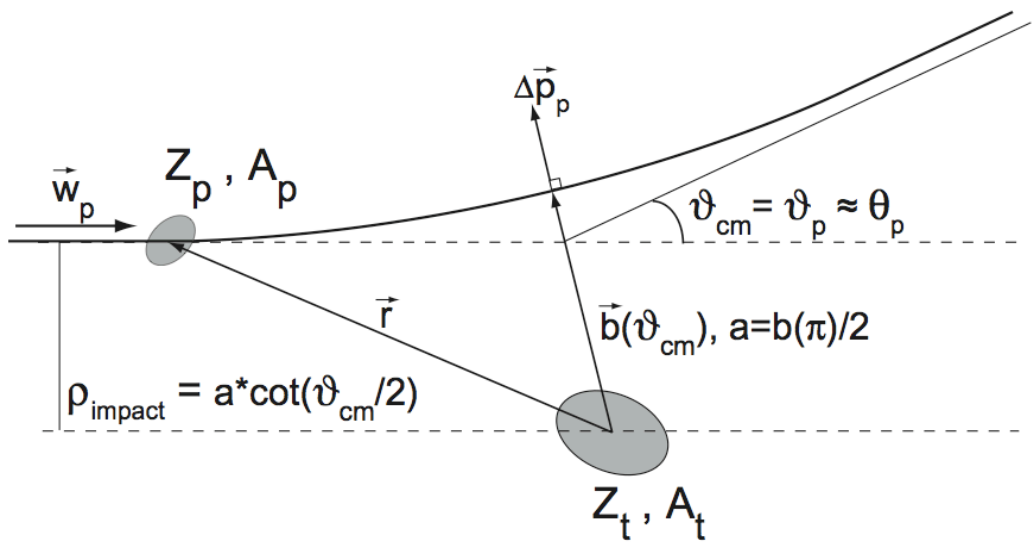
Nuclear Structure 2012

Resolving B(E2) Discrepancies in the Ni, Sn, and Te Isotopes by Coulomb Excitation in Inverse Kinematics



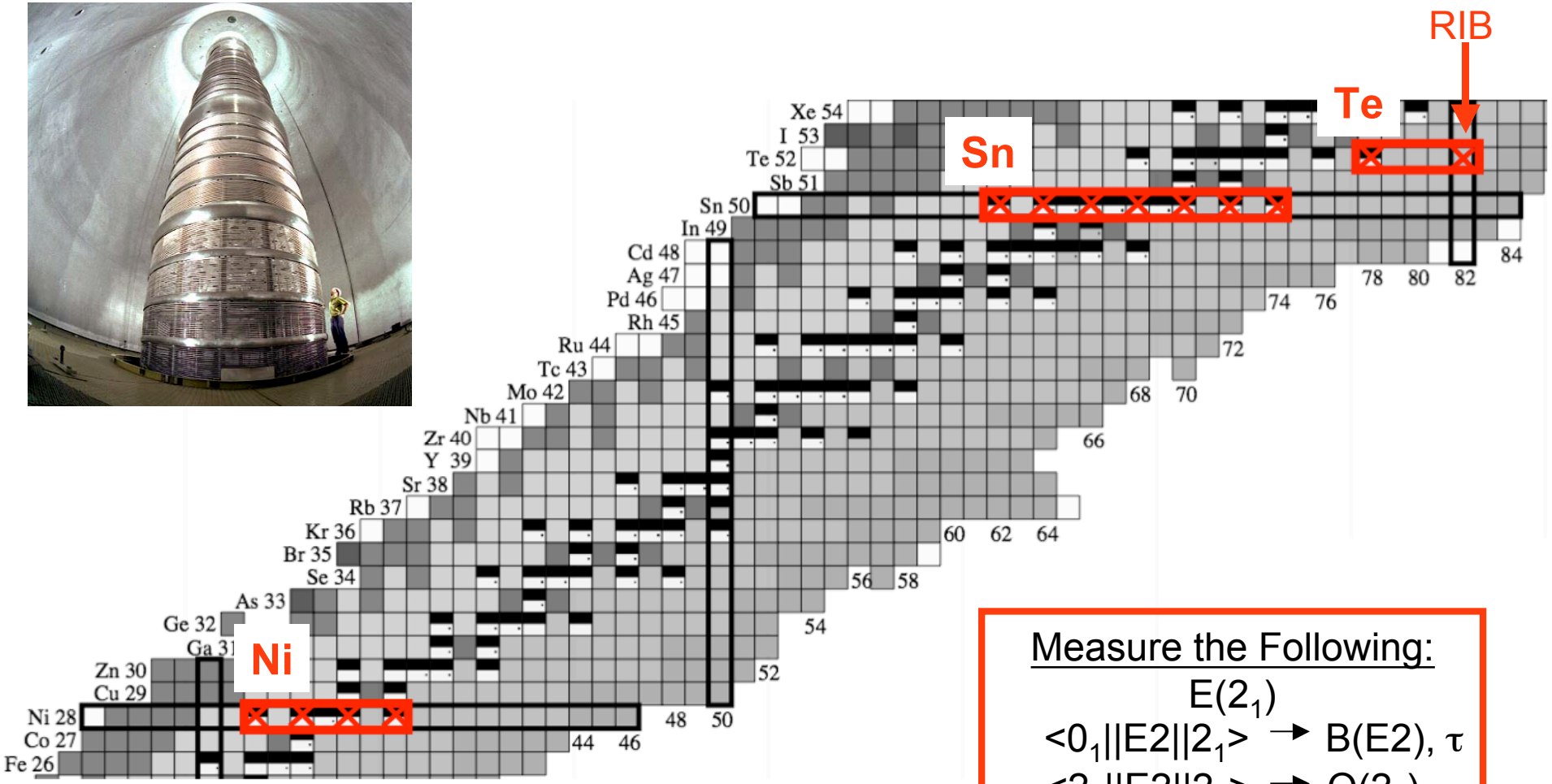
J.M. Allmond

JIHIR, Oak Ridge National Laboratory, Oak Ridge, TN 37831

$^{58\text{-}64}$Ni, $^{112\text{-}124}$Sn, and ^{130,134}Te by Coulex

Pure Ni, Sn, and Te beams can be studied by Coulomb excitation at HRIBF!!!

"Pure Beams"



Measure the Following:

$E(2_1)$

$\langle 0_1 || E2 || 2_1 \rangle \rightarrow B(E2), \tau$

$\langle 2_1 || E2 || 2_1 \rangle \rightarrow Q(2_1)$

$g(2_1)$ -- cf. Stuchbery Talk

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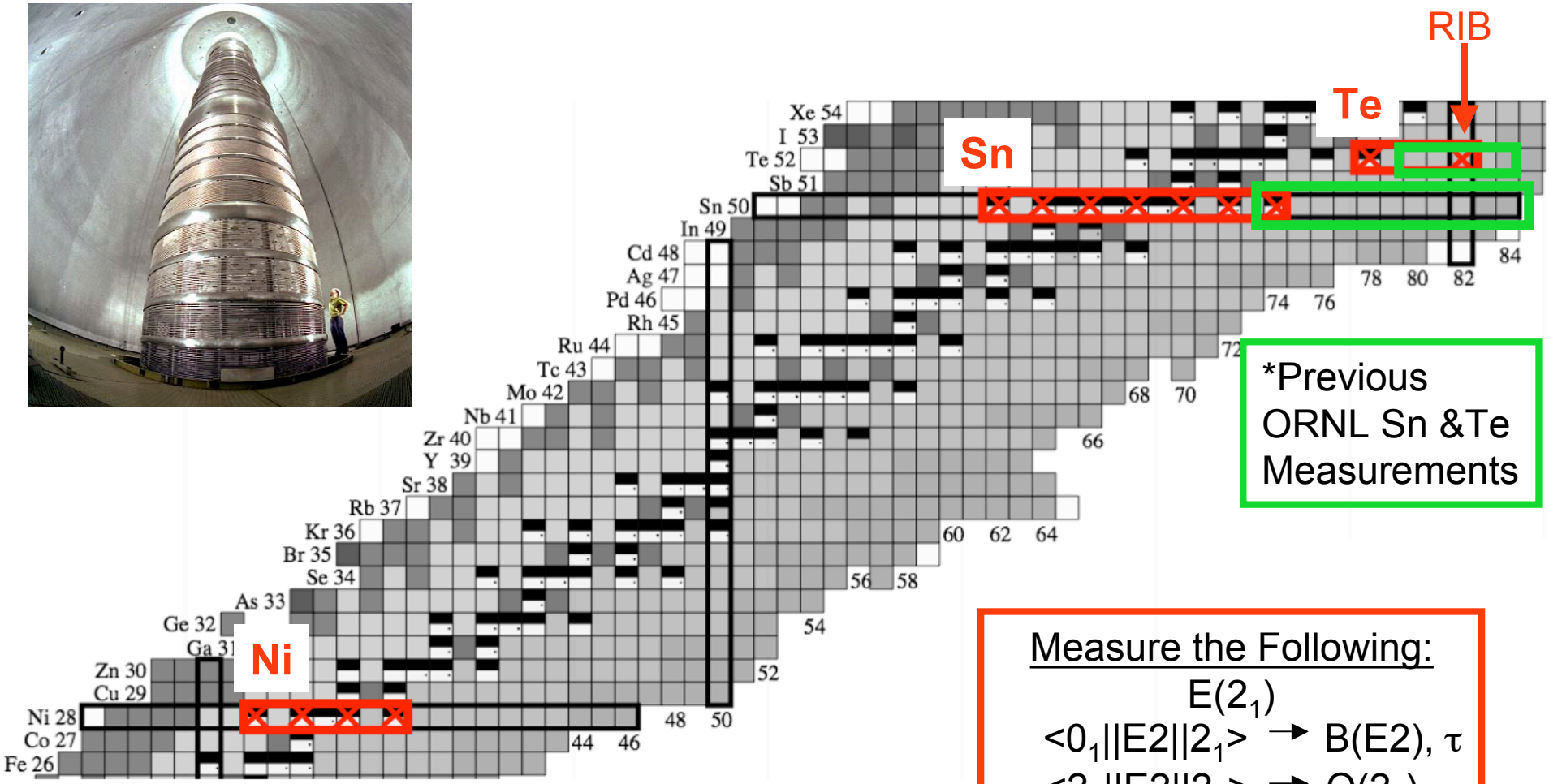

