Application of CLTDs* for the investigation of Z-yield distributions of fission fragments

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*CLTDs – Calorimetric Low Temperature Detectors

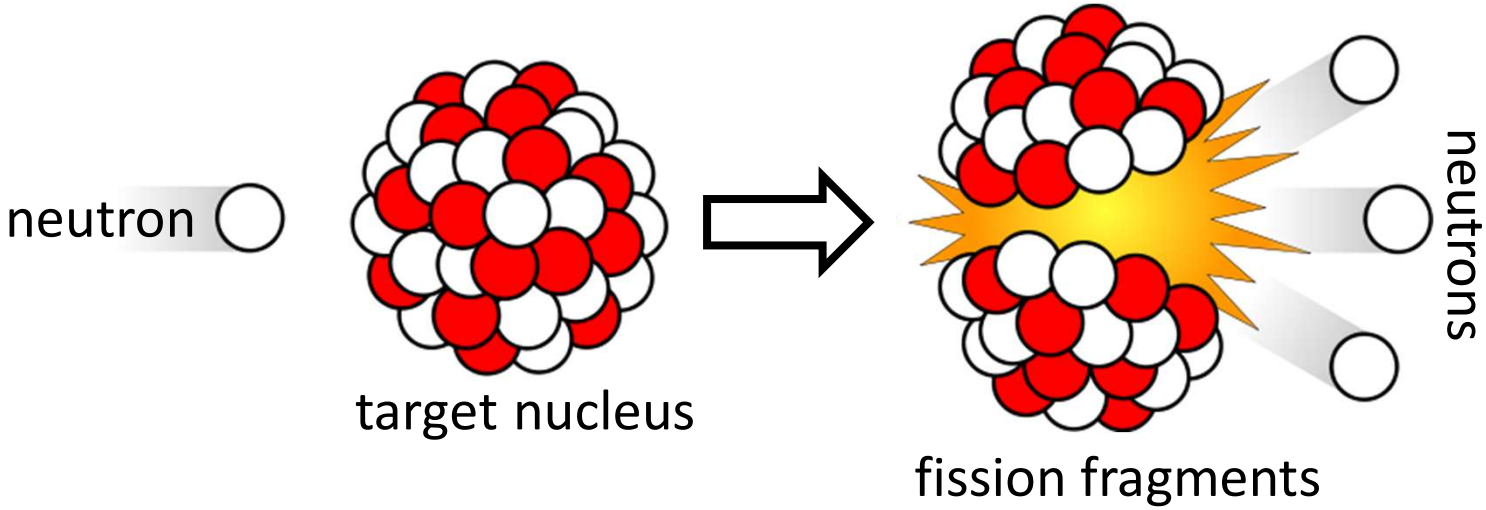
Motivation

motivation for studying fission fragment yields:

- Various nuclear energy applications
- better understanding of the nuclear fission process
- data relevant for reactor physics

Application of CLTDs for fission studies!

Thermal neutron induced fission reactions



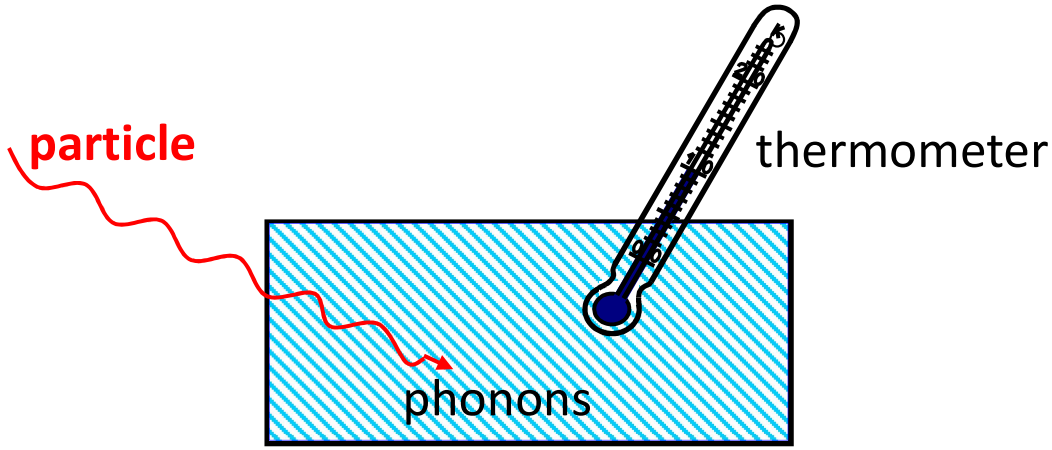
Outline

- **Calorimetric Low Temperature Detectors:**
  - Concept
  - Advantages
  - Design
- **Nuclear Charge Distribution Measurements:**
  - Experimental Set-up
  - Preliminary results:
    - First time direct Z-yield determination for heavy fragment masses
      - Using passive absorber method
    - Proton odd-even effect in masses approaching symmetric fission
      - for ^{239}Pu & ^{241}Pu
      - Important for nuclear model description near scission
    - Precise ^{92}Rb & ^{96}Y yields
      - for ^{235}U, ^{239}Pu, ^{241}Pu (n_{th}, f)
      - Important for <u>reactor antineutrino anomaly</u> studies

CLTDs: Introduction

Calorimetric Detector → detection of heat

Idea: detection of particle energy independent of ionization processes



Interaction of ions with matter:

- Primary:

Ionization → ionization detectors

- Secondary:

thermalization → calorimetric detectors

(conversion of energy to heat

⇒ detection of thermal phonons)

Potential Advantages:

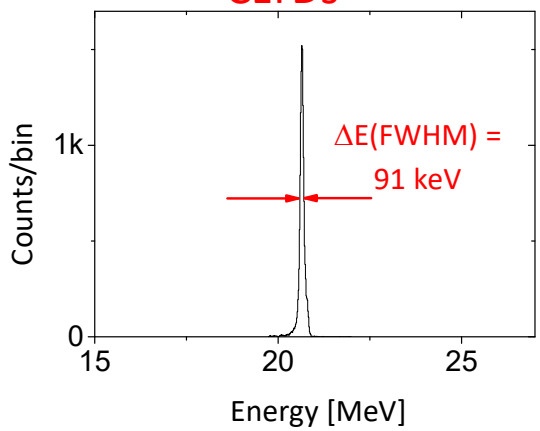
- energy resolution
- energy linearity
- detection threshold
- variety of detector materials

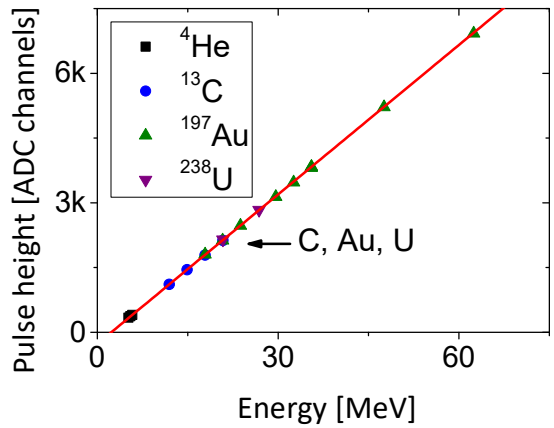
CLTDs: Advantages

Energy Resolution
(^{238}U @ 20.7MeV)

Pulse Height Defect
(^{13}C, ^{197}Au, ^{238}U)

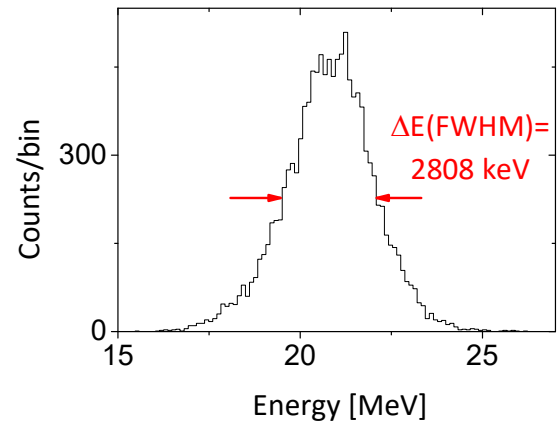
CLTDs

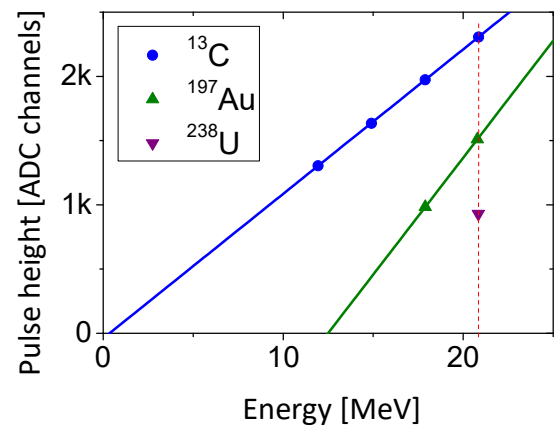




More complete energy detection
→Better resolution and linearity

Si Detector

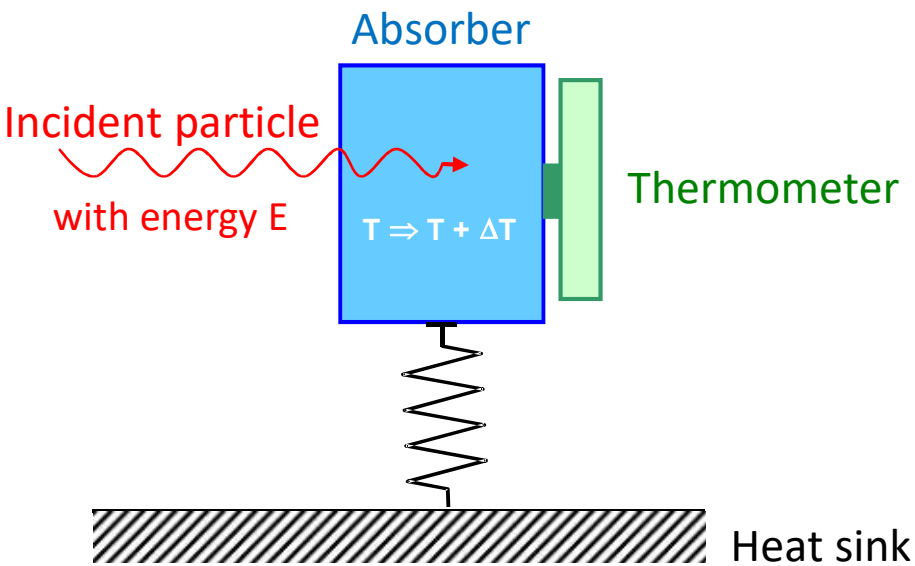




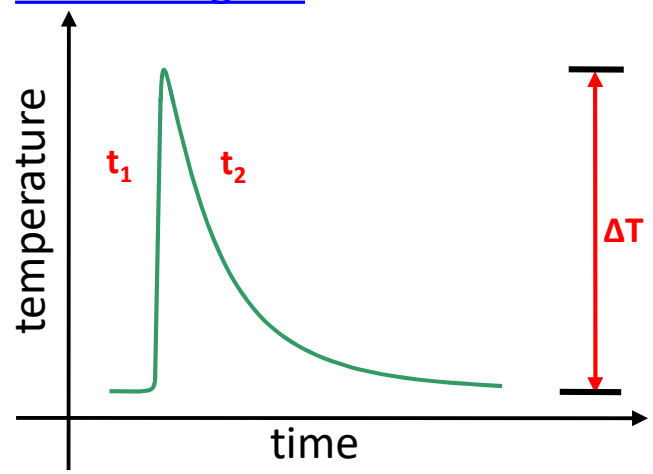
Losses at energy conversion:
Due to dead layer,
charge recombination

Plots from: Kraft-Bermuth et al., Rev. Sci. Instrum. 80, 103304 (2009)

CLTDs: Detection Principle



thermal signal:



Rise-Time	**1 – 10 μs**
Decay-Time (C/k)	**100 μs – 10 ms**

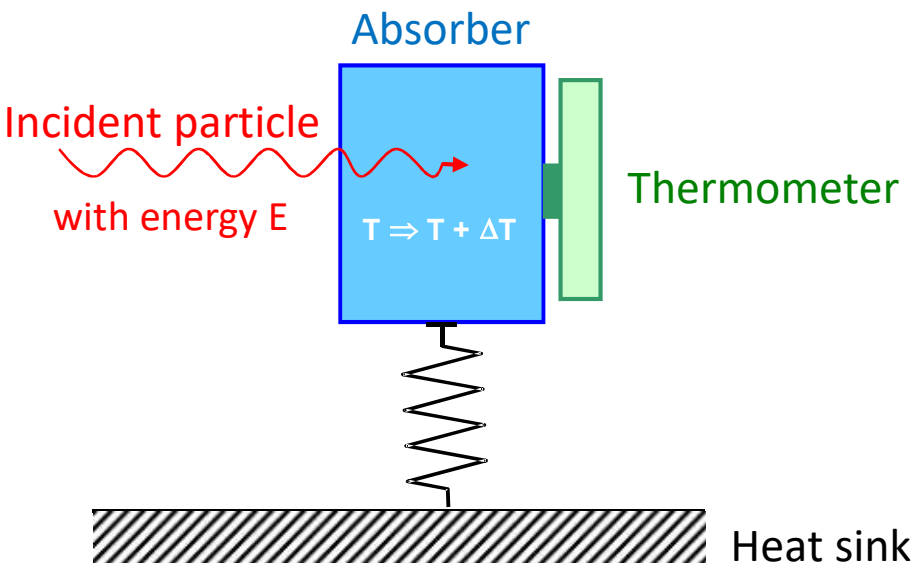
Absorber:

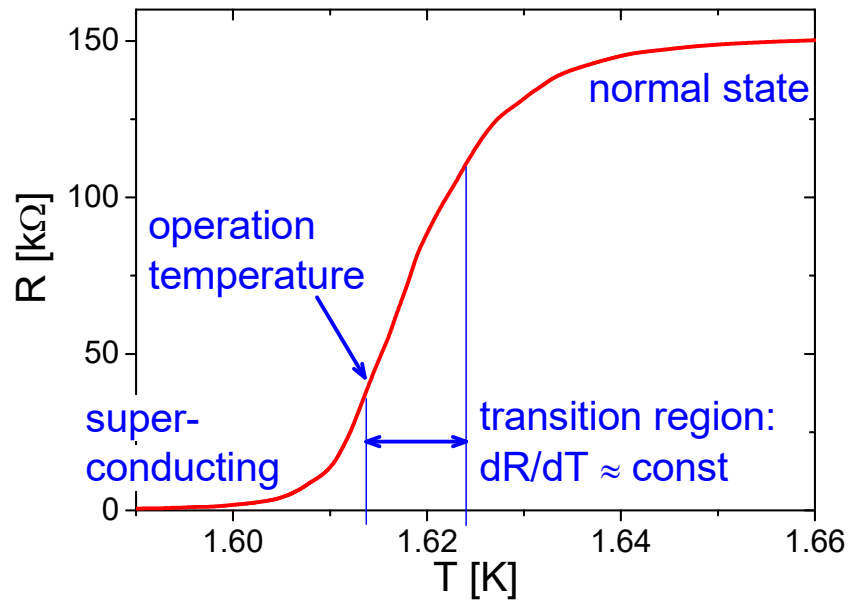
Particle energy is converted into heat,

$$\Delta T = \frac{E}{c \cdot m}$$

- High sensitivity for small specific heat c and small mass
- c ~ (T^3/Θ_D^3) from Debye law (for insulators, superconductors)
- Operation at Low Temperatures

CLTDs: Detection Principle



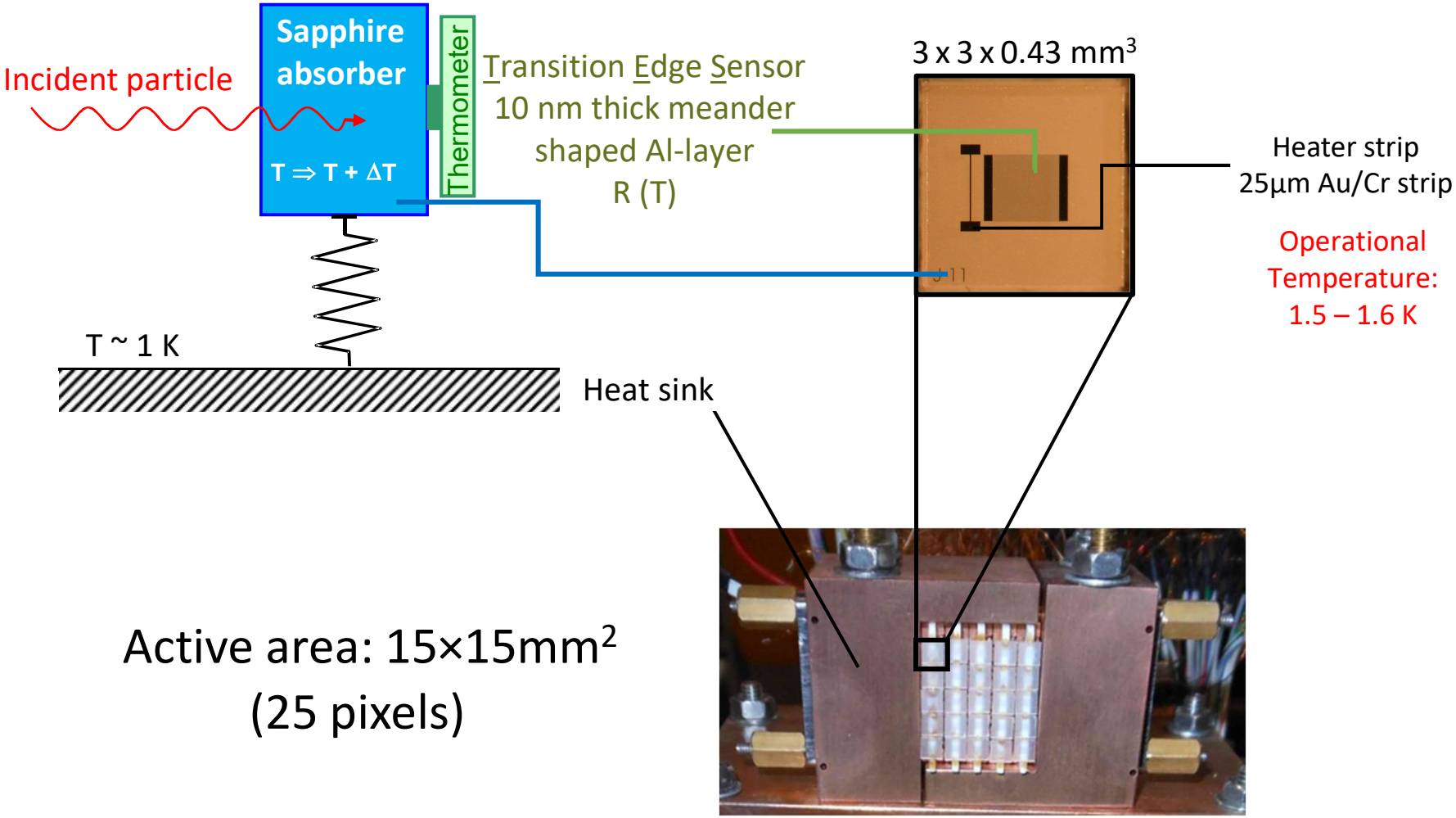


Thermometer:

Transition Edge sensors are used.

- Resistance (superconductor) biased with constant current.
- ΔT→ΔR(T)→ΔV voltage signal is detected.
- Detector temperature stabilized in phase transition region → high dR/dT.

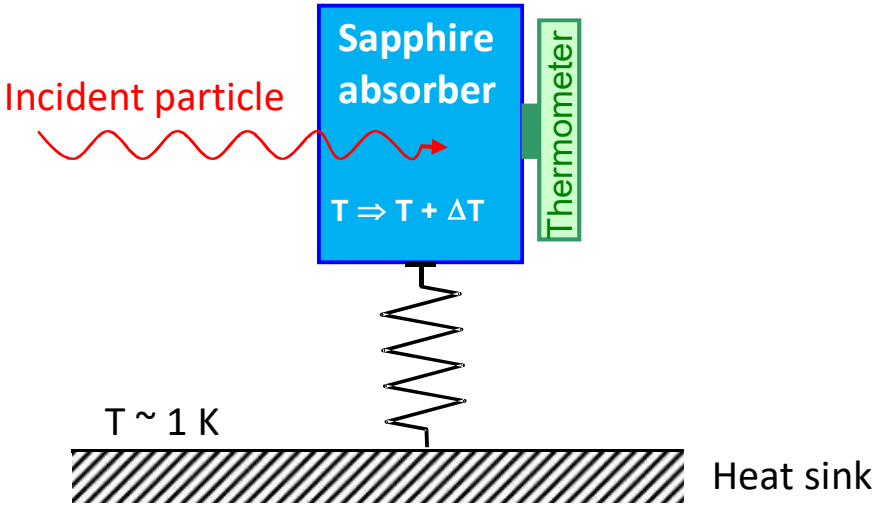
CLTDs: Current Detector Design



Active area: 15×15mm^2
(25 pixels)

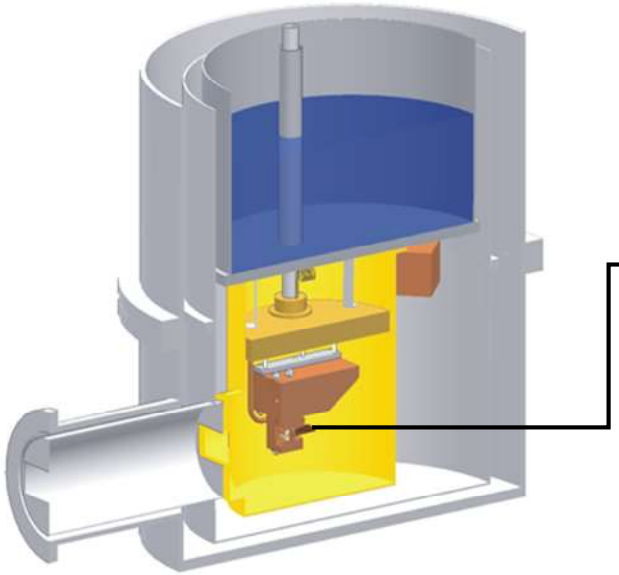
S. Kraft-Bermuth et al., Rev. Sci. Instrum. **80**, 2009
A.Echler et al., J. Low Temp. Phys. **167**, 2012,

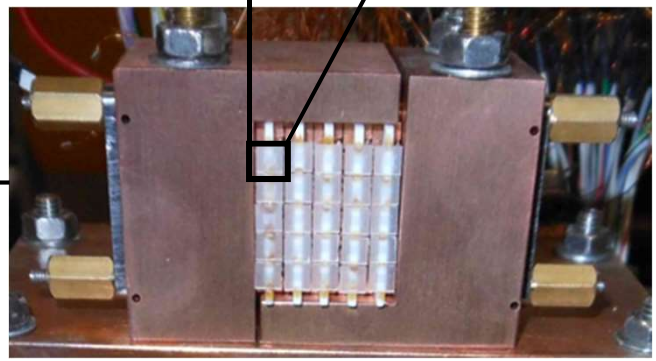
CLTDs: Current Detector Design



windowless ^{4}He bath cryostat

Operational Temperature: 1.5 – 1.6 K





Z- distributions of fission fragments (n_{th},f)

Methods for Z- separation:

- ➢ Radio chemistry
- ➢ γ-spectroscopy

⇒ restricted to particular nuclides

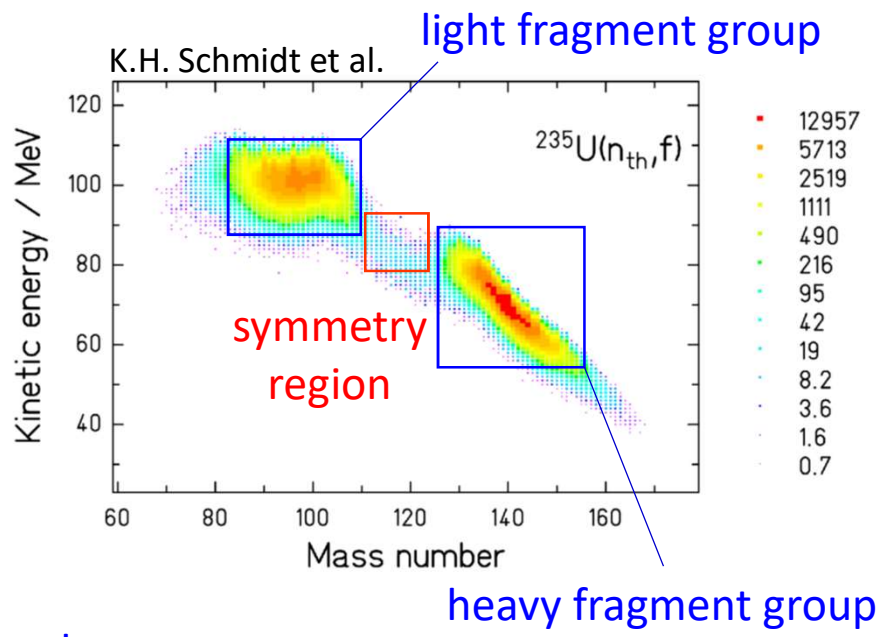
- ➢ Passive-absorber method

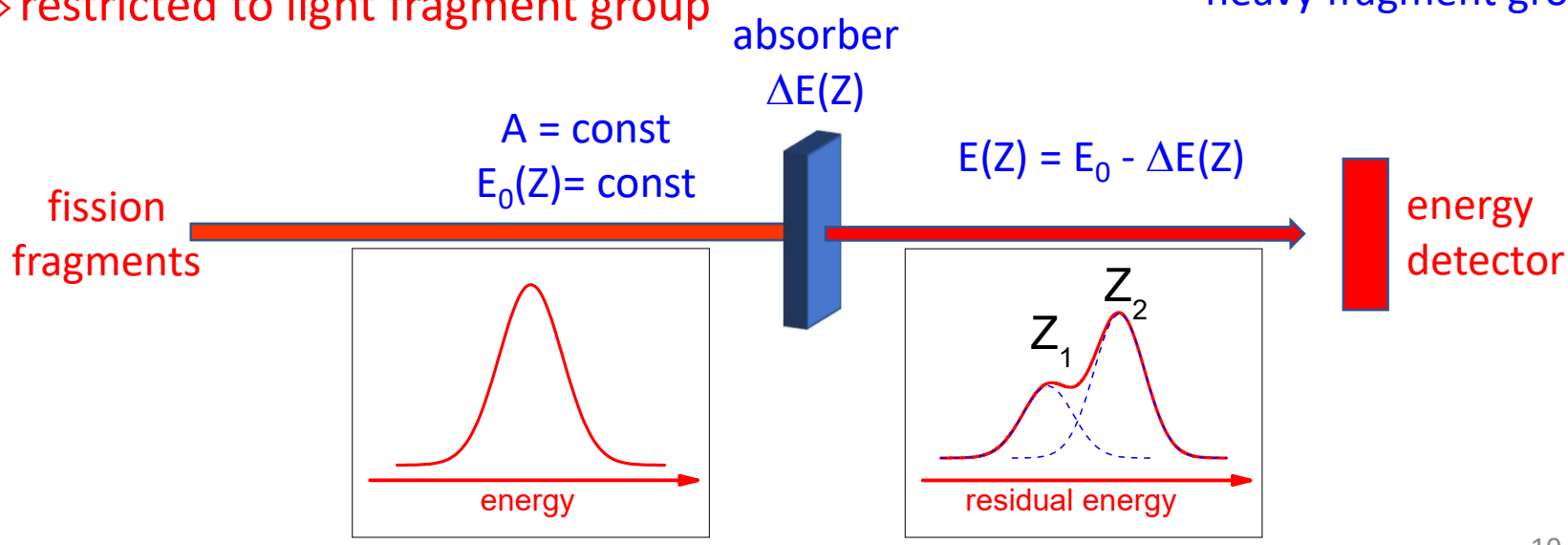
U. Quade et al., Nucl. Phys. A487 (1988) 1

best Z-resolution with:

- Parylene C absorbers
- ionization chamber

⇒ restricted to light fragment group





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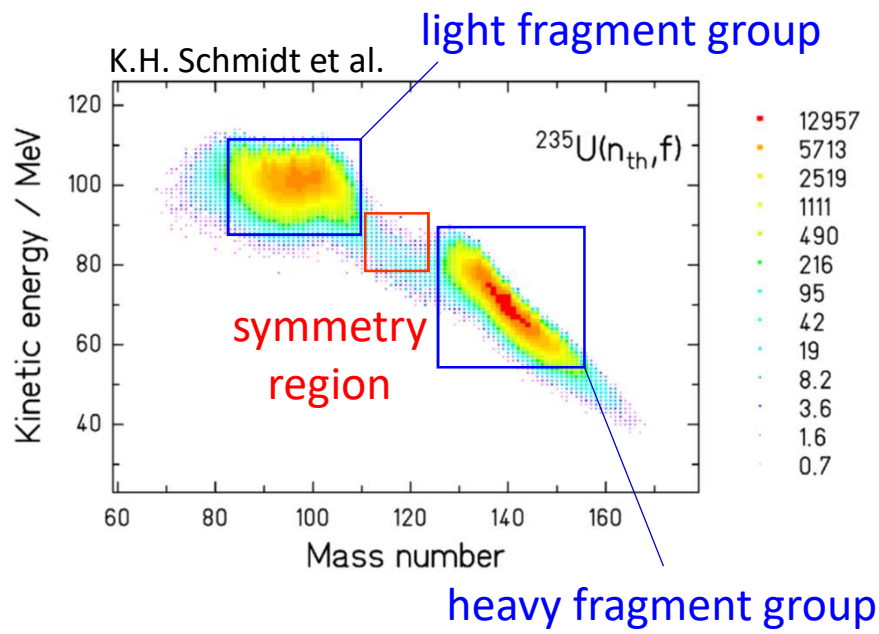


Preliminary results from CLTDs using SiN absorber foils:

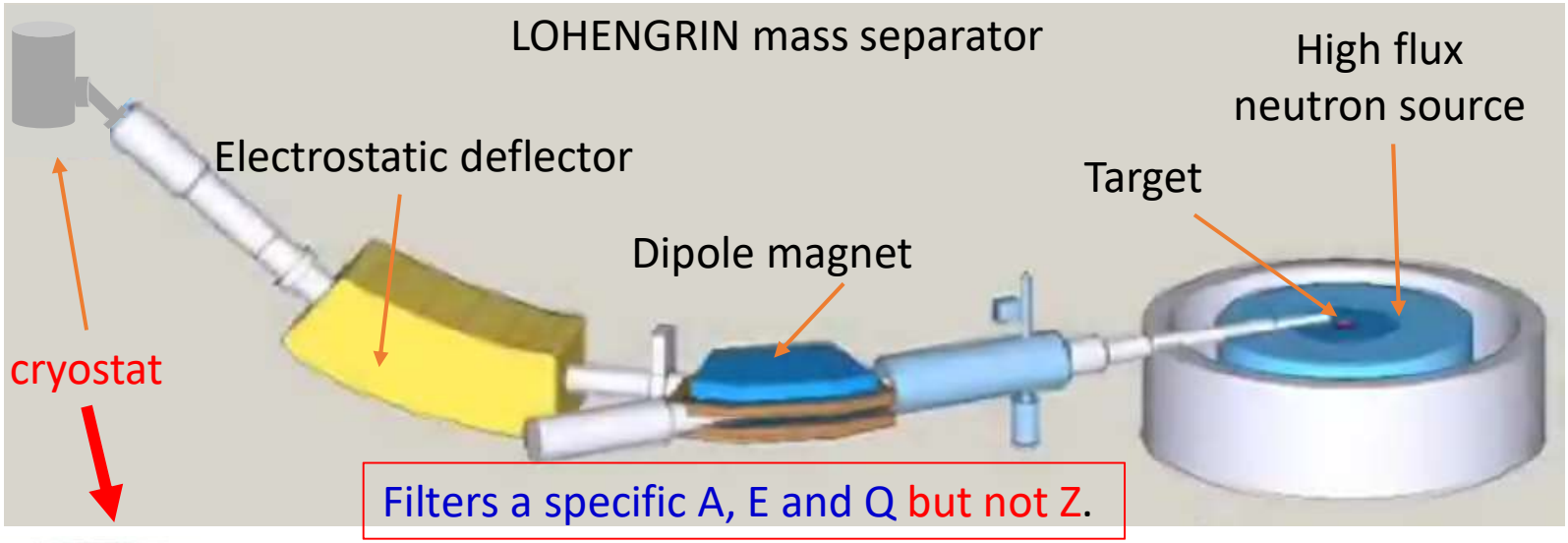
- First time possible to measure in the heavy mass region.
- New measurements in the light mass region approaching symmetric fission for $^{239}P(n_{th},f)$ and $^{241}Pu(n_{th},f)$.
- Precise yield determination of ^{92}Rb, ^{96}Y.

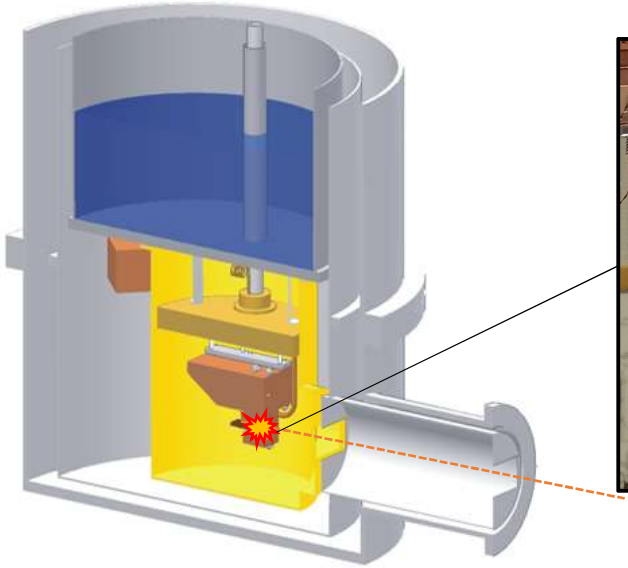
SiN foils:

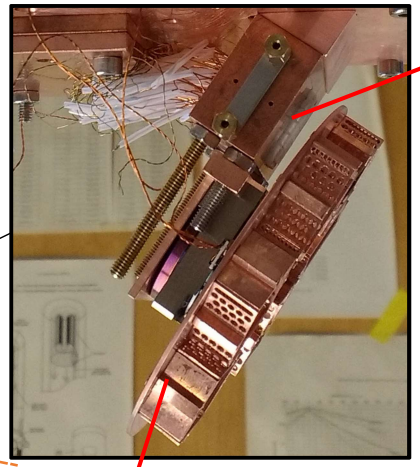
- Homogeneity
- High thermal stability
- Extreme hardness
- Chemical inertness

Investigation of Z- distributions of fission fragments (n_{th},f)

