Studies of the Reaction ^{48}Ca + ^{238}U @ BGS

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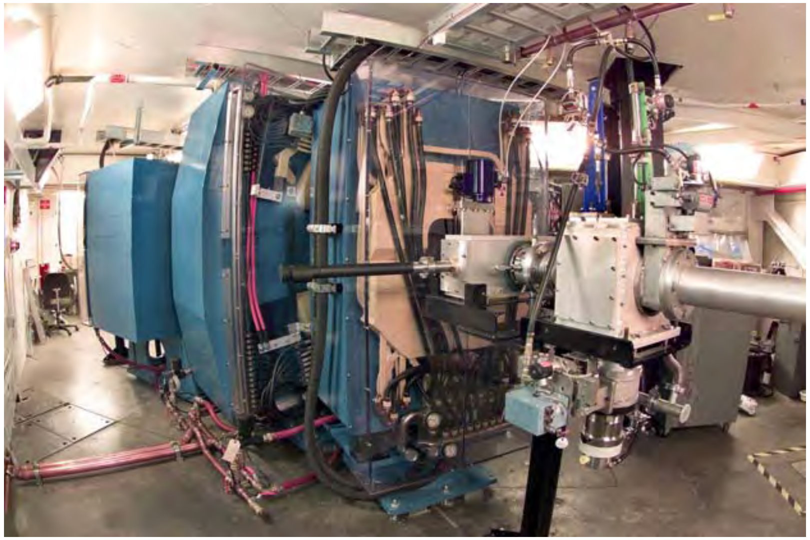
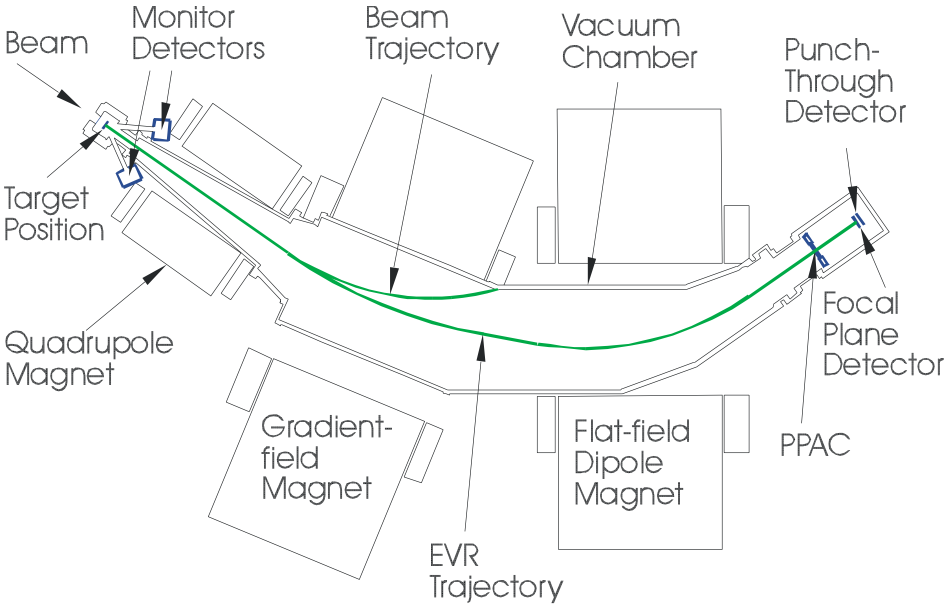
(There has been NO INDEPENDENT CONFIRMATION of ***ANY*** isotope with A > 277)

Goal: Independent confirmation of ***ONE*** of the DUBNA SHE results

Berkeley Gas-filled Separator (BGS)



- Construction “completed” fall 1999
- Recycled Bevalac magnets
- Innovative design gives Ω=45msr
- 70^{o} 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)

^{283}112 history ^{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: Vassillissa 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 < 0.8 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)

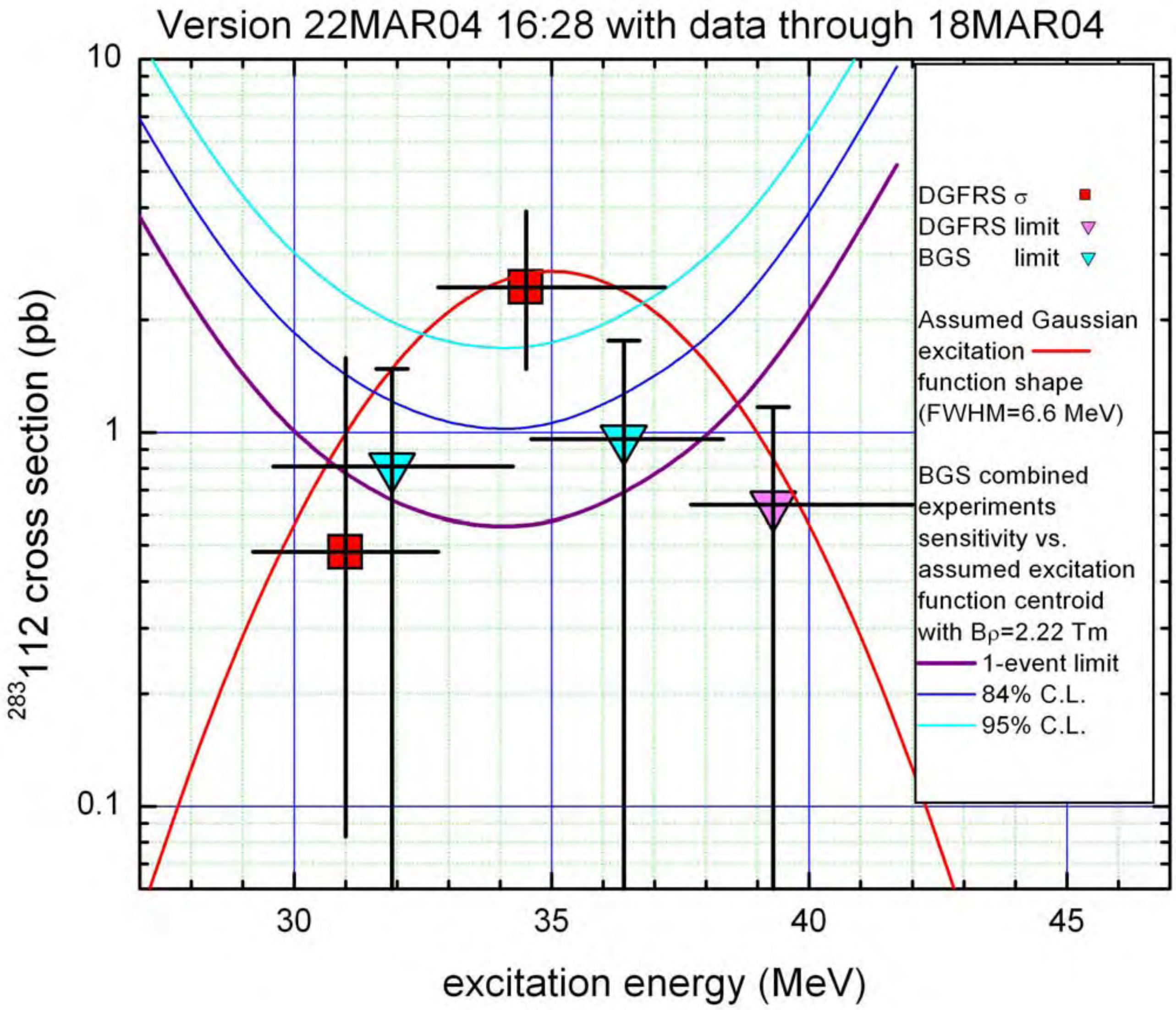
2003: DGFRS 9.5-MeV α after 10.0-MeV α-decay of ^{287}114 half-life ~ 5s
seen in both ^{244}Pu(^{48}Ca,5n)^{287}114 and ^{242}Pu(^{48}Ca,3n) reactions

2003: Vassilissa No SF observed < 1.2 pb @ 231±3 MeV
2 SF observed ~ 4.0 pb @ 234± 3 MeV new ^{283}112 half-life = 5.1 min

2004: DGFRS 9.5 MeV α ~1.3 pb @ 231±3 MeV half-life ~4s
9.5 MeV α ~2.5 pb @ 234±3 MeV half-life ~ 4s
None observed <1.3 pb @ 240±3 MeV

2004: BGS No SF observed < 0.96 pb @ 233-238 MeV Bρ(in He) = 2.19-2.31 Tm

^{283}112 Cross Sections and Upper Limits



Why Don't We see 4-s 9.54-MeV ^{283}112?

Is there a problem with the BGS targets?

Is there a systematic difference in beam energies from the accelerators at LBNL and Dubna?

Do we have a different beam energy in our uranium targets due to errors in energy loss calculations?

