COMEX5

Electromagnetic excitation of nuclei in photoabsorption reactions and in UPC

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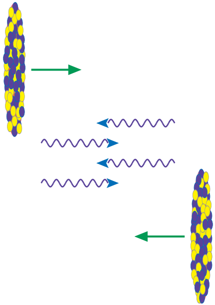
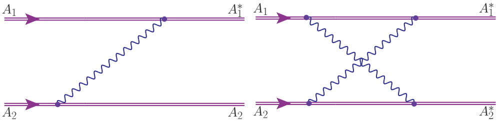
ELECTROMAGNETIC EXCITATION OF NUCLEI

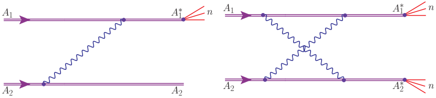
- Heavy ion collision $\rightarrow$ photons fluxes [v $\approx$ c]



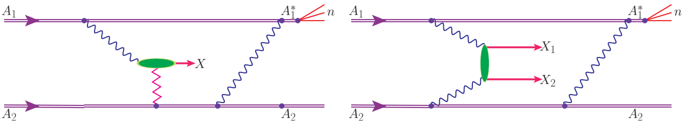
- Photon $\rightarrow$ nucleus excitation



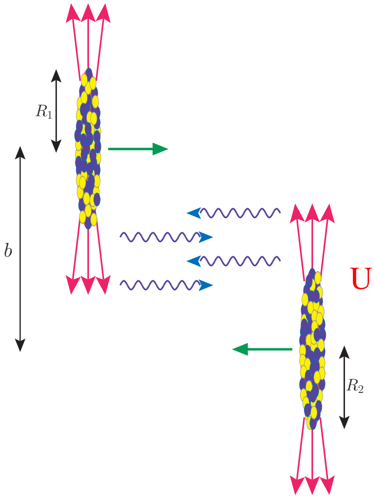
- De-excitation
  $\rightarrow$ system breakup
  $\rightarrow$ neutron emission



- Meson production with neutron emission



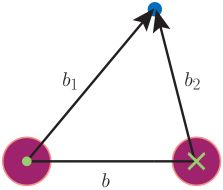
Equivalent Photon Approximation



The strong electromagnetic field is a source of photons that can induce electromagnetic reactions in ion-ion collisions.

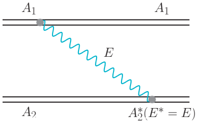
UltraPeripheral Collisions

$$b > R_{min} = R_1 + R_2$$



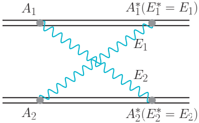
EM EXCITATION IN UPC

Single



$$\sigma\left(A_1 A_2 \to A_1 A_2^*\right) = \int \mathrm{d}^2\mathbf{b}\, P_{surv}(\mathbf{b}) P^{exc}_{A_2}(\mathbf{b})$$

Mutual



$$\sigma\left(A_1 A_2 \to A_1^* A_2^*\right) = \int \mathrm{d}^2\mathbf{b}\, P_{surv}(\mathbf{b}) P^{exc}_{A_2}(\mathbf{b}) P^{exc}_{A_1}(\mathbf{b})$$

$$P_{surv}(\mathbf{b}) \sim \theta\left(|\mathbf{b}| - (R_1 + R_2)\right)$$

$$P^{exc}_{A_2}(\mathbf{b}) = \overline{n}_{A_2}(\mathbf{b}) \exp\left[-\overline{n}_{A_2}(\mathbf{b})\right]$$

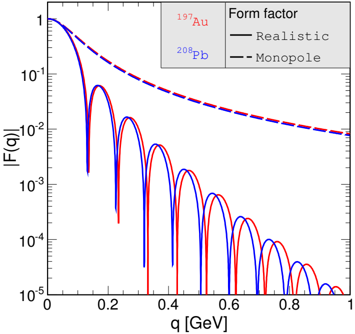
$$\overline{n}_{A_2}(\mathbf{b}) = \int_{E_{min}}^{\infty} \mathrm{d}E\, N_{A_1}(E, \mathbf{b}) \sigma_{tot}(\gamma A_2; E)$$

