Photoproduction of ρ^0 in Ultra-Peripheral Nuclear Collisions at ALICE

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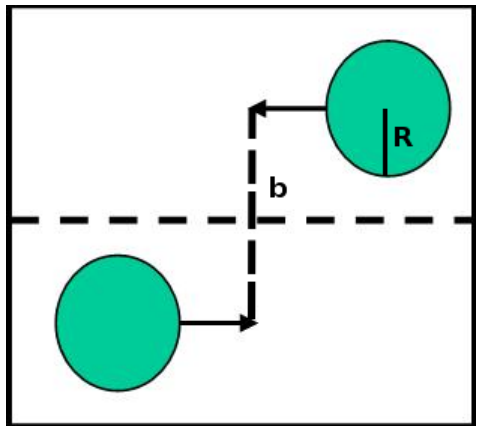
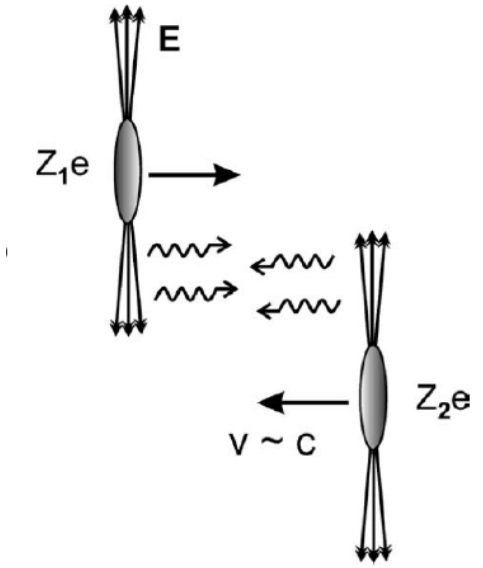
Outline

Ultra-Peripheral Collisions



- Collision between two hadrons (protons, nuclei) where they geometrically miss each other.
- Implies impact parameters $b > 2R$. Typically $b \sim 200 - 300$ fm for light vector meson production at the LHC.
- Electromagnetic interactions $\Leftrightarrow$ Flux of equivalent photons.



Different kinds of UPCs

Coherent interactions:

- The photon interacts with the whole nucleus coherently.
- Both nuclei in most cases remain intact.
- Transverse momentum determined by the nuclear form factor, $\langle p_T \rangle \sim 60$ MeV/c.
- Examples:
  - Two photon interaction: $Pb + Pb \rightarrow Pb + Pb + \mu^+ + \mu^- / e^+ + e^-$; $\gamma + \gamma \rightarrow \mu^+ + \mu^- / e^+ + e^-$
  - Photonuclear interaction: $Pb + Pb \rightarrow Pb + Pb + V$, $V = J/\psi,\ \psi',\ \rho^0,\ \Upsilon,\ \omega,\ \phi$, with $\gamma P \rightarrow V$

Incoherent interactions (quasi–elastic collisions):

- The photon interacts with a single nucleon.
- One of the nuclei breaks up.
- $\langle p_T \rangle \sim 500$ MeV/c.

A general photonuclear interaction:

- Example:
  - $Pb + Pb \rightarrow Pb + X + Q\overline{Q}$, with $\gamma + g \rightarrow Q\overline{Q}$.

Coherent event characteristics

- For the photonuclear interaction: $Pb + Pb \rightarrow Pb + Pb + V$, $V = J/\psi,\ \psi',\ \rho^0,\ \Upsilon,\ \omega,\ \phi$, with $\gamma P \rightarrow V$
- Two tracks, otherwise empty event.
- $\sum Q_i = 0$, Q_i is the charge of track i.
- $\sum p_T \leq\sim 100$ MeV/c (PbPb)
- PID: $\pi^+ + \pi^-$ (ρ^0)

