# Implementation of the recoil distance Doppler-shift technique at ISOLDE

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1. **The MINIBALL Plunger device for RDDS experiments at ISOLDE: Considerations and construction**

2. **The first RDDS campaign at ISOLDE:**
   **→ incomplete fusion reactions**
   **→ Coulomb excitation**

*RDDS: recoil distance Doppler-shift*

Funded by the German BMFTR, Joint Project 05P2024 – ISOLDE, Grant No. 05P24PK2

Federal Ministry of Research, Technology and Space

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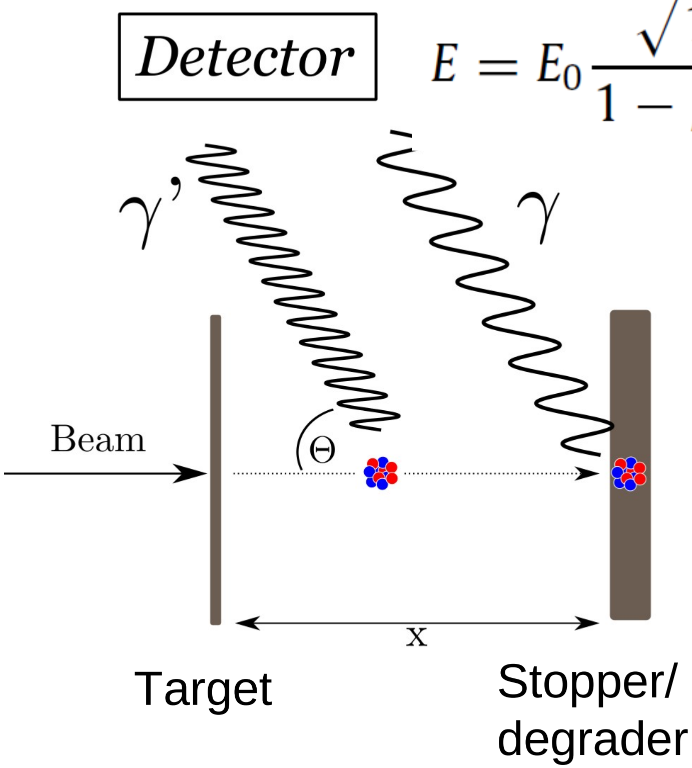
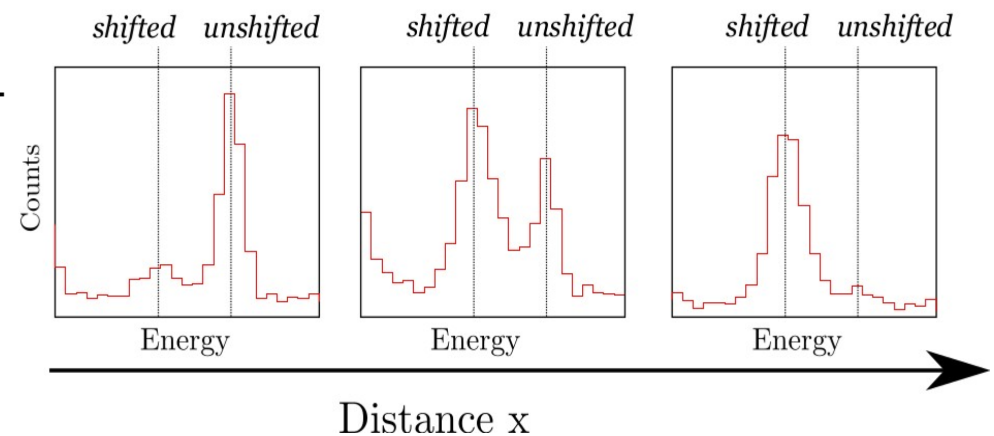
# The recoil distance Doppler-shift (RDDS) technique

RDDS: level lifetimes in ps range:
→ absolute transition strengths
→ independent of reaction mechanism (but recoil velocity > 1%c)
fusion-evaporation, also incomplete; Coulex; direct reactions; transfer,...

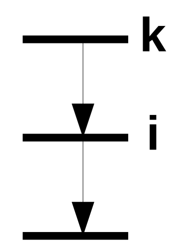



$$E = E_0 \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\theta)}$$




Analysis: e.g., differential decay curve method DDCM

$$\tau_i(x) = \frac{1}{v} \cdot \frac{-R_i(x) + \sum_k b_{ki}\alpha_{ki}R_k(x)}{\frac{d}{dt}R_i(x)}$$




*A. Dewald et al., Z. Phys. A 334, 163 (89)*
*A. Dewald et al., Prog. Part. Nucl. Phys 67, 786 (12)*

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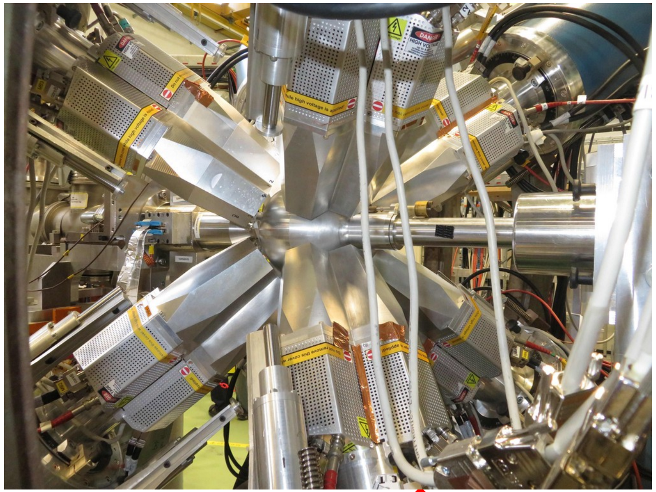
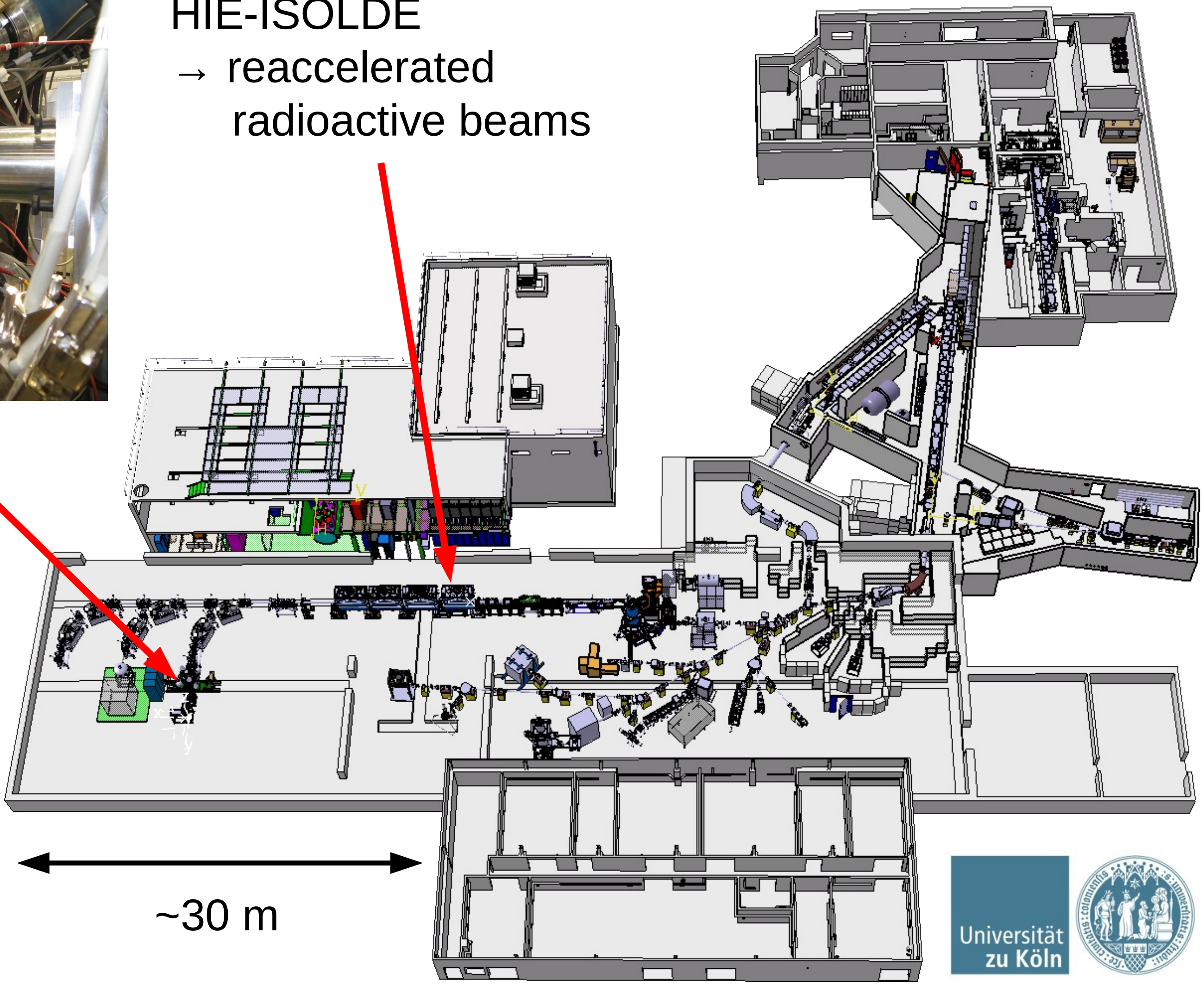
# First RDDS campaign at ISOLDE, summer 2025



MINIBALL γ-ray spectrometer
8 HPGe 3-fold clusters (6-fold segmented):
→ 4 clusters @ 45°
→ 4 clusters @ 135°
→ optimized for Doppler-shift exp.

