DIPOLE-STRENGTH IN N=50 NUCLEI STUDIED IN PHOTON-SCATTERING EXPERIMENTS AT ELBE

R. Schwengner[1], G. Rusev[1], N. Benouaret[1,2], R. Beyer[1], F. Dönau[1], M. Erhard[1], E. Grosse[1,3], A. R. Junghans[1], K. Kosev[1], J. Klug[1], C. Nair[1], N. Nankov[1,4], K. D. Schilling[1], A. Wagner[1]

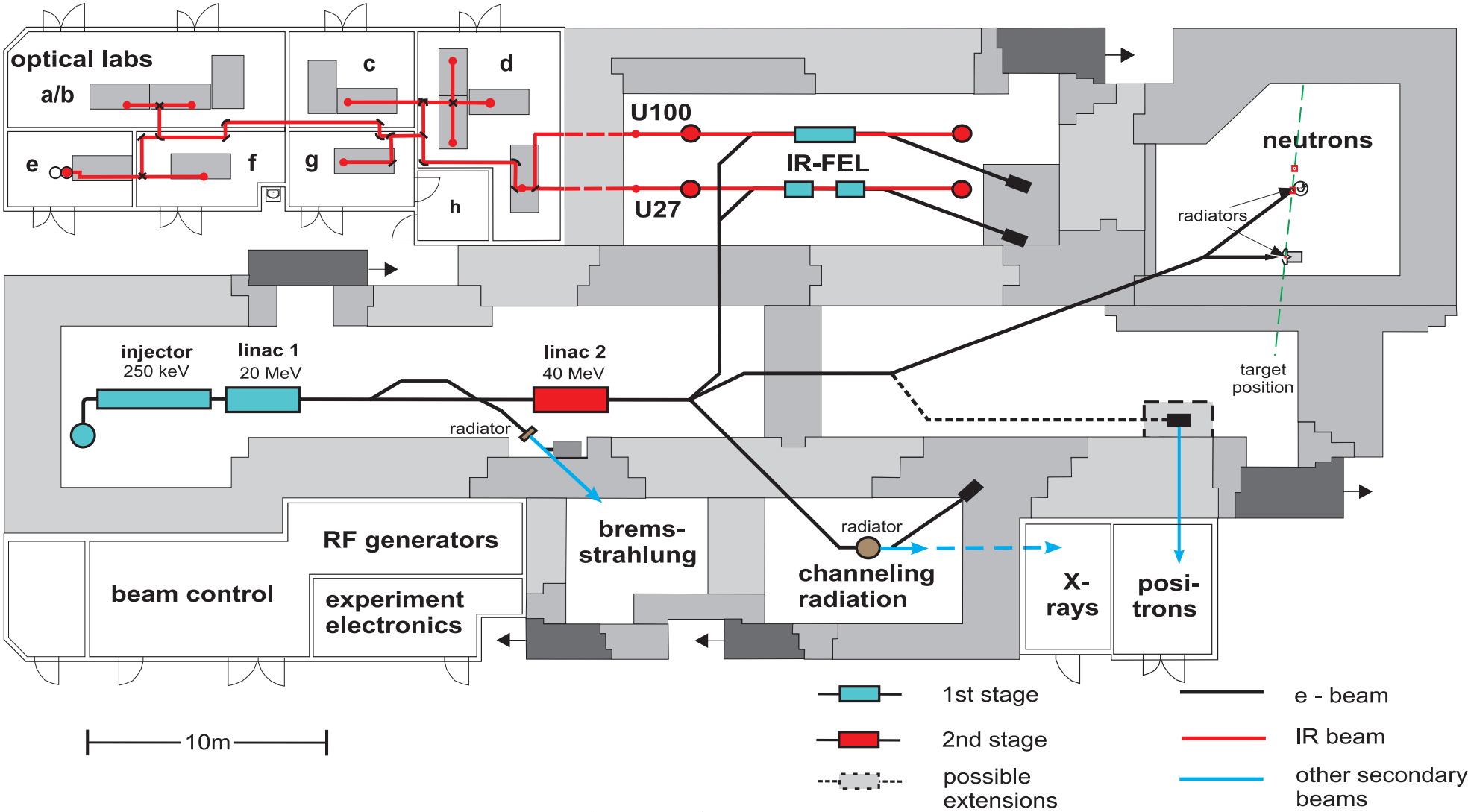
[1] *Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany*
[2] *Faculté de Physique, Université des Sciences et de la Technologie d'Alger, 16111 Bab-Ezzouar-Alger, Algerie*
[3] *Institut für Kern- und Teilchenphysik, Technische Universität Dresden, 01062 Dresden, Germany*
[4] *Institute for Nuclear Research and Nuclear Energy, BAS, 1784 Sofia, Bulgaria*

- The bremsstrahlung facility
- Photon-scattering experiments
- Data analysis and results
- Comparison with model predictions

Supported by Deutsche Forschungsgemeinschaft

The radiation source ELBE

Electron Linear accelerator of high Brilliance and low Emittance

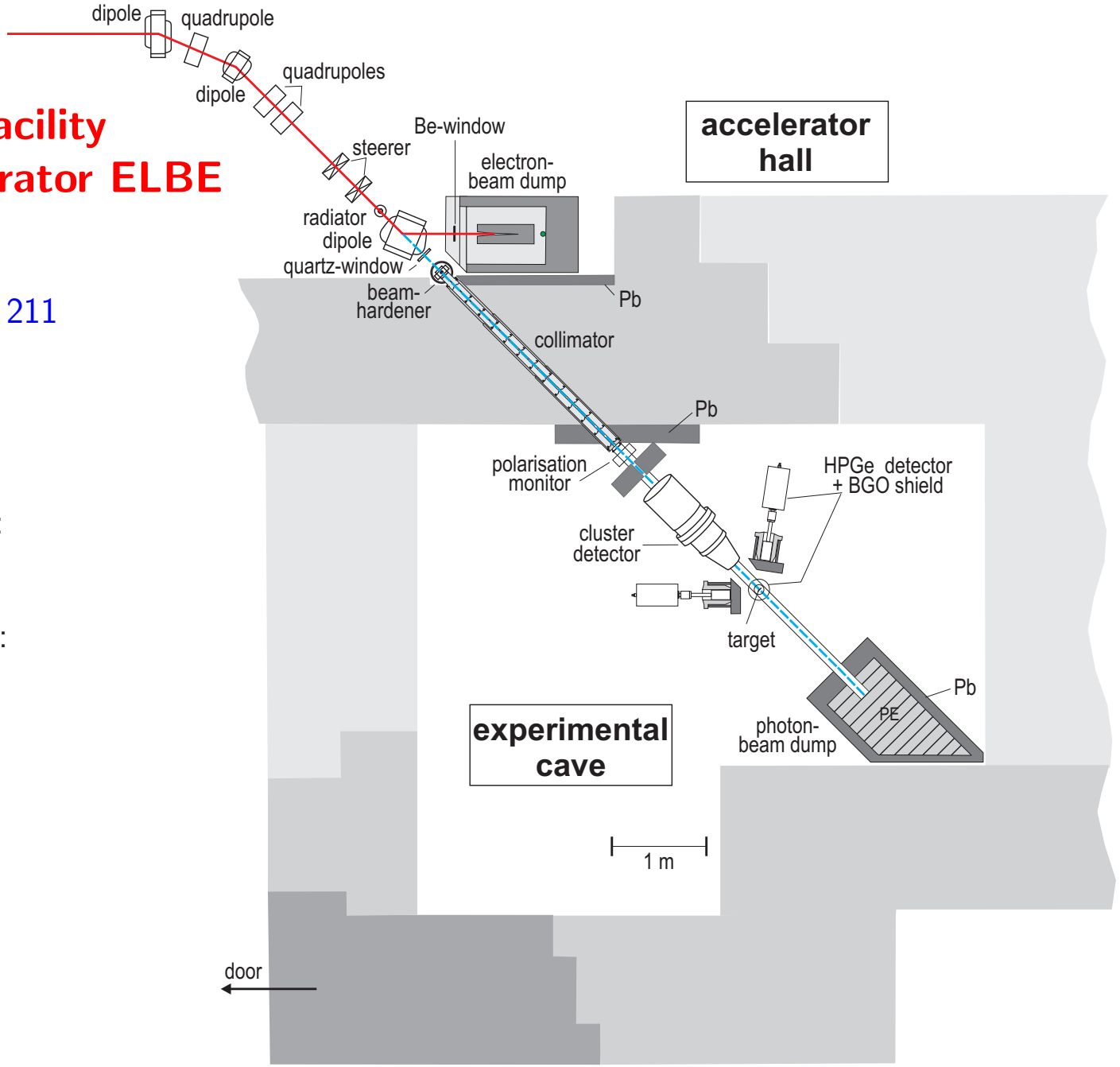


The bremsstrahlung facility at the electron accelerator ELBE

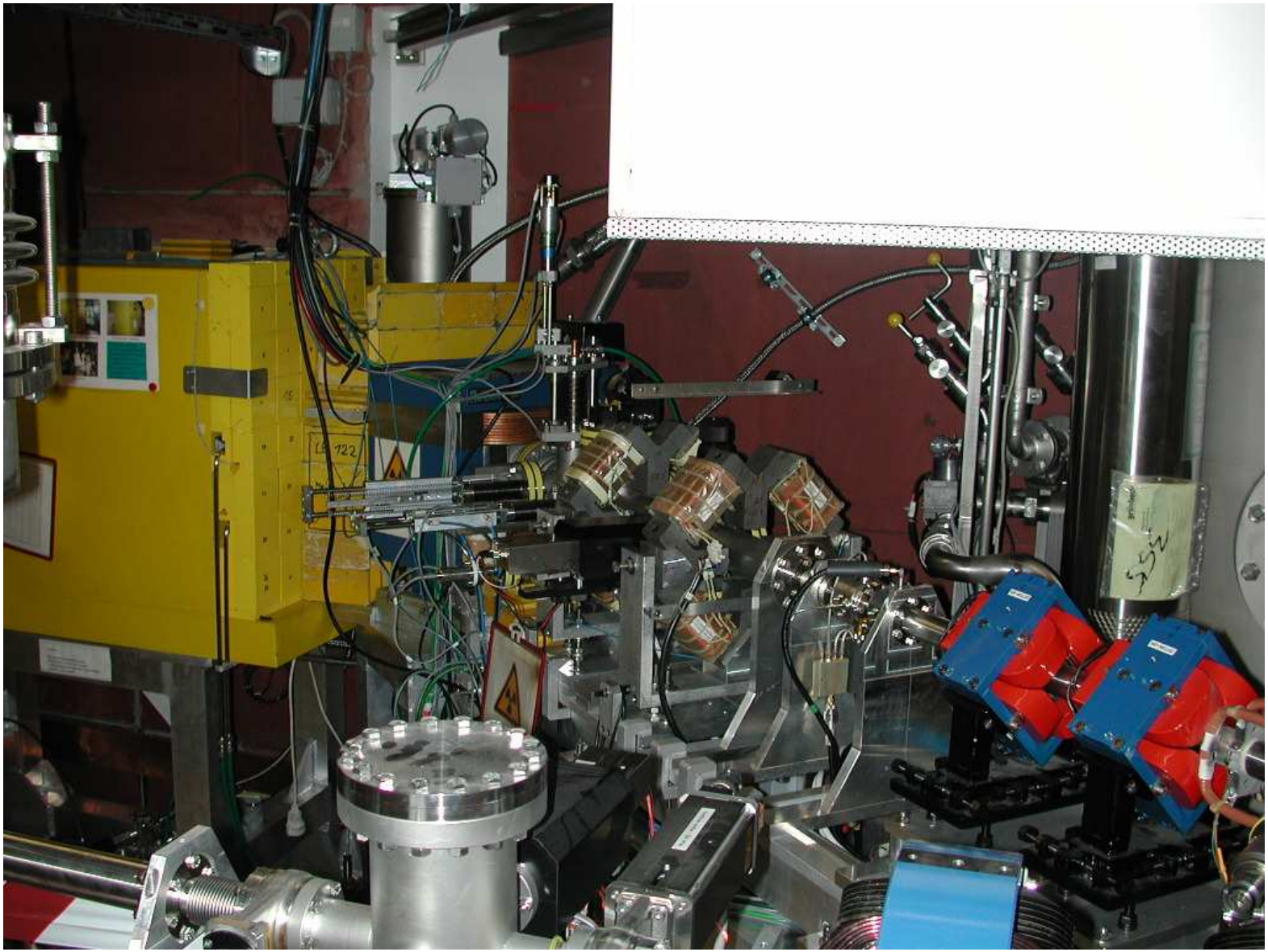
R.S. et al., NIM A 555 (2005) 211

Accelerator parameters:

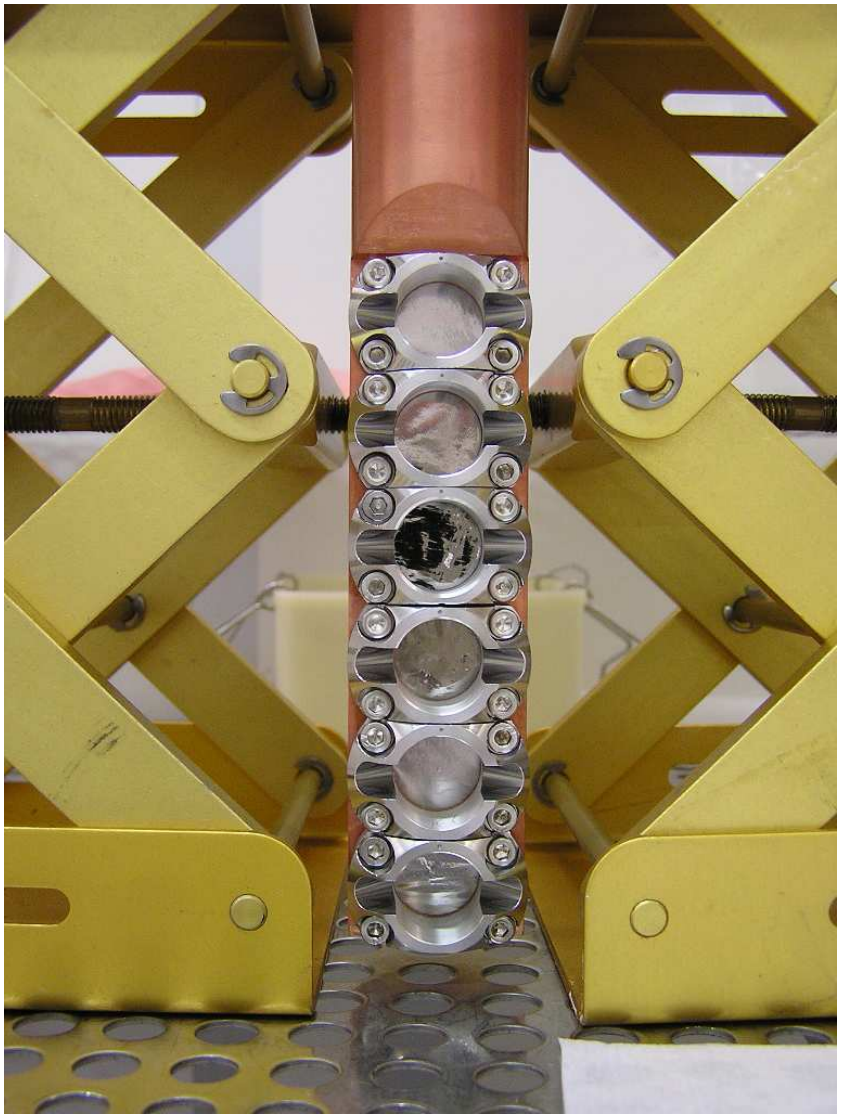
- Maximum electron energy:
  18 MeV
- Maximum average current:
  1 mA
- Micro-pulse rate:
  13 MHz
- Micro-pulse length:
  $\approx$ 5 ps



