Triaxiality in Neutron-Rich Mo and Ru Isotopes from DSAM Lifetime Measurements

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Nuclear Structure 2012 Poster Session

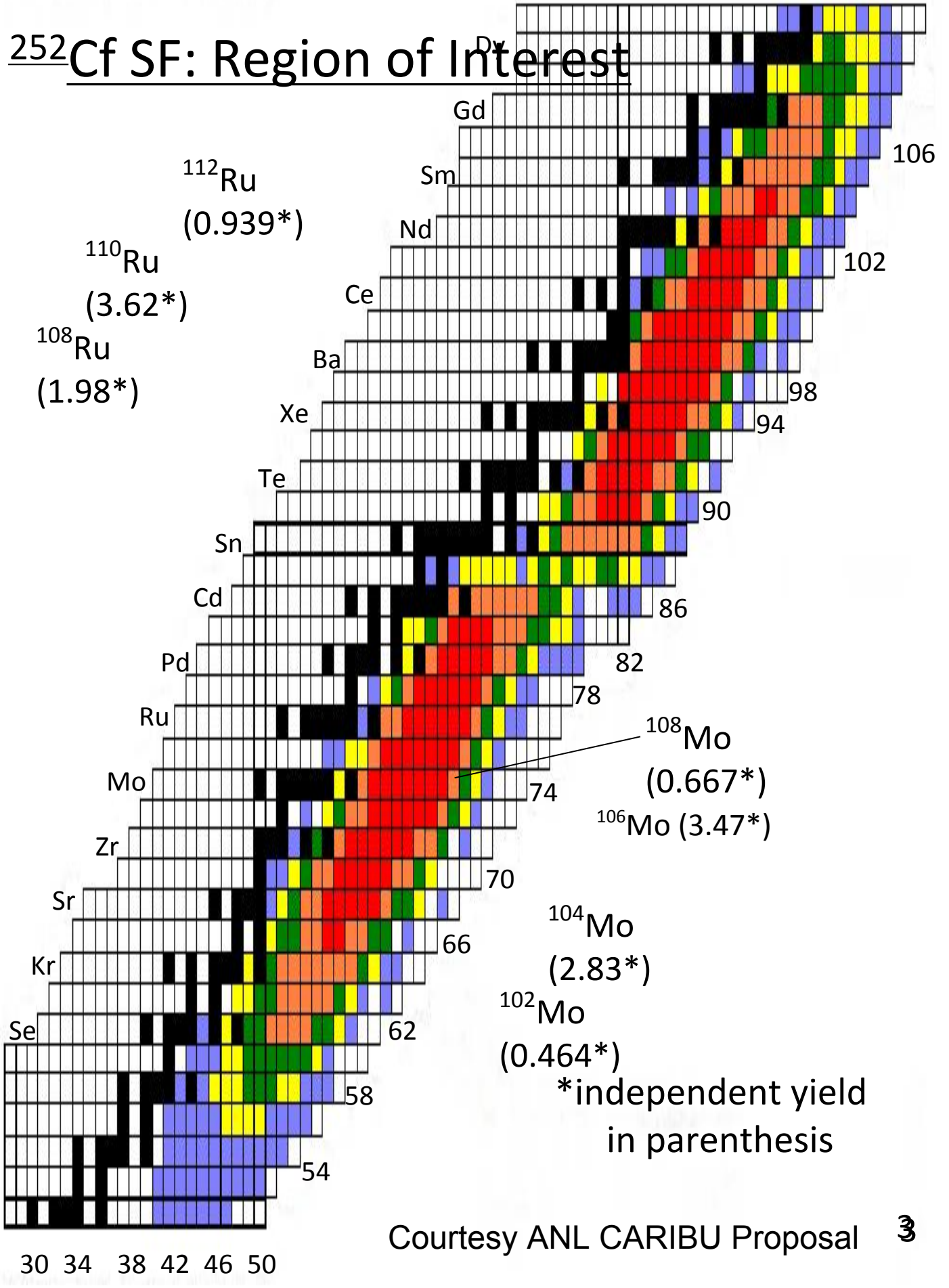
Introduction

The nuclear shape has a threefold sensitivity: (i) to the single-particle structure of the nucleus, (ii) to its collective behavior, and (iii) to the total angular momentum the nucleus carries. Related to the latter, nuclear rotation perturbs the microscopic structure. This may lead to a shape change as spin changes.

An active area of research is the study of triaxial shapes, see e.g. the recent ultra-high spin work of Refs. **Wan-11** and **Shi-12**. The crucial parameter is the measured transition quadrupole moment that may provide a signature for nuclear triaxiality in a model-dependent way. Suggestions for regions with prominent "γ soft" or permanently triaxial shapes include the heavy-Zr region ($Z \geq 40$, $A \geq 100$).

This region is hard to approach by nuclear reactions. The main method to access the region is still using the spontaneous fission (**SF**) process of e.g. a ^{252}Cf source.

