Direct reaction studies with the ISOLDE Solenoidal Spectrometer

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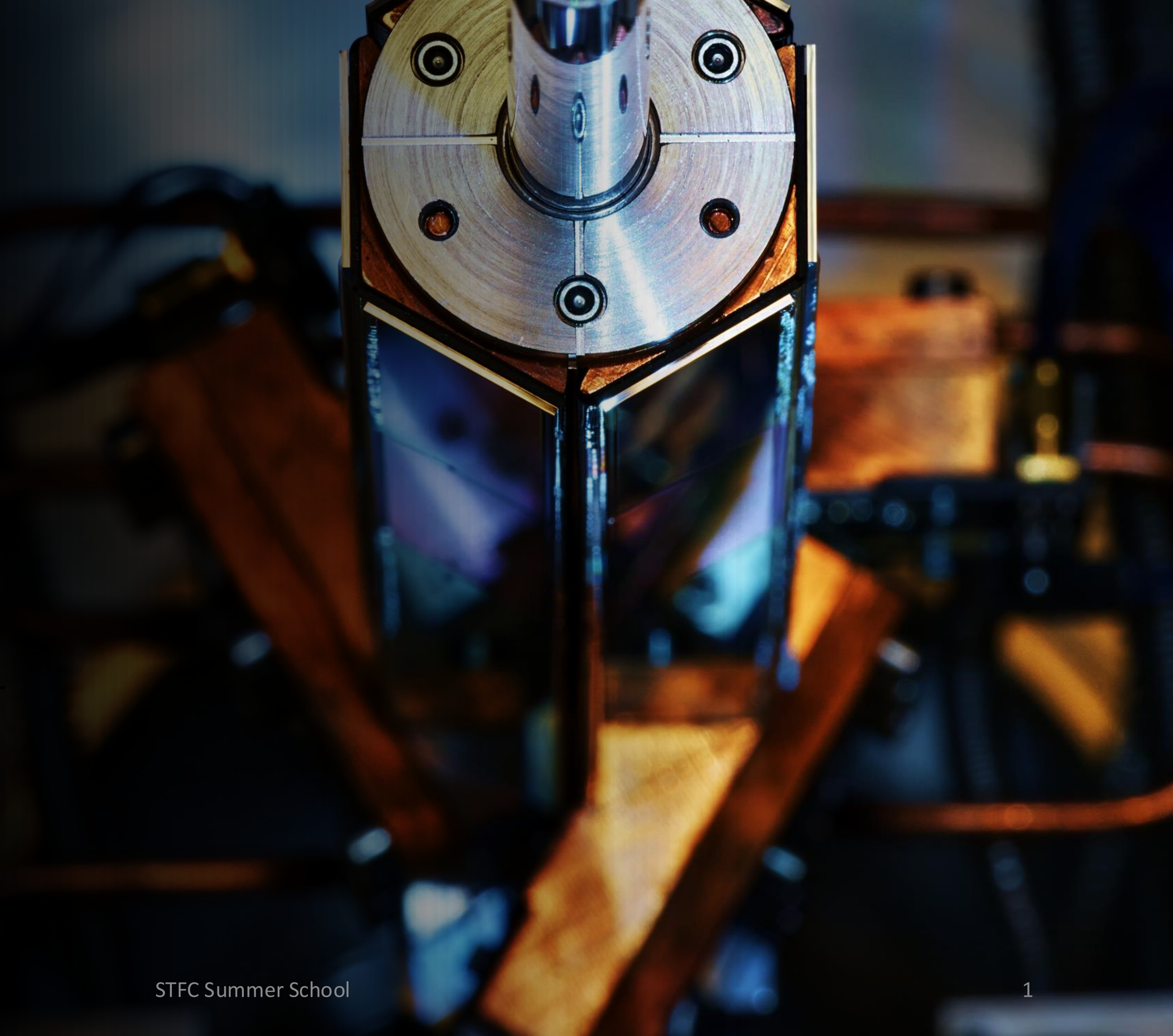
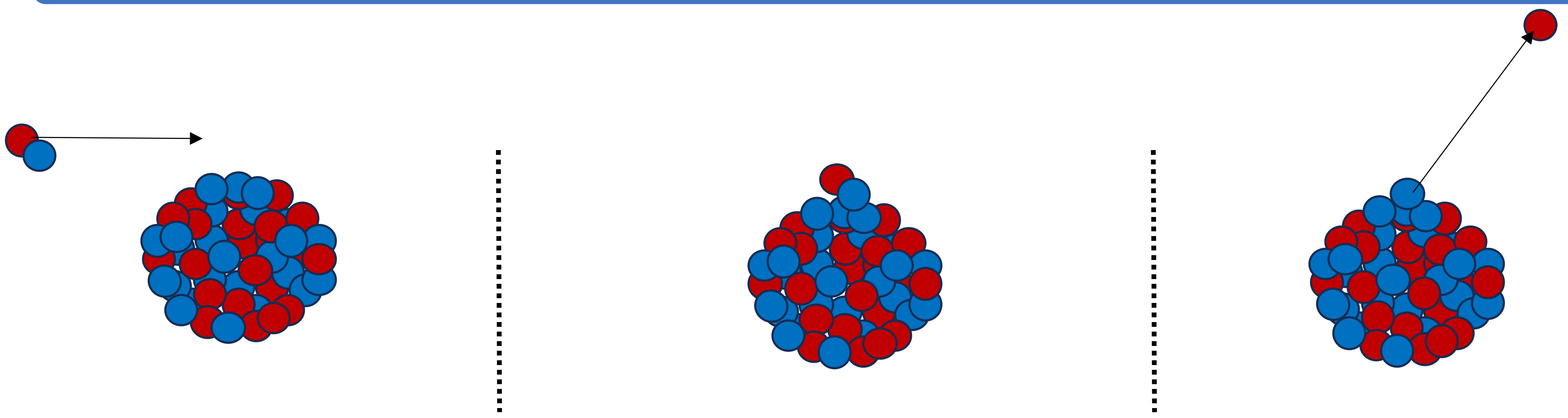
ISOLDE Solenoidal Spectrometer

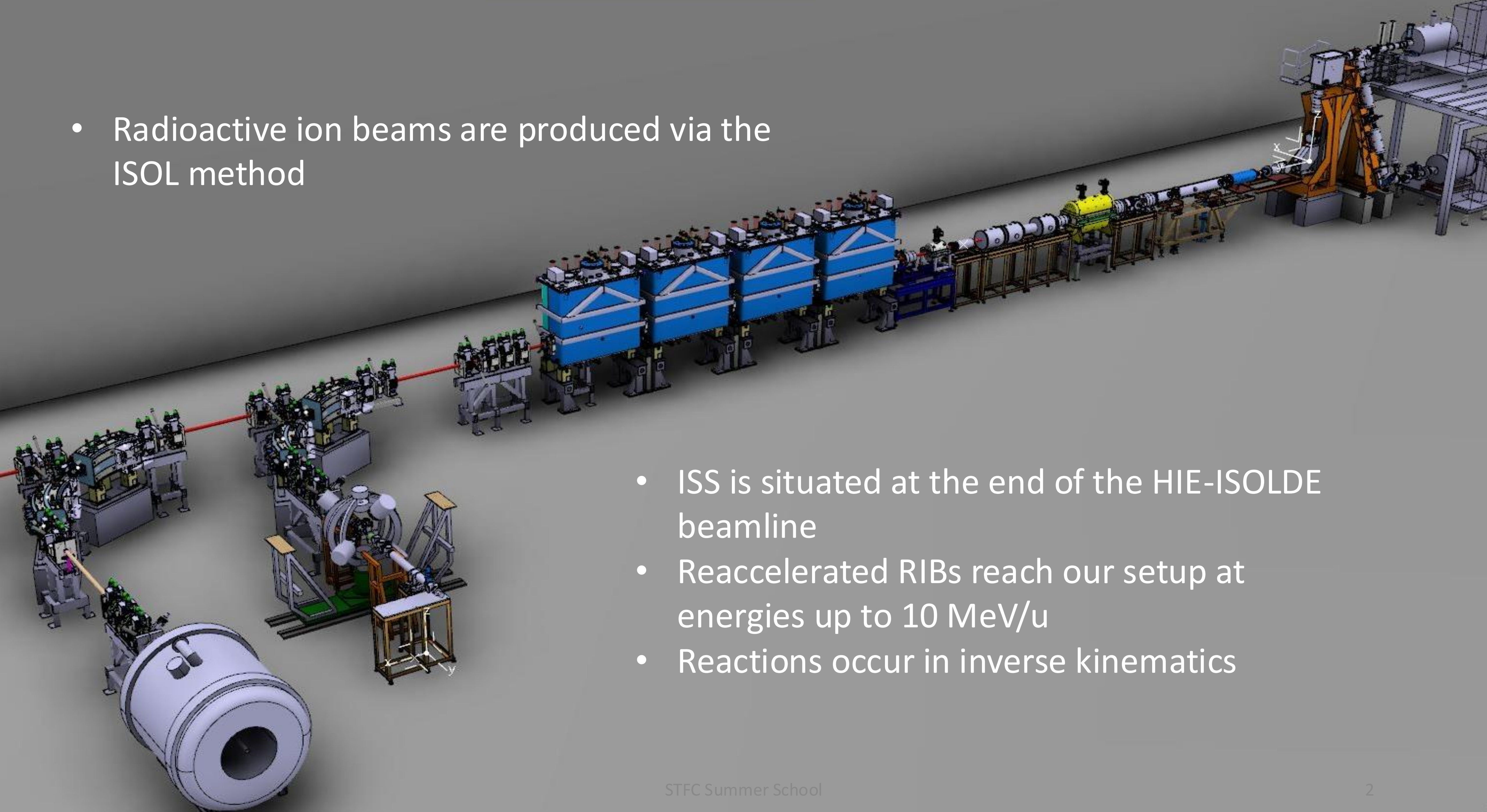


Direct reactions

- (d,p), (p,d) - reveal information about single particle states
- (t,p), (p,t) - gives information on pairing correlations
- (d,d'), (p,p') - used as a probe for collective behavior



