Gas Phase Chemistry at the BGS:

Scientific Opportunities

and

Technical Challenges

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for the LBNL heavy element group

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Acknowledgments

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Stable and reliable beams delivered by the 88" operators and ion-source staff is gratefully acknowledged.

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Outline

Introduction

- Experimental setup at LBNL
- Some recent chemistry results

New scientific opportunities

Isotopes for TAN chemistry @ BGS / TASCA

- Production & delivery to chemistry
- Technical challenges
  - (or: how to build a better RTC)

Summary / Outlook

Present: TAN gas phase chemistry

Elements 104 (Rf) – 108 (Hs):

$SgO_2(OH)_2$ HsO_4 $DbOCl_3$ $RfBr_4$ BhO_3Cl

Simple inorganic molecules:

(Oxy)halides, oxides, hydroxides

Plan & first attempts 112 / 114:

114 112

Elemental state

> **→This is a very limited set of chemical systems compared to lighter elements!**

Main problems:

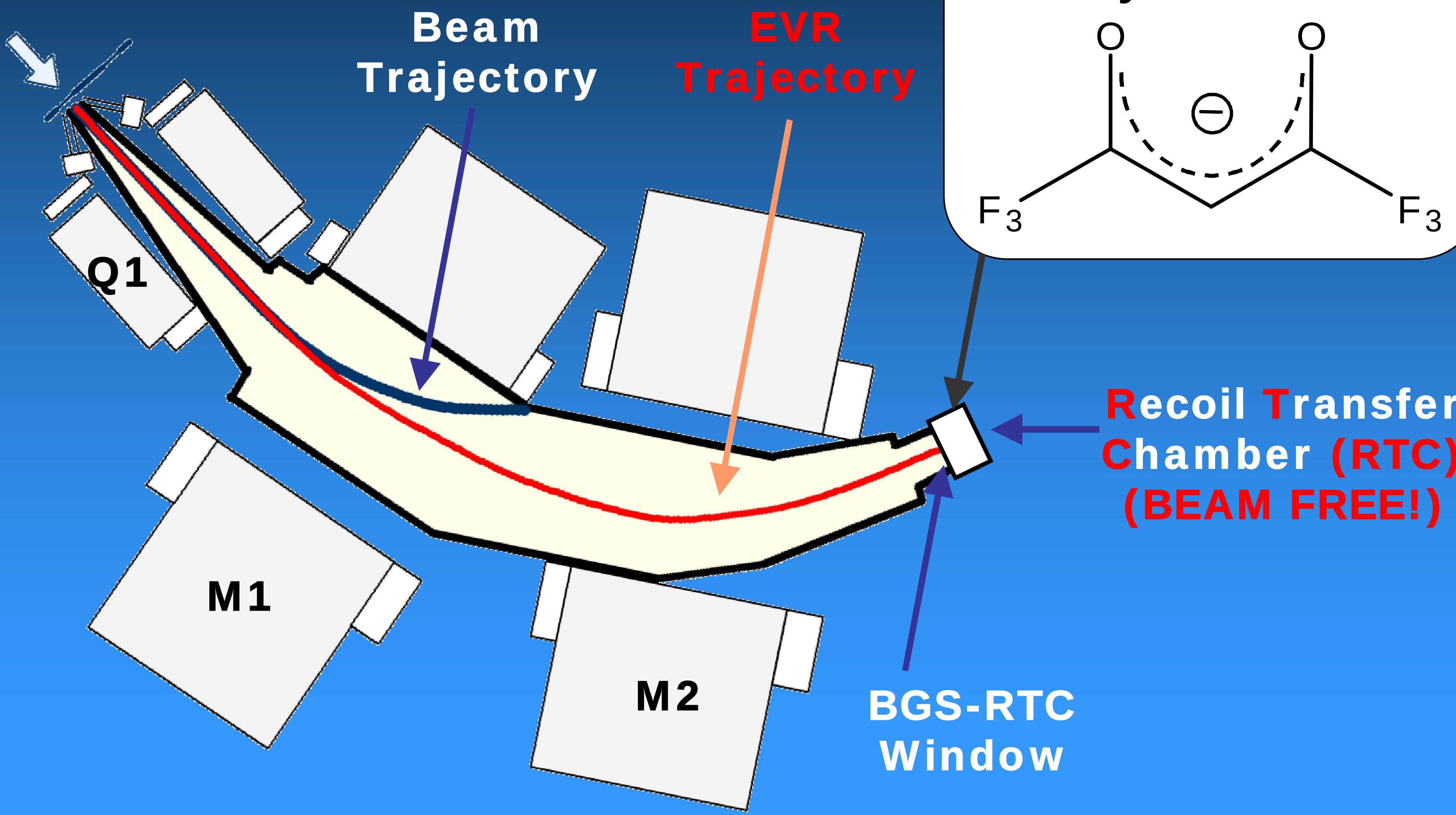
- **-Plasma caused by intense heavy-ion beam;**
- **-high temperatures to release radionuclides from C-aerosol particles used in gas-jet transport**

Pre-separation in BGS: No beam!

