Ultra-peripheral collisions in heavy ions at the LHC

Daniel Tapia Takaki

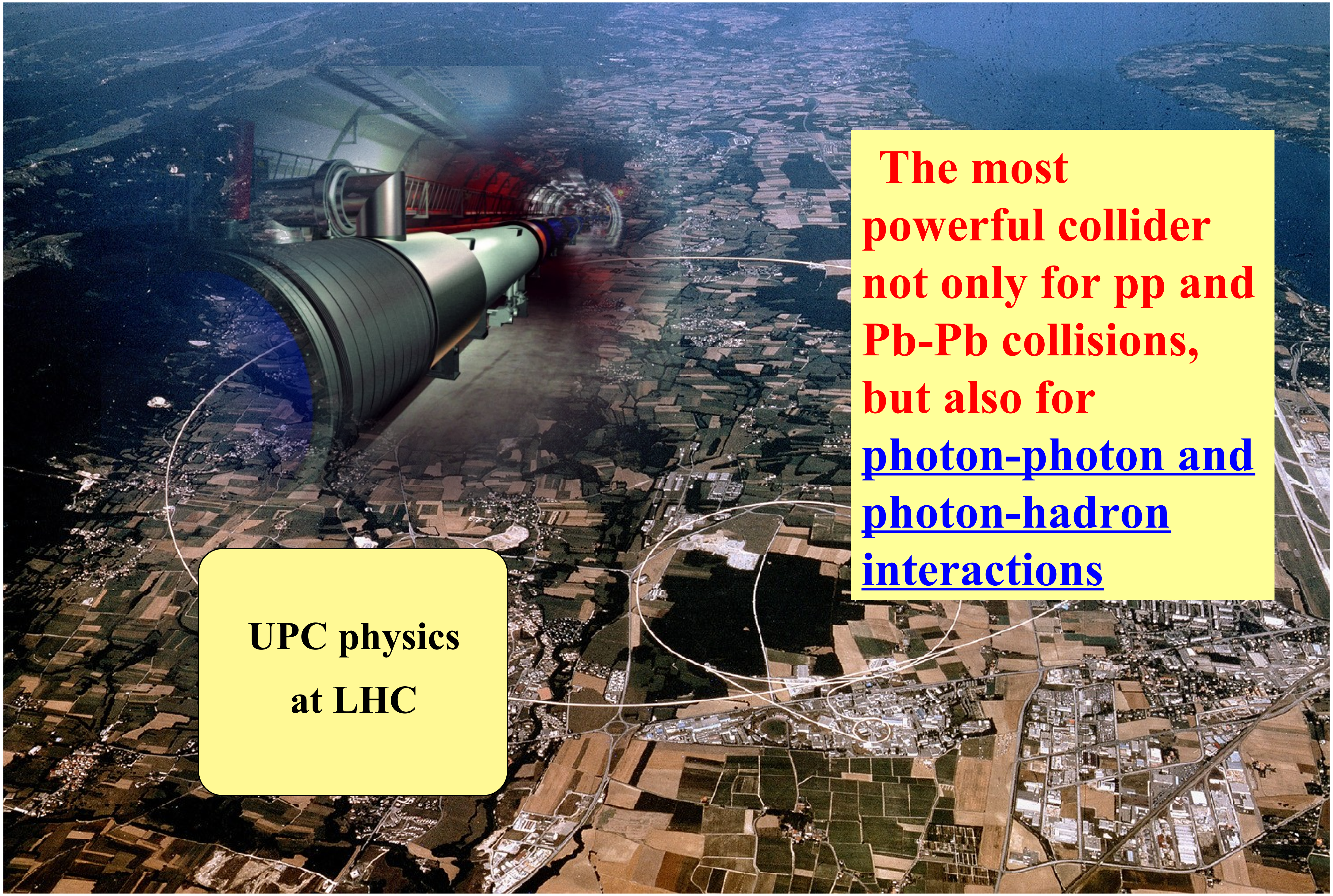
Diffraction:
International Workshop on Diffraction in High-Energy Physics
Catania, Sicily - 7 September 2016

UPC experimental talks at Diffraction

- ALICE:
  - J. Adam: two-photon process and VM results in gamma-p
  - G. Contreras: VM results in gamma-Pb
- ATLAS:
  - M. Arrieta: two-photon process
- CMS:
  - A. Bylinkin: VM result in gamma-p

sort of summary talk from experimental results

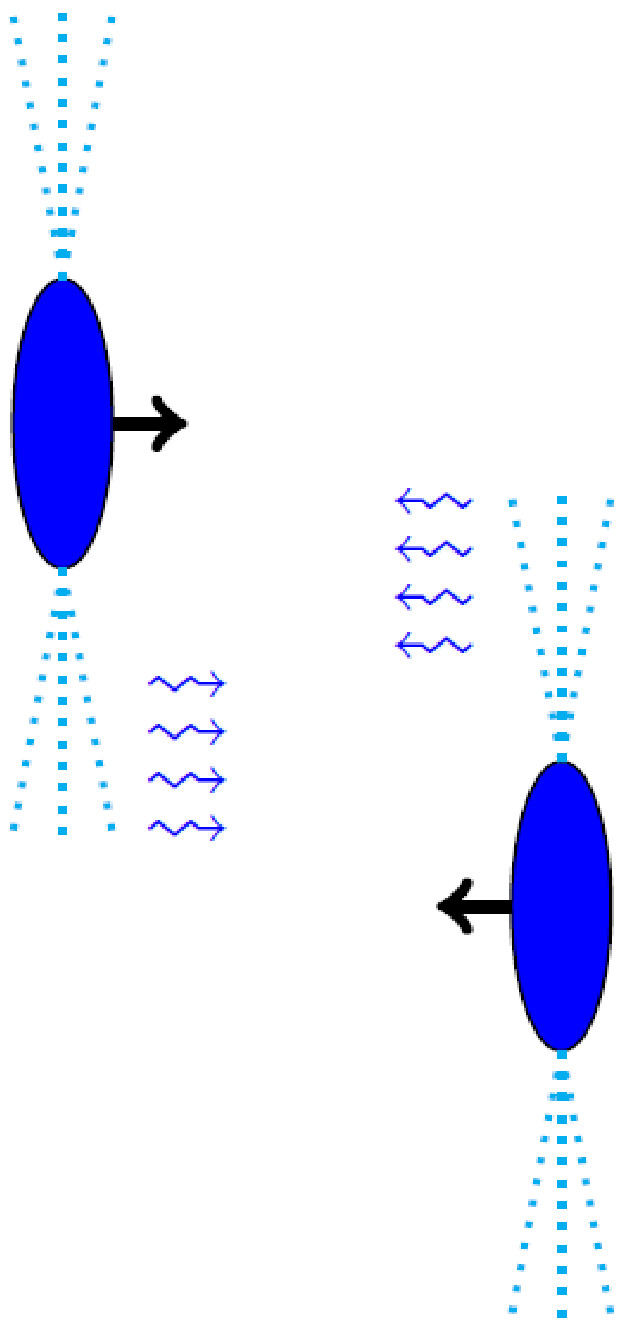
Using the LHC as a γγ, γPb, γp collider



The most powerful collider not only for pp and Pb-Pb collisions, but also for photon-photon and photon-hadron interactions

UPC physics at LHC

Why Ultra-Peripheral collisions

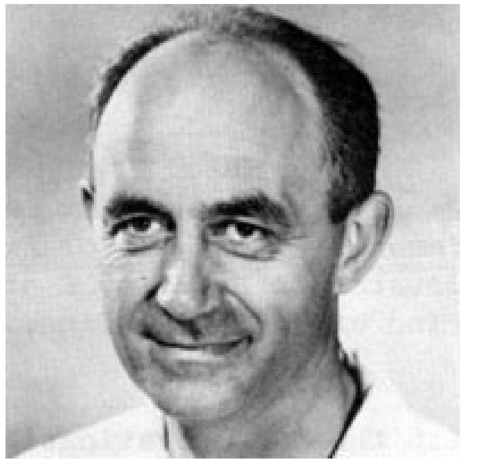


Nuovo Cim.,2:143-158,1925

http://arxiv.org/abs/hep-th/0205086

Therefore, we consider that when a charged particle passes near a point, it produces, at that point, a variable electric field. If we decompose this field, via a Fourier transform, into its harmonic components we find that it is equivalent to the electric field at the same point if it were struck by light with an appropriate continuous distribution of frequencies.

High photon flux ~ Z^2
→ well described by the Weizsäcker-Williams approximation

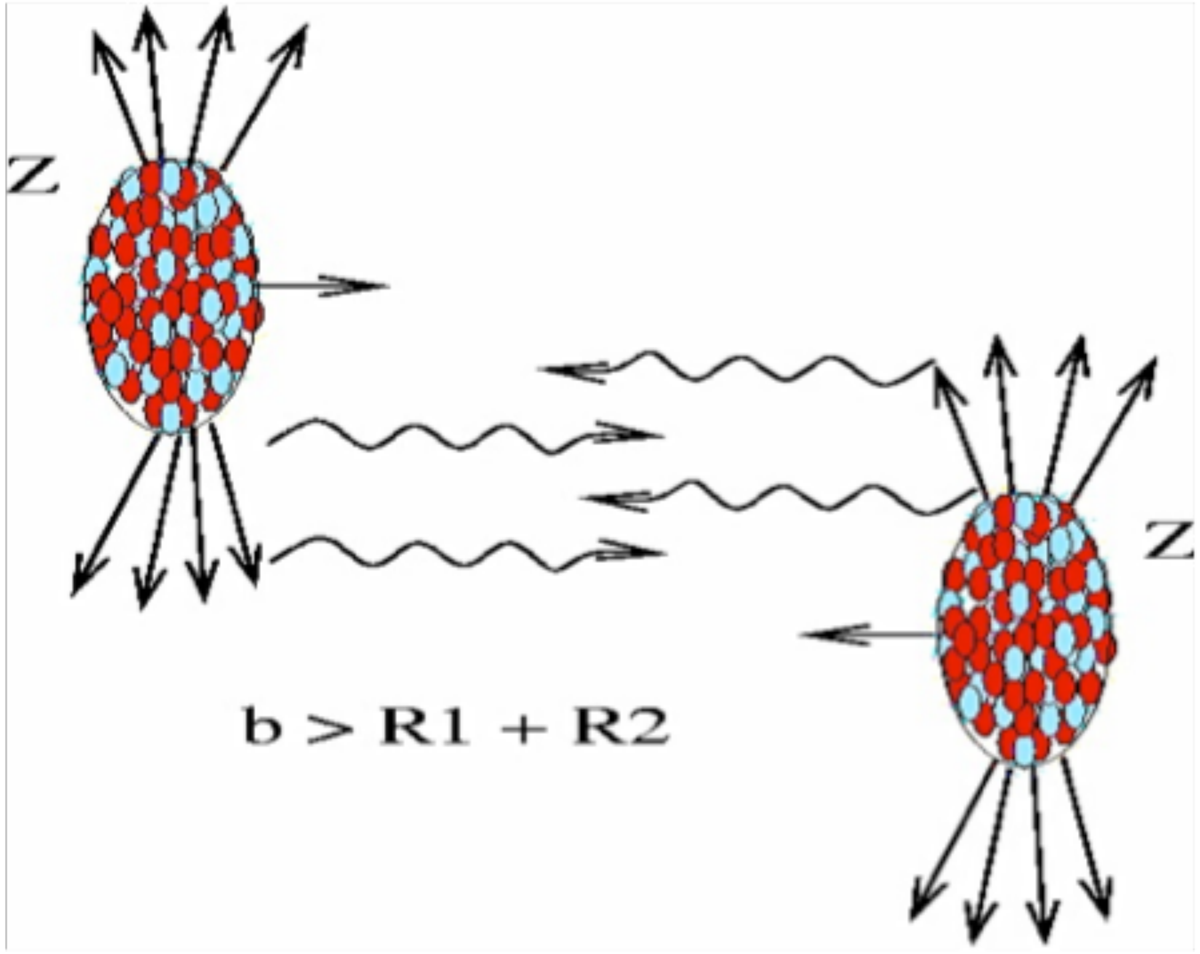


Enrico FERMI

The electromagnetic field surrounding these protons/ions can be treated as a beam of quasi real photons

Two ions (or protons) pass by each other with impact parameters b > 2R. **Hadronic interactions are strongly suppressed**

LHC: *the most energetic photon source ever built*



Photon-induced collisions at the Tera-eV scale

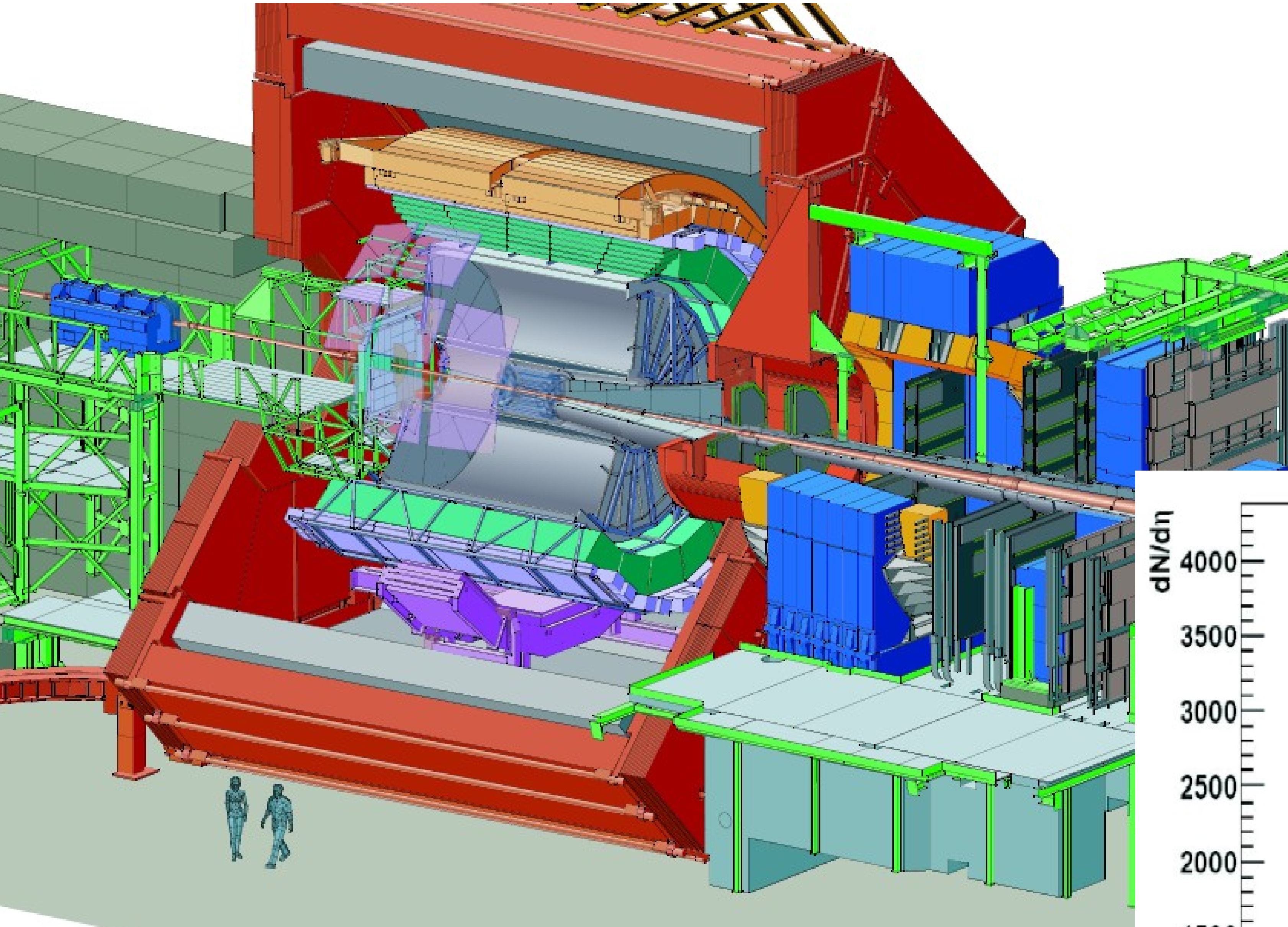
UPCs: multiple studies are possible

- Understanding of the initial state produced in high energy nucleus-nucleus collisions
- Understanding gluons and their self-interactions in nucleons/nuclei
- Glueballs, exotic quarkonia …
- QED physics, radiative decays, strong fields
- Electro-weak final states
- Beyond the Standard Model

9 UPC studies with heavy ions at the LHC

- *Coherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at sNN=2.76 TeV* Phys.Lett. B718 (2013) 1273-1283
- *Charmonium and e+e− pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at sNN√=2.76 TeV* Eur.Phys.J. C73 (2013) 11, 2617
- *Exclusive J/ψ photoproduction off protons in ultra-peripheral p-Pb collisions at sNN√=5.02 TeV* Phys.Rev.Lett. 113 (2014) 23, 232504
- *Coherent ρ0 photoproduction in ultra-peripheral Pb-Pb collisions at sNN =2.76 TeV* JHEP 1509 (2015) 095
- *Coherent ψ(2S) photo-production in ultra-peripheral Pb Pb collisions at sNN = 2.76 TeV* Phys.Lett. B751 (2015) 358-370
- *Measurement of an excess in the yield of J/\psi at very low pT in Pb-Pb collisions at sNN = 2.76 TeV* Phys. Rev. Lett.116 (2016) 22, 222301
- *Coherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at sNN=2.76 TeV with the CMS detector* CMS-PAS-HIN-12-009. Submitted to PLB
- *Measurement of exclusive Upsilon in pPb collisions at sNN = 5.02 TeV* CMS-PAS-FSQ-13-009
- *Measurement of high-mass dimuon pairs from ultraperipheral lead-lead collisions at sNN =5.02 TeV with the ATLAS detector at the LHC* ATLAS-CONF-2016-025

The ALICE experiment at LHC



Central rapidity

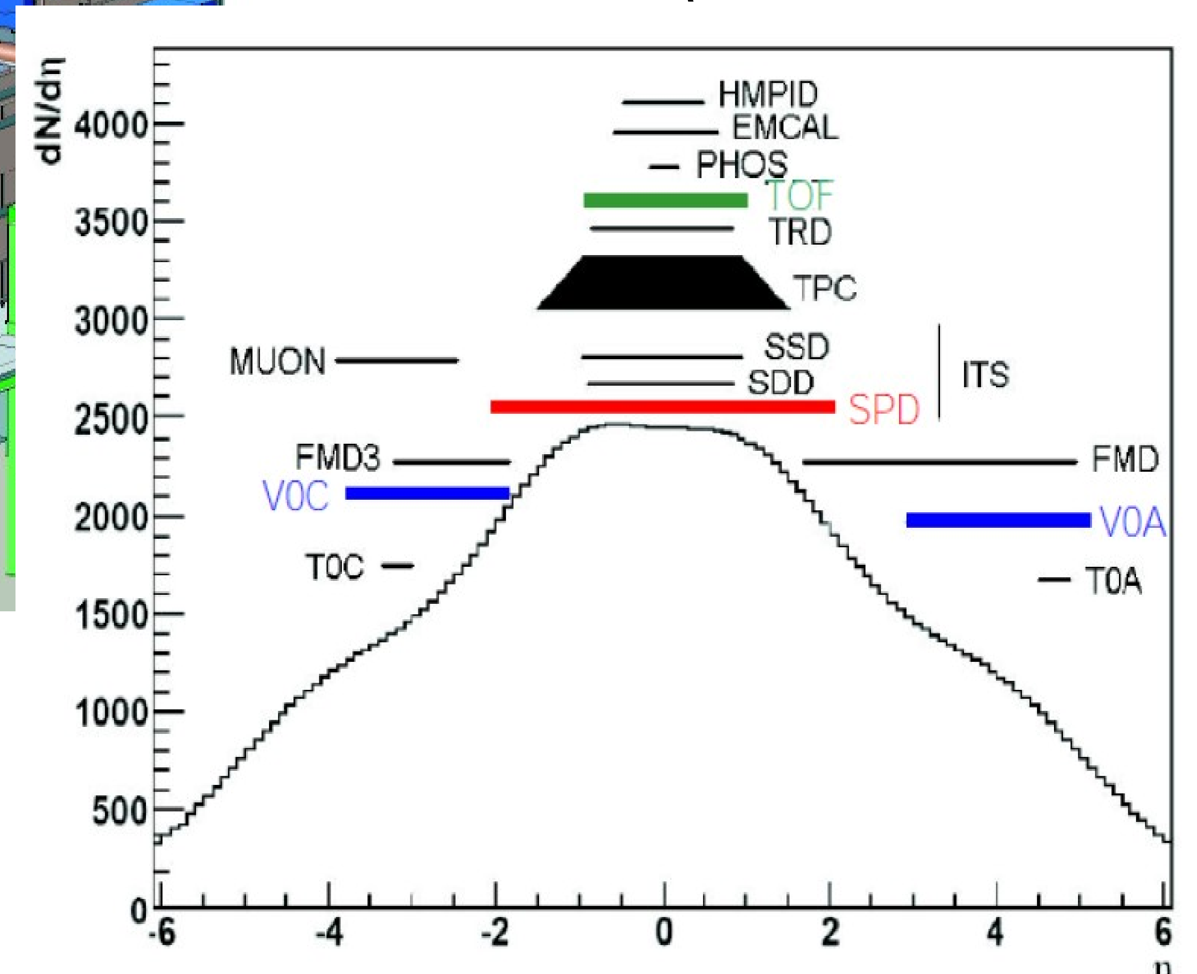
Inner Tracking (ITS), Time Projection Chamber (TPC), Time-of-Flight, TRD, EMCAL

$|\eta| < 0.9$

Forward rapidity

Muon Spectrometer

$-4 < \eta < -2.5$

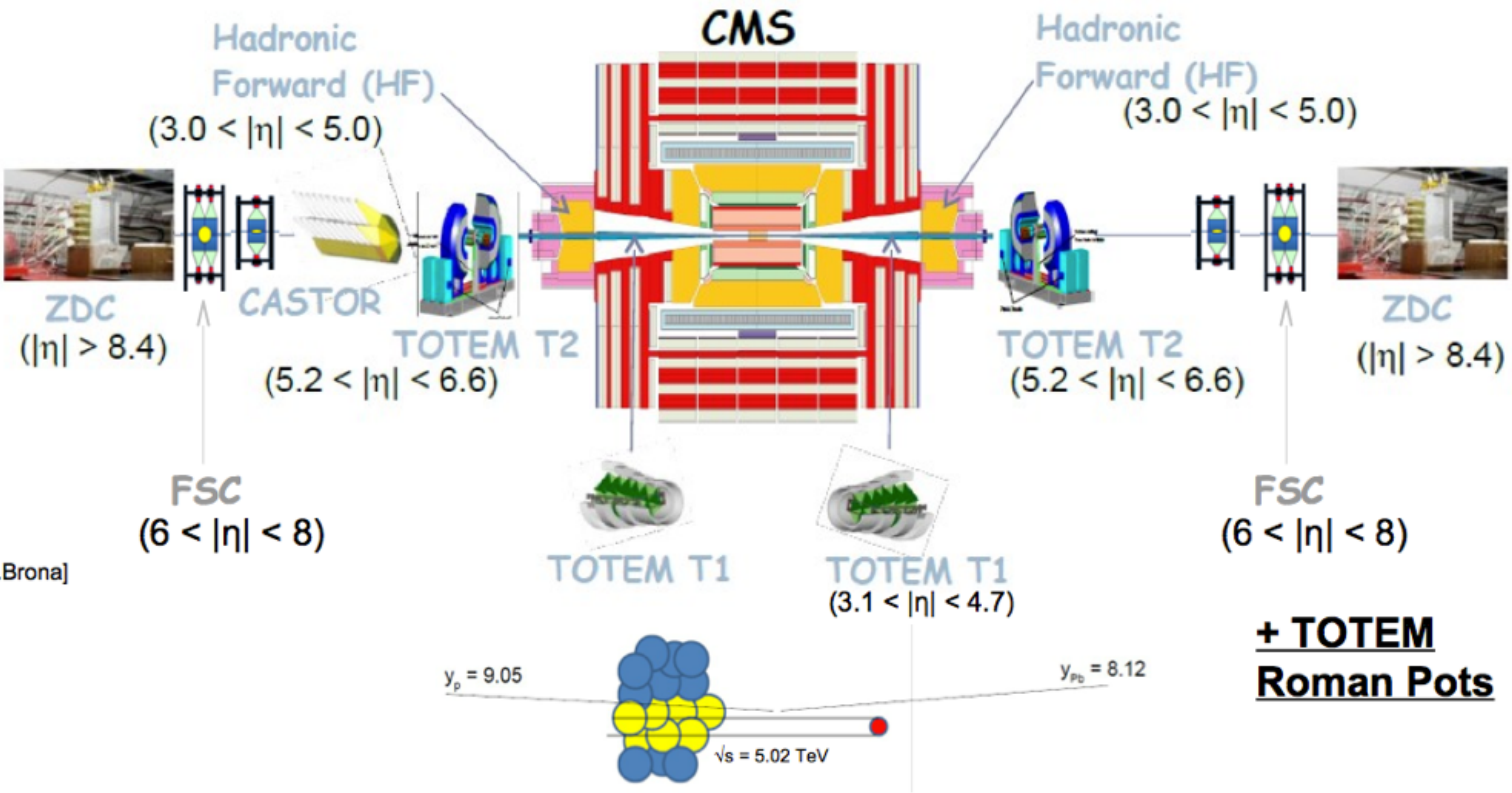


Dedicated triggers for UPC, using VZERO forward detectors for vetoing And MUON, TOF and SPD

