Ultra-peripheral collisions at ALICE

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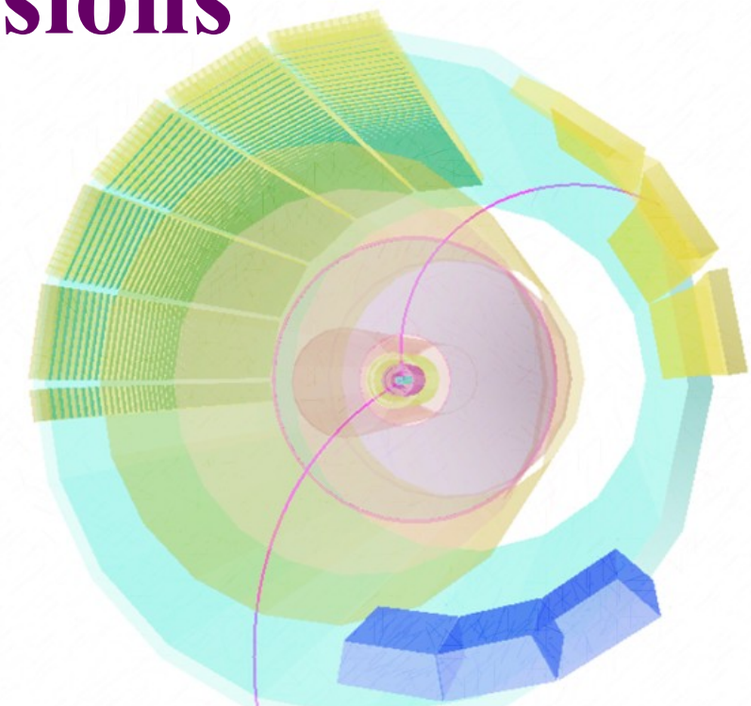
Strangeness in Quark Matter - SQM

Birmingham, United Kingdom, 26 July 2013

Plan of this talk

- **Ultra-Peripheral (pp/pA/AA) Collisions**
  - What are UPC
  - Why at the LHC
  - Why at ALICE



Recent ALICE results

- Coherent/Incoherent J/ψ in γPb
- Exclusive J/ψ in γp
- Two-photon process from UPC in p-Pb
- ρ^0 and four-pion photoproduction UPC Pb-Pb

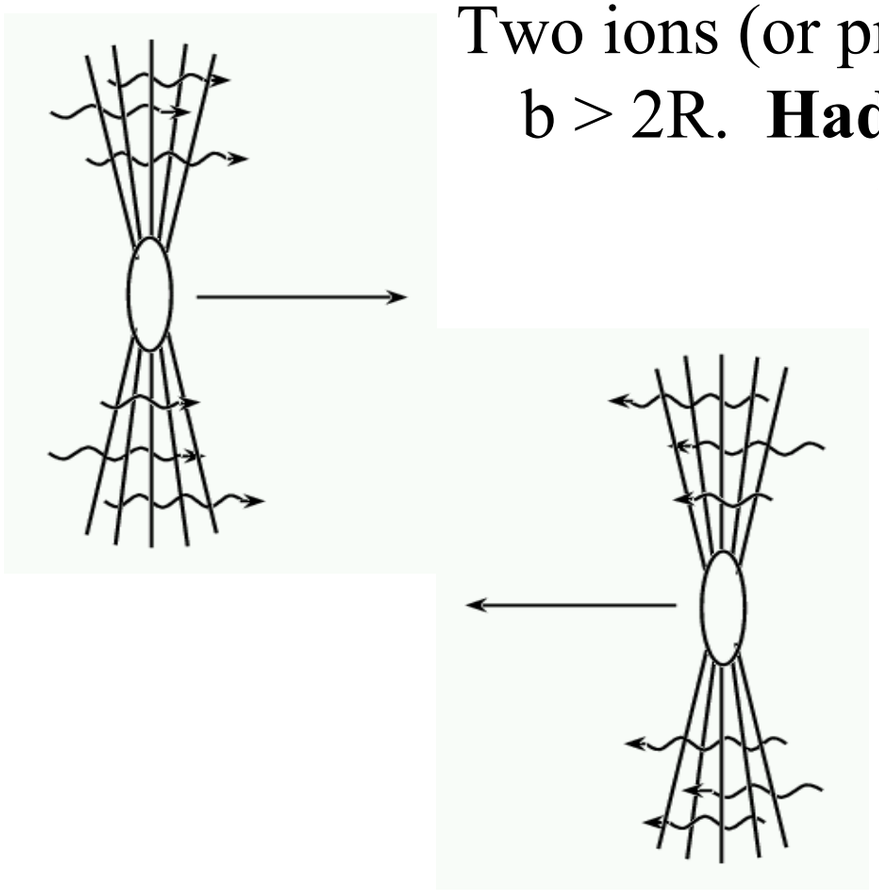
Outlook

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

UPCs in Pb-Pb

Why ultra-peripheral heavy-ion collisions

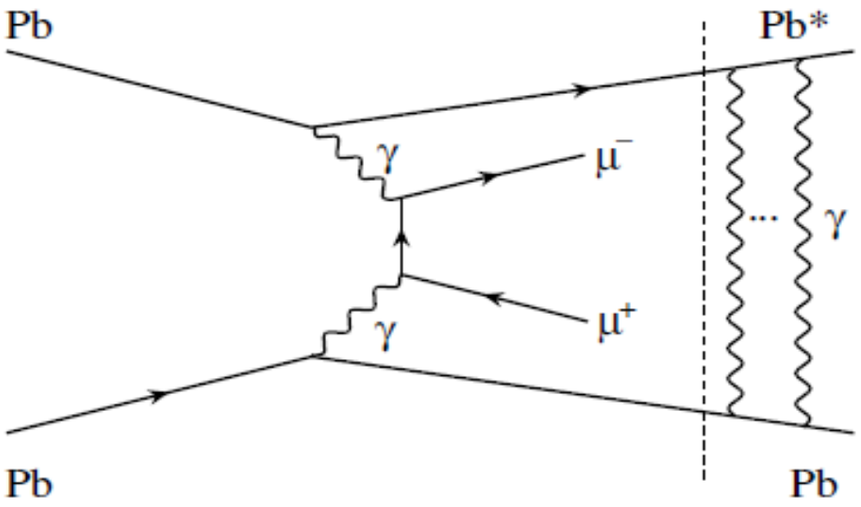


Two ions (or protons) pass by each other with impact parameters b > 2R. **Hadronic interactions are strongly suppressed**

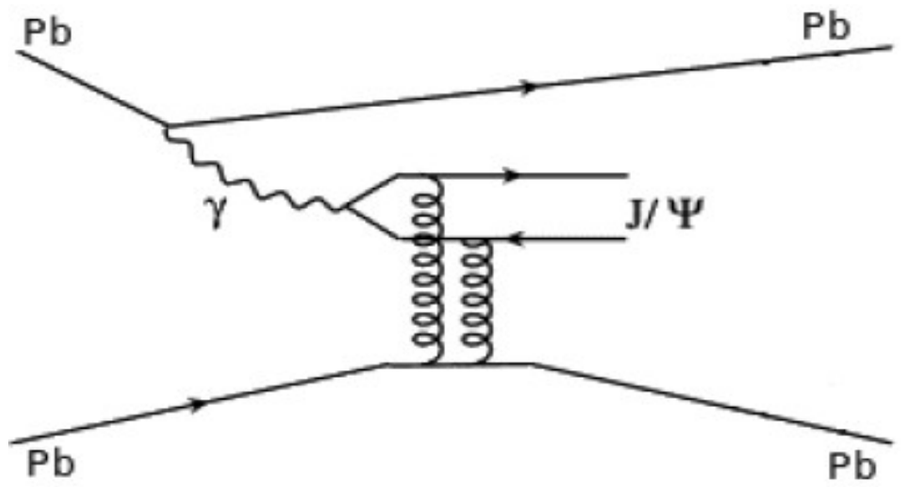
Number of photons scales like Z^2 for a single source ⇒ exclusive particle production in heavy-ion collisions dominated by electromagnetic interactions.

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

Photon-induced reactions



Two-photon production



γ + p → J/ψ + 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...

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

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

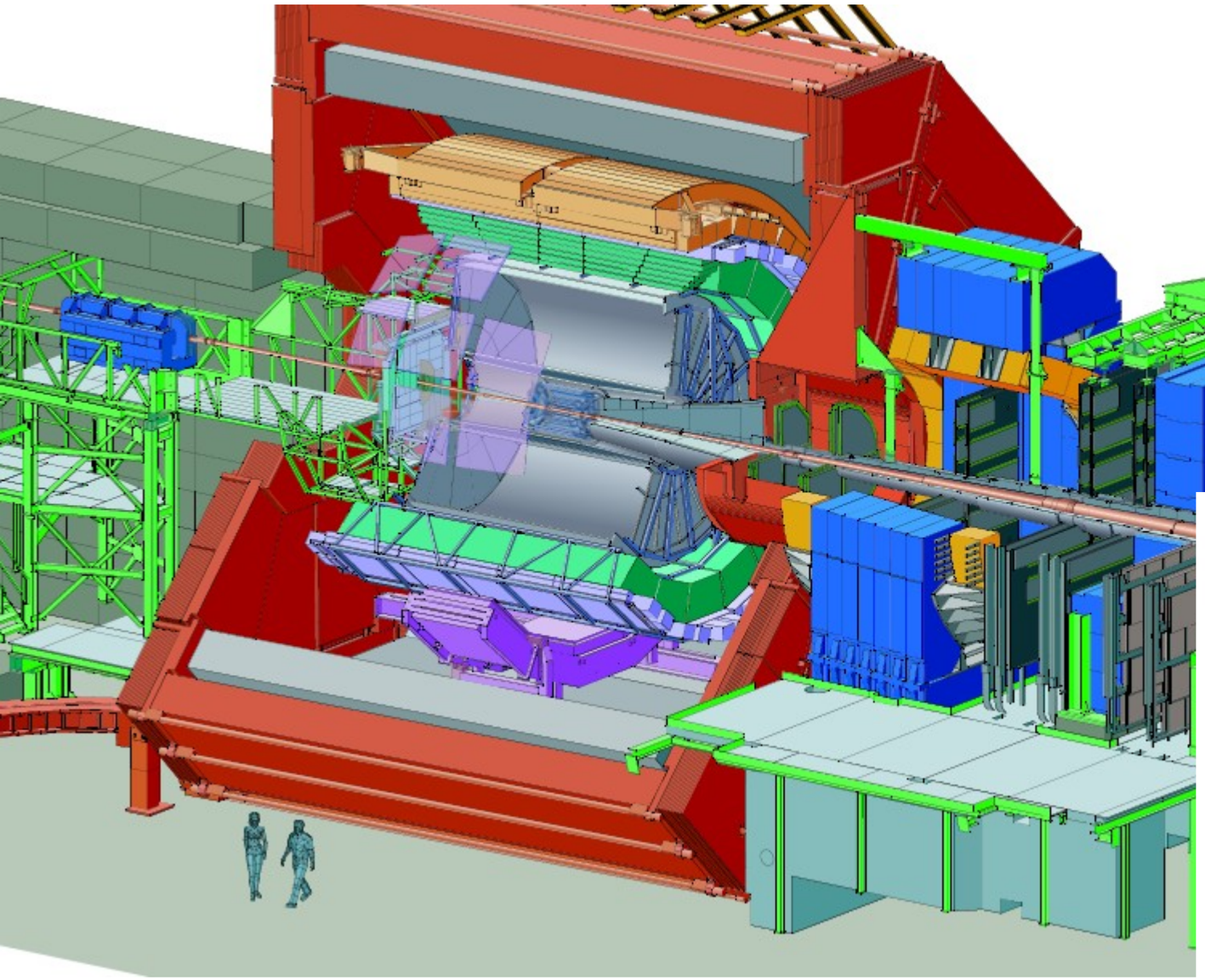
$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xg\left(x, \frac{M_V^2}{4}\right)\right]^2$$ Ryskin 1993

