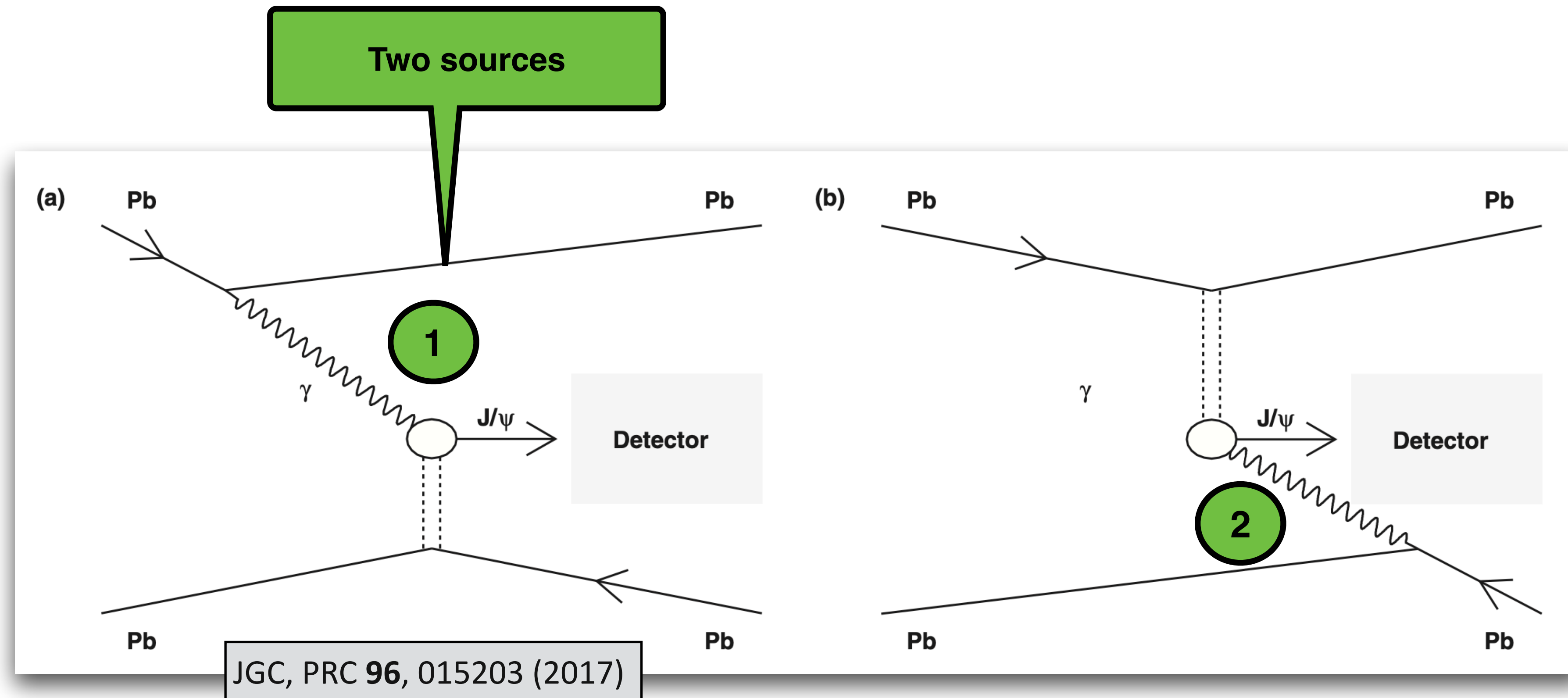
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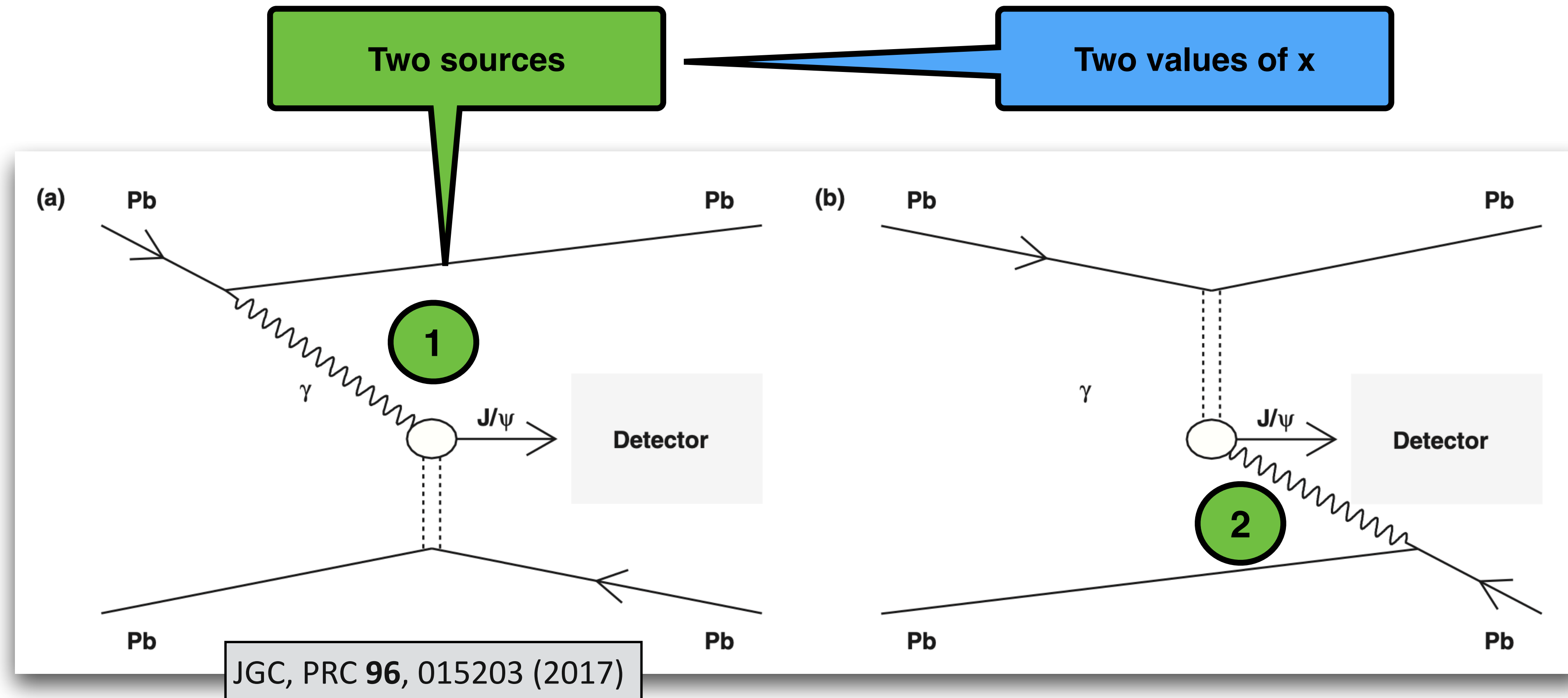
Open question:
Where is saturation?

Try to plot vs x ?

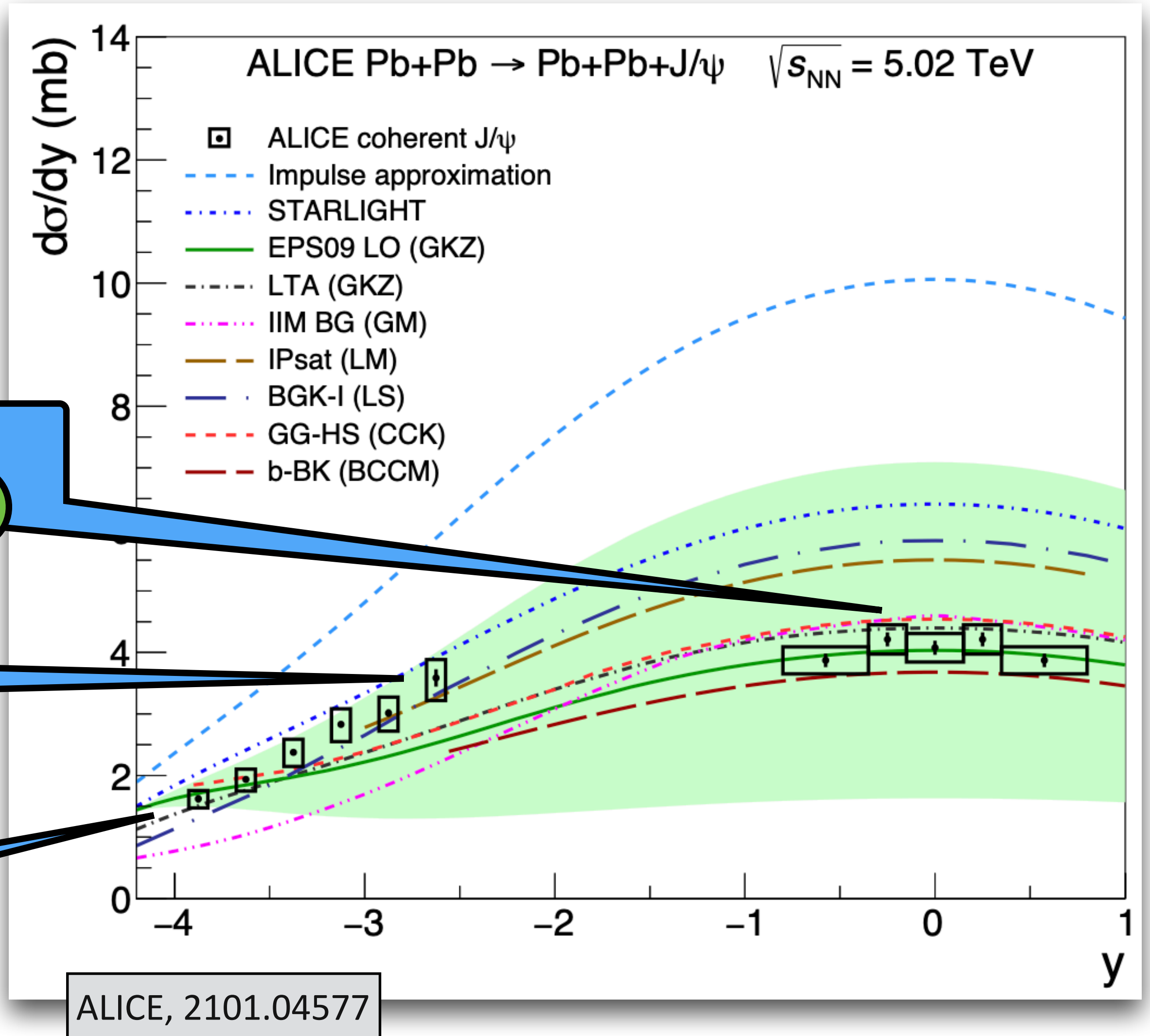
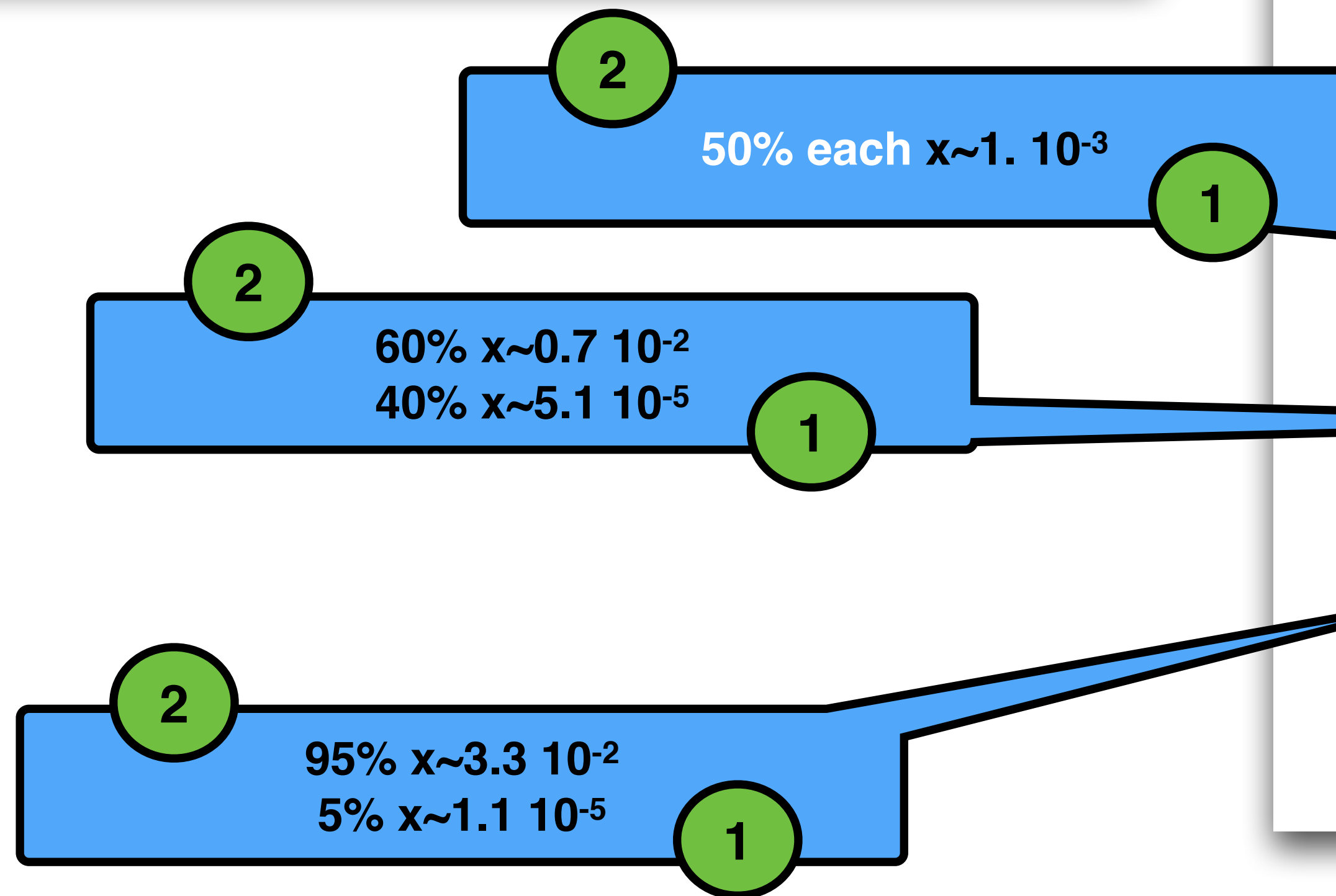
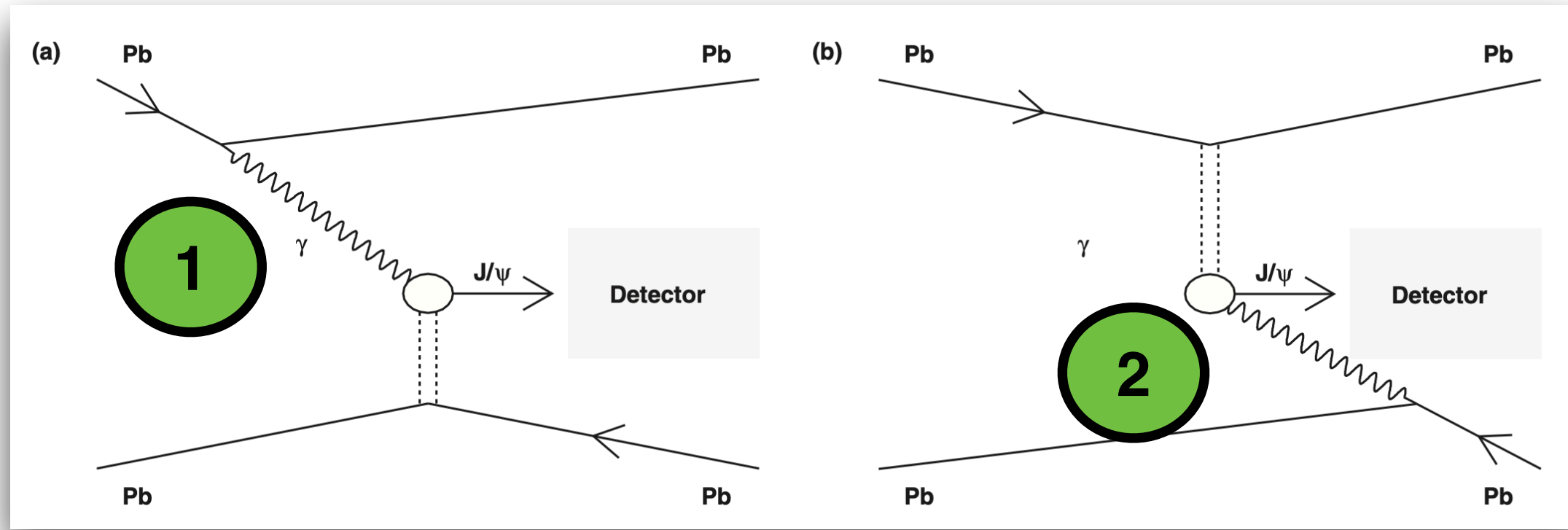
Rapidity dependence: ambiguity problem



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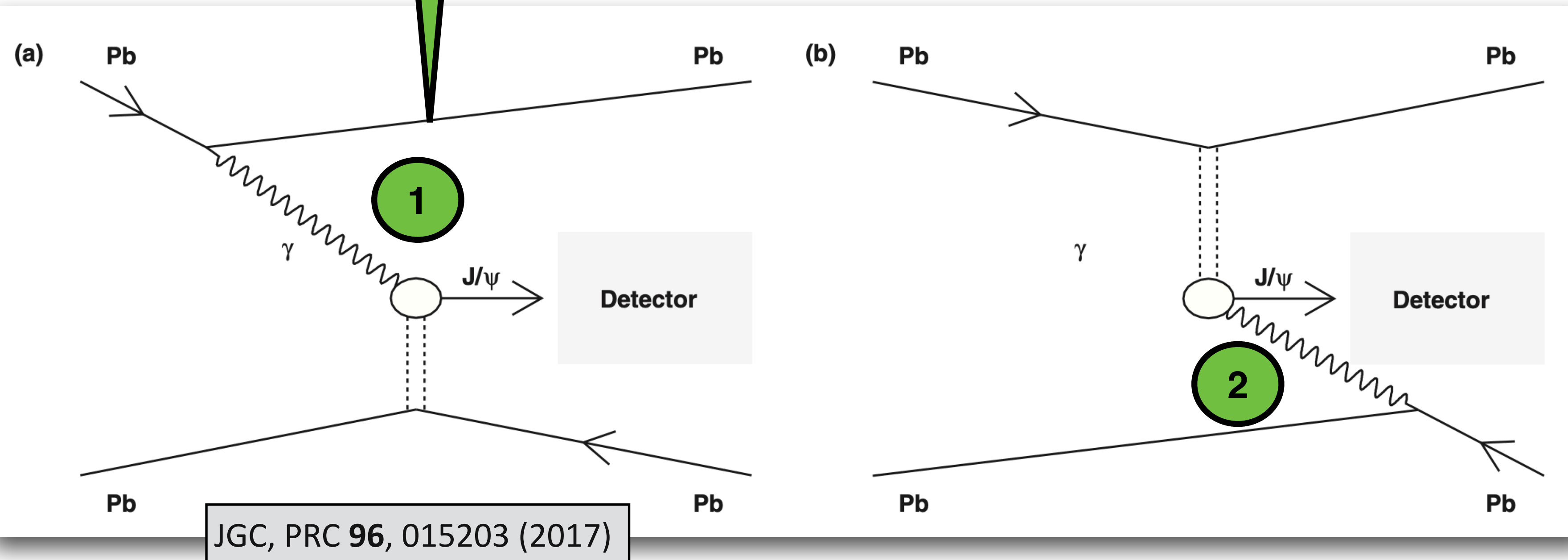
Rapidity dependence: ambiguity problem



Rapidity dependence: ambiguity problem

Open question: how to disentangle both contributions?

Two sources

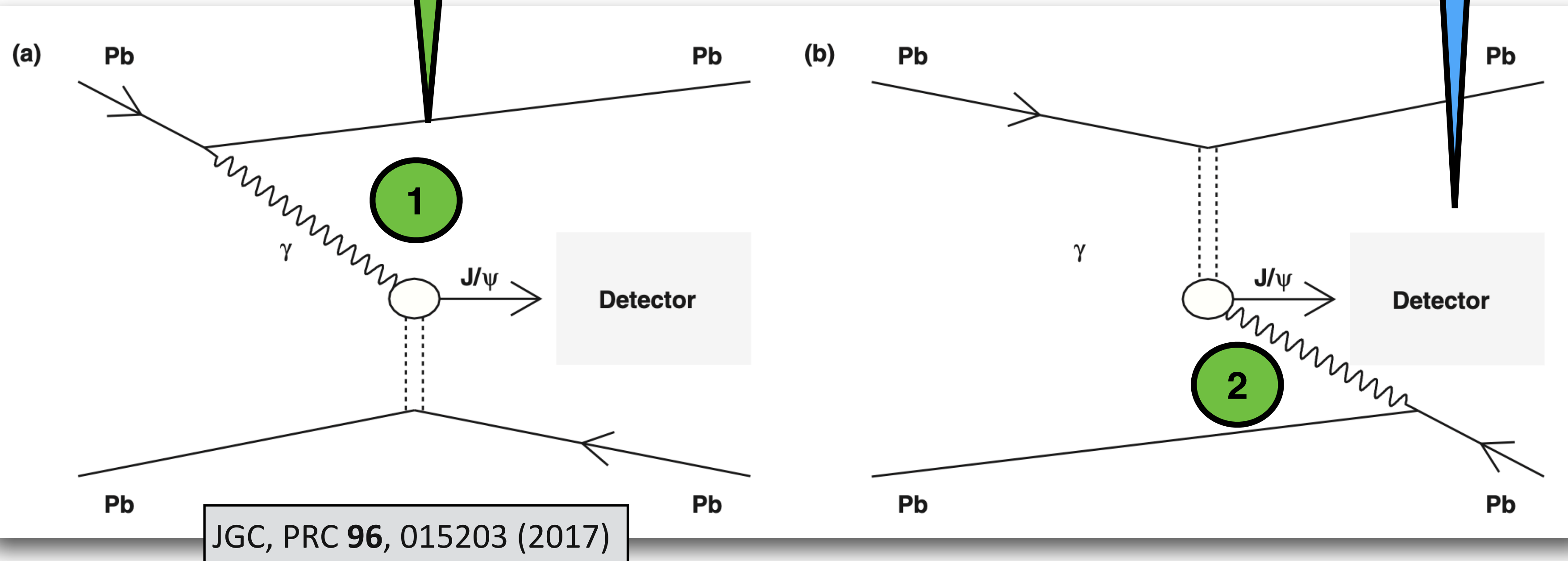


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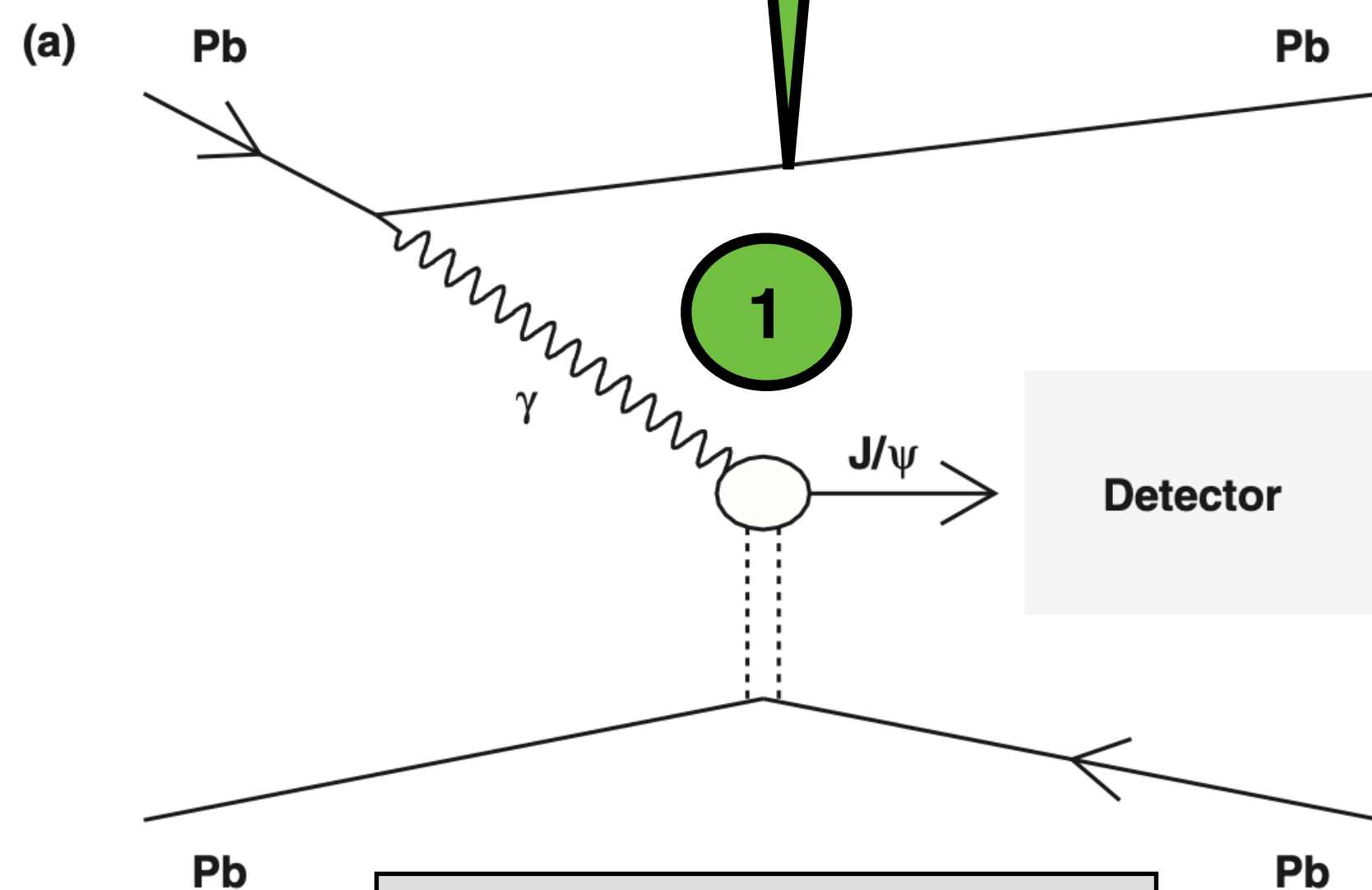
Another independent measurement
needed at the same rapidity



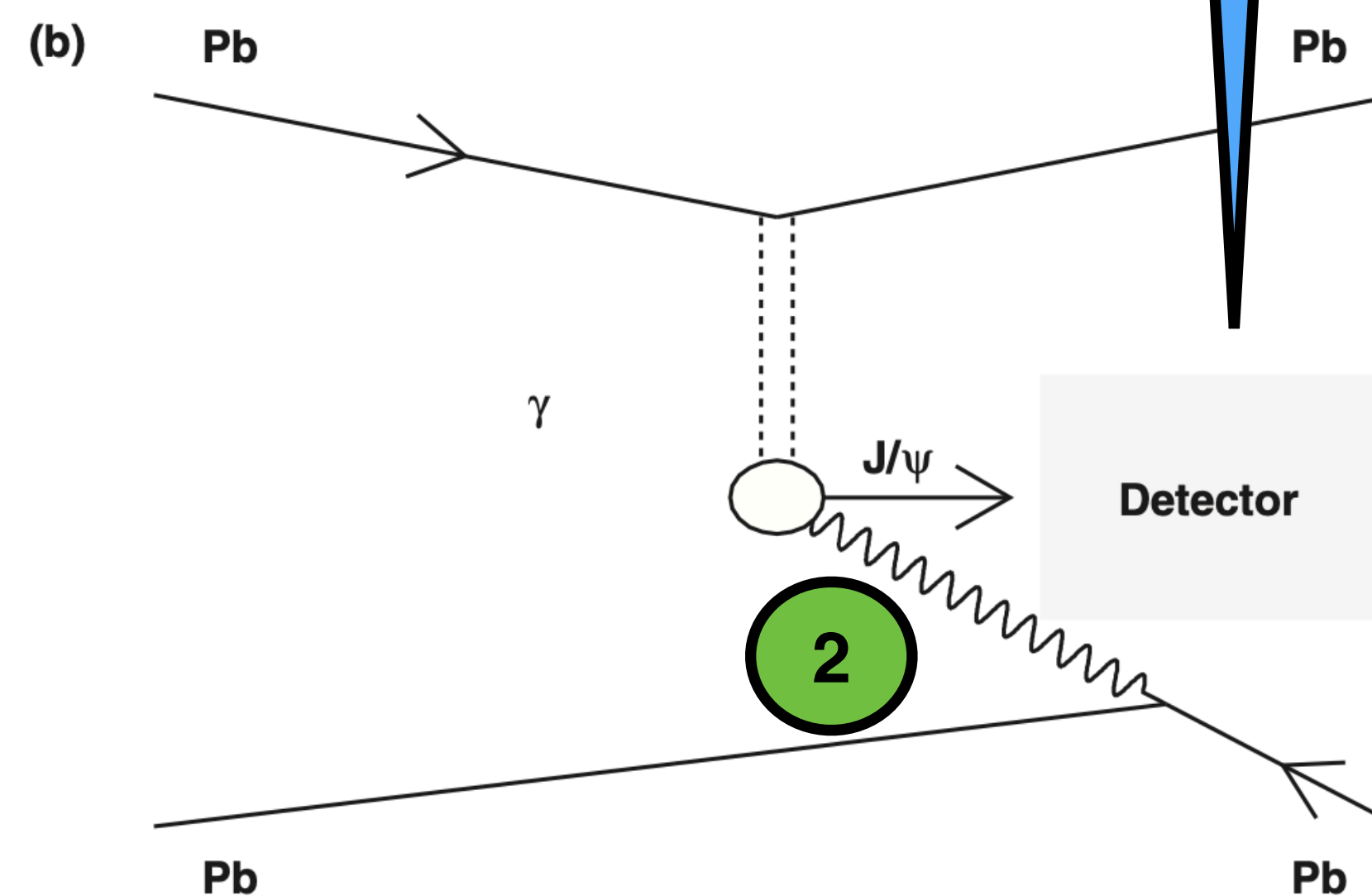
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JGC, PRC 96, 015203 (2017)



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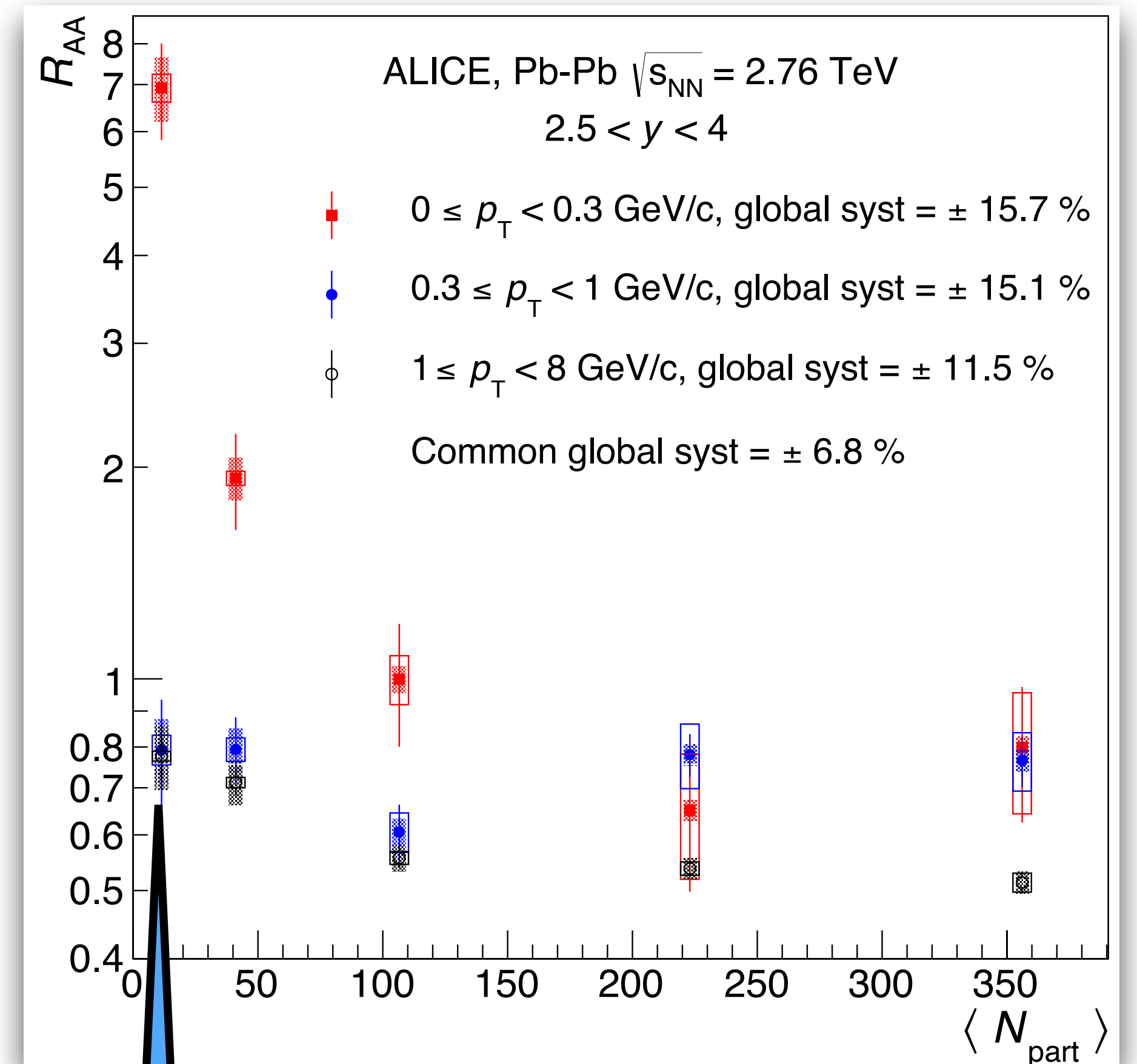
Up to now, two options:

Measure the same process in
peripheral collisions

Measure the same process with
electromagnetic dissociation (**EMD**)

Both options select different
regions of the **impact parameter**

ALICE, PRL 116 (2016) 222301

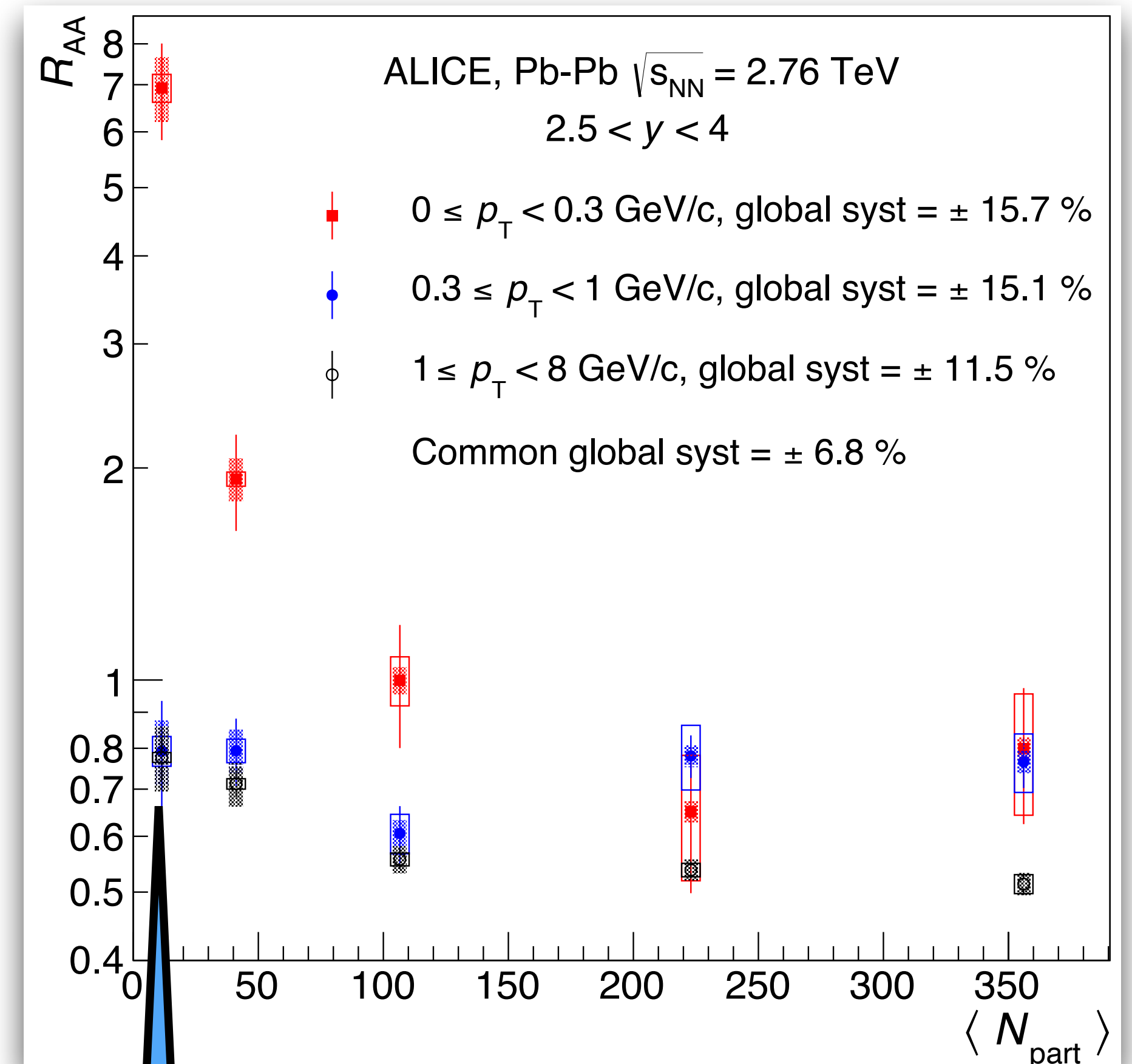


**J/ψ production in Pb-Pb collisions:
 expected that $R_{AA} \sim 1$ for $\langle N_{part} \rangle$ small**

At low p_T , RAA values a lot larger than 1
have been measured

⇒ coherent photoproduction process!

ALICE, PRL 116 (2016) 222301



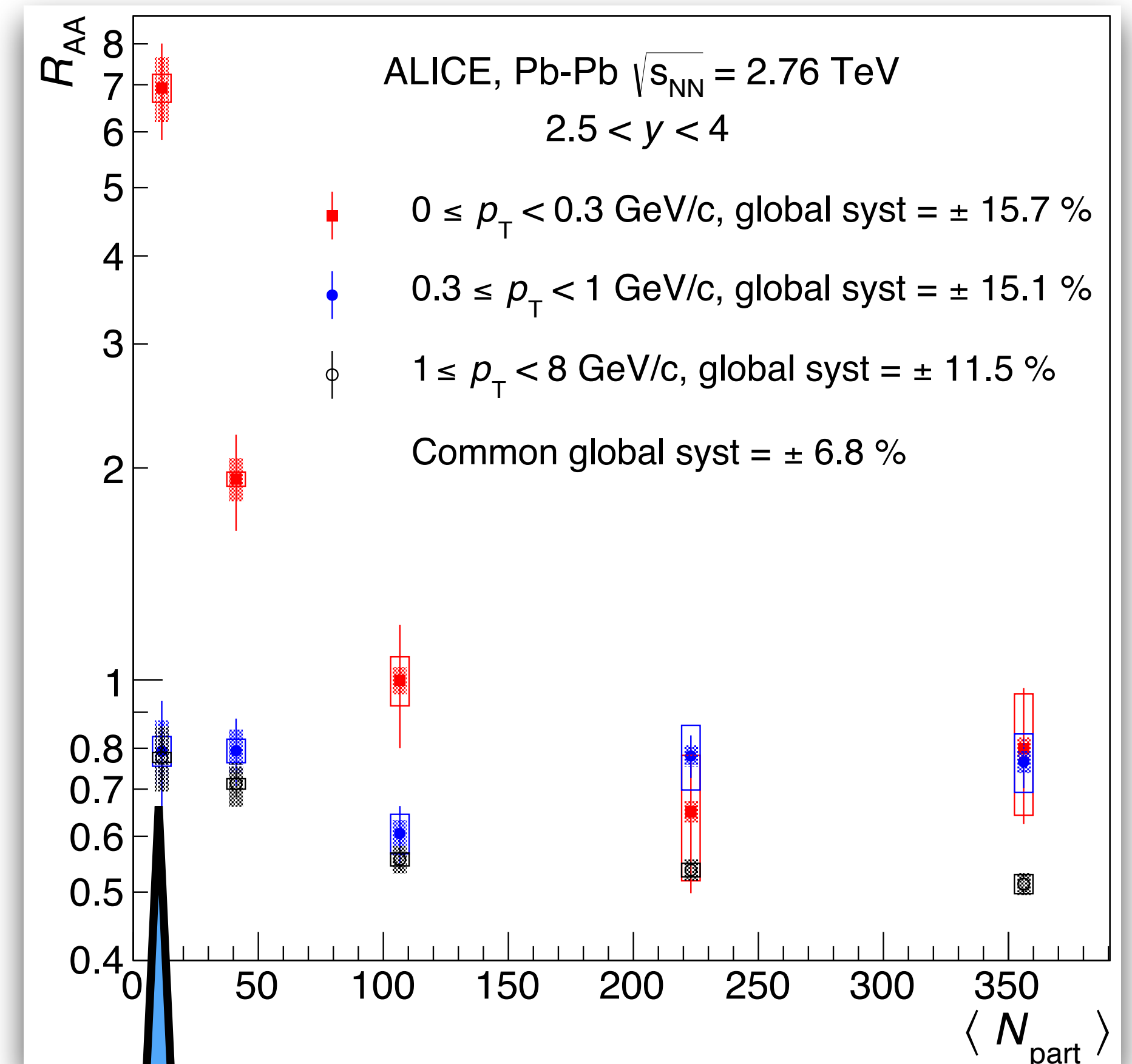
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In coherent processes p_T is related to the inverse of the size of the target hadron:
expect very low p_T off Pb ions

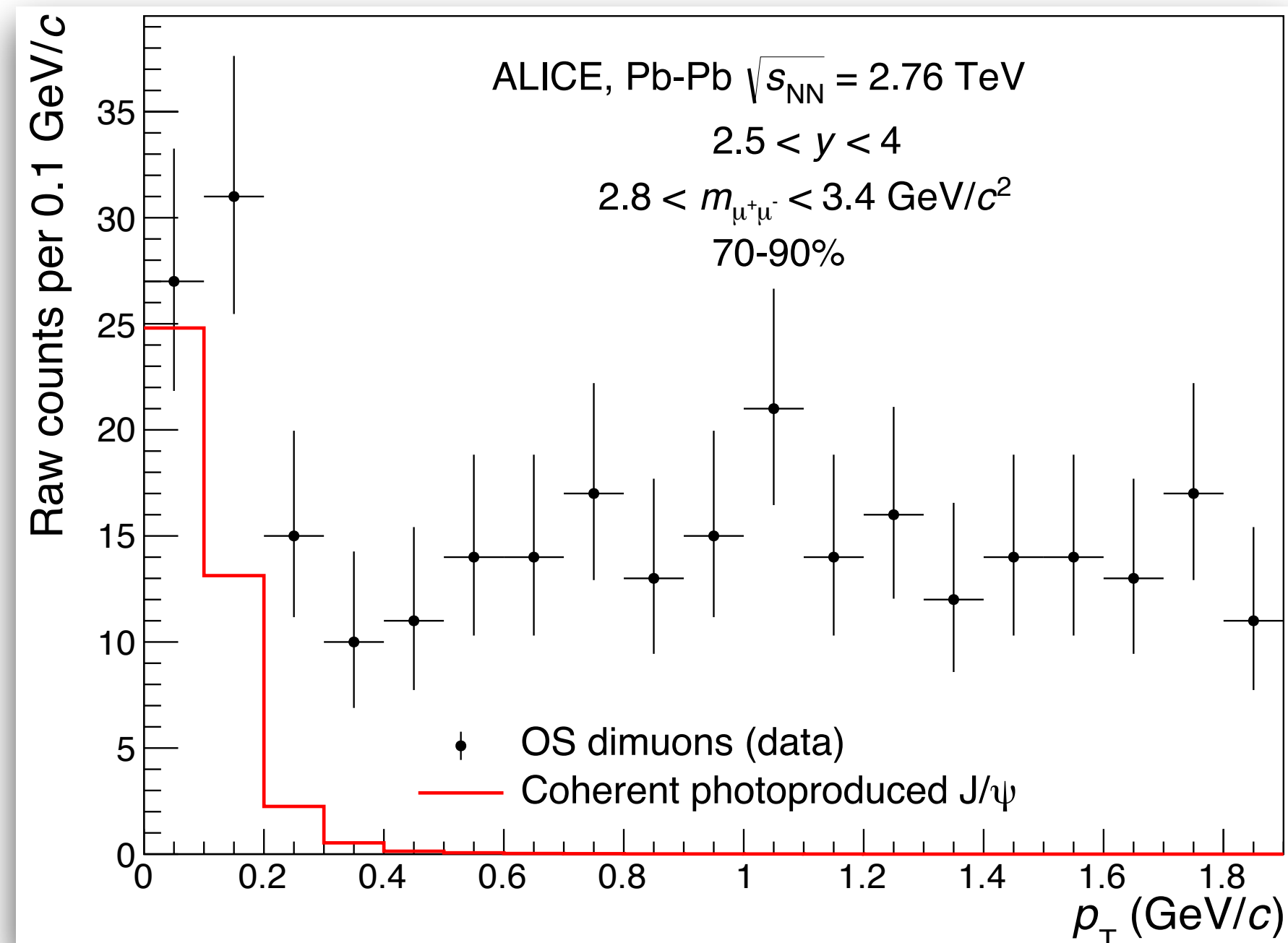
ALICE, PRL 116 (2016) 222301



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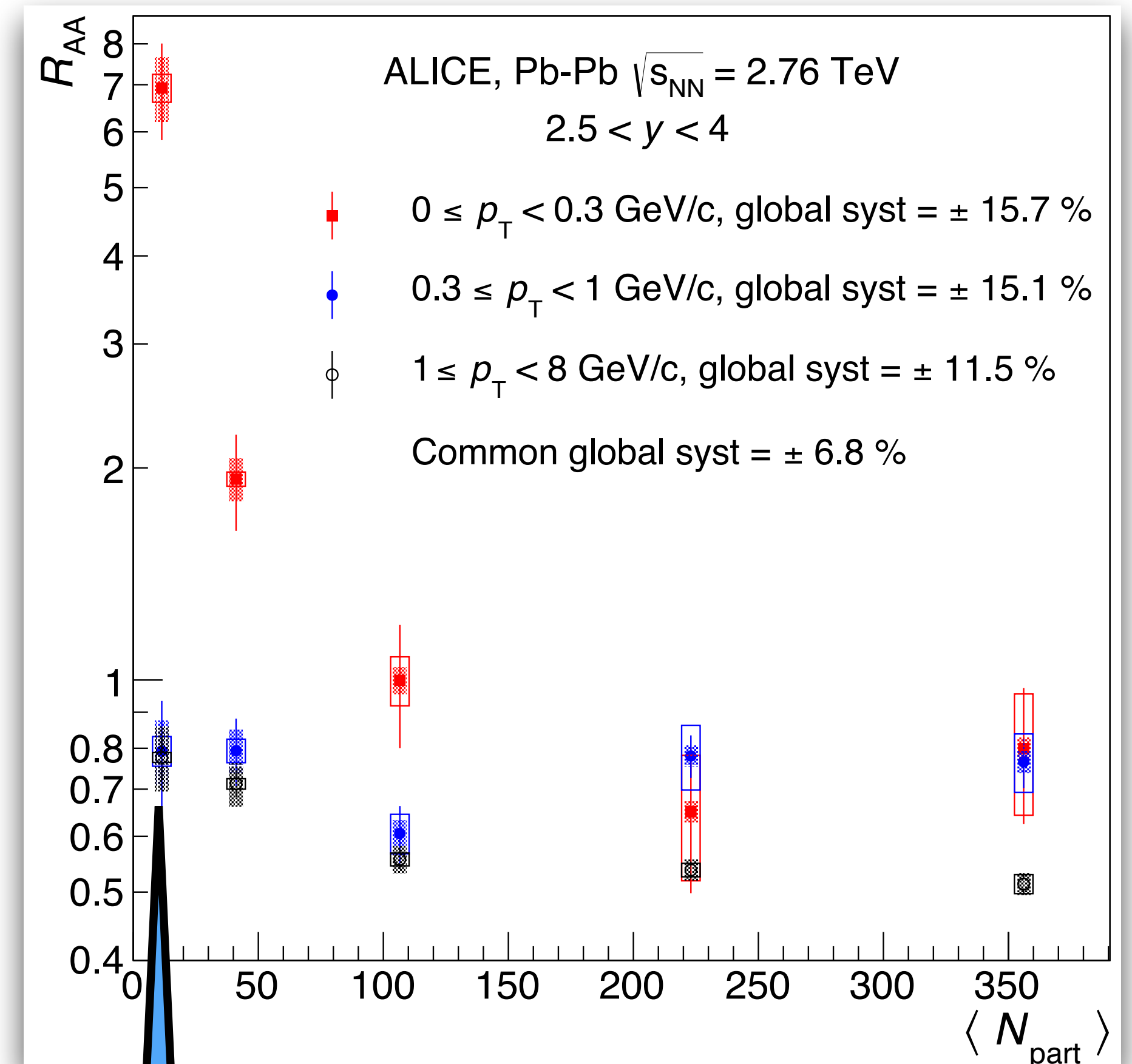
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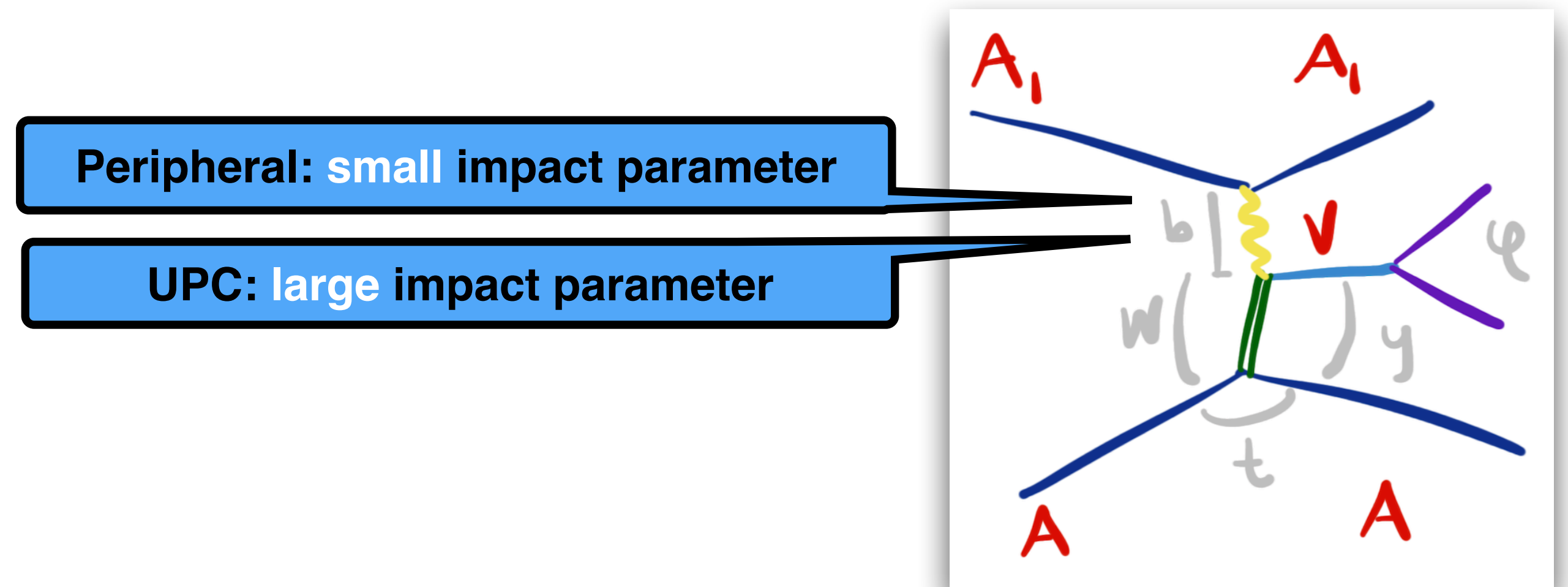
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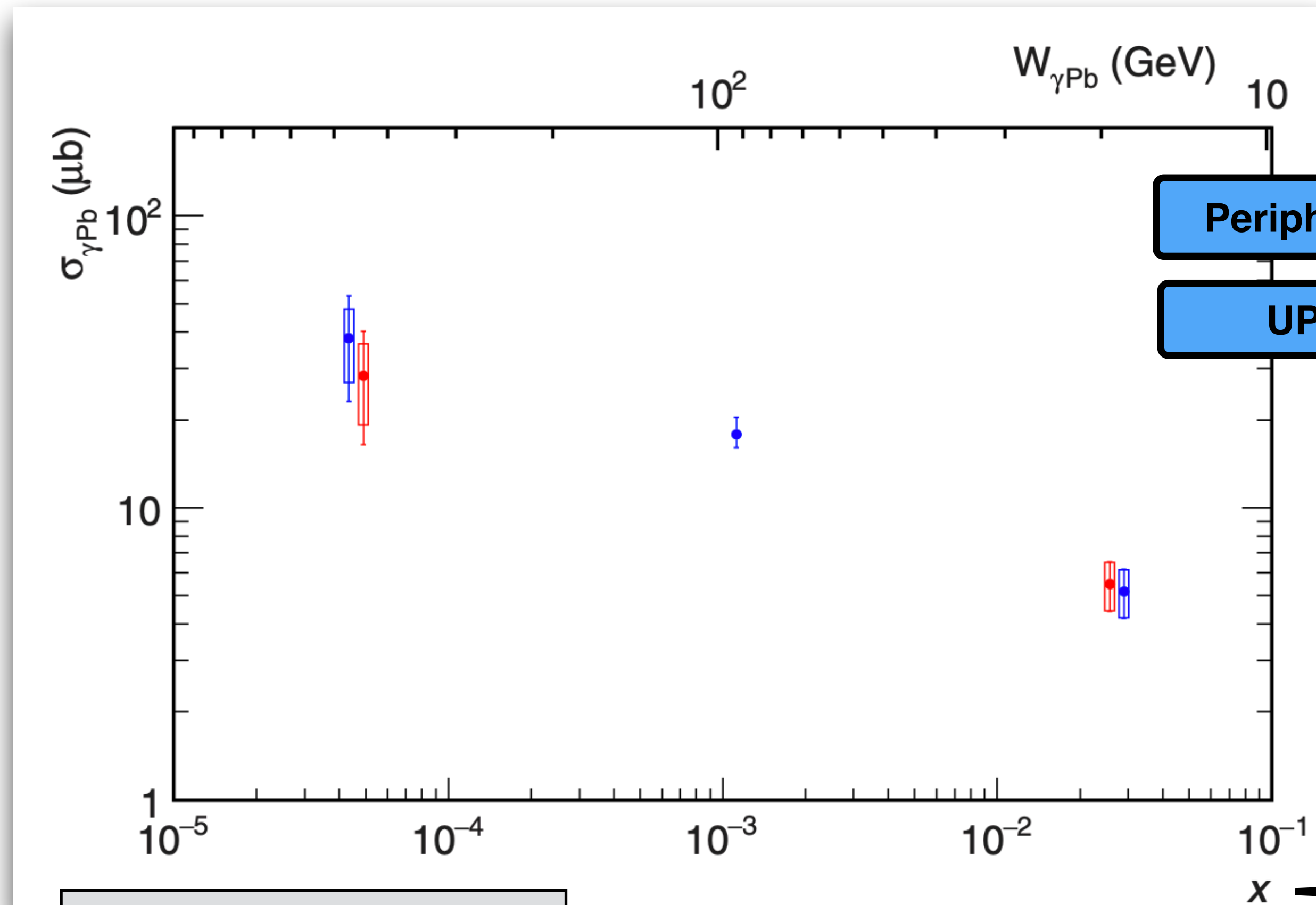


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Rapidity dependence: From ultra + peripheral collisions measured by ALICE



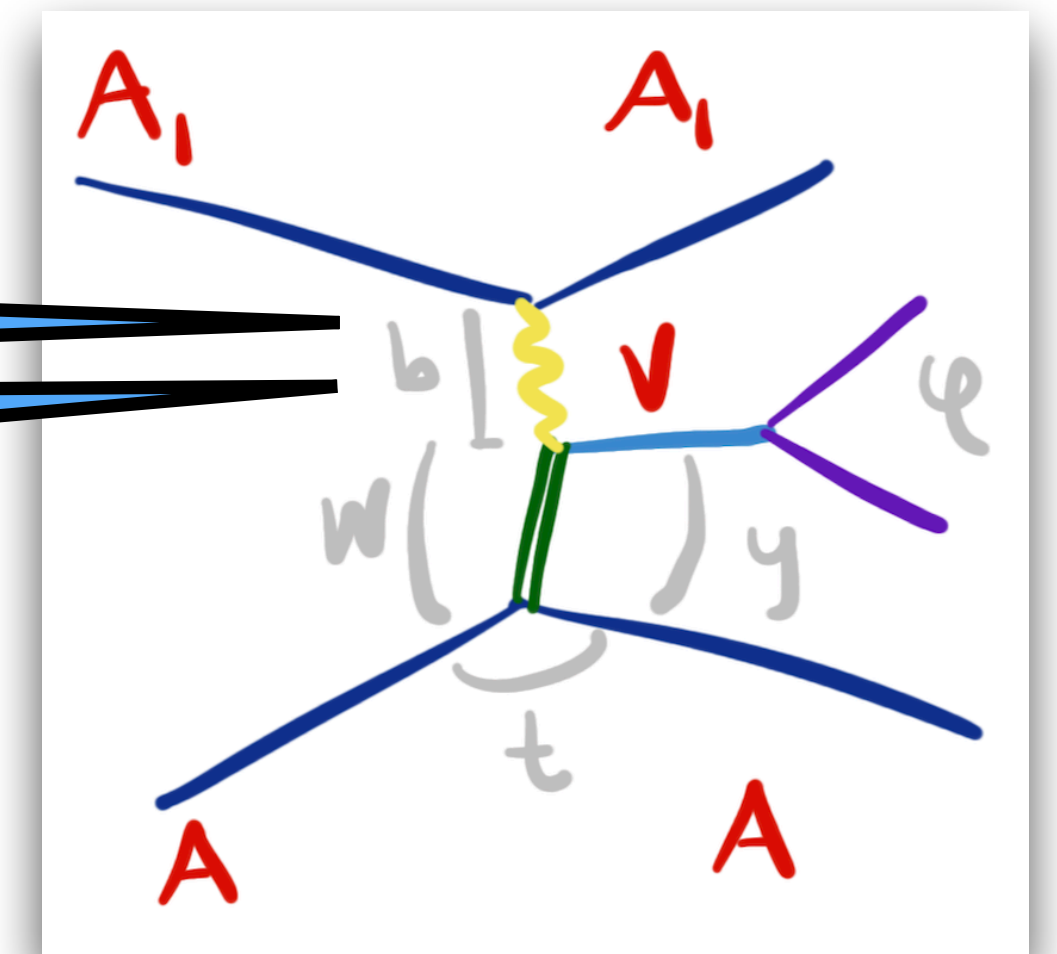
Rapidity dependence: From ultra + peripheral collisions measured by ALICE



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

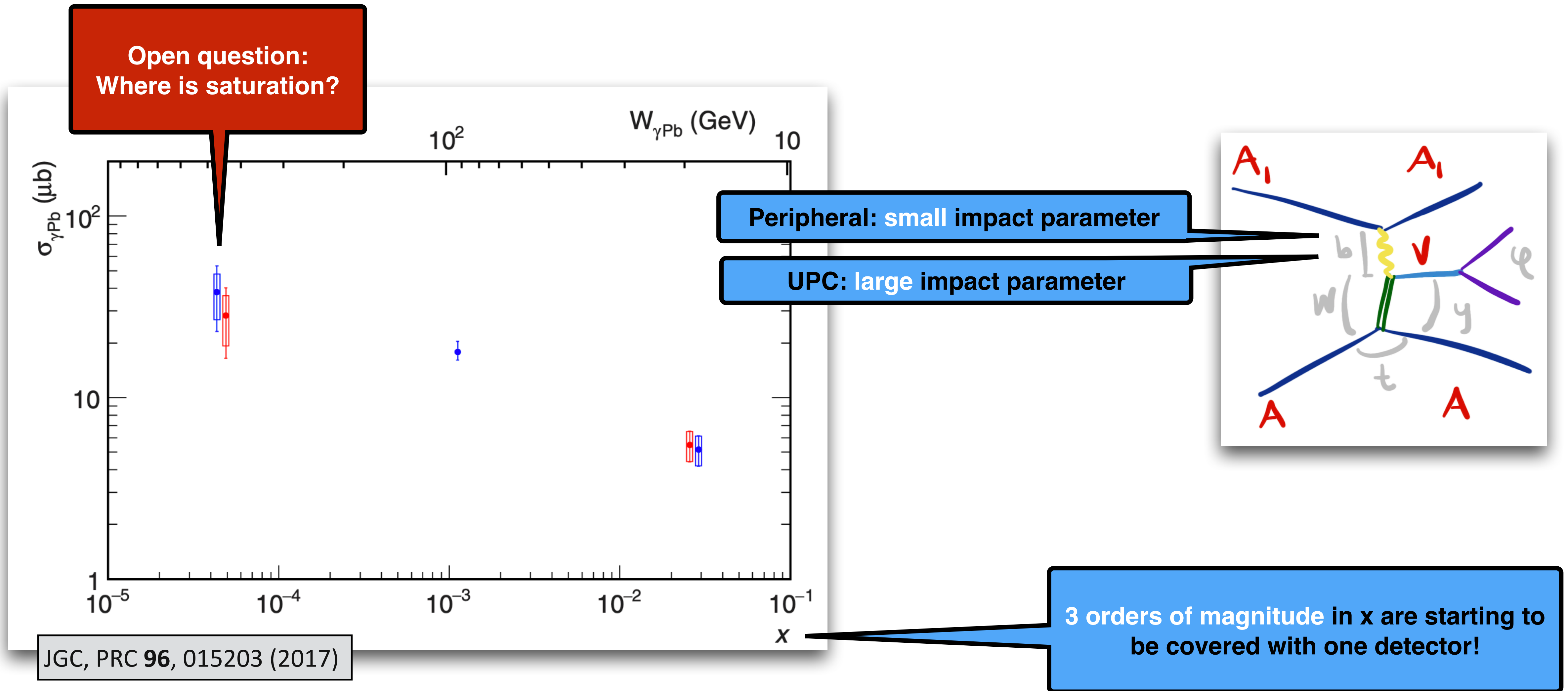
Peripheral: **small** impact parameter

UPC: **large** impact parameter

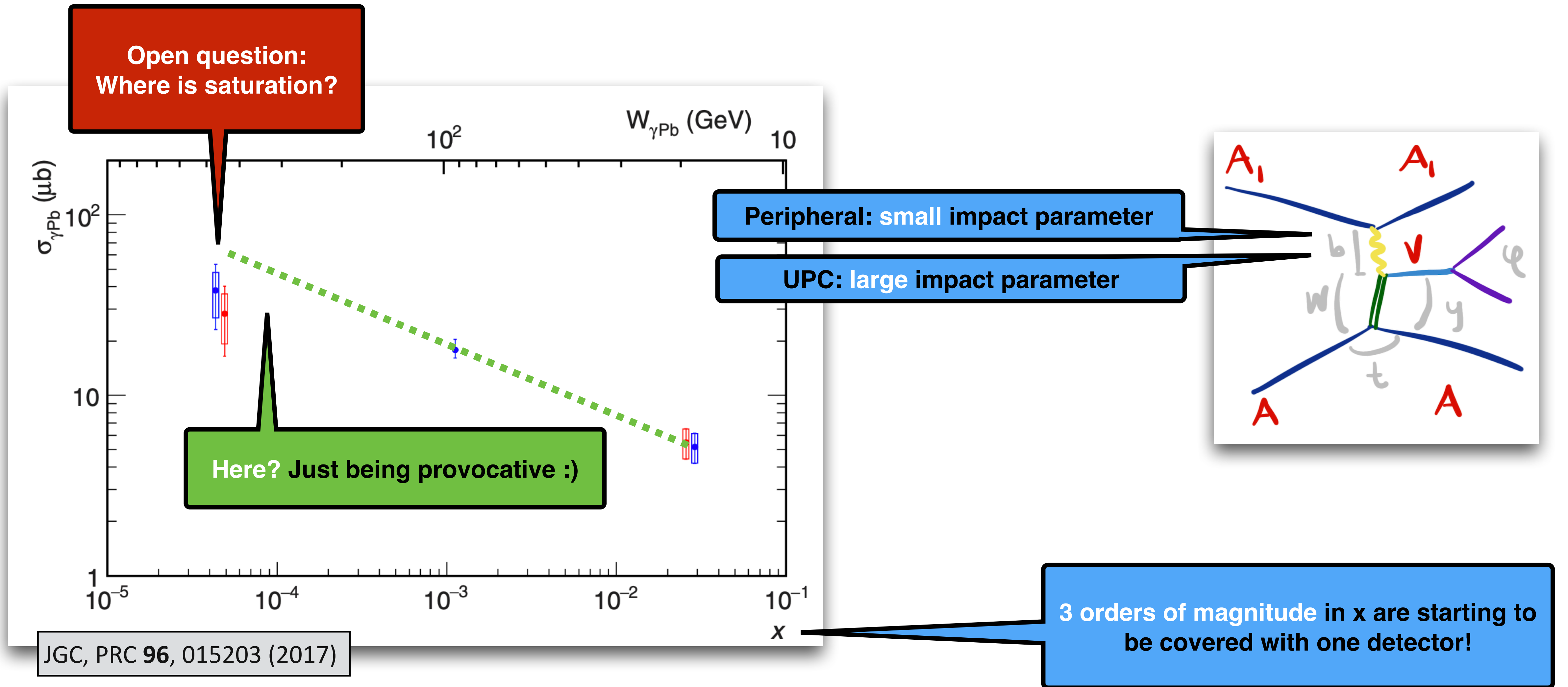


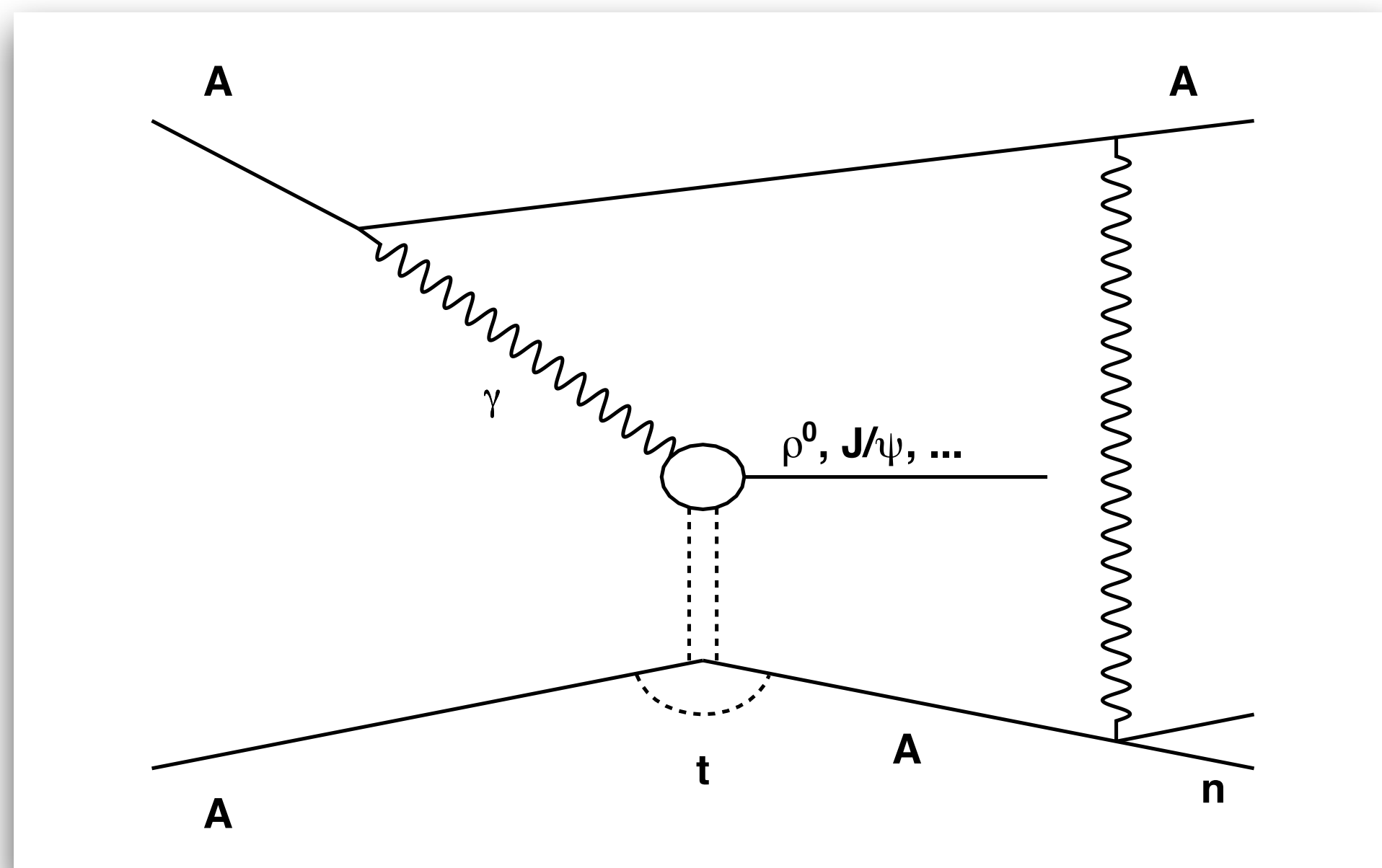
3 orders of magnitude in x are starting to be covered with one detector!

