Production of various elements in ultraperipheral ^{208}Pb–^{208}Pb collisions at the LHC

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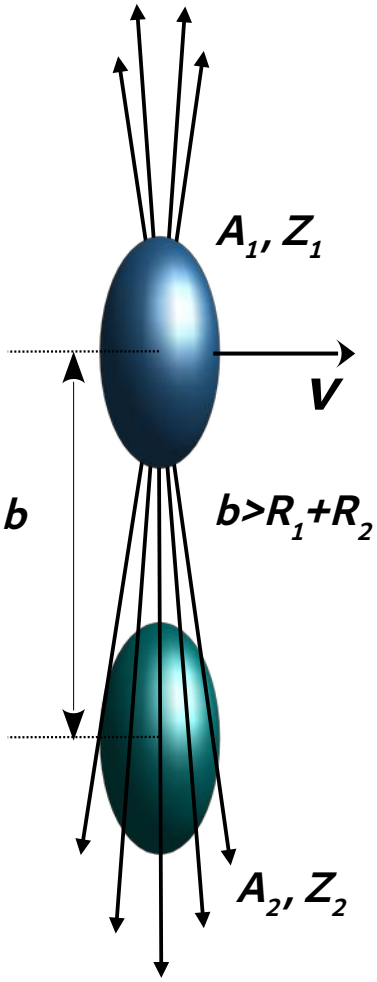
Outline

- Physics of ultrapheripheral collisions:
  - Weizsäcker–Williams method
  - Photoabsorption
  - RELDIS model
- Production of secondary nuclei calculated with RELDIS
- Impact of the various photoabsorbtion processes on the production of secondary nuclei
- Summary

Ultraperipheral collisions

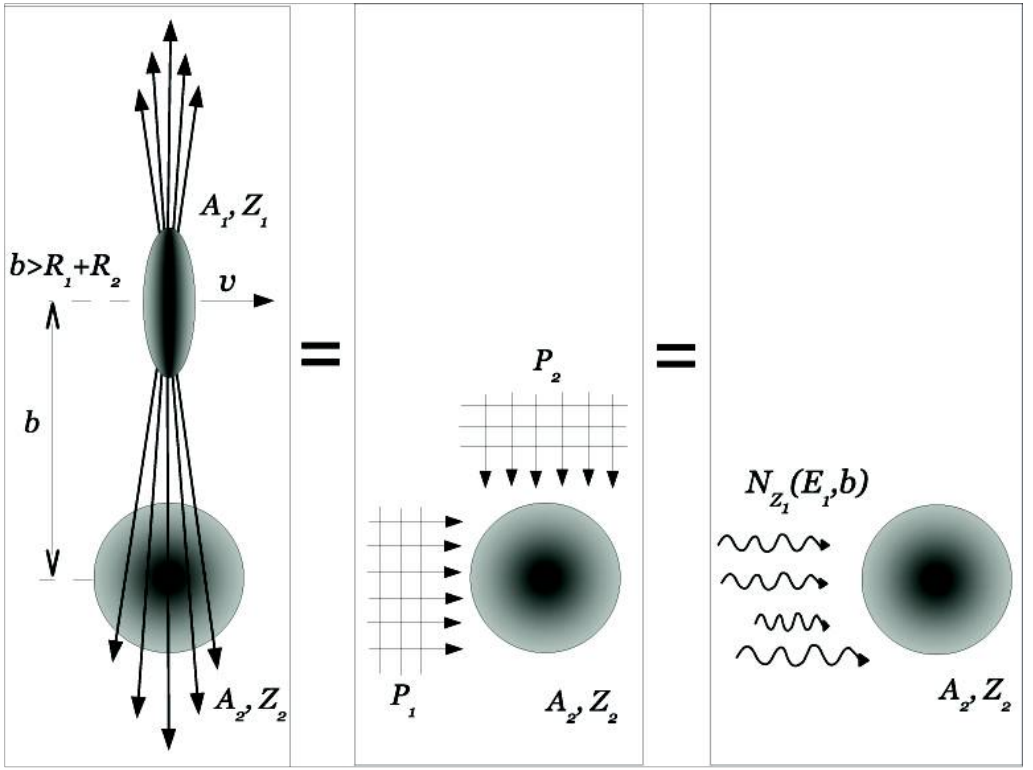
- Hadronic interactions of nuclei with significant overlap of nuclear densities and multiple particle production are mostly studied at RHIC and at the LHC.
- In **ultraperipheral collisions (UPC)** colliding nuclei interact electromagnetically leading to their break-up – **electromagnetic dissociation (EMD)** of nuclei.
- The total cross section of EMD (~ 211 b for ^{208}Pb) at the LHC is much larger than the hadronic cross section (7.7 b).
- In most cases, EMD results in the emission of one or few nucleons with the production of a single residual nucleus.
- As expected,various heavy secondary nuclei are produced in EMD at the LHC. These nuclei are not detectable, but they can pass through the collimator system and impact collider elements.

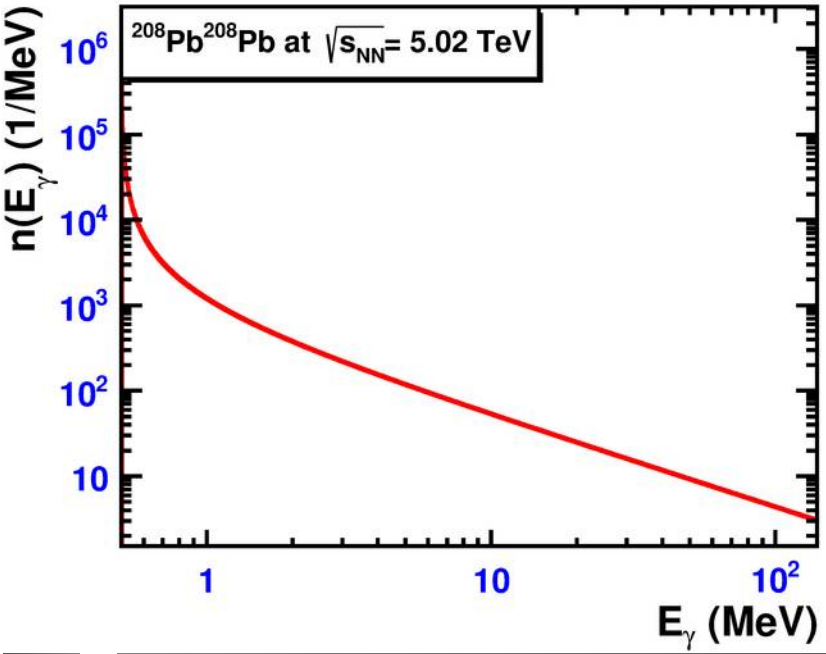


A. J. Baltz, Phys Rep 458, 1 – 171 (2008)
R. Bruce et al., Phys Rev ST Accel Beams 12, 071002 (2009)

Weizsäcker–Williams method

The impact of the Coulomb field of the nucleus A_1 to A_2 can be represented by the absorption of one or more equivalent photons by the target nucleus A_2.