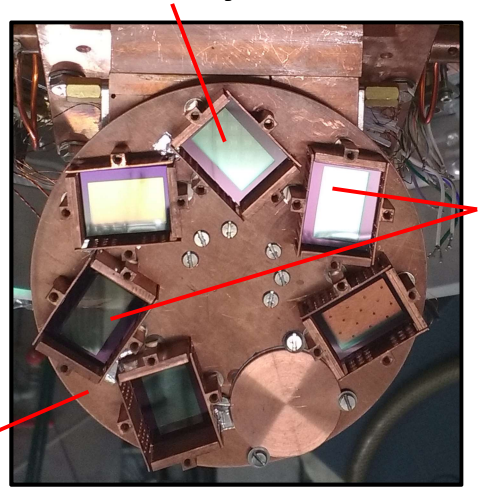
Experimental Set-up







CLTD array



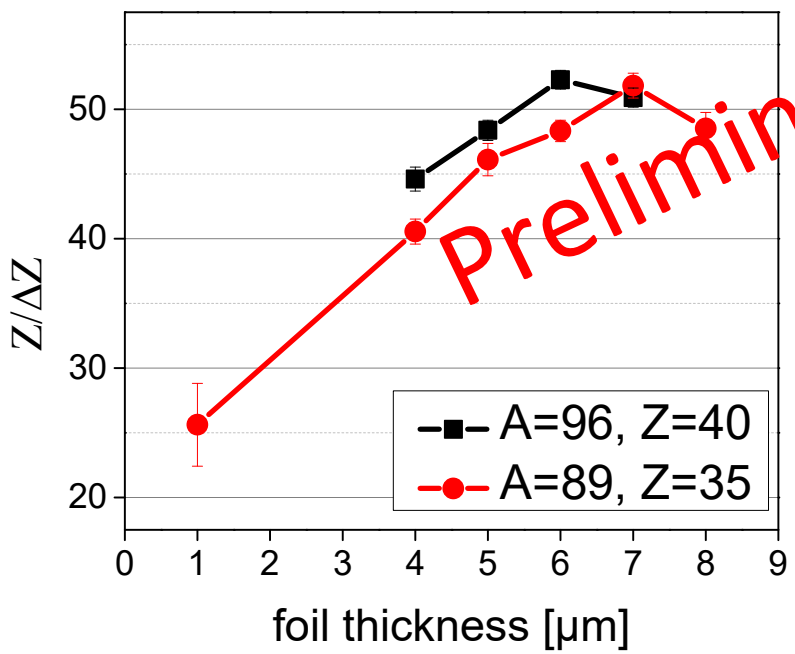
SiN absorber foil stacks
10×16mm

Manipulator for changing foil stacks

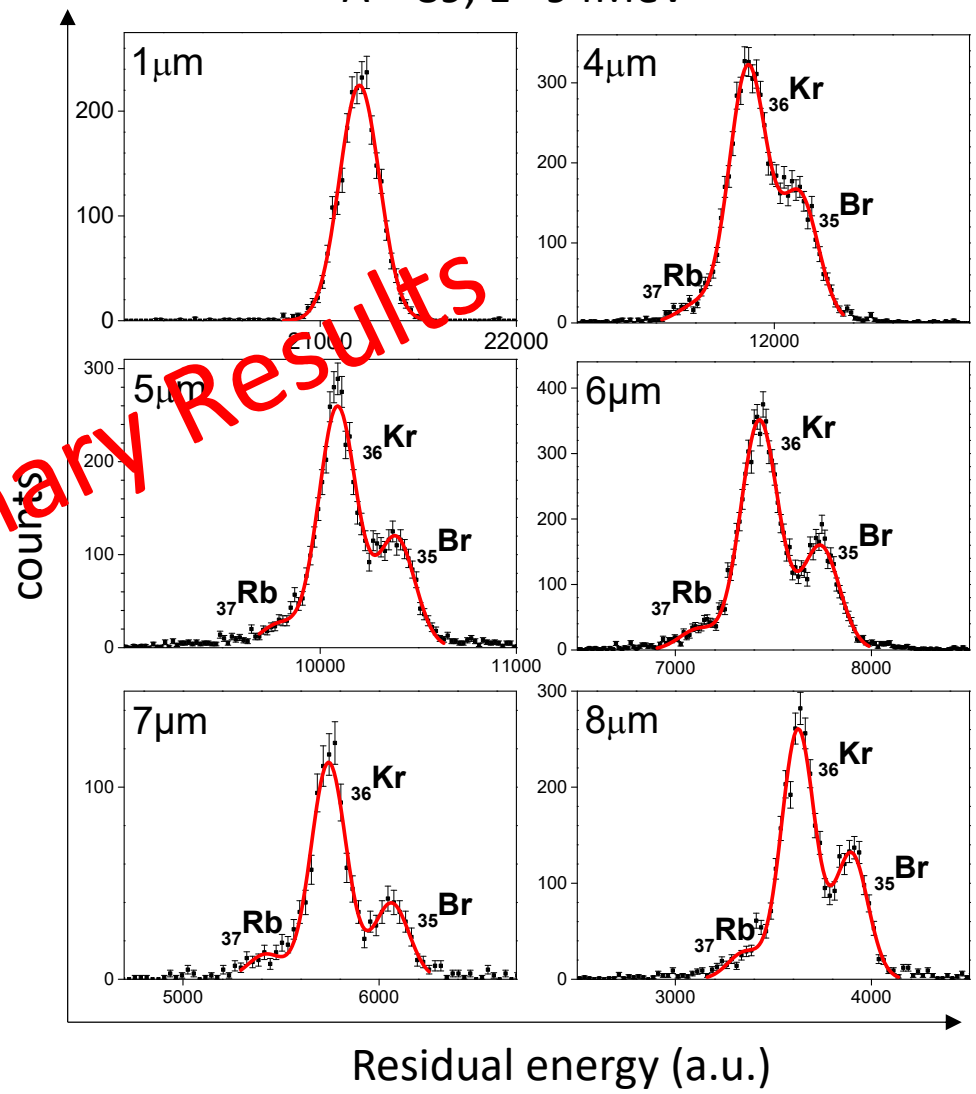
Z-Resolution: Optimum thickness of SiN

Systematic studies: Z-Resolution vs SiN foil thickness

$$Z/\Delta Z := Z \times \frac{\delta E(Z) - \delta E(Z-1)}{FWHM}$$

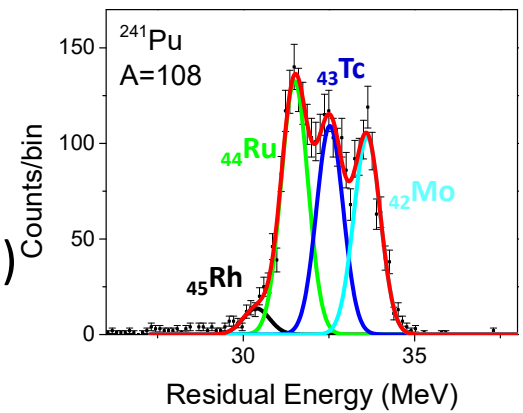


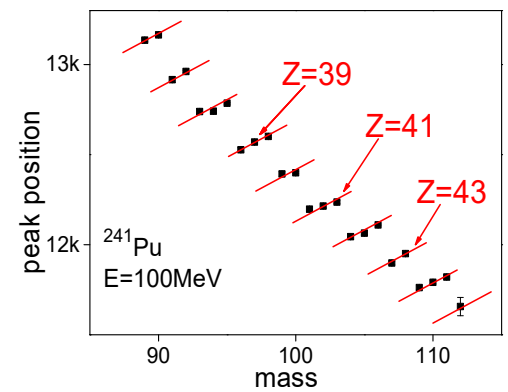
residual energy spectra
A = 89, E= 94MeV

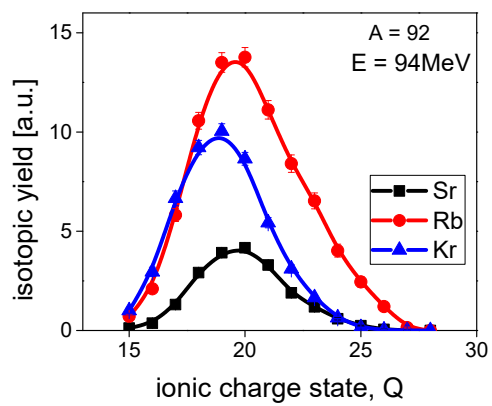


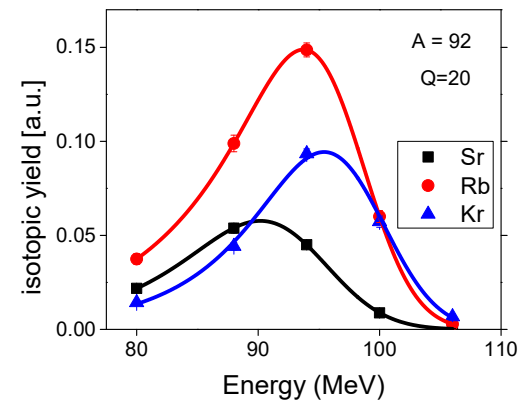
Procedure for determining Z-yields

- fit of spectrum
- relative Z-Yield
- line shape from Tandem experiment (for heavy masses)
- Z-Identification
- take into account
- energy dependence
- electronic charge state dependence (ns-isomers)
- absolute normalization
- target burnup



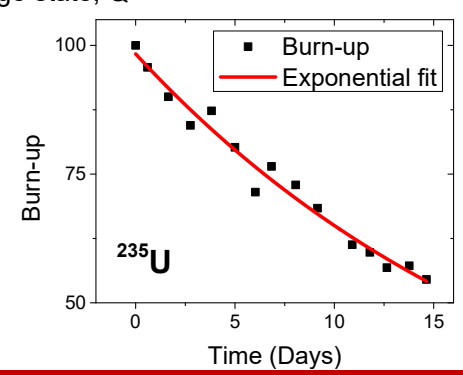






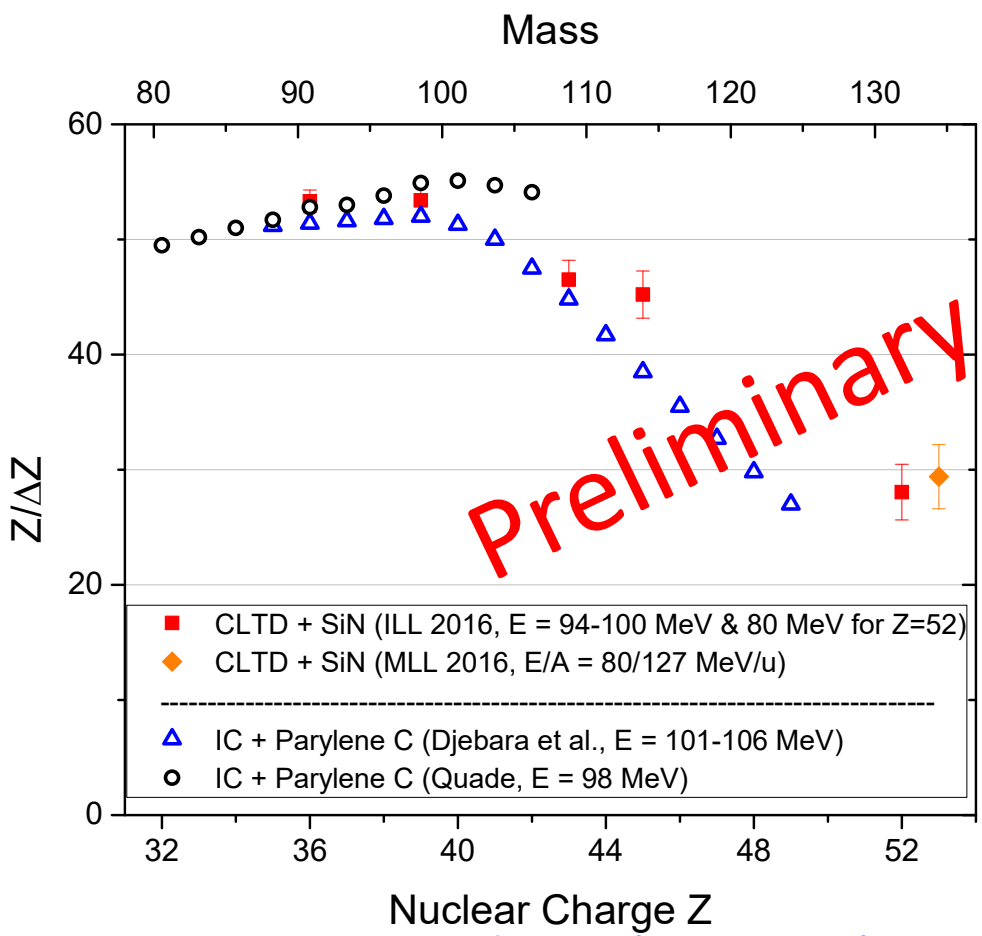
for Z-Yield of one mass:

⇒ upto 300 spectra to be analyzed

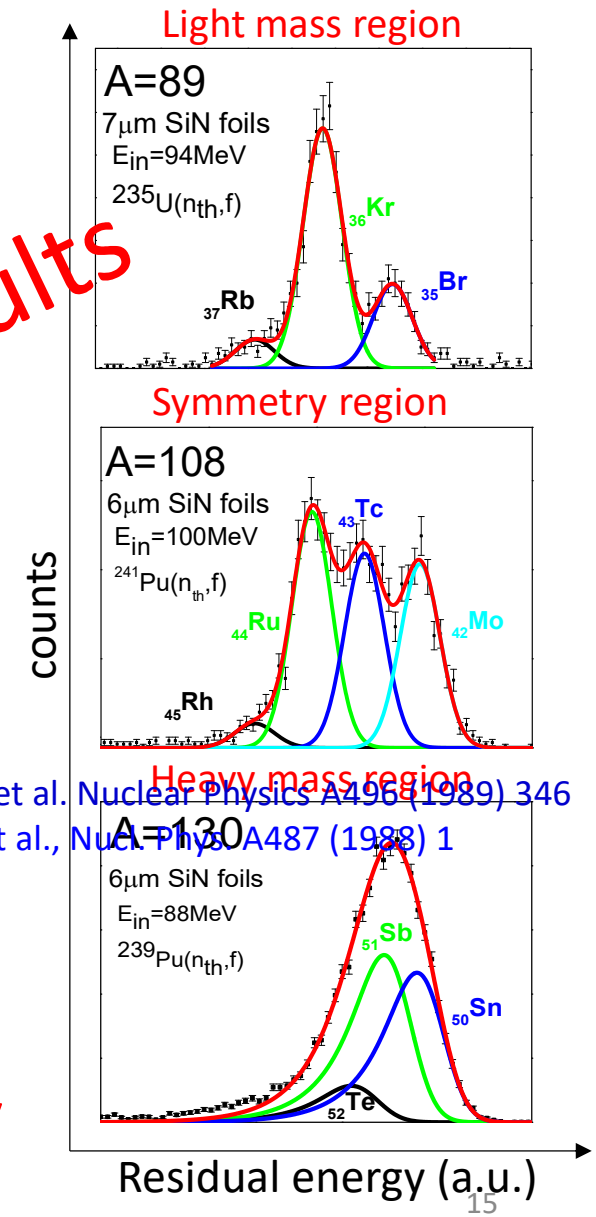


Resolution

Quality of Z-Separation



Preliminary Results



A. Djebara et al. Nuclear Physics A496 (1989) 346
U. Quade et al., Nucl. Phys. A487 (1988) 1

CLTD+SiN: good resolution & linearity

→Possibility to measure in symmetry & heavy mass region

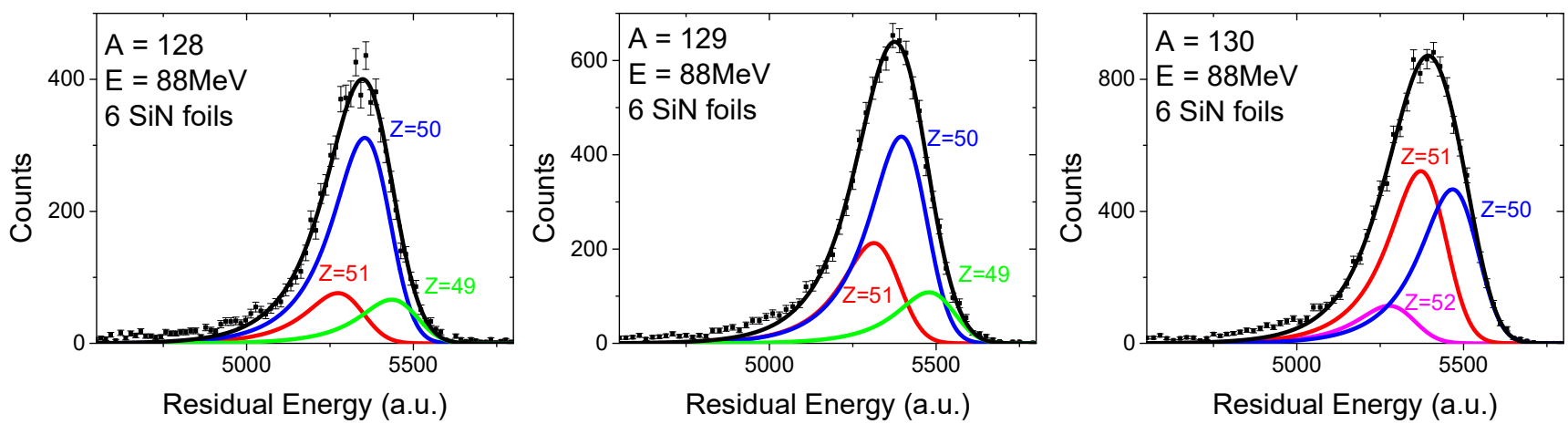
Heavy mass analysis

First direct Z-yield measurements in Heavy mass region:

- Standard method for unresolved peaks: Constrained fits with
  - good statistics (≈10000 counts)
  - good knowledge of response function

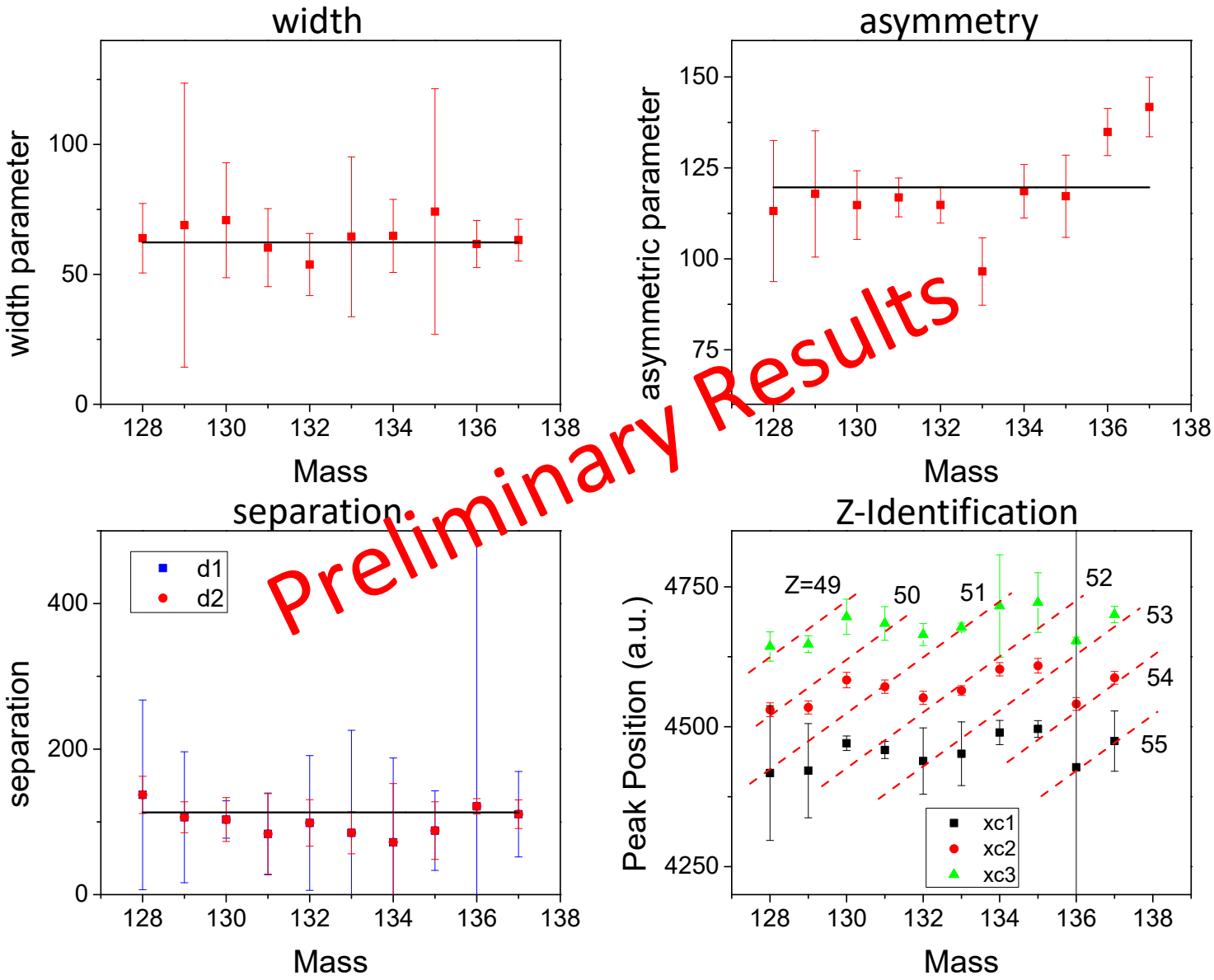
- With same set-up, measurements at similar mass and energy at MLL tandem tandem accelerator, allow to estimate the response function for the residual energy spectra.

- Stable fits for measured distributions.



