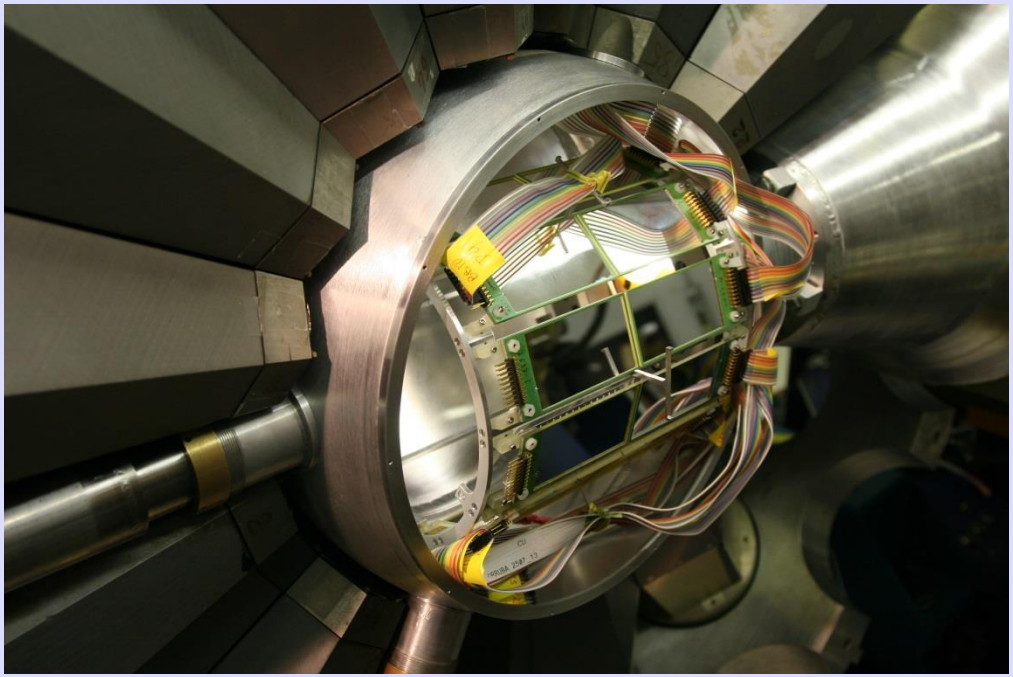
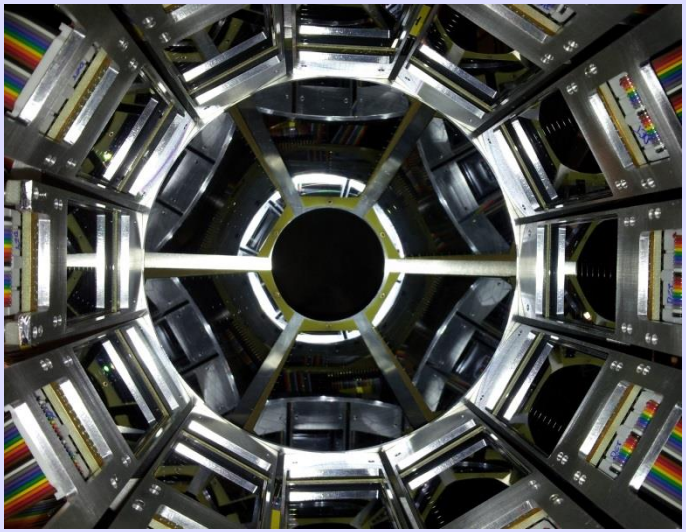
GODDESS

Steven D. Pain

Oak Ridge National Laboratory

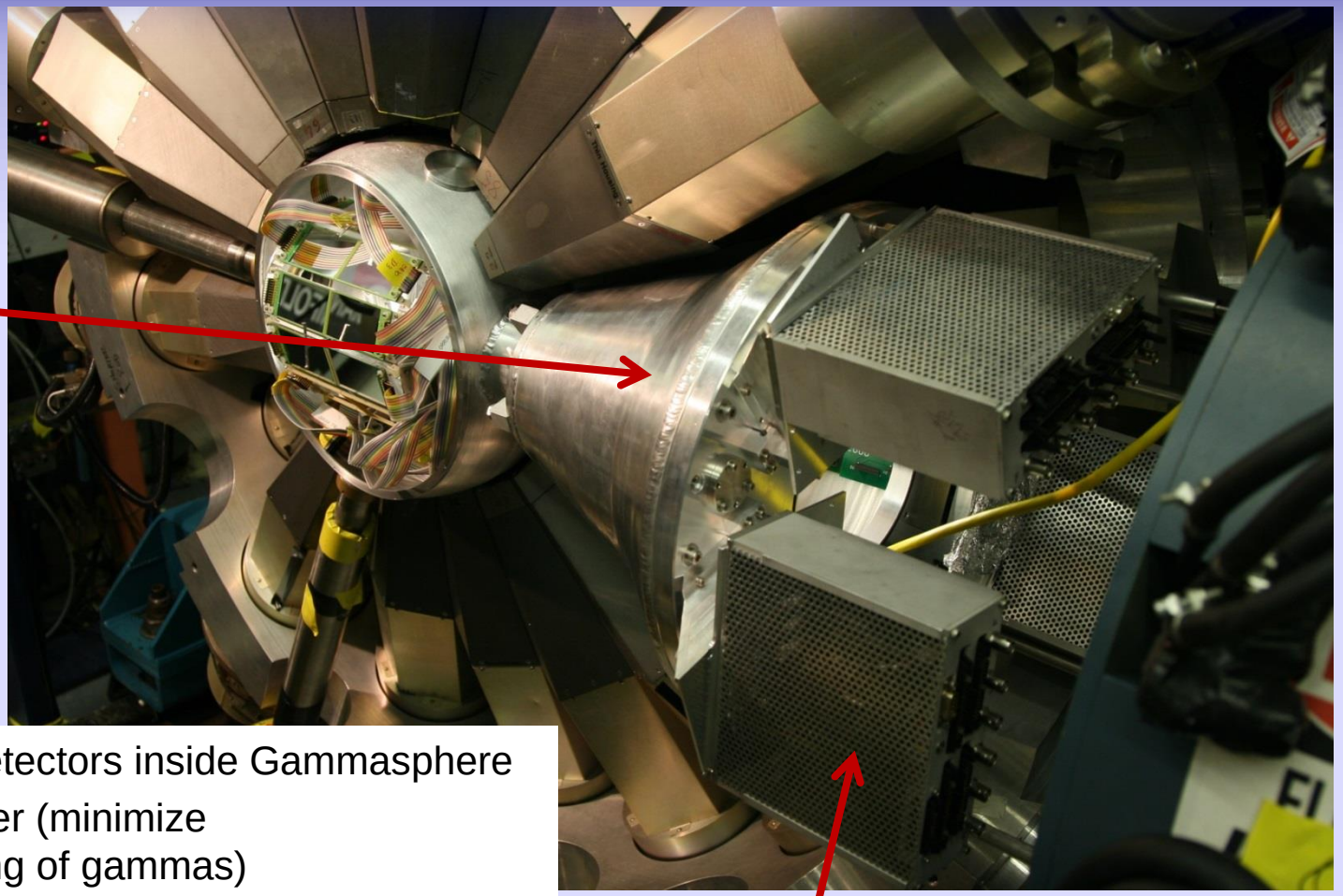
- GODDESS





GODDESS installation

Flowerpot spun to match the BGO profile



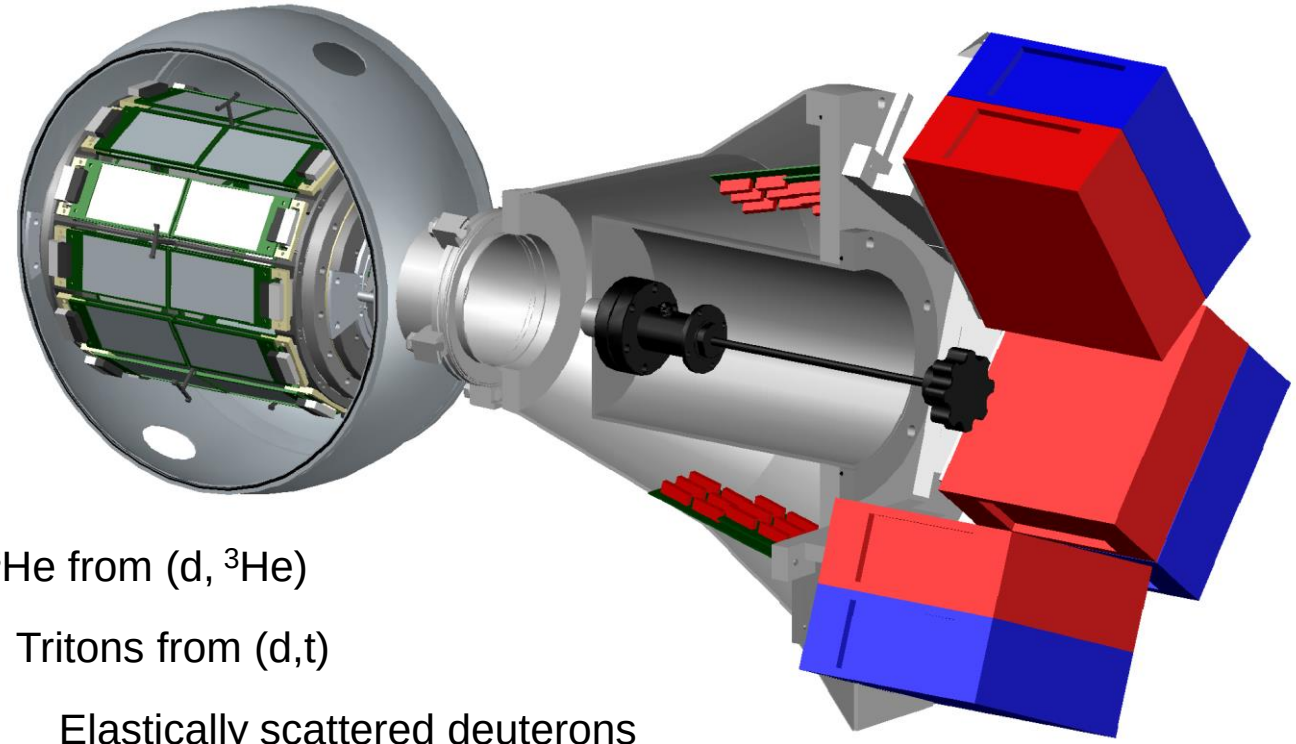
- Mount ORRUBA detectors inside Gammasphere
- Thin-walled chamber (minimize absorption/scattering of gammas)
- Minimize detector-preamplifier distance (<2 feet)
- Maintain possibility of coupling with the FMA
- Fit ~700 preamplifiers within space occupied by 17-deg ring of GS
- Maintain space for 0-degree detector (IC)

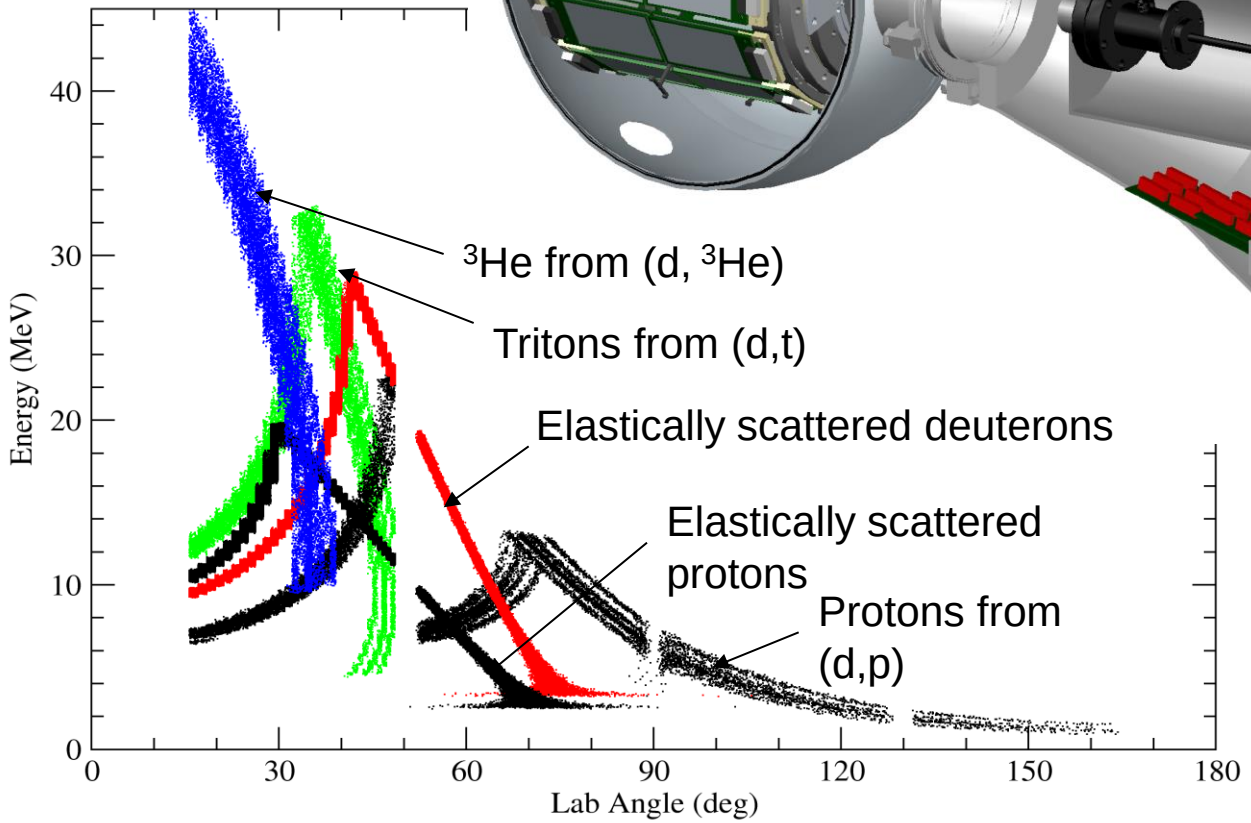
Preamps mounted in space between flowerpot and FMA quad

