Nuclear chirality & lifetime experiment

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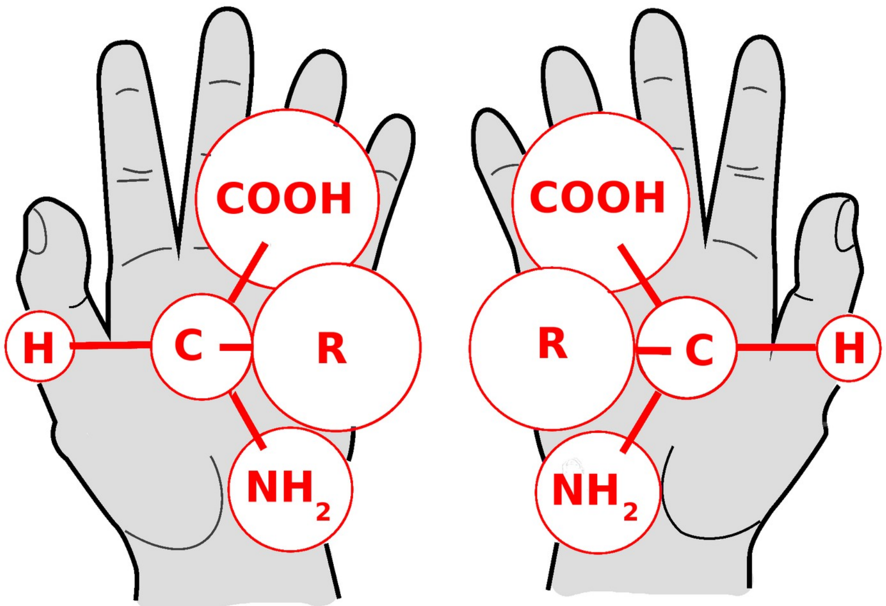
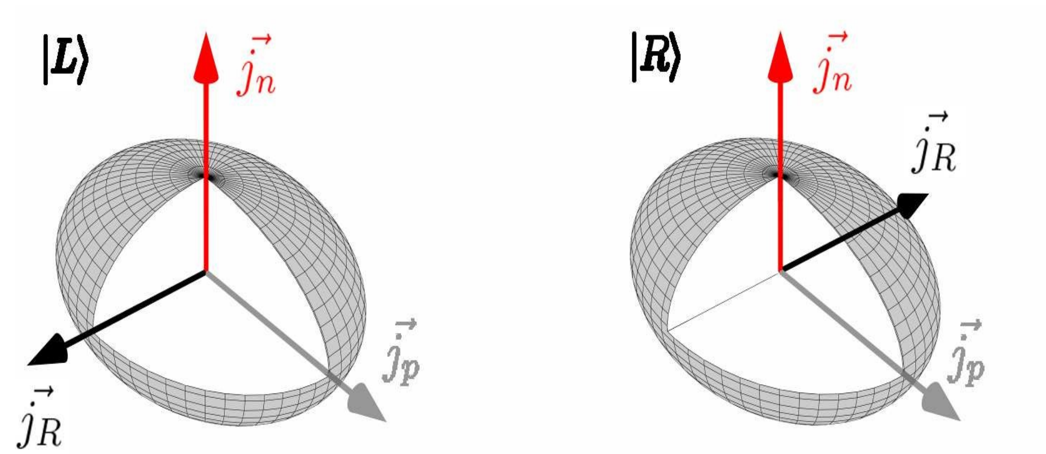
- Title: *Search for chiral to not chiral transition by lifetime measurement of I=10+ state in 128Cs with a PLUNGER technique*
- Where: Heavy Ion Laboratory, Warsaw University
- Beam: 10B (50 – 55 MeV)
- Target: 122Sn
- Nucleus after reaction: 128Cs (4 neutron emission)
- Goal: determining chirality by measuring lifetime
- How: Recoil Distance Doppler Shift Method
- Equipment used: EAGLE, LOAX, PLUNGER

Table of Contents

- Chirality of nuclei:
  - Differences with standard chirality
  - History
  - How we can see it
- Ways to measure lifetimes of excited states in nuclei:
  - Time ranges
  - Methods using Doppler shift effect
  - Equipment available at HIL
- How to perform an experiment in nuclear physics
  - Before experiment
  - During experiment

Chirality: standard & nuclear



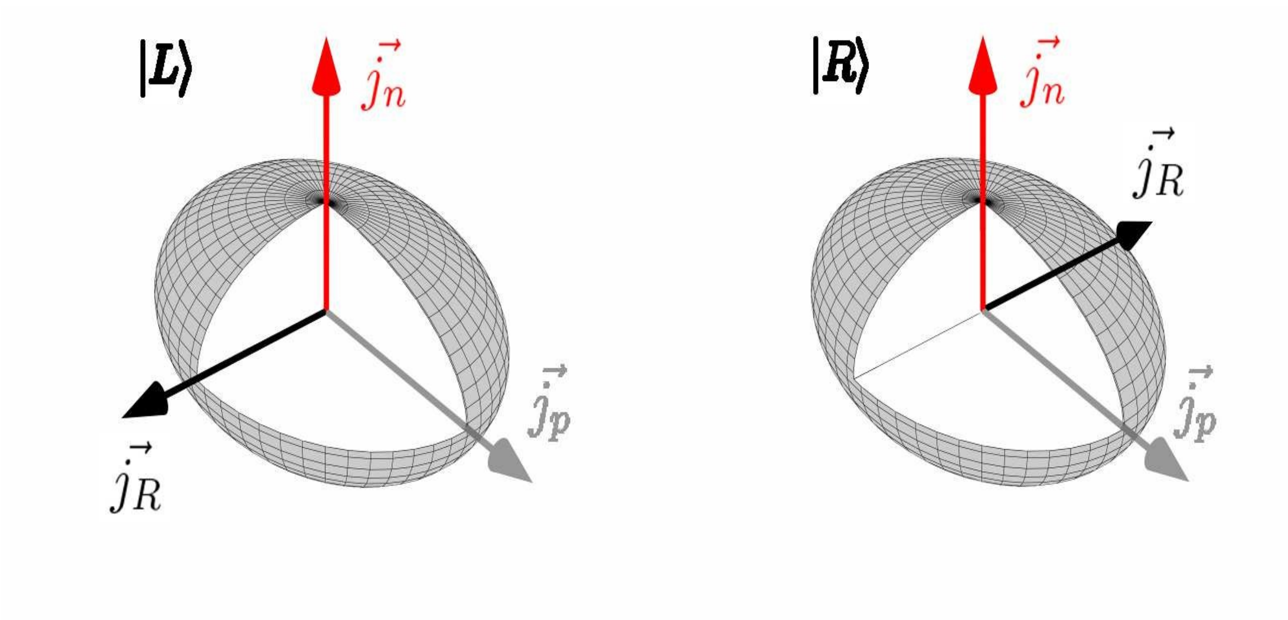


- 3 or more different vectors
- Their order determine its L or R handed
- 2 identical states, transformed by space reflection + rotation

- 3 different pseudo-vectors
- 2 identical states, transformed by time reflection + rotation

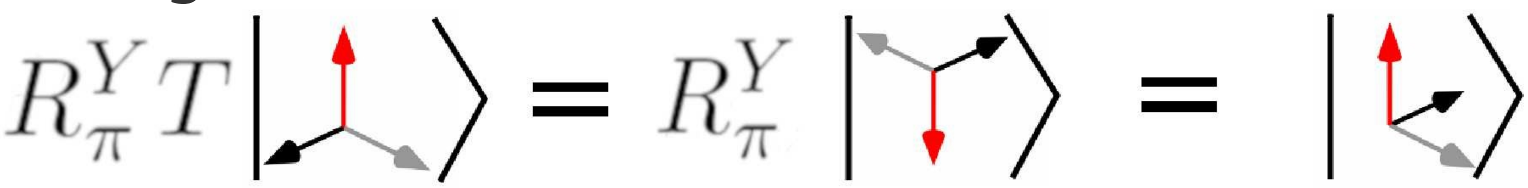
Chirality: nucleus

- Odd-odd nuclei
- 3 spins: core, proton and neutron
- 3 non-planar angular momentum pseudo-vectors leads to 2 arrangements

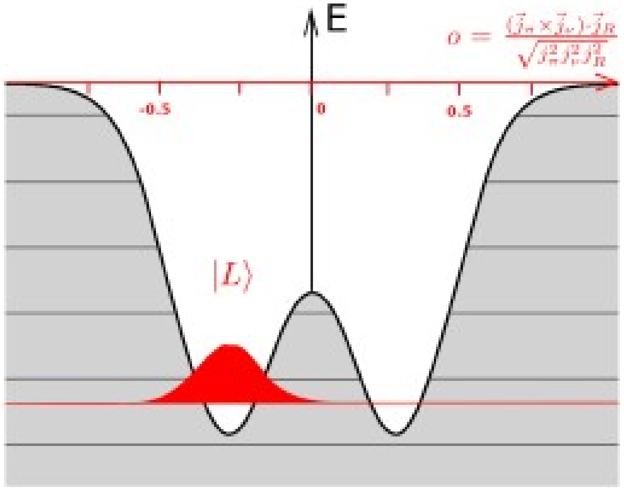


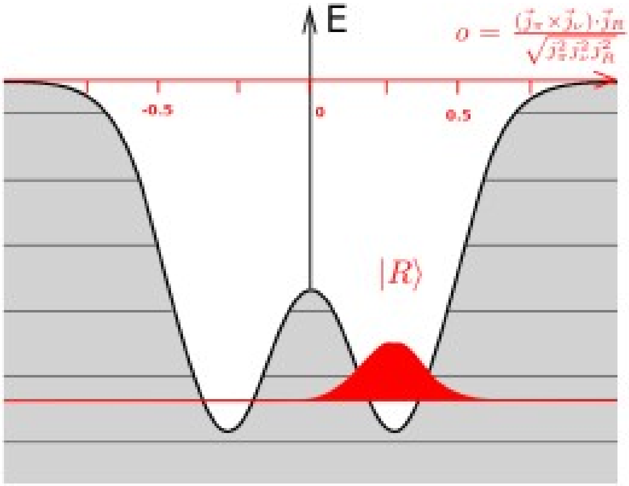
|L> state

|R> state



Chirality: value





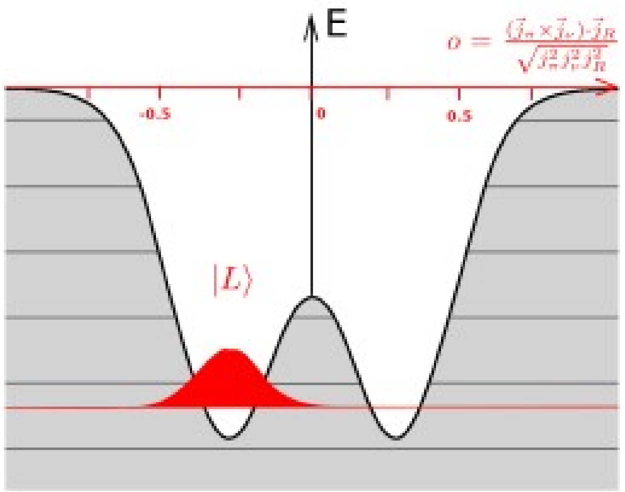
Knowing spins of a core, odd proton and odd neutron we can calculate how chiral the nucleus is:

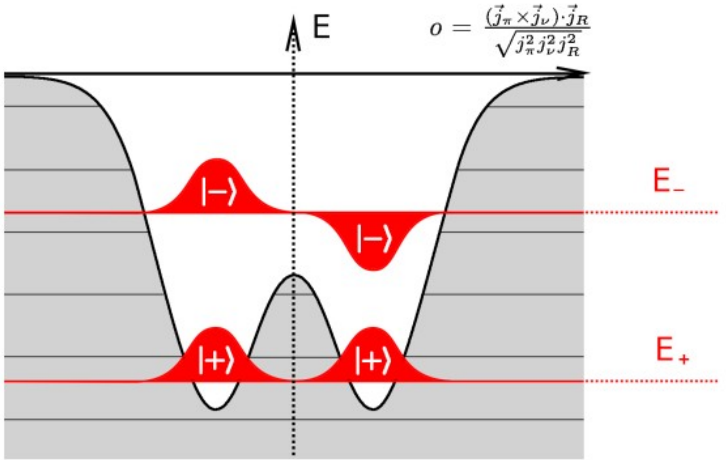
$$o = \frac{(\vec{j}_\pi \times \vec{j}_\nu) \cdot \vec{j}_R}{\sqrt{j_\pi^2 j_\nu^2 j_R^2}}.$$

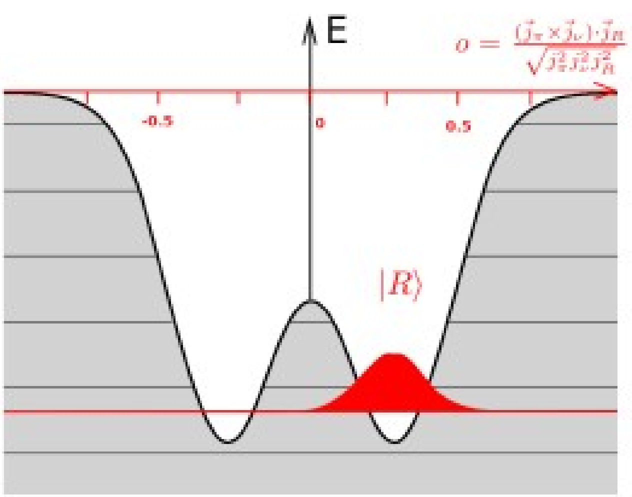
nucleus is:

- o=0 ↔ spins are planar, no chirality
- o<0 ↔ |L> state
- o>0 ↔ |R> state

Chirality: tunneling







|L> and |R> states are not eigenstates of Hamiltonian ==> unstable, tunneling to |+> and |-> states

|+> and |-> states differ slightly by their energies and have very similar properties

History of nuclear chirality

- 1997 – First theoretical paper discussing chirality in nucleons:
  Tilted rotation of triaxial nuclei
  S.Frauendorf, J. Meng, *Nucl. Phys. A* 617, 131 (1997)

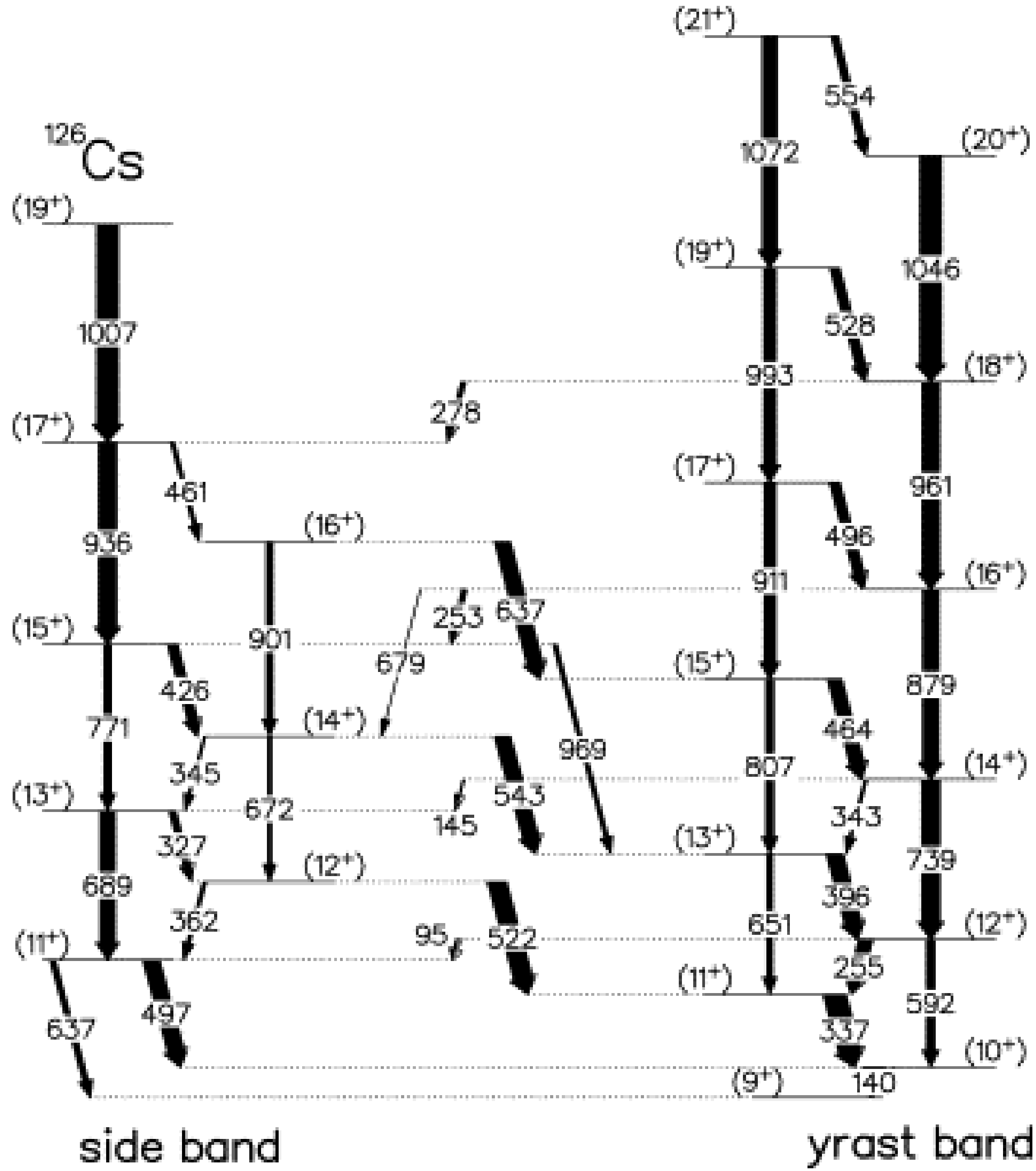
- 2006 – First experimental paper proving existence of chirality, provided by Warsaw team, cited 138 times
  ^{128}Cs as the Best Example Revealing Chiral Symmetry Breaking
  E. Grodner, J. Srebrny, A. A. Pasternak, I. Zalewska, T. Morek, C. Droste, J. Mierzejewski, M. Kowalczyk, J. Kownacki, M. Kisieliński S. G. Rohoziński, T. Koike, K. Starosta, A. Kordyasz, P. J. Napiorkowski, M. Wolińska-Cichocka, E. Ruchowska, W. Płóciennik, and J. Perkowski, *Phys. Rev. Lett.* 97, 172501 (2006).

- 2022 - Direct measurement of g-factor as an indicator of chiral states:
  Examination of nuclear chirality with a magnetic moment measurement of the I = 9 isomeric state in 128 Cs
  E. Grodner, M. Kowalczyk, M. Kisieliński, J. Srebrny, L. Próchniak, Ch. Droste,S. G. Rohoziński, Q. B. Chen, M. Ionescu-Bujor, C. A. Ur, F. Recchia, J. Meng, S.Zhang, P. W. Zhao, G. Georgiev, R. Lozeva, E. Fiori, S. Aydin, and A. Nałęcz-Jawecki, *Phys. Rev. C* 106, 014318 (2022)

- Up now – about 150 papers and 7 nuclei proving chirality

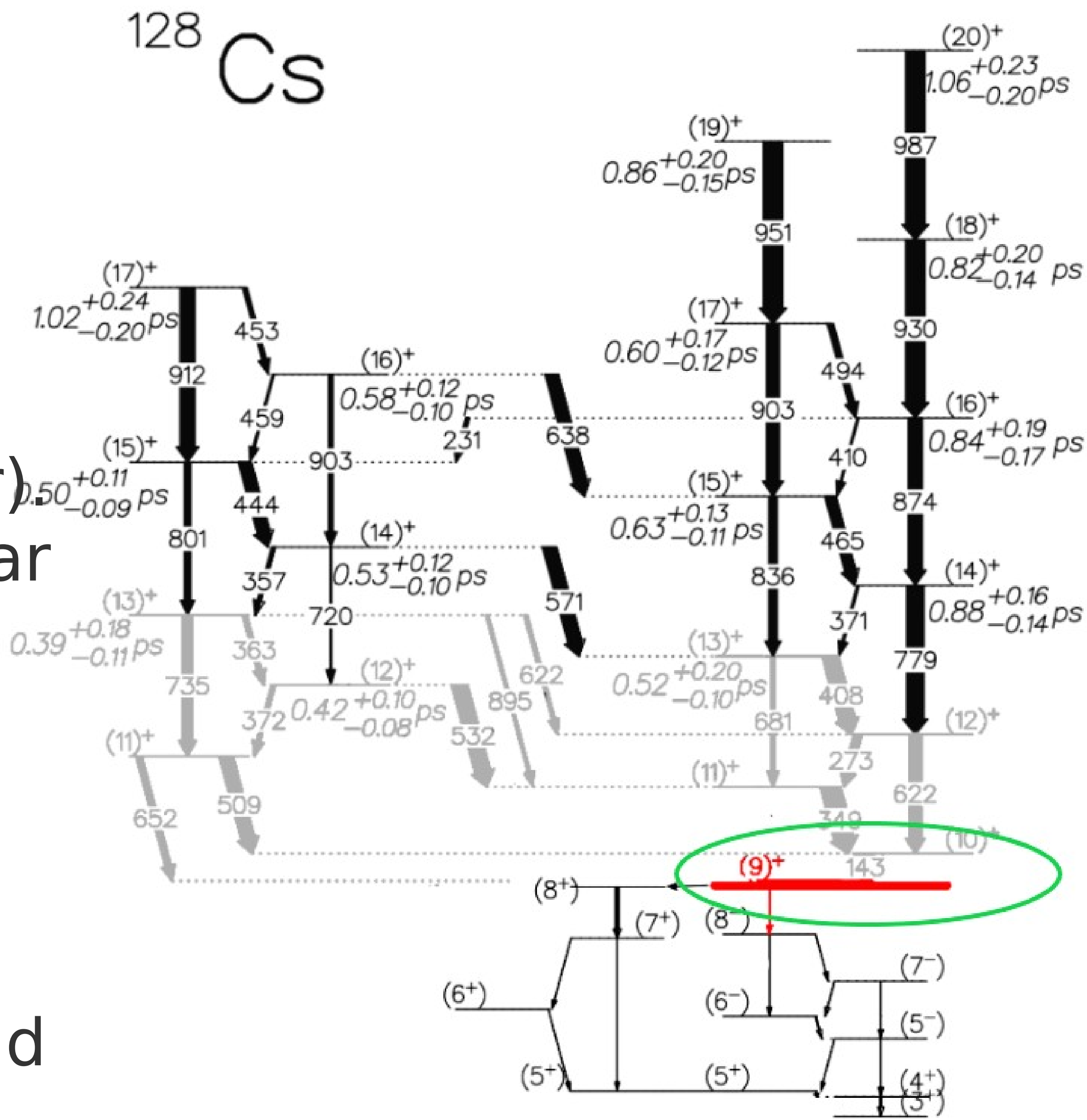
126Cs

- Chiral exited states give 2 bands: yrast (lower energy) and side (higher). They have similar transitions probabilities.
- Those 2-bands systems were found in among others 126Cs and 128Cs



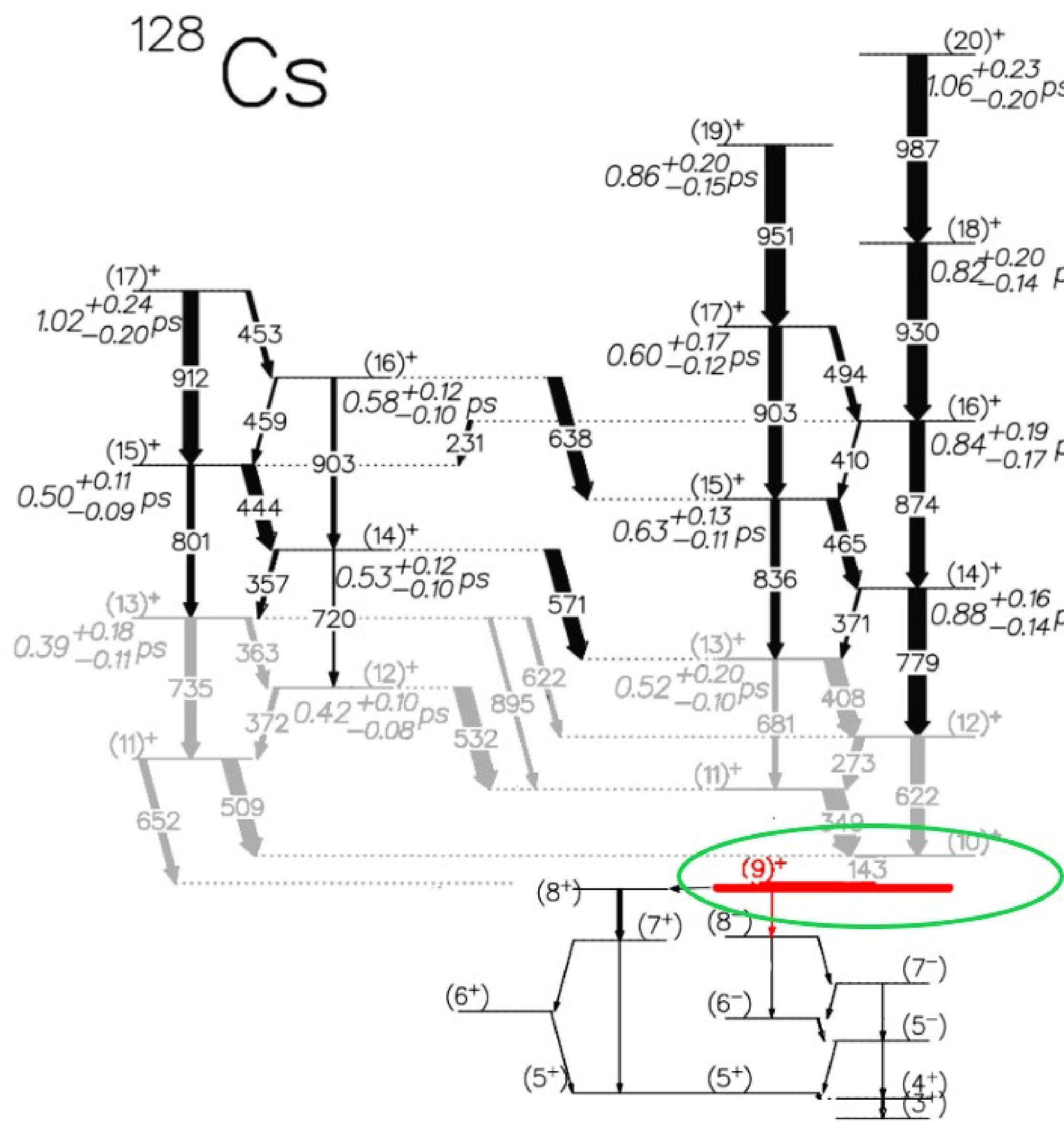
128Cs

- Chiral exited states give 2 bands: yrast (lower energy) and side (higher). They have similar transitions probabilities.
- Those 2-bands systems were found in among others 126Cs and 128Cs