*Previous ORNL Sn &Te Measurements

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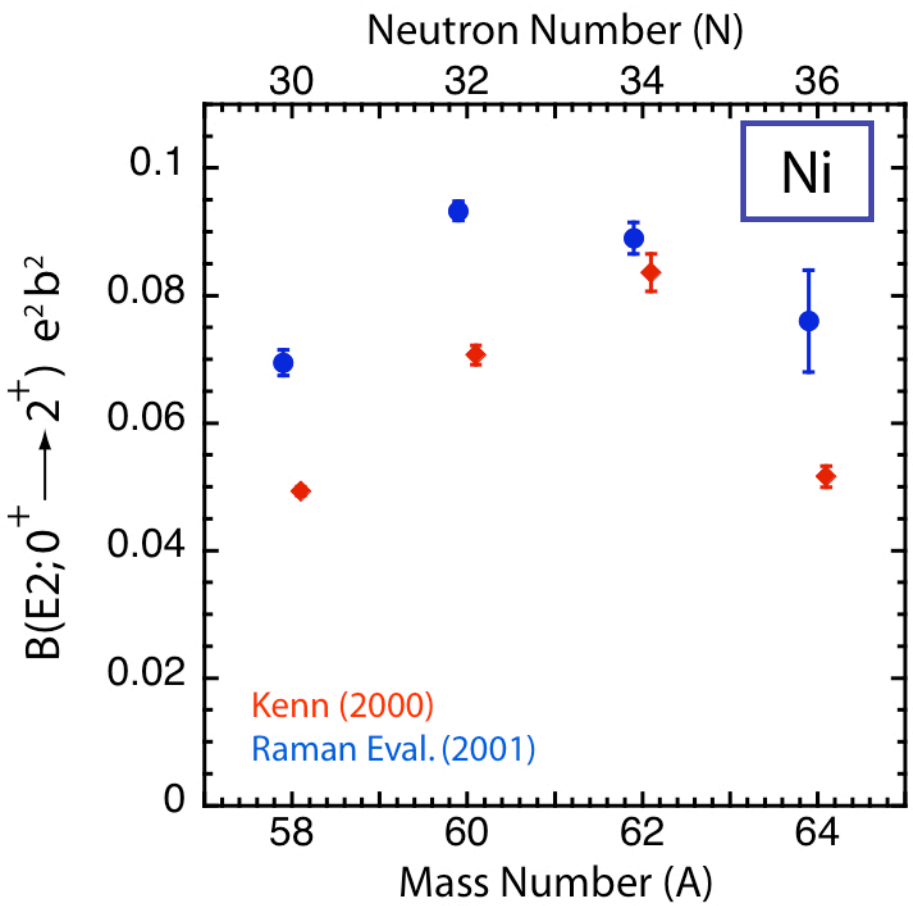
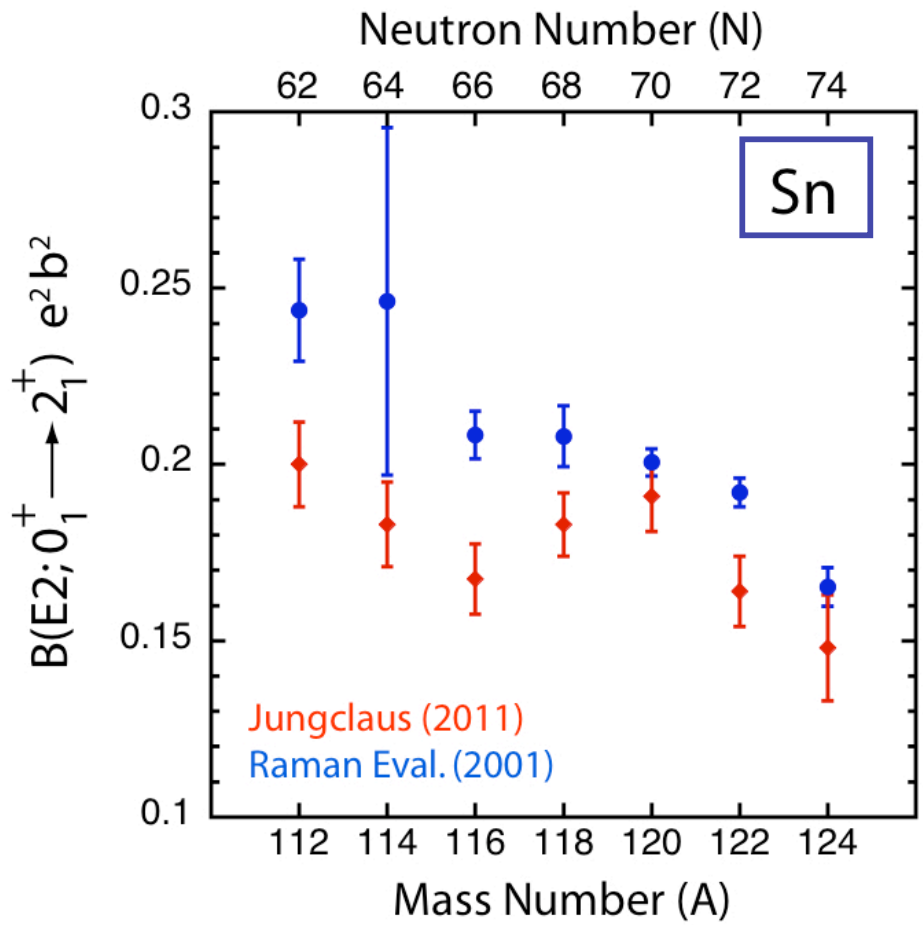
Recent B(E2) Discrepancies by DSAM

Need to resolve discrepancies for these important "shell-model" nuclei!!!





O. Kenn et al., Phys. Rev. C **63**, 021302(R) (2000).
S. Raman et al., At. Data Nucl. Data Tables **78**, 1 (2001).

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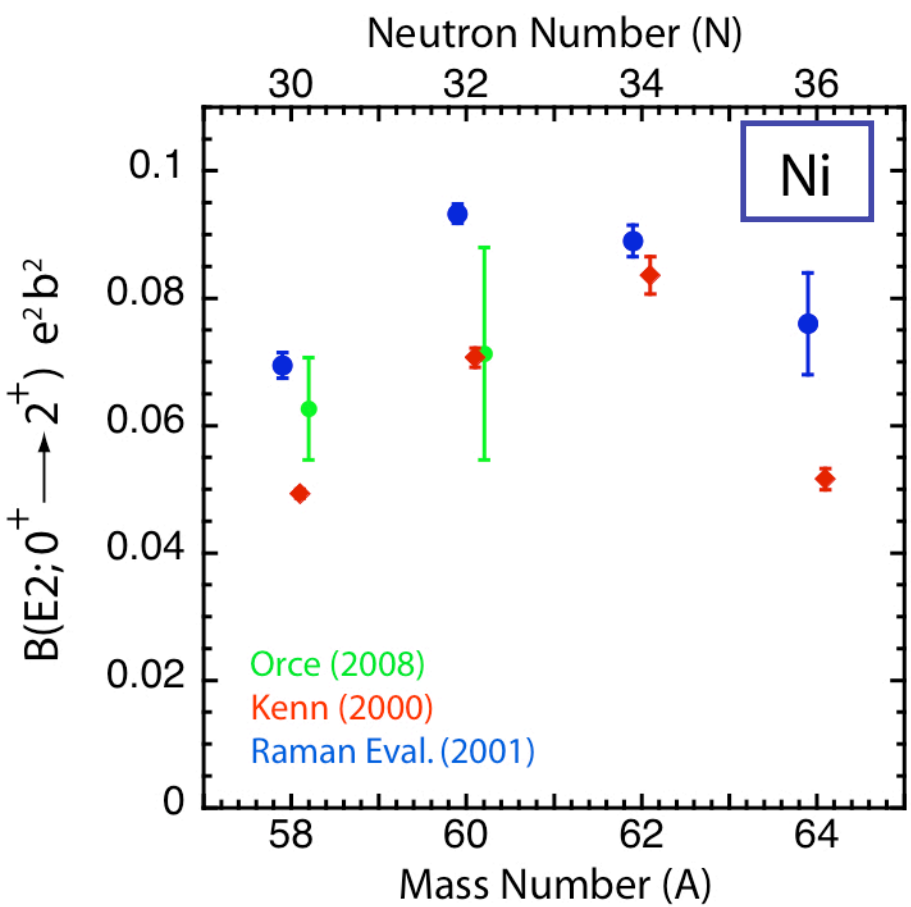