ALICE can measure J/ψ mesons down to zero p_T

ZDC at 116 m from IP, to study neutron/proton emitted at the very forward region

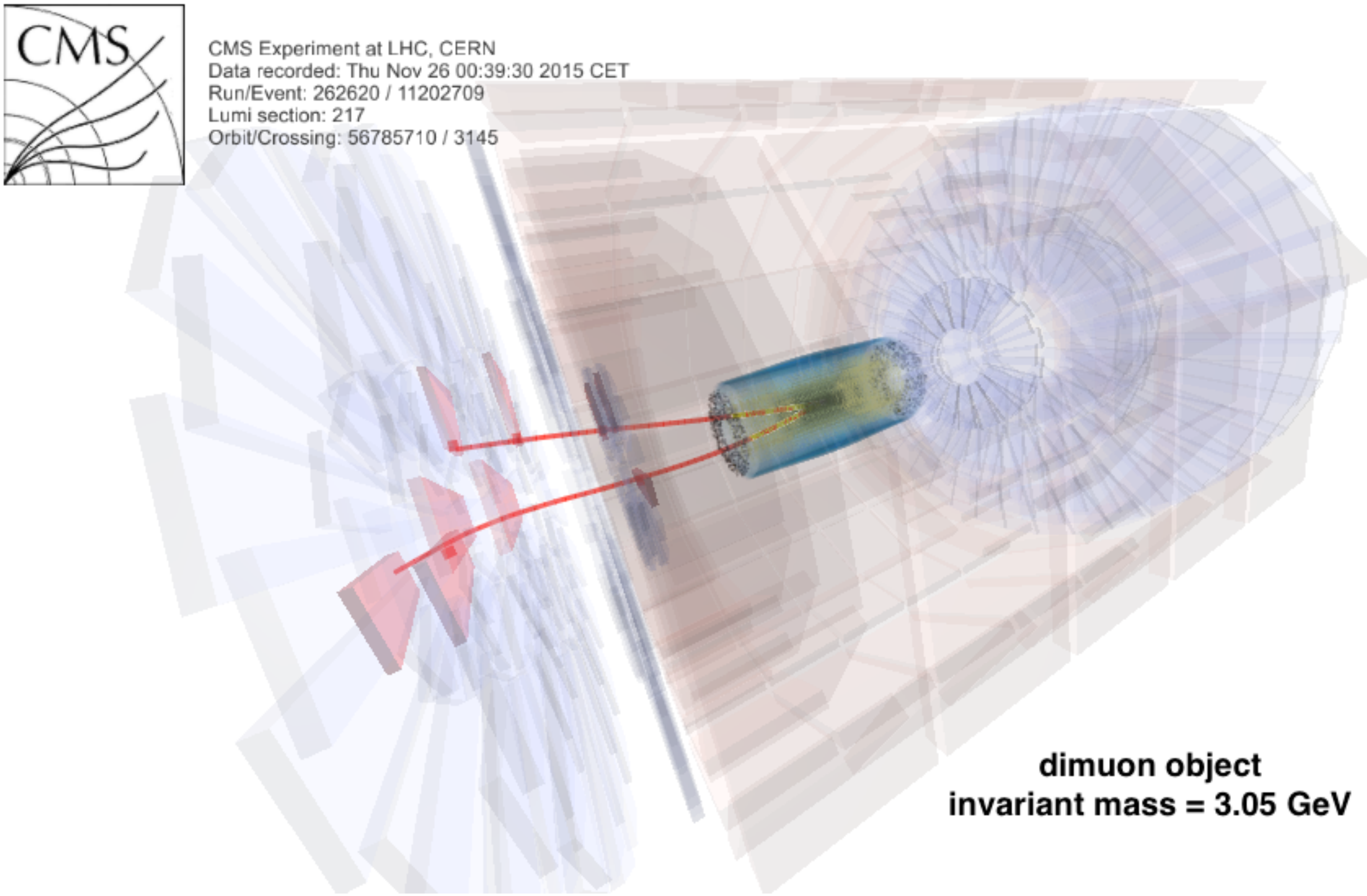
Forward detectors at CMS



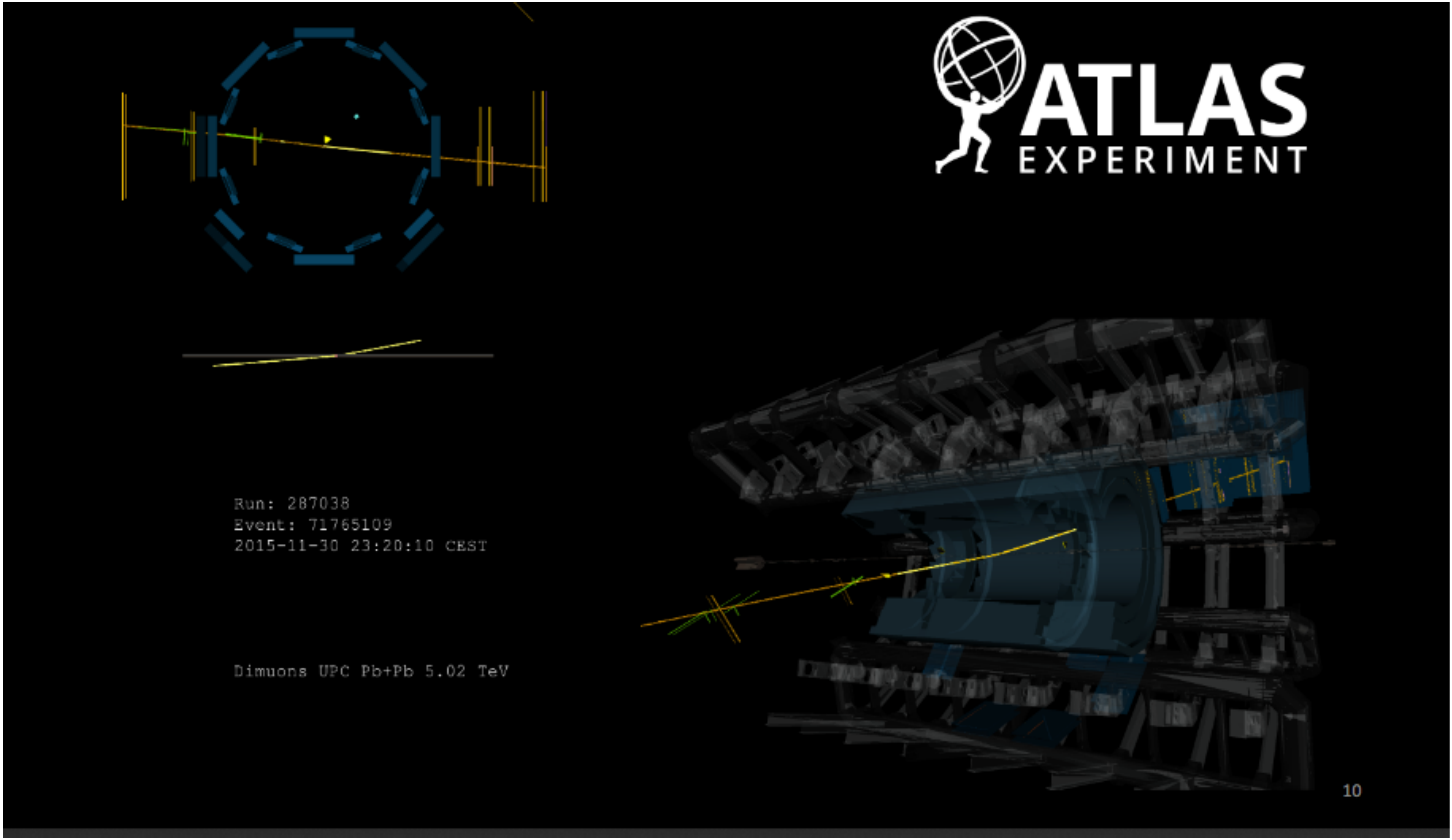
[G.Brona]

+ TOTEM Roman Pots

UPC: *The most gentle collisions*

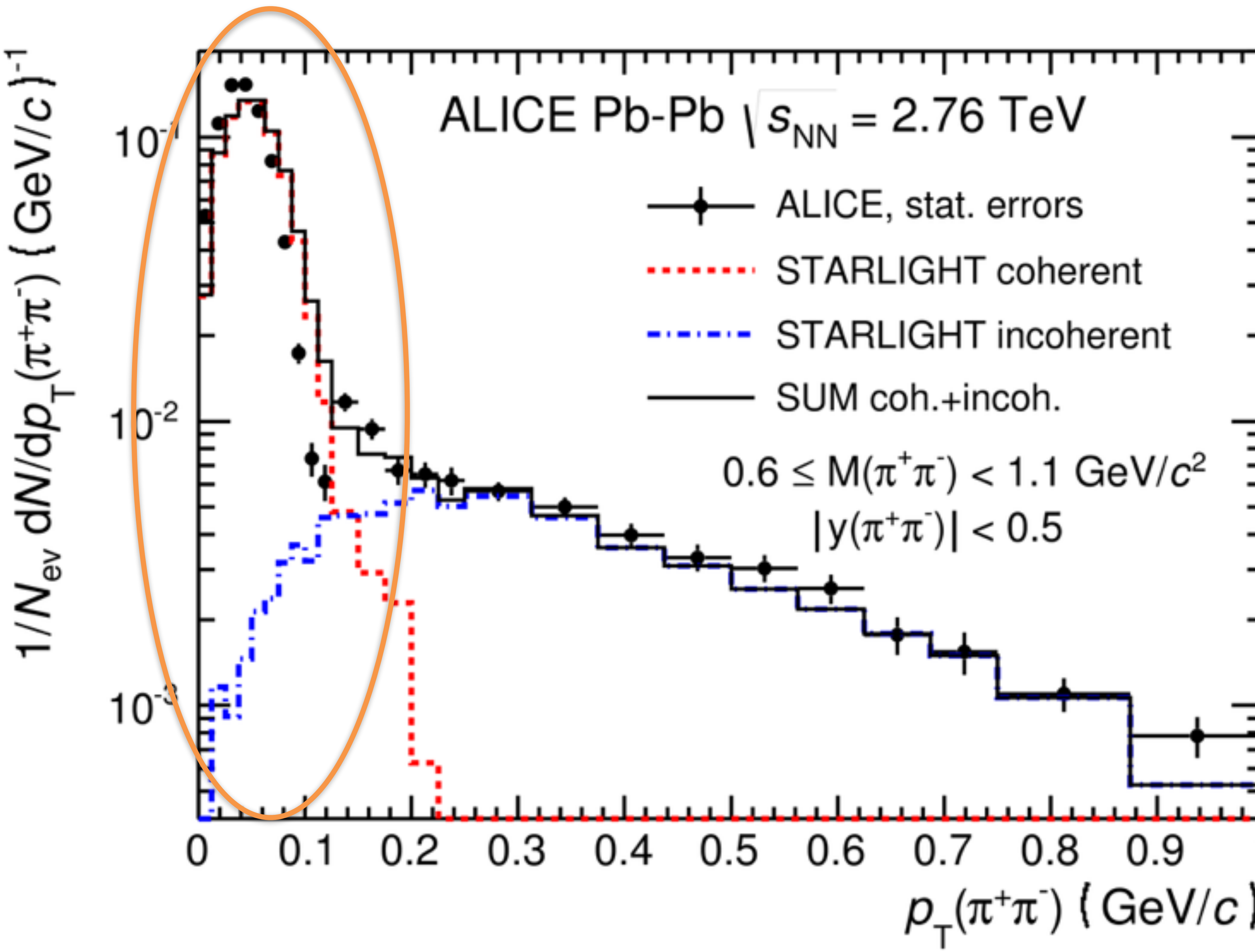


Ultra-peripheral Pb-Pb collisions



Coherent Rho0

JHEP 1509 (2015) 095



Coherent Rho0

ALICE
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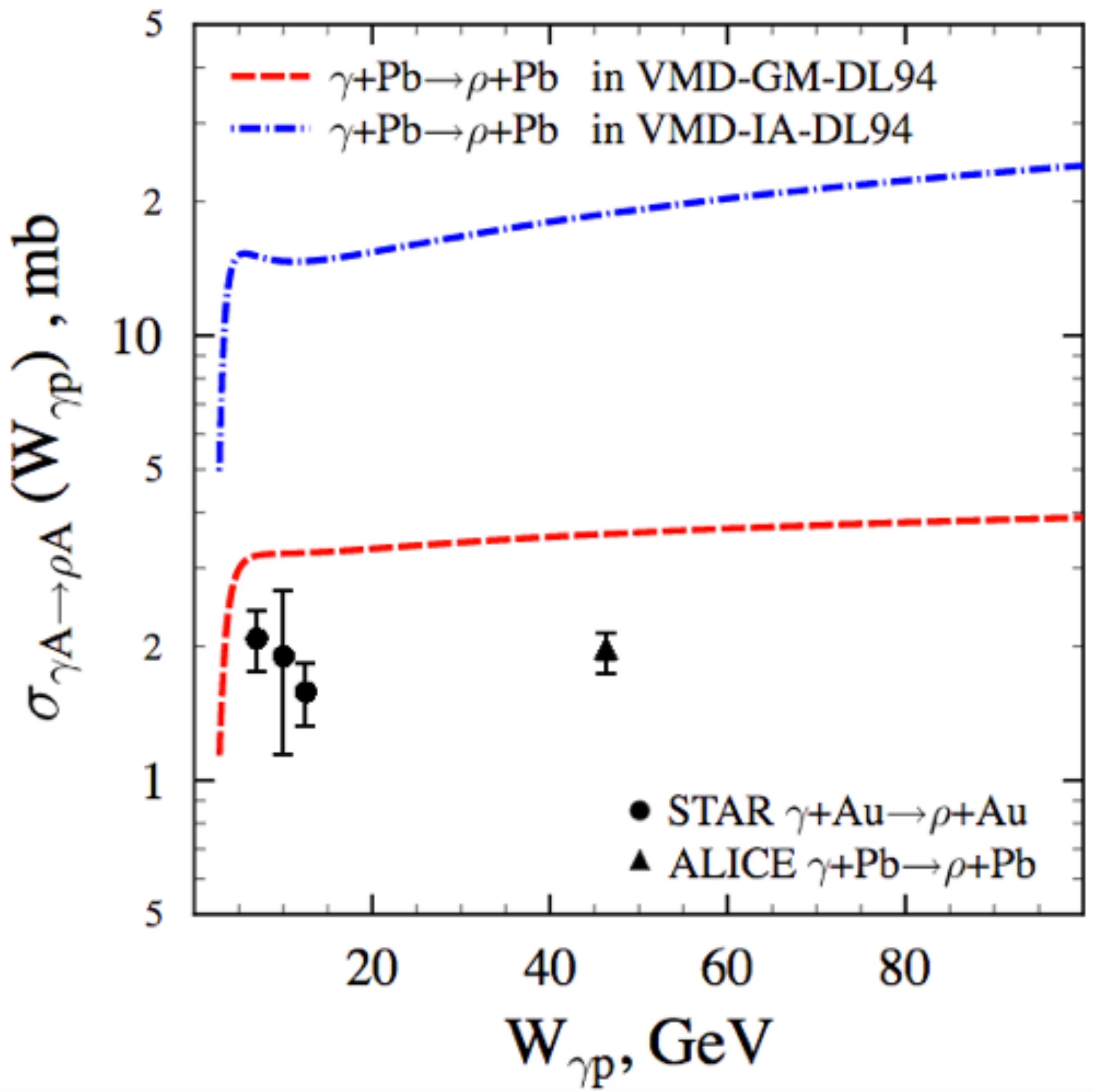


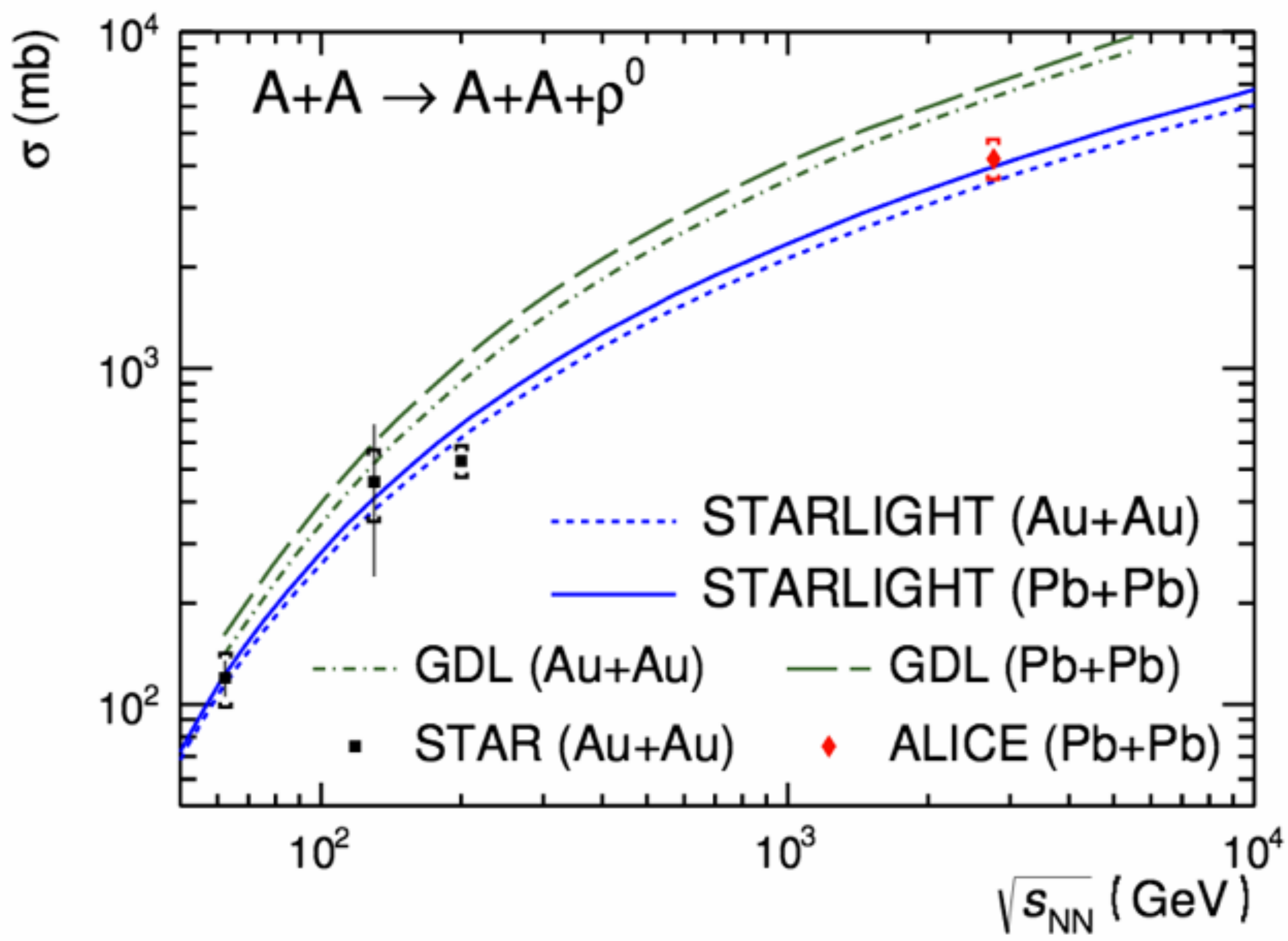
L. Frankfurt et al.
Phys.Lett. B752 (2016) 51-58

Both ALICE and STAR find measured cross section ~40% lower than predicted by Glauber, ….although works fine at fixed-target experiments

Nuclei does not behave like individual nucleons?

Coherent Rho0

JHEP 1509 (2015) 095



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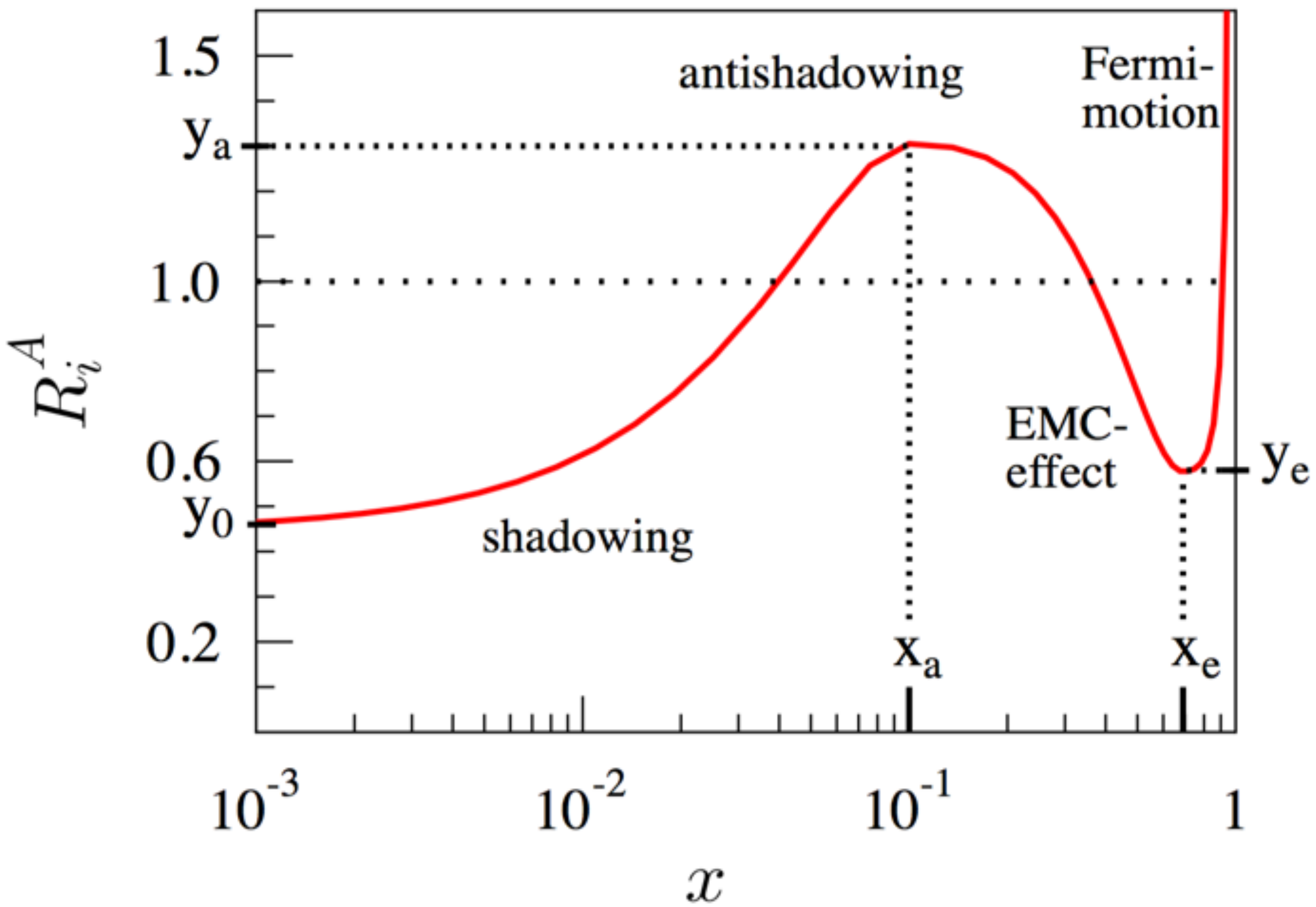
Nuclear effects



