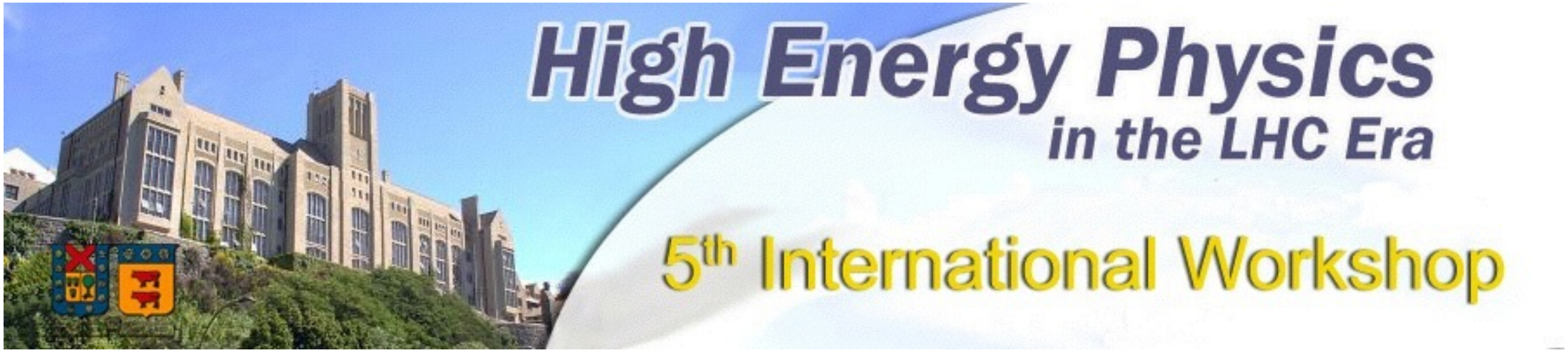
KU

Experimental review and prospects of ultra-peripheral collisions



Daniel Tapia Takaki

The University of Kansas

High Energy Physics in the LHC era

Valparaiso, Chile, 20 December 2013

Plan of this talk

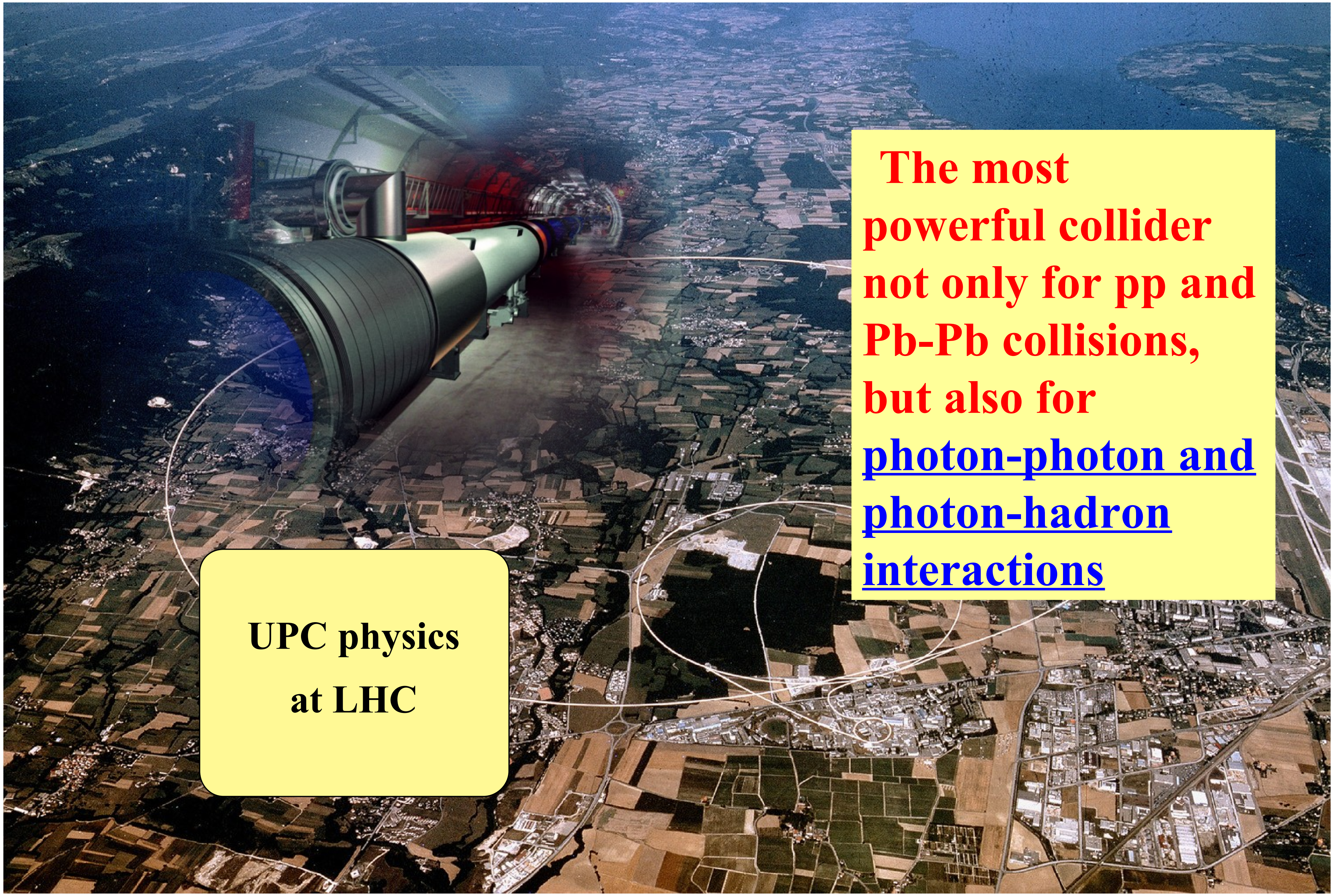
Ultra-Peripheral (pp, pA and AA) Collisions

- What are UPCs
- Why at LHC

Recent results

Future directions

Using the LHC as a $\gamma\gamma$, γPb, γp collider

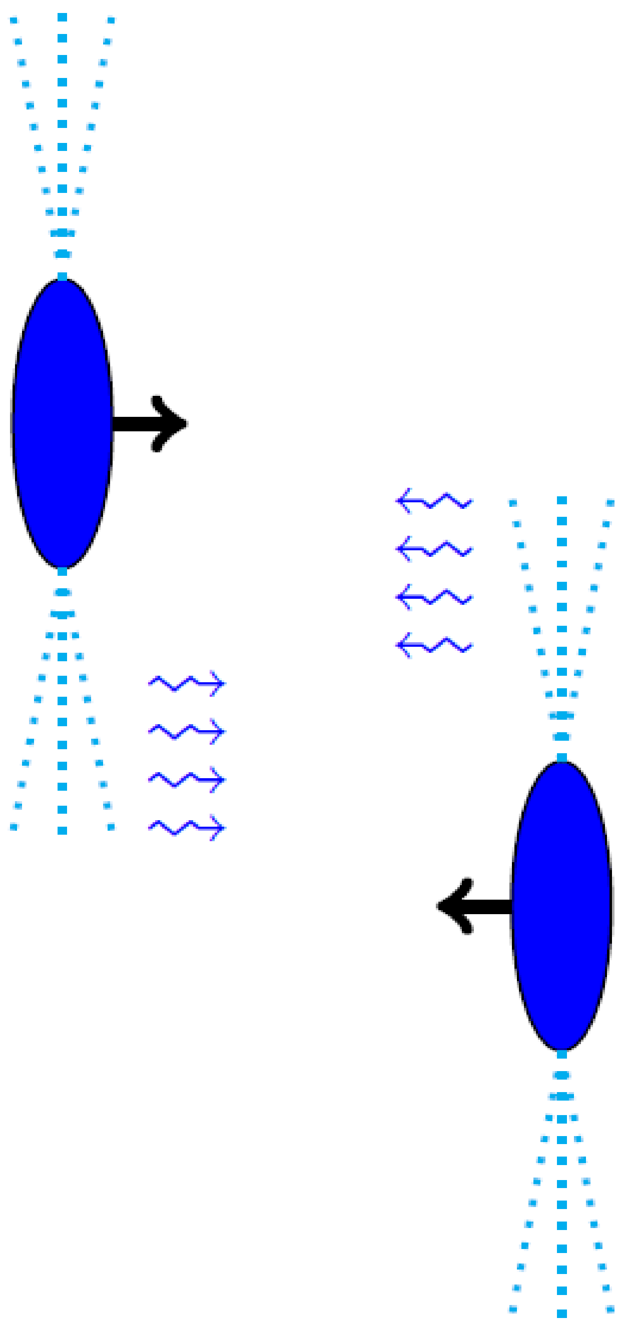


The most powerful collider not only for pp and Pb-Pb collisions, but also for <u>photon-photon and photon-hadron interactions</u>

UPC physics at LHC

UPCs in Pb-Pb

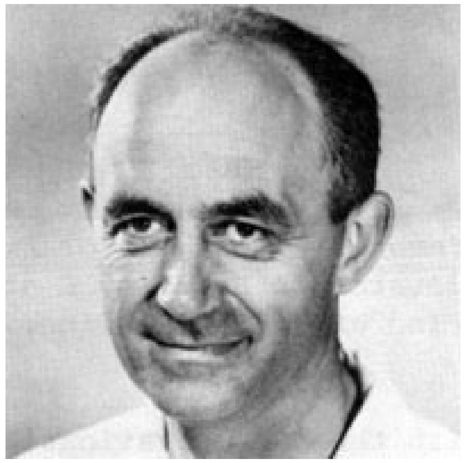
Why Ultra-Peripheral collisions



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.



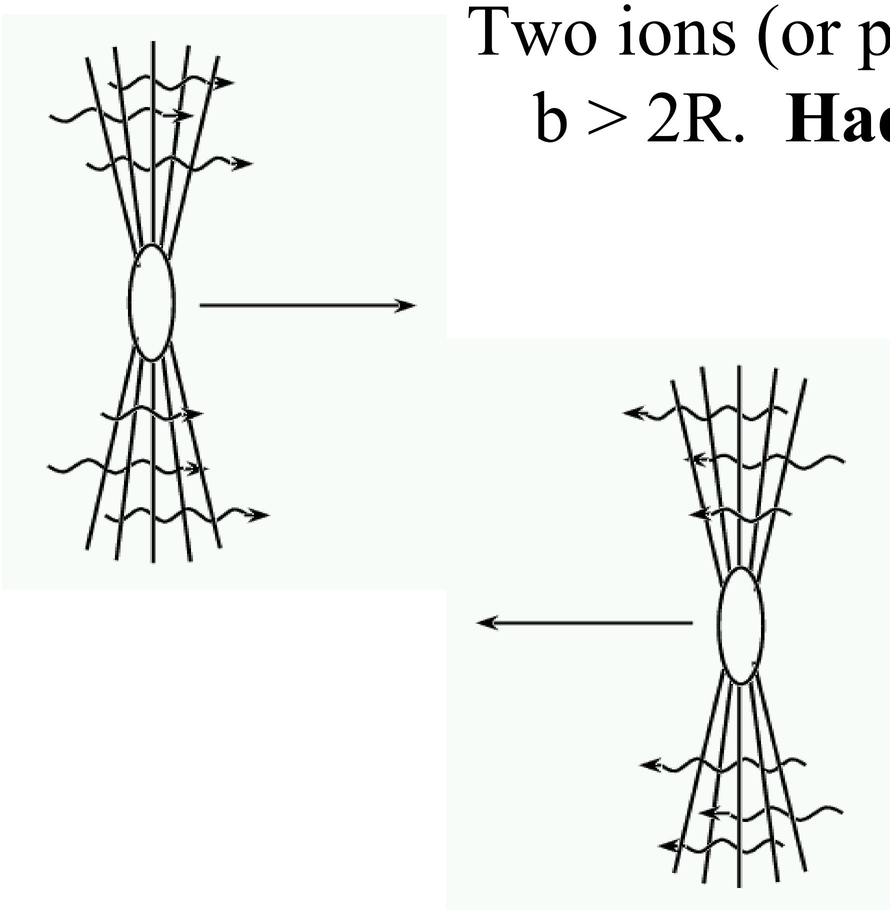
Enrico FERMI

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

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

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

Why ultra-peripheral heavy-ion collisions

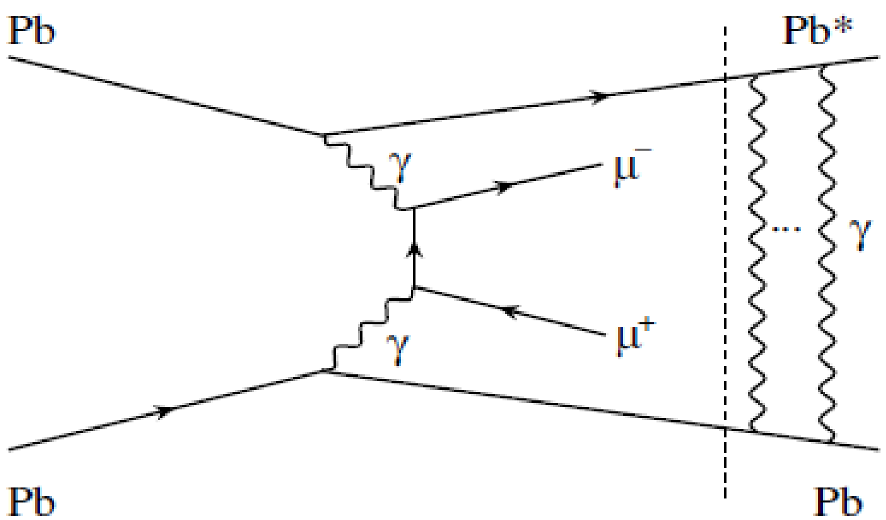


Two ions (or protons) pass by each other with impact parameters b > 2R. **Hadronic interactions are strongly suppressed**

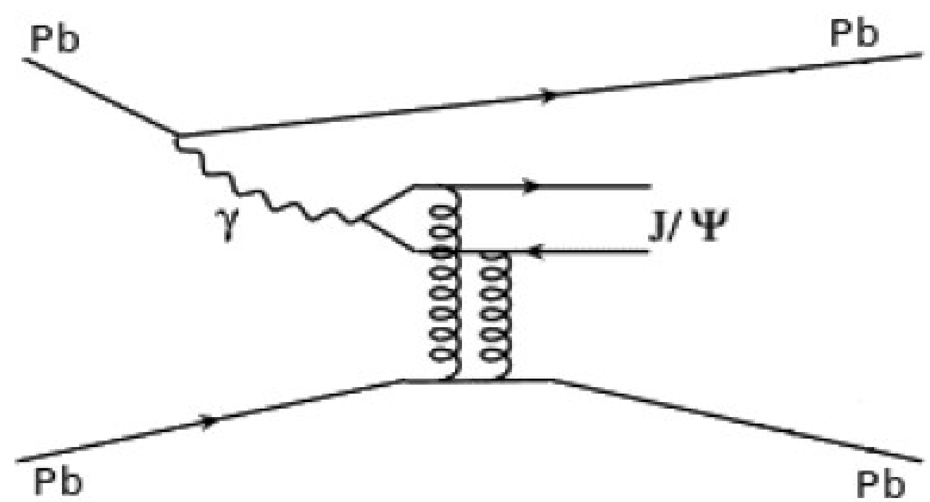
Number of photons scales like Z^2 for a single source ⇒ exclusive particle production in heavy-ion collisions dominated by electromagnetic interactions.

The virtuality of the photons → 1/R ~ 30 MeV/*c*

Photon-induced reactions



Two-photon production



$\gamma + p \rightarrow J/\psi + p$

modelled in pQCD: exchange of two gluons with no net-colour transfer

Why J/ψ photo-production at LHC

Total J/ψ cross section: 23 mb (STARLIGHT) *vs* 10.3 mb Rebyakova, Strikman and Zhalov

Models differ by the way photo-nuclear interaction is treated...

Five model predictions available
– published in the last two years-

STARLIGHT
http://starlight.hepforge.org

Adeluyi and Bertulani (AB)
Phys. ReV. C 85 (2012) 044904

Goncalves and Machado (GM)
Phys. ReV C 84 (2011) 011902

Cisek, Szczurek, Schafer (CSC)
Phys. ReV. C 86 (2012) 014905

Rebyakova, Strikman and Zhalov (RSZ)
Phys. Lett. B 710 (2012) 252

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xg\left(x, \frac{M_V^2}{4}\right)\right]^2$$

Ryskin 1993

$$\frac{\left.\frac{d\sigma(\gamma A \to VA)}{dt}\right|_{t=0}}{\left.\frac{d\sigma(\gamma N \to VN)}{dt}\right|_{t=0}} = \left[\frac{G_A(x, M_V^2/4)}{G_N(x, M_V^2/4)}\right]^2$$

$$\left.\frac{d\sigma_{\gamma A \to J/\psi A}}{dt}\right|_{t=0} = \frac{M_{J/\psi}^3 \Gamma_{ee} \pi^3 \alpha_s^2(Q^2)}{48 \alpha_{em} Q^8} \left[xG_A(x, Q^2)\right]^2$$

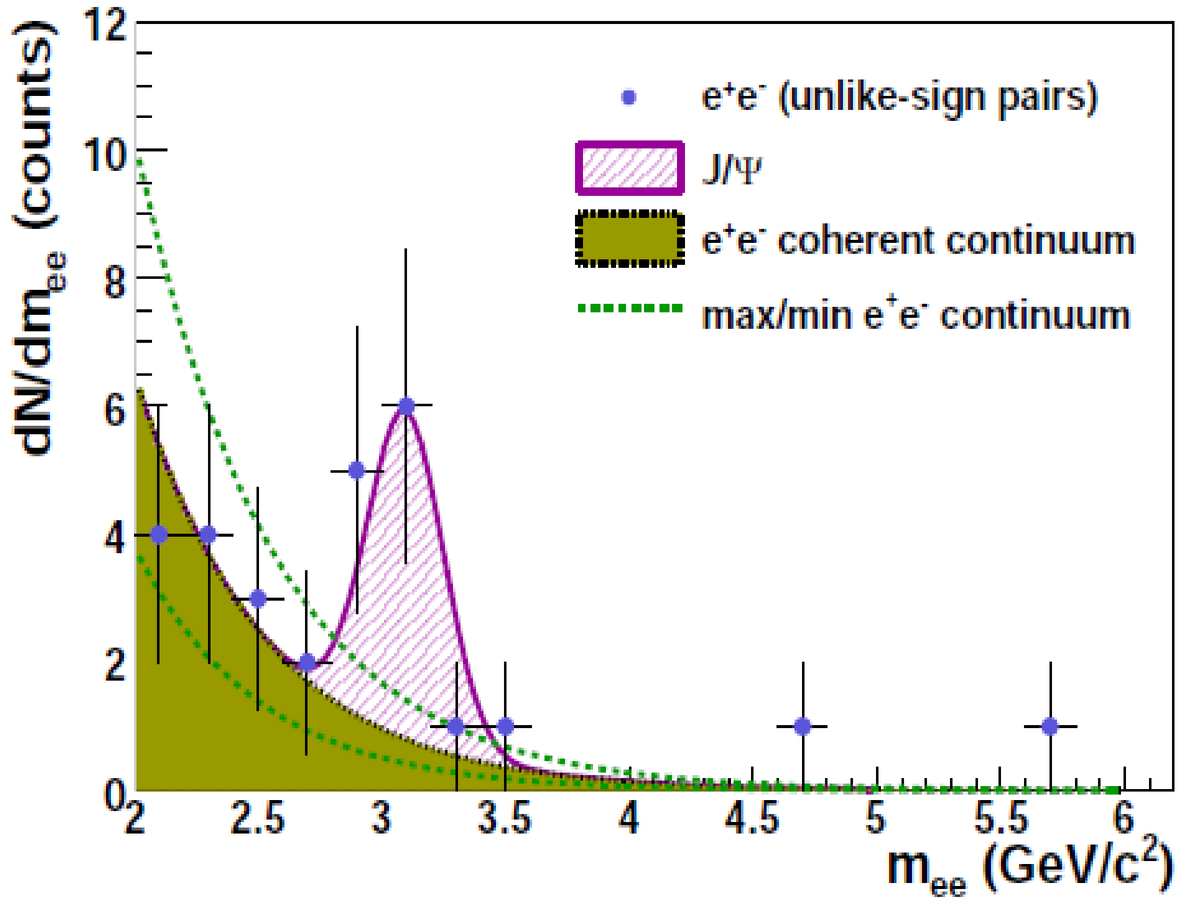
Mass of J/ψ serves as a hard scale: $Q^2 \sim \frac{M_{J/\psi}^2}{4} \sim 2.5\ \mathrm{GeV}^2$