HIE-ISOLDE
→ reaccelerated radioactive beams



~30 m

# Construction principle MINIBALL plunger

→ **Target – degrader distance range: 0 – 15 mm**
recoil velocities 2%c – 8%c = 6 – 24 µm/ps
→ sensitive range: ~ 1 ps – 500 ps

→ **High precision of target – degrader foil distances ~0.1 µm**
active feedback system to keep distance constant (capacitance method)

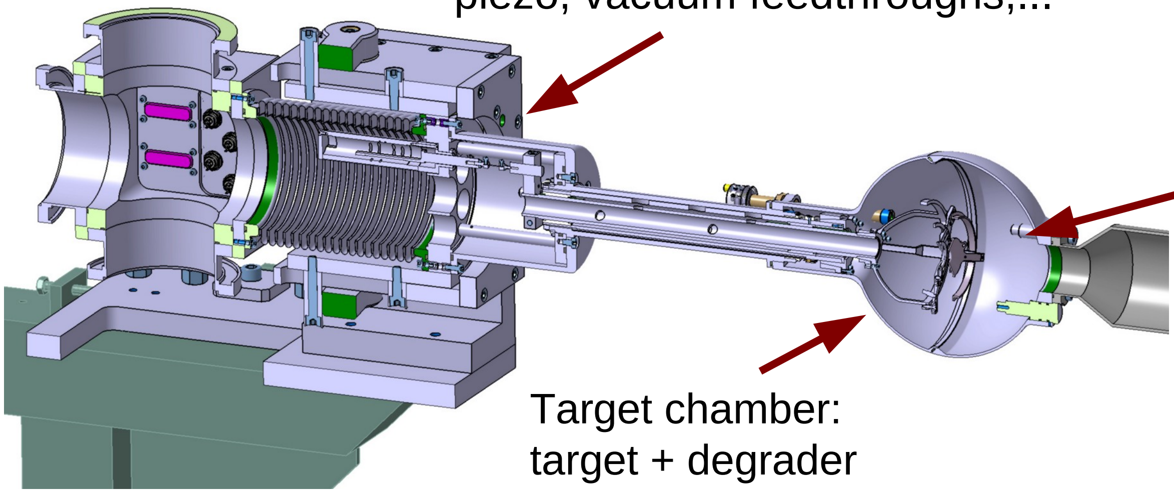
→ **Minimize material in target chamber**
mechanics for distance change, feedback system upstream

→ **DSSSD detector 30 mm after degrader:**
recoil identification, separation of reaction channels

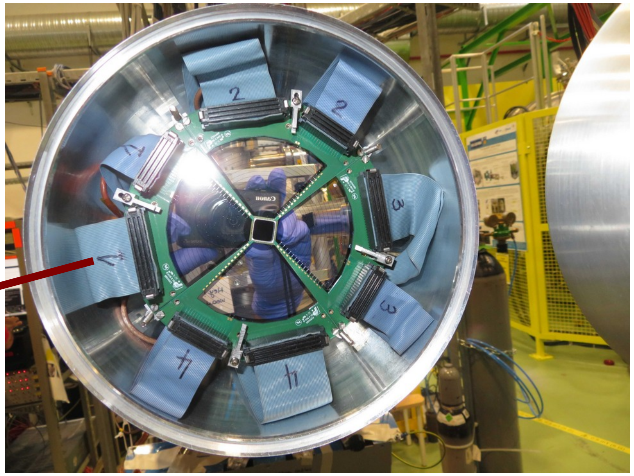
→ **Multifunctional target chamber**
plunger target/degrader easily exchangable with other target holders, e.g., for Coulex only

# Construction principle MINIBALL plunger

Plunger mechanics, motor,
piezo, vacuum feedthroughs,...



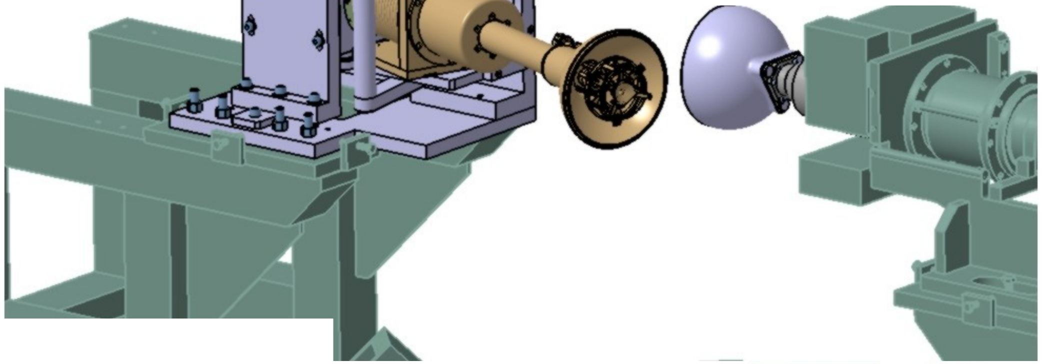
Target chamber:
target + degrader
holders/cones



DSSSD (+ Si PAD)
after target/degrader

Total length of plunger: ~80 cm

Pivot out of beamline
to get access to
chamber: DSSSD very
close to degrader



→ Easy replacement of plunger
target/degrader with target holder,
e.g., for Coulex only

***S. Thiel, IKP Cologne***

# First RDDS campaign at ISOLDE, summer 2025

**IS656 Lifetimes in $^{144}$Ba: commissioning experiment**

June 12 – 16, 2025

→ search for octupole correlations

Incomplete fusion (ICF) $^{144}$Cs @ 4.7 MeV/u + $^{7}$Li → $^{144}$Ba + 3n + $^{4}$He

**CF (IKP Cologne); data analysis: A. Didik, Cologne (PhD thesis)**

**IS761 Coulomb excitation and RDDS measurement of a triaxial superdeformed β-band in $^{162}$Yb**

June 18 – 25, 2025

→ $^{162}$Yb @ 4.1 MeV/u + $^{92}$Mo → $^{162}$Yb*

**R. Bark (iThemba LABS)**

**IS774 Investigation of coupled states near $^{208}$Pb**

July 24 – 31, 2025

→ lifetimes in $^{207}$Tl

ICF $^{206}$Hg @ 5.7 MeV/u + $^{7}$Li → $^{207}$Tl + 2n + $^{4}$He

**C. Porzio (ISOLDE)**

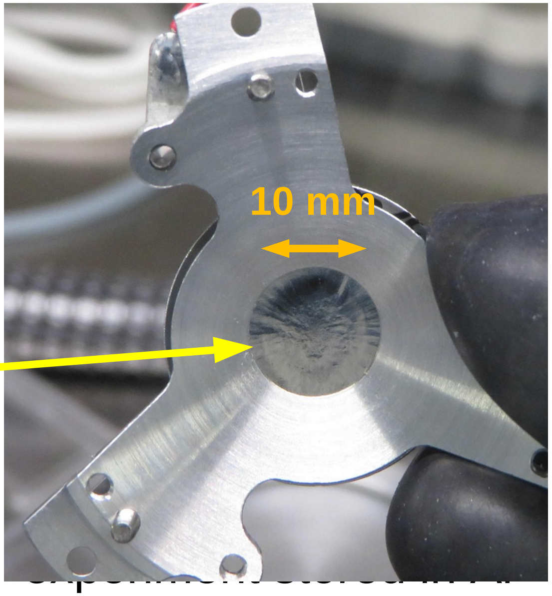
# IS656, IS774: $^{7}$Li plunger targets → a challenge!

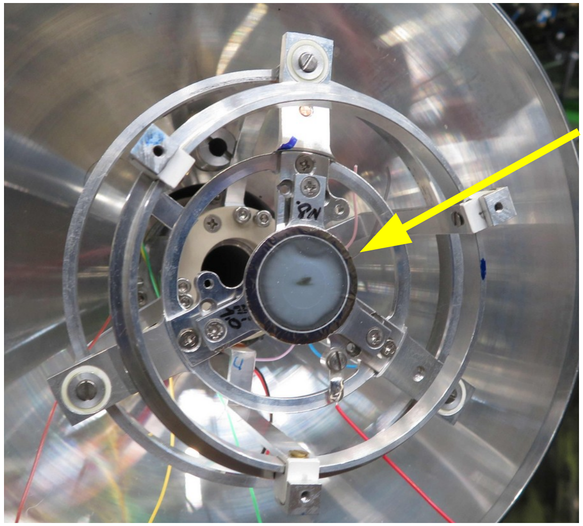
*A. Blazhev, Cologne*

→ Li plunger target: evaporate onto support foil

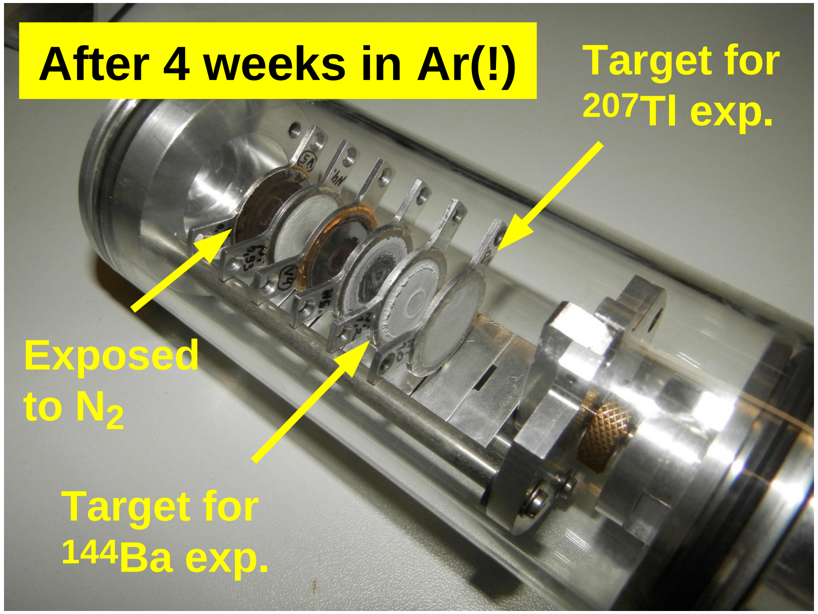
→ Li reacts with nearly everything ($O_2$, $N_2$, $H_2O$, …):
store, stretch under Ar, mount target VERY fast