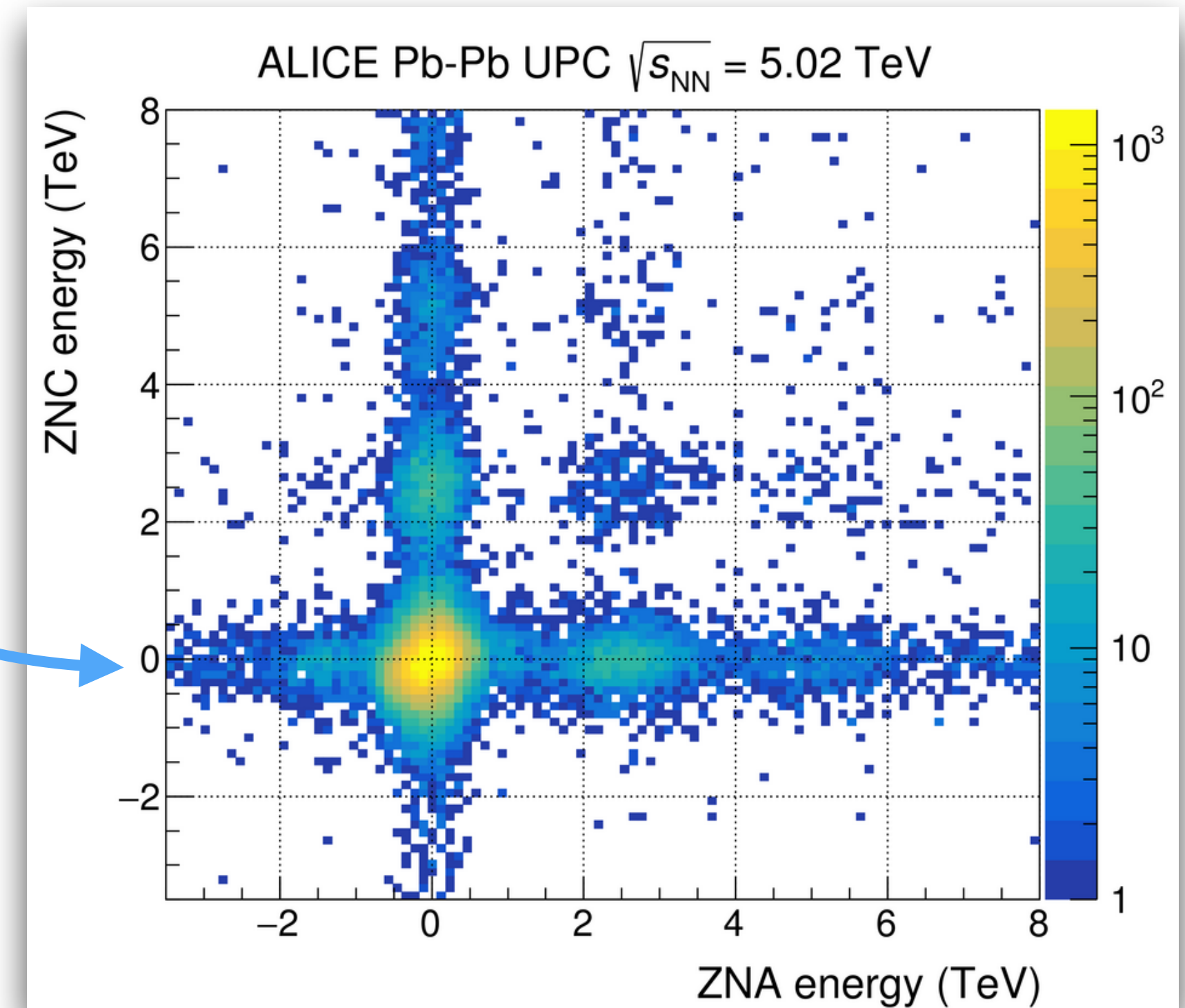
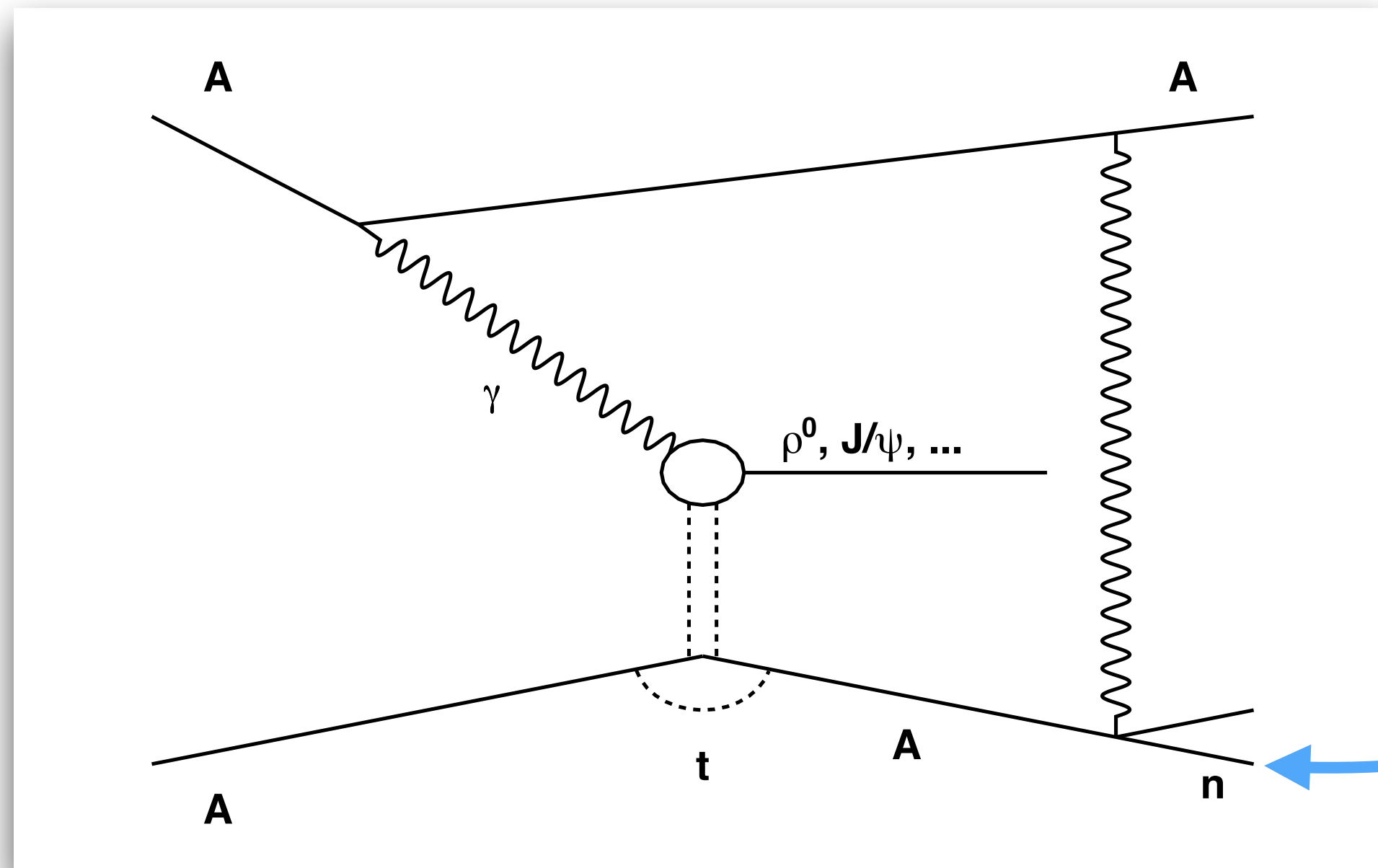
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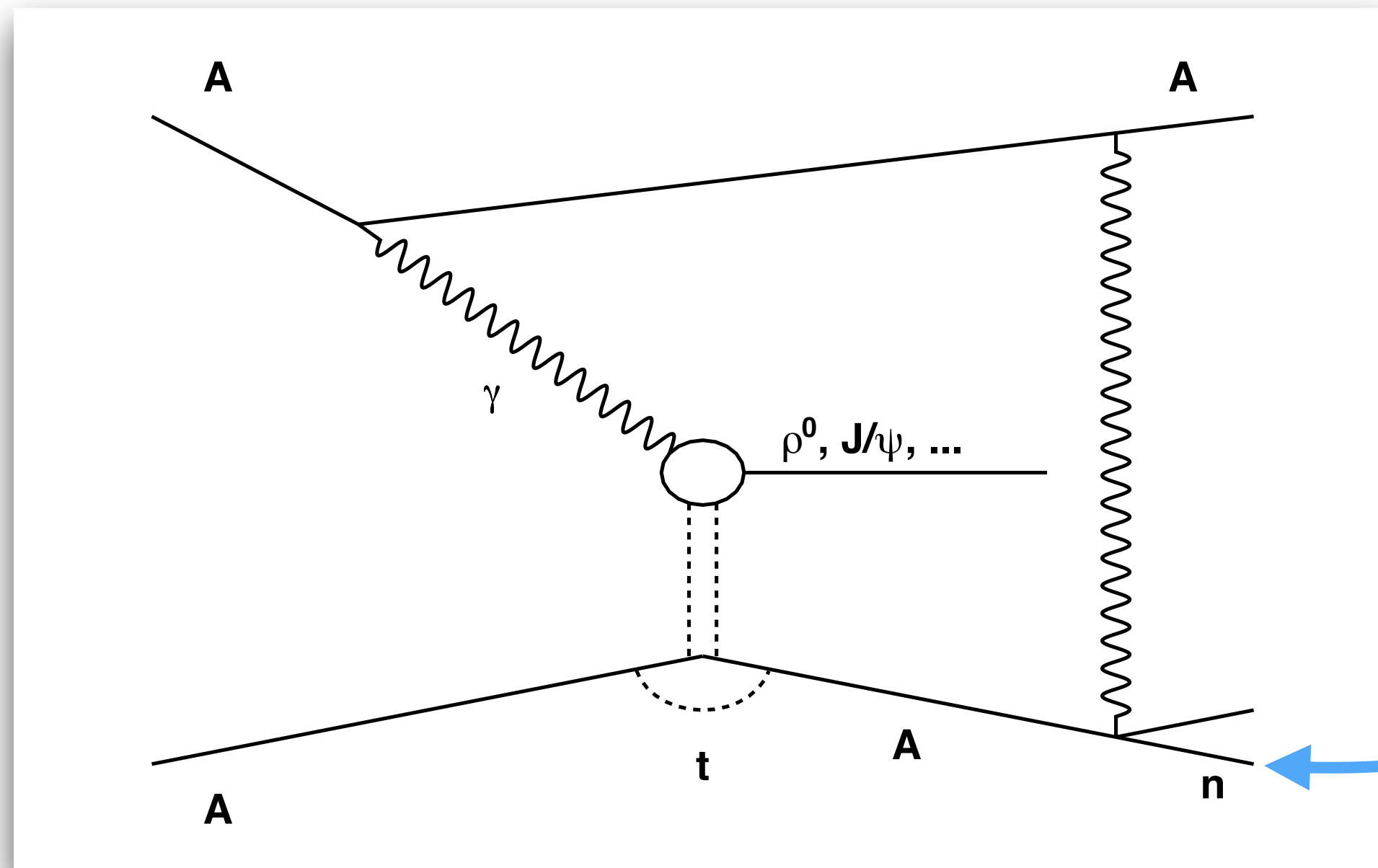
Rapidity dependence: From ultra + peripheral collisions measured by ALICE



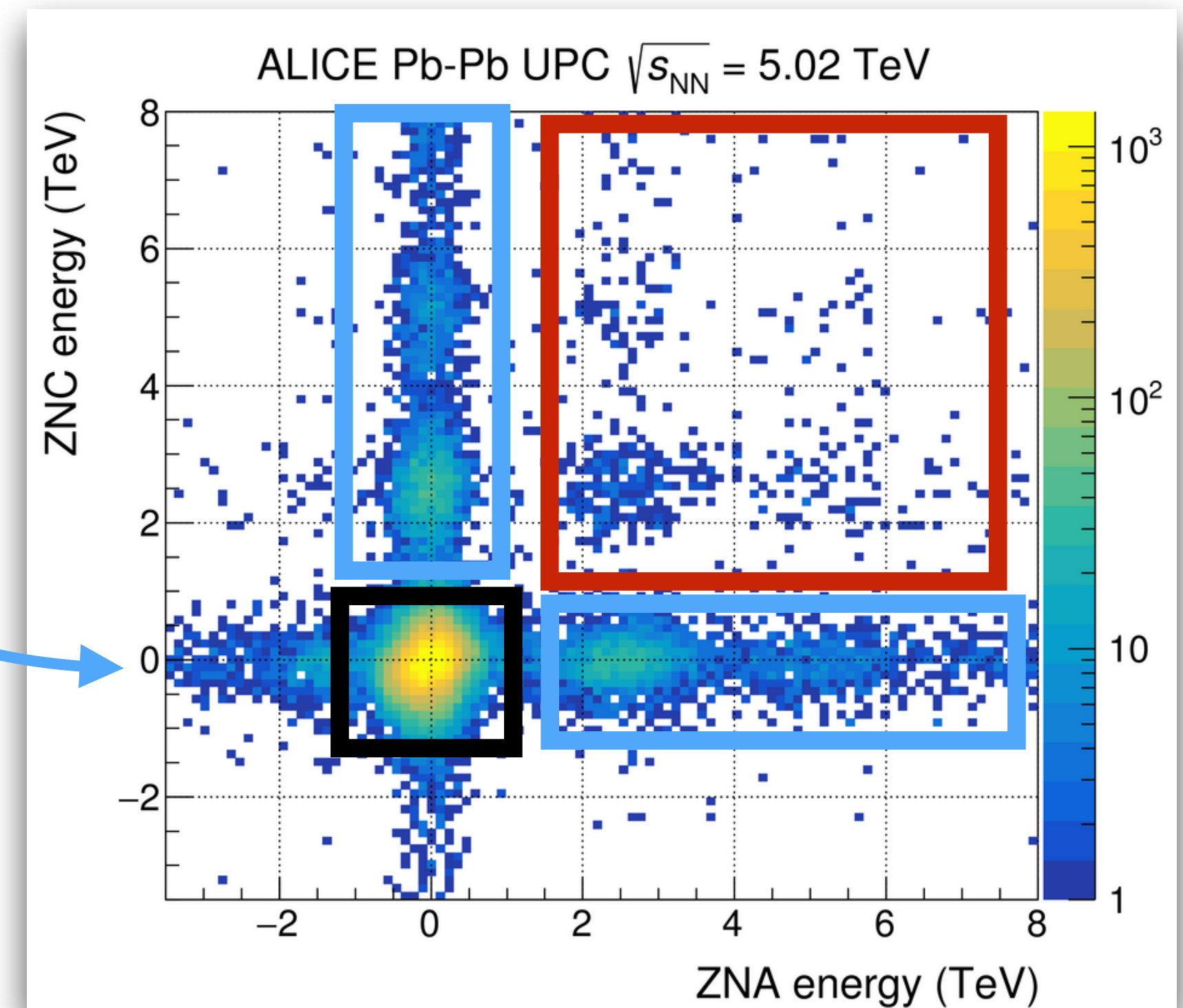




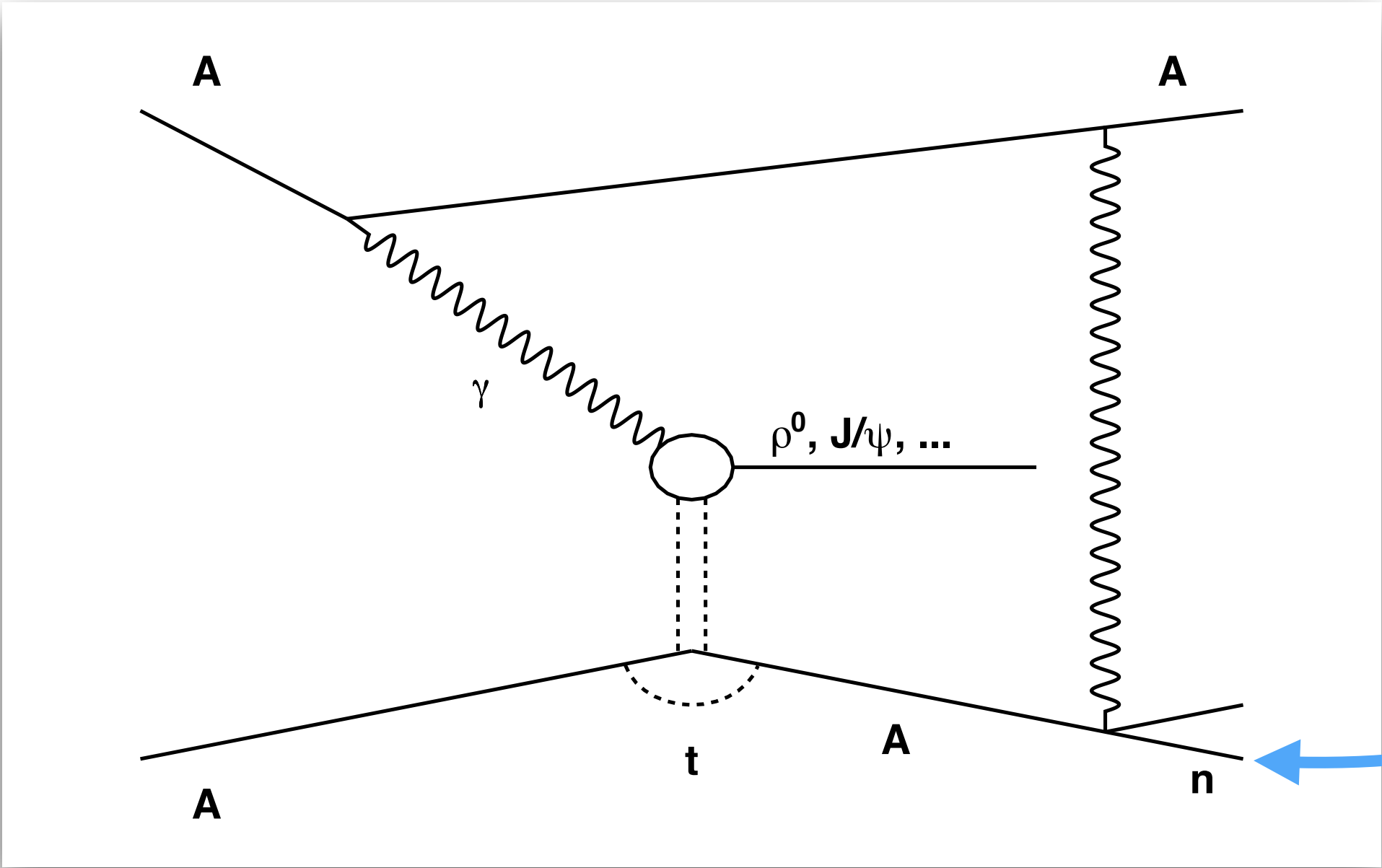
ALICE, JHEP 06 (2020) 035



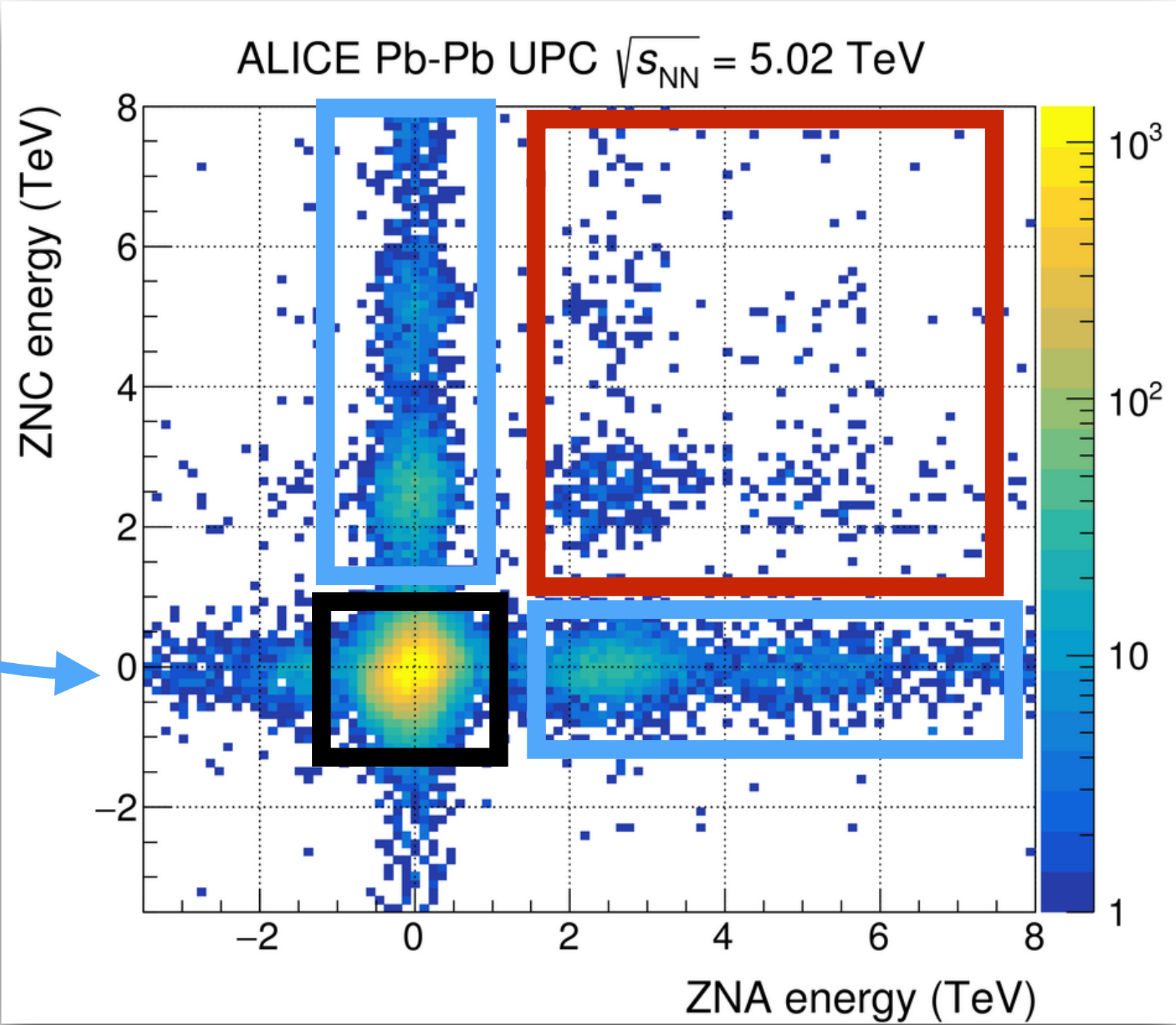
ZDC



ALICE, JHEP 06 (2020) 035

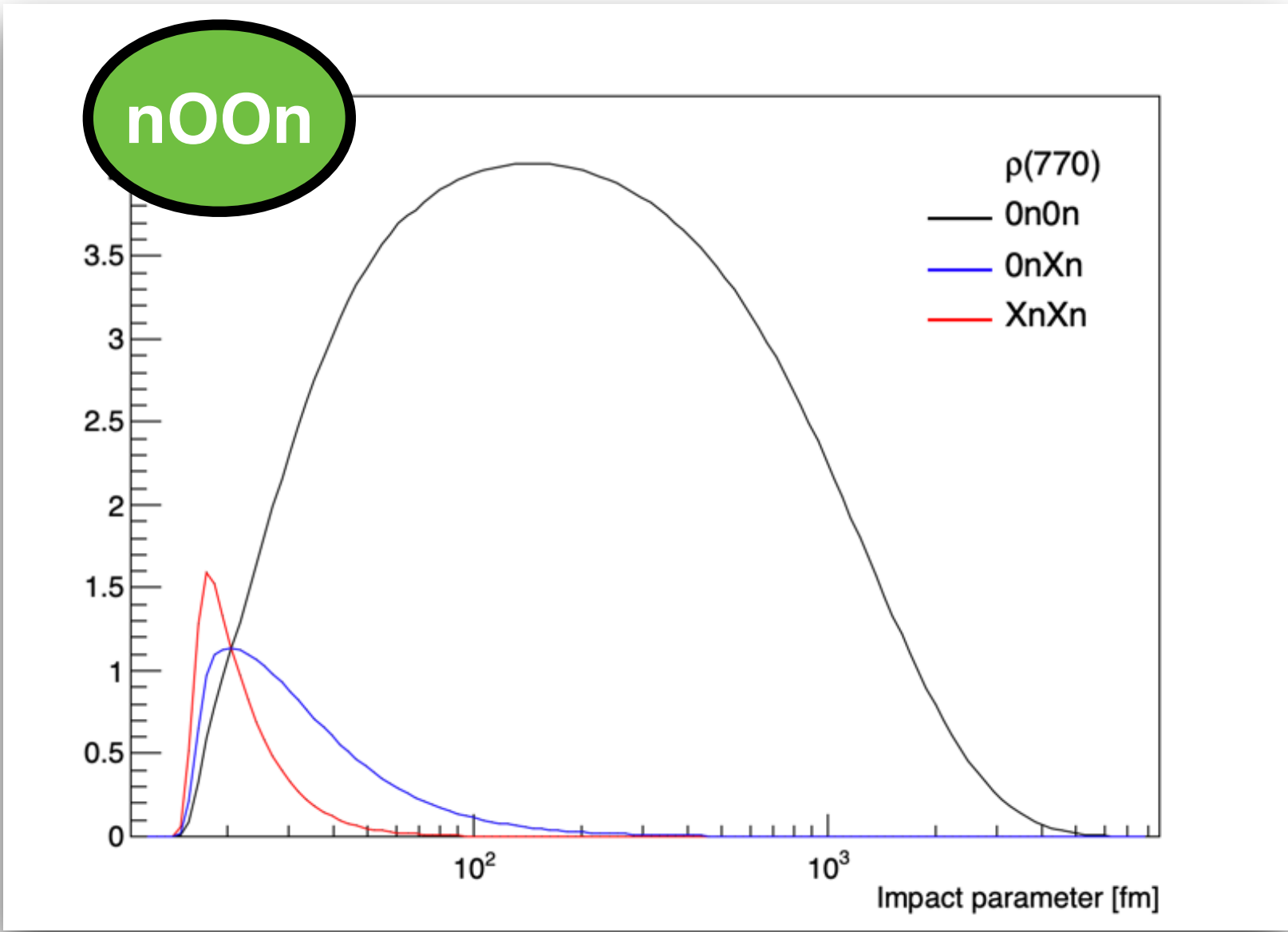


ZDC

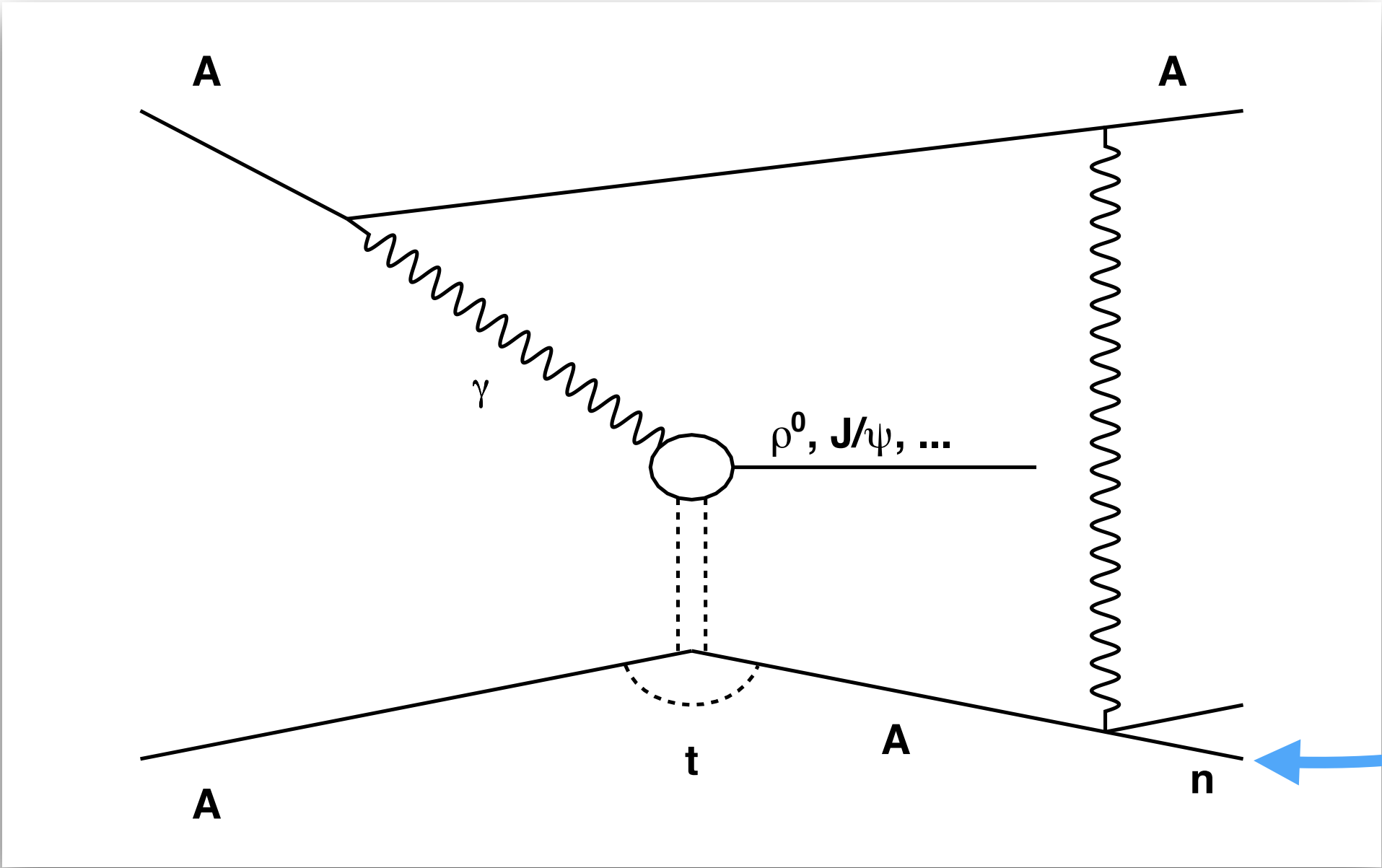


ALICE, JHEP 06 (2020) 035

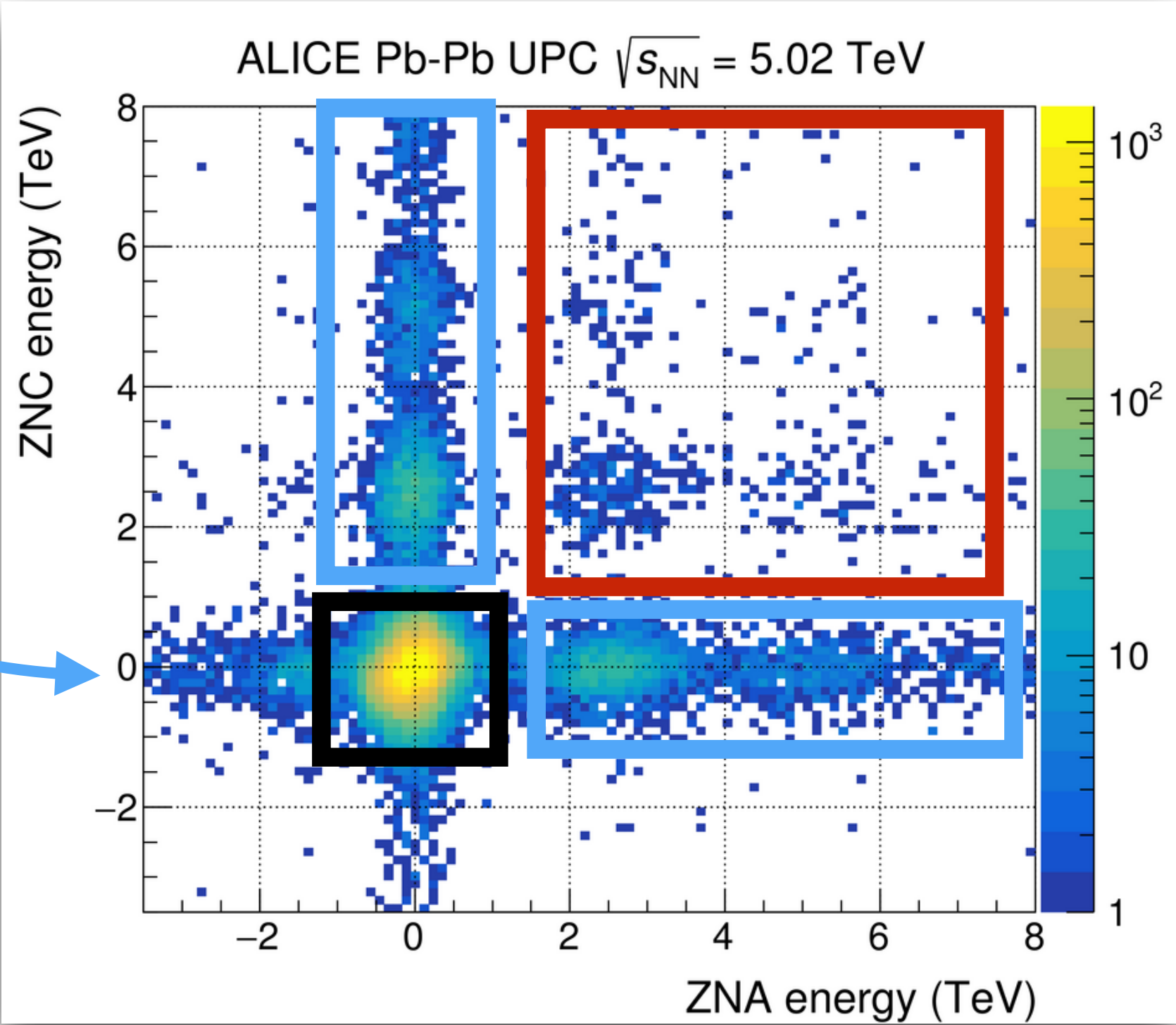
Broz et al., CPC 235 (2020) 107181



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

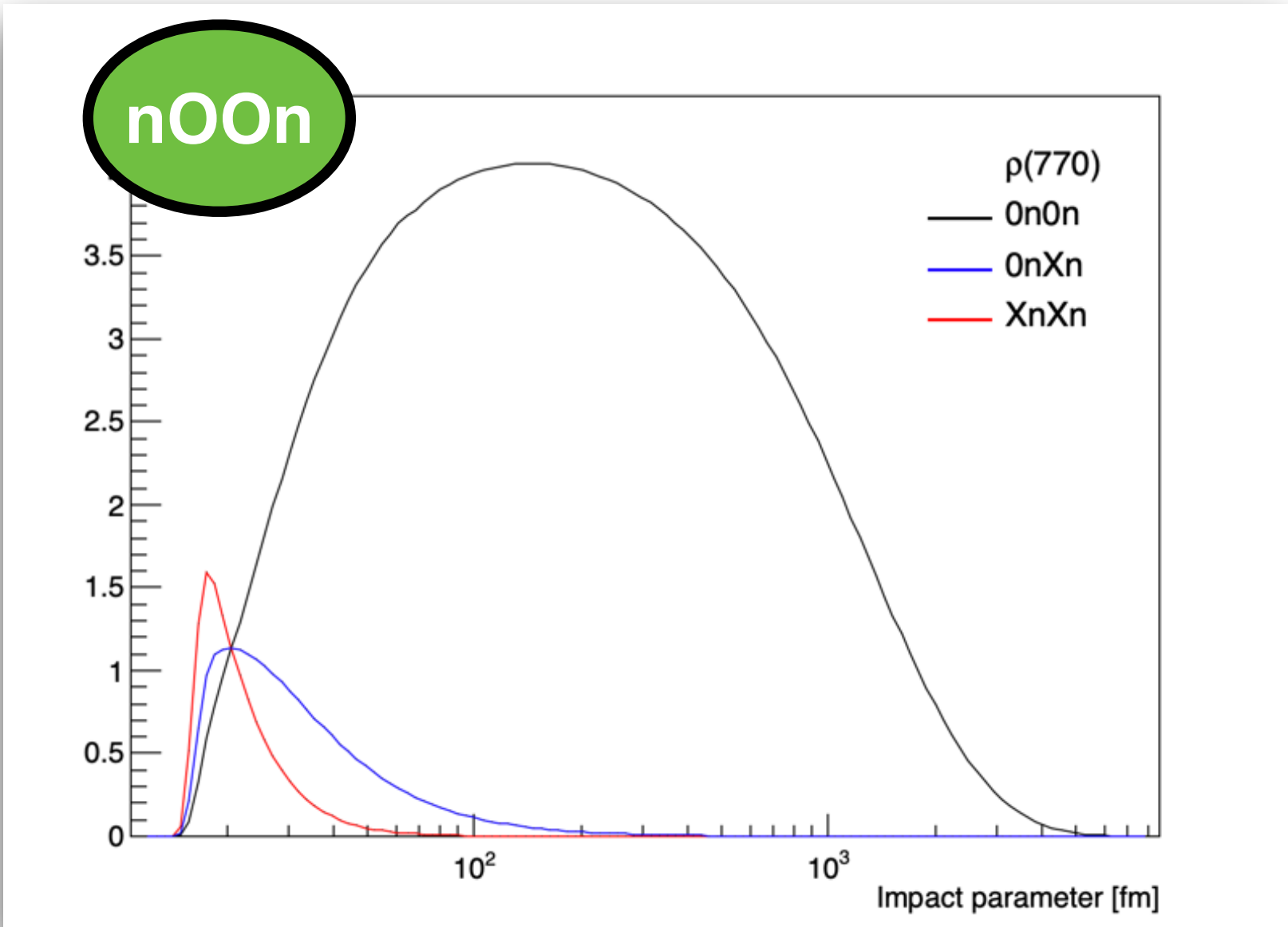


ZDC



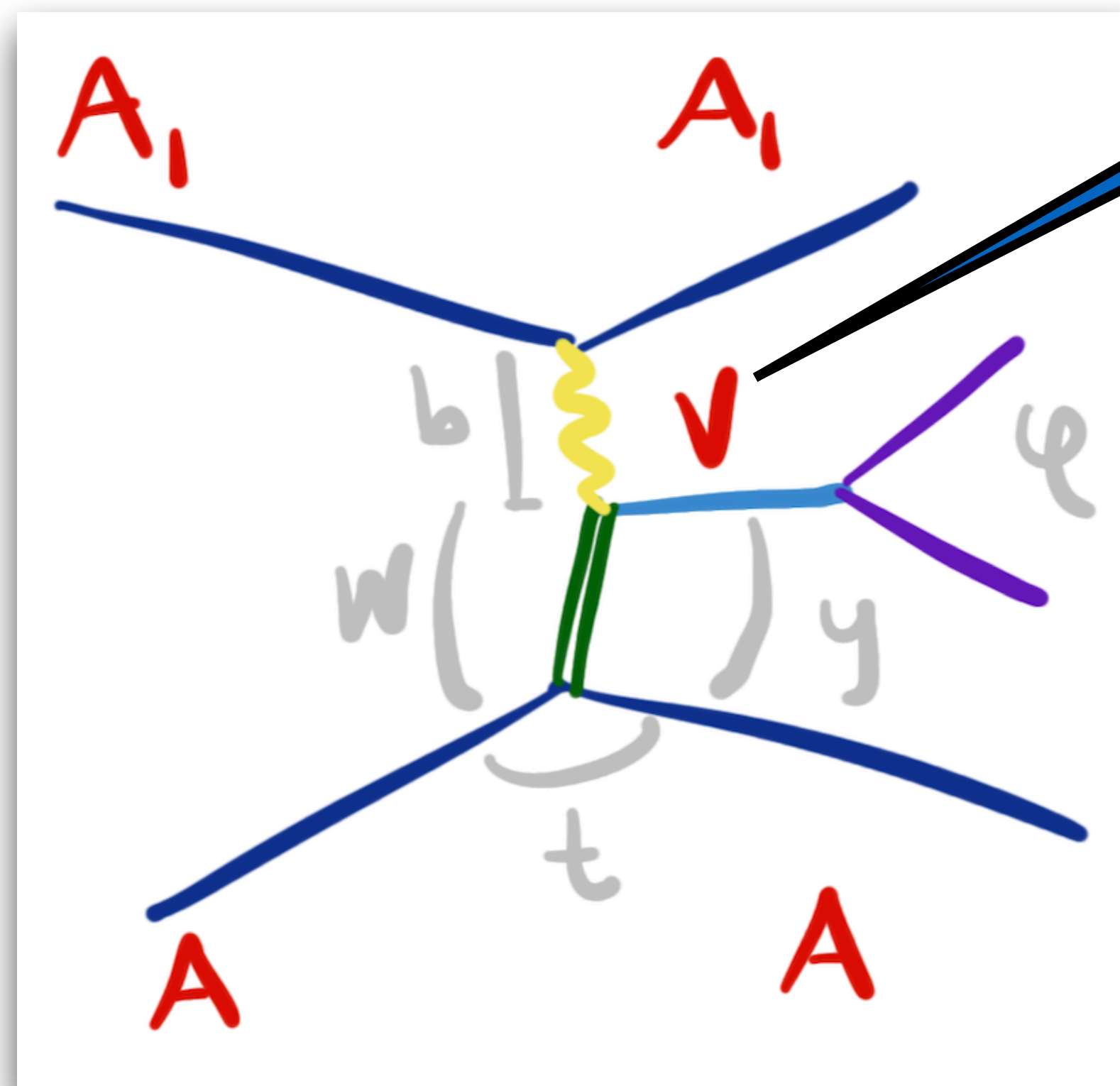
ALICE, JHEP 06 (2020) 035

Broz et al., CPC 235 (2020) 107181

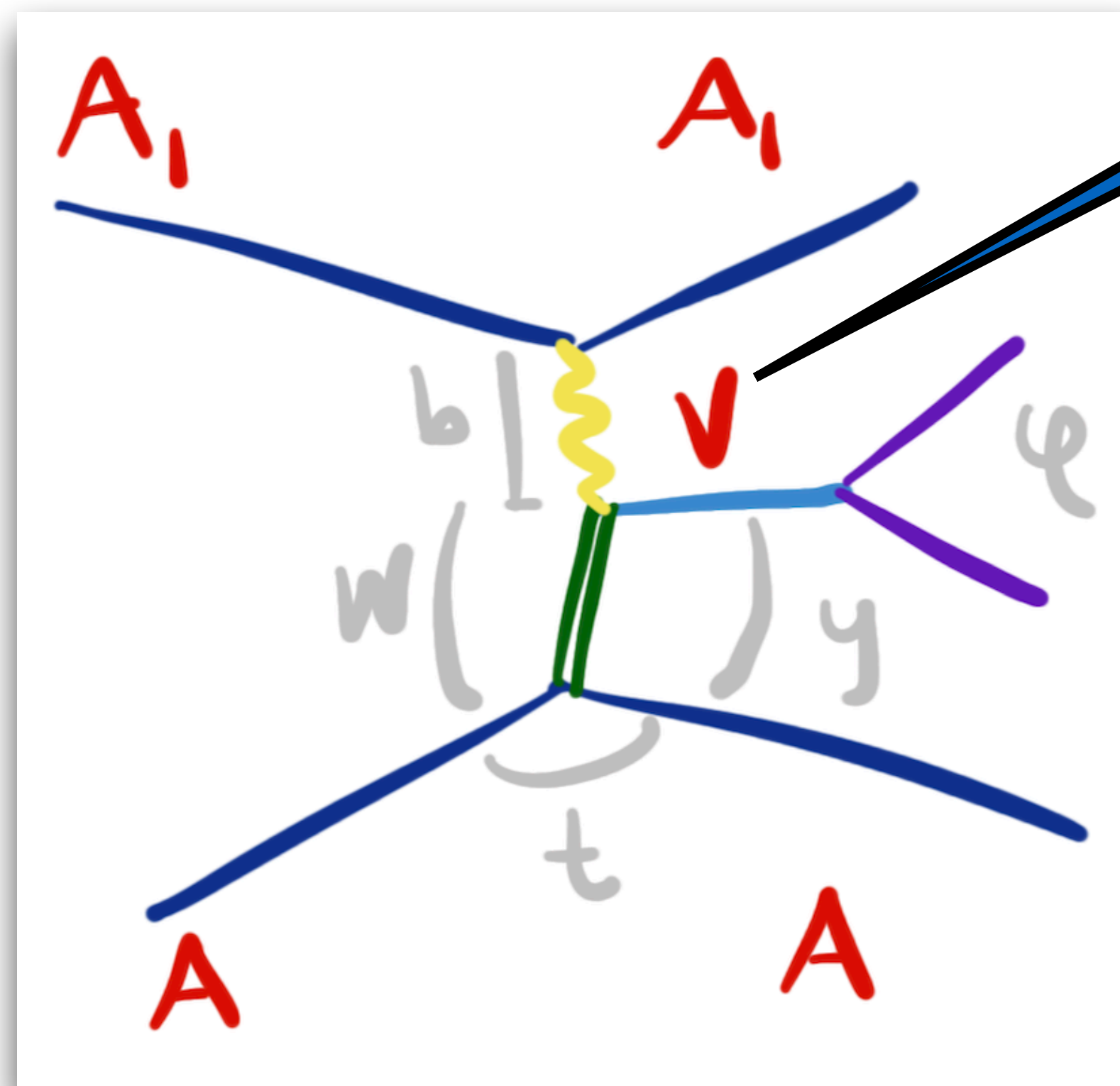


0n0n: large impact parameters
0nXn: smaller impact parameters
XnXn: smallest impact parameters

Few events in XnXn wrt 0n0n

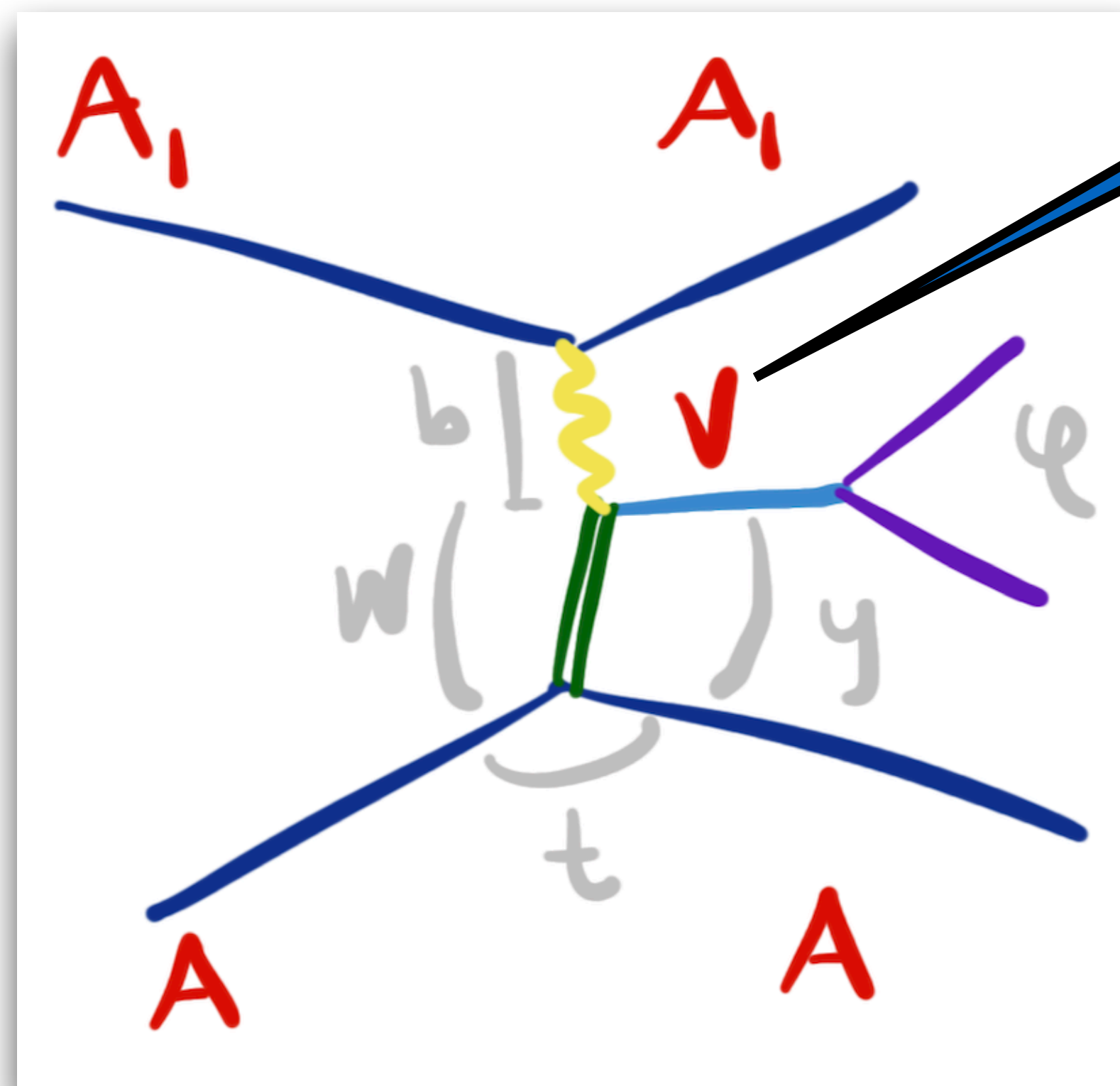


Vector meson mass:
Lower the scale of the process



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Lower the scale of the process

Expectations:
Saturation appears earlier at lower scales

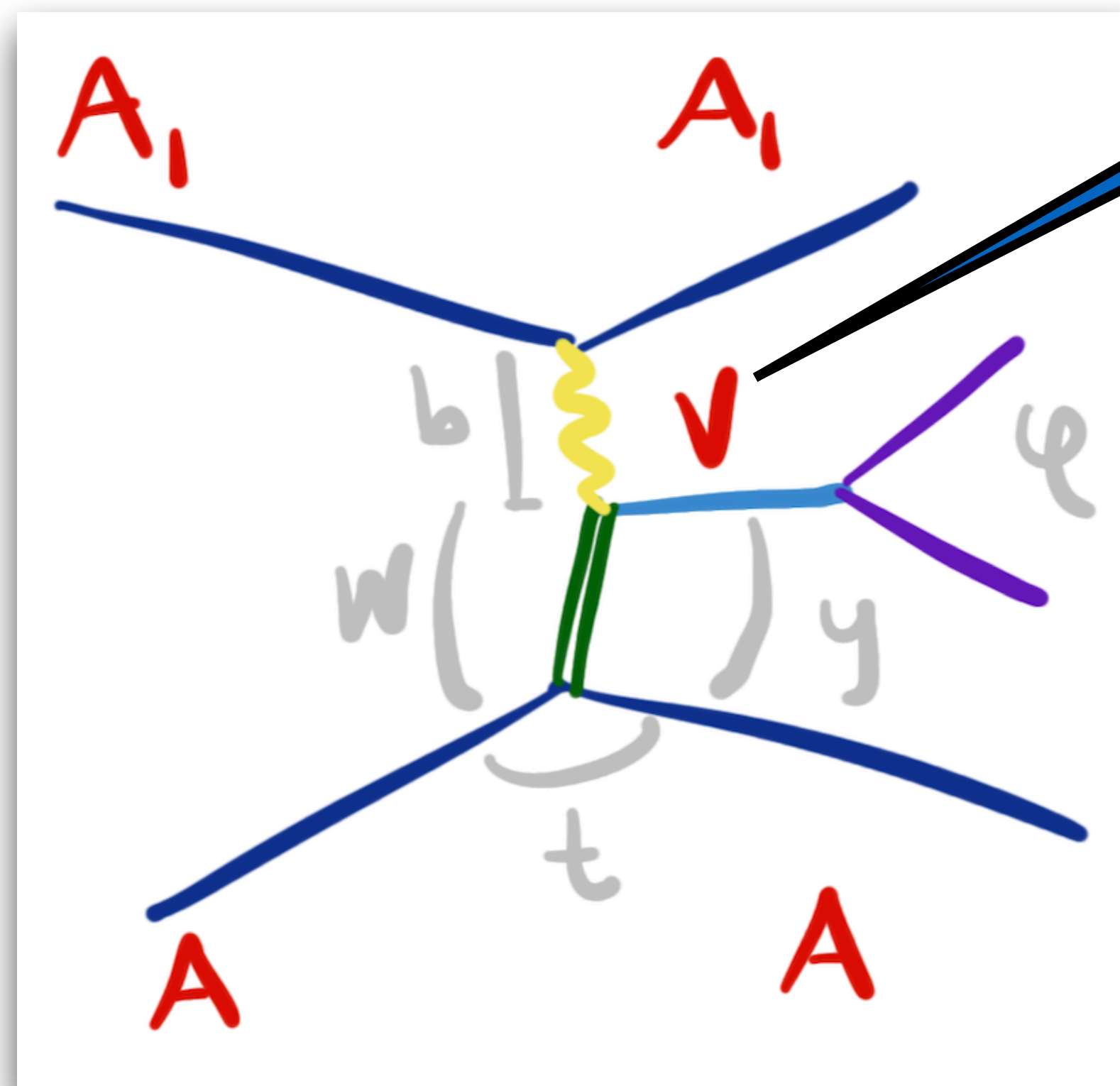


Vector meson mass:
Lower the scale of the process

Expectations:
Saturation appears earlier at lower scales

EIC

Continuous variation of scale using
the virtuality of the photon



Vector meson mass:
Lower the scale of the process

But if the scale is too low, pQCD may
not be applicable any more:
Semi-hard scale \Rightarrow approach to the
black-disc limit of QCD

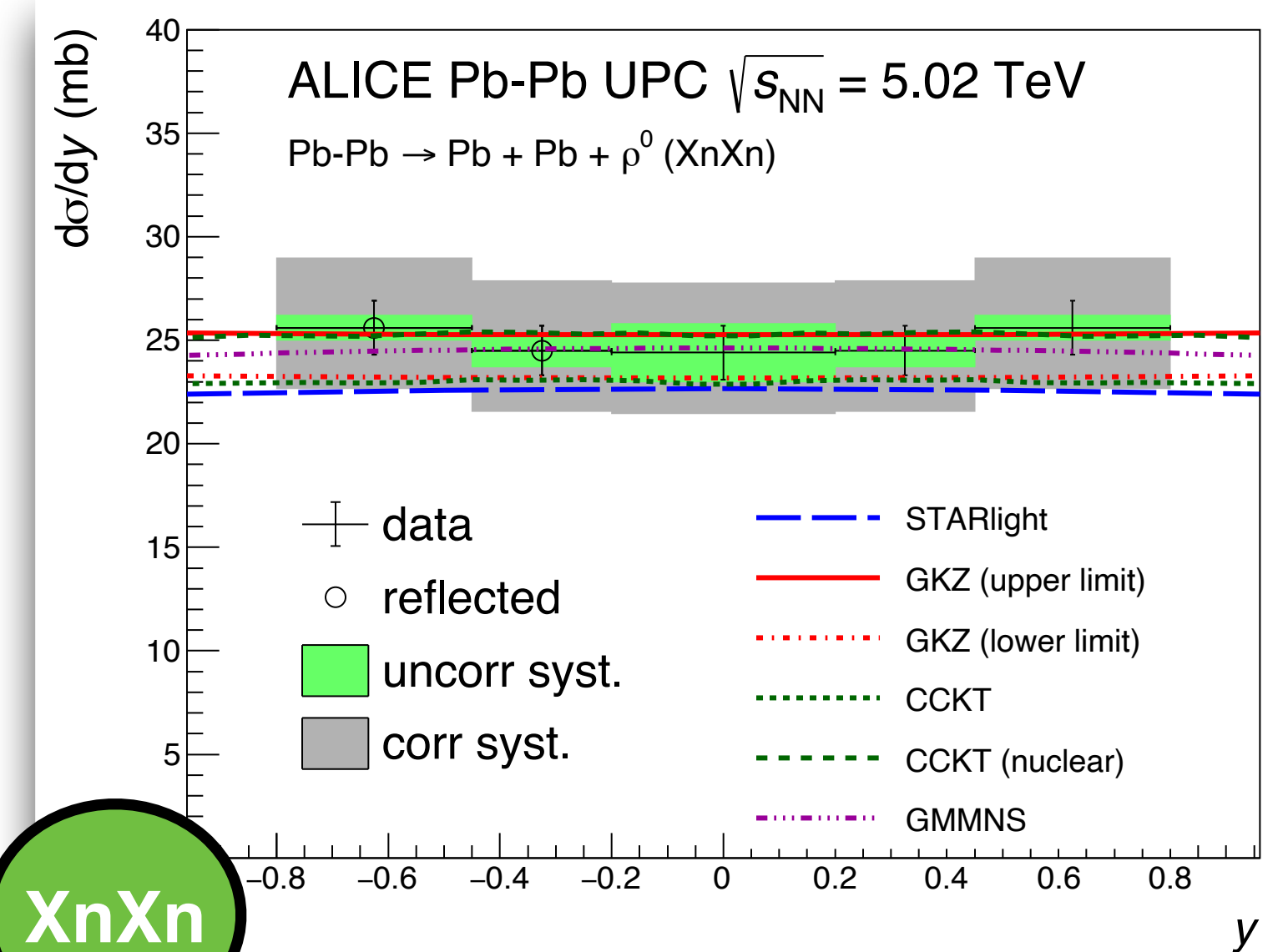
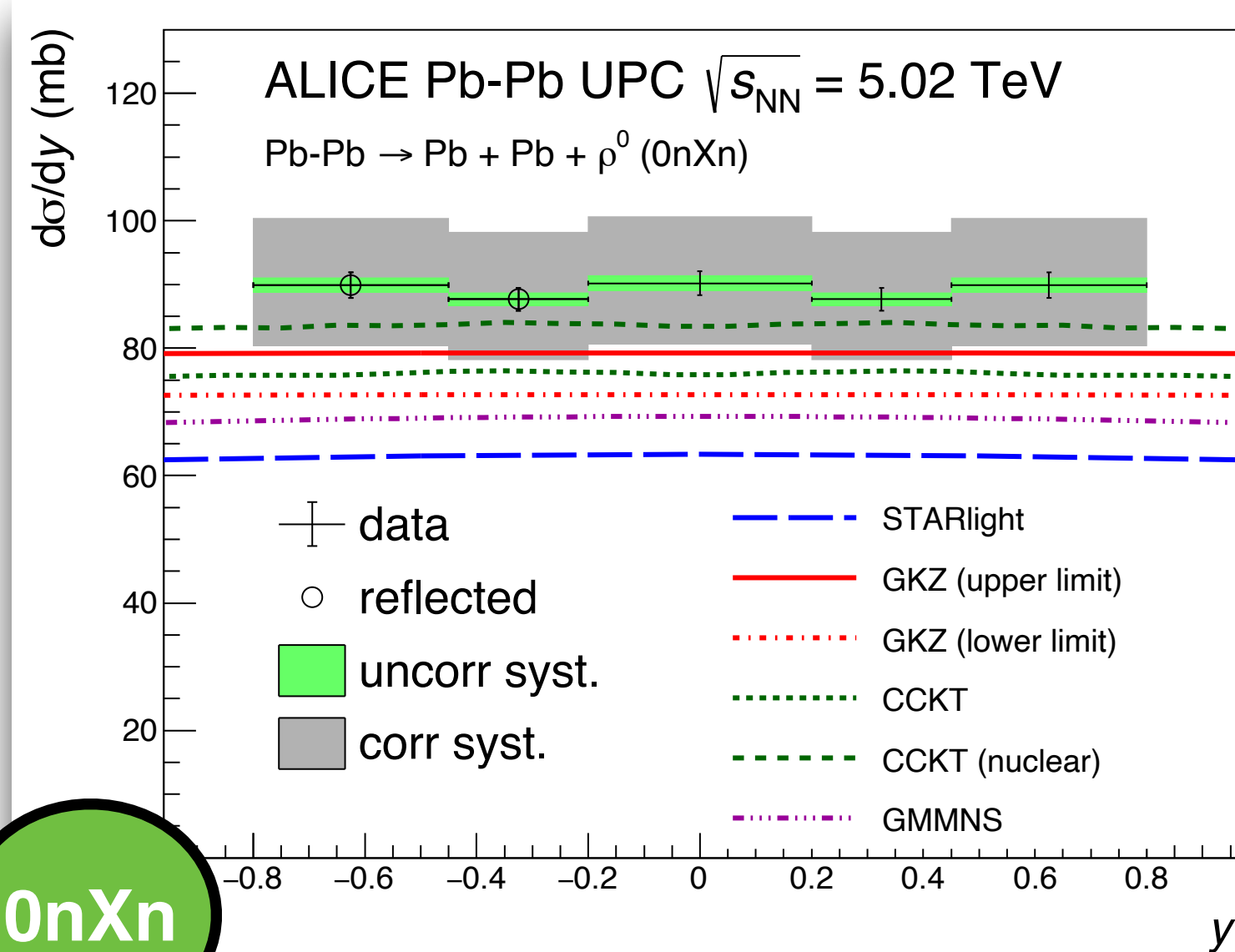
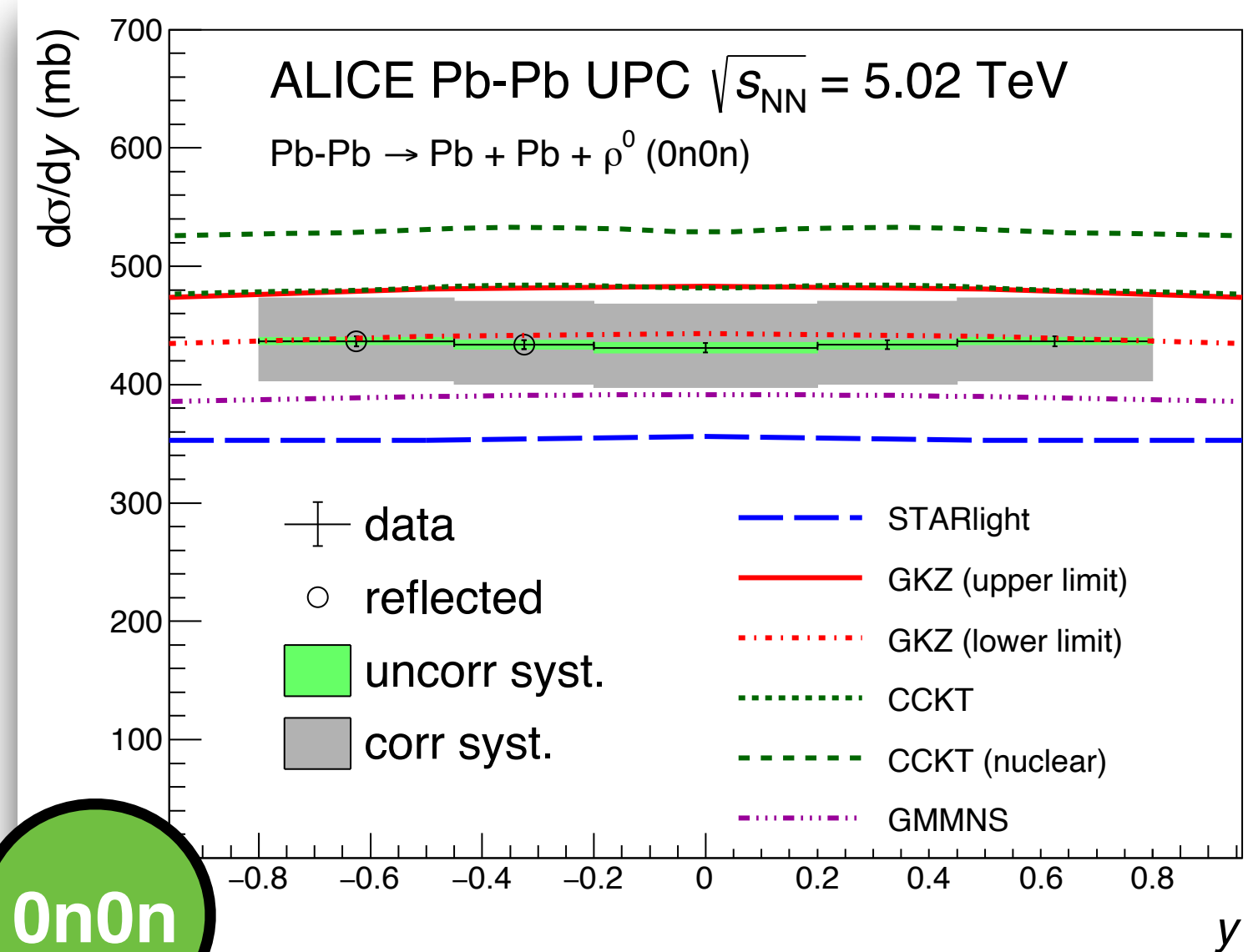
Expectations:
Saturation appears earlier at lower scales