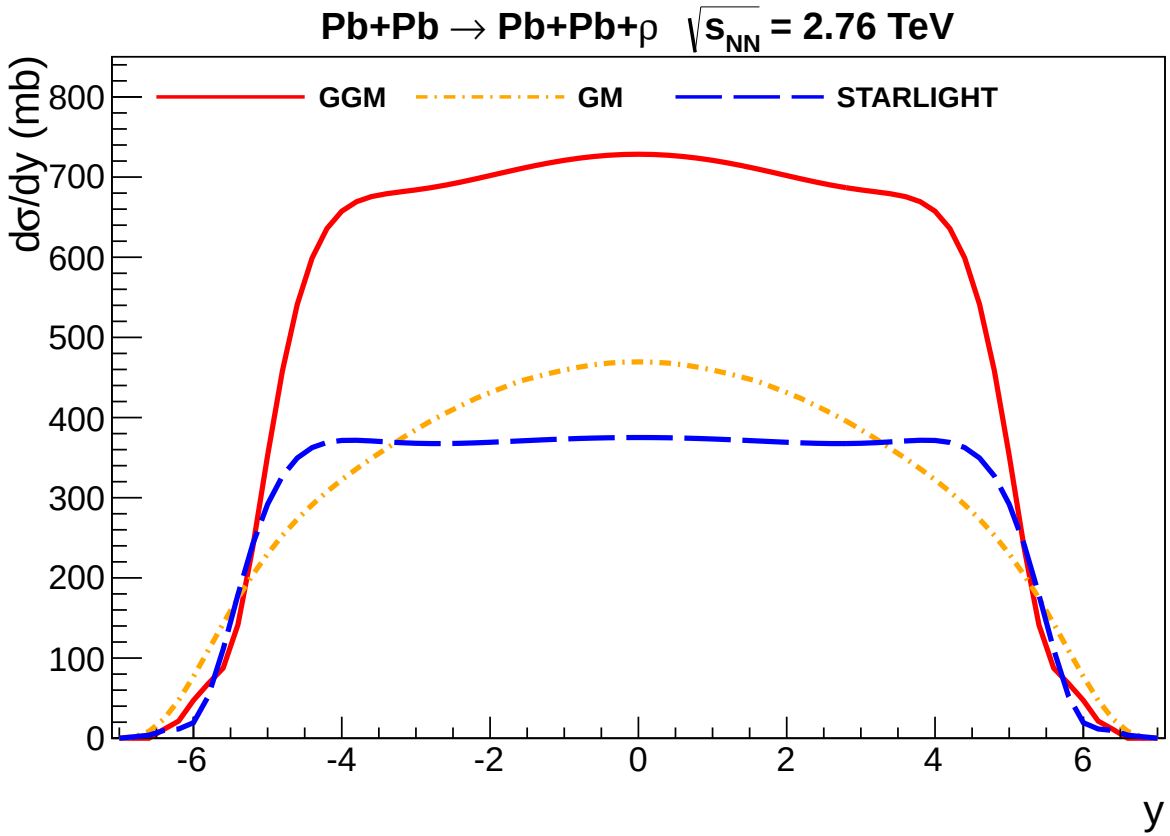
Physics motivation – Models

- Frankfurt, Strikman, Zhalov (GGM), Phys. Lett. B 537 (2002) 51; Phys. Rev. C 67(2003) 034901.
  - Generalized Vector Meson Dominance in the Gribov–Glauber approach.
  - Includes non–diagonal transitions $\gamma \to \rho' \to \rho$.
  - Uses $\sigma(\rho + \text{nucleon})$ from Donnachie–Landshoff model, in agreement with HERA and lower energy data.
- Goncalves, Machado (GM), Phys. Rev. C 84 (2011) 011902.
  - Based on the color dipole model in combination with saturation from a Color Glass Condensate model.
- Klein, Nystrand (Starlight), Phys. Rev. C 60 (1999) 014903, http://starlight.hepforge.org/
  - Uses experimental data for $\gamma + p \to \rho^0 + p$.
  - Uses a Glauber model (neglecting the elastic part of total cross section).

