Quadrupole excitations in self-conjugate nuclei pushing the limit

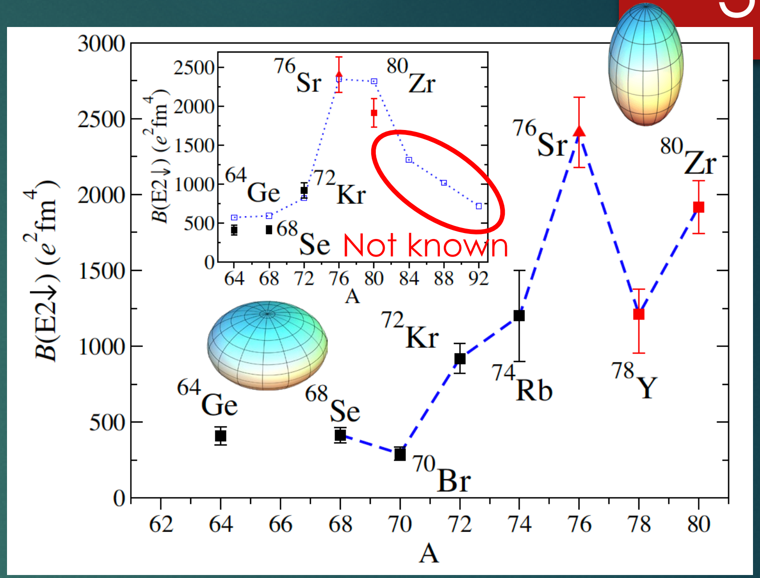
Francesco Recchia, Jeongsu Ha
University and INFN Padova
and the e19034 Collaboration

Physics Motivation

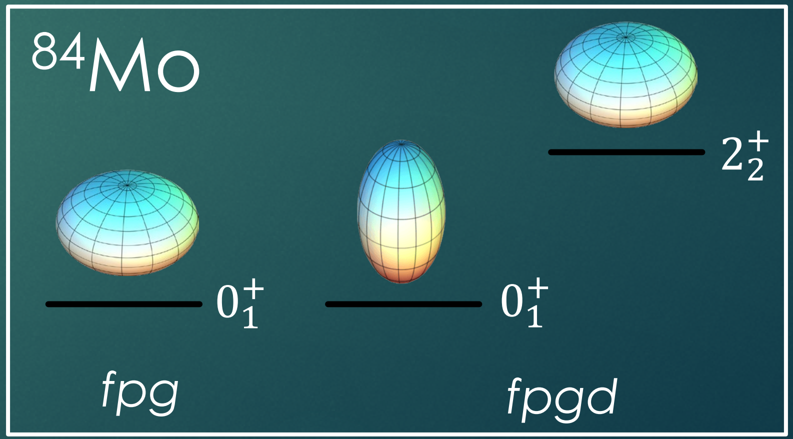
- N = Z nuclei play a special role
  - **(np) collectivity** by the interplay of neutron-proton
  - **spatial overlap** of their respective wave functions at the Fermi surface
  - proton and neutrons act coherently.
- Competing **isoscalar np pairing** and normal isovector (T = 1, I = 0) pairing modes
  - a nuclear superfluid **analogous to "Cooper Pairs"** may exists in nuclei
  - Isoscalar predicted prominent in the ground states of heavier (A > 76) N = Z nuclei
  - Difficult to find a smoking gun signature
  - shell-model predict that **isoscalar pairing enhances collectivity → measurements of B(E2)**

Physics Motivation

- Along $N = Z$: shape change **from oblate** (^{64}Ge, ^{68}Se) **to prolate** around ^{72}Kr
- Large deformation continues up to ^{80}Zr
- Then prolate or oblate??
- Shell model predictions for ^{84}Mo:
  - with ***fpg*** model space: oblate, $\tau(2_1^+) = 75$ ps
  - with ***fpgd*** model space: prolate , $\tau(2_1^+) = 43$ ps



R. D. O. Llewellyn et al., Phys. Rev. Lett. ***124****, 152501 (2020)*



Objectives

- Measurement of the lifetime of the first **2+ state in ^{84}Mo** populated by two-neutron knockout from ^{86}Mo.
- Measurement of the lifetime of the first **2+ state in ^{86}Mo** using inelastic scattering: ^{86}Mo(^{9}Be, ^{9}Be)^{86}Mo*