^{252}Cf SF: Region of Interest

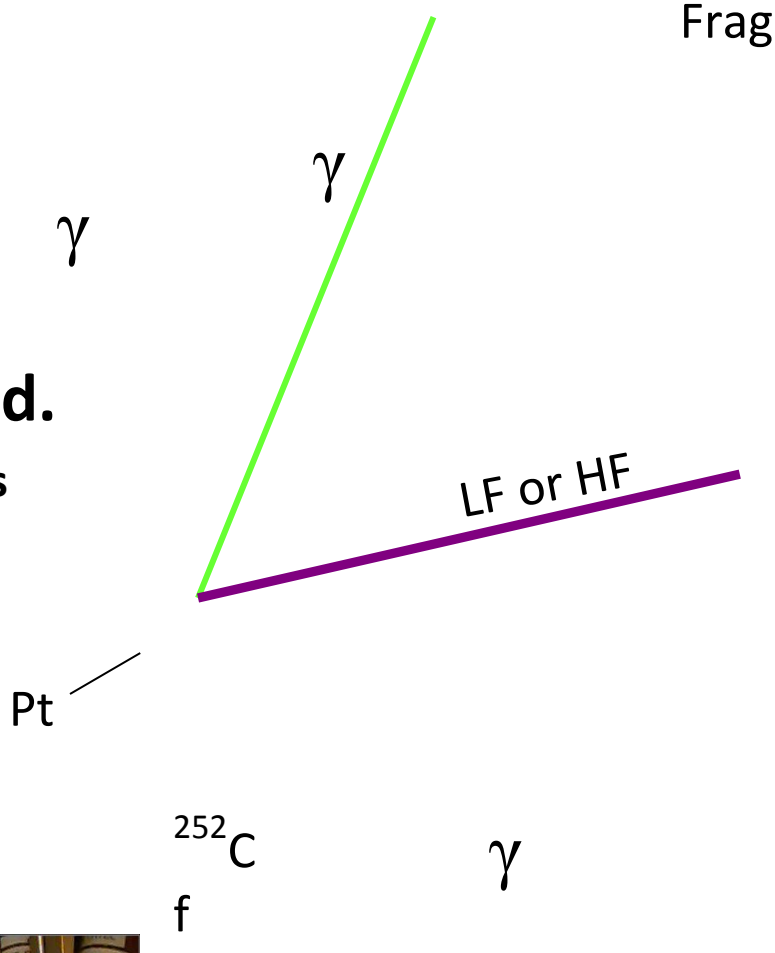


Courtesy ANL CARIBU Proposal

Experimental Setup

Gammasphere
98 Detector Units

LF = Light Fission Fragment
HF = Heavy Fission Fragment



Trigger Cond.

γ^4 + Hercules

CsF Monitoring Detector

Hercules

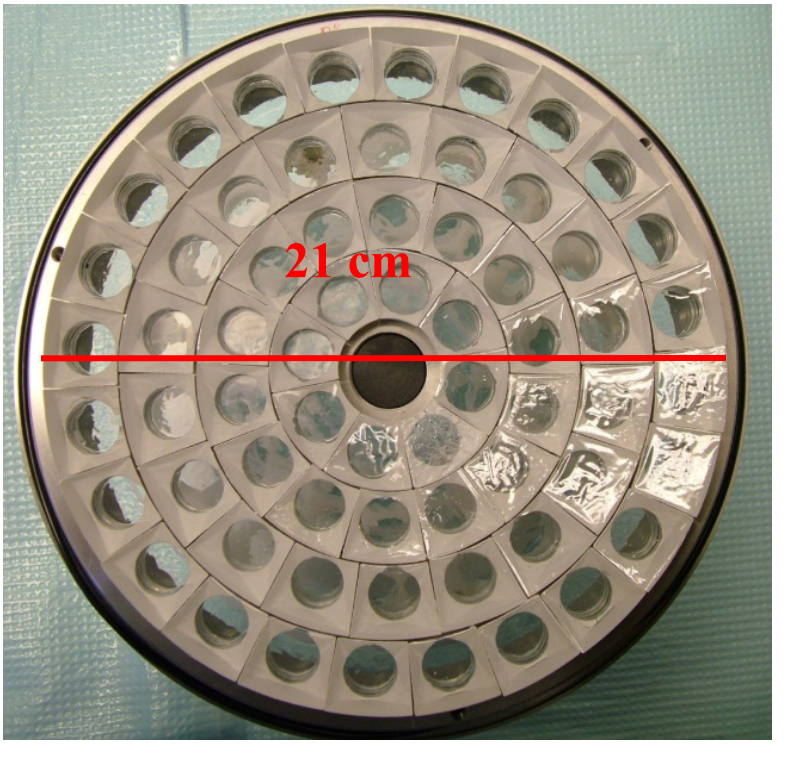
Consists of 64 fast-plastic detectors arranged in 4 rings

Its main use is to facilitate γ spectroscopy in the actinide region in conjunction with Gammasphere (evaporation-residue detector) Ref. **Rev-05**

When used as fission-fragment detector, fast-plastic scintillator foils of 1.5 – 2.5 mg/cm^2 thickness are used

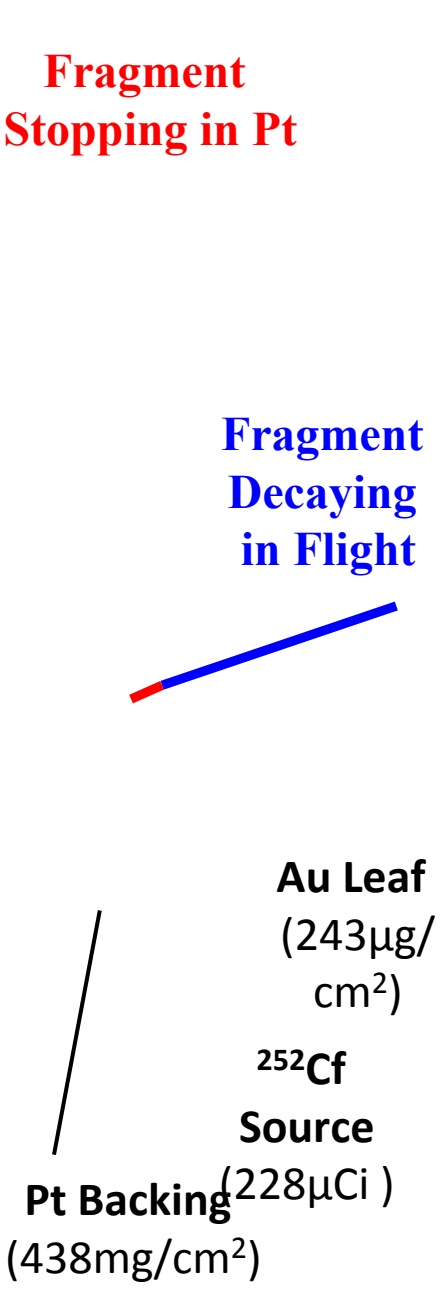
It is located 23.2 cm from the source (or target)

