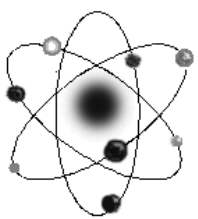
Photons in Nuclear Structure and Nuclear Astrophysics - some Examples

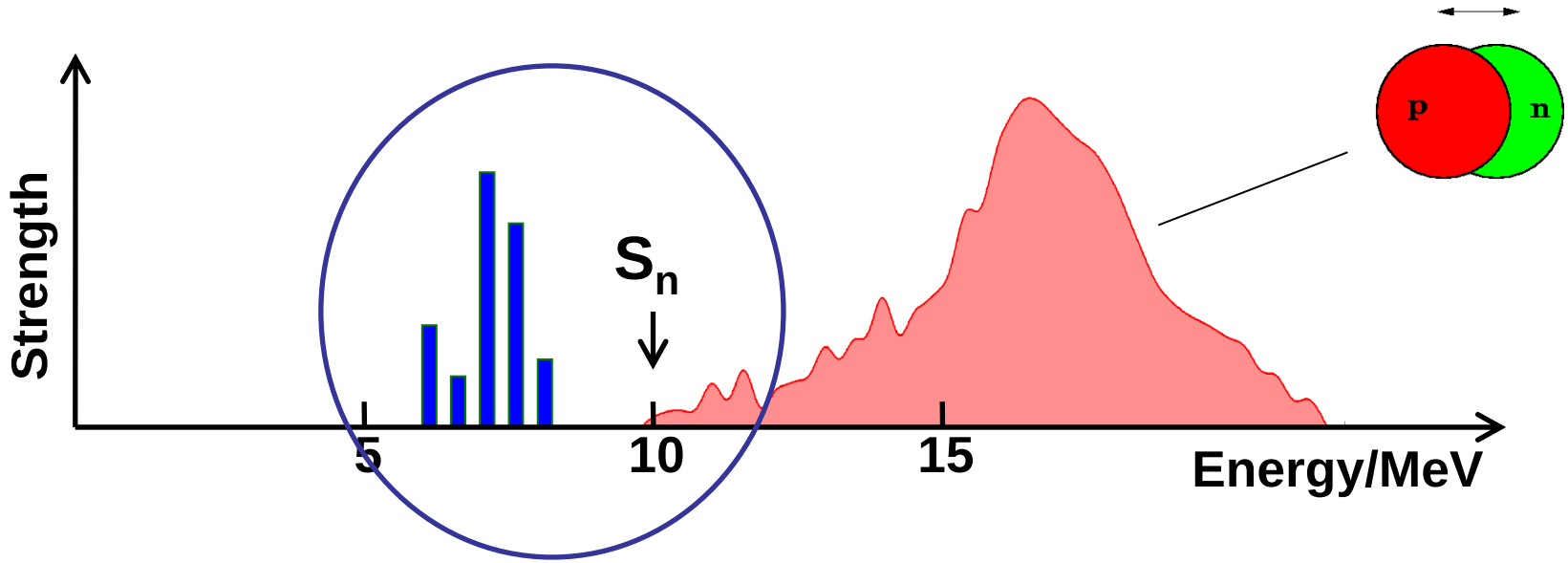
- The photoresponse of atomic nuclei
- The Pygmy Dipole Resonance
- Synthesis of heavy proton rich nuclei



VARNA 2005

Andreas Zilges
Institut für Kernphysik
TU Darmstadt

The photoresponse of atomic nuclei



Considerable E1 strength is predicted around the neutron threshold

- F. Iachello, Physics Letters B 160 (1985) 1
- P. van Isacker, Phys. Rev. C 45 (1992) R13
- G. Colò et al., Physics Letters B 485 (2000) 362
- D. Vretenar, P. Ring et al., Physics Letters B 487 (2000) 334

E1 Excitations around the Particle Threshold

- **Nuclear structure phenomenon**

  Fundamental E1 mode below the GDR

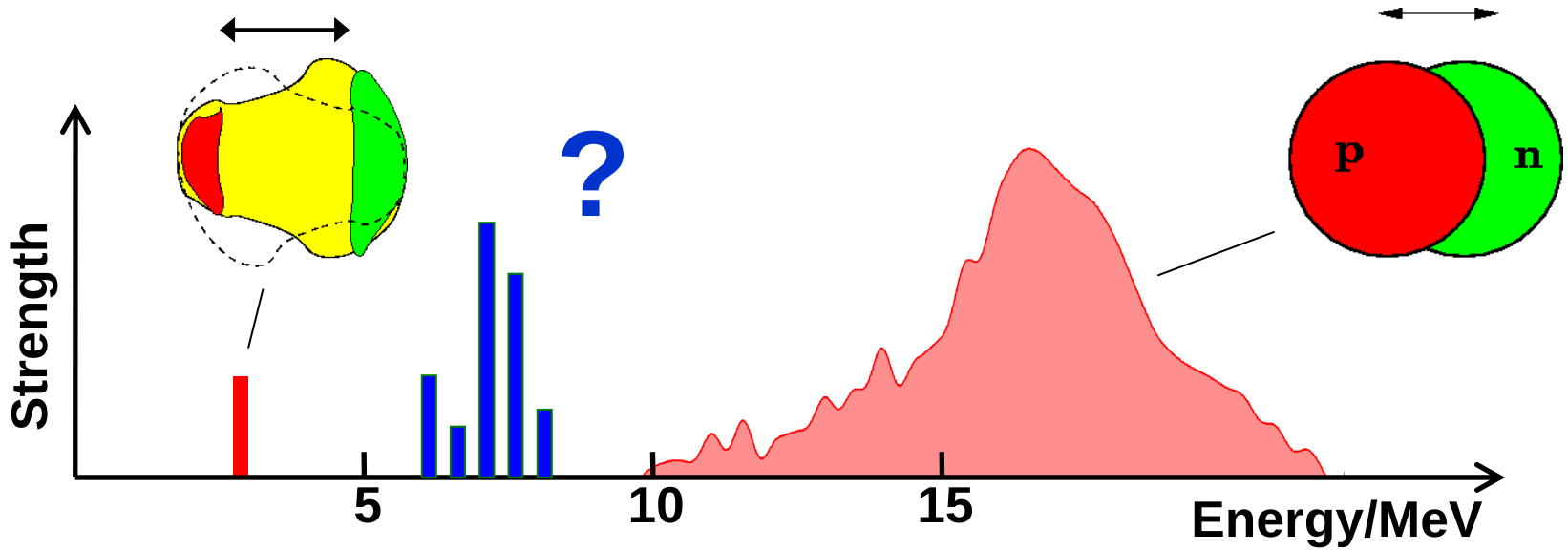
- **Importance for understanding of exotic nuclei**

  E1 strength will be shifted to lower energies in neutron rich systems

- **Impact on nucleosynthesis**

  Gamow window for photo-induced reactions in explosive stellar events

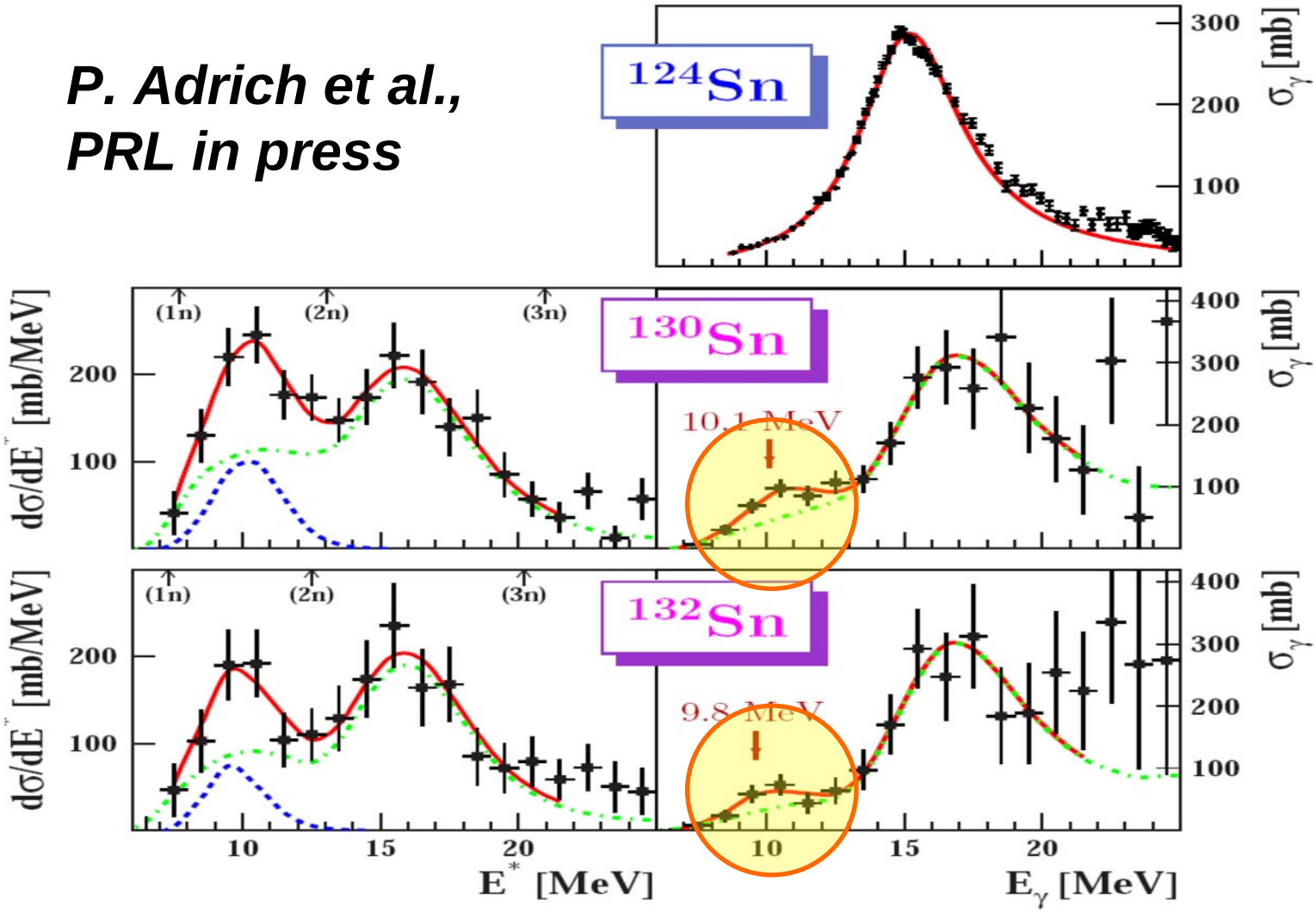
Electric Dipole Strength in Nuclei



- **Two Phonon Excitation: E_x ~ 3 MeV, B(E1) ~ 10^{-2} W.u.**
- **Giant Dipole Resonance: E_x ~ 18 MeV, B(E1) ~ 10 W.u.**
- **Pygmy Dipole Resonance ?**