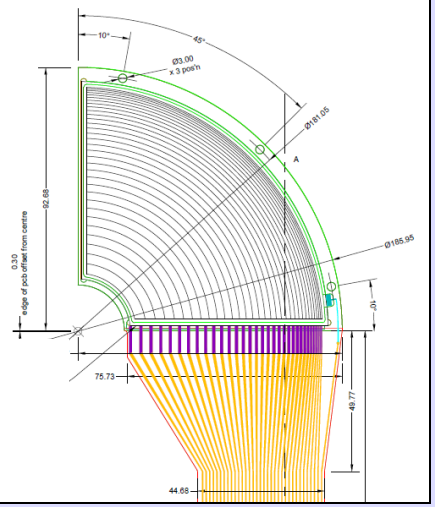
GODDESS

Polar angle coverage

15 to 165 degree coverage (>75%)

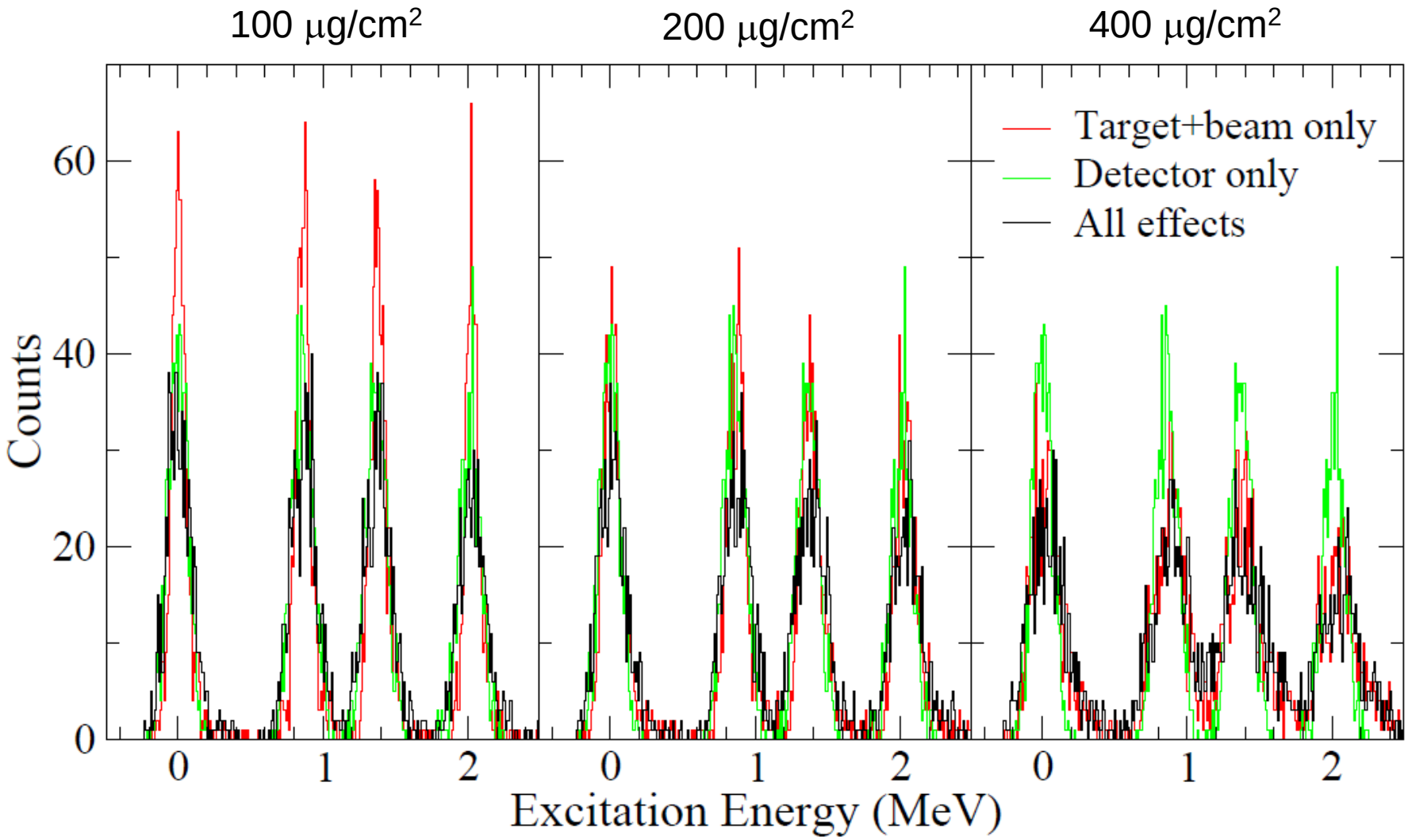






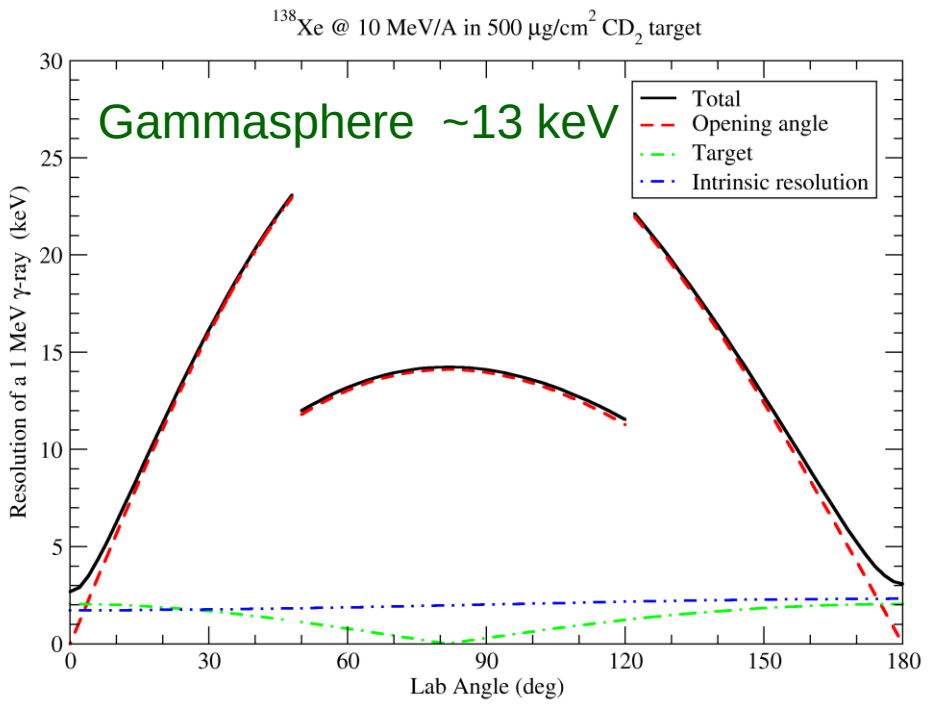
Forward endcap Barrel Backward endcap

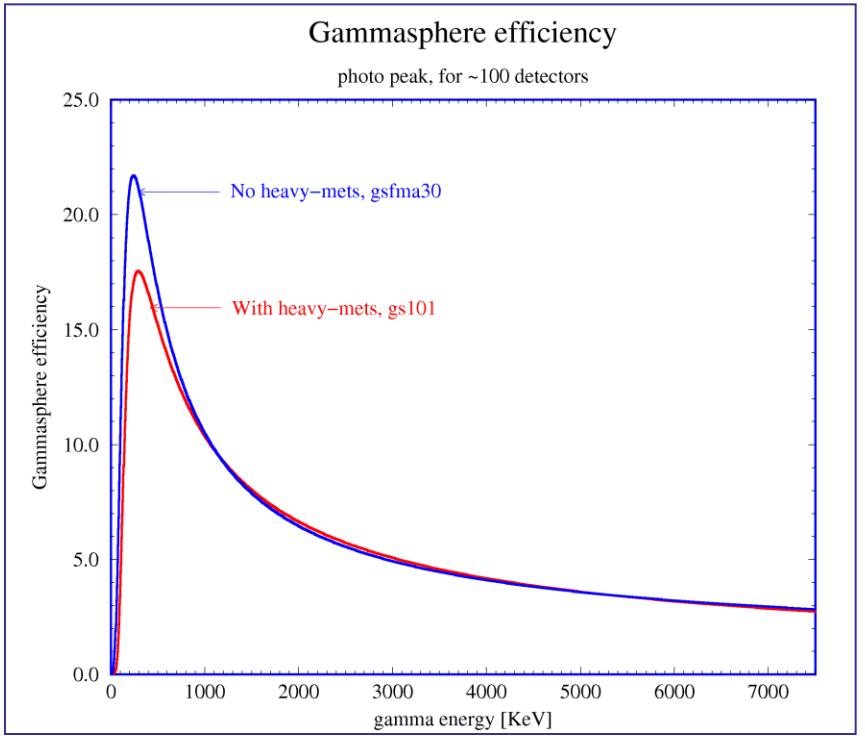
GODDESS – target effects



Gammasphere performance for light-ion transfer reactions

10 A MeV	^{138}Xe(d,p)	^{138}Xe(d,t)
Recoil direction	~0.5 deg (0.05 deg)	~ 1 deg (~0.1 deg)
Recoil energy (target thickness)	~3% (500 μg CD_2)	~3% (500 μg CD_2)
Recoil energy (reaction)	0.01%	0.01%
Intrinsic resolution of Ge detector	2 keV	2 keV
Measured angle of gamma ray	5.5 deg	5.5 deg





