CARIBU at ATLAS: Opportunities for Improving Decay Data for Neutron-rich Fission Products

Argonne NATIONAL LABORATORY

... for a brighter future

U.S. Department of Energy

UChicago Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

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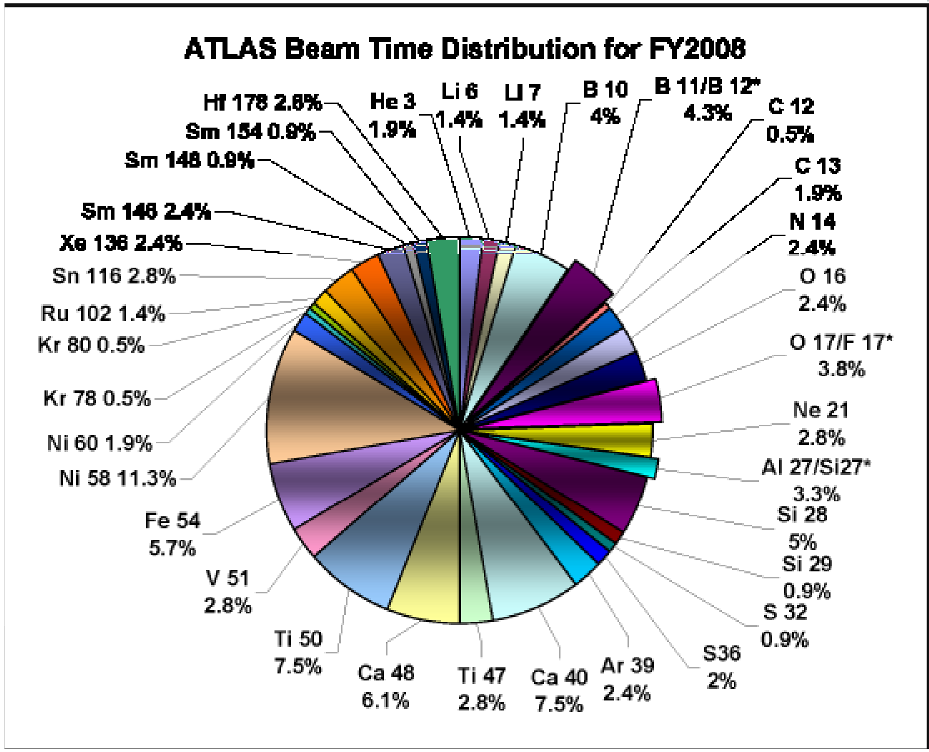
Outline

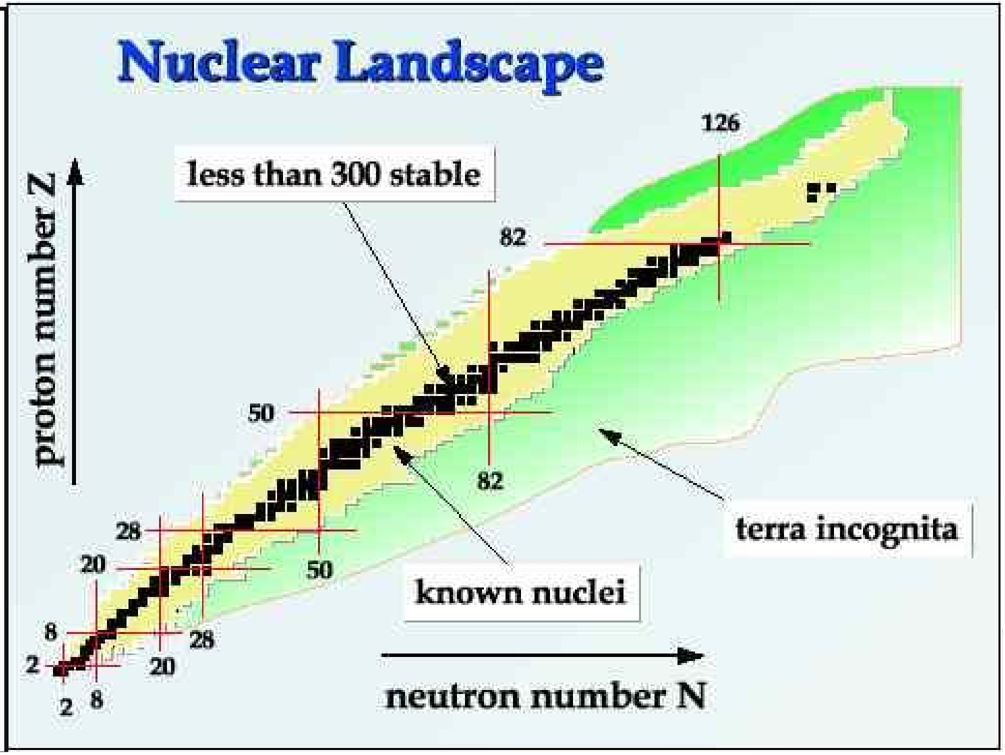
- ATLAS facility at ANL
- CARIBU upgrade
- Infrastructure for decay studies at CARIBU
- Current status and outlook

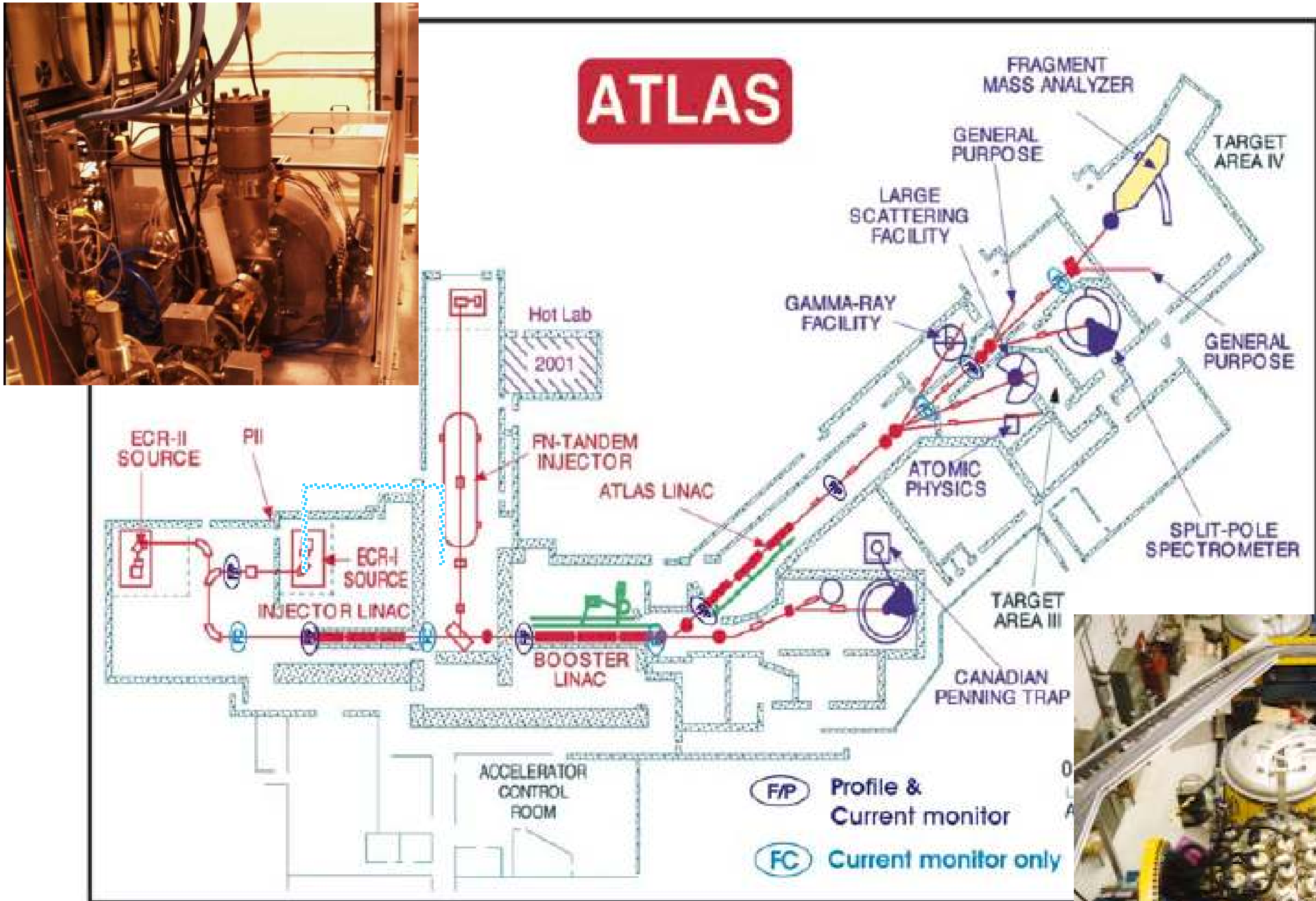
Consultants' Meeting on TAGS, IAEA, January 27-28, 2009

Argonne **T**andem **L**inac **A**ccelerator **S**ystem

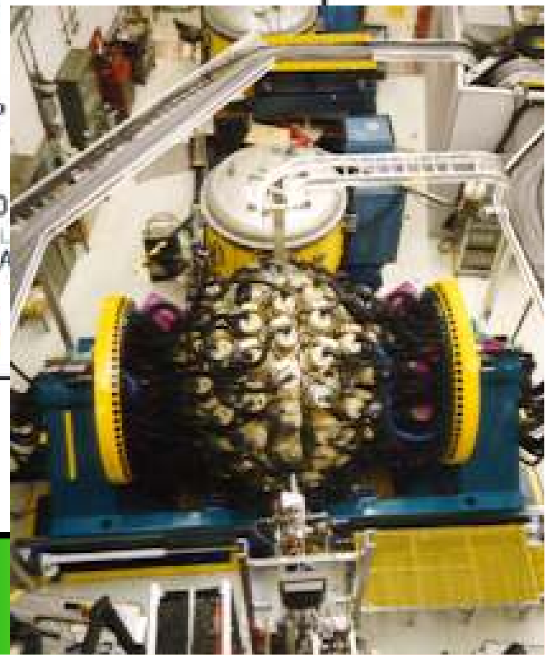
- Office of Science, US DOE (Office of Nuclear Physics) **user** facility
  - ✓ proposals submitted to Program Advisory Committee (PAC)
  - ✓ no cost to researchers for approved proposals
- Stable beam facility (the only stable beam user facility in US!)
  - ✓ accelerate all stable nuclei – from p to ^{238}U (and some rare beams)
  - ✓ energy region – near and above the Coulomb barrier – 6-8 MeV/u
  - ✓ exceptional beam quality: spot size, time & energy resolutions, flexibility