Electron-beam line



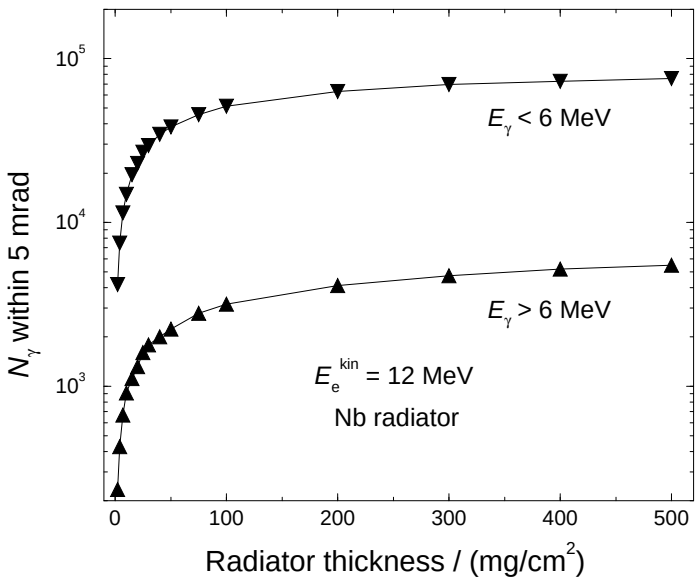
Radiator

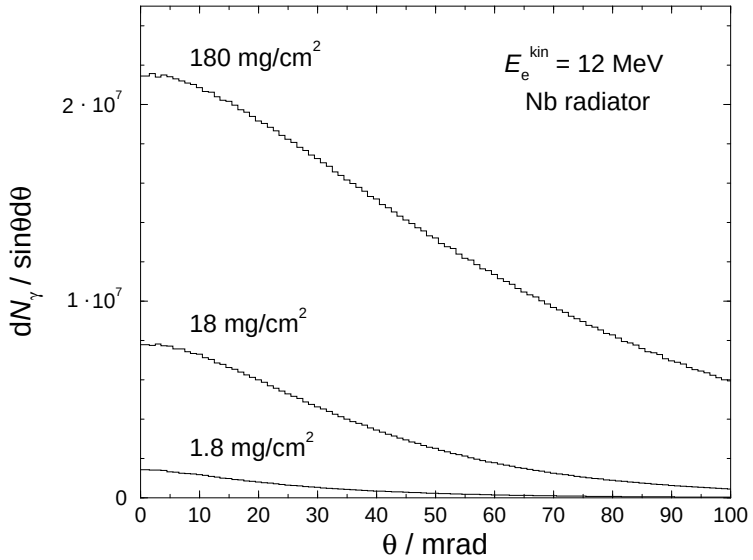


Niobium radiators:

- Six radiator foils of 16 mm diameter mounted on a water-cooled copper rod
- Thicknesses of 2, 3, 4, 5, 7 and 12.5 μm, corresponding to $2 \cdot 10^{-4}$ to 10^{-3} radiation lengths
- Radiator holder can be moved by a DC motor drive to select a radiator without breaking the vacuum

Simulation of the flux of photons passing the collimator





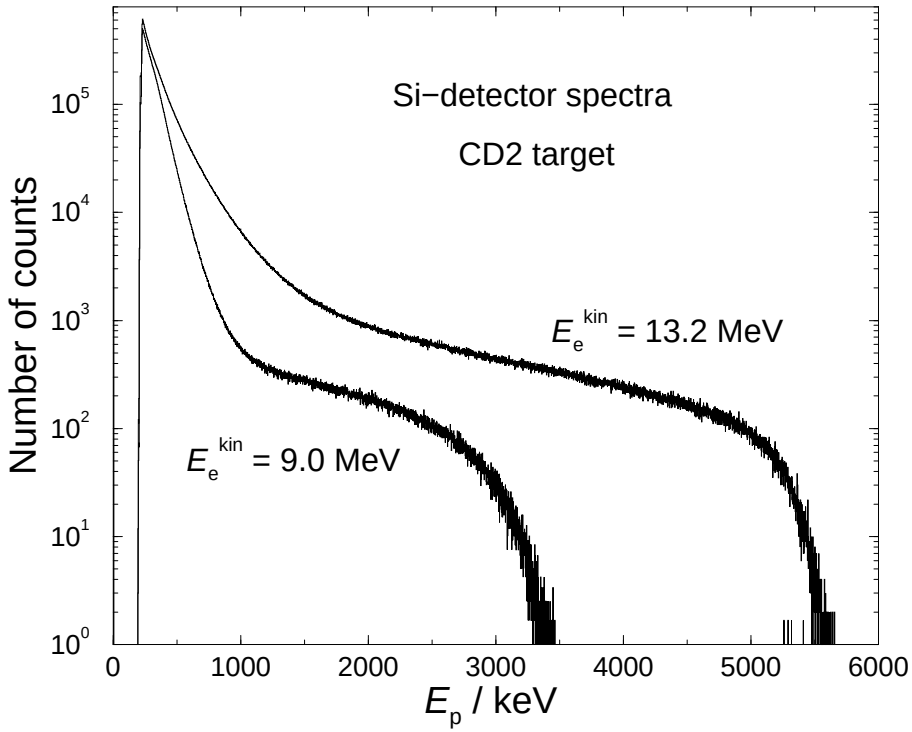
Simulations with GEANT4:

- Number of photons produced by 10^9 electrons of $E_e^{kin} = 12$ MeV in a cone with an opening angle of 5 mrad as a function of the niobium-radiator thickness.

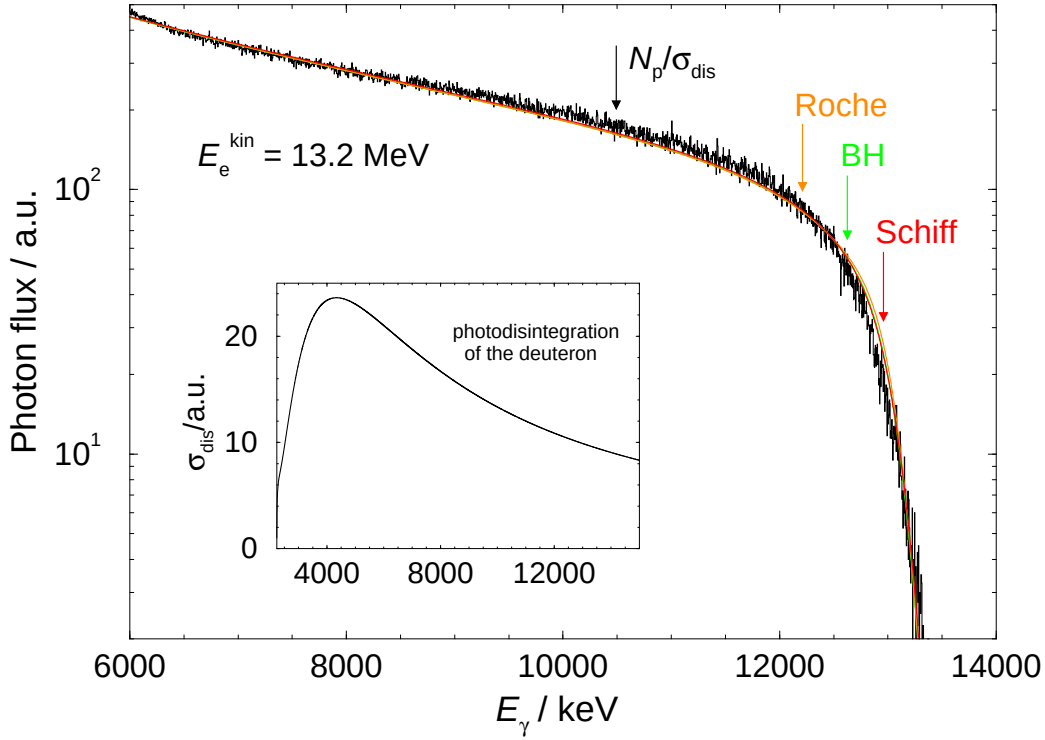
- Number of photons produced by 10^9 electrons of $E_e^{kin} = 12$ MeV in niobium radiators of different thicknesses as a function of the angle between electron beam and photon.

Detector setup

Measurement of the electron energy via photodisintegration of deuterons



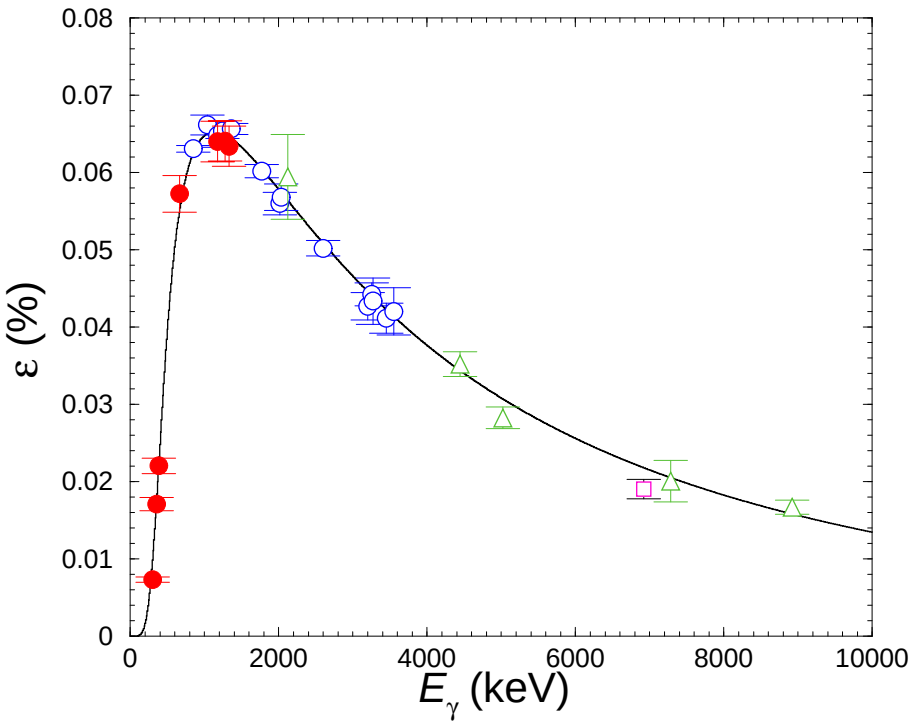
Spectra measured with Si detectors of 300 μm thickness during the irradiation of a deuterated polyethylene film with bremsstrahlung.



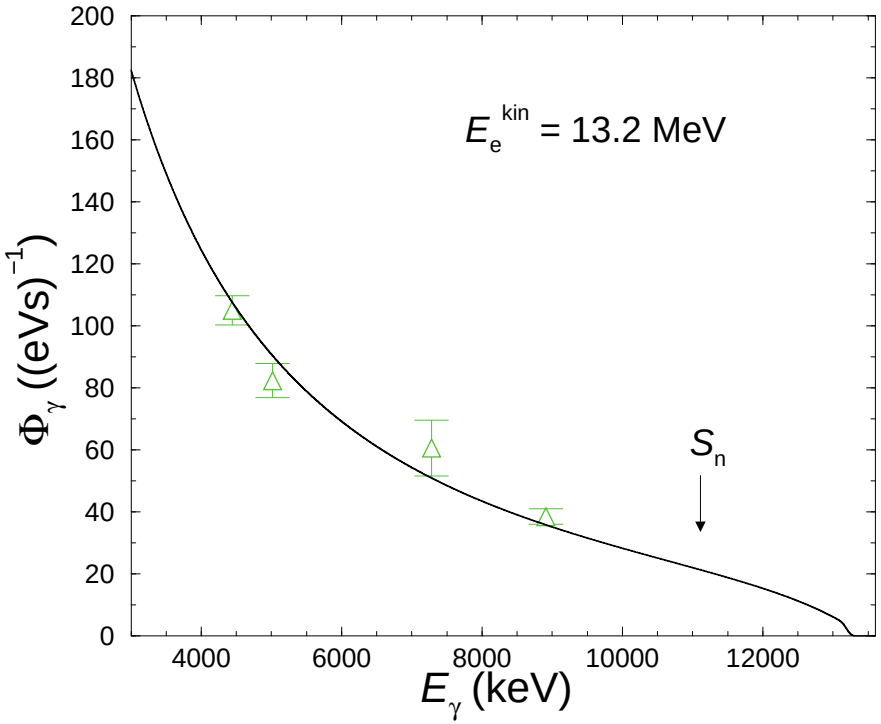
Spectrum of incident photons recalculated from the proton spectrum and the cross section for the disintegration of the deuteron.

σ_{dis}: H. Bethe, C. Longmire, Phys. Rev. 77 (1950) 647
Roche: G. Roche *et al.*, Phys. Rev. A 5 (1972) 2403
BH: H. Bethe, W. Heitler, Proc. Roy. Soc. A 146 (1934) 83
Schiff: L.I. Schiff, Phys. Rev. 83 (1951) 252

Absolute detector efficiency and photon flux

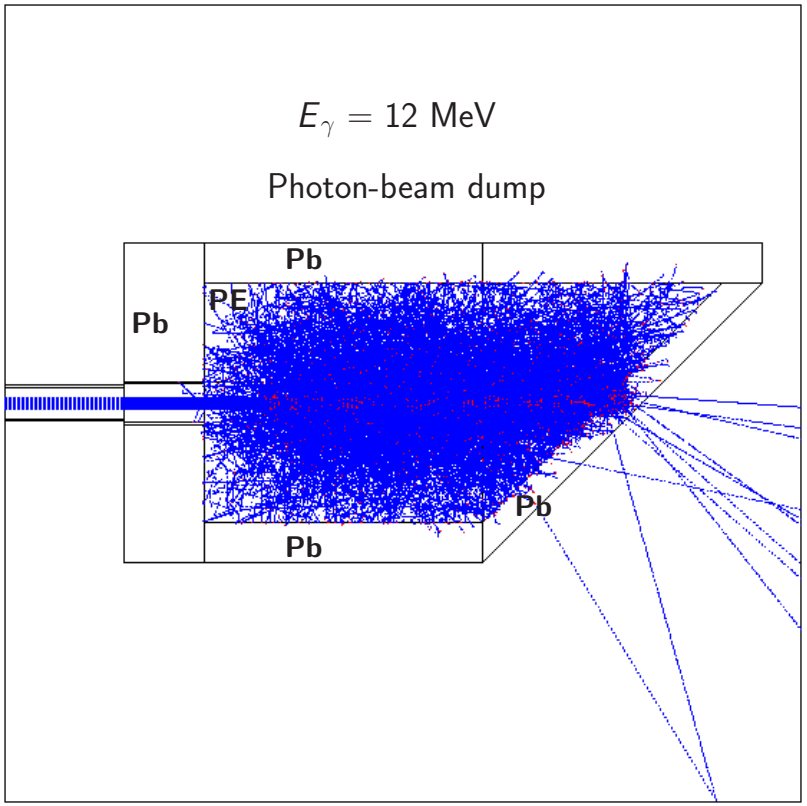


Absolute efficiency of two detectors at 127° deduced from ^{22}Na, ^{60}Co, ^{133}Ba, (filled circles) and simulated with GEANT3 (solid line). Relative efficiencies deduced from ^{56}Co (open circles), ^{11}B (open triangles) and ^{16}O (open square).



