Central Production in pp Collisions and ultra-peripheral PbPb Collisions, with ALICE

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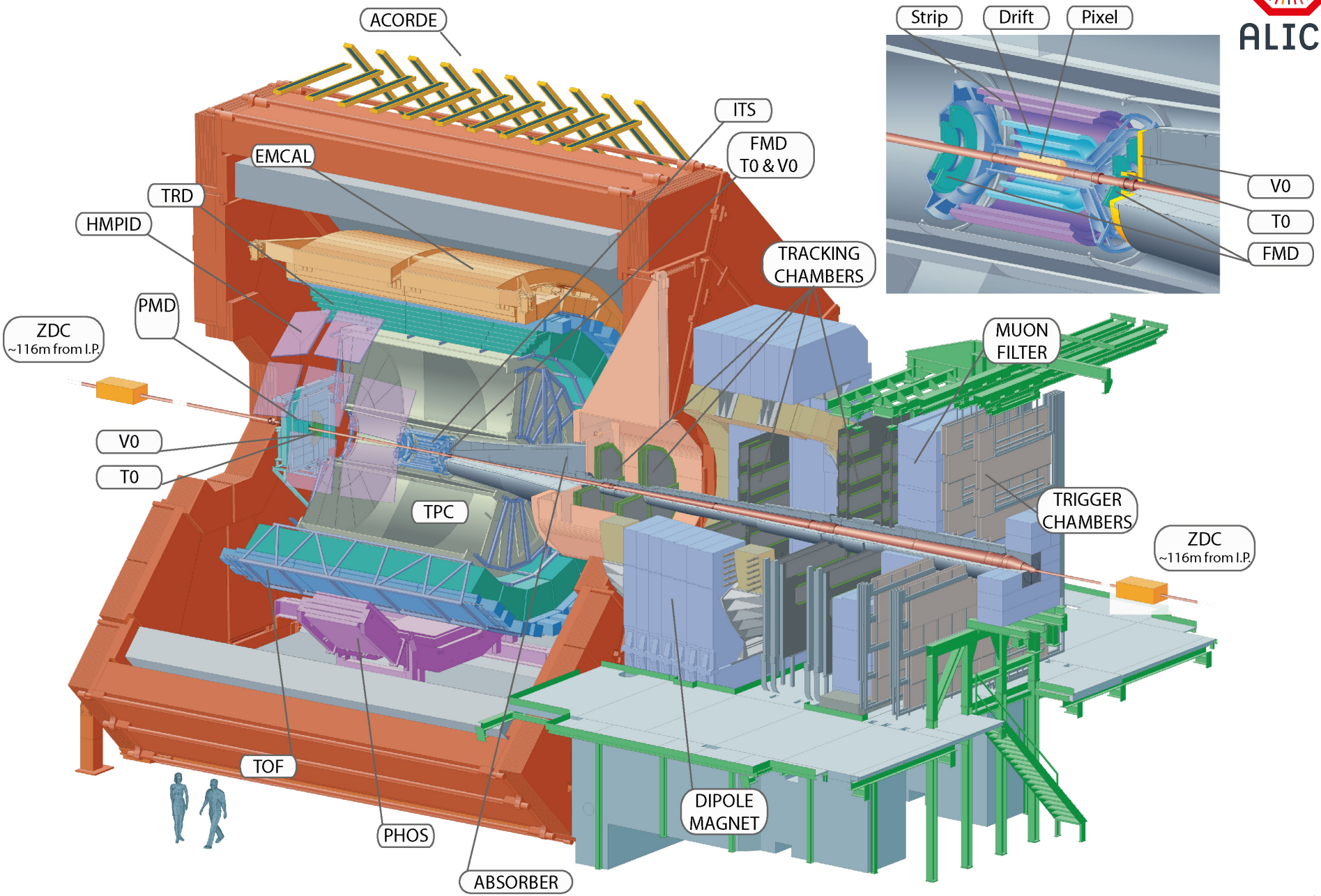
Introduction

Two main topics:

- Central production in pp collisions
  - Goal: study central diffraction
  - First step: we show that there is a signal of events with gaps
- UPC analyses in Pb-Pb collisions
  - ρ^0 production at central rapidity
  - J/Ψ: both at forward and central rapidities.

The ALICE Detector



Central Production in pp Collisions

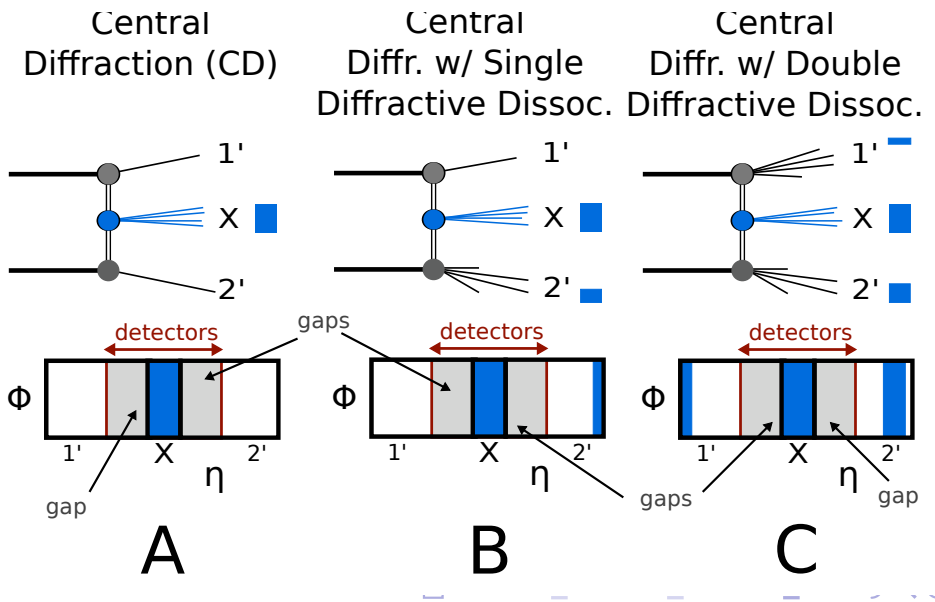
Motivation

We would like to study Central Diffraction (CD):

- CD is a relevant part of the hadronic cross section
- Reggeon contribution to double-gap events expected to be much reduced at the LHC as compared to ISR measurements
- study the overlap of Regge theory and perturbative QCD
- many open questions in double-Pomeron physics:
  - cross sections, nature of the Pomeron

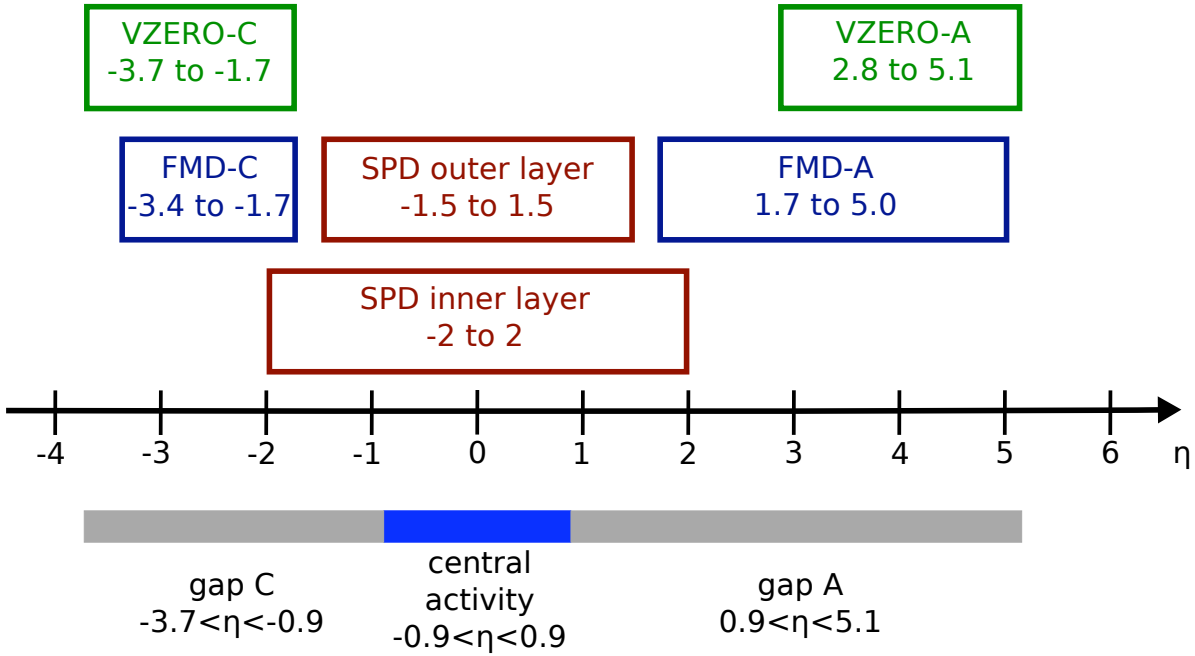
First step: double-gap events in pp collisions:

- double-gap topology is a filter for central diffraction
- all three reaction channels (A,B,C) contribute
- using topology cuts alone Pomeron, Reggeon, Photon exchanges cannot be distinguished



Central Production in pp Collisions

Double-gap definition



continuous coverage for charged particles $-3.7 < \eta < 5.1$, track $p_T > 20$ MeV/c