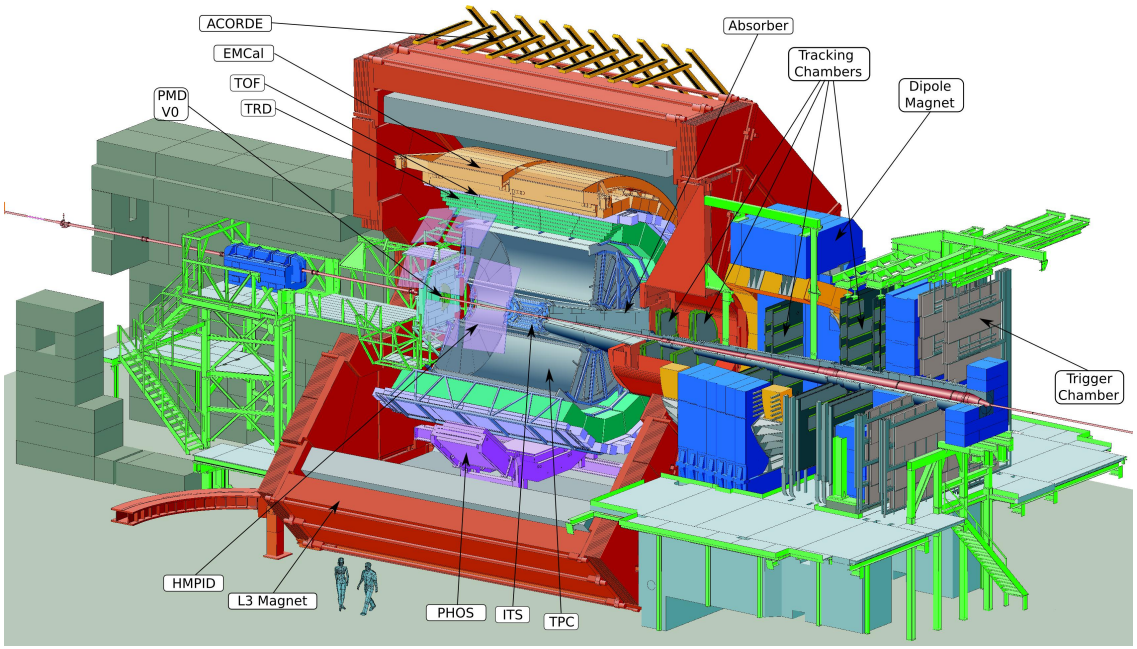
Physics motivation – Predictions

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

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



The ALICE experiment



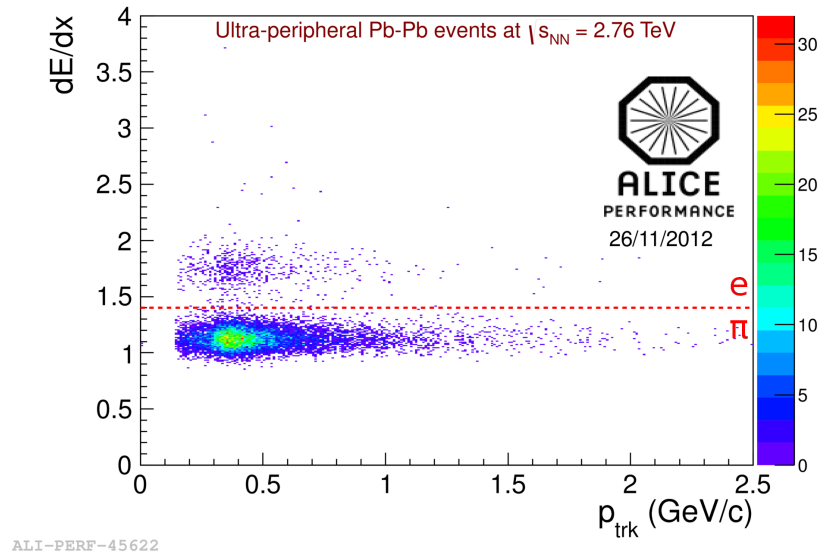
- Inner Tracking System (ITS) and TPC used for tracking and Particle ID.
- $|\eta^{track}| < 0.9$, $p_T^{track} > 150$ MeV/c.
- Si-Pixel (SPD), Time–Of–Flight (TOF), VZERO detectors used for triggering.
- VZERO counters used to define rapidity gaps, VZERO–A ($2.8 \leq \eta \leq 5.1$) VZERO–C ($-3.7 \leq \eta \leq -1.7$).

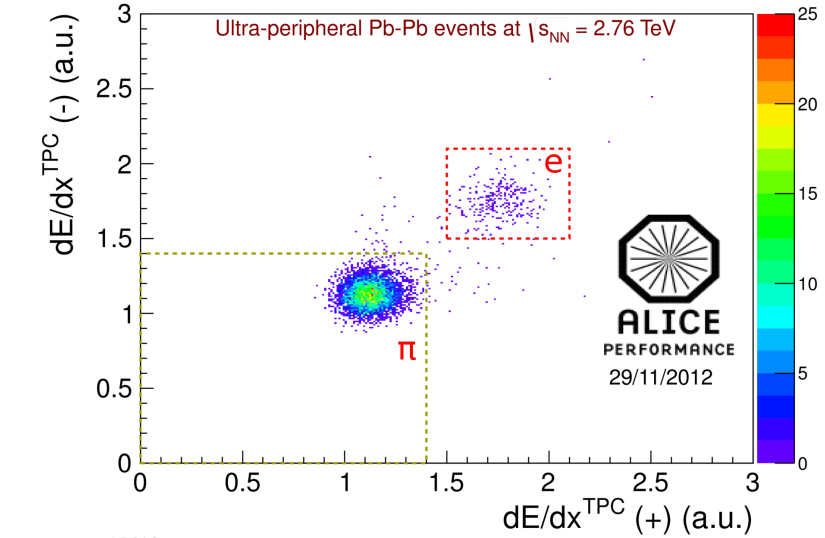
Data sets

- The analysed data sample is from the 2010 Pb–Pb run.
- Two different UPC triggers used:
  - A trigger requiring at least two hits in the TOF detector.
  - A trigger requiring at least two hits in SPD, at least two hits in TOF and a veto on the VZERO counters.

Cuts

- Require the event to trigger the UPC trigger at hardware level.
- Event must have a primary vertex.
- Require exactly two accepted ITS+TPC tracks.
- Z–position of the vertex should be $|V_z| < 10$ cm.
- VZERO detectors empty.
- Pion PID, using TPC dE/dx.
- $|y| < 0.5$
- $p_T < 0.15$ GeV/c
- Opposite charge of the tracks.
- Subtract like sign background.