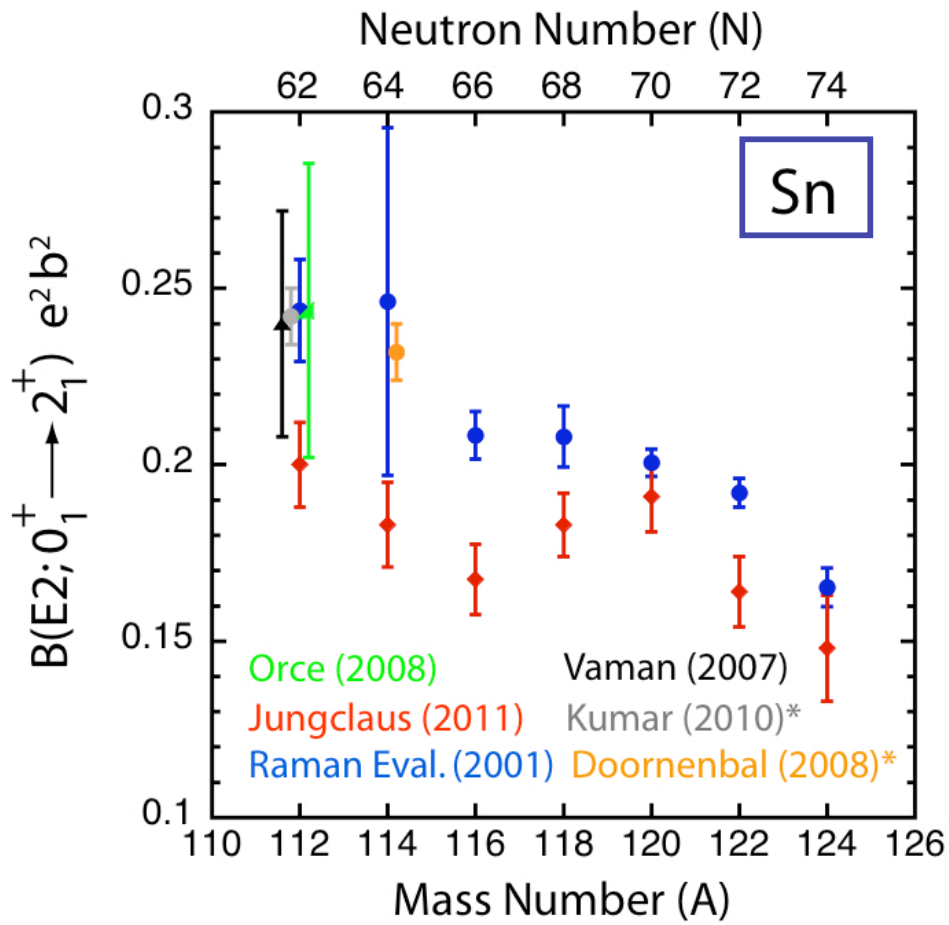

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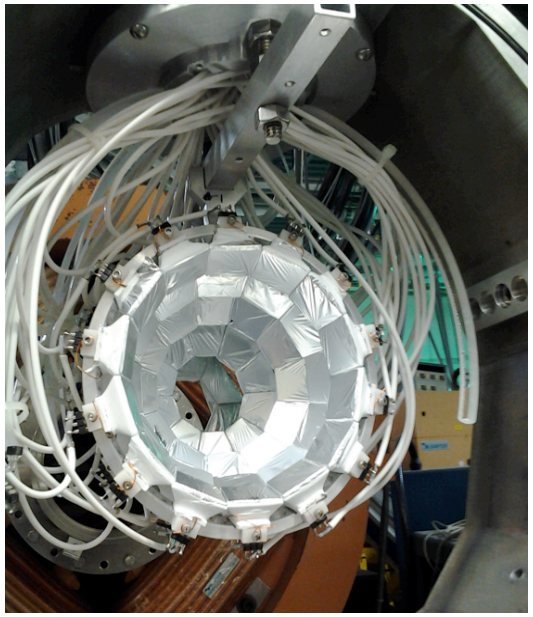
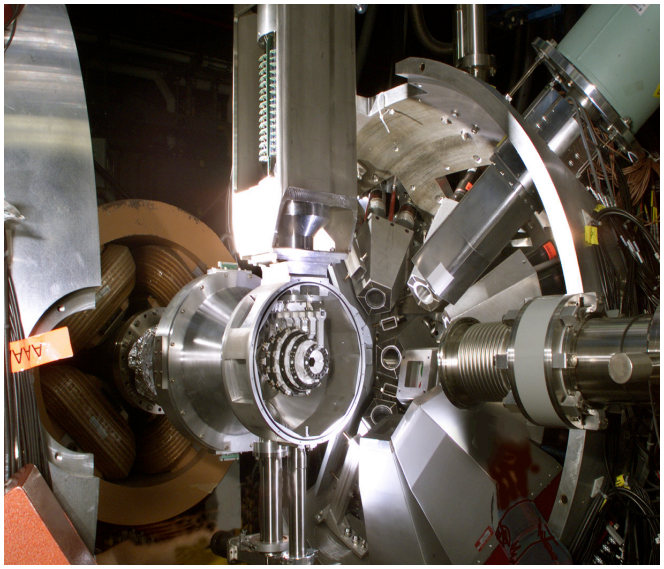
How to Measure: Clarion+Hyball

Can produce "pure" beams & achieve relatively high particle-γ statistics!!!

Stable and Radioactive Beams	Particle Detector	γ-ray Detector
ORIC/ISOL/Tandem	Bare HYBALL(CsI)	CLARION(HPGe)





Pure Beams: Ni, Sn, Te
nat-C Target: 98.9% ^{12}C
nat-Ti Target: 73.8% ^{48}Ti
- Targets ~ 1 mg/cm^2
- Beam Current ~ 50-100 pA
- Livetime > 98 %

Ring 2: 14°-28°(10)
Ring 3: 28°-44°(12)
Ring 4: 44°-60°(12)

90°(5 clovers)
132°(3 clovers)
154°(1 clovers)

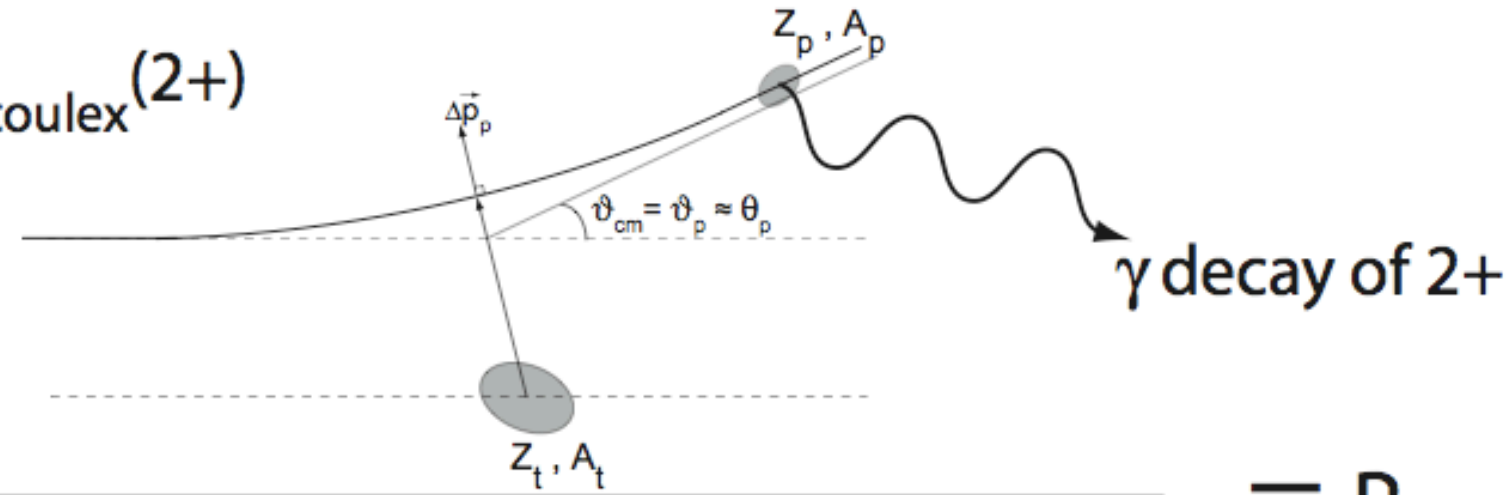
Eff(1000 keV) = 2.44(6) %
FWHM(1000 keV) = 2.57(2) keV

How to Measure: Coulomb Excitation

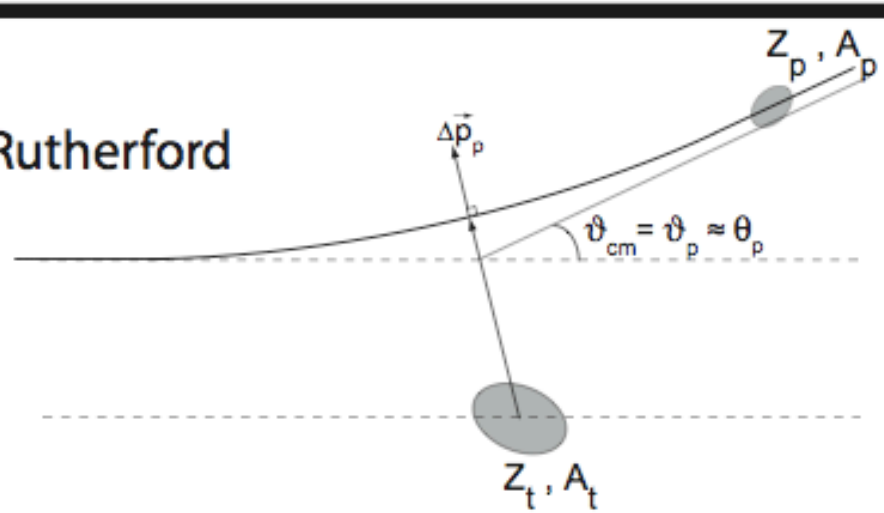
Coulomb excitation cross sections or probabilities let us determine M.E.'s

Normalization to Rutherford is independent of previous measurements!!!

$\sigma_{coulex}(2+)$



$\sigma_{Rutherford}$



$= P_{coulex}(2+)$

↓

E2

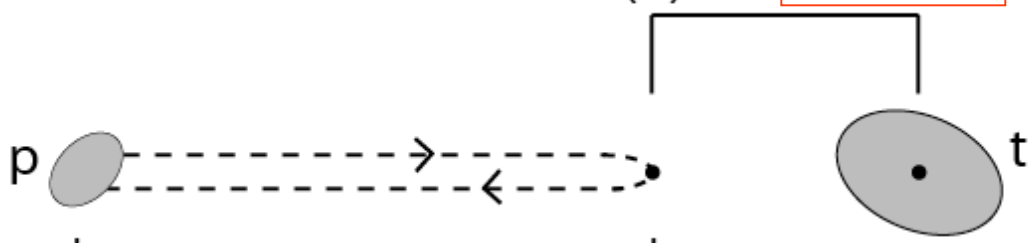
Matrix Elements

"Safe" Distance and Energy

Keep the two nuclei far enough apart to insure only E&M interactions!!!

"Distance of closest Approach"

$b(\pi)=2a$ > 5.1 fm "SAFE"



$$\text{k.e.} = E_{cm} = \frac{A_t}{A_p + A_t} E_p$$

$$\text{p.e.} = 0$$

$$\text{k.e.} = 0$$

$$\text{p.e.} = \frac{e^2}{4\pi\varepsilon_o} \frac{Z_p Z_t}{b(\pi)}$$

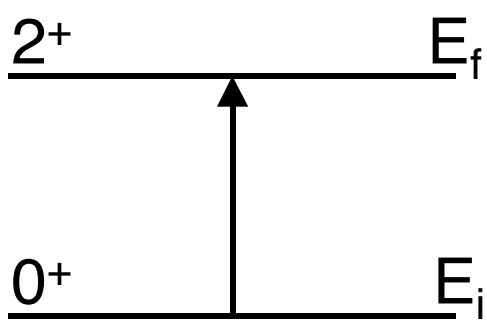
$$b(\pi)=2a=1.43998 \frac{A_p + A_t}{A_t} \frac{Z_p Z_t}{E_p(\text{MeV})} \quad (\text{fm})$$

Simple Two-State System

Qualitative schematic of how one connects data to M.E.s (and signs)!!!

$$< P_{i\to f} >= \frac{\int \frac{d\sigma_C}{d\Omega} d\Omega}{\int \frac{d\sigma_R}{d\Omega} d\Omega} = \frac{\sigma_C}{\sigma_R} \text{ , where } \frac{d\sigma_C}{d\Omega} = \frac{d\sigma_R}{d\Omega} P_{i\to f}$$

$$\left[P_{i\to f} = \frac{1}{2I_i+1} \sum_{M_i, M_f} |a_{i,f}|^2 \right] \propto \langle I_f || E2 || I_i \rangle^2$$



$$P_{0\to 2} \propto \langle 2^+ || E2 || 0^+ \rangle^2$$
$$\propto B(E2)$$

Generalized Two-State System

Qualitative schematic of how one connects data to M.E.s (and signs)!!!