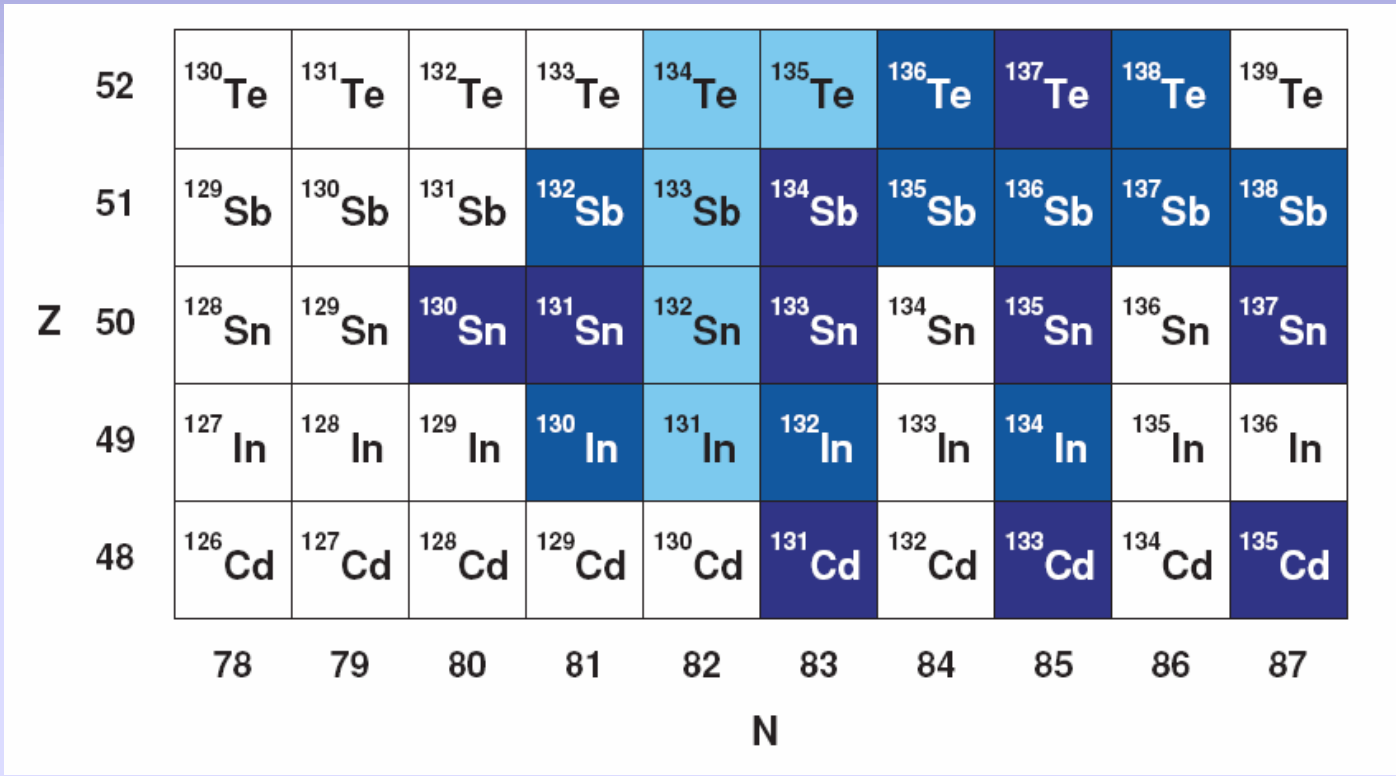
GODDESS capabilities

Search for single-particle/hole states

Measurement of SF/tracking fragmentation of SP states (structure, DSD n-capture)

Surrogate for stat. n capture

Lifetime measurements (DSAM)



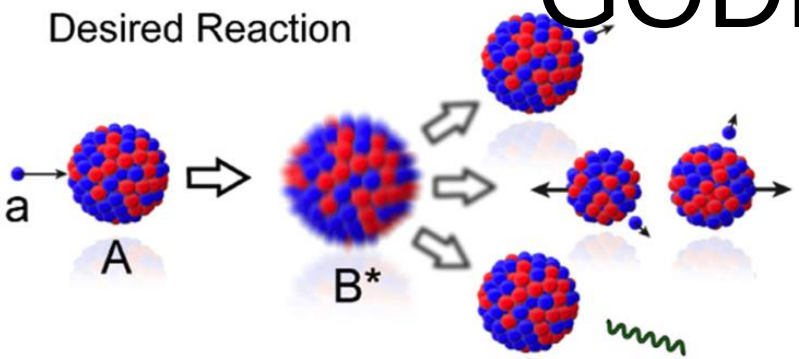
Light ion transfer reactions (d,p) (d,t) (d,^{3}He) (p,t) etc

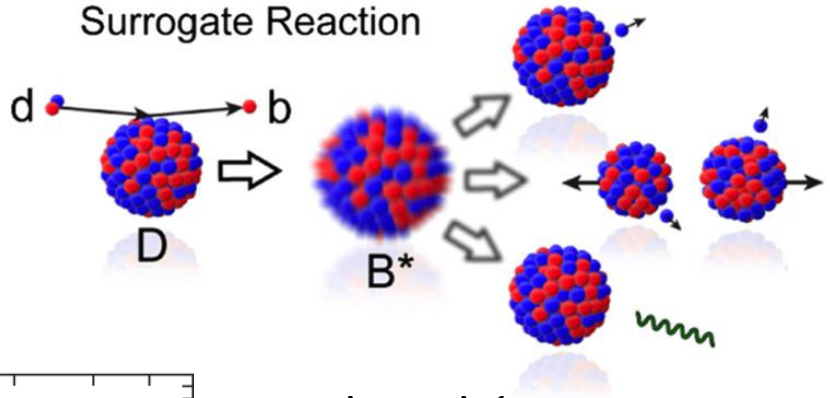
Heavy-ion transfer reactions (^{9}Be,^{8}Be) (^{13}C,^{12}C) (^{7}Li,^{6}He) (^{19}F,^{18}O)

Inelastic scattering

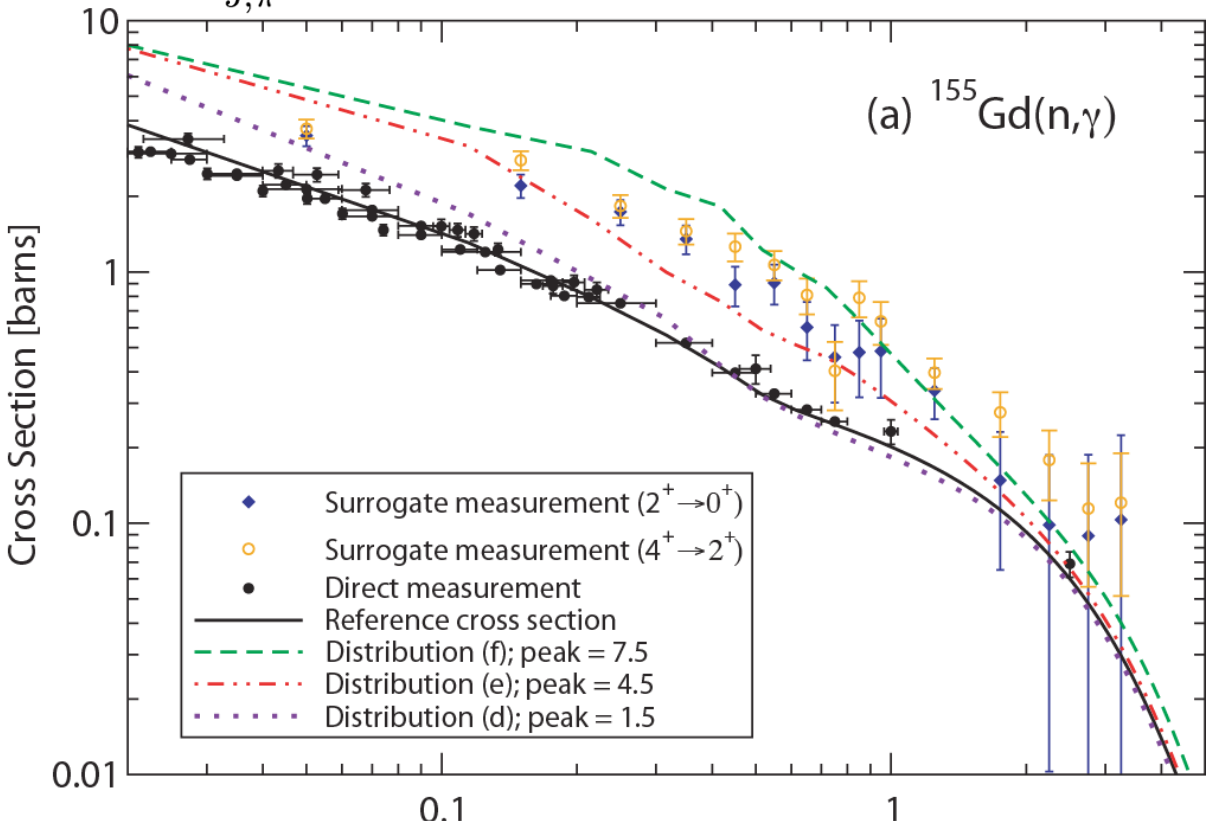
Coulex

GODDESS for Surrogates





$$\sigma_{\alpha\chi}(E_a) = \sum_{J,\pi} \sigma_{\alpha}^{CN}(E_{ex}, J, \pi) G_{\chi}^{CN}(E_{ex}, J, \pi)$$



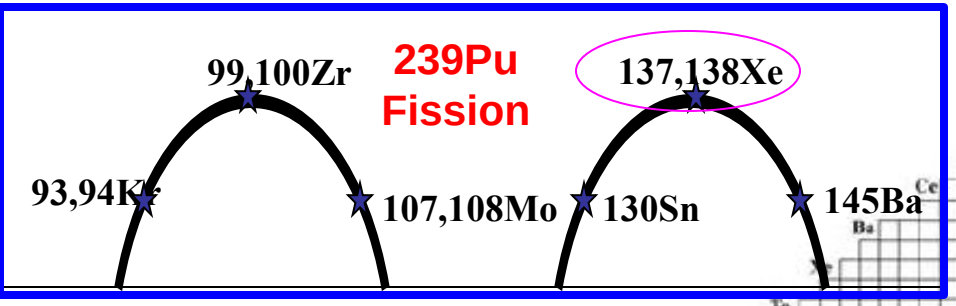
N. Scielzo *et al.* PRC **81** 034608 (2010)

The $^{A}(n,\gamma)^{A+1}$ cross section is described by the formation **and** the decay of the compound nucleus summed over each J and π.

While σ_n^{CN} is easy to calculate, G_γ^{CN} is not. It is thus necessary to measure the branching ratios of the compound nucleus in order to constrain the calculation of the surrogate cross section.

Courtesy A. Ratkiewicz

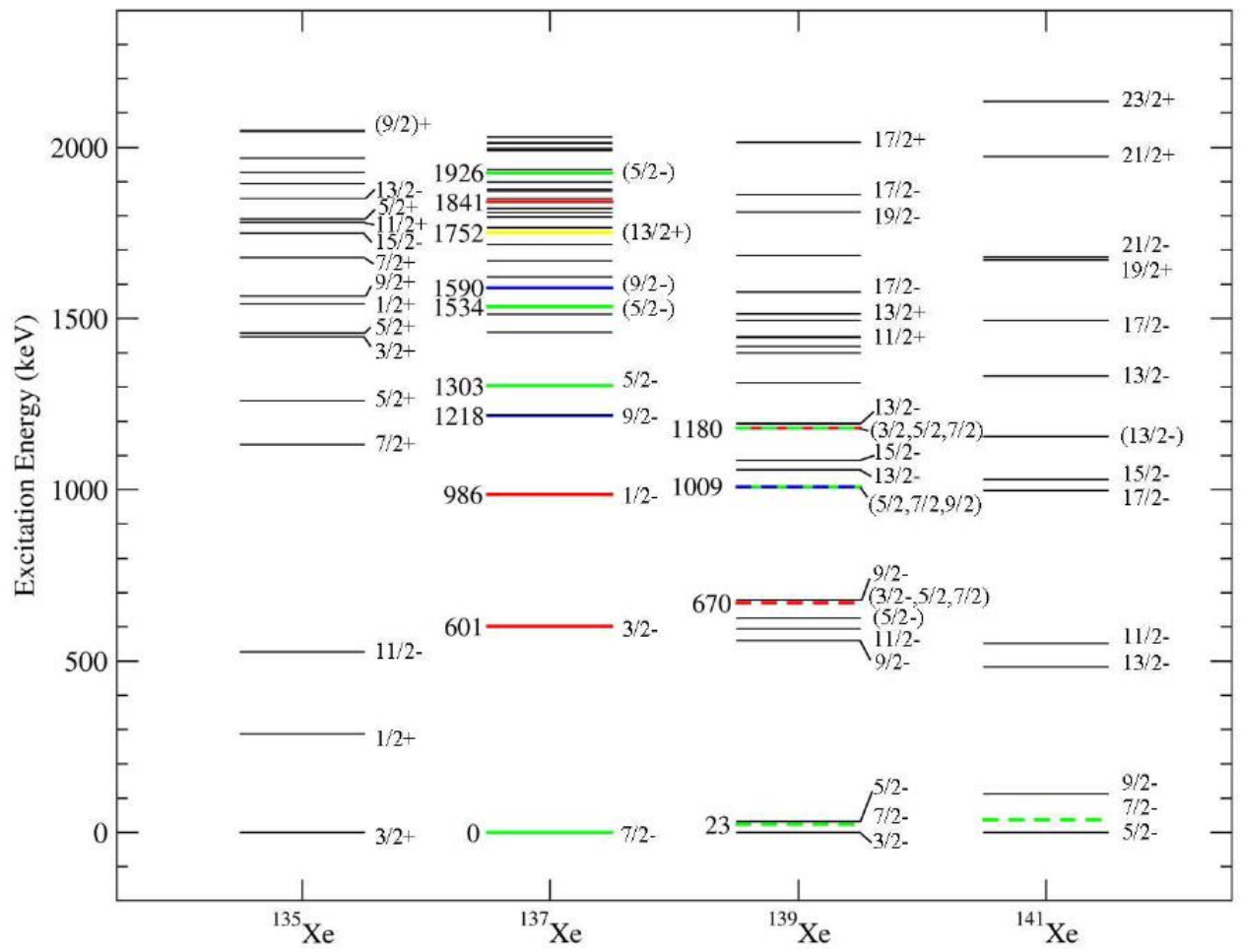
^{252}Cf fission fragment ATLAS beams & ORRUBA + Gammasphere



D.G. Foster and E.D. Arthur, LA-9168, February 1982 (unpublished).