Cuts

Cut	Number of surviving events
Events analysed	3,870,215
Triggered events	1,332,041
Primary vertex	850,409
Two accepted tracks	47,978
$\|V_z\| < 10$ cm	43,413
VZERO veto	8,848
PID cut	7,588
$\|y\| < 0.5$	5,887
$p_T < 0.15$ GeV/c	2,749
Unlike sign tracks	2,699
Like sign tracks	50

Table : Number of events surviving cuts for the TOF–trigger data sample

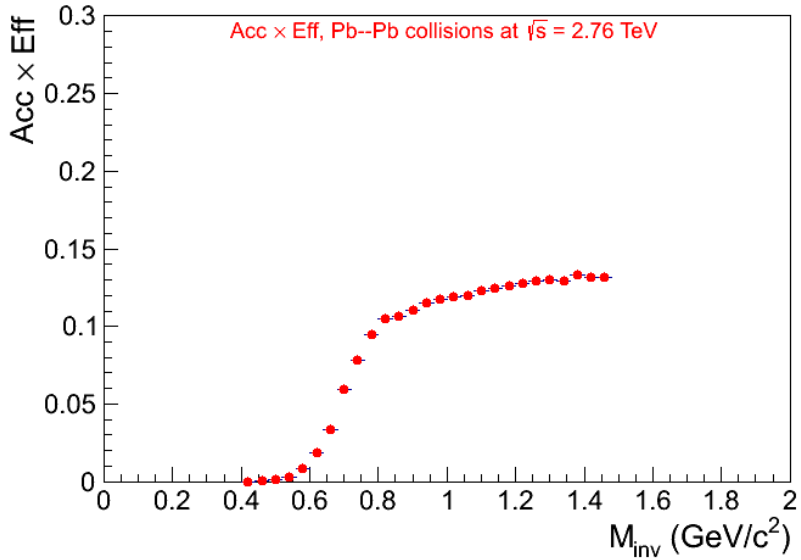
Cut	Number of surviving events
Events analysed	6,057,943
Triggered events	121,487
Primary vertex	103,480
Two accepted tracks	26,217
$\|V_z\| < 10$ cm	24,020
VZERO veto	17,567
PID cut	15,377
$\|y\| < 0.5$	11,928
$p_T < 0.15$ GeV/c	6,195
Unlike sign tracks	6,101
Like sign tracks	94

Table : Number of events surviving cuts for SPD+TOF+!VZERO–trigger data sample

"Events analysed" is the total number of events (all triggers) in the analysed runs.
Like sign background <2% for the final event selection.

Acc $\times$ Eff correction

- Use a flat invariant mass $\pi^+\pi^-$ simulation.
- Assume that the $\pi^+\pi^-$ are emitted from a transversely polarized parent (as expected for coherently produced ρ's).



