A new technique for studies of highly proton rich nuclei in the region of the astrophysical rp-process

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Science & Technology Facilities Council

Argonne NATIONAL LABORATORY

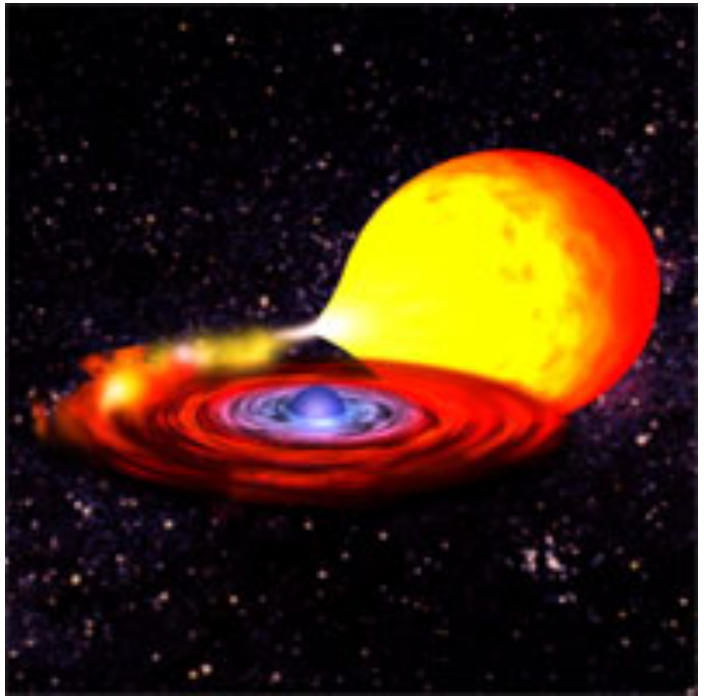
SUPA

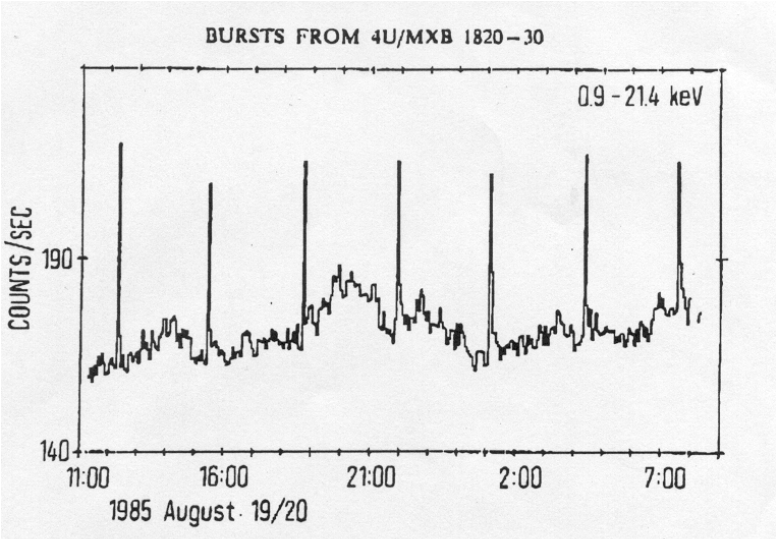
Type I X-ray bursts

- Close binary system: very dense neutron star and companion star

- Matter accretion

- Extreme temperature and density conditions
  ($T > 10^9$ K, $\rho \sim 10^6$ g/cm^3)





- Burst recurrence time of ~hours

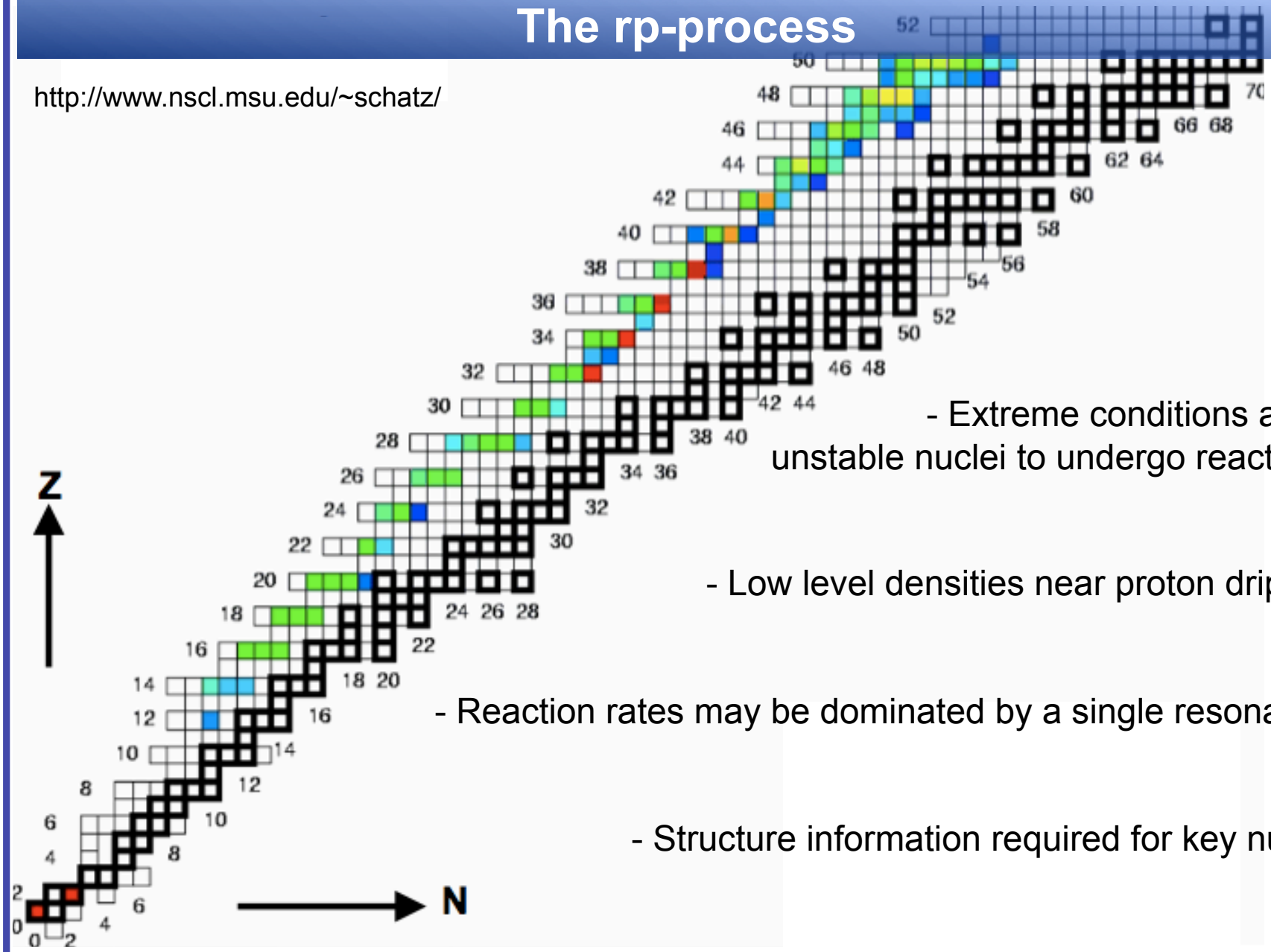
- Burst duration of ~10 – 100s

- Peak luminosity ~ 3 x 10^{38} erg/s (10^5 times more than the sun!)

Lewin, W.H.G., van Paradijs, J. & Taam, R.E., 1993, Sp Sci Rev, 62, 223

The rp-process

http://www.nscl.msu.edu/~schatz/



- Extreme conditions allow unstable nuclei to undergo reactions

- Low level densities near proton dripline

- Reaction rates may be dominated by a single resonance

- Structure information required for key nuclei

Important reactions

Study highlighted key reactions [1]

Reaction	Q-value (keV)	Models affected
$^{25}Si(\alpha,p)^{28}P$	6119(11)	hiZ
$^{26g}Al(\alpha,p)^{29}Si$	4820.68(6)	F08
$^{29}S(\alpha,p)^{32}Cl$	5306(50)	hiZ
$^{30}P(\alpha,p)^{33}S$	1521.36(34)	hiZ
$^{30}S(\alpha,p)^{33}Cl$	2077(3)	hiZ
$^{31}Cl(p,\gamma)^{32}Ar$	2422(50)	short
$^{32}S(\alpha,\gamma)^{36}Ar$	6640.76(14)	long
$^{56}Ni(\alpha,p)^{59}Cu$	−2411(11)	S01, hiZ
$^{57}Cu(p,\gamma)^{58}Zn$	2277(52)	F08
$^{59}Cu(p,\gamma)^{60}Zn$	5120(11)	S01, hiZ
$^{61}Ga(p,\gamma)^{62}Ge$	2442(149)[a]	F08, short, long, hiZ, lowT
$^{65}As(p,\gamma)^{66}Se$	2030(424)[a]	K04, short, long, lowZ, hiZ, lowT
$^{69}Br(p,\gamma)^{70}Kr$	2489(399)[a]	hiT
$^{75}Rb(p,\gamma)^{76}Sr$	4311(38)	long
$^{82}Zr(p,\gamma)^{83}Nb$	2055(387)[a]	lowT
$^{84}Zr(p,\gamma)^{85}Nb$	2946(297)[a]	long
$^{84}Nb(p,\gamma)^{85}Mo$	4513(409)[a]	lowT
$^{85}Mo(p,\gamma)^{86}Tc$	1393(409)[a]	F08
$^{86}Mo(p,\gamma)^{87}Tc$	1855(530)[a]	F08, lowT
$^{87}Mo(p,\gamma)^{88}Tc$	2304(300)[a]	lowT
$^{92}Ru(p,\gamma)^{93}Rh$	2054(499)[a]	long, lowT
$^{93}Rh(p,\gamma)^{94}Pd$	4467(566)[a]	long
$^{96}Ag(p,\gamma)^{97}Cd$	3321(566)[a]	K04, long, lowZ, hiT
$^{102}In(p,\gamma)^{103}Sn$	3554(318)[a]	K04, lowZ
$^{103}In(p,\gamma)^{104}Sn$	4281(107)	lowZ, hiT
$^{103}Sn(\alpha,p)^{106}Sb$	−5508(432)[a]	S01