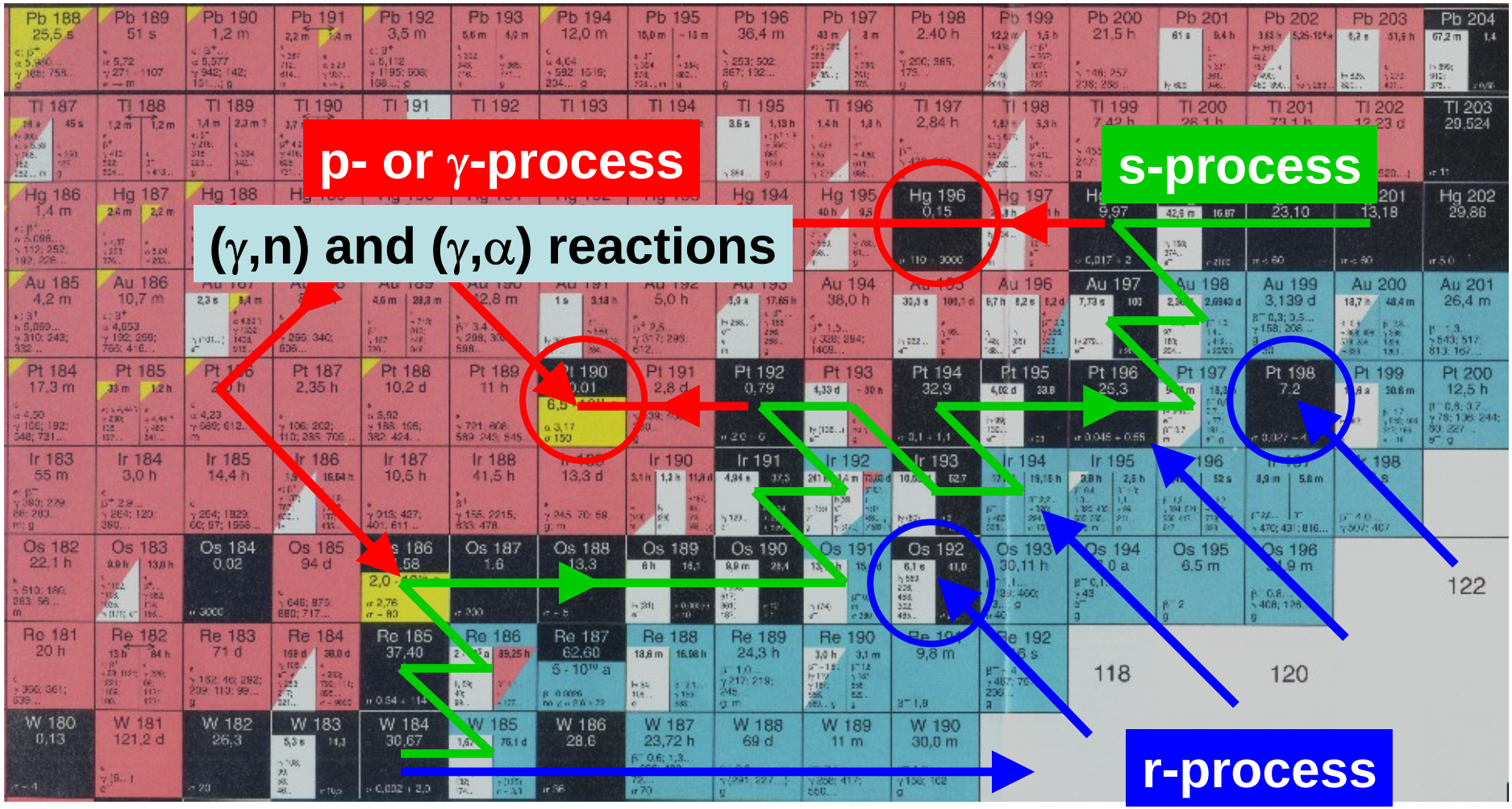
E1 excitations in exotic nuclei

P. Adrich et al.,
PRL in press



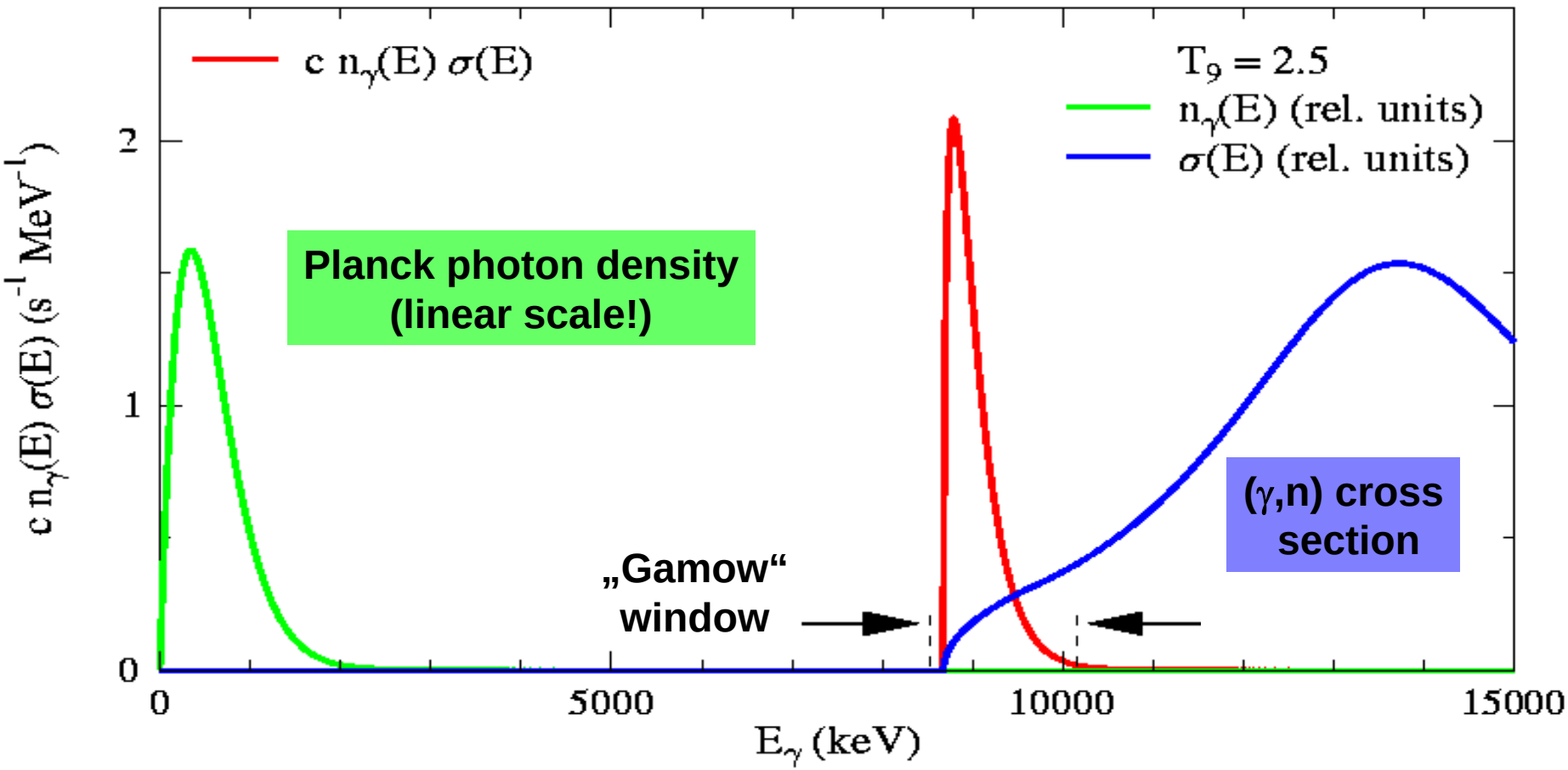
A few % of the EWSR found around 10 MeV

Impact on Nucleosynthesis



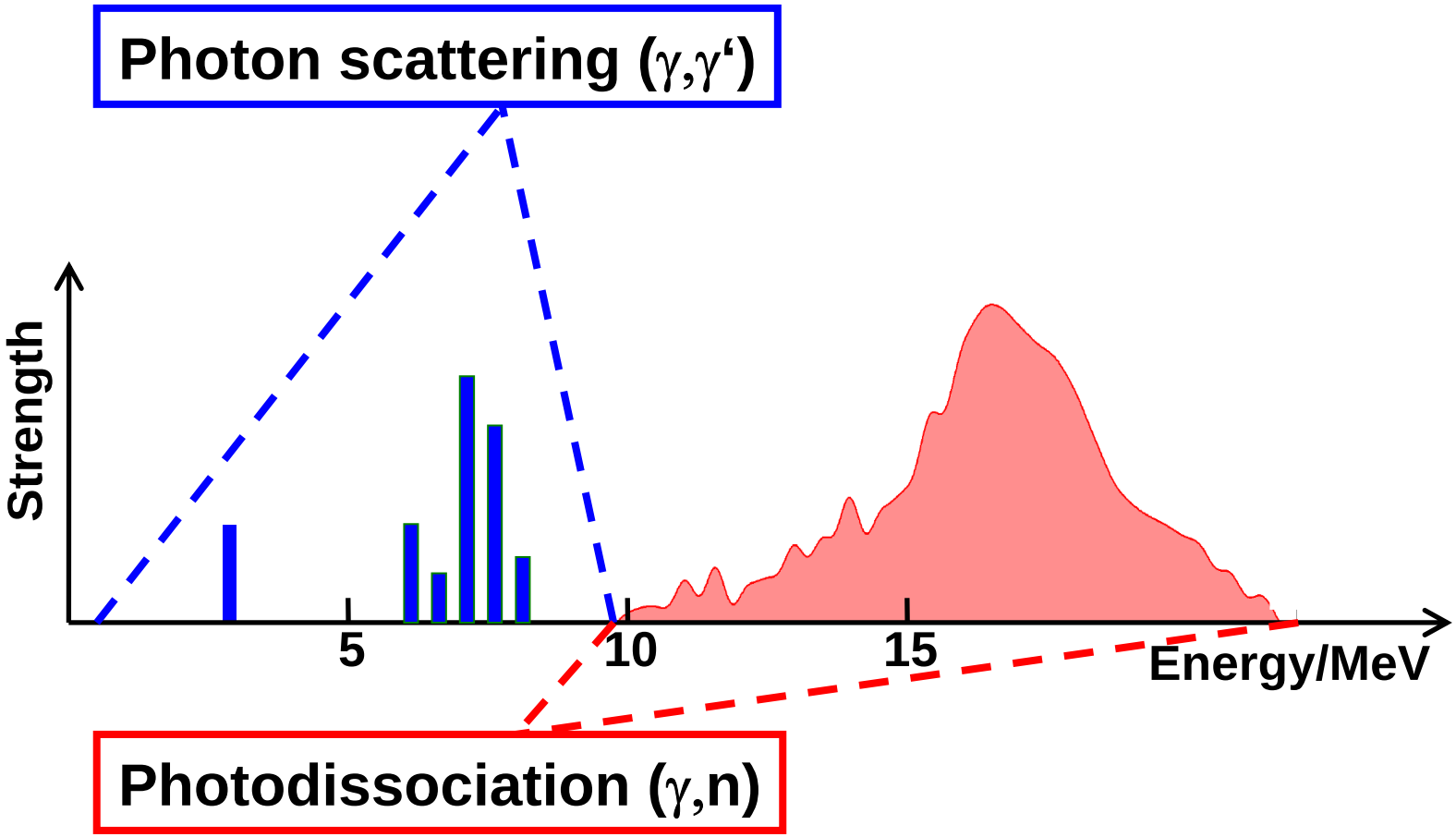
What is the relevant energy range ?

Reaction Rate: $\lambda(T) = c \int n_\gamma(E)\, \sigma(E)\, dE$



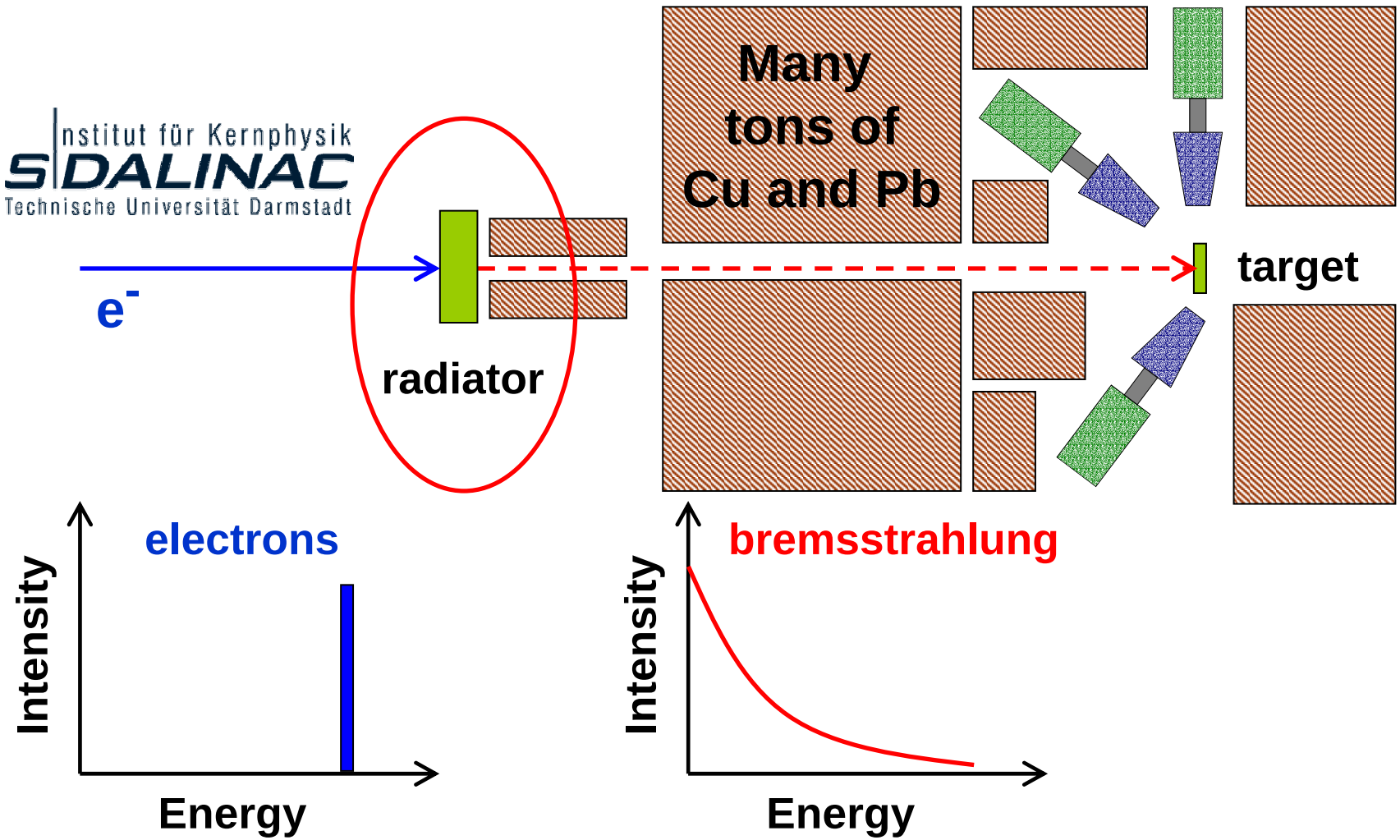
P. Mohr et al., Phys. Lett. B 488 (2000) 127

Experimental tools



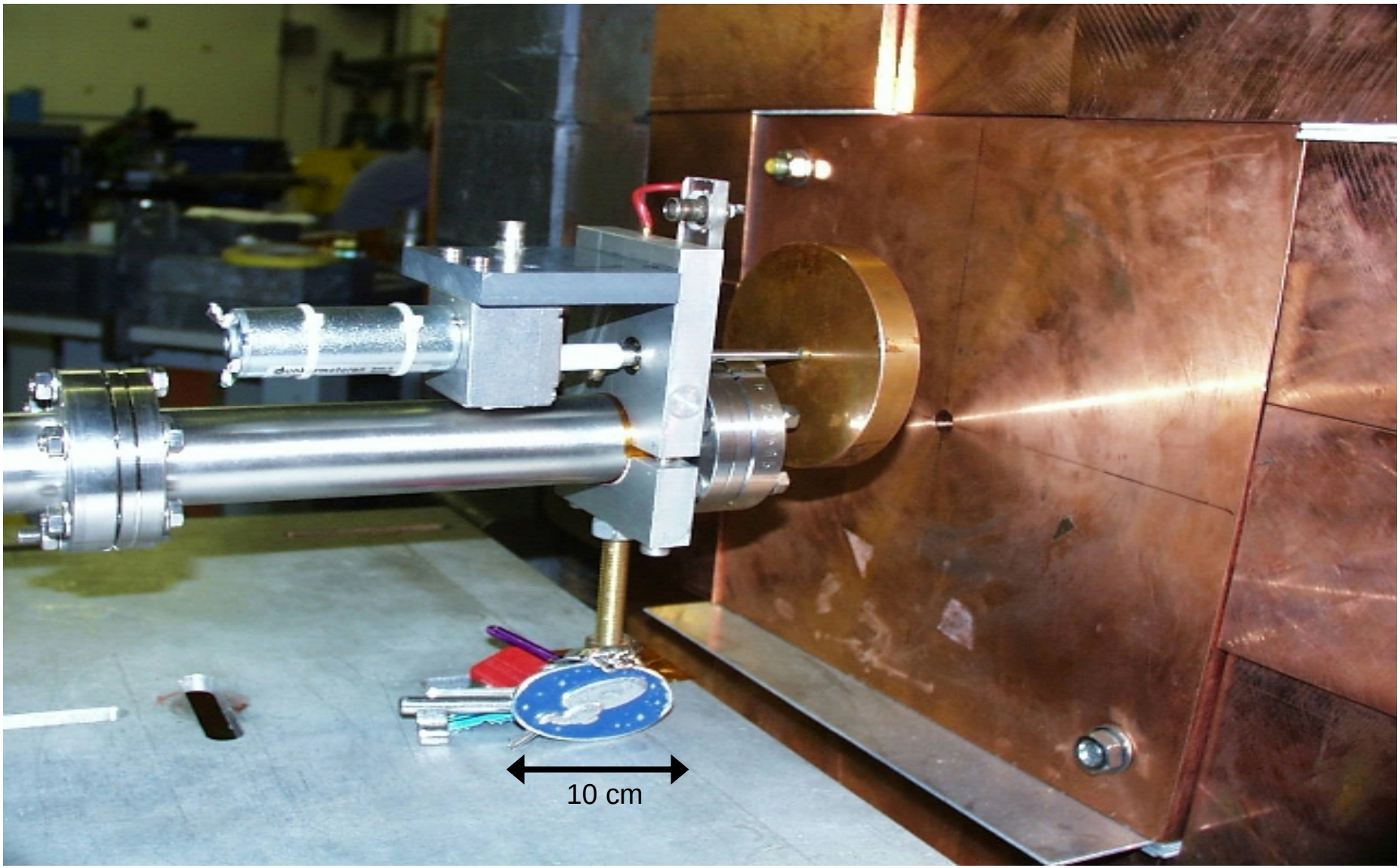
Real and virtual photons can be used for excitation!

