E1 and M1 strength functions at low energy

Ronald Schwengner

Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf,
01328 Dresden, Germany

- *Experiments:*
  - Photon scattering using bremsstrahlung at γELBE and quasi-monoenergetic polarized γ rays at HIγS
  - Data analysis
- *E1 strength in the pygmy region*
- *M1 strength in the spin-flip region*
- *Low-energy M1 strength*

Electromagnetic strength functions

- Electromagnetic strength functions (photon strength functions) describe average electromagnetic transitions strengths - in particular in the quasi-continuum of nuclear states at high excitation energy:

$$f_{fiL}(E_\gamma) = \overline{\Gamma_{fiL}}\ \rho(E_i, J_i)\ /\ E_\gamma^{2L+1} \qquad E_\gamma = E_i - E_f \qquad J_i = 0,\ \ldots,\ J_{\max}$$

- Photoabsorption:

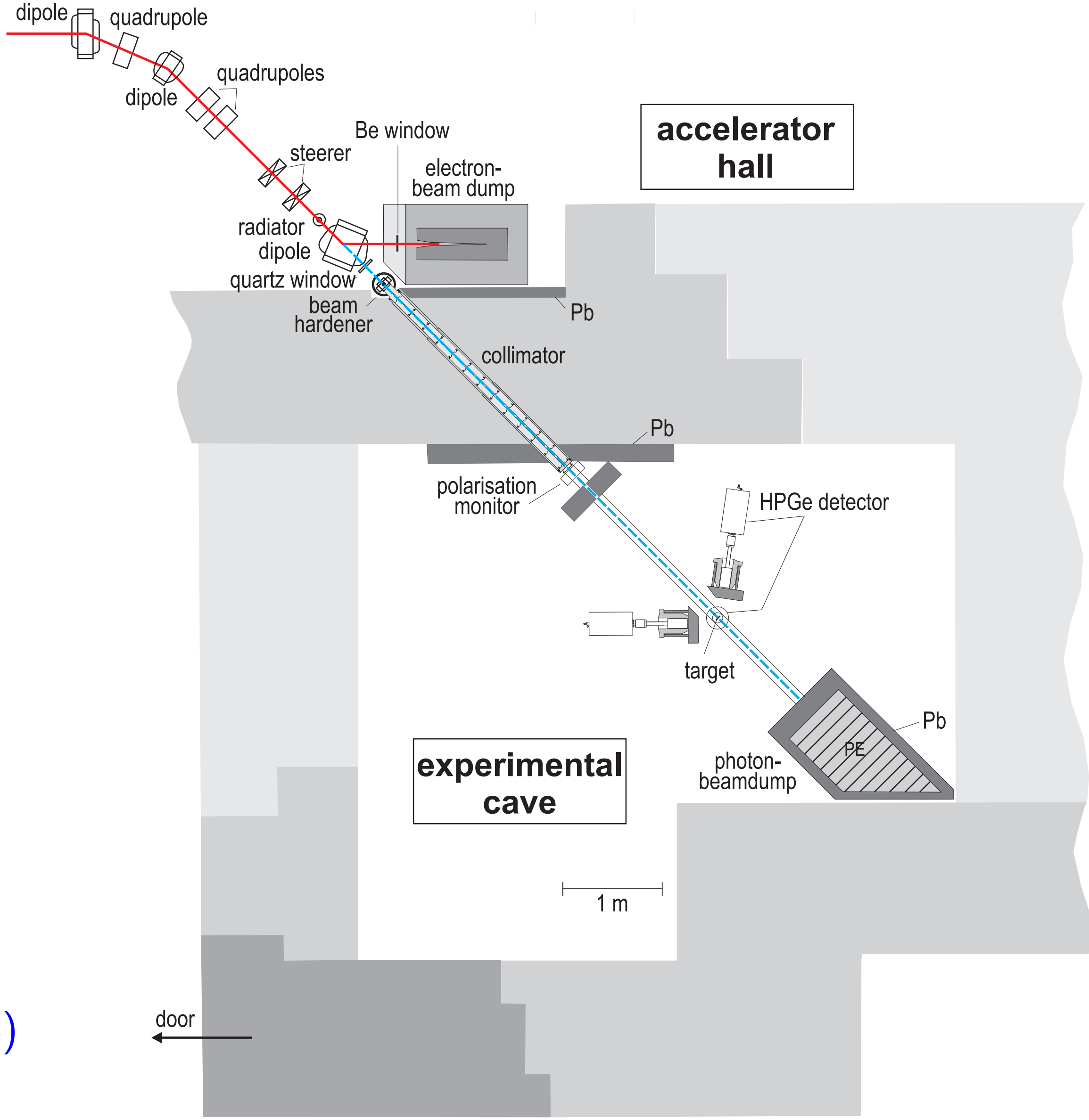
$$f_L = \sigma_\gamma\ /\ [(2J_i{+}1)/(2J_0{+}1)\ (\pi\hbar c)^2\ E_\gamma^{2L-1}] \qquad E_\gamma = E_i \qquad J_i = 1,\ (2)$$

- Brink-Axel hypothesis:
  The strength function does not depend on the excitation energy.
  The strength function for excitation is identical with the one for deexcitation.

The bremsstrahlung facility at the electron accelerator ELBE

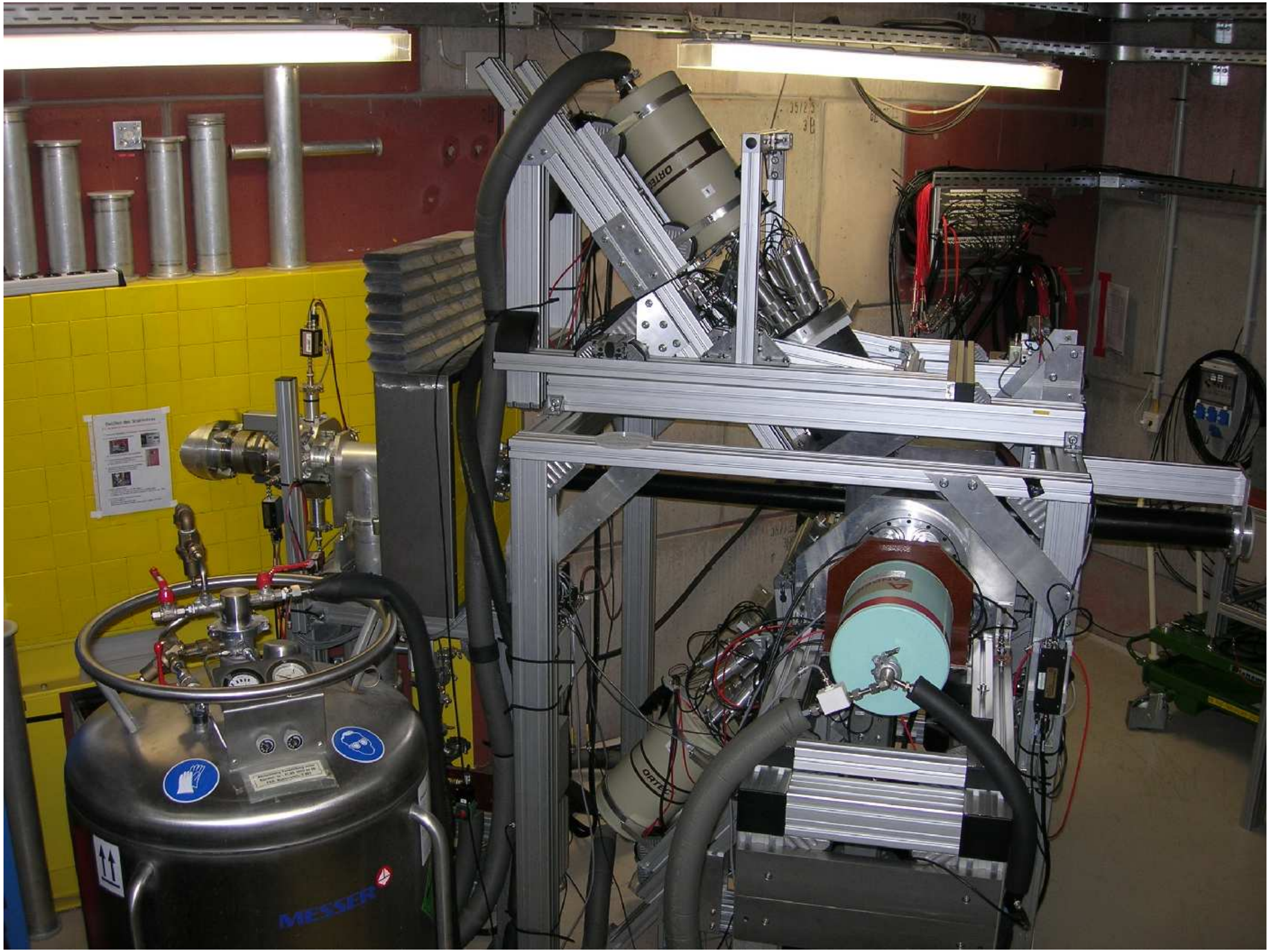
Accelerator parameters:

- Maximum electron energy: $\approx$ 18 MeV
- Maximum average current: $\approx$ 0.8 mA
- Micro-pulse rate: 13 MHz
- Micro-pulse length: $\approx$ 5 ps



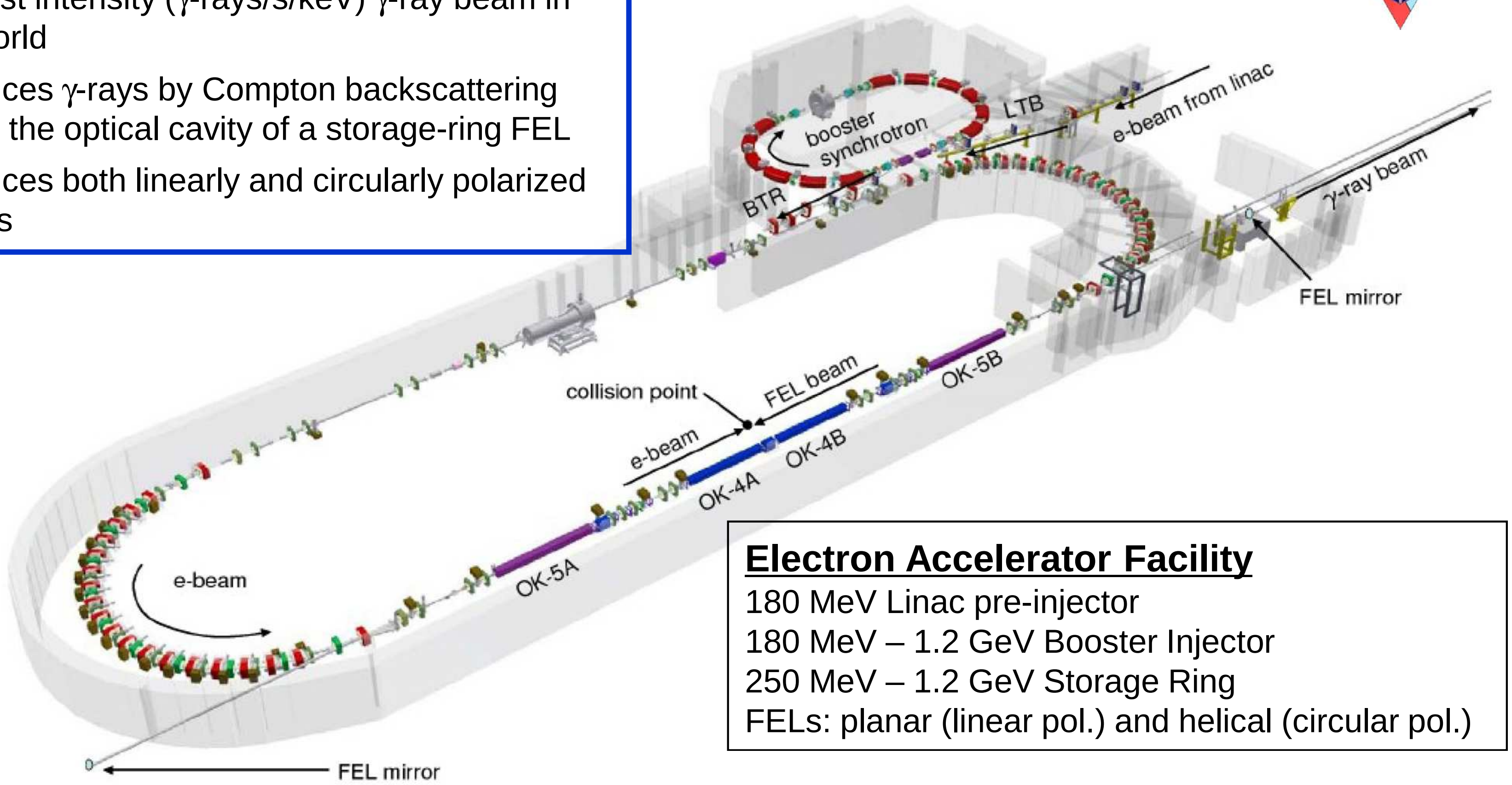
R.S. et al., NIM A 555, 211 (2005)

