Experimental Nuclear Data Activities at ANL

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work supported by the Office of Nuclear Physics, Office of Science, US DOE

Highlights

- **Two projects funded by the Office of Nuclear Physics, Office of Science (ARRA)**
  - ✓ *Measurement of Actinide Neutronic Transmutation Rates with Accelerator mass spectroscopy (MANTRA)* – in collaboration with G. Youinou, G. Palmiotti, M. Salvatores (INL), G. Imel (ISU) and R. Pardo (ANL-PHY)
  - ✓ *Decay data measurements & evaluations for decay heat calculations* – in collaboration with P. Chowdhury (UML) and C. Lister(ANL-PHY)

- **Commissioning of the CARIBU upgrade of ATLAS – very exciting!**
  - ✓ main trust on Nuclear Structure Physics & Nuclear Astrophysics, BUT …
  - ✓ opportunities for significant improvements of Nuclear Data for beta-delayed gamma's (decay heat), beta-delayed neutrons (project funded by DOE/ONP - collaboration led by G. Savard (ANL-PHY) and N. Scielzo (LLNL)); fission yields; FP reaction cross sections

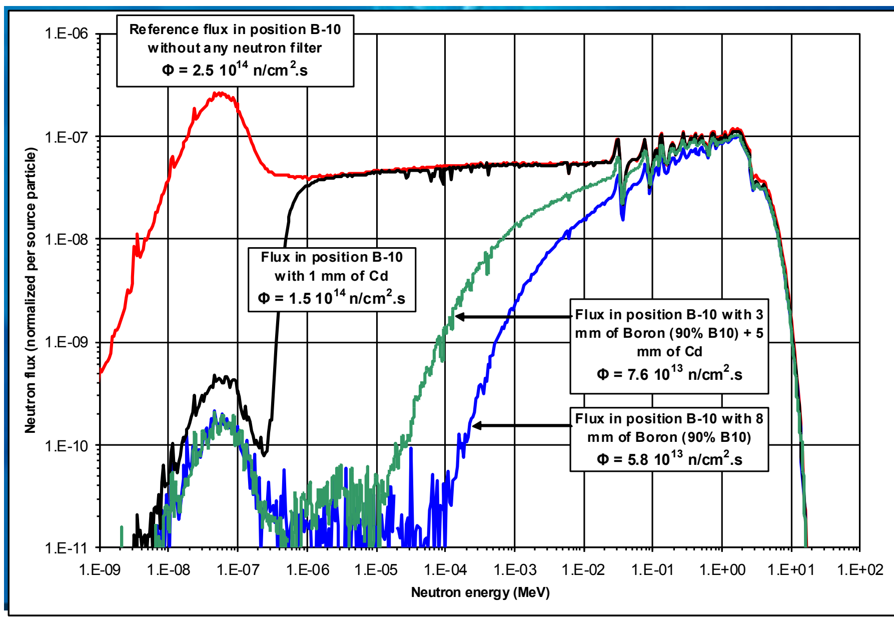
- **Properties of long-lived isomeric states and development of novel detectors and techniques for ND research**
  - ✓ Studies of ^{177m}Lu – inelastic neutron acceleration & medical physics
  - ✓ $LaBr_3$(Ce) scintillation array – a new ANL LDRD in collaboration with M. Carpenter, S. Zhu and D. Seweryniak (ANL-PHY)

MANTRA (Measurement of Actinide Neutronic Transmutation Rates with Accelerator mass spectroscopy)

INL: Gilles Youinou, G. Palmiotti, M. Salvatores
ANL: F.G. Kondev, R. Pardo
ISU: G. Imel.

Basic Concept:

- ✓irradiating (small) samples of pure MA at the ATR facility at INL
- ✓measurements using the AMS technique at the ATLAS facility ANL

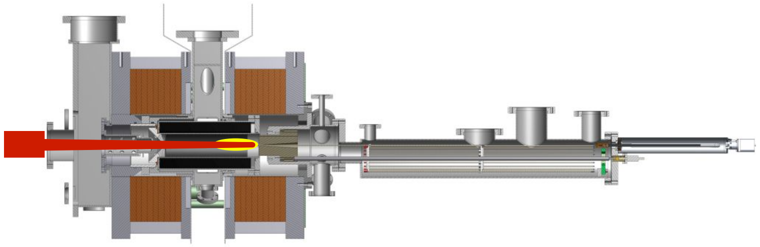


AMS Challenges for MANTRA

- Large number of samples:
  - ✓ 13 high purity target materials
  - ✓ 3 different neutron energy spectra
  - ✓ 2-3 samples for each case
  - ✓ non-irradiated material
  - ✓ blanks
- Desired accuracy of results: ~2%!
  - ✓ No cross-talk between samples
  - ✓ Stable, repeatable transmission between source and ion detector
- Small sample size (few mg total, actinide component <1mg)
  - ✓ Reduce radiological problems with samples
- Limited "Z" (elemental) resolution of the detector system

Improved Configuration for AMS

- Laser ablation of material into ECR Source
- Automated multi-sample changer for source



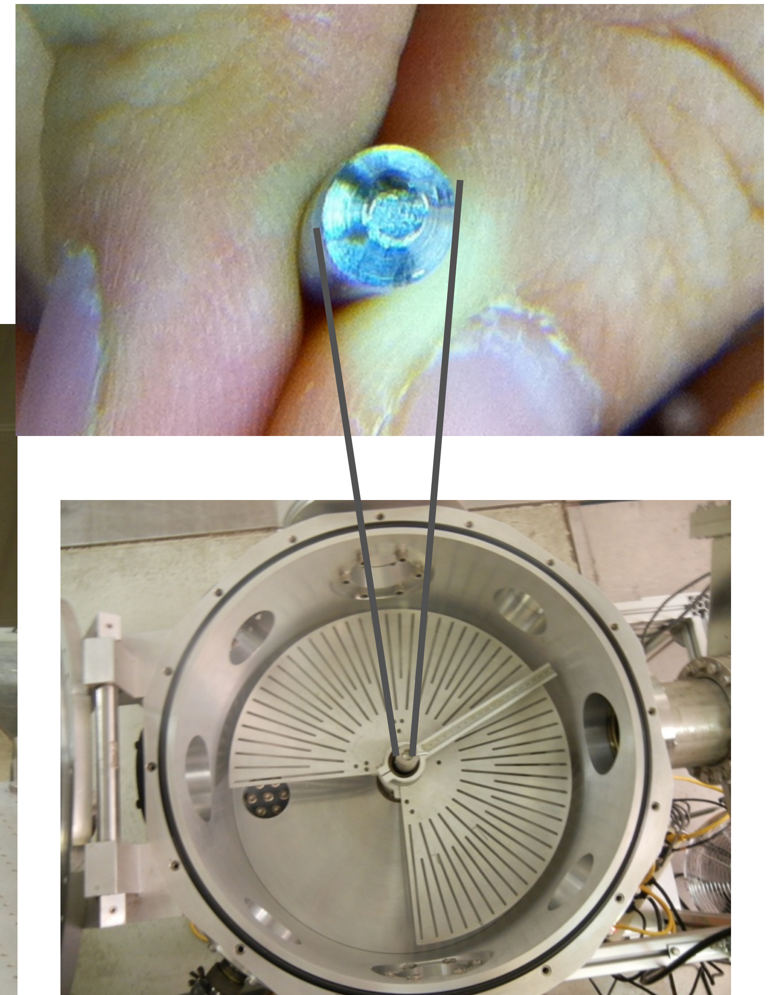
- Fully automate experiment, much as in ^{14}C AMS
  - ✓ Automated switching of accelerator between (m/q) configurations
  - ✓ Automated sample changing
  - ✓ Integrated data acquisition
- Improved detector electronics to improve sensitivity, reduced background and increase in "Z" resolution

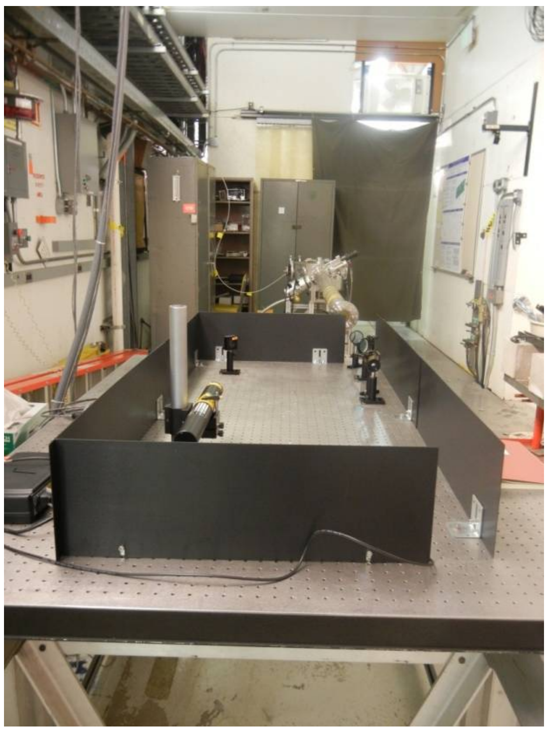
Off line laser ablation test facility

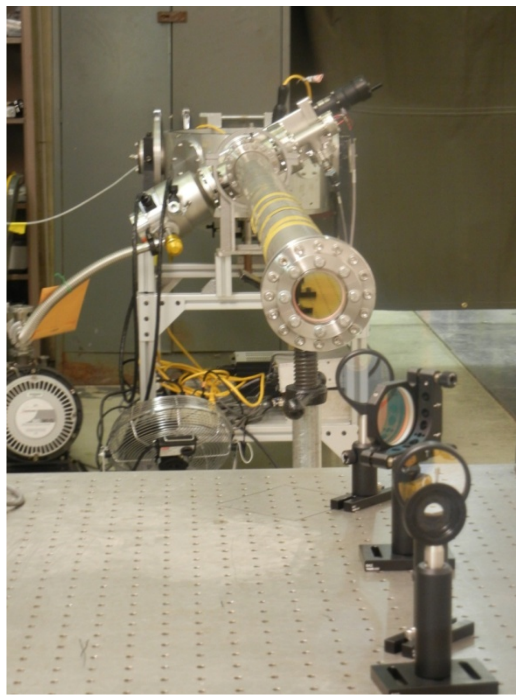
A Passat Diode-Pumped Solid-State HELPP 1064 Laser

First measurements on stable targets

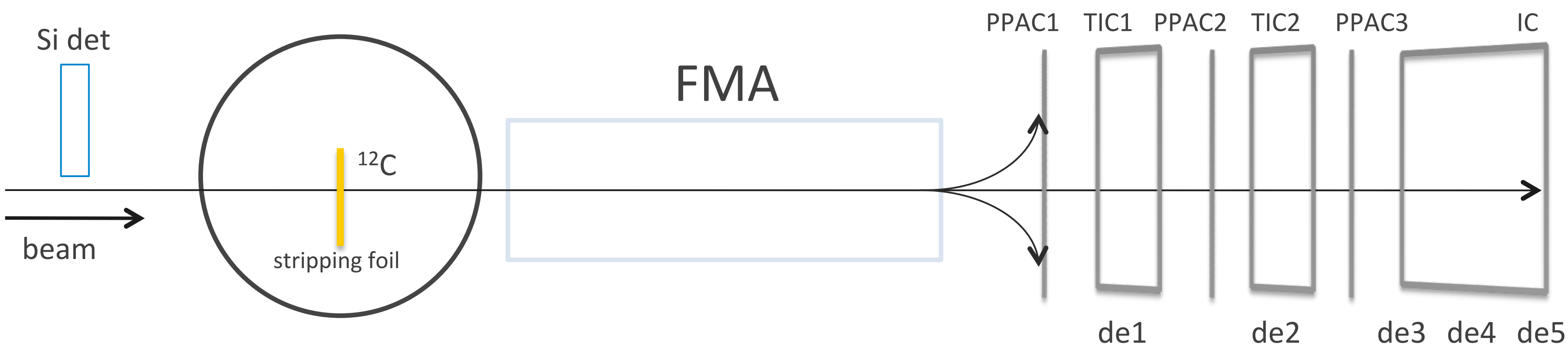
- ✓ Ablation rates appear more than adequate
- ✓ angular distribution of ablated material very sharply peaked at the normal



