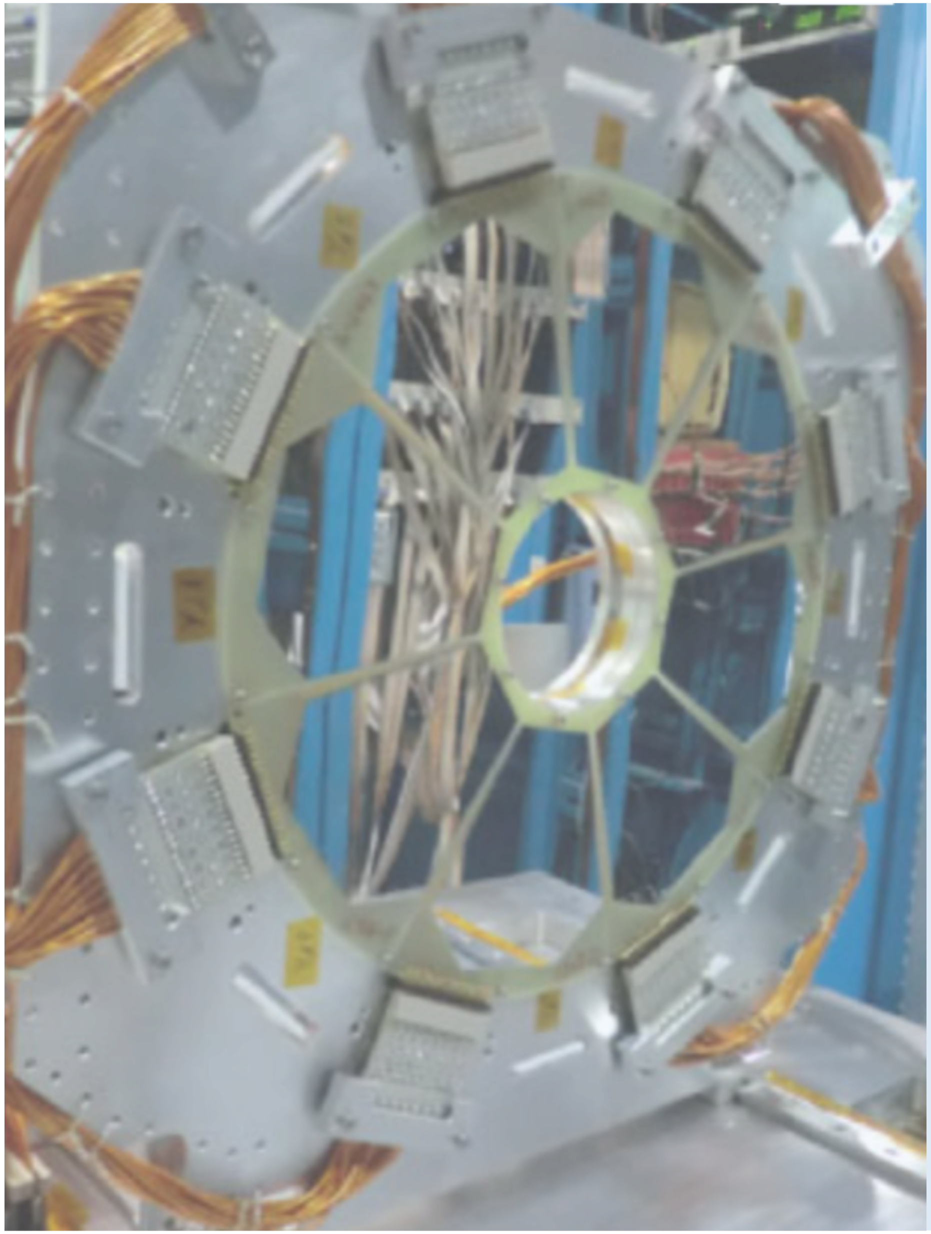


Investigation of N = 32 shell closure through ^{50}Ca(d,p)^{51}Ca

WNPPC 2025

Sora Ishida – Saint Mary's University

Supervisor: Dr. Rituparna Kanungo

Saint Mary's University SCIENCE

TRIUMF

Background

Shell closure and magic numbers.

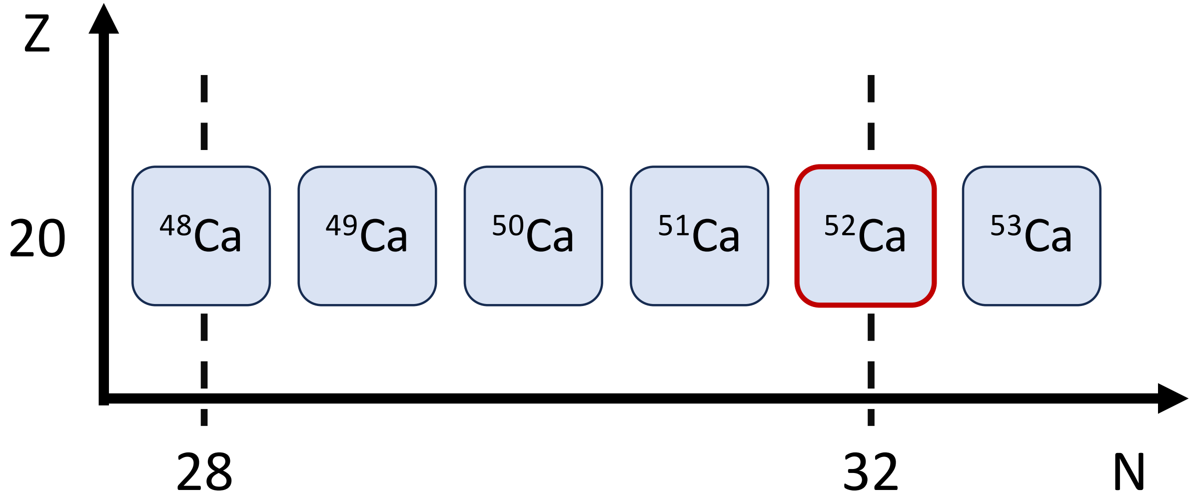
- Extra stability when a certain number of protons/ neutrons filling the shell levels: **2, 8, 20, 28, 50, 82, (126)**.

Neutron-rich nuclei

- Large N/Z ratio
- Short-lived
- Appearance/ disappearance of shell closure

Calcium isotope - ^{52}**Ca**

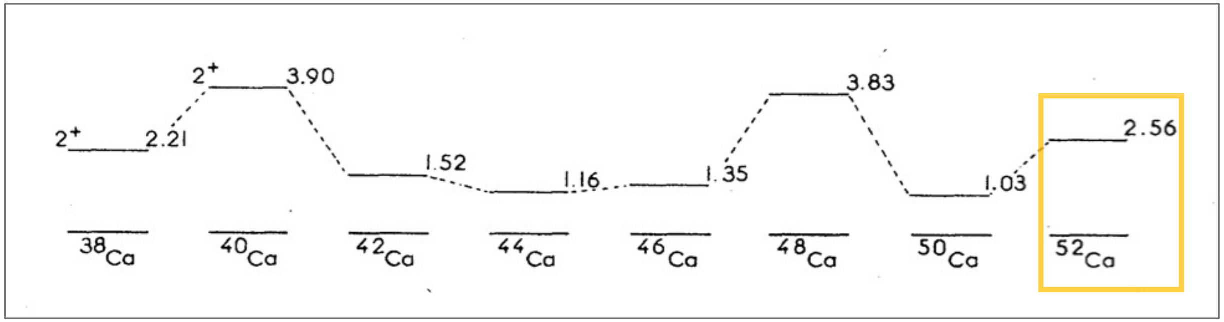
- Proton magic number, Z = 20.
- Potential new shell closure at **N = 32**.



Past experiments on ^{52}Ca

Signs of shell closure:

- **Increase** in excitation energy
- **Increase** in neutron separation energy
- **Local minima** in nuclear charge radii

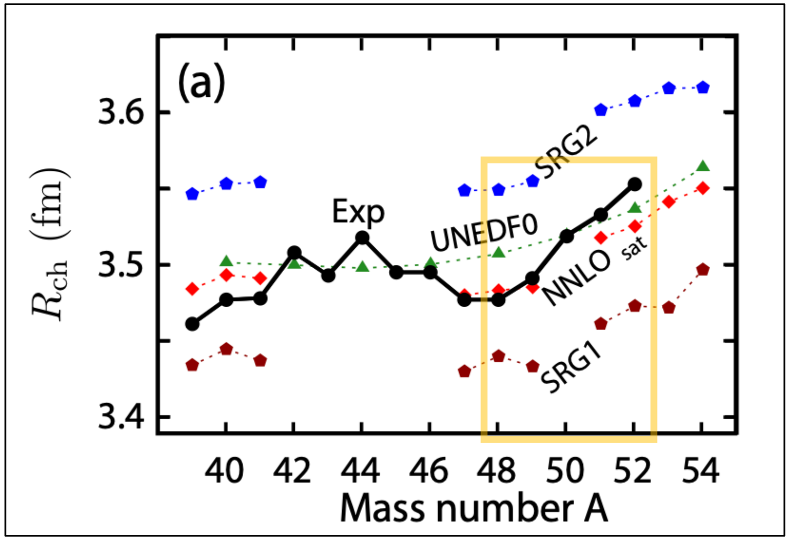


Huck et al. (1985)

Observation of N = 32 shell closure

Large charge radii of ^{52}Ca

- Unexpected rate of increase
- Cannot be reproduced by theoretical calculations.

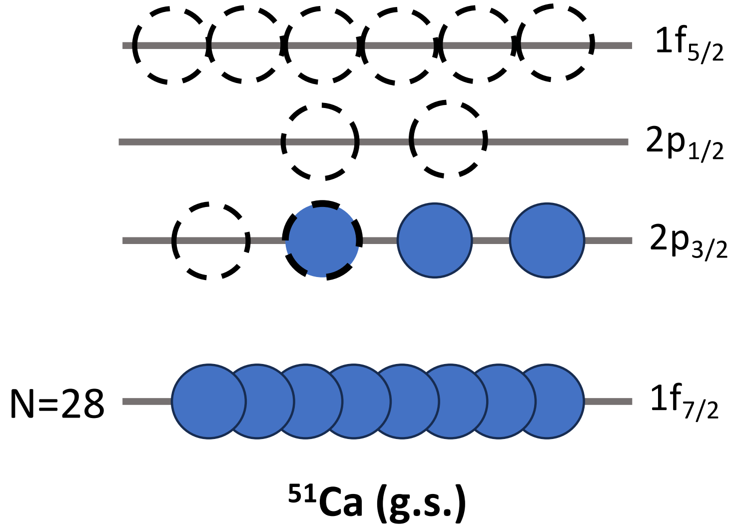


Ruiz et al. (2016)

Project summary

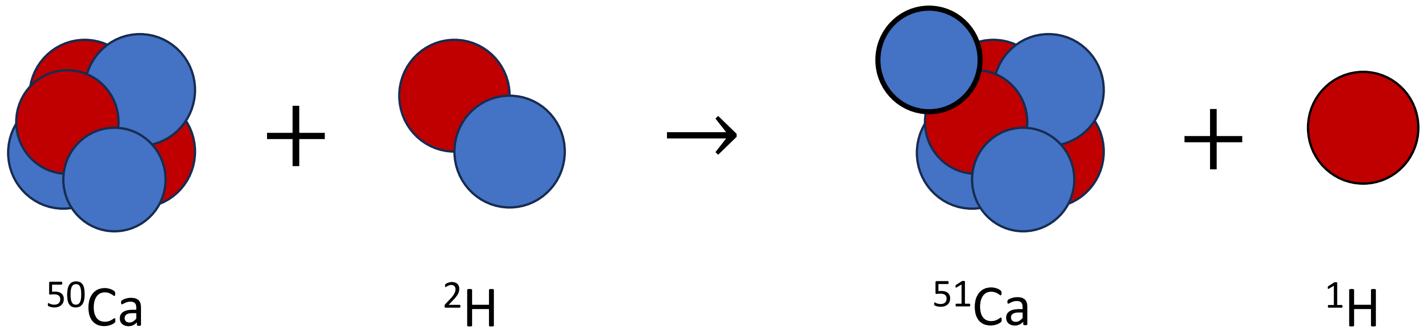
Investigation of the reaction **^{50}Ca(d,p)^{51}Ca**

- Population of ground and excited states.
- Neutron occupancy in **$2p_{3/2}$**, **$2p_{1/2}$**, or **$1f_{5/2}$** shell.



