Complementary measurements of octupole collectivity in ~~^{146}Ce~~ ^{144}Ba

Ben Jones

University of Liverpool

ISS
ISOLDE Solenoidal Spectrometer

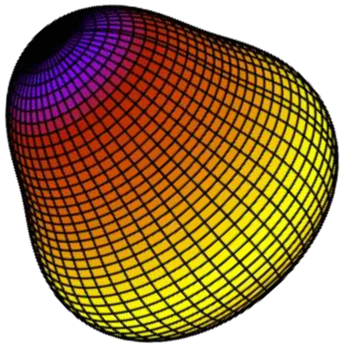
MINI BALL

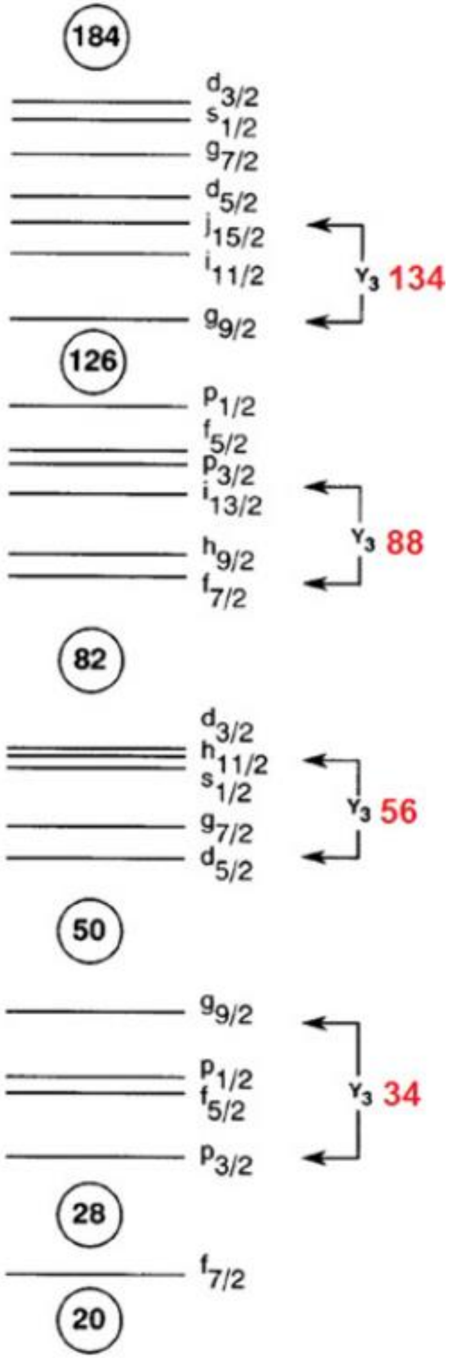
Octupole Collectivity

Microscopically, octupole deformations can be traced back to close-lying pairs of single-particle shells with $\Delta \boldsymbol{j}, \Delta \boldsymbol{l} = 3$ that are coupled by the octupole interaction.

Intruder orbitals with opposite parity near the fermi surface give rise to octupole magic numbers where the enhancement is predicted to be greatest: 34, 56, 88, 134.

Octupole deformation is greatest when both proton and neutron numbers are near these octupole magic numbers.

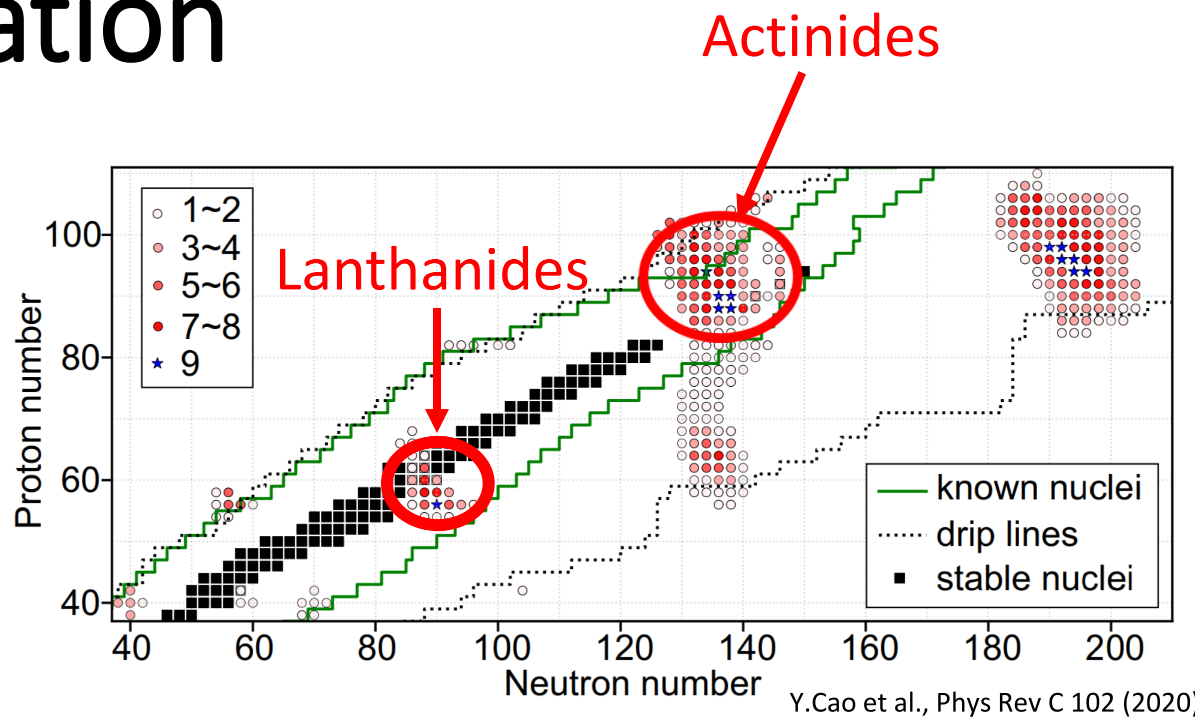




Motivation

Numerous experiments have demonstrated that isotopes in the actinides display octupole correlations.

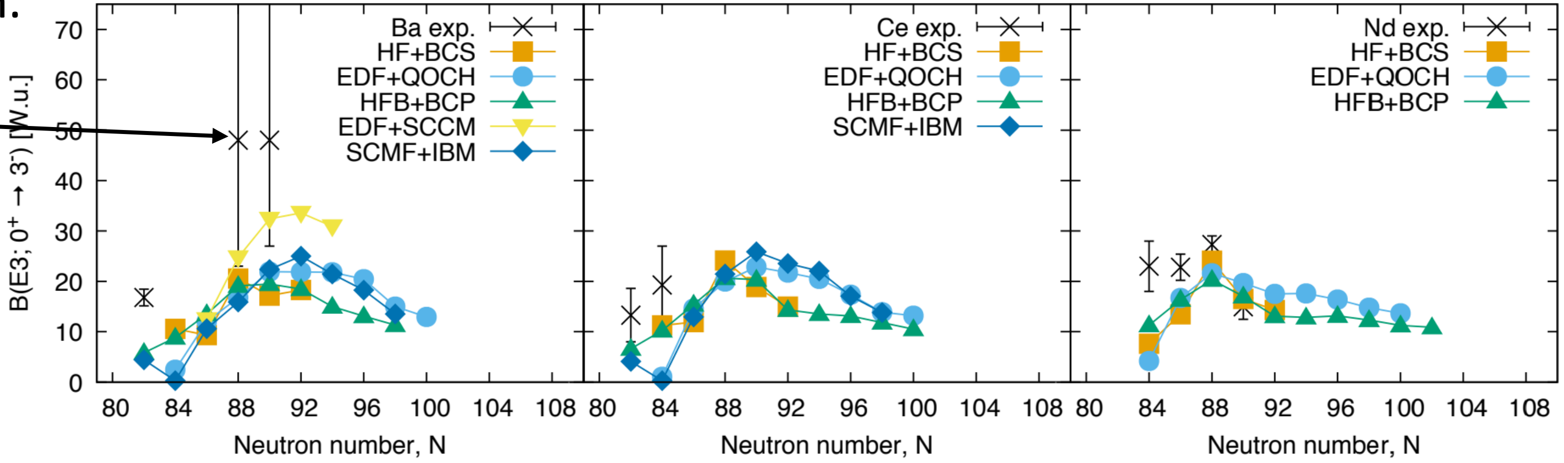
Several Rn isotopes are shown to behave as octupole vibrators [1], and ^{222,224,226}Ra exhibit static octupole deformation in their ground state [2].



Y.Cao et al., Phys Rev C 102 (2020)

Very little experimental data of the $B(E3)$ exists for isotopes in the Lanthanide region.

