Pygmy Dipole Resonance (PDR) in exotic ^{68}Ni

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Introduction

Pygmy Resonance

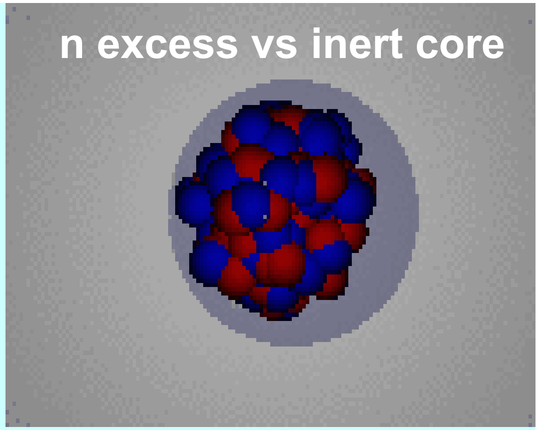
Analysis and Results

RISING data on ^{68}Ni

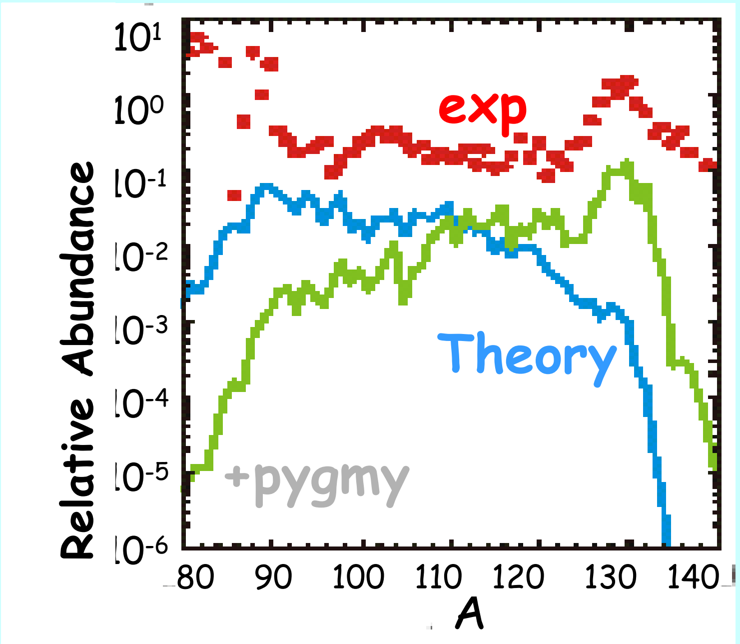
Virtual photon scattering

Conclusions

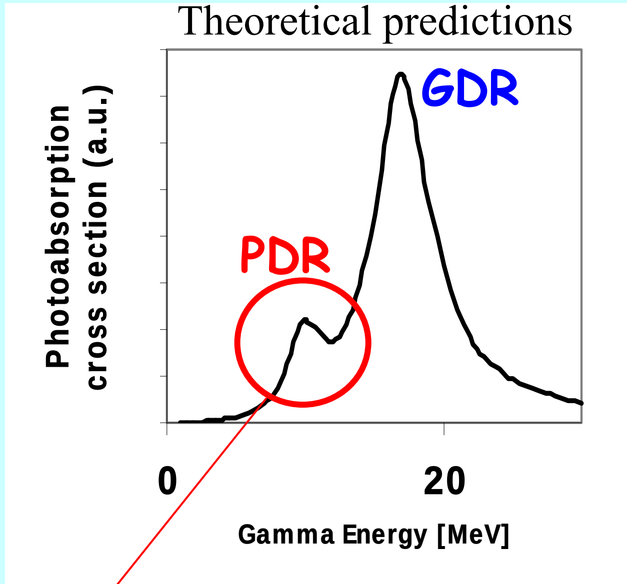
Pygmy Dipole Resonance in n-rich nuclei



- how **collective properties** change with **n** number
- **important** astrophysical implications for r-process



S. Goriely, Phys. Lett. B 436 (1998) 10



E1 strength **shifted** towards low energy

collective or non-collective nature of E1 states ?

Virtual photon scattering technique

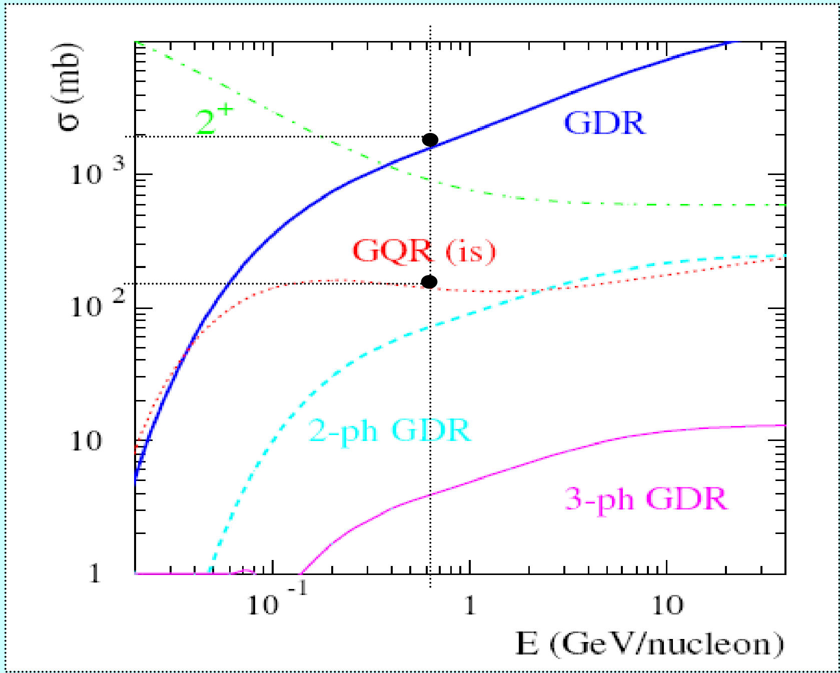
First pygmy coulomb excitation experiment with a fast relativistic beam