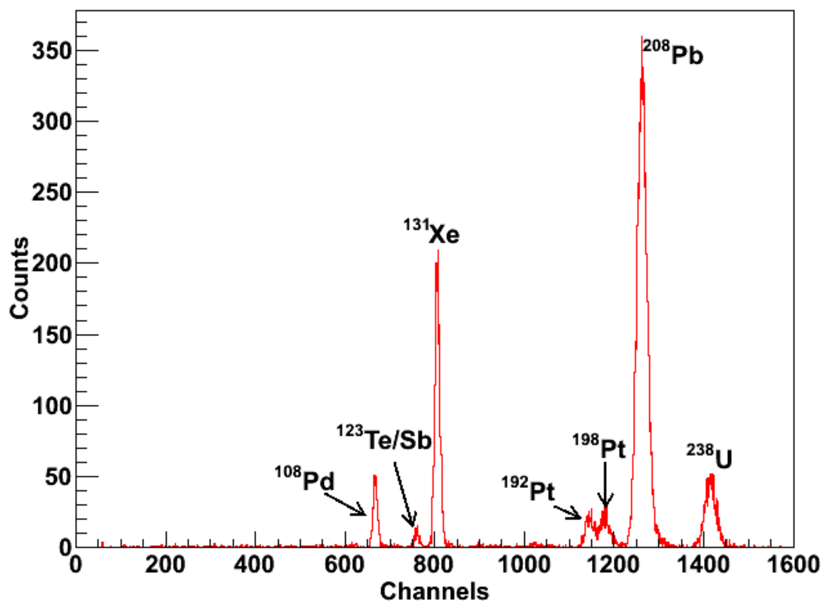




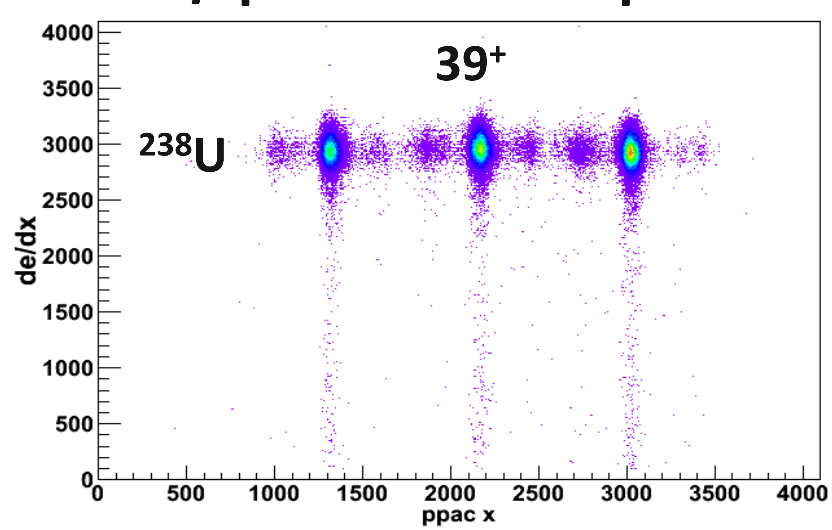
MANTRA test run: December 2010



accelerated beam seen at entrance to FMA

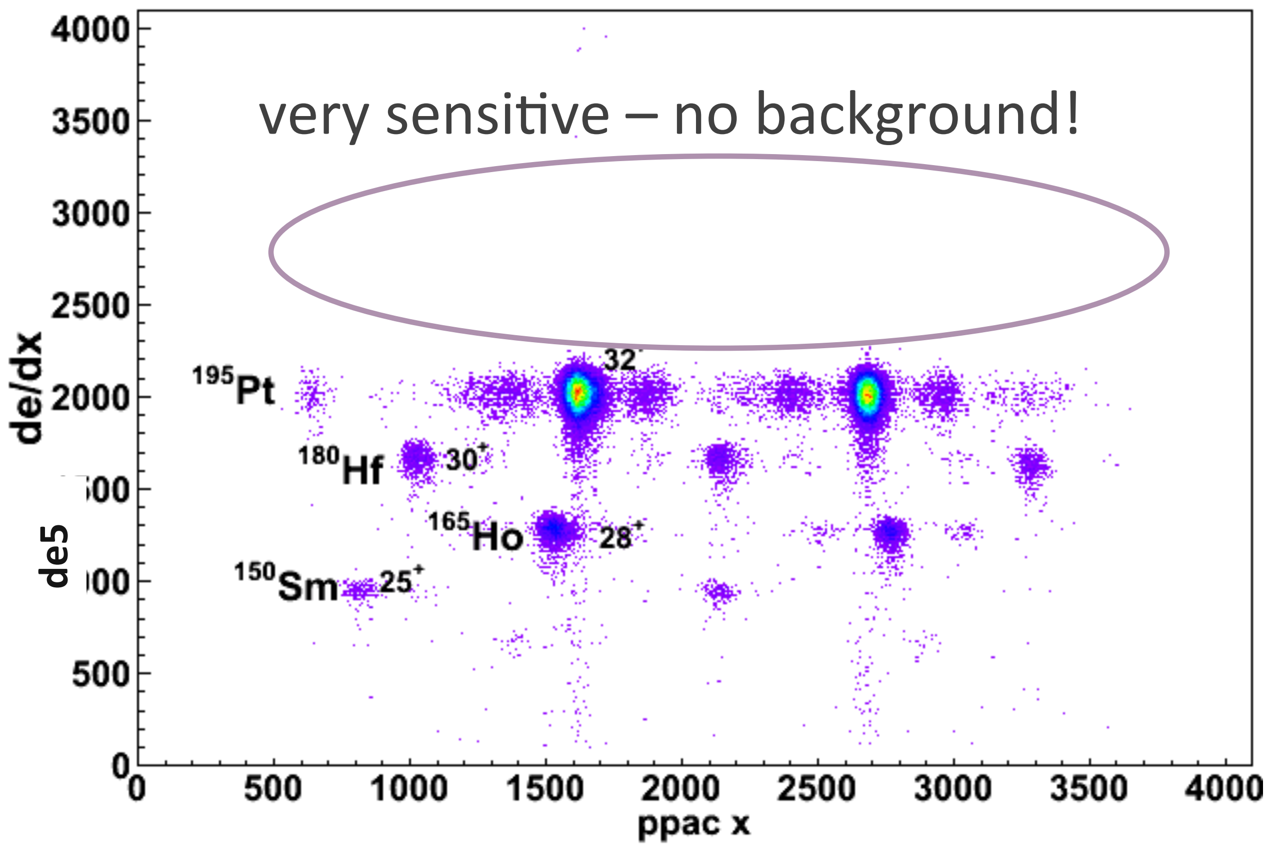


m/q at FMA focal plane



MANTRA test run – cont'd

blank sample: FMA scaled for $^{240}X^{39+}$



bring all components together – full test run in March 2012 – irradiated samples in the summer/fall of 2012

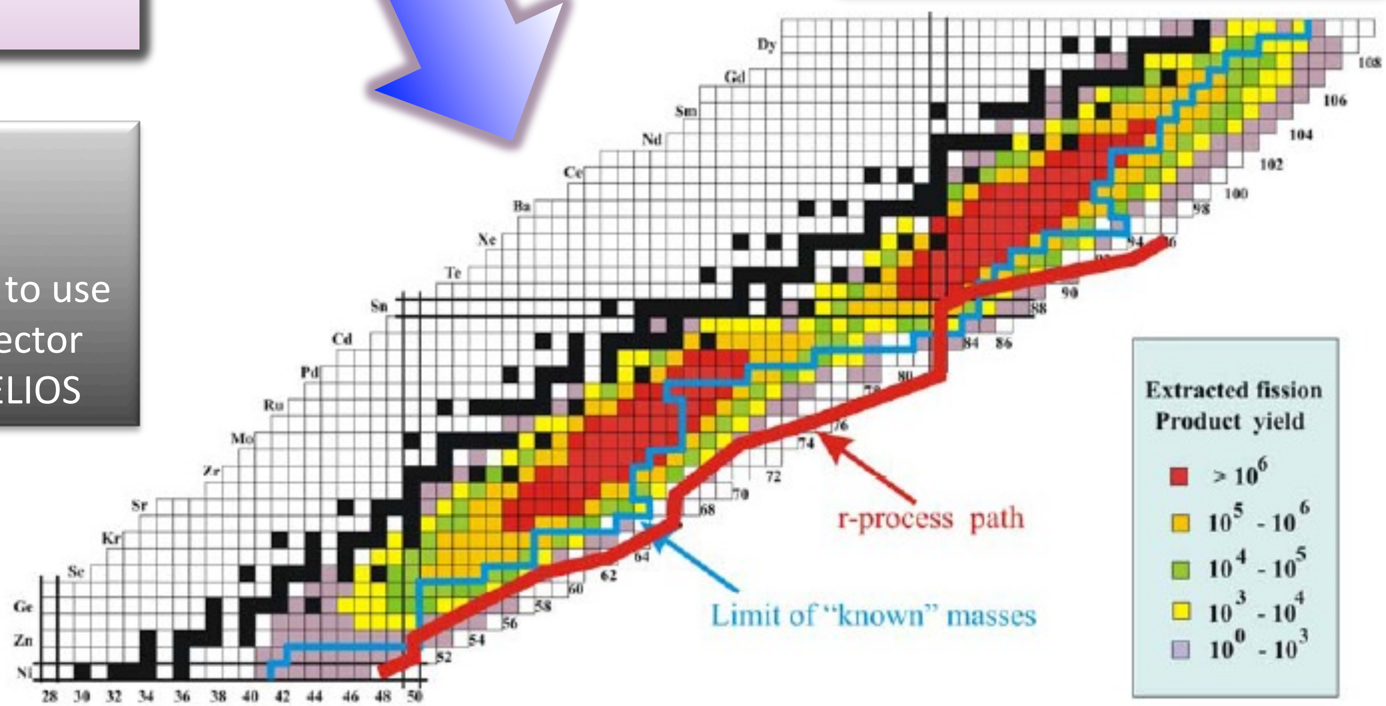
CARIBU

- **CA**lifornium **R**are **I**on **B**reeder **U**pgrade (**CARIBU**) of ATLAS – 1 Ci ^{252}Cf spontaneous fission source (~20% of total activity extracted as ions) - gas catcher and isobar separator - with or without post acceleration

not accelerated - short $T_{1/2}$ and more exotic

no stopovers for refractory elements!

sufficient yields for post accelerated FP decay spectroscopy – capability to use some other powerful detector equipment – GS, FMA, HELIOS

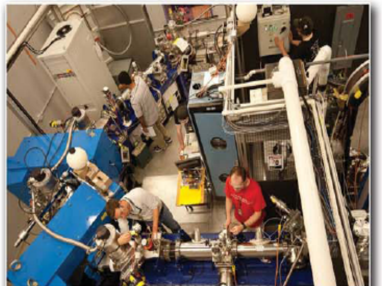


Decay Workshop at ANL

Workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics"

April 14-16, 2011 at

Argonne NATIONAL LABORATORY



A workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics" will be held at Argonne National Laboratory on April 14-16, 2011.

The aim of the workshop is to discuss opportunities for decay studies at the Californium Rare Isotope Breeder Upgrade (CARIBU) of the ATLAS facility with emphasis on advanced fuel cycle (AFC) applications, nuclear structure and astrophysics research. The workshop will consist of review and contributed talks. Presentations by members of the local groups, outlining the status of relevant in-house projects and available equipment, will also be organized. Time will also be set aside to discuss and develop working collaborations for future decay studies at CARIBU.

Topics of interest include:

- Decay data of relevance to AFC applications with emphasis on reactor decay heat
- Discrete high-resolution gamma-ray spectroscopy following radioactive decay and related topics
- Calorimetric studies of neutron-rich fission fragments using Total Absorption Gamma-ray Spectrometry (TAGS) technique
- Beta-delayed neutron emissions and related topics
- Decay data needs for nuclear astrophysics

Workshop Organizers

Dr. Michael Carpenter, Argonne National Laboratory
Prof. Partha Chowdhury, University of Massachusetts Lowell
Dr. Jason Clark, Argonne National Laboratory
Dr. Filip Kondev, Argonne National Laboratory
Dr. Kim Lister, Argonne National Laboratory
Dr. Dariusz Seweryniak, Argonne National Laboratory

Please visit the Workshop web site for additional information about registration, program, lodging and transportation to Argonne.

http://www.ne.anl.gov/capabilities/nd/AFC-Apr11/

http://www.ne.anl.gov/capabilities/nd/AFC-Apr11/program.shtml

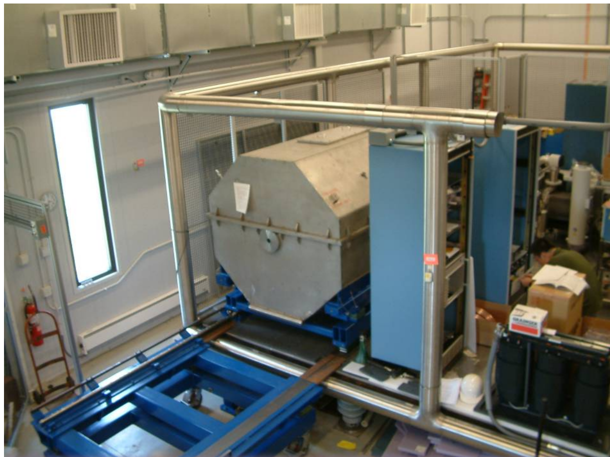
14-16th April 2011

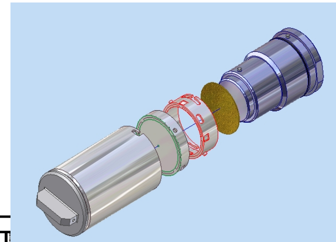
79 Participants from 13 countries and 28 institutions

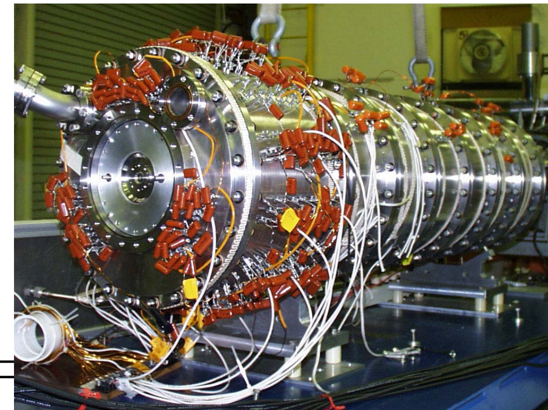
Aimed at engaging the community in CARIBU decay (and accelerated beam) physics.