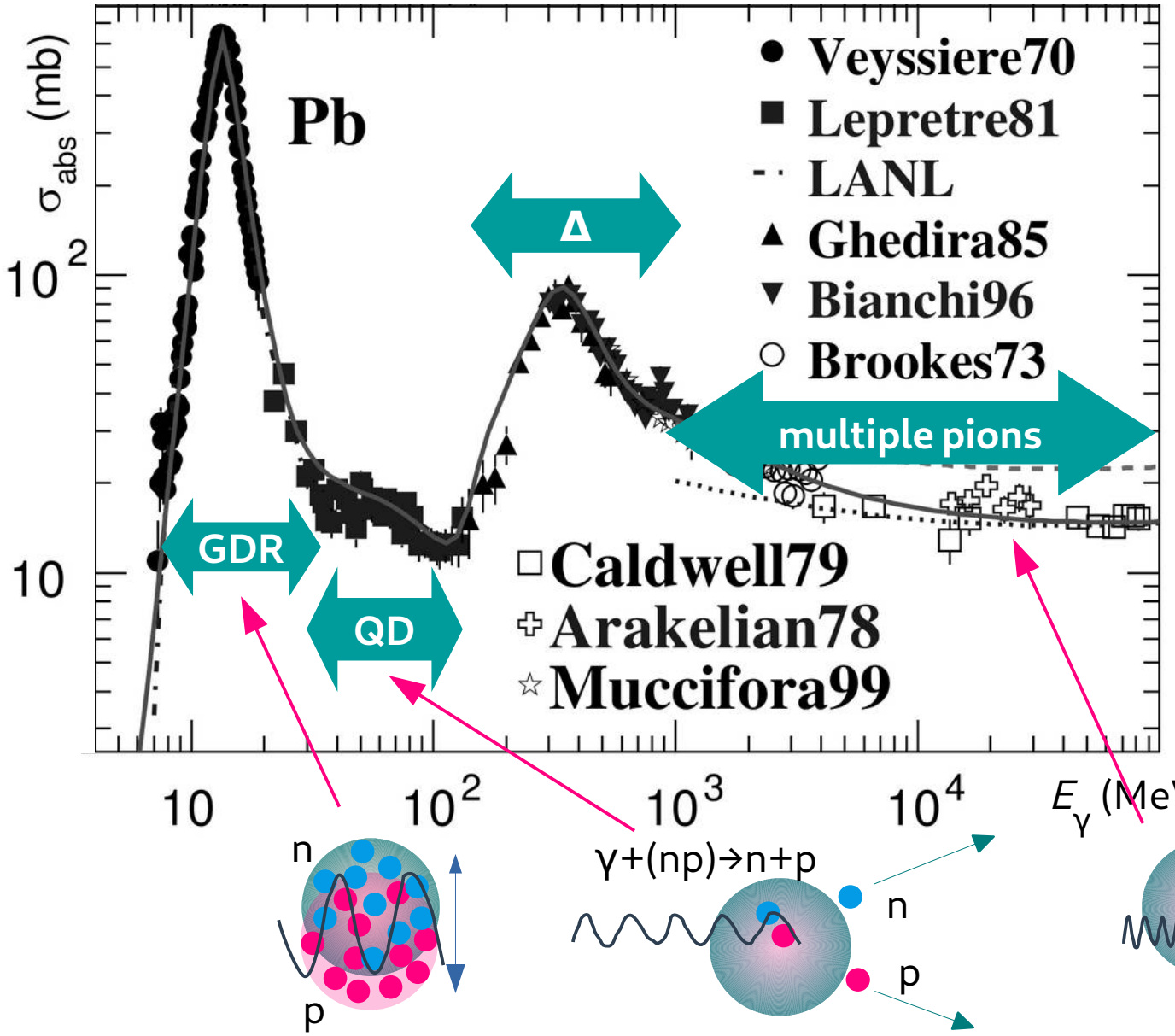
The spectrum of equivalent photons from an ultrarelativistic nucleus $(\gamma >> 1)$ with charge Z_1 is given as:

$$n(E_\gamma) = \frac{2\alpha Z_1^2}{\pi\beta^2 E_\gamma}\left(\mathrm{x}K_0(\mathrm{x})K_1(\mathrm{x}) - \frac{\mathrm{x}^2\beta^2}{2}(K_1^2(\mathrm{x}) - K_0^2(\mathrm{x}))\right),$$

$$\mathrm{x} = \omega b/\gamma v = E_\gamma b/\gamma\beta\hbar c$$

Various processes of photoabsorption

Nuclear ...



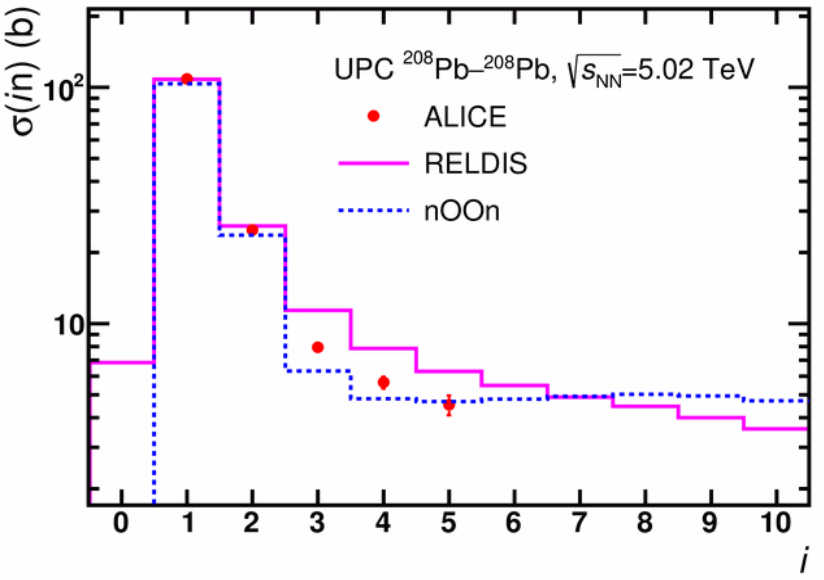
...and hadronic degrees of freedom

Relativistic ELectromagnetic DISsociation (RELDIS) model

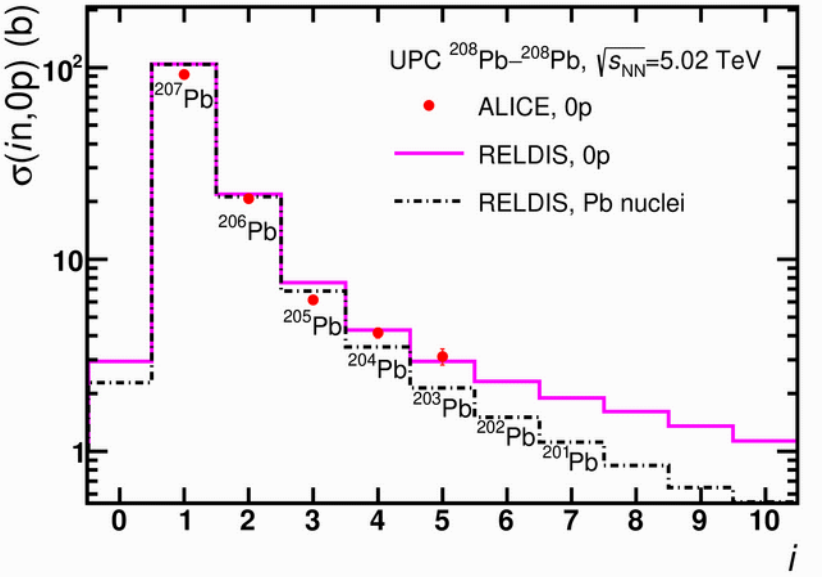
- RELDIS describes electromagnetic interactions between nuclei in UPCs by means of the Weizsäcker–Williams method.
- The model takes into account single and double photon absorption and includes the excitations of giant resonances, intranuclear cascades of produced hadrons, and statistical decay of excited residual nuclei.
- The UPC of lead nuclei at the LHC were simulated with RELDIS to evaluate the contributions of photonuclear reactions in the domain of quasideuteron absorption and at higher photon energies.

