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New developments of the Recoil Distance Doppler-Shift Technique

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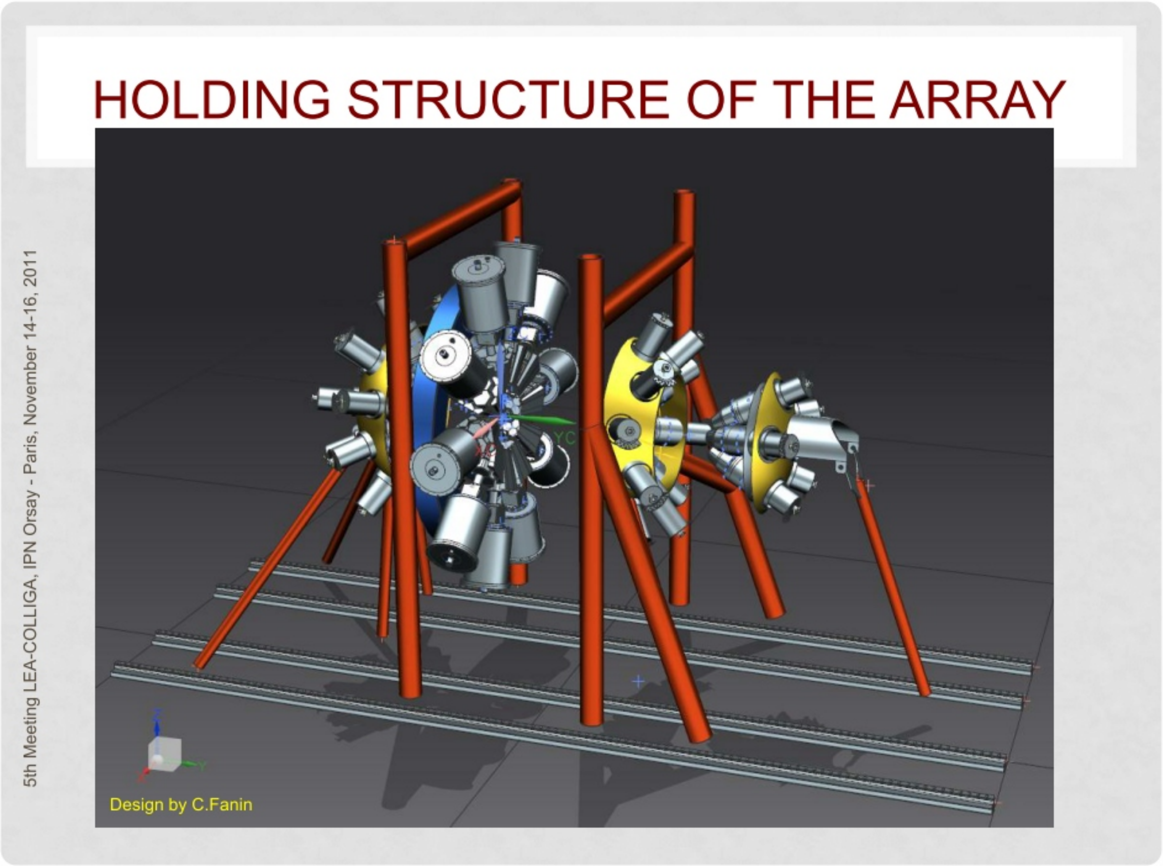
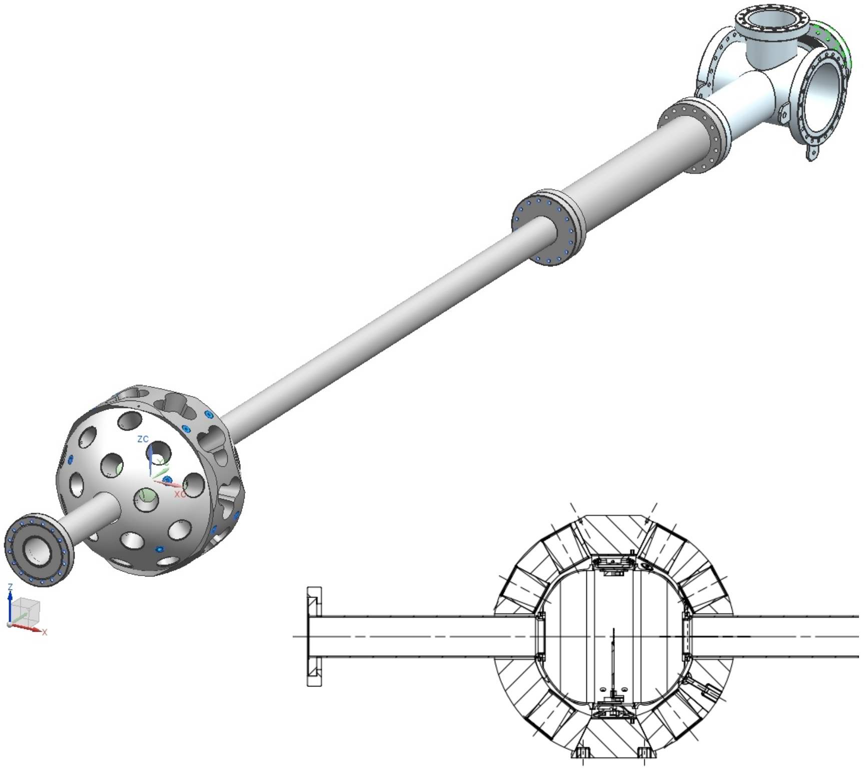
- **A new plunger device for the GALILEO spectrometer @ LNL**
  - mechanical constraints, construction
  - commissioning run at LNL in Feb. 2016:
    (re-)measurement of lifetimes in ^{180}Pt, ^{154}Sm, ^{181}Ta

- **Recent plunger experiments at GANIL: an overview**

- **Plunger experiment of our group at GANIL:**
  „Evolution of the shell structure in the region of n-rich Ti isotopes“

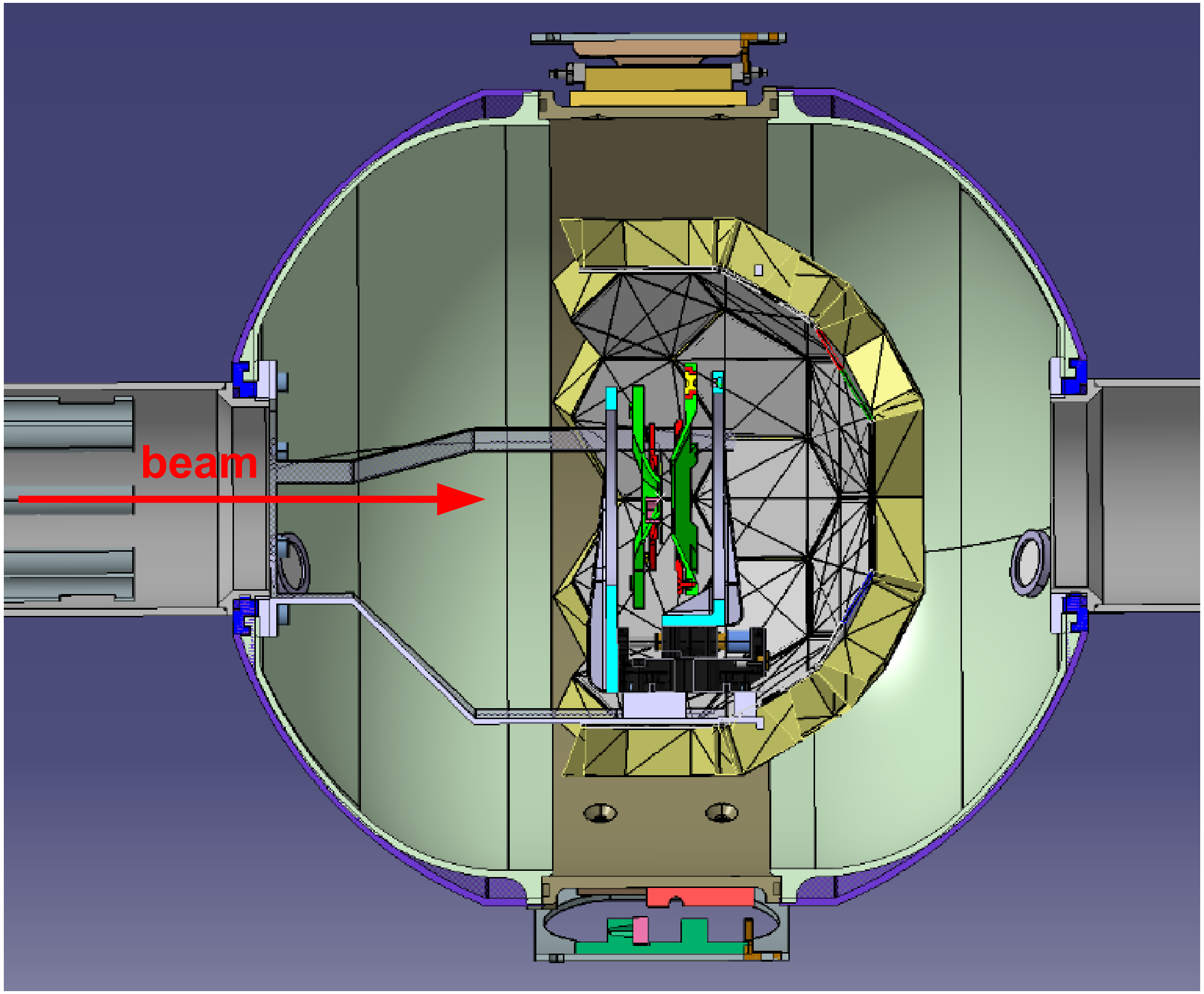
New plunger device for the GALILEO spectrometer





None of existing plunger devices can be used
→ construction of GALILEO
→ constraints in target chamber
→ usage with EUCLIDES Si detector array essential for future lifetime measurements with RDDS at GALILEO: particle detectors to separate weak reaction channels

Construction of a new plunger device for GALILEO



→ Mounted inside existing GALILEO target chamber.