Detector setup at γELBE



High Intensity Gamma-ray Source (HIGS) at TUNL

- Highest intensity (γ-rays/s/keV) γ-ray beam in the world
- Produces γ-rays by Compton backscattering inside the optical cavity of a storage-ring FEL
- Produces both linearly and circularly polarized beams



Electron Accelerator Facility

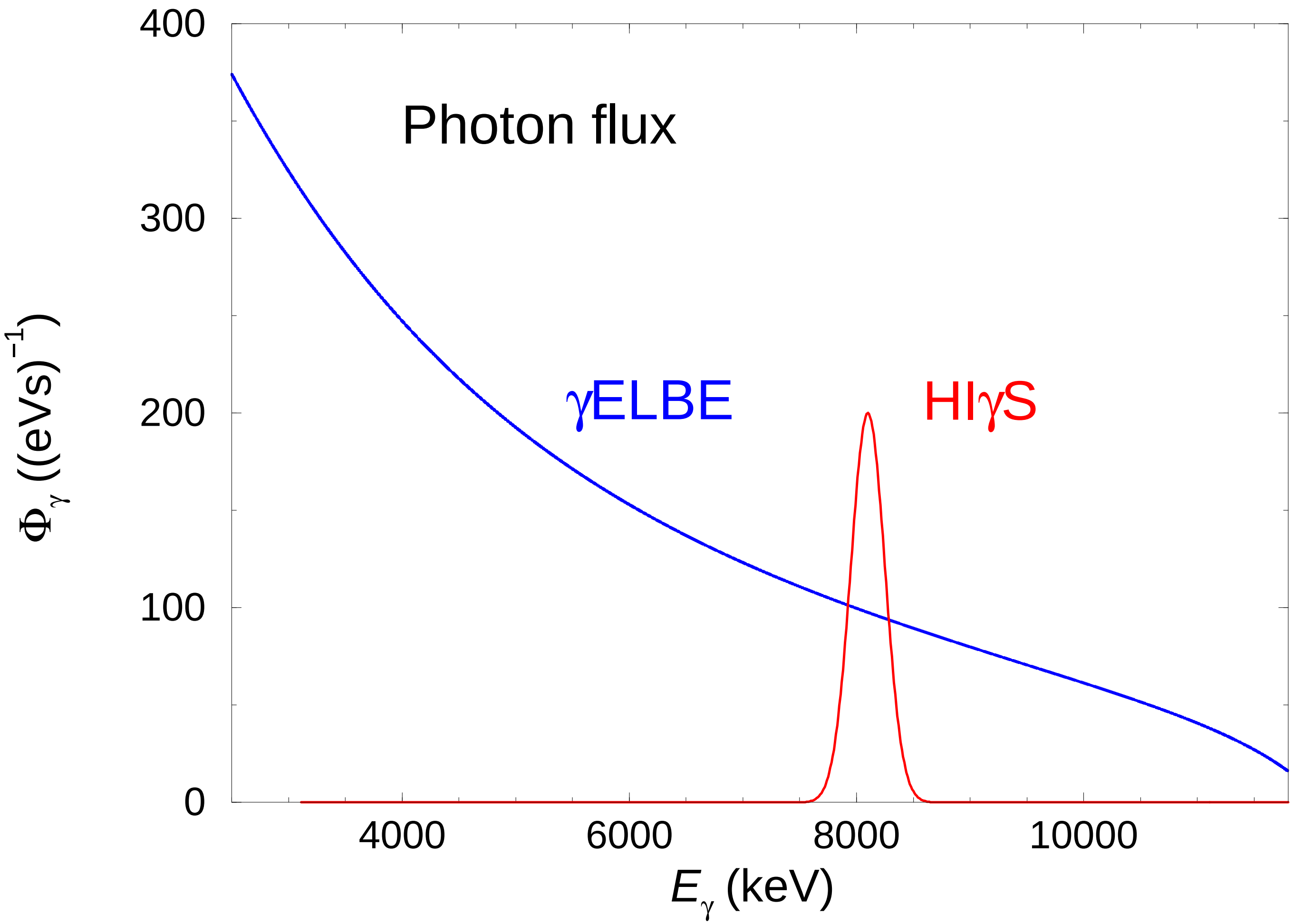
180 MeV Linac pre-injector
180 MeV – 1.2 GeV Booster Injector
250 MeV – 1.2 GeV Storage Ring
FELs: planar (linear pol.) and helical (circular pol.)

γ-ray beam parameters	Values
Energy	1 – 100 MeV
Linear & circular polarization	> 95%
Intensity with 5% $\Delta E_\gamma/E_\gamma$	> 10^7 γ/s

For more details see:
http://www.tunl.duke.edu/higs/

Courtesy of C. Howell (TUNL)

Flux spectra at γELBE and HIγS



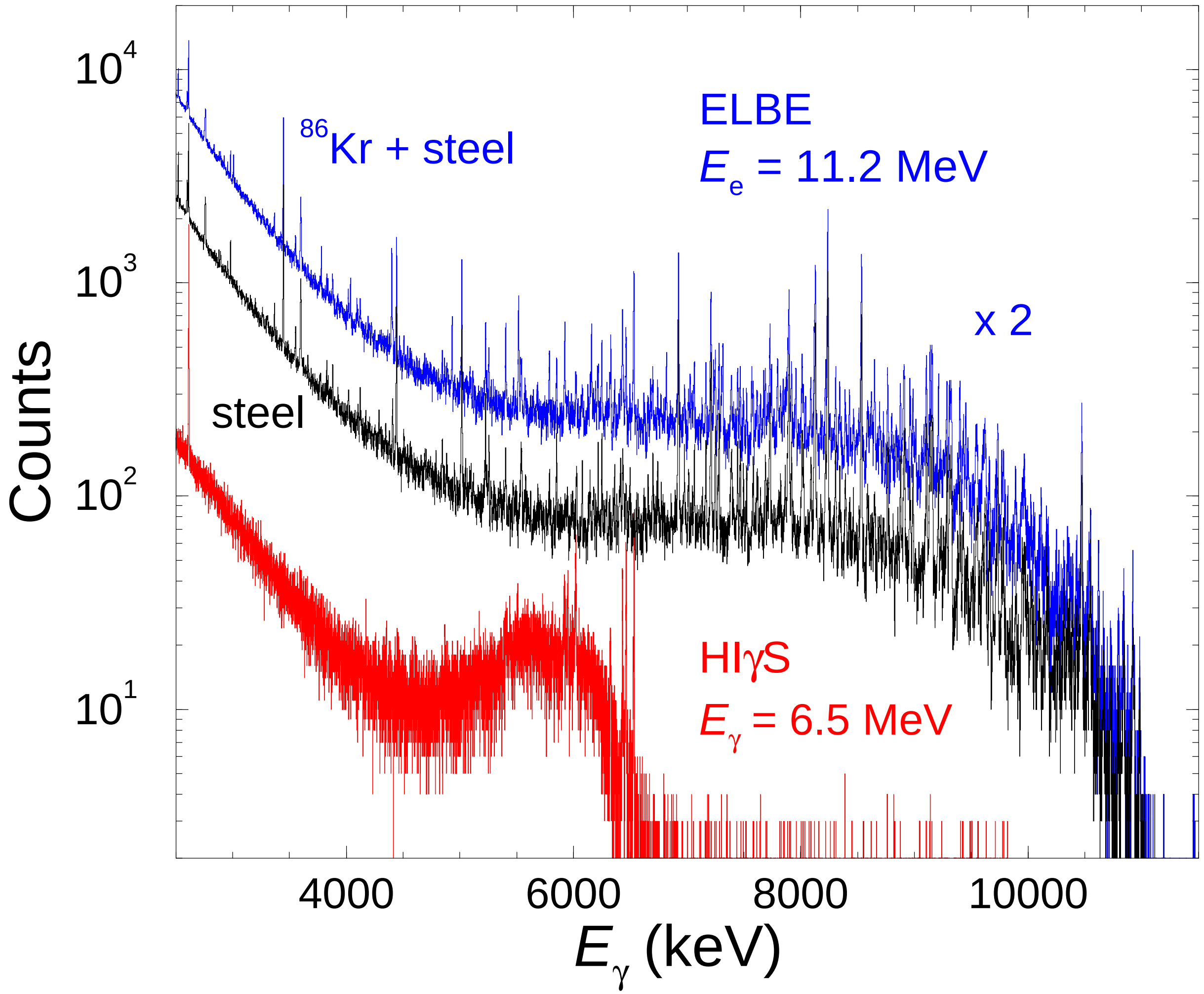
High-pressure gas target

Technology as described in NIM A 608, 152 (2009).

Sphere of stainless steel;
inner diameter 20 mm,
wall thickness 0.5 mm.

1.007 g of ^{86}Kr at a pressure of about 60 bar.

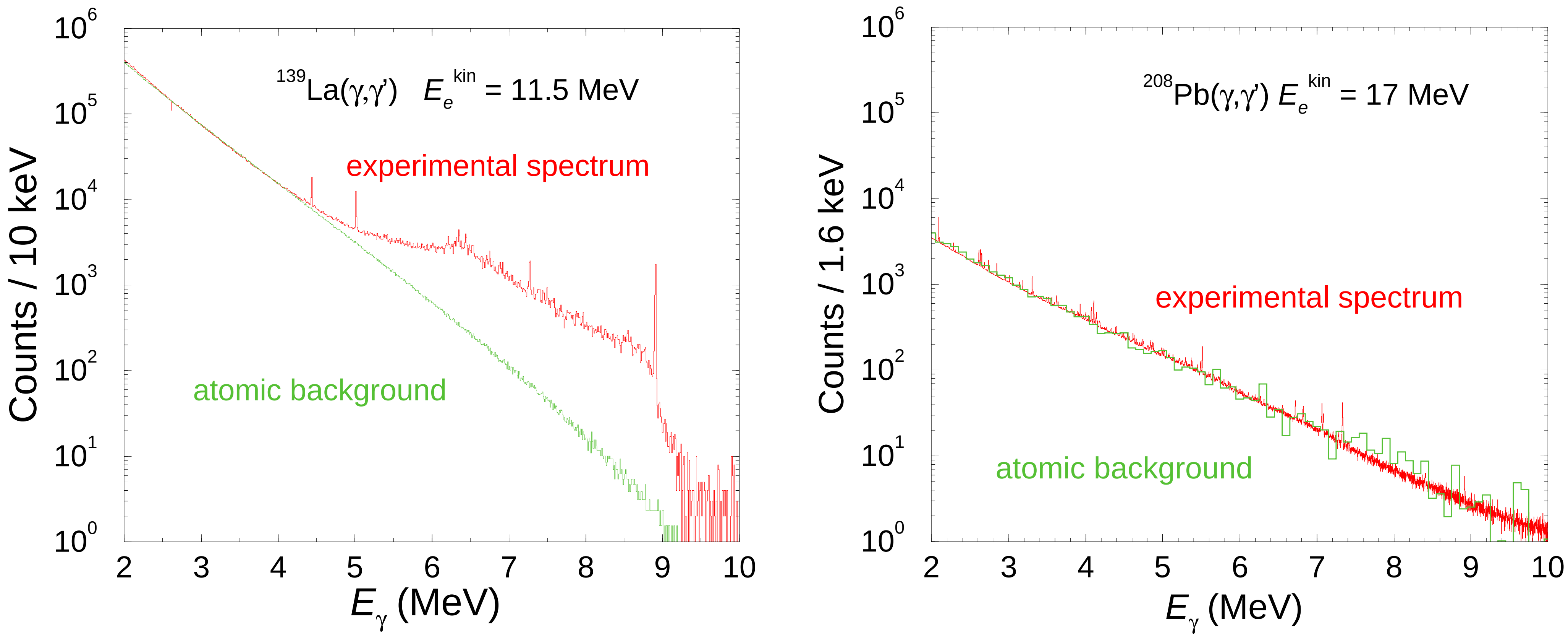
Measurements at γELBE and HIγS



Identification of transitions in ^{86}Kr by comparison of spectra measured with the filled and with the empty steel container.