GDR - PYGMY Excitation

600 MeV/u $^{68}Ni + ^{197}Au$ (April 2005)
400 MeV/u $^{68}Ni + ^{197}Au$ (May 2004)

- **High selectivity for dipole excitation**

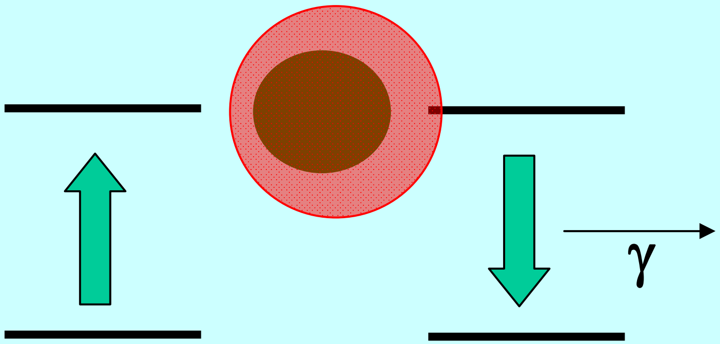
$$\frac{\sigma(GDR)}{\sigma(GQR)} \approx 20$$



T.Aumann et al EPJ 26(2005)441

→At large energies the cross section for the Coulomb excitation of the GR overcomes the nuclear geometrical cross section!

Virtual photon excitation and decay of **GDR - PYGMY**



Coulex

GDR Ground state decay branching ratio ~ 2% measured on ^{208}Pb

[Beene et al PRC 41(1990)920]

Coulomb excitation of ^{68}Ni @ 600 AMeV

RISING ARRAY

Euroball **15 Clusters**

Located at 16.5°, 33°, 36° degrees
Energetic threshold ~ 100 keV

Hector **8 BaF_2**

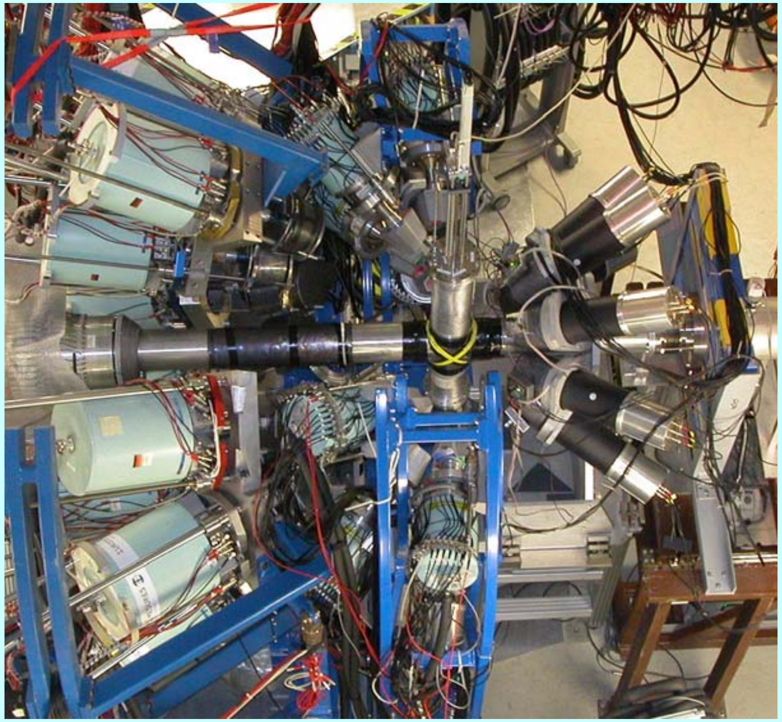
Located at 142° and 88° degrees
Energetic threshold ~ 2 MeV

Miniball **7 HPGe segmented** detectors

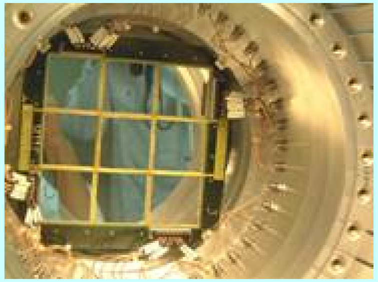
Located at 46°, 60°, 80°, 90° degrees
Energetic threshold ~ 100 keV

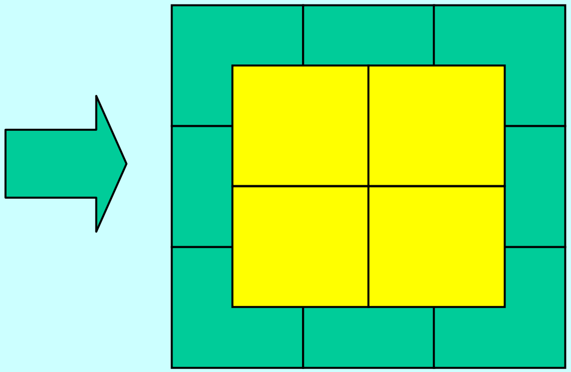
Beam identification and **tracking detectors**

