Coherent photo-production of ρ^0 mesons in ultra-peripheral Pb+Pb collisions at the LHC, measured by ALICE

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13th International Workshop on
Meson Production, Properties and Interaction
Kraków, Poland

Overview

Two main topics:

- Coherent photo-production of ρ^0 in Pb-Pb
  - There are several model predictions varying by a factor ≈ 2
  - Nuclear breakup in coincidence with photo-production
- Two-photon production of electron pairs in Pb-Pb
  - QED process
  - Measurements can constrain higher-order corrections

Ultra-peripheral Pb-Pb Collisions

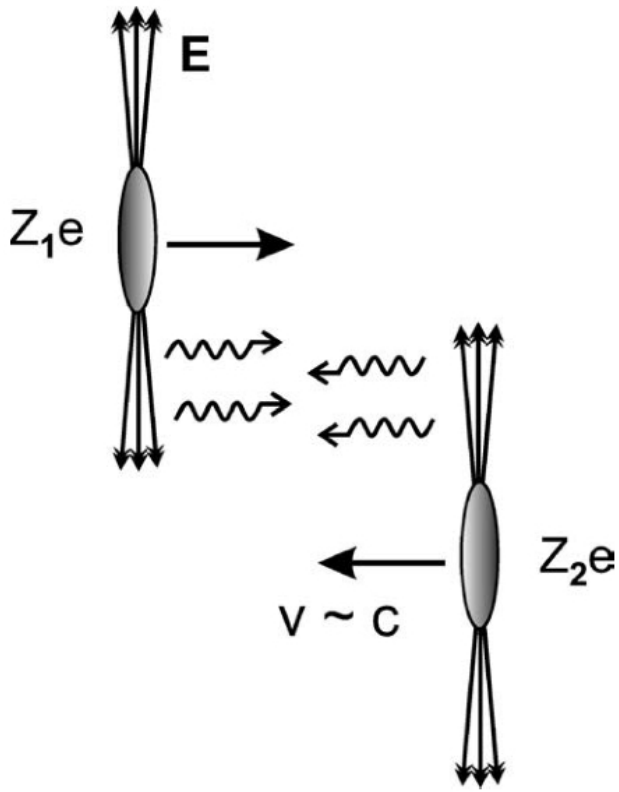
Motivation

- 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.*, Pb+Pb $\rightarrow$ Pb+Pb + J/Ψ, ρ^0
  - Photon-Photon, *e.g.*, $\gamma\gamma \rightarrow e^+e^-$
- Strong electromagnetic field around lead ions:
  number of photons $\sim Z^2$
- 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 part of the nucleus
  - $\langle p_T \rangle \sim 500$ MeV/c
  - target nucleus normally[a] does break up