At low scales, the cross section is larger
 \Rightarrow more events available

EIC

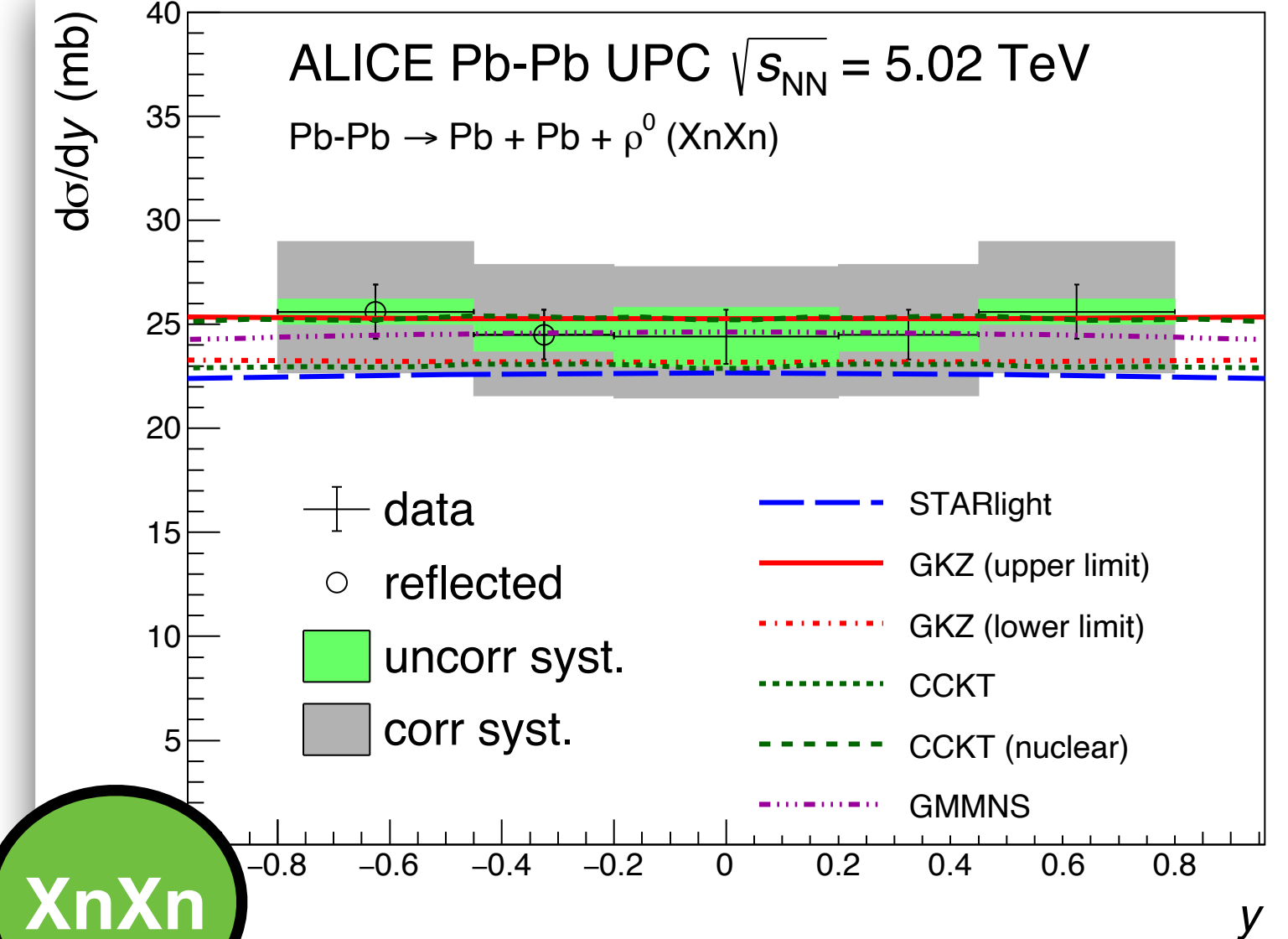
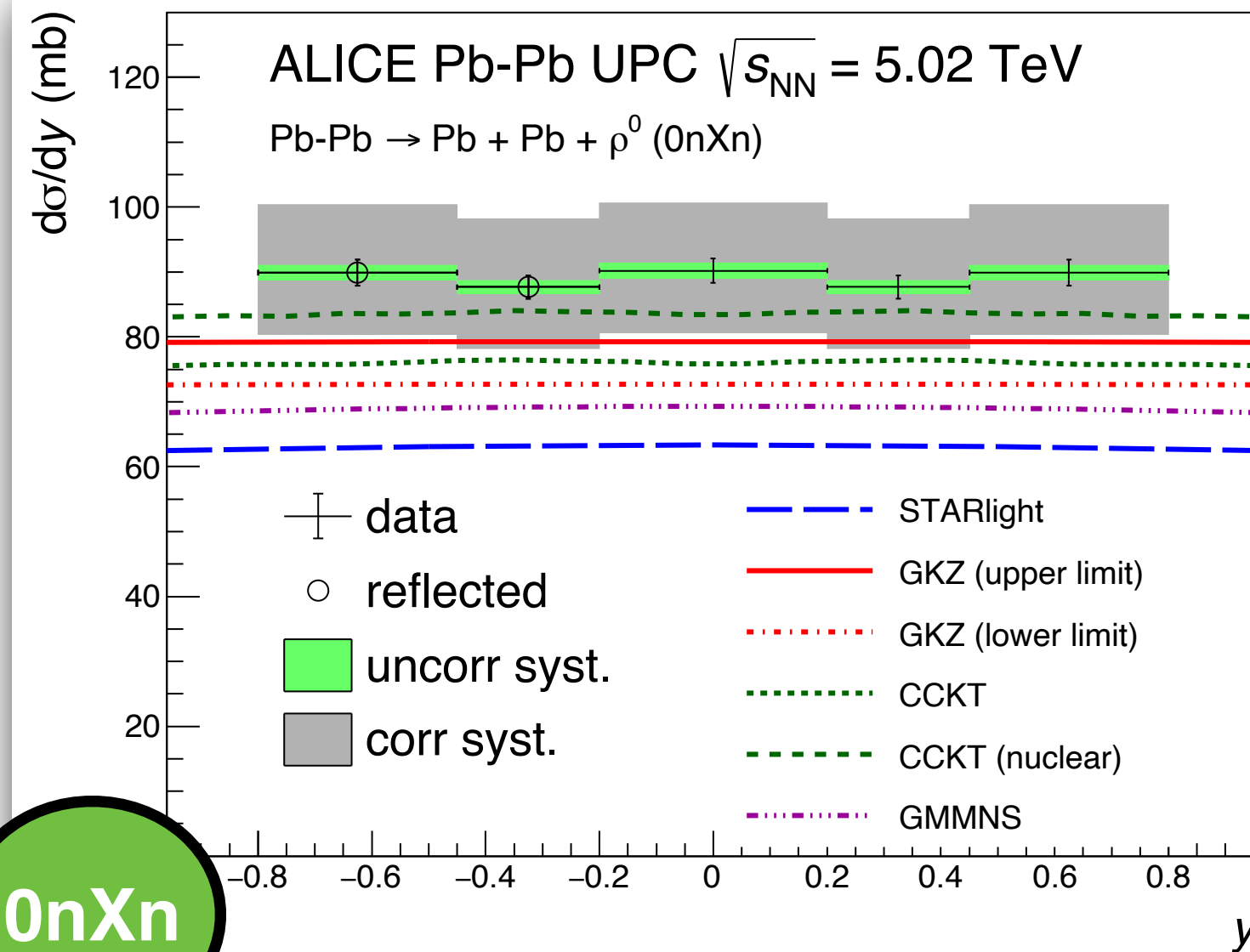
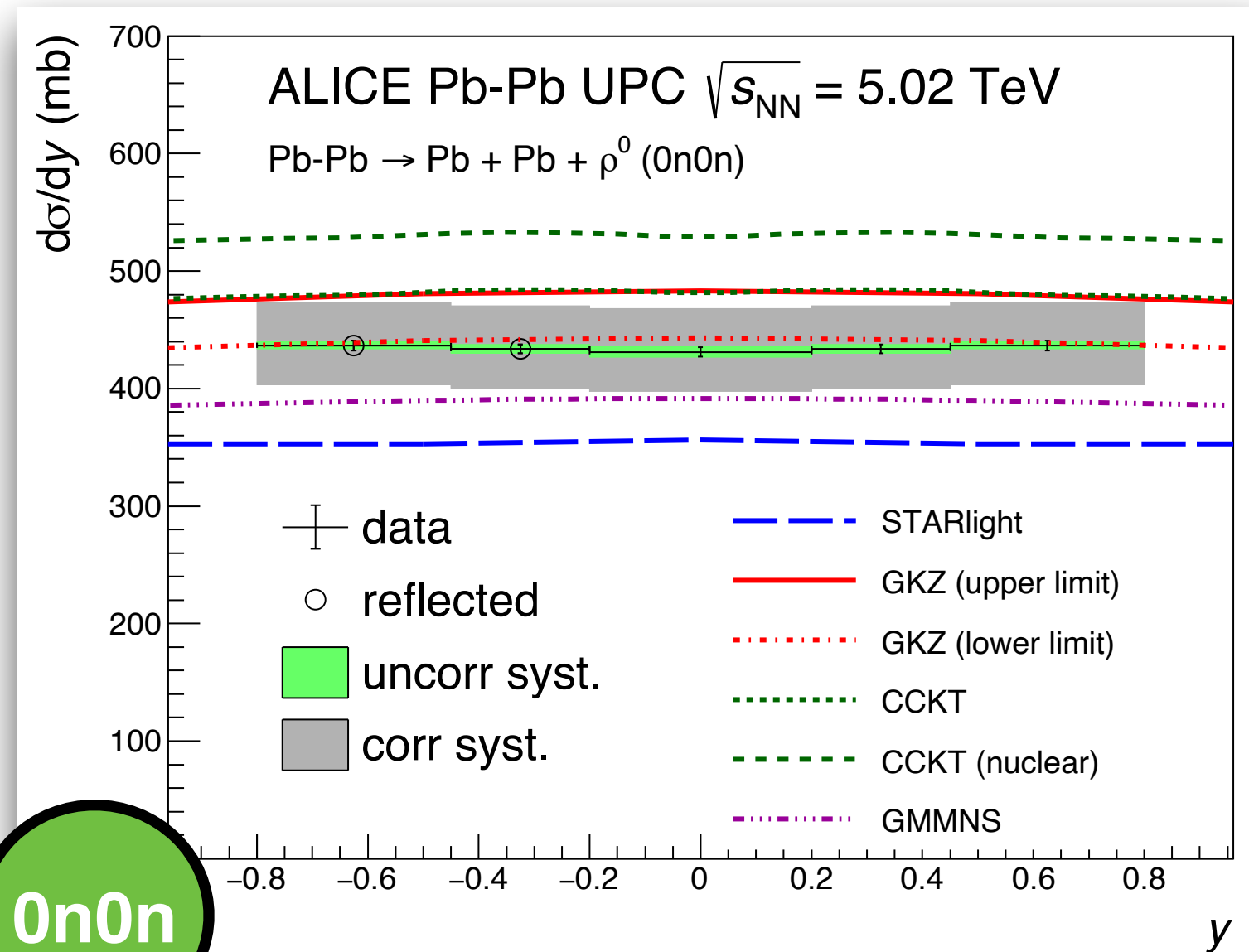
Continuous variation of scale using
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Testing the EMD method at midrapidity



ALICE, JHEP 06 (2020) 035

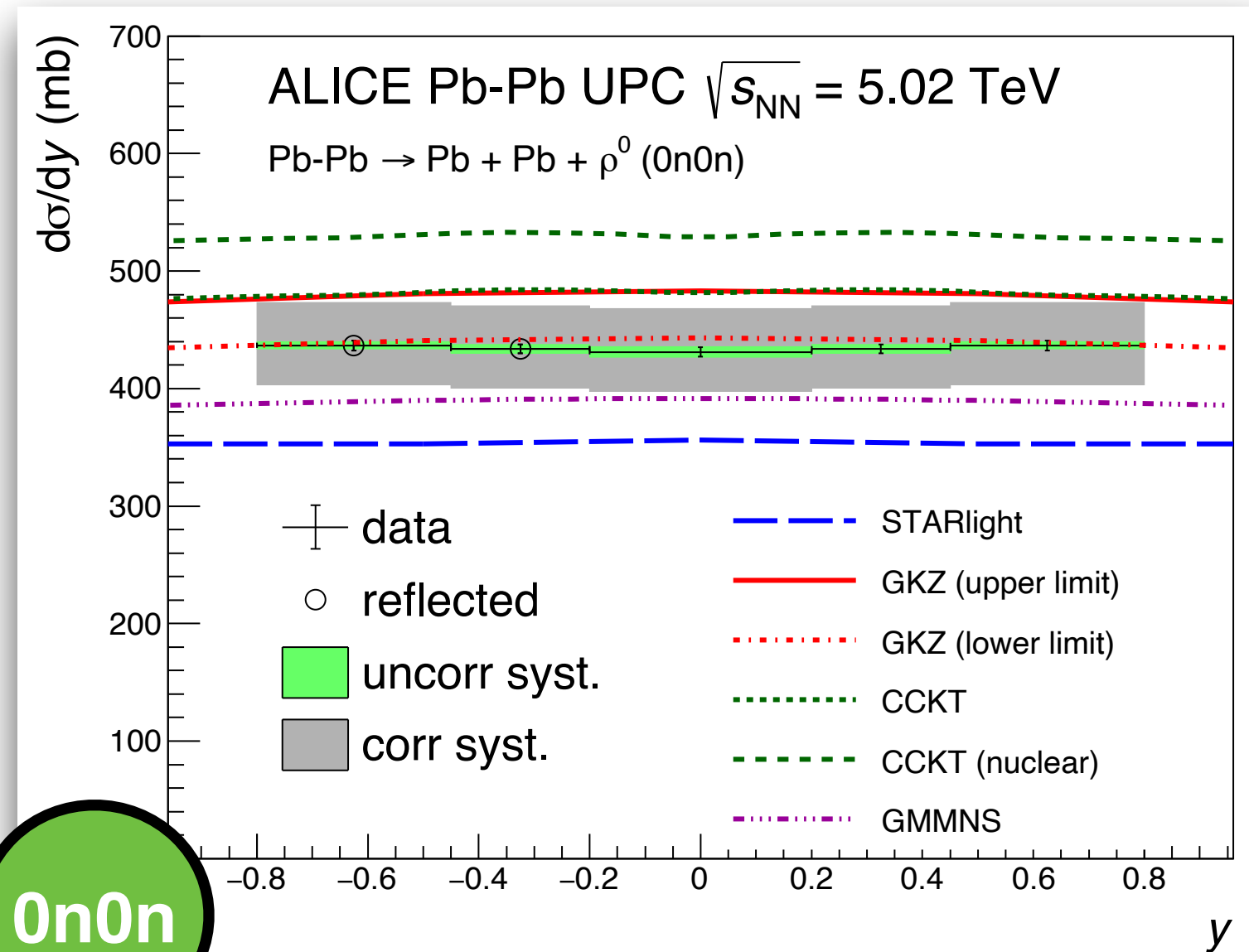
Testing the EMD method at midrapidity



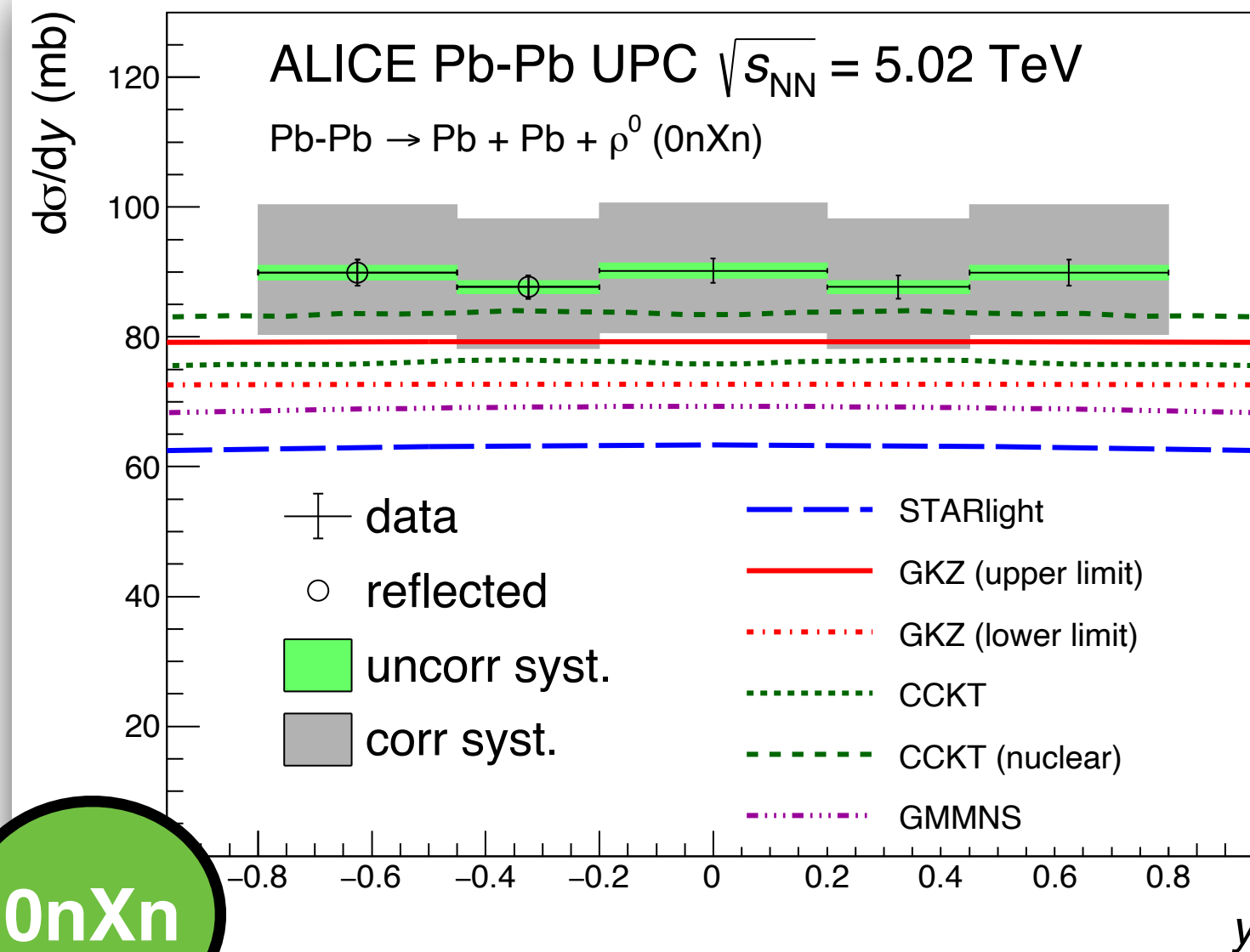
ALICE, JHEP 06 (2020) 035

Models more or less follow the data, the idea seems to work!

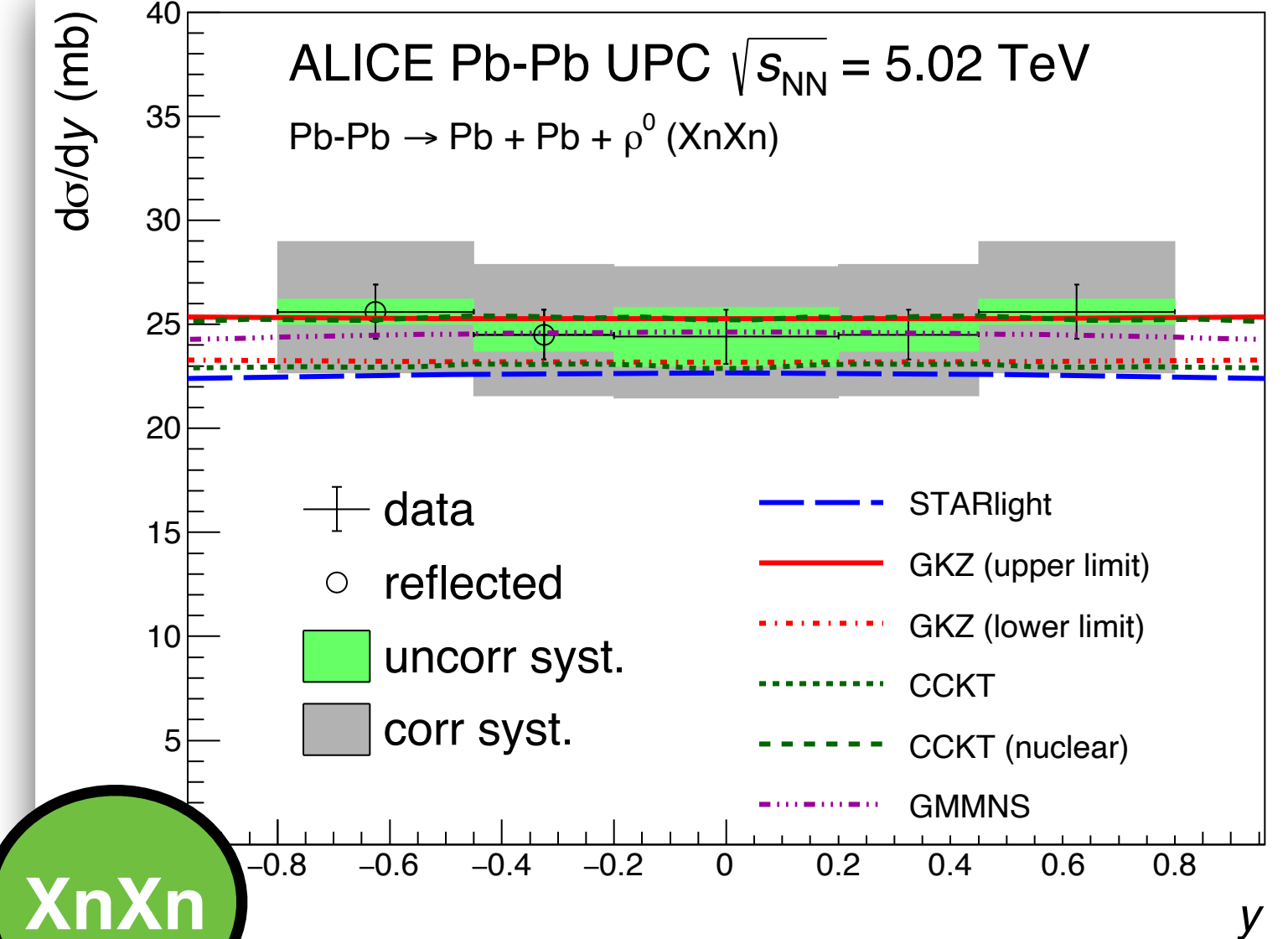
Testing the EMD method at midrapidity



0n0n



0nXn



XnXn

ALICE, JHEP 06 (2020) 035

Models more or less follow the data, the idea seems to work!

Run 2

To be applied to J/ψ data at all rapidities

Parenthesis: a comment on the exclusivity condition

Once the precision of the measurement goes to the percent level,
implementation of the exclusivity condition requires care

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The use of the same detector to measure UPCs and head-on Pb-Pb collisions, jeopardises single track sensitivity
⇒ the separation of peripheral and UPCs gets complicated

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The precision is increased with more events

⇒ In Run 3+4 this implies more **pile-up**

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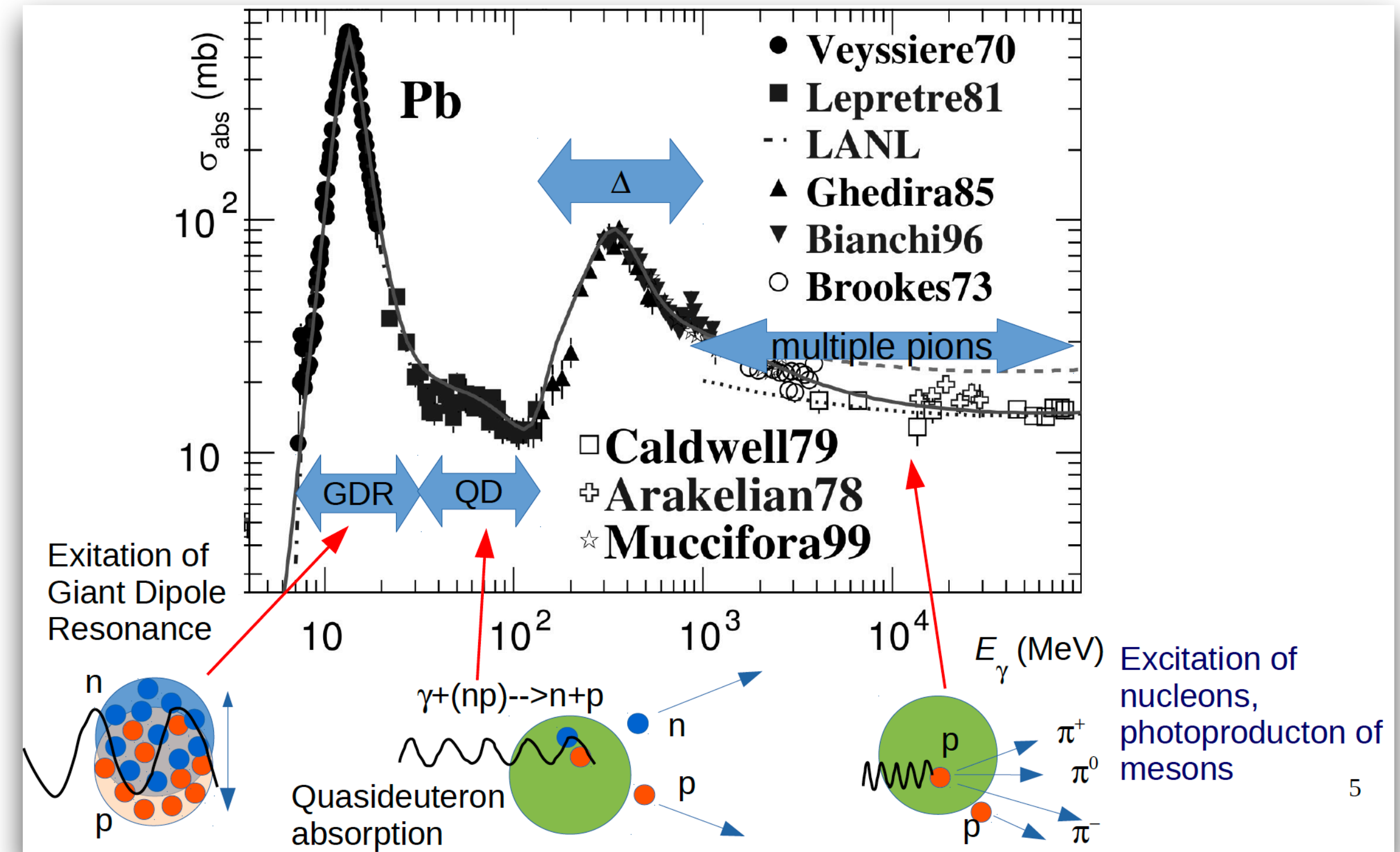
⇒ the separation of peripheral and UPCs gets complicated

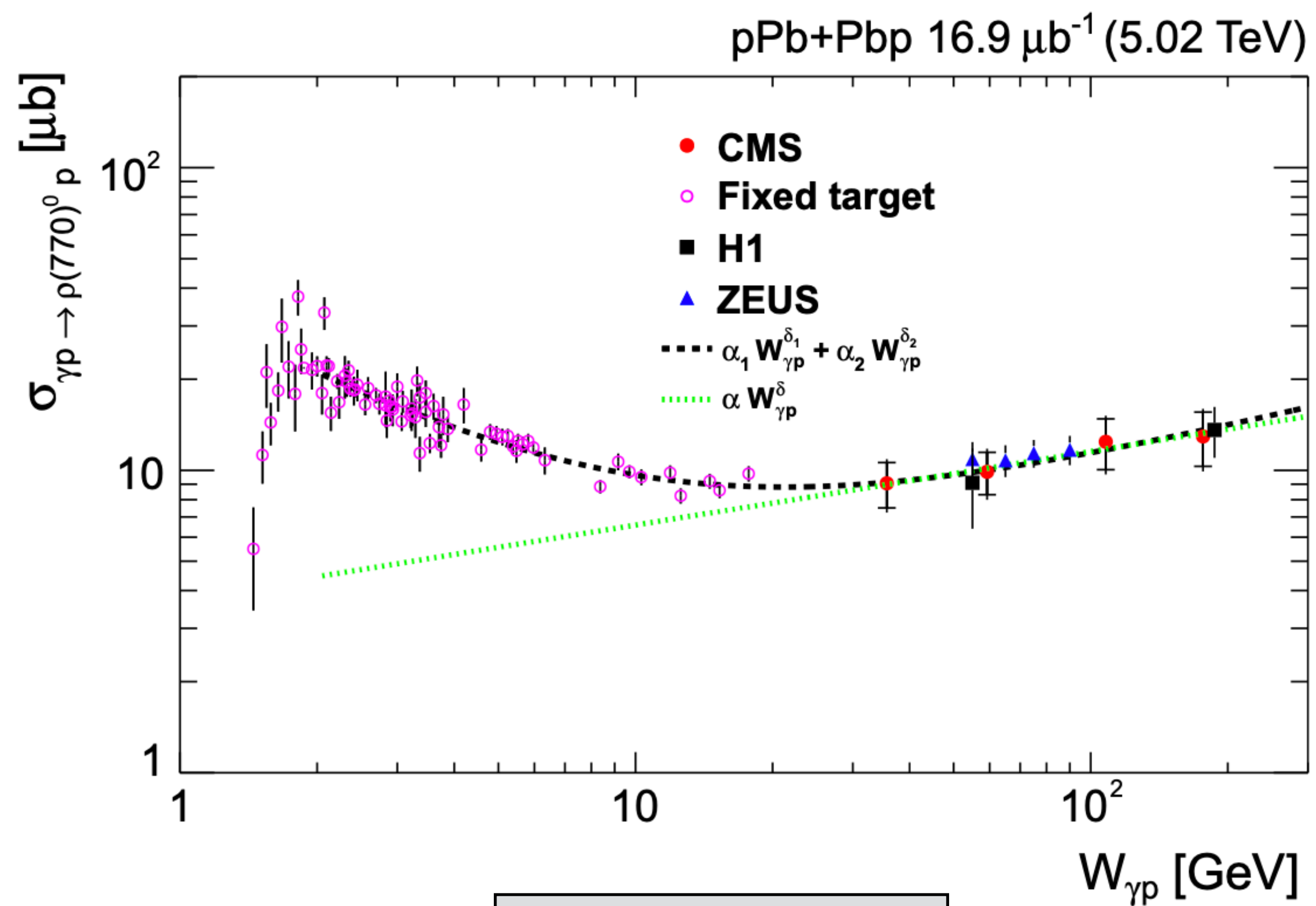
Once the precision of the measurement goes to the percent level, implementation of the exclusivity condition requires care

EMD also produces charged particles

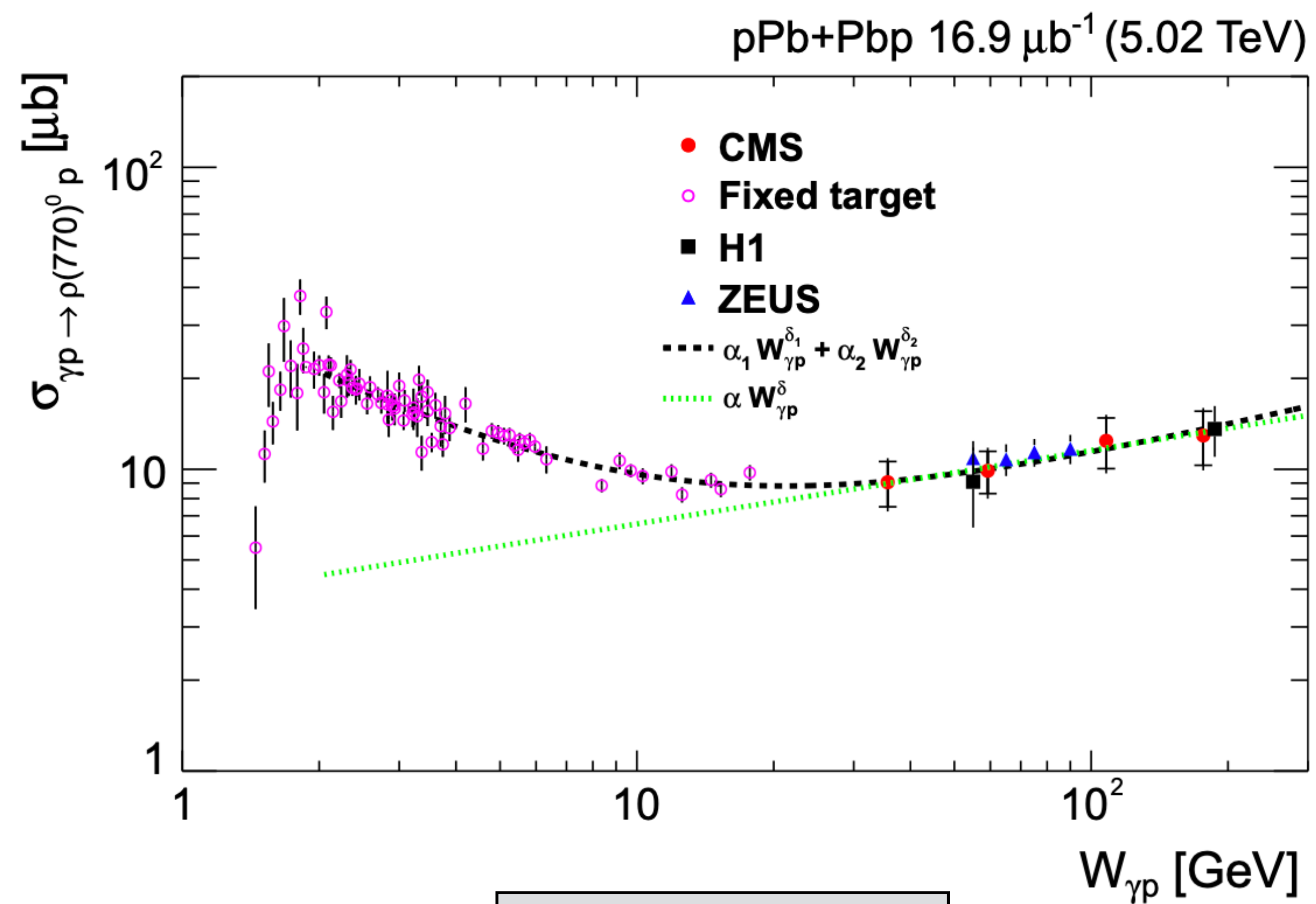
⇒ **activity vetoes** are inefficient

Slide from Igor Pshenichnov



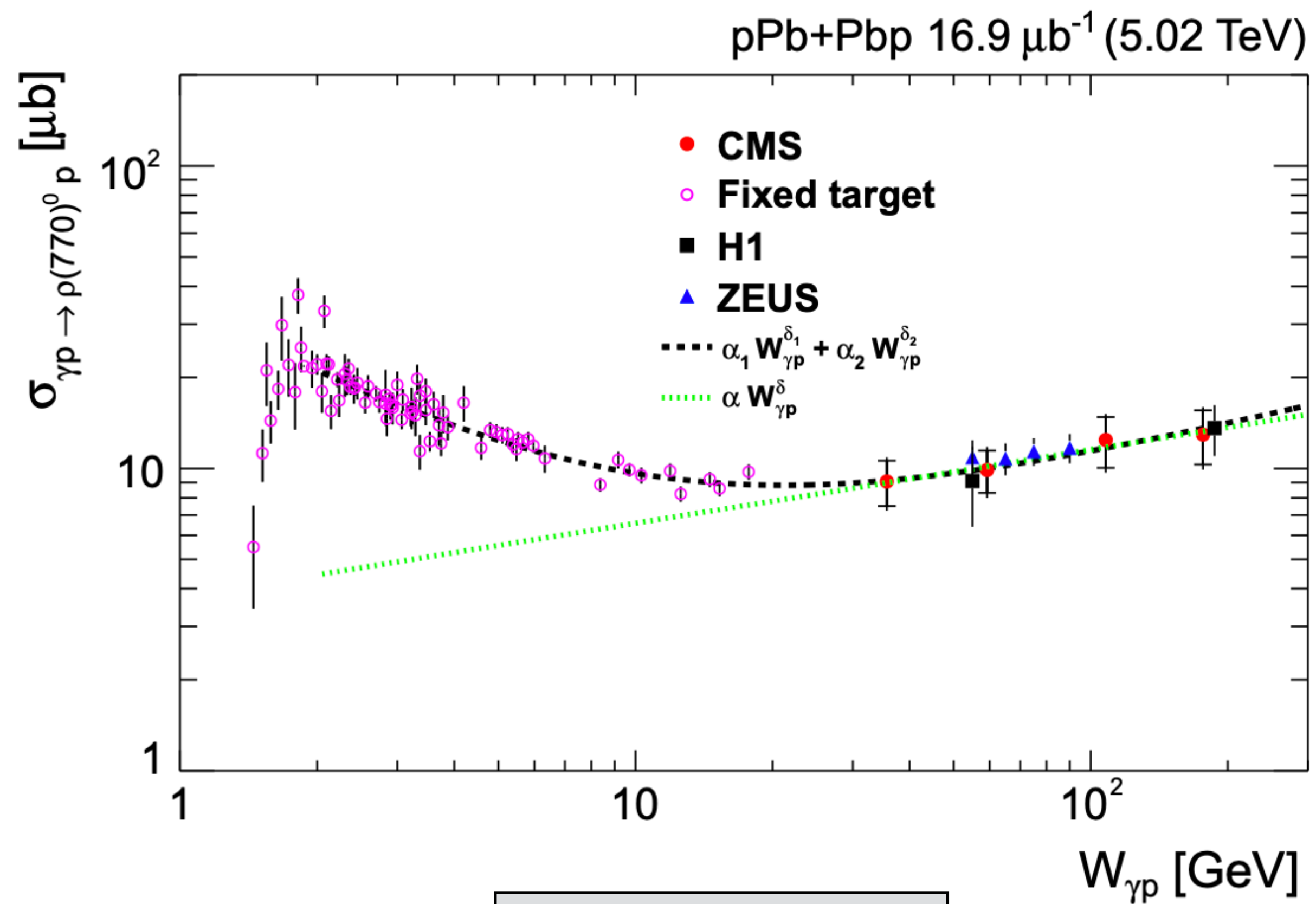


CMS, EPJ C79 (2019) 702



CMS, EPJ C79 (2019) 702

Up to now, similar energy range as in HERA
Cross section slowly growing

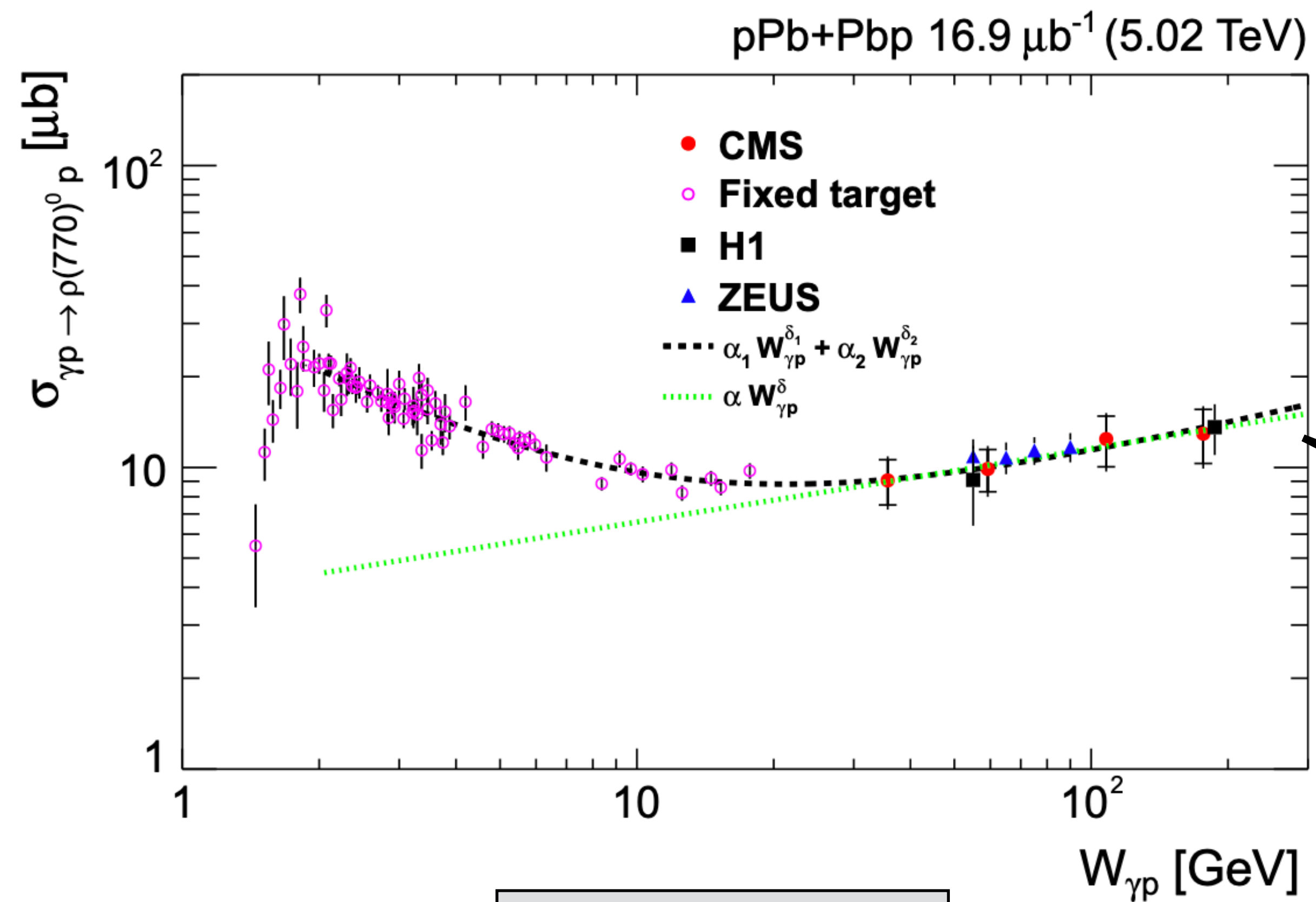


CMS, EPJ C79 (2019) 702

Run 3+4

LHCb and ALICE may be able
to measure this at higher energies

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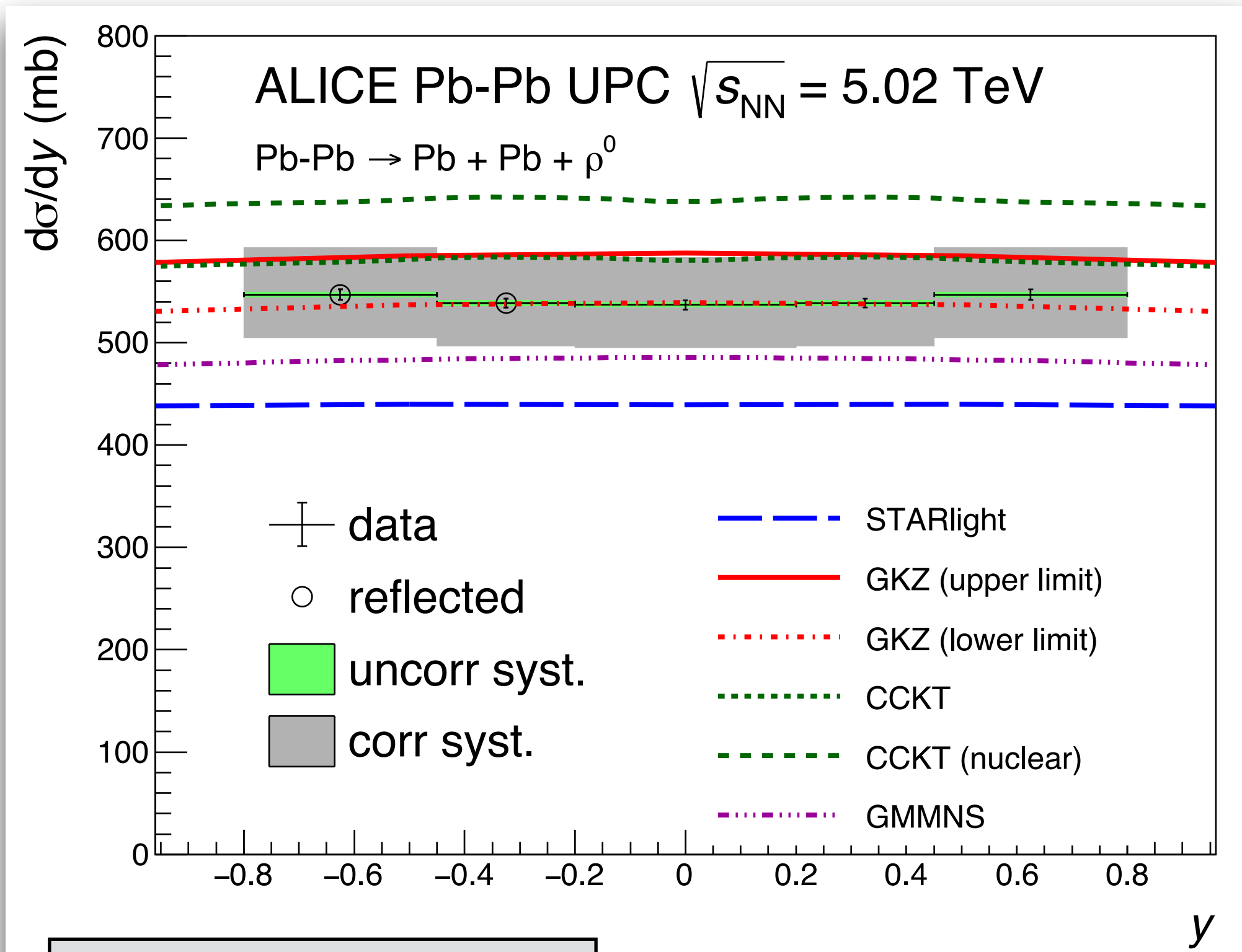
CMS, EPJ C79 (2019) 702

Run 3+4

LHCb and ALICE may be able
to measure this at higher energies

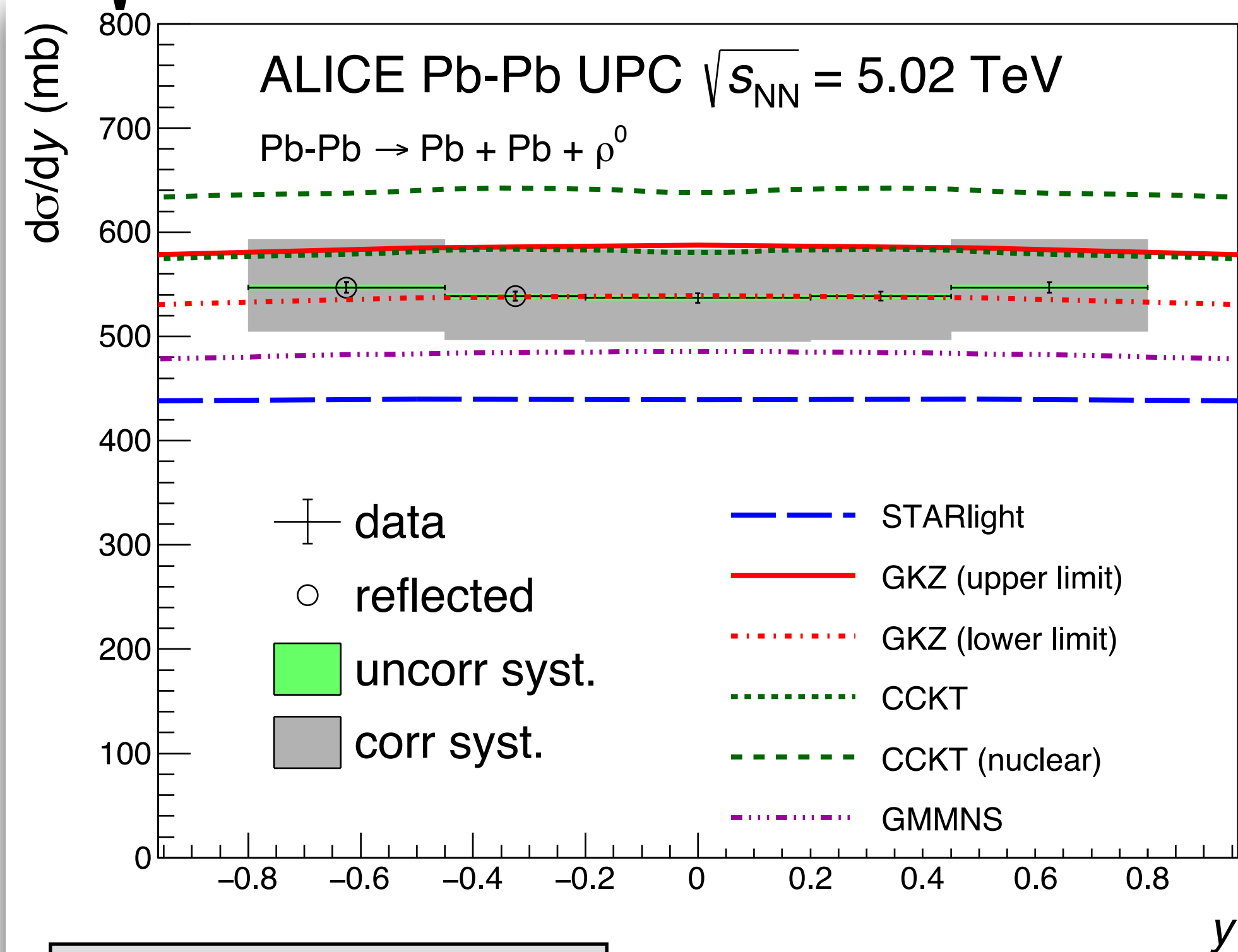
How does this rise with energy looks like for Pb?

Up to now, similar energy range as in HERA
Cross section slowly growing



ALICE, JHEP 06 (2020) 035

Huge cross section!

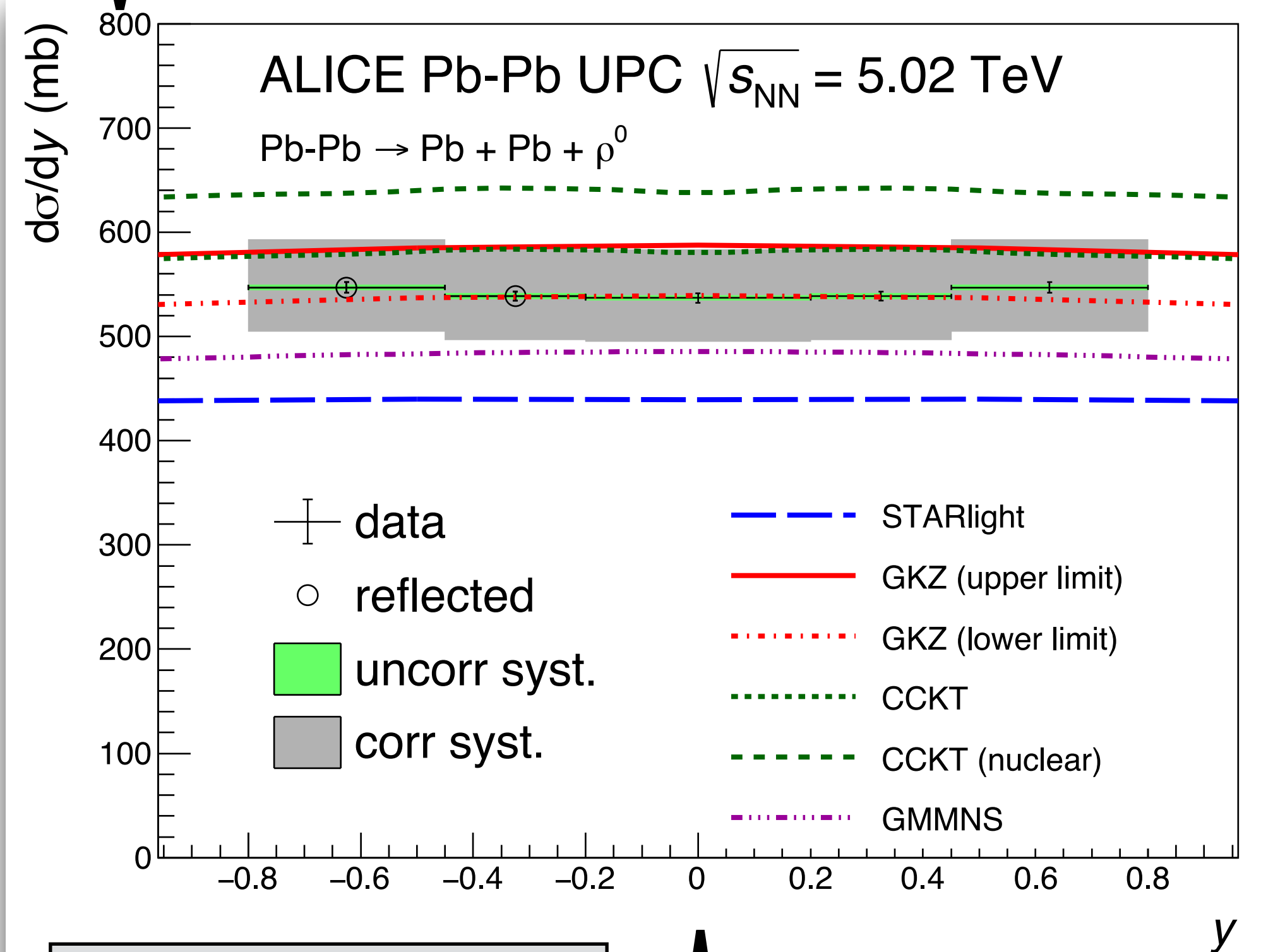


ALICE, JHEP 06 (2020) 035

$\rho(770)$

$\rho(770)$ as seen by many experiments

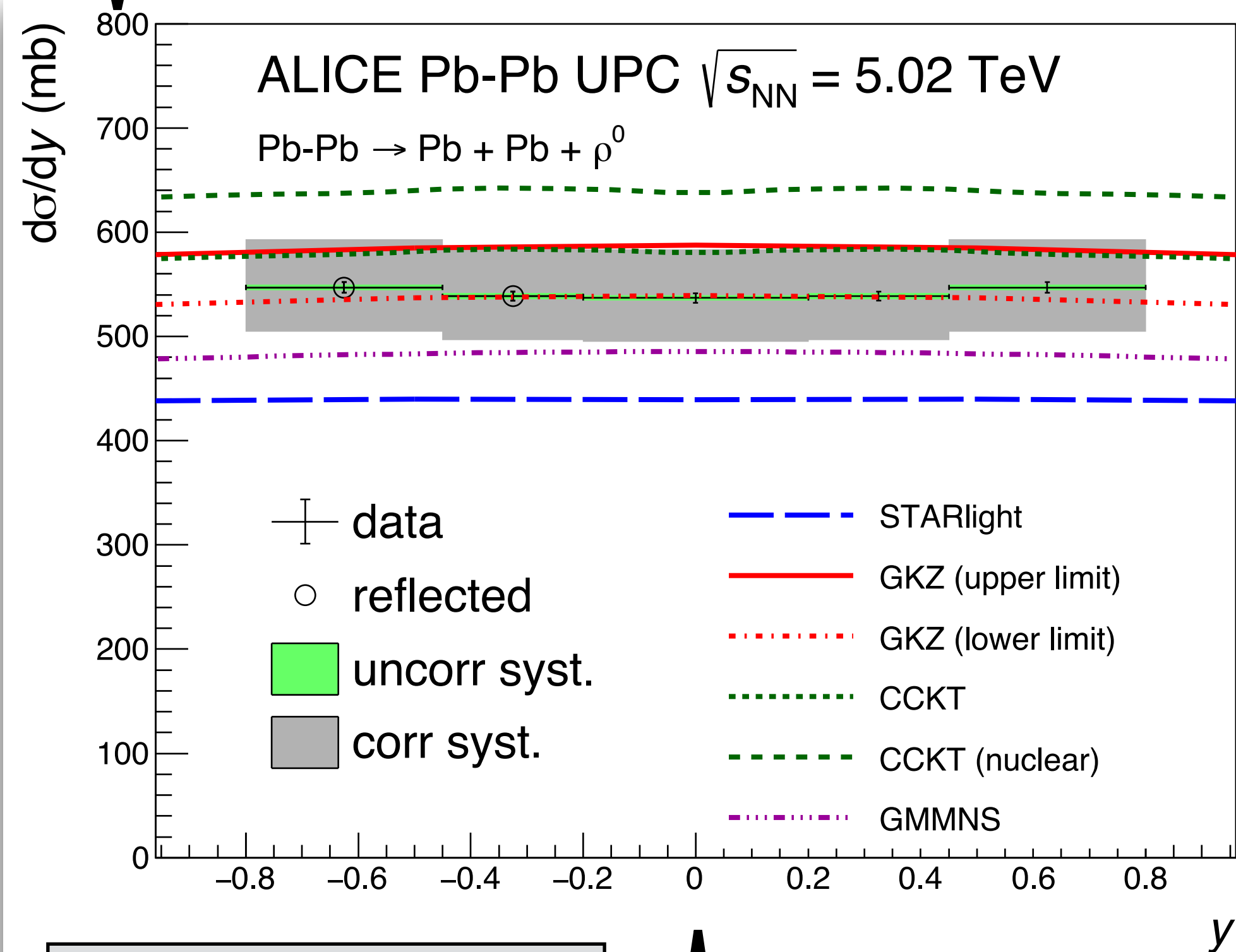
Huge cross section!



