Differential Cross Section Measurements at the University of Kentucky
-- Adventures in Analysis

- J.R. Vanhoy, S.F. Hicks, B.R. Champine, B.P. Crider, E.A. Garza, S.L. Henderson, S.H. Liu, E.E. Peters, F.M. Prados-Estévez, M.T. McEllistrem, T.J. Ross, L.C. Sidwell, J.L. Steves, and S.W. Yates

- *US Naval Academy, Annapolis, MD 21402*
- *University of Dallas, Irving, TX 75062*
- *University of Kentucky, Lexington, KY 40506*
- *US Military Academy, West Point, NY*

Scott Lucas,EAWorldView

NEUP Nuclear Energy University Programs
U.S. Department of Energy

NSF

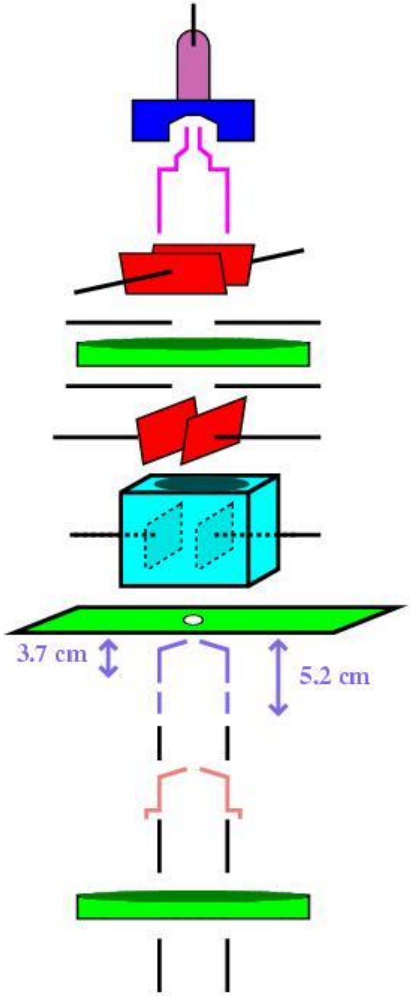
- General Intro to the Laboratory
- Sample results for recent ^{23}Na, ^{54}Fe, ^{nat}Fe (n,n') & (n,n'γ)
- Adventures in Analysis
  - Ambiguities in Neutron Detection Efficiency attributed to ^{3}H(p,n) $d\sigma/d\Omega$
    - The technique
    - Choices for $d\sigma/d\Omega$
    - Impact on Efficiency (E)
  - Challenges in Normalizing (n,n'γ)
    - What we did for 23Na(n,n'γ)
    - What will we do for 54,56Fe ?
  - How well do we know the finite geometry corrections?
    - Proving our correction code is rigorous
- Conclusion

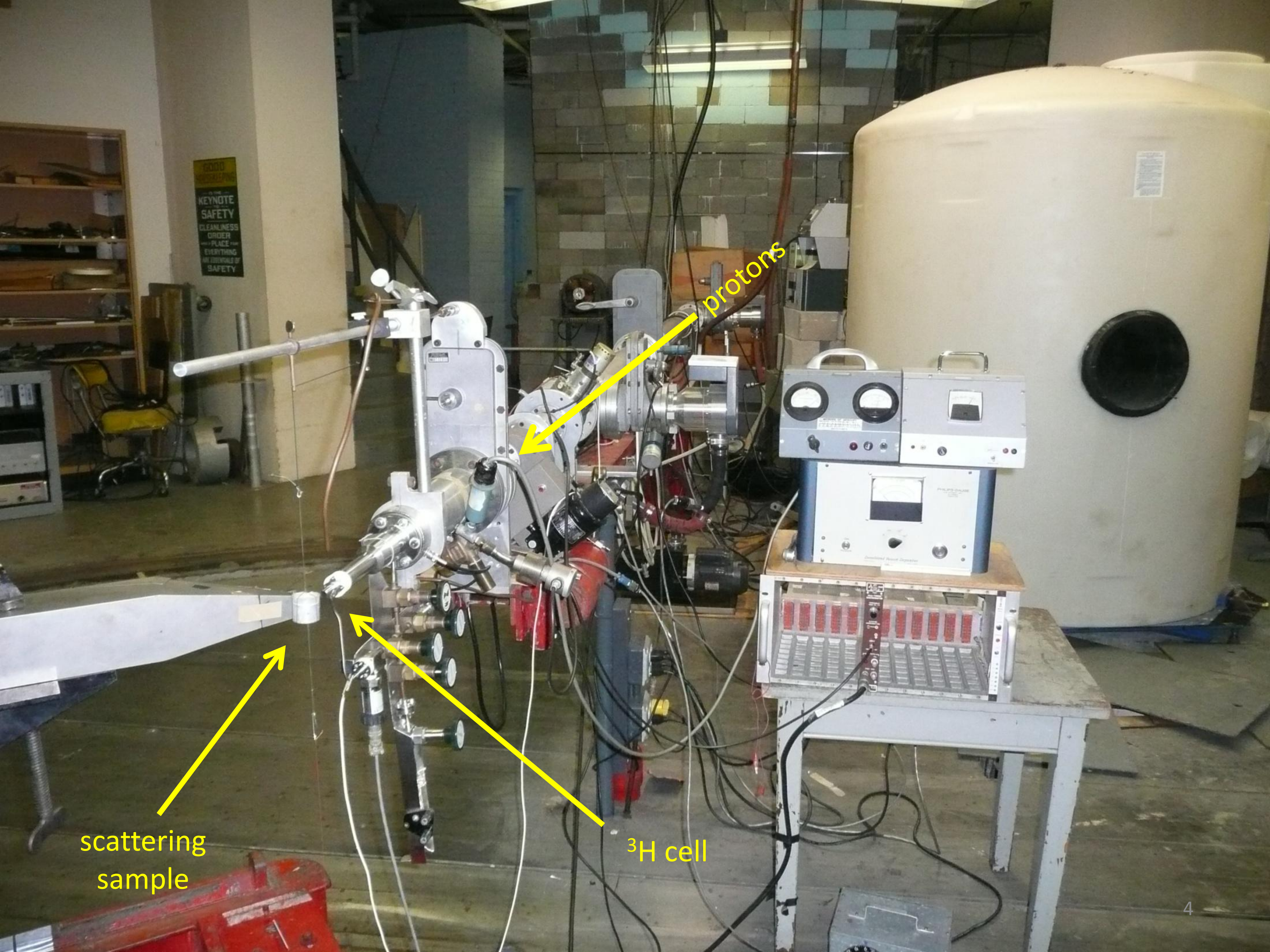
UNIVERSITY OF DALLAS

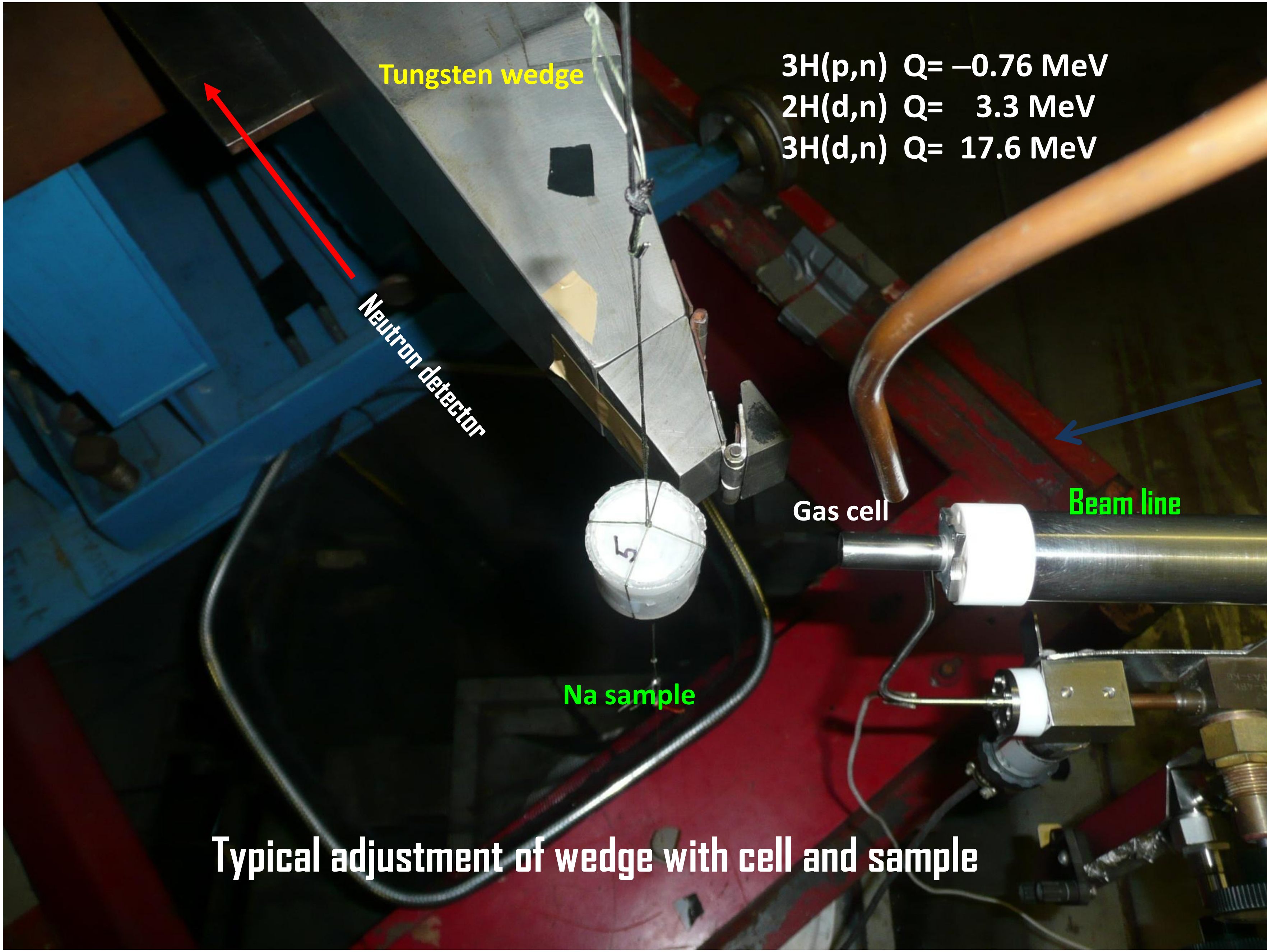
UK
UNIVERSITY OF KENTUCKY

ARUNA
Association for Research
at University Nuclear Accelerators

- **Accelerator**
  - HVEC Model CN: 7 MV
  - rf source
  - p, d, ^{3}He, α, … ions
  - Authorized for 3H gas targets
  - 1 ns pulse widths
- **Basic Nuclear Science**
  - Nuclear Structure via (n,n'γ)
    - Level Schemes & Transitions
    - Spectroscopic Information
    - DSAM Lifetimes
  - (3He,nγ)
- **Applied Nuclear Science**
  - Differential (n,n') Cross Sections
    - ^{23}Na, ^{54}Fe, ^{56}Fe
  - Detector Development
    - Univ Guelph
    - Univ Mass @ Lowell
    - RMD

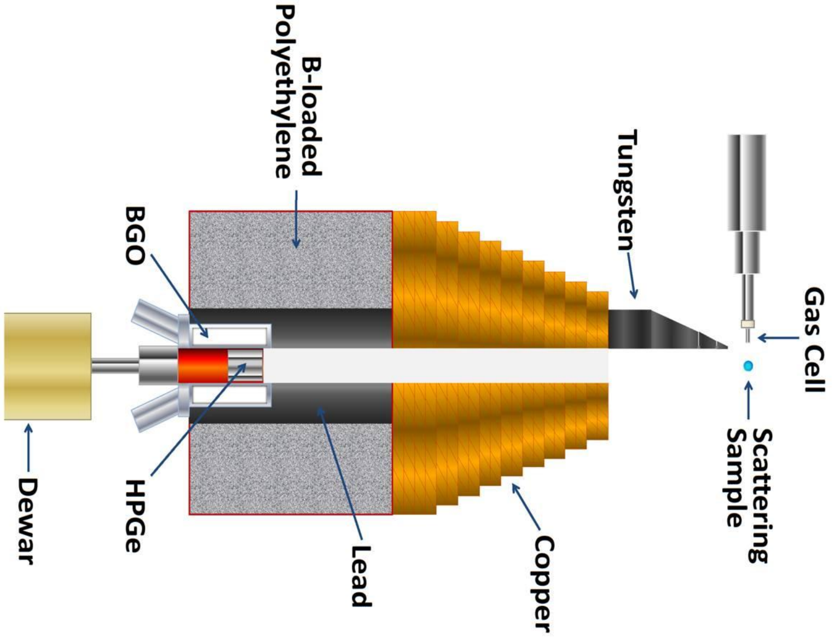



protons
scattering sample
^{3}H cell



3H(p,n) Q= –0.76 MeV
2H(d,n) Q= 3.3 MeV
3H(d,n) Q= 17.6 MeV

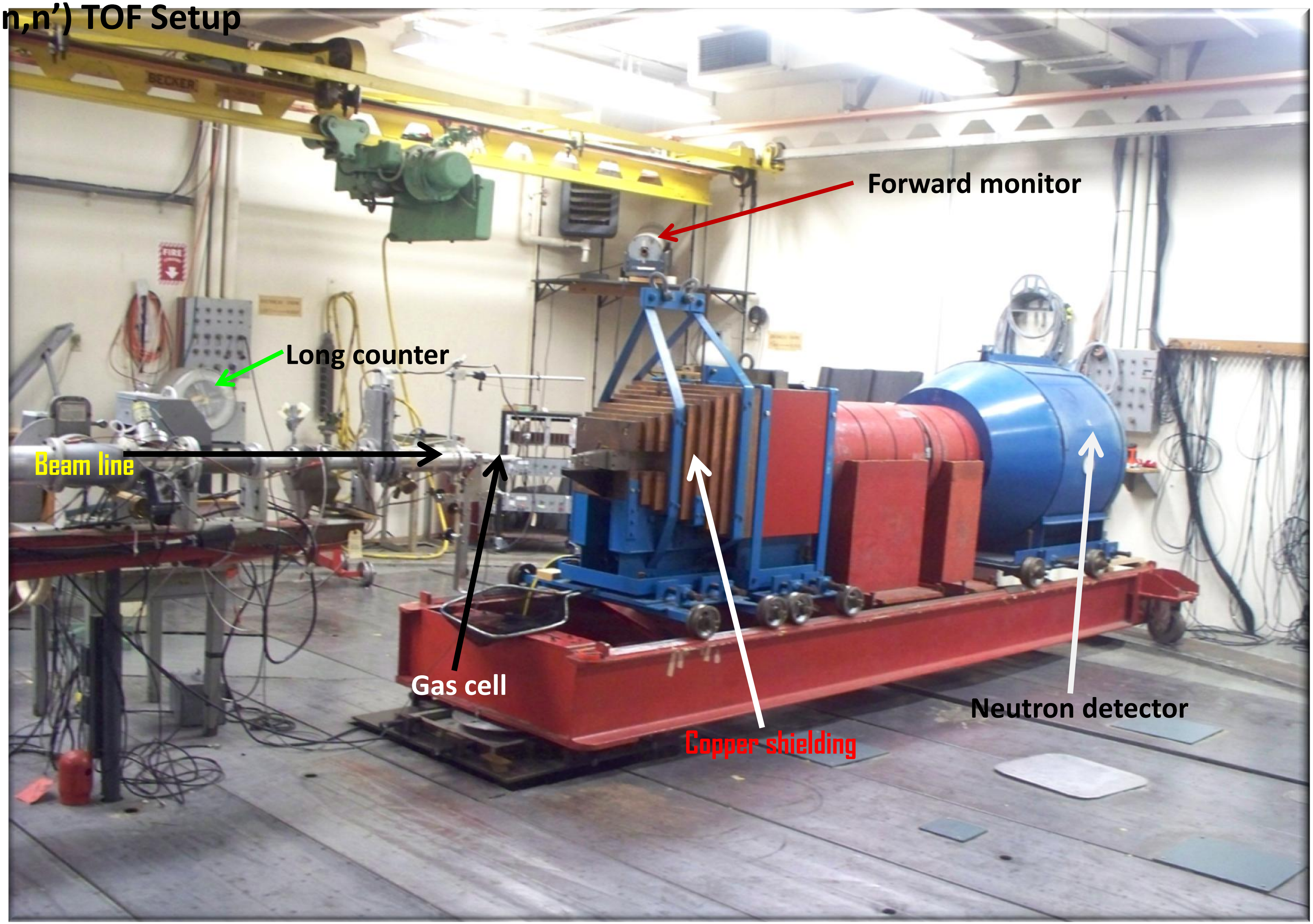
Typical adjustment of wedge with cell and sample



γ-Ray Detection

(singles setup)

(n,n') TOF Setup

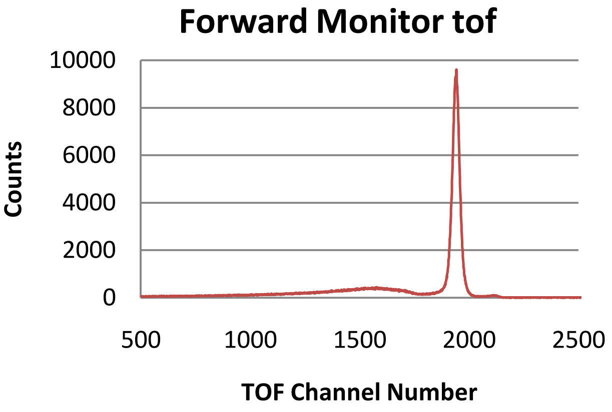

Forward monitor
Long counter
Beam line
Gas cell
Copper shielding
Neutron detector

Monitoring Neutron Production

- **Forward Monitor**
  - C_6D_6 liquid scintillator
  - Best choice for n angular distributions
  - Views source neutrons from gas cell
  - PSD cleanly identifies neutrons

- **Long Counter(Hanson & McKibben 1947)**
  - Moderated BF3 tubes
  - Generally used for excitation functions
  - Insensitive to γ-rays
  - Insensitive to room thermals
  - Placement at large angles reduces concern over resonances in LC efficiency.

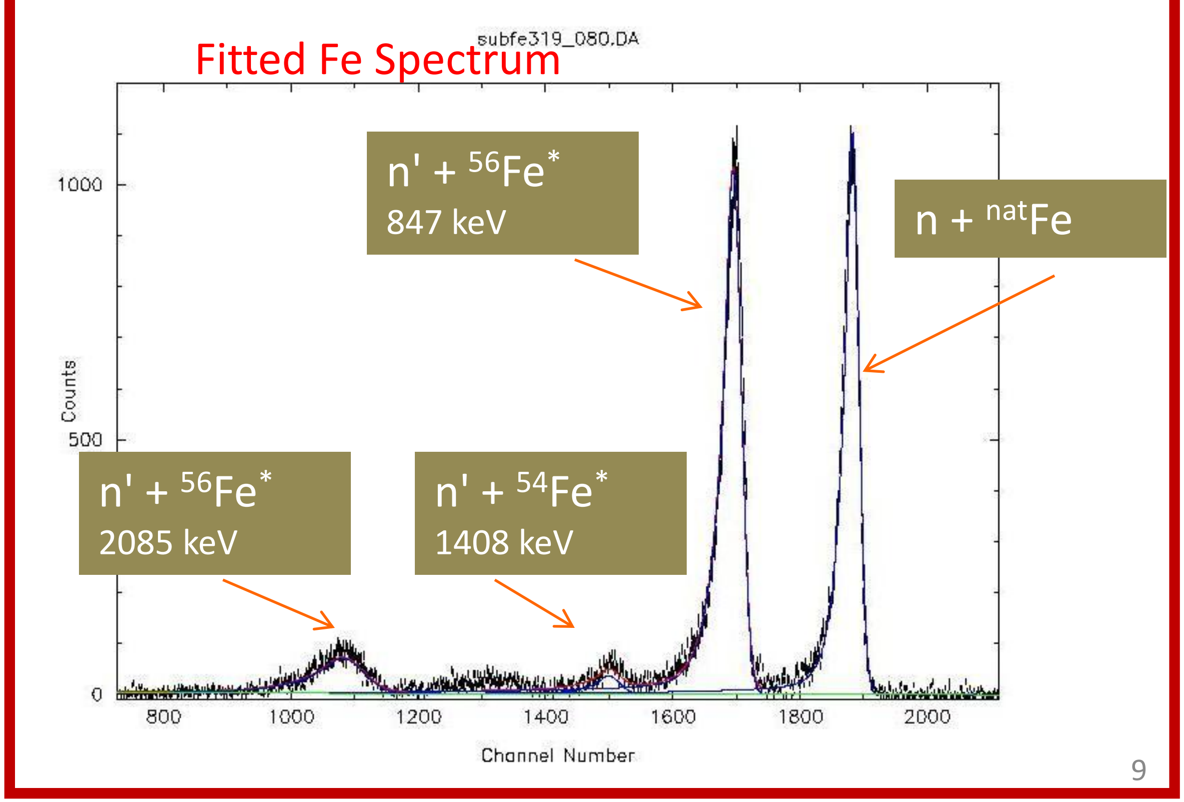
- **^{74}Ge(n,g) 140-keV line in HPGe**
  - Measures prompt-thermal fraction during beam pulse.