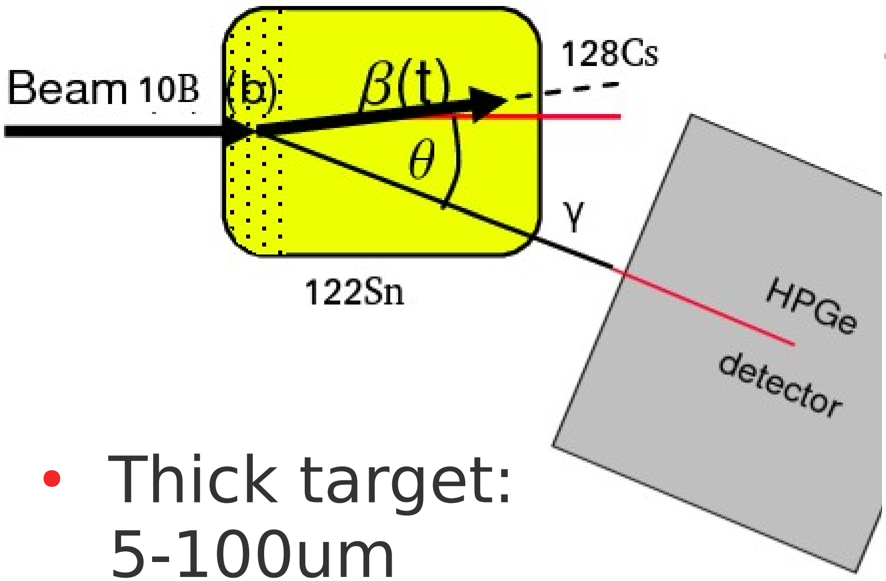
Time ranges

- Germanium detectors time resolution ~7ns
- Doppler Shift Attenuation Method ~1ps
- Everything between – Recoil Distance Doppler Shift Method

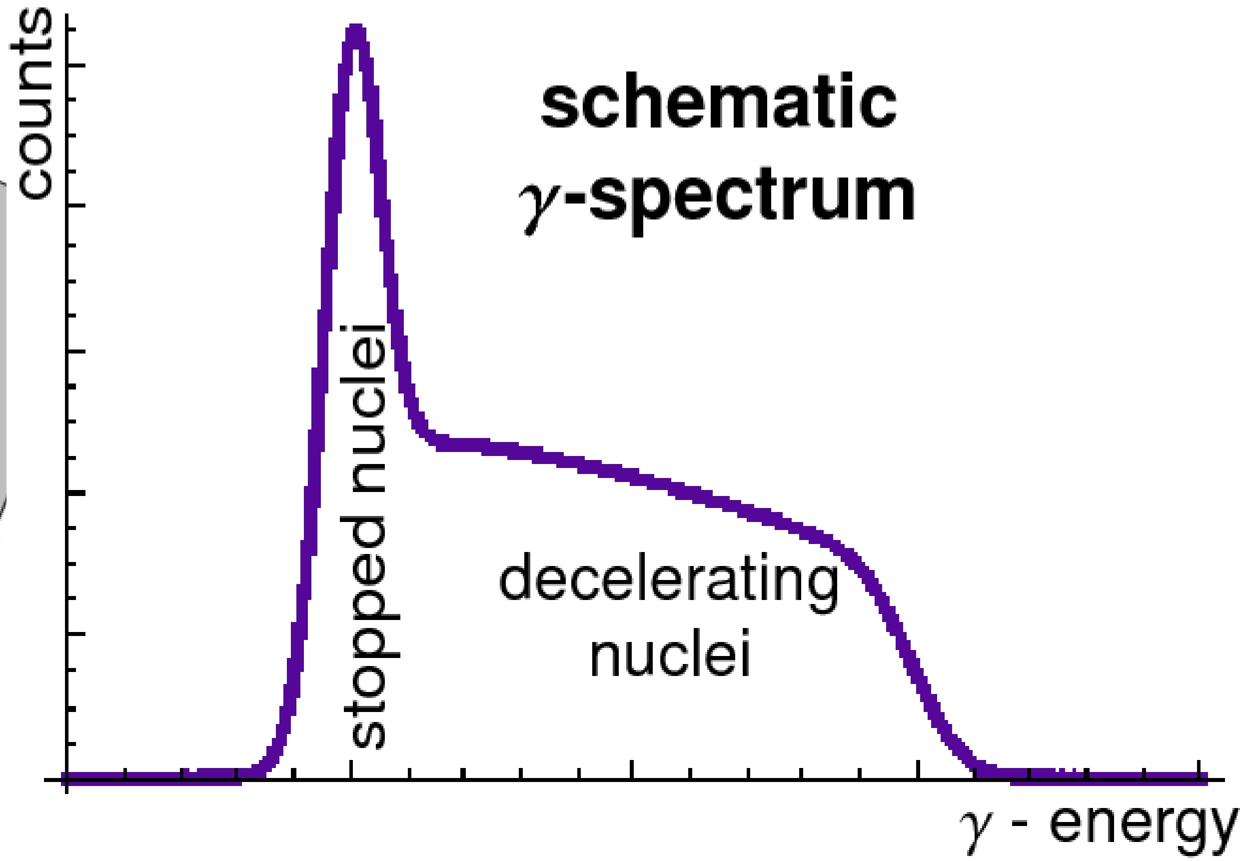


Doppler Shift Attenuation Method

$$E_\gamma = E_0 (1 + v/c * \cos(\theta))$$

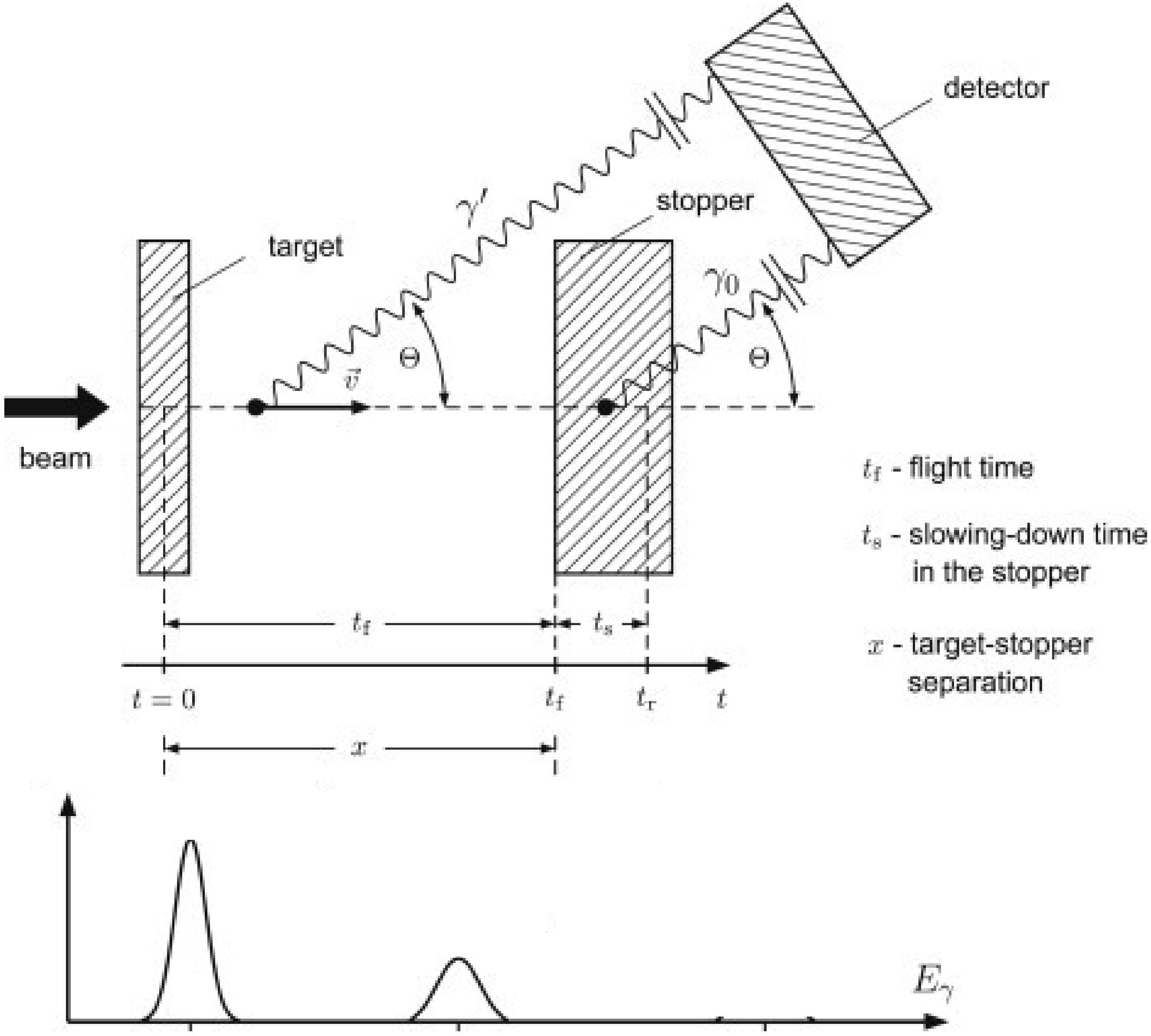


- Thick target: 5-100um
- Velocities: 0.005c-0.05c
- Stopping time: ~1ps



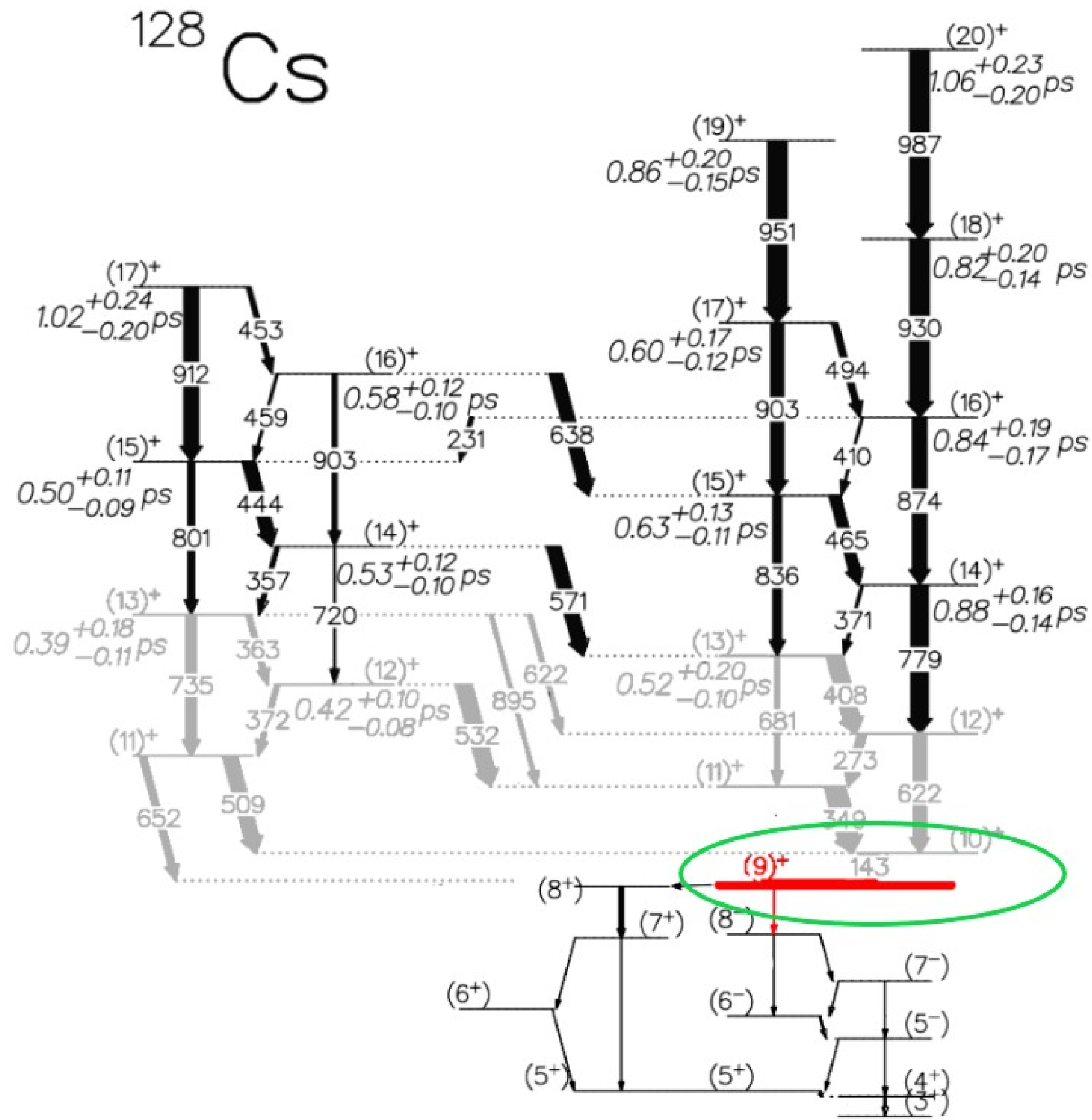
Recoil Distance DS method

- Lifetime 10-1000ps much larger than stopping time
- Thin target
- Nuclei can get out of the target
- Stops in the stopper
- Target – stopper distance controlled by PLUNGER
- Distance from ~15um up to ~5mm