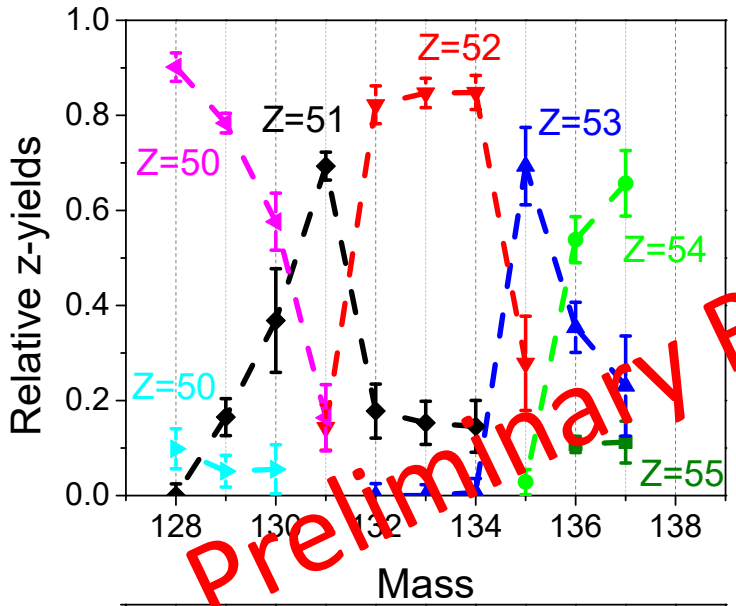
Preliminary Results

Heavy masses Z-yields Analysis

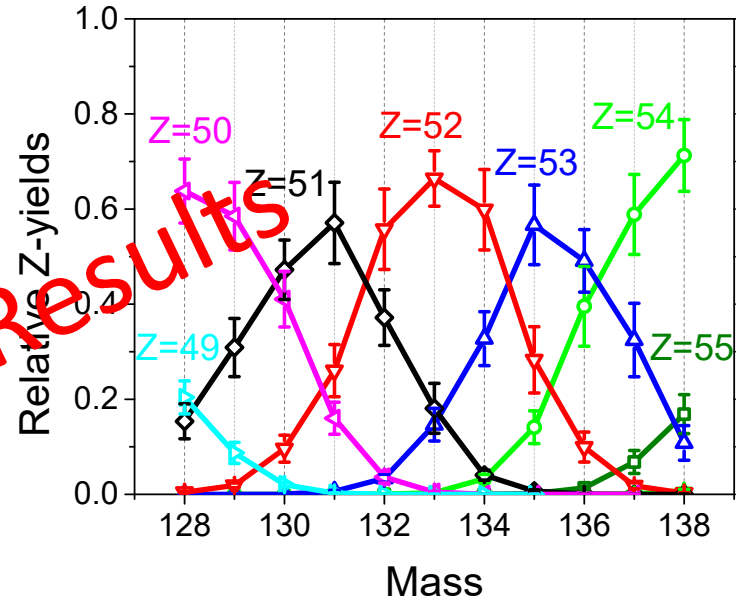


Heavy masses Z-yields: $^{239}Pu(n_{th},f)$

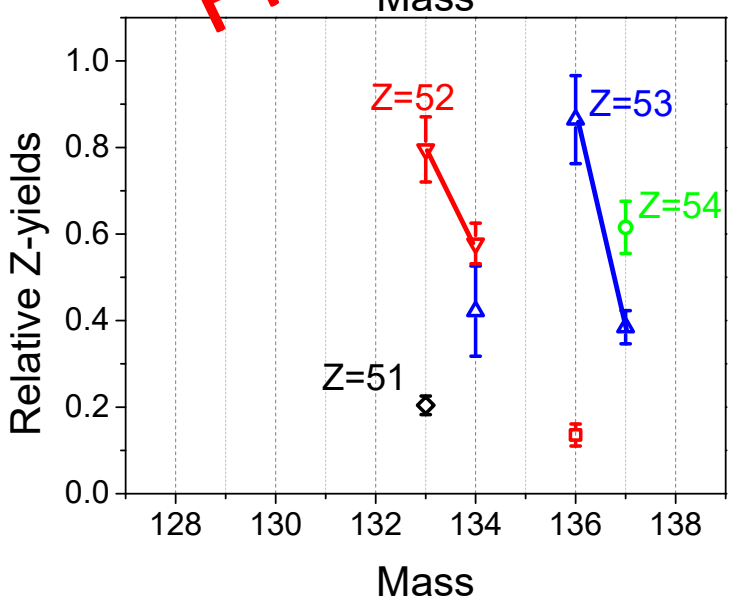
Our Expt.
Prelim. Results
$E_{LOH.}$=80MeV



Jeff Data base 3.1.1



Gamma
Spectroscopy*
Incl. all E & Q

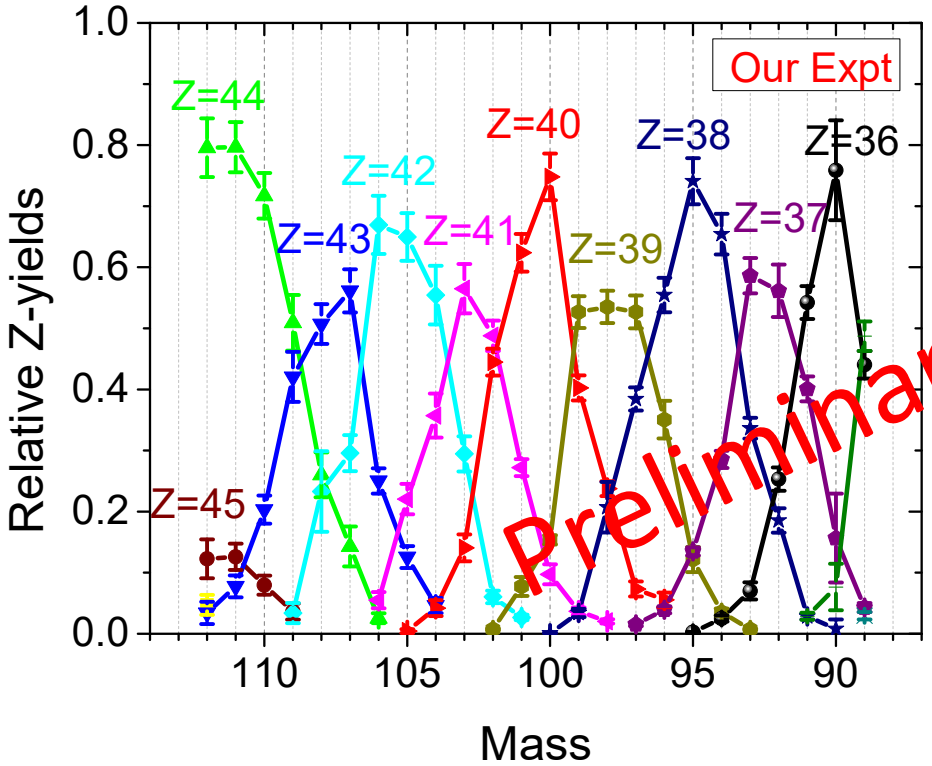


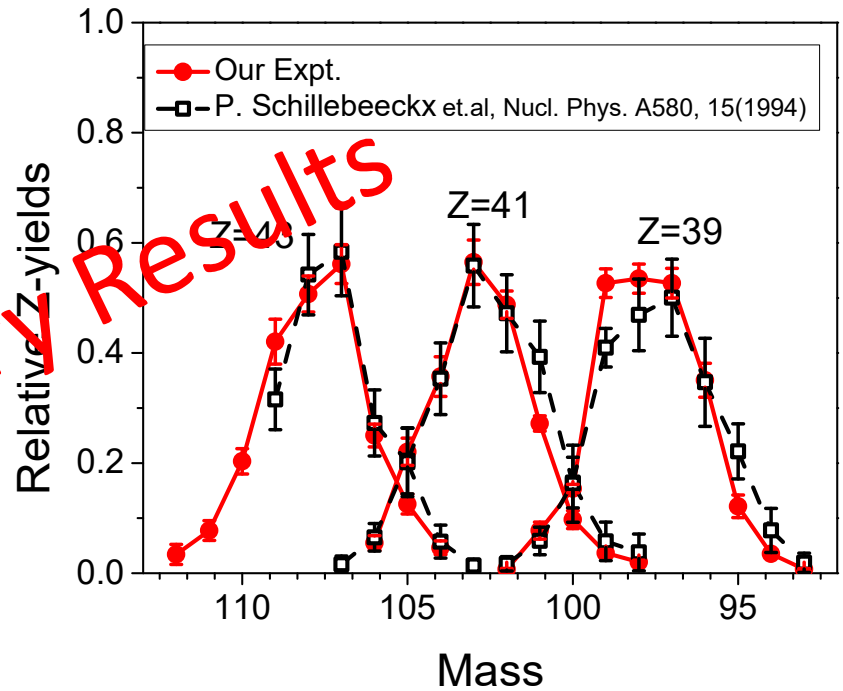
*A. Bail et al. Phys. Rev. C 84 (2011) 034605

$^{241}Pu(n_{th},f)$ Z-yield

First LOHENGRIN data on Z-yields for A > 89 were determined for $^{241}Pu(n_{th},f)$

Good comparison with P.Schilleebeeckx et.al. data – measurement with a different technique (Cosi-Fan-Tutte Spectrometer)