→ Li alloys with many metals:
support foils of Ta, V, Au,… get very brittle
Li on Ni rather well stretchable



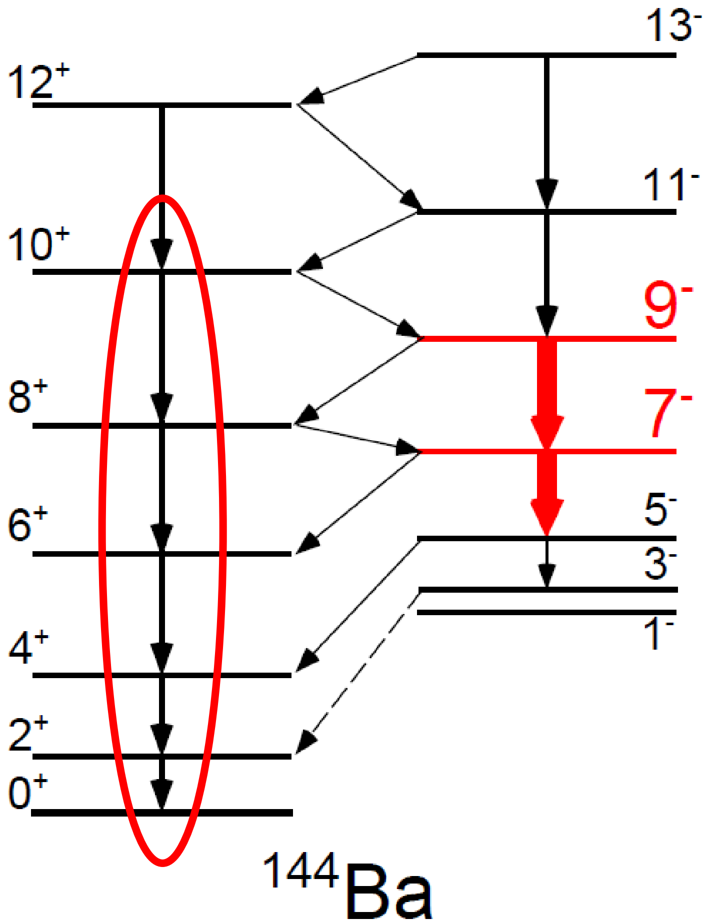



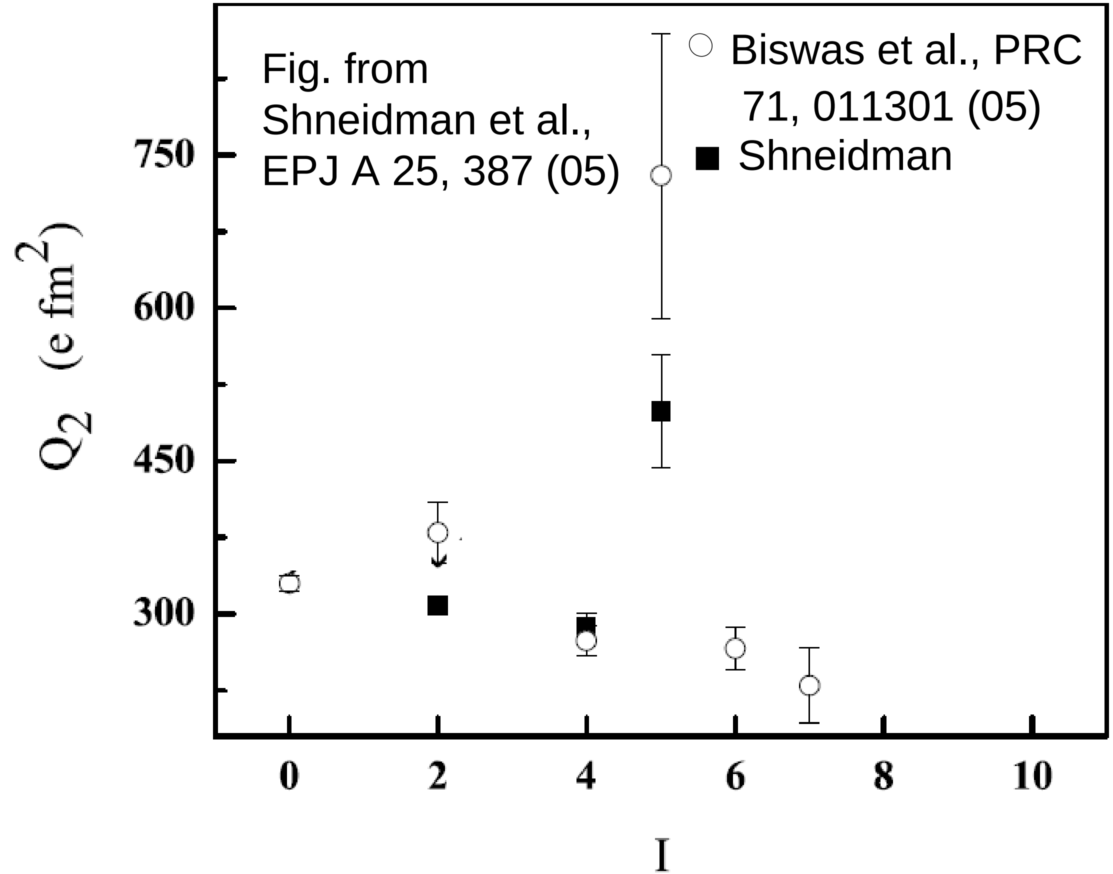
$^{7}$Li on Ni for
$^{207}$Tl exp.
→ stretchable,
→ ~30 μm offset




→ Alternative: LiF
But: ~5 times less Li for same thickness
LiF might crack off suport foil

# IS656: Investigation of octupole correlations in $^{144}$Ba
## Motivation

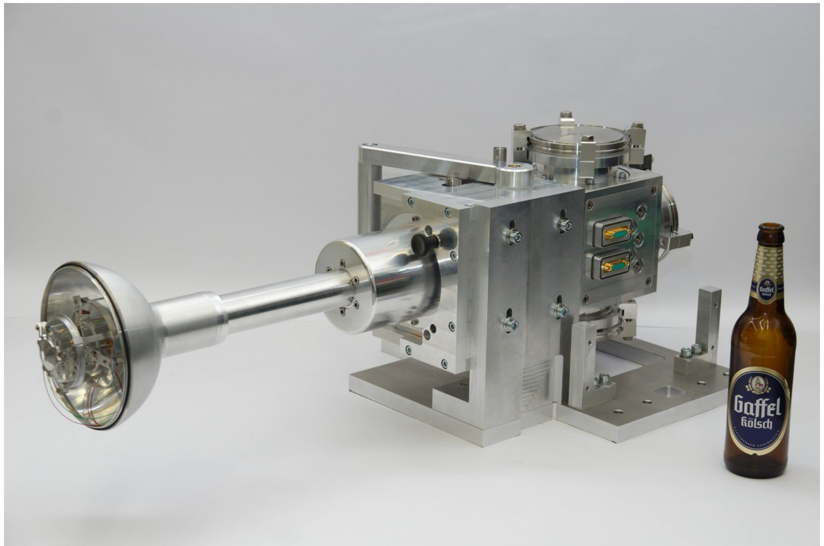


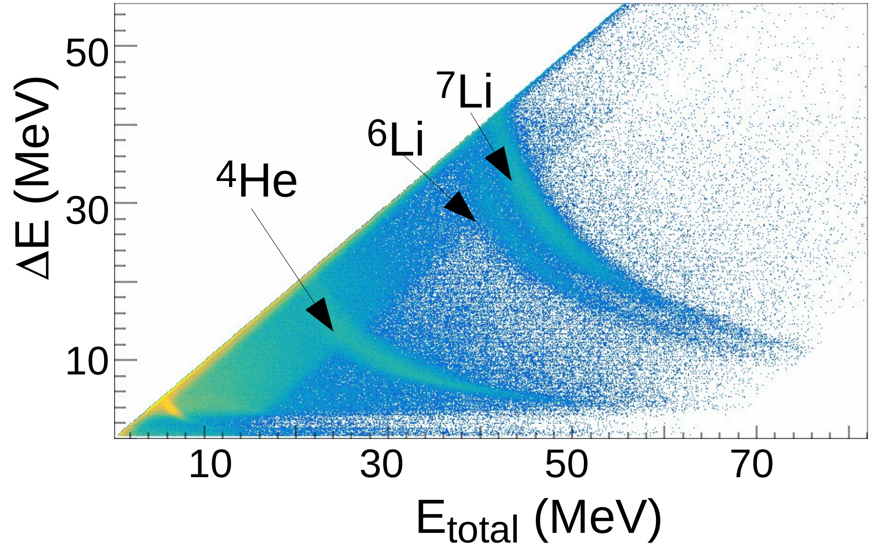




**Yrast B(E2) known:**
**$B(E2)_{yrast}$ ~ 50 W.u.**

- → **Shneidman: higher weight of quadrupole def. in negative parity band?**
- → **But B(E2; $9^- \rightarrow 7^-$) comparable to yrast B(E2)**
- → **B(E2; $7^- \rightarrow 5^-$) = 200 W.u. or 400 W.u.?**
- → **remeasure $\tau$ ($7^-$, $9^-$); measure $\tau$ ($5^-$) !**