Recent ALICE@LHC results on neutron emission: RELDIS validation

One, two or three neutrons (1n, 2n and 3n) are emitted frequently in UPC of ^{208}Pb. This is mostly due to the excitation and decay of Giant Dipole Resonances (GDR) in colliding nuclei typically below the proton emission threshold.



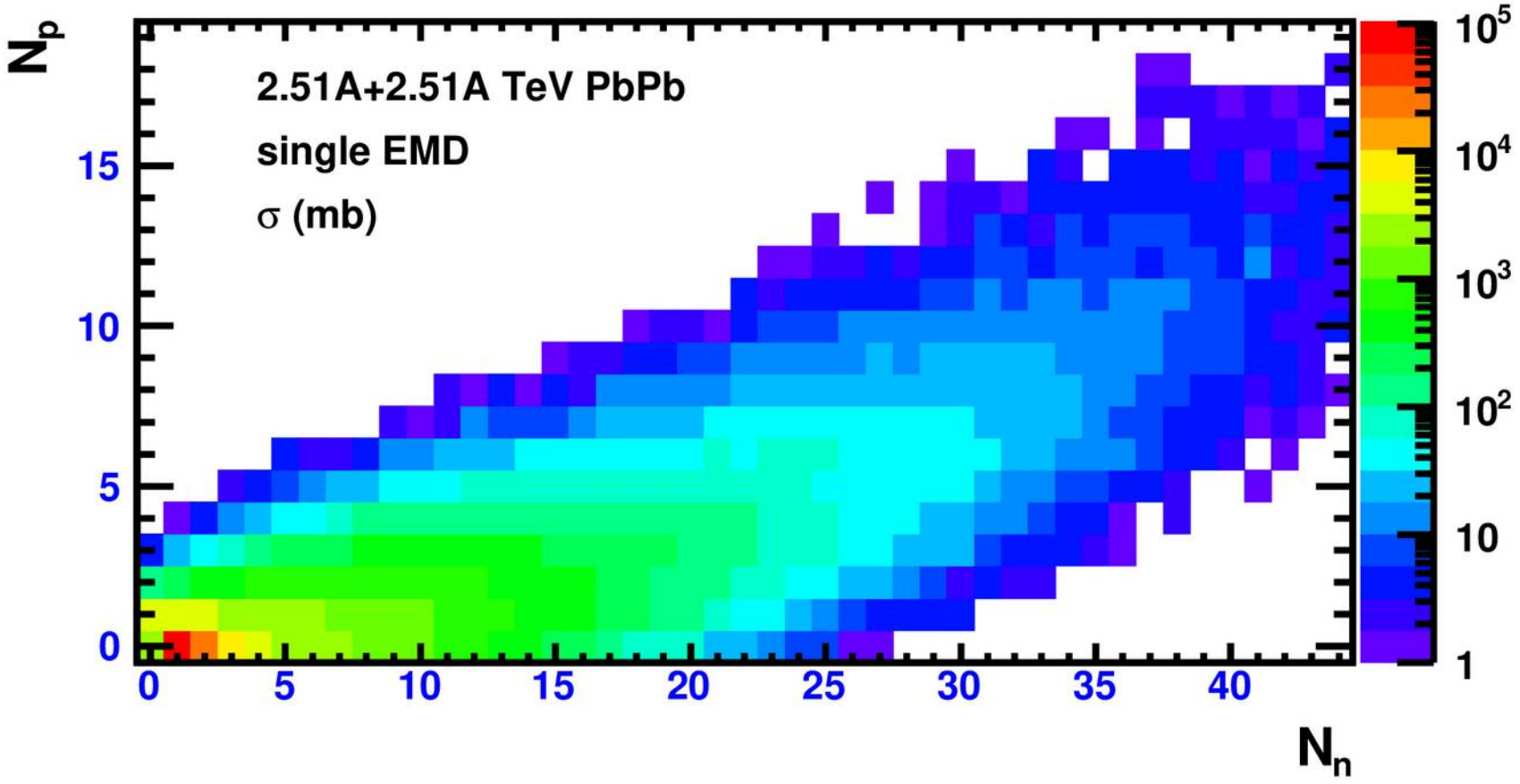
According to RELDIS, the cross sections of production of ^{207,206,205,204,203}Pb isotopes can be approximated by the cross sections of the neutron emission without protons.



ALICE Colaboration. *Neutron emission in ultraperipheral Pb-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV*. arXiv:2209.04250 [nucl-ex]

Numbers of emitted neutrons and protons in EMD ...

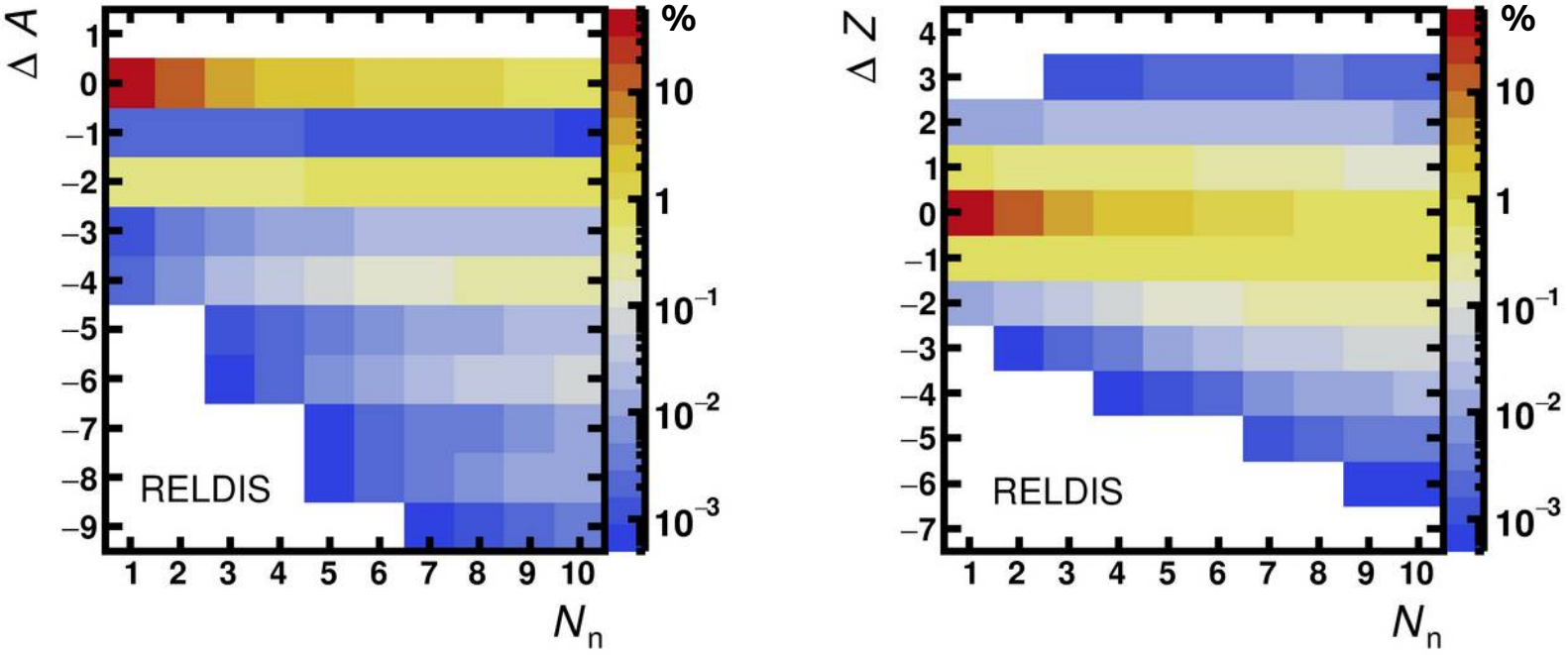
... reach ~50 and ~20, respectively.