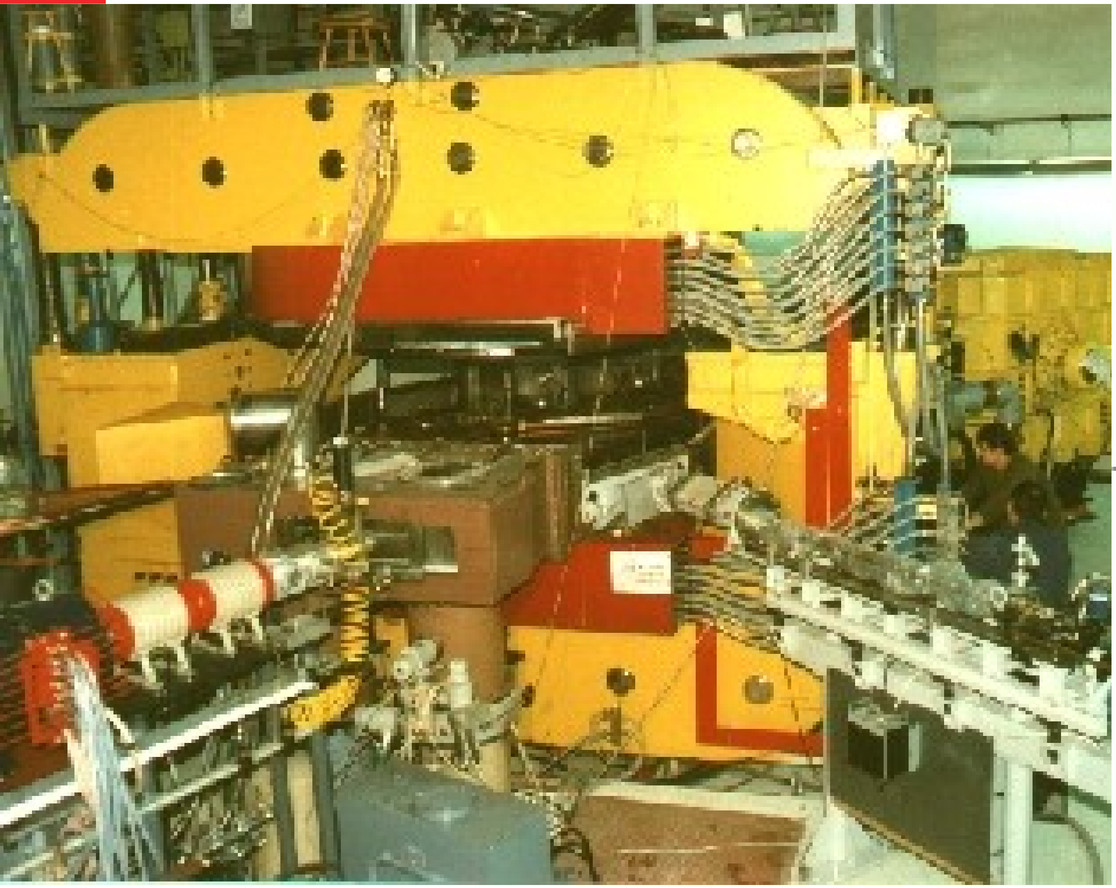


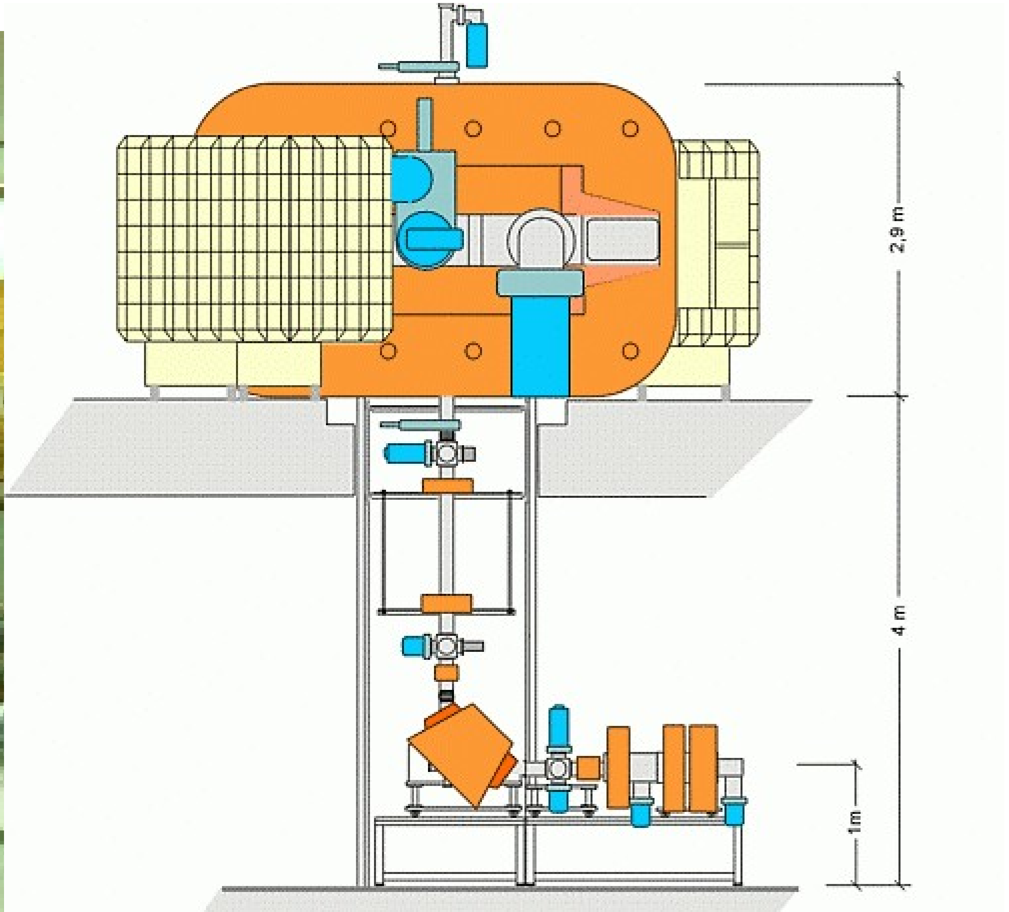
Transition times

- 9^+ state: long living (~50 ns), non-chiral
- 13+ and higher: chiral, lifetimes ~1ps
- 11^+, 12^+ – from theory 1-10 ps
- 10^+ state:
  - if chiral ~150 ps
  - non-chiral ~10 ps



Cyclotron at HIL, Warsaw

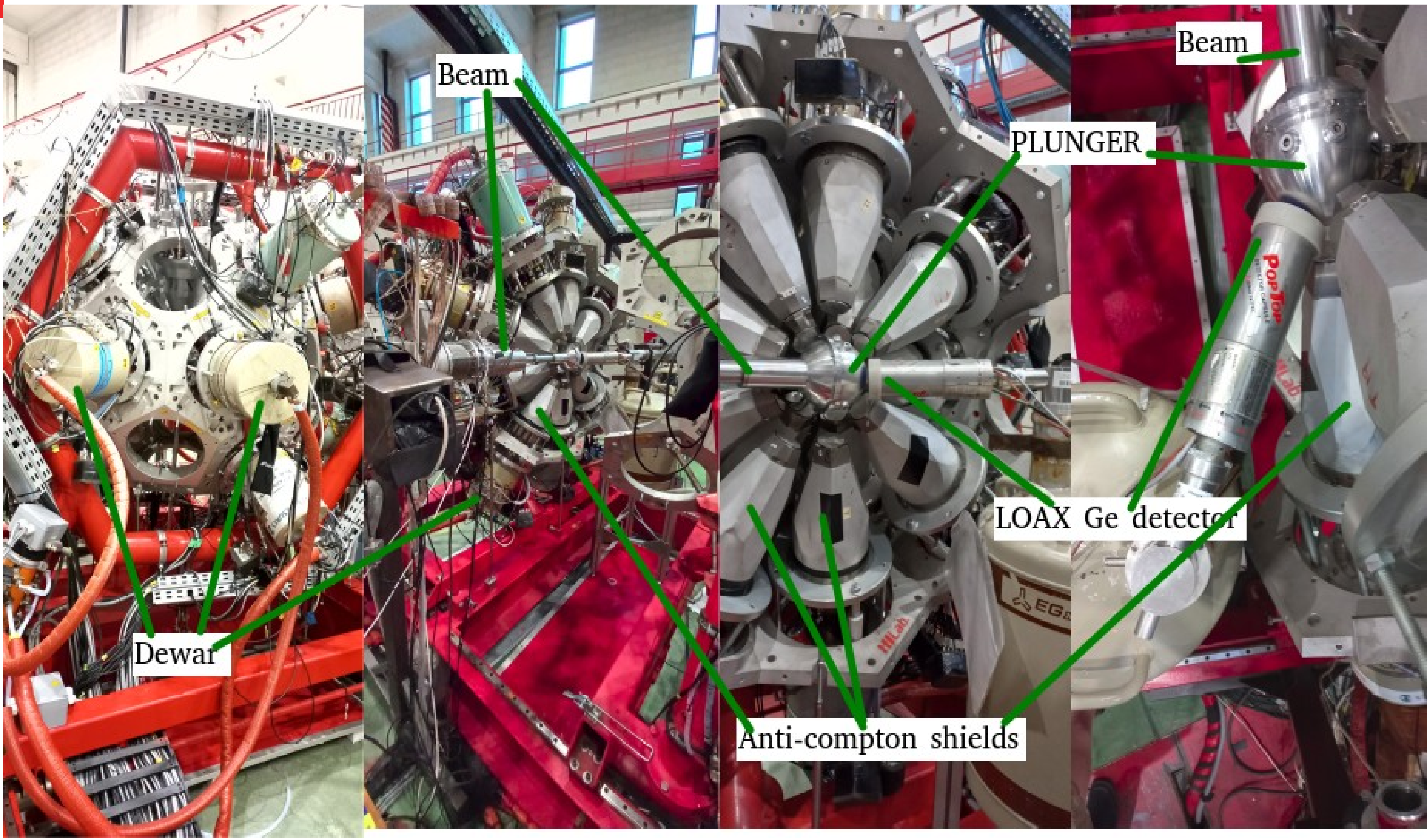




- Diameter: 2m
- Energy: 2-10 MeV/A
- Ratio: 10^10-10^12 particles per second

- About 30 different nuclei
- Up to 40Ar
- Since 1994

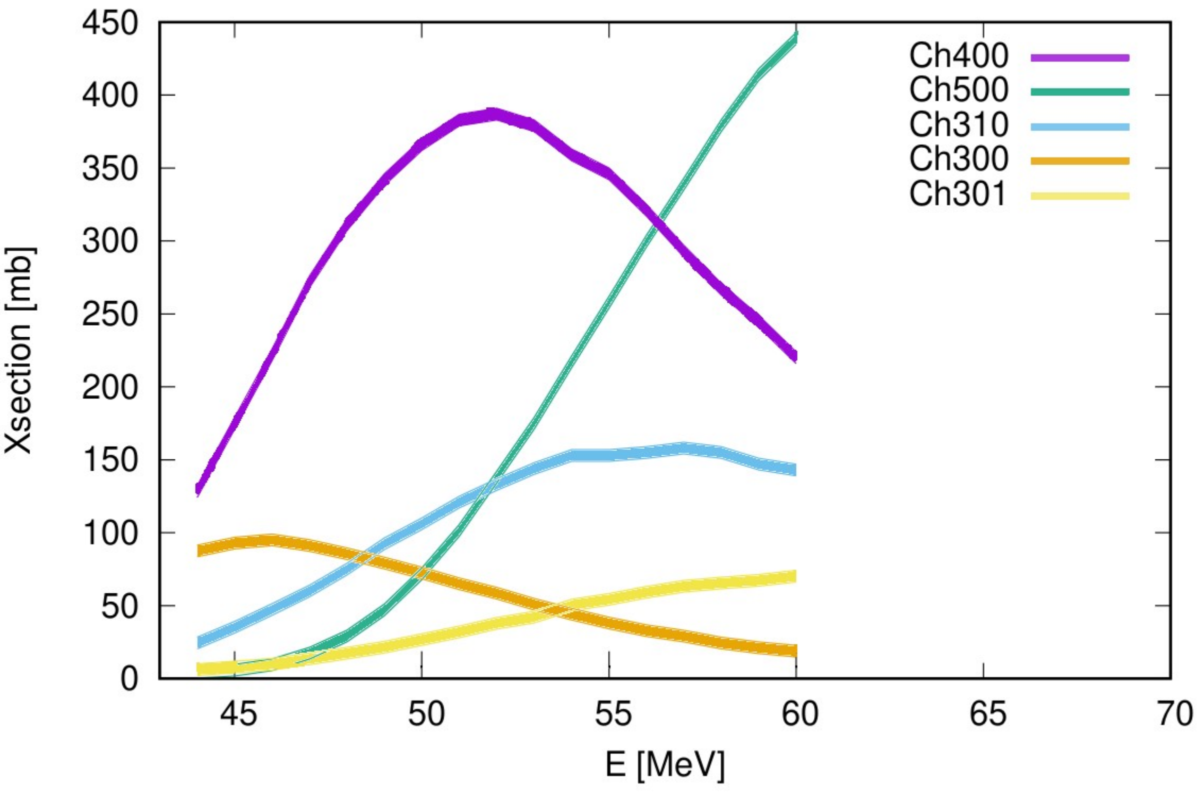
Experiment setup - EAGLE



Procedures before experiment

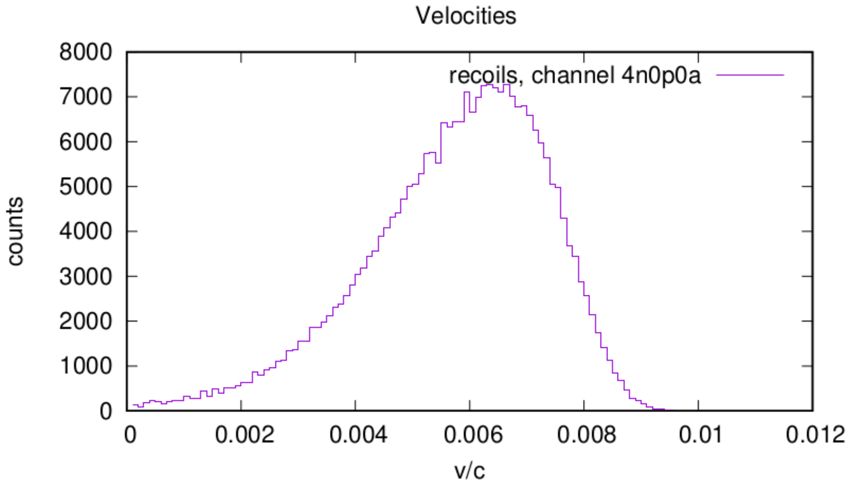
- Choosing reaction
  - stable nuclei
  - enough cross-section
- Choosing projectile energy
  - by-products
  - provided by cyclotron

