Attempt to confirm superheavy element formation in the ^{48}Ca + ^{238}U reaction

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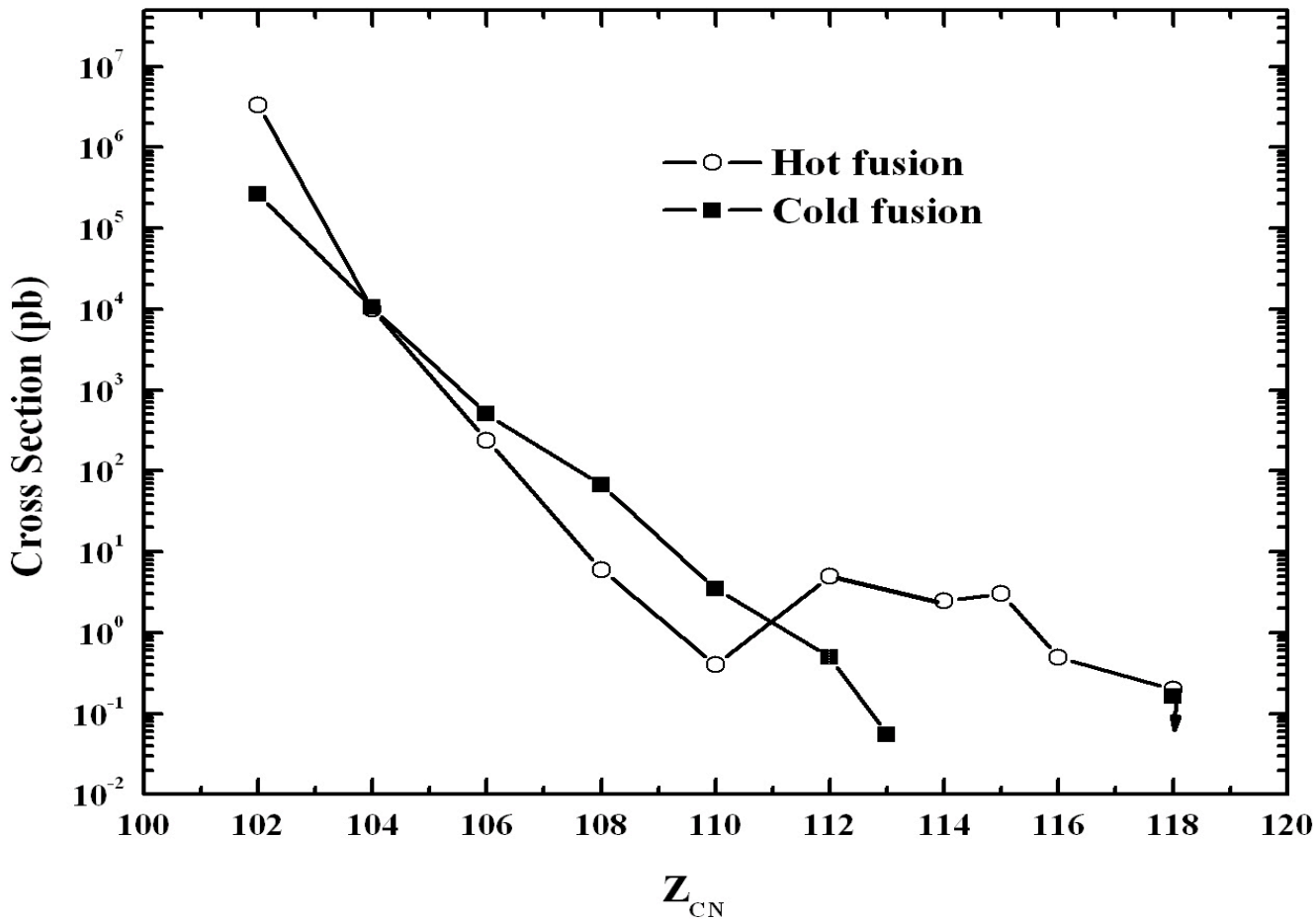
Heavy Element Synthesis



Search for Element 112 in the $^{238}U(^{48}Ca,3n)$ Reaction

- Y.T. Oganessian et al. reported (Eur. J. Phys A5, 63 (1999))
- 231 MeV $^{48}Ca + ^{238}U \rightarrow ^{286}112 \rightarrow ^{283}112 \rightarrow SF$
- Two events were observed (t_ = 81 (+147, -32) s)
- Dose = 3.5 x 10^{18}, σ = 5.0 (+6.3, -3.2) pb
- Somewhat unexpected decay mode

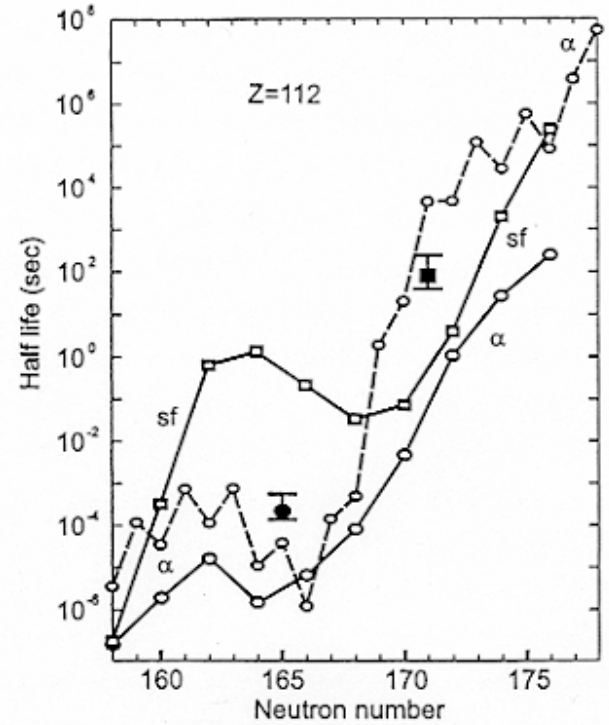


Fig. 2. Theoretical predictions for partial α and SF half-lives for isotopes of element Z = 112. Open circles and open squares connected by solid lines: $T_{1/2,\alpha}$ and $T_{1/2,SF}$ from [16]. Open circles connected by a dashed line: $T_{1/2,\alpha}$ from [12]. Filled cir- $T_{1/2,\alpha,exp}$ for $^{277}112$ from [14]. Filled square: $T_{1/2,SF,exp}$ this work and tentatively assigned to $^{283}112$

What is so special about $^{283}112$ and its synthesis?