$^{116/120/124}Sn(^{50}Ti,xn)^{162/165/169}Hf$

$^{nat}Ge(^{18}O,xn)^{85}Zr$

hfa is introduced directly into the RTC



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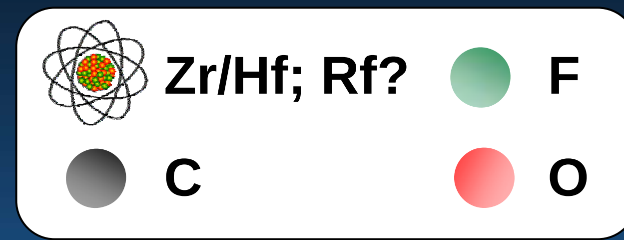
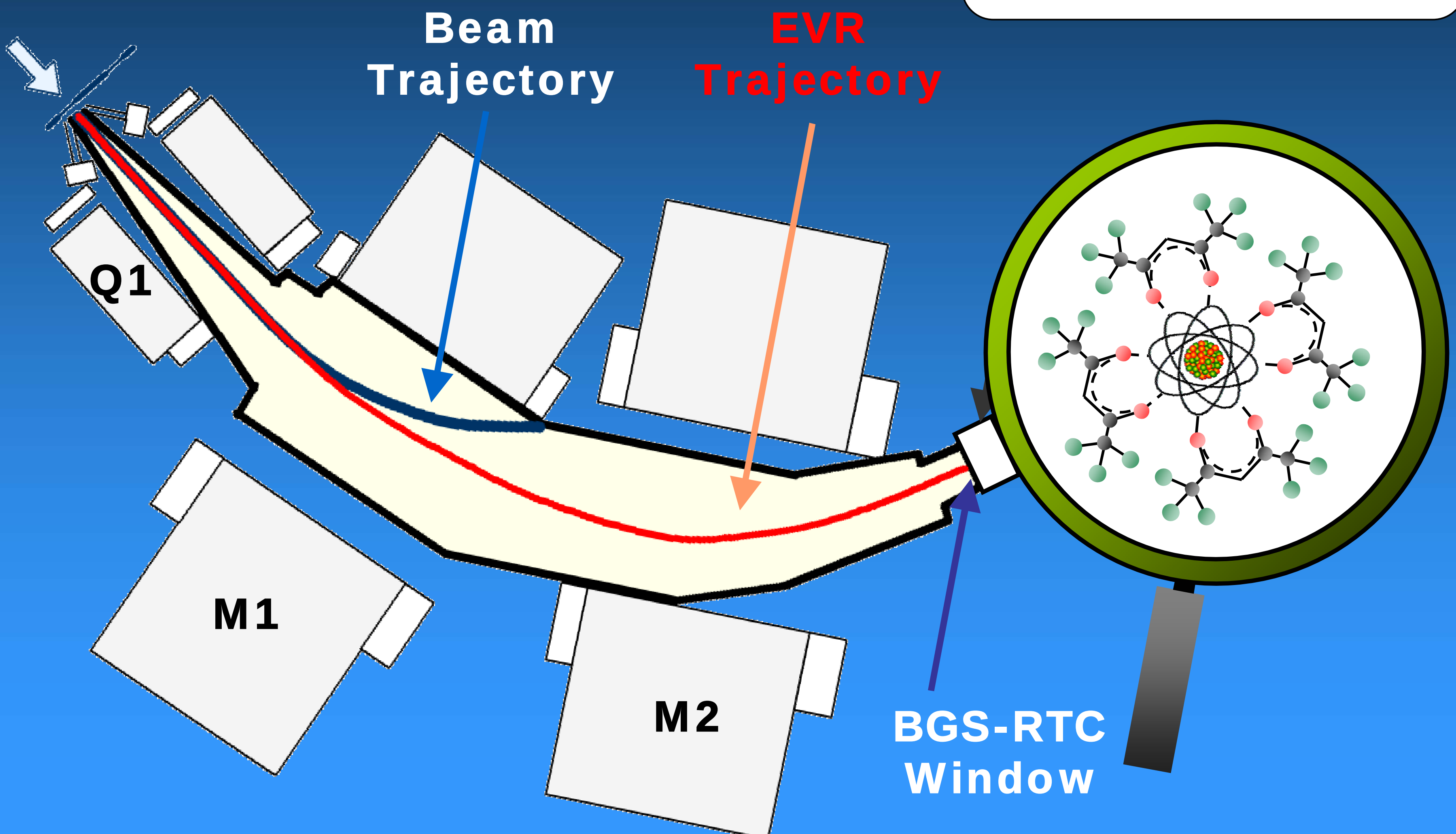
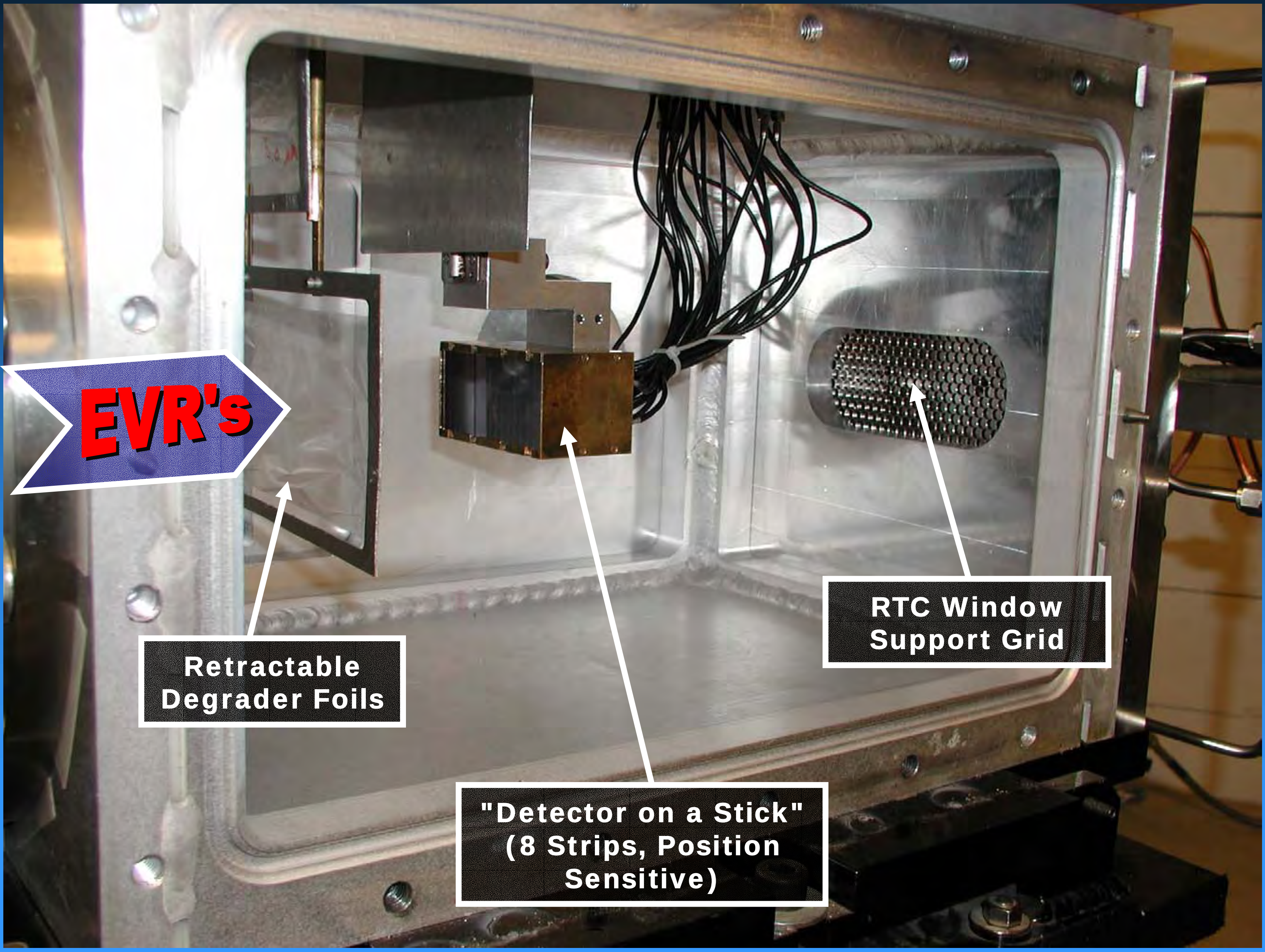
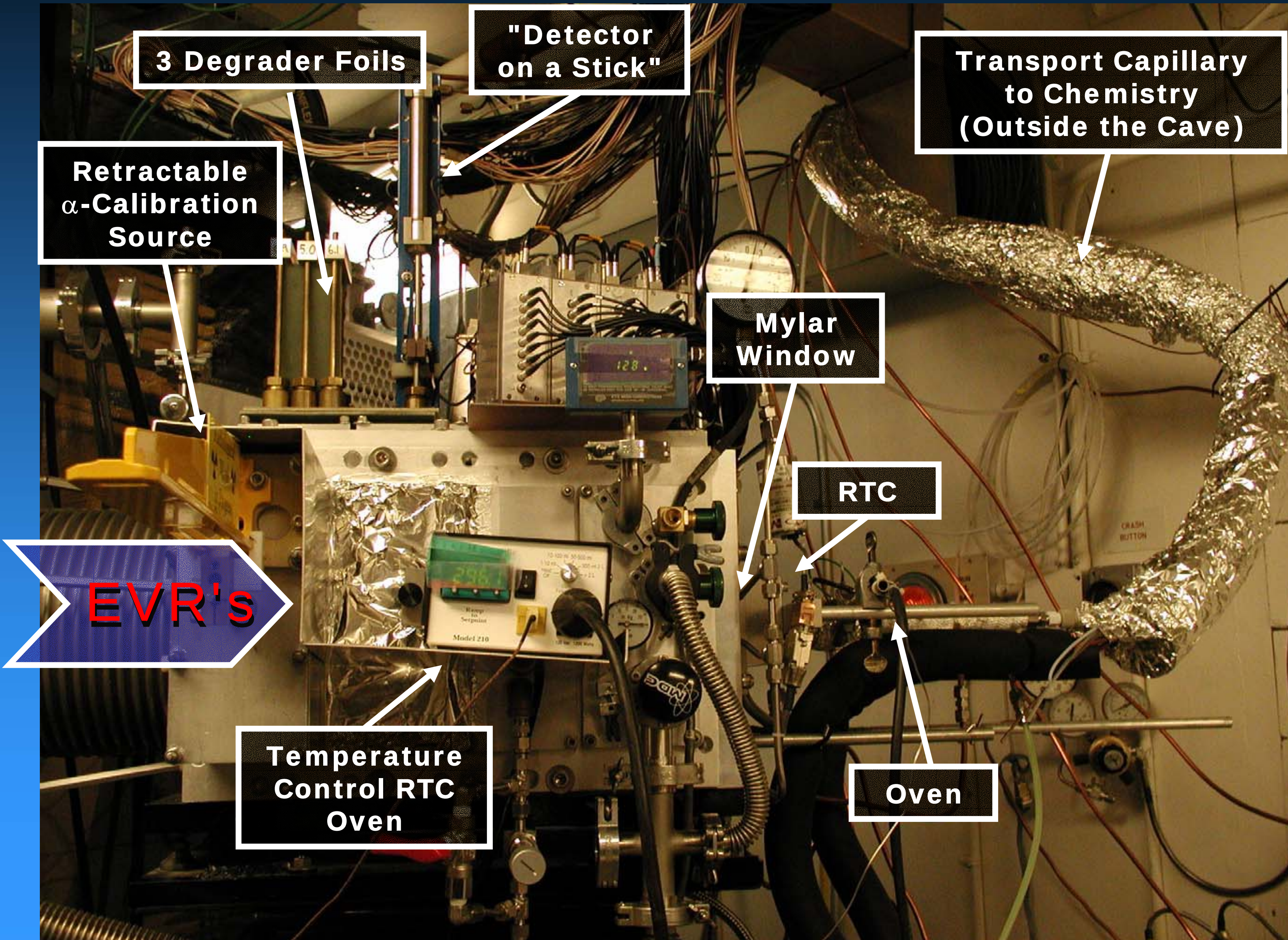