(d,p) reaction – a single neutron is added to the nucleus



- Radioactive ion beams are produced via the ISOL method

- ISS is situated at the end of the HIE-ISOLDE beamline
- Reaccelerated RIBs reach our setup at energies up to 10 MeV/u
- Reactions occur in inverse kinematics

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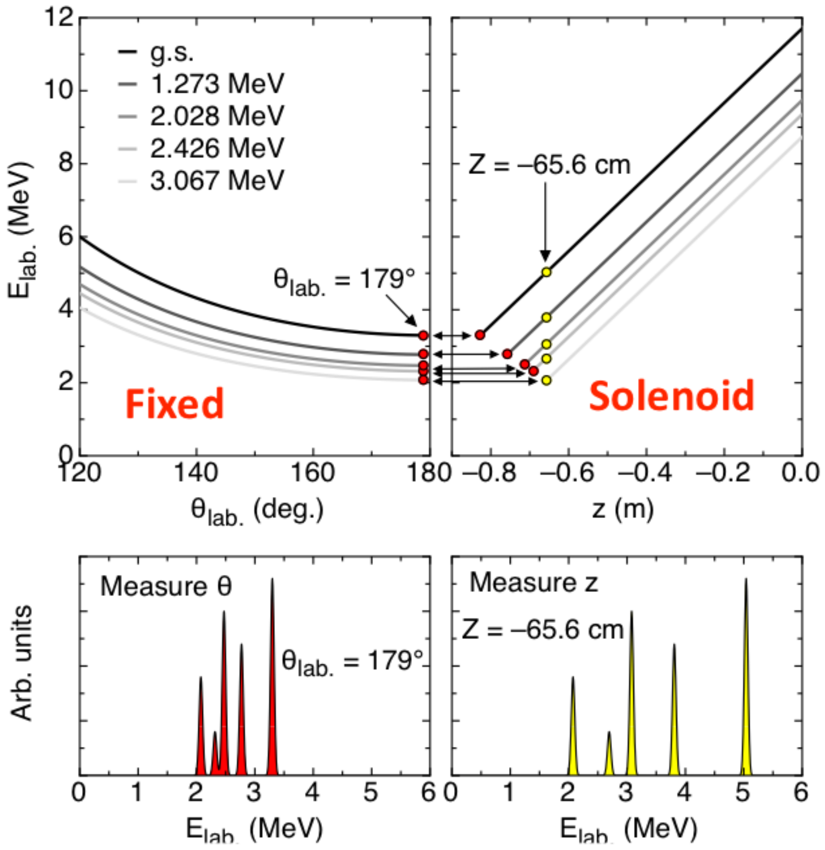
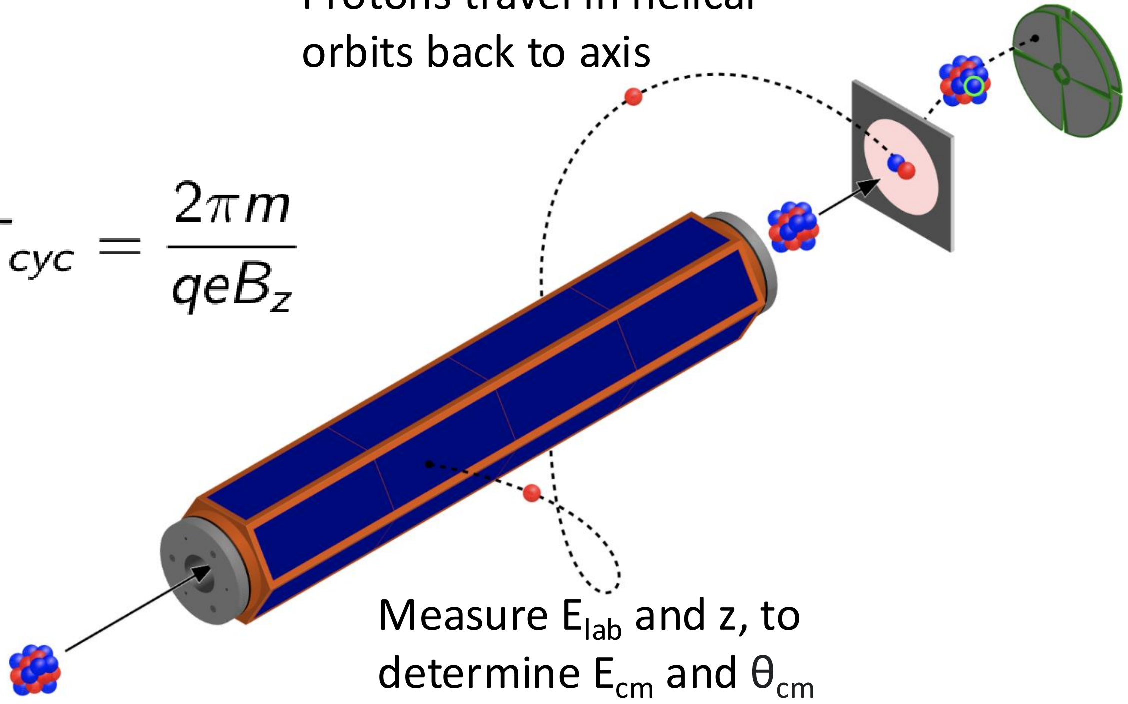
ISOLDE Solenoidal Spectrometer

Solenoidal technique



Protons travel in helical orbits back to axis

$$T_{cyc} = \frac{2\pi m}{qeB_z}$$

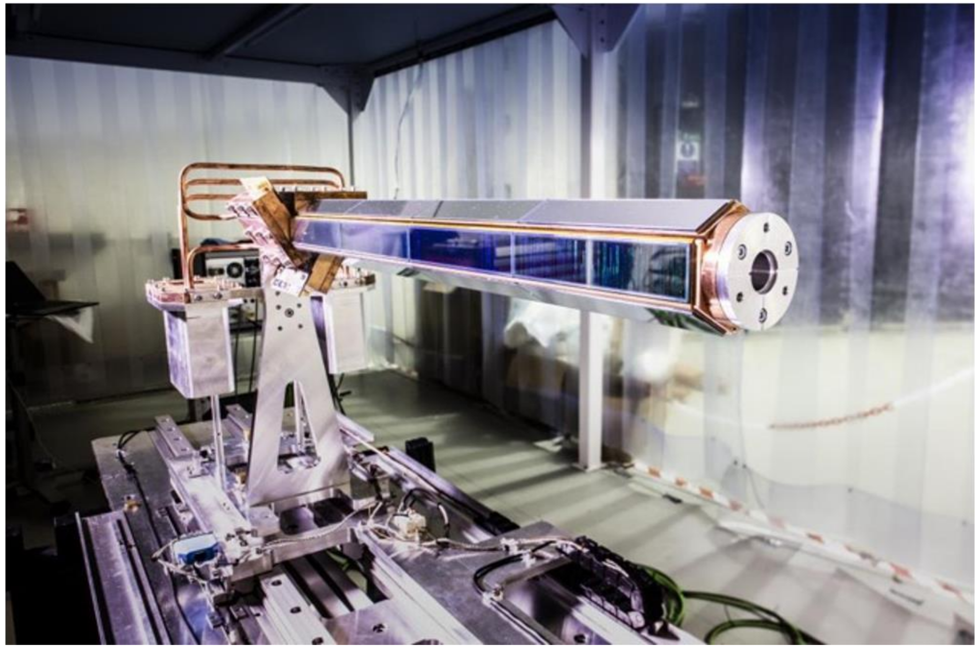


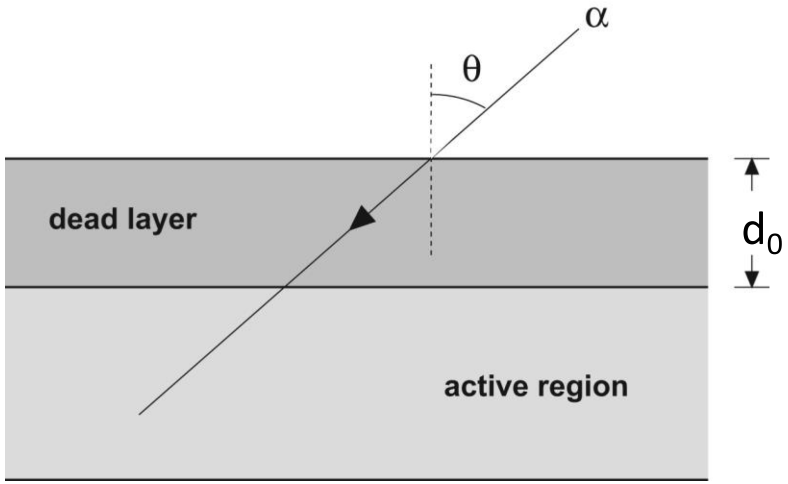
Measure E_{lab} and z, to determine E_{cm} and θ_{cm}

$$E_{cm} = E_{lab} + \frac{mV_{cm}^2}{2} - \frac{mzV_{cm}}{T_{cyc}}$$

Calibrations

- Hexagonal array of 24 position sensitive DSSDs
- Composite α-source used to calibrate the ISS array
- Manufacturer states Al dead layer is 0.4 μm
- Energy loss is ~100 keV/μm in Al dead layer
- Need to correct for energy losses in the dead layer to properly calibrate the DSSDs