For absolute dσ/dΩ values, use
^{1}H(n,n) for neutrons
& _____ for γ-rays

early ^{nat}Fe spectrum

Fitted Fe Spectrum



$n' + {}^{56}Fe^*$
847 keV

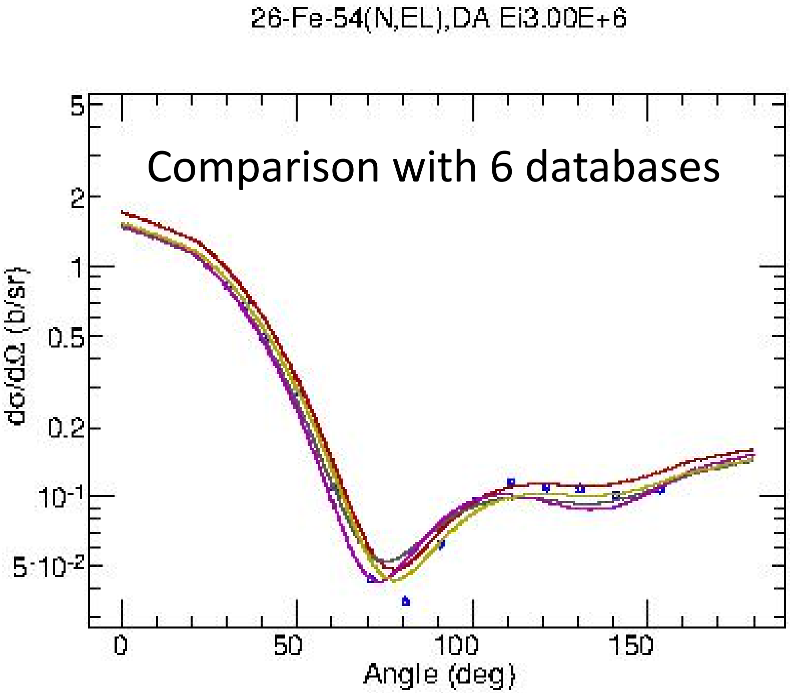
$n + {}^{nat}Fe$

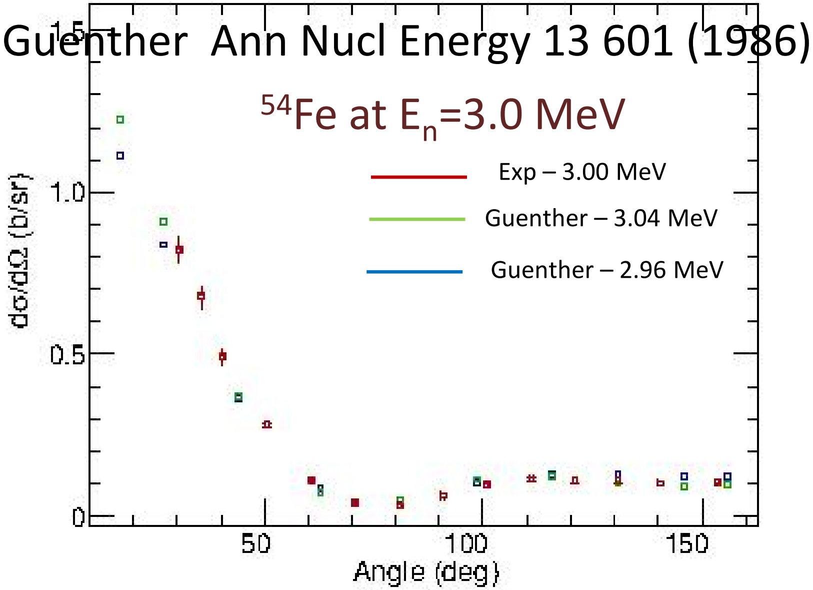
$n' + {}^{56}Fe^*$
2085 keV

$n' + {}^{54}Fe^*$
1408 keV

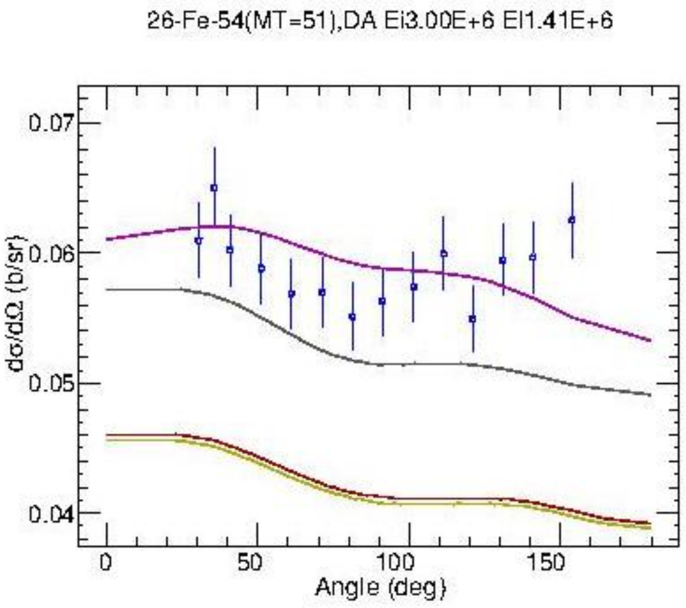
^{54}Fe(n,n)

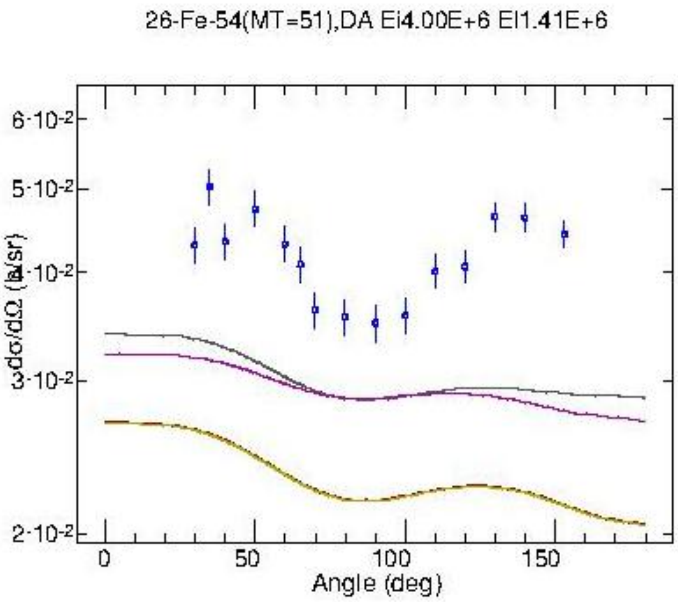
PRELIM ANALYSIS BY SALLY HICKS


Comparison with 6 databases


Guenther Ann Nucl Energy 13 601 (1986)

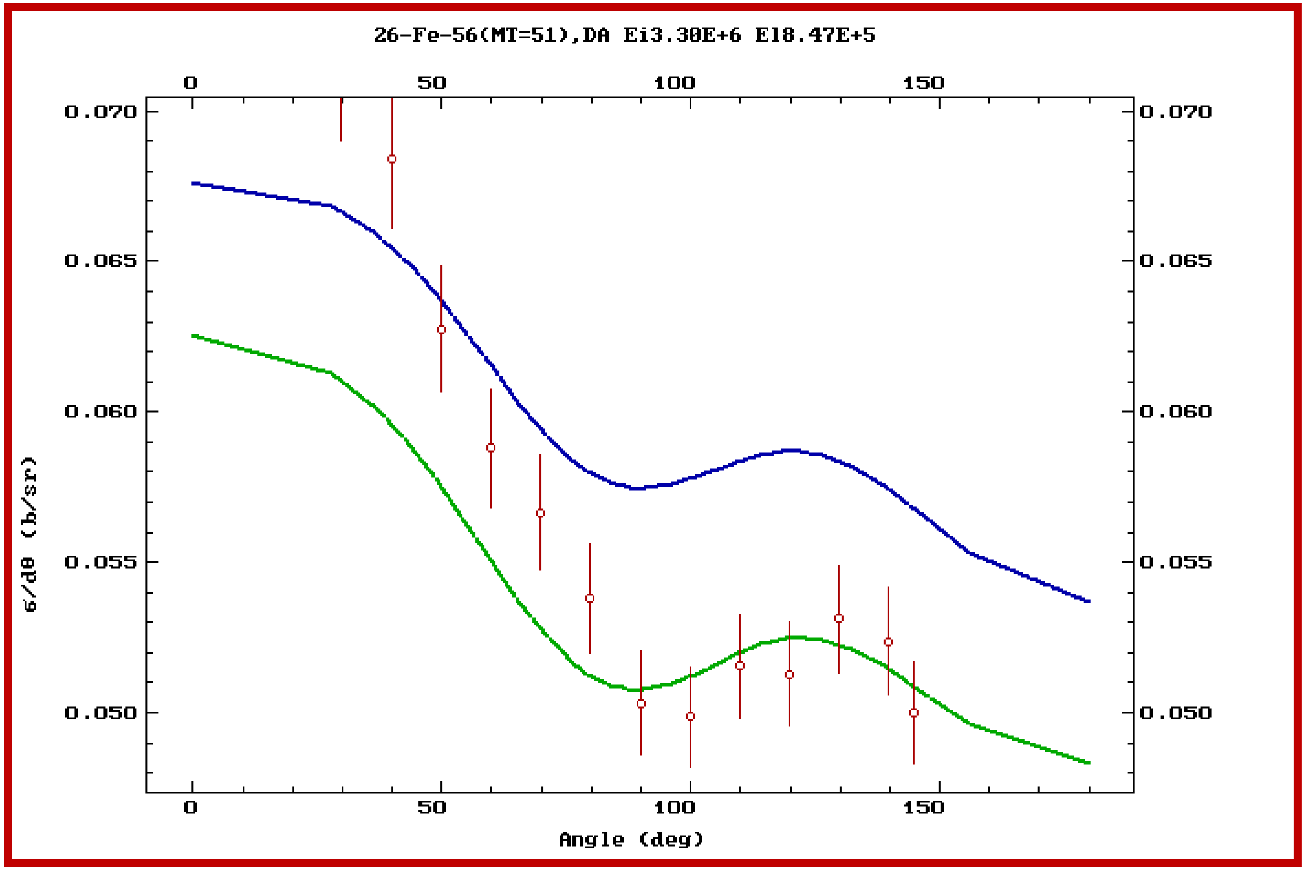
^{54}Fe at E_n=3.0 MeV





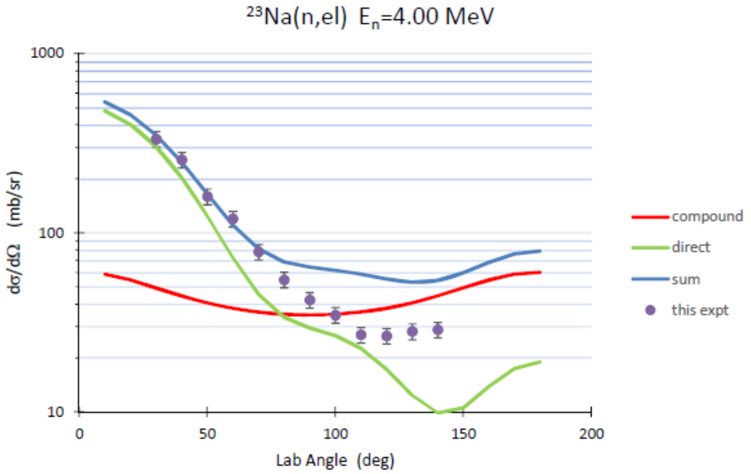
^{56}Fe(n,n$_1$) using ^{nat}Fe

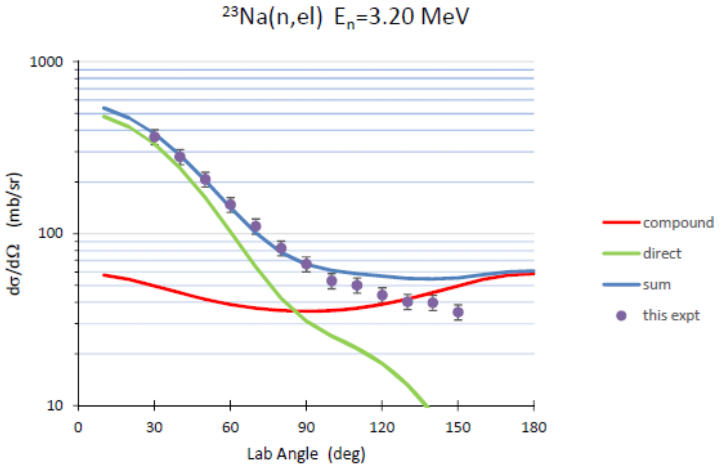
PRELIM ANALYSIS BY SALLY HICKS

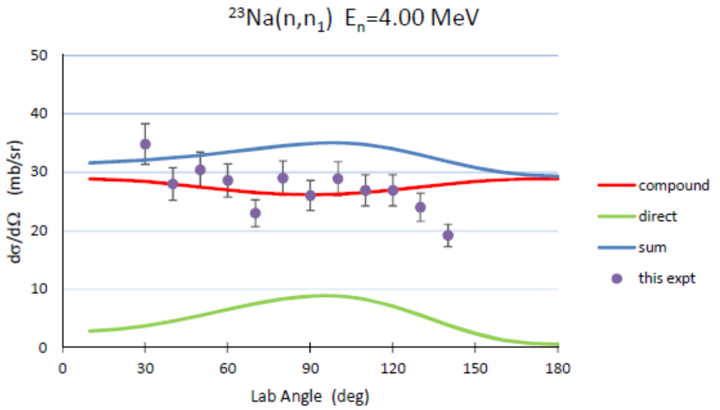


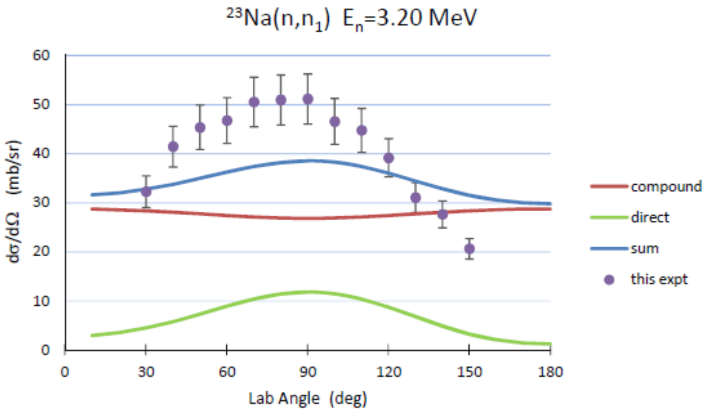
^{23}Na(n,n)

ECIS06 Calculations


^{23}Na(n,el) E_n=4.00 MeV

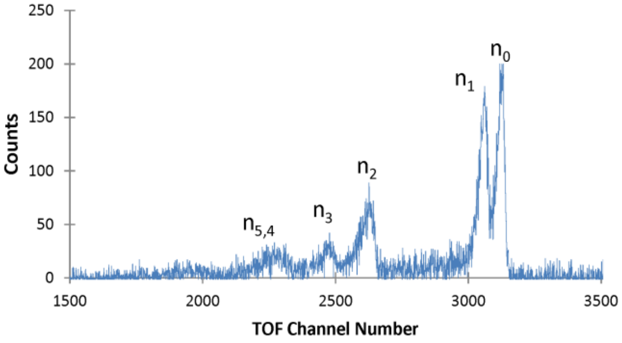

^{23}Na(n,el) E_n=3.20 MeV

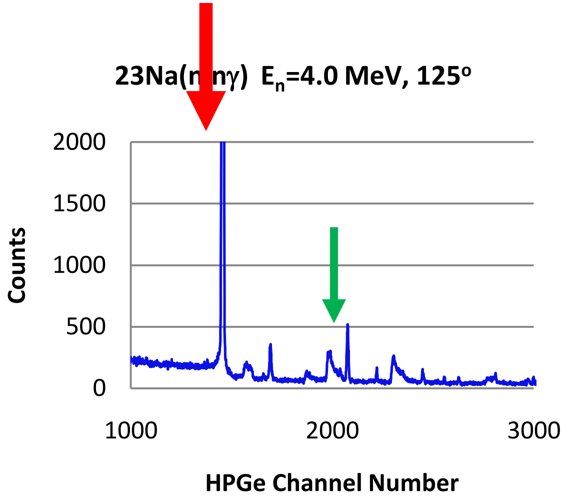

^{23}Na(n,n_1) E_n=4.00 MeV

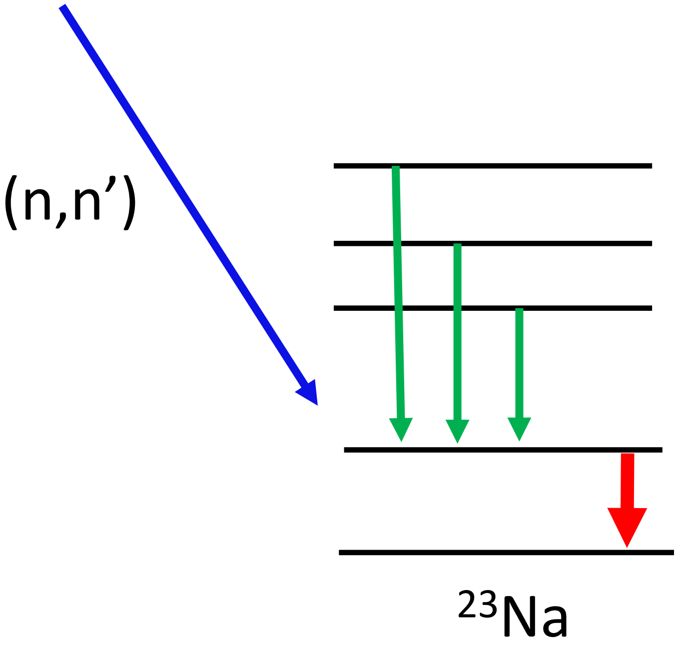

^{23}Na(n,n_1) E_n=3.20 MeV

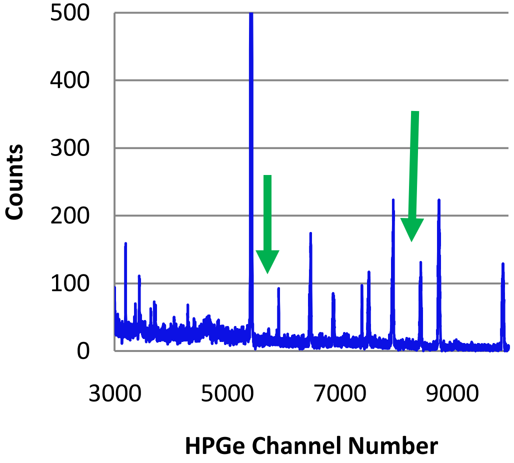
Inelastic Cross Sections --Two Techniques

$\sigma_{n,n'} \Leftarrow \Rightarrow \sigma_{n,n'\gamma}$



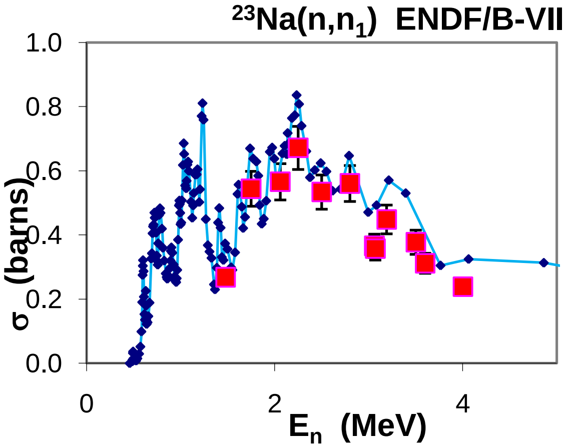


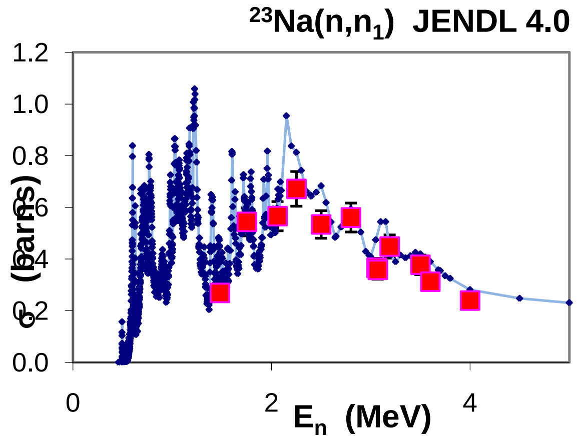




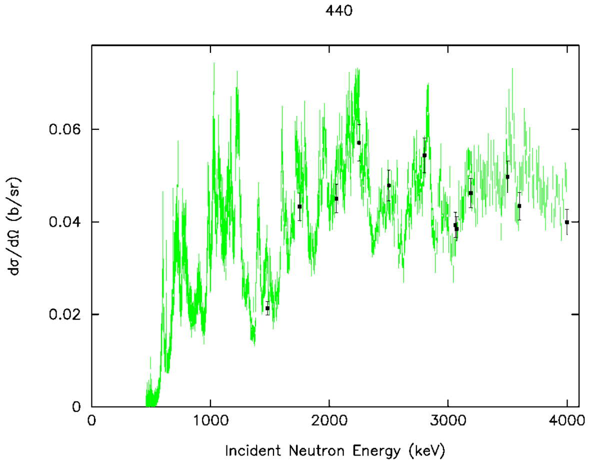
$$\sigma_{n,n'_k} = \sum \sigma_{de-excitation} - \sum \sigma_{feeders}$$

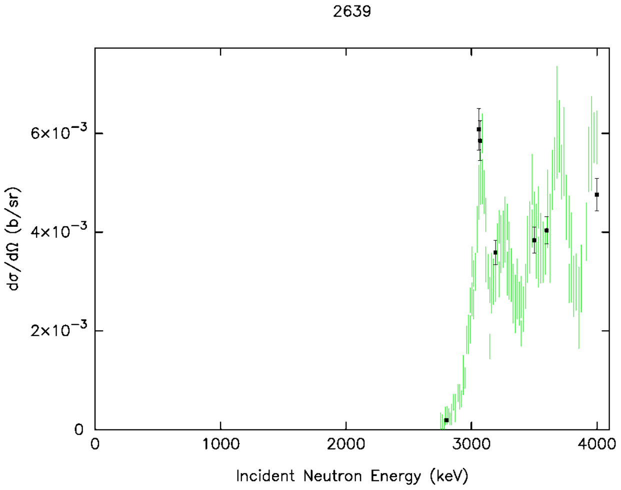
^{23}Na(n,n'γ)





Comparison of inelastic (n,n$_k$) cross sections as determined from (n,n'γ) measurements with values in the evaluated nuclear libraries. ENDF over-predicts the data by ~15%, while the data track JENDL quite nicely. The JEFF library (not shown) undershoots the data by ~15%.