Absolute photon flux deduced from transitions in ^{11}B (open triangles) using the calculated efficiency shown in the left panel and relative photon flux calculated according to G. Roche et al. (code by E. Haug).

Beam dump

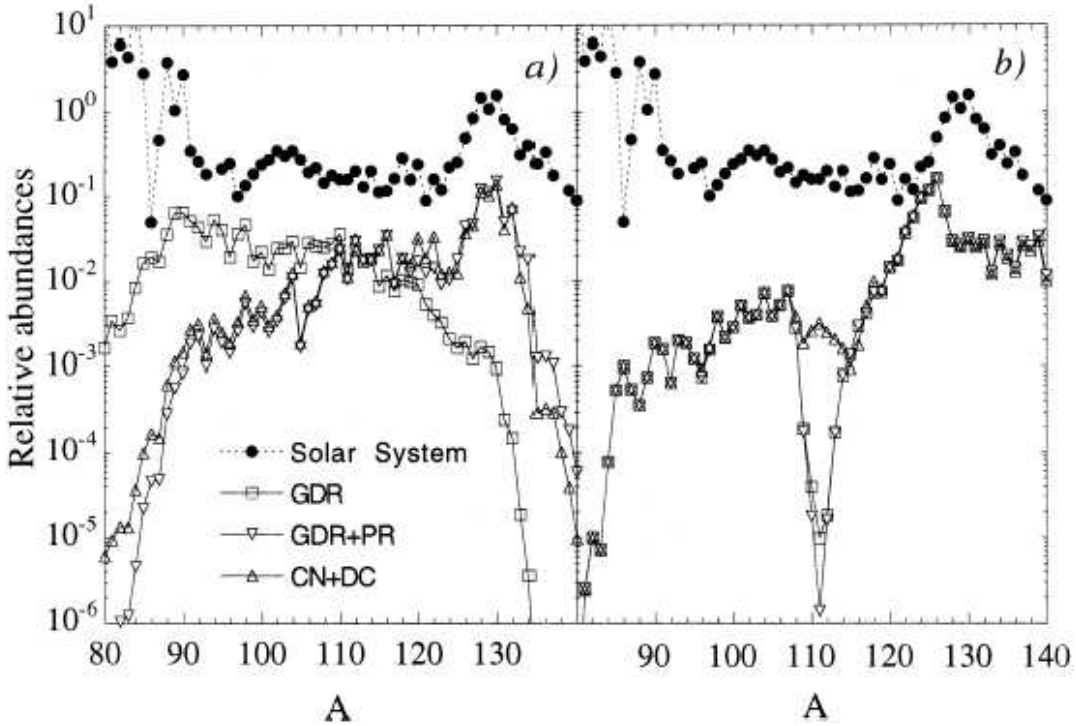


GEANT3 simulation with 1000 trajectories of 12 MeV photons.

About 0.3 % of the photons are scattered back towards the detectors.

Dipole strength close to the particle-separation energy

- Understanding of astrophysical processes:
  - Influence on (γ,n) reaction rates for the production of particular neutron-deficient nuclei in the so-called p-process.
- Open problems:
  - Precise knowledge of the $E1$ strength on the low-energy tail of the Giant Dipole Resonance.
  - Properties of the $E1$ strength distributions for varying proton and neutron numbers.

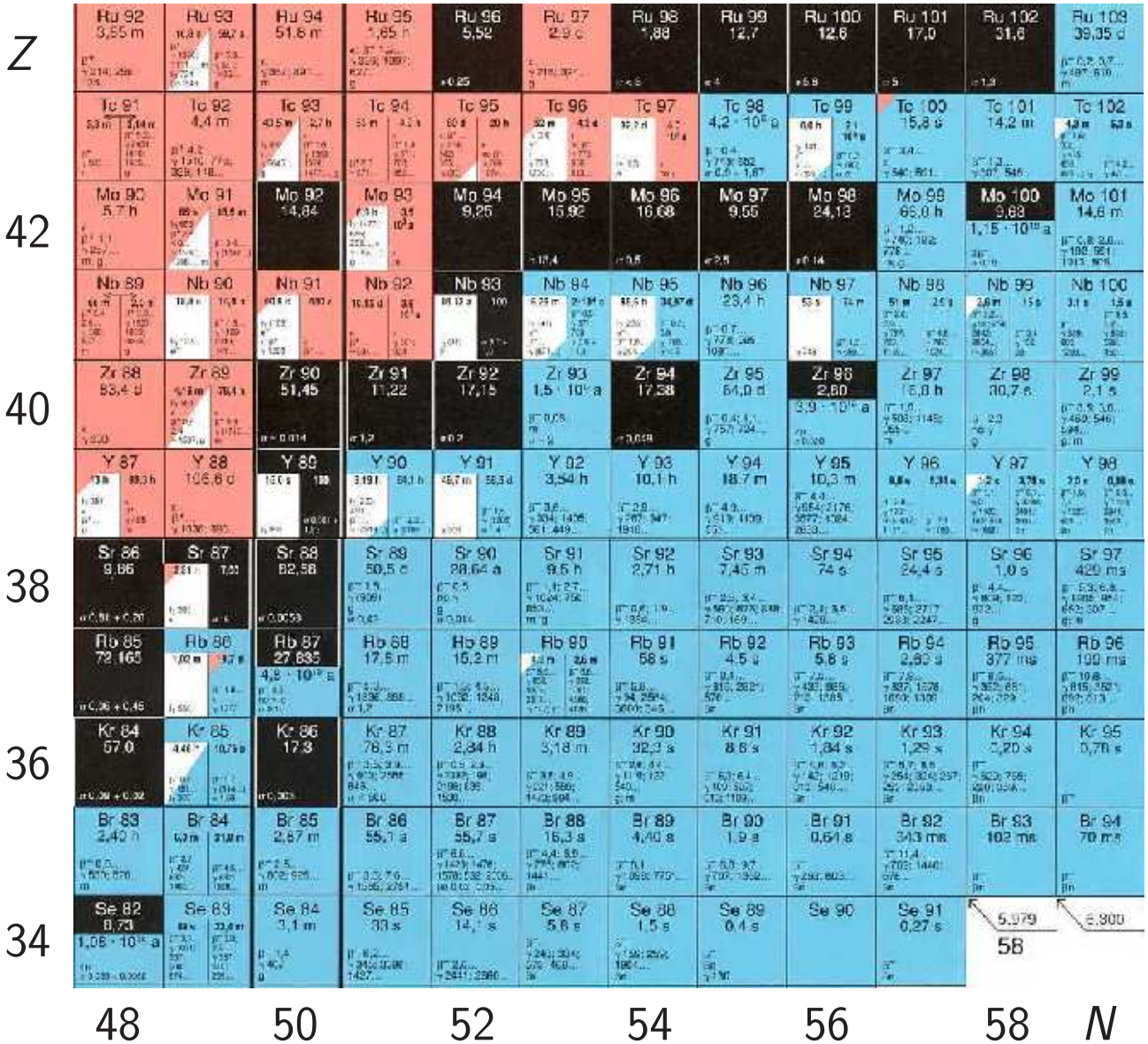


$T = 1.0 \times 10^9$ K $\quad$ $T = 1.5 \times 10^9$ K

$N_n = 10^{20}$ cm^2 $\quad$ $N_n = 10^{28}$ cm^2

S. Goriely, PLB 436 (1998) 10

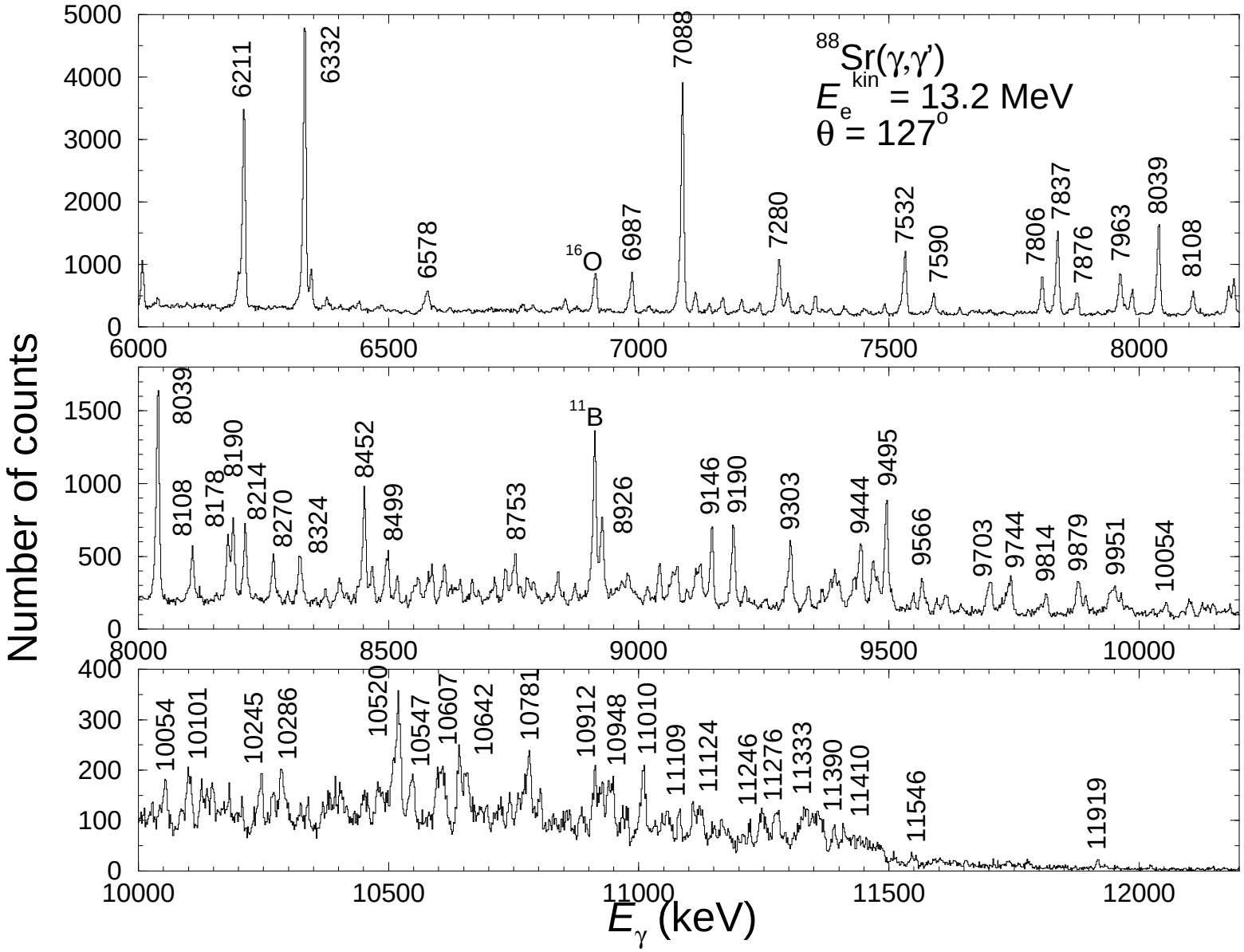
Nuclides under investigation in photon-scattering experiments



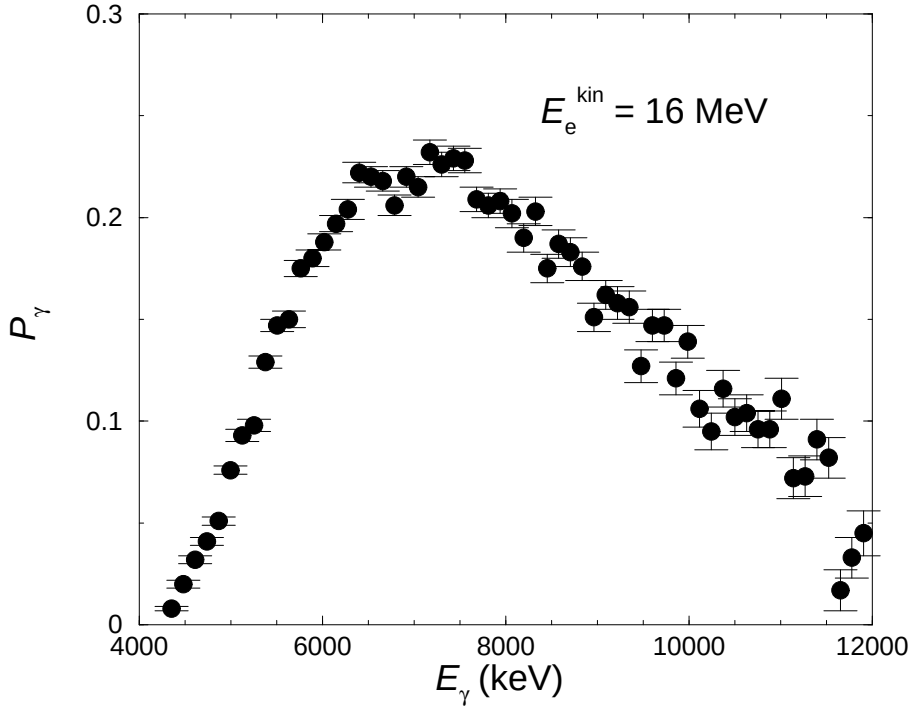
nuclide	S_n MeV	E_e^{kin} (MeV) ELBE
^{92}Mo	12.7	6.0[a], 13.2[b,c]
^{94}Mo	9.7	13.2
^{96}Mo	9.2	13.2
^{98}Mo	8.6	(3.3, 3.8)[a,d], 8.5, 13.2[b,c]
^{100}Mo	8.3	(3.2, 3.4, 3.8)[a] 7.8, 13.2[b,c]
^{90}Zr	12.0	7.0, 9.0, 12.8
^{89}Y	11.5	7.0[e], 9.5, 13.2
^{88}Sr	11.1	6.8[f], 9.0, 13.2, 16.0
^{87}Rb	9.9	4.0[g], 13.2

[a] G. Rusev et al., PRC 73 (2006) 044308
[b] G. Rusev et al., EPJA 27 (2006) s01, 171
[c] R. Schwengner et al., NPA 788 (2007) 331c
[d] G. Rusev et al., PRL 95 (2005) 062501
[e] J. Reif et al., NPA 620 (1997) 1
[f] L. Käubler et al., PRC 70 (2004) 064307
[g] L. Käubler et al., PRC 65 (2002) 054315