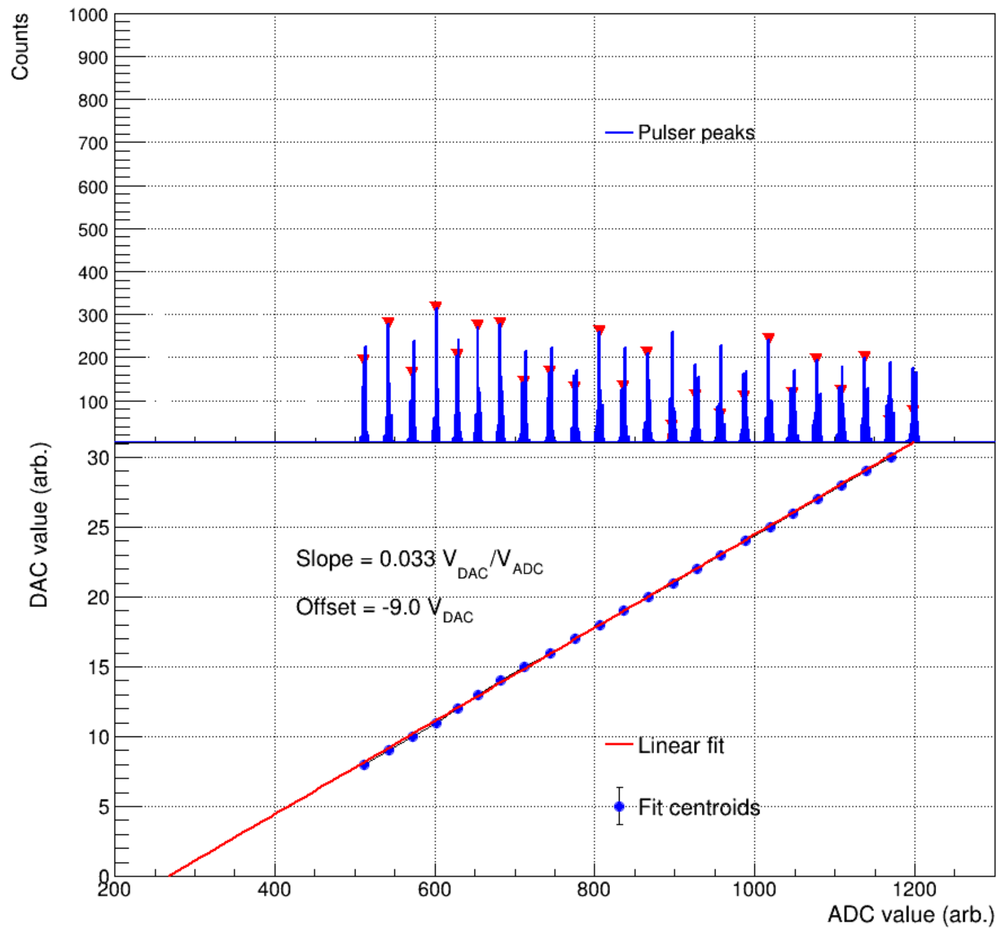
$$\Delta E_w = \int_0^{d_w} \frac{dE}{dx}\, dx \simeq \left\langle \frac{dE}{dx} \right\rangle \frac{d_0}{\cos\theta}$$

$$E_{det} = E_0 - \left\langle \frac{dE}{dx} \right\rangle \frac{d_0}{\cos\theta}$$

Dead layer determination

- Use ASICs internal pulser to send equally spaced signals into each channel on the DSSD
- "Align" uncalibrated channels with by subtracting offset

$$E_{det} = E_{ADC} * Gain + \cancel{Offset}$$



Dead layer determination

- By measuring the dependance of the n-side energy on θ, the dead-layer can be determined

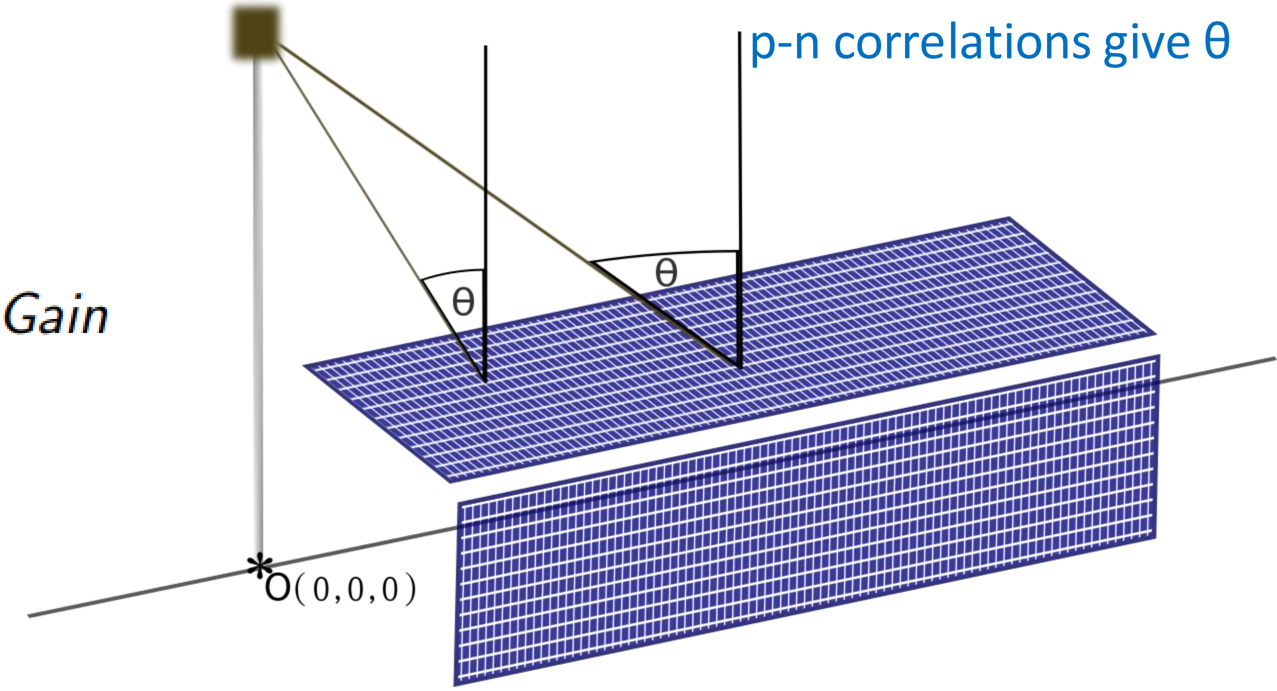
$$E_{arb} = E_{det} * 1/Gain = \left(E_0 - \left\langle \frac{dE}{dx} \right\rangle \frac{d_0}{\cos\theta}\right) * 1/Gain$$

$$m = \left\langle \frac{dE}{dx} \right\rangle d_0 * 1/Gain, \quad c = E_0 * 1/Gain$$

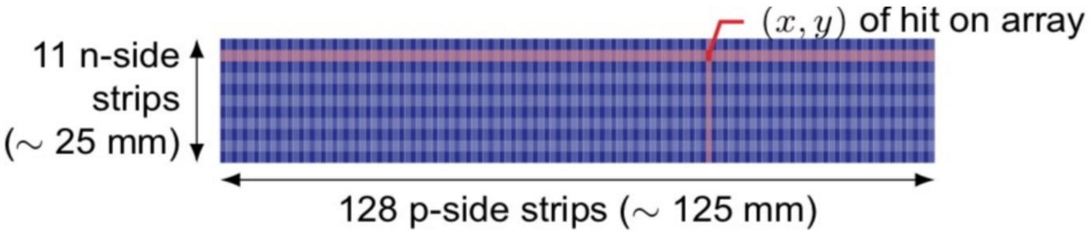
$$d_0 = -\frac{m \cdot E_0}{\left\langle \frac{dE}{dx} \right\rangle \cdot c}$$