- $^{283}112$ occurs in the decay of $^{291}116$ formed in the $^{245}Cm + ^{48}Ca$ reaction.
- $^{283}112$ occurs in the decay of $^{287}114$ formed in the $^{244}Pu + ^{48}Ca$ reaction.
- $^{283}112$ should be the most easily reachable hot fusion product.

Chronology of Studies of $^{238}U(^{48}Ca,3n)\ ^{283}112$ Reaction

- **1999--Vassilissa group reports synthesis of $^{283}112$ with σ ~ 5 pb, $t_{1/2}$ ~ 3 m, decay =SF, E_{lab}=231 MeV**
- **2002--BGS group fails to find $^{283}112$, σ_{upper}~ 0.9 pb, 0<$t_{1/2}$<1000s, decay =α,SF, E_{beam} =231 MeV**
- **2004--Vassilissa group fails to find $^{283}112$ at E_{beam} ~ 231 MeV, σ_{upper} ~ 2.2 pb.**
- **2004--Vassilissa group finds $^{283}112$ at E_{beam} ~ 234 MeV, σ ~ 4 pb, $t_{1/2}$ ~5.1 m, decay = SF**
- **2004--DGFRS group fails to find 5 min SF activity, says $^{283}112$ is an α-emitter with $t_{1/2}$ ~ 6 s (produces this nucleus directly and in decay of $^{291}116$ and $^{287}114$.)**
- **2004--BGS group tries again to make $^{283}112$ at E_{beam} ~ 236 MeV without success.**
- **2005--Swiss group fails to confirm DGFRS or Vassilisa results**
- **2005--GSI group fails to confirm DGFRS or VASSILISSA results but finds one event (t~7 s, decay =SF, σ=0.5 pb)--disagrees with everyone.**

Summary of BGS Experiments

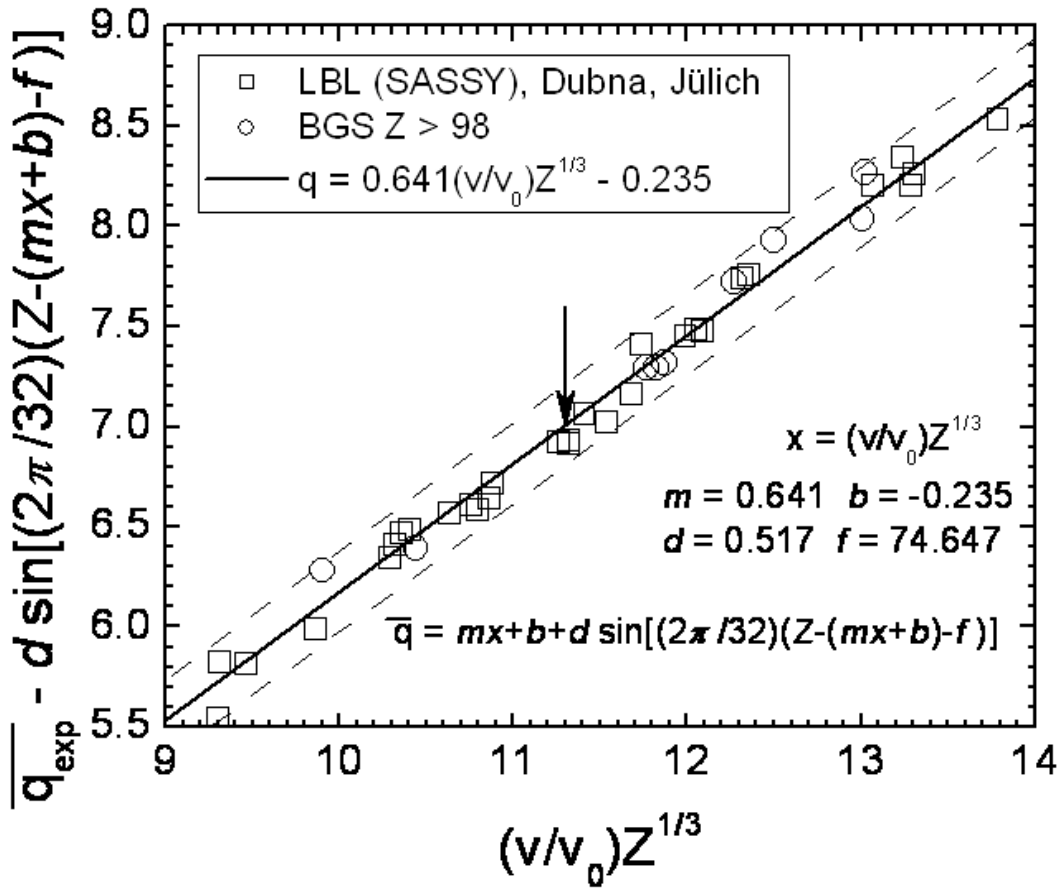
Energy (MeV)	230.3	235.6
No. of runs	2	1
E*(MeV)	31.9	36.3
Dose	2.3×10^{18}	1.9×10^{18}
1 event upper limit (pb)	0.8	0.96
84% CL Upper Limit (pb)	1.6	2.0

