Superheavy Element Research at Berkeley

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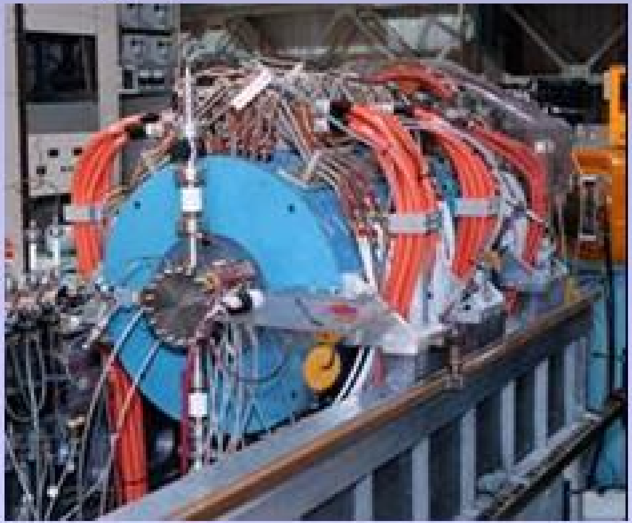
Festcolloquium and Workshop on the Future of Superheavy Elements
February 17-18, 2004
Gesellschaft für Schwerionenforschung

The LBNL 88-Inch Cyclotron

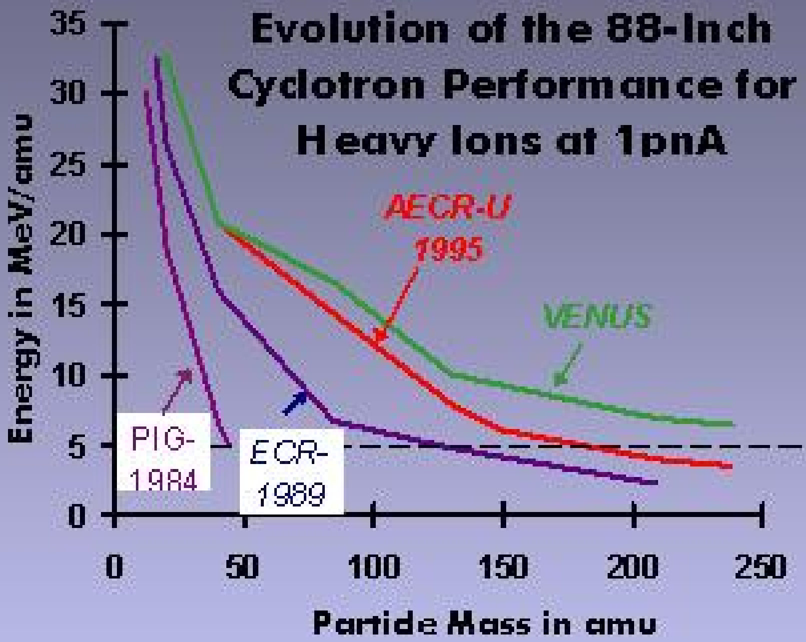
K130 Sector focused cyclotron
A/q ≤ 5 for Coulomb Barrier

First Operation in 1961



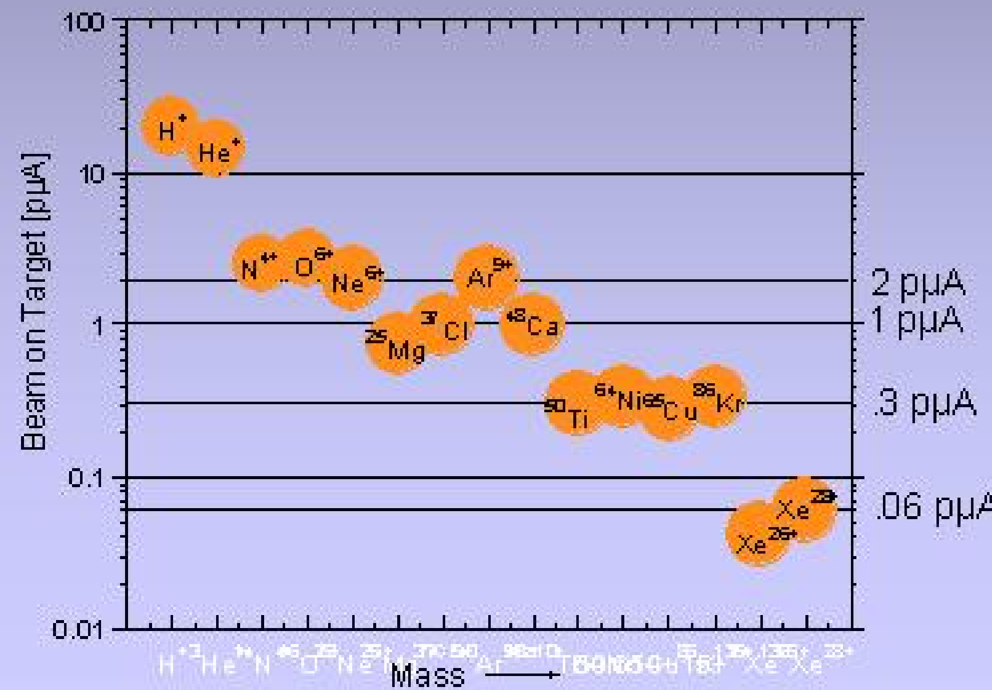
AECRU
(present)
and
VENUS
(Spring ’05)

Accelerator Capabilities



Mass range and maximum energy

Routinely available Coulomb barrier beam intensities



Present Operating Status

$2M/year - National Reconnaissance Office and US Air Force
Berkeley Accelerator Space Effects Facility (BASEF) to study the effect of radiation on microelectronics, optics, and materials for spacecraft

$3M/year - US. Department of Energy Office of Science
for basic Nuclear Science Research