Selection Criteria for the Double-Gap Topology:

- activity in the central barrel ($-0.9 < \eta < 0.9$)
  detector: SPD, requirement of ≥ 1 hits in SPD
- two gaps (inactivity) outside of the central barrel
  (A-side: $0.9 < \eta < 5.1$, C-side: $-3.7 < \eta < -0.9$)
  detectors: VZERO,FMD,SPD

Central Production in pp Collisions

Data Analysis

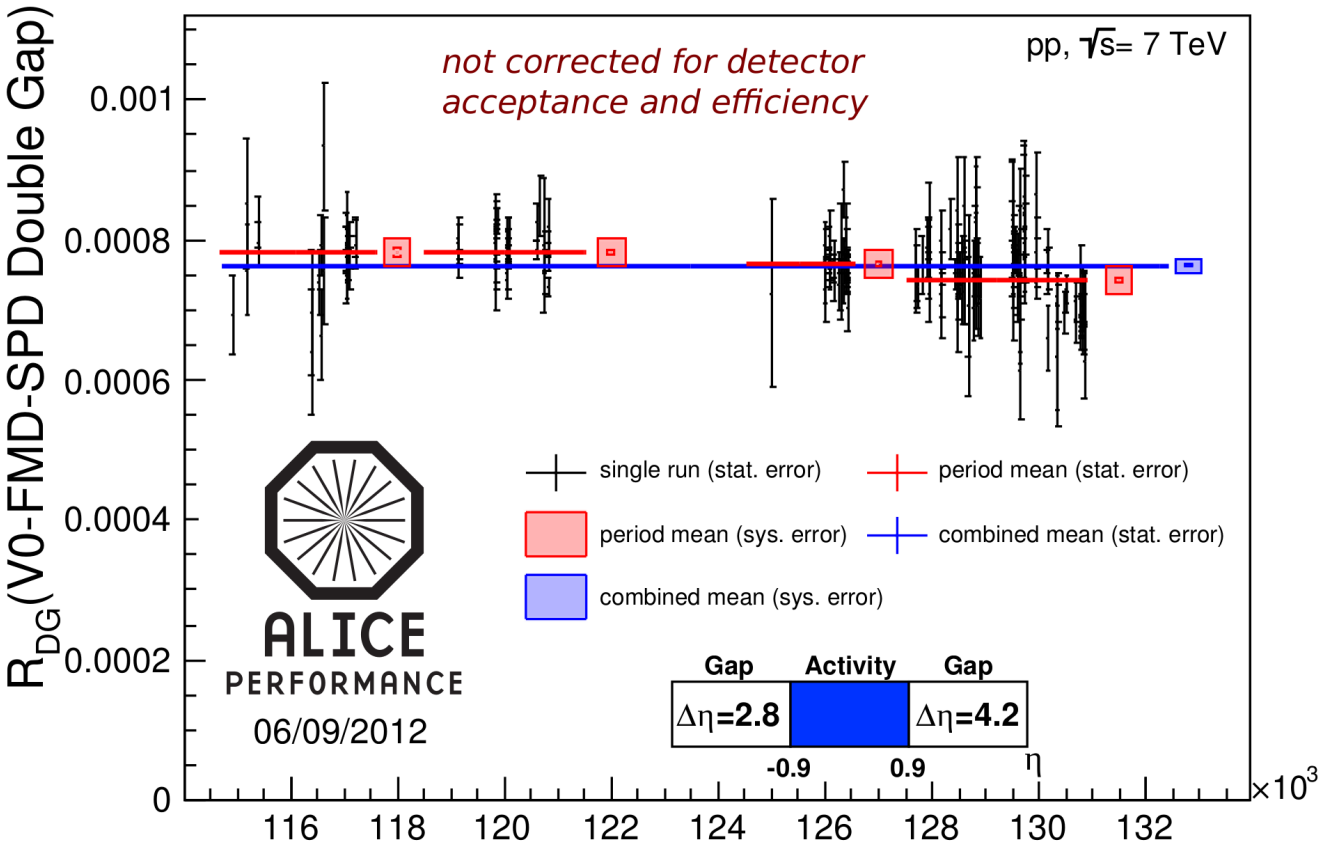
- minimum-bias proton-proton data at $\sqrt{s} = 7$ TeV, taken in 2010
- low luminosity and low pile-up data sample
- minimum-bias trigger (MBOR): logical OR composed of VZERO-A and VZERO-C and Pixel-Trigger
- luminosity determination by van-der-Meer scans using the logical AND of VZERO-A and VZERO-C triggers signals, called MBAND, available
- monitoring of the gap-fraction for all detectors run-by-run and rejection of runs deviating more than three sigmas from the data-taking period mean

Error Estimation

missing the central activity due to acceptance and inefficiency	≈5%
missing a charged particle in the gap region	5%
uncorrelated error estimated from the spread of the data-taking period means:	1.4%

Central Production in pp Collisions

Double-gap Fraction



systematic error estimated from the spread of the period means, doesn't include detector effects

$$R_{DG} \equiv \frac{N_{DG}}{N_{MBAND}} = \left(7.63 \pm 0.02_{\text{stat.}} \pm 0.87_{\text{comb. syst.}}\right) \times 10^{-4}$$

Very uniform behavior; no apparent influence of run conditions

Ultra-peripheral Pb-Pb Collisions

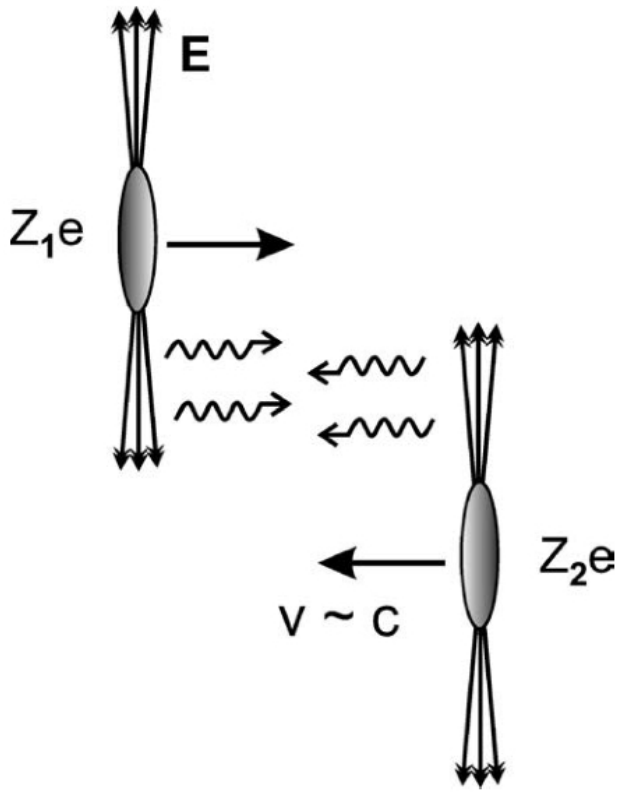
Motivation

- Ultra-peripheral collisions (UPC): impact parameter $b > 2R_A$
  $\longrightarrow$ hadronic interactions are strongly suppressed
  $\longrightarrow$ electro-magnetic interactions
- UPC interactions:
  - Photon-Nucleus, *e.g.* PbPb $\rightarrow$ PbPb + J/Ψ, PbPb $\rightarrow$ PbPb + ρ^0
  - Photon-Photon, *e.g.* $\gamma\gamma \rightarrow e^+e^-$
- Strong electromagnetic field around lead ions:
  number of photons $\sim Z^2$
- J/Ψ: photons probe the color sub-structure of nucleons
  - allows to study the gluon-distribution $g(x, q^2)$ in the Pb-Pb system
  - Accessible partonic momentum fractions $x \sim 10^{-2}$–10^{-5}
  - Gluon shadowing
- ρ^0: photons *do not* see the color sub-structure of nucleons
  - disambiguation between models with different cross section predictions
- $\gamma\gamma$: can constrain the size of perturbative higher order corrections

Ultra-peripheral Pb-Pb Collisions

Exclusive Vector Meson Production

- Coherent
  - Photon couples coherently to all the nucleons
  - $\langle p_T \rangle \sim 60$ MeV/c
  - target nucleus normally[a] does not break up
- Incoherent
  - Photon couples to a single nucleon
  - $\langle p_T \rangle \sim 500$ MeV/c
  - target nucleus normally[a] does break up