Decay Heat
Astrophysics
Nuclear Structure

CARIBU “front end” layout

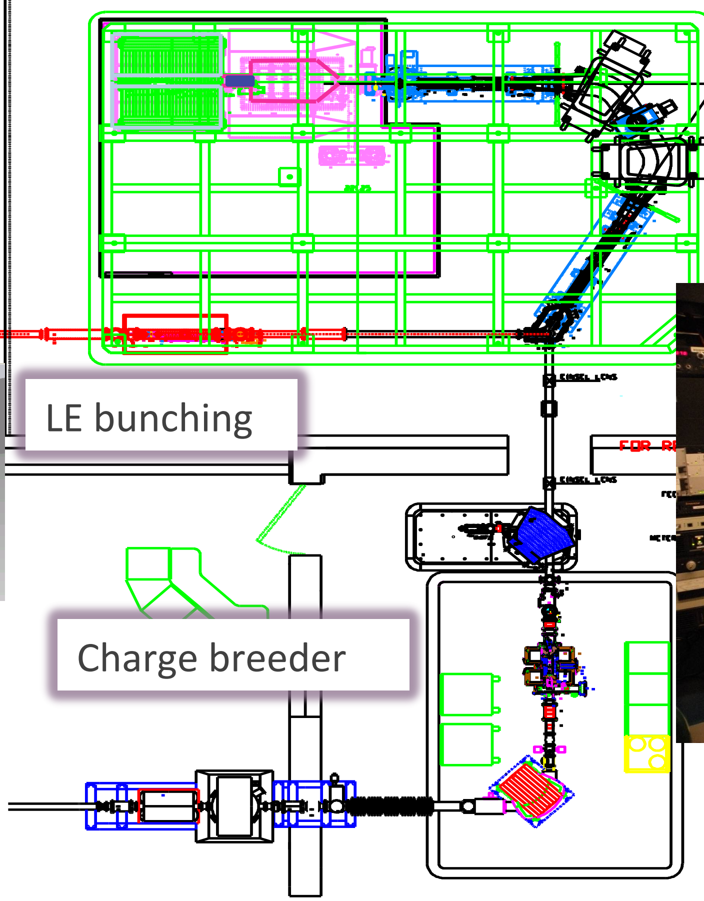


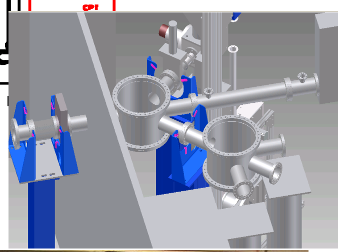




1Ci of ^{252}Cf - 1.9 mg material deposited on a ~2 cm disk

✓ FP thermalization
✓quick FP extraction – 5-20 ms with high efficiency -45%
✓ form a low-emittance beam for post-acceleration



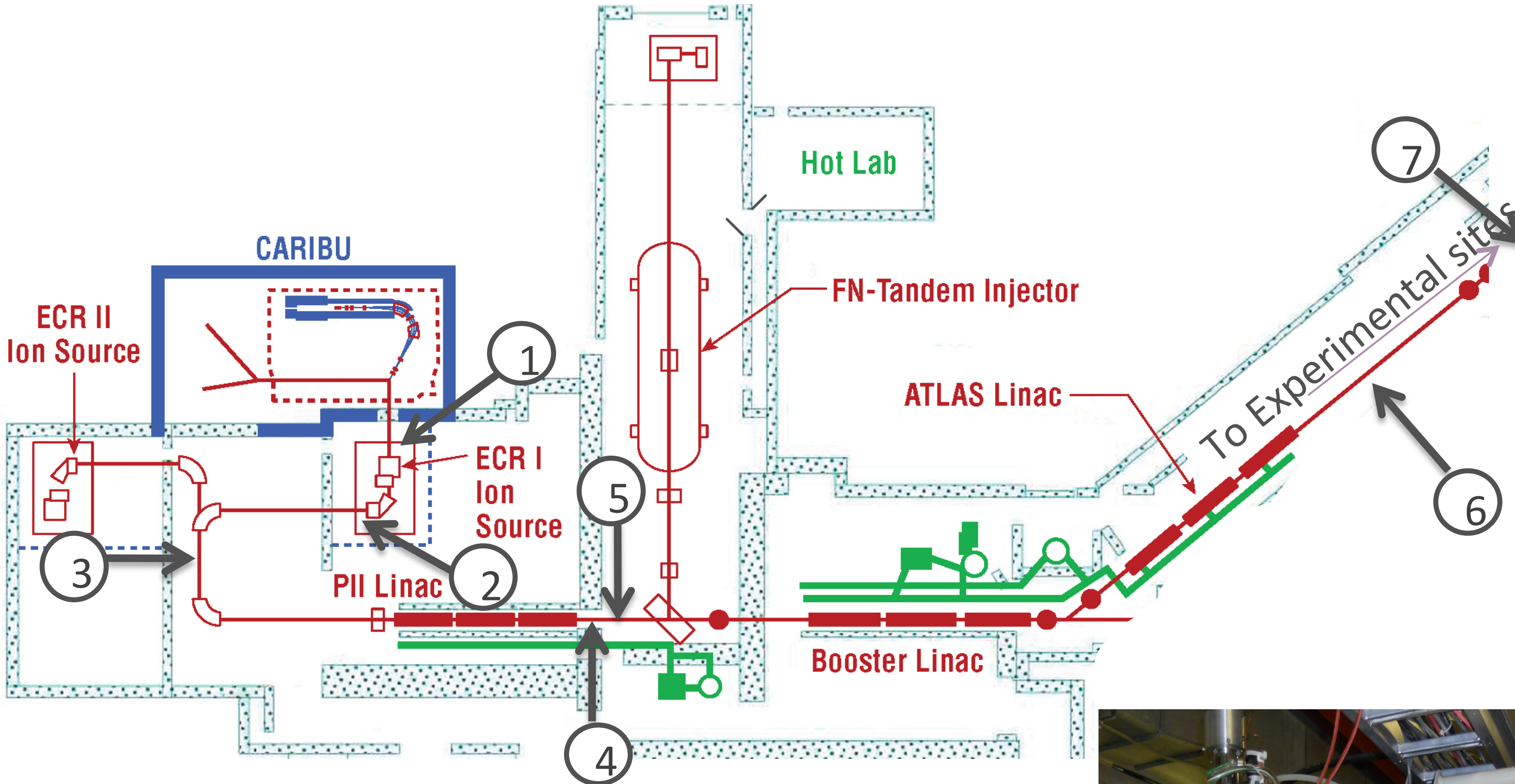


LE bunching

Charge breeder

purifying the beam
ΔM/M~1/20000

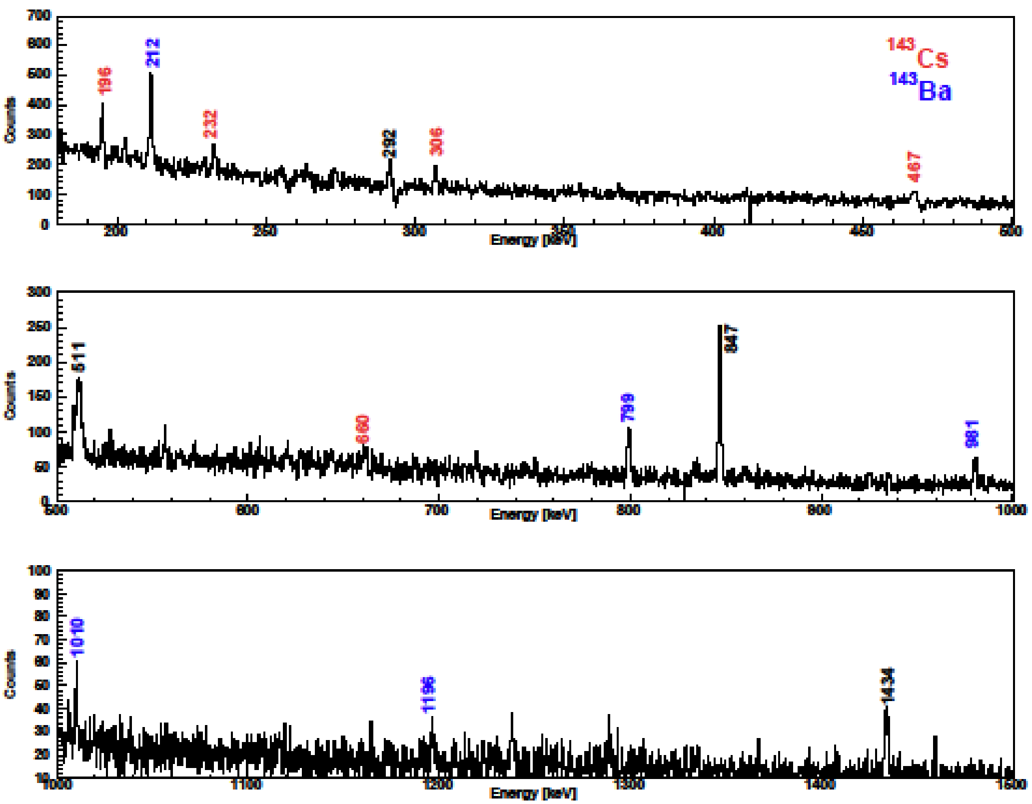
Beam intensities - “Reference points”

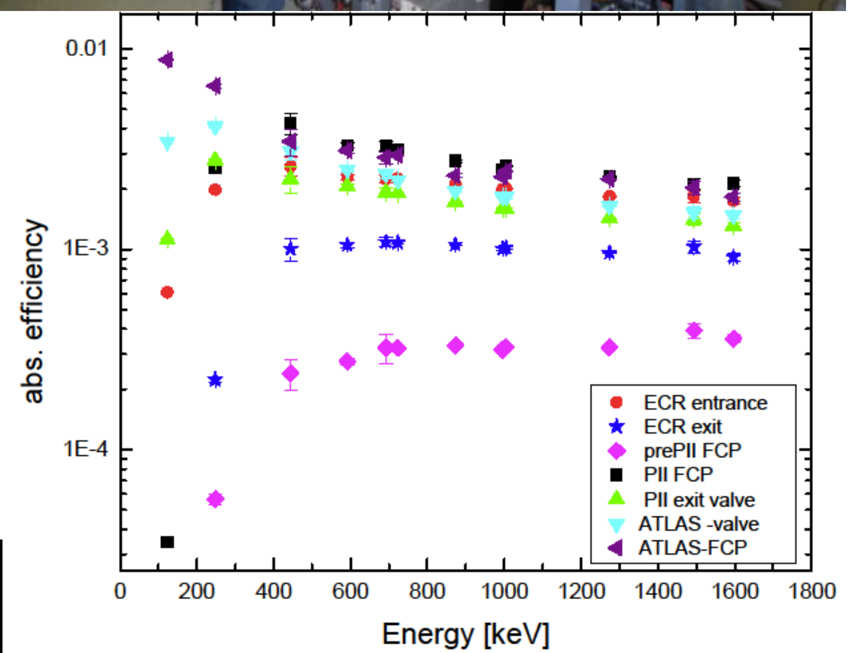


- ✓ 1- ECR entrance
- ✓ 2- ECR exit
- ✓ 3- pre-PII FCP
- ✓ 4 – PII FCP
- ✓ 5- PII exit valve
- ✓ 6- ATLAS valve
- ✓ 7-ATLAS FCP

CARIBU Beam Diagnostics through ATLAS

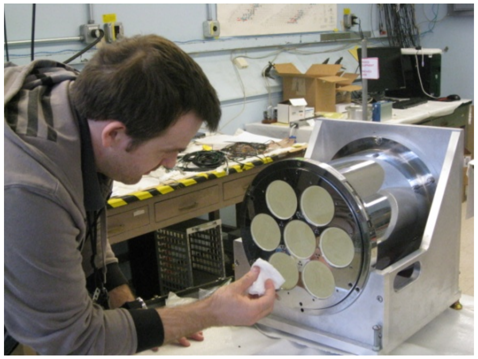
As always with gamma rays …..
ABSOLUTE yields need careful calibration……





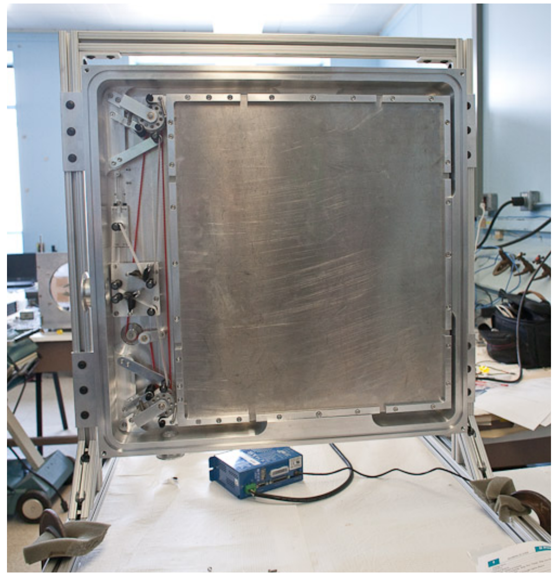
Data: Chithra Nair (NE)

Decay Station at CARIBU



TAGS

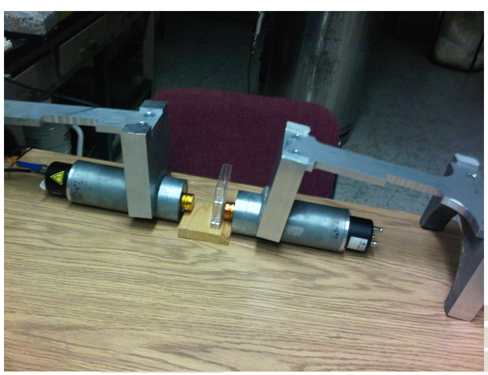
NaI from INL (Greenwood et al.)