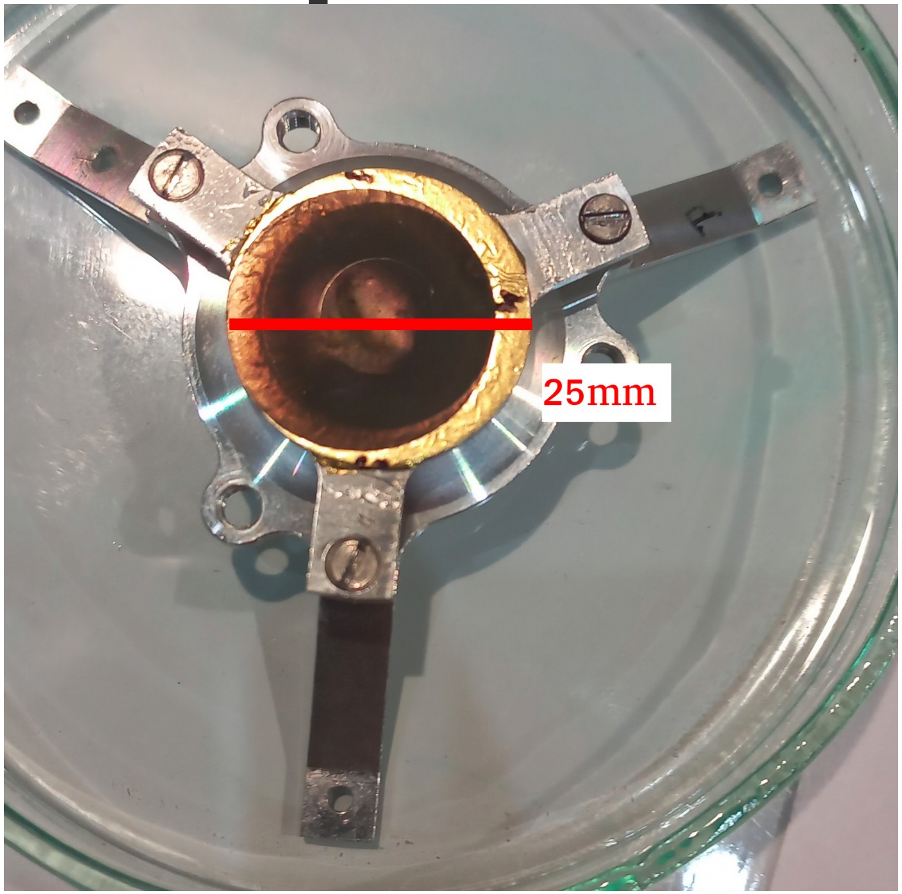
$^{122}Sn\ (^{10}B,4n)\ ^{128}Cs$



Procedures before experiment

- Target thickness
  - thin – low intensity
  - thick – velocity dispersion
- Target support
  - material
  - thickness



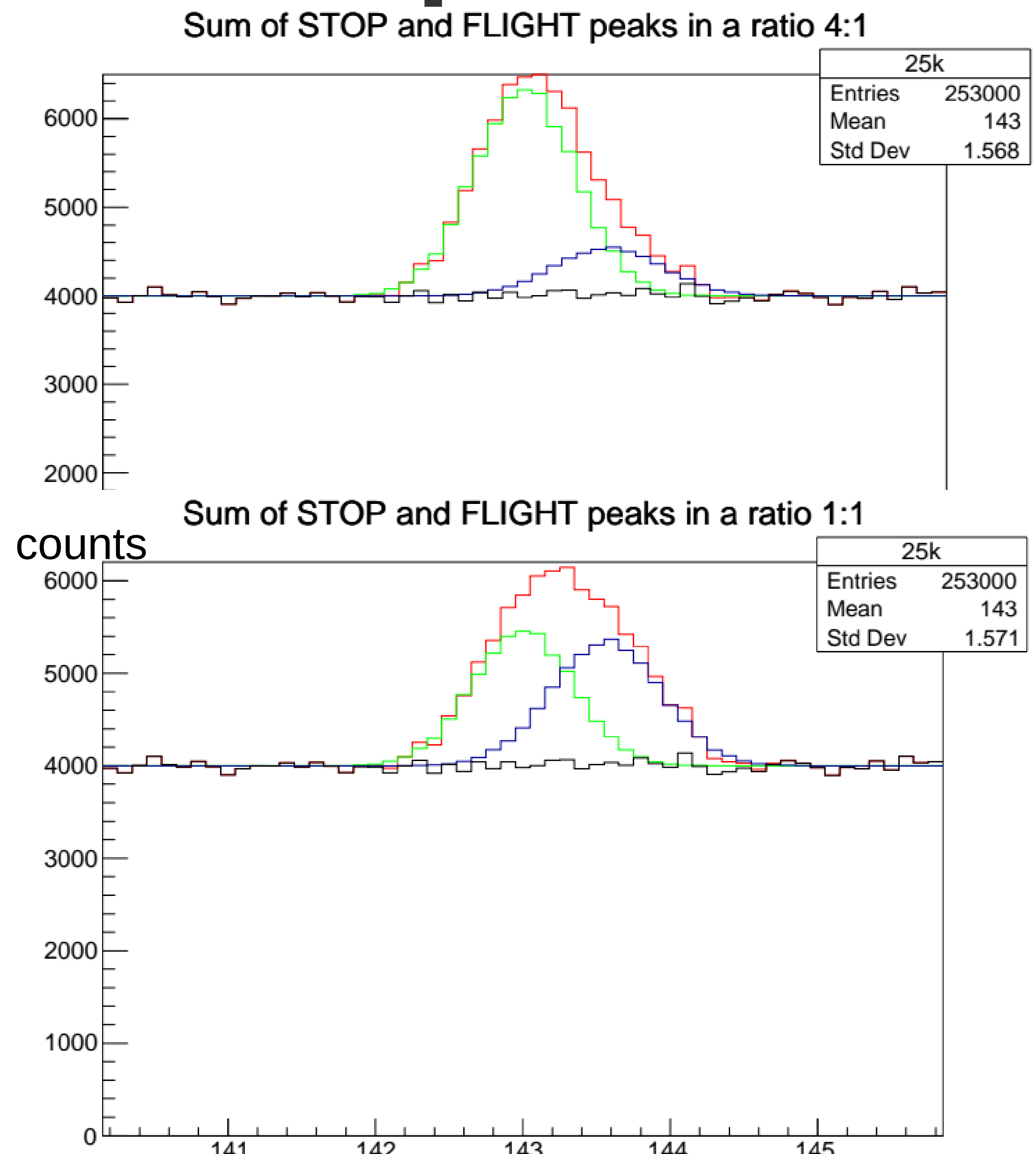


0.4 mg/cm^2 =0.6 um ^{122}Sn target,
2.5 um gold support

Procedures before experiment

Other problems:

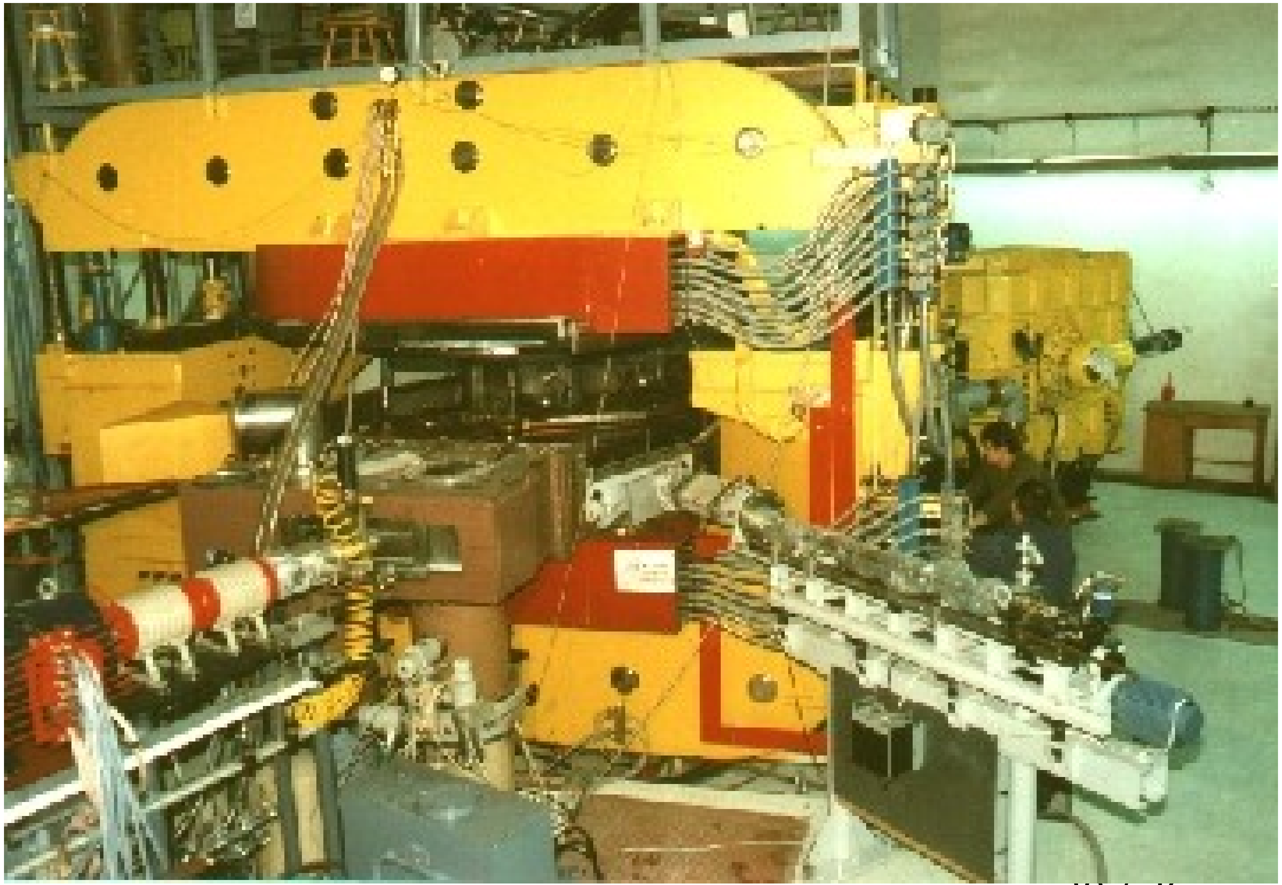
- Peak separation
  - Doppler shift ~0.8keV
  - HPGe resolution: 2keV
  - LOAX resolution: ~0.7keV
- Beamtime needed
  - Number of distances
  - Precision
- Ways to check if experiment goes wrong
- Etc.