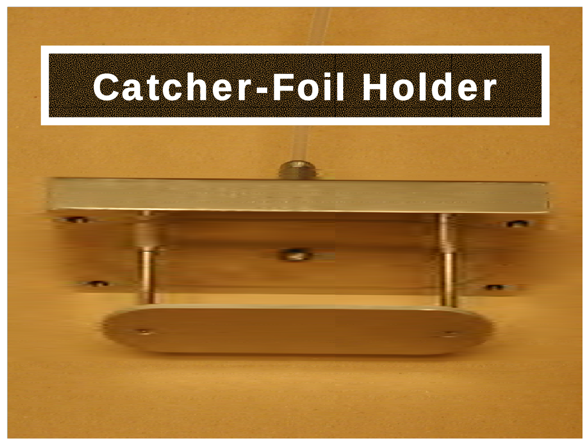
Berkeley Gas-filled Separator / Recoil Transfer Chamber

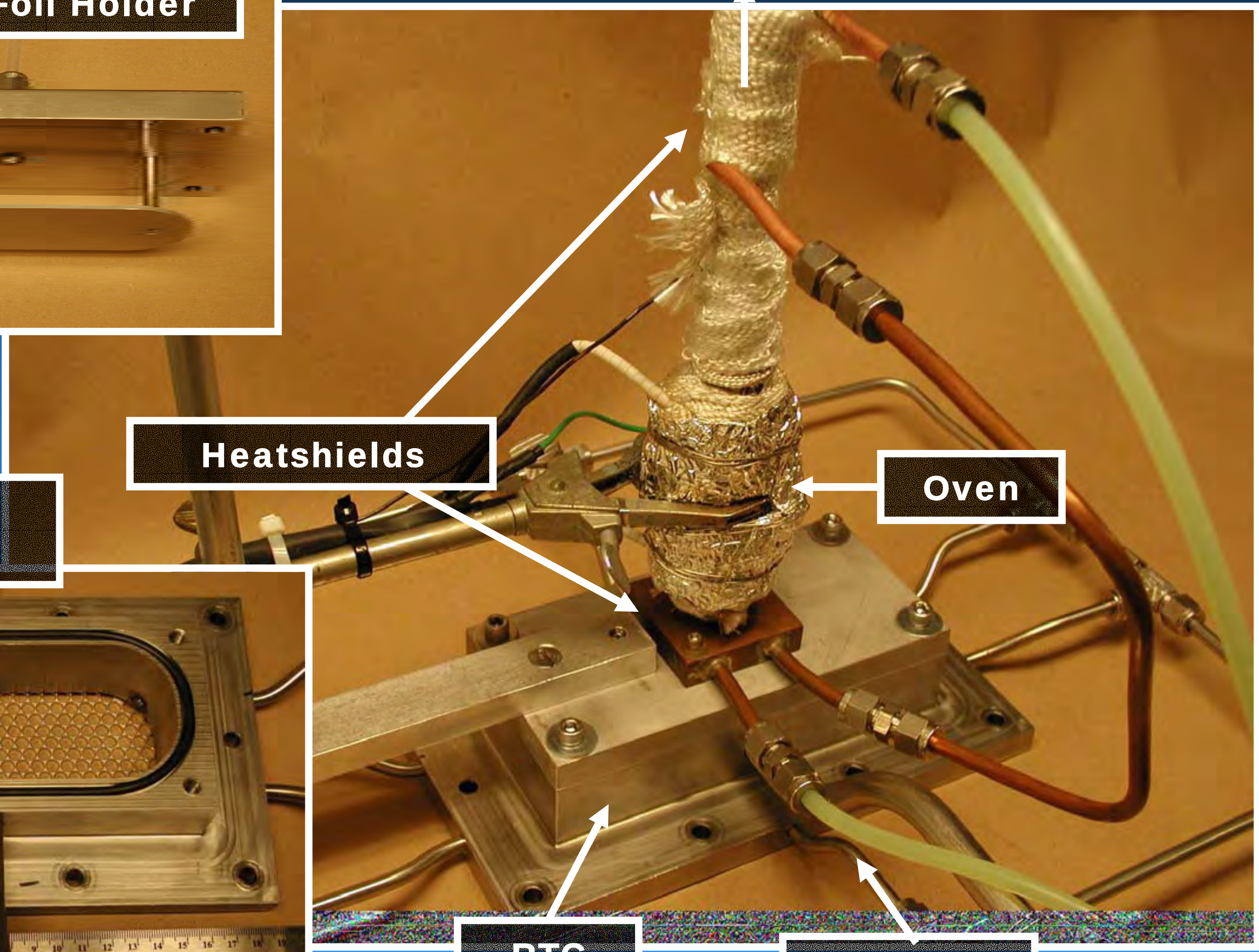


The device: BGS / RTC



The device: RTC





Chemistry results

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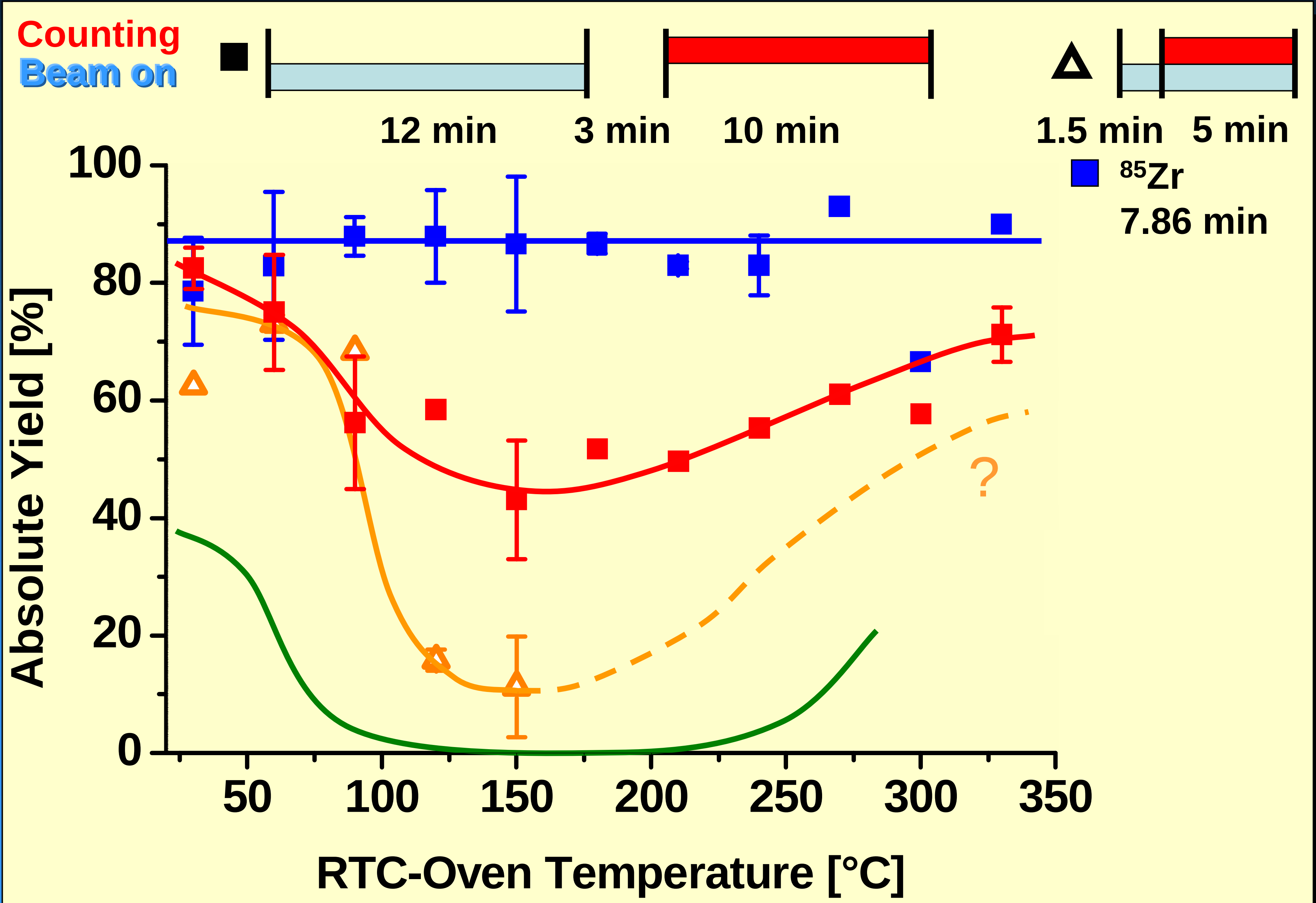
NRC 6

in Aachen, Aug. 29 - Sep. 03, 2004

Current PRELIMINARY results



The best route to the "Chemistry TAN Isotopes"

Highest cross sections for a given element:
Cold fusion with Pb/Bi targets.

