Nuclear Incompressibility, K_∞, and the Asymmetry Term, K_τ, from Measurements of the Giant Monopole Resonance in Neutron-Rich Nuclei

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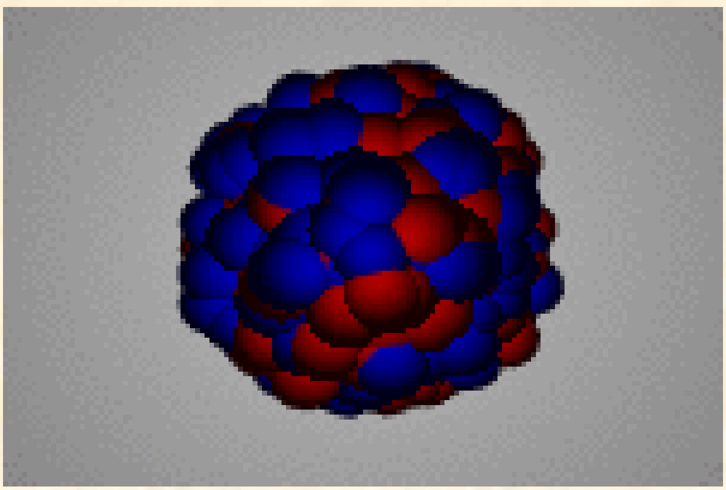
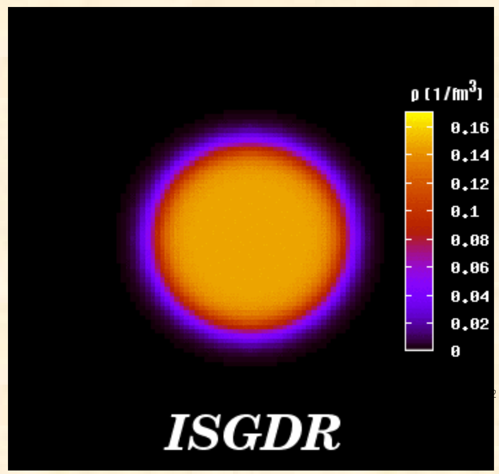
August 20, 2024

The Compressional Mode Giant Resonances

GMR	ISGDR
l = 0	l = 1



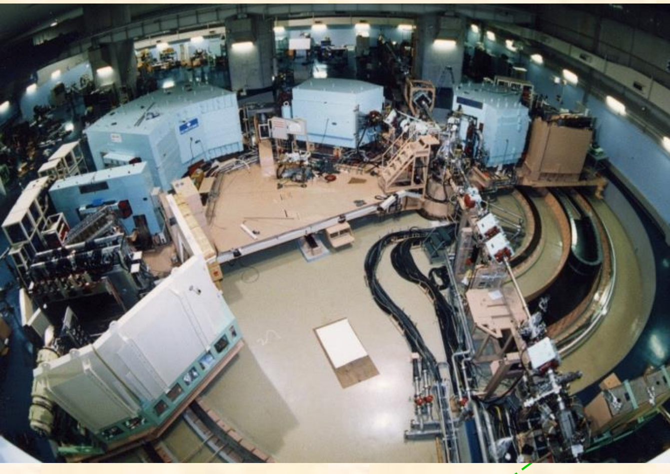


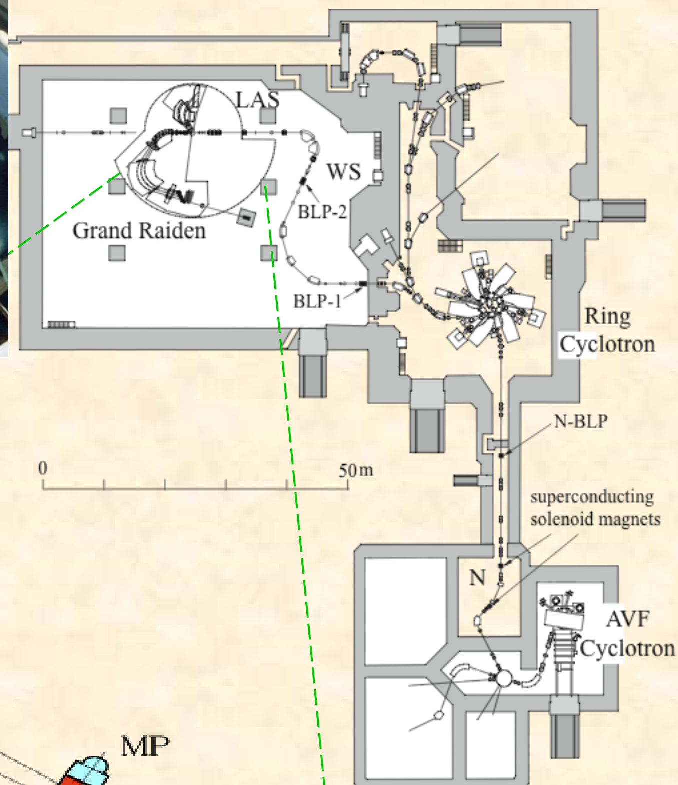
"Breathing Mode"	"Squeezing Mode"
$\sum r_i^2$	$\sum r_i^3 Y_1$
$2\hbar\omega$	$3\hbar\omega$

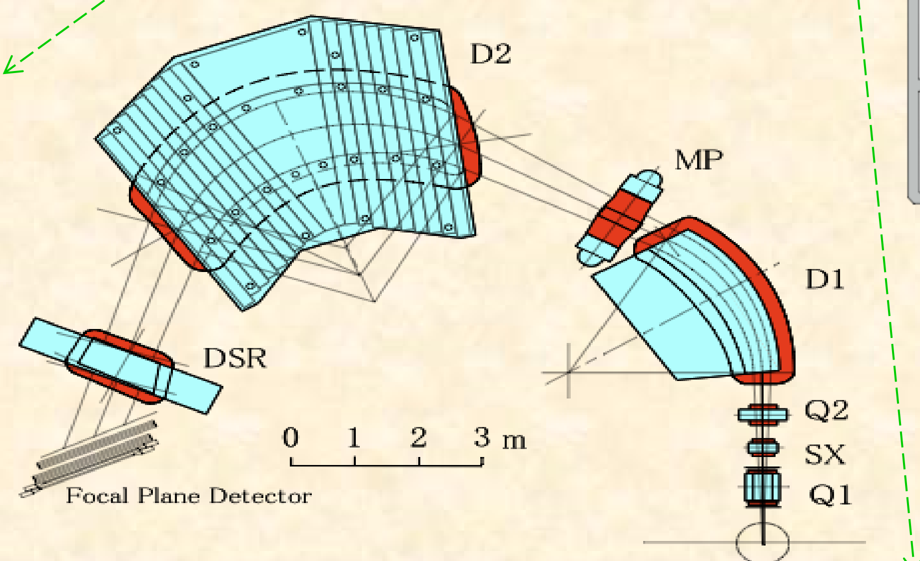
The energies of both these resonances are directly related to Nuclear Incompressibility.

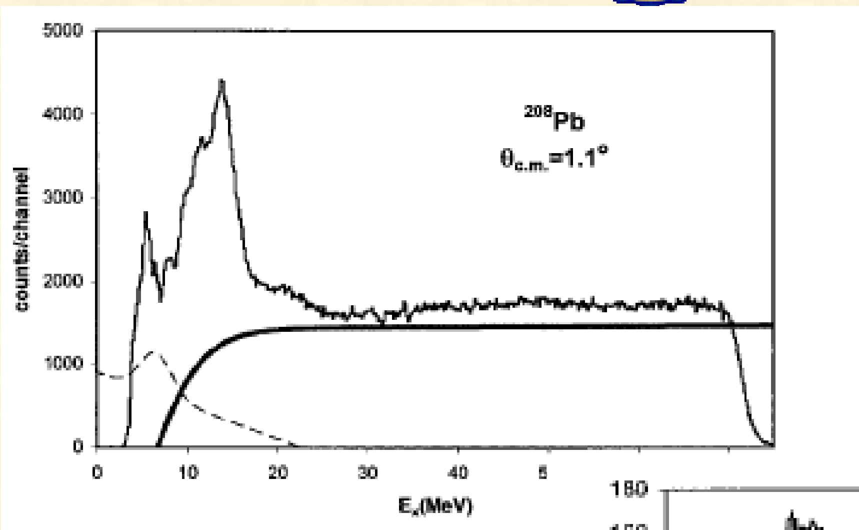
$$E_{GMR} = \hbar\sqrt{\frac{K_A}{m\langle r^2\rangle}}$$

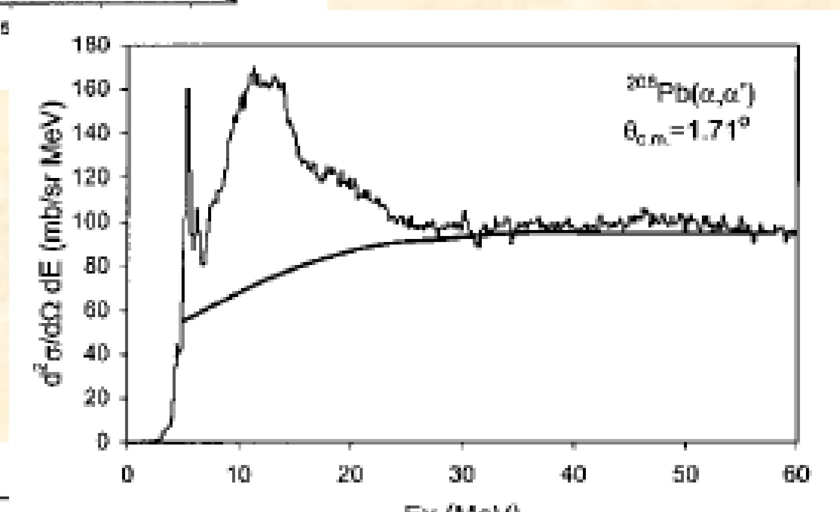
$$E_{ISGDR} = \hbar\sqrt{\frac{7}{3}\frac{K_A + \frac{27}{25}\varepsilon_F}{m\langle r^2\rangle}}$$

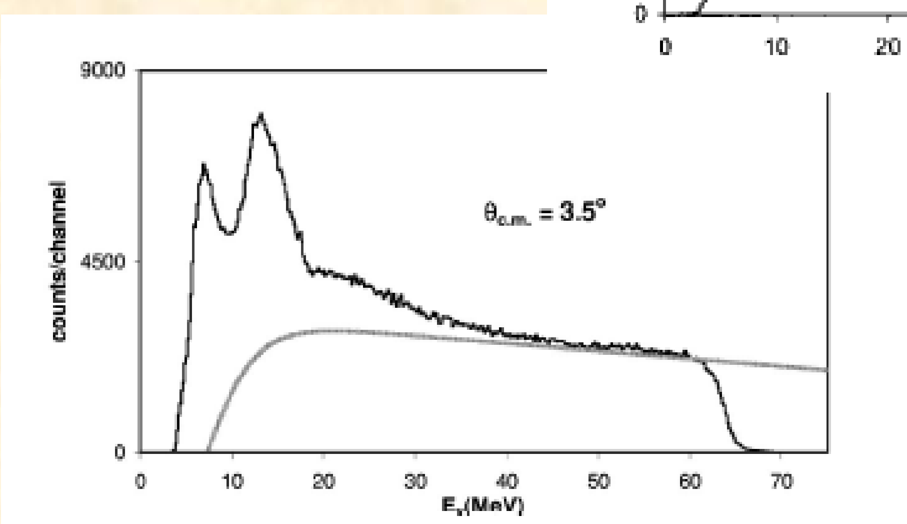



LAS
WS
BLP-2
Grand Raiden
BLP-1
Ring Cyclotron
N-BLP
0
50m
superconducting solenoid magnets
N
AVF Cyclotron