Photon Scattering (Nuclear Resonance Fluorescence – NRF)

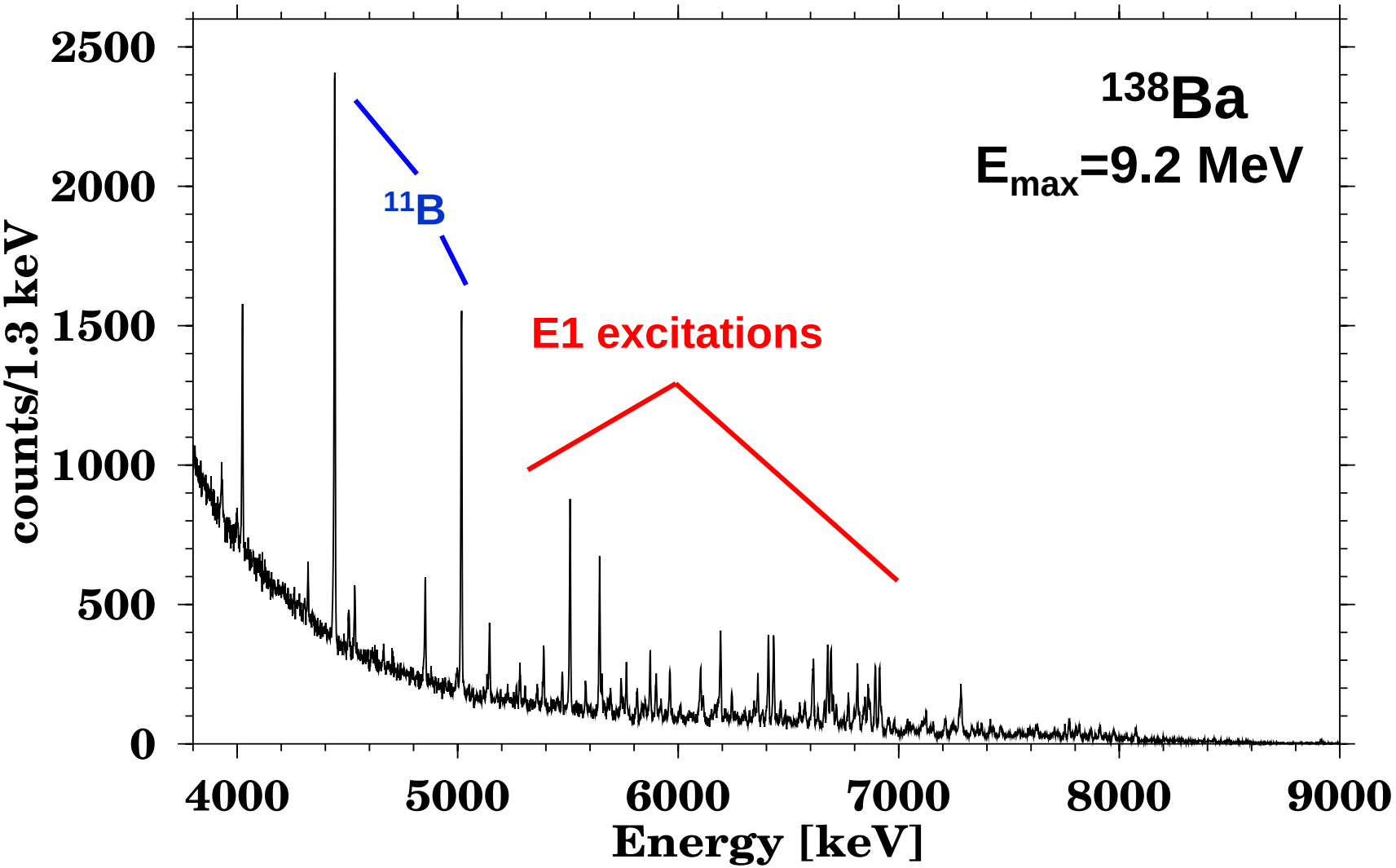


Review: U. Kneissl, H.H. Pitz, and A.Z., Prog. Part. Nucl. Phys. 37 (1996) 349

Radiator and Collimator at the S-DALINAC

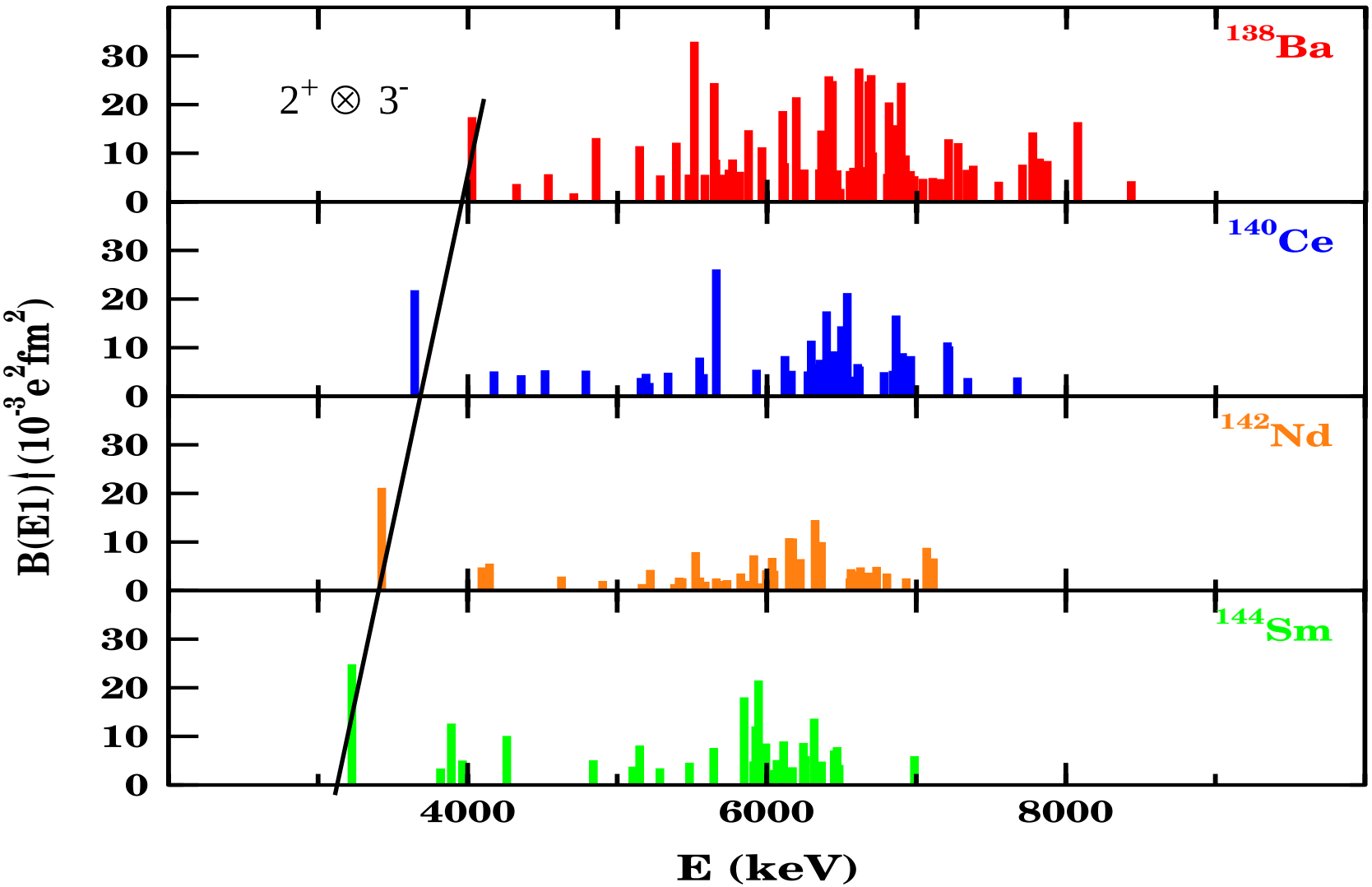


Photon scattering off ^{138}Ba



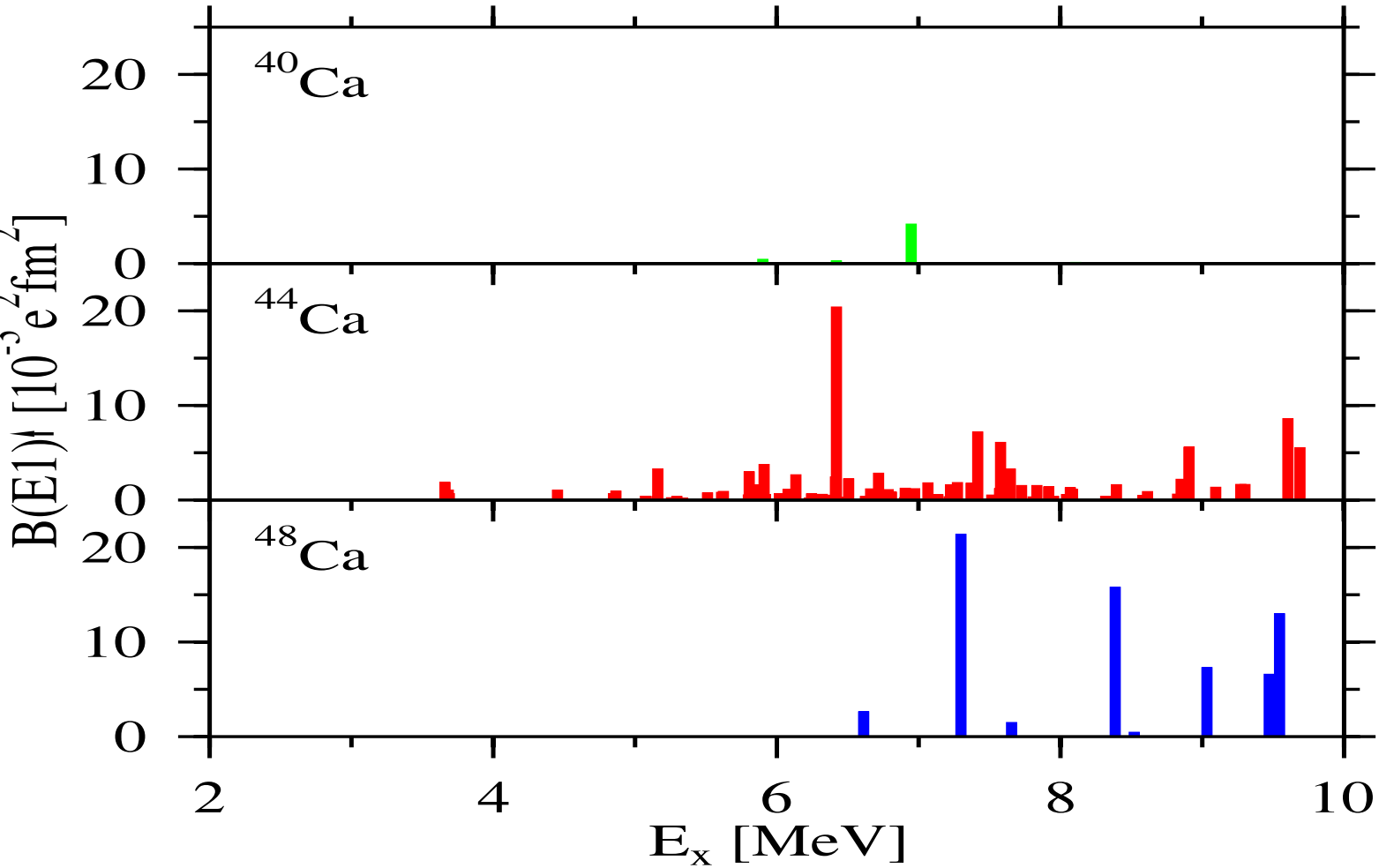
*A. Z. et al., Phys. Lett. B **542** (2002) 43*

E1 strength distribution in N=82 nuclei



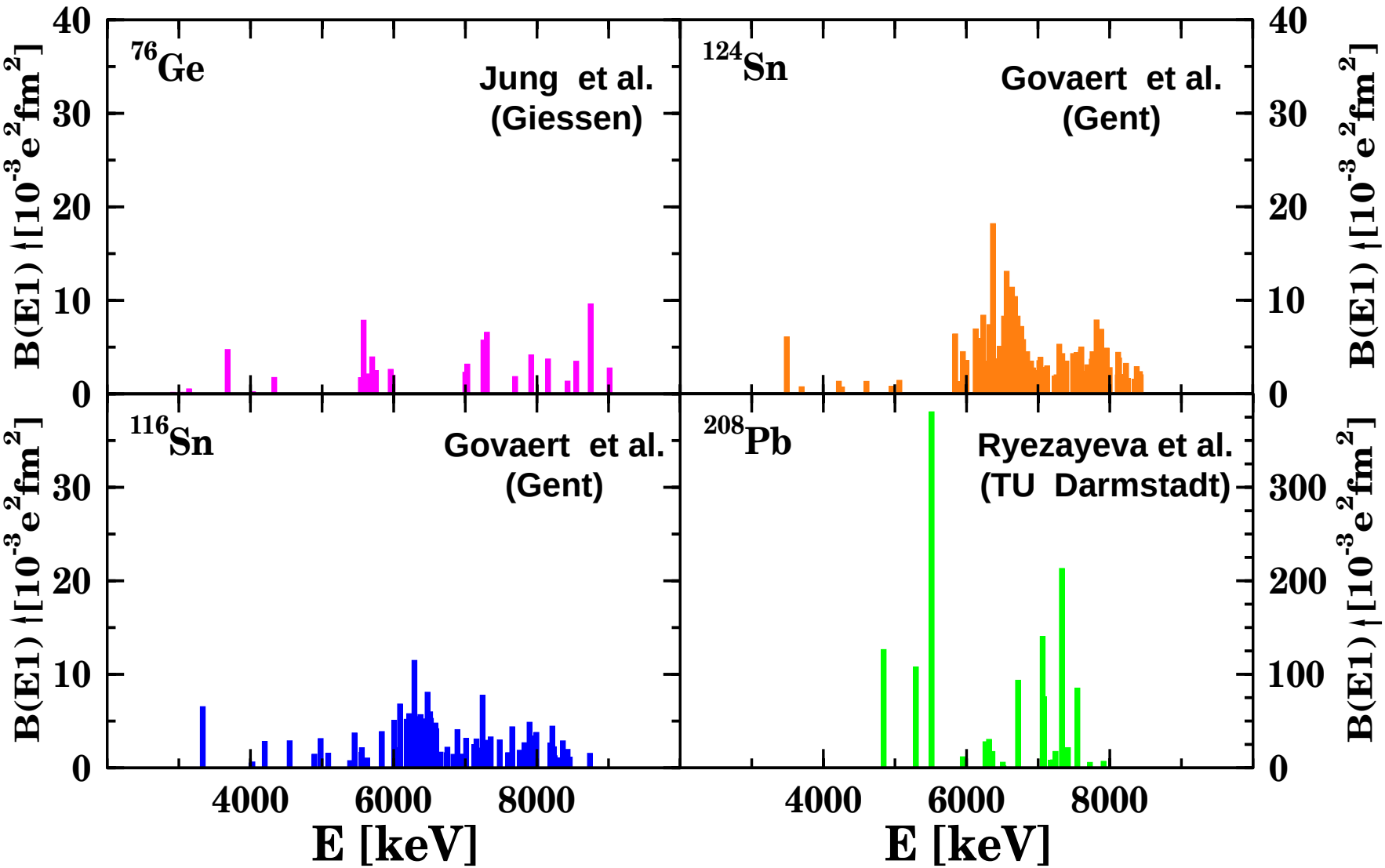
*A. Z. et al., Phys. Lett. B **542** (2002) 43*

