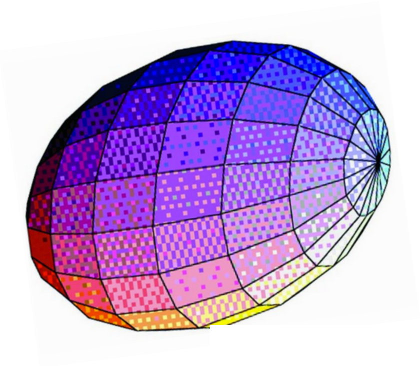
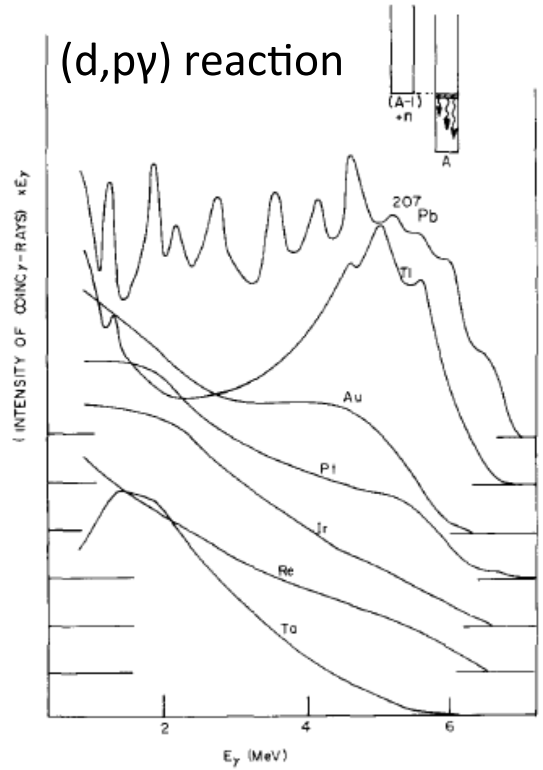
Observation of low-lying resonances in the quasicontinuum of $^{195,196}Pt$ and enhanced astrophysical reaction rates

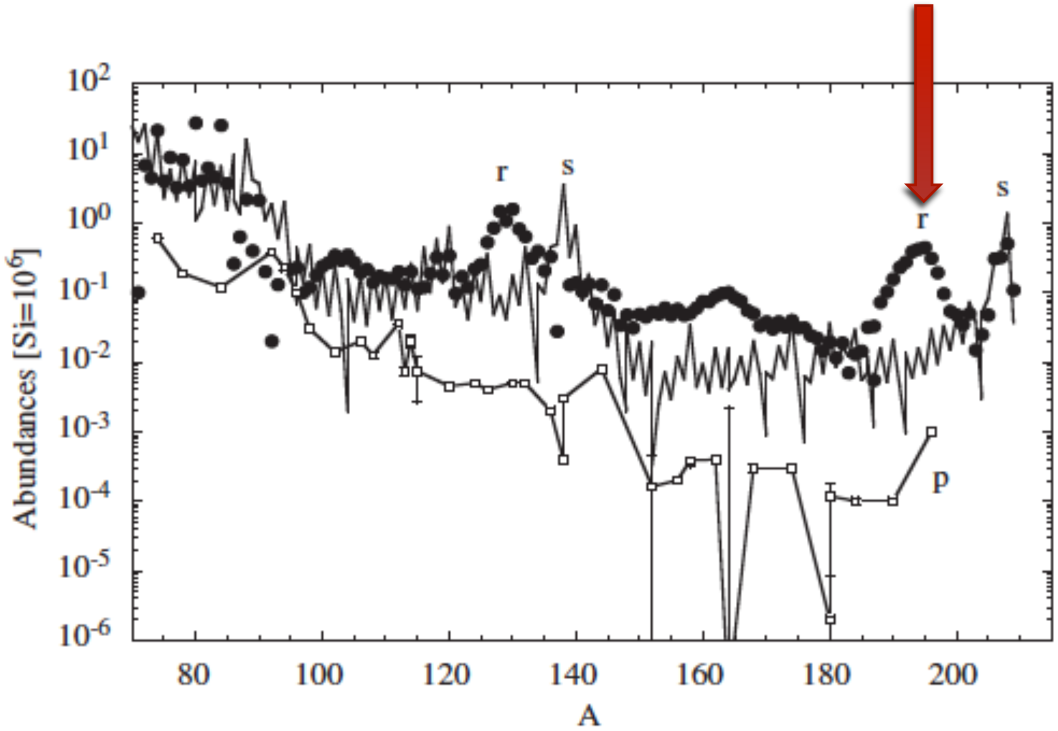
Francesca Giacoppo

15th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics - Dresden, August 25-29, 2014

Why Platinum?







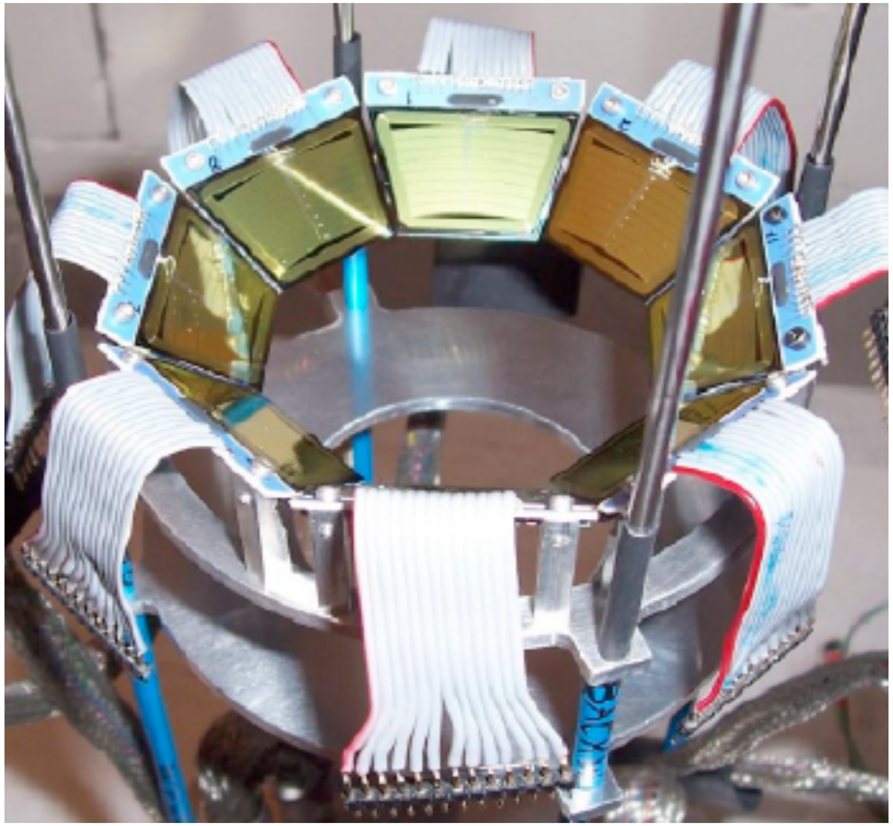
Kinsey and Bartholomew, Phys. Rev. 93, 1260 (1954)

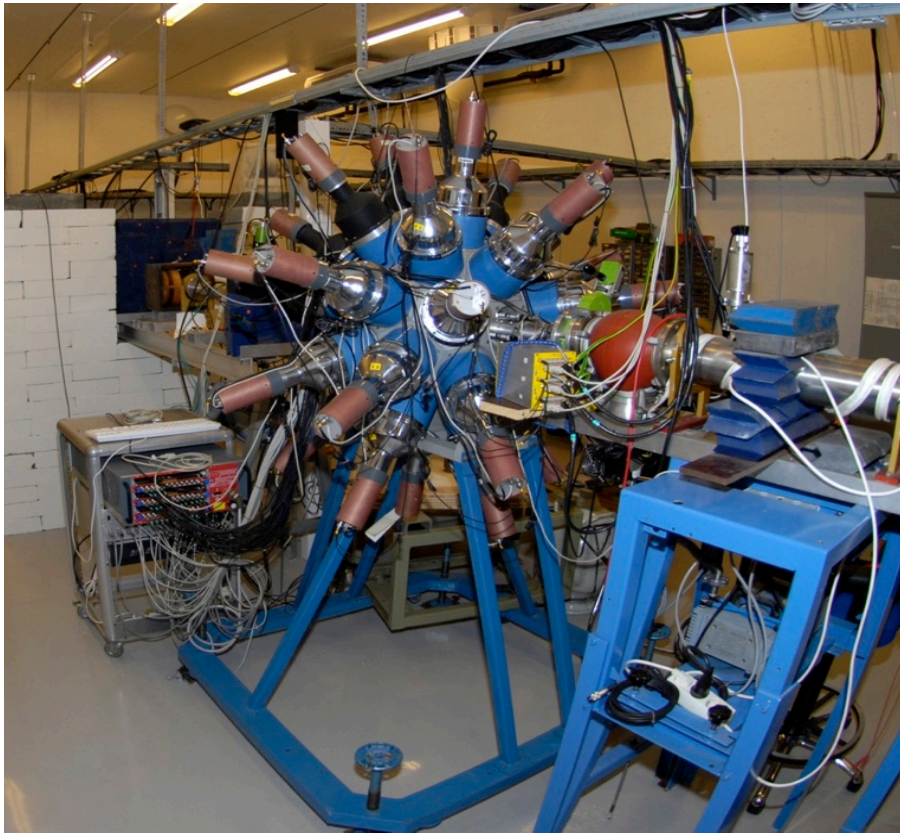
Bartholomew et al., Phys. Lett. 24B, 47 (1967)

Experimental Setup

OCL

Silicon Ring (SiRi): 8x8 DE-E particle detectors Δϑ≈2º (~9% of 4π)

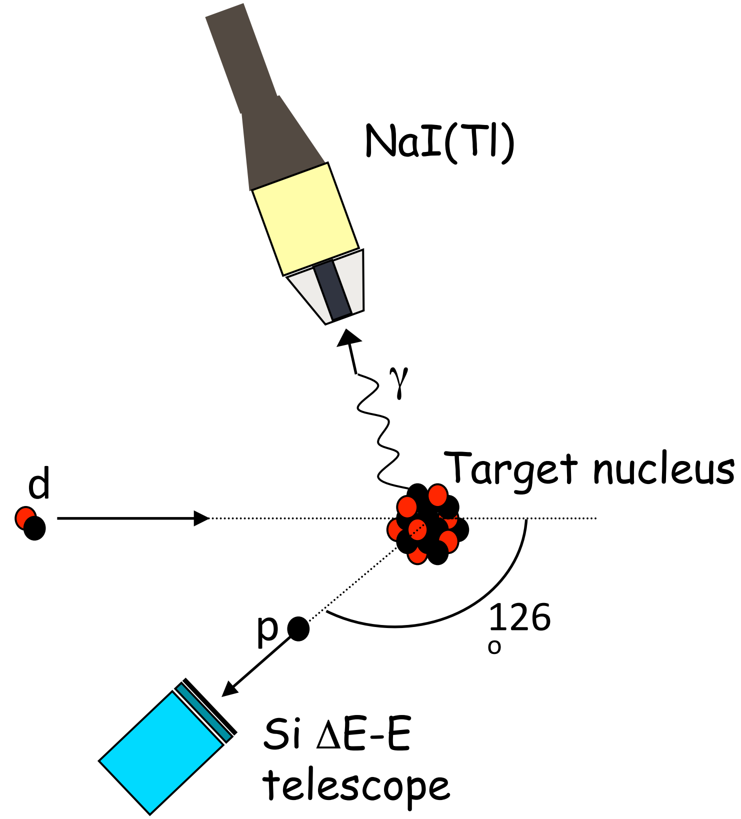




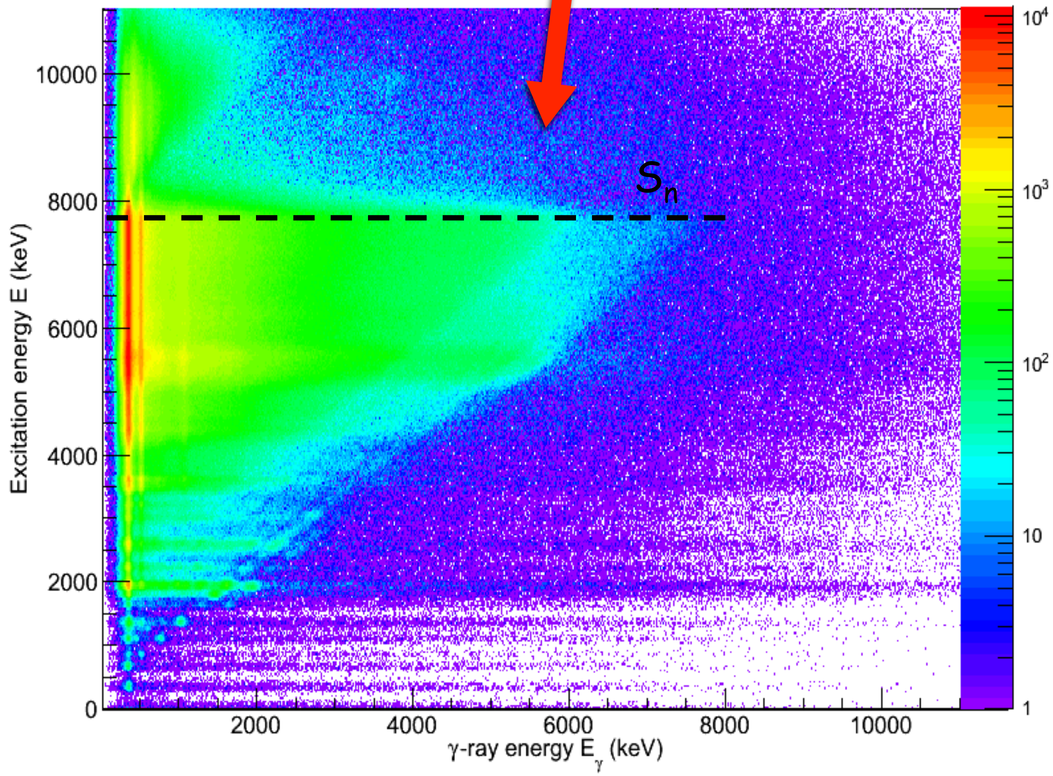
CACTUS: 28 5" × 5" collimated NaI(Tl) gamma detectors
ε ≈ 15% at $E_γ$= 1.33 MeV