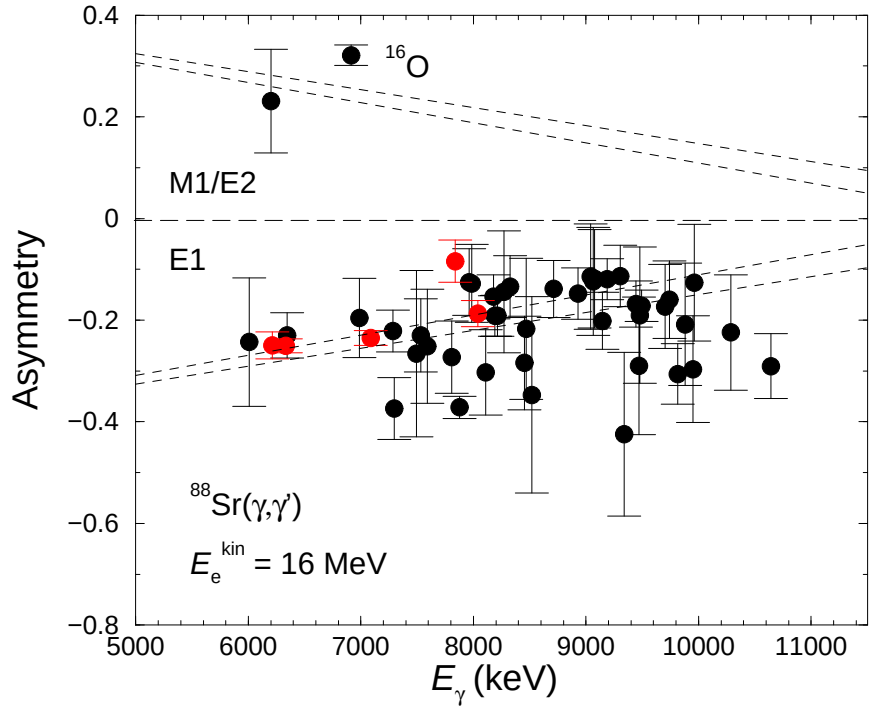
Photon scattering from ^{88}Sr



Measurement with polarised photons

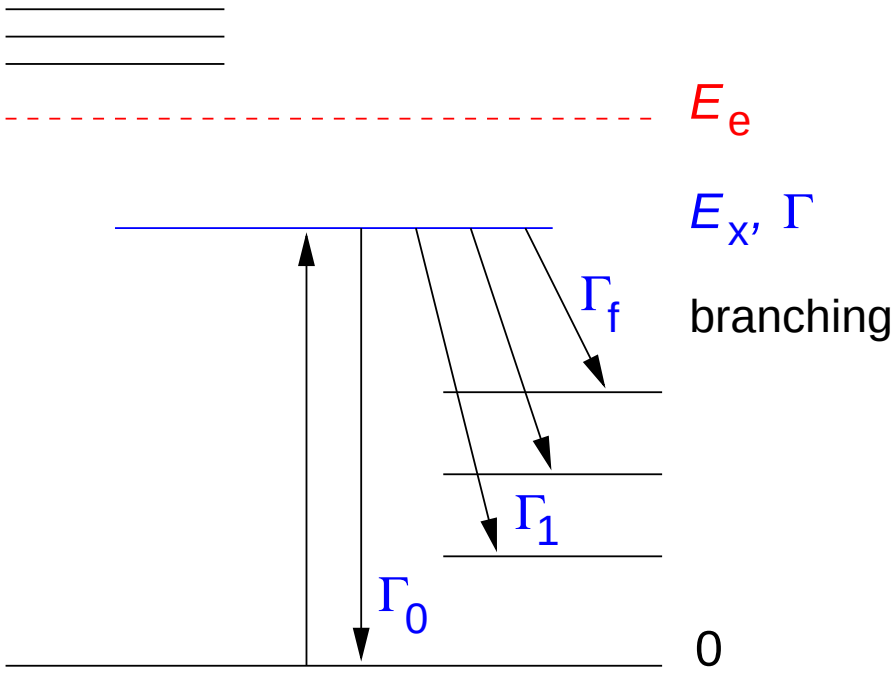


Degree of polarisation as deduced from spectra of protons emitted in the disintegration of deuterons $d(\vec{\gamma}, p)n$.



Asymmetries $(N_{\gamma\parallel}-N_{\gamma\perp})/(N_{\gamma\parallel}+N_{\gamma\perp})$ *of intensities of* γ *rays in* ^{88}*Sr.*

Problem of feeding and branching



Measured intensity of a γ transition:

$$I_\gamma(E_\gamma, \Theta) = I_s(E_x)\, \Phi_\gamma(E_x)\, \epsilon(E_\gamma)\, N_{at}\, W(\Theta)\, \Delta\Omega$$

Scattering cross section integral:

$$I_s = \int \sigma_{\gamma\gamma}\, dE = \frac{2J_x + 1}{2J_0 + 1} \left(\frac{\pi\hbar c}{E_x}\right)^2 \frac{\Gamma_0}{\Gamma}\, \Gamma_0$$

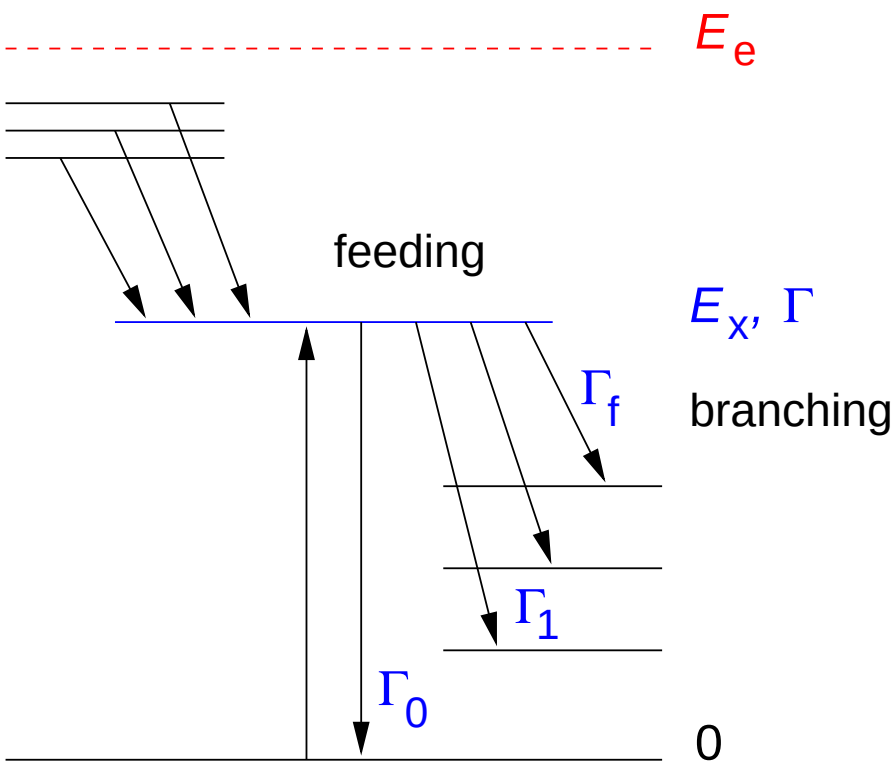
Absorption cross section:

$$\sigma_\gamma = \sigma_{\gamma\gamma} \left(\frac{\Gamma_0}{\Gamma}\right)^{-1}$$

E1 strength:

$$B(E1) \sim \Gamma_0 / E_\gamma^3$$

Problem of feeding and branching



Measured intensity of a γ transition:

$$I_\gamma(E_\gamma, \Theta) > I_s(E_x)\, \Phi_\gamma(E_x)\, \epsilon(E_\gamma)\, N_{at}\, W(\Theta)\, \Delta\Omega$$

Scattering cross section integral:

$$I_s = \int \sigma_{\gamma\gamma}\, dE = \frac{2J_x + 1}{2J_0 + 1} \left(\frac{\pi\hbar c}{E_x}\right)^2 \frac{\Gamma_0}{\Gamma}\, \Gamma_0$$

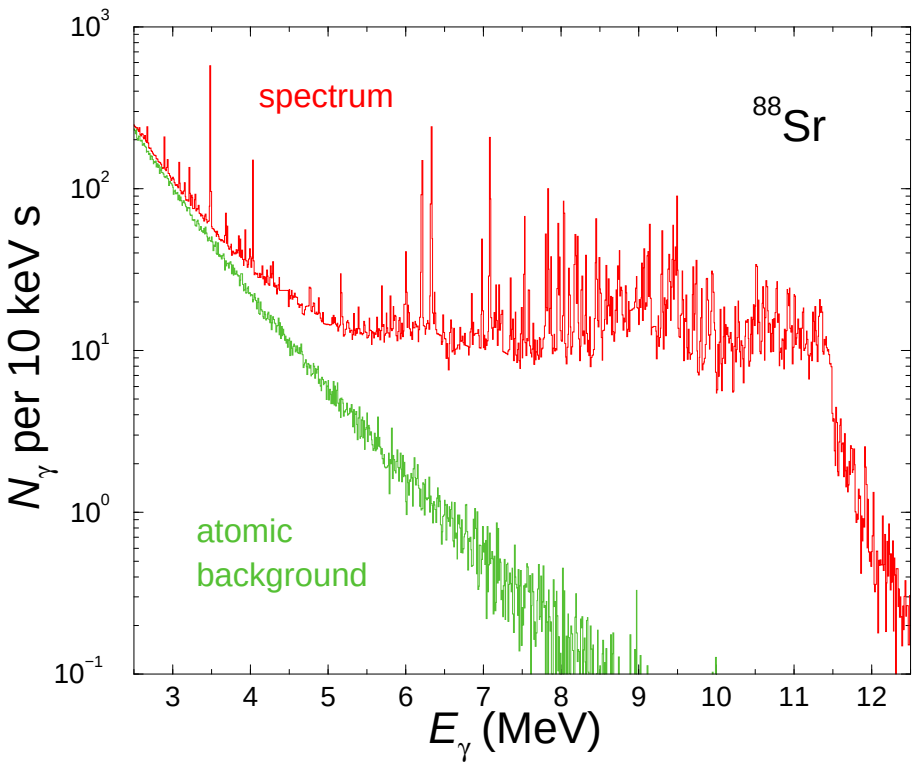
Absorption cross section:

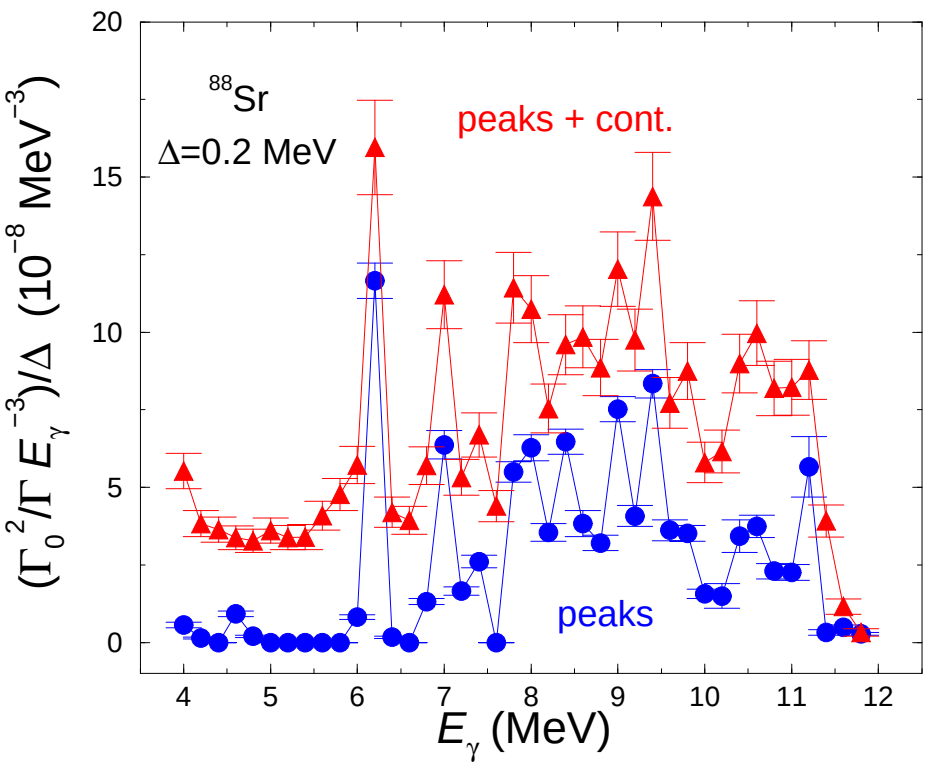
$$\sigma_\gamma = \sigma_{\gamma\gamma} \left(\frac{\Gamma_0}{\Gamma}\right)^{-1}$$

E1 strength:

$$B(E1) \sim \Gamma_0 / E_\gamma^3$$

Unresolved strength in the continuum

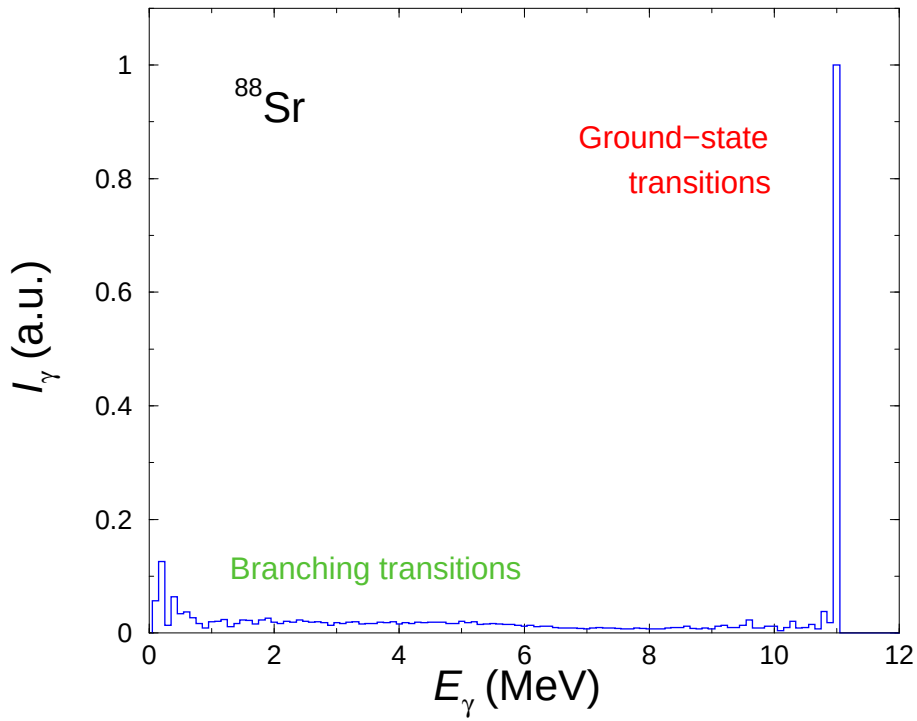




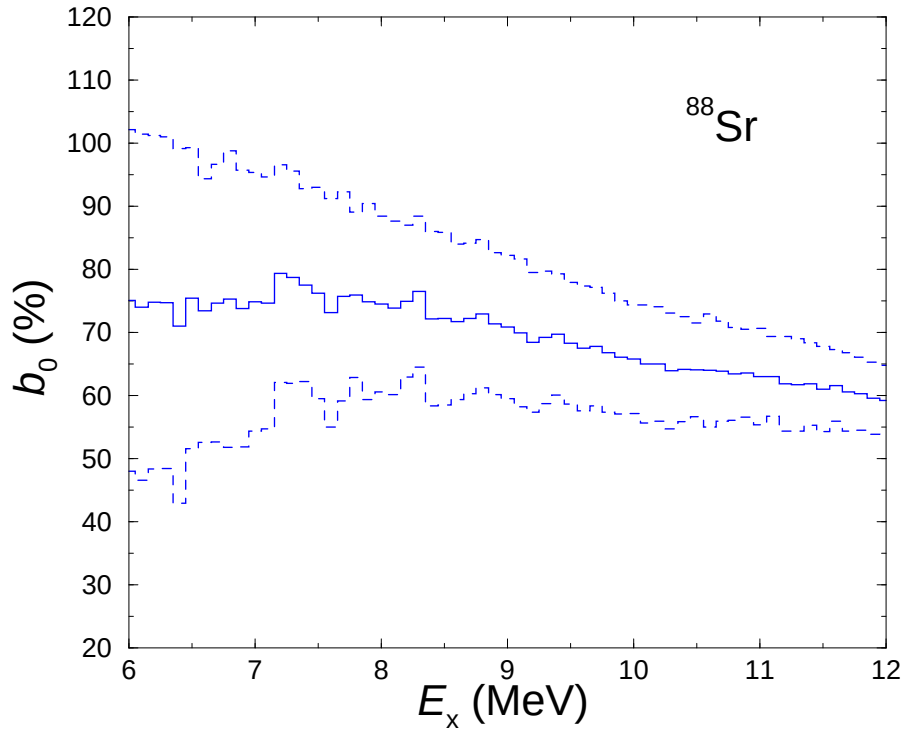
Experimental spectrum of ^{88}Sr (corrected for room background, detector response, efficiency, measuring time) and simulated spectrum of atomic background.