This funding plan is guaranteed for at least two years

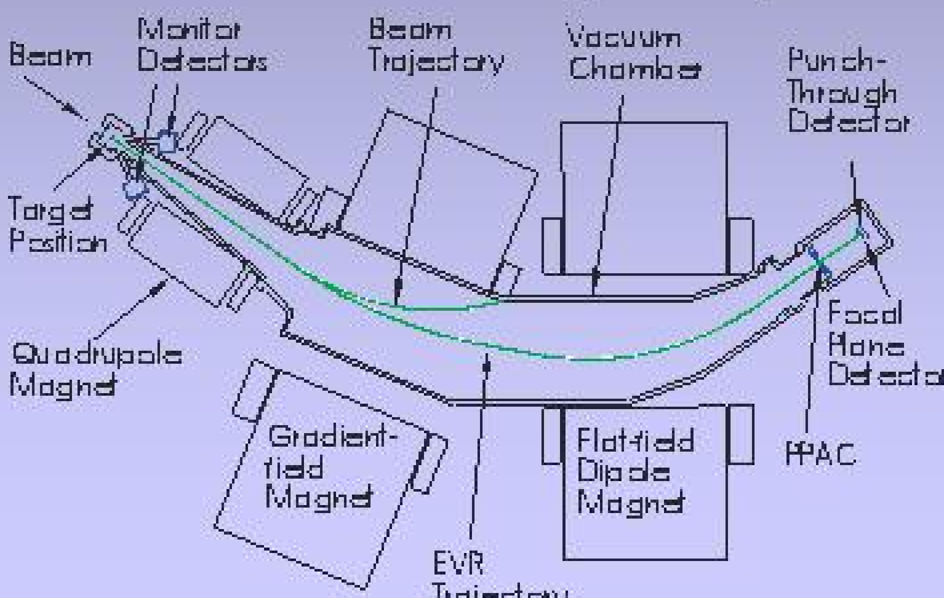
Is This Good for Heavy Element Experiments in Berkeley?

YES! BGS could get up to 2000 hr/year of beamtime

NO! Scheduling and political conflicts with BASEF have already set back the Heavy Element Program

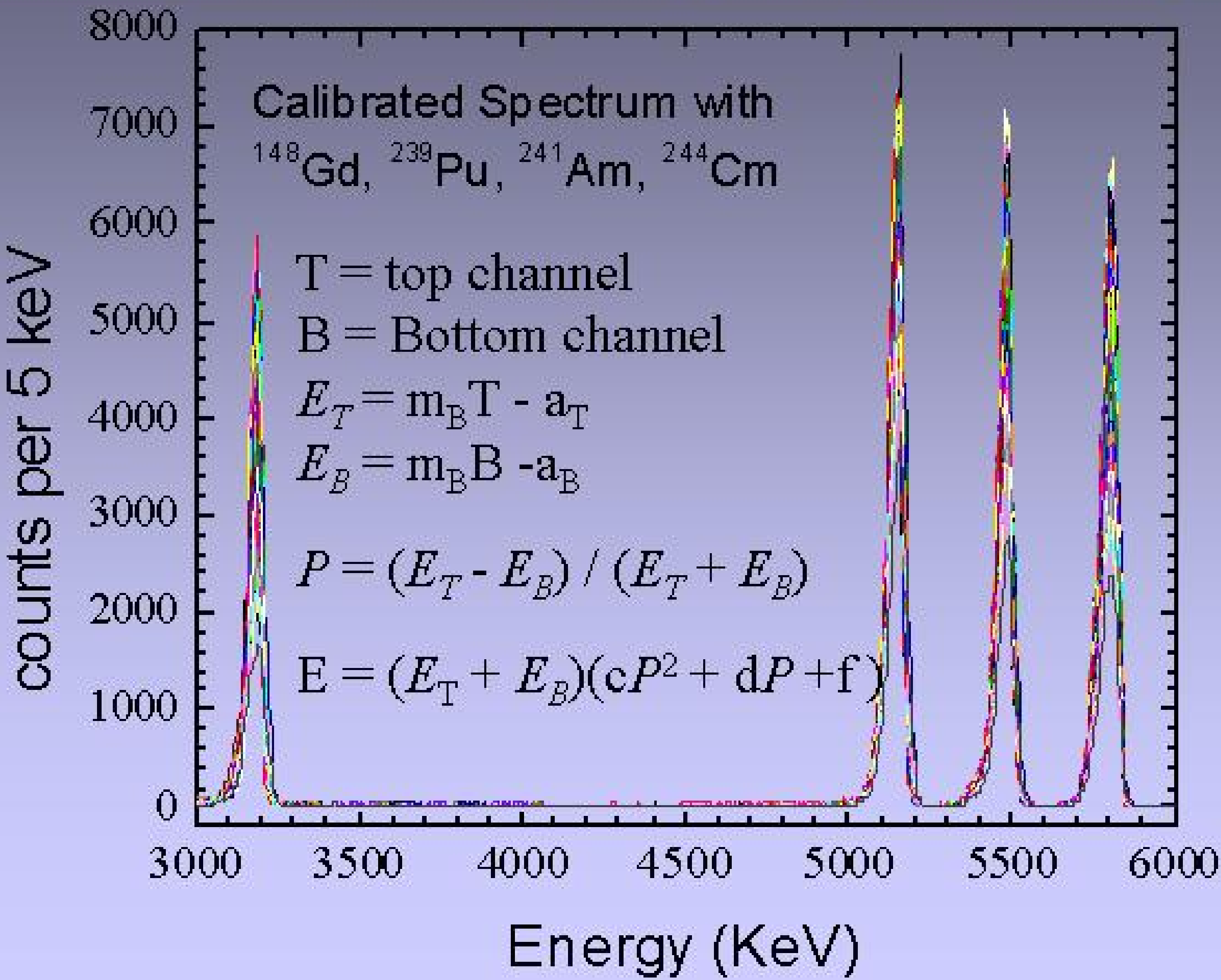
Berkeley Gas-filled Separator (BGS)

- Construction "completed" fall 1999
- Recycled Bevalac magnets
- Innovative design gives Ω=45msr
- 70° bend gives superior separation
- ~1 mBar He fill gives full momentum and charge acceptance



- Beam rejection up to 10^{15}
- Transit time ~μs
- Rotating target allows beam intensities up to pμA range
- Beam intensity, target thickness, and efficiency give 1 event/(picobarn*week)

Automated Energy and Position Calibration Procedure



Understanding the Position Resolution

Ignoring the $(cP^2 + dP + f)$ factor: $E = E_T + E_B$

This is standard error propagation,
BUT
The CROSS TERM is important, because the fluctuations in the signals from the top and bottom of a strip are ANTI-CORRELATED

$$\sigma_E^2 = \left(\frac{\delta E}{\delta E_T}\right)^2 \sigma_{E_T}^2 + \left(\frac{\delta E}{\delta E_B}\right)^2 \sigma_{E_B}^2 + 2\left(\frac{\delta E}{\delta E_T}\right)\left(\frac{\delta E}{\delta E_B}\right)\sigma_{E_T E_B}$$

$$\sigma_P^2 = \left(\frac{\delta P}{\delta E_T}\right)^2 \sigma_{E_T}^2 + \left(\frac{\delta P}{\delta E_B}\right)^2 \sigma_{E_B}^2 + 2\left(\frac{\delta P}{\delta E_T}\right)\left(\frac{\delta P}{\delta E_B}\right)\sigma_{E_T E_B}$$