Experimental Technique

Particle –γ coincidence measurements

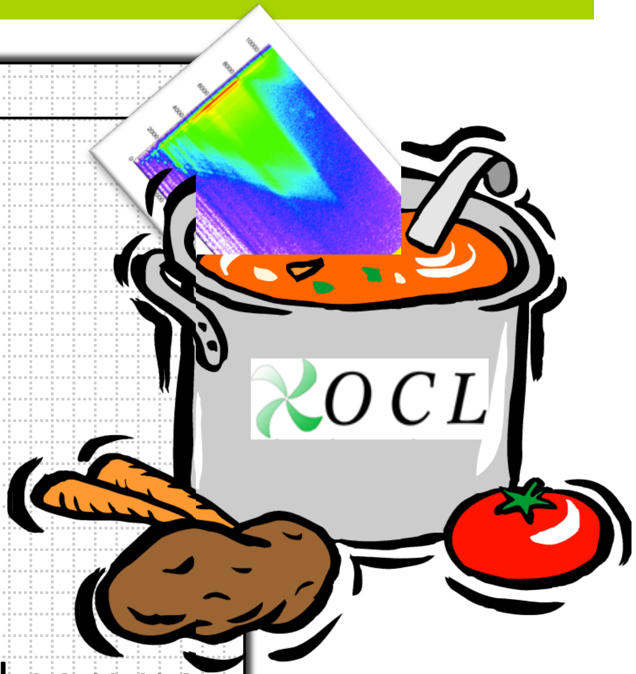


- $^{195}Pt(p,p'\gamma)^{195}Pt$ @11.3 MeV
- $^{195}Pt(d,p\gamma)^{196}Pt$ @16.5 MeV



^{195}Pt target 1.5(2) mg/cm^2 thick
97.3(1)% enrichment

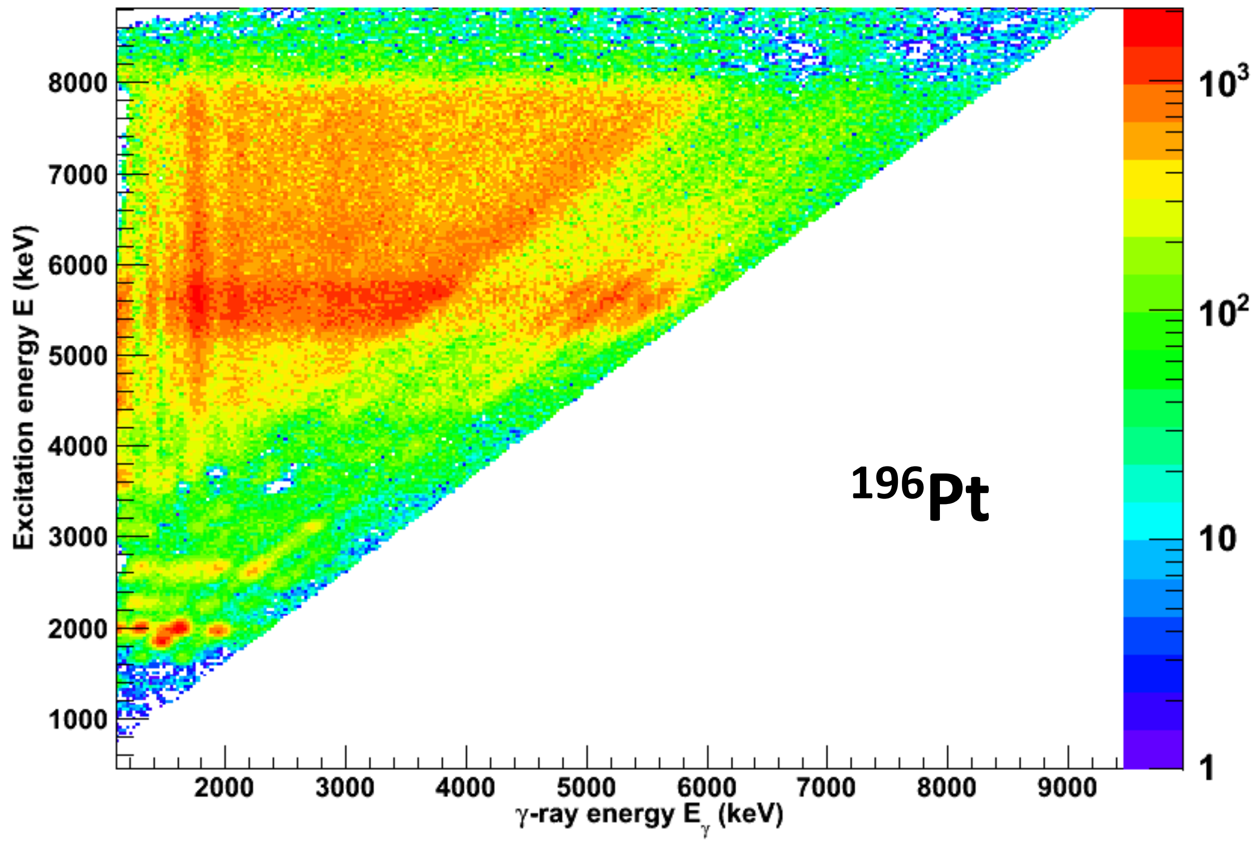
The Oslo Method recipe



- **Unfolding:** correct gamma spectra with detector response
  [M.Guttormsen et al., NIM A 374,371 (1996)]
- **First generation**: extract primary gammas from the total gamma spectra
  [M. Guttormsen et al., NIM A 255, 518 (1987)]
- Simultaneous extraction of level density and gamma strength from the matrix of primary gammas
  [A. Schiller et al., NIM A 447, 498 (2000)]
- **Normalization**
  [A.C. Larsen et al., PRC 83, 034315 (2011)]

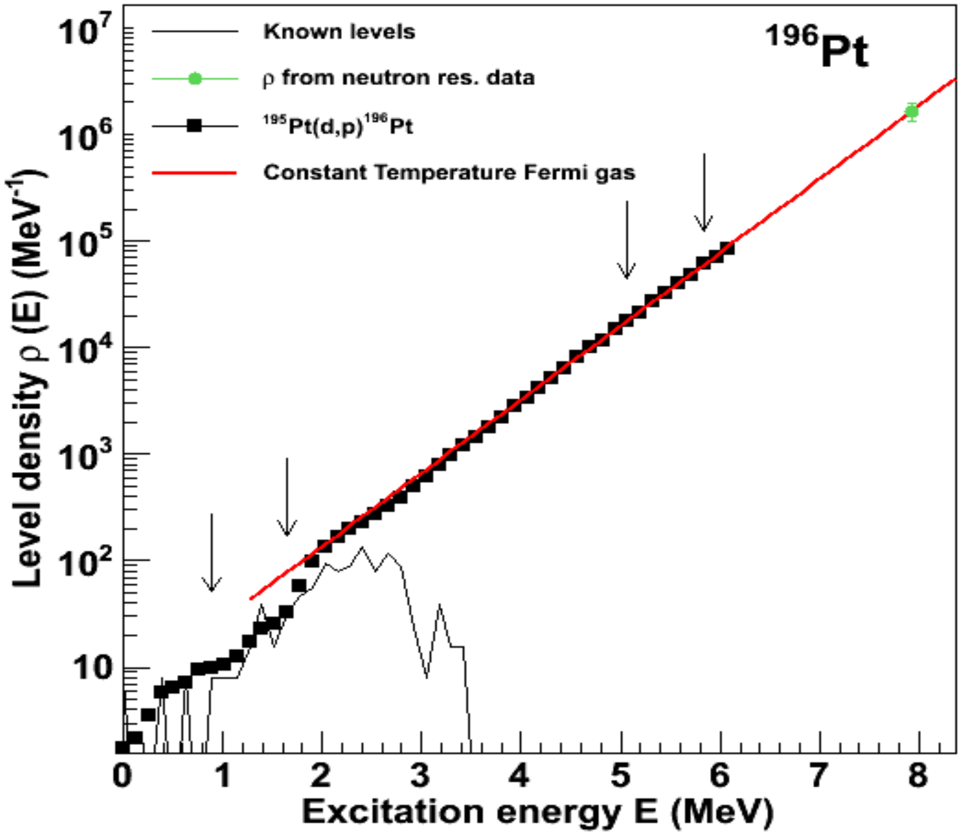
Extraction of LD and γSF

$$P(E_i, E_\gamma) \propto \rho(E_f)\mathrm{T}(E_\gamma)$$



Normalization ρ(E)

$$\tilde{\rho}(E-E_\gamma) = A\exp[\alpha(E-E_\gamma)]\rho(E-E_\gamma)$$



- $$\rho(E)_{CT} = \frac{1}{T}\exp\left[(E-E_o)/T\right]$$

- $$\rho_0(S_n) = \frac{2\sigma^2}{D_0}\left\{(I_t+1)\exp\left[-\frac{(I_t+1)^2}{2\sigma^2}\right] + I_t\exp\left[-\frac{I_t^2}{2\sigma^2}\right]\right\}^{-1}$$

Koehler, Guber, PRC 88, 035802 (2013).

- $$g(E,I) = \frac{2I+1}{2\sigma^2}\exp\left[-\frac{(I+1/2)^2}{2\sigma^2}\right]$$

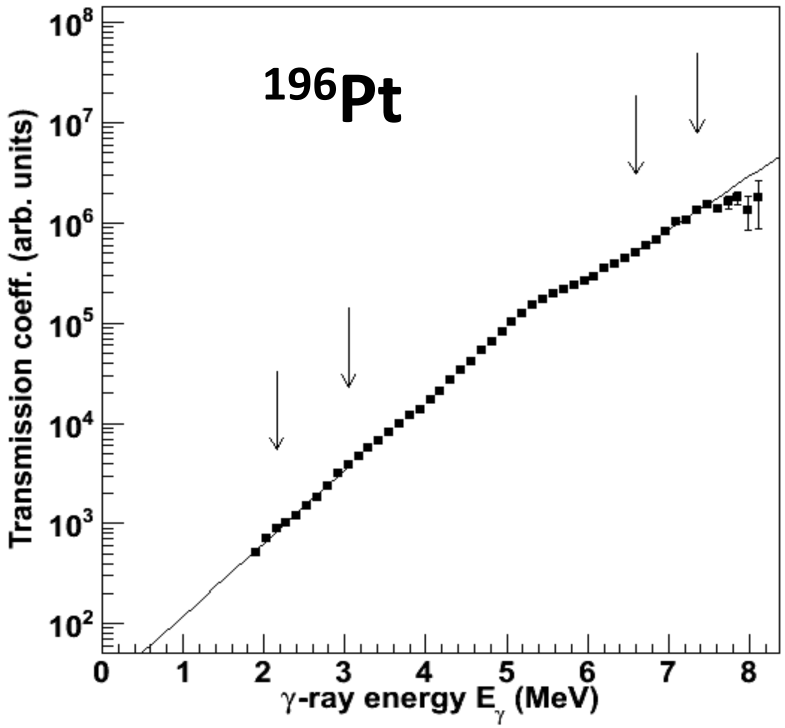
Ericson et al., Advances in Physics 9, 425 (1960)

Von Egidy, Bucurescu, PRC 80, 054310 (2009)

Normalization $f(E_\gamma)$

$$\tilde{T}(E_\gamma) = B\exp(\alpha E_\gamma)T(E_\gamma)$$

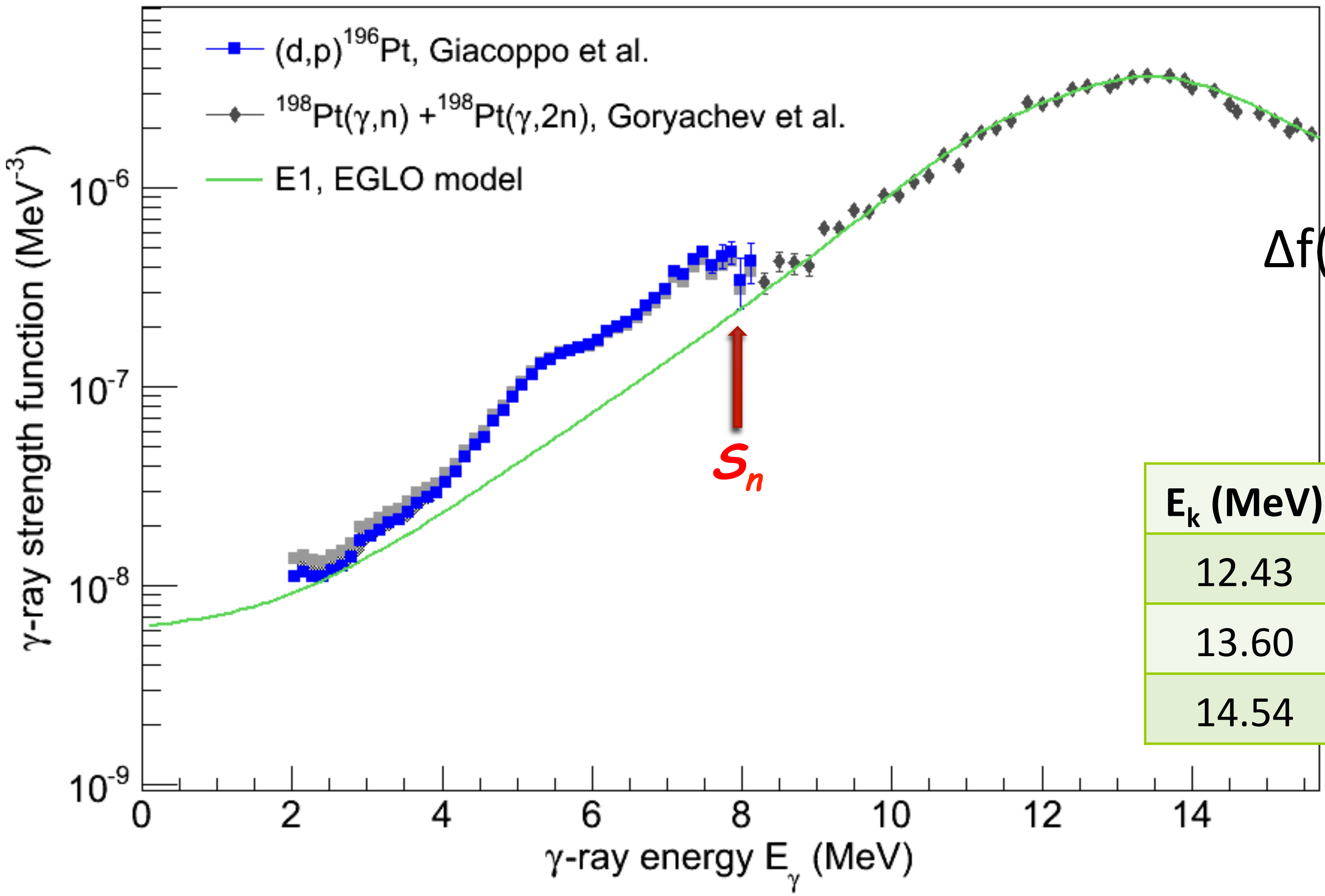
$$\langle \Gamma_\gamma(S_n, I_t \pm 1/2, \pi_t)\rangle = \frac{D_0}{4\pi}\int_{E_\gamma=0}^{S_n} dE_\gamma B T(E_\gamma)\rho(S_n - E_\gamma)\sum_{I=-1}^{1} g(S_n - E_\gamma, I_t \pm 1/2 + I)$$