→ Attached to upstream beam line

→ Vacuum feedthroughs for plunger operation in upstream beam line

→ use of downstream part of Euclides

Motor LPS-24
travel dist.:
15 mm
sensor res.:
20 nm

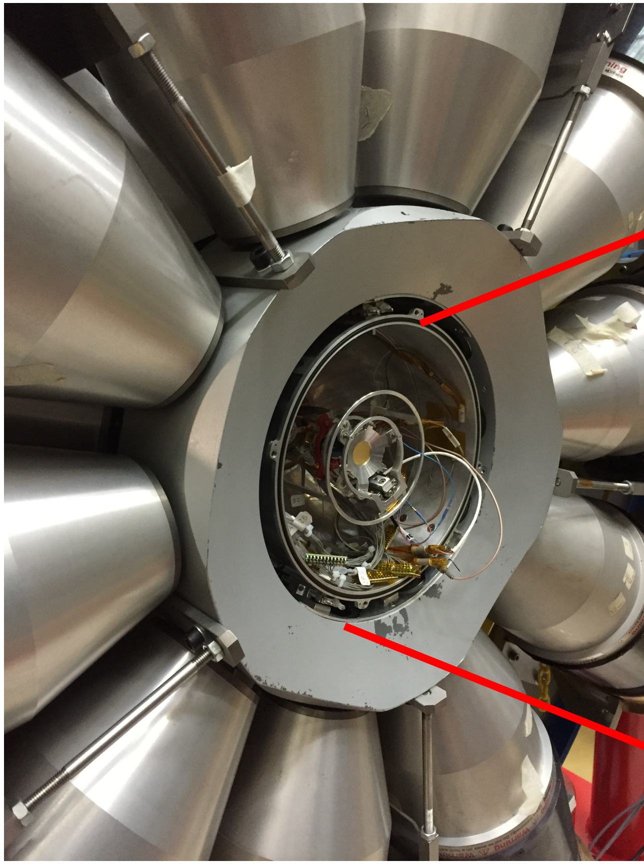
→ Compact construction to avoid shielding of Euclides and HPGe detectors

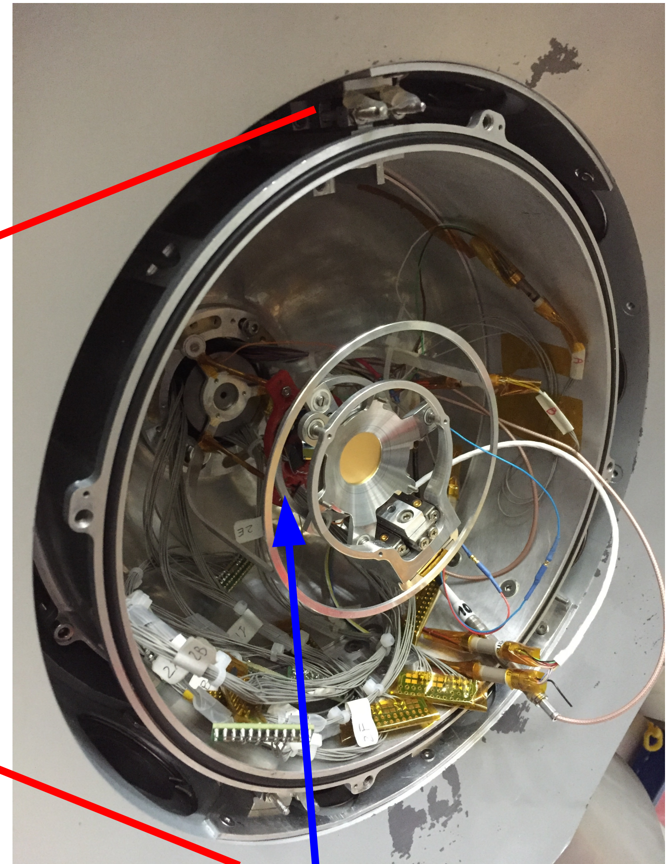
→ no separate piezo crystal and distance measuring system: feedback with motor solely

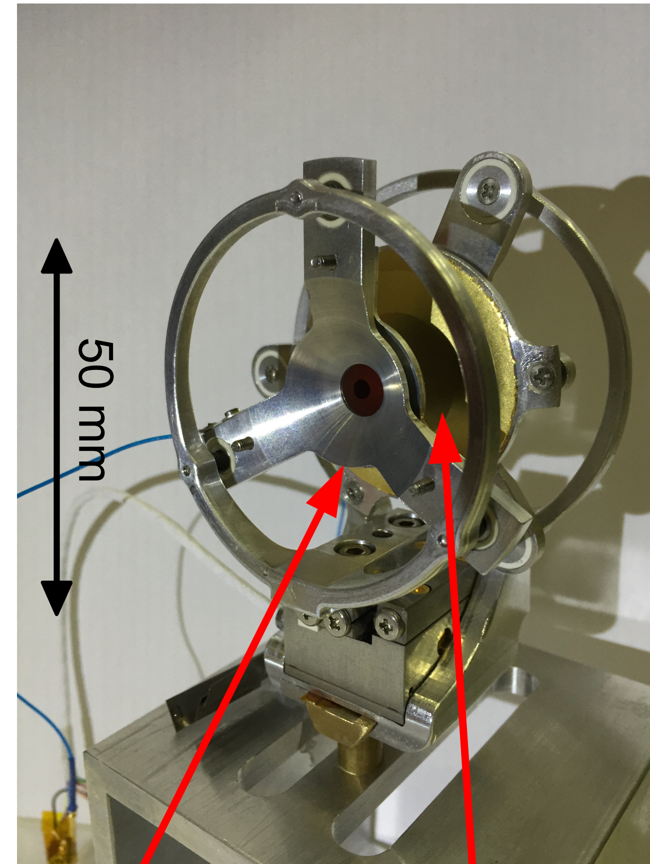
→ Motor: compact motor PI type LPS-24.

New plunger device for GALILEO

Plunger in GALILEO chamber, EUCLIDES detector array removed



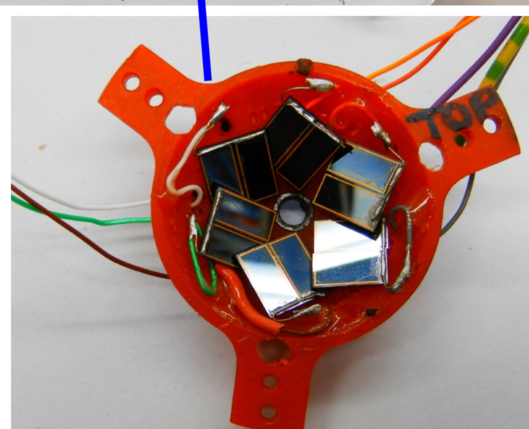




Target cone

Degrader (+ cone)

Solar cell calotte:
Compact charged particle detector array under backward angle



Commissioning experiment with new plunger at LNL

→ Prove the function of new plunger device in combination with GALILEO and particle detectors
→ continue very fruitful collaboration LNL – IKP Cologne.

3 RDDS measurements simultanously (4 days in Feb. 2016)

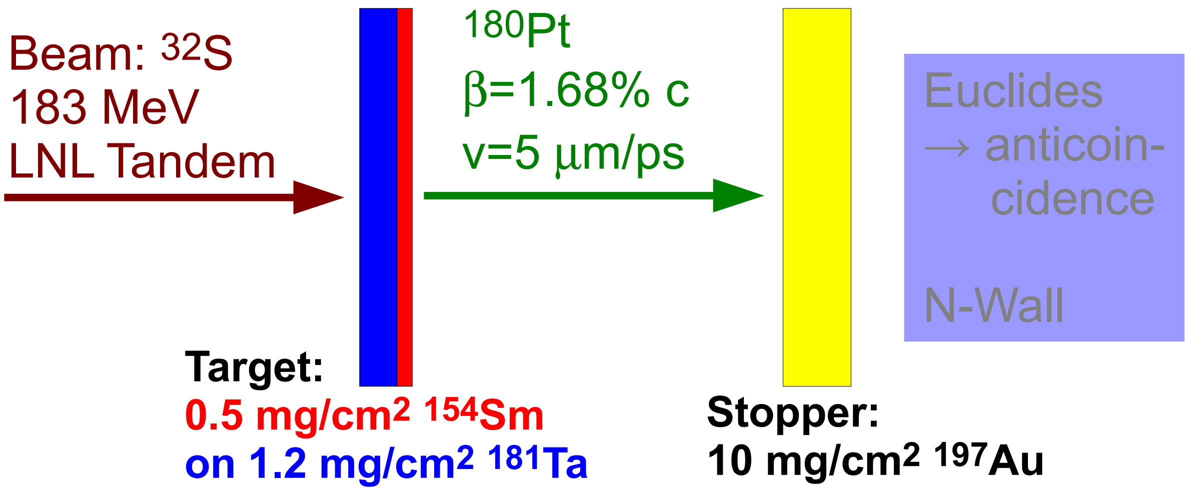
1. (re-)measurement of well-known lifetimes of yrast states in ^{180}Pt with ^{154}Sm(^{32}S,6n)^{180}Pt: known from plunger experiment of our group at JYFL.

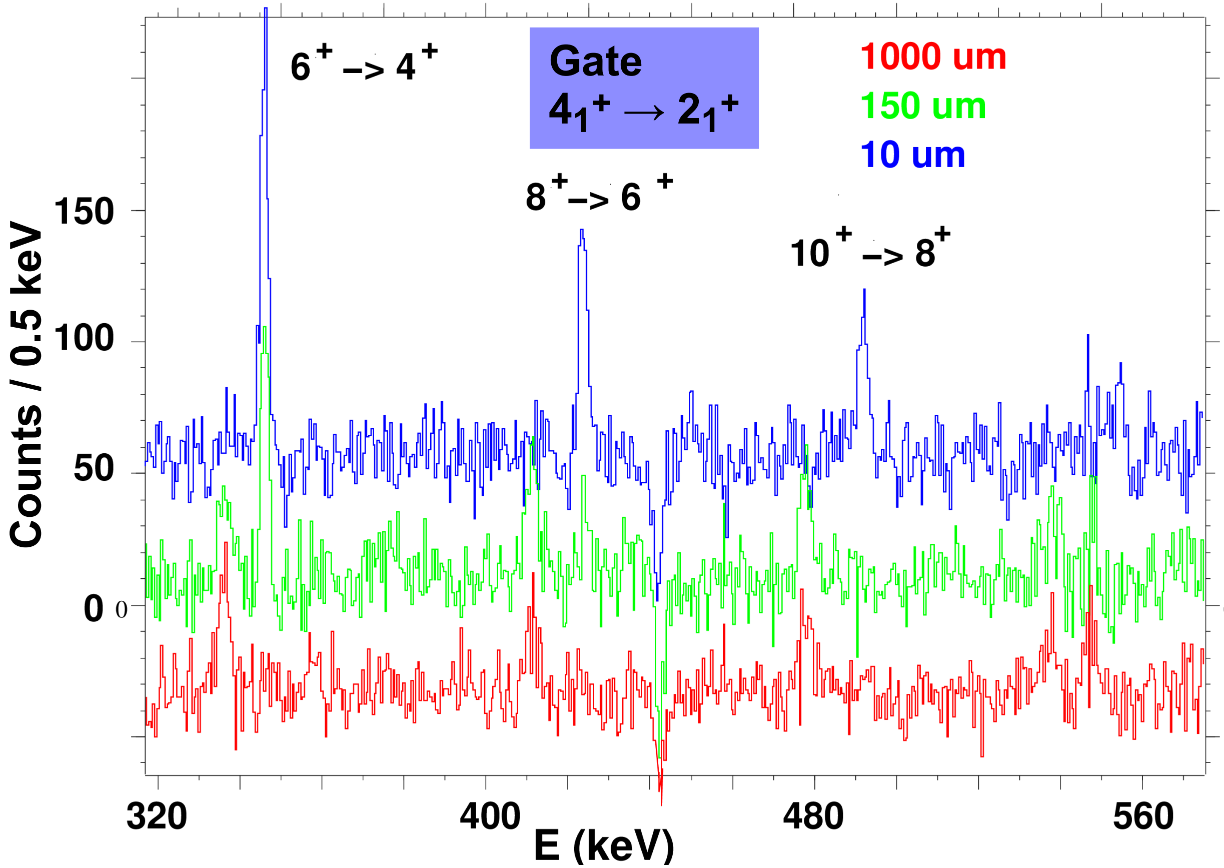
2. measurement of absolute target – stopper distances with known lifetimes of ^{181}Ta target backing facing beam using Coulomb excitation ^{181}Ta(^{32}S,^{32}S*) and particle-γ coincidences.