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

Also a more recent calculation

T. Lappi, H. Mäntysaari
Phys. Rev. C 87 (2013) 032201.

The ALICE experiment at LHC



Central rapidity

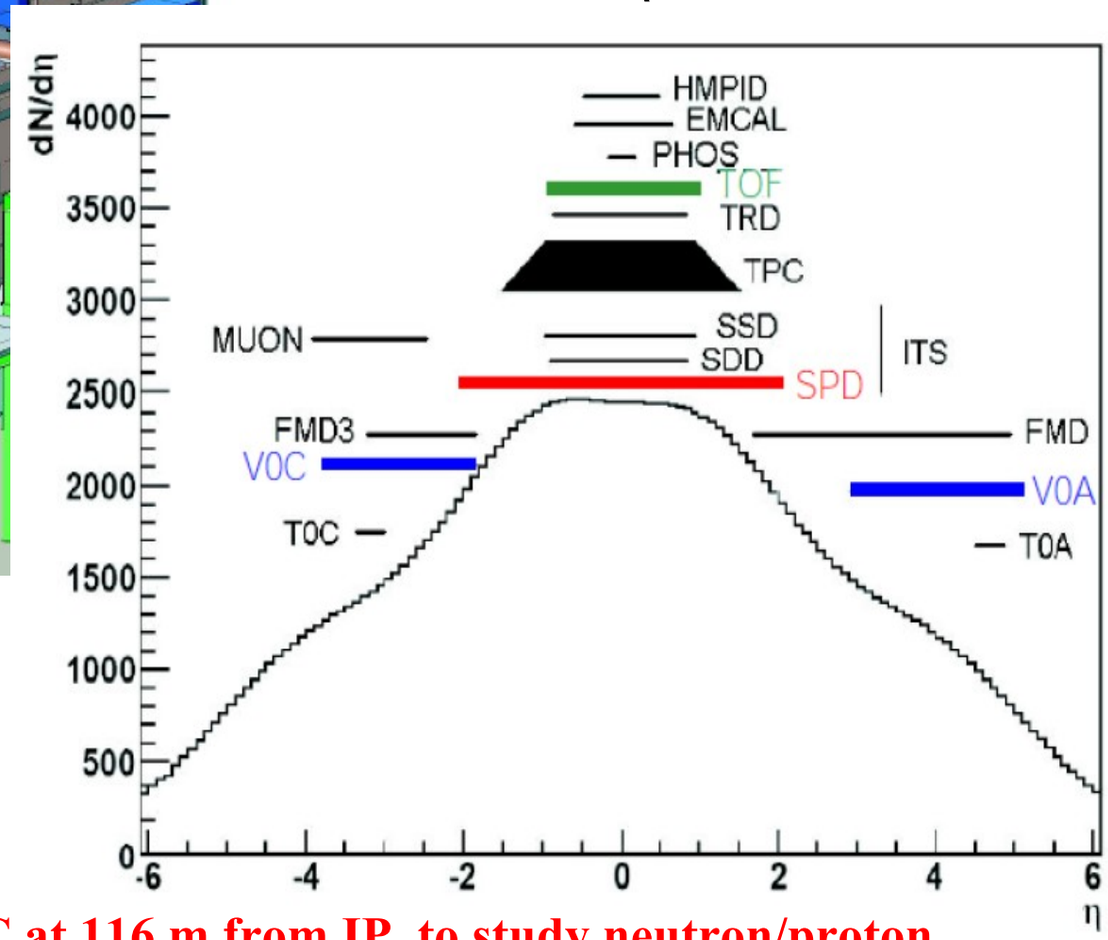
Inner Tracking (ITS), Time Projection Chamber (TPC), Time-of-Flight, TRD, EMCAL

$|\eta| < 0.9$

Forward rapidity

Muon Spectrometer

$-4 < \eta < -2.5$

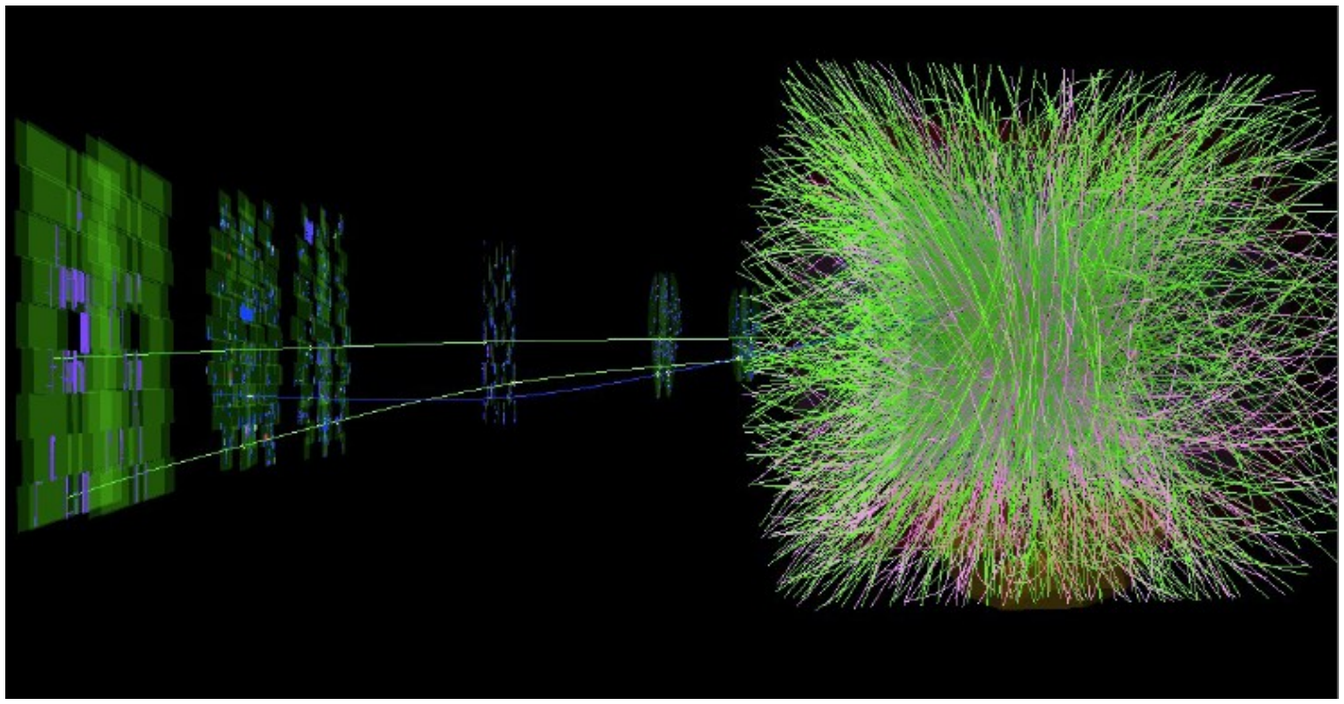


Dedicated triggers for UPC, using VZERO forward detectors for vetoing And MUON, TOF and SPD

ALICE can measure J/ψ mesons down to zero p_T

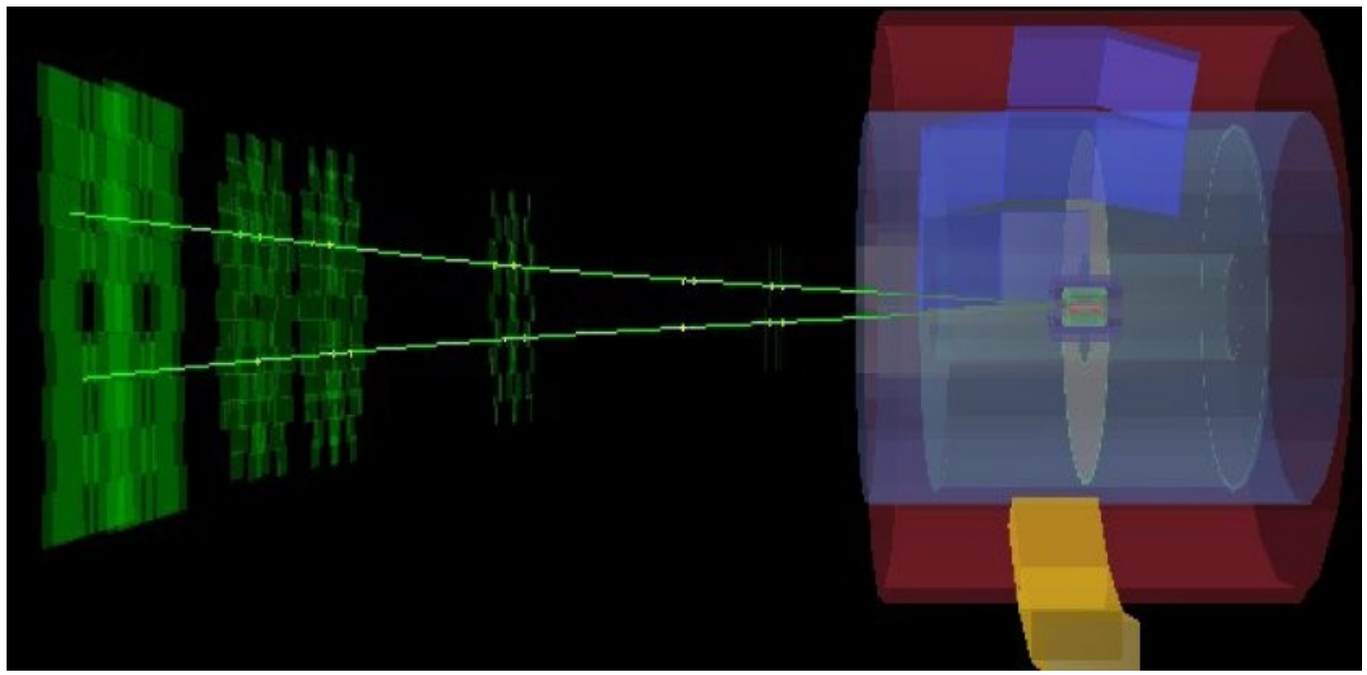
ZDC at 116 m from IP, to study neutron/proton emitted at the very forward region