[1] A. Parikh, J. José, F. Moreno and C. Iliadis, Astrophys. J. Suppl. Ser. **178**, 110 (2008)

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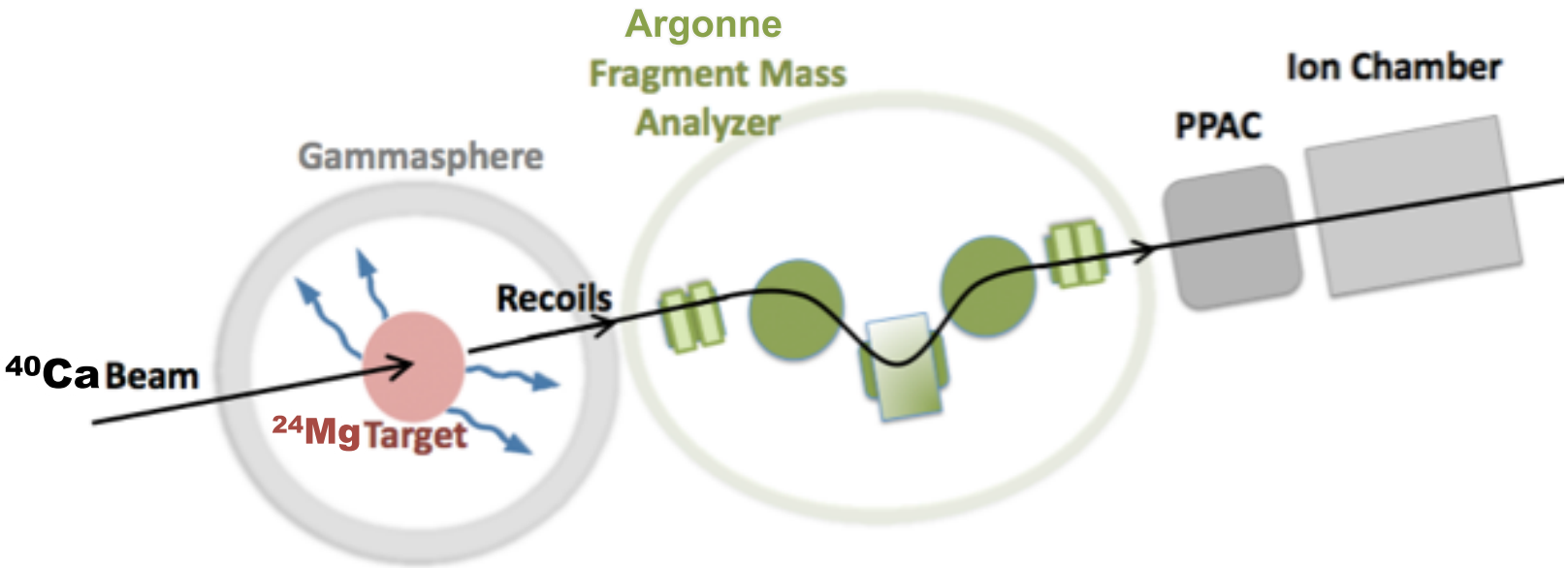
Producing exotic rp-nuclei



- Compound nucleus formed in fusion reaction

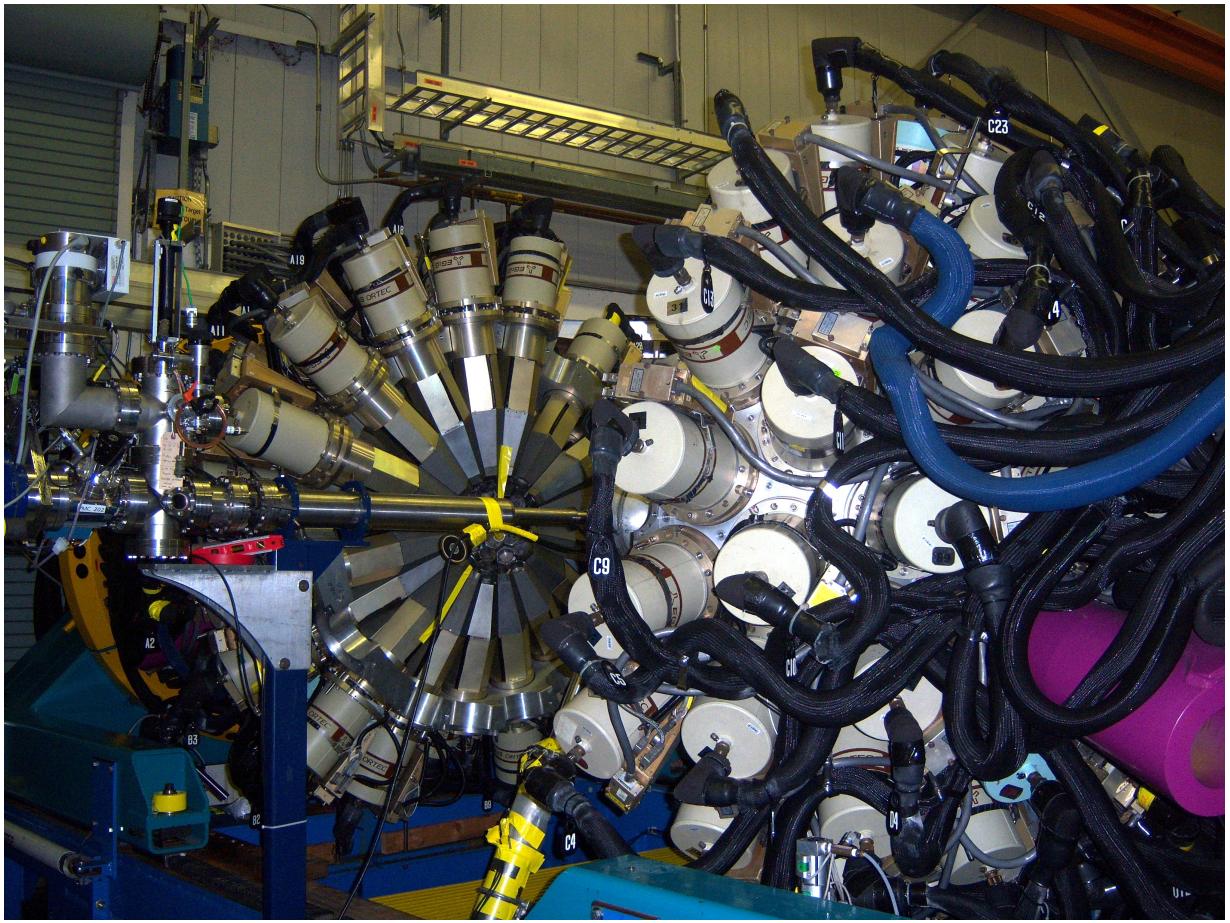
- Mass A=62 fusion evaporation products analysed at 0^{o} by FMA

BUT, the FMA disperses recoils by mass-to-charge ratio.

⇒ Isobaric contaminants!

Gammasphere

- Array of ~100 HPGe γ-ray detectors with almost 4π geometric coverage



- Background from isobaric contaminants and some nuclei in different charge states swamp γ-rays from nuclei of interest