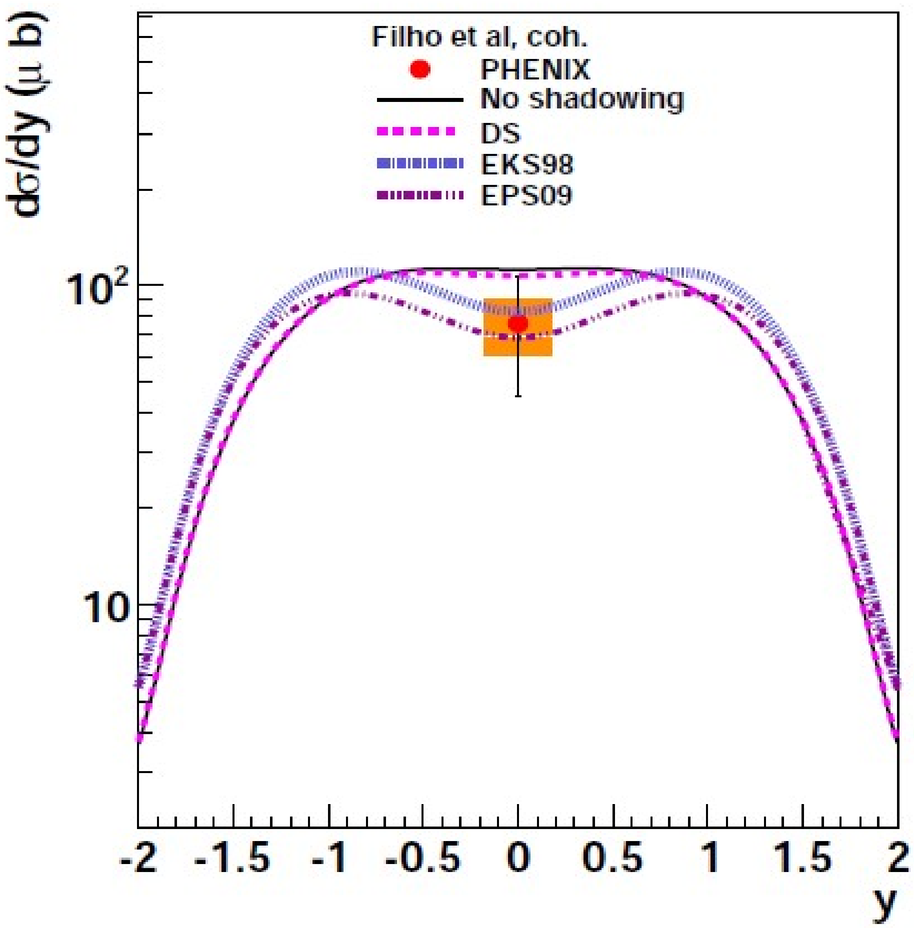
Bjorken x ~ $10^{-2} - 10^{-5}$ accessible at LHC: $x = \frac{M_{J/\psi}^2}{W_{\gamma p}^2}$

Also a more recent calculation

T. Lappi, H. Mäntysaari
http://arxiv.org/abs/1301.4095

RHIC results by PHENIX



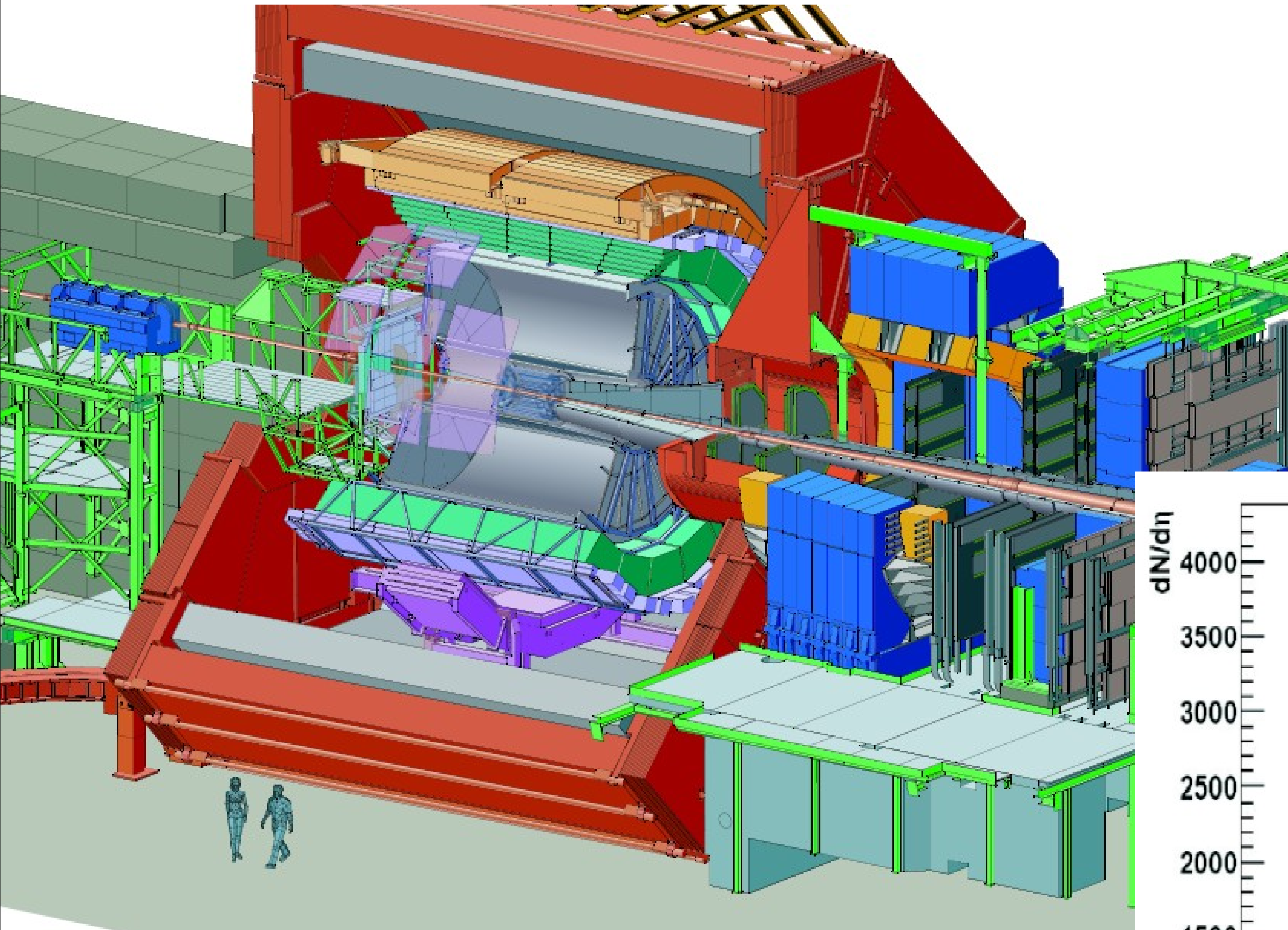


Au+Au collisions at 200 GeV

PHENIX study:

PLB Vol 679, issue 4, p. 321-333

The ALICE experiment at LHC



Central rapidity

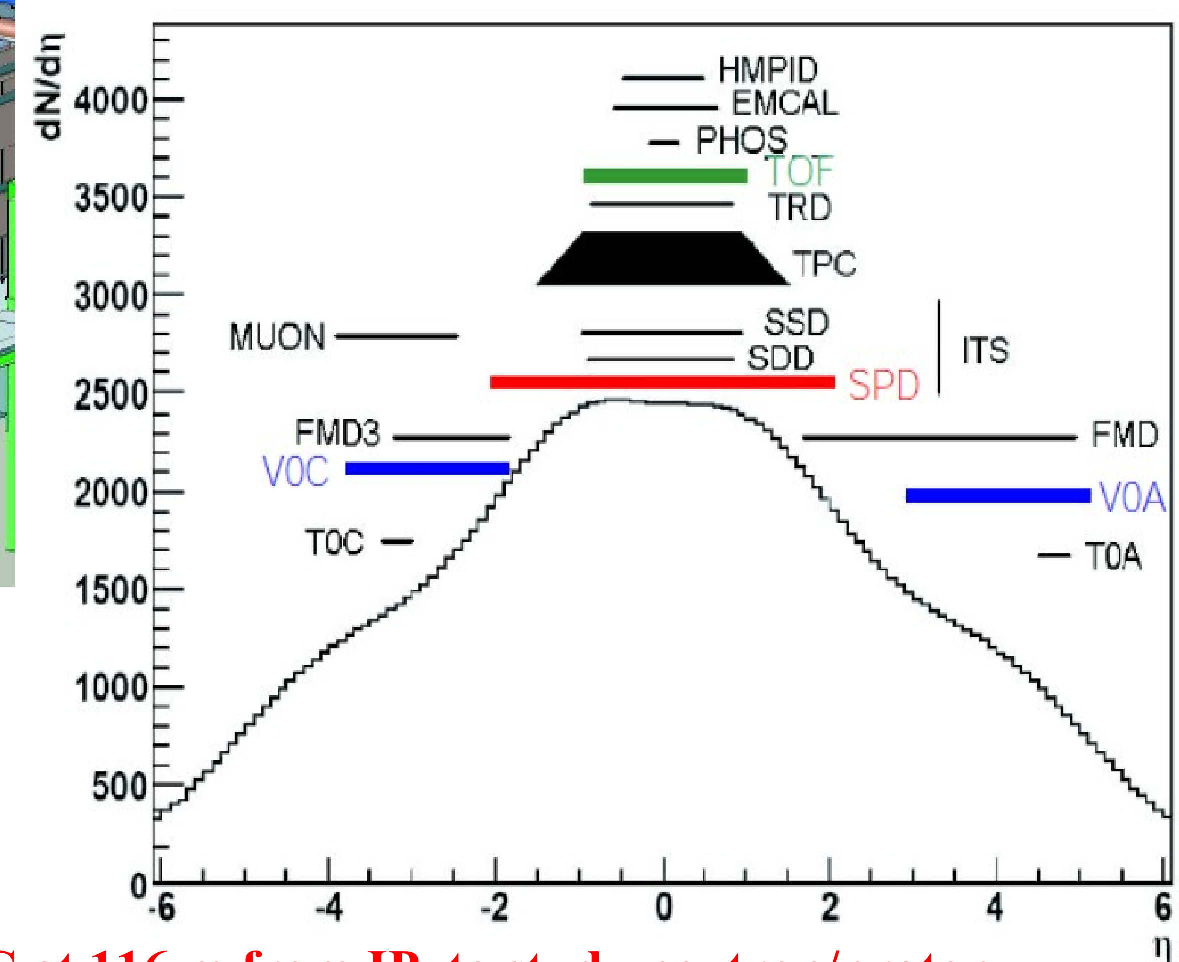
Inner Tracking (ITS), Time Projection Chamber (TPC), Time-of-Flight, TRD, EMCAL

$|\eta| < 0.9$

Forward rapidity

Muon Spectrometer

$-4 < \eta < -2.5$

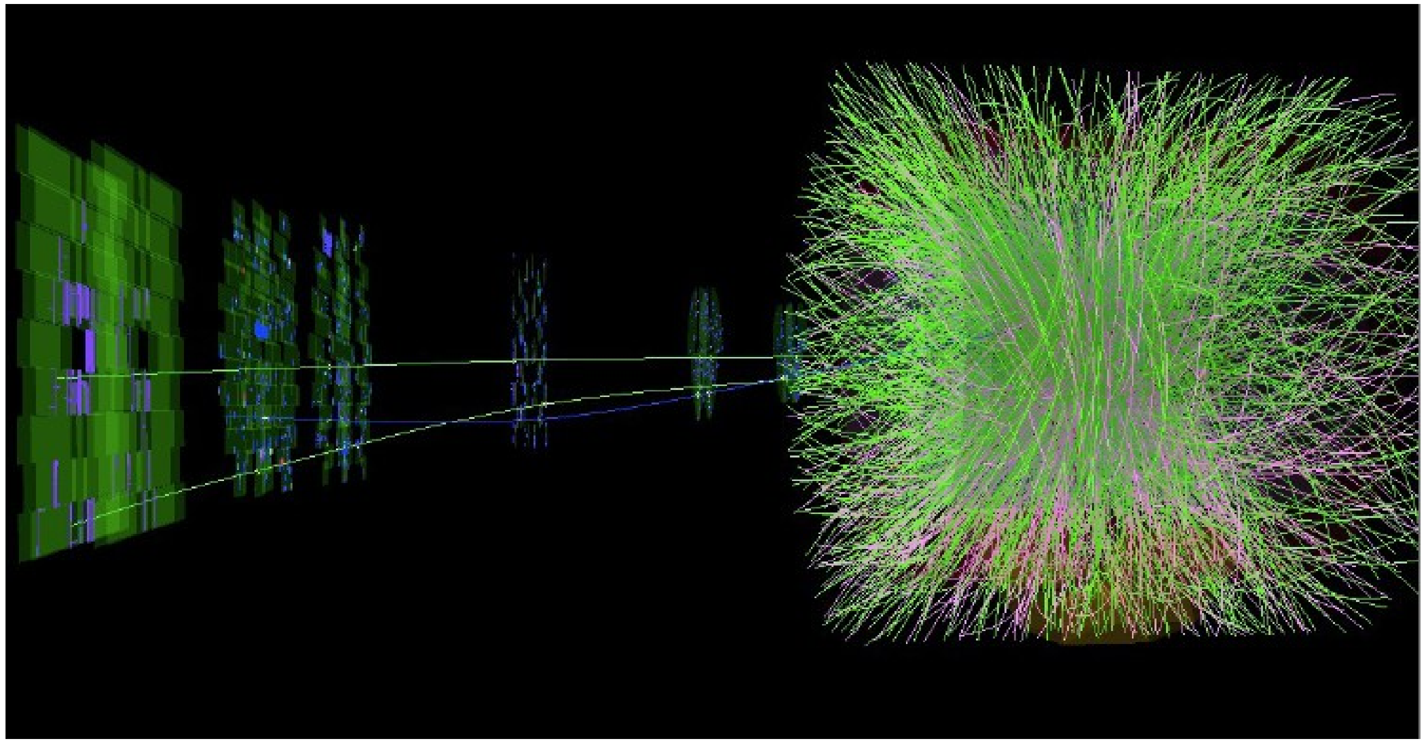


Dedicated triggers for UPC, using VZERO forward detectors for vetoing And MUON, TOF and SPD

ALICE can measure J/ψ mesons down to zero p_T

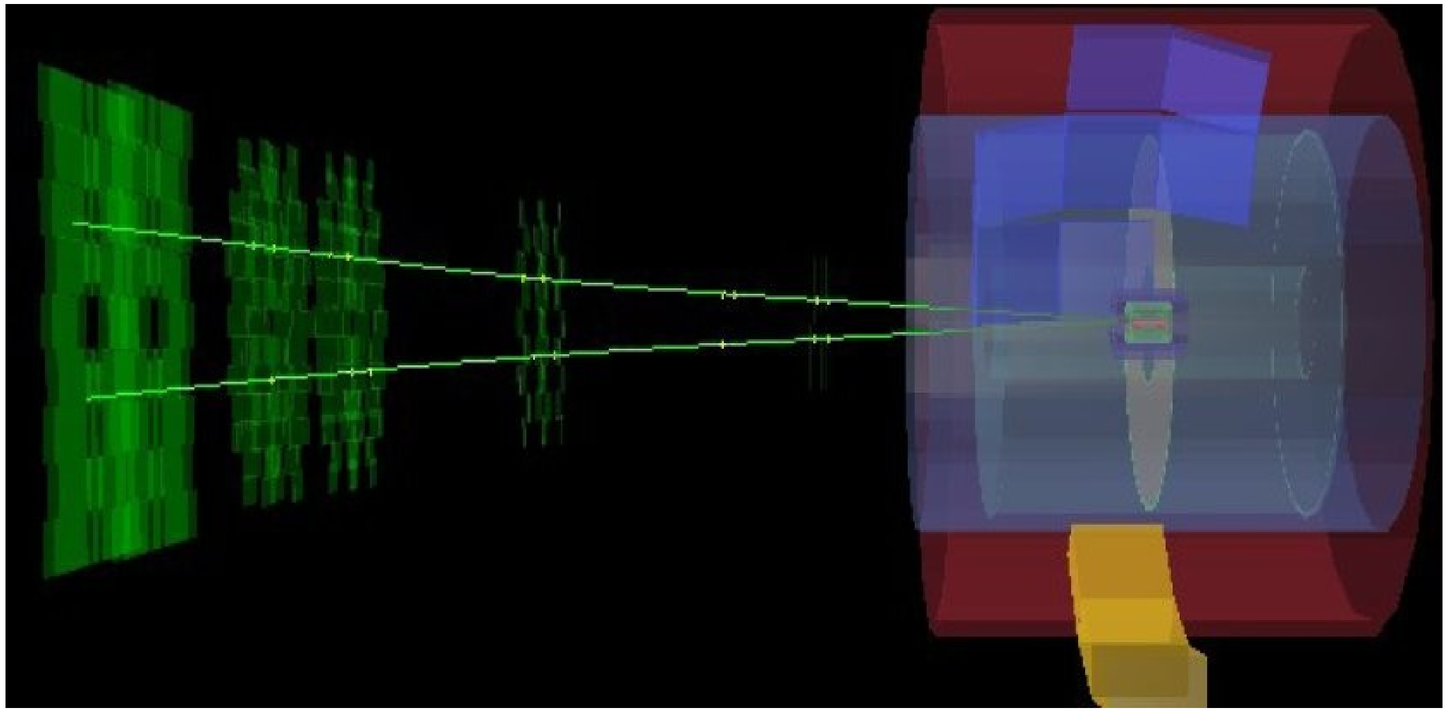
ZDC at 116 m from IP, to study neutron/proton emitted at the very forward region

Exclusive J/ψ analysis at **forward rapidity**



From a typical inclusive J/ψ candidate in Pb-Pb collisions...

….to an exclusive J/ψ candidate

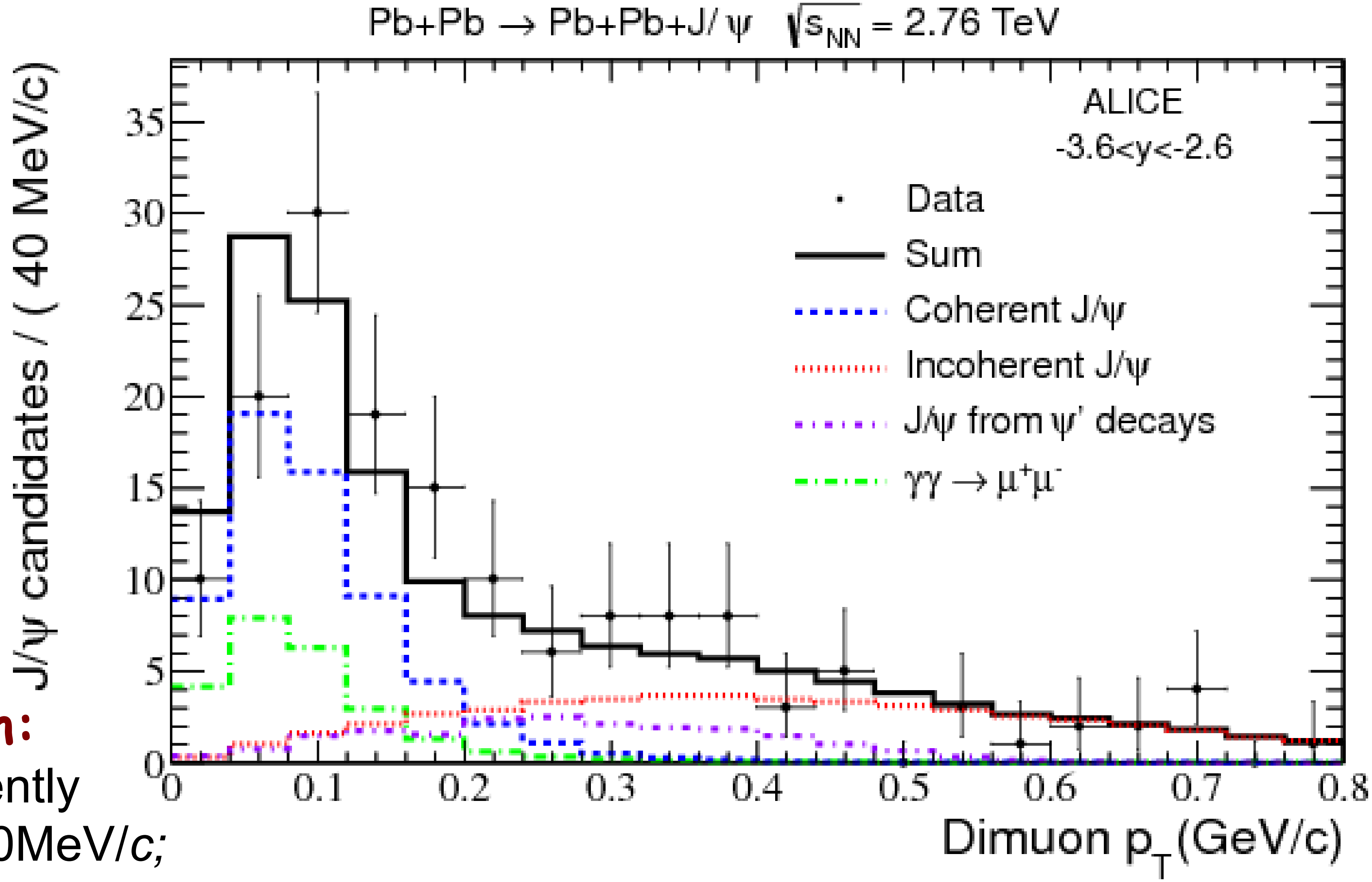


Two UPC publications by ALICE

Phys.Lett. B718 (2013) 1273-1283

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

p_T distribution for J/ψ candidates



Coherent production:

Photon couples coherently to all nucleons $<p_T>$~60MeV/*c*;

target nucleus does not break up, in most cases

Incoherent production

Photon couples to a single nucleon

Quasi-elastic scattering off a single nucleon

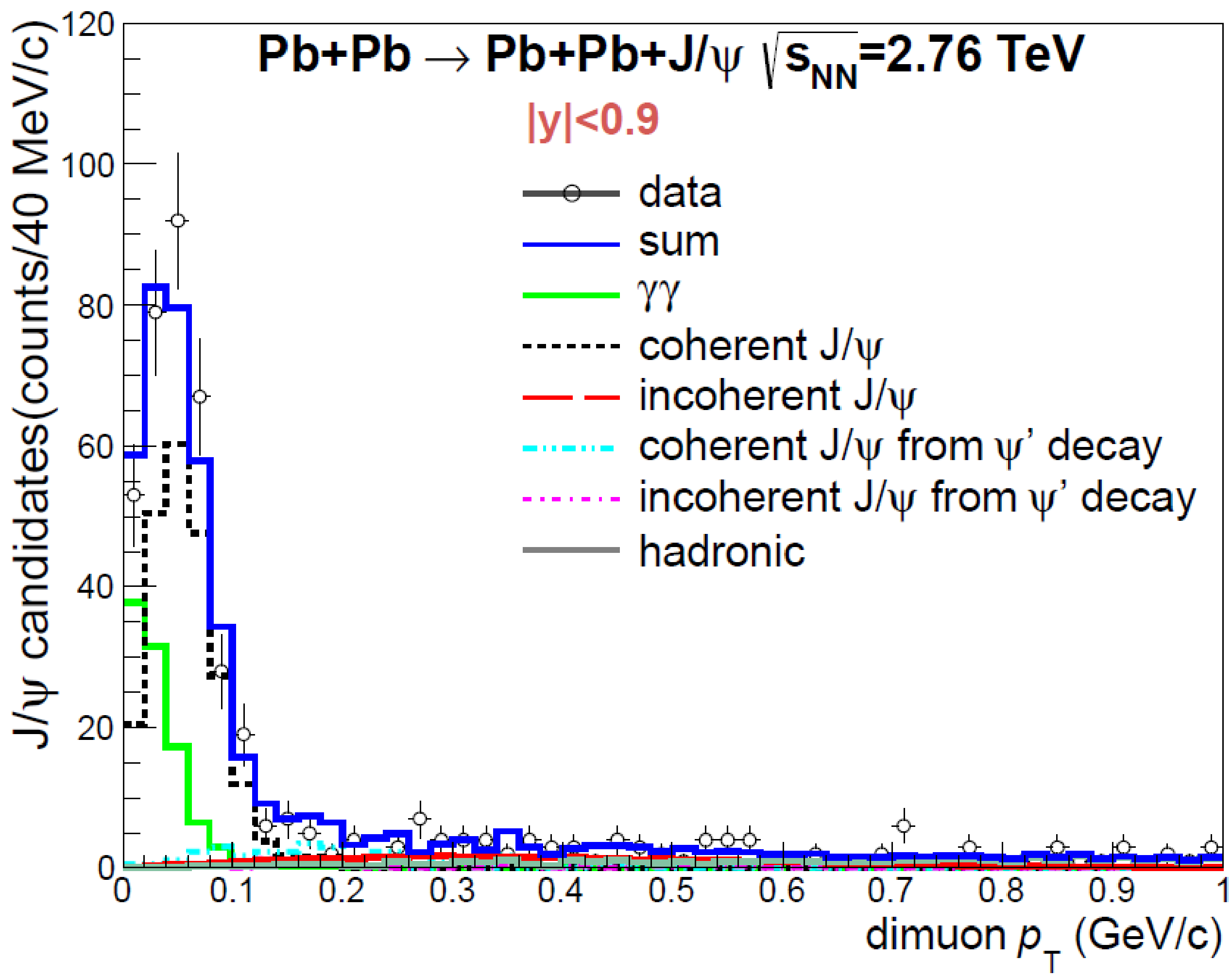
$<p_T>$~500 MeV/*c*

Four physics processes:

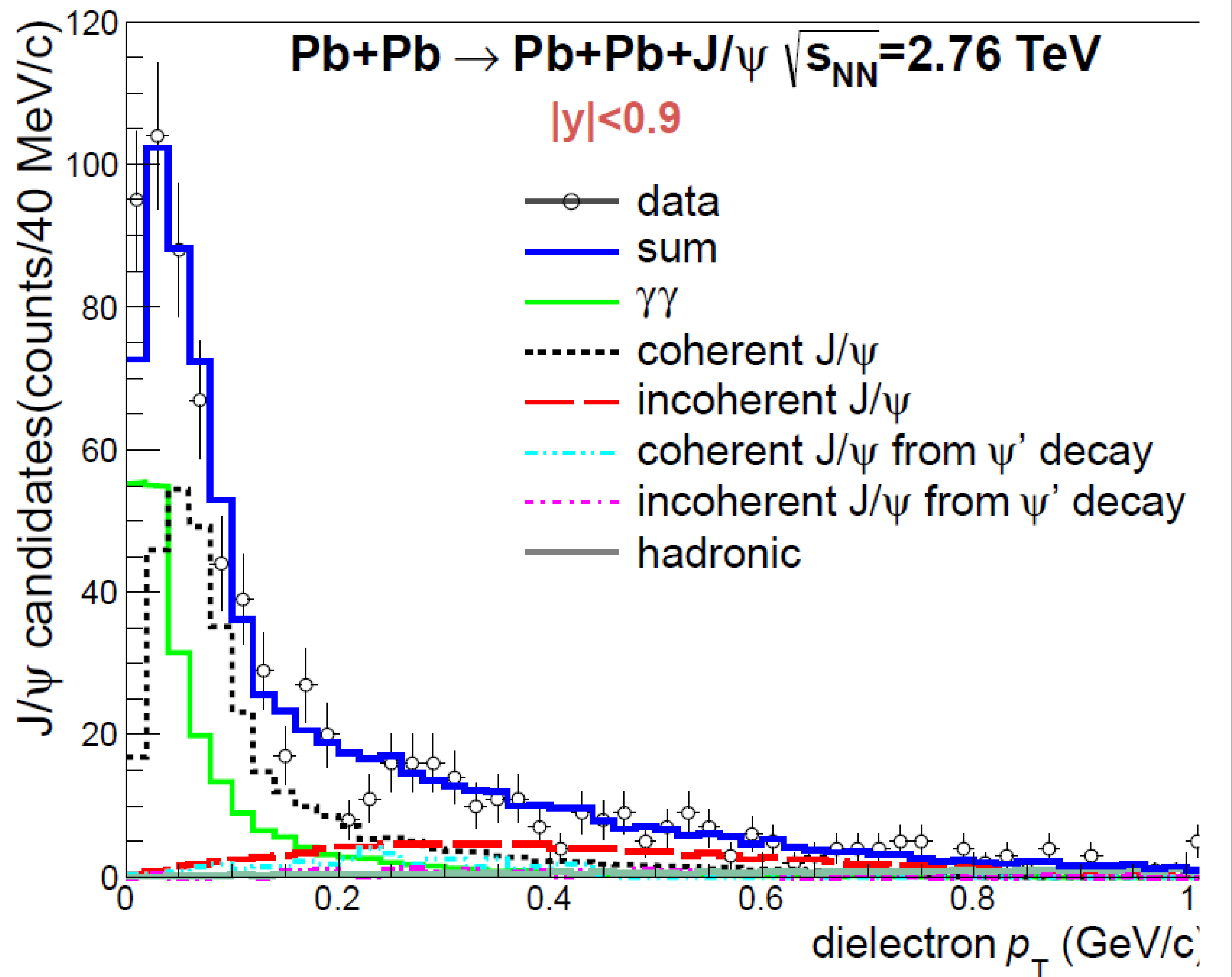
- Coherent J/ψ
- Incoherent J/ψ
- J/ψ from ψ' decays
- $\gamma\gamma \rightarrow \mu^+\mu^-$

Central barrel measurements in UPC

J/ψ in the dimuon channel



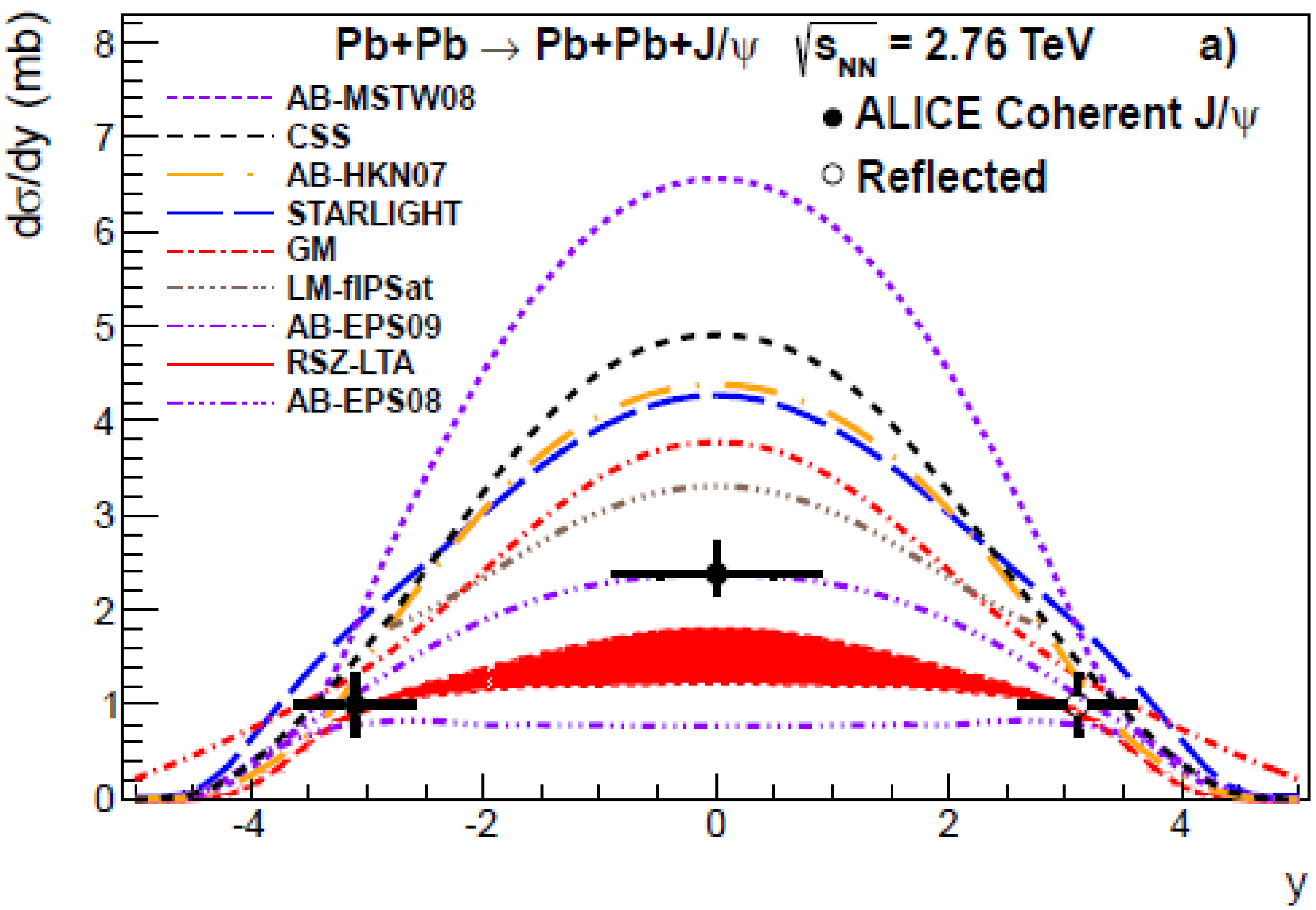
J/ψ in the dielectron channel



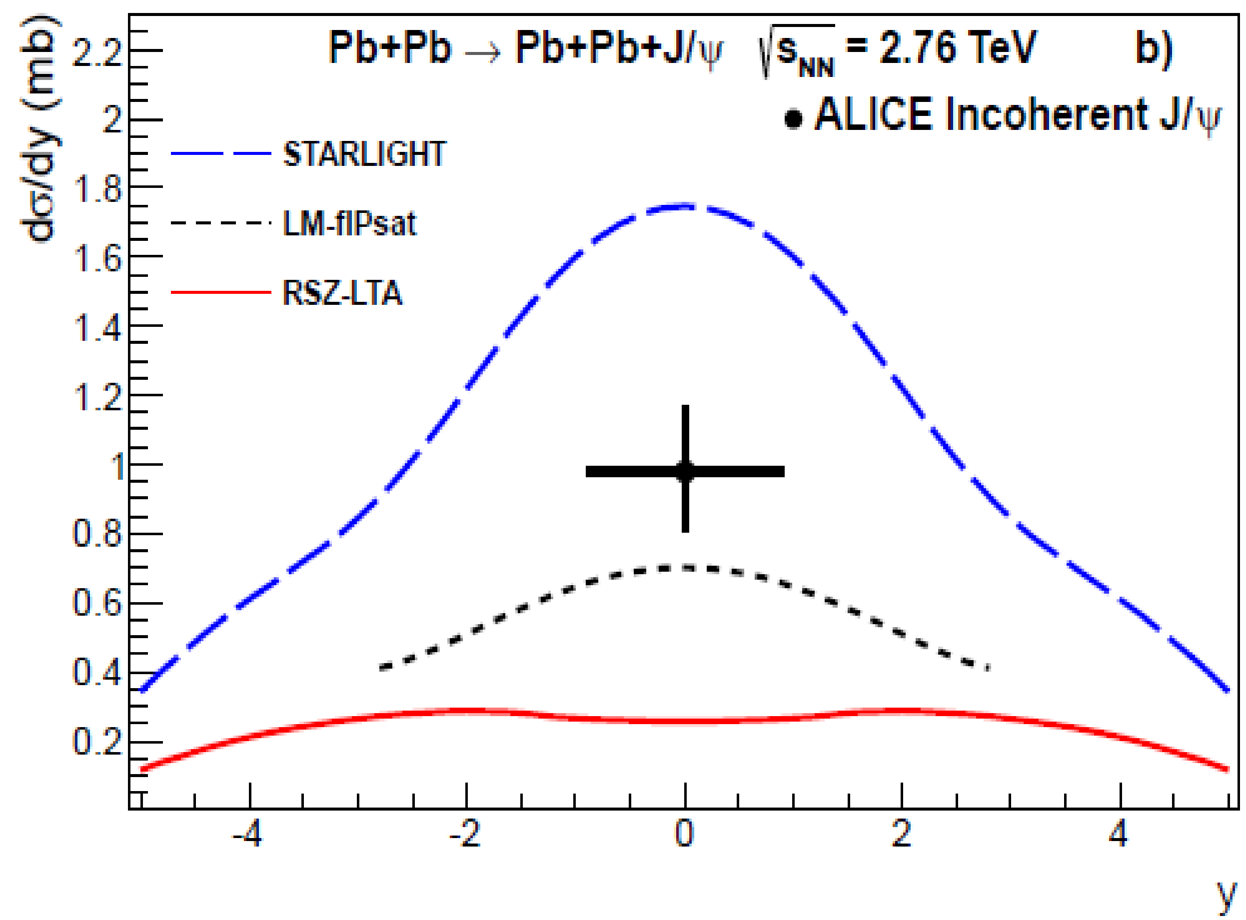
Data is well described by signals/backgrounds expected in UPC

Data *and* theoretical predictions

Coherent J/ψ



Incoherent J/ψ



Best agreement with EPS09 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)

Nuclear gluon shadowing from ALICE data

V. Guzei, E. Kryshen, M. Strikman, M. Zhalov. Phys. Lett. B726 (2013) 290

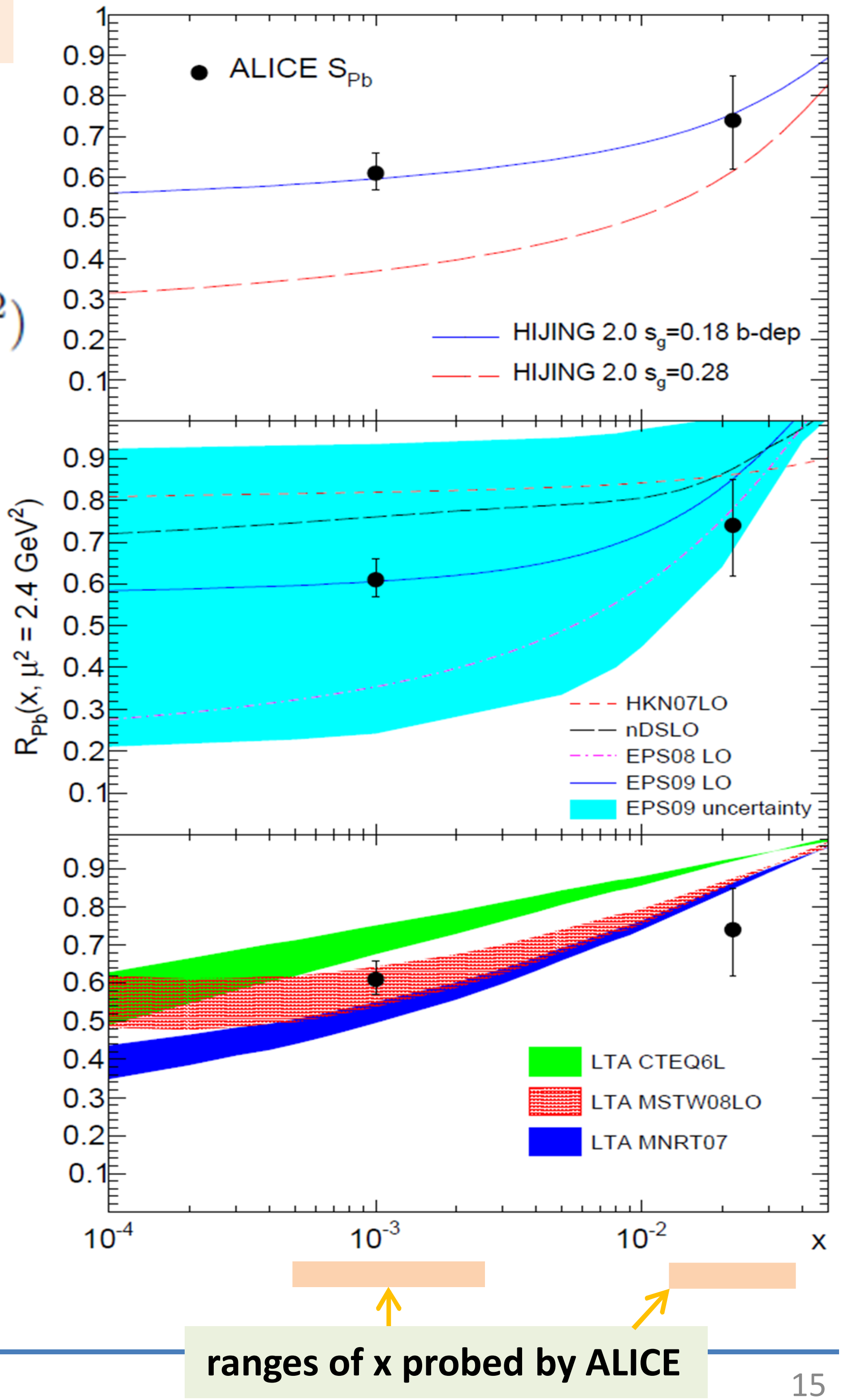
Nuclear suppression factor in J/ψ photoproduction:

ALICE data corrected for photon flux

$$S(W_{\gamma p}) \equiv \left[\frac{\sigma^{\rm exp}_{\gamma {\rm Pb}\to J/\psi {\rm Pb}}(W_{\gamma p})}{\sigma^{\rm IA}_{\gamma {\rm Pb}\to J/\psi {\rm Pb}}(W_{\gamma p})}\right]^{1/2} \Rightarrow R(x, \mu^2 = 2.4\ {\rm GeV}^2)$$