RESULTS

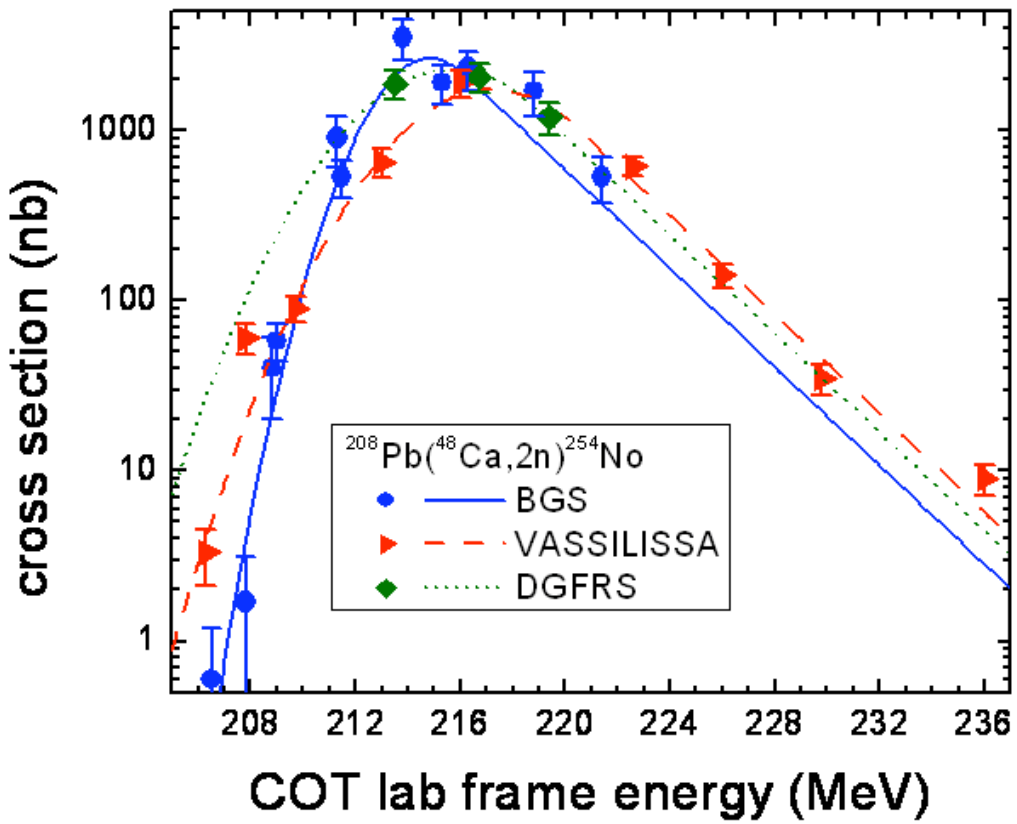
No SF events in any irradiation

No EVR-α-α correlations (T < 20 s) in any irradiation.

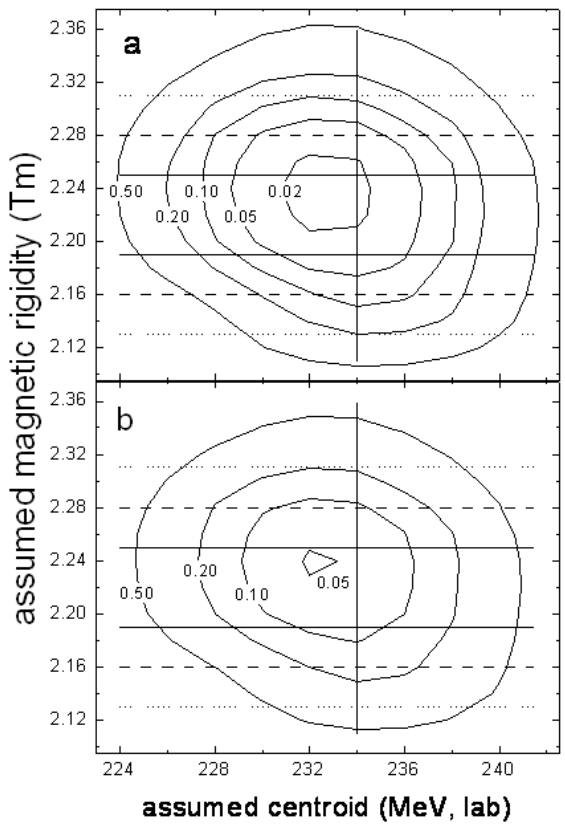
Do we understand Bρ(q)?



Did we use the wrong beam energy?



Consistency with Dubna/Livermore results?



$^{48}Ca + ^{238}U \rightarrow ^{286-x}112 + xn$ at DGFRS and SHIP

E*/MeV	dose/10^{19}	events	$T_{1/2}$ (parent)	x	σ/pb (1 ev. limits)
31.4	0.58	1 (ER-[α]-sf)*	(3.4 s)	3	0.5 +1.2 −0.4
32.0	0.7	0	--		< 0.8
35.0	0.71	2 (ER-[α]-sf) 3 (ER- α -sf) 1 (ER-4α-sf)	(1.4 s) 2.7 s 6.1 s	3	2.5 +1.8 −1.1
34.5	1.0	1 (ER-sf)	5.2 s	?	0.7 +1.6 −0.6
39.8	0.52	1 (ER-sf)	0.14 ms	4	0.6 +1.6 −0.5
37.0	1.2	0	--	--	< 0.6

* Dubna work: $T_{1/2}(^{279}Ds) = 0.18$ s, $b_{sf} = 0.9$

GSI

Summary of Experiments

- Vassilissa group $^{283}112$ is SF nucleus, with $t_{1/2}$ ~ 5 min, σ ~ 4 pb
- DGFRS group $^{283}112$ is α emitter (SF < 10%), $t_{1/2}$ = 6 s, σ ~ 2.5 pb
- GSI group $^{283}112$ is SF nucleus, $t_{1/2}$ ~ 5 s, σ ~ 0.7 pb
- BGS group $^{283}112$ not found, σ_{upper} ~ 0.9 pb