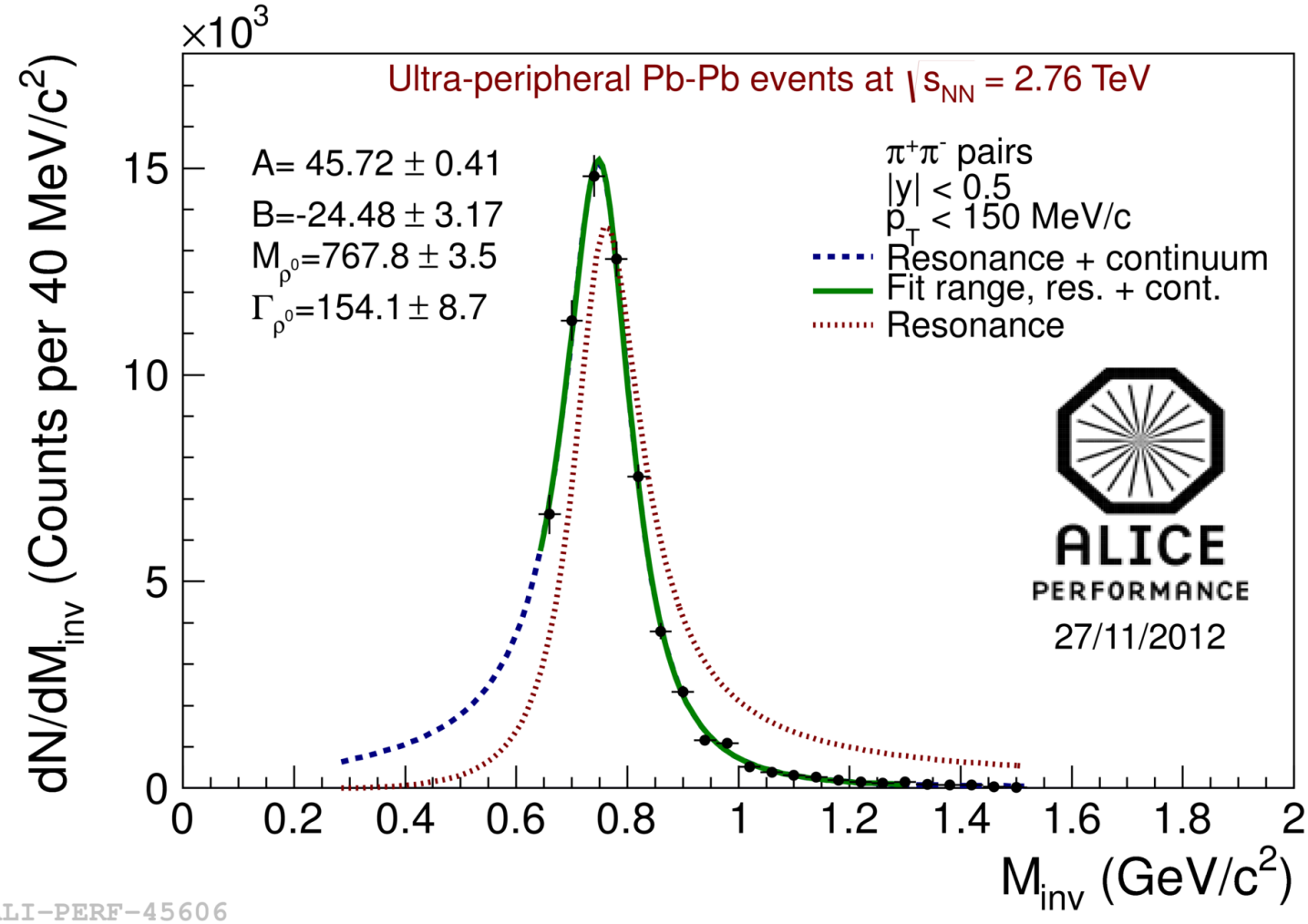
Fit function

- The acc×eff corrected invariant mass distribution is fitted with a Breit–Wigner function with continuum correction:

$$\frac{d\sigma}{dM_{\pi\pi}} = \left| A\frac{\sqrt{M_{\pi\pi}M_{\rho^0}\Gamma(M_{\pi\pi})}}{M_{\pi\pi}^2 - M_{\rho^0}^2 + iM_{\rho^0}\Gamma(M_{\pi\pi})} + B \right|^2 \quad (1)$$

- $\Gamma(M_{\pi\pi}) = \Gamma_0 \cdot (M_{\rho^0}/M_{\pi\pi}) \times [(M_{\pi\pi}^2 - 4m_\pi^2)/(M_{\rho^0}^2 - 4m_\pi^2)]^{3/2}$ is the momentum dependent width of the ρ^0
- A is the amplitude of the Breit-Wigner function.
- B is the amplitude of the direct (non–resonant) $\pi^+\pi^-$ production.
- Previously used by the STAR (Phys. Rev. C 77 (2008) 034910) and H1 (Nucl. Phys. B436 (1996) 3) collaborations

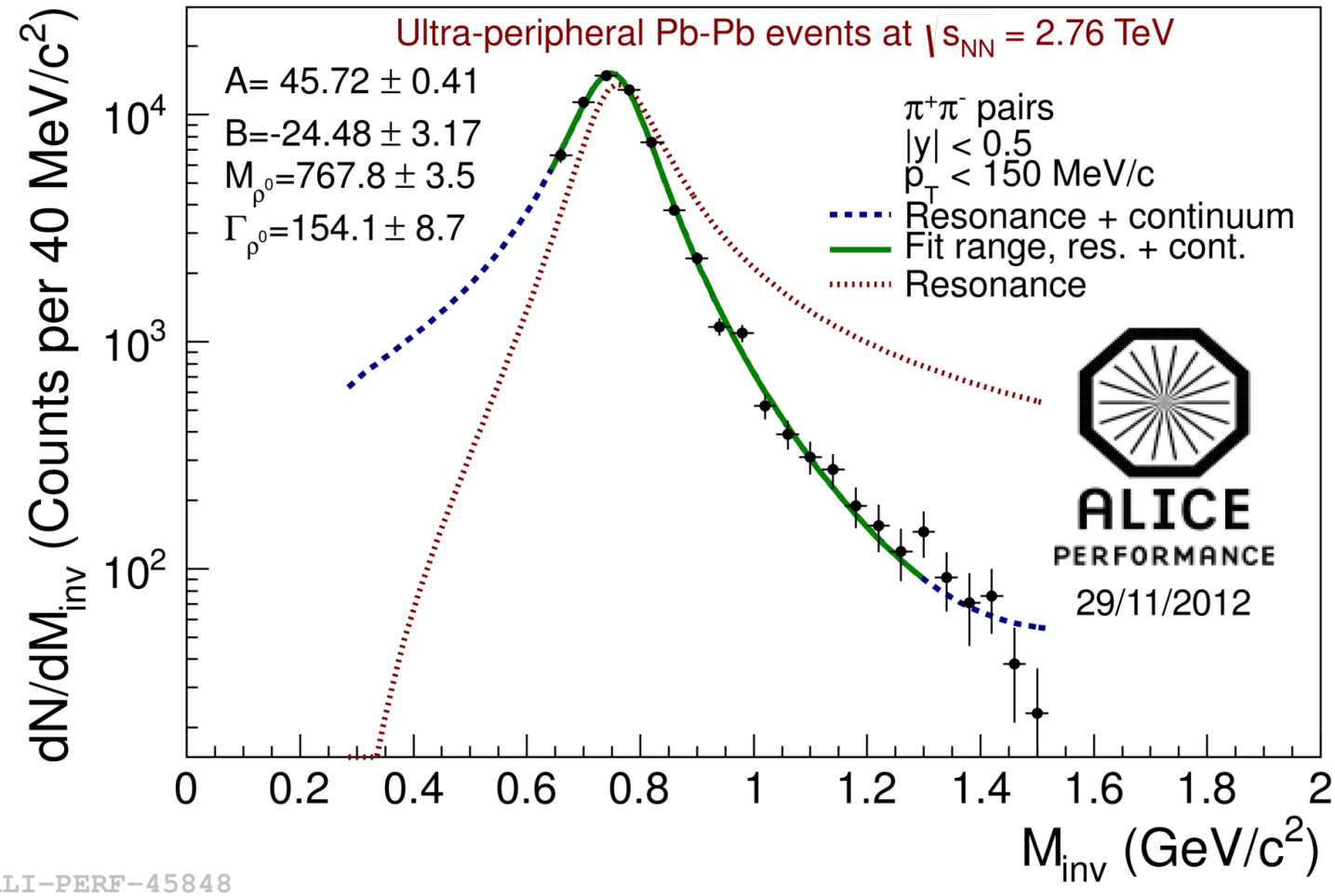
Fit of acc×eff corrected M_{inv} distribution