Understanding the Position Resolution

Plugging in the derivatives and solving:

$$\sigma_{E_T E_B} = \frac{\sigma_E^2 - \sigma_{E_T}^2 - \sigma_{E_B}^2}{2}$$

This one is easy, because the partial derivatives are 1

This one is harder, because high school was a long time ago

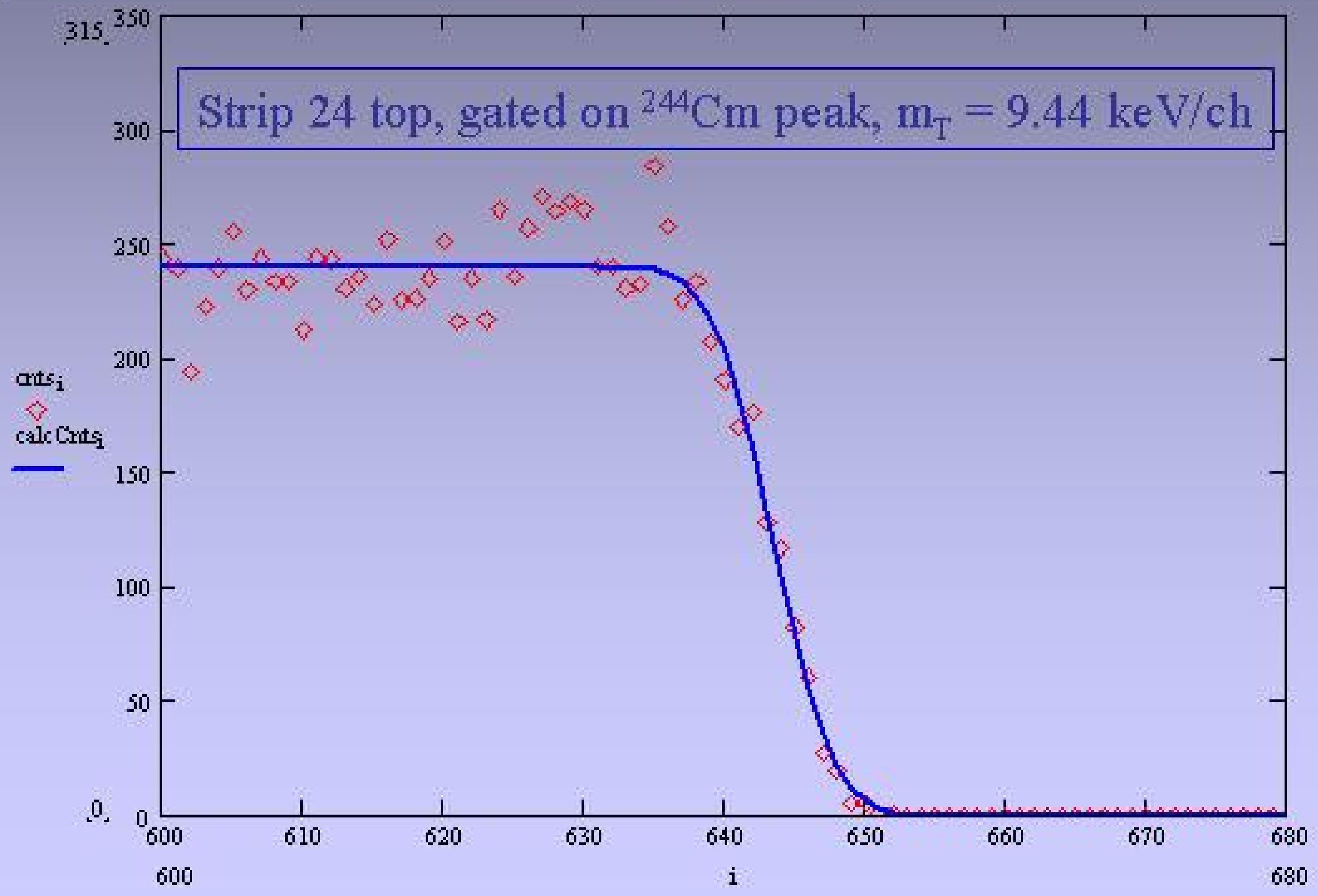
$$\sigma_P^2 = \frac{4E_B^2\sigma_{E_T}^2 + 4E_T^2\sigma_{E_B}^2 - 8E_T E_B \sigma_{E_T E_B}}{E^4}$$

Note: σ_E is known from the widths of the α peaks

σ_{E_T} and σ_{E_B} can be found by . . .

Understanding the Position Resolution

measuring the E_T and E_B signals through a NARROW slit OR fitting the end of the E_T (or E_B) spectrum with an error function . . .



Understanding the Position Resolution

From calibration data taken one week ago (room temperature):

$$\sigma_E^2 = 290\,\mathrm{keV}^2 \quad (\sigma_E = 17\ \mathrm{keV},\ \mathrm{FWHM} = 40\ \mathrm{keV})$$

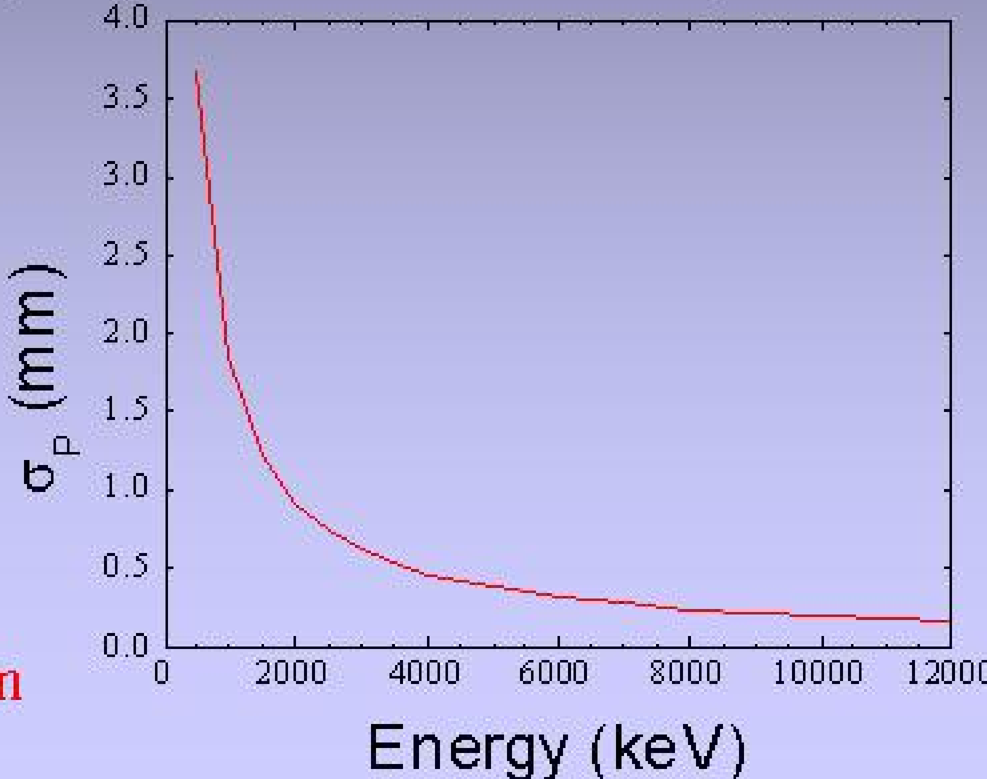
$$\sigma_T^2 = \sigma_B^2 = 1090\,\mathrm{keV}^2 \quad (\sigma_T = \sigma_B = 33\ \mathrm{keV},\ \mathrm{FWHM} = 78\ \mathrm{keV})$$

$$\sigma_{E_T E_B} = -940\,\mathrm{keV}^2 \quad (<0\ \text{indicates anti-correlated})$$