Excitation spectrum

- Detection of protons



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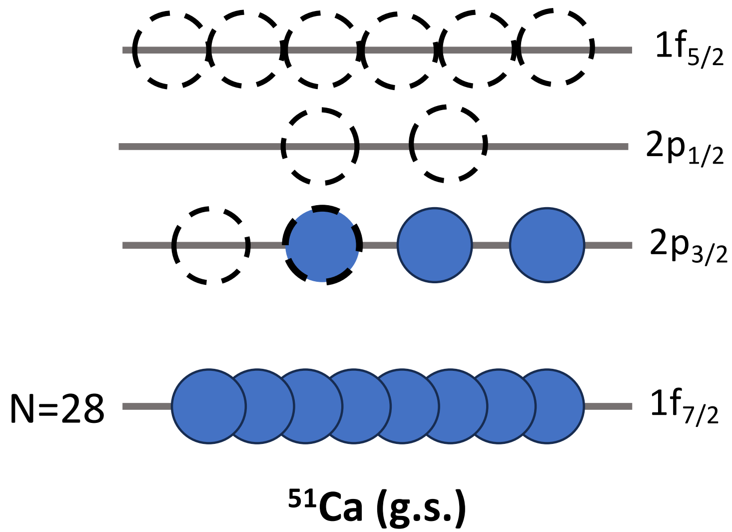

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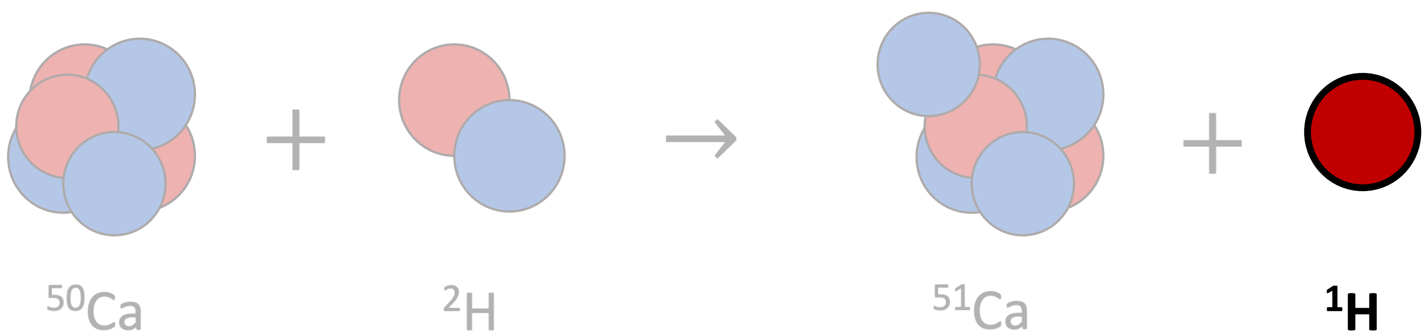
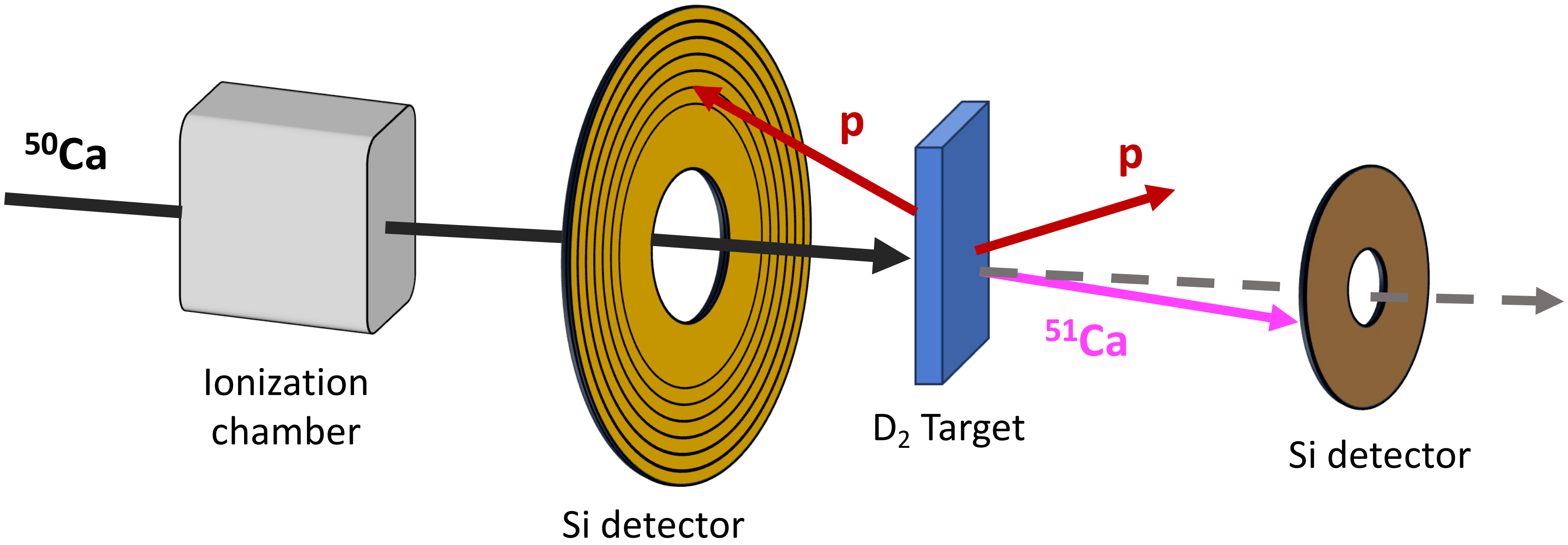
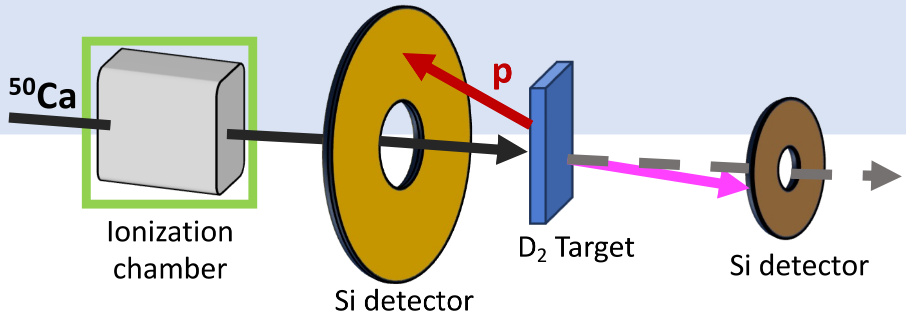


Experiment setup

IRIS facility at TRIUMF – particle accelerator centre (Vancouver, BC)



IC - Beam identification

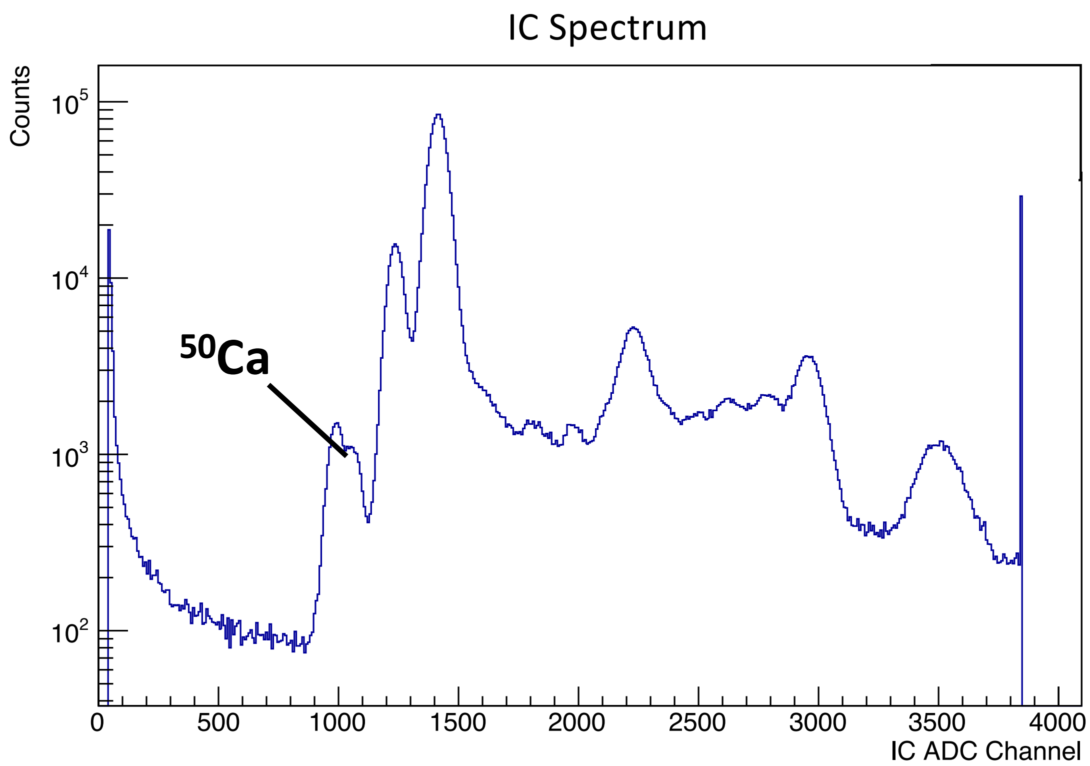


^{50}Ca beam

- Produced using Isotope mass Separation On-Line (ISOL) technique.
- Delivered at 7.2 AMeV (360 MeV)

Ionization chamber (IC)