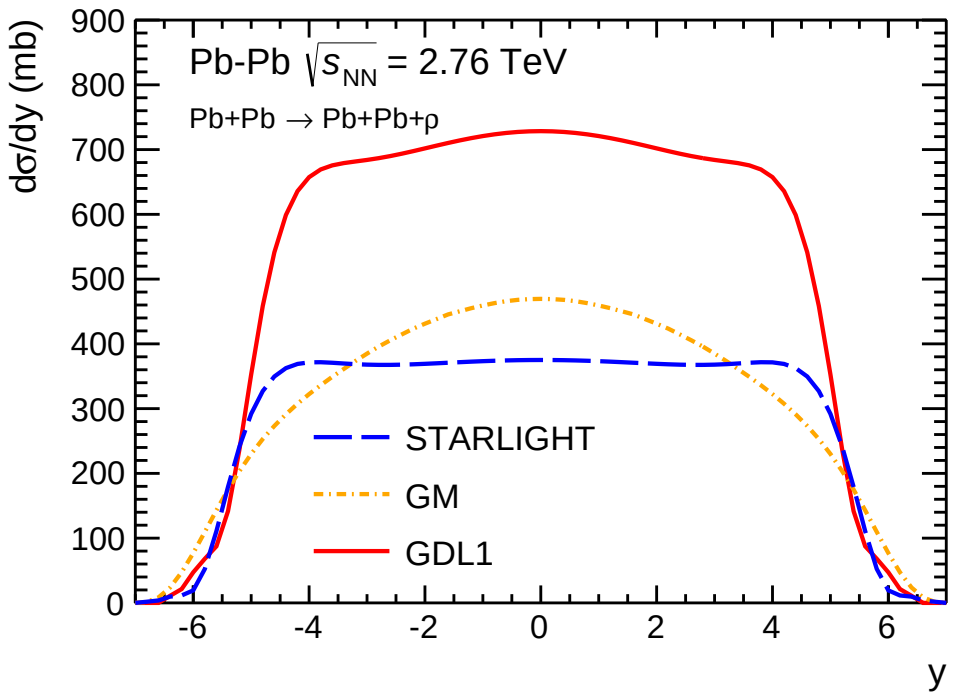
[a] in $\approx 80\%$ of the events

ρ^0 photo-production in Pb-Pb

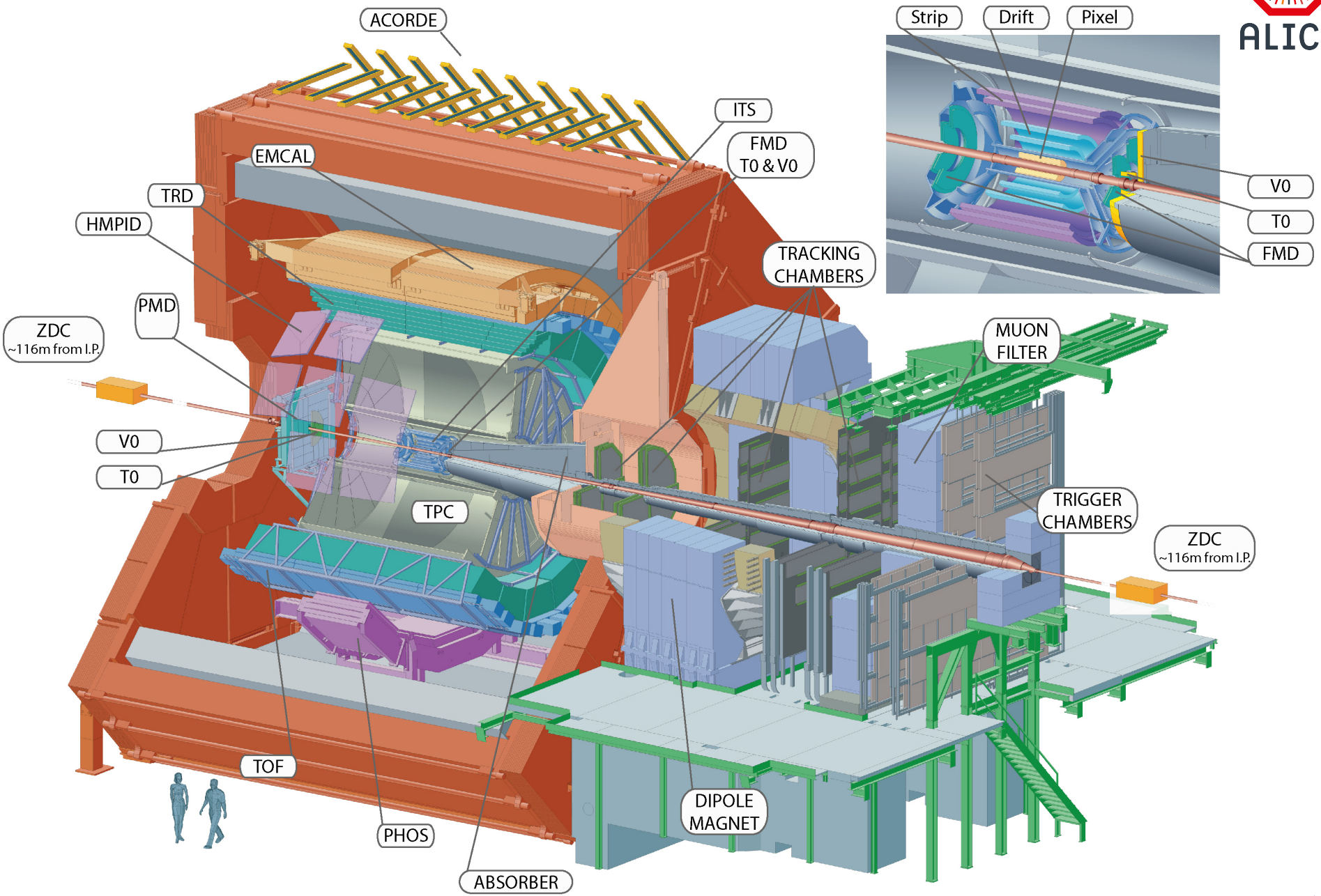
Motivation

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

- Frankfurt, Strikman, Zhalov (**GDL**), *Phys. Lett.* B 537 (2002) 51; *Phys. Rev.* C67 (2003) 034901; *Phys. Lett.* B710 (2012) 647.
- Gonçalves, Machado (**GM**), *Phys. Rev.* C84 (2011) 011902.
- Klein, Nystrand (**STARLIGHT**), *Phys. Rev.* C60 (1999) 014903, http://starlight.hepforge.org/.
- Szczurek *et al.*: work in progress



The ALICE Detector



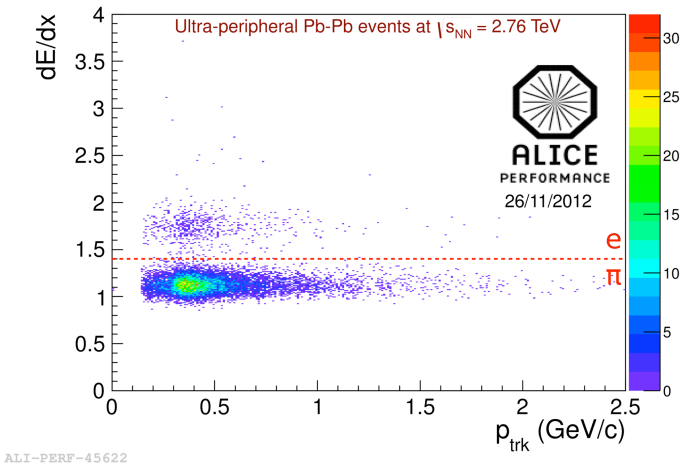
ρ^0 photo-production in Pb-Pb

Data Selection

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

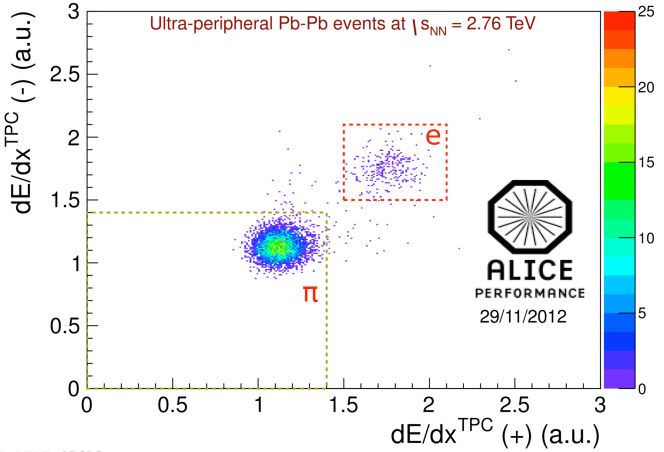
Trigger:

- 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



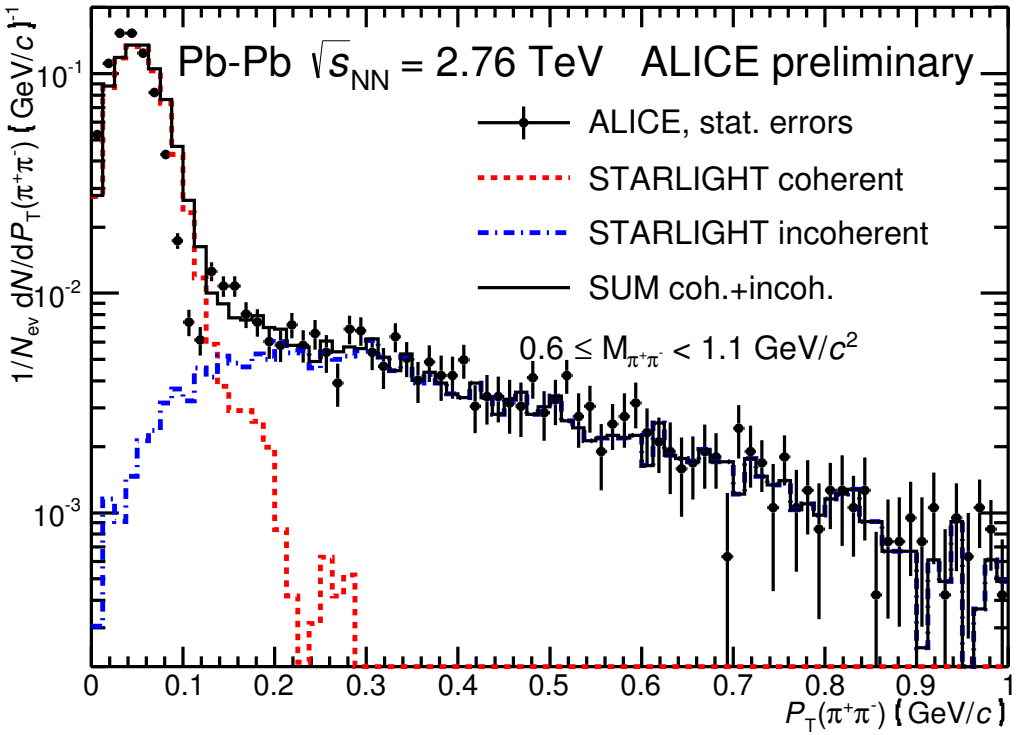
Offline Event Selection:

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



ρ^0 photo-production in Pb-Pb

Subtraction of incoherent contribution



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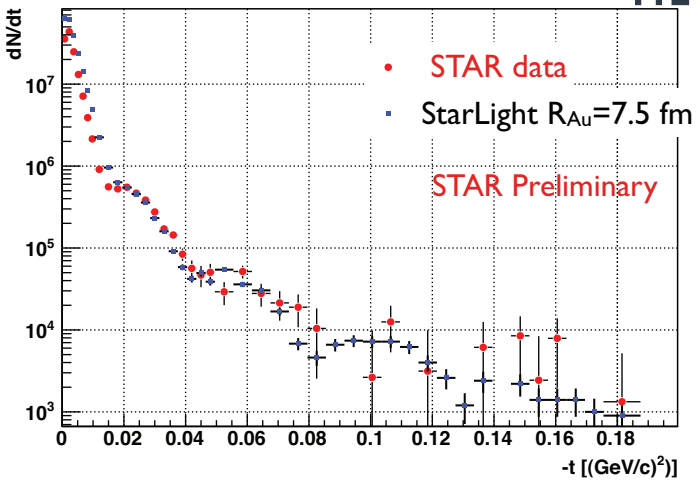


$-t \approx p_T^2$ distribution for photo-nuclear ρ^0 production at RHIC. Note: The default STARLIGHT $R_{Au} = 6.38$ fm

(STAR collaboration *J. Phys. Conf. Ser.* 389 (2012) 012042)

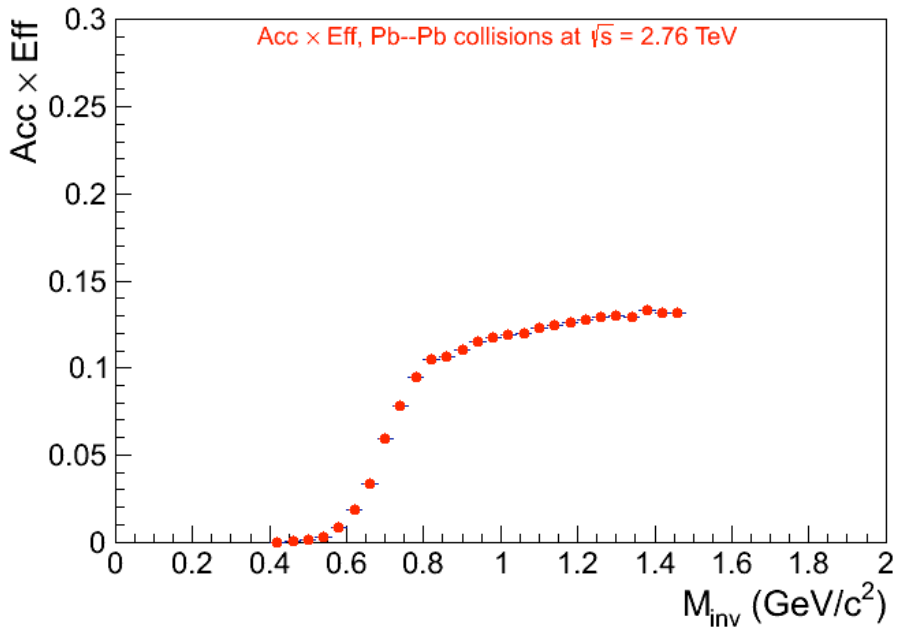
- Data narrower than MC (same observation at RHIC)
- Experimental resolution has a negligible effect on the width
  (check: comparing MC generated and MC reconstructed)
- Acc×Eff is flat as function of p_T in the coherent range 0-0.15 GeV/c.
- Cross-check for incoh. contribution: fit of exp. functions to the p_T^2 distribution

ρ^0 photo-production in Pb-Pb

Acc. $\times$ Eff. estimation

- We use a MC generator which is flat in invariant mass:
  - flat $M(\pi^+\pi^-) \in [2 \cdot m_\pi,\ 1.5\ \mathrm{GeV}/c^2]$
  - flat $p_T(\pi^+\pi^-) \in [0,\ 0.15]$ GeV/c
  - flat $y(\pi^+\pi^-) \in [-0.5,\ 0.5]$
  - $\frac{d\theta}{d\cos\theta} \sim \sin^2\theta$ (leading term for spin-1)

- The correction is performed for each bin in invariant mass
- Acc$\times$eff has been cross-checked with STARLIGHT
- Sharp decrease of acc$\times$eff below 0.8 GeV/c^2: TOF trigger condition



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

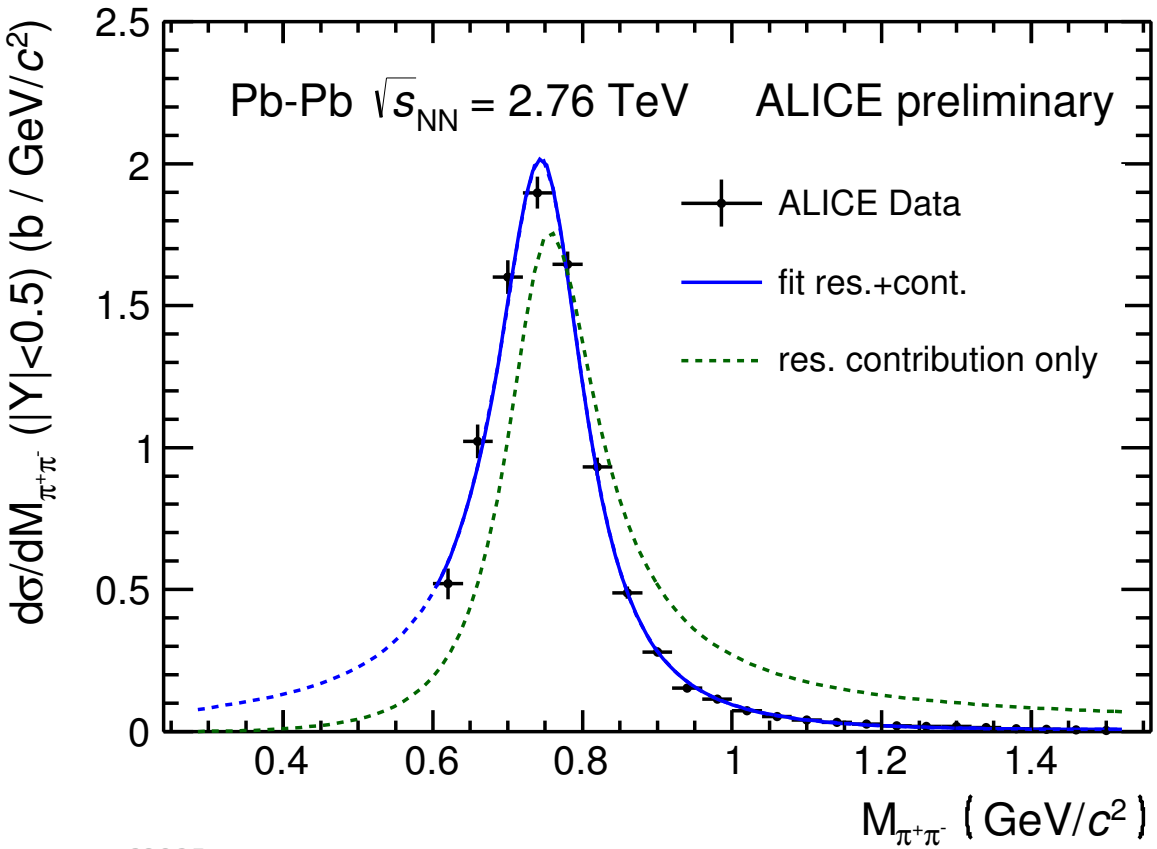
This formula was previously used by the STAR[1] and H1[2] collaborations