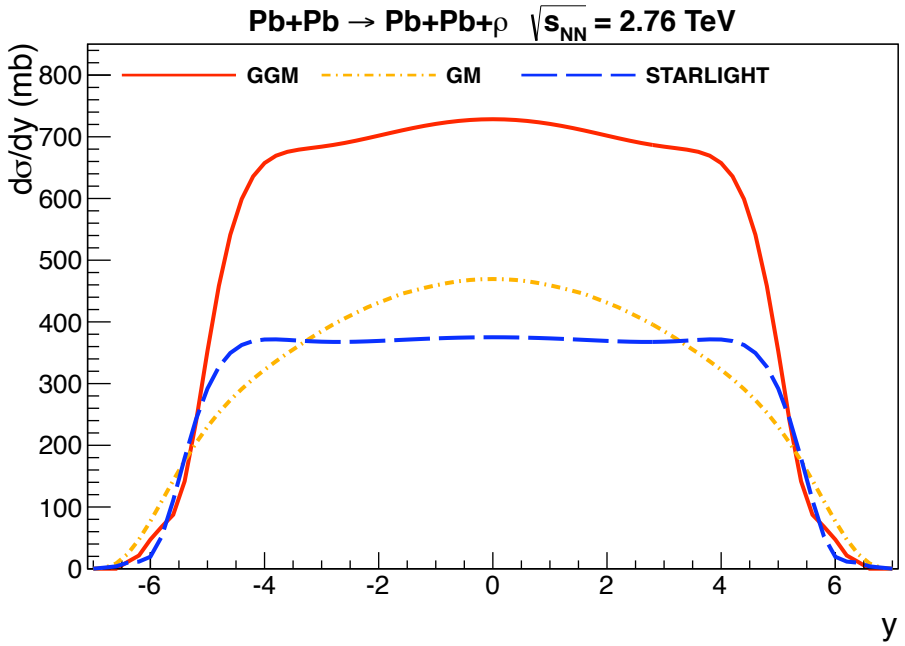
[a] in $\approx 80\%$ of the events

ρ^0 photo-production in Pb-Pb

Motivation

There are several models for ρ^0 photo-production in Pb-Pb at the LHC:

- Frankfurt, Strikman, Zhalov (GGM), Phys. Lett. B 537 (2002) 51; Phys. Rev. C 67 (2003) 034901.
- Gonçalves, Machado (GM), Phys. Rev. C 84 (2011) 011902.
- Klein, Nystrand (STARLIGHT), Phys. Rev. C 60 (1999) 014903, http://starlight.hepforge.org/
- Szczurek et al. work in progress



Predictions at $y = 0$ at the LHC (Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV)

- GGM: 720 mb
- GM: 470 mb
- STARLIGHT: 380 mb

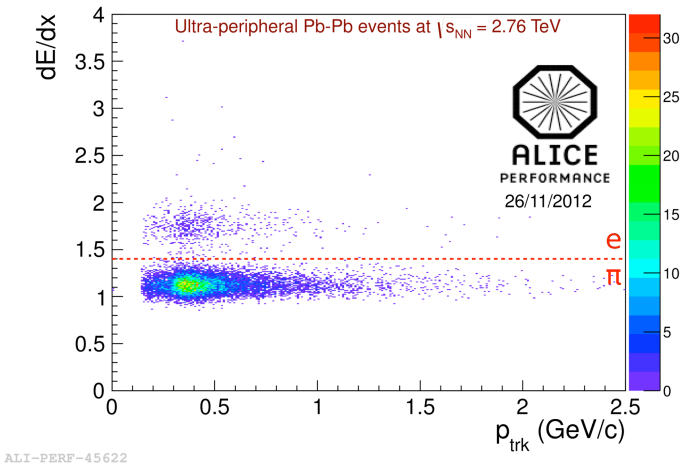
ρ^0 photo-production in Pb-Pb

Data Selection

Data Sample: 2010 Pb-Pb, 2.76 TeV, $\mathcal{L}^{\text{int.}} \sim 0.2\ \mu\text{b}^{-1}$

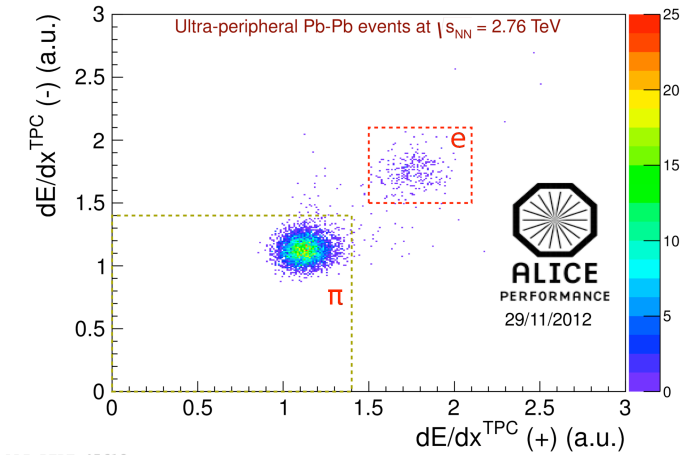
Trigger:

- Veto in VZERO-C ($2.8 < \eta < 5.1$)
- Veto in VZERO-A ($-3.7 < \eta < -1.7$)
- $N \geq 2$ hits in SPD
- $N \geq 2$ fired trigger pads in TOF



Offline Event Selection:

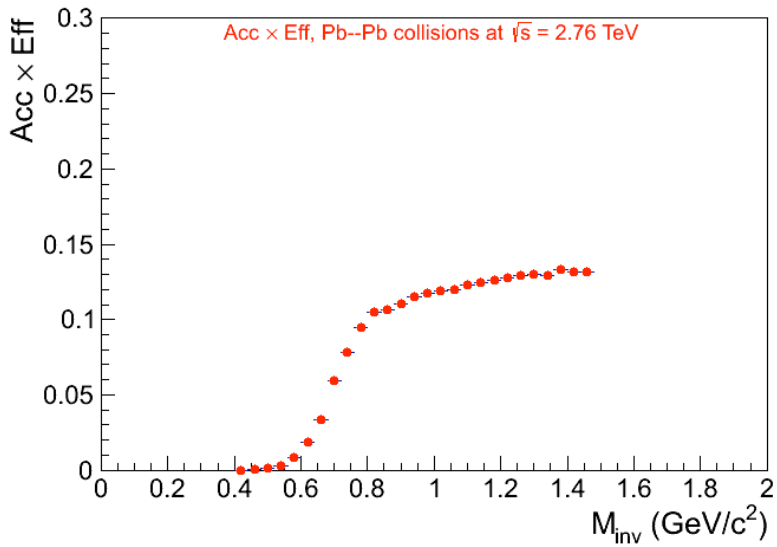
- Vertex: $|v_z| < 10$ cm
- Two good tracks, Pion PID using TPC dE/dx
- Kinematic Cuts:
  - two-pion rapidity $|y| < 0.5$
  - pair-$p_T < 0.15$ (coherent)
- Opposite-sign events: signal,
  Like-sign events: background



ρ^0 photo-production in Pb-Pb

Acc. $\times$ Eff. estimation

- We use a MC generator which is flat in invariant mass:
  - flat $m_{inv} \in [2 \cdot m_\pi,\ 1.5\ \mathrm{GeV}/c^2]$
  - flat $p_T \in [0,\ 0.15]$ GeV/c
  - flat $Y \in [-0.5,\ 0.5]$
  - $\frac{d\theta}{d\cos\theta} \sim \sin^2\theta$
- The correction is performed for each bin in invariant mass
- Optional: binning in pair-rapidity in addition to invariant mass



ρ^0 photo-production in Pb-Pb

Shape of the minv spectrum

The acc. $\times$ eff. corrected minv spectrum is fitted using

$$\frac{\mathrm{d}\sigma}{\mathrm{d}m_{\pi\pi}} = \left| A \frac{\sqrt{m_{\pi\pi} M_{\rho^0} \Gamma(m_{\pi\pi})}}{m_{\pi\pi}^2 - M_{\rho^0}^2 + i M_{\rho^0} \Gamma(m_{\pi\pi})} + B \right|^2$$

with minv-dependent width:

$$\Gamma(m_{\pi\pi}) = \Gamma_{\rho^0} \frac{M_{\rho^0}}{m_{\pi\pi}} \left(\frac{m_{\pi\pi}^2 - 4m_\pi^2}{M_{\rho^0}^2 - 4m_\pi^2} \right)^{3/2}$$

- A is the amplitude of the Breit-Wigner function
- B is the amplitude of the non-resonant continuum $\pi^+\pi^-$ production