E1 strength distribution in Ca isotopes

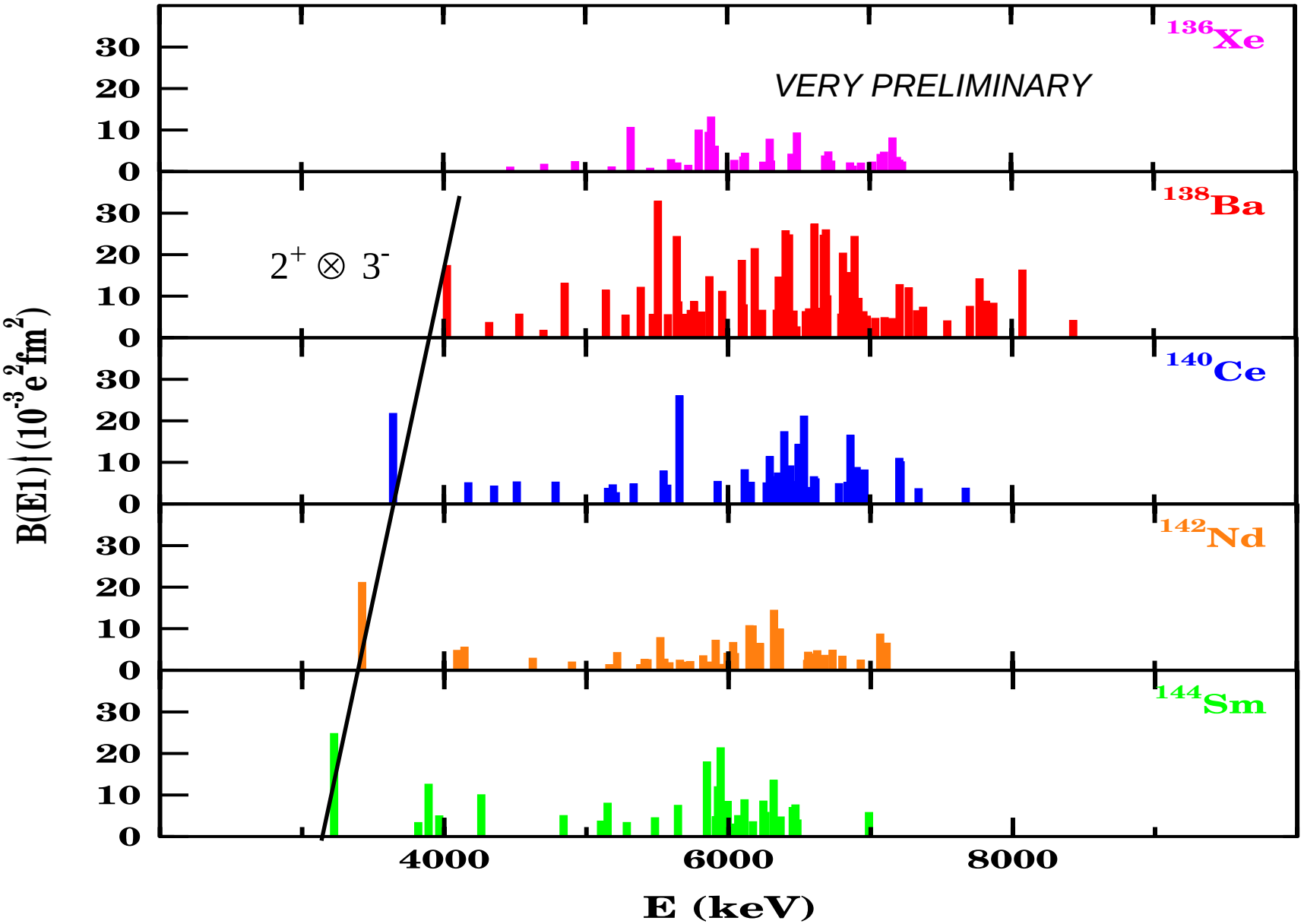


T. Hartmann et al., Phys. Rev. Lett. ***93*** *(2004) 192501,*
Phys. Rev. C ***65*** *(2002) 034301,*
Phys. Rev. Lett. ***85*** *(2000) 274*

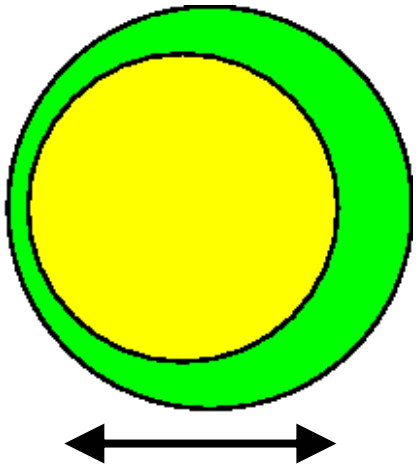
E1 strength distribution in nuclei



E1 strength distribution in N=82 nuclei



Neutron/proton „skin“ excitations

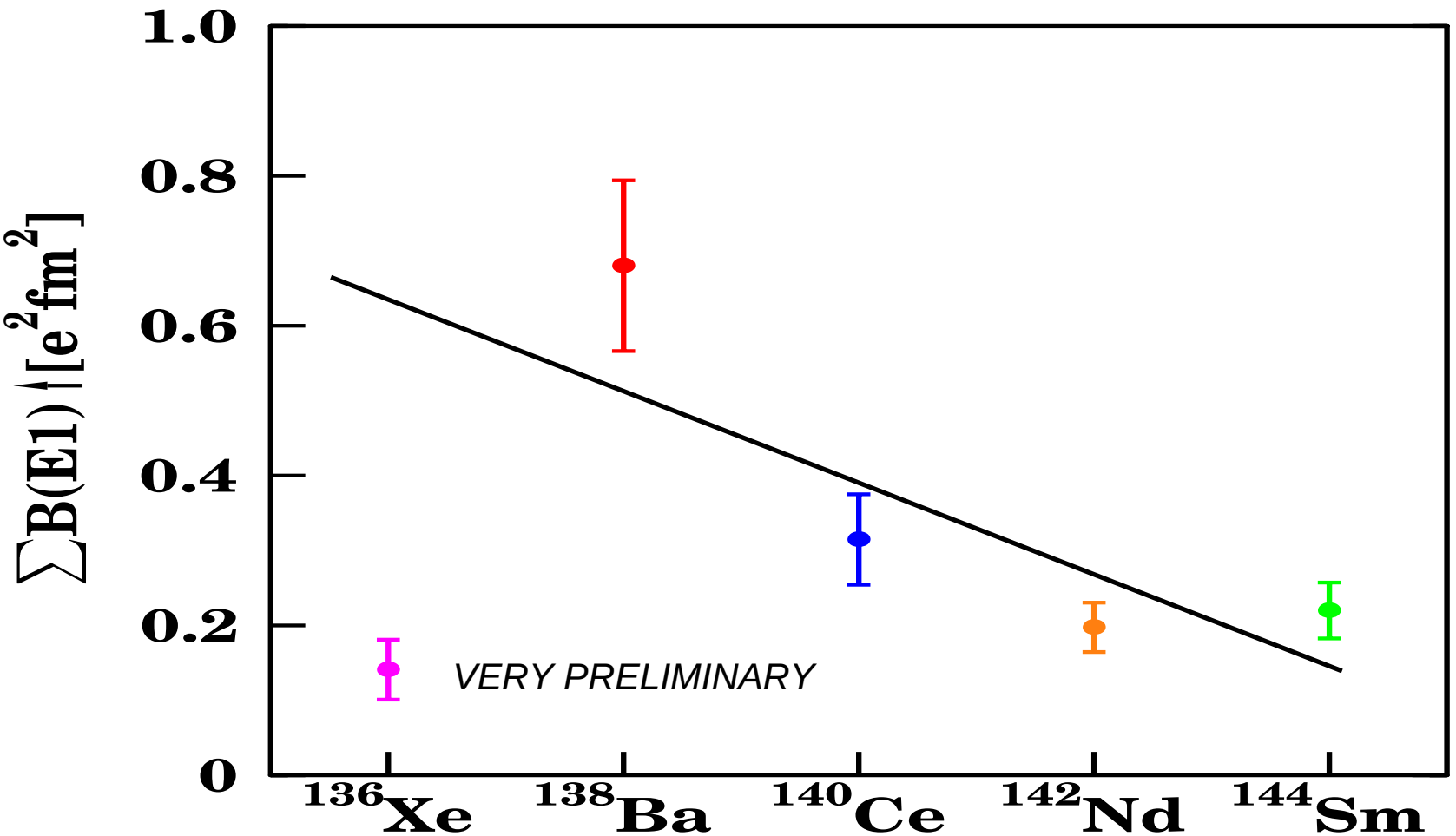


Oscillations of a neutron or proton rich periphery vs. the core leads to electric dipole excitations

ΣB(E1) should scale with N/Z ratio !

*see e.g.: J. Chambers et al., Phys. Rev. C **50** (1994) R2671*
*P. van Isacker et al., Phys. Rev. C **45** (1992) R13*

E1 strength below 9 MeV in N=82 nuclei



A. Z. et al., Phys. Lett. B ***542*** *(2002) 43, and*
S. Volz et al., to be published

Models generating E1 strength around the neutron threshold

- Relativistic RPA

  D. Vretenar, A. Wandelt, P. Ring, Pl

  Talk this morning

  *D. Vretenar, N. Paar, P. Ring et al., Phys. Rev. C **65** (2002) 021301*

- Quasiparticle Phonon Model (QPM), QRPA

  *V. Ponomarev, J. Wambach et al., Phys. Rev. Lett. **89** (2002) 241*
  *N. Tsoneva, H. Lenske, Ch. Stoyanov, Phys. Lett. B **586** (2004) 213*

  Talks on Wednesday

- QRPA with co[illegible]S

  *G. Colò, P.F. Bortignon et al., Phys. Lett. B **485** (2000) 362*
  *T. Hartmann, E. Litvinova et al., Phys. Rev. Lett. **93** (2004) 192501*

- Local Isospin Resonances

  *F. Iachello, Phys. Lett. B **160** (1985) 1*
  F. Iachello, priv. com. 2004

Summary

- An E1 resonance exhausting up to 1% of the EWSR is observed in all examined nuclei around about 7 MeV
- We do not know the complete systematics, the isospin character, the decay pattern and the form factor of these states
- More resonance like strength is found above the particle threshold in n-rich systems
- We do not understand the connection between the strength below and above the threshold and the strength in stable and exotic nuclei

Outlook

- **Systematic strength measurements**

  [(γ,γ') and (γ,n) @ S-DALINAC and at GSI]

- **Isospin character**, **branching ratios**

  [$(\alpha,\alpha'\gamma)$ @ KVI]

- **Branching ratios, parities**

  [$(\vec{\gamma},\gamma')$ @ HIγS, Duke University]

- **Form Factors**

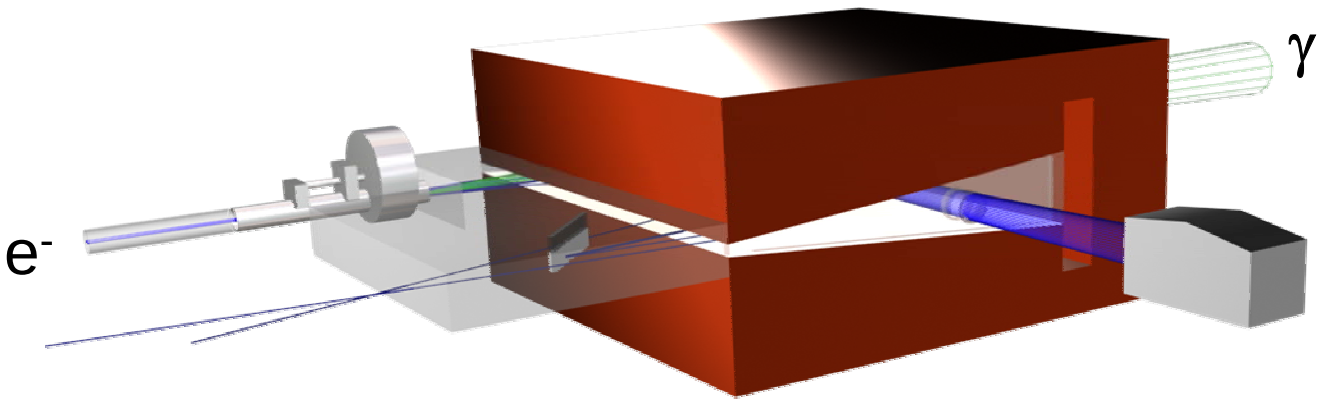
  [(e,e') @ S-DALINAC]

- **Improved model calculations**

  [Predictive power, applications in nuclear astrophysics]

(γ,n) cross section measurements – Determination of E1 strength in the tail of the GDR