- Isobutane gas
- Beam profile, counts
- $\frac{dE}{dx} \propto \frac{Z^2}{v^2}$



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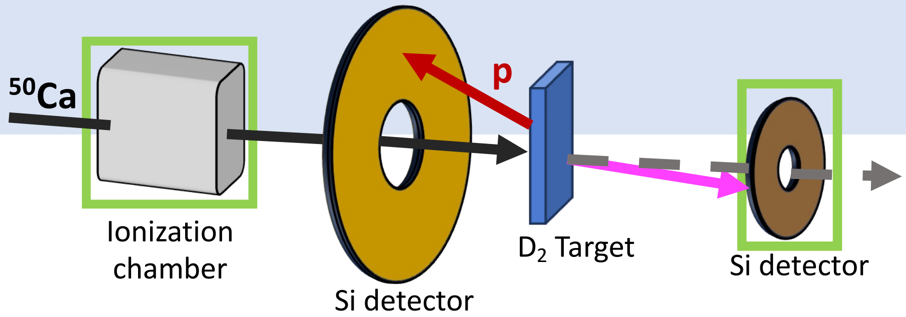
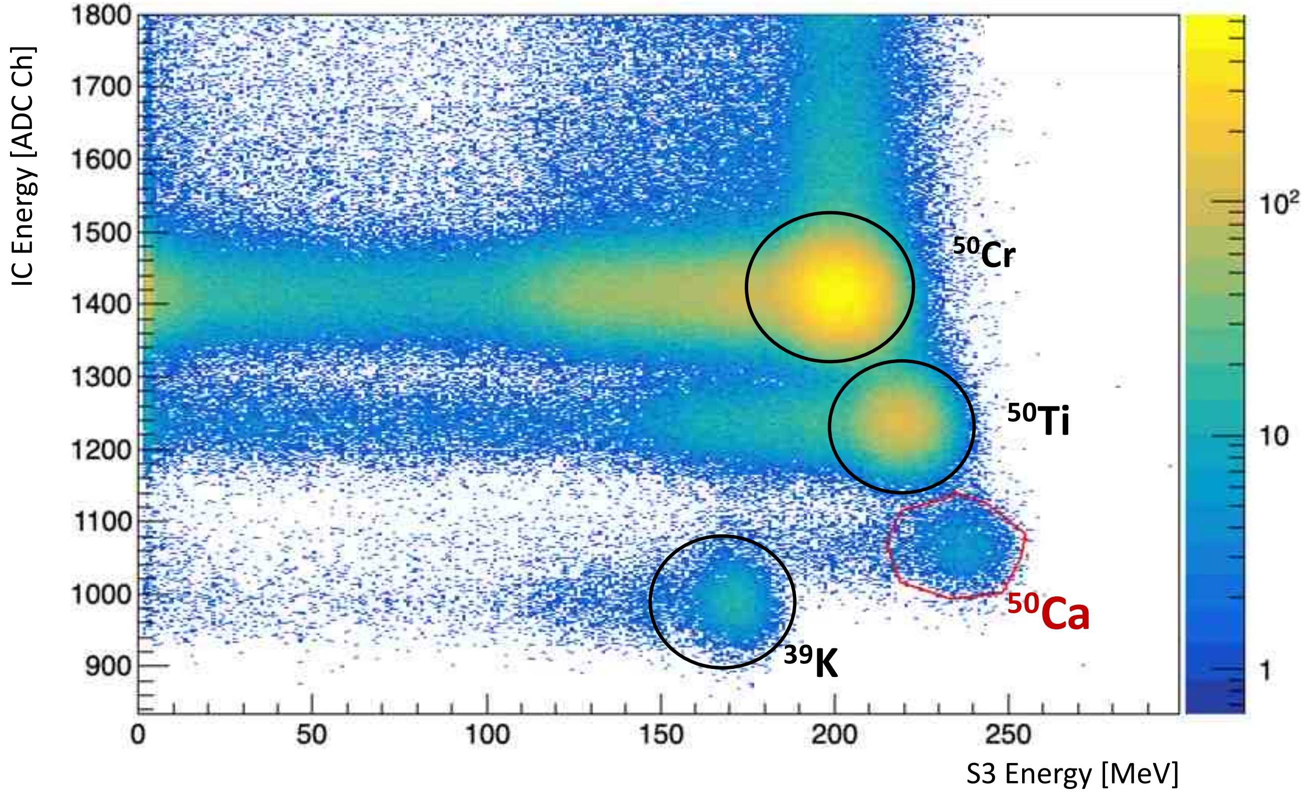
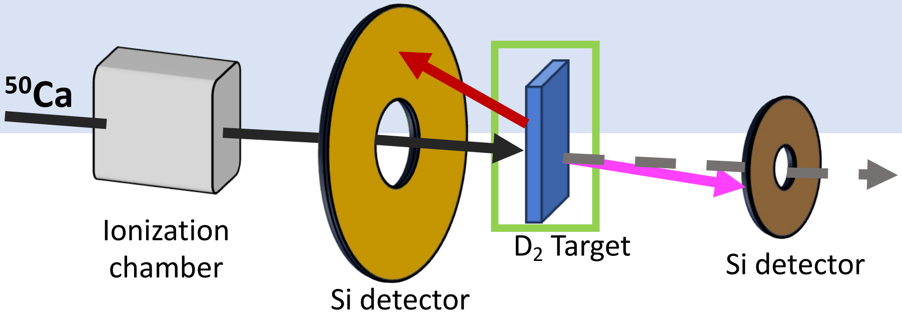


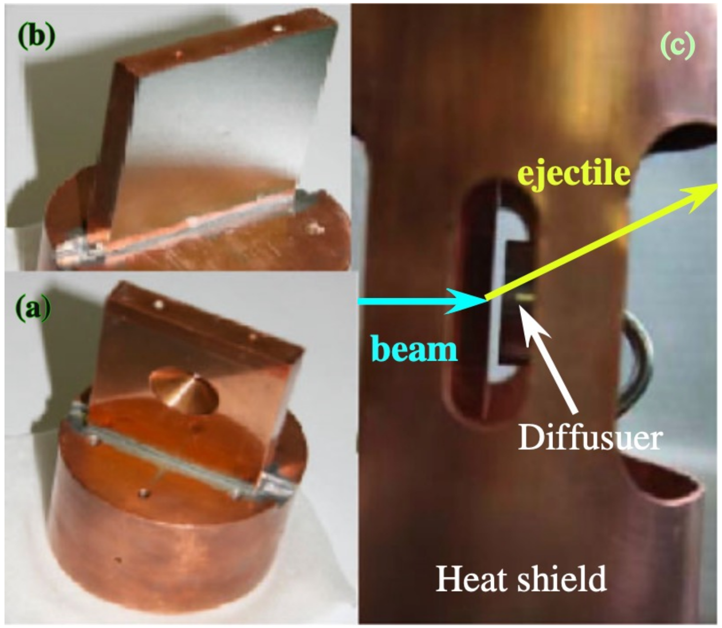
Energy deposit in **IC** vs **Si** detector



Solid deuterium target

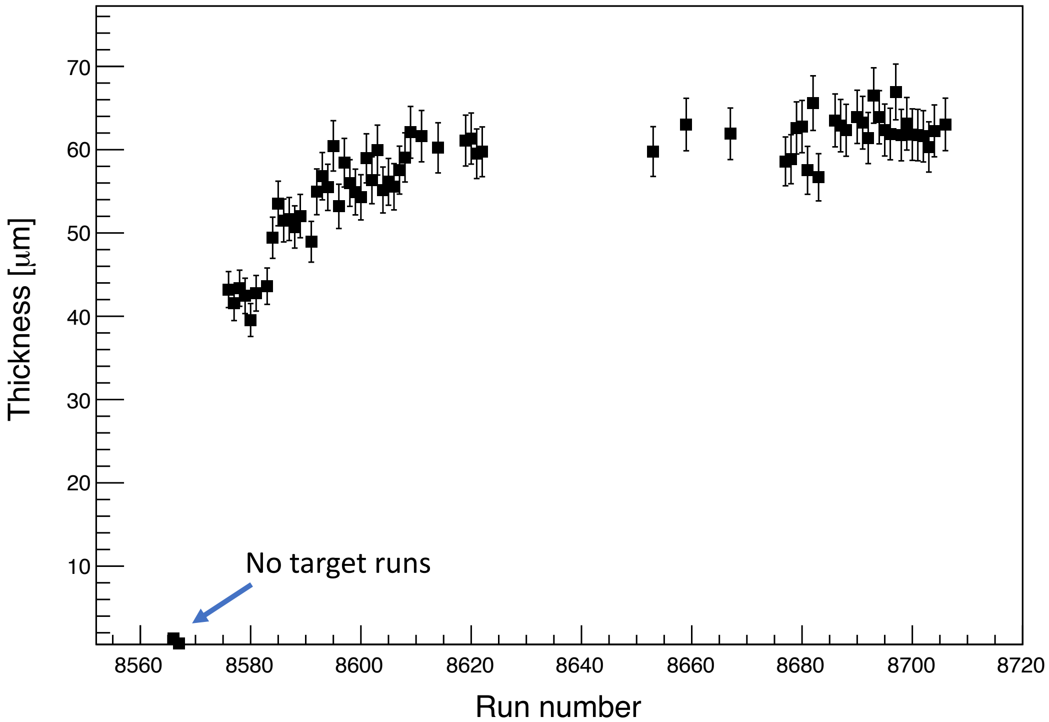


Thin windowless D_2 target
- **Higher density**, better statistics
- Less contaminants/ energy loss

