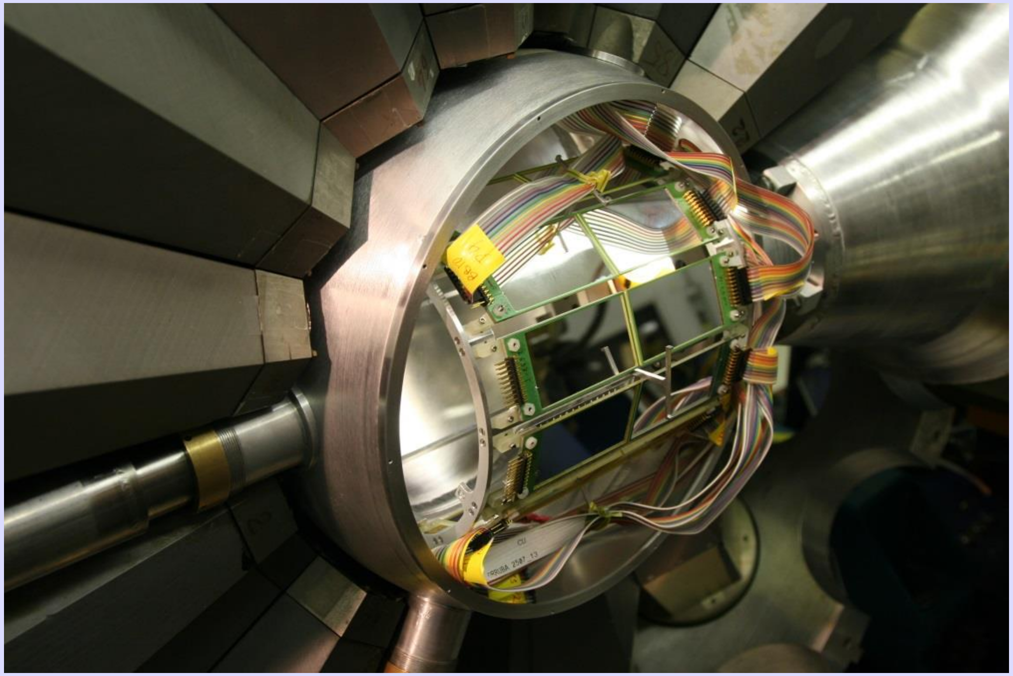
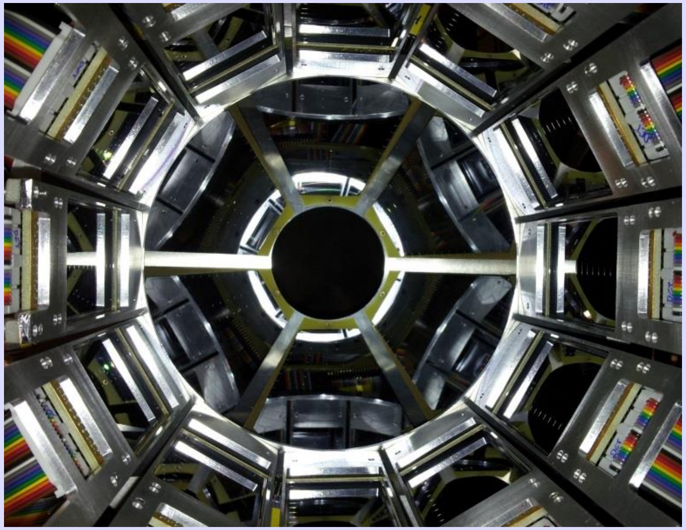
Transfer reactions for r-process nucleosynthesis

Steven D. Pain

Oak Ridge National Laboratory

- r-process nucleosynthesis
- Transfer program at Oak Ridge
- Measurements with SPES Phase I