# IS656: Investigation of octupole correlations in $^{144}$Ba




$^{7}$Li($^{144}$Cs, $^{144}$Ba) $^{4}$He + 3n

distances: 20 µm, 150 µm, 450 µm

Al 13 µm: stop heavy recoils

$^{144}$Cs
4.7 MeV/u

$10^{6}$ pps

$^{144}$Ba
8.0% c
24 µm/ps

$^{144}$Ba
4.4% c
13 µm/ps

$^{3}$H, $^{4}$He: average emission angle: 30°

$^{7}$Li: ~60°

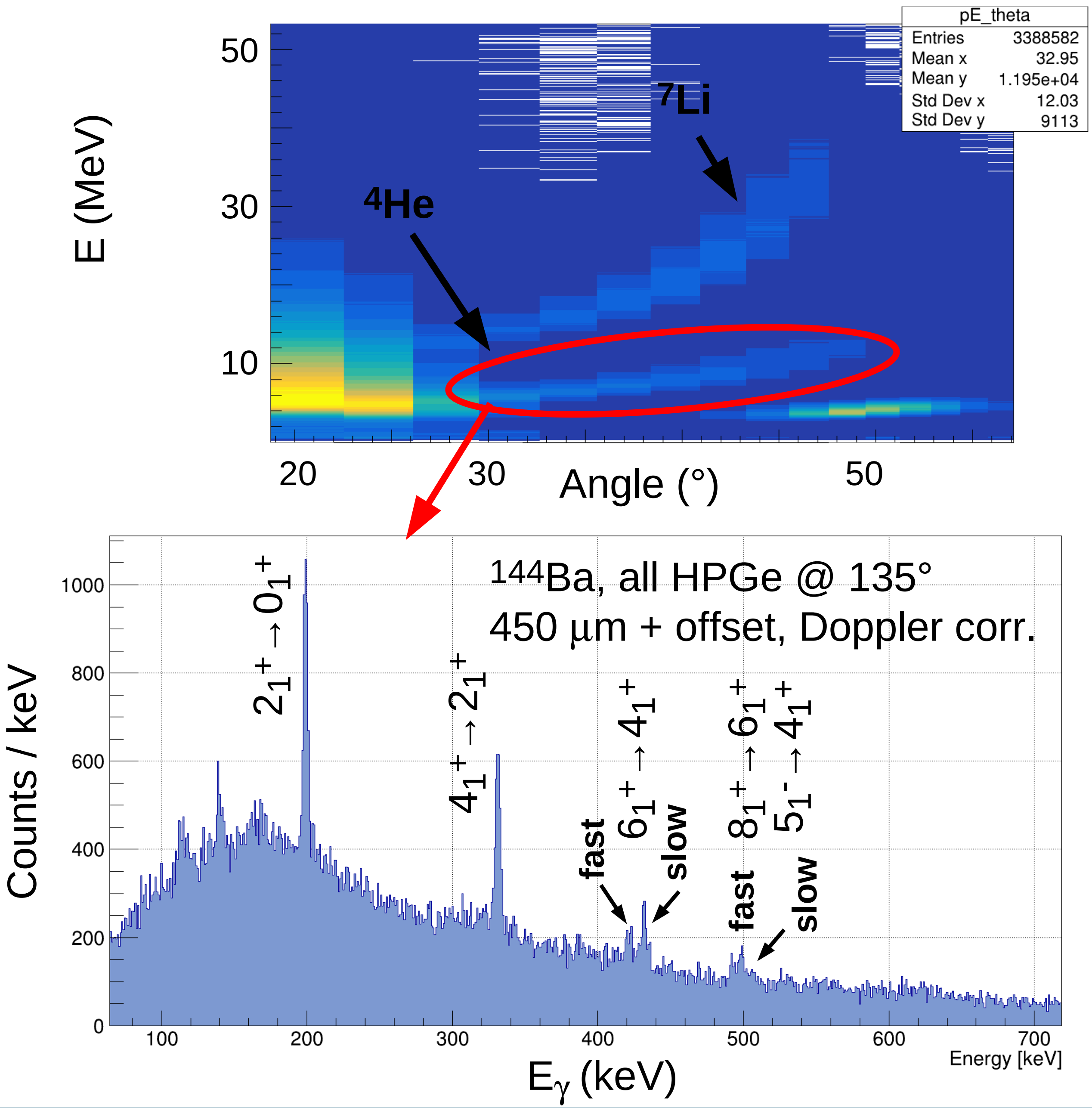
**_A. Didik, Cologne_**

Target
0.93 mg/cm$^{2}$ Ni
+ 1.3 mg/cm$^{2}$ $^{7}$Li

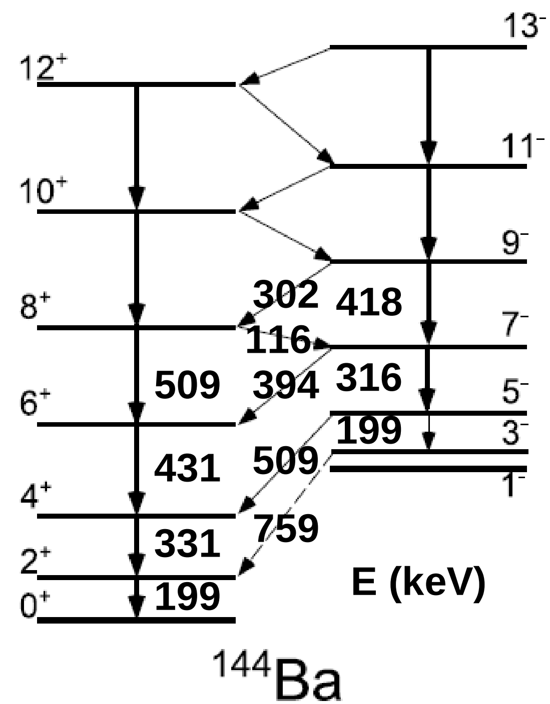
Degrader
11.5 mg/cm$^{2}$ Ta

147 um DSSSD
1.5 mm Si PAD
→ Θ, $\Delta E - E$
→ $^{3}$H, $^{4}$He, $^{7}$Li, ...