EMD: single residue with several nucleons

$\Delta A = A_{res} + N_n + N_p - 208,$ $\Delta Z = Z_{res} + N_p - 82,$

Z_{res} and A_{res} – the charge and mass of the heaviest residual nucleus,
N_n и N_p – the numbers of emitted neutrons and protons.

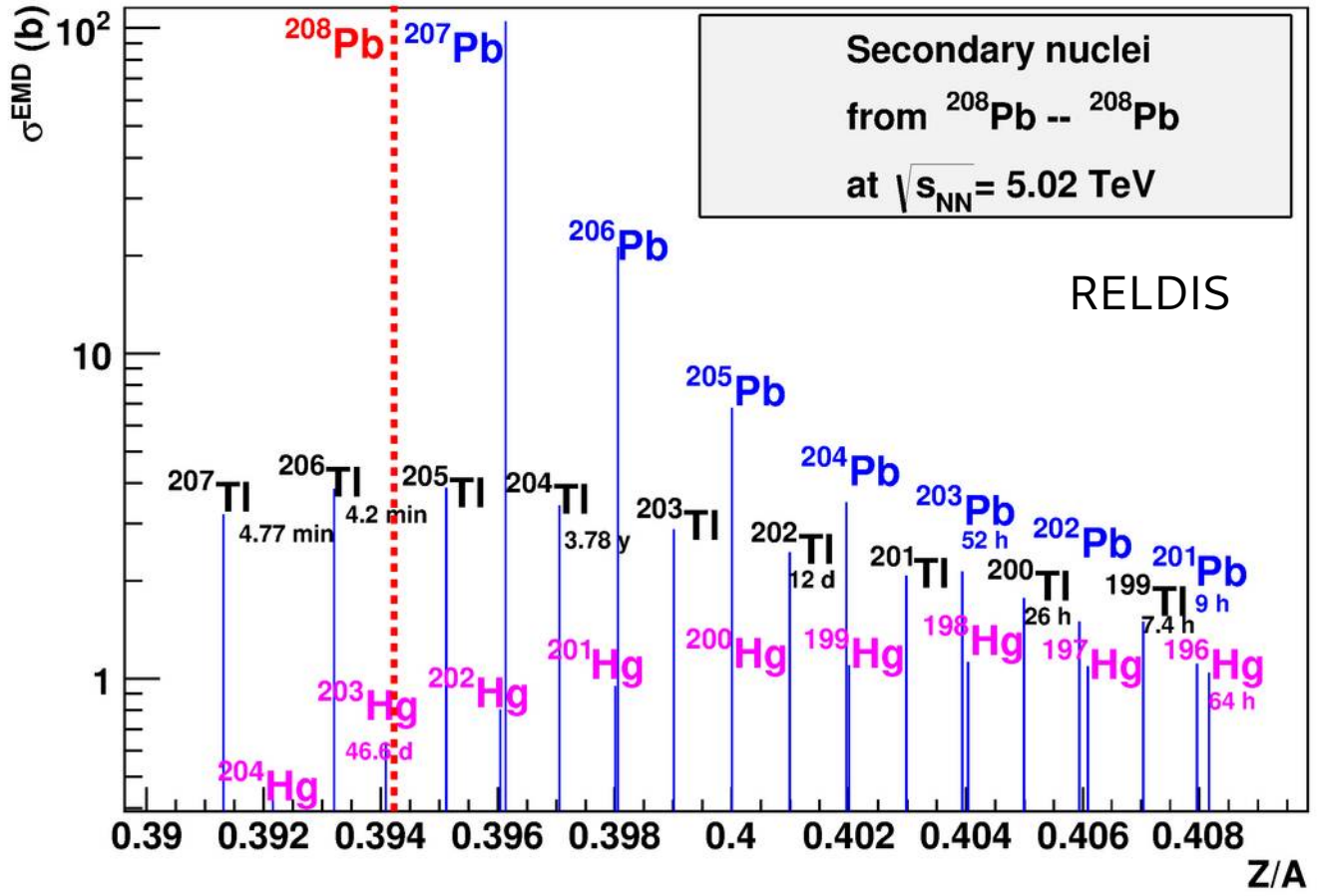


Direct measurments of secondary nuclei at the LHC is impossible.

The cross sections of the production of specific elements can be well approximated by the proton emission cross sections, which can be measured in the ALICE experiment at the LHC.

ALICE Colaboration. *Neutron emission in ultraperipheral Pb-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV*. arXiv:2209.04250 [nucl-ex]

Production of Pb, Tl and Hg isotopes



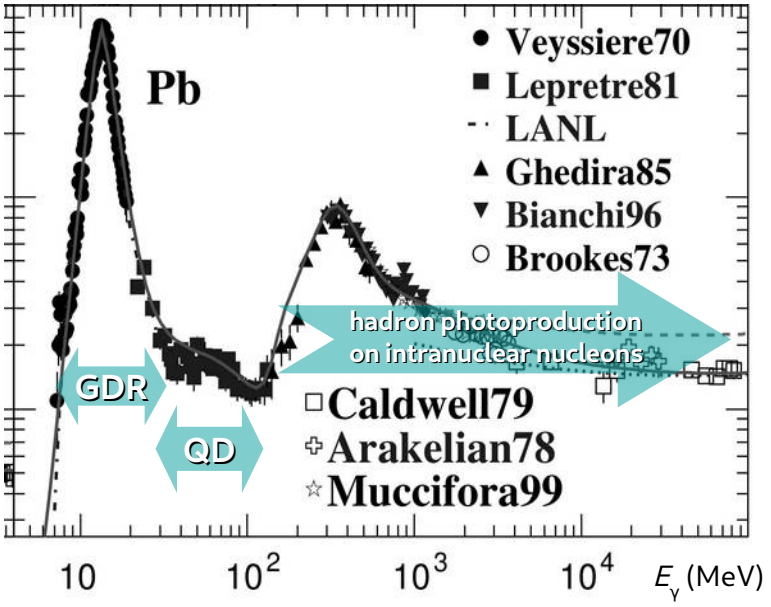
Z/A ratio characterizes the proximity of the trajectories of secondary nuclei in the magnetic field of the LHC to the beam.