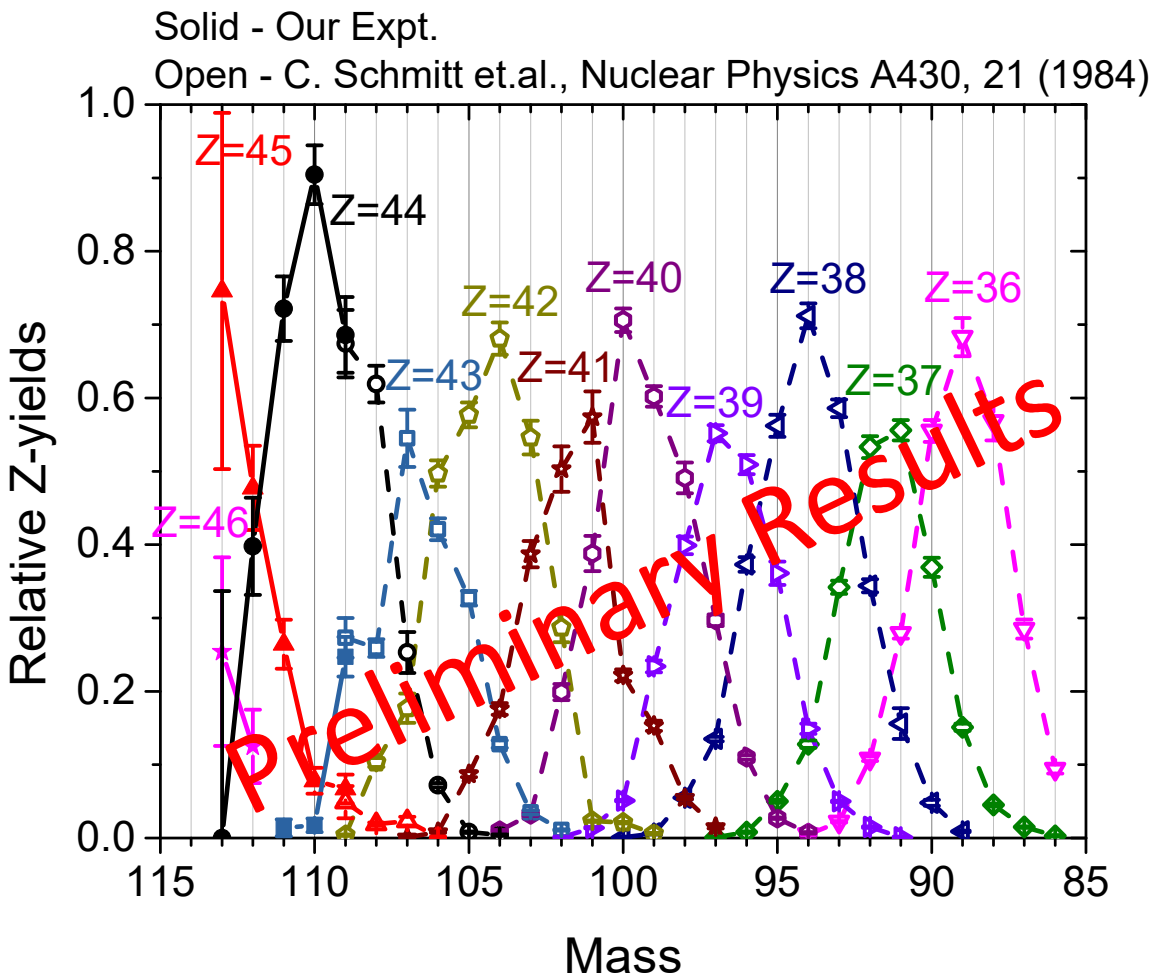


Preliminary Results

Prelim. Results

$^{239}Pu(n_{th},f)$ Z-yield

Also new data for A = 109 to 113 were determined for $^{239}Pu(n_{th},f)$



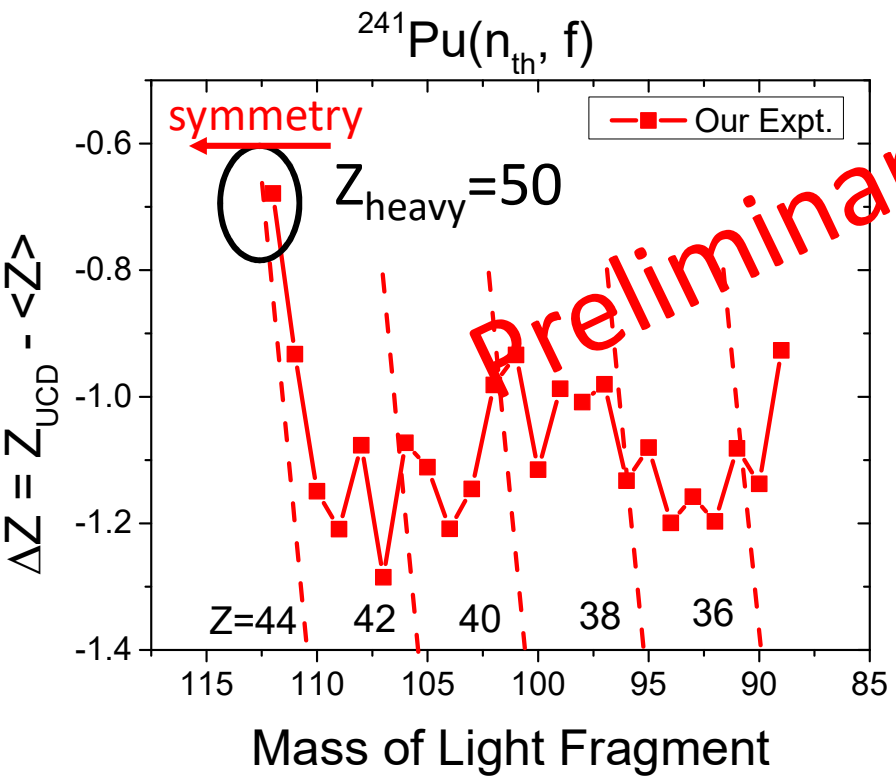
Prelim. Results

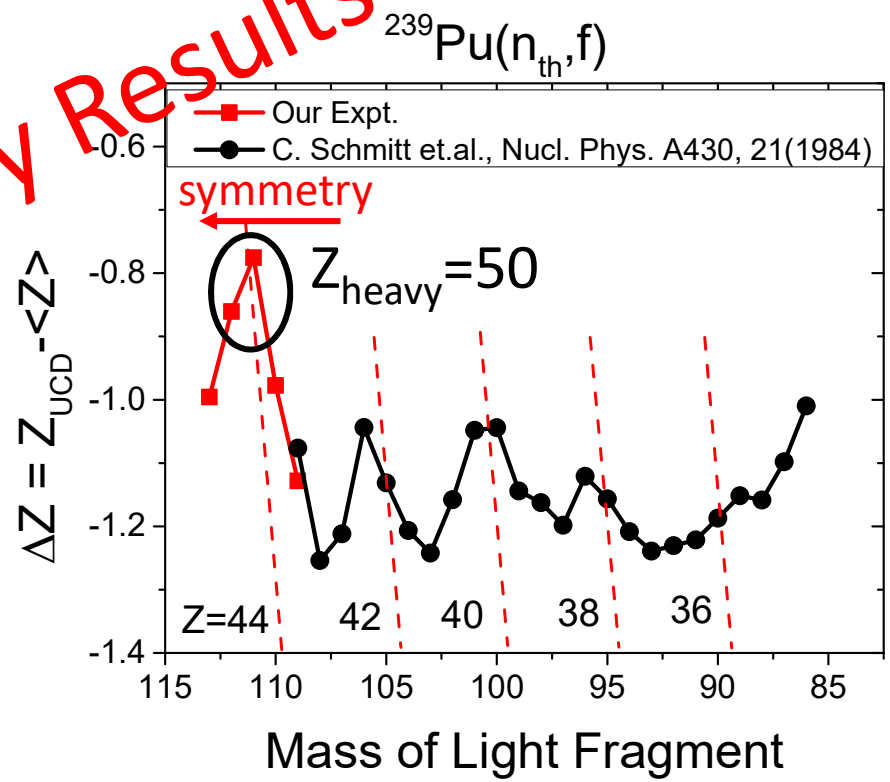
Odd-Even effect near symmetry

ΔZ = deviation from "democratic" distribution of neutron excess

$$\Delta Z = Z_{UCD} - \langle Z \rangle$$

$$Z_{UCD}(^{241}Pu) = \frac{94}{242}A \qquad Z_{UCD}(^{239}Pu) = \frac{94}{24}A$$





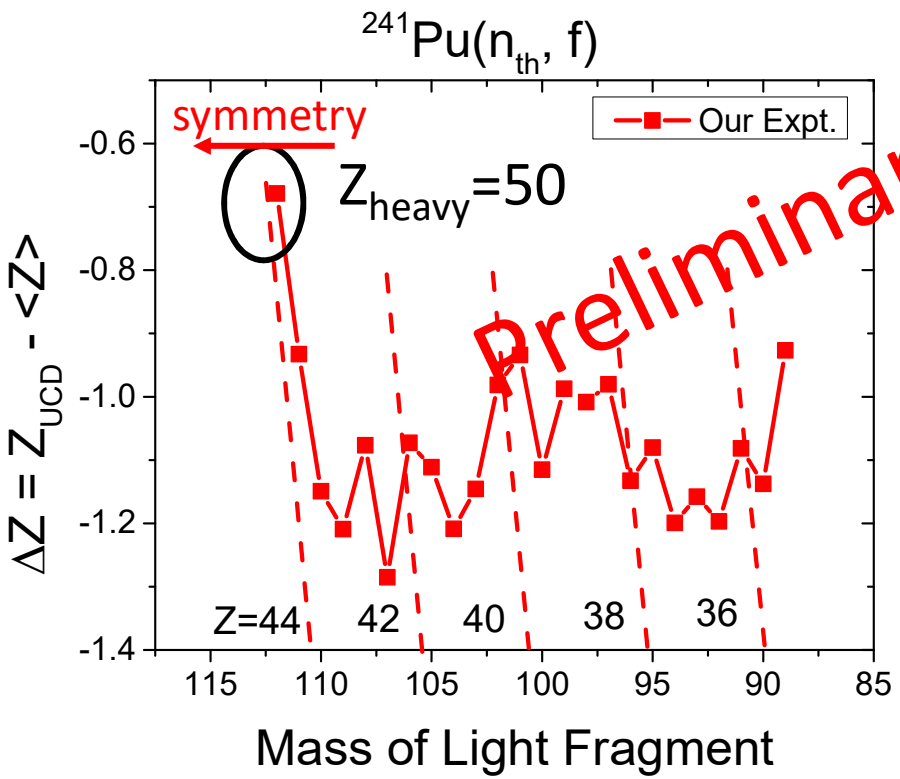
Preliminary Results

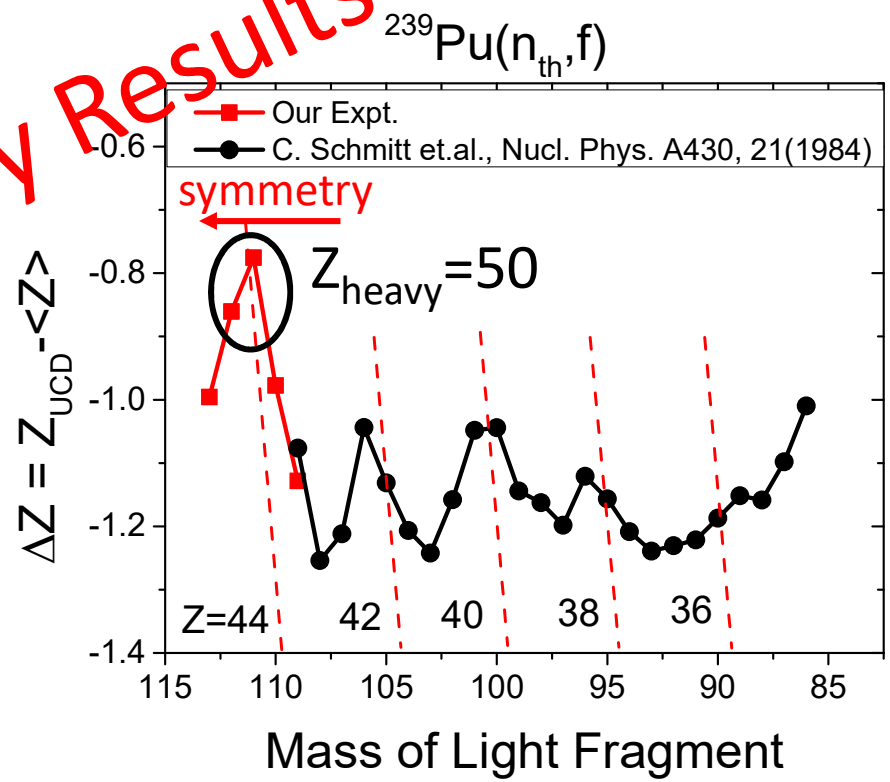
Prelim. Results

Odd-Even effect near symmetry

Rise in ΔZ towards corresponding heavy mass with closed shell, Z=50

For the first time in case of ^{239}Pu, we observe a drop in ΔZ beyond Z_{heavy}=50





Preliminary Results

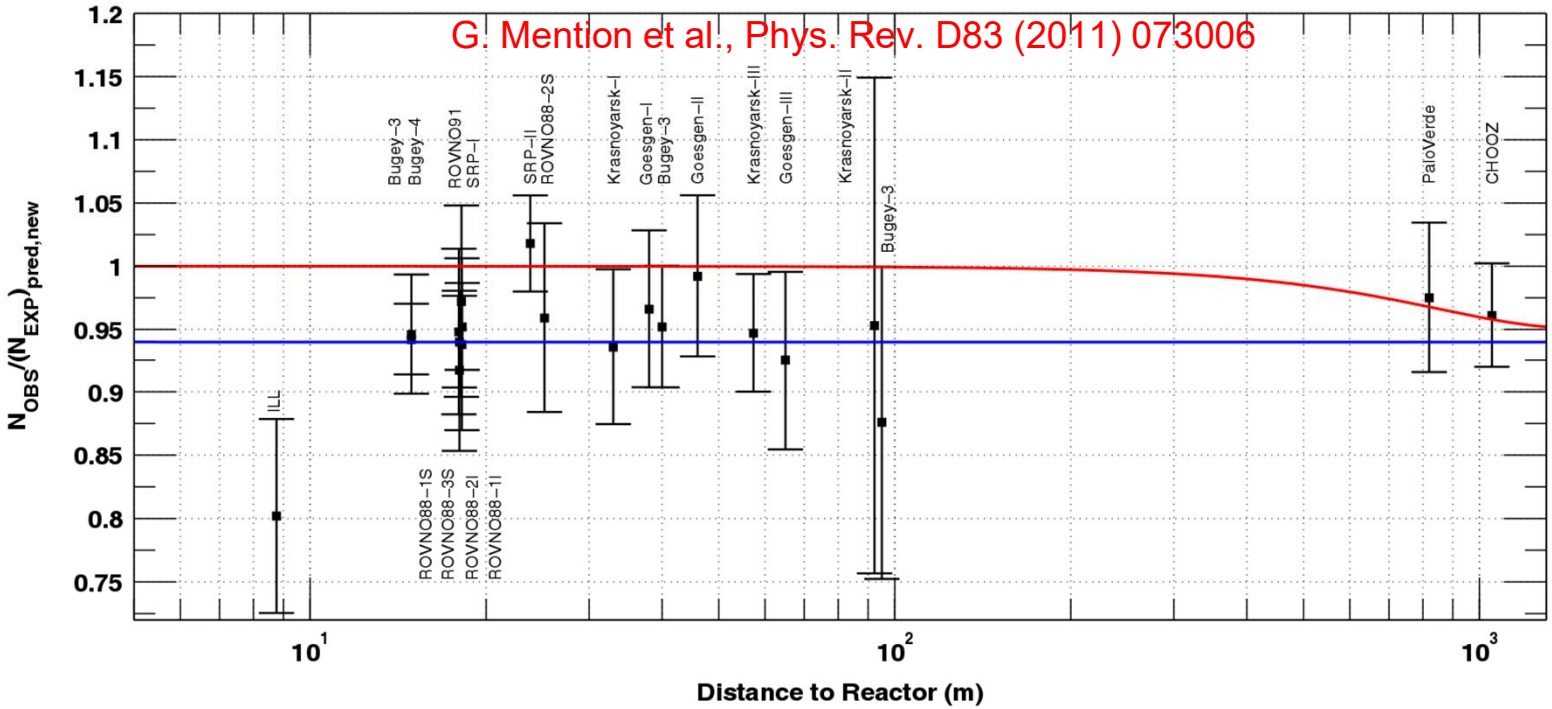
Prelim. Results

^{92}Rb & ^{96}Y yield

Motivation

Motivation for investigating Mass 92: The Reactor Antineutrino Anomaly

⇒ 5.7% deficit of measured antineutrinos
as expected from β-decay data of fission fragments