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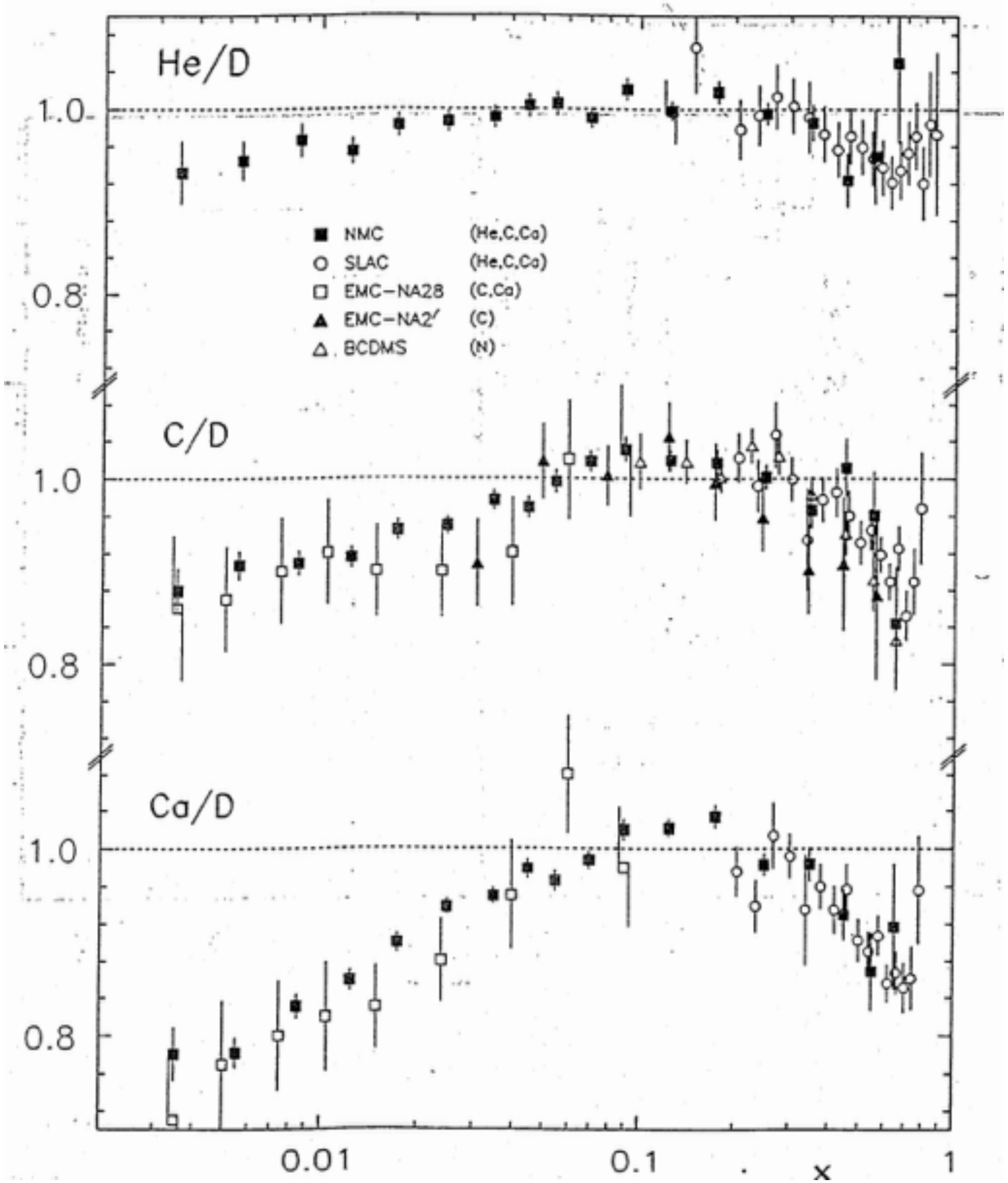
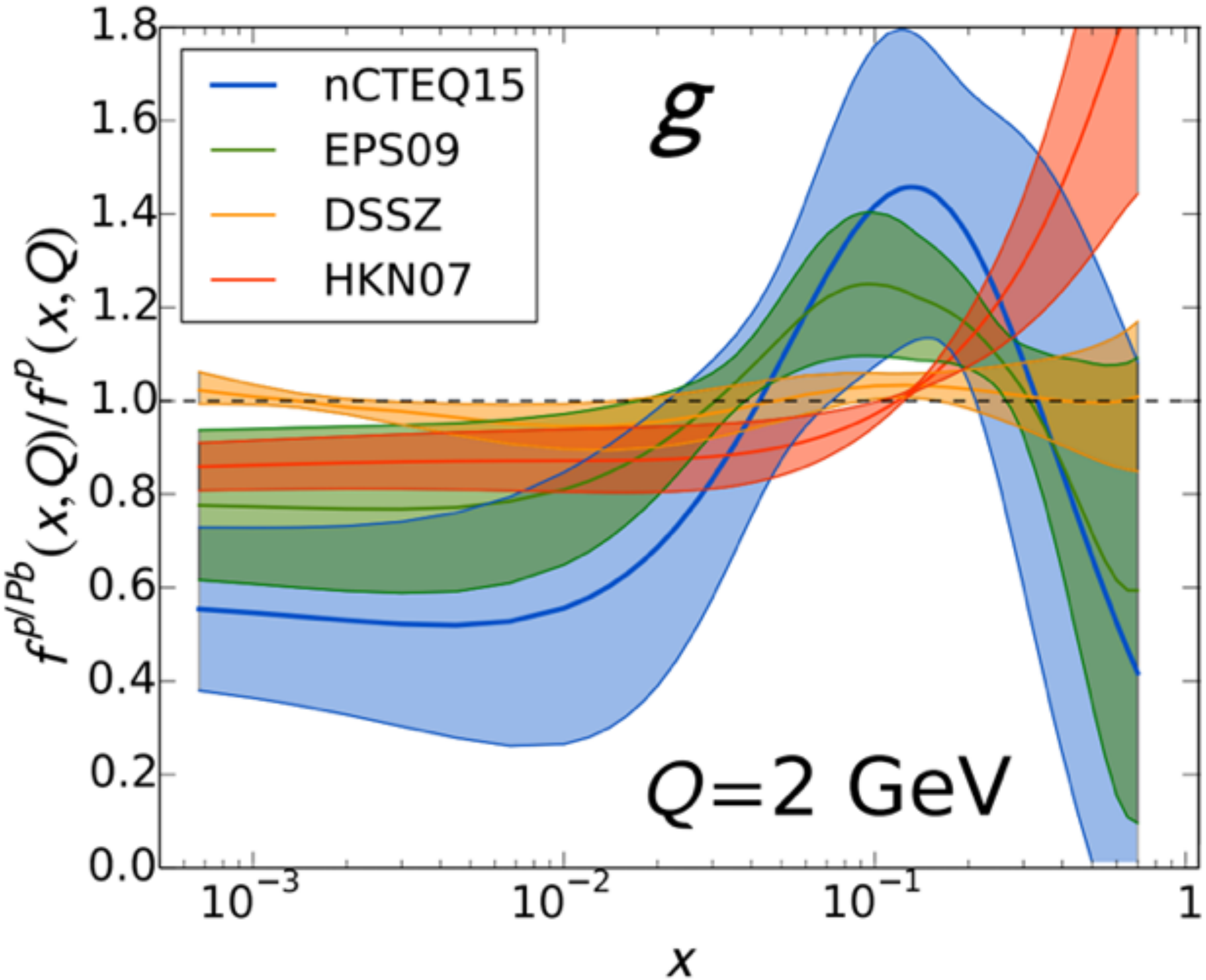


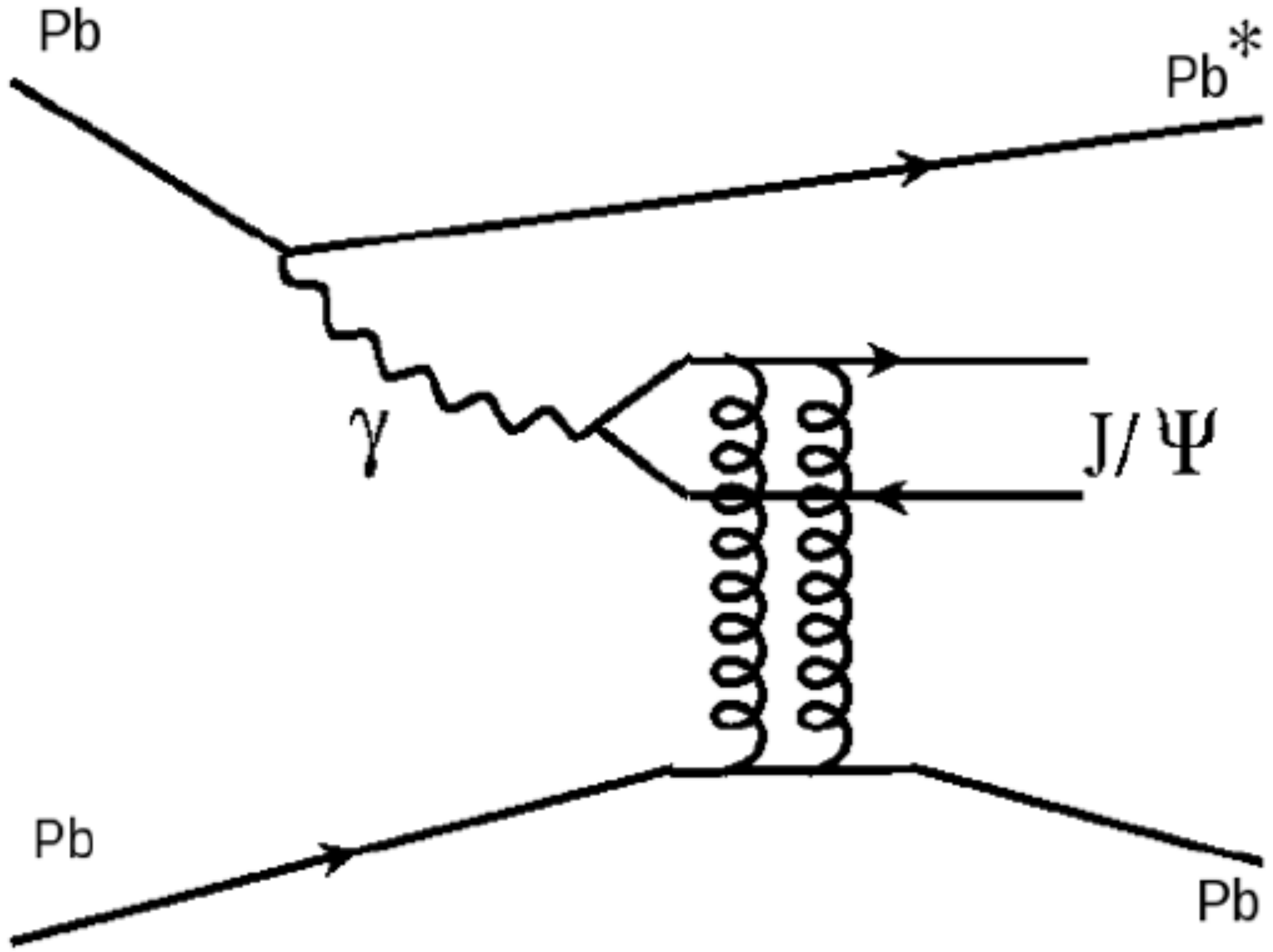
Nuclear gluon density



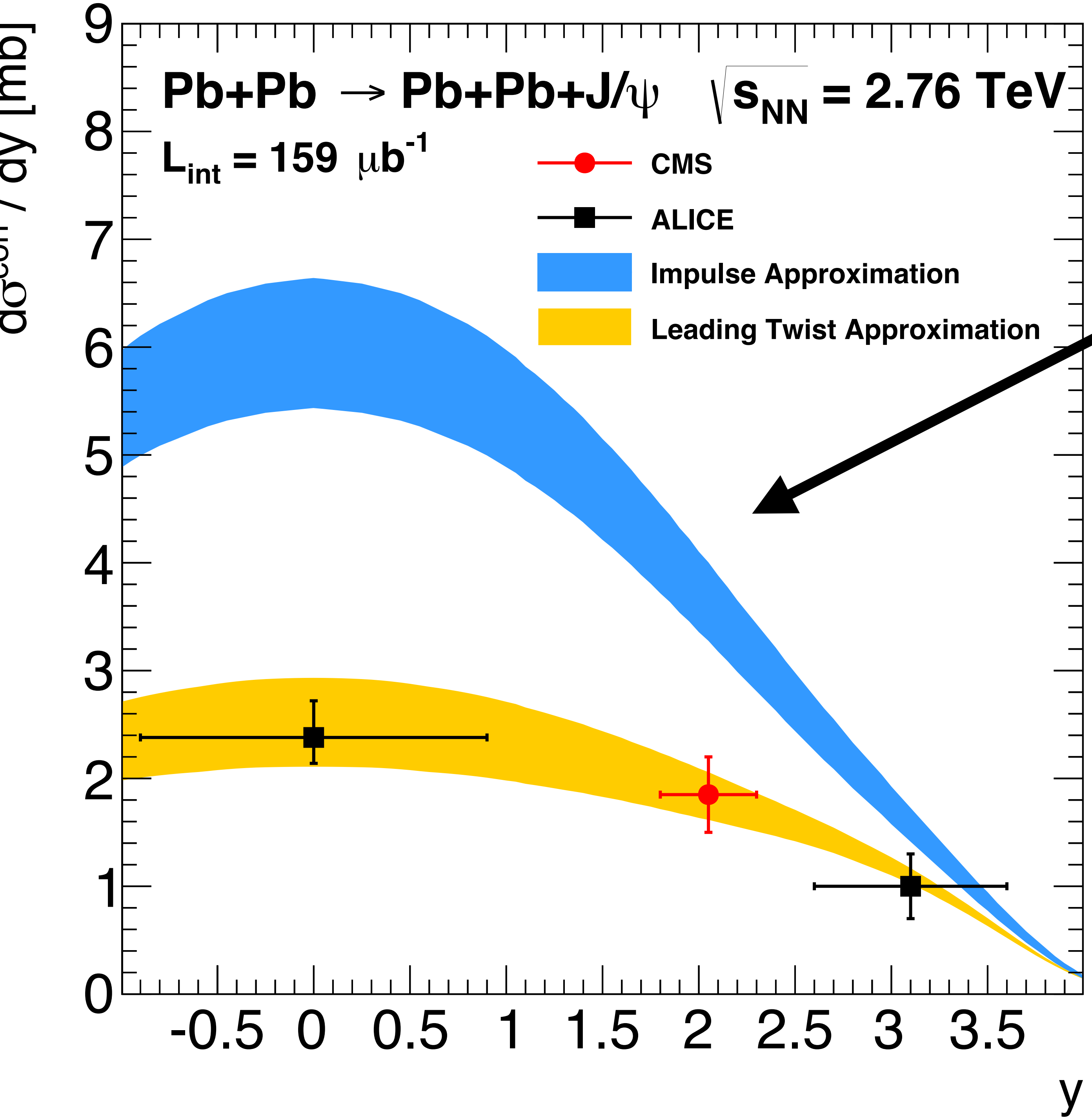
UPC studies provide the best information the community will get for the next 10 years before, the EIC turns on

Vector meson photoproduction

$$\left.\frac{d\sigma_{\gamma A\to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l+l-}}{3\alpha M_{J/\Psi}^5}\right)[xG_A(x,\mu^2)]^2$$



Coherent J/Ψ photoproduction

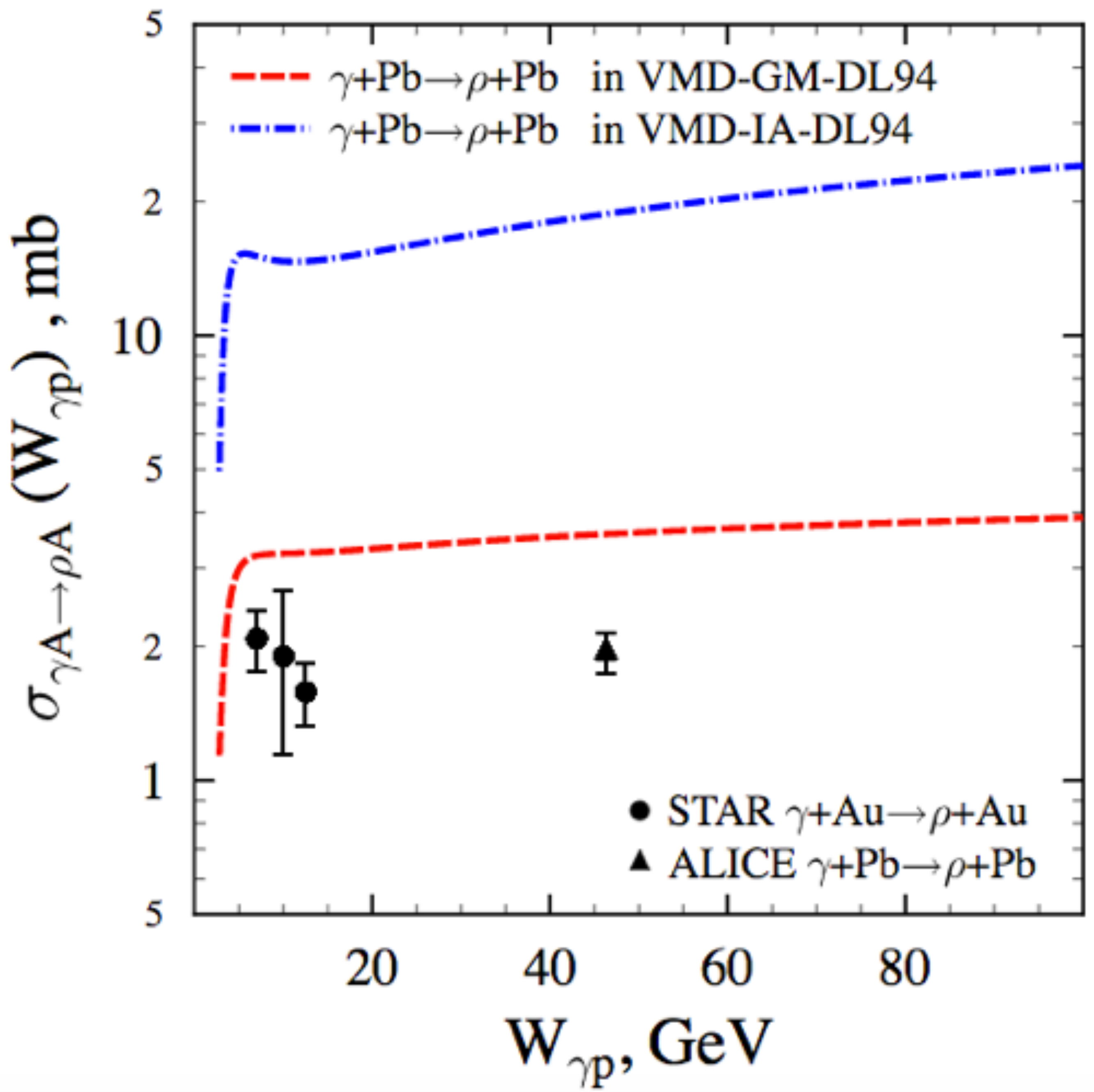


Essentially Model independent. Parametrization of exclusive J/Ψ data in gamma-proton
i.e. No nuclear effects

Experimental evidence of nuclear gluon effects at low Bjorken-x and low virtuality

Coherent Rho0

ALICE
JHEP 1509 (2015) 095



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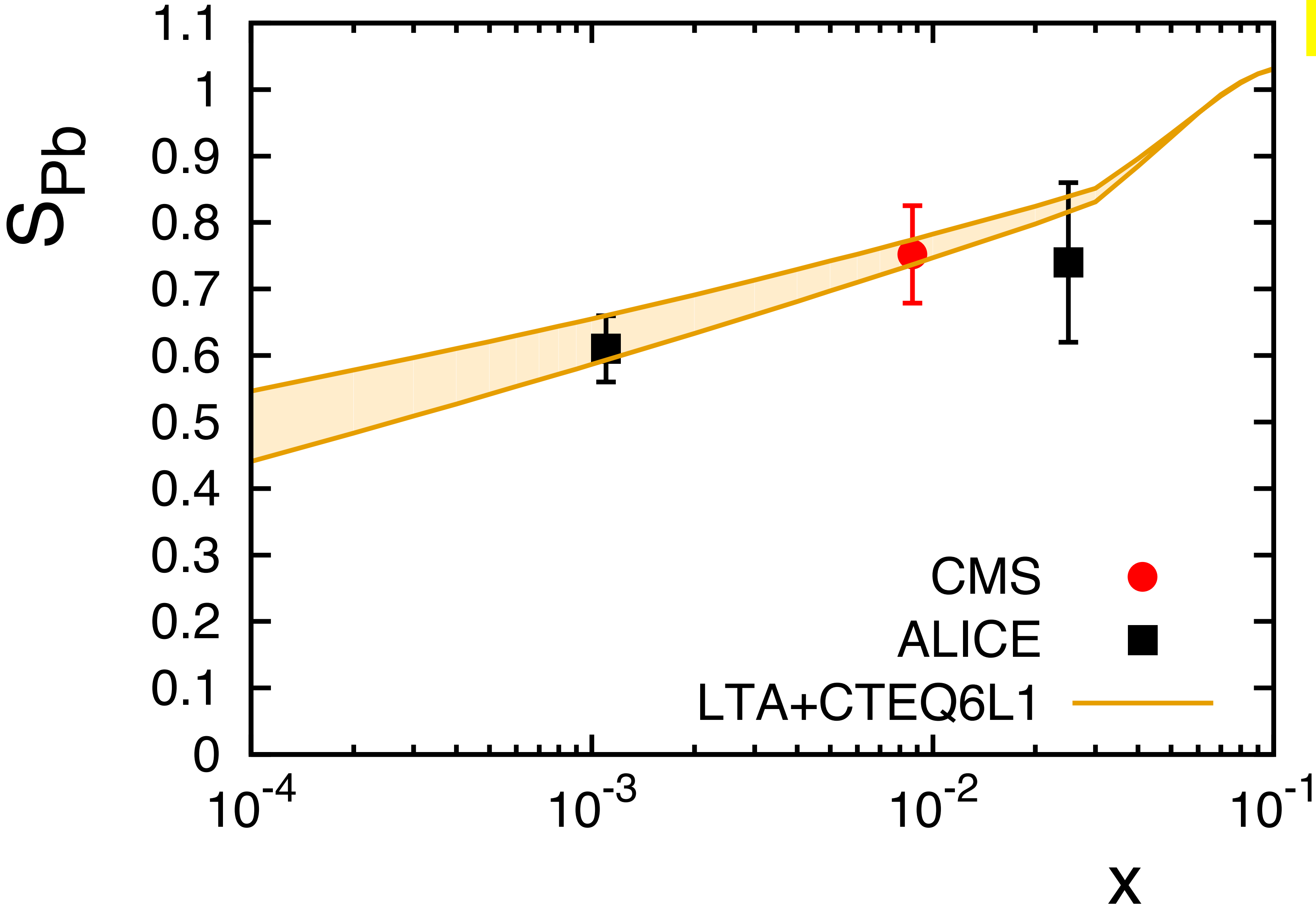
Nuclear gluon density

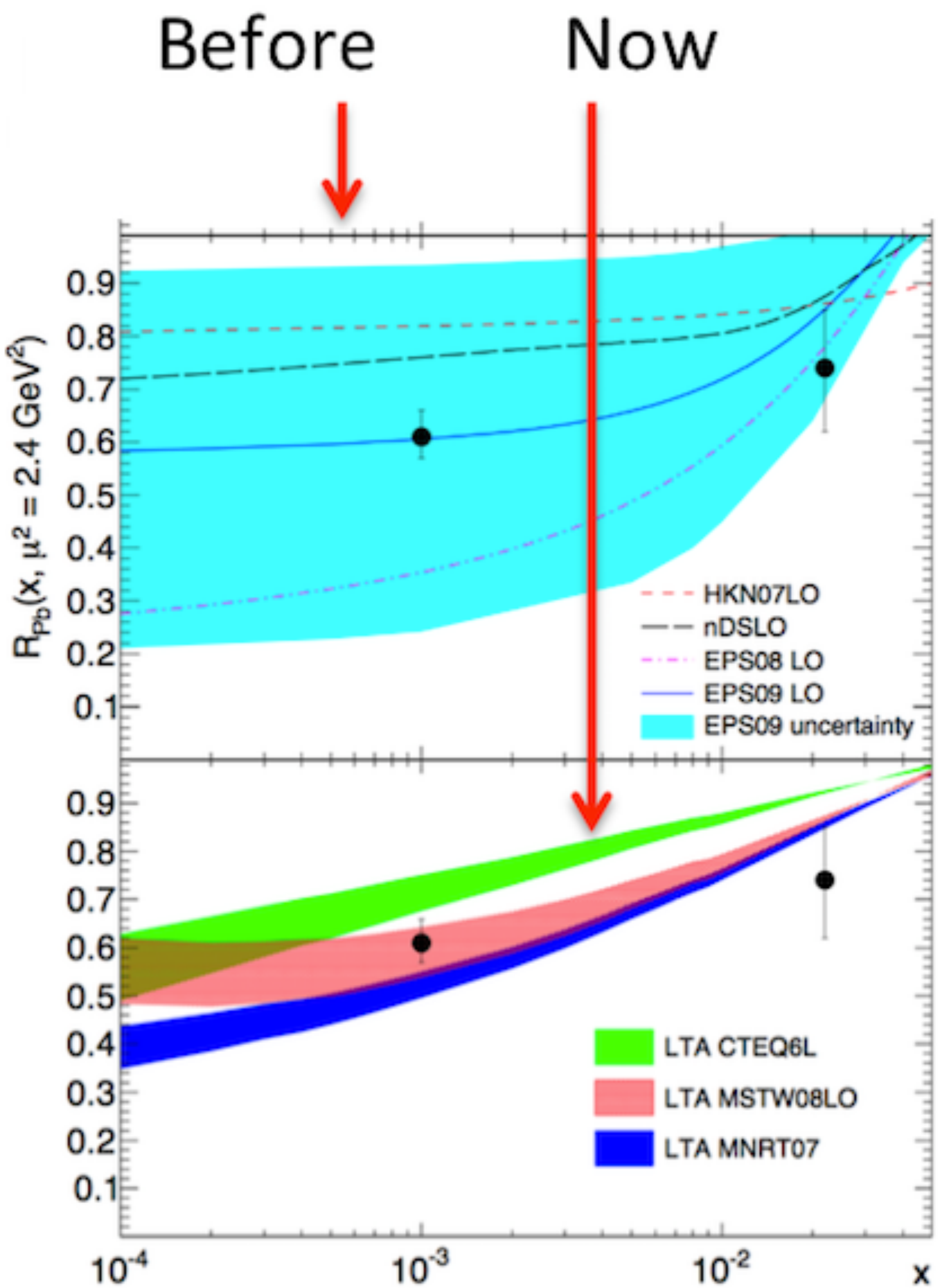
V. Guzey et al.