$$T(E_\gamma) = 2\pi\sum_{XL} E_\gamma^{2L+1} f_{XL}(E_\gamma)$$

with X=E,M
L=multipolarity

γSF of ^{196}Pt



$\Delta f(E\gamma) \approx 20 - 23\%$

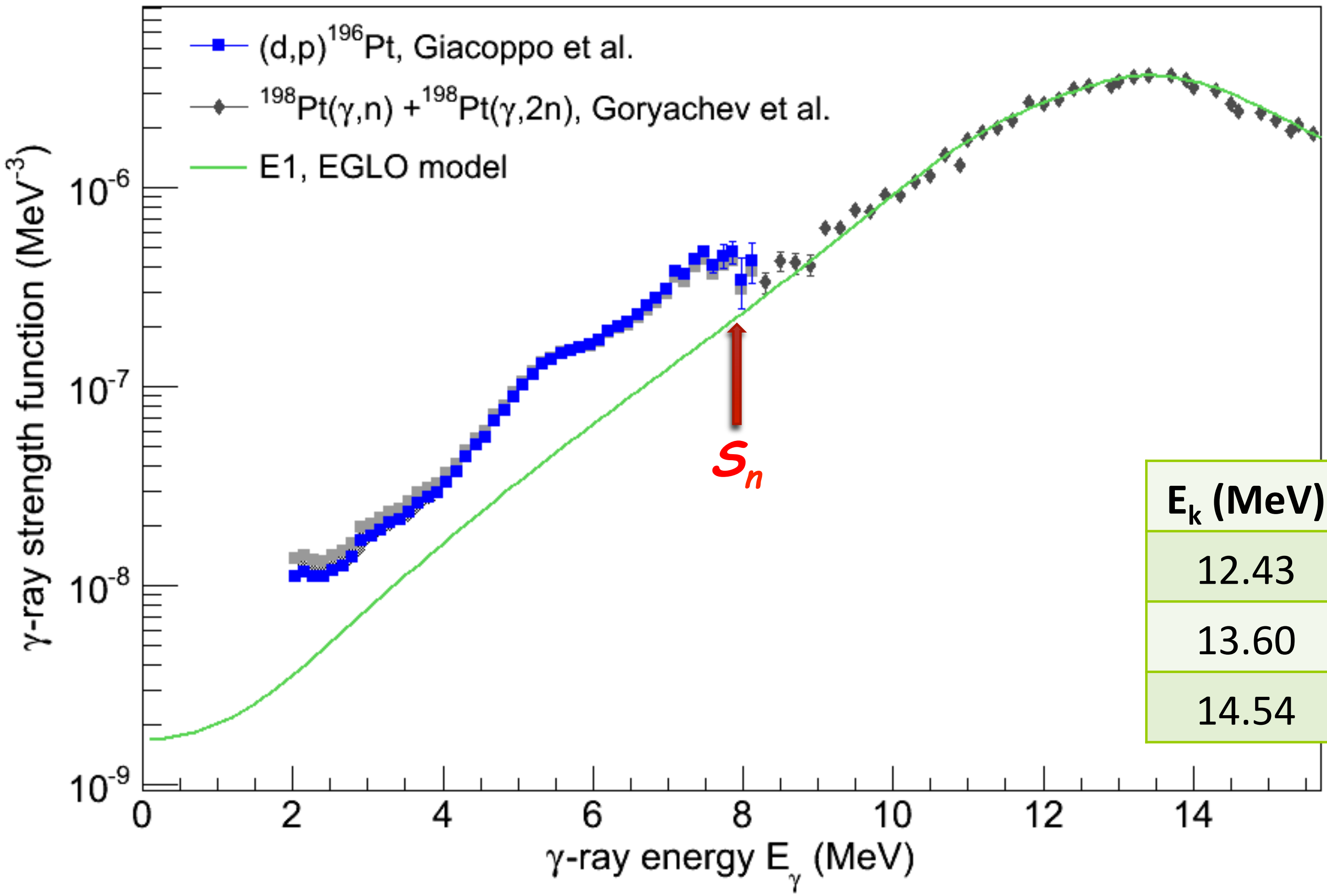
E_k (MeV)	Γ_k (MeV)	σ_k (mb)
12.43	4.90	180
13.60	3.44	280
14.54	3.70	190

T_f=0.31 MeV

F. Giacoppo et al., PRL submitted (2014) and arXiv:1402.2451[nucl-ex](2014).

A.M. Goryachev and G.N. Zalesnyy, Sov. J. Nucl. Phys. 27, 779 (1978)

γSF of ^{196}Pt



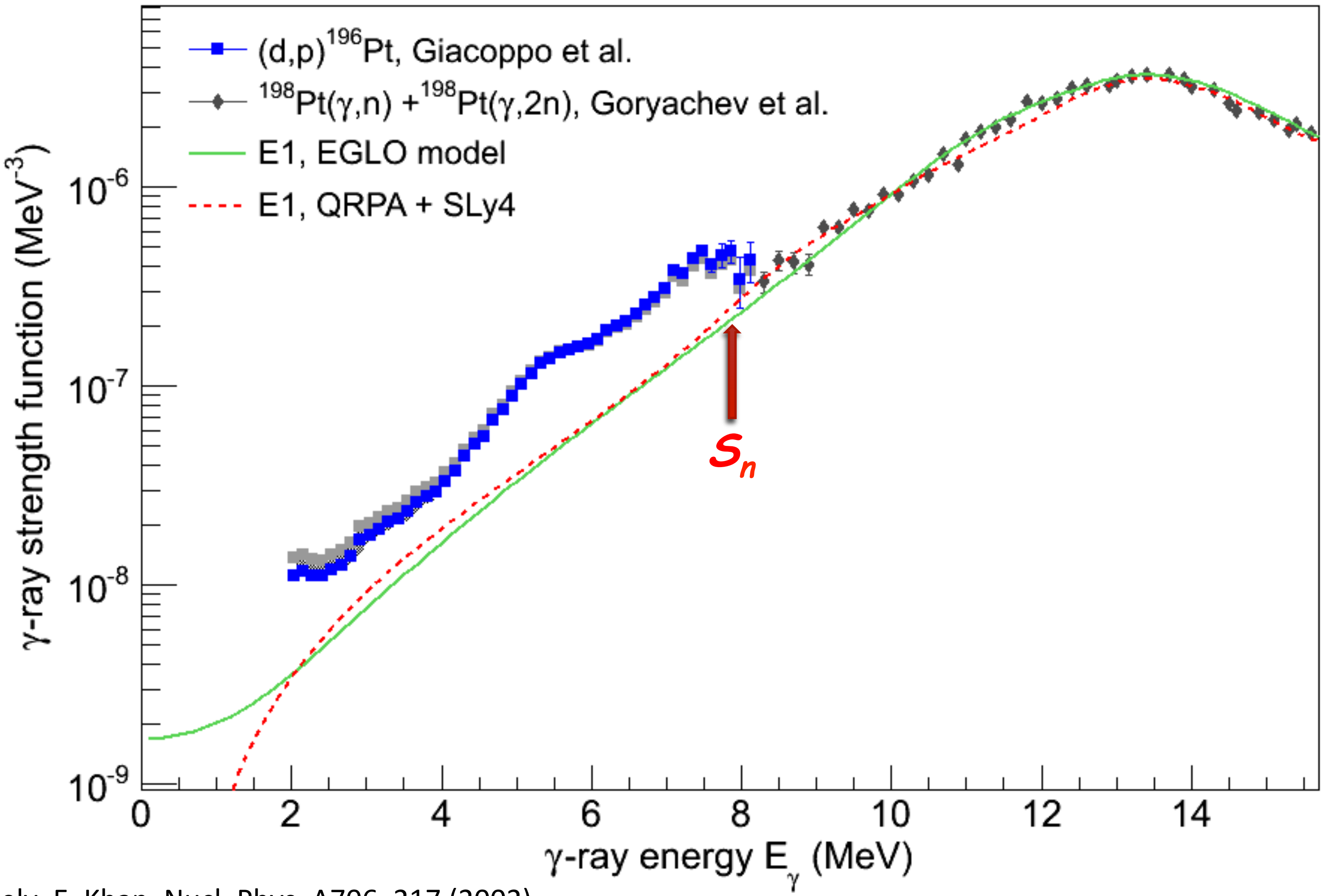
E_k (MeV)	Γ_k (MeV)	σ_k (mb)
12.43	4.90	180
13.60	3.44	280
14.54	3.70	190

T_f=0.16 MeV

F. Giacoppo et al., PRL submitted (2014) and arXiv:1402.2451[nucl-ex](2014).

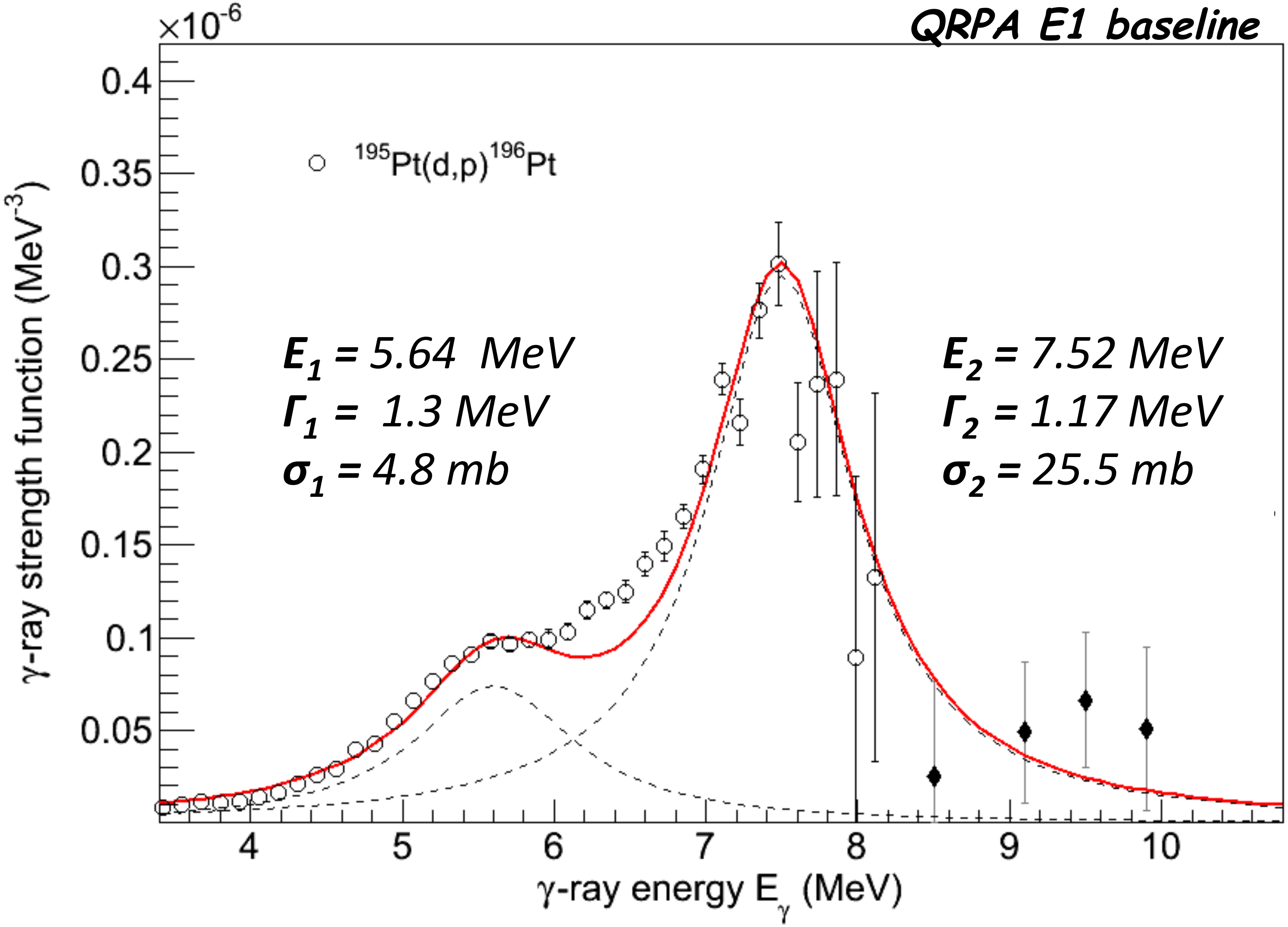
A.M. Goryachev and G.N. Zalesnyy, Sov. J. Nucl. Phys. 27, 779 (1978)