[1] *Phys. Rev.* C77 (2008) 034910

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

ρ^0 photo-production in Pb-Pb

Diff. cross section w.r.t. invariant mass



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$$M(\rho^0) = \left(761.6 \pm 2.3(\text{stat.})\, ^{+6.1}_{-3.0}(\text{sys.})\right) \text{MeV}/c^2 \qquad \text{PDG } 769 - 775\ \text{MeV}/c^2$$

$$\Gamma(\rho^0) = \left(150.2 \pm 5.5(\text{stat.})\, ^{+12.0}_{-5.6}(\text{sys.})\right) \text{MeV}/c^2 \qquad \text{PDG } 148 - 152\ \text{MeV}/c^2$$

$$|B/A| = \left(0.50 \pm 0.04(\text{stat.})\, ^{+0.10}_{-0.04}(\text{sys.})\right) (\text{GeV}/c^2)^{-1/2}$$

ρ^0 photo-production in Pb-Pb

Comparison to Models

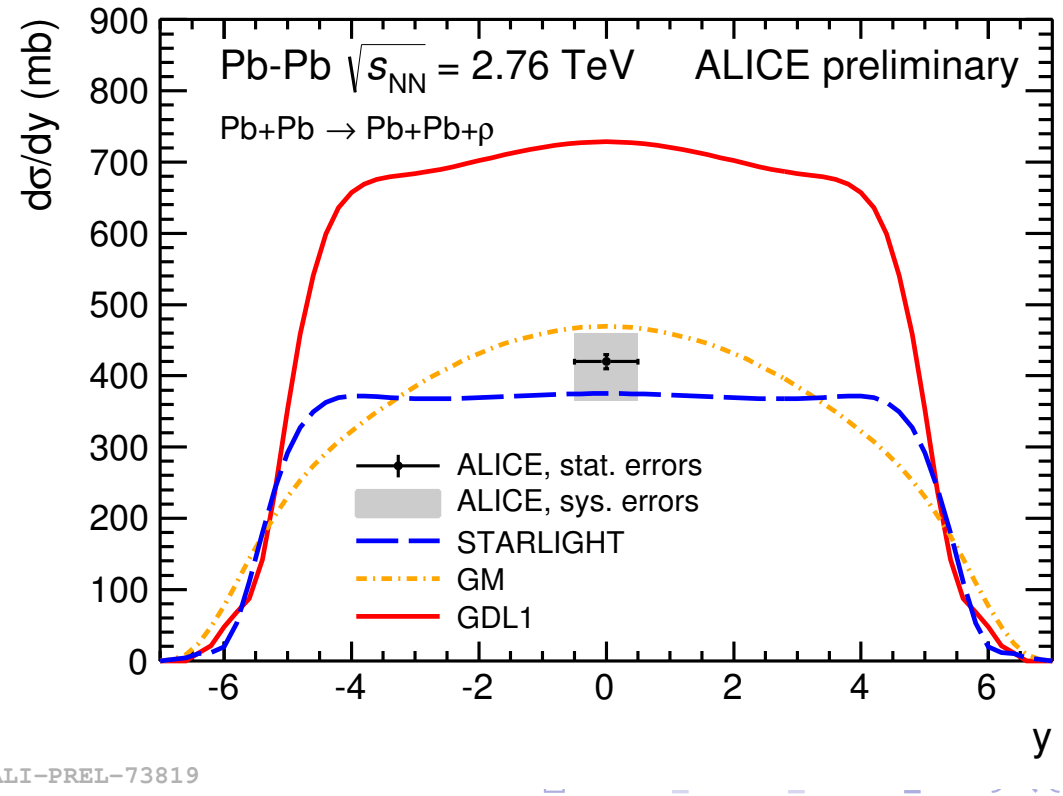
Cross section obtained by integrating the resonant contribution over $[2m_\pi, M_{\rho^0} + 5\Gamma_{\rho^0}]$. Same range in M_{ρ^0} as used by STAR and ZEUS.

$$\left.\frac{\mathrm{d}\sigma(\rho^0)^{\mathrm{coh.}}}{\mathrm{d}y}\right|_{|y|<0.5} = \left(420 \pm 10(\mathrm{stat.})\,^{+39}_{-55}(\mathrm{sys.})\right)\ \mathrm{mb}$$

GDL – Proper QM Glauber calculation for scaling $\sigma(\gamma p) \to \sigma(\gamma A)$, uses Donnachie-Landshoff model for $\sigma(\gamma p)$

GM – Based in the color dipole model with saturation implemented by the Color Glass Condensate formalism

STARLIGHT – Scales the exp. measured γp cross section using a Glauber model, neglecting the elastic nuclear cross section