It is compatible with 98 Gammasphere HPGe-BGO units



θ = 4.1° - 26.8° (D_{tgt}=23.2 cm)
Measure ToF, pulse height, & fragment direction

Technique: Traditional DSAM



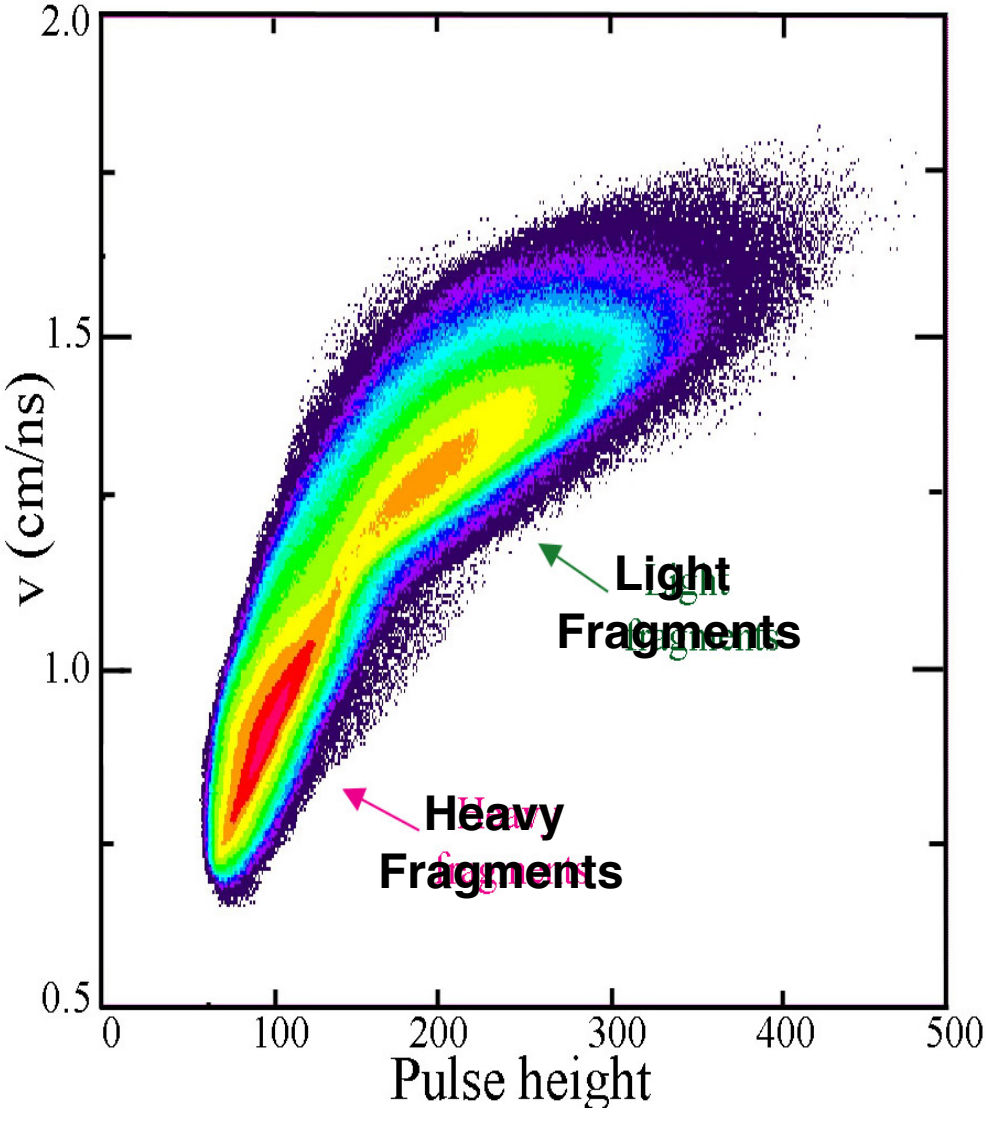
Hercules detects the fission fragments (**FF**) that escape the source arrangement and determines the fission axis, which serves as orientation axis for the subsequent DSAM analysis.

The Pt backing stops the complimentary FF in ~1ps.

"Stopped" and "shifted" γ–ray peaks are detected by Gammasphere. The γ–ray spectra are sorted according to angles (e.g. 60°,90°,120°)with respect to the orientation axis. Asymmetric peaks (lineshapes) are obtained like in a "traditional" DSAM analysis.