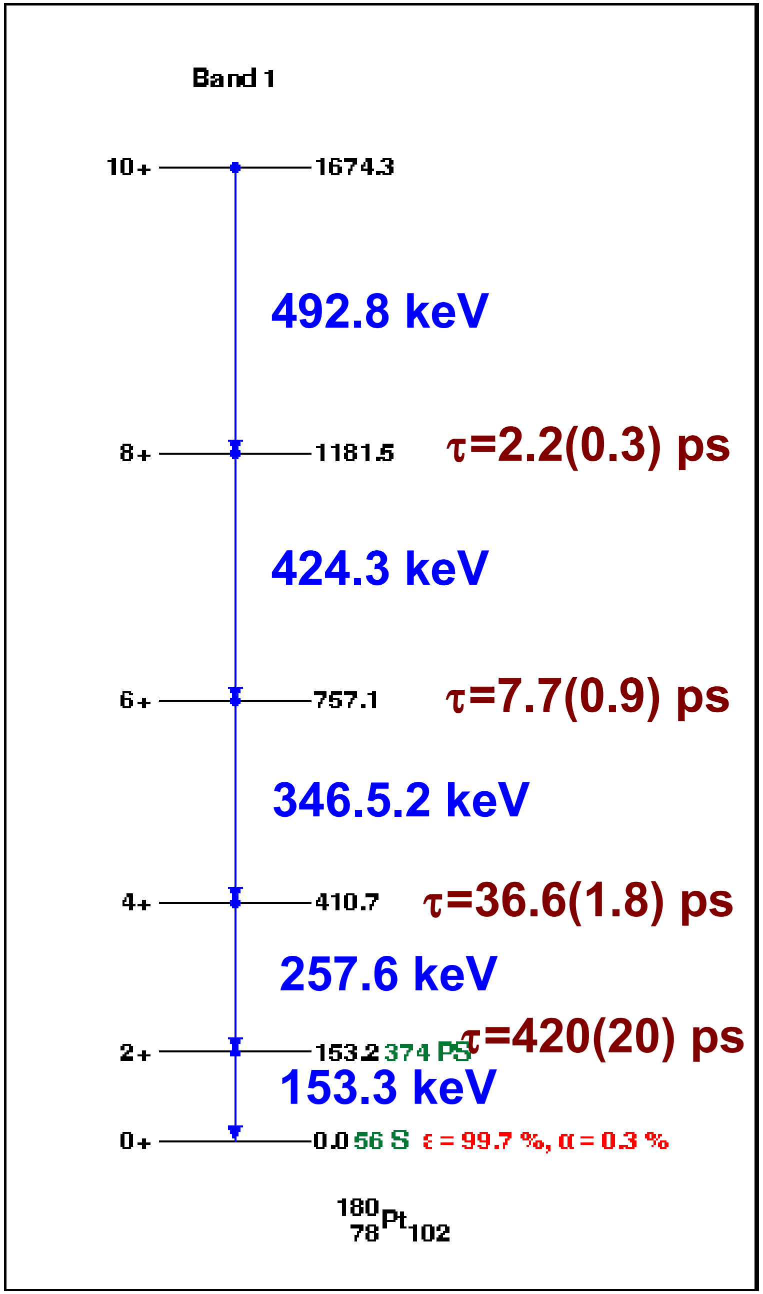
3. determination of precisely known lifetimes in ^{154}Sm with Coulomb excitation ^{154}Sm(^{32}S,^{32}S*) and particle-γ coincidences.

4. study target heating effects using different beam currents (1 pnA – 3 pnA).

1. Lifetimes in ^{180}Pt, reaction ^{154}Sm(^{32}S,4n)^{180}Pt

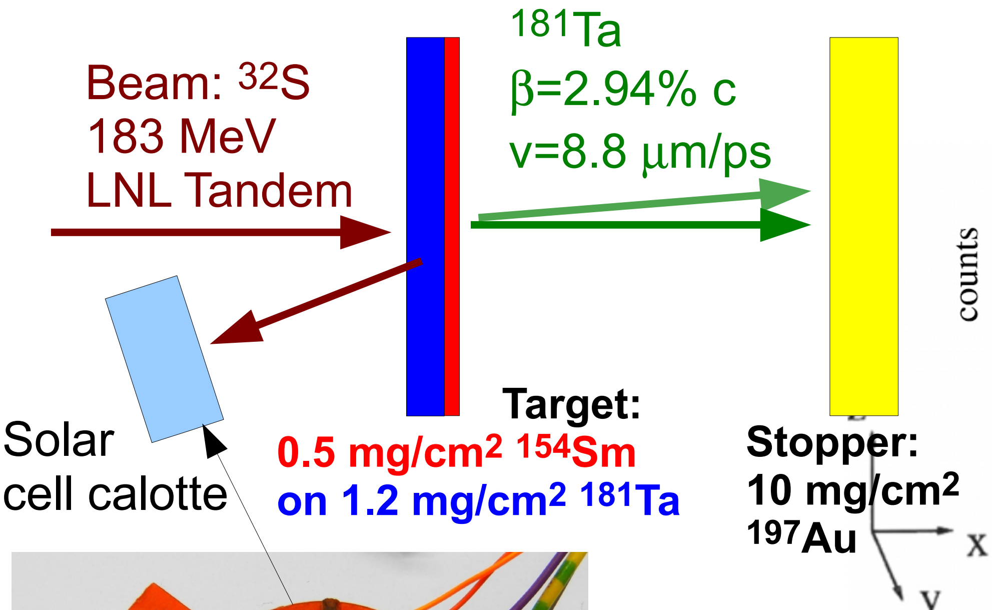


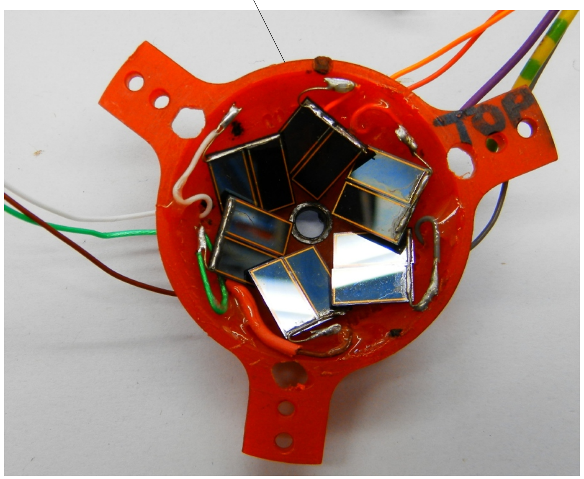




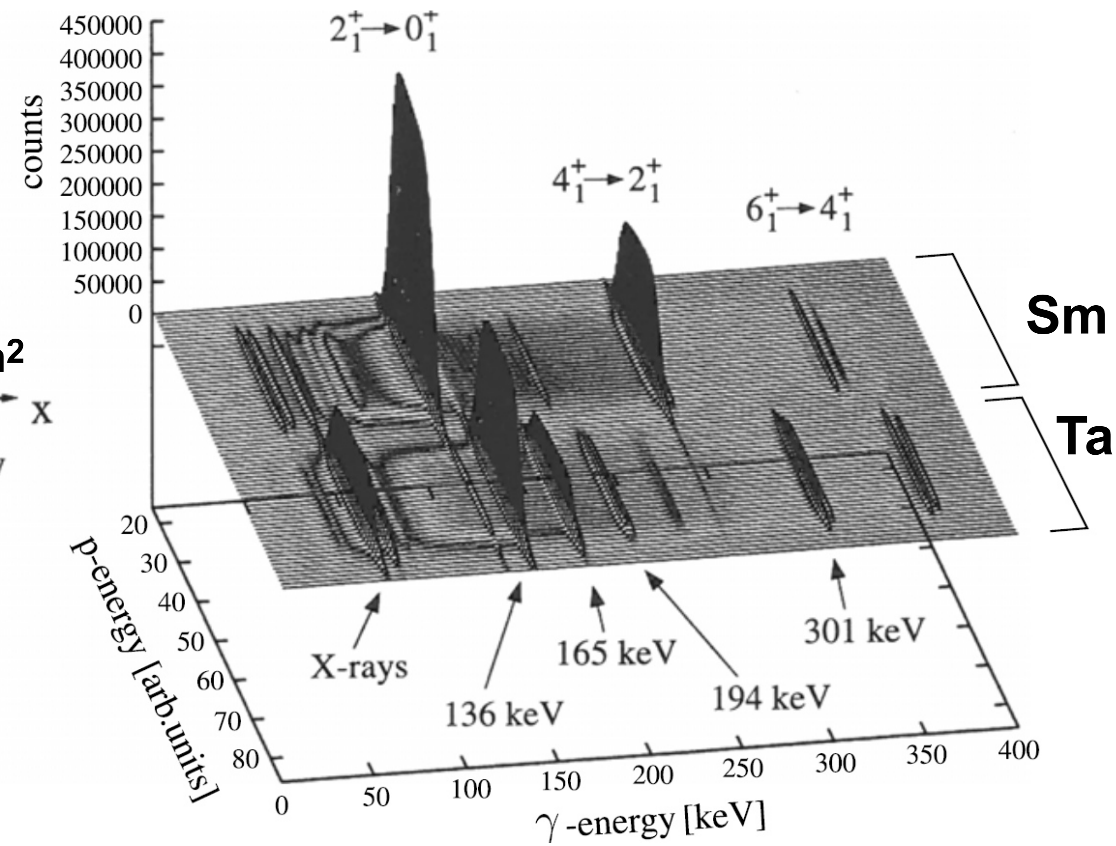
2. ^{181}Ta Coulomb excitation

Determine absolute distances target – stopper from precisely known lifetimes





A. Dewald et al., Prog. Part. Nucl. Phys. 67, 786 (2012)



→ stable operation of new plunger device!