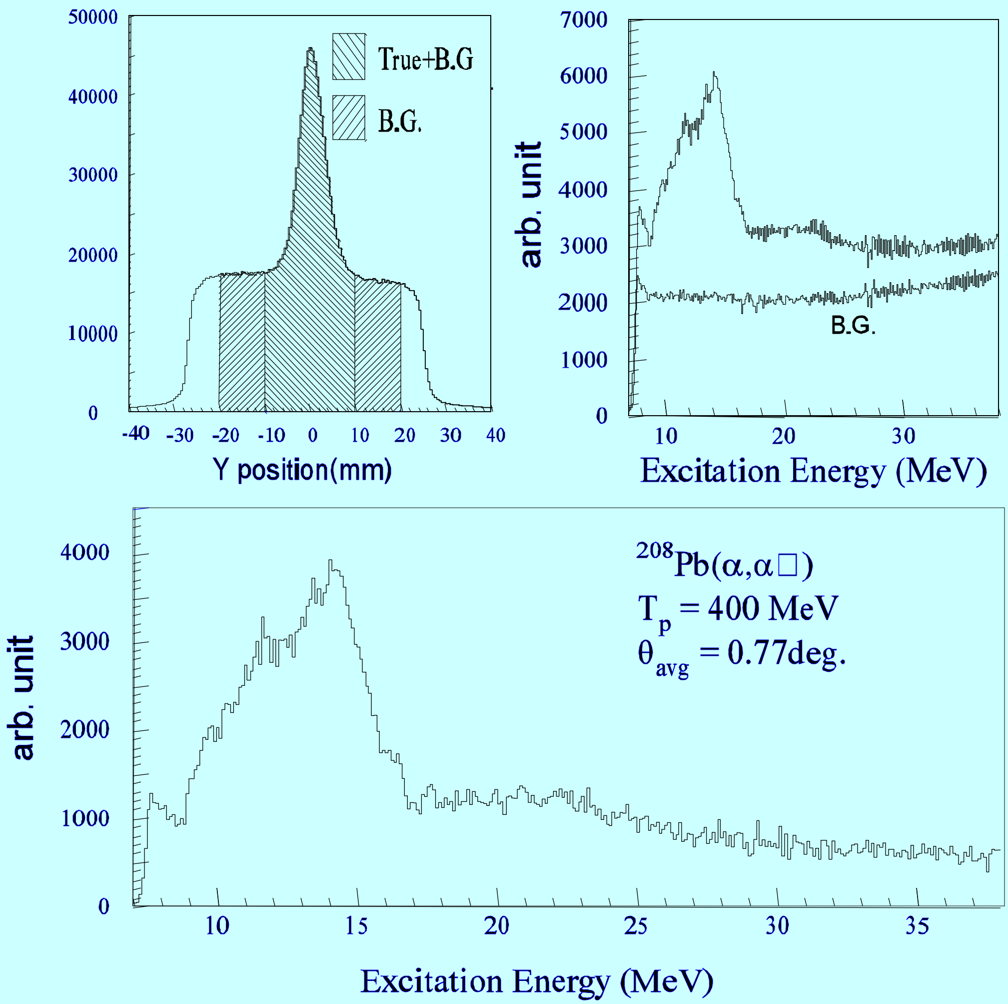

D2
MP
D1
DSR
Q2
SX
Q1
0 1 2 3 m
Focal Plane Detector







240 MeV (α,α') [Texas A & M]



True+B.G
B.G.
Y position(mm)
arb. unit
B.G.
Excitation Energy (MeV)
arb. unit
208Pb(α,α□)
Tp = 400 MeV
θavg = 0.77deg.
Excitation Energy (MeV)

From GMR data on ^{208}Pb and ^{90}Zr

$K_{\infty} = 240 \pm 20$ MeV

This number is consistent with both GMR and ISGDR data and with non-relativistic and relativistic calculations

We know K_A from E_{GMR}:

$$E_{GMR} = \hbar\sqrt{\frac{K_A}{m\langle r^2\rangle}}$$

In an approximate way, K_A may be expressed as:

$$K_A \sim K_\infty\,(1 + cA^{-1/3}) + K_\tau\,((N - Z)/A)^2 + K_{Coul}\,Z^2A^{-4/3}$$

$$c \sim -1$$

K_{Coul} is, basically, model independent

K_τ ??

Measurements over a series of isotopes gives K_τ

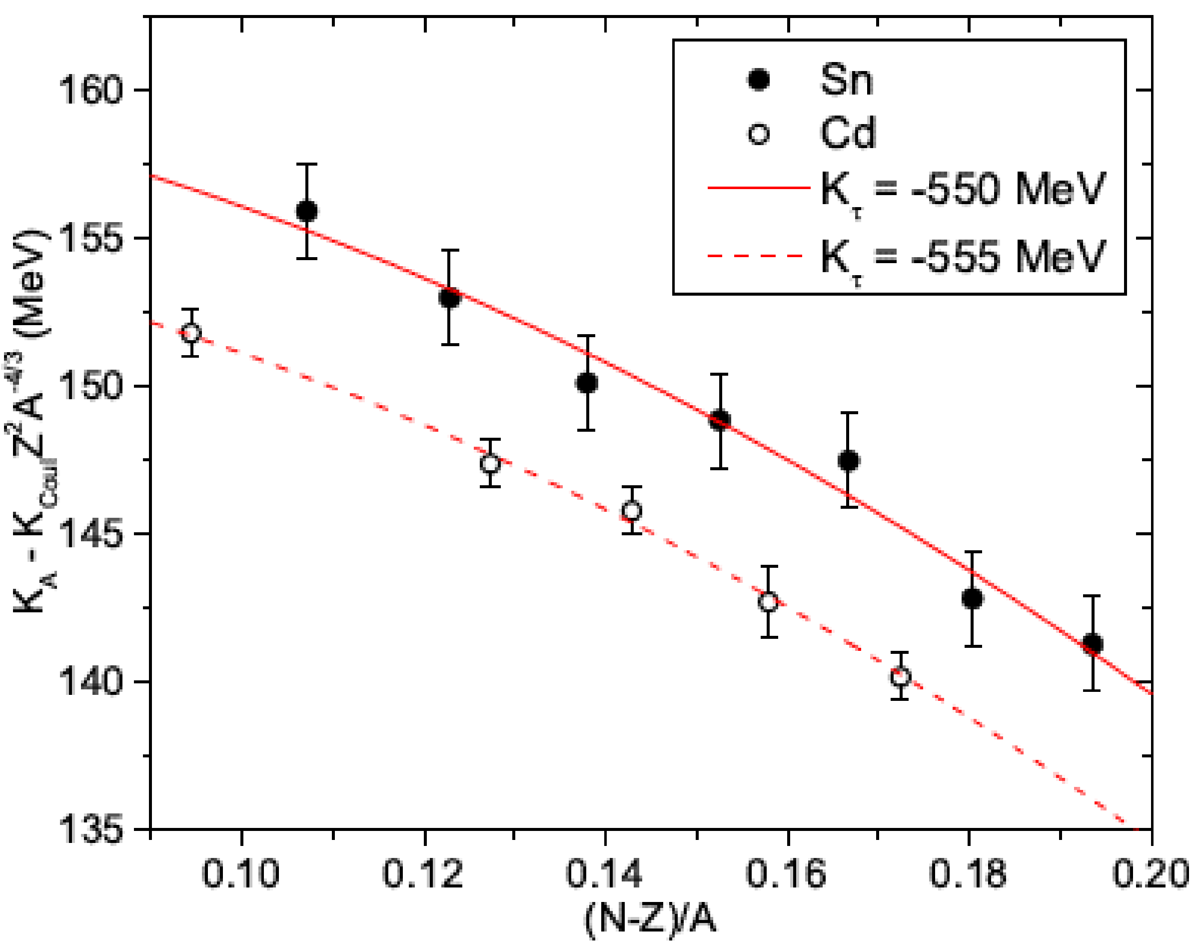
$$K_\tau = K_{sym} - 6L - Q_0L/K_\infty$$

$$K_A \sim K_{vol} (1 + cA^{-1/3}) + K_\tau ((N - Z)/A)^2 + K_{Coul} Z^2 A^{-4/3}$$

$$K_A - K_{Coul} Z^2 A^{-4/3} \sim K_{vol} (1 + cA^{-1/3}) + K_\tau ((N - Z)/A)^2$$

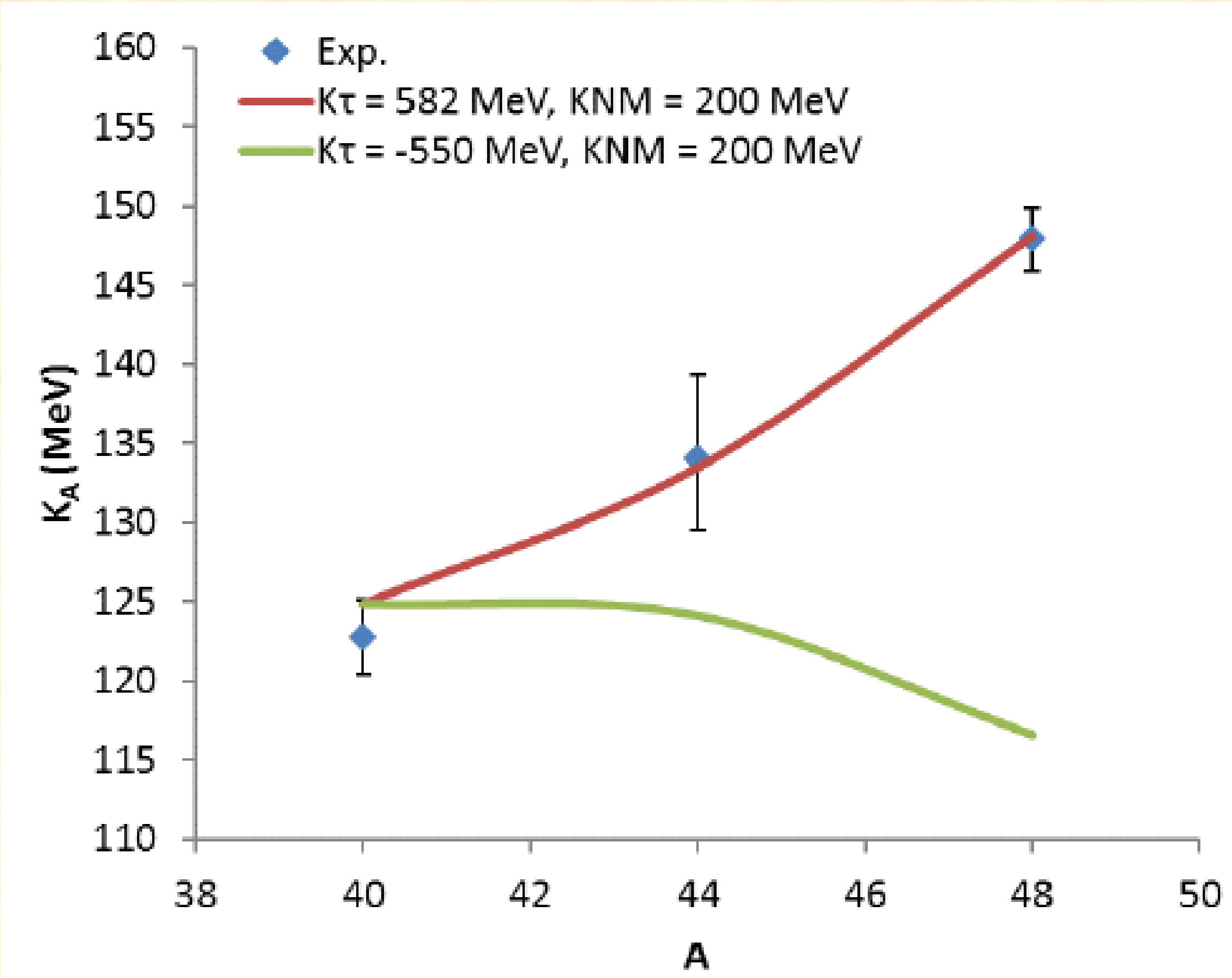
$$\sim \text{Constant} + K_\tau ((N - Z)/A)^2$$

We use $K_{Coul} = - 5.2$ MeV (from Sagawa)