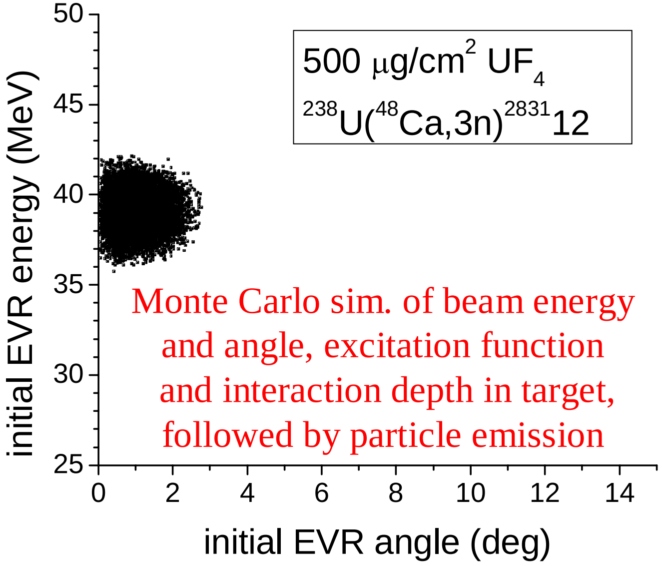
Did we run the BGS at the wrong magnet settings?

Are the UF_4 Targets Any Good?

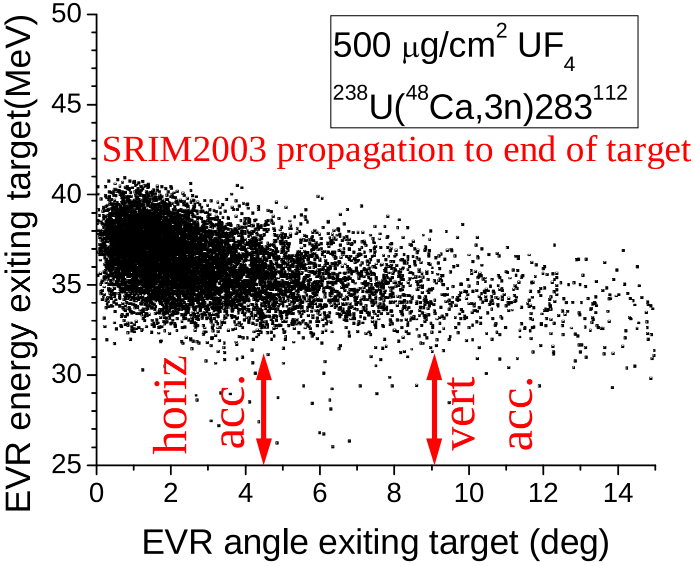
Targets are 475-611μg/cm^2 UF_4 evaporated onto 2-μm Al foils. This thickness is good for the BGS.

Are the UF_4 Targets Any Good?

Are the 475-611 μg/cm2 targets too thick?



Monte Carlo sim. of beam energy and angle, excitation function and interaction depth in target, followed by particle emission

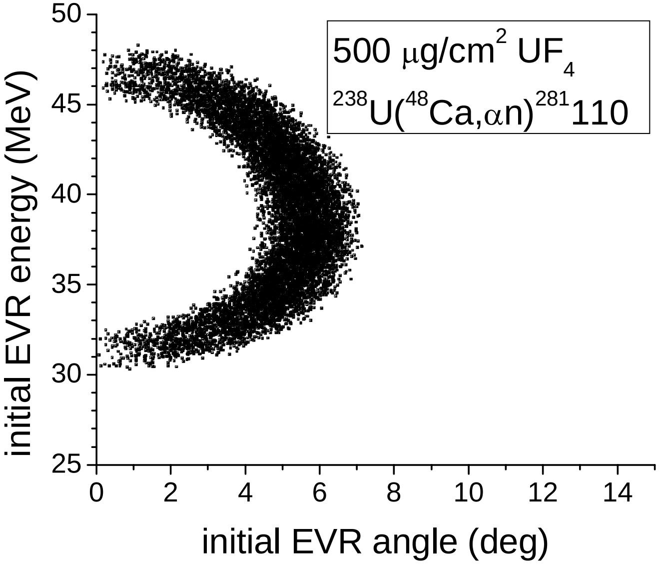


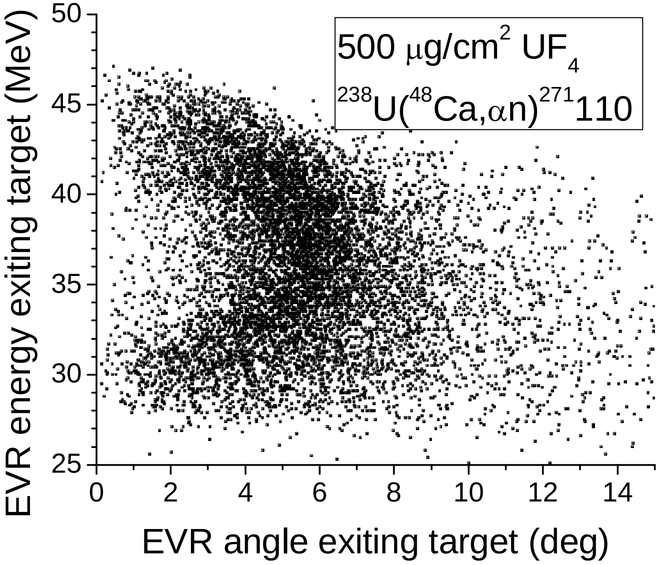
SRIM2003 propagation to end of target

Monte Carlo sim. of particle trajectories in gas-filled magnets

BGS efficiency for ^{238}U(^{48}Ca,3n)^{283}112

59%





BGS efficiency for ^{238}U(^{48}Ca,αn)^{281}Ds

42%

Are the UF_4 Targets Any Good?

Targets are 475-611μg/cm^2 UF_4 evaporated onto 2-μm Al foils. This thickness is good for the BGS.

On two sets of targets, some of the UF_4 flaked off the Al foils during the first minutes of irradiation (with low-intensity ^{48}Ca beams). Luminocity is determined by # of Rutherford-scattered ^{48}Ca ions . . . The cross section limits given are correct.

α-spectroscopy of the ^{238}U shows no large change in the thickness 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.

Atomic Force Microscopy shows a change in the UF_4 structure. Thickness variations are within acceptable limits.

Conclusion: Targets are good (although not perfect)

Why Don't We see 5-s 9.5-MeV ^{283}112?

Is there a problem with the BGS targets?

Yes, but luminocity is determined with Rutherford-scattered beam.

Is there a systematic difference in beam energies from the accelerators at LBNL and Dubna?

No, ^{48}Ca + ^{208}Pb excitation functions match to within 2 MeV.

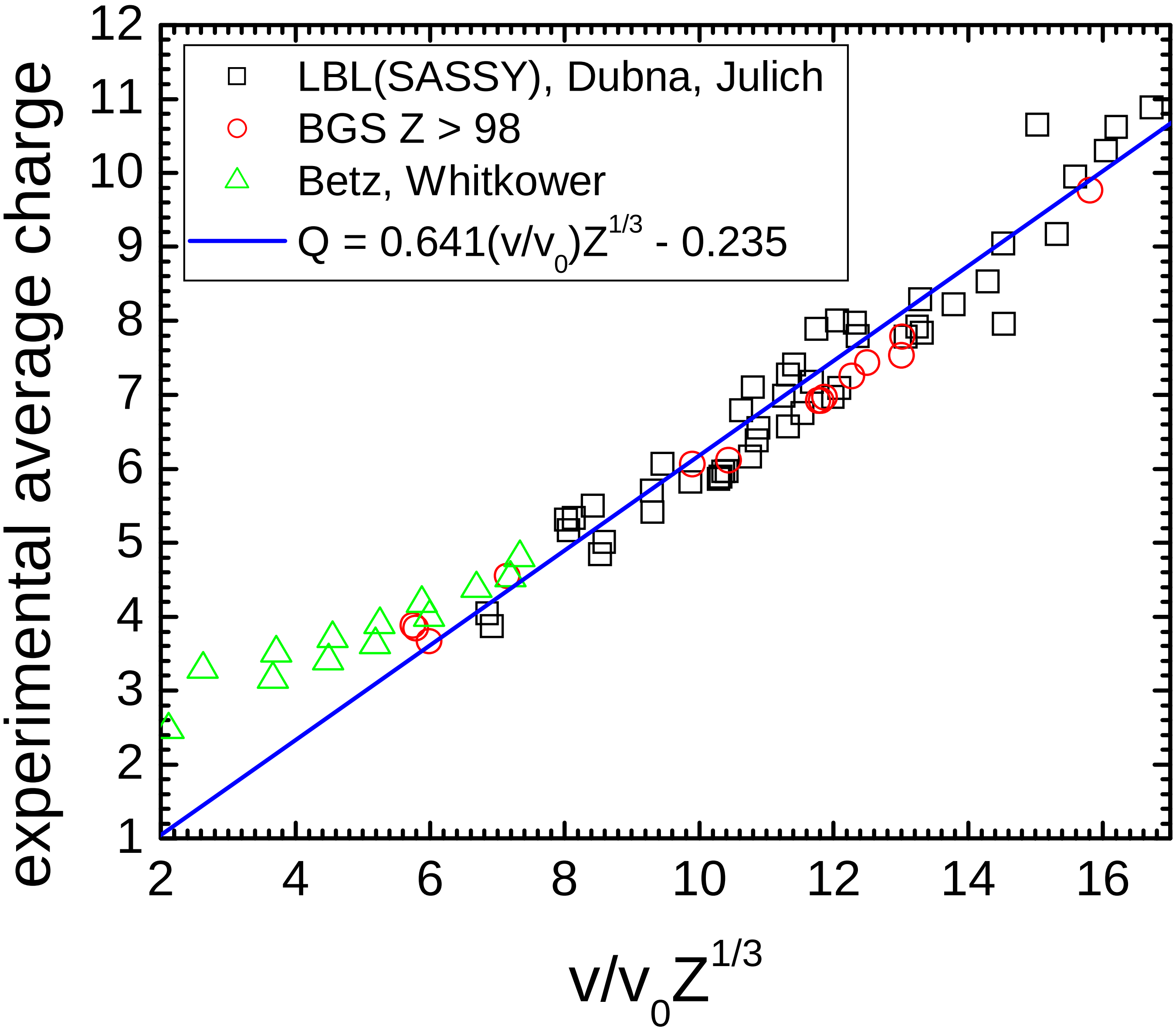
Do we have a different beam energy in our uranium targets due to errors in energy loss calculations?

