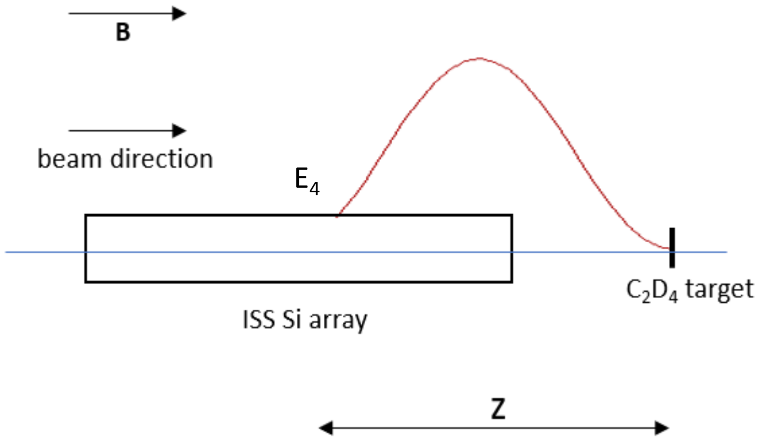
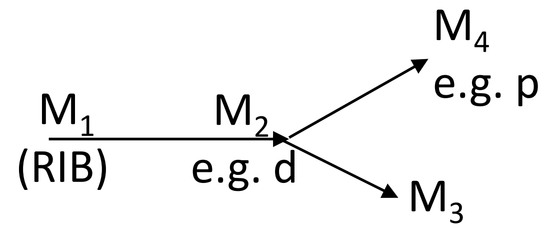
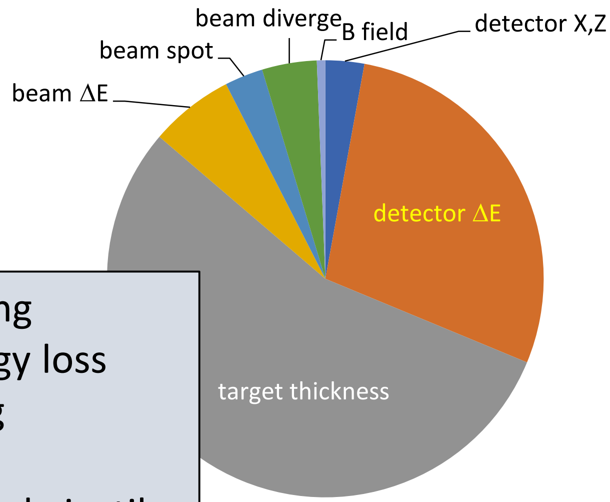
HELIOS principle – ISOLDE Solenoidal Spectrometer (ISS)





$$Q = aE_4 + bz + c$$



multiple scattering
variation in energy loss
energy straggling

for both beam and ejectile

7.6 MeV/u $^{212}Rn(d,p)^{213}Rn$

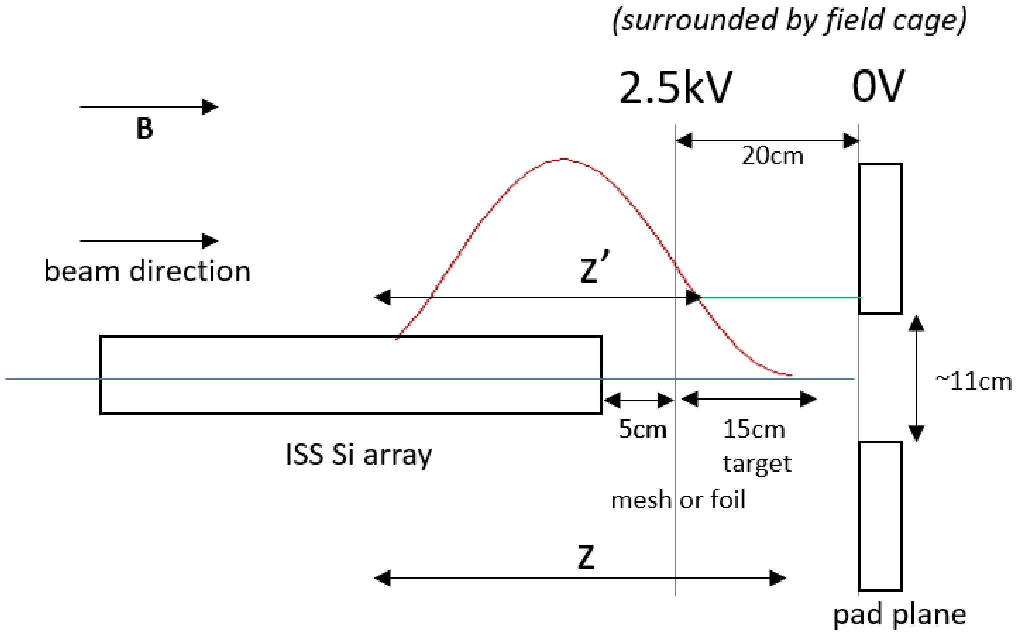
B = 2.5T

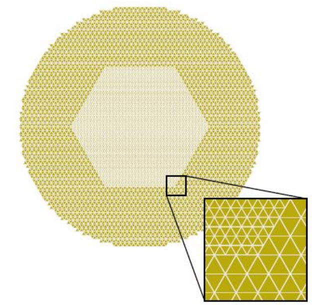
Detector ΔE 60keV FWHM

Target thickness 0.125 mg/cm^2

Estimated ΔQ = 110 keV FWHM

ISS-HELIOS-TPC mode of operation





MSU AT-TPC Micromegas
x, y from pad position
z' from time of flight (< 10μs)