γSF of ¹⁹⁶Pt

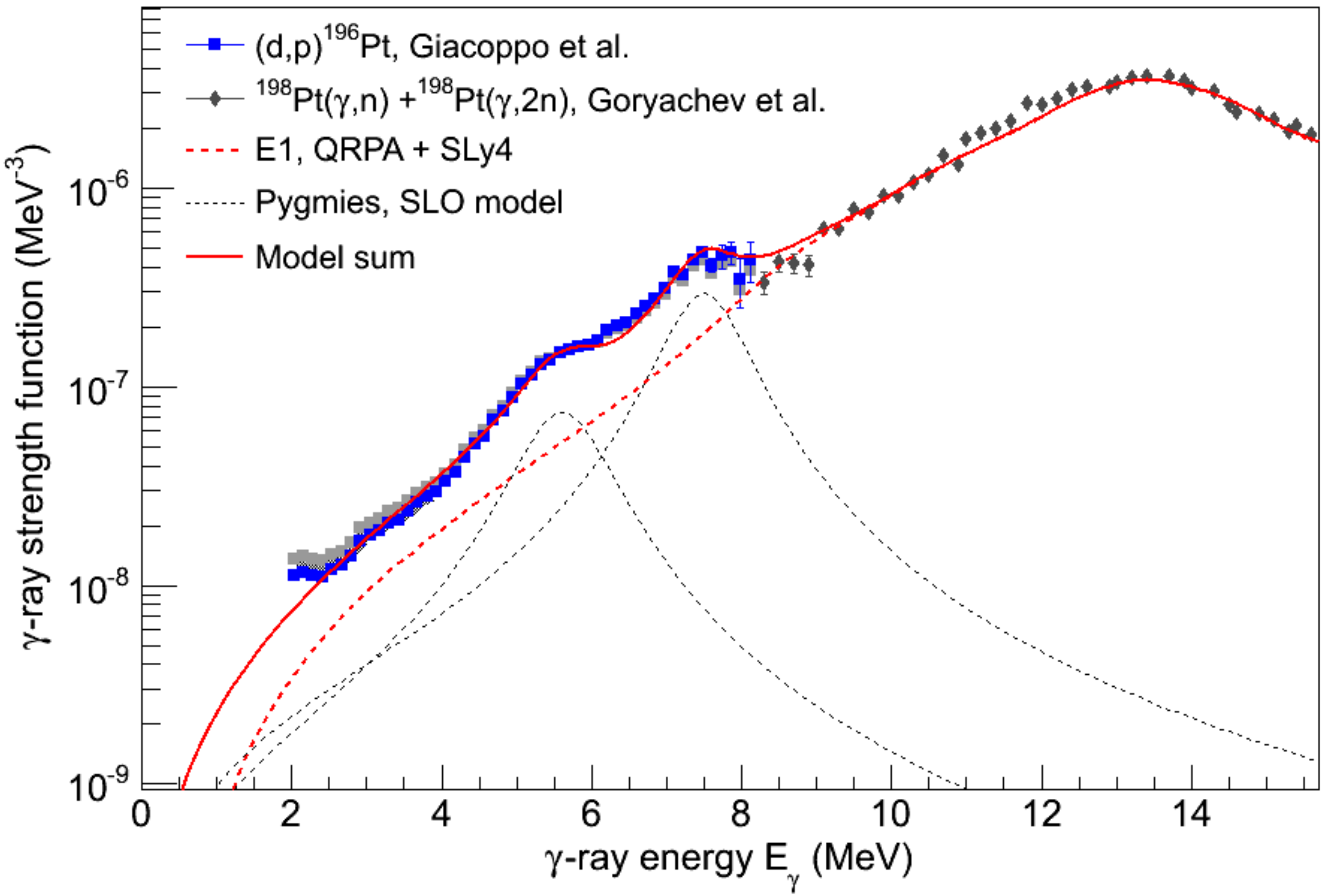


S. Goriely, E. Khan, Nucl. Phys. A706, 217 (2002)

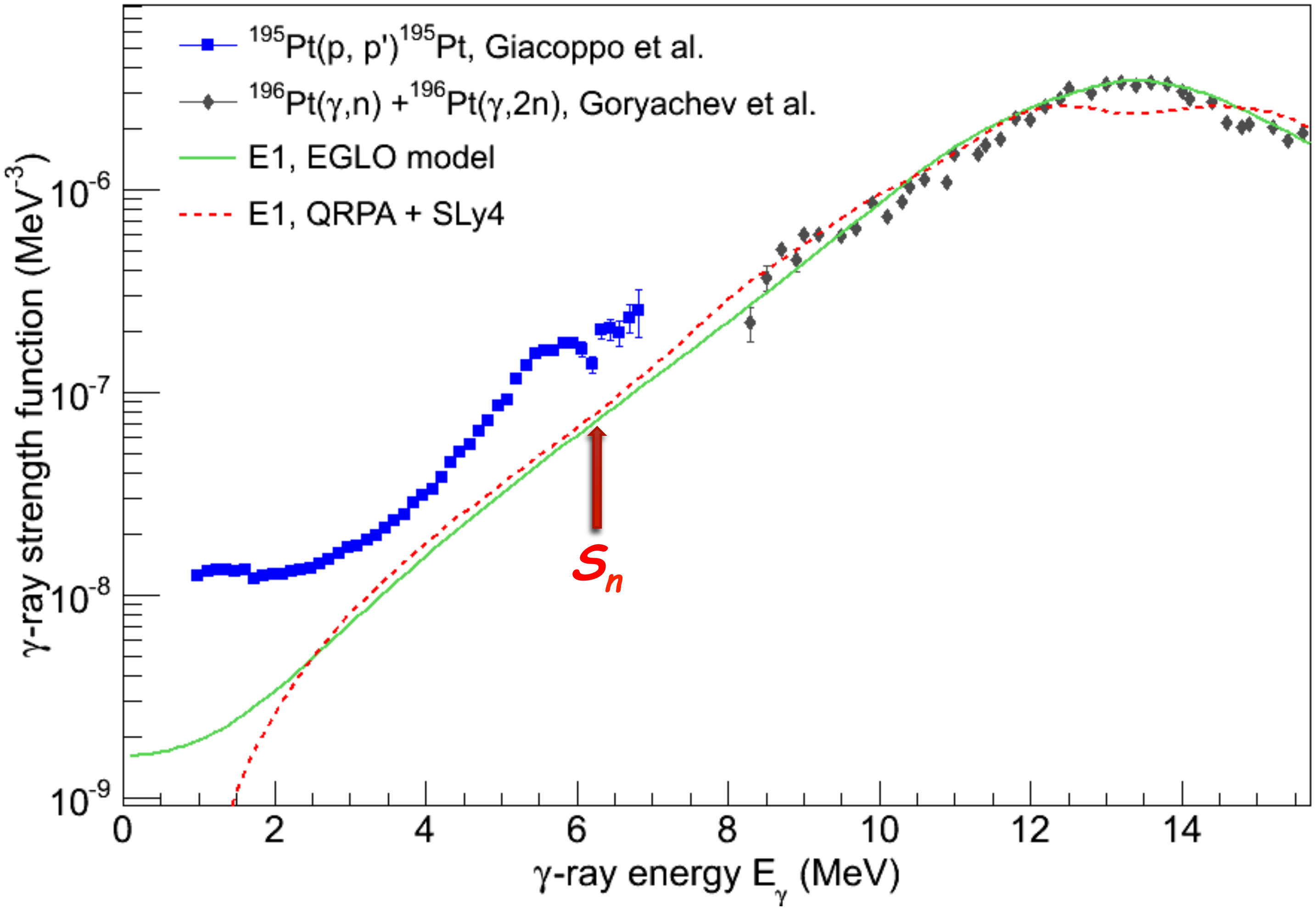
Extra strength ^{196}Pt



γSF of ^{196}Pt


(d,p)196Pt, Giacoppo et al.
198Pt(γ,n) +198Pt(γ,2n), Goryachev et al.
E1, QRPA + SLy4
Pygmies, SLO model
Model sum
γ-ray strength function (MeV-3)
10-6
10-7
10-8
10-9
0
2
4
6
8
10
12
14
γ-ray energy Eγ (MeV)