The data set typically consists of FF-γ^3 events, subject to gating. The measured lineshapes are analyzed with the code of Ref. **Wel-96**

Hercules Gating



Available Data

2.1 x 10^9 Fission Fragments

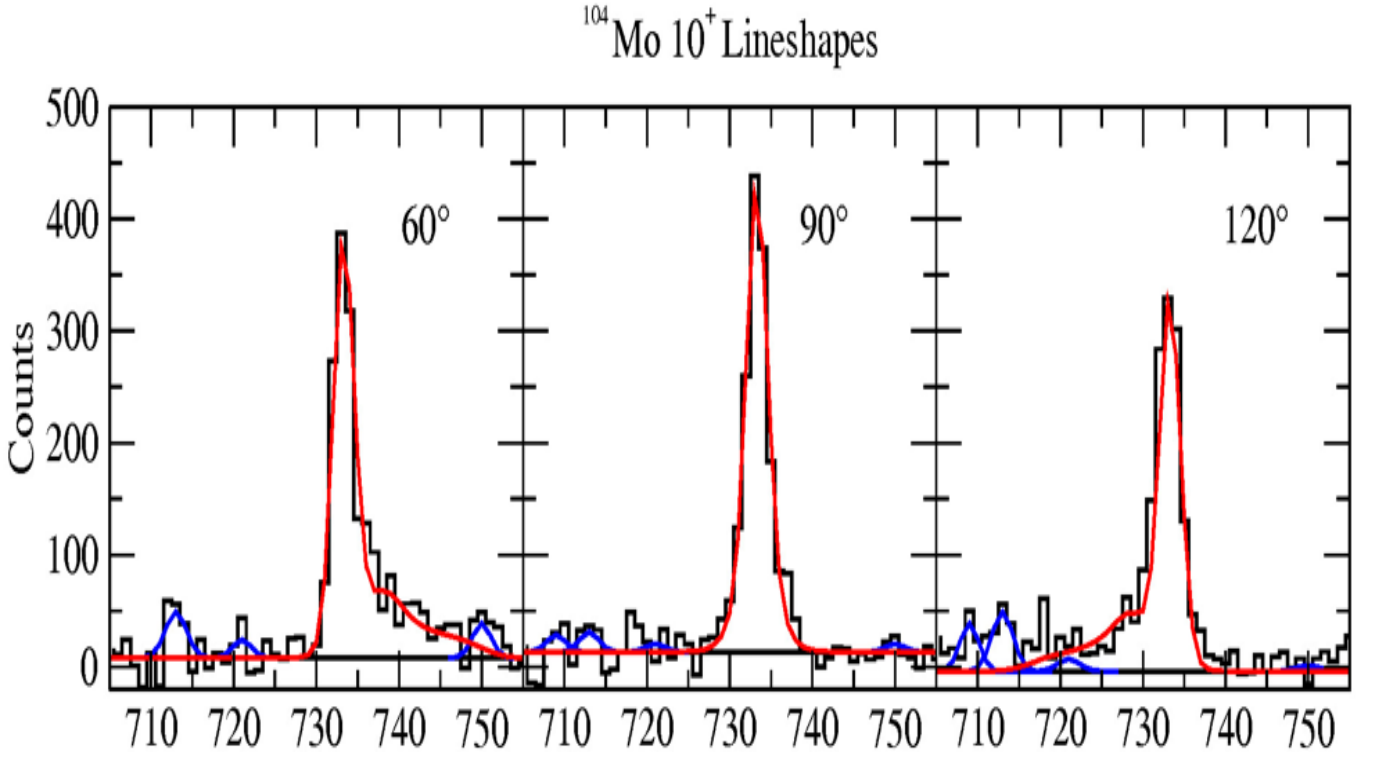
2.5 x 10^{10} Total γ-rays