Simulated shifted (blue), not shifted (green) and sum of those (red) peaks

Program Acceptance Committee commissioning

- Warsaw Heavy Ion Laboratory
- Once or twice a year
- Proposal paper
- Proposal talk
- 9 experiments
- Very positive opinion, so full requested time was obtained
- Last exp. before it was turned off due to no money from ministry



After PAC commissioning

- Experiment simulation
- Preparing target
  - Tin evaporation
  - Thickness measurement
  - 5 targets in case they brake
- Data acquisition tests
  - Detector signal amplification and cutoff
  - Checking noises in detectors

Just before experiment

- Moving detectors
  - 7 out of 15 detectors had to be moved
  - LOAX detector with its Dewar flask (thermos with liquid nitrogen)
- Target and PLUNGER:
  - Installing target and stopper
  - Parallel them up to 1um
- Detector calibration by 152Eu source
- “Cleaning” cyclotron

During experiment

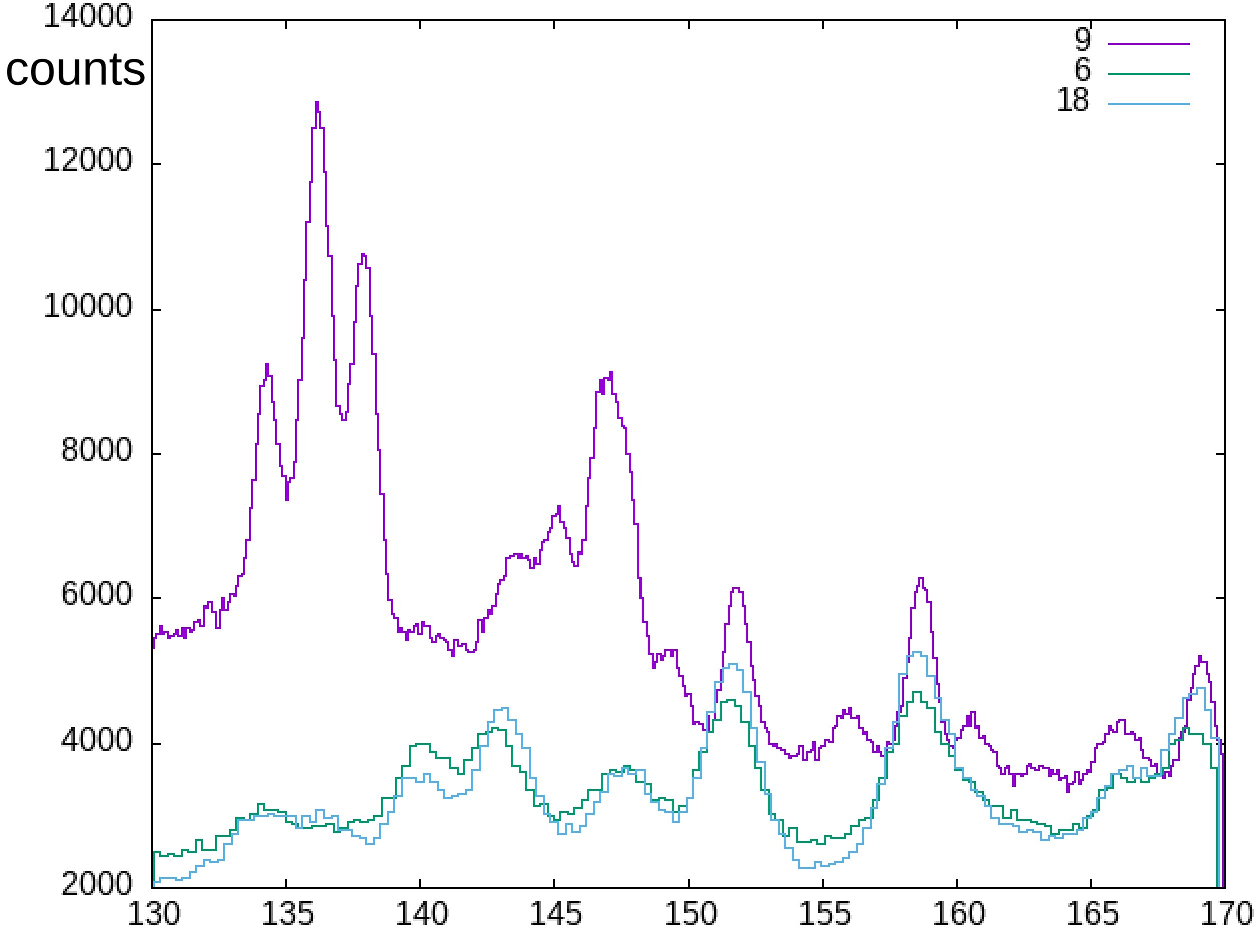
- 24h control in 8h shifts:
  - PLUNGER check
  - Reporting problems in a matter of minutes
  - Changing distances
- Resolving problems:
  - Beam energy out of range
  - Too high neutron emission injuring detectors
  - High noises from 2 detectors, etc.
- Prompt data analysis to choose distances

People involved in experiment

- Basic group – 6 people
- Cyclotron operators – 10 people
- Shift helpers - 11 people
- Target preparing – 2 people
- Detector specialists – 3 people
- DAQ and PLUNGER specialists – 4 people
- Help with prompt data analysis – 2 people
- Total - 39 people

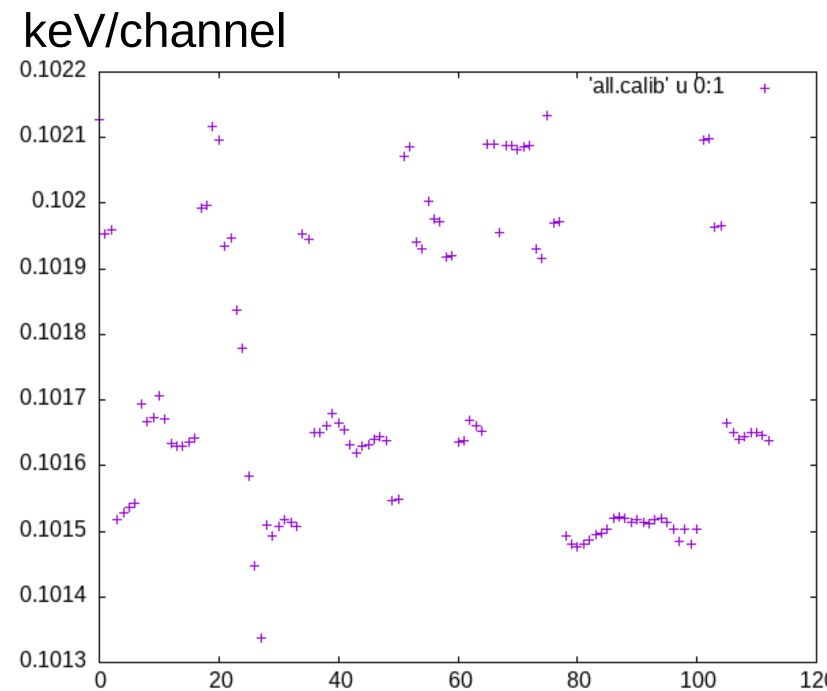
Future

- 1-year long analysis
- Verification of theoretical models



Spectrum from 3 different detectors in the area of the most interest

keV



Calibration change during experiment

run number

Thank you for listening

Sources:

[1] E. Grodner, autoreferat, 2019

[2] Lifetime Measurements of Excited Nuclear States of Astrophysical Interest via the Doppler Shift Attenuation Method, C. Herlitzius, S. Bishop, *AIP Conference Proceedings* 1213, 205 (2010)

[3]Developing the Recoil Distance Doppler-Shift technique towards a versatile tool for lifetime measurements of excited nuclear states, A.Dewald, O.Möller, P.Petkov, *Progress in Particle and Nuclear Physics* 67, 3 (2012), 786-839

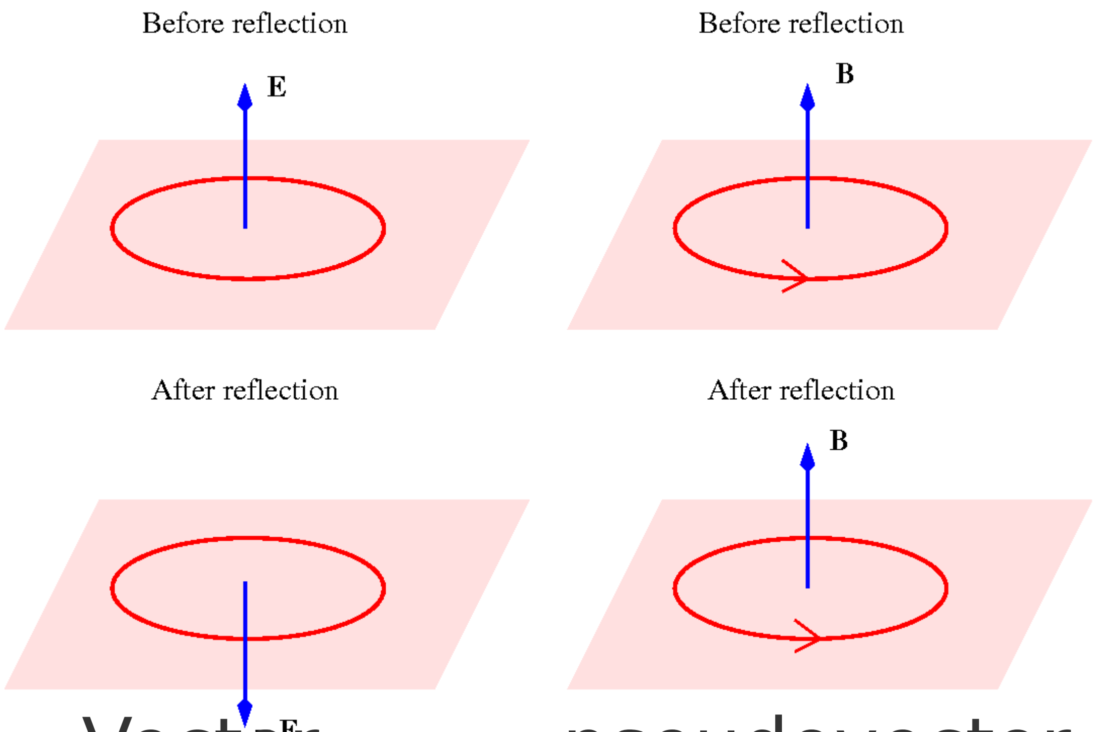
Cross-check by coincidence measurements

- EAGLE setup with HPGe 70% GAMMAPOOL detectors for coincidences
- From single mode we will know limit of lifetime of 11+ and 12+ states, and we will be able to choose proper distances for coincidences
- Gates on FLIGHT peaks of 349 and 622 keV – transitions feeding 10^{+} state – can help to eliminate effect of band- and side-feeding times.
- 2 distances for about 80-100h each

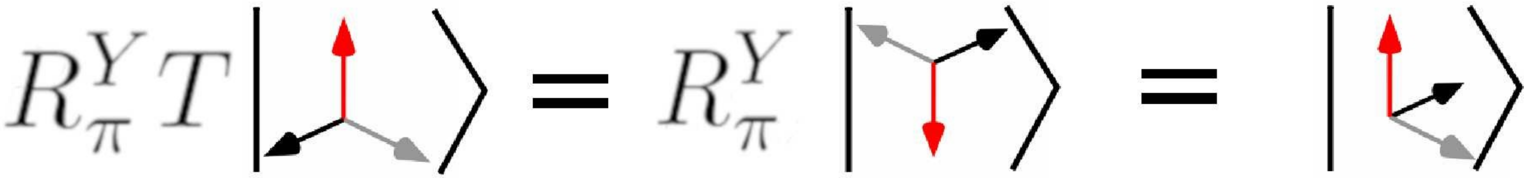
Chirality: pseudovectors

- Pseudovectors, such as B or j, transforms differently than vectors, such as E
- They are indifferent to space reflection, need time reflection
- Possible spontaneous time-symmetry breaking

Spacial reflection:



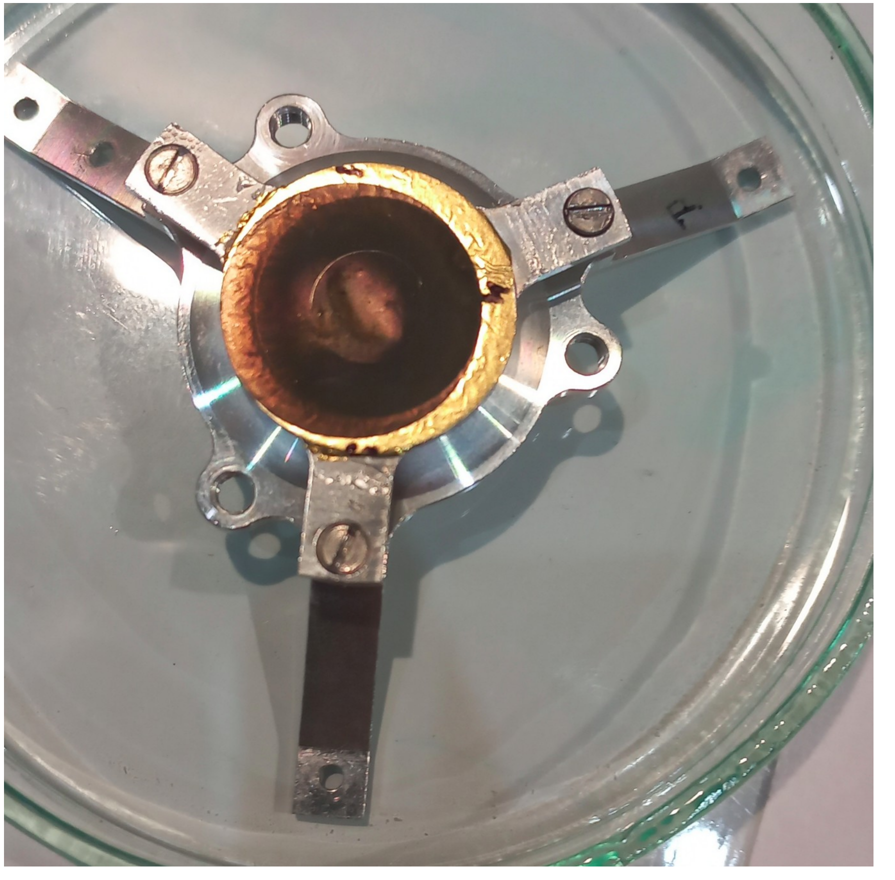
Vector pseudovector

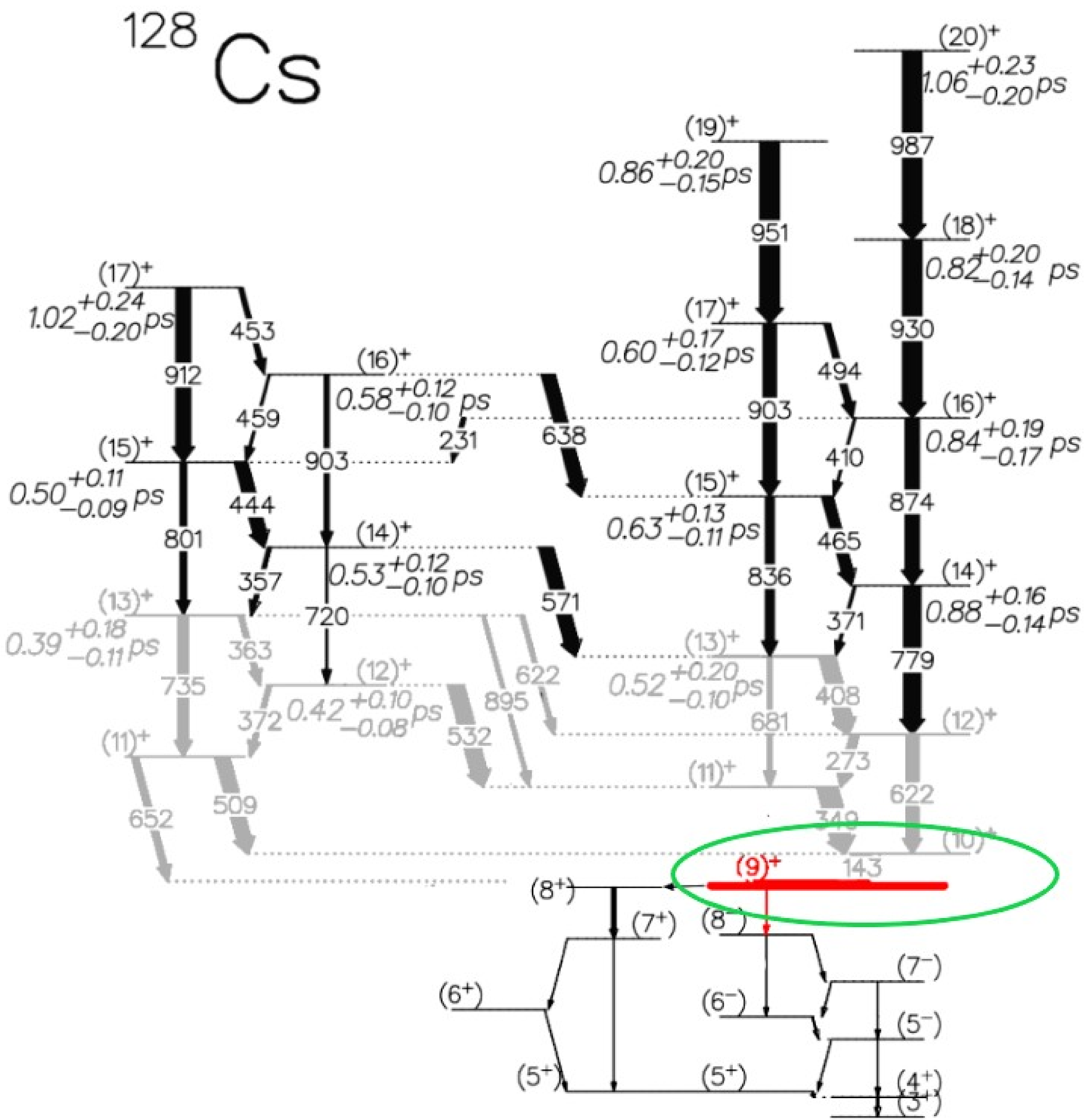


Target

- We decided to use tin target of thickness about 0.4 mg/cm^2, which is 0.5 um
- Too thin to hold itself, therefore on 2.5 um gold supporter
- Perfectly flat and extremely delicate

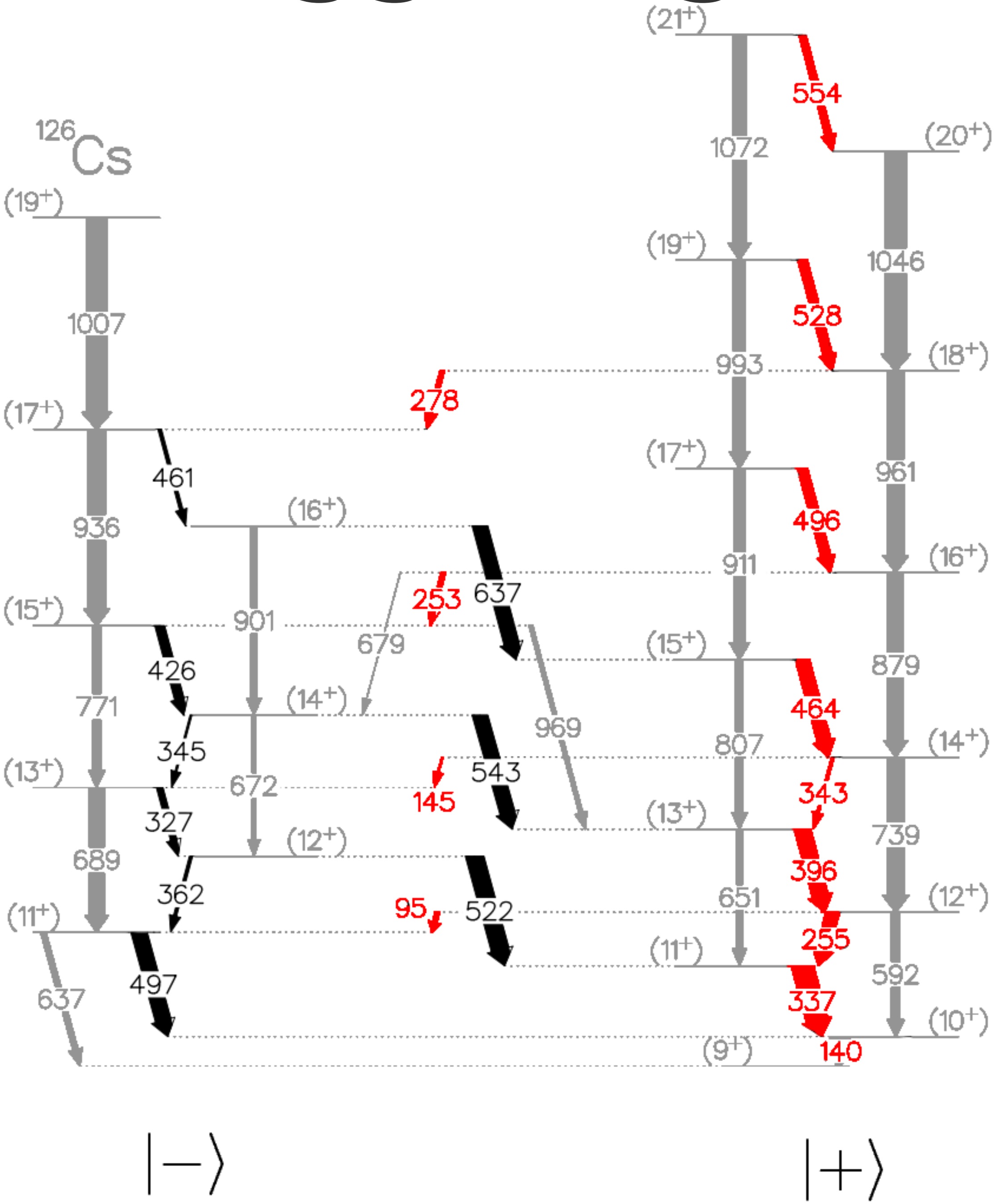
25 mm



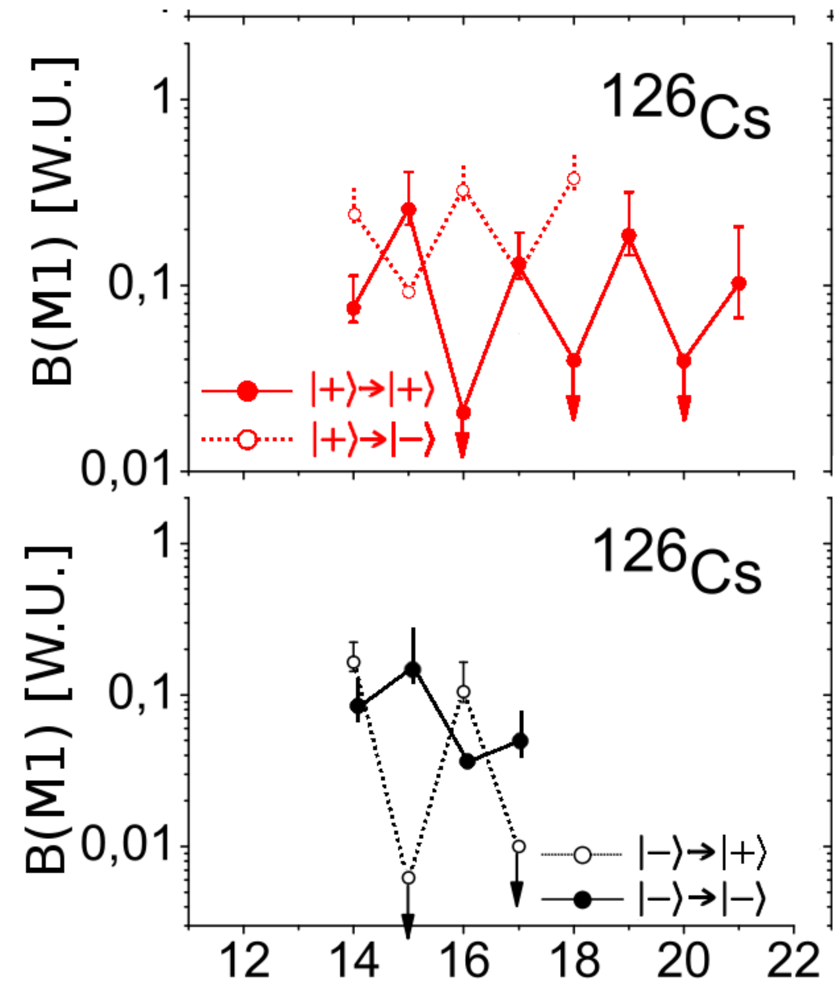


128 Cs
(20)+
1.06 +0.23 −0.20 ps
987
(19)+
0.86 +0.20 −0.15 ps
951
(18)+
0.82 +0.20 −0.14 ps
930
(17)+
1.02 +0.24 −0.20 ps
453
912
(17)+
0.60 +0.17 −0.12 ps
494
(16)+
0.58 +0.12 −0.10 ps
459
903
(16)+
0.84 +0.19 −0.17 ps
231
638
(15)+
0.50 +0.11 −0.09 ps
903
410
(15)+
0.63 +0.13 −0.11 ps
874
444
801
(14)+
0.53 +0.12 −0.10 ps
465
836
(14)+
0.88 +0.16 −0.14 ps
357
571
371
(13)+
0.39 +0.18 −0.11 ps
720
(13)+
0.52 +0.20 −0.10 ps
779
363
622
735
(12)+
0.42 +0.10 −0.08 ps
895
408
372
532
681
(12)+
(11)+
273
(11)+
622
652
509
349
(10)+
(9)+
143
(8+)
(7+)
(8−)
(7−)
(6+)
(6−)
(5−)
(5+)
(5+)
(4+)
(3+)

Staggering



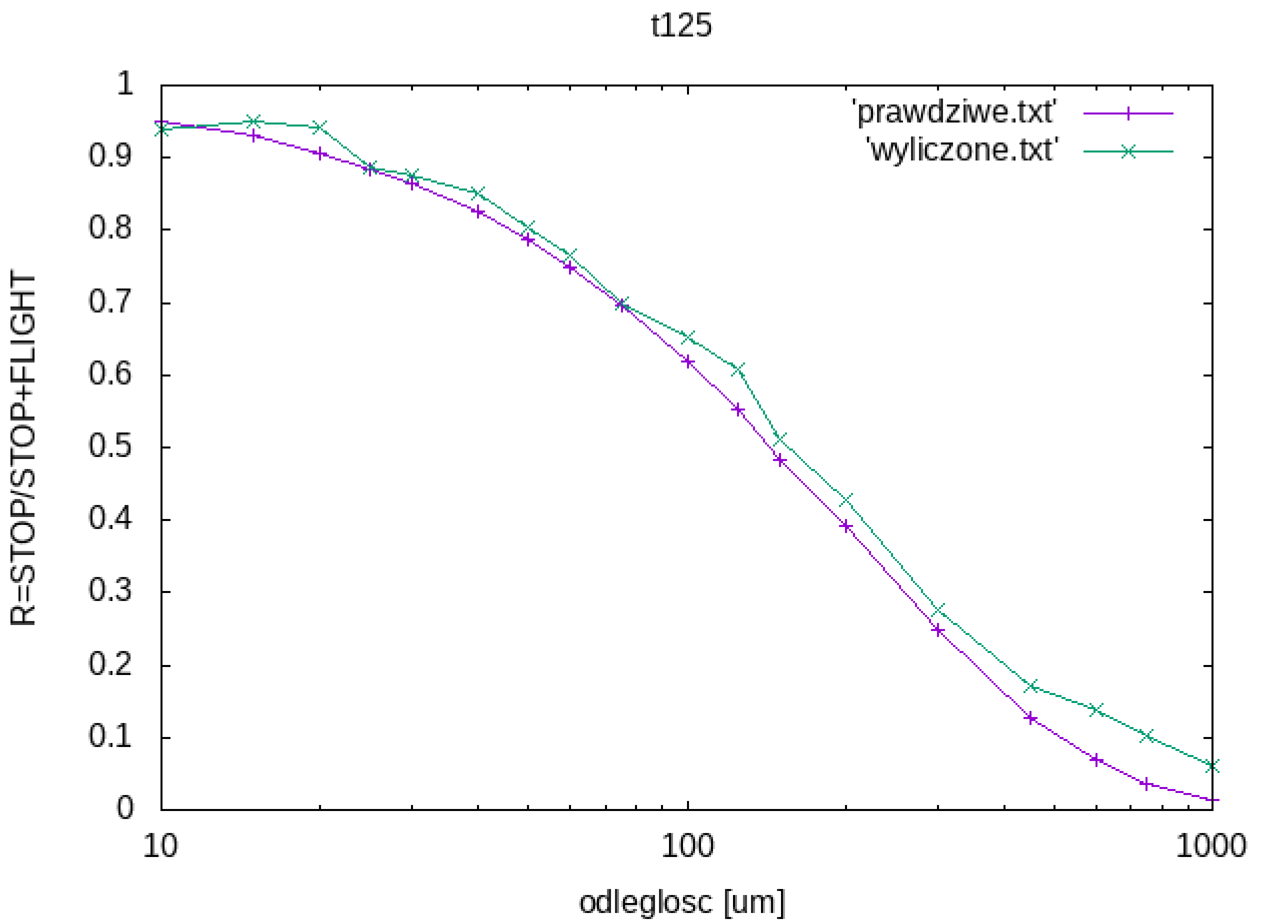
126Cs
(21+)
554
1072
(20+)
(19+)
1046
528
1007
(19+)
993
(18+)
278
(17+)
(17+)
461
961
496
936
(16+)
(16+)
911
253
637
(15+)
901
679
(15+)
426
879
969
771
(14+)
464
(14+)
807
345
543
(13+)
672
145
343
(13+)
327
739
689
(12+)
396
362
95
522
651
(12+)
(11+)
255
(11+)
592
637
497
337
(10+)
(9+)
140
|−⟩
|+⟩