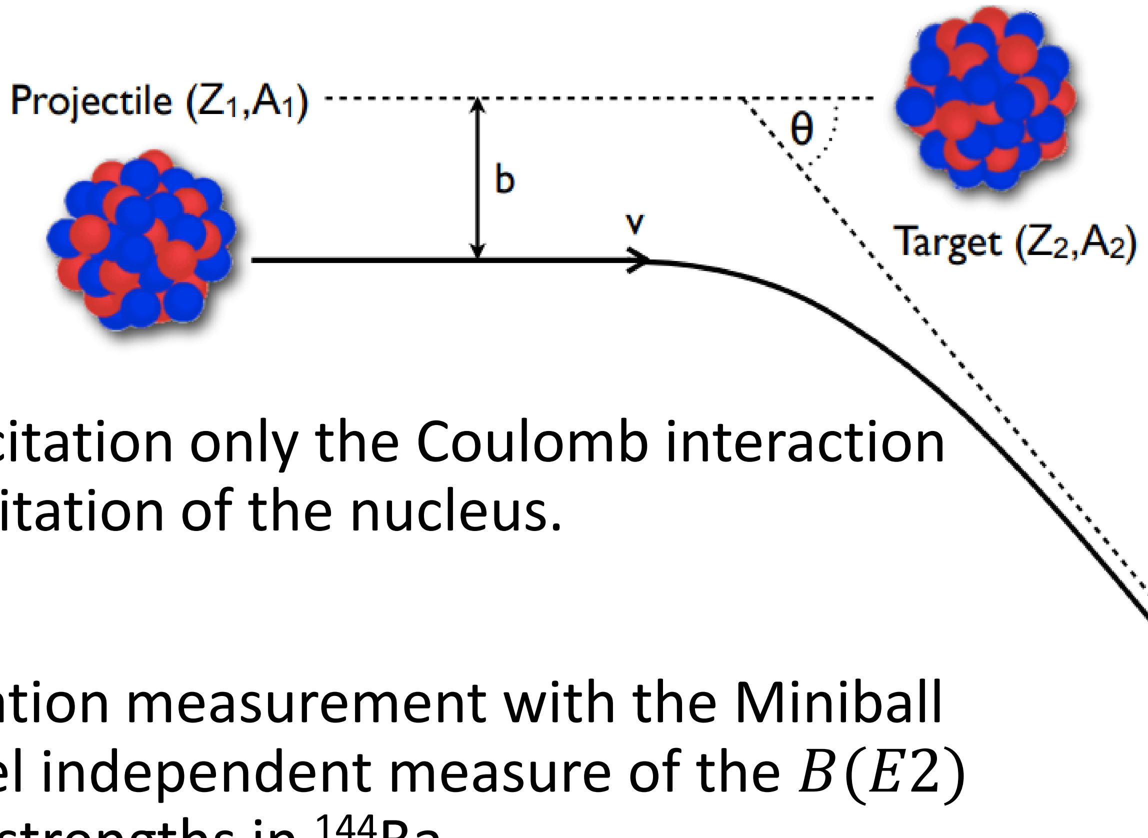
Previous measurement of the $B(E3)$ for ^{144}Ba near the expected peak by Bucher et al., ANL [3].



This measurement indicates a significant enhancement but has a large associated uncertainty.

1. P. A. Bulter et al., Nat Commun. 2019 Jun 6;10(1):2473
2. P. A. Bulter et al., Phys. Rev. Lett. 124, 042503 – Published 31 January, 2020
3. B. Bucher et al., Phys. Rev. Lett. 116, 112503 – Published 17 March, 2016

Miniball – Coulomb excitation



Sommerfeld parameter:

$$\eta = \frac{Z_1 Z_2 e^2}{\hbar v}$$

"Safe" Coulex:

$$\eta \gg 1$$

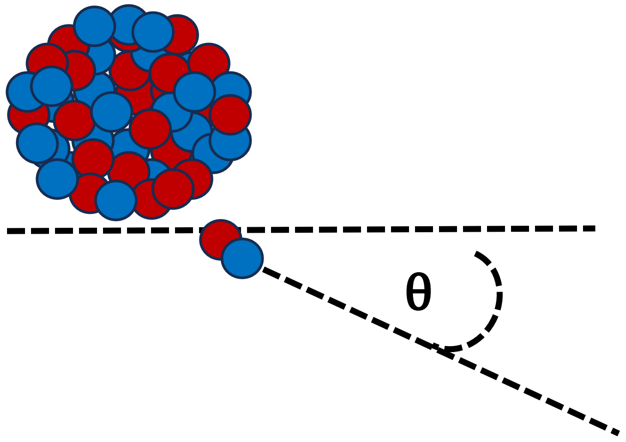
In "Safe" Coulomb excitation only the Coulomb interaction contributes to the excitation of the nucleus.

"Safe" Coulomb excitation measurement with the Miniball array provides a model independent measure of the $B(E2)$ and $B(E3)$ transition strengths in ^{144}Ba.

However, isobaric contamination provides a major challenge for producing beams in this region of the nuclear chart, placing sensitivity constraints on measuring the $B(E3)$ transition strengths from gamma-ray decays.

ISS – Inelastic scattering

Using inelastic scattering (d,d’) as a probe for the transition probabilities should overcome sensitivity constraints associated with gamma-ray detection.



Although the probability for excitation is lower for (d,d’) compared to coulomb excitation, the improvement in efficiency means it becomes competitive.

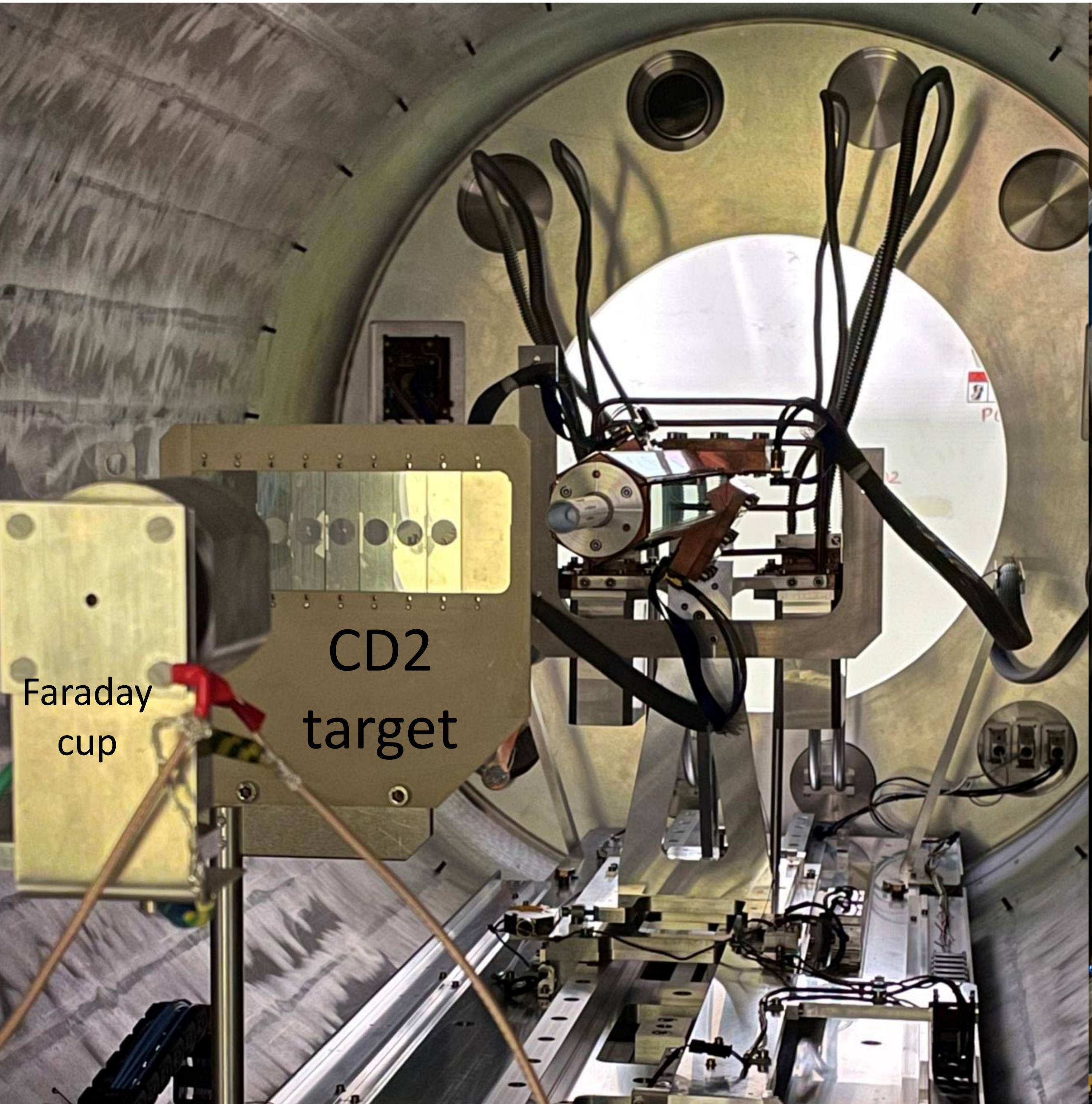
The ^{144}Ba(d,d’) reaction will excite both ^{144}Ba($0^+ \rightarrow 2^+$) and ^{144}Ba($0^+ \rightarrow 3^-$) directly via the Coulomb + nuclear interaction.