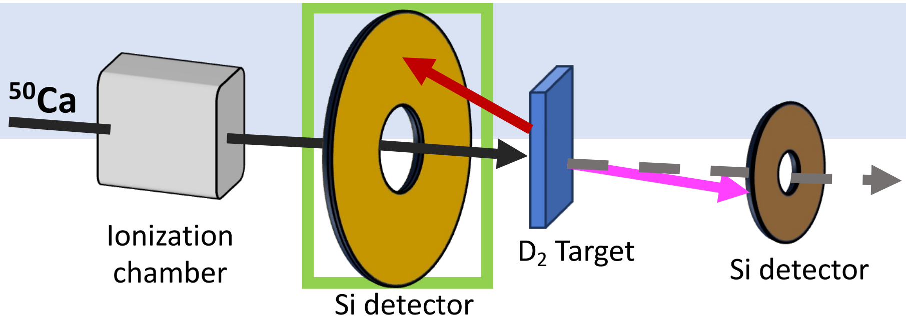


a) Target cell; b) Silver foil backing; c) Heat shield

D2 Target Thickness



Proton detection



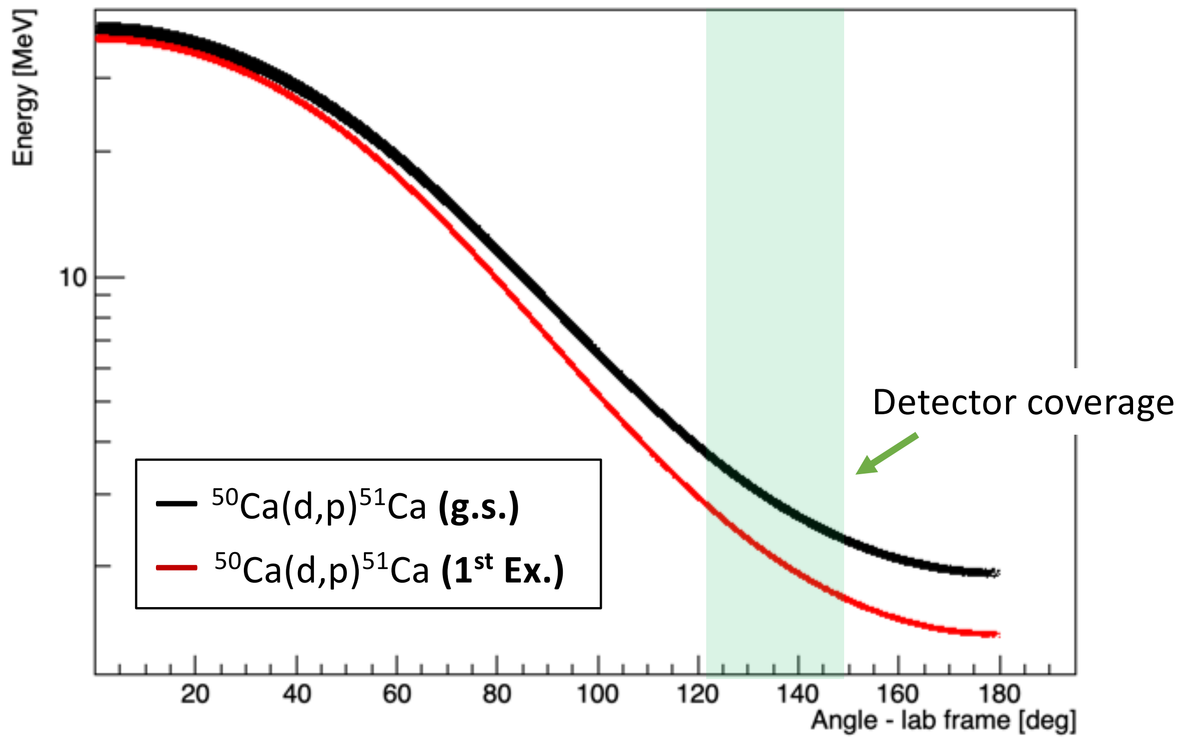
Protons in **upstream** of target

- High reaction cross section
- Distinguishable energy for different states

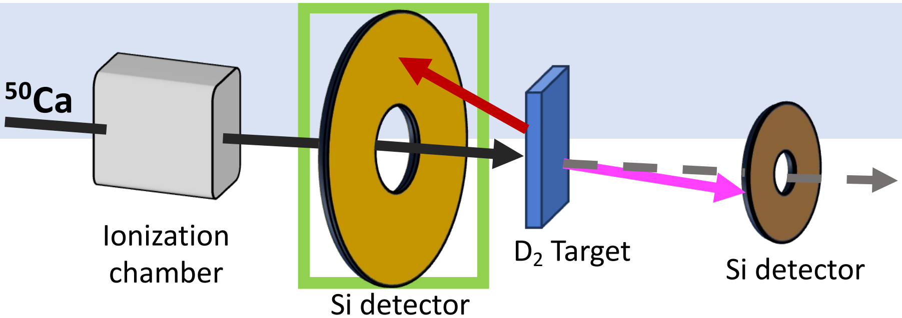
Upstream detector

- **Annular silicon detector** array
- Wide angle coverage
- Light particles

Simulated kinematic plot : proton

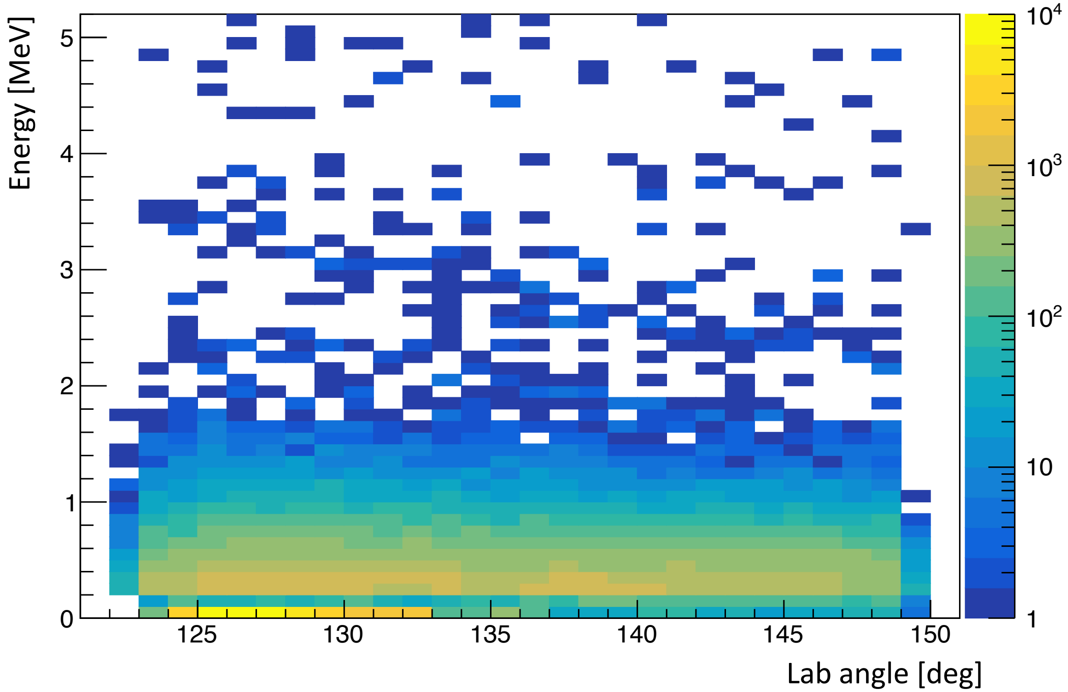


Proton detection

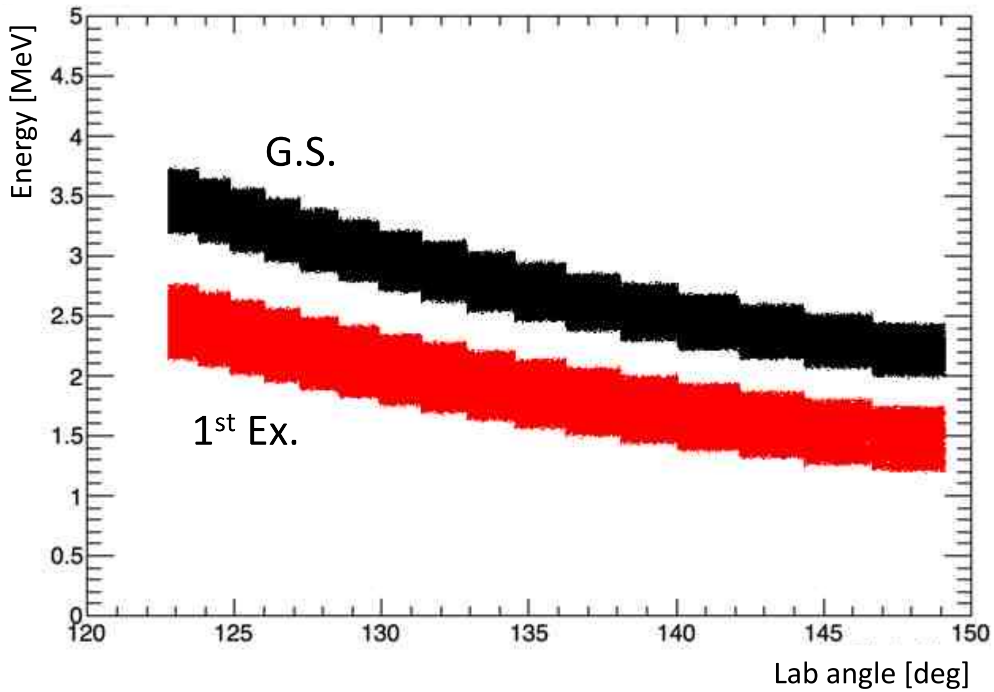


Energy deposit in upstream detector:

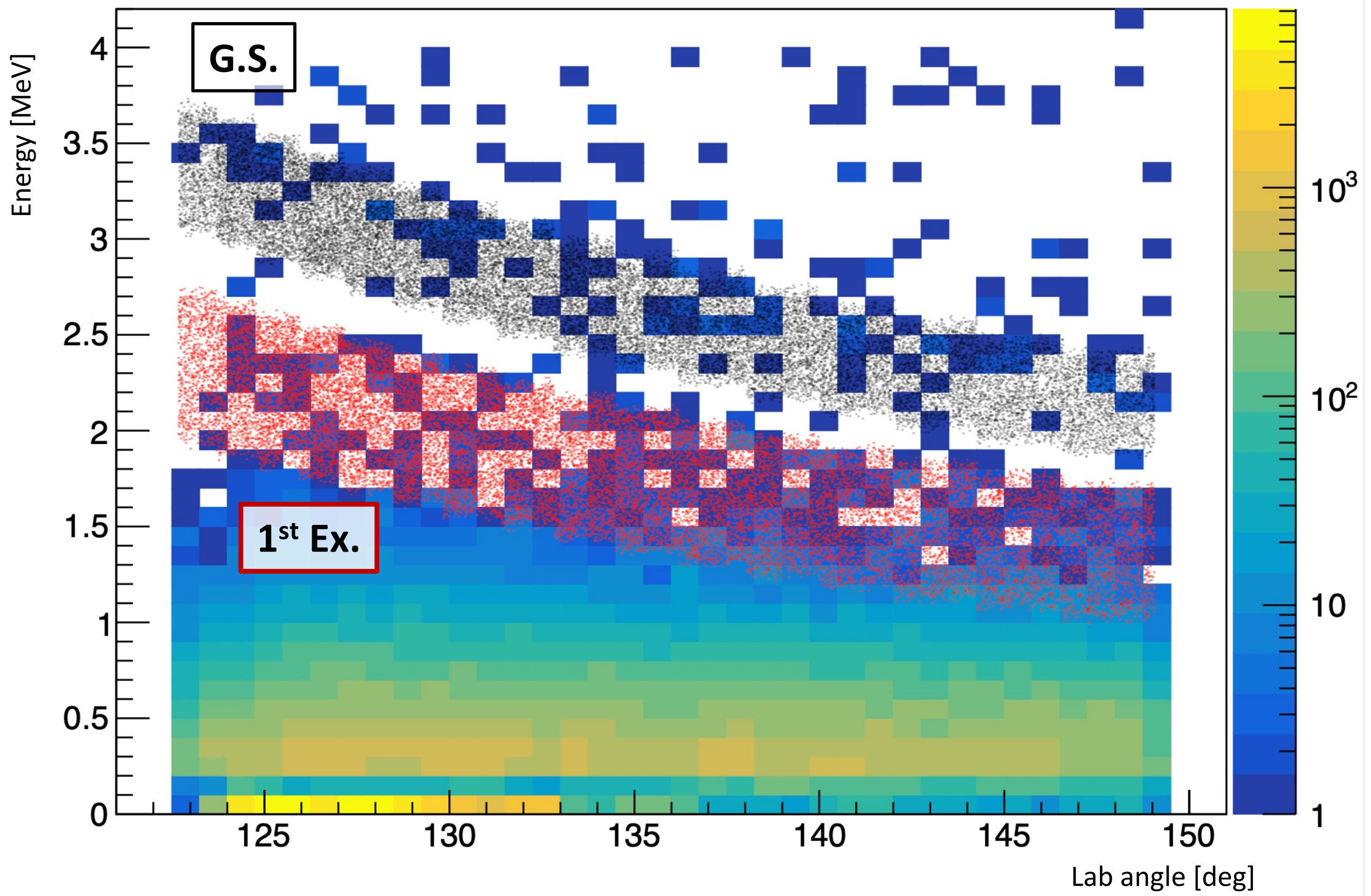
Data



Simulation



Proton detection



Identification of ground / excited state

Missing mass technique - $^{50}Ca(d,p)^{51}Ca$

$$Q = m_{50Ca} + m_d - m_p - \boxed{m_{51Ca}}$$

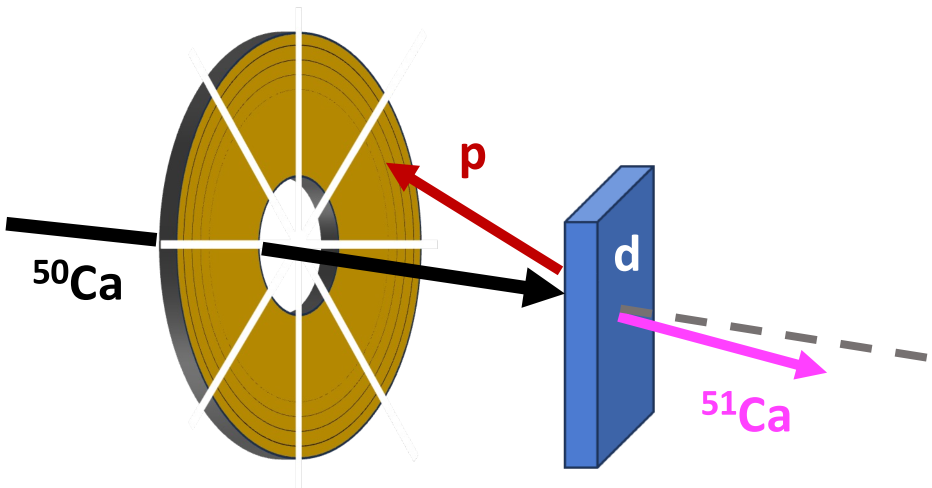
$$\boldsymbol{m_{51Ca}} = \sqrt{\begin{matrix} m_{50\mathrm{Ca}}^2 + m_\mathrm{p}^2 - m_\mathrm{d}^2 + 2(E_{50\mathrm{Ca}} + m_{50\mathrm{Ca}}) \\ -2(E_{50\mathrm{Ca}} + m_{50\mathrm{Ca}} + m_\mathrm{d})(E_\mathrm{p} + m_\mathrm{p}) + 2P_{50\mathrm{Ca}}P_\mathrm{p}\cos(\theta_\mathrm{p}) \end{matrix}}$$

Q: energy released or absorbed

E_A: **kinetic energy** of particle A

P_A: relativistic **momentum** of A

θ_p: **scattering angle** of proton



Excitation spectrum

$E_{ex} = Q_{g.s.} - Q$

1st excited state peak around **1.5 MeV**

Identification of ground / excited state

Missing mass technique - $^{50}Ca(d,p)^{51}Ca$

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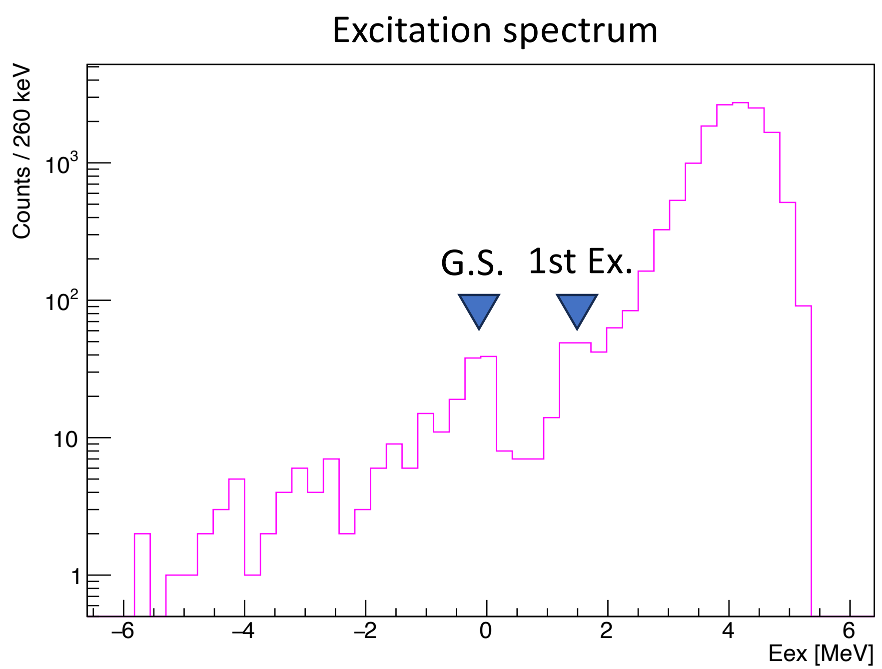
Excitation spectrum