The result is . . . σ_P is very weakly position dependent and nearly proportional to 1/E

FWHM for 8 MeV - 8 MeV α-α correlation should be 0.93 mm

FWHM for 8 MeV - 1 MeV α-escape corr. should be 5.3 mm



Notes on the Position Resolution Equations (or . . . These Equations Behave as Expected)

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If $\sigma_{E_T}^2 = \sigma_{E_B}^2 = -\sigma_{TB}$, top and bottom signals are fully anti-correlated

$$\sigma_p = \frac{2\sigma_{E_T}}{E}$$

position resolution is independent of vertical position

If $\sigma_{E_T} = \sigma_{E_B}$ and $\sigma_{E_T E_B} = 0$, top and bottom are uncorrelated

$$\sigma_p = \frac{2\sigma_T}{E}\left(1 - \sqrt{\frac{E_T E_B}{2E^2}}\right)$$

At the top or bottom edge (E_B or $E_T = 0$, respectively) position resolution is the same as in the anti-correlated case.
Position resolution at center is better by a factor of $1/\sqrt{2}$

$^{238}U(^{48}Ca,3n)^{283}112$

1999:	Vassillissa	2 SF observed	5.6 pb	@ 231 ± 3 MeV	half-life = 81 sec
		No SF observed	< 4.0pb	@ 238 ± 3 MeV	
1999:	Vasillissa	SF observed after 10.29-MeV α-decay of $^{287}114$			new $^{283}112$ half-life ~ 3 min
2001:	BGS	No SF observed	< 1.6 pb	@ 228-234 MeV	Bρ(in He) = 2.19-2.31 Tm
2001:	Dubna	Chemistry	~2.0 pb	fissions could be long-lived $^{283}112$ with Rn-like Chemistry	
2002:	BGS	No SF observed	< 0.7 pb	@ 228-234 MeV	Bρ(in He) = 2.19-2.31 Tm
2003:	PSI@GSI	Hg-Rn chemistry gave inconclusive result (sensitive only to long-lived SF activity)			
2003:	DGFRS	9.5-MeV α after 10.0-MeV α-decay of $^{287}114$ seen in both $^{244}Pu(^{48}Ca,5n)^{287}114$ and $^{242}Pu(^{48}Ca,3n)$ reactions			half-life ~ 5s
2003:	Vassilissa	No SF observed	< 1.2 pb	@ 231±3 MeV	
		2 SF observed	~ 4.0 pb	@ 234± 3 MeV	new 283112 half-life = 5.1 min
2004:	DGFRS	9.5 MeV α	~3.0 pb	@ 234±3 MeV	half-life ~ 5s
		None observed	<1.0 pb	@ 240±3 MeV	

^{283}112 Summary

The 5-minute SF activity reported by Vassilissa is incorrect

- Based on information in 1999 and 2004 reports, random probabilities for correlation to an EVR on a several-minutes time-scale are HIGH
- Determination of mass based on q/A and TOF for two events is NOT POSSIBLE
- Implied α-decay hindrance factor for ^{283}112 is unusually large

~5-sec 9.5-MeV α-decay of ^{283}112 is more likely correct

- followed by ~200-ms SF of ^{279}110 provides strong signature
- E_α and half-life are consistent with decay systematics in the region
- ^{279}110 occasionally decays by α, resulting in a long α-decay chain

Optimum ^{48}Ca beam energy is between 234 and 237 MeV

^{238}U(^{48}Ca,xn)$^{286-x}$112 experiments begin at the BGS on ~~February 9~~ ~~February 25~~ March 2

Are the UF_4 Targets Any Good?

Targets are ~600μg/cm^2 UF_4 evaporated onto 2-μm Al foils

α-spectroscopy of the ^{238}U shows no large change in the thickness or uniformity of the UF_4 layer

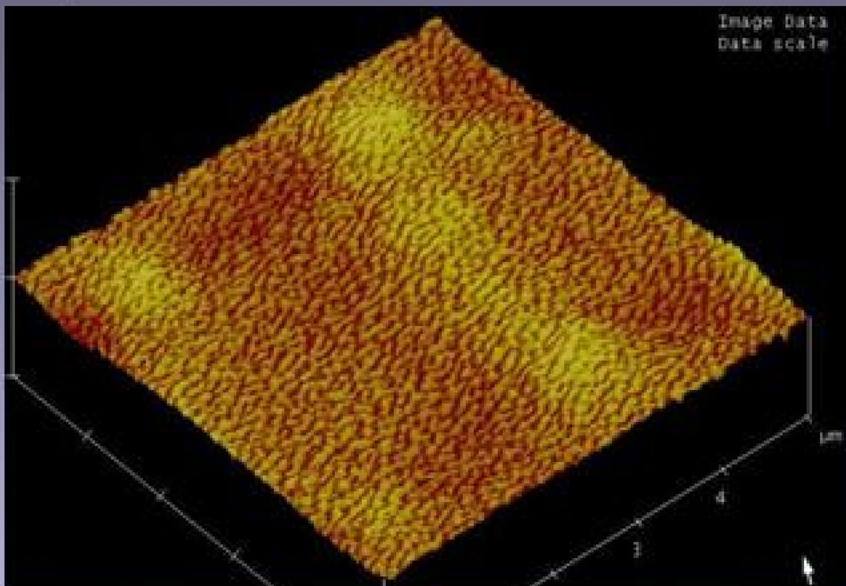
α-particle energy loss measurements indicate that there is no large change in of UF_4 thickness or Al thickness during the experiments

α-particle energy loss measurements show the Al is actually 2.2 μm (in-target beam energies are about 0.6 MeV lower than expected)

Atomic Force Microscopy shows a change in the UF_4 structure (pictures to come)

Conclusion: Targets are good (although not perfect)

