Photon-Scattering off Natural Zirconium

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HIC for FAIR
Helmholtz International Center

Motivation

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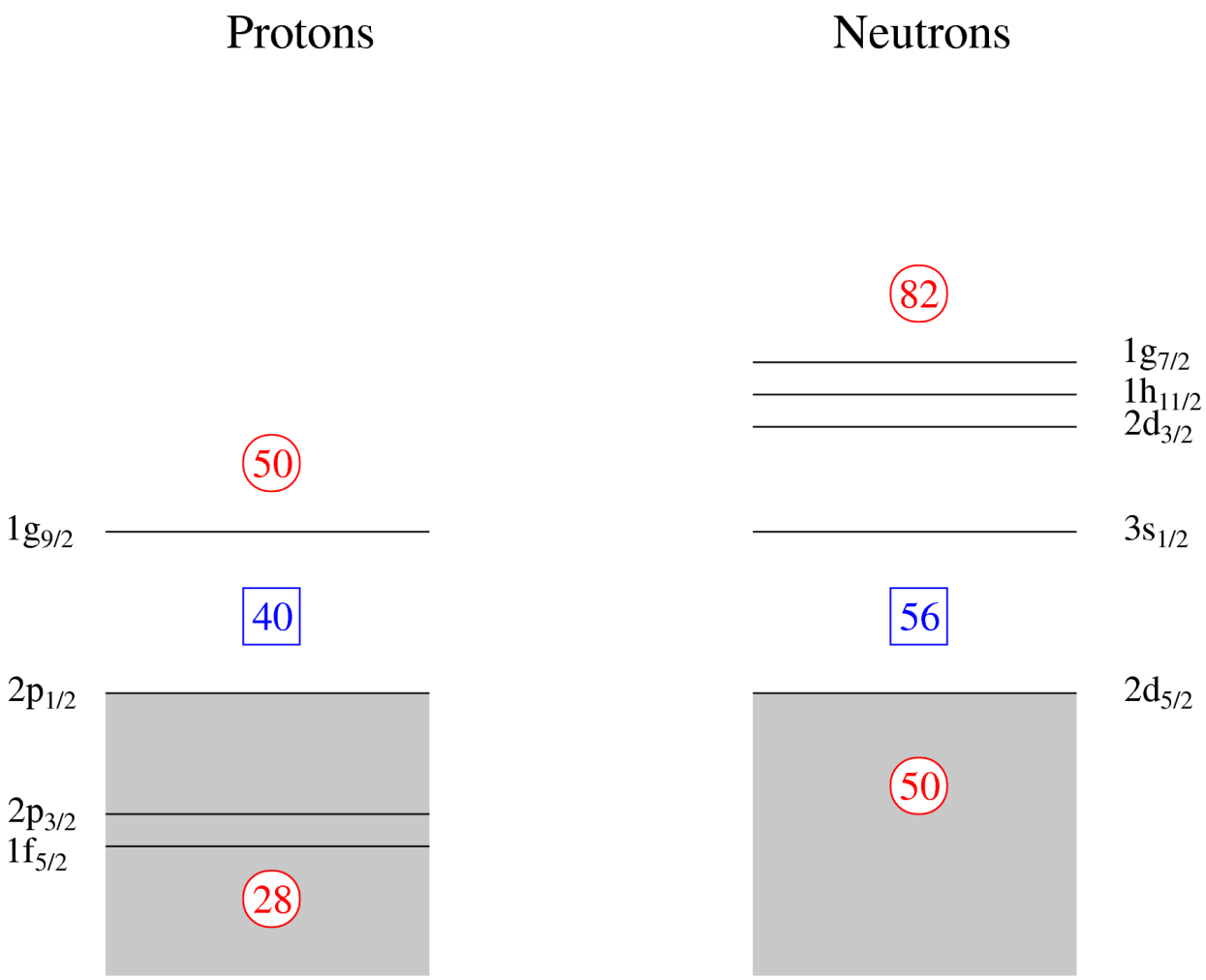
N=50

Z=50

	^{100}Sn 0.94 s	^{101}Sn 3 s	^{102}Sn 3.4 s	^{103}Sn 7 s	^{104}Sn 20.8 s	^{105}Sn 34 s	^{106}Sn 2.1 m	^{107}Sn 2.9 m	^{108}Sn 10.3 m	^{109}Sn 18.0 m	^{110}Sn 4.11 h	^{111}Sn 35.3 m	^{112}Sn 0.97	^{113}Sn 115.1 d	^{114}Sn 0.65
^{98}In	^{99}In	^{100}In 6.1 s	^{101}In 16 s	^{102}In 22.1 s	^{103}In 60 s	^{104}In 1.8 m	^{105}In 4.8 m	^{106}In 6.26 m	^{107}In 32.4 m	^{108}In 58.0 m	^{109}In 4.2 h	^{110}In 4.9 h	^{111}In 2.81 d	^{112}In 14.4 m	^{113}In 4.3
^{97}Cd 2.8 s	^{98}Cd 9.2 s	^{99}Cd 16 s	^{100}Cd 49.1 s	^{101}Cd 1.2 m	^{102}Cd 5.5 m	^{103}Cd 7.3 m	^{104}Cd 57.7 m	^{105}Cd 55.5 m	^{106}Cd 1.25	^{107}Cd 6.5 h	^{108}Cd 0.89	^{109}Cd 462.6 d	^{110}Cd 12.49	^{111}Cd 12.80	^{112}Cd 24.13
^{96}Ag 4.5 s	^{97}Ag 25.3 s	^{98}Ag 46.7 s	^{99}Ag 2.1 m	^{100}Ag 2.0 m	^{101}Ag 11.1 m	^{102}Ag 13 m	^{103}Ag 1.1 h	^{104}Ag 69.2 m	^{105}Ag 41.29 d	^{106}Ag 24 m	^{107}Ag 51.84	^{108}Ag 2.41 m	^{109}Ag 48.16	^{110}Ag 24.6 s	^{111}Ag 7.45 d
^{95}Pd	^{96}Pd 2.0 m	^{97}Pd 3.1 m	^{98}Pd 17.7 m	^{99}Pd 21.4 m	^{100}Pd 3.7 d	^{101}Pd 8.47	^{102}Pd 1.02	^{103}Pd 16.96 d	^{104}Pd 11.14	^{105}Pd 22.33	^{106}Pd 27.33	^{107}Pd $7*10^6$ a	^{108}Pd 26.46	^{109}Pd 13.43 h	^{110}Pd 11.72
^{94}Rh 25.8 s	^{95}Rh 5.0 m	^{96}Rh 9.9 m	^{97}Rh 31 m	^{98}Rh 8.7 m	^{99}Rh 16 d	^{100}Rh 20.8 h	^{101}Rh 3.3 a	^{102}Rh 207 d	^{103}Rh 100	^{104}Rh 42 s	^{105}Rh 35.4 h	^{106}Rh 30 s	^{107}Rh 21.7 m	^{108}Rh 16.8 s	^{109}Rh 80 s
^{93}Ru 59.7 s	^{94}Ru 51.8 m	^{95}Ru 1.65 h	^{96}Ru 5.52	^{97}Ru 2.9 d	^{98}Ru 1.88	^{99}Ru 12.7	^{100}Ru 12.6	^{101}Ru 17.0	^{102}Ru 31.6	^{103}Ru 39.35 d	^{104}Ru 18.7	^{105}Ru 4.44 h	^{106}Ru 373.6 d	^{107}Ru 3.8 m	^{108}Ru 4.5 m
^{92}Tc 4.4 m	^{93}Tc 2.7 h	^{94}Tc 4.9 h	^{95}Tc 20 h	^{96}Tc 4.3 d	^{97}Tc $4*10^6$ a	^{98}Tc $4*10^6$ a	^{99}Tc $2*10^5$ a	^{100}Tc 15.8 s	^{101}Tc 14.2 m	^{102}Tc 5.3 s	^{103}Tc 54.2 s	^{104}Tc 18.2 m	^{105}Tc 7.6 m	^{106}Tc 36 s	^{107}Tc 21.2 s
^{91}Mo 15.5 m	^{92}Mo 14.84	^{93}Mo $4*10^3$ a	^{94}Mo 9.25	^{95}Mo 15.92	^{96}Mo 16.68	^{97}Mo 9.55	^{98}Mo 24.13	^{99}Mo 66 h	^{100}Mo 9.63	^{101}Mo 14.6 m	^{102}Mo 11.2 m	^{103}Mo 67.5 s	^{104}Mo 1.0 m	^{105}Mo 35.6 s	^{106}Mo 8.7 s
^{90}Nb 14.6 h	^{91}Nb 680 a	^{92}Nb $4*10^7$ a	^{93}Nb 100	^{94}Nb $2*10^4$ a	^{95}Nb 34.97 d	^{96}Nb 23.4 h	^{97}Nb 74 m	^{98}Nb 2.9 s	^{99}Nb 15 s	^{100}Nb 1.5 s	^{101}Nb 7.1 s	^{102}Nb 1.3 s	^{103}Nb 1.5 s	^{104}Nb 4.8 s	^{105}Nb 2.95 s
^{89}Zr 78.4 h	^{90}Zr 51.45	^{91}Zr 11.22	^{92}Zr 17.15	^{93}Zr $2*10^6$ a	^{94}Zr 17.38	^{95}Zr 64.0 d	^{96}Zr 2.80	^{97}Zr 16.8 h	^{98}Zr 30 s	^{99}Zr 2.1 s	^{100}Zr 7.1 s	^{101}Zr 2.1 s	^{102}Zr 2.9 s	^{103}Zr 1.3 s	^{104}Zr 1.2 s
^{88}Y 106.6 d	^{89}Y 100	^{90}Y 64.1 h	^{91}Y 58.5 d	^{92}Y 3.54 h	^{93}Y 10.1 h	^{94}Y 18.7 m	^{95}Y 10.3 m	^{96}Y 5.34 s	^{97}Y 3.75 s	^{98}Y 0.55 s	^{99}Y 1.47 s	^{100}Y 0.73 s	^{101}Y 448 ms	^{102}Y 0.30 s	^{103}Y 0.23 s
^{87}Sr 7.00	^{88}Sr 82.58	^{89}Sr 50.5 d	^{90}Sr 28.64 a	^{91}Sr 9.5 h	^{92}Sr 2.71 h	^{93}Sr 7.45 m	^{94}Sr 74 s	^{95}Sr 24.4 s	^{96}Sr 1.0 s	^{97}Sr 429 ms	^{98}Sr 653 ms	^{99}Sr 269 ms	^{100}Sr 202 ms	^{101}Sr 118 ms	^{102}Sr 69 ms