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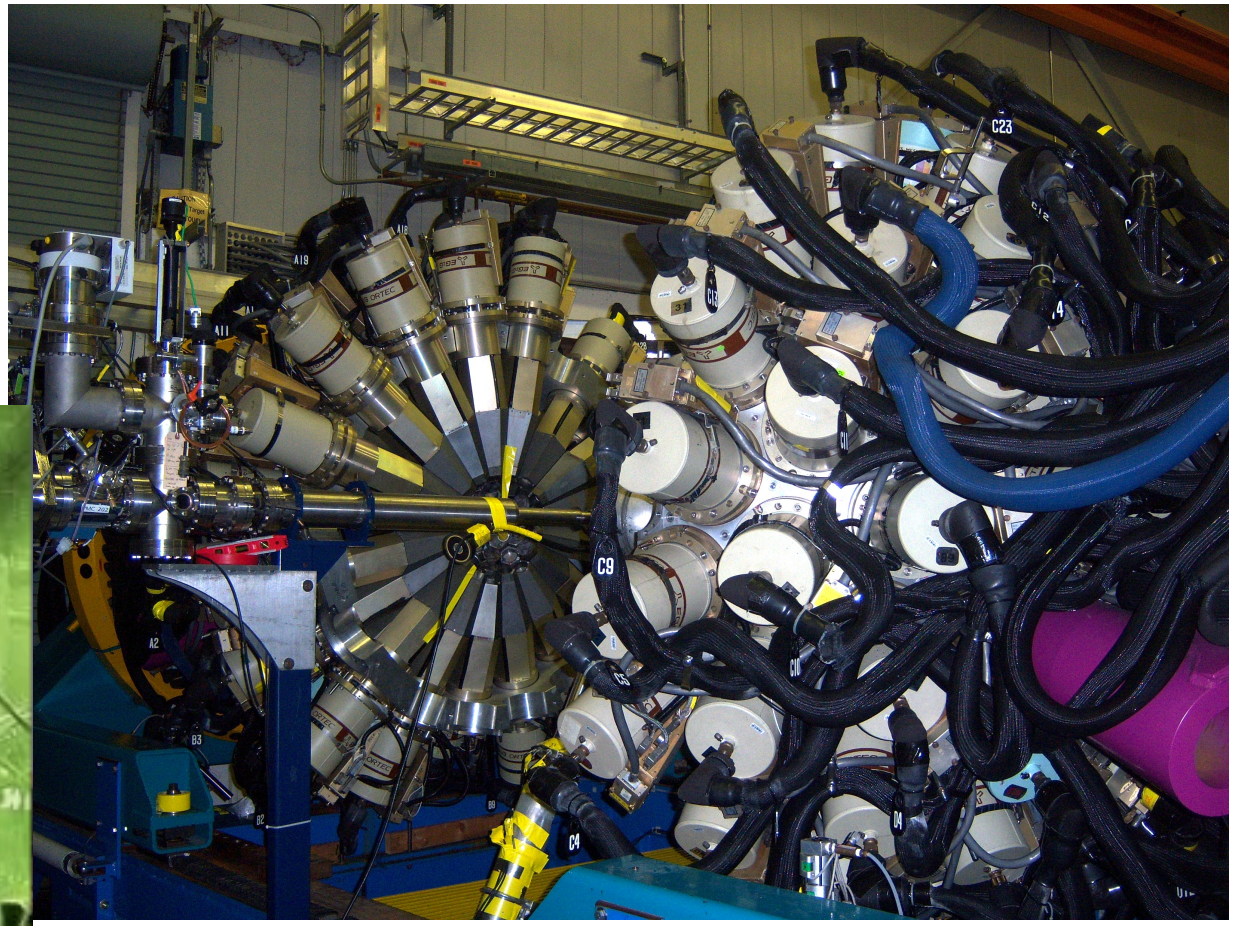

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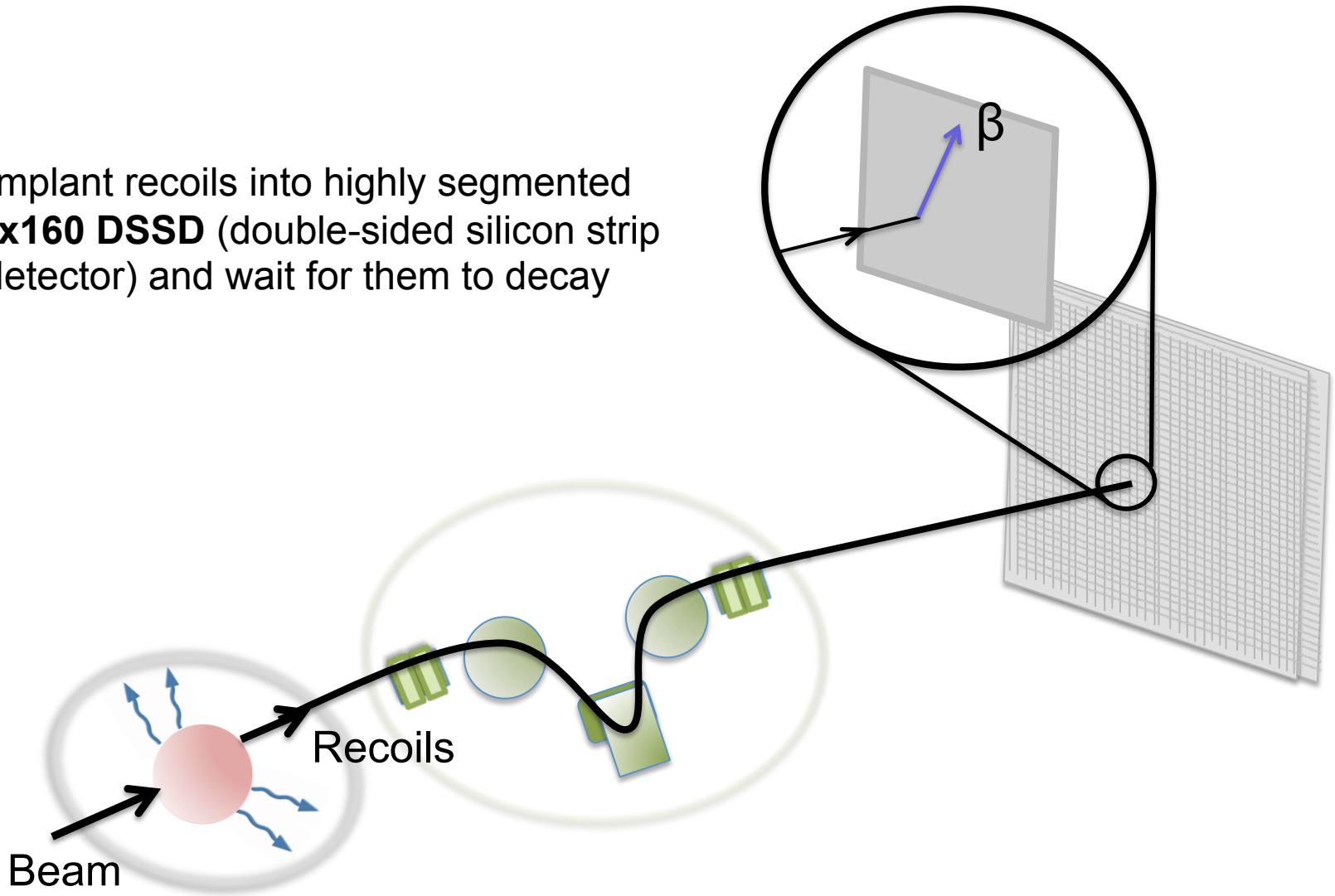
Additional selectivity?

- Take advantage of **fast β-decays** exhibited by many exotic nuclei in the region of the rp-process

$$^{62}\mathrm{Ge} \xrightarrow{\tau_{1/2} \sim 100\mathrm{ms}} {}^{62}\mathrm{Ga} \xrightarrow{\tau_{1/2} \sim 100\mathrm{ms}} {}^{62}\mathrm{Zn} \xrightarrow{\tau_{1/2} \sim 9\mathrm{hrs}} {}^{62}\mathrm{Cu}$$

New highly segmented implantation detector

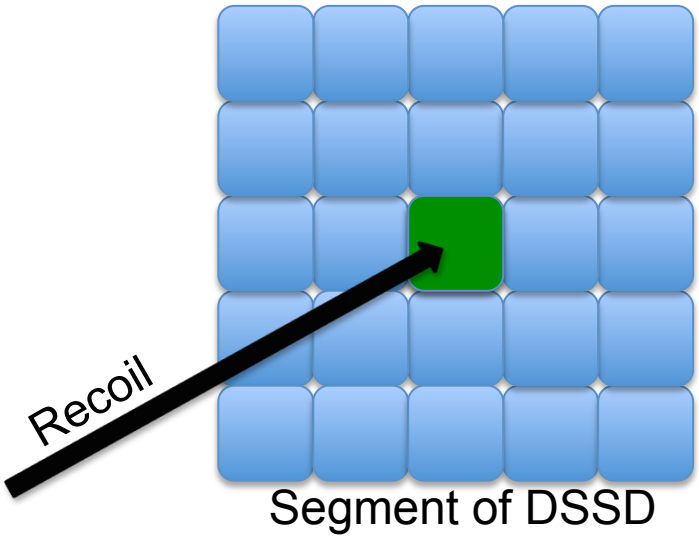
- Implant recoils into highly segmented **160x160 DSSD** (double-sided silicon strip detector) and wait for them to decay



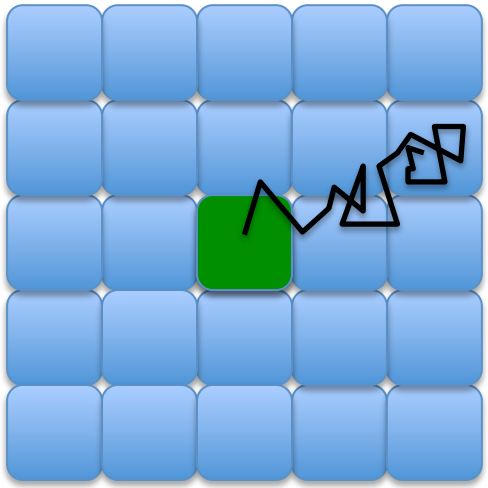
See also A.N. Steer *et al*. NIM A, 565, 630, (2006)