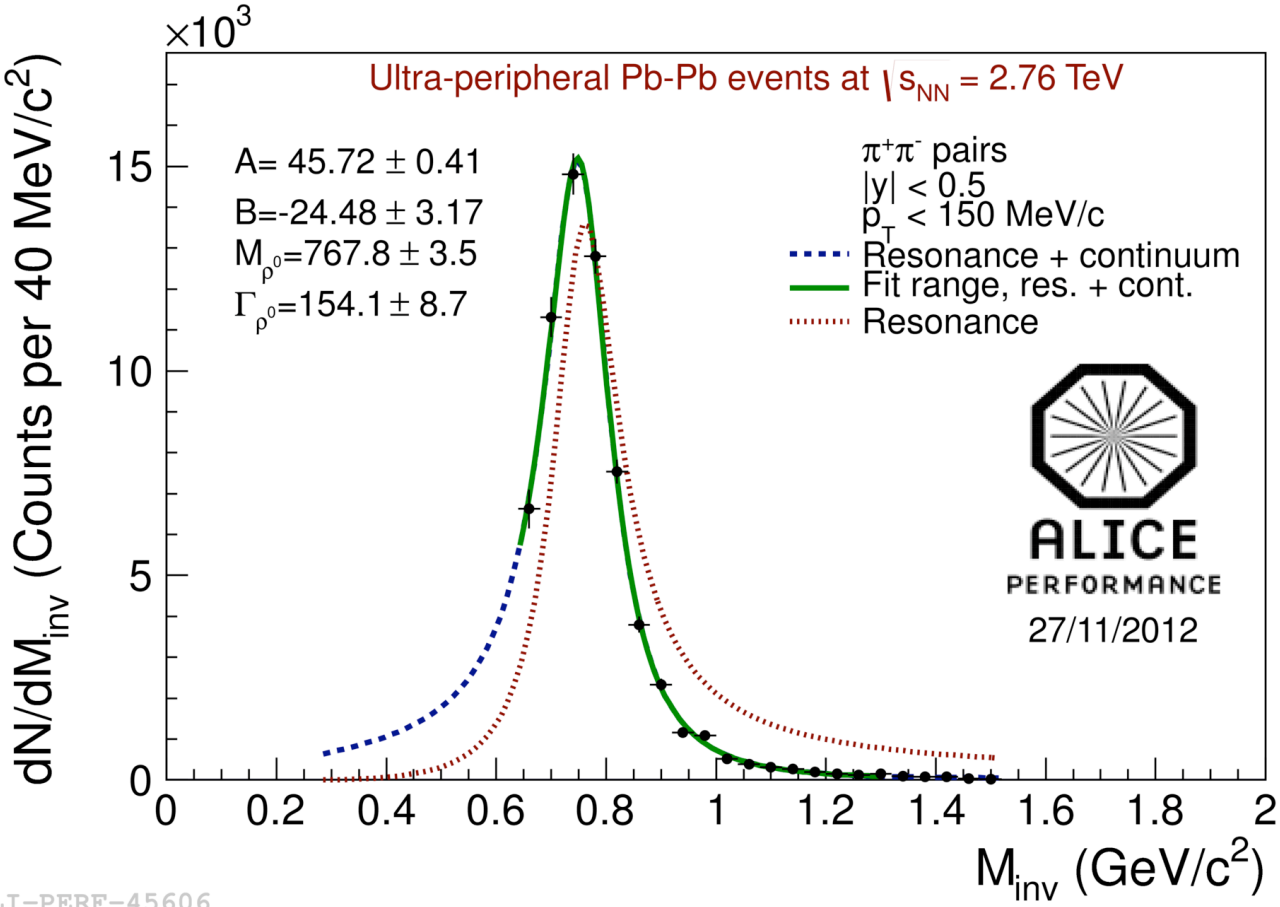
This formula was previously used by the STAR[1] and H1[2] collaborations

[1] Phys. Rev. C 77 (2008) 034910

[2] Nucl. Phys. B436 (1996) 3

ρ^0 photo-production in Pb-Pb

Acc×eff corrected minv spectrum

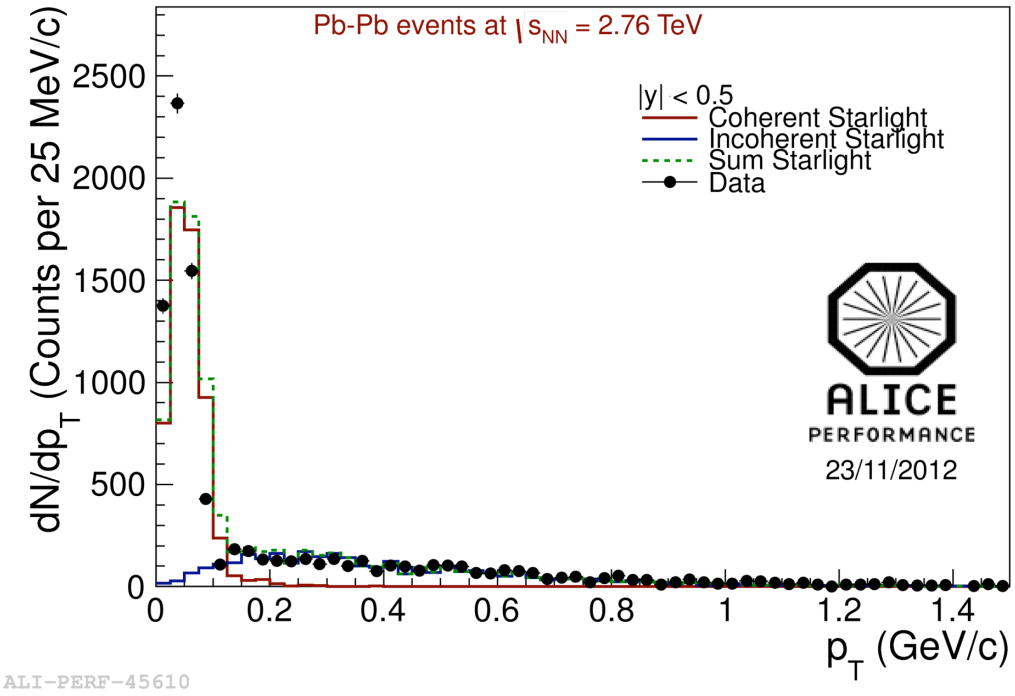


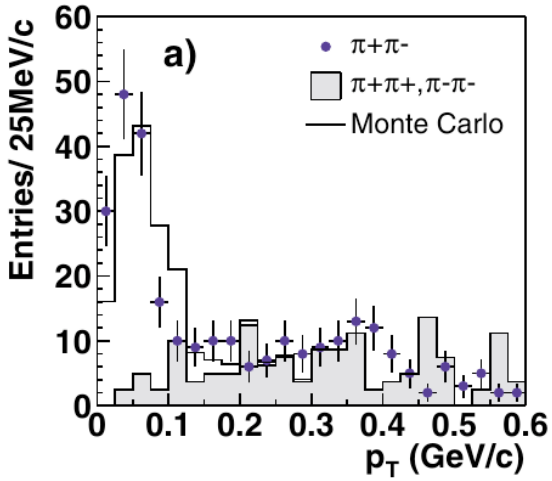
PDG: $M_{\rho^0} = (775.49 \pm 0.34)$ MeV/c^2, $\Gamma_{\rho^0} = (149.1 \pm 0.8)$ MeV/c^2.

The absolute cross section will be released soon.

ρ^0 photo-production in Pb-Pb

Subtraction of incoherent contribution





- coherent/incoherent template-pair-p_T distributions: from STARLIGHT
- data are narrower than MC
- same observation was made at RHIC

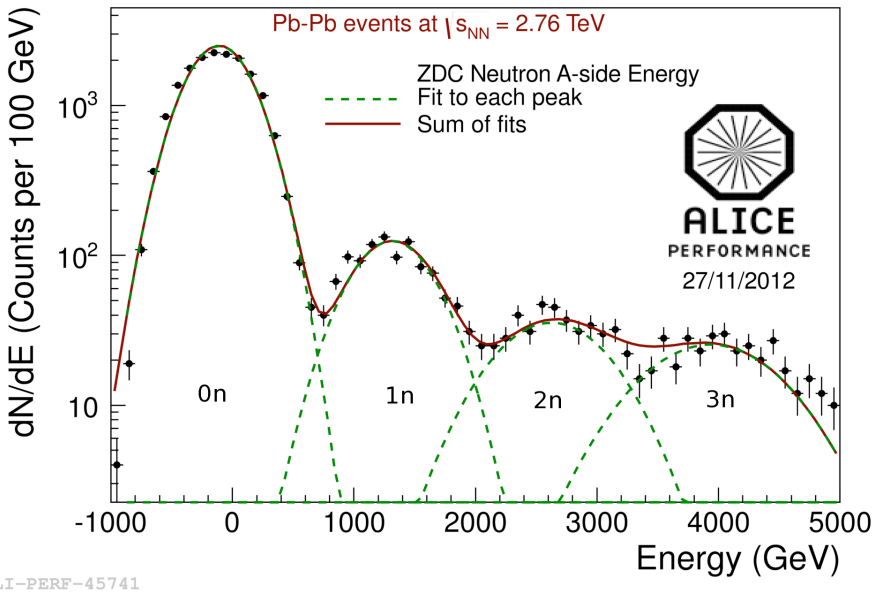
p_T distribution for photo-nuclear ρ^0 production at RHIC. (STAR collaboration Phys. Rev. Lett. 89 (2002) 272302)

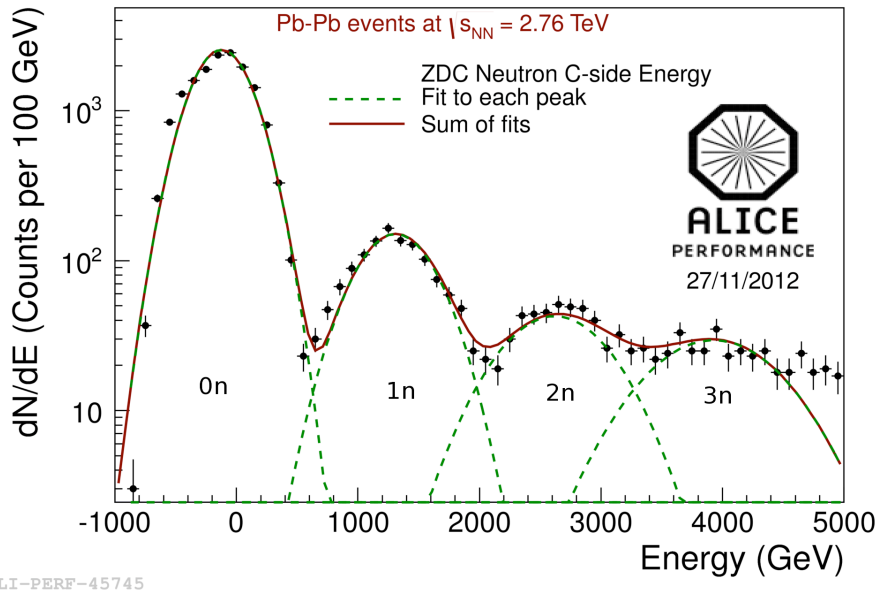
Result: $\approx$ 7 % contribution from incoherent events with pair-p_T $<$ 150 MeV/c

ρ^0 photo-production in Pb-Pb

Nuclear Breakup

- Exchange of additional photons may lead to coherent vector meson production in coincidence with nuclear break up[3]
- The ALICE zero-degree calorimeters (ZDC) can measure single neutron emission:





[3] Baltz, Klein, and Nystrand, Phys. Rev. Lett. 89 (2002) 012301

ρ^0 photo-production in Pb-Pb

Nuclear Breakup – comparison with STARLIGHT

Modes:

0n0n:	No break up
Xn:	One or both nuclei break up
Xn0n:	One of the nuclei break up
XnXn:	Both nuclei break up

0n – no neutrons,

Xn – any number of neutrons ≥ 1

	Percentage, data	**Percentage, Starlight**
Total	100%	100%
0n0n	$(80.9 \pm 2.3$ (stat.))%	78.9%
Xn	$(19.1 \pm 0.9$ (stat.))%	21.1%
Xn0n	$(15.6 \pm 0.8$ (stat.))%	15.9%
XnXn	$(3.6 \pm 0.4$ (stat.))%	5.2%

Good agreement between data and STARLIGHT.