# IS656: Investigation of octupole correlations in $^{144}$Ba

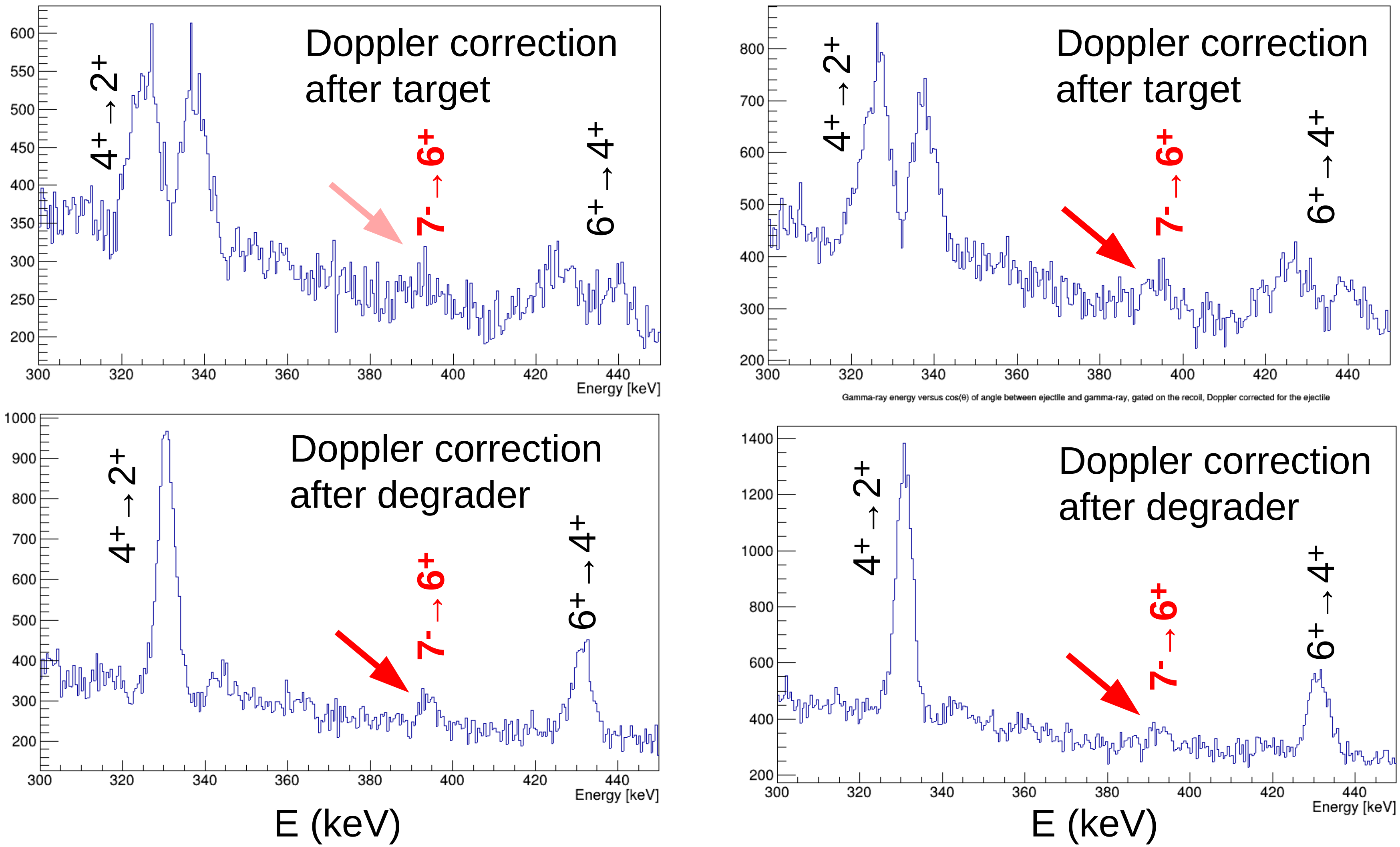



**Increase statistics (~x2)**
Only use ΔE(DSSSD)
+ angle(DSSSD)
→ avoid pile-up in PAD



# IS656: spectra $^{144}$Ba, all MINIBALL detectors @ 45°, 135°

**20 µm** **A. Didik, Cologne** **150 µm**



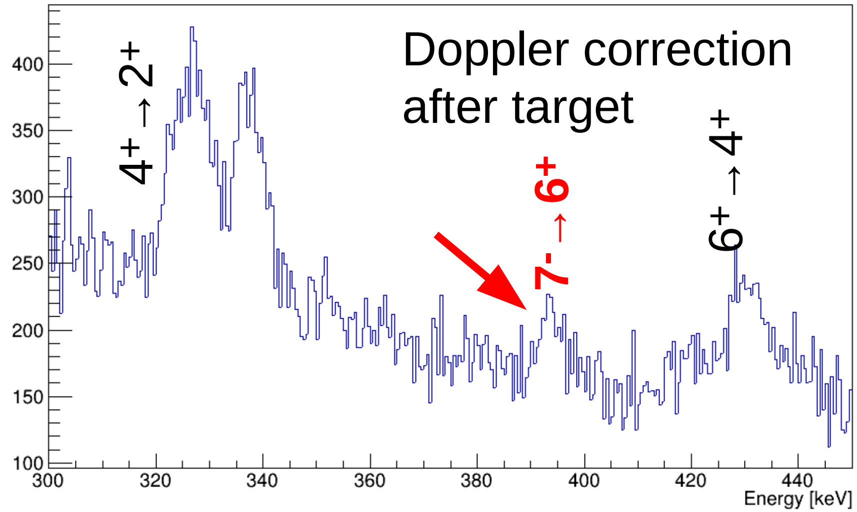

Known: $\tau(4^+)$ = 71(6) ps, $\tau(6^+)$ = 22(2) ps

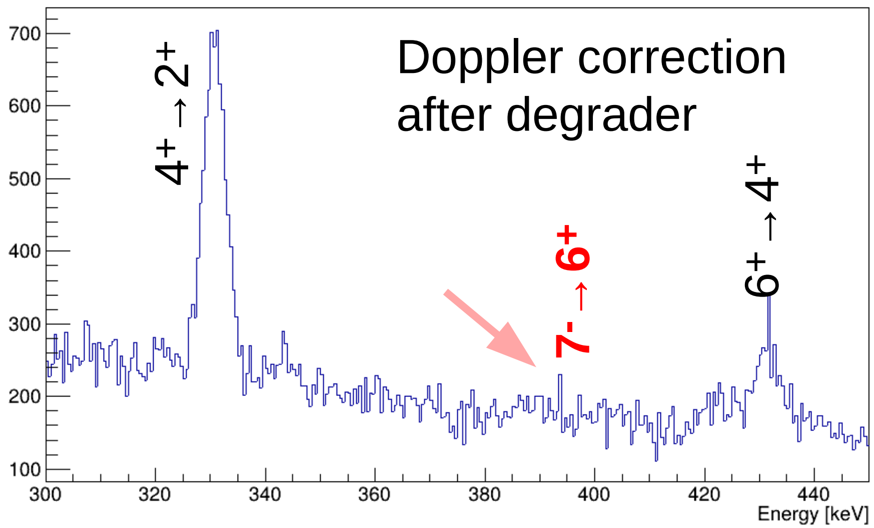
$v_T$ = 24 µm/ps, $v_D$ = 13 µm/ps

# IS656: spectra $^{144}$Ba, all MINIBALL detectors @ 45°, 135°

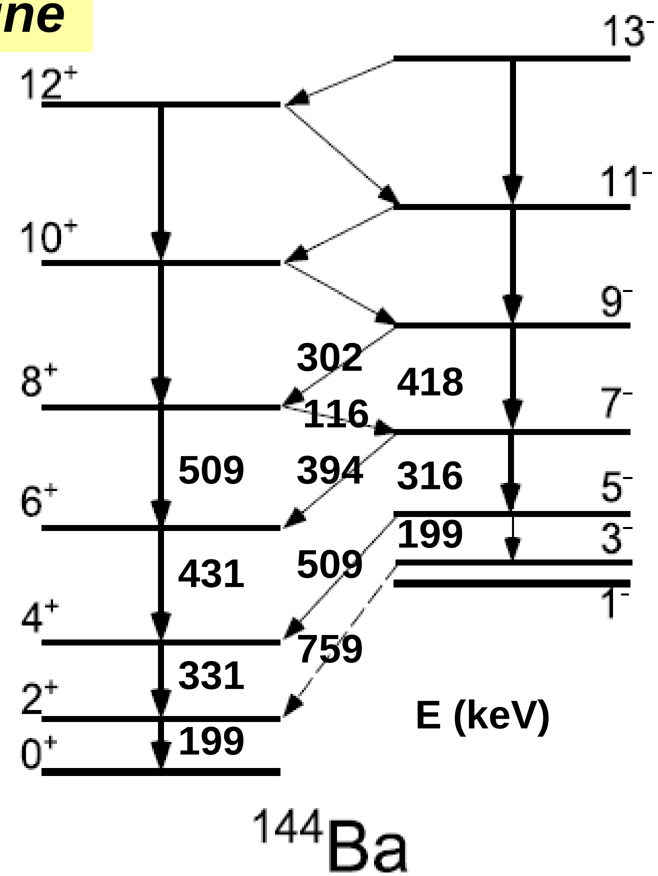
**450 µm**

***A. Didik, Cologne***




E (keV)




A first guess from our new data:

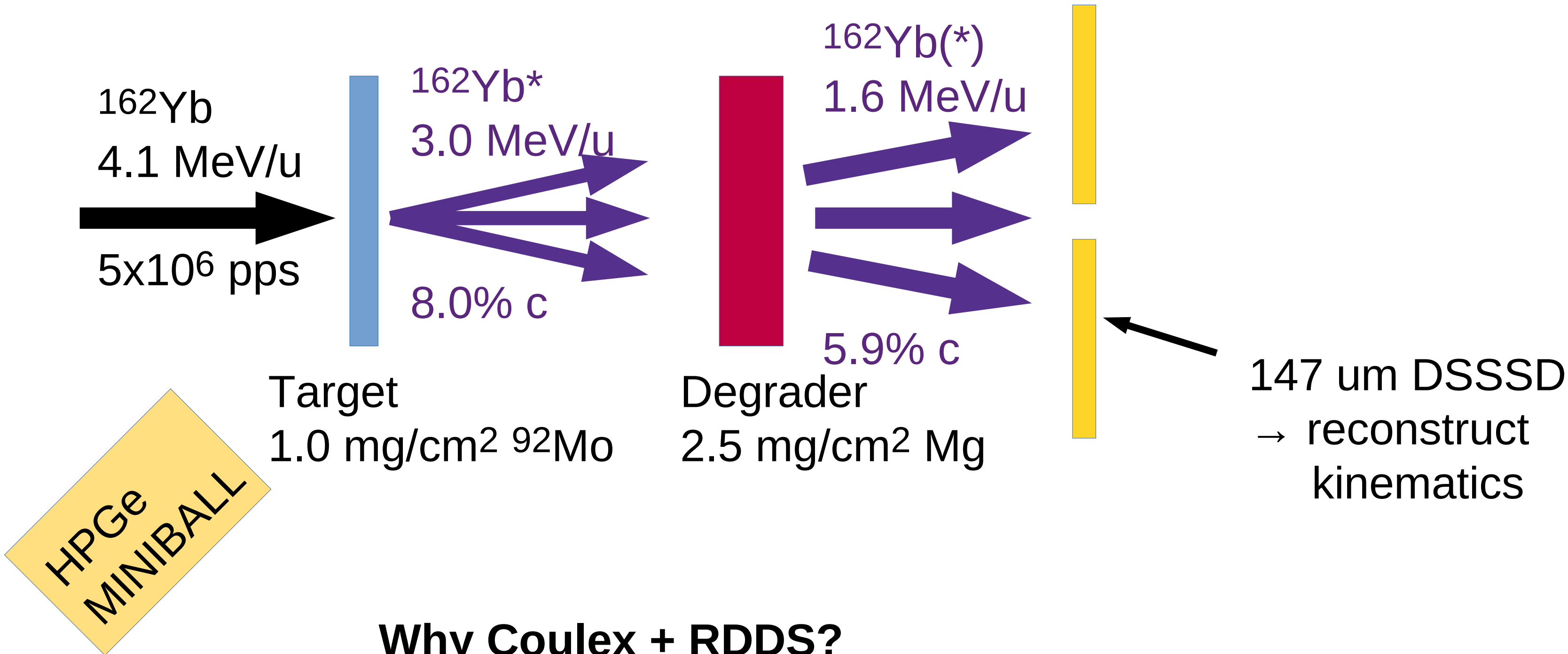
**τ(7⁻) = 15 ps**

→ B(E2; 7⁻ → 5⁻) ~ 69 W.u.

→ close to yrast B(E2), e.g.,

B(E2; 4⁺ → 2⁺) = 63 (5) W.u.