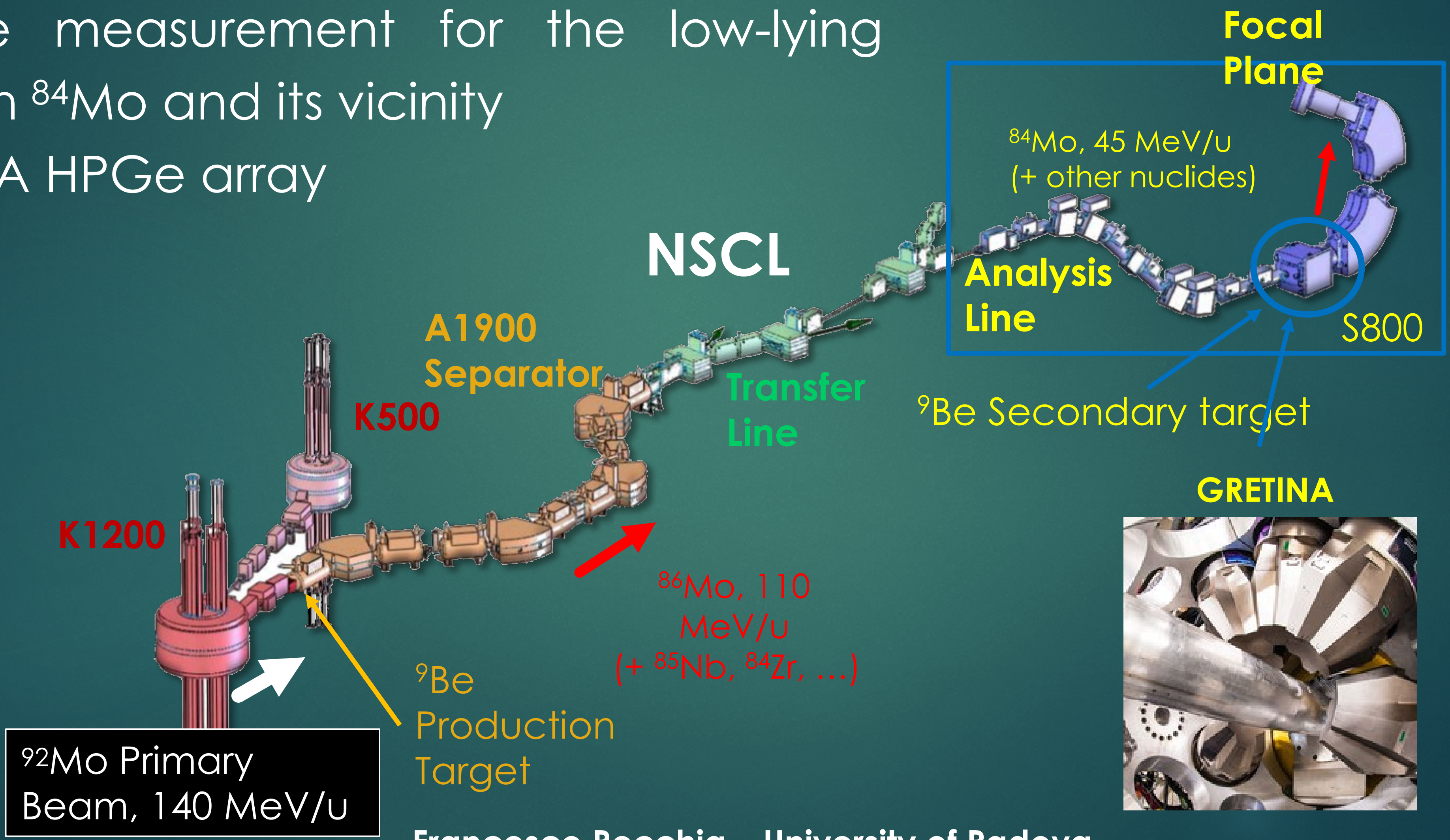
- Understanding the collectivity, shape, of ^{86}Mo and ^{84}Mo by comparing to the shell model calculation