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



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

....to an exclusive J/ψ candidate

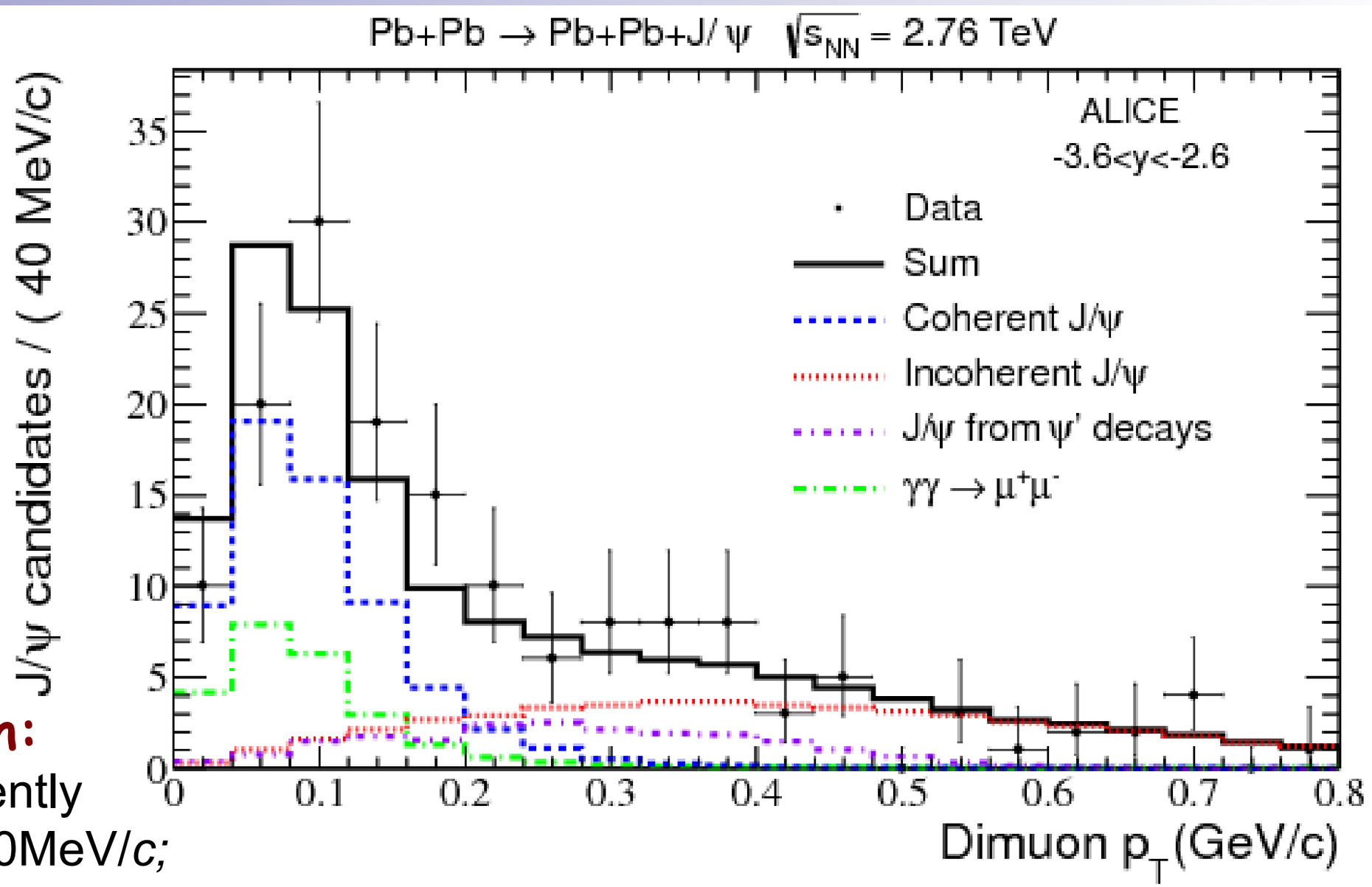


Two UPC publications by ALICE

Phys.Lett. B718 (2013) 1273-1283
arXiv:1305.1467 [nucl-ex]

p_T distribution for J/ψ candidates at forward y

Phys.Lett. B718 (2013) 1273-1283



Coherent production:

Photon couples coherently to all nucleons $\langle p_T \rangle \sim 60$ MeV/*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

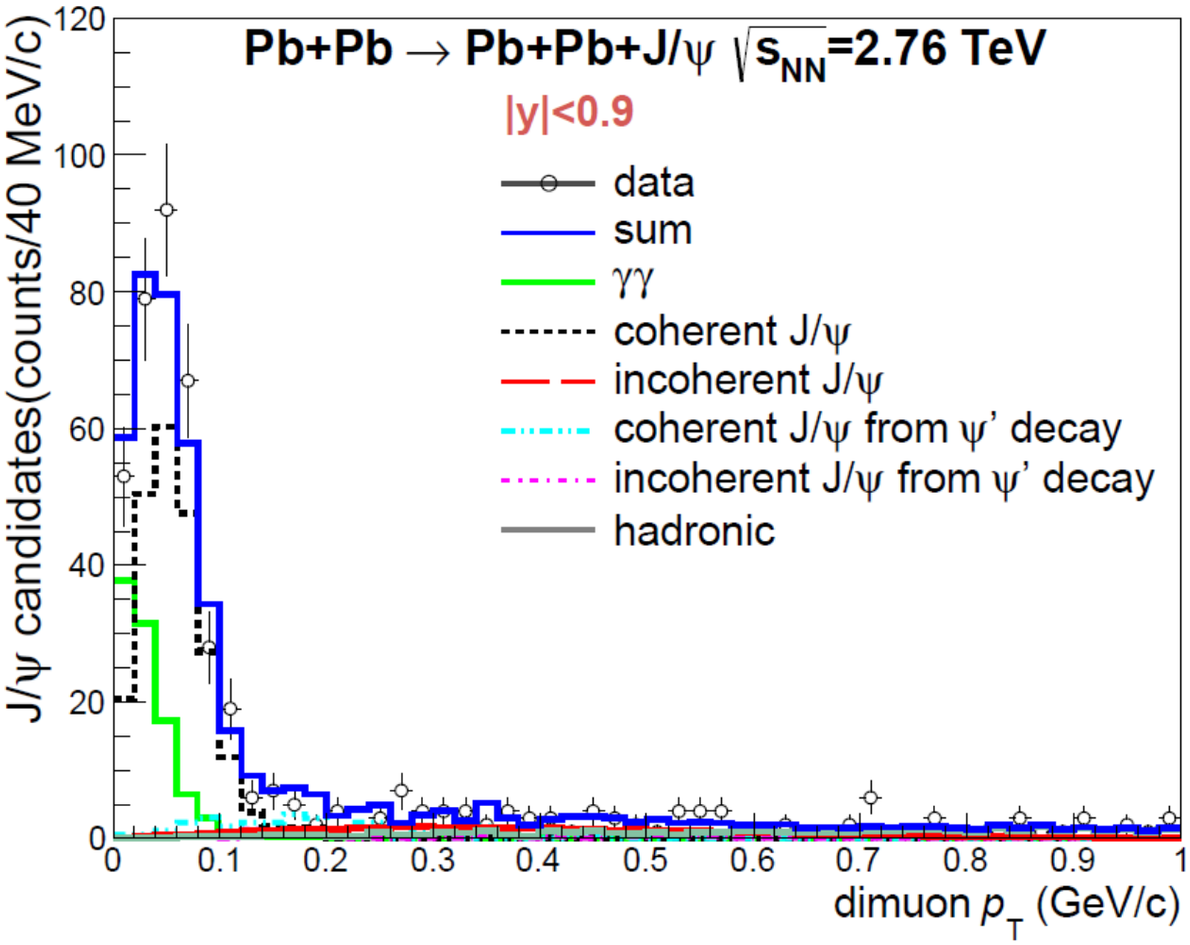
$\langle p_T \rangle \sim 500$ MeV/*c*

Four physics processes:

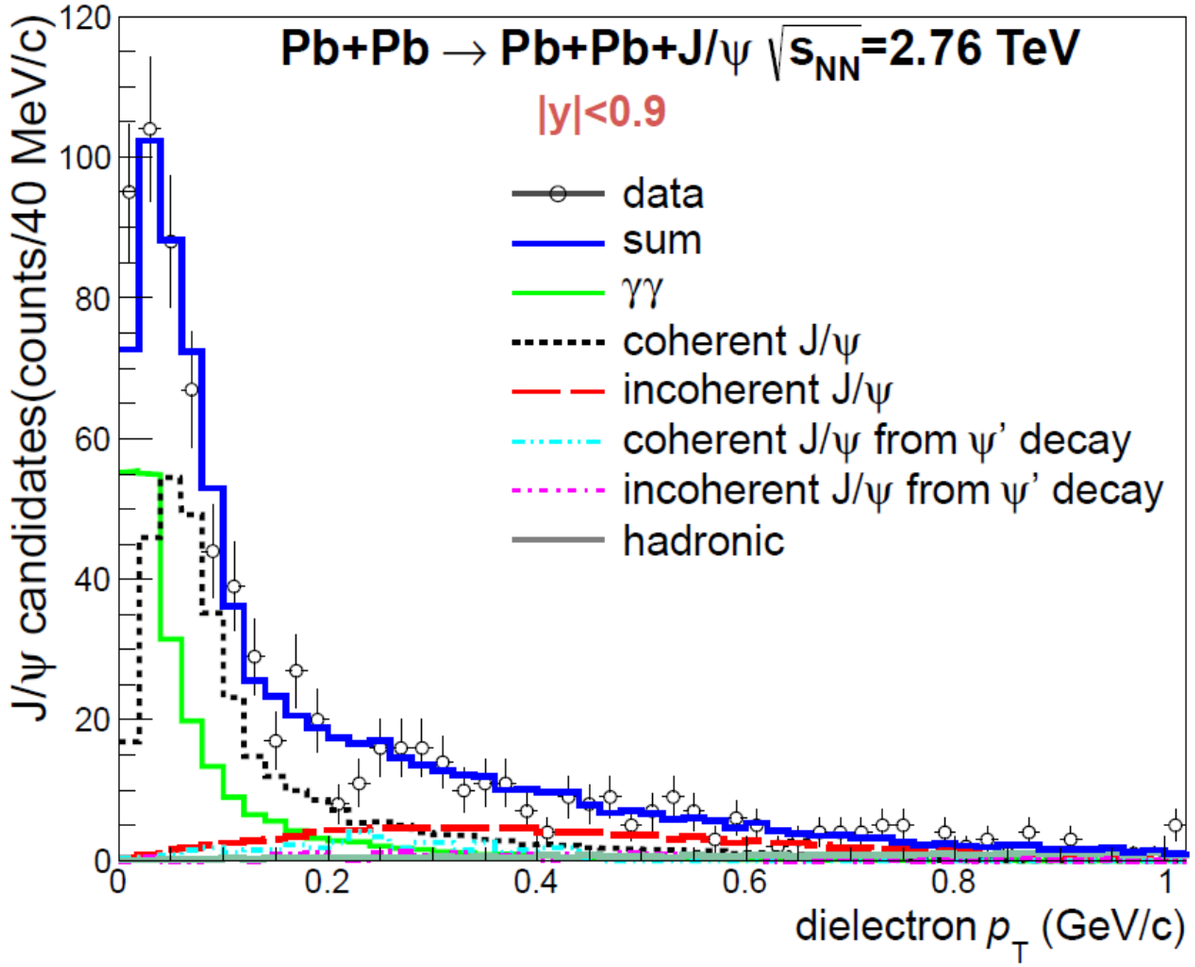
- Coherent J/ψ
- Incoherent J/ψ
- J/ψ from ψ' decays
- γγ → μ⁺μ⁻