R.S. et al., PRC 87, 024306 (2013)

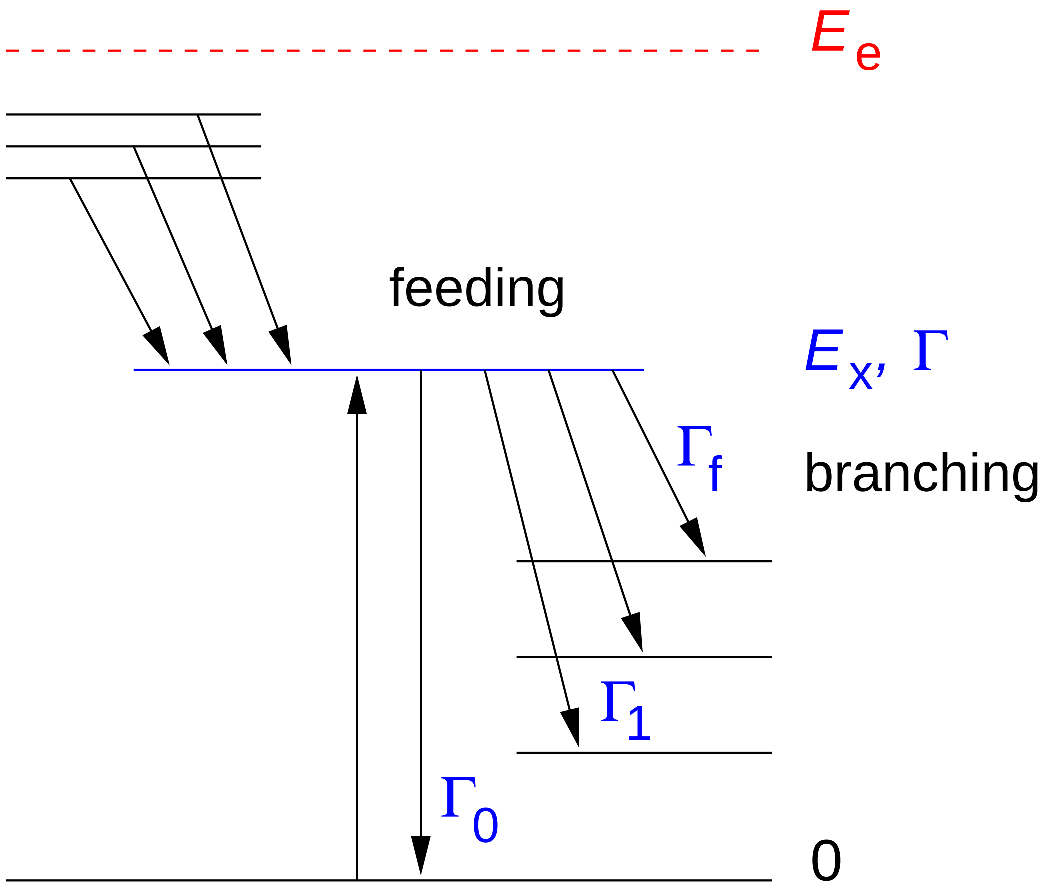
Unresolved strength in the quasicontinuum

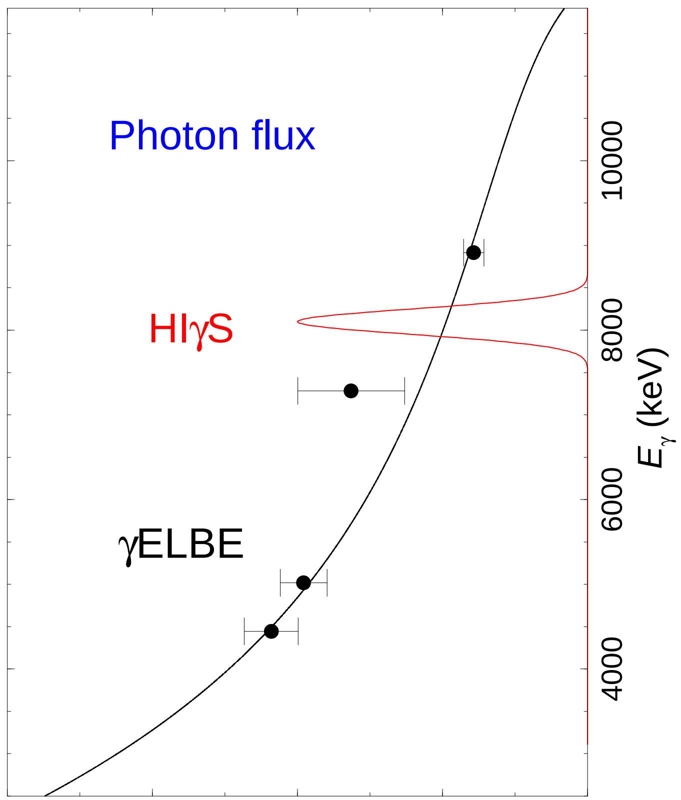


Experimental spectra (corrected for room background, detector response and efficiency) and simulated spectra of atomic background.

^{139}La data: A. Makinaga et al., PRC 82, 024314 (2010).
^{208}Pb data: R.S. et al., PRC 81, 054315 (2010).

Photon scattering - feeding and branching





Simulations of γ-ray cascades

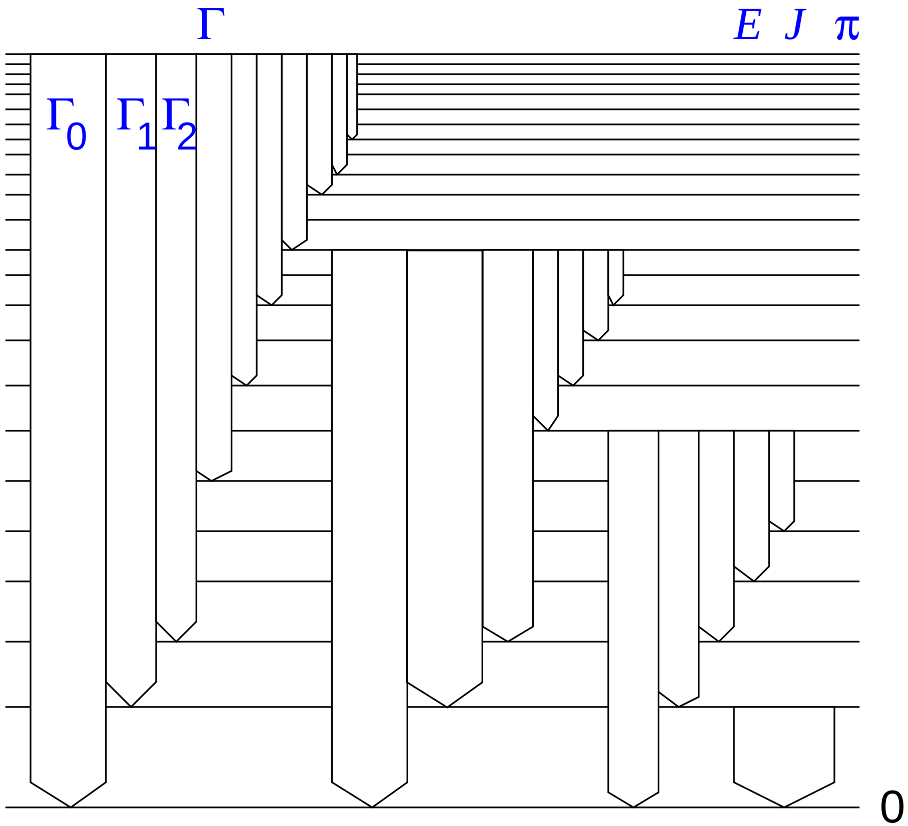
Monte Carlo:

G. Rusev et al., PRC 77, 064321 (2008)

Code γDEX:

G. Schramm et al., PRC 85, 014311 (2012)

R. Massarczyk et al., PRC 86, 014319 (2012); PRC 87, 044306 (2013)



⇒ Level scheme of $J = |J_0 \pm 1, \ldots, 5|$ states in 10 keV energy bins constructed by using:

∘ Constant-Temperature Model with level-density parameters from T. v. Egidy, D. Bucurescu, PRC 80, 054310 (2009).

∘ Parity distribution of level densities according to S. I. Al-Quraishi et al., PRC 67, 015803 (2003).

∘ Wigner level-spacing distributions.

⇒ Partial decay widths calculated by using:

∘ Photon strength functions approximated by Lorentz curves (www-nds.iaea.org/RIPL-2).

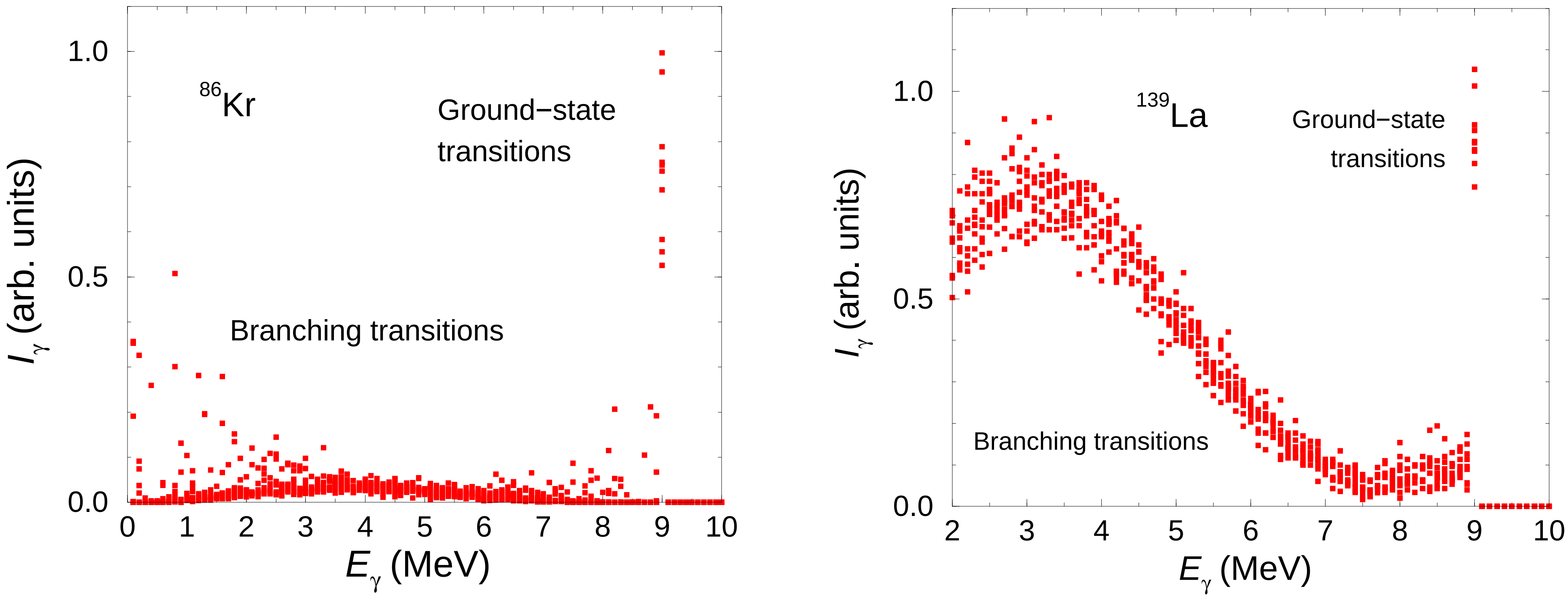
∘ Porter-Thomas distributions of decay widths.

⇒ Subtraction of feeding intensities and correction of intensities of g.s. transitions with calculated branching ratios Γ_0/Γ.

⇒ Determination of the absorption cross section.