No, pulse-height of Rutherford-scattered ^{48}Ca is within ~1 MeV.

Did we run the BGS at the wrong magnet settings?

What is the ^{283}112 magnetic rigidity?

Back to basics . . .



Back in 1948, Neils Bohr suggested a

$q = vZ^{1/3}$ dependence

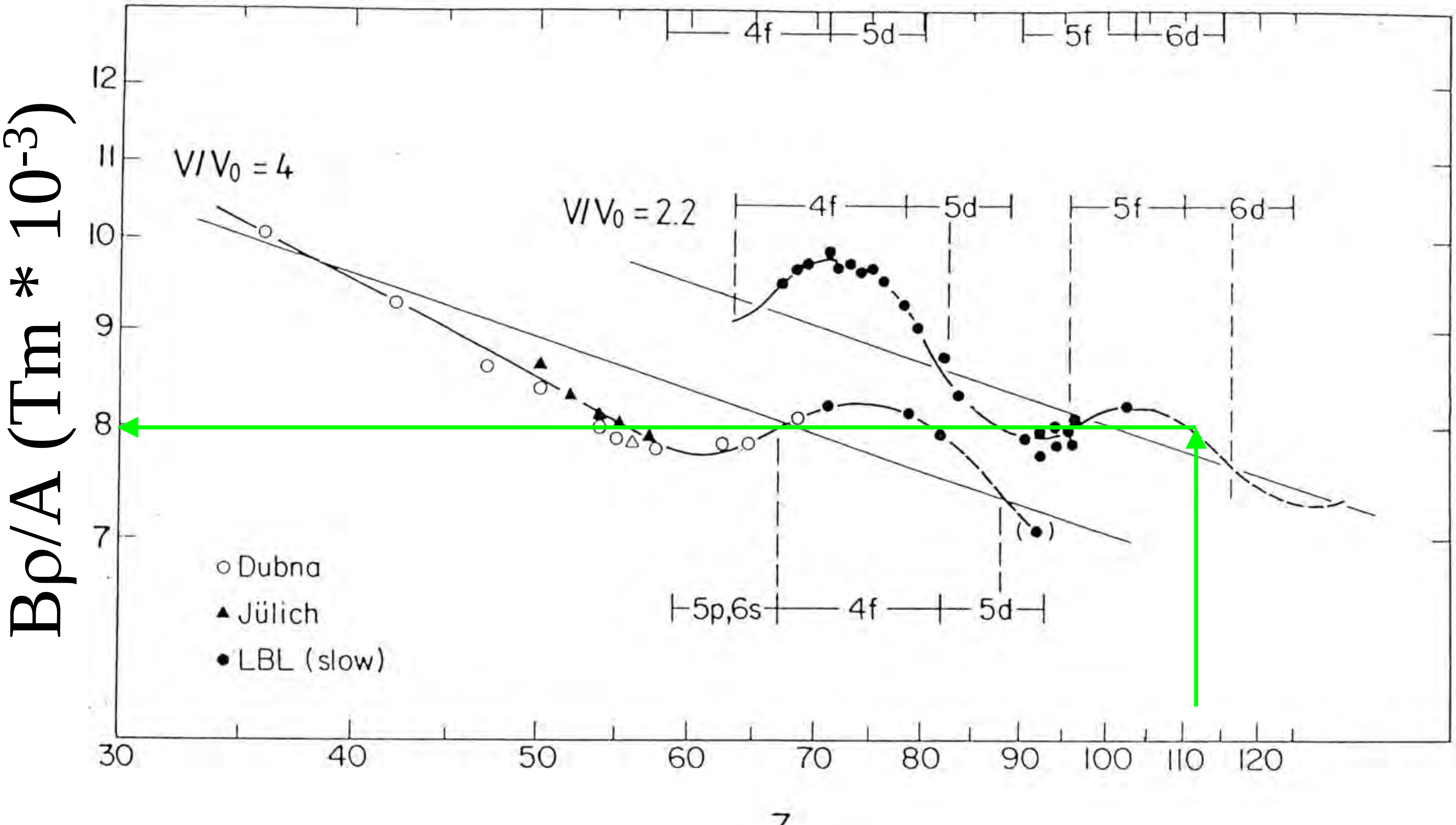
This fit shows much scatter. Deviations are +/- 10%. Can this be understood in terms of the electronic shell structure of the stripped ions?

What is the $^{283}112$ magnetic rigidity?

According to Ghiorso and Armbruster . . .

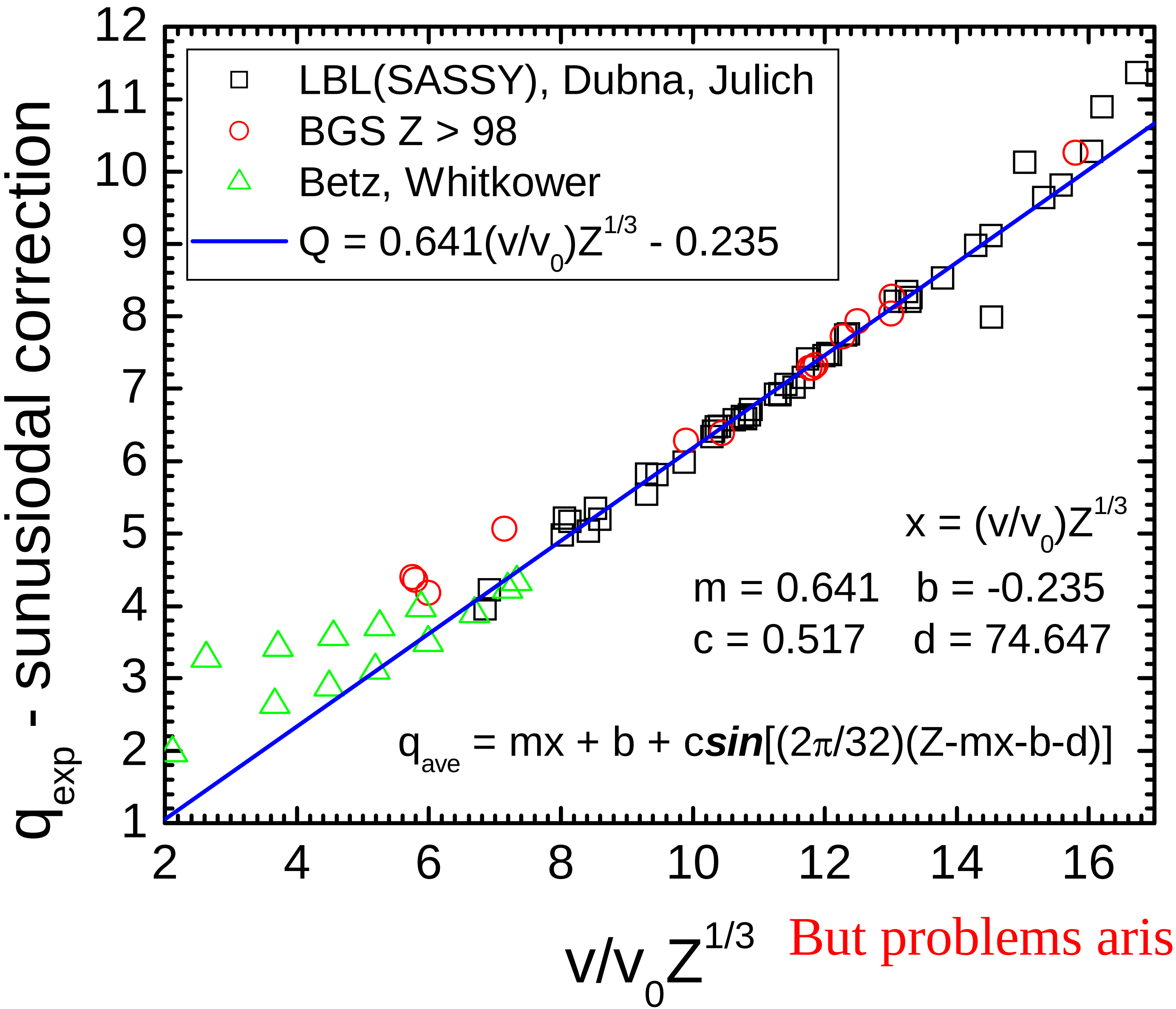
$B\rho/A = 7.96$ $B\rho = 2.25$ Tm

Clearly, the electronic shell structure of the stripped ion is important



What is the ^{283}112 magnetic rigidity?