High Resolution Photon Tagger @ S-DALINAC



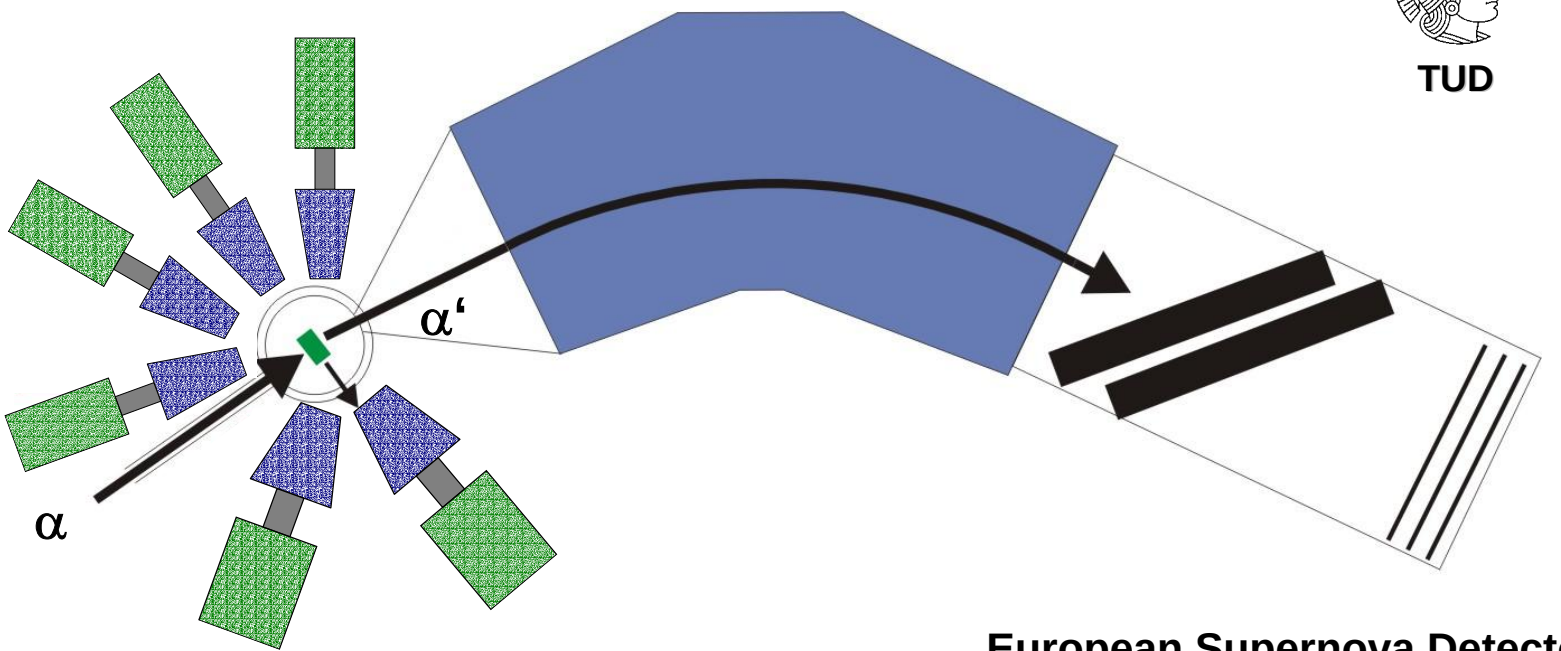
- „Clam Shell“ magnet design
- scintillating fibres for electron detection
- energy resolution < 0.25 % for 8 MeV < E_γ < 16 MeV

→ talk by Jens Hasper on Sunday morning

The new ISOSPIN-Meter at KVI

Big Bite Spectrometer (BBS)

TUD



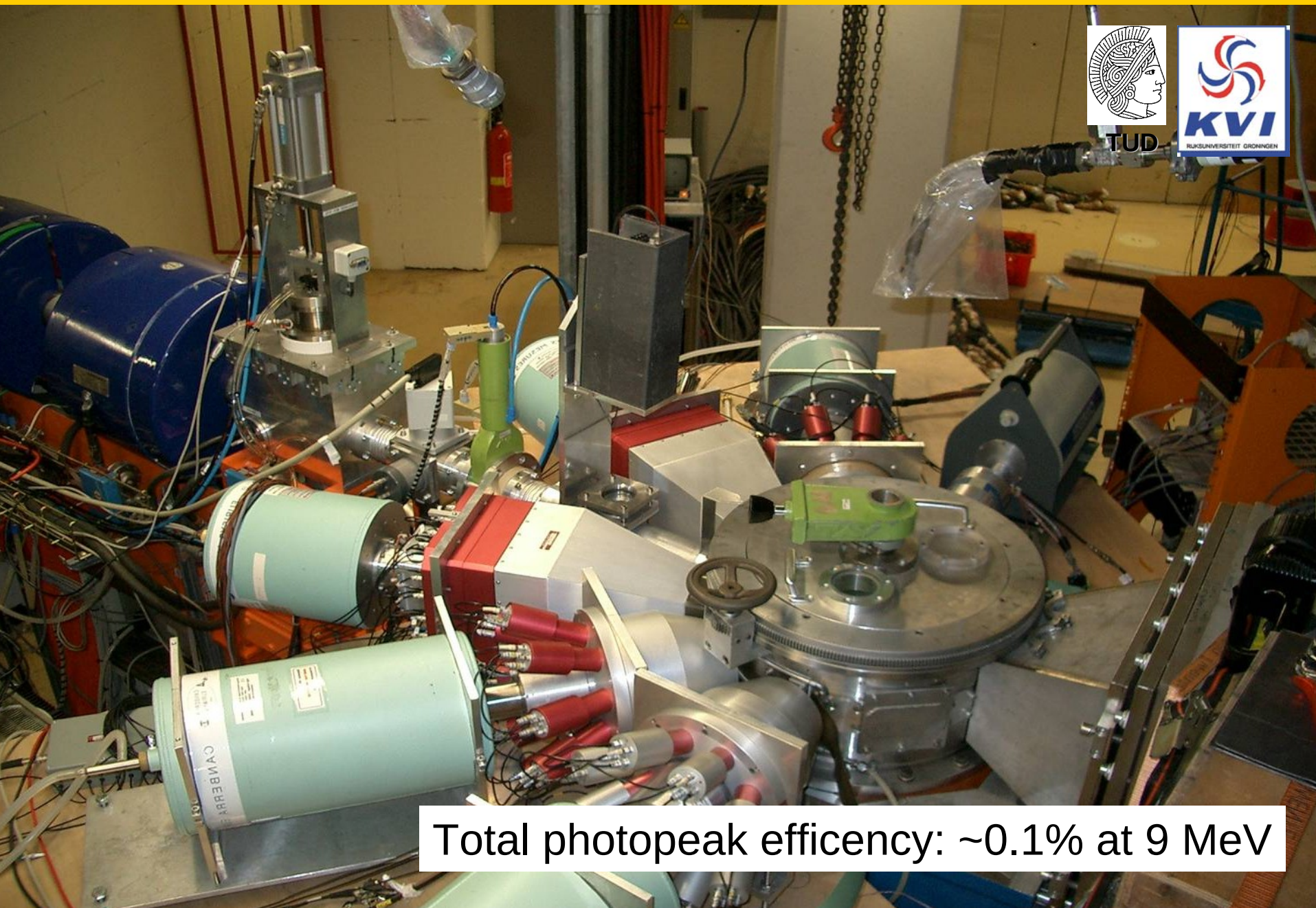
Ge detector array for measurement of γ decays

European Supernova Detector for detection of α particles, ΔE ~ 100-200 keV

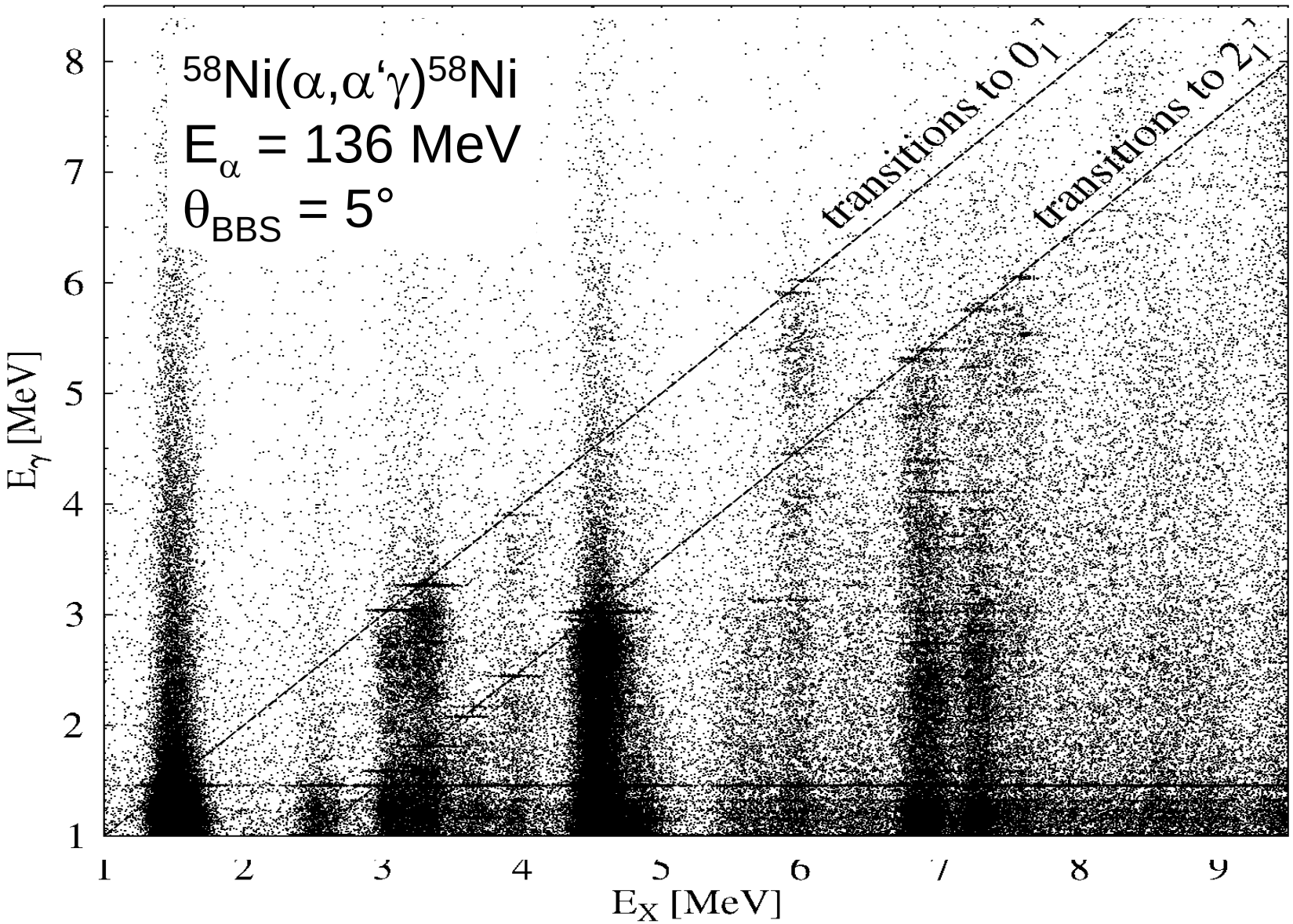
This setup allows to investigate the isospin character of bound states !