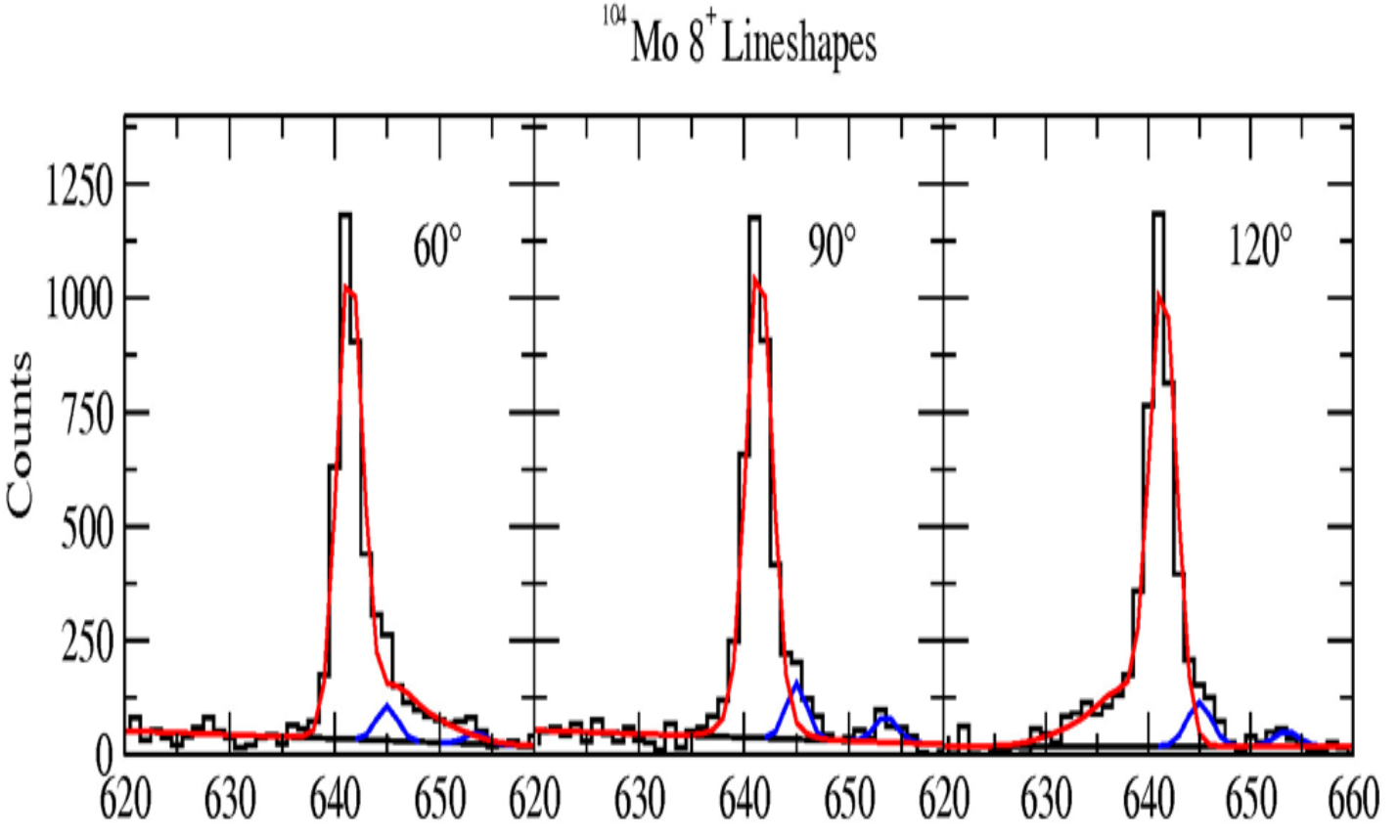
Most Probable Velocities

v_{LF} = 1.35 cm/ns

v_{HF} = 0.95 cm/ns

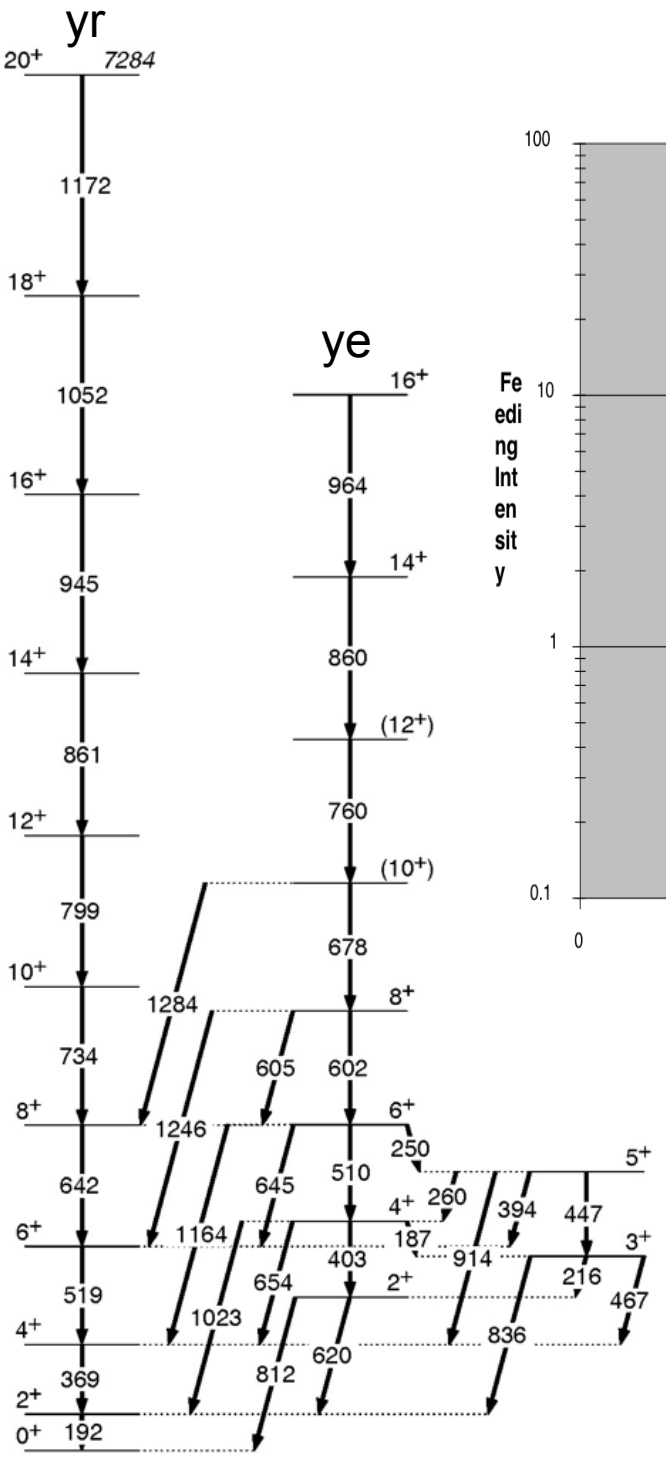
By gating on the fission-fragment mass peak of interest, the γ–ray spectrum is enriched in the corresponding lines.