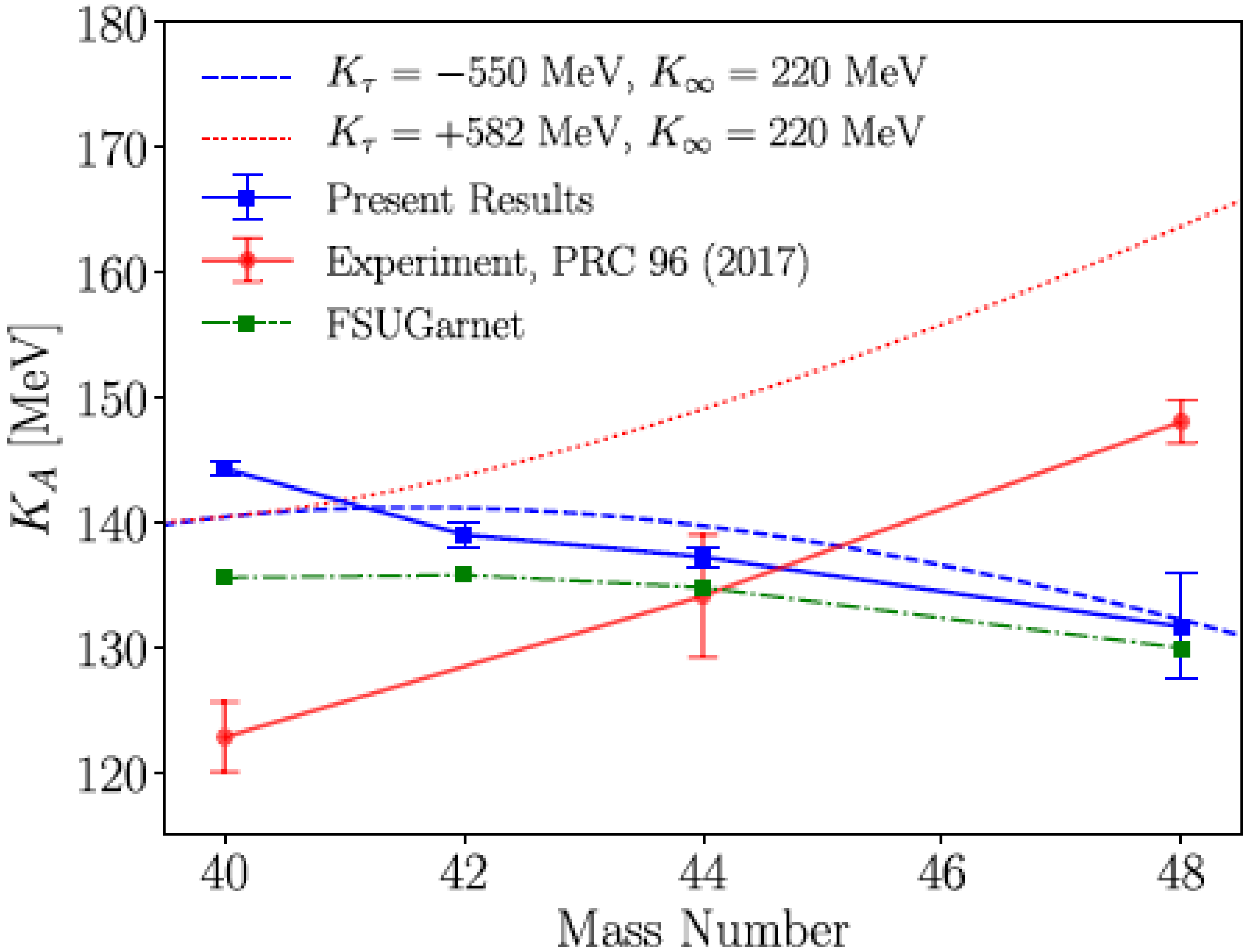


$$K_\tau = \text{-}550 \pm 100\ \text{MeV}$$

$$K_\tau = K_{sym} - 6L - Q_0 L / K_\infty$$



J. Button et al., Phys. Rev. C **96**, 054330 (2017)

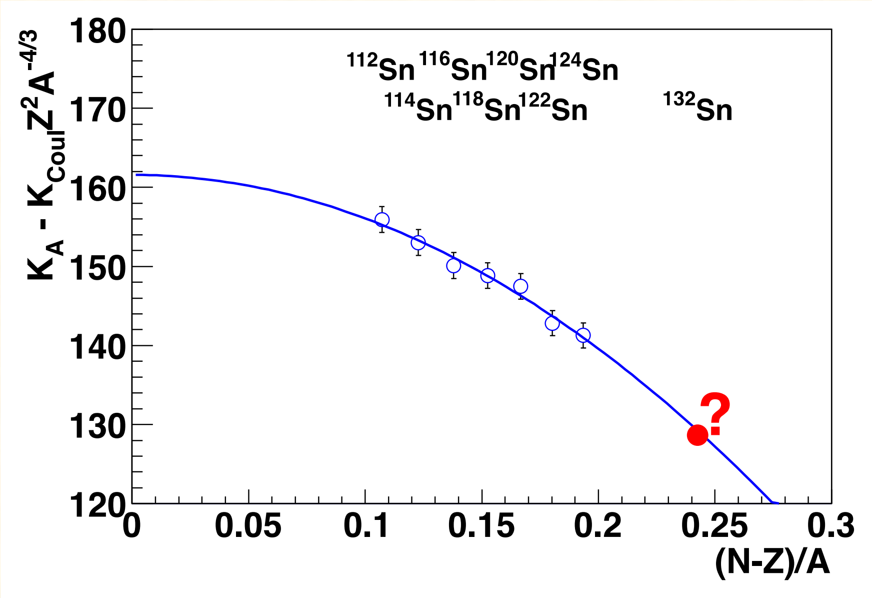


K. B. Howard et al., Phys. Lett. B **801**, 135185 (2020)

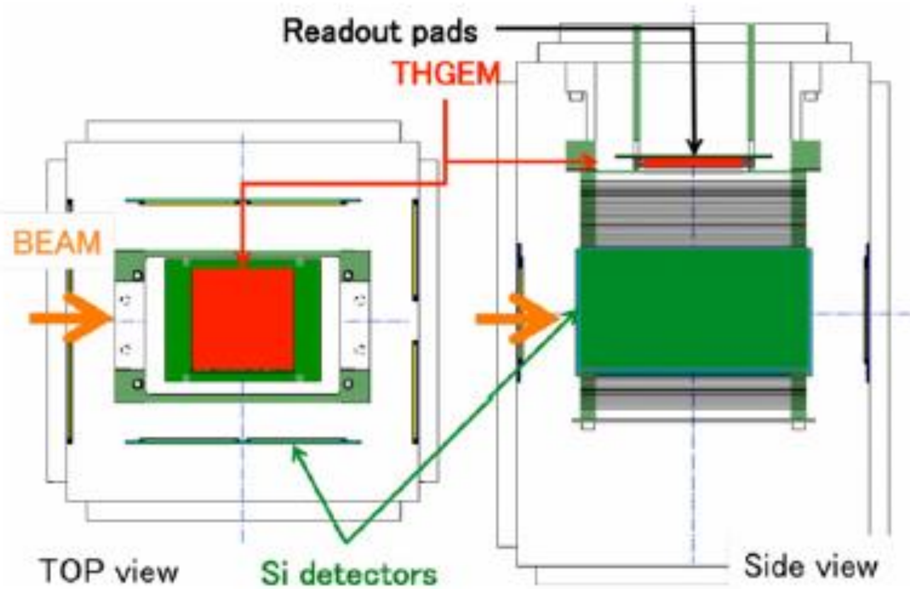
Can we do any better on K_∞ and K_τ ?

-- Not much, I think, on K_∞

-- Can hope for improvement in K_τ



± 50 MeV, perhaps

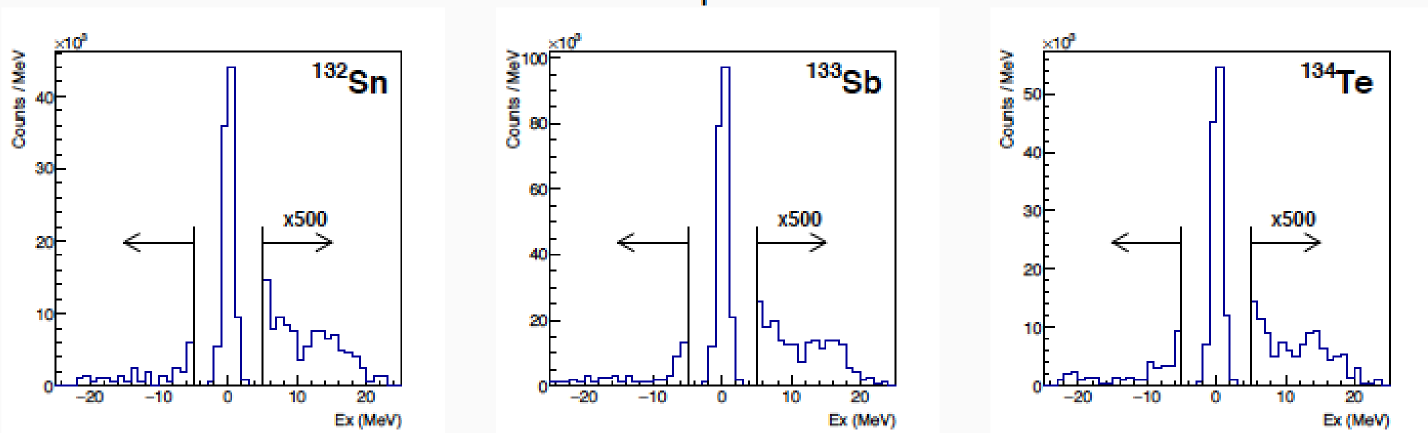


RIBF 113

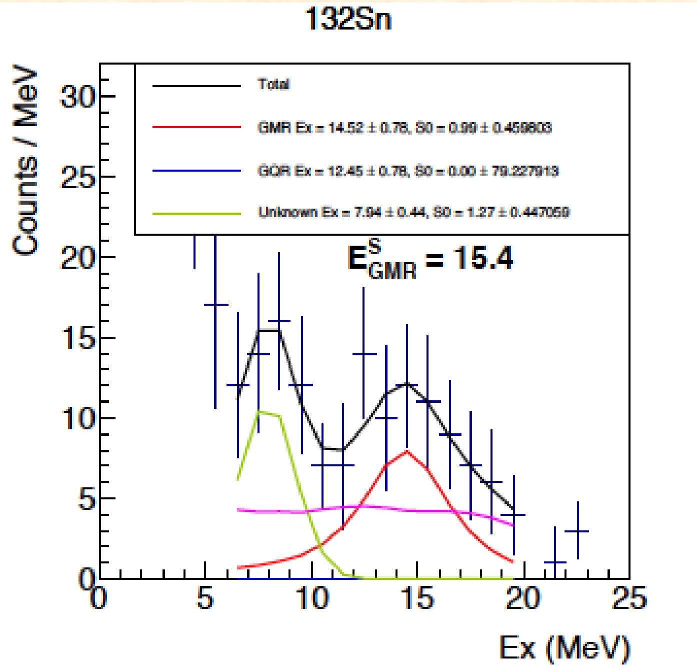
$^{132}Sn + {}^{2}H$
100 MeV/A
>50 kHz ^{132}Sn

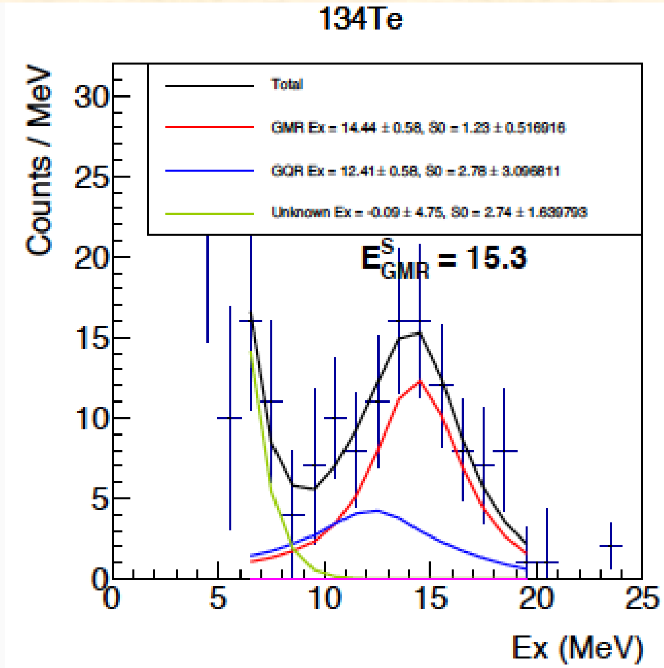
Preliminary uncorrected energy spectra for ^{132}Sn, ^{133}Sb, and ^{134}Te.

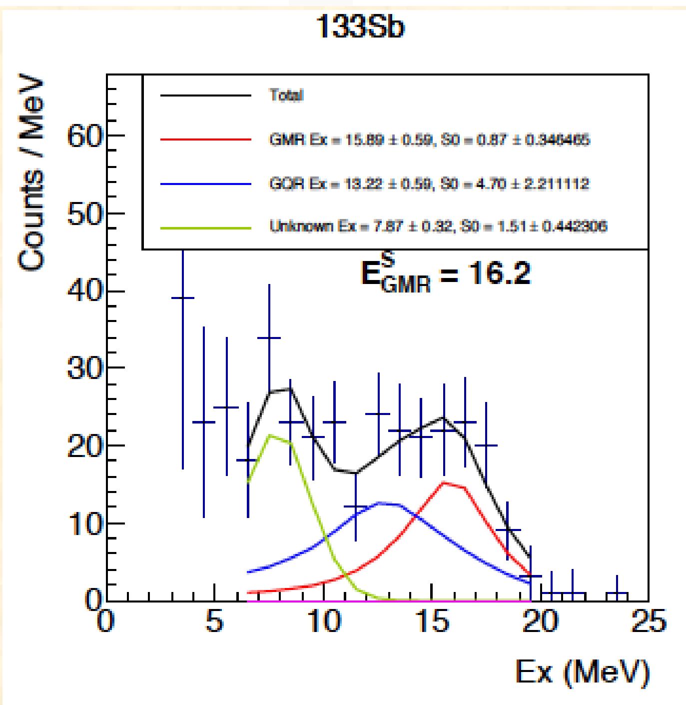
Particle identifications of beam and recoil particles have been done.