ρ^0 photo-production in Pb-Pb

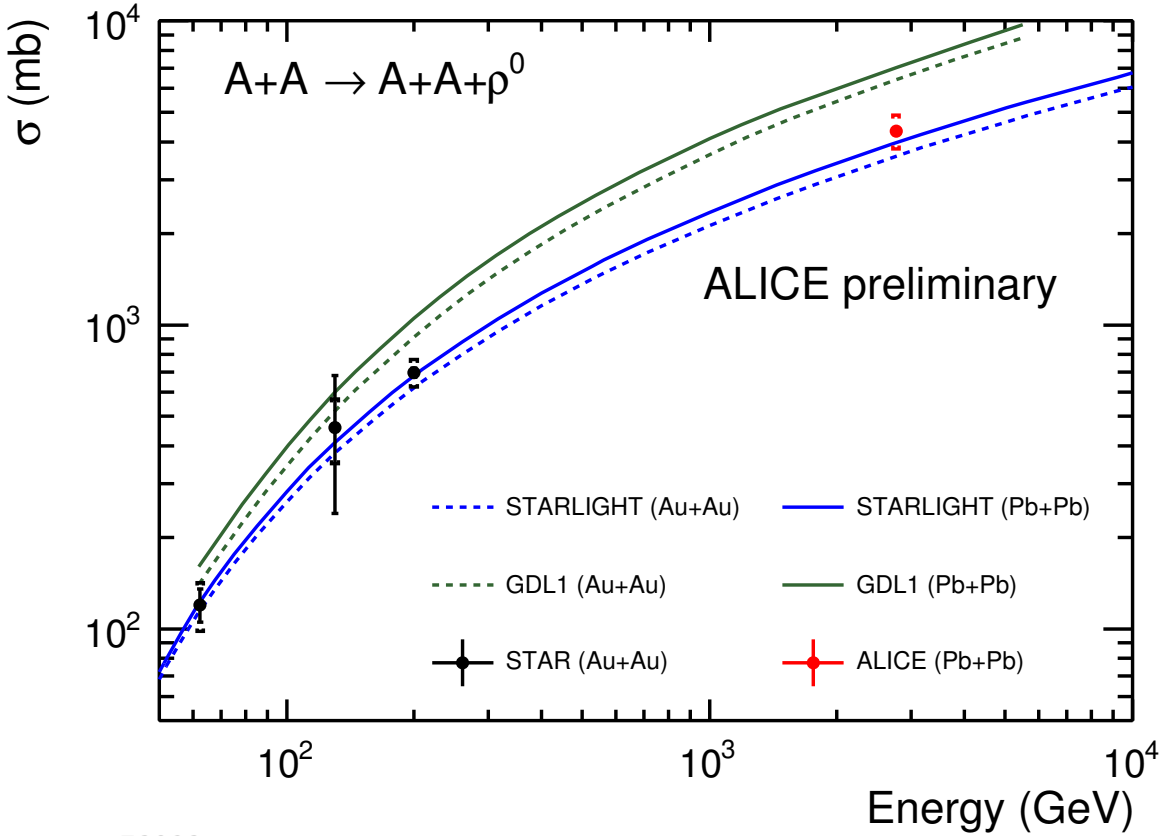
Comparison to Models

The total cross section is obtained by integrating over all rapidities:

$$\sigma(\rho^0)^{\text{coh.}} = \left(4.3 \pm 0.1(\text{stat.})\, ^{+0.6}_{-0.5}(\text{sys.})\right) \text{ b}$$

- Enables comparison with STAR results
- Additional sys. error from the shape of $d\sigma/dy$: difference between GM and STARLIGHT models

STAR Collaboration Data:
Phys. Rev. Lett. 89 (2002) 272302;
Phys. Rev. C77 (2008) 034910;
Phys. Rev. C85 (2012) 014910.



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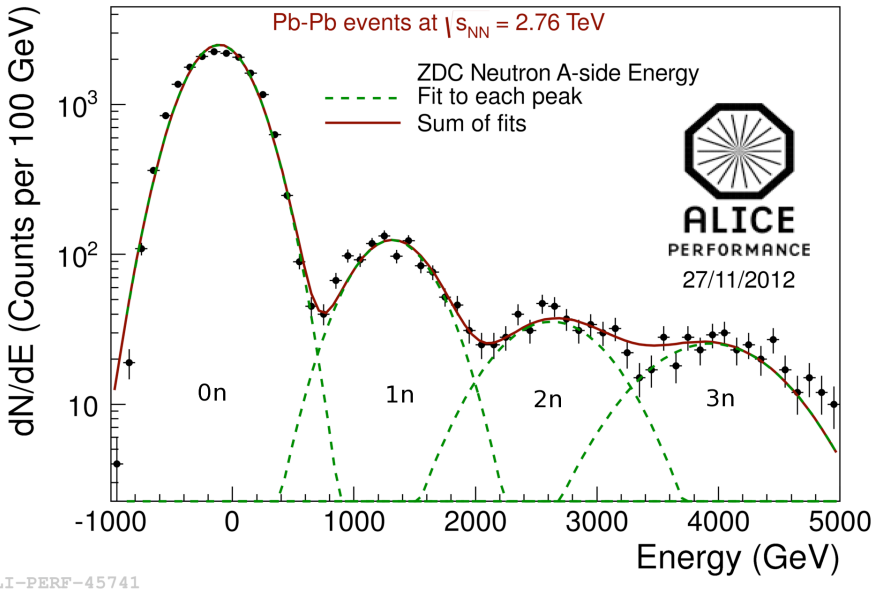
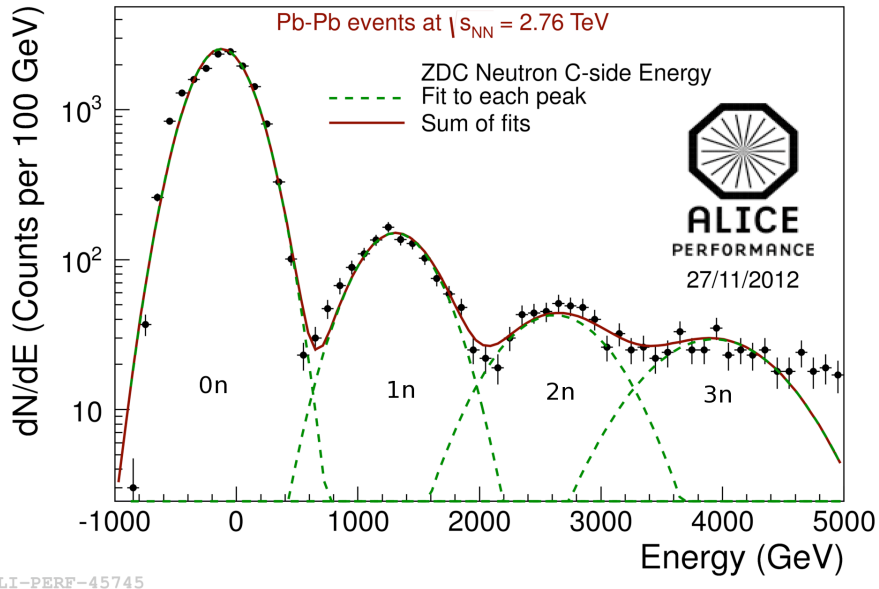
ρ^0 photo-production in Pb-Pb

Nuclear Breakup

- The strong fields associated with heavy-ions lead to large probabilities for exchanging additional photons when a ρ^0 is produced at small impact parameters.
- These photons will excite one or both of the nuclei (typically GDR excitations) and lead to break up[3]
- The ALICE zero-degree calorimeters (ZDC) can measure single neutron emission:





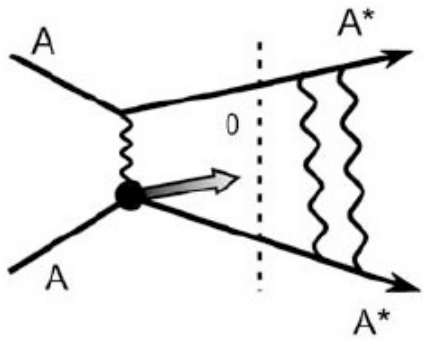
[3] Baltz, Klein, and Nystrand, *Phys. Rev. Lett.* 89 (2002) 012301