Experiment at NSCL, Michigan

Performed in July 2020

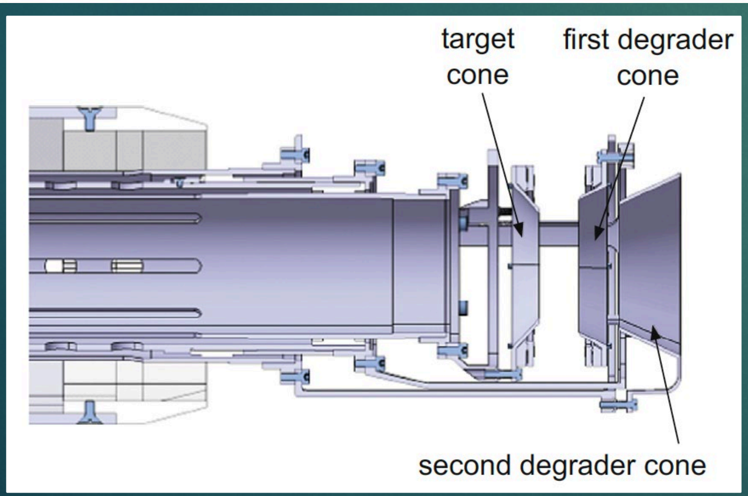
Lifetime measurement for the low-lying states in ^{84}Mo and its vicinity

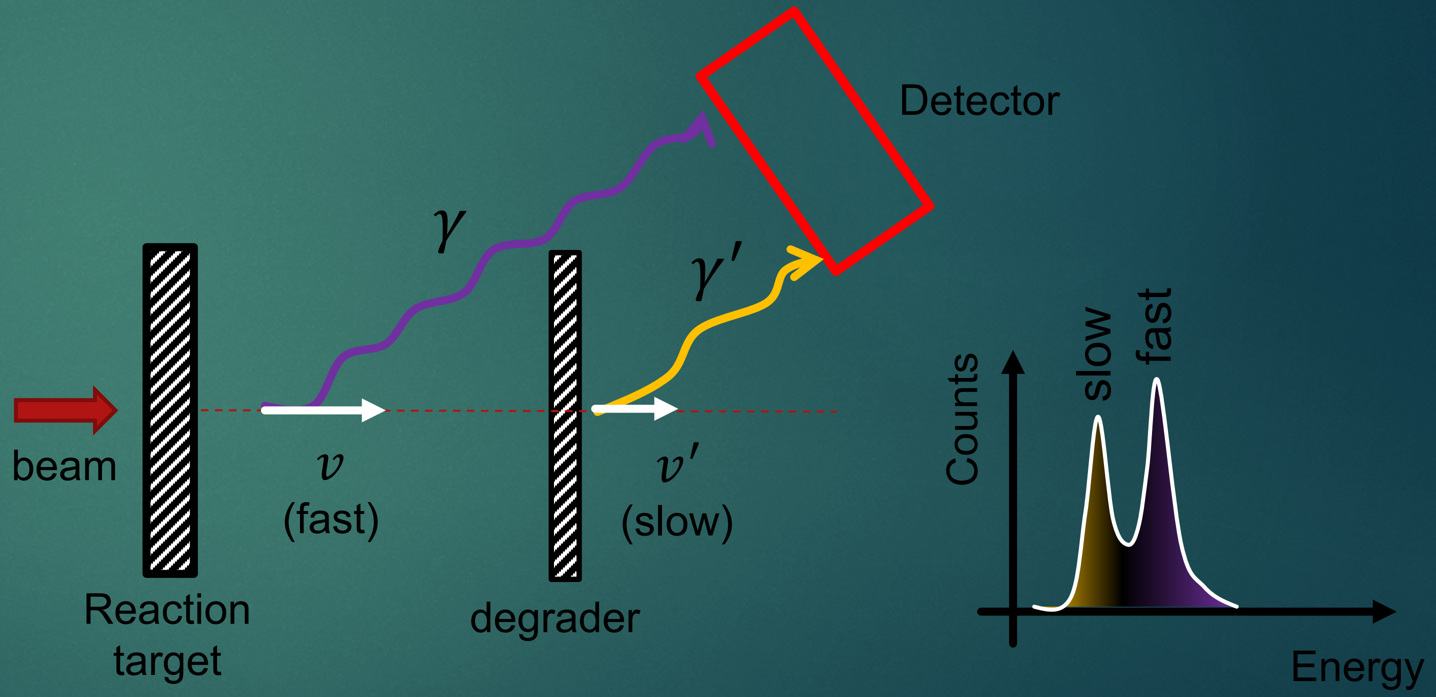
GRETINA HPGe array



Experimental (e19034@NSCL, MSU)