HZDR

Simulations of γ-ray cascades

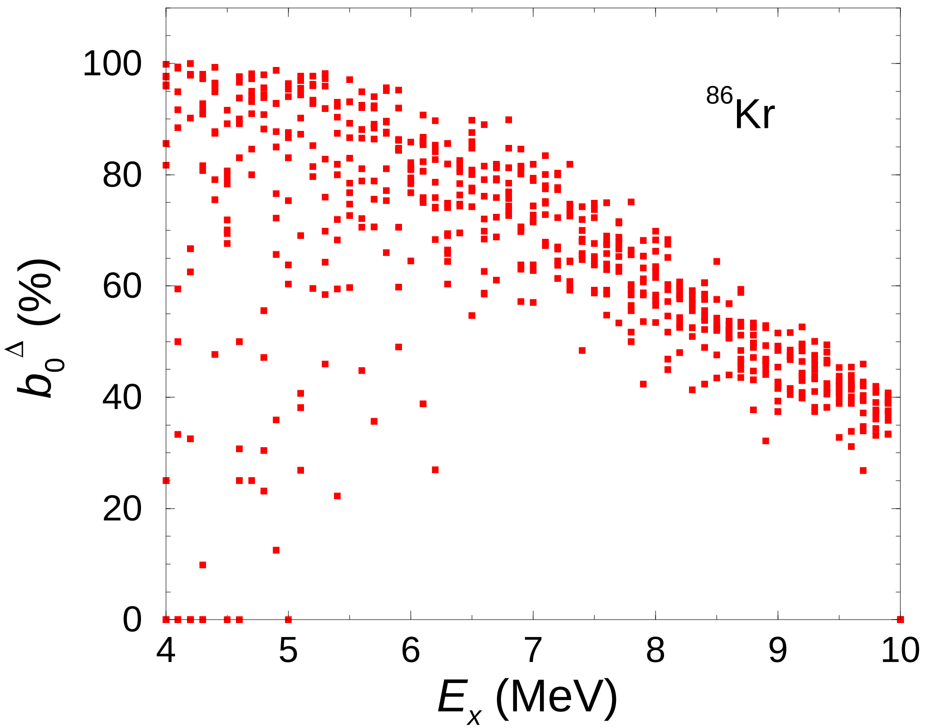


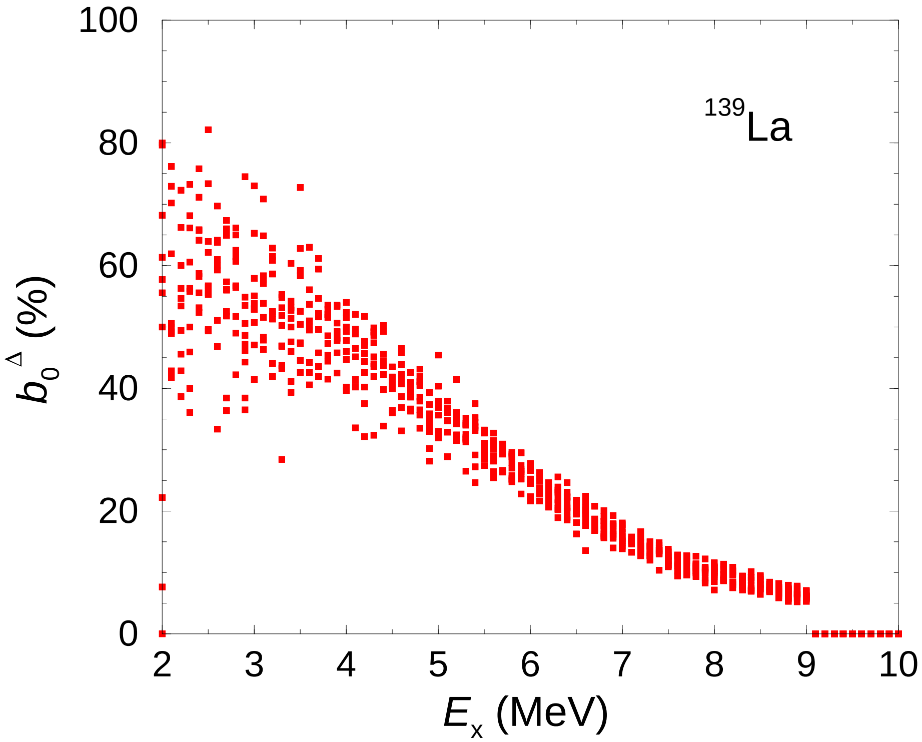
Simulated intensity distribution of transitions depopulating levels in a 100 keV bin around 9 MeV.

$\Rightarrow$ Subtraction of intensities of branching transitions.

^{86}Kr data: R.S. et al., PRC 87, 024306 (2013).
^{139}La data: A. Makinaga et al., PRC 82, 024314 (2010).

Simulations of γ-ray cascades



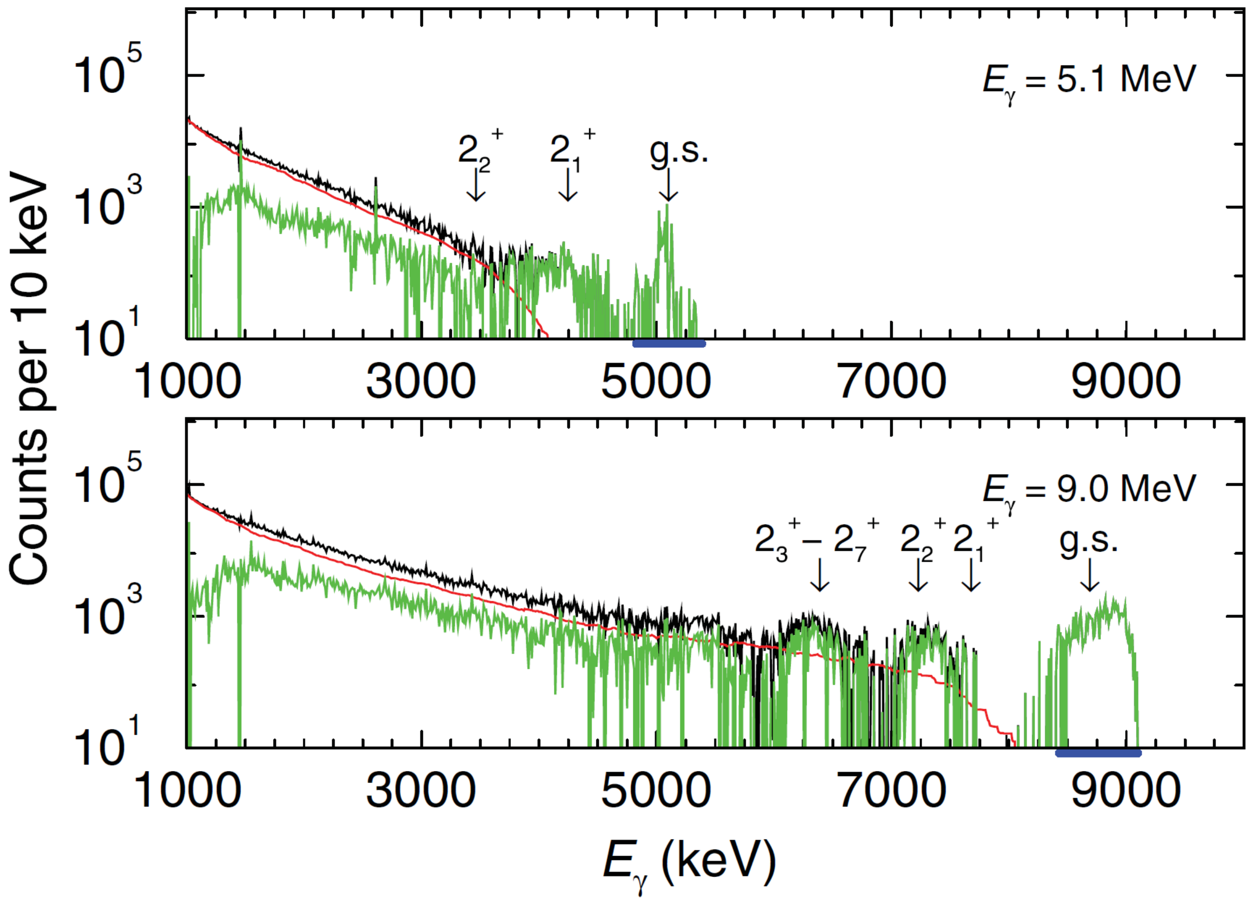


Distribution of branching ratios $b_0 = \Gamma_0/\Gamma$ versus the excitation energy as obtained from the simulations of γ-ray cascades.

$\Rightarrow$ Estimate of Γ_0 and σ_γ.

^{86}Kr data: R.S. et al., PRC 87, 024306 (2013).
^{139}La data: A. Makinaga et al., PRC 82, 024314 (2010).

Branching ratios in ^{136}Ba from measurements at HIγS



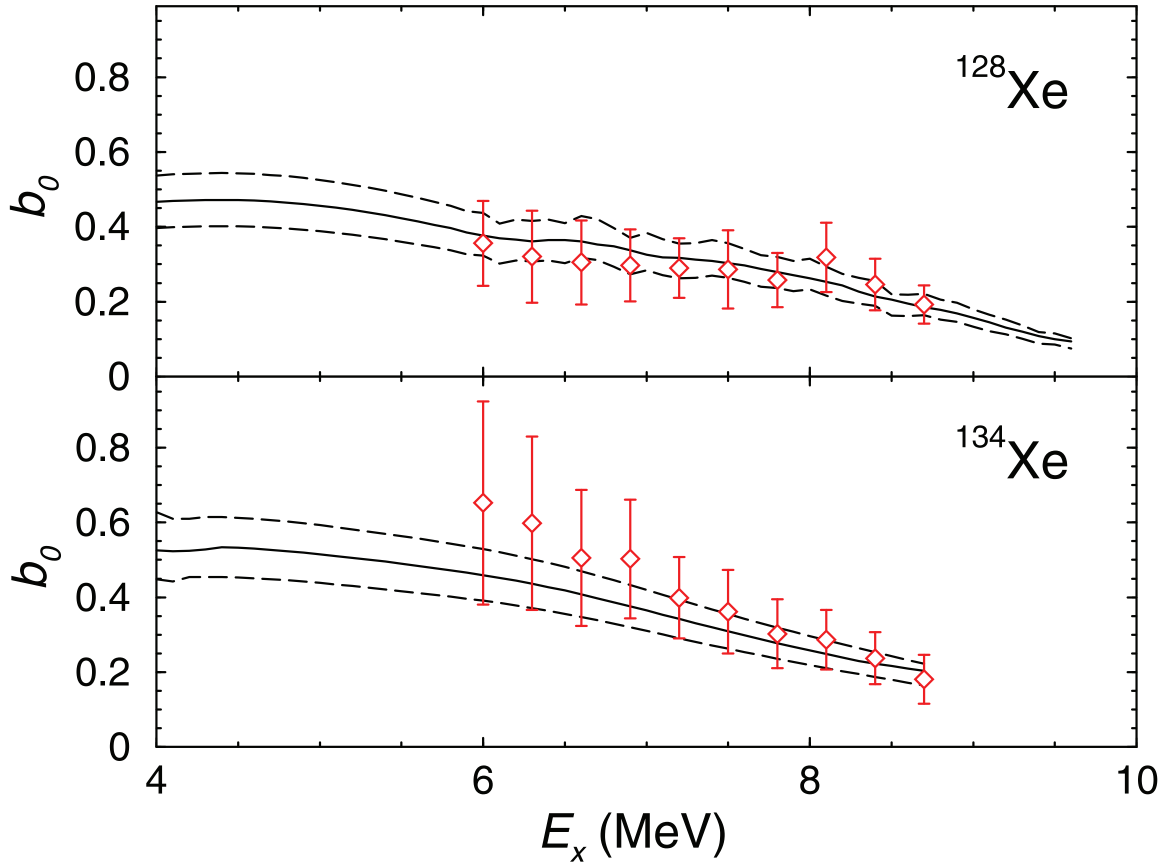
Response-corrected spectra.

Simulated spectra of γ rays scattered by atomic processes.

Subtracted spectra contain bunches of transitions to the ground state and to excited states.