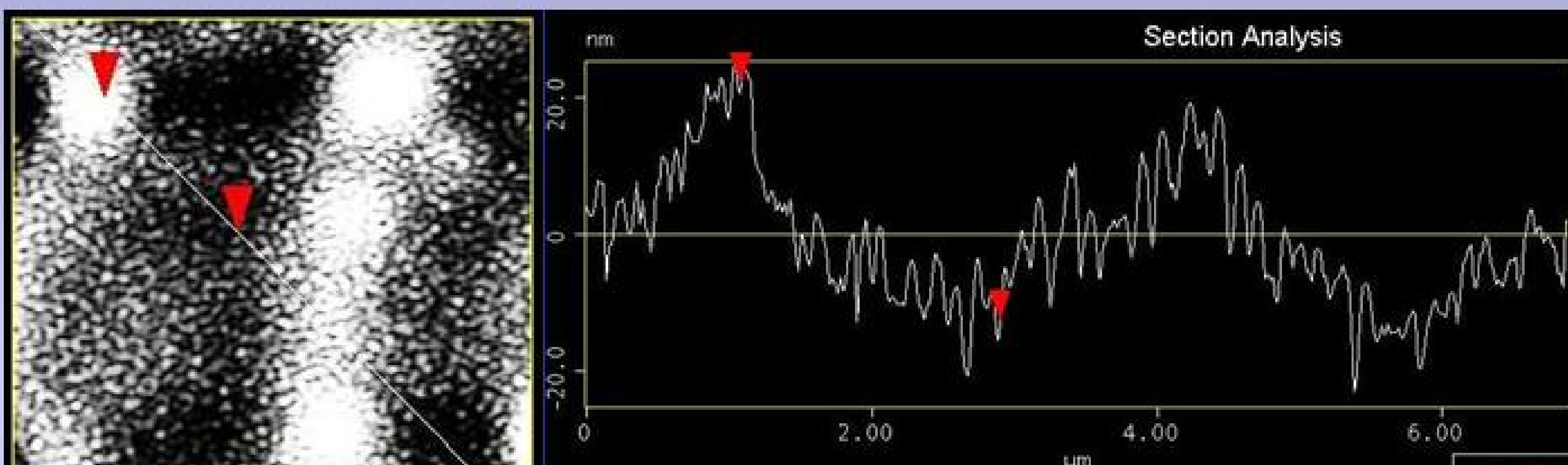
AFM of the edge of the UF_4 layer (outside the visible beam stripe)



Overall UF_4 thickness is 900 nm

Crystalline structure

Thickness variations up to +/- 2%



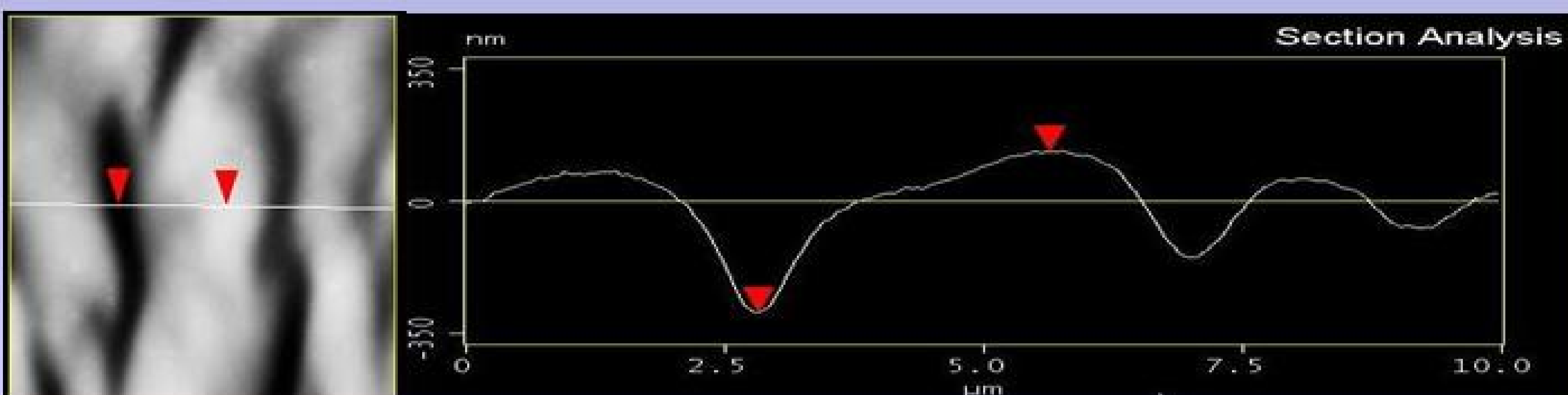
AFM of the center of the UF4 layer (inside the visible beam stripe)