Excitation spectrum

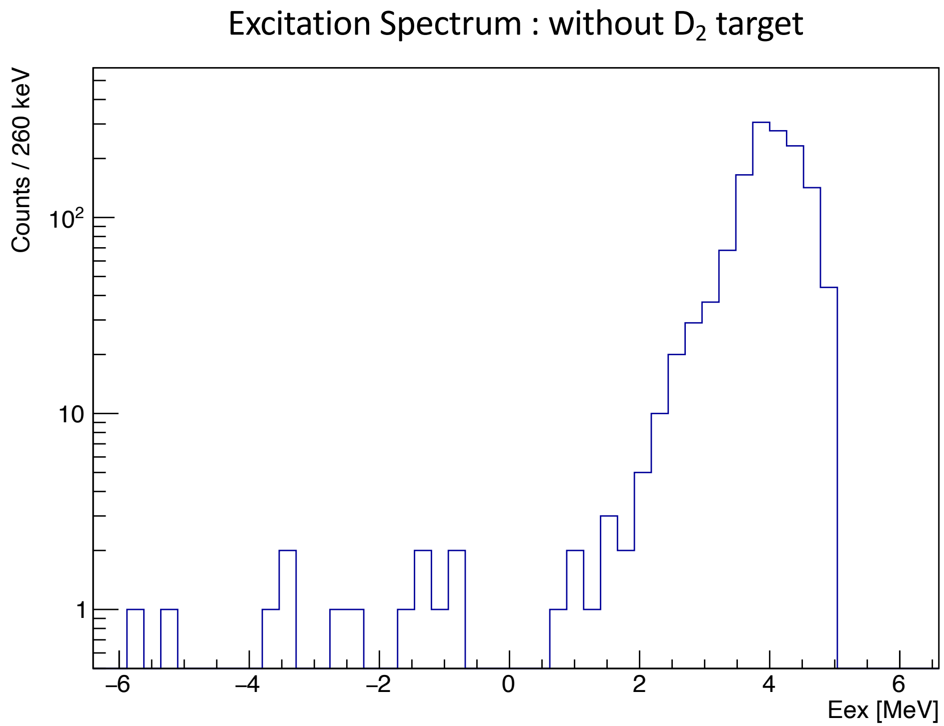
$\mathbf{E_{ex}} = Q_{g.s.} - Q$

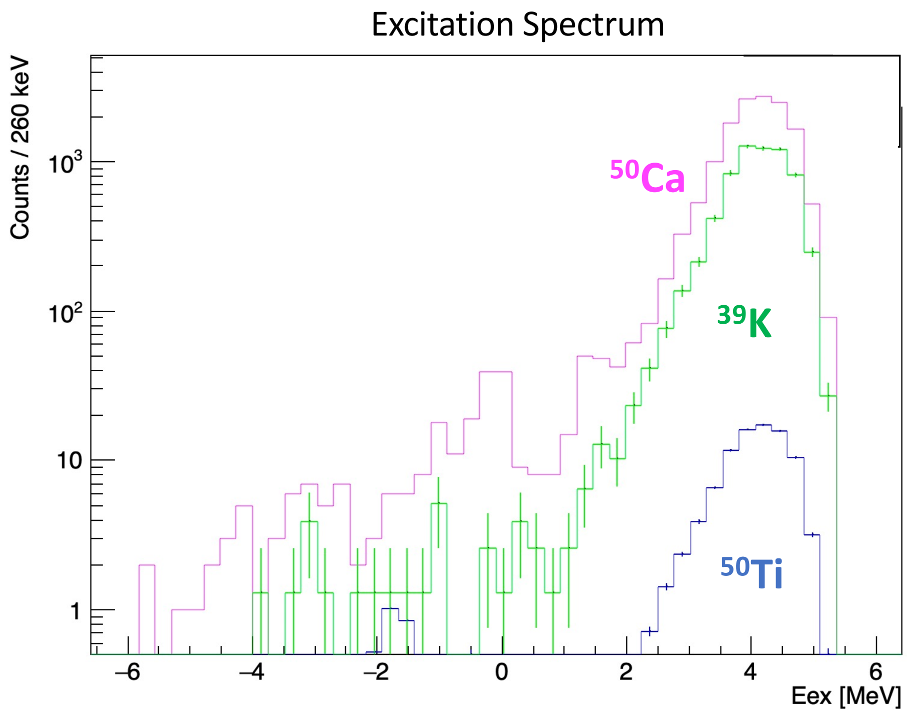
1^{st} excited state peak around **1.5 MeV**

Identification of ground / excited state

Excitation spectrum

- Signal from **Ag foil backing**
- Contribution from **beam contaminants**





Summary and Future Outlook

- Spectroscopic study of ^{51}Ca via **^{50}Ca(d,p)^{51}Ca** reaction in IRIS facility at TRIUMF.

- Detecting protons from the reaction and investigate the energy of the populated states in ^{51}Ca.

- Clear observation of **ground state** and **1st excited state** (∼1.5 MeV).

- Resolving contributions from background reaction and beam contaminants.

- Differential cross section of the reaction, provide insights on N=32 shell closure.

Acknowledgement

Dr. Rituparna Kanungo - Supervisor

Dr. Greg Christian - Supervisory committee member

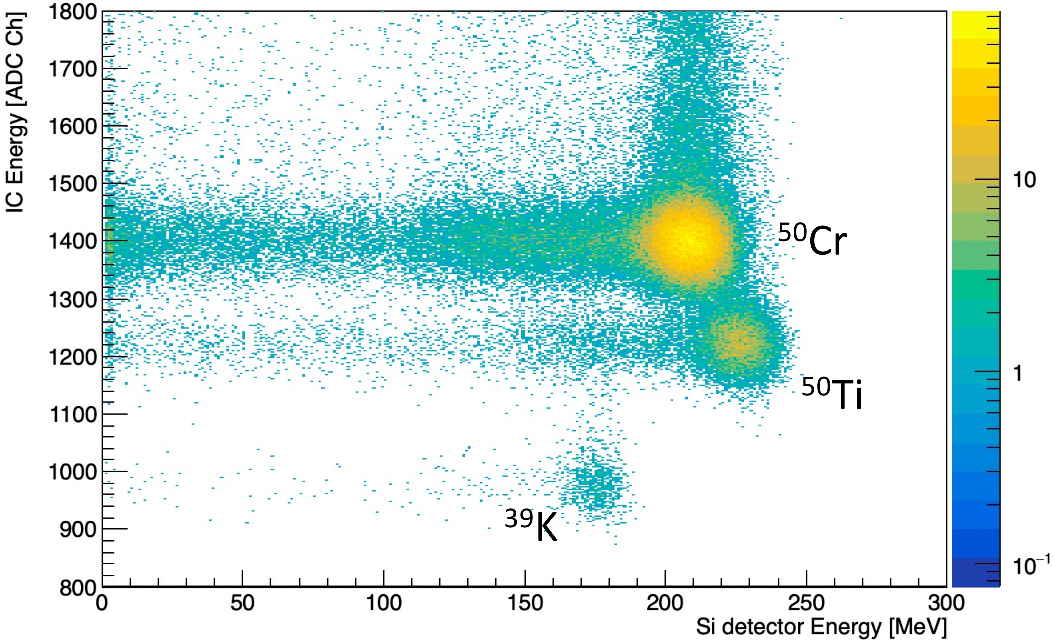
Dr. Ian Short - Supervisory committee member

Collaborators:

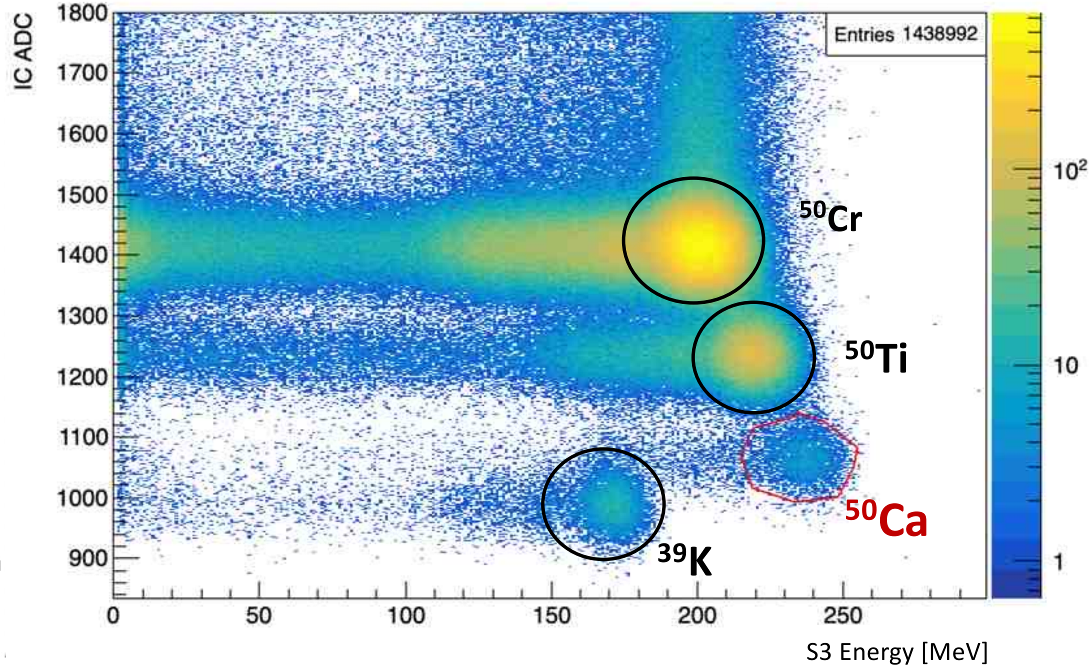
M. Alcorta, C. Andreoiu, C. Angus, S. Bagchi, N. Bhati, S.S. Bhattacharjee, S. Buck, K. Butler, M. Cavenaile, G. Christian, R. Coleman, G. Desmarais, E.G. Fuakye, P.E. Garrett, G. Grinyer, G. Hackman, K. Kapoor, J. Liang, C. O'Keefe, J. Park, T. Psaltis, M. Rocchini, N. Saei, D. Shah, M. Singh, P. Spagnoletti, M. Talebitaher, S. Upadhyayula, and F. Wu