R. Massarczyk et al., PRC 86, 014319 (2012).

Test of simulated branching ratios - measurements at HIγS



Red diamonds:

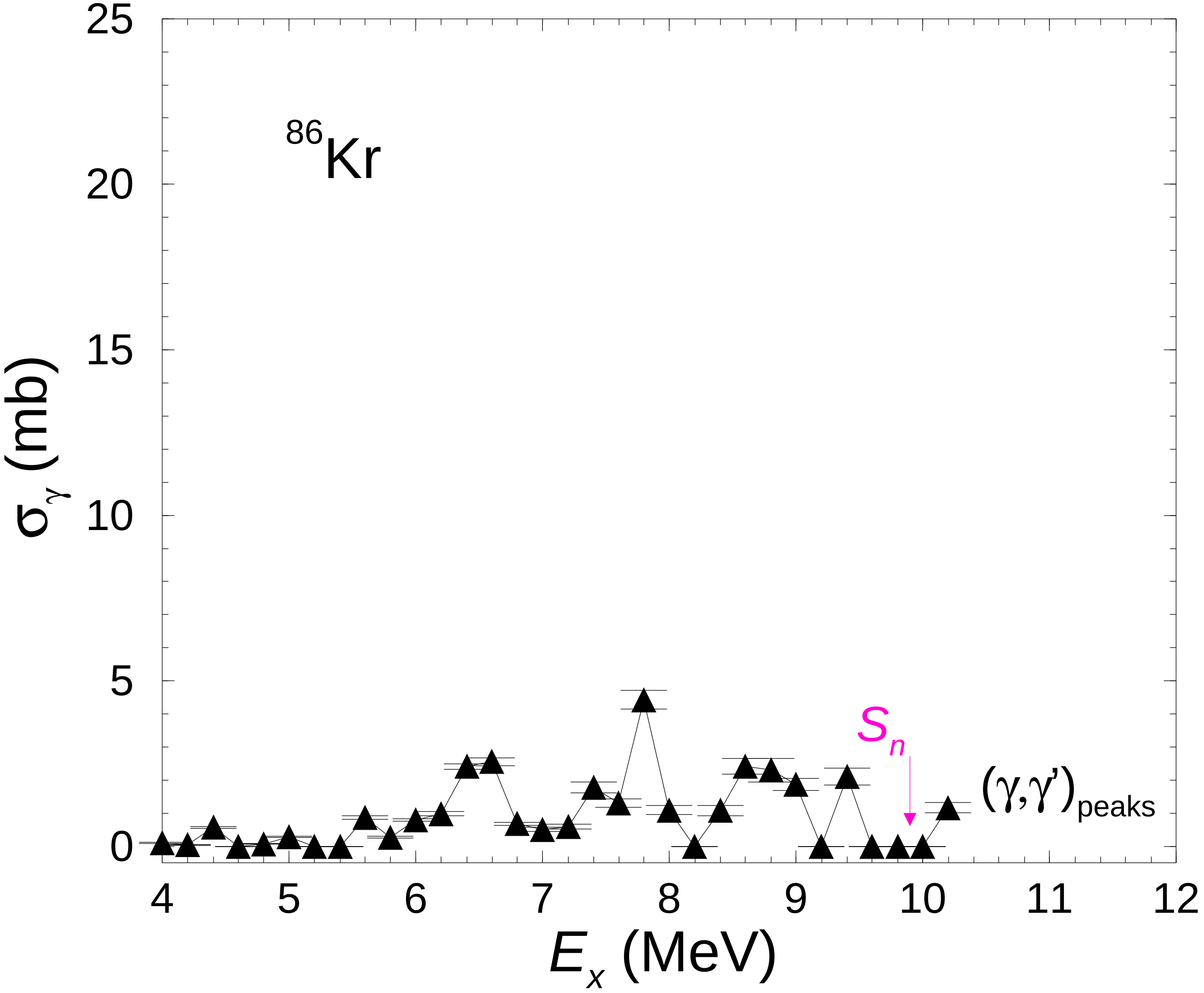
Branching ratios deduced from measurements with monoenergetic γ rays at HIγS ($\Delta E \approx 200$ keV).

Black lines:

Average branching ratios (solid) $b_0 = \Gamma_0/\Gamma$ versus the excitation energy as obtained from simulations of γ-ray cascades and their uncertainties (dashed).

R. Massarczyk et al., PRC 90, 054310 (2014).

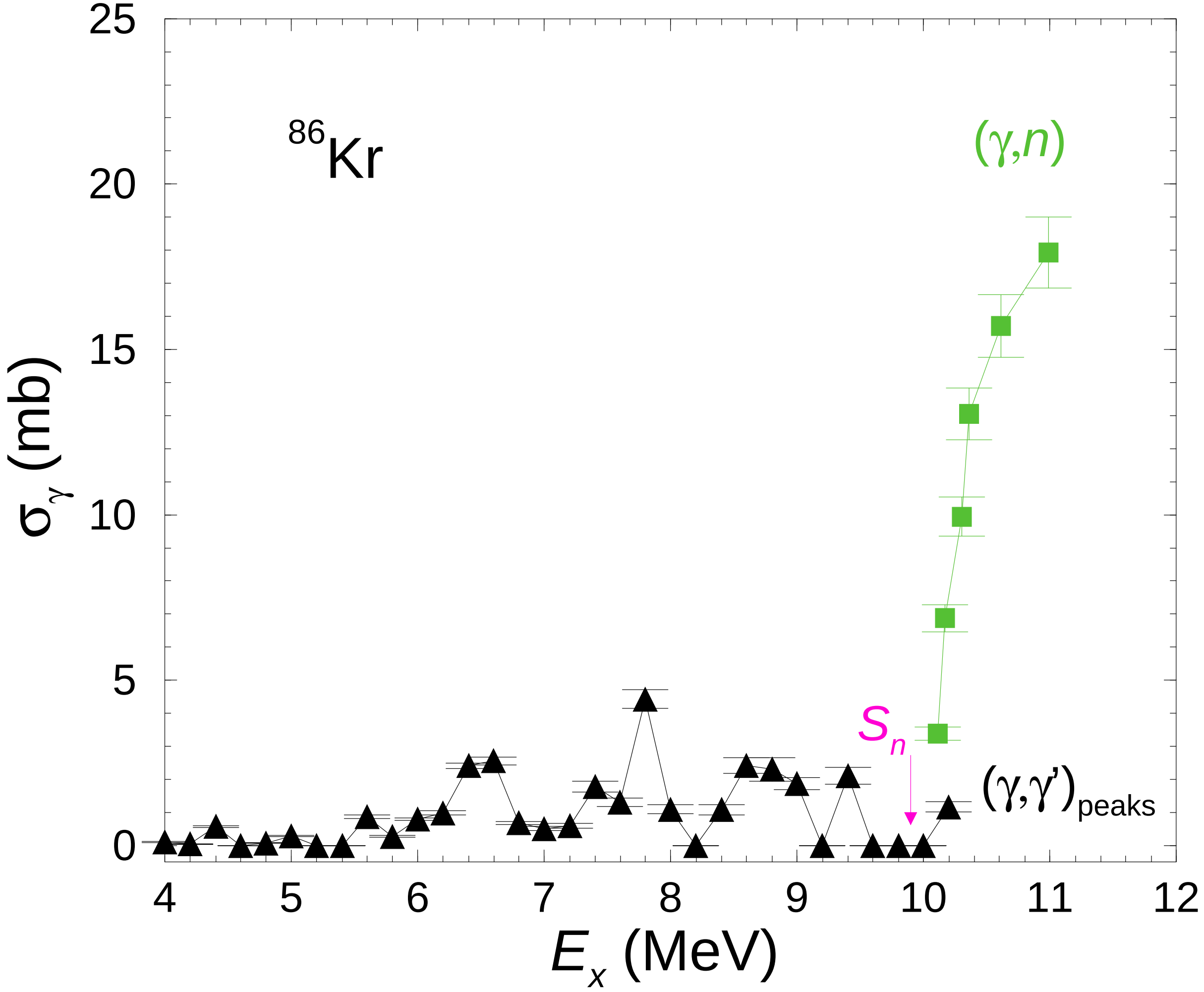
Absorption cross section in ^{86}Kr



(γ, γ') data from γELBE

R.S. et al., PRC 87, 024306 (2013)

Absorption cross section in ^{86}Kr



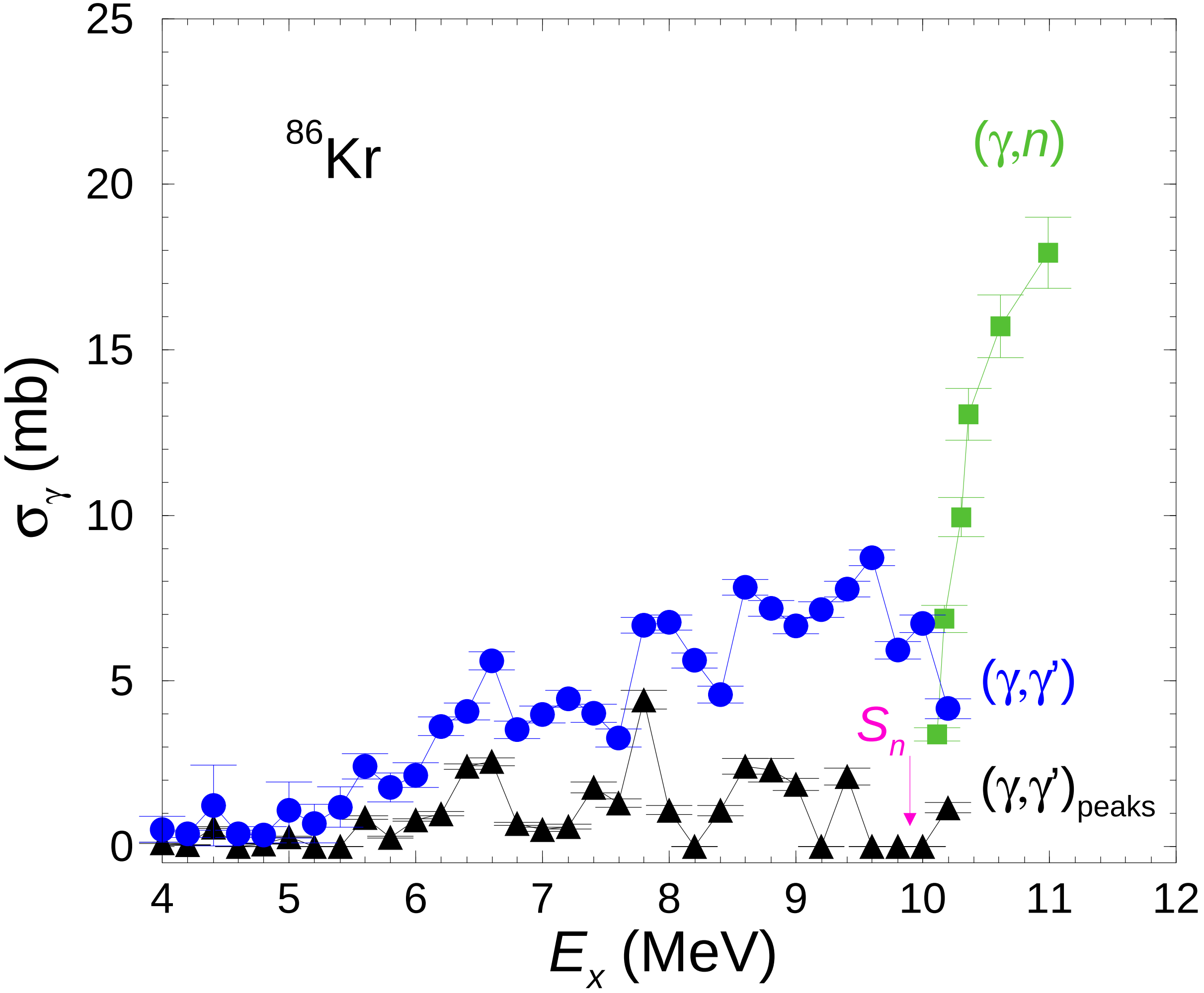
(γ, γ') data from γELBE

R.S. et al., PRC 87, 024306 (2013)

(γ, n) data from HIγS

R. Raut et al., PRL 111, 112501 (2013)

Absorption cross section in ^{86}Kr



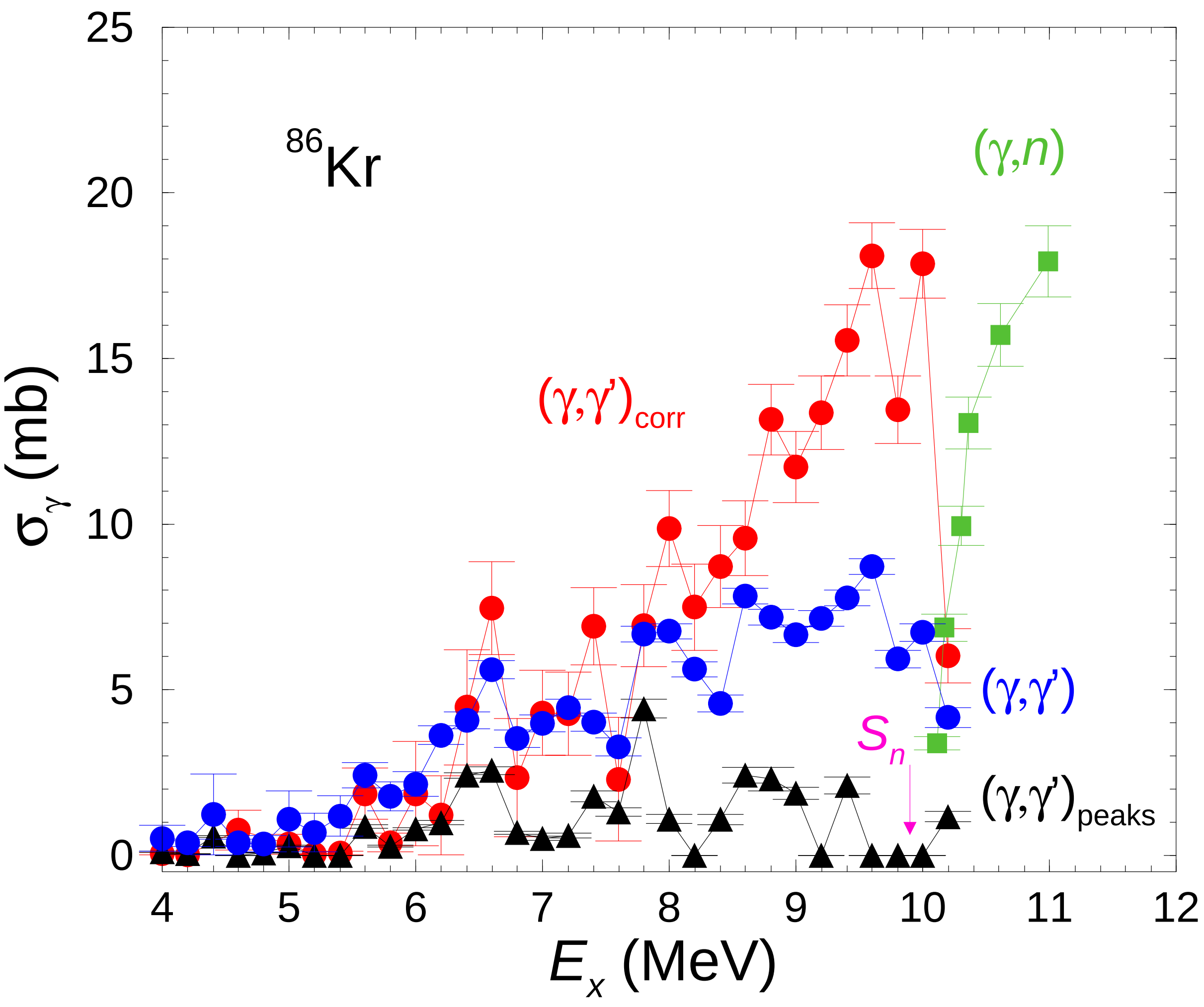
(γ, γ') data from γELBE

R.S. et al., PRC 87, 024306 (2013)