ISS vessel contains gas, e.g. 50 torr D_2, in electric field **E** parallel to **B**

From x, y, z' can deduce z

Equivalent C_2D_4 target thickness 0.67 mg/cm^2

Estimated ΔQ = 80 keV FWHM (*after correction for energy loss in gas*)

Can use H_2, D_2 (*no carbon*), N_2, $^{3,4}He$ (with 5% CO_2), possibly $^3H_2$

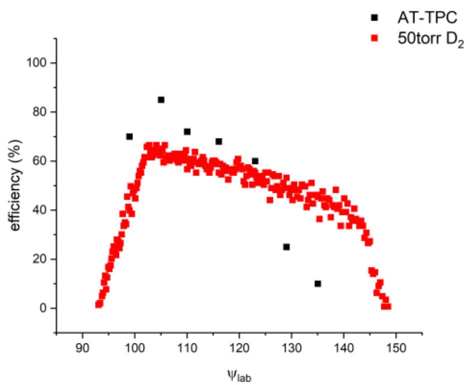
Dream of ISOL-SRS: $^{224}Ra(d,d')$, Si ΔE 10keV, beam manipulated, 12.5 torr (≡ 0.17 mg/cm^2 C_2D_4), ΔQ = 28 keV

Luminosity comparison

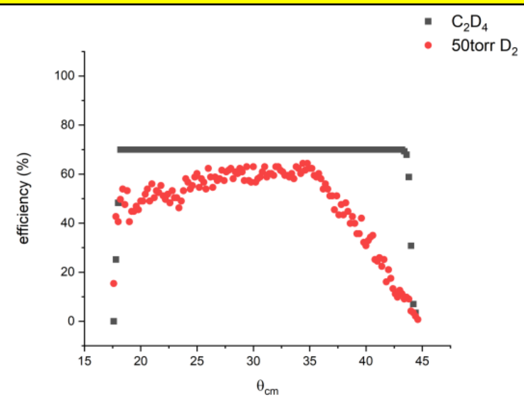
luminosity = beam intensity x target thickness x efficiency

beam intensity limited by:

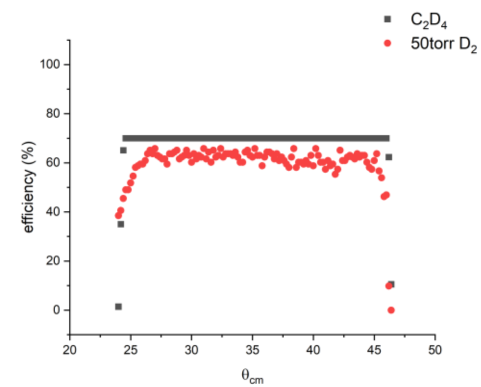
- maximum average rate of target elastics, say 10^3/s
- maximum instantaneous rate of target elastics, say 1/μs
- maximum beam intensity available from post-accelerator



^{22}Mg(α,p) (B=2.5T, R=35cm)



^{206}Hg(d,p) (B=2.5T, R=35cm)

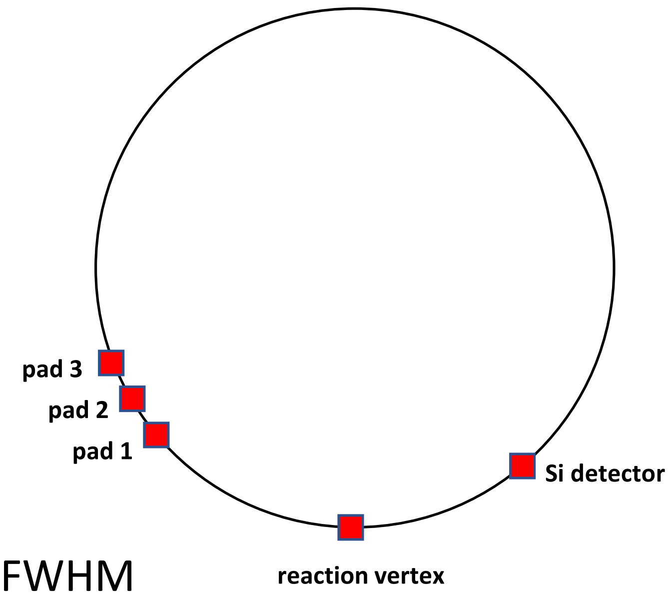


^{146}Ce(d,d') (B=2.5T, R=45cm)