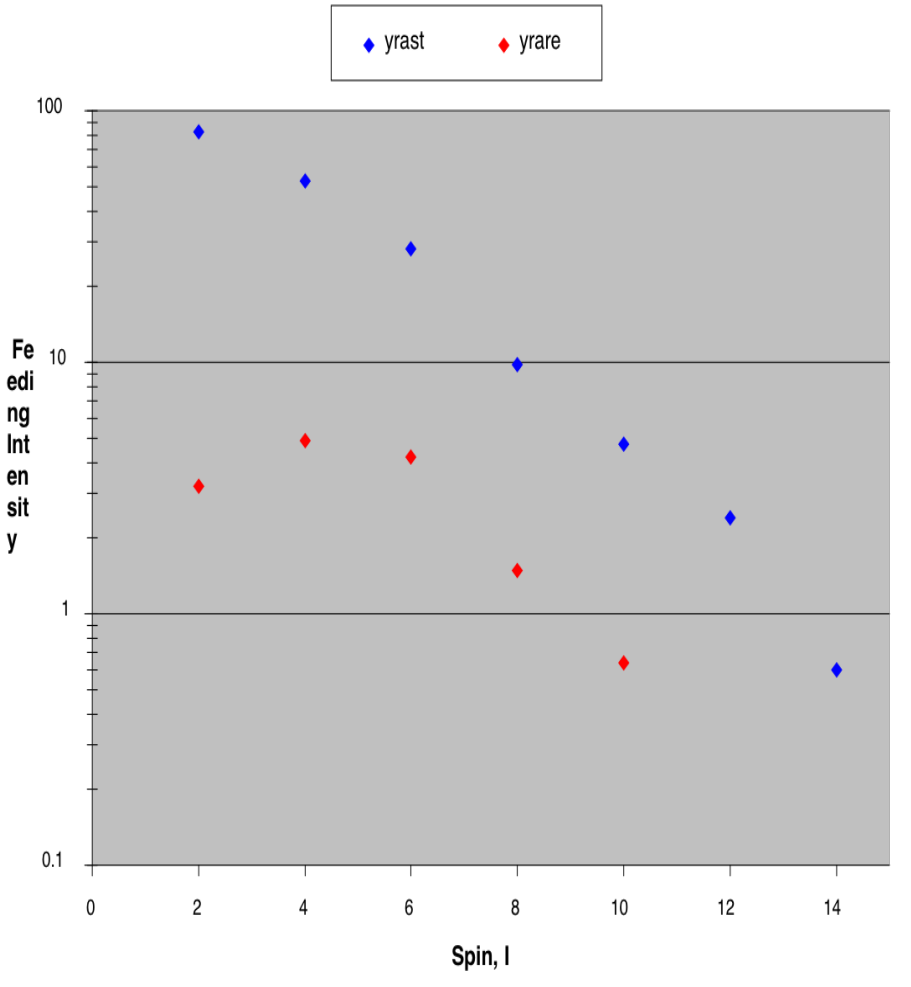




Known contaminants lines (blue) are taken into account.

^{104}Mo (partial)

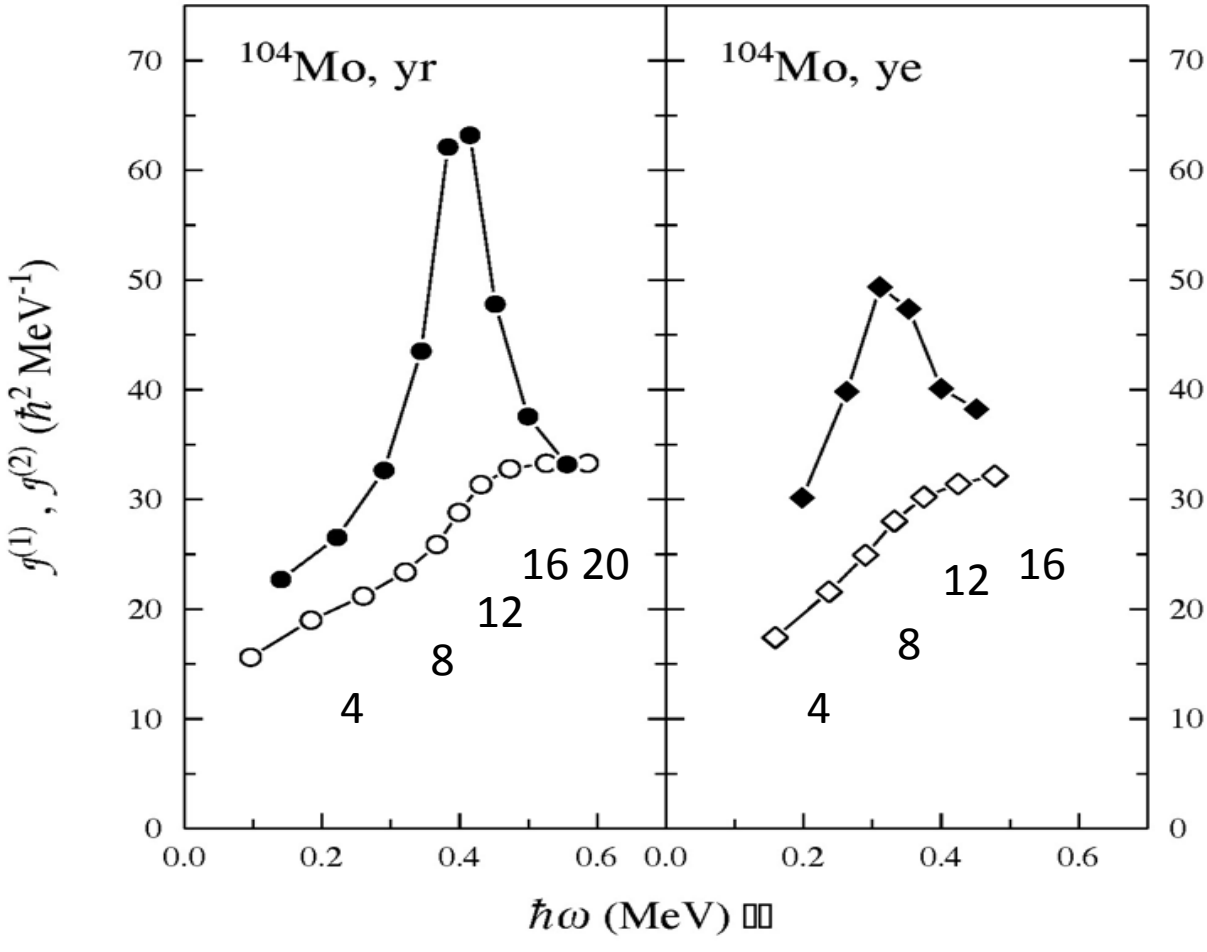




= lifetimes measured

Features of ^{104}Mo level scheme

i. There is a band crossing, due to $(\nu h_{11/2})^2$ alignment, at rather low spin. See moment of inertia plots.



ii. The even-spin side band (ye) is assigned K = 2, based on measured branching-ratios and $B(E2)_{in}/B(E2)_{out}$ ratios (Alaga rule).

iii. The 2_2^+ state has a low excitation energy (620 keV relative to the 2_1^+ state). For comparison, γ bands in the rare-earth region are located ~ 1 MeV relative to the yrast band. The features (ii) and (iii) suggest that ^{104}Mo is "γ soft".