Comparison of measured γ-ray excitation functions with those of the GELINA/IRMM group [Rouki *et al*, NIM A 673, 83 (2012)]. UnivKY data points are in black. The agreement is striking considering the experiments use different normalization techniques and the neutron energy resolutions are significantly different.

1

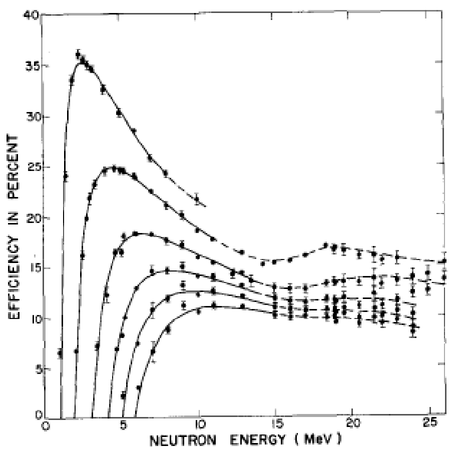


Fig. 4. Measured efficiency points for biases at 0.4, 1.0, 2.0, 3.0, 4.0 and 5.0 times Cs and calculated fits (solid lines). The dashed lines are handfitted.

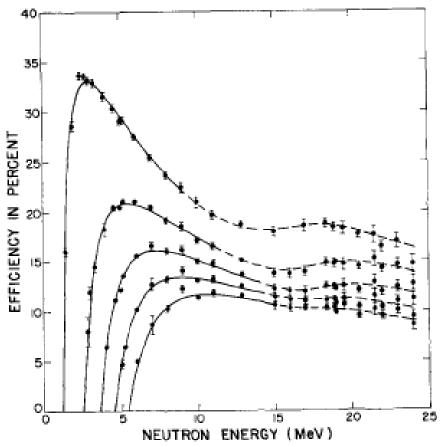


Fig. 5. Same as fig. 4, but for biases at 0.5, 1.5, 2.5, 3.5, and 4.5 times Cs.

ADVENTURES IN ANALYSIS

-- NEUTRON DETECTION EFFICIENCY

Main Detector

relative

Efficiency

1

T-cell spectrum

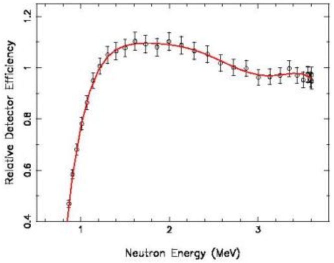
FM spectrum

fit peak SAN12

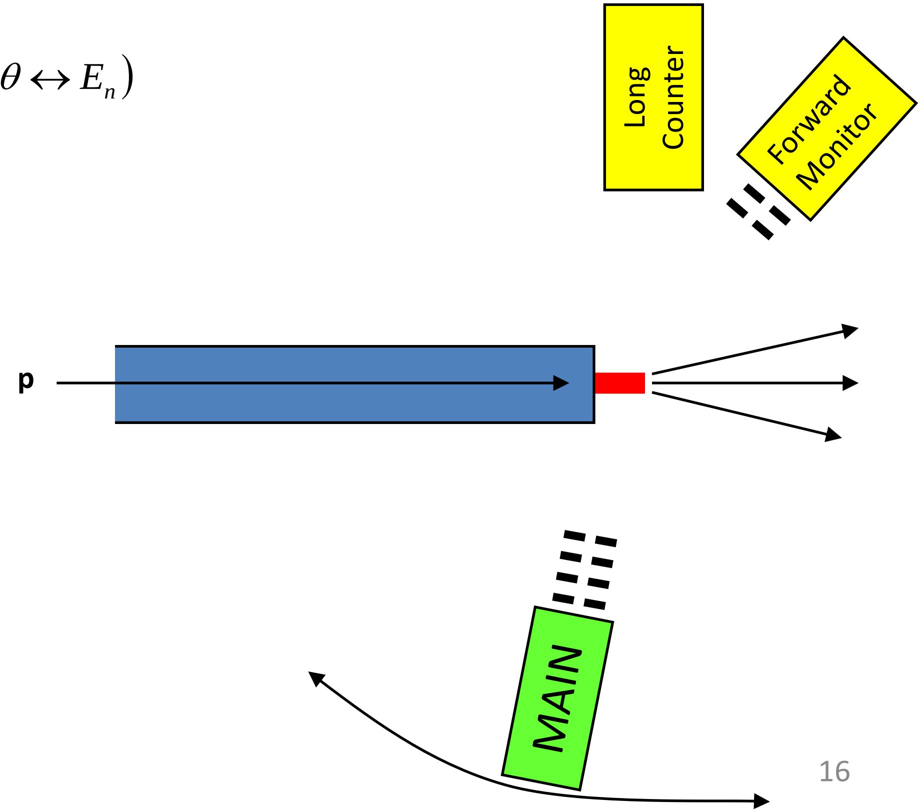
fit peak SAN12

$$eff\,(E_n) = \frac{Yield}{FM \bullet \dfrac{d\sigma}{d\Omega}_{Tpn}}$$

$$\frac{d\sigma}{d\Omega}_{3H(p,n)} \quad (\theta \leftrightarrow E_n)$$



$$eff\,(E_n)$$

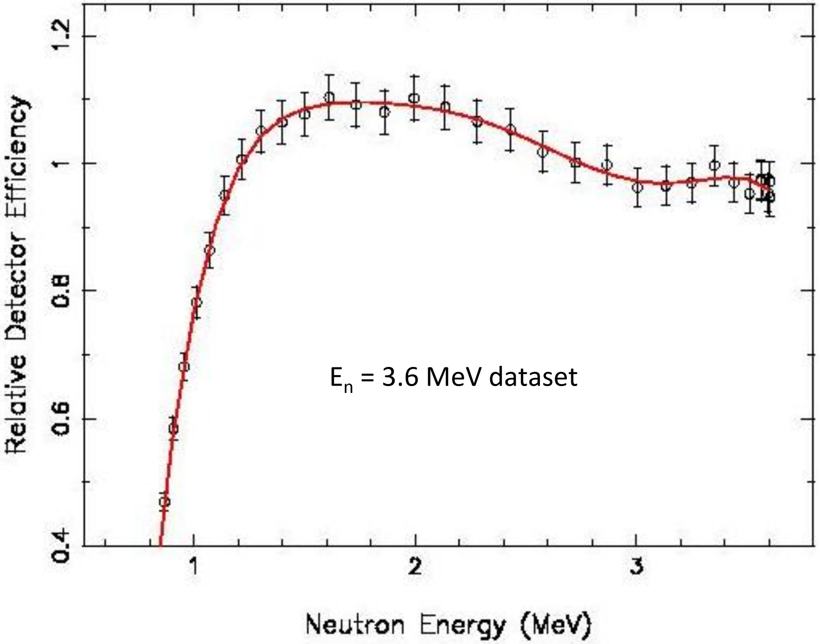


1

$$eff\,(E_n) = \frac{Yield}{FM \bullet \frac{d\sigma}{d\Omega}_{Tpn}}$$

Main Detector
relative
Efficiency

- Neutron detection efficiency
  - Main detector
    - Amplifier gain
    - Thresholds
    - PSD cuts
  - Forward Monitor detector
    - Amplifier gain
    - Thresholds
    - PSD cuts
- Variances arise
  - Yield in ^{3}H cell spectrum (<<1%)
  - Yield in FM spectrum (<<1%)
  - Fit quality
  - Knowledge of T(p,n) angular variation (3% ??)

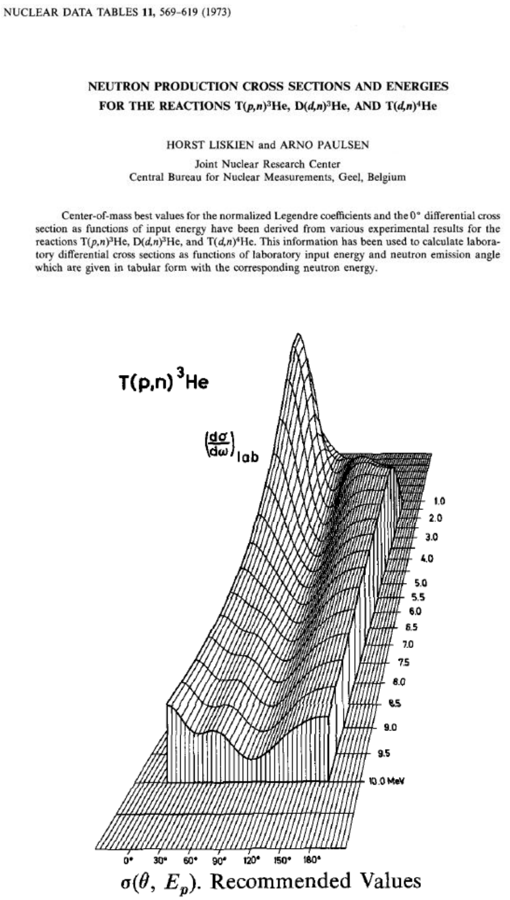


Sources for T(p,n) dσ/dΩ

H.Liskien & A.Paulsen

M. Drosg

G. Hale



NUCLEAR DATA TABLES **11**, 569–619 (1973)

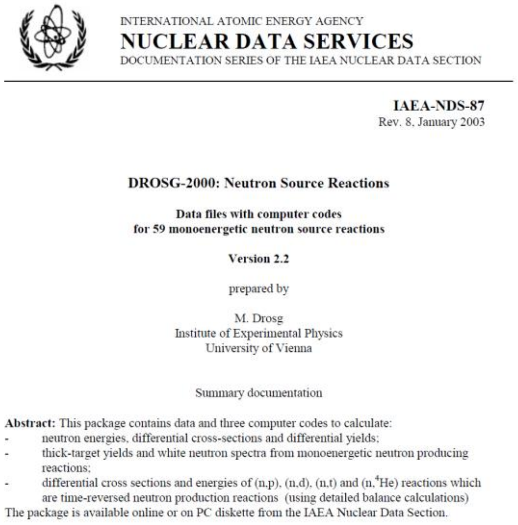
NEUTRON PRODUCTION CROSS SECTIONS AND ENERGIES FOR THE REACTIONS T(*p*,*n*)^{3}He, D(*d*,*n*)^{3}He, AND T(*d*,*n*)^{4}He

HORST LISKIEN and ARNO PAULSEN

Joint Nuclear Research Center
Central Bureau for Nuclear Measurements, Geel, Belgium

Center-of-mass best values for the normalized Legendre coefficients and the 0° differential cross section as functions of input energy have been derived from various experimental results for the reactions T(*p*,*n*)^{3}He, D(*d*,*n*)^{3}He, and T(*d*,*n*)^{4}He. This information has been used to calculate laboratory differential cross sections as functions of laboratory input energy and neutron emission angle which are given in tabular form with the corresponding neutron energy.

$\sigma(\theta, E_p)$. Recommended Values



INTERNATIONAL ATOMIC ENERGY AGENCY
NUCLEAR DATA SERVICES
DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

IAEA-NDS-87
Rev. 8, January 2003

DROSG-2000: Neutron Source Reactions

Data files with computer codes for 59 monoenergetic neutron source reactions

Version 2.2

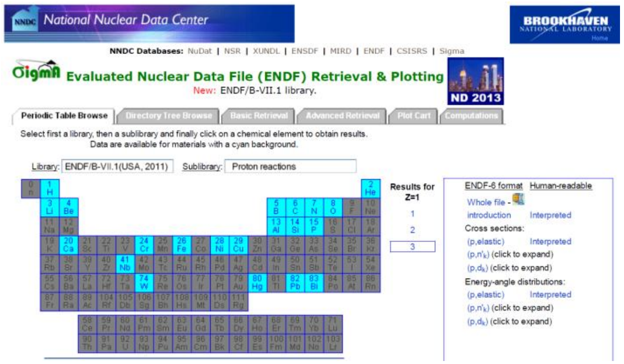
prepared by

M. Drosg
Institute of Experimental Physics
University of Vienna

Summary documentation

Abstract: This package contains data and three computer codes to calculate:
- neutron energies, differential cross-sections and differential yields;
- thick-target yields and white neutron spectra from monoenergetic neutron producing reactions;
- differential cross sections and energies of (n,p), (n,d), (n,t) and (n,^{4}He) reactions which are time-reversed neutron production reactions (using detailed balance calculations)

The package is available online or on PC diskette from the IAEA Nuclear Data Section.



National Nuclear Data Center

NNDC Databases: NuDat | NSR | XUNDL | ENSDF | MIRD | ENDF | CSISRS | Sigma

Evaluated Nuclear Data File (ENDF) Retrieval & Plotting
New: ENDF/B-VII.1 library.

Select first a library, then a sublibrary and finally click on a chemical element to obtain results.
Data are available for materials with a cyan background.

Library: ENDF/B-VII.1(USA, 2011)
Sublibrary: Proton reactions

Results for Z=1

ENDF-6 format | Human-readable
Whole file -
introduction | Interpreted
Cross sections:
(p,elastic) | Interpreted
(p,n'$_k$) (click to expand)
(p,d$_k$) (click to expand)
Energy-angle distributions:
(p,elastic) | Interpreted
(p,n'$_k$) (click to expand)
(p,d$_k$) (click to expand)

phase shift
inter-comparisons

(d,p) (d,d)

(n,p)

(**n**$_{pol}$,n)

^{4}He
project

(**d**$_{pol}$,p)

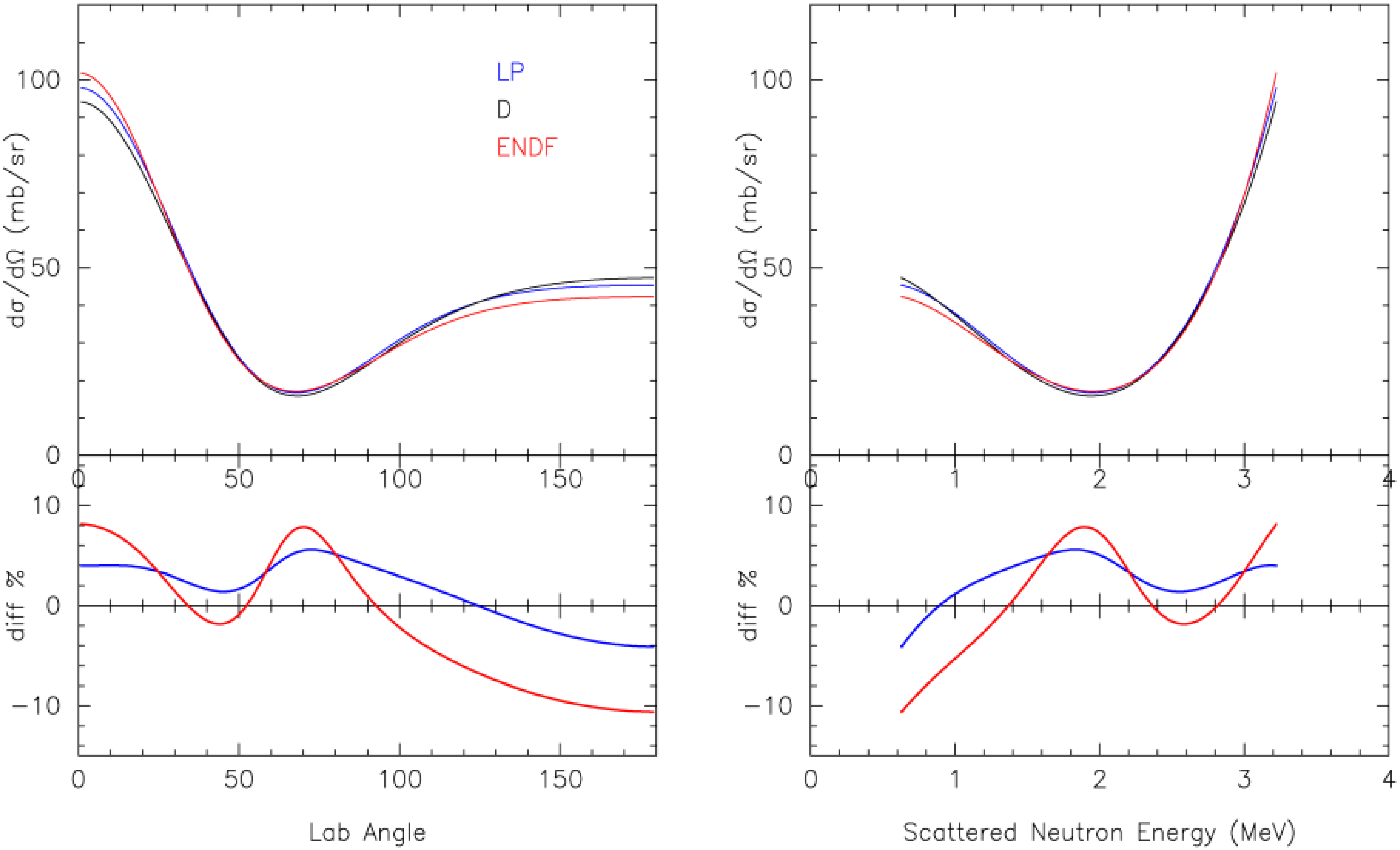
(p,p)

(p,n) (d,n) (**d**$_{pol}$,d)

(**p**$_{pol}$,p)