$$S_A(W_{\gamma p}) = \frac{G_A(x,\mu^2)}{AG_N(x,\mu^2)} \quad \mathbf{= 0.61}$$

For x ~10^-3 and Q2 = 3 GeV2

Nuclear gluon density



$$S_A(W_{\gamma p}) = \frac{G_A(x,\mu^2)}{AG_N(x,\mu^2)} = \mathbf{0.61}$$

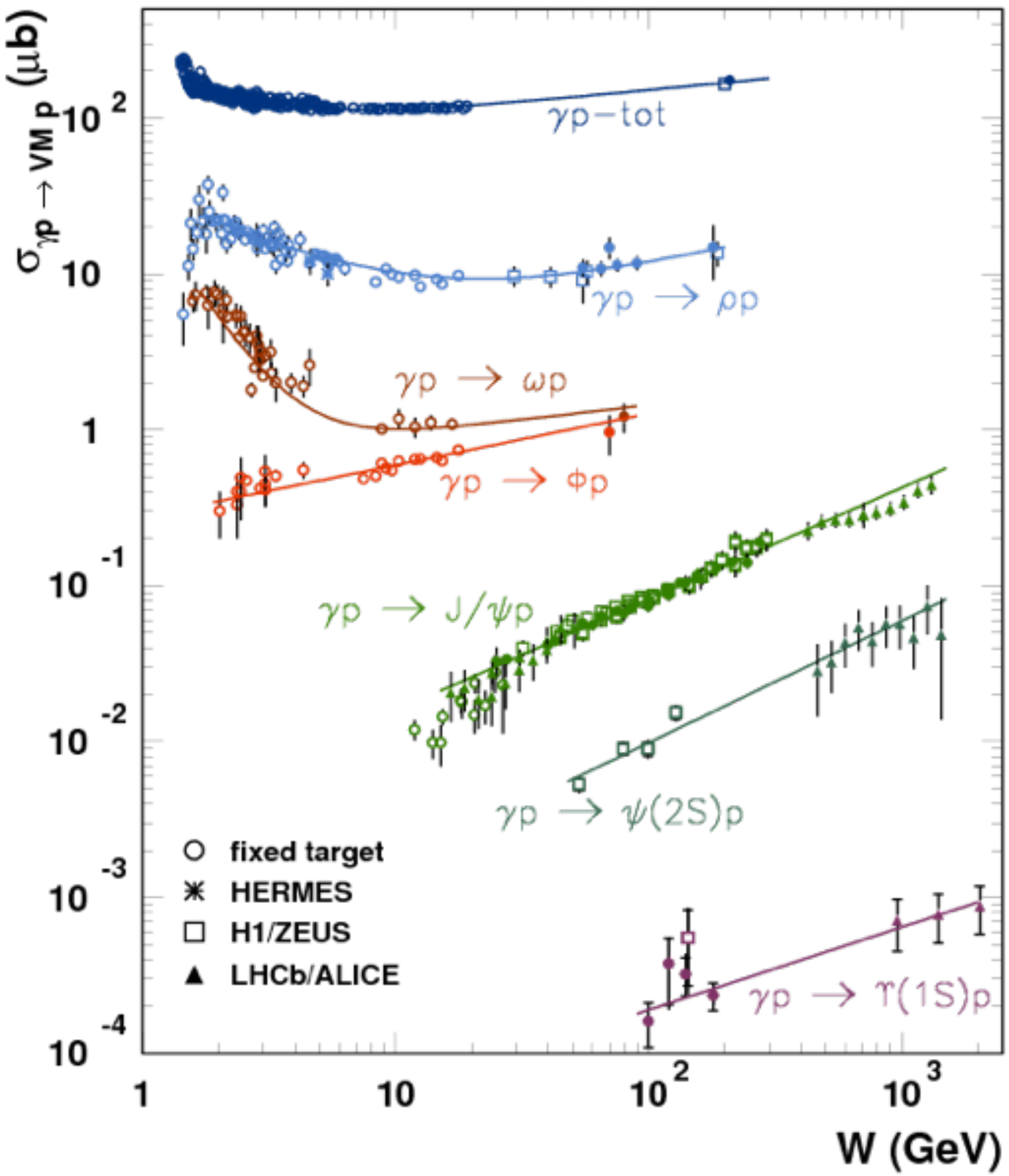
For x ~10^-3 and Q2 = 3 GeV2

Recent: CTEQ group is starting to study UPC data for nPDF

See F. Olness, C. Bertulani, et al.

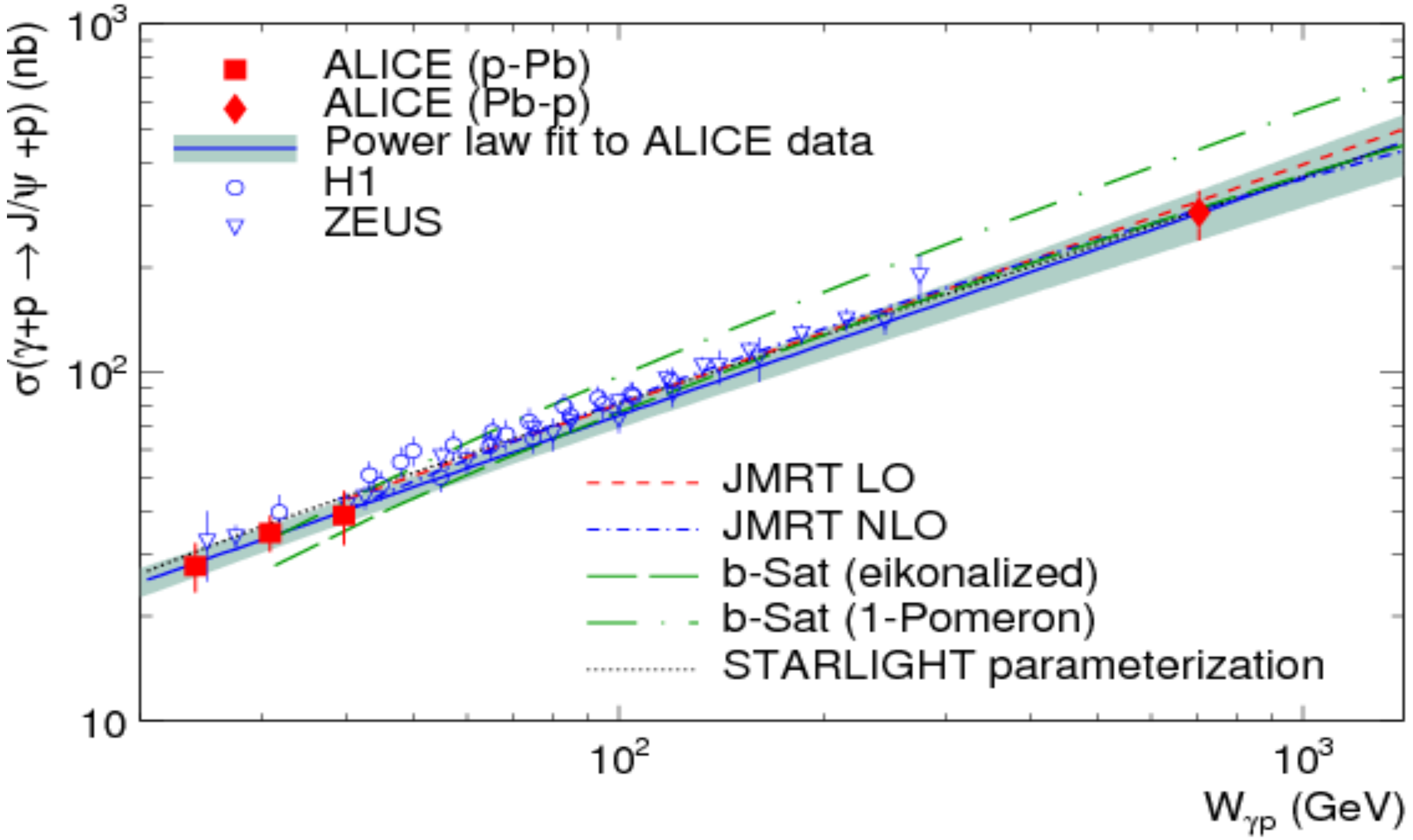
http://arxiv.org/abs/arXiv:1603.01919

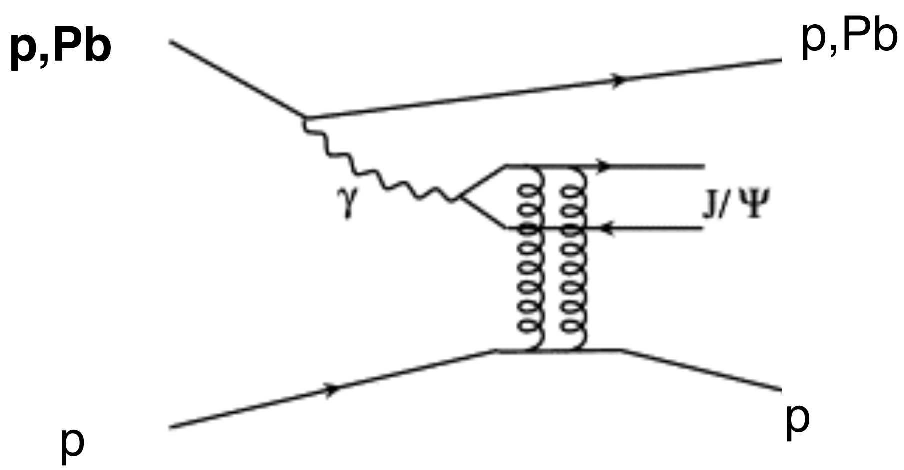
VM photoproduction data



Exclusive J/psi photoproduction

Phys.Rev.Lett. 113 (2014) 23, 232504





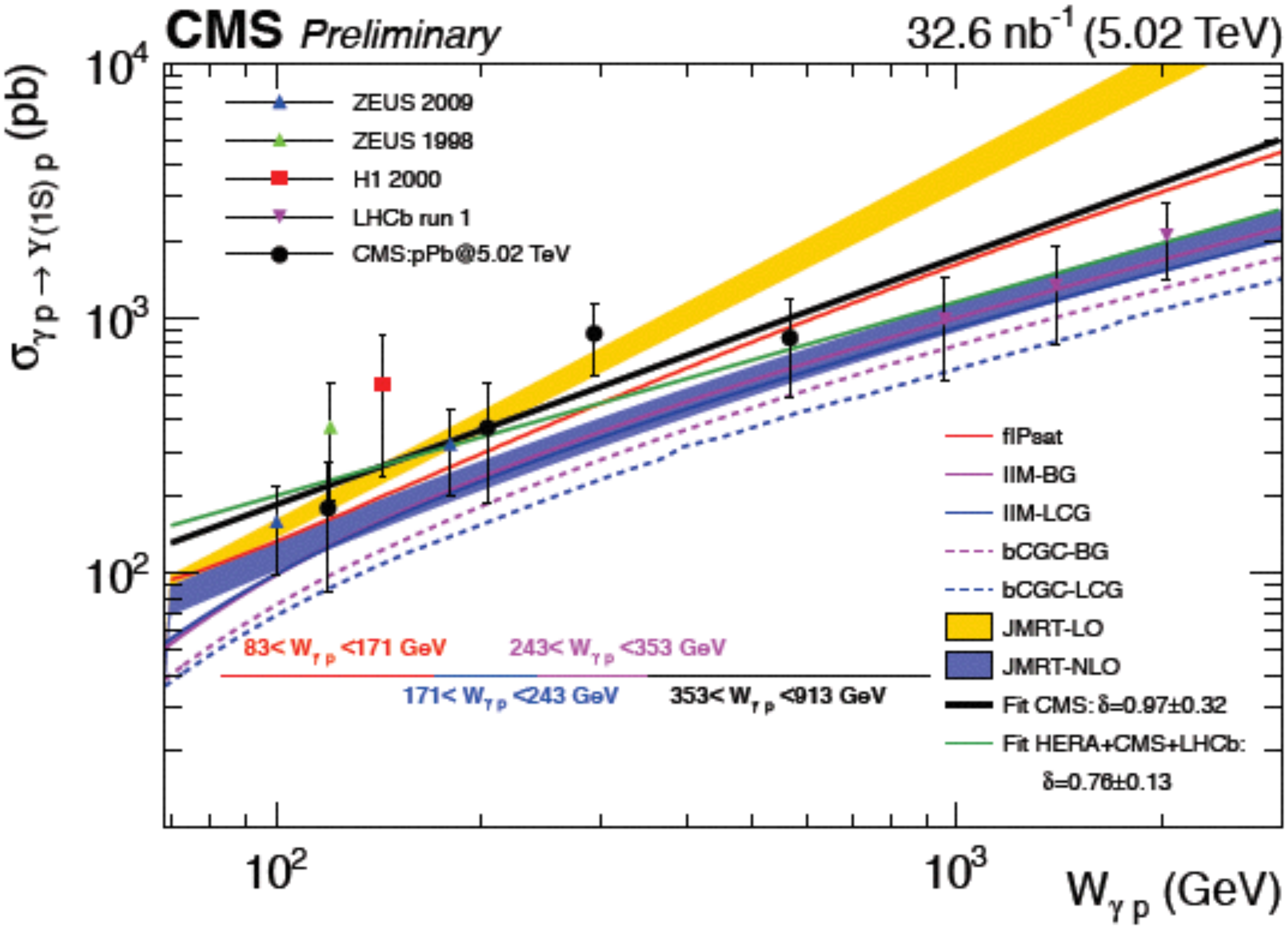
$$\frac{d\sigma_{\gamma \mathrm{Pb} \rightarrow J/\psi \mathrm{Pb}}(t=0)}{dt} = \frac{16\,\Gamma_{ee}\pi^3}{3\alpha_{em}M^5_{J/\psi}}\left[\alpha_s(Q^2)xG_{\mathrm{Pb}}(x,Q^2)\right]^2$$

UPC VM in pp, p-Pb is a direct tool to measure saturation

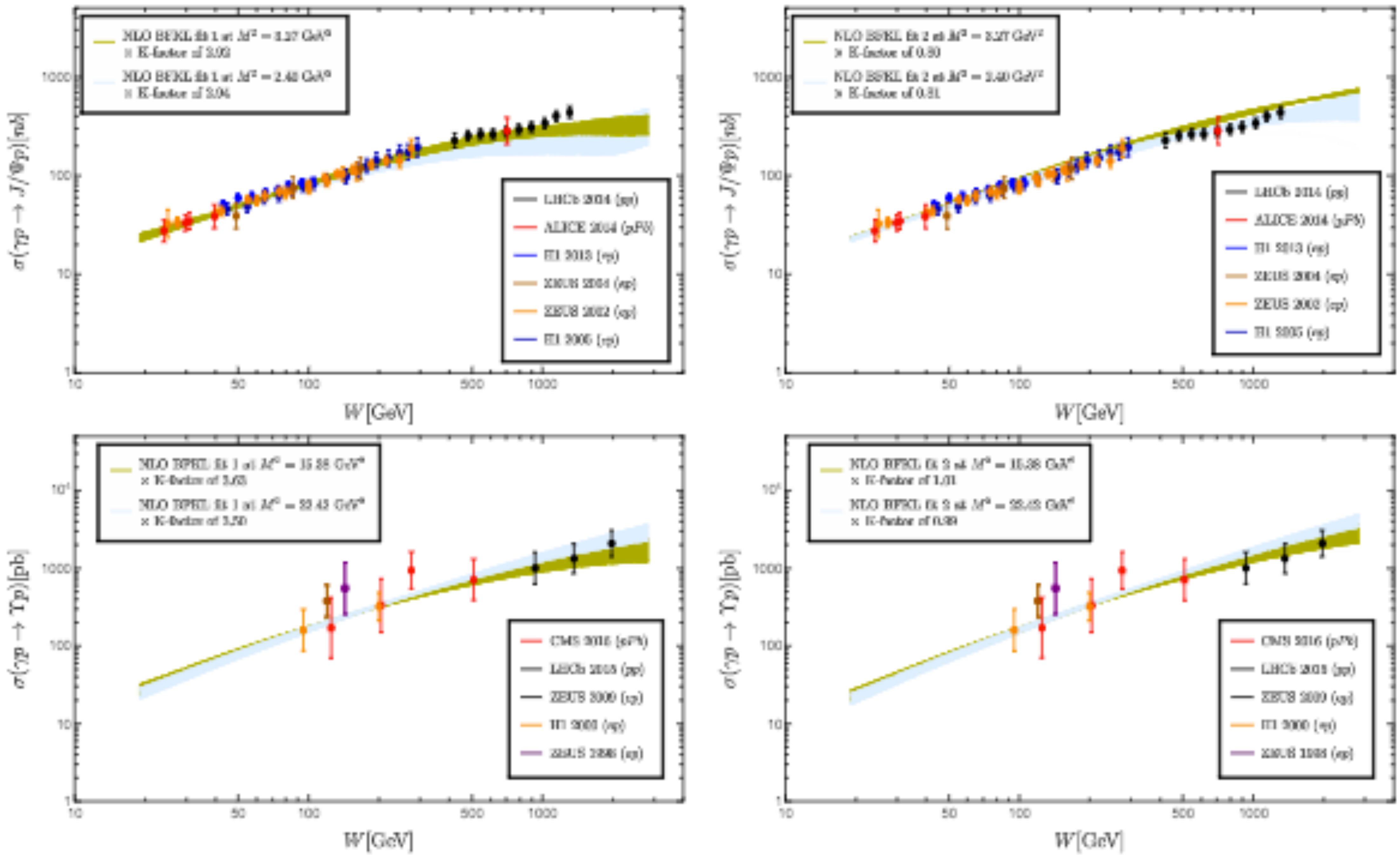
Bjorken $x \sim 10^{-2} - 10^{-5}$

accessible at LHC

Exclusive Upsilon photoproduction in **p-Pb** collisions at 5.02 TeV

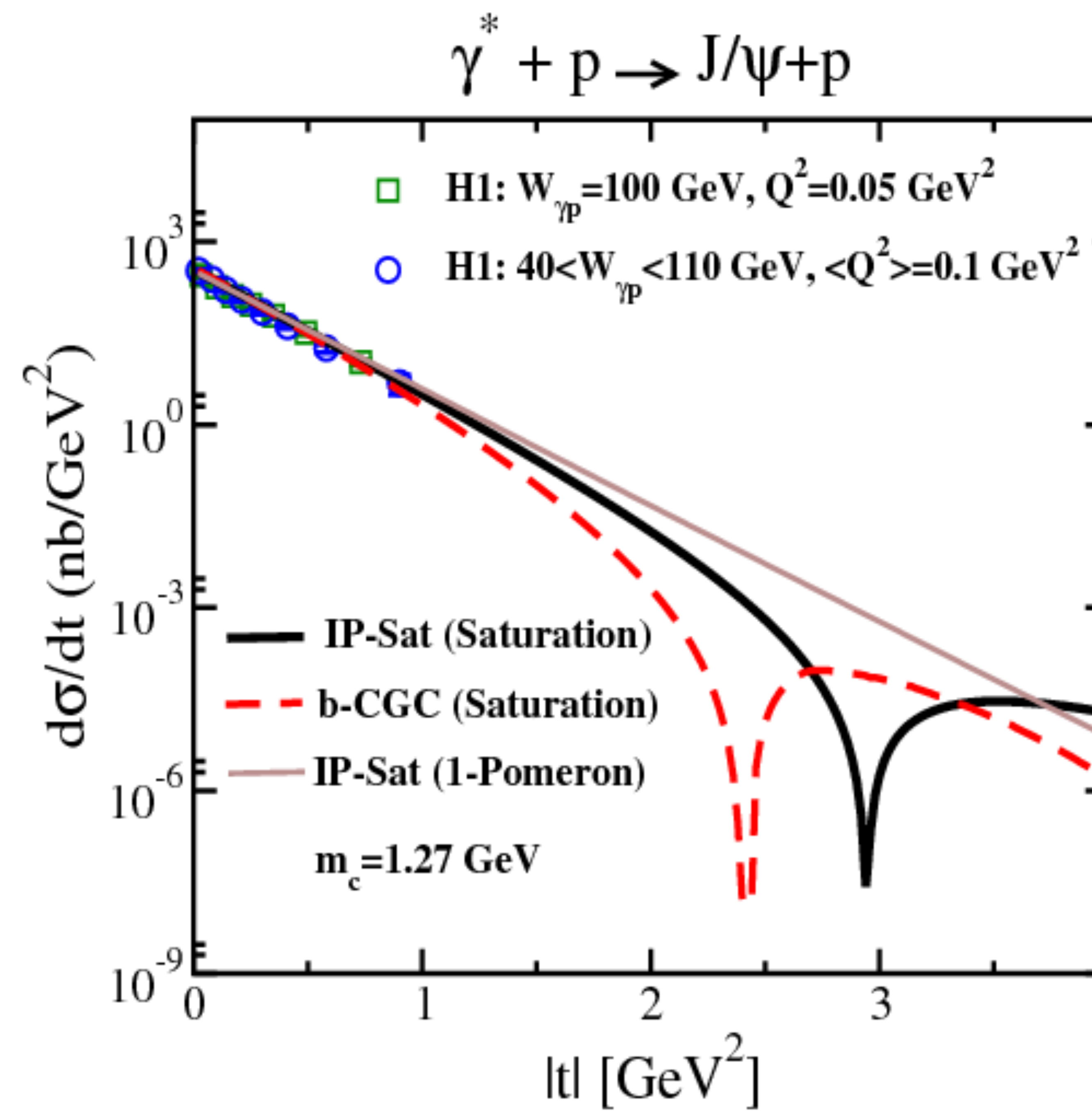


Martin Hentschinski



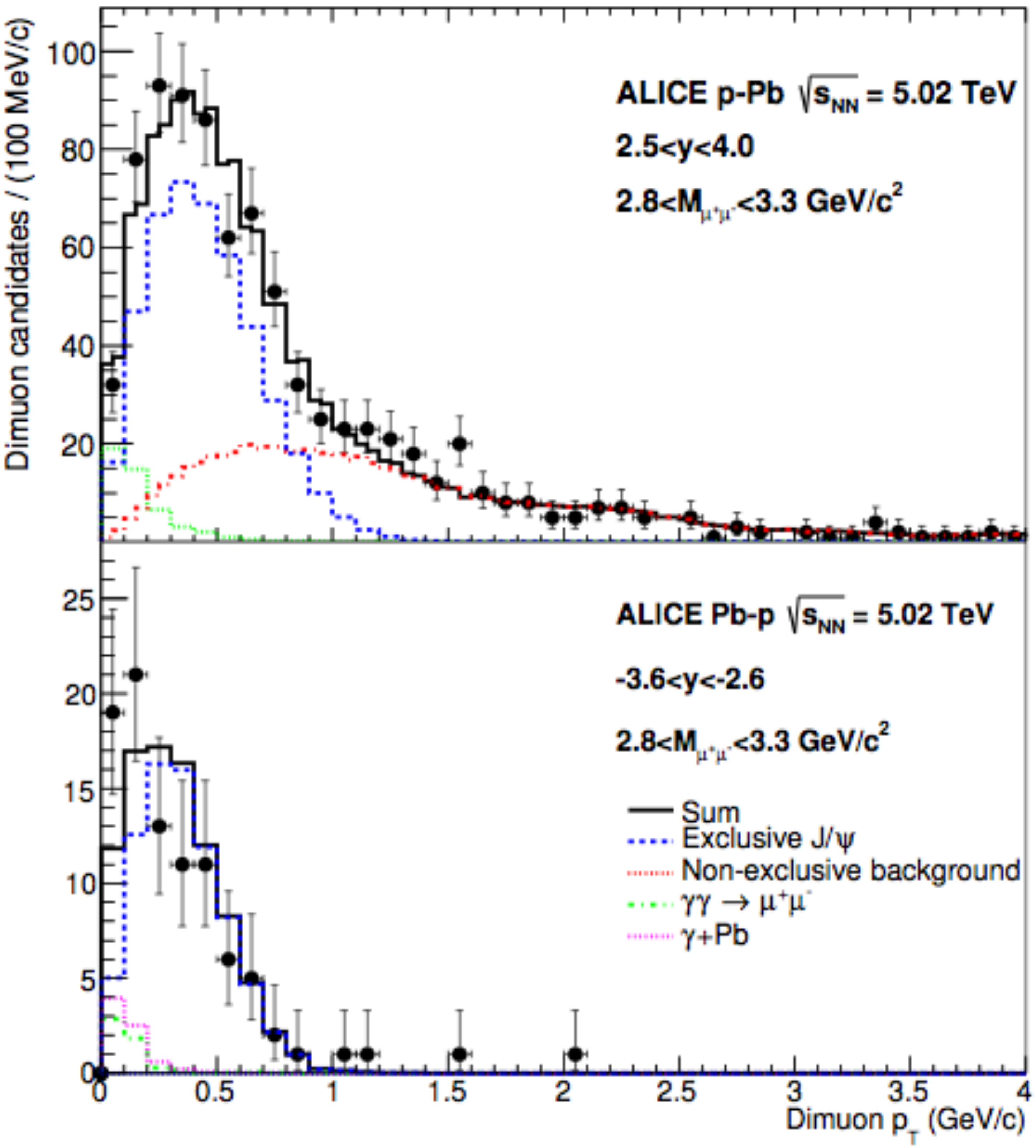
t-distribution

- t-differential measurements give a gluon tranverse mapping of the hadron/ nucleus.