(γ, n) data from HIγS

R. Raut et al., PRL 111, 112501 (2013)

Absorption cross section in ^{86}Kr



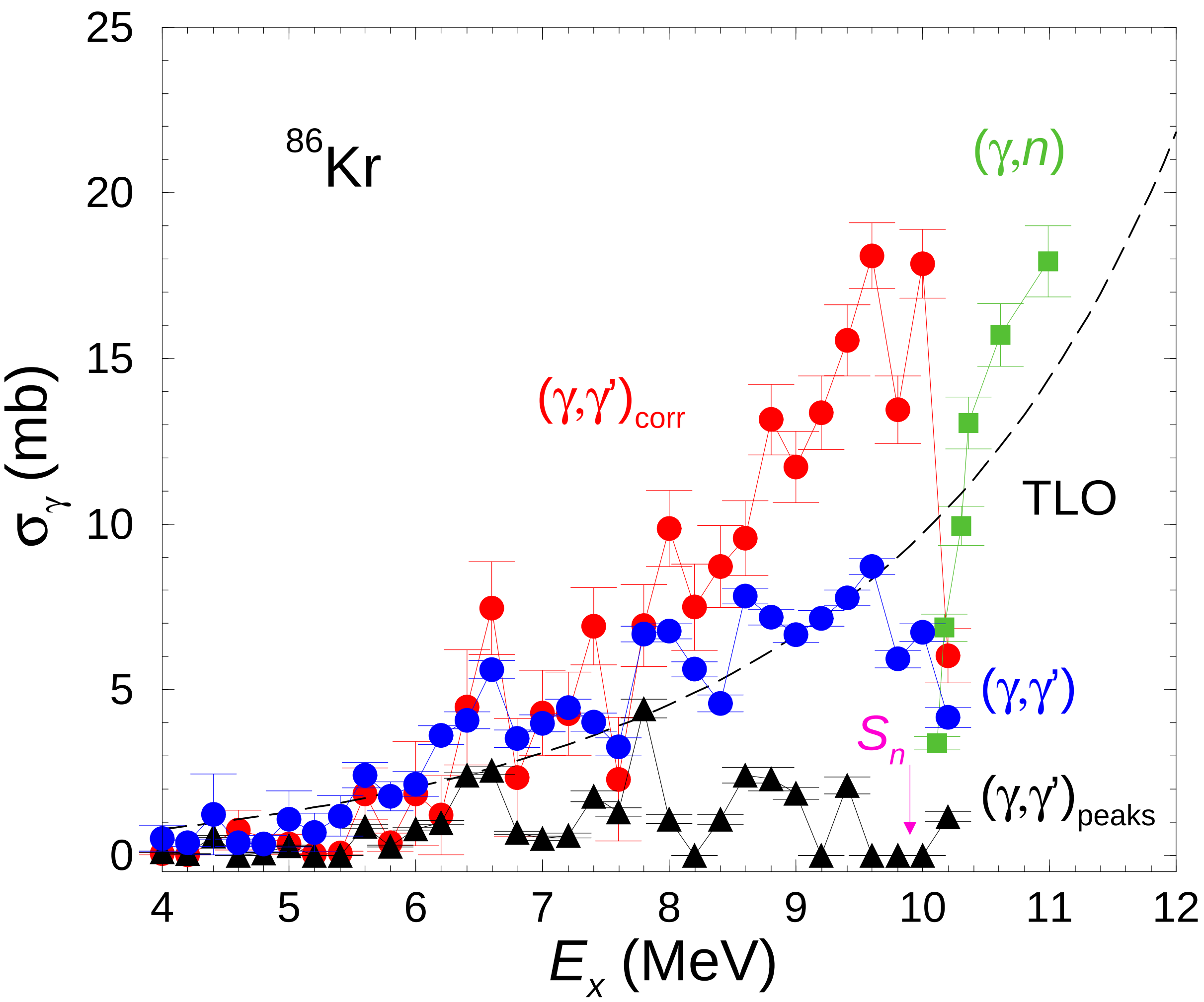
(γ,γ') data from γELBE

R.S. et al., PRC 87, 024306 (2013)

(γ,n) data from HIγS

R. Raut et al., PRL 111, 112501 (2013)

Absorption cross section in ^{86}Kr



(γ, γ') data from γELBE

R.S. et al., PRC 87, 024306 (2013)

(γ, n) data from HIγS

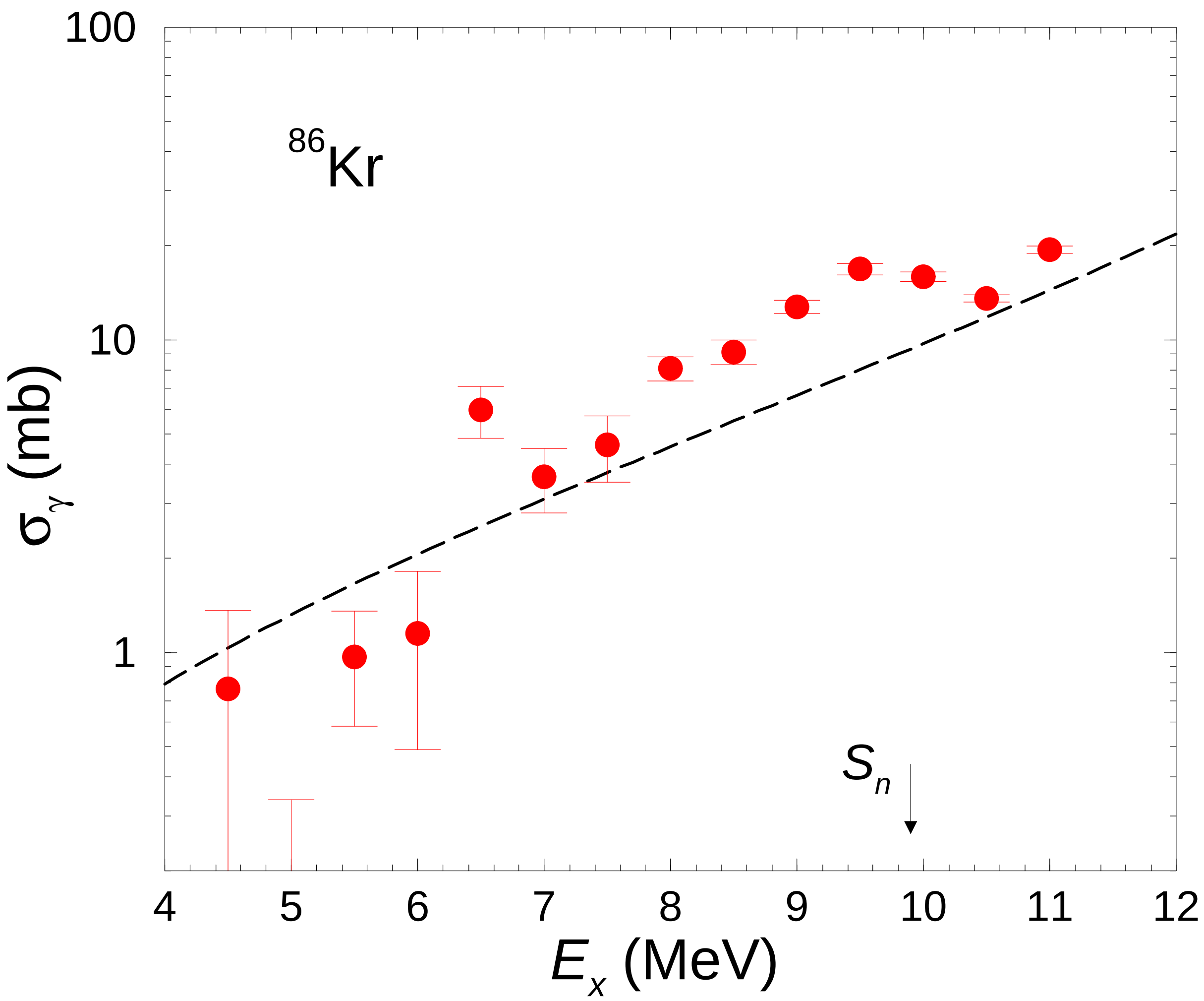
R. Raut et al., PRL 111, 112501 (2013)

TLO

A.R. Junghans et al.,

PLB 670, 200 (2008)

Absorption cross section in ^{86}Kr

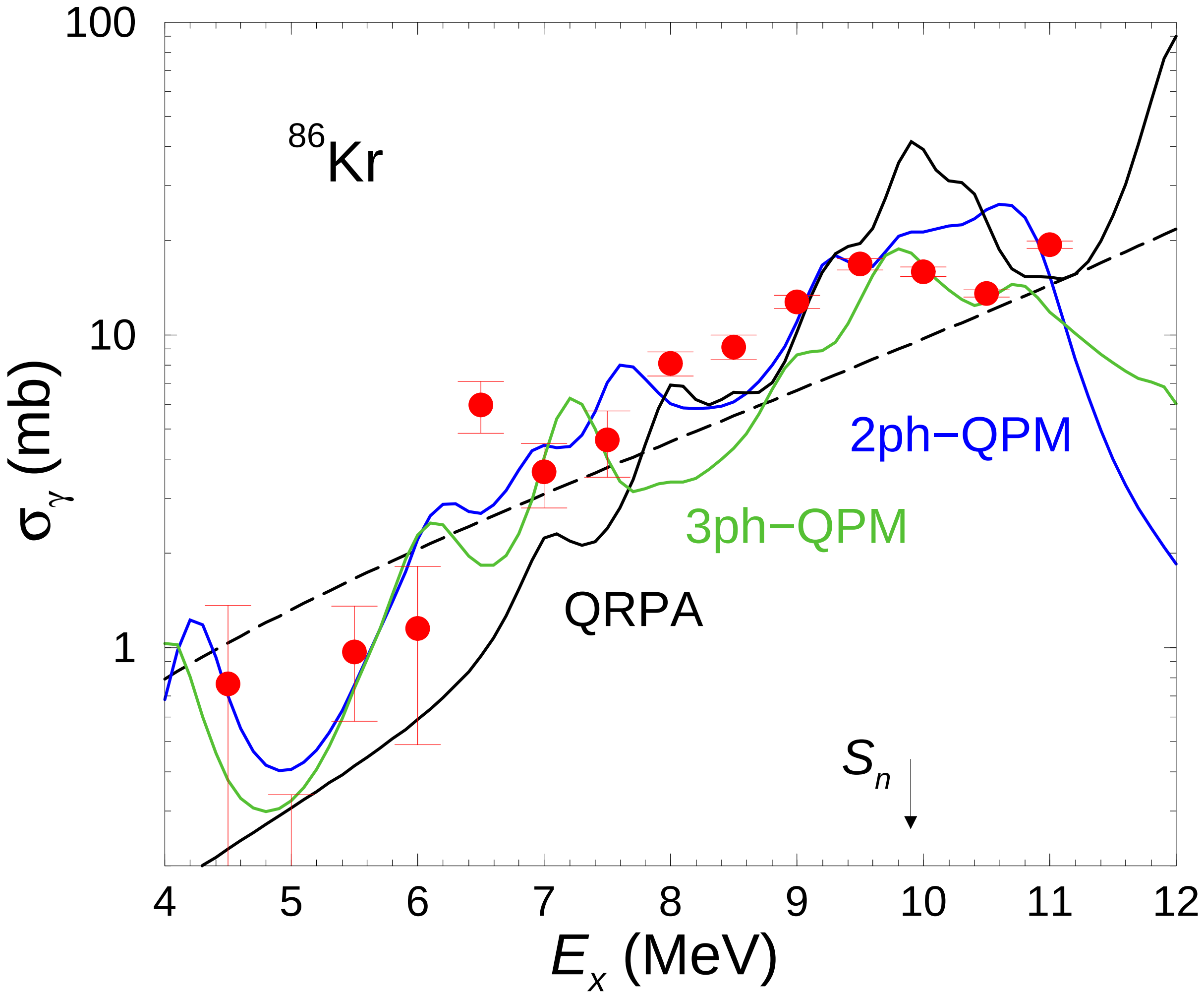


(γ,γ') data from ELBE +
(γ,n) data from HIγS

TLO

R.S. et al., PRC 87, 024306 (2013)