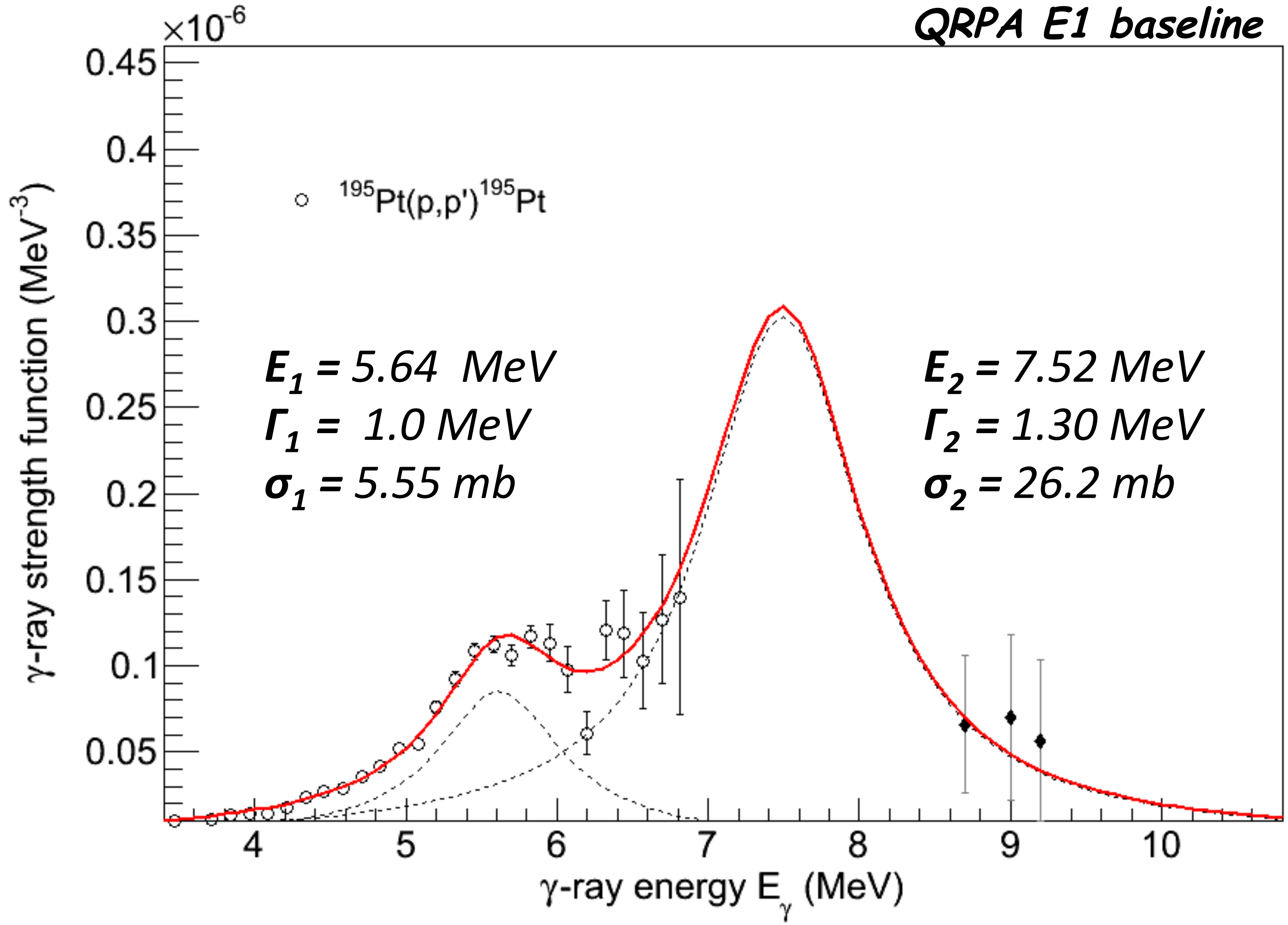
γSF of ^{195}Pt



F. Giacoppo et al., Phys. Rev. Lett. submitted (2014) and arXiv:1402.2451[nucl-ex](2014).

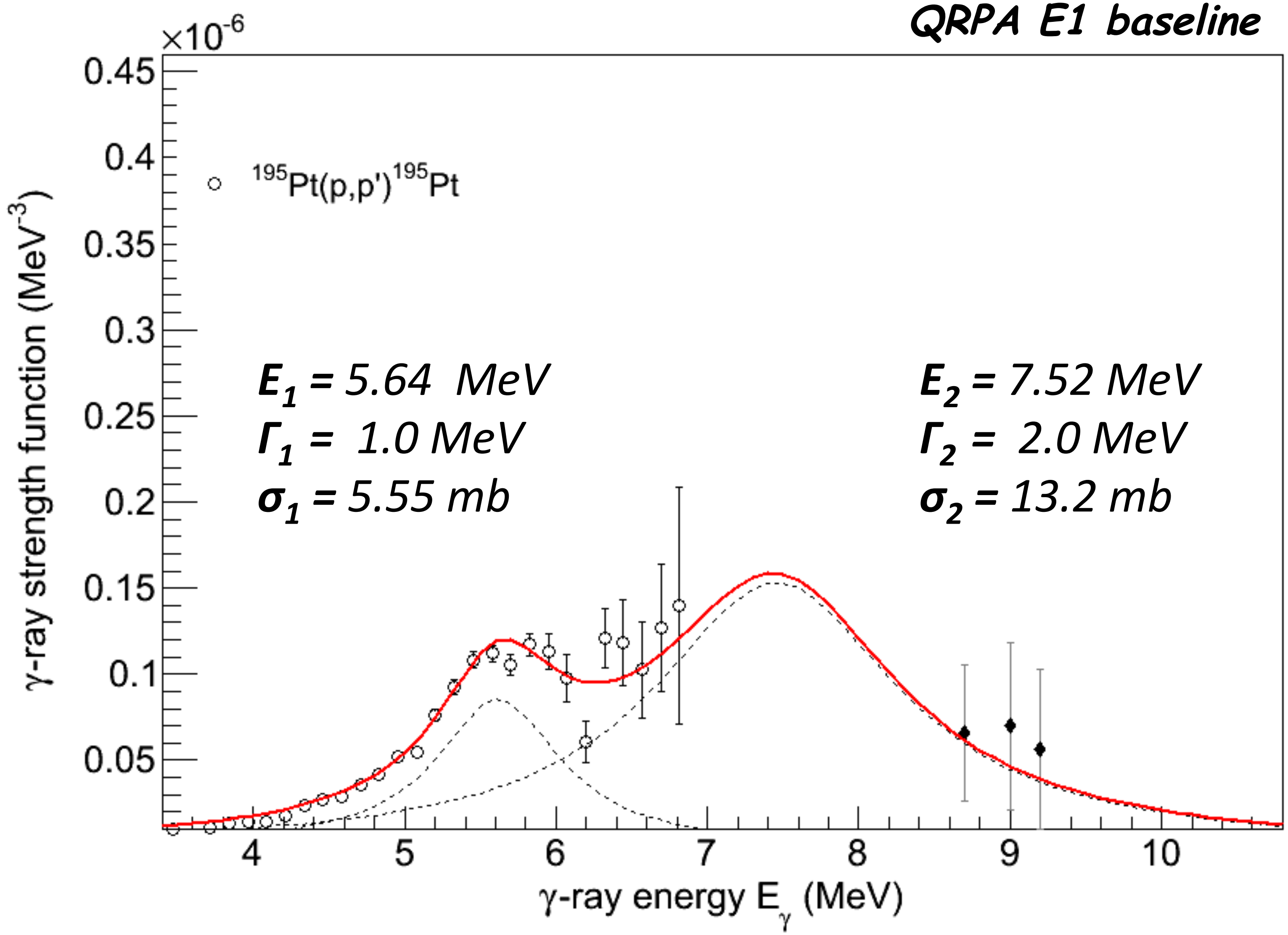
A.M. Goryachev and G.N. Zalesnyy, Sov. J. Nucl. Phys. 27, 779 (1978)

Extra strength ^{195}Pt

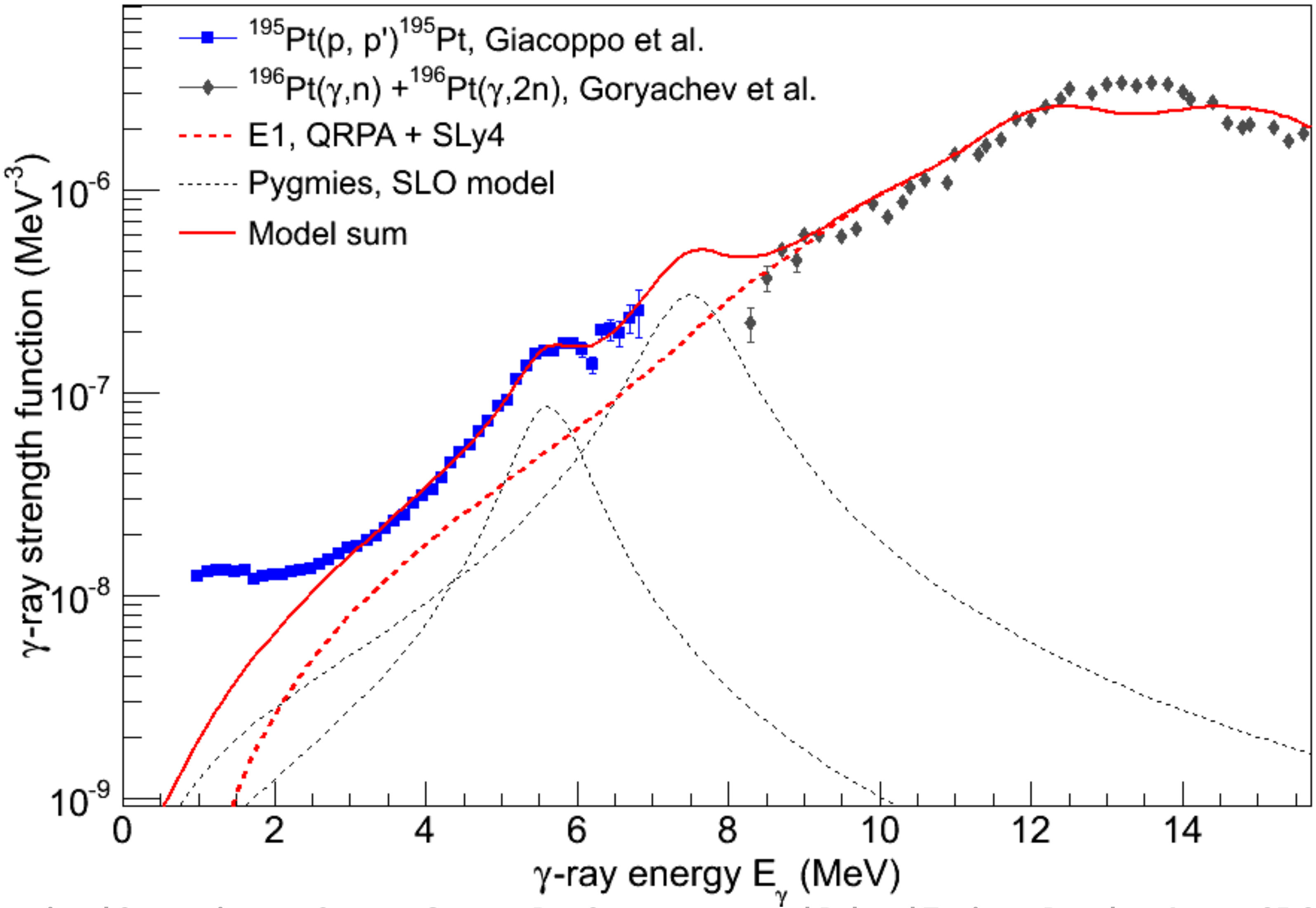


Extra strength ^{195}Pt

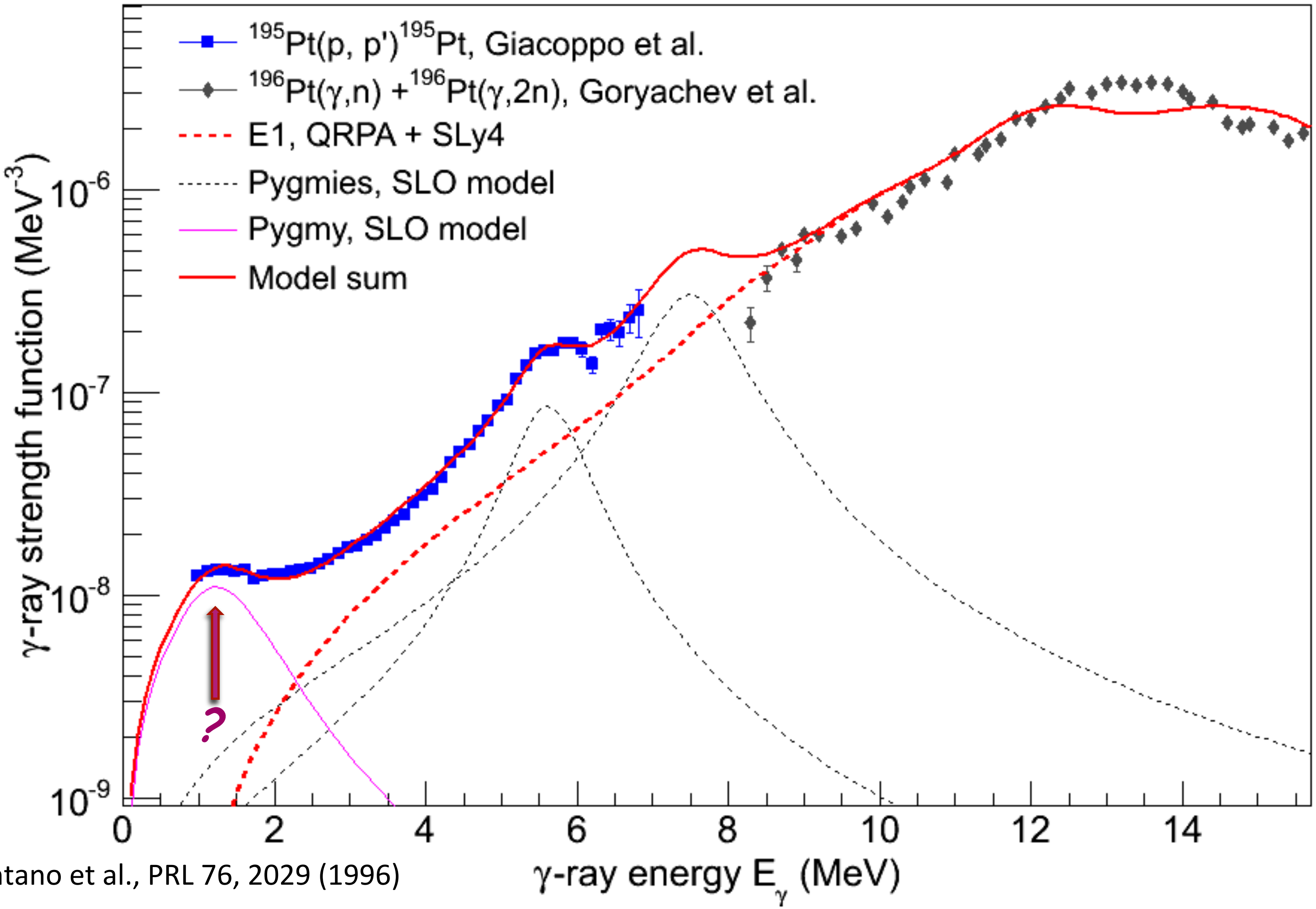
QRPA E1 baseline



γSF of ^{195}Pt

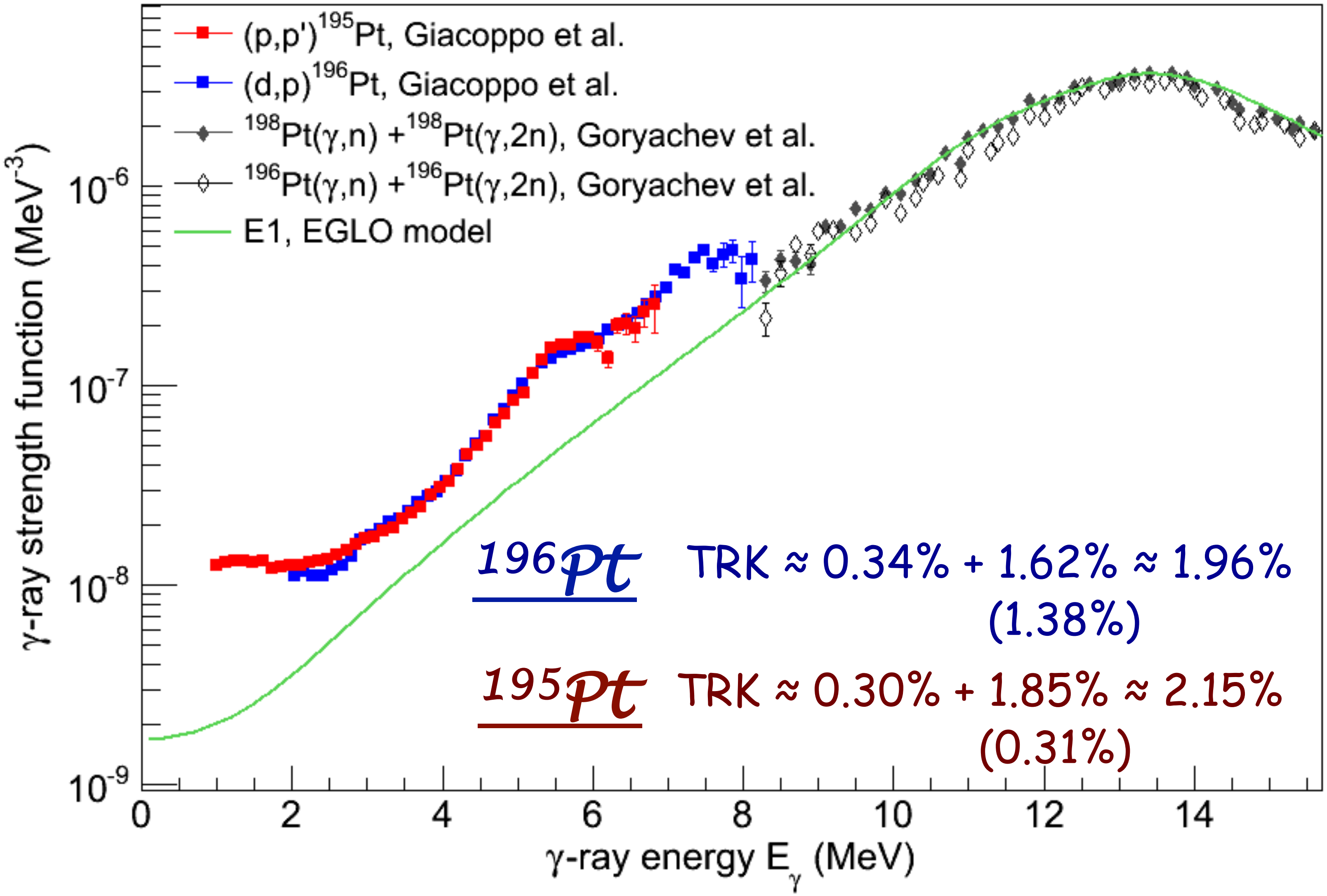

^{195}Pt(p, p')^{195}Pt, Giacoppo et al.
^{196}Pt(γ,n) + ^{196}Pt(γ,2n), Goryachev et al.
E1, QRPA + SLy4
Pygmies, SLO model
Model sum
γ-ray strength function (MeV^{-3})
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0
2
4
6
8
10
12
14
γ-ray energy $E_γ$ (MeV)