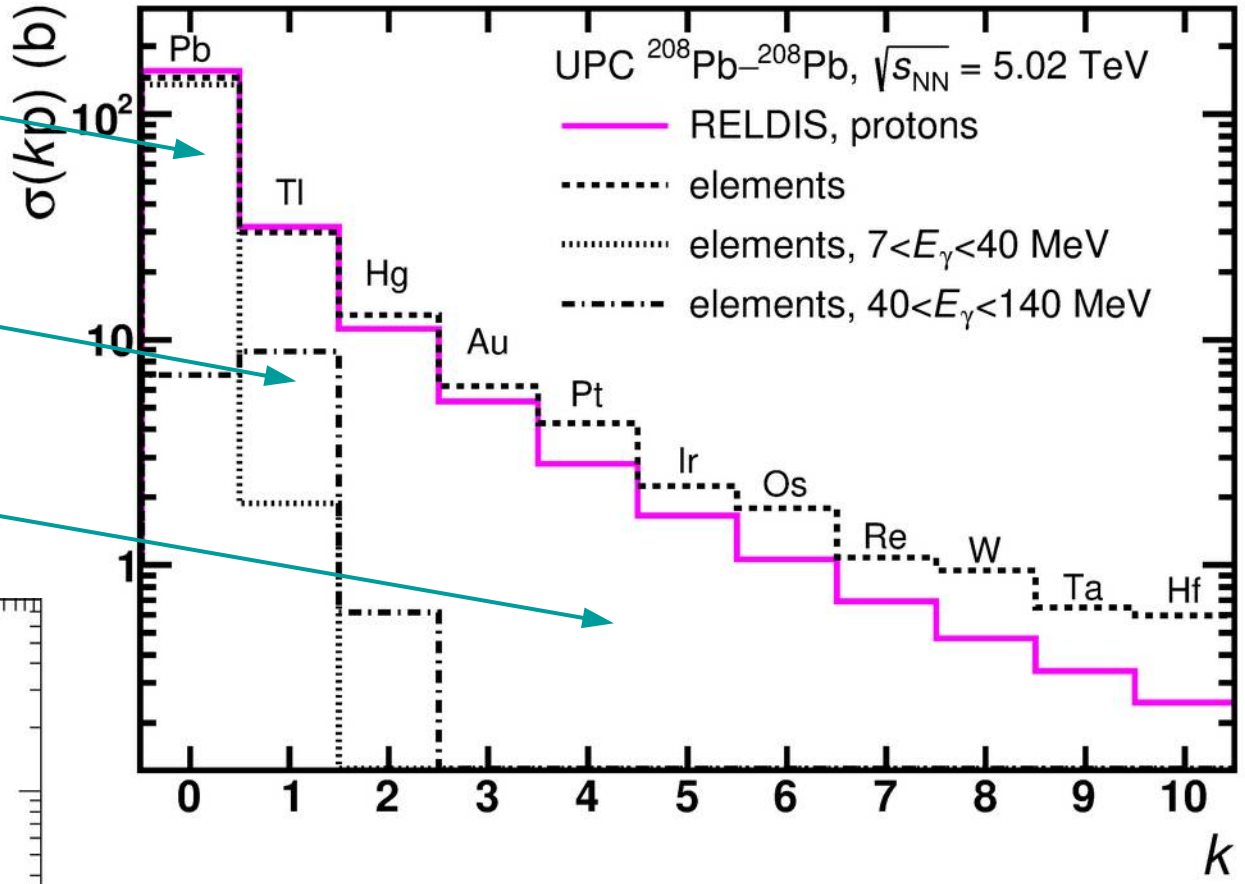
Production of secondary nuclei

7 – 40 MeV, GDR excitations

40 – 140 MeV, quasideuteron absorption

> 140 MeV, hadron photoproduction on intranuclear nucleons

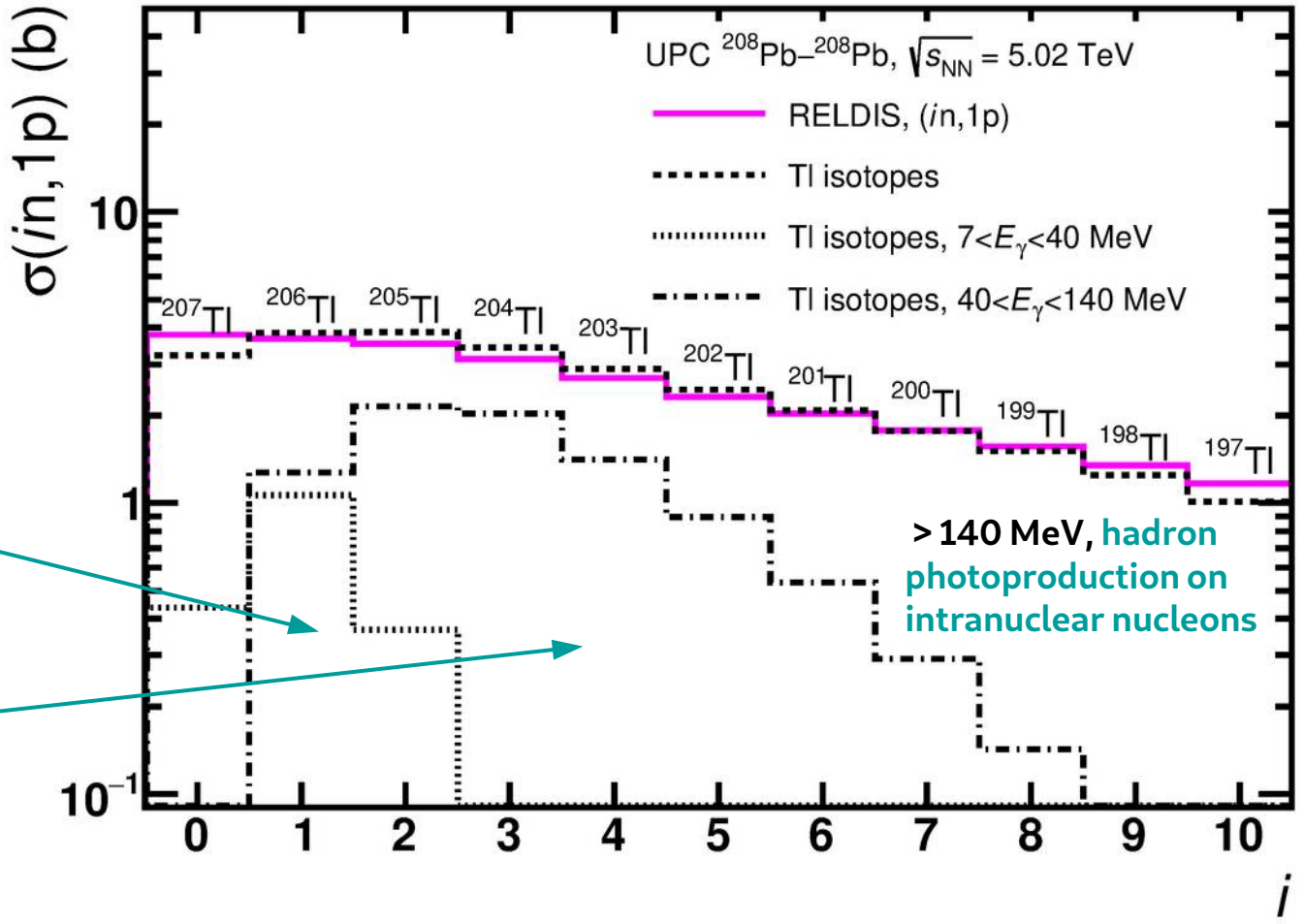




Pb isotopes are mostly produced due to GDR decay.

Starting with gold nuclei, only hadron photoproduction on intranuclear nucleons is responsible for the production of secondary nuclei.

Production of Tl isotopes



7 – 40 MeV, GDR excitations

40 – 140 MeV, quasideuteron absorption

> 140 MeV, hadron photoproduction on intranuclear nucleons

^{206,205}Tl are frequently produced by low energy photons.