PDG:

- $M_{PDG} = 775.49 \pm 0.34$ MeV/c^2
- $\Gamma_{PDG} = 149.1 \pm 0.8$ MeV/c^2

Fit of acc×eff corrected M_{inv} distribution, log scale



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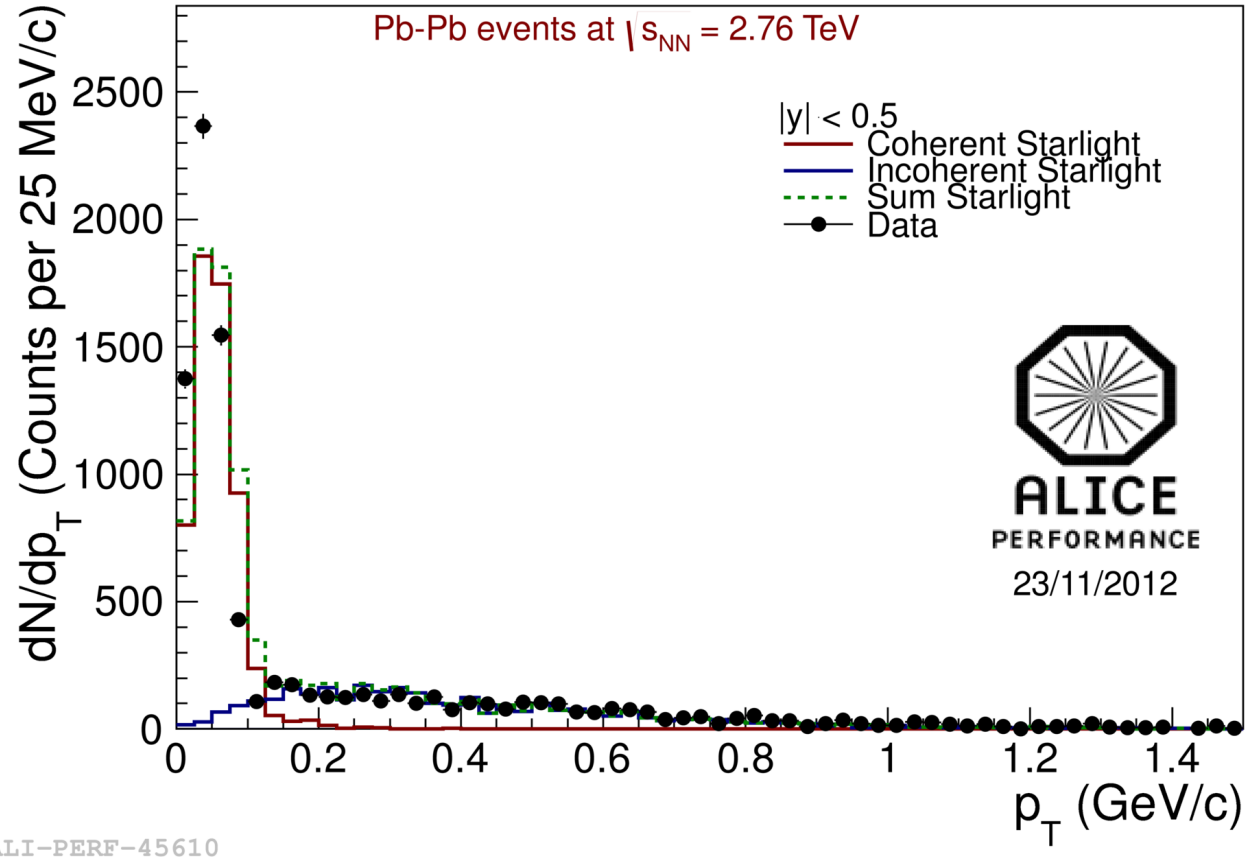
- $\Gamma_{PDG} = 149.1 \pm 0.8$ MeV/c^2

Subtraction of incoherent contribution

- Most of the events with $p_T < 150$ MeV/c are coherent, but a small part of the incoherent events survive this cut.
- To correct for this we have to find the percentage of inchorent events in the range $0 < p_T < 150$ MeV/c.
- Use the MC generator Starlight[1] to make templates for coherent and incoherent ρ^0 production, including the detector response.

