The first results of photon scattering from ^{78}Se at FZD – ELBE and preparations for cold - neutron capture by ^{77}Se at IKI Budapest

A. Matić[1)], T. Belgya[3)], F. Becvar[5)], R. Beyer[1)], E. Birgersson[1)], E. Grosse[1,2)], R. Hannaske[1,2)], A. Junghans[1)], M. Krtička[4)], R. Massarczyk[1,2)], R. Schwengner[1)], L. Szentmiklosi[3)], J. Weil[3)], A. Wagner[1)]

1) Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf
2) Technische Universität Dresden
3) Department of Nuclear Research Institute of Isotopes, Hungarian Academy of Sciences, Budapest
4) Institute of Particle & Nuclear Physics Charles University, Prague
5) Department of Low Temperature Physics, Faculty of Mathematics and Physics, Prague

Forschungszentrum Dresden Rossendorf

Outline

- Gamma strength function
- Motivation for $^{78}Se(\gamma,\gamma')$ and $^{77}Se(n,\gamma)$ experiments
- Experimental setup for $^{78}Se(\gamma,\gamma')$ experiment at FZD
- Important steps in data analysis
- Experimental setup for $^{77}Se(n,\gamma)$ experiment at IKI Budapest
- Conclusion

Gamma strength function

Defined as:

$$f_{XL}(E_\gamma) = E_\gamma^{-(2L+1)} \frac{\langle \Gamma_i^{XL}(E_\gamma) \rangle}{D(E_x)} \quad - G.\ A.\ Bartholomew\ et\ al.\ Adv.\ Nucl.\ Phys\ 7, 229\ (1973)$$

Γ_i^{XL} – partial *width* for *transition* to *level* – *i*

X *is* E or B, L – *multipolarity*

$D(E_x)$ *is average spacing of levels near the excited resonance* E_x

$E1\ strength \sim \Gamma_0 / E_\gamma^3$

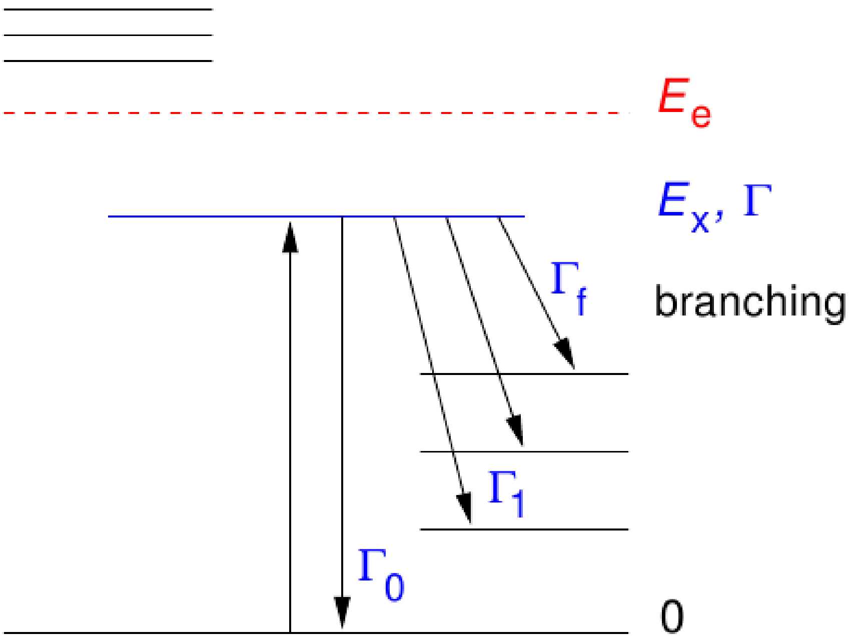
Importance for

Astrophysics:

- (γ,n) reaction rates for the p-process
- (n,γ) reaction rates for the s-process

Studies for future nuclear – fuel cycles

- or (n,γ) reactions



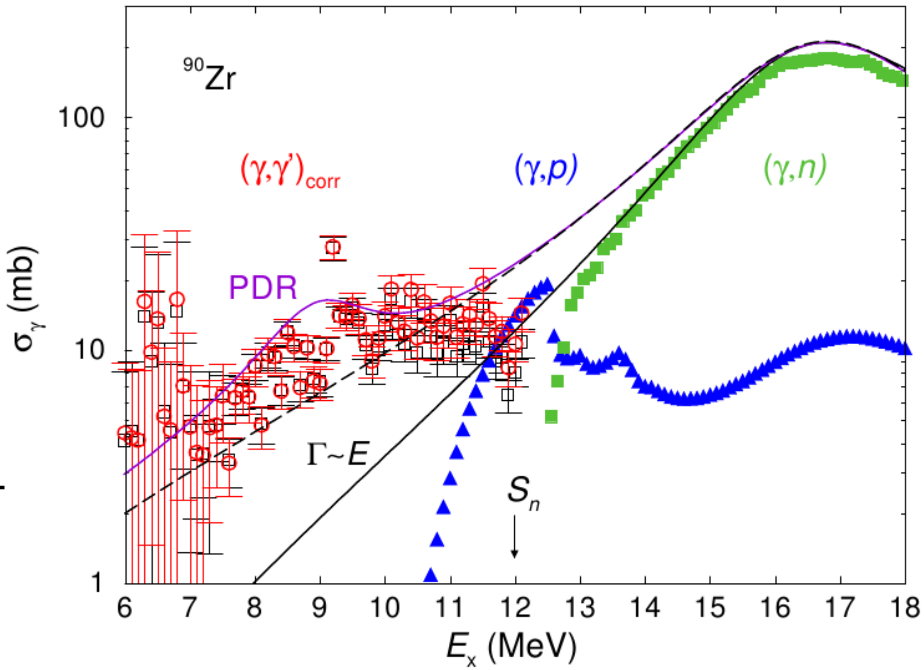
Courtesy to R. Schwengner

Open problems

Open problems
- precise knowledge of the dipole strength on the low – energy tail of GDR below particle threshold
- properties of GSF with variation of proton and neutron numbers

- Different models give different extrapolation
- Gamma strength functions obtained from experiments with photon beams differ from gamma strength function obtained by neutron capture experiments:
(Different activation processes populate different levels?)