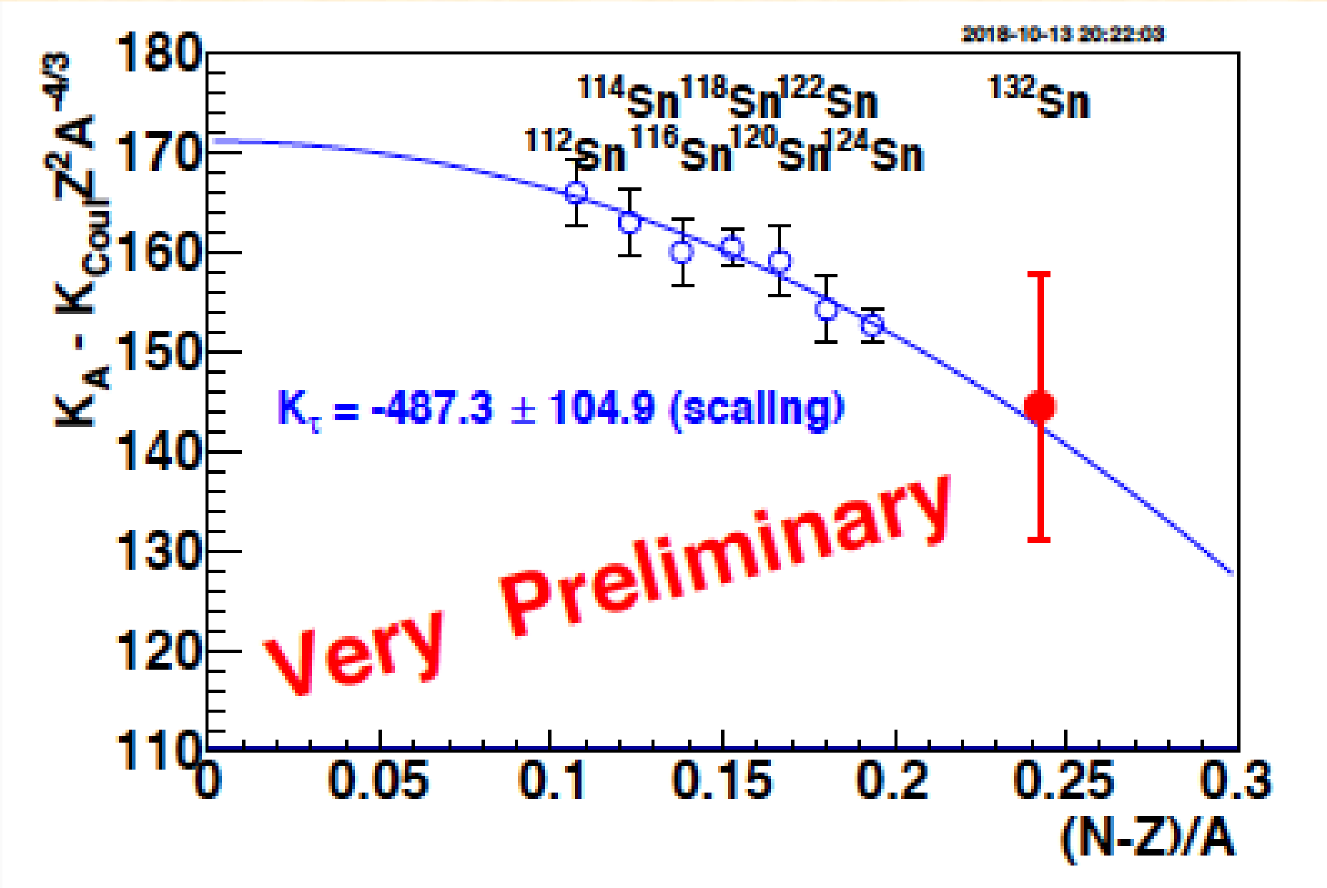
Preliminary results from RIKEN *d*(^{132}Sn, ^{132}Sn’)*d* experiment



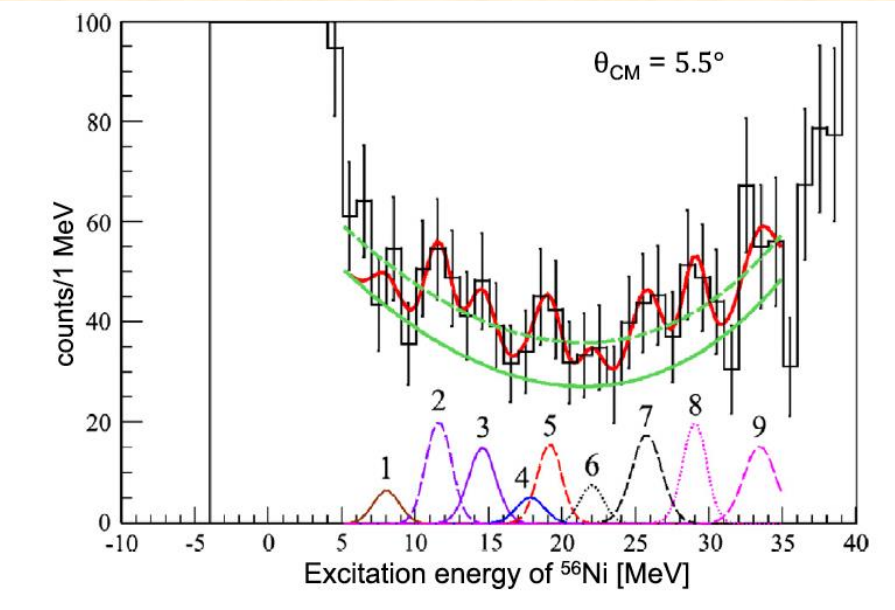




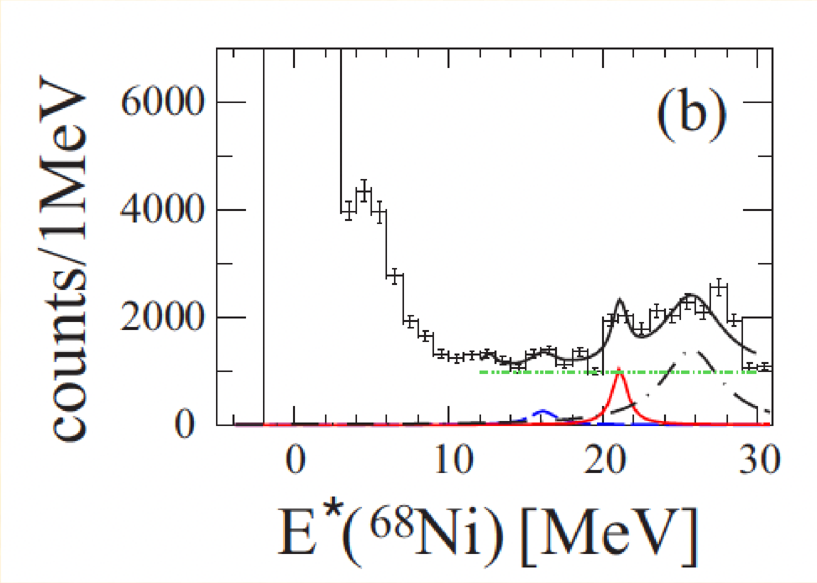
Preliminary results from RIKEN *d*(^{132}Sn, ^{132}Sn')*d* experiment



Preliminary results from RIKEN *d*(^{132}Sn, ^{132}Sn')*d* experiment



^{56}Ni
GANIL



^{68}Ni
GANIL

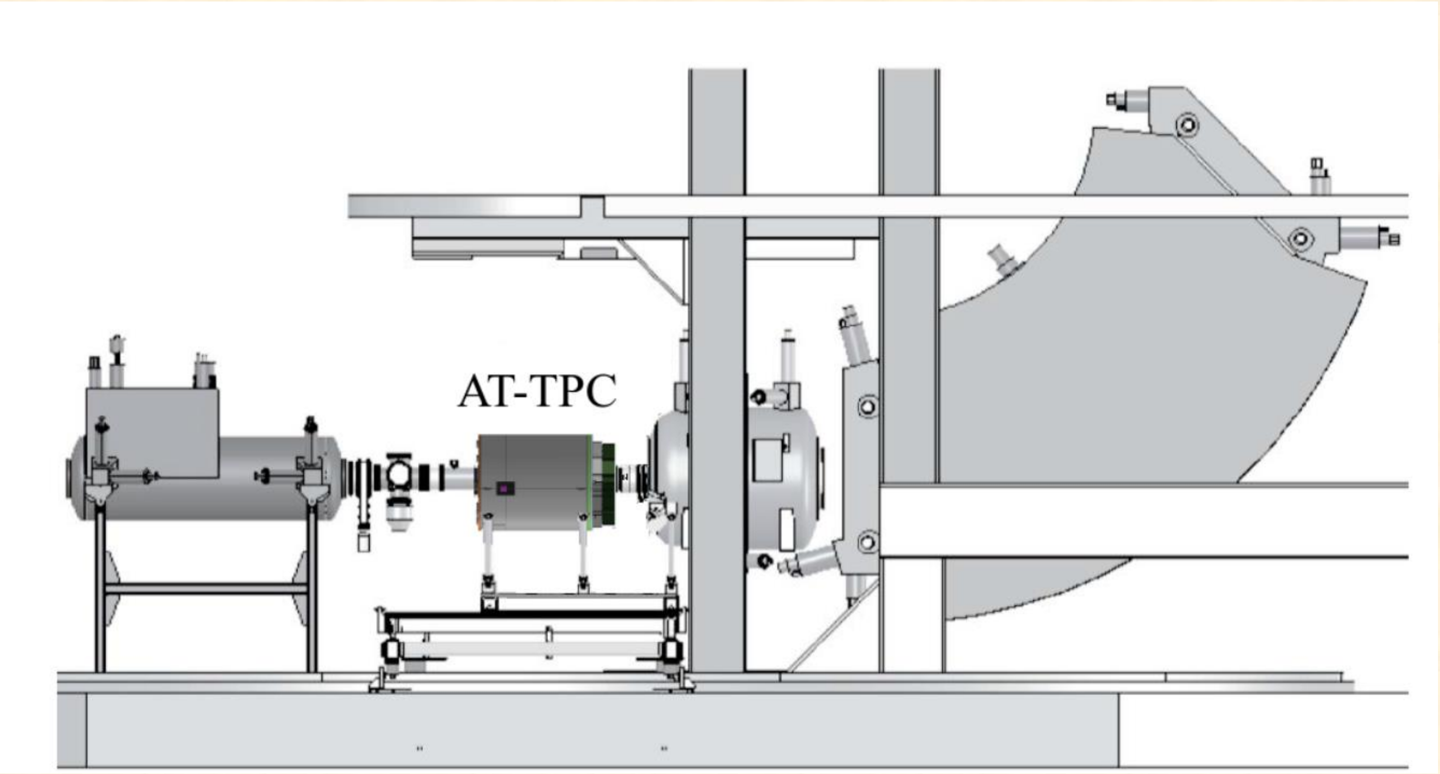
50 MeV/A (α, α'); He with 5% CF_4

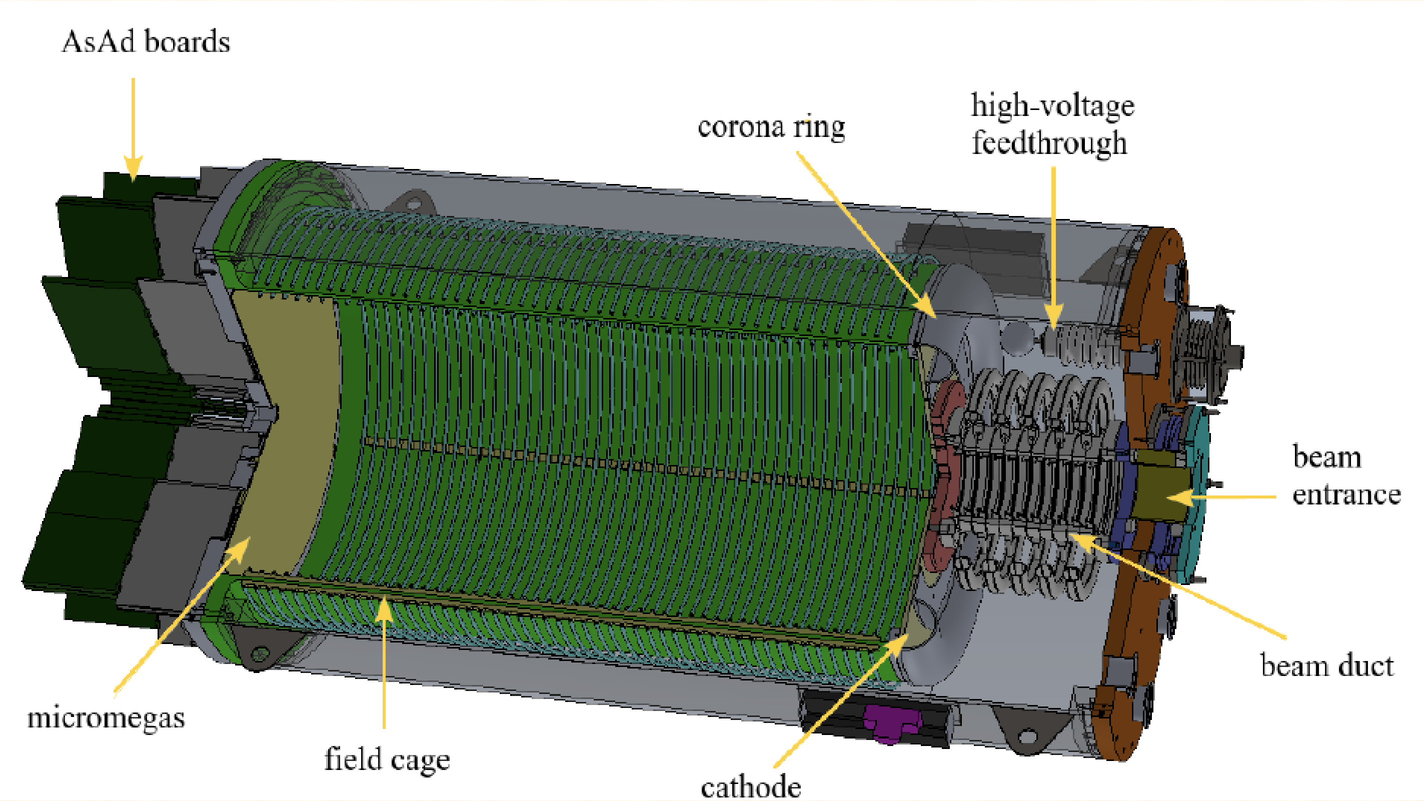
$^{4}He(^{70}Ni, ^{70}Ni')^{4}He$ @ NSCL