p_T distribution for J/ψ candidates at mid-rapidity

J/ψ in the dimuon channel



J/ψ in the dielectron channel

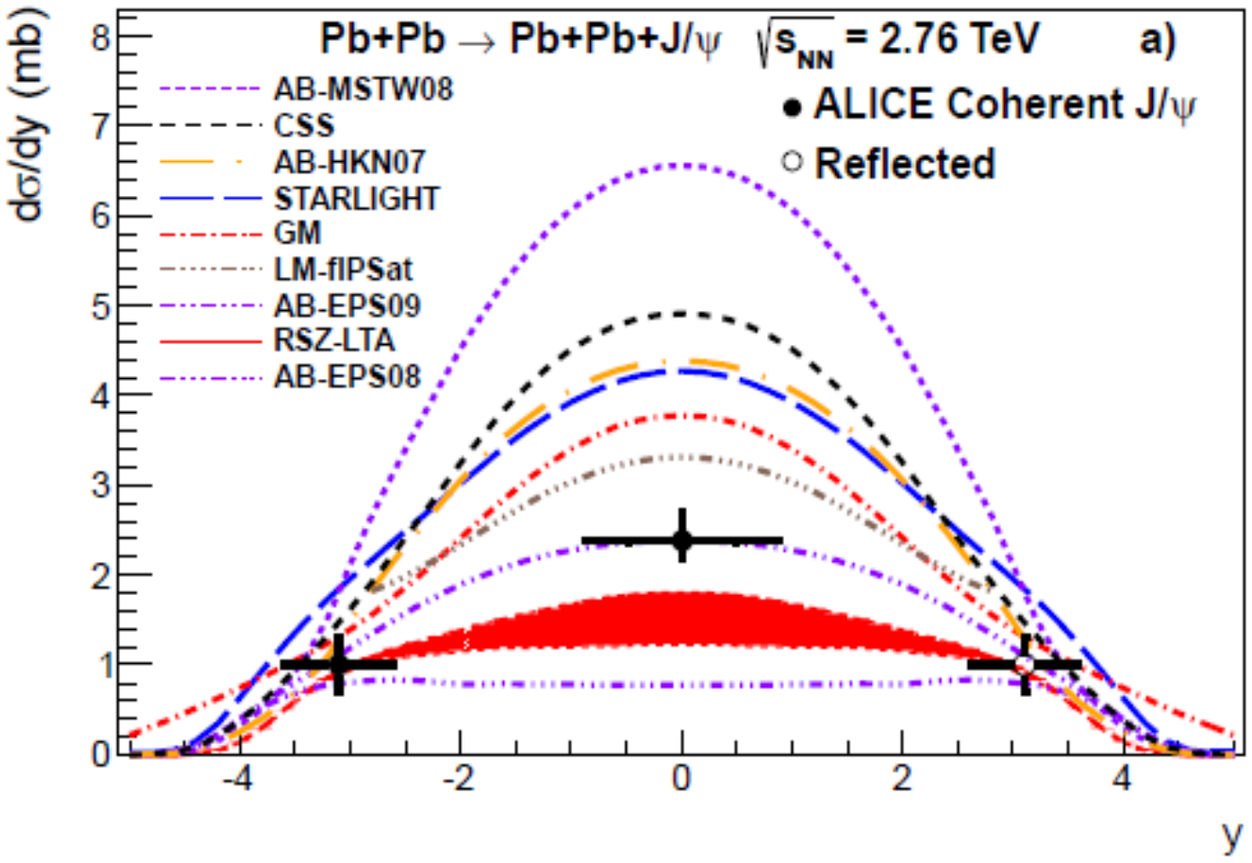


Data is well described by signals/backgrounds expected in UPC

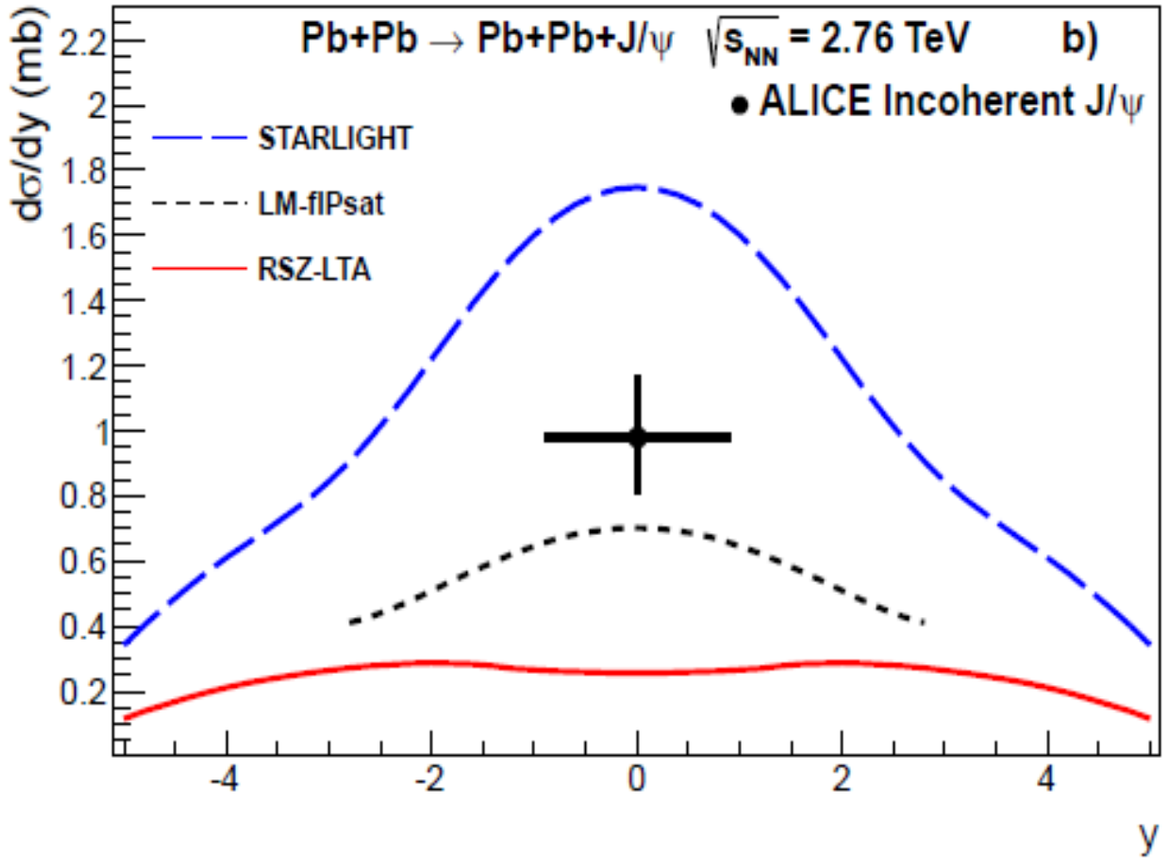
arXiv:1305.1467 [nucl-ex]
Submitted to EPJ C

Data *and* theoretical predictions

Coherent J/ψ



Incoherent J/ψ



Best agreement with EPS09 shadowing

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

Two UPC publications by ALICE

Phys.Lett. B718 (2013) 1273-1283
arXiv:1305.1467 [nucl-ex]

UPC J/ψ in p-Pb

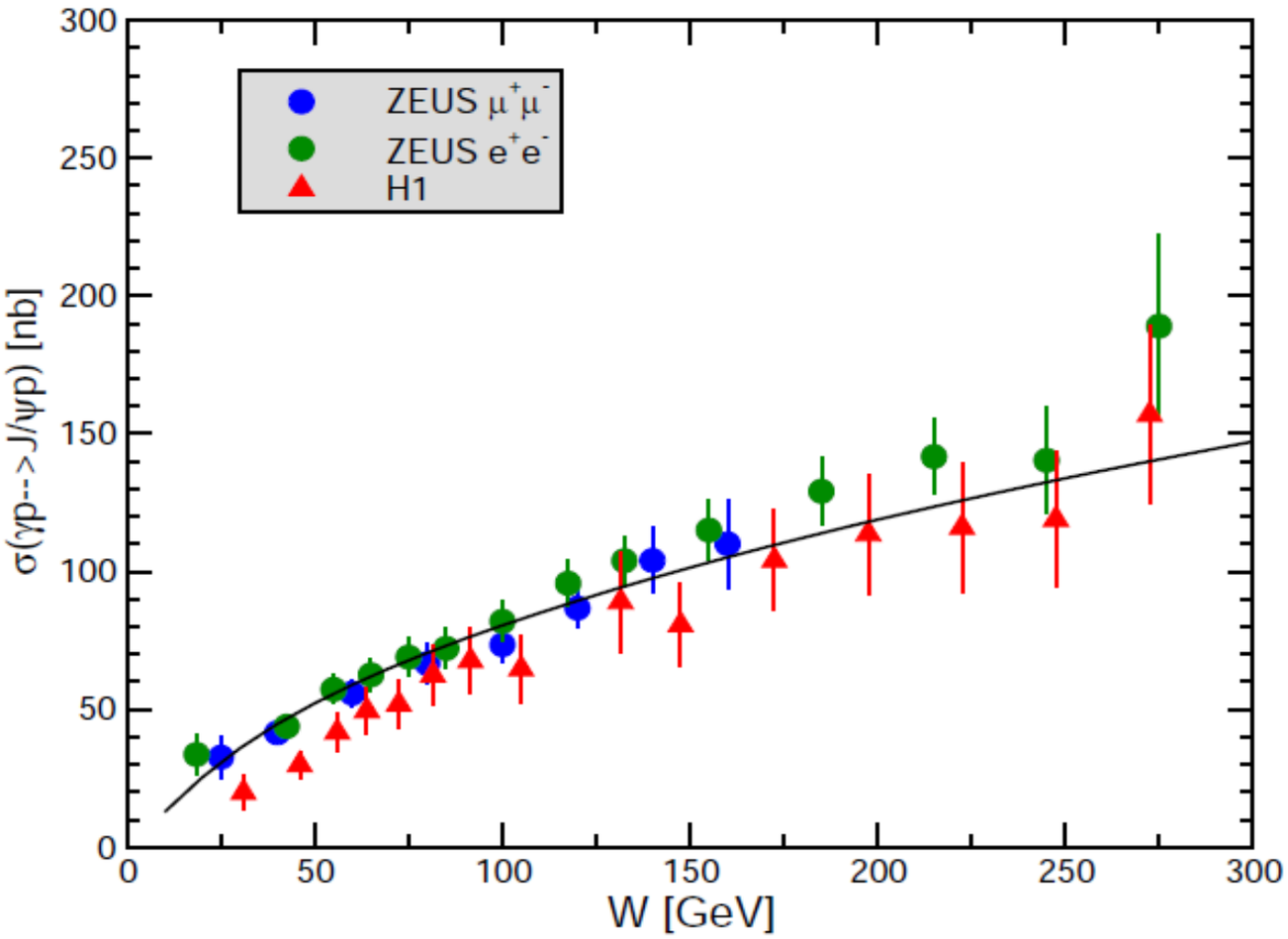
New results on J/ψ in γp – presented at EPS last week