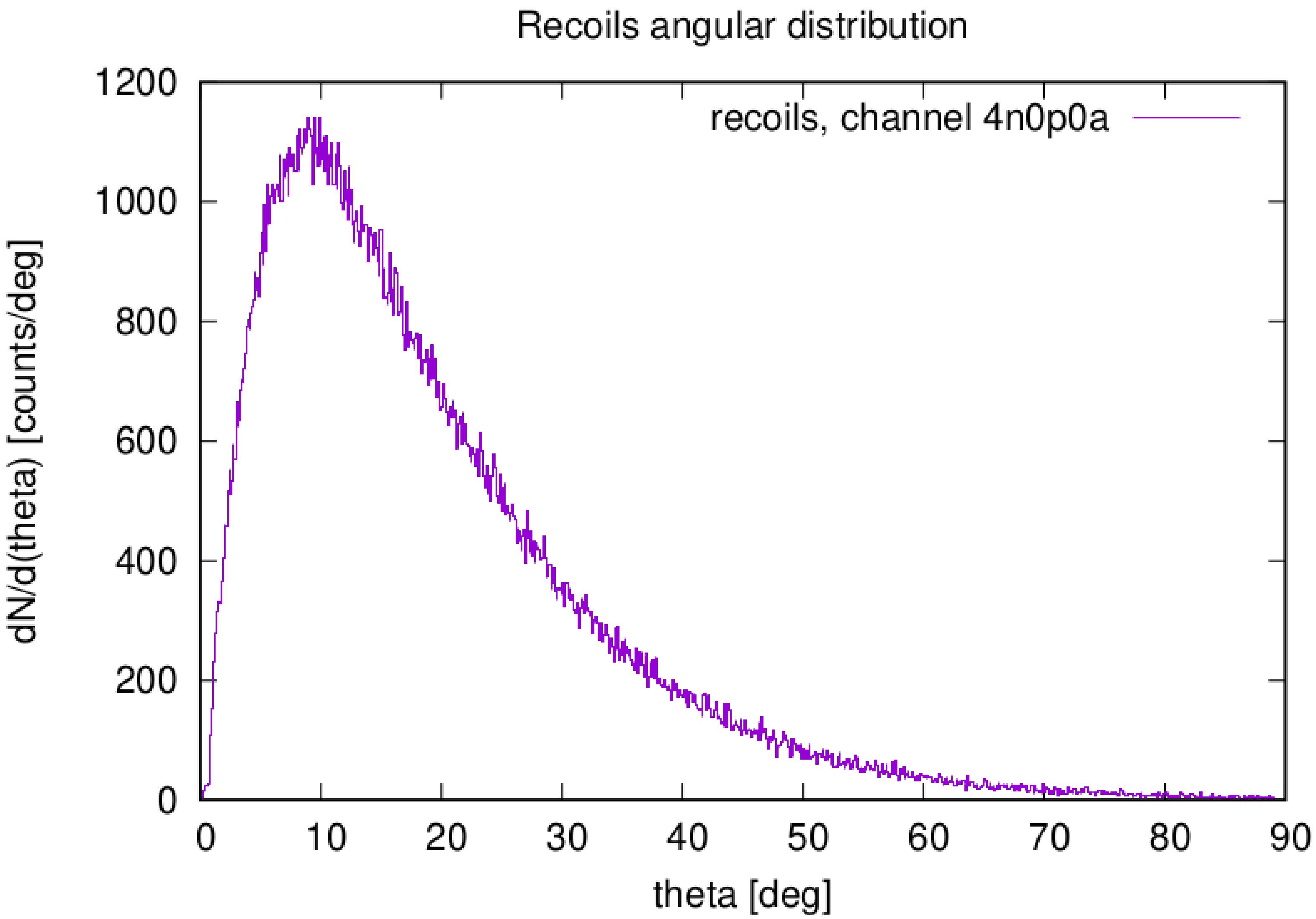
B(M1) [W.U.]
126Cs
1
0,1
0,01
|+⟩→|+⟩
|+⟩→|−⟩
B(M1) [W.U.]
126Cs
|−⟩→|+⟩
|−⟩→|−⟩
12
14
16
18
20
22

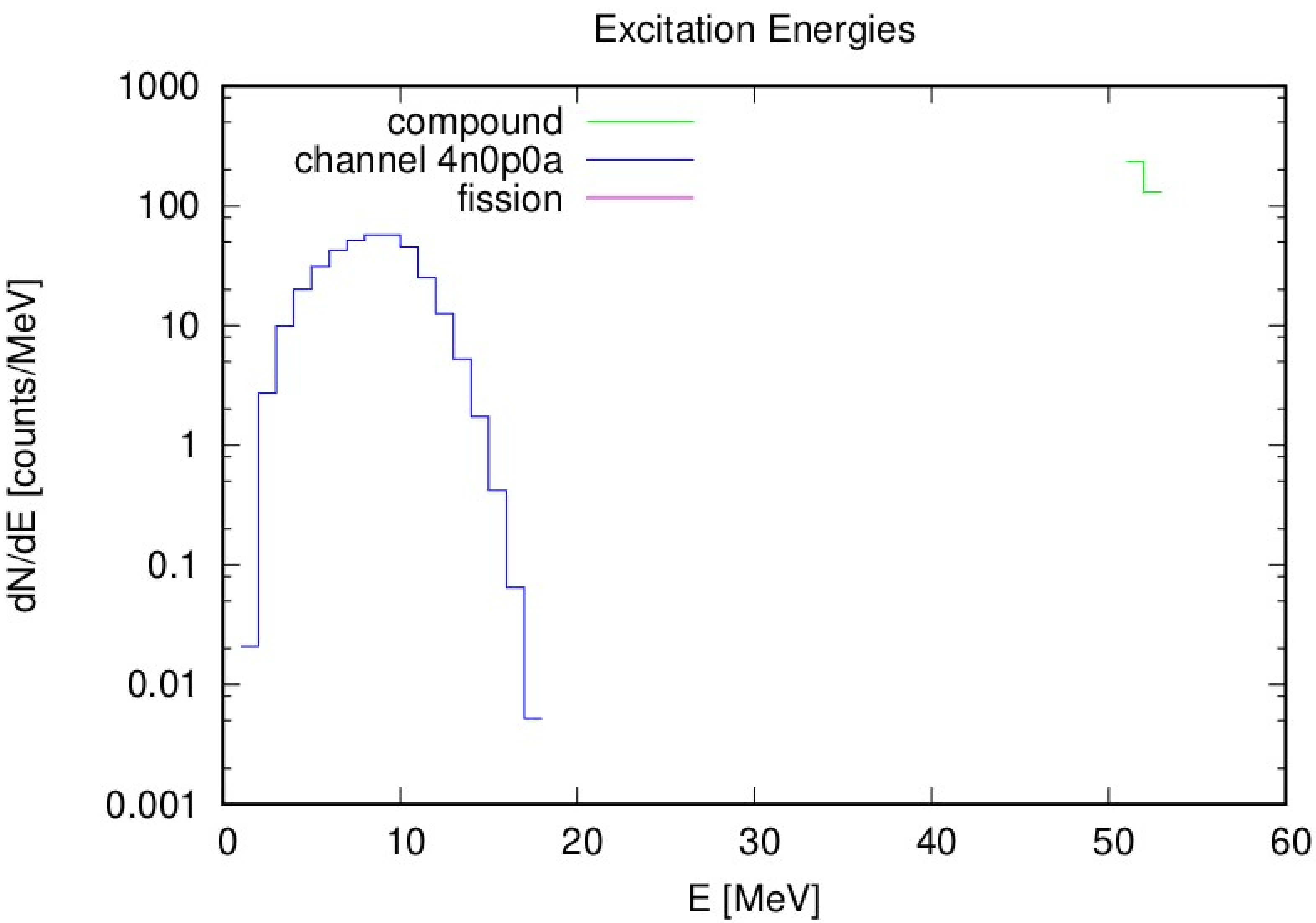
Plunger

- Plunger is a device letting us change target-stopper distance
- It operates at distances 10-5000 um
- We measure what part of gammas where not shifted out of all gammas of interesting energy
- This ratio R differs with distances



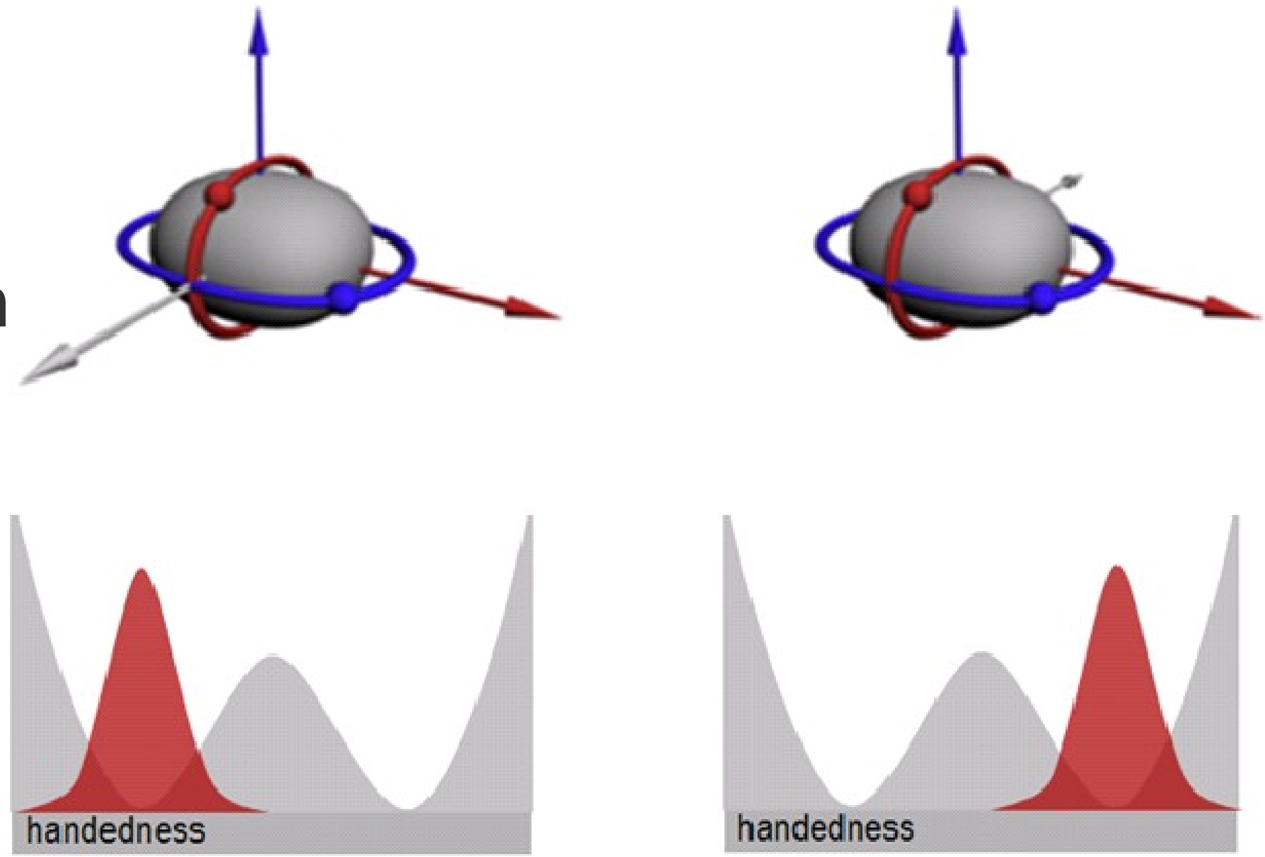
Simulated dependence R(d)


Recoils angular distribution
recoils, channel 4n0p0a
dN/d(theta) [counts/deg]
theta [deg]
0
200
400
600
800
1000
1200
0
10
20
30
40
50
60
70
80
90


Excitation Energies
1000
100
10
1
0.1
0.01
0.001
compound
channel 4n0p0a
fission
dN/dE [counts/MeV]
0
10
20
30
40
50
60
E [MeV]

Chirality: nuclea

- Odd-odd triaxial nuclei
- 3 spins: core, proton and neutron
- 3 perpendicular angular momentum pseudovectors leads to 2 arrangements



|L> state

|R> state