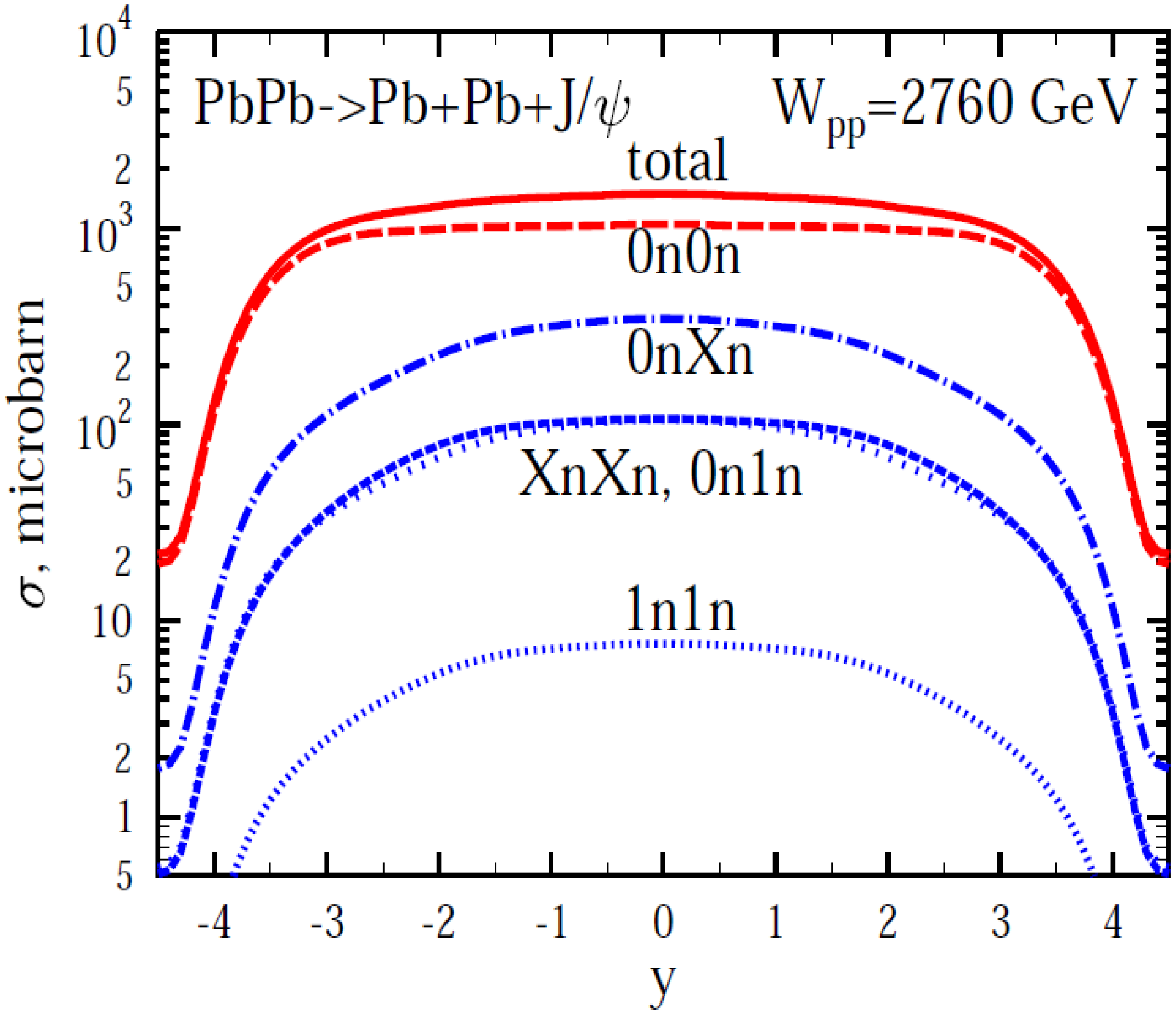
Impulse Approximation: J/ψ photoproduction cross section from HERA corrected for the integral over squared Pb form-factor

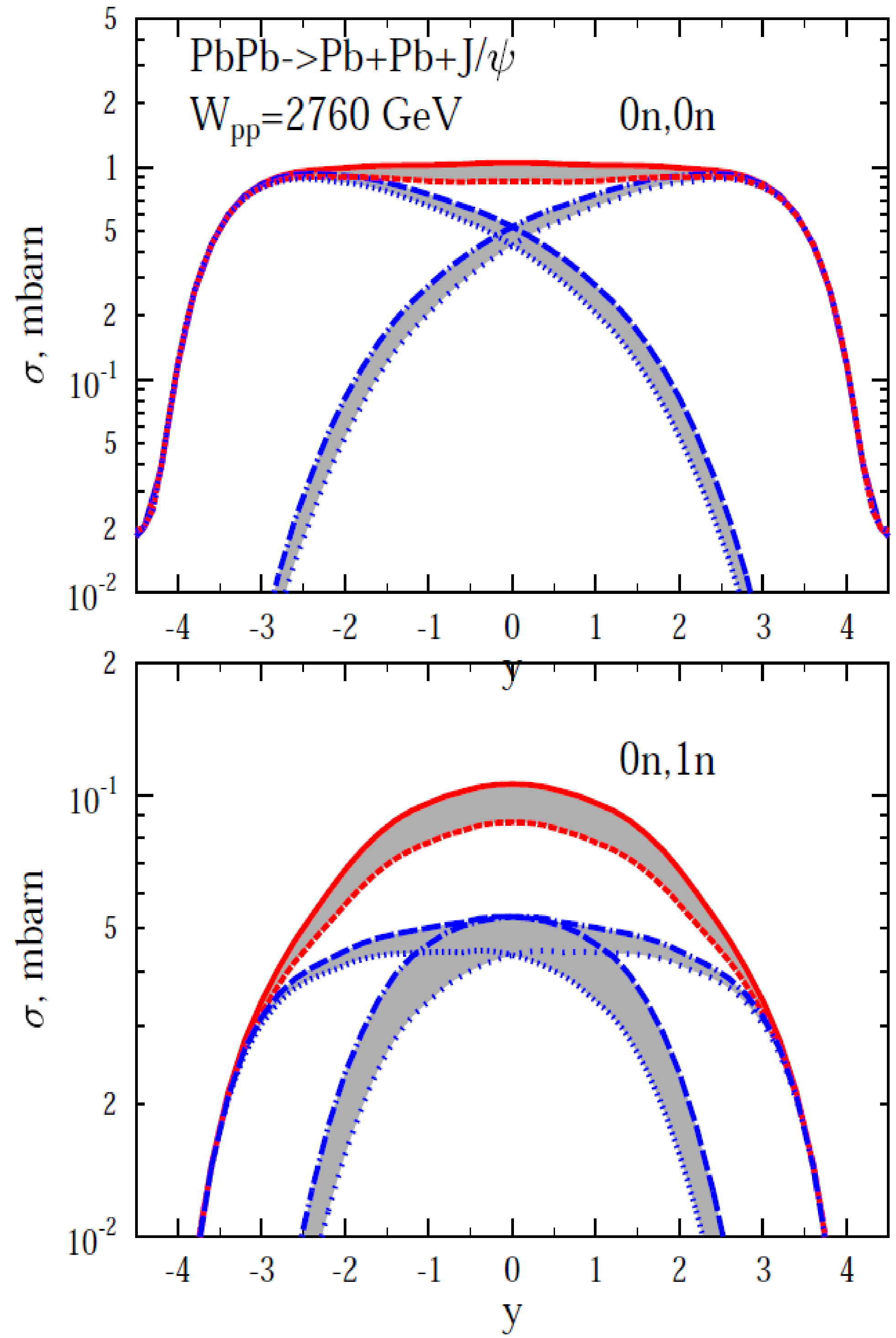
- **Hijing:** scale-independent gluon shadowing, characterized by parameter s_g
- **Shadowing parametrizations (EPS,nDS,HKN07)** use DIS and Drell-Yan data + π^0 data from RHIC (EPS) – gluon shadowing essentially unconstrained at low x
- **Leading twist approximation:** propagation of color dipoles in nuclei via intermediate diffractive states (Gribov-Glauber shadowing theory). Incorporates diffractive parton distributions in proton (from HERA)



New at the LHC: Dependence on neutron emission

Using Zero Degree Calorimeters (ZDC) it is possible to select coherent production with ion excitation, where neutrons are emitted from at least one of the nuclei





Different configurations:

1n1n: one neutron emission by each ion;

XnXn: emission of several neutrons;

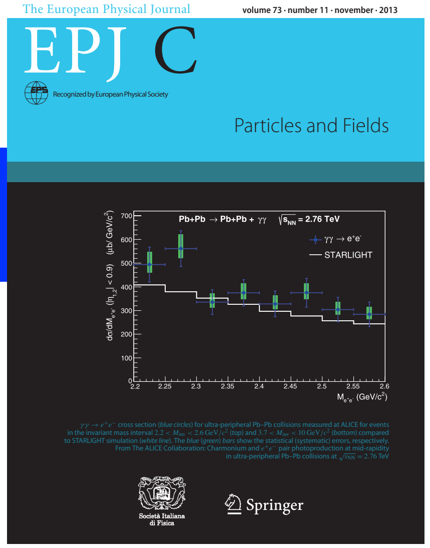
0n1n and 0nXn: excitation and decay of one of the ions, and

0n0n: no neutron emission

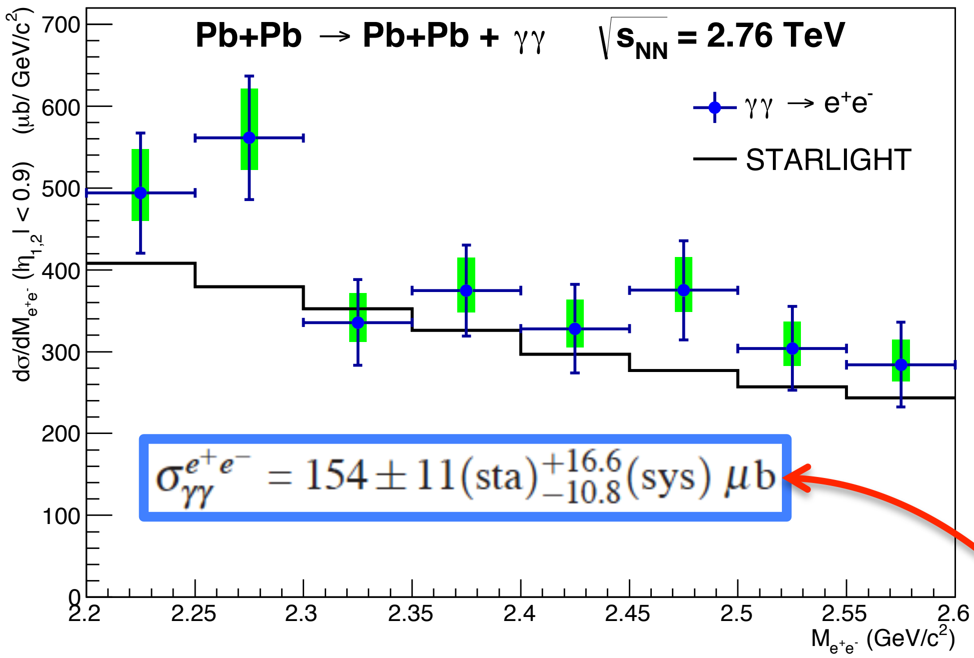
V. Rebyakova, M. Strikman and M. Zhalov
ArXiv:1109.0737, Sept 2011

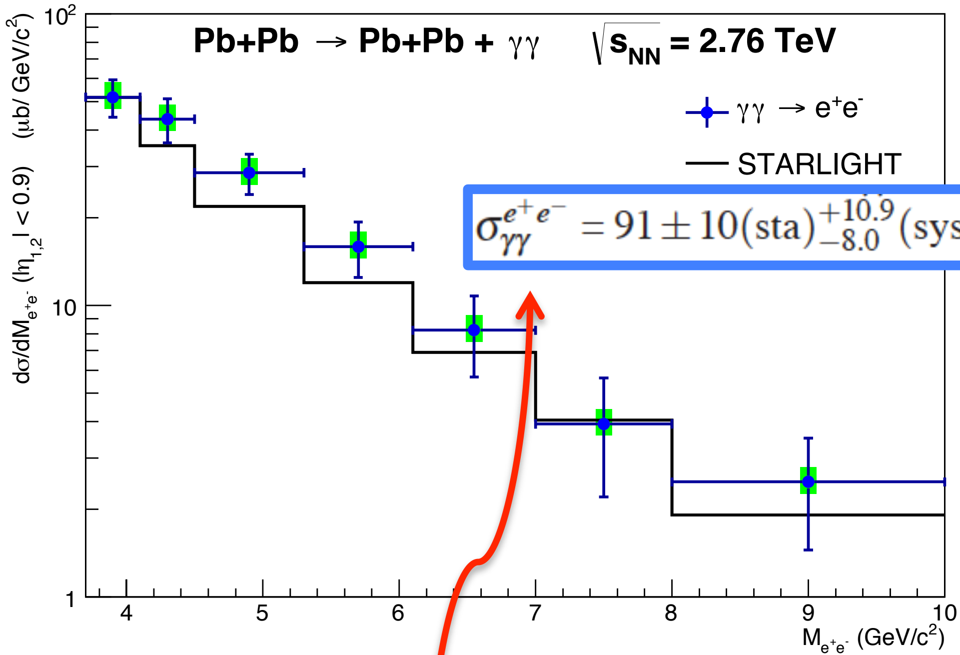
Shaded area: Uncertainty on nuclear gluon shadowing

γ+γ→e⁺+e⁻ production in Pb-Pb (Central Barrel)



Eur. Phys. J. C (2013) 73:2617





- ✓ QED process … but uncertainties due to
  - ➢ Higher order corrections because the coupling is enhanced by a factor of Z
  - ➢ Nuclear form factor and the minimum momentum transfer in the interaction
- → Different models predict a reduction of the LO cross section up to 30%
- → (see for example: A. J. Baltz, Phys. Rev. C 80 (2009) 034901; Phys. Rev. Lett. 100 (2008) 062302)

- ✓ Measurement in two different mass ranges: [2.2,2.6] and [3.7,10] GeV/c²
- ✓ Precision of 12% and 16% respectively
- ✓ Data slightly above STARLIGHT, a LO prediction

ALICE data sets stringent limits on the contribution from high order terms

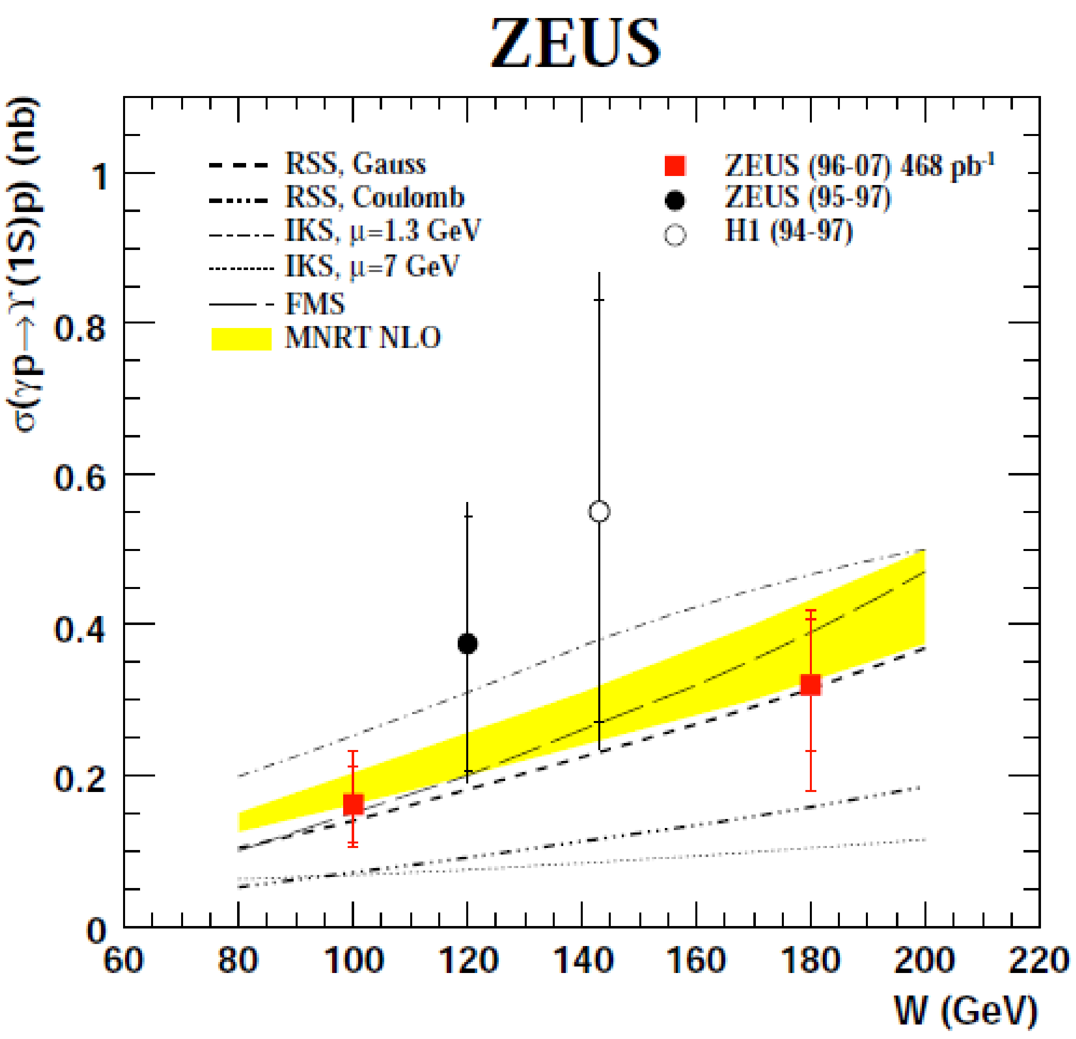
Eur. J. Phys. C73, 2617 (2013)

Upsilon photoproduction

γ + p → Υ + p : possible thanks to strong photon flux of the proton hitting the Pb nuclues

Very limited statistics from HERA (H1 and ZEUS) ~ 100 candidates

Uncertainty in measured cross section larger than a factor 3



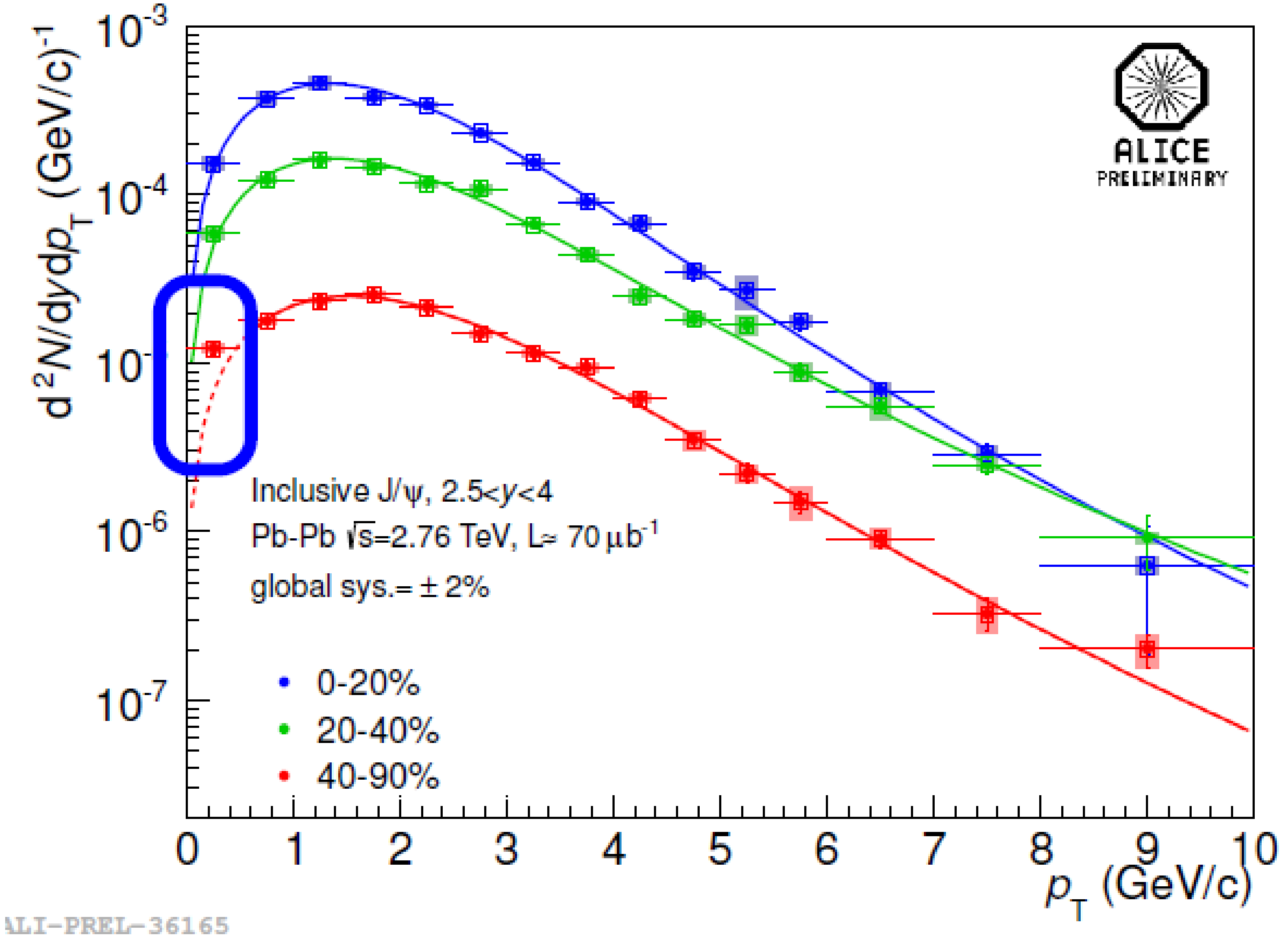
Ideal way to measure this process at LHC