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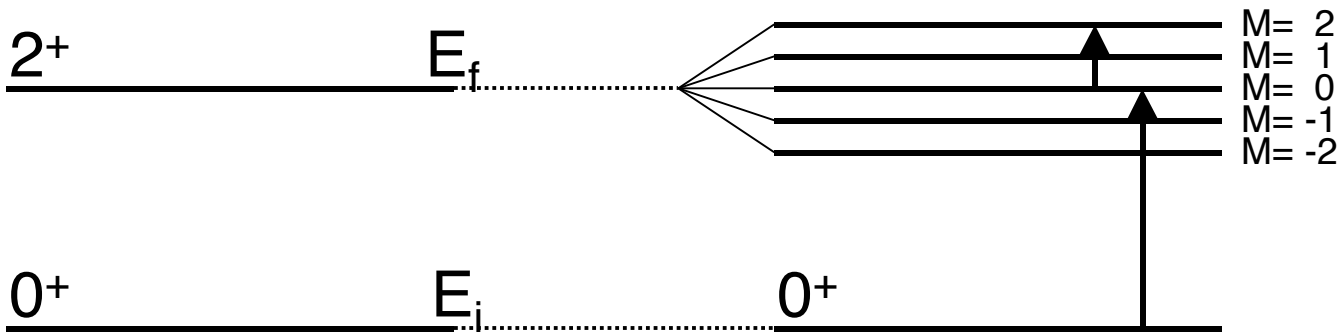

$$P_{0^+\to 2^+} \propto |a_{02} + a_{022}|^2$$

$$\propto |c_1\langle 2^+||E2||0^+\rangle + c_2\langle 2^+||E2||2^+\rangle\langle 2^+||E2||0^+\rangle|^2$$

but not always ~0

$$\propto c_1^2\langle 2^+||E2||0^+\rangle^2 + 2c_1c_2\langle 2^+||E2||0^+\rangle^2\langle 2^+||E2||2^+\rangle + \cancel{c_2^2\langle 2^+||E2||2^+\rangle^2}$$

$$\propto \langle 2^+||E2||0^+\rangle^2[1 + \langle 2^+||E2||2^+\rangle k]$$

$$\propto B(E2)[1 + Q(2^+)k']$$

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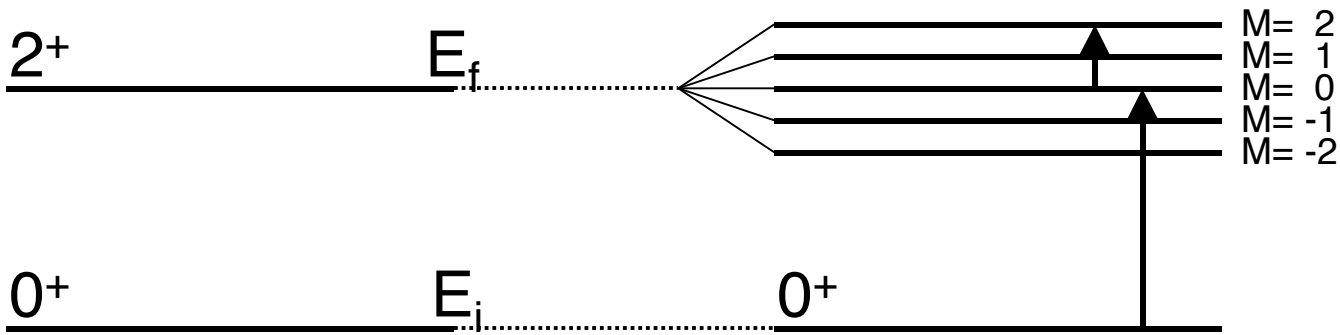

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$$\propto B(E2)[1 + Q(2^+)k']$$

K'(C target)~0.1

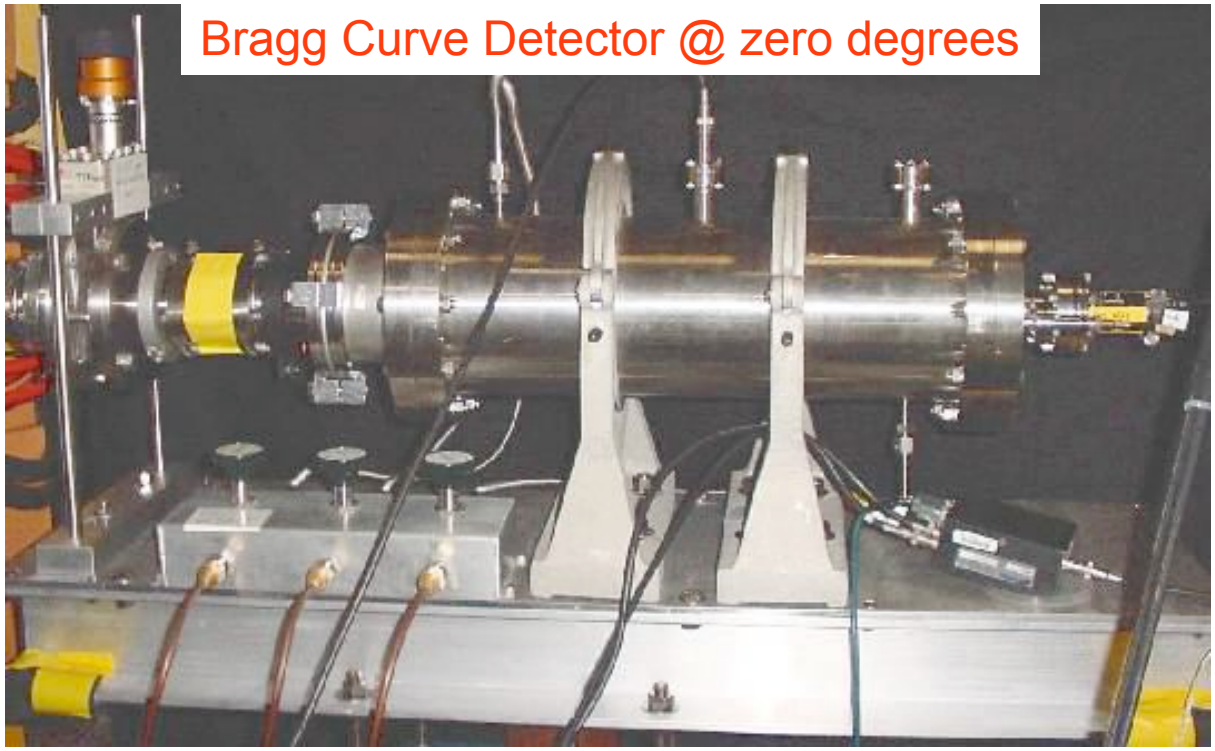
K'(Ti target)~0.5

Measure Target Thickness / Eloss

Cross sections are dependent on energy loss through target. Measure it!!!

WARNING!!!
Do not trust the quoted "nominal" target thickness or the energy loss calculated from the "nominal" target thickness.

$$\frac{\sigma_{coulex}}{\sigma_{Rutherford}}$$ is sensitive to the energy loss through the target