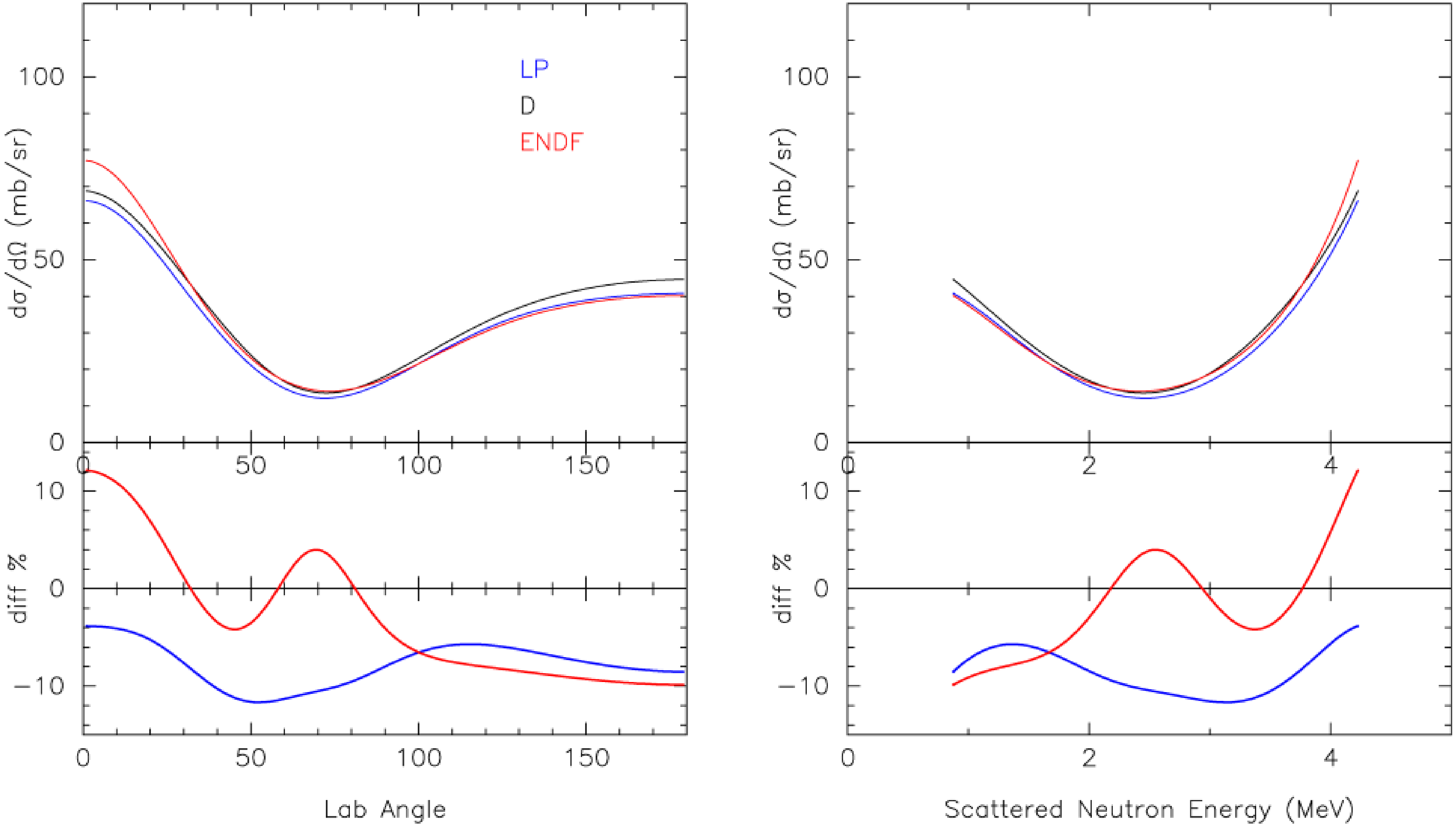
1

T(p,n) at E_p = 4.0 MeV



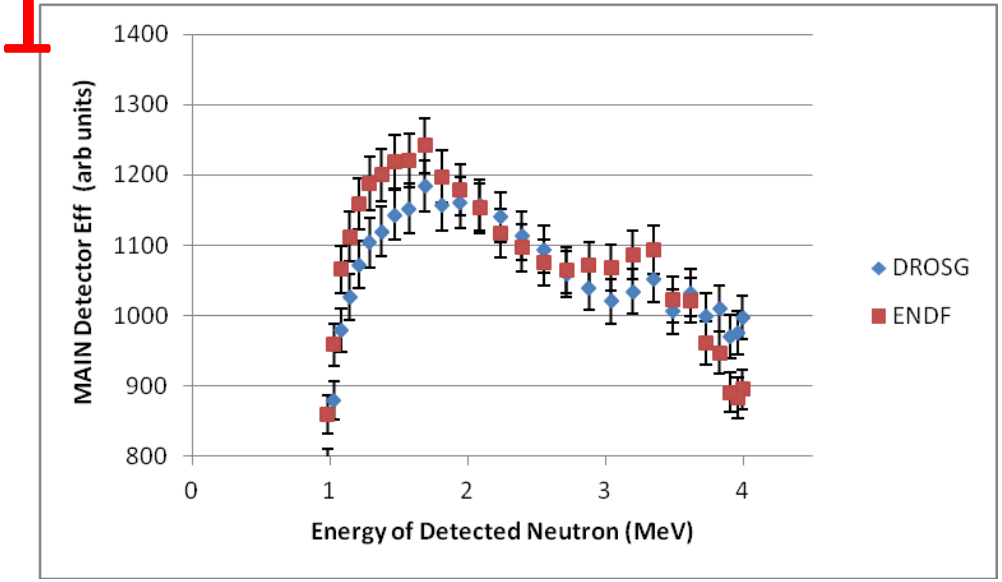
1

T(p,n) at E_p = 5.0 MeV

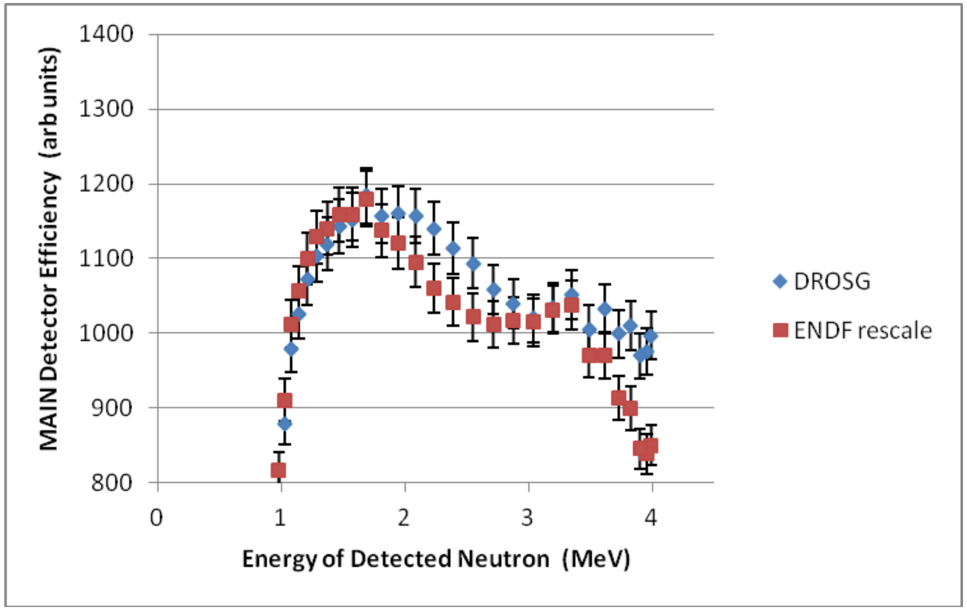


1

Example Efficiency Curve E_p=4.77 / $E_{n,max}$ = 4.0



Efficiency Curve for Ep=4.77 MeV / En = 4.0



Same as above, but rescaled to accentuate differences.

Reaction	Angular Range	$E_{scattered}$ (MeV)
23Na(n,n0)	30-150	3.95-3.43
23Na(n,n0)	30-150	3.52-3.02
23Na(n,n0)	30-150	1.87-1.52
Normalization H(n,n)	30-50	3.00-1.65

1

Comparisons at Various Energies

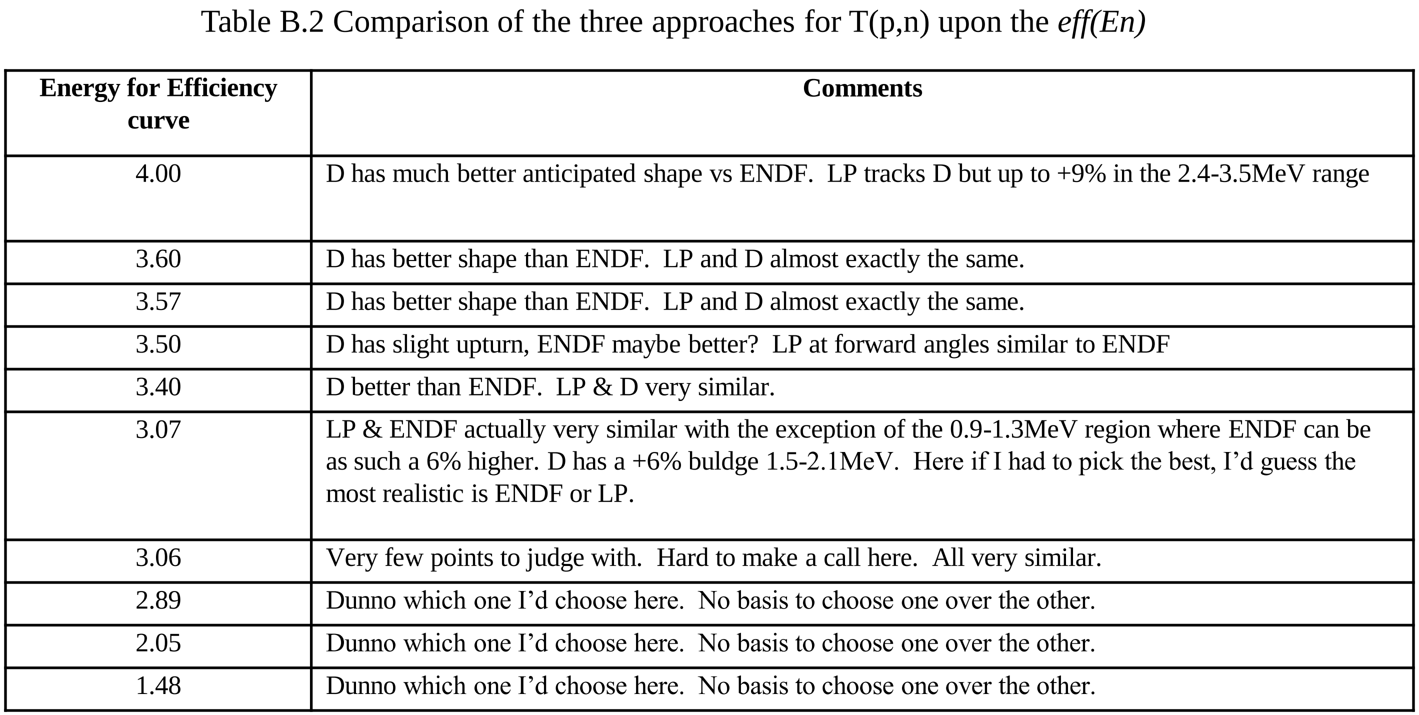


Table B.2 Comparison of the three approaches for T(p,n) upon the *eff(En)*

Energy for Efficiency curve	**Comments**
4.00	D has much better anticipated shape vs ENDF. LP tracks D but up to +9% in the 2.4-3.5MeV range
3.60	D has better shape than ENDF. LP and D almost exactly the same.
3.57	D has better shape than ENDF. LP and D almost exactly the same.
3.50	D has slight upturn, ENDF maybe better? LP at forward angles similar to ENDF
3.40	D better than ENDF. LP & D very similar.
3.07	LP & ENDF actually very similar with the exception of the 0.9-1.3MeV region where ENDF can be as such a 6% higher. D has a +6% buldge 1.5-2.1MeV. Here if I had to pick the best, I'd guess the most realistic is ENDF or LP.
3.06	Very few points to judge with. Hard to make a call here. All very similar.
2.89	Dunno which one I'd choose here. No basis to choose one over the other.
2.05	Dunno which one I'd choose here. No basis to choose one over the other.
1.48	Dunno which one I'd choose here. No basis to choose one over the other.

E_p < 4.0 MeV, no basis to chose one description over the other.

E_p > 4.0 MeV, Drosg and Liskien & Paulsen preferred.

2

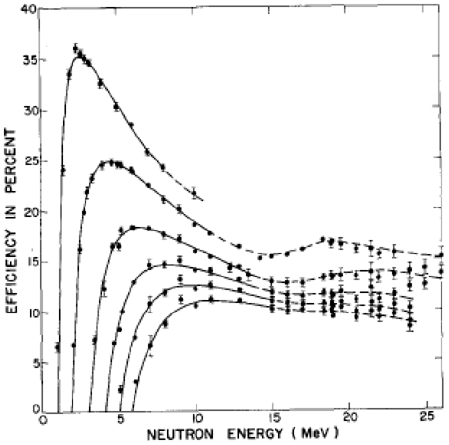


Fig. 4. Measured efficiency points for biases at 0.4, 1.0, 2.0, 3.0, 4.0 and 5.0 times Cs and calculated fits (solid lines). The dashed lines are handfitted.

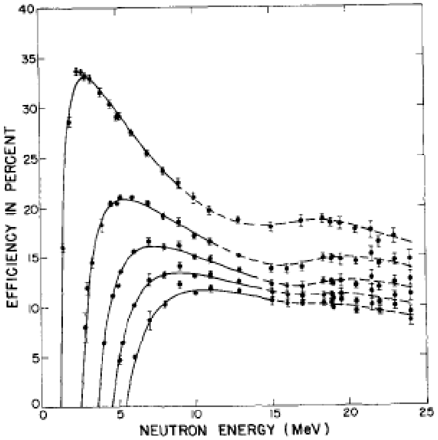


Fig. 5. Same as fig. 4, but for biases at 0.5, 1.5, 2.5, 3.5, and 4.5 times Cs.

ADVENTURES IN ANALYSIS -- CONVERTING γ-RAY YIELDS TO CROSS SECTIONS

2

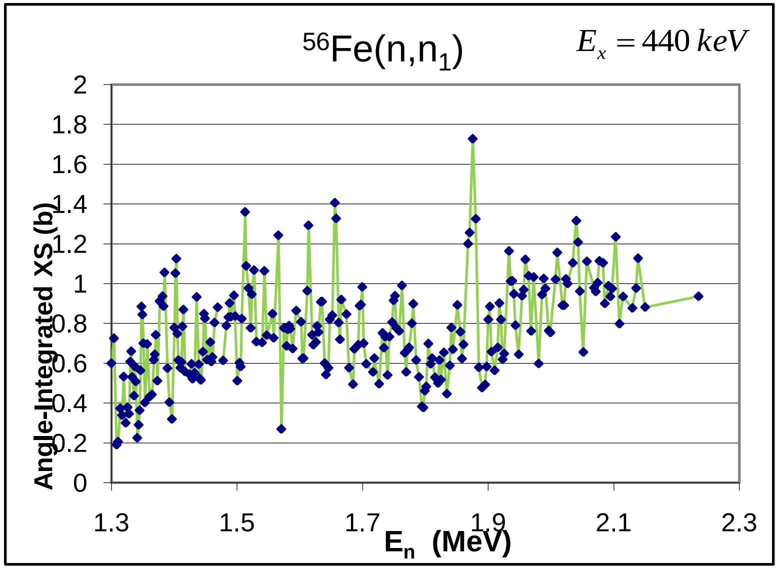
Scaling 23Na Yields to ENDF ^{56}Fe Cross Sections

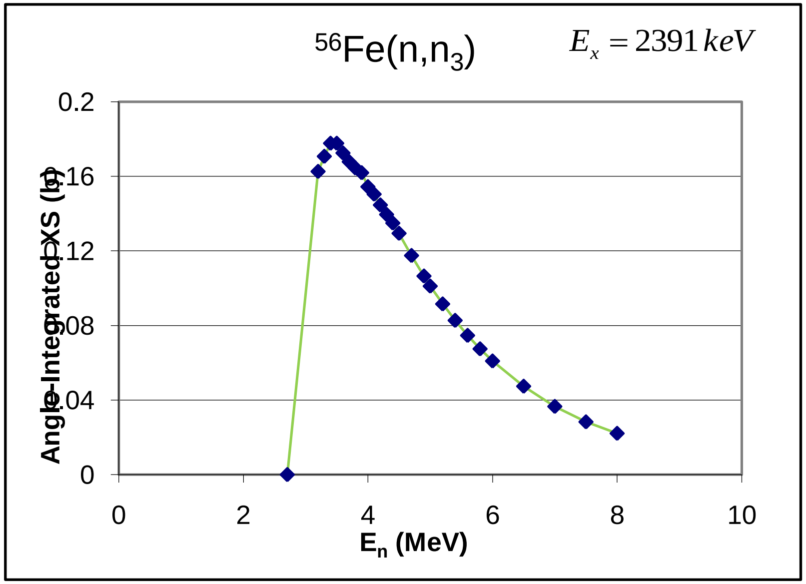
-- use γ-rays from Fe sample to discover the conversion factor

$$\sigma_{Na,\gamma-rayi} \sim \frac{Na\ Corrected\ Yield \big/ \#\,Na}{Fe\ Corrected\ Yield \big/ \#\,Fe}\ \bar{\sigma}_{Fe}$$

Comparison to evaluated data

26-Fe- 56 LANL,ORNL EVAL-SEP96 M.B.Chadwick,P.G.Young,C.Y.Fu CH99,FU86,Fu91



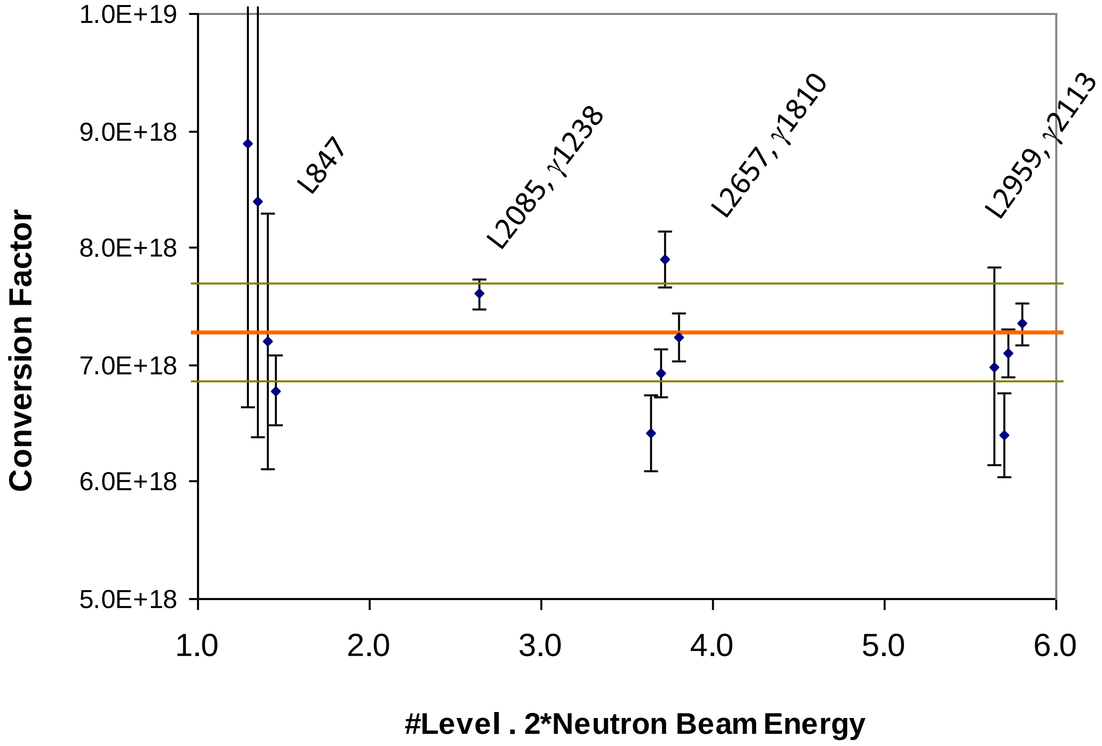


2

Scaling to ENDF ^{56}Fe Cross Sections

$$\sigma_{Na,\gamma-rayi} \sim \frac{Na\ Corrected\ Yield \big/ \# Na}{Fe\ Corrected\ Yield \big/ \# Fe}\, \bar{\sigma}_{Fe}$$

$$\sigma_{Na,\gamma-rayi} = Na\ Corrected\ Yield_{\gamma-rayi} \big/ \# Na \bullet \left\langle \frac{br_{j\,transition\,k}\ \bar{\sigma}_{Fe,level\,j}}{Fe\ Corrected\ Yield_{j\,transition\,k} \big/ \# Fe} \right\rangle$$



$$\langle \quad \rangle = 7.27(41) \bullet 10^{18}$$

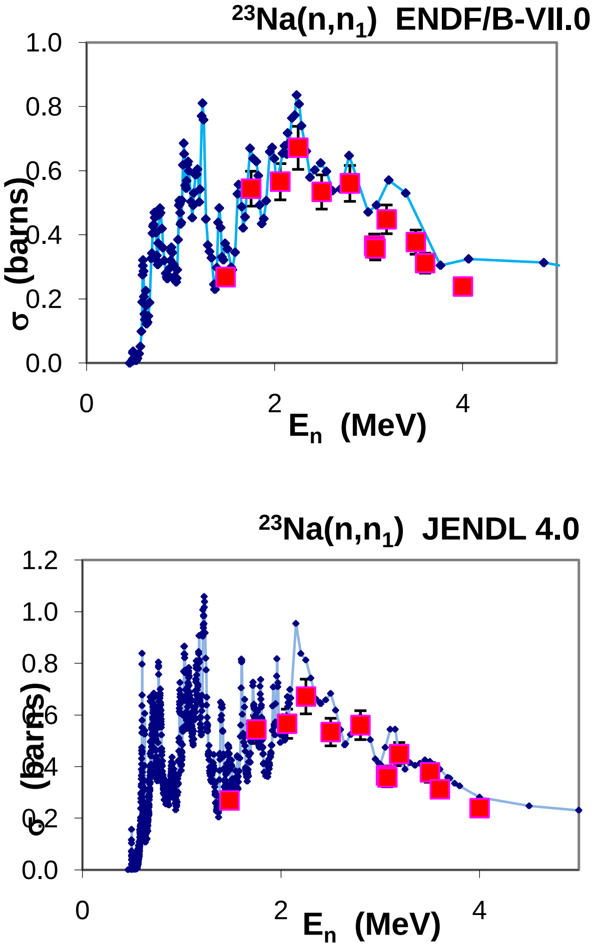
uncertainty ~ 6%

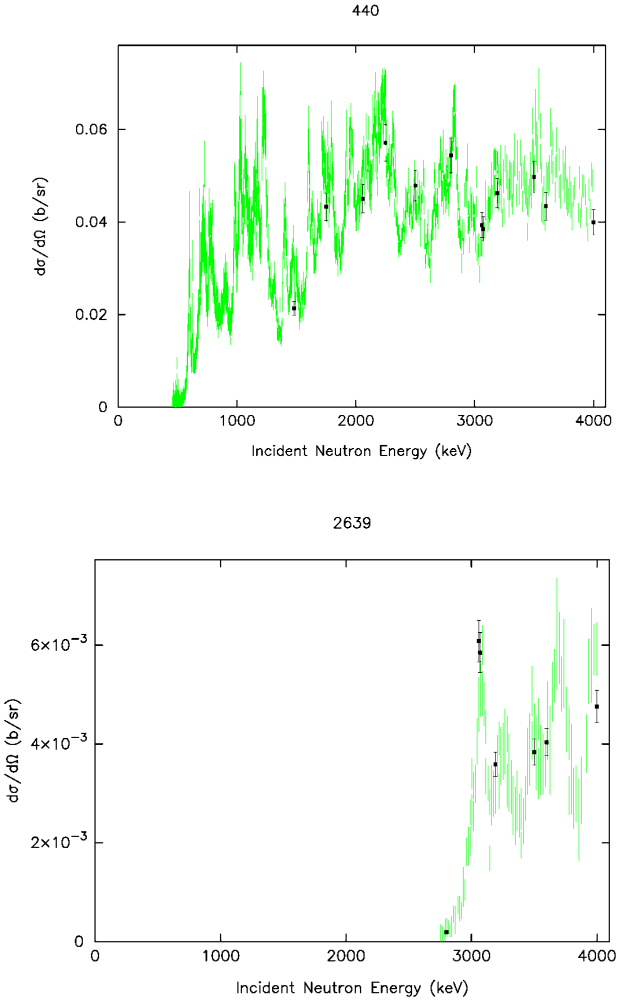
$$\bar{x} = \frac{\sum w_i x_i}{\sum w_i} \qquad w_i = 1 \big/ \sigma_i^2$$

$$\sigma^2 \approx \frac{N \sum w_i (x_i - \bar{x})^2}{(N-1) \sum w_i}$$

2

^{23}Na(n,n'γ)





Comparison of inelastic (n,n$_k$) cross sections as determined from (n,n'γ) measurements with values in the evaluated nuclear libraries. ENDF over-predicts the data by ~15%, while the data track JENDL quite nicely. The JEFF library (not shown) undershoots the data by ~15%.