Exclusive J/psi in p-Pb

Phys.Rev.Lett. 113 (2014) 23, 232504



Data well described by templates

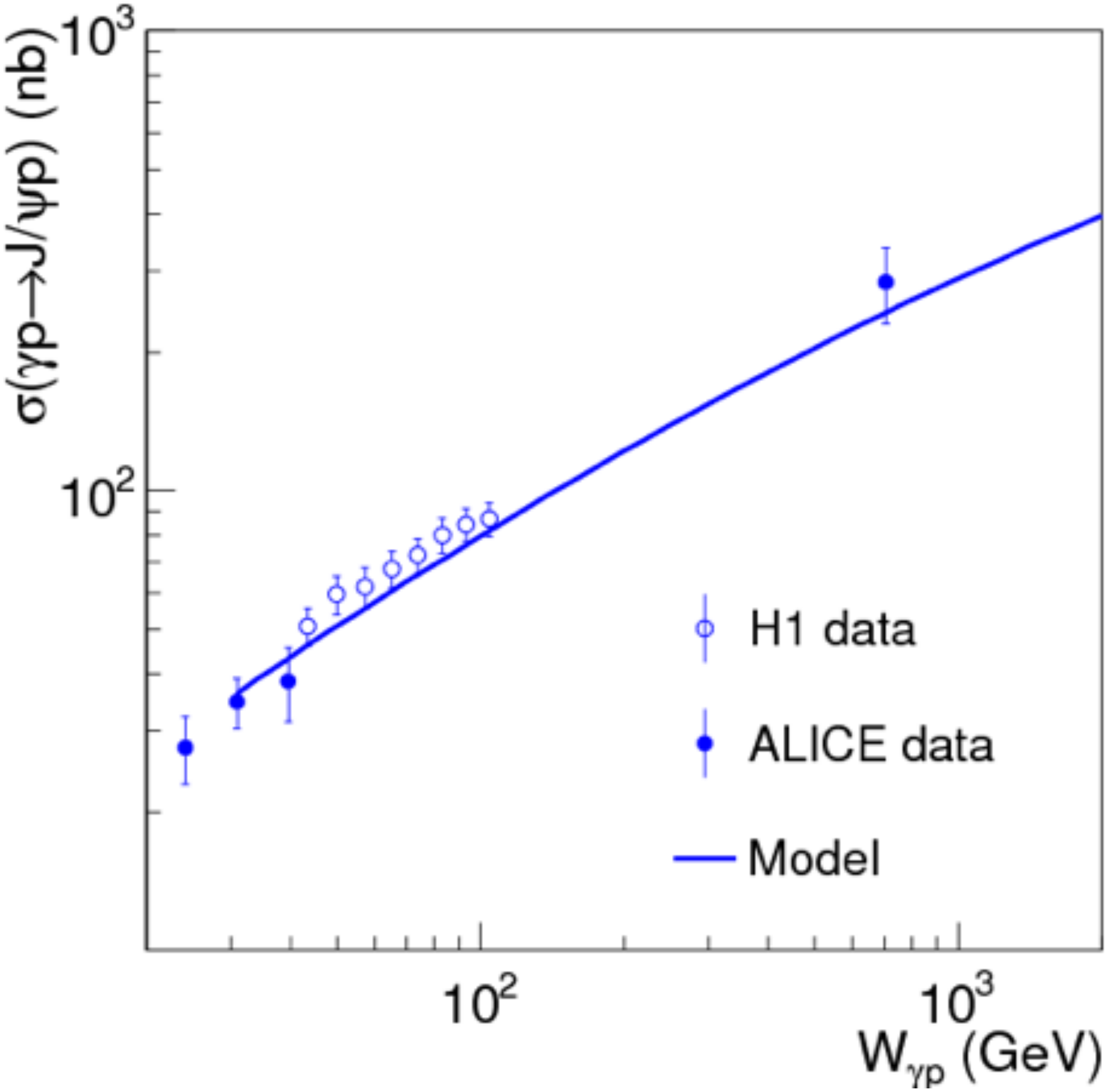
Energy dependence is clearly visible

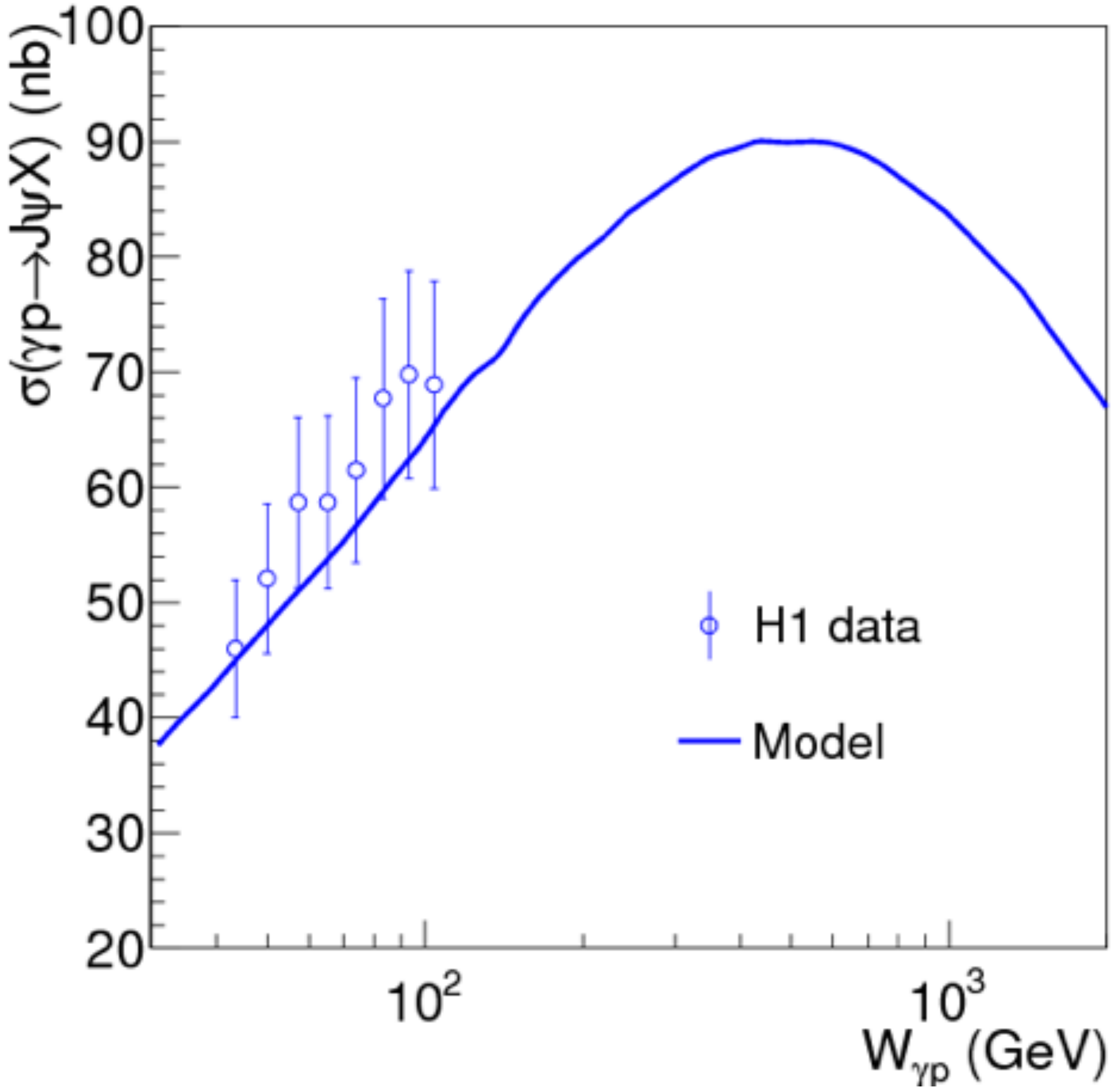
Low W_{gp} energy point
$\langle W_{gp} \rangle \sim 30$ GeV

High W_{gp} energy point
$\langle W_{gp} \rangle \sim 700$ GeV

Energy dependence of dissociative photoproduction: *signature of gluon saturation*

J. Cepina, G. Contreras and DTT arXiv:1608.07559 [hep-ph]





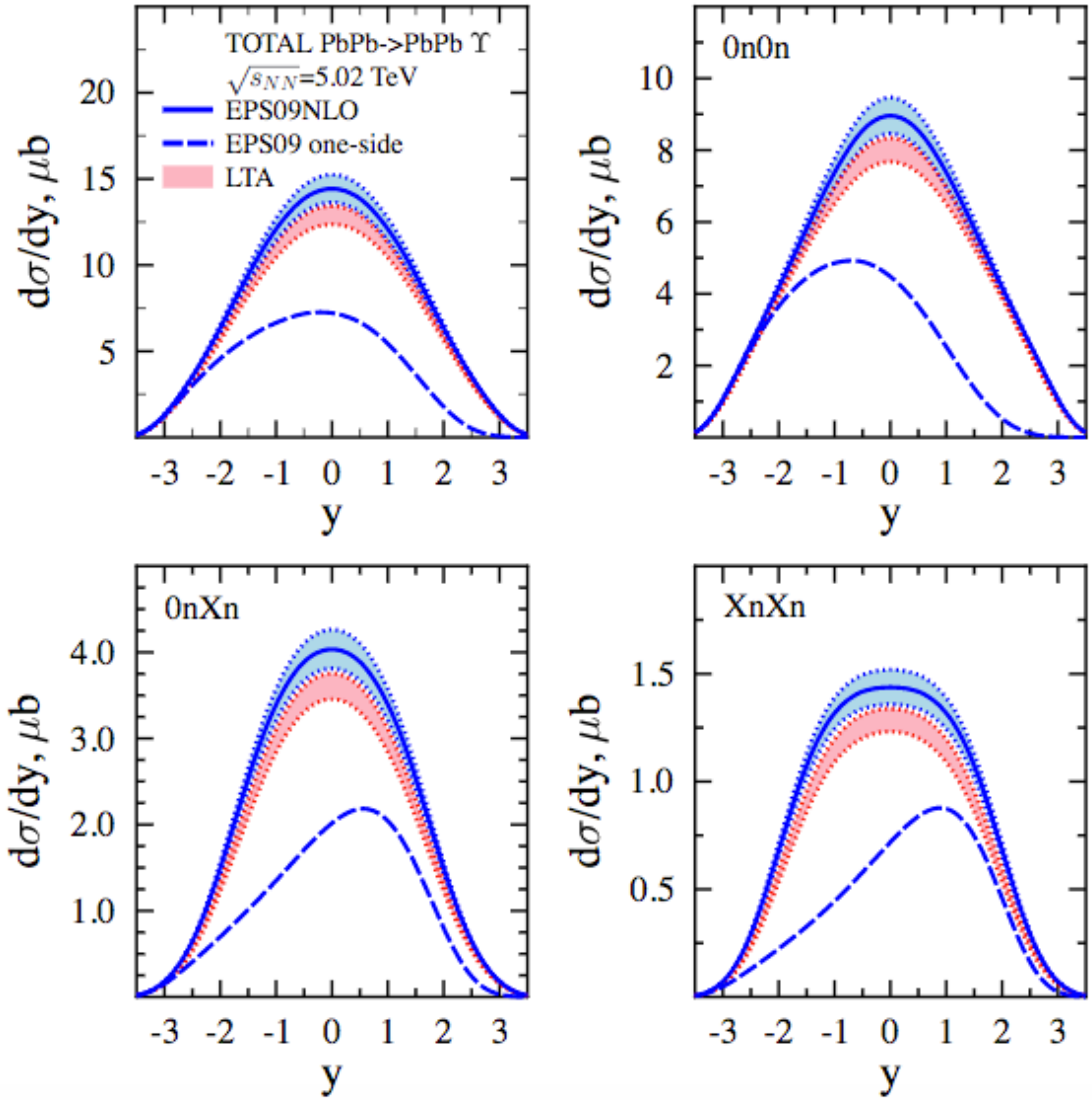
VM photoproduction in UPC Pb-Pb

$$\frac{d\sigma_{\mathrm{PbPb}}(y)}{dy} = N_{\gamma/\mathrm{Pb}}(y, M)\sigma_{\gamma\mathrm{Pb}}(y) + N_{\gamma/\mathrm{Pb}}(-y, M)\sigma_{\gamma\mathrm{Pb}}(-y)$$

Neutron dependence

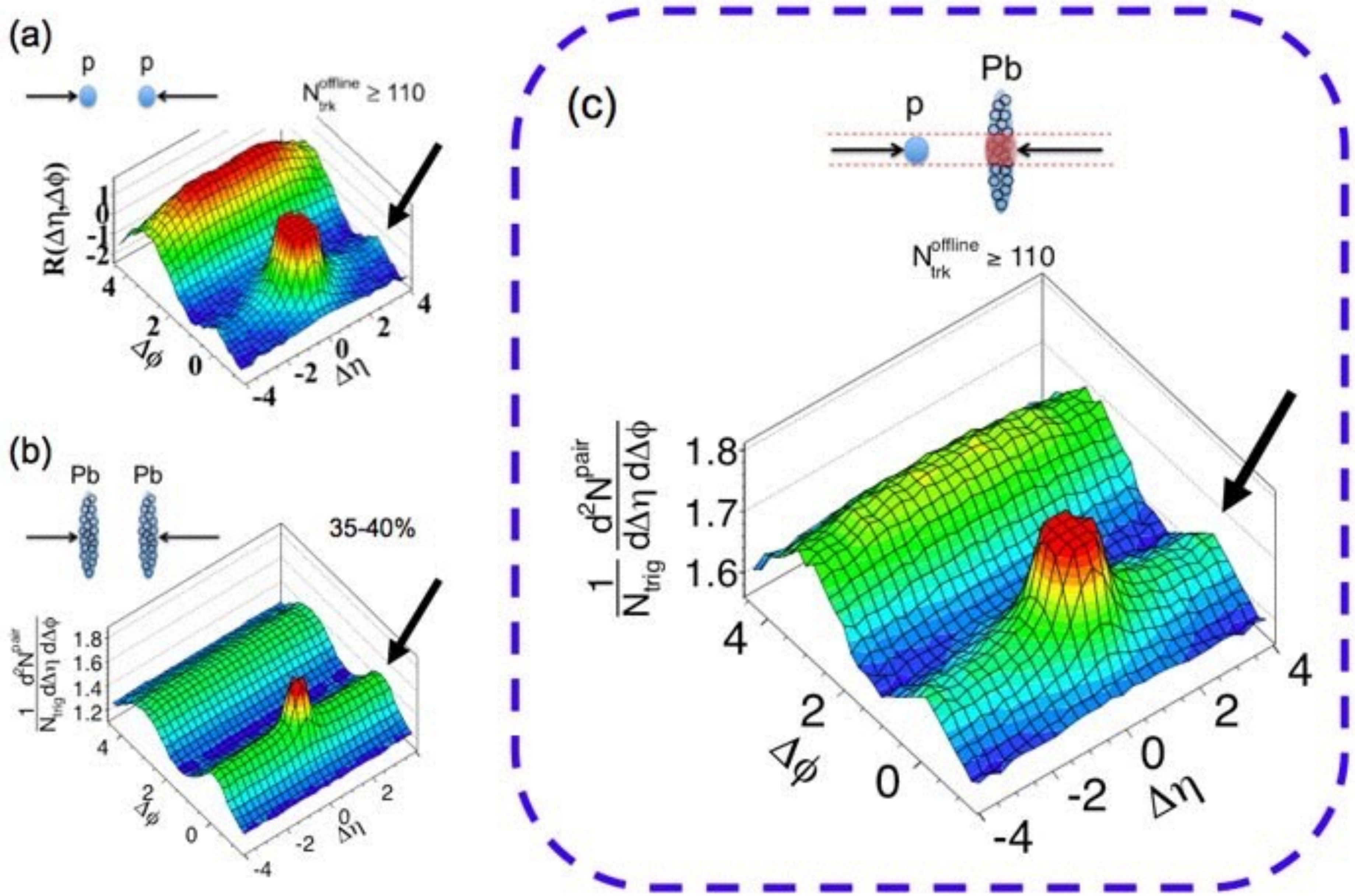
$$d\sigma(\mathrm{total})/dy = d\sigma(\mathrm{0n0n})/dy + 2d\sigma(\mathrm{0nXn})/dy + d\sigma(\mathrm{XnXn})/dy$$

Coherent J/psi predictions for Run 2



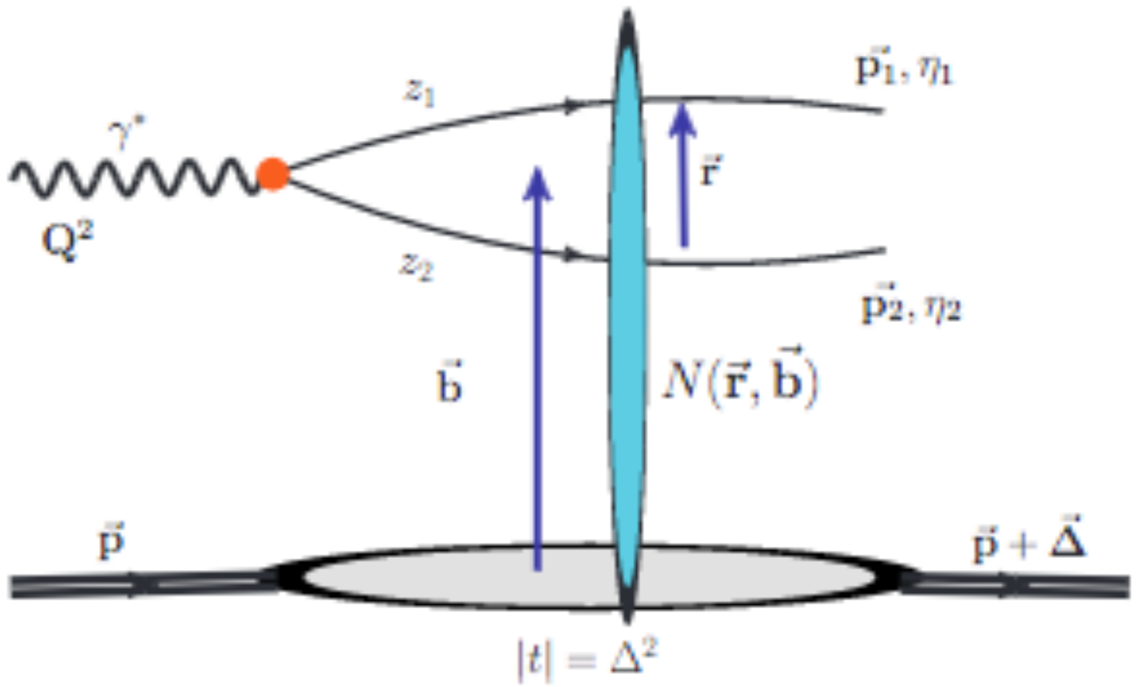
V. Guzey et al.
arXiv:1602.01456 [nucl-th]

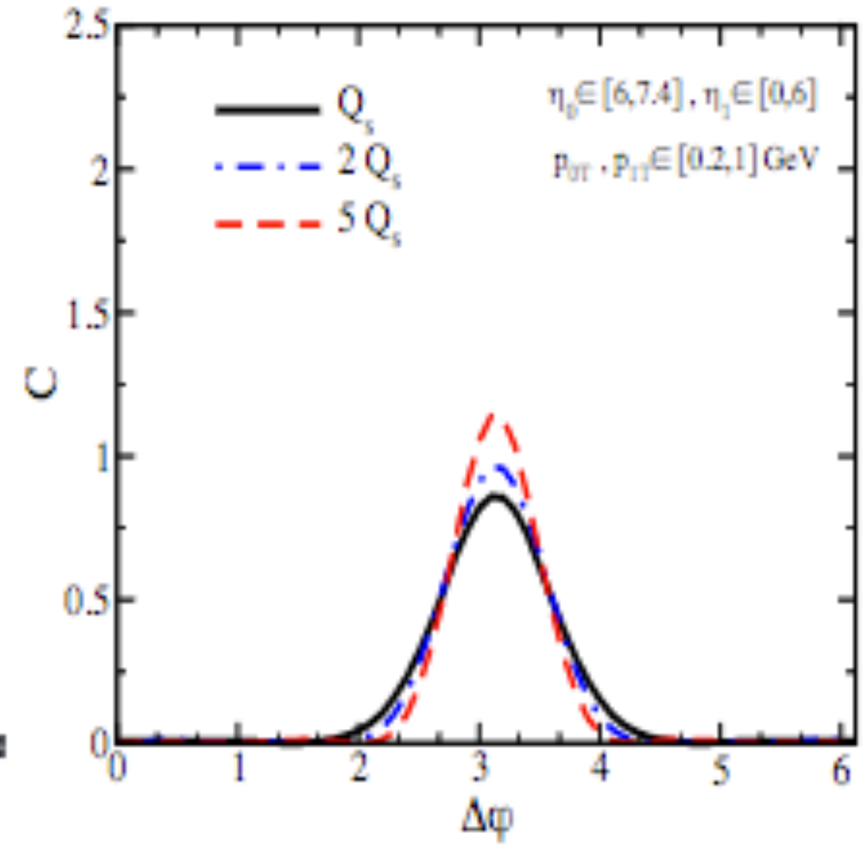
The Ridge in small systems



The ridge in UPC collisions ?