γSF of ^{195}Pt

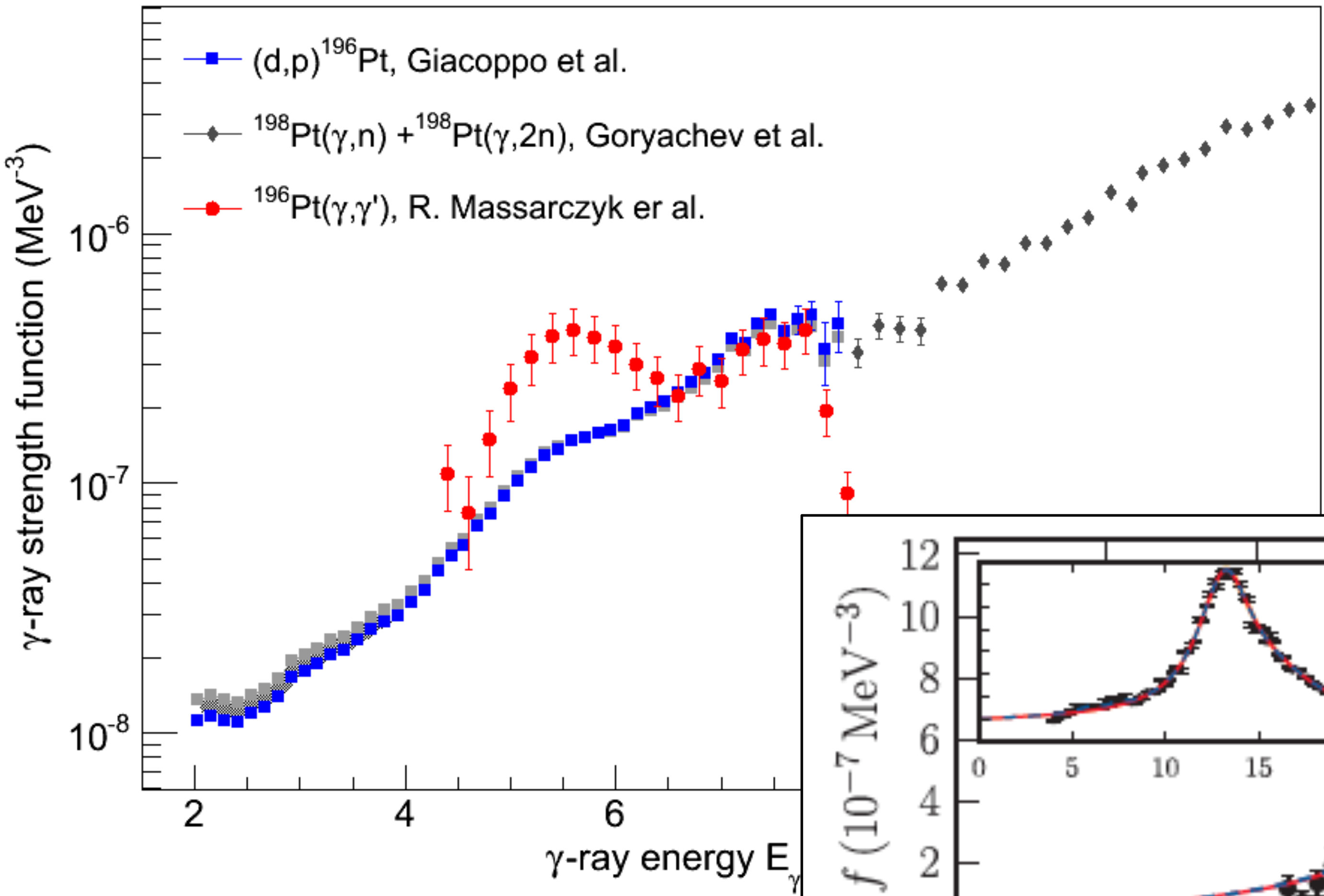


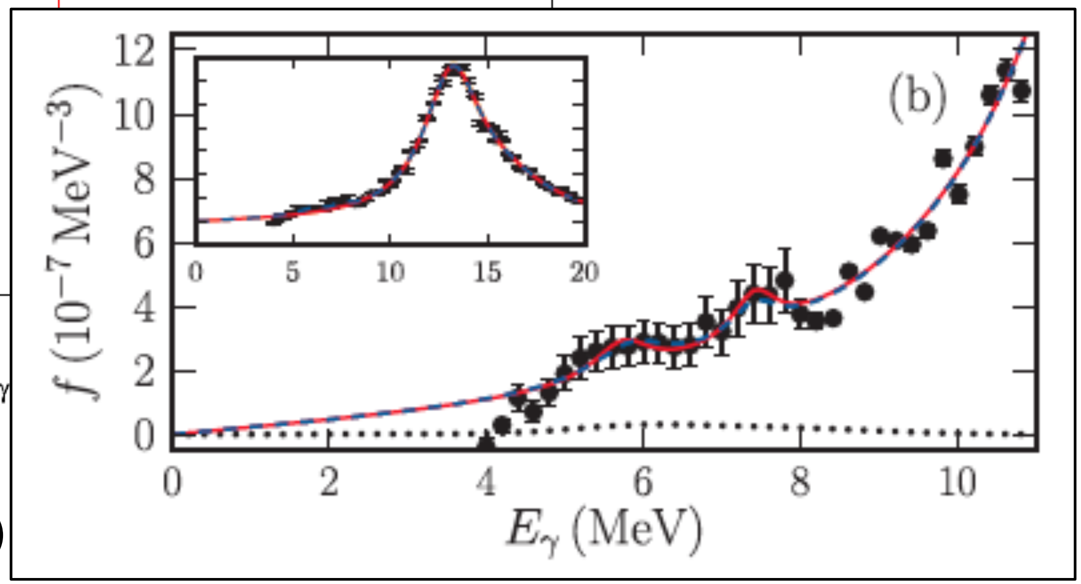
Von Brentano et al., PRL 76, 2029 (1996)

γSF $^{195,196}Pt$



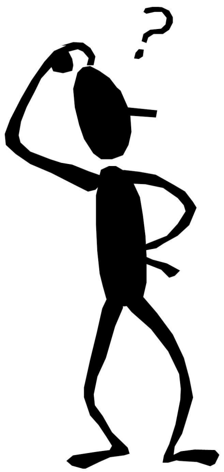
Oslo vs Dresden: ^{196}Pt





R. Massarczyk et al., PRC 87, 044306 (2013)

Nature of the strength excess?



- *Electromagnetic character? E1 and/or M1?*
- *Collective?*

- *Why it's a double-hump structure?*

  (^{154}Sm: Frekers et al., Phys. Lett. B 244, 178)

- *It occurs also in neighbour nuclei?*

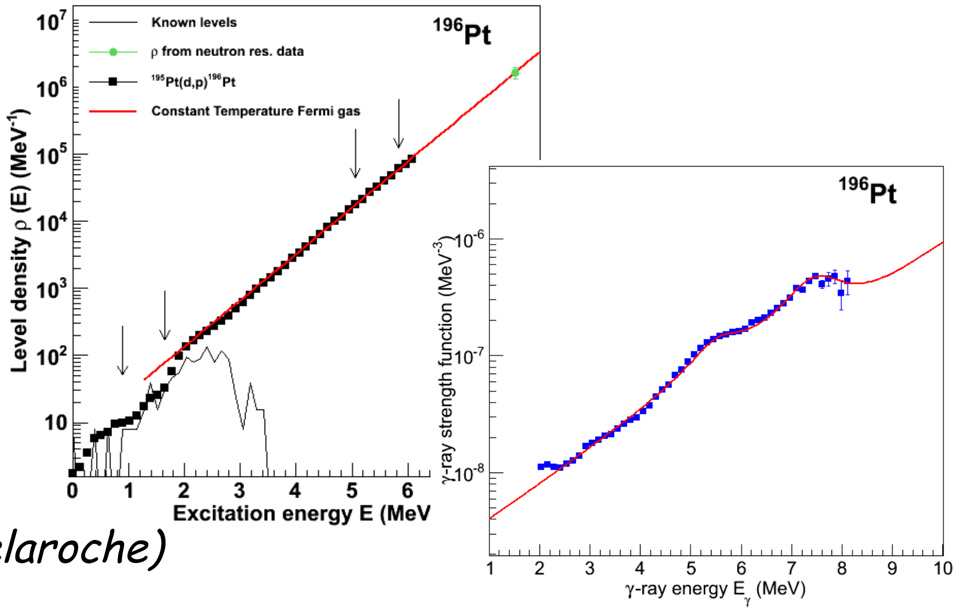
Neutron capture cross-sections

Hauser Feshbach model:

- $$\sigma_{ac}^{fl} = \frac{1}{(2s_a+1)(2I_a+1)} \frac{\pi}{k_a^2} \sum_{J,\pi} (2J+1) \frac{Y_a(J,\pi) Y_c(J,\pi)}{\sum_b Y_b(J,\pi)} .$$
- $$Y_c(J,\pi) = \sum_{j=|J-I_c|}^{J+I_c} \sum_{l=|j-s_c|}^{j+s_c} f(l,\pi) T_l^j$$
- $$Y_c(E^* - \varepsilon_c - S, J, \pi) \Longrightarrow Y_c(E^* - \varepsilon_c - S, J, \pi) \rho_c(\varepsilon_c, I_c) d\varepsilon_c \,.$$

Inputs:

1. Level density →EXP.
2. Gamma strength →EXP.
3. Optical potential → local OMP (Koning and Delaroche)

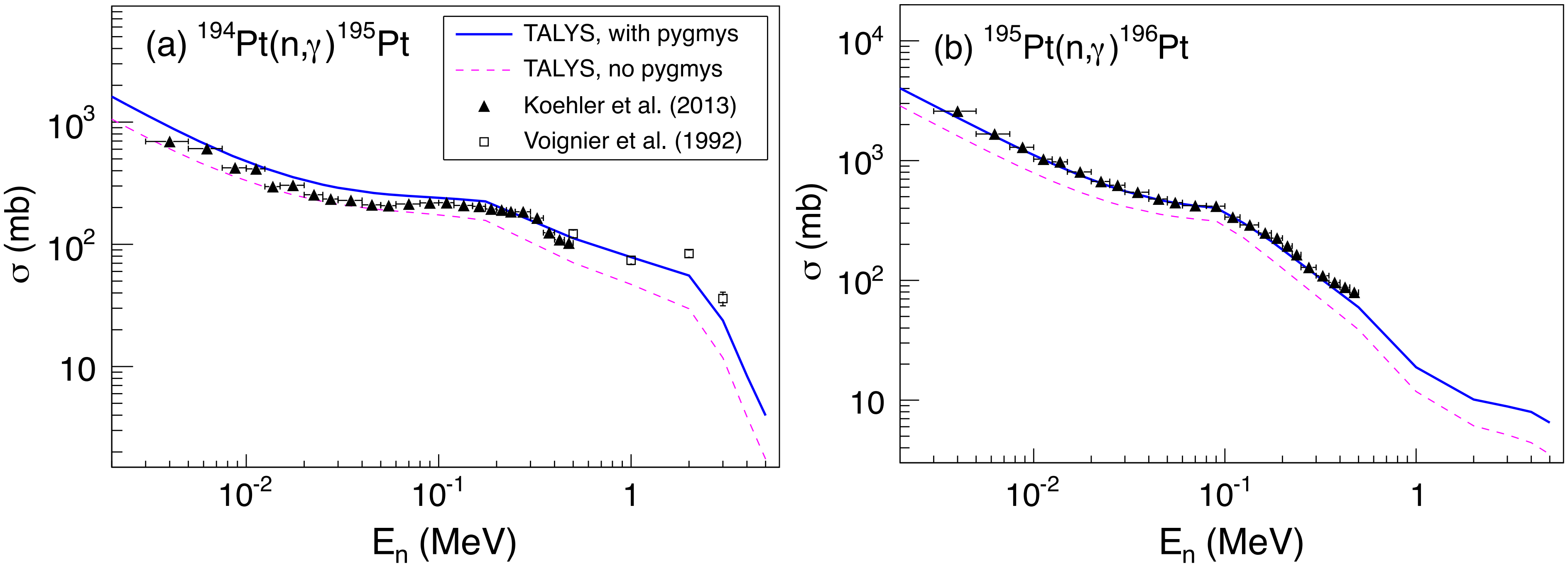


(n,γ) cross section

F. Giacoppo et al., PRL submitted (2014) and arXiv:1402.2451[nucl-ex](2014).

J. Voignier, S. Joly and G. Grenier, Nucl. Sc. and Eng. 112, 87 (1992).

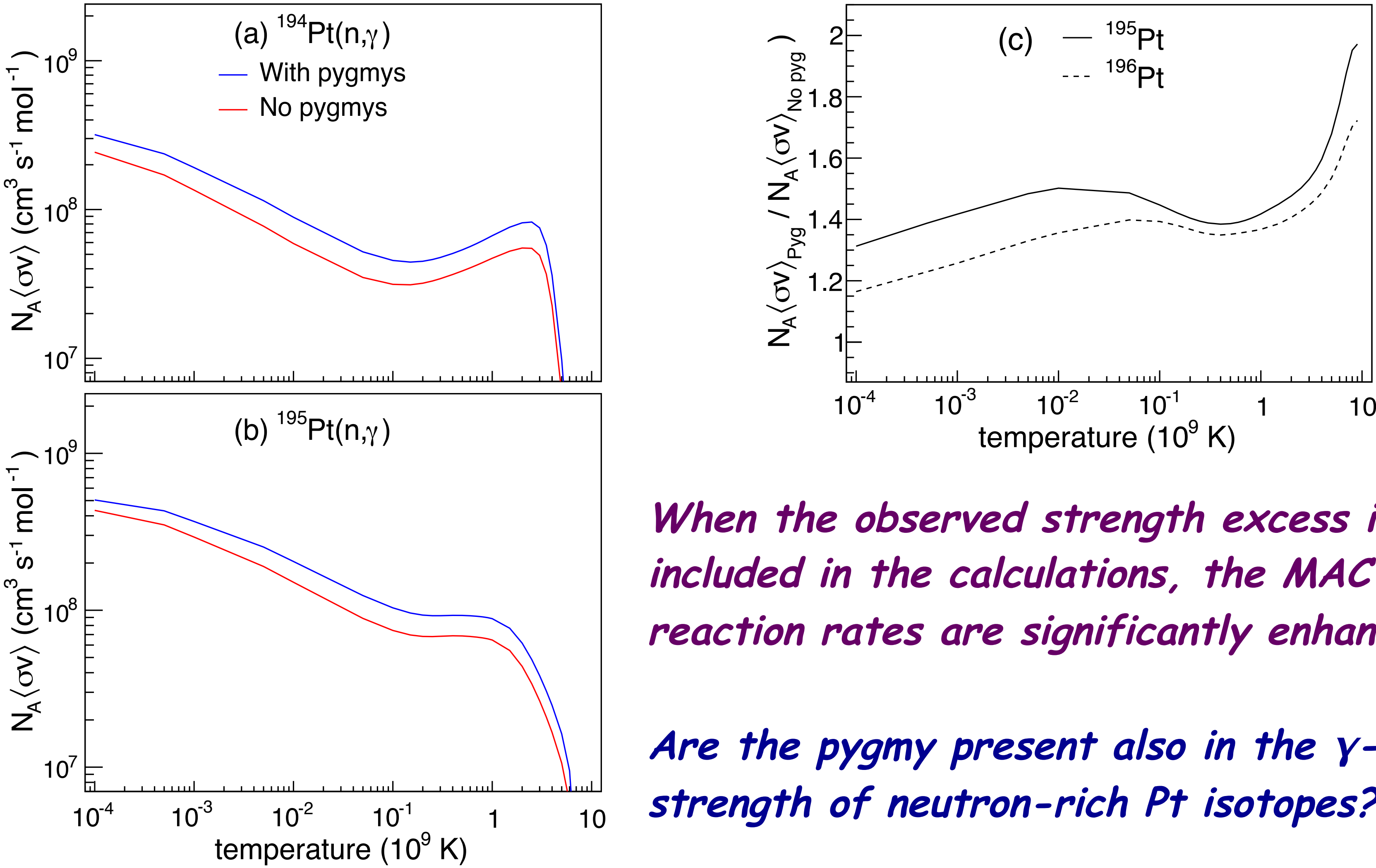
P.E. Koehler, K.H. Guber, PRC 88, 035802 (2013).



Peak at E = 5.64 MeV →M1
Peak at E = 7.52 MeV → E1
(swapping only gives a ≤ 6% relative difference

Resonances increase ≈85% and ≈230% the $(n,\gamma)^{195,196}Pt$ for 5 MeV incoming neutron

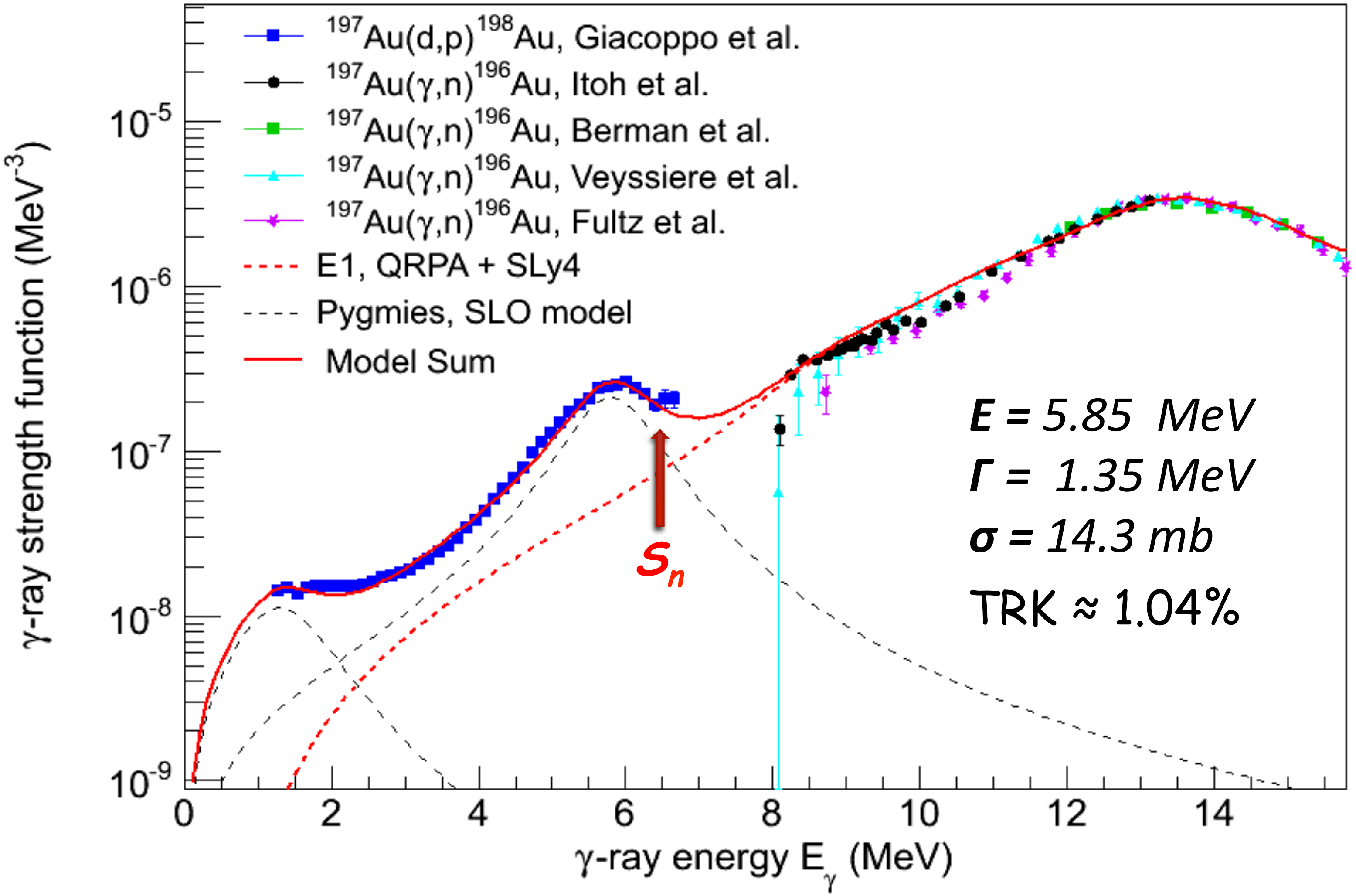
(n,γ) reaction rates



When the observed strength excess is included in the calculations, the MAC reaction rates are significantly enhanced.

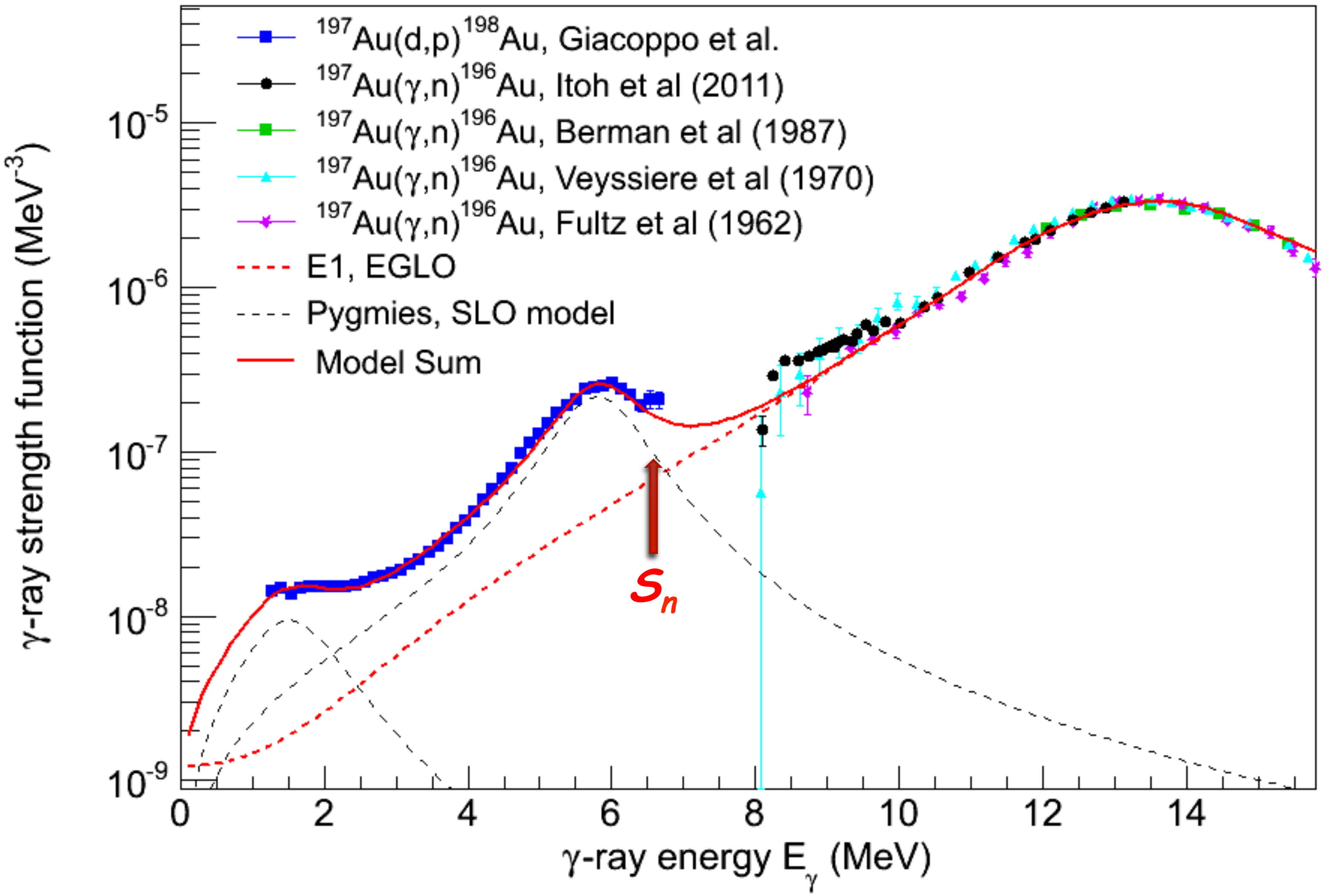
Are the pygmy present also in the γ-strength of neutron-rich Pt isotopes?

γSF ^{198}Au



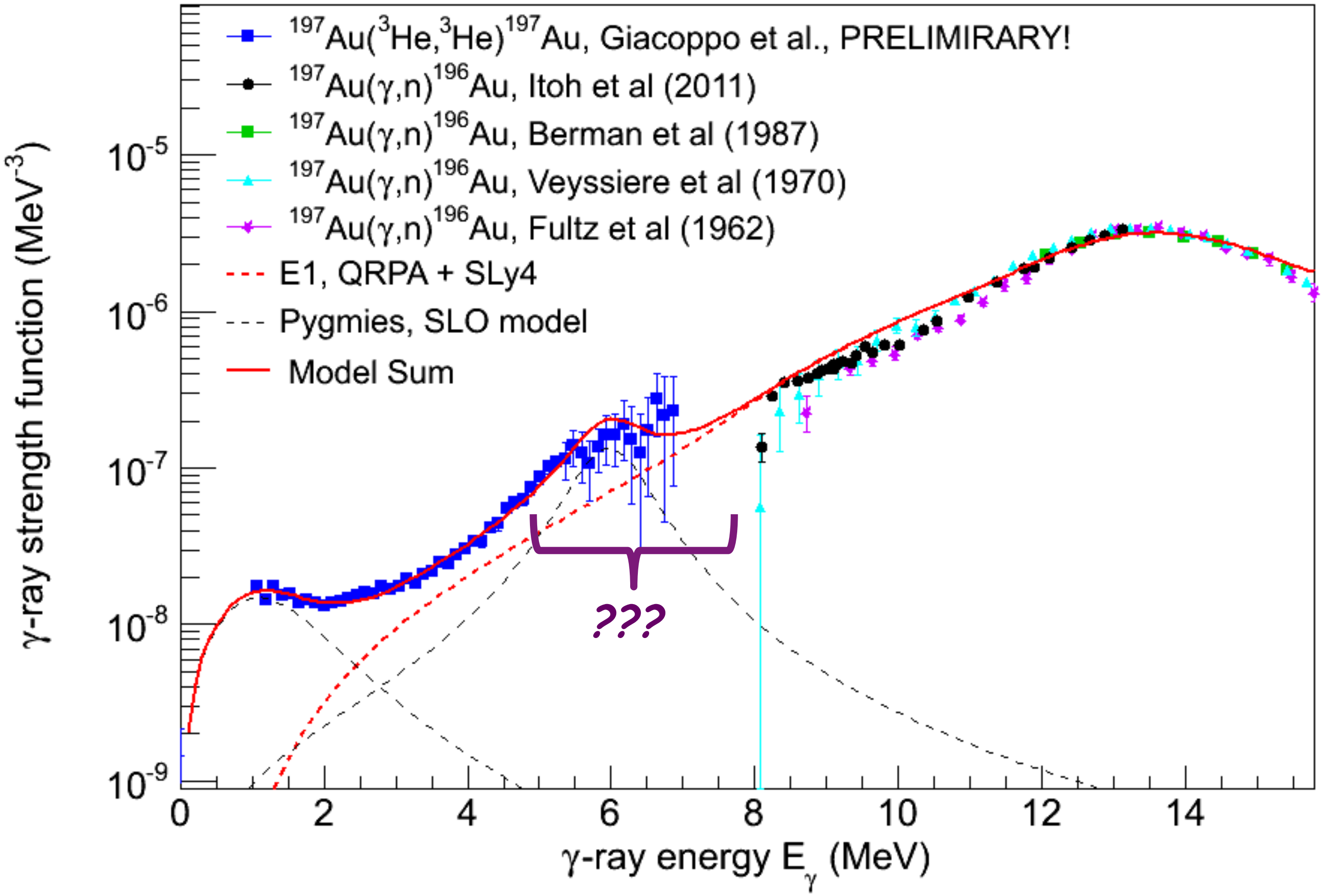
F. Giacoppo et al., EPJ Web of Conferences 66, 02041 (2014) and PRC in preparation.