- GRETINA was coupled to the plunger TRIple PLunger for EXotic beams (TRIPLEX)
- With a secondary target, the TRIPLEX plunger can hold up to two degrader foils which facilitate to extract the lifetime from a single measurement
- Only one degrader was employed in the experiment

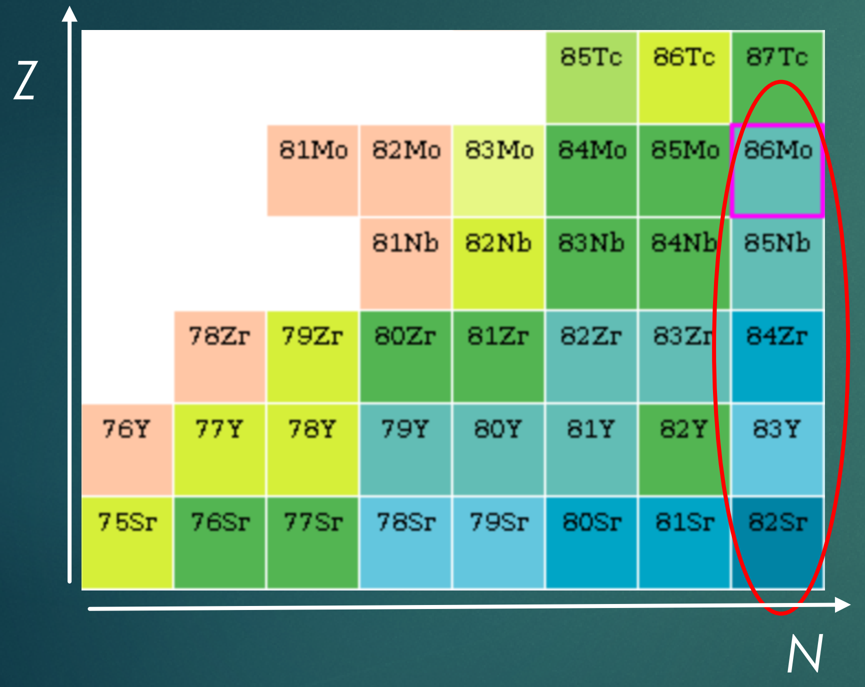


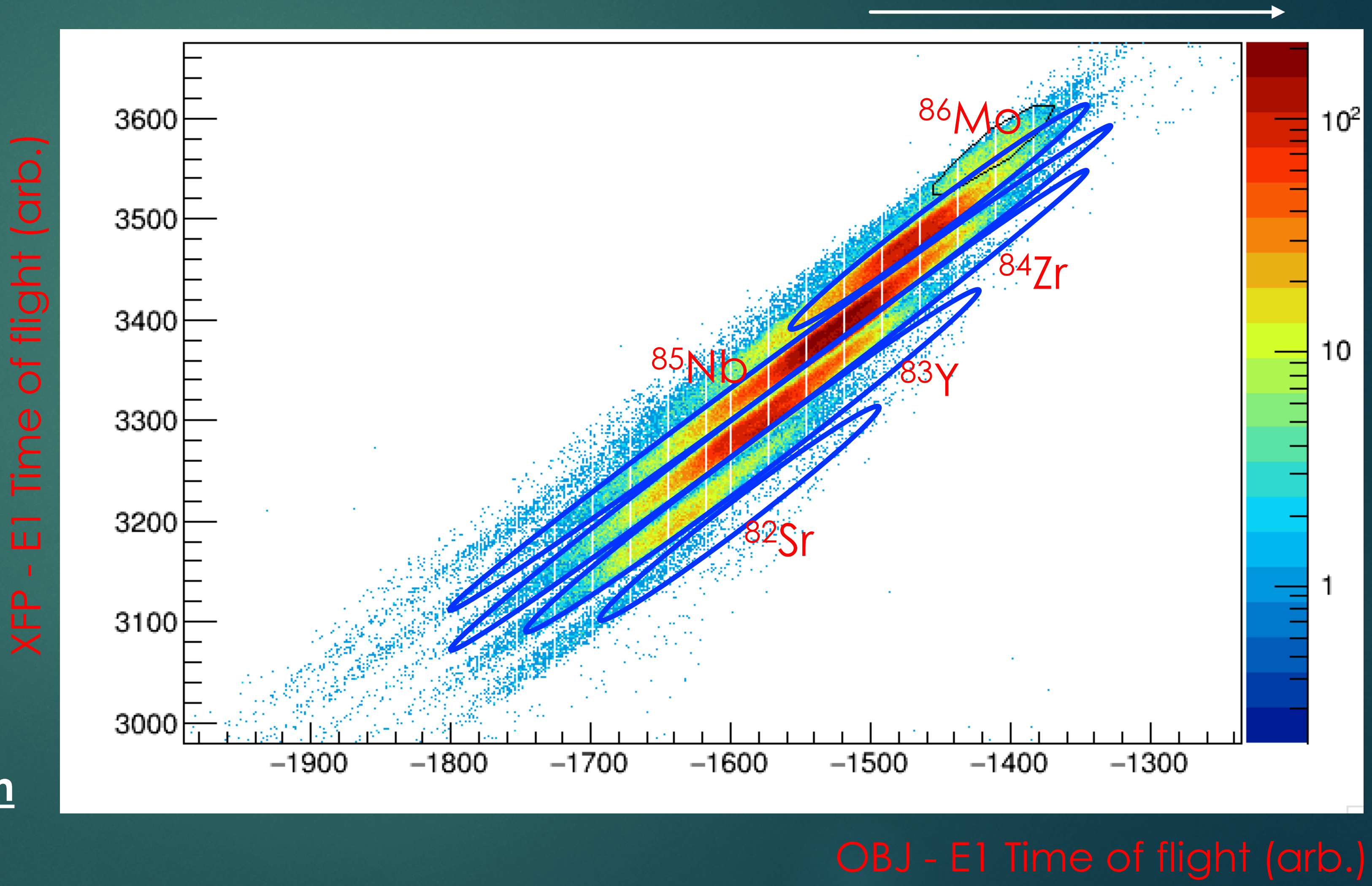


H. Iwasaki et al., Nuclear Inst. and Methods in Physics Research A ***806****, 123 (2016)*

Incoming PID

[Selection of the incoming beam]