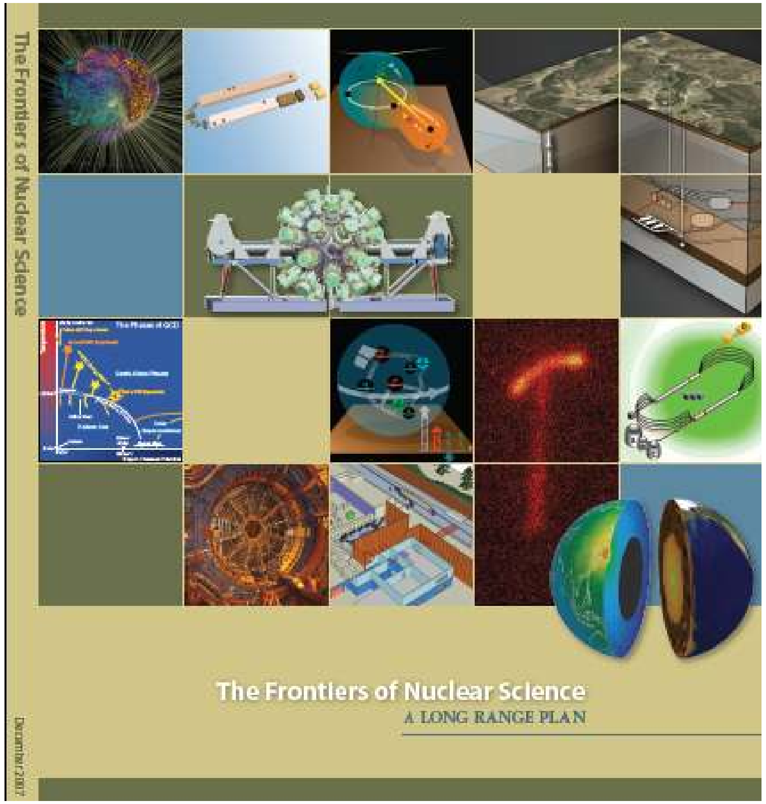


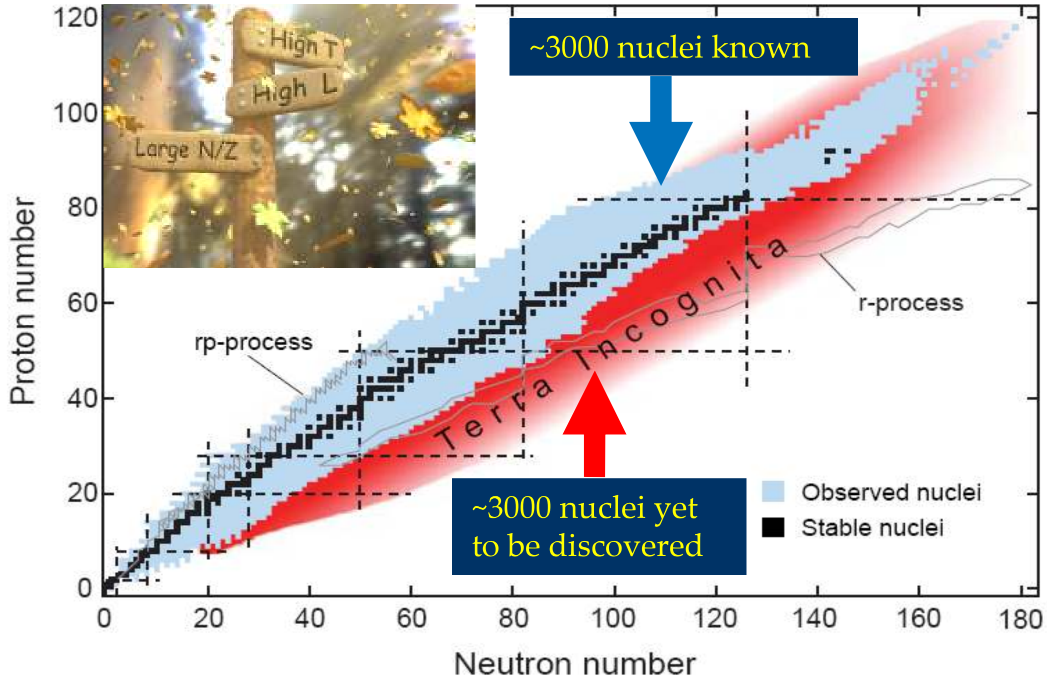
ATLAS
FRAGMENT MASS ANALYZER
TARGET AREA IV
GENERAL PURPOSE
LARGE SCATTERING FACILITY
GAMMA-RAY FACILITY
GENERAL PURPOSE
Hot Lab
2001
FN-TANDEM INJECTOR
ATLAS LINAC
ECR-II SOURCE
PII
ECR-I SOURCE
INJECTOR LINAC
BOOSTER LINAC
ATOMIC PHYSICS
SPLIT-POLE SPECTROMETER
TARGET AREA III
CANADIAN PENNING TRAP
ACCELERATOR CONTROL ROOM
F/P Profile & Current monitor
FC Current monitor only



Evolution of physics program at ATLAS

- Region of neutron-rich nuclei
  - ✓mostly unexplored – much more difficult to access – RB are needed
  - ✓significant changes in nuclear structure are possible and the required probes are not available





Overseas: RIKEN, TRIUMF, GANIL, CERN, GSI (planned)

U.S. (main) facilities: ORNL (ISOL) & MSU (Fragmentation)

FRIB – to be build at MSU

ANL – has its own project - CARIBU

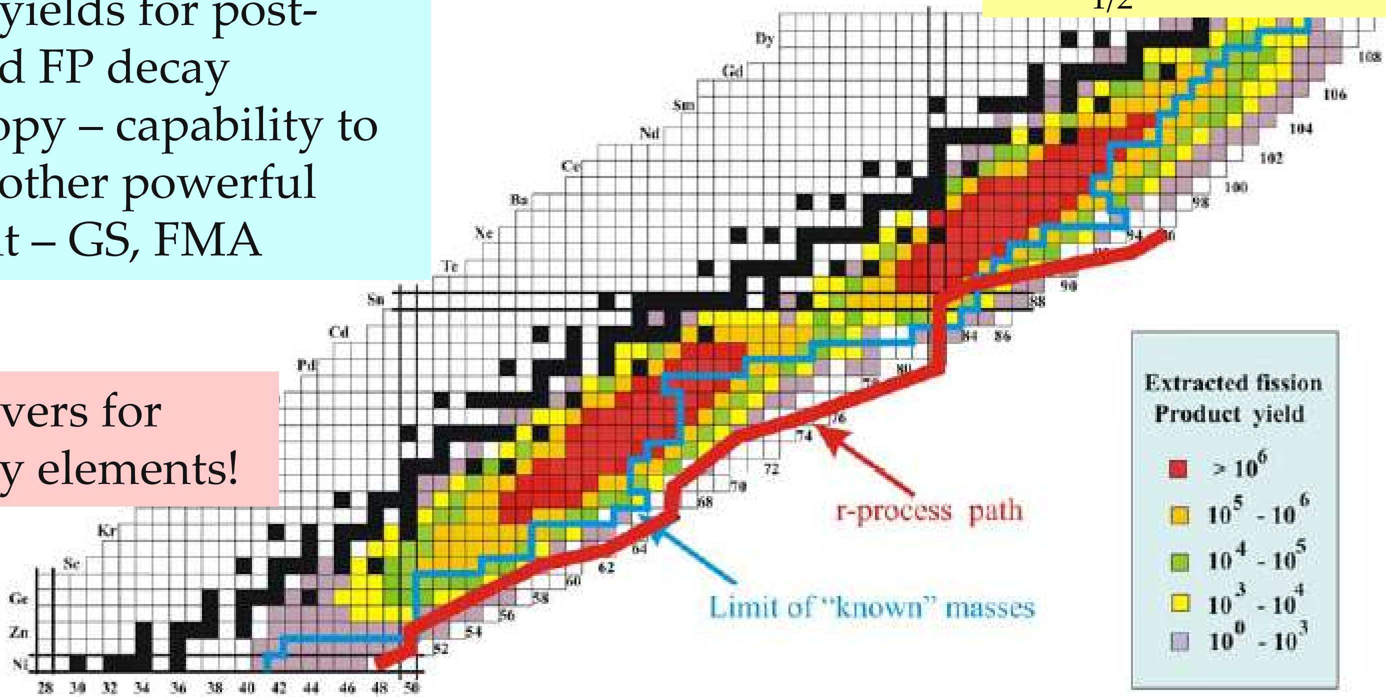
Opportunities at ANL

- **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) – large improvement over existing ISOL-based facilities

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

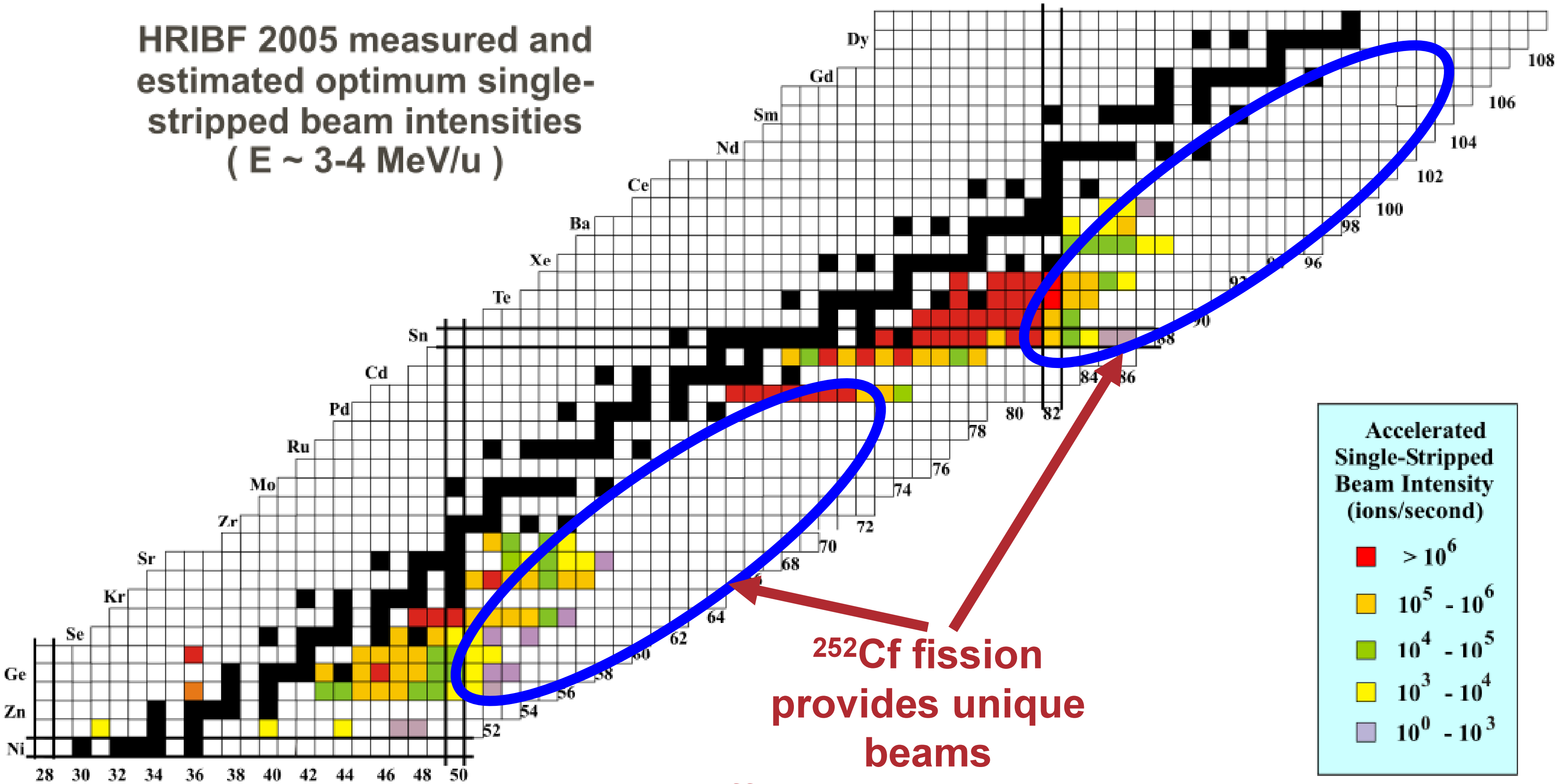
✓ sufficient yields for post-accelerated FP decay spectroscopy – capability to use some other powerful equipment – GS, FMA

✓ no stopovers for refractory elements!