Tape Systems (deployed at CARIBU)

adopted design from LSU design, but with increased tape-advance rate (~2m in 0.1s)

Construction: P. Bertone / B. DiGiovine

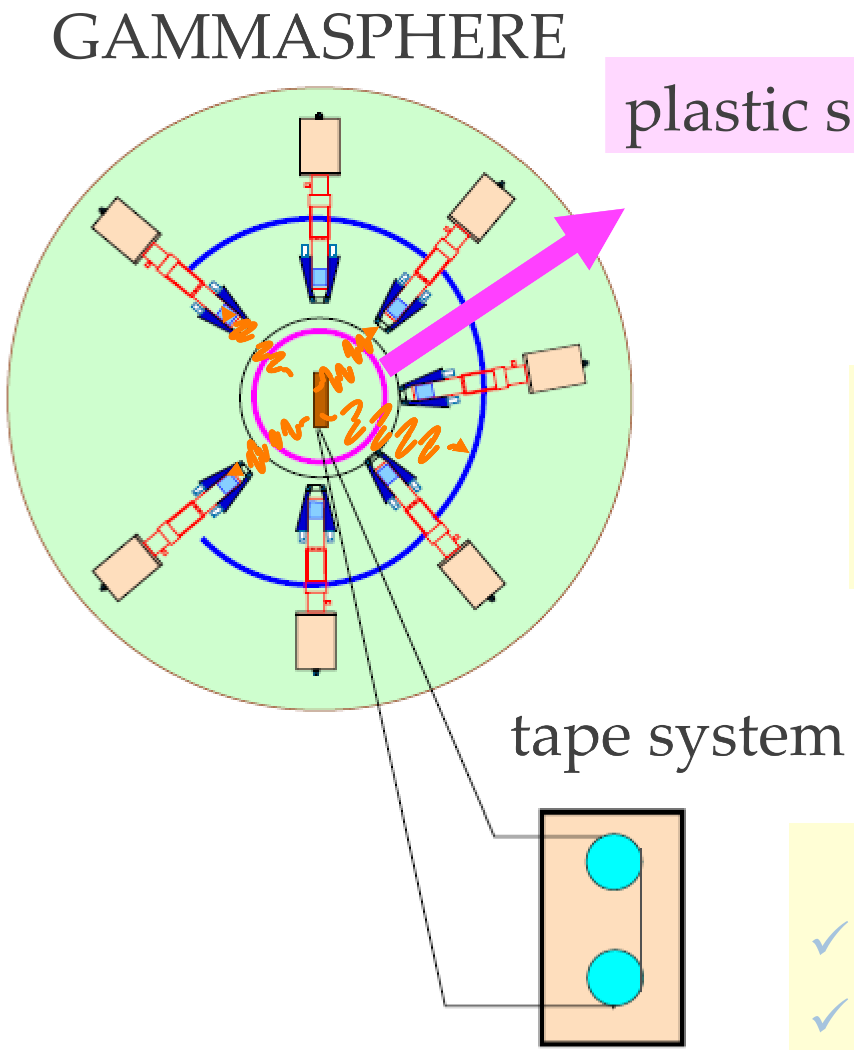


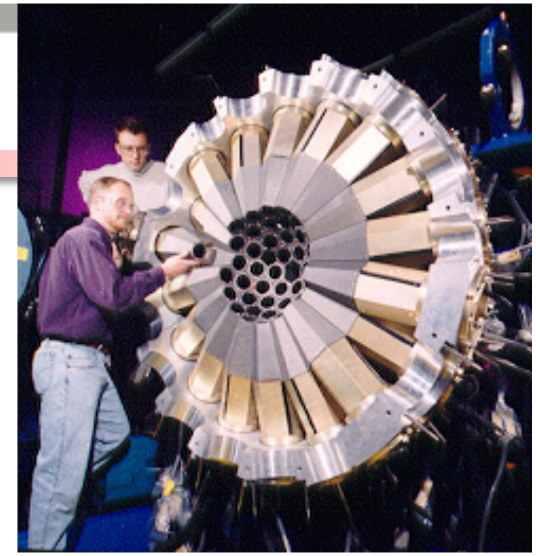
plastic scintillators & Si detectors
$LaBr_3(Ce)$ – a new LDRD grant – M.P. Carpenter & F.G. Kondev – up to 10 det.

X-array

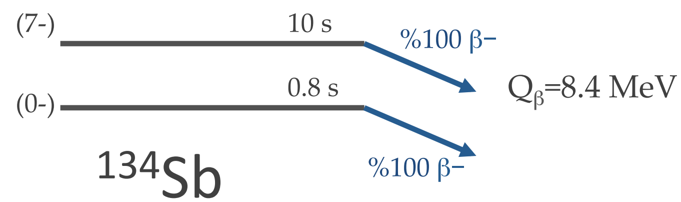
One "Super-Clover" & four 70 X 70 mm crystals - a pack with ~275 % efficiency relative to a 3" x 3" NaI

β− counting station with GS





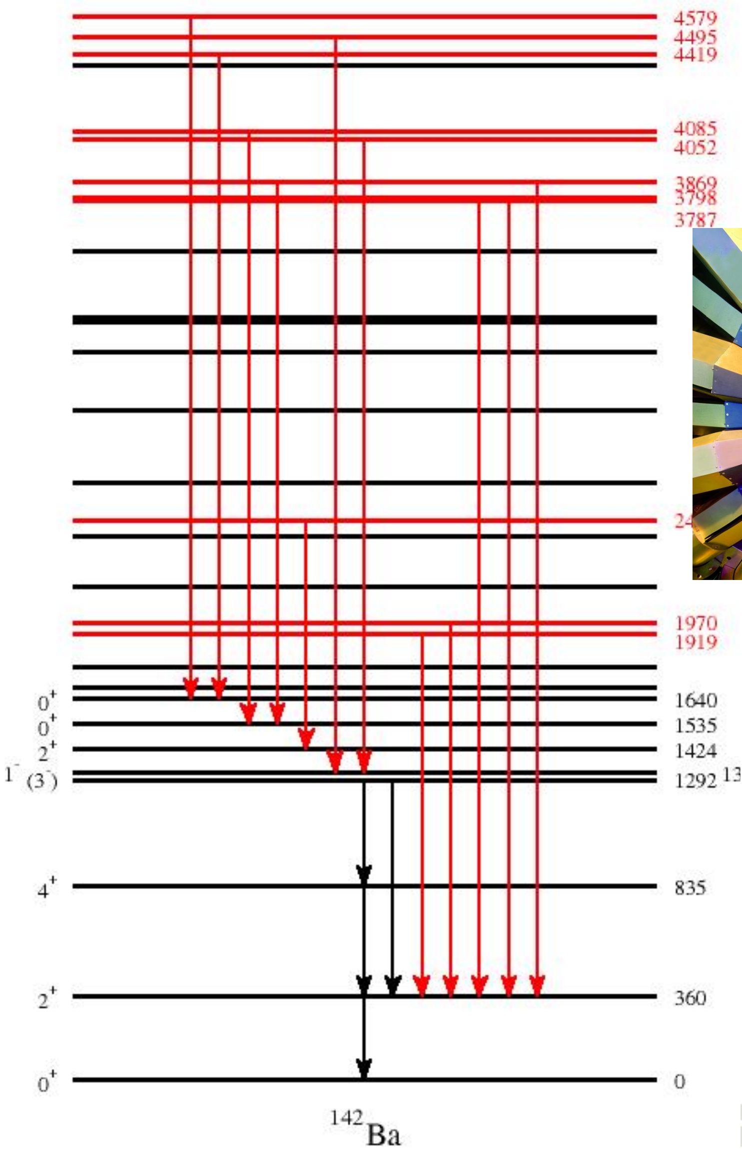
- ✓ high resolution & sensitivity
- ✓ powerful β−γ−γ coin – resolving weak cascades & isomers!

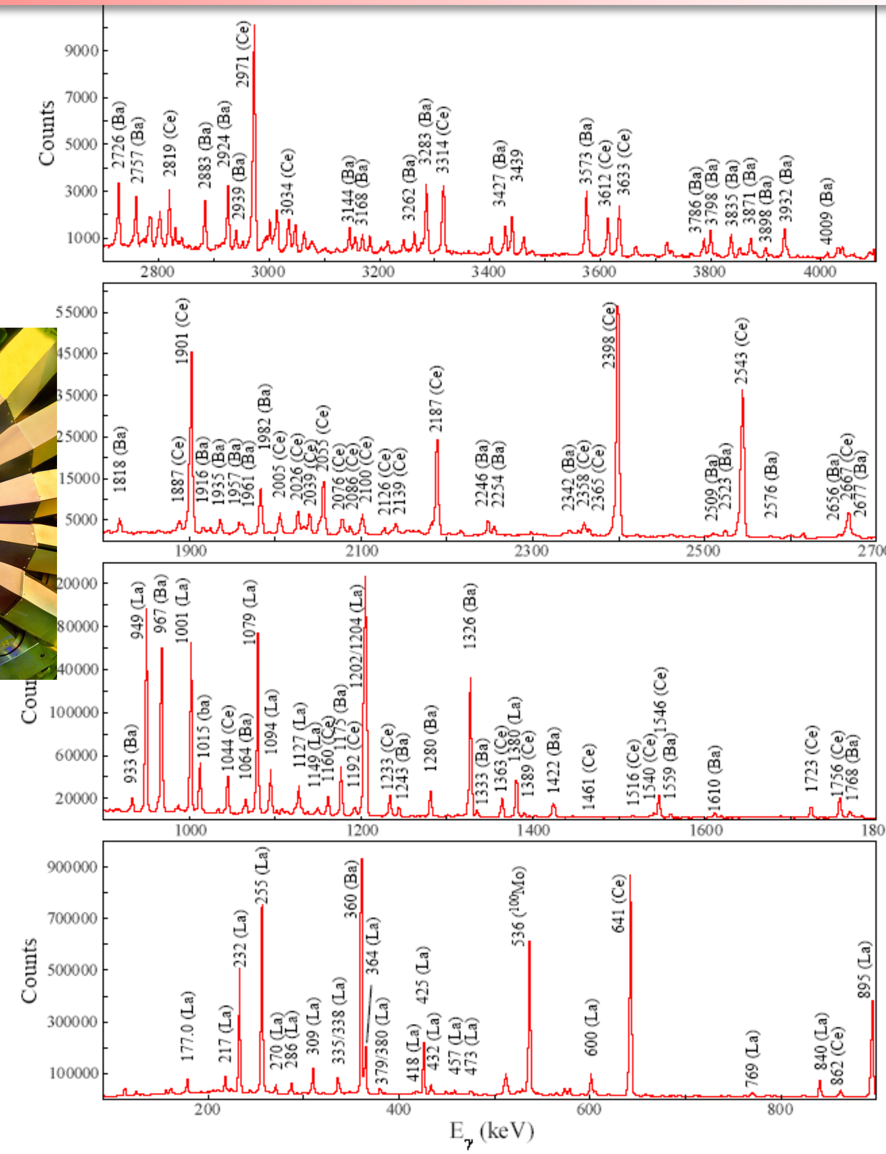


GS as a calorimeter

- ✓ P. Reiter et al. Phys. Rev. Lett. 84, 3542 (2000)
- ✓ with a modest upgrade – suitable for β− decay studies – HRGS & TAGS