FORM FACTOR

$$N(E,b) = \frac{Z^2\alpha_{em}}{\pi^2}\left|\int u^2 J_1(u) \frac{F\left(\frac{\left(\frac{Eb}{\gamma}\right)^2+u^2}{b^2}\right)}{\left(\frac{Eb}{\gamma}\right)^2+u^2}\right|^2$$

- **REALISTIC**

$$F(q) = \frac{4\pi}{q}\int \rho(r)\sin(qr)\,rdr$$



- **MONOPOLE**

$$F(q) = \frac{\Lambda^2}{\Lambda^2+q^2}$$

$$\Lambda = \sqrt{\frac{6}{<r^2>}}$$

  - ${}^{197}Au \Rightarrow \sqrt{< r^2 >} = 5.3$ fm, $\Lambda = 91$ MeV,
  - ${}^{208}Pb \Rightarrow \sqrt{< r^2 >} = 5.5$ fm, $\Lambda = 88$ MeV.

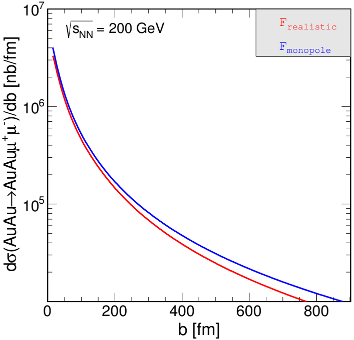
In the literature:

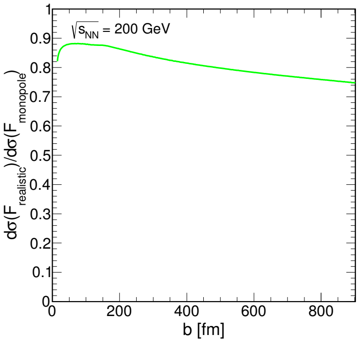
$\Lambda = (80-90)$ GeV

- **POINT-LIKE**

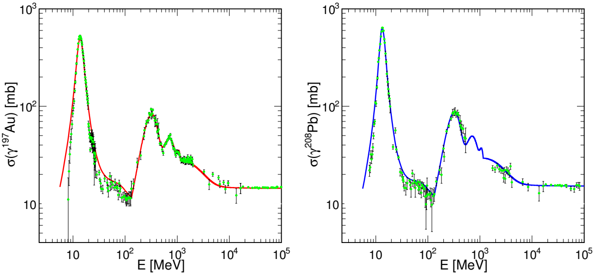
$$F(q) = 1$$

$$\mathrm{AuAu} \to \mathrm{AuAu}\ \mu^+\mu^-$$





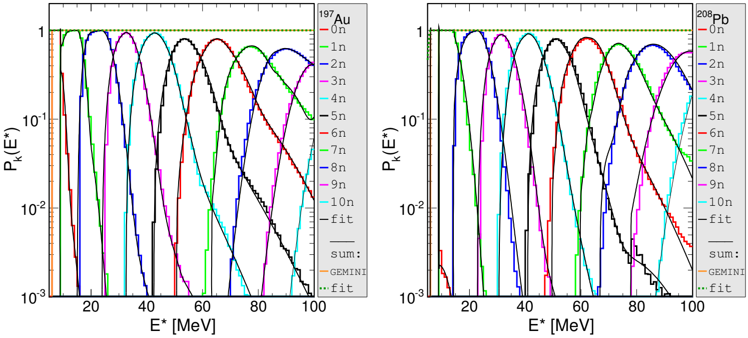
$\gamma^{197}Au$ & $\gamma^{208}Pb$



$$\sigma_{\gamma A} = \sigma_{\rm GDR} + \sigma_{\rm QD} + \sigma_{\rm nucleon\ res.} + \sigma_{\rm nucleon\ cont.}$$

1. $E_\gamma < 40$ MeV - $\sigma_{\rm GDR}$
2. $E_\gamma = (40-100)$ MeV - $\sigma_{\rm QD}$
3. $E_\gamma = (100-1000)$ MeV - $\sigma_{\rm nucleon\ resonances}$
4. $E_\gamma = (1-8)$ GeV - $\sigma^{\rm low-energy}_{\rm nucleon\ continuum}$
5. $E_\gamma > 8$ GeV - $\sigma^{\rm high-energy}_{\rm nucleon\ continuum}$