Comparison to ORNL (ISOL) facility

HRIBF 2005 measured and estimated optimum single-stripped beam intensities
(E ~ 3-4 MeV/u)



^{252}Cf fission provides unique beams

Effort complementary to HRIBF and other U fission based facilities

Physics questions to be addressed

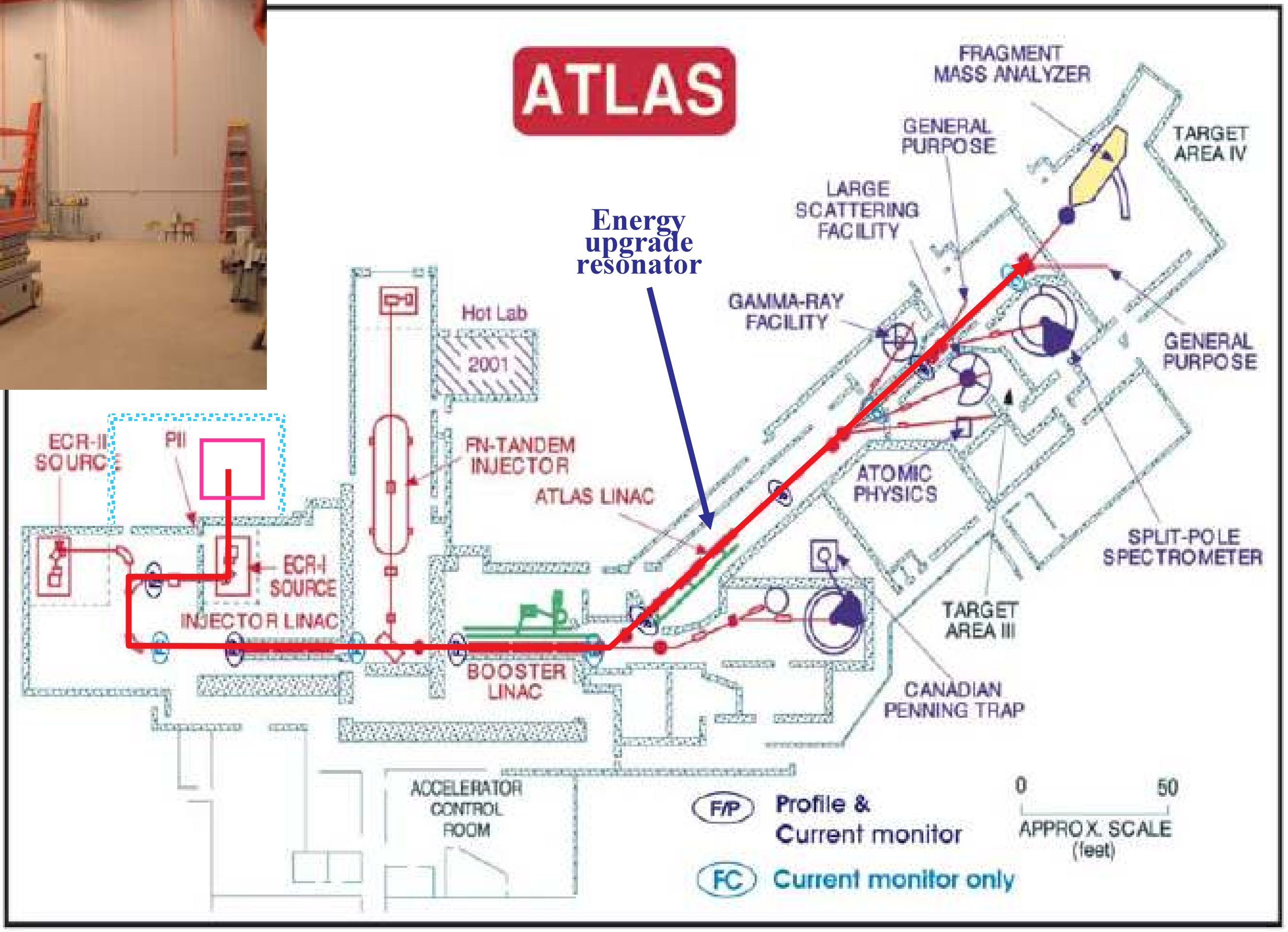
- modification of nuclear structure in neutron-rich systems
  - ✓shell-structure quenching
  - ✓single particle structure near neutron-rich magic nuclei
  - ✓pairing interaction in weakly-bound systems
- collective behavior in neutron-rich systems
- r-process path (astrophysics)
  - ✓ground-state information
    - *mass*
    - *lifetime*
    - *beta-delayed neutron branching ratio*
  - ✓neutron capture rate
  - ✓fissionability of very heavy neutron-rich isotopes

What does CARIBU offers?

- New target/source approaches
  - ✓ gas catcher, isobar separator & ECR technology ←

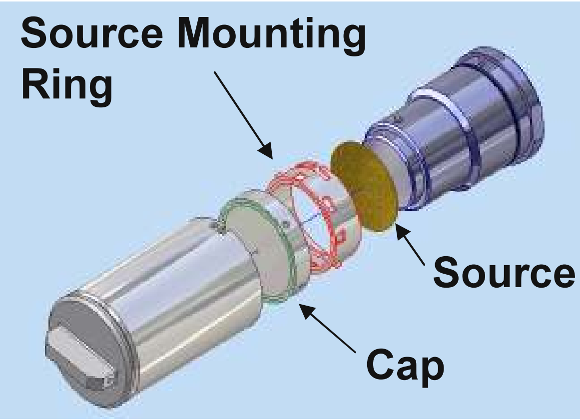
    can be used to efficiently to turn a non-conventional source of n-rich isotopes, such as a spontaneous fission source, into a low-energy beam
- Very high acceleration efficiency
  - ✓ post-accelerator based on ATLAS ←
- Existing experimental equipment and infrastructure for radioactive beam physics
  - ✓ CPT, Gammasphere, HELIOS, FMA

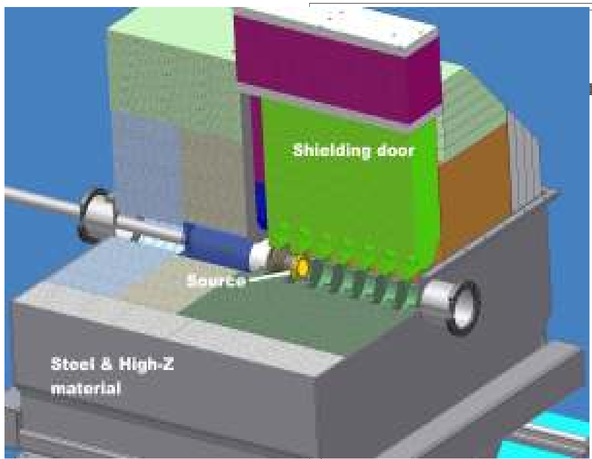
Modifications to ATLAS

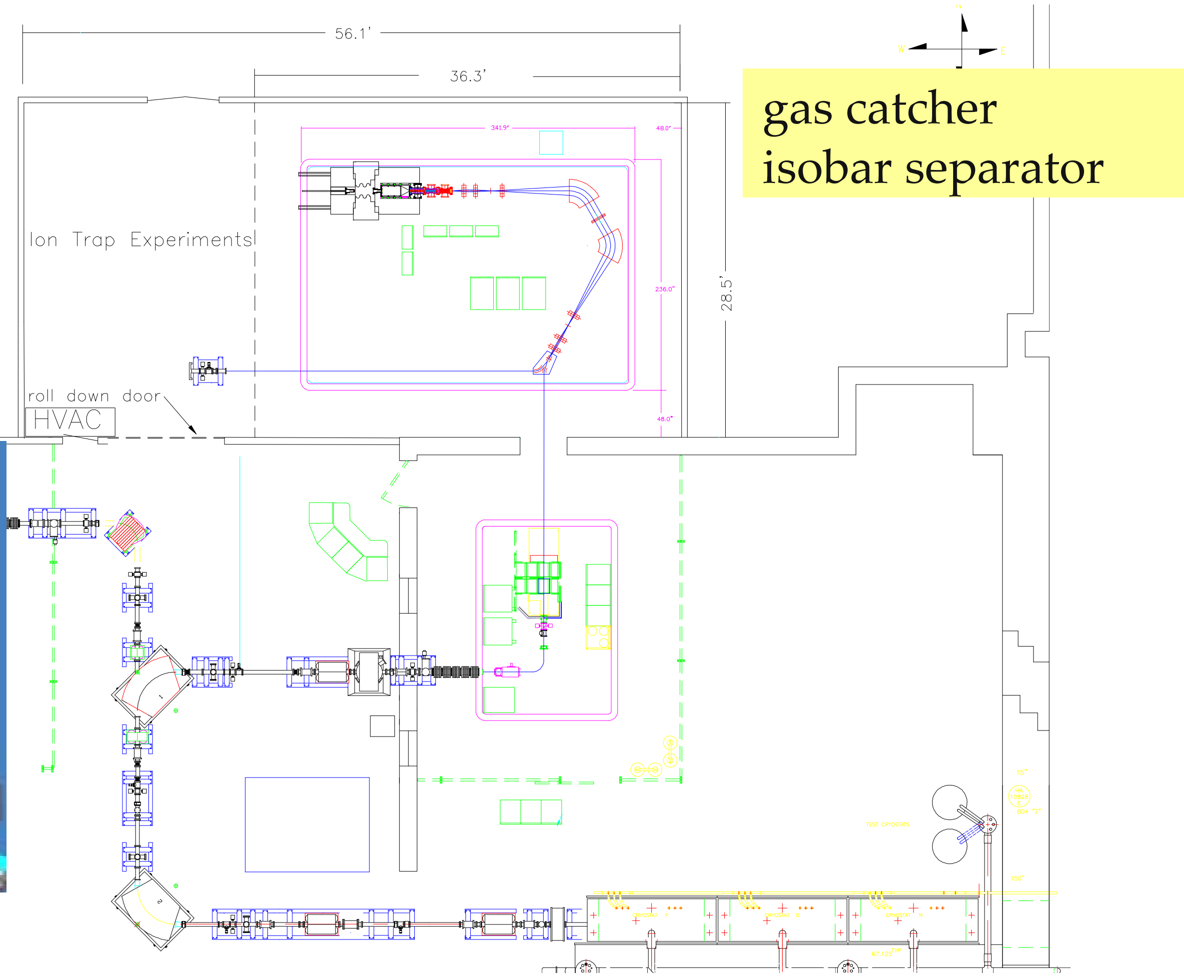


ATLAS floor plan showing planned low-intensity profile monitors and beam current monitors. Beam delivery to four stations is assumed.