The Armbruster/Ghiorso plot suggests a sinusoidal correction . . .



Semi-empirical understanding of why this works:

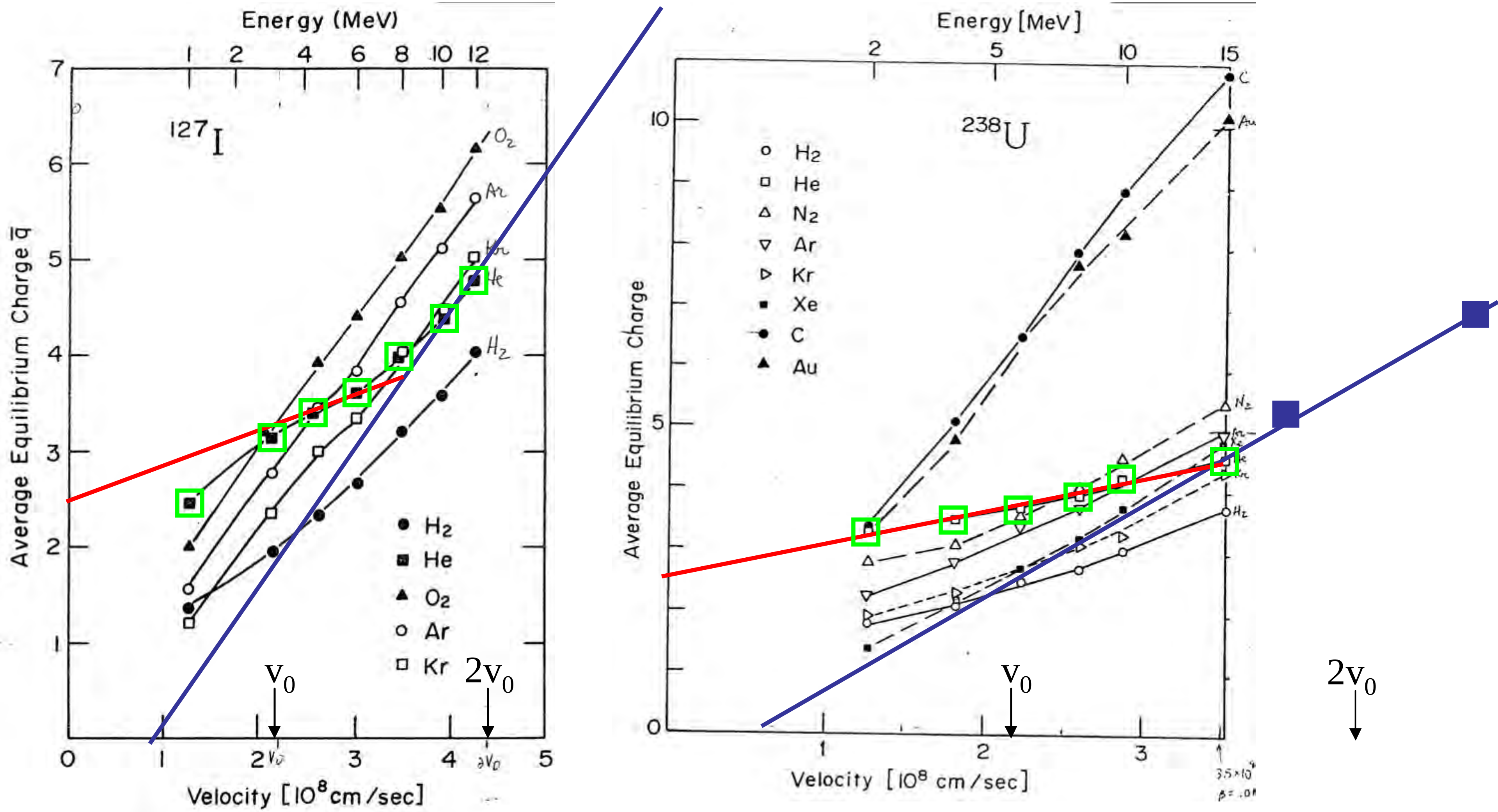
If the stripped ion is in an f-orbital, the most loosely bound electrons are inner electrons, and are less available for stripping by the gas, giving a lower q.

If the stripped ion is in a p-orbital, the most loosely bound electrons are outer electrons, and are readily available for stripping by the gas, giving a higher q.

But problems arise at low velocities!

What is the $^{283}112$ magnetic rigidity?

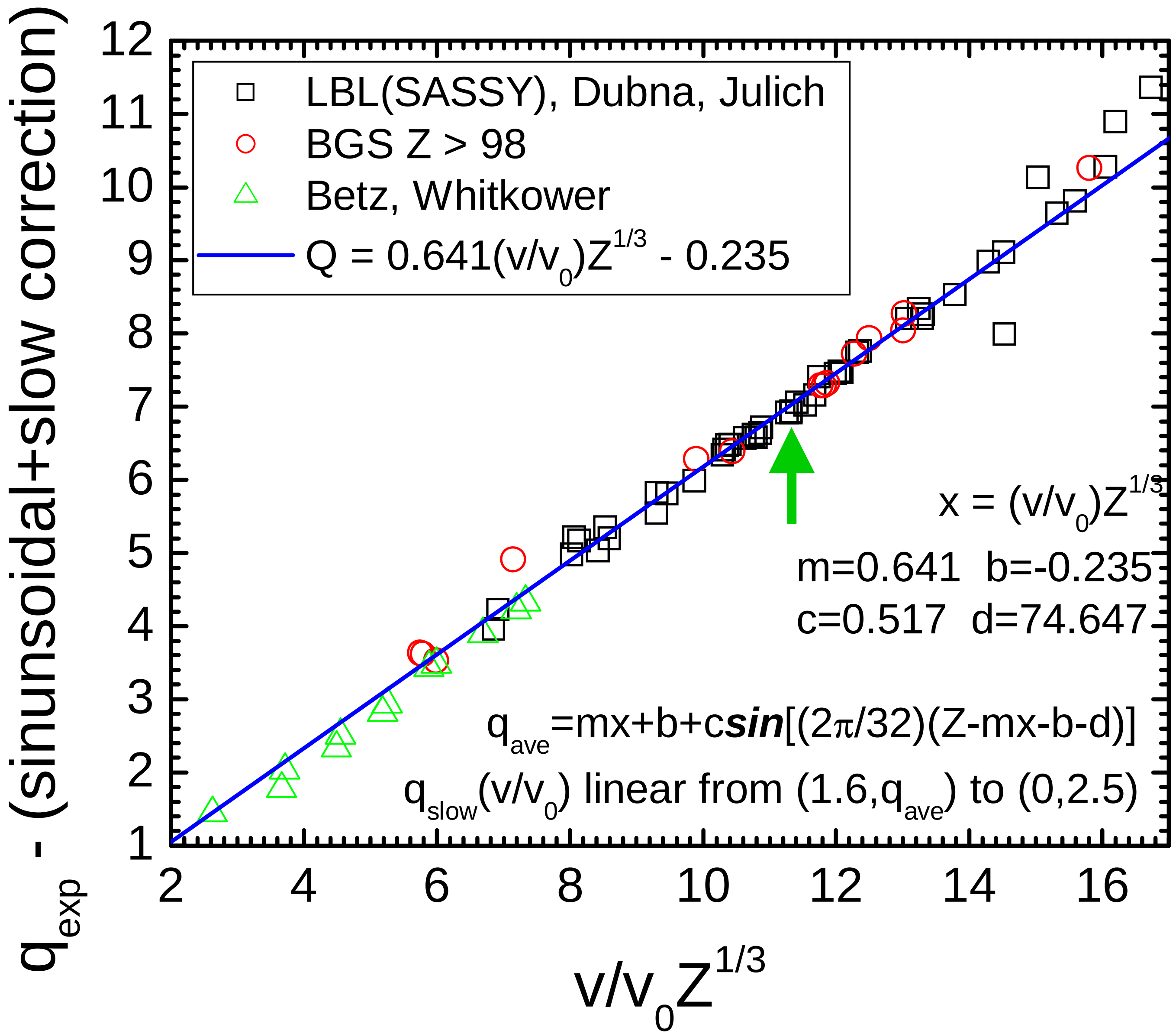
Iodine and uranium data show a break at $v = 1.6v_0$



The red lines trend toward q = 2.5 at v = 0 because the first of ionization potential of He is 25 eV. This is usually between the second and third ionization potentials of heavy elements.

What is the ^{283}112 magnetic rigidity?

Putting it all together . . .