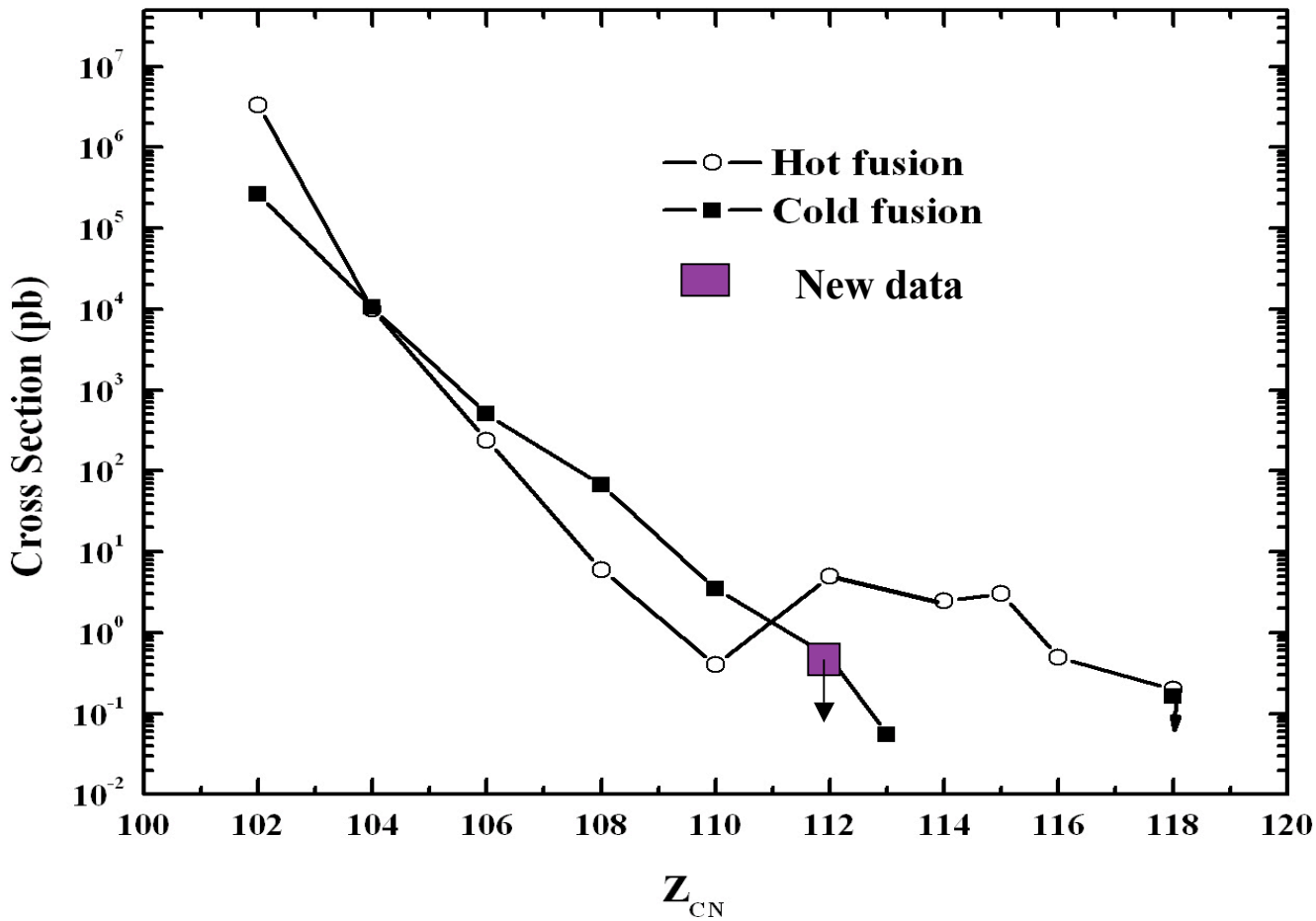
$^{238}U(^{48}Ca,xn)^{286-x}112$ Meta-analysis

Assume Gaussian excitation function with FWHM = 6.6 MeV, c = 234 MeV, A = 2.17 pb

Experiment	E_{cot} (MeV)	ΔE (MeV)	Dose (10^{18})	(pb/evt)	events expected	events observed
DGFRS 2004	230	3.1	5.8	0.5	1.6	1
DGFRS 2004	234	3.2	7.1	0.4	4.9	6
DGFRS 2004	240	3.1	5.2	0.6	0.4	0
					total=7.0	*total=7*
Vassilissa 1999	231	2.7	3.5	2.5	0.6	0
Vassilissa 1999	238	2.7	2.2	4.0	0.2	0
Vassilissa 2004	231	3.2	5.9	1.2	1.0	0
Vassilissa 2004	234	3.1	4.7	1.5	1.4 _=3.2	0
BGS 2001, 2005	230.3	4.7	2.3	0.8	1.5	0
BGS 2005	235.6	3.9	1.8	0.9	2.2 _=3.7	0
SHIP 2005	230.4	3.9	7.0	0.8	1.5	0
SHIP 2005	233.4	3.9	10.0	0.7	3.4	≤1
SHIP 2005	236.4	3.9	12.0	0.6	3.0 _=7.9	0
					total=14.8	*≤1*

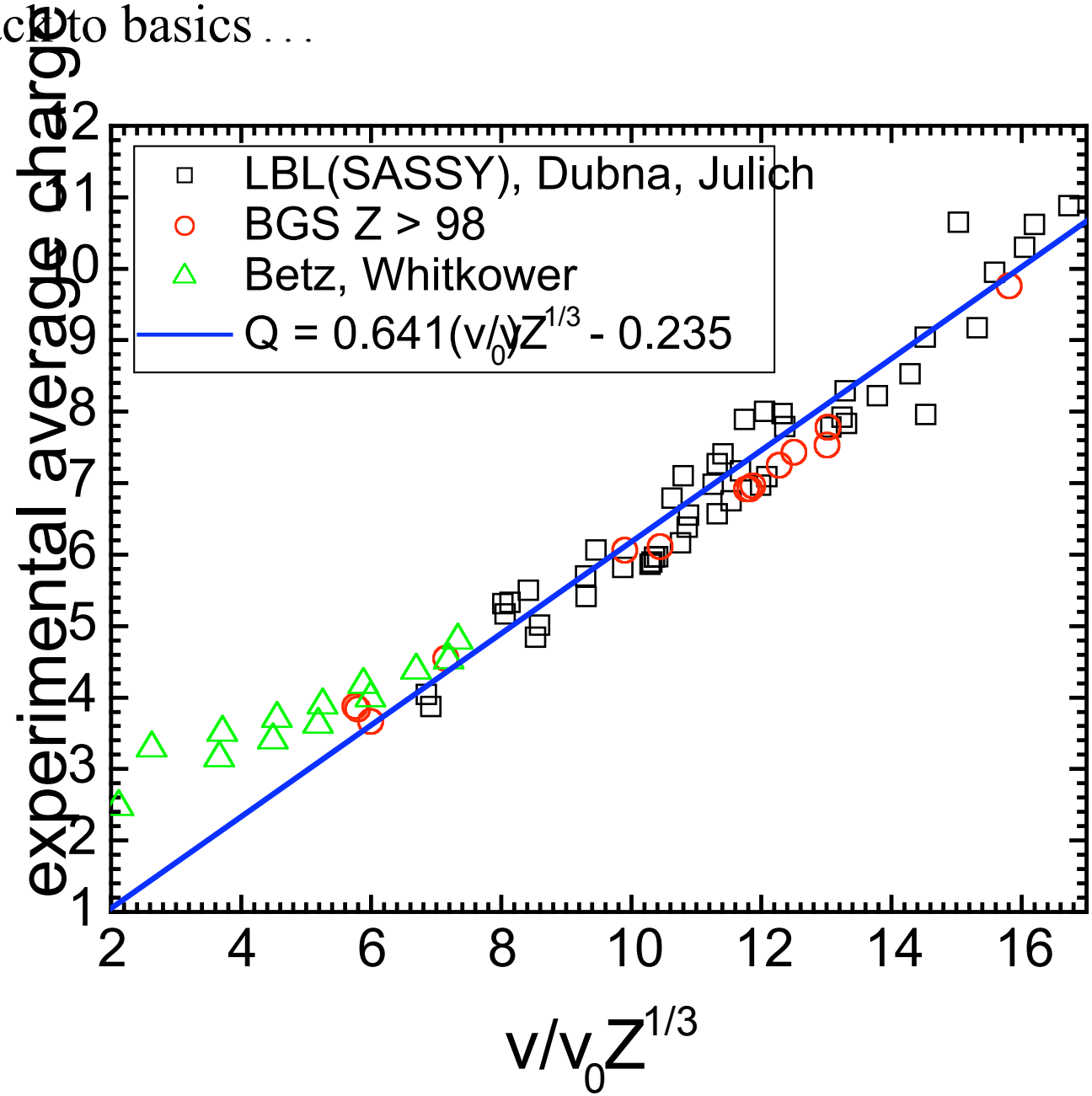
Similar results are obtained assuming larger energy spread in the targets or different true centroids

Heavy Element Synthesis



Understanding Magnetic Rigidity in He Gas

Back to basics . . .