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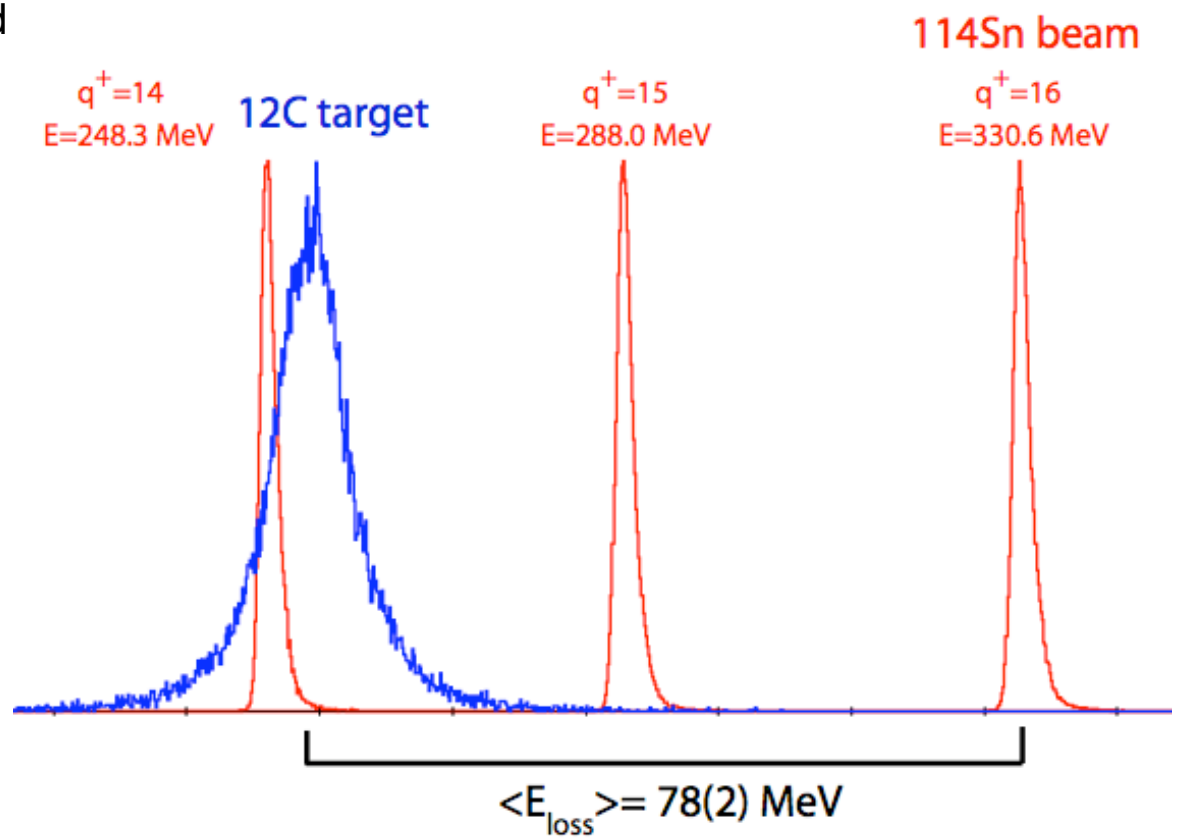
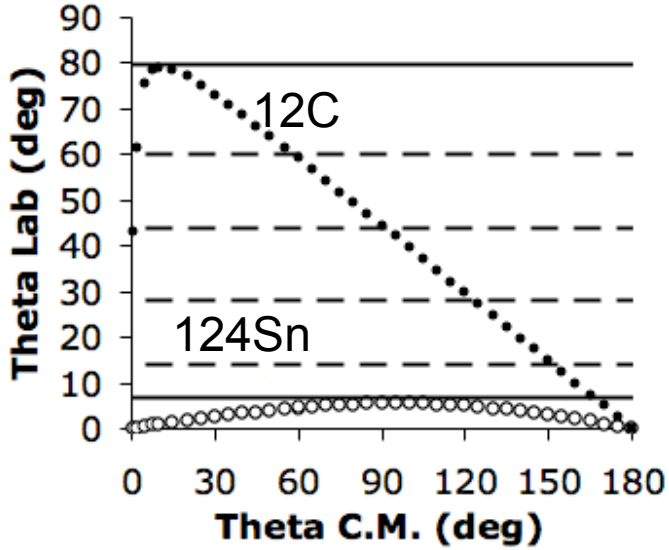
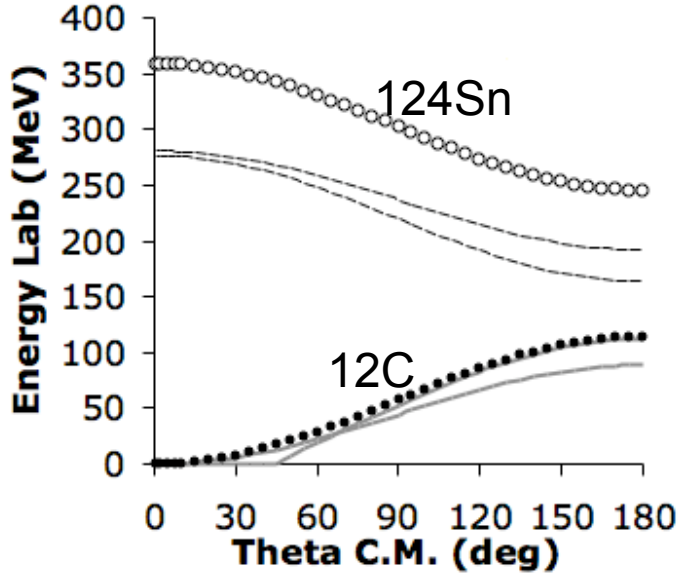


Inelastic (Inverse) Kinematics

Kinematics are well understood (can infer properties not directly measured)!!!



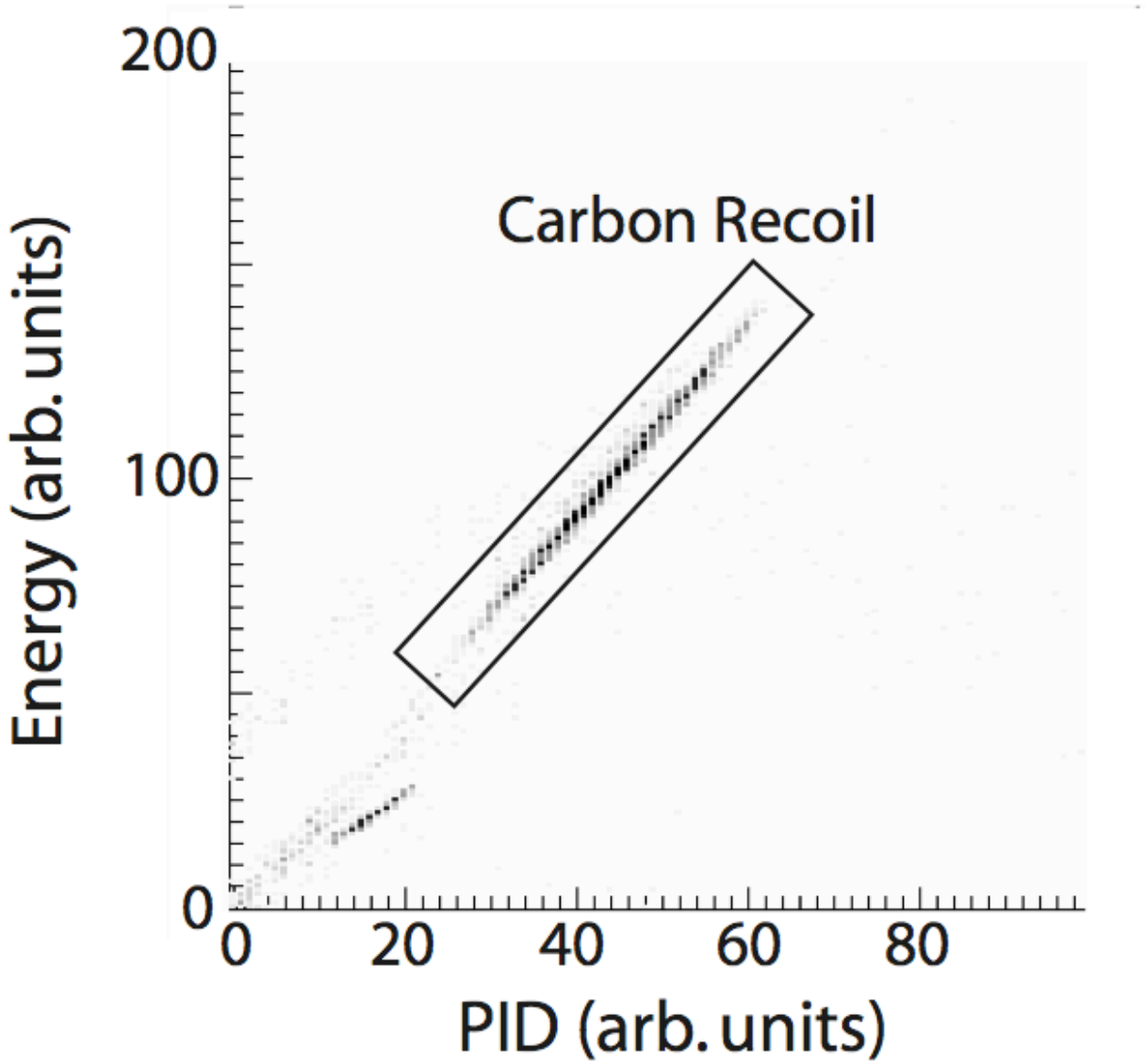


Example!!!

$^{124}Sn + ^{12}C$

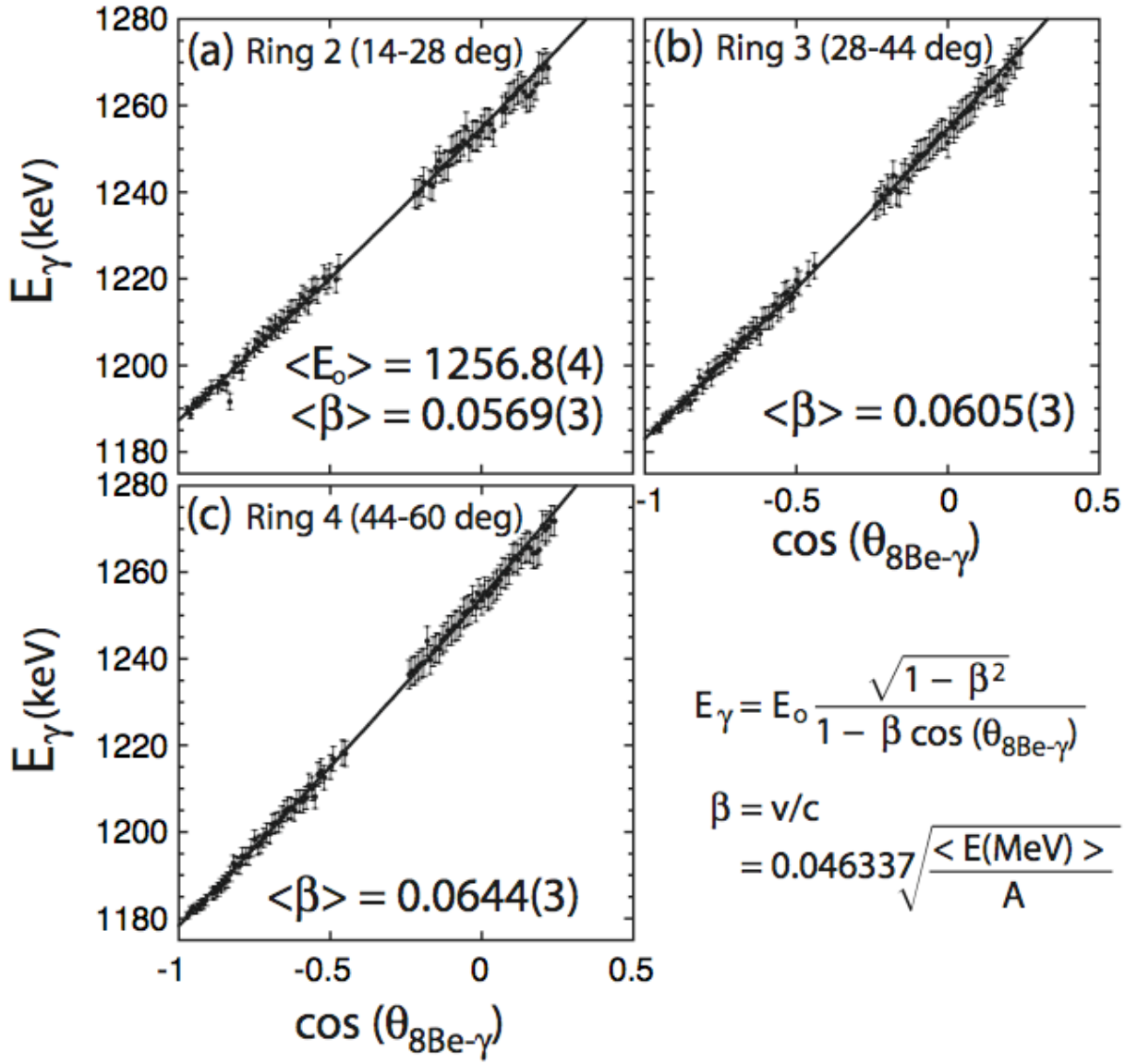
Particle Identification with CsI(Tl)

Can cleanly select recoiling target nuclei!!!