# IS761: Coulomb excitation and RDDS measurement of a triaxial superdeformed β-band in $^{162}$Yb




**Why Coulex + RDDS?**

→ large Coulex cross section: lifetime measurements with low intensity beams
→ no knowledge of absolute cross section needed
→ Coulex only a tool: can run near or above Coulomb barrier:
enhance cross section, interference from nuclear force not relevant

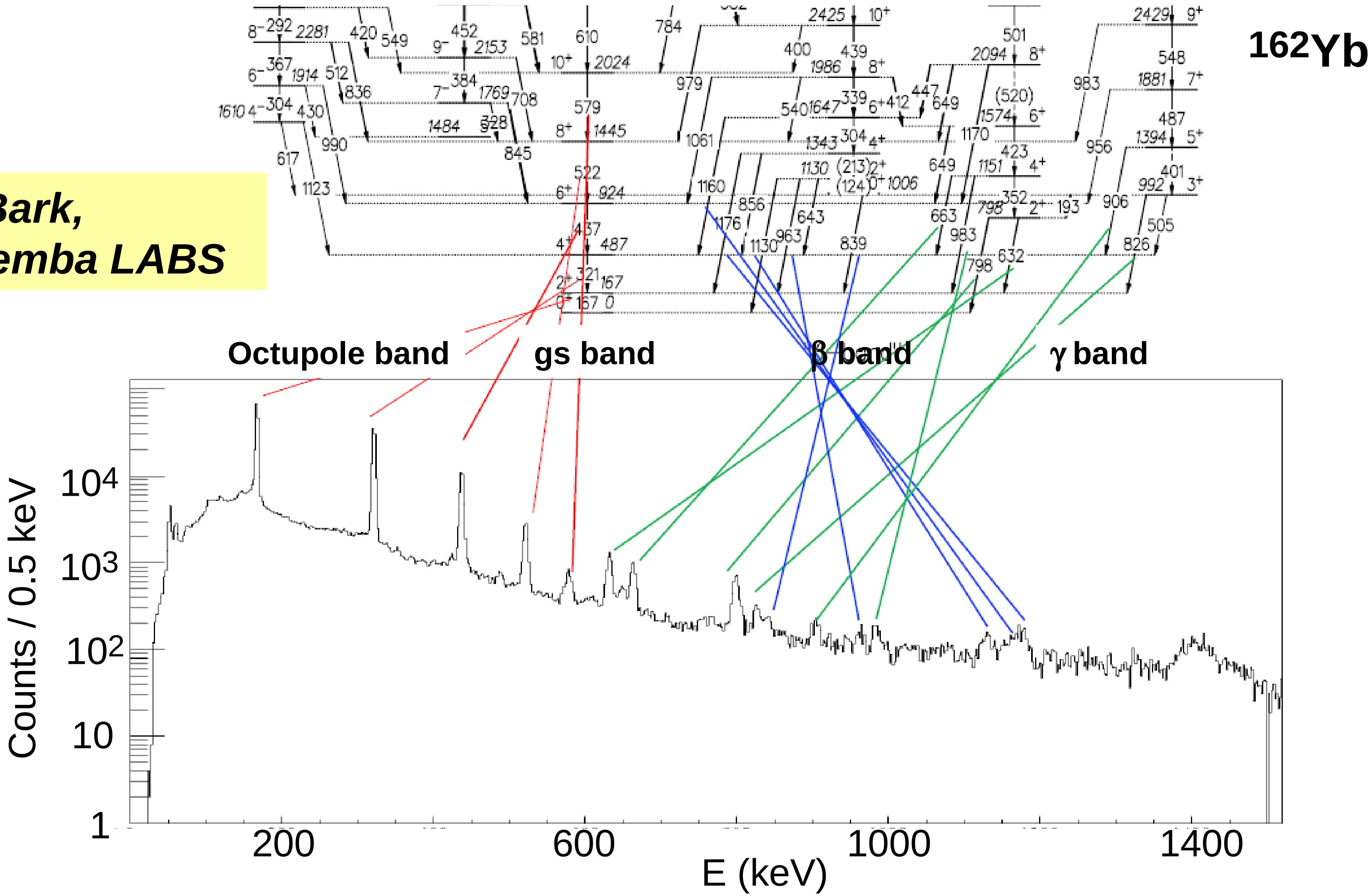
***R. Bark,***
***iThemba LABS***

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

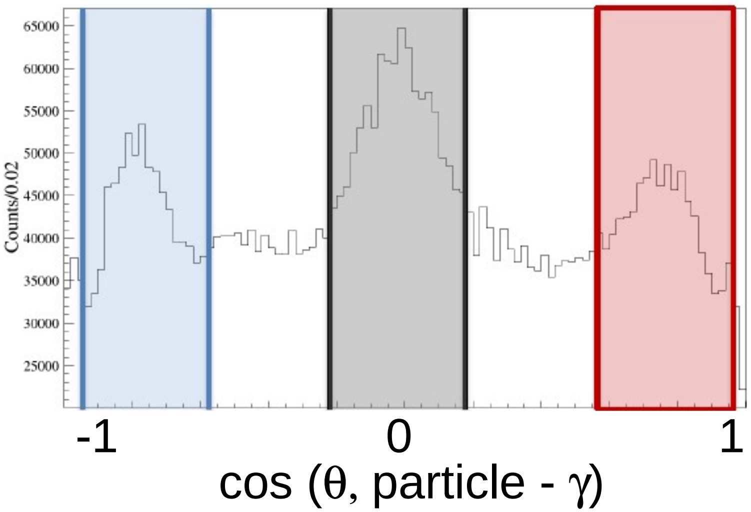
NRF National Research Foundation

# IS761: Coulomb excitation and RDDS measurement of a triaxial superdeformed β-band in $^{162}$Yb

***R. Bark, iThemba LABS***



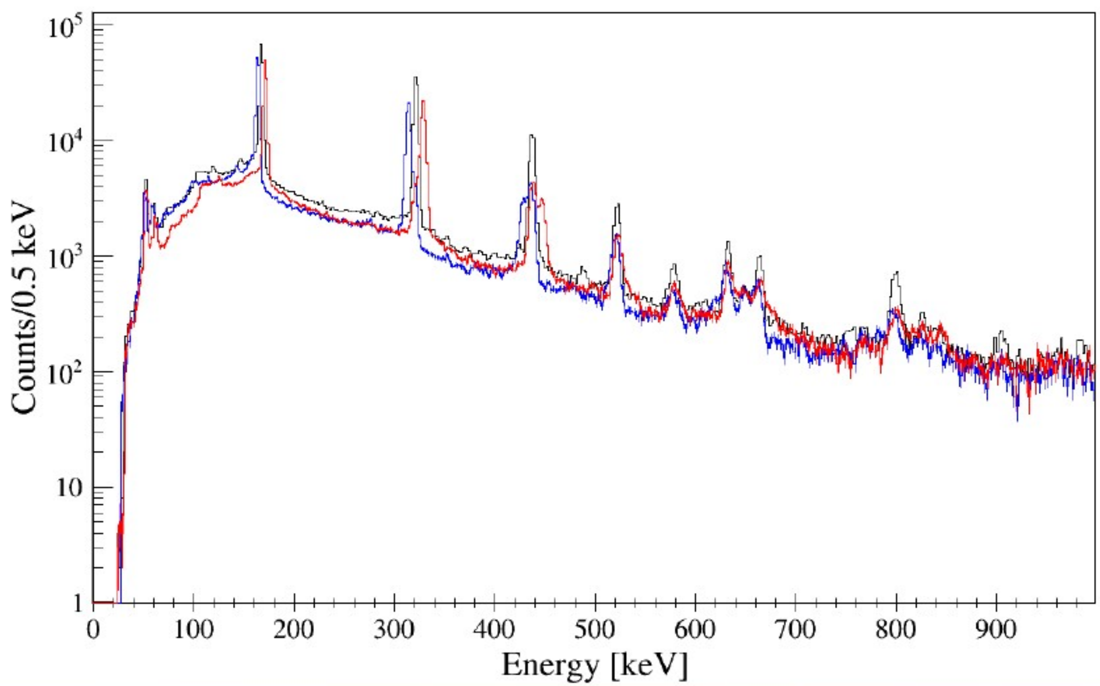
# IS761: Coulomb excitation and RDDS measurement of a triaxial superdeformed β-band in $^{162}$Yb