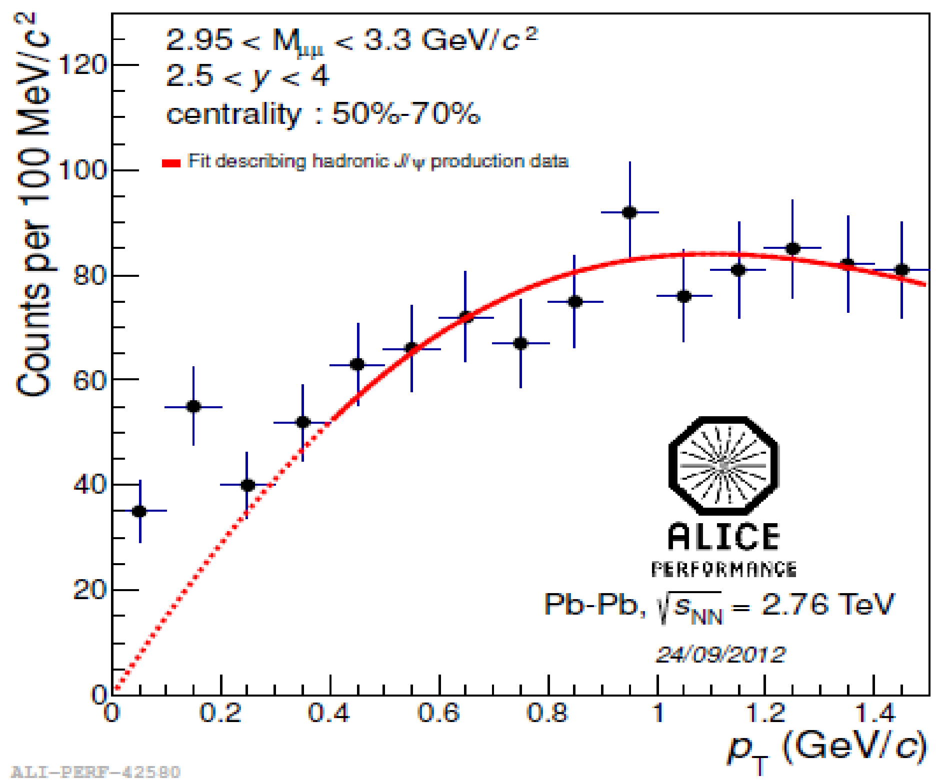
Needed to have a baseline for

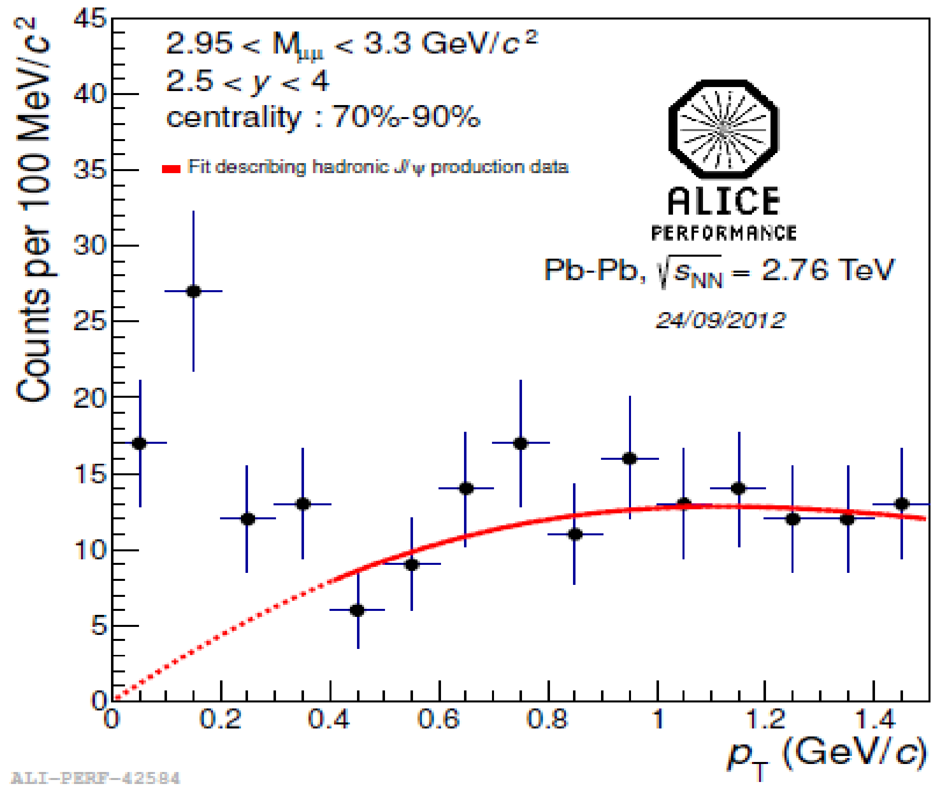
γ + Pb → Υ + Pb

Here CMS is very competitive as Upsilon acceptance is down to zero transverse momenta

UPC in inclusive peripheral Pb-Pb at forward rapidity?!





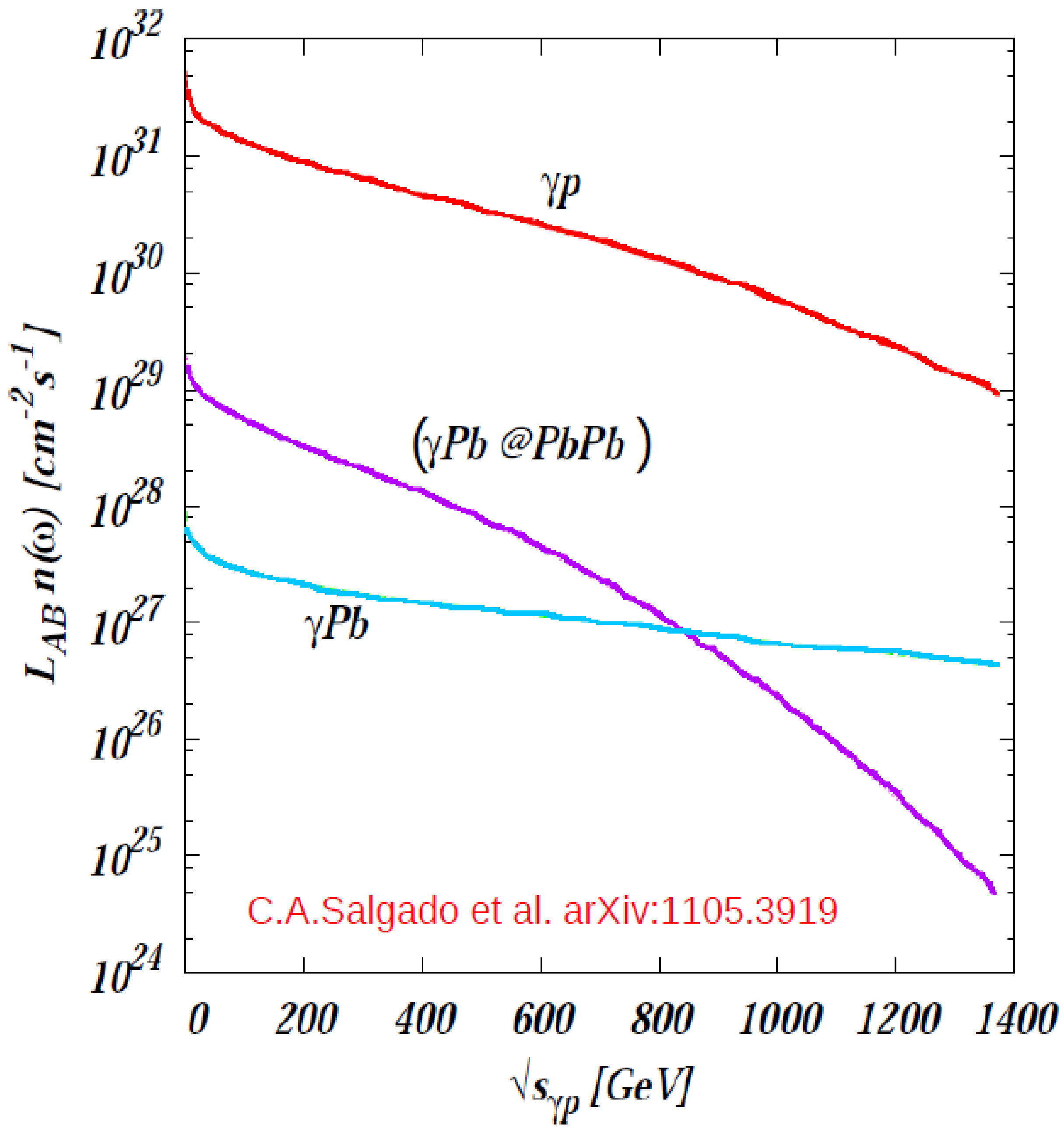


p

UPCs in Pb-Pb

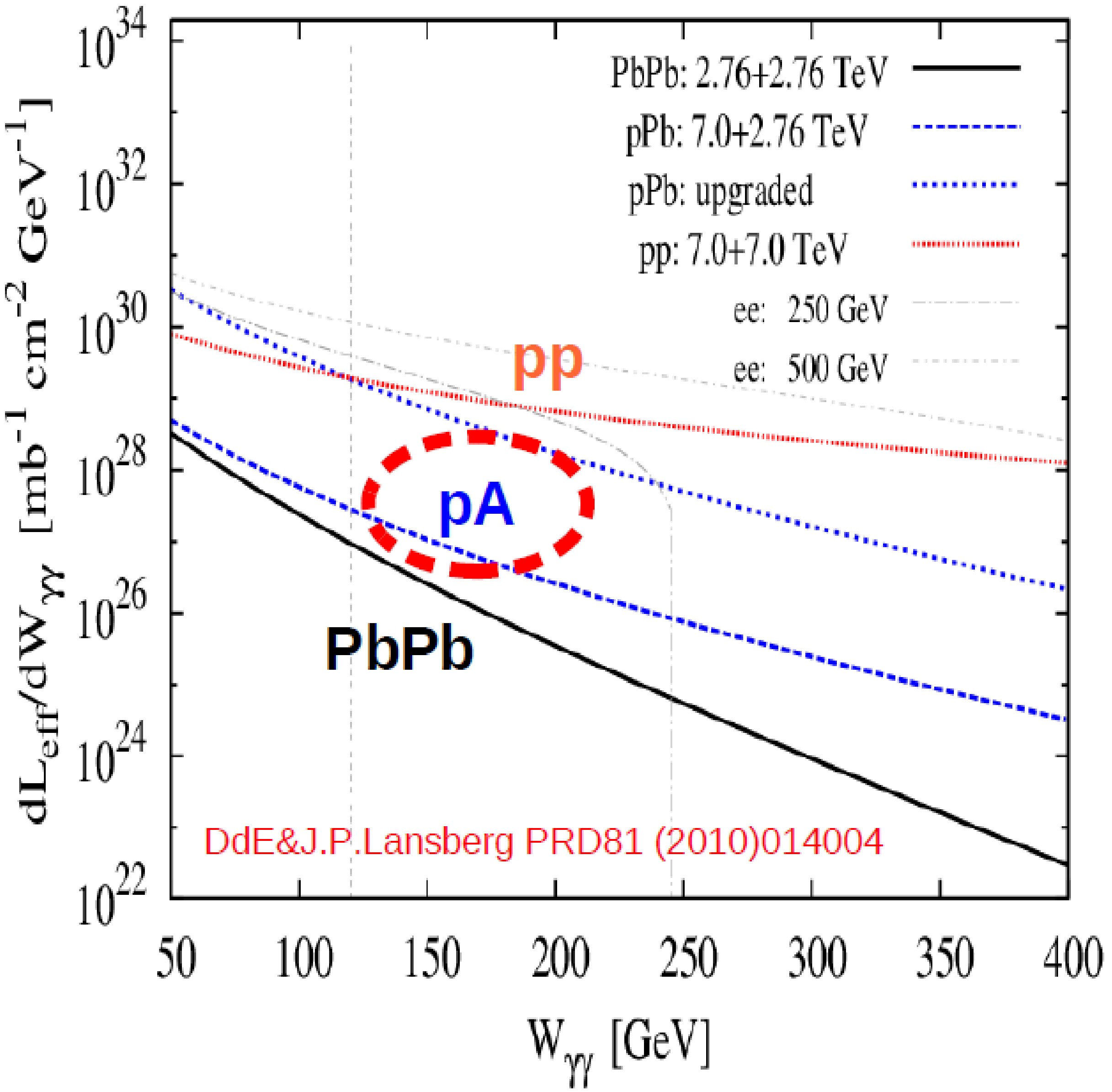
Effective luminosities in UPC

p-Pb @ 8.8 TeV



Beyond ~1 TeV scale

p-Pb vs p-p,Pb-Pb,e^+e^-

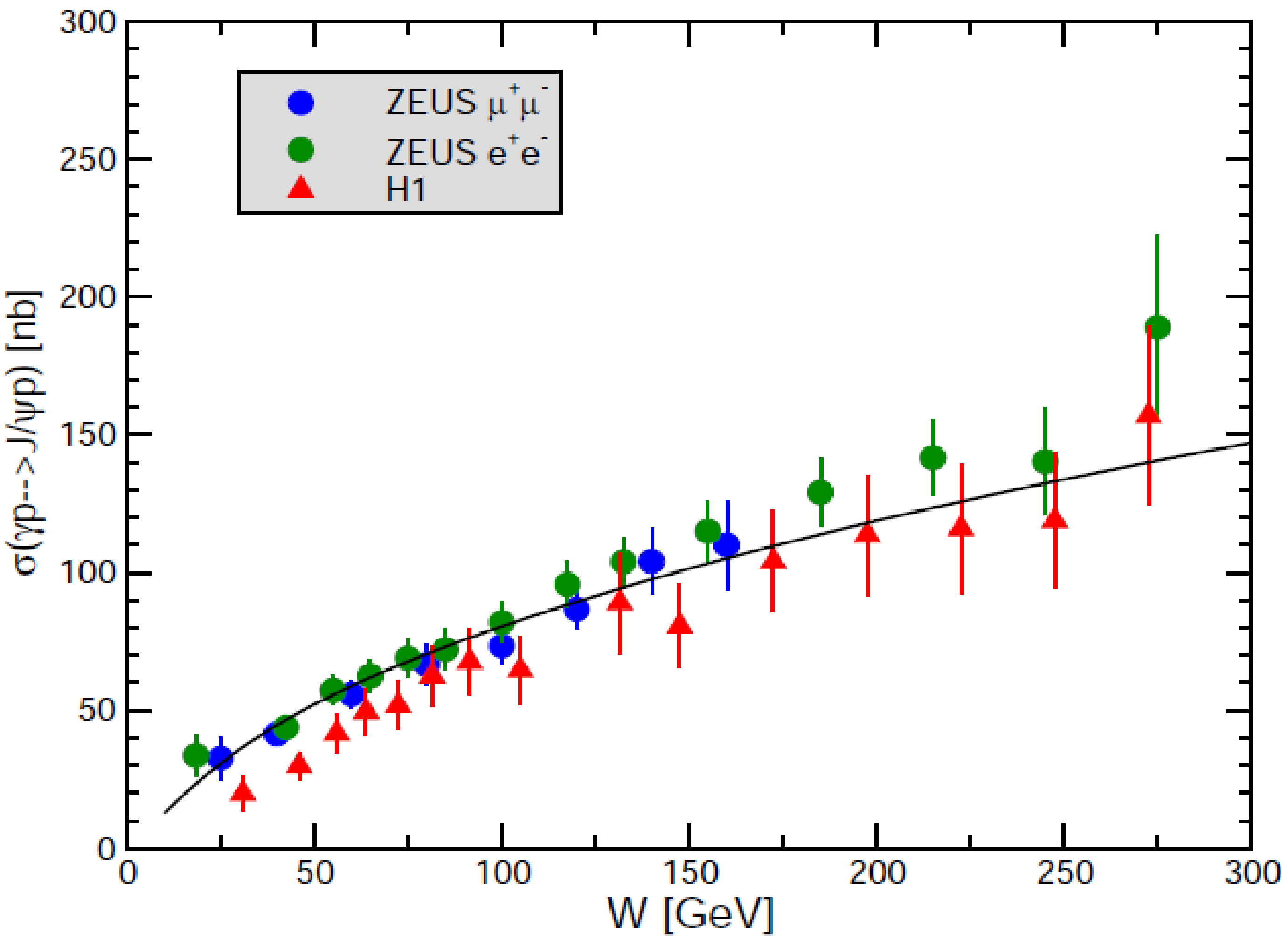


$$\mathcal{L}^{\rm eff}_{\gamma\gamma} \equiv \mathcal{L}_{AB}\, d\mathcal{L}_{\gamma\gamma}/dW_{\gamma\gamma}$$

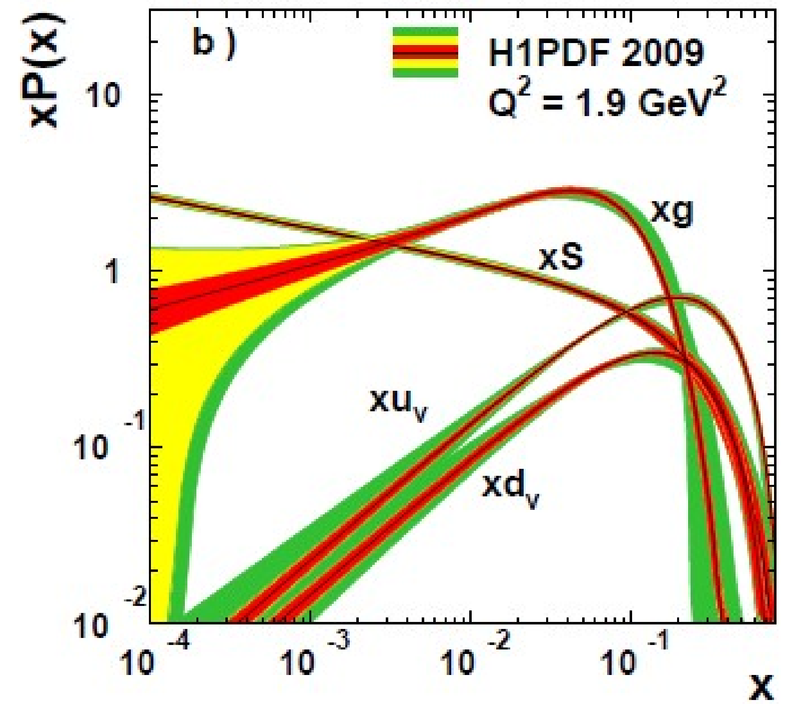
J/ψ photoproduction in γp

$$\frac{d\sigma_{\gamma p\to pJ/\psi}}{dt} = \frac{\Gamma_{ee}M^3_{J/\psi}\pi^3}{48\alpha_{em}} \cdot \frac{\alpha_S^2(\bar{Q}^2)}{\bar{Q}^8}\left[xg_N(x,\bar{Q}^2)\right]^2 \exp[B_{J/\psi}(s)t]$$

The Pb nucleus acts as photon emitter (enhanced flux by factor $Z^2 \approx 7000$ compared to the photon flux from the proton