Dipole strengths in ^{88}Sr, not corrected for branching and averaged over energy bins of 0.2 MeV, as derived from the difference of the experimental spectrum and the atomic background (triangles) and from the isolated peaks only (circles).

Correction of feeding and branching by using statistical methods

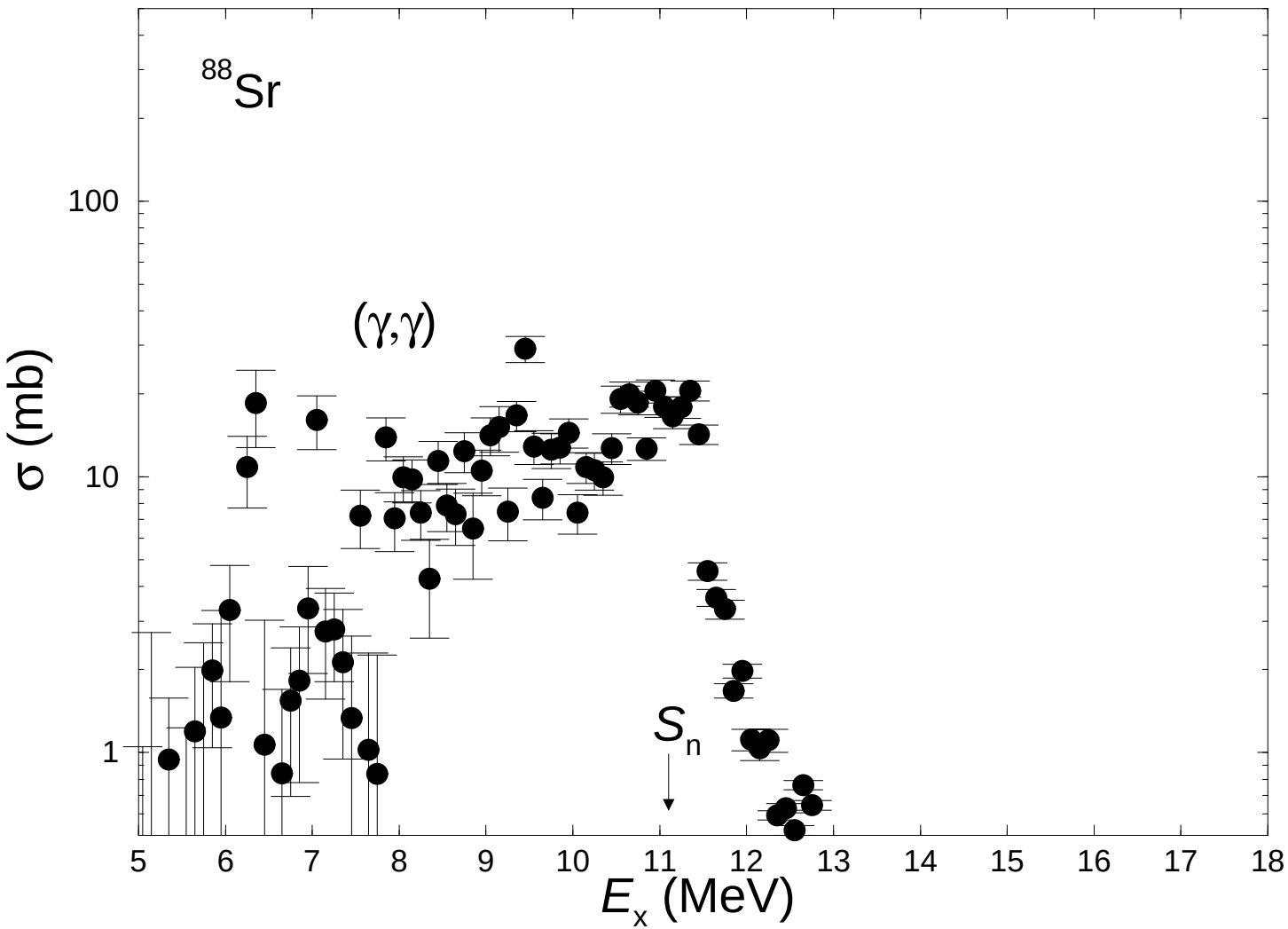


Simulated intensity distribution of transitions depopulating levels in a 100 keV bin around 11 MeV.



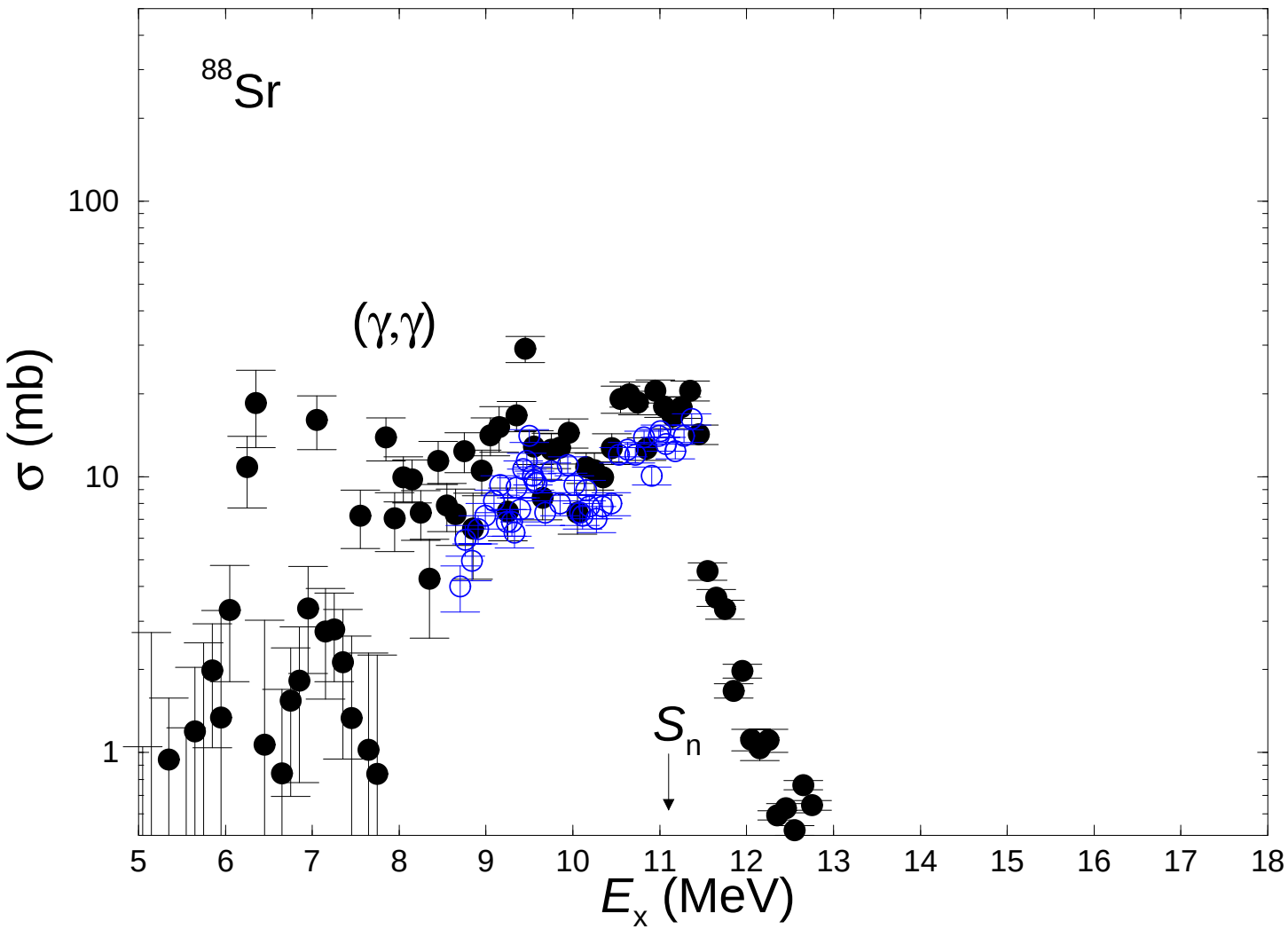
Distribution of branching ratios $b_0 = \Gamma_0/\Gamma$ versus the excitation energy as obtained from the simulations of γ-ray cascades for ^{88}Sr. Solid line: mean values of b_0. Dashed lines: maximum uncertainties of b_0 resulting from the various nuclear realizations.