IC – Beam Identification

Without RIB (^{50}Ca) beam

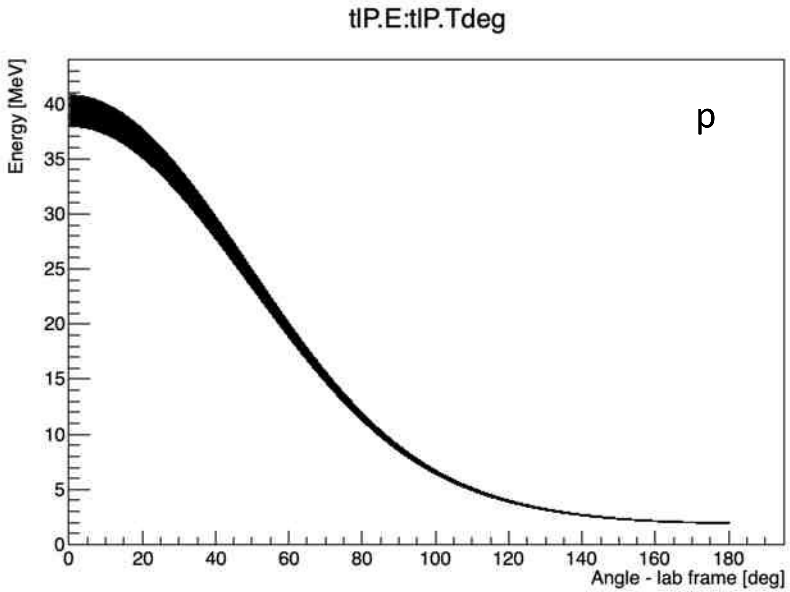


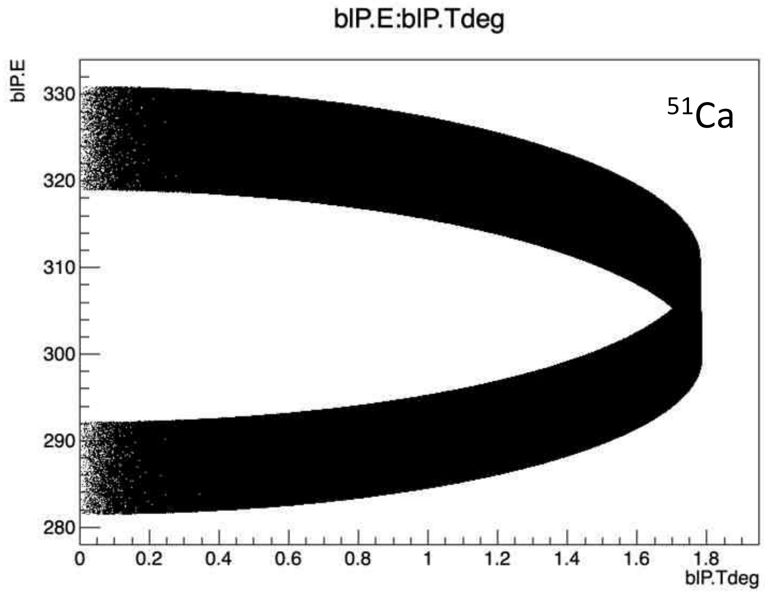
With RIB (^{50}Ca) beam



Simulation - Kinematics

- Detection of **p** and **^{51}Ca**:
  - Yu angle coverage: 122.73 deg – 149.09 deg
  - S3d1 angle coverage: 2.65 deg – 8.38 deg





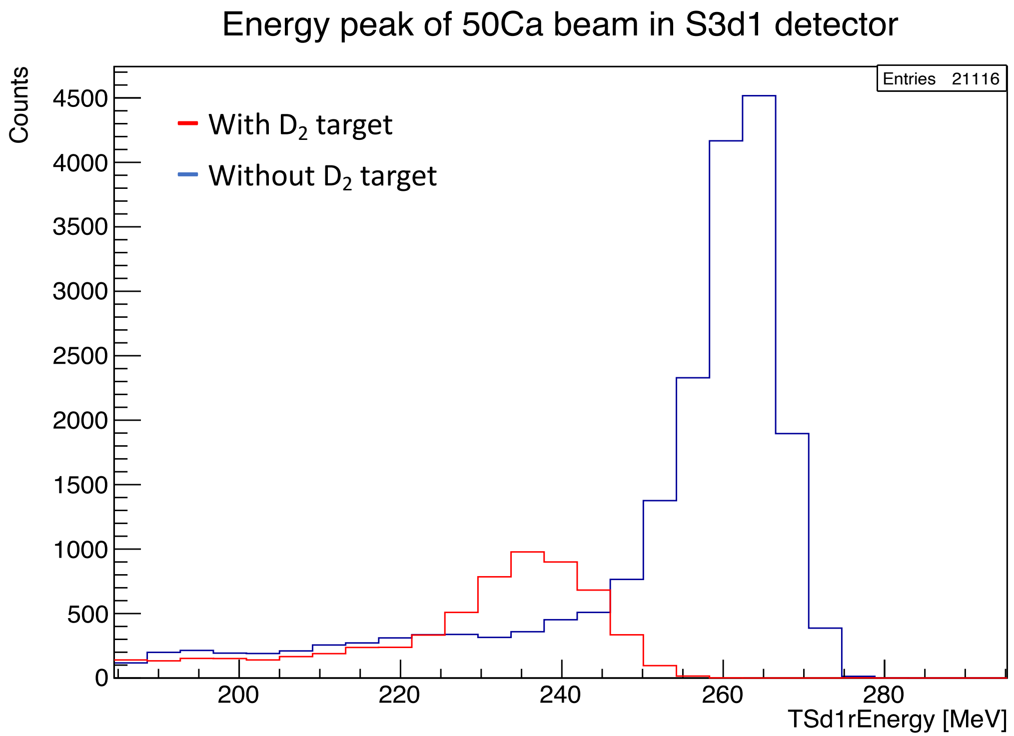
Target Thickness

Energy difference between "with-" and "without-target" runs.

$$t = \int_{E0}^{E1} \frac{1}{S(E)} dE$$

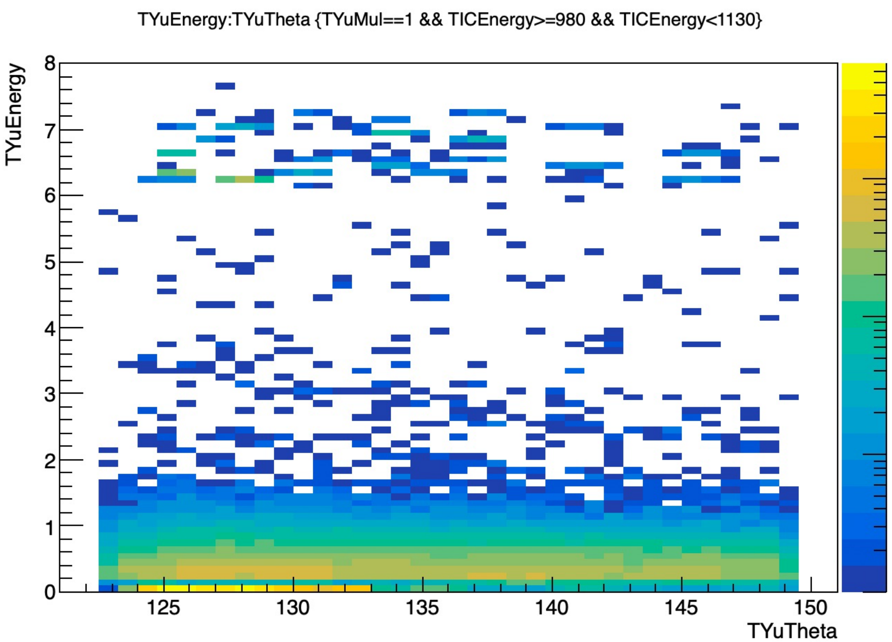
t: thickness

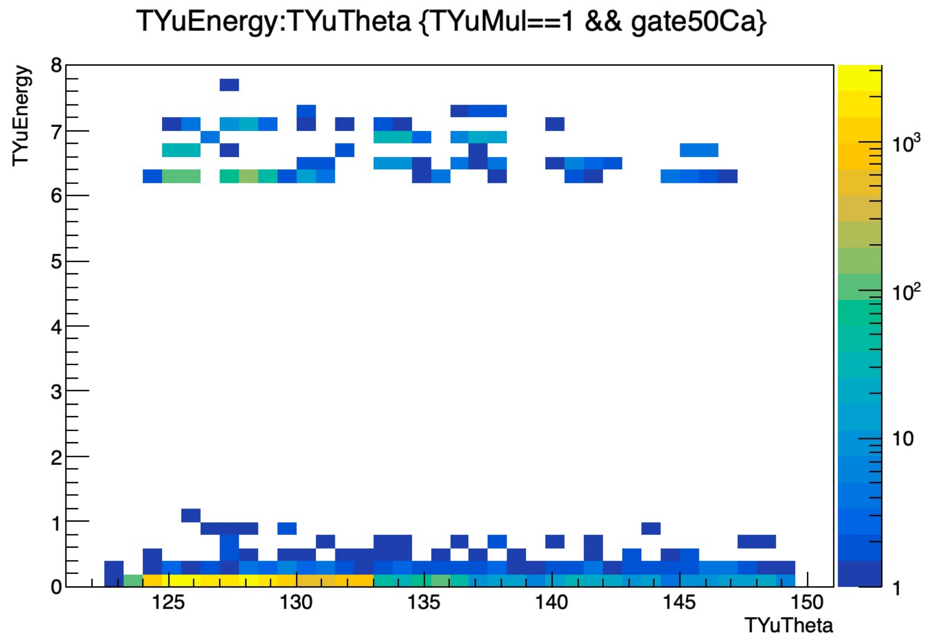
S(E): stopping power (-dE/dx)



Gate on ^{50}Ca peak

- Gating on the ^{50}Ca peak observed in the IC energy vs Si energy plot
  - Not enough statistics
  - Lose the data in the energy range of interest