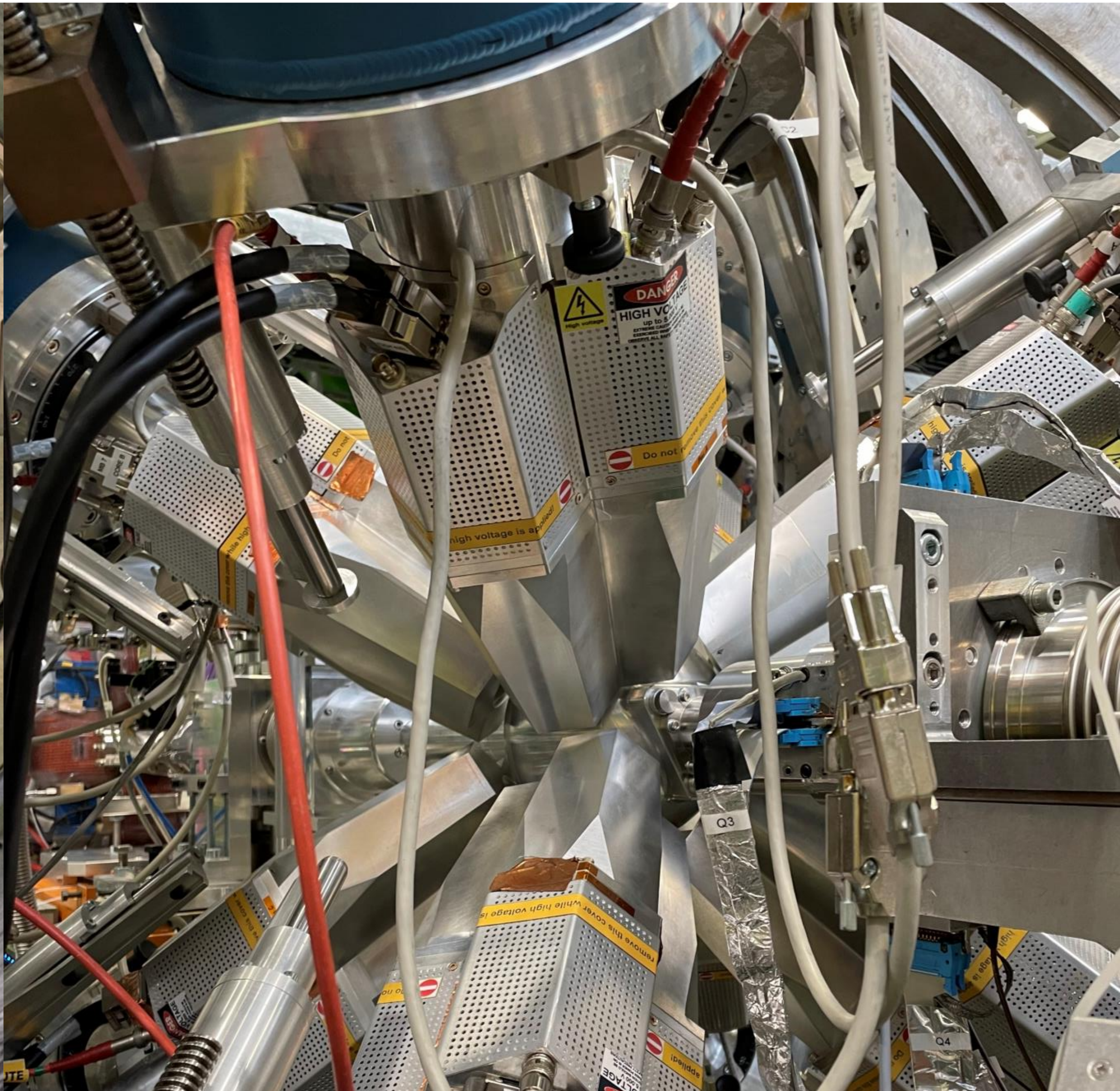
However, nuclear optical models are required for the interpretation of the cross-section data and the extraction of the deformation lengths, β_γ.

Therefore, a combination of the two techniques will provide a complementary measurement.