Back in 1948, Neils Bohr suggested a

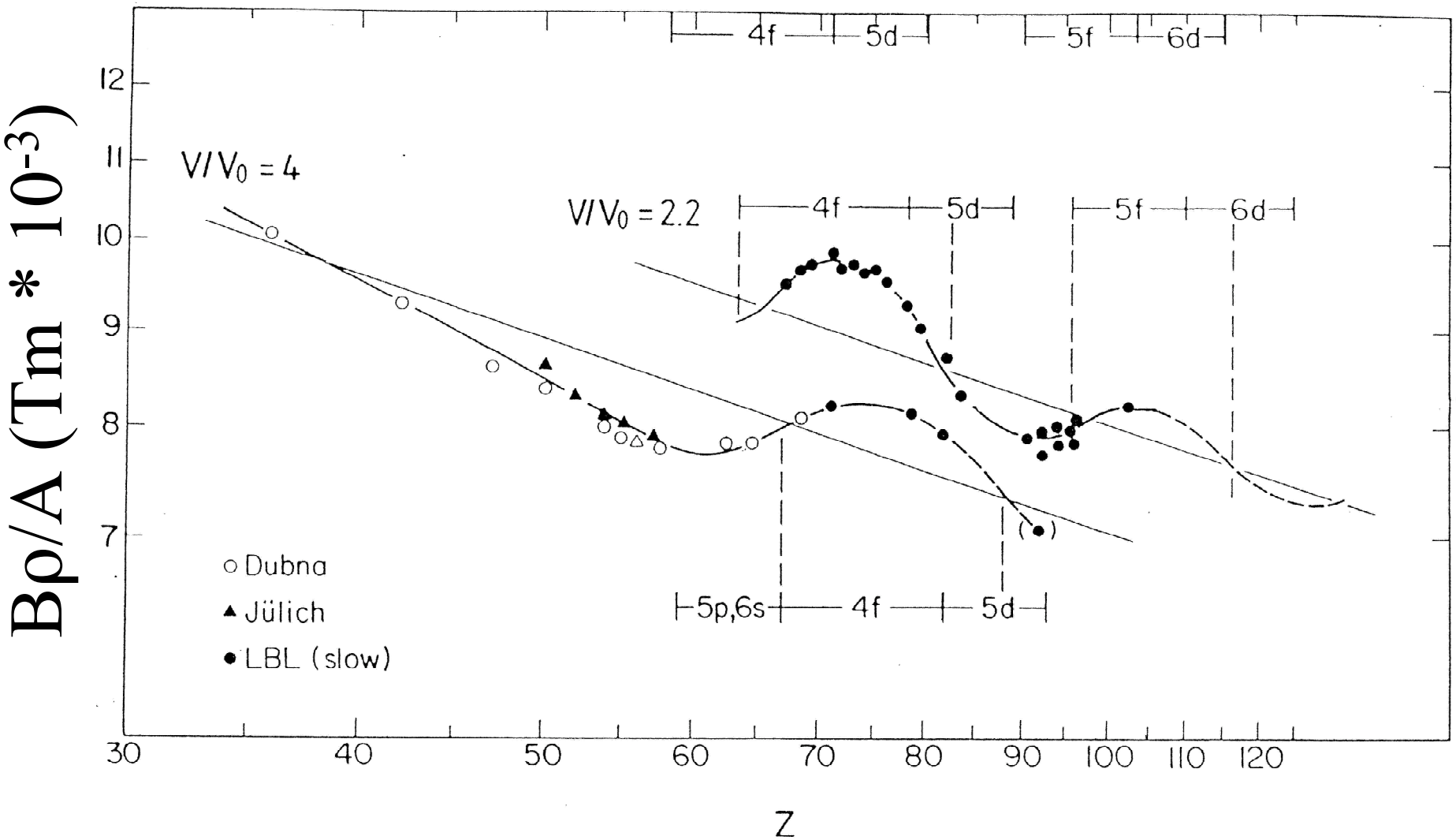
$q = vZ^{1/3}$ dependence

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

Strong deviations at low velocities due to the High ionization potential of He

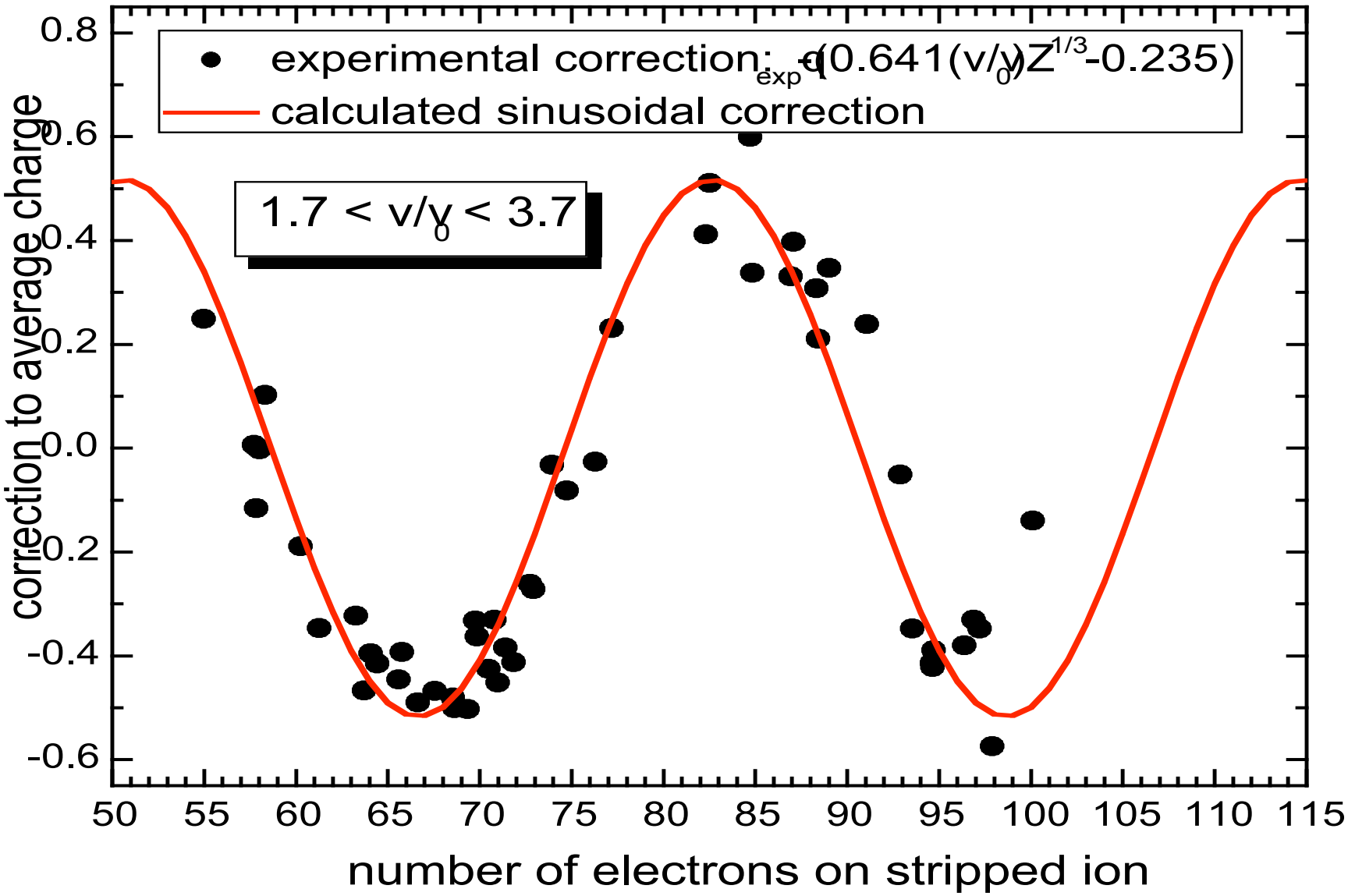
Understanding Magnetic Rigidity in He Gas