Comparison of measured γ-ray excitation functions with those of the GELINA/IRMM group [Rouki *et al*, NIM A 673, 83 (2012)]. UnivKY data points are in black. The agreement is striking considering the experiments use different normalization techniques and the neutron energy resolutions are significantly different.

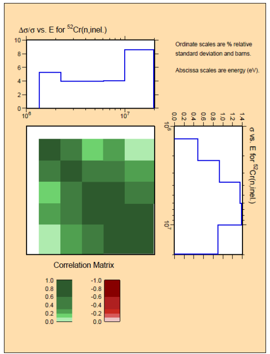
Use several samples in an attempt to average out the deficiencies of each?

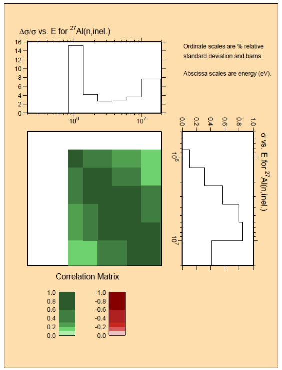
Unfortunately this produces
'better estimates'
rather than
"2ndry standards'

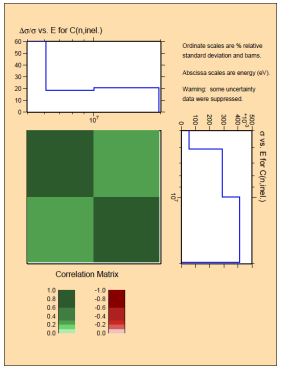
^{nat}Ti ^{27}Al ^{56}Fe ^{12}C

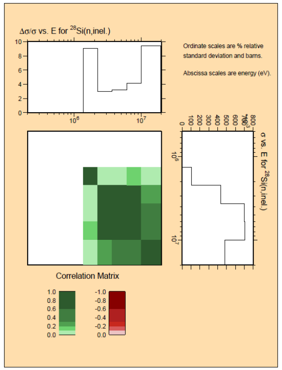
^{nat}Si ^{52}Cr ^{51}V

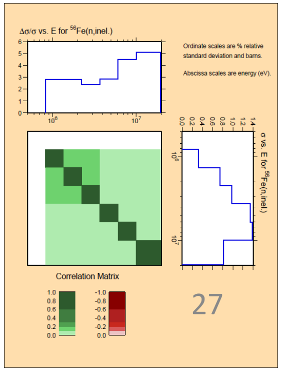
Oblozinsky, "Progress on Nuclear Covariances: AFCI-1.2 Covariance Library" BNL-90897-2009



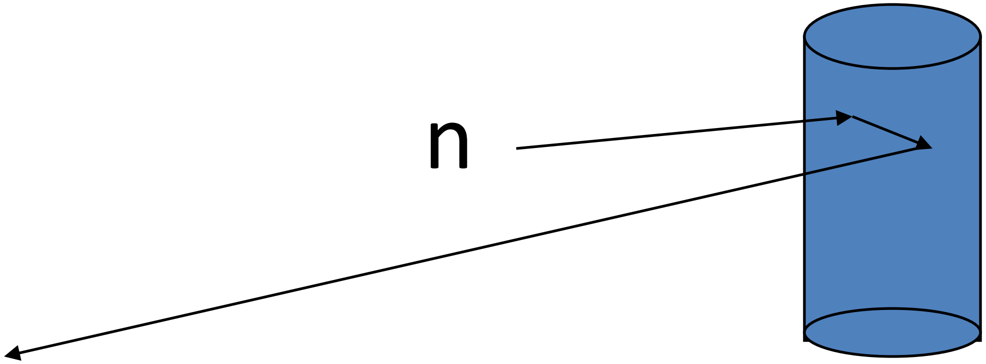








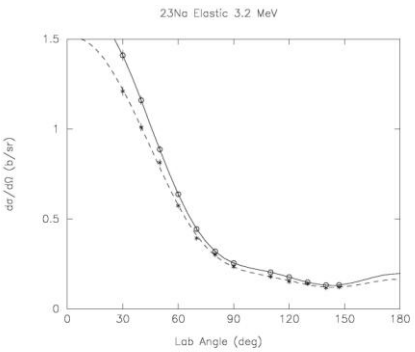
3



ADVENTURES IN ANALYSIS
-- ATTENUATION AND MULTIPLE SCATTERING CORRECTIONS

MT McEllistrem MULCAT (…)
JR Lilley "…Monte Carlo Multiple Scattering Correction…", CEA-DAM P2N-934-80 (1980)
DE Velkey, "… with Analytic & Monte Carlo Methids", NIM 129, 231 (1975)
WE Kinney "Finite Sample Corrections…" NIM 83, 15 (1970).

3 Multiple Scattering and Attenuation Correction using MULCAT



for a typical sample:

$\Sigma_{tot}^{-1} \sim 16$ cm

double/singl = 10^{-4}

triple/dble = 10^{-4}

- Issues
  - Single element
  - Extensive experience using the routine on medium-mass nuclei
  - Limited # of $\sigma_{tot}(E_n)$ values
  - Elastic angular distribution used at one E_n
  - Runs **** histories

$init\ guess\ at\ `true`\ \hat{\sigma}(\theta)$

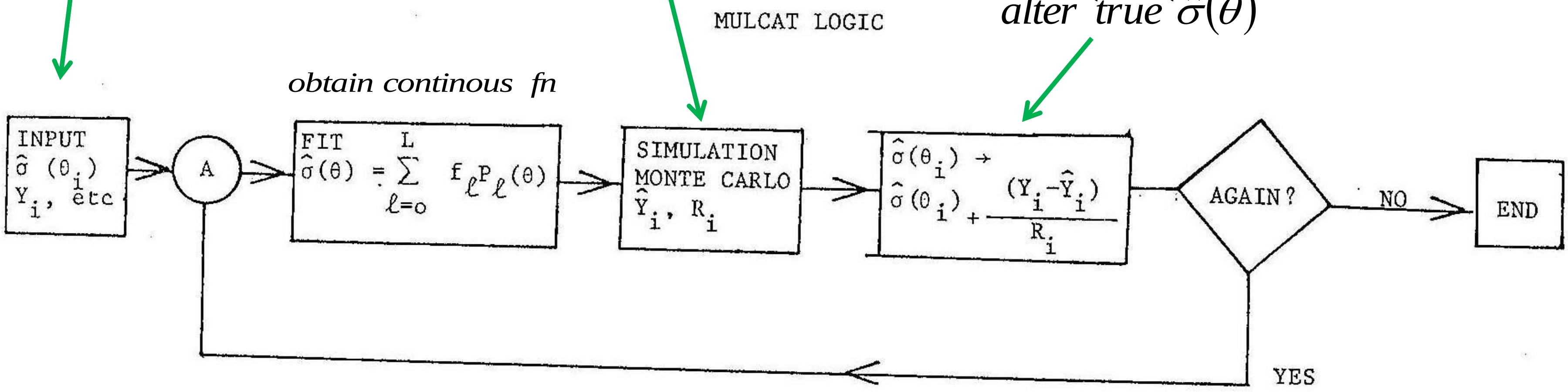
$finite\ sample\ Y(\theta)$

$predict\ perturbed\ \hat{Y}(\theta)$

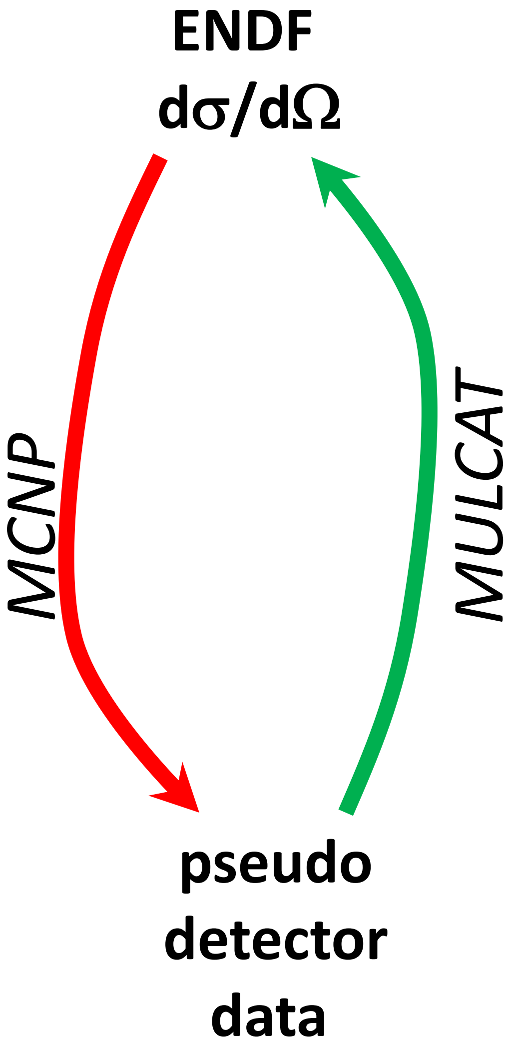
$finite\ sample\ correction\ R(\theta)$

$alter\ `true`\ \hat{\sigma}(\theta)$

$obtain\ continous\ fn$



3

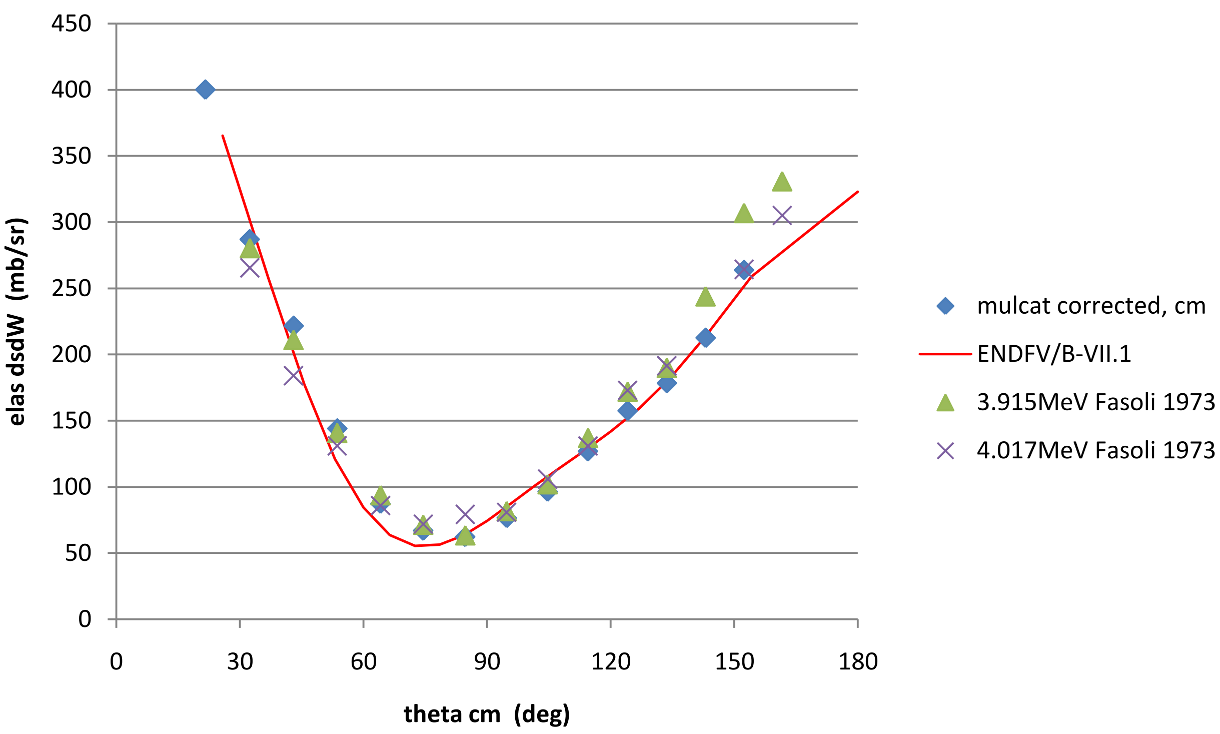


ENDF
dσ/dΩ

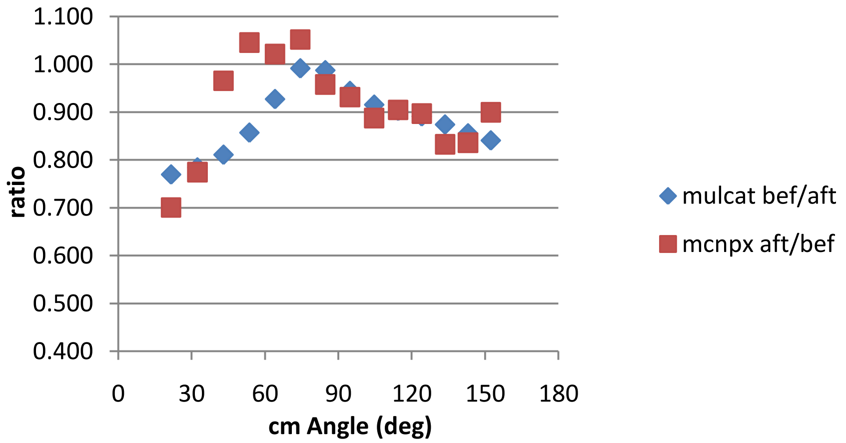
MCNP

MULCAT

pseudo
detector
data



mulcat-corrected mcnpx calculation: 12C

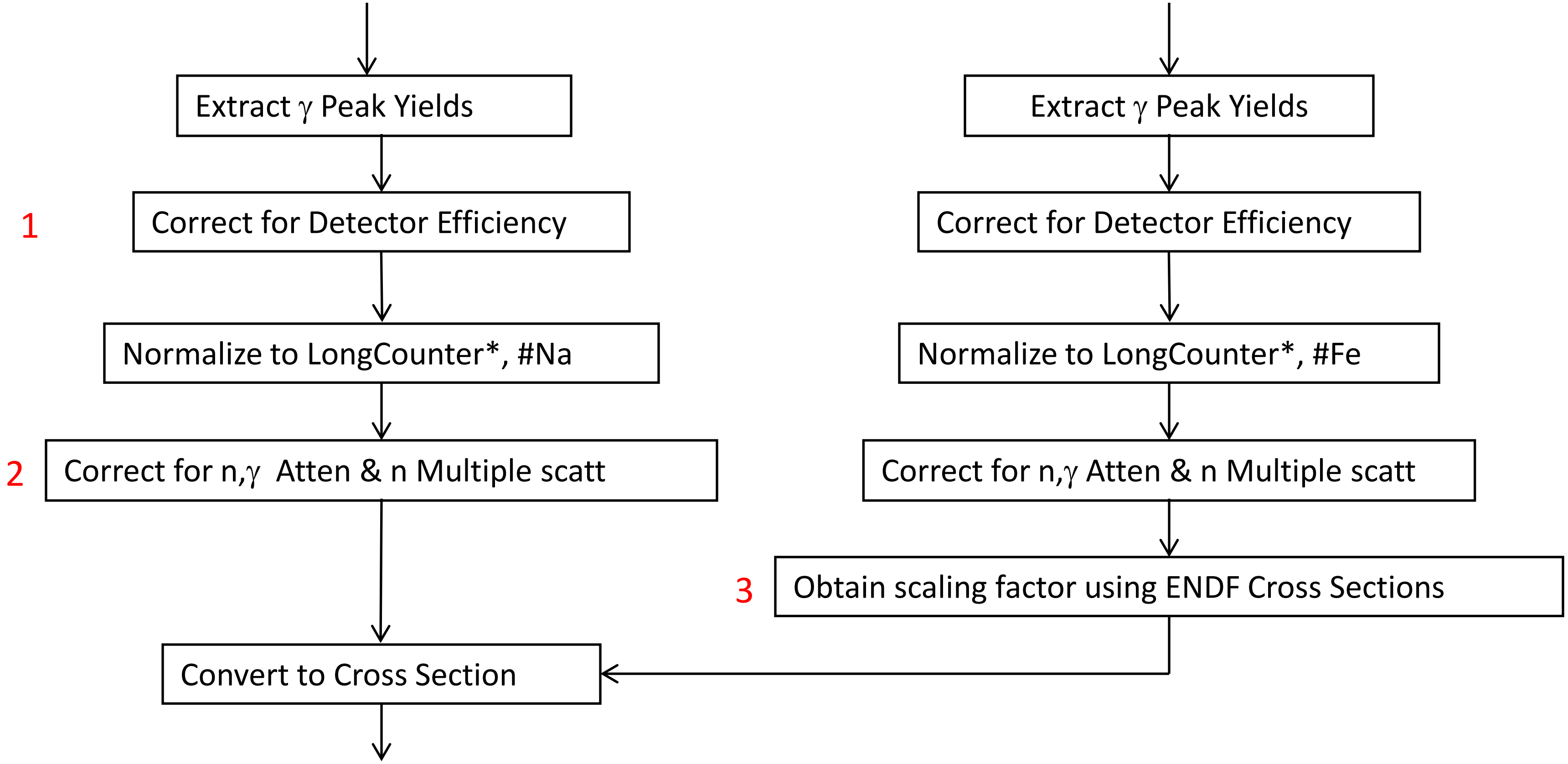


- General Intro to the Laboratory
- Sample results for recent ^{23}Na, ^{54}Fe, ^{nat}Fe (n,n') & (n,n'γ)
- Adventures in Analysis
  - Ambiguities in Neutron Detection Efficiency attributed to ^{3}H(p,n) dσ/dΩ
    - The technique
    - Choices for dσ/dΩ
    - Impact on Efficiency (E)
  - Challenges in Normalizing (n,n'γ)
    - What we did for 23Na(n,n'γ)
    - What will we do for 54,56Fe ?
  - How well do we know the finite geometry corrections?
    - Proving our correction code is rigorous
- Conclusion

ARUNA Association for Research at University Nuclear Accelerators

DATA REDUCTION OVERVIEW FOR (N,N’) & (N,N’G)