- Validating surrogate (d,pγ) with ^{95}Mo
- Heavy and light ^{252}Cf fission fragments
  - ^{134}Te(d,pγ) approved
  - ^{137,138}Xe(d,pγ) and others important to applications & astrophysics

Example (d,pγ) measurements with CARIBU beams



Example - track the fragmentation of SP energies along the Xe chain

Measurement of particle and hole states at same time

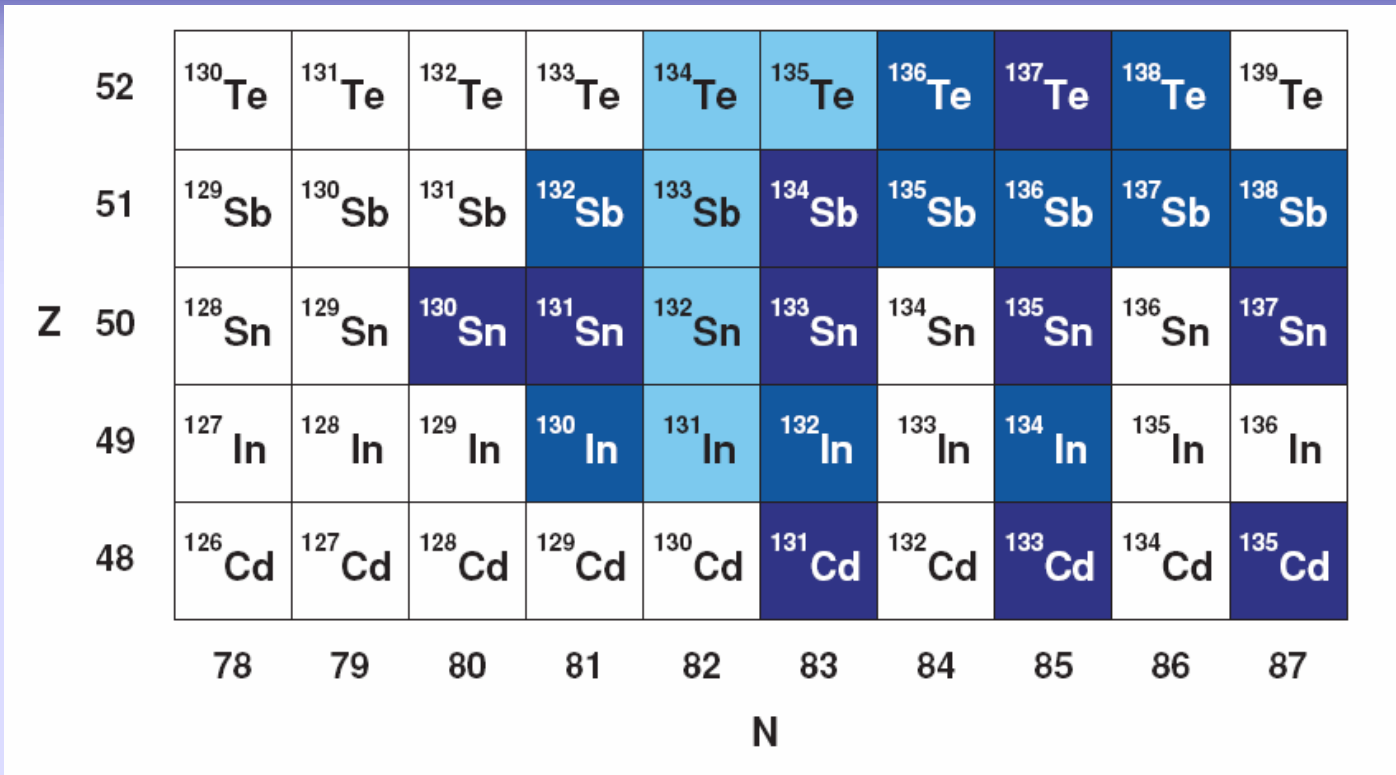
Factor of ~2 below GS in efficiency

Beam	E_{Beam} (MeV)	I_{Beam} (pps)	Target (μg/cm^2)	Days	Total protons ($f_{7/2}, p_{3/2}, p_{1/2}, f_{5/2}$)	Total protons (SF=0.3) ($f_{7/2}, p_{3/2}, p_{1/2}, f_{5/2}$)	Total p-γ (SF=0.3) ($f_{7/2}, p_{3/2}, p_{1/2}, f_{5/2}$)
^{138}Xe	1380	1.5×10^4	400	10	5920, 4170, 1970, 5600	1973, 1390, 656, 1867	197, 139, 65, 186
^{140}Xe	1400	1.0×10^4	400	14	5530, 3906, 1834, 5222	1843, 1302, 611, 1740	184, 130, 61, 174
^{134}Te	1340	9.9×10^3	1000	7	6846, 4830, 2275, 6468	2282, 1610, 758, 2156	228, 161, 75, 215

GODDESS Experiments – neutron transfer

Tracking neutron single-particle and single-hole states

Fragmentation of spectroscopic strength



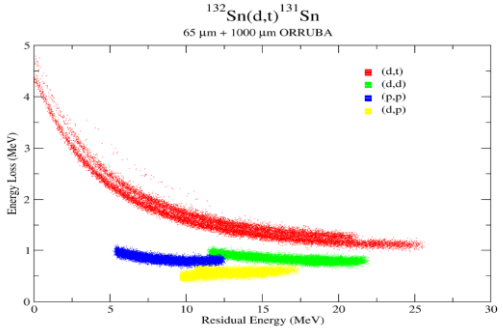
Location of ½+ state in ^{133}Sb ^{134}Sb(d,t) 3e3 pps

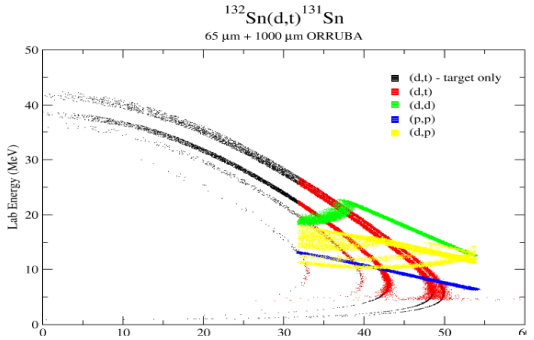
SP spec factors in ^{135}Sb ^{134}Sb(d,p) 3e3 pps

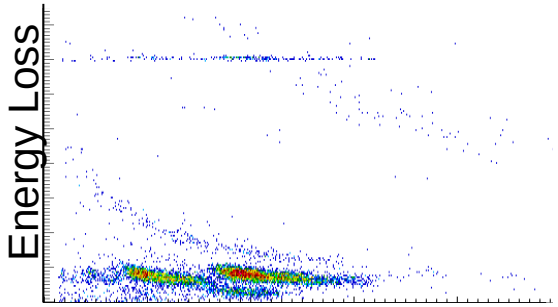
Find negative parity single-particle states in ^{137}Te [^{136}Te(d,p) 4e3 pps]

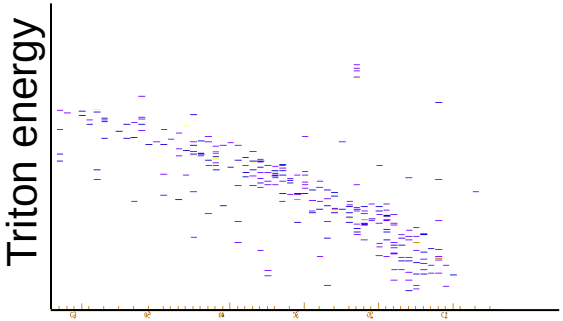
Location of positive parity SP states in ^{135}Te [^{136}Te(d,t)
SF of positive parity proton hole states in ^{133}Te [^{134}Te(d,t)

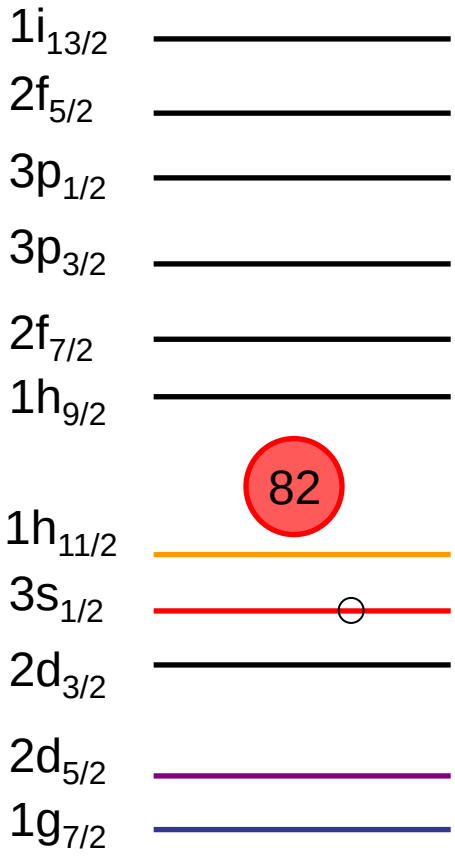
^{132}Sn(d,t)^{131}Sn Riccardo Orlandi (JAEA, Tokai)