$v/v_0 = 2.35$ (>>1.6)

no slow EVR correction

$(v/v_0)Z^{1/3} = 11.33$

gives q = 6.86

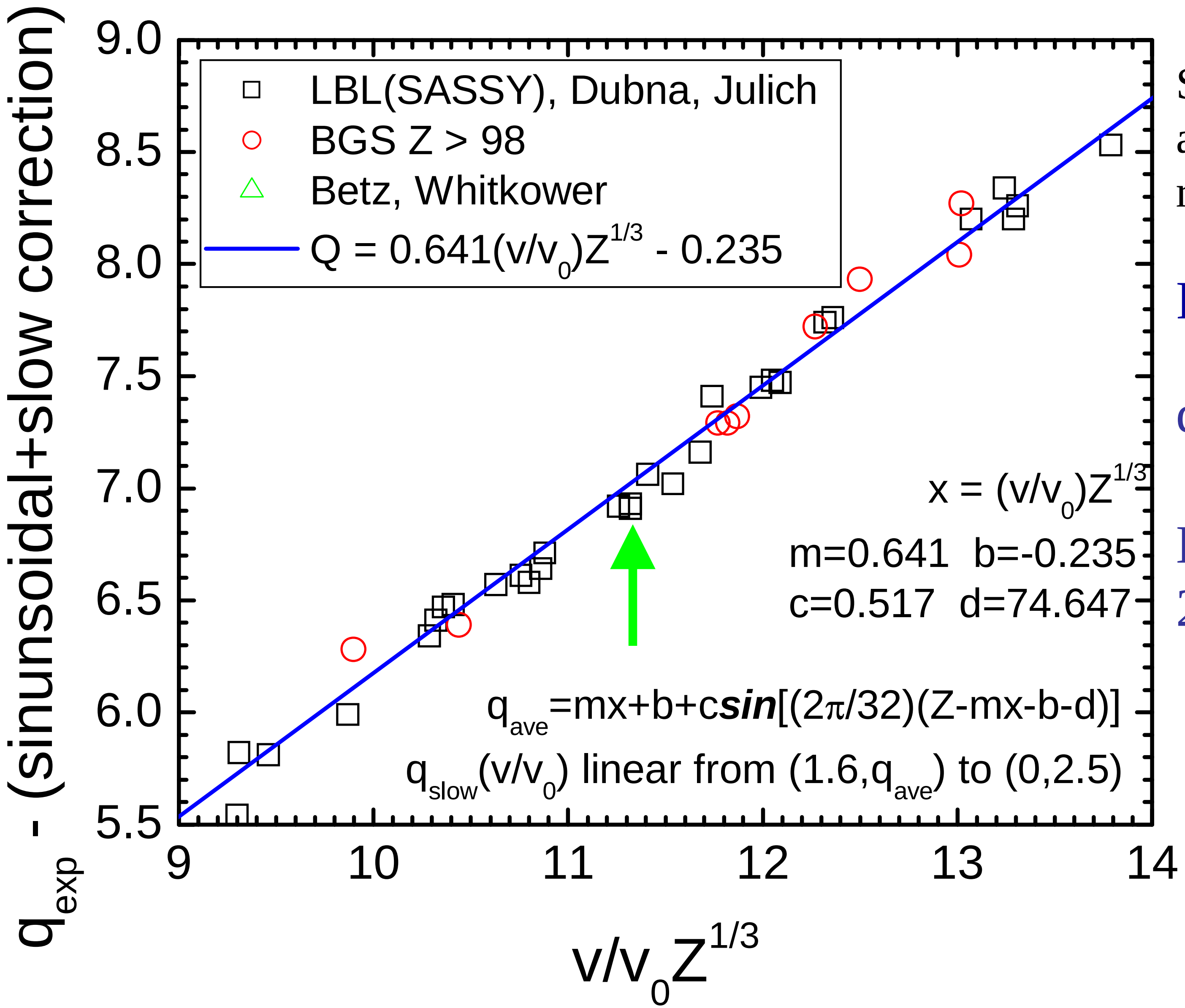
in the region of best fit to q vs. $(v/v_0)Z^{1/3}$ data

Bρ = 2.20 Tm

compares well with RIKEN and SASSY predictions of 2.17 Tm and 2.25 Tm

What is the ^{283}112 magnetic rigidity?

Estimating the uncertainty in the ^{283}112 Bρ prediction



Standard deviation about the fit in this region is 0.103

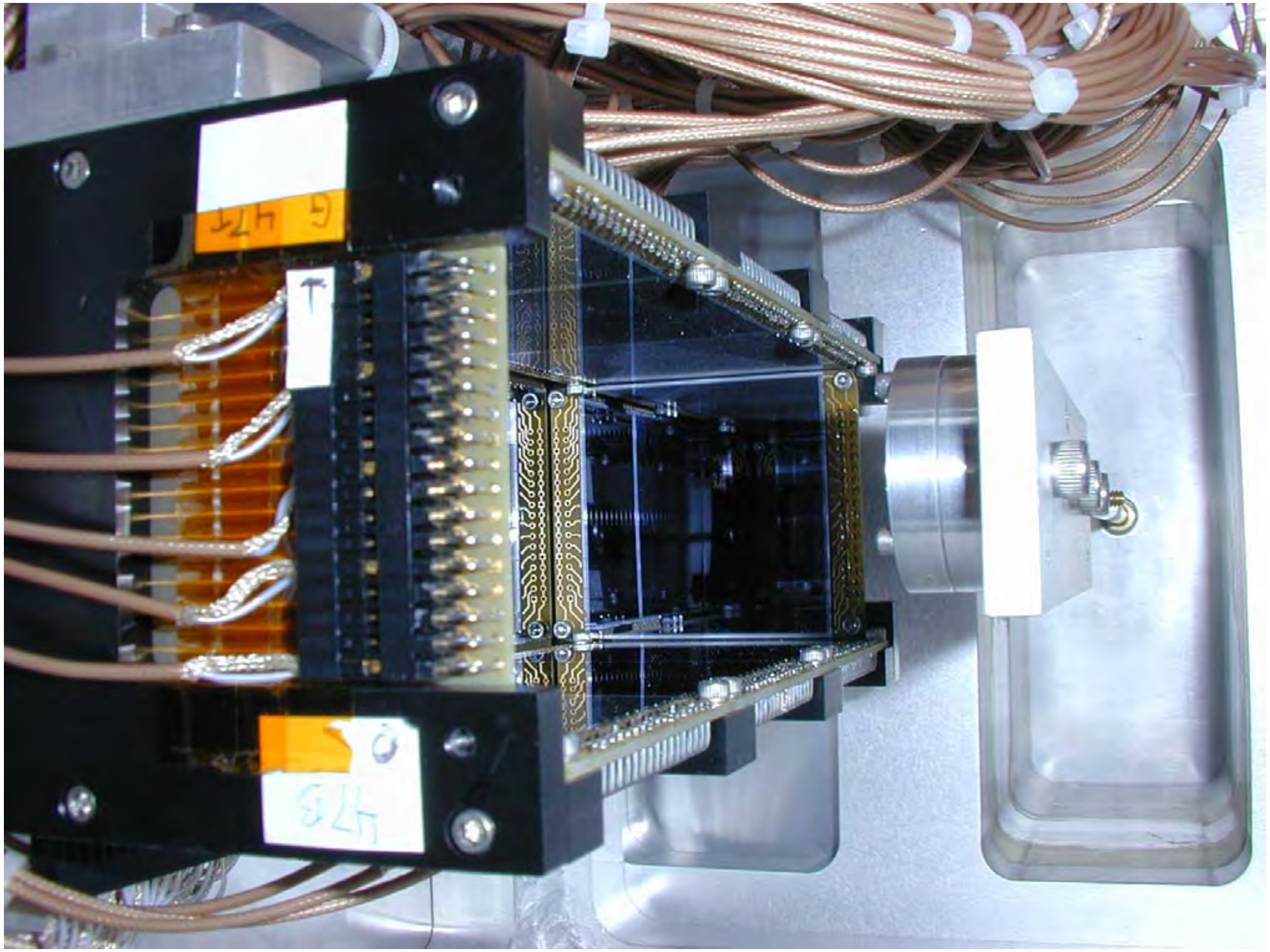
For our ^{283}112:

$q = 6.86 \pm 0.103$

Bρ =
2.20 ± 0.032 Tm

What is the ^{283}112 magnetic rigidity?

Effect of the uncertainty in the ^{283}112 $B\rho$ prediction



$B\rho = 2.20 \pm 0.032$

$B\rho = 2.20 \pm 1.5\%$

BGS $\delta x'/\delta B\rho = 1.8$ cm/%

16-cm wide MWAC and
18-cm wide Si-strip array:
detector covers 9% in $B\rho$
(+/– 4.5%)

a 3σ $B\rho$ error results in half of the EVR distribution missing the detector, and would double the cross section upper limits.

Why Don’t We see 5-s 9.5-MeV ^{283}112?

Is there a problem with the BGS targets?

Yes, but luminocity is determined with Rutherford-scattered beam.

Is there a systematic difference in beam energies from the accelerators at LBNL and Dubna?

No, ^{48}Ca + ^{208}Pb excitation functions match to within 2 MeV.