J/Ψ photo-production in Pb-Pb

Forward Rapidity

Data sample: 2011 Pb-Pb 2.76 TeV, $\mathcal{L}^{\text{int.}} \sim 55\ \mu\text{b}^{-1}$

Trigger:

- Single muon trigger with $p_T > 1$ GeV/c
- At least one hit in VZERO-C ($2.8 < \eta < 5.1$)
- No hits in VZERO-A ($-3.7 < \eta < -1.7$)

Beam gas and hadronic rejection:

- $<$ 6 neutrons in both zero-degree calorimeters ($\pm$ 116 m distance to IP)
- Veto on SPD activity at central rapidity

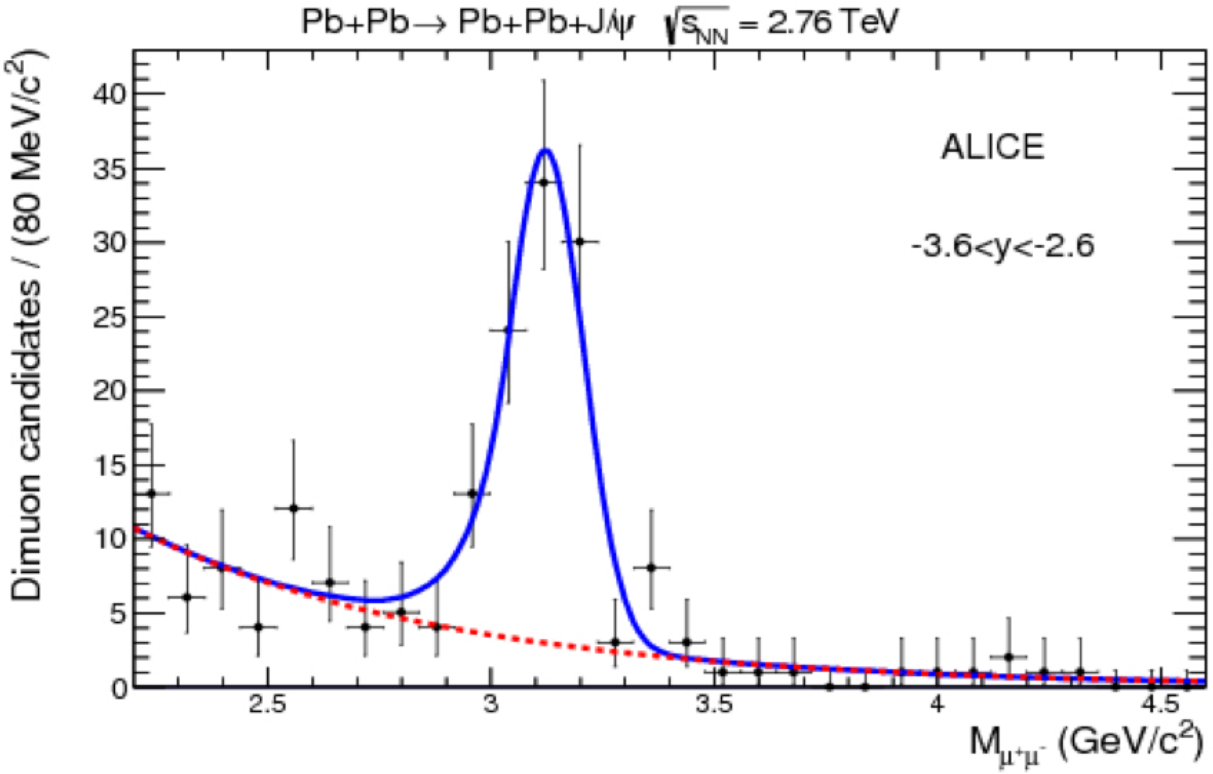
Offline event selection:

- Two reconstructed muon tracks with opposite charges
- p_T-dependent DCA cut
- Matching of one muon track with track of triggered muon
- Acceptance selection (dimuon) :
  $-3.6 < y < -2.6, \quad 2.8 < M_{\text{inv}} < 3.4\ \text{GeV}/c^2, \quad p_T < 0.3\ \text{GeV}/c$

Number of remaining J/Ψ candidates: **117**

J/Ψ photo-production in Pb-Pb

Forward Rapidity

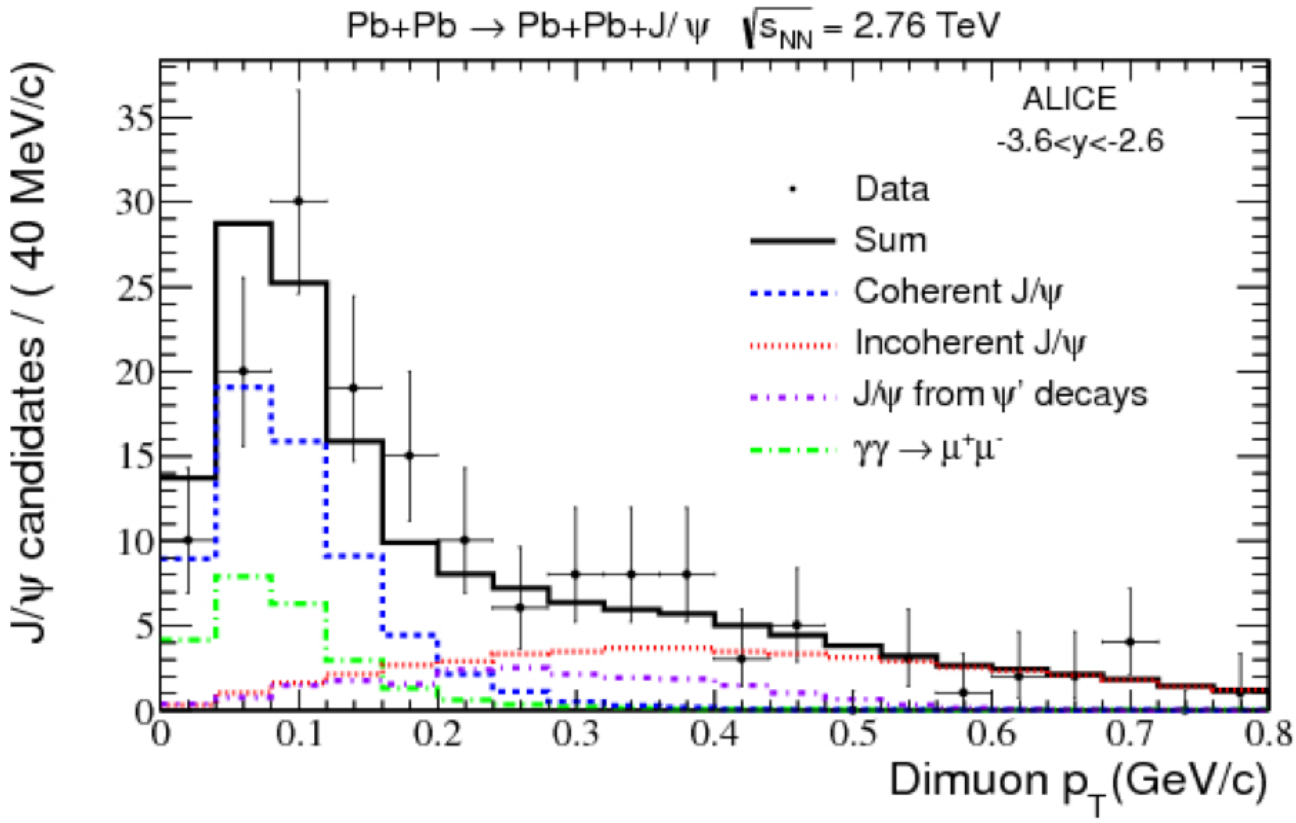


B. Abelev *et al.* (ALICE Collaboration) arXiv:1209.3715, accepted by *Phys. Lett. B*.

- Background from like-sign contribution: 2 events
- Fitting functions: Crystal Ball and exponential
- Exponential slope parameters
  data: $(-1.4 \pm 0.2)\ \mathrm{GeV}^{-1}c^2$, MC: $(-1.39 \pm 0.01)\ \mathrm{GeV}^{-1}c^2$