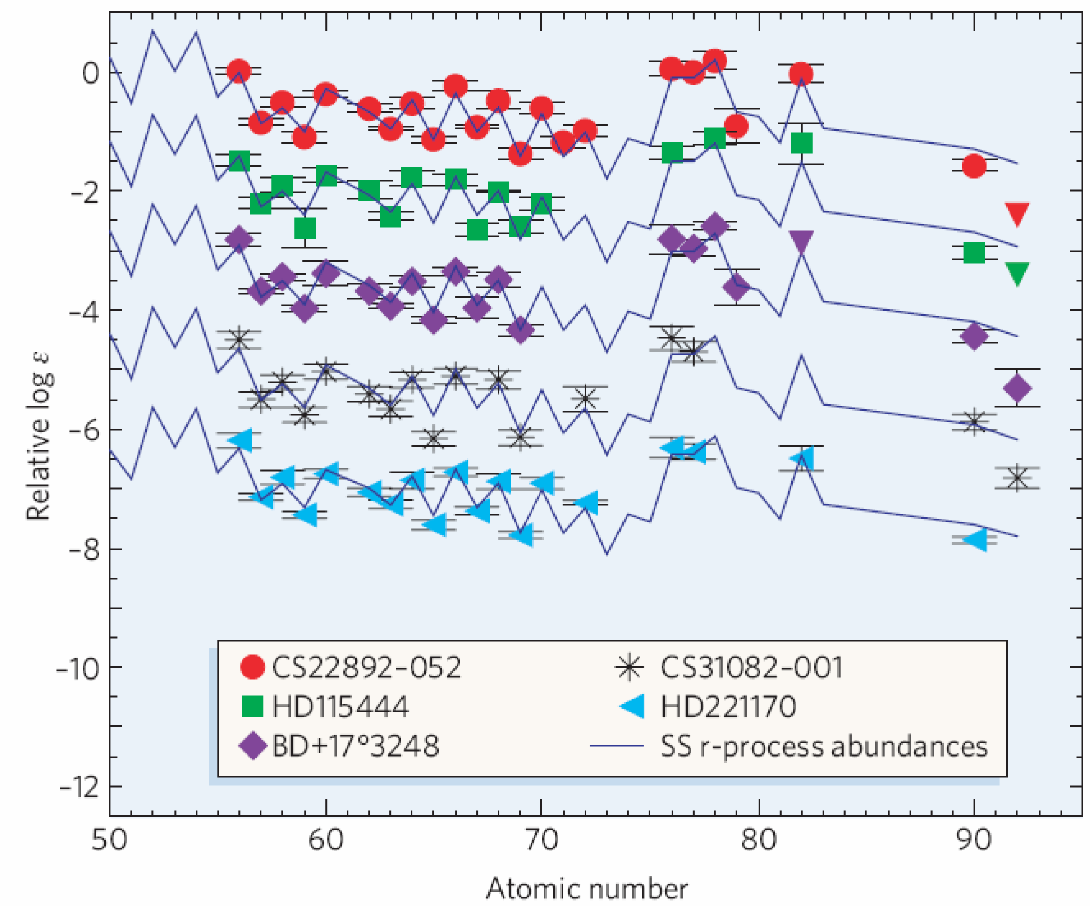




SPES 2nd International Workshop, 2014

r-process abundance patterns

Elemental abundances from individual metal-poor halo stars constraining r-process abundance patterns

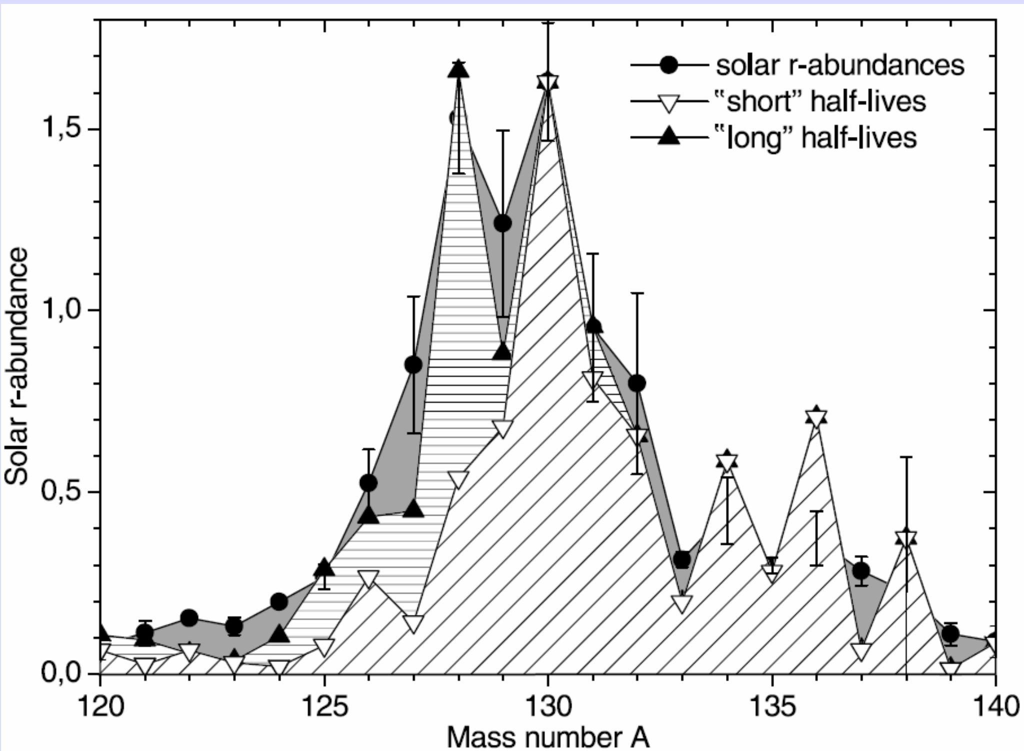


J.J Cowan and C. Sneden, *Nature* **440**, 1151 (2006)