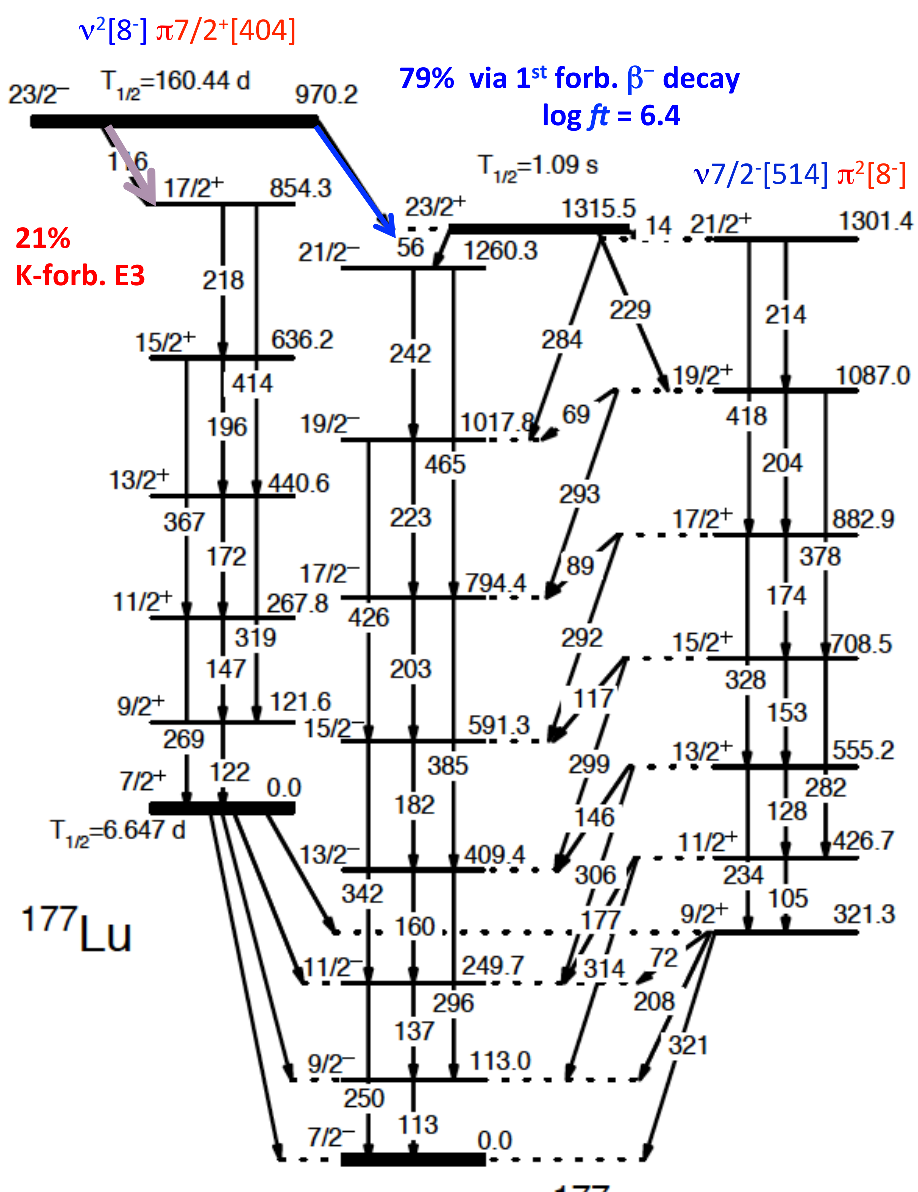
First decay schemes from CARIBU Ions





Data from Shaofei Zhu (PHY)

$K^{\pi}=23/2^{-}$ isomer in ^{177}Lu



discovered by M. Jorgensen et al., 1962

PHYSICAL REVIEW C 83, 064617 (2011)

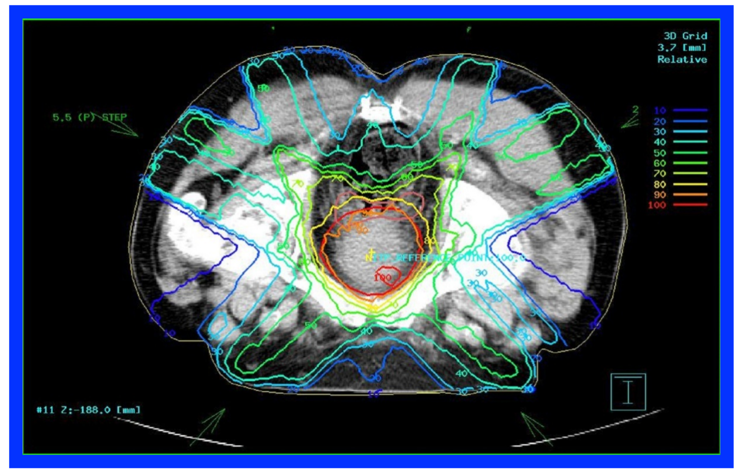
Direct evidence for inelastic neutron "acceleration" by $^{177}Lu^{m}$

O. Roig,[1,*] V. Méot,[1] B. Rossé,[1] G. Bélier,[1] J.-M. Daugas,[1] A. Letourneau,[2] A. Menelle,[3,4] and P. Morel[1]

huge cross section

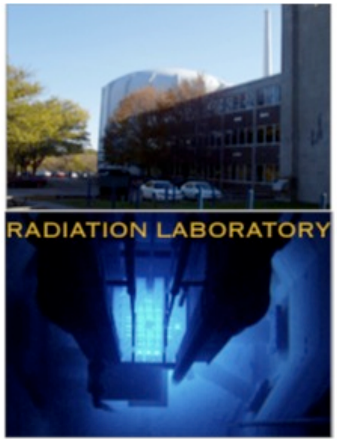
σ=146 (19) b vs 258 (58) b

still need explanation



impurity in the production of the medical isotope ^{177}Lu ($T_{1/2}$=6.647 d)

^{177m}Lu Isomer production



^{176}Lu(n,γ)^{177m}Lu @ UML

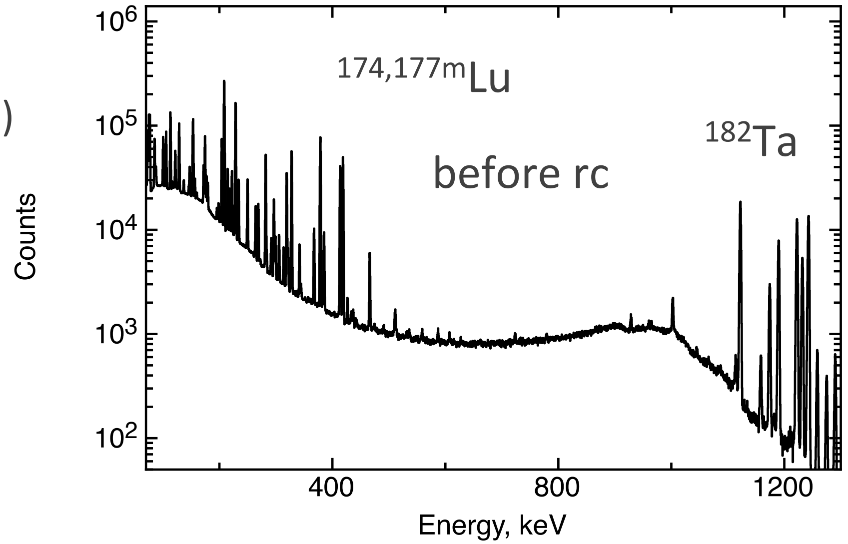
- ✓ natural Lu target material
- ✓ irradiation (4/24/2003 – 4/18/2006)
- ✓ total neutron fluence: 3.5x10^{19}
- ✓ ~4 yr of cooling

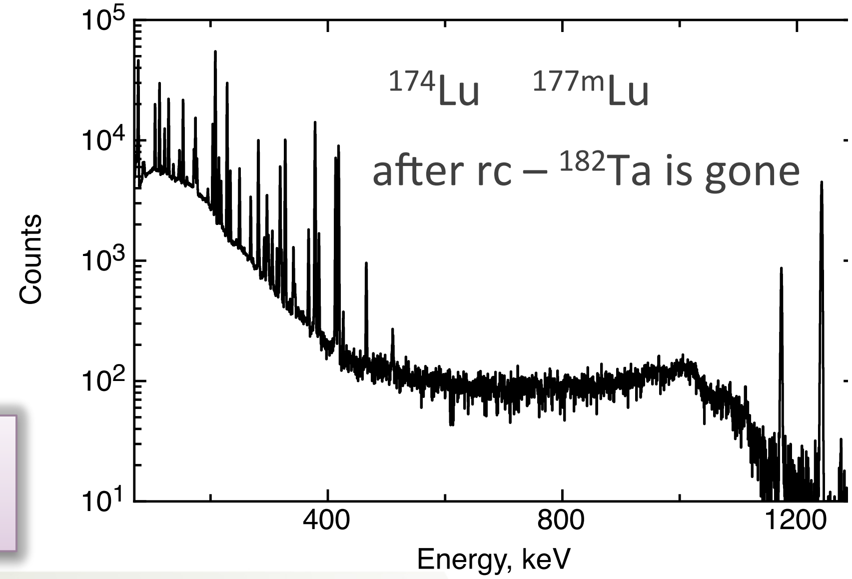
177W 132 M ε: 100.00%	178W 21.6 D ε: 100.00%	179W 37.05 M ε: 100.00%	180W 1.8E+18 Y 0.12% α: 100.00%	181W 121.2 D ε: 100.00%	182W >8.3E+18 Y 26.50% α	183W >1.3E+19 Y 14.31% α	184W >2.9E+19 Y 30.64% α
176Ta 8.09 H ε: 100.00%	177Ta 56.56 H ε: 100.00%	178Ta 9.31 M ε: 100.00%	179Ta 1.82 Y ε: 100.00%	180Ta 8.154 H ε: 86.00% β-: 14.00%	181Ta STABLE 99.988%	182Ta 114.43 D β-: 100.00%	183Ta 5.1 D β-: 100.00%
175Hf 70 D ε: 100.00%	176Hf STABLE 5.26%	177Hf STABLE 18.60%	178Hf STABLE 27.28%	179Hf STABLE 13.62%	180Hf STABLE 35.08%	181Hf 42.39 D β-: 100.00%	182Hf 8.90E+6 Y β-: 100.00%
174Lu 3.31 Y ε: 100.00%	175Lu STABLE 97.41%	176Lu 3.76E+10 Y 2.59% β-: 100.00%	177Lu 6.647 D β-: 100.00%	178Lu 28.4 M β-: 100.00%	179Lu 4.59 H β-: 100.00%	180Lu 5.7 M β-: 100.00%	181Lu 3.5 M β-: 100.00%

^{181}Ta(n,γ)^{182}Ta - impurities

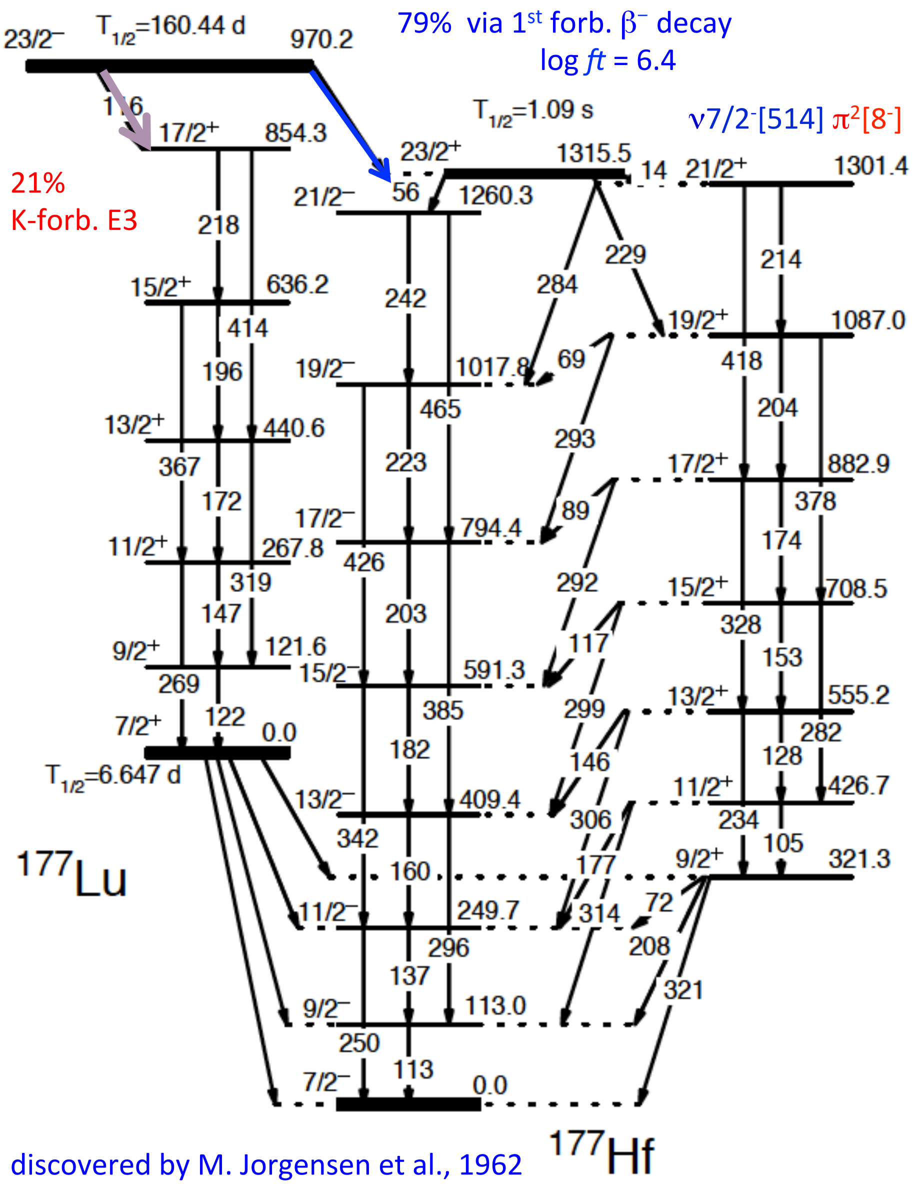
radiochemical separation
John Green & Irshad Ahamd