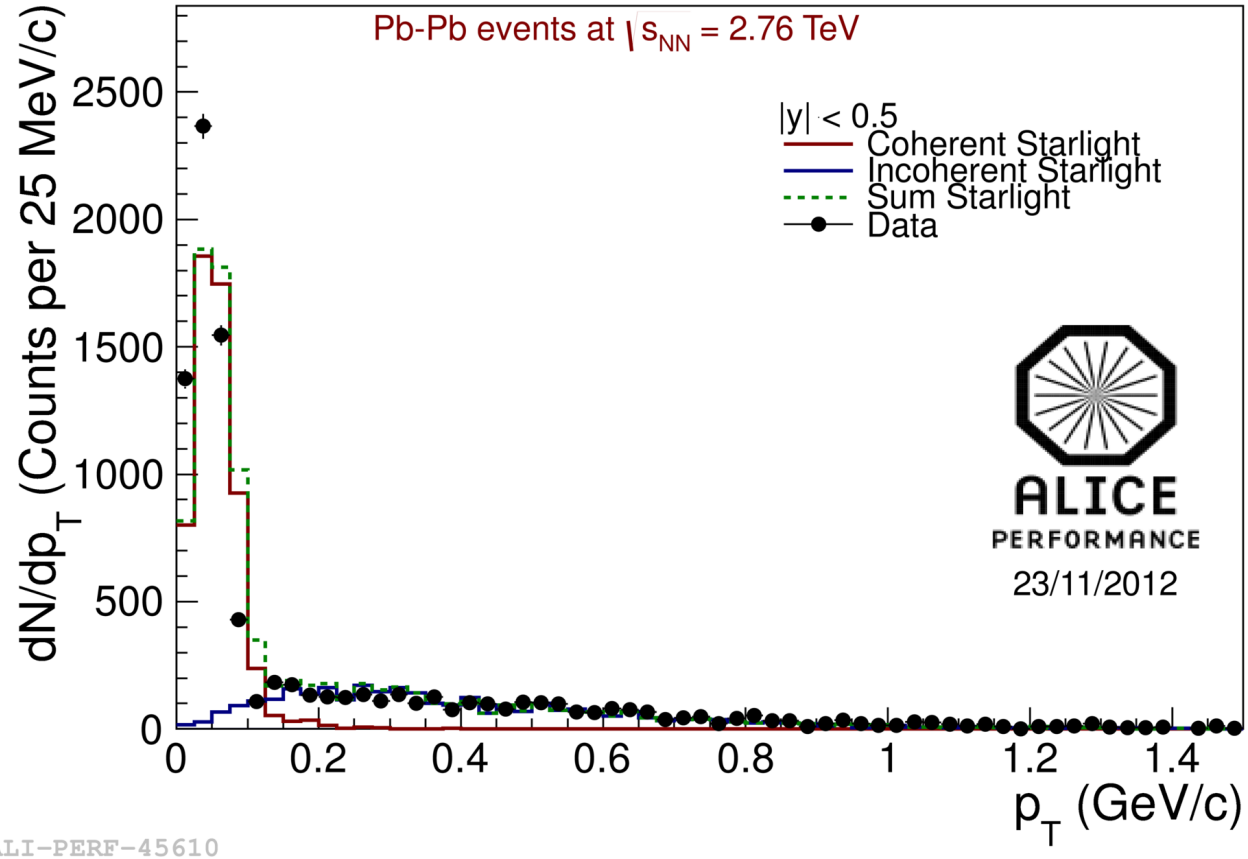
[1] http://starlight.hepforge.org/

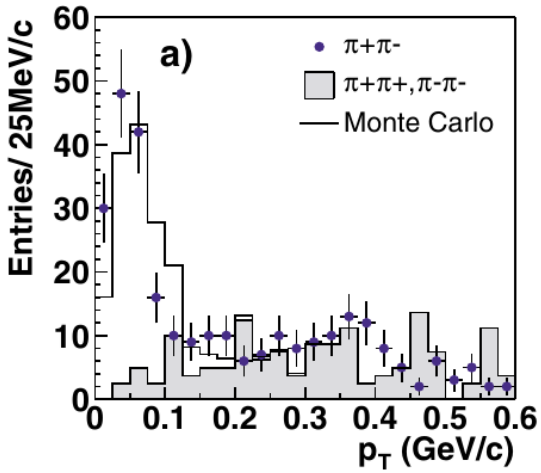
Subtraction of incoherent contribution



- $\sim$ 7% contribution from incoherent events under the coherent peak ($p_T < 150$ MeV/c).