Absorption cross section in ^{88}Sr



Present (γ, γ) data

Absorption cross section in ^{88}Sr

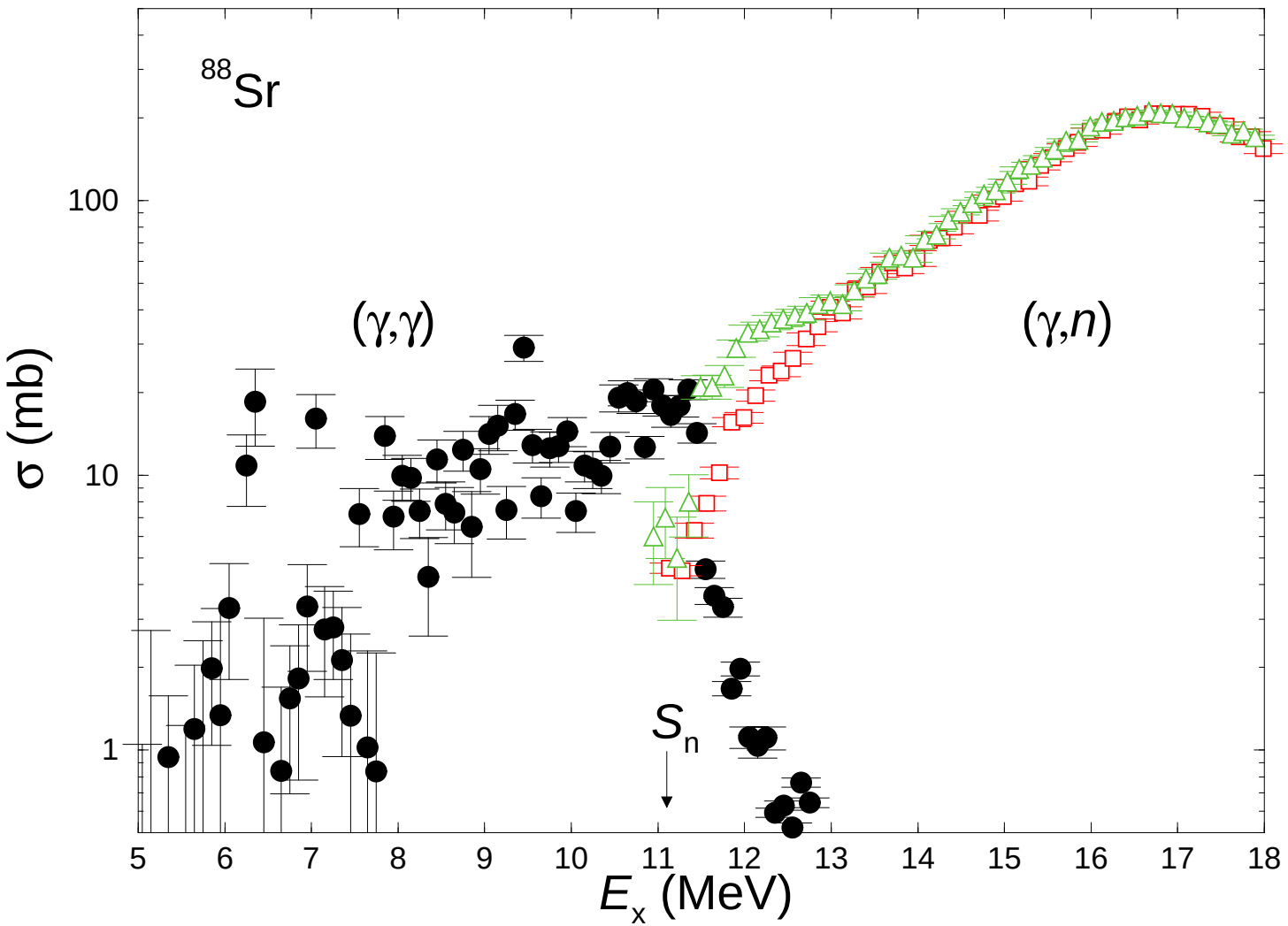


Present (γ, γ) data

Monoenergetic photons

PRC 8 (1973) 1421

Absorption cross section in ^{88}Sr

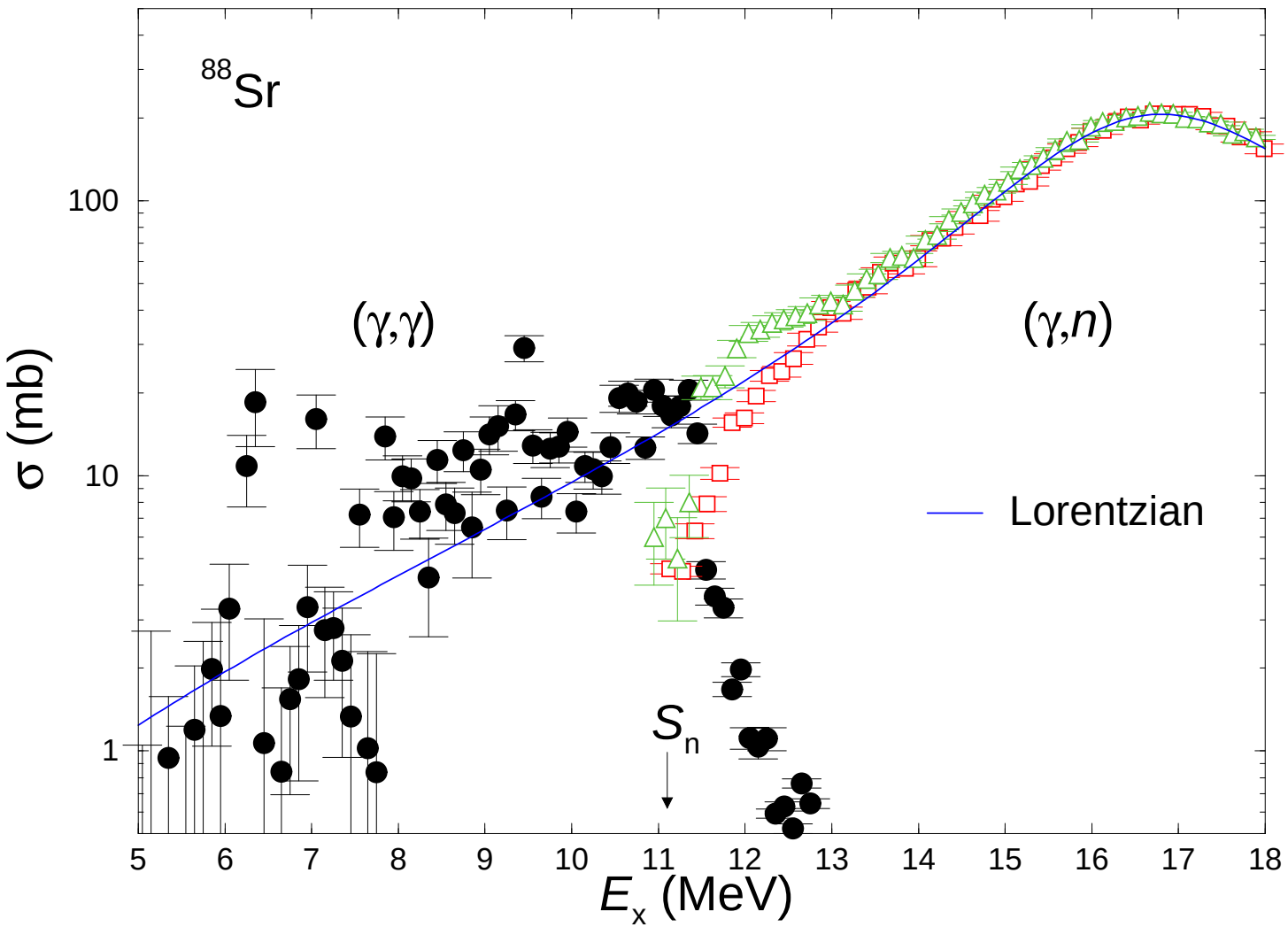


Present (γ, γ) data

(γ, n) data
NPA 175 (1971) 609

(γ, n) data
VTYF 8 (1982) 121

Absorption cross section in ^{88}Sr



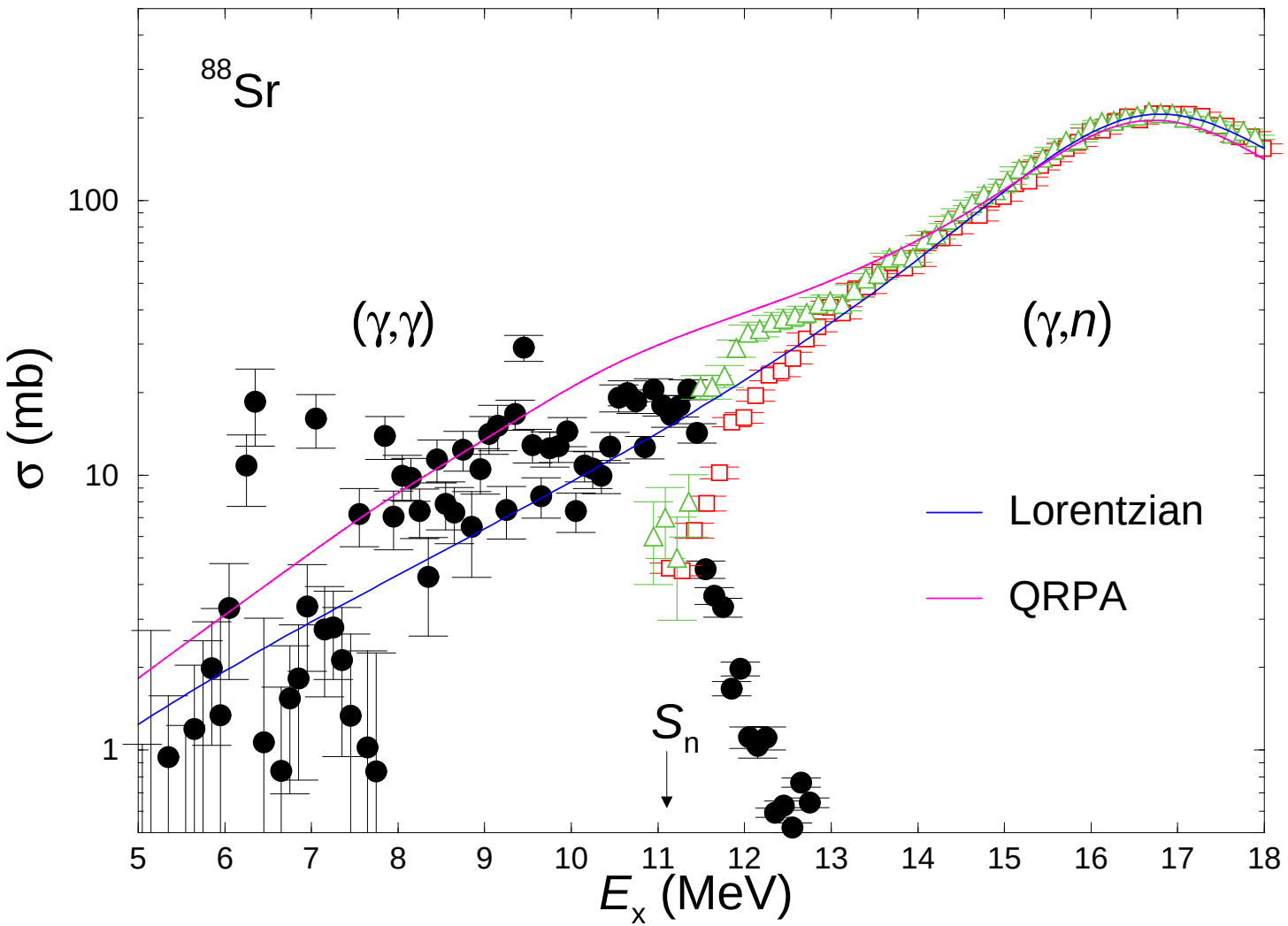
Present (γ, γ) data

(γ, n) data
NPA 175 (1971) 609

(γ, n) data
VTYF 8 (1982) 121

Lorentz curve:
$E_0 = 16.8$ MeV
$\Gamma = 4.0$ MeV
$\frac{\pi}{2}\sigma_0\Gamma = 60\ \frac{NZ}{A}$ MeV mb

Absorption cross section in ^{88}Sr



Present (γ, γ) data

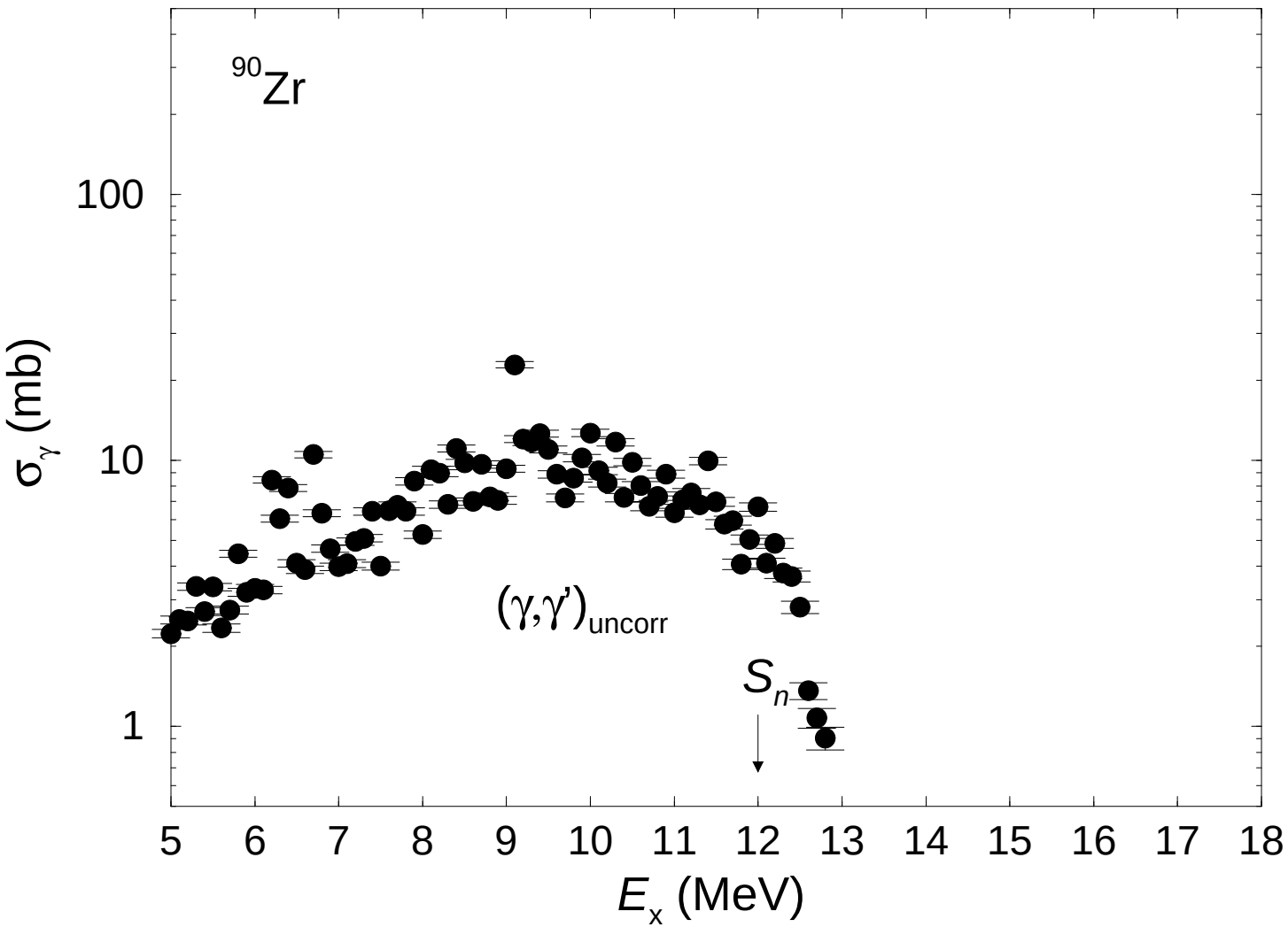
(γ, n) data
NPA 175 (1971) 609

(γ, n) data
VTYF 8 (1982) 121

Lorentz curve:
$E_0 = 16.8$ MeV
$\Gamma = 4.0$ MeV
$\frac{\pi}{2}\sigma_0\Gamma = 60\ \frac{NZ}{A}$ MeV mb

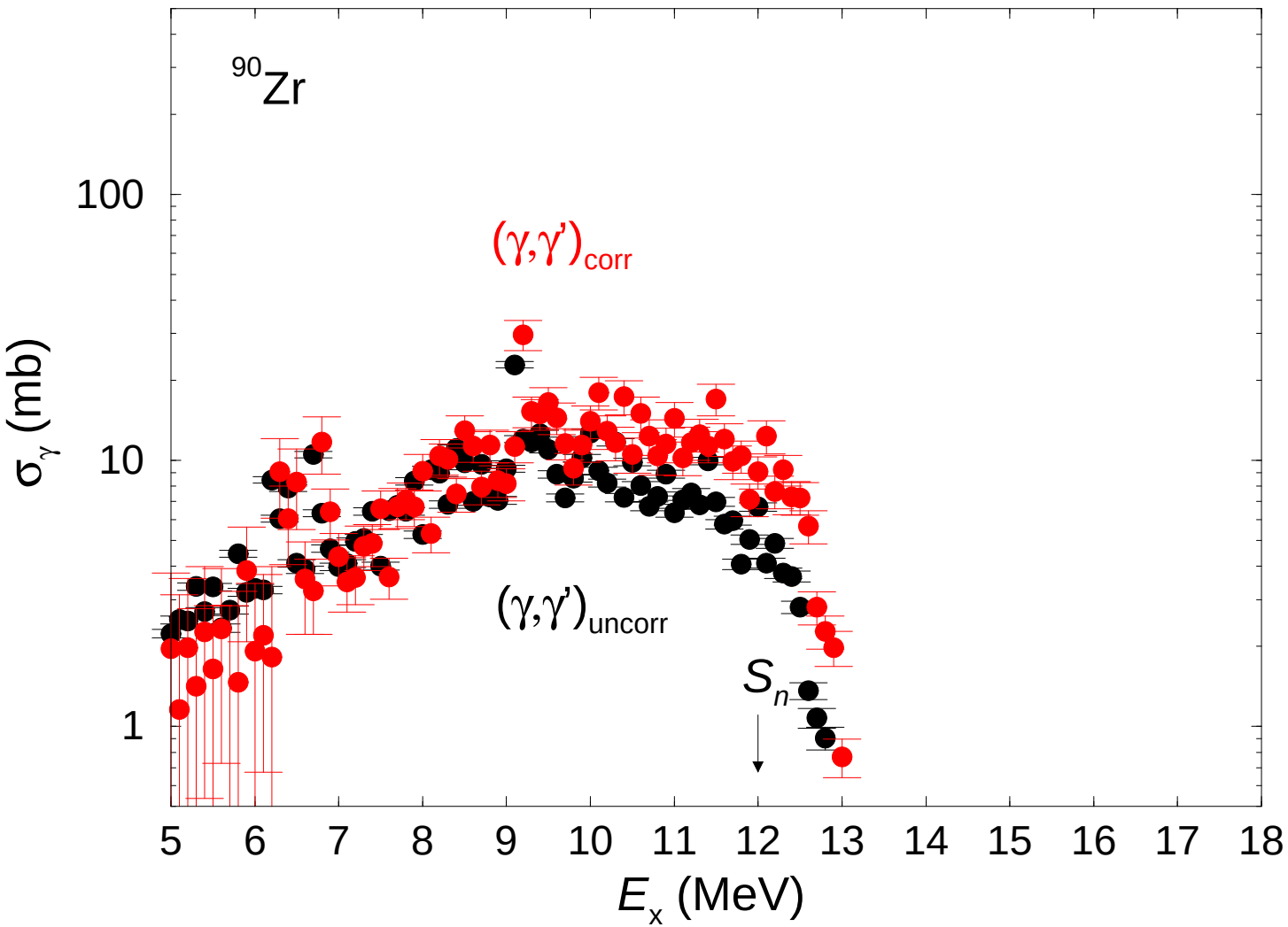
QRPA on Nilsson basis
$\Gamma = 3.5$ MeV