New results in γγ in UPC p-Pb

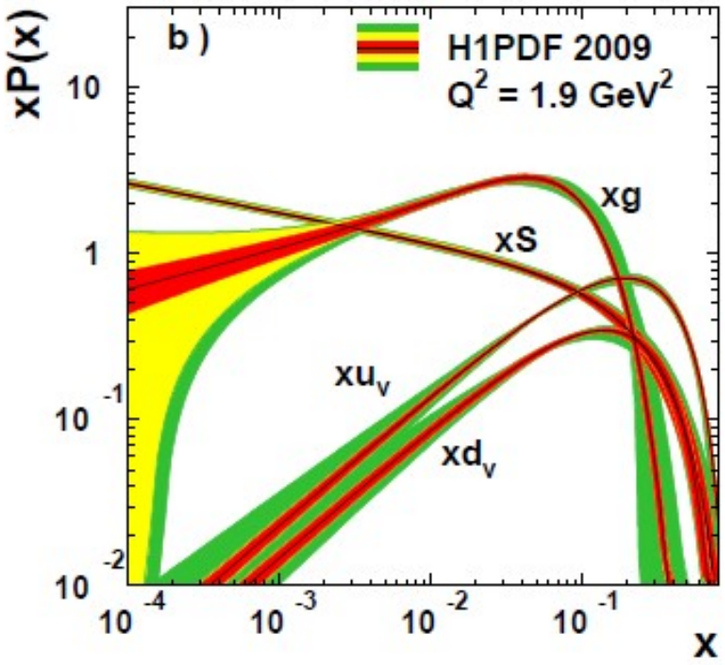
J/ψ photoproduction in γp

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

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



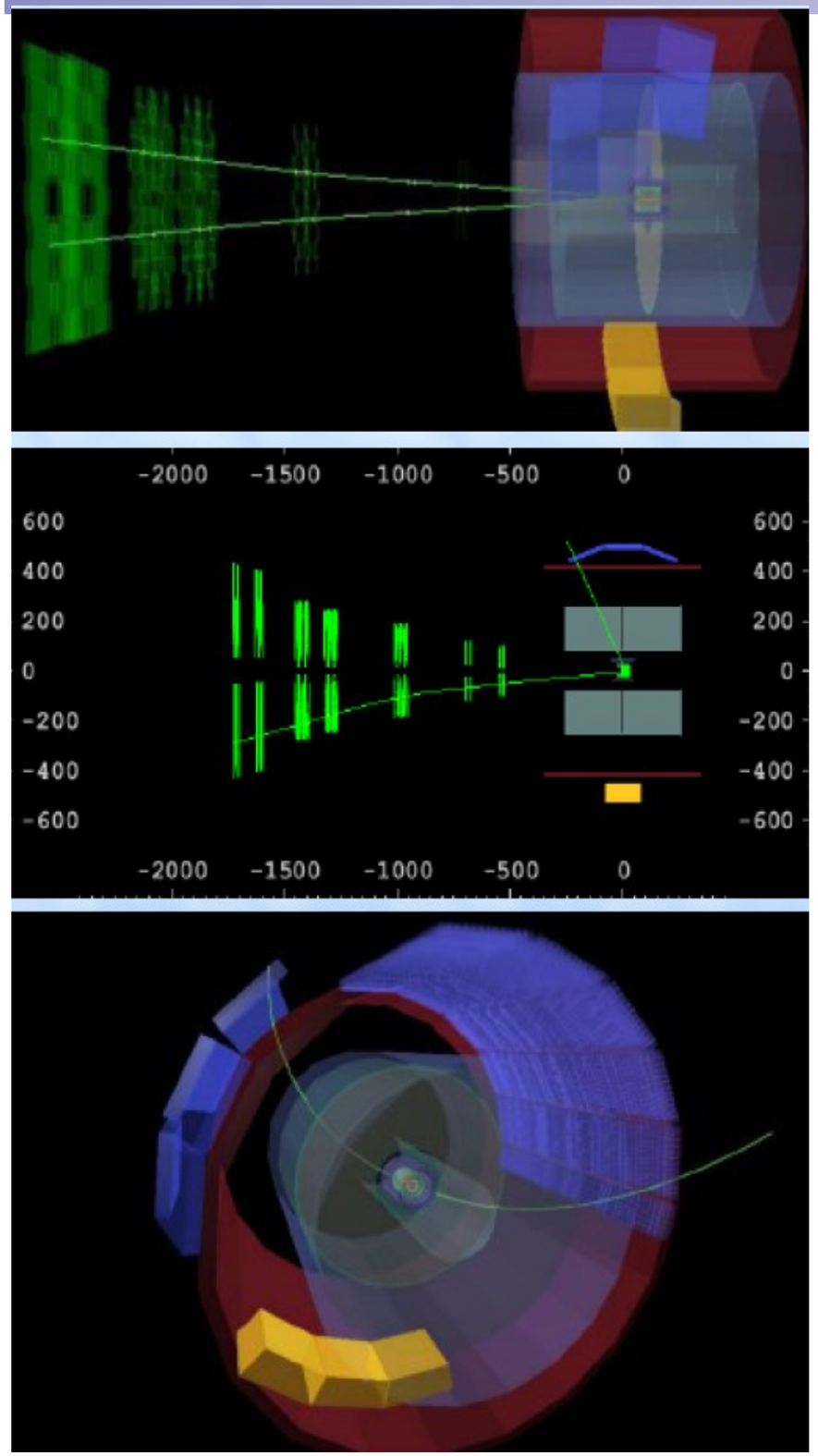
H1: A. Aktas *et al.* Eur.Phys. J.C46:585-603,2006
ZEUS:S. Chekanov et al., Nucl. Phys. B695 (2004) 3.
A. Martin et al. Phys.Lett. B 662:252-258, 2008