Doppler Corrections: ^{112}Sn Example

Double chi-square fits can determine experimental Eγ and β values !!!

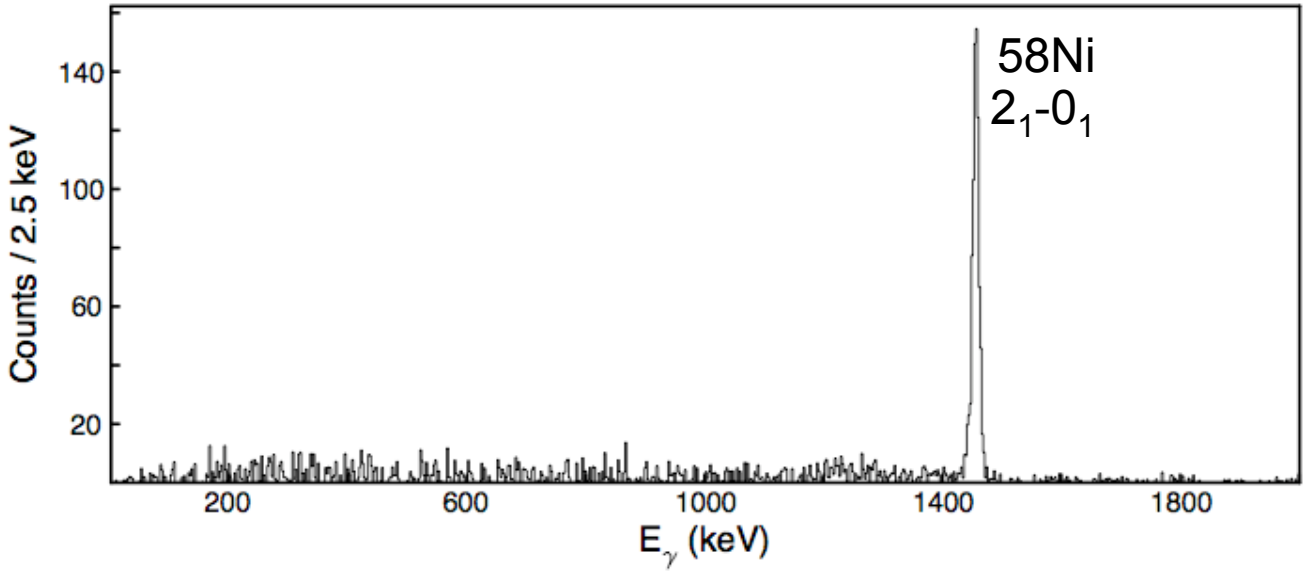


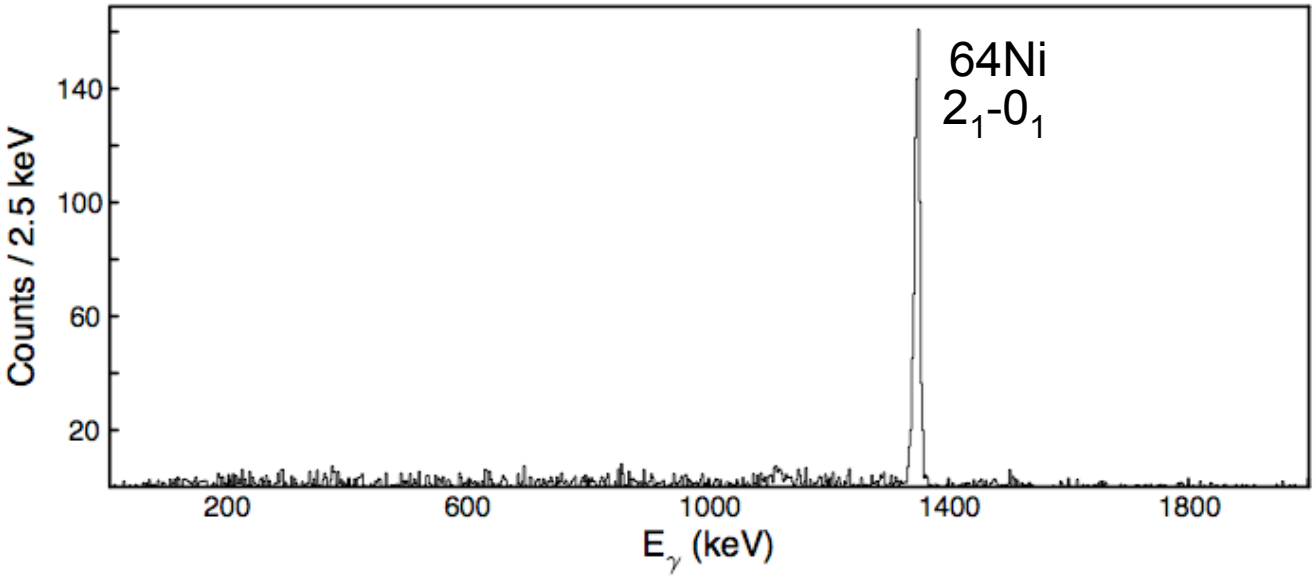
$$E_\gamma = E_o \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\theta_{8Be-\gamma})}$$

$$\beta = v/c = 0.046337\sqrt{\frac{<E(MeV)>}{A}}$$

Doppler Corrected γ Spectra

Can accurately measure peak areas (intensities) after Doppler correction!!!