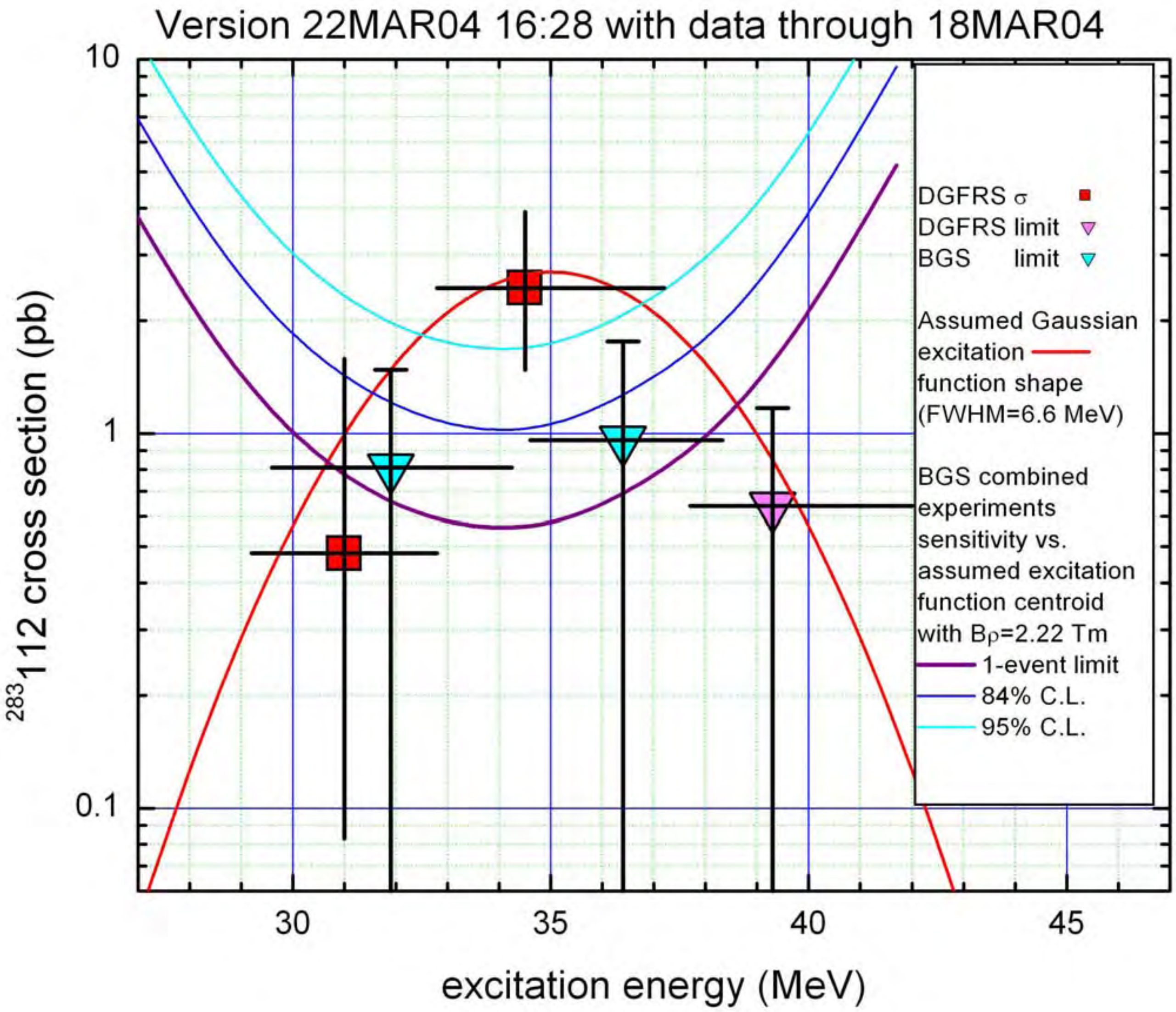
Do we have a different beam energy in our uranium targets due to errors in energy loss calculations?

No, pulse-height of Rutherford-scattered ^{48}Ca is within ~1 MeV.

Did we run the BGS at the wrong magnet settings?

No, this would require a 3σ deviation from systematics.

^{283}112 Cross Sections and Upper Limits



What’s next?

Development of ^{244}Pu target capability

^{244}Pu(^{48}Ca,xn)^{292}114 in 2005

Radiochemistry with BGS-RTC using reactions such as

Rf:	$^{244}\mathrm{Pu}(^{22}\mathrm{Ne},5n)^{261}\mathrm{Rf}$	$t_{1/2} = 78$ s	$^{208}\mathrm{Pb}(^{50}\mathrm{Ti},n)^{257}\mathrm{Rf}$	$t_{1/2} = 4$ s
Db:	$^{244}\mathrm{Pu}(^{23}\mathrm{Na},5n)^{262}\mathrm{Db}$	$t_{1/2} = 34$ s	$^{209}\mathrm{Bi}(^{50}\mathrm{Ti},n)^{258}\mathrm{Db}$	$t_{1/2} = 4$ s
Sg:	$^{244}\mathrm{Pu}(^{26}\mathrm{Mg},5n)^{265}\mathrm{Sg}$	$t_{1/2} = 17$ s		
Bh:	$^{244}\mathrm{Pu}(^{27}\mathrm{Al},4n)^{267}\mathrm{Bh}$	$t_{1/2} = 17$ s		
Hs:	$^{244}\mathrm{Pu}(^{30}\mathrm{Si},5n)^{269}\mathrm{Hs}$	$t_{1/2} = 19$ s		

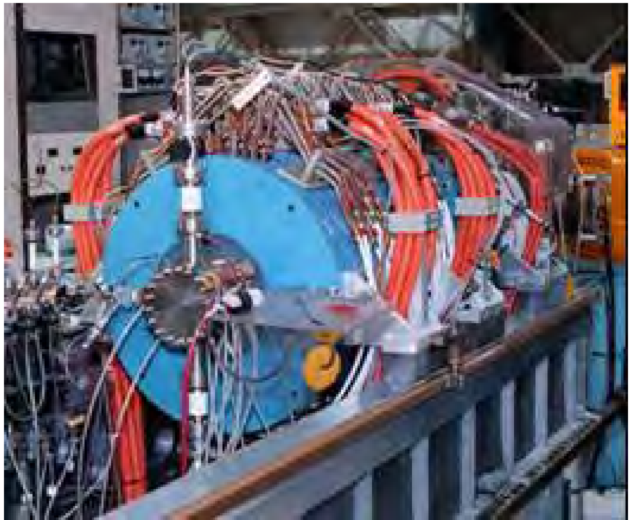
112: $^{244}\mathrm{Pu}(^{4}\ \mathrm{Ca},3n)^{287}114 \rightarrow {}^{283}112$ $t_{1/2} = 4$ s

. . .