a single HpGe detector

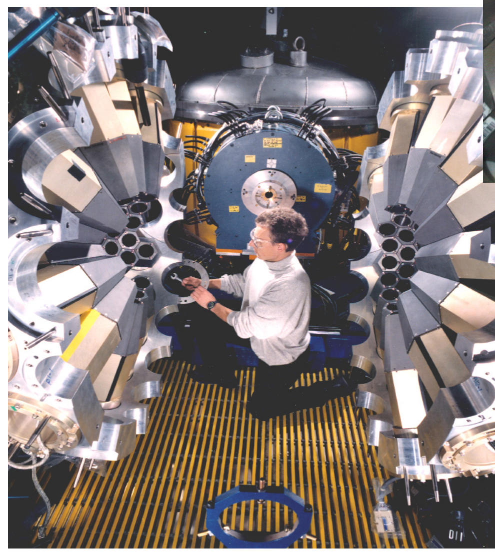


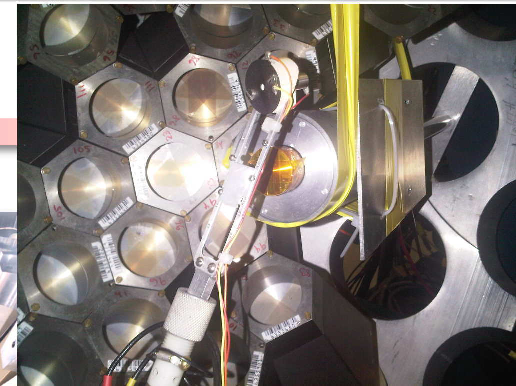


Decay of $K^{\pi}=23/2^{-}$ isomer



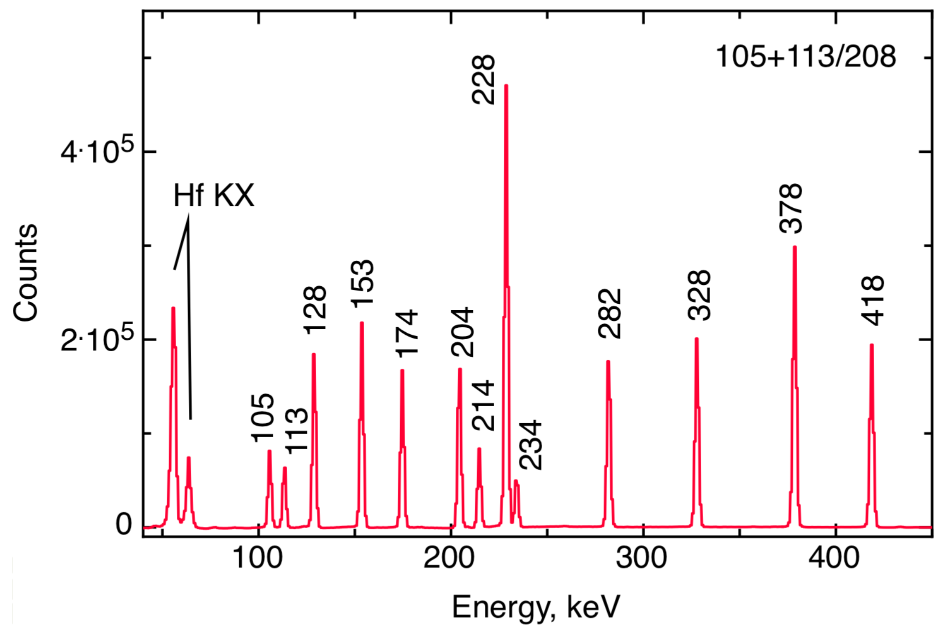
discovered by M. Jorgensen et al., 1962





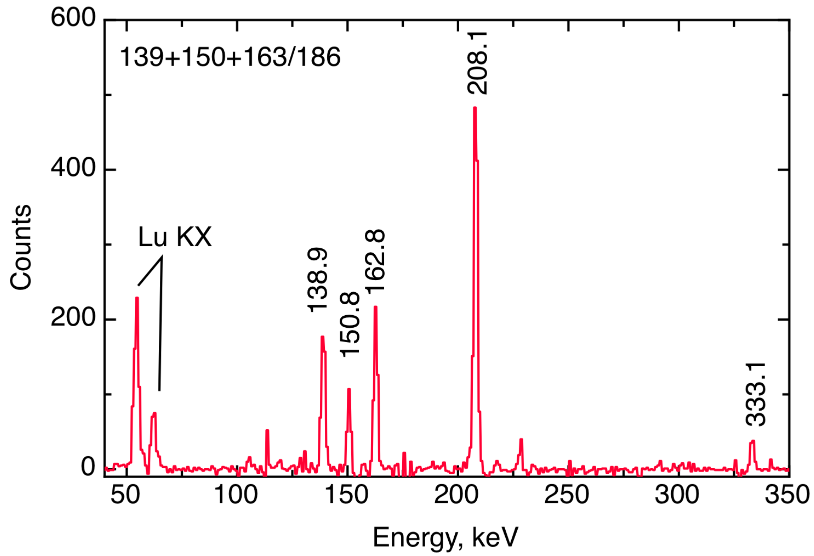
LaBr₃(Ce)

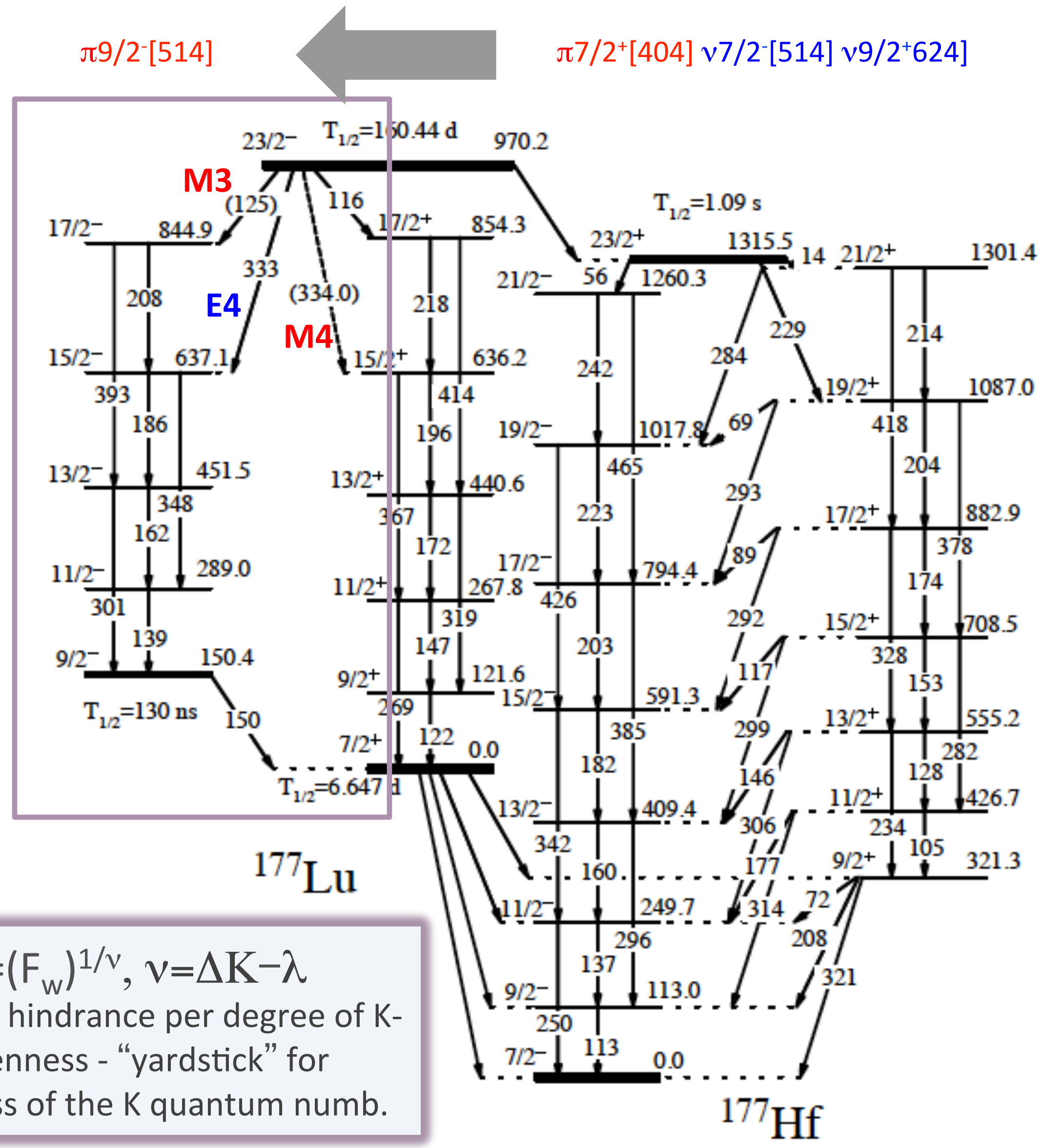
PMT - **XP20D0B** – Photonis
collaborators Univ. Sofia
1″ by 1″; 2% at 1.3 MeV



Decay of $K^{\pi}=23/2^{-}$ isomer – cont.

$\alpha_T(M3)=94$ - $\alpha_T(E4)=1$

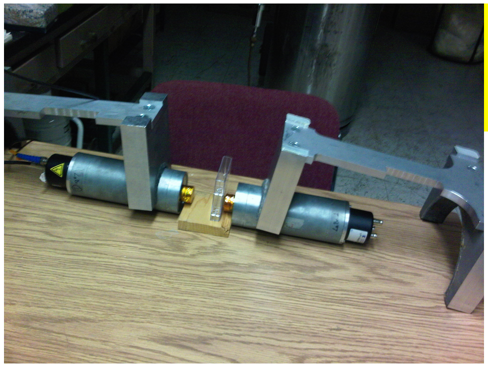




E, keV	Mult	ν	f_ν
116	E3	5	61.5(6) 66 (^{178}Hf)
125	M3	4 3	470 (40) 83 (^{177}Hf)
333	E4	3	980 (80)
334	M4	4	>53 72 (^{178}Hf)

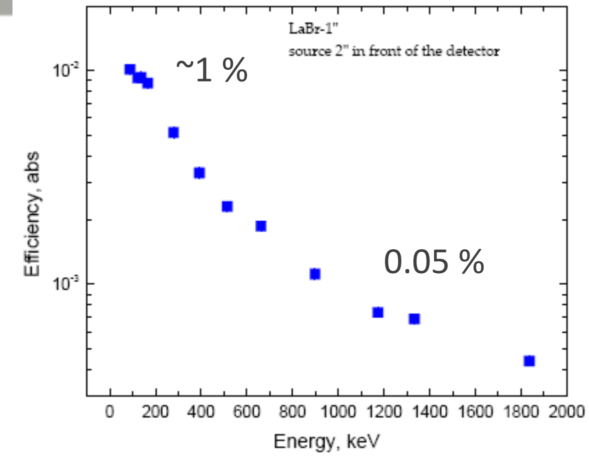
$f_\nu=(F_W)^{1/\nu}$, $\nu=\Delta K-\lambda$

reduced hindrance per degree of K-forbiddenness - “yardstick” for goodness of the K quantum numb.