$(n,n'\gamma)$



Na (n,n'γ) spectrum

Extract γ Peak Yields

1 Correct for Detector Efficiency

Normalize to LongCounter*, #Na

2 Correct for n,γ Atten & n Multiple scatt

Fe (n,nγ) spectrum

Extract γ Peak Yields

Correct for Detector Efficiency

Normalize to LongCounter*, #Fe

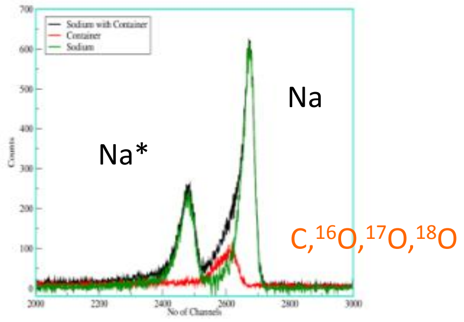
Correct for n,γ Atten & n Multiple scatt

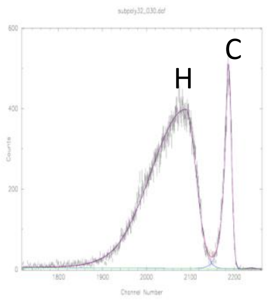
3 Obtain scaling factor using ENDF Cross Sections

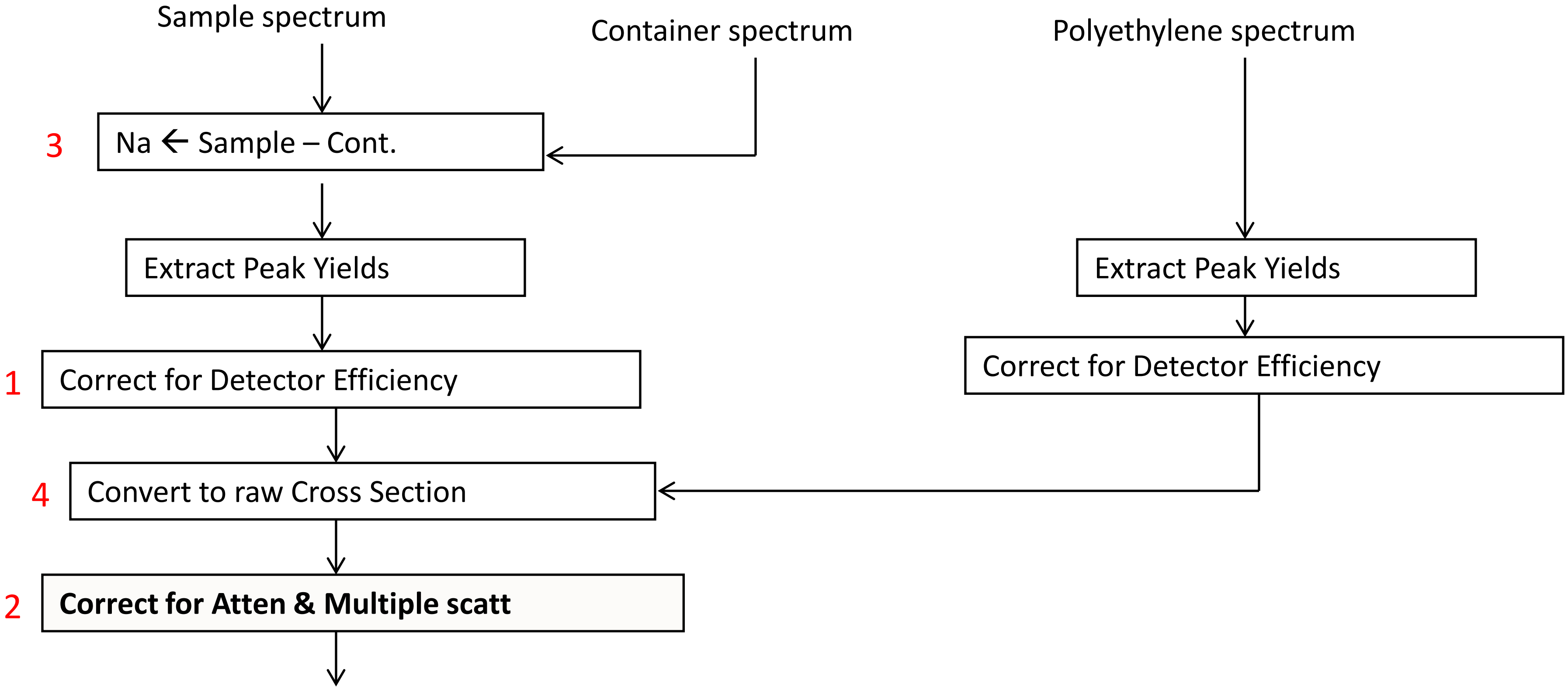
Convert to Cross Section

http://kenokazaki.com/tag/pot-of-gold/

2







Sample spectrum

Container spectrum

Polyethylene spectrum

3 Na ← Sample – Cont.

Extract Peak Yields

Extract Peak Yields

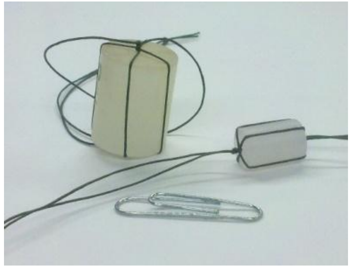
1 Correct for Detector Efficiency

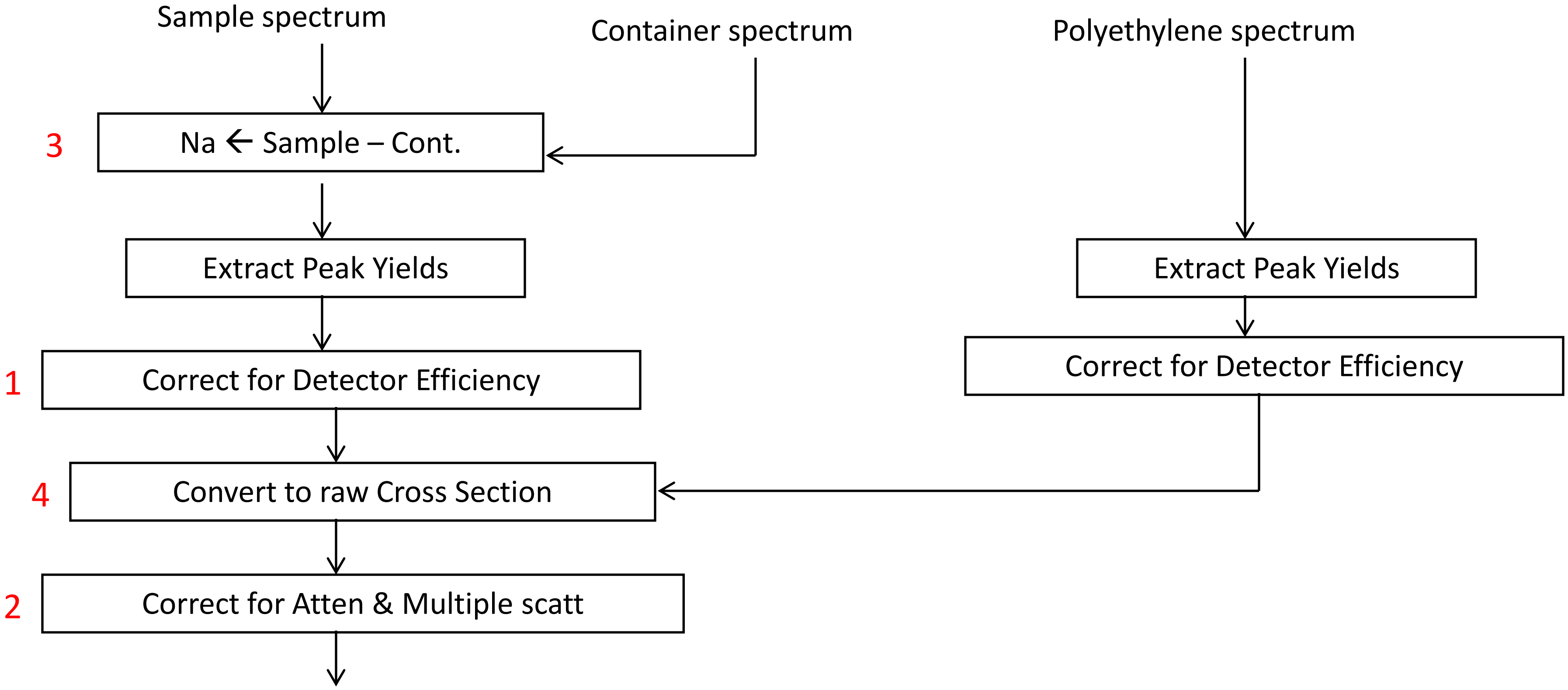
Correct for Detector Efficiency

4 Convert to raw Cross Section

2 **Correct for Atten & Multiple scatt**

http://kenokazaki.com/tag/pot-of-gold/





Sample spectrum

Container spectrum

Polyethylene spectrum

3 Na ← Sample – Cont.

Extract Peak Yields

Extract Peak Yields

1 Correct for Detector Efficiency

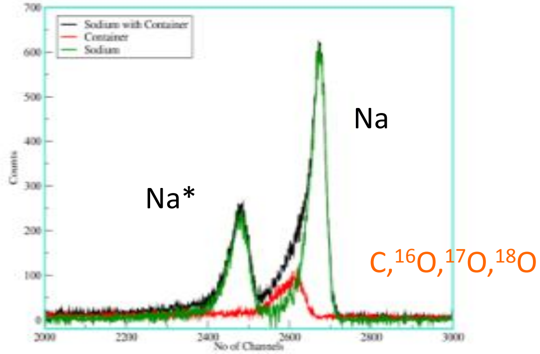
Correct for Detector Efficiency

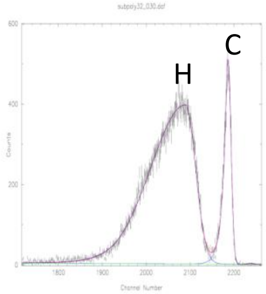
4 Convert to raw Cross Section

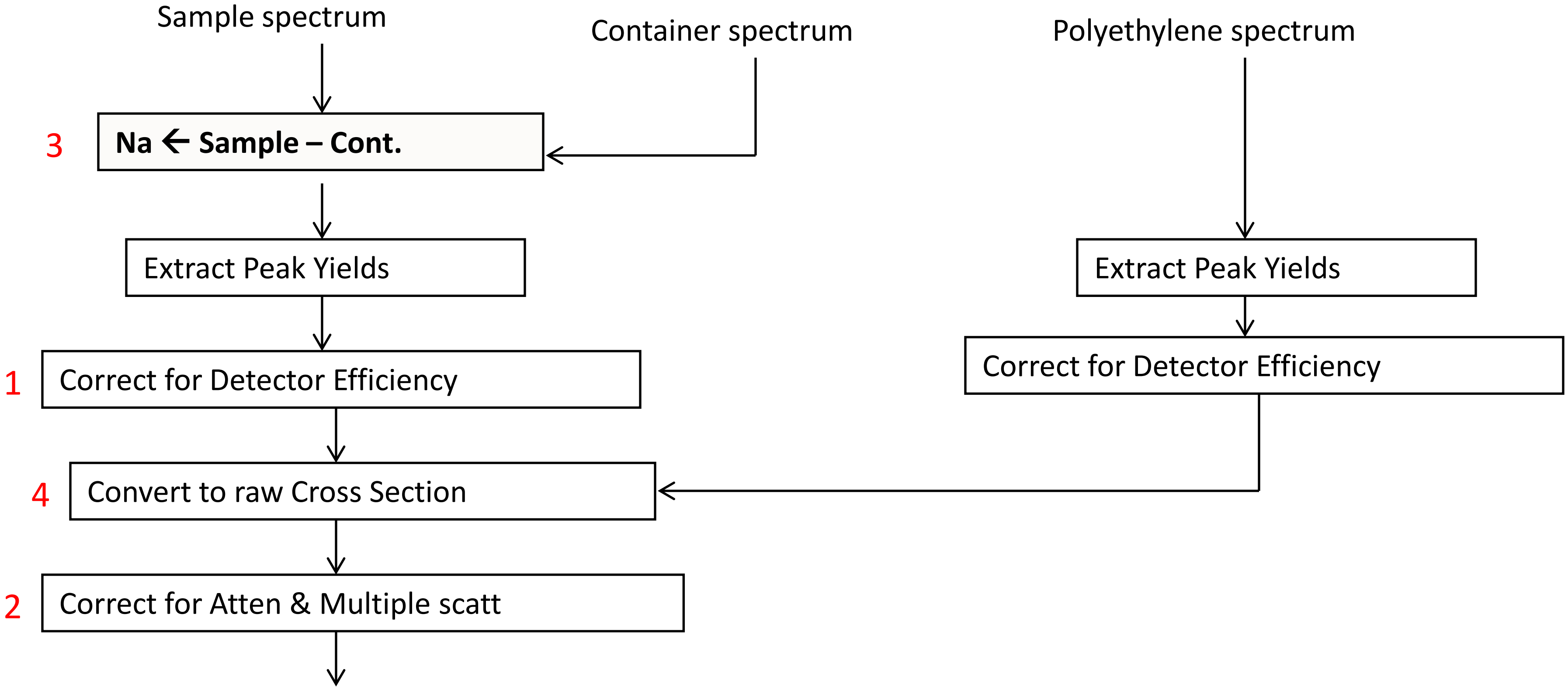
2 Correct for Atten & Multiple scatt

http://kenokazaki.com/tag/pot-of-gold/

3







Sample spectrum

Container spectrum

Polyethylene spectrum

3 **Na ← Sample – Cont.**

Extract Peak Yields

Extract Peak Yields

1 Correct for Detector Efficiency

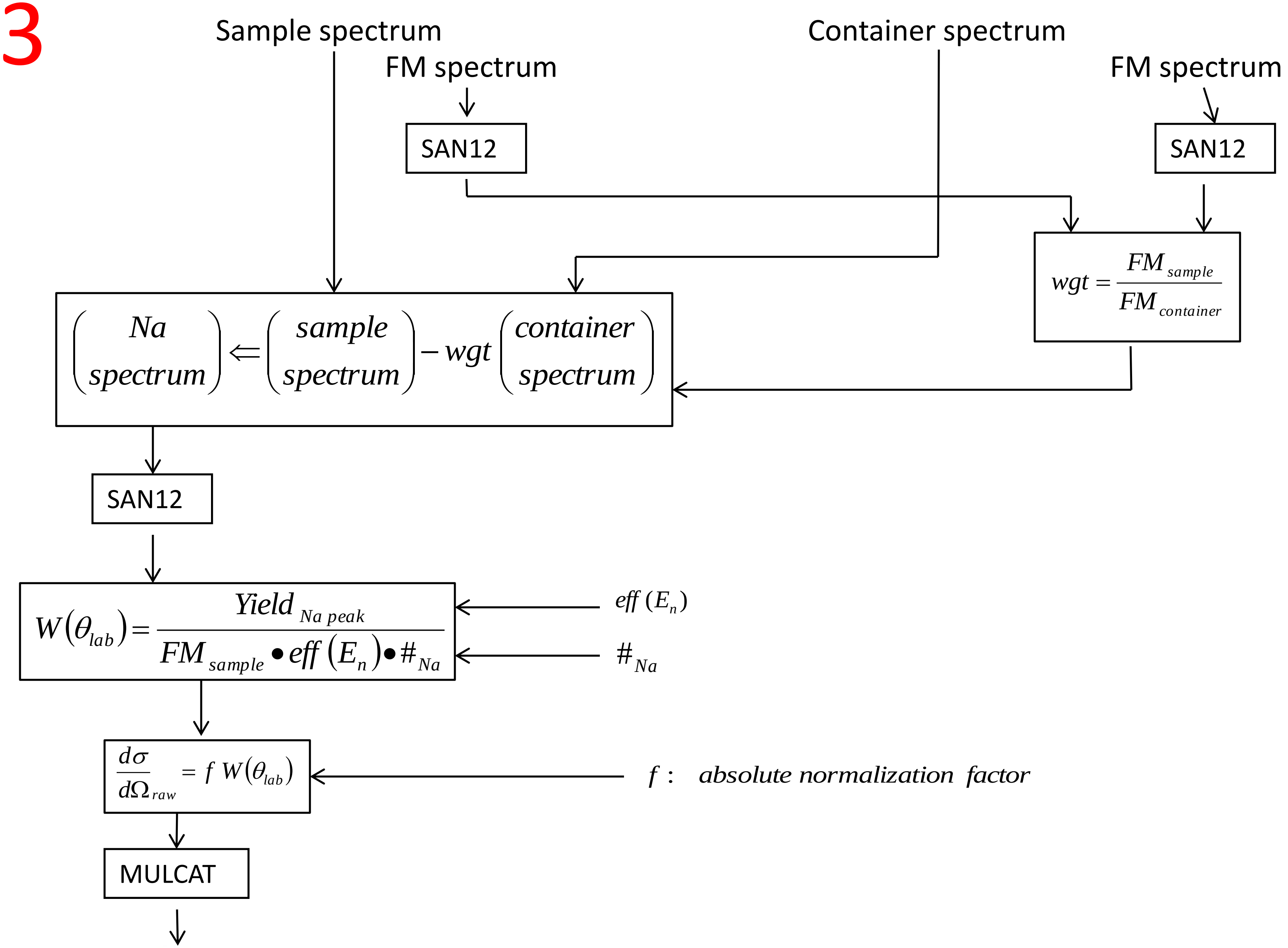
Correct for Detector Efficiency

4 Convert to raw Cross Section

2 Correct for Atten & Multiple scatt

http://kenokazaki.com/tag/pot-of-gold/

3



Sample spectrum

FM spectrum

SAN12

Container spectrum

FM spectrum

SAN12

$$wgt = \frac{FM_{sample}}{FM_{container}}$$

$$\begin{pmatrix} Na \\ spectrum \end{pmatrix} \Leftarrow \begin{pmatrix} sample \\ spectrum \end{pmatrix} - wgt \begin{pmatrix} container \\ spectrum \end{pmatrix}$$

SAN12

$$W(\theta_{lab}) = \frac{Yield_{Na\ peak}}{FM_{sample} \bullet eff\,(E_n) \bullet \#_{Na}}$$

$eff\,(E_n)$

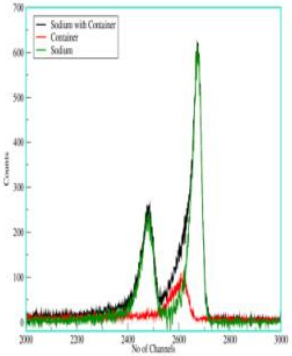
$\#_{Na}$

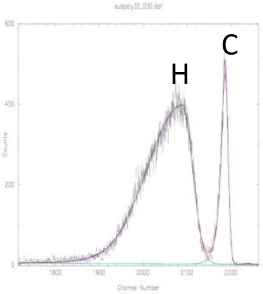
$$\frac{d\sigma}{d\Omega}_{raw} = f\ W(\theta_{lab})$$