Simulated: 15cm 50 torr gas					Experiment or *proposal*				
Reaction	Energy MeV/u	beam Intensity /s	luminosity I x t x ε	FWHM keV	beam Intensity /s	target mg/ cm^{-2}	luminosity I x t x ε	FWHM keV	FWHM keV (sim.)
^{22}Mg(α,p)	5	6×10^5	4.6×10^4	110	900	13	6.6×10^3	~300	-
^{28}Mg(d,p)	9.47	10^6	7.8×10^4	80	10^6	0.12/4	2.1×10^4	~130[1]	100
^{206}Hg(d,p)	7.38	3×10^5	2.5×10^4	80	5×10^5	0.17/4	1.5×10^4	~140	145
^{146}Ce(d,d')	7.5	4×10^5	4.0×10^4	95	*10^6*	*0.1/4*	*1.75×10^4*	*~100*	95

JS Randhawa *et al.*, Phy. Rev. Lett. **125** 202701 (2020)
PT MacGregor *et al.*, Phys. Rev C **104** L051301 (2021)
TL Tang *et al.*, Phys. Rev. Lett. **124** 062502 (2020)
LP Gaffney *et al.*, INTC–P-609

Tracking – how much?



$2\pi r_{pad}$ = 350 mm

simulations assume:
3mm pitch, Δz = 1mm FWHM

For reactions such as (d,p) and (α,p), $\psi_{lab} > 90^0$:

z' (pad 2) < z' (pad 1), otherwise reject

For reactions such as (d,d') $\psi_{lab} < 90^0$:

reaction vertex, pad 1, and Si detector define circle

check diameter of circle from E_4 and z

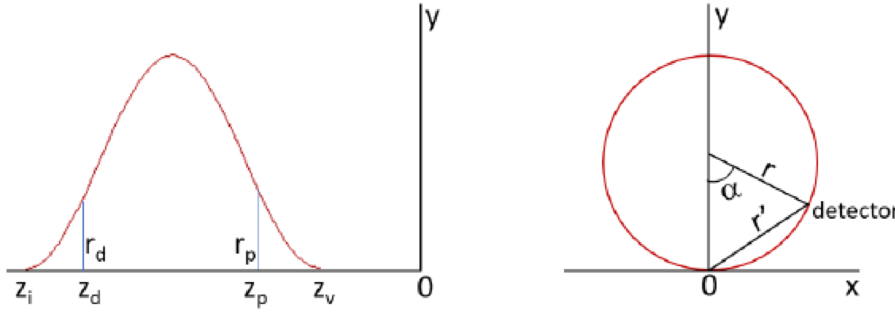
Collaborations

R. Raabe *et al.* (Leuven) have built the active target SpecMAT that sits inside the magnet volume of the ISS

D. Bazin, Y. Ayyad *et al.* (MSU) have developed the AT-TPC spectrometer that resides inside a magnetic field as part of SOLARIS, at ReA3/FRIB

A. Laird *et al.* (York) have constructed the active target TACTIC, installed at TRIUMF

Appendix: Algorithm to extrapolate intersection on beam axis from x, y, z measurement



First step: estimate the value of z_v of the reaction vertex from z_p, a value for the ejectile trajectory measured using the pad detector. (All expressions below are non-relativistic.)

In the RH figure the corresponding radial position of the trajectory (from x_p, y_p) is given by

$$r' = r_p = \rho_{max} \sin\frac{\alpha_p}{2}$$

where $$\rho_{max} = 2r = 0.2879\,\frac{\sqrt{E_4 M_4}}{qB}\,\sin\theta_{lab}\,,$$

and $$\cos\theta_{lab} = 1.105\,(z_i - z_v)/\frac{\sqrt{E_4 M_4}}{qB}\,.$$

The value of $z = z_i - z_v$ (z_i is position of intersection on beam axis after one cyclotron period) can be estimated using equation 1. As $z_i - z_v >> z_p - z_v$ a nominal value of Q can be used to make an initial estimate of z.

Now,

$$(z_p - z_v)/(z_i - z_v) = \alpha_p/2\pi\ ,$$

allowing z_v to be determined.

Second step: estimate z_i more accurately from z_d, measured using the Si detector.

As above except that the radial position at the Si detector (from x_d, y_d) is given by

$$r' = r_d = \rho_{max} \sin\frac{\alpha_d}{2}$$

The initial estimate of $(z_i - z_v)$ is $(z_d - z_v)$, and $\cos\theta_{lab}$, ρ_{max} determined as above.

In this case

$$(z_i - z_d)/(z_i - z_v) = \alpha_d/2\pi\ ,$$

from which a better estimate of z_i can be determined.

The whole procedure is repeated and rapidly converges.