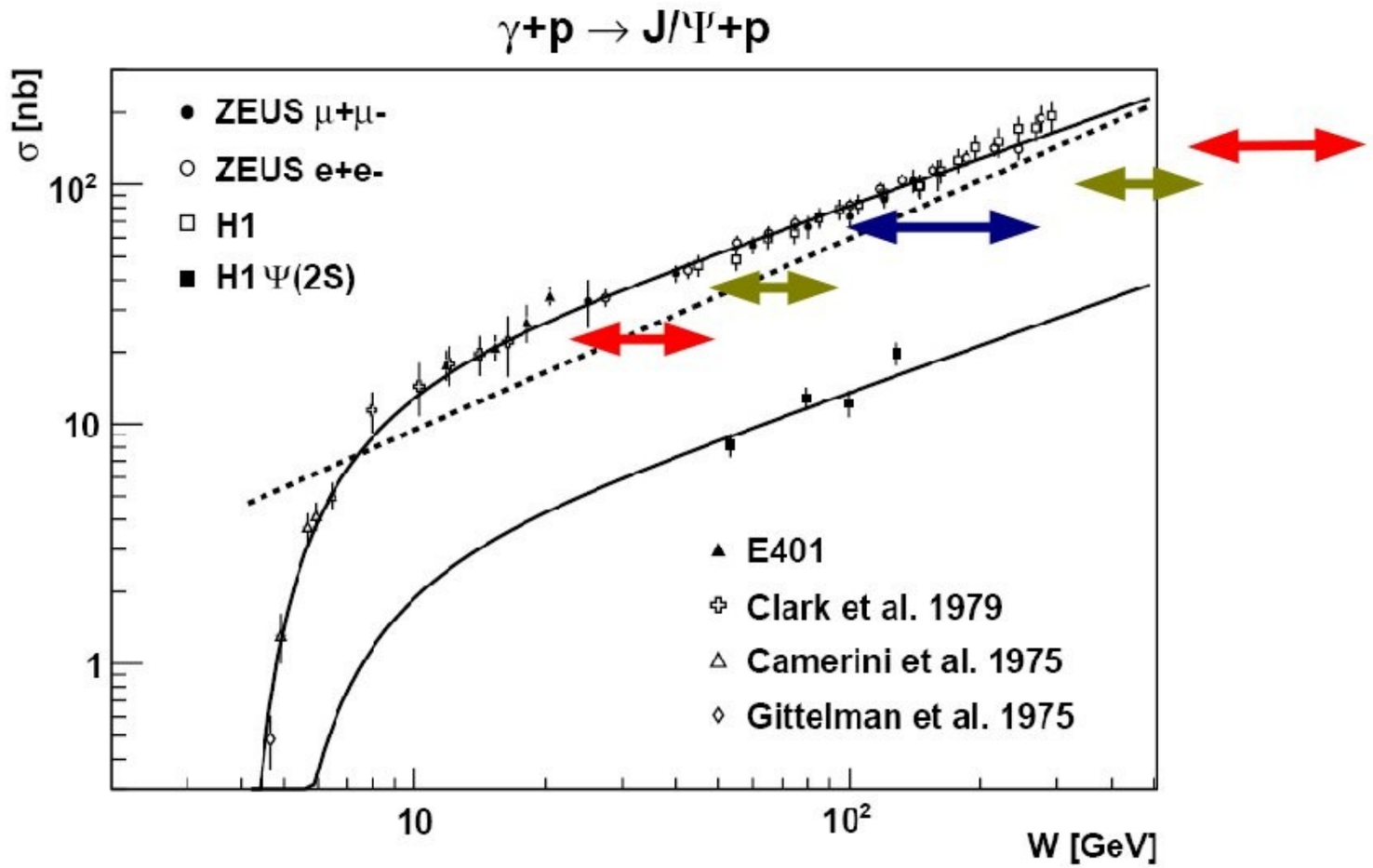


At LHC Bjorken-*x* down to 10^{-5}

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

ALICE physics potential

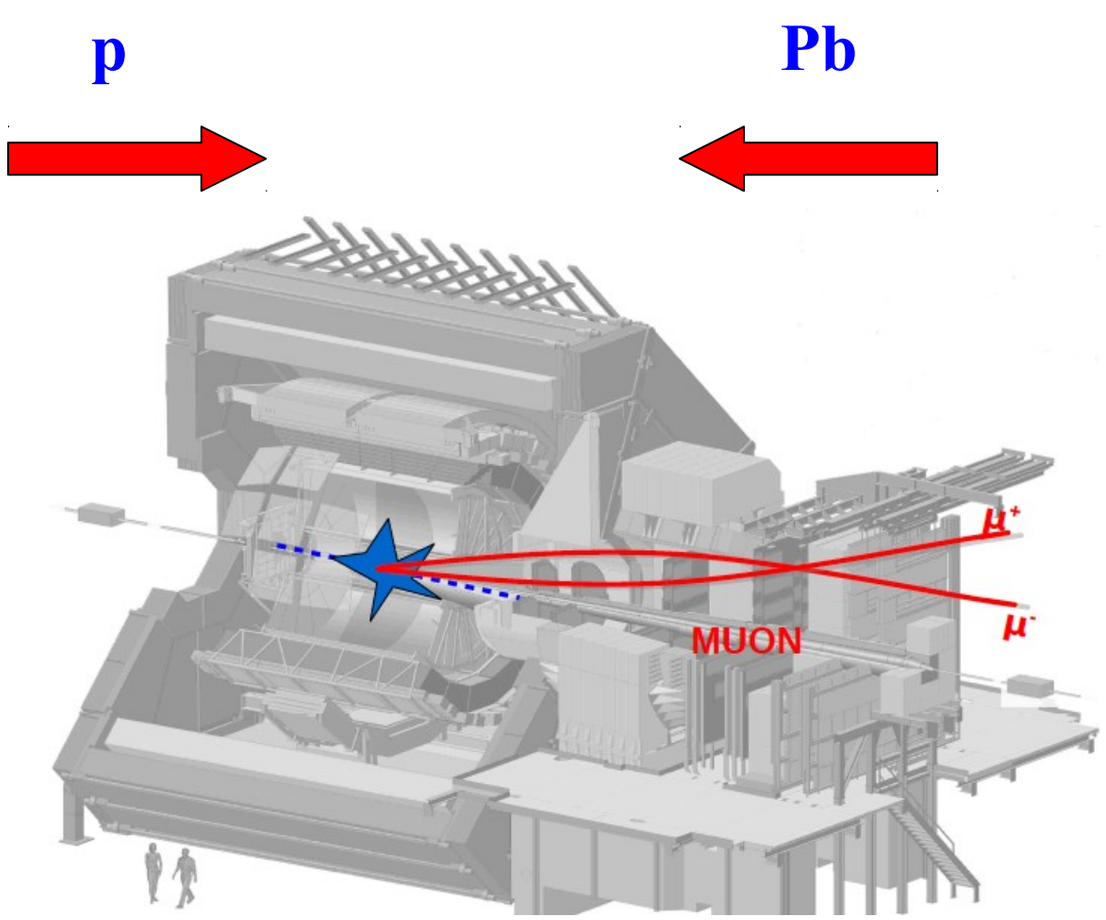




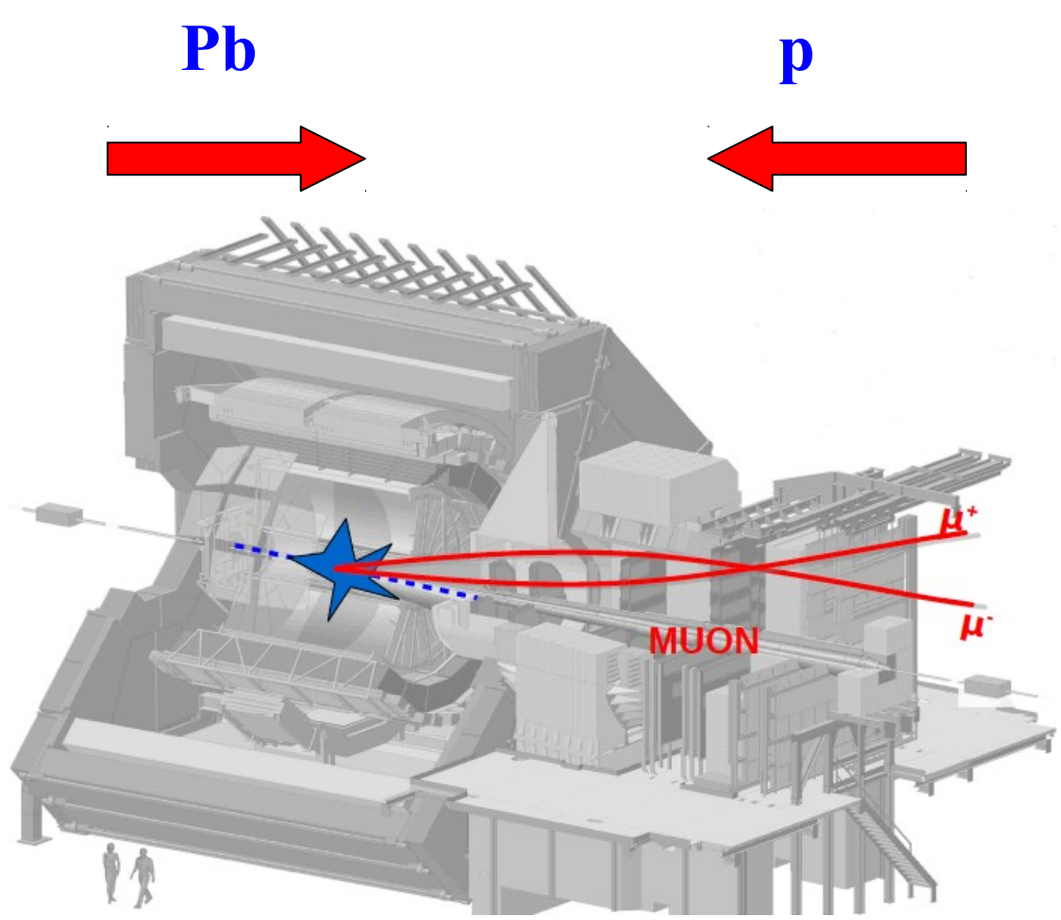
Ranges in gamma+proton CM energies:

Muon arm p-Pb:	$21 \leq W_{\gamma p} \leq 45$ GeV
Muon+Barrel p-Pb:	$45 \leq W_{\gamma p} \leq 82$ GeV
Central barrel:	$100 \leq W_{\gamma p} \leq 250$ GeV
Muon+Barrel Pb-p:	$300 \leq W_{\gamma p} \leq 550$ GeV
Muon arm Pb-p:	$550 \leq W_{\gamma p} \leq 1160$ GeV