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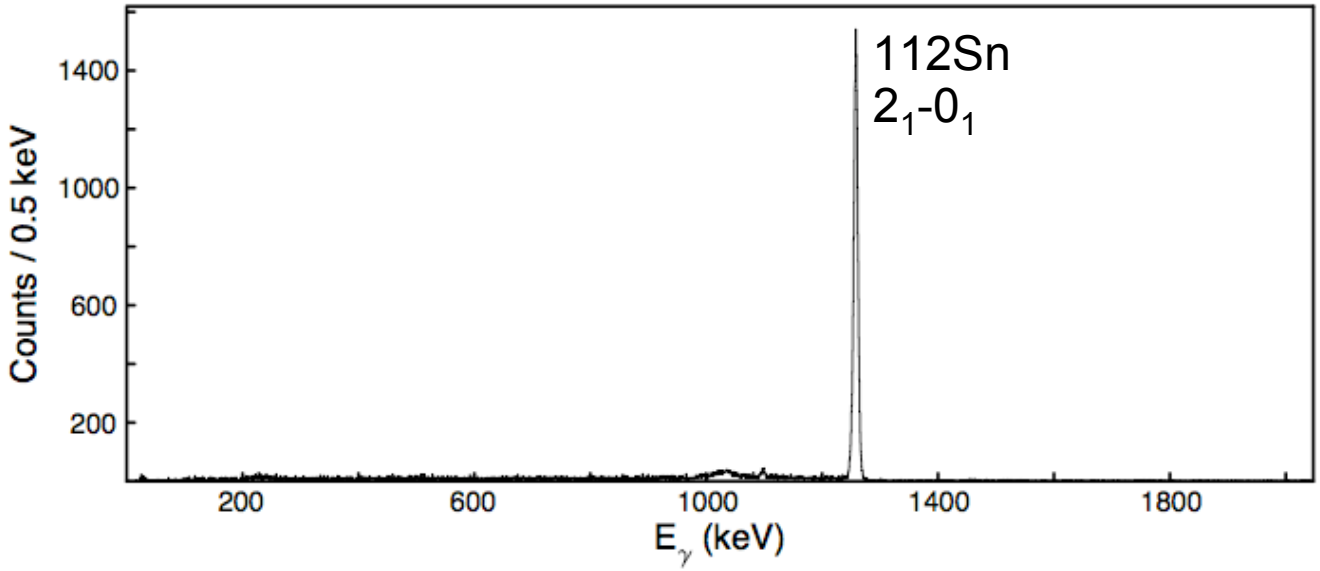
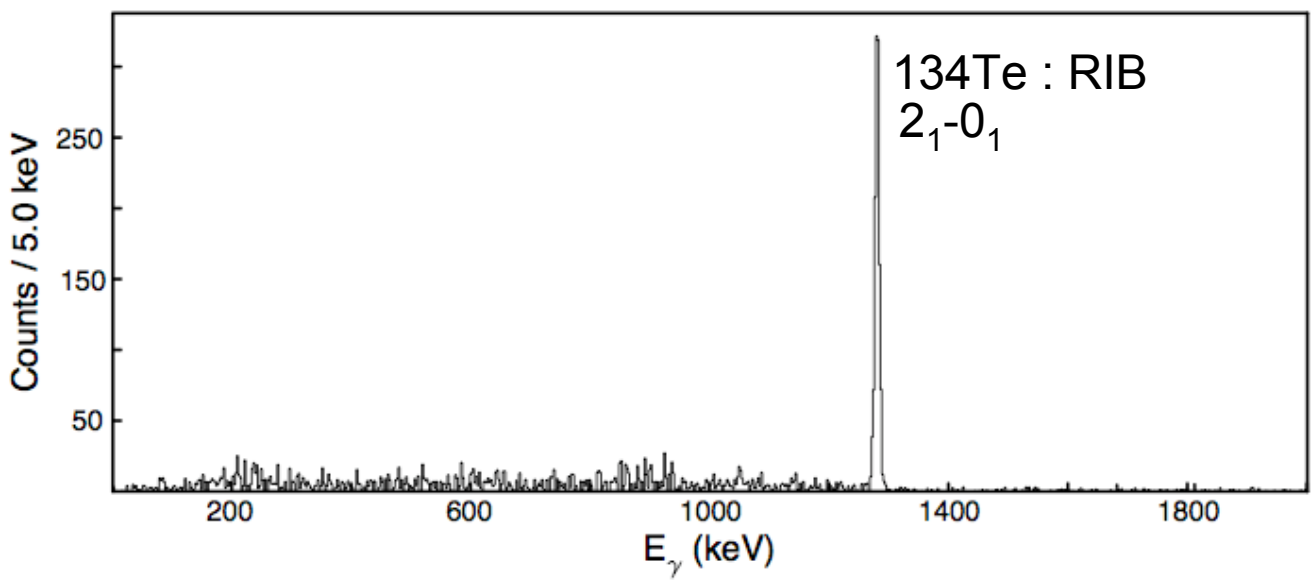
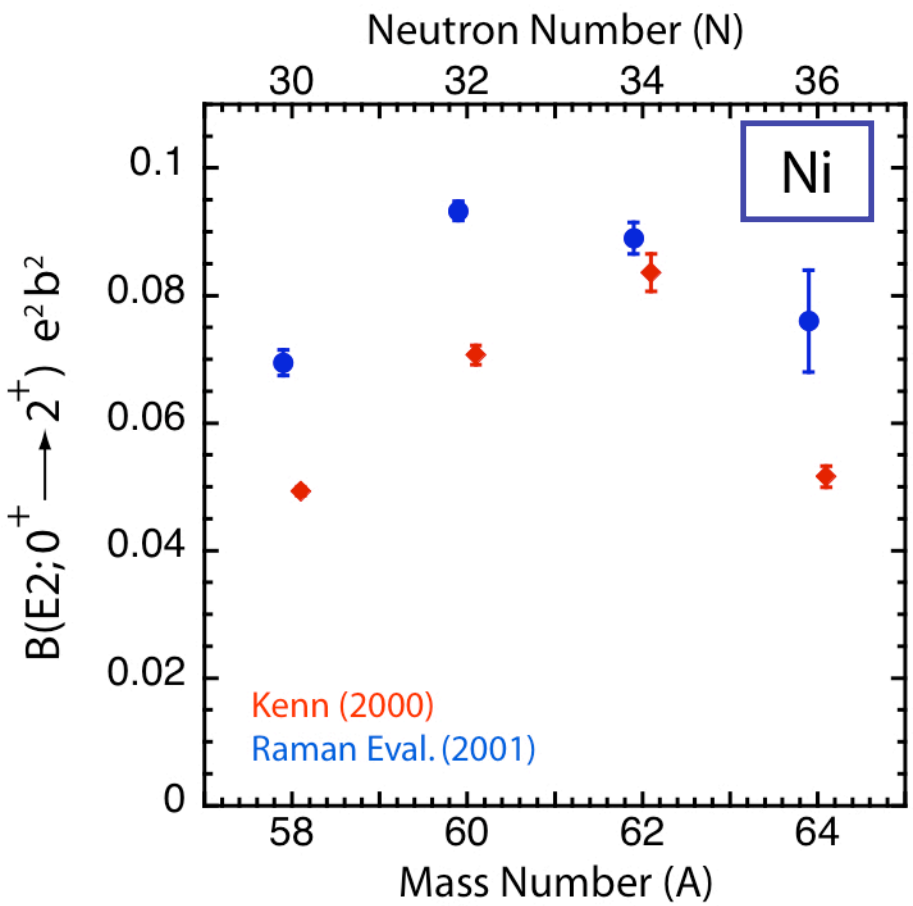
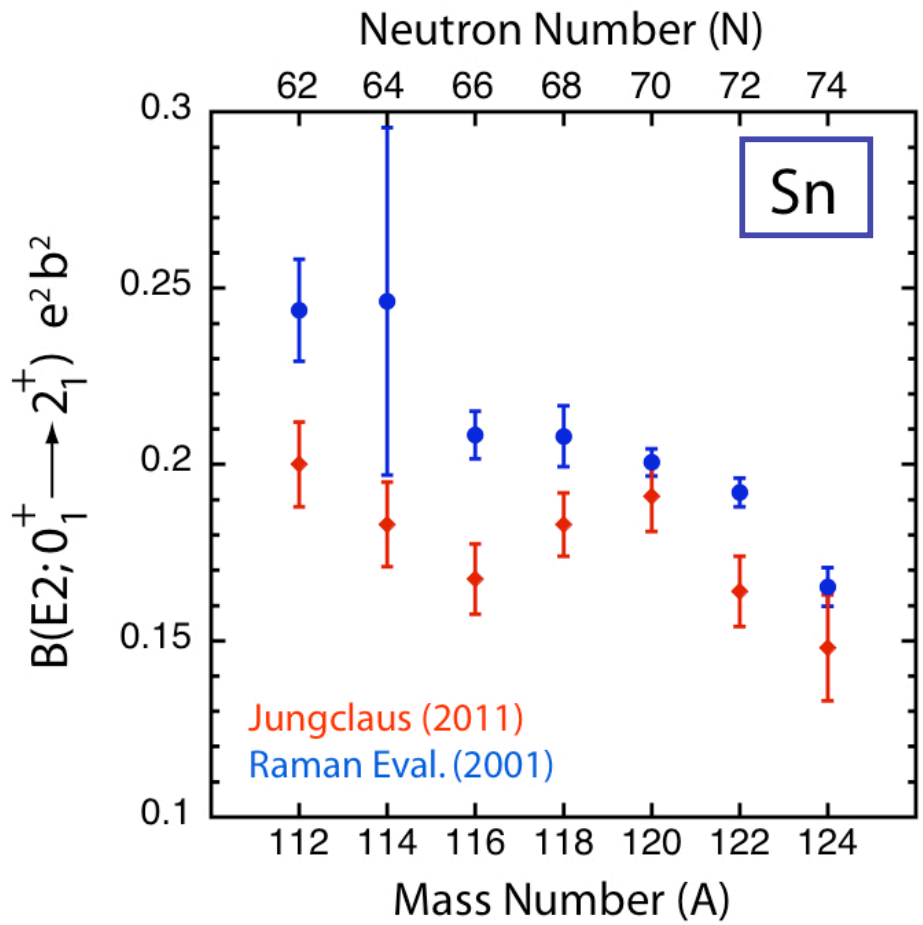




Recent B(E2) Discrepancies by DSAM

Need to resolve discrepancies for these important "shell-model" nuclei!!!





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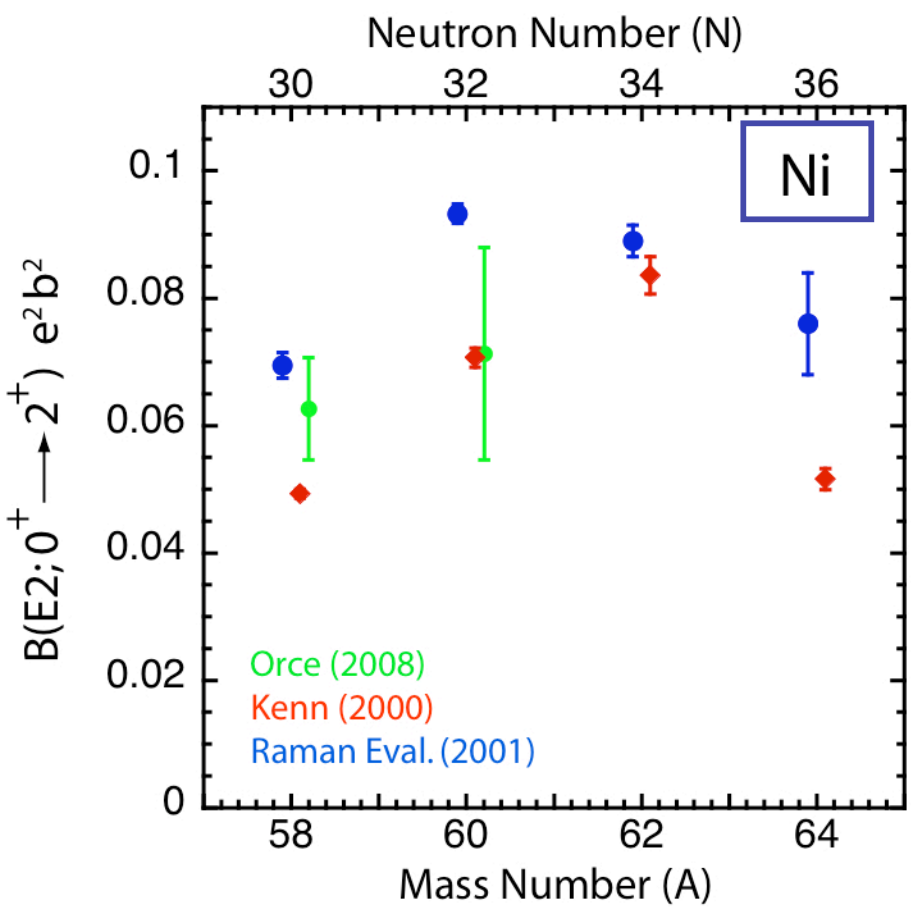