ISS

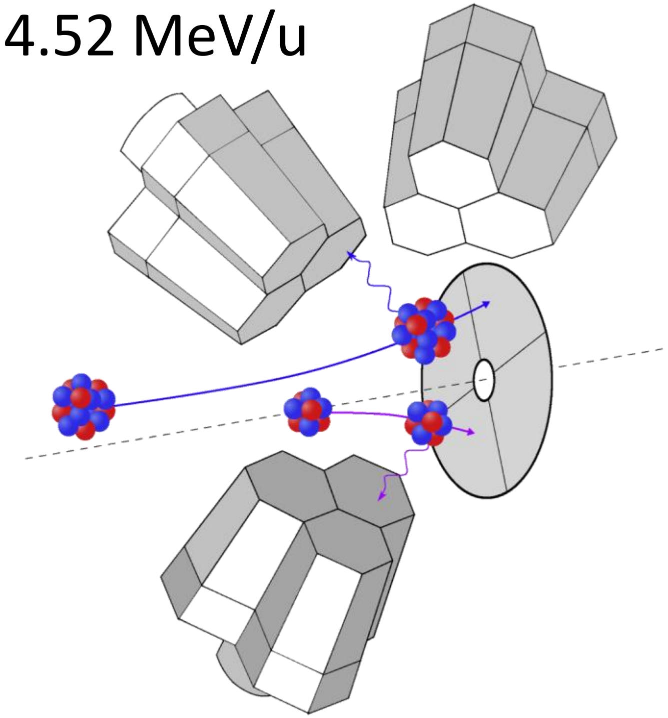
MINIBALL



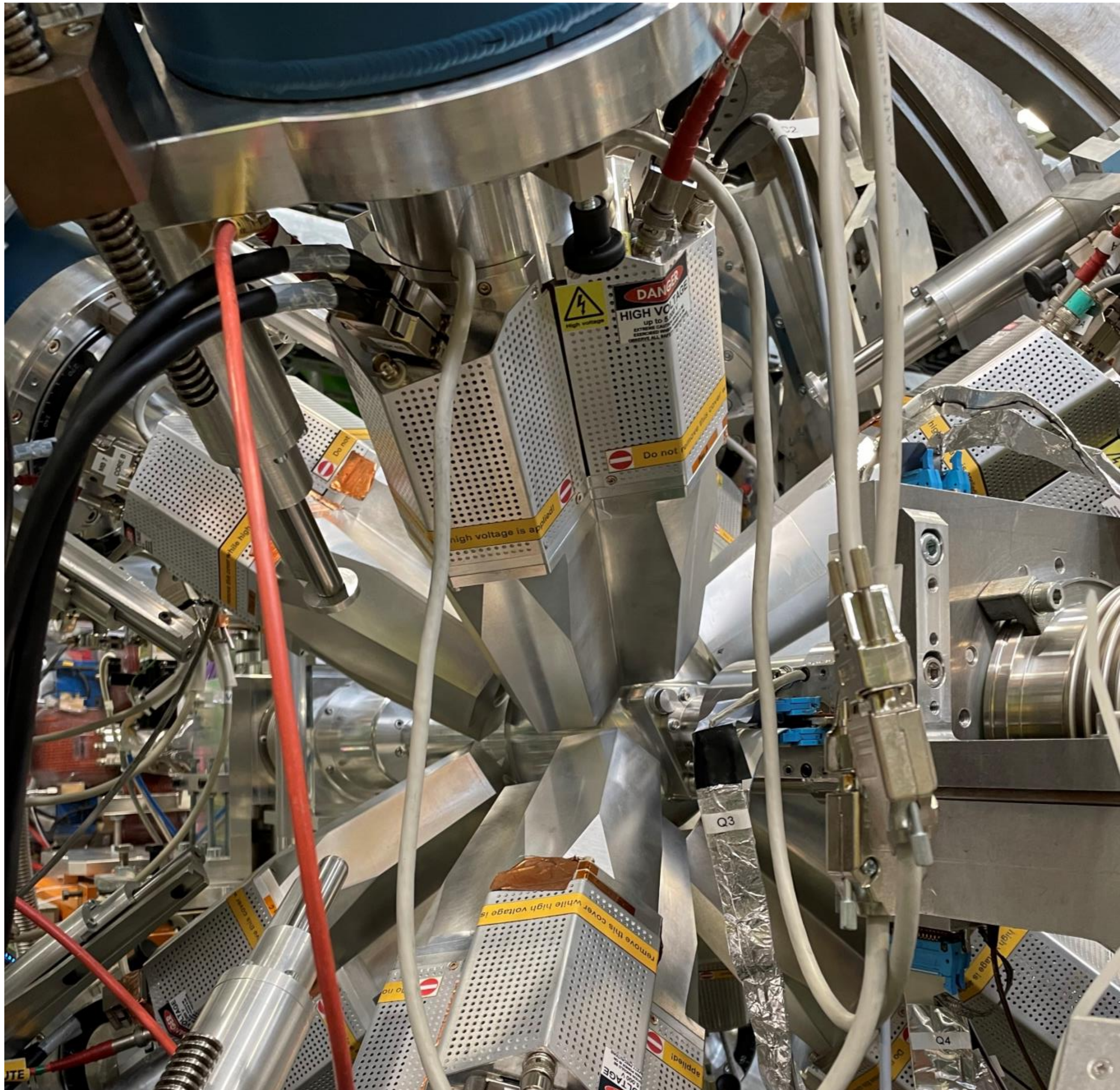


Setup

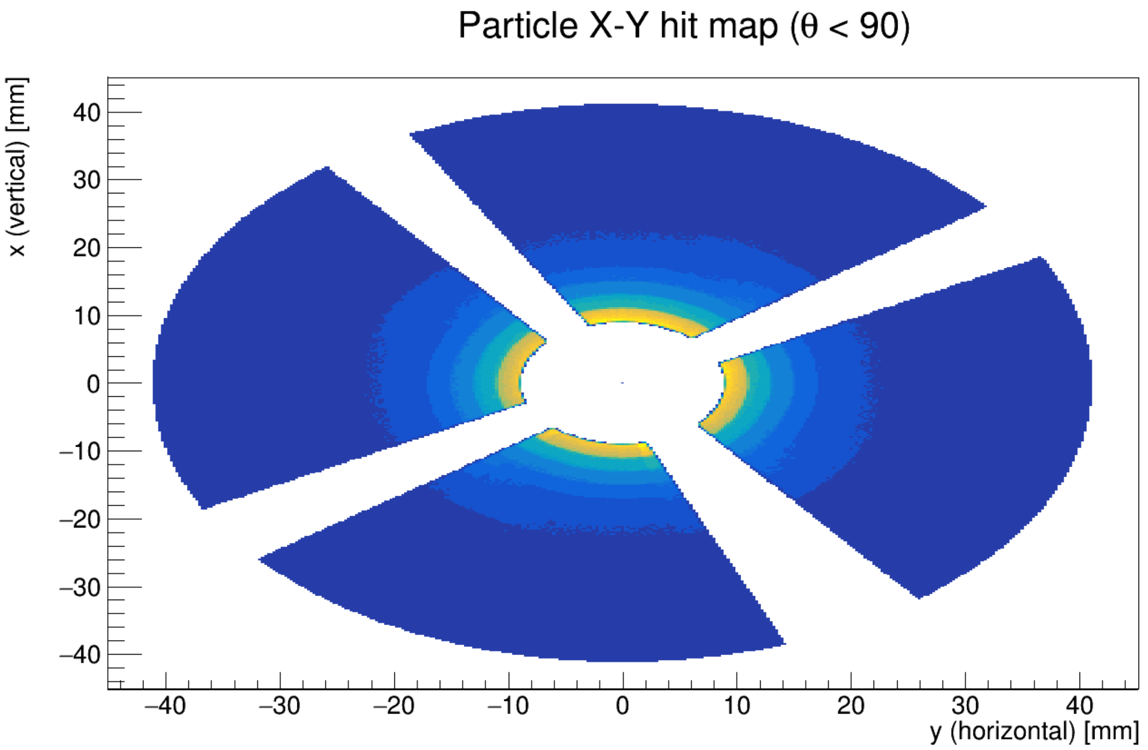
- 7 HPGe clusters centred around the target position, plus a silicon CD detector placed downstream of the target
- Target: 2.5 mg/cm^2, ^{208}Pb
- Beam Energy: 4.52 MeV/u