Blue gate = Blue spectrum
Black gate = Black spectrum
Red gate = Red Spectrum

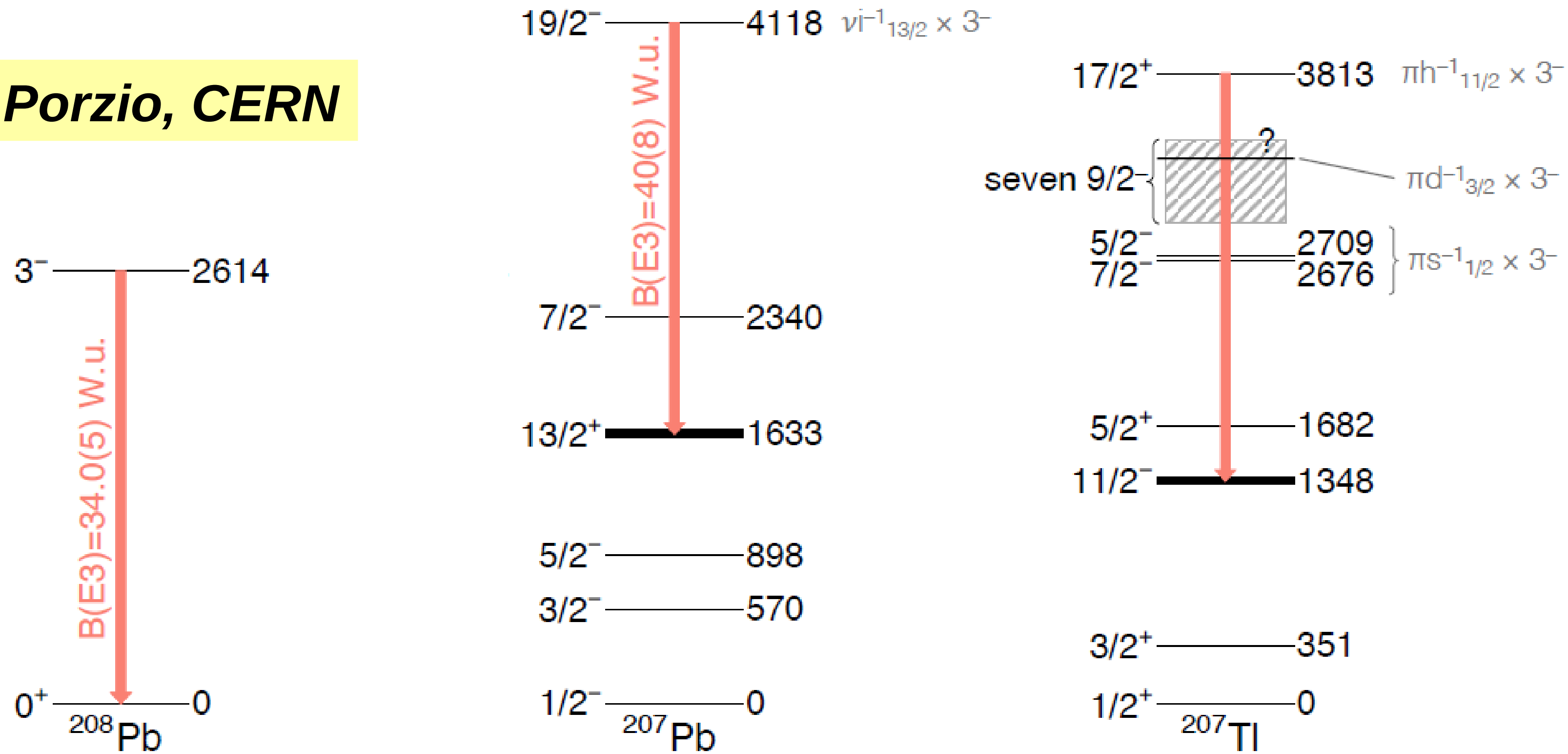
***R. Bark,***
***iThemba LABS***

Doppler corrected for fast comp. (after target)
target – degrader distance: 116 µm



# IS774: Investigation of coupled states near $^{208}$Pb

***C. Porzio, CERN***




Main goal: investigate collective, octupole nature of $17/2^+$ at 3813 keV in $^{207}$Tl

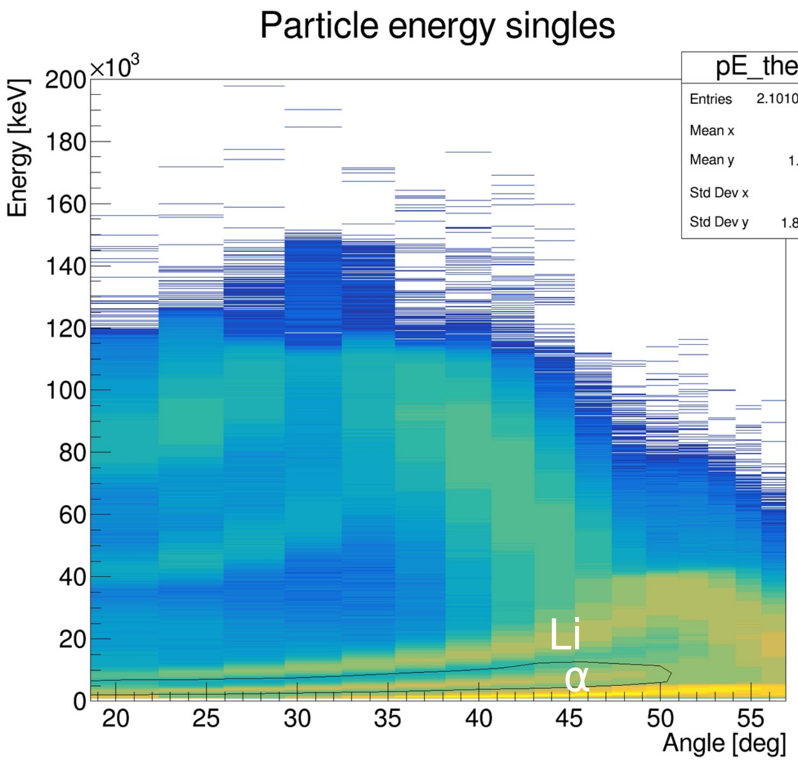
→ highest spin member of $\pi h^{-1}_{11/2} \times 3^-$ multiplet

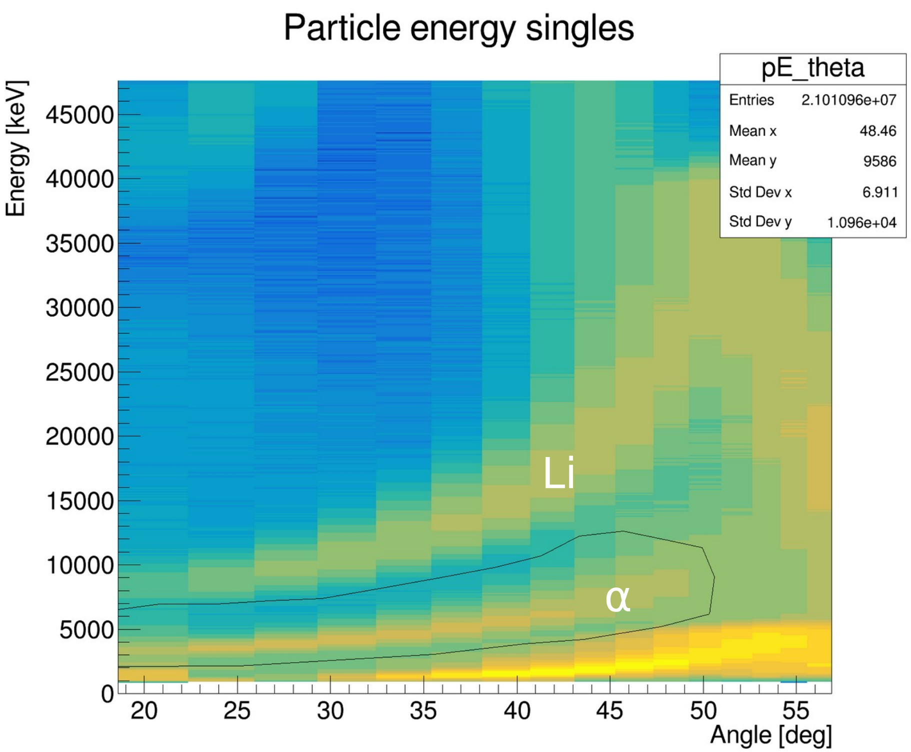
*M. Rejmund et al., EPJ A 8, 161 (2000)*

→ expect $\tau(17/2^+)$ ~ some ten ps

# IS774: Investigation of coupled states near $^{208}Pb$

Incomplete fusion with $^{3}H$ after $^{7}Li$ breakup to $^{206,207}Tl$:
gate on $^{4}He$ with DSSD → kinematics line identification in the ΔE_theta plot.
Avoid problems with pile-up in PAD




***C. Porzio, CERN***

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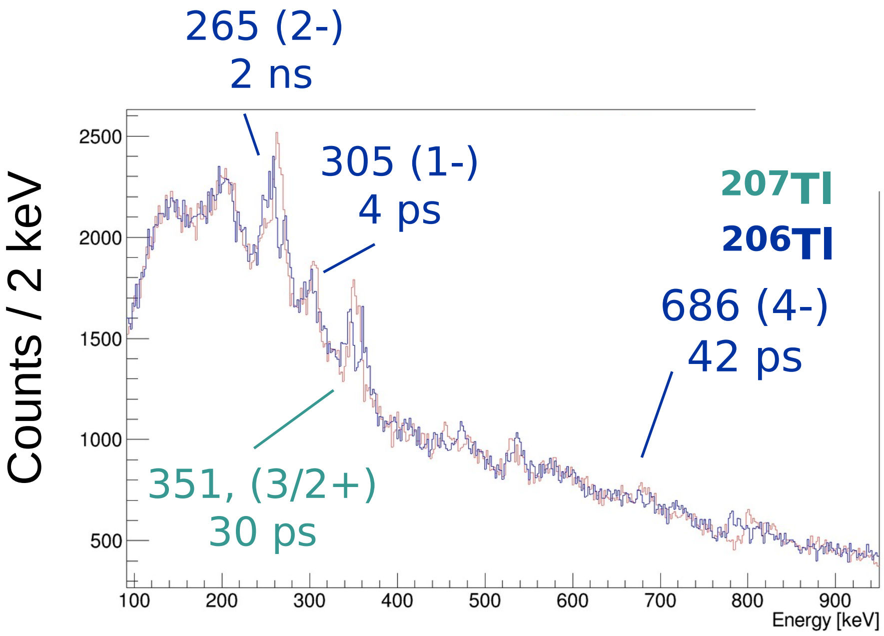
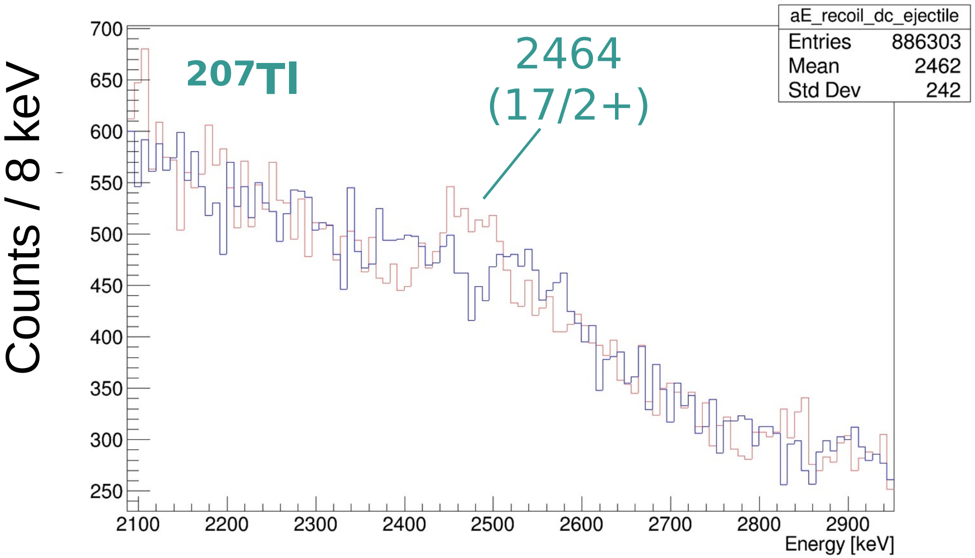
# IS774: Investigation of coupled states near $^{208}$Pb