Before and after the target

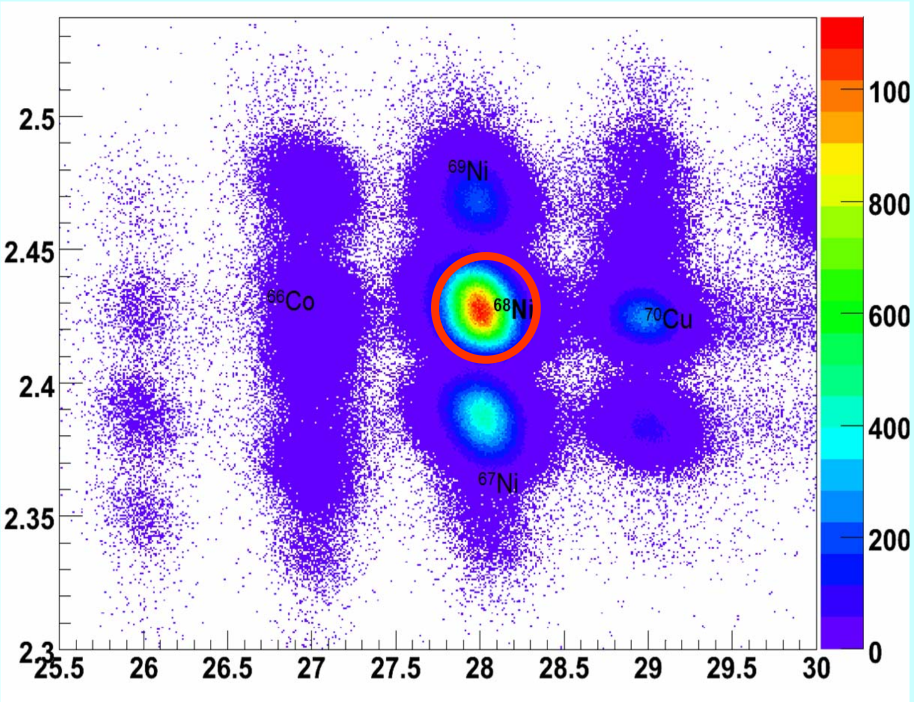


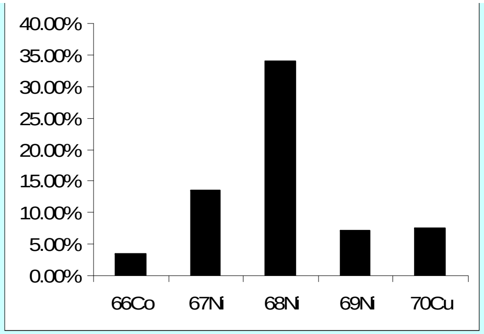
Calorimeter
Telescope
for beam identification
CATE
Position sensitive

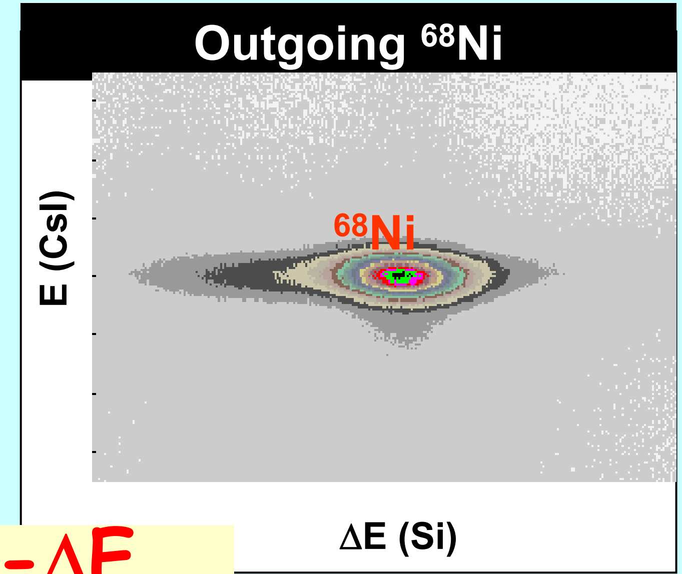




4 CsI
9 Si

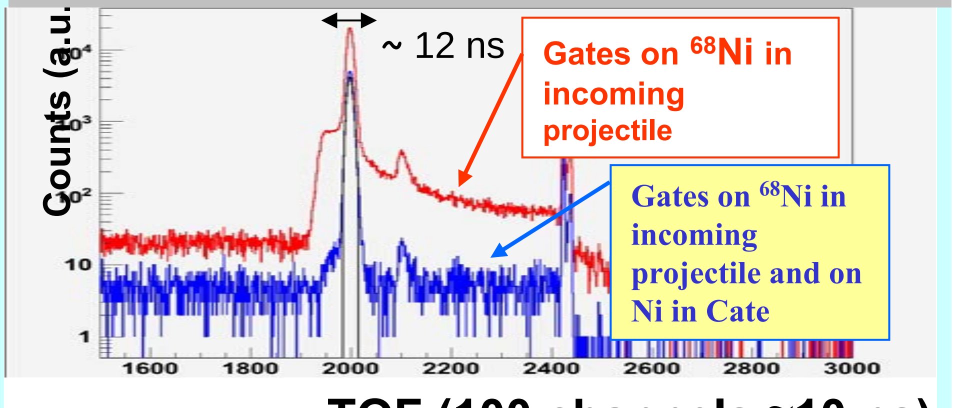






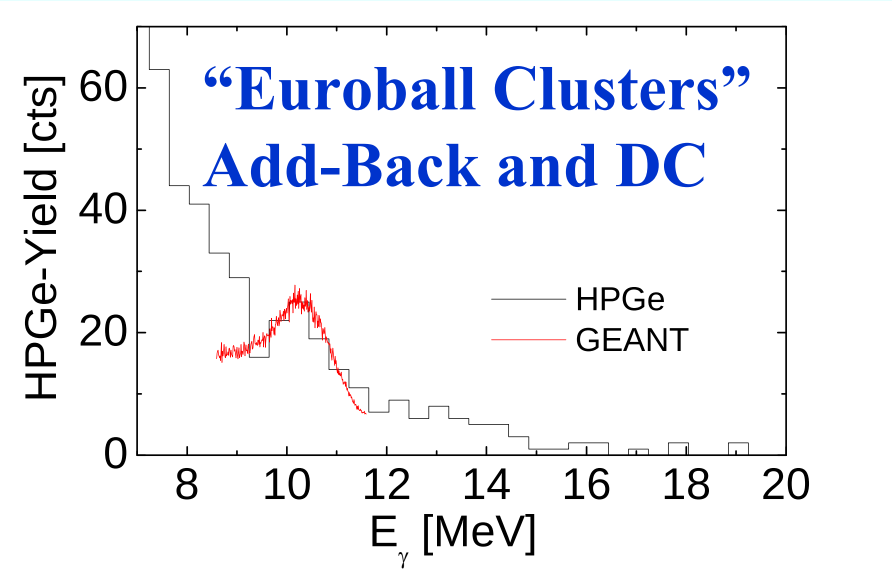
E-ΔE telescopes

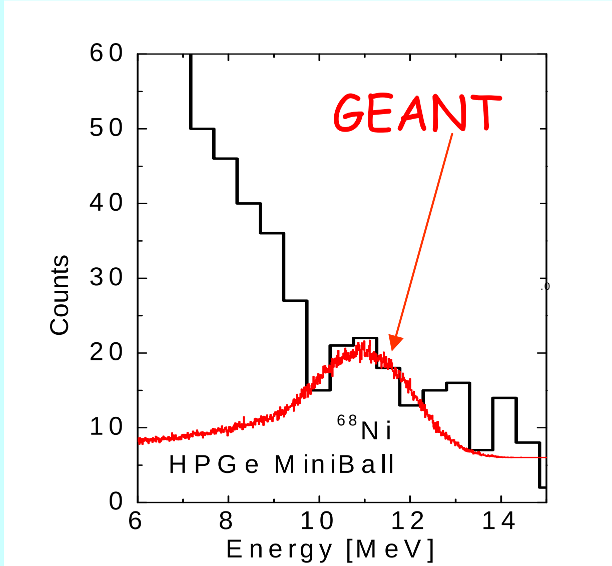
BaF$_2$ TOF Spectra



TOF (100 channels ≈10 ns)