Forward J/ψ in pA

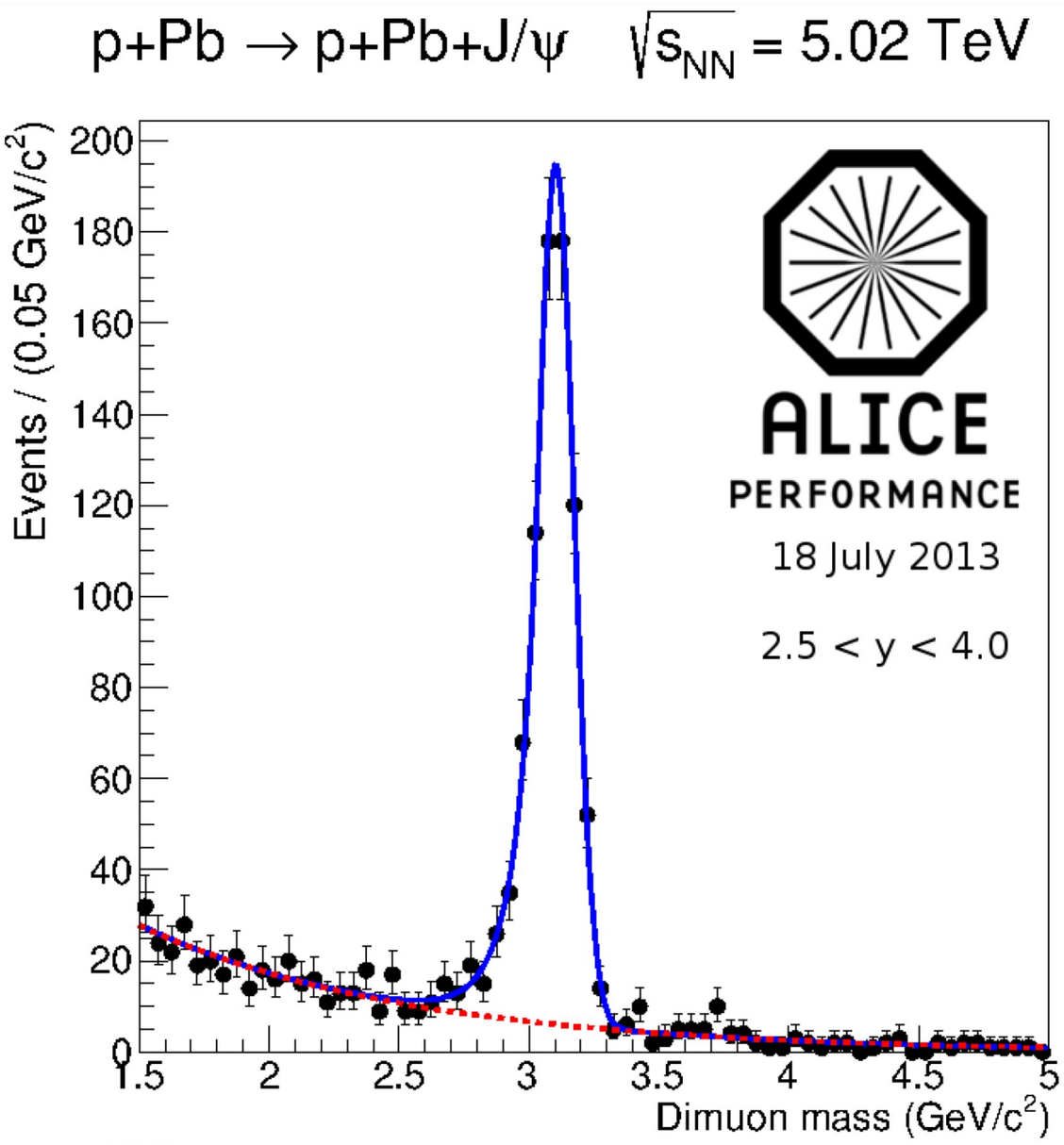


$21 < W_{\gamma p} < 45$ GeV

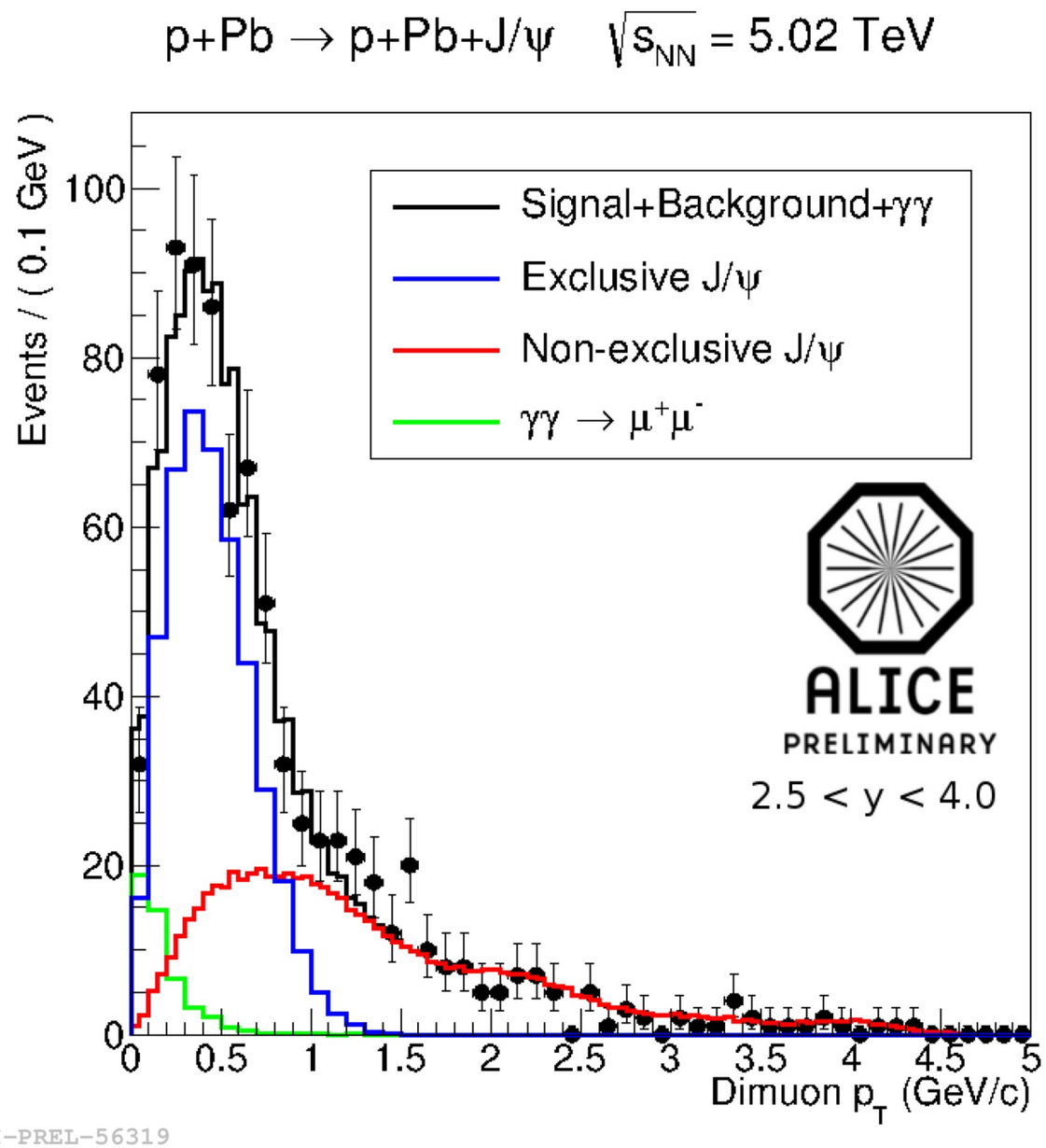


$549 < W_{\gamma p} < 1163$ GeV

UPC J/ψ candidates in p-Pb



ALI-PERF-56323



ALI-PREL-56319

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

UPC J/ψ candidates in p-Pb

Preliminary cross sections – after feed-down corrections from ψ(2S)
The rapidity is given in the Lab frame

$d\sigma(p+Pb\to p+Pb+J/\psi)/dy$ $(-4.0<y<-2.5)$ = **6.18 ± 0.42 (stat) ± 0.56 (sys) μb**

$d\sigma(p+Pb\to p+Pb+J/\psi)/dy$ $(-4.0<y<-3.5)$ = **5.50 ± 0.72 (stat) ± 0.52 (sys) μb**

$d\sigma(p+Pb\to p+Pb+J/\psi)/dy$ $(-3.5<y<-3.0)$ = **6.26 ± 0.55 (stat) ± 0.57 (sys) μb**

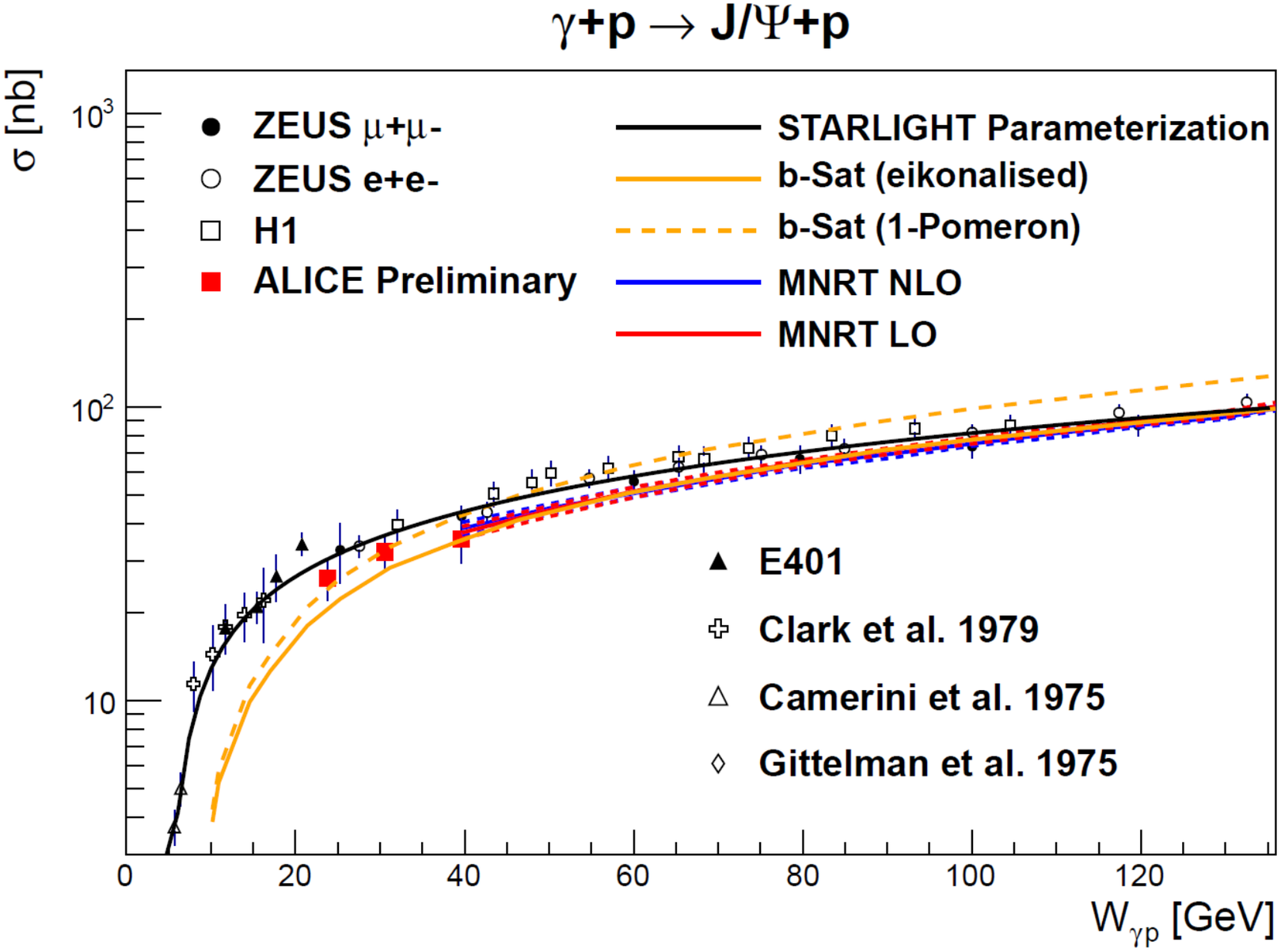
$d\sigma(p+Pb\to p+Pb+J/\psi)/dy$ $(-3.0<y<-2.5)$ = **6.39 ± 0.94 (stat) ± 0.59 (sys) μb**

These ALICE results are between fixed target experiments and HERA

$$21 < W_{\gamma p} < 45 \text{ GeV}$$
$$\langle W_{\gamma p} \rangle \sim 30 \text{ GeV}$$

UPC J/ψ candidates in p-Pb

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



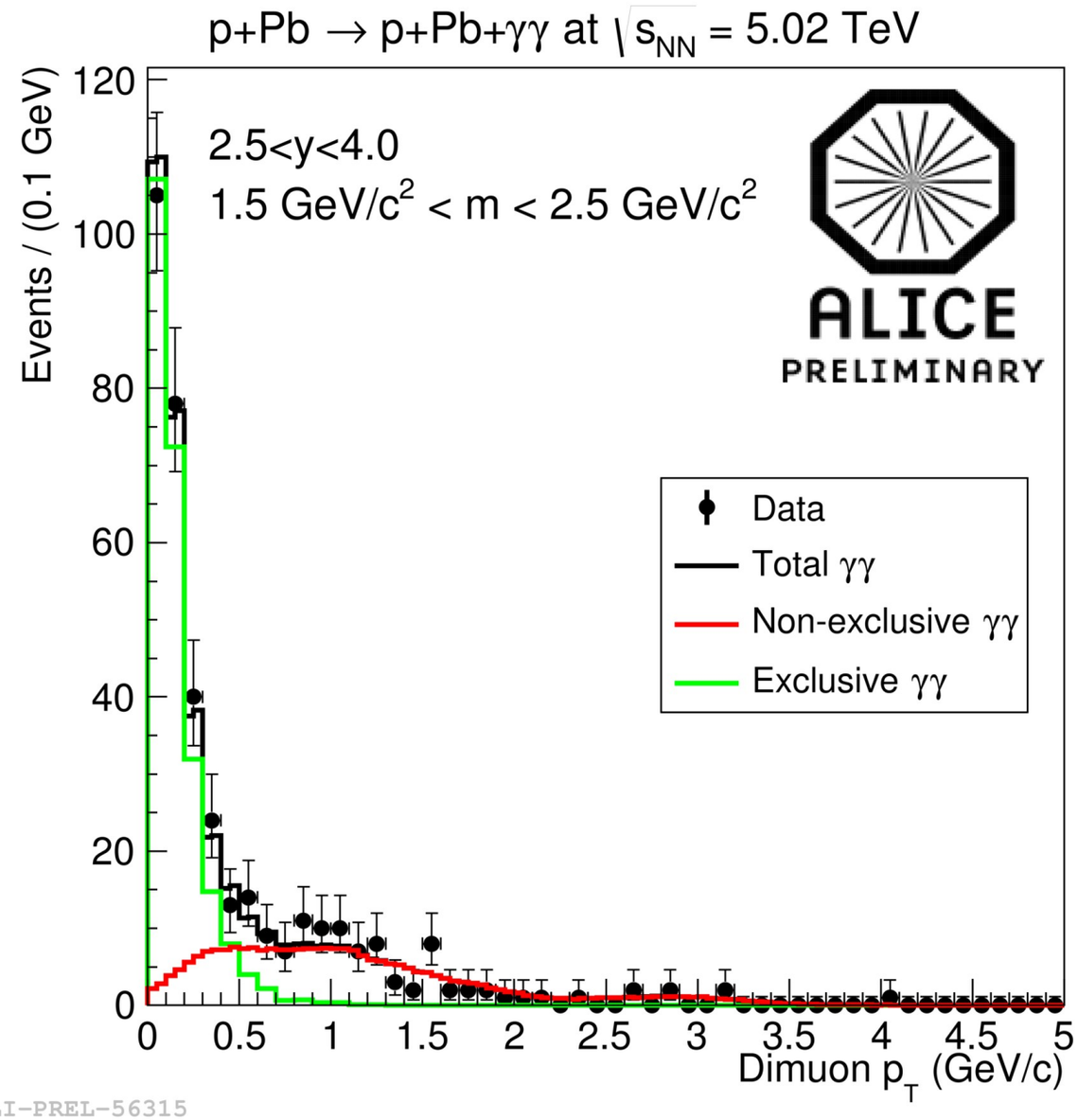
Model calculations

b-Sat: arxiv:1206.2913; 1211.4831.