Ghiorso and Armbruster say look at electronic shells . . .



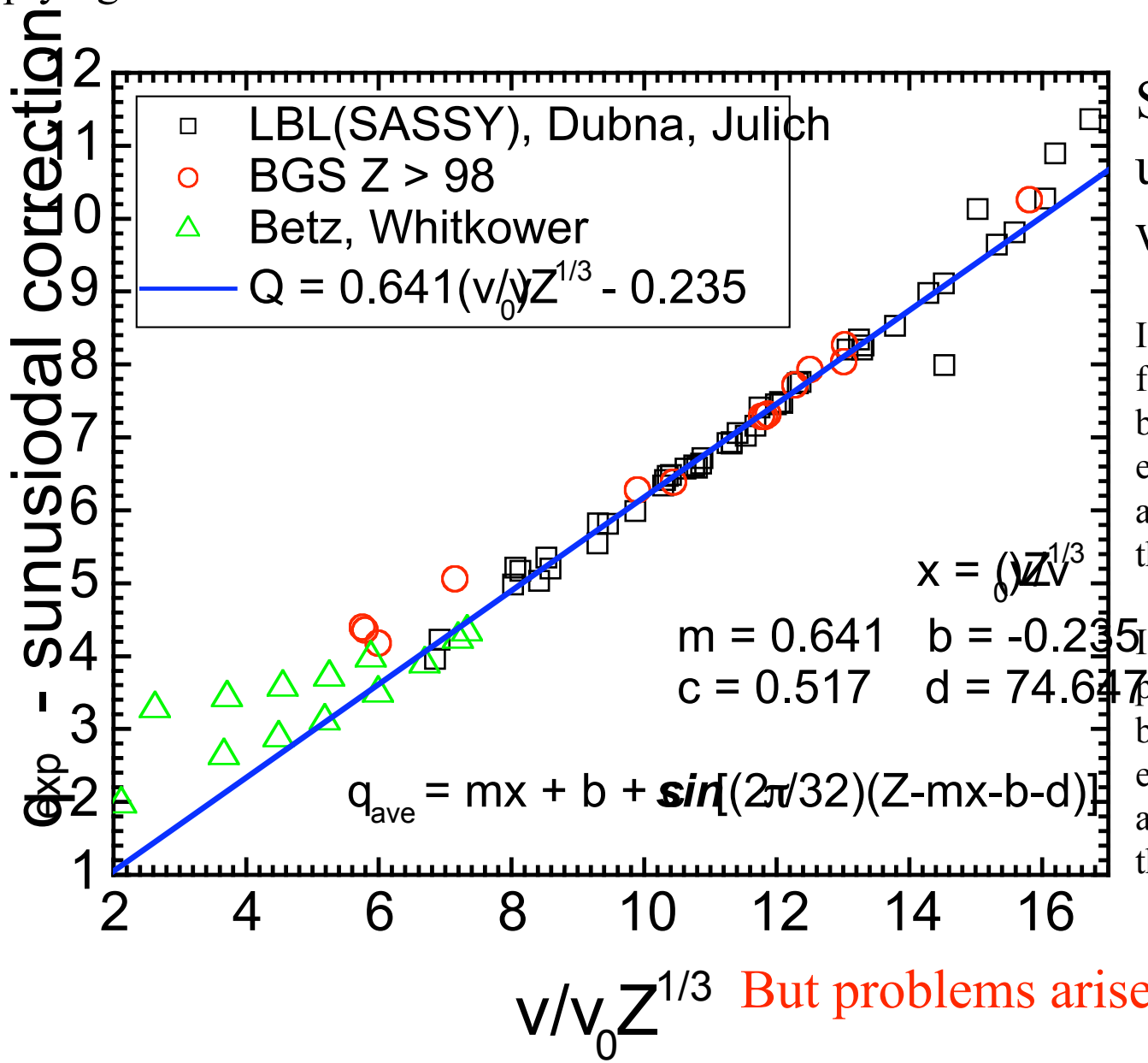
Sinusoidal Corrections to Average Charge in He

Comparison of experimental and calculated



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

Applying a sinusoidal correction . . .



But problems arise at low velocities!