New building addition for CARIBU project



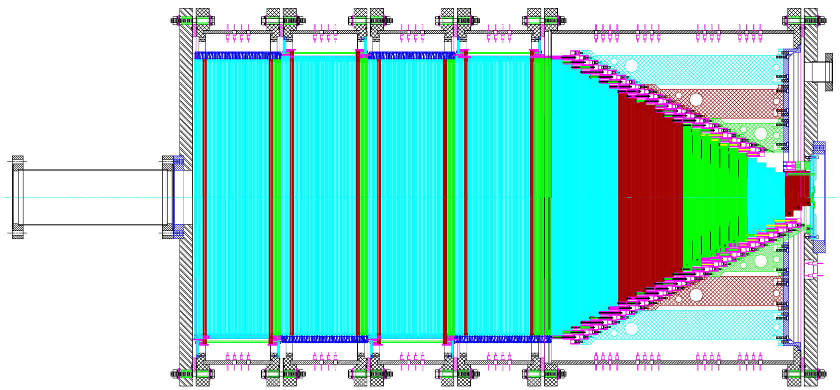


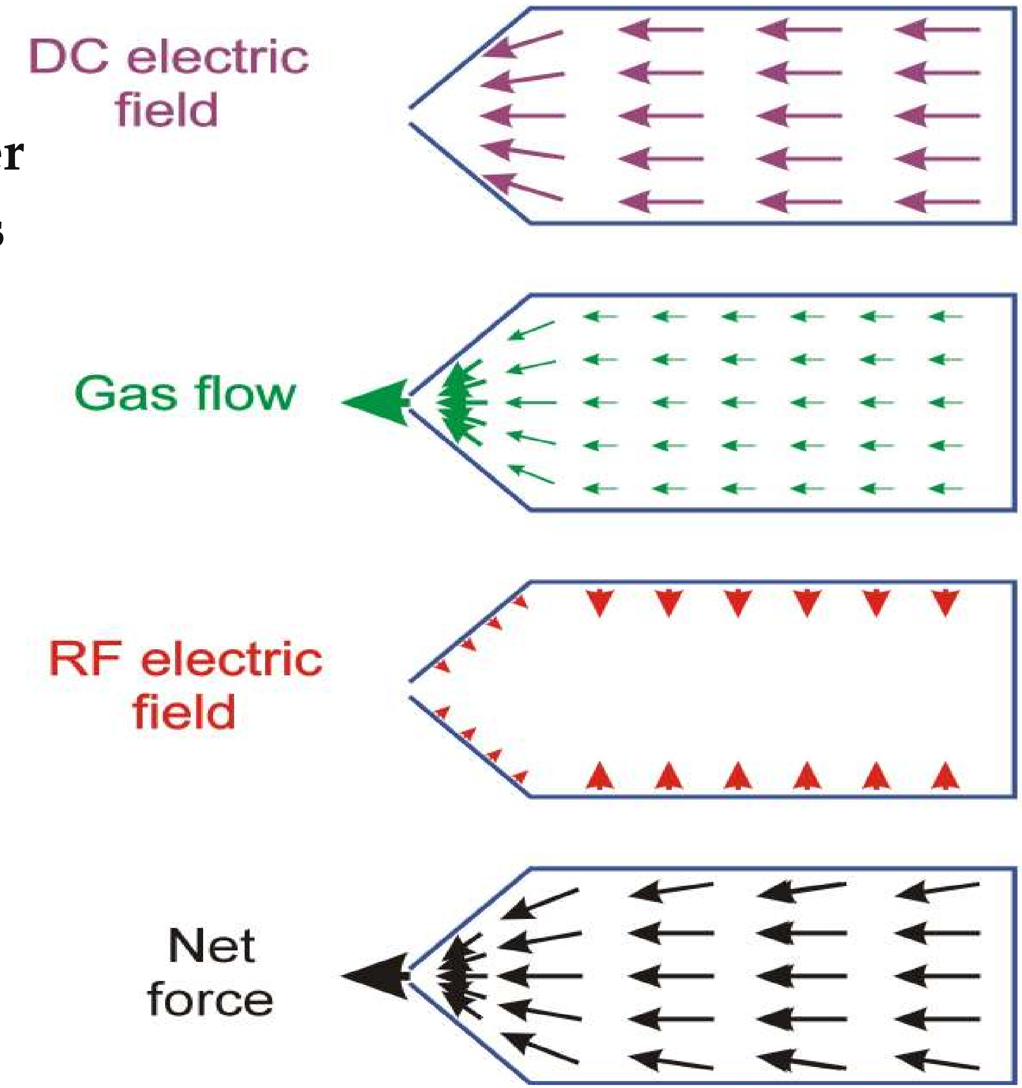


1Ci of ^{252}Cf is 1.9 mg; over an 3x6 cm ellipse area this yield a density of ~150 μg/cm2

CARIBU gas catcher design

- ❑ Device similar to FRIB gas catcher
  - ✓ Stop Fission Fragments in gas
  - ✓ Using (RF +DC + gas flow) to extract Fission Fragments as ions

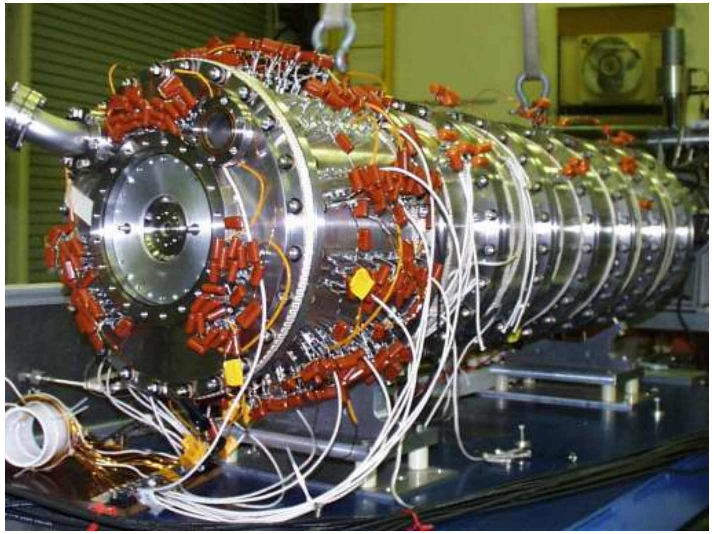




CARIBU gas catcher design - cont

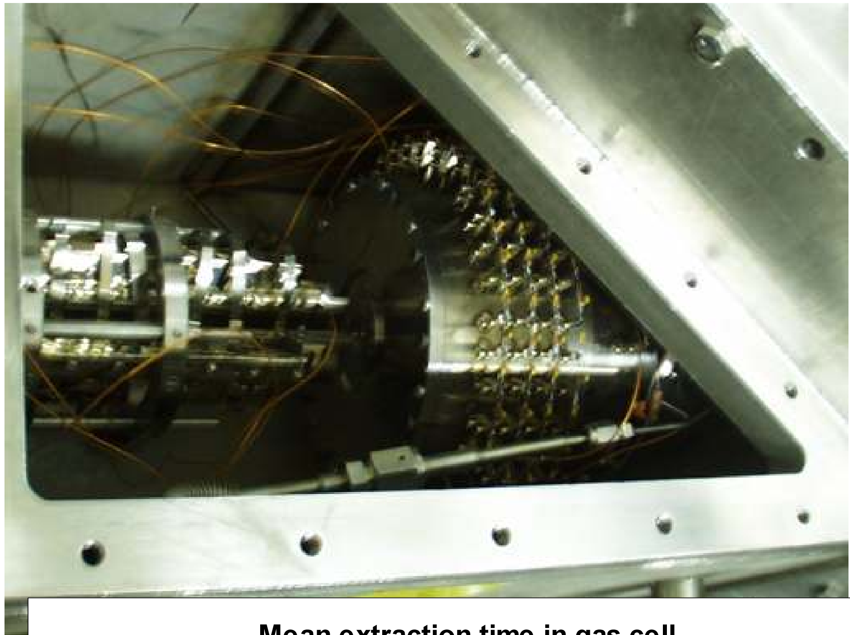
- Shortened version of FRIB gas catcher can efficiently stop fission products from a fission source
- About 45% of those can be extracted as charged ions
- Very efficient and fast source, provides cooled bunched beams for post-acceleration
- Production peaks in new regions and extraction is element independent … new isotopes available
- Gas catcher operation at the required ionization densities has been already demonstrated at ANL

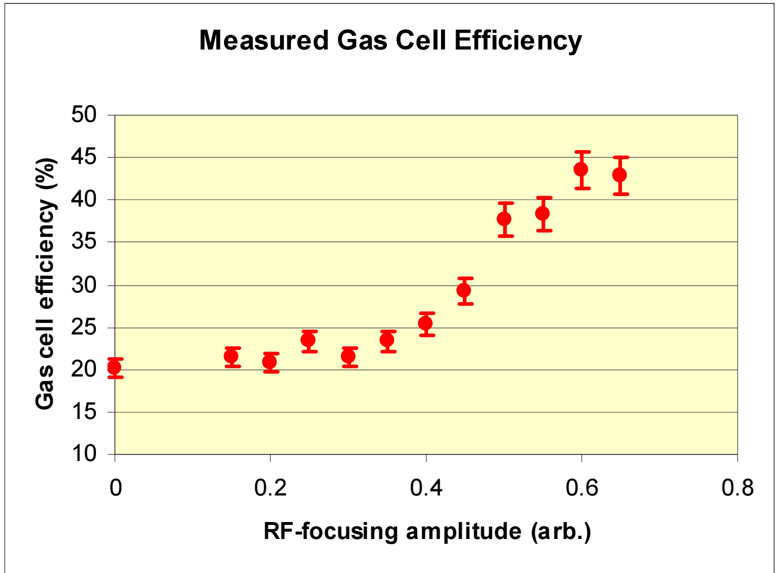
Gas catcher technology developed, tested and now routinely used at ATLAS for CPT and RIA programs

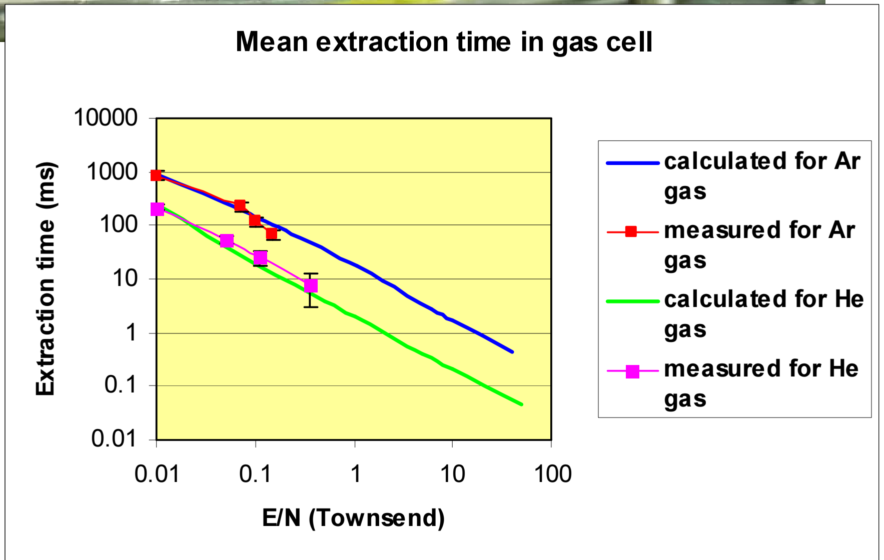


Gas catcher at Canadian Penning Trap (CPT)