MNRT: PLB 662 (2008) 252.

ALICE covers the lowest energies measured at HERA (and of course can go much higher in Pb+p).

Two-photon cross section in p-Pb



Preliminary cross section for two-photon production

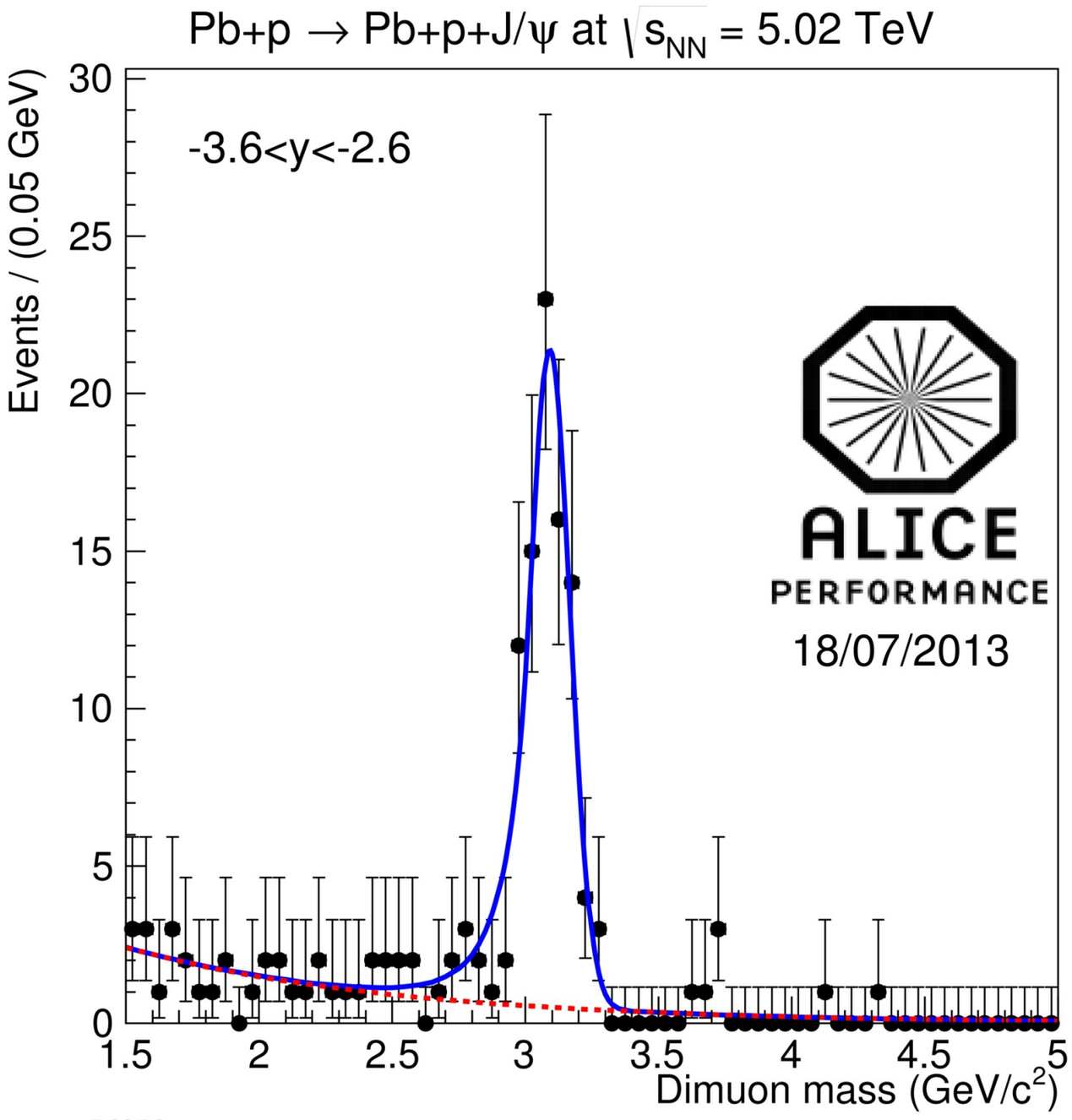
First time measurements in p-Pb collisions

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 Pb-p



578 < $W_{\gamma p}$ < 972 GeV

<$W_{\gamma p}$> ~ 686 GeV

Analysis is ongoing

One more thing...

Exclusive four-pion production

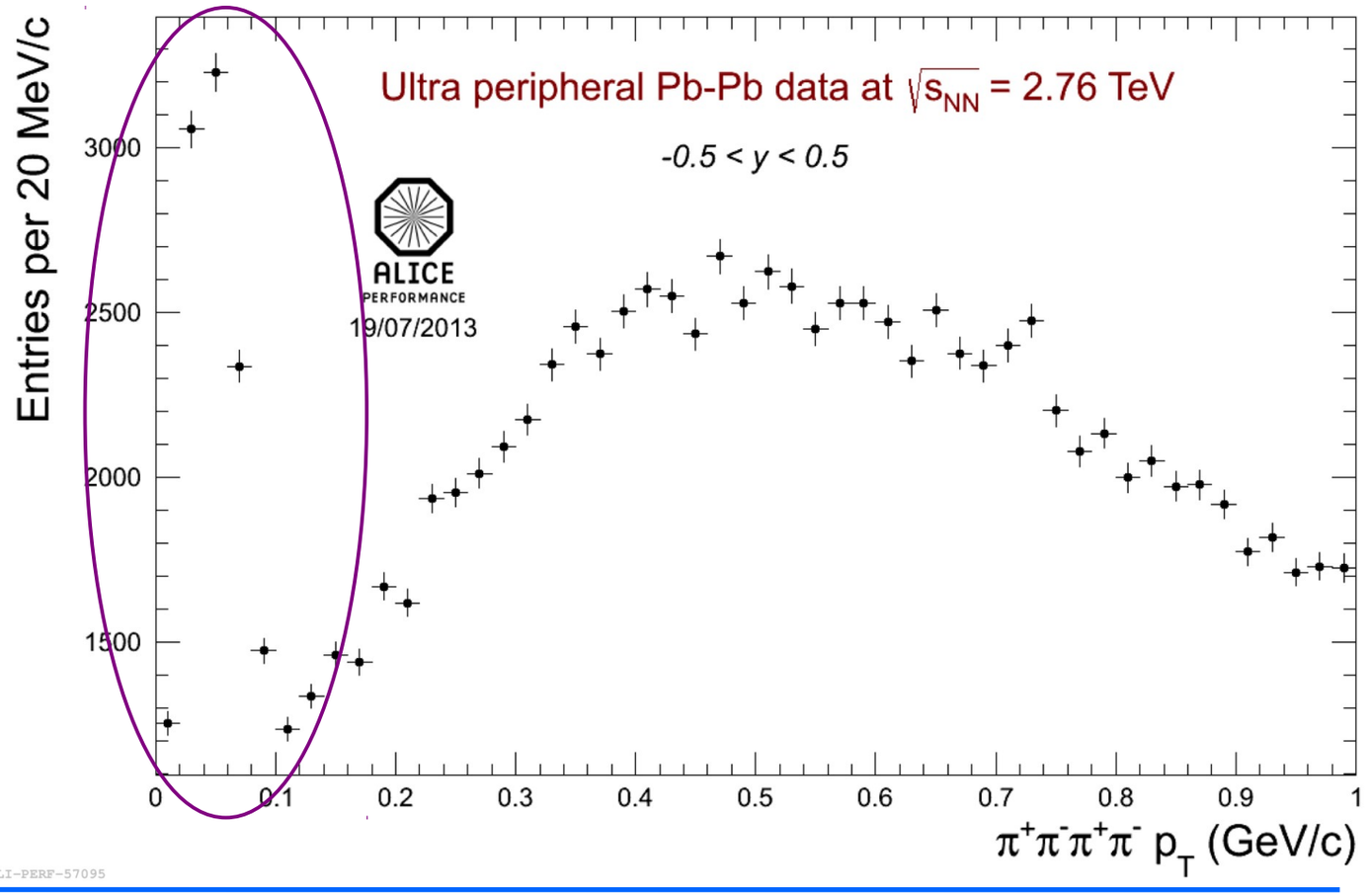
Why to look for excited states of ρ^0 in photo-production with Pb+Pb and p+Pb data?

- ✧ Not clear how many excited states exist, or their possible quantum number (see special PDG review)
- ✧ STAR already published a paper on four-pion production in UPC
- ✧ No HERA papers on the photo-production of a ρ^0 excited state

Clear coherent four-pion

10 times more statistics than in STAR

Phys. Rev C 81 1:044901, 2010



Summary on UPC analyses at ALICE

ALICE is the first LHC experiment (so far the only) to provide results on ultra-peripheral collisions

Exploring novel kinematic regimes
potential for new discoveries

UPC from Pb-Pb: ***Agreement with models including moderate nuclear gluon shadowing in J/ψ***

- Coherent J/ψ at forward rapidity

  Phys.Lett. B718 (2013) 1273-1283

- Coherent/incoherent J/ψ at mid-rapidity, and γγ

  arXiv:1305.1467 [nucl-ex]

- Other ongoing analyses at mid-rapidity
  - ρ^0 photoproduction
  - Exclusive four-pion photoproduction

UPC from p-Pb: ***Good agreement on J/ψ photoproduction from previous experiments at <W> ~ 30 GeV***

- First results on exclusive J/ψ in γp and γγ
- Results at higher energies 578 < $W_{\gamma p}$ < 972 GeV soon