Absorption cross section in ^{90}Zr



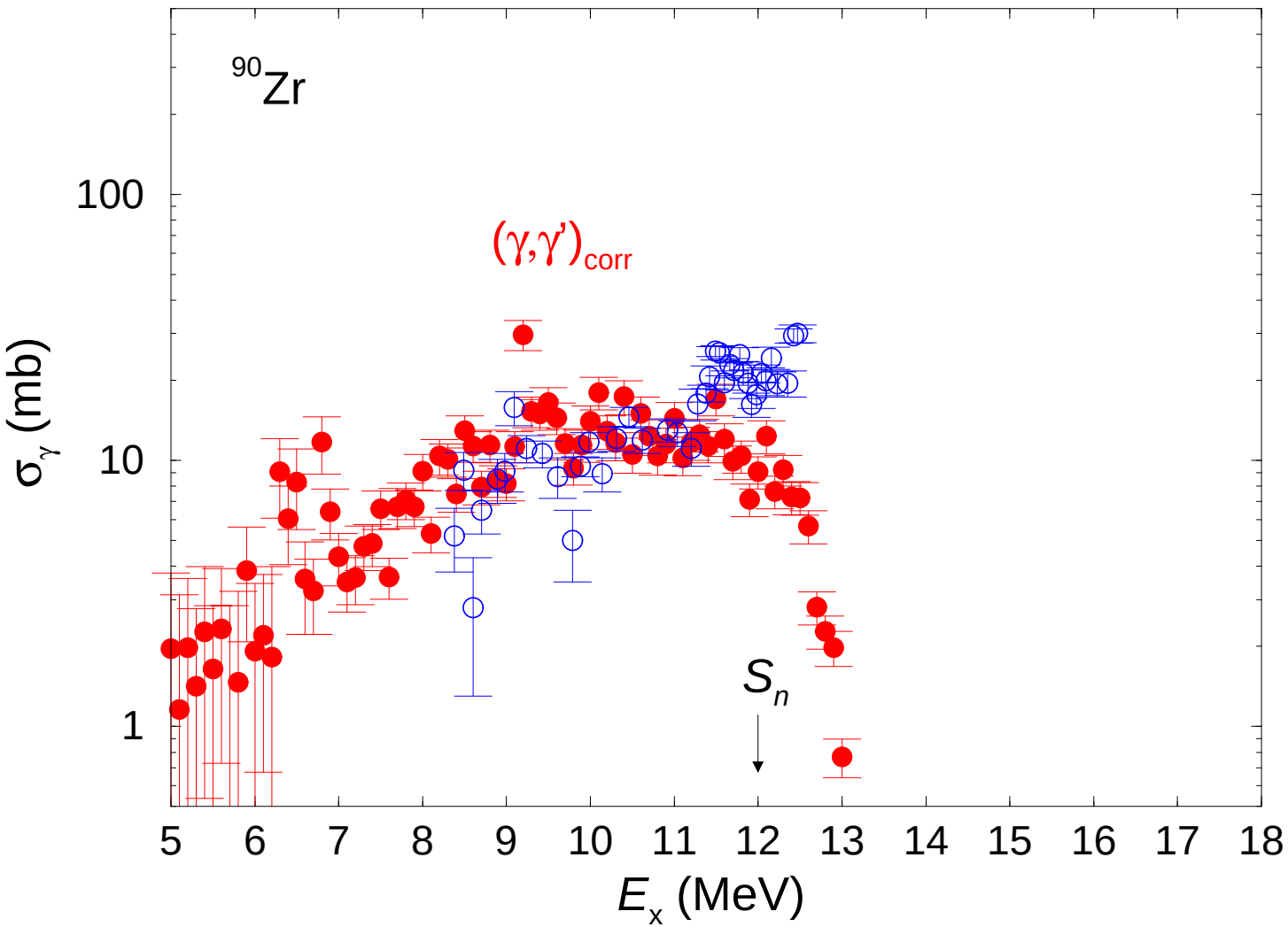
Present (γ, γ) data

Absorption cross section in ^{90}Zr



Present (γ, γ) data

Absorption cross section in ^{90}Zr

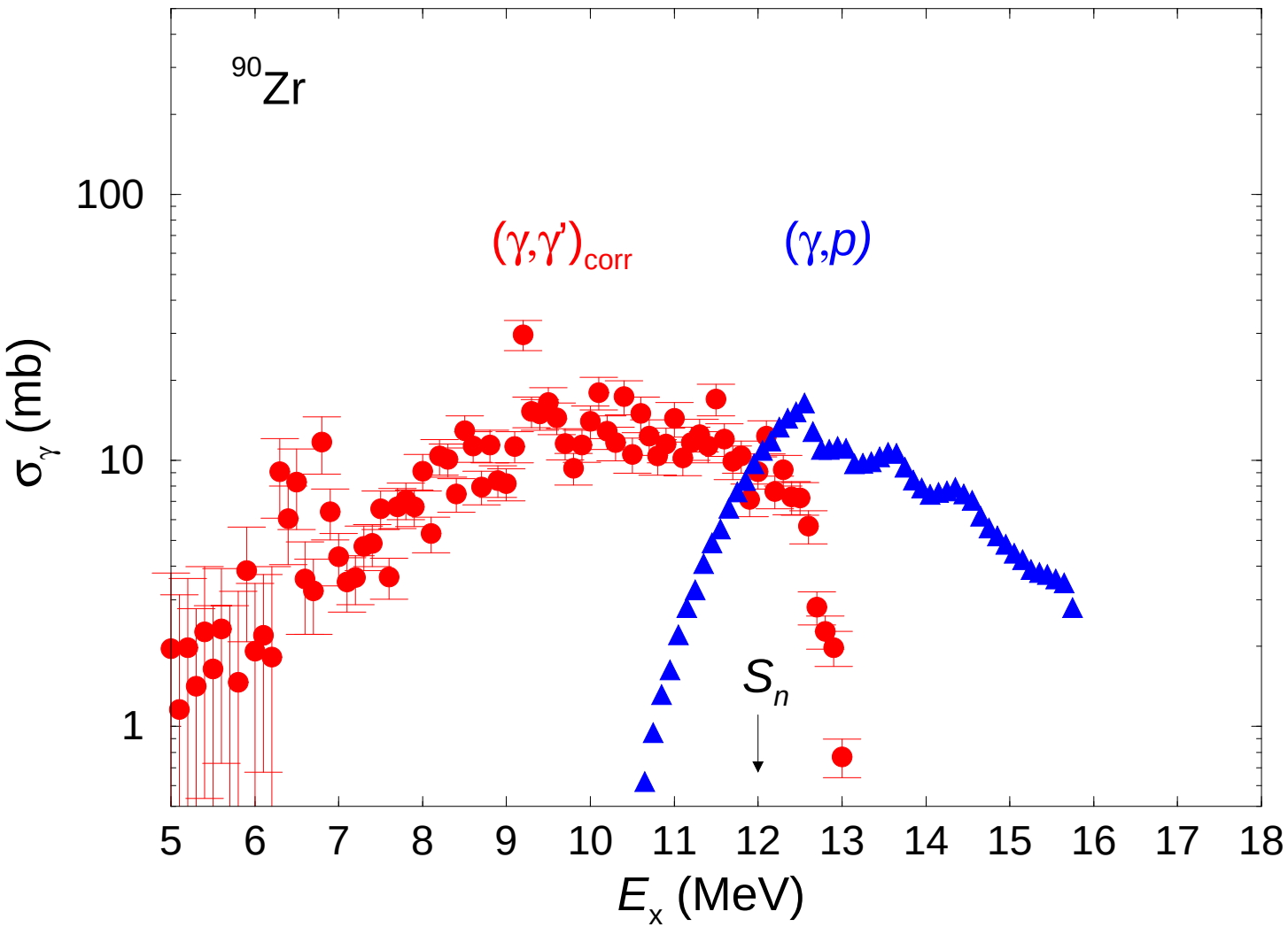


Present (γ, γ) data

Monoenergetic photons

PRC 2 (1970) 689

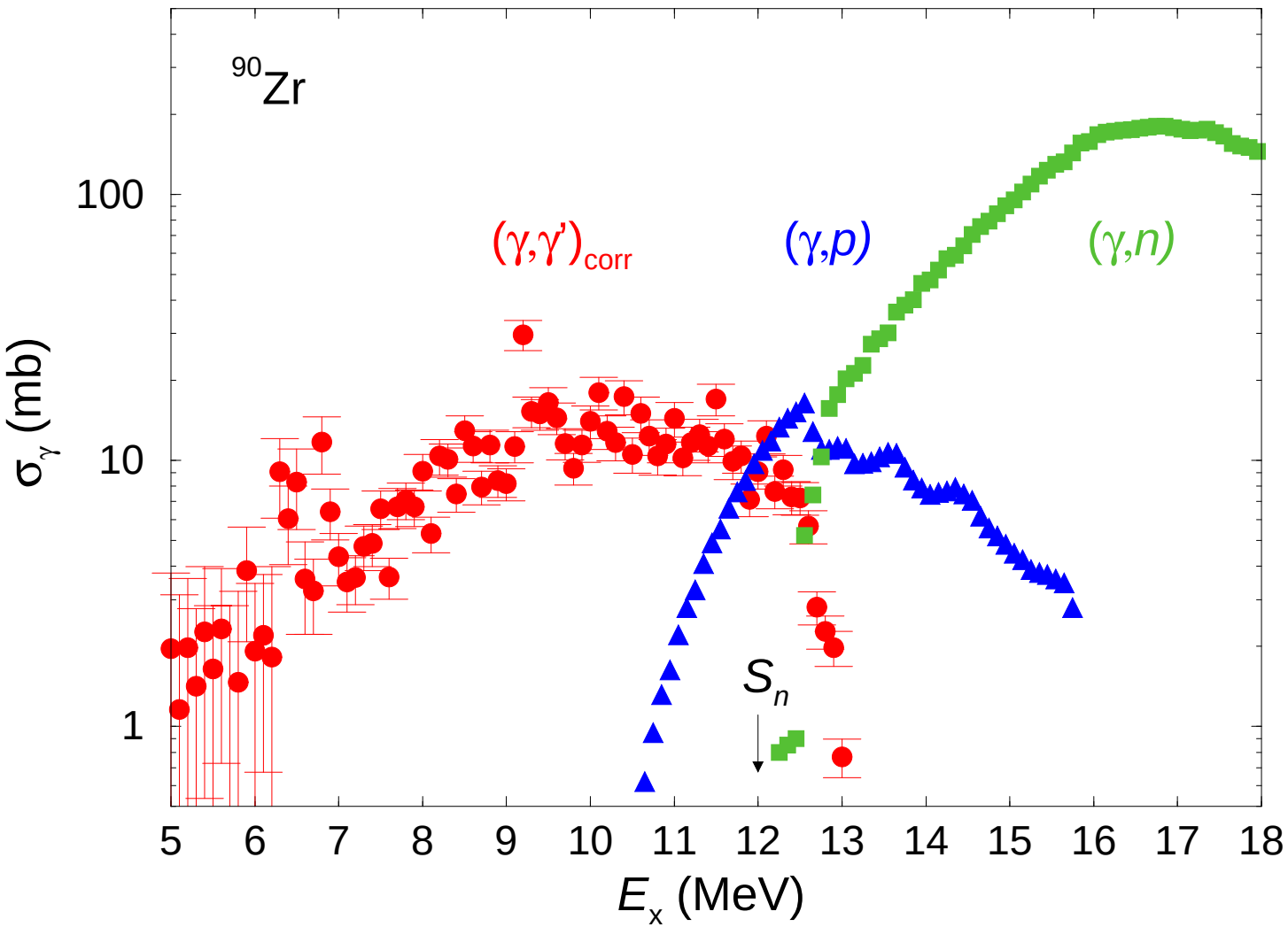
Absorption cross section in ^{90}Zr



Present (γ, γ) data

(γ, p) calculated
ADNDT 88 (2004) 1

Absorption cross section in ^{90}Zr

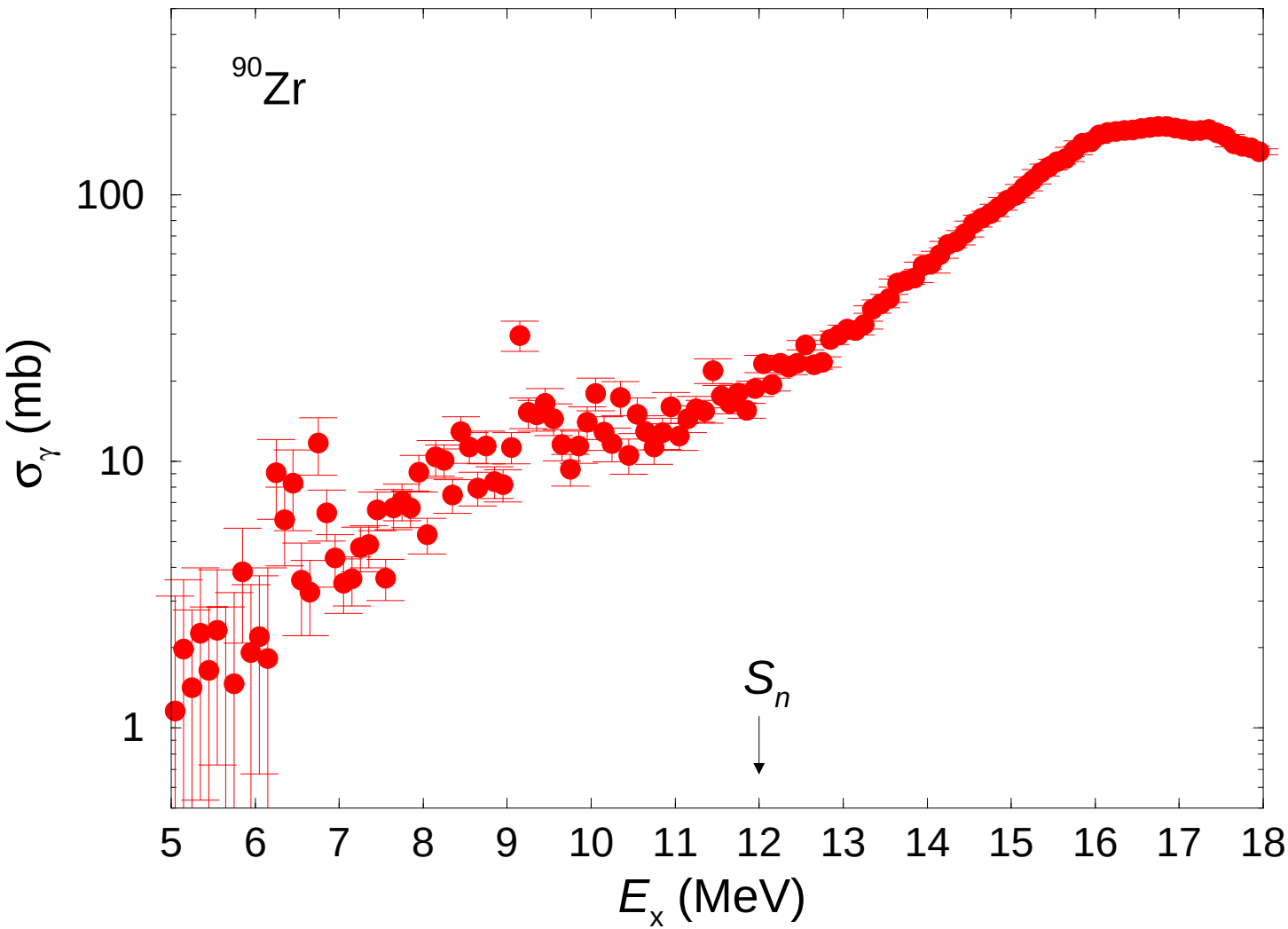


Present (γ, γ) data

(γ, p) calculated
ADNDT 88 (2004) 1

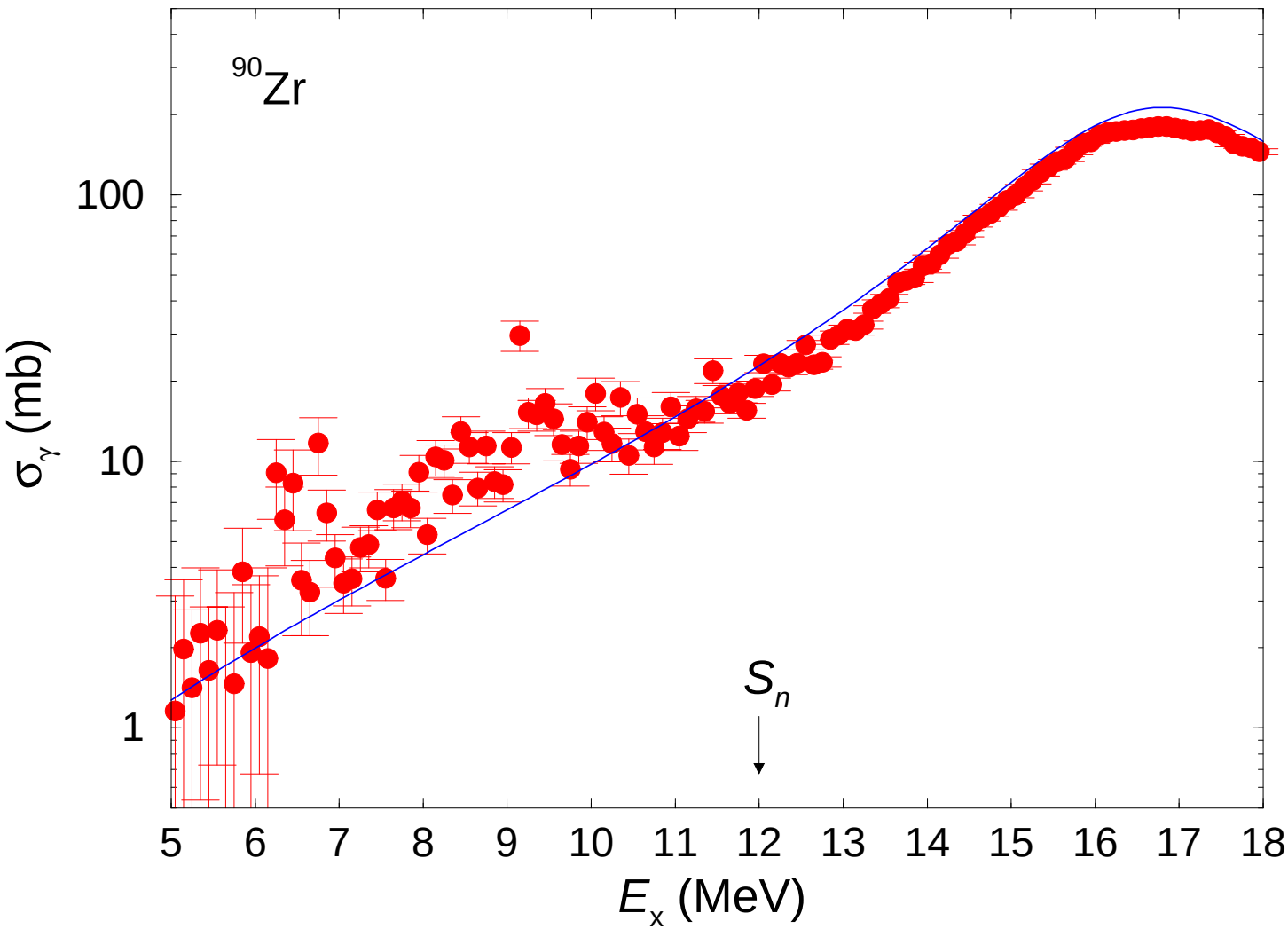
(γ, n) data
PR 162 (1967) 1098

Total absorption cross section in ^{90}Zr



Present (γ, γ) data
$+ (\gamma, p)$ calculated
$+ (\gamma, n)$ data

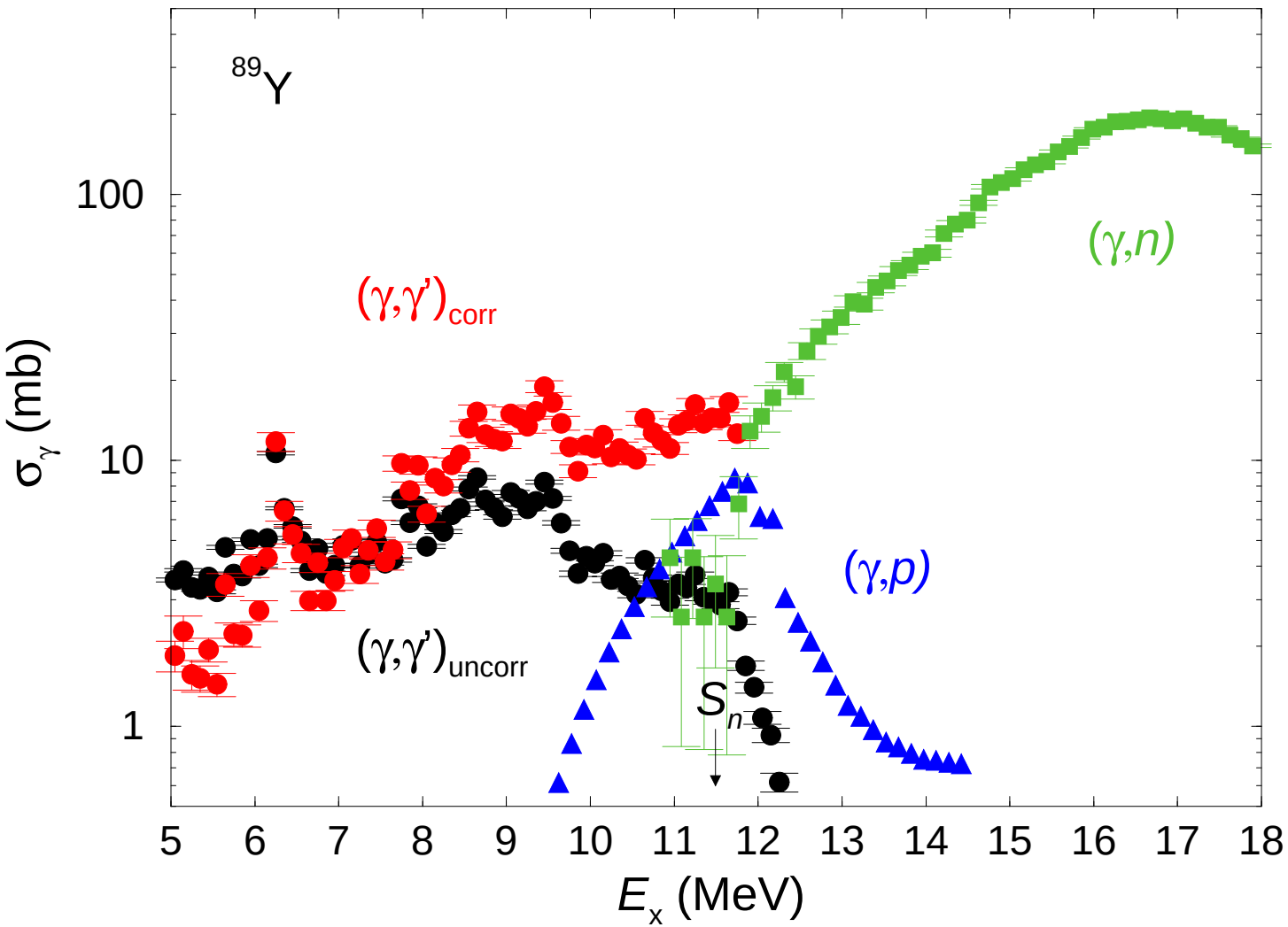
Total absorption cross section in ^{90}Zr



Present (γ, γ) data
$+ (\gamma, p)$ calculated
$+ (\gamma, n)$ data

Lorentz curve:
$E_0 = 16.8$ MeV
$\Gamma = 4.0$ MeV
$\frac{\pi}{2}\sigma_0\Gamma = 60\ \frac{NZ}{A}$ MeV mb

Absorption cross section in ^{89}Y

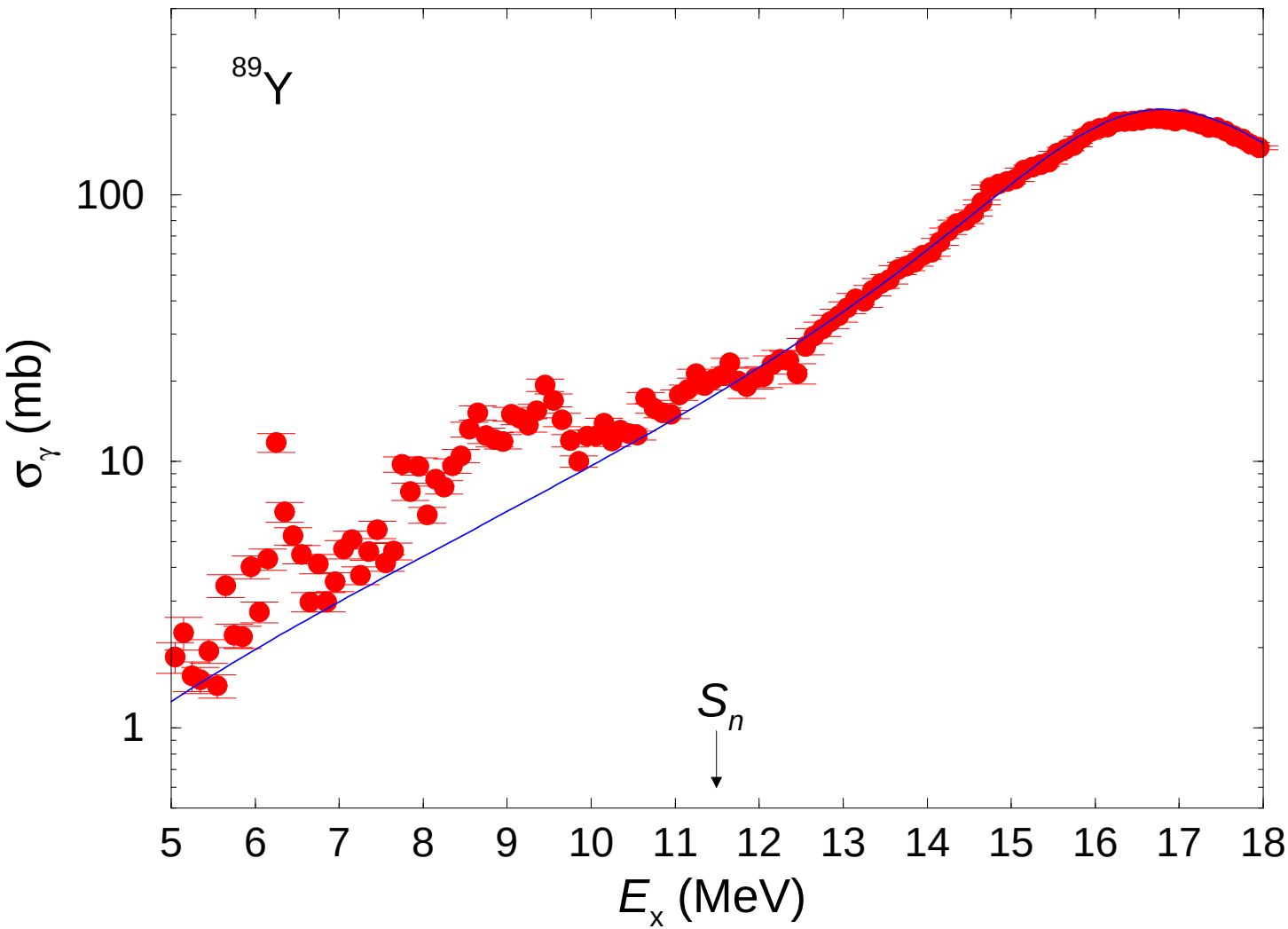


Present (γ, γ) data

(γ, p) calculated
ADNDT 88 (2004) 1

(γ, n) data
NPA 175 (1971) 609

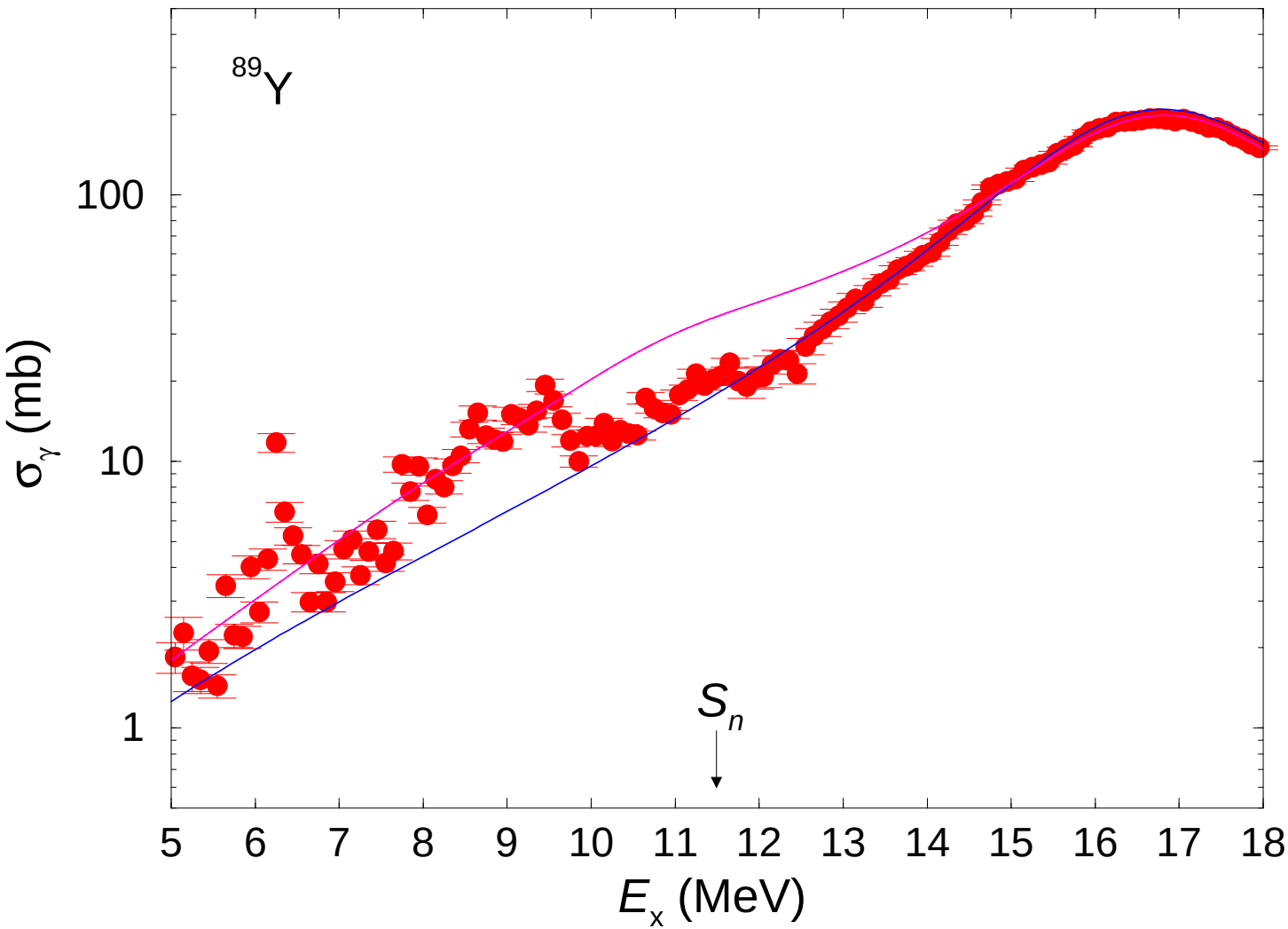
Total absorption cross section in ^{89}Y



Present (γ, γ) data