Subtraction of incoherent contribution



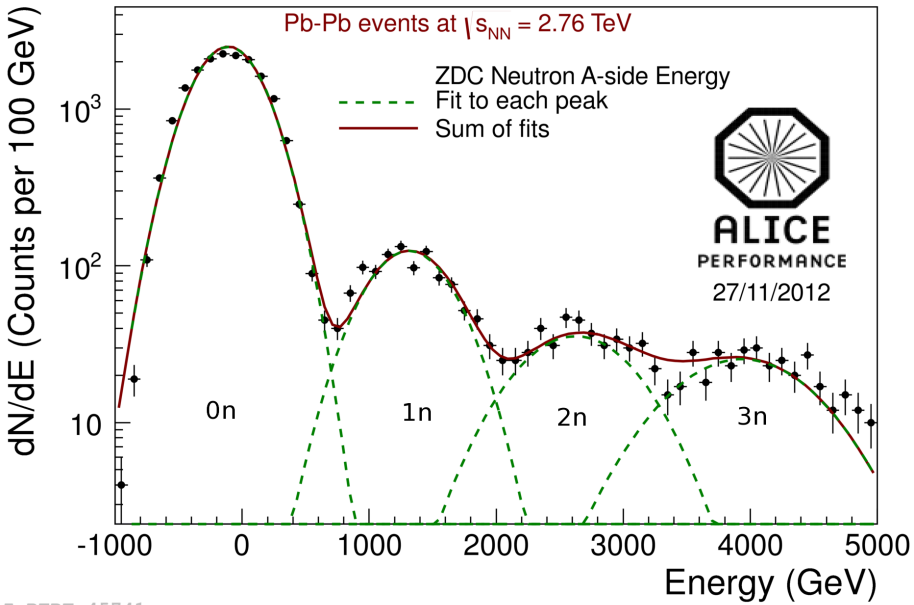


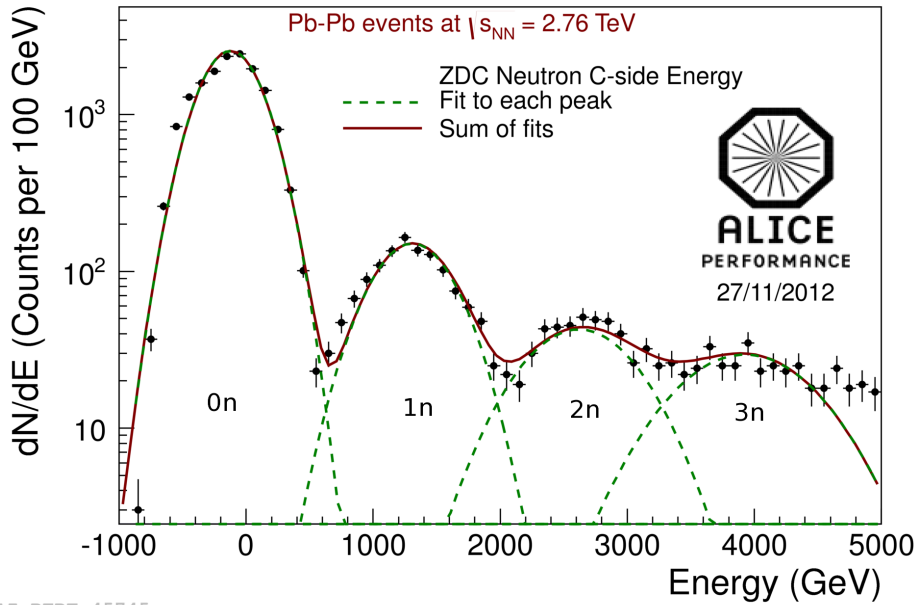
p_T distribution for photonuclear ρ^0 production at RHIC. (STAR collaboration Phys. Rev Lett. 89 (2002) 272302)

- $\sim$ 7% contribution from incoherent events under the coherent peak ($p_T < 150$ MeV/c).

Nuclear break up from ZDC information

Exchange of additional photons may lead to coherent vector meson production in coincidence with nuclear break up. (Baltz, Klein, Nystrand Phys. Rev. Lett. 89 (2002) 012301)
Using ZDC Neutron counters to count the number of neutron emitted from the nuclei.





Nuclear break up from ZDC information

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

Relative yield in data compared with relative coherent ρ^0 cross section from Starlight.

	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%

Table : Nuclear break up

Good agreement with Starlight for the different break up modes.

Photoproduction of J/ψ at forward rapidity

- Photonuclear production of J/ψ also studied by ALICE.
- See talk by Guillermo Contreras from Monday:

"Coherent photoproduction of J/ψ at forward rapidity in PbPb with the ALICE detector"

Conclusion and outlook

- Exculsive photonuclear production of ρ^0 has been studied.
- For the photonuclear production of ρ^0 the p_T distribution appears broader in Starlight than in data. Similar trend seen is STAR data?
- The production cross sections are being evaluated.