α-source positioned off axis

p-n correlations give θ

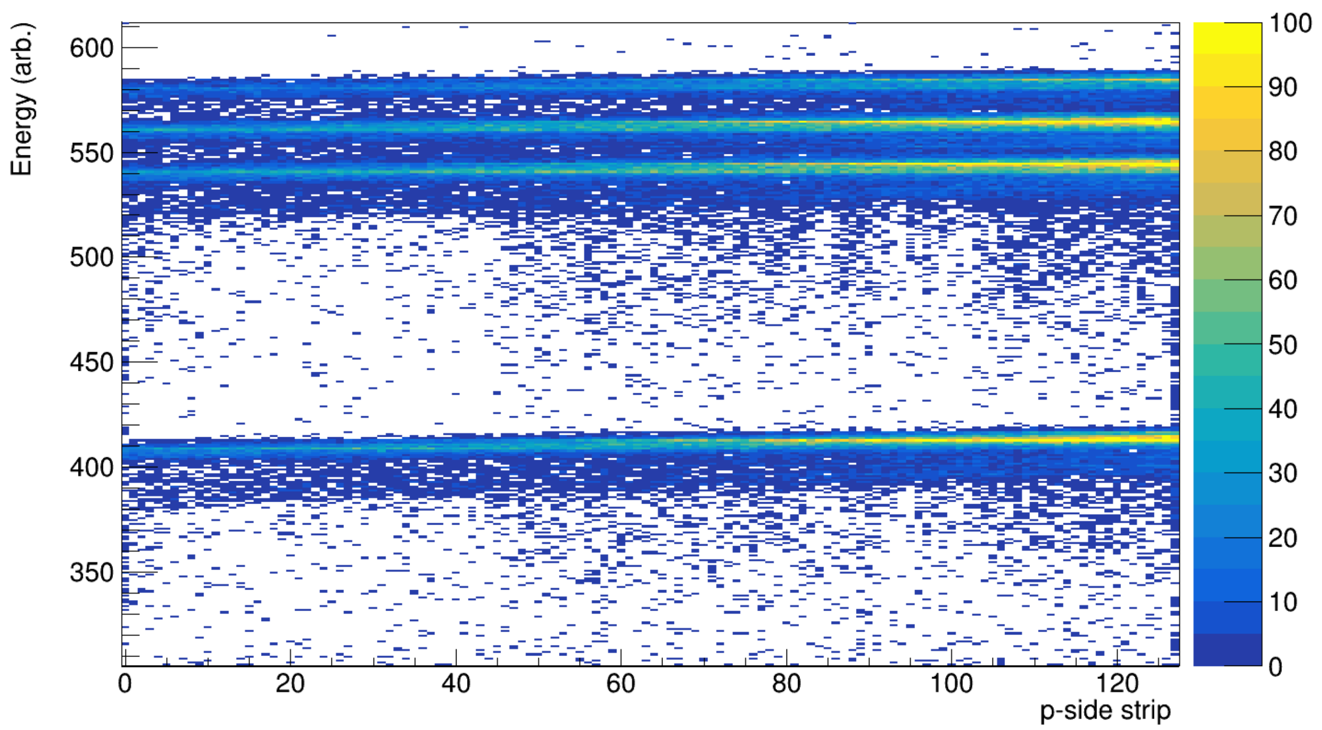


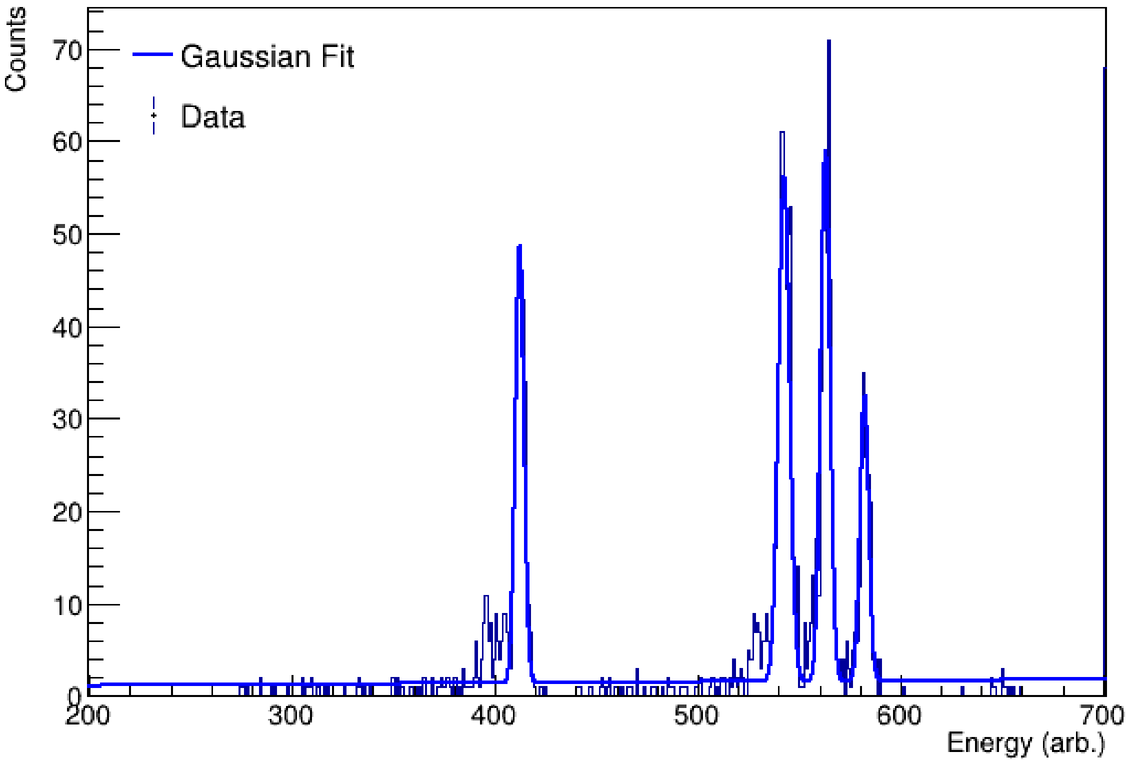
Energy taken from "aligned" n-sides



Dead layer determination

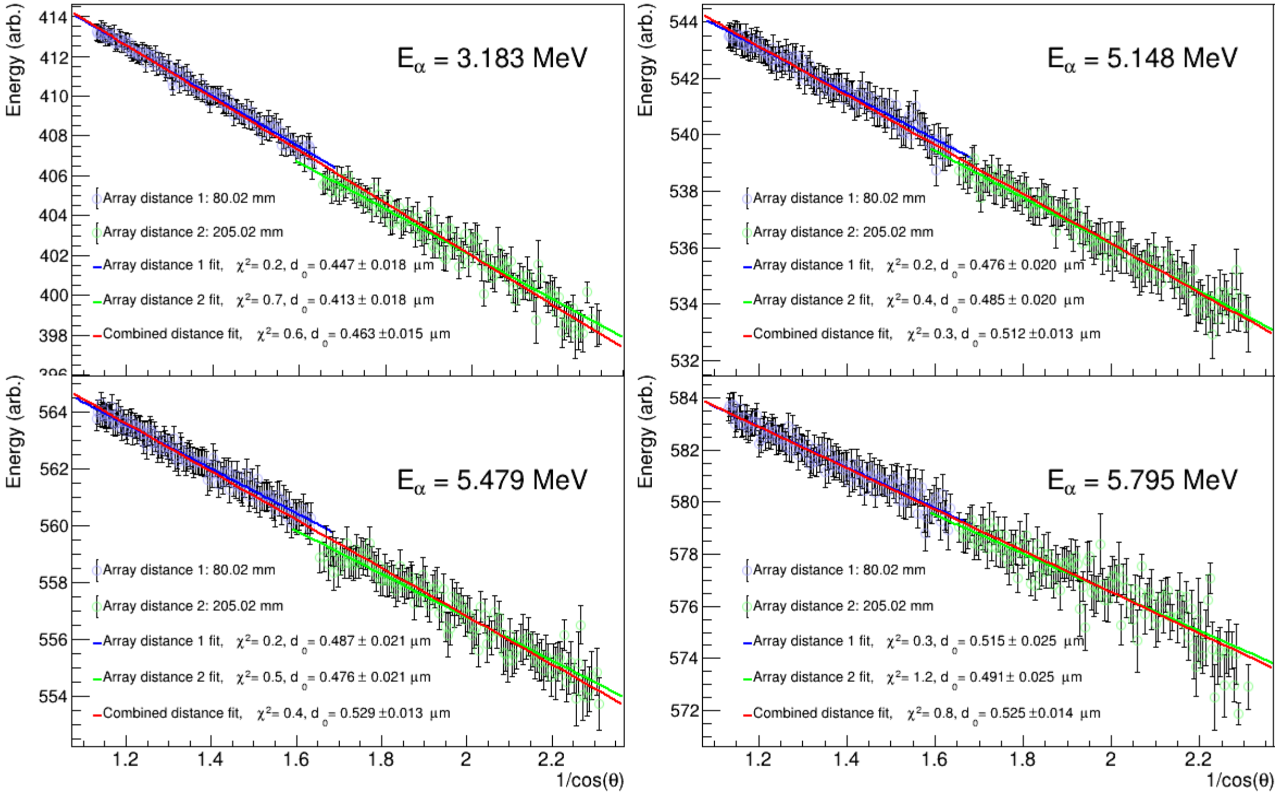
- 128 pixels per n-side gives many data points
- Measurement was performed for a total of 5 days at 2 different distances