- 20 cm long gas cell
- ε ~ 45%
- mean delay time below 10 ms
- tested off-line with fission products and on-line with fusion–evaporation reactions



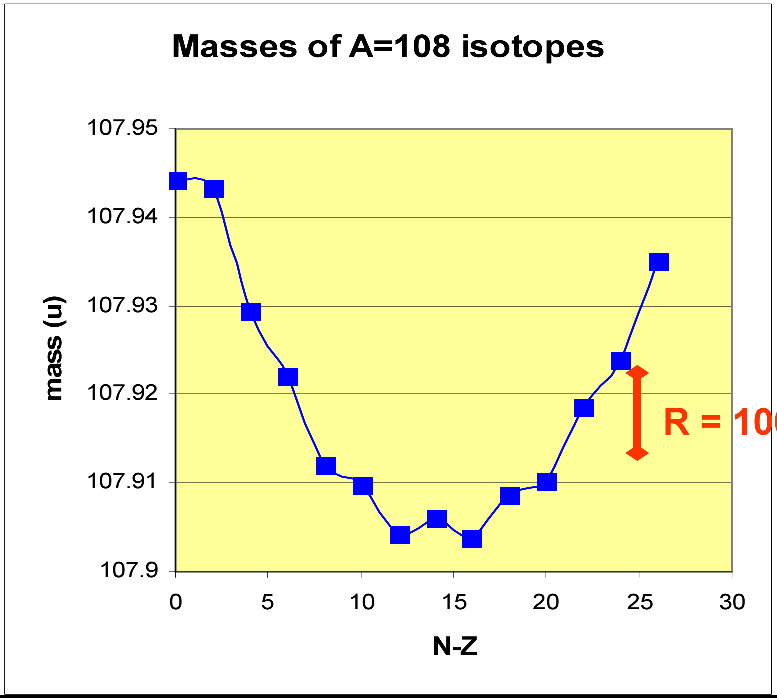


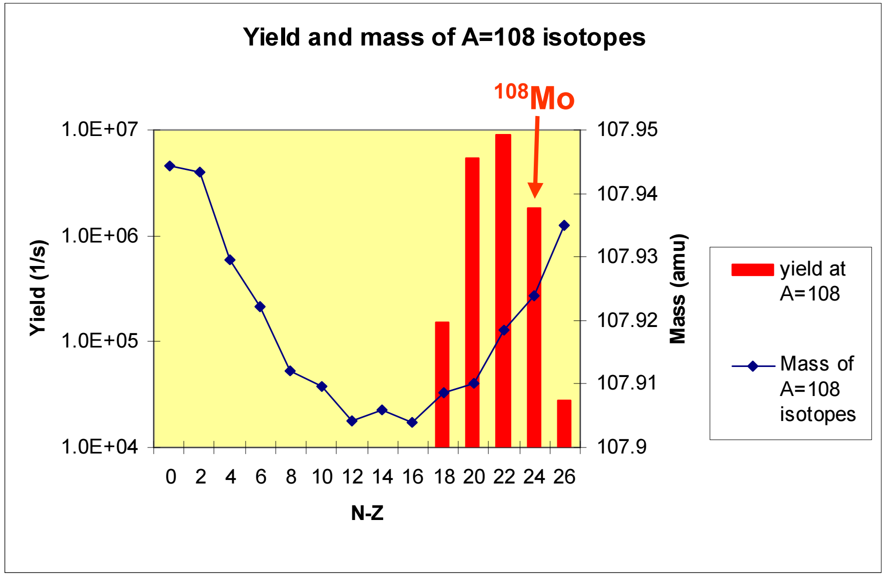


Purification of radioactive ion beam

Contaminant of neighboring masses are handled easily by most experiments. Same mass contaminants are more difficult. The resolution (R=M/ΔM) required to remove contamination is:

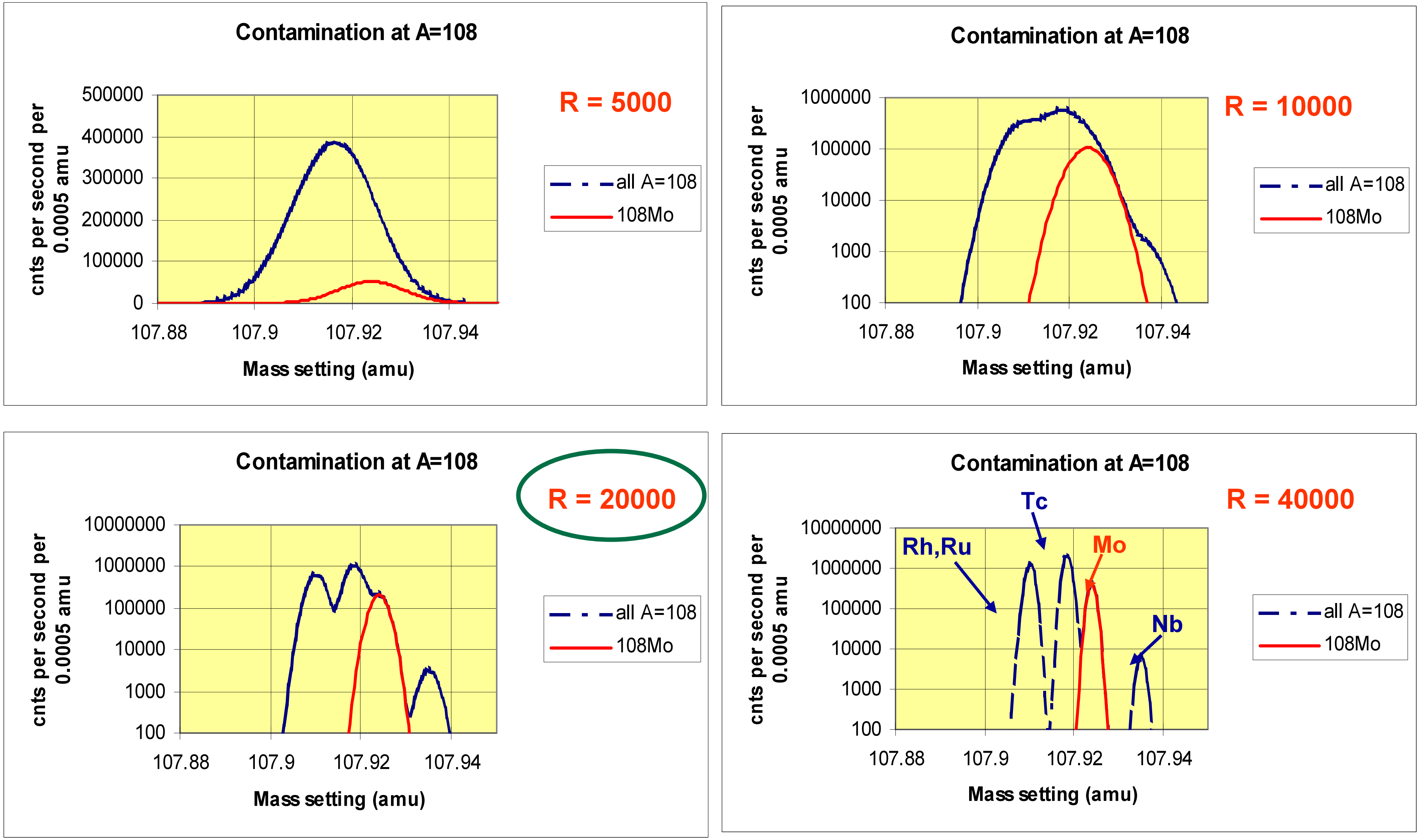
- neighboring masses — R = 250
- molecular ions — R = 500 - 1000
- isobars — R = 5000 – 50000 (far/close to stability)
- isomers — R = 10^5 - 10^6





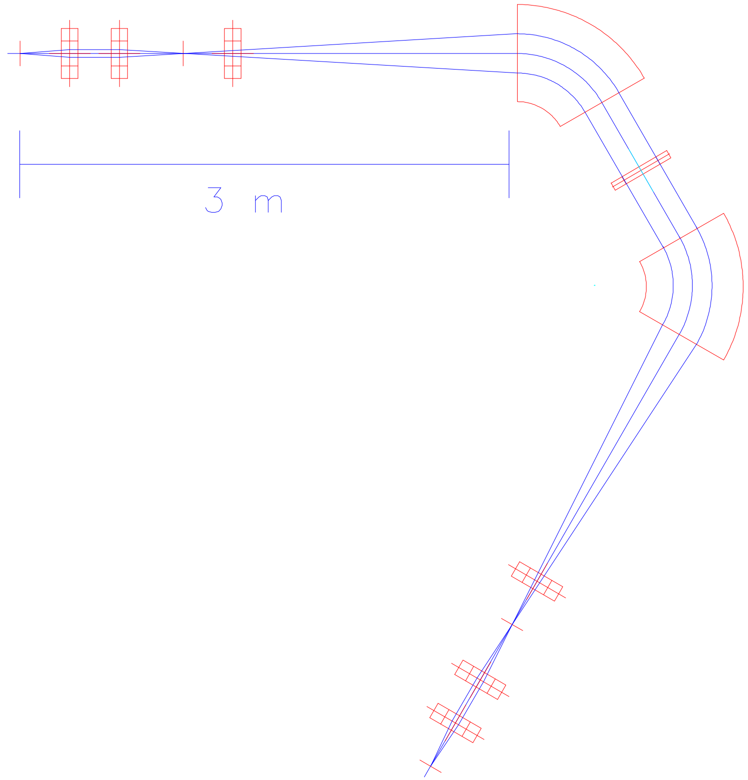
Relative yield and lifetime are also important

Contamination at A=108



Compact isobar mass separator

- modified scaled down version of FRIB mass separator … **taking advantage of low emittance and energy spread of extracted beams**
- matching sections at entrance and exit
- 120 degrees total bend
- high transmission (> 95 %)
- M/ΔM >20,000
- small enough footprint to fit on HV platform