$\Rightarrow$ Too short-lived (neutron-poor)

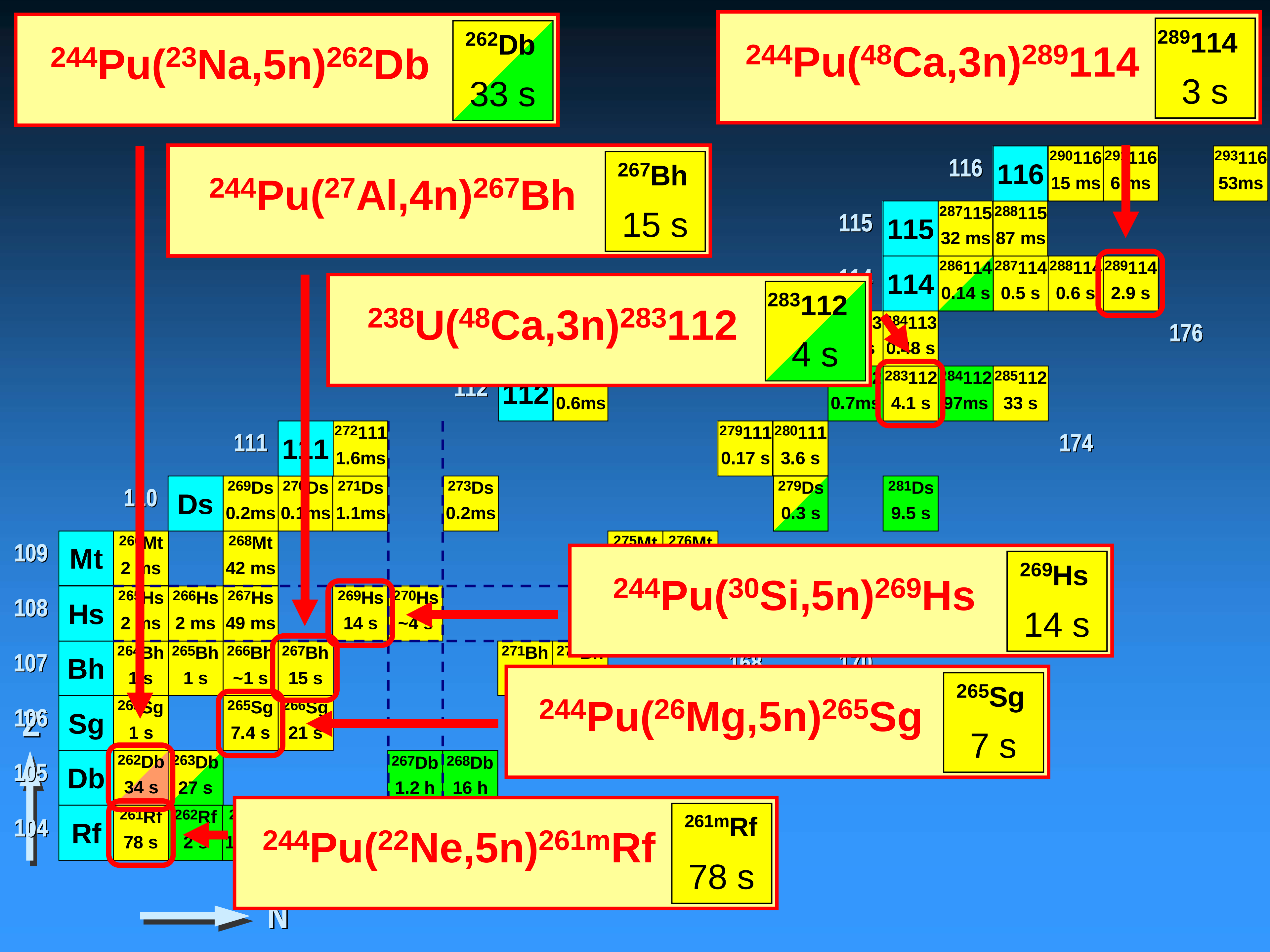
Longer-lived ones are accessible in asymmetric reactions. "Best" target traditionally: ^{248}Cm

$\Rightarrow$ Too slow recoils

Lightest target yielding these isotopes is ^{244}Pu.

$\Rightarrow$ σ is probably again lower, but their recoil energies are higher than with ^{248}Cm:

^{248}Cm(^{18}O,5n)^{261m}Rf vs. ^{244}Pu(^{22}Ne,5n)^{261m}Rf: 1.5x



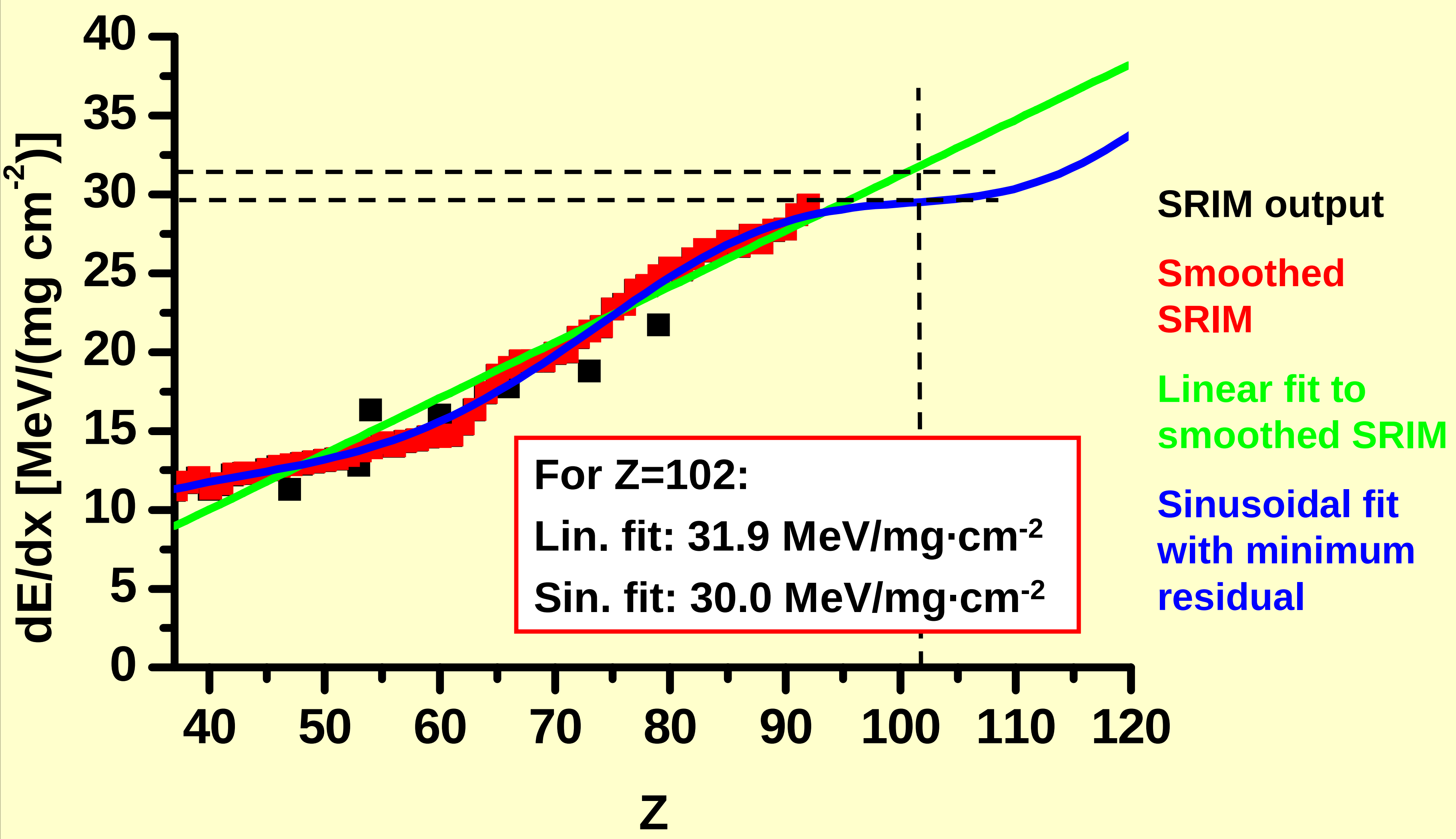
$^{244}Pu(^{23}Na,5n)^{262}Db$
^{262}Db 33 s
$^{244}Pu(^{48}Ca,3n)^{289}114$
$^{289}114$ 3 s
$^{244}Pu(^{27}Al,4n)^{267}Bh$
^{267}Bh 15 s
$^{238}U(^{48}Ca,3n)^{283}112$
$^{283}112$ 4 s
$^{244}Pu(^{30}Si,5n)^{269}Hs$
^{269}Hs 14 s
$^{244}Pu(^{26}Mg,5n)^{265}Sg$
^{265}Sg 7 s
$^{244}Pu(^{22}Ne,5n)^{261m}Rf$
^{261m}Rf 78 s
116
$^{290}116$ 15 ms
$^{293}116$ 53ms
115
$^{287}115$ 32 ms
$^{288}115$ 87 ms
114
$^{286}114$ 0.14 s
$^{287}114$ 0.5 s
$^{288}114$ 0.6 s
$^{289}114$ 2.9 s
176
$^{283}112$ 4.1 s
97ms
$^{285}112$ 33 s
112
0.6ms
0.7ms
174
111
$^{272}111$ 1.6ms
$^{279}111$ 0.17 s
$^{280}111$ 3.6 s
Ds
^{269}Ds 0.2ms
^{271}Ds 1.1ms
^{273}Ds 0.2ms
^{279}Ds 0.3 s
^{281}Ds 9.5 s
109
Mt
^{268}Mt 42 ms
108
Hs
^{266}Hs 2 ms
^{267}Hs 49 ms
^{269}Hs 14 s
107
Bh
^{265}Bh 1 s
^{267}Bh 15 s
^{271}Bh
106
Sg
^{265}Sg 7.4 s
21 s
105
Db
^{262}Db 34 s
^{263}Db 27 s
^{267}Db 1.2 h
^{268}Db 16 h
104
Rf
^{261}Rf 78 s
^{262}Rf
Z
N