Probability of neutron multiplicity

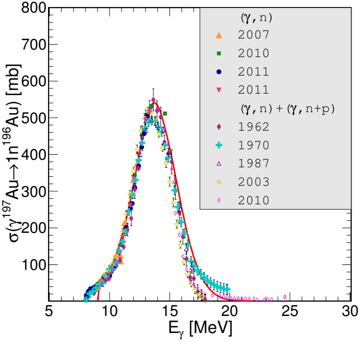


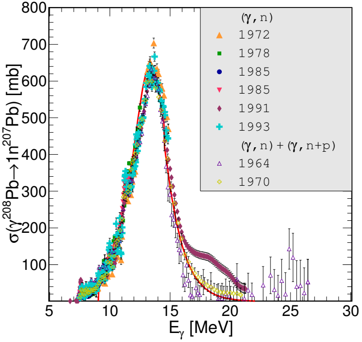
GEMINI++

evaporation process is described by the Hauser-Feshbach formalism

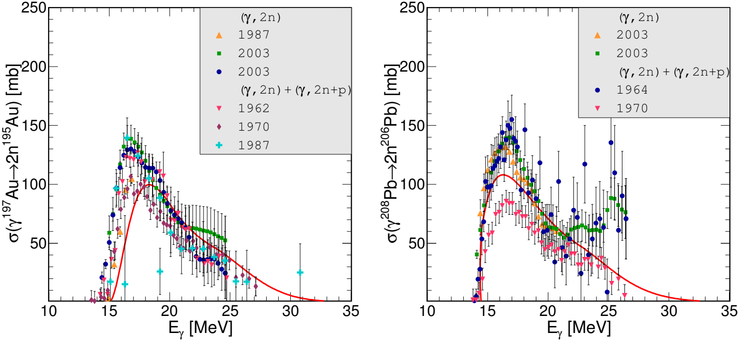
More details $\mapsto$ back-up slides

$\gamma^{A}Au/_{Pb} \rightarrow 1n^{(A-1)}Au/_{Pb}$

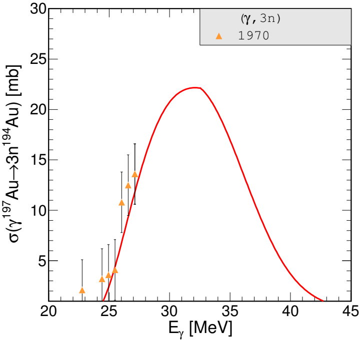


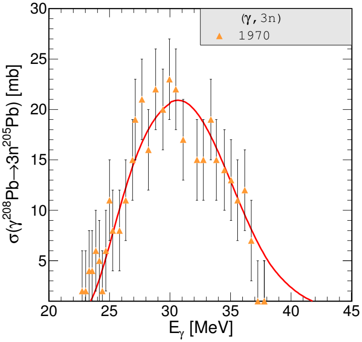


$\gamma\, {}^{A}Au/Pb \rightarrow 2n\, {}^{(A-2)}Au/Pb$



$\gamma\,{}^{A}Au/_{Pb} \rightarrow 3n\,{}^{(A-3)}Au/_{Pb}$





The ALICE Zero Degree Calorimeters

Placed at 0° w.r.t LHC axis, ~114 m far from IP on both sides (A and C)

- 2 neutron calorimeters (ZNA and ZNC) placed between the beam pipes $|\eta| > 8.7$
- 2 proton calorimeters (ZPA and ZPC) close to the outgoing beam pipe
- 2 small electromagnetic calorimeters (ZEM1, ZEM2) placed at ~7.5 m from the IP, at ±8 cm from LHC axis, only on A side covering $4.8 < \eta < 5.7$