82 MeV/A; ~20k pps

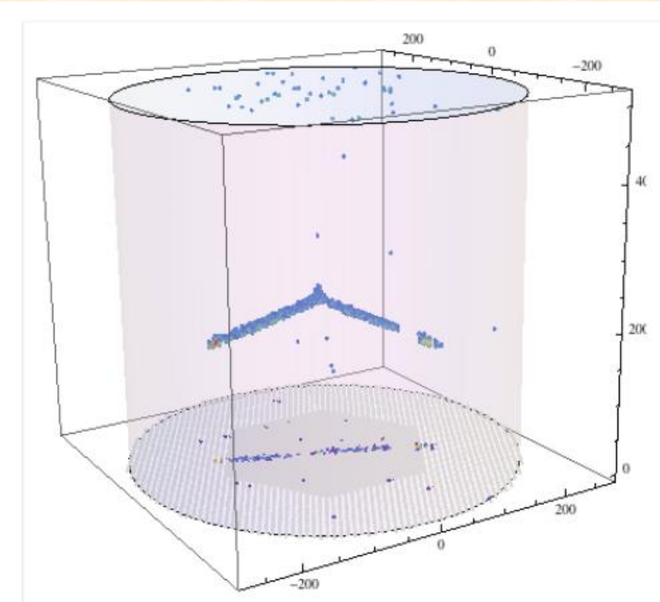
e18207

$^{4}He(^{70}Ni, ^{70}Ni')^{4}He$ @ NSCL



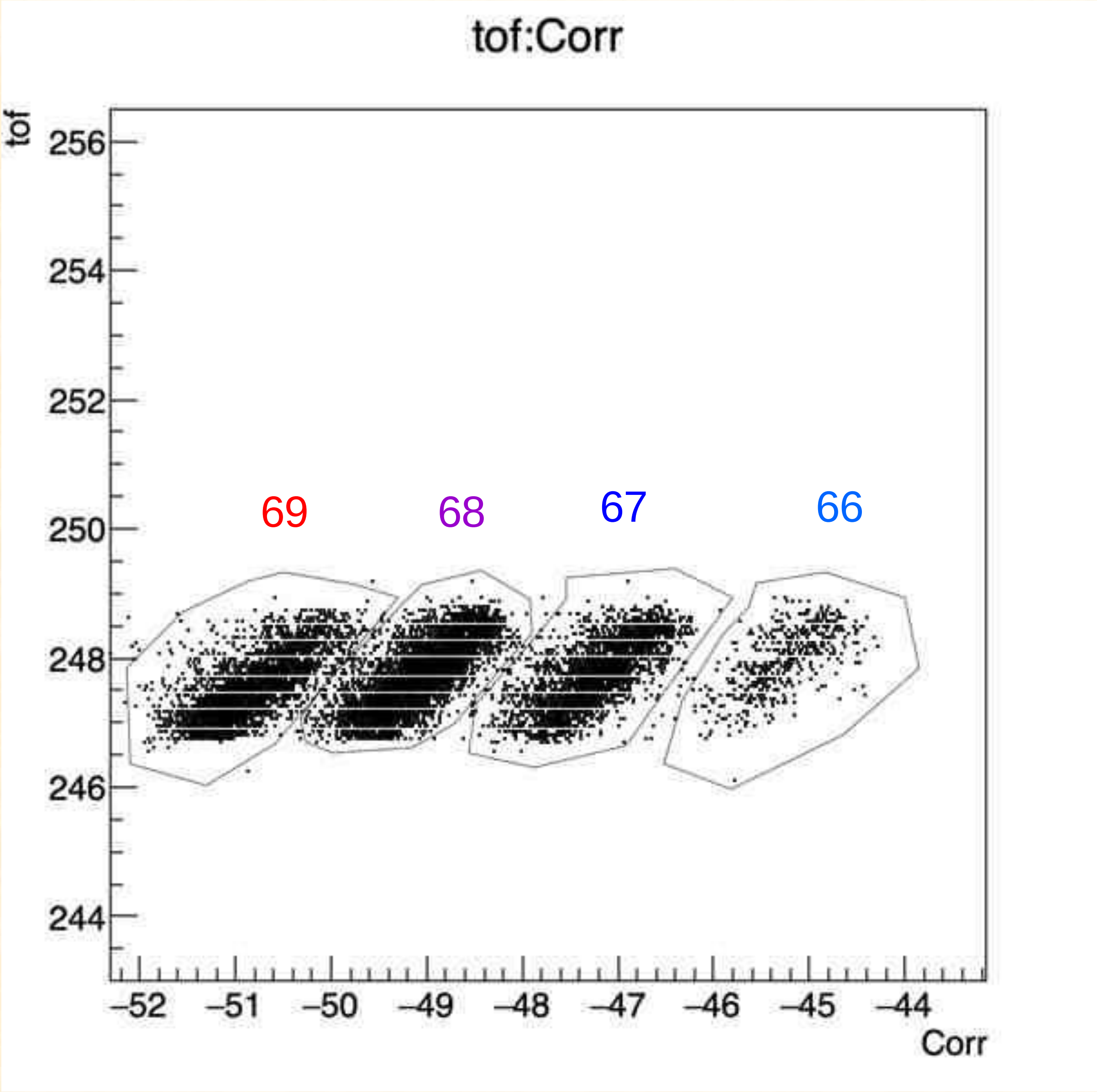


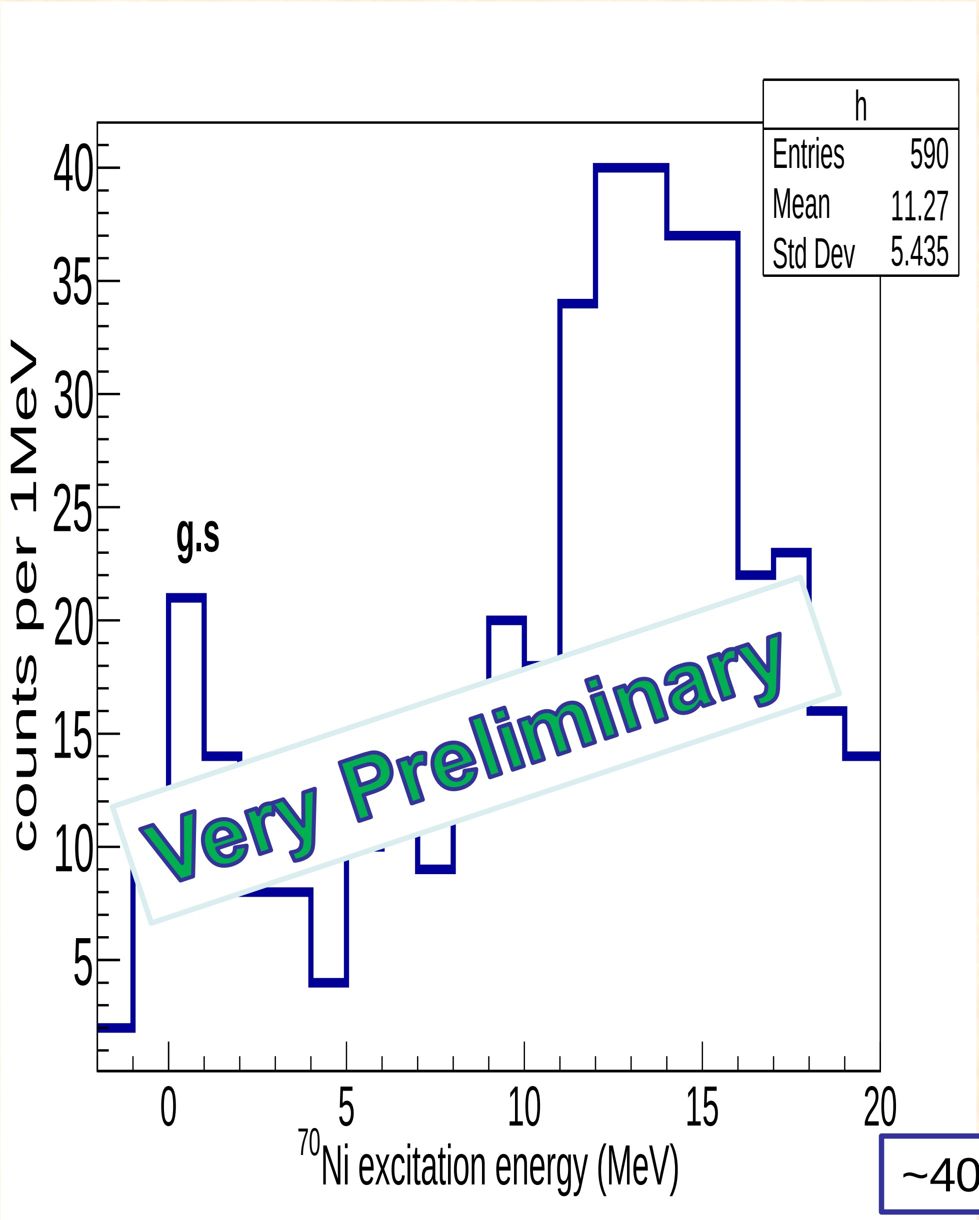
150 torr of
pure ^{4}He gas



J. Bradt et al., Nucl. Inst. Meth. Phys. Res. A **875**, 65 (2017)

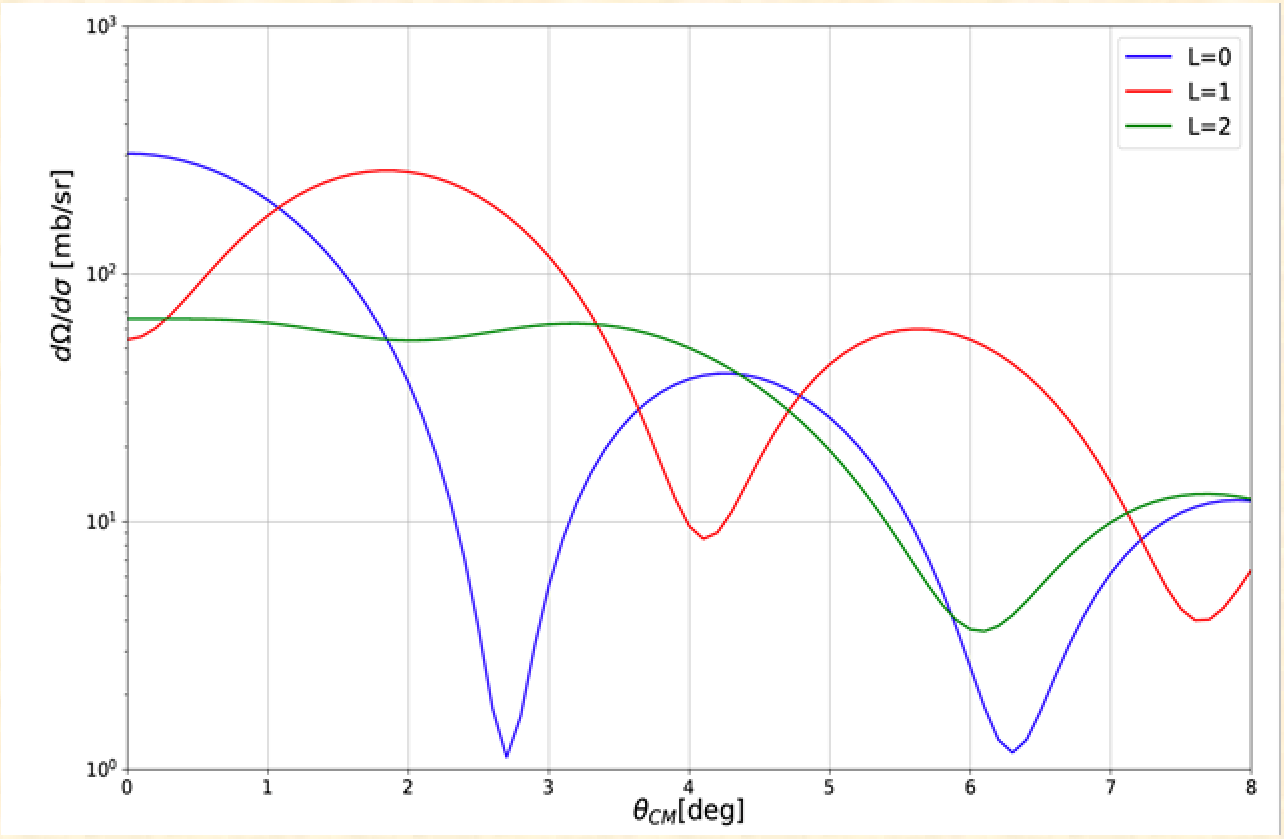
Giraud et al., Nucl. Inst. Meth. Phys. Res. **A** 1051, 168213 (2023)


tof:Corr
tof
256
254
252
250
248
246
244
69
68
67
66
−52
−51
−50
−49
−48
−47
−46
−45
−44
Corr