ρ^0 photo-production in Pb-Pb

Nuclear Breakup – comparison with models

Breakup modes:

0n0n	No break up
Xn	One or both nuclei break up
0nXn	One of the nuclei breaks up
XnXn	Both nuclei do break up



ALICE measurement:

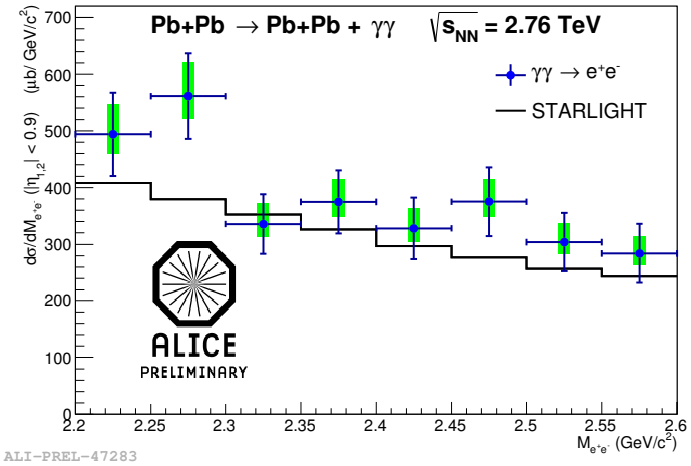
The neutrons are detected in the ZDCs

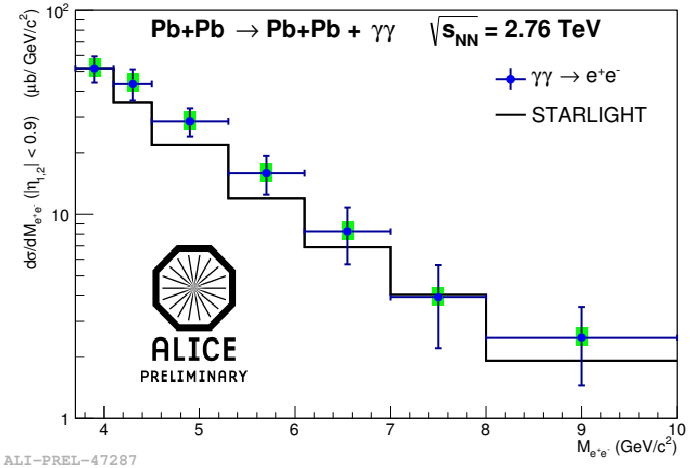
All events	7293		STARLIGHT	RSZ
0N0N	6175	$\left(84.7 \pm 0.4(\text{stat})\,^{+0.4}_{-1.9}(\text{sys})\right)\%$	79% (-2.9σ)	84% (-0.4σ)
XN	1174	$\left(16.1 \pm 0.4(\text{stat})\,^{+2.2}_{-0.5}(\text{sys})\right)\%$	21% $(+2.2\sigma)$	16% (-0.2σ)
0NXN	958	$\left(13.1 \pm 0.4(\text{stat})\,^{+0.9}_{-0.3}(\text{sys})\right)\%$	16% $(+2.9\sigma)$	12% (-2.2σ)
XNXN	231	$\left(3.2 \pm 0.2(\text{stat})\,^{+0.4}_{-0.1}(\text{sys})\right)\%$	5.2% $(+4.5\sigma)$	3.7% $(+1.1\sigma)$

STARLIGHT: Baltz, Klein, Nystrand, *Phys. Rev. Lett.* 89 (2002) 012301.
RSZ: Rebyakova, Strikman, Zhalov, *Phys. Lett.* B710 (2012) 647.

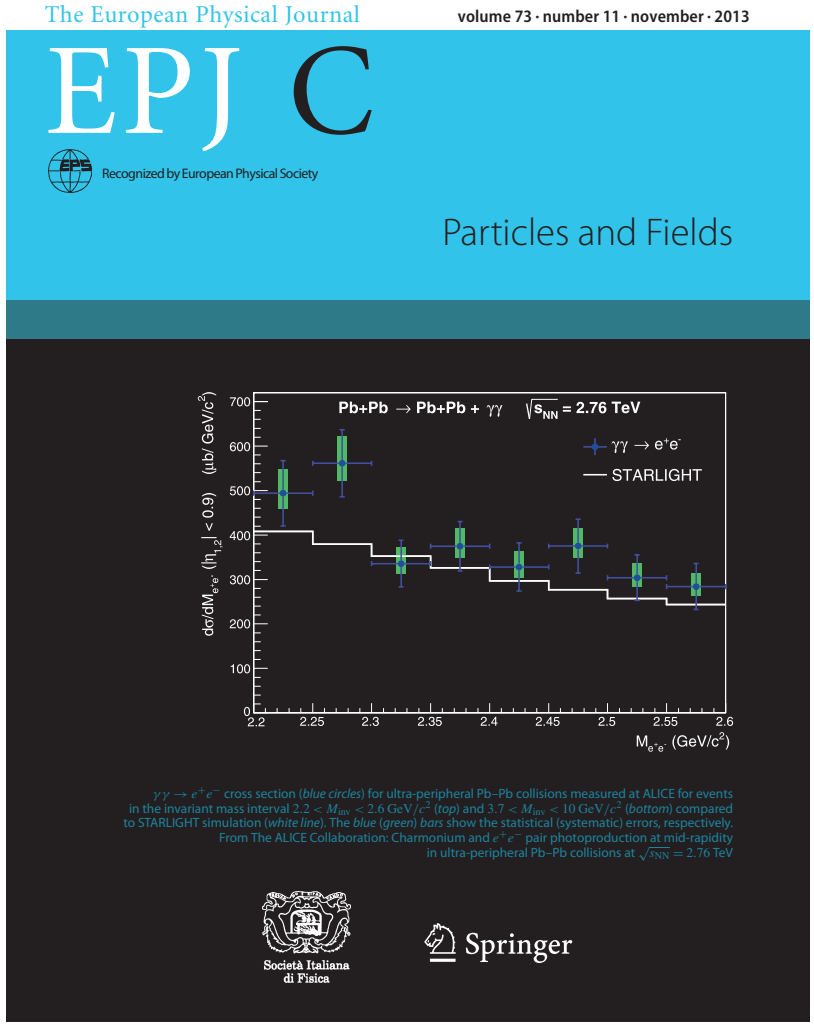
Two-photon production of electron pair in Pb-Pb