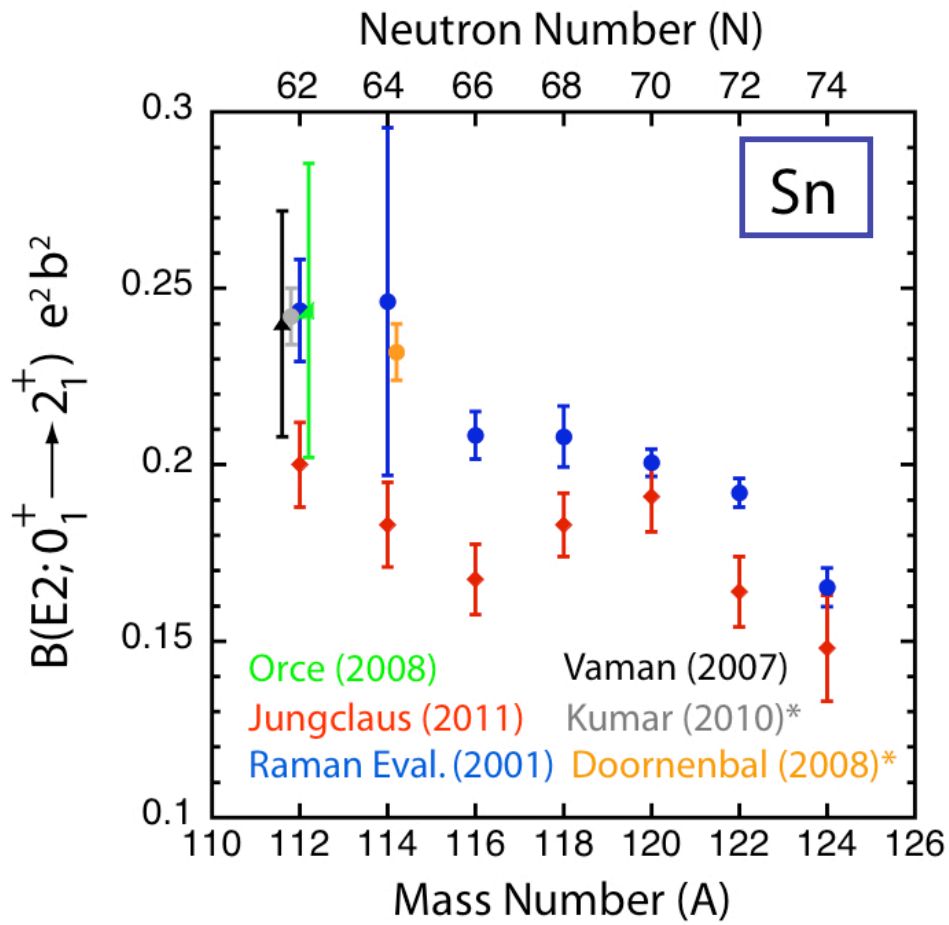

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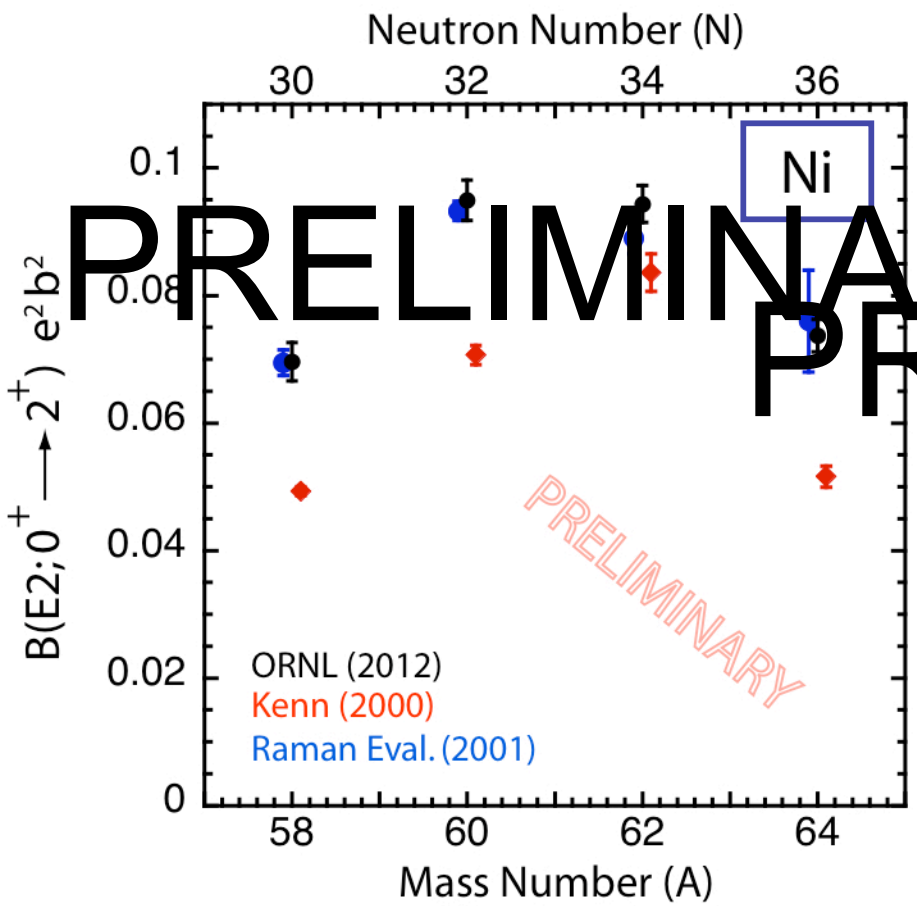
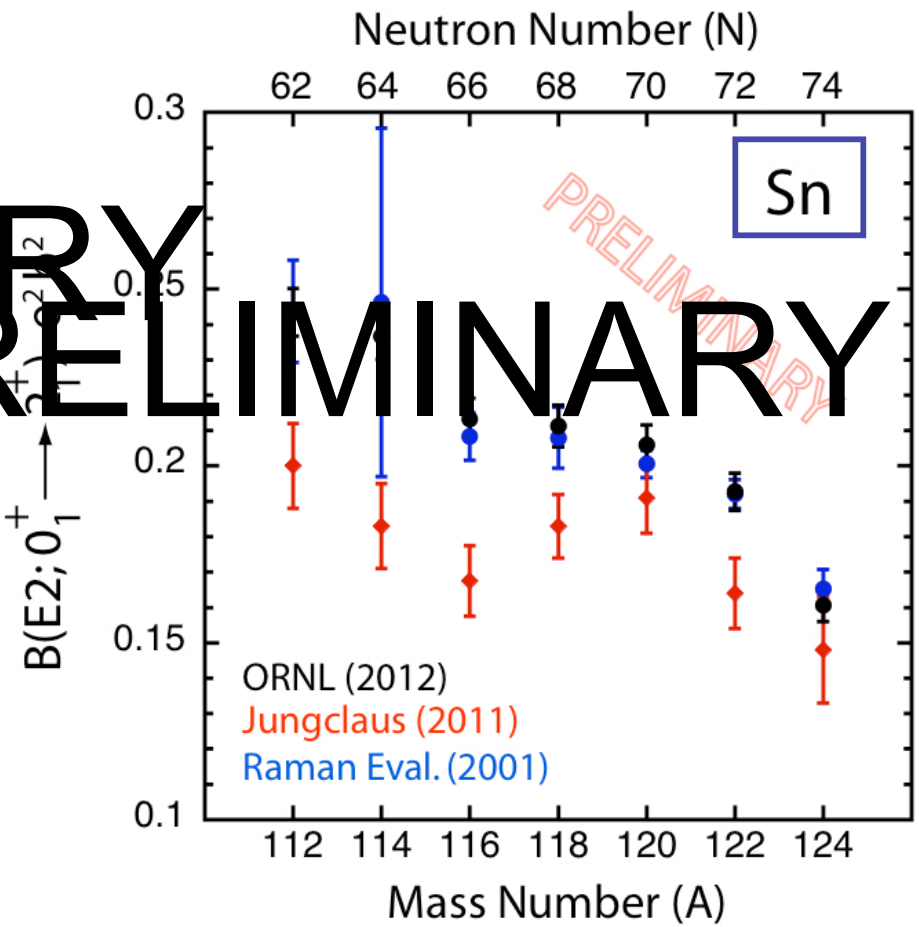
B(E2) Results from Coulomb Excitation

The present study disagrees with recent DSAM but agrees with Raman!!!



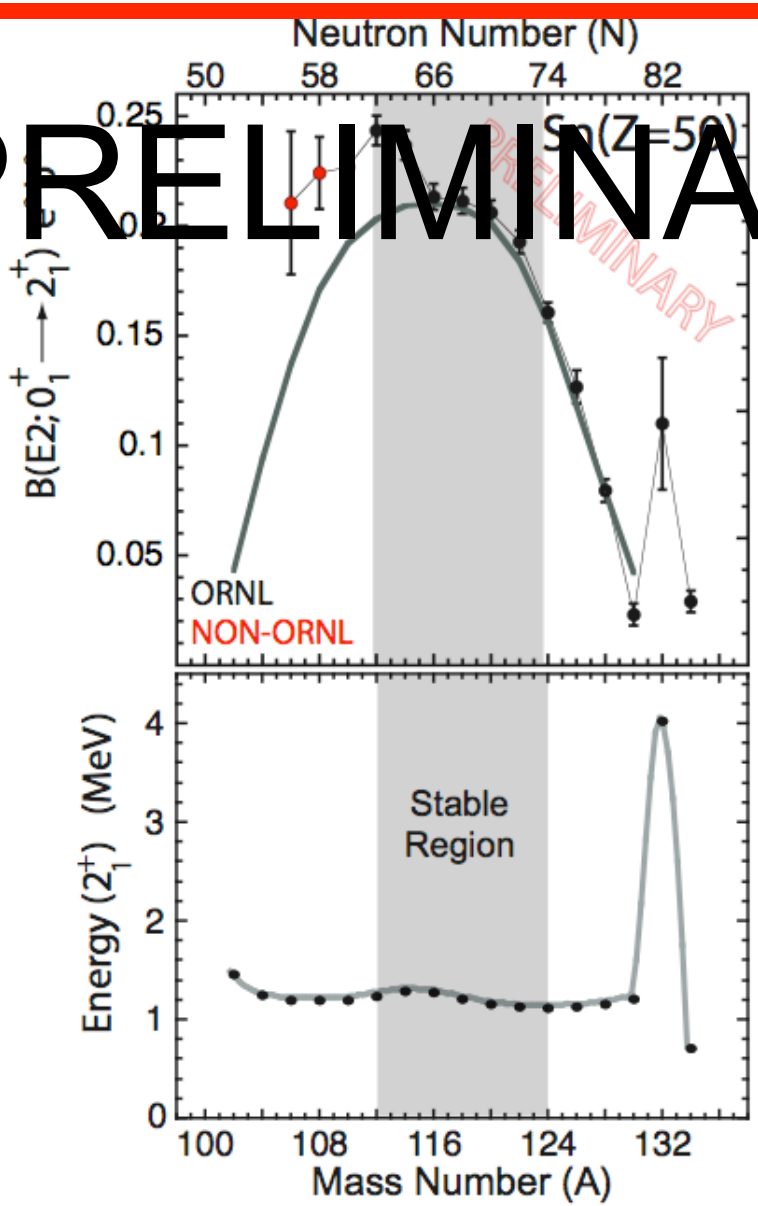


PRELIMINARY

PRELIMINARY

Summary of Sn Systematics

Current view of Sn systematics shows "two parabolas"!!! N=64 Subshell?



ORNL DATA
Allmond (present)
Allmond (2011)
Radford (2005)

NON-ORNL Data
Vaman 2007
Ekstrom 2008
Cederkall 2007
Banu 2005

100Sn Core Theory
A.Banu et al.,
Phys. Rev. C **72**, 061305(R) (2005).

Thanks to all of the Collaborators !!!

A. Galindo-Uribarri[2,3], A.E. Stuchbery[4], E. Padilla-Rodal[5], D.C. Radford[2],
J.C. Batchelder[6], J.R. Beene[2], C.R. Bingham[3], M.E. Howard[7], J.F. Liang[2], B. Manning[7],
S.D. Pain[2], N.J. Stone[3,8], R.L. Varner[2], C.-H. Yu[2]

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5 Instituto de Ciencias Nucleares, UNAM, AP 70-543, 04510 Mexico, D.F., Mexico
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