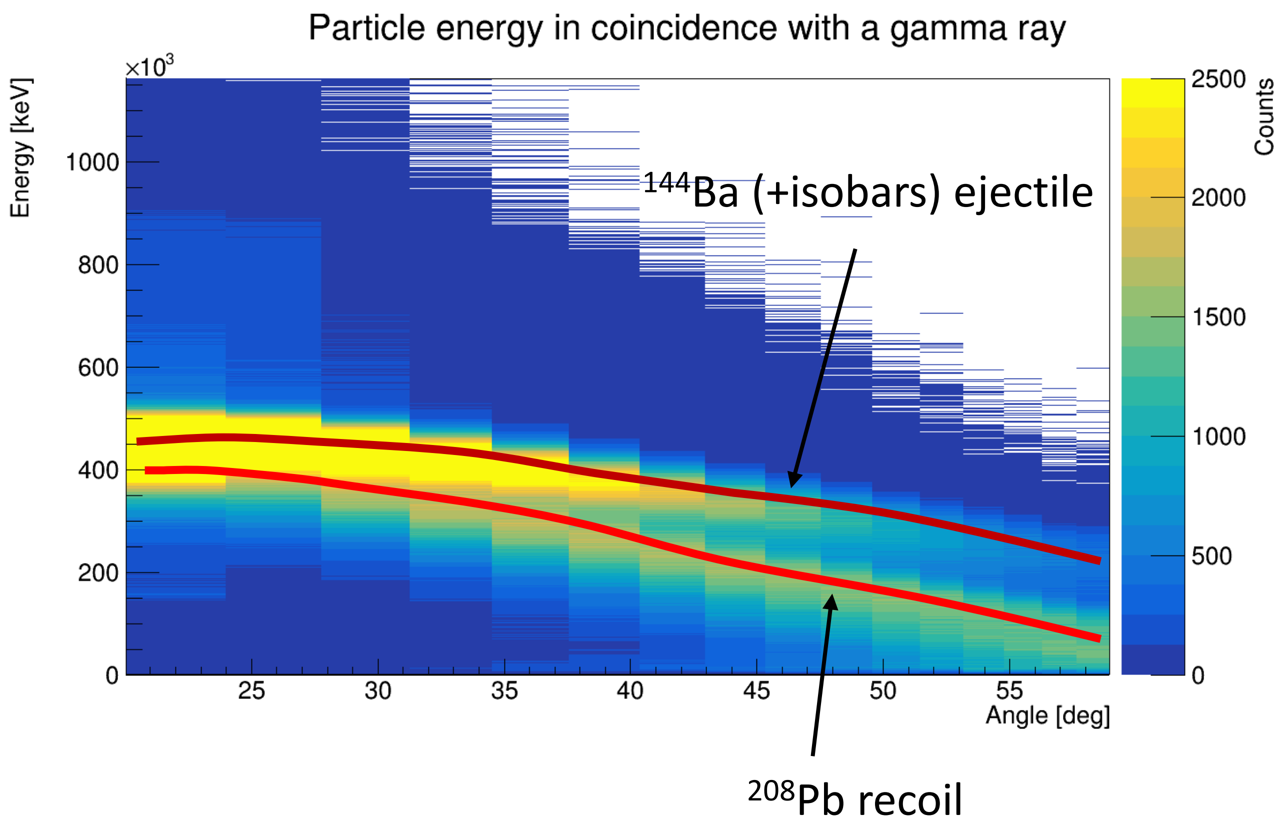


MINIBALL



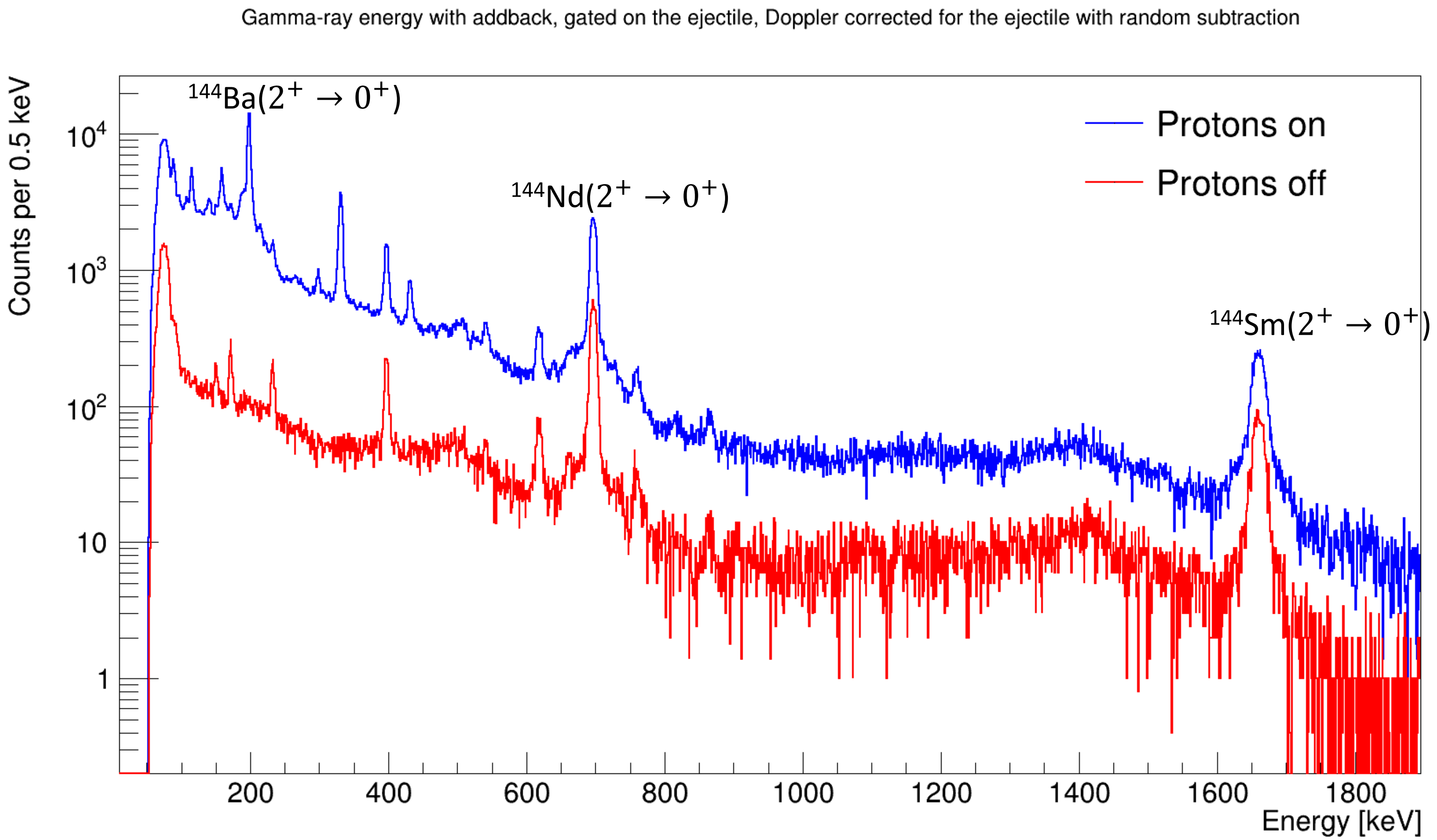
Miniball data





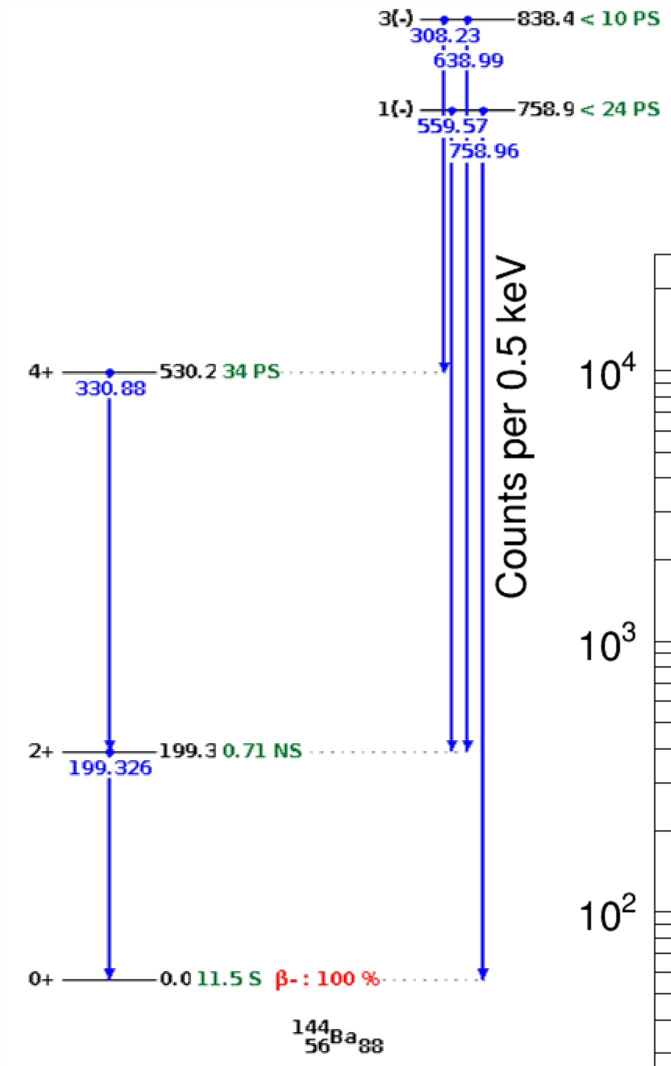
Very high instantaneous rate from isobaric contaminants in the CD detector

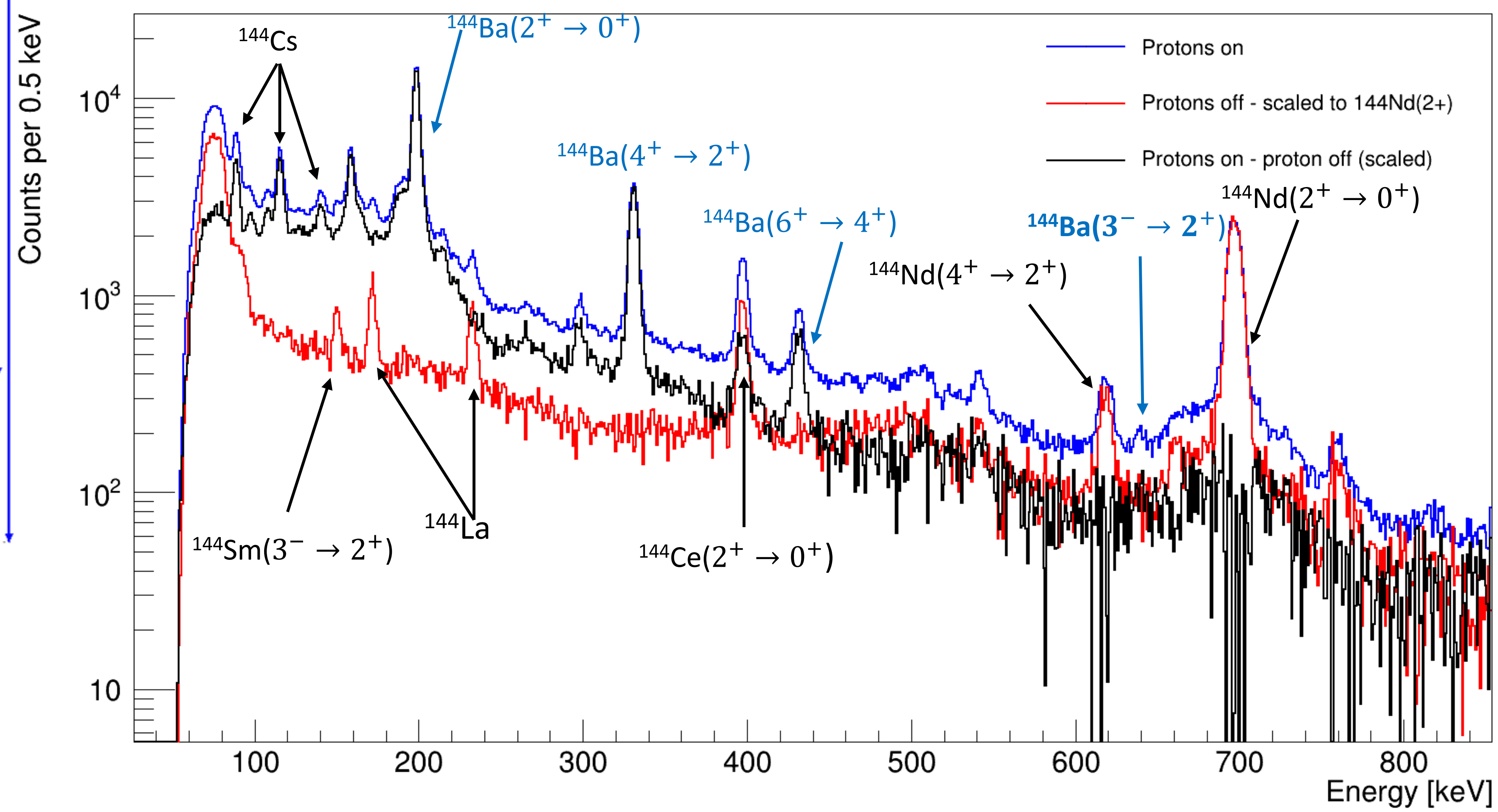
Miniball data



Comparison between runs with protons on the target vs protons off. The plot shows the large quantity stable ^{144}Nd and ^{144}Sm being constantly produced by the target, along with the ^{144}Ba.