ALICE 2011 data





Topology cut in trigger:
$M_{e^+e^-} > 2.2$ GeV/c^2

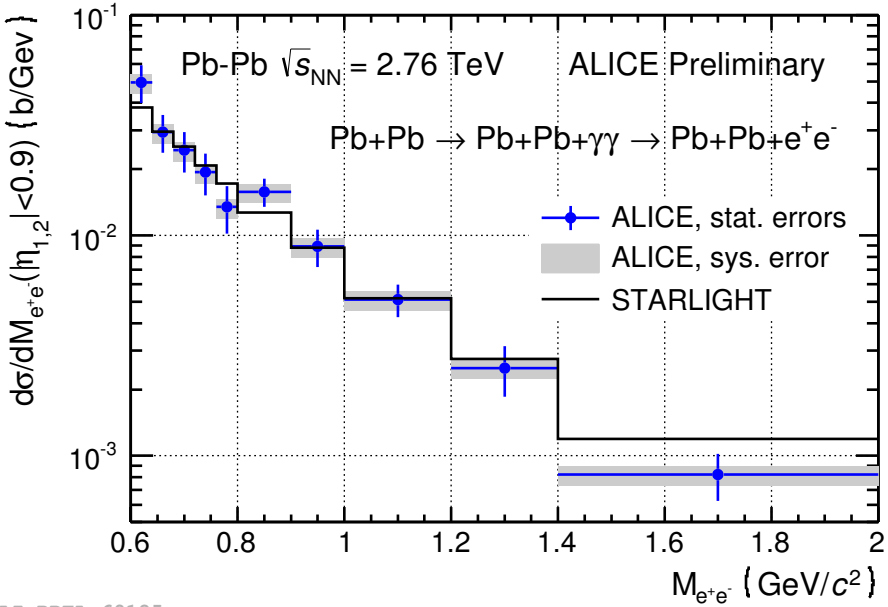


ALICE Collaboration, EPJC 73 (2013) 2617 (Central Barrel).

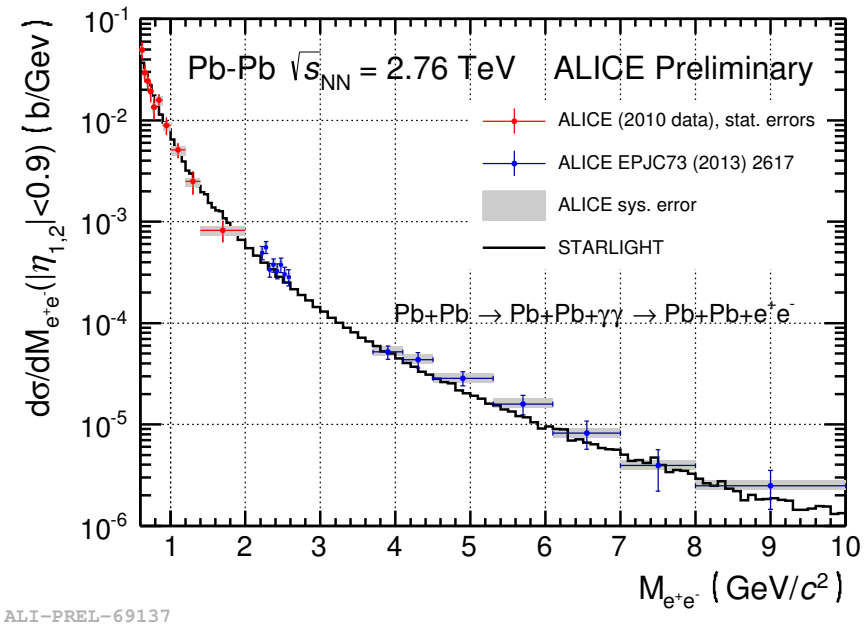
Two-photon production of electron pair in Pb-Pb

ALICE 2010 data

With 2010 data this range can be extended down to 0.6 GeV/c^2:



And the results can be combined to cover the range $M_{e^+e^-} \in [0.6, 10]$ GeV/c^2:

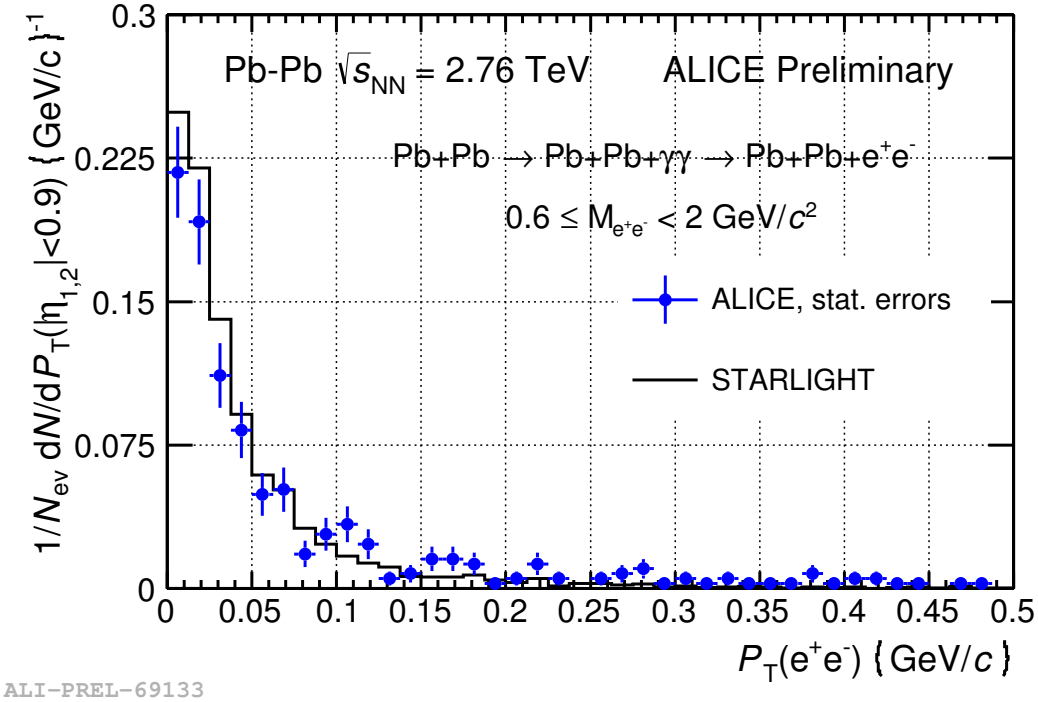


	Data	STARLIGHT
$\sigma\left(M_{e^+e^-} \in [0.6, 2.0]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$:	$\left(9.8 \pm 0.6(\mathrm{stat.})\,^{+0.9}_{-1.2}(\mathrm{sys.})\right)$ mb	9.7 mb
$\sigma\left(M_{e^+e^-} \in [2.2, 2.6]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$:	$\left(154 \pm 11(\mathrm{stat.})\,^{+17}_{-11}(\mathrm{sys.})\right)$ mb	128 μb
$\sigma\left(M_{e^+e^-} \in [3.7, 10.0]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$:	$\left(91 \pm 10(\mathrm{stat.})\,^{+11}_{-8}(\mathrm{sys.})\right)$ mb	77 μb