R. Schwengner, PRC 78, 064314



A cross check between (γ,γ') and (n,γ) experiments

Pair of:

Even isotope (A,Z) with 0^+ g.s. for γ scattering experiment

Odd isotope (A-1,Z) with -½ g.s. for (n,γ) experiment

For mass region A<100

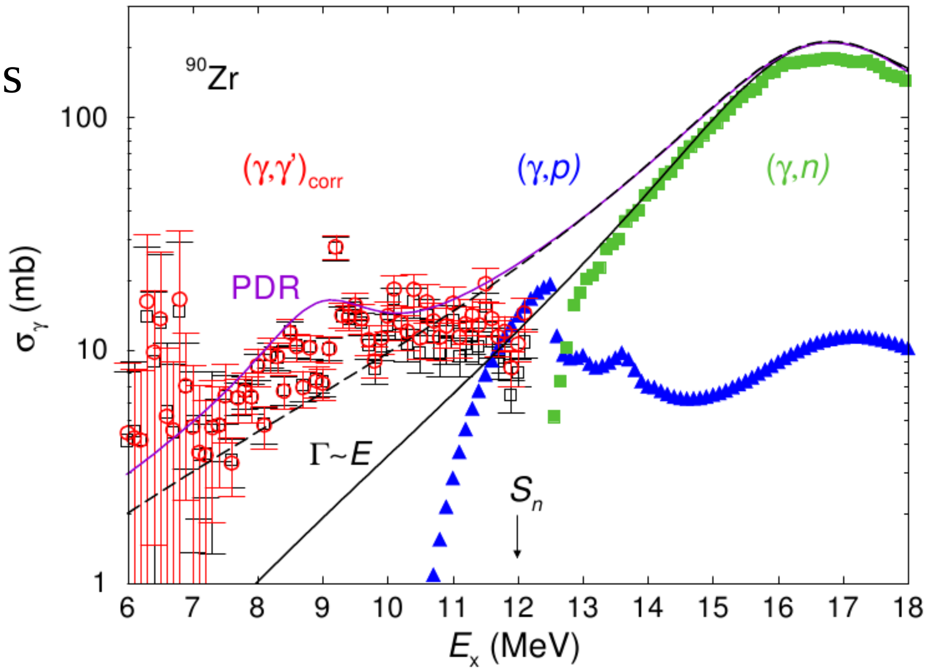
^{78}Se(γ,γ') will populate mainly L=1 states

^{77}Se(n,γ) will populate 0^- and 1^- states

For mass region ~ 200

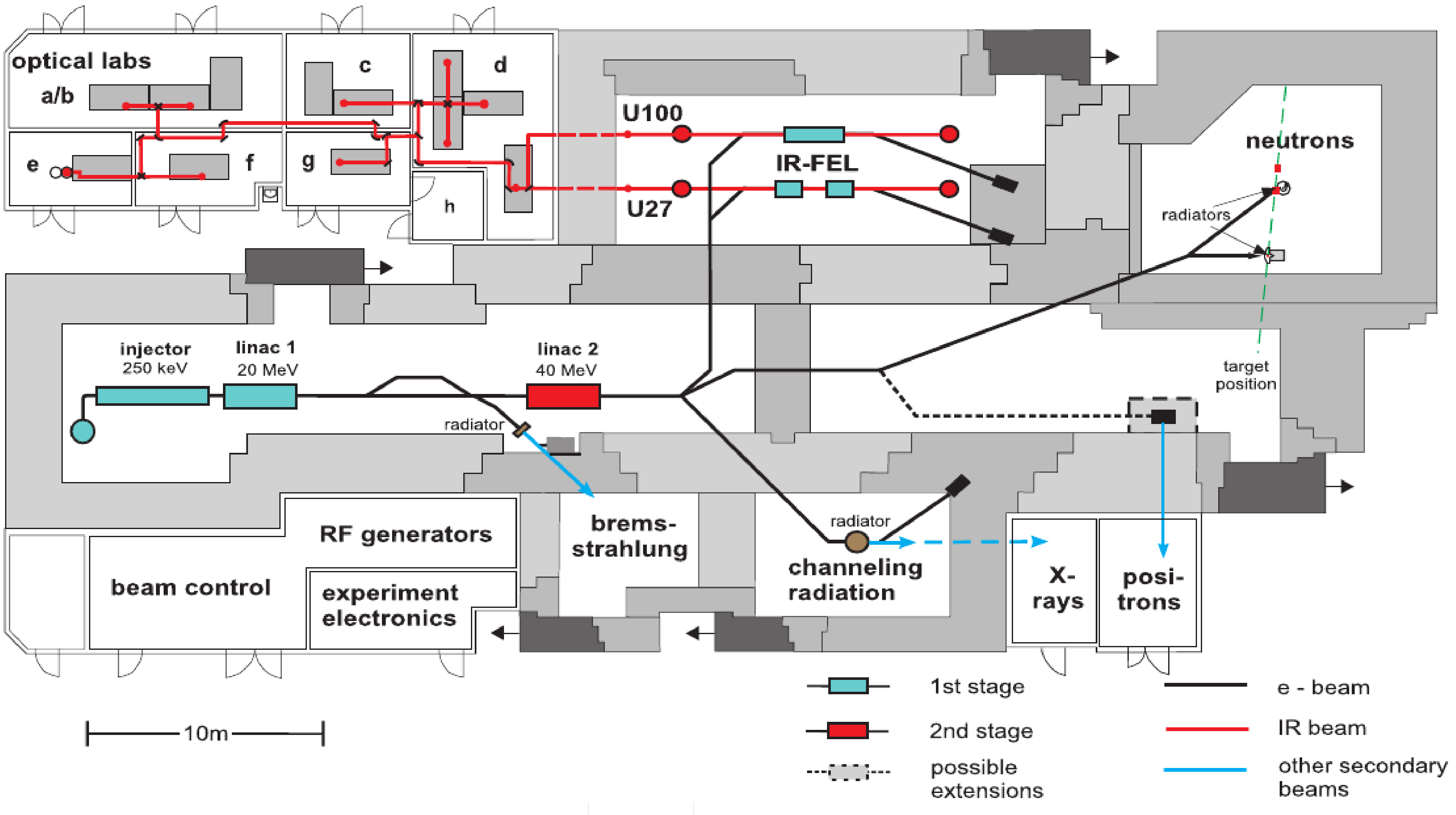
^{196}Pt(γ,γ') will populate mainly L=1 states