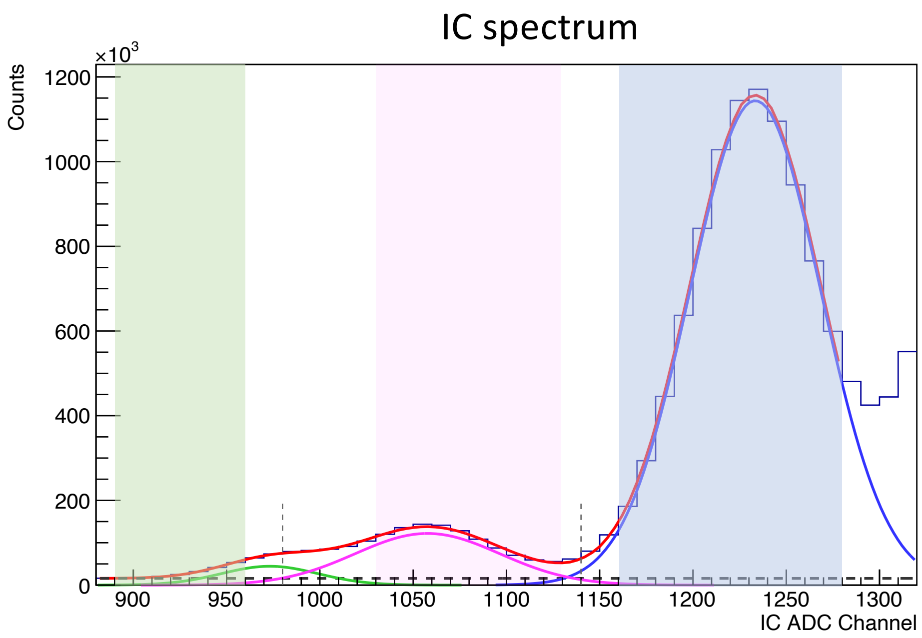


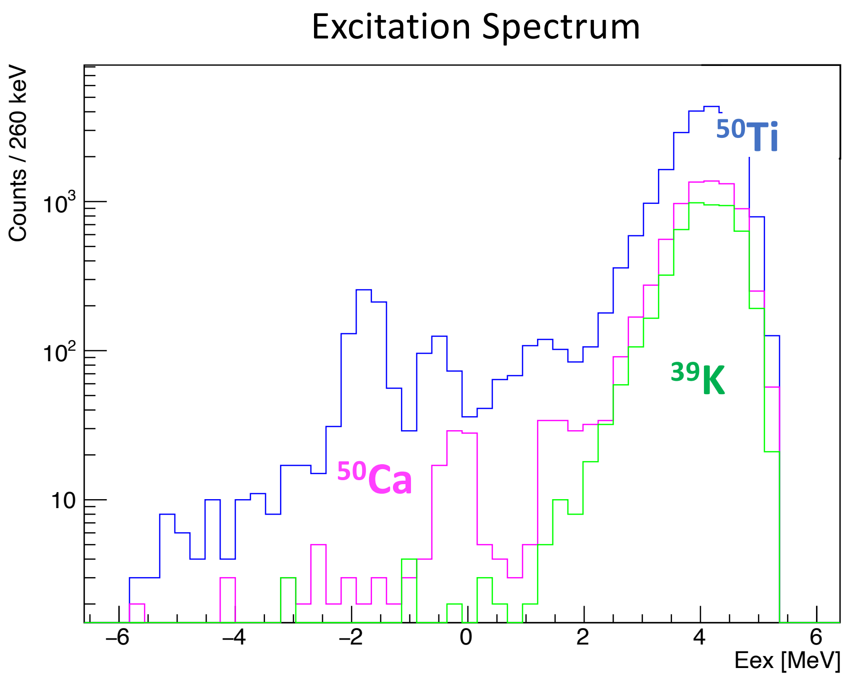


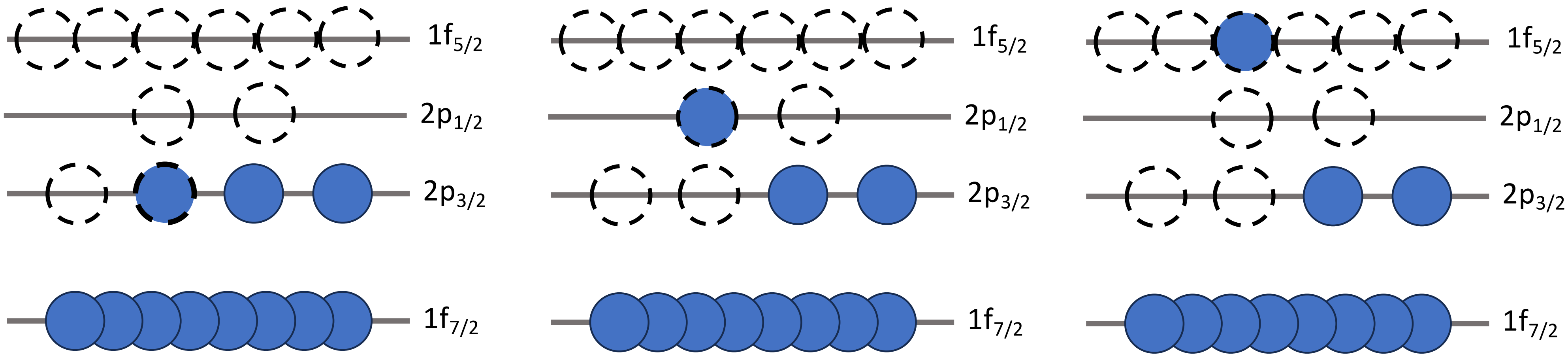
Identification of ground / excited state

Excitation spectrum

- Contribution from beam contaminants







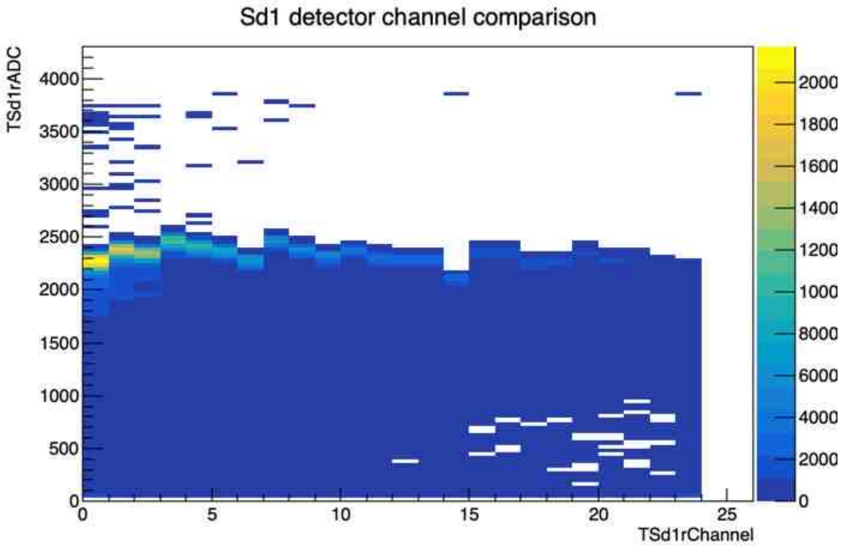
$^{51}Ca_{3/2-}$ (g.s.) **$^{51}Ca_{1/2-}$ (1.72 MeV)** **$^{51}Ca_{5/2-}$ (3.47 MeV)**

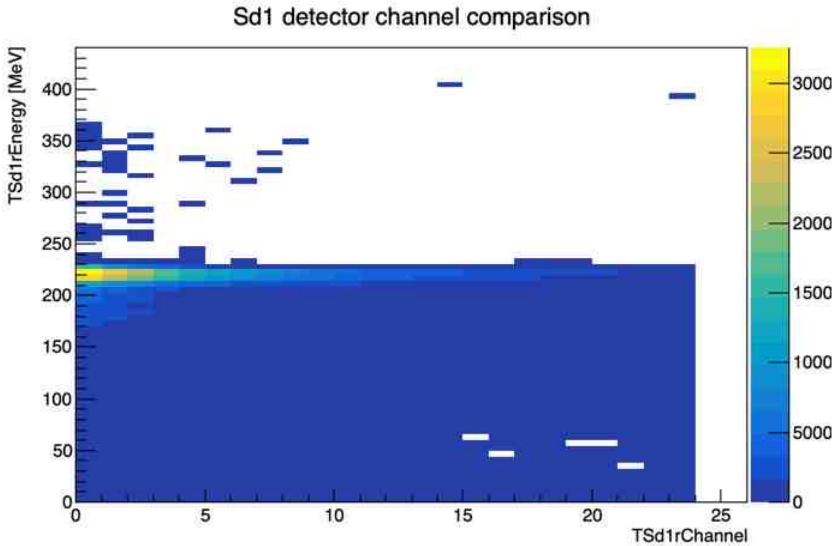
Detector Calibration

- Alpha source and ^{40}Ar stable beam
- Convert ADC channel to energy value (MeV)

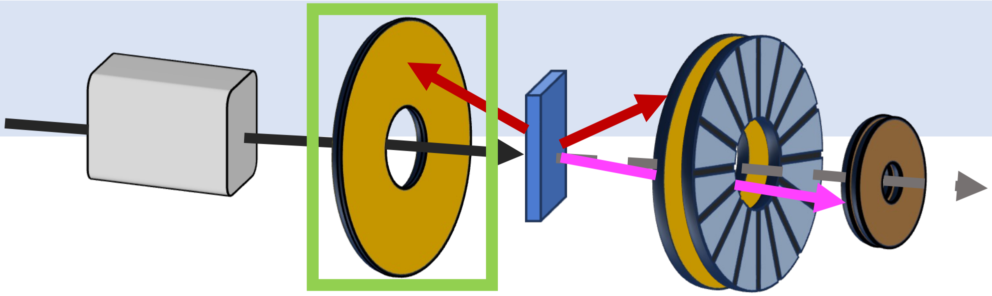
$$E = g(c - p)$$

  - Determine gain value g for each channel of the detector





Proton detection

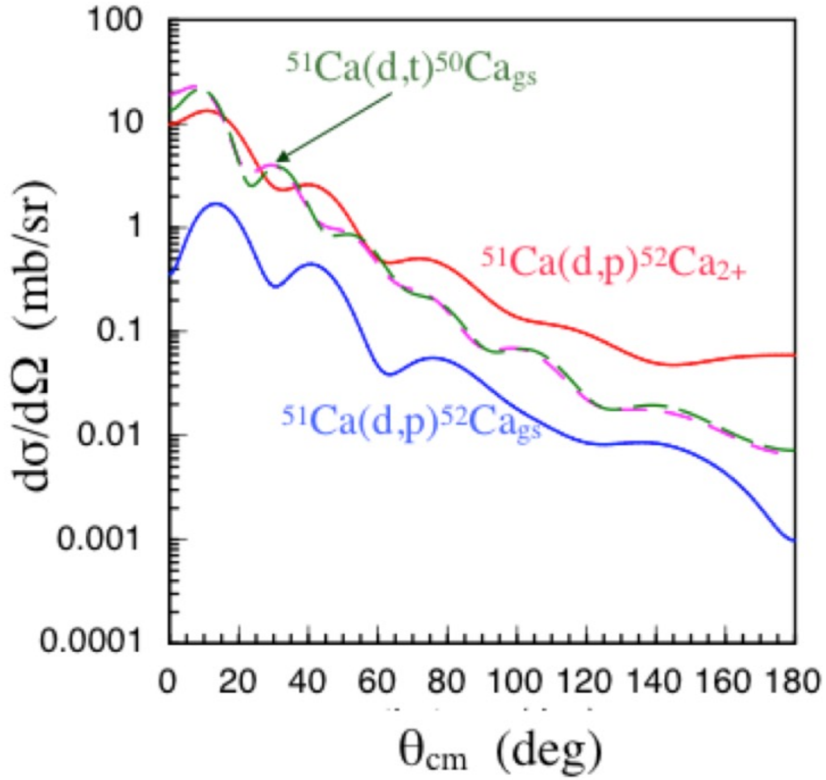


Protons in upstream

- Higher reaction cross section.

Upstream Si detector covrage:

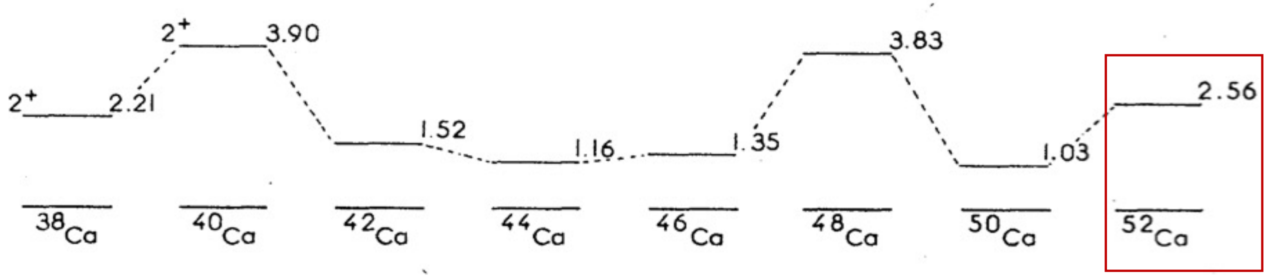
- $\theta_{\mathrm{lab}} = 122° - 149°$
- $\theta_{\mathrm{cm}} \sim 10° - 20°$



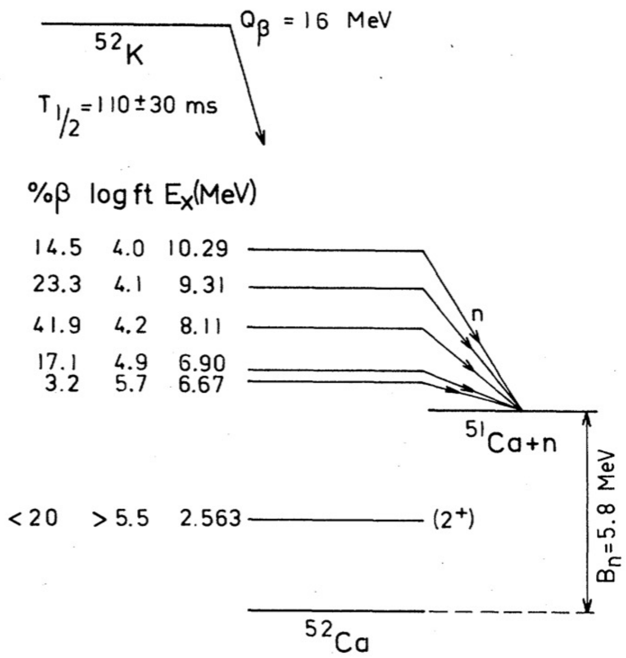
Energy of excited states

An increase in the energy of the first excited state (Huck et al., 1985).