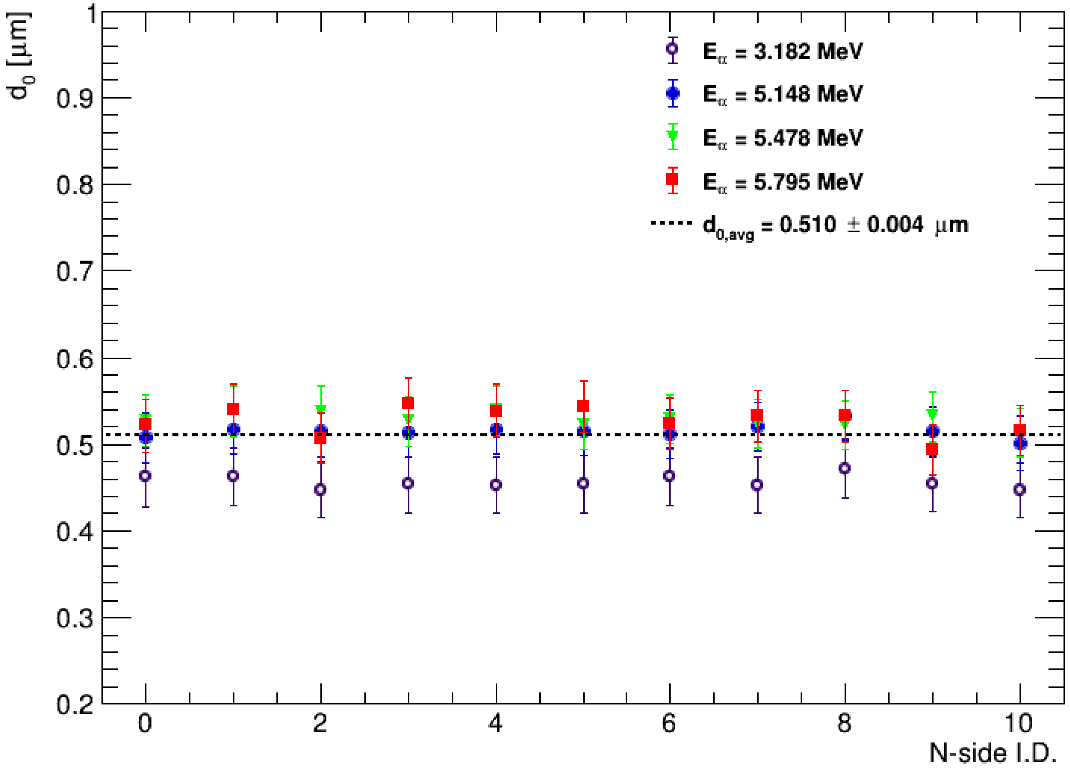




Dead layer determination

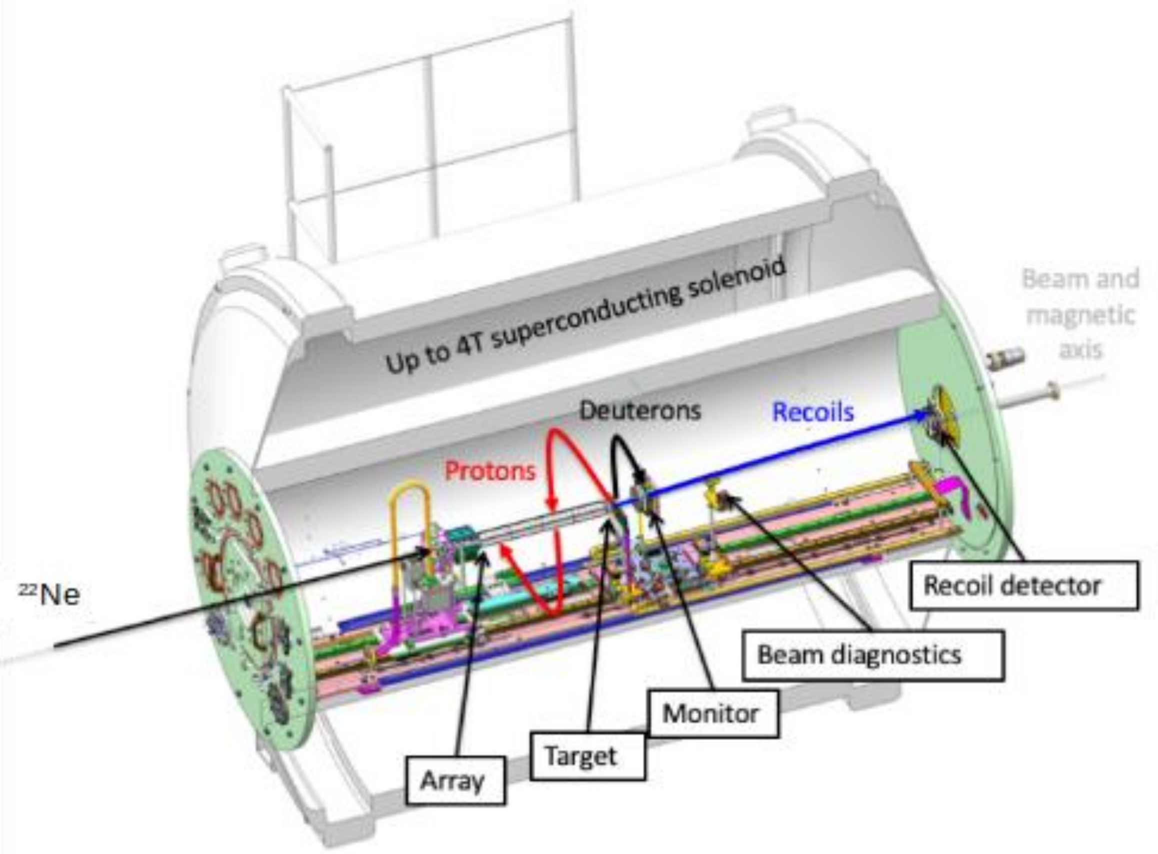
- Measured value deviates from manufacturers value by 0.1 μm, meaning the α loses ~ 15 keV more in the dead layer than originally thought





Proof of principle experiment

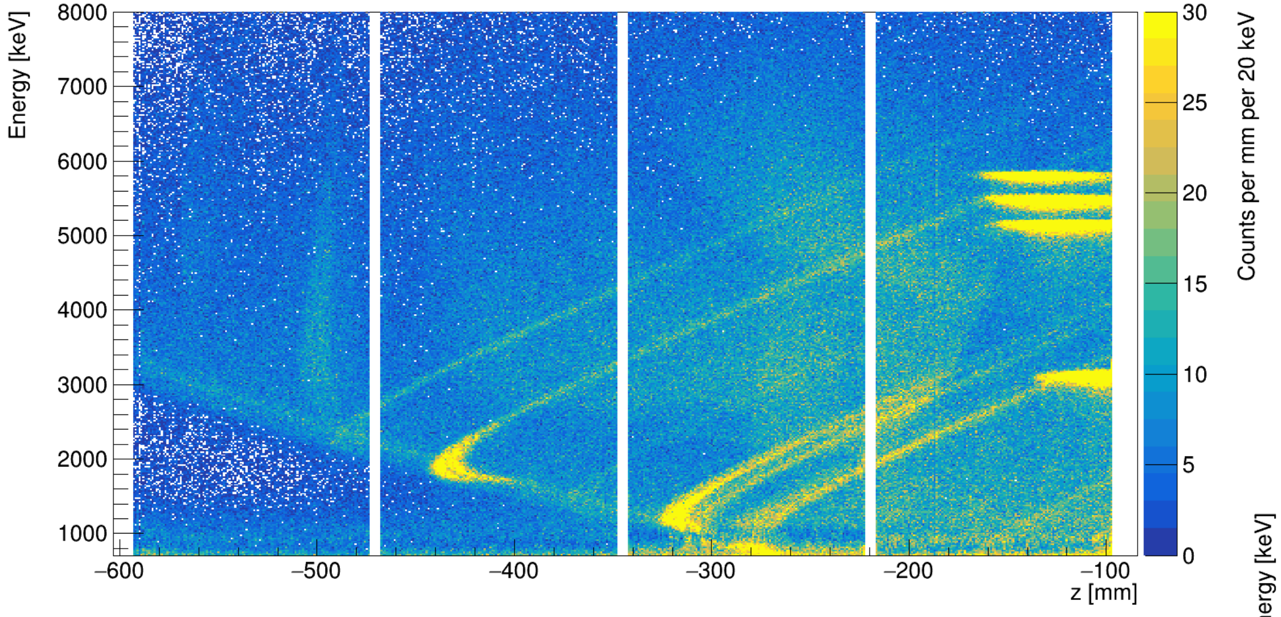
- ^{22}Ne(d,p)^{23}Ne at 6.05 MeV/u chose as a commissioning experiment for ISS to match experiment performed in normal kinematics with a gas target



- Blocker infront of the array to stop double turns
- 76 μg/cm^2 CD_2 target
- Luminosity monitor measures elastically scattered deuterons for absolute normalisation
- dE-E recoil detector can be used to remove fusion evaporation background