Inclusive v. diffractive two-particle production

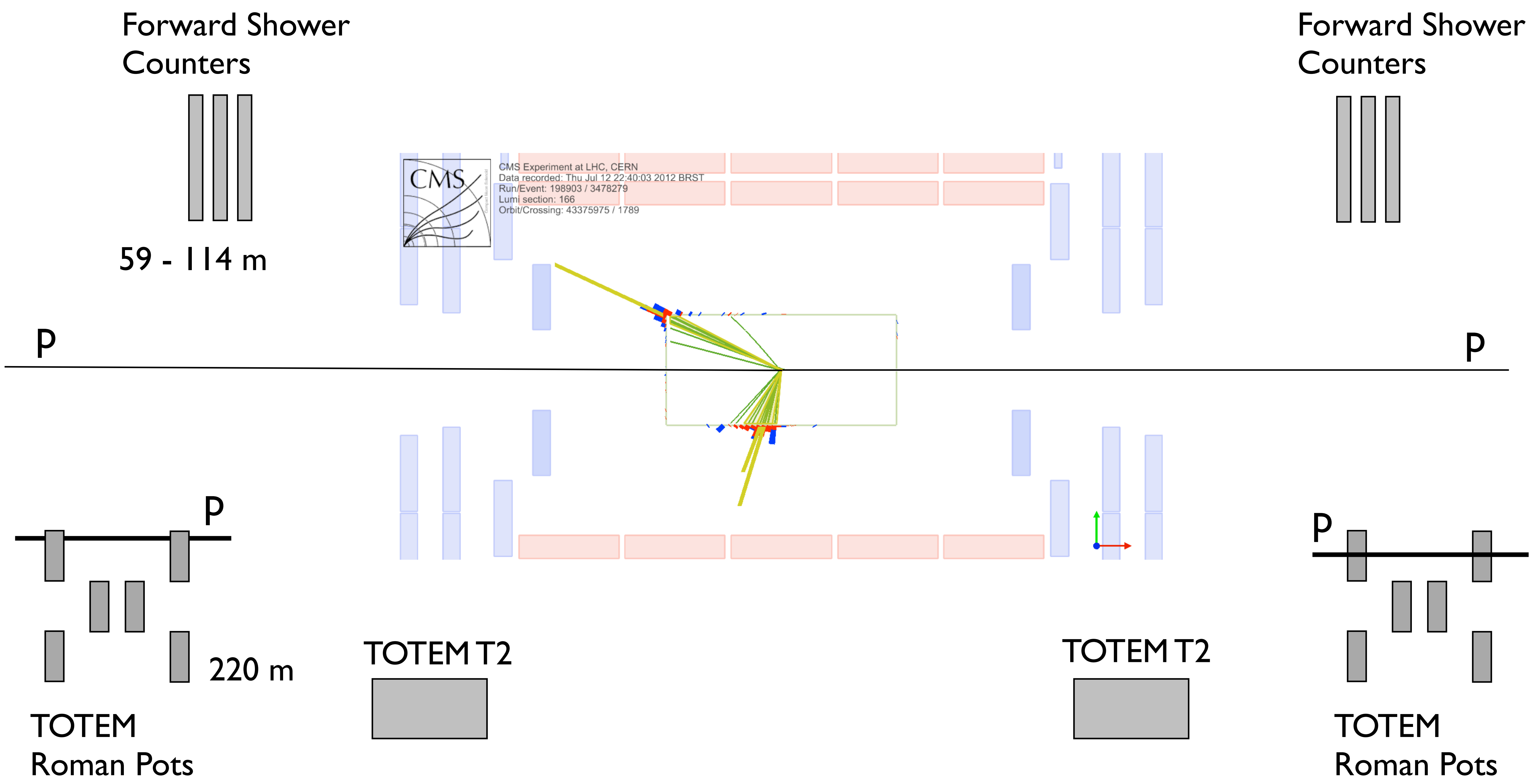




- **Diffractive** dijet photoproduction:
  Back-to-back correlation gets **enhanced** due to the saturation scale.
  Balance between: $p_{1T}, p_{2T}, \vec{\Delta}, Q_s$
- **Inclusive** dijet:
  Back-to-back correlation gets **suppressed** due to the saturation scale.
  Balance between: p_{1T}, p_{2T}, Q_s

Amir Rezaeian (UTFSM, Valparaiso) Sep 3, 2016 14 / 20

Exclusive Dijet in pp: CMS+TOTEM



CMS: |η| < 5 **T2: 5.3 < |η| < 6.5** **FSC: 6 < |η| < 8** **TOTEM RP** **very large rapidity coverage !**

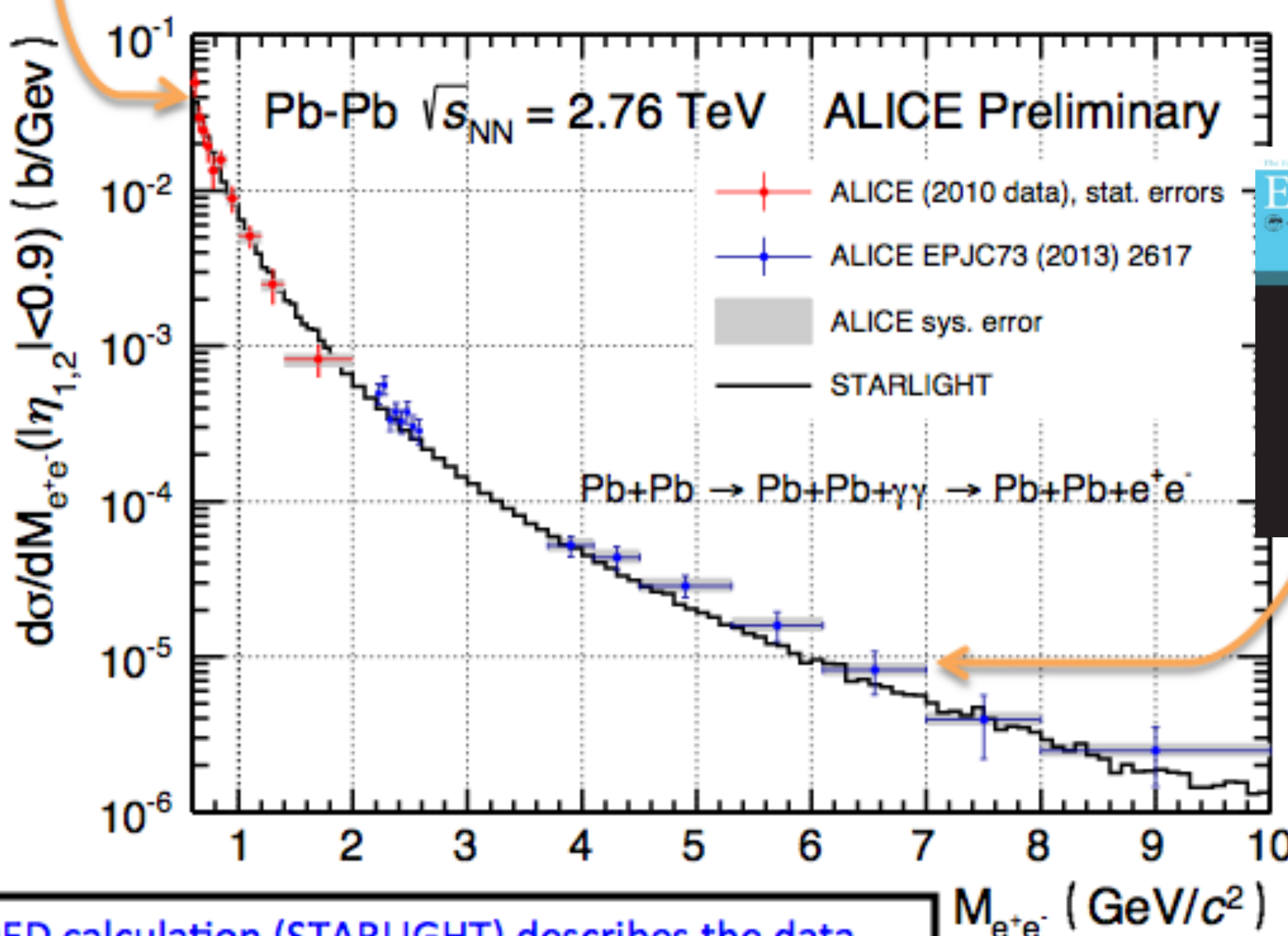
QED physics, radiative decays, strong fields:

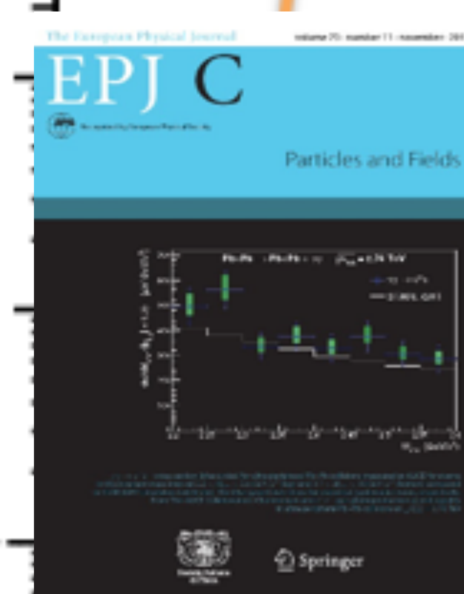
….Two-photon production of lepton pairs

Eur. Phys. J. C73 (2013) 2617

2010: Low luminosity, but trigger allows to cover the low mass region

2011: High luminosity, measurement to higher masses possible



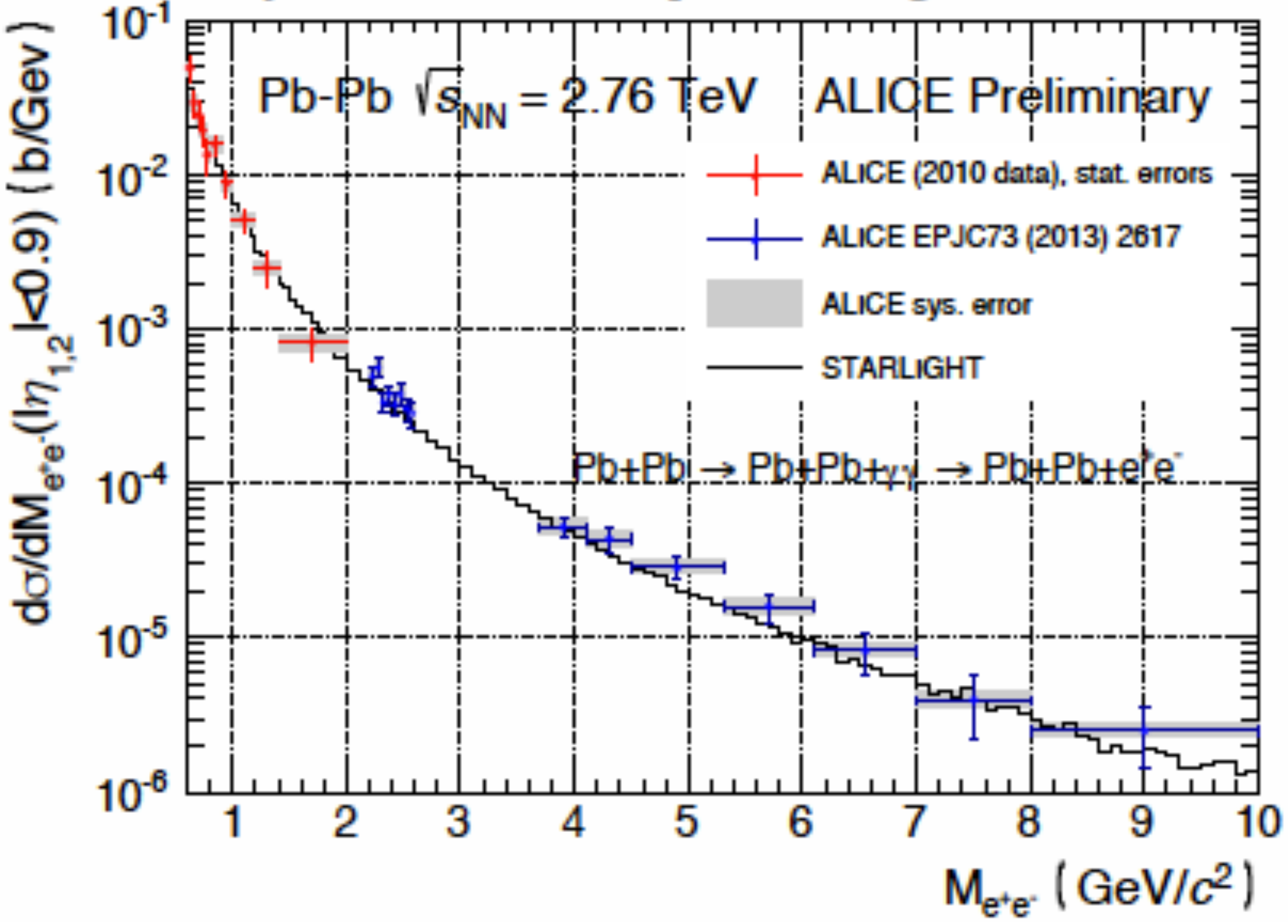


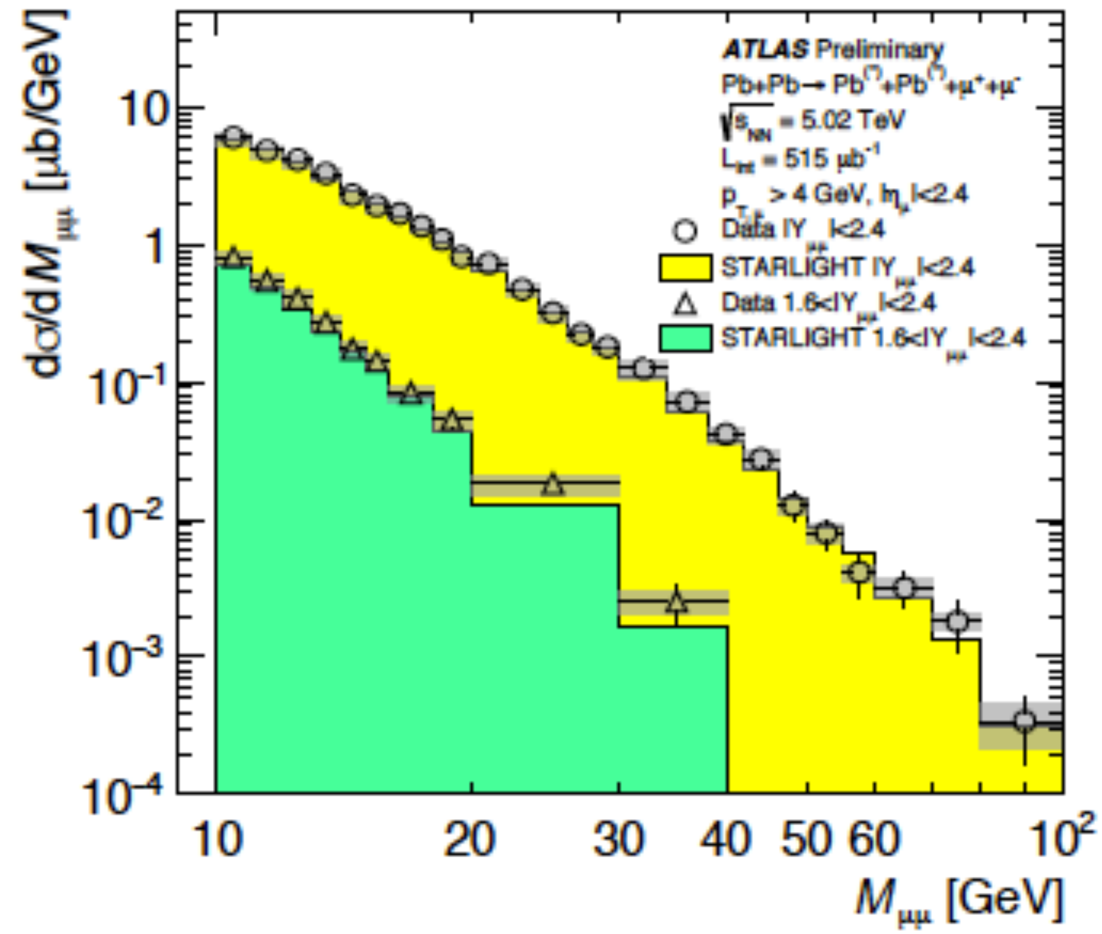
A LO QED calculation (STARLIGHT) describes the data
Strong constraint on NLO contributions

ALICE & ATLAS RESULTS

STARLIGHT = Breit-Wheeler cross section is convoluted with the photon spectra from the two nuclei

J. Nystrand (ALICE), https://arxiv.org/abs/1408.0811





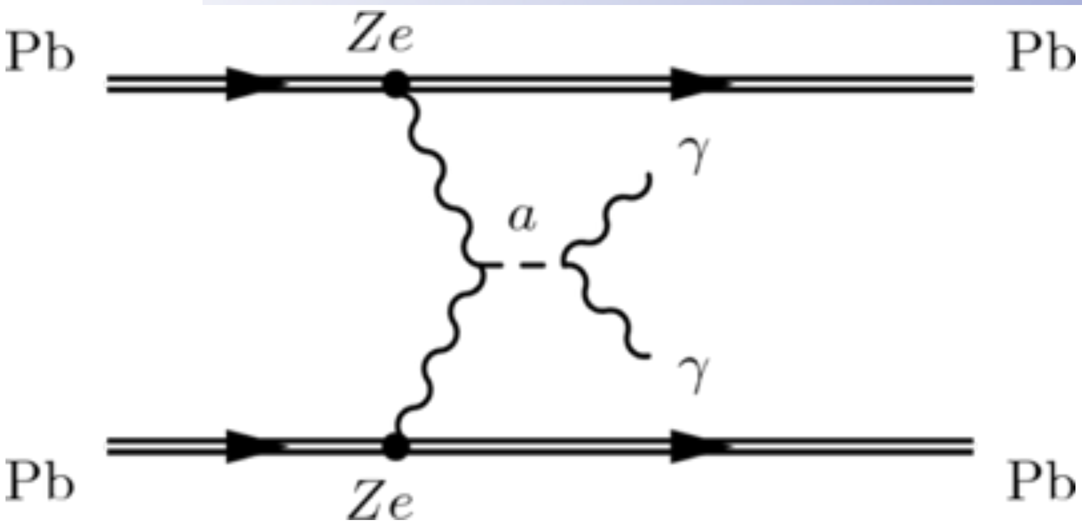
Different beam energies, but confirms expectations over >2 orders of magnitude in M_{ll}