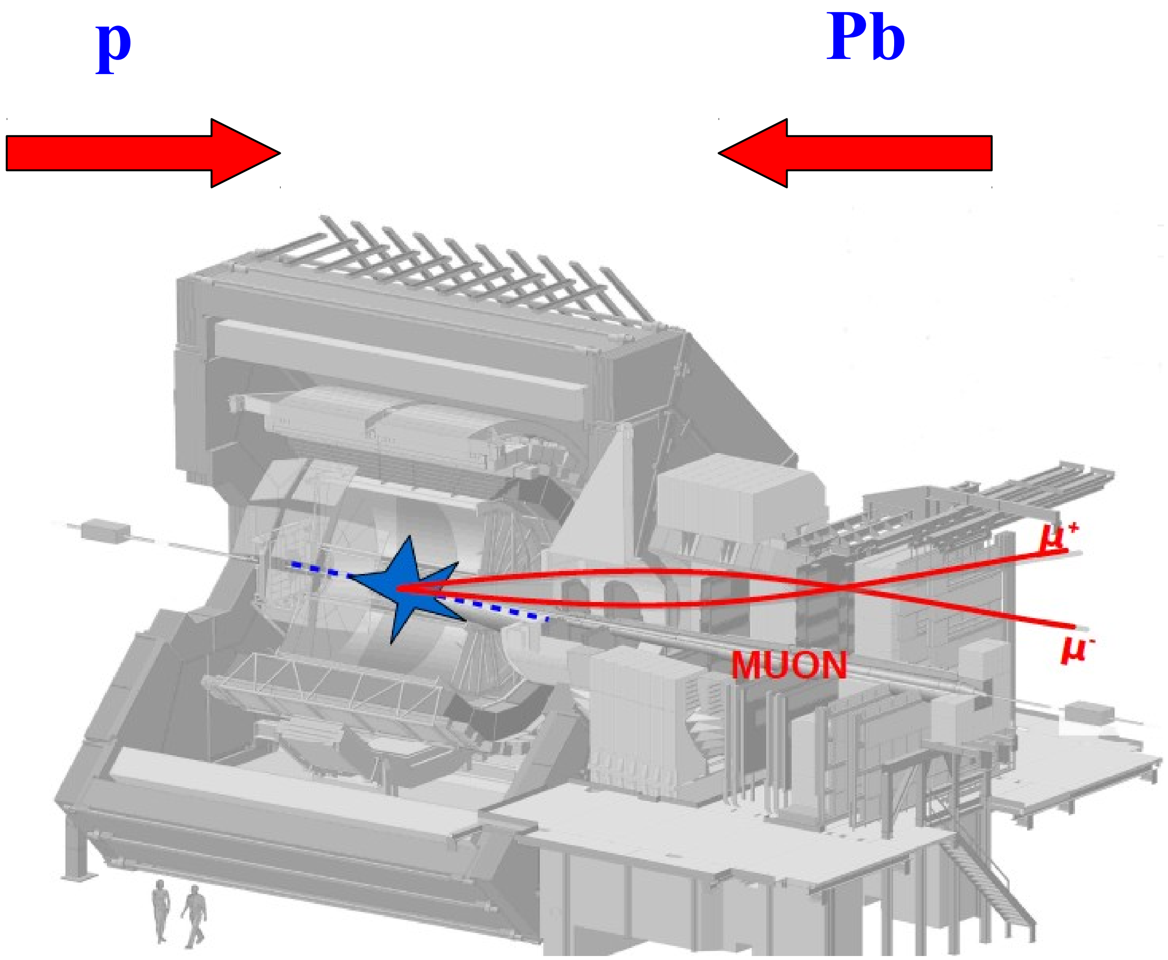


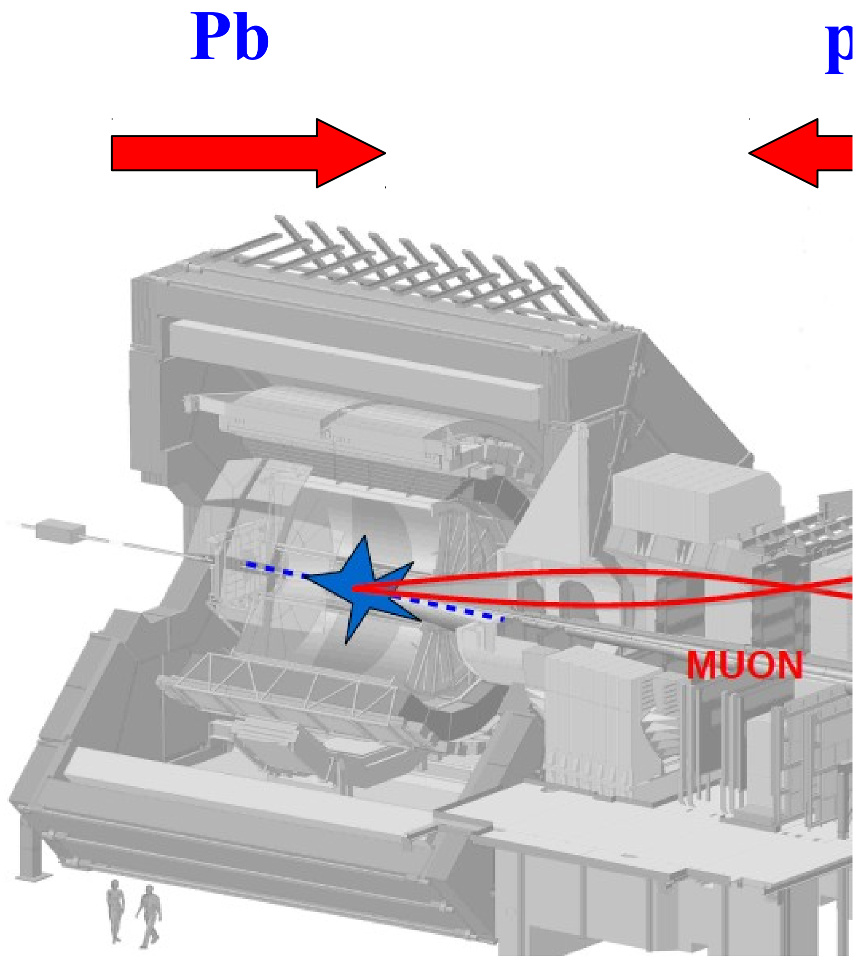
H1: A. Aktas *et al.* Eur.Phys. J.C46:585-603,2006
ZEUS:S. Chekanov et al., Nucl. Phys. B695 (2004) 3.
A. Martin et al. Phys.Lett. B 662:252-258, 2008



At LHC Bjorken-*x* down to 10^{-5}

γp centre-of-mass energies at the 1 TeV energy scale





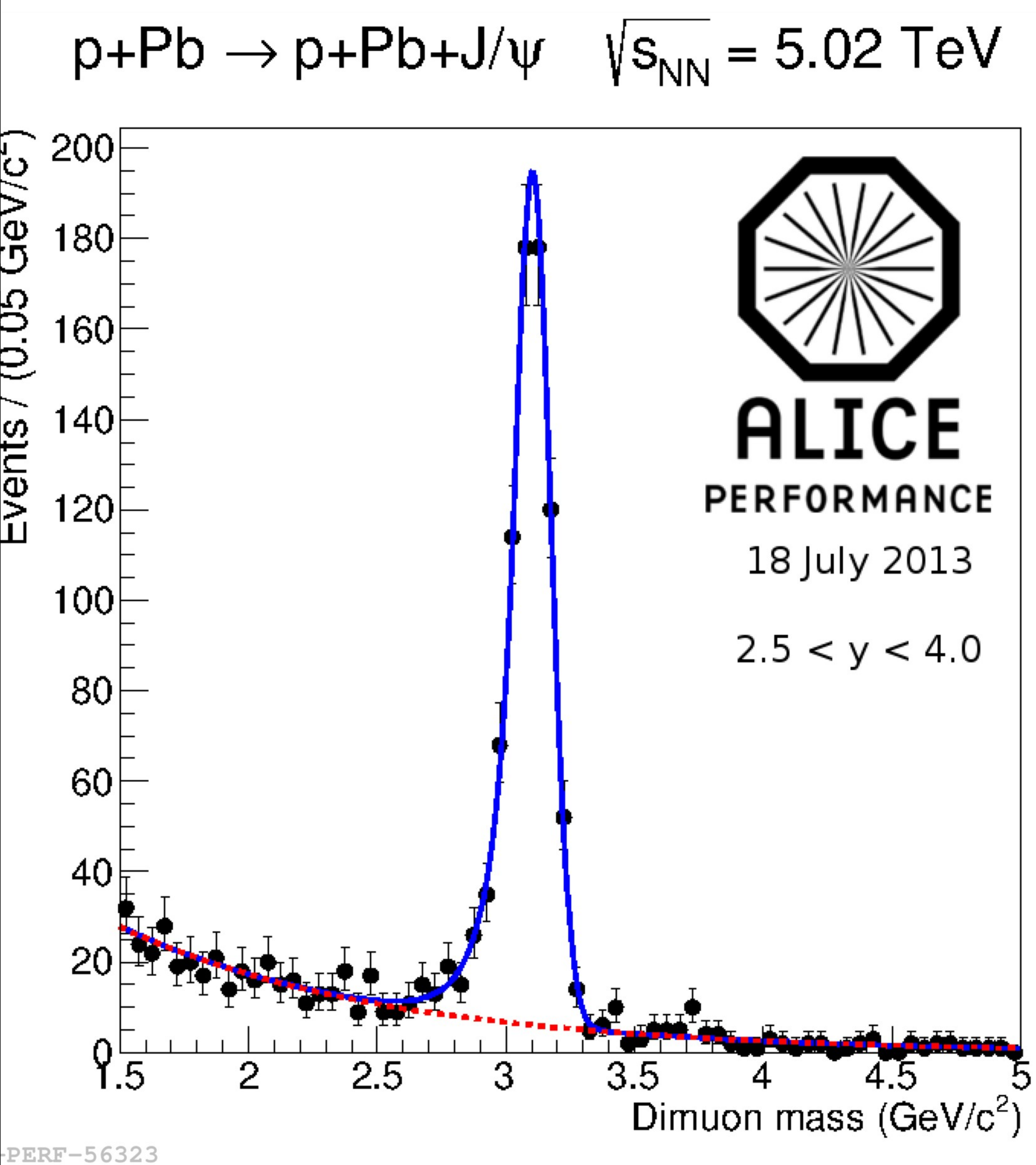
$21 < W_{\gamma p} < 45$ GeV

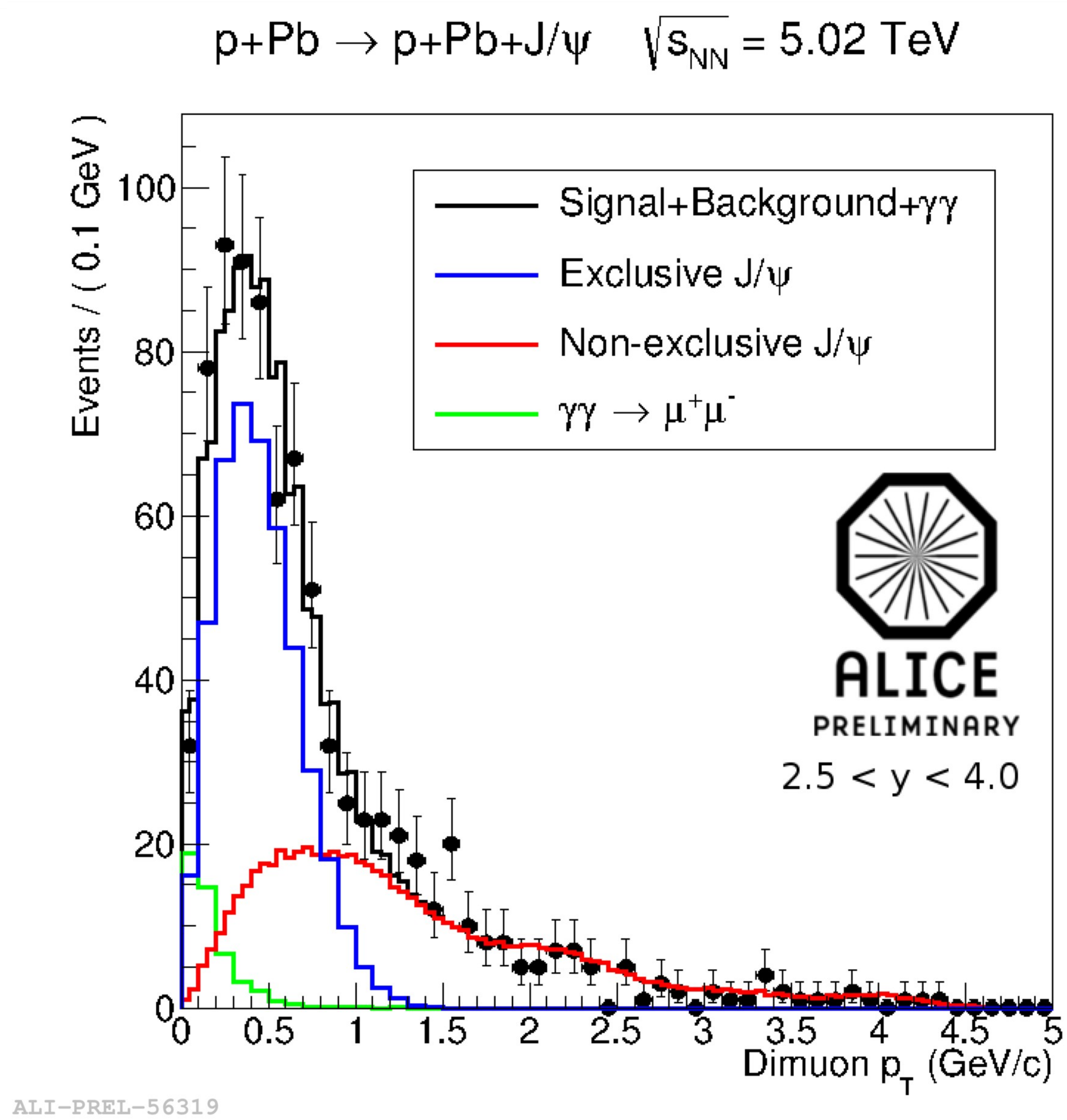
$549 < W_{\gamma p} < 1163$ Ge

- The fact that the Pb nucleus is the dominant photon emitter allows us to separate the two $W_{\gamma p}$ regimes unambiguously.
  - "p-Pb" (*) corresponds to the lower energy range
  - "Pb-p" corresponds to the higher energy range.

$$x = \left(M_{J/\psi} / \sqrt{s_{NN}}\right)\exp(\pm y)$$

UPC J/ψ candidates in p-Pb



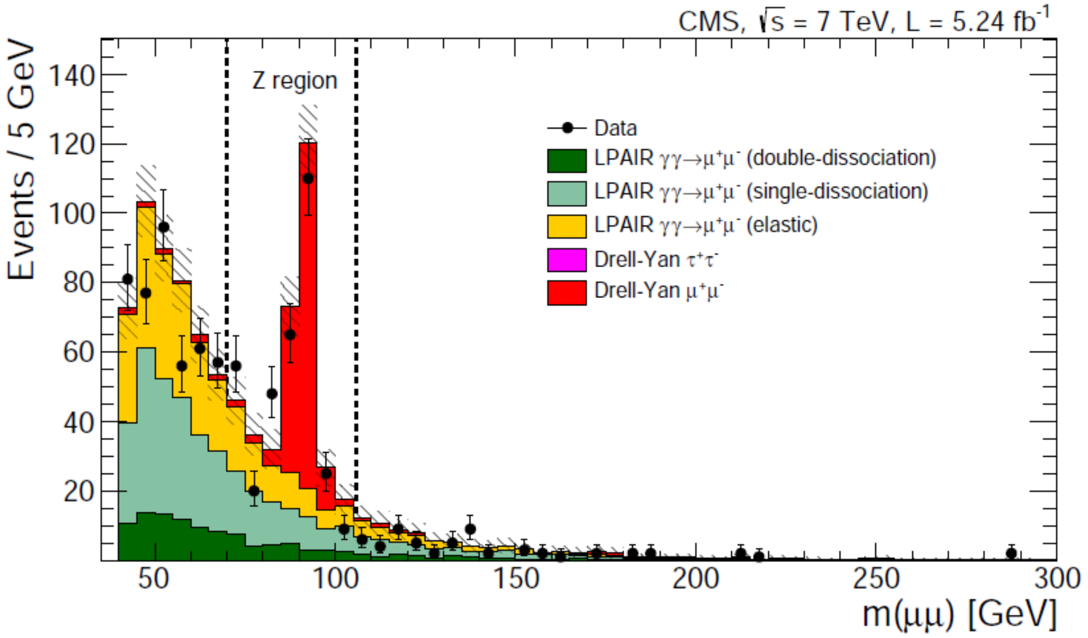


$21 < W_{\gamma p} < 45$ GeV

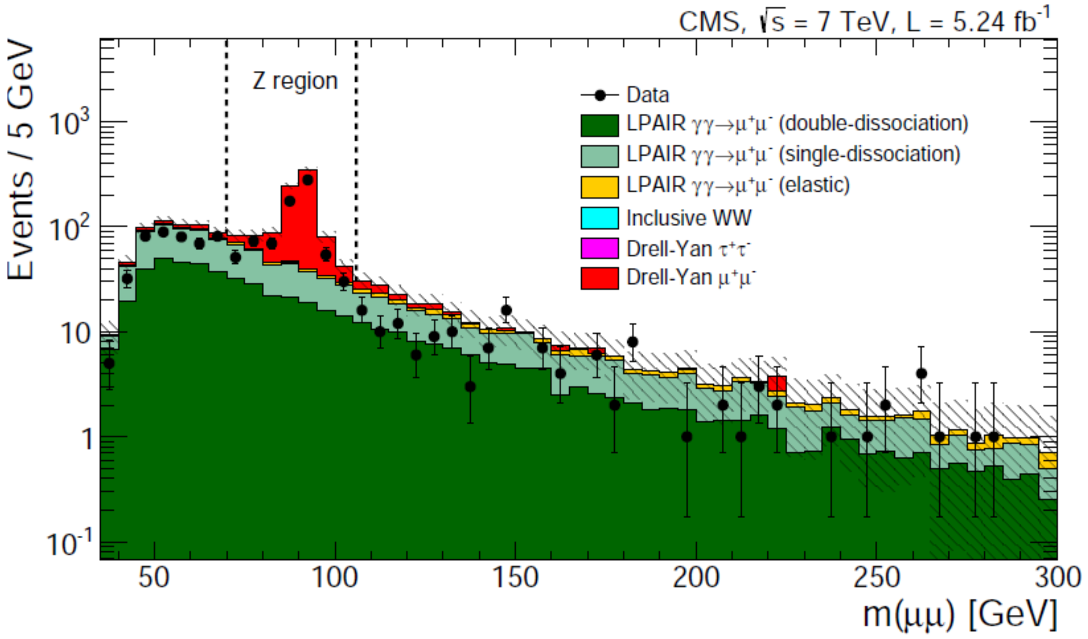
$\langle W_{\gamma p} \rangle \sim 30$ GeV

Contribution from events where the proton breaks up (dissociation). Non-exclusive J/ψ p_T shape estimated from data by requiring events with more than 2 hits in VZERO-C

Two methods were used by CMS



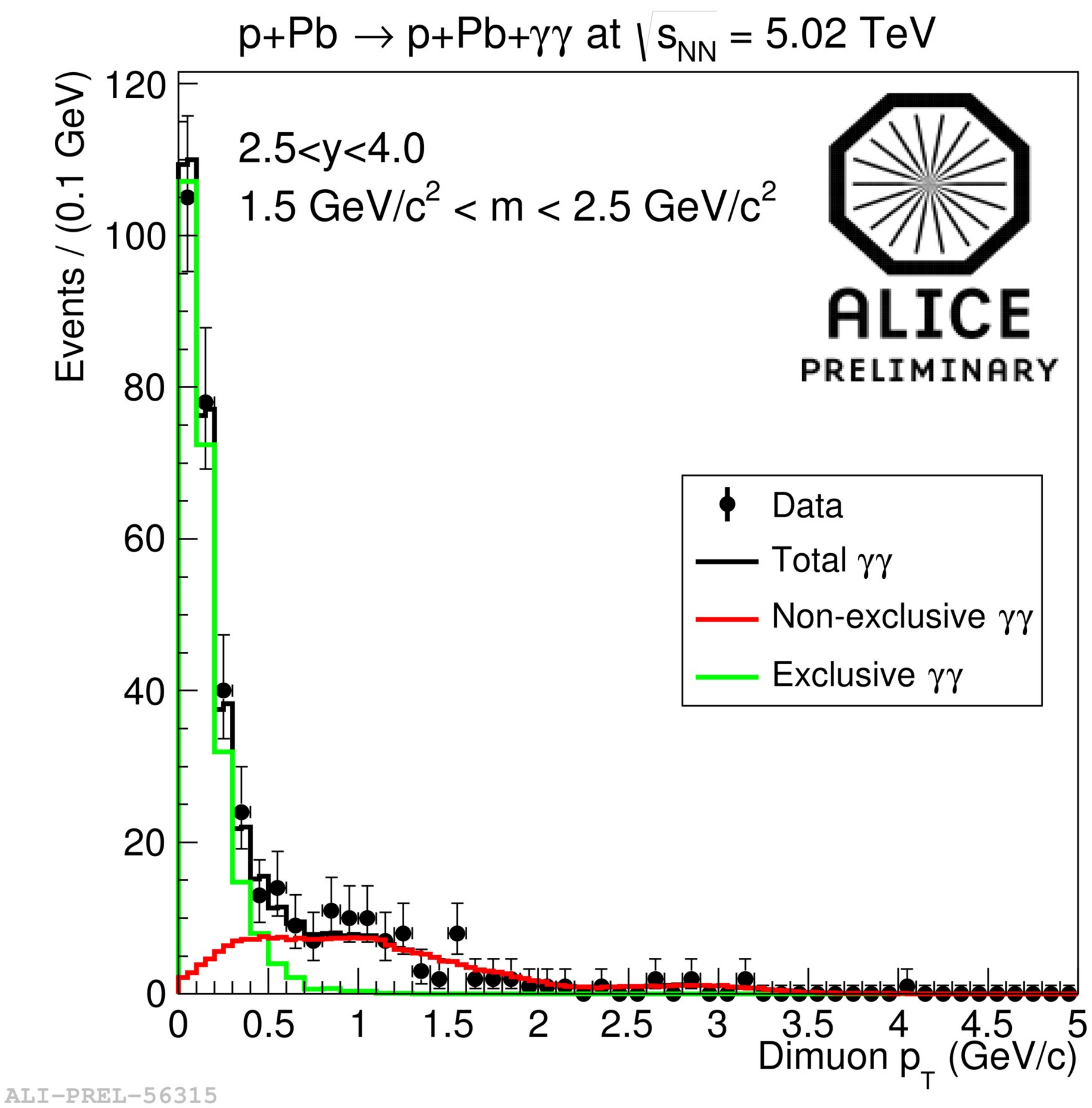
Signal-enhanced



Background-enhanced

46

Two-photon cross section in p-Pb



Preliminary cross section for two-photon production

First time measurements in p-Pb collisions

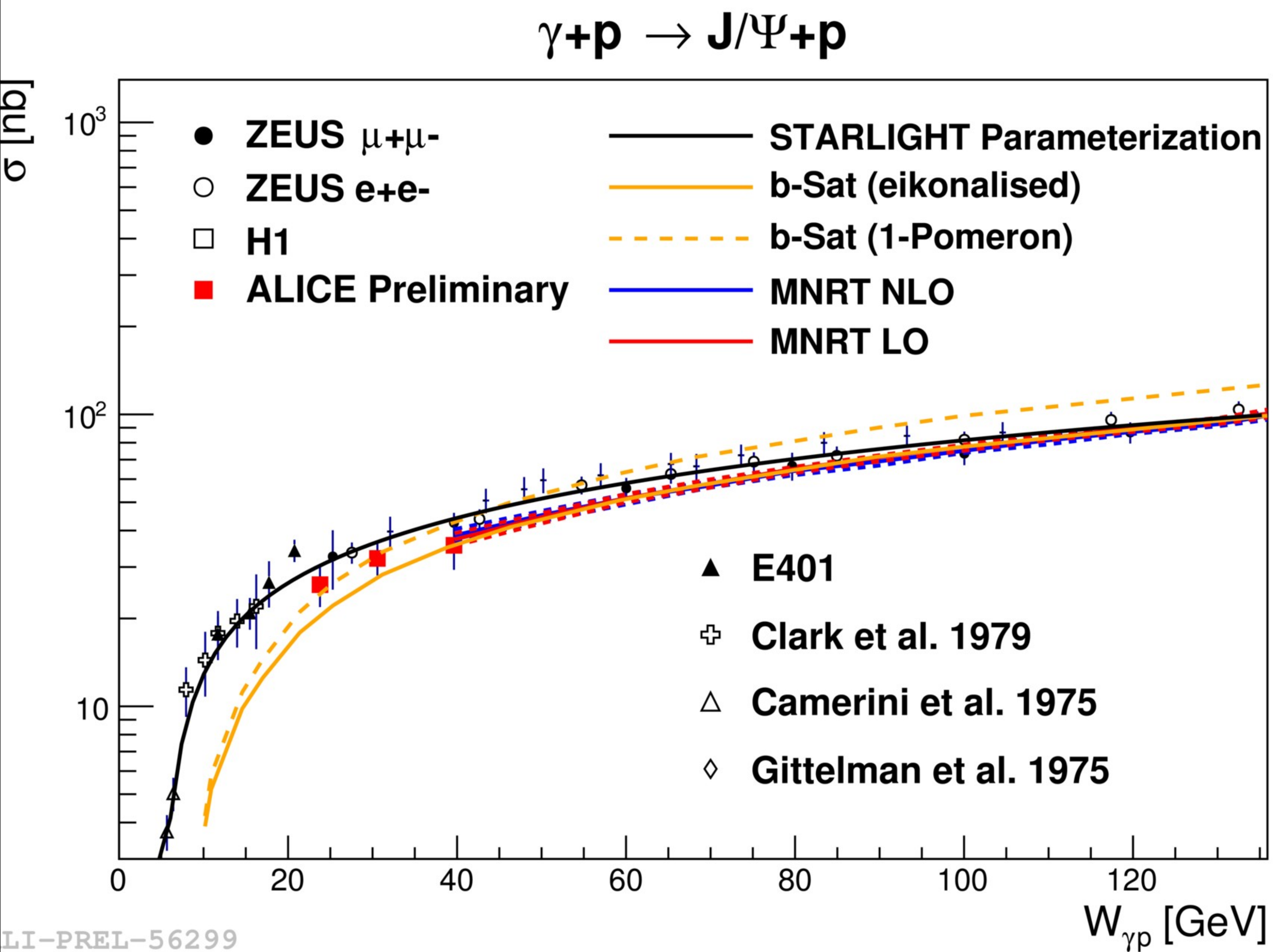
Preliminary results consistent with STARLIGHT prediction