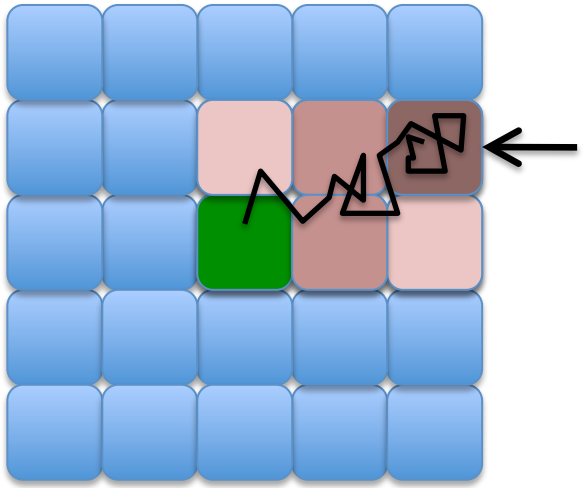
Looking for correlations

Recoils are implanted into DSSD

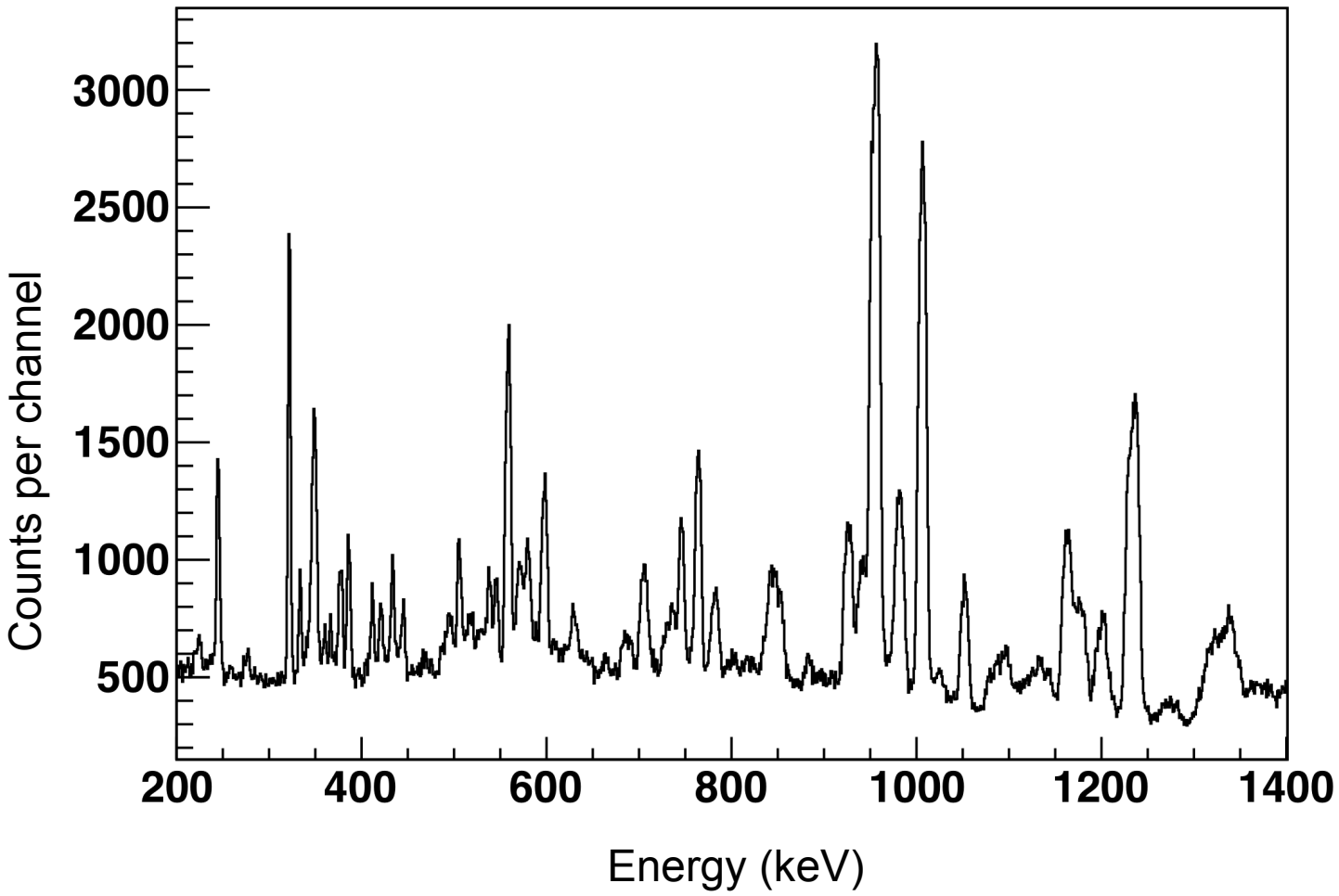


Subsequent β-decay

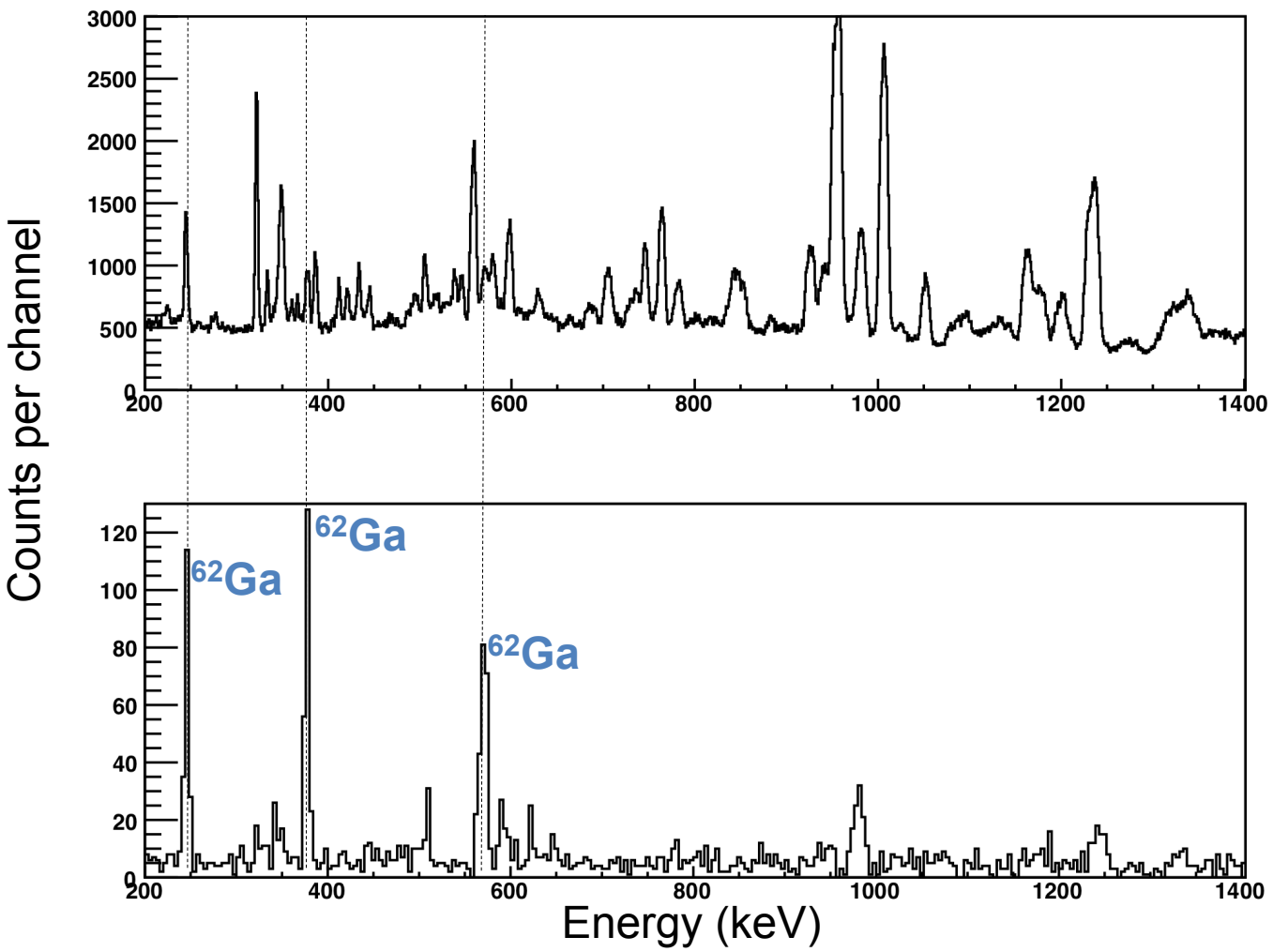




γ spectrum measured in coincidence with implanted recoils