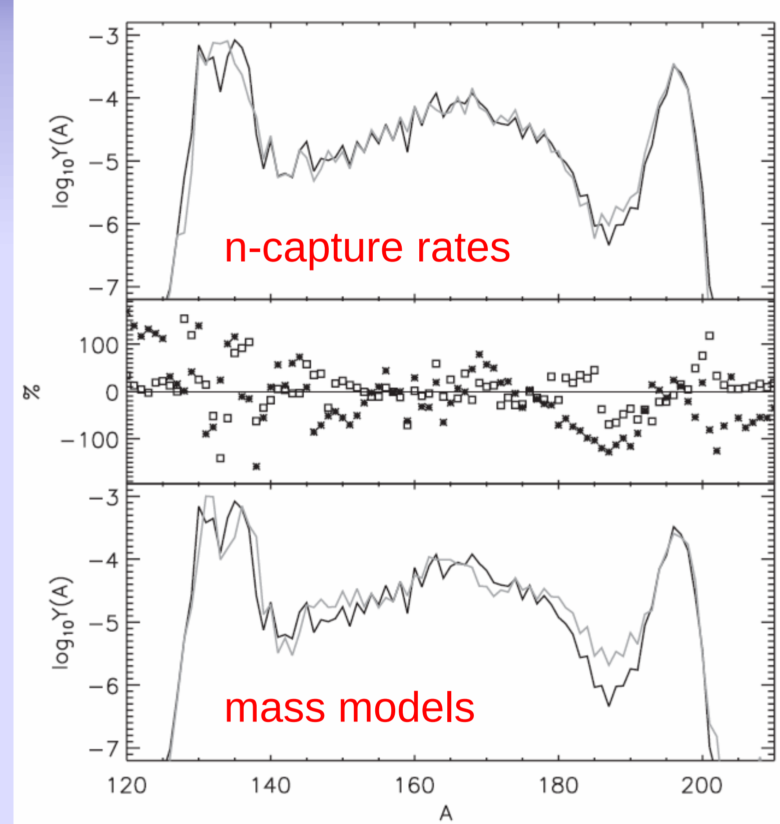
r-process sensitivities

Sensitivities to global structure, and to individual n-capture rates

Adjustment of TBME to reproduce 1+ state in ^{130}In



I. Dillman *et al., Phys. Rev. Lett*. **91**, 162503 (2003)



Z	78	79	80	81	82	83	84	85	86	87
52	^{130}Te	^{131}Te	^{132}Te	^{133}Te	^{134}Te	^{135}Te	^{136}Te	^{137}Te	^{138}Te	^{139}Te
51	^{129}Sb	^{130}Sb	^{131}Sb	^{132}Sb	^{133}Sb	^{134}Sb	^{135}Sb	^{136}Sb	^{137}Sb	^{138}Sb
50	^{128}Sn	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn	^{134}Sn	^{135}Sn	^{136}Sn	^{137}Sn
49	^{127}In	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In	^{133}In	^{134}In	^{135}In	^{136}In
48	^{126}Cd	^{127}Cd	^{128}Cd	^{129}Cd	^{130}Cd	^{131}Cd	^{132}Cd	^{133}Cd	^{134}Cd	^{135}Cd