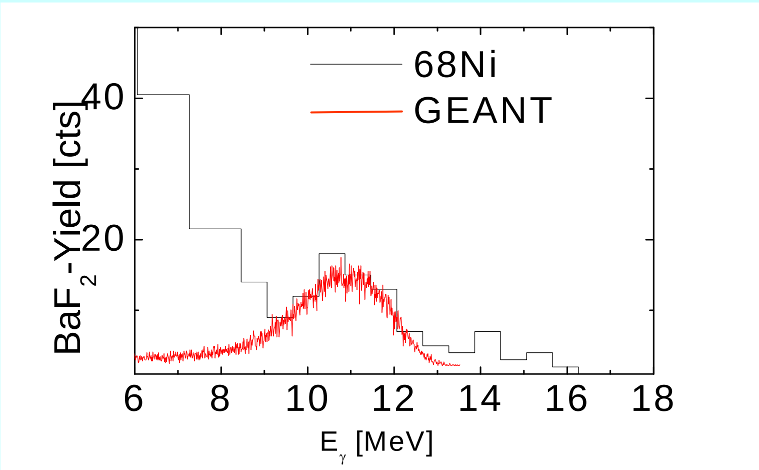
- ~ 6 Days of effective beam time
- ~ 400 GB of data recorded
- ~ 3 10^8 Events recorded
- ~ 1 10^8 ^{68}Ni recorded
- ~ 3 10^7 ‘ good ^{68}Ni events ‘ recorded