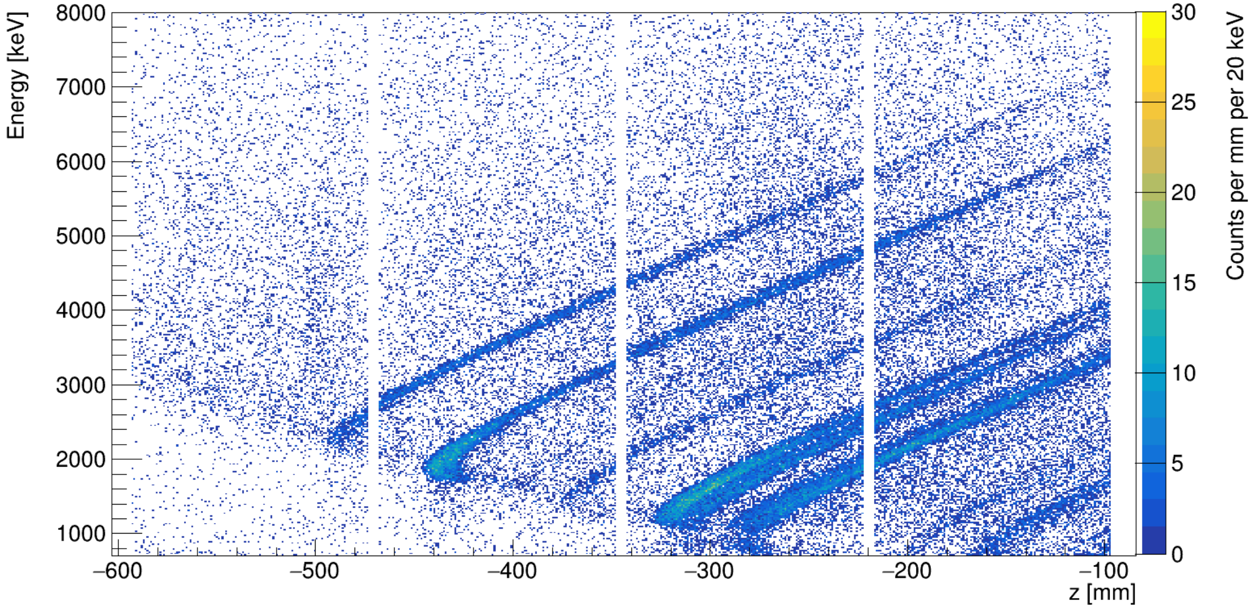
Lab energy vs z-distance

Singles - Energy vs z



- Large fusion evaporation background in singles spectra

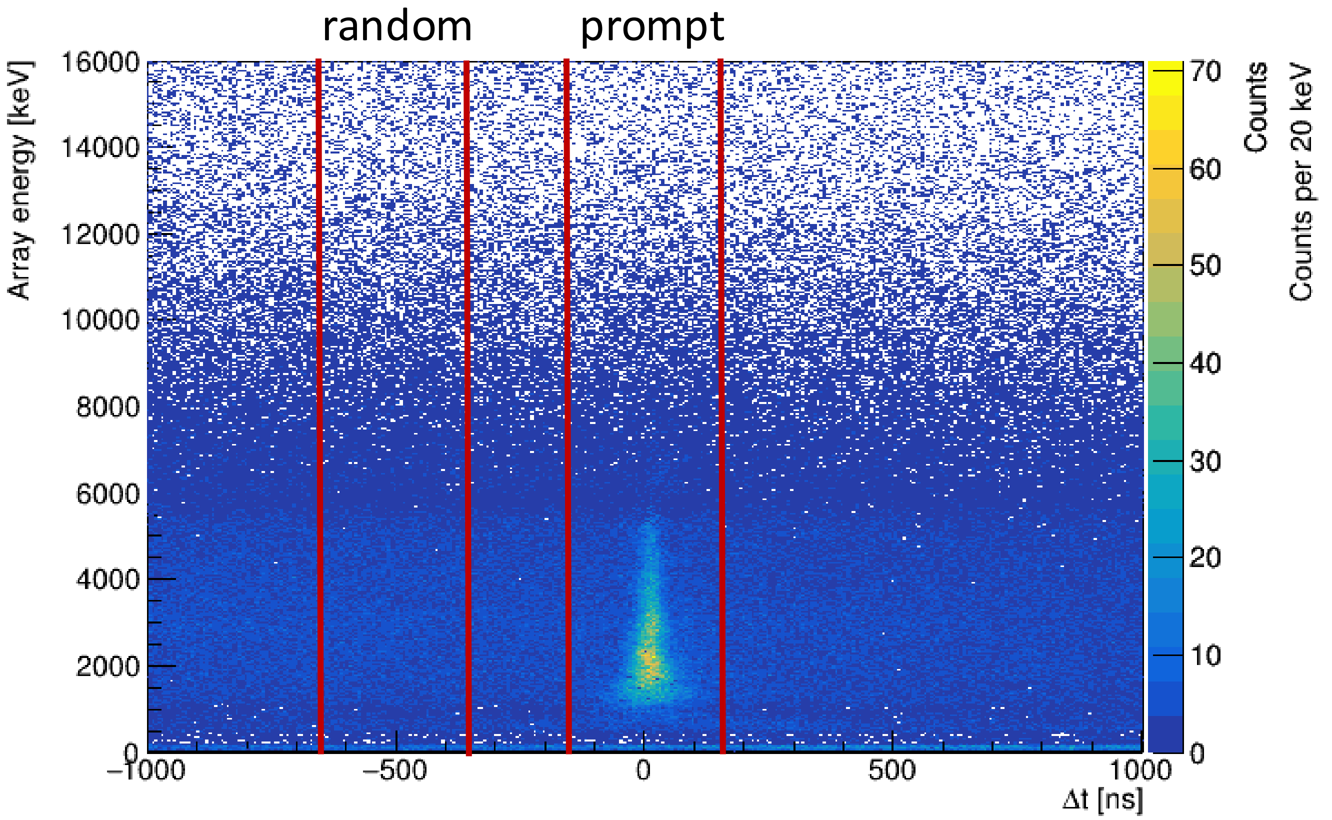
Recoil gated – Energy vs z

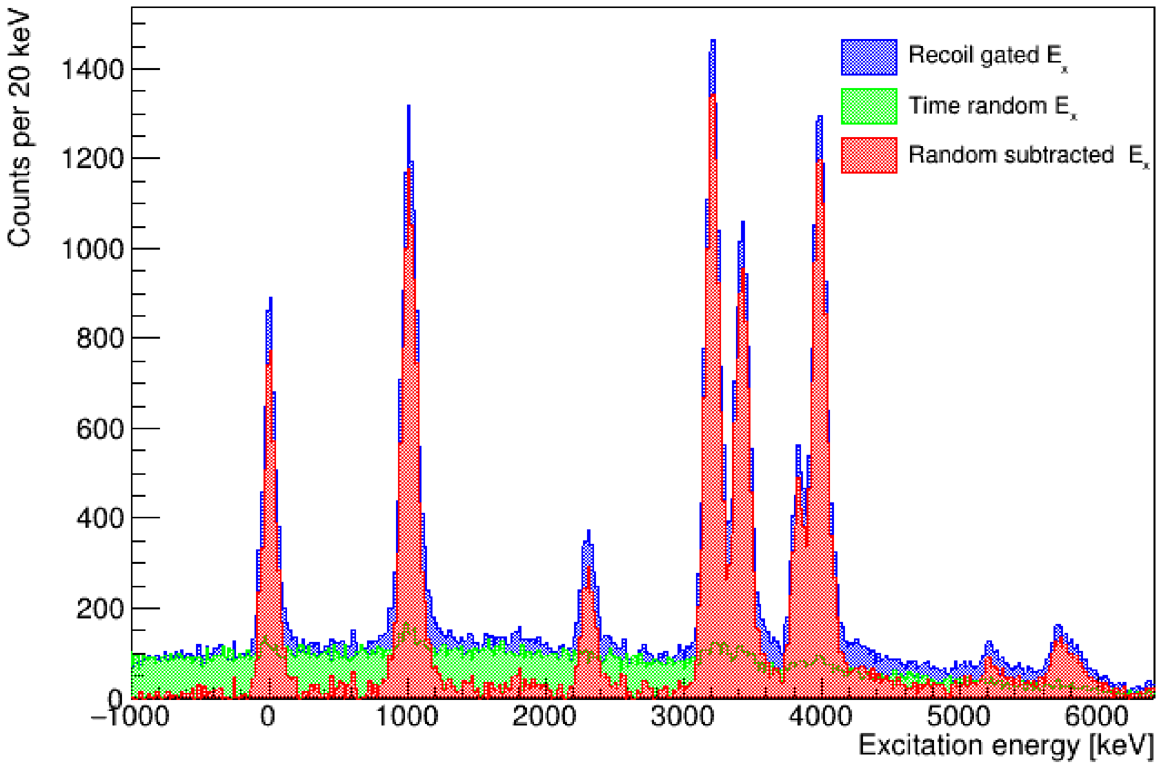


- Gating on recoils removes a large amount of background
- Kinematic lines for $^{22}Ne(d,p)^{23}Ne$ clearly visible

Excitation energy

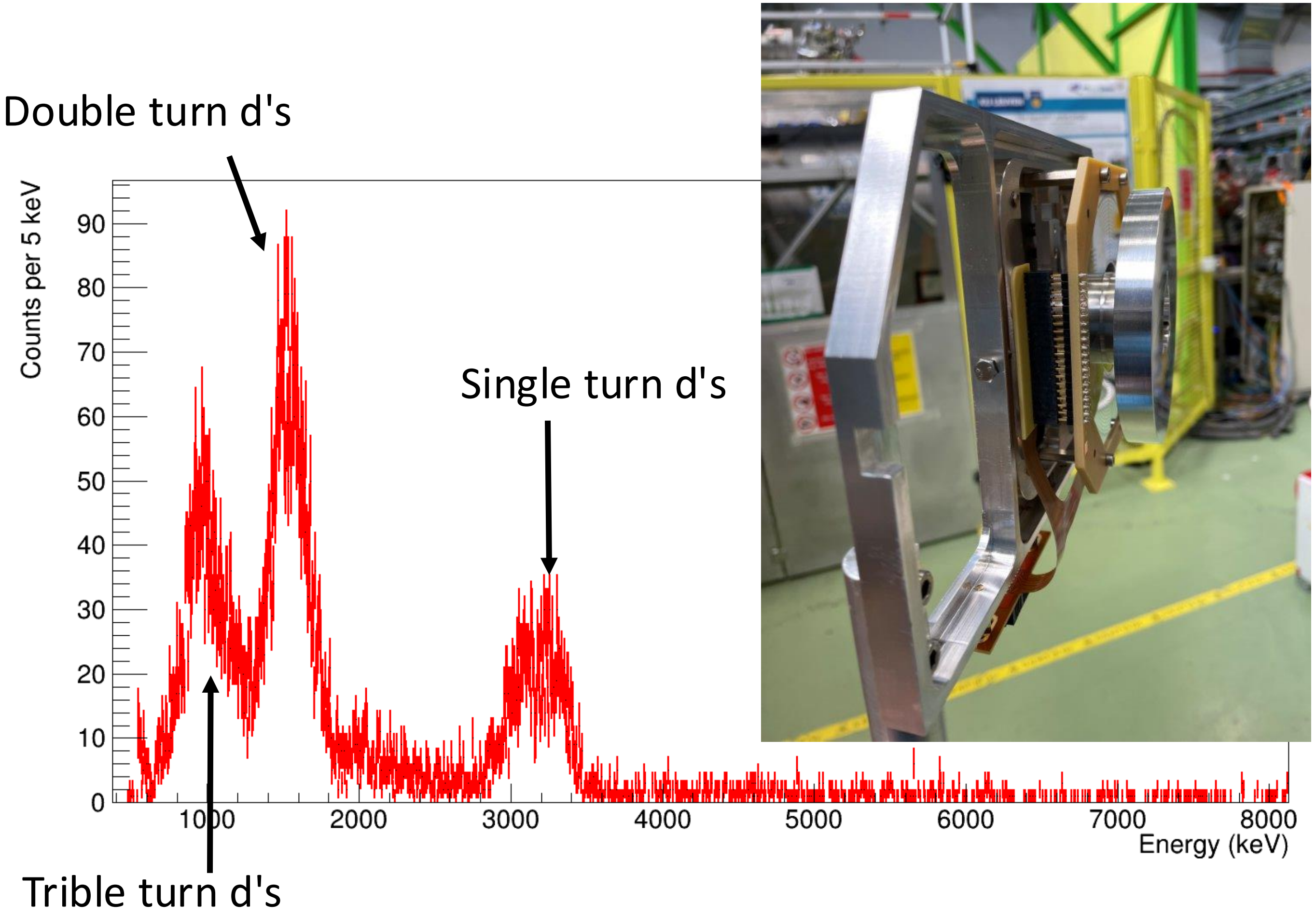
- Time-random subtraction then gives even better signal-background
- Resolution of 100 keV -> good separation between states