N

R. Surman, J. Beun, G. C. McLaughlin, and W. R. Hix, *Phys. Rev. C* **79**, 045809 (2009)

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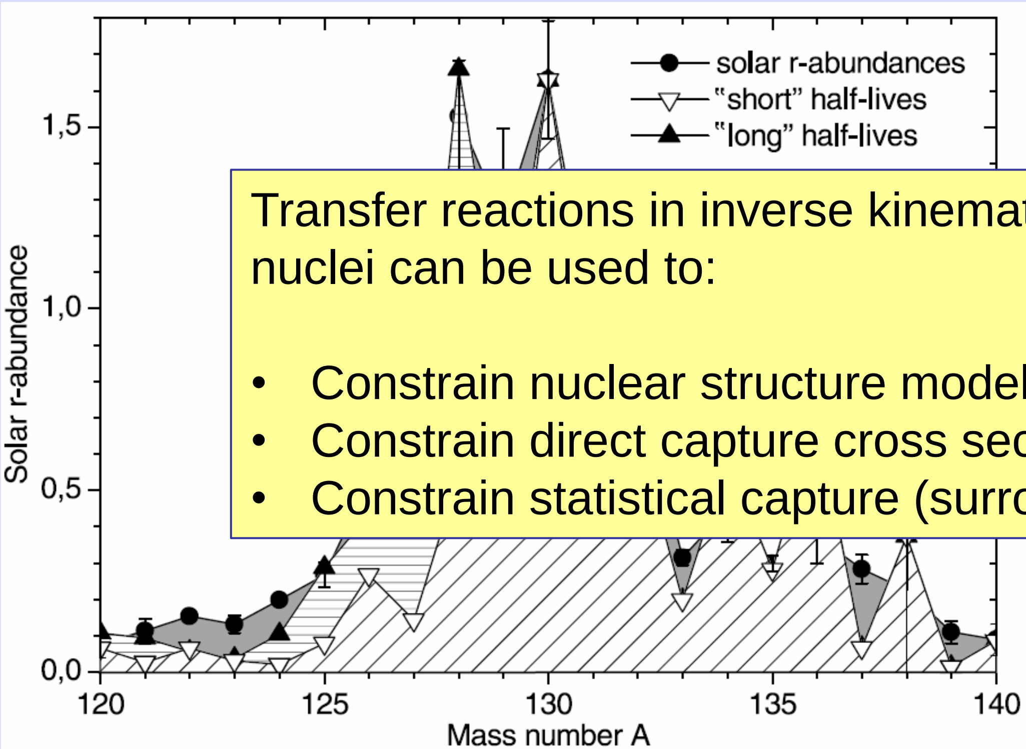
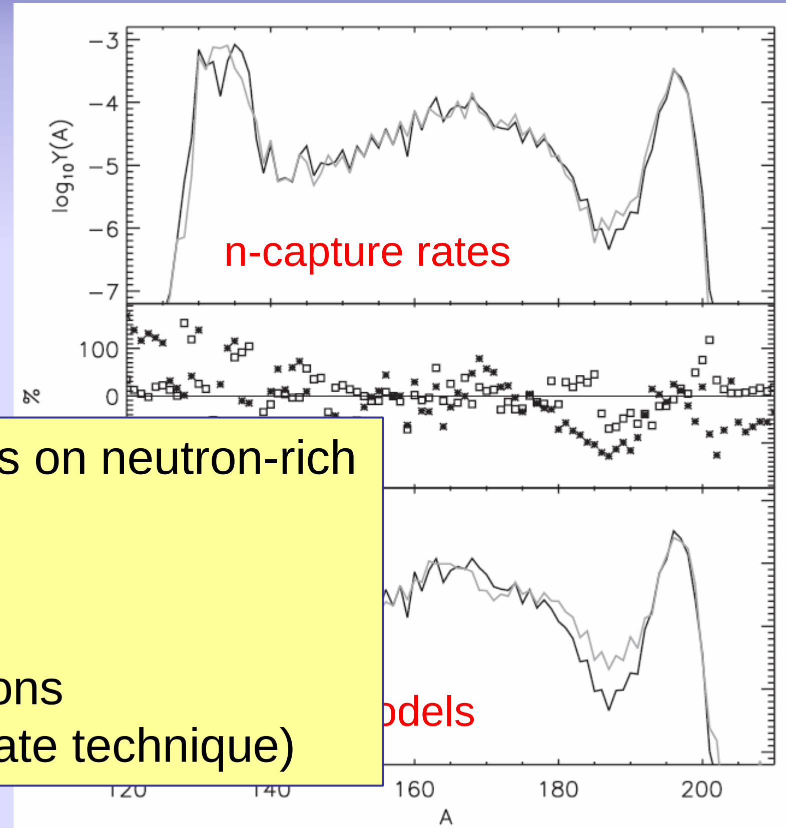


I. Dillman *et al., Phys. Rev. Lett*. **91**, 162503 (2003)

Transfer reactions in inverse kinematics on neutron-rich nuclei can be used to:

- Constrain nuclear structure models
- Constrain direct capture cross sections
- Constrain statistical capture (surrogate technique)



Z \ N	78	79	80	81	82	83	84	85	86	87
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51	^{129}Sb	^{130}Sb	^{131}Sb	^{132}Sb	^{133}Sb	^{134}Sb	^{135}Sb	^{136}Sb	^{137}Sb	^{138}Sb
50	^{128}Sn	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn	^{134}Sn	^{135}Sn	^{136}Sn	^{137}Sn
49	^{127}In	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In	^{133}In	^{134}In	^{135}In	^{136}In
48	^{126}Cd	^{127}Cd	^{128}Cd	^{129}Cd	^{130}Cd	^{131}Cd	^{132}Cd	^{133}Cd	^{134}Cd	^{135}Cd