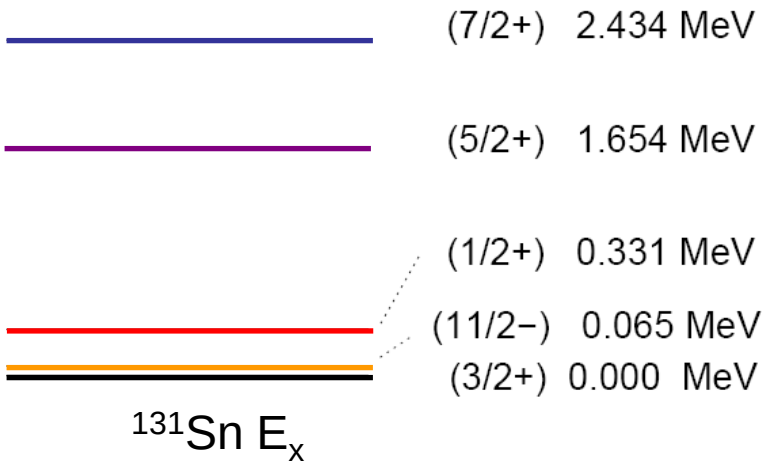


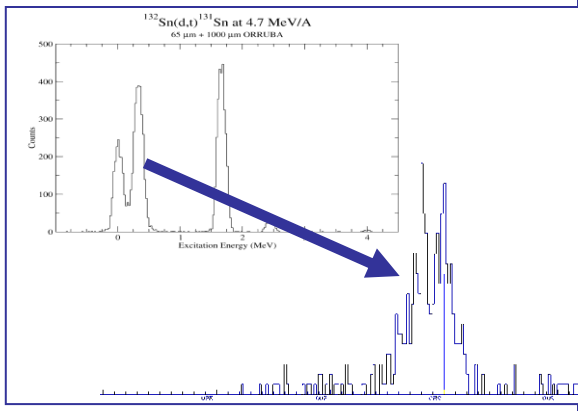








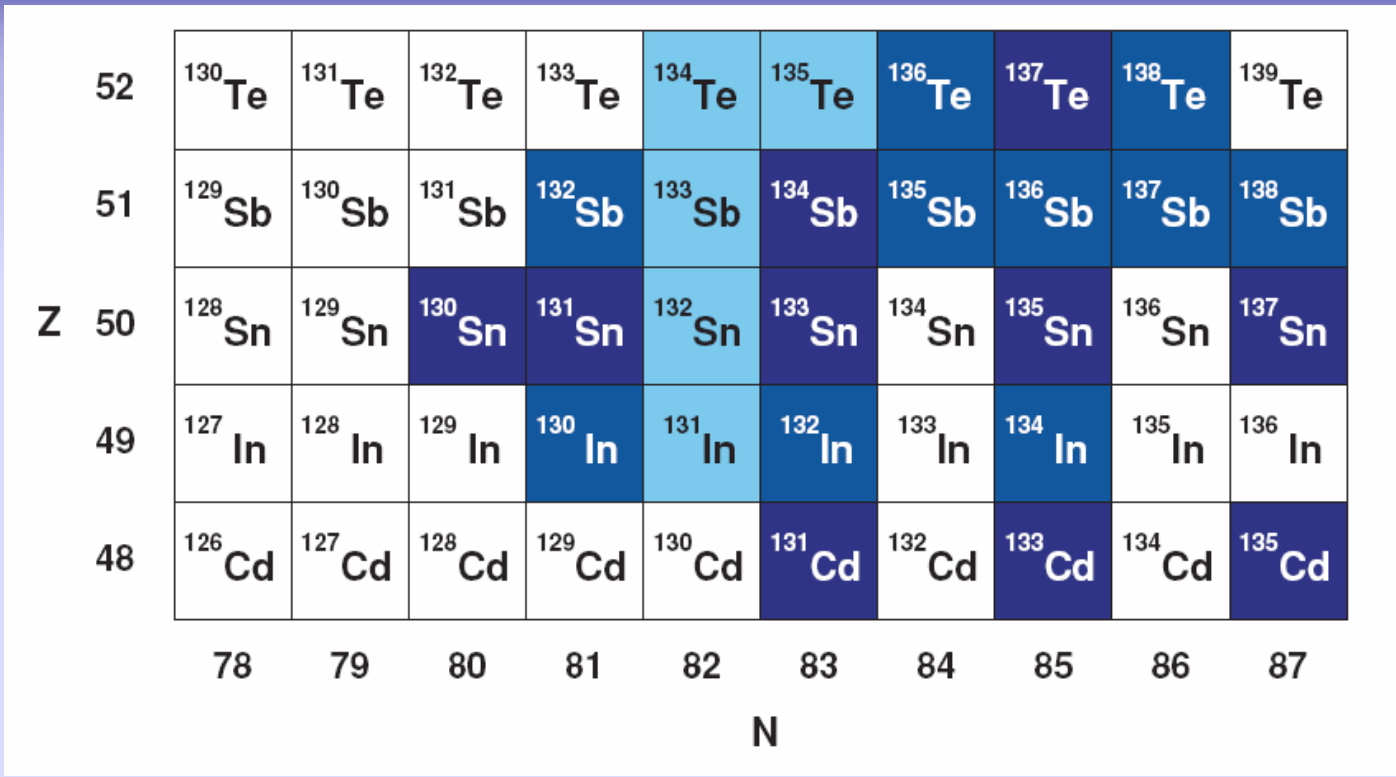




GODDESS Experiments – proton pickup

Tracking proton single-hole states

Fragmentation of spectroscopic strength



E.g. location of negative-parity proton hole states in:

^{133}Sb [^{134}Te(d,^{3}He) 1e4 pps]

^{131}Sb [^{132}Te(d,^{3}He) 3e3 pps]

^{137}I [^{138}Xe(d,^{3}He) 1.5e4 pps]

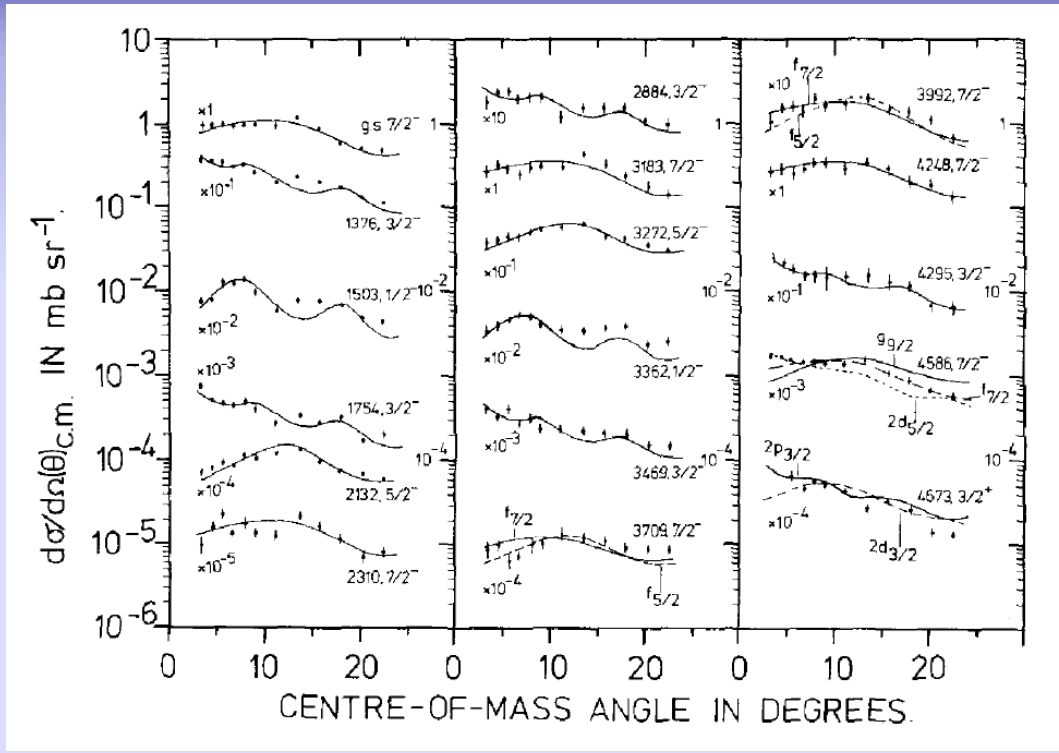
^{139}I [^{140}Xe(d,^{3}He) 1e4 pps]

GODDESS Experiments – proton stripping

Tracking proton single-hole states

SF

In addition, (^{7}Li,t) (^{7}Li,α) etc



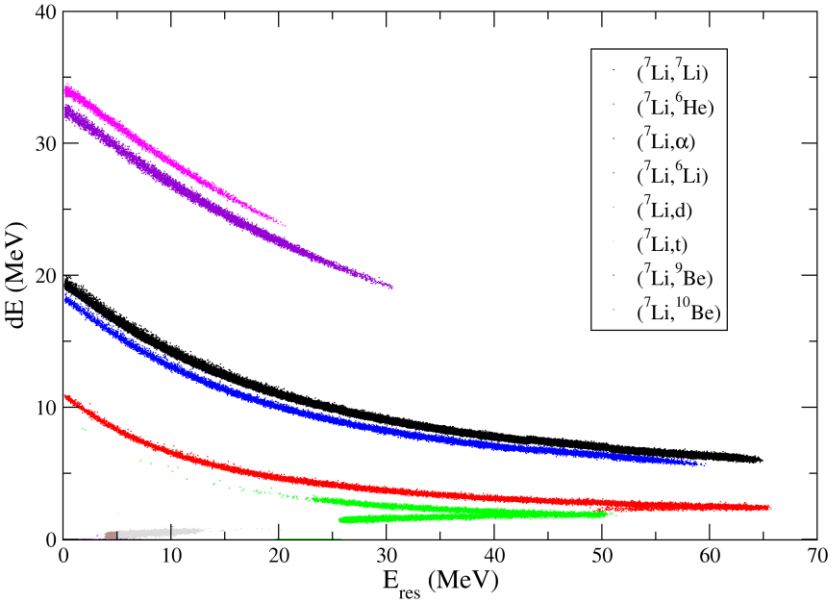
(^{7}Li,^{6}He) reaction for proton transfer

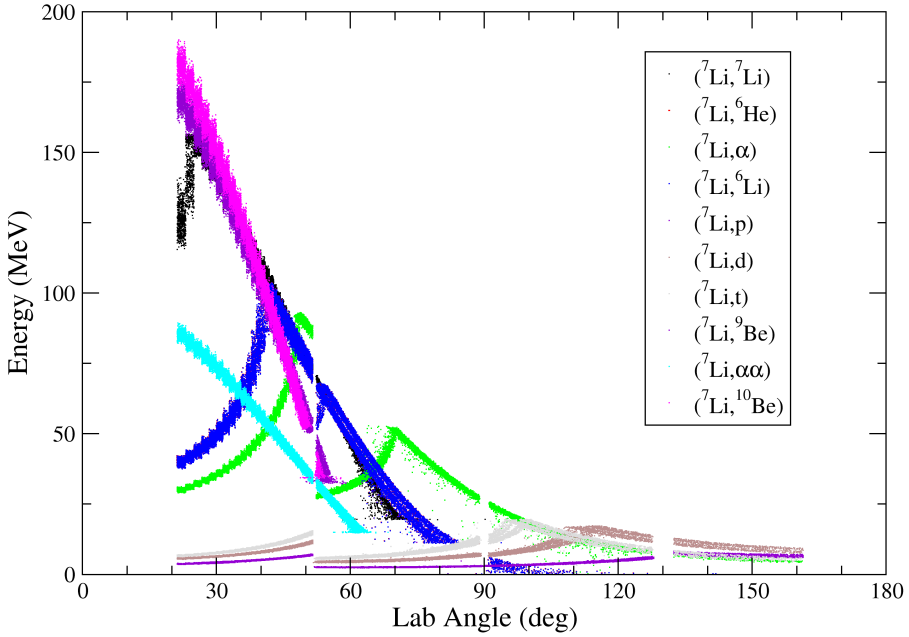
E.g. location of negative-parity proton hole states in: ^{137}I [^{136}Xe(^{7}Li,^{6}He) stable]

^{139}I [^{138}Xe(^{7}Li,^{6}He) 1.5e4 pps]

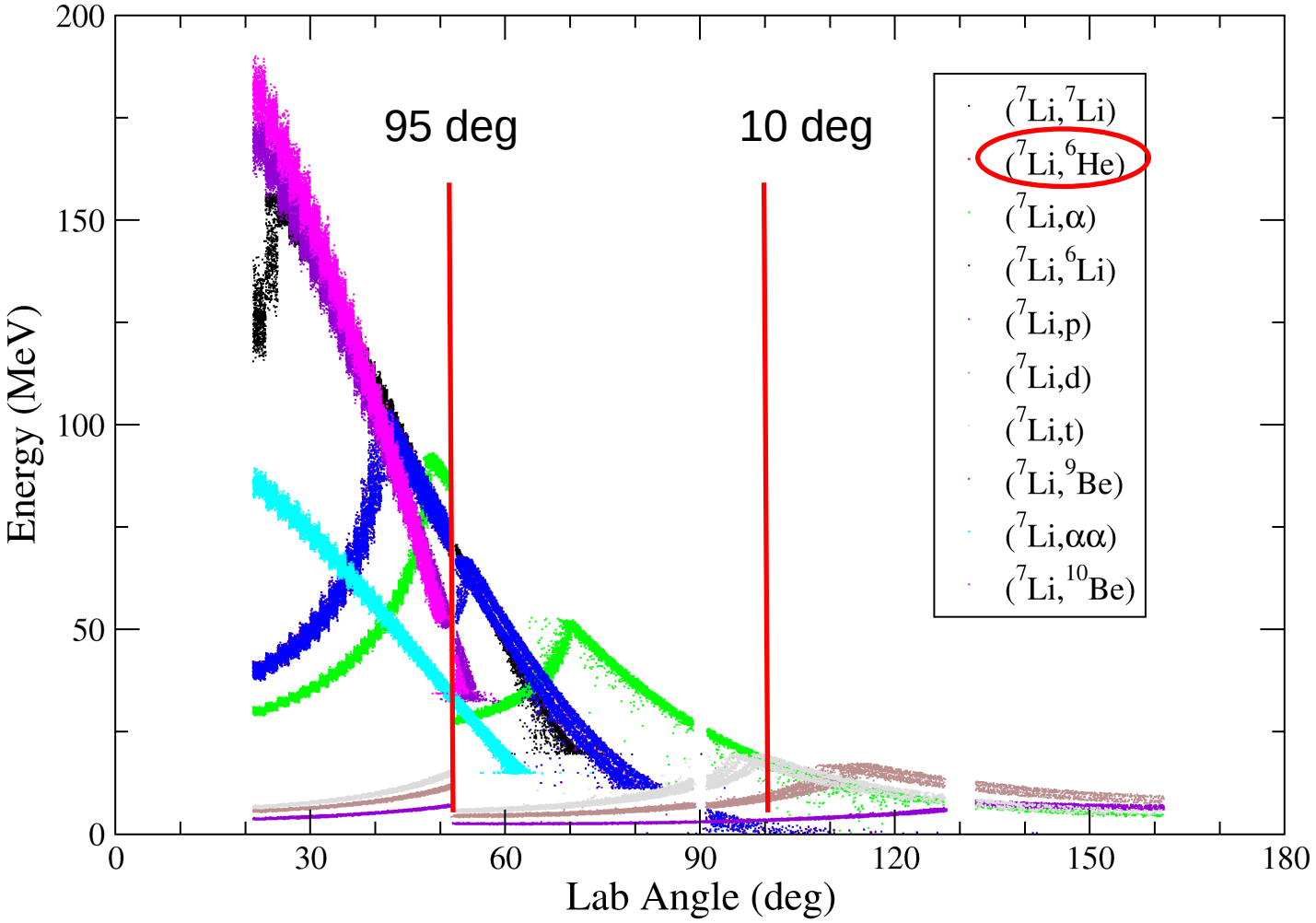
^{141}I [^{140}Xe(^{7}Li,^{6}He) 1e4 pps]
^{131}Sb [^{130}Sn(^{7}Li,^{6}He) 1.5e3 pps]
^{133}Sb [^{132}Sn(^{7}Li,^{6}He)]