- β-decay of ^{52}K
- Shell level scheme of ^{52}Ca
- Sign of shell closure at N = 32



Energy of first excited state of Ca isotope chain
Huck et al. (1985)



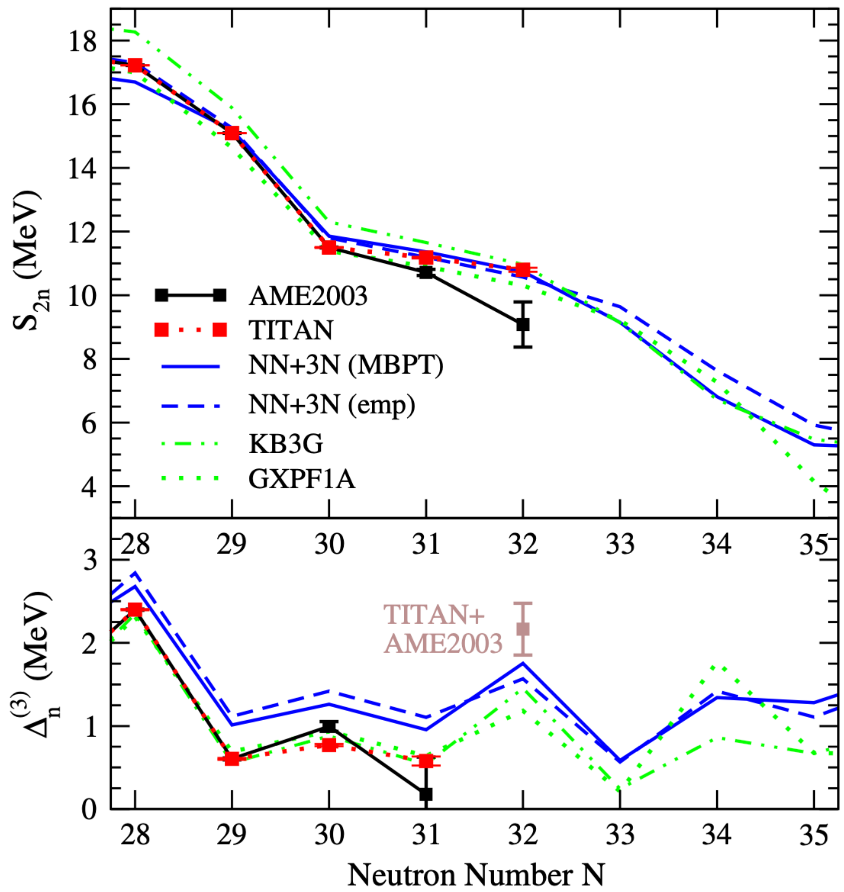
Level scheme of ^{52}Ca
Huck et al. (1985)

Neutron separation energy

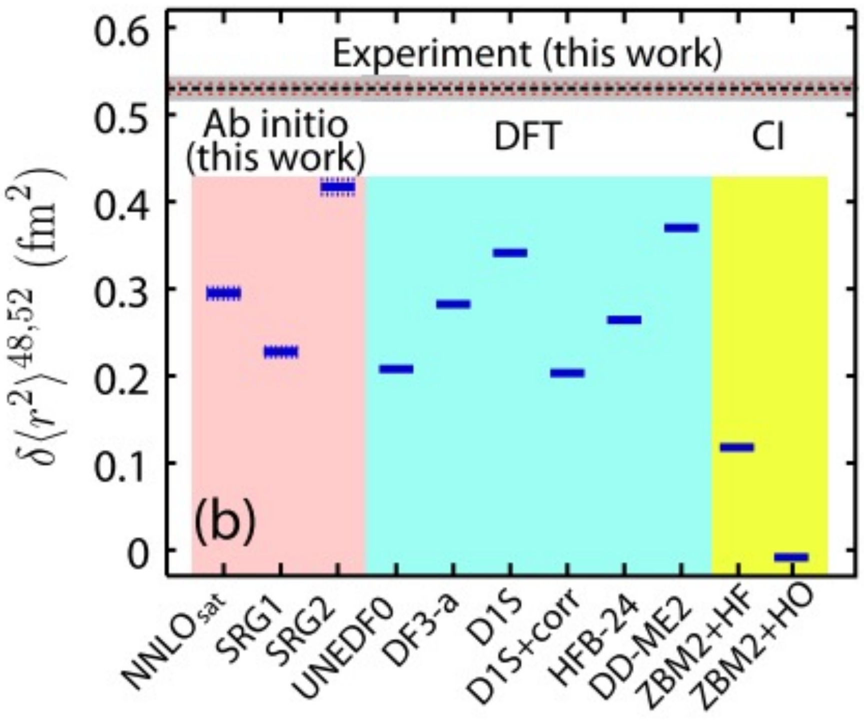
Direct mass measurement of **K** and **Ca** isotopes (Gallant et al., 2012):

- More precise and accurate mass measurement
- Measurement of neutron separation energy (S_{2n})

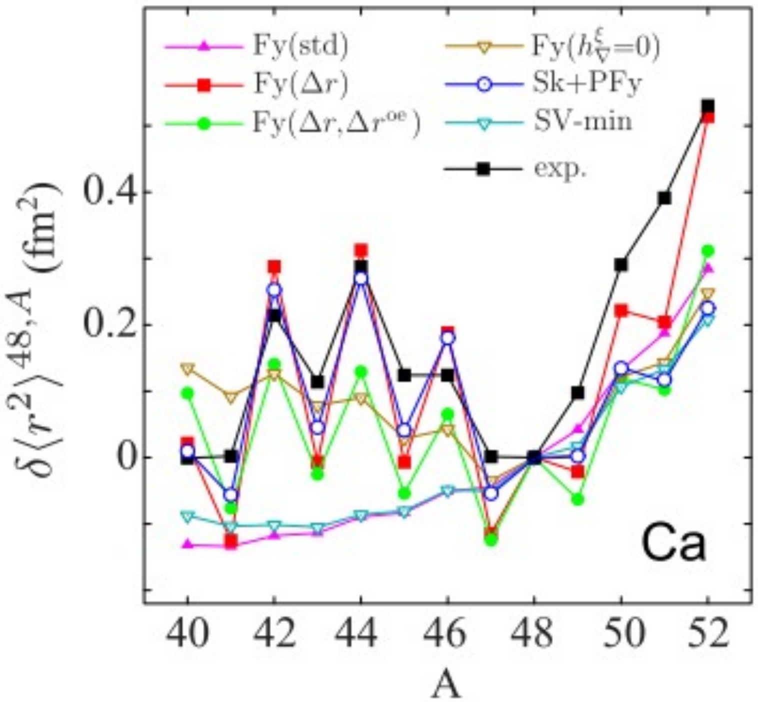
- ^{52}Ca more bound by **1.74 MeV** than existing dataset.
- In agreement with the modern theoretical calculations



Charge radii of ^{52}Ca



Ruiz et al. (2016)



Reinhard et al. (2017)

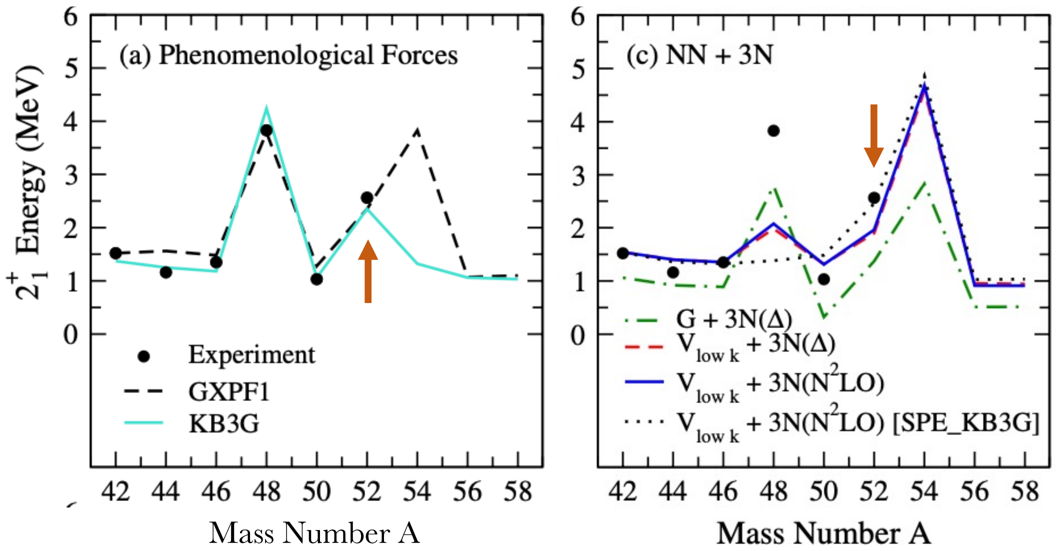
Theoretical aspect

Development of shell model/ interactions:

- Prediction of shell configuration in unstable nuclei.
- More realistic, reaching to non-observable properties.

Signs of shell closure at N = 32.

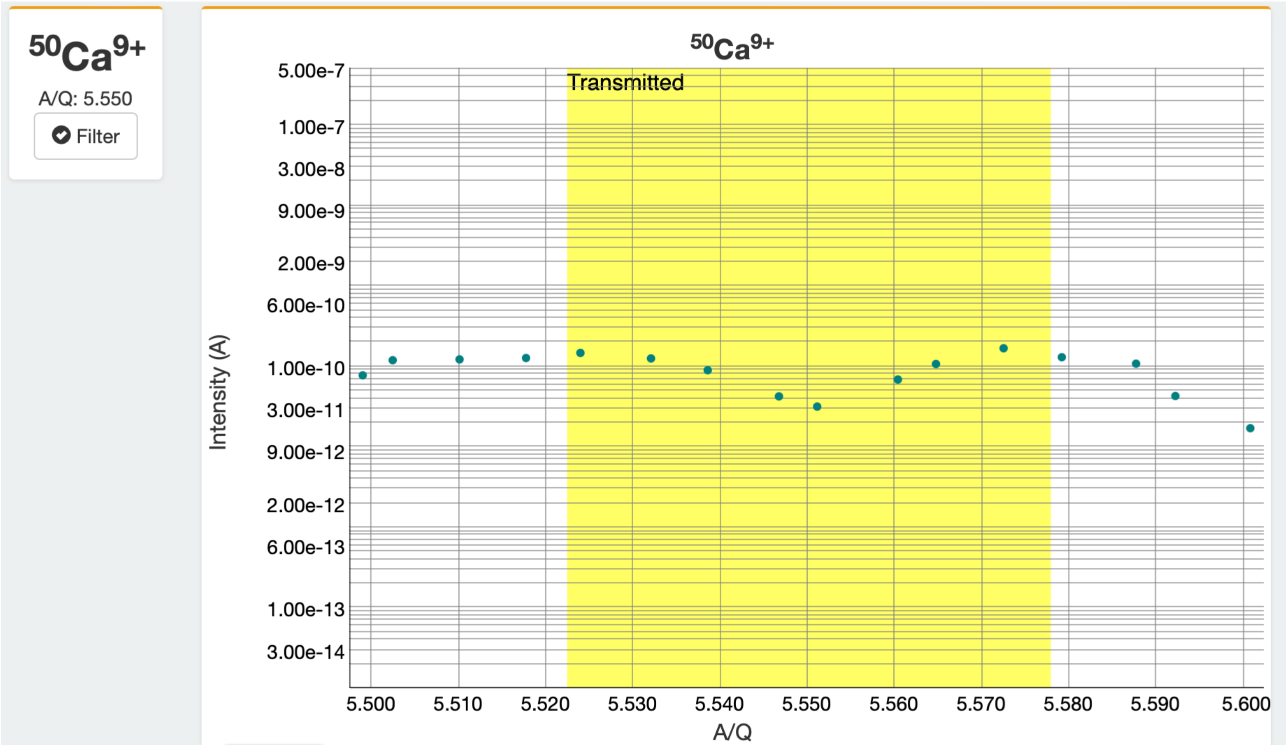
Discrepancy between experiment data and models.



Holt et al. (2012)

Radioactive ion beam – ^{50}Ca

- Beam contaminants share a similar A/Q



CSB Known Stable Contaminants

Species	A/Q
$^{50}Ti^{9+}$	5.549
$^{50}Cr^{9+}$	5.549
$^{61}Ni^{11+}$	5.539

Other Possible Stable Contaminants

Species	A/Q
$^{39}K^{7+}$	5.566
$^{50}V^{9+}$	5.549
$^{72}Ge^{13+}$	5.532