J/Ψ photo-production in Pb-Pb

Forward Rapidity



B. Abelev *et al.* (ALICE Collaboration) arXiv:1209.3715, accepted by *Phys. Lett. B*.

Four physics processes:
coherent+incoh. J/Ψ, feed-down from Ψ′ decays, $\gamma\gamma \to \mu^+\mu^-$

J/Ψ photo-production in Pb-Pb

Forward Rapidity

$$\frac{\mathrm{d}\sigma^{\mathrm{coh}}_{\mathrm{J}/\Psi}}{\mathrm{d}y} = \frac{1}{\mathrm{BR}\left(\mathrm{J}/\Psi \to \mu^+\mu^-\right)} \cdot \frac{N^{\mathrm{coh}}_{\mathrm{j}/\Psi}}{N_{\gamma\gamma}} \cdot \frac{\left(\mathrm{Acc} \times \epsilon\right)_{\gamma\gamma}}{\left(\mathrm{Acc} \times \epsilon\right)_{\mathrm{J}/\Psi}} \cdot \frac{\sigma_{\gamma\gamma}}{\Delta y}$$

The QED process $\gamma\gamma \to \mu^+\mu^-$ is used for cross section normalization:

- uncertainties from minimum momentum transfer and nuclear form factor
- higher order terms: coupling is $Z\sqrt{\alpha}$

Theoretical uncertainty of $\gamma\gamma \to \mu^+\mu^-$: 20%

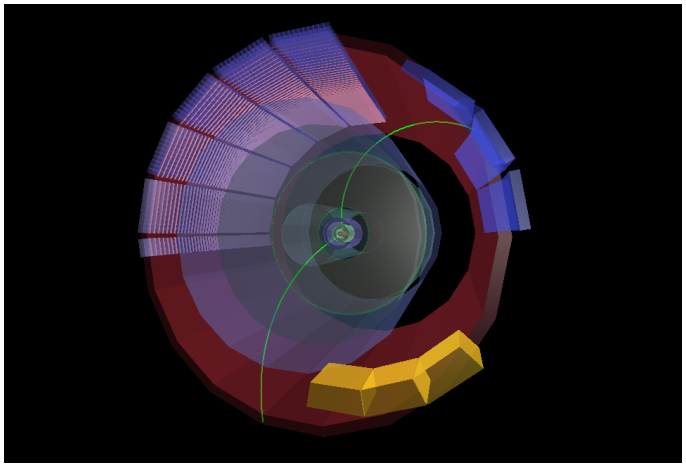
Result:

$$\frac{\mathrm{d}\sigma^{\mathrm{coh}}_{\mathrm{J}/\Psi}}{\mathrm{d}y} = \left(1.00 \pm 0.18(\mathrm{stat}) \ {}^{+0.24}_{-0.26}(\mathrm{syst})\right) \mathrm{mb} \ ,$$

$$-3.6 < y < -2.6 \ , \quad p_T^{\mu^+\mu^-} < 0.3 \ \mathrm{GeV}/c$$

J/Ψ photo-production in Pb-Pb

Central Rapidity



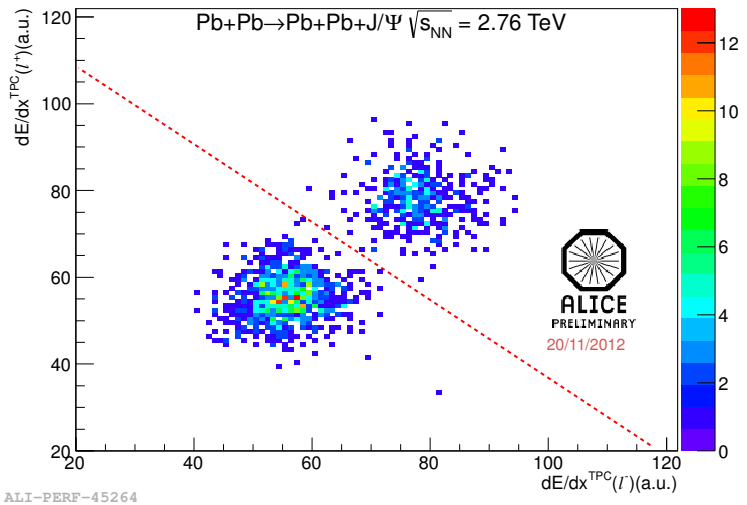
Data set: 2011 PbPb data, $\mathcal{L}^{\text{int}} \sim 20\ \mu\text{b}^{-1}$

Trigger:

- Veto on VZERO-A and VZERO-C
- ≥ 2 hits in SPD
- $2 \leq N \leq 6$ fired trigger pads in TOF and topology $150° \leq \Delta\phi \leq 180°$

Beam gas suppression:

- Absence of V0 signal in offline time window (wider than online time window)
- p_T-dependent DCA cut

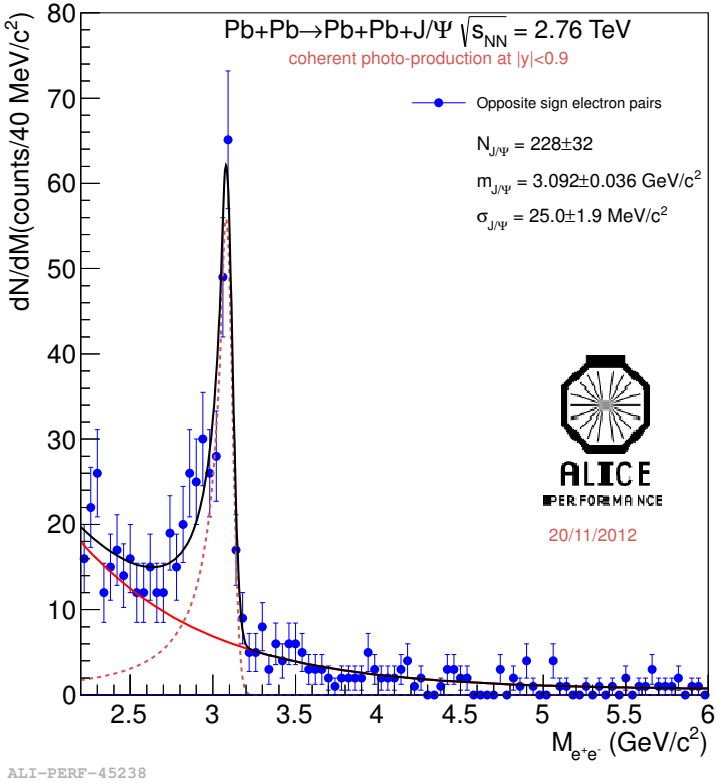


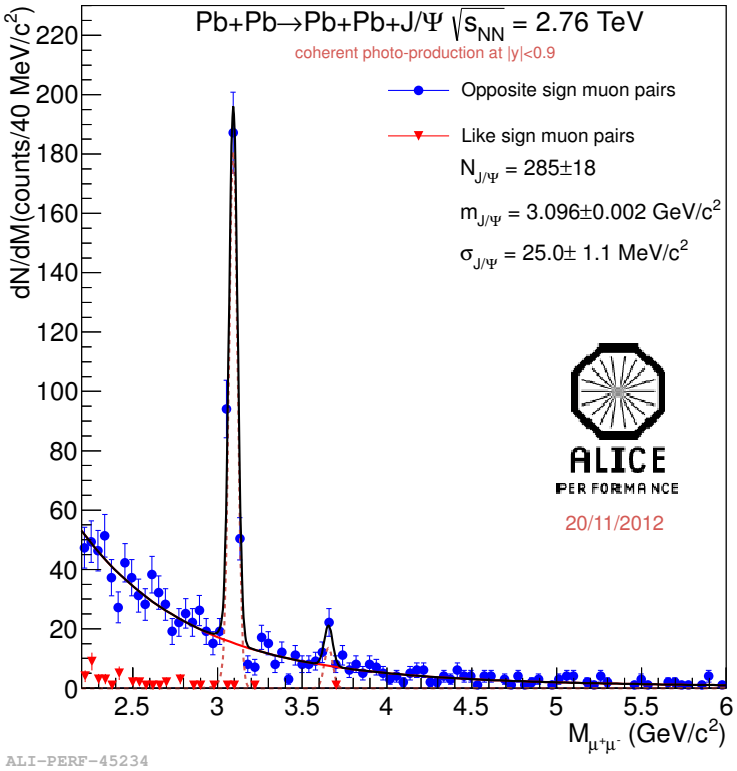
Event Selection:

- Exactly two tracks passing track quality cuts
- $\mathrm{d}E/\mathrm{d}x$ for the two tracks compatible with muon/electron $\mathrm{d}E/\mathrm{d}x$