Forward : EUROBALL

Center: MINIBALL



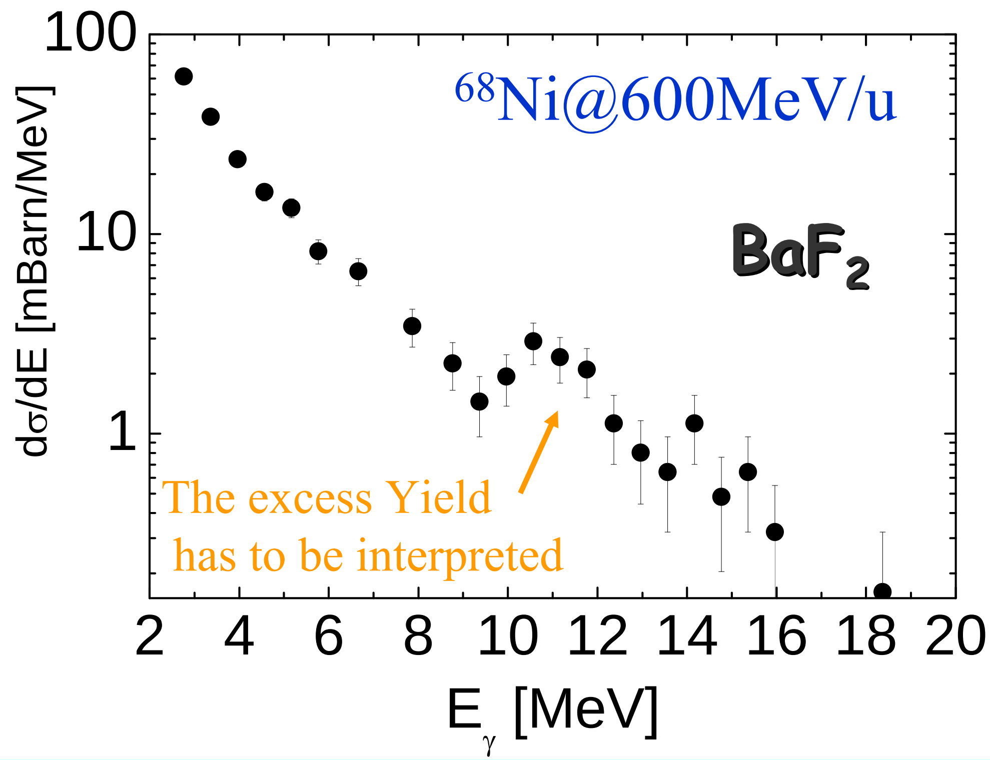
Backward HECTOR

Structure @ 10.5 MeV in *all* detectors

ANALYSIS and final RESULTS

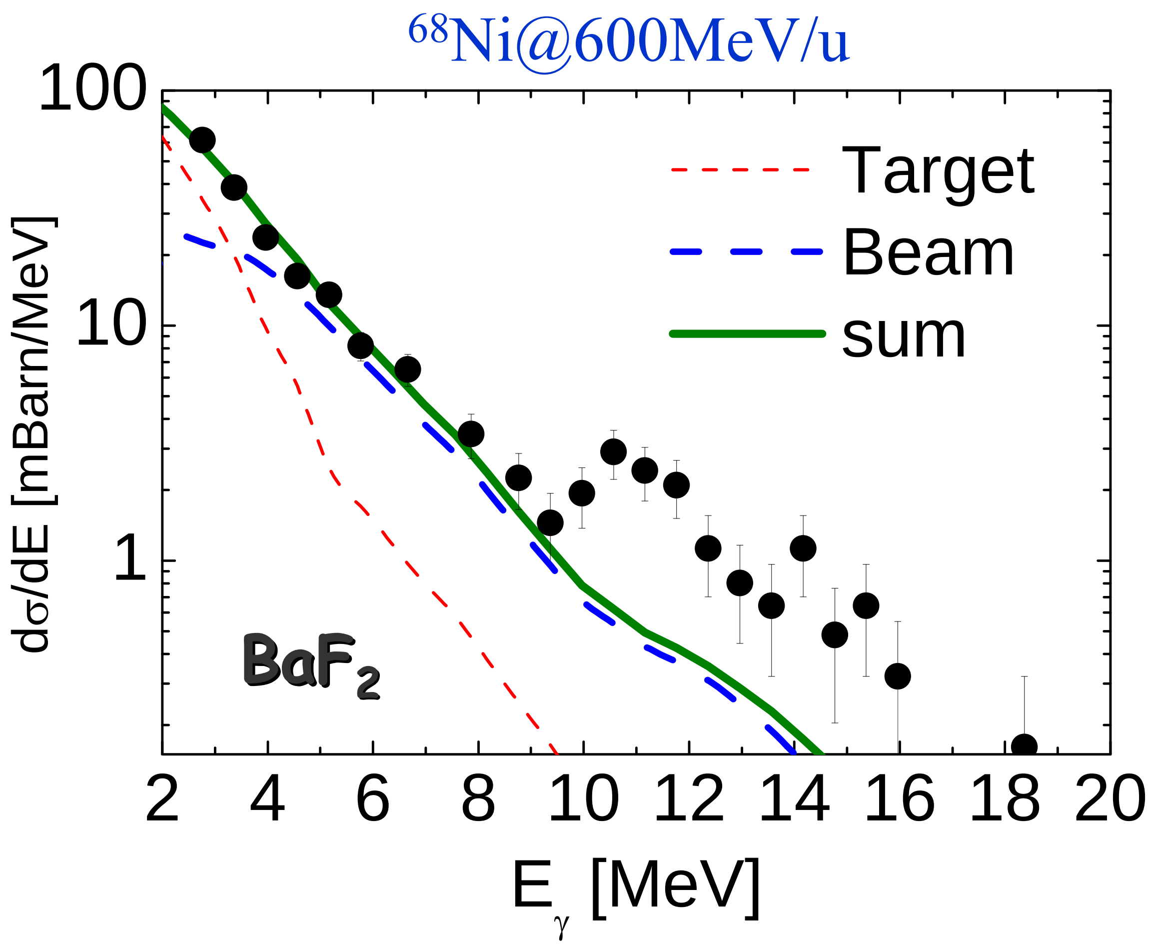
1. **Counts into cross Section**

$$\sigma_{i \to f} = \frac{N_\gamma}{N_B \cdot N_T \cdot \varepsilon}$$



Background ??

2. Evaluation of Background



Statistical model (Cascade) calculation of γ-rays following statistical equilibration of excited **target** nuclei (^{197}Au) and of the excited
beam nuclei (^{68}Ni) folded with RF and in the CM system
[see f.ex. J.Ritman et al. PRL70(1993)533]

3. Data Analysis

Calculate the ground state γ-ray decay from a GR state following a Coulomb excitation

! Coulomb excitation probability is directly proportional to the Photonuclear cross section

[Eisenberg,Greiner, Bertulani,Alder,Winther,…]

Coulomb excitation Yield is product of 3 terms:

Virtual photo number, photoabsorption cross section, Branching

$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

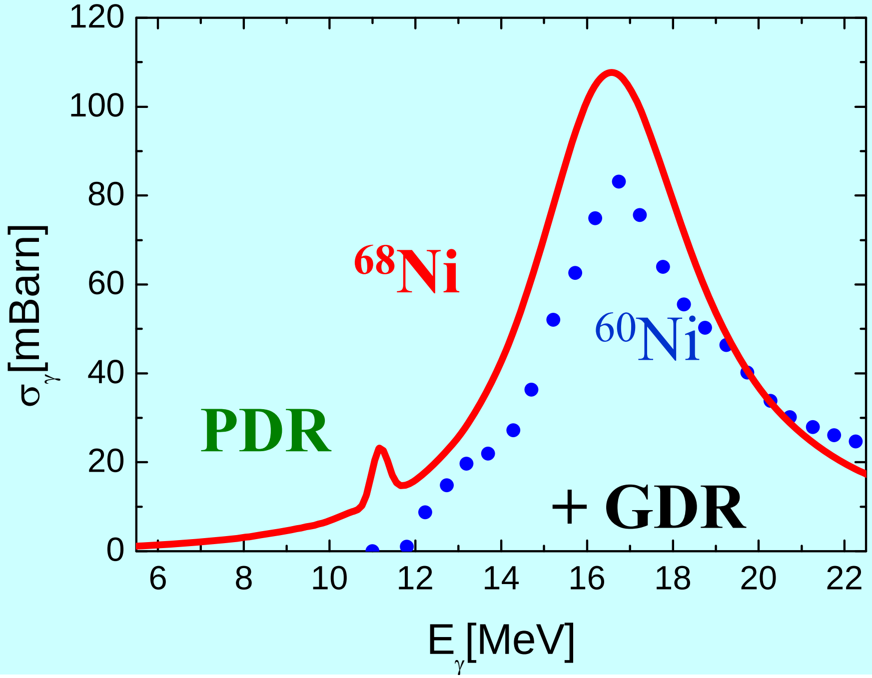
[… Beene, Bortignon, Bertulani …]

$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

Photo absorption cross section

the Thomas-Reiche-Kuhn sum rule for $E1$ excitations,

$$\int \sigma_\gamma^{E1}(\epsilon)\, d\epsilon \simeq 60 \frac{NZ}{A}\ \mathrm{MeV\,mb}$$



$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

The functions $n_{\pi\lambda}(\varepsilon)$ are called the *virtual photon numbers*, and are given by

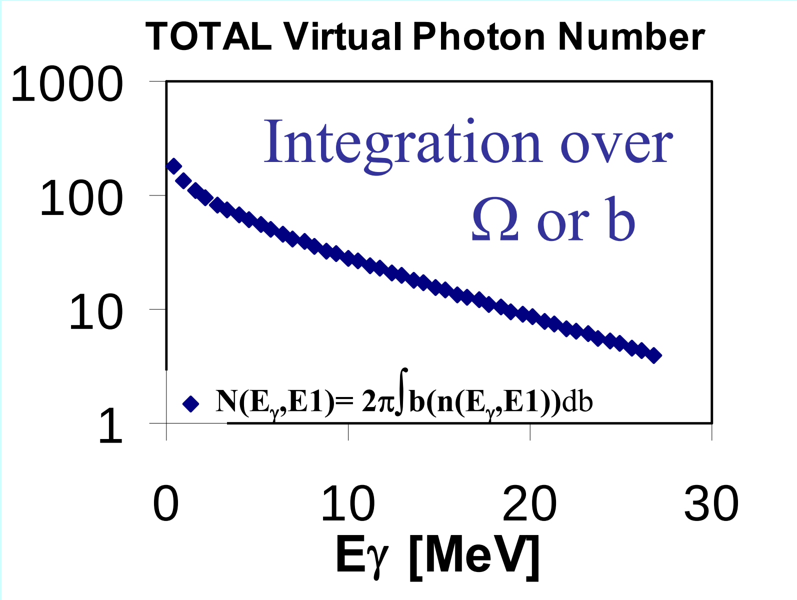
$$n_{E1}(b,\varepsilon) = \frac{Z_1^2\alpha}{\pi^2}\frac{\xi^2}{b^2}\left(\frac{c}{v}\right)^2\left\{K_1^2 + \frac{1}{\gamma^2}K_0^2\right\}$$

= number of equivalent photons

Does NOT depend on the nuclear structure !