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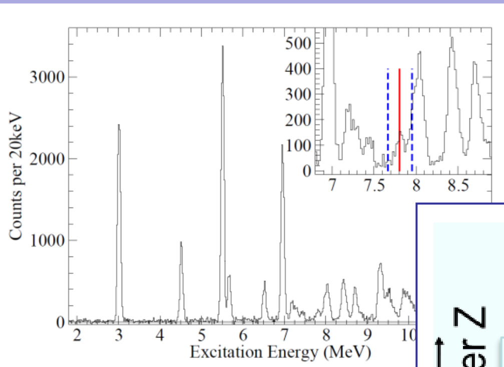
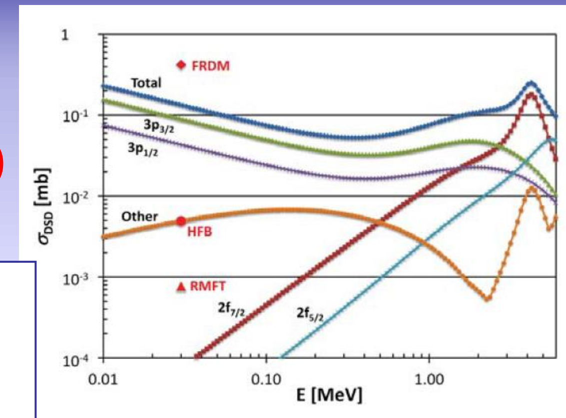
Transfer program at Oak Ridge

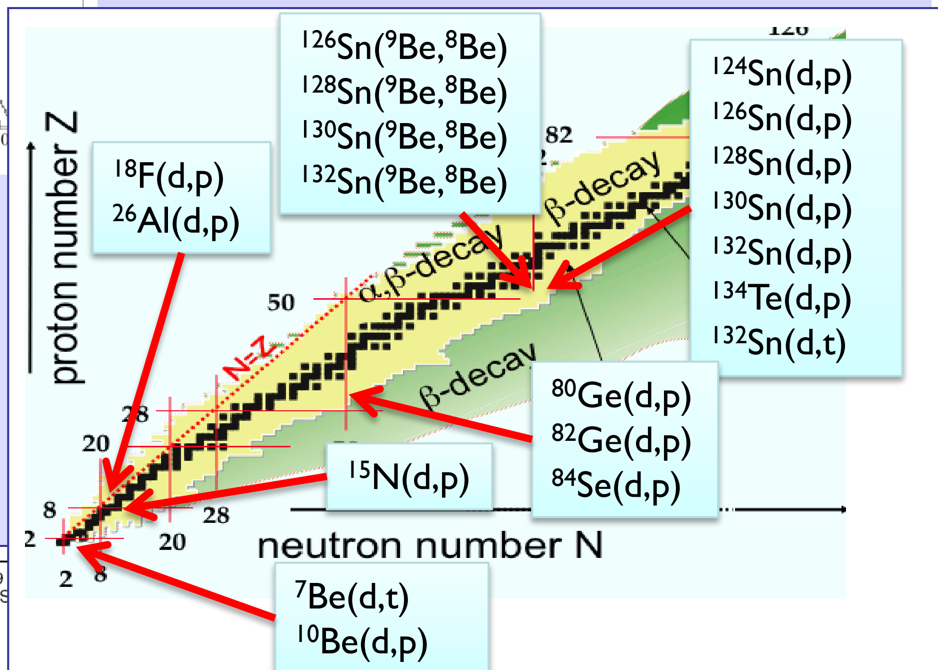


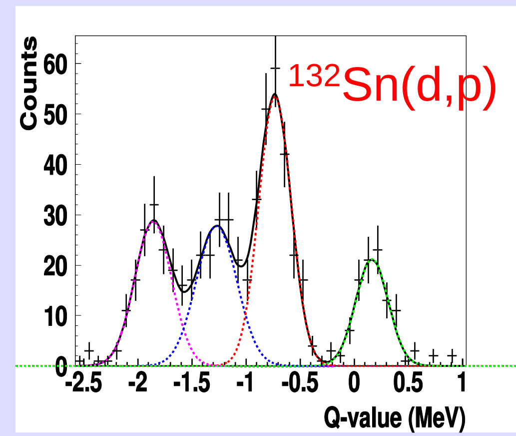
^{26}Al(d,p)

FWHM ~ 75 keV (CoM)

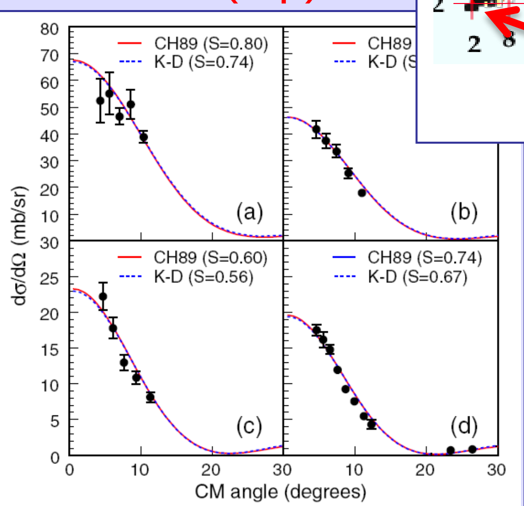
Constraint of DSD n-capture via ^{130}Sn(d,p)