Inclusion of new detector



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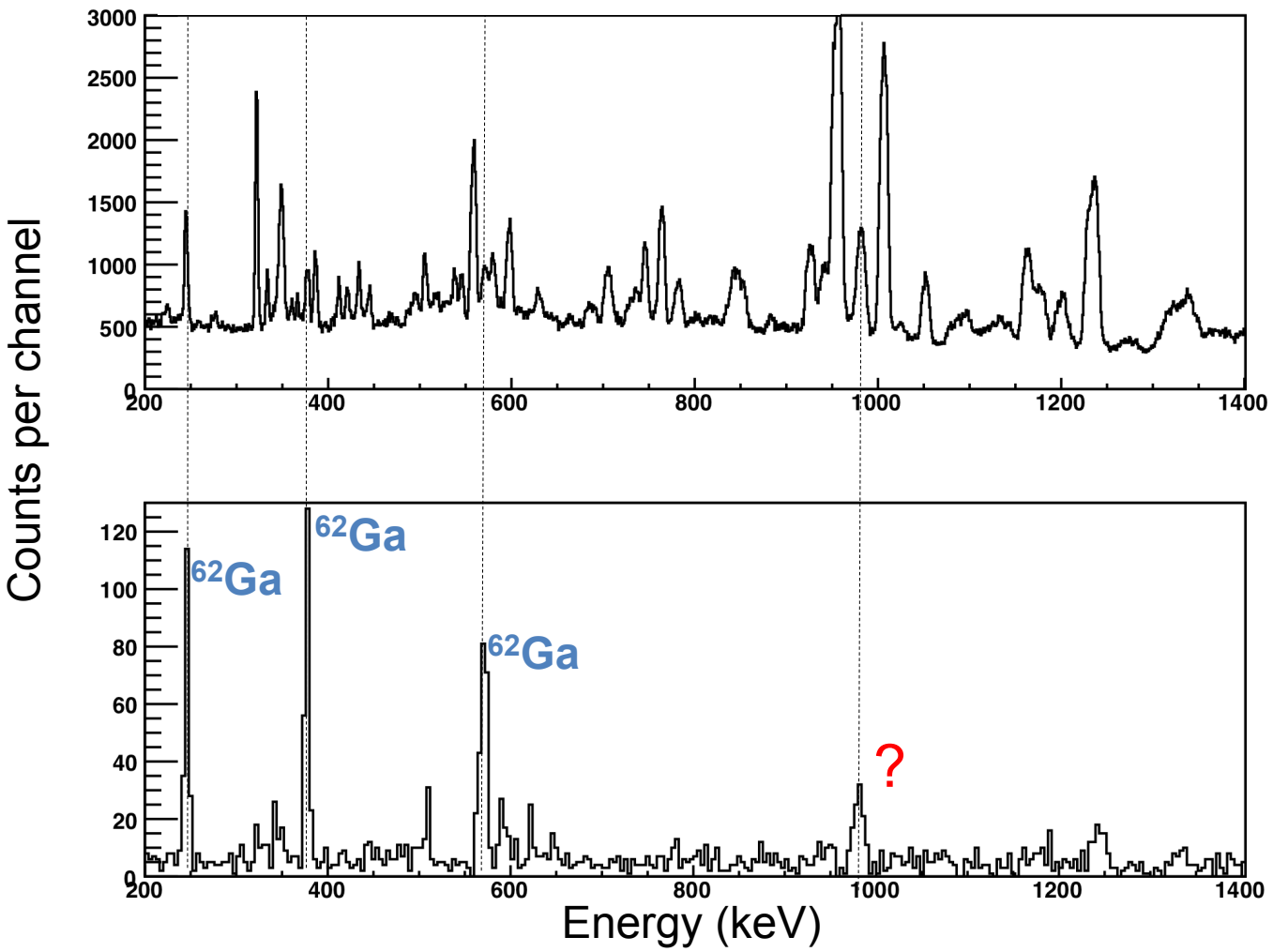

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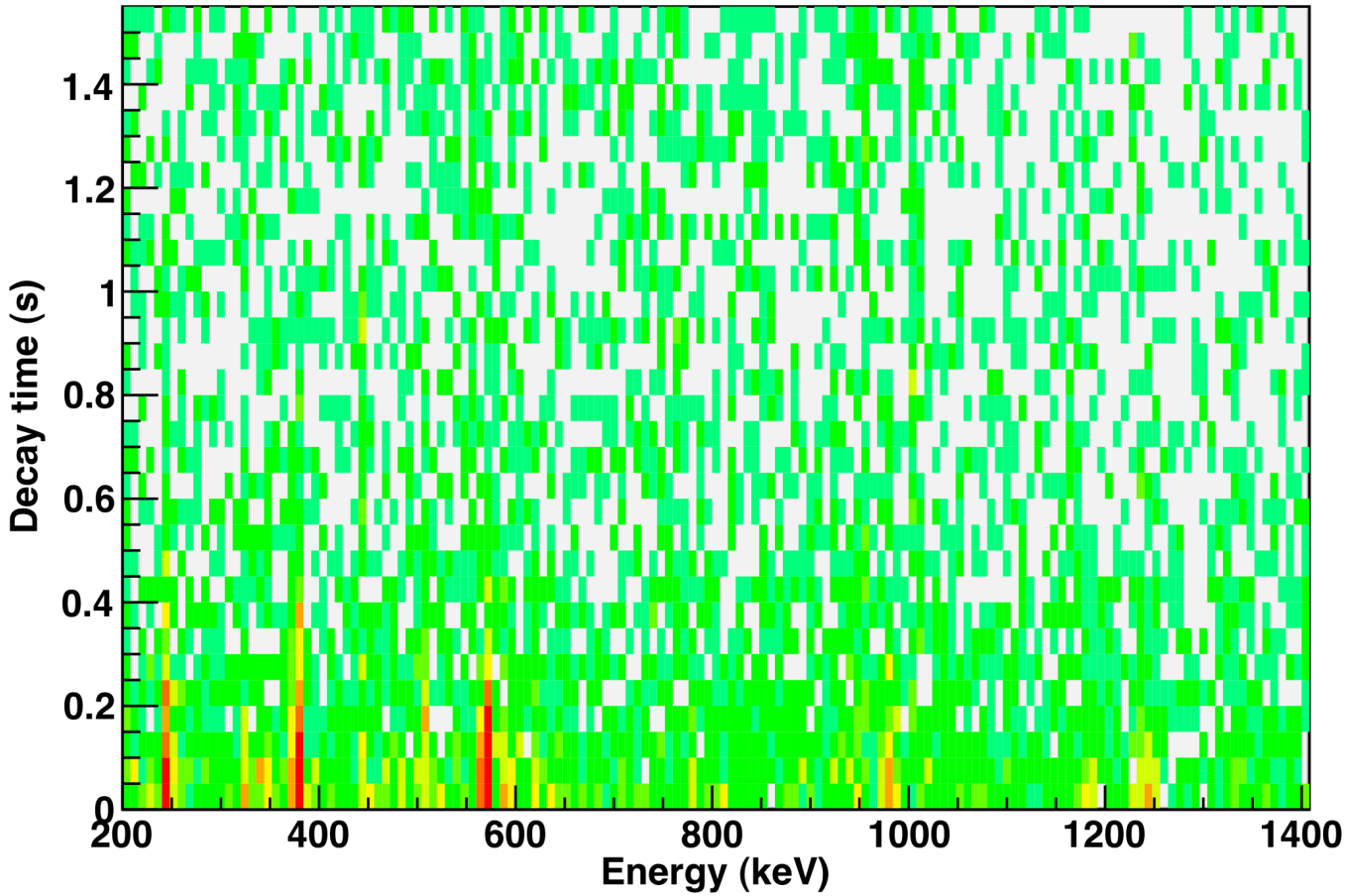
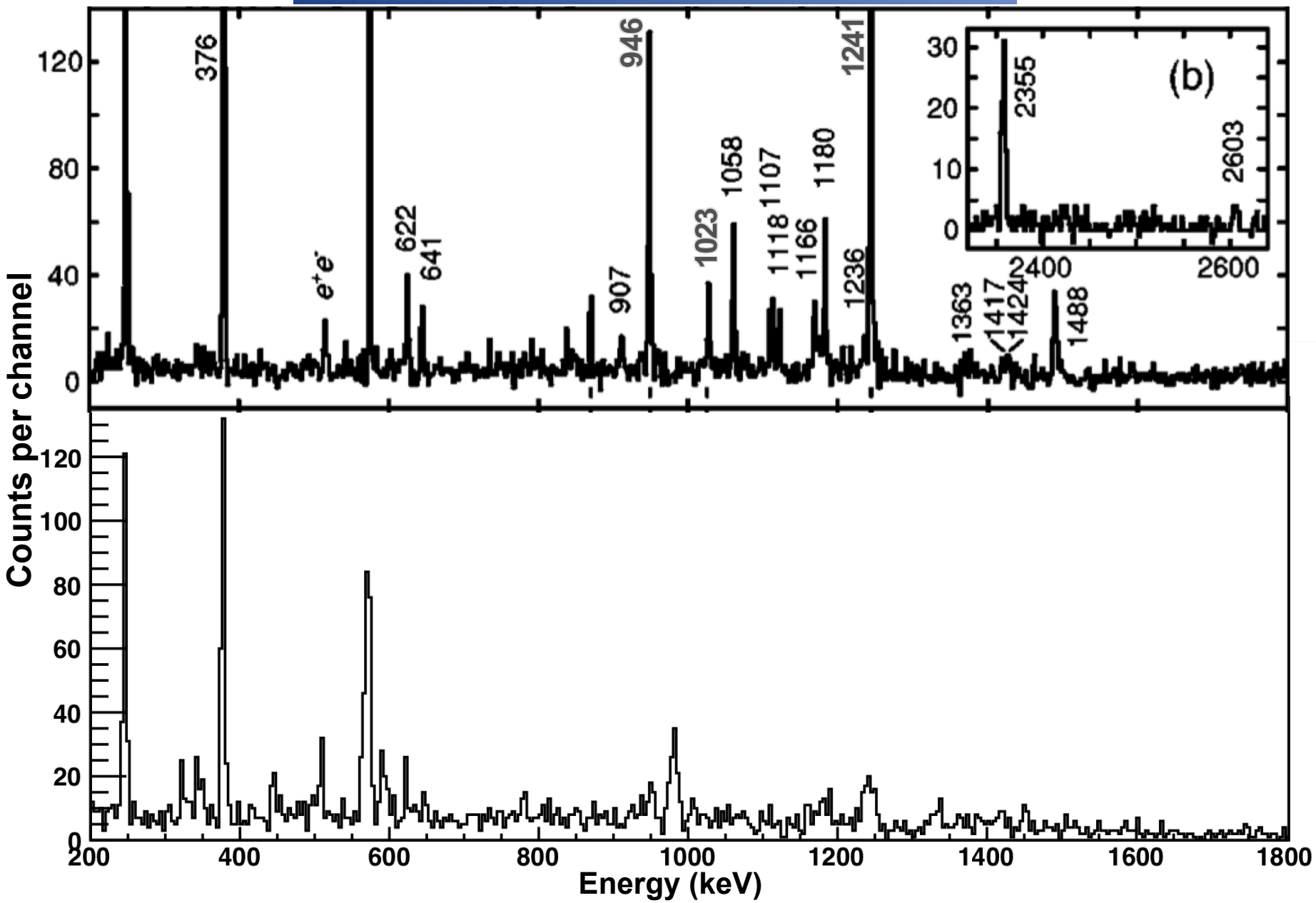
Sensitivity to half-life