C.N. Davids & D. Peterson, NIM B266 (2008) 4449

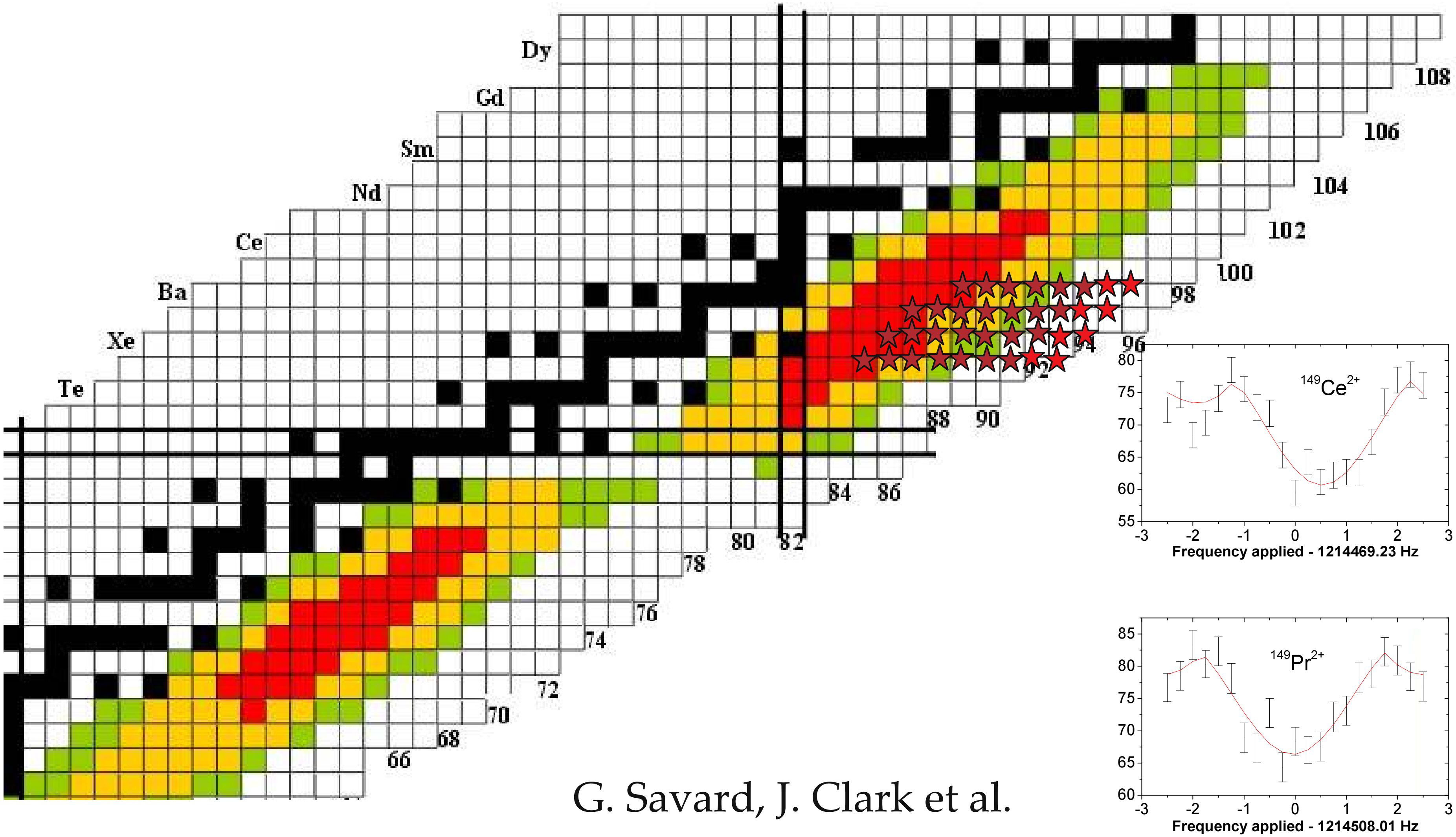
Expected Yields for some nuclei of interest

- **N**on **A**ccelerated beams (~10^5-10^6 ions/sec)
- **AC**cellerated beams (10^4-10^5 ions/sec)

Nuclide	P	$Q_{\beta-}$, keV	Half-life	NA, ions/sec	AC, ions/sec
35-Br-86	1	7626 (11)	55.1 s	5.70E+04	2.10E+03
35-Br-87	1	6852 (18)	55.65 s	3.00E+05	1.10E+04
35-Br-88	1	8960 (40)	16.36 s	4.60E+05	1.70E+04
36-Kr-89	1	4990 (50)	3.15 min	4.70E+05	3.40E+04
36-Kr-90	1	4392 (17)	32.32 s	9.00E+05	6.60E+04
37-Rb-90m	2	6690 (15)	258 s	2.00E+05	7.40E+03
37-Rb-92	?	8096 (6)	4.49 s	9.30E+05	3.40E+05
38-Sr-97	2	7470 (16)	0.429 s	1.60E+06	5.40E+04
39-Y-96	?	7096 (23)	5.34 s	1.50E+05	5.40E+03
40-Zr-99	3	4558 (15)	2.1 s	3.30E+06	1.20E+05
40-Zr-100	2	3335 (25)	7.1 s	5.50E+06	2.00E+05
41-Nb-99	1	3639 (13)	15.0 s	2.50E+04	9.20E+02
41-Nb-100	1	6245 (25)	1.5 s	7.60E+05	2.80E+04
41-Nb-101	1	4569 (18)	7.1 s	3.50E+06	1.30E+05
41-Nb-102	2	7210 (40)	1.3 s	5.40E+06	2.00E+05
42-Mo-103	1	3750 (60)	67.5 s	4.00E+06	1.50E+05
42-Mo-105	1	4950 (50)	35.6 s	8.20E+06	3.00E+05

Nuclide	P	$Q_{\beta-}$, keV	Half-life	NA, ions/sec	AC, ions/sec
43-Tc-103	1	2662 (10)	54.2s	1.50E+05	5.60E+03
43-Tc-104	?	5600 (50)	18.3 min	1.20E+06	4.30E+04
43-Tc-105	?	3640 (60)	7.6 min	5.70E+06	2.10E+05
43-Tc-106	1	6547 (11)	35.6 s	5.90E+06	2.20E+05
43-Tc-107	2	4820 (90)	21.2 s	9.80E+06	3.60E+05
51-Sb-132	1	5509 (14)	2.79 min	1.90E+06	7.00E+04
52-Te-135	?	5960 (90)	19.0 s	4.80E+06	1.80E+05
53-I-136	1	6930 (50)	83.4 s	3.70E+06	1.30E+05
53-I-136m	1	7580 (120)	46.9 s	2.50E+06	9.20E+04
53-1-137	1	5877 (27)	24.13 s	4.20E+06	1.60E+05
54-Xe-137	1	4166 (7)	3.82 min	7.00E+06	5.10E+05
54-Xe-139	1	5057 (21)	39.68 s	9.40E+06	6.90E+05
54-Xe-140	1	4060 (60)	13.6 s	6.90E+06	5.00E+05
55-Cs-142	?	7308 (11)	1.69 s	6.80E+06	2.50E+05
56-Ba-145	2	5570 (110)	4.31 s	5.50E+06	2.00E+05
57-La-143	2	3425 (15)	14.2 min	2.80E+06	1.00E+05
57-La-145	2	4110 (80)	24.8 s	6.80E+06	2.50E+05