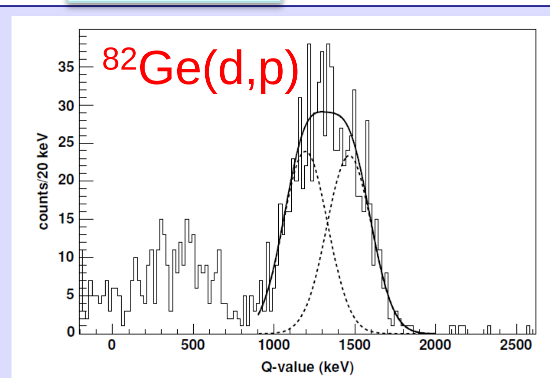


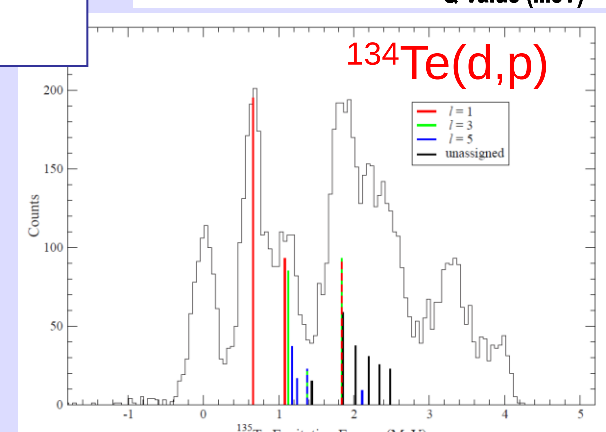




^{10}Be(d,p)