Two-photon production of electron pair in Pb-Pb

ALICE 2010 data

ALICE EPJC 73 (2013) 2617



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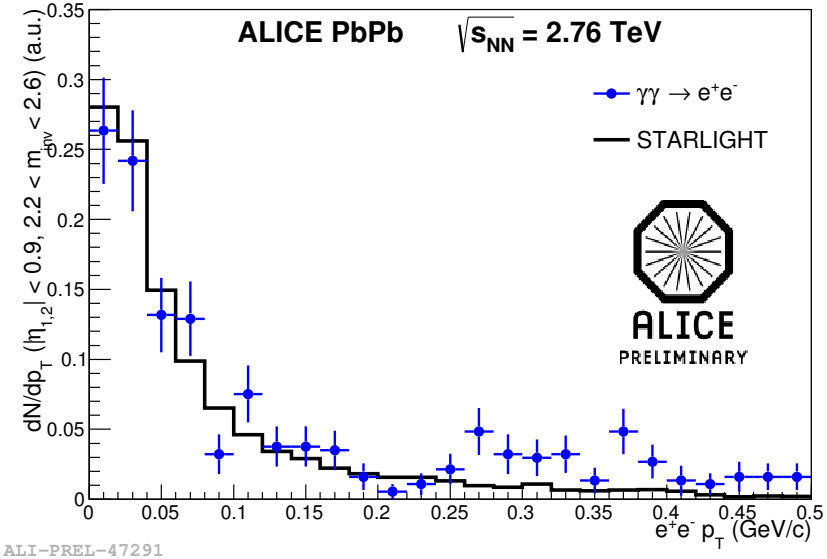

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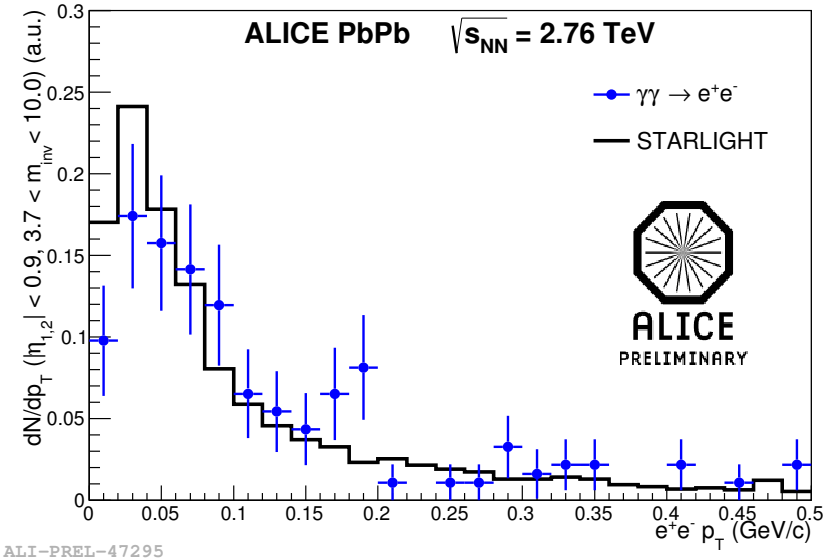

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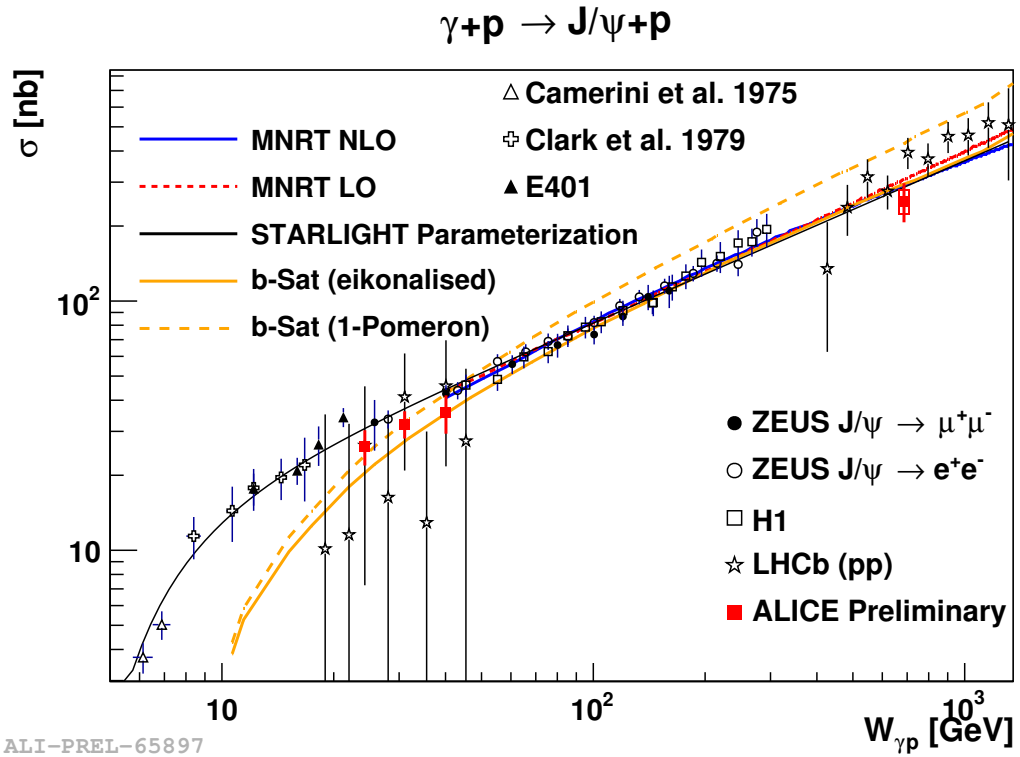
- The transverse-momentum distribution is well -described by the STARLIGHT Monte-Carlo simulation for $0.6 \leq M_{e^+e^-} < 10.0$ GeV/c^2.
  - Left: 2010 Pb-Pb data
  - Right: 2011 Pb-Pb data (EPJC paper)
- Broadening of pair-p_T with increasing $M_{e^+e^-}$

Conclusions

- ALICE has made the first measurement of coherent photo-production of ρ^0 in Pb-Pb collisions at the LHC.
  - Cross section for ρ^0 is in agreement with STARLIGHT and GM, about a factor of 2 below GDL. Similar to what was observed at RHIC.
- Two photon cross section
  - Good agreement with STARLIGHT Monte Carlo (leading order QED).
  - Sets constraints on the contribution from higher-order terms ($\sqrt{Z}$ coupling).
- Recent ALICE UPC results not shown here:
  - First measurement of coherent photo-production of $\Psi(2S)$ in Pb-Pb collisions at the LHC.
  - Coherent photo-production of J/Ψ in p-Pb collisions $\longrightarrow$ last slide

Outlook: UPC J/Ψ measured in p-Pb collisions

2013 data



- Measurement of J/Ψ production over a wide range in Bjorken-*x* is possible
- Kinematic range of HERA extended both to the lower and higher γp energies
- Analyses for semi-forward and for mid-rapidity: work in progress