Equivalent(virtual)-photon method

Flux of virtual photons per unit area impinging on collision partners.



$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma)=\frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

Branching **R**atio$_\gamma$

Two-stage approximation of single sharp states,

considering the direct GR decay + the compound states :

$$R_\gamma(E_\gamma,\rho_{LD})=\frac{\Gamma_0^{GR}}{\Gamma^{GR}}+\frac{\Gamma^{GR\downarrow}}{\Gamma^{GR}}C\frac{\langle\Gamma_0^c\rangle}{\langle\Gamma^c\rangle}.$$

[Beene,B[4]]

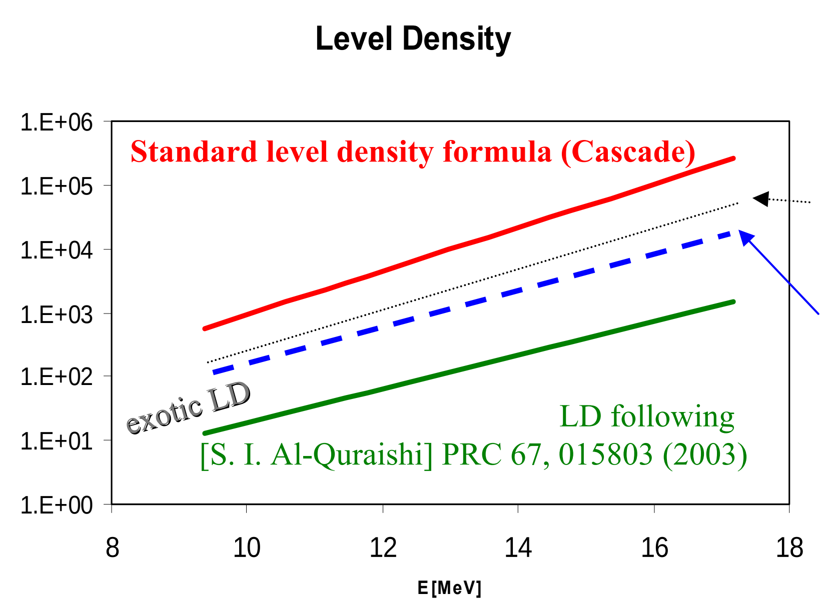
CN

$\langle\Gamma^C_0\rangle=2/\pi*\Gamma_{\gamma 0}/\Gamma^{GR\downarrow}/\rho_{LD}$

Level Density

$\langle\Gamma_{\gamma 0}\rangle=16\pi/27*[E/\hbar c]^3 B(E1\uparrow)$

$\langle\Gamma^C\rangle$ w. Hauser Feshbach

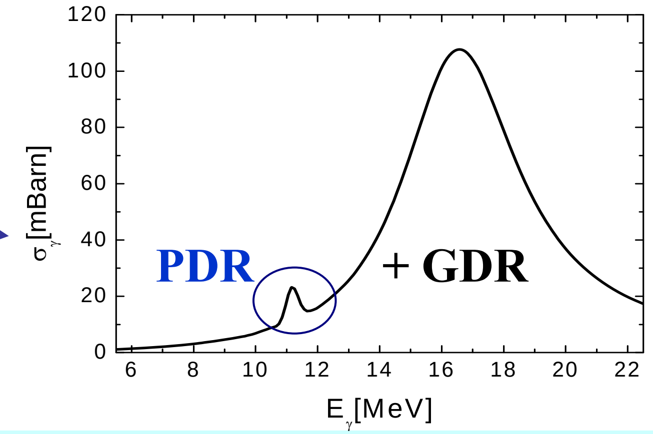


Hartree-Fock-BCS approach (S. Goriely)
[from EMPIRE-Code,
www.nndc.bnl.gov/empire219]

Yoram Alhassid
[AIP Conf. P 769(2005)1283 and private. com.]
Microscopic nuclear level densities
(ab initio shell model Monte Carlo method)

$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma)=\frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

photoabsorption cross section



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Equivalent(virtual)-photon method

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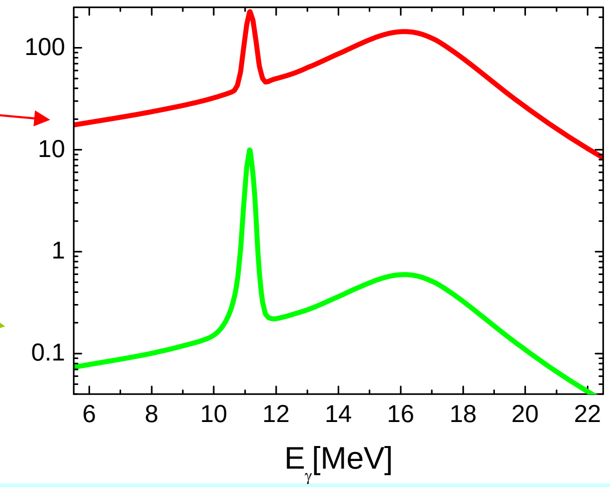
Branching