^{195}Pt(n,γ) will populate 0^- and 1^- states



The radiation source ELBE

Electron **L**inear accelerator of high **B**rilliance and low **E**mittance

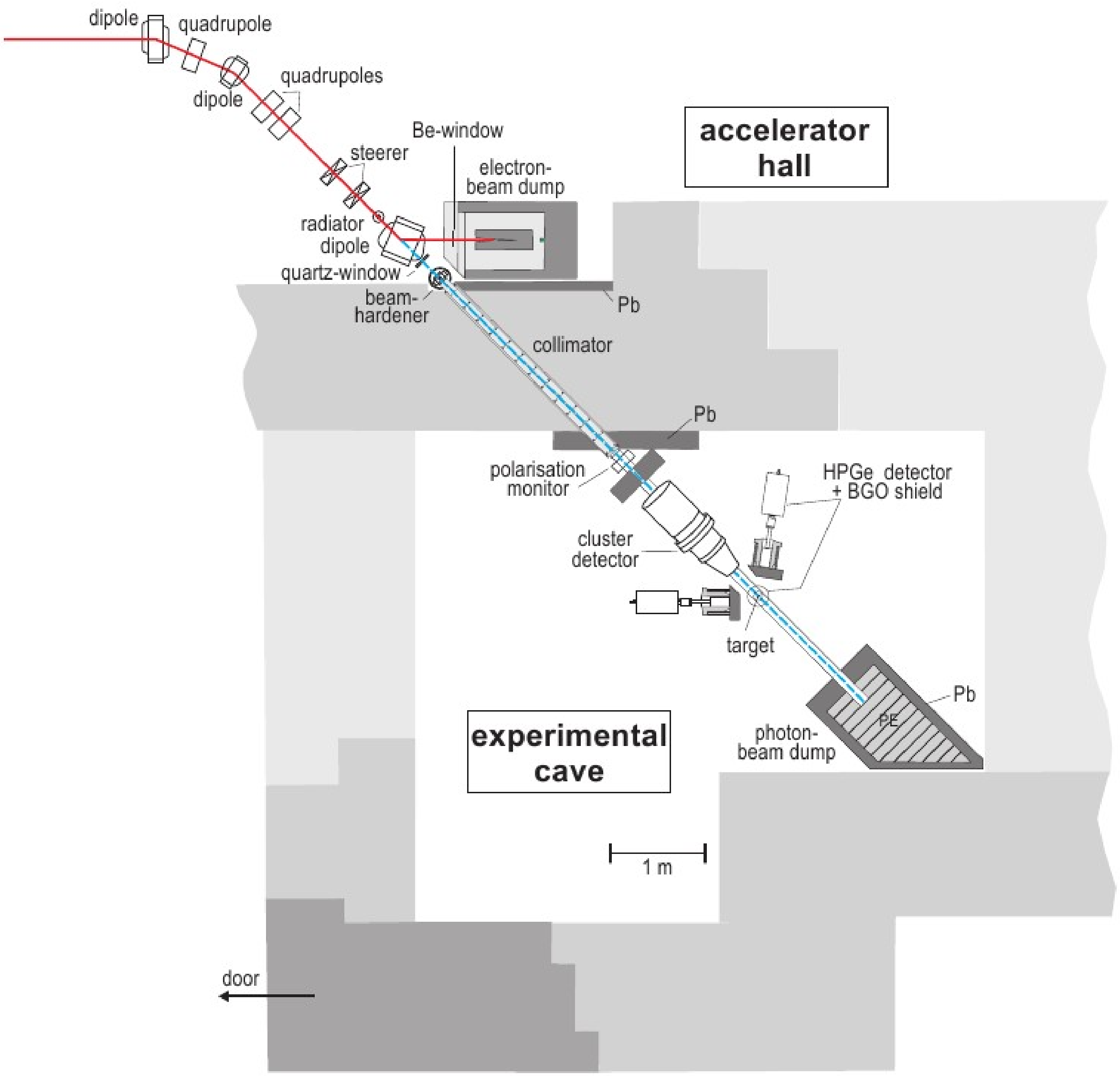


The bremsstrahlung facility at ELBE

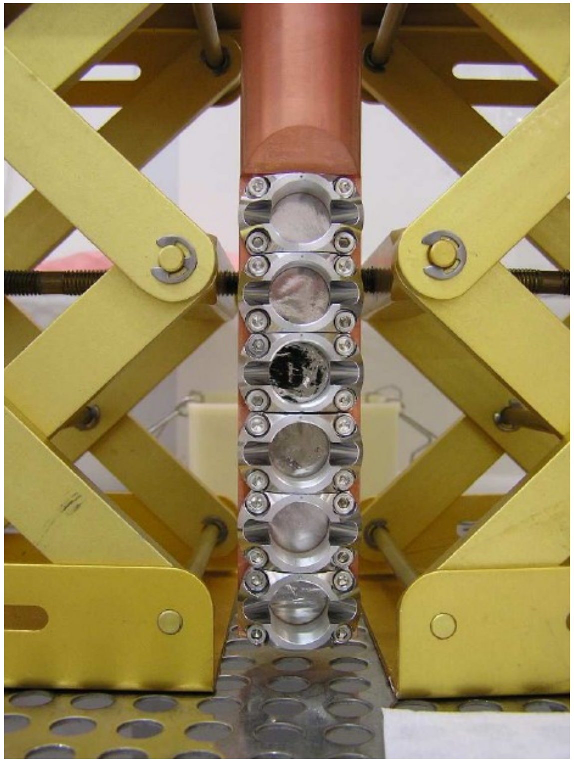
R.S. et al., NIM A 555 (2005) 211

Accelerator parameters:

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

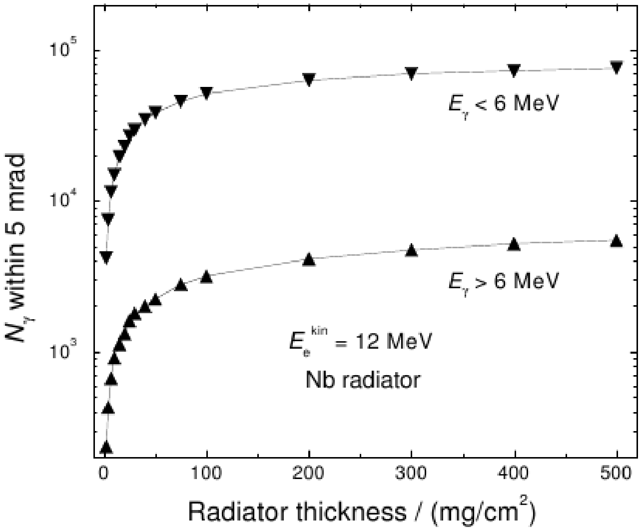


Radiator



Simulated 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 niobium* $-$ *radiator thicknes*



Niobium radiators:

$-$*Six radiator foils of* 16 *mm diameter mounted on a water* $-$ *cooled copper rod*