At which energies are the recoils produced?

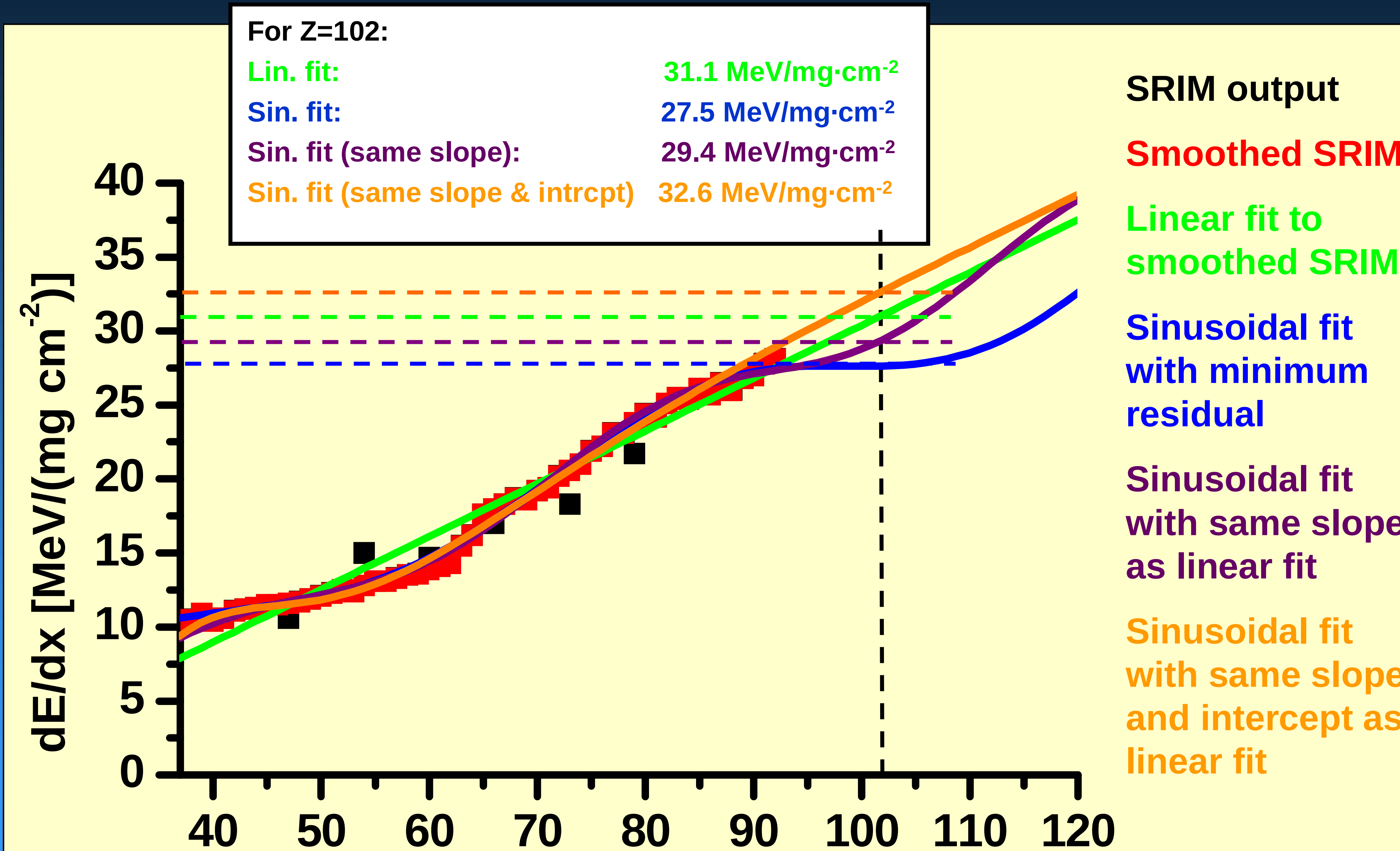
Assuming beam energies that correspond to σ_{max} in HIVAP (Db-Hs) or experimental data (Rf; 112; 114)