Absorption cross section in ^{86}Kr



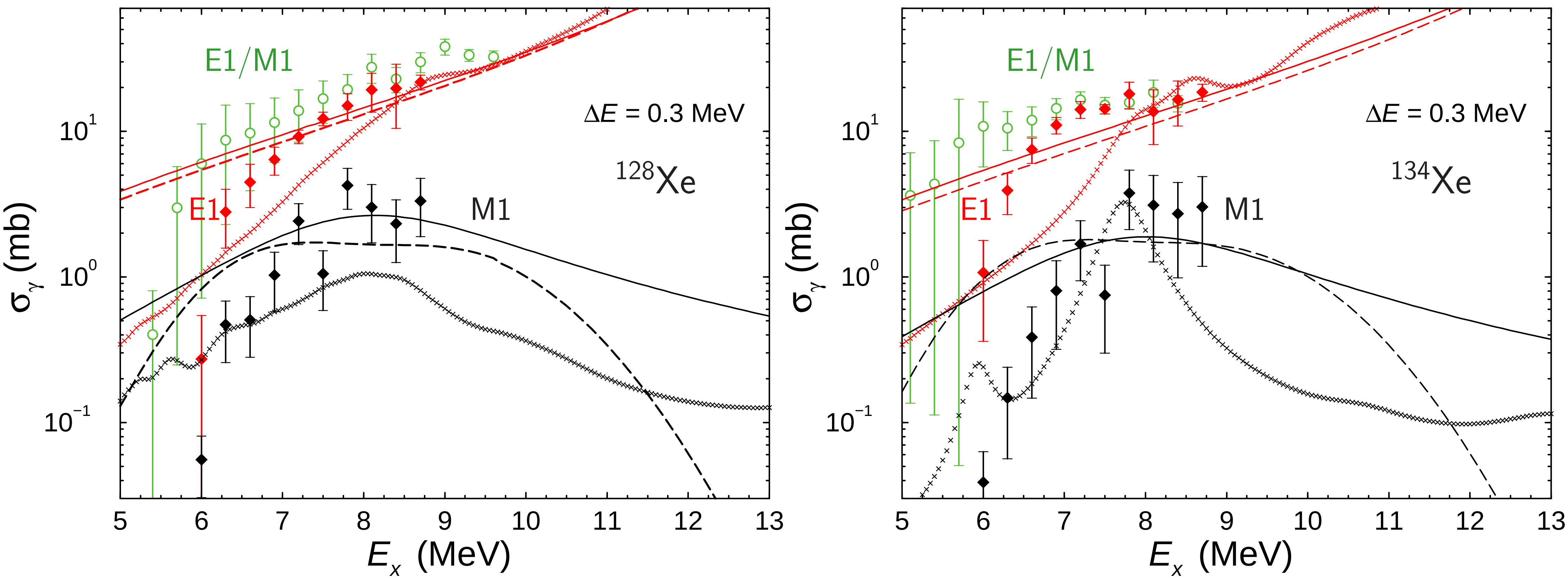
(γ,γ') data from ELBE +
(γ,n) data from HIγS

TLO

Calculations by N. Tsoneva

R.S. et al., PRC 87, 024306 (2013)

E1 strength in the PDR region and M1 strength in the spin-flip region

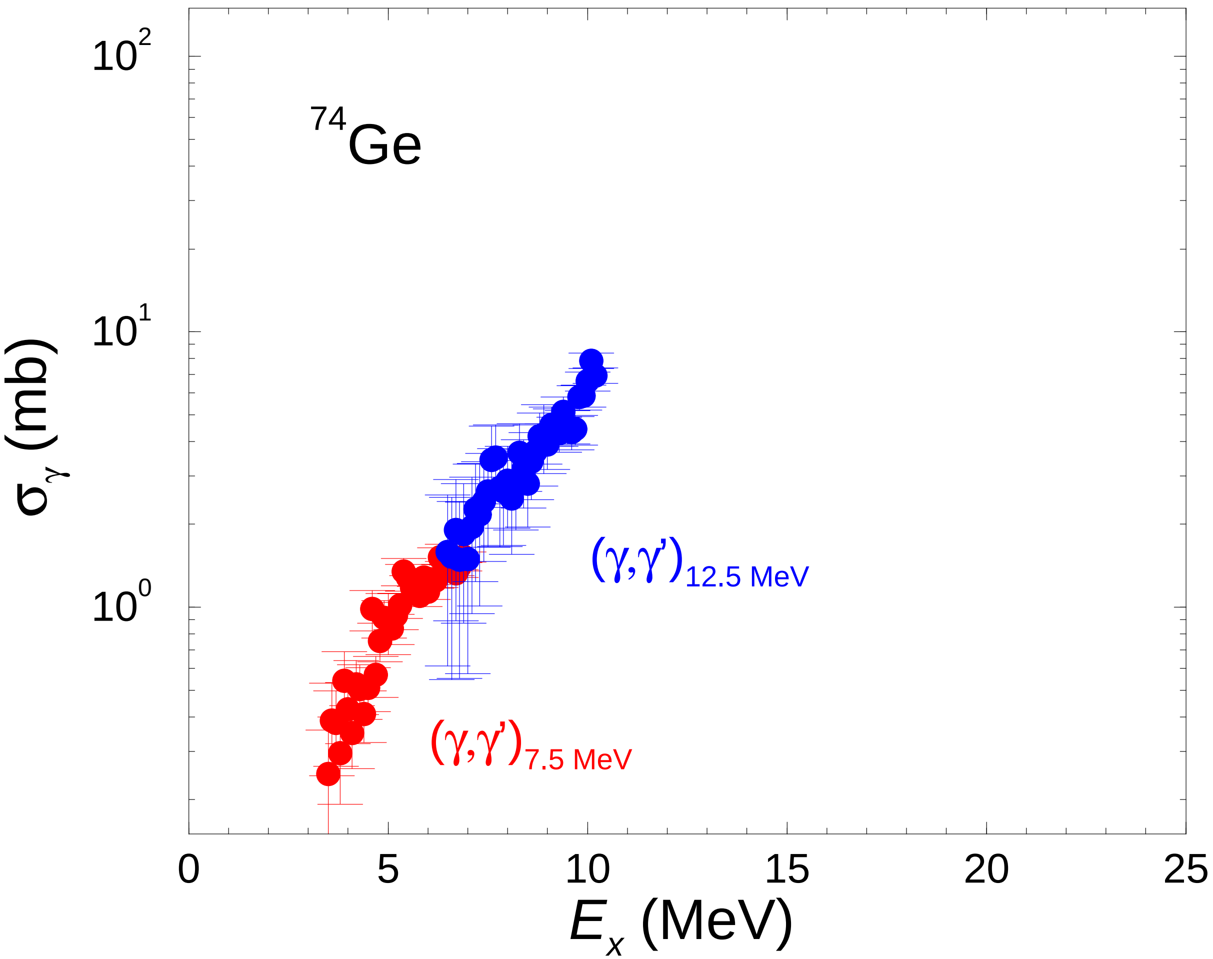


E1/M1: strength from experiments at γELBE.

E1 and M1: strengths from experiments at HIγS. Intensities include quasicontinuum.

R. Massarczyk et al., PRC 90, 054310 (2014)

Absorption cross section of ^{74}Ge

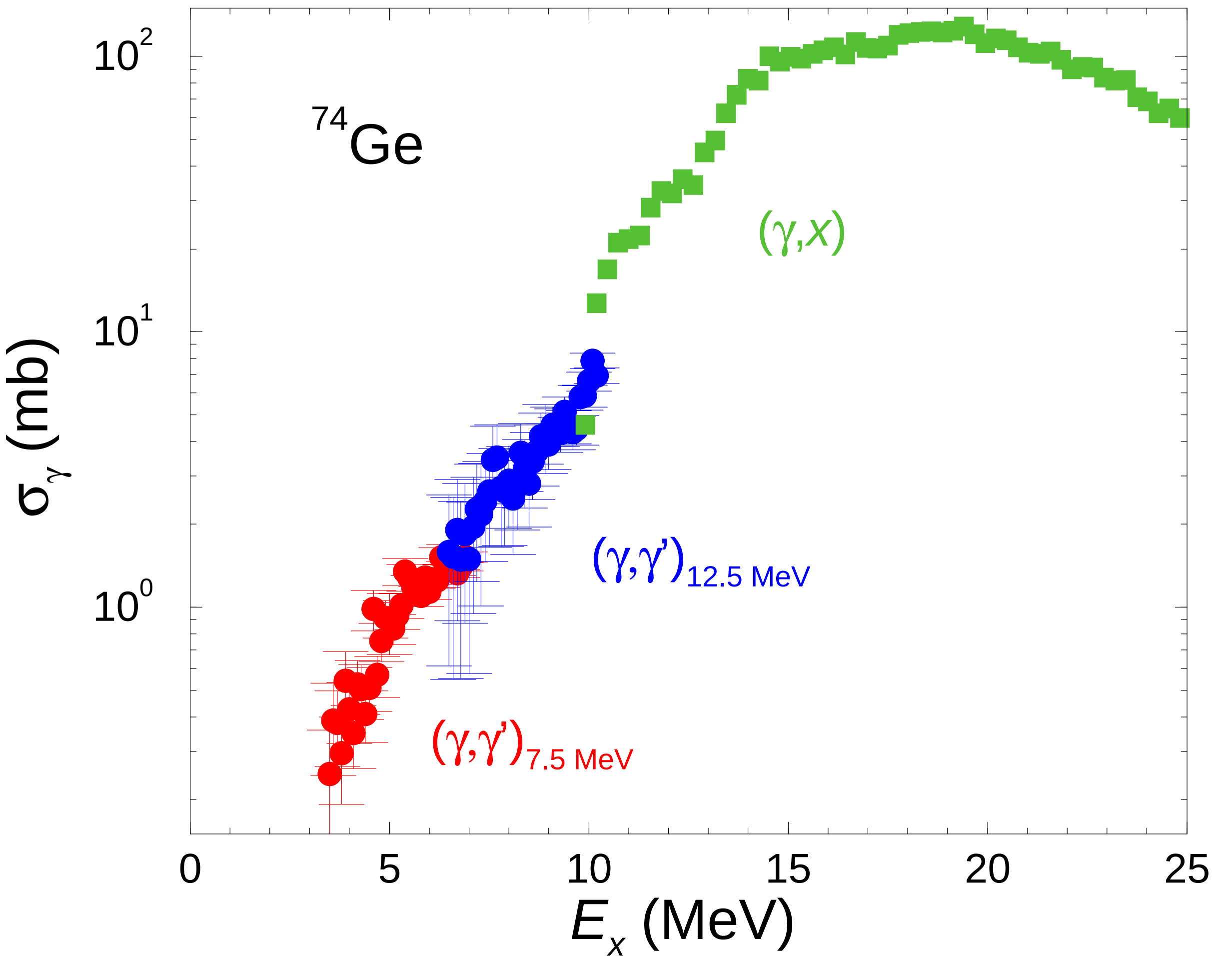


(γ, γ') data (HZDR):

R. Massarczyk et al.

PRC 92, 044309 (2015)

Absorption cross section of ^{74}Ge



(γ, γ') data (HZDR):