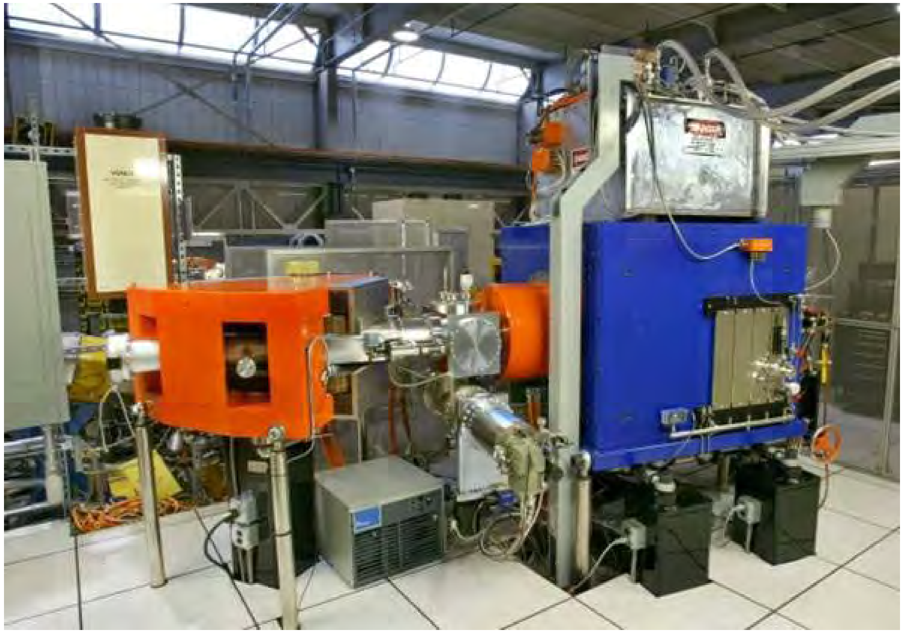
The LBNL 88-Inch Cyclotron

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

First Operation in 1961

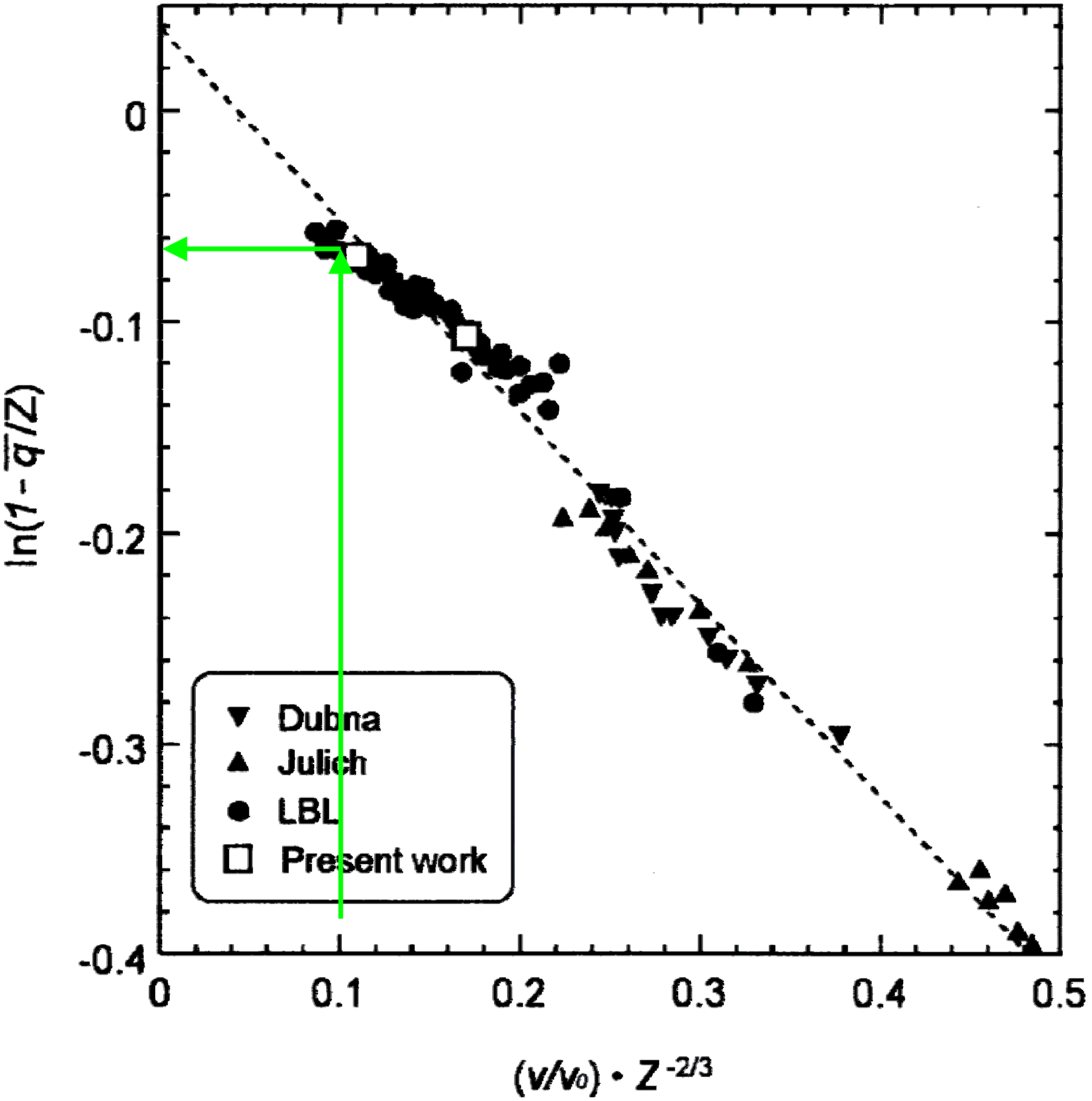


AECRU
(present)
and
VENUS
(Spring ’05)



What is the ^{283}112 magnetic rigidity?

According to RIKEN GARIS systematics . . .



$v/v_0 = 11.33$

$(v/v_0)Z^{-2/3} = 0.1012$

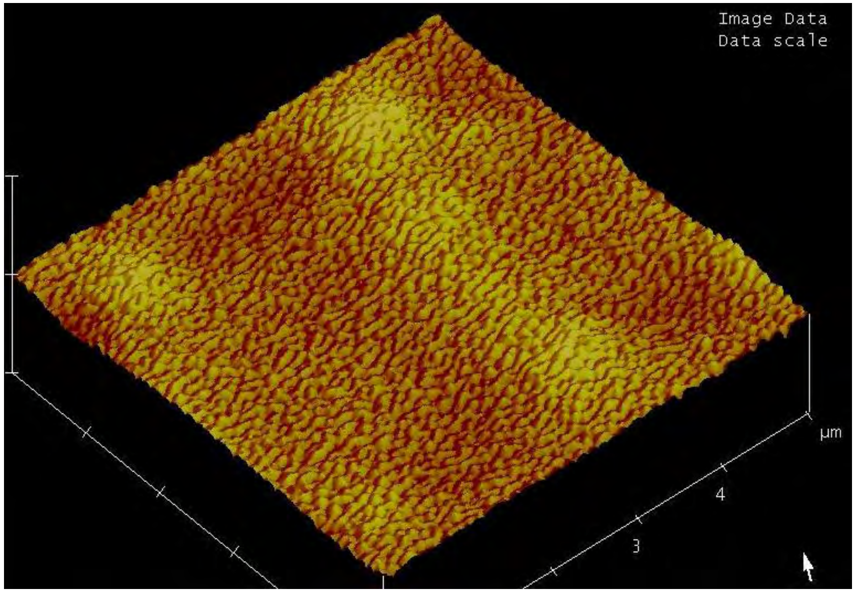
$\ln(1-q/Z) = -0.064$

$q = 6.94$

$B\rho = 2.17$ Tm

for small values of $\ln(1-q/z)$
small errors in $\ln(1-q/Z)$
lead to large errors in q

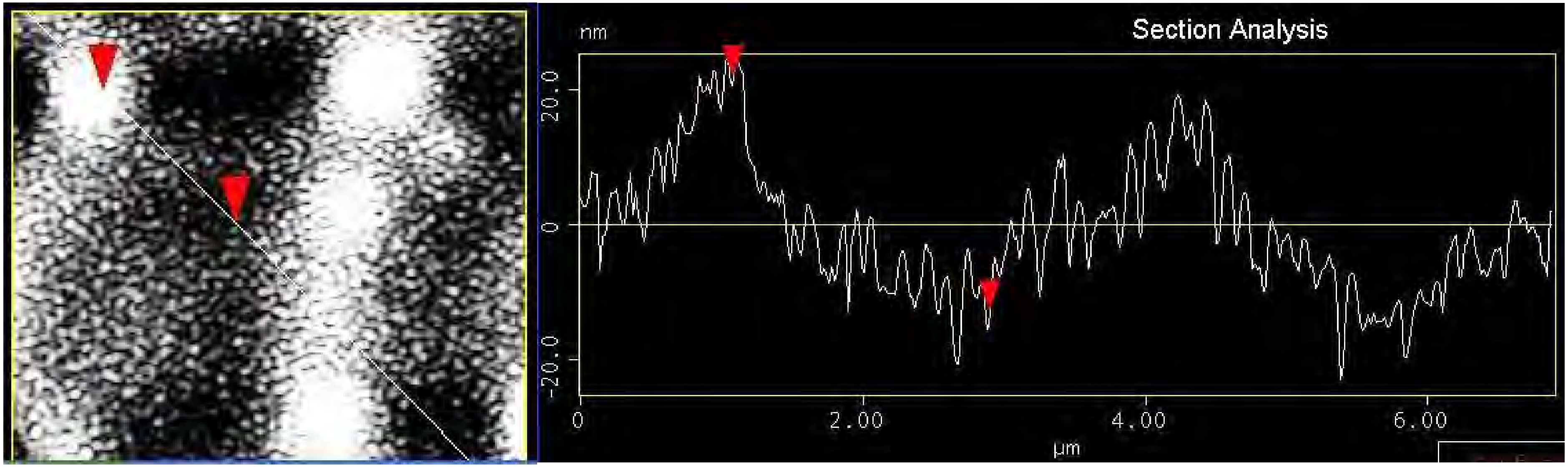
AFM of the edge of the UF_4 layer (outside the visible beam stripe)