ALICE, JHEP 06 (2020) 035

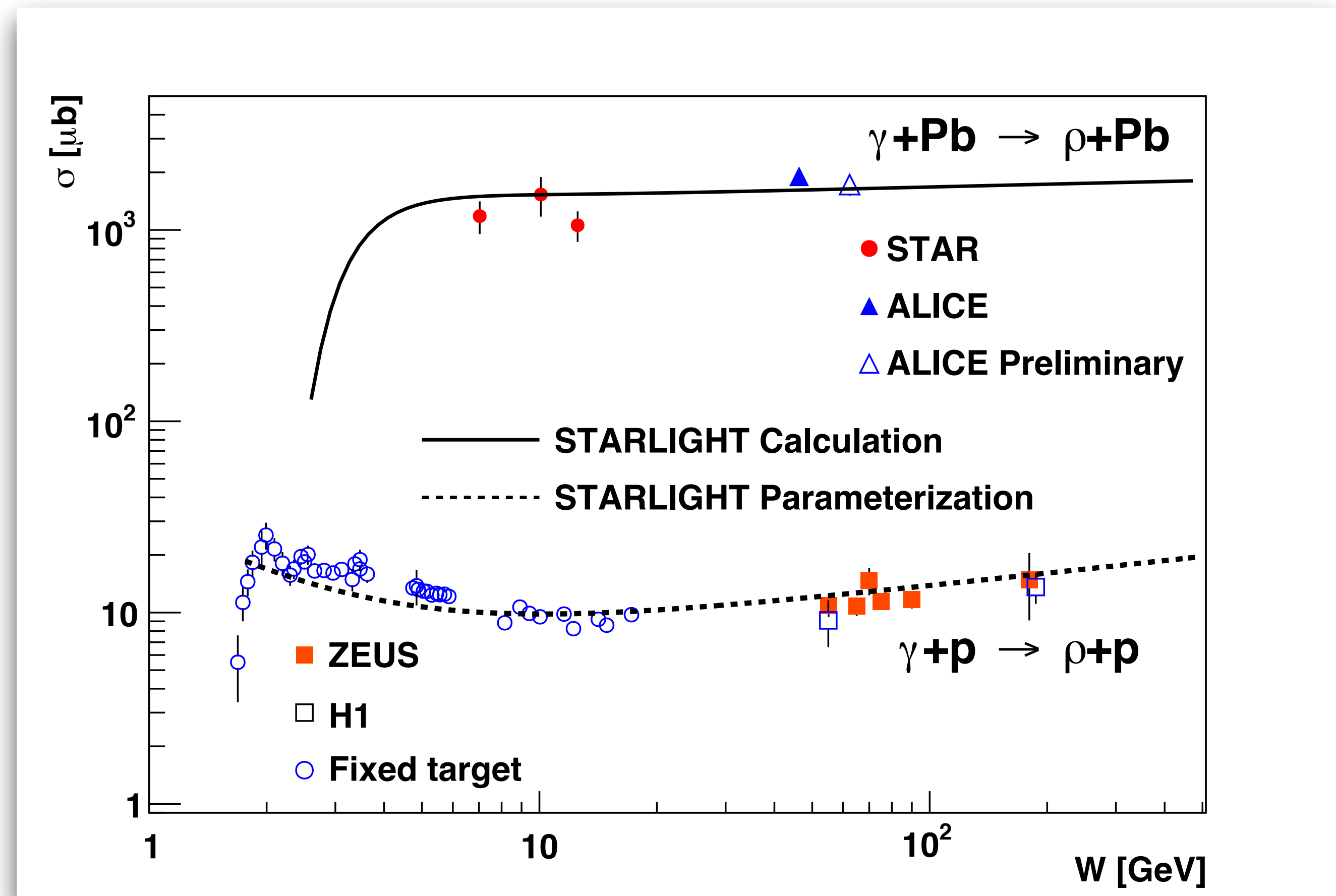
Measurement at $y=0$
 \Rightarrow no ambiguity

Huge cross section!



ALICE, JHEP 06 (2020) 035

Measurement at $y=0$
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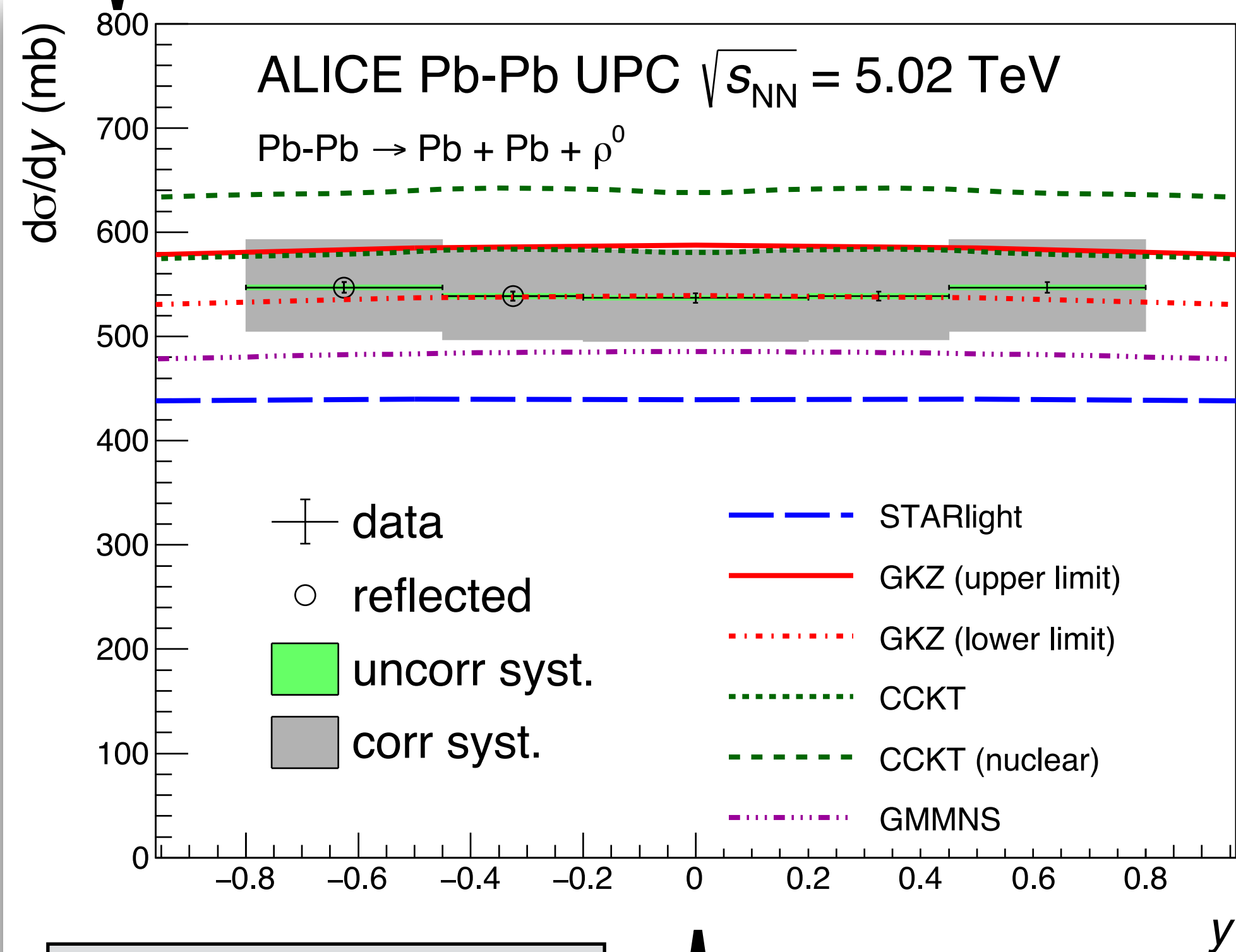


Plot produced by Joakim Nystrand
(personal communication, 2018)

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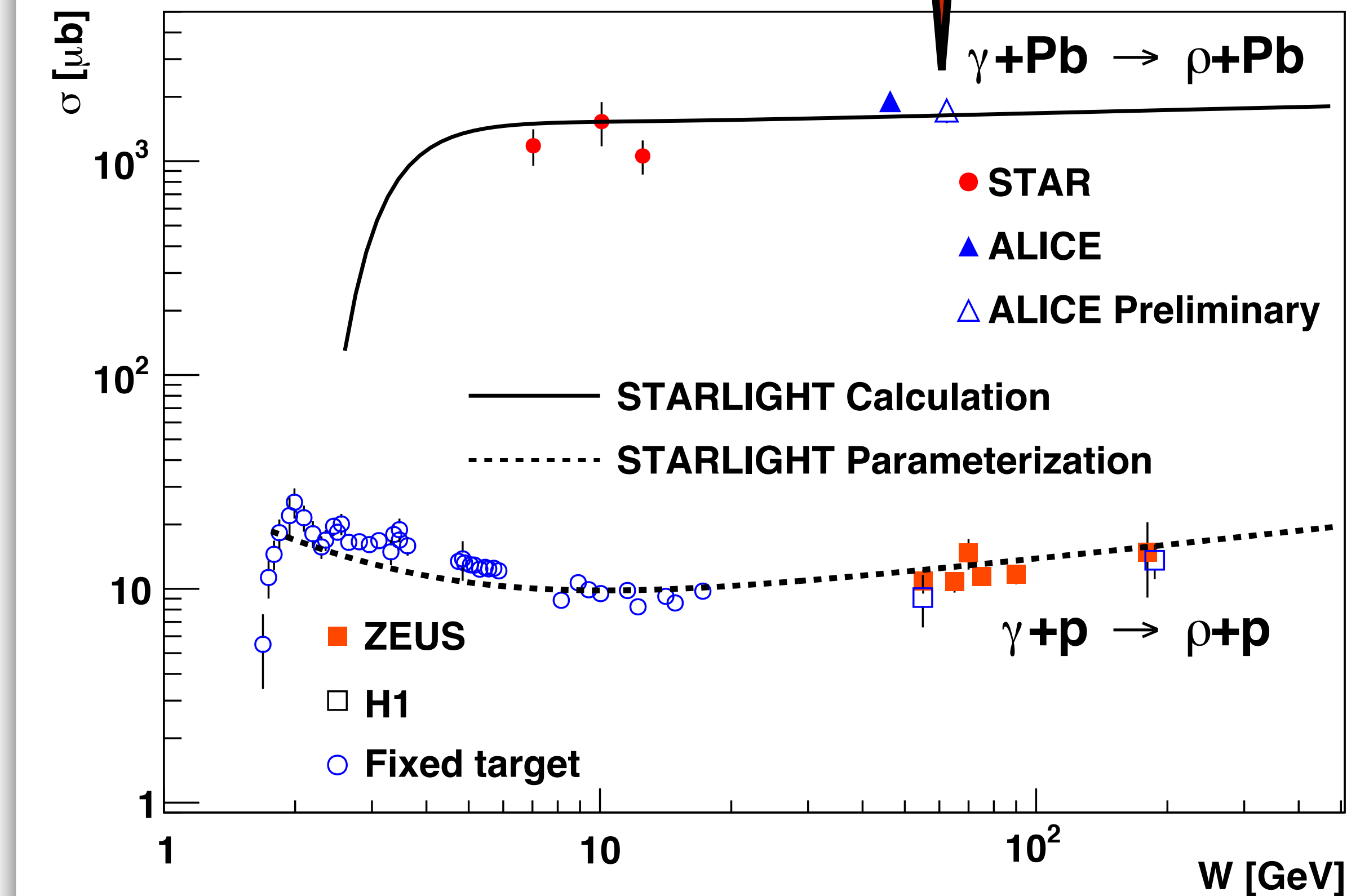
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ALICE, JHEP 06 (2020) 035

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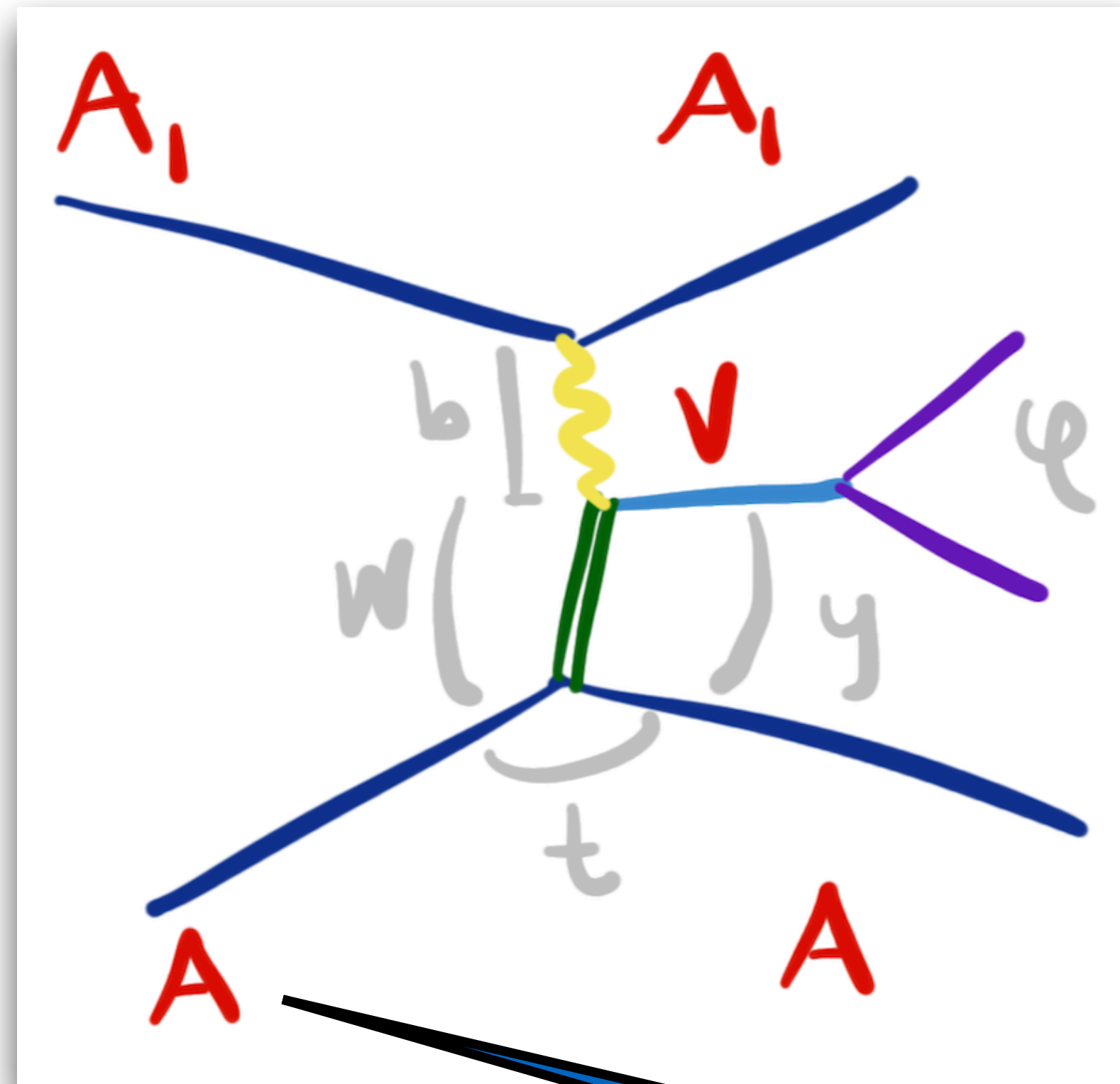
Open question:
Have we reached the black-disc limit?



Plot produced by Joakim Nystrand
(personal communication, 2018)

A

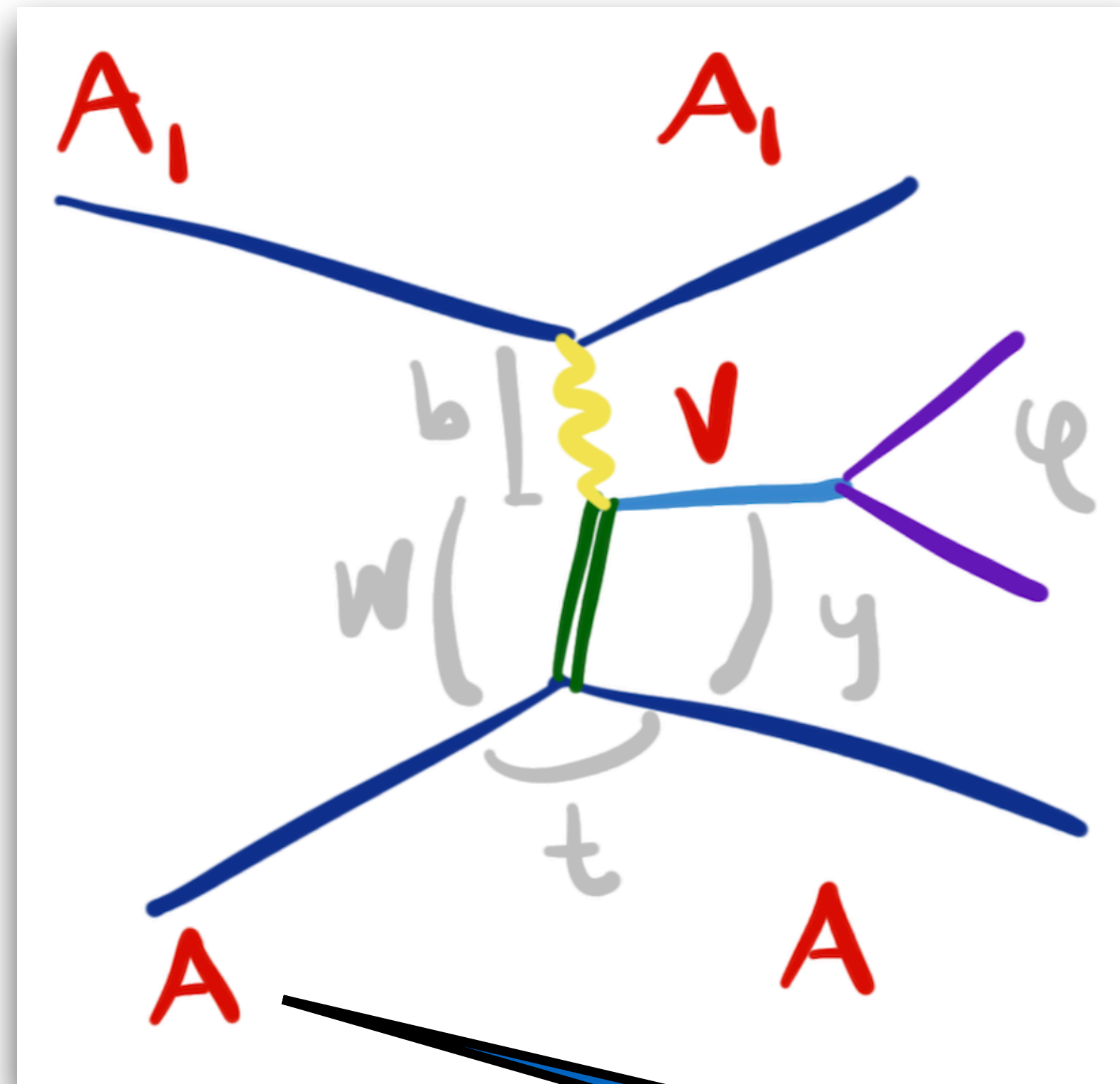
Dependence of the gluon distribution on A



Mass number dependence:
Early appearance of saturation?

A

Dependence of the gluon distribution on A

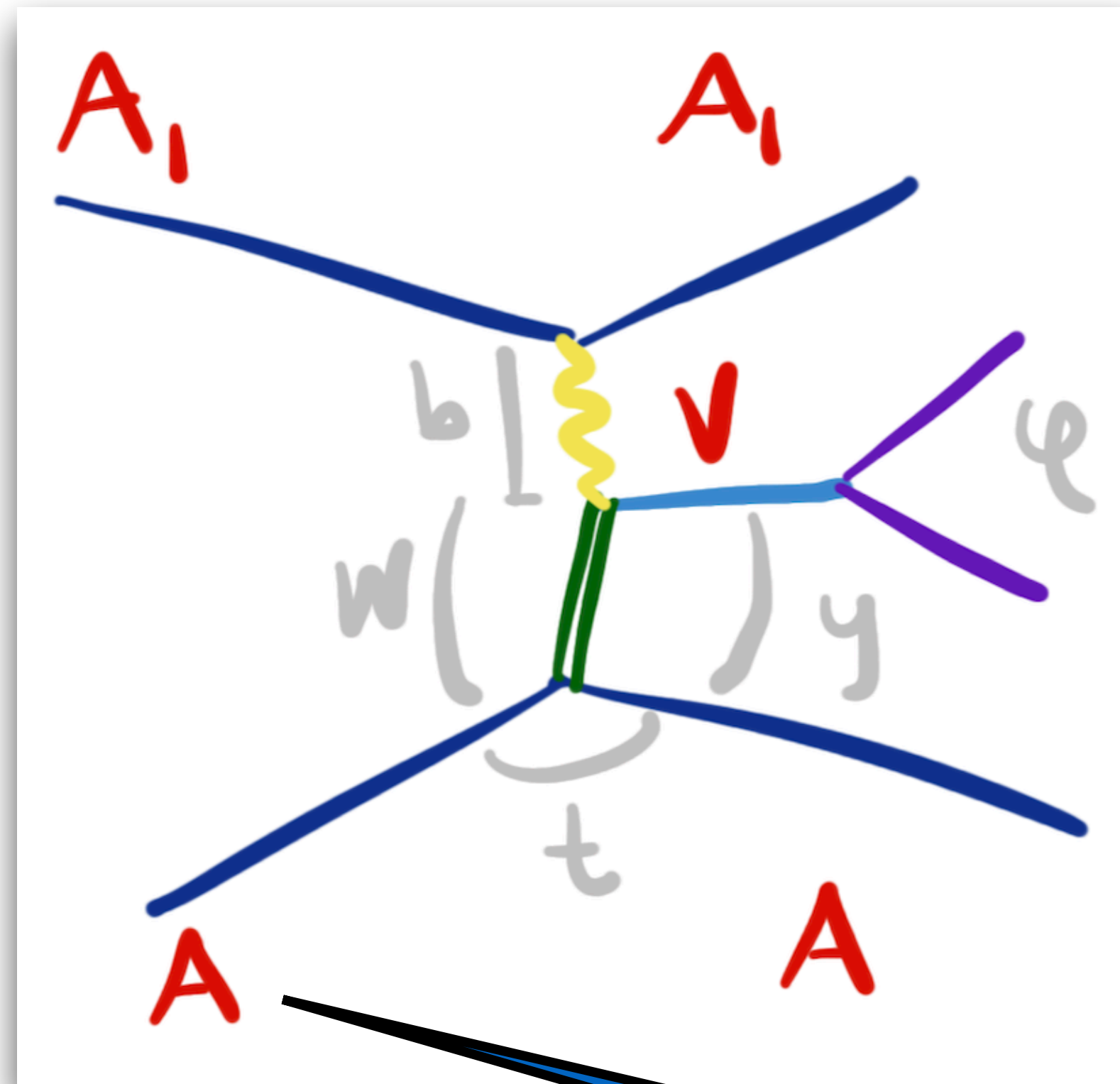


Expectations:
Different A dependence of a pure nuclear form factor and of the black-disc limit

Mass number dependence:
Early appearance of saturation?

A

Dependence of the gluon distribution on A



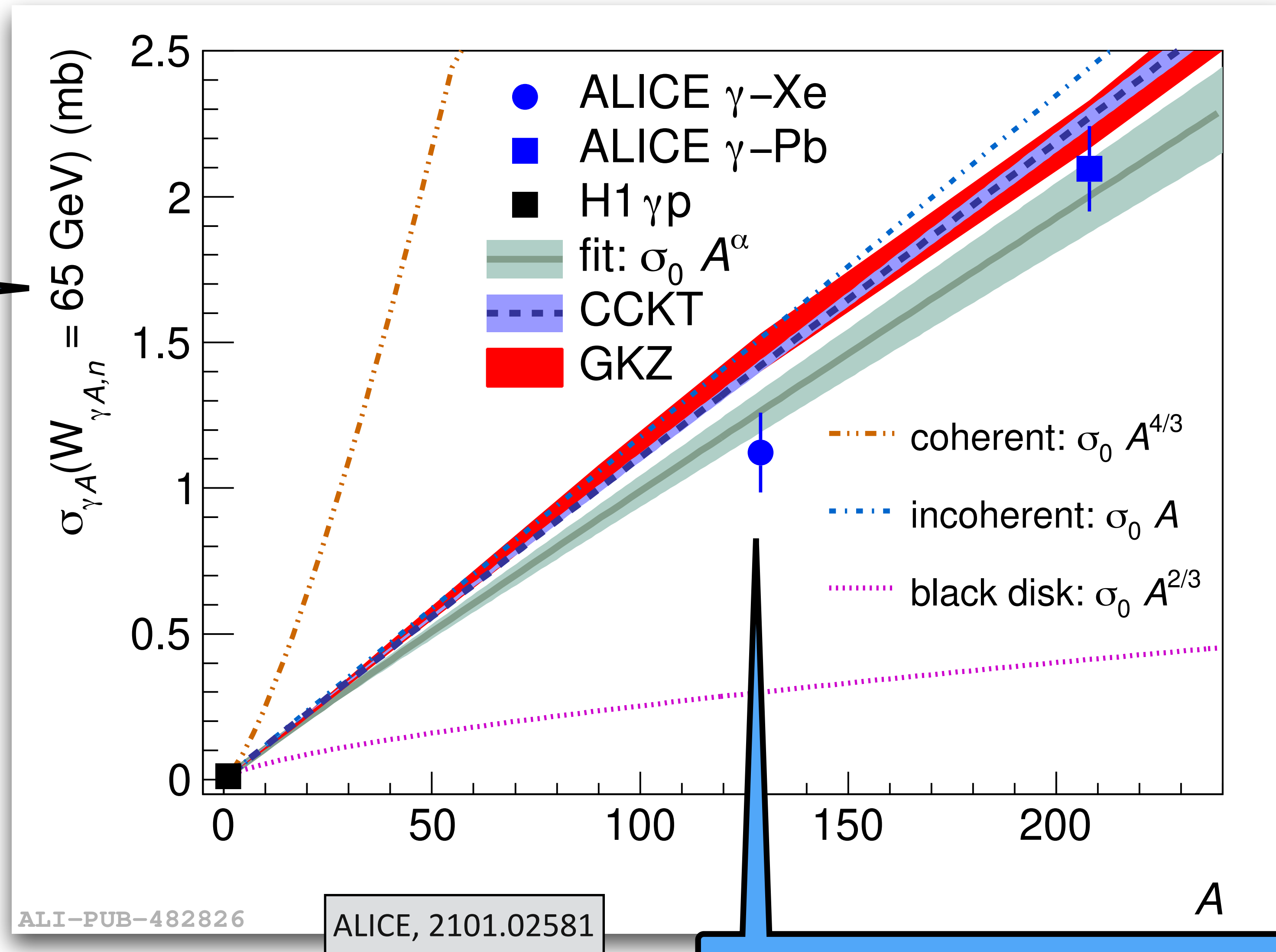
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Different A dependence of a pure nuclear form factor and of the black-disc limit

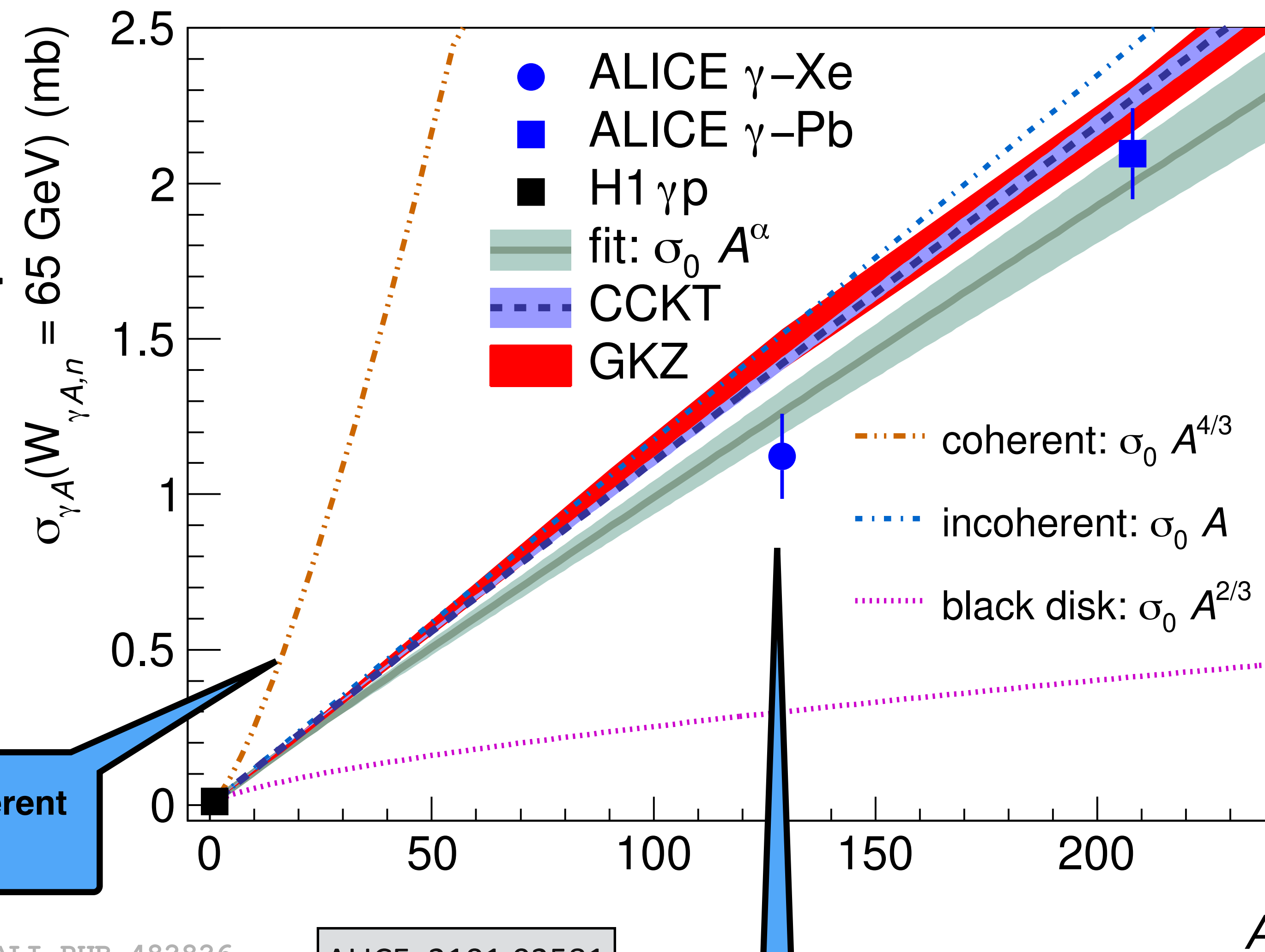
EIC

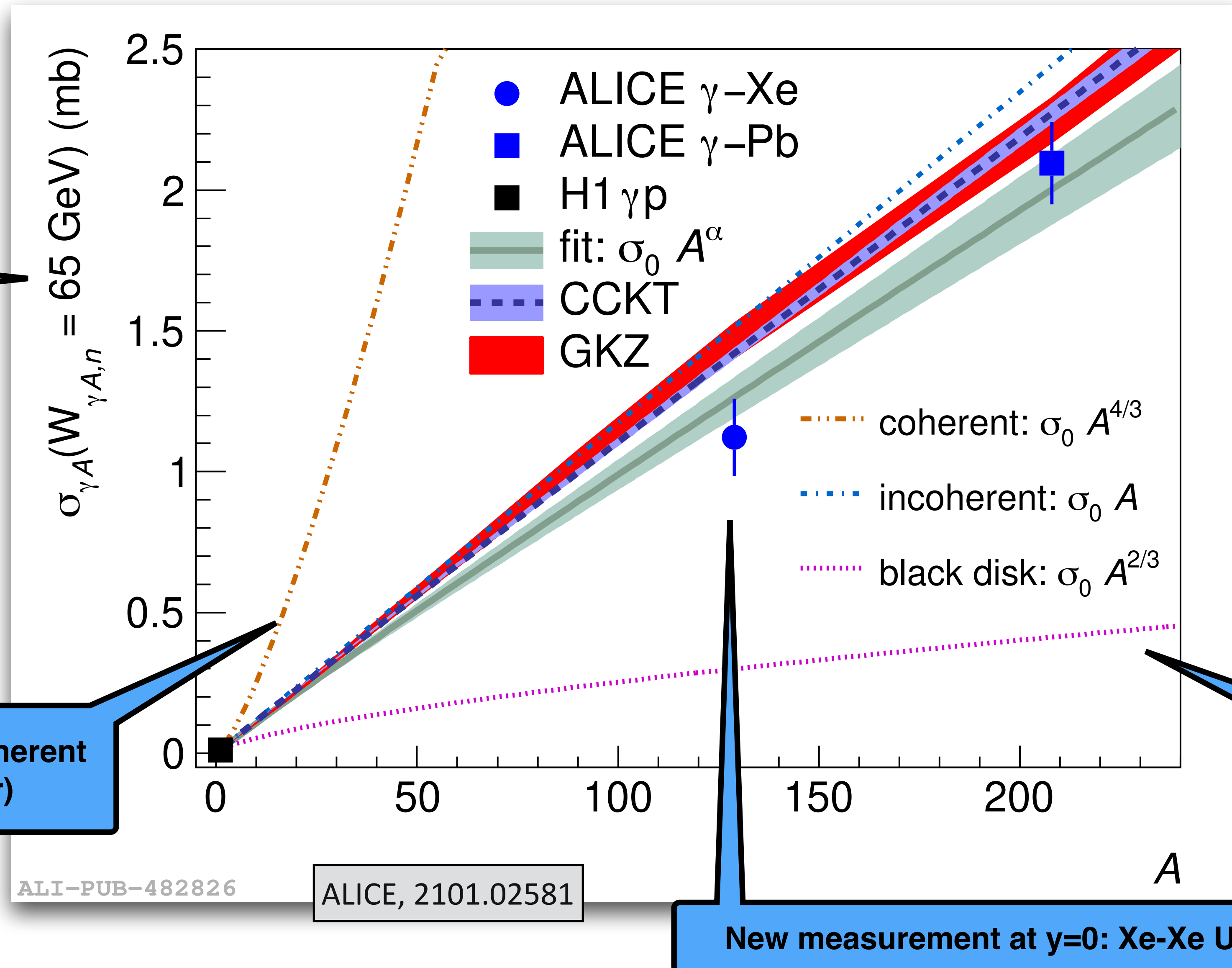
Many different nuclei can be studied

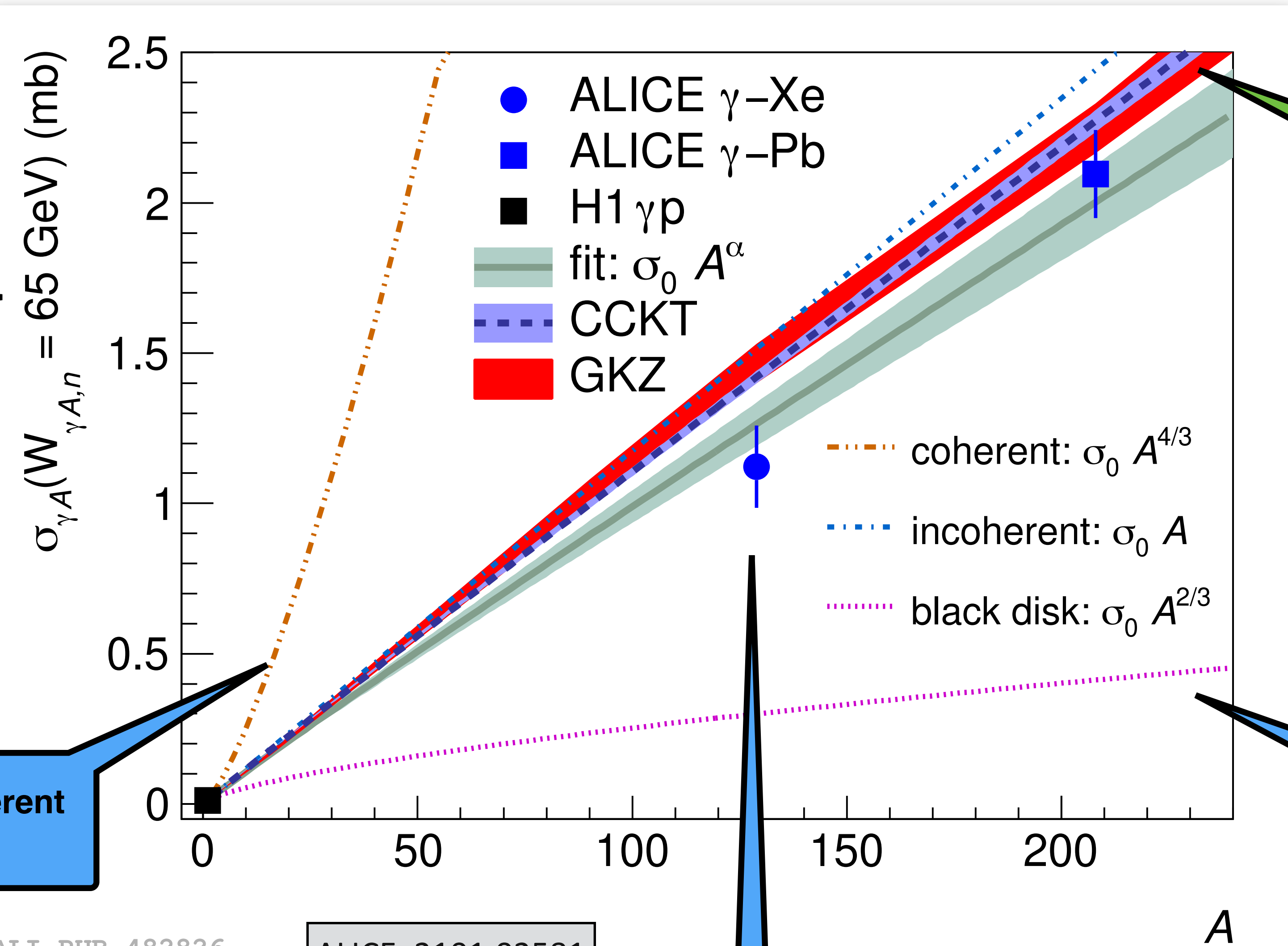
Mass number dependence:
Early appearance of saturation?

Fixed energy

New measurement at $y=0$: Xe-Xe UPC







Fixed energy

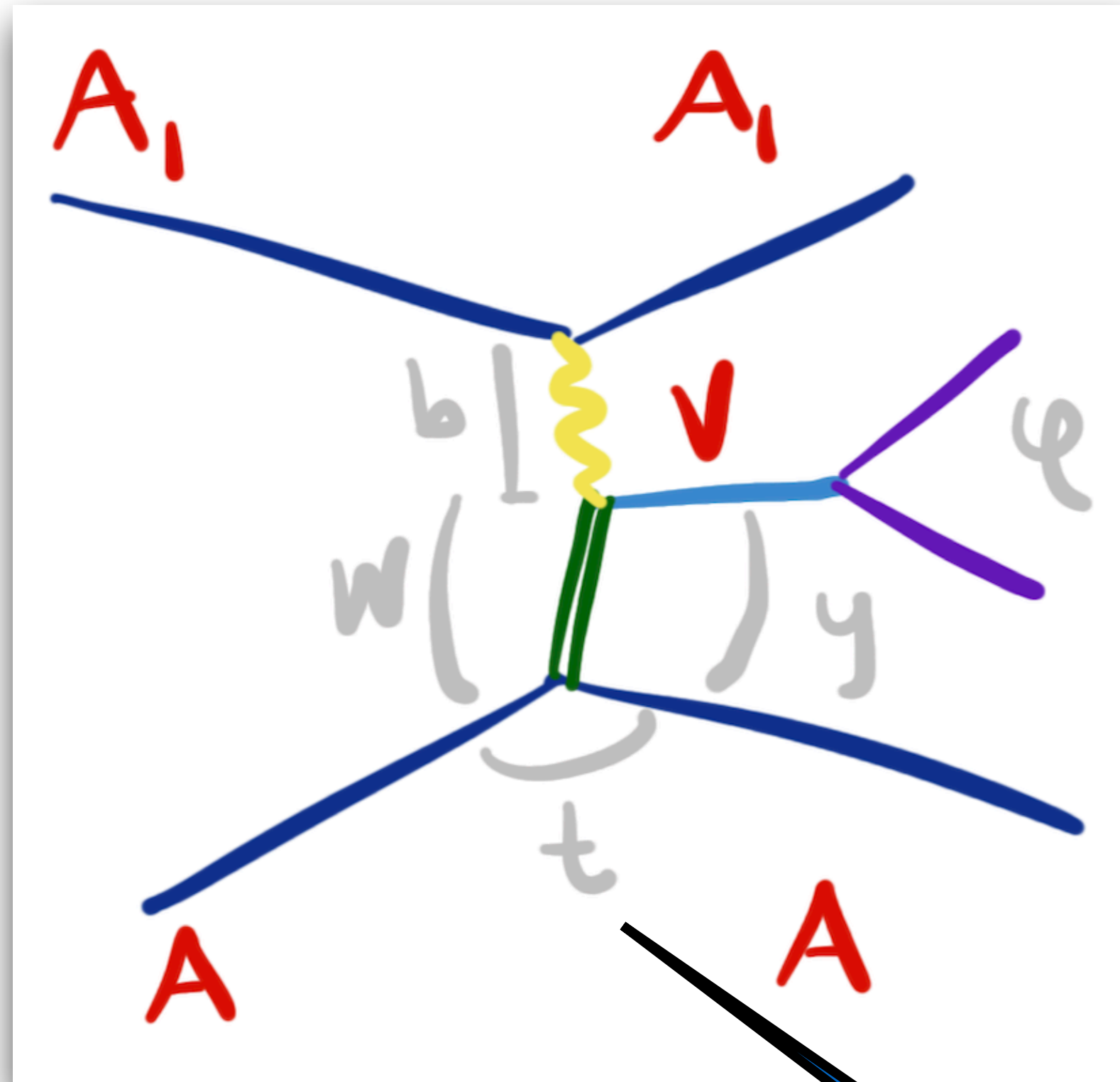
Expectation from coherent
(just form factor)A shadowing based, and a
colour dipole model with
saturation and hot spots,
close to dataExpectation from the
black disc limitNew measurement at $y=0$: Xe-Xe UPC

ALI-PUB-482826

ALICE, 2101.02581

$|t|$

Momentum transferred at the target vertex



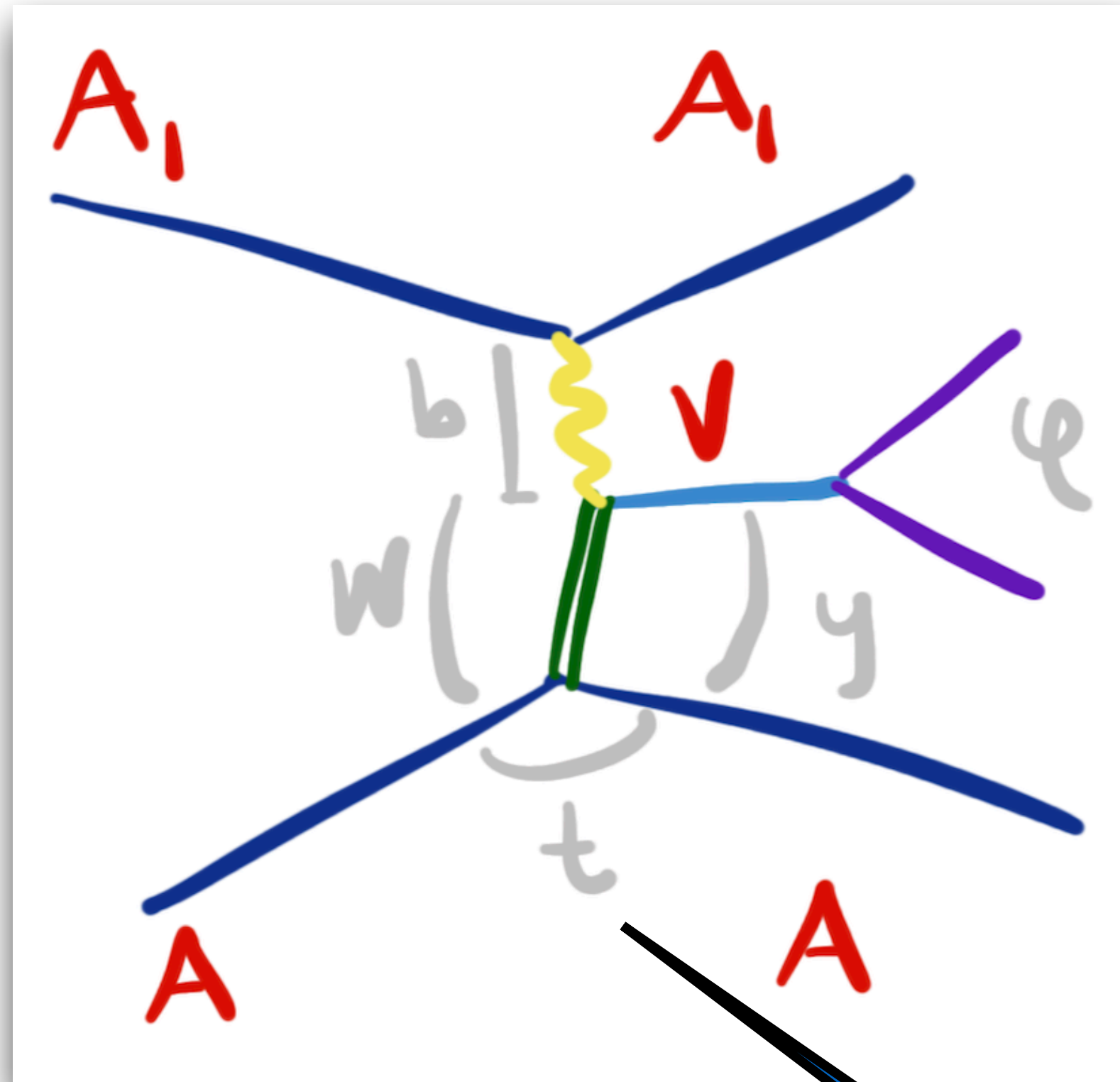
$|t|$ dependence



A window to transverse structure

$|t|$

Momentum transferred at the target vertex

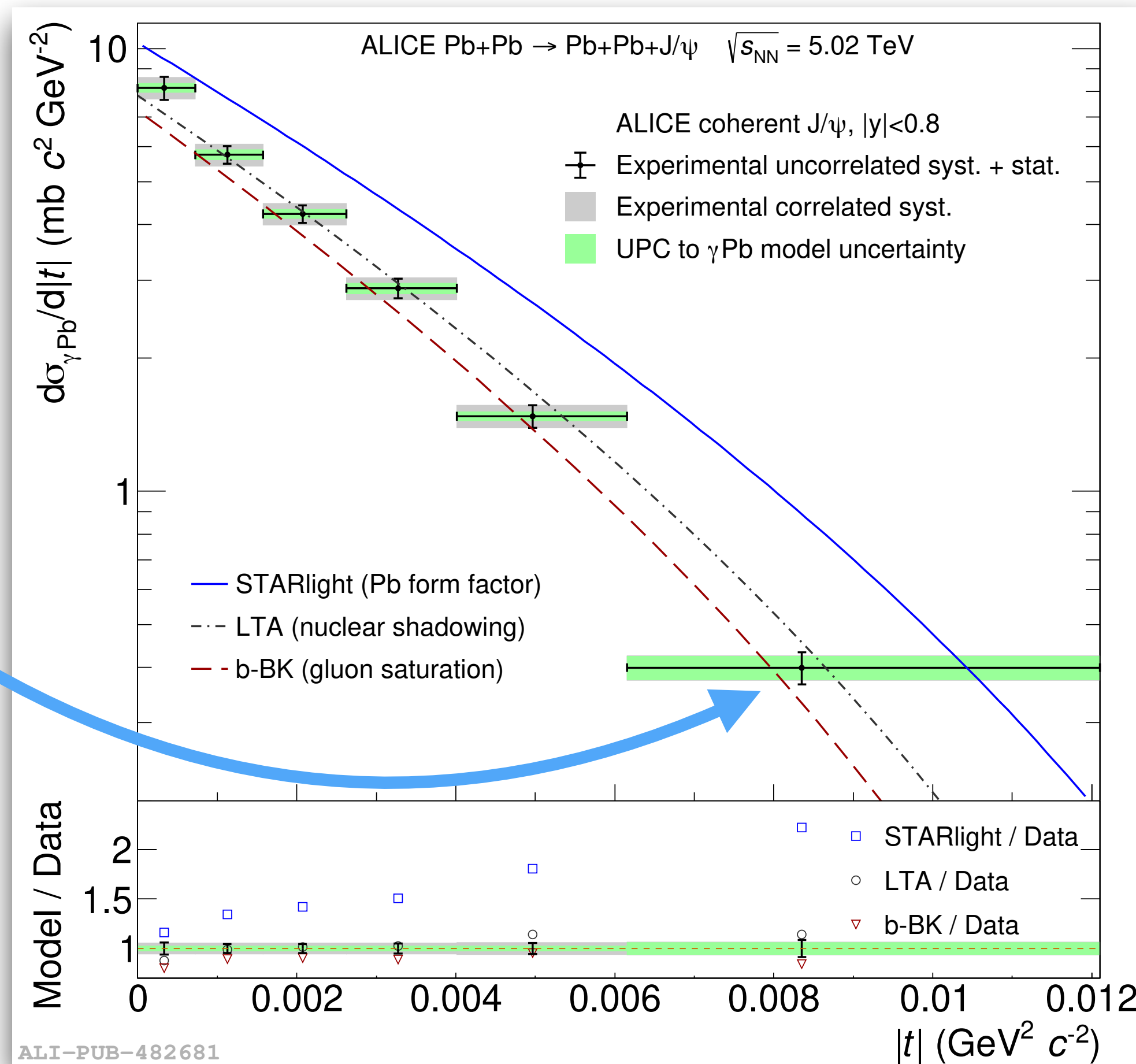
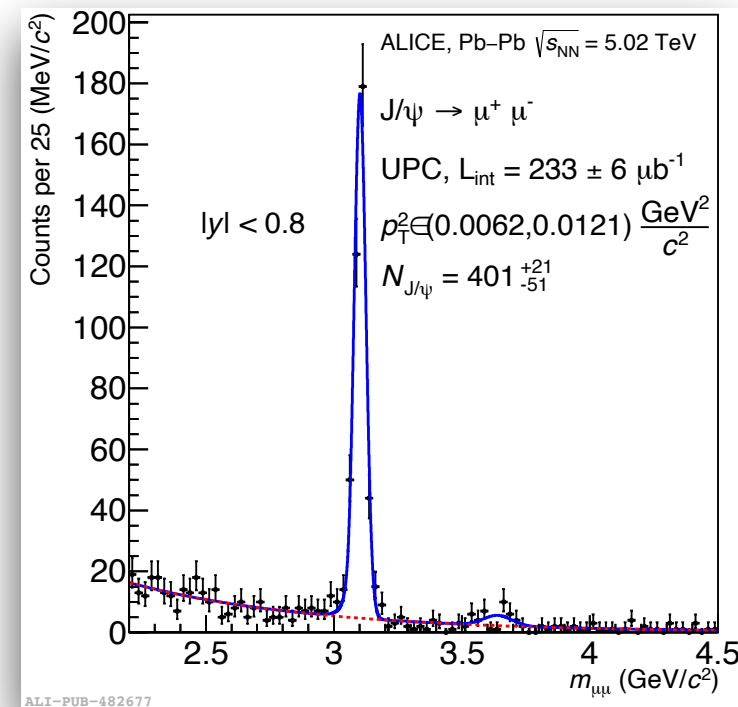
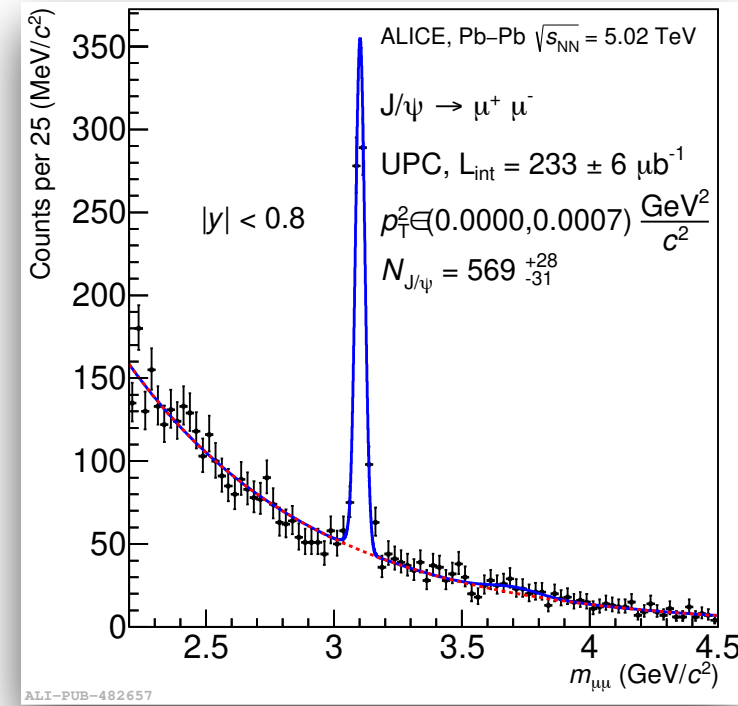


Expectations:
The distribution of gluons in the transverse plane is sensitive to saturation effects

$|t|$ dependence
 \Rightarrow
A window to transverse structure

J/ψ

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

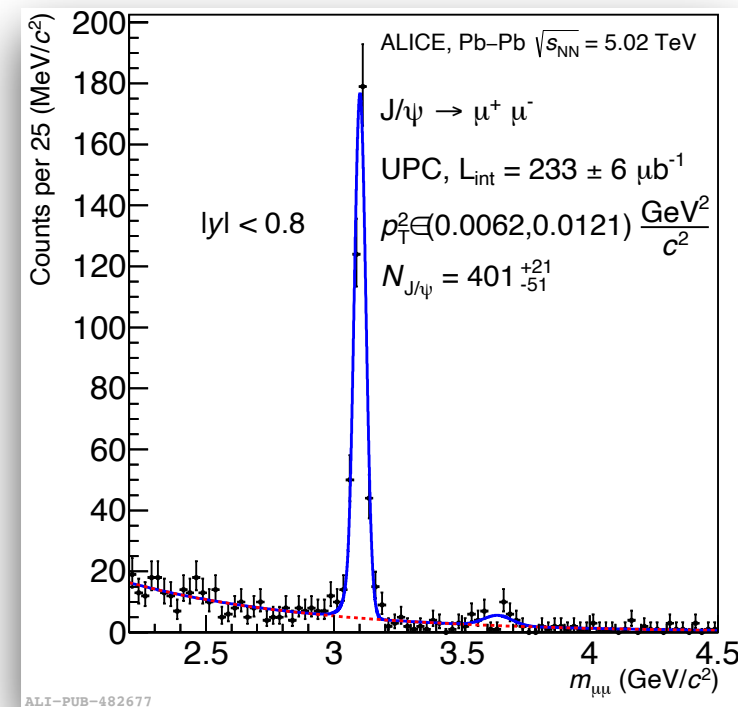
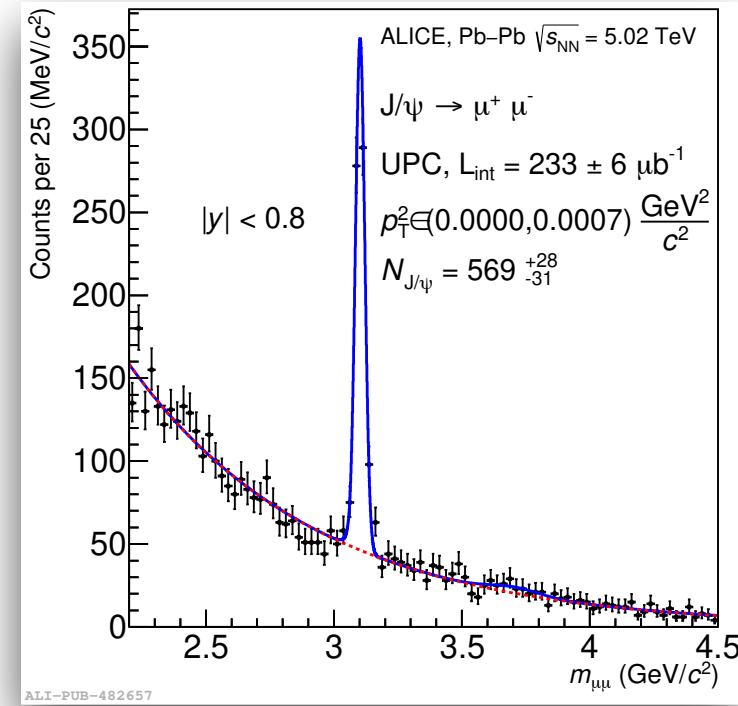


Very clear signals

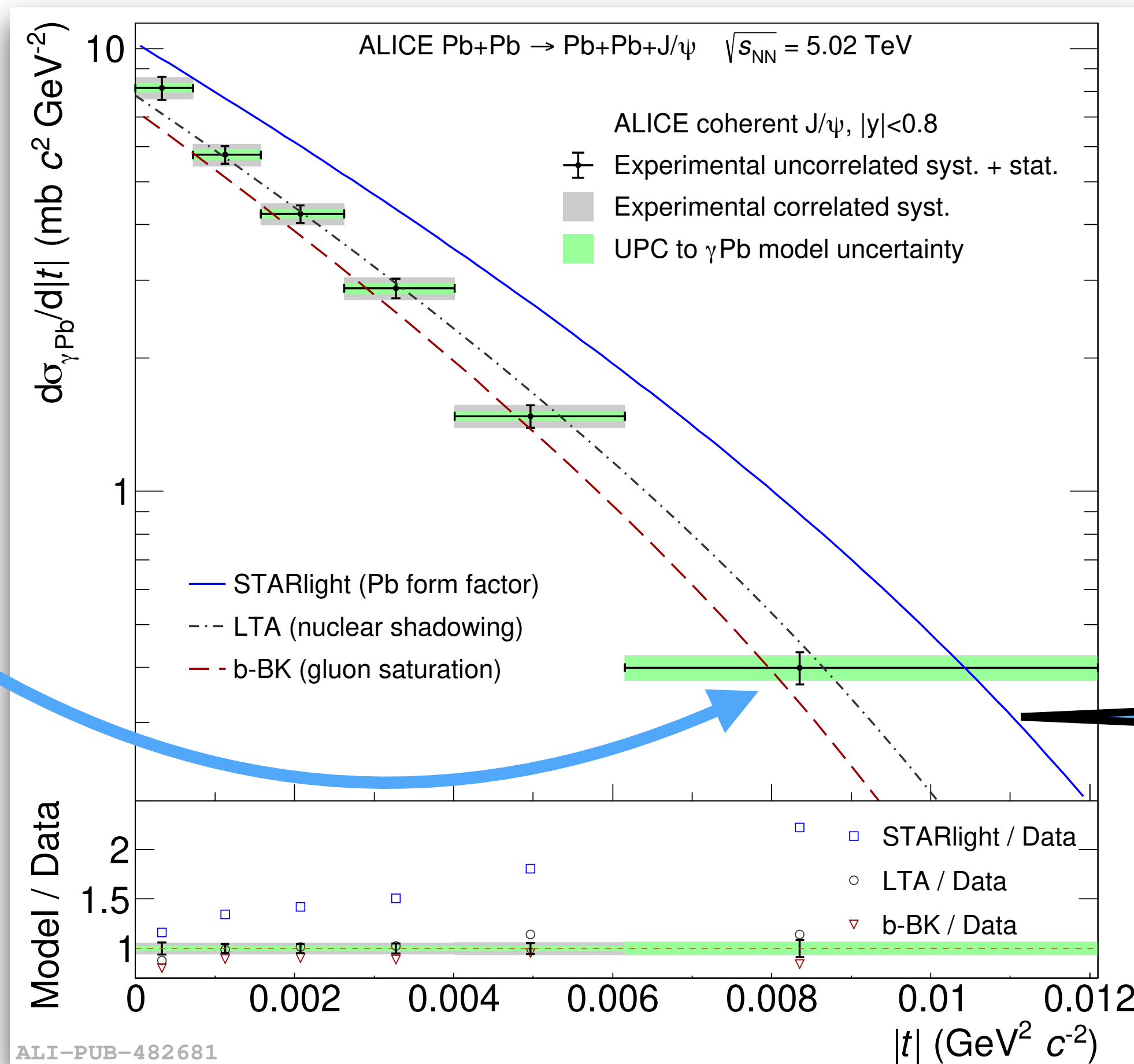
ALICE, PLB 817(2021) 136280

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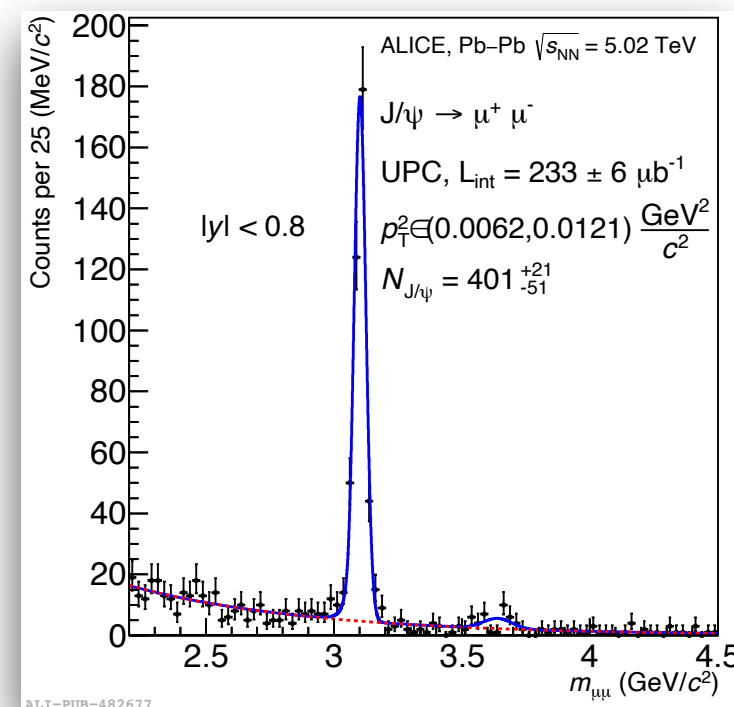
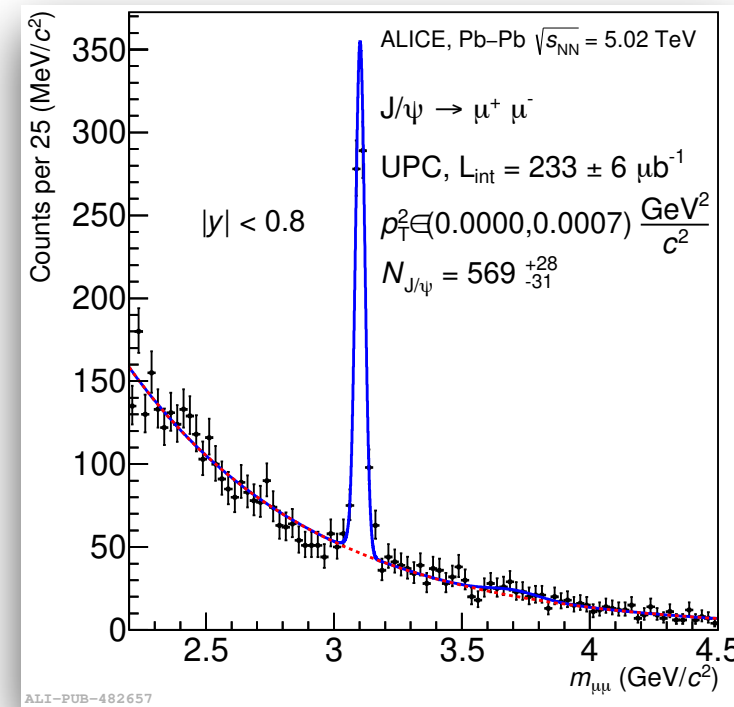