R. Massarczyk et al.

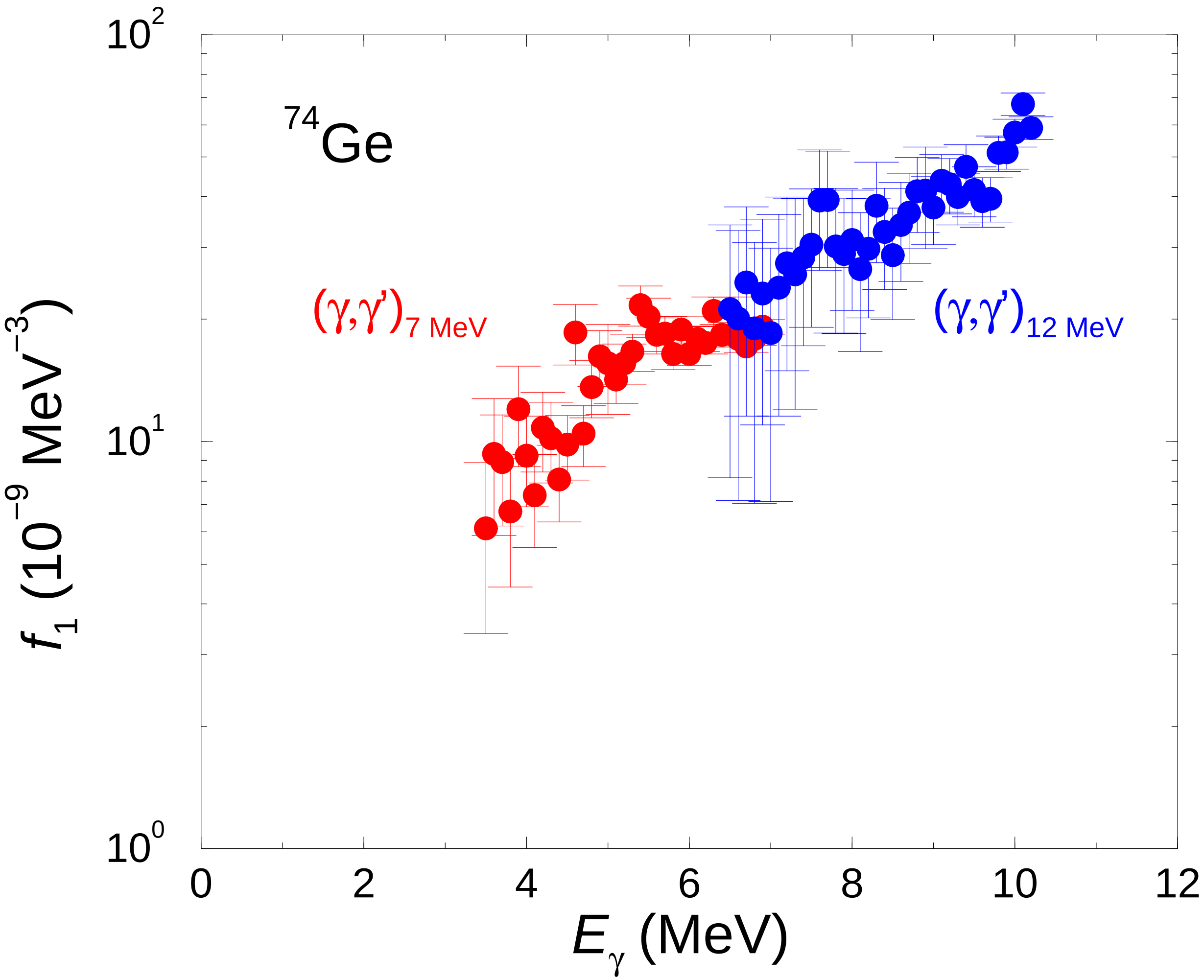
PRC 92, 044309 (2015)

(γ, x) data:

P. Carlos et al.,

NPA 258, 365 (1976)

Dipole strength functions in ^{74}Ge

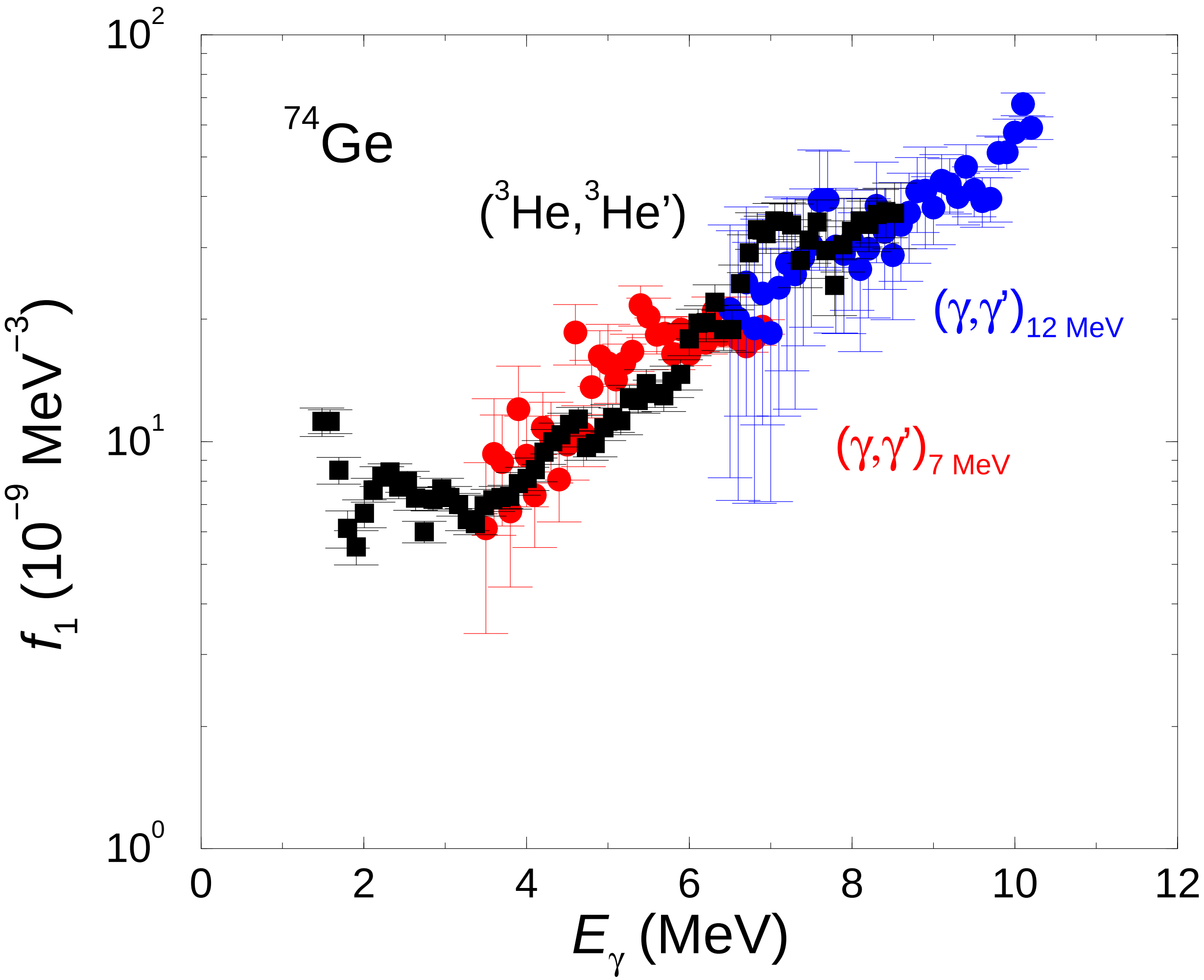


(γ, γ') data (HZDR):

R. Massarczyk et al.

PRC 92, 044309 (2015)

Dipole strength functions in ^{74}Ge



(γ, γ') data (HZDR):

R. Massarczyk et al.

PRC 92, 044309 (2015)

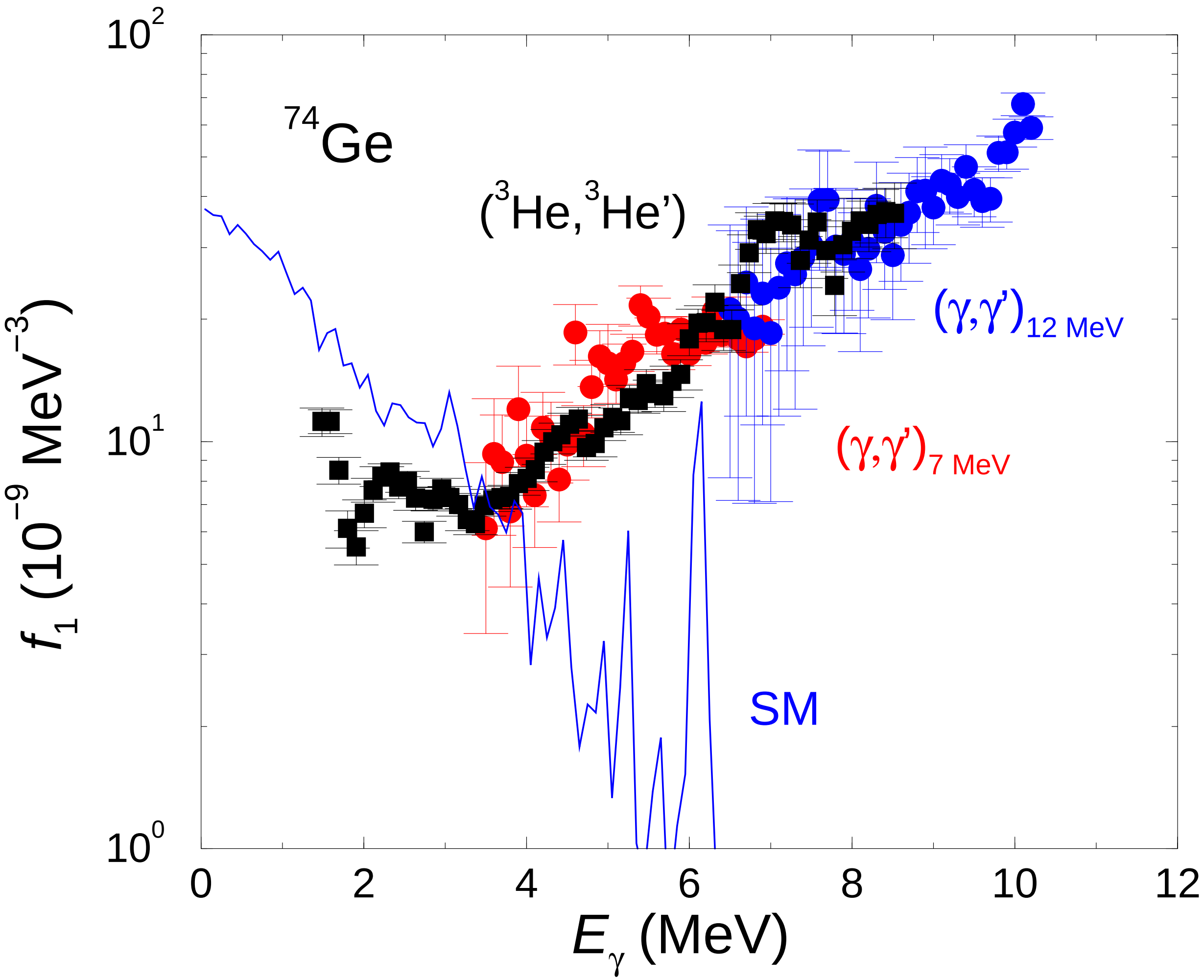
(^{3}He,^{3}He') data (OCL):

T. Renstrøm et al.

PRC 93, 064302 (2016)

$\Rightarrow$ Low-energy upbend

Dipole strength functions in ^{74}Ge



(γ, γ') data (HZDR):

R. Massarczyk et al.

PRC 92, 044309 (2015)

(^{3}He,^{3}He') data (OCL):

T. Renstrøm et al.

PRC 93, 064302 (2016)

⇒ Low-energy upbend

Shell-model calculations:

cf. R.S. et al.,

PRL 111, 232504 (2013)

Summary

- Photon-scattering experiments with bremsstrahlung at γELBE and with quasi-monoenergetic γ rays at HIγS.
- Strength in the quasicontinuum included. Observed strength corrected for branching and feeding by means of statistical methods.
- Experimental information about E1 strength in the pygmy region and M1 strength in the spin-flip region for nuclides around masses 80, 130 and 180.
- Shell-model calculations of M1 and E2 strength.
- Description of the experimental low-energy upbend by enhanced M1 strength. Information about E2 strength at low energy.
- Modification of phenomenological strength functions needed.

$\Rightarrow$

Collaborators

Data analysis:	R. Massarczyk (HZDR/LANL) G. Rusev (HZDR/LANL)
Calculations:	B.A. Brown (NSCL/MSU) F. Dönau (HZDR) N. Tsoneva (Univ. Gießen)
Experiments at γELBE (HZDR):	D. Bemmerer, R. Beyer, R. Hannaske, A.R. Junghans, T. Kögler, A. Makinaga, K. Schmidt, A. Wagner *et al.*
Experiments at HIγS (TUNL):	C. Bhatia, M. Bhike, H. Kelley, E. Kwan, M.E. Gooden, R. Raut, A.P. Tonchev, W. Tornow