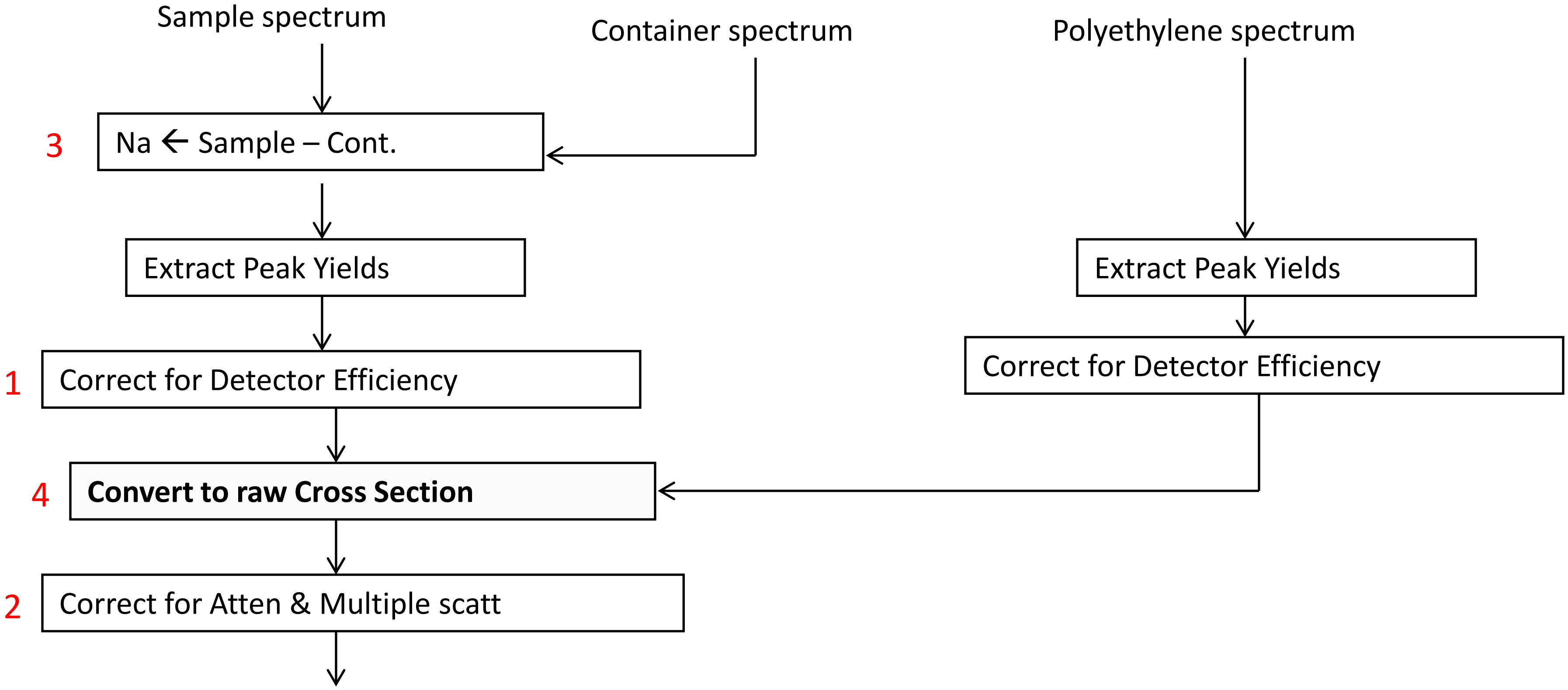
f : *absolute normalization factor*

MULCAT

http://kenokazaki.com/tag/pot-of-gold/







Sample spectrum

Container spectrum

Polyethylene spectrum

3 Na ← Sample – Cont.

Extract Peak Yields

1 Correct for Detector Efficiency

4 Convert to raw Cross Section

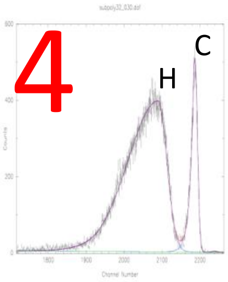
2 Correct for Atten & Multiple scatt

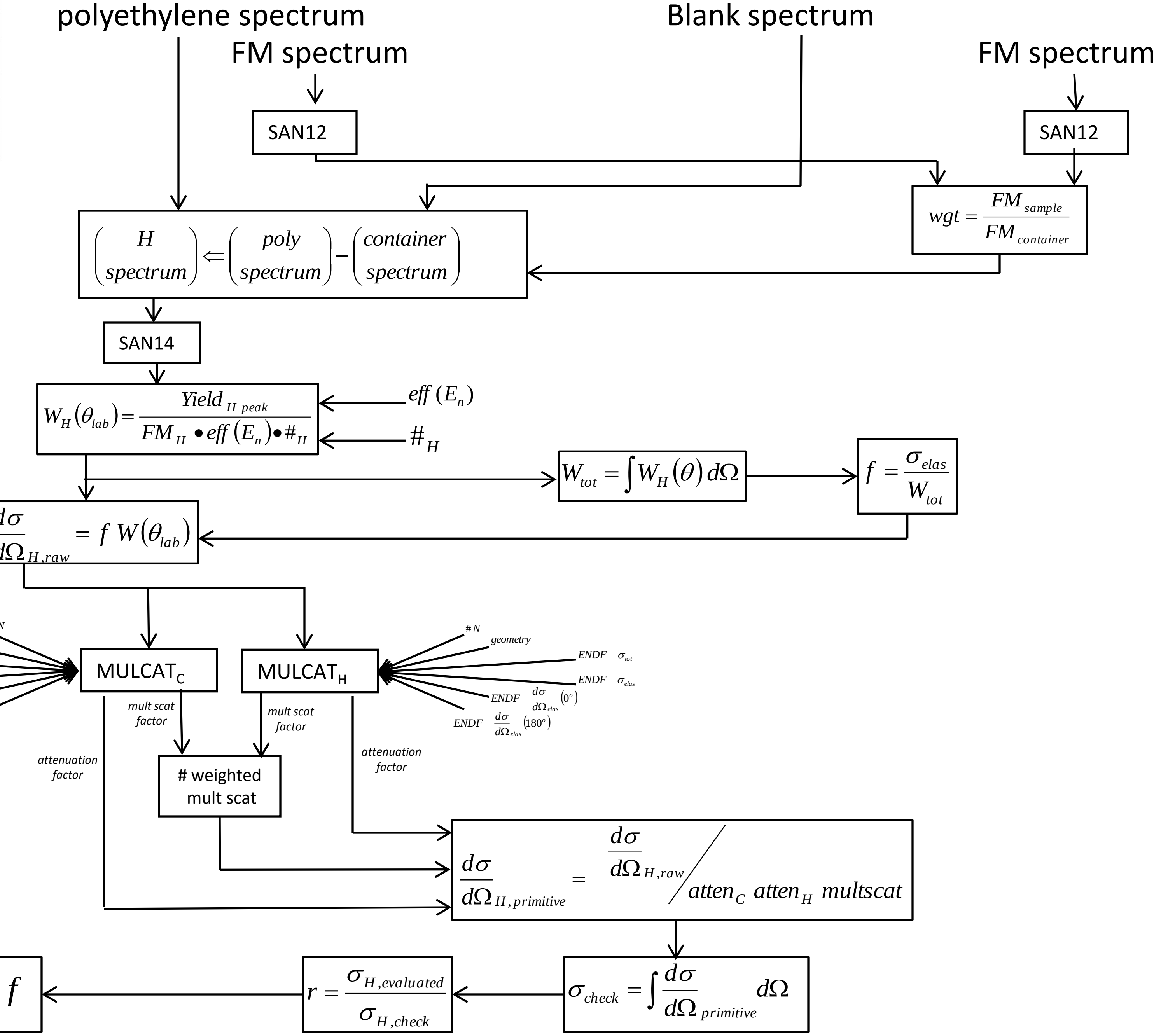
Extract Peak Yields

Correct for Detector Efficiency

http://kenokazaki.com/tag/pot-of-gold/

4





polyethylene spectrum

FM spectrum

Blank spectrum

FM spectrum

SAN12

SAN12

$$wgt = \frac{FM_{sample}}{FM_{container}}$$

$$\begin{pmatrix} H \\ spectrum \end{pmatrix} \Leftarrow \begin{pmatrix} poly \\ spectrum \end{pmatrix} - \begin{pmatrix} container \\ spectrum \end{pmatrix}$$

SAN14

$$W_H(\theta_{lab}) = \frac{Yield_{H\ peak}}{FM_H \bullet eff(E_n) \bullet \#_H}$$

$eff(E_n)$

$\#_H$

$$W_{tot} = \int W_H(\theta)\, d\Omega$$

$$f = \frac{\sigma_{elas}}{W_{tot}}$$

$$\frac{d\sigma}{d\Omega}_{H,raw} = f\, W(\theta_{lab})$$

$\# N$

geometry

ENDF σ_{tot}

ENDF σ_{elas}

ENDF $\frac{d\sigma}{d\Omega_{elas}}(0^\circ)$

ENDF $\frac{d\sigma}{d\Omega_{elas}}(180^\circ)$

MULCAT$_C$

MULCAT$_H$

$\# N$

geometry

ENDF σ_{tot}

ENDF σ_{elas}

ENDF $\frac{d\sigma}{d\Omega_{elas}}(0^\circ)$

ENDF $\frac{d\sigma}{d\Omega_{elas}}(180^\circ)$

attenuation factor

mult scat factor

mult scat factor

attenuation factor

weighted mult scat

$$\frac{d\sigma}{d\Omega}_{H,primitive} = \frac{d\sigma}{d\Omega}_{H,raw} \Big/ atten_C\ atten_H\ multscat$$

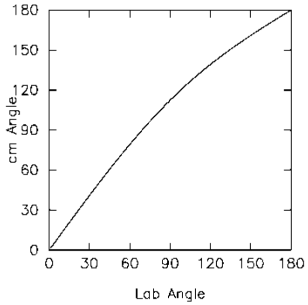
$$\sigma_{check} = \int \frac{d\sigma}{d\Omega}_{primitive} d\Omega$$

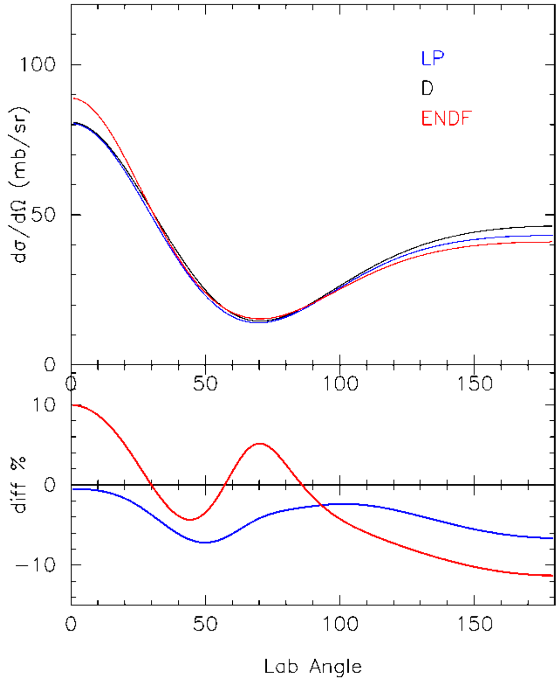
$$r = \frac{\sigma_{H,evaluated}}{\sigma_{H,check}}$$

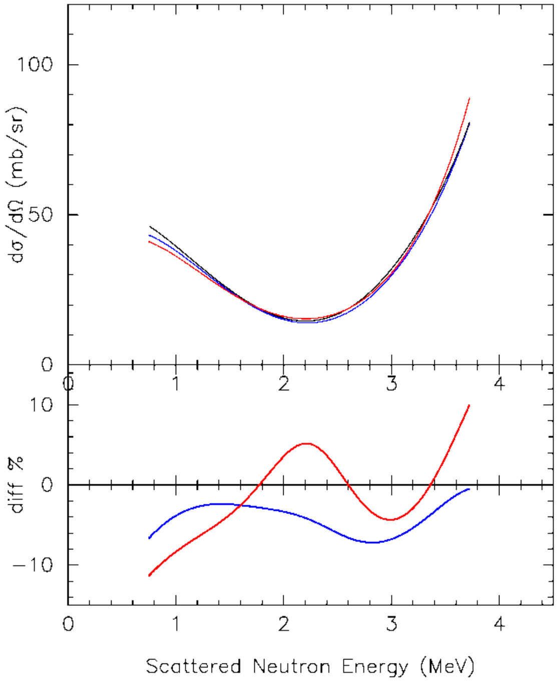
(should get r = 1.00)

$$f \leftarrow r\, f$$

E_p =4.5 MeV


180
150
120
90
60
30
0
cm Angle
0
30
60
90
120
150
180
Lab Angle


LP
D
ENDF
100
50
0
dσ/dΩ (mb/sr)
0
50
100
150
10
0
−10
diff %
0
50
100
150
Lab Angle


100
50
0
dσ/dΩ (mb/sr)
0
1
2
3
4
10
0
−10
diff %
0
1
2
3
4
Scattered Neutron Energy (MeV)

Ambiguities in Neutron Detection Efficiency attributed to 3H(p,n) dsdW
-- choices for dsdW --

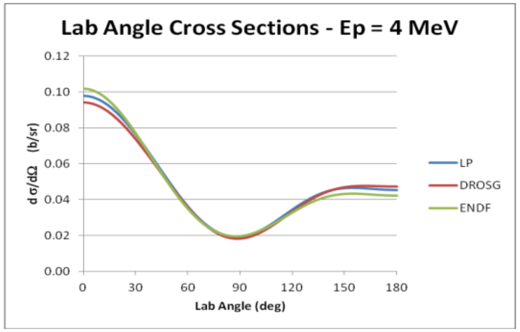
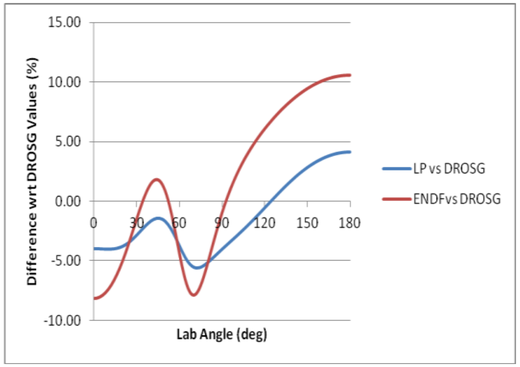
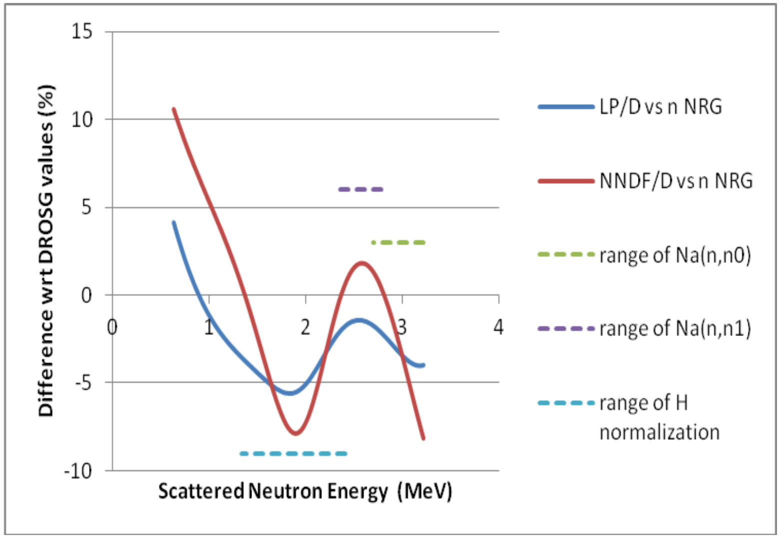


FIG. 6. Comparison of the three reference T(p,n) cross sections at E_p=4 MeV. The lower subfigure displays the percentage difference with respect to the DROSG parameterization. Differences between descriptions can be as much as ±10% and vary with angle.

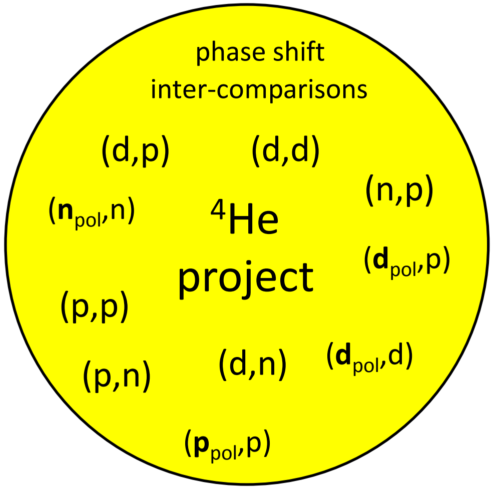




1

Actually need dσ/dΩ

^{3}H(p,n)



phase shift
inter-comparisons

(d,p) (d,d)

(n,p)

(**n**$_{pol}$,n)

^{4}He
project

(**d**$_{pol}$,p)

(p,p)

(p,n) (d,n) (**d**$_{pol}$,d)

(**p**$_{pol}$,p)

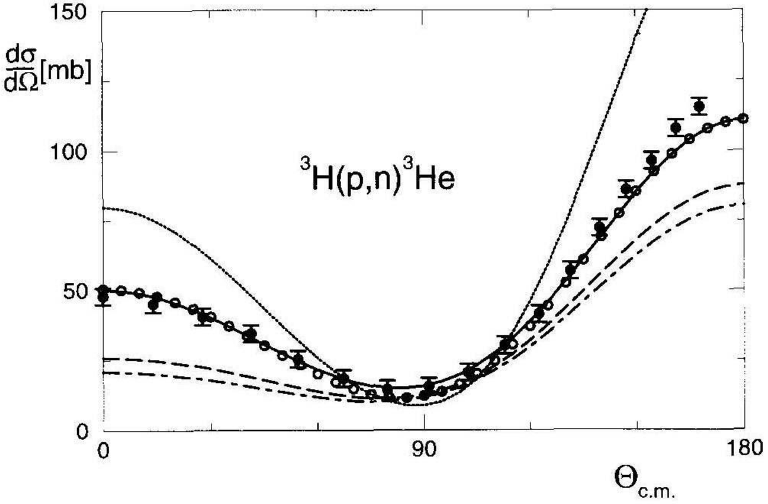


Fig. 18. Differential cross section of the reaction ^{3}H$(p,n)^3$He calculated for $E_{cm} = 3.0$ MeV. Th
for 4.101 MeV protons from Ref. [31]. The labeling is as in Fig. 16.

solid line R-matrix analysis

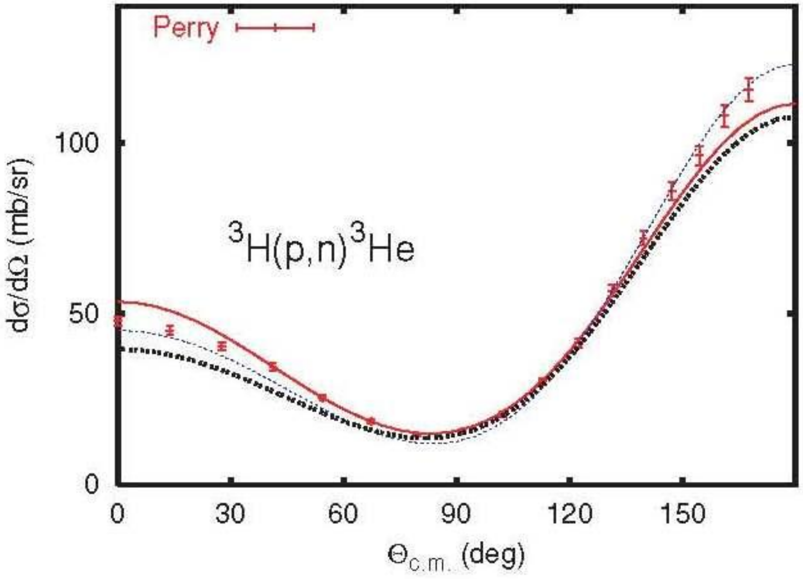
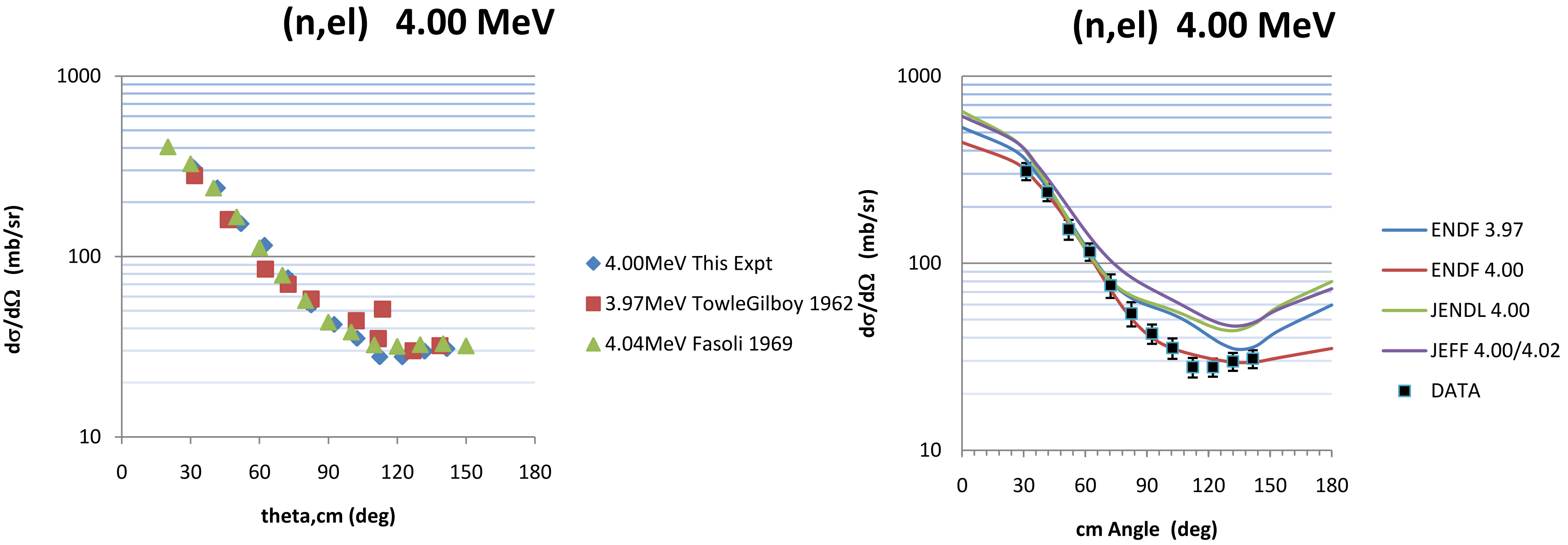


FIG. 17. (Color online) Differential cross section for the reaction ^{3}H$(p,n)^3$He calculated at 3.0 MeV $E_{c.m.}$. The data at 3.08 MeV are from Perry *et al.* [43].