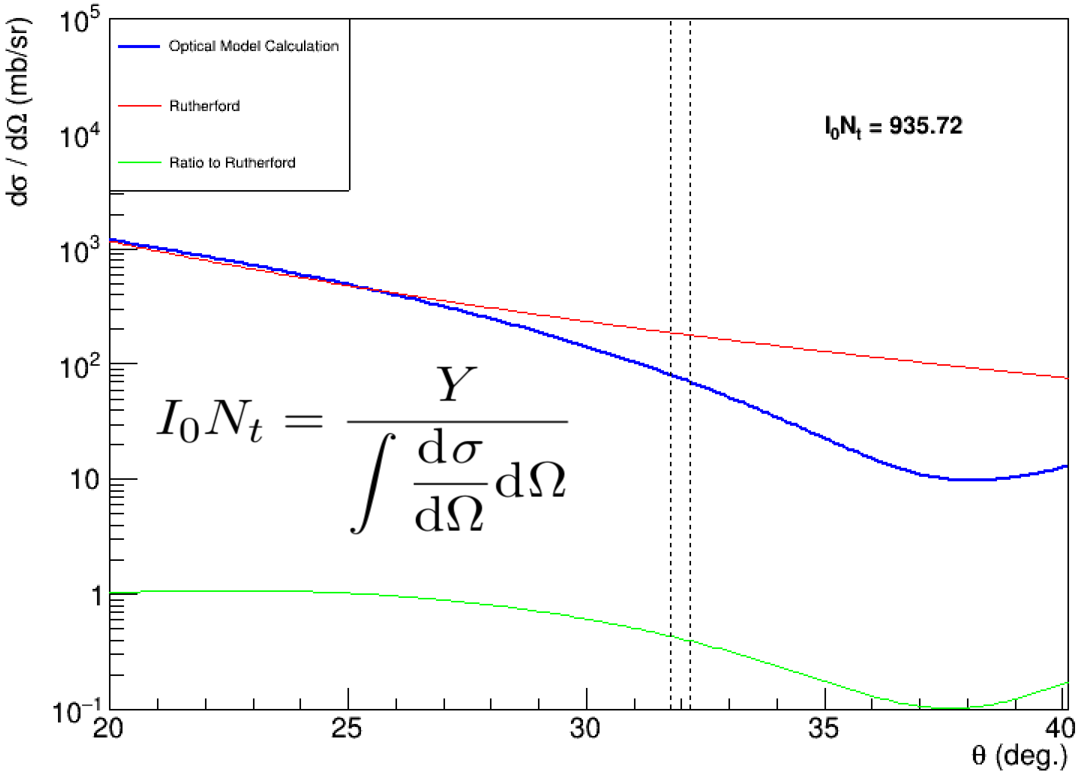




Beam Intensity

- Normalization determined from yield of elastically scattered deuterons



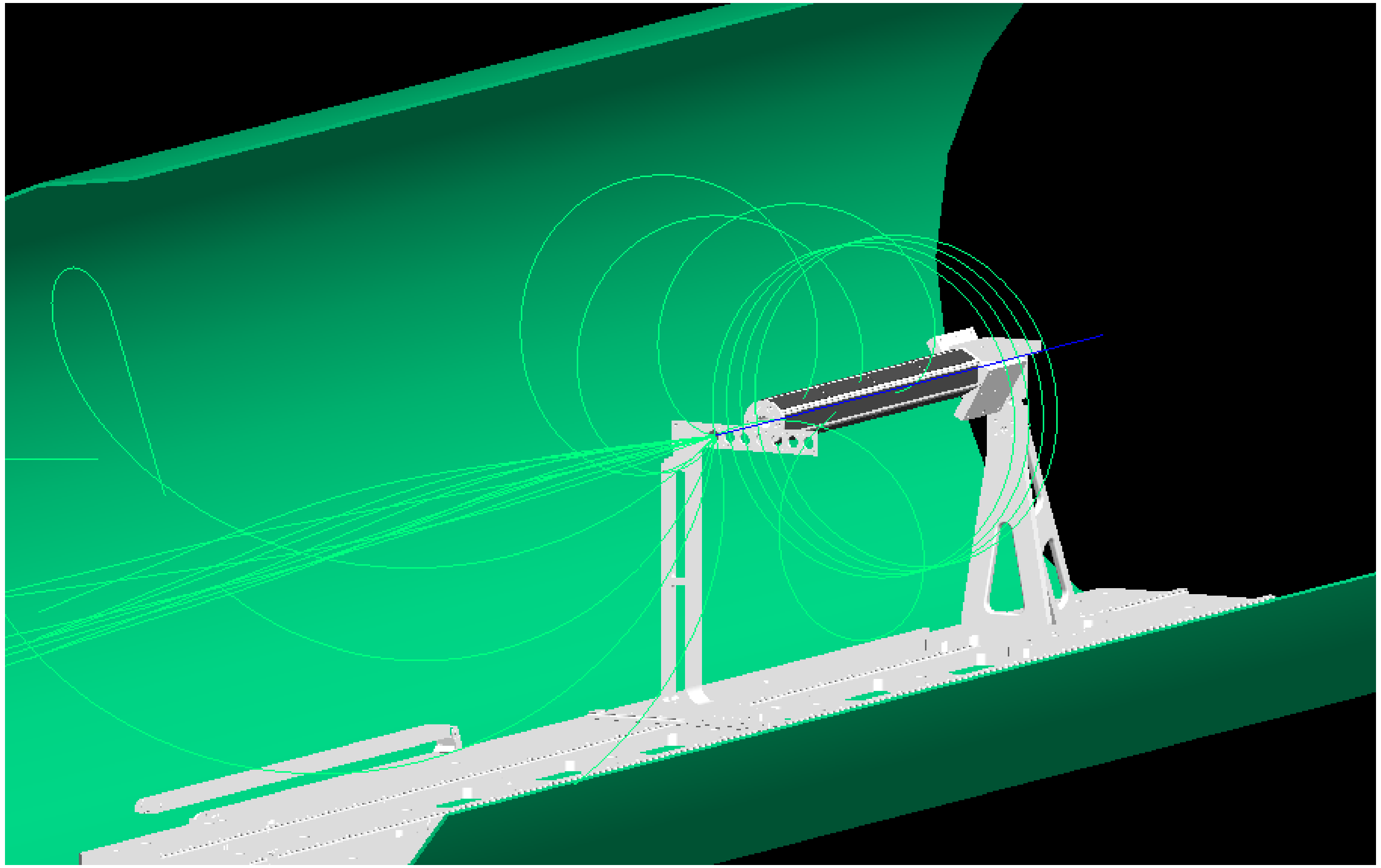


Extracted cross sections

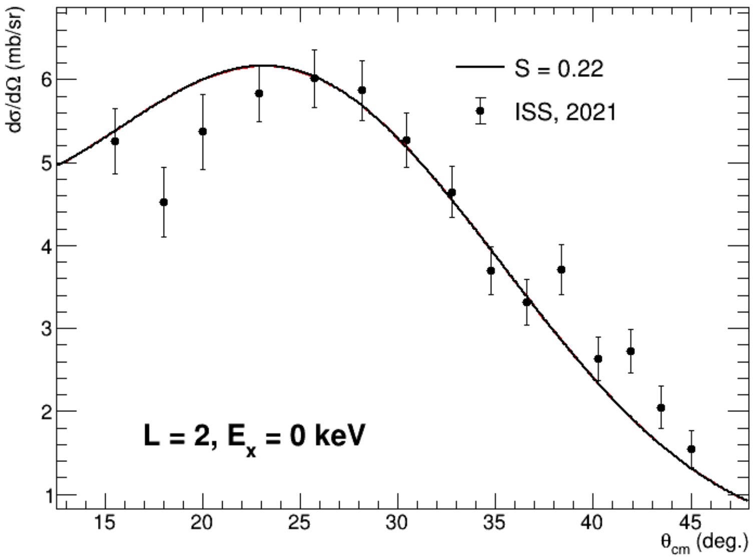
- Cross sections for each can be extracted from the measured yield

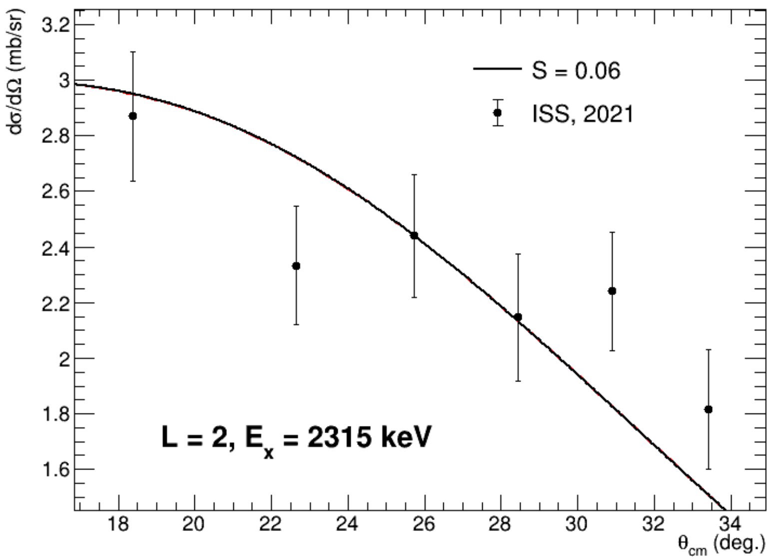
$$\frac{d\sigma}{d\Omega} = \frac{Y}{IN_0 \Delta\Omega \varepsilon}$$