γSF ^{198}Au



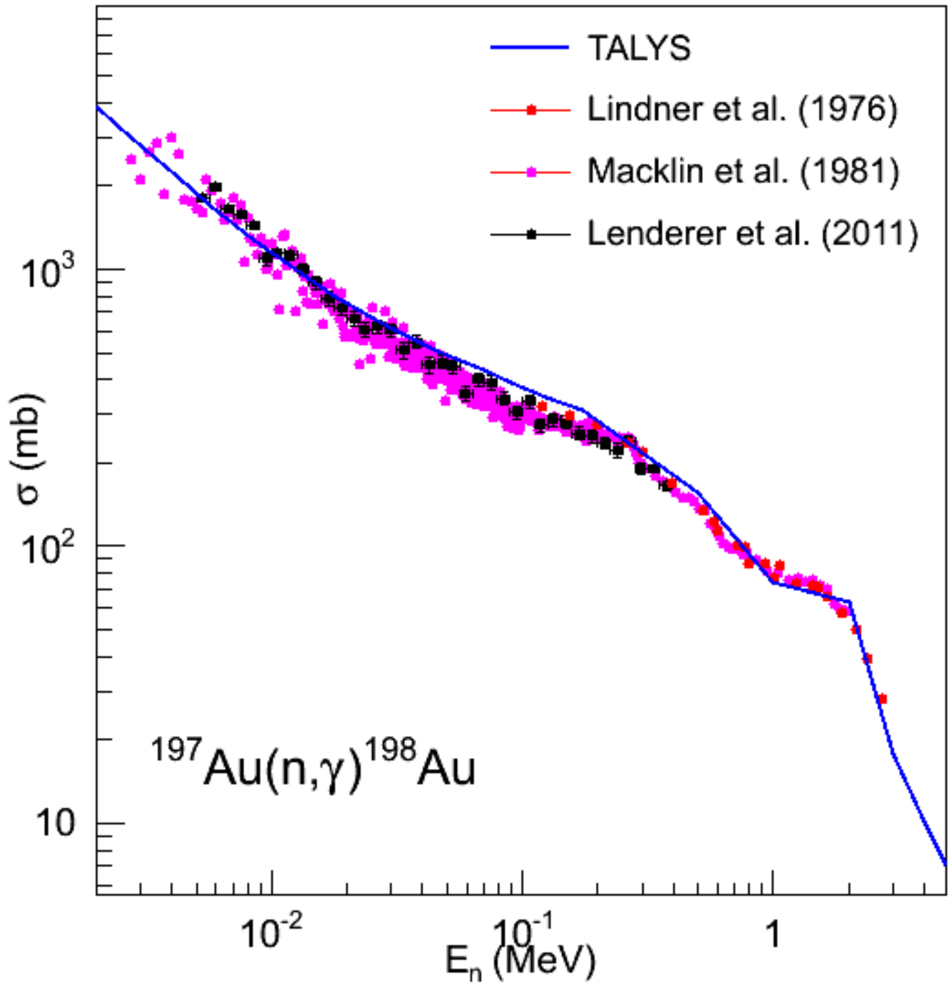
197Au(d,p)198Au, Giacoppo et al.
197Au(γ,n)196Au, Itoh et al (2011)
197Au(γ,n)196Au, Berman et al (1987)
197Au(γ,n)196Au, Veyssiere et al (1970)
197Au(γ,n)196Au, Fultz et al (1962)
E1, EGLO
Pygmies, SLO model
Model Sum
Sn
γ-ray strength function (MeV-3)
γ-ray energy Eγ (MeV)

γSF 197Au



197Au(3He,3He)197Au, Giacoppo et al., PRELIMIRARY!
197Au(γ,n)196Au, Itoh et al (2011)
197Au(γ,n)196Au, Berman et al (1987)
197Au(γ,n)196Au, Veyssiere et al (1970)
197Au(γ,n)196Au, Fultz et al (1962)
E1, QRPA + SLy4
Pygmies, SLO model
Model Sum
???
γ-ray strength function (MeV-3)
γ-ray energy Eγ (MeV)
10-5
10-6
10-7
10-8
10-9
0
2
4
6
8
10
12
14

Neutron capture cross section



Lindner et al., J. NSE 59,381,197604 (1976)

Macklin et al., J. NSE 79, 265, 8111 (1981)

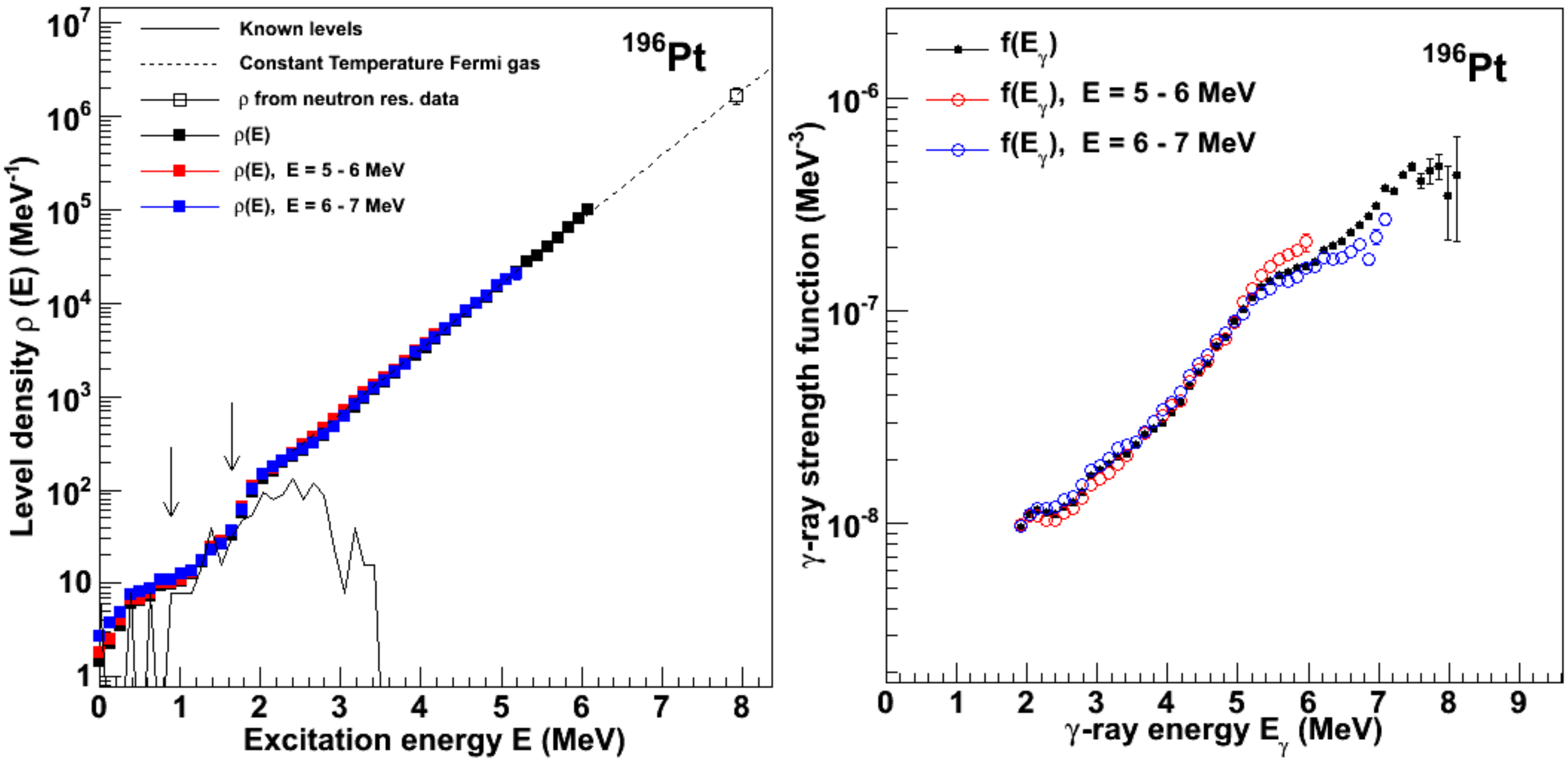
Lederer et al., PRC 83, 034608 (2011)

Conclusions

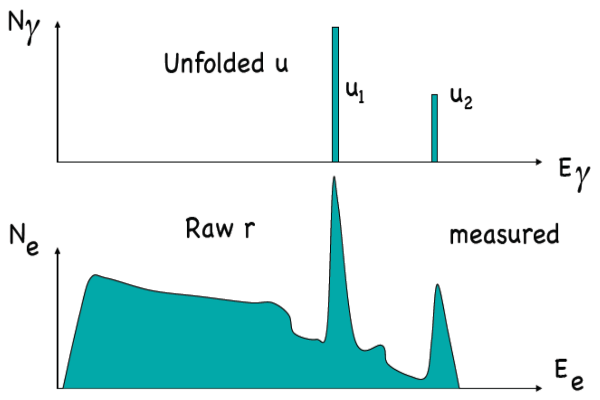
- ✧ Two resonance-like structures are observed close to the neutron binding energy in ^{196}Pt (and ^{195}Pt). They exhaust about 2% of the total γ-strength. The strength converge around two distinct region at $E_\gamma \approx 5.6$ and 7.5 MeV.
- ✧ Complementary experiments to further investigate the nature of such strength excess are planned.
- ✧ These resonances impact the calculated neutron capture cross section and reaction rates.
- ✧ A single resonance is observed in ^{198}Au, the presence of an higher energy peak cannot be proved.
- ✧ To investigate systematically the presence of structures on the tail of the GDR in this mass region, a recent experiment on ^{192}Os has been performed in Oslo (analysis in progress).

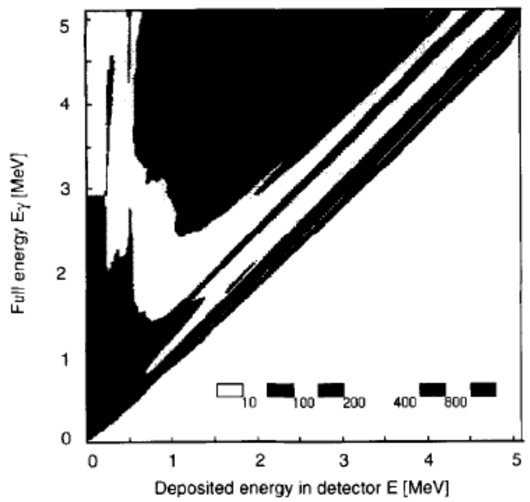
THANK YOU!!!

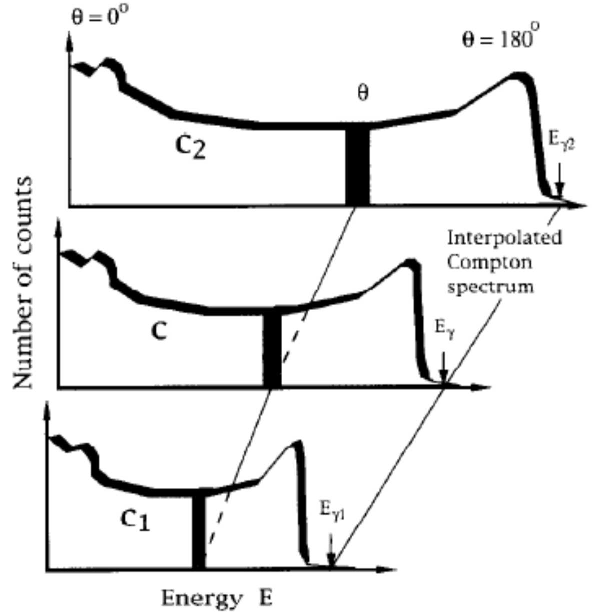
Brinkel-Axel



Unfolding







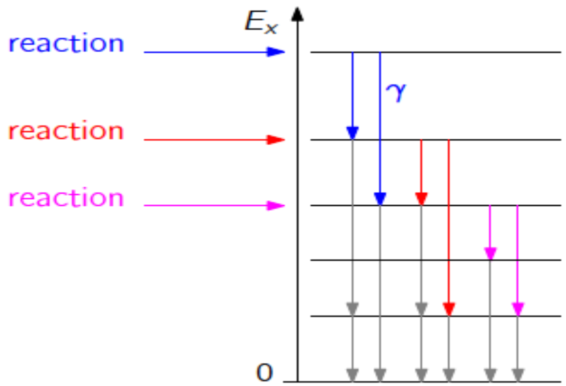
- **f = Ru**

$$\begin{pmatrix} f_1 \\ f_2 \\ \vdots \\ f_N \end{pmatrix} = \begin{pmatrix} R_{11} R_{12} \cdots R_{1N} \\ R_{21} R_{22} \cdots R_{2N} \\ \cdots \\ R_{N1} R_{N2} \cdots R_{NN} \end{pmatrix} \begin{pmatrix} u_1 \\ u_2 \\ \vdots \\ u_N \end{pmatrix}$$

- *Iterative procedure with r as first trial function* $\mathbf{u}^0 = \mathbf{r}$
- *Compton subtraction method*

See M. Guttormsen et al., NIM A 374 (1996) 371-376 for the details!

First generation



M. Guttormsen et al., NIM A NIM A 255, 518 (1987)

coloured = 1[st] generation
gray = higher generations