Recent plunger experiments at GANIL: an overview

Year	Code	Spokesperson	Nuclei of Interest	Plunger
2015	E663	Ljungvall	^{62,64,66}Fe	Orsay
	E669	Verney	$\sim^{83}$Ge	Orsay
	E664	Valiente-Dobon	^{106,108}Sn	Cologne
	E682	Domingo-Pardo	^{94}Ru	Cologne
	E672	Georgiev	$\sim^{208}$Pb	Cologne
2016	E696	Fransen	$\sim^{54}$Ti	Cologne
	E708	Celikovic	^{73,75}Ga	Cologne

Nearly 9 weeks of beam-time for 7 experiments.

Setup: AGATA + Plunger + VAMOS++

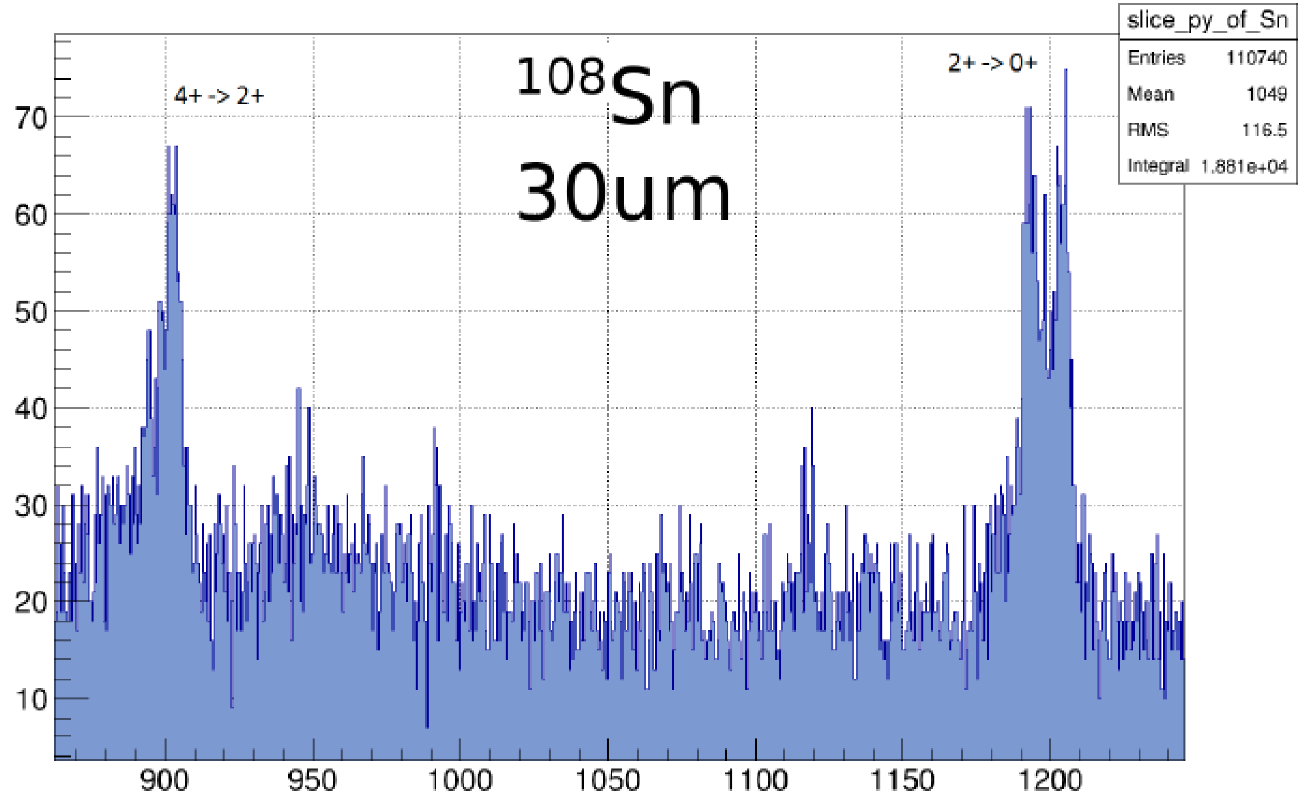
→ spectra promizing
→ in 2015: plunger instabilities due to beam instabilities

Plunger experiment on ^{106,108}Sn at GANIL

Code	**Spokesperson**	**Nuclei of Interest**
E664	Valiente-Dobon	^{106,108}Sn

Reaction: $^{106}\mathrm{Cd} + {}^{58}\mathrm{Ni} \rightarrow {}^{106,108}\mathrm{Sn}$ at $\mathrm{E} \approx 7.3\,\mathrm{AMeV}$, $I \sim 0.5\,\mathrm{pnA}$

Plunger: Eight distances between $10\,\mu\mathrm{m}$ and $500\,\mu\mathrm{m}$

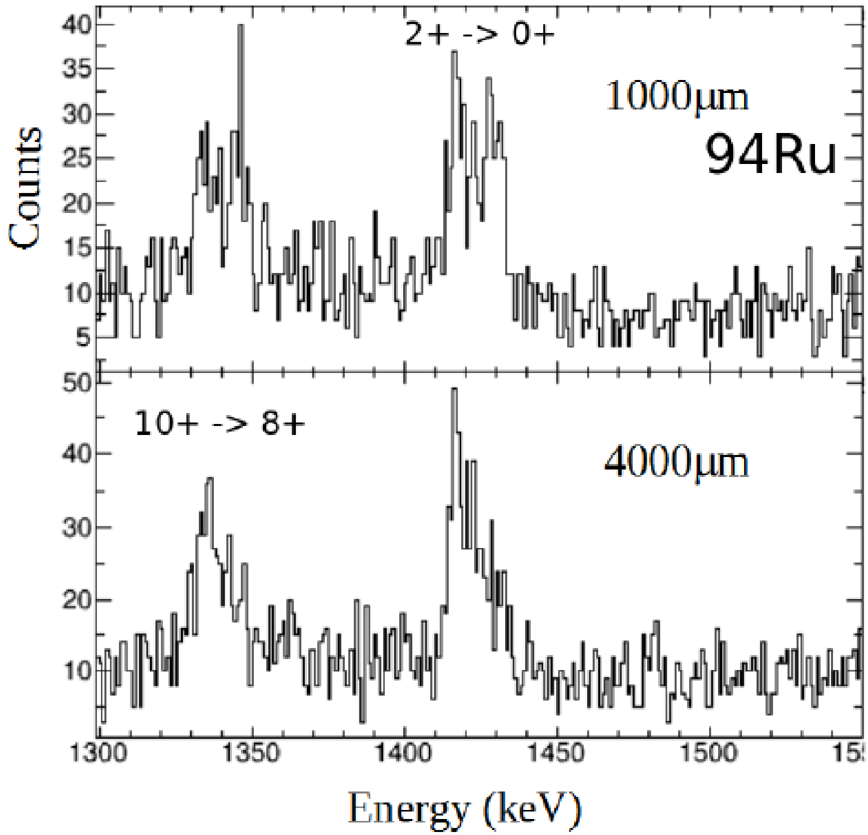


Spectrum received from Marco Siciliano

Plunger experiment on ^{94}Ru at GANIL

Code	Spokesperson	Nuclei of Interest
E682	Domingo-Pardo	^{94}Ru

Reaction: $^{92}\mathrm{Mo} + {}^{92}\mathrm{Mo} \rightarrow {}^{94}\mathrm{Ru}$ at $\mathrm{E} \approx 7.8\,\mathrm{AMeV}$, $I \sim 0.8\,\mathrm{pnA}$
Plunger: Seven distances between $10\,\mu$m and $4000\,\mu$m



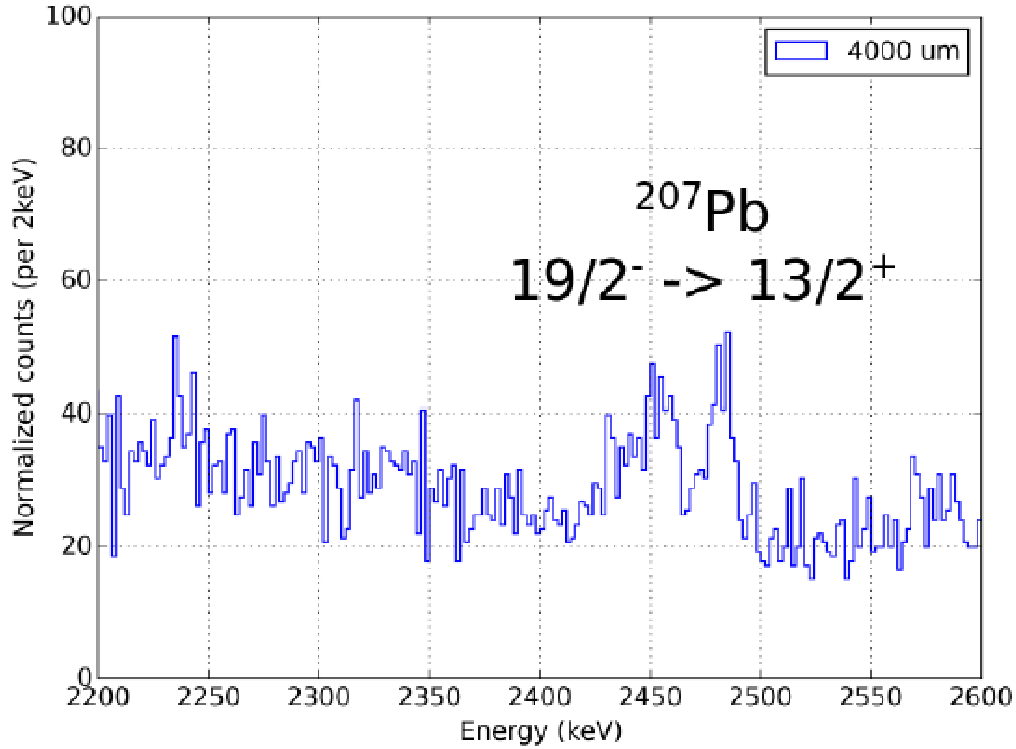
Spectrum: Rosa Perez

Lifetime and g factor measurements of short-lived states in vicinity of 208Pb

Code	Spokesperson	Nuclei of Interest
E672	Georgiev	$\sim {}^{208}\mathrm{Pb}$

Reaction: $^{208}\mathrm{Pb} + {}^{100}\mathrm{Mo} \rightarrow \sim {}^{208}\mathrm{Pb}$ at $E = 6.25$ AMeV, $I \sim 0.7$ pnA
Plunger: Eight distances between 30 μm and 4000 μm

Clarify shell structure across Z=82, N=126



Spectrum: Damian Ralet

Plunger experiment at GANIL (April 2016):
„Evolution of the shell structure in the region of n-rich Ti isotopes“

Motivation

- Phase transition:
  collective structures in ^{58}Fe
  → neutron subshell closure developing
  for ^{56}Cr → ^{54}Ti → ^{52}Ca