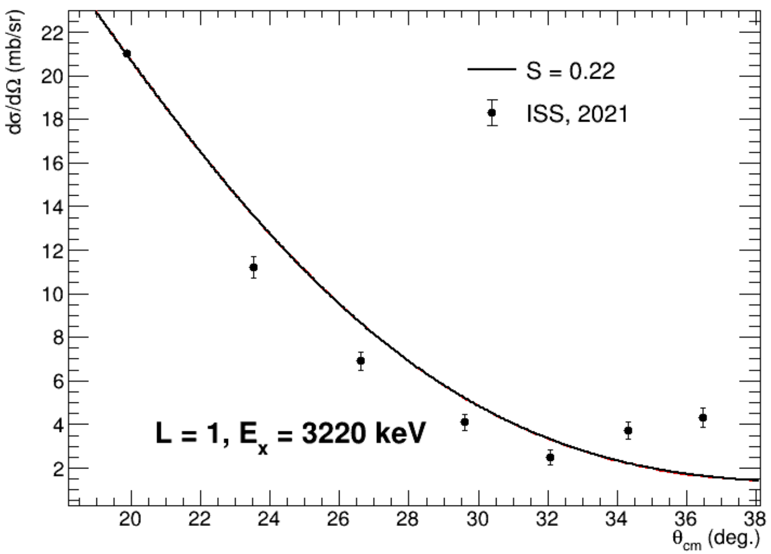
- Geometric efficiency from blocked trajectories determined using a Geant4 simulation
- Solid angle coverage is 94% in θ and 70% in ϕ

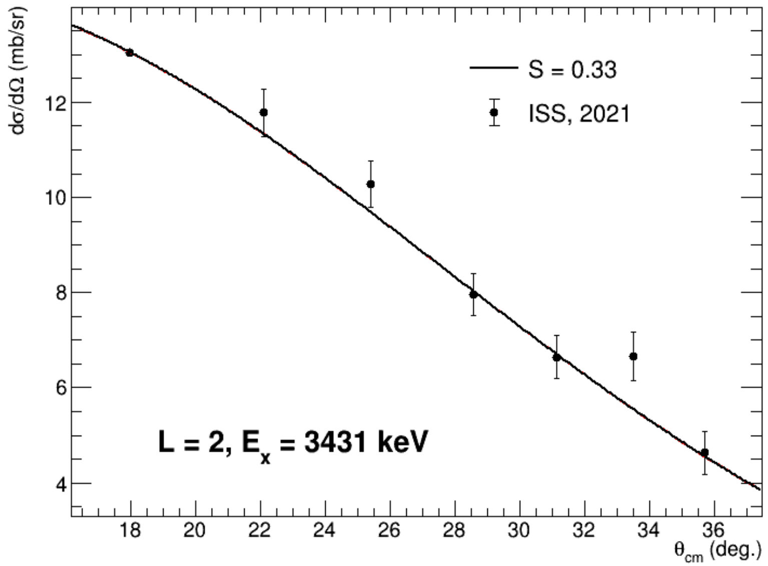


Extracted cross sections





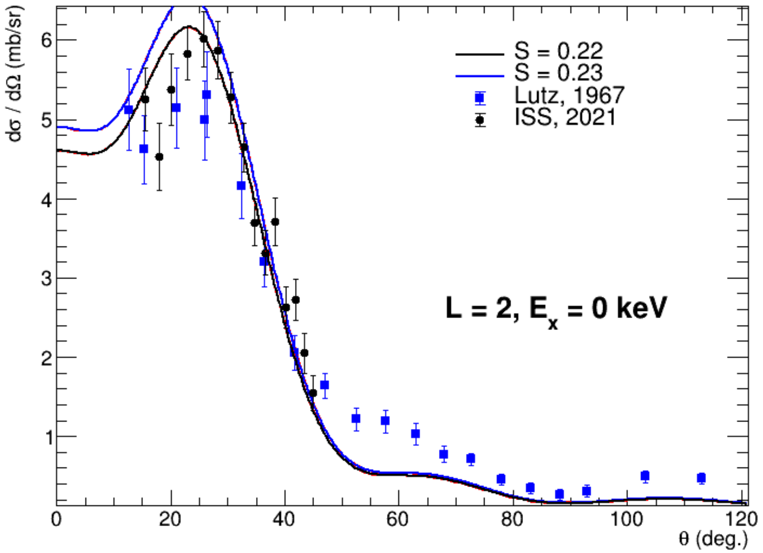


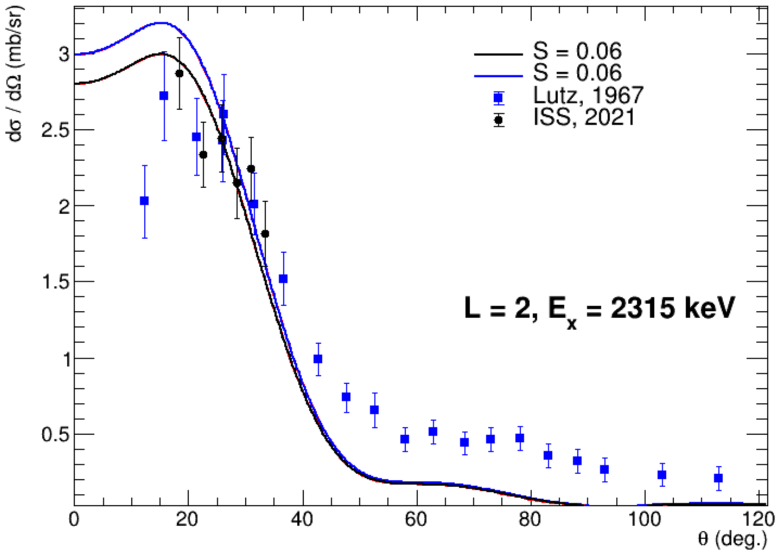


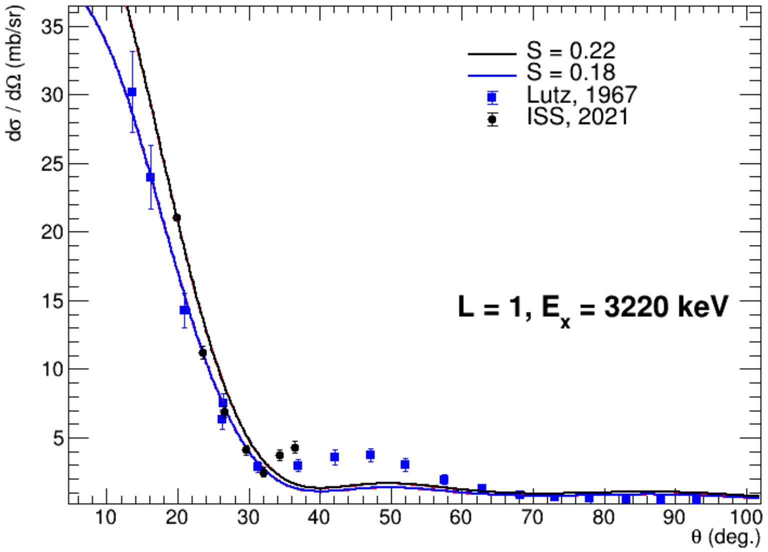
- Spectroscopic factors extracted from DWBA fit using the Ptolemy reaction code

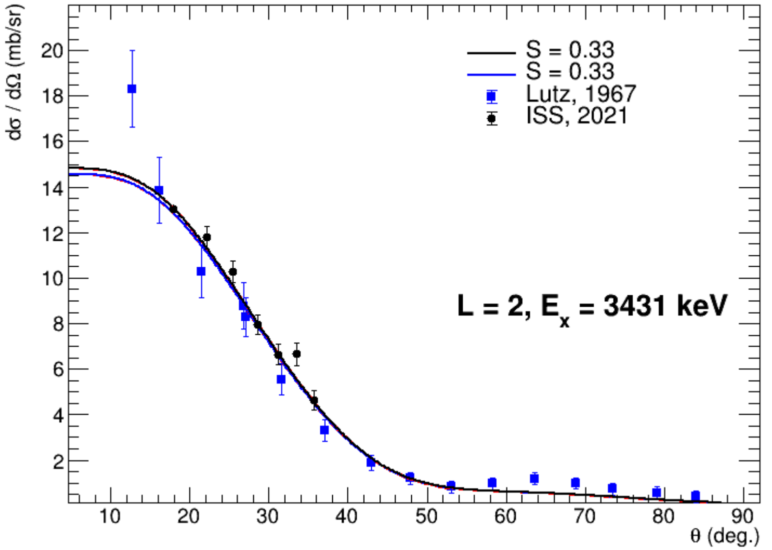
$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = S\left(\frac{d\sigma}{d\Omega}\right)_{DWBA}$$

Extracted cross sections









- Measured cross sections and spectroscopic factors are similar for the ISS experiment and the experiment performed in normal kinematics by Lutz et al.
- Provides confidence in measurements performed on exotic nuclei

Thanks for listening!

Summary and Outlook

- Proof of principle measurement provides confidence in cross sections measured with ISS
- Plans to measure ^{146}Ce(d,d') at ISS to probe octupole collectivity