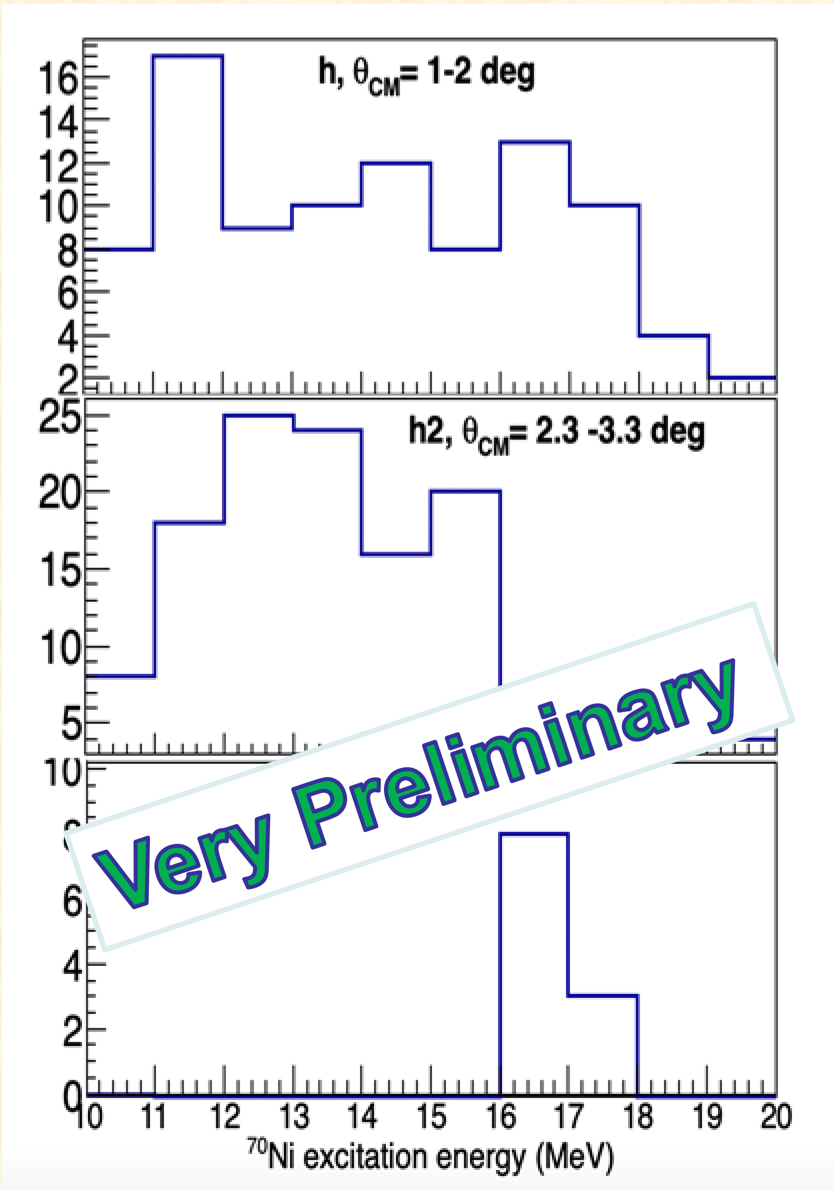


~40 hrs data

Preliminary results from J.S. Randhawa et al.



- L=0 : Minima at ~ 2.7 degrees
- L=2 : nearly flat in 1-4 degrees

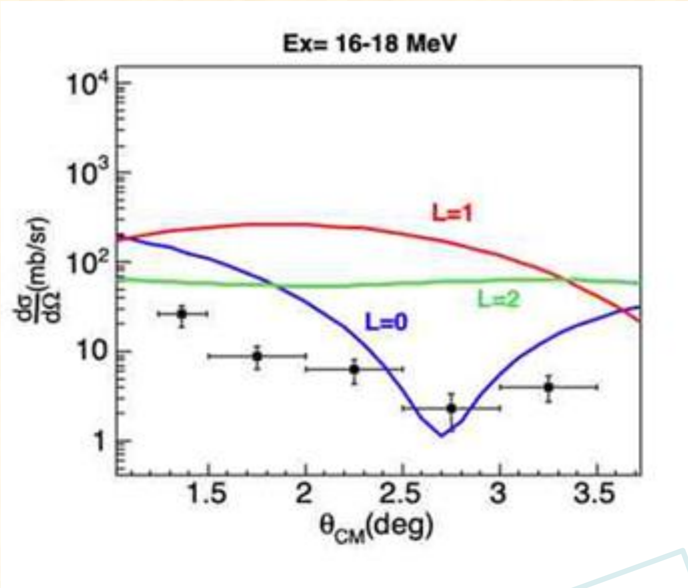


1^o—2^o

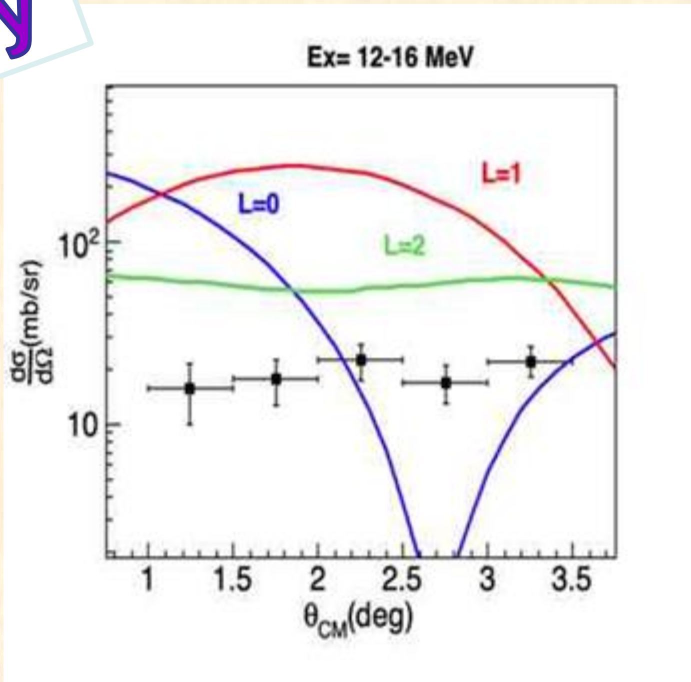
2.3^o—3.3^o

In ^{70}Ni GMR expected at ~17 MeV

Preliminary results from J.S. Randhawa et al.



Very Preliminary



Preliminary results from J.S. Randhawa et al.

$^{4}He(^{132}Sn,\ ^{132}Sn')^{4}He$ @ FRIB

Aims

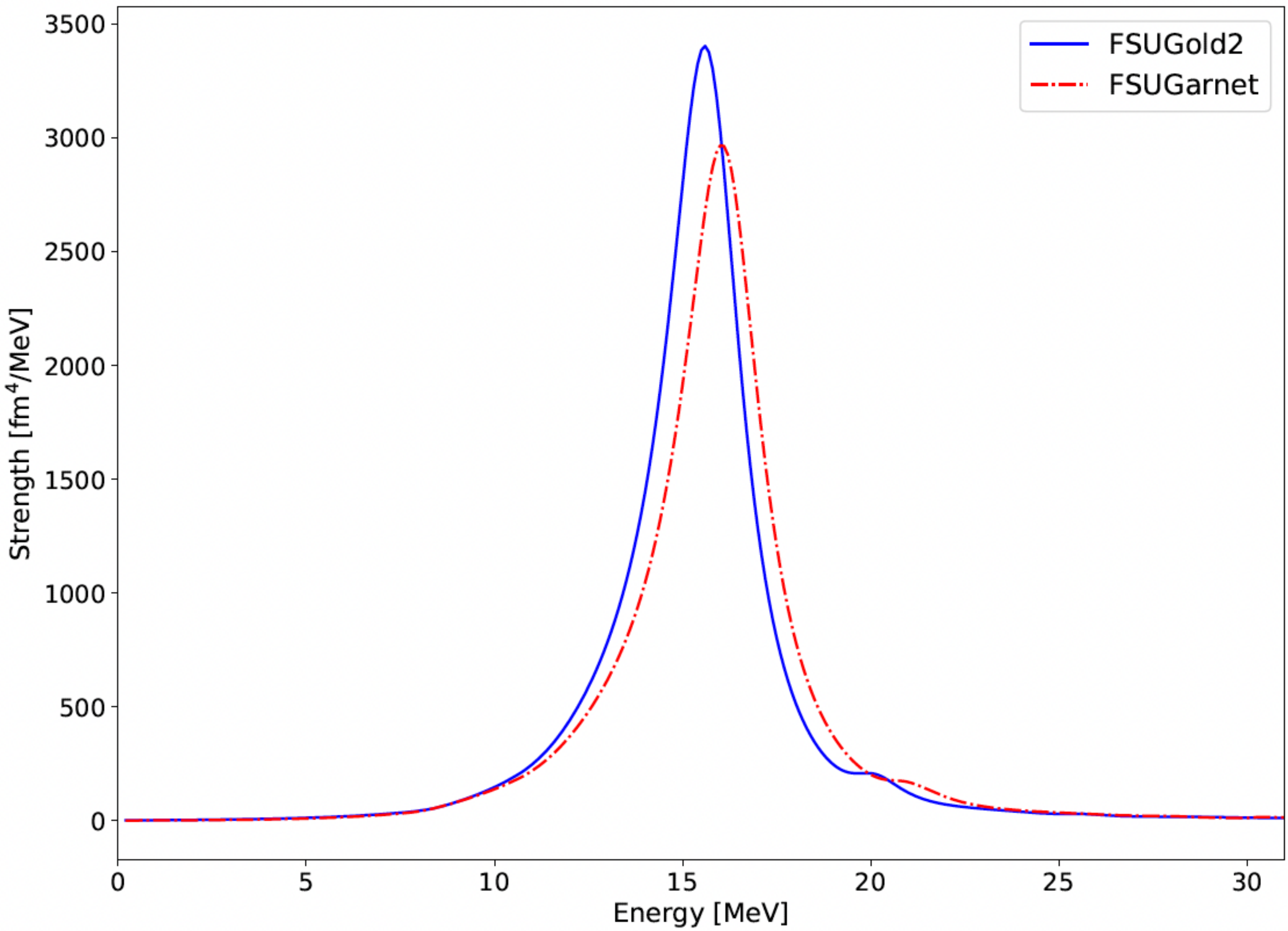
To investigate:

i) the asymmetry term in the nuclear incompressibility;

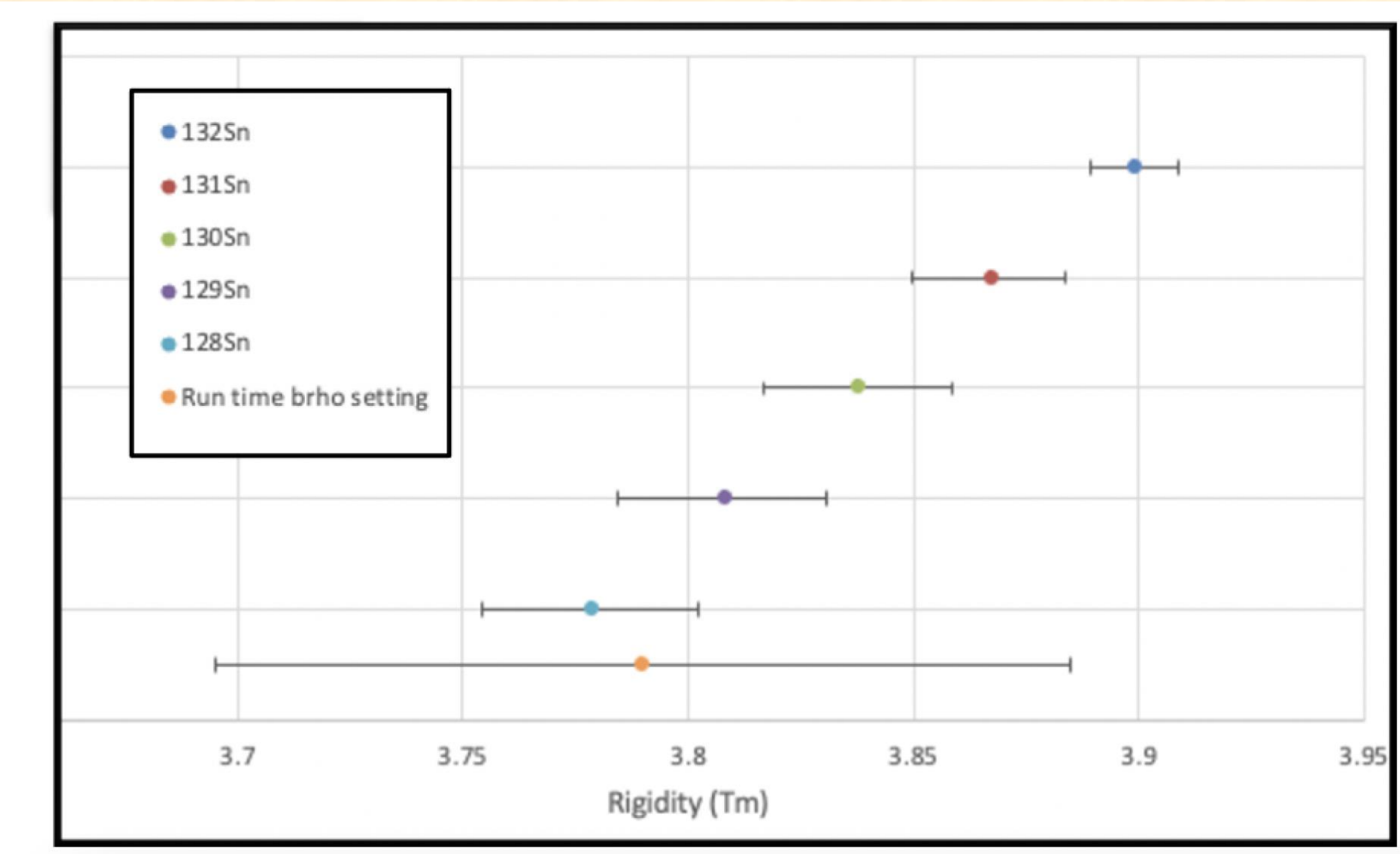
ii) the phenomenon of “softness” of open-shell nuclei as observed in the ISGMR strength distributions in the Sn and Cd nuclei; and,

iii) to directly test the impact of the recent results from PREX-II on the observed ISGMR strengths in very neutron-rich nuclei.