A model based on the form factor does not describe data

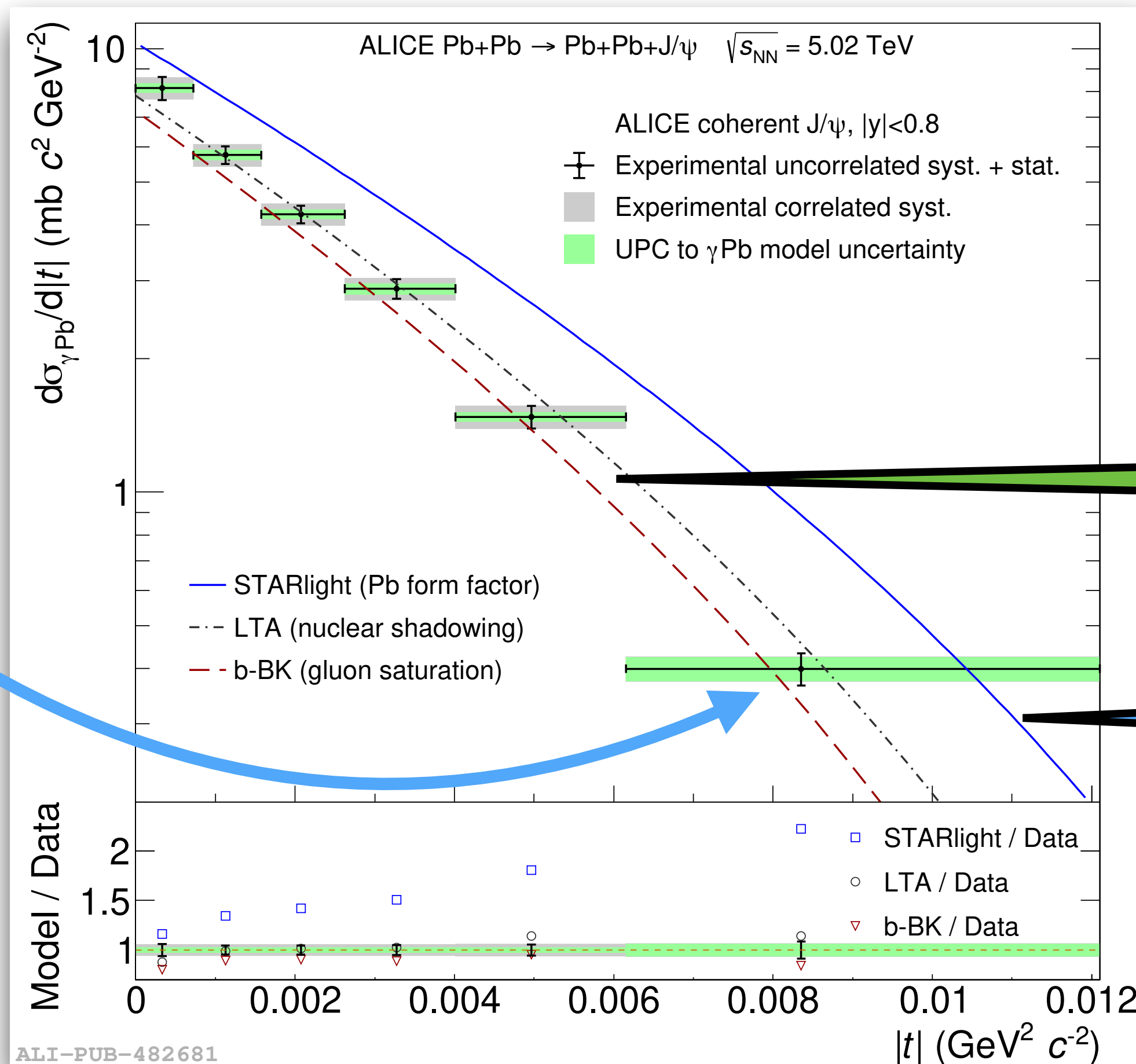
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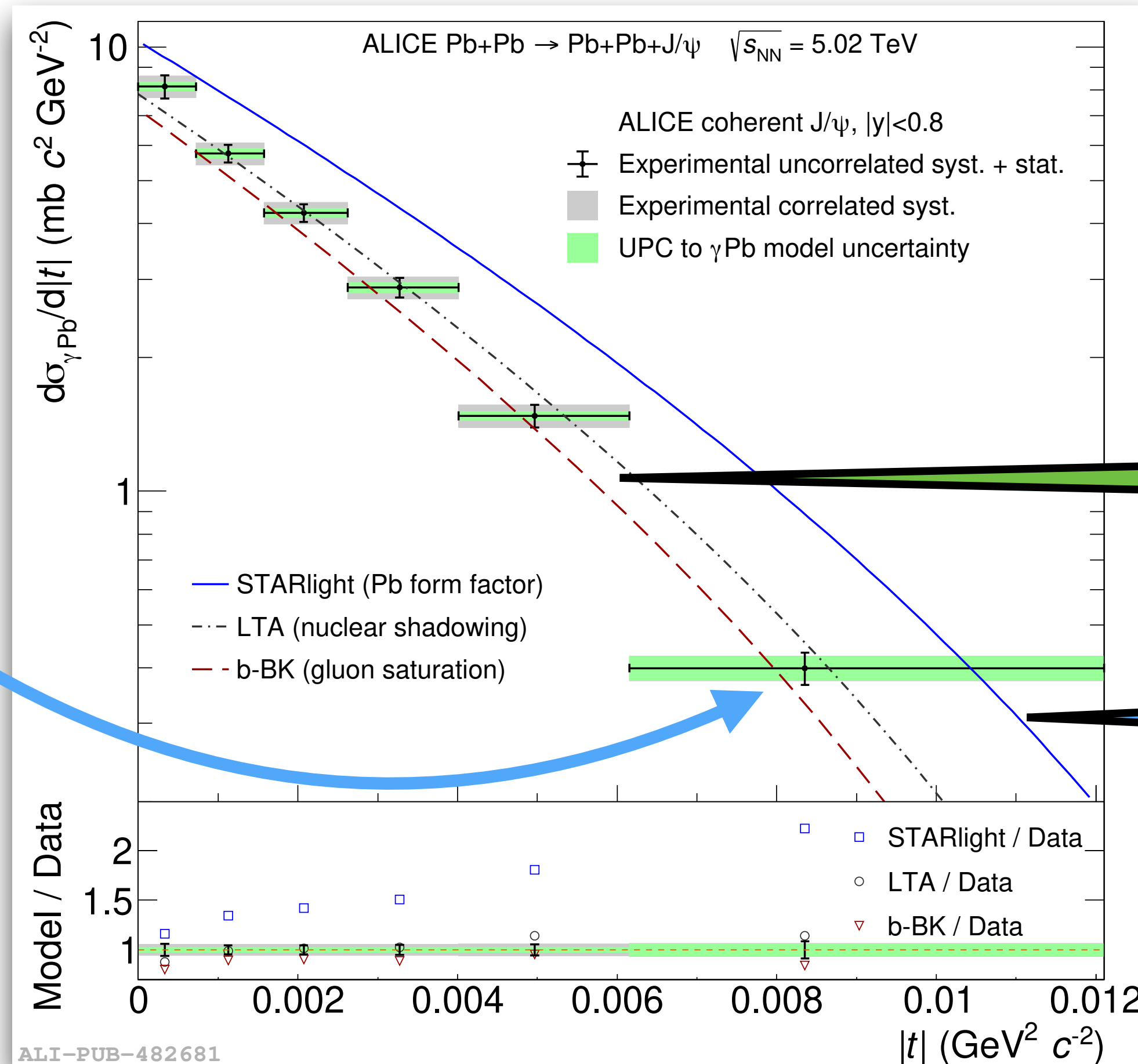
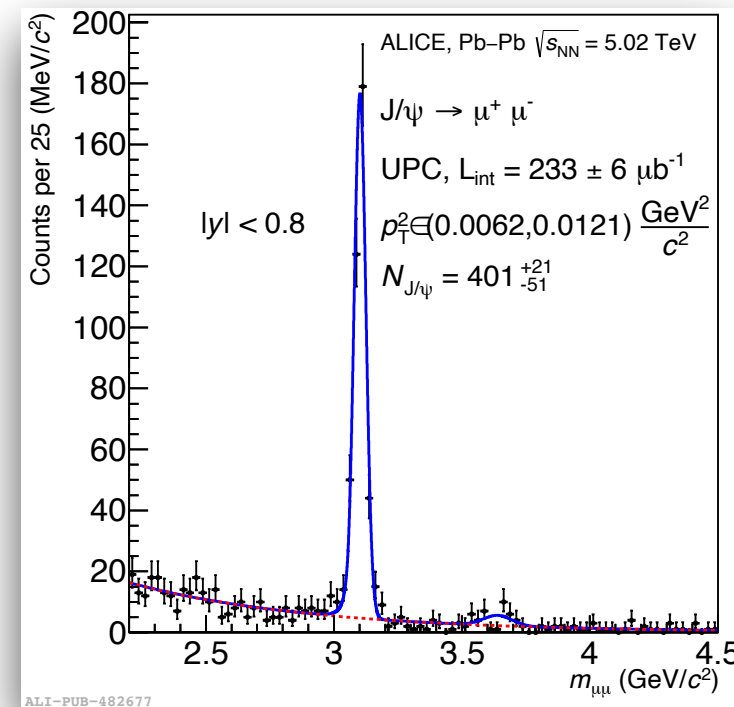
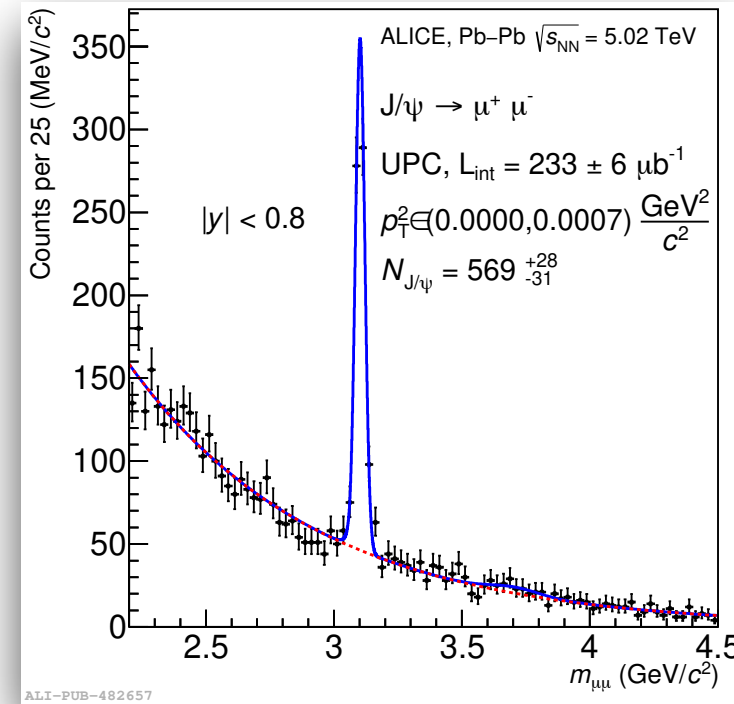
A shadowing based, and a BK computation with impact-parameter dependence, close to data

A model based on the form factor does not describe data

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 BK
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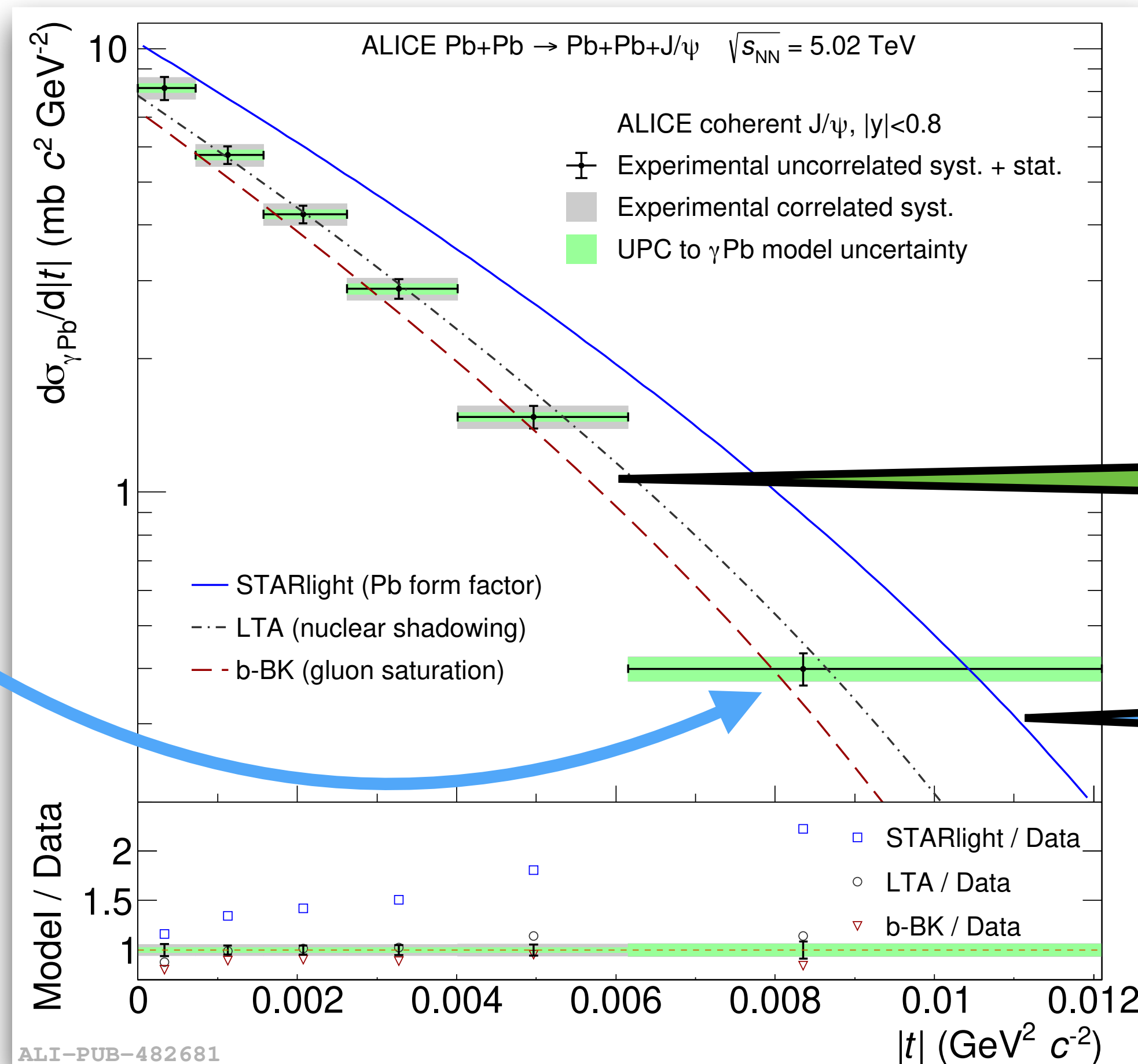
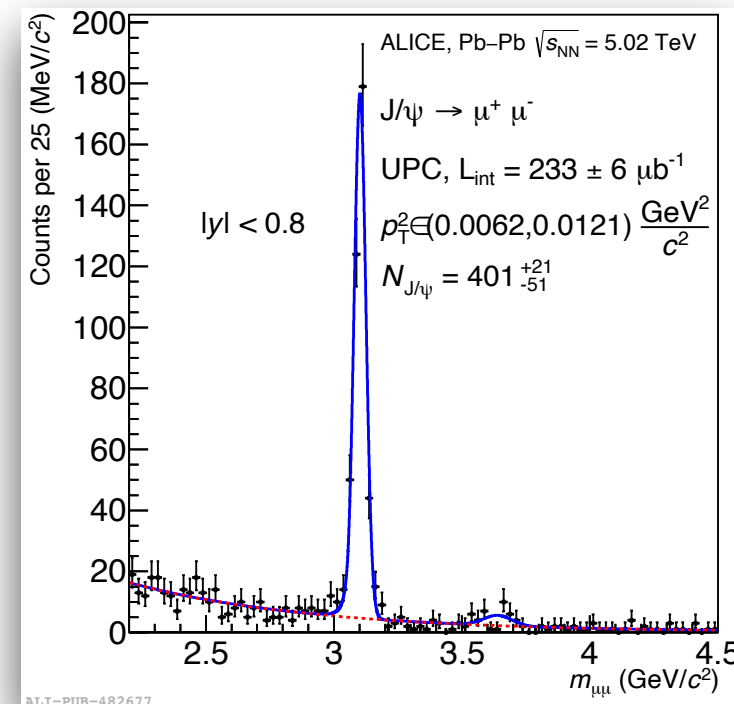
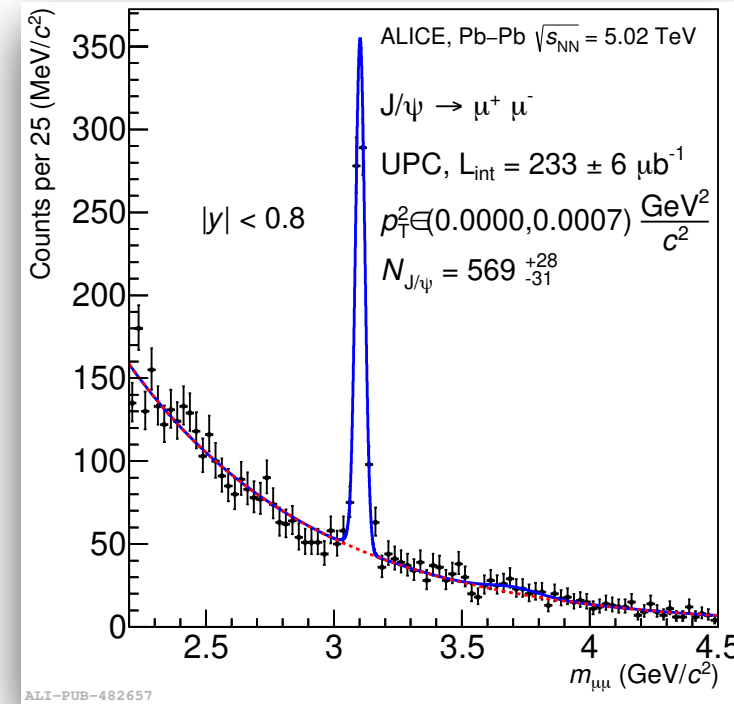
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ALICE, PLB 817(2021) 136280

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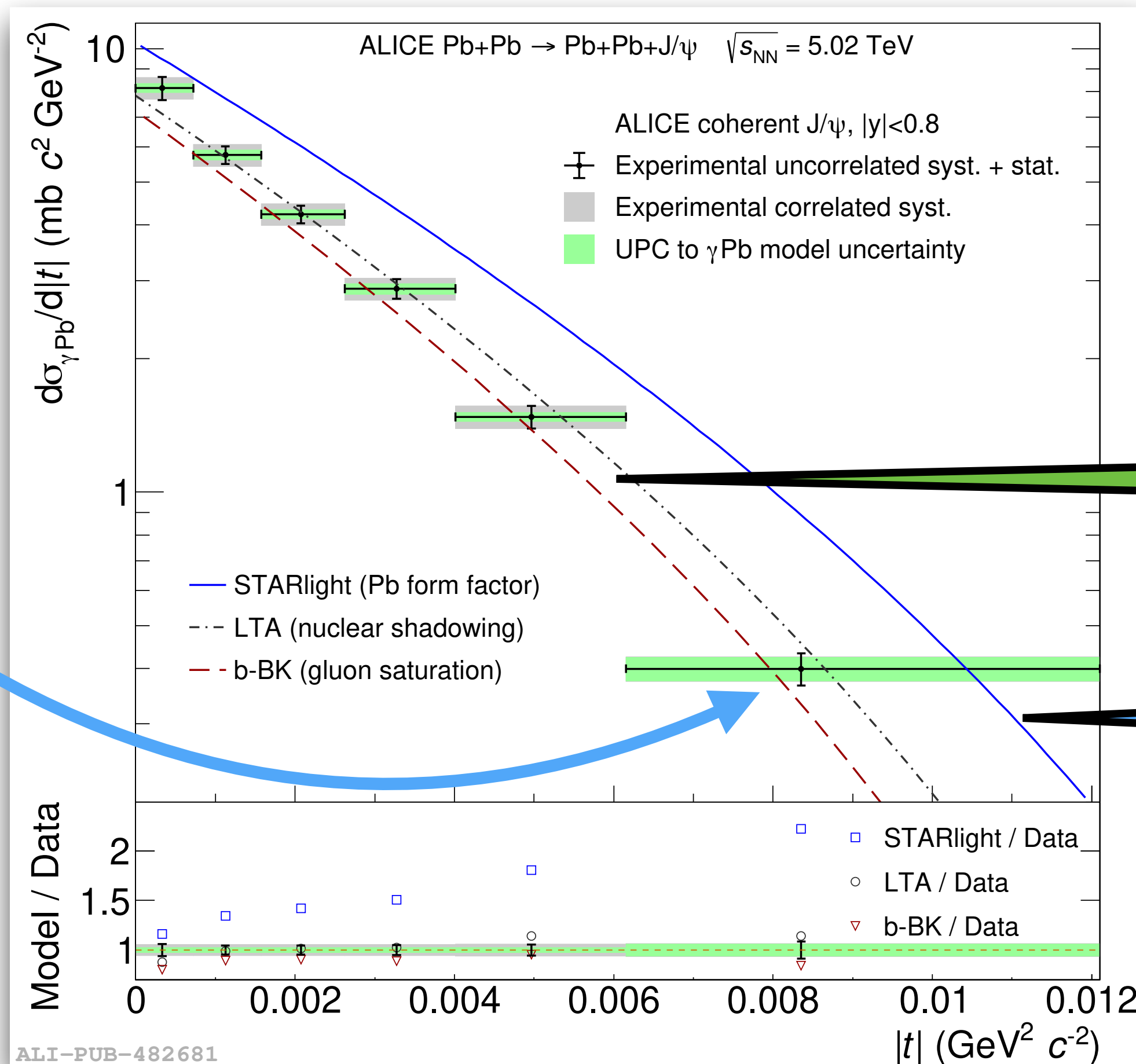
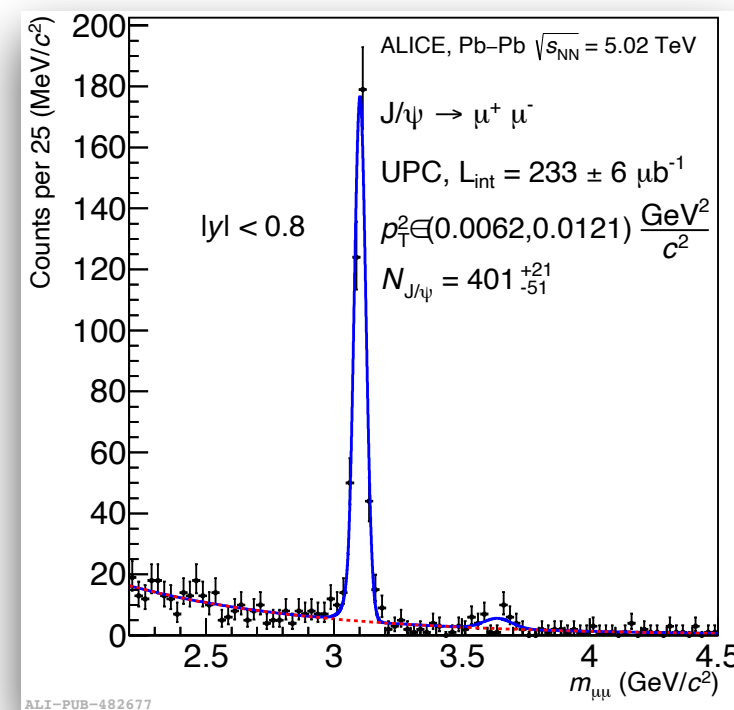
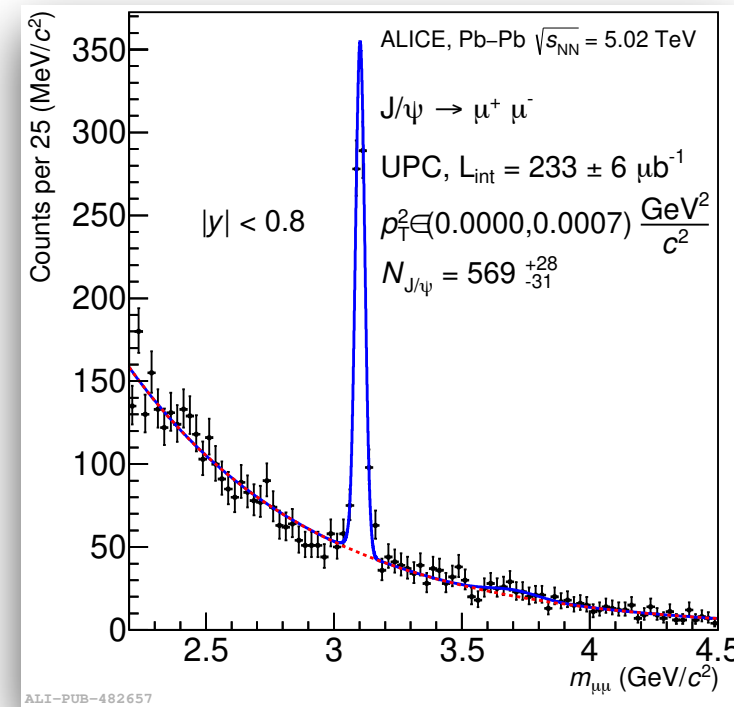
Open question:
Can we reach larger $|t|$ at the LHC?

Very clear signals

ALICE, PLB 817(2021) 136280

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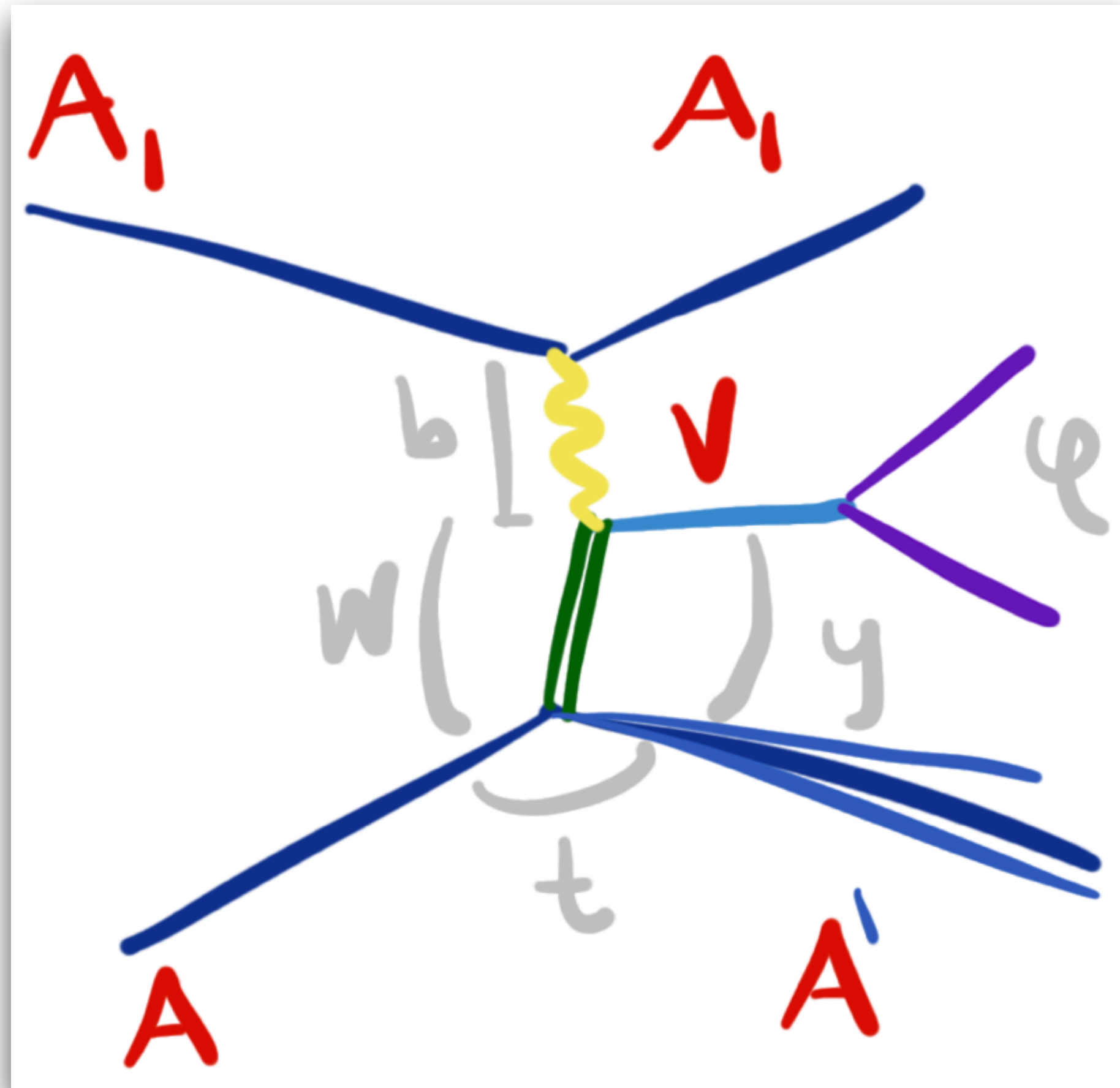
Very clear signals

ALICE, PLB 817(2021) 136280

Use 0n0n events to suppress incoherent production

$$\langle A^2 \rangle - \langle A \rangle^2$$

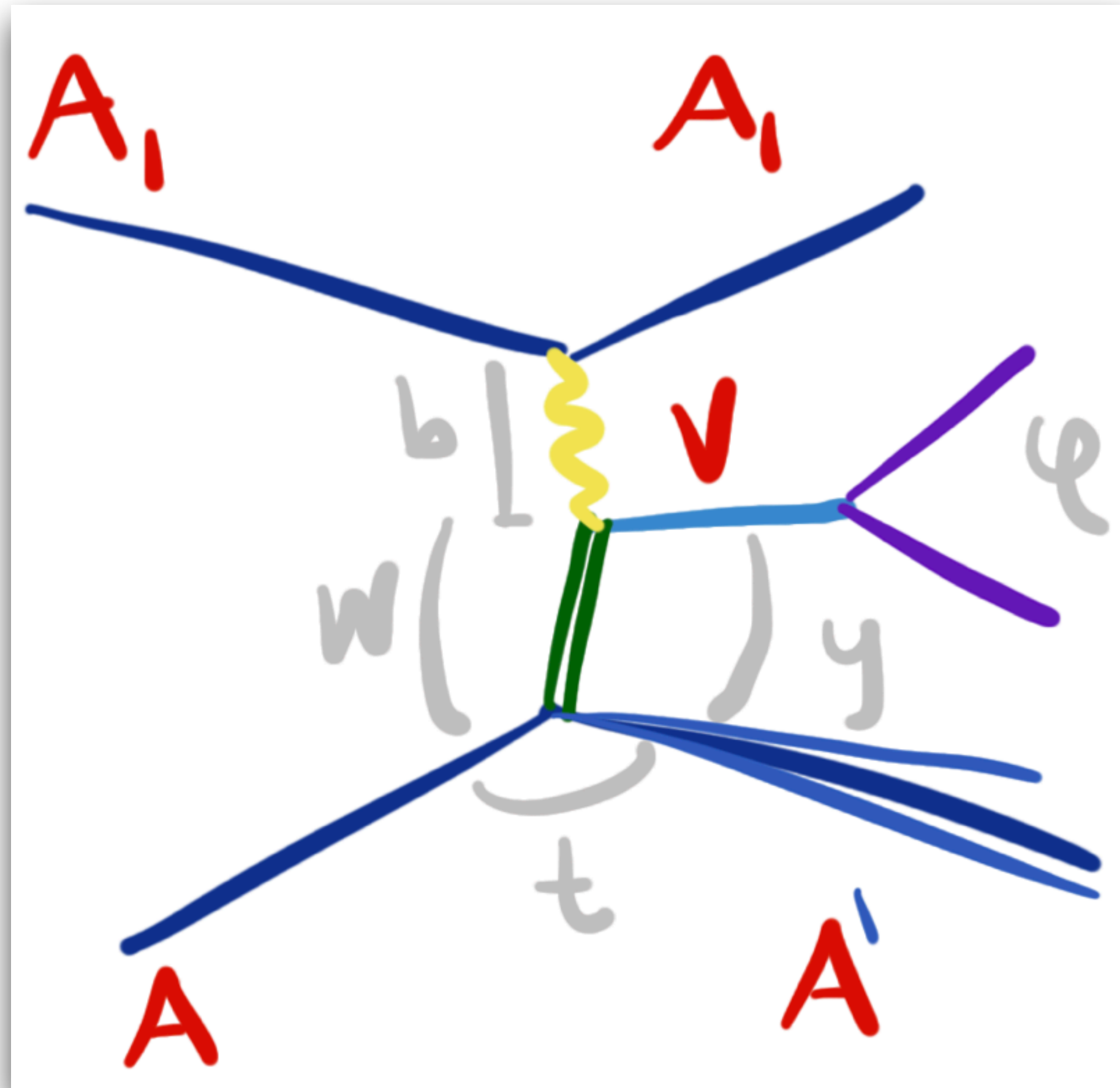
Fluctuations of quantum fields



Incoherent production
 \Rightarrow
Accessing quantum fluctuations

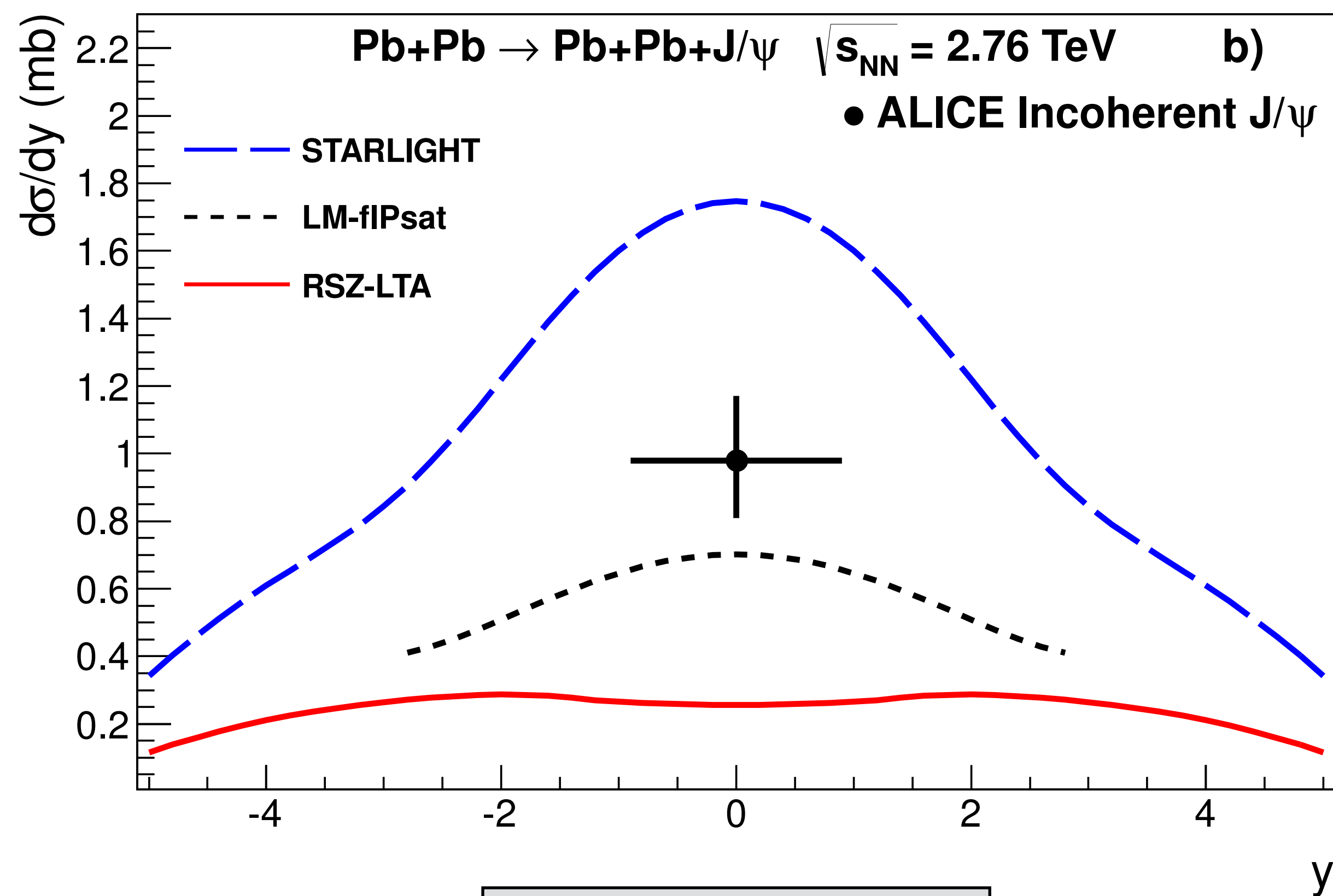
$$\langle A^2 \rangle - \langle A \rangle^2$$

Fluctuations of quantum fields



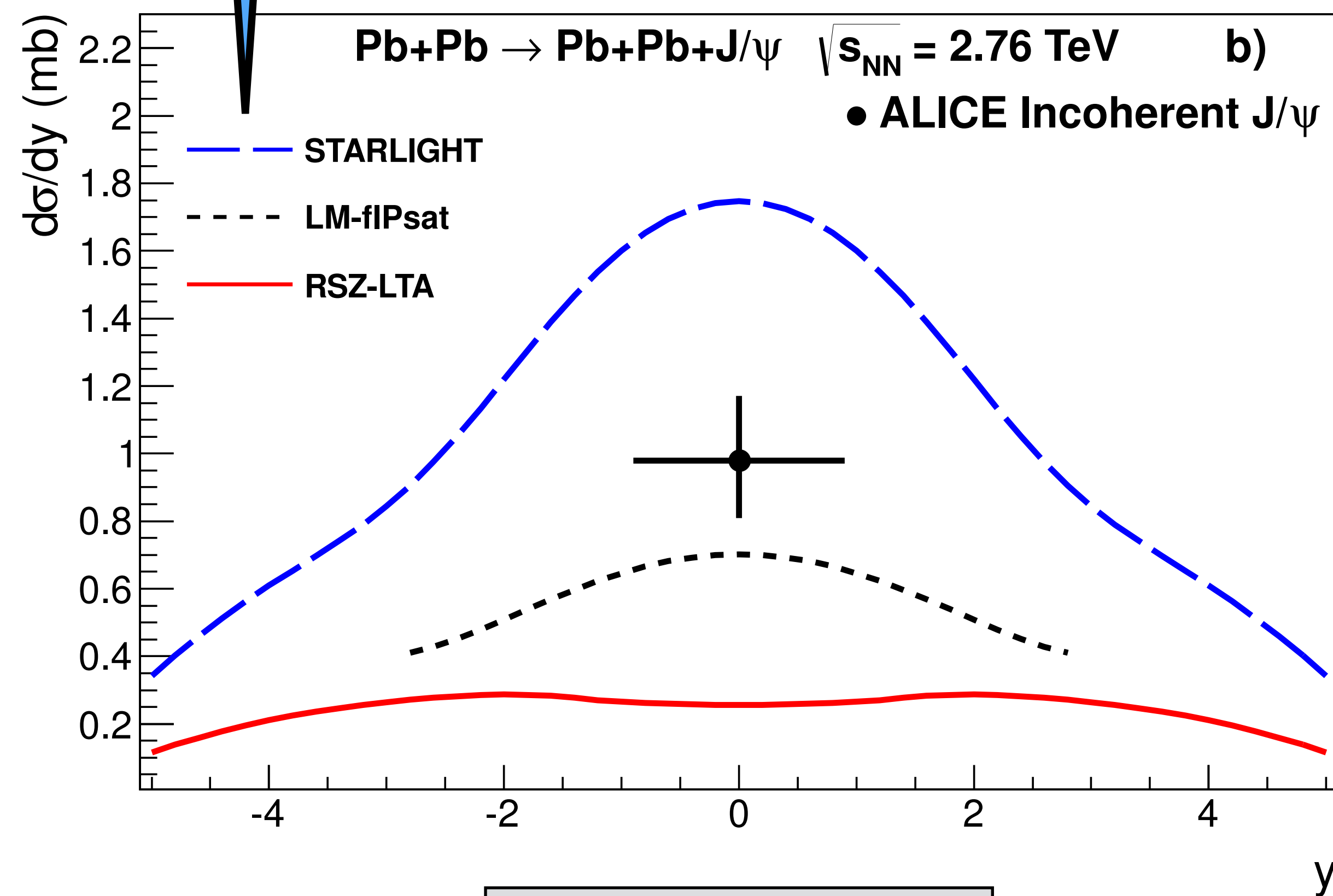
Expectations:
The variance of fluctuations provides new
signals of saturation

Incoherent production
 \Rightarrow
Accessing quantum fluctuations



ALICE, EPJ C 73 (2013) 2617

Models do not describe data, but large uncertainties in models and in data



ALICE, EPJ C 73 (2013) 2617

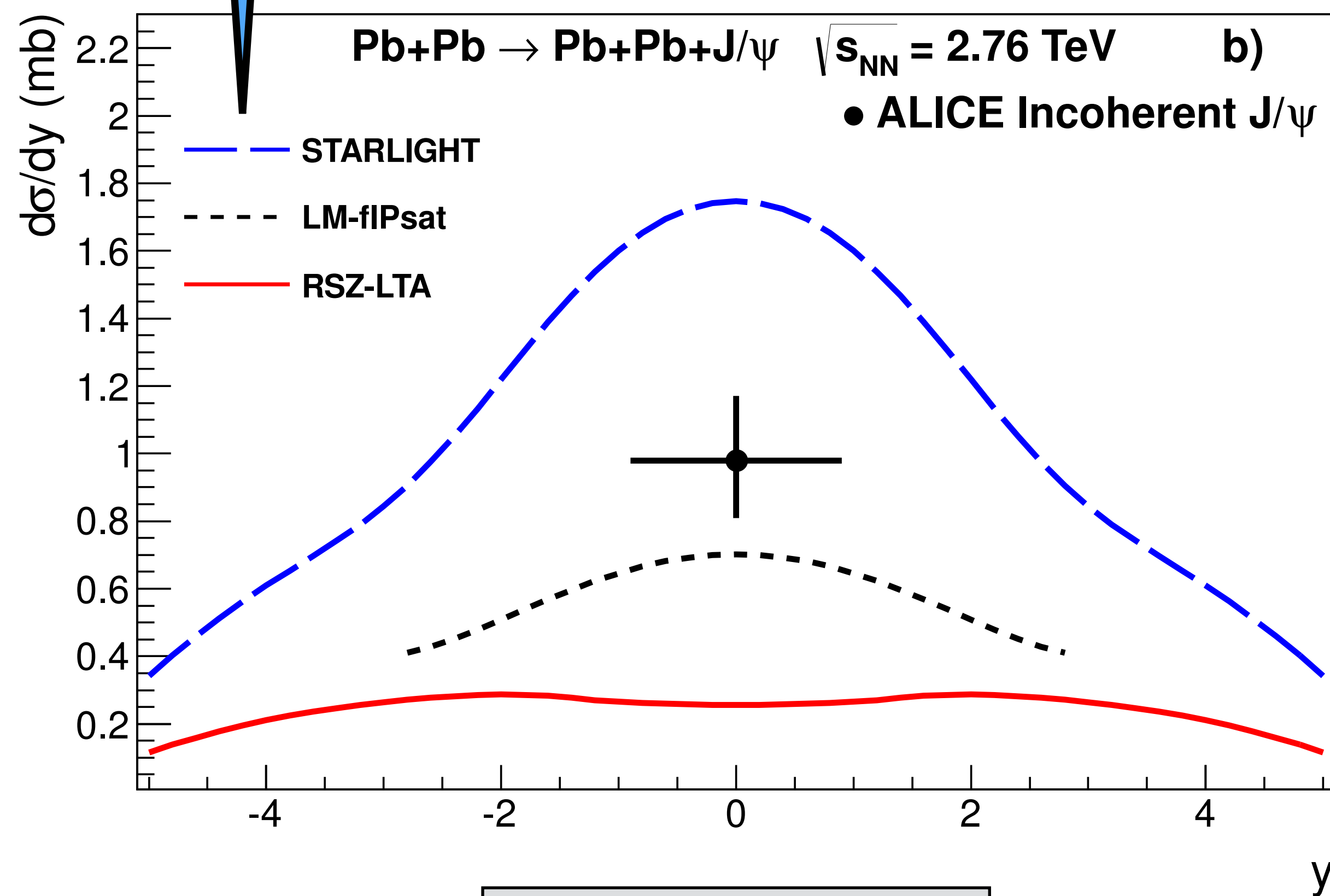
J/ψ

Incoherent J/ψ as seen by ALICE

Run 2

New data being analysed

Models do not describe data, but large uncertainties in models and in data



ALICE, EPJ C 73 (2013) 2617

J/ψ

Incoherent J/ψ as seen by ALICE

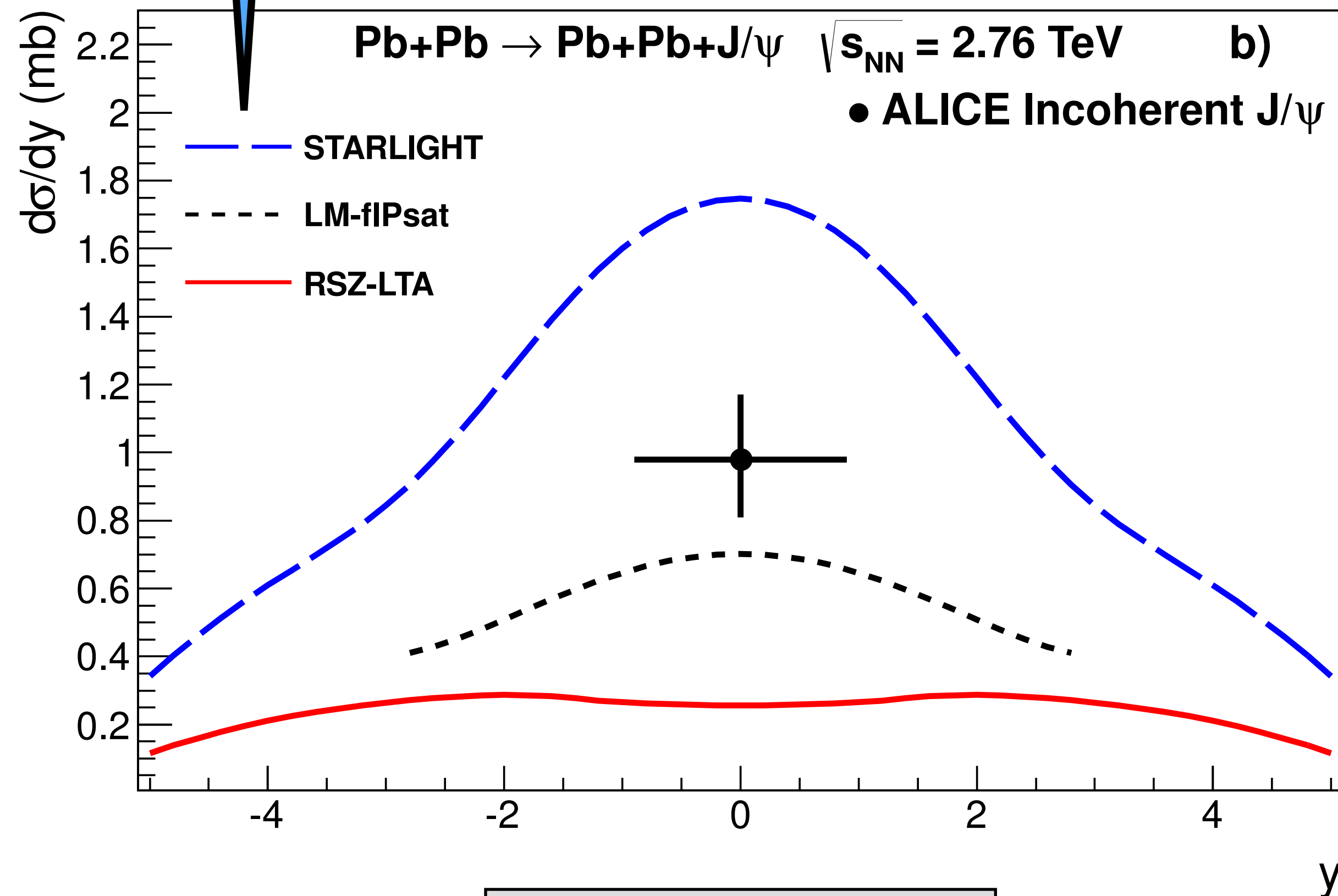
Run 2

New data being analysed

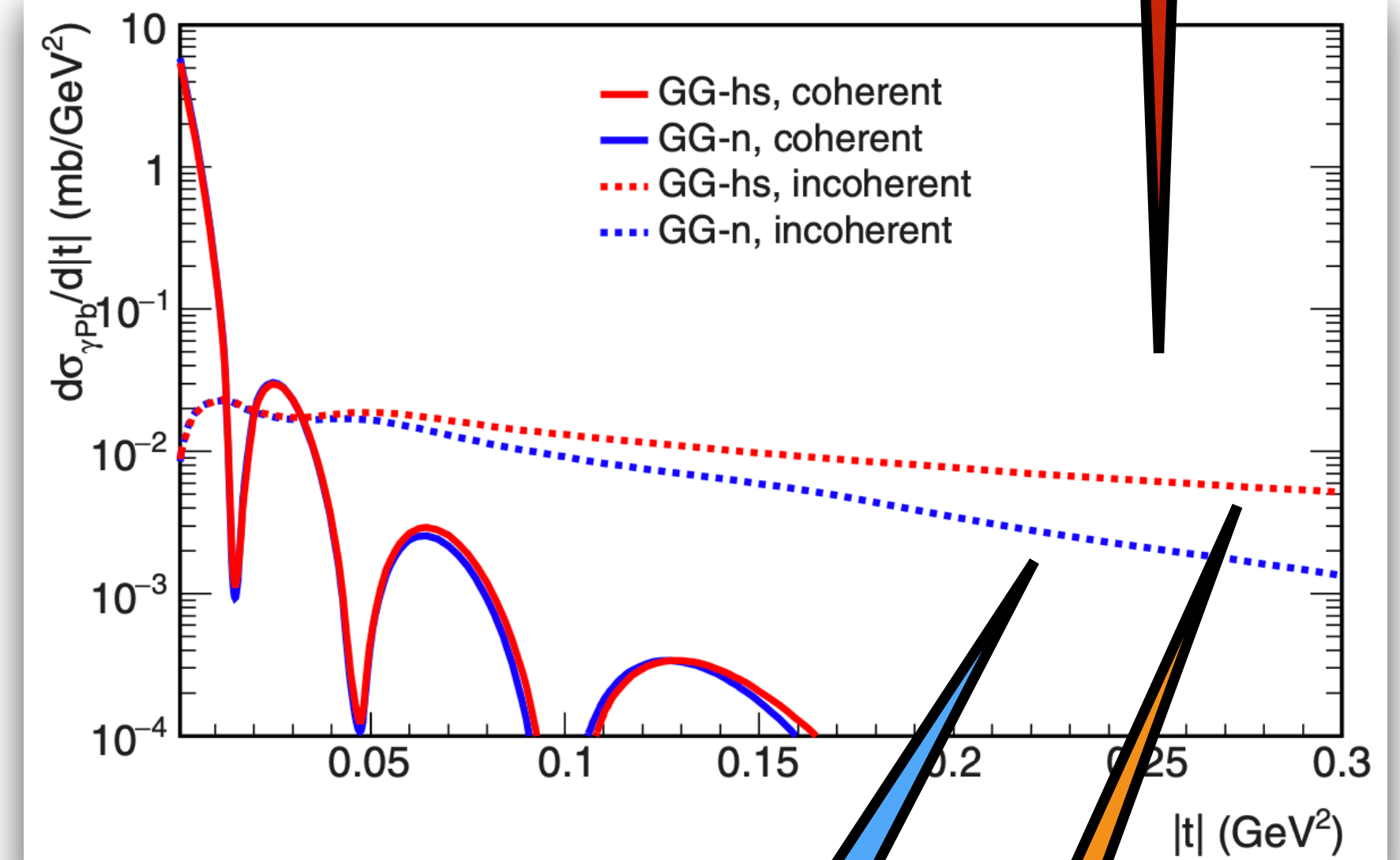
Models do not describe data, but large uncertainties in models and in data

Open question:
How much can we learn from the $|t|$ dependence?

JGC et al, PRC 97 (2018), 024901



ALICE, EPJ C 73 (2013) 2617



Nucleon fluctuations

Sub-nucleon fluctuations

J/ψ

Incoherent J/ψ as seen by ALICE

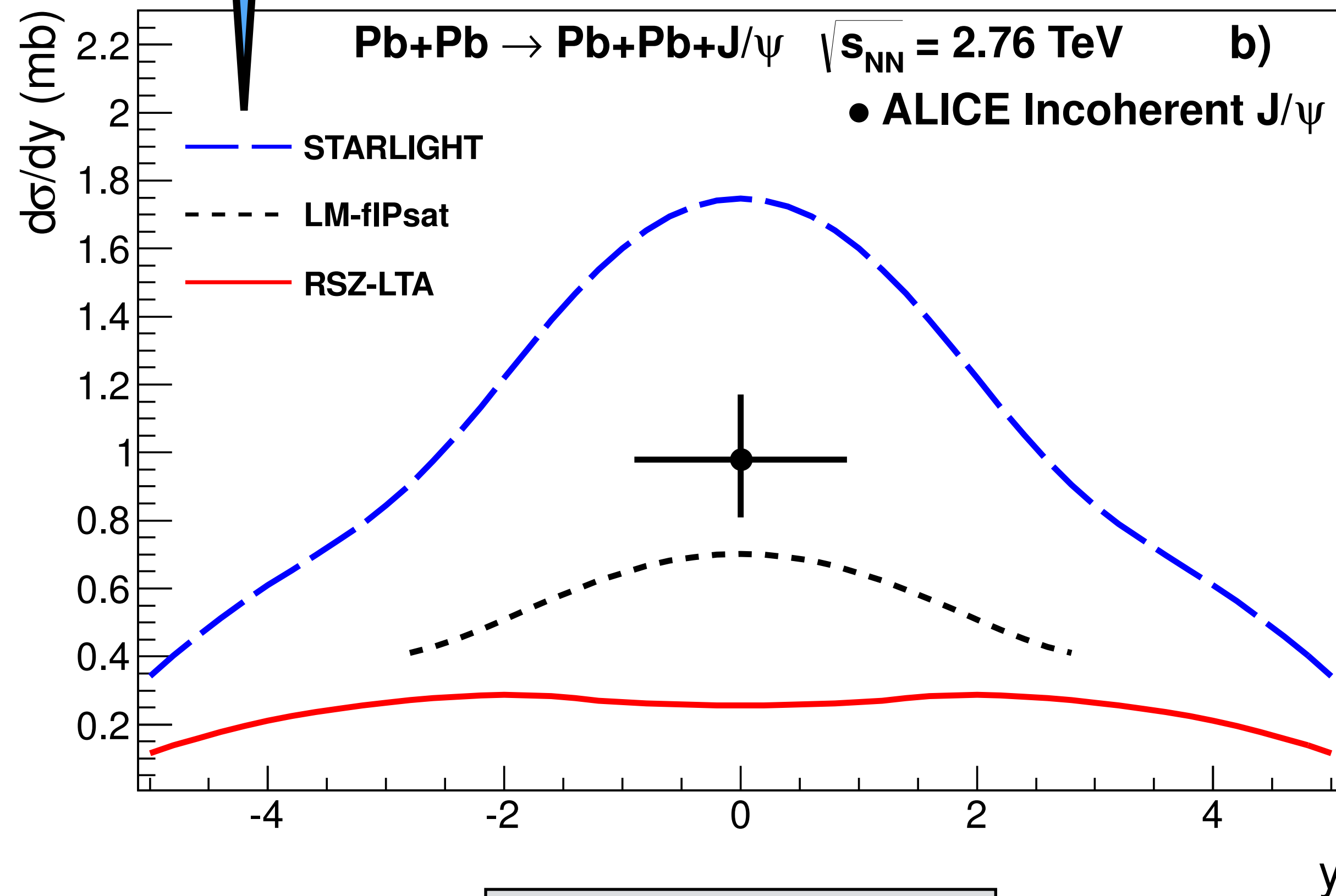
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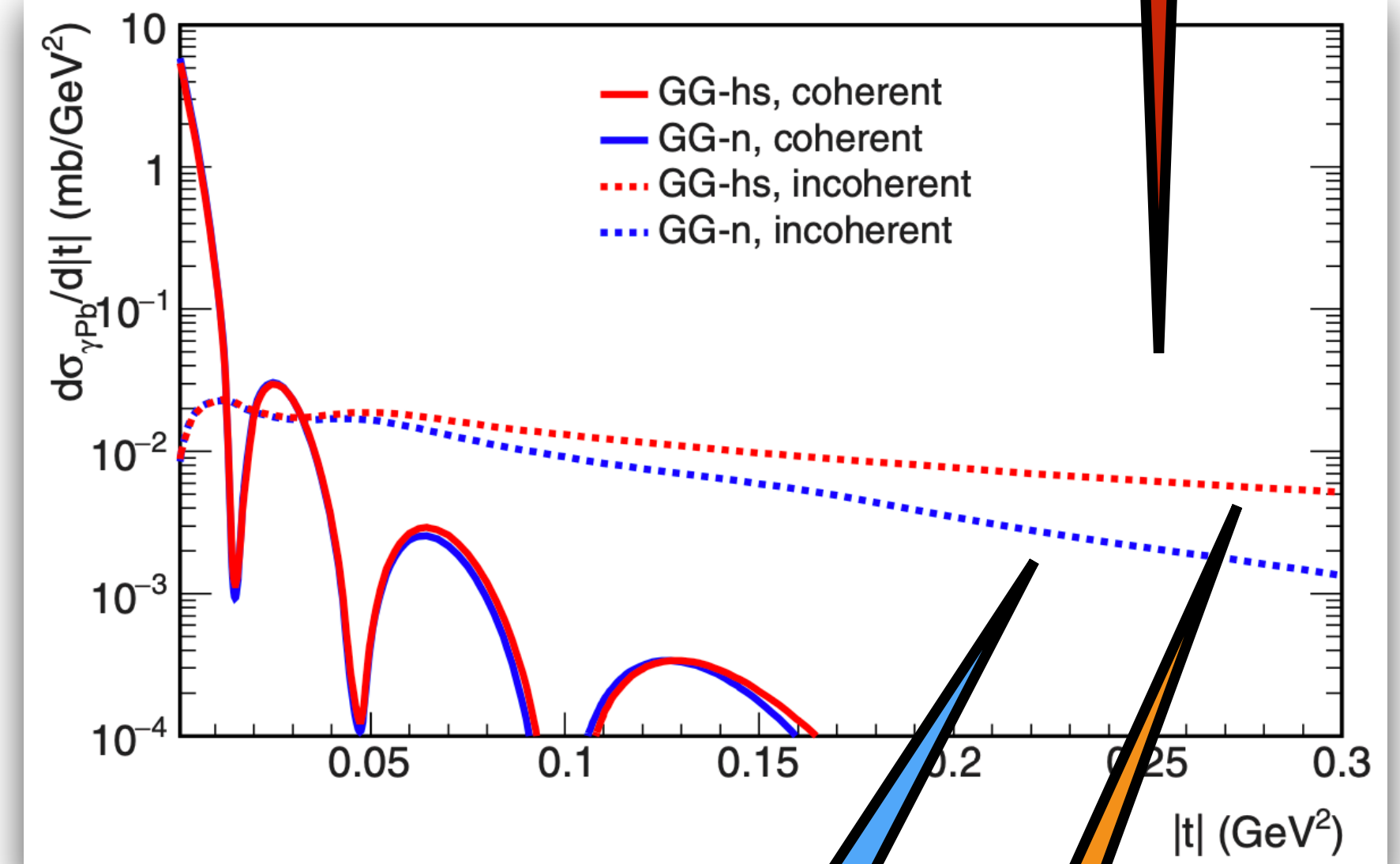
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JGC et al, PRC 97 (2018), 024901



ALICE, EPJ C 73 (2013) 2617

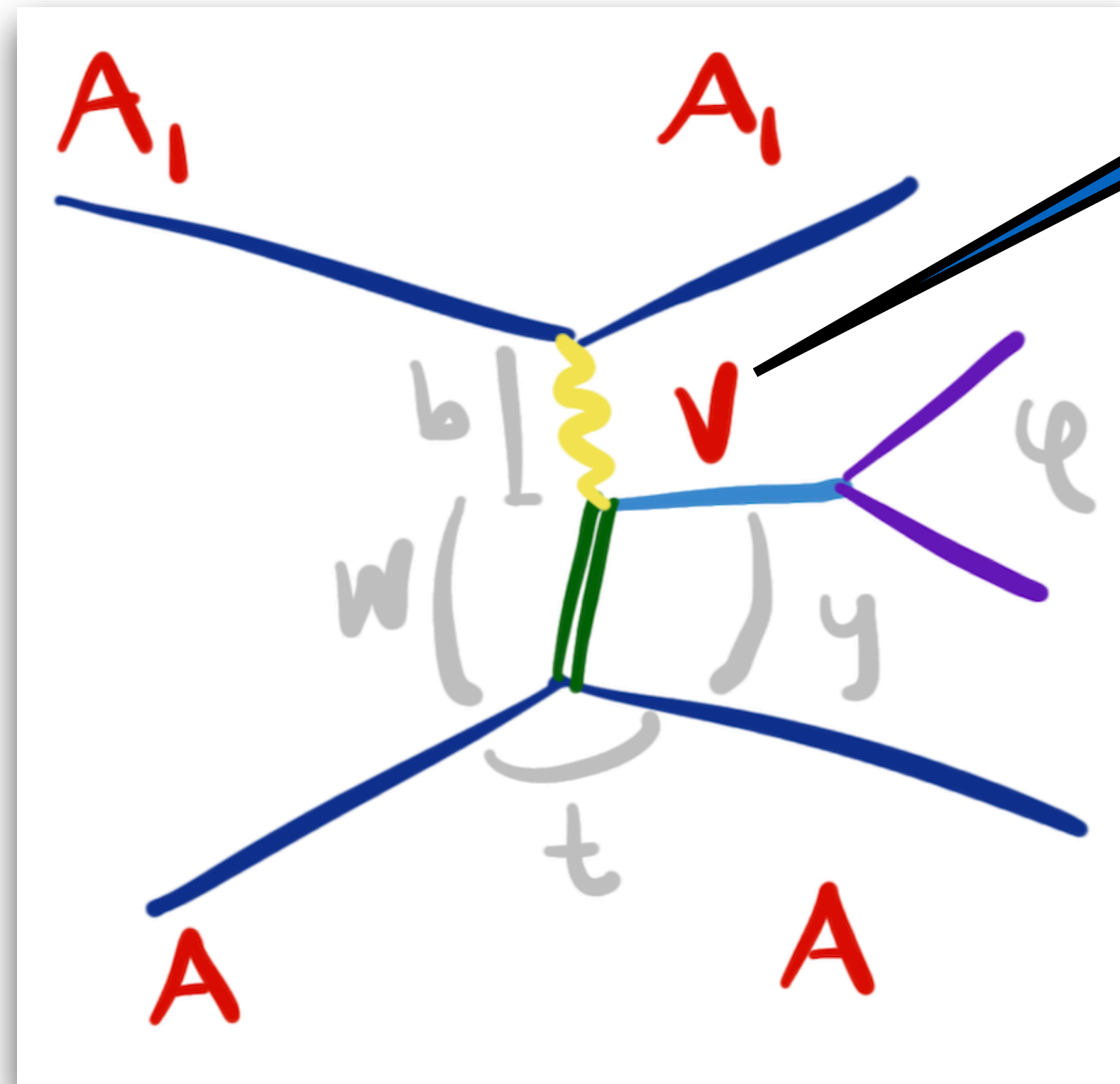


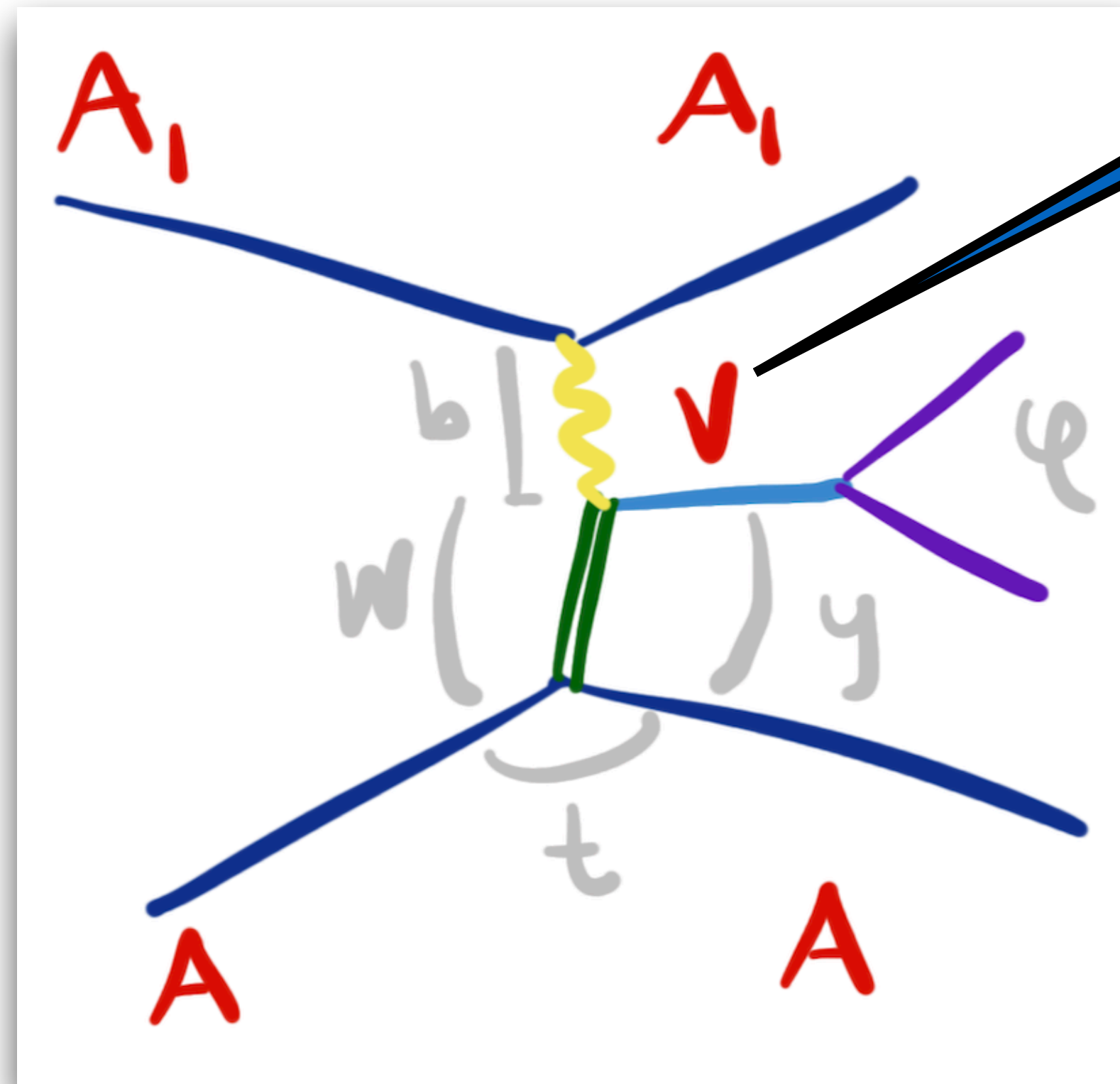
Nucleon fluctuations

Sub-nucleon fluctuations

Open question:
Can we constraint the knowledge of the wave function?