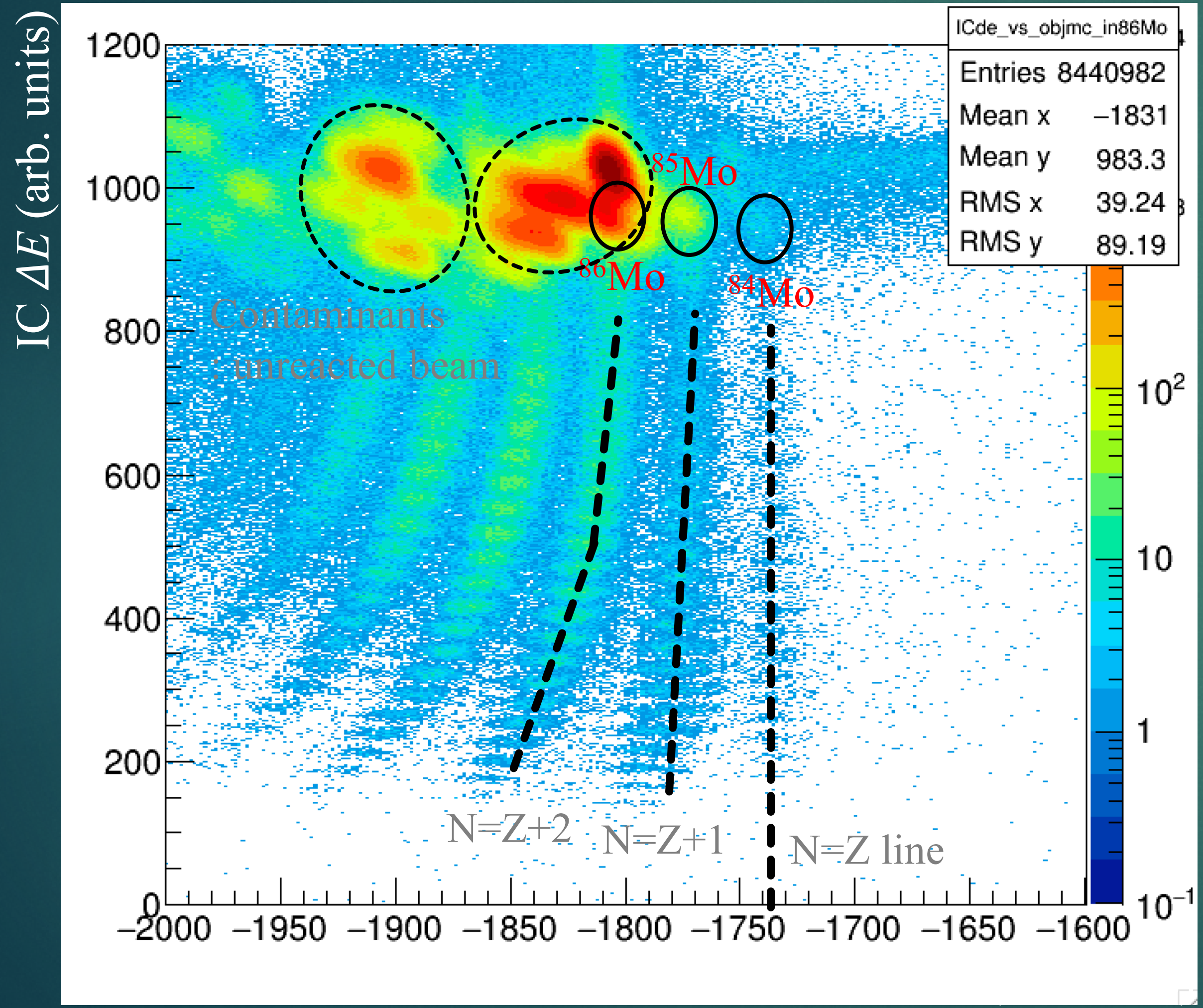


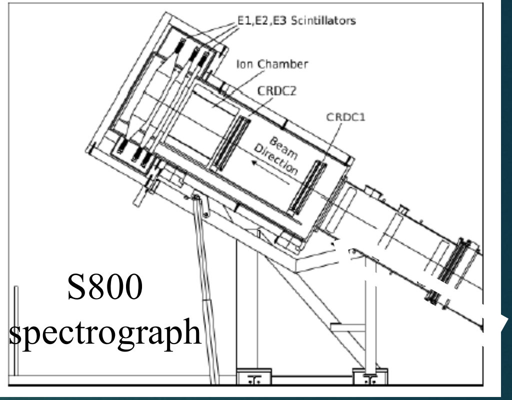


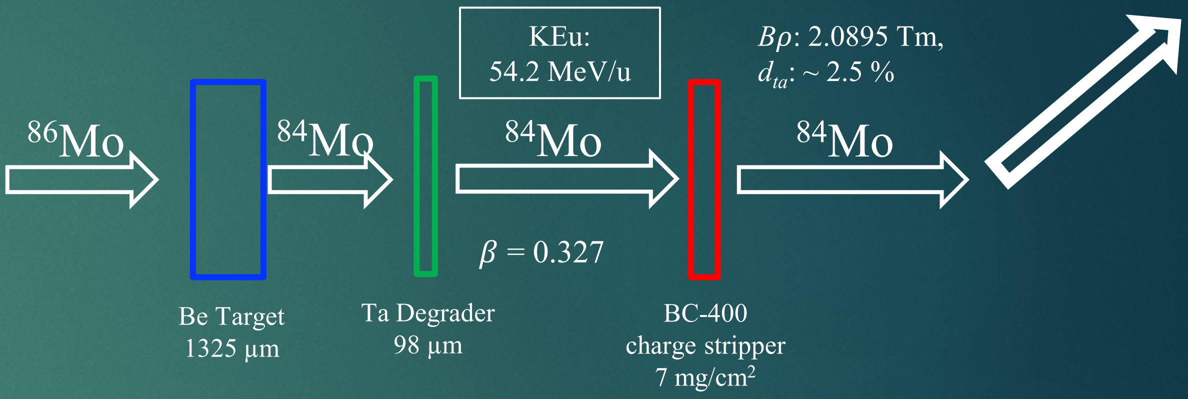
^{86}Mo was 0.8% of incoming beam

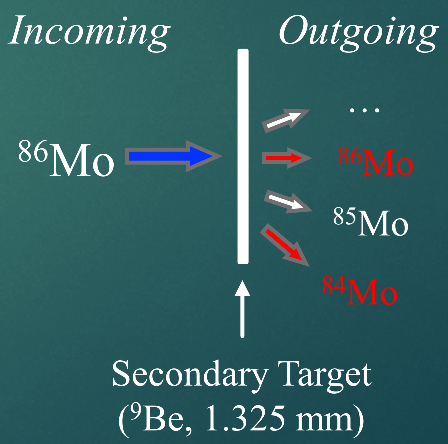
Analysis

[Outgoing beam PID plot for incoming ^{86}Mo beam]









Comparison to full Monte Carlo

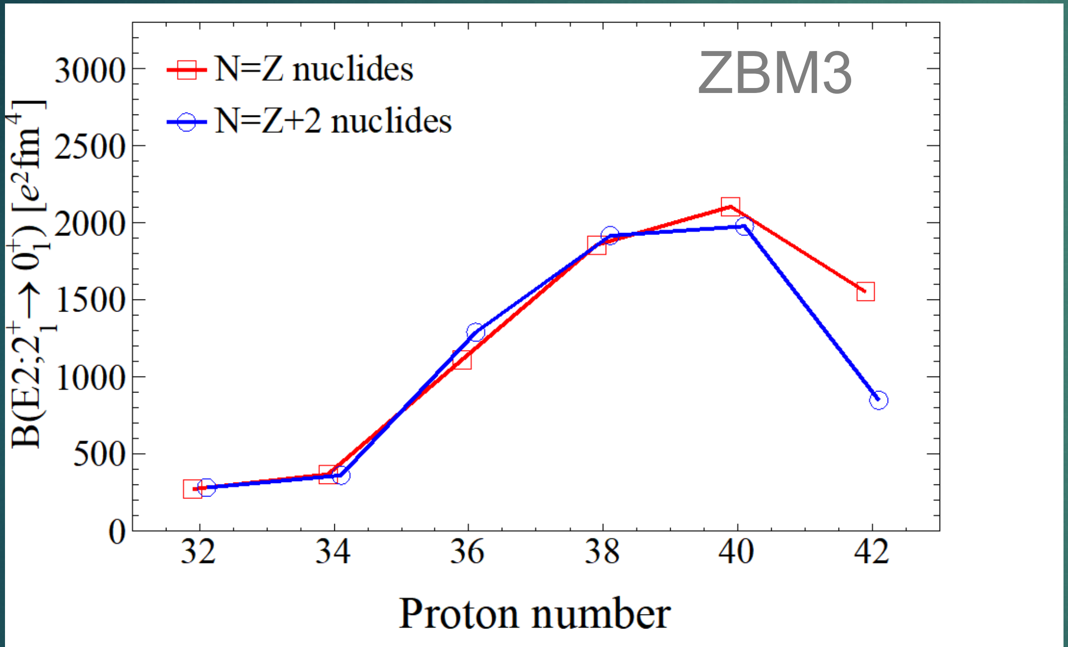
- The spatial and energy distribution of the secondary beam are reproduced in the **simulation**
- Strong **direct** population to 2^+
  - Residual population to 4^+ states that decays by a fast transition

$B(E2;\ 2_1^+ \rightarrow 0_1^+)$ along N=Z

- First 2^+ state in ^{84}Mo understandable in terms of **prolate deformation**
- Inclusion of $d_{5/2}$ is needed – lifetime shorter than expected - quadrupole correlations