J/Ψ photo-production in Pb-Pb

Central Rapidity – coherent



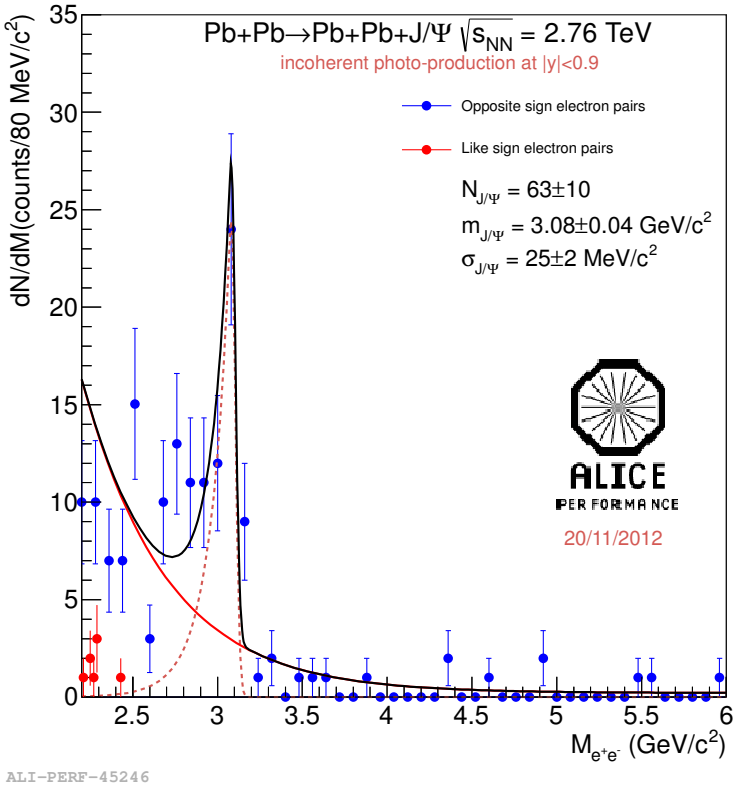


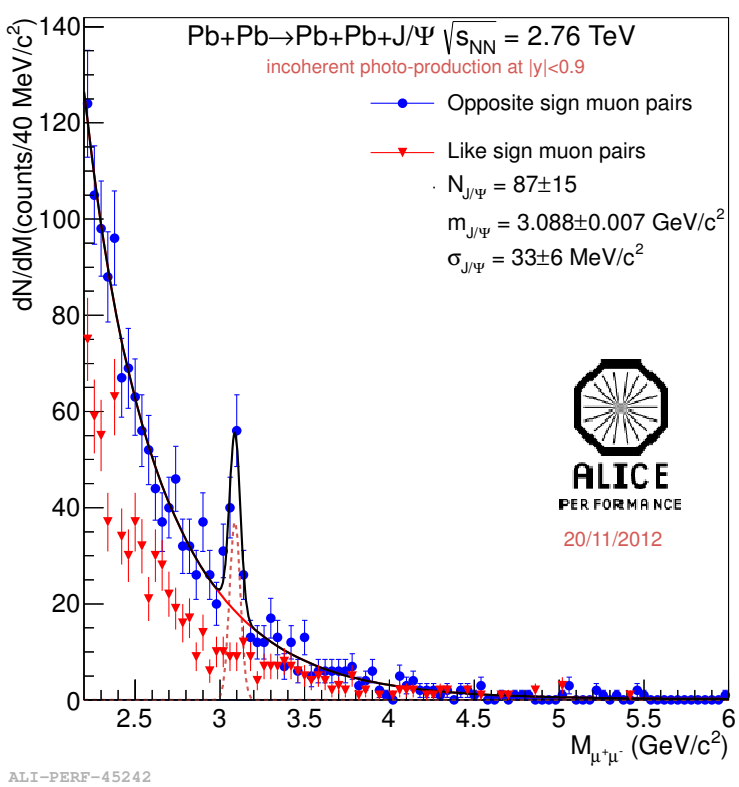
Left: di-electron channel, Right: dimuon channel.

- Fit: Crystal Ball + exponential
- Coherent: pair-p_T(J/Ψ) $<$ 200 MeV/c (dimuon),
  pair-p_T(J/Ψ) $<$ 300 MeV/c (di-electon)

J/Ψ photo-production in Pb-Pb

Central Rapidity – incoherent



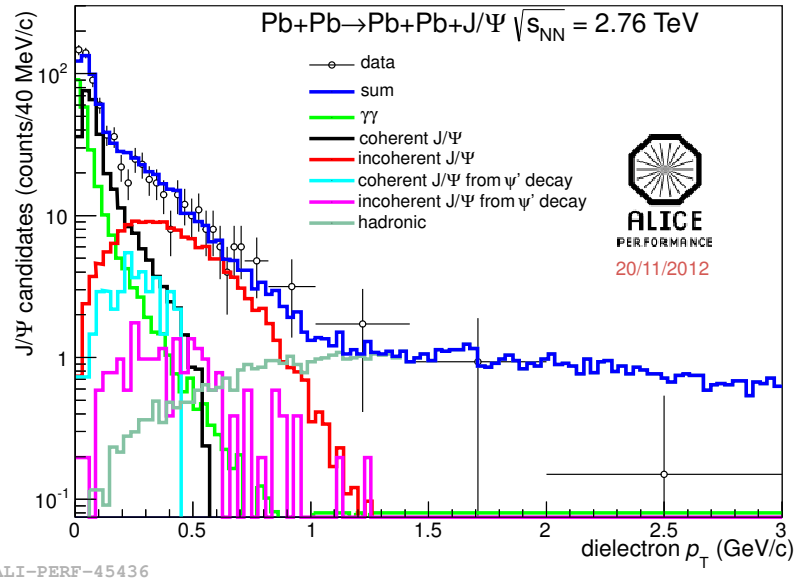


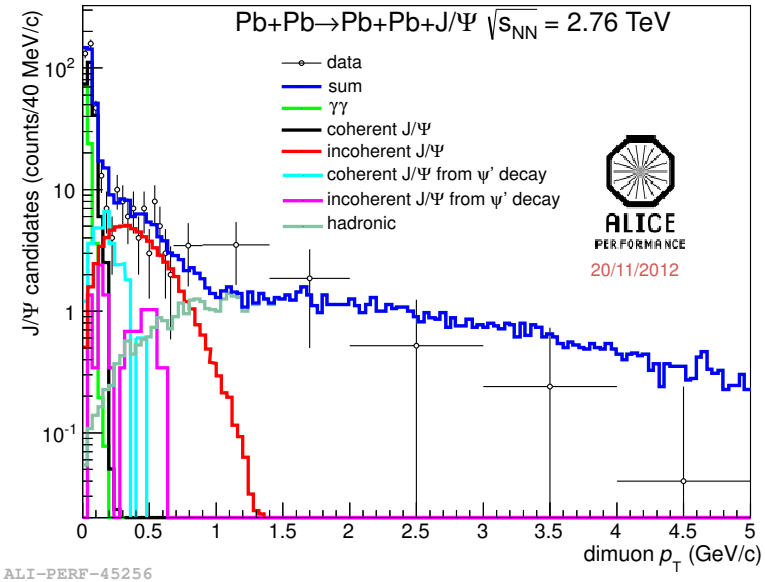
Left: di-electron channel, Right: dimuon channel.

- Fit: Crystal Ball + exponential
- Incoherent: pair-p_T(J/Ψ) $>$ 200 MeV/c (dimuon),
  pair-p_T(J/Ψ) $>$ 300 MeV/c (di-electron)

J/Ψ photo-production in Pb-Pb

Central Rapidity - pair-p_T





Left: di-electron channel, Right: dimuon channel.

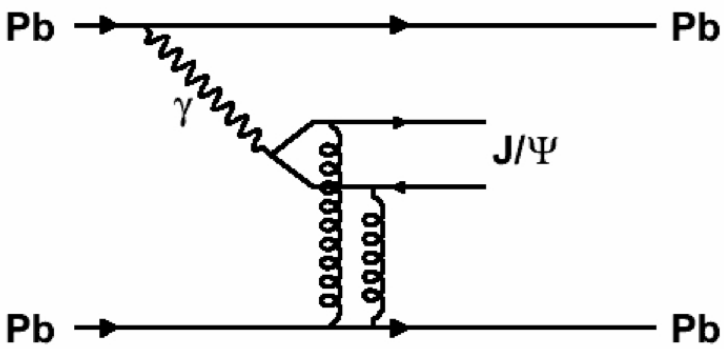
6 Components:

- coherent+incoherent J/Ψ
- feed-down from coherent+incoherent Ψ′-decay
- hadronic J/Ψ events, and continuum $\gamma\gamma \rightarrow e^+e^-(\mu^+\mu^-)$