$+ (\gamma, p)$ calculated
$+ (\gamma, n)$ data

Lorentz curve:
$E_0 = 16.8$ MeV
$\Gamma = 4.0$ MeV
$\frac{\pi}{2}\sigma_0\Gamma = 60\ \frac{NZ}{A}$ MeV mb

Total absorption cross section in ^{89}Y



Present (γ, γ) data
$+ (\gamma, p)$ calculated
$+ (\gamma, n)$ data

Lorentz curve:
$E_0 = 16.8$ MeV
$\Gamma = 4.0$ MeV
$\frac{\pi}{2}\sigma_0\Gamma = 60\ \frac{NZ}{A}$ MeV mb

QRPA on Nilsson basis
$\Gamma = 3.5$ MeV

Summary

- Study of dipole-strength distributions of N=50 isotones up to the neutron-separation energies at the photon-scattering facility of ELBE.
- Measurement with polarised photons for ^{88}Sr: Multipolarity $E1$ deduced for 50 g.s. transitions above 6 MeV including 63% of the total $E1$ strength of all g.s. transitions.
- Comparison of measured spectrum with calculated atomic background: about 40% of the total dipole strength in resolved peaks and about 60% in continuum.
- Simulations of statistical γ cascades: Estimate of intensities of branching transitions.
- The reconstructed σ_γ connect smoothly with (γ,n) data.
- There is extra strength with respect to a Lorentz parametrisation of the GDR in the energy range from 6 to 11 MeV.
- QRPA calculations reproduce the extra strength.
- QPM calculations in progress to analyse the nature of the extra strength (Pygmy strength?).