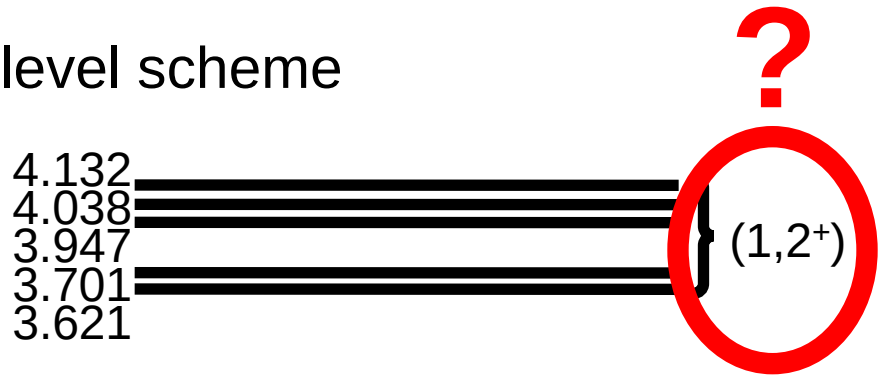
Z=40
N=56

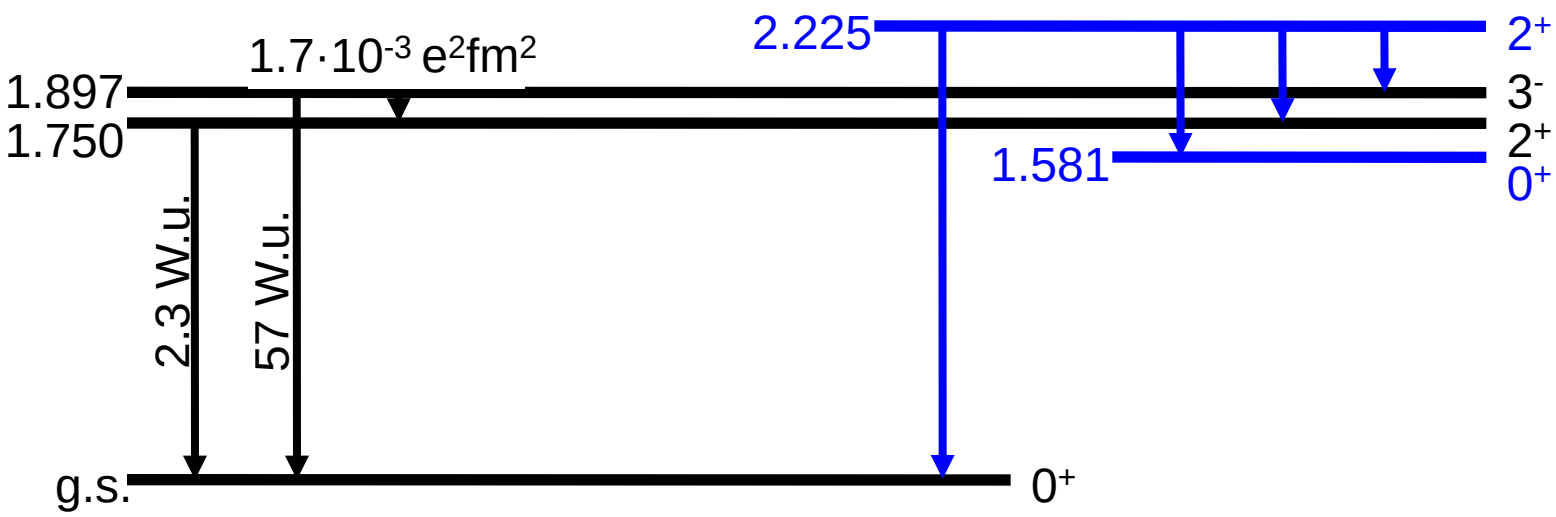
Motivation ^{96}Zr



Motivation ^{96}Zr

^{96}Zr partial level scheme





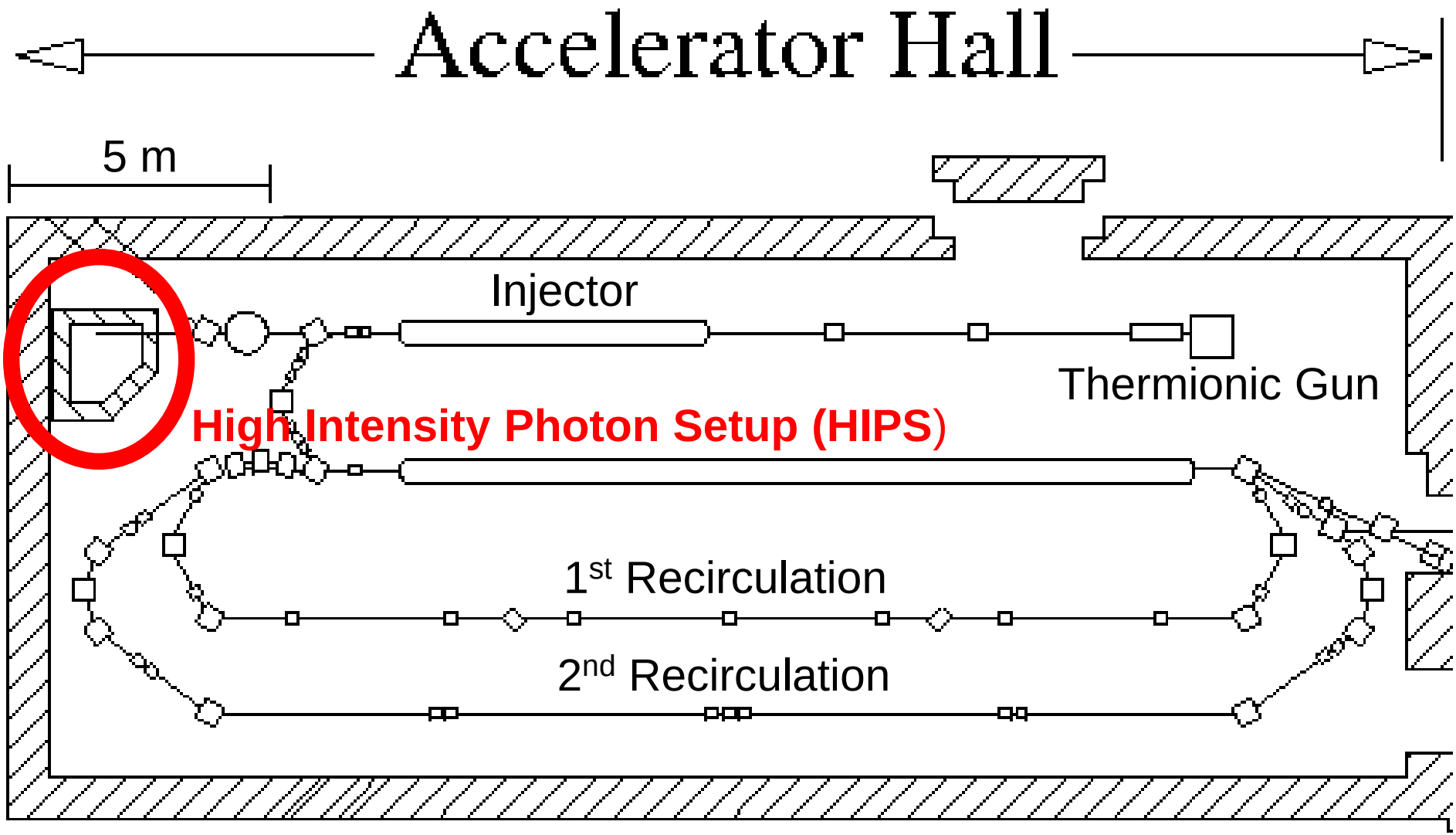
Motivation ^{nat}Zr

- Look for new states of the Zr-isotopes in low energy region