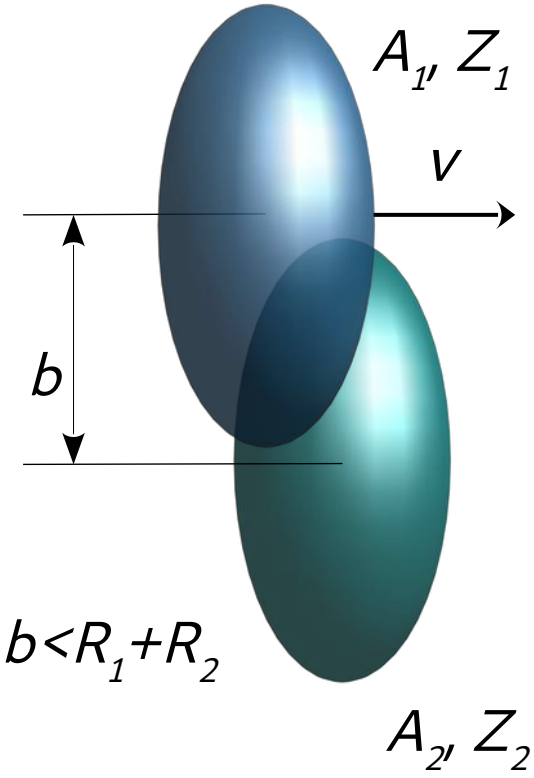
Summary

- According to RELDIS, the cross sections of the production of secondary nuclei can be well approximated by the cross sections to emit corresponding numbers of neutrons and protons.
- Pb isotopes are mostly produced by low energy photons.
- Production of Tl and Hg isotopes is observed for the higher energies of photons: combination of different photoabsorption processes.
- Au, Pt ..., Hf isotopes can be produced in EMD only by energetic photons (> 140 MeV). This process is similar to photospallation.

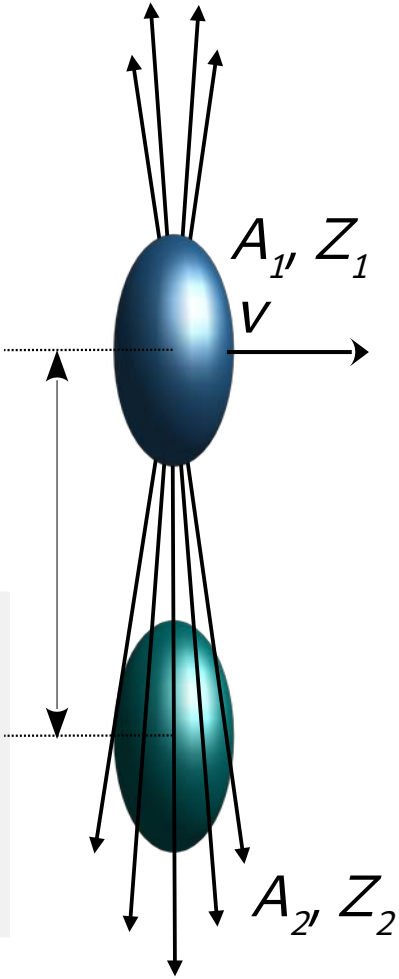
THANK YOU
FOR YOUR ATTENTOIN

Hadronic and electromagnetic interactions of nuclei

with overlap of nuclei densities



without overlap of nuclei densities



RELDIS predictions are validated experimentally : cross sections of emission of one and two neutrons

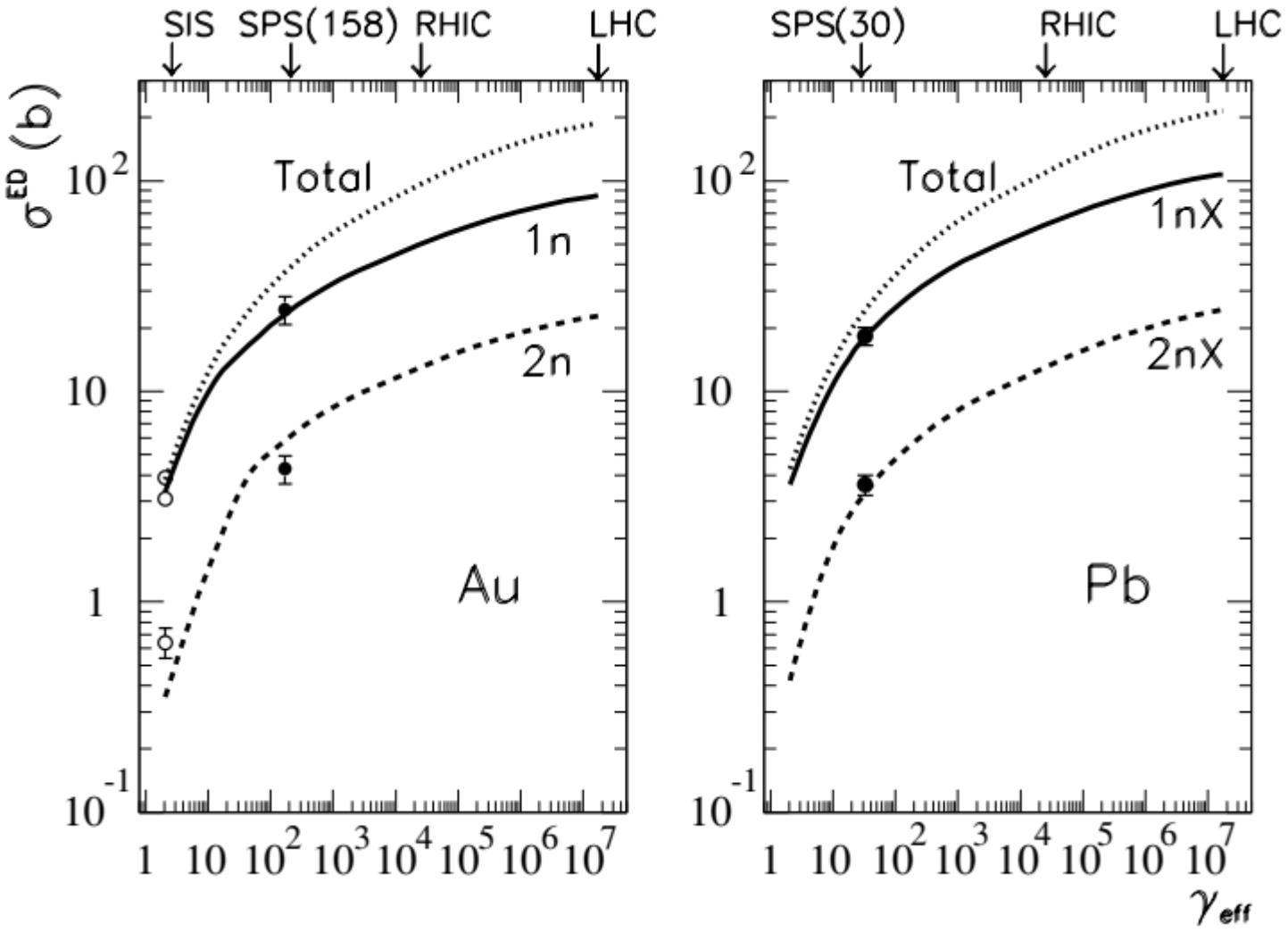
- SIS
- SPS

RELDIS:

total EMD cross section

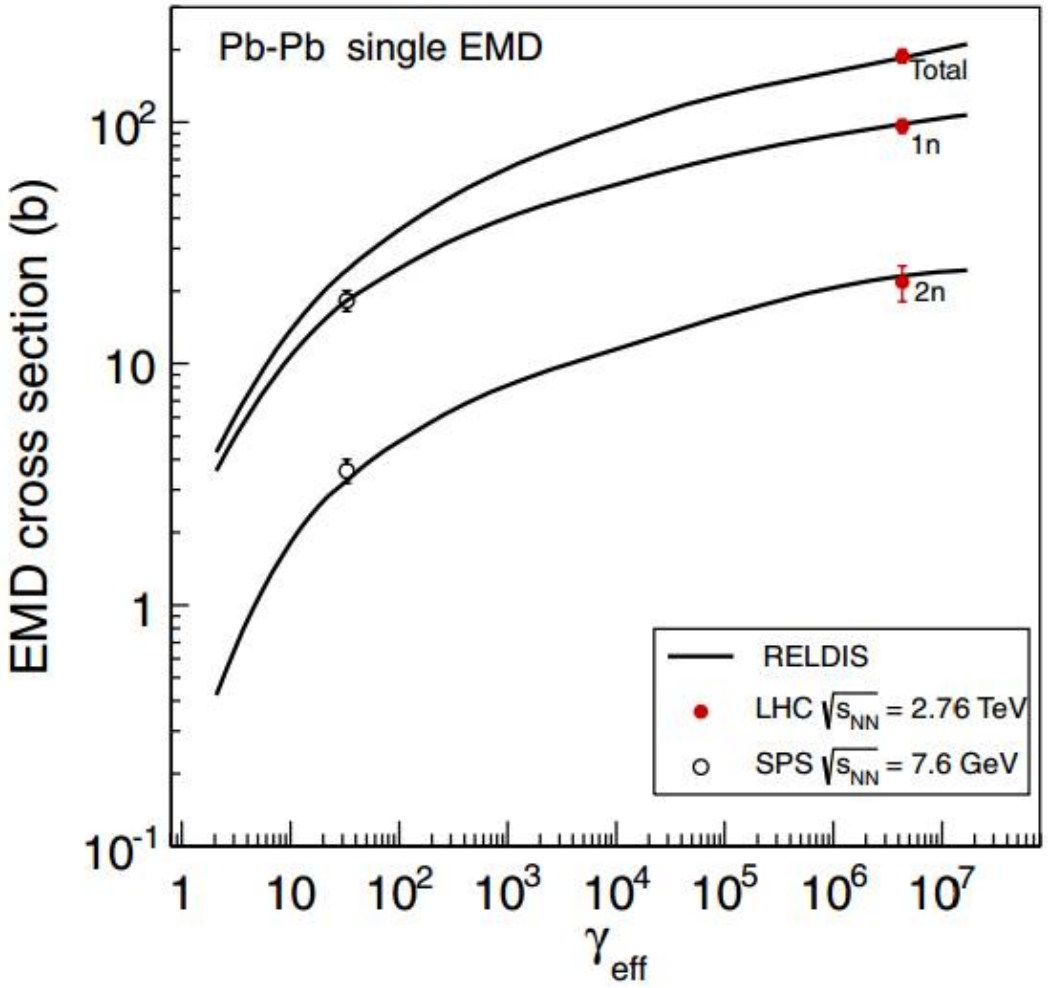
— cross section of emission of one neutron

--- cross section of emission of two neutrons



M. B. Golubeva et al. PHYSICAL REVIEW C 71, 024905 (2005)

… also at the LHC



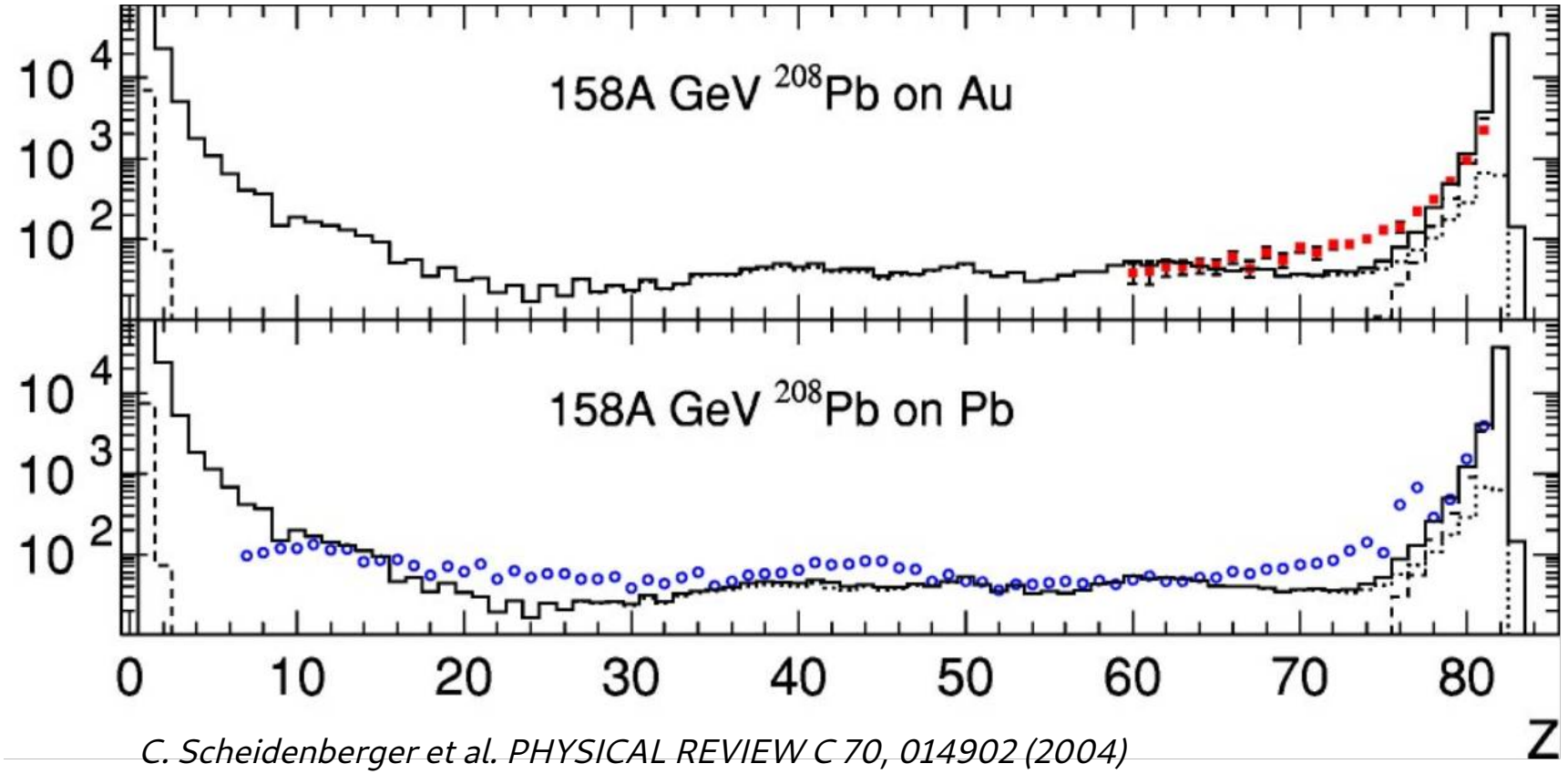
Charge-changing cross sections

Red • and blue ∘ circles – experimental data.