σ(1.5 GeV<m<2.5 GeV,-4.0<y<-2.5) = 1.76 ± 0.12 (stat) ± 0.16 (sys) μb

STARLIGHT prediction = 1.8 μb

UPC J/ψ candidates in p-Pb

σ(J/ψ in γp) obtained using the corresponding photon spectrum



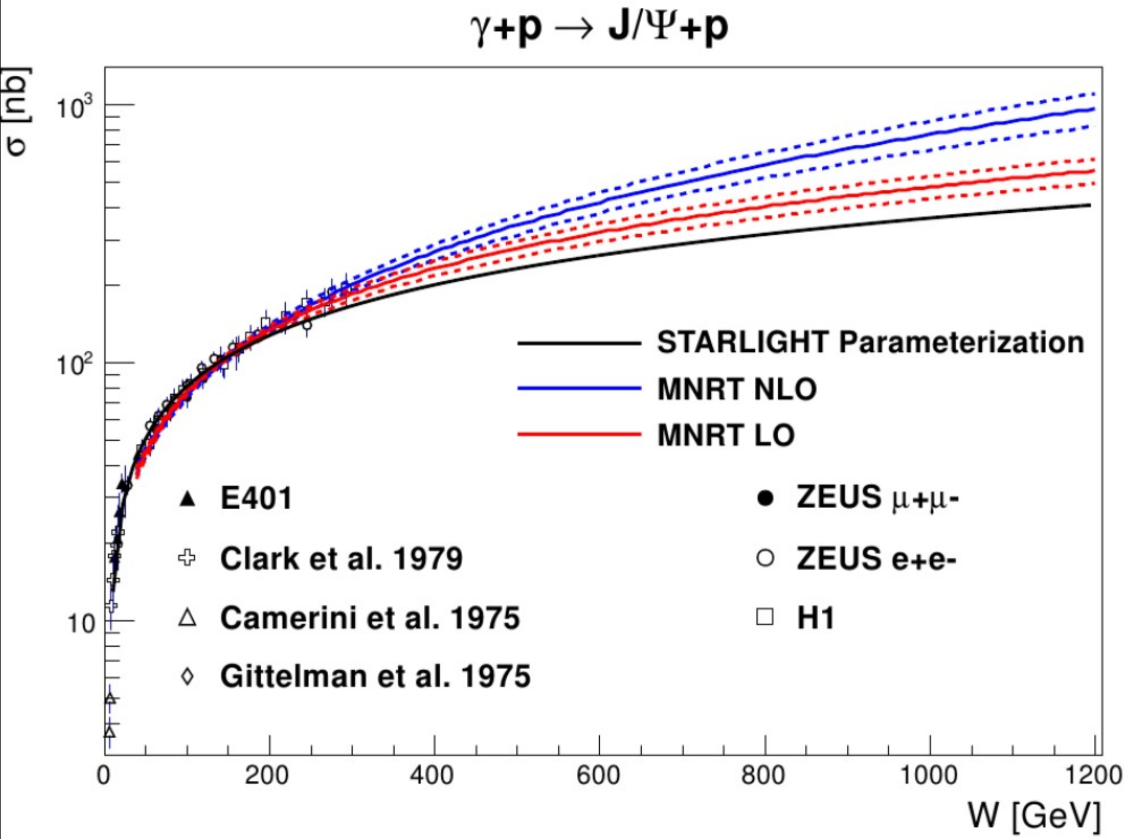
Model calculations

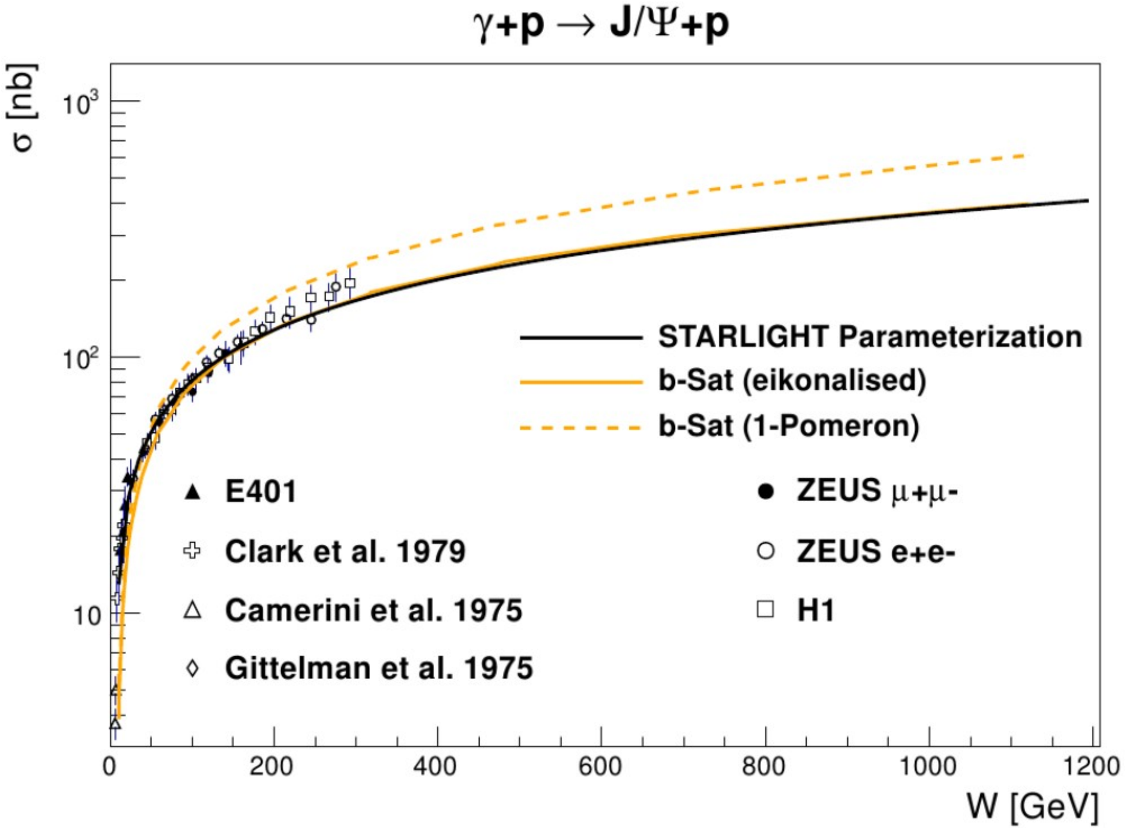
b-Sat: arxiv:1206.2913; 1211.4831.

MNRT: PLB 662 (2008) 252.

ALICE results – New data between fixed target experiments and HERA

Model predictions





A. Martin *et al.*

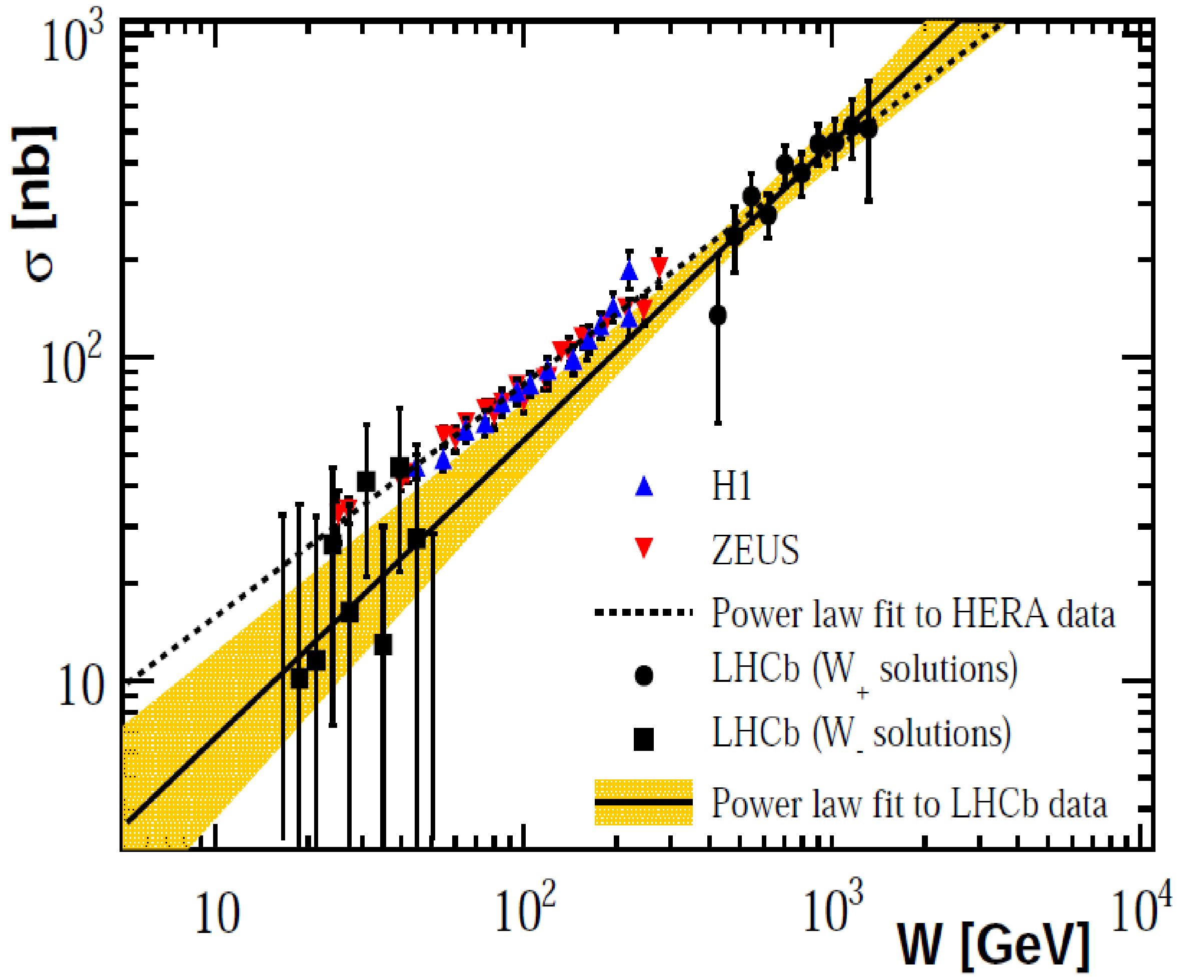
NLO leads to an increase cross section

G. Watt *et al.*

Saturation effects lead to a reduction in the cross section

More than a factor 2 difference between the most extreme predicted values at around 1 TeV

LHCb results from pp data



Contrary to J/ψ photoproduction in p+p, in p+A we know the photon source

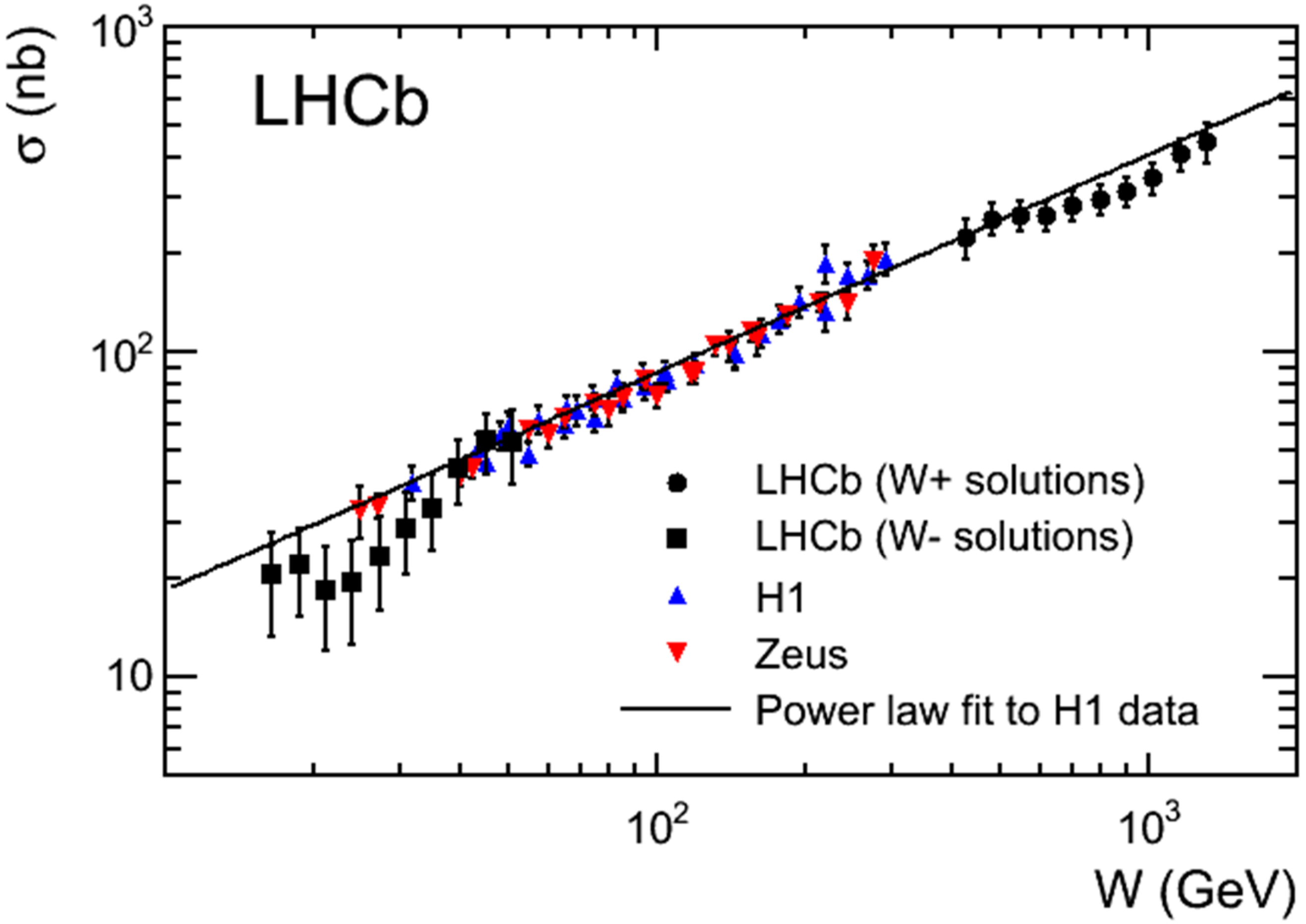
LHCb had to assume that the energy dependence follows a power law!

R. Aaij *et al.* (LHCb collaboration)
J. Phys. G 40 (2013) 045001

Recent LHCb preliminary results presented at MPI 2013

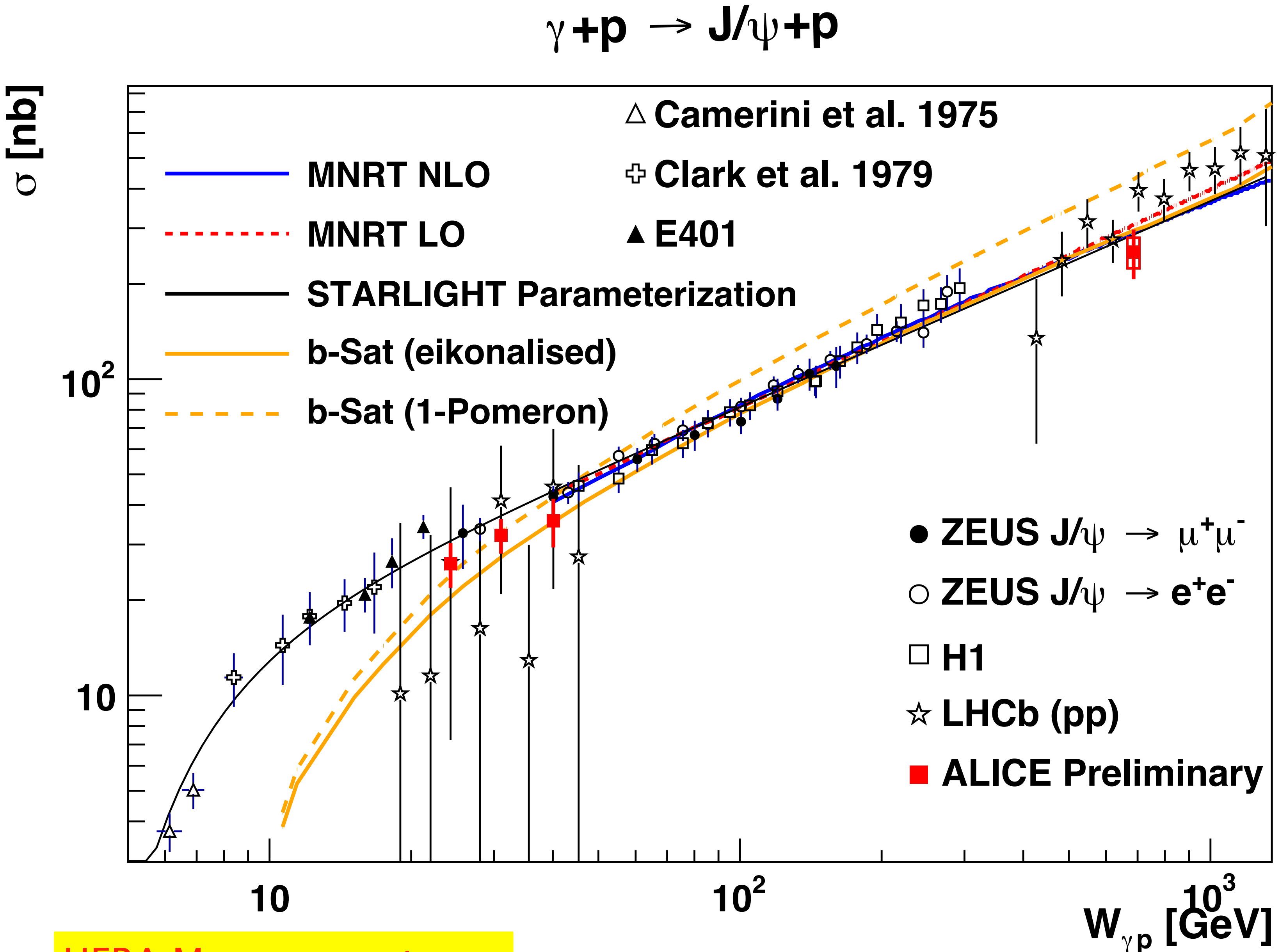
Experimental ambiguity on the photon source
A built-in power-law dependence

$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+\frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W_+) + k_-\frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W_-)\right]$$