- Use ^{nat}Zr-measurement as help for normalization

  - Aluminium target container with ^{96}Zr larger than beam spot
  => effective mass unknown

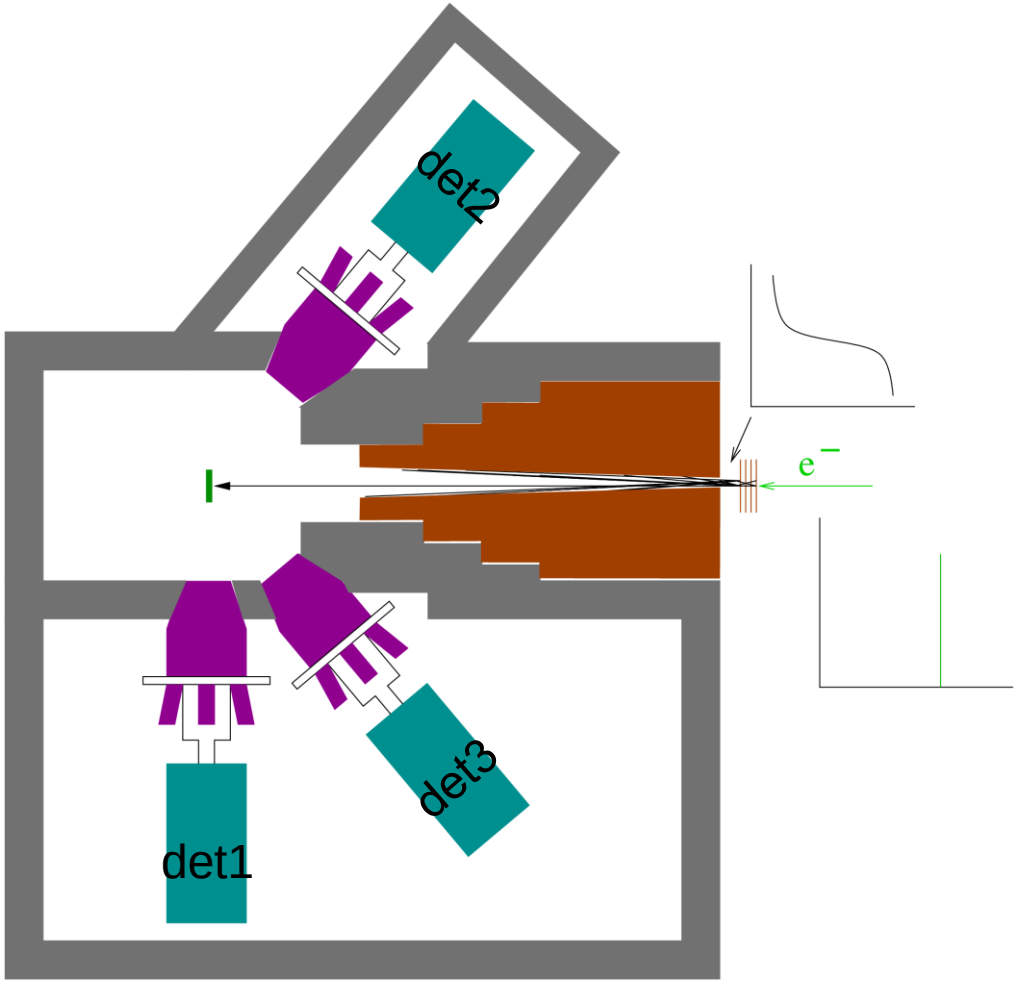
S-DALINAC


Accelerator Hall
5 m
Injector
Thermionic Gun
High Intensity Photon Setup (HIPS)
1st Recirculation
2nd Recirculation