Comparison with previous work



Rudolph *et al.*, Phys. Rev. C **69**, 034309 (2004)

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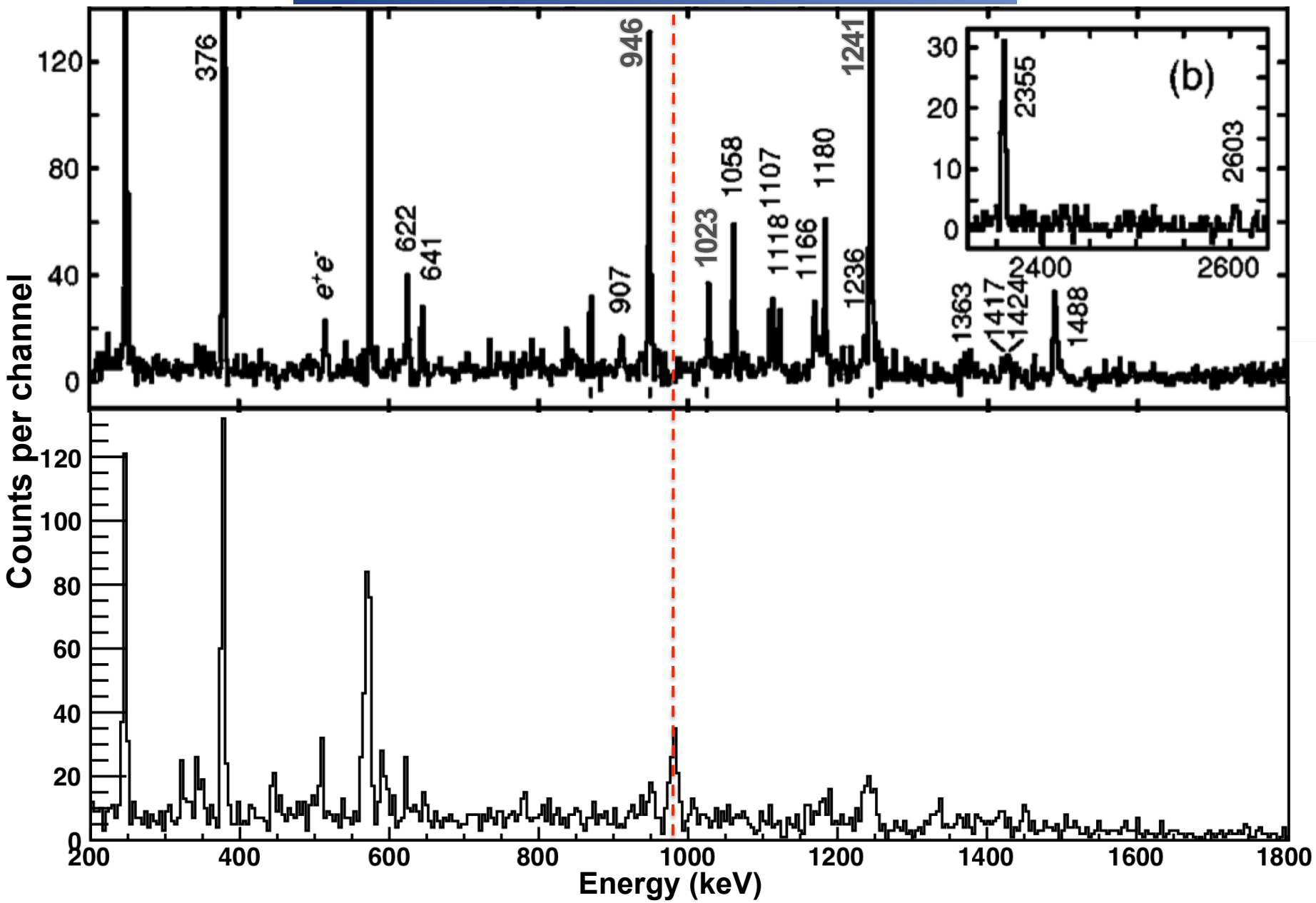

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Previous work

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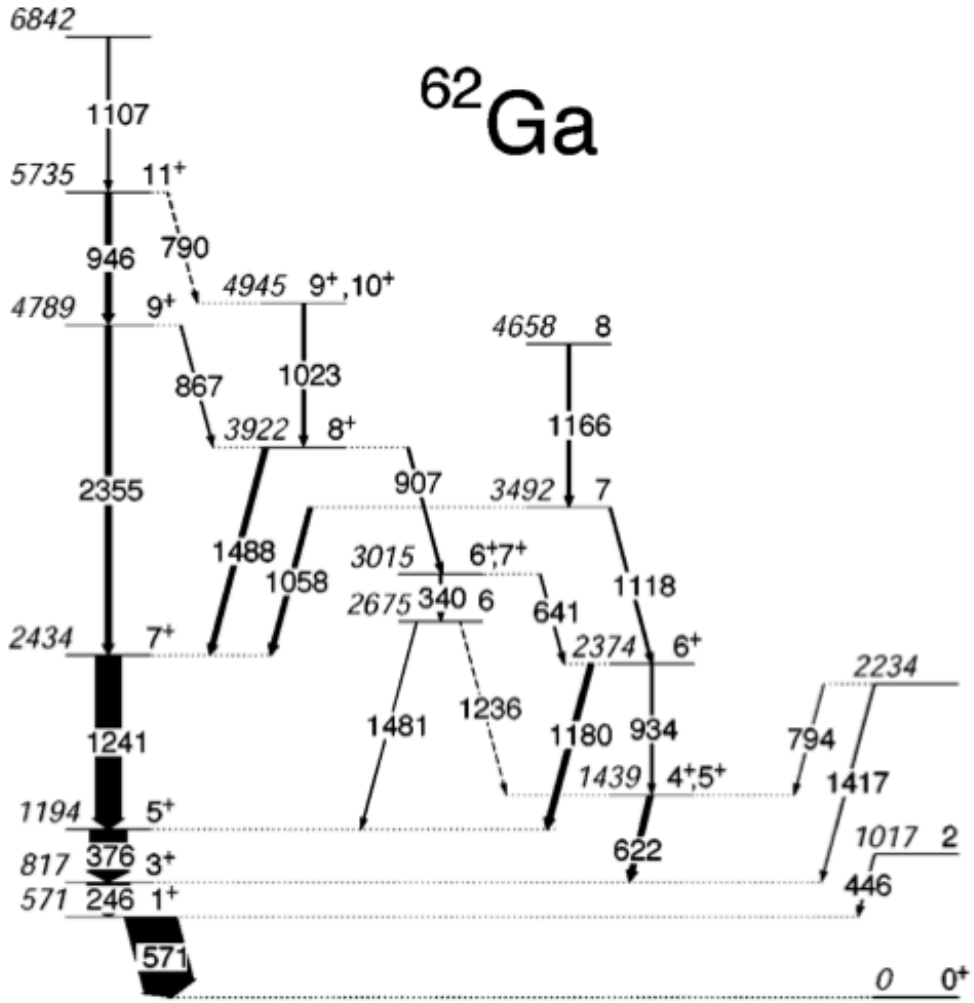