High-precision mass measurements at CPT

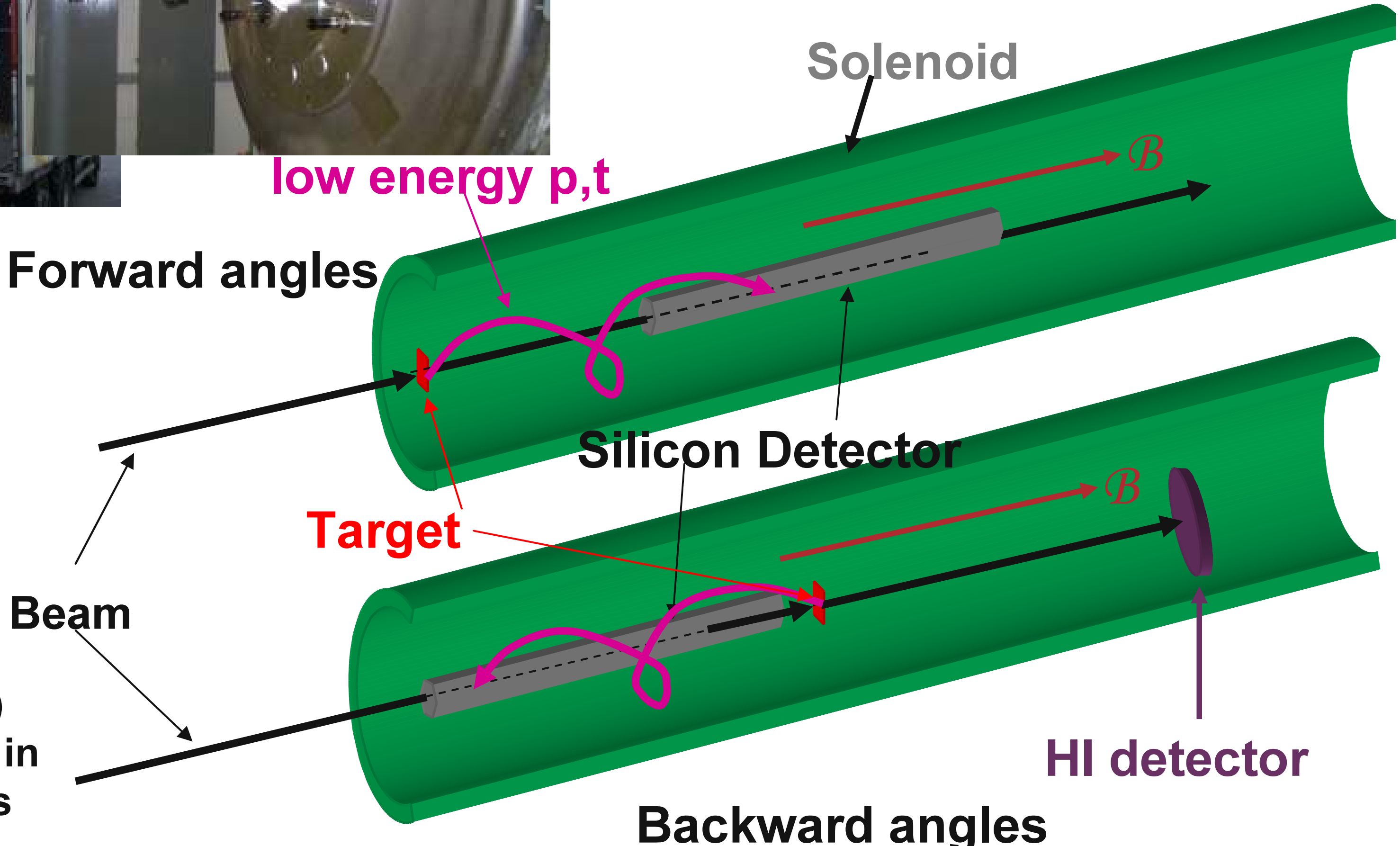


G. Savard, J. Clark et al.

HELIOS - Transfer Reactions Studies

A. Wuosmaa et al., NIM A580 (2007) 1290

B. Back, K.E. Rehm, J.P. Schiffer et al.



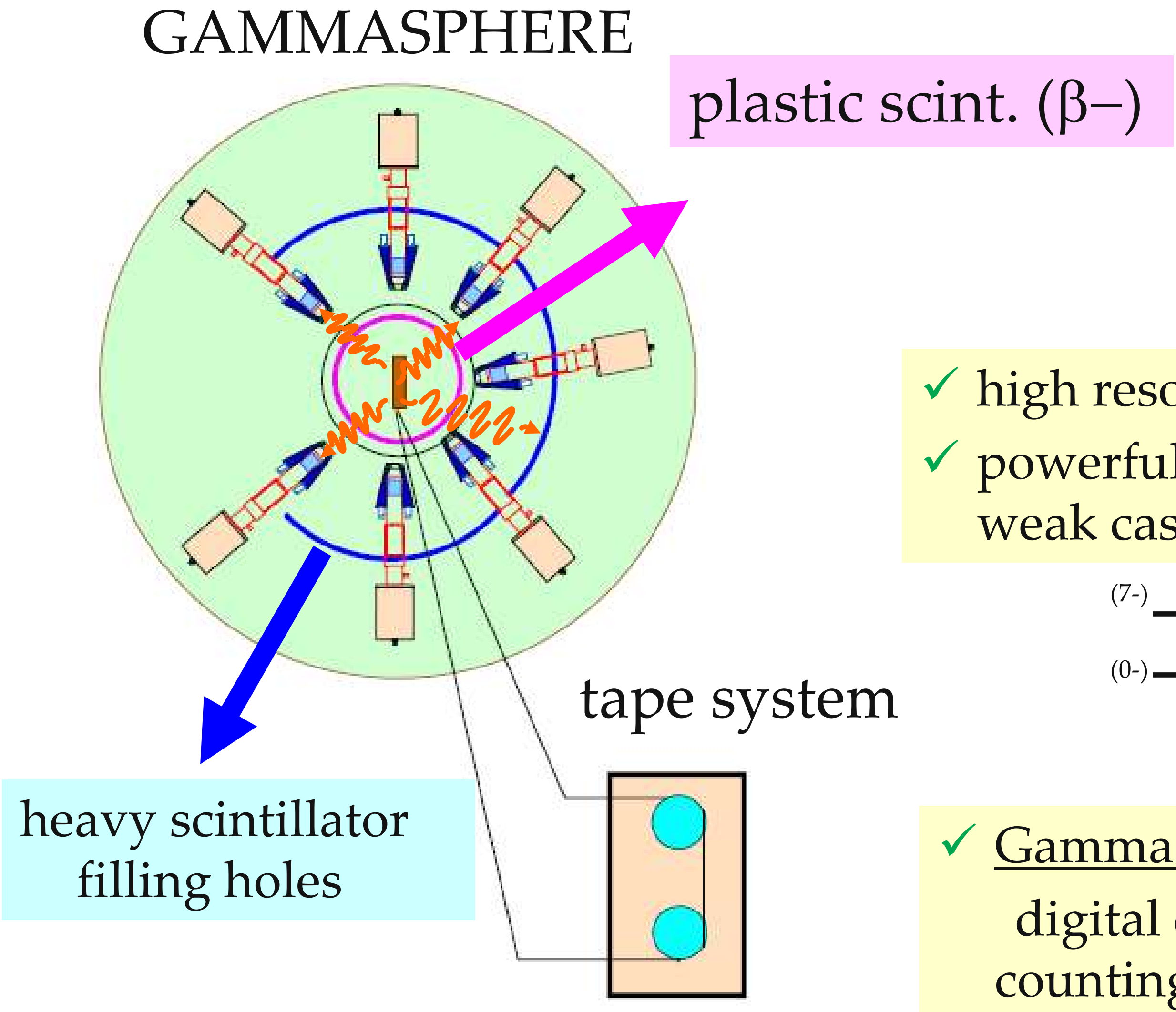
- (d,p), (^{3}He, α), (α,t) transfer reactions in inverse kinematics

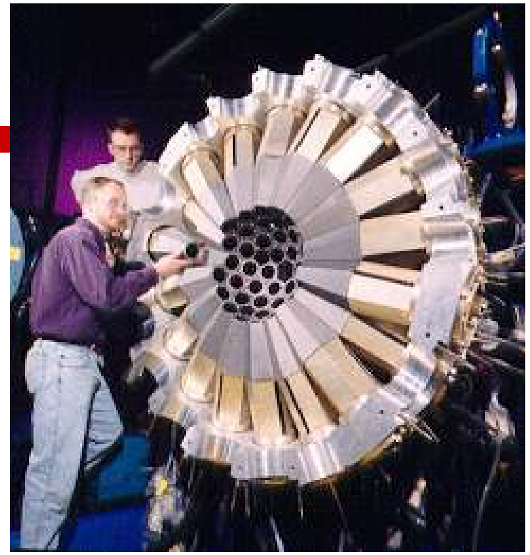
Gamma-ray Spectroscopy Studies

- Coulomb excitation of FF beams - yield precision BE(2)'s and other information via multiple Coulomb excitation – using GS and associated instruments
- Fission products γ–ray spectroscopy:
- (prompt) have been studied with fission sources working off-line inside GS
  - ✓ gamma ray energies and intensities measured
  - ✓ low-energy levels determined
  - ✓ little additional information except for most intense fragments
- (delayed) decay studies – combination of both high-resolution γ–ray spectroscopy & TAGS

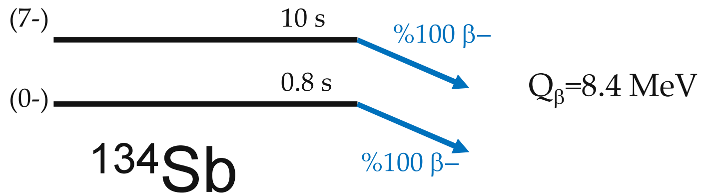
R.V.F. Janssens, M. Carpenter, F.G. Kondev, T. Lauritsen, K. Lister, D. Seweryniak et al.

β– counting station with GS





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



- ✓ <u>Gammasphere improvements:</u>
  digital electronics – faster
  counting & singles – triggerless

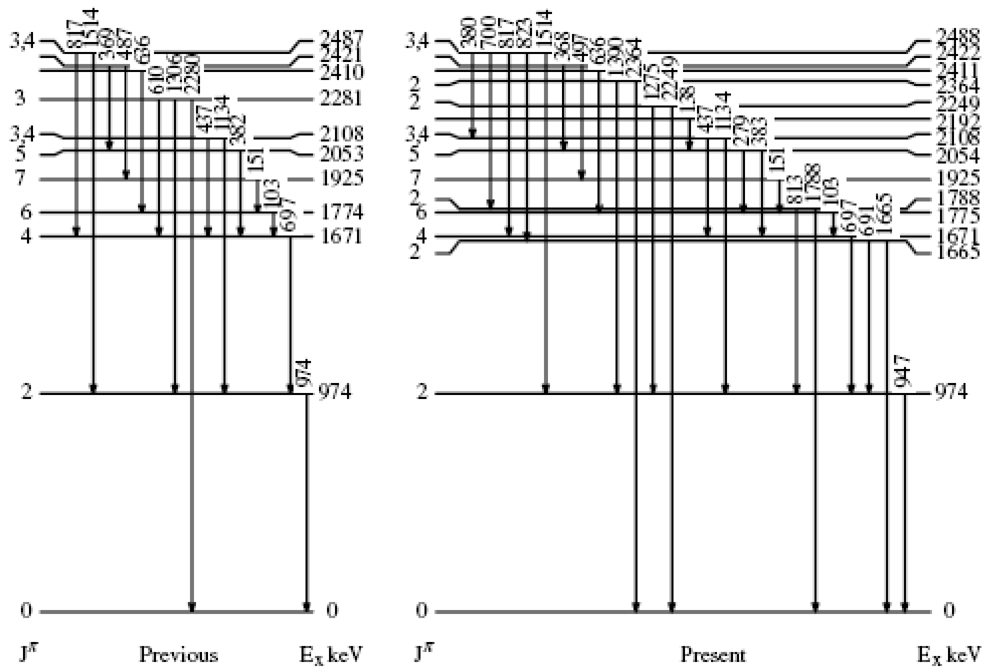
The power of larger γ–ray arrays

PHYSICAL REVIEW C **71**, 044311 (2005)

γ-ray spectroscopy of ^{132}Te through β decay of a ^{132}Sb radioactive beam

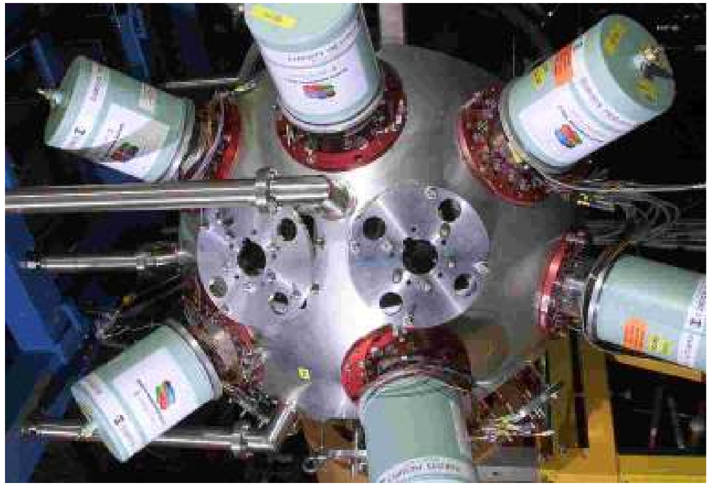
R. O. Hughes,[1,2] N. V. Zamfir,[1,3,4] D. C. Radford,[5] C. J. Gross,[5] C. J. Barton,[6] C. Baktash,[5] M. A. Caprio,[1,7] R. F. Casten,[1]
A. Galindo-Uribarri,[5] P. A. Hausladen,[5] E. A. McCutchan,[1] J. J. Ressler,[1] D. Shapira,[5] D. W. Stracener,[5] and C.-H. Yu[5]

- ✓ using ^{132}Sb beam (10^7 pps) at 396 MeV produced from proton-induced fission

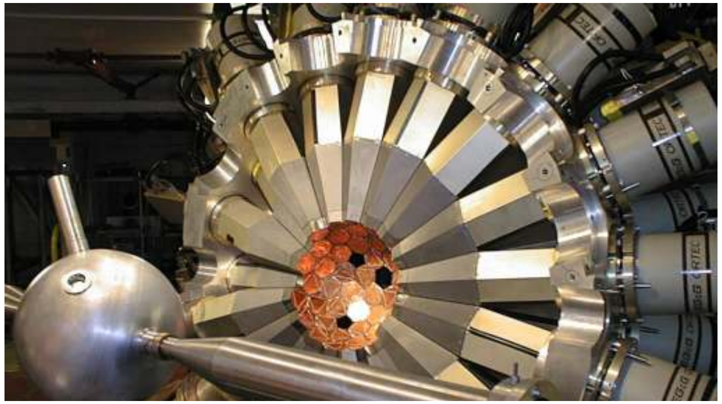


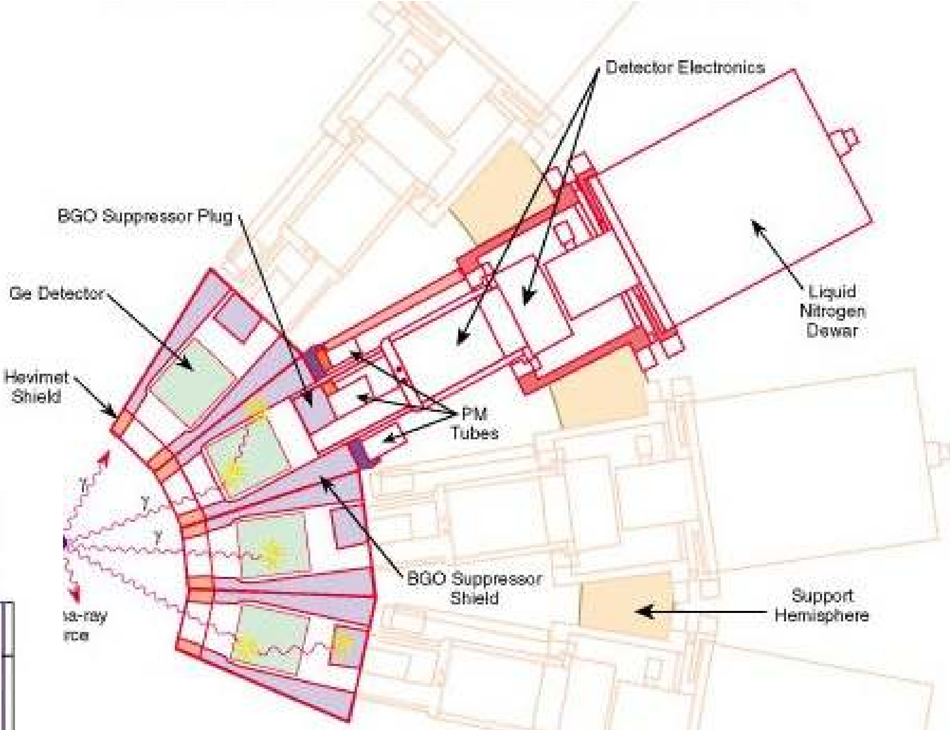
- ✓ Significantly revised level scheme
- ✓ More than 195 new transitions added