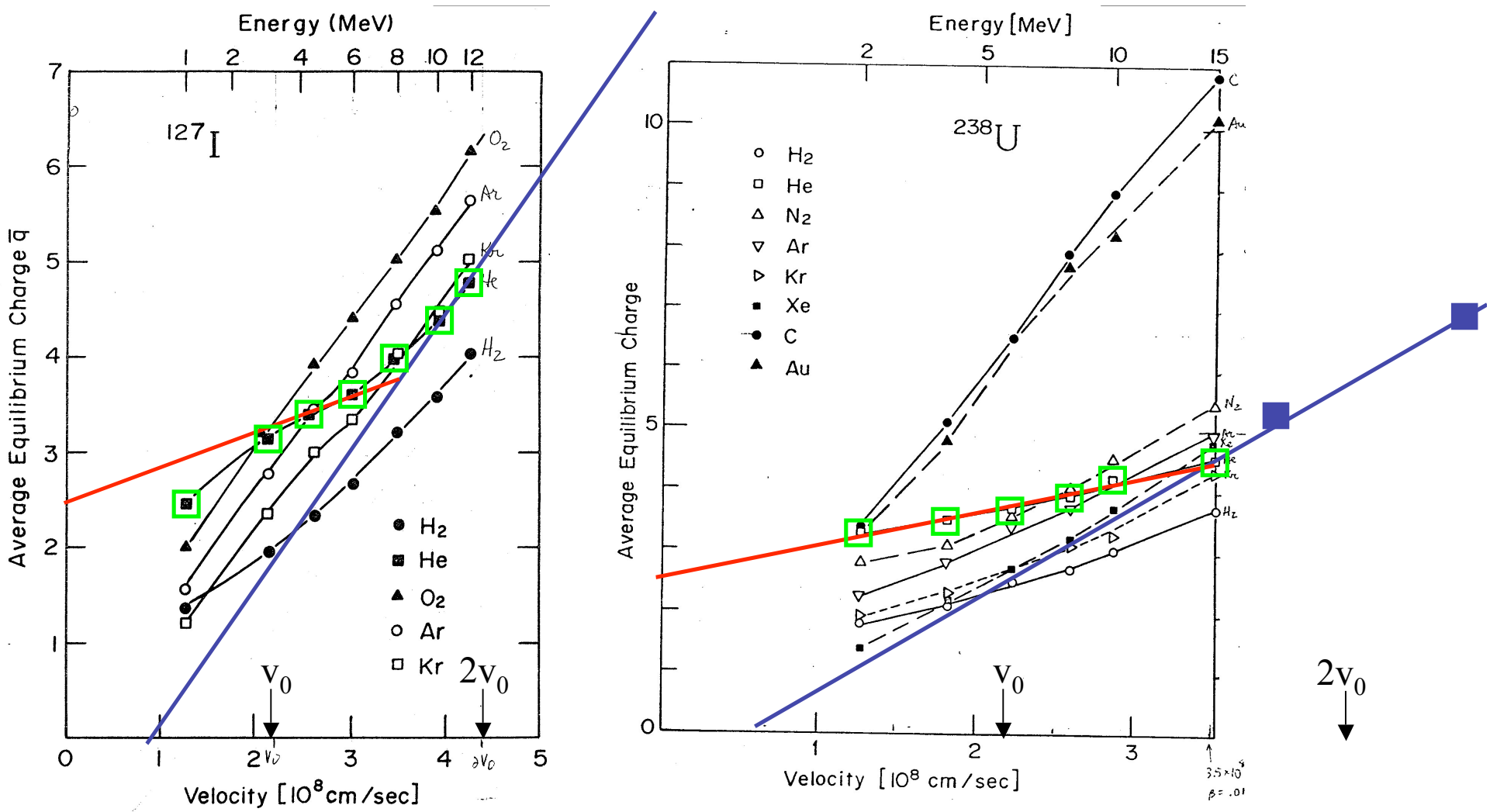
Semi-empirical understanding of why this works:

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.

Understanding Magnetic Rigidity in He Gas

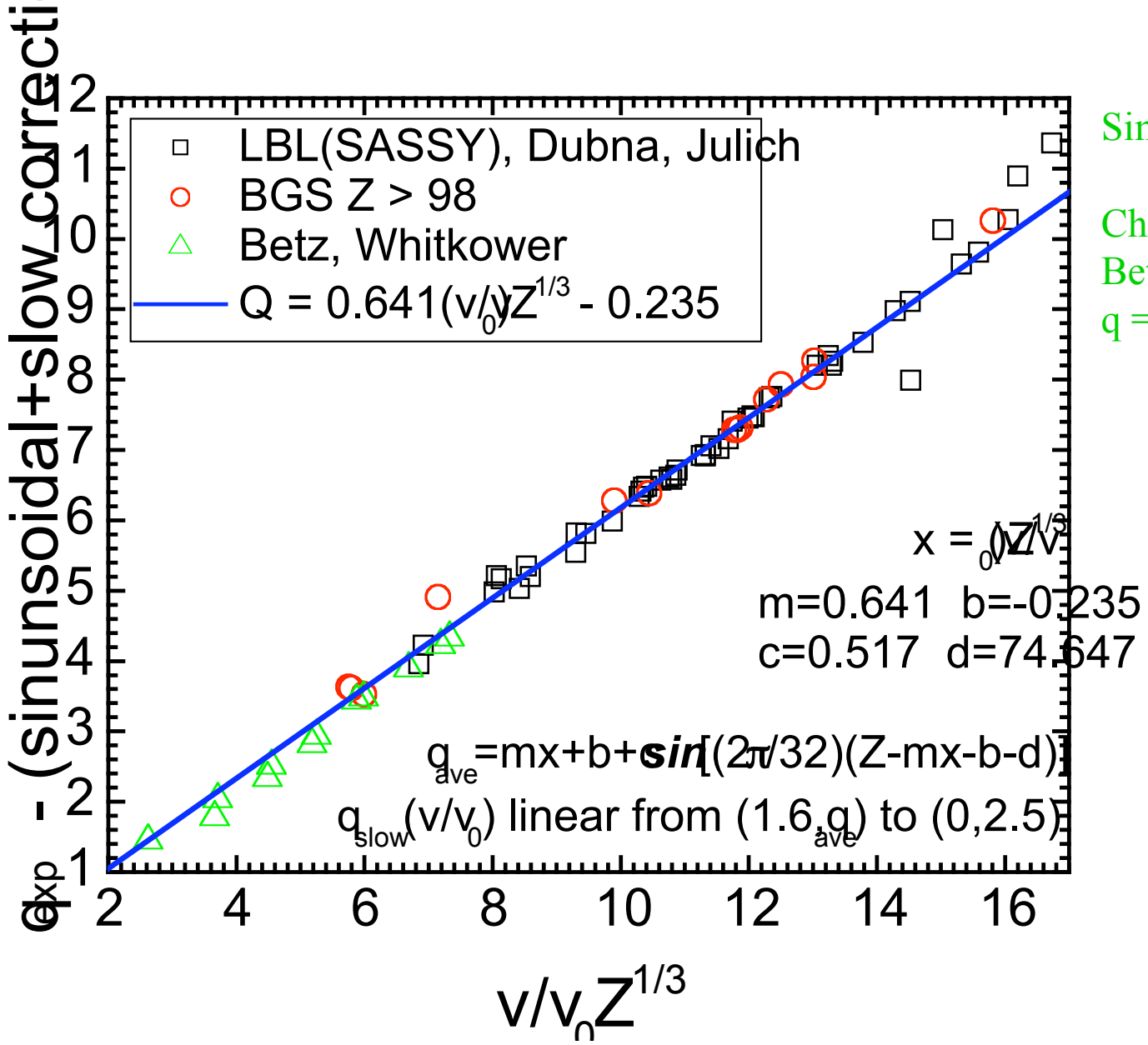
Iodine and uranium data show a break below $v = 1.6v_0$