abrasion-ablation model for hadronic contribution

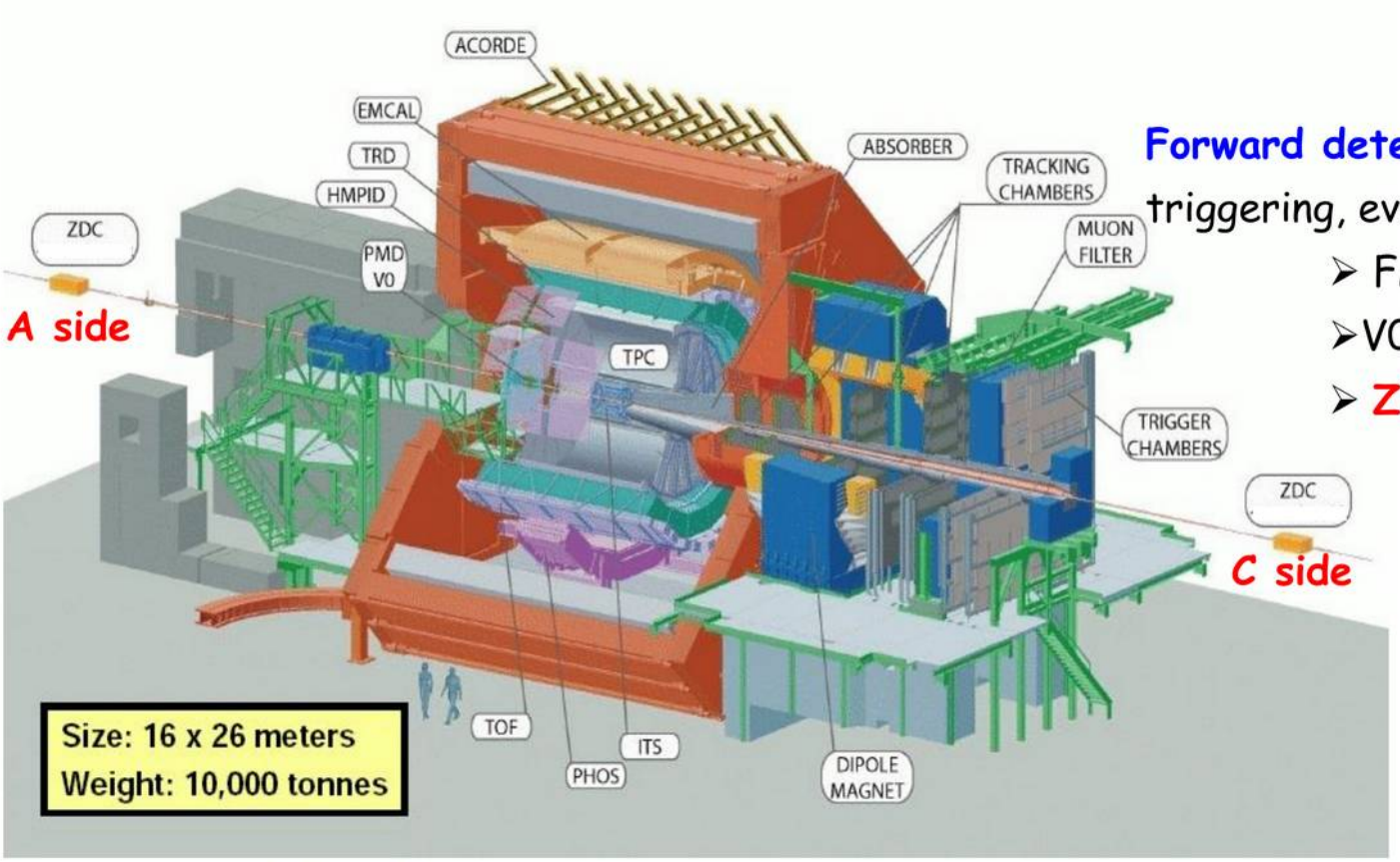
--- RELDIS model for electromagnetic contribution

— their sum



C. Scheidenberger et al. PHYSICAL REVIEW C 70, 014902 (2004)

Zero Degree Calorimeters (ZDC)



Forward detectors ($|\eta|>3$)

triggering, event characterization

- FMD, PMD, T0
- V0 ($2.8<\eta<5.1$, $-3.7<\eta<-1.7$)
- **ZDC** ($|\eta|>8.8$)

ALICE

Central Barrel ($|\eta|<0.9$)

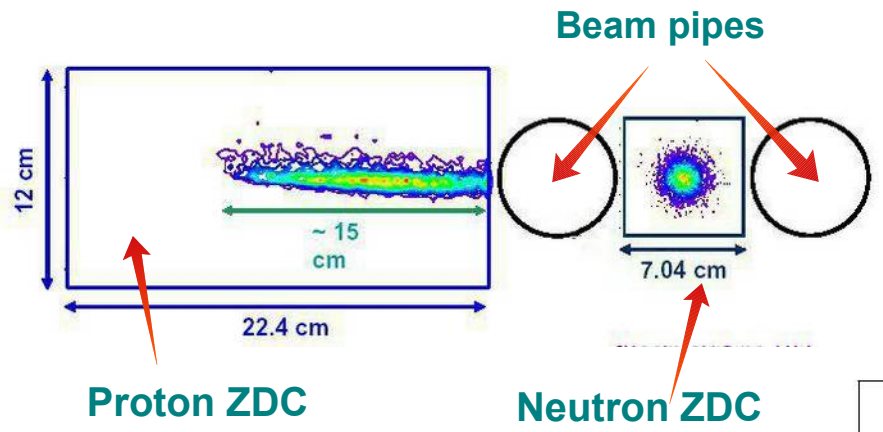
study of hadronic signals, photons and dielectrons

Dimuon arm ($-4<\eta<-2.5$)

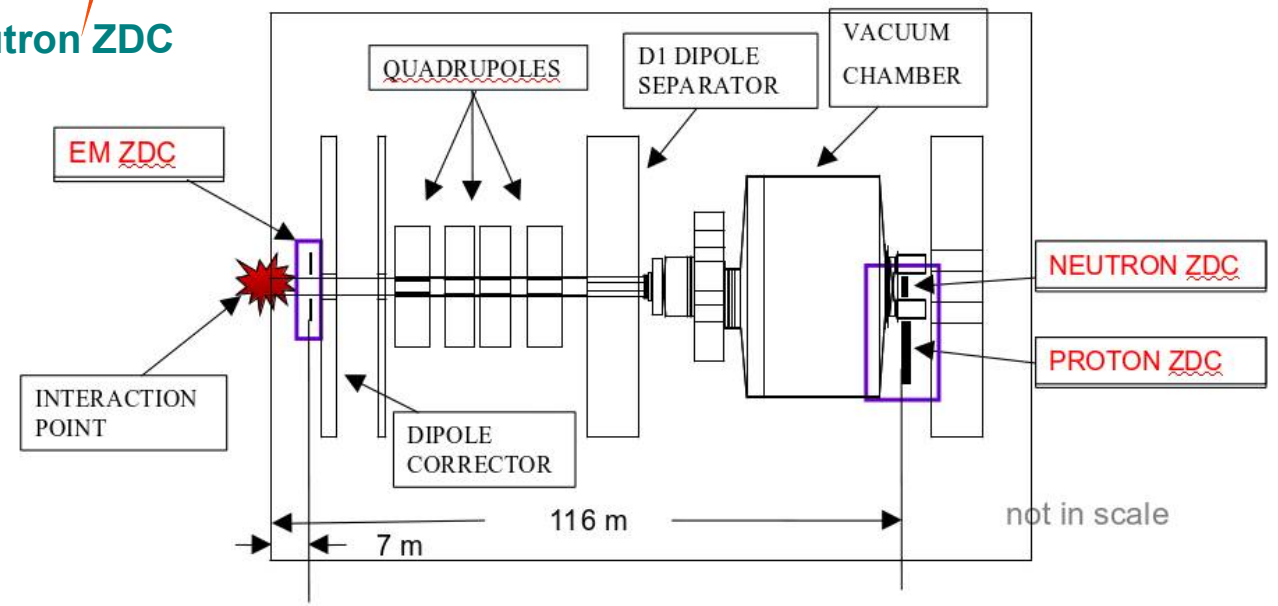
study of muon pair production

C.Oppedisano et al., Nucl.Phys.B (Proc.Suppl.) 197(2009)206

ALICE ZDC



ZDC are places far from IP and the are partially overlapped by collimators and other collider components.



M. Gallio
Joint LHC Machine-Experiment Workshop
25 January 2007