GODDESS


dE (MeV)
E_res (MeV)
(7Li,7Li)
(7Li,6He)
(7Li,α)
(7Li,6Li)
(7Li,d)
(7Li,t)
(7Li,9Be)
(7Li,10Be)

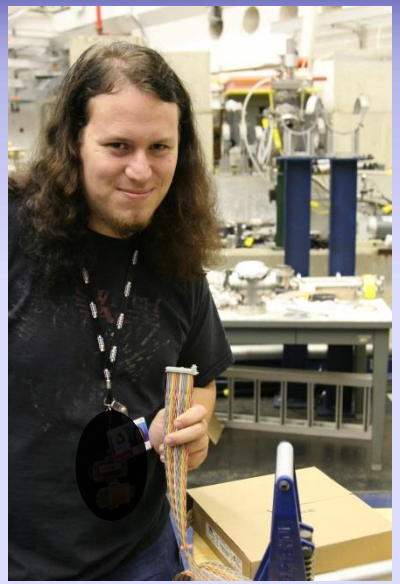

Energy (MeV)
Lab Angle (deg)
(7Li,7Li)
(7Li,6He)
(7Li,α)
(7Li,6Li)
(7Li,p)
(7Li,d)
(7Li,t)
(7Li,9Be)
(7Li,ααα)
(7Li,10Be)

GODDESS


95 deg
10 deg
(^{7}Li,^{7}Li)
(^{7}Li,^{6}He)
(^{7}Li,α)
(^{7}Li,^{6}Li)
(^{7}Li,p)
(^{7}Li,d)
(^{7}Li,t)
(^{7}Li,^{9}Be)
(^{7}Li,αα)
(^{7}Li,^{10}Be)
Energy (MeV)
Lab Angle (deg)
0
50
100
150
200
0
30
60
90
120
150
180

GODDESS Acknowledgements

Steven Hardy - cable crusher



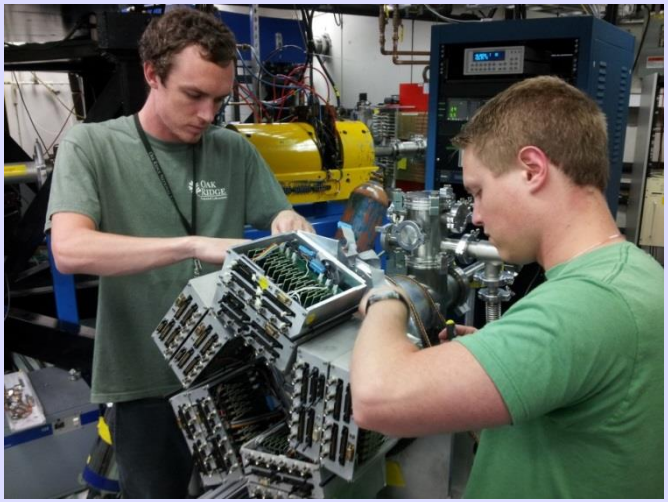
Student

Callum Shand testing his test stand

Travis Baugher – Simulating GODDESS

Postdoc

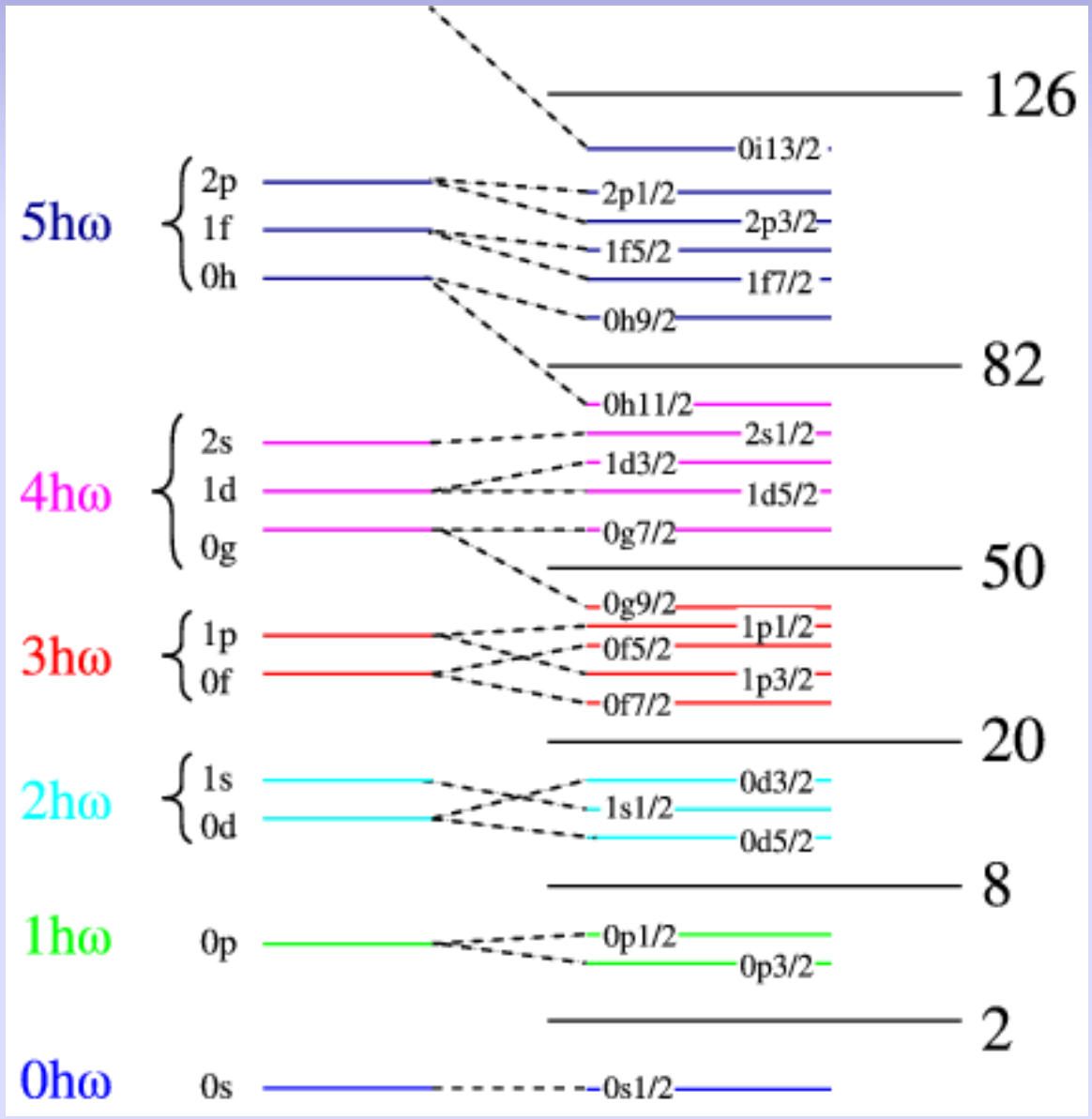
Thanks also to the help from Argonne – Darek Seweryniak, Mike Carpenter, Shaofei Zhu and Kim Lister….



Andrew Ratkiewicz – not entirely convinced by the pineapple-eating dinosaurs at the creation museum

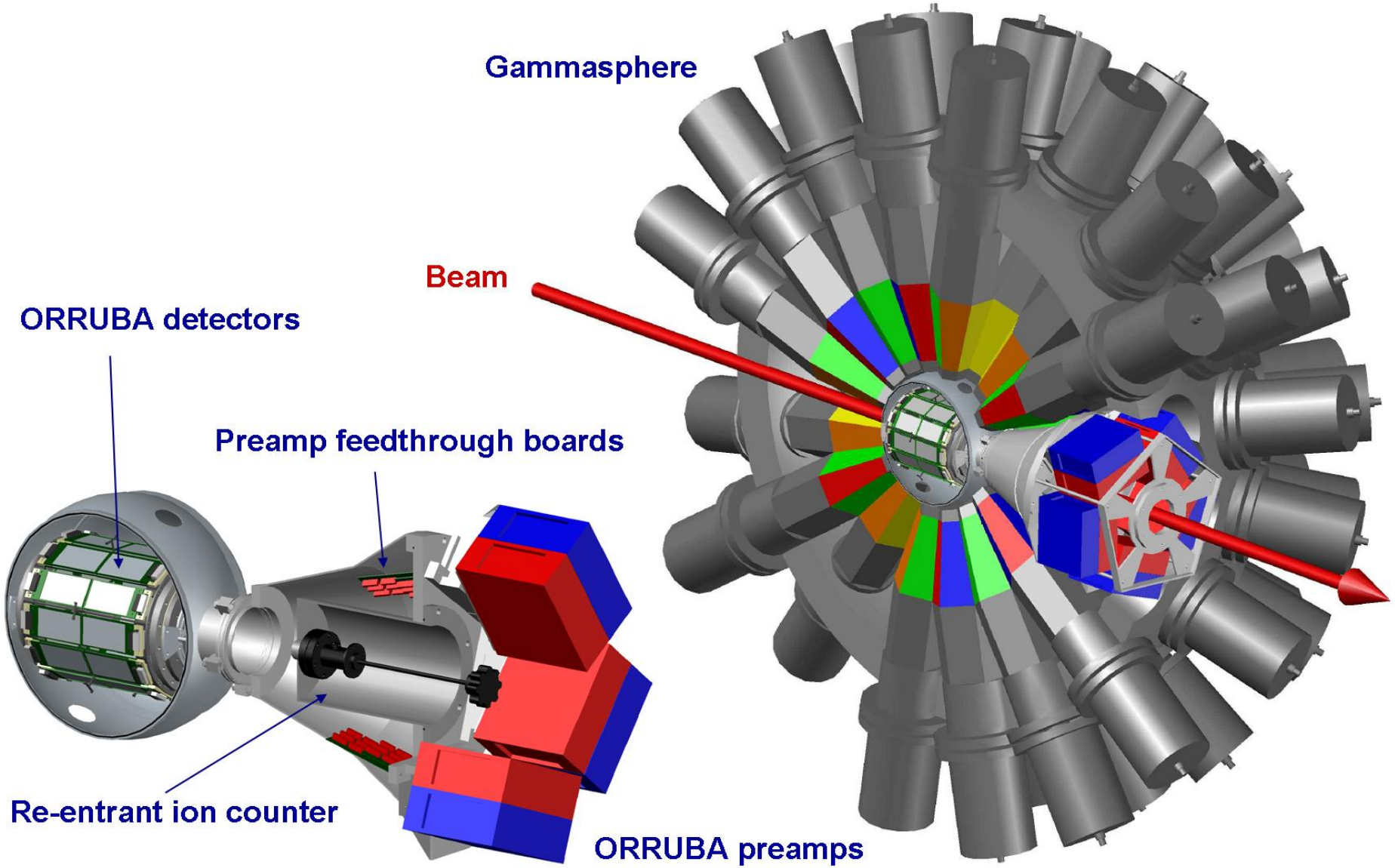
Sean Burcher and **Ian Marsh** assembling GODDESS for the first time

GODDESS


126
82
50
20
8
2
5hω
4hω
3hω
2hω
1hω
0hω
2p
1f
0h
2s
1d
0g
1p
0f
1s
0d
0p
0s
0i13/2
2p1/2
2p3/2
1f5/2
1f7/2
0h9/2
0h11/2
2s1/2
1d3/2
1d5/2
0g7/2
0g9/2
1p1/2
0f5/2
1p3/2
0f7/2
0d3/2
1s1/2
0d5/2
0p1/2
0p3/2
0s1/2

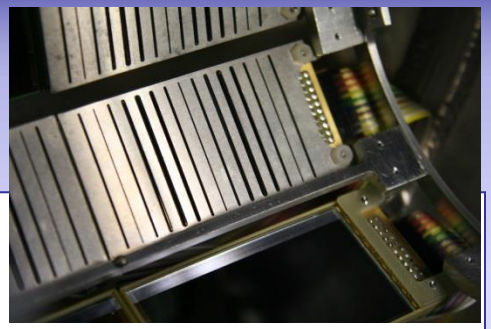
GODDESS

*G*ammasphere *O*RRUBA: *D*ual *D*etectors for *E*xperimental *S*tructure *S*tudies