No hits of strong field effects

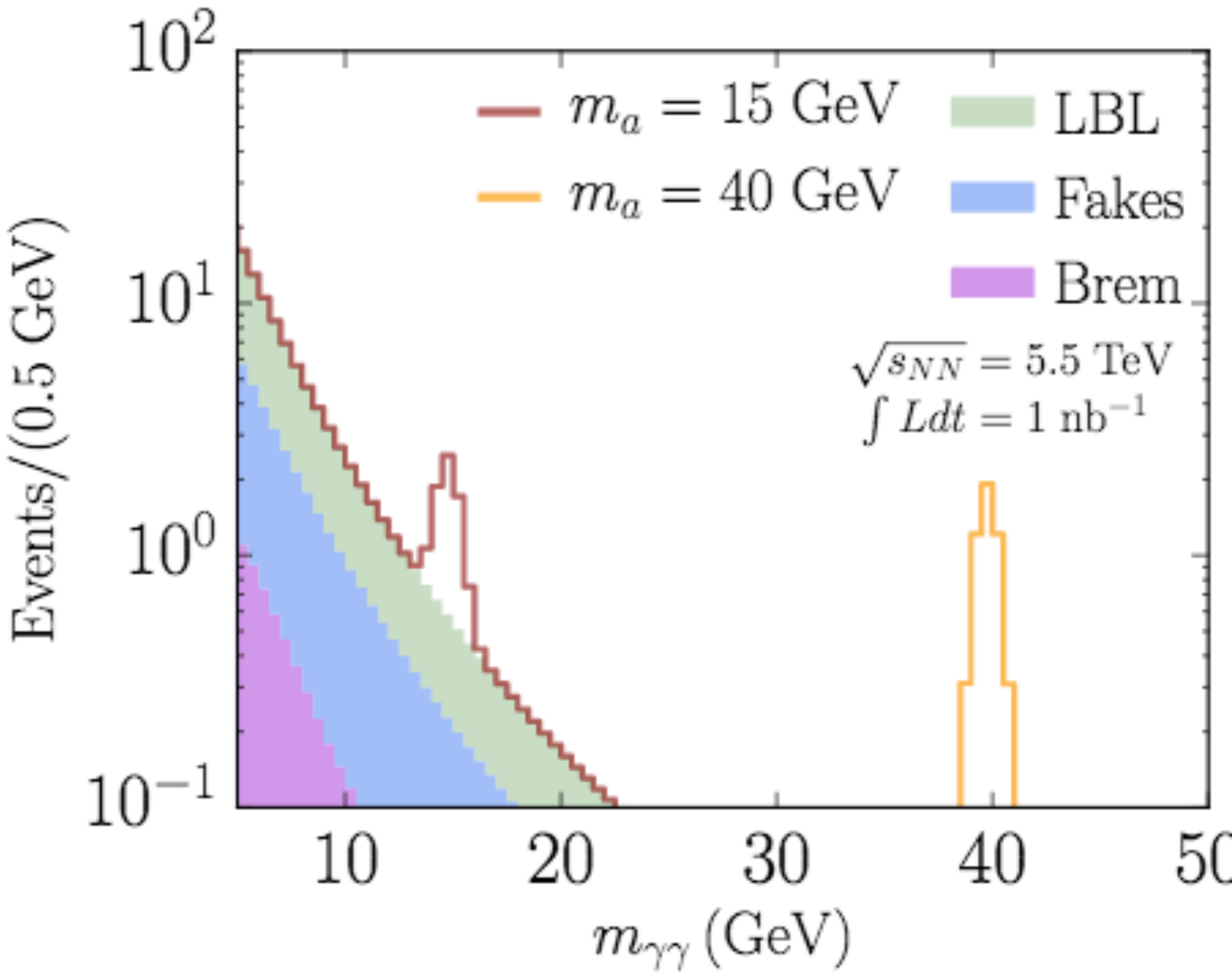
18

Beyond the Standard Model

UPCs and Axion-like particles



S. Knapen, et al.
arXiv:1607.06083 Jul 2016



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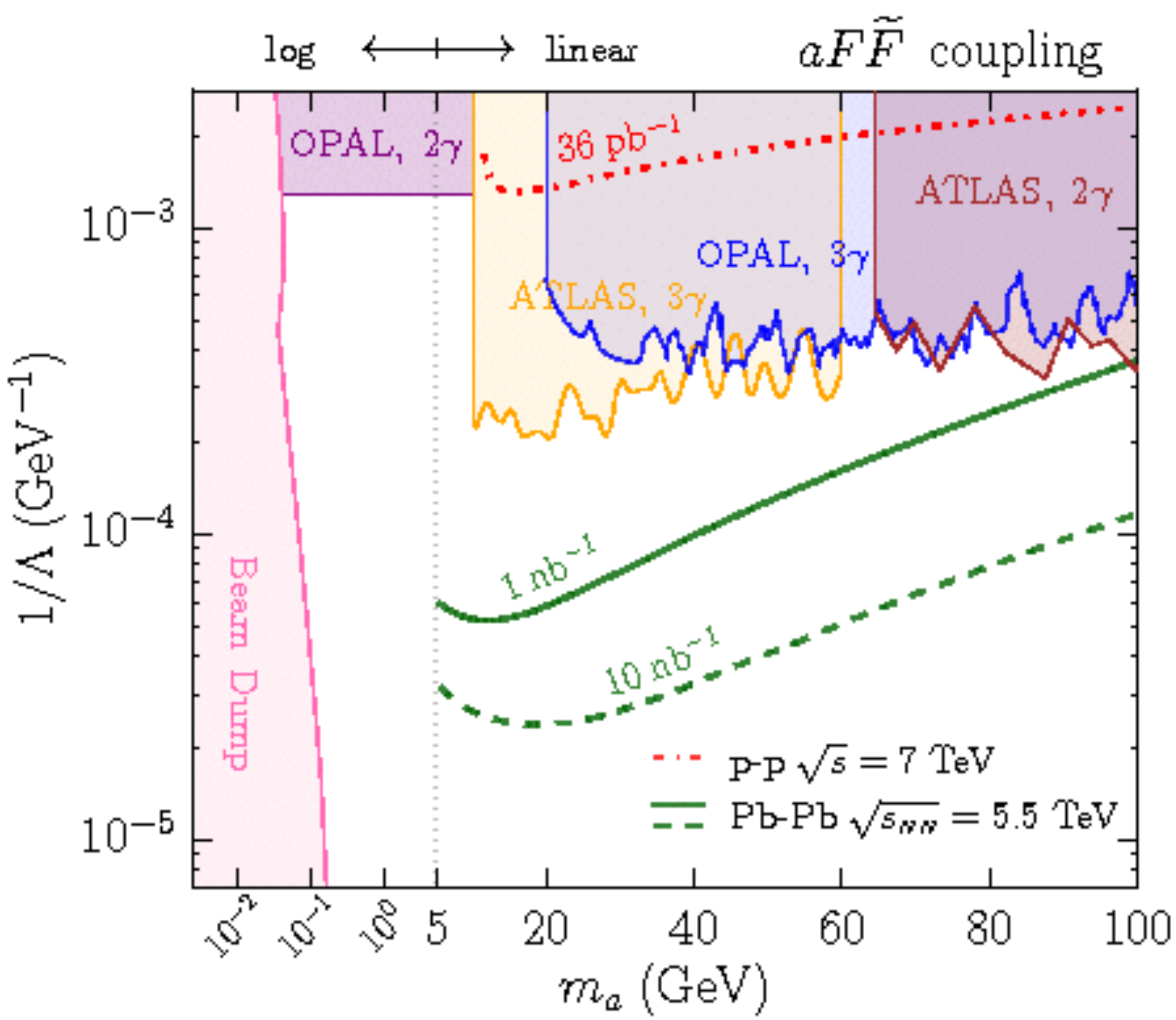
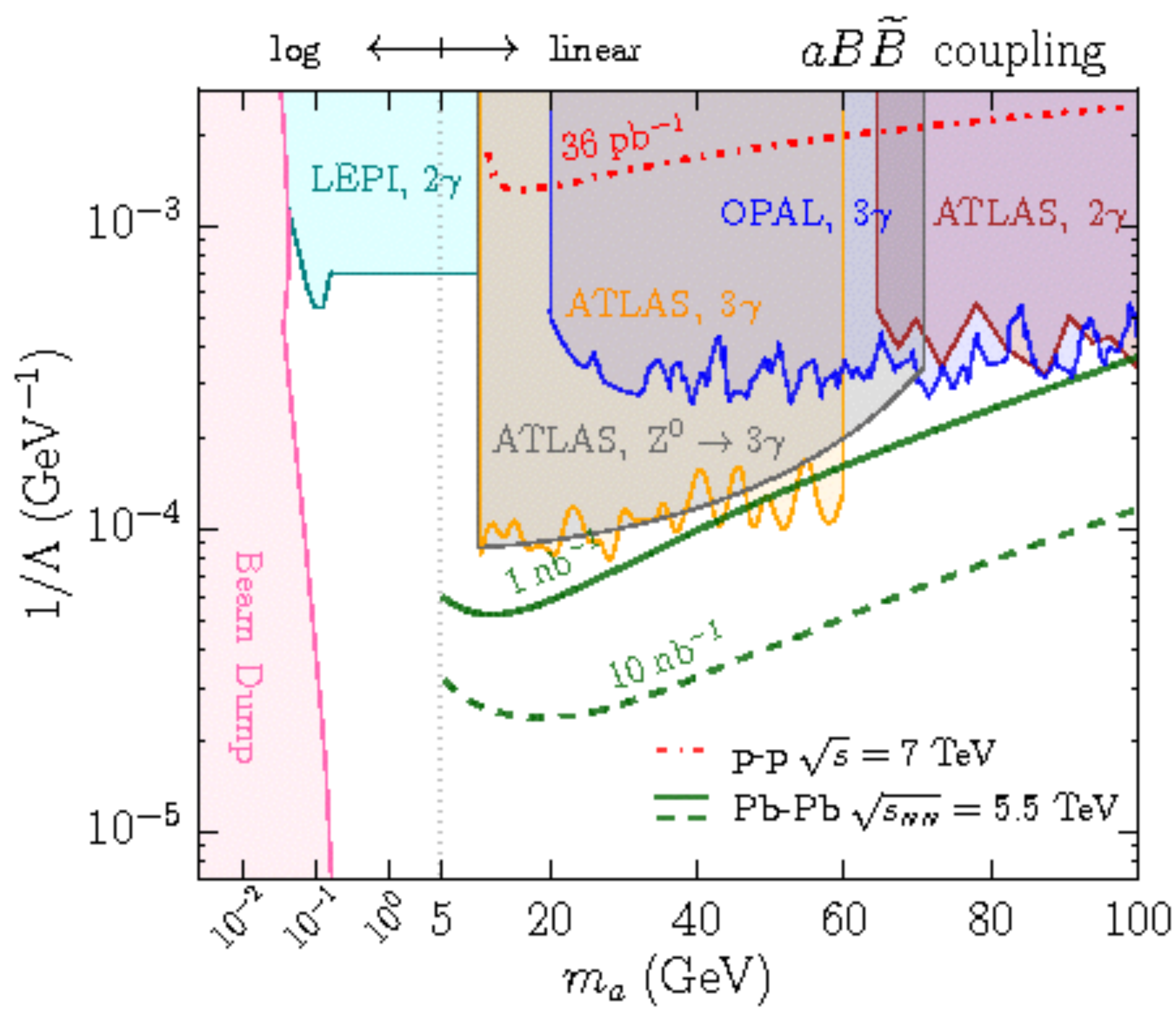
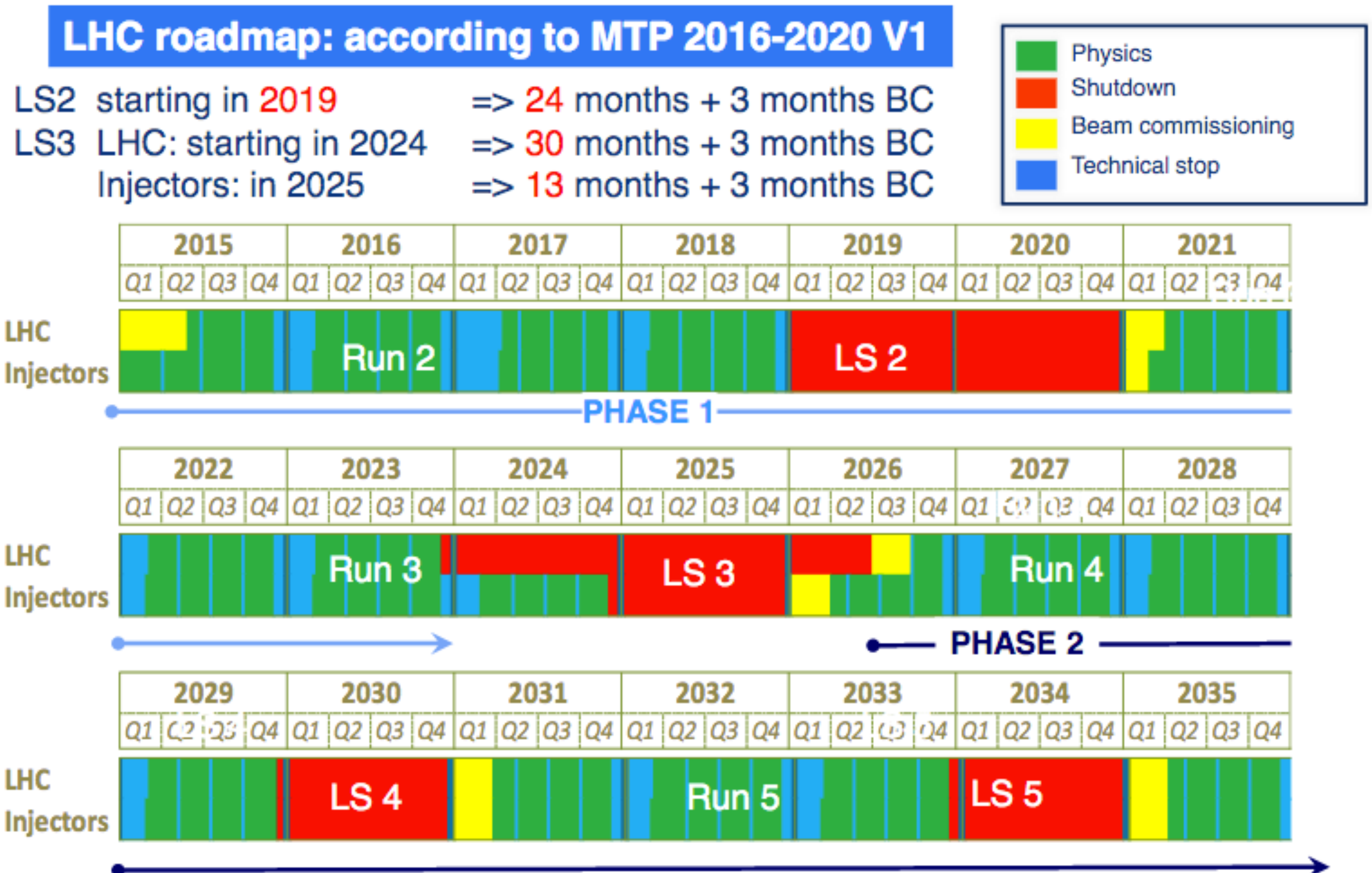




LHC schedule

CERN Yellow Report: ***CERN-PH-LPCC-2015-001***



At the very least, UPC physics at the LHC is a good testbed of EIC physics

Summary and outlook

- Studying QCD with high energy photon-photon, photon-proton and photon-nuclear interactions at the LHC
  - Searching for saturation effects in the proton
  - Nuclear effects at both low and high Bjorken-x
- So far, most analyses have been carried out for exclusive VM photoproduction but new studies possible for other final states (dijets, double VM, diphoton, etc)
- Inclusive photo-nuclear and photon-proton reactions also possible

Summary

- **It is now time to**

  .….discuss and prepare for future LHC runs

  …discuss/work on theoretical challenges

  …discuss applications for future experimental facilities such as the EIC

Additional slides

Coherent and incoherent J/Ψ photoproduction

Event-by-event fluctuations:

- Coherent diffraction: target remains intact

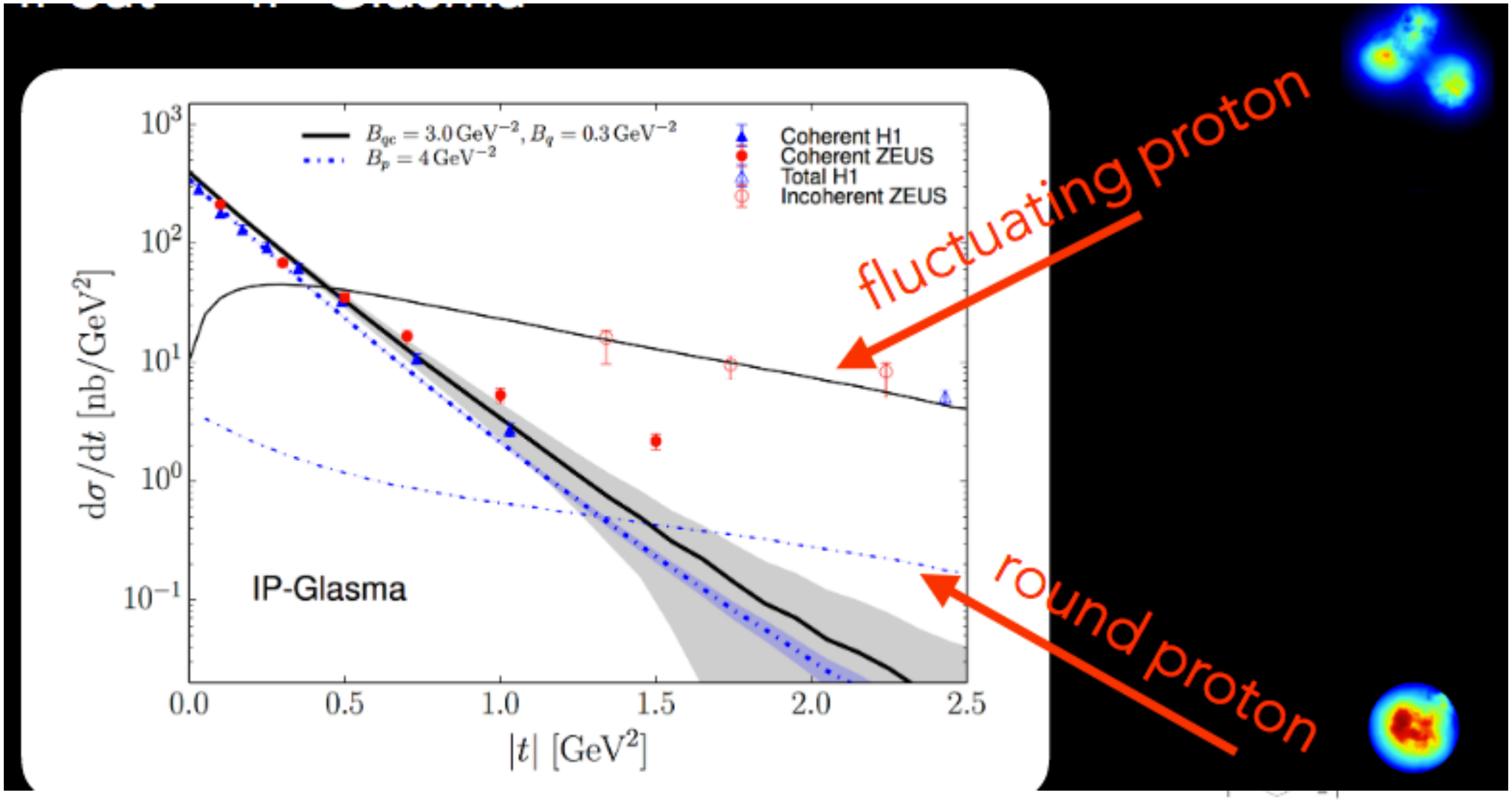
$$\frac{\mathrm{d}\sigma^{\gamma^* A \to VA}}{\mathrm{d}t} \sim \left|\langle \mathcal{A}(x, Q^2, t) \rangle\right|^2$$

- Incoherent, target breaks up: variance

$$\frac{\mathrm{d}\sigma^{\gamma^* A \to VA^*}}{\mathrm{d}t} \sim \langle |\mathcal{A}(x, Q^2, t)|^2 \rangle - \left|\langle \mathcal{A}(x, Q^2, t) \rangle\right|^2$$

$\langle\rangle$ = Target average.

Constraining proton fluctuations in $\gamma + p \to J/\Psi + p^*$

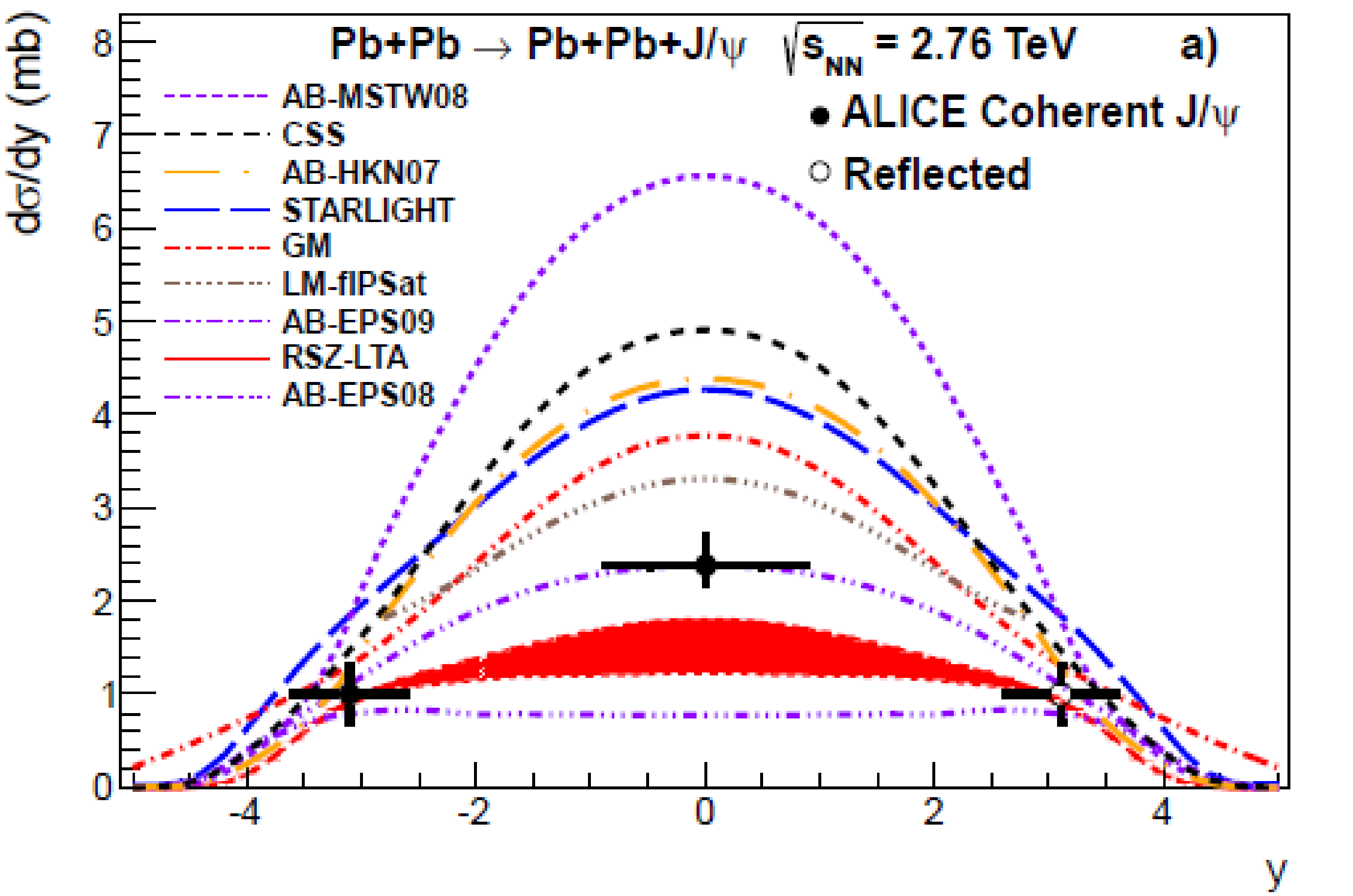


H.M., B. Schenke, arXiv:1603.04349

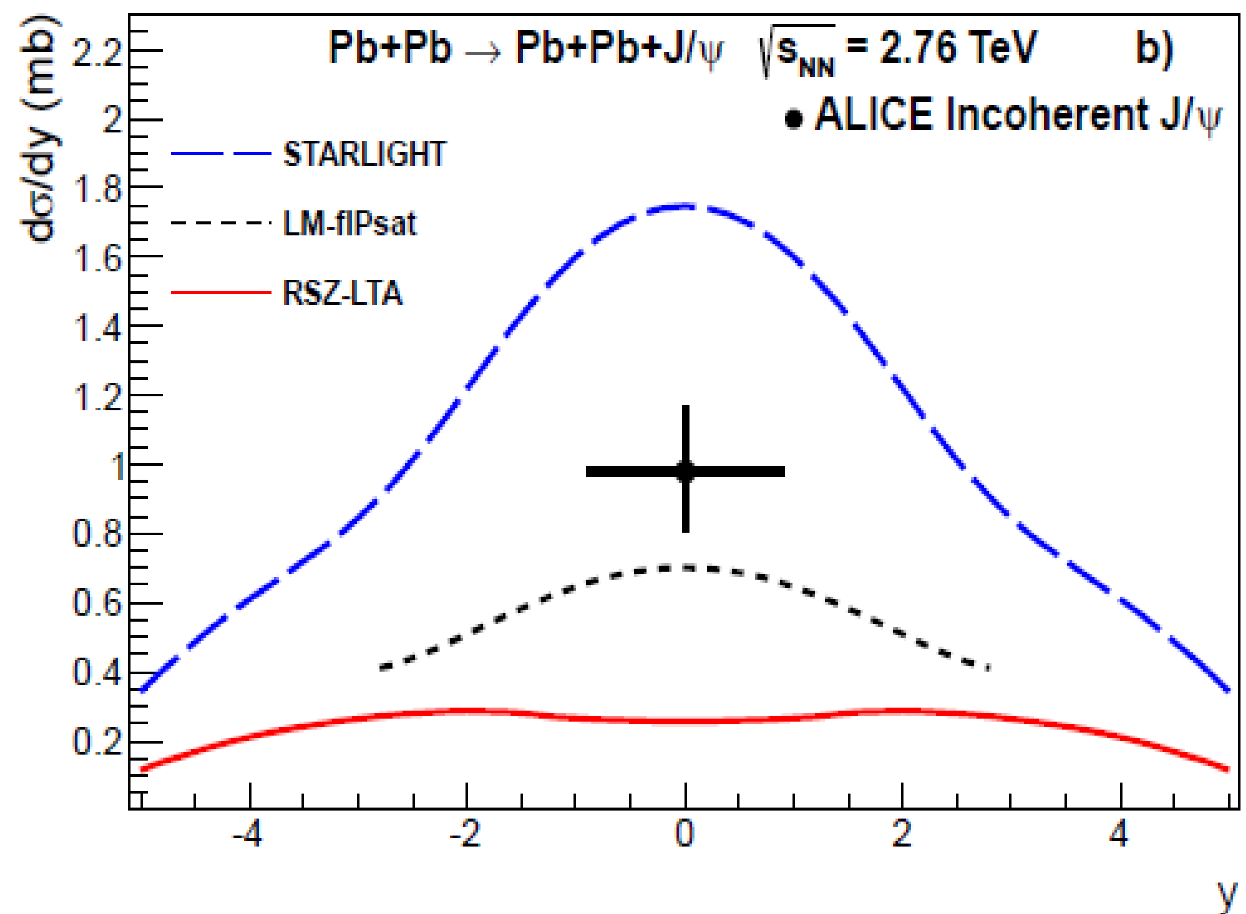
- Incoherent data requires large fluctuations

Data *and* theoretical predictions

Coherent J/ψ



Incoherent J/ψ



Direct evidence of nuclear gluon shadowing

At mid-rapidity, Bjorken-*x* ~ 10^{-3}

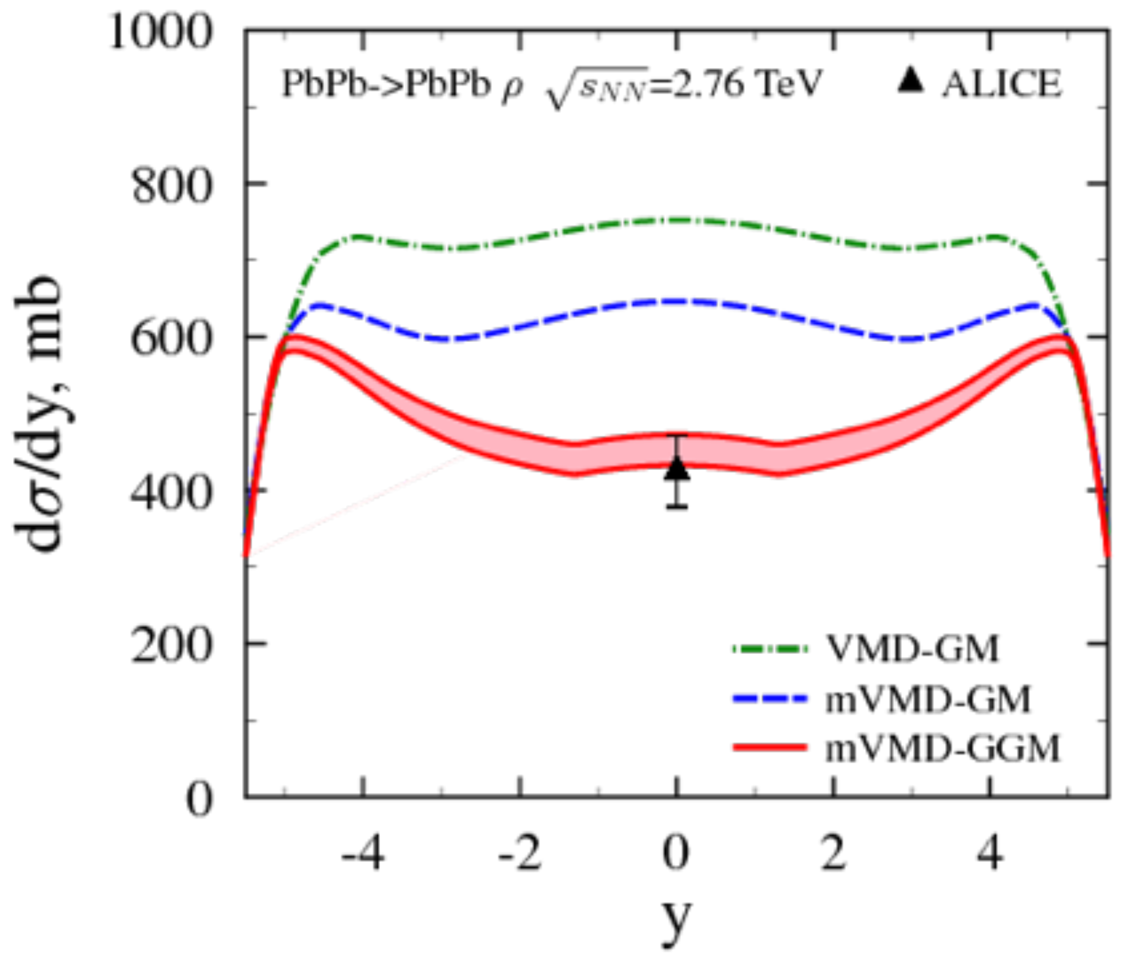
ALICE shows that the distribution in $x \approx 10^{-2} - 10^{-3}$ range is consistent with the EPS09 parameterization