Reaction	Nuclide	Half-life	Recoil energy
^{244}Pu(^{48}Ca,3n)^{289}114	^{289}114	3 s	39.9 MeV
^{238}U(^{48}Ca,3n)^{283}112	^{283}112	4 s	39.3 MeV
^{244}Pu(^{30}Si,5n)^{269}Hs	^{269}Hs	14 s	18.1 MeV
^{244}Pu(^{27}Al,4n)^{267}Bh	^{267}Bh	15 s	14.4 MeV
^{244}Pu(^{26}Mg,5n)^{265}Sg	^{265}Sg	7 s	13.5 MeV
^{244}Pu(^{23}Na,5n)^{262}Db	^{262}Db	33 s	10.8 MeV
^{244}Pu(^{22}Ne,5n)^{261m}Rf	^{261m}Rf	78 s	9.5 MeV

dE/dx of ions of mass 256 with 10 MeV in He gas



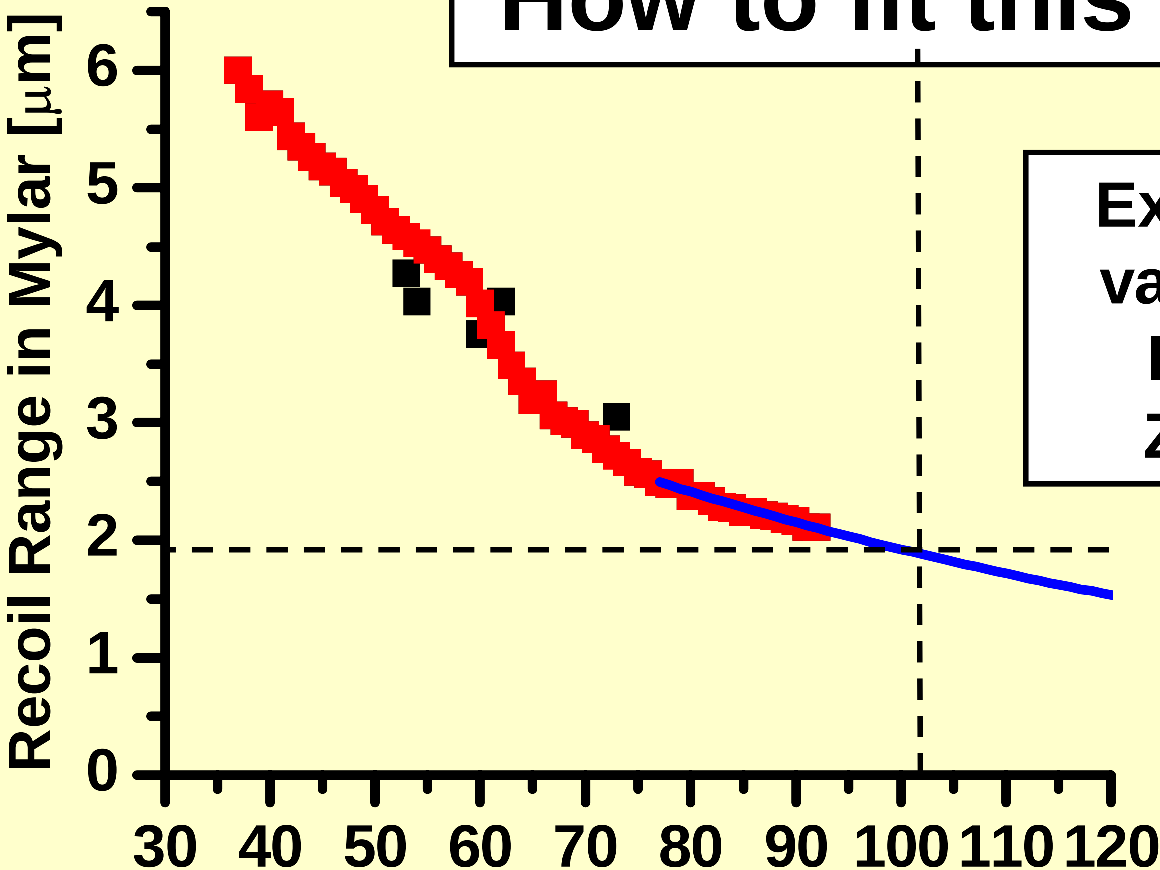
dE/dx of ions of mass 256 with 8 MeV in Mylar



Slope of sin. fit is 22% smaller than slope of lin. fit!

Recoil range of 8-MeV mass 256 ions in Mylar

How to fit this curve?



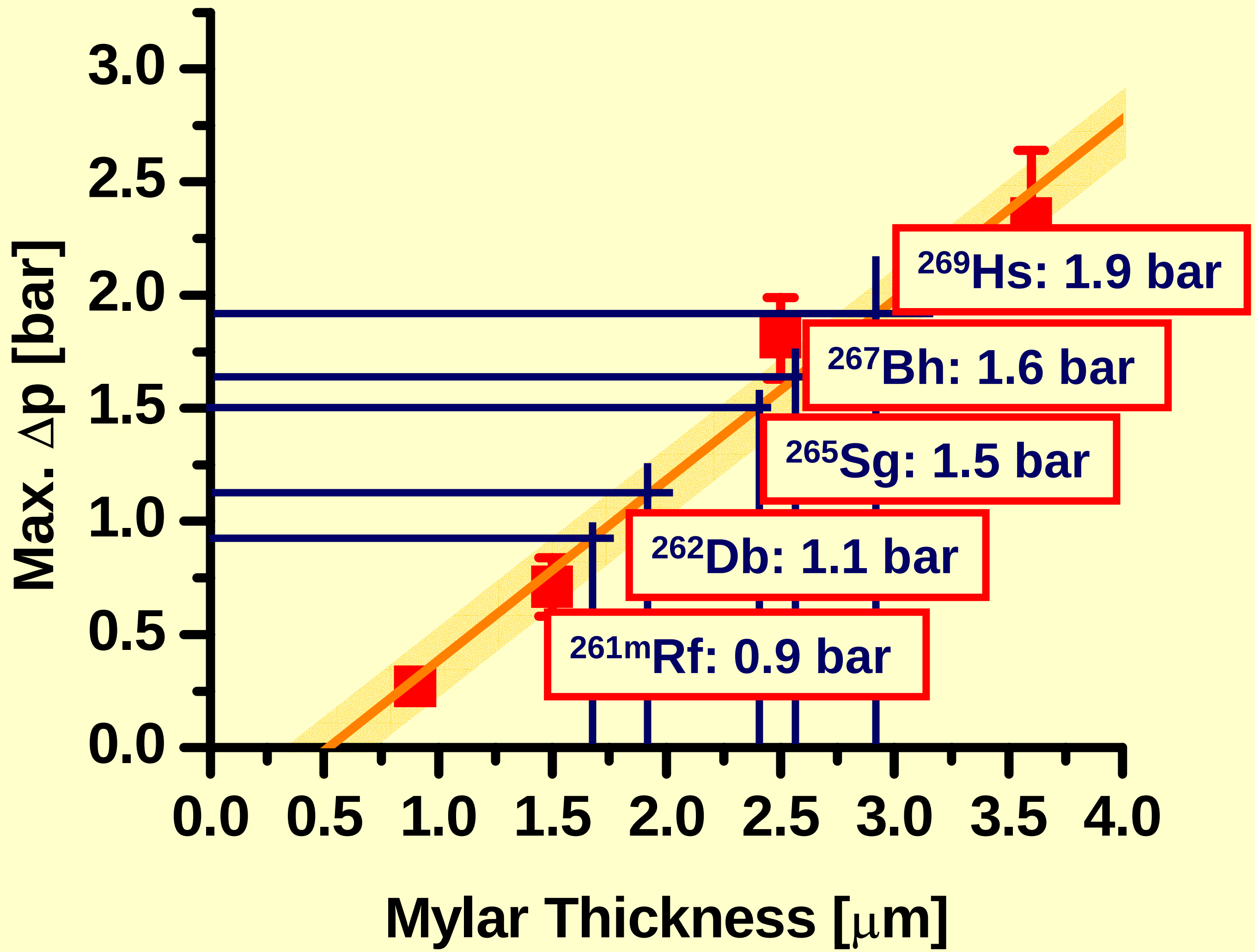
Exponential fit to values Z = 77-92. Prediction for Z=102: 1.9 μm