Overall UF4 thickness 900 nm

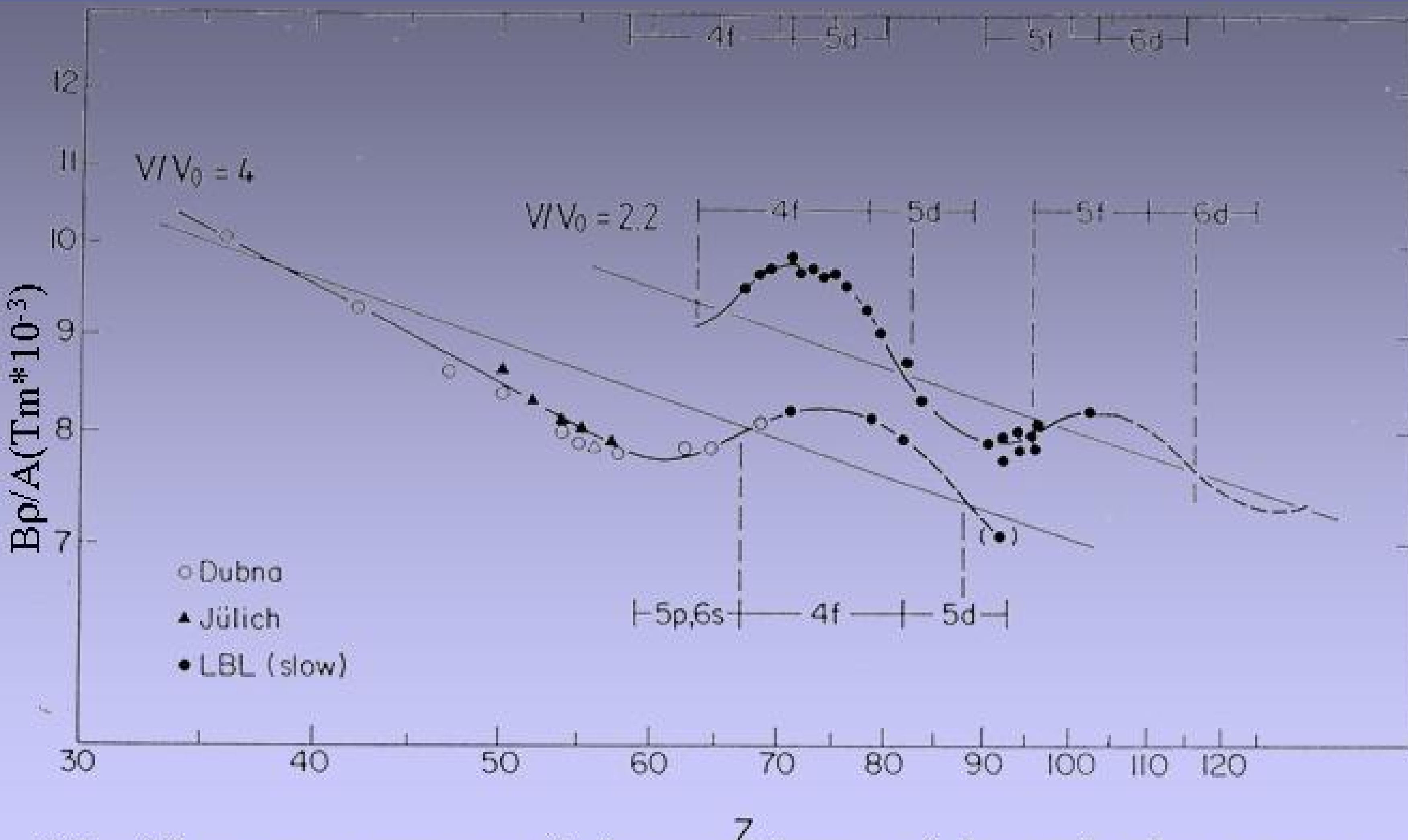
large-scale melting of UF_4

Variations up to +/- 20%

RMS thickness variations are much less than 10%



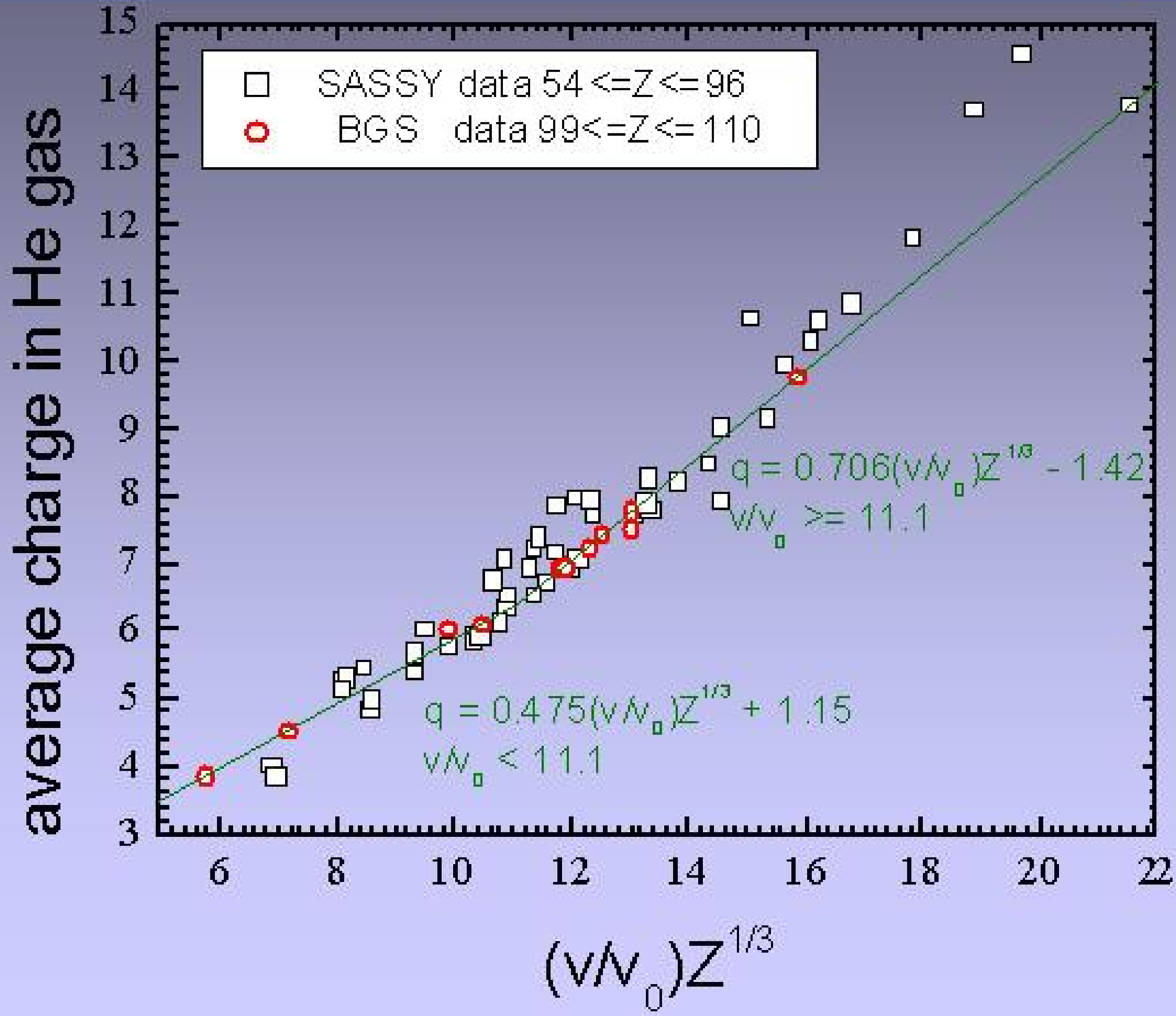
What is the ^{283}112 Magnetic Rigidity?