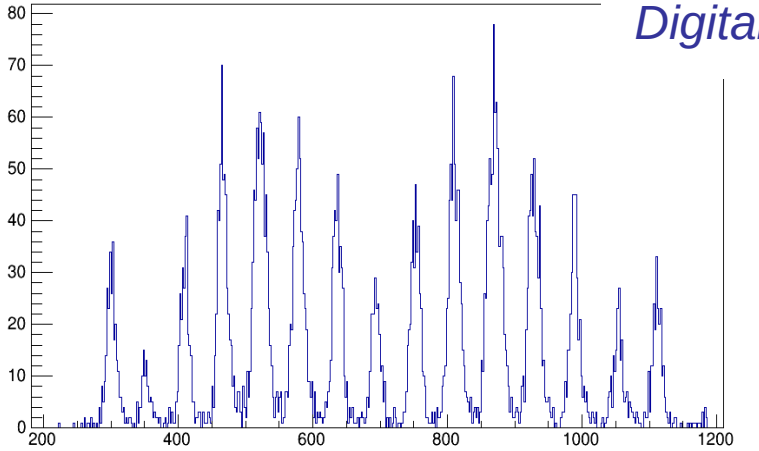
GODDESS Performance with trapezoidal filters

Data taken with GRETINA-style digitizers

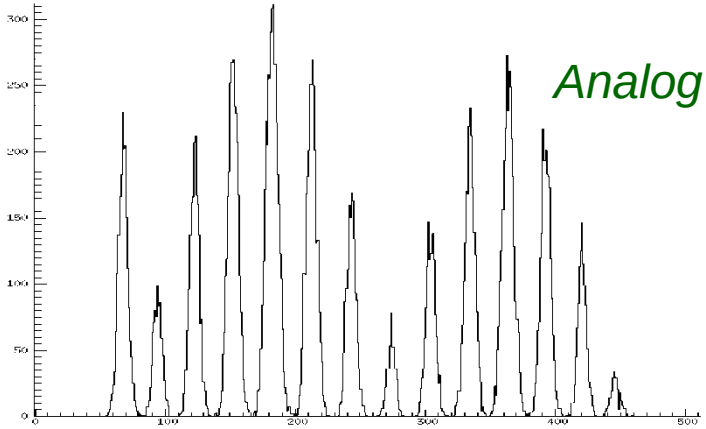


~1.2 mm resolution

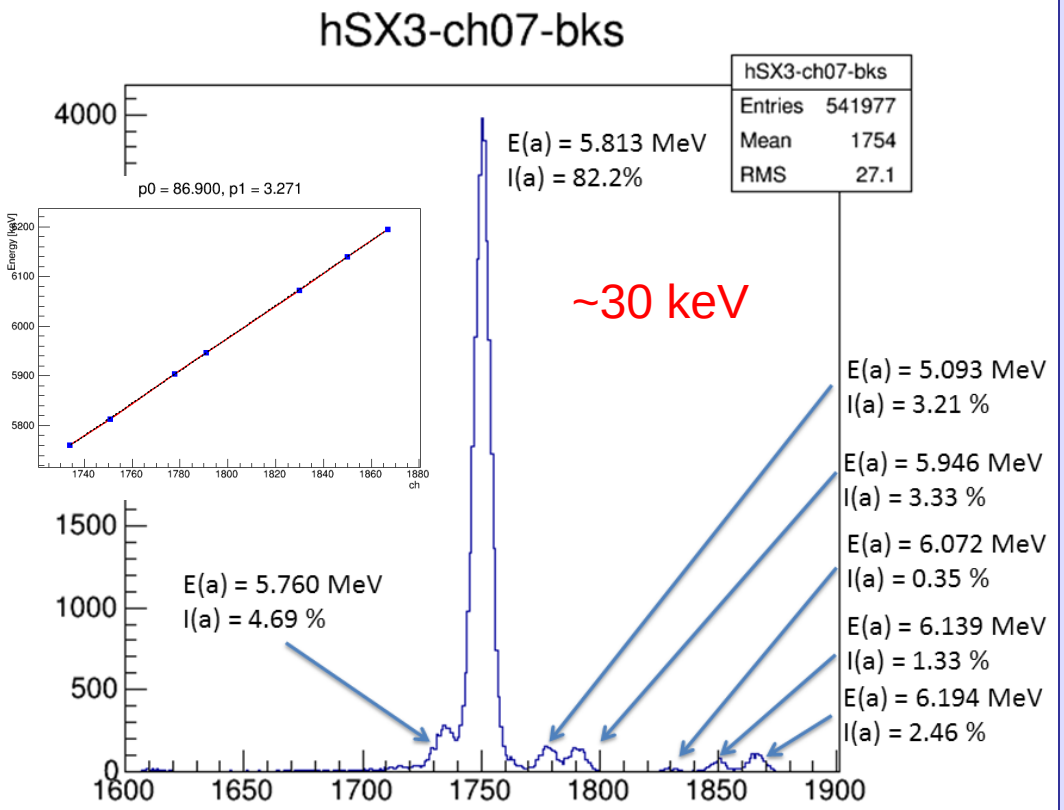
Digital



Analog



Digital

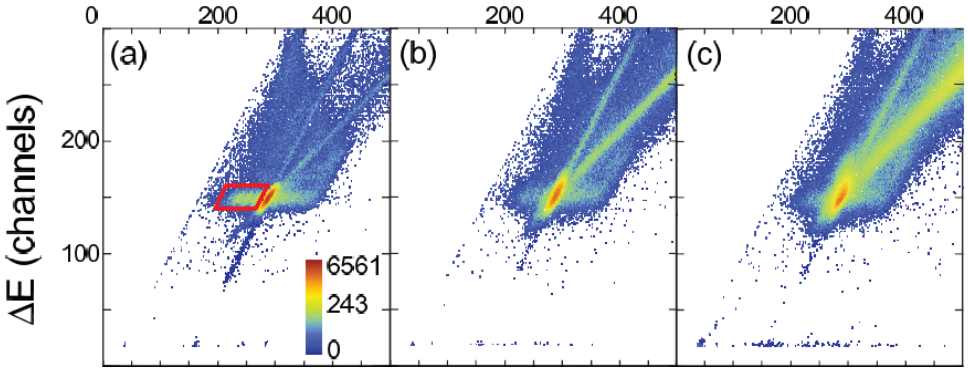


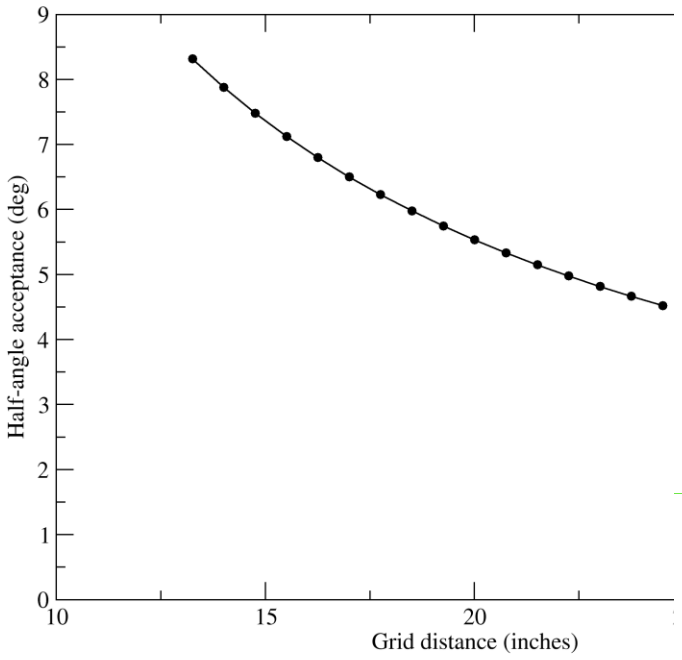
GODDESS Ionization Chamber

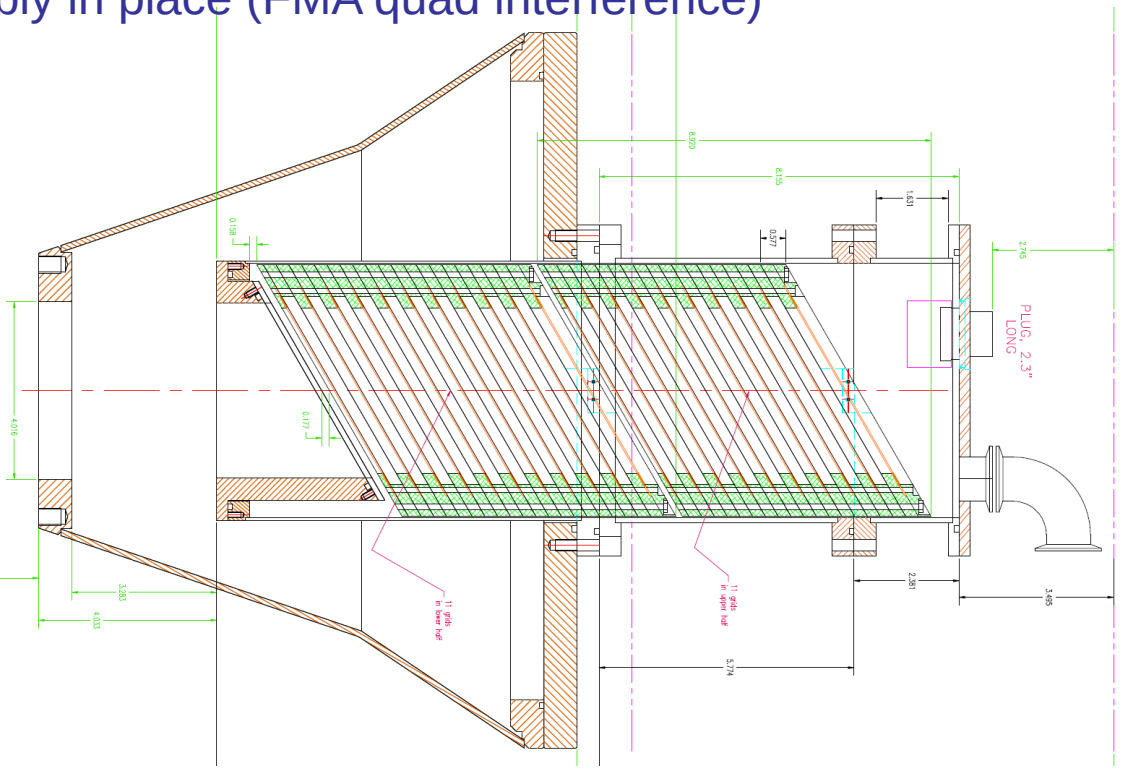
- Re-entrant
- Tilted-grid wire electrodes

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

- >2 x 10^5 pps rate (previous ORNL IC)
- Acceptance of 4.5 deg +
- 2-part design to enable assembly in place (FMA quad interference)