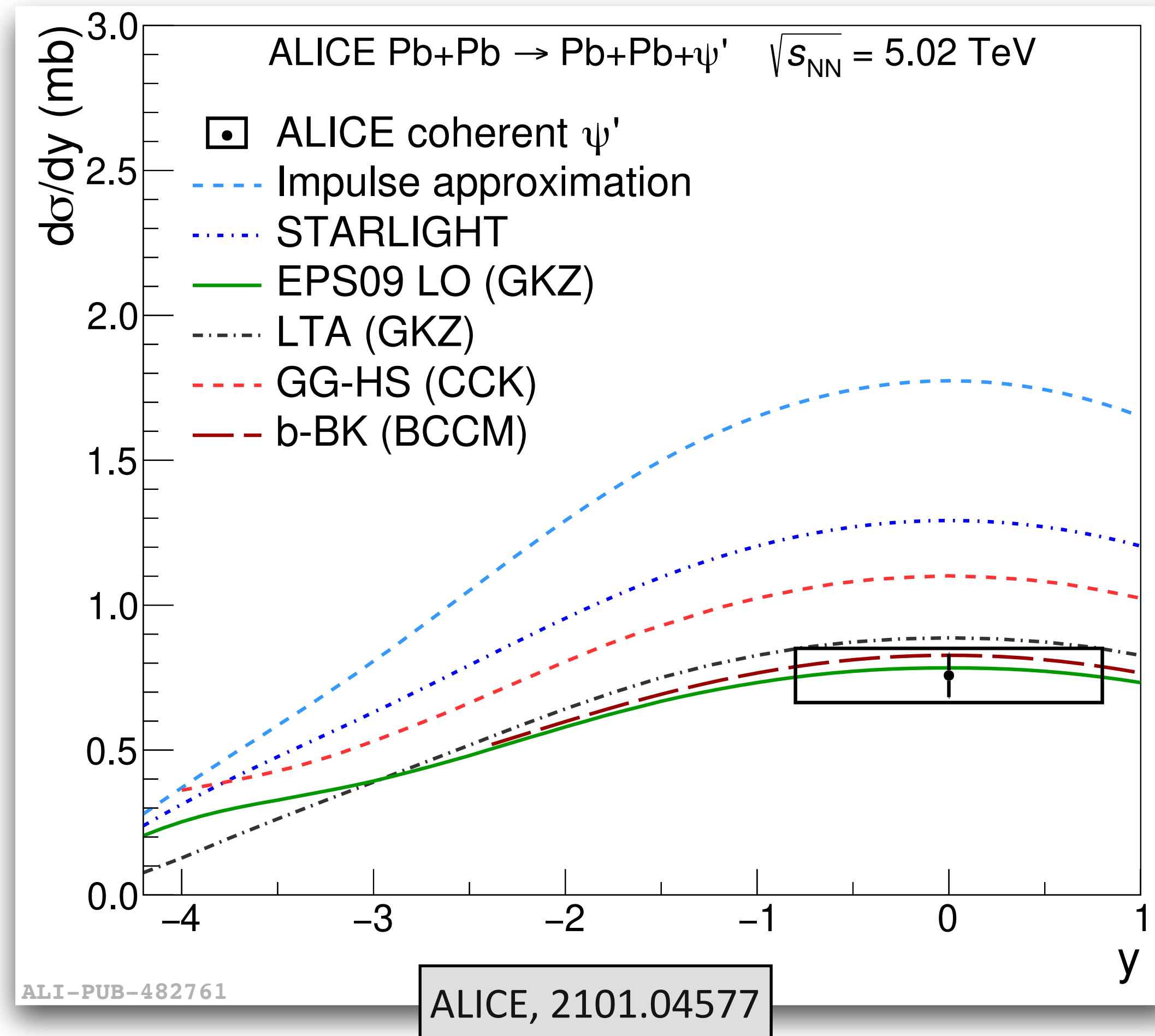
Excited states
Constraining the wave function

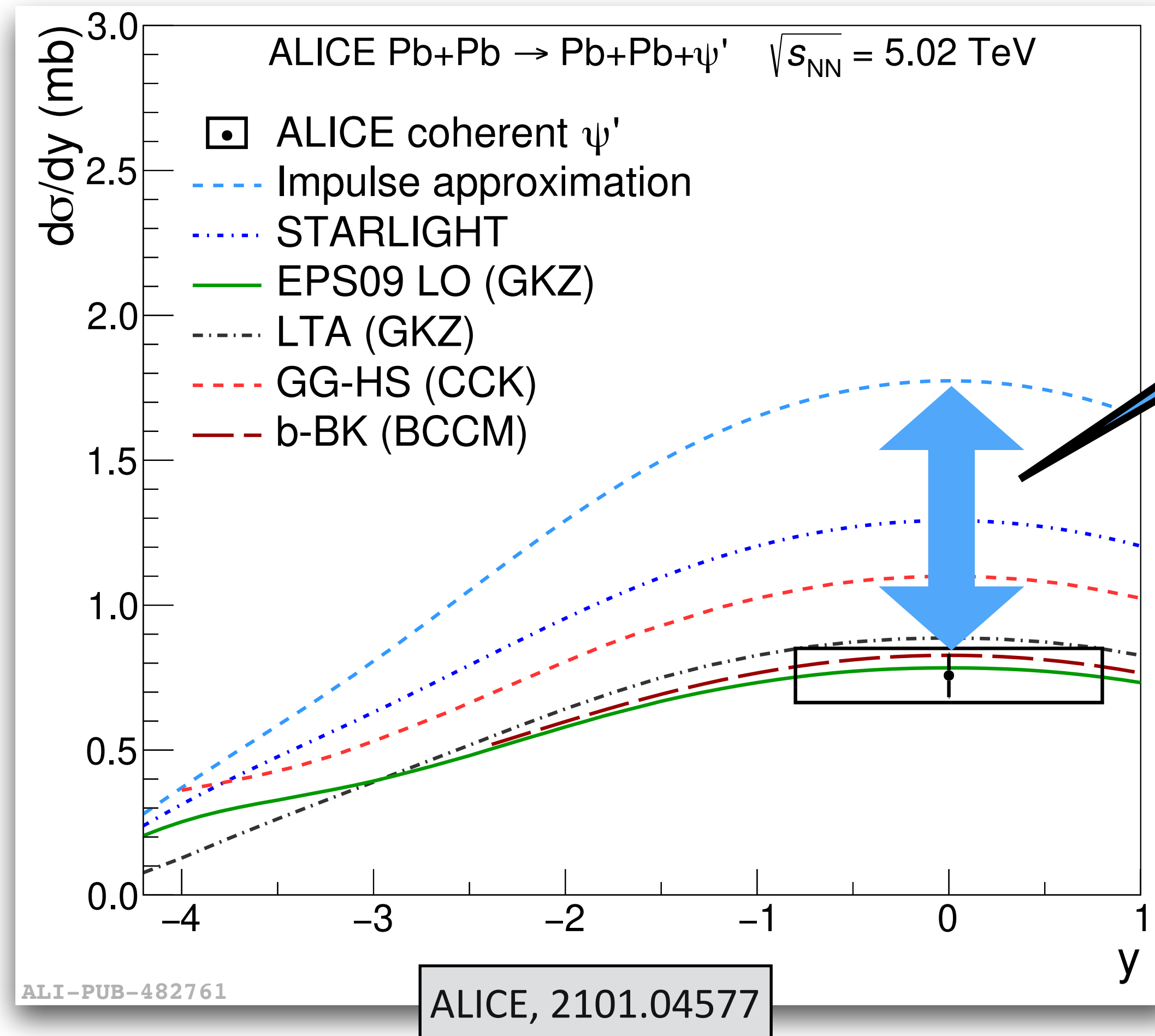




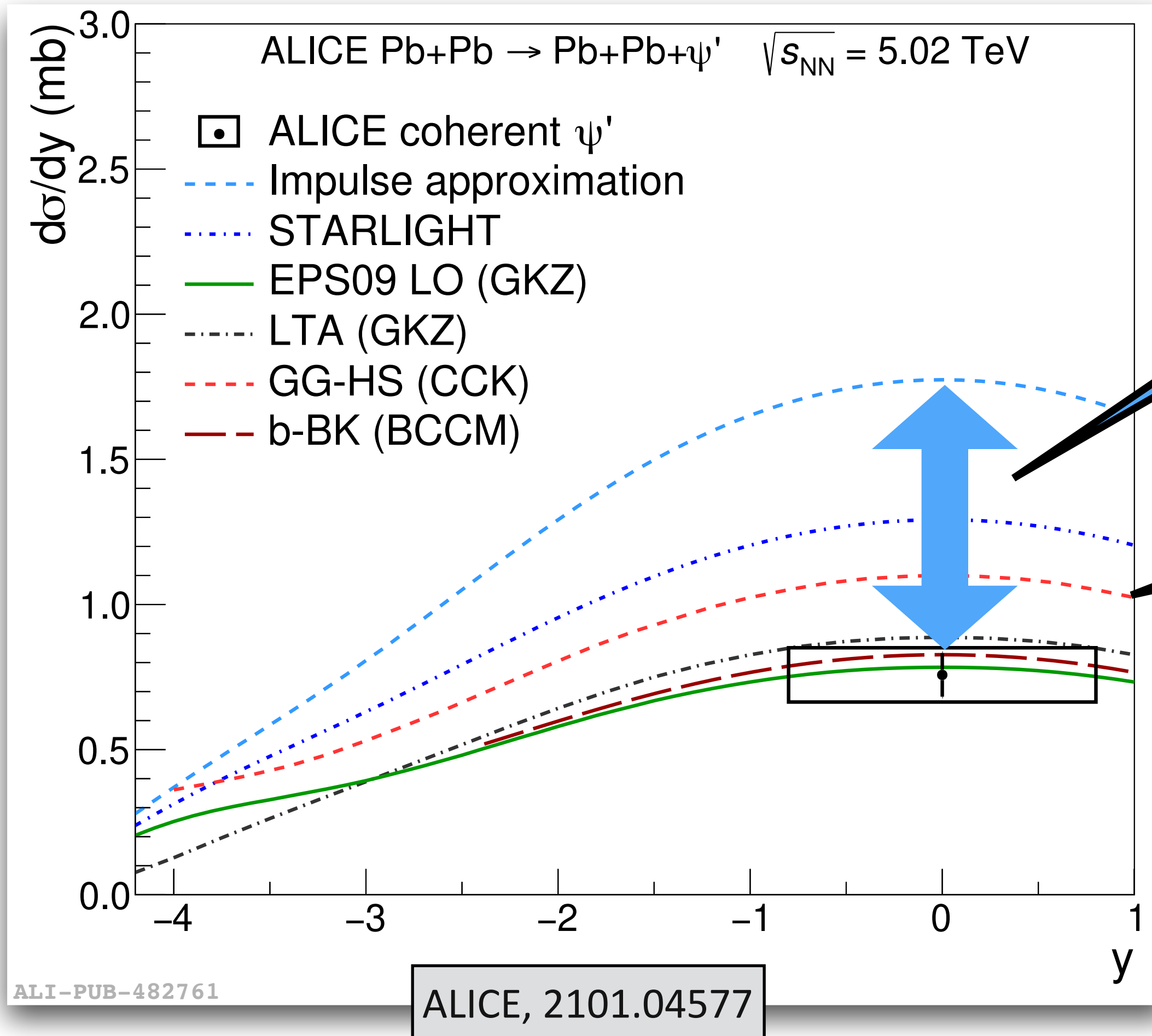
Excited states
Constraining the wave function

Expectations:
The angular momentum structure of the wave function may enhance/suppress some effects



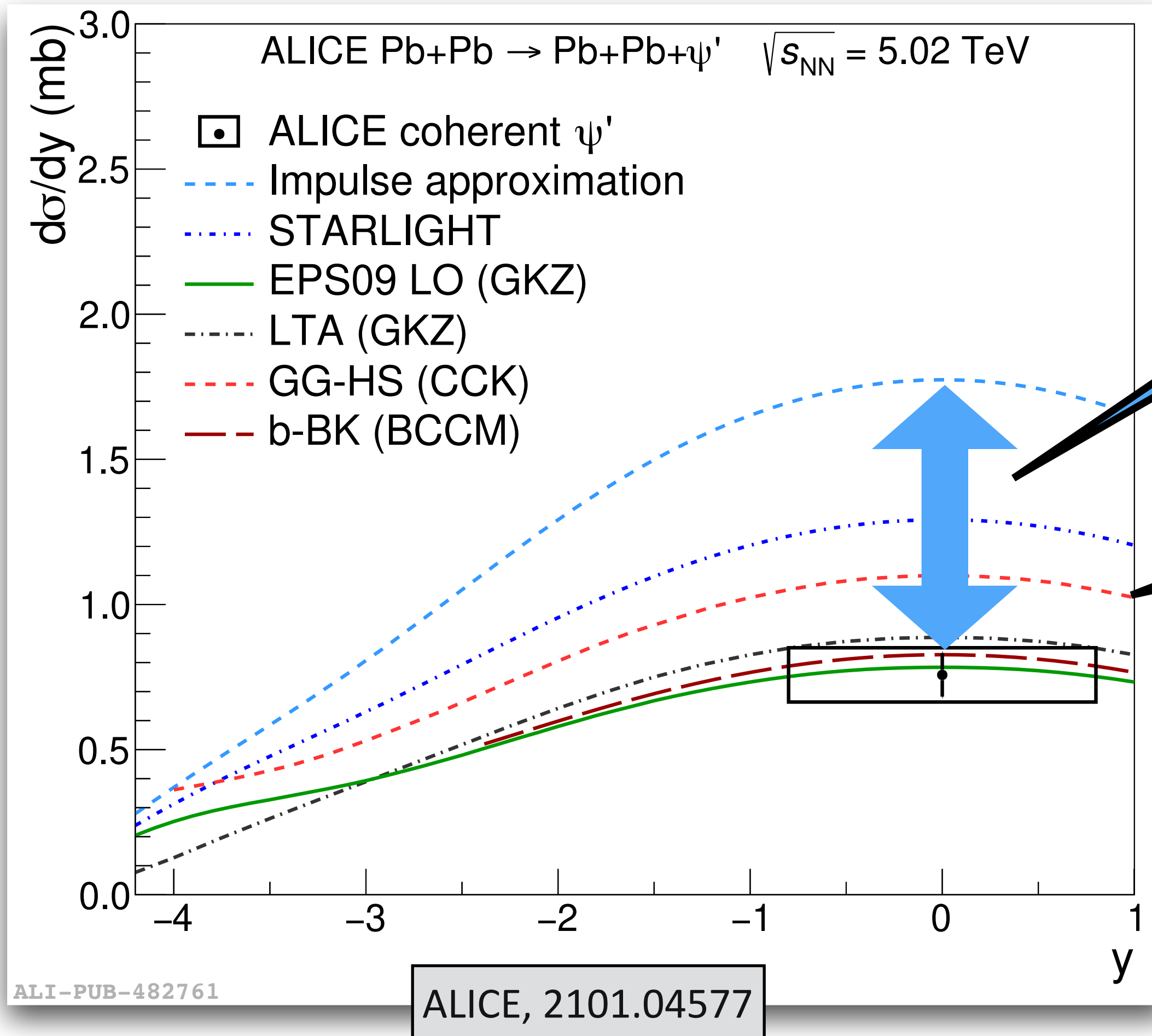


Same nuclear suppression factor as found for J/ψ



Same nuclear suppression factor as found for J/ψ

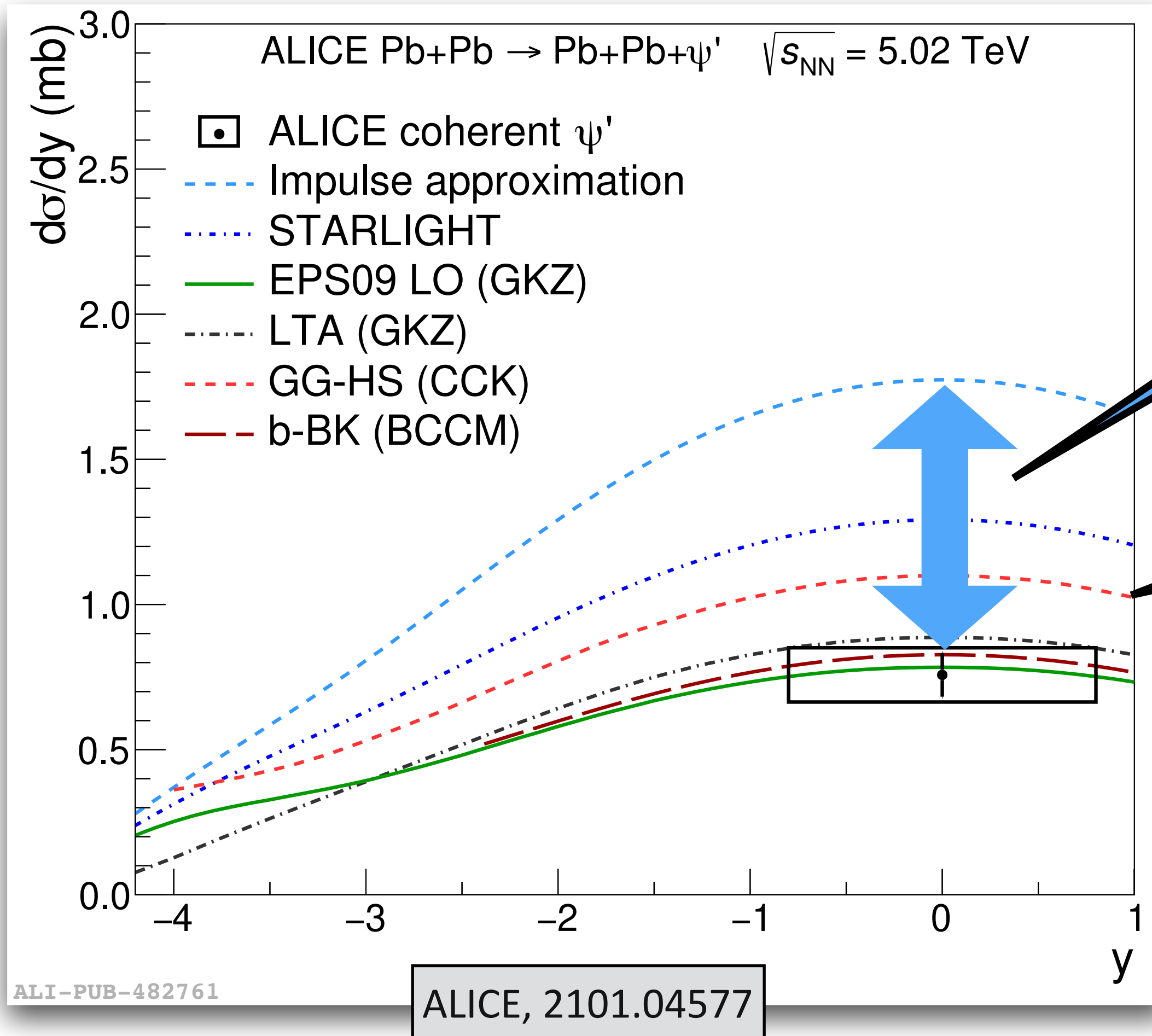
Some models that describe the J/ψ cross section do not describe $\psi(2S)$ so well



Same nuclear suppression factor as found for J/ψ

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Open question:
How much can we constrain the modelling of the wave function by comparing 1S and 2S states?



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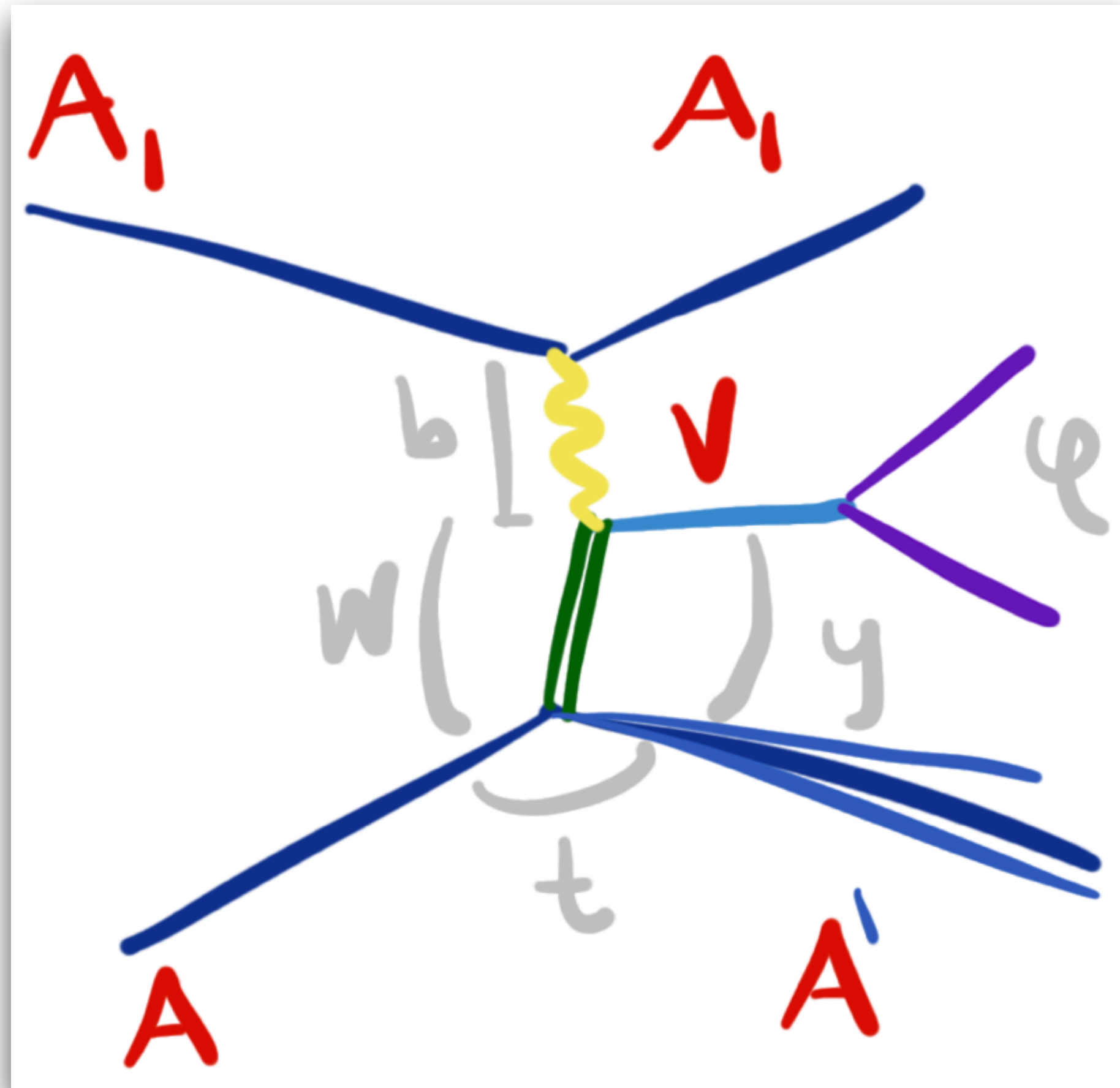
EIC

Q^2 dependence important in this context

Cepila et al, EPJC 79 (2019) 6, 495

p→n

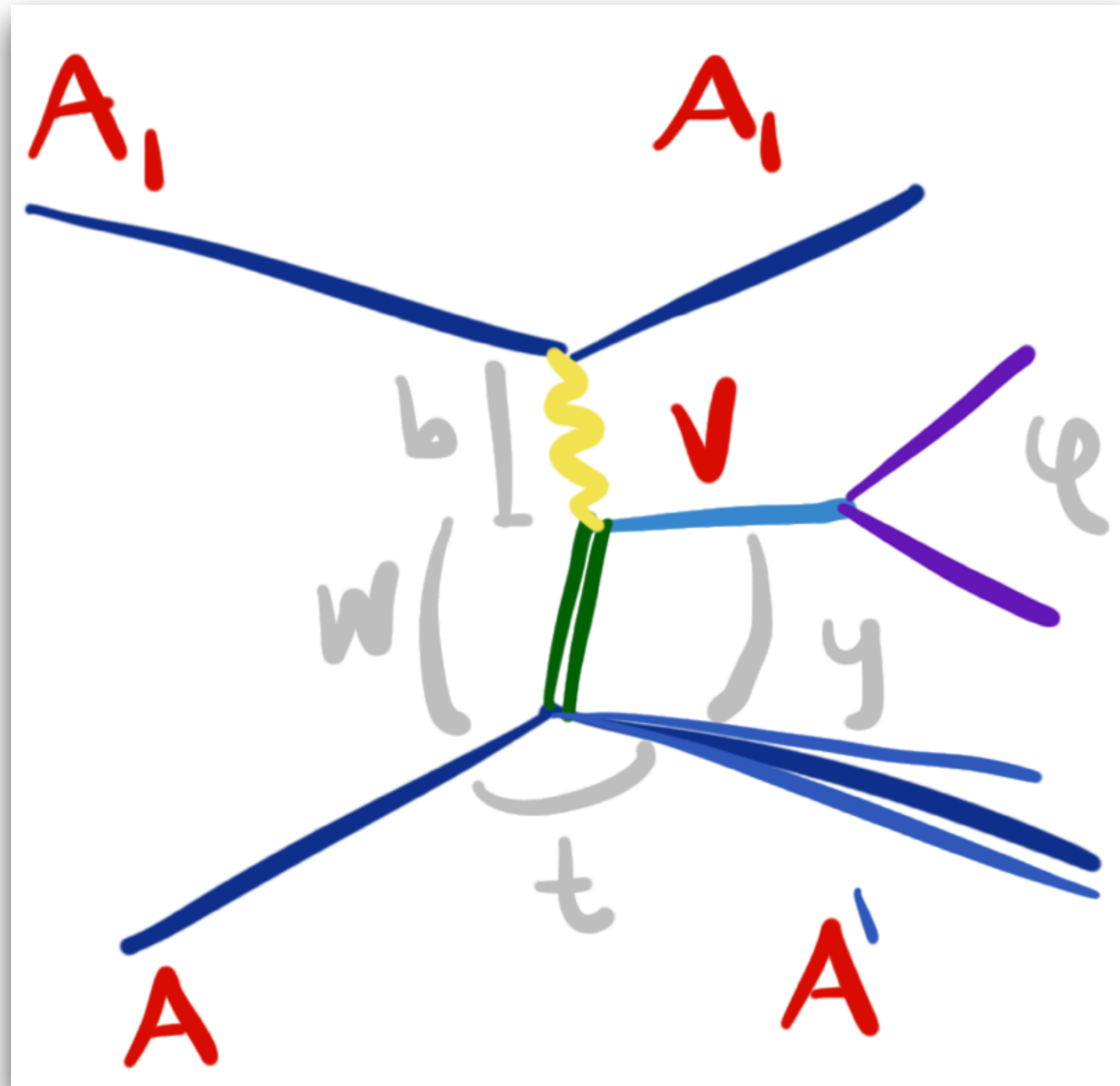
Structure of the pion



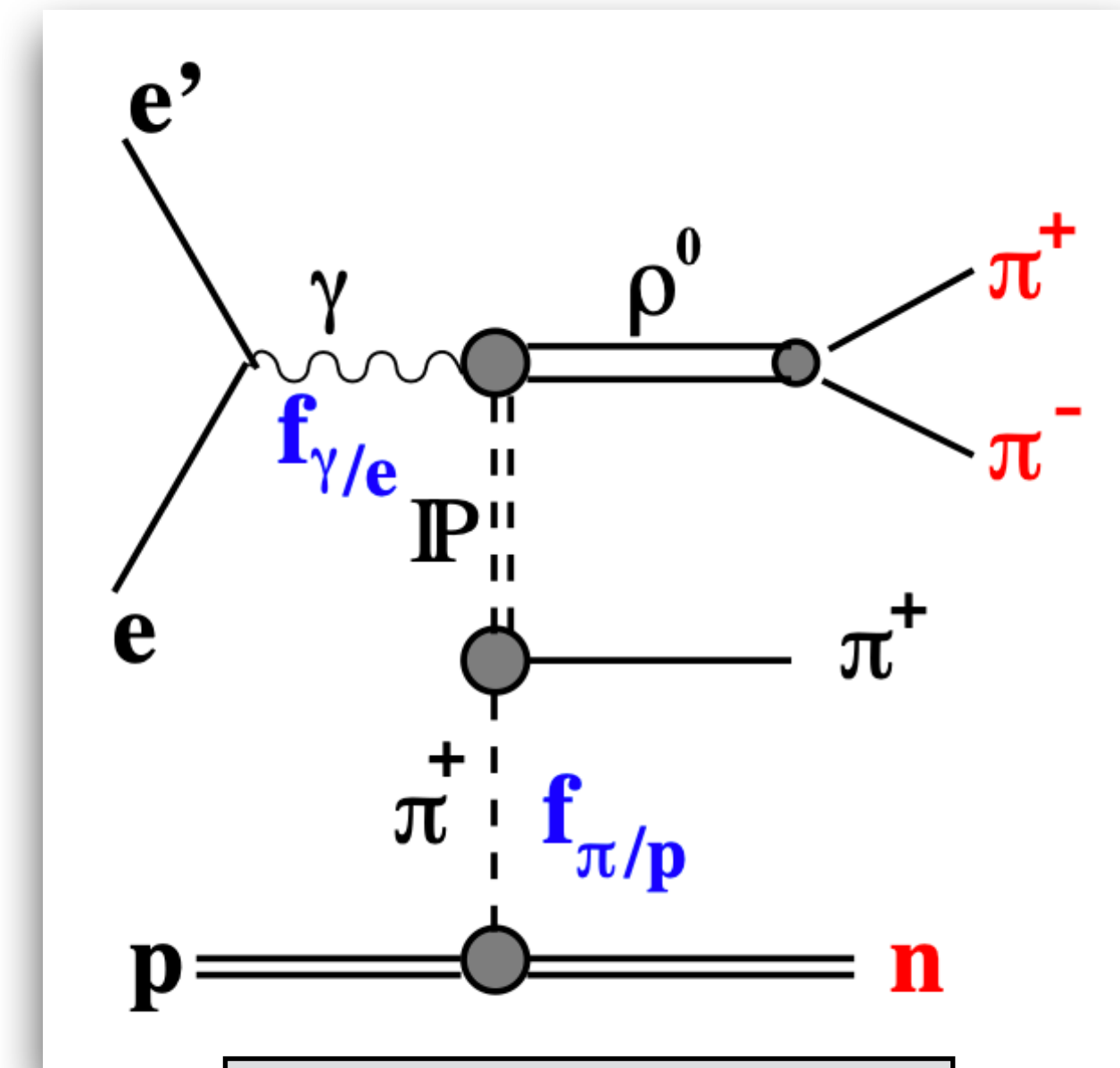
If A is a proton and A' is a single neutron
⇒
Access the **pion** structure!

p→n

Structure of the pion



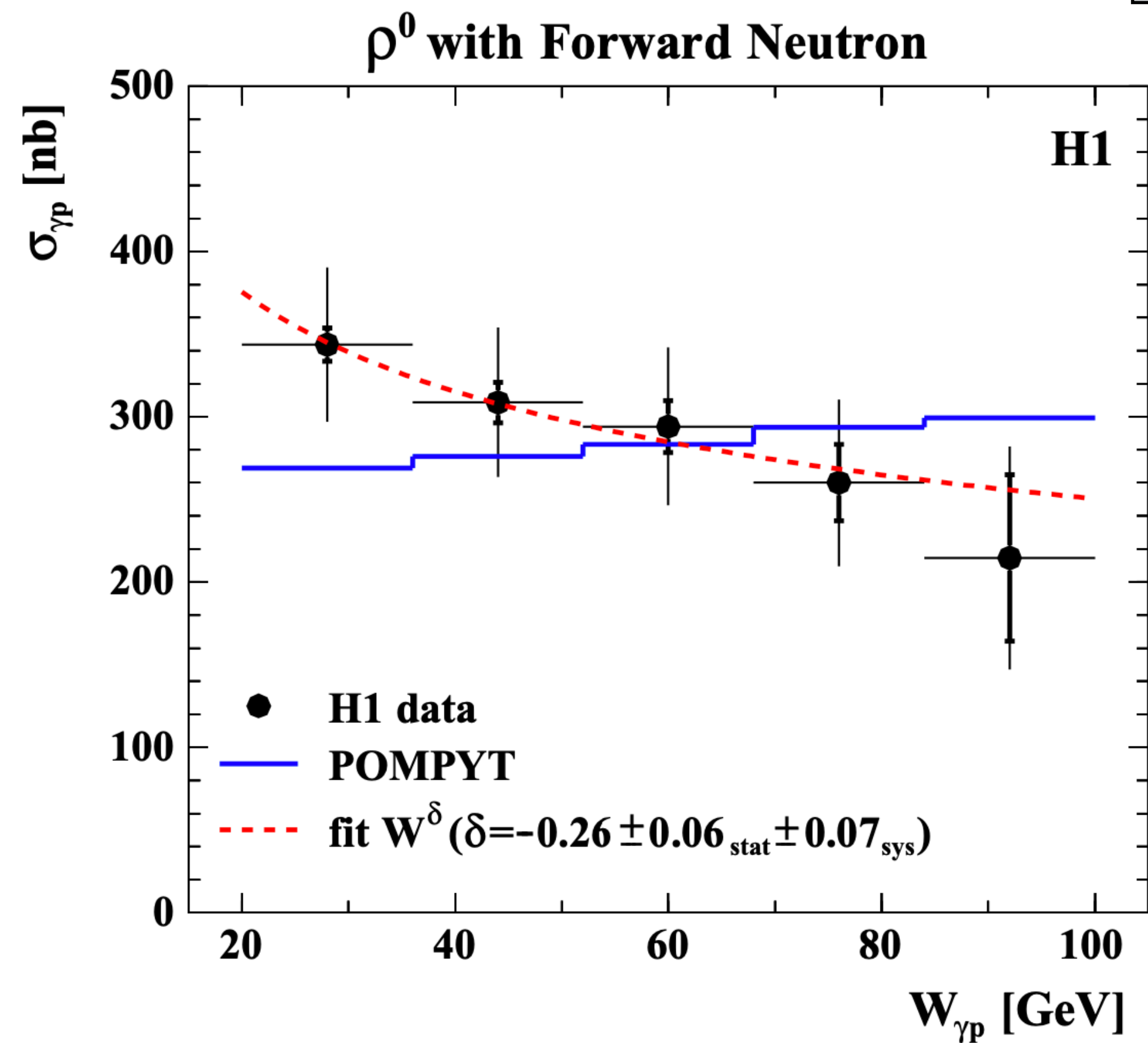
Expectations:



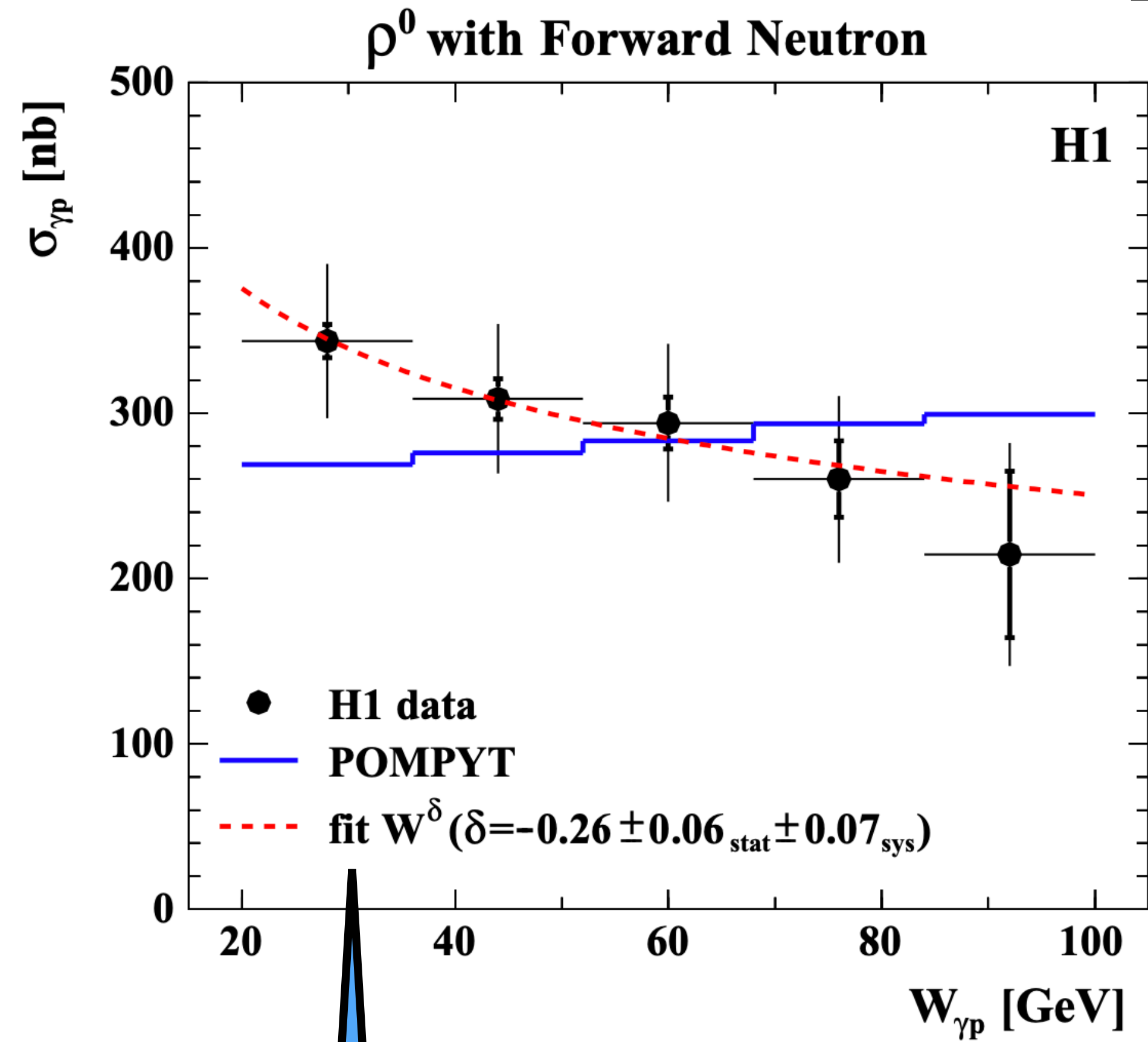
H1, EPJ C76 (2016) 1, 41

If A is a proton and A' is a single neutron
 \Rightarrow
Access the **pion** structure!

H1, EPJ C76 (2016) 1, 41

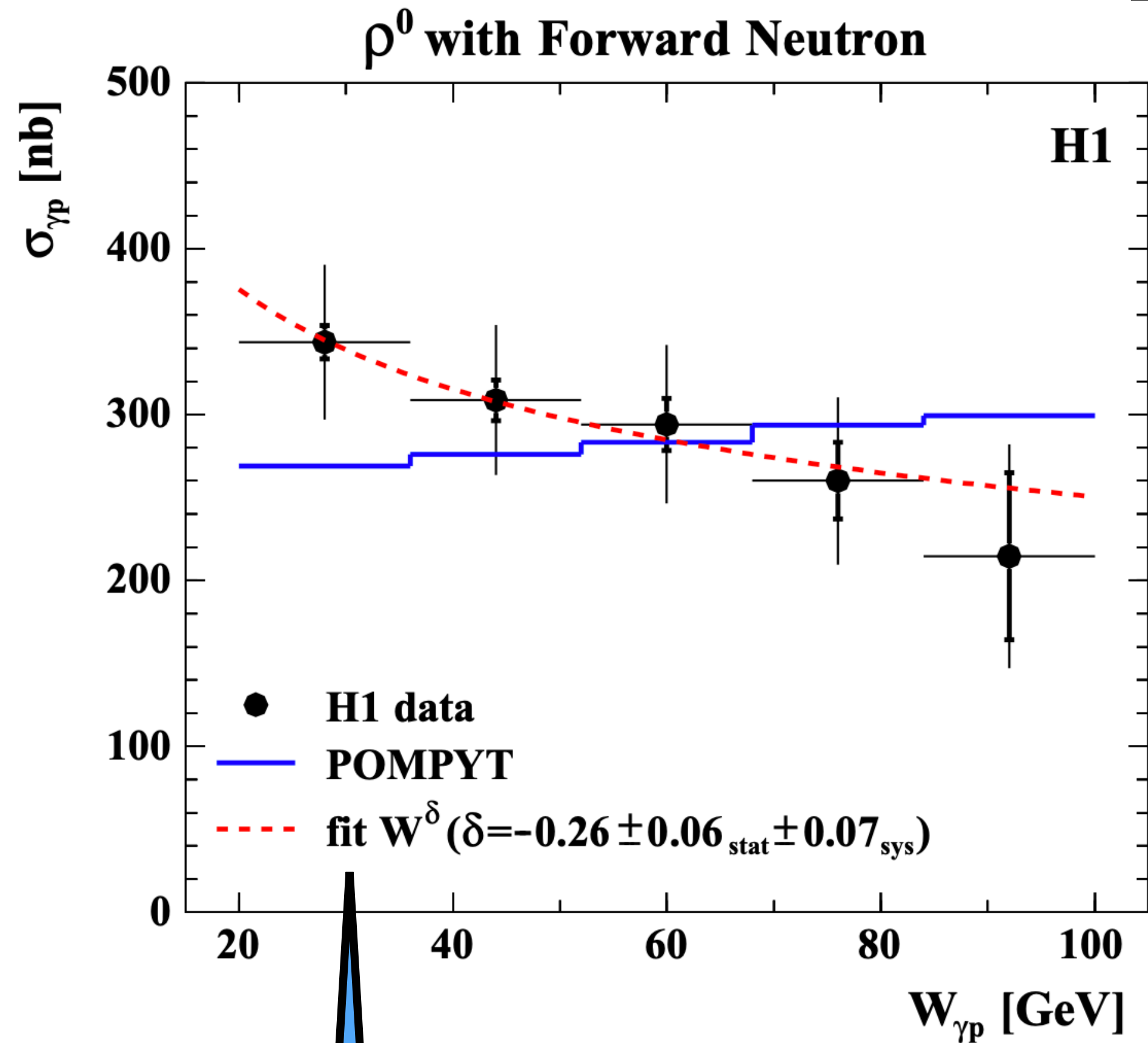
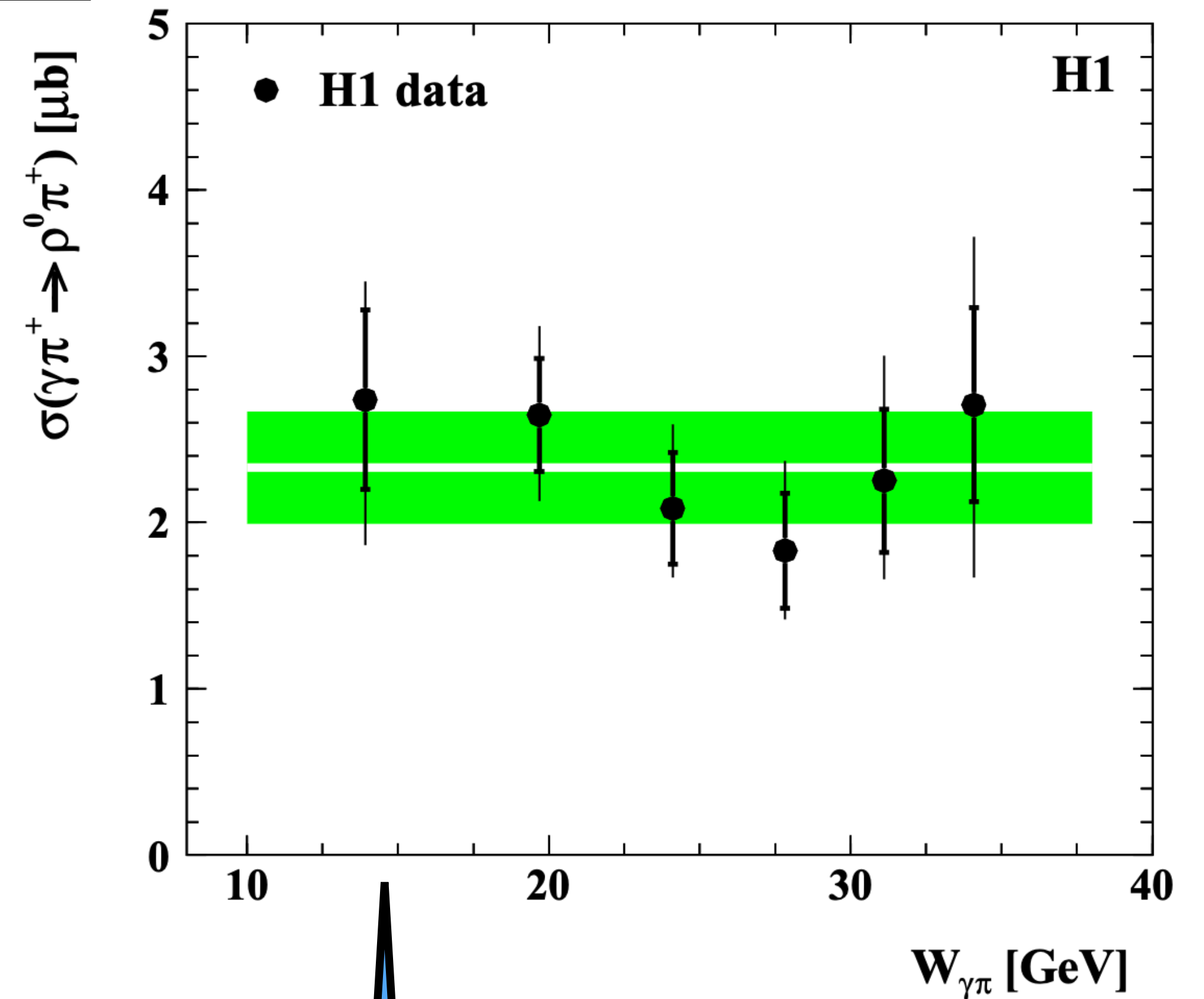


H1, EPJ C76 (2016) 1, 41



The $\gamma\rho$ cross section decays with energy

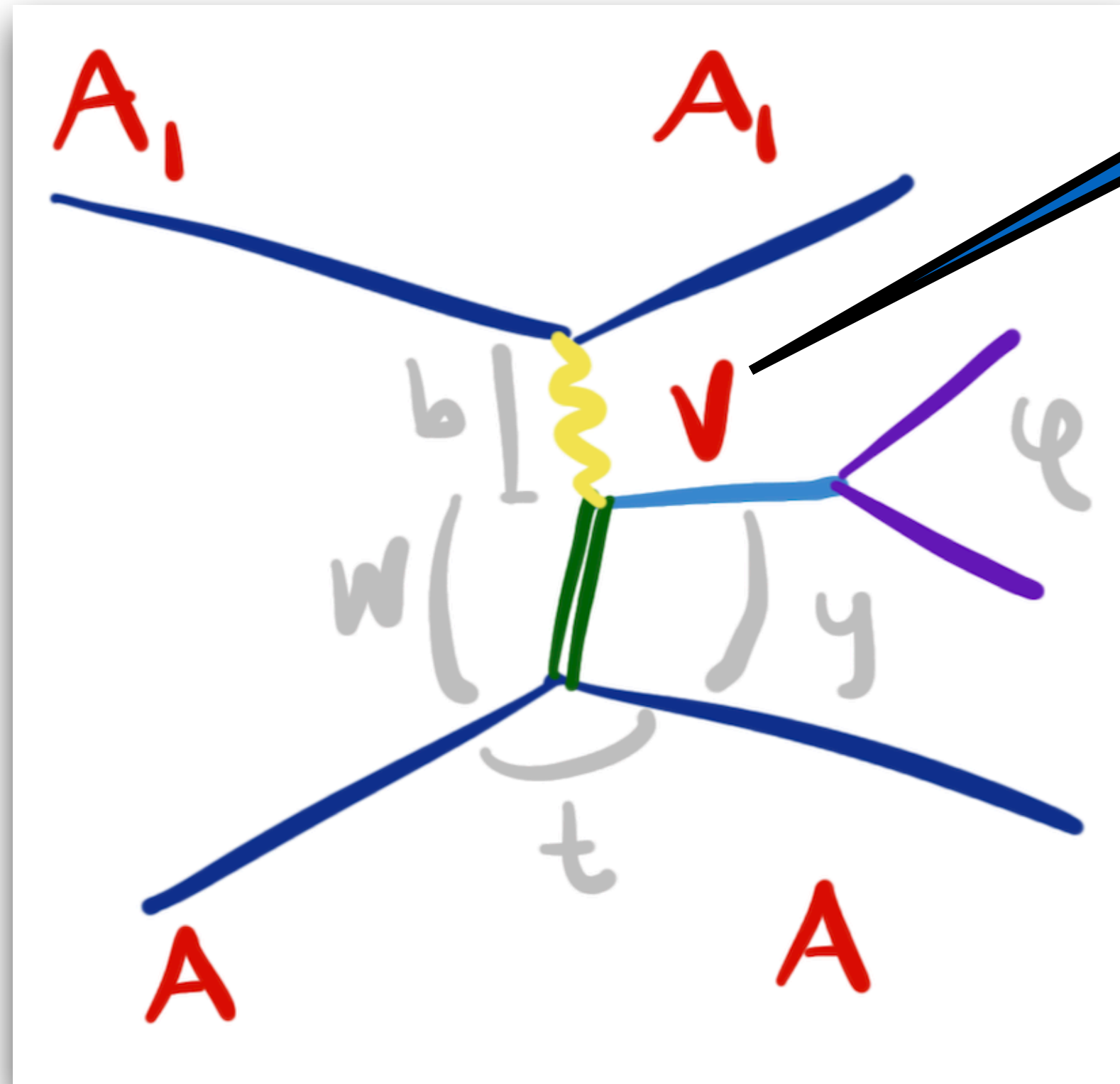
H1, EPJ C76 (2016) 1, 41

The γp cross section decays with energyThe $\gamma\pi$ cross section is constant in this energy range

?

Studying new states

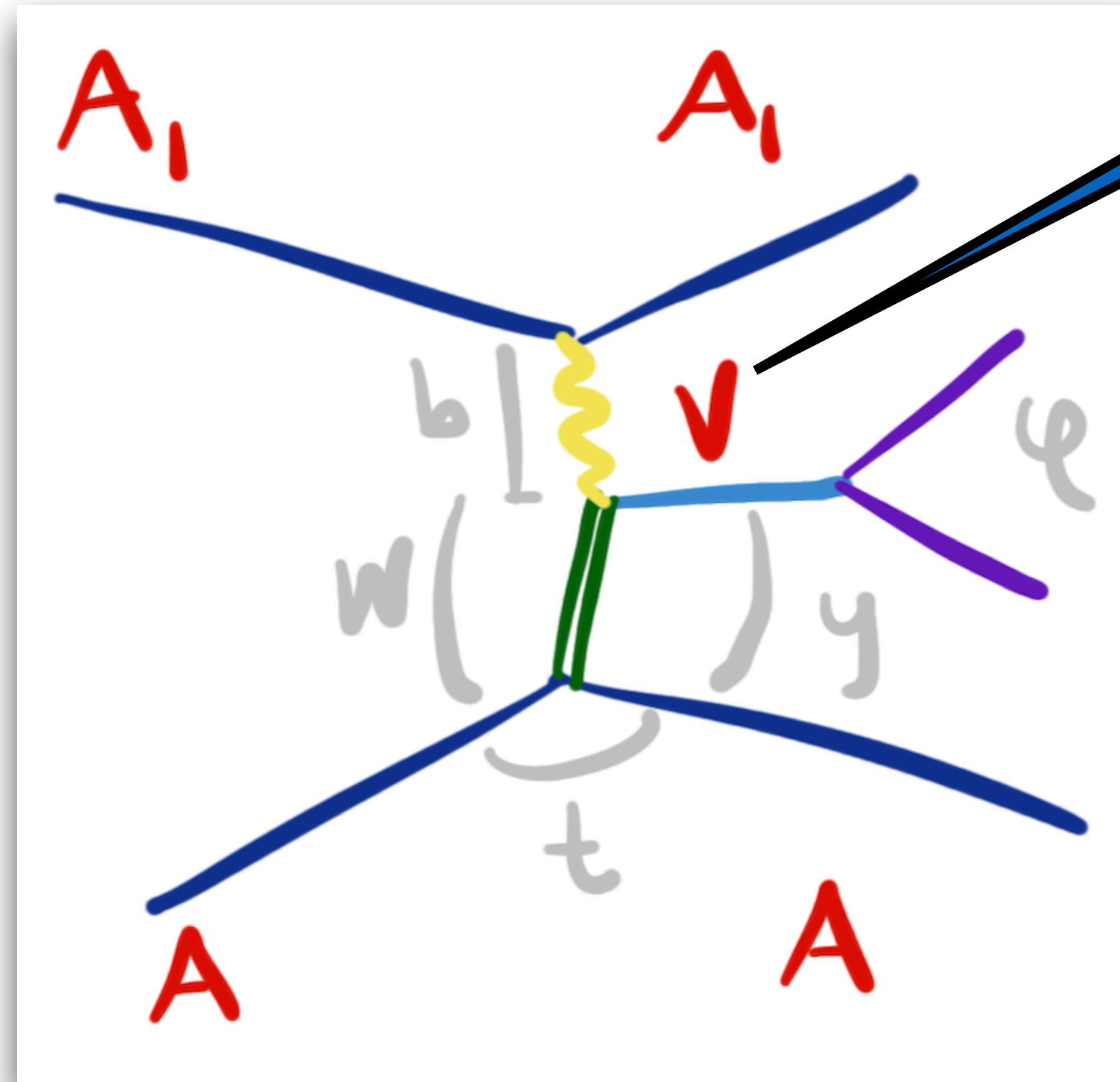
Vector meson mass:
Are there new photoproduced states?



?