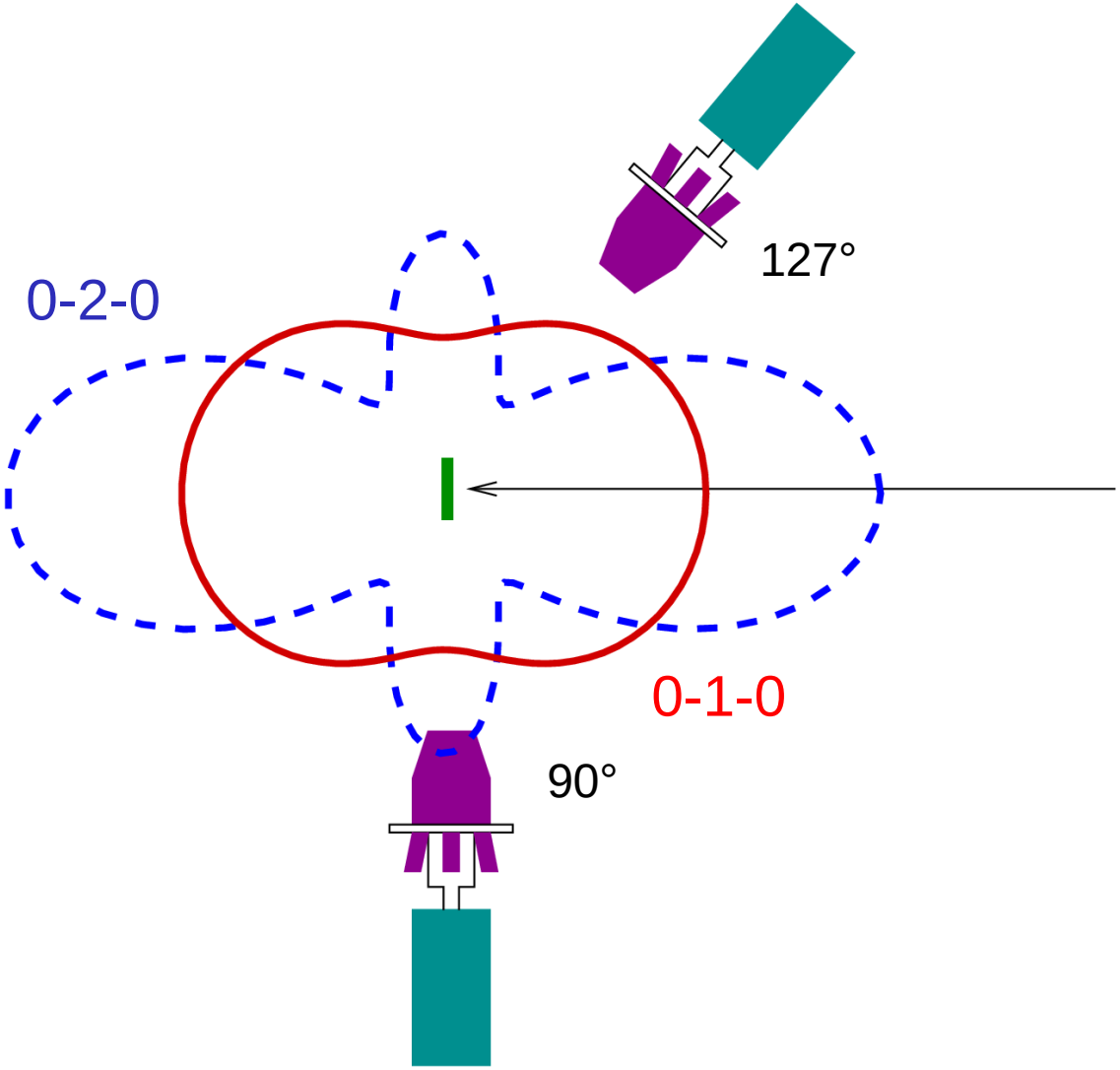
Setup

- Electron-beam on segmented Copper-target
- Resulting photonflux on target

  ~ 10^6 keV^{-1} cm^{-2} s^{-1}@ 4 MeV
- 3 HPGe-detectors with BGO-shielding



Angular Distributions



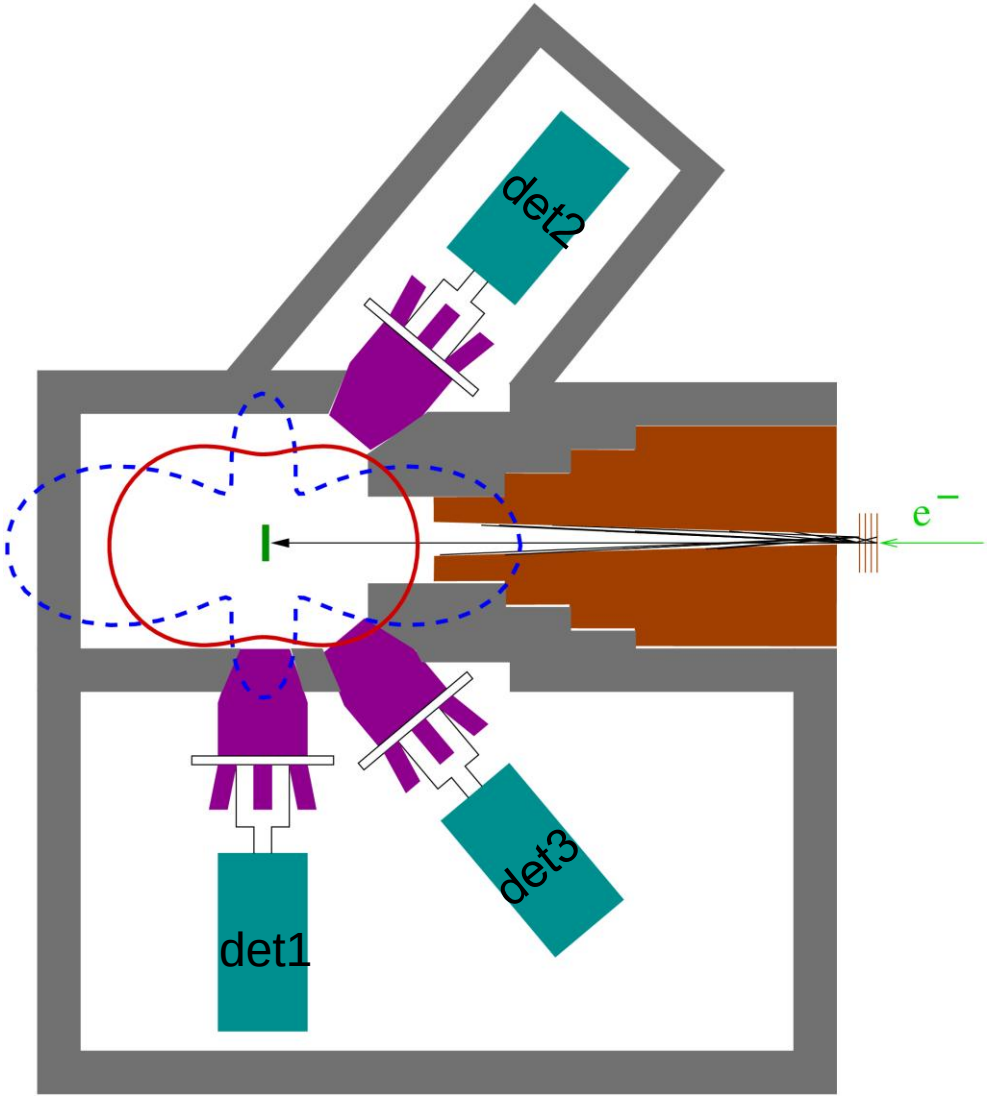
$w = W(\Theta_1) / W(\Theta_2)$

maximal w:

$\Theta_1 = 90°$

$\Theta_2 = 127°$

Details of the Measurement

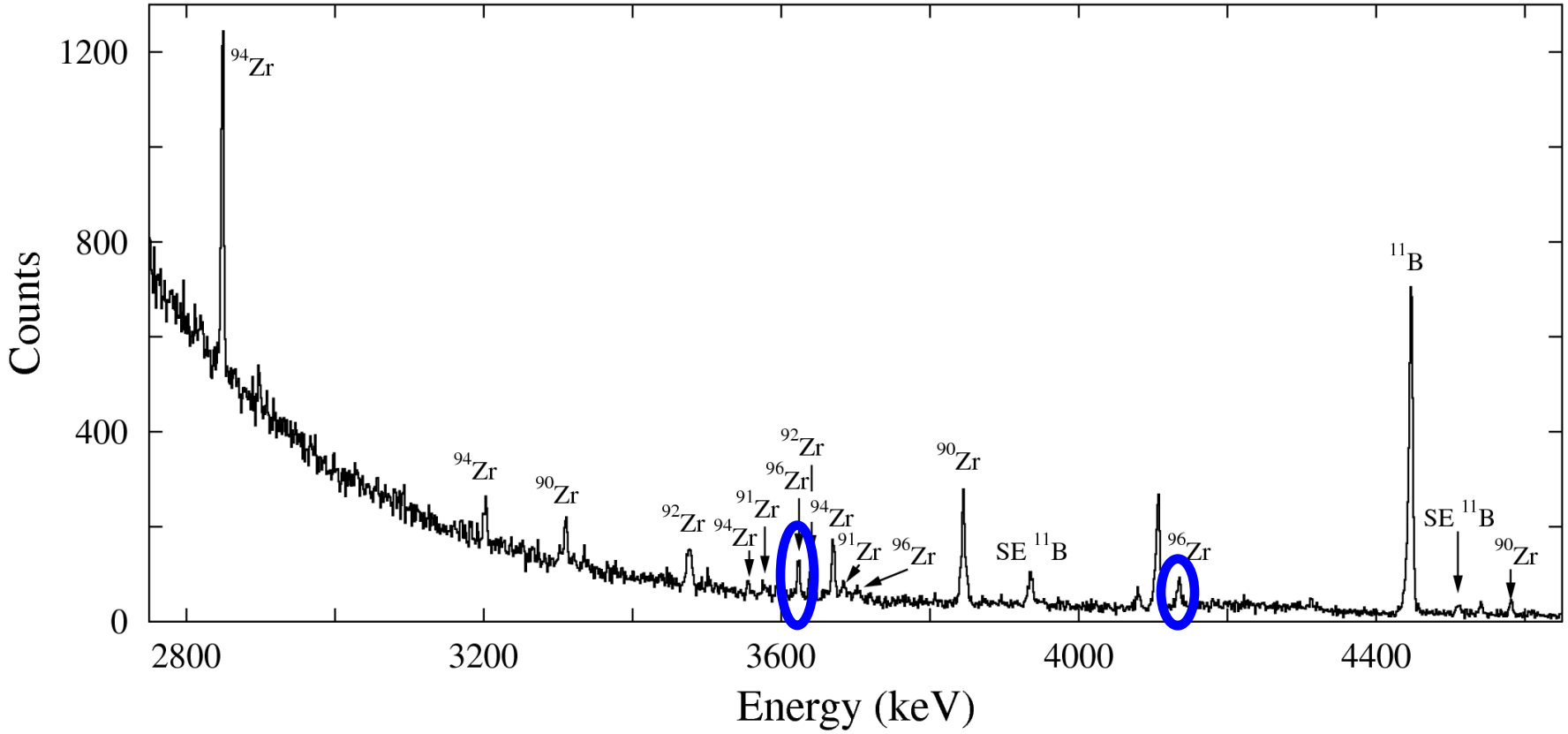


- 1x detector @ 90°
  2x detectors @ 130°
- Endpoint energy ~ 5.1 MeV
- Time of measurement ~ 6 d
- Mass of target :

~ 3 g ^{nat}Zr

~ 0.3 g ^{11}B

Spectrum of ^{nat}Zr



Single-Escape-Correction of 3620 keV Peak

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- Taking four measurements of the same beamtime:

  ^{56}Co

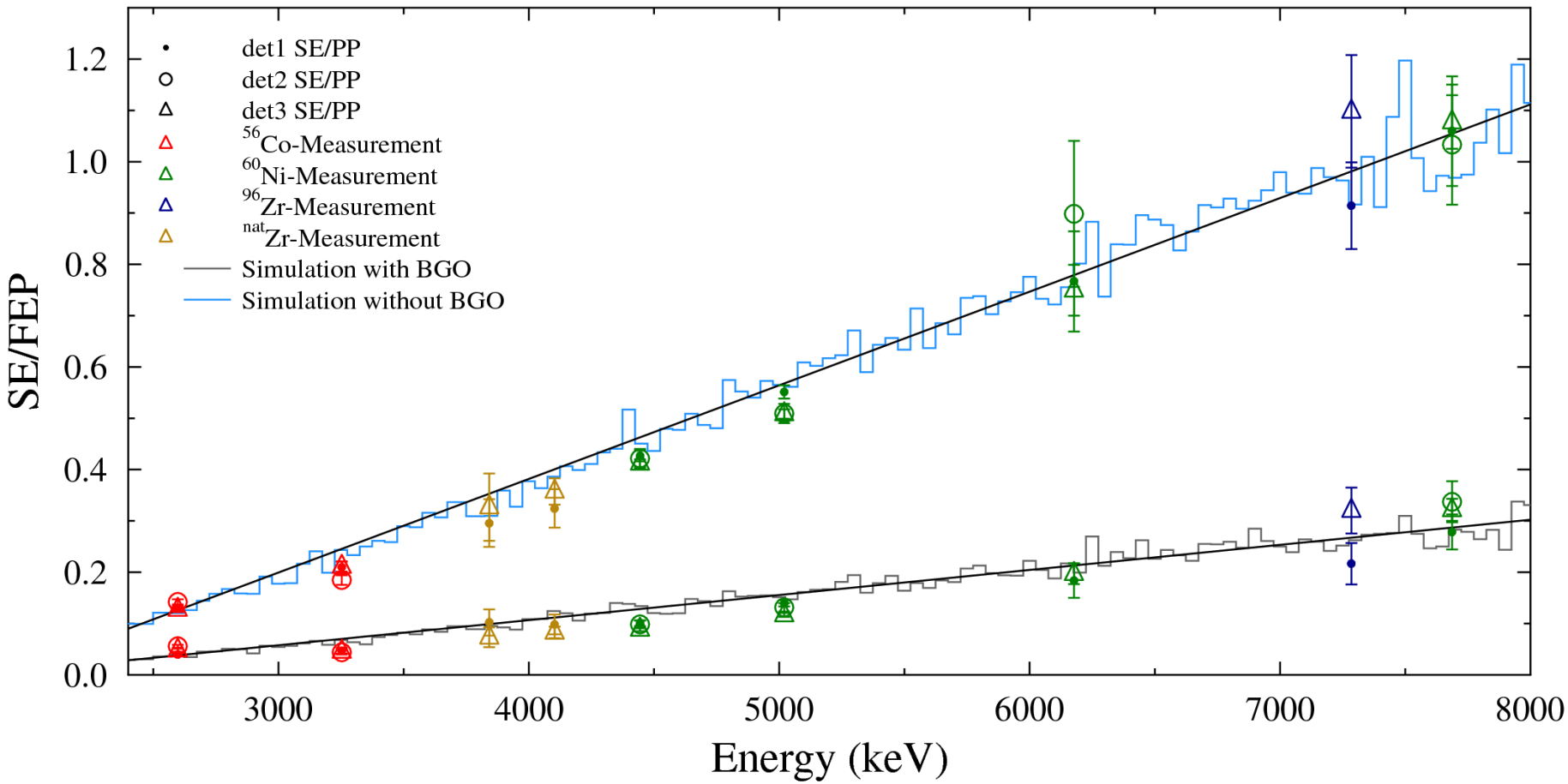
  ^{60}Ni @ 8 MeV

  ^{nat}Zr @ 5.1 MeV

  ^{96}Zr @ 7.7 MeV

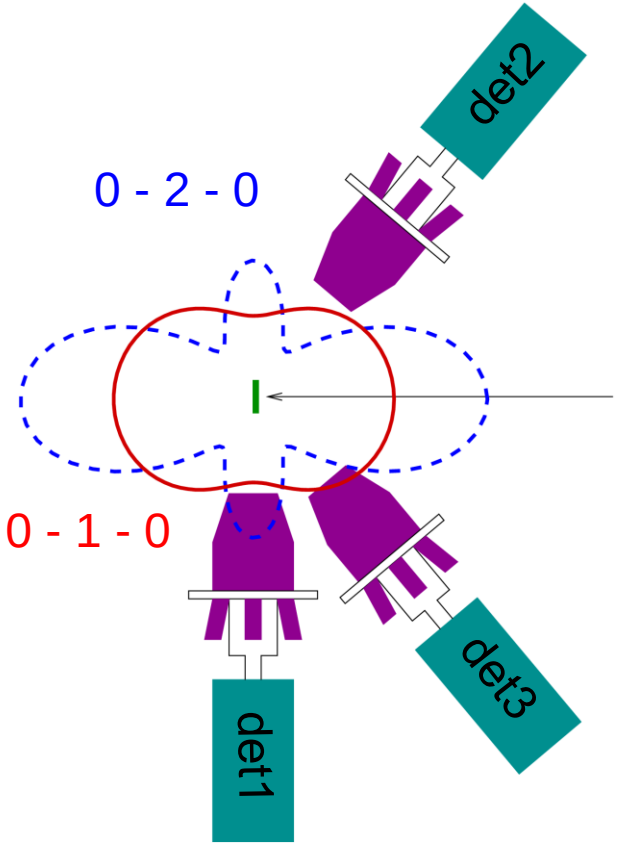
- Determine ratios of SE to FEP
- Comparison with simulation