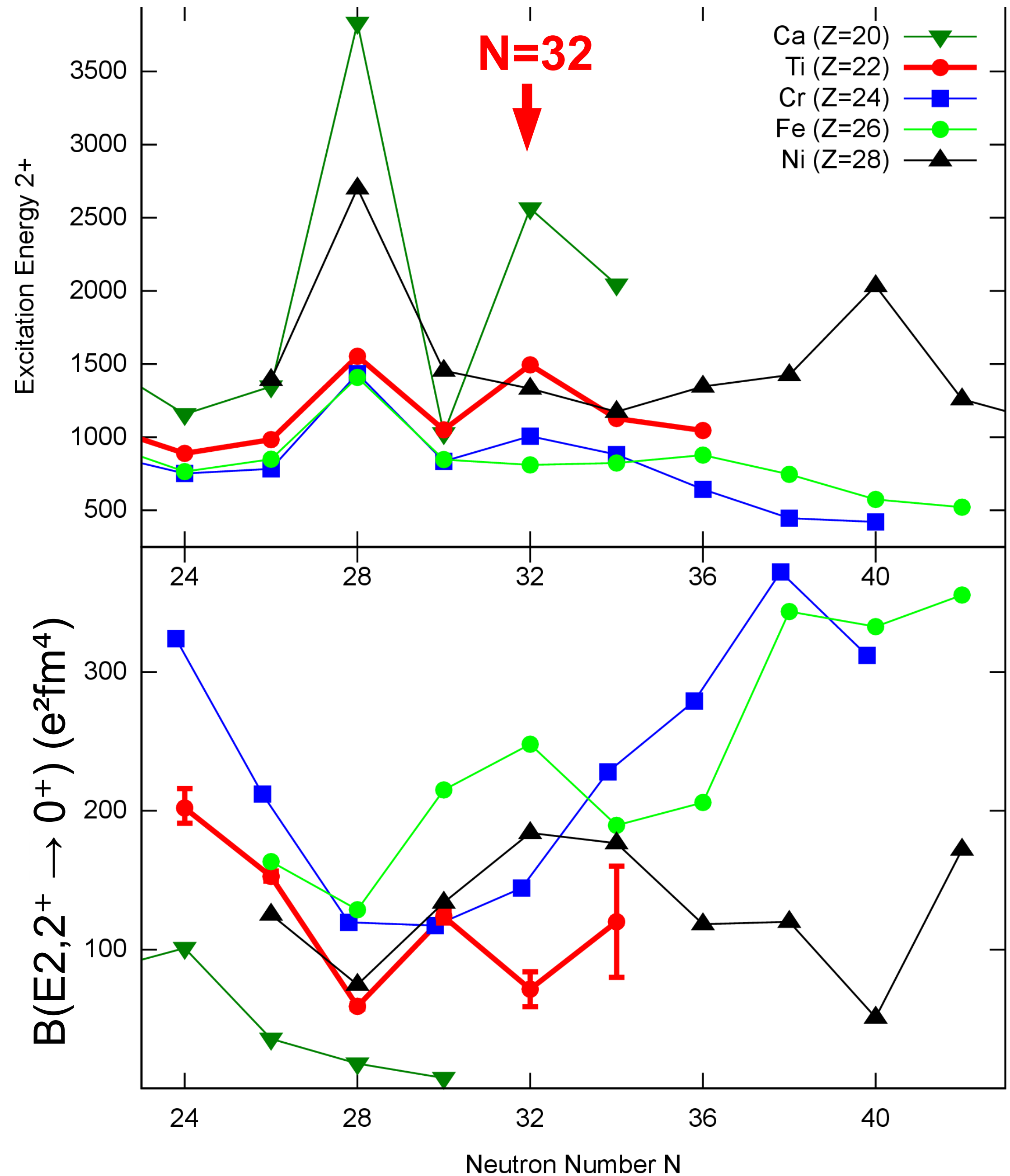
- $\pi\ f_{7/2}$ orbital emptied:
  weakening of $\pi\ f_{7/2} - \nu\ f_{5/2}$
  monopole interaction
  → increasing gap $\nu\ p_{3/2}$, $\nu\ p_{1/2}$

Aim: investigate shell structure in neutron rich ^{54}Ti, ^{55}V from transition strengths between low-lying states:

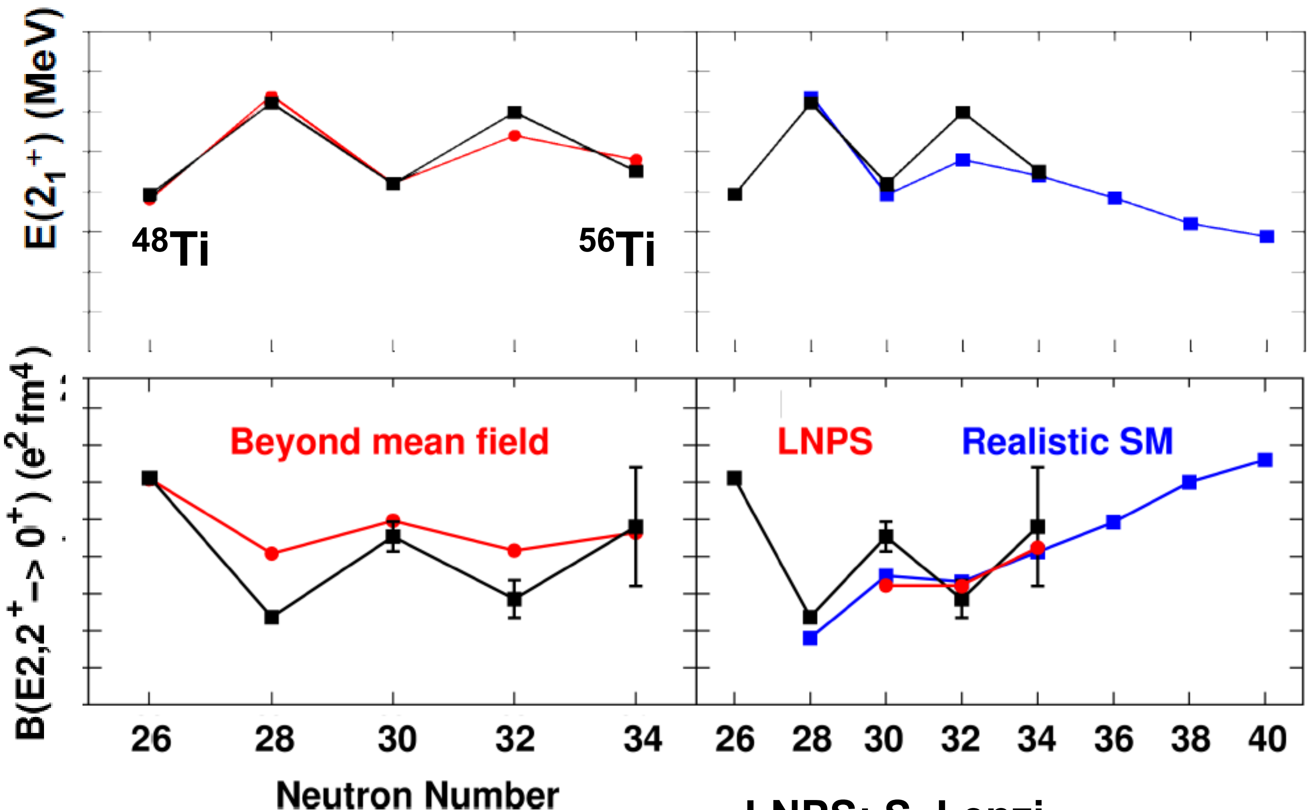
^{54}Ti: only $B(E2;2_1^+ \rightarrow 0_1^+)$ known from intermediate Coulex,

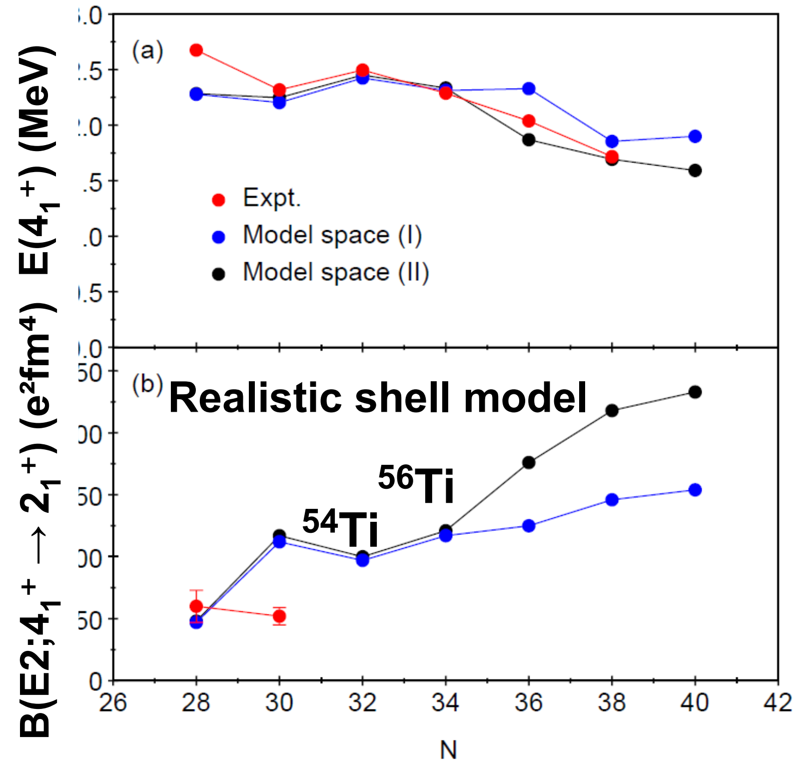
^{54}Ti: $\Delta B(E2) = 17\%$

^{55}V: no lifetimes / no $B(\pi L)$



Theoretical approaches for n-rich Ti





Rodriguez, Egido
PRL 99, 062501 (07)
Finite density dependent Gogny interaction
Shell closure for N=32