J/Ψ photo-production in Pb-Pb

Predictions for exclusive J/Ψ production at LHC

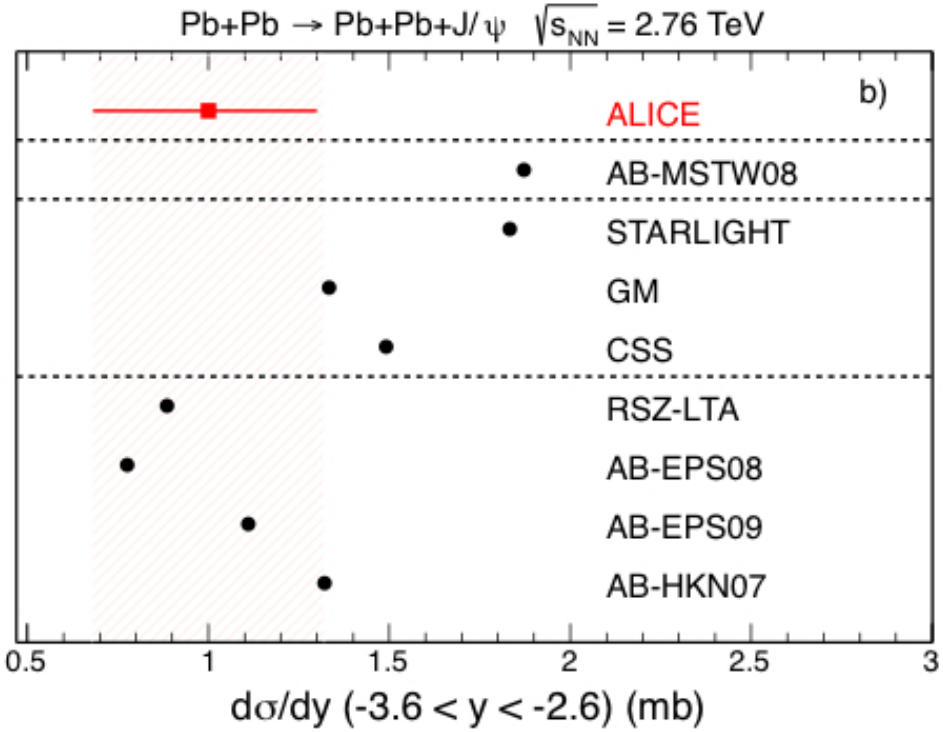
$$PbPb \rightarrow PbPb + J/\Psi$$



- S. Klein, J. Nystrand (STARLIGHT), *Phys. Rev.* C60 (1999) 014903.
- Adeluyi and Bertulani (AB), *Phys. Rev.* C85 (2012) 044904.
- Gonçalves and Machado (GM), *Phys. Rev.* C84 (2011) 011902.
- Cisek, Szczurek, Schäfer (CSS), *Phys. Rev.* C86 (2012) 014905.
- Rebyakova, Strikman, Zhalov (RSZ), *Phys. Lett.* B 710 (2012) 252.

J/Ψ photo-production in Pb-Pb

Comparison to models – forward rapidity / 1

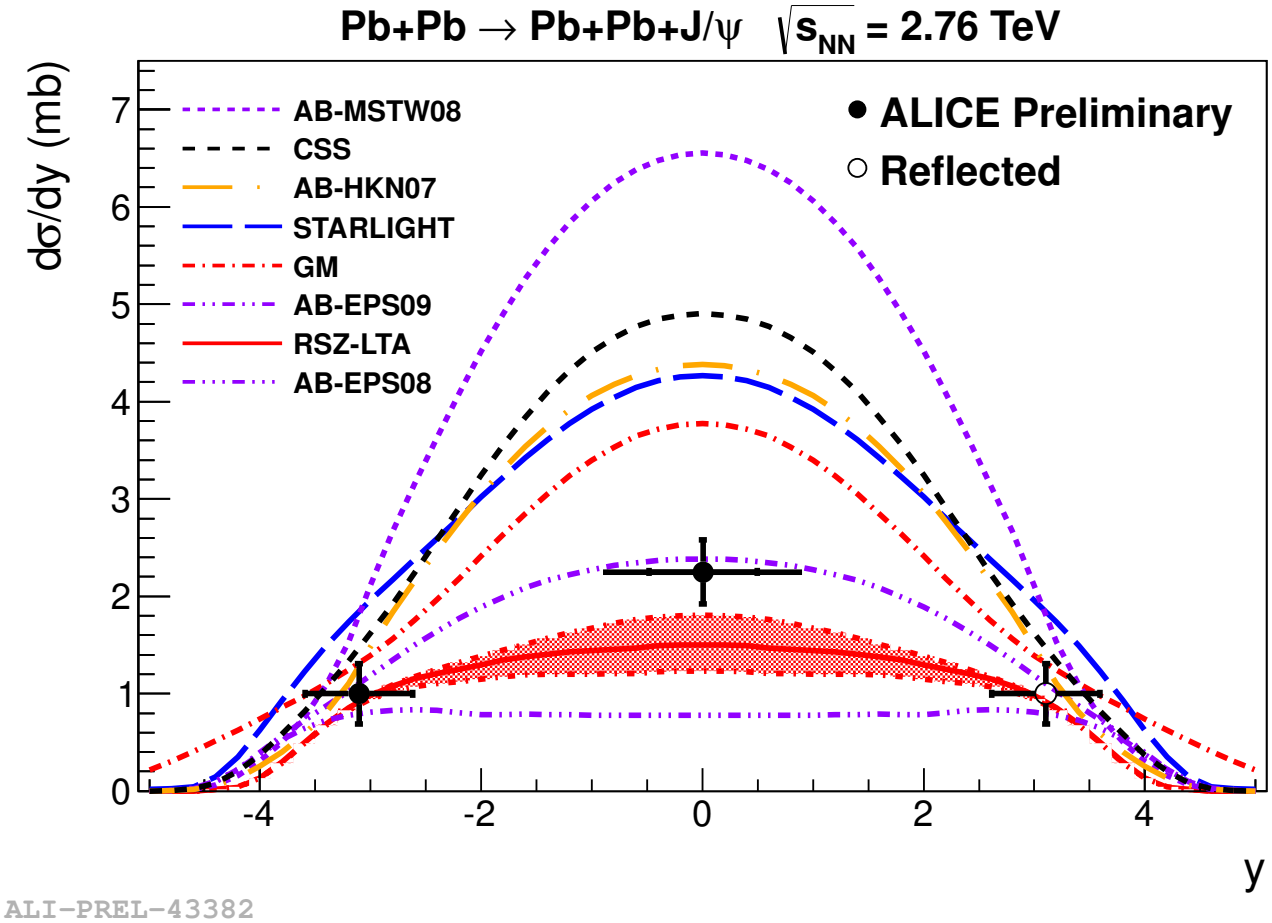


B. Abelev *et al.* (ALICE Collaboration) arXiv:1209.3715, accepted by *Phys. Lett. B*.

- No nuclear effects: AB-MSTW08
- Glauber approach: STARLIGHT, GM, CSS
- Partonic models: RSZ-LTA, AB-EPS08,09, AB-HKN07

J/ψ photo-production in Pb-Pb

Comparison to models – forward rapidity / 2



- Differences between models: gluon shadowing, use of Glauber models
- Central rapidity: better discrimination power; **preliminary result**

Conclusions/Outlook

Conclusions

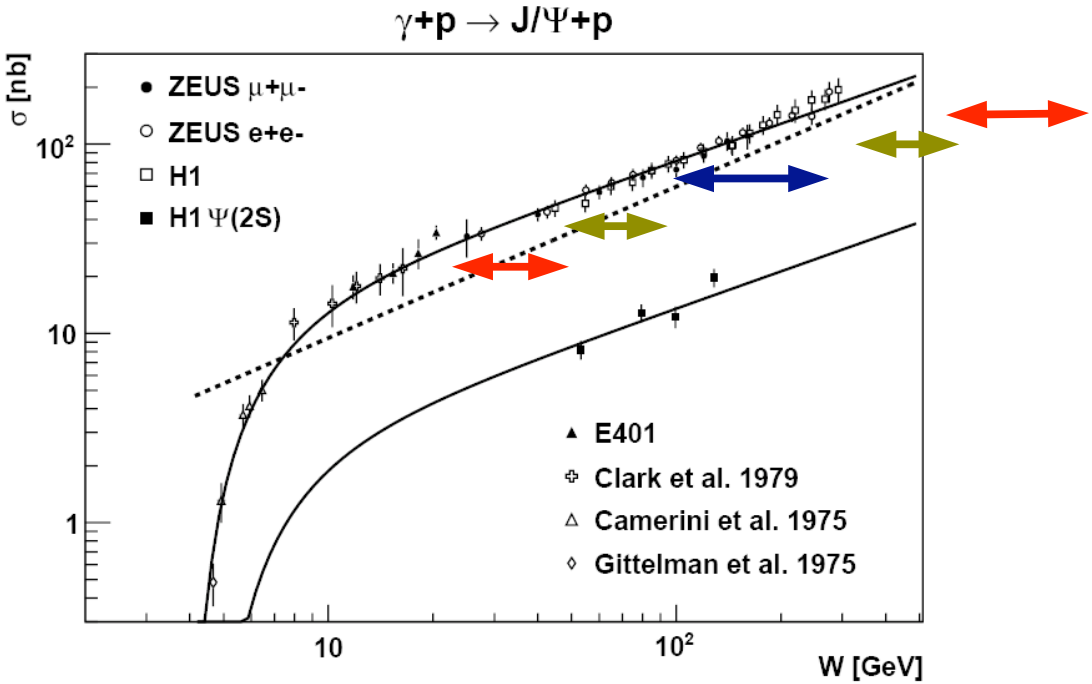
- Central production in pp collisions:
  We have measured the rate of double-gap events
- Ultra-peripheral Pb-Pb collisions:
  - Pb+Pb $\rightarrow$ Pb+Pb + J/Ψ (at forward and at central rapidity)
    cross section measurements
  - Pb+Pb $\rightarrow$ Pb+Pb + ρ^0 (at central rapidity)
    nuclear breakup is consistent with STARLIGHT prediction

Outlook

- Central production in pp
  - we are now studying the properties of the centrally produced system
- Results to be *soon* released:
  - J/Ψ and ρ^0 cross sections at central rapidity
  - Measurement of $\gamma\gamma \rightarrow e^+e^-$ cross section

Outlook: p-Pb collisions in 2013

Plot provided by Joakim Nystrand



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

Measurement of J/Ψ production **over a wide range in Bjorken-x** will be possible