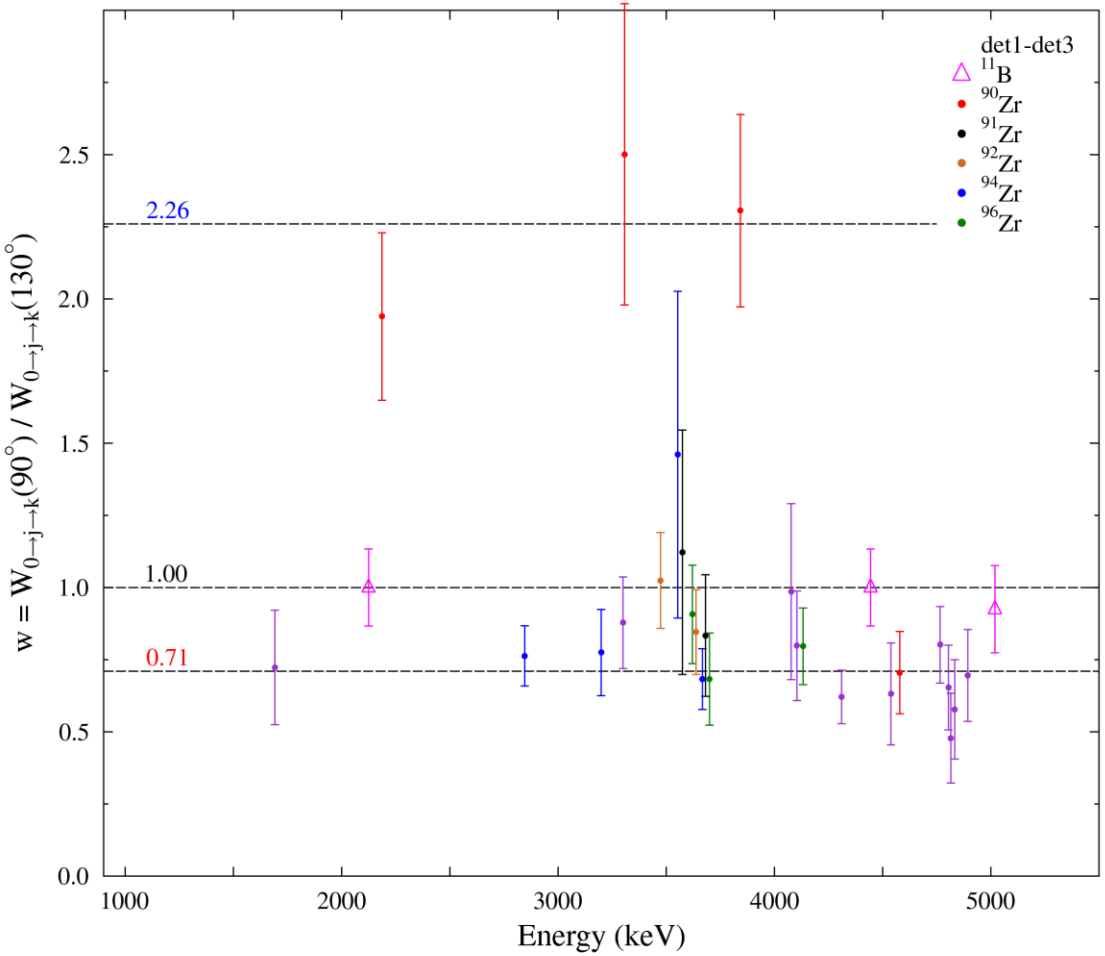
Single Escape / Full Energy Peak Ratios



Simulation done by Jens Hasper

Angular Distributions





Comparison with Literature

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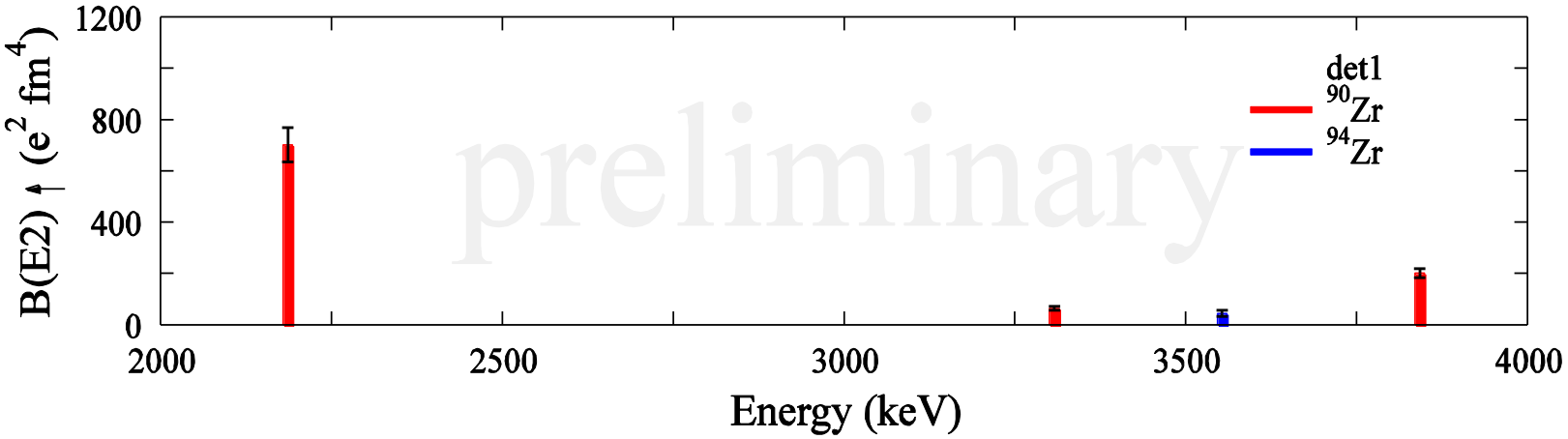
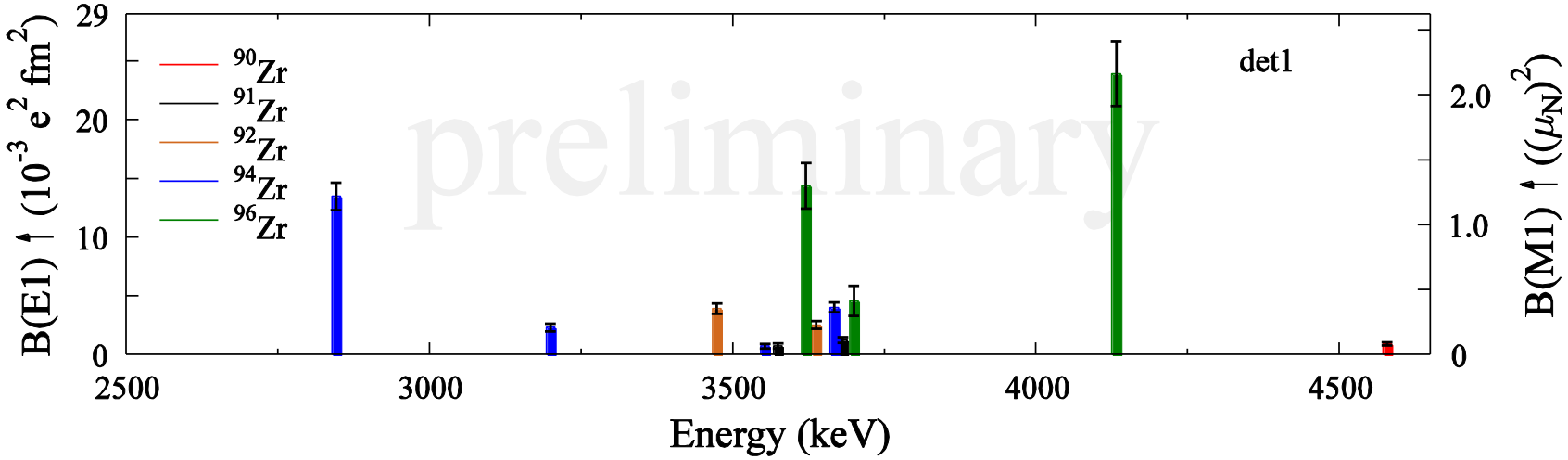
Nuclide	E [keV]	w	assigned $J^{(\pi)}$	Literature	Reference
^{90}Zr	2185.99	1.94(29)	2^+	1, 2^+	NNDC
	3307.84	2.50(52)	2^+	2^+	NNDC
	3842.45	2.31(33)	2^+	2^+	NNDC
	4578.40	0.71(14)	1	1	NNDC
^{91}Zr	3574.79	1.12(42)	$(\frac{3}{2})$	$(\frac{3}{2})^-$	NNDC
	3681.43	0.83(21)	$(\frac{3}{2})$	$\frac{3}{2}^+$	NNDC
^{92}Zr	3472.93	1.02(17)	1	1^+	C.Fransen et al.,Phys.Rev.C **71**, 054304(2005)
	3637.67	0.85(15)	1	1^-	C.Fransen et al.,Phys.Rev.C **71**, 054304(2005)
^{94}Zr	2845.79	0.76(10)	1		
	3199.57	0.77(15)	1		
	3553.24	1.46(57)	1		
	3553.24	1.46(57)	2		
	3666.93	0.68(11)	1		
^{96}Zr	3620.34	0.91(17)	1	1, 2^+	NNDC
	3699.47	0.52(16)	1	1, 2^+	NNDC
	4132.23	0.80(13)	1	1, 2^+	NNDC