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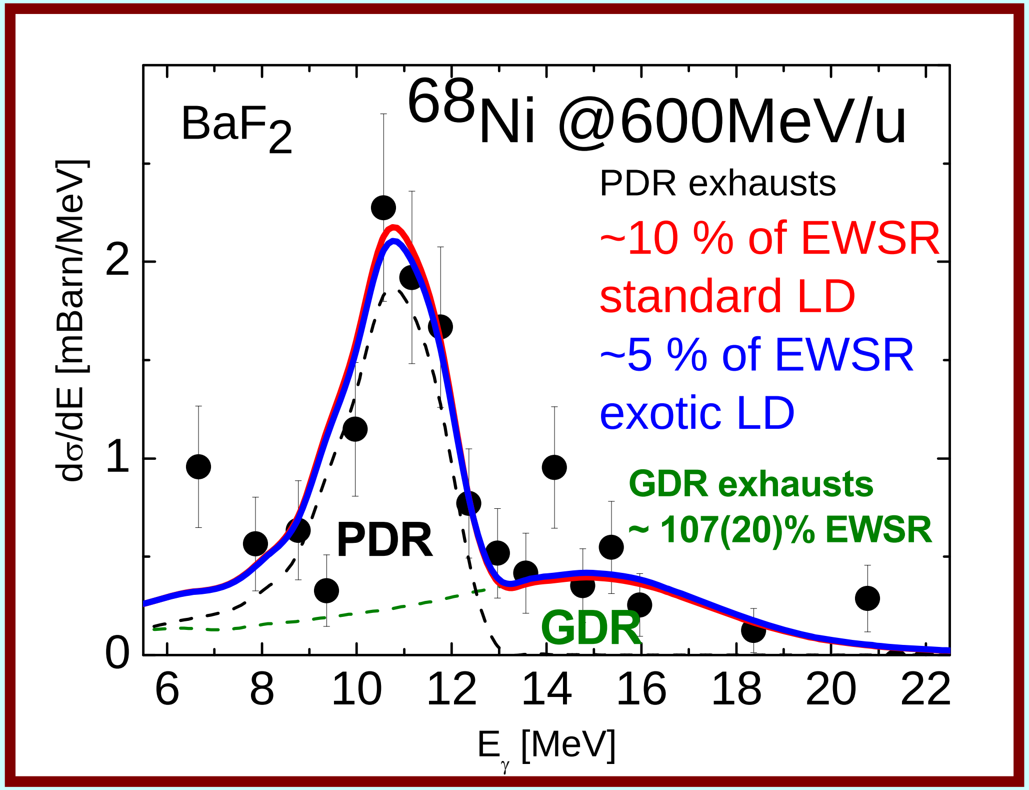
Detector Response Function…

Folded with the **detector response function** to compare to measured data points ●:



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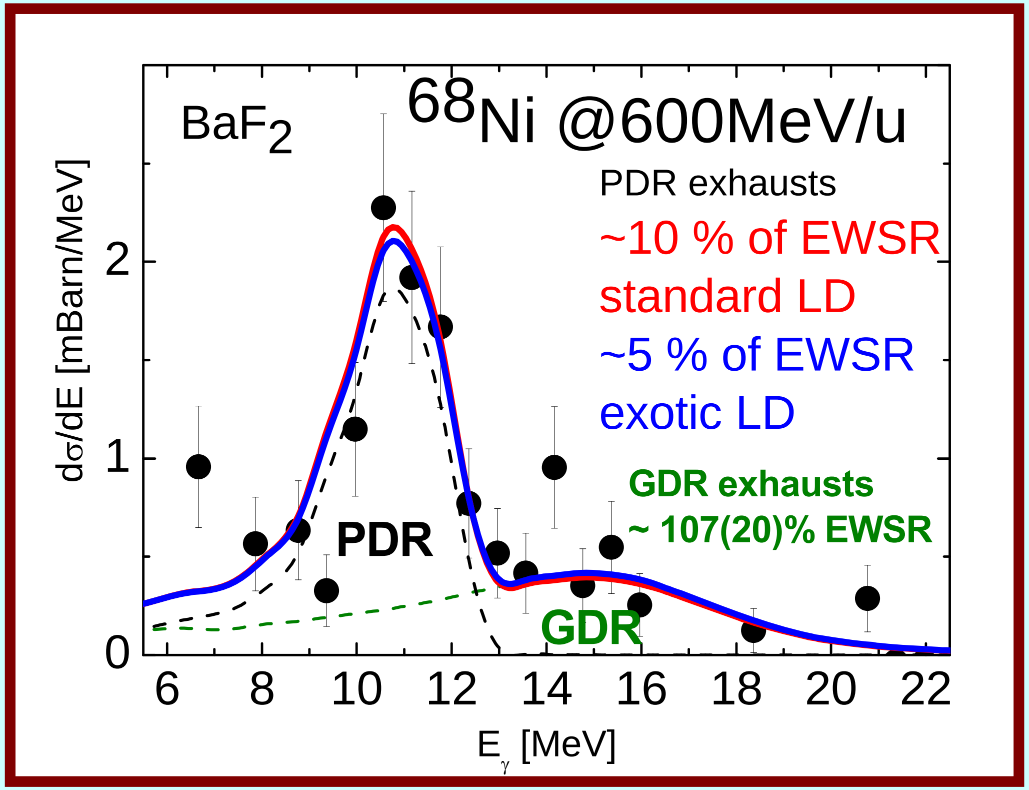
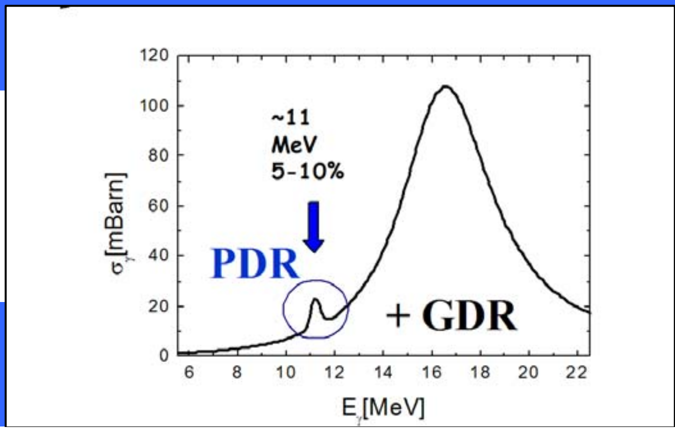