D. Savran, H.J. Wörtche, M. Harakeh, K. Ramspeck, A. van den Berg, A.Z.

The new ISOSPIN setup at KVI

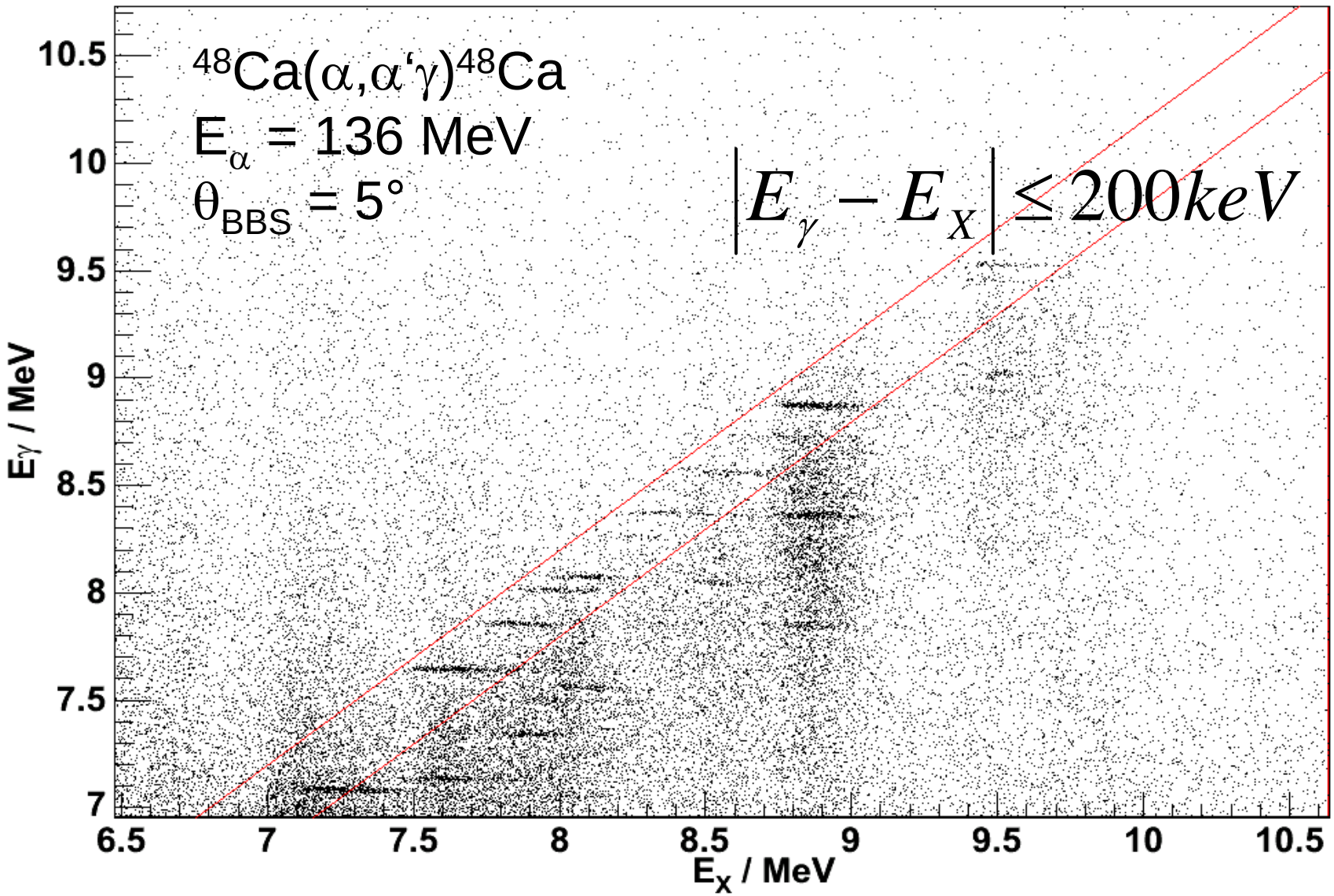


Investigation of E1 strength in ^{58}Ni



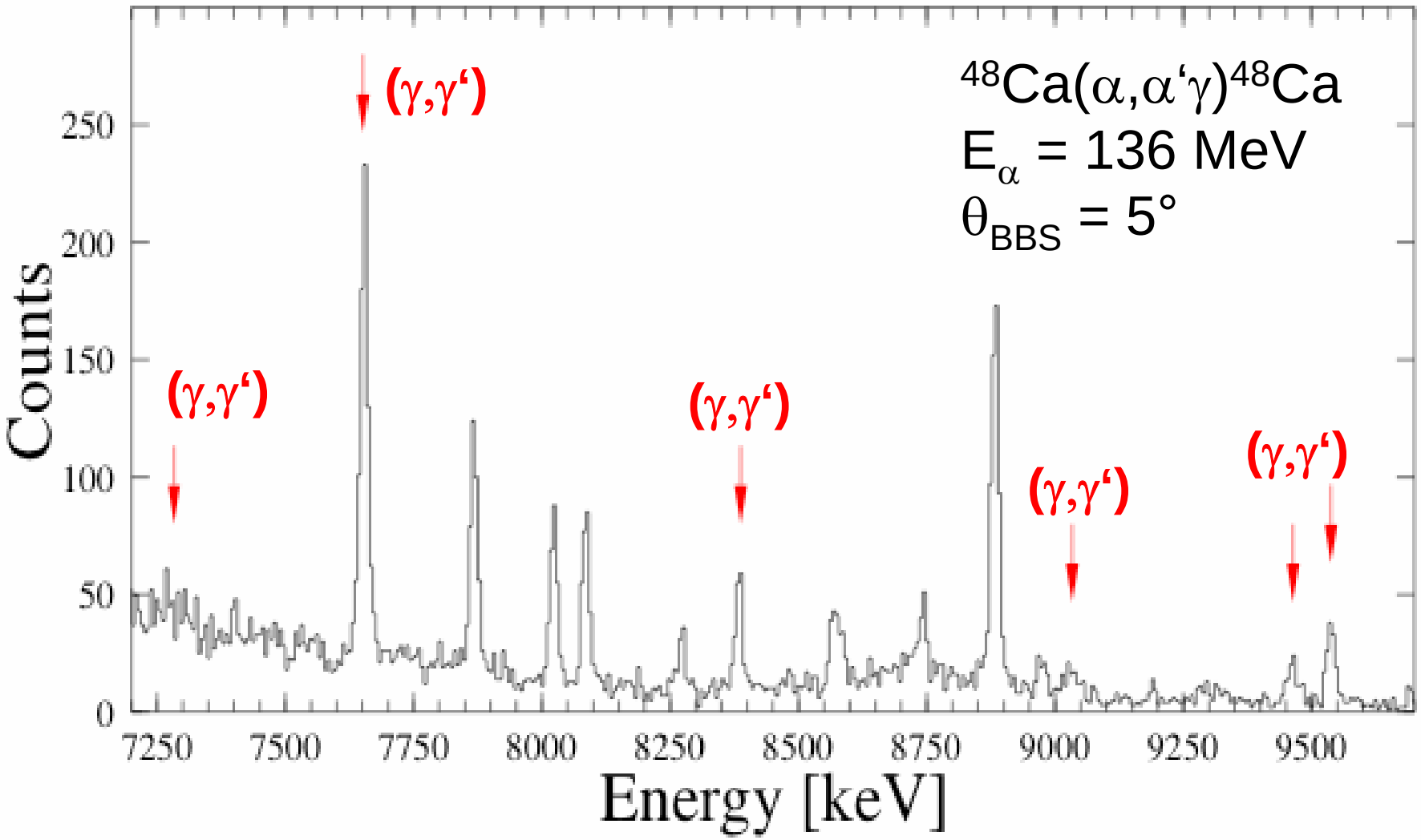
D. Savran, H.J. Wörtche, M. Harakeh, K. Ramspeck, A. van den Berg, A.Z.

Investigation of E1 strength in ^{48}Ca



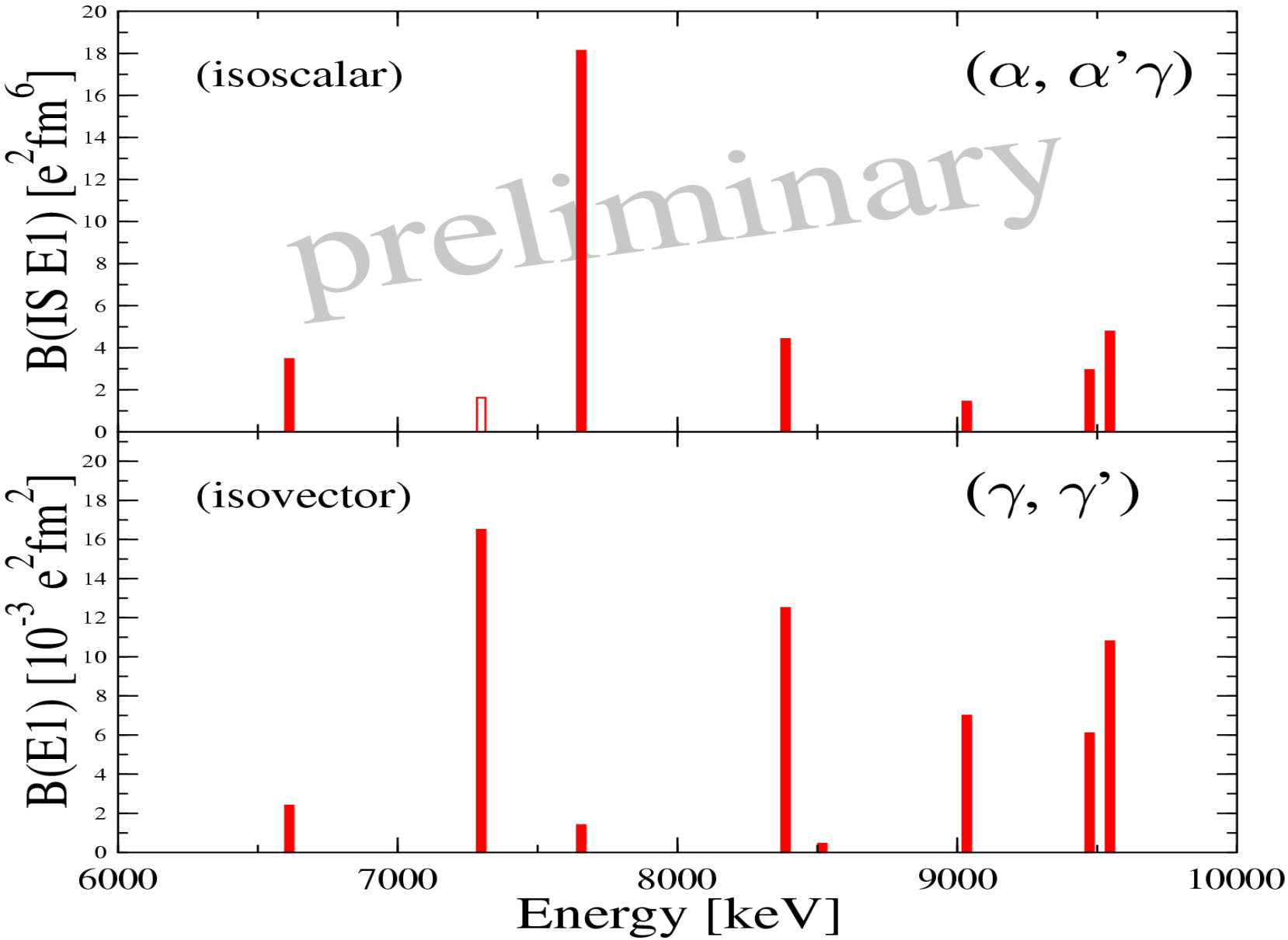
D. Savran, H.J. Wörtche, M. Harakeh, K. Ramspeck, A. van den Berg, A.Z.

Investigation of E1 strength in ^{48}Ca

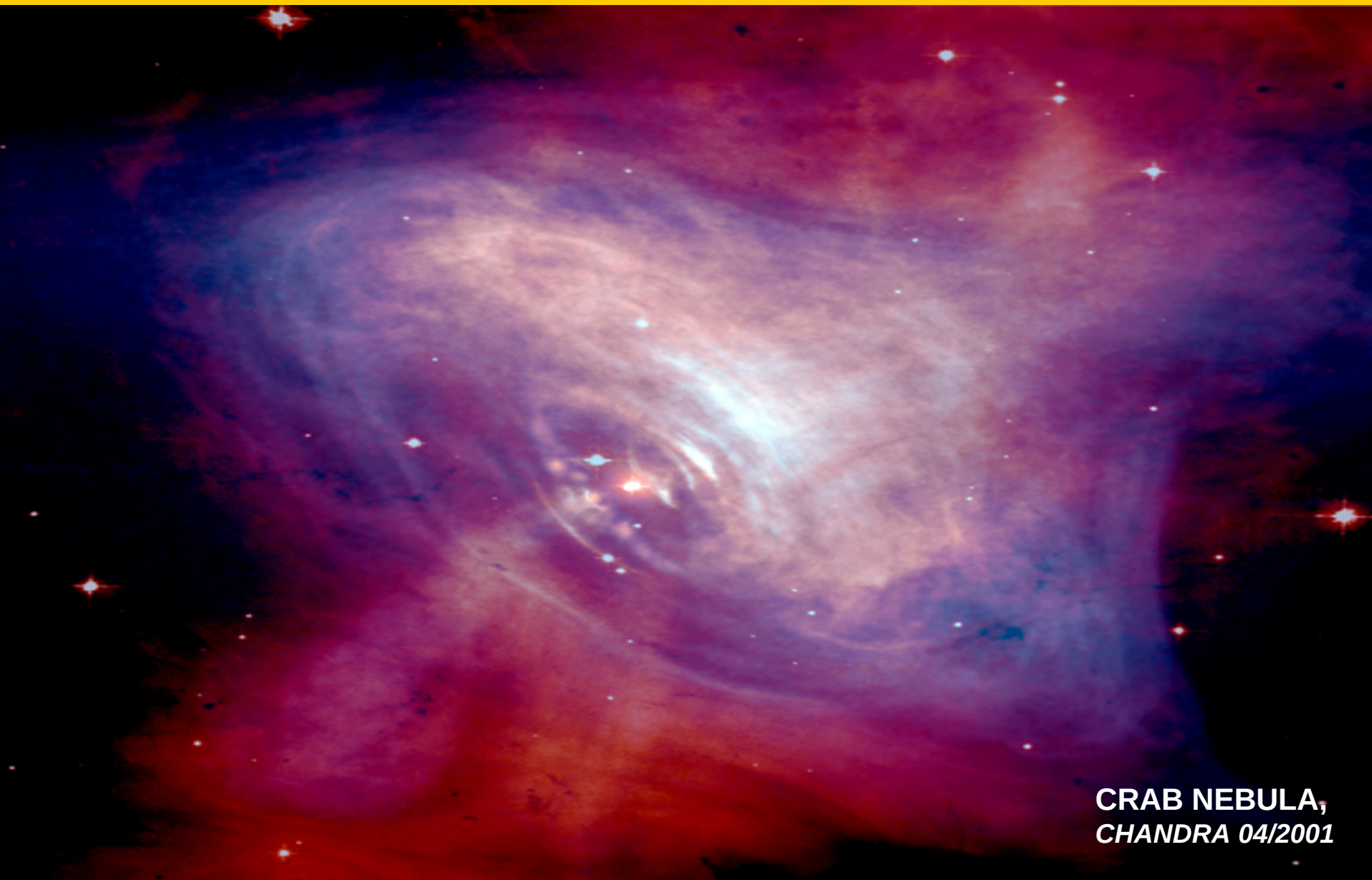


D. Savran, H.J. Wörtche, M. Harakeh, K. Ramspeck, A. van den Berg, A.Z.

Investigation of E1 strength in ^{48}Ca



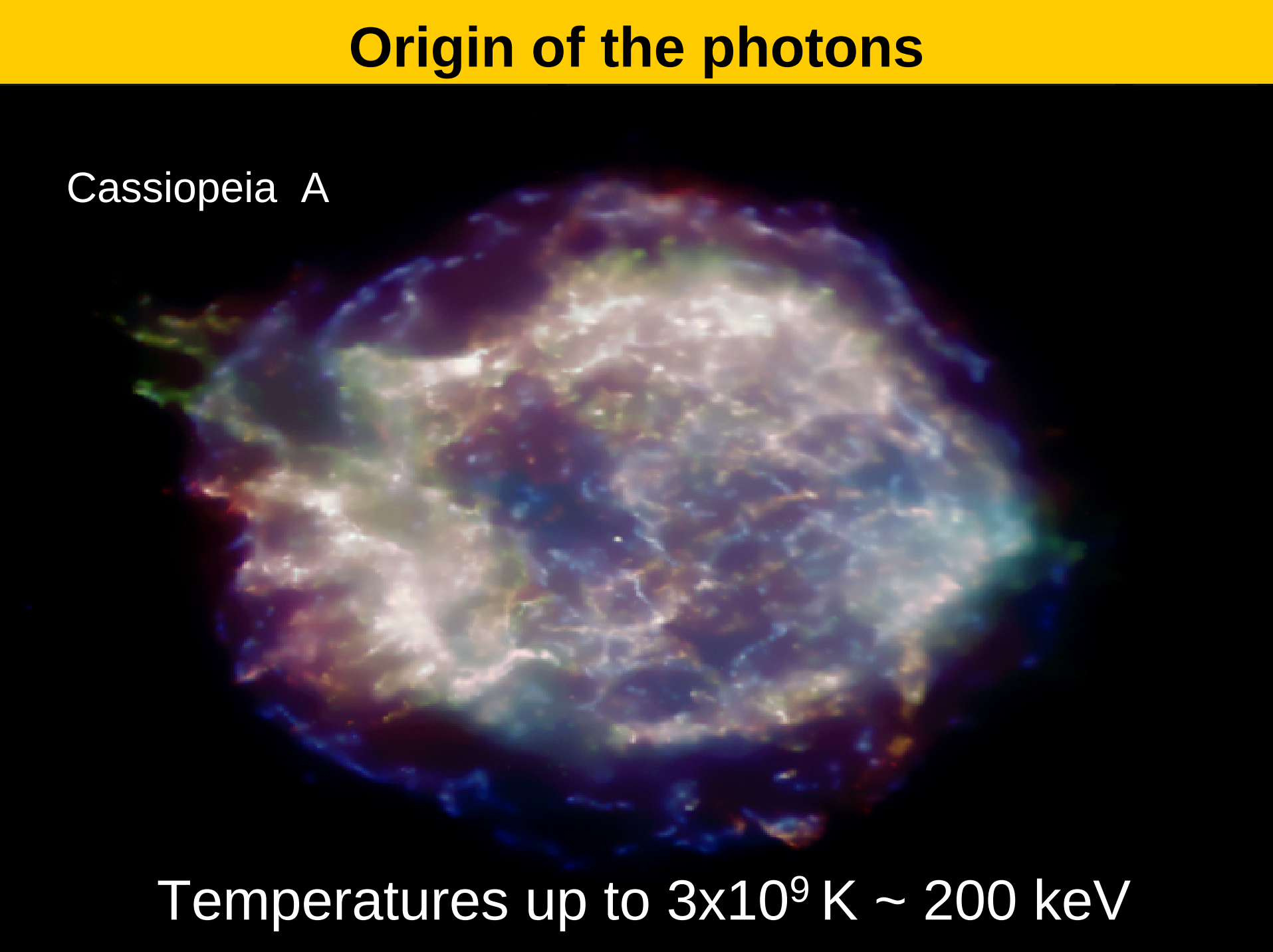
Why are photons important to understand the synthesis of heavy nuclei ?