Theoretical model (CRHB+LN)

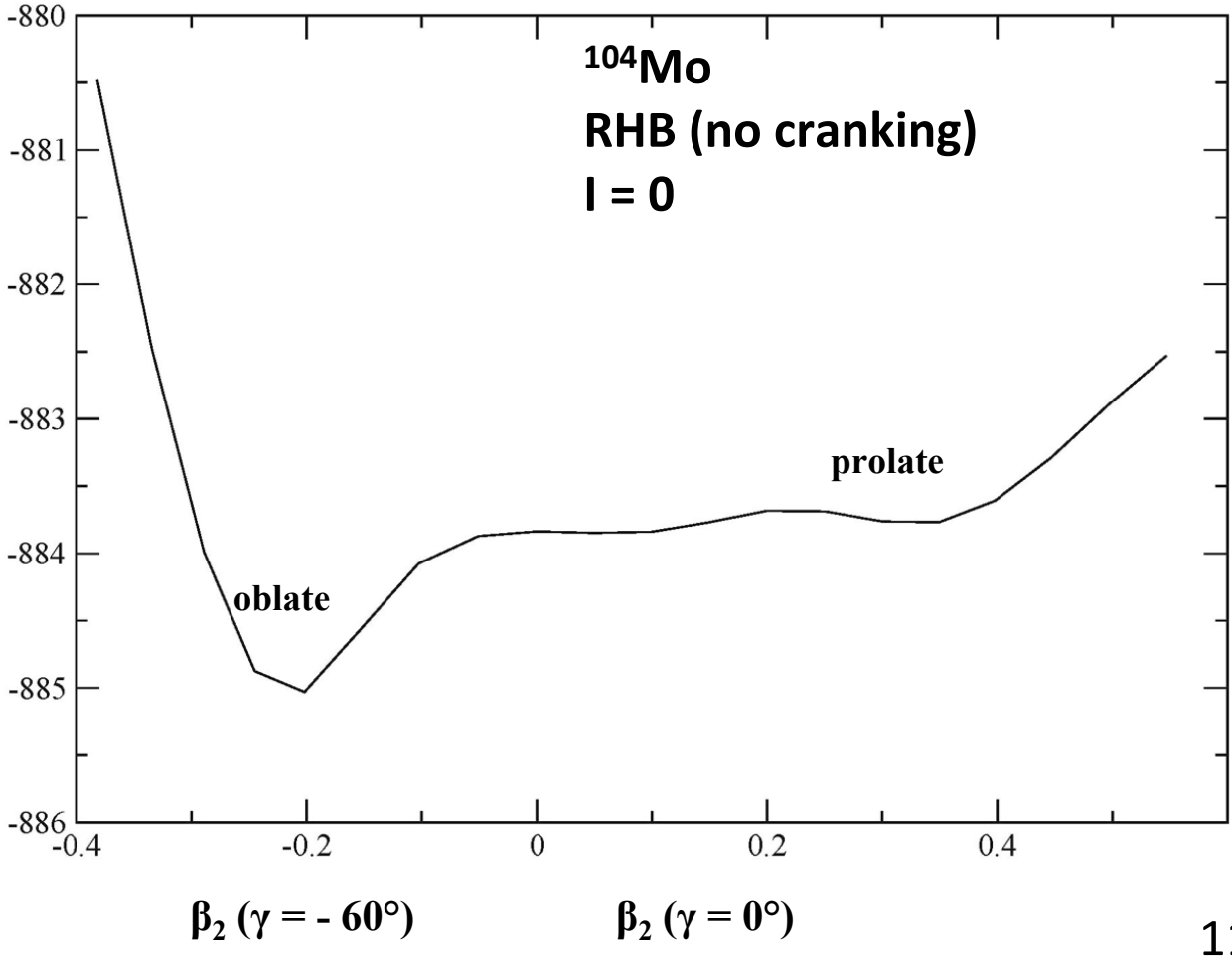
Cranked **R**elativistic **H**artree-**B**ogoliubov (**CRHB**) method for deformation

Lipkin-**N**ogami (**LN**) method for treatment of pairing

NL3* parameterization of the Relativistic Mean Field Lagrangian

See Refs. **Afa-00**, **Afa-05**

Example: Potential Energy Surface



Observations and first conclusions

The quadrupole moments as a function of spin show overall a nearly constant behavior. Perhaps the trend is that of a step function with a small step "down" at and above the band crossing, which occurs in the range roughly between $I^{\pi} = 8^{+}$ and 12^{+}.

The quadrupole moments for the positive-parity side band tend to be somewhat larger than those for the yrast band. This may be attributed to the two-quasiparticle nature of the side band.

Legend

● ♦ ↑: Present data

● (yrast), ♦ (side band), ↑ (yrast lower-limit)

○ (Ref. **Lit-xx**)

Full and dotted lines (CRHB+LN calculations)
Dashed lines (fixed-deformation calculations)

Note that lines correspond to prolate solutions unless indicated otherwise. Lines are labeled by their γ value if two solutions are found.