At **230-um distance:** expect ~20% fast component and ~80% slow component for $T_{1/2}$ = 25 ps

Spectra after 14 hours:




***C. Porzio, CERN***

**Red:**
**Doppler correction after degrader → for slow comp.**

**Blue:**
**Doppler correction after target → for fast comp.**

# Conclusion

- **The MINIBALL plunger**
  a multifunctional target chamber for lifetime measurements
  with the RDDS technique, but also for other experiments (Coulex, ...)

- **The first RDDS campaign at ISOLDE in Summer 2025**
  investigation of
  → $^{144}$Ba, $^{207}$Tl (incomplete fusion)
  → $^{162}$Yb (Coulex)

- **Successful implementation of the RDDS technique at ISOLDE**

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# Thanks to all collaborators

R. Abels, D. Al Daas, A. Blazhev, A. Didik, F. Dunkel, A. Esmaylzadeh, C. Fransen, H. Hess, C. Heymer, J. Jolie, H. Kleis, C.-D. Lakenbrink, M. Ley, P. Reiter, S. Thiel, N. Warr*, M. Weinert
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** also University of Liverpool, UK*

F. Browne *University of Manchester, UK*

C. Porzio *CERN*

F. Browne, L. Gaffney, B. Jones, J. Curry, F. Rowntree, P. Spagnoletti
*University of Liverpool, UK*

T. Kröll *TU Darmstadt, Germany*

R. Bark, S. Ntshangase, L. Makhathini, S. Majola, S. Mumbwa, X. Ngwadla
*iThemba LABS, Univ. of Zululand, Univ. of Johannesburg, Univ. of Western Cape, South Africa*

G. Willmot *University of Surrey, UK*

C. Unsworth *DSTFC UKRI (Daresbury), UK*

R.A. Lopez *University of Lund, Sweden*

C. Müller-Gatermann *Argonne National Laboratory, Lemont, Illinois, USA*

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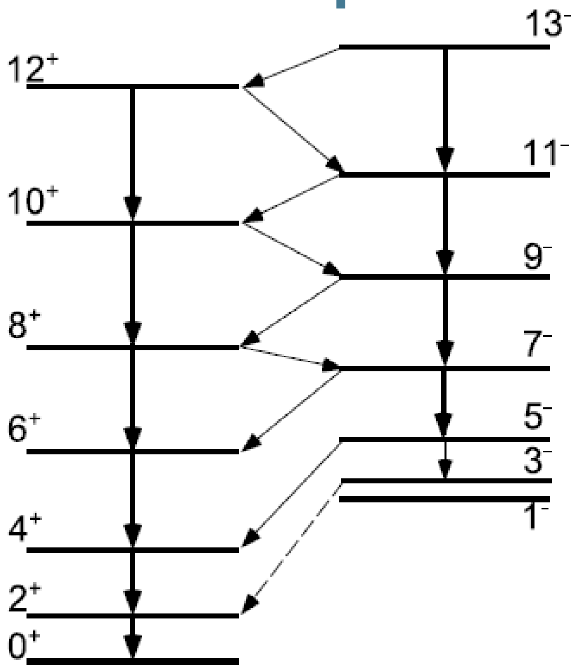
# Experiment on $^{144}$Ba at HIE-ISOLDE

Reaction:

→ incomplete fusion (ICF) $^{144}$Cs @ 4.4 MeV/u on $^{7}$Li
→ $^{7}$Li breakup in $^{4}$He and $^{3}$H
→ fusion $^{144}$Cs + $^{3}$H → $^{147}$Ba → $^{144}$Ba + 3n, ~50 mb
→ tested @ ISOLDE with stable $^{98}$Rb beam: S. Bottoni et al., PRC 92, 024322 (2015)
→ lifetimes in $^{144}$Ba with recoil distance Doppler-shift technique

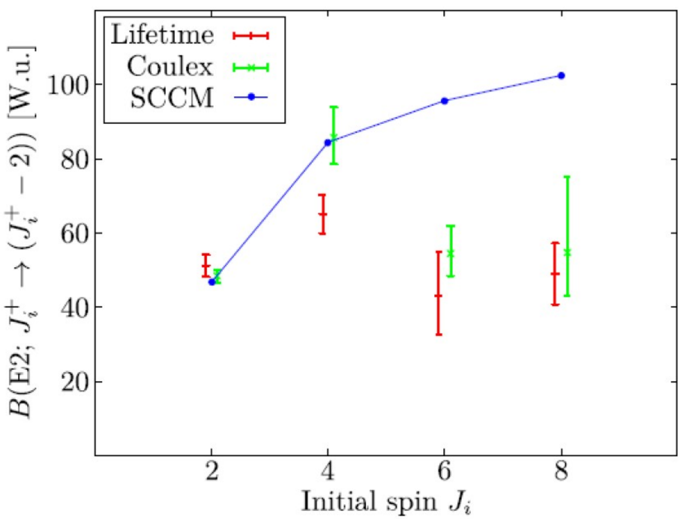
| | This proposal | [Bot15] |
|---|---|---|
| Beam | $^{144}$Cs | $^{98}$Rb |
| Target | $^{7}$Li | $^{7}$Li |
| $t$-ICF comp. | $^{147}$Ba | $^{101}$Sr |
| $E^{calc.}_{t-ICF}$ | 17.7 | 17.1 |
| $E^{exp.}_{t-ICF}$ | – | 19 |
| $S_{2n}$ (keV) | 8890 | 9190 |
| $S_{3n}$ (keV) | 12710 | 13347 |
| $S_{4n}$ (keV) | 18611 | 19262 |
| main channels | 2n,3n (expected) | 2n,3n |
| $E^{calc.}_{t-ICF} - S_{3n}$ | $^{144}$Ba 5.0 | $^{98}$Sr$^{calc}$ 4.1 |
| $E^{calc.}_{t-ICF} - S_{2n}$ | $^{145}$Ba 8.8 | $^{98}$Sr$^{exp.}$ 6.0 |

# Octupole correlations in $^{144}$Ba?




$^{144}$Ba: yrast B(E2), B(E3;$3^- \rightarrow 0^+$)

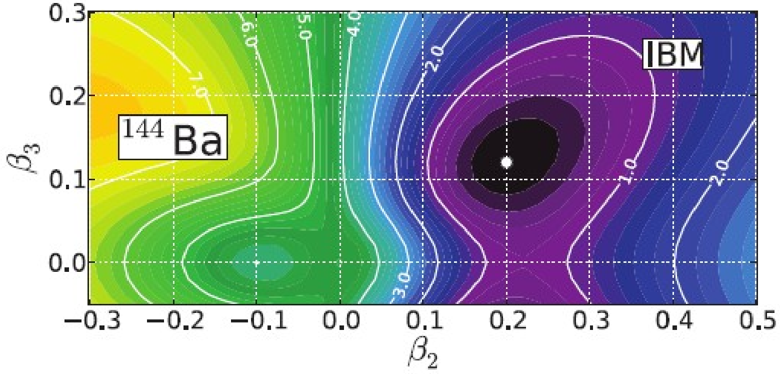
B. Bucher et al., PRL 112, 112503 (16)

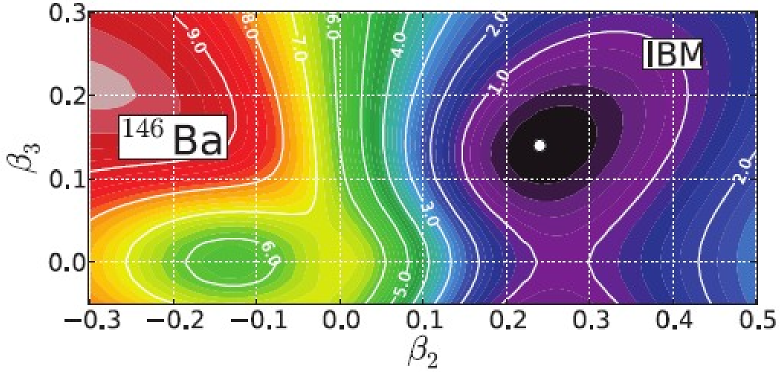



Calculations in IBM

→ $^{144,146}$Ba octupole deformed

Nomura et al., PRC 024312 (2012)




$^{146}$Ba: direct evidence octupole correlations

B(E3;$3^- \rightarrow 0^+$) = $49^{+21}_{-29}$ W.u.

B. Bucher et al., PRL 118, 152504 (17)