Studying new states

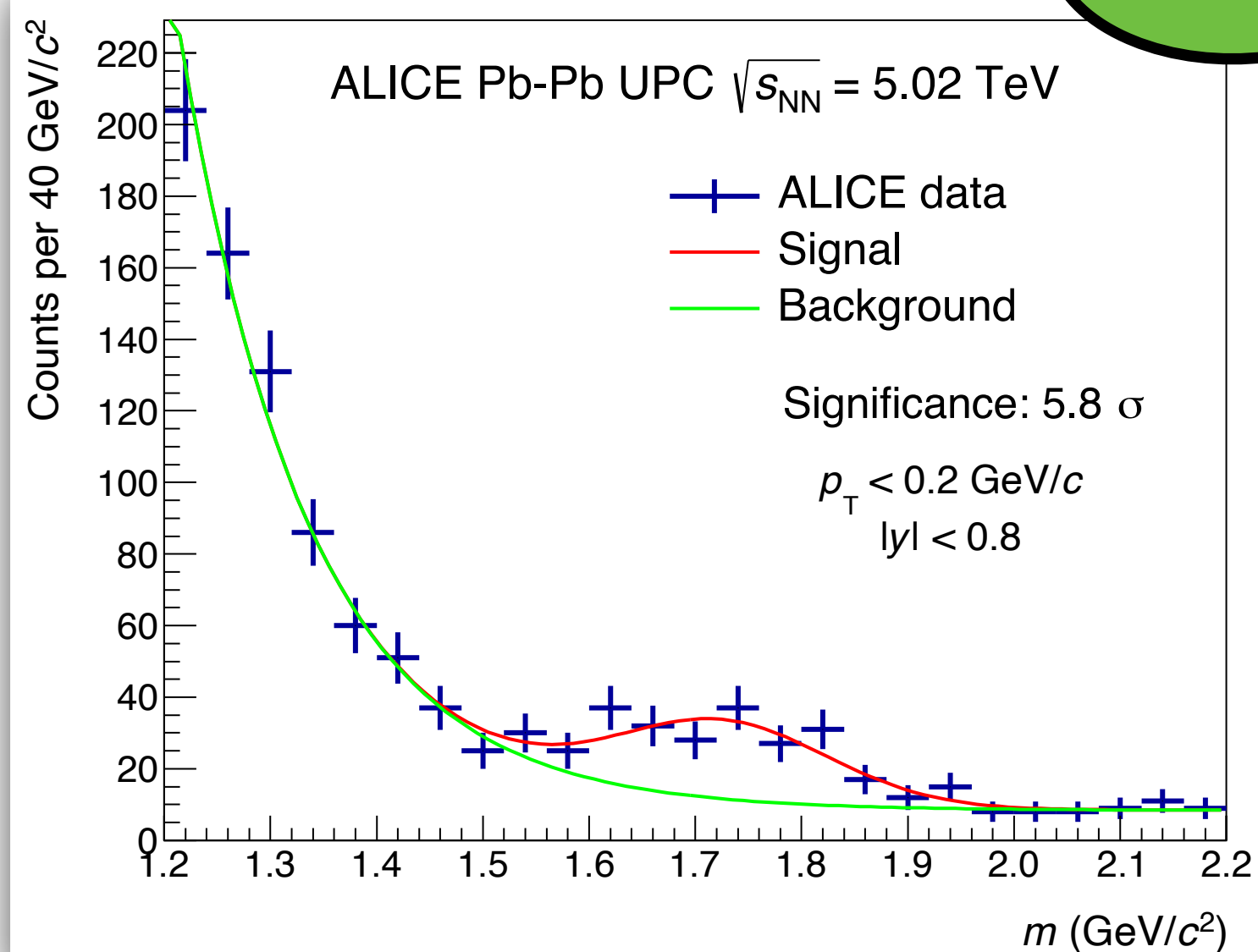
Vector meson mass:
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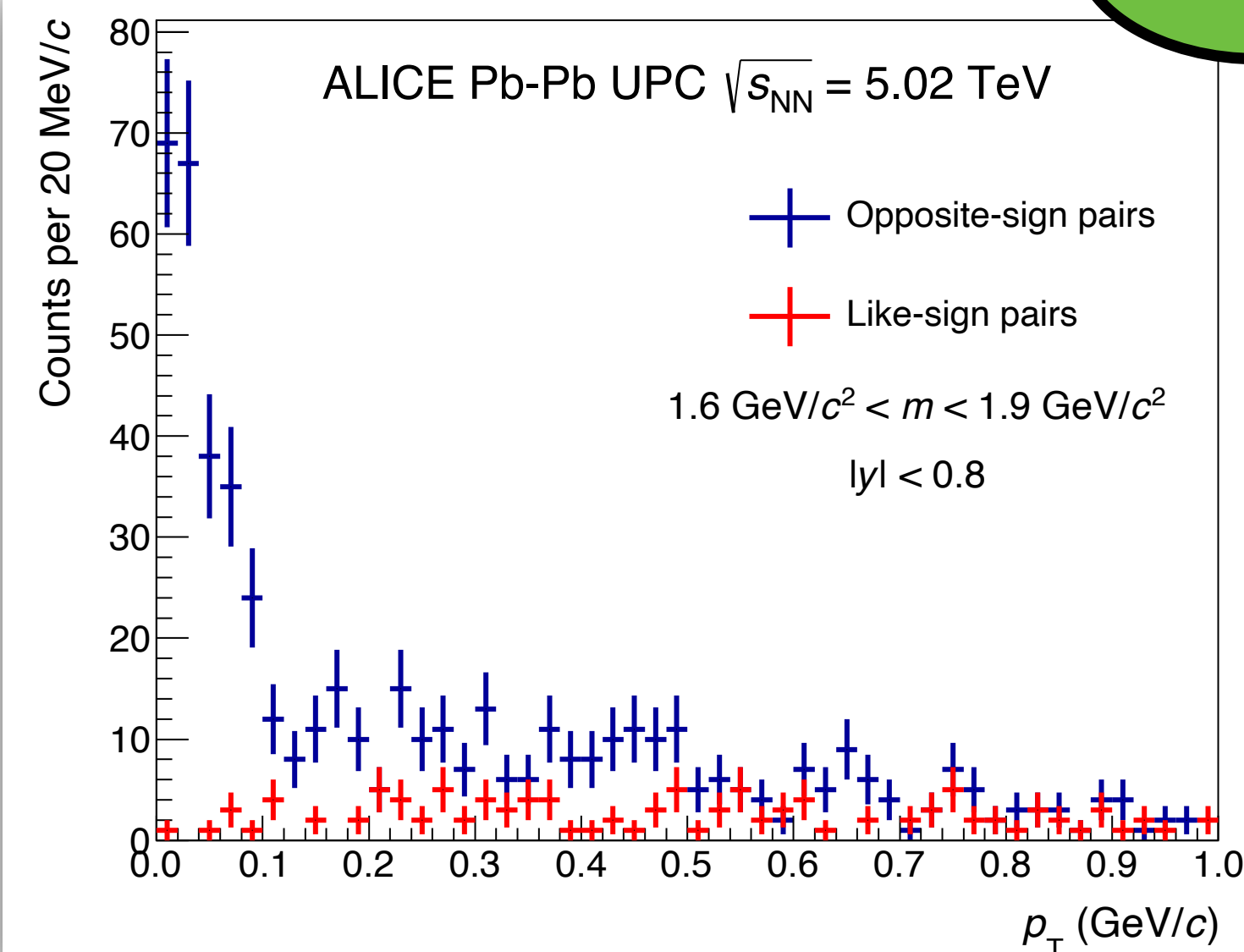
Expectations:
Such a clean environment should be ideal to
spot new states

ALICE, JHEP 06 (2020) 035

Mass

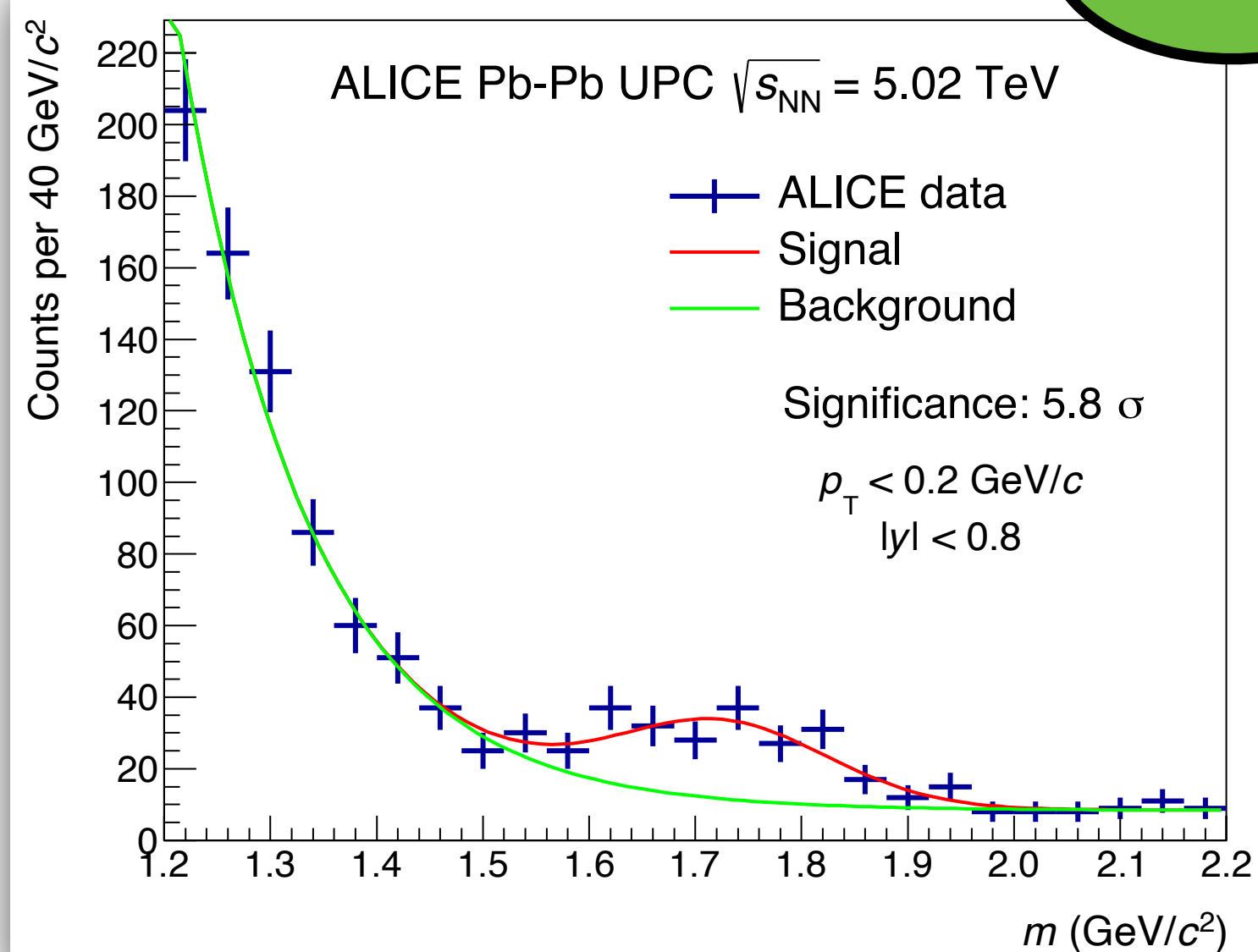


pT

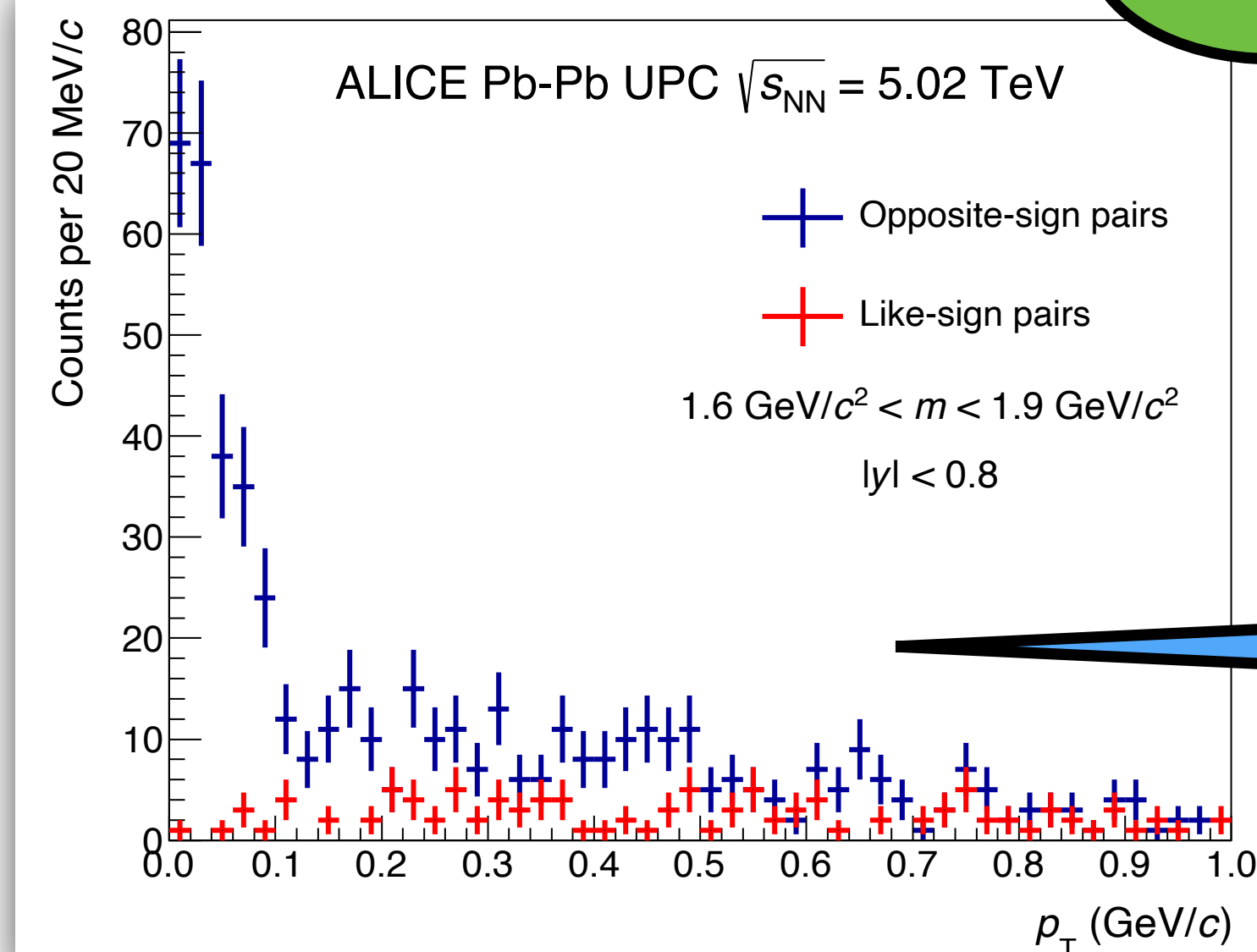


ALICE, JHEP 06 (2020) 035

Mass



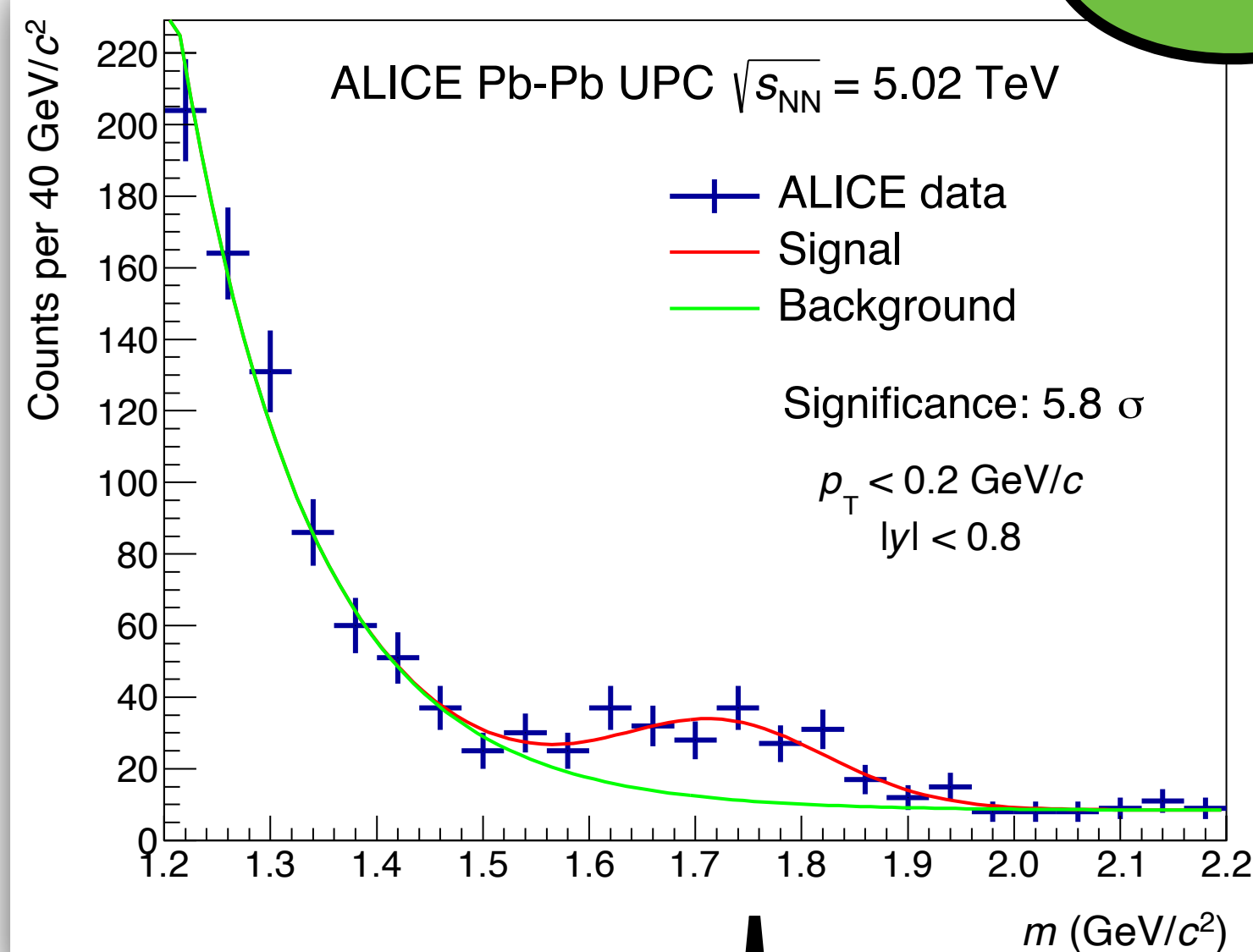
pT



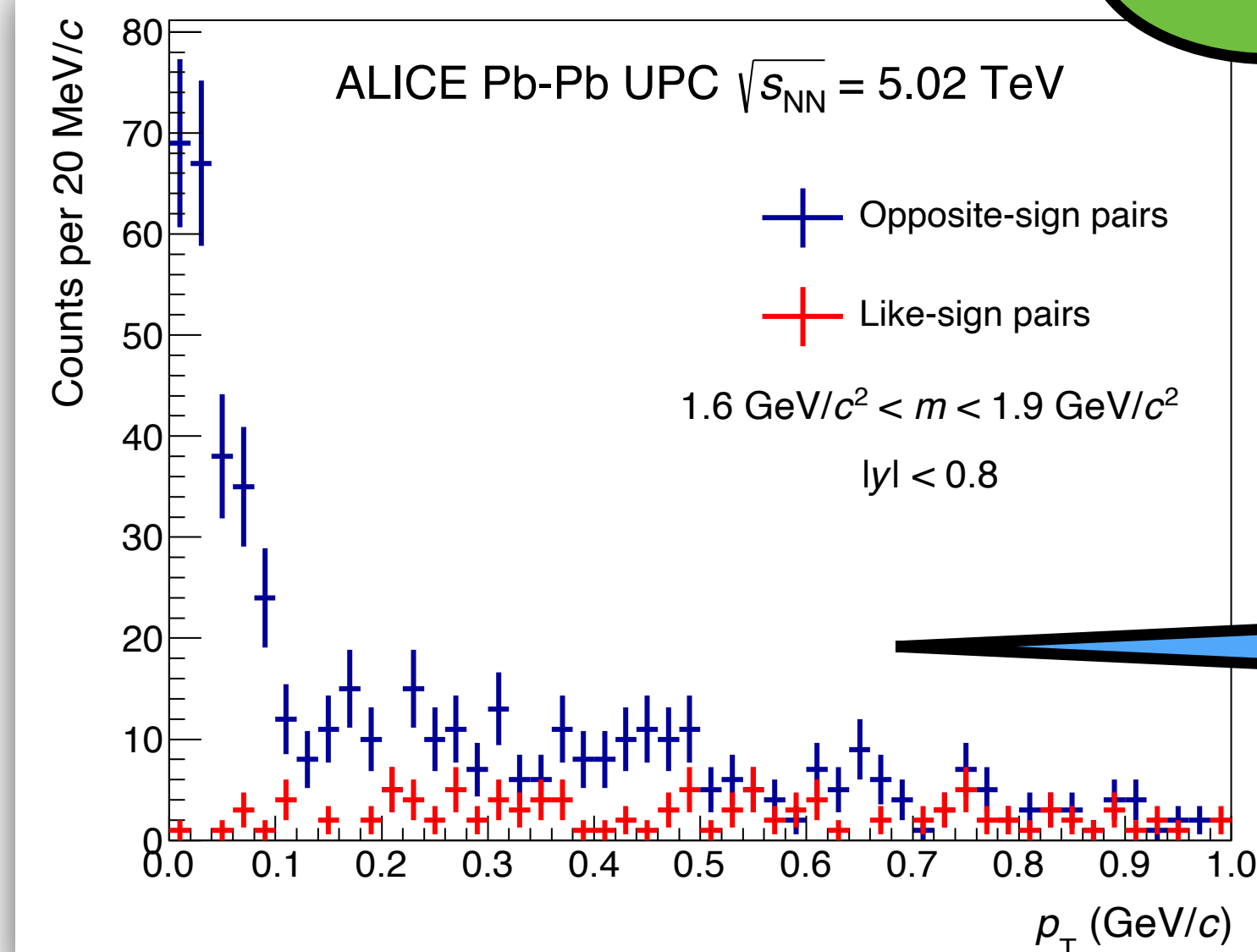
pT distribution typical of
coherent photoproduction

ALICE, JHEP 06 (2020) 035

Mass



pT



pT distribution typical of
coherent photoproduction

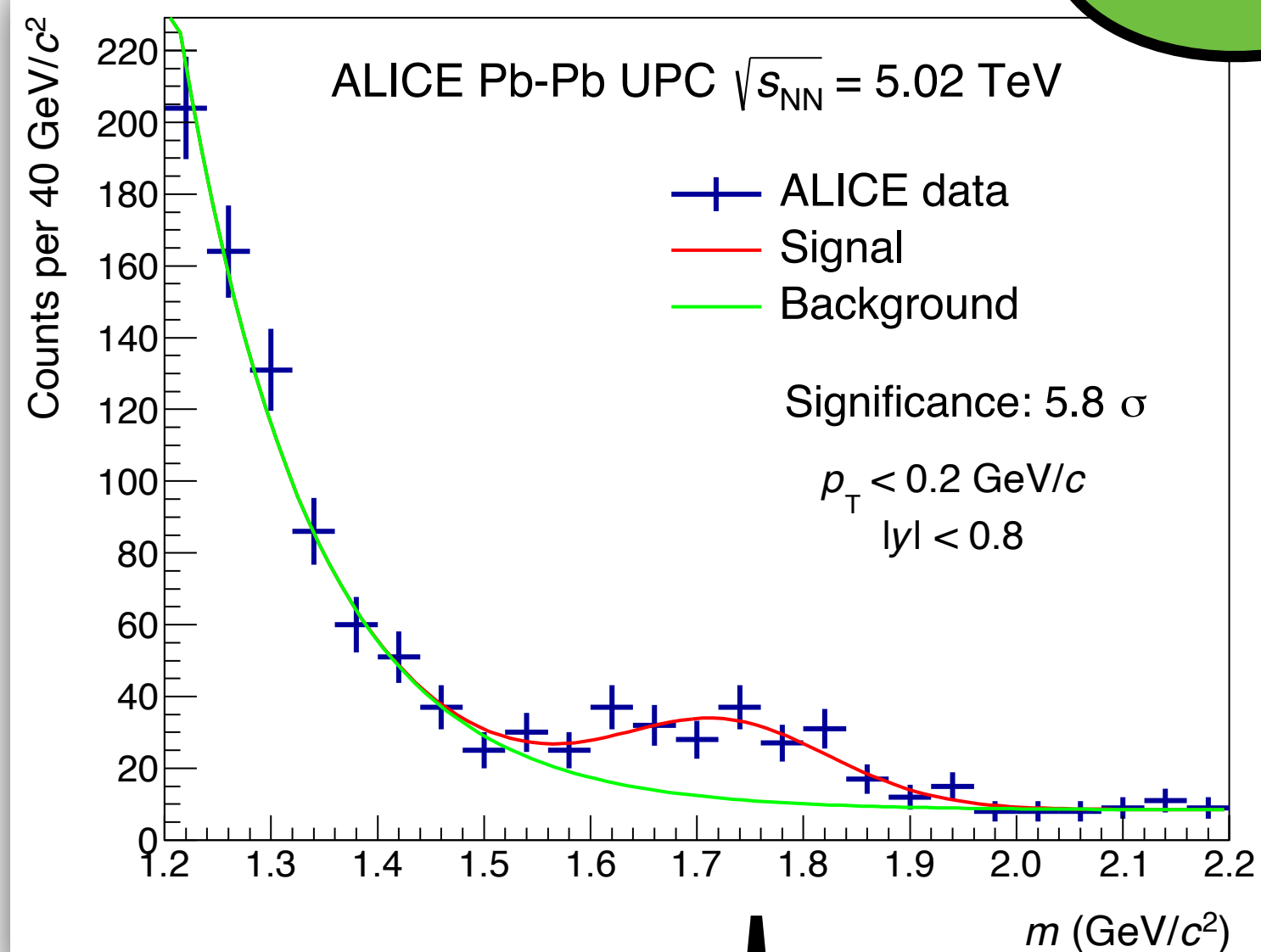
Bump seen in the invariant mass distribution. Similar (not 100% equal) bumps seen by H1 and STAR

$\rho' (?)$

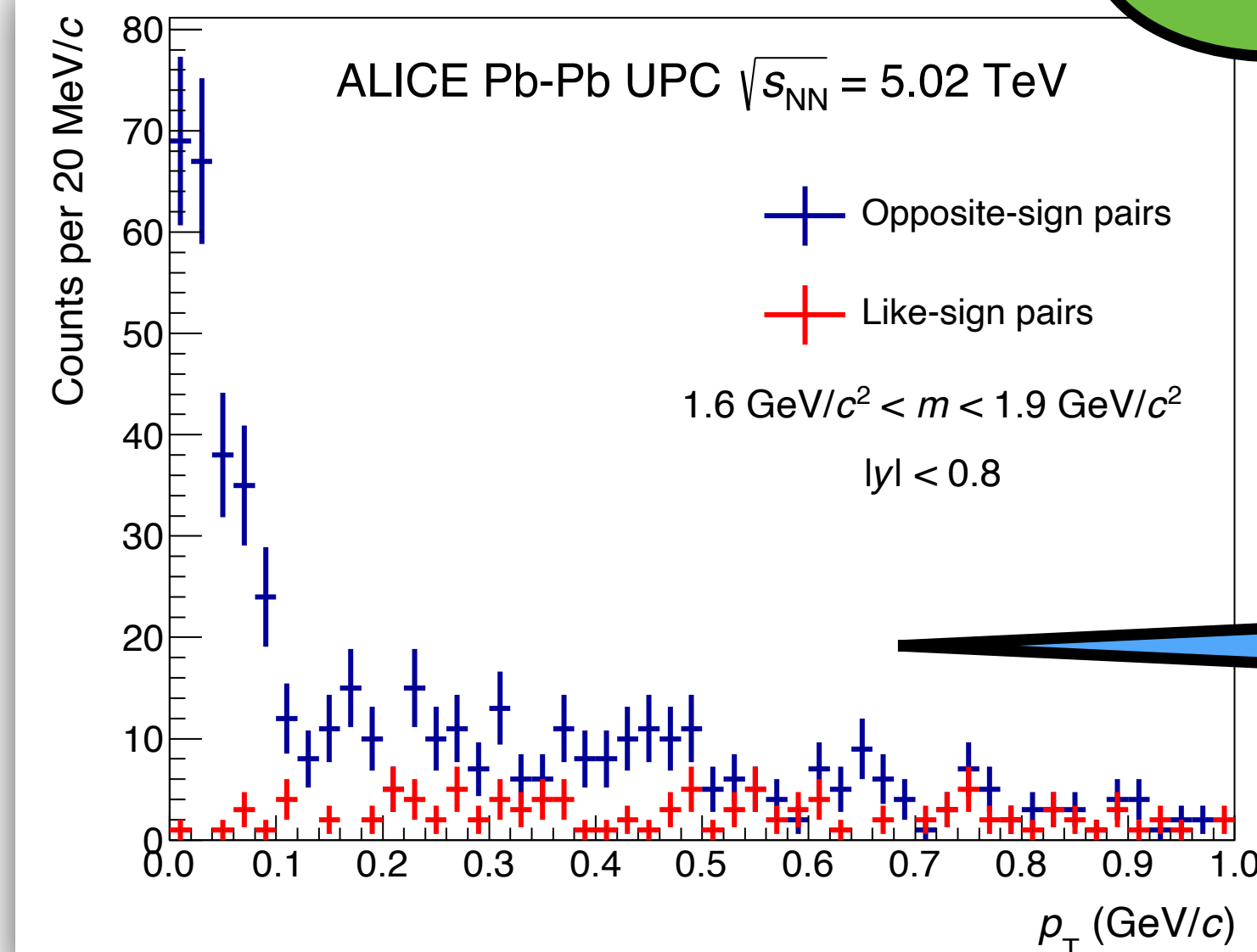
$\pi\pi$ pairs in Pb-Pb as seen by ALICE

ALICE, JHEP 06 (2020) 035

Mass



pT



pT distribution typical of coherent photoproduction

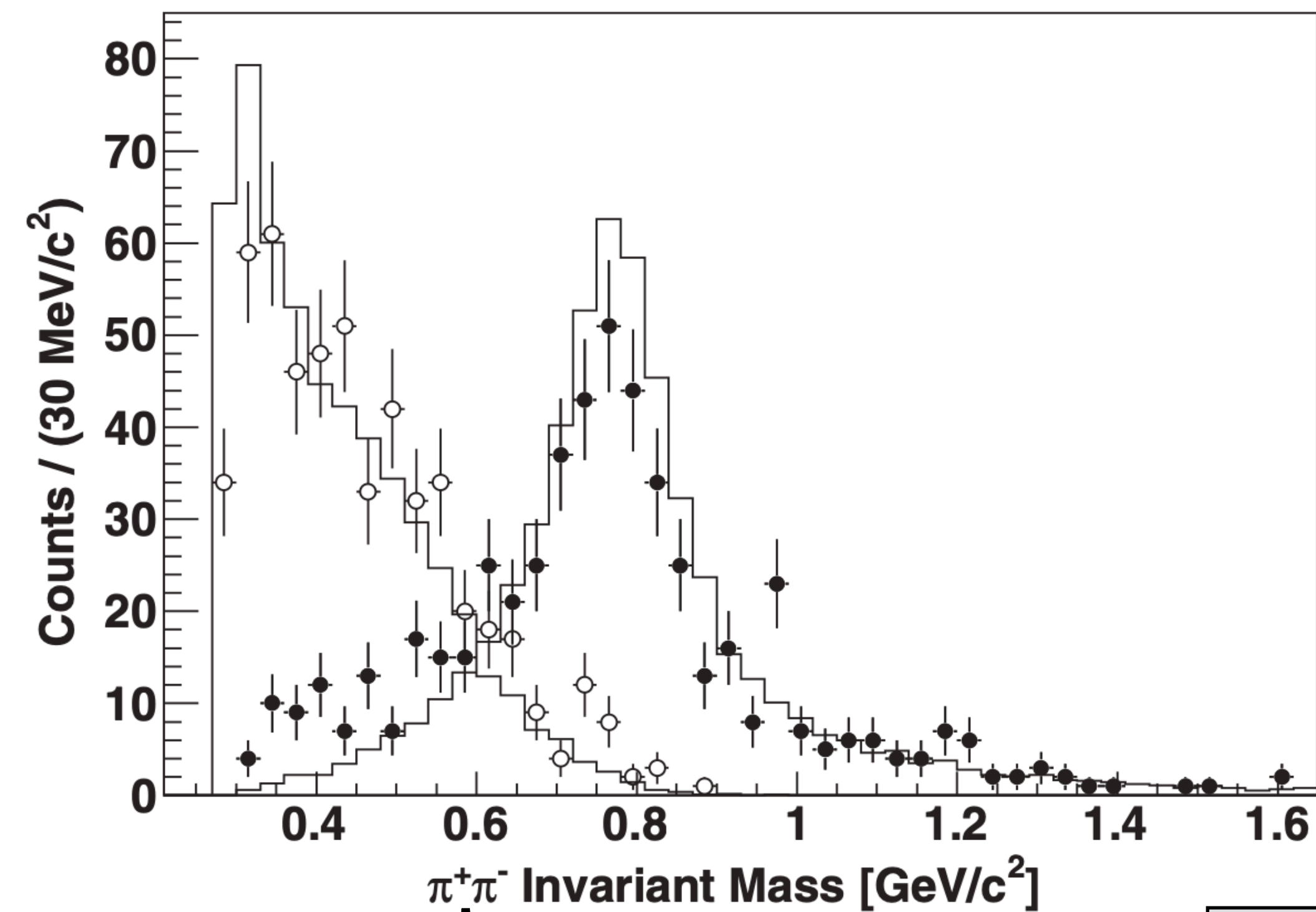
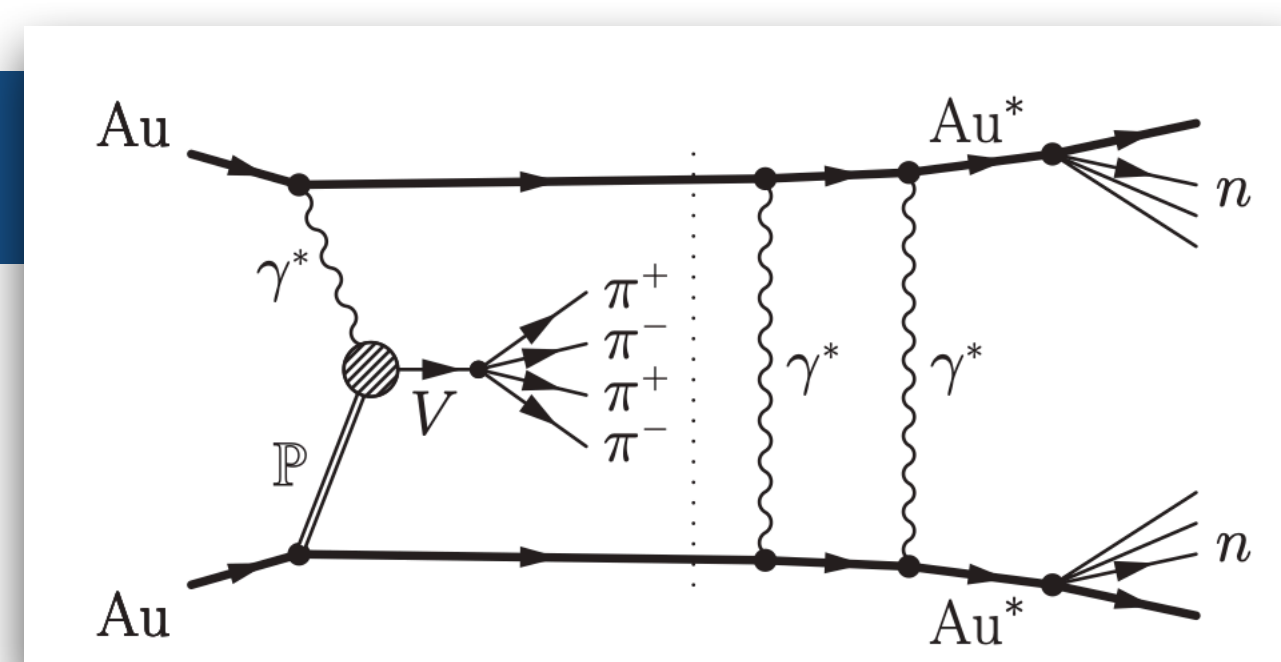
Bump seen in the invariant mass distribution. Similar (not 100% equal) bumps seen by H1 and STAR

EIC

Should also be accessible at the EIC

$\rho' (?)$

$\pi^+\pi^-\pi^+\pi^-$ in Au-Au as seen by STAR

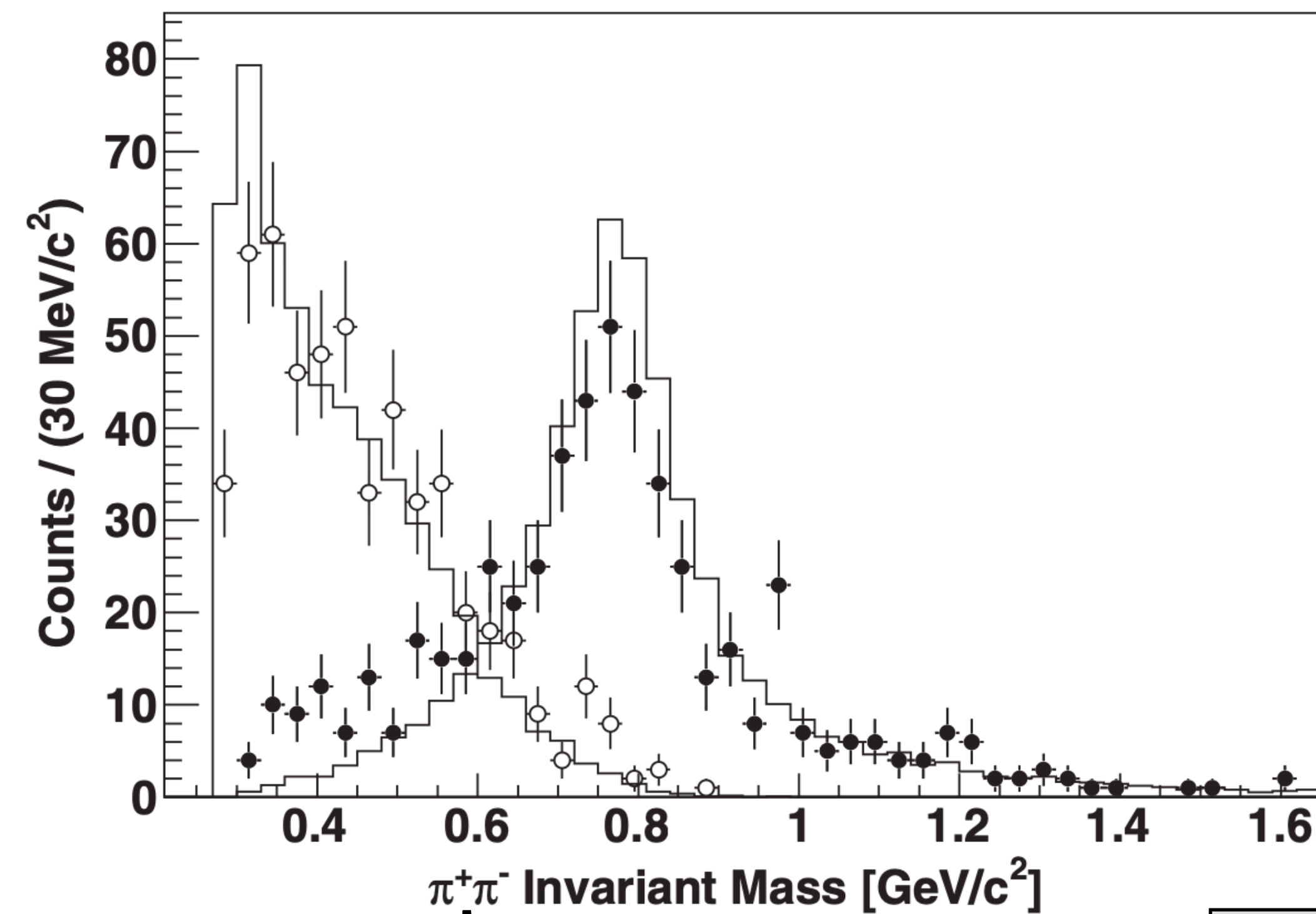
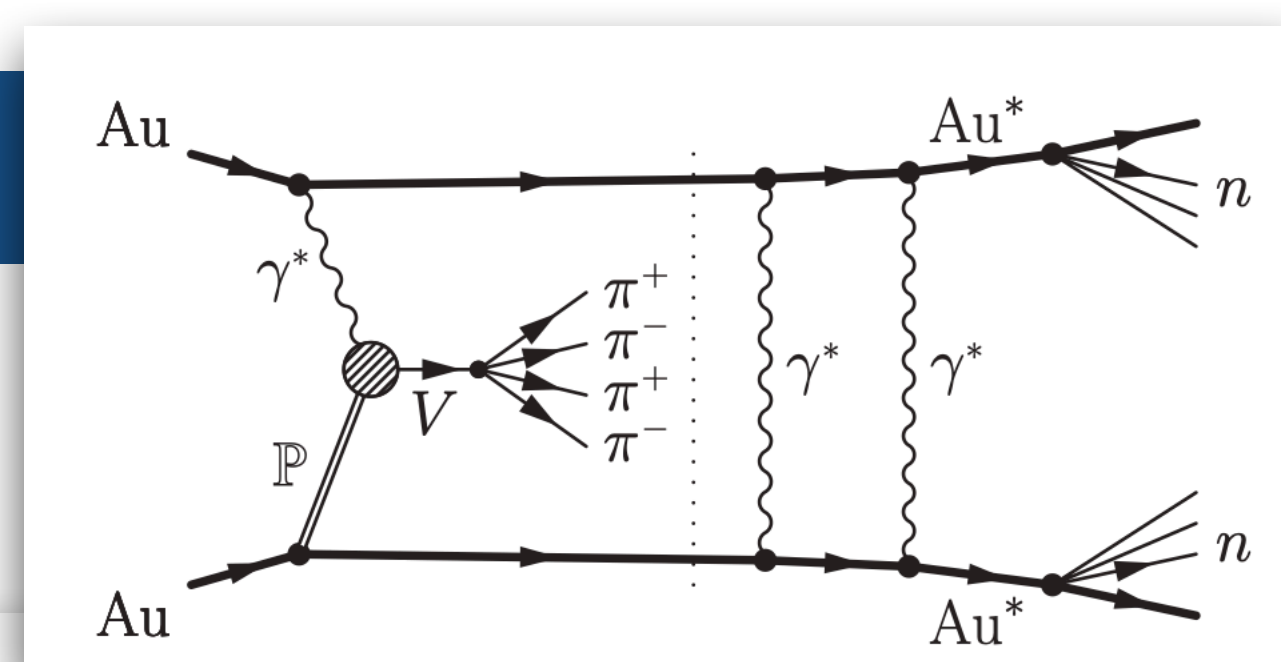


STAR, PRC 81,044901 (2010)

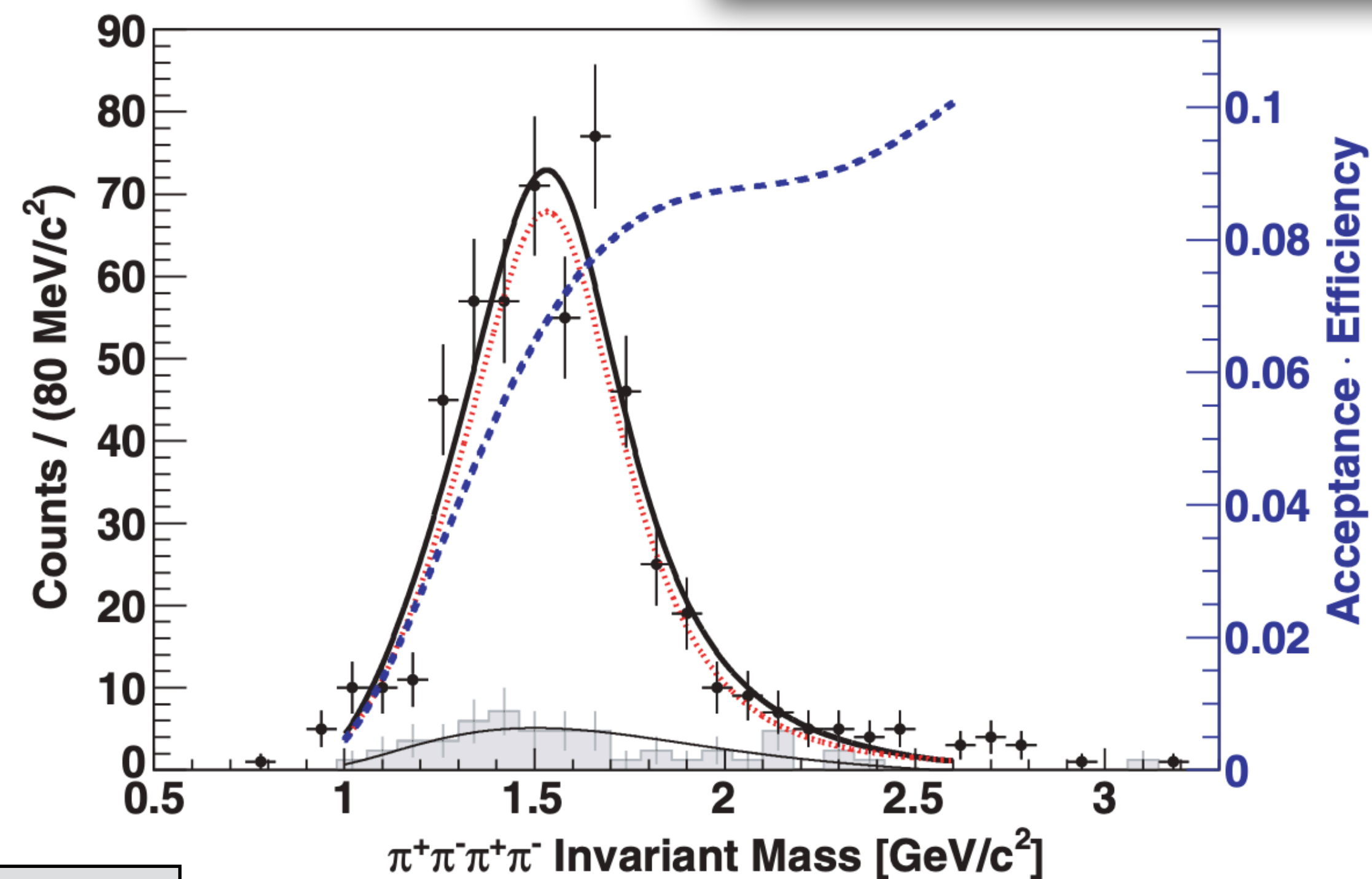
Mass of pairs compatible with decay to a $\rho(770)$ and an $f_0(600)$

$\rho' (?)$

$\pi^+\pi^-\pi^+\pi^-$ in Au-Au as seen by STAR



STAR, PRC 81,044901 (2010)

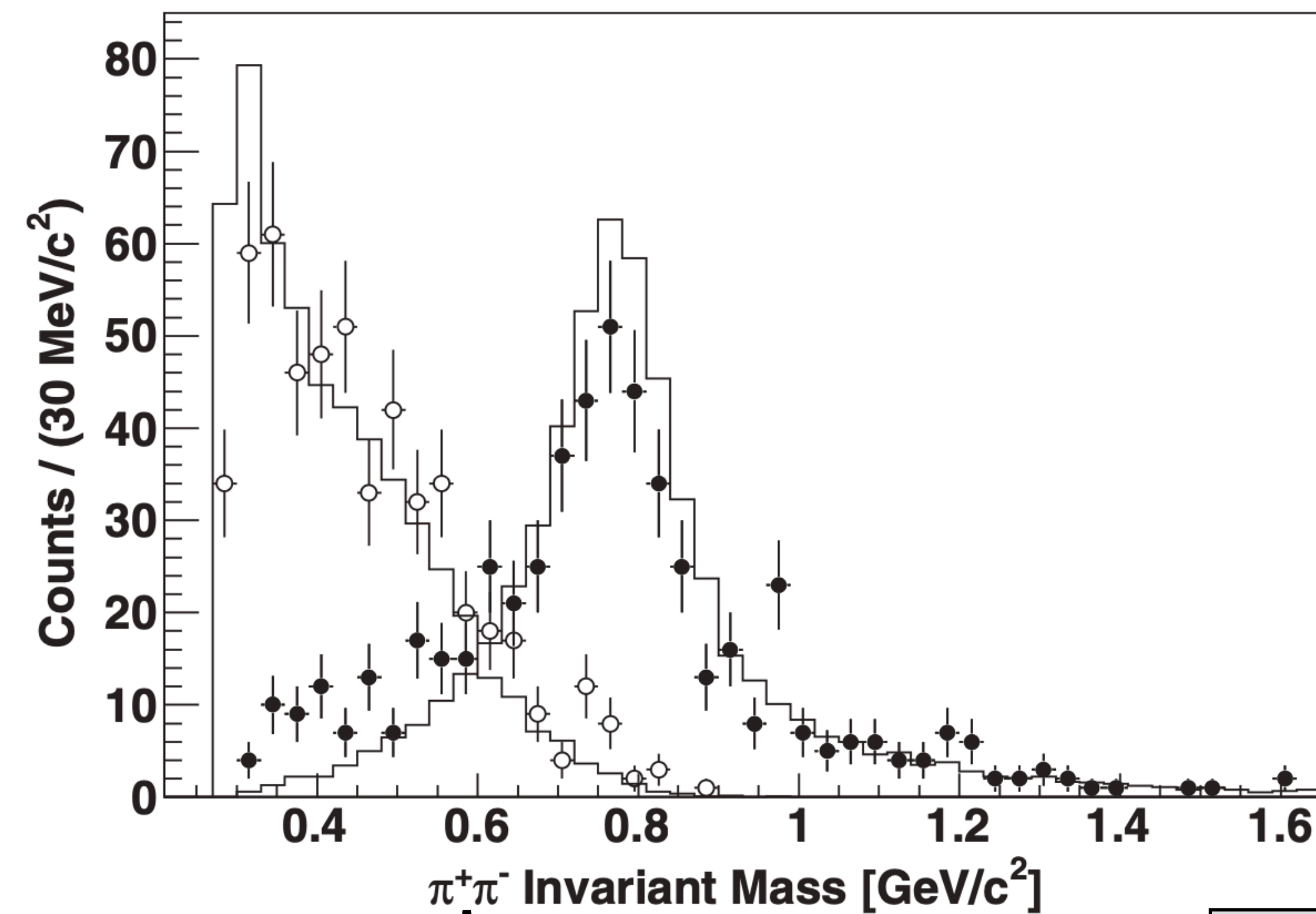
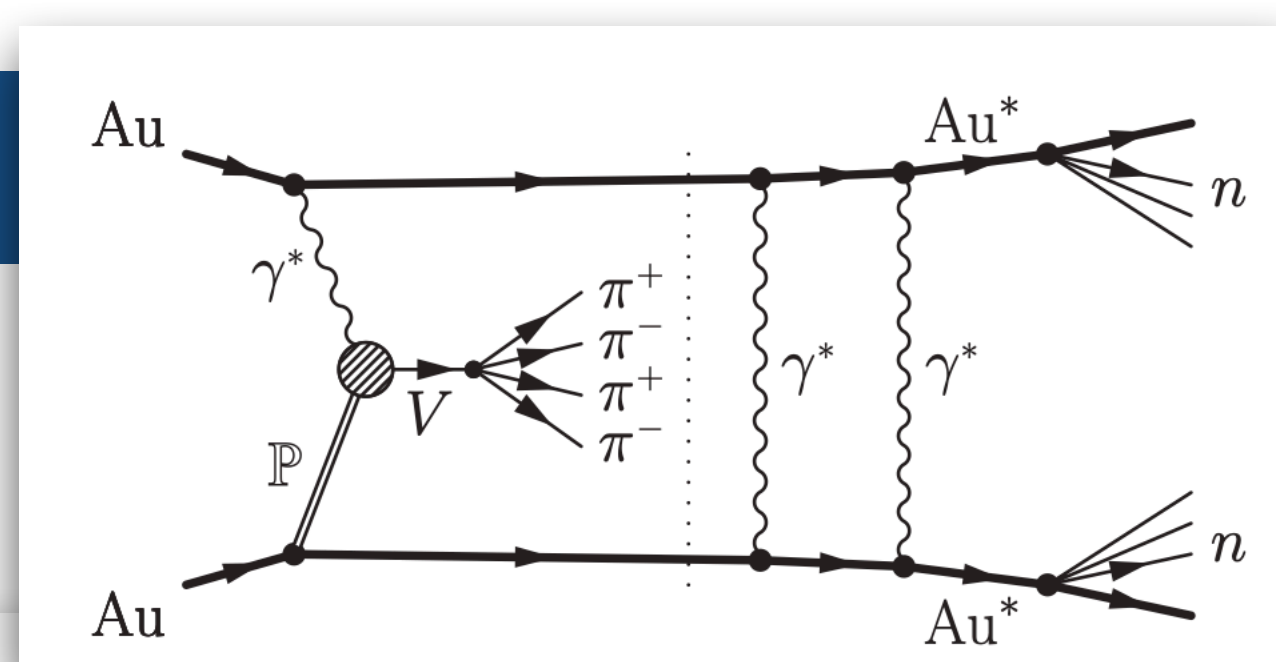


Mass of pairs compatible with decay to a $\rho(770)$ and an $f_0(600)$

$\rho' (?)$

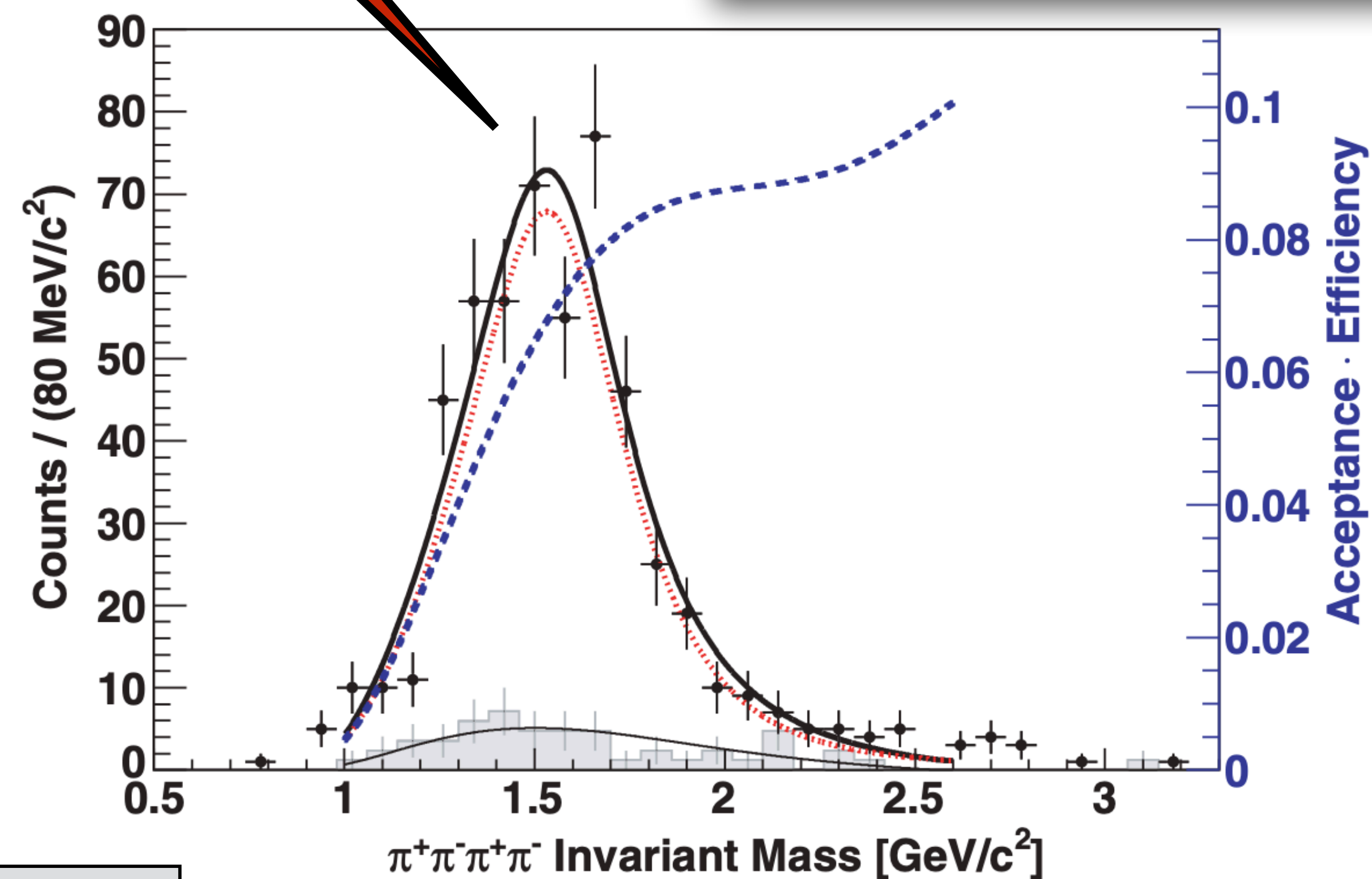
$\pi^+\pi^-\pi^+\pi^-$ in Au-Au as seen by STAR

Open question:
How many resonances are here?



Mass of pairs compatible with decay to a $\rho(770)$ and an $f_0(600)$

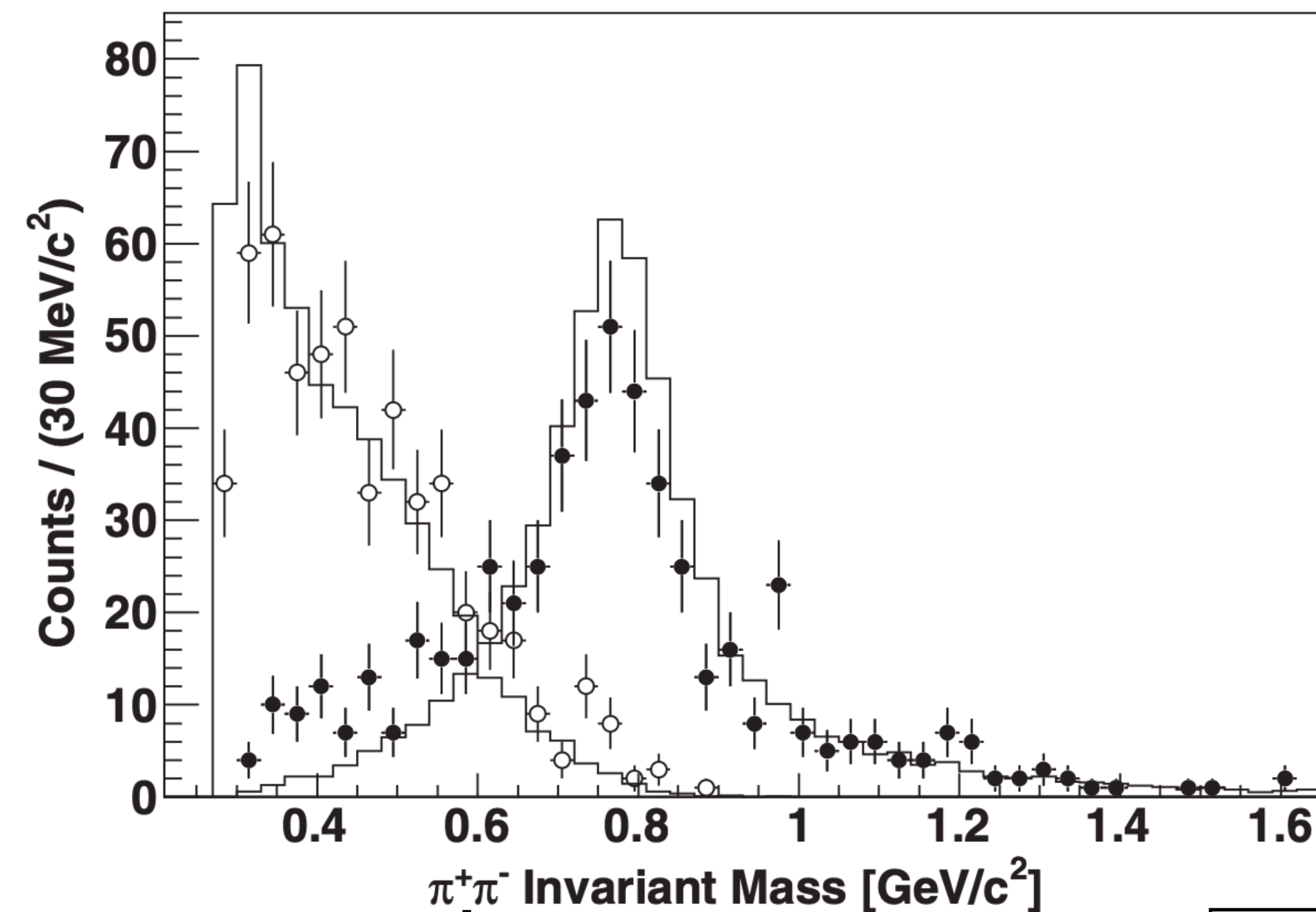
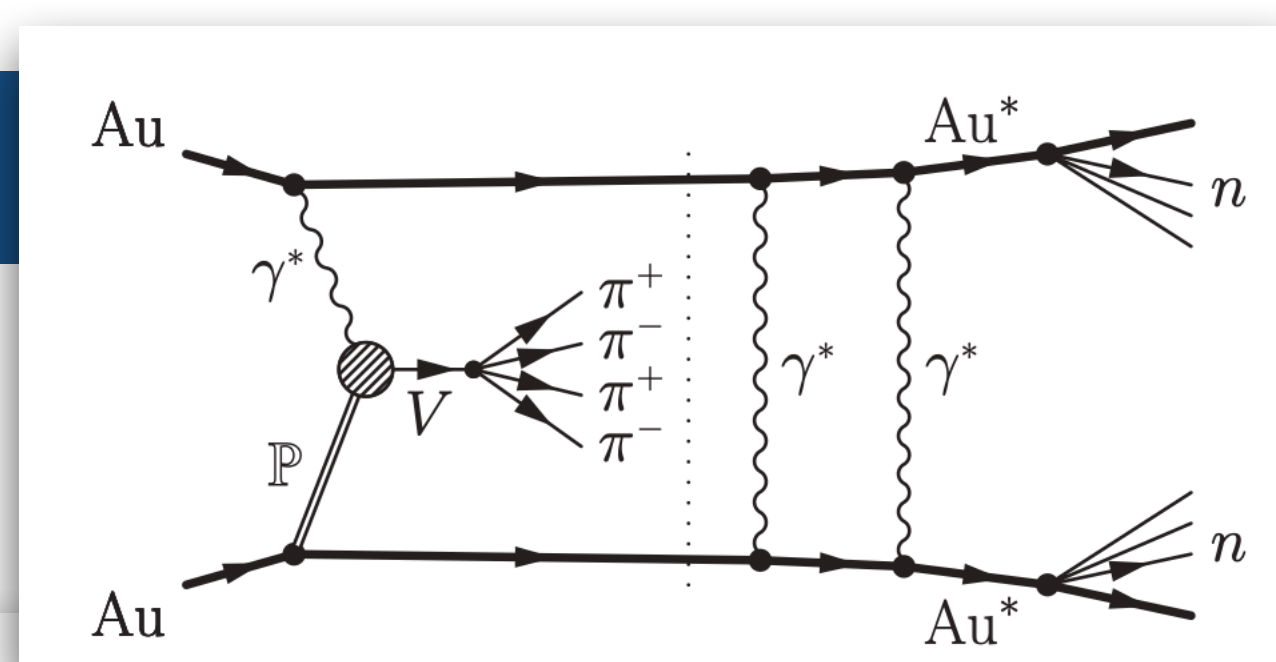
STAR, PRC 81,044901 (2010)



$\rho' (?)$

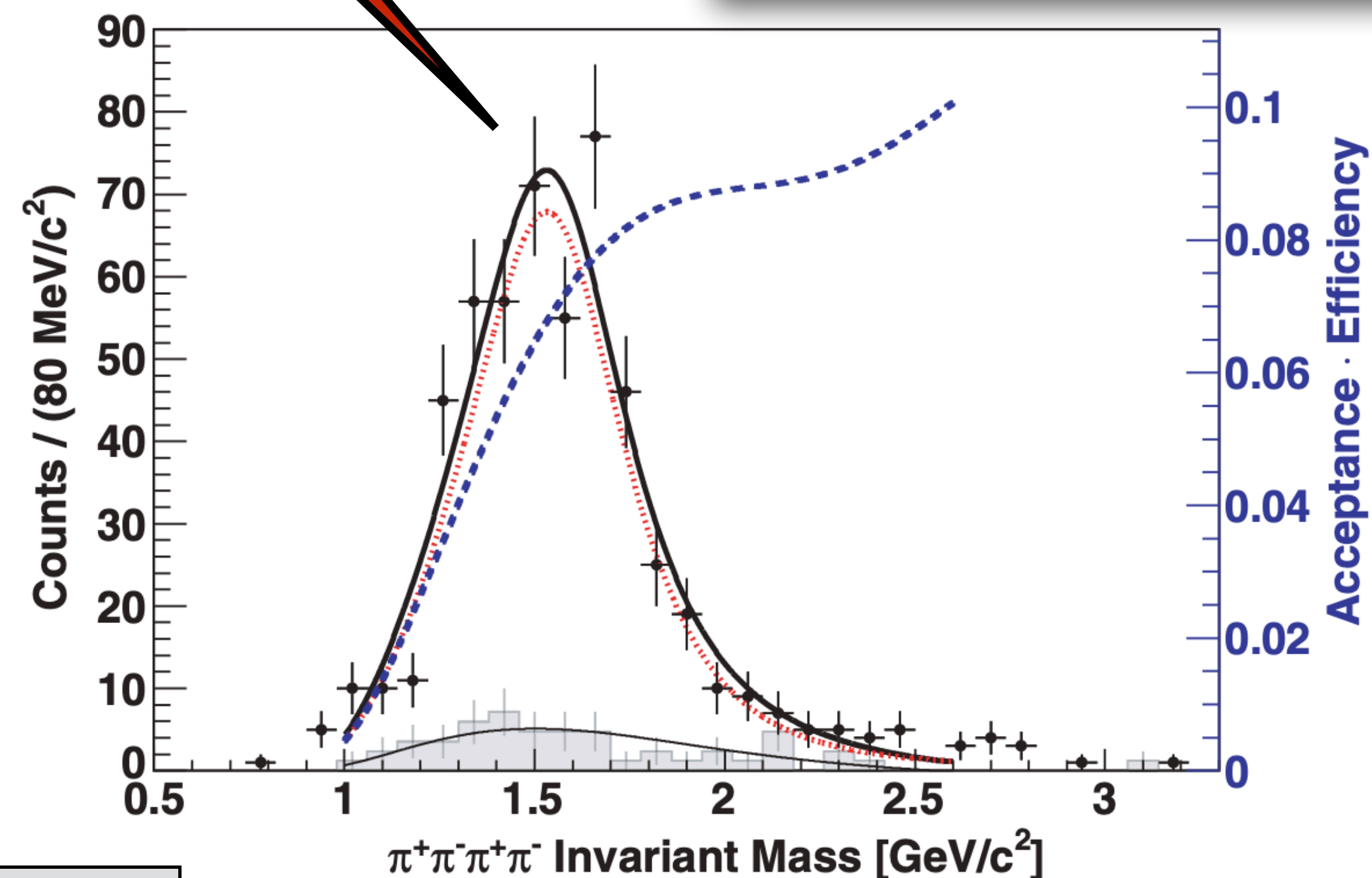
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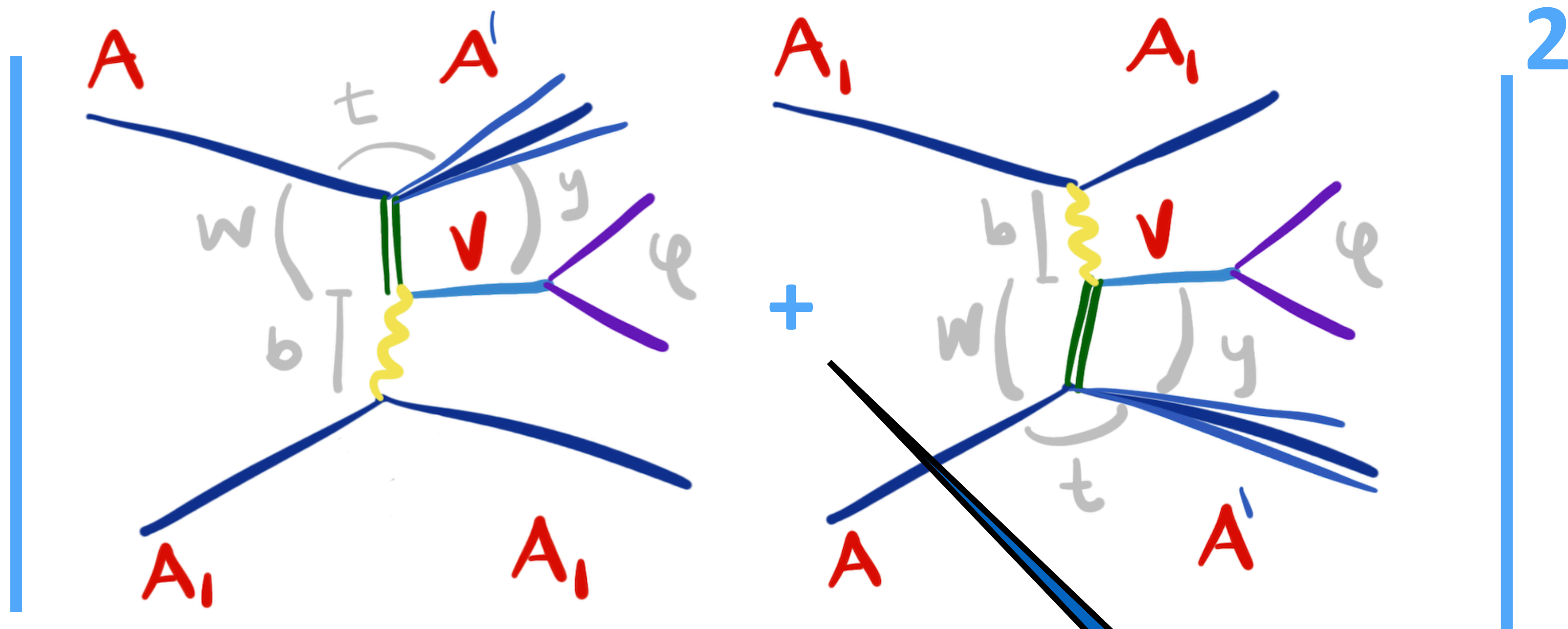
STAR, PRC 81,044901 (2010)