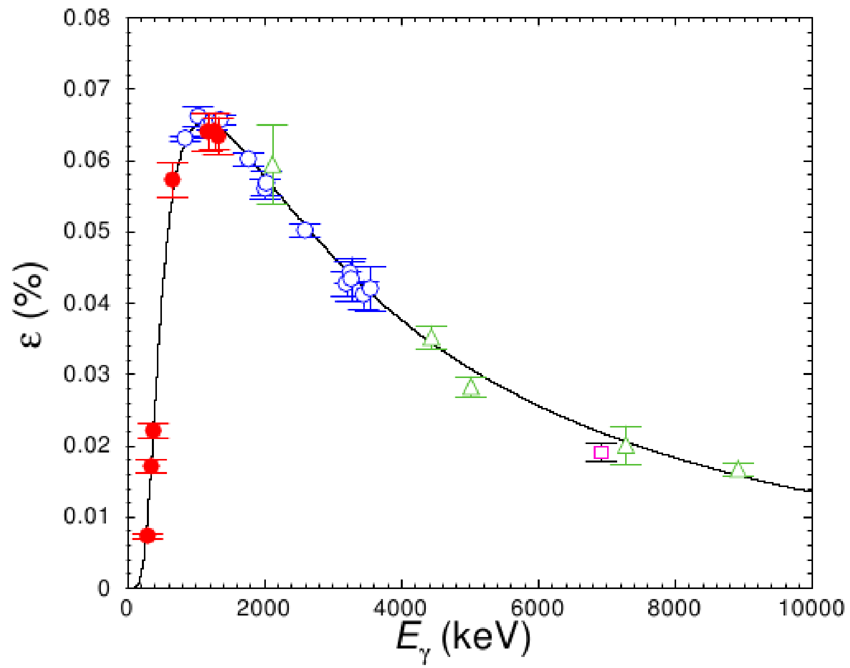
$-$*Ticknesses of* 2, 3, 5, 7 and 12 μm

$-$*Radiator holder can be moved by a DC motor drive without breaking the vacuum*

Setup

4 n-type HPGe detectors (2 vertical at 90 ^{o}, 2 horizontal at 90 ^{o} or 127 ^{o})
Every HPGe is surrounded by escape – suppression shields (8 BGO detectors)

Absolute detector efficiency and photon flux



Absolute efficiency of two detectors at 127° deduced from ^{22}Na, ^{60}Co and ^{133}Ba, (filled circles)/ Relative efficiency deduced from ^{56}Co (open circles), ^{11}B (open triangles) and ^{16}O (open square). Compared to the Efficiency simulated by GEANT3.

^{77}Se(γ,γ') experimental conditions

- 11.5 MeV electron beam
- 600 µA beam current
- 7 µm Niobium radiator
- 1 week
- 2 detectors at 90^{o}, 2 detectors at 127^{o}
- 2 g ^{78}Se target

How to measure dipole strength function

Measured intensity of a γ transition:

$$I_\gamma(E_\gamma,\Theta) > I_s(E_x)\cdot\Phi(E_x)\cdot\varepsilon(E_\gamma)\cdot N_{at}\cdot W(\theta)\frac{\Delta\Omega}{4\pi}$$

Scattering cross section integral:

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

$\Phi(E_x)$ − *absolute photon flux at* E_x

$\varepsilon(E_\gamma)$ − *abolute full-energy-peak efficiency*

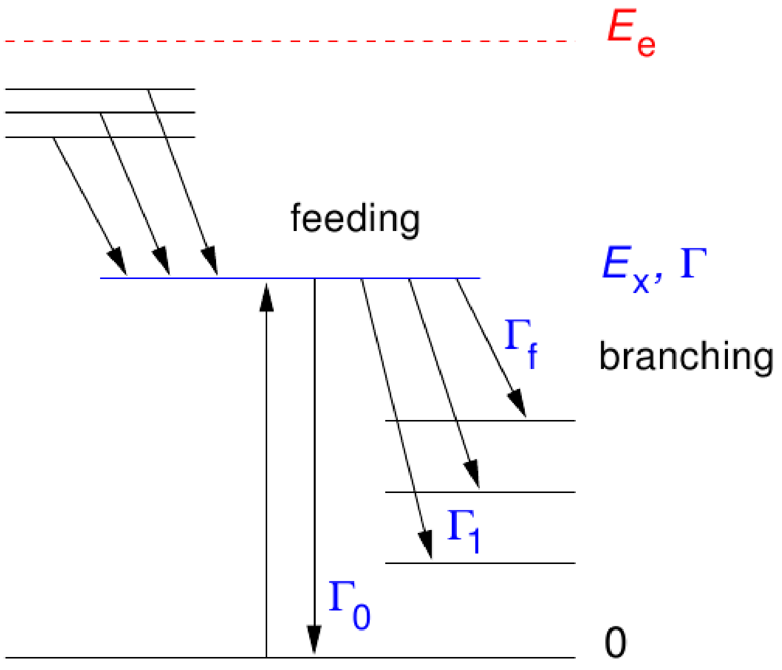
N_{at} − *number of atoms in the sample*

$W(\Theta)$ − *angular correlation of the transition*

$\Delta\Omega$ − *solid angle of a detector*

Absorption cross section:

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

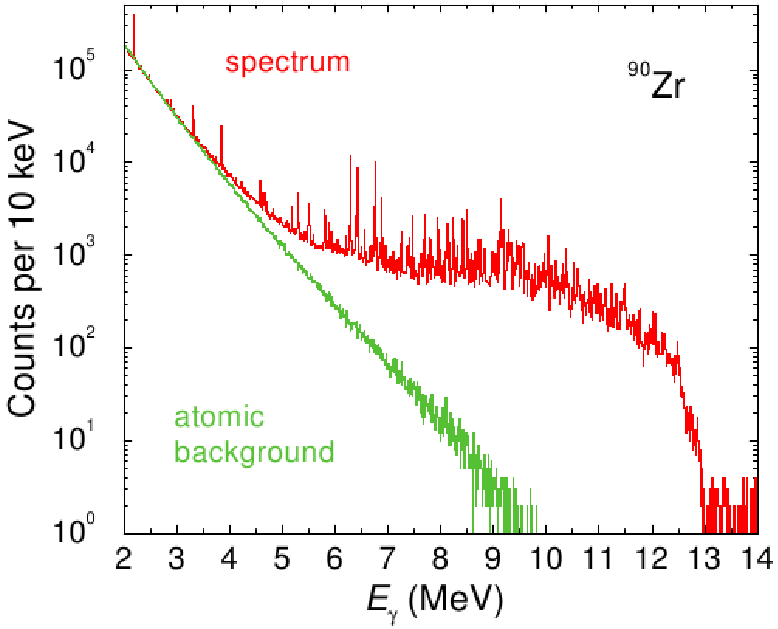


FZD experience in (γ,γ) experiments

nuclide	S_n MeV	E_e^{kin} (MeV) ELBE
^{92}Mo	12.7	6.0[a], 13.2[b,c,d]
^{94}Mo	9.7	13.2[d]
^{96}Mo	9.2	13.2[d]
^{98}Mo	8.6	(3.3, 3.8)[a,e], (8.5, 13.2)[b,c,d]
^{100}Mo	8.3	(3.2, 3.4, 3.8)[a], (7.8, 13.2)[b,c,d]
^{90}Zr	12.0	(7.0, 9.0, 13.2) [f]
^{89}Y	11.5	7.0, (9.5, 13.2) [g]
^{88}Sr	11.1	6.8, (9.0, 13.2, 16.0)[h]
^{87}Rb	9.9	4.0, 13.2
^{86}Kr	9.9	11.2