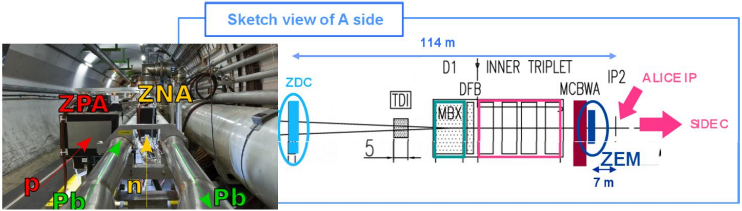
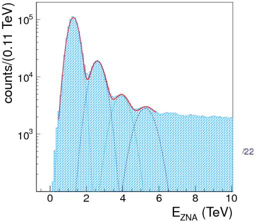


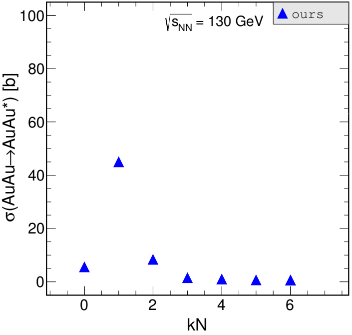
FIG. ZNA energy spectrum requiring signal over threshold in ZNA but not in ZNC, rejecting thus neutron emission on the opposite side. The dashed lines represent the single fits of the different peaks (1n, 2n,...), while the continuous line is the sum of all the contributions.



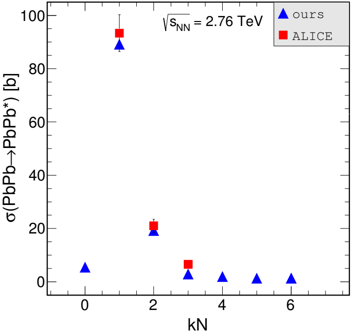
P. Cortese, International Conference on New Frontiers in Physics 2012

Single excitation in UPC

Au+Au @ $\sqrt{s_{NN}} = 130$ GeV



Pb+Pb @ $\sqrt{s_{NN}} = 2.76$ TeV

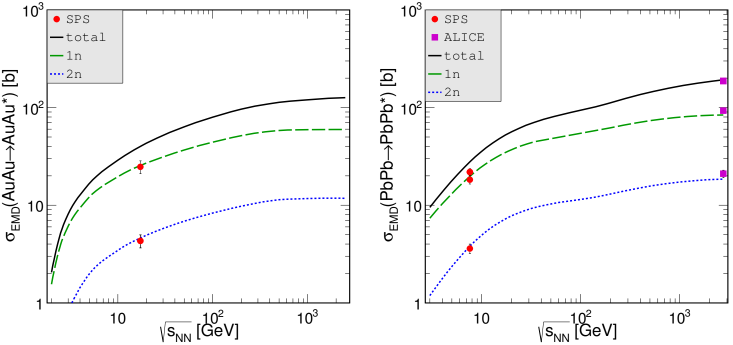


- given multiplicity of neutrons
- single-nucleus, single-photon excitation

$\frac{2n}{1n} \rightsquigarrow$ ALICE$= (22.5 \pm 0.5$ (stat) ± 0.9 (syst)$)\%$

ours$= 21.6\%$

SINGLE EXCITATION IN UPC



Mutual excitations

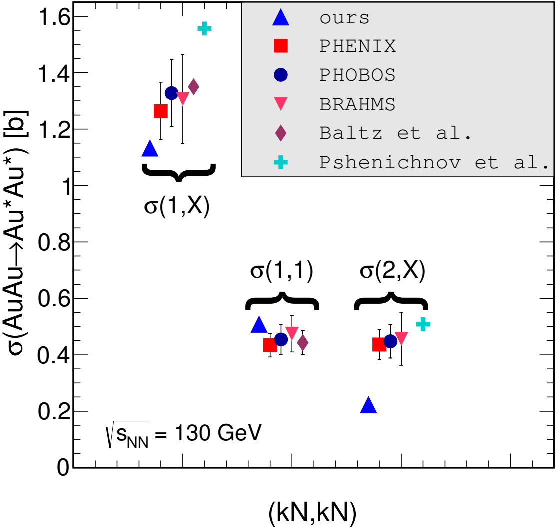
Cross section (in barns) for Au+Au @ $\sqrt{s_{NN}} = 130$ GeV