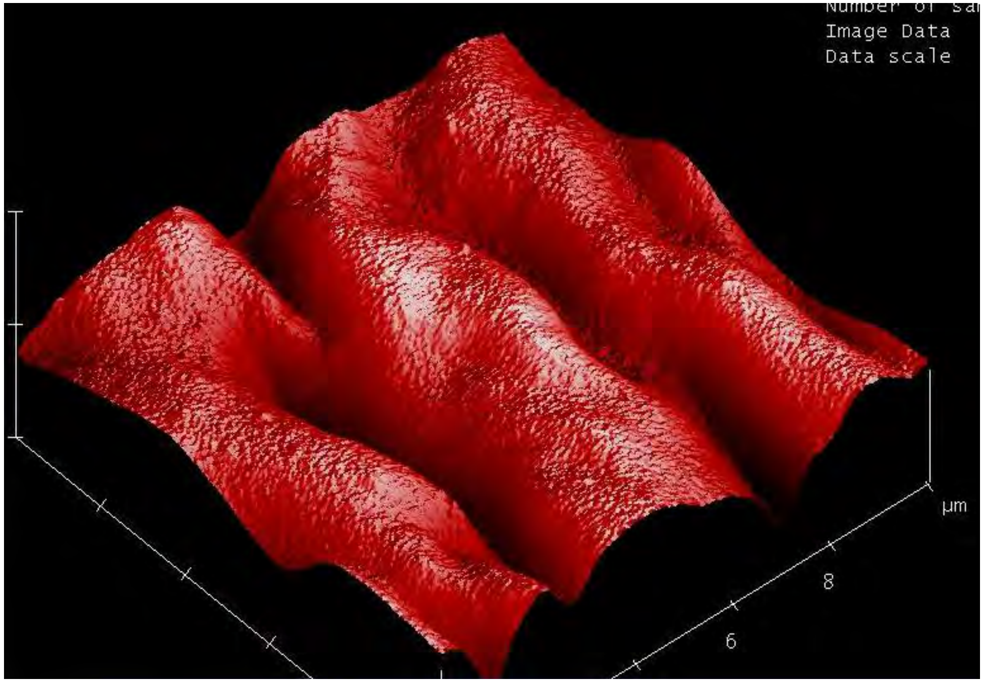
Overall UF_4 thickness is 900 nm

Crystalline structure

Thickness variations up to +/- 2%



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

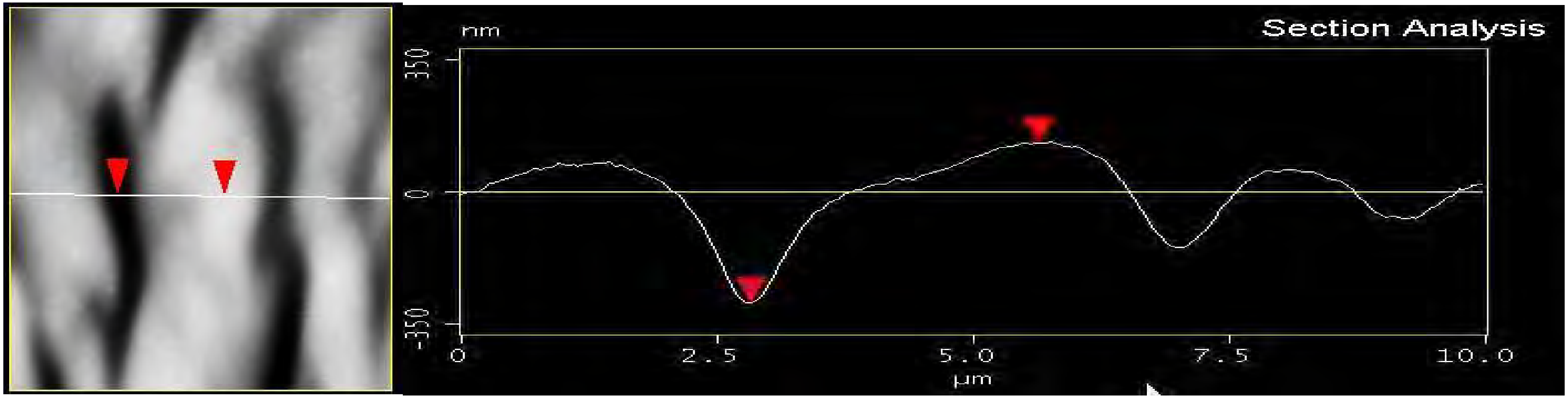


Overall UF4 thickness 900 nm

large-scale melting of UF_4

Variations up to +/- 20%

RMS thickness variations are much less than 10%



Why Don’t We see 4-s 9.54-MeV $^{283}112$?

Is there a problem with the BGS targets?

Is there a systematic difference in beam energies from the accelerators at LBNL and Dubna?

Do we have a different beam energy in our uranium targets due to errors in energy loss calculations?

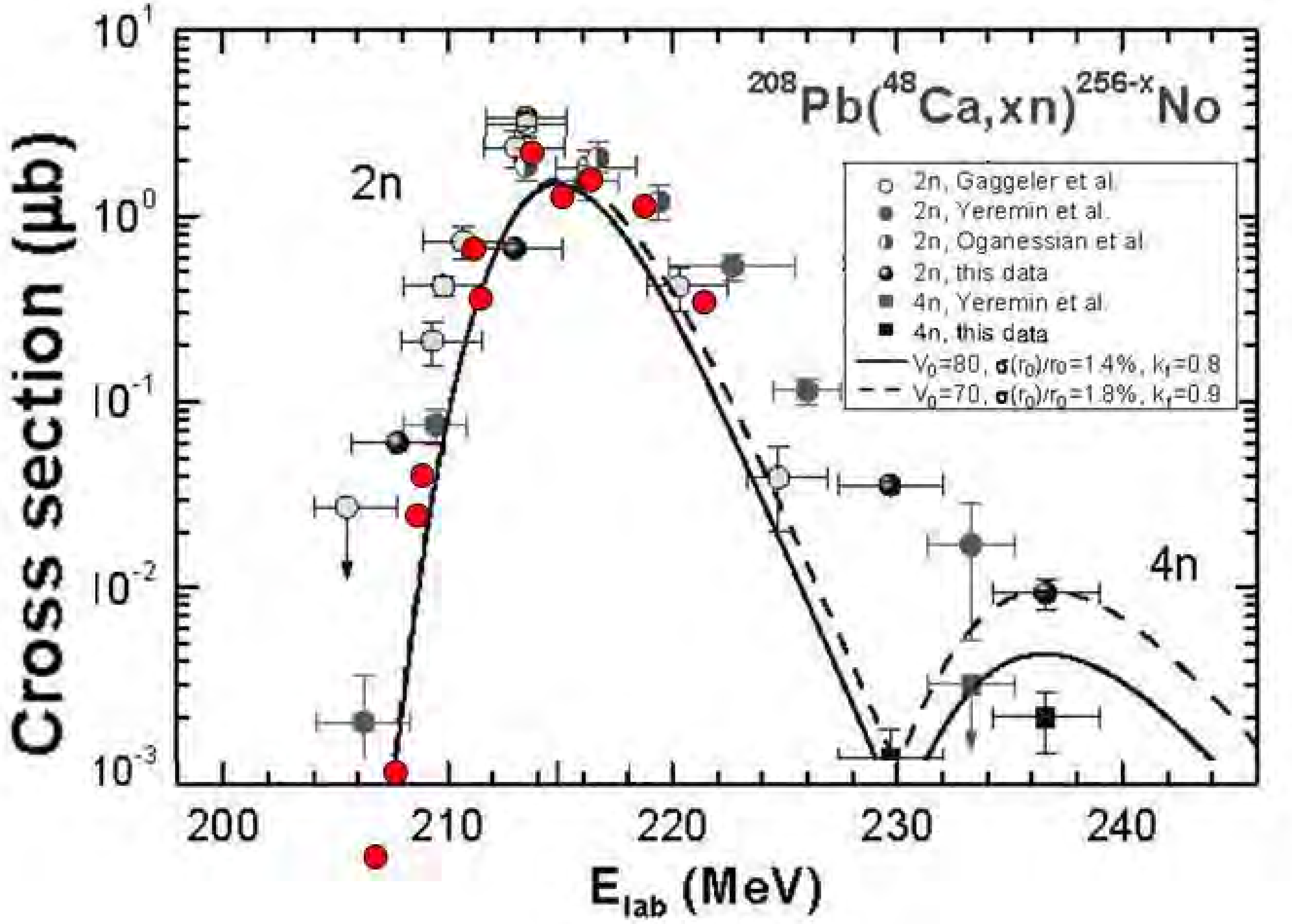
Did we run the BGS at the wrong magnet settings?

Is there a systematic difference in beam energies from the two accelerators?

Measurement of $^{208}Pb(^{48}Ca,2n)^{254}No$ shows that . . .

Absolute beam energy is accurate to within 1% (from comparison of excitation functions at right)

Beam energy reproducibility is accurate to within 0.5% FWHM (from a plot of pulse-height in a PIN diode vs. the square of the cyclotron frequency)



Are there errors in the energy loss calculation?

Measurement of pulse-heights for Rutherford-scattered beam particles, and a comparison with those for the Ca + Pb reactions show that the energies in our ^{48}Ca + ^{238}U experiments were accurate to within 0.5% (1.2 MeV)

Conclusion: There is no doubt that our TWO BEAM ENERGIES cover the peak of the Dubna excitation function.

Run052	RE Ca + ^{206}Pb	RW Ca + ^{206}Pb	RE Ca + ^{238}U	RW Ca + ^{238}U
48Ca E at end of tgt	211.7	211.7	227.6	227.6
^{48}Ca E after scatter	202.7	202.4	218.0	217.6
E-P.H.D.	197.7	197.4	**212.8**	**212.4**
peak channel	1743.7	2348.5	1884.5	2527.5
E by Ruth. Ratio			**213.7**	**212.4**

Run070	RE Ca + ^{207}Pb	RW Ca + ^{207}Pb	RE Ca + ^{238}U	RW Ca + ^{238}U
48Ca E at end of tgt	211.8	211.8	233.5	233.5
^{48}Ca E after scatter	202.8	202.5	223.6	223.3
E-P.H.D.	197.8	197.5	**218.3**	**218.0**
peak channel	1556.7	1585.8	1724.2	1763.5
E by Ruth. Ratio			**219.1**	**219.6**