Comparison with Theory

Results from two types of calculations are shown: so-called fixed-deformation calculations, which are self-consistent only in the pairing part, and CRHB+LN calculations. The results from prolate (fixed deformation) and near-prolate solutions (CRHB+LN), are quite close to the data. The latter solutions **typically** have parameter values of γ between -20° and -30°. The exception is ^{102}Mo, where solutions with γ = -15° and 20° are found. Oblate solutions, thought to be energetically favorable at low spin, are excluded by the Q_t (and $J^{(1)}$) data.

The lack of theoretical curves roughly between I = 8 and 12, in most of the cases, is due to the fact that the calculations are done as a function of rotational frequency. In the band-crossing region, spin values are missing. Here configuration mixing also plays a role. For I > 12, the situation is sort of rescued: the band crossing reduces pairing and, thus, the mixing becomes weaker. A general problem is the softness of the potential energy surface. The small height of the barrier between the oblate and prolate minima makes the relative energy between the two minima strongly parameterization dependent.

Conclusions

New transition quadrupole moments for rotational states in $^{102\text{-}108}$Mo and $^{108\text{-}112}$Ru are reported. The highest spin state reached in these measurements is 18^+ (^{106}Mo).

The quadrupole moments are compared with mean-field calculations, in particular calculations using the CRHB+LN approach. It is found that the oblate solution does not fit the data and can be discarded. The prolate solutions are closer to the data and fit some aspects of the data.

More calculations are in progress. The emphasis is on searching for prolate solutions with $\gamma > 0°$ in cases other that ^{102}Mo. Models that go beyond mean-field approaches are also being considered, e.g. those based on the generator-coordinate method.

References

Afa-00 A.V. Afanasjev, P. Ring, J. Konig, NPA 676, 196 (2000)

Afa-05 A.V. Afanasjev and S. Frauendorf, PRC 71, 064318 (2005)

Lit-xx Literature values from NNDC data base and Ref. Smi-12

Rev-05 W. Reviol et al., NIMA 541, 478 (2005)

Shi-12 Y. Shi et al., PRL 108, 092501 (2012)

Smi-12 A.G. Smith et al., PRC 86, 014321 (2012)

Wan-11 X. Wang et al., PLB 702, 127 (2011)

Wel-96 J.C. Wells and N. Johnson (private communication)

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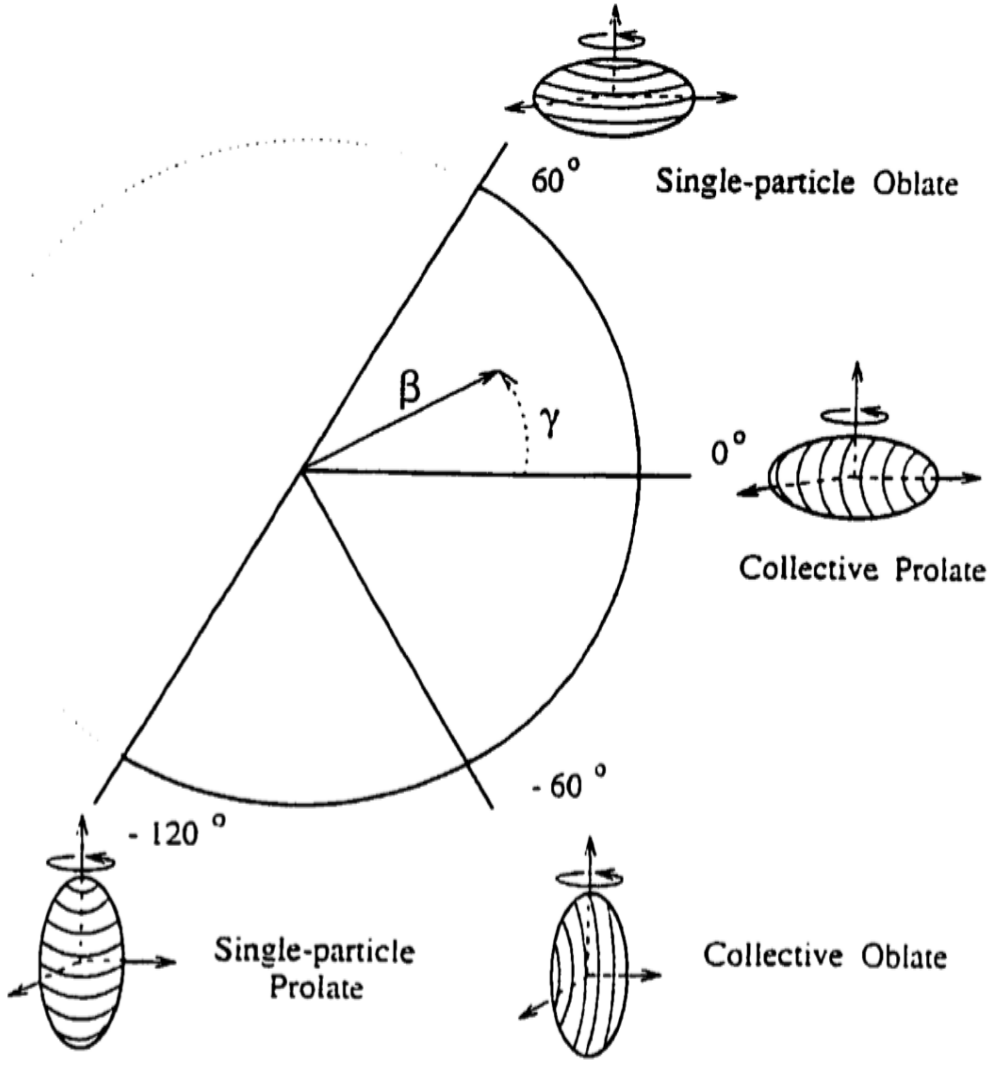
Lund Convention