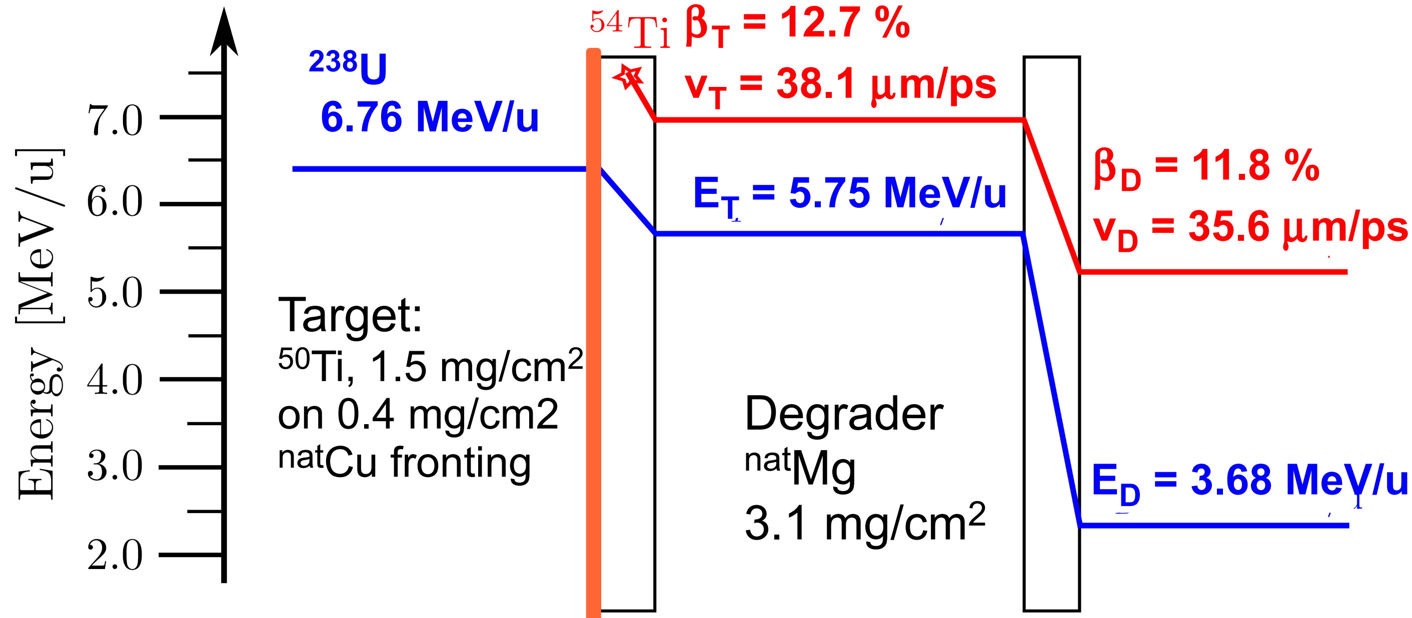
LNPS: S. Lenzi

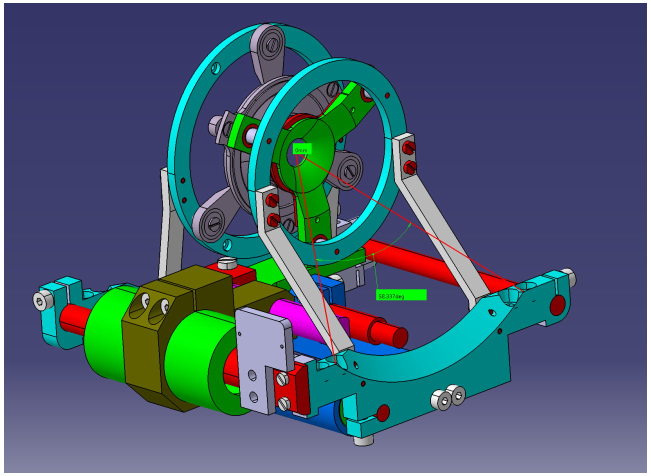
L. Coraggio et al., PRC89, 024319 (14)
Realistic shell model, model space:
p $1f_{7/2}$, $2p_{3/2}$
n $2p_{3/2}$, $2p_{1/2}$, $1f_{7/2}$, $1g_{9/2}$, $2d_{5/2}$

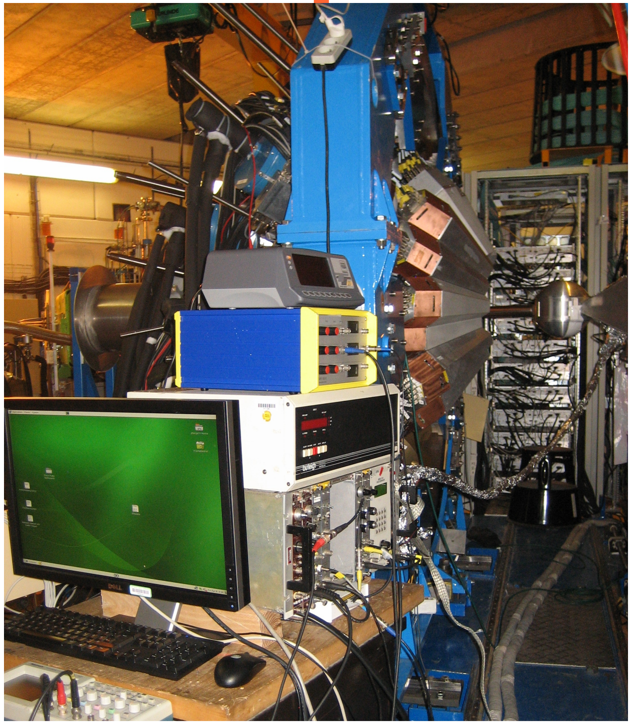
Insufficient theoretical description of n-rich Ti

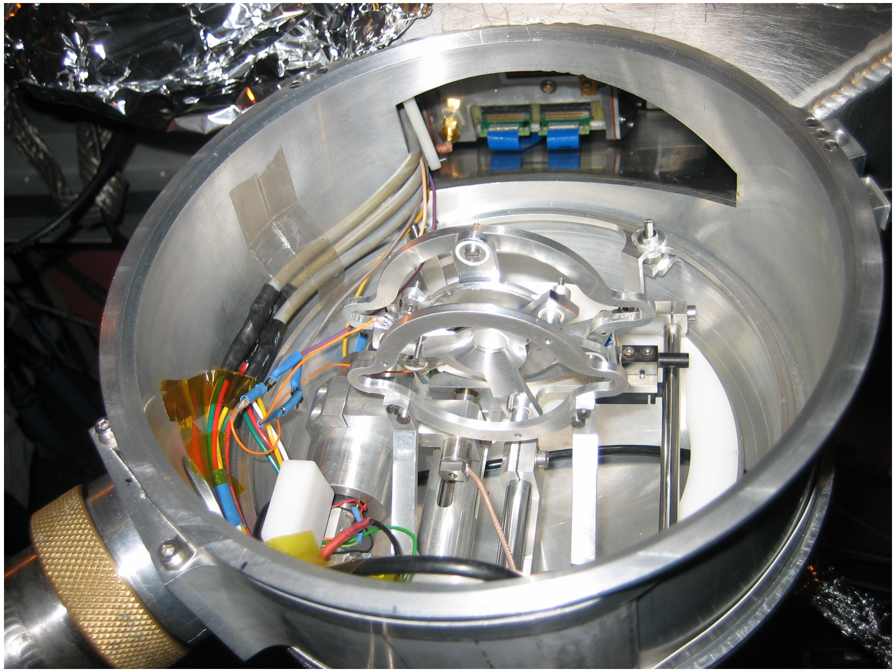
→ ^{54}Ti: determine yrast B(E2), ^{55}V: transition strengths between low-lying states, Δ ~ 10%
  → conclusive picture of evolving structure,
  → contributions of different orbitals to 4_1^+, 6_1^+ (^{54}Ti)

Experiment on nuclei in the region of ^{54}Ti

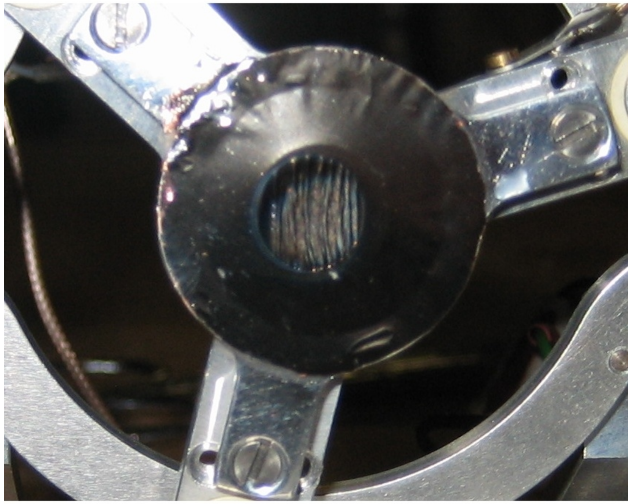








Target problems: caused by thermal effects?



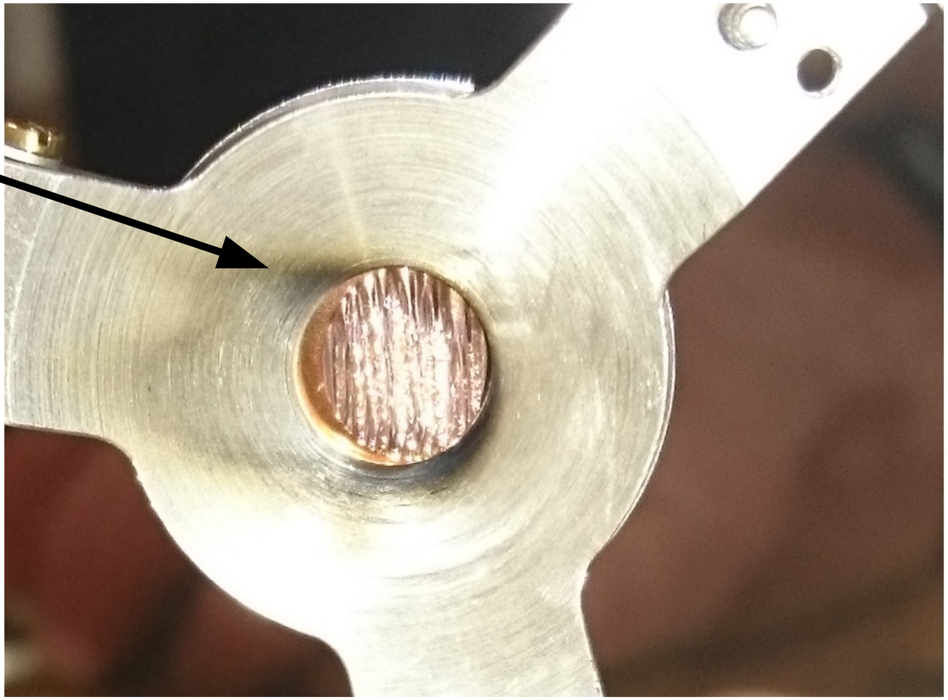
→ not predicted by estimates of target temperature:
original target 0.9 mg/cm^2 ^{54}Cr on 0.6 mg/cm^2 Mg fronting
got wrinkles (~100 µm), same for ^{50}Ti, self-supp.