Experiment: ≥ 1.5 μm

(Target: 158 μg/cm^2 UF_4; BGS at 0.5 torr)

Reaction	Nuclide	E_{Recoil}	R_{Mylar}
$^{244}Pu(^{48}Ca,3n)^{289}114$	$^{289}114$ 3 s	39.9 MeV	✓
$^{238}U(^{48}Ca,3n)^{283}112$	$^{283}112$ 4 s	39.3 MeV	✓
$^{244}Pu(^{30}Si,5n)^{269}Hs$	^{269}Hs 14 s	18.1 MeV	2.9 μm
$^{244}Pu(^{27}Al,4n)^{267}Bh$	^{267}Bh 15 s	14.4 MeV	2.6 μm
$^{244}Pu(^{26}Mg,5n)^{265}Sg$	^{265}Sg 7 s	13.5 MeV	2.4 μm
$^{244}Pu(^{23}Na,5n)^{262}Db$	^{262}Db 33 s	10.8 MeV	1.9 μm
$^{244}Pu(^{22}Ne,5n)^{261m}Rf$	^{261m}Rf 78 s	9.5 MeV	1.7 μm

Maximum allowable pressure on Mylar



These numbers are for our 80%-transparency honeycomb support; the accuracy is limited, but it should give some feeling for what will be possible. Suggestions for better materials and and support designs are highly welcome!

Summary / Outlook

Preseparated isotopes are available @ BGS

Beam-free environment in RTC opens up new possibilities for gas-phase chemistry.

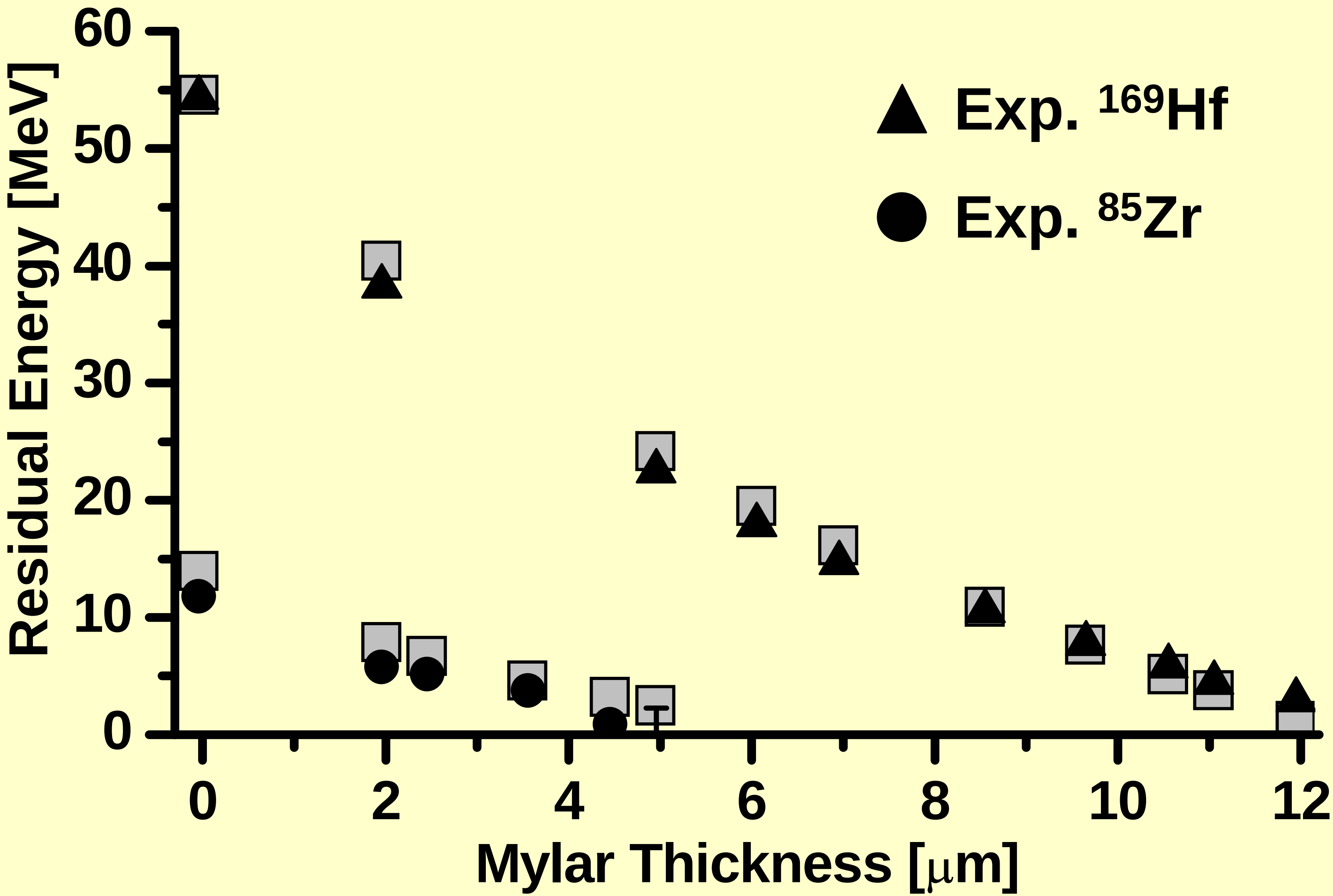
First results with Zr and Hf are encouraging.

^{244}Pu is probably a good target to study Rf-Hs.

Problem: Recoils are slow, their ranges in Mylar are not known, but they are short.

RTC window design and material need to be (and can be!) improved.

Energy loss of recoils in Mylar



Pulse height defect corrected according to Moulton et al. NIM 157 (1978) 325