	1n	2n	3n	4n	5n	6n
1n	0.5082	0.1002	0.0195	0.0137	0.0096	0.0091
2n	0.1002	0.0198	0.0038	0.0027	0.0019	0.0018
3n	0.0195	0.0038	0.0007	0.0005	0.0004	0.0003
4n	0.0137	0.0027	0.0005	0.0004	0.0003	0.0002
5n	0.0096	0.0019	0.0004	0.0003	0.0002	0.0002
6n	0.0091	0.0018	0.0003	0.0002	0.0002	0.0002
$\sum$	0.6603	0.1302	0.0252	0.0178	0.0126	0.0118
$\sum$			0.8579			

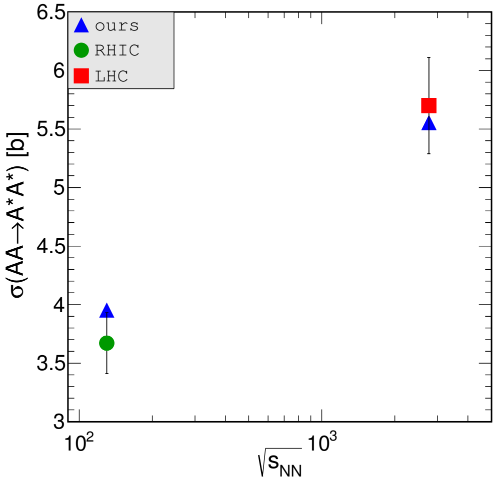
Mutual excitations

Cross section (in barns) for Au+Au @ $\sqrt{s_{NN}} = 130$ GeV

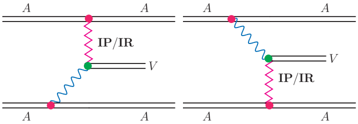
	6n
1n	)091
2n	)018
3n	)003
4n	)002
5n	)002
6n	)002
$\sum$	)118
$\sum$	

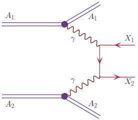


Mutual excitations

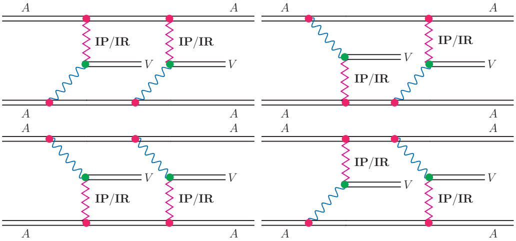


Application to exclusive processes



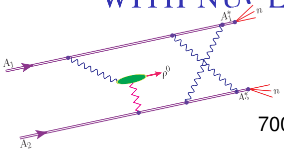


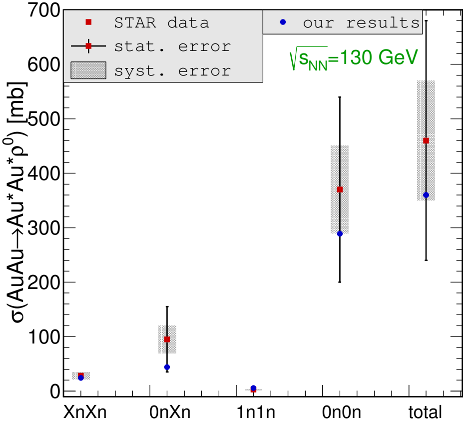
- $AA \to AA\rho^0(\to \pi^+\pi^-)$
- $AA \to AAJ/\psi$
- $AA \to AA\rho^0\rho^0(\to 4\pi)$
- $AA \to AAl^+l^-$