Shell structure of the stripped ion is important

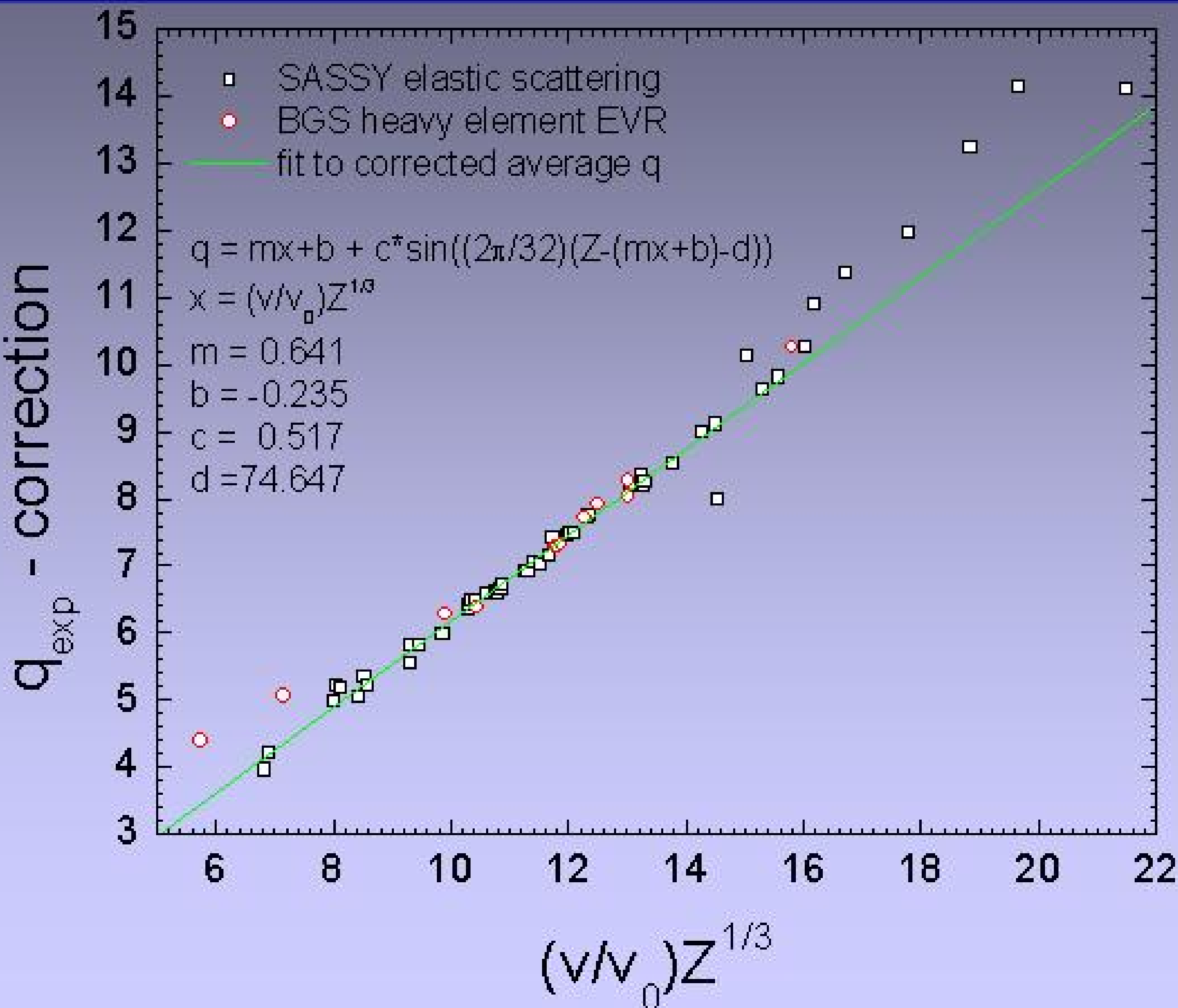
New Fit to Bρ Data

No correction for stripped ion electronic configuration



New Fit to Br Data

sinusoidal correction for stripped ion electron configuration



^{283}112 from $^{238}U(^{48}Ca,3n)$ should have:

$v/v_0 Z^{1/3} = 11.3$

$\overline{q} = 6.86$

$B\rho = 2.21$ Tm

New BGS Focal Plane Detectors Cover 9% in Bρ

New experiment will be run at 2.21 Tm (2.11-2.31 Tm)

compared to previous expt. @ (2.19-2.31 Tm)

Do We Know the Beam Energy?

Reproducibility of beam energies is good to within 0.5% FWHM

Absolute beam energies accurate to within 2 MeV
(comparison of $^{208}Pb(^{48}Ca,xn)^{256-x}No$ excitation functions)

New beam TOF detectors to be installed *this week* in adjacent beamline

Will be available for all 88-Inch Cyclotron users

Beam energy measurement should take 5-10 minutes

Future SHE Experiments at the BGS

$^{238}U(^{48}Ca,xn)^{286-x}112$: Independent confirmation of SHE production

Systematic study of production cross sections and magnetic rigidities for asymmetric reactions with actinide targets

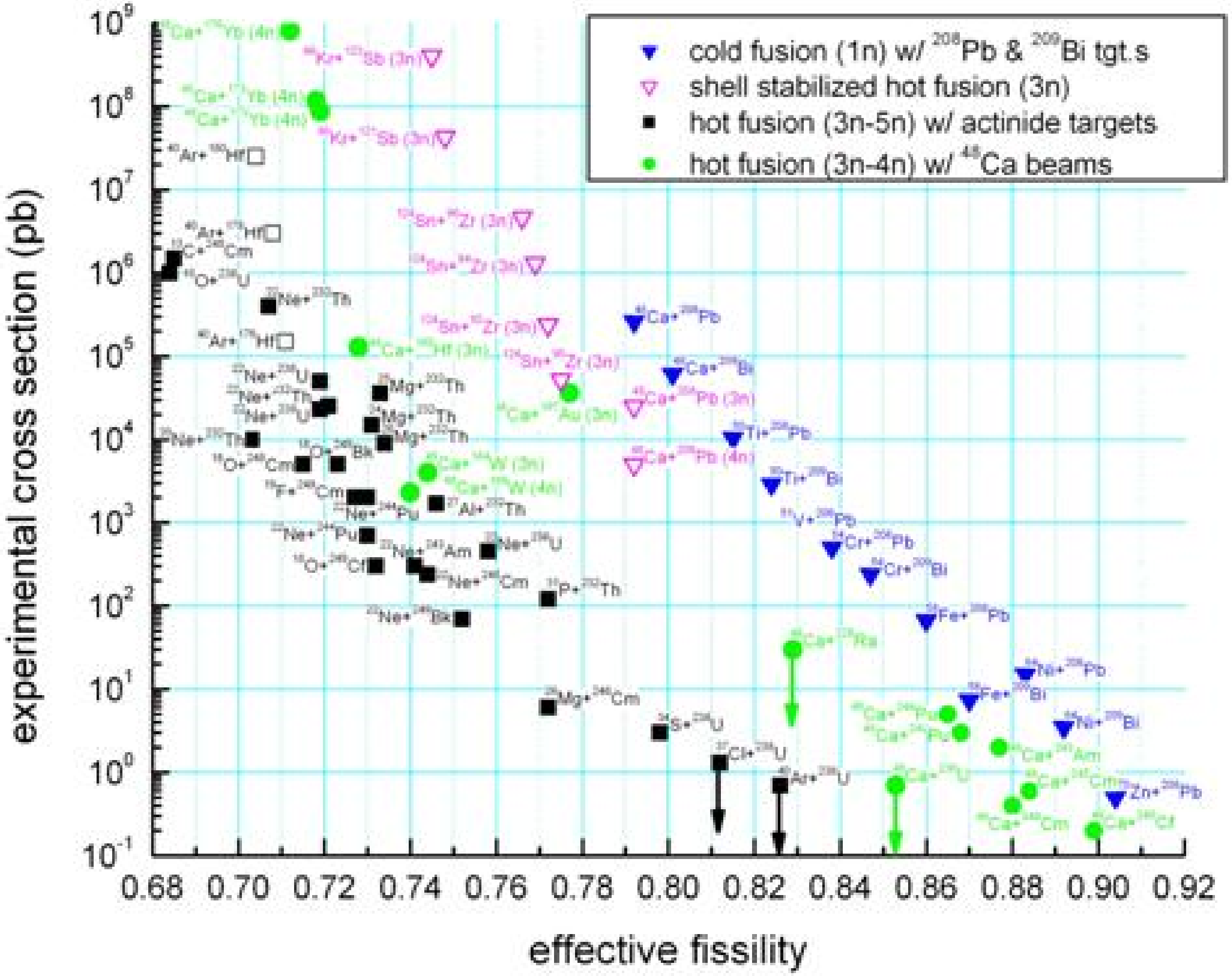
Heavier projectiles: $^{238}U(^{50}Ti,xn)^{288-x}114$, etc.