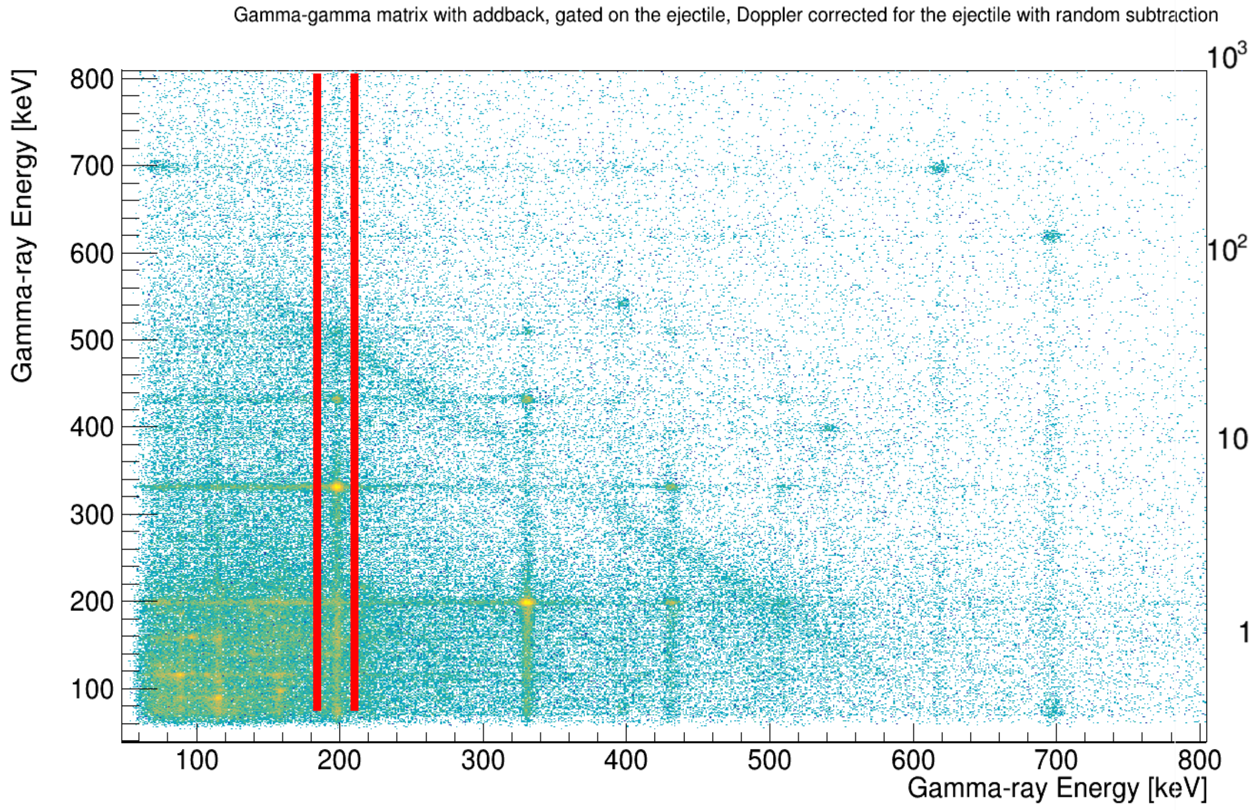
Miniball data

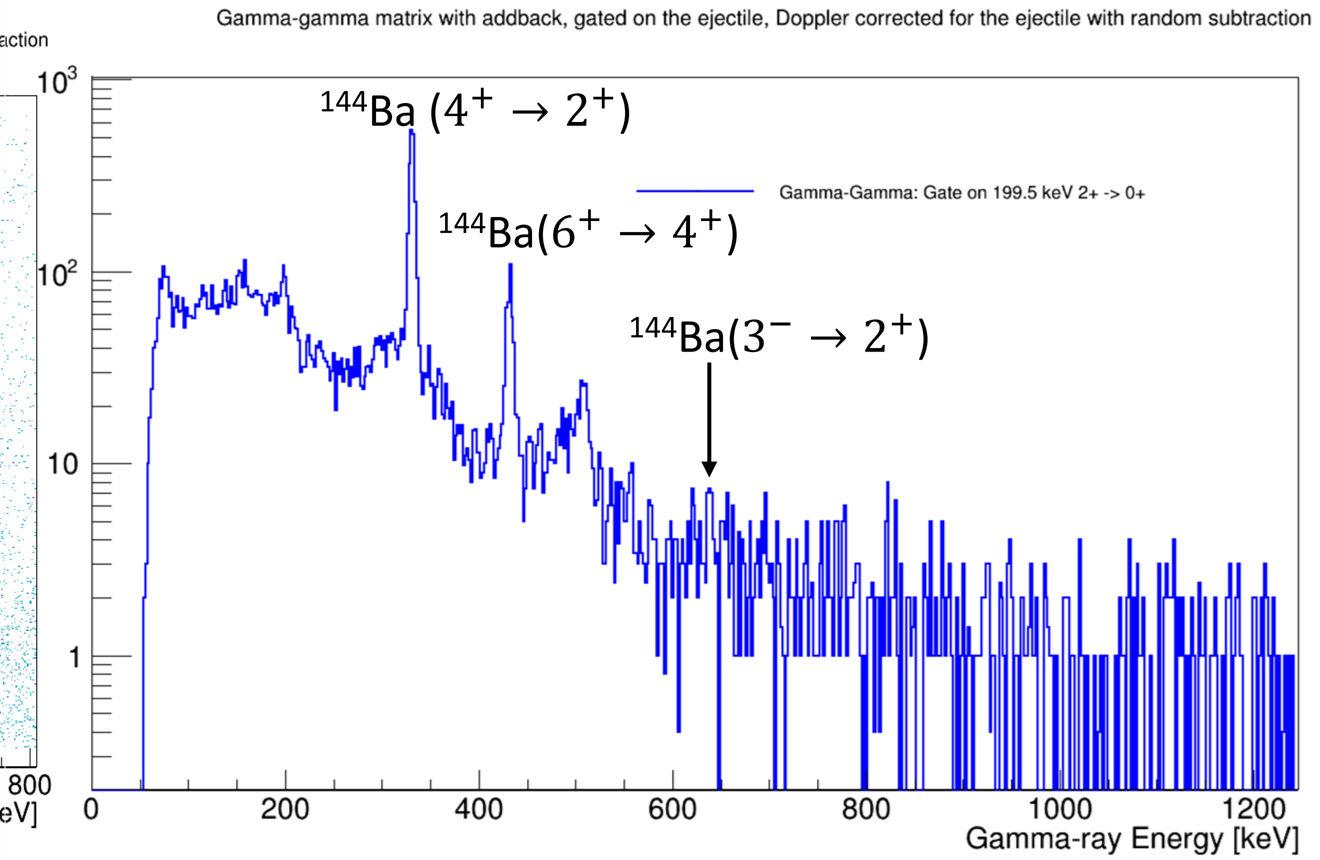




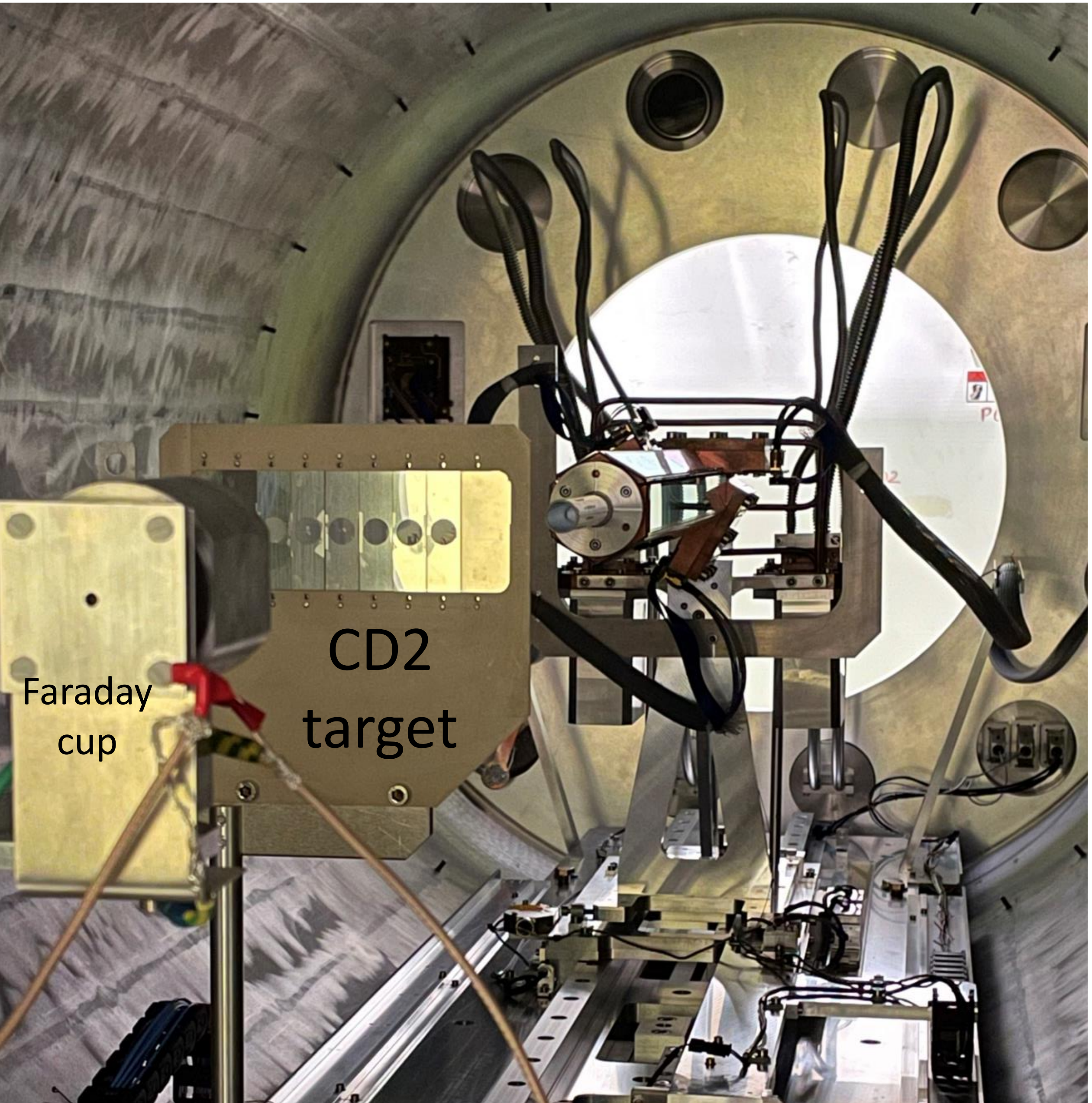
Miniball data

Gamma-gamma gate on the 199.5 keV ^{144}Ba $(2^+ \rightarrow 0^+)$ decay





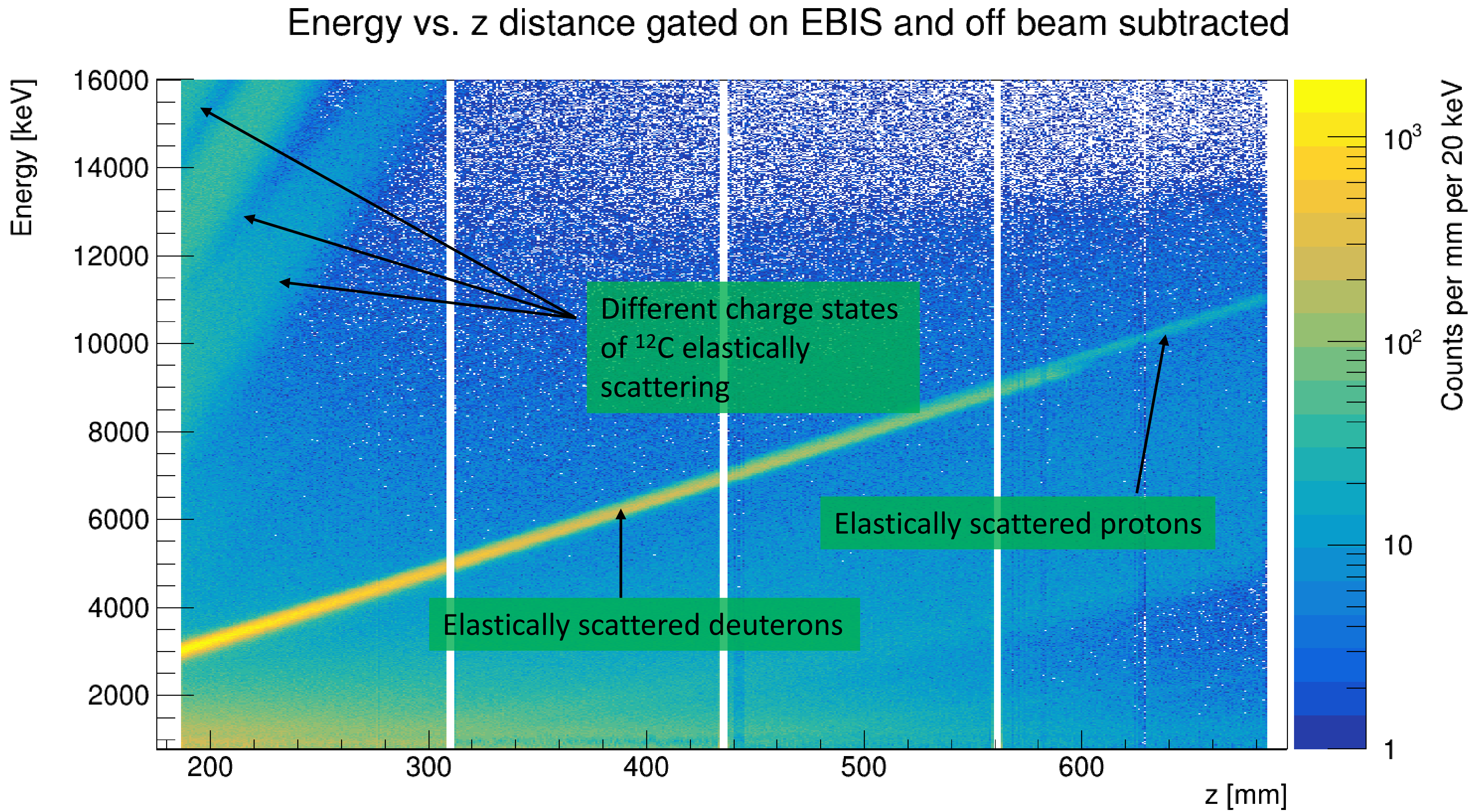
ISS



Setup

- ISS silicon array placed in the downstream position (for the first time)
- Target: 200 μg/cm^2, CD_2
- Beam Energy: 8.38 MeV/u
- Magnetic field: 2.5 T