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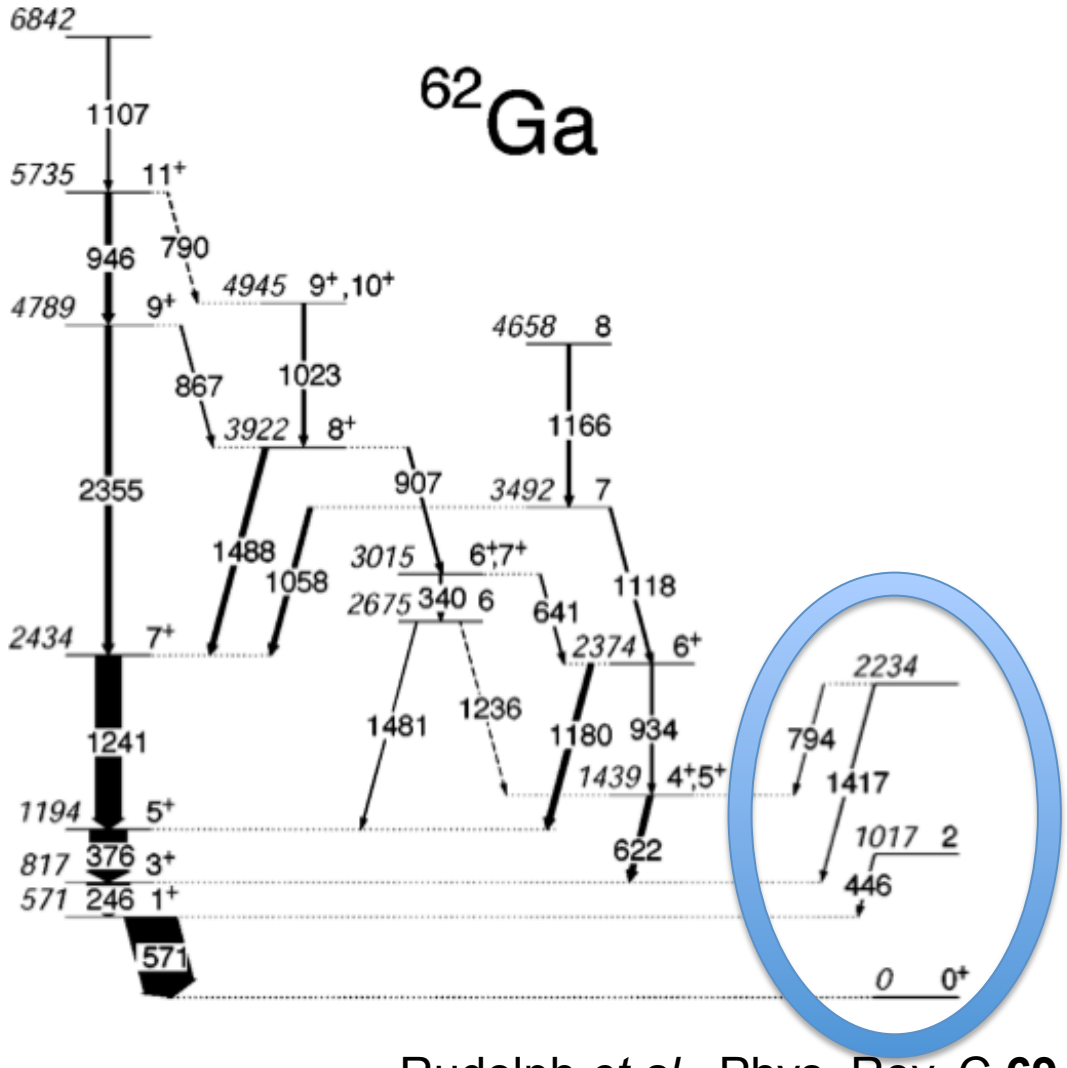

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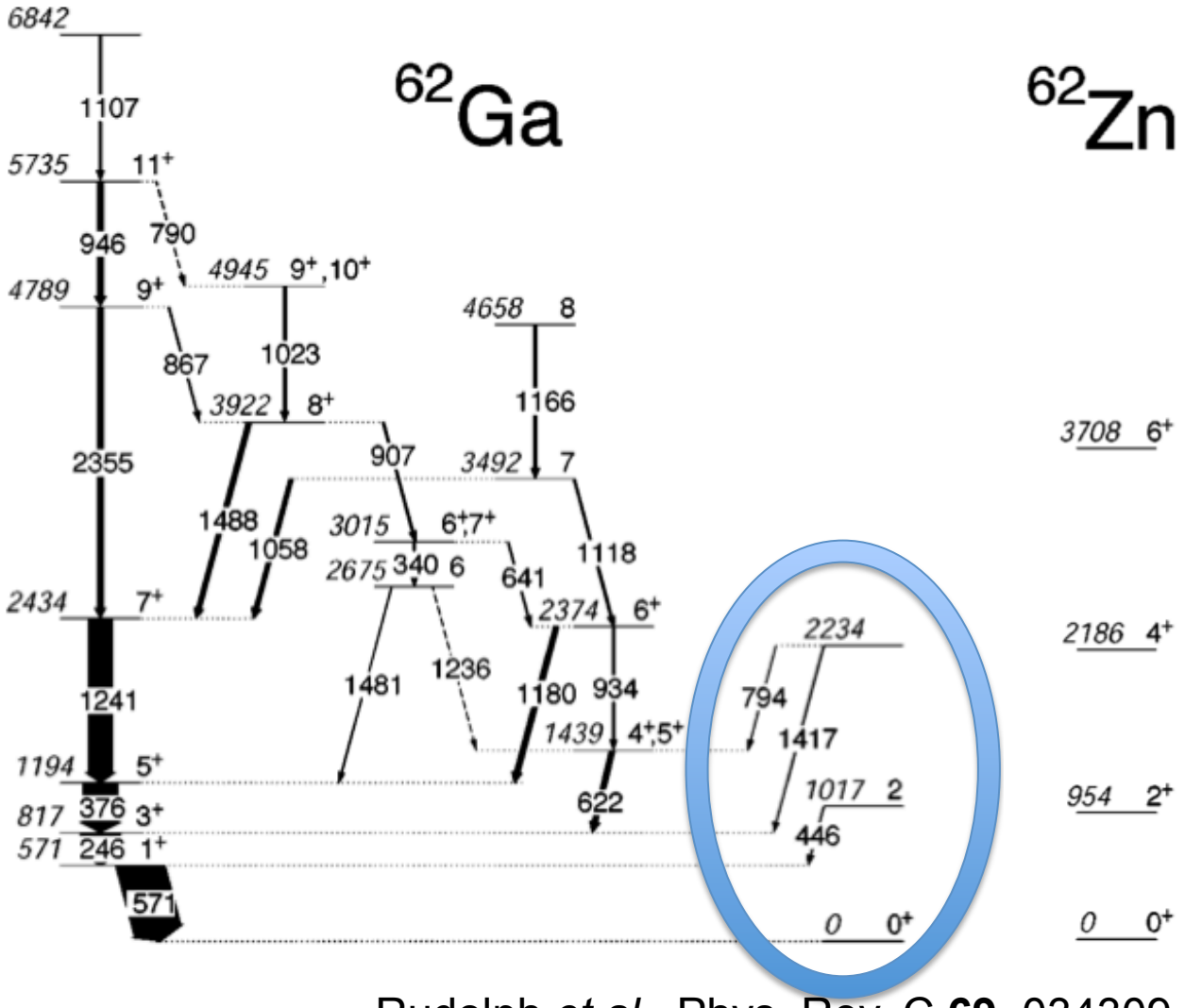


Rudolph *et al.*, Phys. Rev. C **69**, 034309 (2004)

Conclusions

New method demonstrates high selectivity on fast β-emitters

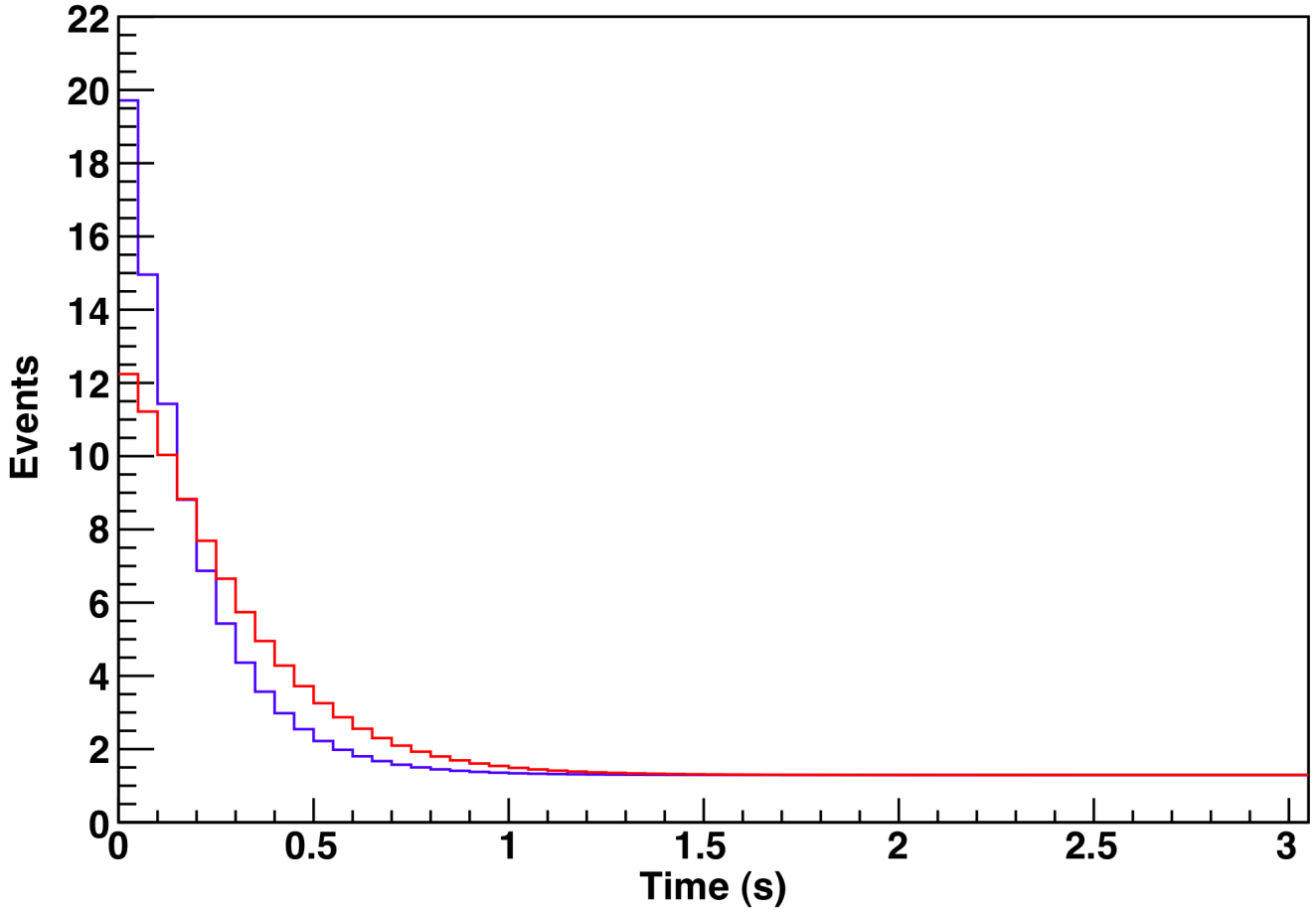
Provides ability to produce very clean γ-ray spectra without requirement of coincidences