Width of the PDR is: $\Gamma < 500$kev



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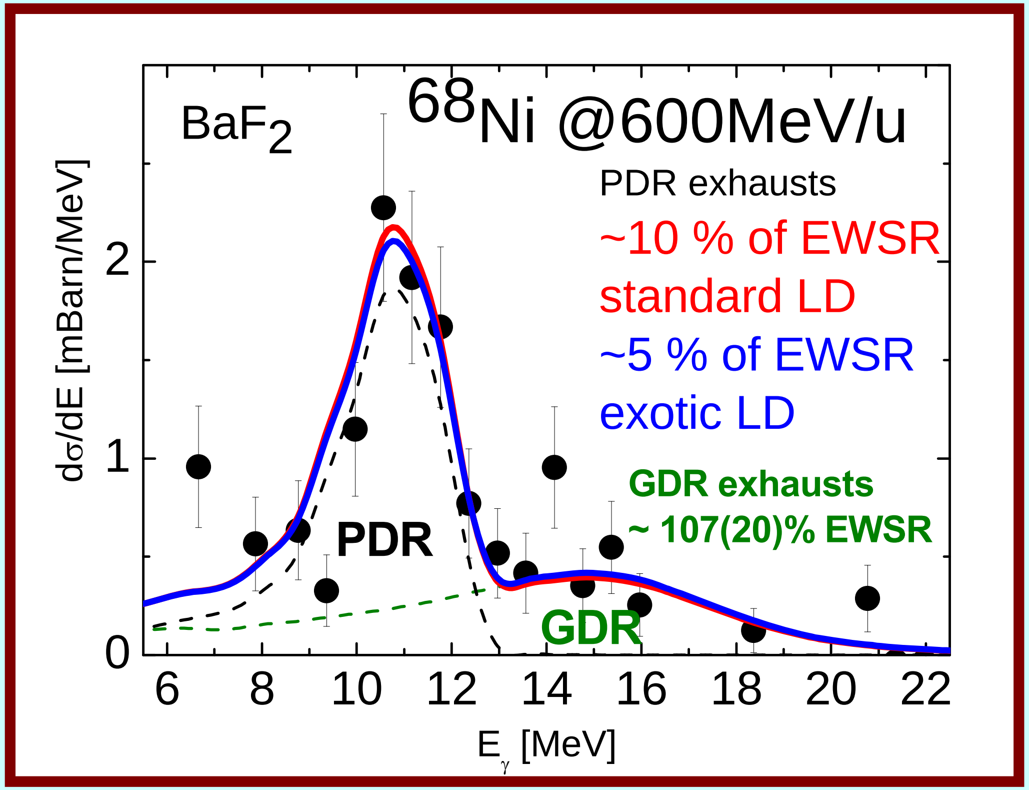
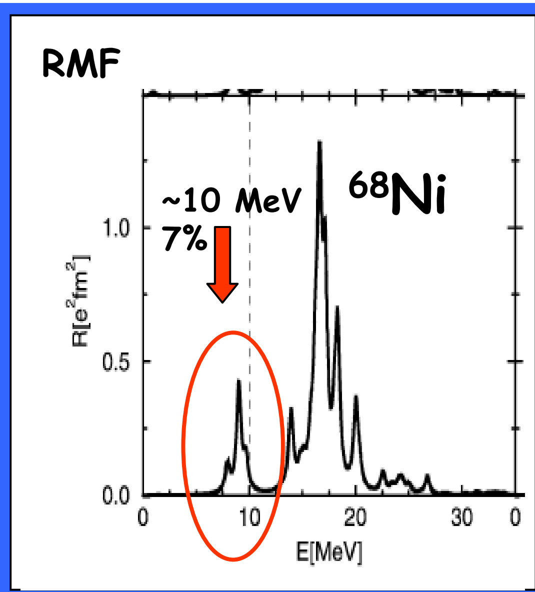
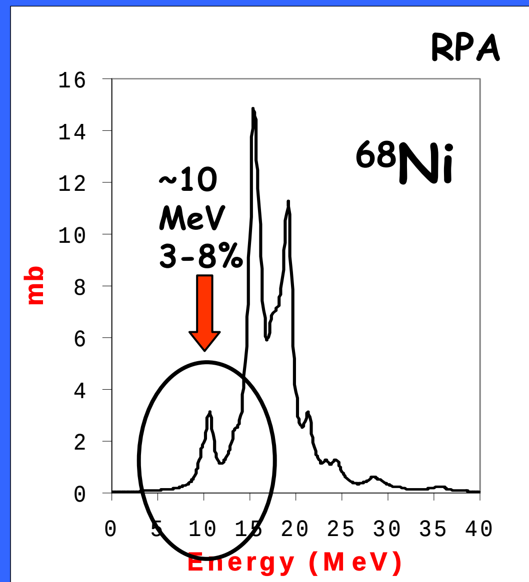


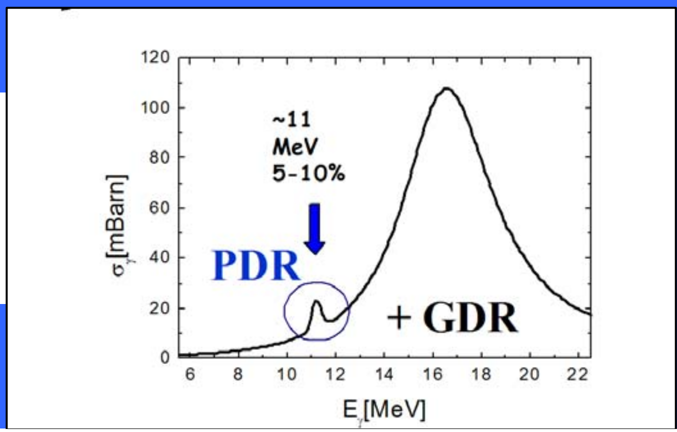


D. Vretnar et al. NPA 692(2001)496



G. Colo private communications

Width of the PDR is: $\Gamma < 500$kev



✚ J. Liang et al., PRC75(2007) fRPA: 7-8%:

Conclusions

- Measured high energy γ-rays from Coulex of ^{68}Ni at 600 MeV/u

  - First experiment of this type ever performed (GSI is the only possible Laboratory)

  - We have measured with 3 different detectors a structure around 11 MeV

  - **We found an extra strenght at 11 MeV with around 5% to 10 % of the EWSR. The error is related by the assumption of the Level density.**
    The theory (RMF and RRPA calculations) predicts 4-8%.

  - **The results open new perspectives for other experiments and are very promising for Future measurements especially with high resolution**

Thank you

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