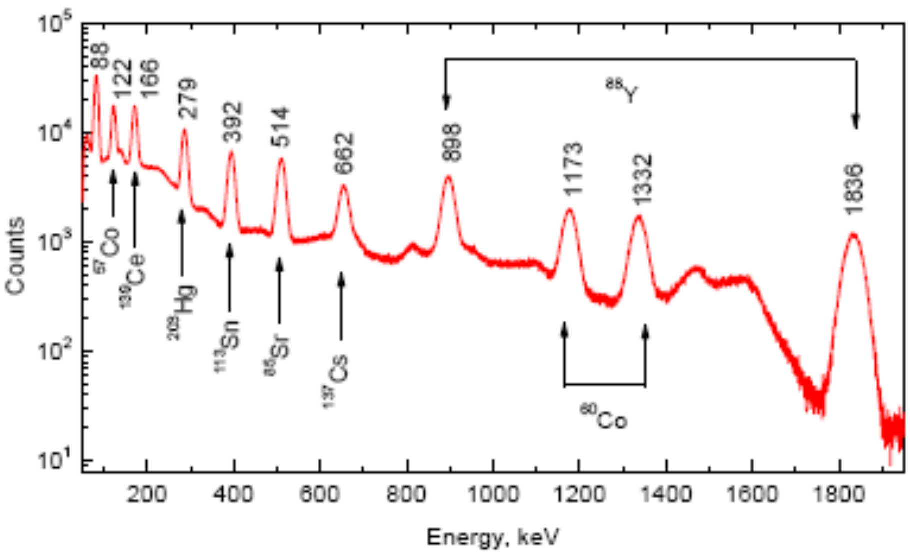
$LaBr_3(Ce)$

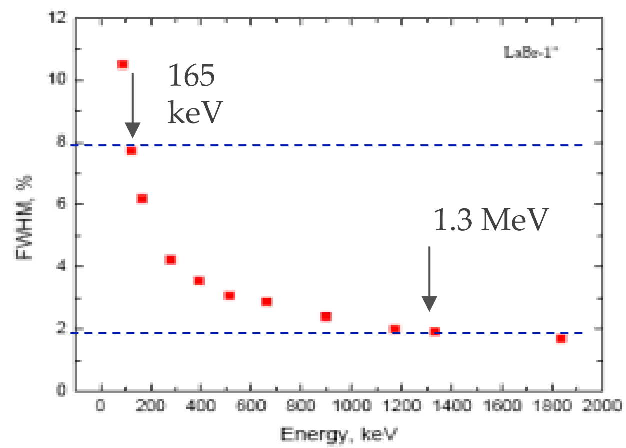
	LaBr	NaI	BaF_2
Density [g/cm^3]:	5.29	3.67	4.88
Decay Time [ns]:	16	250	0.7
Light yield [ph/keV]:	63	38	1.8



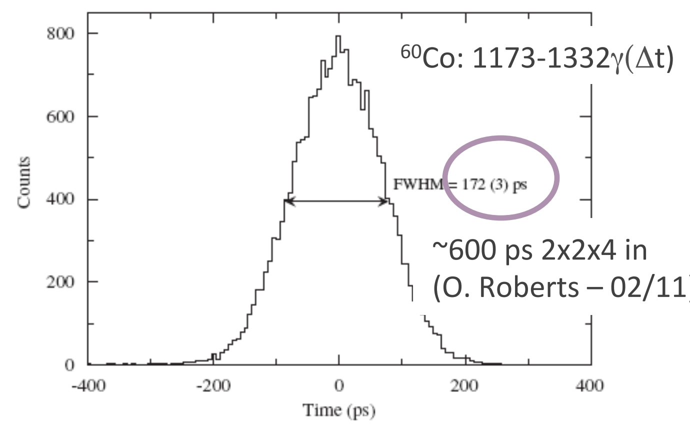
PMT - **XP20D0B** – Photonis

collaborators Univ. Sofia



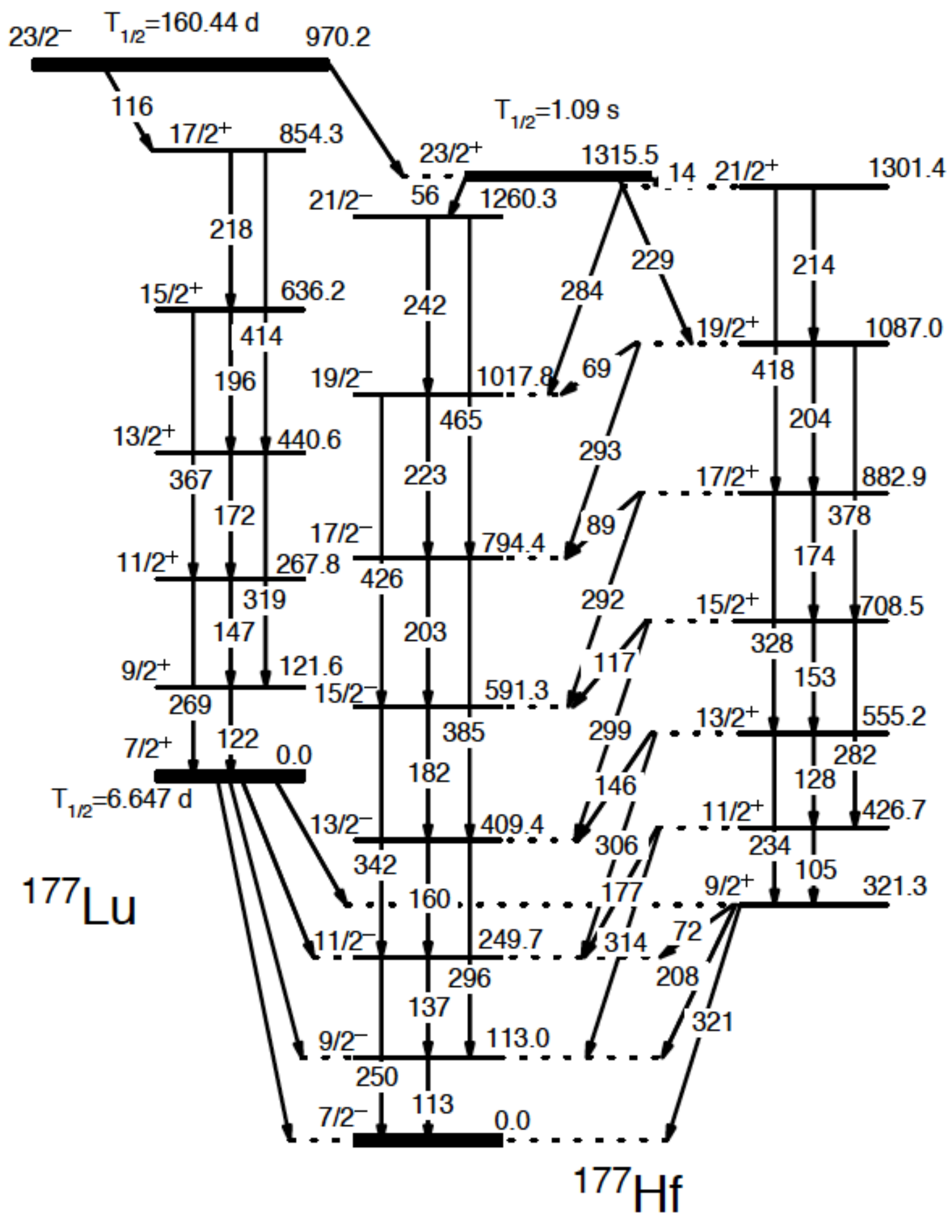


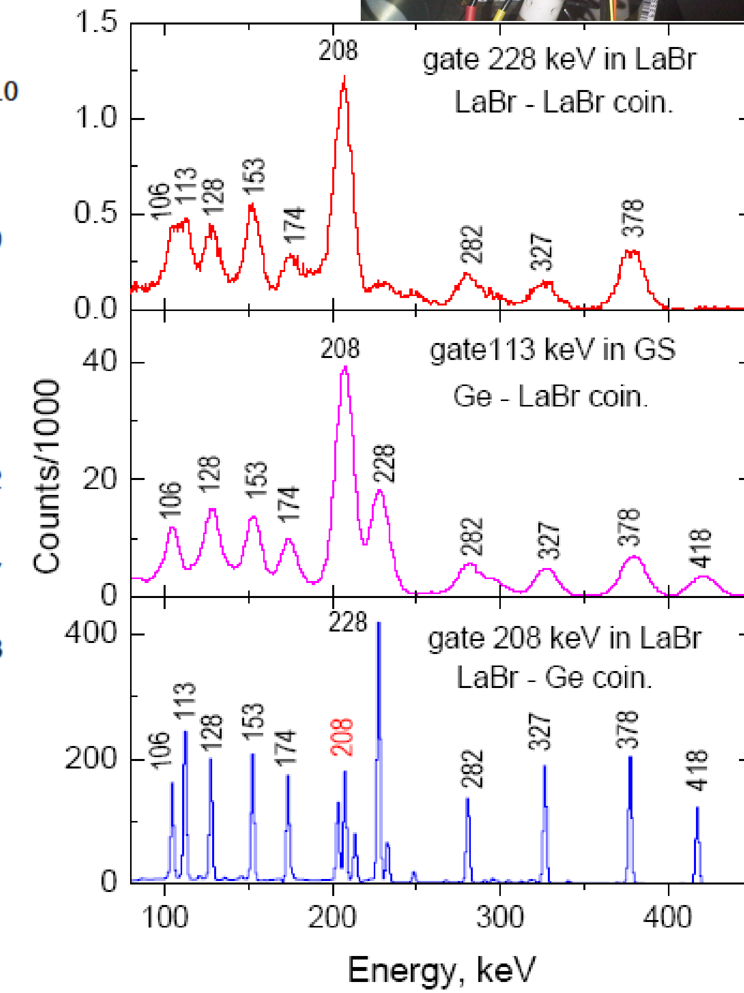
calibrated source & a single HpGe detector



Good energy resolution & high efficiency

GS-LaBr$_3$(Ce) coincidences

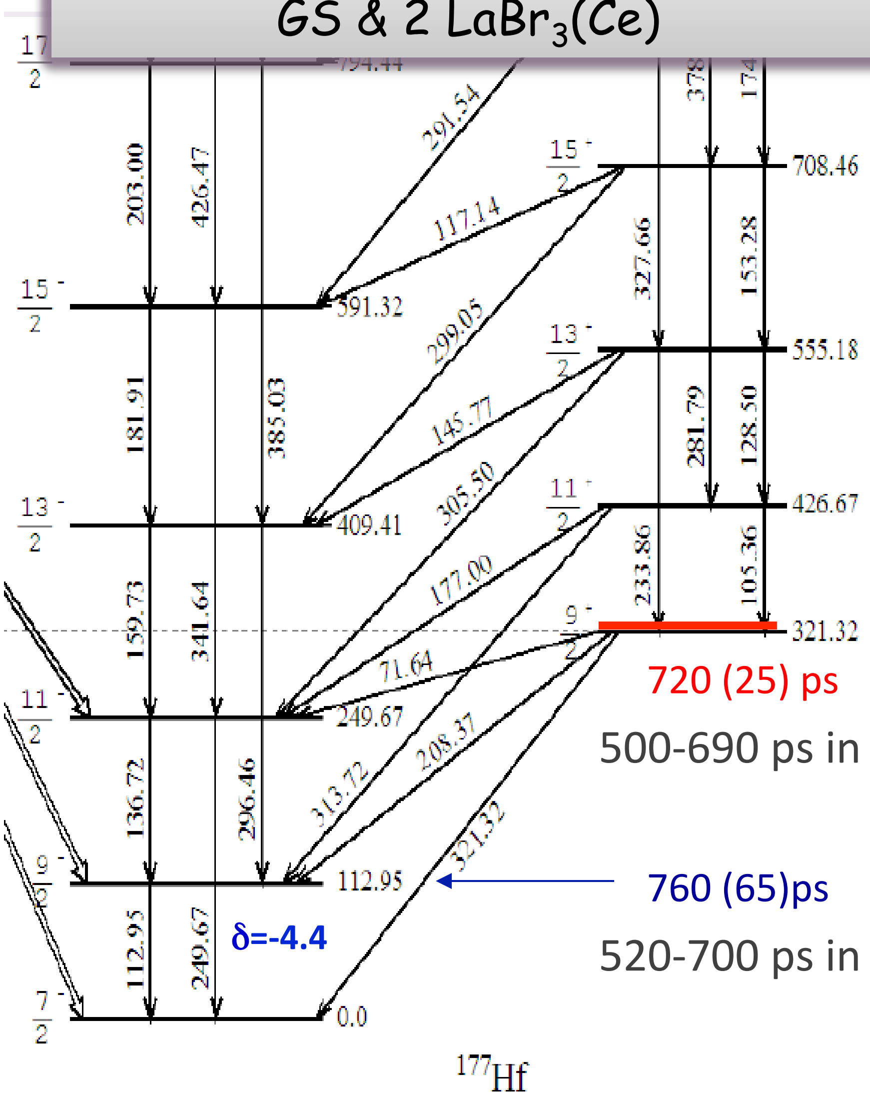




Fast timing measurements

Direct (electronic) timing – γ-γγ(Δt)

GS & 2 $LaBr_3(Ce)$



720 (25) ps

500-690 ps in *NDS*

760 (65)ps

520-700 ps in *NDS*

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γ–ray coincidence and fast-timing measurements using $LaBr_3(Ce)$ detectors and gammasphere ☆