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.

Understanding Magnetic Rigidity in He Gas

After applying a slow velocity correction . . .

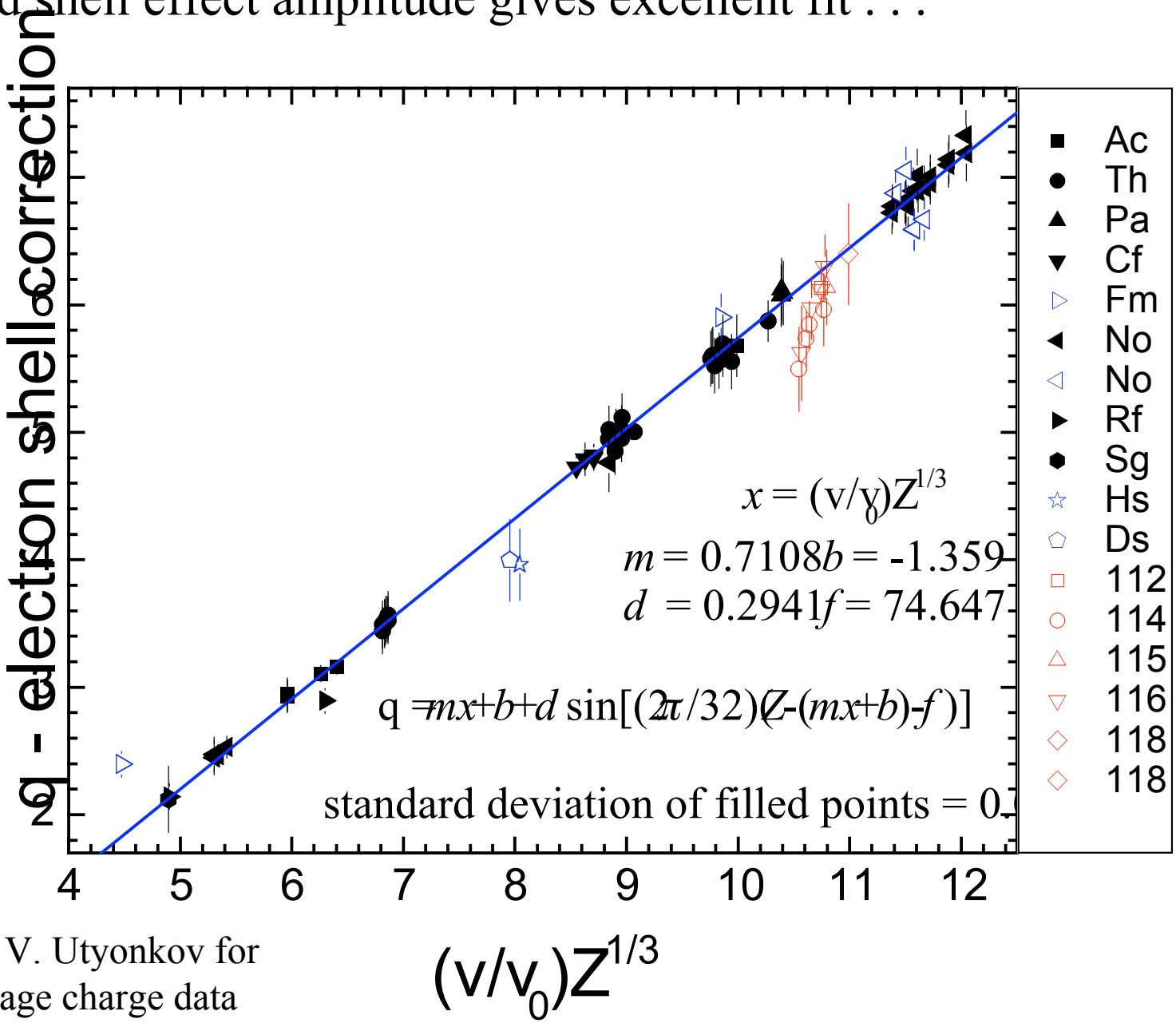


Simplest assumption:

Charge changes linearly Between $v/v_0 = 1.6$ and $q = 2.5$ at $v=0$

Understanding Magnetic Rigidity in H_2 Gas

Reduced shell effect amplitude gives excellent fit . . .



Thanks to V. Utyonkov for latest average charge data

SHE Summary and Outlook

It has been six years since the first announcements of superheavy element production in reactions of ^{48}Ca projectiles and Actinide targets

The DGFRS group has published an extensive and internally consistent set of results:

1) Cross bombardments produce isotopes with the same decay properties
2) Excitation functions provide a consistent interpretation of Z and A
3) Decay properties are internally consistent and match predictions

None of the results have been confirmed outside of the DGFRS

Possible exception in the chemical isolation of a SF activity from $^{48}Ca + ^{243}Am$

There is something wrong with the $^{48}Ca + ^{238}U$ reaction

Three independent separator experiments had sufficient sensitivity, but failed to observe 4-sec 9.5-MeV alpha followed by 180 ms SF

Next experiments at the BGS: $^{244}Pu(^{48}Ca,xn)^{292-x}114$

Target apparatus will be tested within the next few months

^{244}Pu target production during winter 2006

Experiments expected sometime during 2006

“We”

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