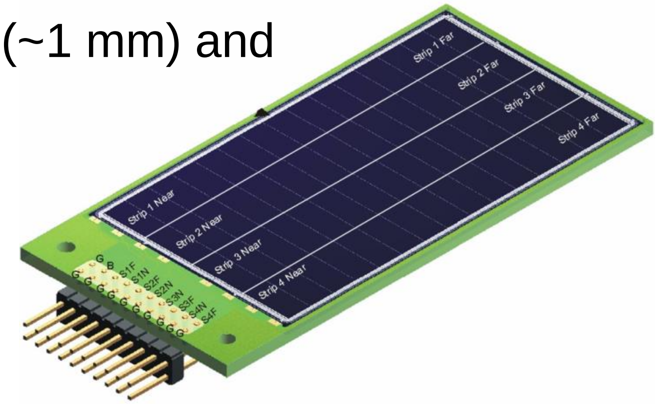


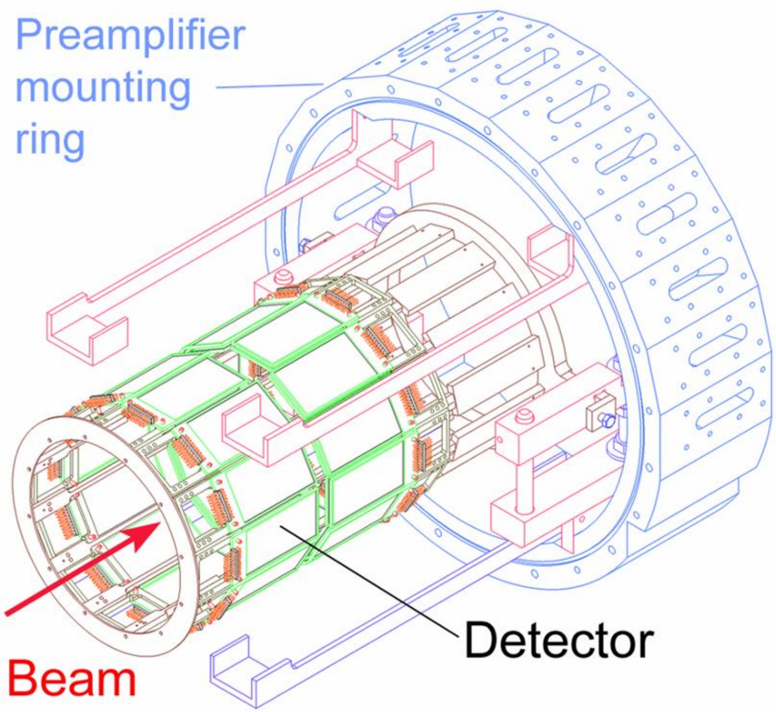


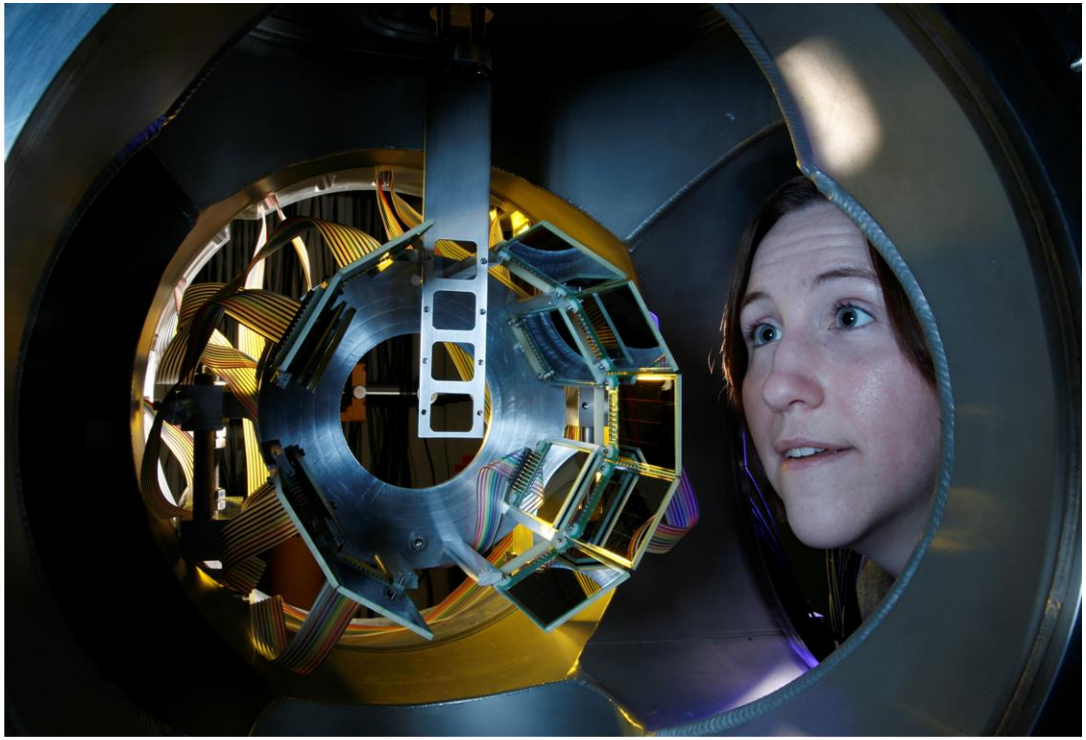


Oak Ridge Rutgers University Barrel Array

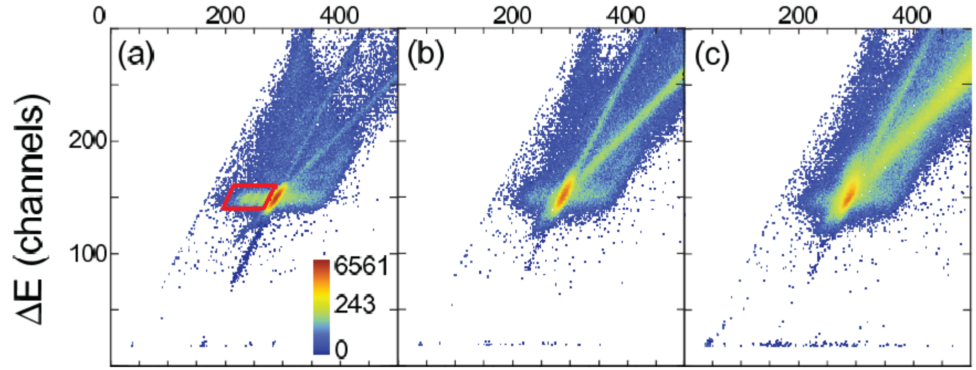
- Barrel array of ion-implanted silicon strip detectors
- Custom resistive design used to achieve good position (~1 mm) and energy (<60 keV)
- 2 rings – $\theta < 90°$: 12 telescopes (1000μm R + 65μm NR)
  – $\theta > 90°$: 12 detectors (500μm R)
- ORRUBA gives ~80% ϕ coverage over θ = 45° → 135°
- 288 electronics channels