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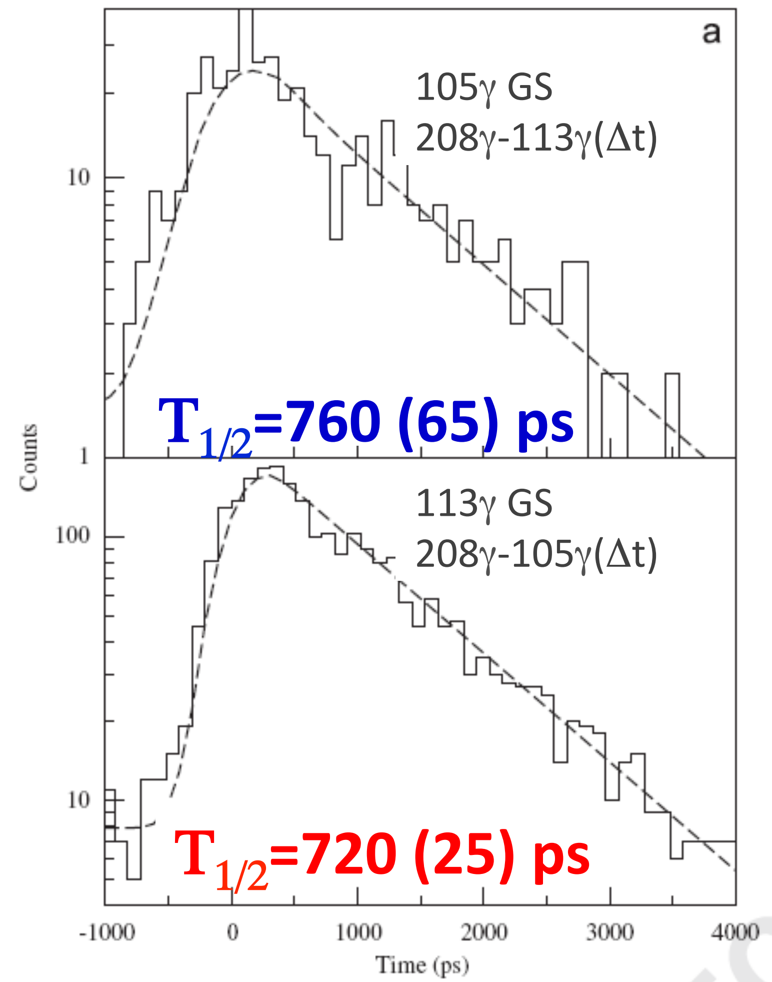
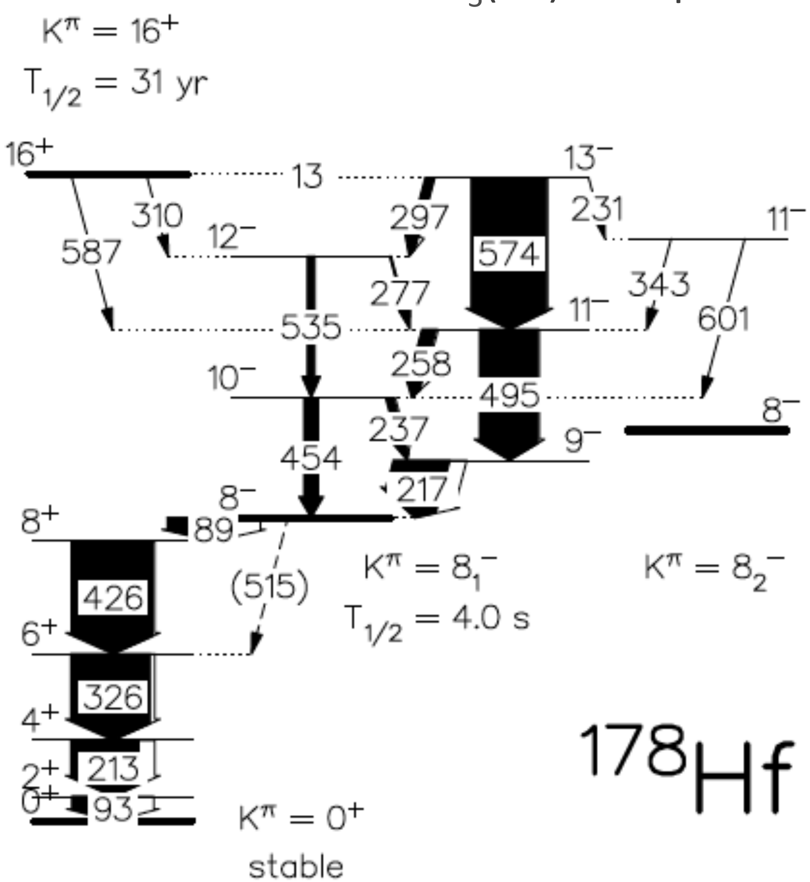


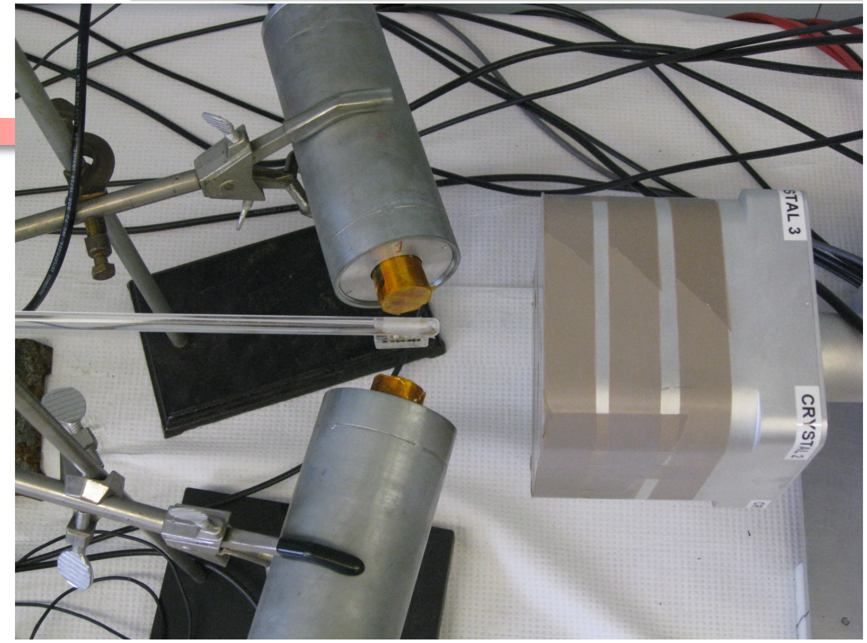
$T_{1/2}$=760 (65) ps

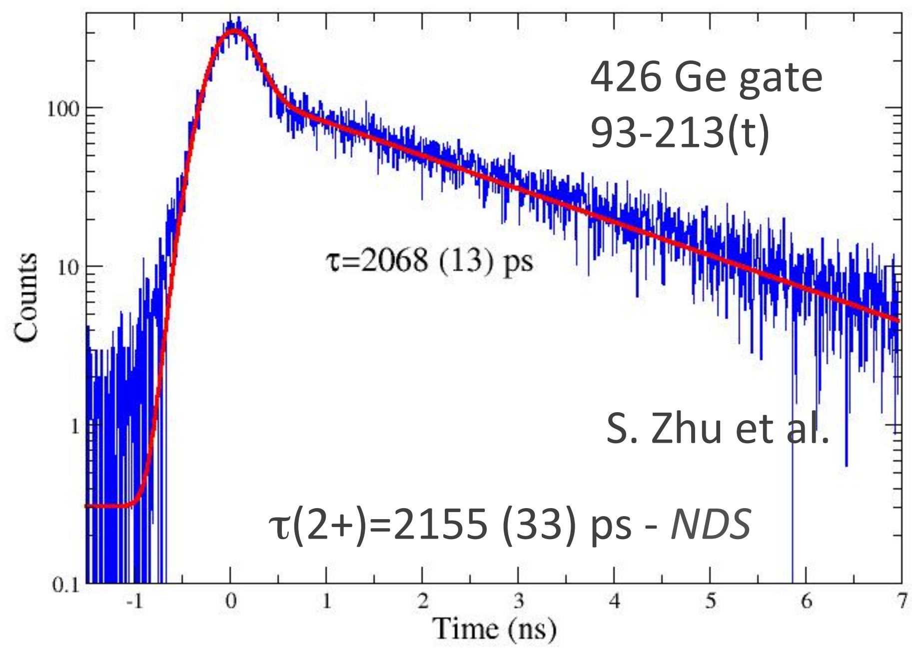
$T_{1/2}$=720 (25) ps

Studies of ^{178m}Hf decay

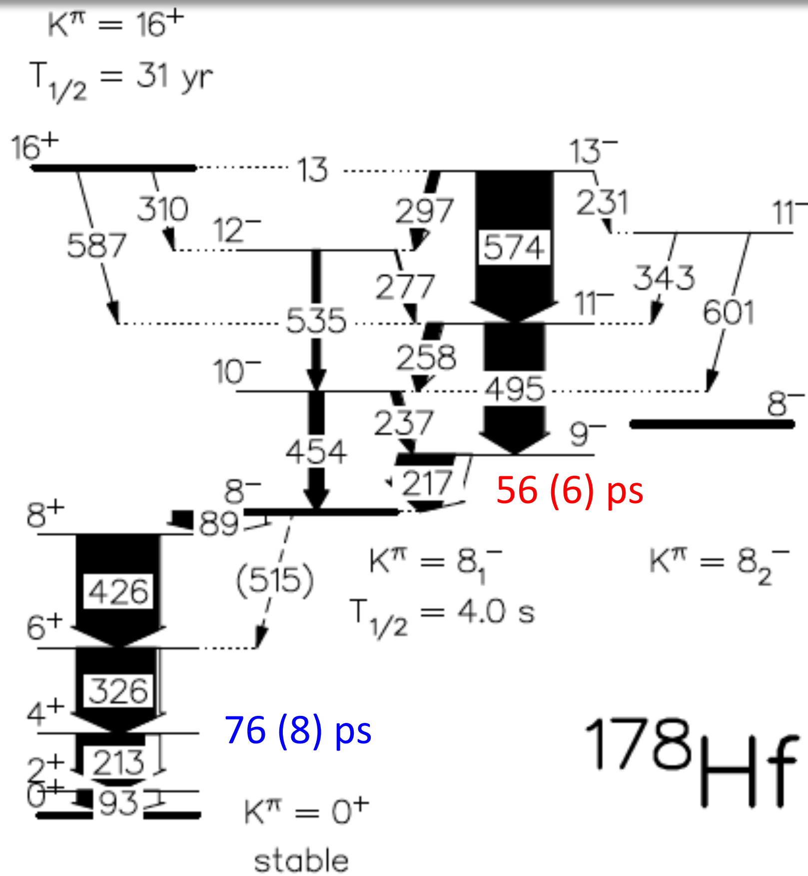
~μC source produced at LANL
2 $LaBr_3(Ce)$ + 1 HpGe clover

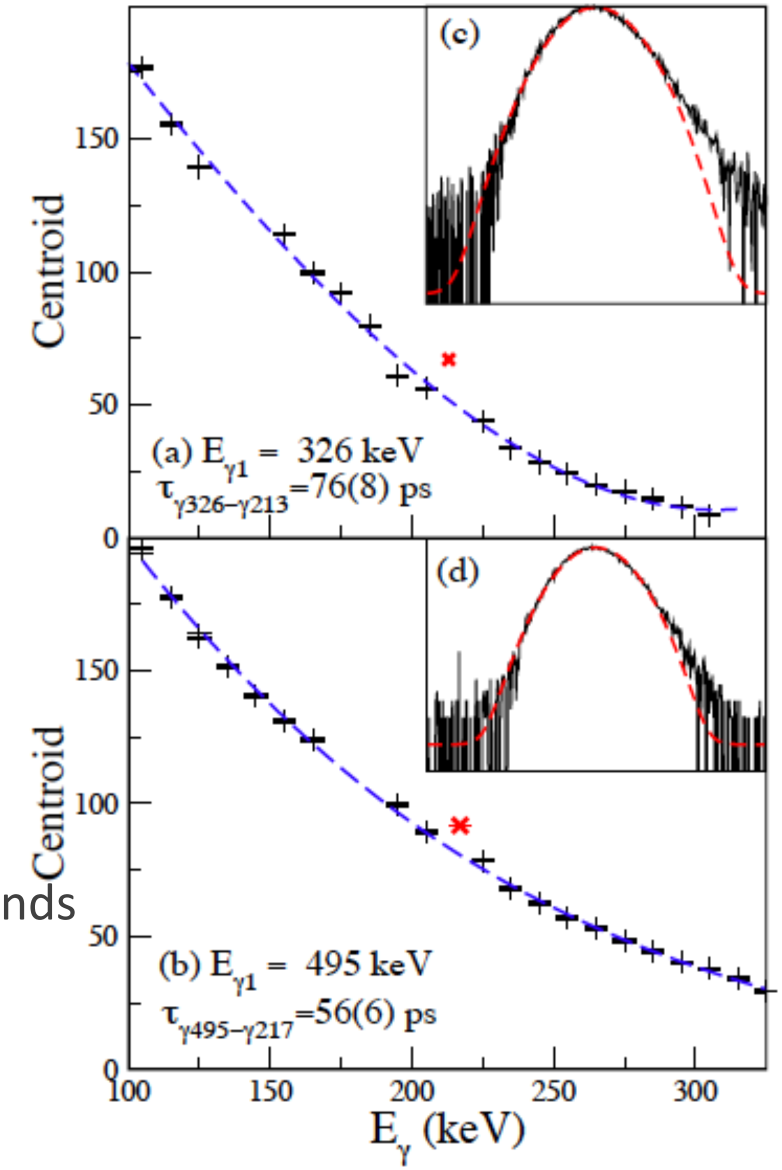






Lifetime of states above the K^{π}=8- isomer





Configuration mixing between π^2 and ν^2 [8-] bands

- ✓ from log ft values in ^{178}Lu beta decay
- ✓ from in-band branching ratios
- ✓ B(M1) ~ (gk-gr)