- $AA \to AA\rho^0\rho^0(\to \pi^+\pi^-\pi^+\pi^-)$
- $AA \to AAJ/\psi J/\psi$

ρ^0 PRODUCTION IN HEAVY ION UPC WITH NUCLEAR EXCITATION





very preliminary

CONCLUSIONS

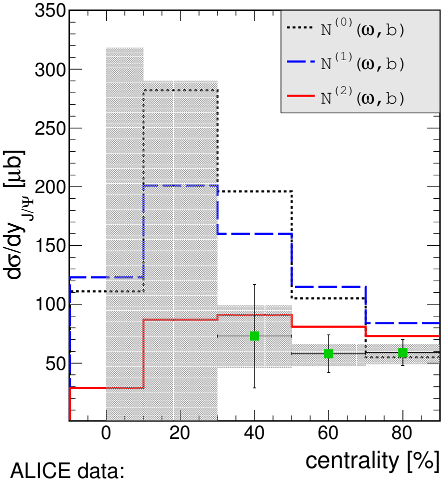
- Impact parameter space approach
- Neutron emission $\longleftarrow$ Hauser-Feshbach formalism
- Good description of experimental data for
  - the excitation functions for $\gamma+^{197}$Au and $\gamma+^{208}$Pb
    - photoabsorption
      + giant resonances
      + quasi-deuteron
      + excitation of nucleon resonances
      + breakup of nucleon
    - with fixed number of neutrons
  - UPC heavy-ion collision (RHIC and LHC energy)
    - single
    - mutual excitations

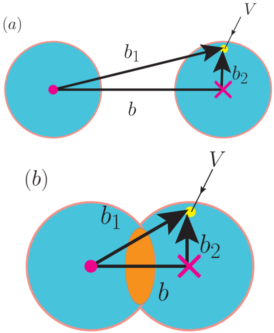
Reference:
M. K-G, M. Ciemała, W. Schäfer and A. Szczurek, Phys. Rev. **C89** (2014) 054907,
"Electromagnetic excitation of nuclei and neutron evaporation in ultrarelativistic ultraperipheral heavy ion collisions"

- AuAu $\rightarrow$ Au*Au$^*\rho^0$(770) - theory & experiment

CONCLUSIONS

- not only UPC ⇝ PbPb→PbPbJ/ψ





Reference:
M. K-G and A. Szczurek,
arXiv: 1509.03173 [nucl-th],
"Photoproduction of J/ψ mesons in peripheral and semi-central heavy ion collisions"

ALICE data:
talk given by Laura Massacrier at EDS Blois workshop, 29th June - 4th July 2015, Borgo, Corsica, France

Back-up slides

DECAYS OF EXCITED NUCLEAR SYSTEM

$$\Gamma_i = \frac{1}{2\pi\rho(E^*, S_{CN})} \int d\epsilon \sum_{S_d=0}^{\infty} \sum_{J=|S_{CN}-S_d|}^{S_{CN}+S_d} \sum_{\ell=|J-S_i|}^{J+S_i} T_\ell(\epsilon)\rho(E^* - B_i - \epsilon, S_d) \;, \tag{1}$$

where S_d is the spin of the daughter nucleus, S_i, J and ℓ are spin, total and angular momentum of the evaporated particle, ϵ, B_i are kinetic and separation energies, T_ℓ is its transmission coefficient, ρ and ρ_{CN} are level densities of the daughter and compound nucleus, which can be calculated from the formula:

$$\rho(E^*, S) \propto (2S+1)\exp\left(2\sqrt{a(U,S)U}\right) \;, \tag{2}$$

where $U = E^* - E_{rot}(S) - \delta P$ is thermal excitation energy calculated by taking into account pairing corrections to the empirical mass formula (δP) and rotational energy $E_{rot}(S)$.
Level density parameter $a(U, S)$ was calculated as:

$$a(U,S) = \tilde{a}(U)\left(1 - h(U/\eta + S/S_\eta)\frac{\delta W}{U}\right) \;, \tag{3}$$

where δW is the shell correction to the liquid-drop mass and $\tilde{a}$ is smoothed level-density parameter, the function specifying the rate of fadeout is $h(x) = \tanh x$, the fadeout parameter η was set to 18.52 MeV and the parameter S_η was set to 50 $\hbar$.
The smoothed level density parametrization depends on the excitation energy of nucleus as:

$$\tilde{a}(U) = \frac{A}{k_\infty - (k_\infty - k_0)\exp\left(-\frac{\kappa}{k_\infty - k_0}\frac{U}{A}\right)} \;, \tag{4}$$

where $k_0 = 7.3$, $k_\infty = 12$ and $\kappa = 0.00517\exp(0.0345A)$.