- Faraday cup for beam tuning

ISS data

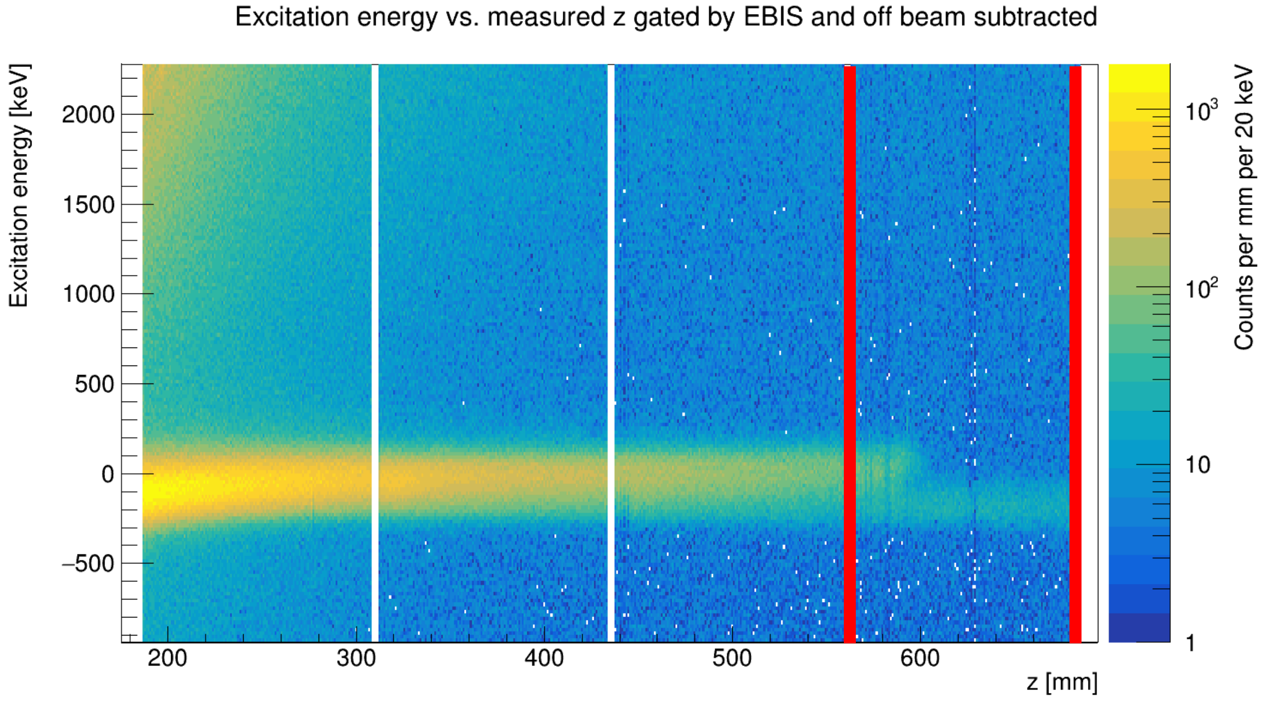


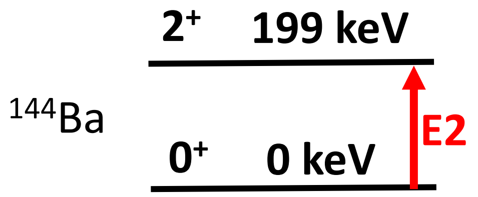
Energy vs. z distance gated on EBIS and off beam subtracted
Energy [keV]
16000
14000
12000
10000
8000
6000
4000
2000
200
300
400
500
600
z [mm]
Counts per mm per 20 keV
1
10
10^2
10^3
Different charge states of ^{12}C elastically scattering
Elastically scattered protons
Elastically scattered deuterons