BE1/BM1 & BE2 Transition Strengths





Results

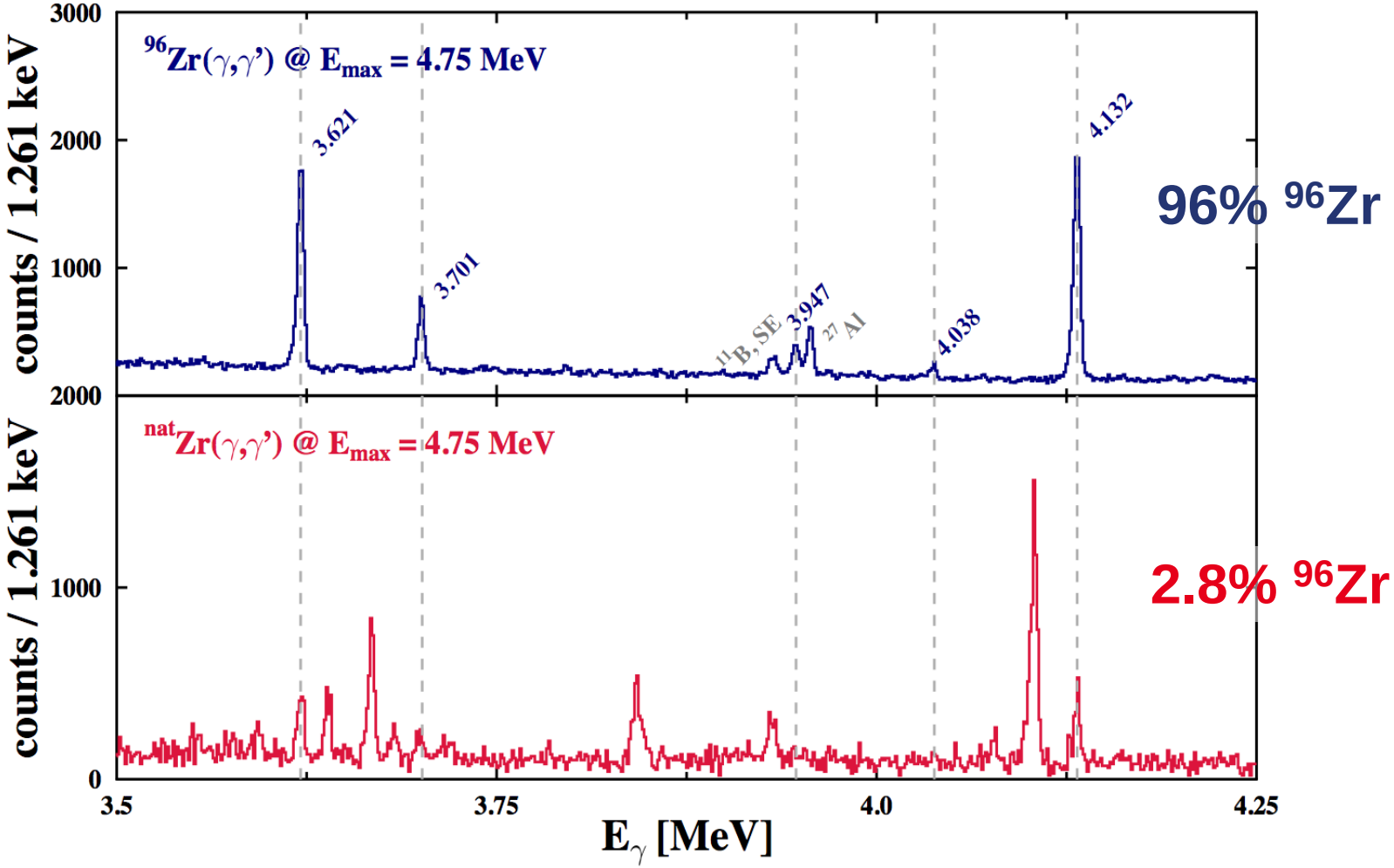
Nuclide	E [keV]	$J^{(\pi)}$	B(E1)↑ [10^{-3} e^2fm^2]	B(E2)↑ [e^2fm^4]	Literature*
^{90}Zr	2185.99	2^+	-	804(48)	646(22)
	3307.84	2^+	-	61.5(55)	78.7(43)
	3842.45	2^+	-	216(12)	226(15)
	4578.40	1	0.84(7)	-	1.56(23)
^{91}Zr	3574.79	$\frac{3}{2}$	0.70(13)	-	0.84(14)
	3681.43	$\frac{3}{2}$	1.41(14)	-	0.88(33)
^{92}Zr	3472.93	1^+	0.275(17)	-	0.371(42)
	3637.67	1^-	2.12(14)	-	2.24(29)
^{94}Zr	2845.79	1	13.77(67)	-	
	3199.57	1	2.18(15)	-	
	3553.24	1	0.44(9)	-	
	3553.24	2	-	52(10)	
	3666.93	1	4.32(23)	-	
^{96}Zr	3620.34	1	12.23(93)	-	5.5(32)
	3699.47	1	6.15(59)	-	4.3(21)
	4132.23	1	21.6(14)	-	-

* data calculated from lifetimes

Outlook ^{96}Zr

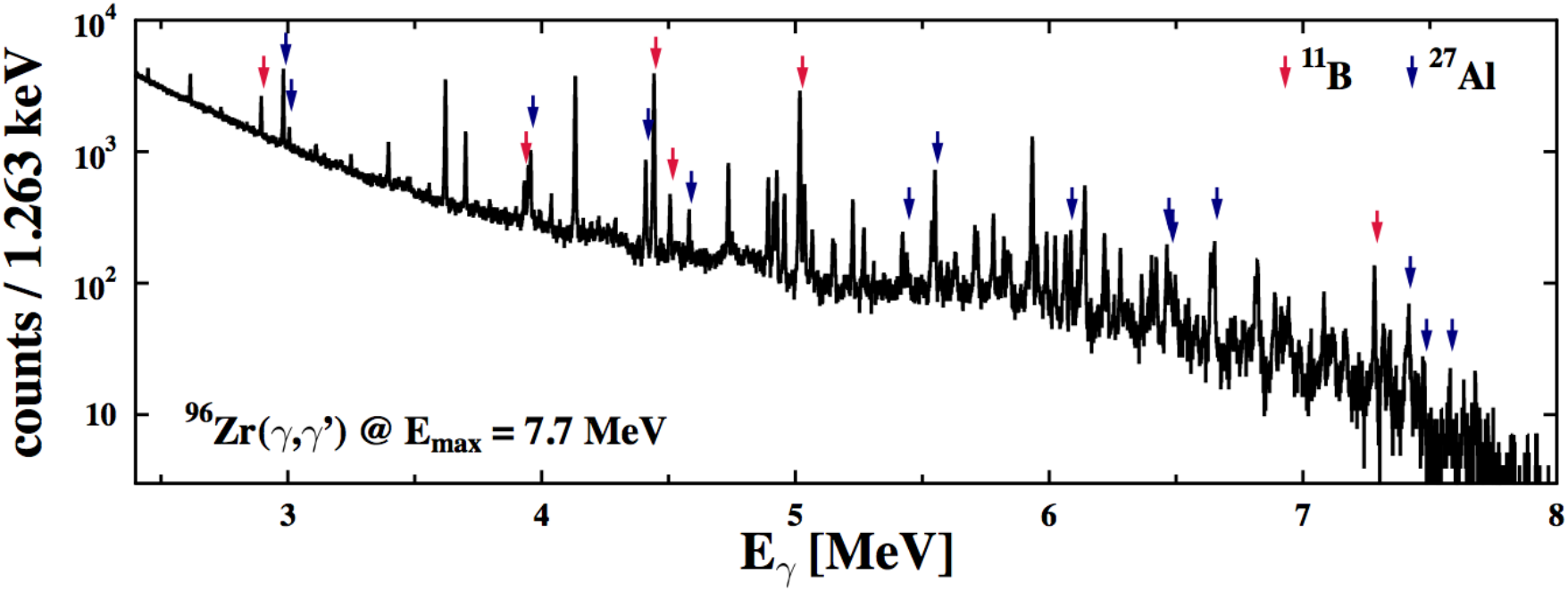
- Measured endpoint energies 5 and 7.7 MeV
- Both measurements below neutron separation energy (enriched target borrowed from Giuseppe Tagliente)
- K. Sonnabends data analysis in very good agreement with ^{nat}Zr data

Outlook ^{96}Zr - 5.1 MeV Spectra



N. Pietralla et al., Nuclear Structure and Related Topics, Proceedings of the International Conference, Dubna, June 30- July 4, 2009, Volume II, Ed. A.I. Volovin, V.V. Voronov, R.V. Jolos (JINR)

Outlook ^{96}Zr - 7.7 MeV Spectrum



N. Pietralla et al., Nuclear Structure and Related Topics, Proceedings of the International Conference, Dubna, June 30- July 4, 2009, Volume II, Ed. A.I. Volovin, V.V. Voronov, R.V. Jolos (JINR)

Summary

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- Transition strength determination in ^{nat}Zr
- Normalization of ^{96}Zr-data possible
- Study of the 1^- state of quintuplet
- Information of PDR in doubly-closed subshell nuclei

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Many Thanks to

TECHNISCHE UNIVERSITÄT DARMSTADT

Giuseppe Tagliente

(Istituto Nazionale di Fisica Nucleare, Bari, Italy)

for providing the ^{96}Zr-target,

everybody who helped during the experiment,

the organising committee of the workshop for the support

and

you for your attention!