Design and construction of an actinide target capability for BGS

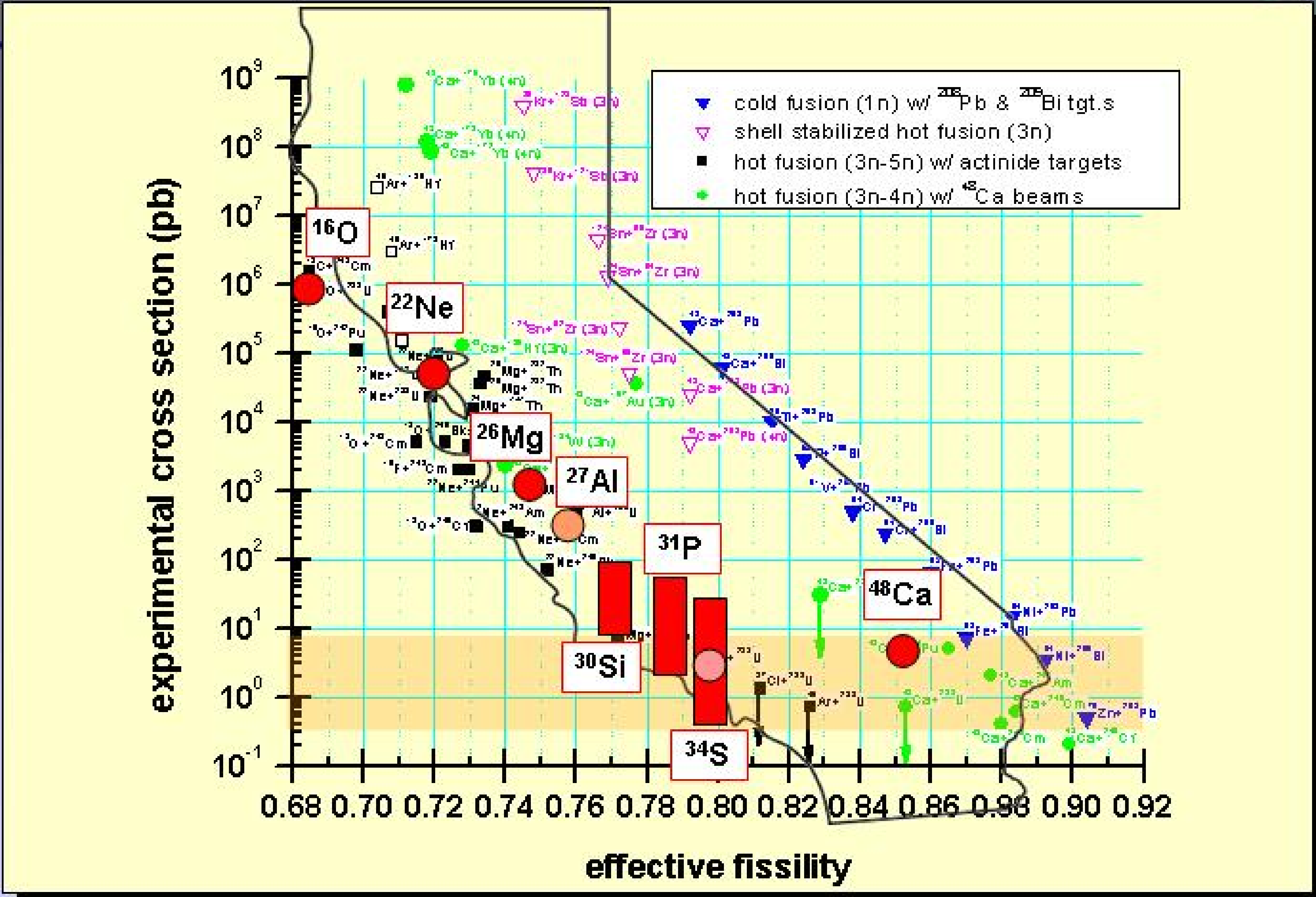
SHE chemistry using BGS as a preseparator

Enhanced sensitivity with high-intensity beams from VENUS

Cross Section Systematics



The "California Plot"



Recoil Transfer Chamber v.3

- Smaller (fixed) volume
- Honeycomb grid allows thinner MYLAR
- Catcher foil holder for yield measurement
- Used w/ heated capillary for gas-phase volatile organometallic chemistry

Transactinide Element Liquid-Liquid Extractions using

BGS

Berkeley Gas-filled Separator

Rf and Db (Z=104,105) isotopes are produced at the LBNL 88-Inch Cyclotron by bombardment of Pb and Bi targets with ^{50}Ti. Rf and Db are separated from other nuclear reaction products with the BGS.

RTC

Recoil Transfer Chamber

At the end of the BGS, Rf or Db atoms pass through a Mylar foil into the RTC and stop in He gas. These products become attached to aerosols are then transported through a 20-m long capillary to SISAK.

SISAK

Short-lived Isotopes Studied by the AKufve technique

Continuous liquid-liquid extractions are performed with SISAK. The alpha-decay of the separated transactinide atoms is assayed by performing liquid scintillation pulse-height analysis on the flowing solution.

Result: Successful proof-of-principle experiments demonstrating atom-at-a time chemical separations of transactinide elements with half-lives of only a few seconds, an important new capability for heavy element studies.

These experiments were performed in collaboration with the U. of Oslo, the U. of Gothenburg, and U. of Mainz.

For more details please see: http://folk.uio.no/jonpo/SISAK_and_preseparation_ASR2001_Aug2001_v6.pdfResult