CRAB NEBULA,
CHANDRA 04/2001

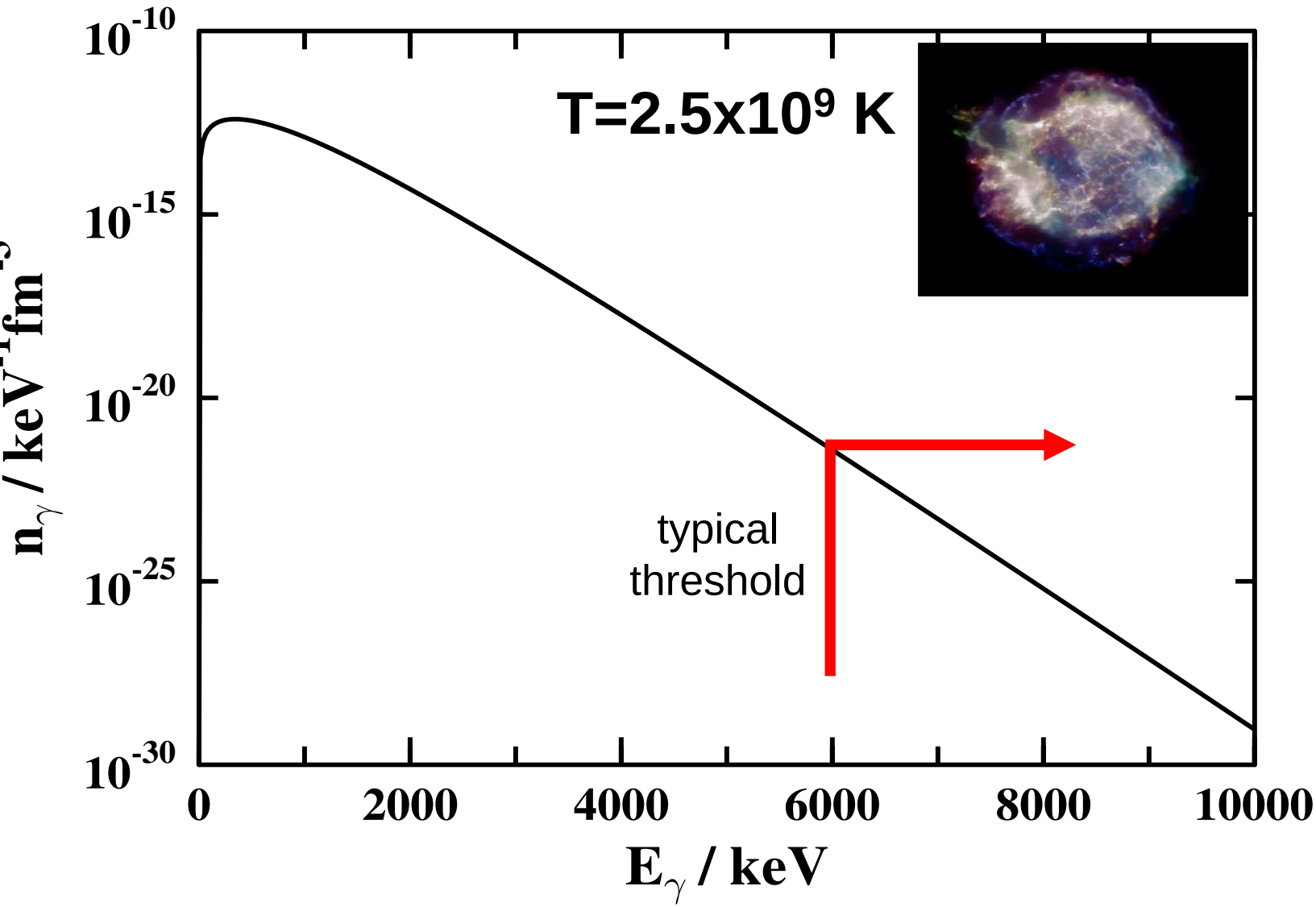
Origin of the photons

Cassiopeia A

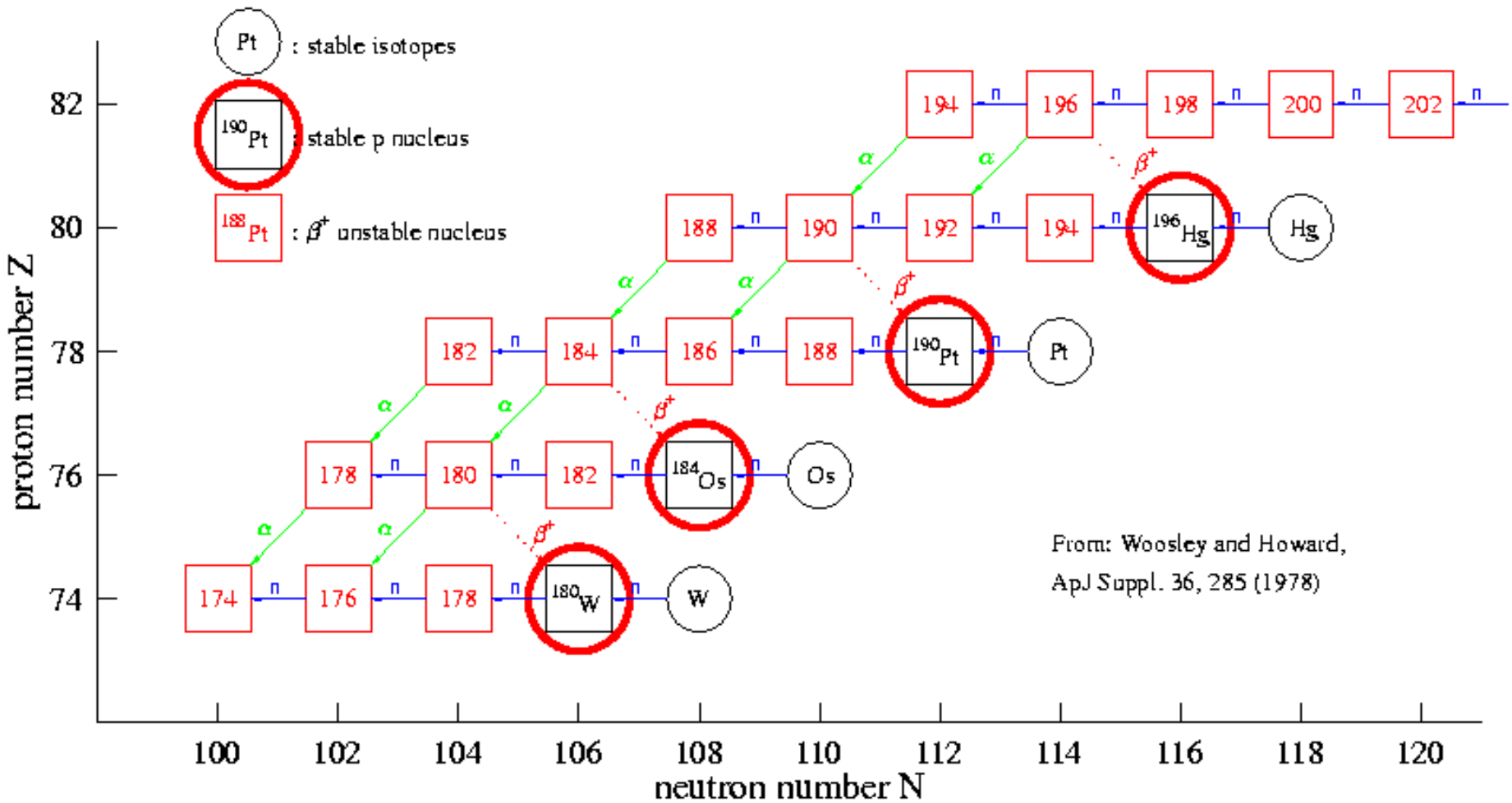


Temperatures up to 3×10^9 K ~ 200 keV

The photon density – a Planck distribution

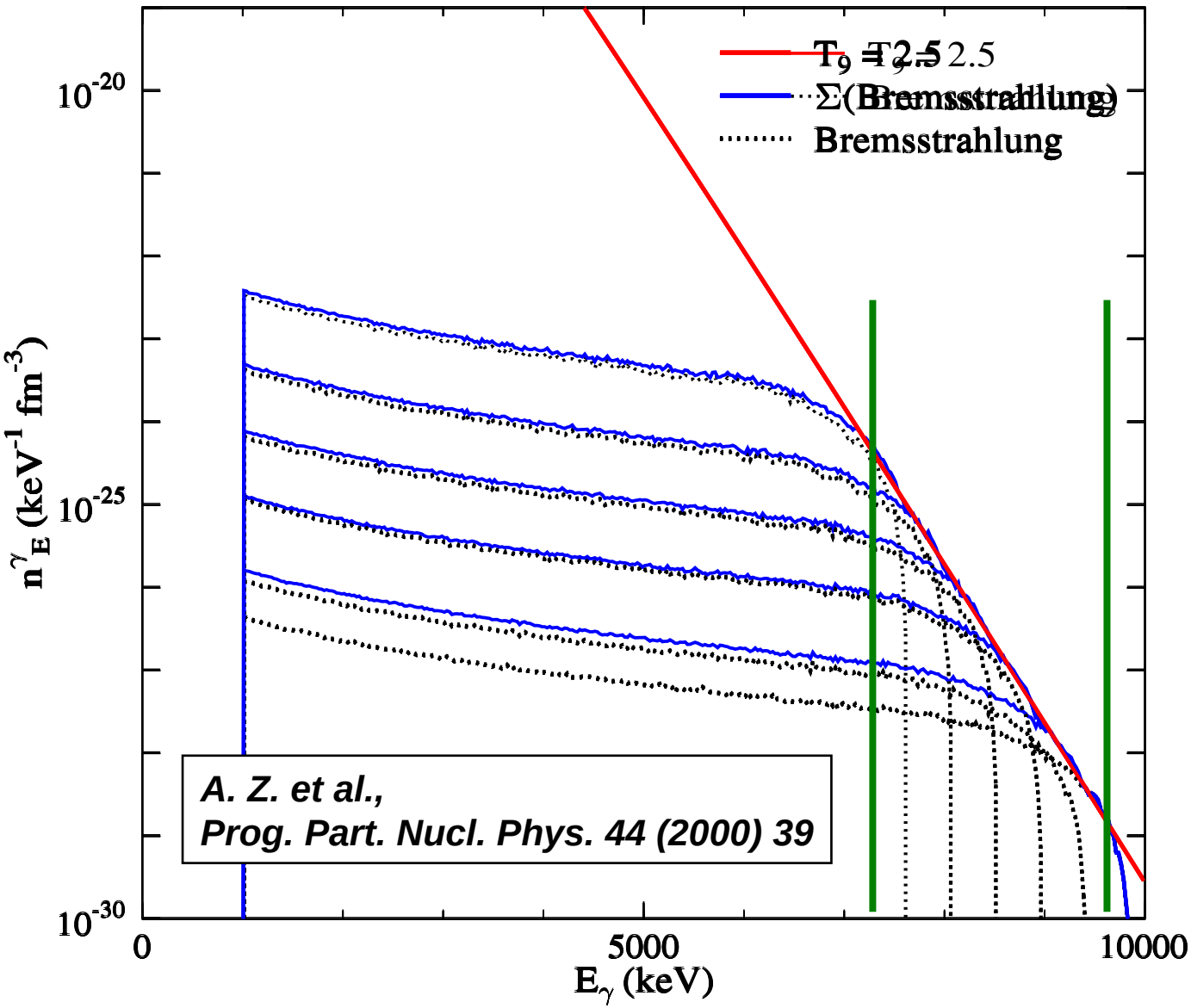


p-process reaction network around A~190

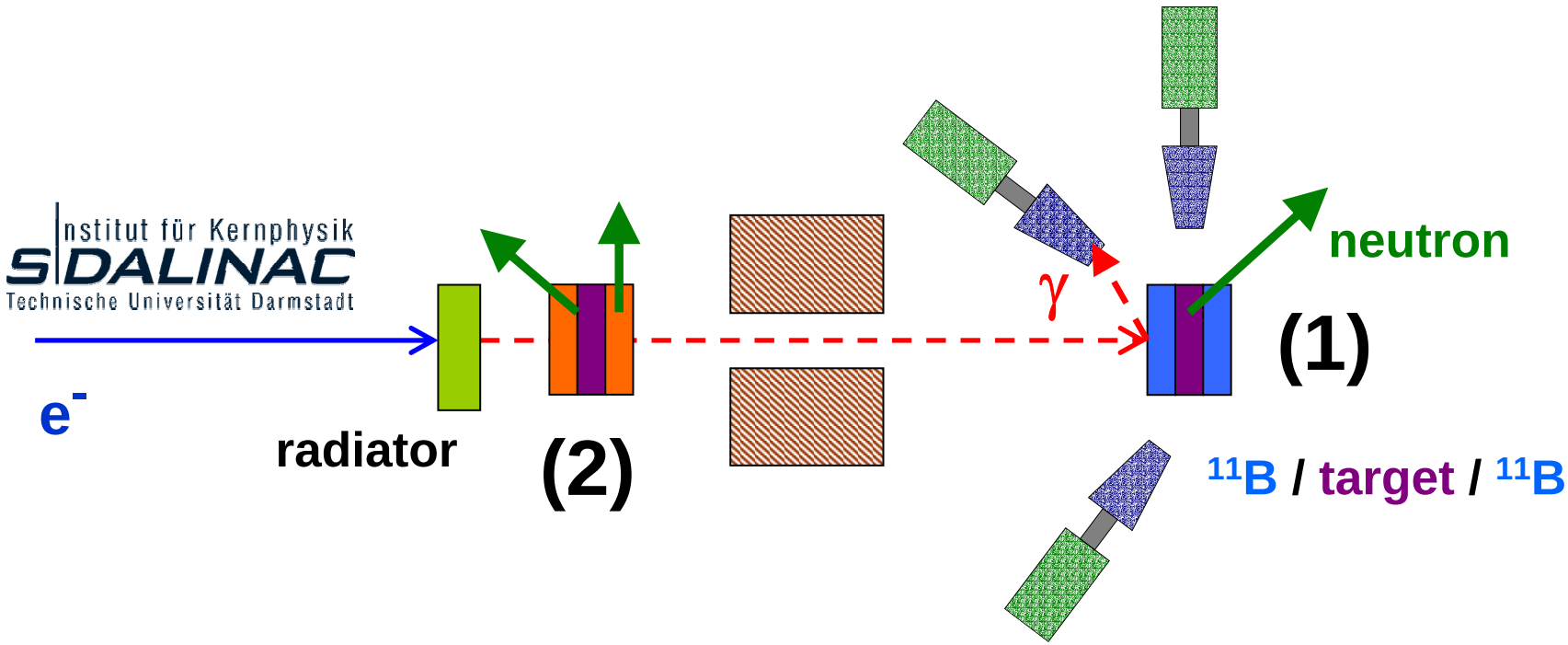


Nearly no reaction rates are experimentally known!