Future: use system to study T_z=-1 nuclei in region of rp-process e.g. ^{62}Ge

Collaboration

G.Lotay[1], P.J. Woods[1], D. Seweryniak[2], M. Carpenter[2], C.J. Chiara[2], H.M. David[1], T. Davinson[1], C. Hoffman[2], R.V.F Janssens[2], D. Jenkins[3], T.L. Khoo[2], T. Lauritson[2], C.J. Lister[2], Z. Liu[1], E. A. McCutcheon[2], A. Rodgers[2], J.P. Wallace[1] and S. Zhu[2]

[1]University of Edinburgh, Edinburgh, EH9 3JZ, UK
[2]Physics Division, Argonne National Laboratory, Argonne IL 60439, USA
[3]Department of Physics, University of York, Heslington, York YO10 5DD, UK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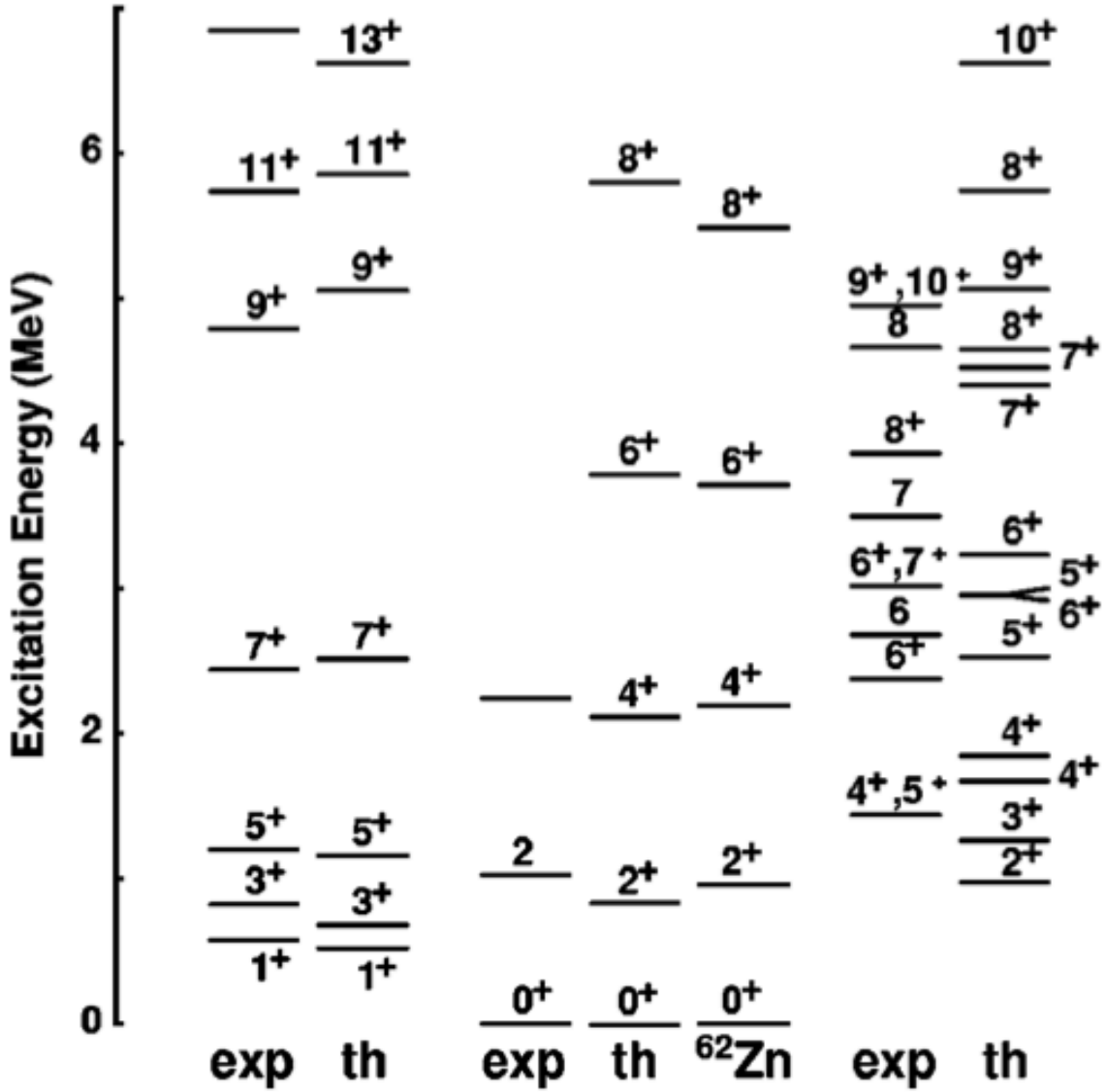

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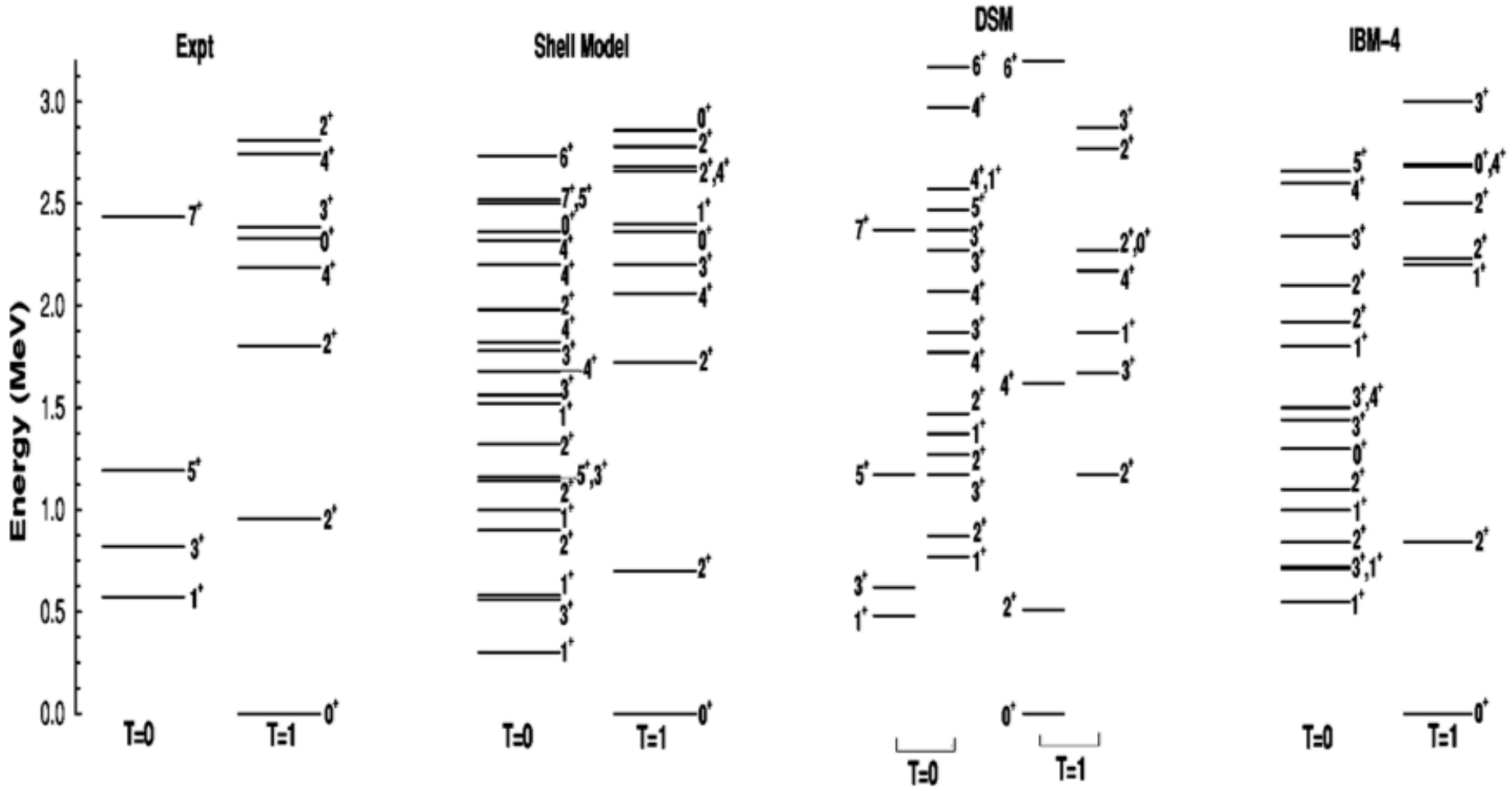

R. Sahu and V. K. B. Kota, Phys. Rev. C **66**, 024301 (2002)