Discussion with ZBM3

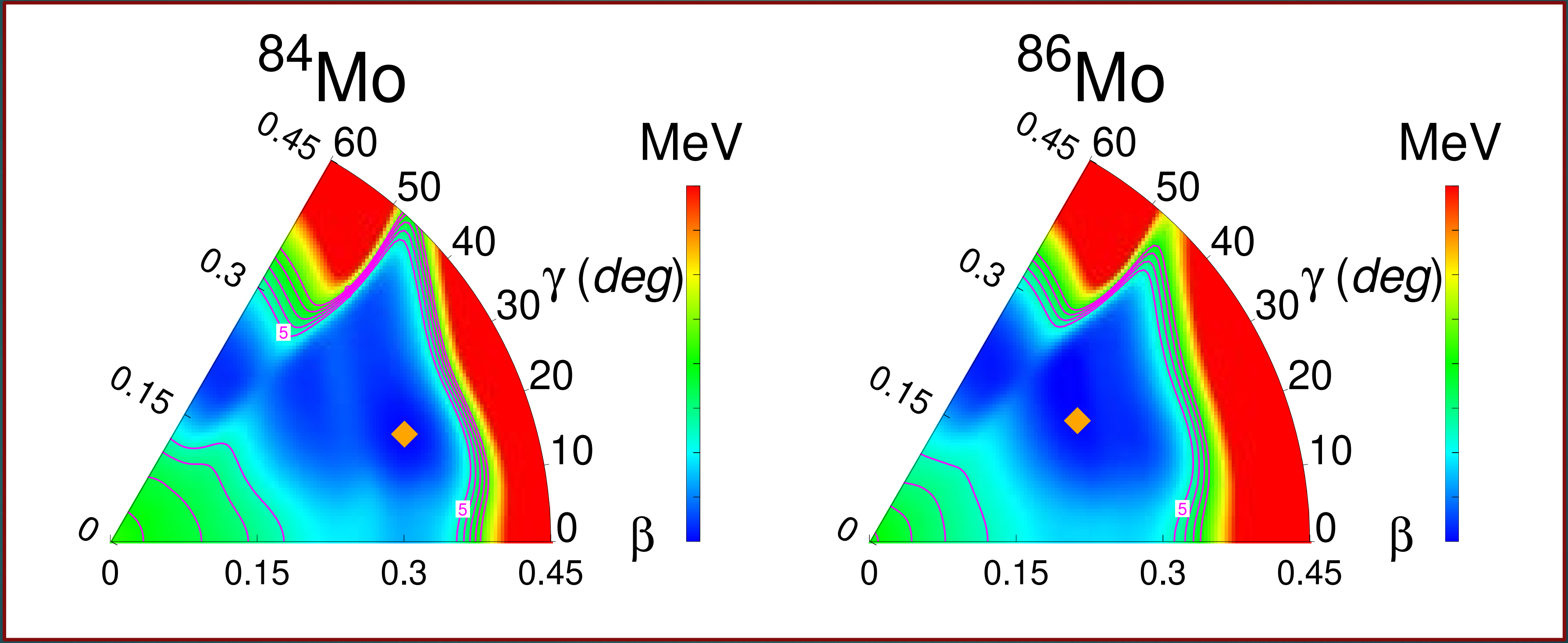
- The shell model calculation with ZBM3 (*r3gds* model space)
- The $B(E2;\, 2_1^+ \rightarrow 0_1^+)$ calculation shows consistency for $N = Z$ and $N = Z + 2$ nuclides



A. P. Zuker, A. Poves, F. Nowacki, and S. M. Lenzi, Phys. Rev. C ***92****, 024320 (2015)*
A. P. Zuker, B. Buck, and J. B. McGrory, Phys. Rev. Lett. ***21****, 39 (1968)*

Discussion with ZBM3

- The $\beta - \gamma$ plane for ^{84}Mo and ^{86}Mo show triaxial ground-state shapes
- Soft potential surface towards oblate shapes for both ^{84}Mo and ^{86}Mo



Conclusion

- Advanced RIB Facilities and instrumentation allow progress
  - Measure collectivity by B(E2) along N=Z
  - New challenges for theoretical description of the B(E2) measured in the center of the $g_{9/2}$ shell
  - **Quadrupole correlations beyond expectations**; possible **triaxiality**... calculation still in progress
- Limit of present facilities is reached. Looking forward for the new ones
  - odd-odd nuclides (^{82}Nb, ^{86}Tc, …) shape competition and coexistence.

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