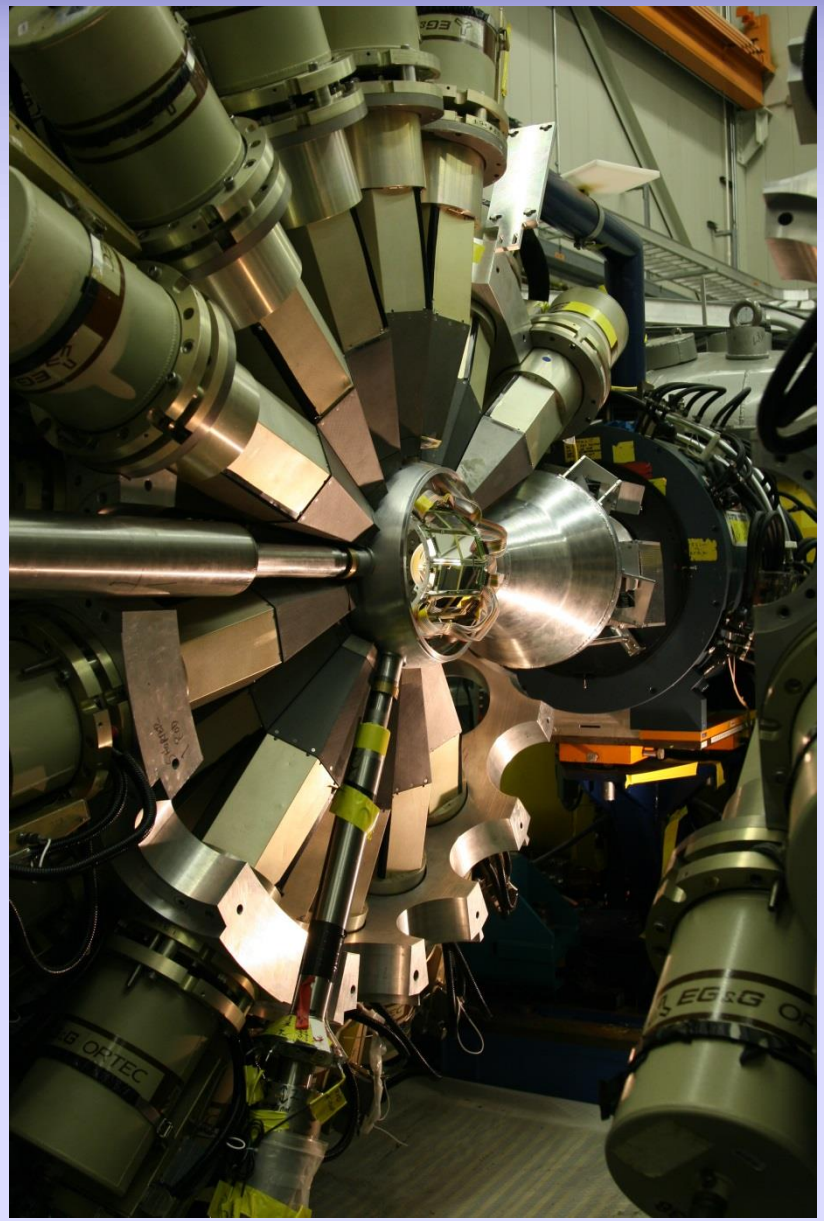




Beam time approved by the ATLAS PAC

Coupling the ORRUBA and Gammasphere arrays: a request for equipment development time (S.D. Pain *et al*)	*stable beam for equipment development*
Developing the (d,pγ) reaction as a surrogate for (n,γ) in inverse kinematics: ^{95}Mo(d,pγ) with Gammasphere (J.A. Cizewski *et al*)	*^{95}Mo beam for (d,pγ) surrogate development*
Measurements of (d,pg) on neutron-rich Xe and Te with CARIBU beams (S.D. Pain *et al*)	*^{134}Te CARIBU beam for (d,pγ) measurement*
Study of the Near-Threshold Levels in ^{19}Ne and the ^{18}F(p,α)^{15}O Rate in Novae (D.W. Bardayan *et al*)	*^{3}He beam for ^{19}F(^{3}He,tγ)^{19}Ne measurement*

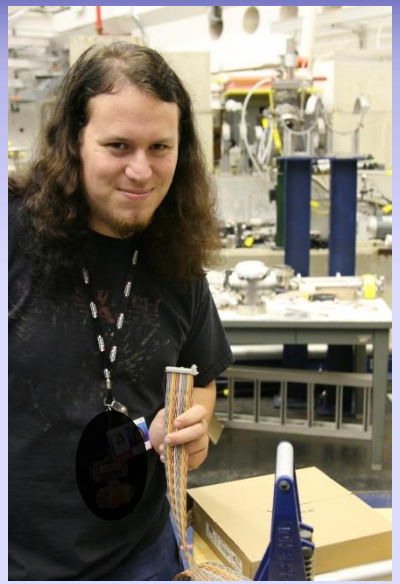
GODDESS status



- Powerful array for measuring multiple reactions (simultaneously!)
- Hardware constructed, vacuum tested and installed and operated with GS
- ~ 30 keV energy resolution (sX3) (>2 times better than standard ORRUBA!)
- Analog position resolution matched with trapezoidal filter (1.2 mm @ 5.8 MeV)
- Improvements to position extraction being investigated
- Endcap detectors designed and ordered
- IC under construction
- Preamp box modifications for cooling
- 4 slots of beam time approved

GODDESS Acknowledgements

Steven Hardy - cable crusher



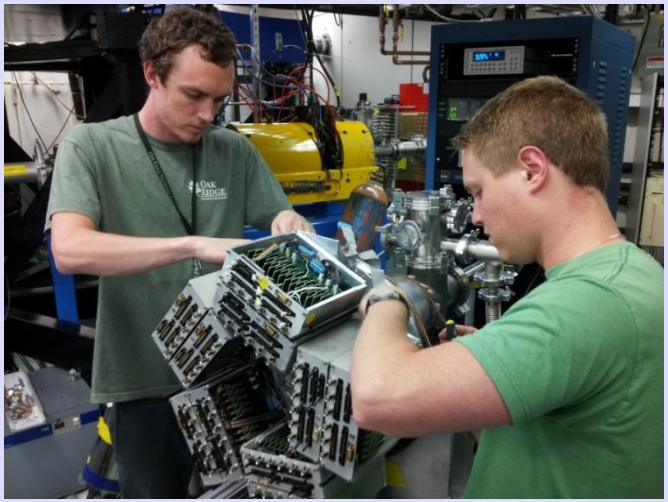
Student

Callum Shand testing his test stand

Travis Baugher – Simulating GODDESS

Postdoc

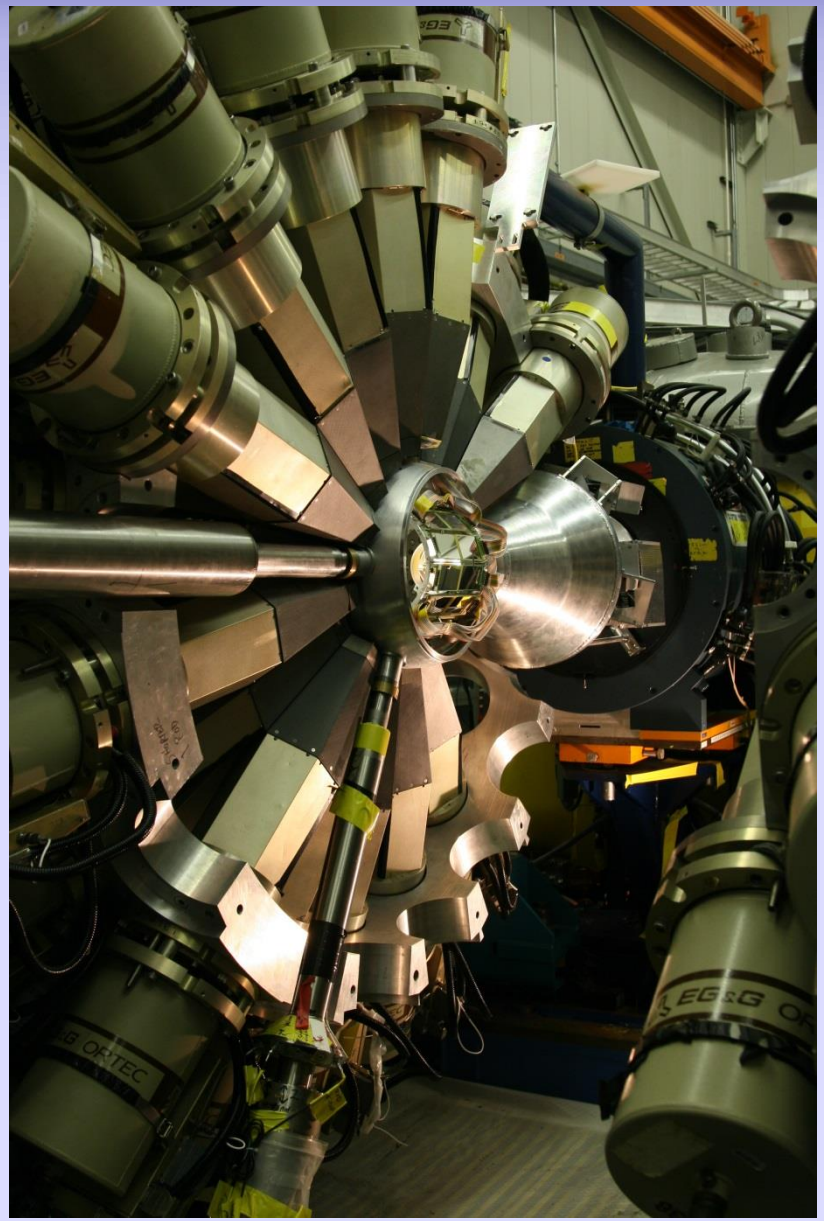
Thanks also to the help from Argonne – Darek Seweryniak, Mike Carpenter, Shaofei Zhu and Kim Lister….



Andrew Ratkiewicz – not entirely convinced by the pineapple-eating dinosaurs at the creation museum

Sean Burcher and **Ian Marsh** assembling GODDESS for the first time

Summary



- ^{26}Al highly studied astronomical signal
- Improved knowledge of destruction (hence production) rate for massive stars through (d,p) measurement
- GODDESS - a powerful system for measuring multiple reactions (optimized for charged particles and gammas)
- Hardware constructed, vacuum tested and installed and operated with GS
- Digital instrumentation tests ~30 keV energy resolution (>2 times better than standard ORRUBA)
- Improvements to position extraction being investigated (Sarah Lonsdale)
- Endcap detectors designed and ordered
- IC under construction
- 4 slots of beam time approved

Keep on the physics…

Collaborators

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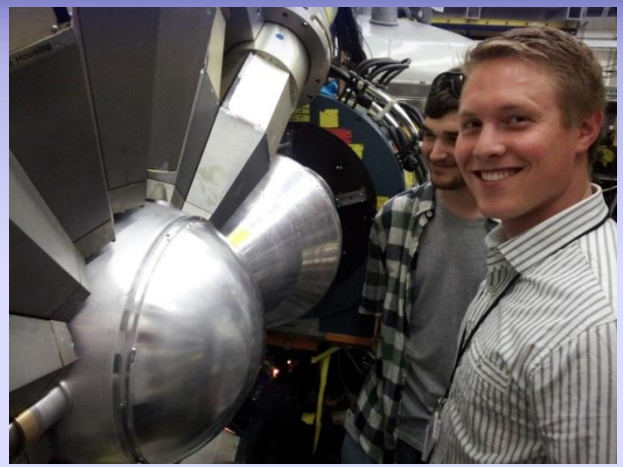
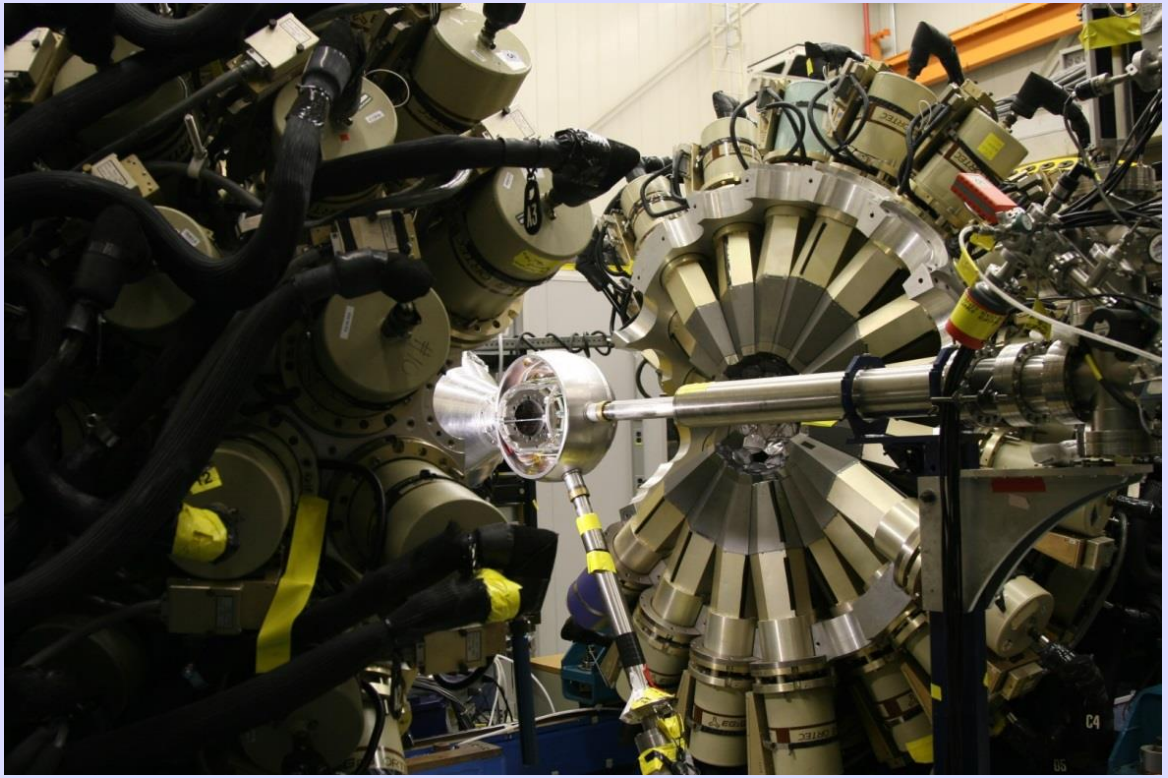
Louisiana State University

M. Carpenter, D. Seweryniak, S. Zhu
Argonne National University

OAK RIDGE National Laboratory





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