Mass of pairs compatible with decay to a $\rho(770)$ and an $f_0(600)$

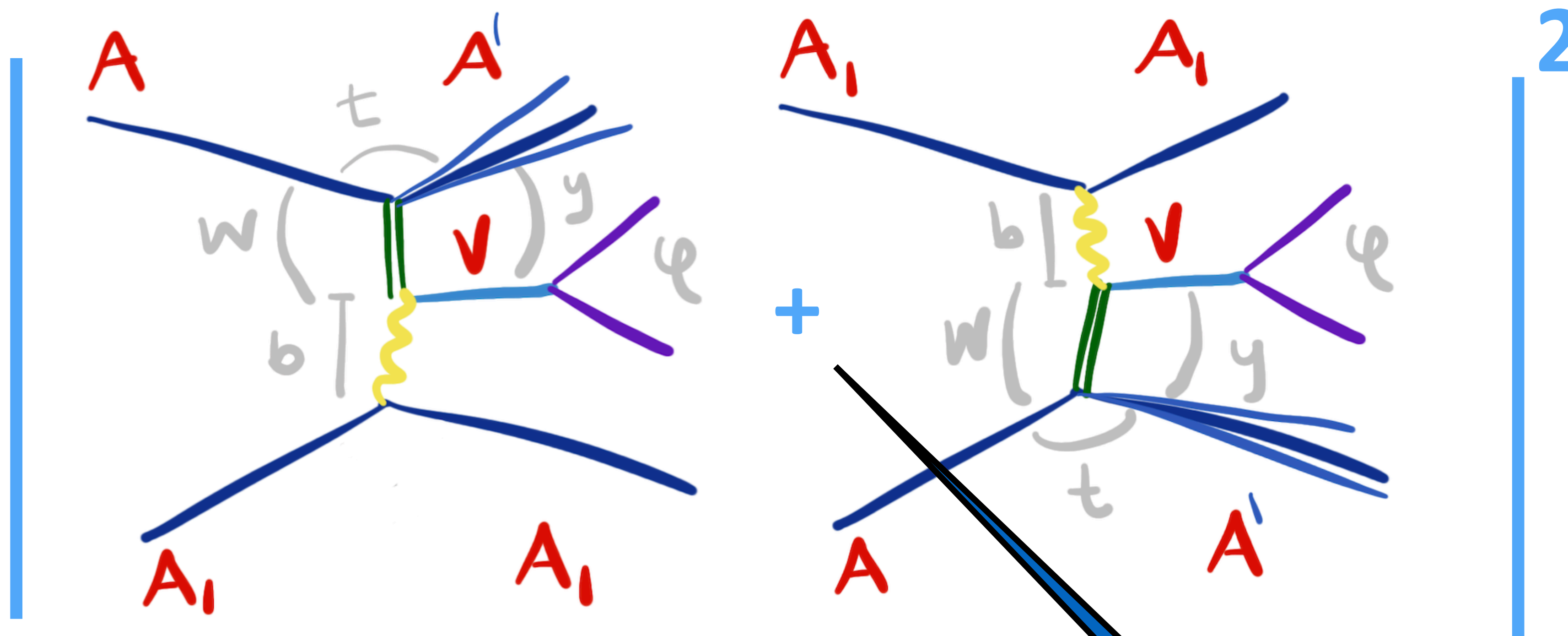


EIC

Should also be accessible at the EIC



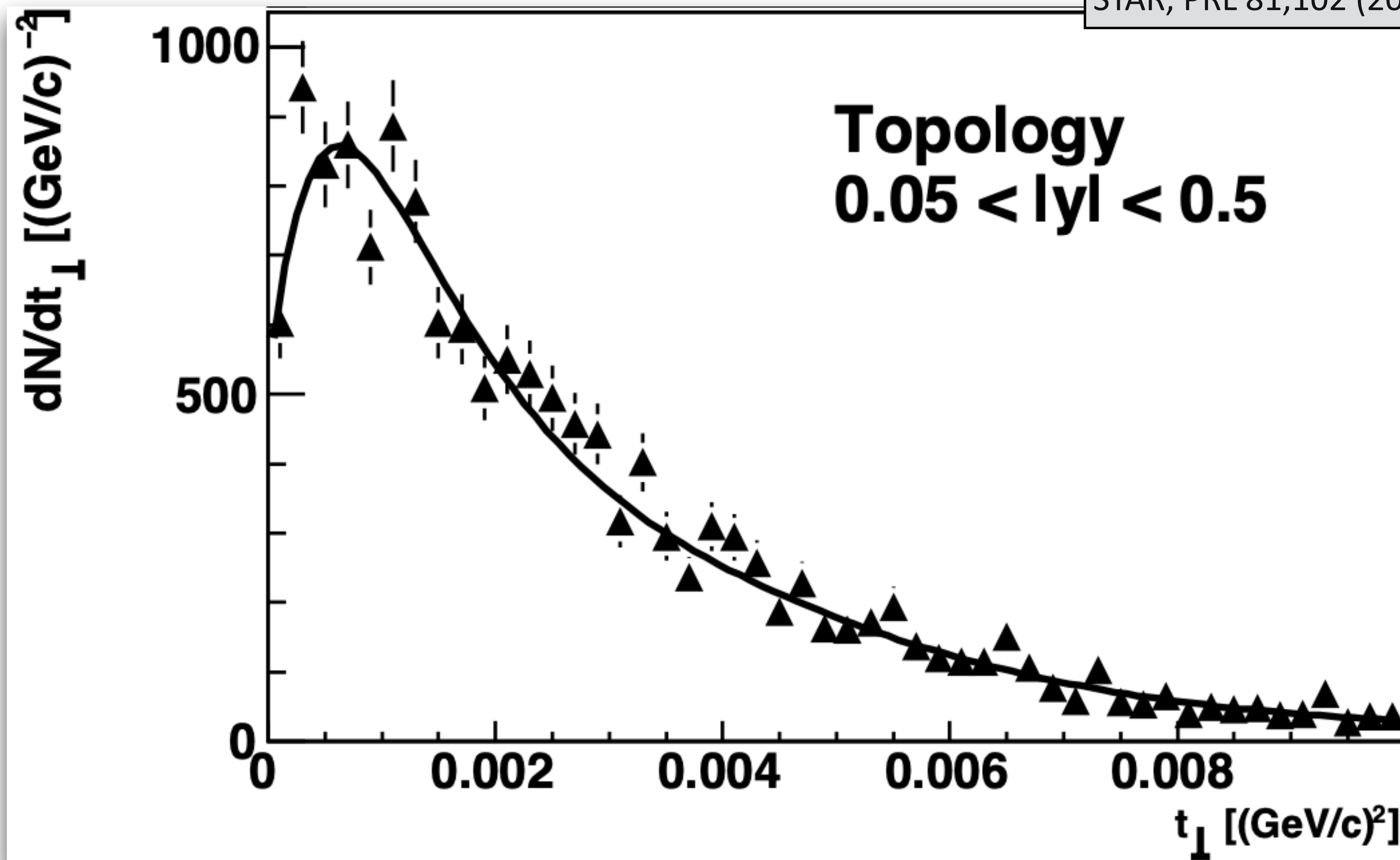
Two potential sources
 \Rightarrow
 QM interference effects



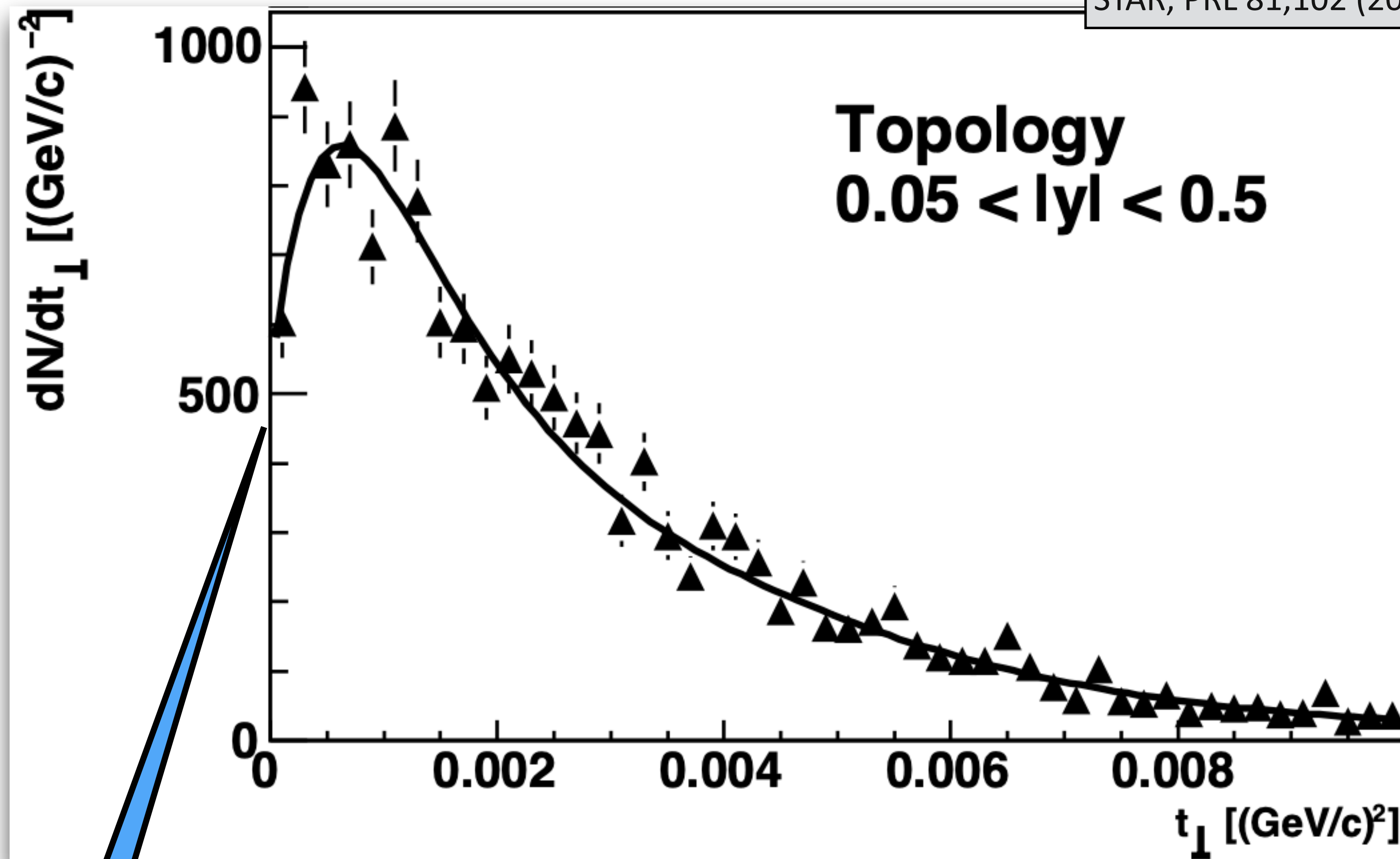
Expectations:
Interference important at low
pT and midrapidity

Two potential sources
⇒
QM interference effects

STAR, PRL 81,102 (2009) 112301

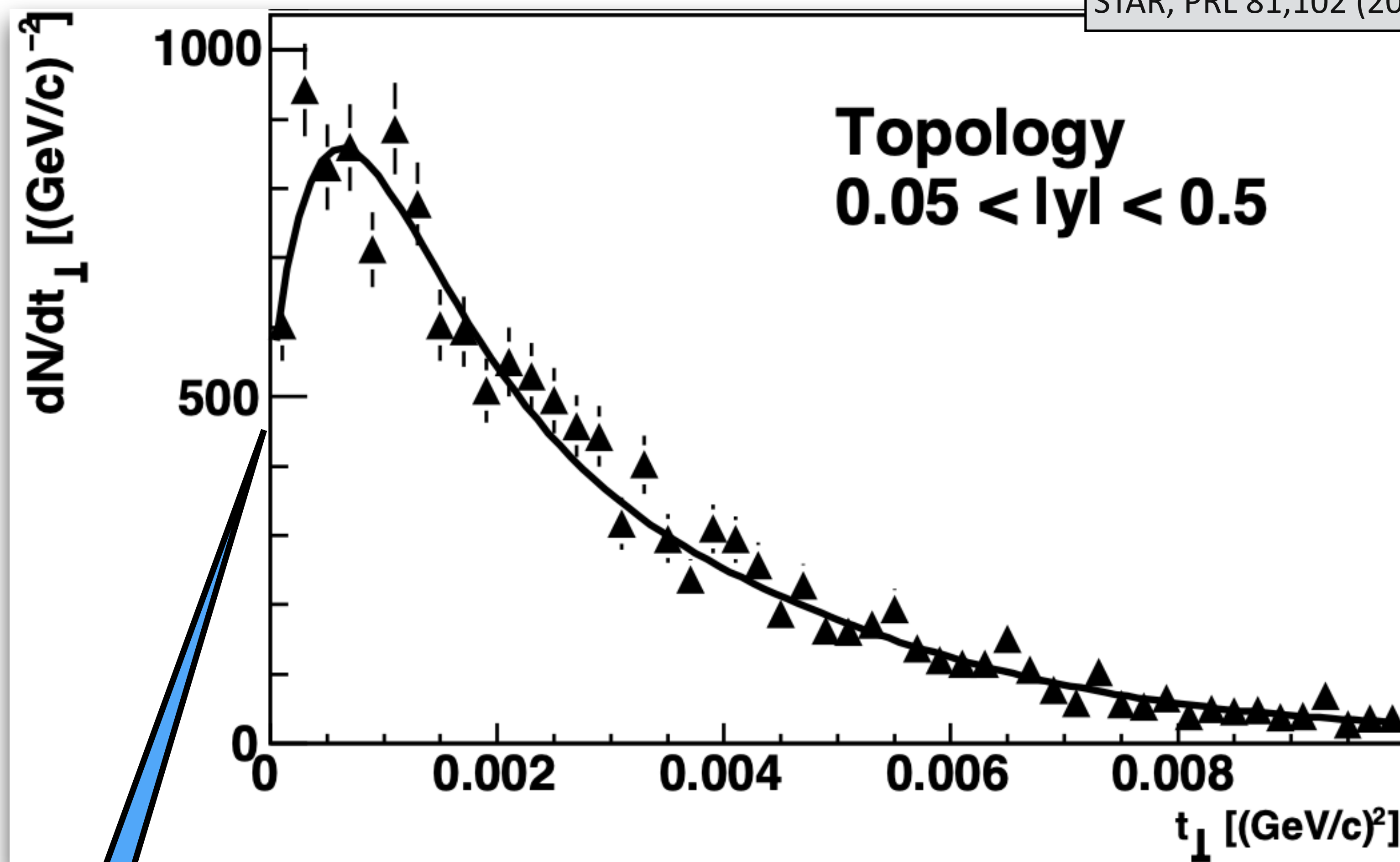


STAR, PRL 81,102 (2009) 112301



Destructive interference
observed

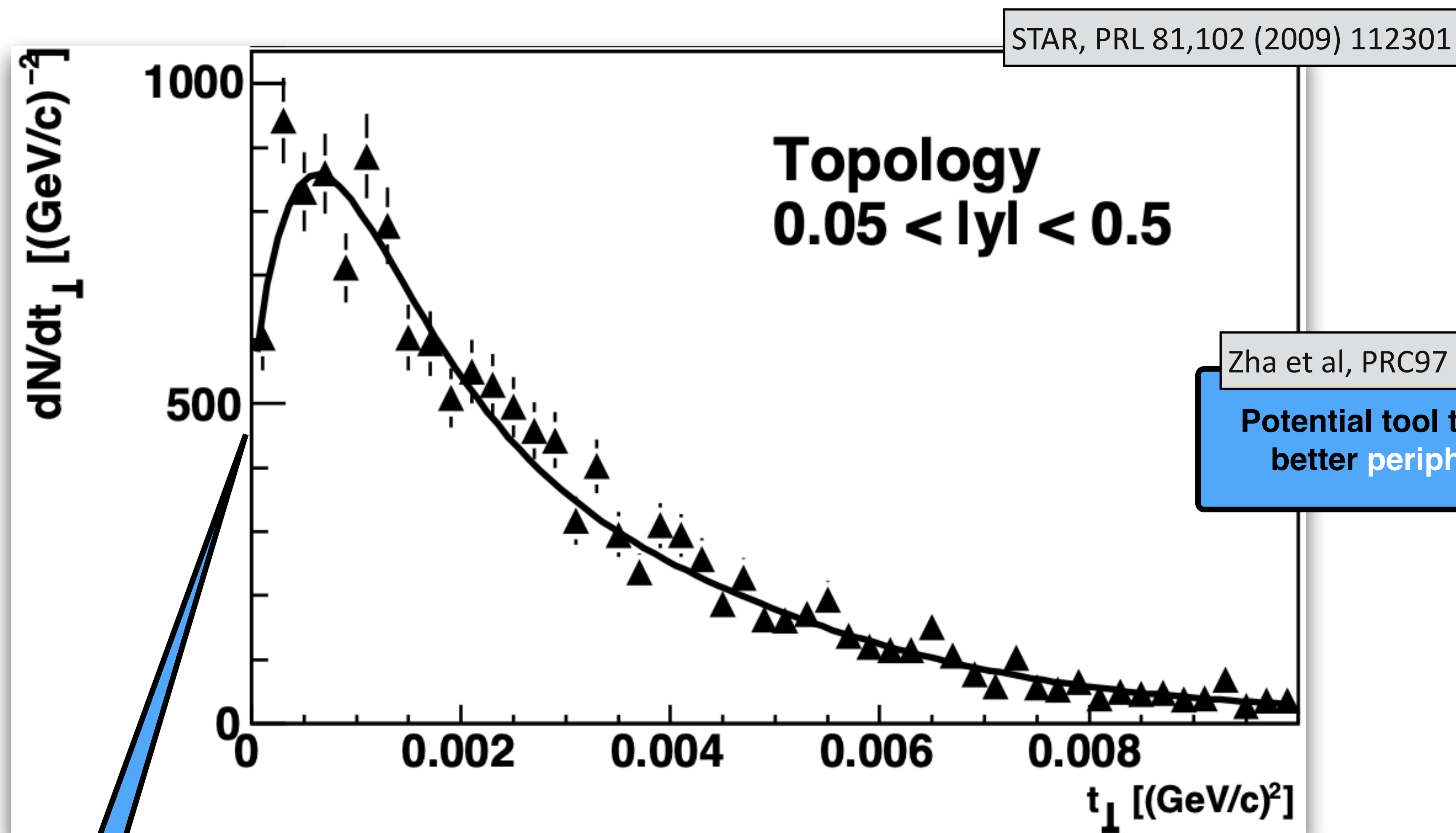
STAR, PRL 81,102 (2009) 112301



Destructive interference
observed

Run 3+4

Should be visible also for J/ψ



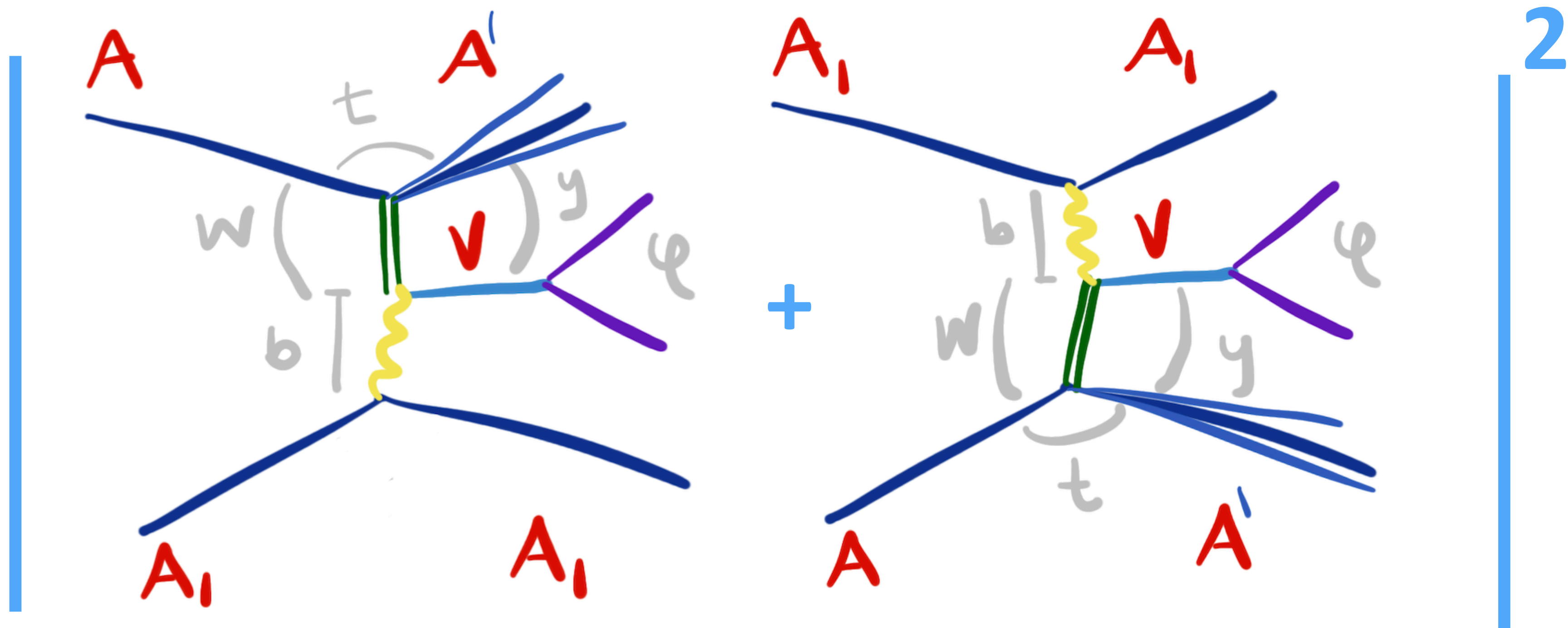
Zha et al, PRC97 044910 (2018)

Potential tool to understand
better **peripheral** eventsDestructive interference
observed

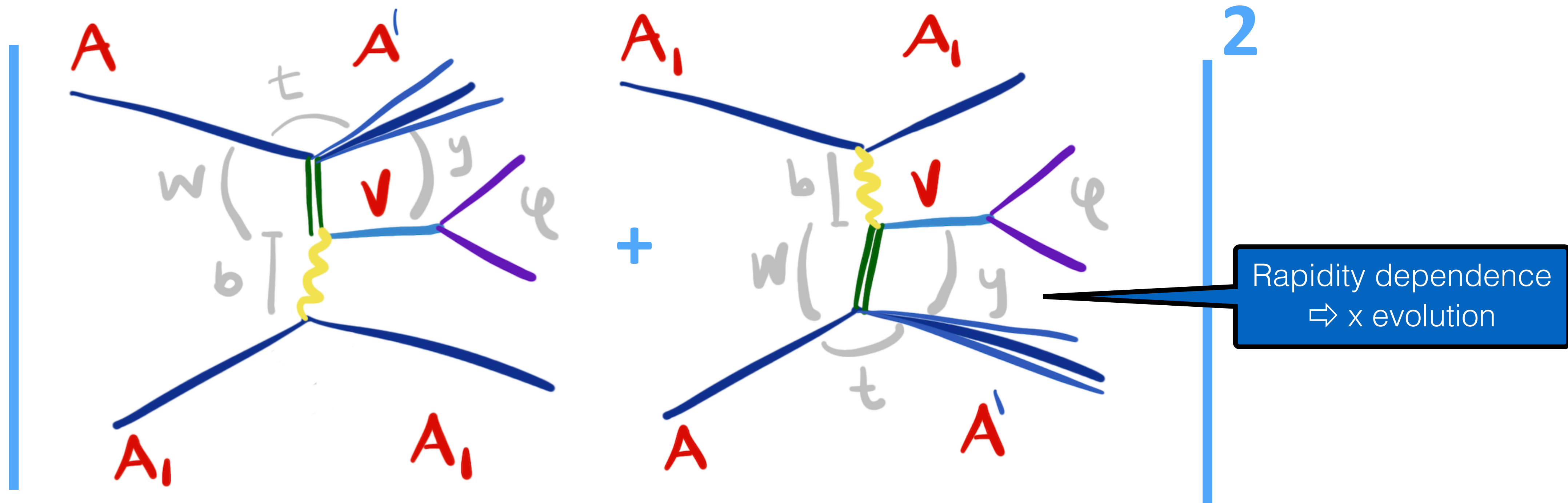
Run 3+4

Should be visible also for J/ψ

Instead of a summary:

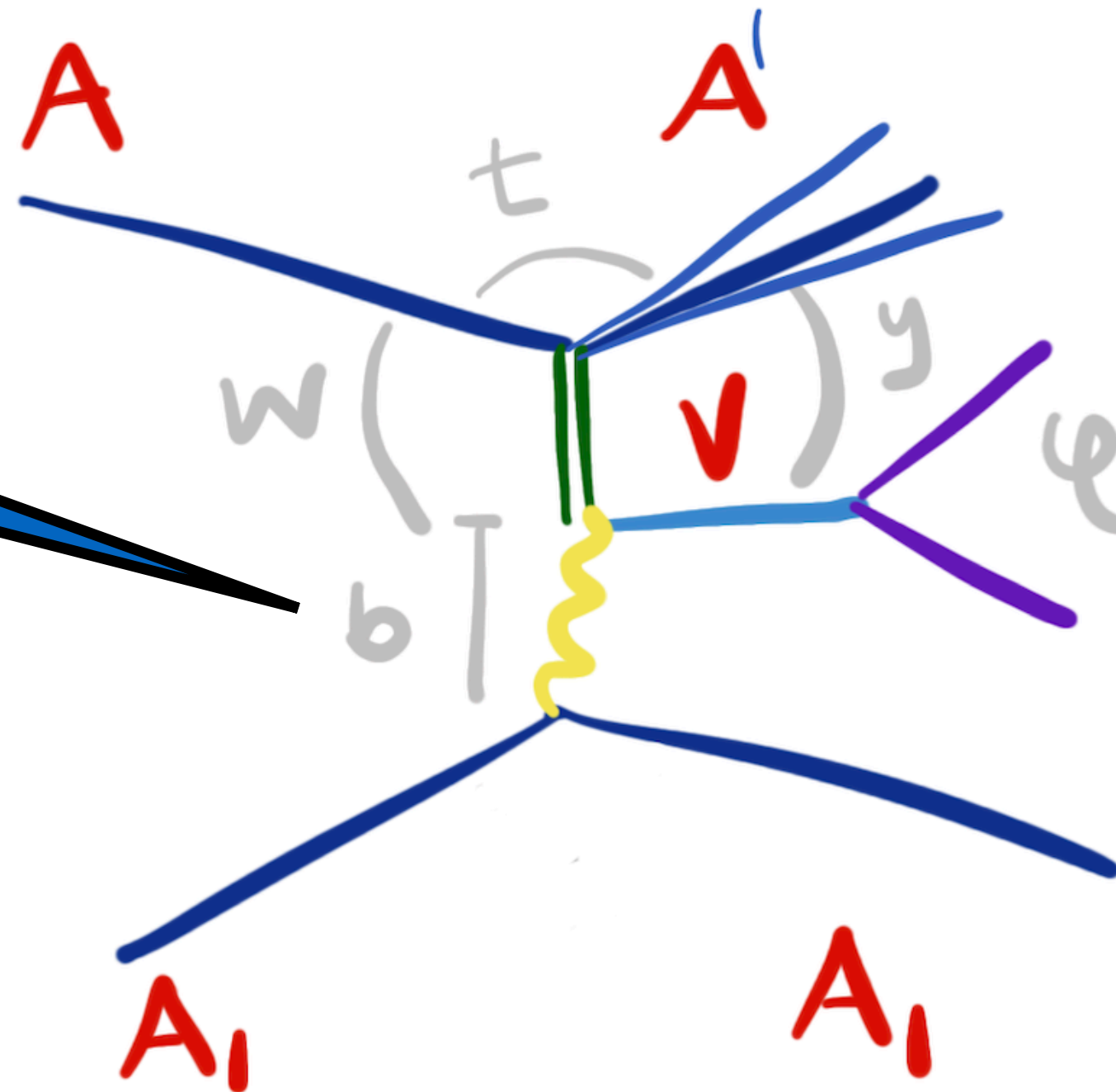


Instead of a summary:

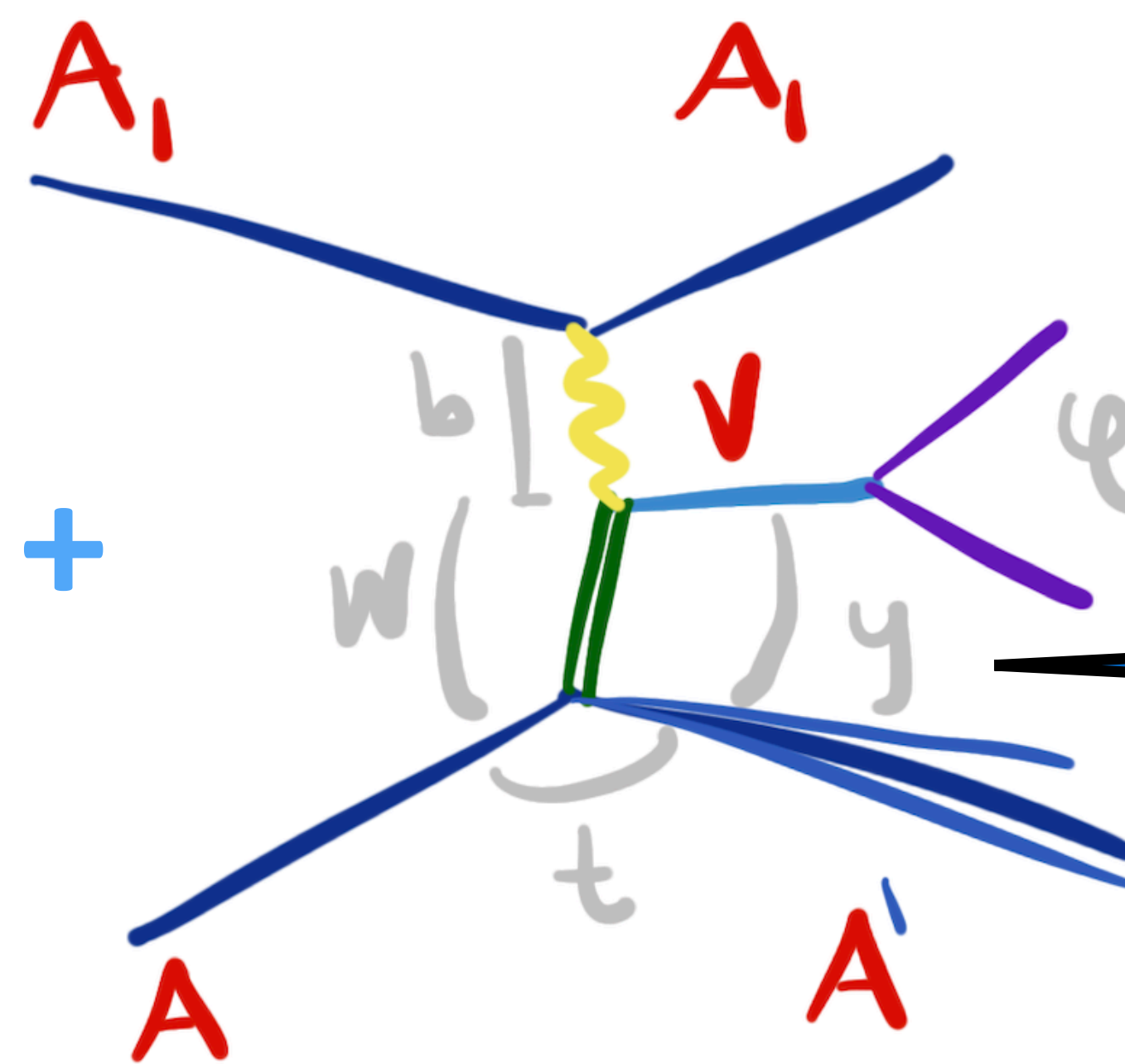


Instead of a summary:

b dependence
 \Rightarrow x evolution



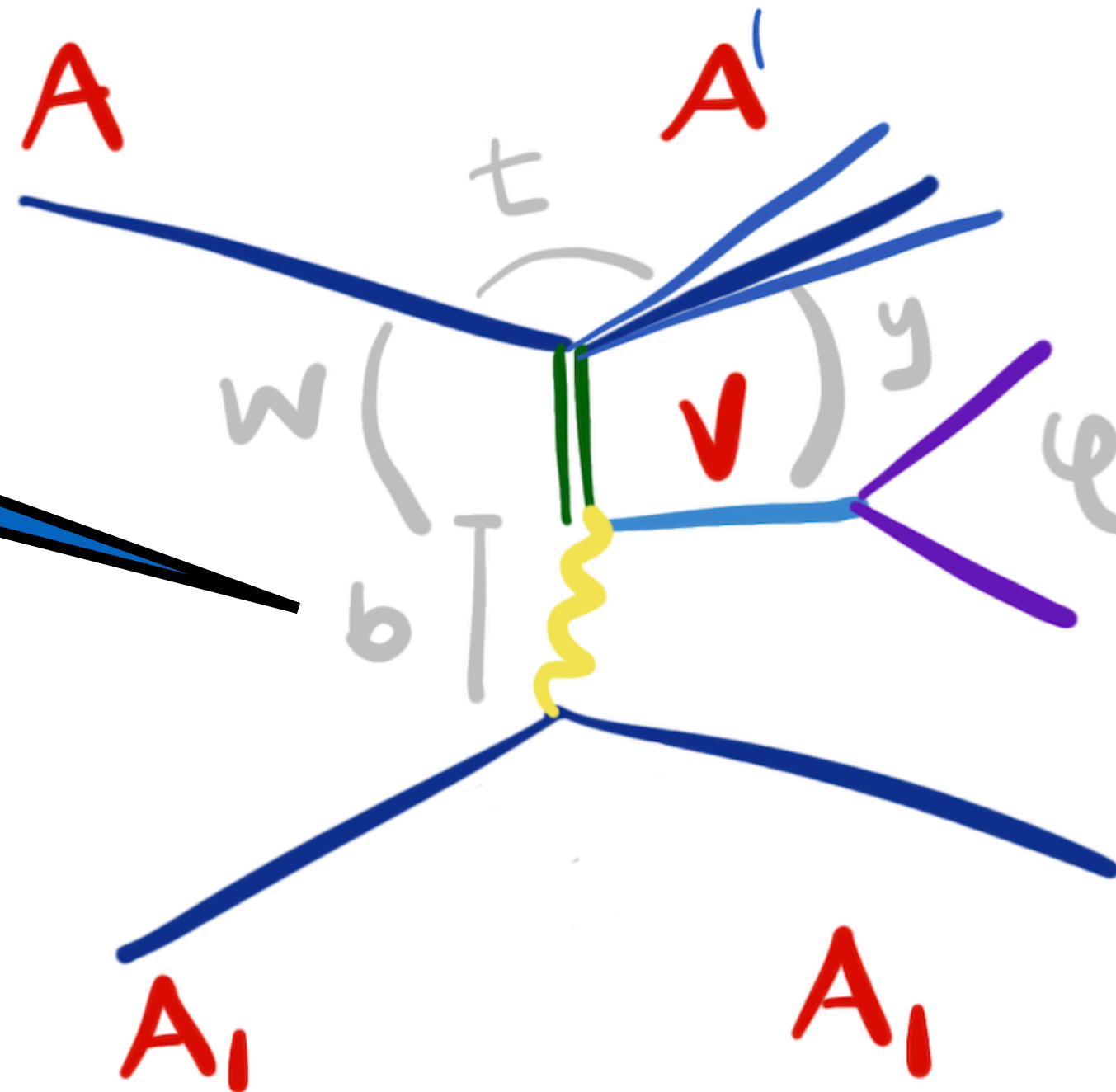
+



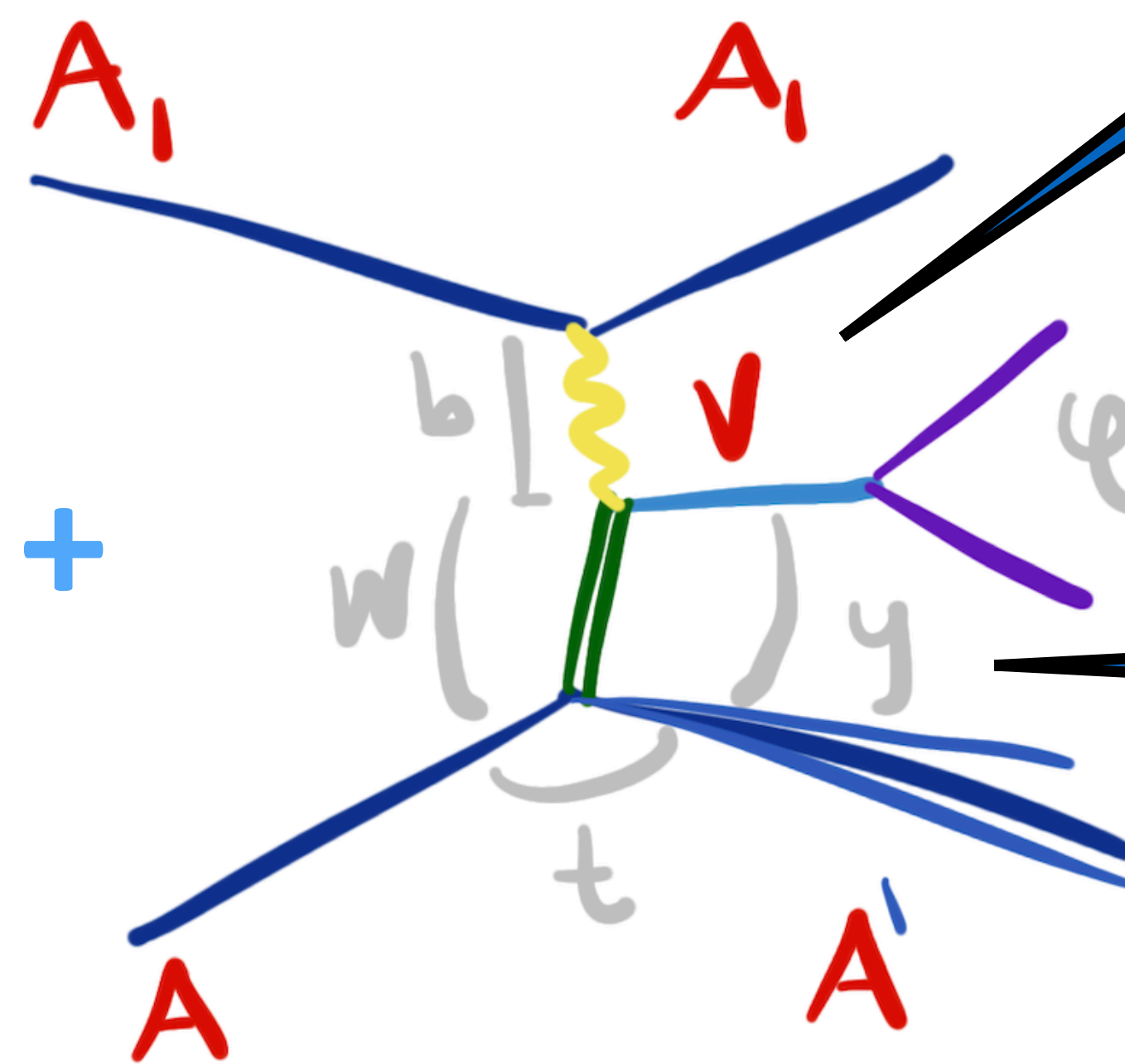
Rapidity dependence
 \Rightarrow x evolution

Instead of a summary:

b dependence
 \Rightarrow x evolution



+

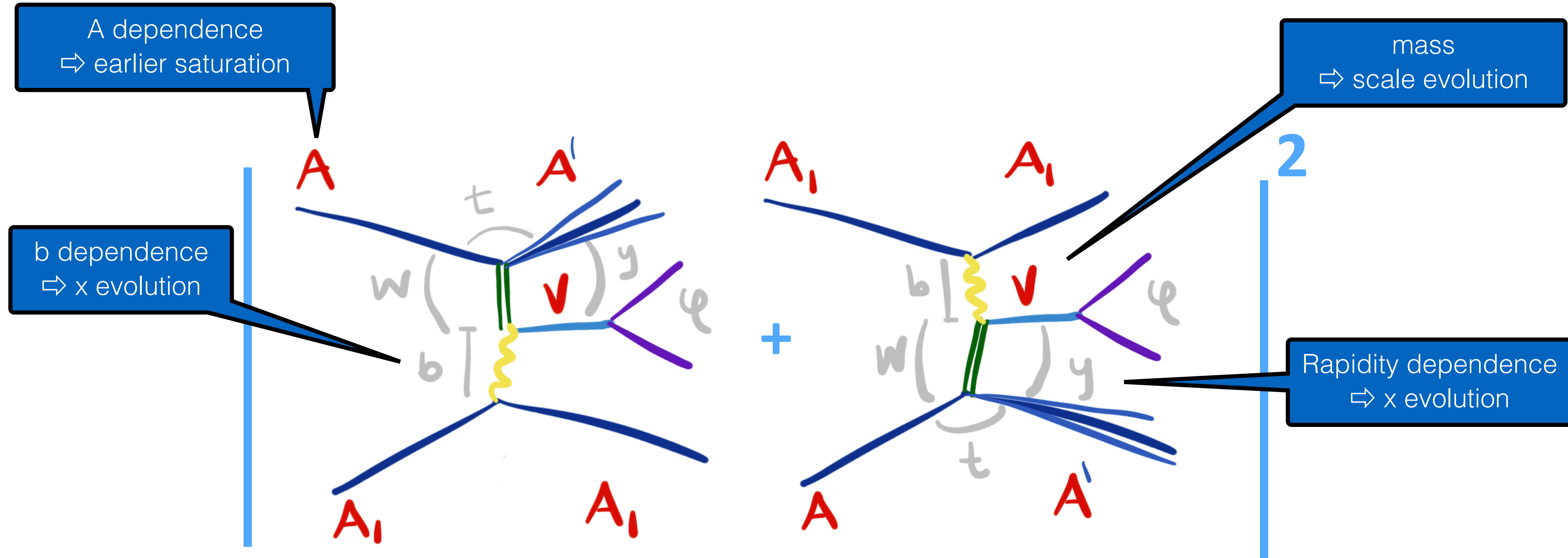


mass
 \Rightarrow scale evolution

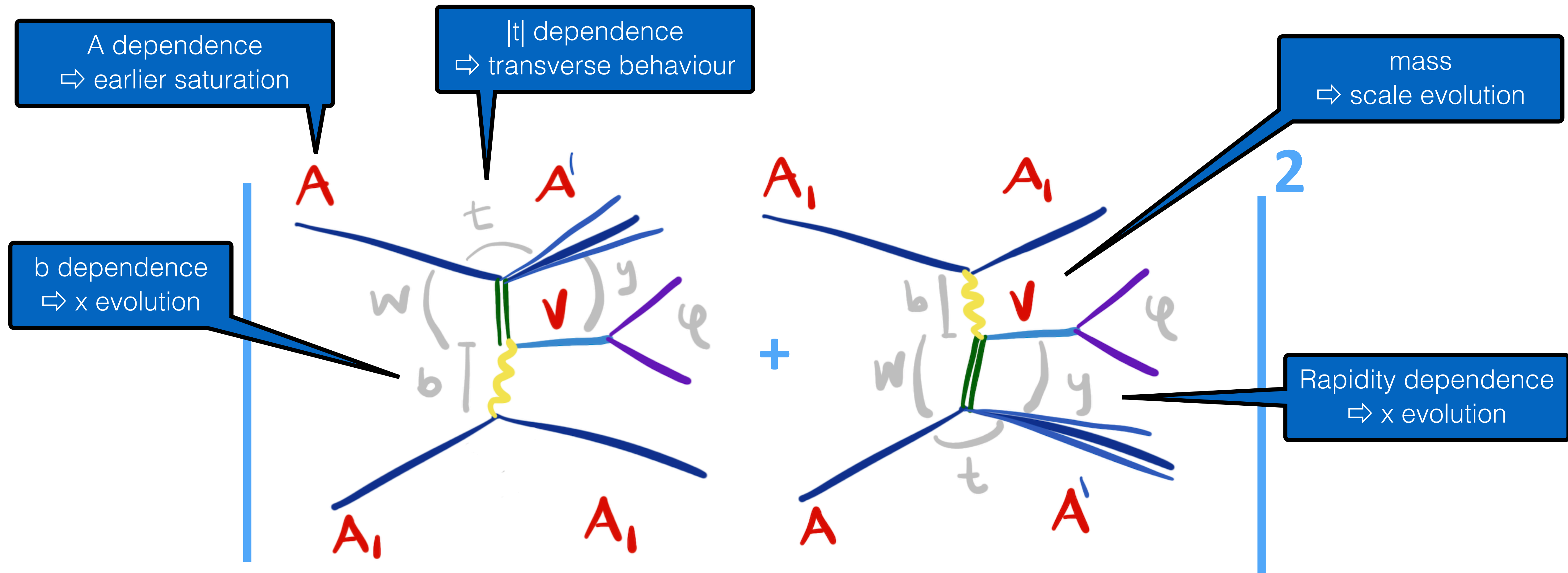
2

Rapidity dependence
 \Rightarrow x evolution

Instead of a summary:



Instead of a summary:



Instead of a summary:

A dependence
 \Rightarrow earlier saturation

$|t|$ dependence
 \Rightarrow transverse behaviour

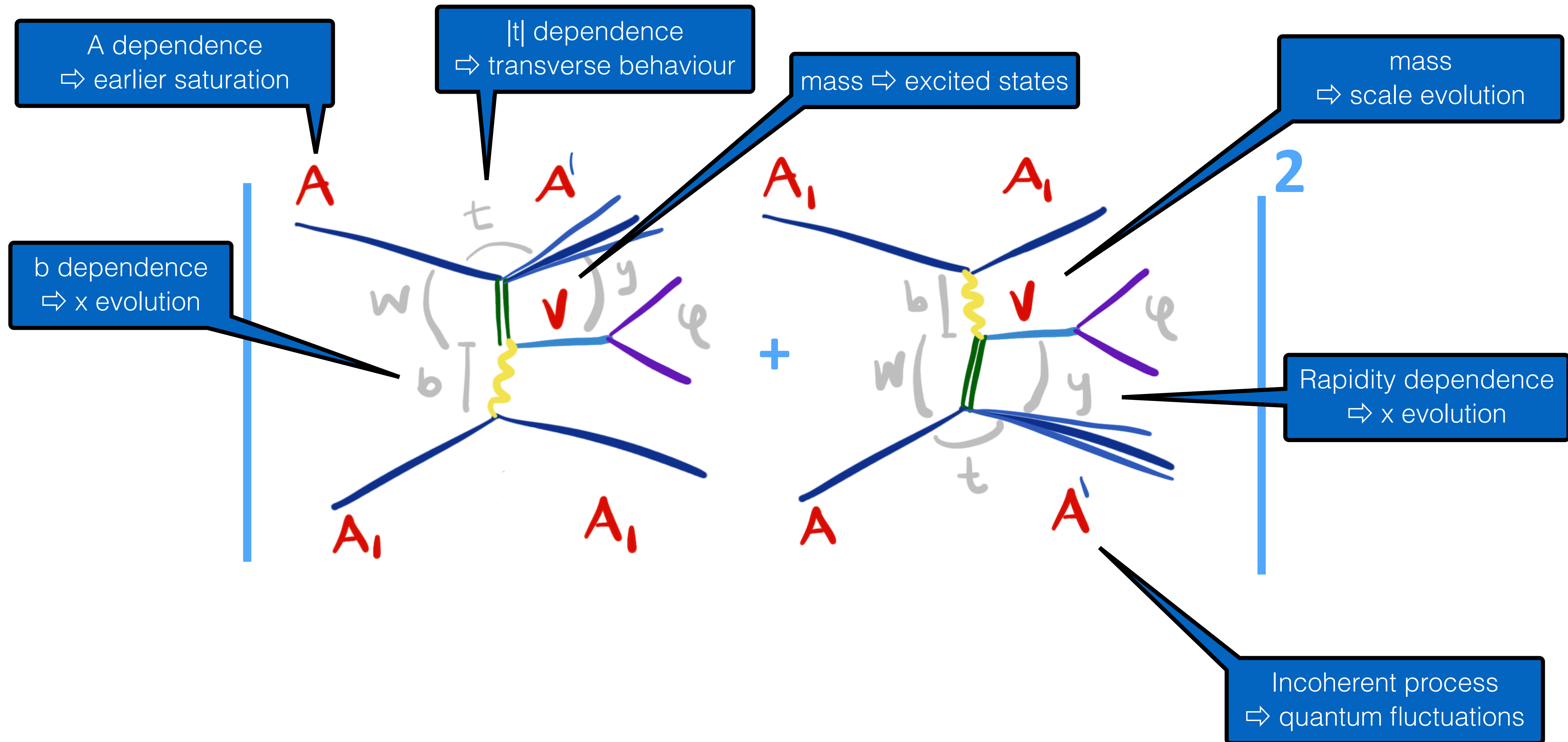
b dependence
 \Rightarrow x evolution

mass
 \Rightarrow scale evolution

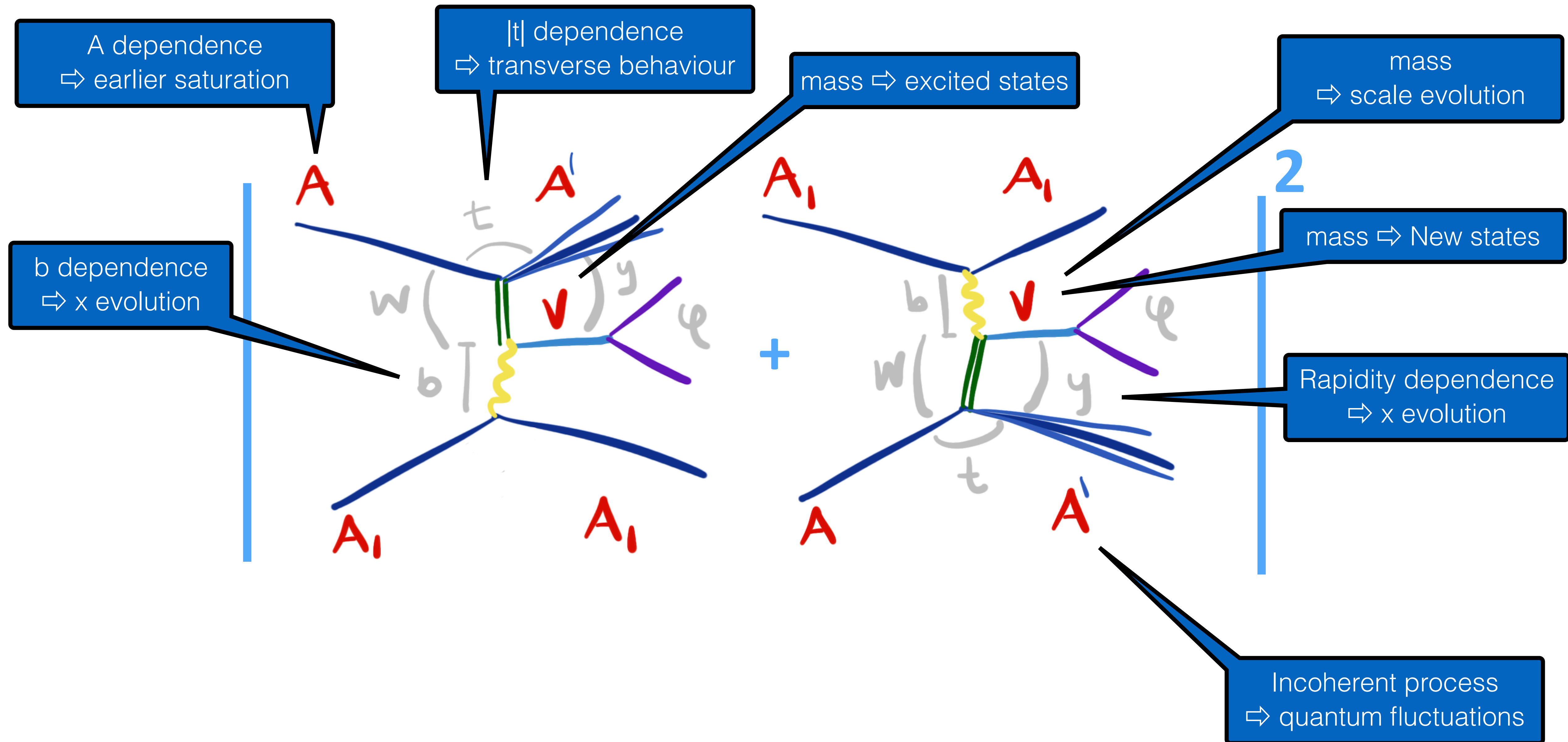
Rapidity dependence
 \Rightarrow x evolution

Incoherent process
 \Rightarrow quantum fluctuations

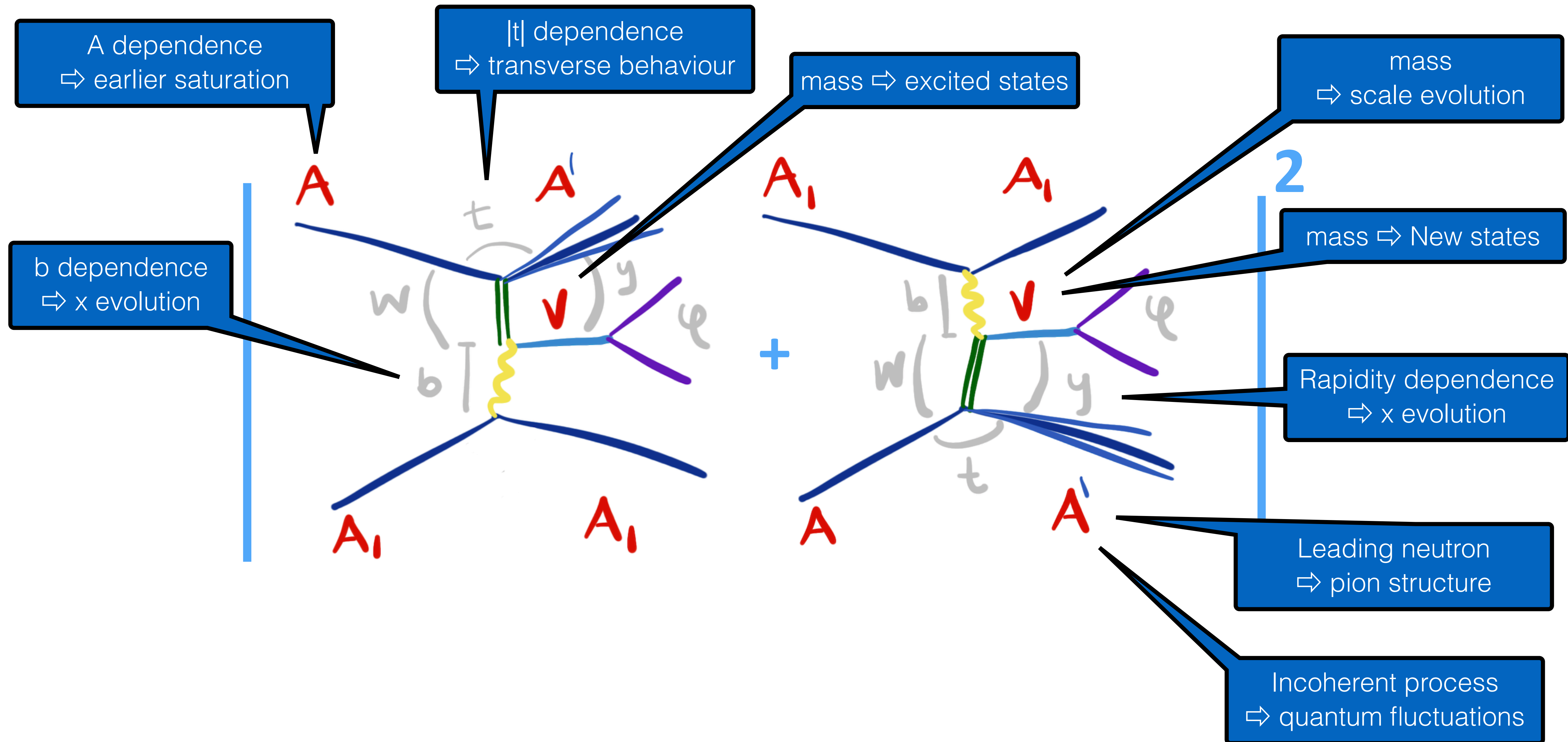
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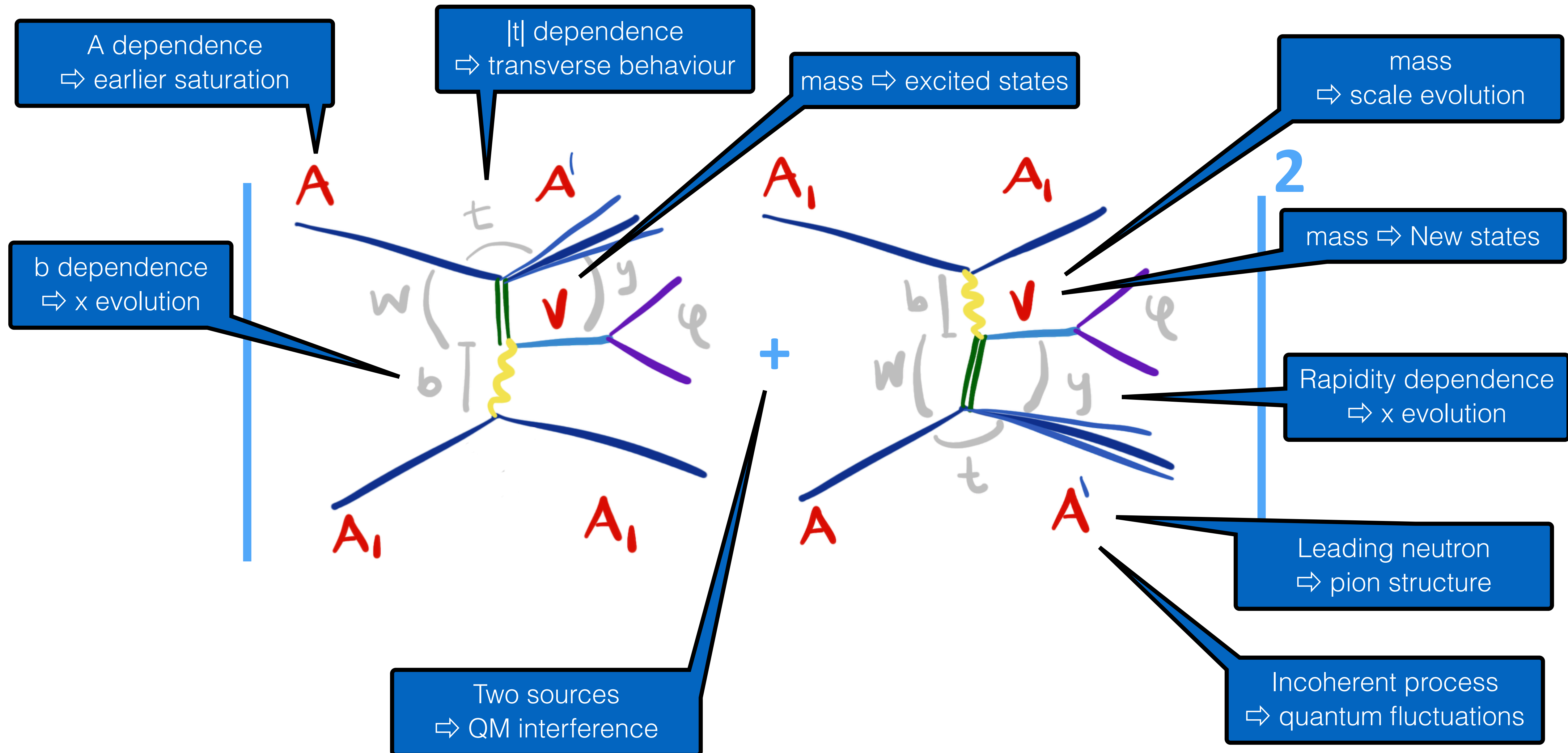
Instead of a summary:



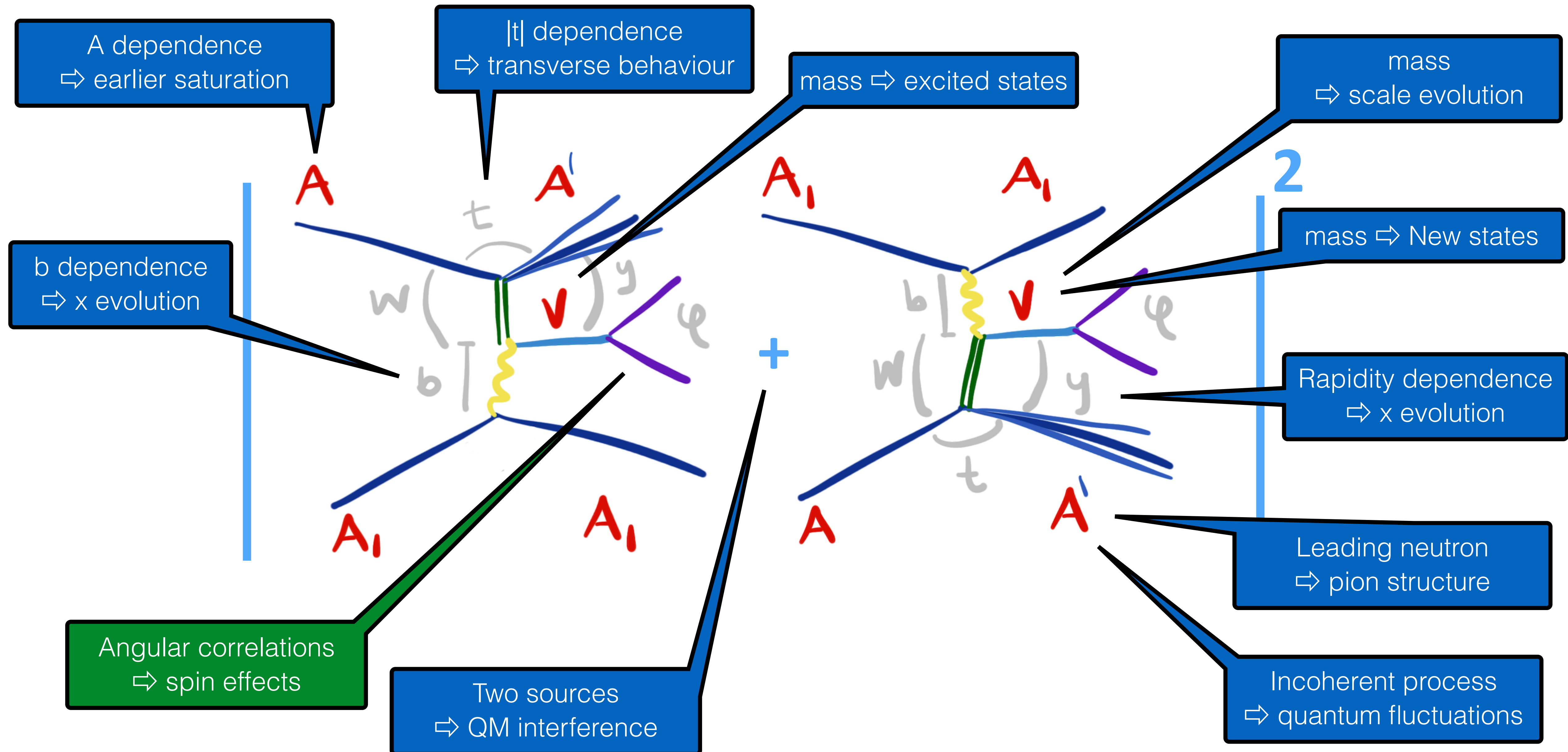
Instead of a summary:



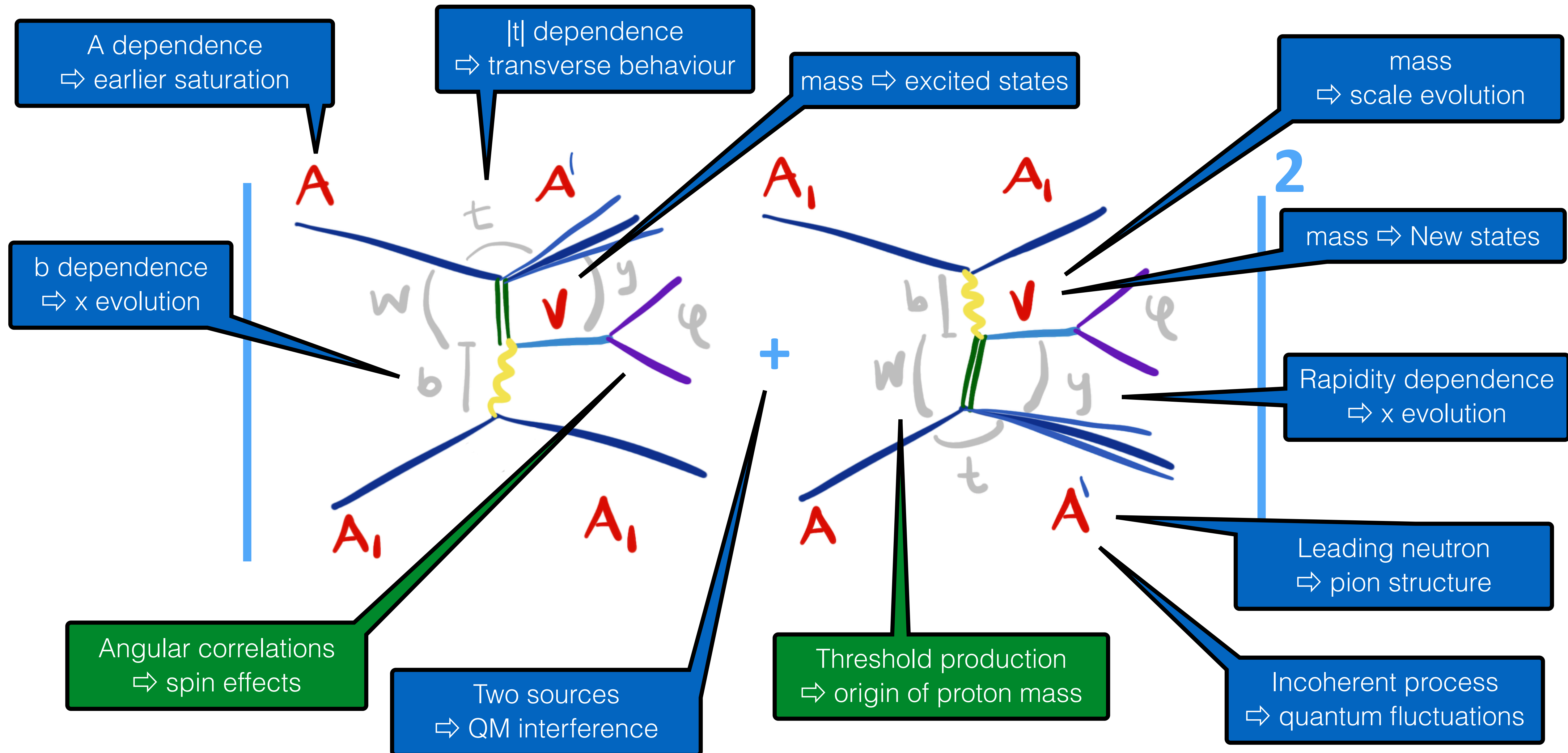
Instead of a summary:



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