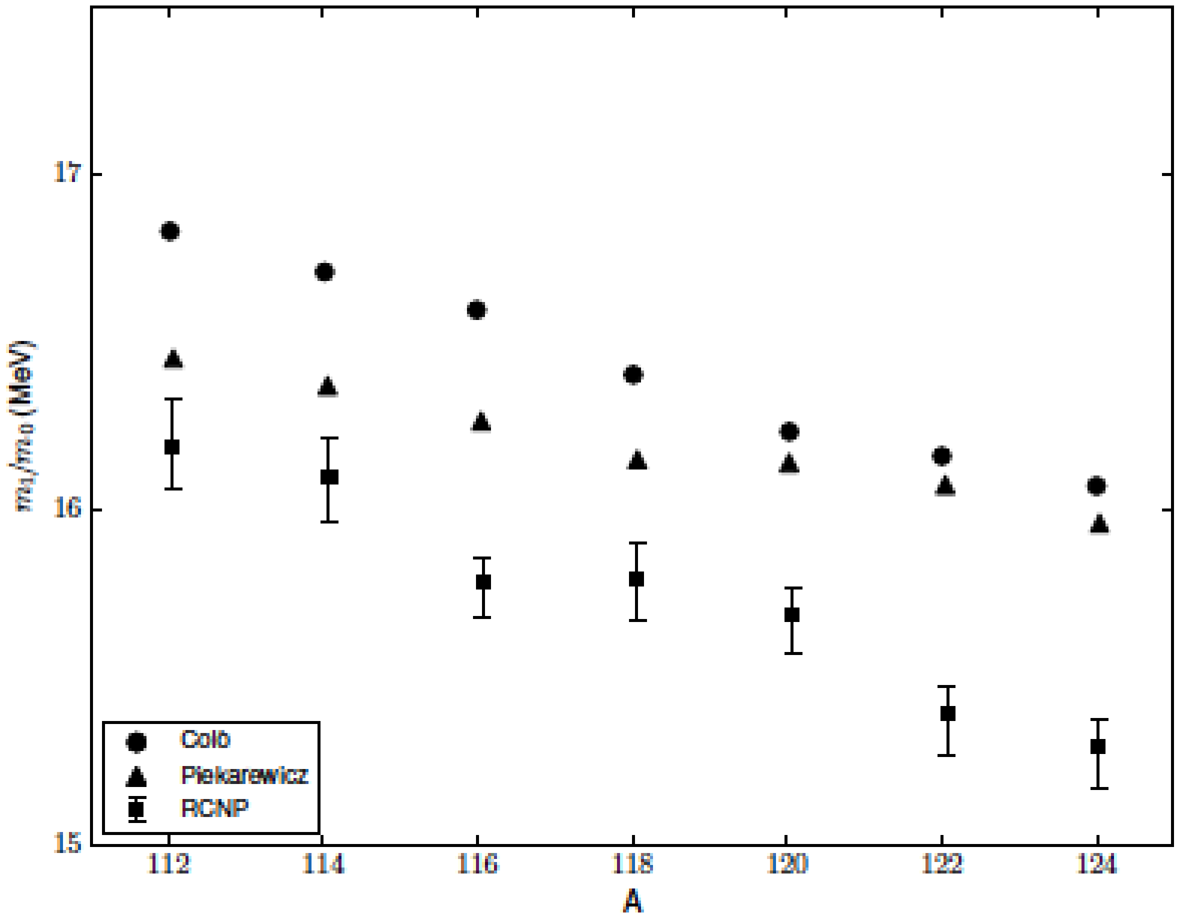
$^{4}He(^{132}Sn, ^{132}Sn')^{4}He$ @ FRIB



Calculations courtesy Prof. J. Piekarewicz.



Rigidities of Sn-isotopes and S800 acceptance are shown. The bars for the Sn isotope points represent their expected momentum spread



Why are tins so "Fluffy"?

T. Li *et al.*, Phys. Rev. Lett. **99**, 162503 (2007)

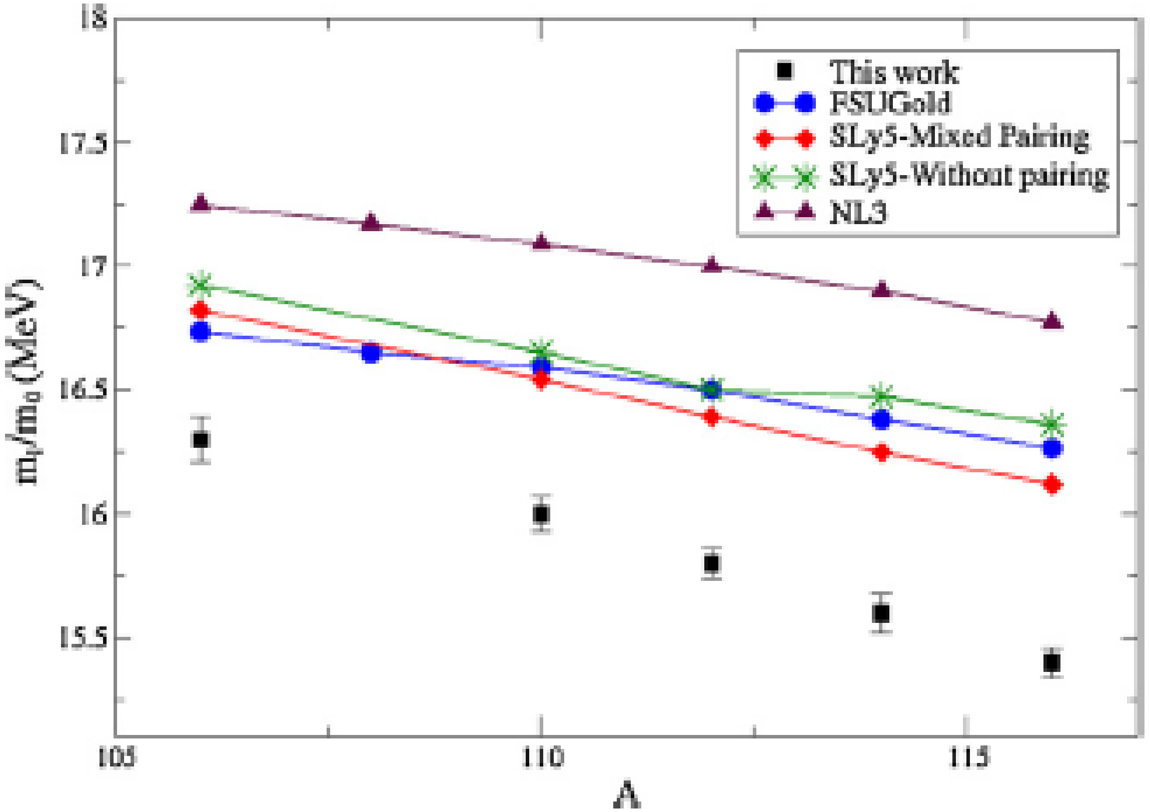
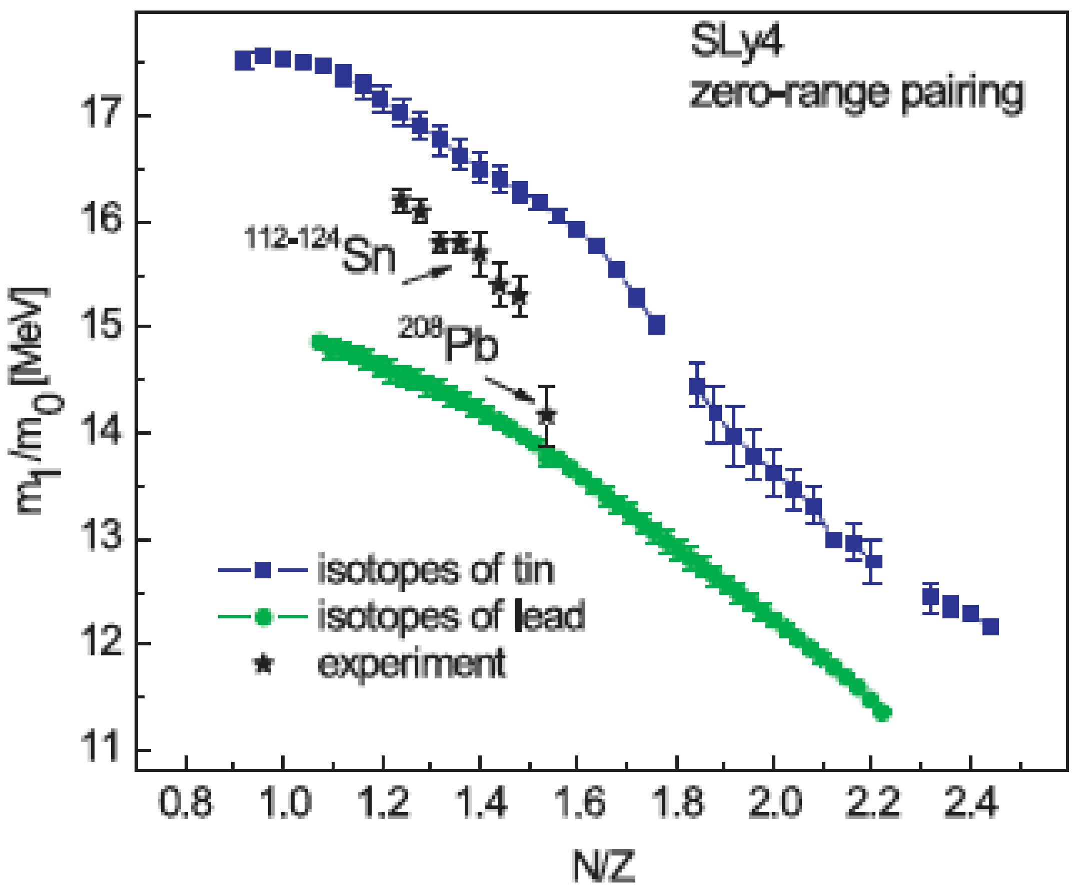
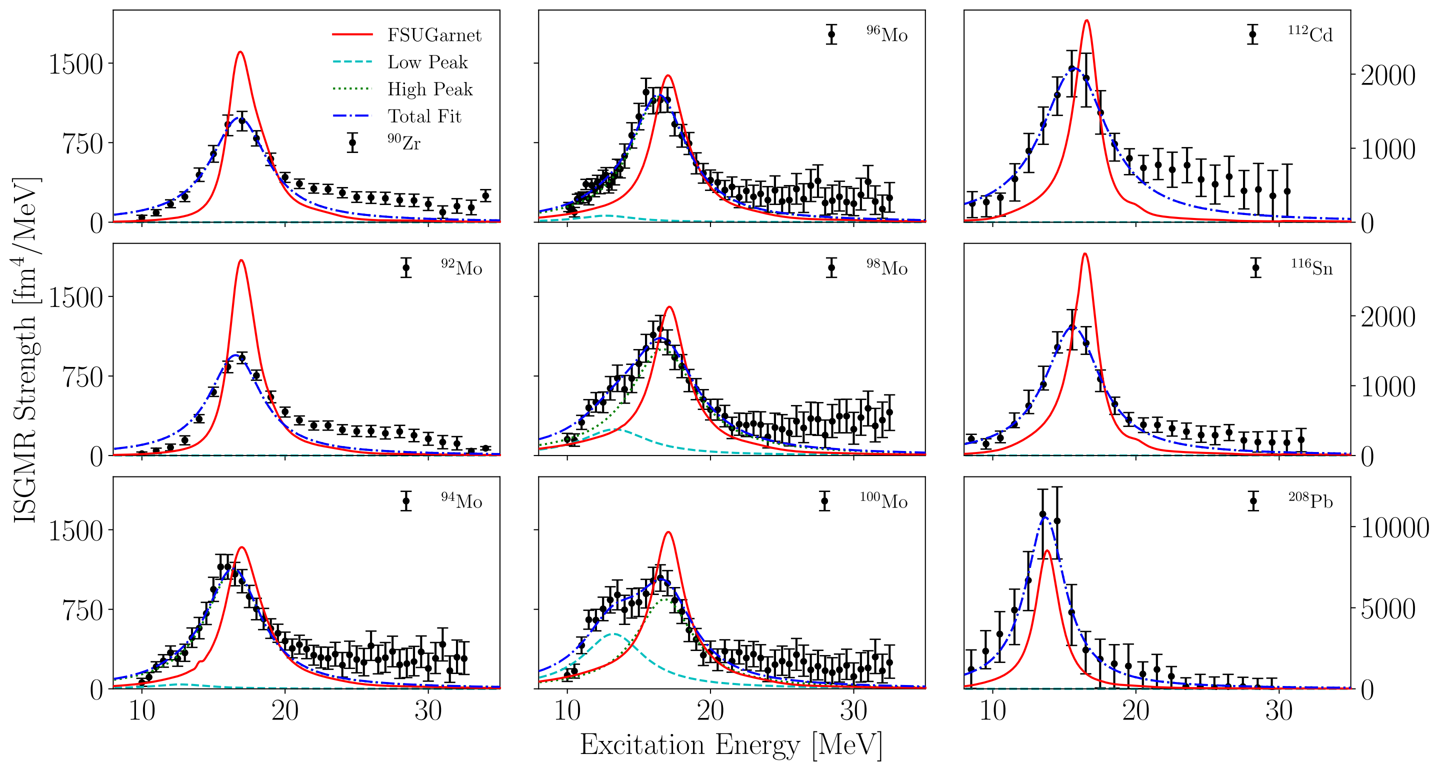