Simulation of a Planck spectrum



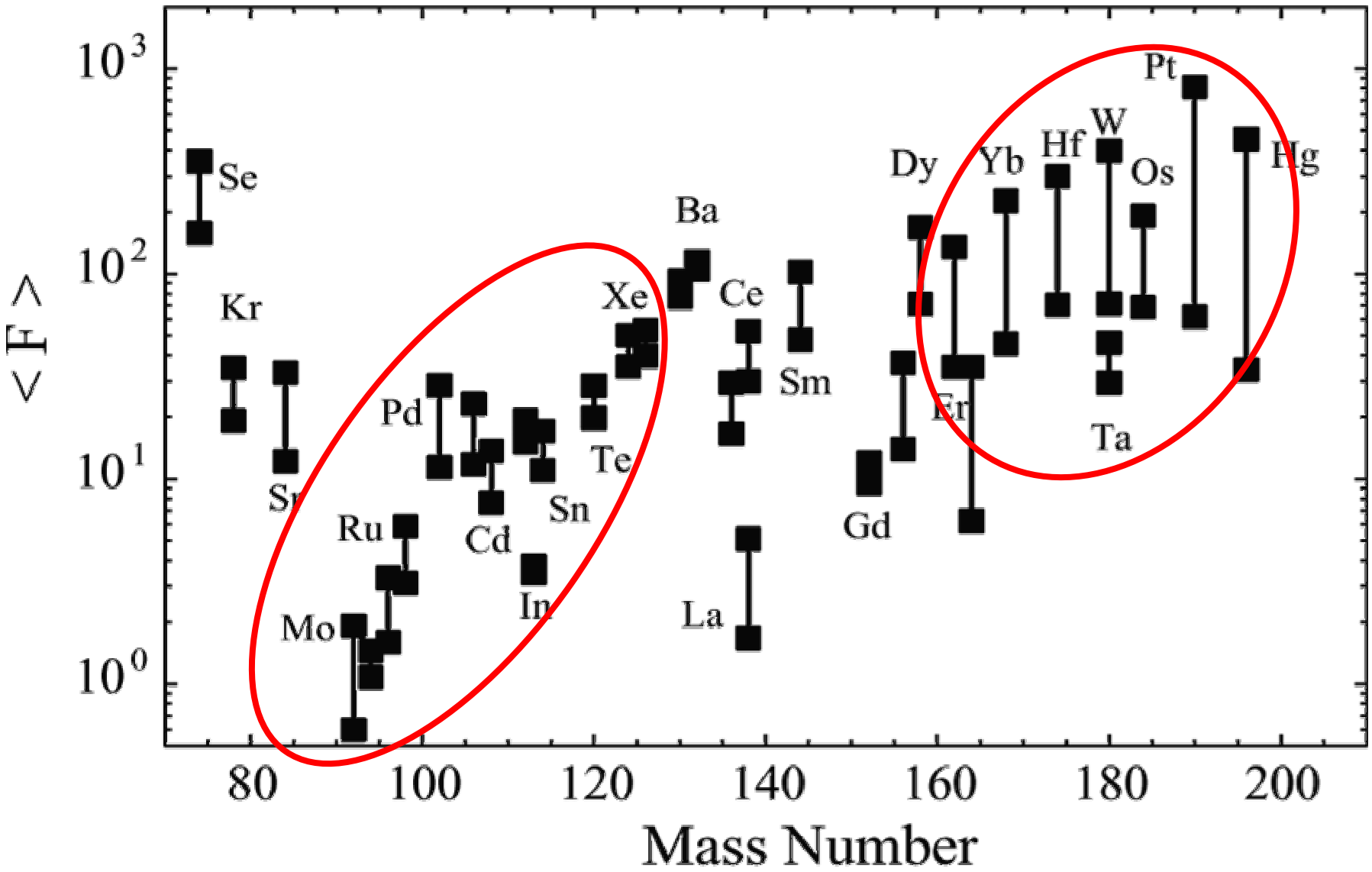
Photodissociation at S-DALINAC



(1) Photon flux ~10^6 γ / (keV s cm^2)
N_γ calibration with $^{11}B(\gamma,\gamma')$, activate target

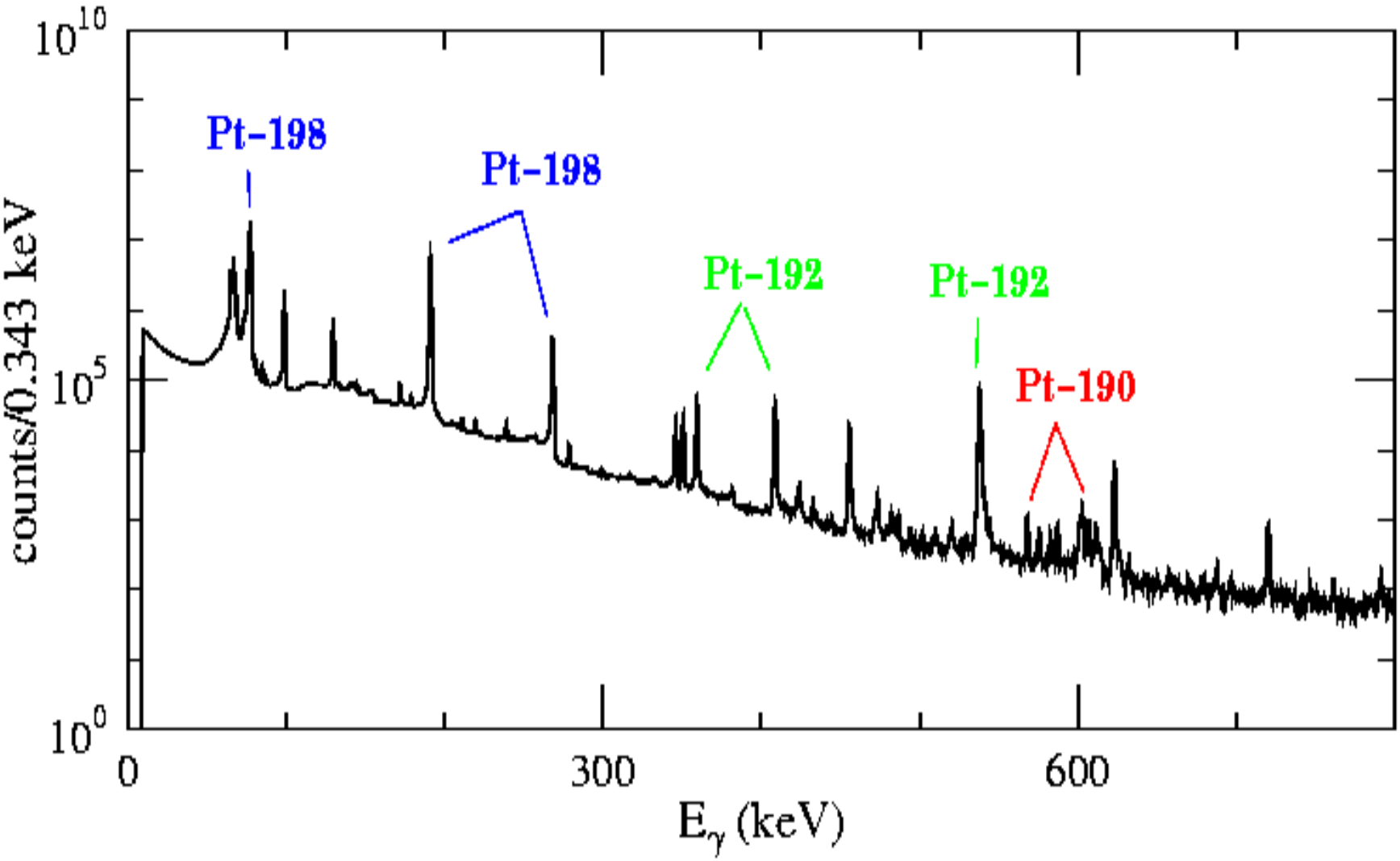
(2) Photon flux ~10^8 γ / (keV s cm^2)
N_γ calibration with $^{197}Au(\gamma,n)$, activate target

Abundance of p-nuclei: model vs. experiment



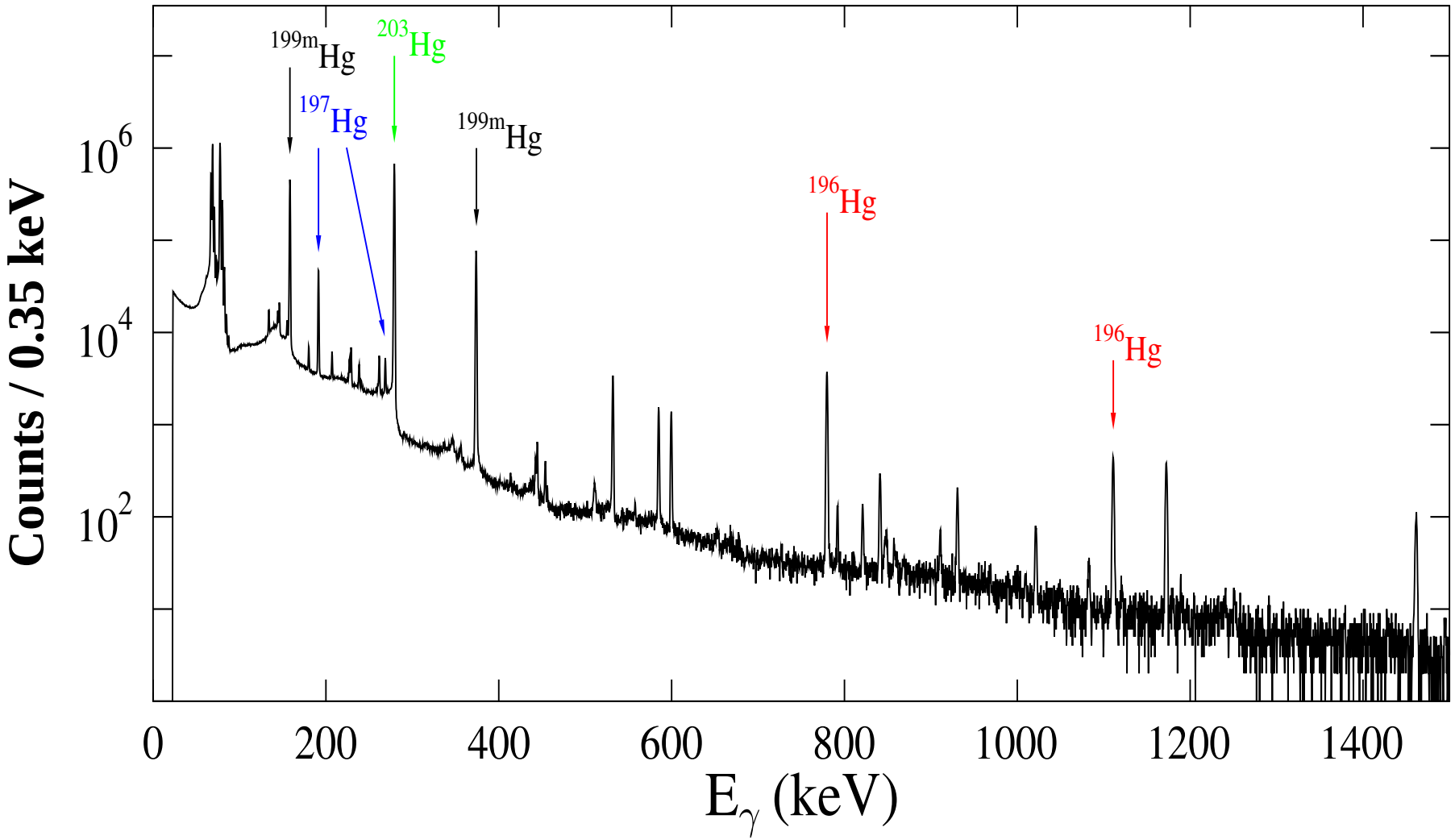
M. Arnould and S. Goriely, Phys. Rep. 384 (2003) 1

Activation spectrum of ^{nat}Pt



K. Vogt et al., Phys. Rev. C 63 (2001) 055802

Activation spectrum of ^{nat}Hg



K. Sonnabend et al., Phys. Rev. C 70 (2004) 035802

Groundstate reaction rates

Kern	S_n (MeV)	λ_{exp} (s^{-1})	λ_{NONS} (s^{-1})	λ_{MOST} (s^{-1})
^{190}Pt	8911	0.4(2)*	0.18	0.29
^{192}Pt	8676	0.5(2)	0.58	0.56
^{198}Pt	7557	87(21)	50	110
^{197}Au	8071	6.2(8)	4.81	5.6
^{196}Hg	8840	0.42(7)*	0.32	0.58
^{198}Hg	7103	2.0(3)	1.36	2.1
^{204}Hg	7495	57(21)	73.3	170
^{204}Pb	8394	1.9(3)	1.53	3.0

Temperature: $T=2.5 \times 10^9$ K

T. Rauscher and F.-K. Thielemann, ADNDT 75 (2000) 1

S. Goriely, priv. comm.

Summary

- **The photoresponse around the n-threshold is important for the synthesis of p-rich nuclei**

- **The Planck photon bath can be simulated with bremsstrahlung**

- **The new photon tagger @ S-DALINAC will enable direct measurements of (γ,n) rates** *(contribution by J. Hasper on Sunday)*

- **Coulomb dissociation measurements on radioactive nuclei in inverse kinematics have been performed at GSI Darmstadt** *(S. Müller et al.)*

Photons in Nuclear Structure and Nuclear Astrophysics

M. Babilon, W. Bayer, D. Galaviz, J. Hasper, T. Hartmann, L. Kern, K. Lindenberg, S. Müller, K. Ramspeck, D. Savran, K. Sonnabend, S. Volz, M. Zarza

(Institut für Kernphysik, TU Darmstadt)

Supported by DFG *(SFB 634 and Zi 510/2-2)*

More information and references: www.zilges.de