[a] G. Rusev et al., PRC 73 (2006) 044308
[b] R. Schwengner et al., NPA 788 (2007) 331c
[c] G. Rusev et al., PRC 77 (2008) 064321
[d] A. Wagner et al., JPG 35 (2008) 014035
[e] G. Rusev et al., PRL 95 (2005) 062501
[f] R. Schwengner et al., PRC 78 (2008) 064314
[g] N. Benouaret et al., PRC 79 (2009) 014303
[h] R. Schwengner et al., PRC 76 (2007) 034321

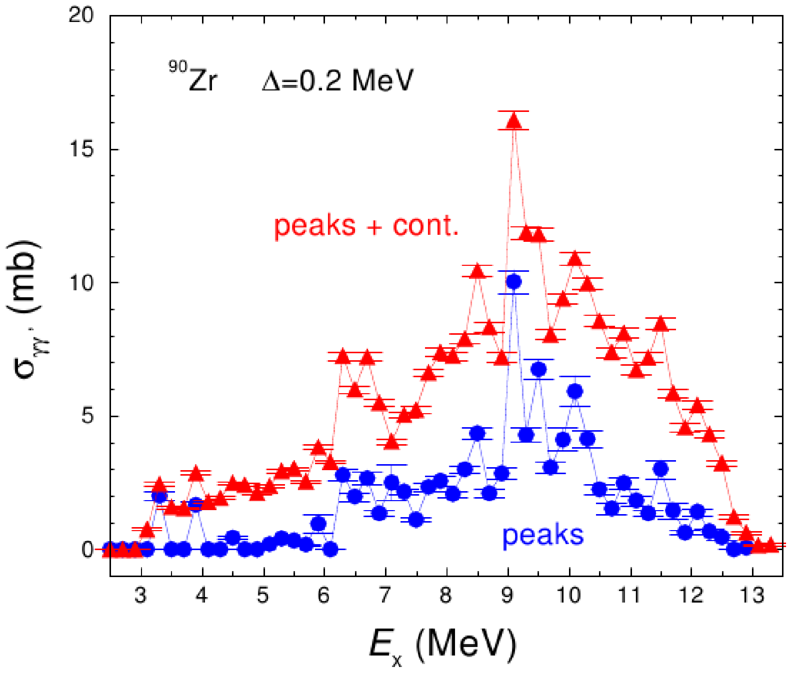
Examples from ^{90}Zr



Experimental spectrum of ^{90}Zr (corrected for room background, detector response, efficiency, measuring time) and simulated spectrum of atomic background.

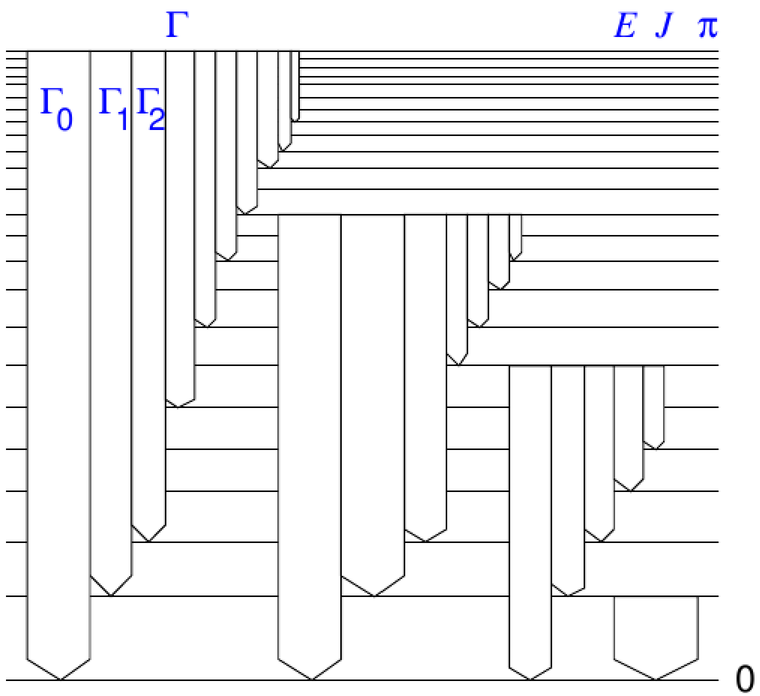
Unresolved strength in the continuum

Examples from ^{90}Zr



Scattering cross sections in ^{90}Zr averaged over energy bins of 0.2 MeV, not corrected for branching, derived from the difference of the experimental spectrum and the atomic background (triangles) and from the resolved peaks only (circles).

Correction of the strength function by using statistical methods developed by G. Rusev (*FZD PhD dissertation 2007*):



Correction of the strength function by using statistical methods:
(G. Rusev, FZD PhD thesis)

a) Monte Carlo simulations of γ-ray cascades from groups of levels in 100 keV bins over the whole energy range

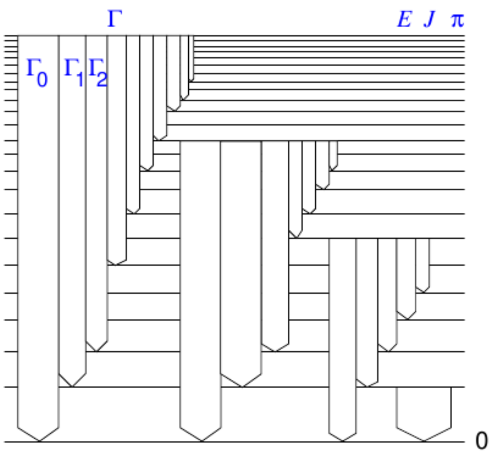
b) Level scheme of *J*=0, 1 and 2 states constructed using:

* Back-shifted Fermi-gas model
* Wigner level-spacing distributions

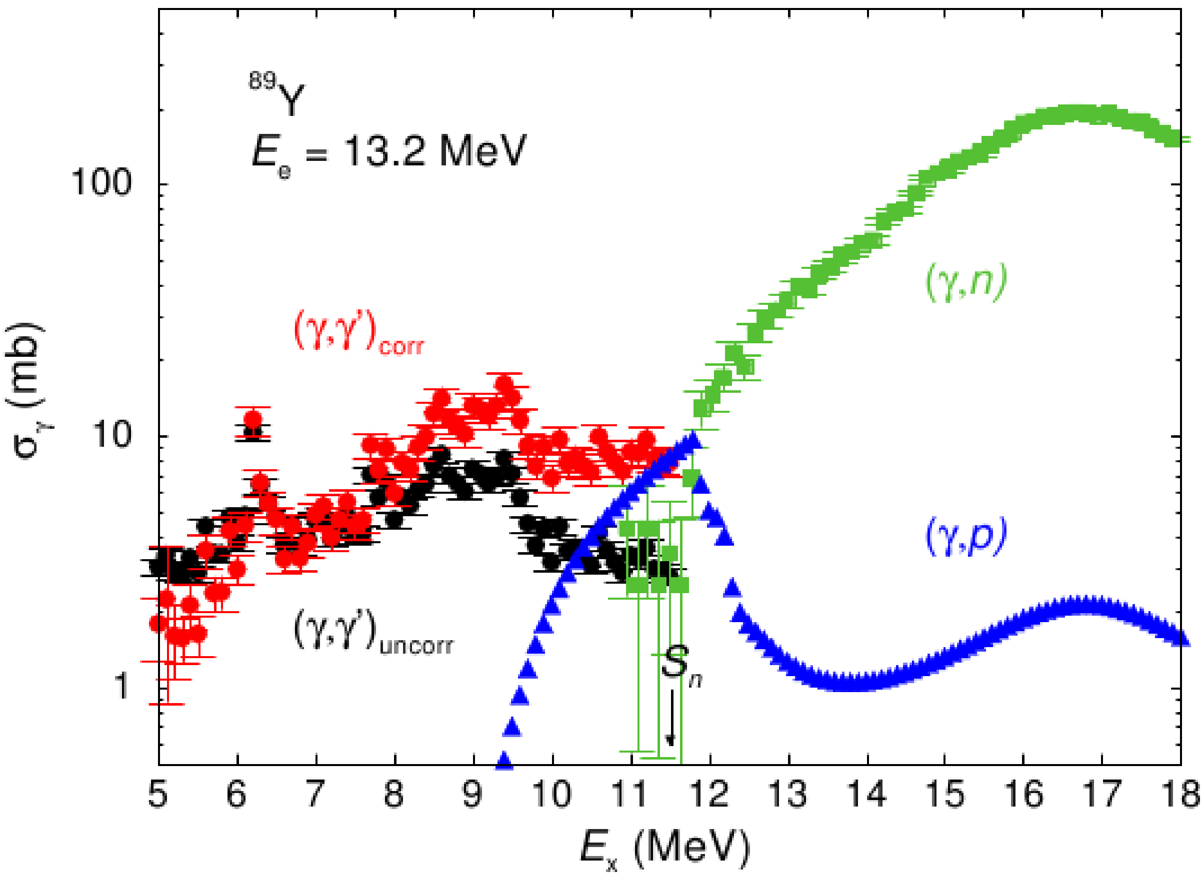
c) Partial decay widths calculated by using:

* Photon strength functions approximated by Lorentzian parametrisations
* Porter-Thomas distributions of decay widths

d) Feedings intensities subtracted and intensities of *g.s.* Transitions corrected with calculated branching ratios Γ_0/Γ.



Examples of branching corrected gamma strength for ^{89}Y

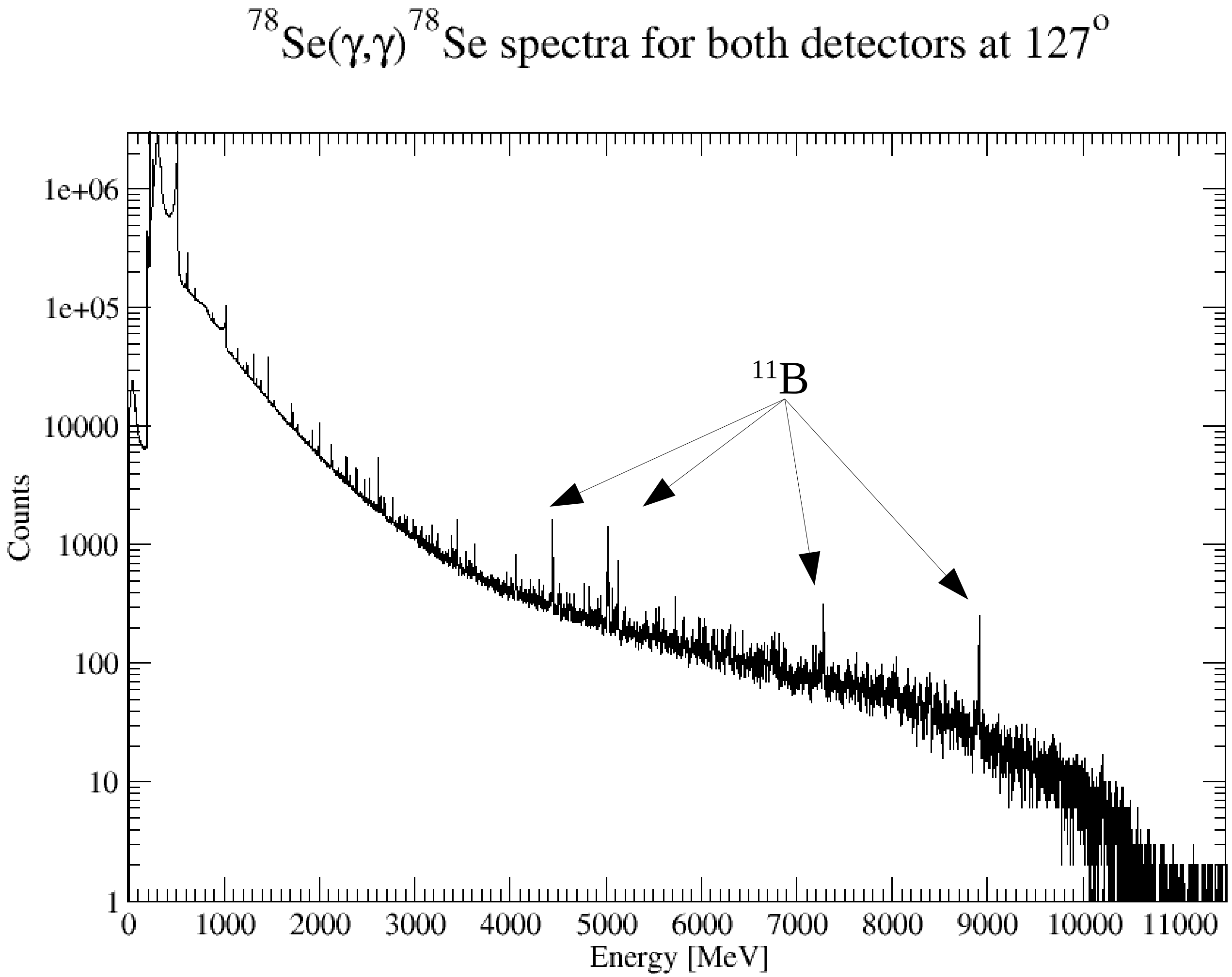


^{89}Y(γ,γ')