Fig. 3. (Color online.) Systematics of the moment ratio, m_1/m_0 for the ISGMR strength distributions in the Cd isotopes investigated in this work. The experimental results (squares) are compared with relativistic calculations performed using the FSUGold (circles) and NL3 (triangles) effective interactions. Also presented are results from non-relativistic calculations performed using the Sly5 parameter set in the HF-BCS + QRPA formalism with and without the mixed pairing interaction (diamonds and stars, respectively) [36]. The solid lines are to guide the eye.

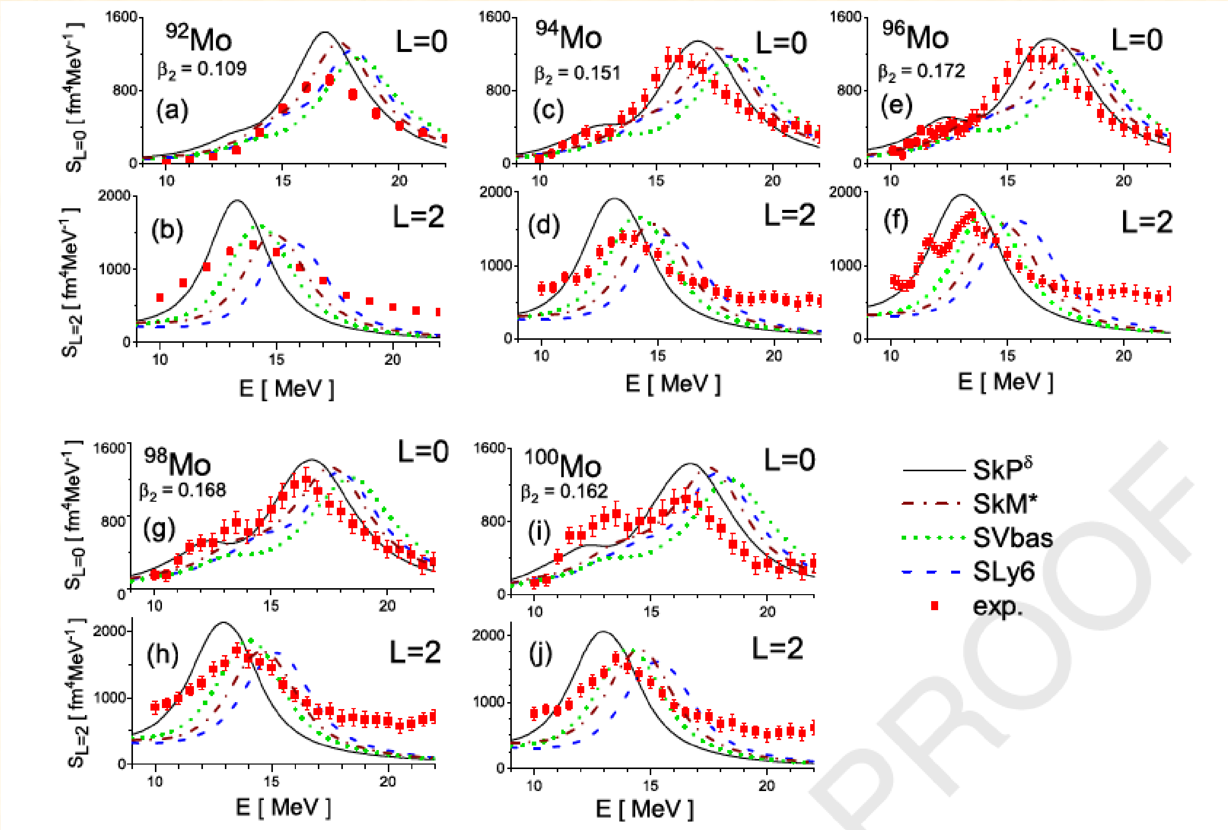
D. Patel *et al.*, Phys. Lett. B **718**, 447 (2012)



P. Vesely *et al.*, Phys. Rev. C 86, 024303 (2012)

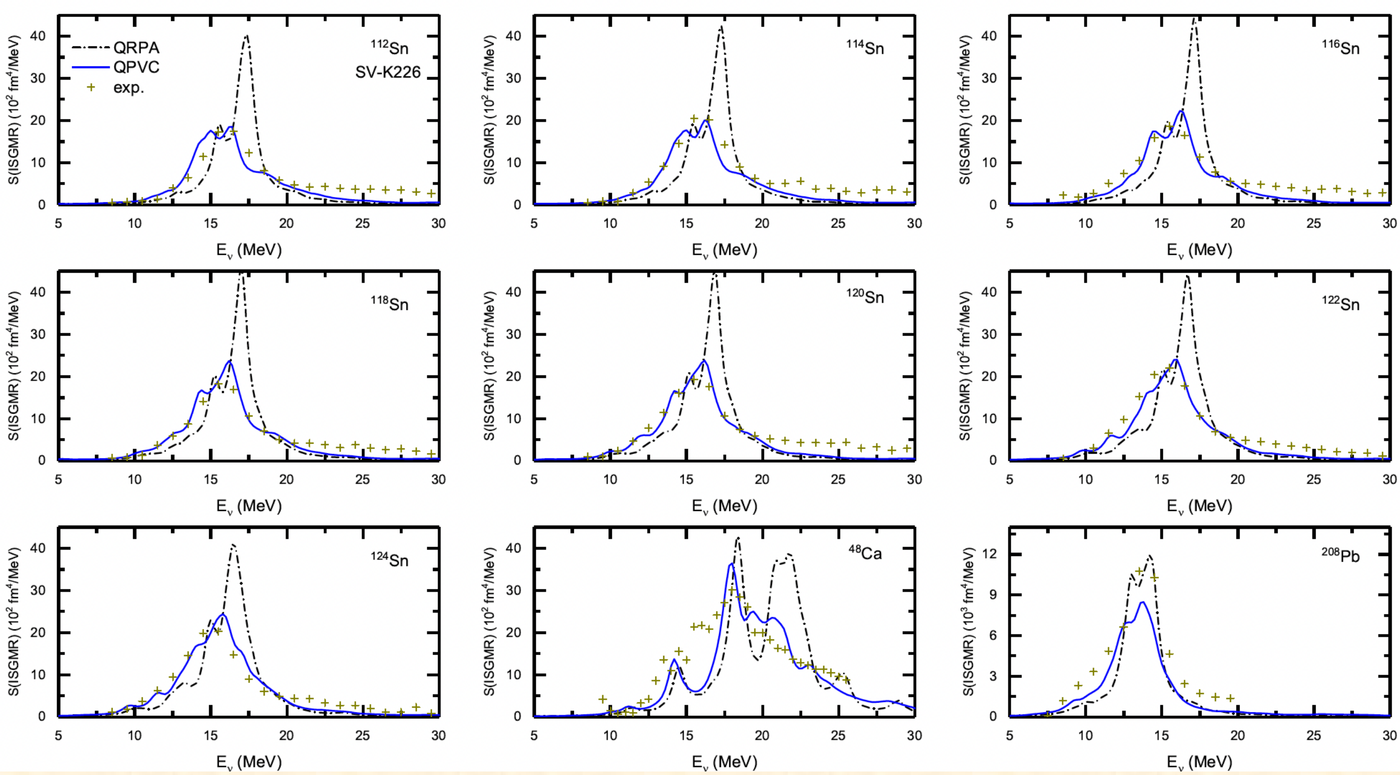


K. B. Howard et al., Phys. Lett. B **807**, 135608 (2020)



the connection between the line shape of the monopole strength ISGMR and the deformation-induced coupling between the ISGMR and the K = 0 branch of the ISGQR. The ISGMR is best described by the force SkP$^\delta$, having a low incompressibility K_∞ = 202 MeV.

Gianluca Colò et al., Phys. Lett. B **811**, 135940 (2020)



Z. Z. Li, Y. F. Niu, and G. Colo, arXiv:2211.01264v1

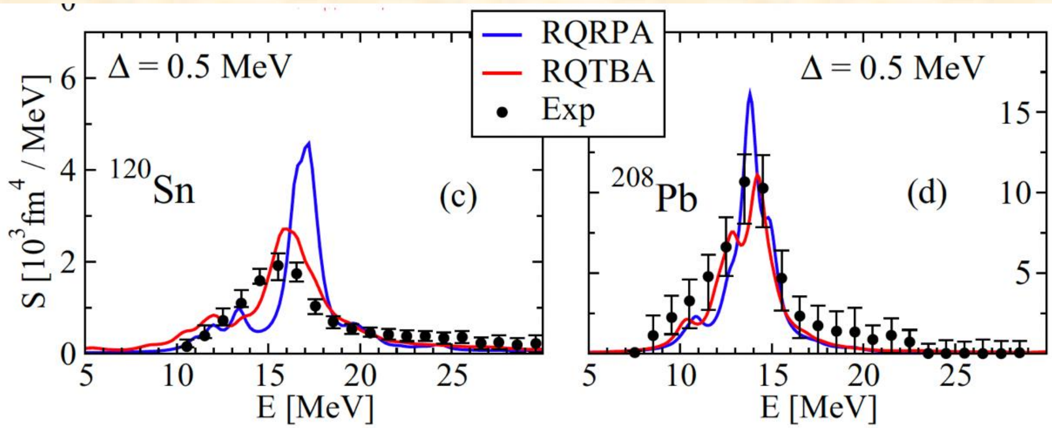
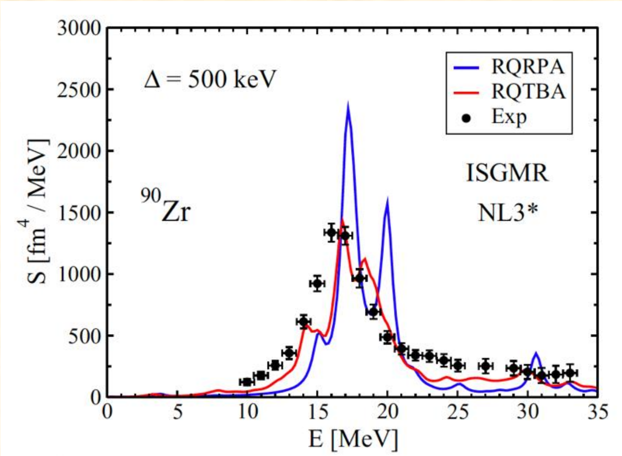


FIG. 1. ISGMR in ^{120}Sn and ^{208}Pb: RQRPA and RQTBA strength distributions compared to experimental data [35] (^{120}Sn) and [1] (^{208}Pb).



Elena Litvinova, Phys. Rev. C **107**, L041302 (2023).

- We have "experimental" values now for K_∞ and K_τ. There is a lot of room for "improvement" in the latter.

- We have completed a measurement at NSCL on ^{70}Ni using pure ^{4}He gas and trigger with S800. Very clean spectra have been observed with a "peak" at ~17 MeV consistent with GMR.

- An experiment to measure ISGMR in ^{132}Sn was approved in the "first round" proposals for FRIB.

- In the Cd and Sn isotopes, the ISGMR energy was significantly lower than that expected from the accepted value of K_∞.

- The "fluffiness" appears in the Mo isotopes, beginning with ^{92}Mo, just two nucleons out of the "doubly-closed" nucleus ^{90}Zr.

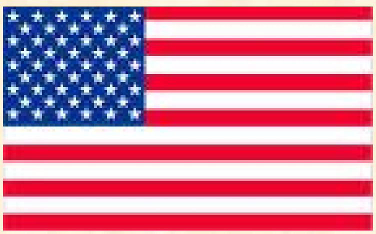
- Until very recently, there had been no satisfactory theoretical explanation of this "fluffiiness" of open-shell nuclei.

MAYBE, Now there is!

Merci

धन्यवाद

Thanks!



The Question Kitten