→ modified target to increase heat conductivity:
^{50}Ti, 1.2 mg/cm^2 on 0.4 mg/cm^2 ^{nat}Cu

→ run experiment with this target, low ^{238}U beam current:
3 enA = 0.1 pnA, beam diameter as large as possible

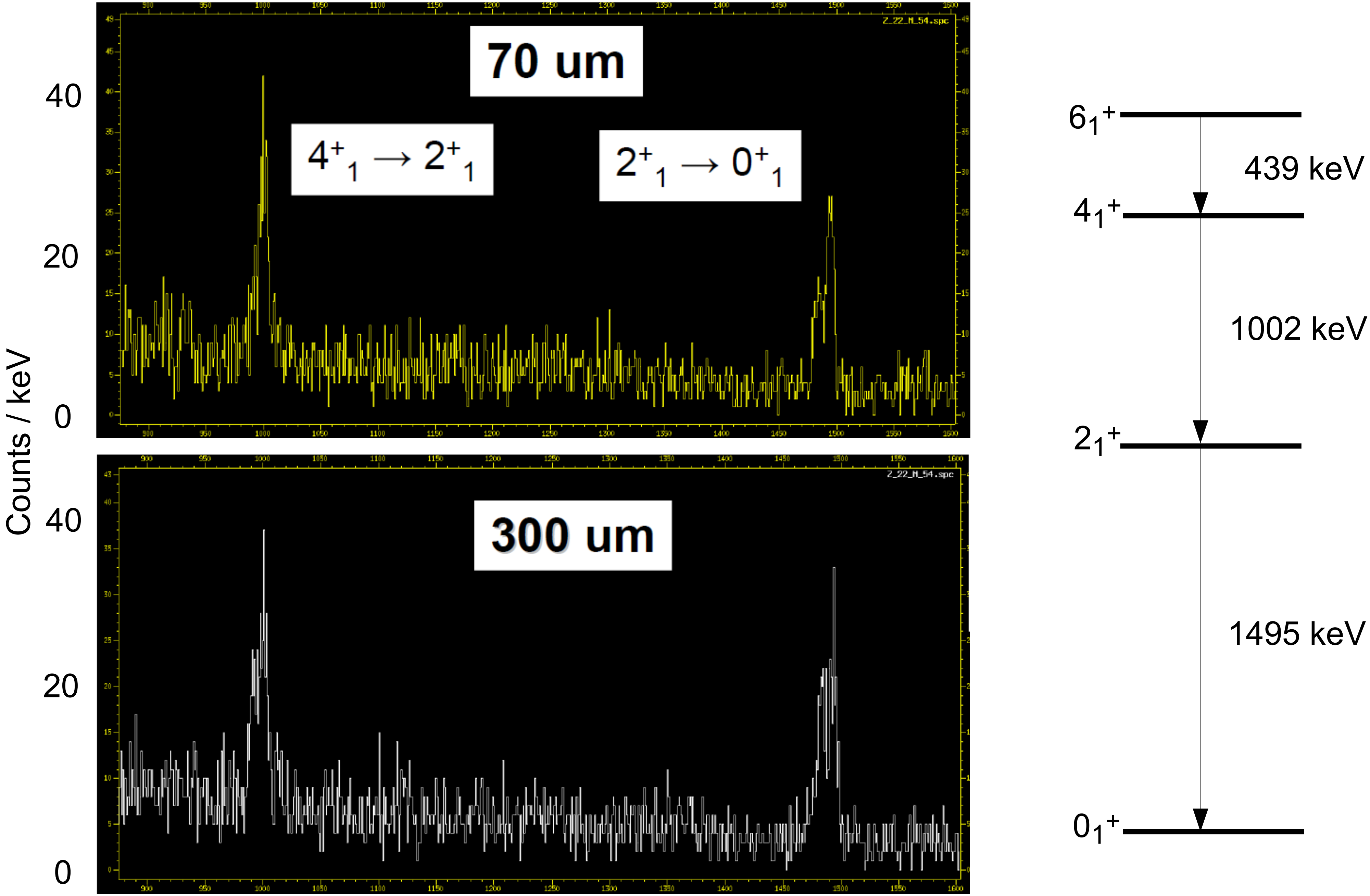
→ distances measured: 70 mm, 150 mm, 180 mm, 240 mm, 300 mm, 1000 mm
each for 4 – 5 shifts

→ however, afterwards...

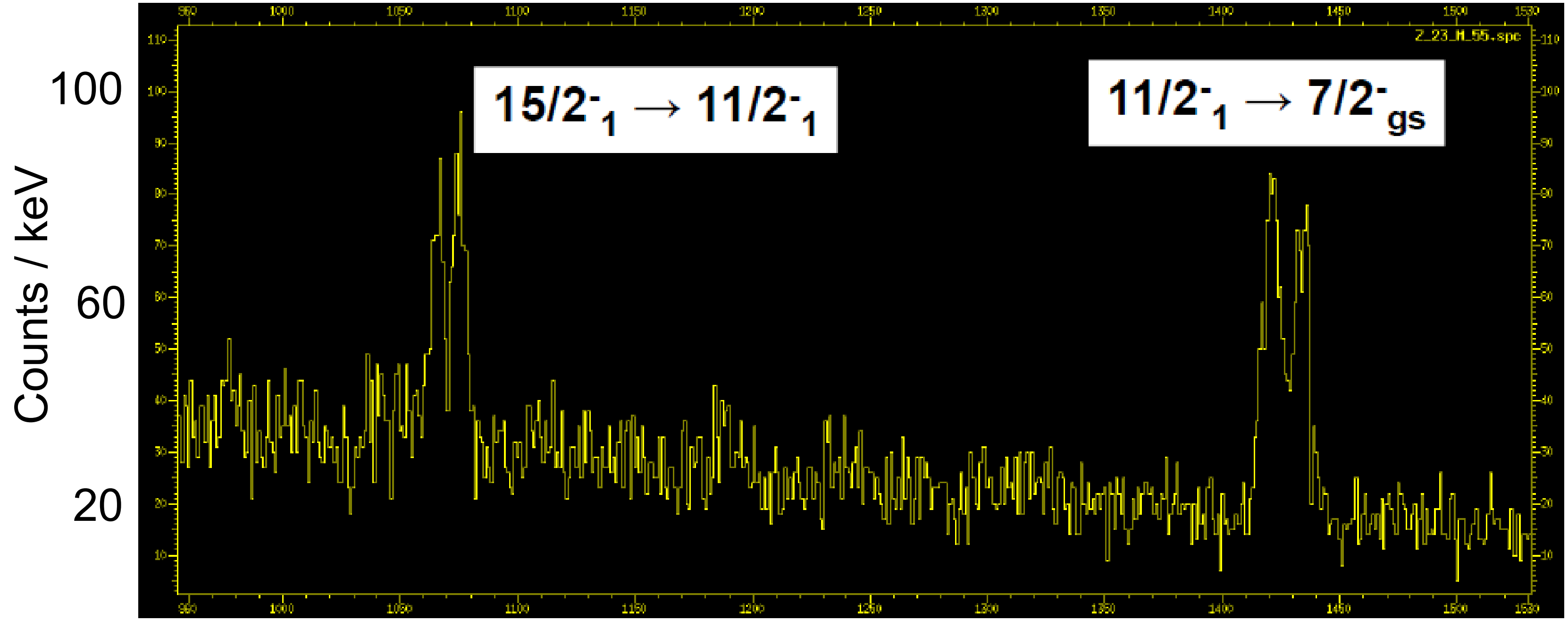


Modified target shows wrinkles again.
→ assumption: caused by change
of crystalline structure in ^{238}U beam.
→ detailed investigation will be done
(solid state physics)
→ feedback system data show:
change of structure after a short time in beam
→ analyze lifetime data: use well-known
lifetimes of neighboring nuclei (^{51,52}Ti)