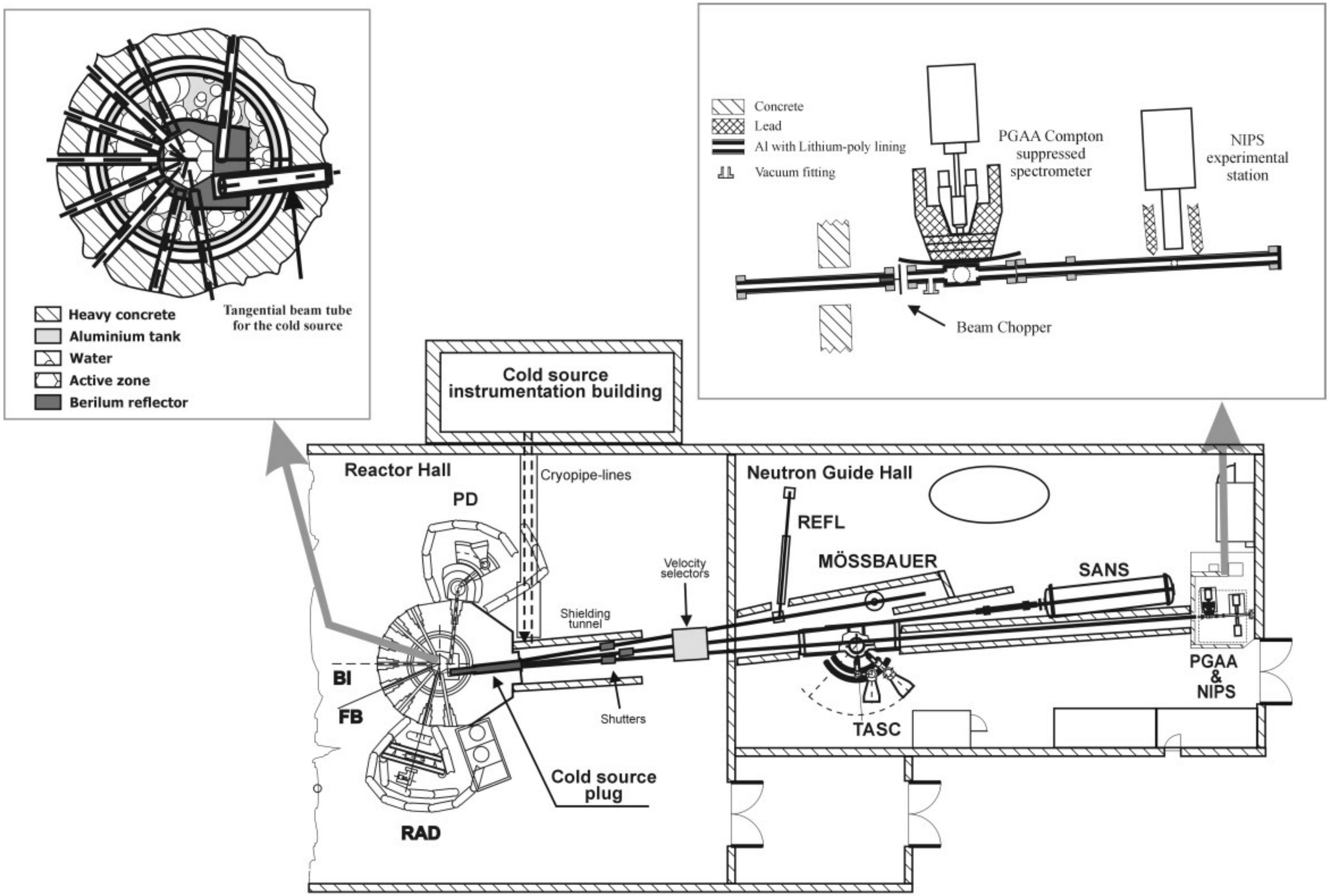
(γ, p) calculated
Talys

(γ, n) data
NPA 175 (1971) 609

Present $^{77}Se(\gamma,\gamma')$ spectrum from 127° detectors



Top view of the BRR and the guide hall



Courtesy to L. Szentmikloski

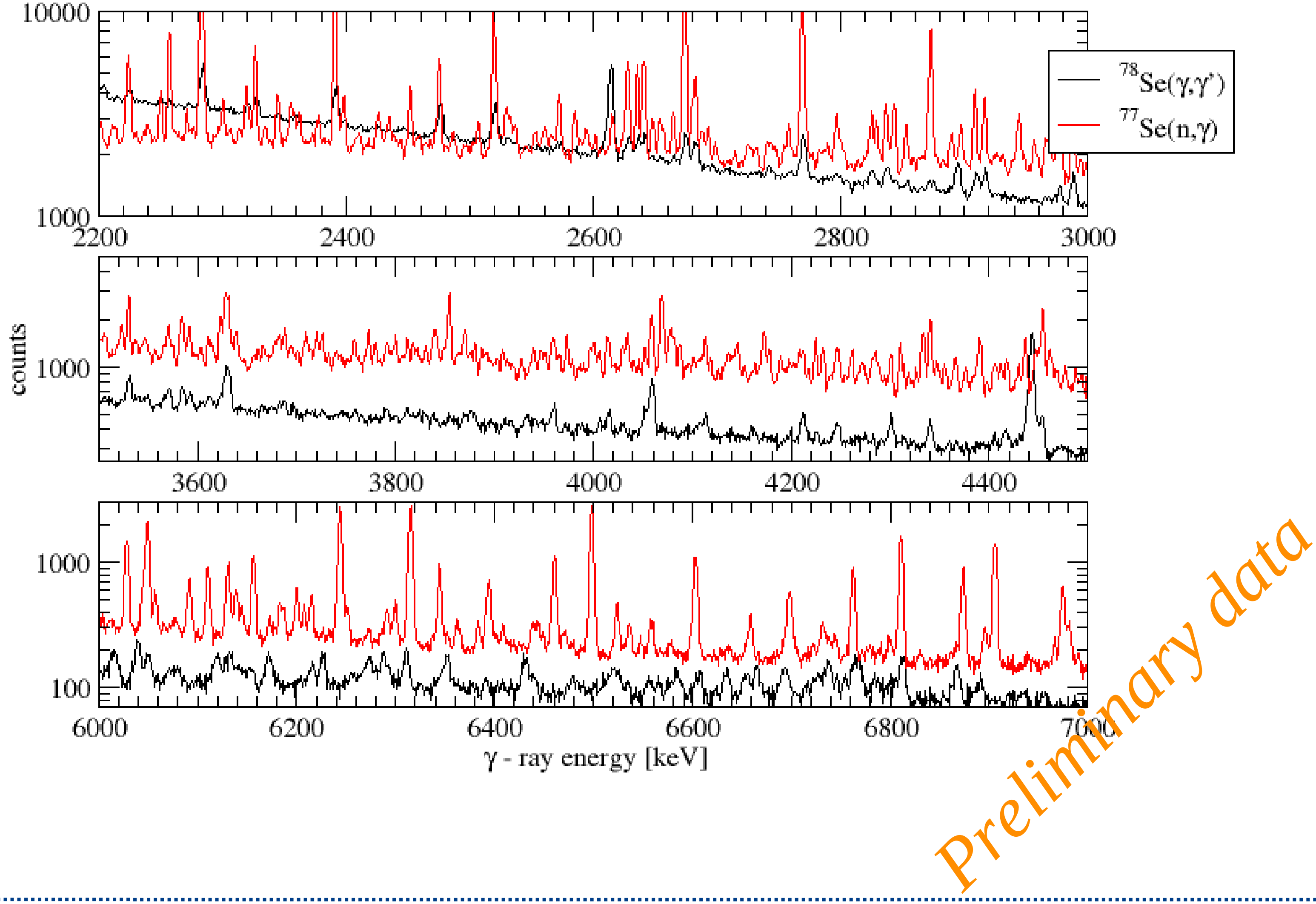
Experimental area at IKI

Target chamber

~ 42 b cross section for $^{77}Se(n,\gamma)$ reaction

We collimated cold neutron beam with 10 mm^2 collimator and obtained 6000 counts/ s with standard detector at PGAA station

Comparison between $^{78}Se(\gamma,\gamma')$ and $^{78}Se(n,\gamma)$ measurements



$^{77}Se(n,\gamma)$ test measurement

June 2008 at IKI Budapest ^{77}Se test measurement is performed:

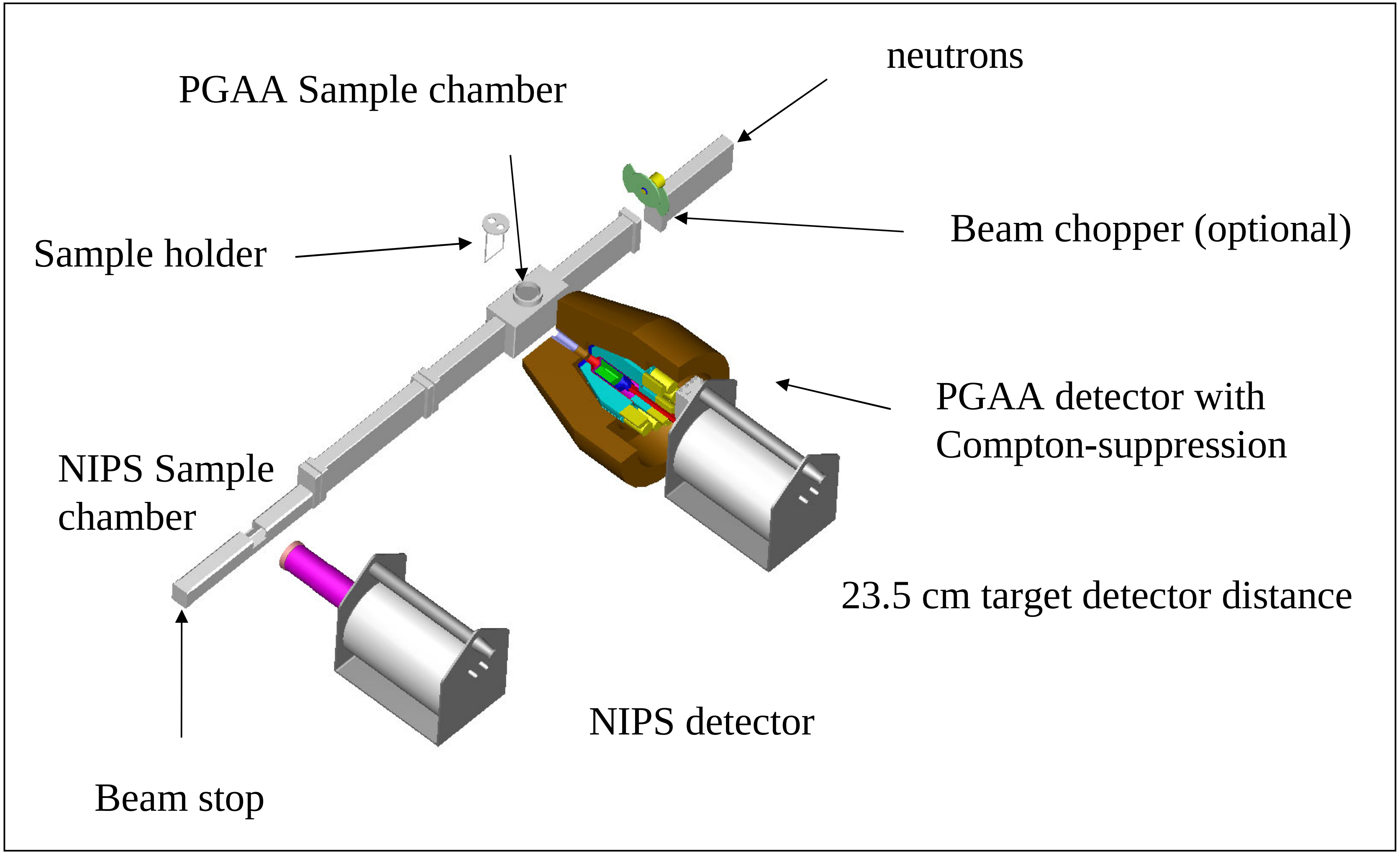
PGAA station
- Compton suppression shielded, 25 % n-type Germanium detector
- 23.5 cm target – distance
- Thermal – equivalent flux at target is 5 x 10^7 $cm^{-2}s^{-1}$
- 10 mm^2 collimated cold neutron beam
- 100 mg enriched ^{77}Se target
- 6000 counts/ sec

- $^{77}Se(n,\gamma)^{78}Se$ experiment will be performed at beginning of October 2009 at IKI, Budapest.
- 100% n-type HPGe with BGO Compton shield from FZD will be used

Outlook

^{78}Se(γ,γ') successfully performed at FZD
^{77}Se(n,γ) is scheduled for October 2009
^{196}Pt(γ,γ') and ^{195}Pt(n,γ) are proposed to EFNUDAT scientific board
(γ,γ') data analysis will be done at FZD Rossendor.
(n,γ) data will be analyzed at FZD with expertise help from IKI
Data analysis procedures are well established.
Two step cascade measurements ^{77}Se(n,γ) and {^{195}Pt(n,γ)} will be performed at Řež, Czech Republic.

A schematic view of PGAA and NIPS stations



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