Two UPC publications by ALICE

Phys.Lett. B718 (2013) 1273-1283

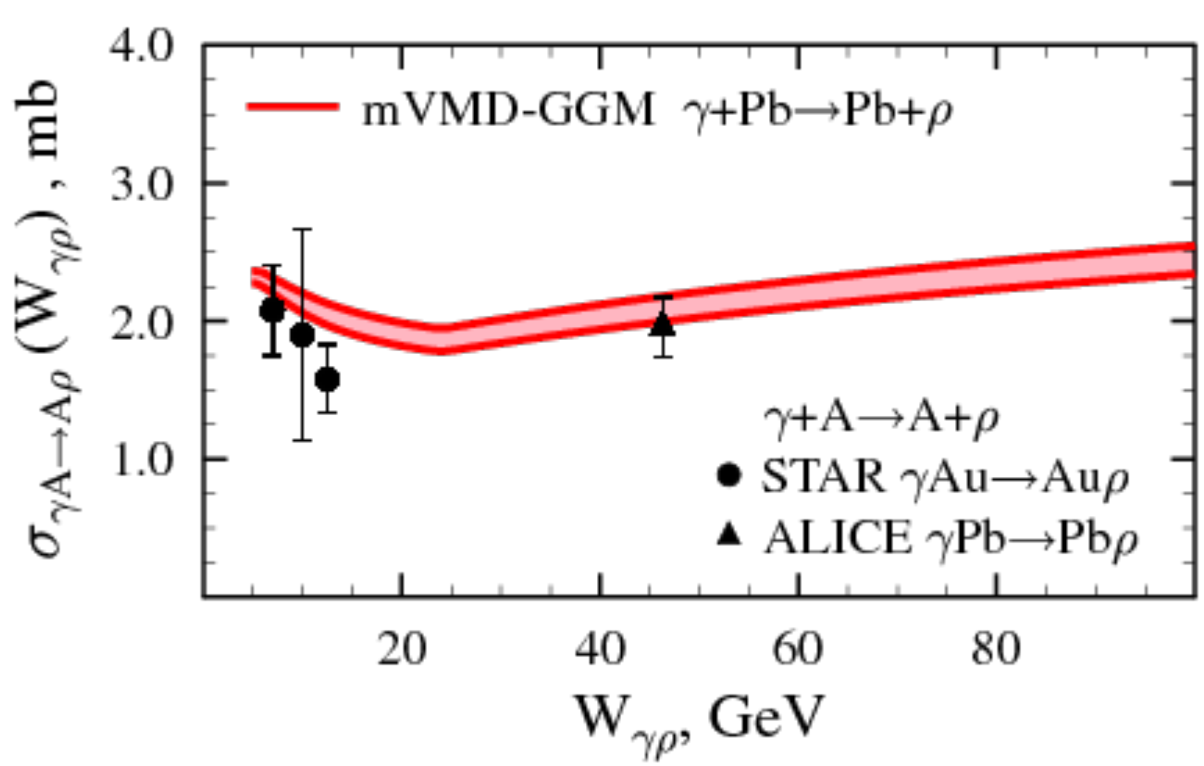
Eur. J. Phys. C73, 2617 (2013)

Color fluctuation effects in UPCs

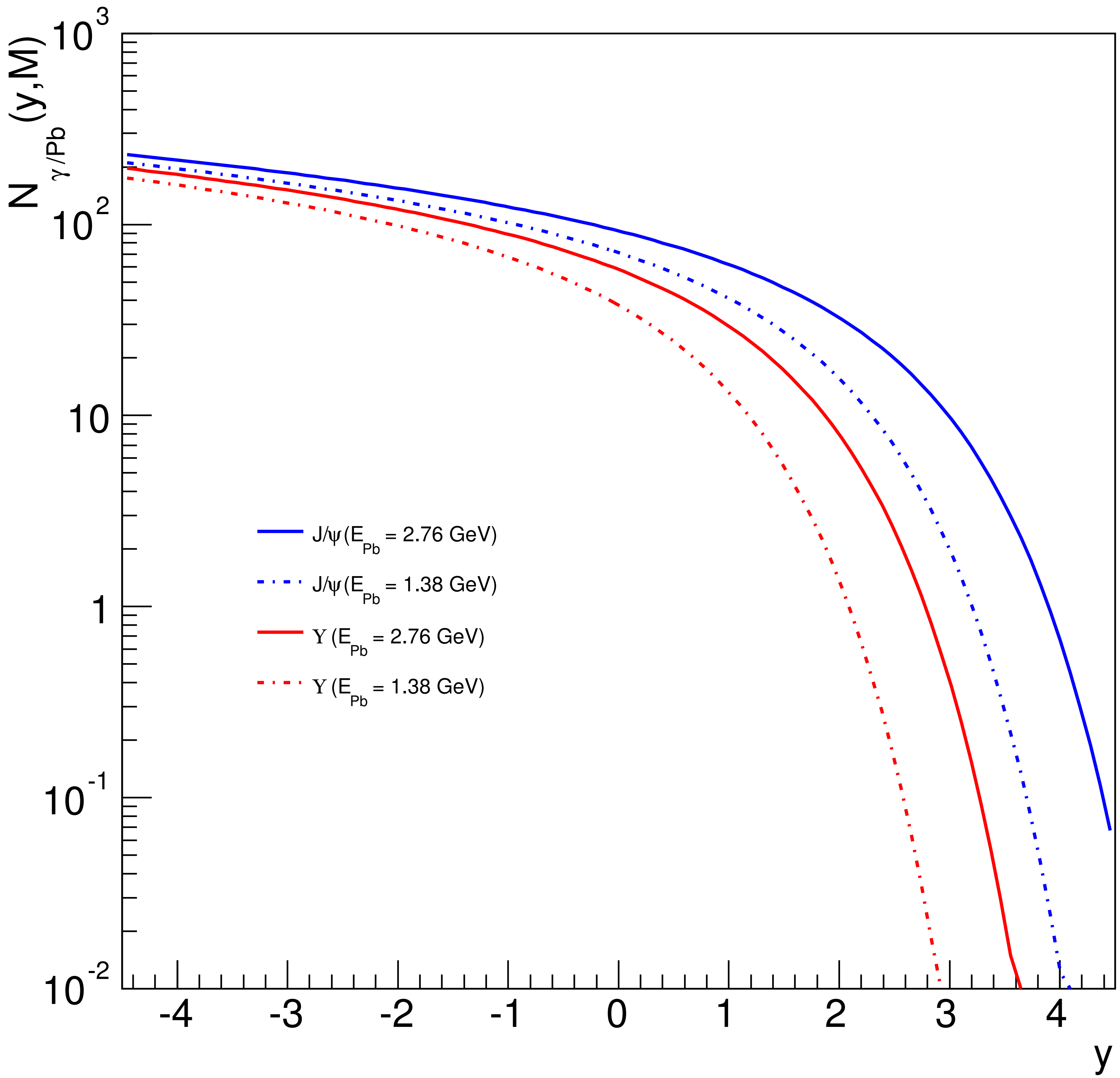


Color fluctuations are much larger than in the case of the proton interactions resulting in a large enhancement of the nuclear shadowing

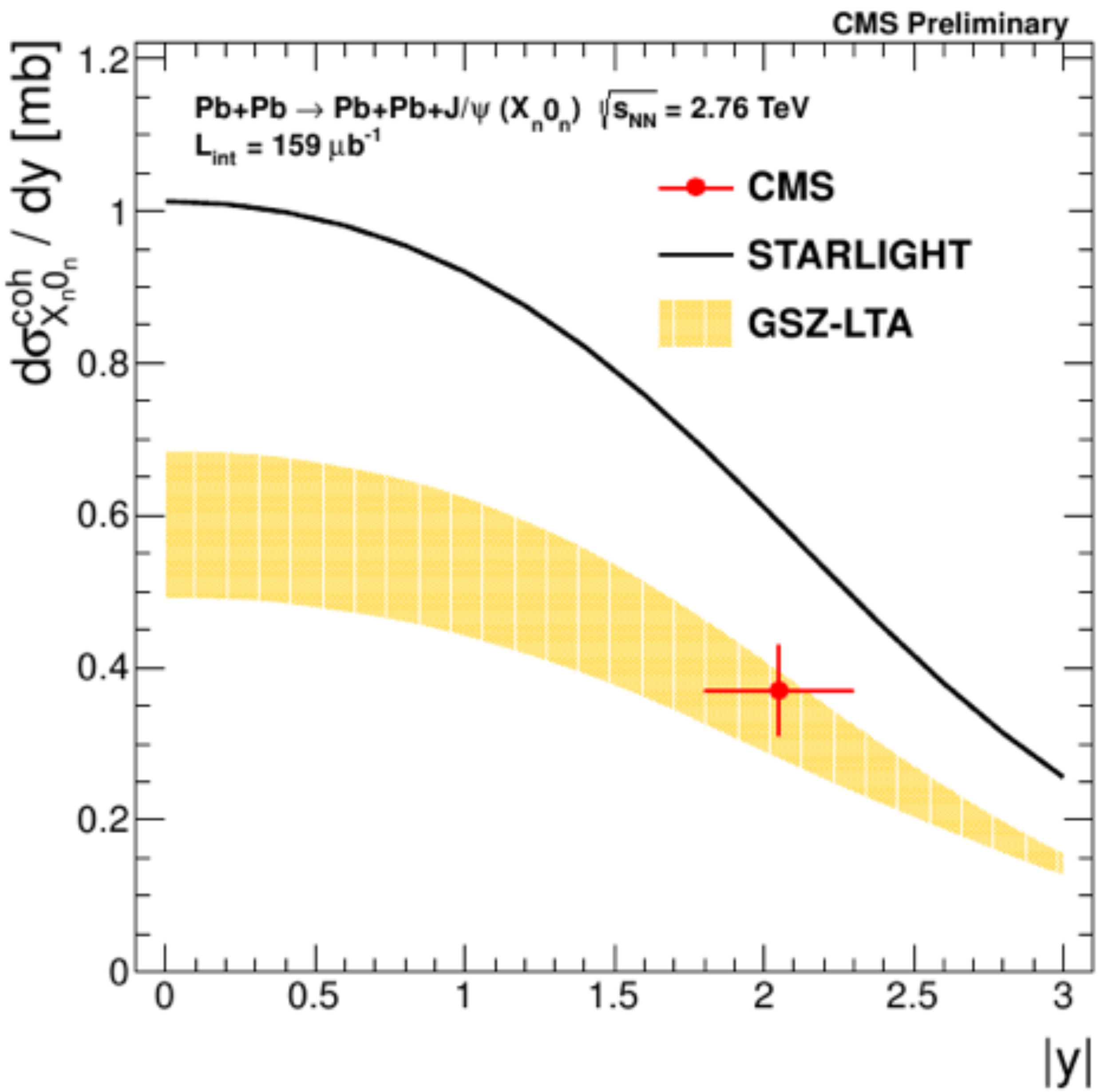
L. Frankfurt et al.
Phys.Lett. B752 (2016) 51-58

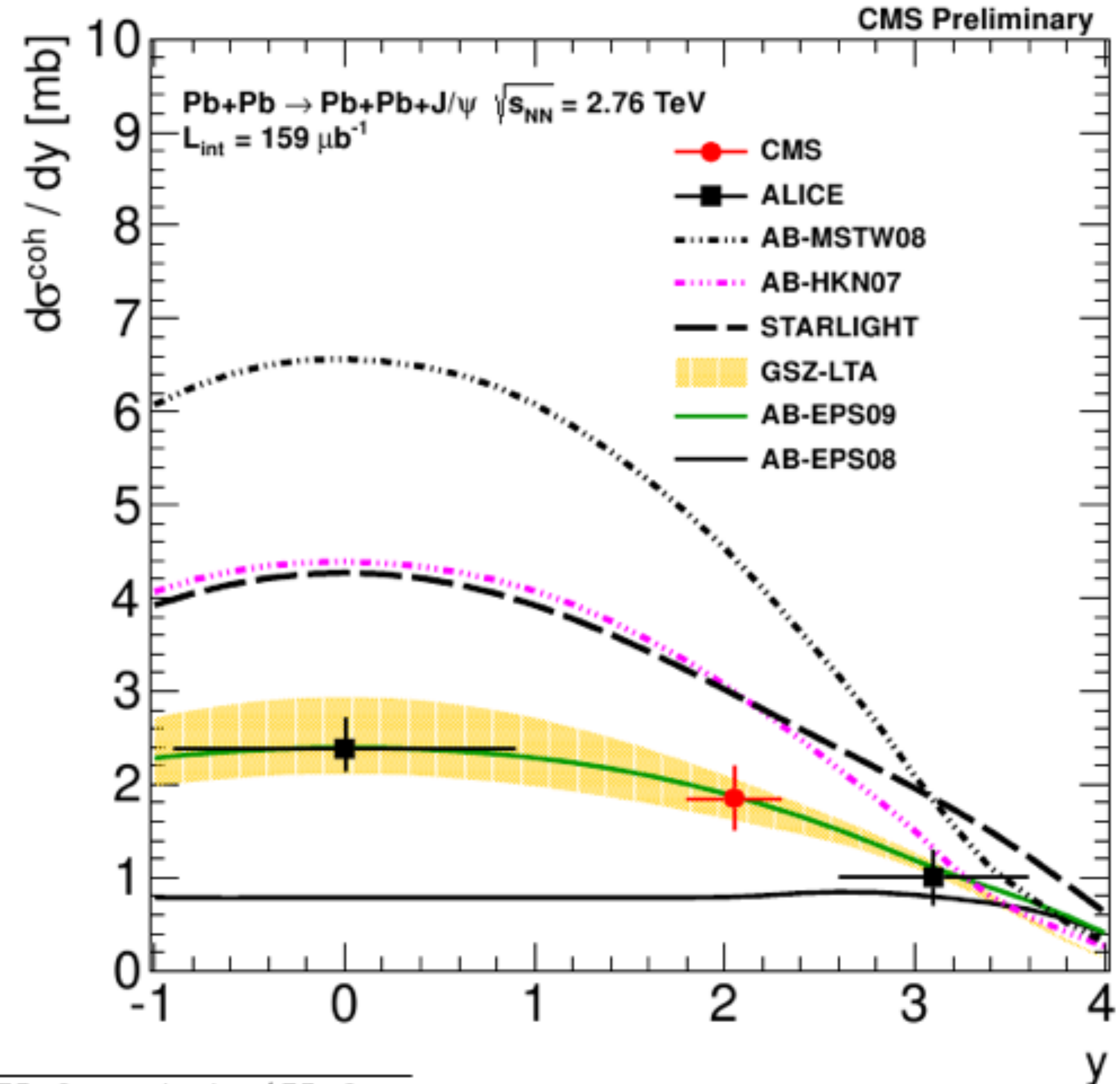


Prospects for Run 2



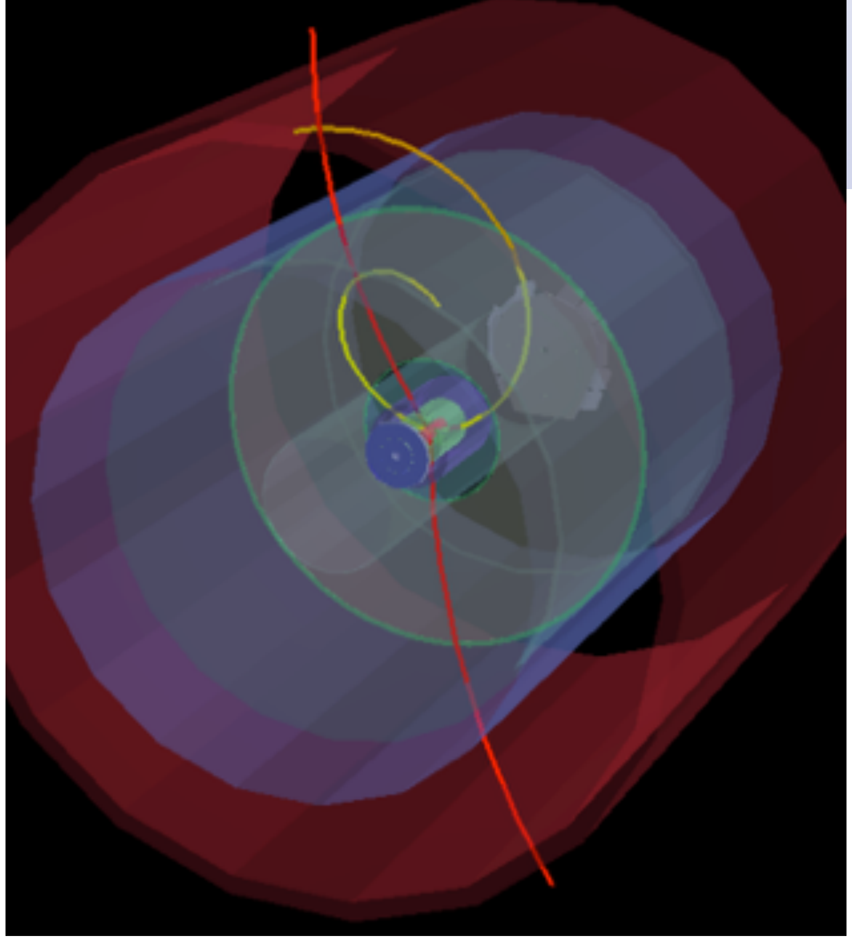
Coherent J/ψ photoproduction

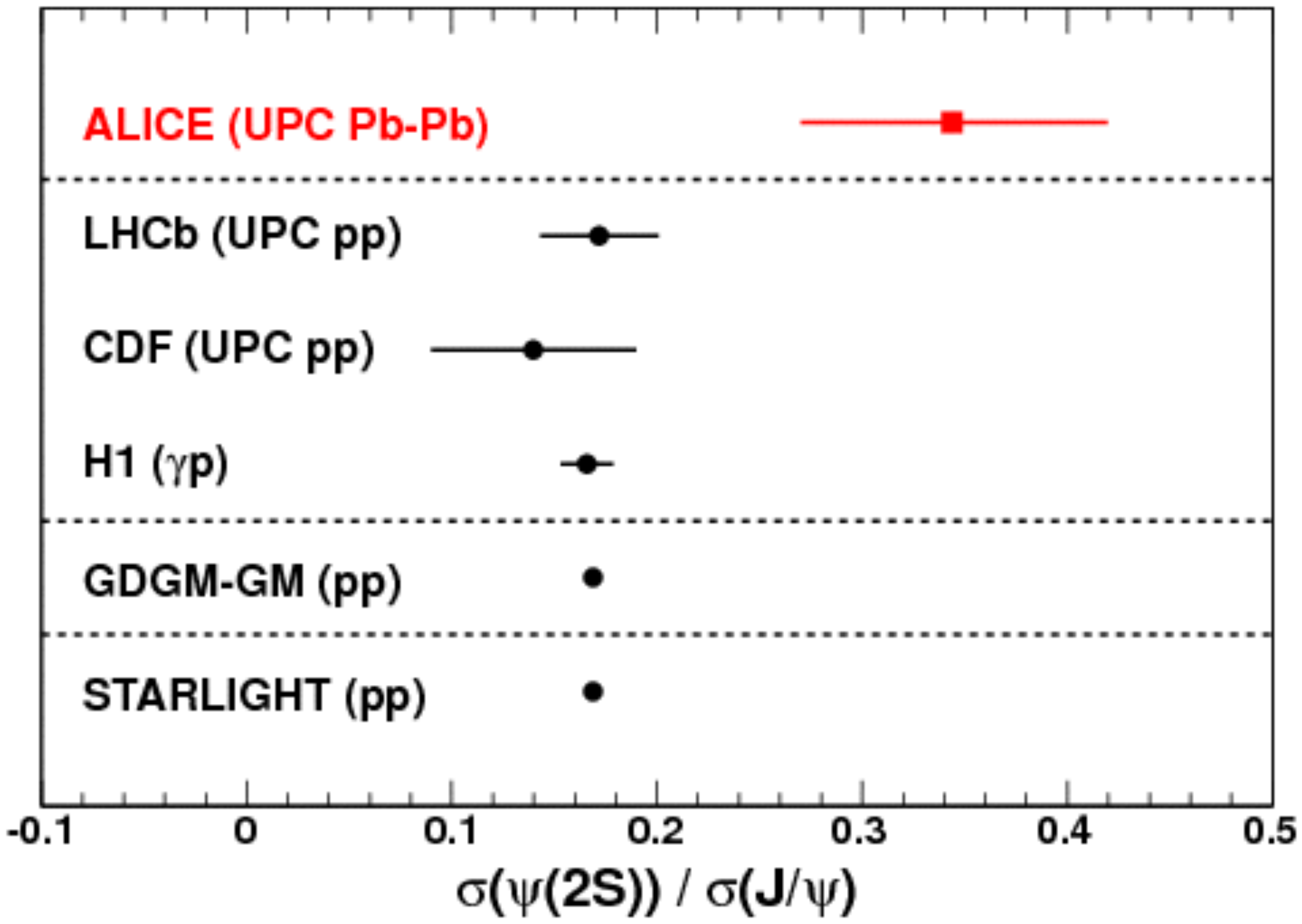




J/ψ with $p_T < 0.15$ GeV/c	X_nX_n/X_n0_n	$1_n0_n/X_n0_n$	$1_n1_n/X_n0_n$
Data	0.36±0.04	0.26±0.03	0.03±0.01
STARLIGHT	0.37	N/A	0.02
GSZ	0.32	0.30	0.02

Ψ(2s) photonuclear

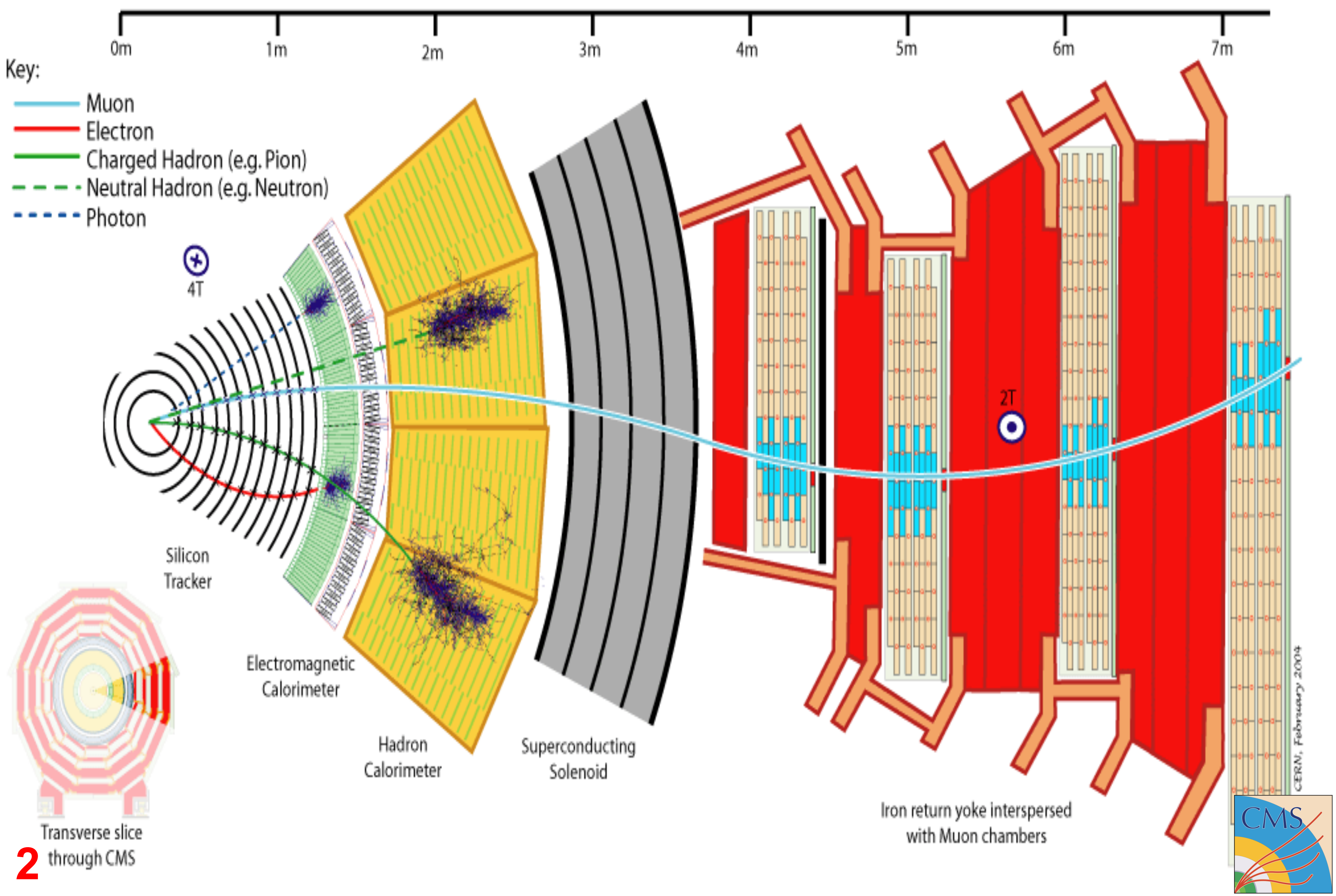




Do nuclear effects affect differently 1S and 2S states? Need more precise data!

Ψ(2s)/J/Ψ enhancement in gamma+Pb collisions

A transverse slice through CMS



Forward detectors at CMS