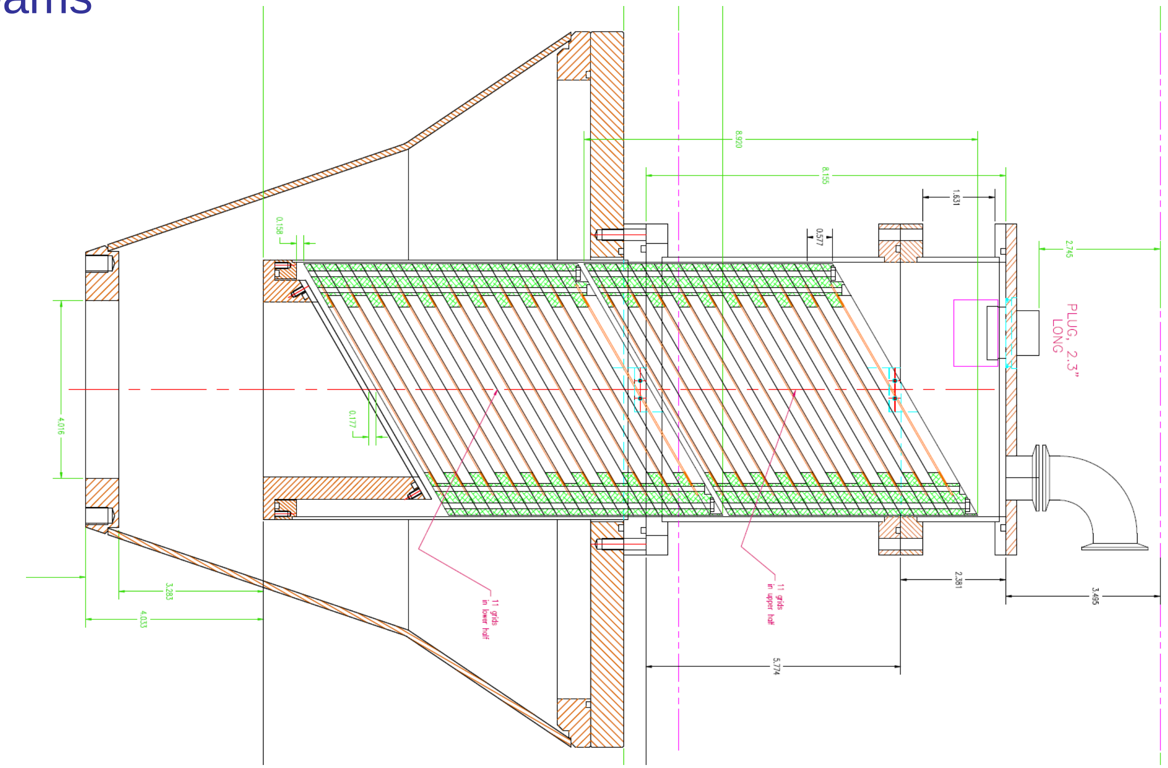
Ionization Chamber



- Re-entrant
- Tilted-grid wire electrodes

[K.Y. Chae *et al.*, *NIM A* **715C**, 6 (2014)]

- ~3 x 10^5 pps rate +
- Acceptance of 4.5 deg +
- PRISMA for more intense beams



Letter of Intent for transfer reaction measurements at SPES for r-process nucleosynthesis

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TABLE I: Example experiments that could be performed with projected Phase 1 beams from SPES. In each case, data from the (d,p), (d,t) and (d,^{3}He) reactions could be acquired simultaneously. In the case of experiments motivated primarily by constraining n-capture cross sections, the (d,p) reaction of foremost interest, but data on pickup reactions would also be acquired in such a measurement.

Beam	Projected intensity	Reactions	Primary motivation
^{80,81}Ge	8×10^4	(d,t) (d,^{3}He)	structure
^{81}Ge	1×10^4	(d,p) (d,t) (d,^{3}He)	n-capture
^{78,80,81}Ga	8×10^4, 1.5×10^4, 3.5×10^3	(d,p) (d,t) (d,^{3}He)	n-capture
^{84}Se	7×10^4	(d,t) (d,^{3}He)	structure
^{129,131}Sn	8.7×10^6, 1.7×10^6	(d,p) (d,t) (d,^{3}He)	n-capture
^{130}Sn	4×10^6	(d,t) (d,^{3}He)	structure
^{132}Sb	9×10^5	(d,p) (d,t) (d,^{3}He)	structure
^{134}Sb	1.5×10^4	(d,p) (d,t) (d,^{3}He)	n-capture
^{132,134,136,138}Te	2×10^7, 5.8×10^6, 2.7×10^5, 1.1×10^4	(d,p) (d,t) (d,^{3}He)	structure, n-capture
^{137}Xe	4×10^4	(d,p) (d,t) (d,^{3}He)	n-capture
^{138,140,142}Xe	5.6×10^6, 3.4×10^5, 1.8×10^4	(d,p) (d,t) (d,^{3}He)	structure, n-capture

Resolution contributions – 100, 200, 400 μg/cm² target