possible explanations: ⇒ 4th non standard „sterile“ neutrino

⇒ wrong Z-yields of fission fragments

^{92}Rb & ^{96}Y yield

A. A. Sonzogni et al., Phys. Rev. C91 (2015) 011301 (R)

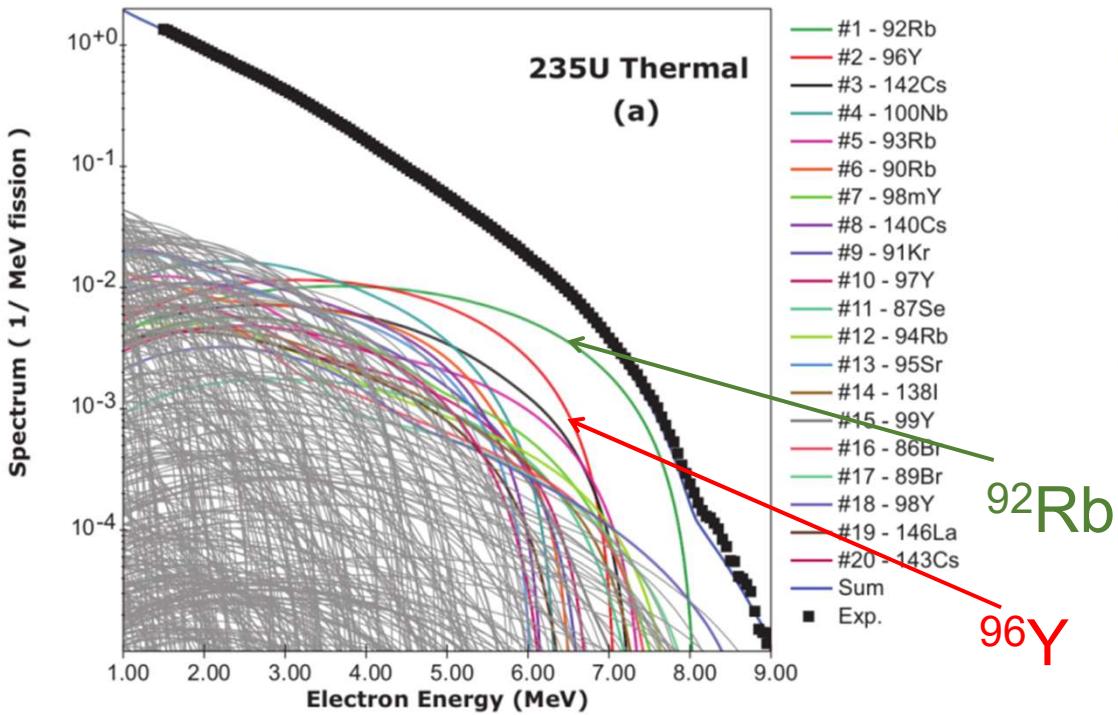


TABLE III. Same as Table II, except the strongest contributors from ^{235}U at 5.5 MeV are summarized.

Nuclide	Q_β (MeV)	GS BR (%)	$J^\pi_{gs} \rightarrow J^\pi_{gs}$	Contr. (%)
^{92}Rb	8.1	95.2(7)	$0^- \rightarrow 0^+$	21.6
^{96}Y	7.1	95.5(5)	$0^- \rightarrow 0^+$	14.5
^{142}Cs	7.3	56(5)	$0^- \rightarrow 0^+$	6.8
^{100}Nb	6.4	50(7)	$1^+ \rightarrow 0^+$	4.7
^{93}Rb	7.5	35(3)	$5/2^- \rightarrow 7/2^+$	4.6
^{90}Rb	6.6	33(4)	$0^- \rightarrow 0^+$	3.4
^{98m}Y	9.0	12(5)[a]	$(4,5) \rightarrow 4^+$	2.8
^{140}Cs	6.2	36(2)	$1^- \rightarrow 0^+$	2.4
^{91}Kr	6.8	18(3)[b]	$5/2^{(+)} \rightarrow (5/2^-)$	2.4

[a]Strongest branch to a low-lying state is to a 4^+, 1843-keV level.
[b]Strongest branch is to a $(5/2^-)$, 109-keV level.

for ^{235}U target: contribution of ^{92}Rb to the β-spectrum at 5.5 MeV

⇒ JEFF 3.1.1 data basis: 21.6%

⇒ S.V.Tipnis et al. Phys. Rev. C 58, 905 (1998): 30.0%

A. A. Sonzogni et. al.:

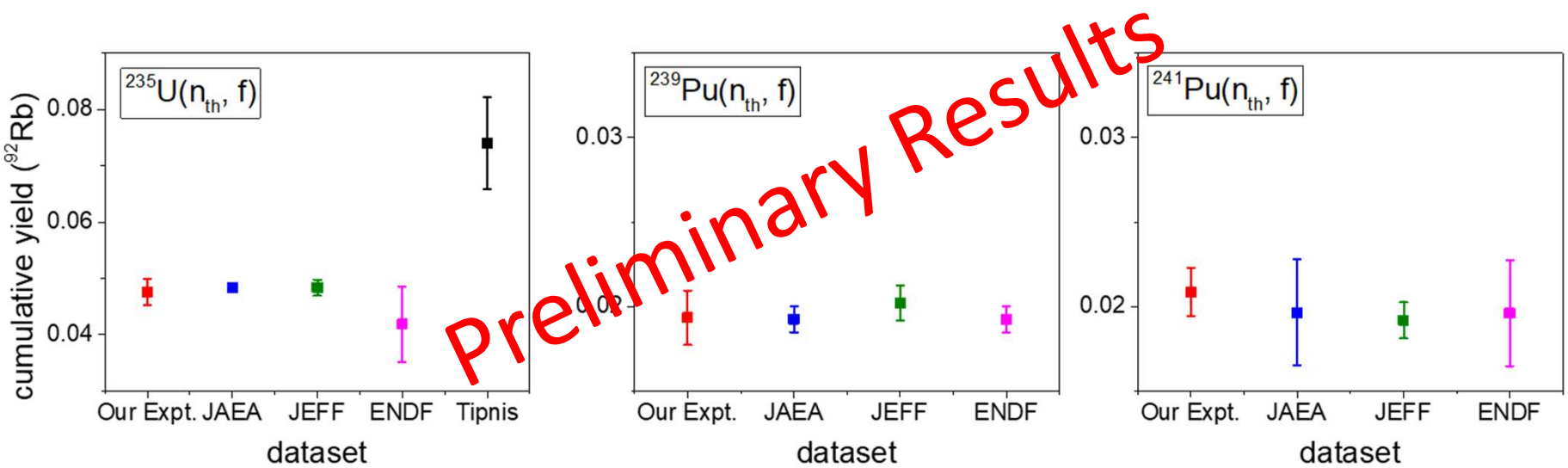
The ^{92}Rb cumulative fission yield following the thermal fission of ^{235}U definitely merits a new measurement.

^{92}Rb yield

Several measurements at different kinetic energies and ionic charges were made to precisely determine the cumulative yields

- Agreement with standard Data bases
- In case of ^{235}U, disagreement with data by S.V.Tipnis et al. Phys. Rev. C 58, 905 (1998)

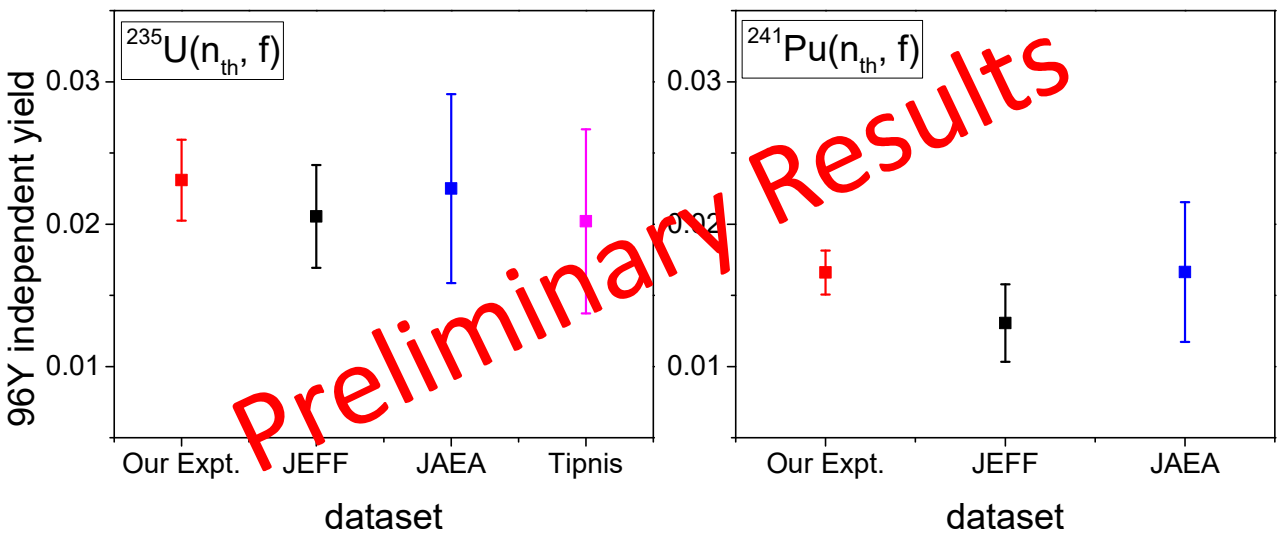
^{92}Rb



^{96}Y yield

- In agreement with the standard Data bases.

^{96}Y



S.V. Tipnis et al. Phys. Rev. C 58, 905 (1998)

Summary

- Successful application of CLTDs for Z-yield measurements.

- CLTD + SiN: First time direct Z-yield measurements of heavy fragment masses.

A new method to measure also masses inaccessible with current technology e.g. gamma spectroscopy.

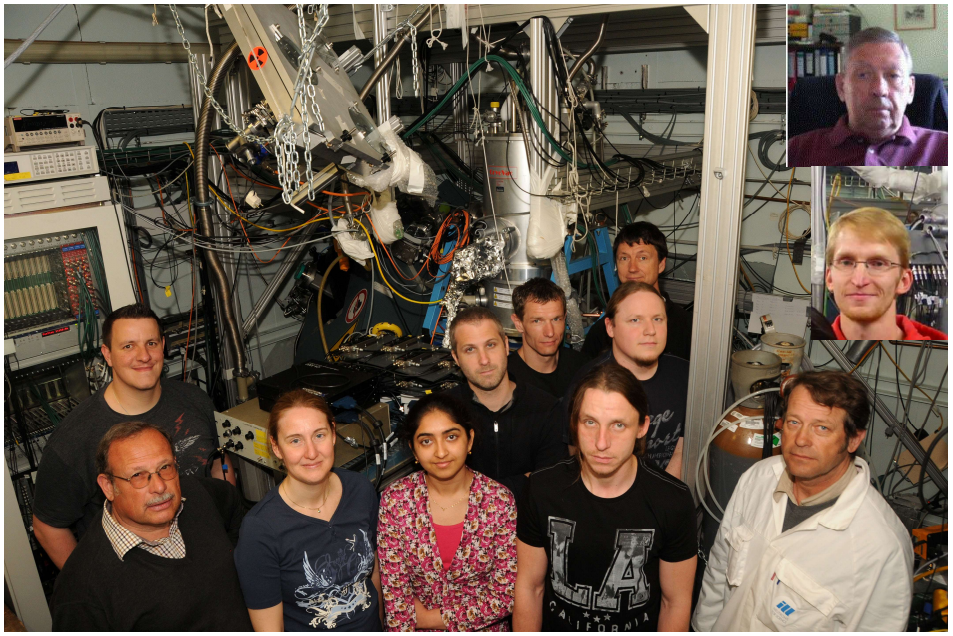
- Odd-even effect approaching symmetric fission for ^{239}Pu & ^{241}Pu

Important measurements for nuclear fission model description near scission

- Precise ^{92}Rb & ^{96}Y yields for ^{235}U, ^{239}Pu, ^{241}Pu (n_{th}, f)

Highest contributor to neutrino oscillations and reactor antineutrino anomaly studies

Thank you



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