2010 data: 36 pb^{-1}
LHCb, J. Phys. G40 (2013) 045001
2011 data: 930 pb^{-1}

ALICE preliminary presented at Krakow and MPI



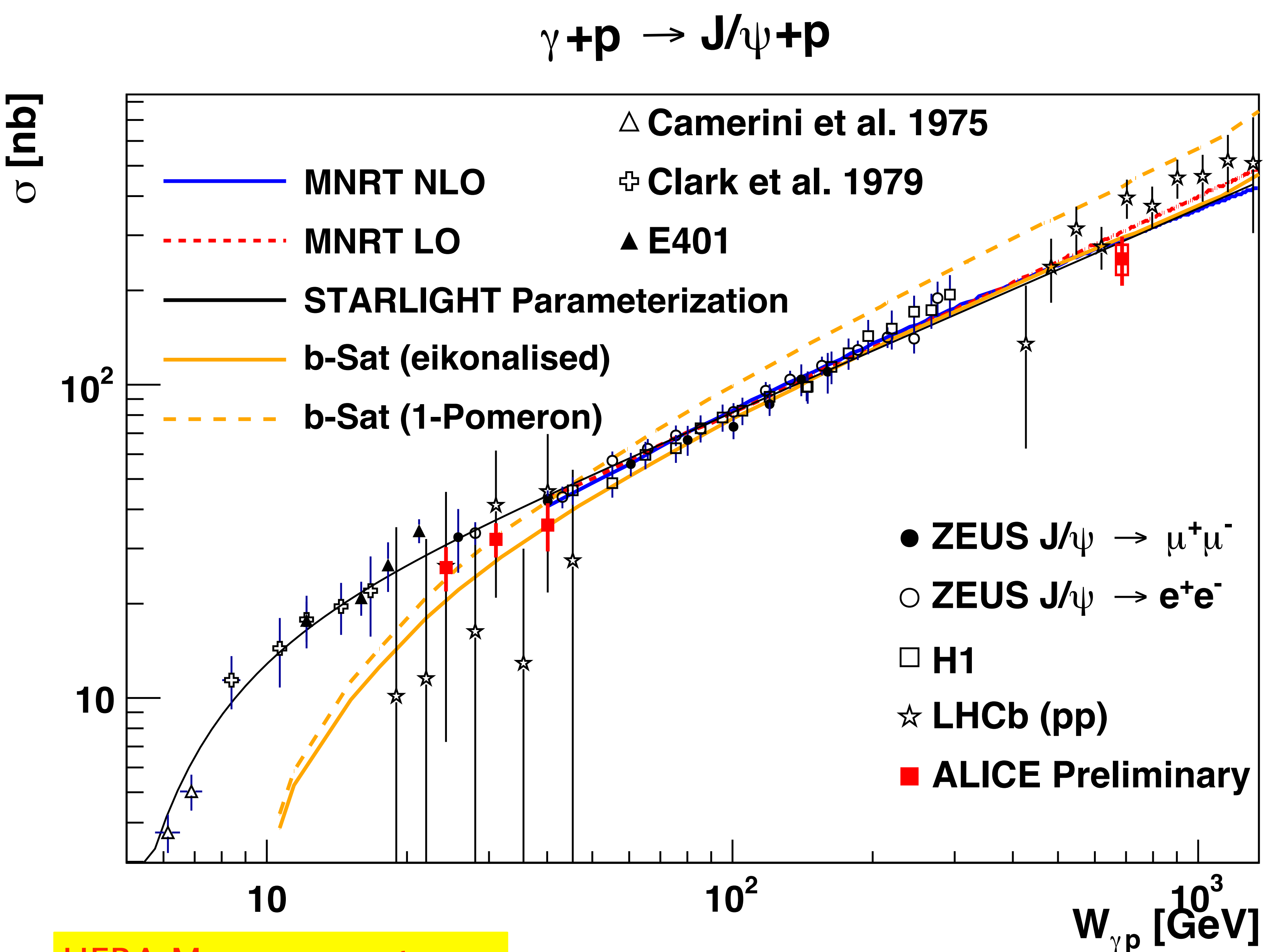
- Our knowledge of the photon emitter allows us to solve for $\sigma(W_{\gamma p})$ using the measured dσ/dy
- A power law fit ($\sigma(W) \sim W^{\delta}$) to ALICE data points gives $\delta = 0.67 \pm 0.06$.

HERA Measurements

H1	$\delta = 0.67 \pm 0.03$
ZEUS	$\delta = 0.69 \pm 0.02$

$$\frac{d\sigma}{dy}\left(p + Pb \rightarrow p + Pb + J/\psi\right) = k\frac{dn}{dk}\sigma\left(W_{\gamma p}\right)$$

ALICE results presented at Krakow and MPI



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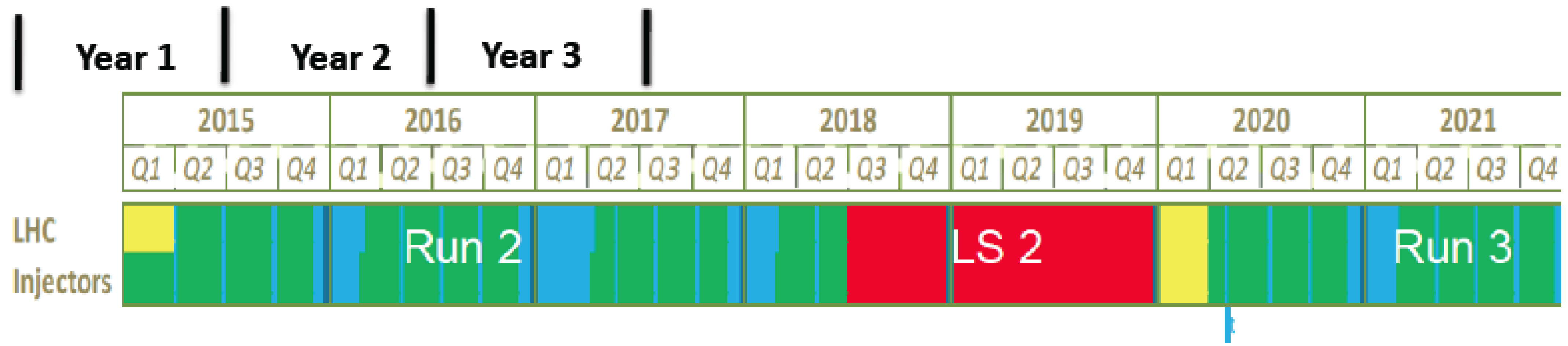
$$\frac{d\sigma}{dy}(p + Pb ® \; p + Pb + J/\psi) = k\frac{dn}{dk}\sigma\left(W_{\gamma p}\right)$$

- MNRT give two models, one LO and one with additional NLO terms. ALICE data lie about 1 sigma below curve.

  b-Sat (eikonalized) model gives a very similar prediction

- Recent LHCb measurements in pp collisions give $\delta=0.92\pm0.15$. LHCb data are about one sigma below ours (low energy) or one sigma above (high energy).



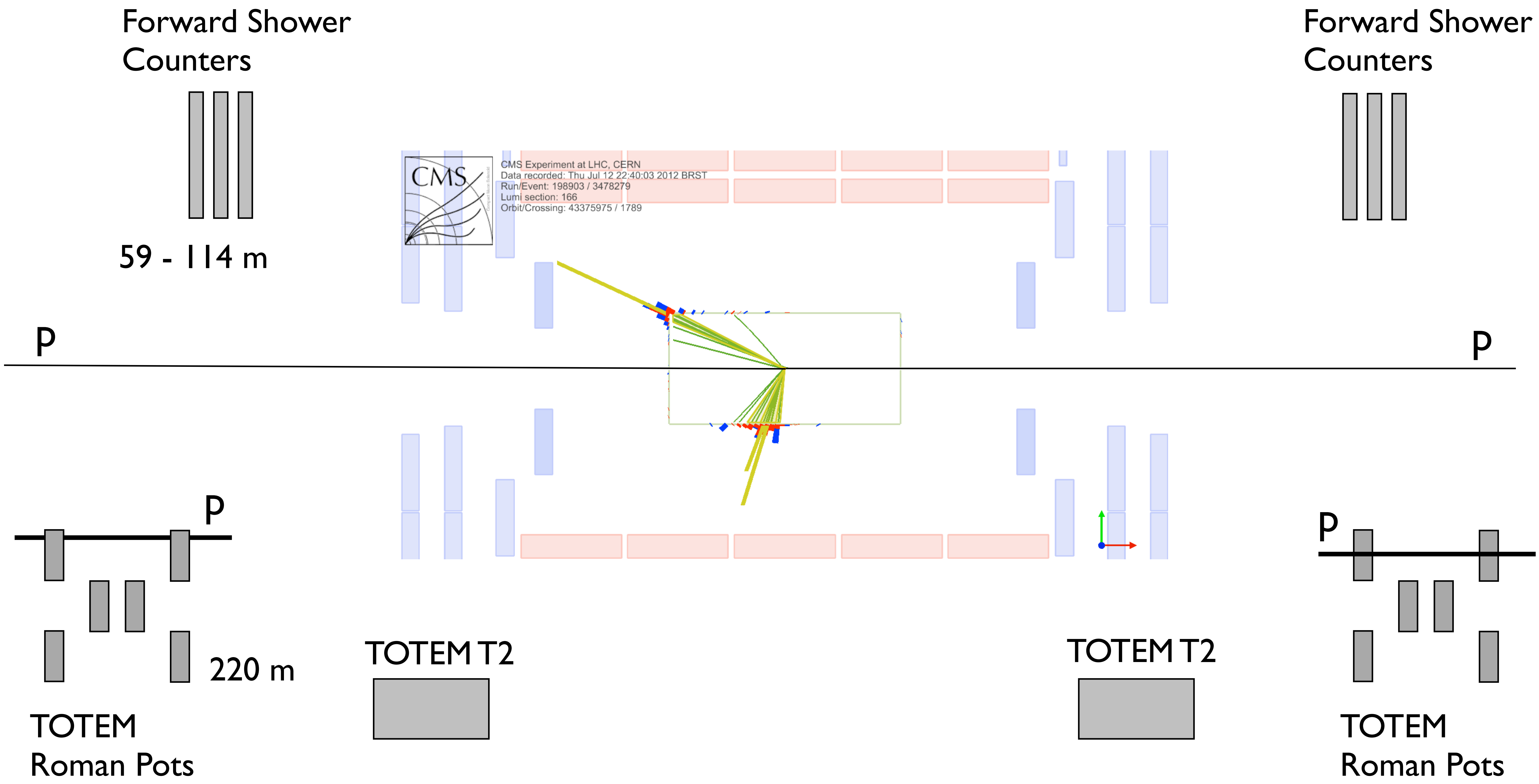
5.1 TeV for the 2015 Pb-Pb run

1 nb-1 for CMS/ATLAS

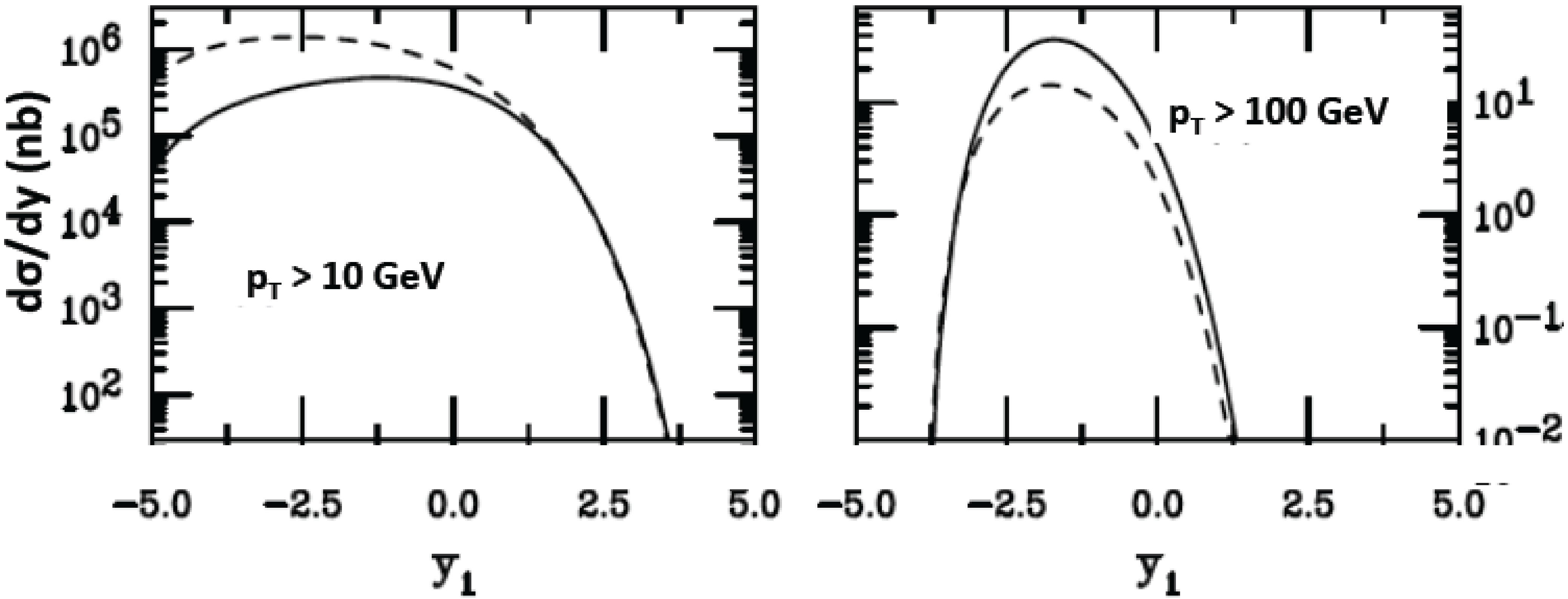
Next p-Pb run in 2017

Another heavy-ion run in 2016

Dijet: CMS+TOTEM



Dijet production in UPC



The photon is coming from the left and its direction can be resolved by the correlation with neutrons in the ZDCs.

In the direct process (solid), the entire photon energy contributes to the hard process while in the resolved case (d part does.

LHC WG meeting on difraction and forward physics & Future directions on UPC

May 27-30, 2014

Lawrence, KS

http://cern.ch/lawrence2014

Summary

Several physics processes can be studied in UPCs

Already a few interesting analyses at RHIC, Tevatron and LHC

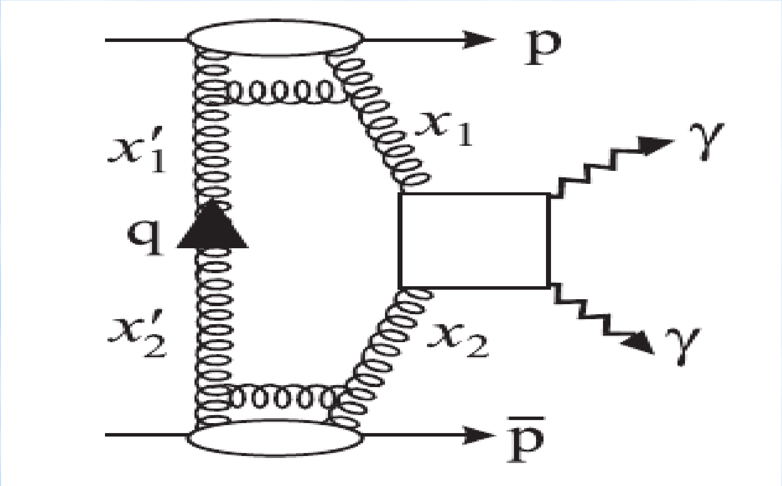
Many new interesting topics still there to study QCD and New Physics at high energies/ luminosities: Excited states of vector mesons,

Higgs production,…

Exclusive production in pp vs. AA

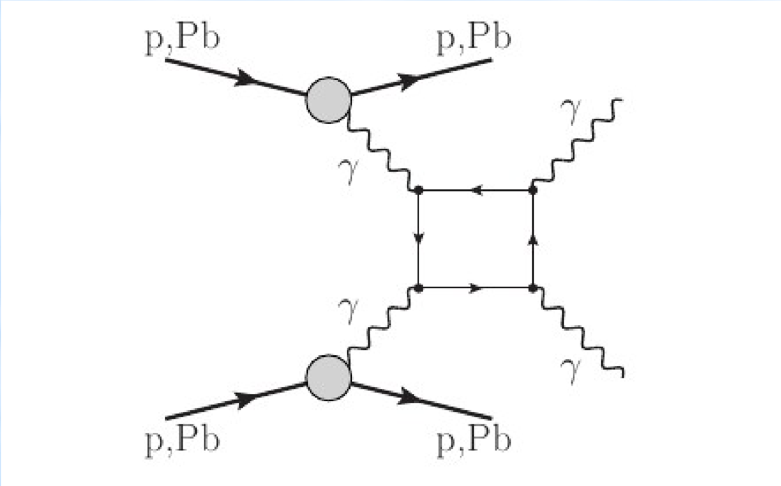
Different production mechanisms may dominate. Consider exclusive $\gamma\gamma$ (or Higgs) production:

p-p



V. A. Khoze, A.D. Martin, M.G. Ryskin, W.J. Stirling, Eur. Phys. J C 38 (2005) 475.

Pb-Pb

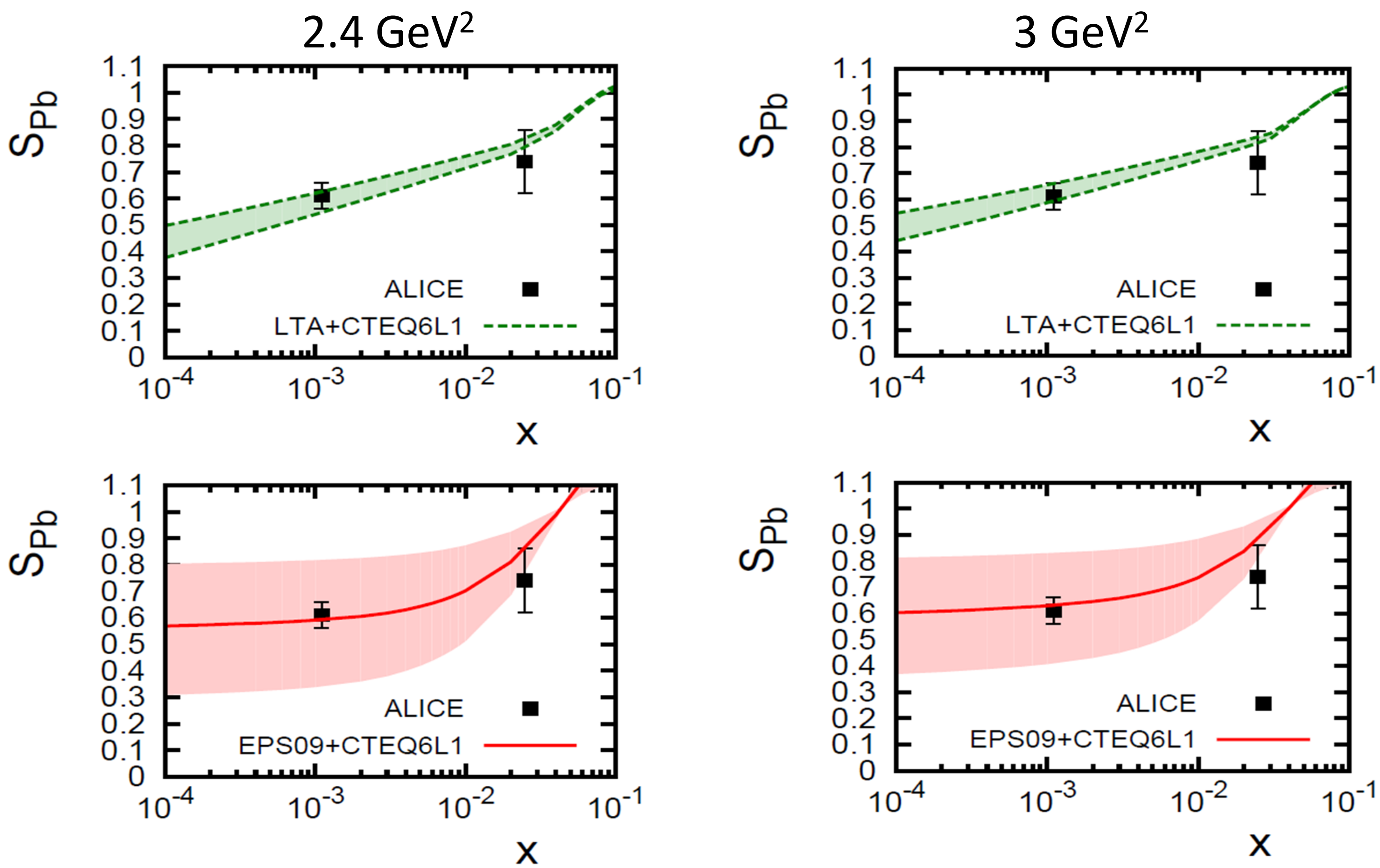


D. d'Enterria, G.G. Silveira, PRL 111 (2013) 080405.

In p-p collisions, 3 (or more) gluon exchange dominate, whereas for heavy-ion collisions, $\gamma\gamma\rightarrow\gamma\gamma$ dominate.

Scale dependence

- Studied in detail in Guzey, Zhalov: JHEP 1310 (2013) 207.
- Scale of 3 GeV^2 found to be most appropriate for the description of J/ψ photoproduction data



EPS09, variation of scale by factor 4:

$R(x=0.011, Q^2 = 2.4\ \text{GeV}^2) = 0.569$

$R(x=0.011, Q^2 = 9.6\ \text{GeV}^2) = 0.671$

Future measurements of heavier vector mesons (ψ‘, ϒ) will further elucidate the importance of the scale