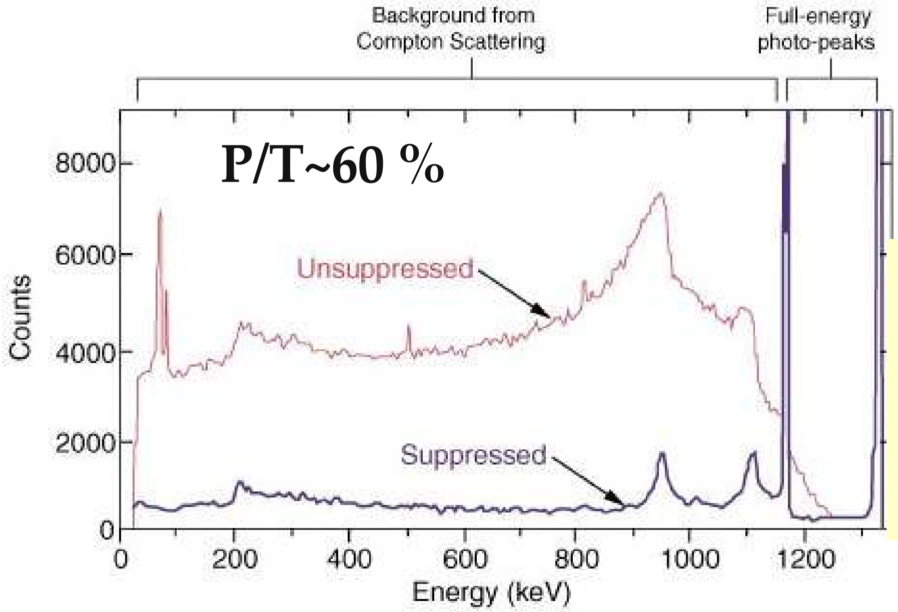
CLARION – 11 Clovers, ORNL



Compton Suppression – improving P/T







GS as a calorimeter

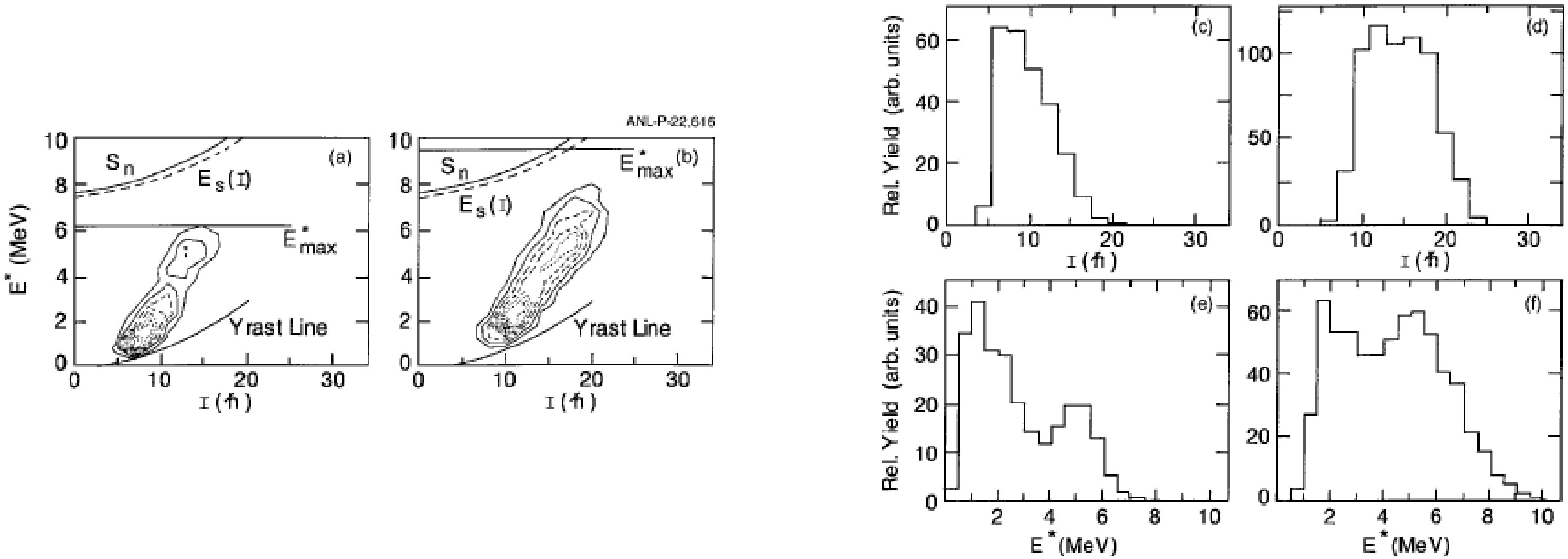
- ✓ P. Reiter et al. Phys. Rev. Lett. 84, 3542 (2000)
- ✓ with a modest upgrade – suitable for β– decay studies – HRγS & TAGS

Gammasphere as a calorimeter

VOLUME 84, NUMBER 16 PHYSICAL REVIEW LETTERS 17 APRIL 2000

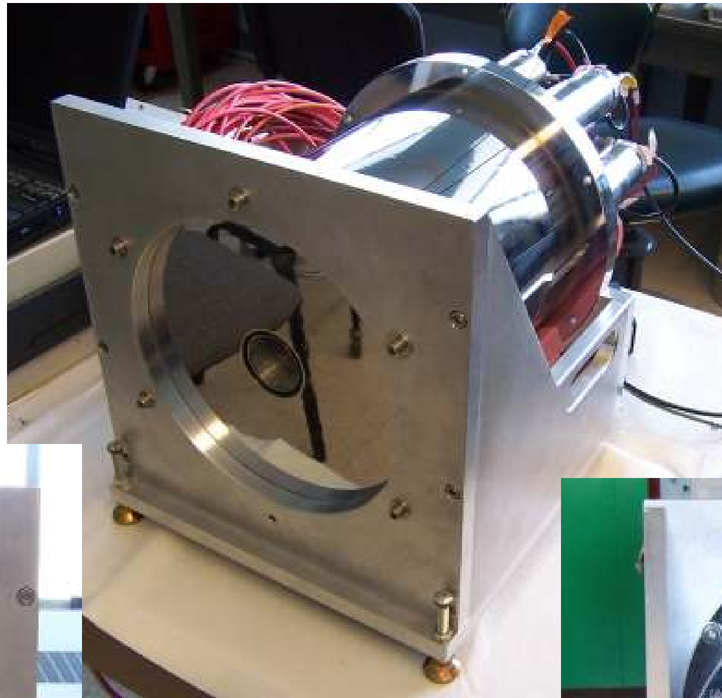
Entry Distribution, Fission Barrier, and Formation Mechanism of $^{254}_{102}$No

P. Reiter,[1,2] T. L. Khoo,[1] T. Lauritsen,[1] C. J. Lister,[1] D. Seweryniak,[1] A. A. Sonzogni,[1] I. Ahmad,[1] N. Amzal,[3] P. Bhattacharyya,[4] P. A. Butler,[3] M. P. Carpenter,[1] A. J. Chewter,[3] J. A. Cizewski,[1,5] C. N. Davids,[1] K. Y. Ding,[5] N. Fotiades,[5] J. P. Greene,[1] P. T. Greenlees,[3] A. Heinz,[1] W. F. Henning,[1] R.-D. Herzberg,[3] R. V. F. Janssens,[1] G. D. Jones,[3] H. Kankaanpää,[7] F. G. Kondev,[1] W. Korten,[6] M. Leino,[7] S. Siem,[1,8] J. Uusitalo,[1] K. Vetter,[9] and I. Wiedenhöver[1]



TAGS at CARIBU

Greenwood et al. - INL



Na(I) detector

25.4 cm diam.
30.5 cm length

5.1 cm well diam.
20.0 cm well depth

TAGS at CARIBU – cont.

- Current Status (small LDRD funding):
  - ✓ testing/characterizing the detector
  - ✓ signals from 7 PMTs optimized for similar response, summed to single output
  - ✓ study response with single- and few-line γ-ray sources
  - ✓ design of a dedicated tape system
  - ✓ development of a fast spectrum-deconvolution algorithm and a Monte-Carlo procedure to determine uncertainties of the decay-feeding profile

What makes studies at CARIBU unique?

- ❑ **the superiority of CARIBU**
  - ✓ intensity and purity of neutron-rich FP beams
  - ✓ gas-cell technology - no stopovers for refractory elements
  - ✓ FP can be delivered to other key instruments at ANL – CPT and FMA

- ❑ **combination of high-resolution γ–ray spectroscopy & TAGS**
  - ✓ discrete spectroscopy may suffer from "pandemonium", but TAGS cannot do it alone either – having capabilities to do both at a single facility is a "perfect marriage"
  - ✓ development of beta-delayed neutron measurements capabilities – currently under discussion

Some practical remarks …

- ❑ CARIBU/ATLAS is a DOE Office of Science USER facility
  - ✓ expected to be commissioned in the second half of CY2009
  - ✓ would have to go for PAC approval, but no cost to run
- ❑ the driving motivation behind CARIBU is SCIENCE – the main interest is at exotic nuclei that are not necessary of importance to applications - some applications related research would be supported - we expect additional DOE support for work on nuclei that are on the IAEA/NEA list
  - ✓ a formal proposal has been submitted to Office of Nuclear Physics (SC-DOE) two years ago under the "Nuclear Data needs for AFC" initiative, but the funding was postponed – a new call for proposals is expected some time during FY2009 (still uncertain)
- ❑ we are open for collaboration (and would very much welcome such!) with other interested groups from EU and elsewhere – share equipment, expertise & experience - work together at experiments, data analysis & publications
  - ✓what to expect: 2-3 experimental campaigns, up to 2 weeks each – would allow to study many isotopes – the data analysis would be time consuming, but again the data can be distributed within the collaboration