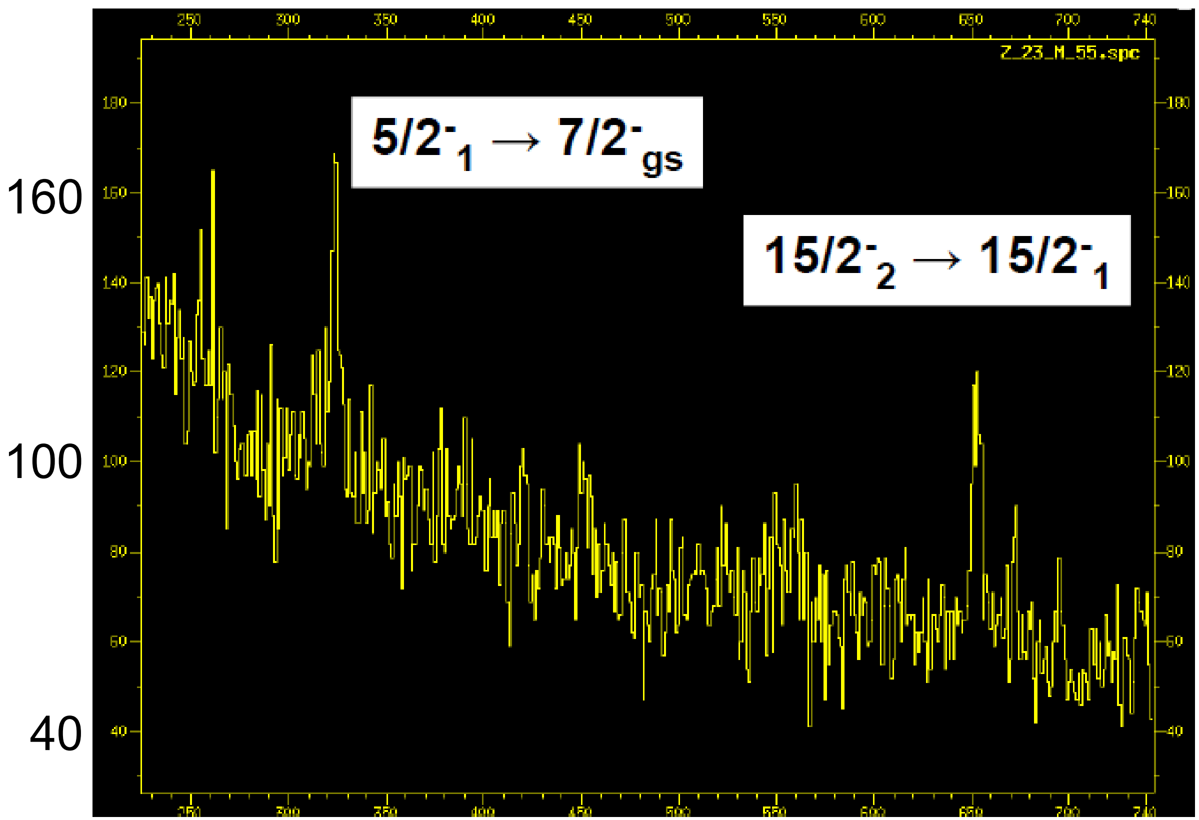
Spectra ^{54}Ti



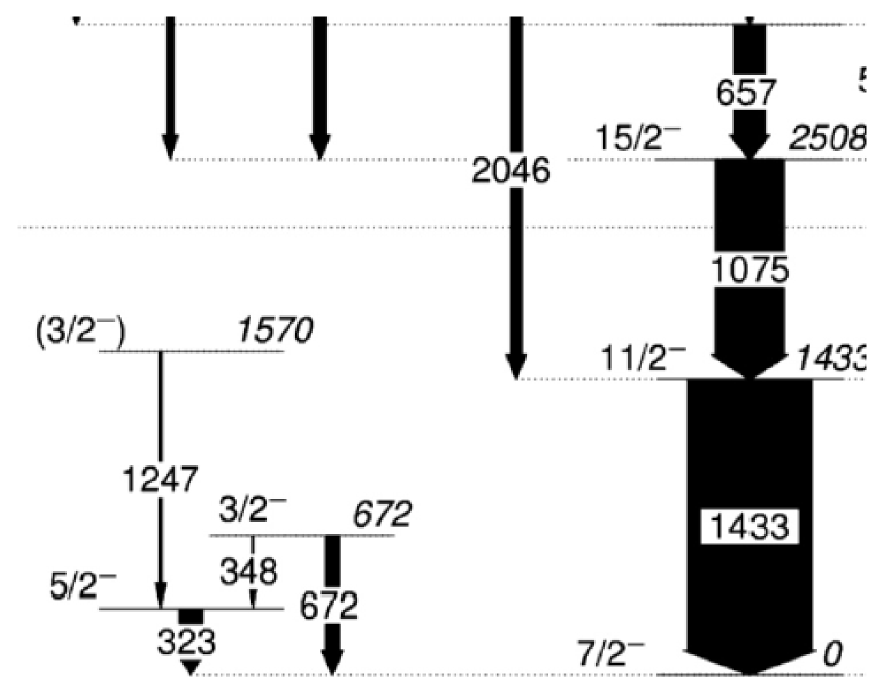
^{55}V



Counts / keV
100
60
20
$15/2^-_1 \rightarrow 11/2^-_1$
$11/2^-_1 \rightarrow 7/2^-_{gs}$
Z_23_M_55.spc



160
100
40
$5/2^-_1 \rightarrow 7/2^-_{gs}$
$15/2^-_2 \rightarrow 15/2^-_1$
Z_23_M_55.spc



657
15/2⁻ 2508
2046
1075
(3/2⁻) 1570
11/2⁻ 1433
1247
3/2⁻ 672
348
672
5/2⁻
323
1433
7/2⁻ 0

Collaboration

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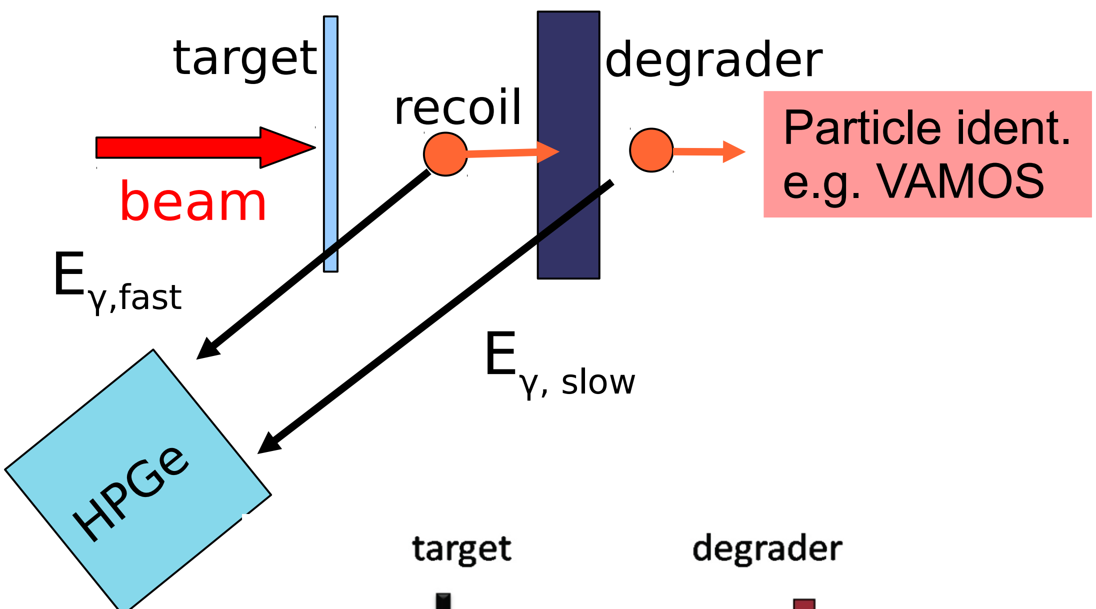
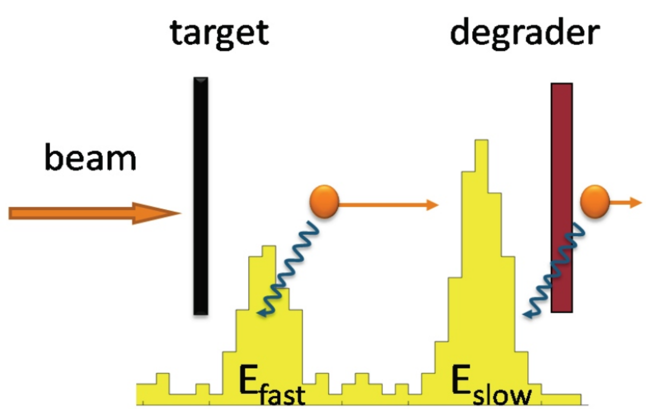
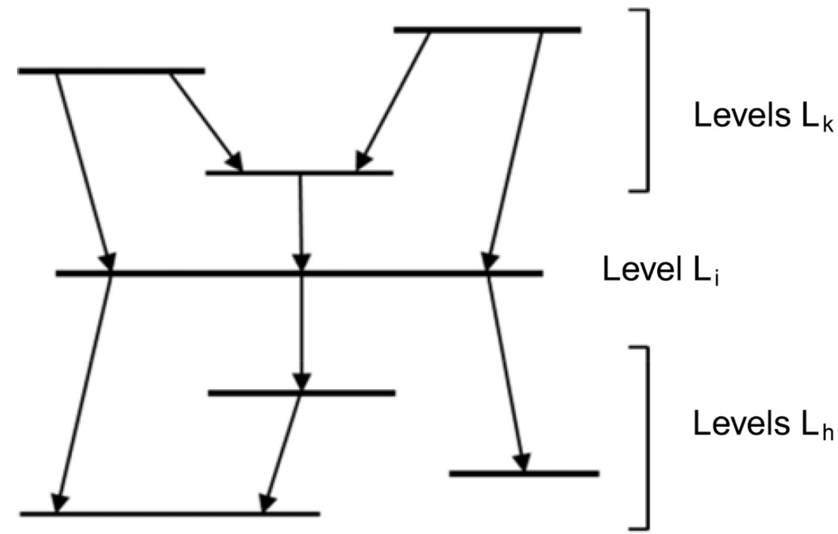
S. Bondili, D. Cullen
University of Manchester, UK

Experimental details: The RDDS method

$$E_S = E_U \cdot \left(1 + \frac{v}{c} \cdot \cos\Theta\right)$$







$$\tau_i(x) = -\frac{Q_i(x) - \sum_k \alpha_k Q_k(x)}{v \frac{dQ_i}{dx}(x)},$$

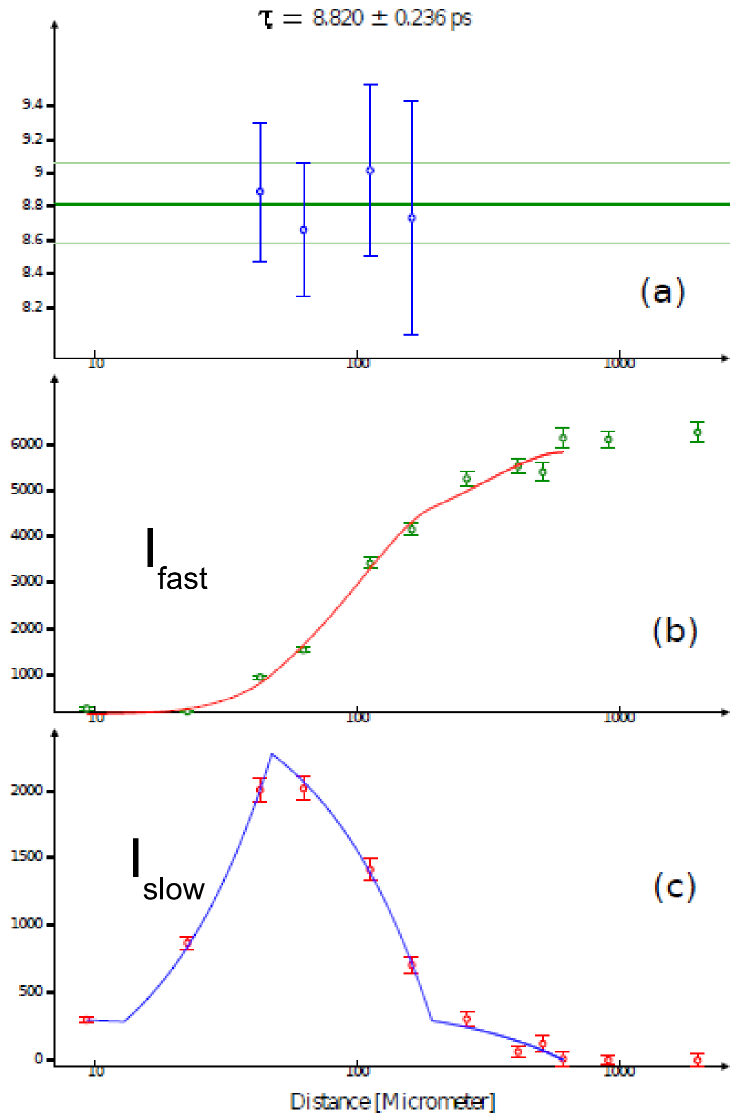
$$\text{intensity ratio } Q_i(x) = I_i^s / I_i$$

→ Need to know all feeders

→ Typically: unobserved feeding
→ analyse coincidence data.
often not possible for exotic nuclei

→ Exotic nuclei: often only singles
estimate sidefeeding effects

The plunger technique



γγ coincidence measurement

- Plot ratio $I_1/I_1 + I2$ vs distance
- Every distance d_i gives $\tau_{d_i} = f_{d_i}(\frac{I_1}{I_1+I_2})$
- More reliable*: **D**ifferential **D**ecay **C**urve **M**ethod
- Differential: $\frac{d}{dt} = \frac{d}{dx}\frac{dx}{dt} = v\frac{d}{dx}$

* Depending on statistics and distances measured.

Eventually: consider deorientation for long flight times:
→ flight distance of some 100 μm for v/c=0.1