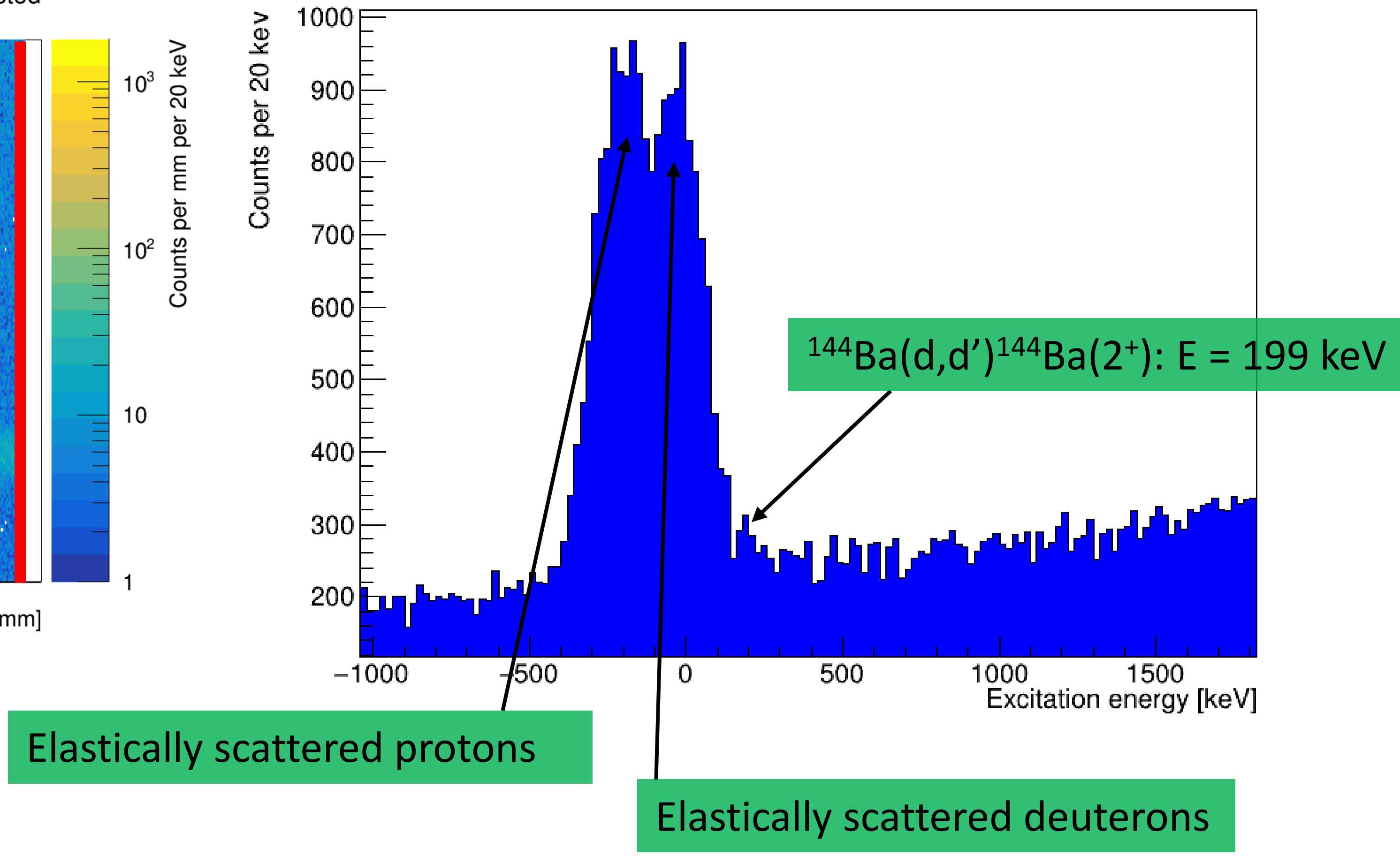
ISS data

Excitation energy reconstructed from the kinematics

Slice of events from 570 mm to 684 mm

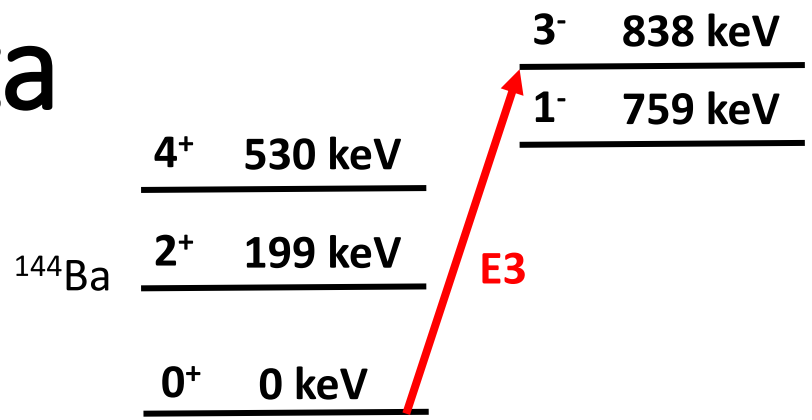




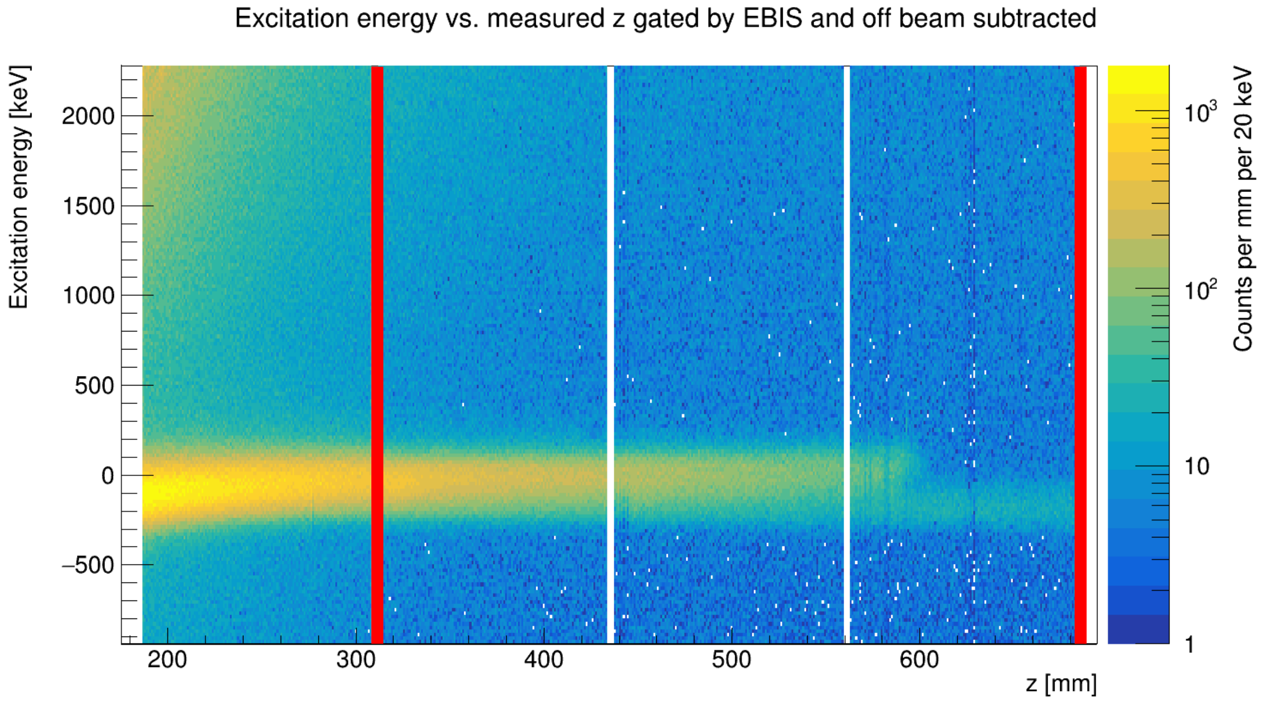


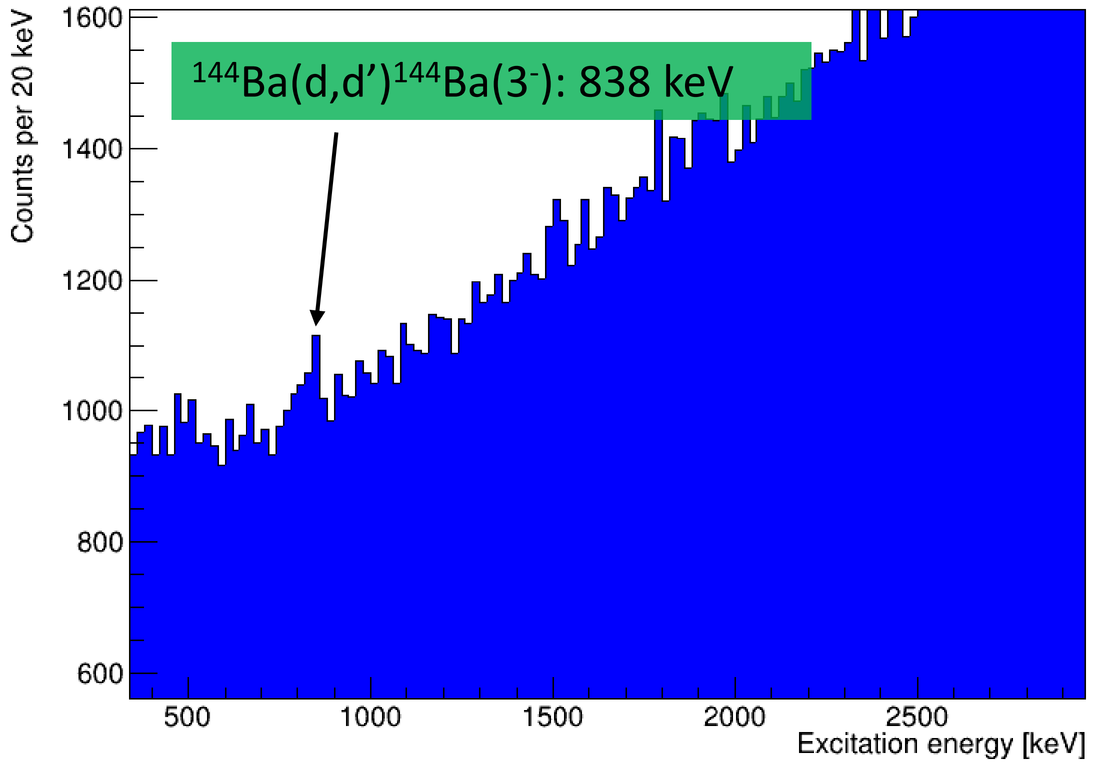
The 2^+ is only visible on the last row due to the resolution and size of the elastic peak.

ISS data



Slice of events from 312 mm to 684 mm





Almost the entire detector can be used to see the 3^- since its far enough away from the elastic scattering peak.

Summary

- Statistics of the ^{144}**Ba** $(\mathbf{3^{-} \rightarrow 2^{+}})$ transition from the Miniball Coulomb excitation experiment indicate that the $B(E3)$ will be able to calculated with a lower uncertainty than the previous measurement
- Preliminary calculations indicate the $B(E3)$ is closer to what theories predict and is lower than the value quoted by Bucher et al., ANL.
- First measurement of an inelastic scattering reaction with ISS!
- First measurement of a forward going reaction at ISS (lots of lessons learnt)!

Outlook

- Analysis of the Miniball coulomb excitation data using GOSIA to extract matrix elements and transition strengths
- Improve the peak-to-background ratio and energy resolution of the ISS data to then extract cross-sections

Thanks to collaborators

UNIVERSITY OF LIVERPOOL

MANCHESTER 1824
The University of Manchester

KU LEUVEN

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

CERN

ISS
ISOLDE Solenoidal Spectrometer

CHALMERS
UNIVERSITY OF TECHNOLOGY

UKRI
Science and Technology Facilities Council

ISOLDE

TECHNISCHE UNIVERSITÄT DARMSTADT

HIL
Heavy Ion Laboratory

Universität zu Köln

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

MINIBALL

UNIVERSITY OF THE WEST of SCOTLAND
UWS

LUND UNIVERSITY