dσ/dΩ predictable to

- <5% for $\theta_{cm} < 50^o$
- Really good for $50^o < \theta_{cm} < 140^o$

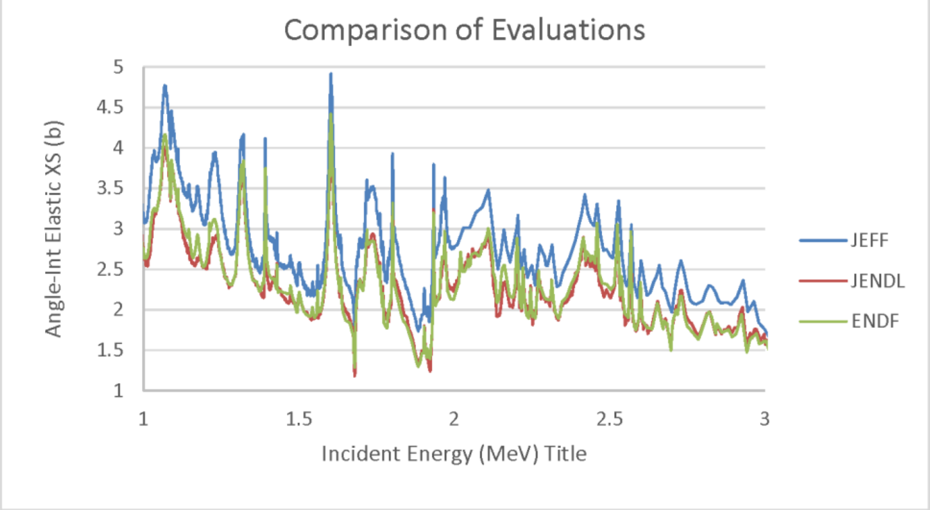
^{23}Na(n,el)

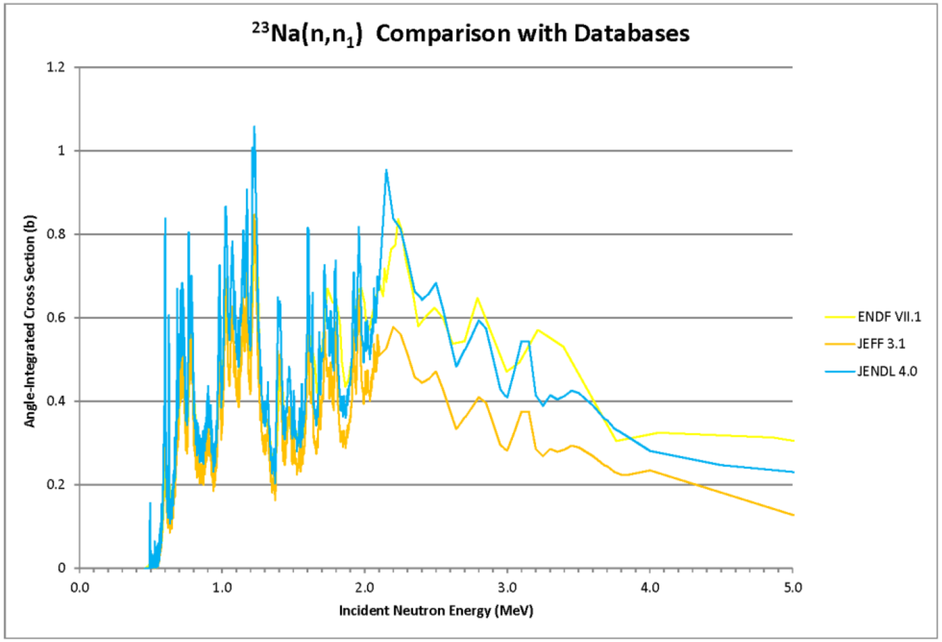


Comparison of our elastic cross sections to previous measurements (top) and the evaluated nuclear libraries (bottom). The shape of dσ/dΩ changes quickly at angles >80° with energy and is sensitive to the reaction mechanism.

^{23}Na(n,el)

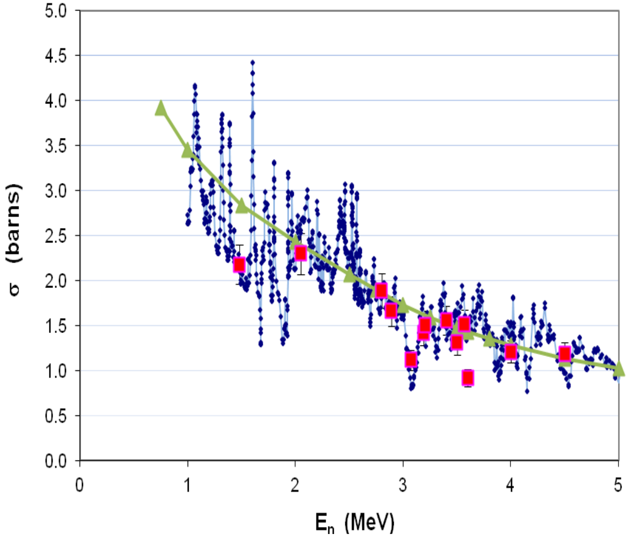
EVALUATIONS



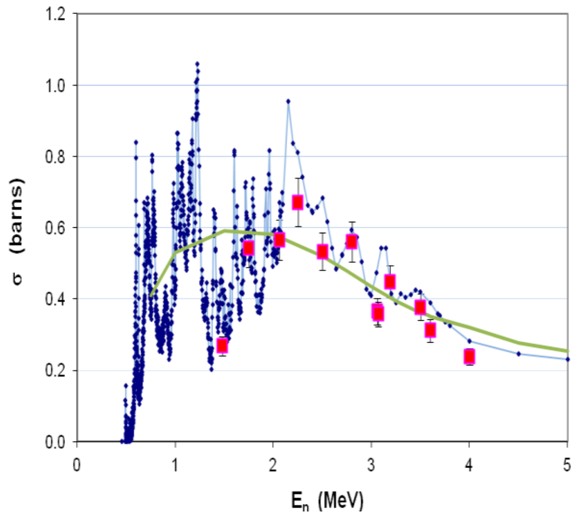


EXPERIMENTAL DATA

^{23}Na(n,n$_0$) ENDF/B-VII.1

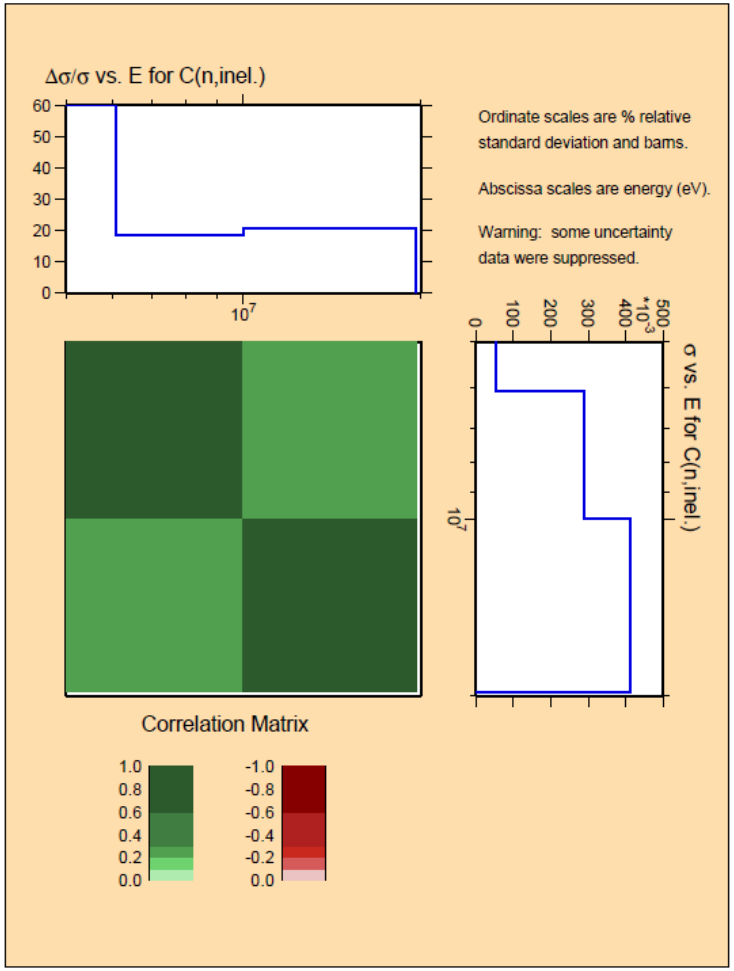


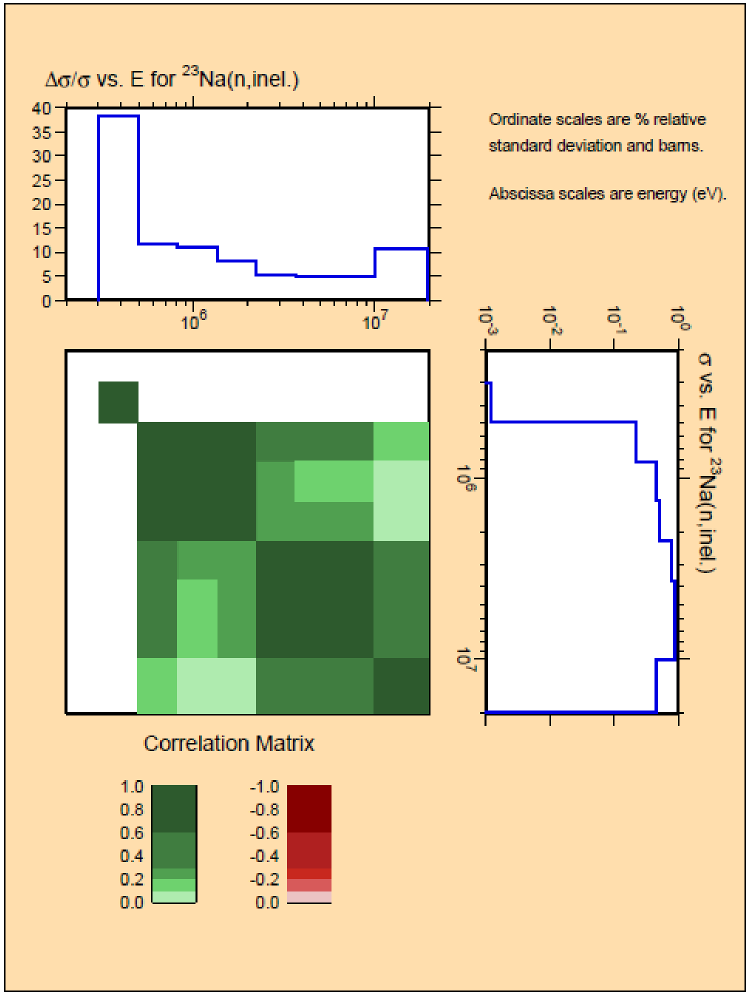
^{23}Na(n,n$_1$) JENDL 4.0

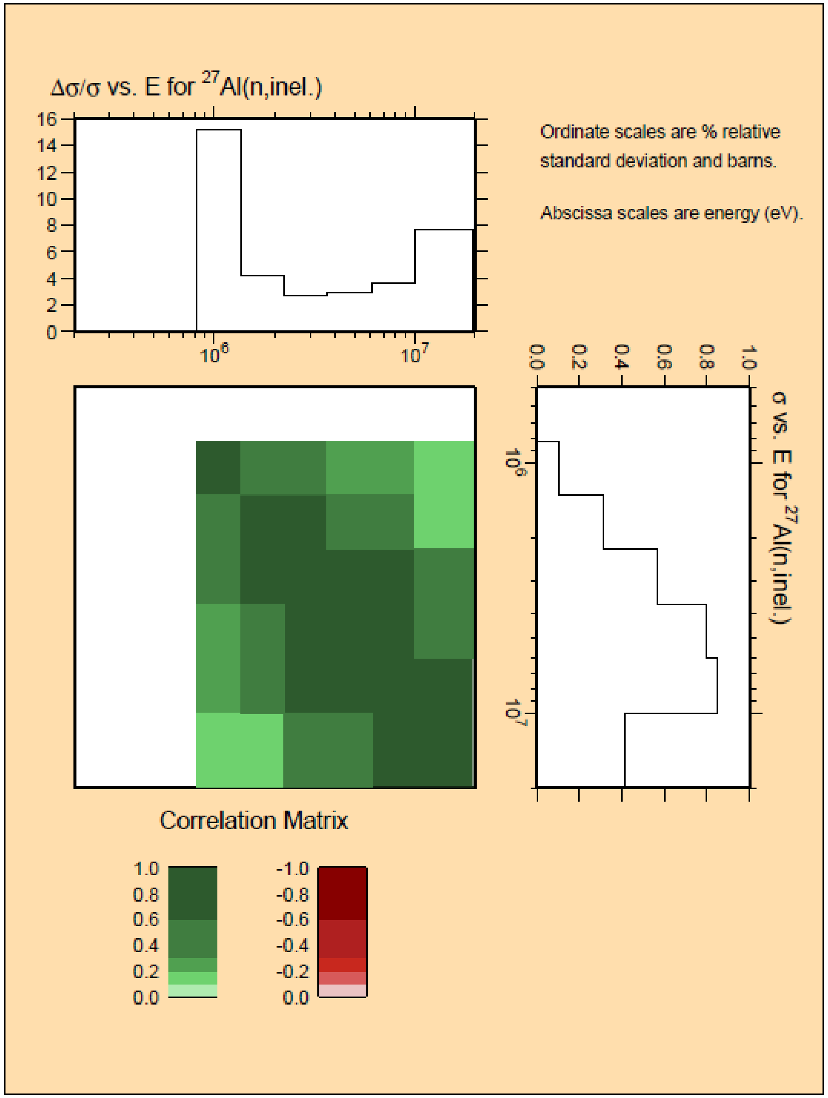


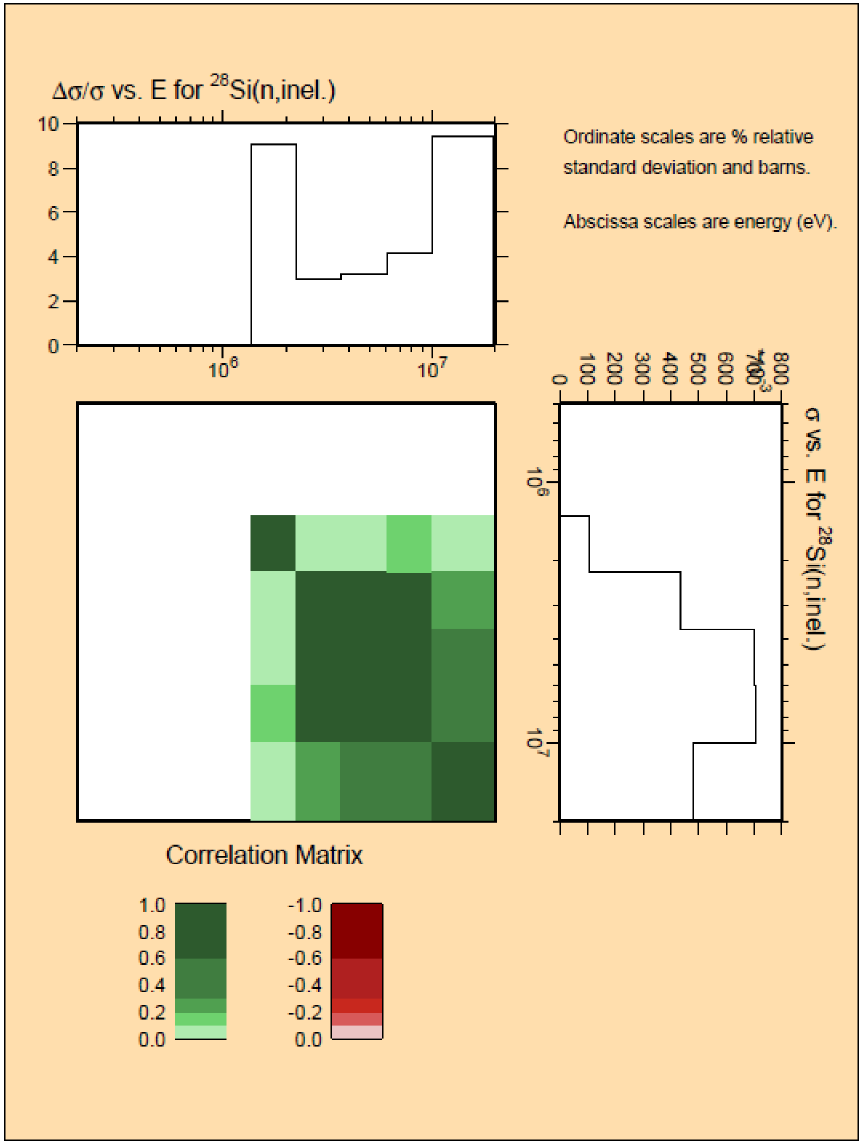
(LEFT: There can be significant disagreements between the libraries for cross sections. RIGHT: Our measurements determine the best choices. Our measurements indicate that both the ENDF & JENDL libraries have good values for elastics, while only the JENDL properly describes the inelastic.)

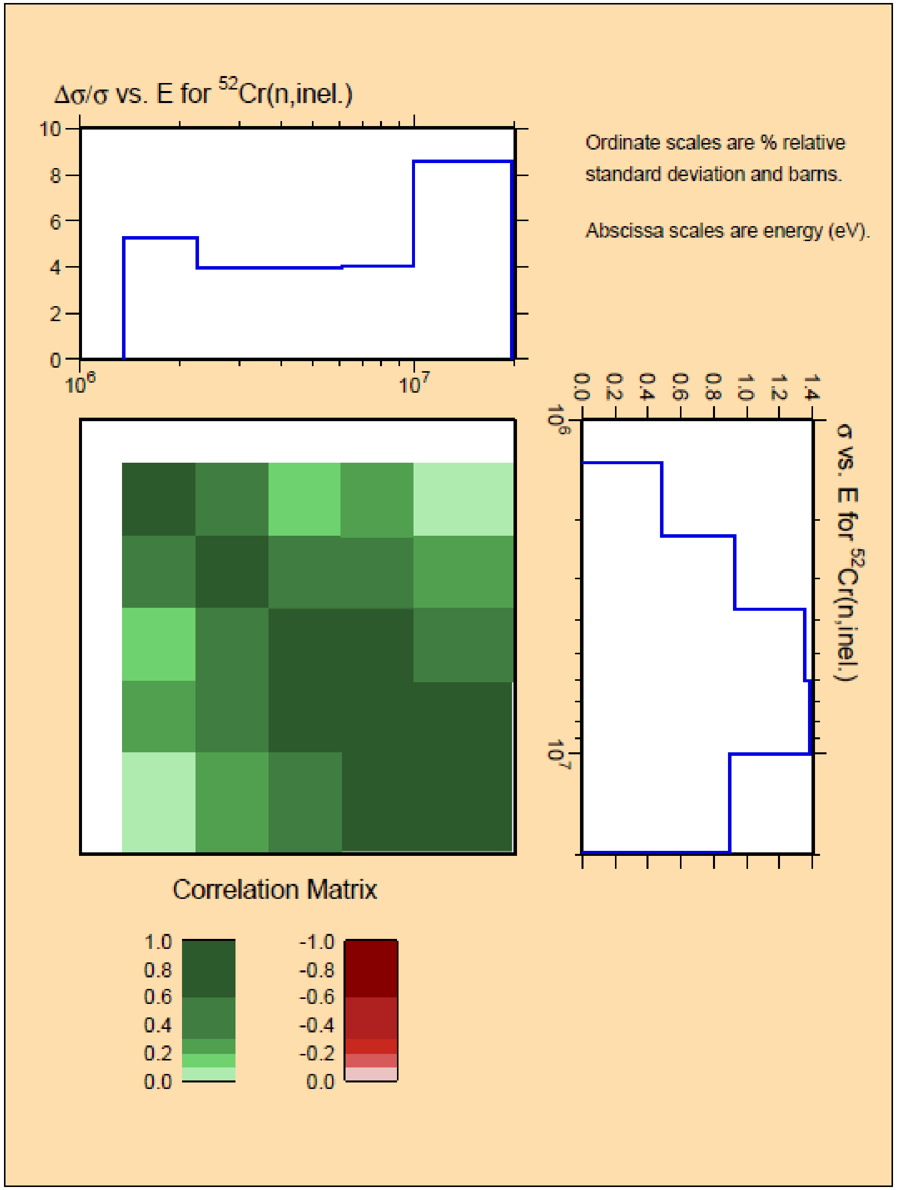
Oblozinsky, “Progress on Nuclear Covariances: AFCI-1.2 Covariance Library” BNL-90897-2009






Δσ/σ vs. E for ²⁷Al(n,inel.)
16
14
12
10
8
6
4
2
0
10⁶
10⁷
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
0.0
0.2
0.4
0.6
0.8
1.0
σ vs. E for ²⁷Al(n,inel.)
Correlation Matrix
1.0
0.8
0.6
0.4
0.2
0.0
-1.0
-0.8
-0.6
-0.4
-0.2
0.0


Δσ/σ vs. E for ²⁸Si(n,inel.)
10
8
6
4
2
0
10⁶
10⁷
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
0
100
200
300
400
500
600
700
800
×10⁻³
σ vs. E for ²⁸Si(n,inel.)
Correlation Matrix
1.0
0.8
0.6
0.4
0.2
0.0
-1.0
-0.8
-0.6
-0.4
-0.2
0.0

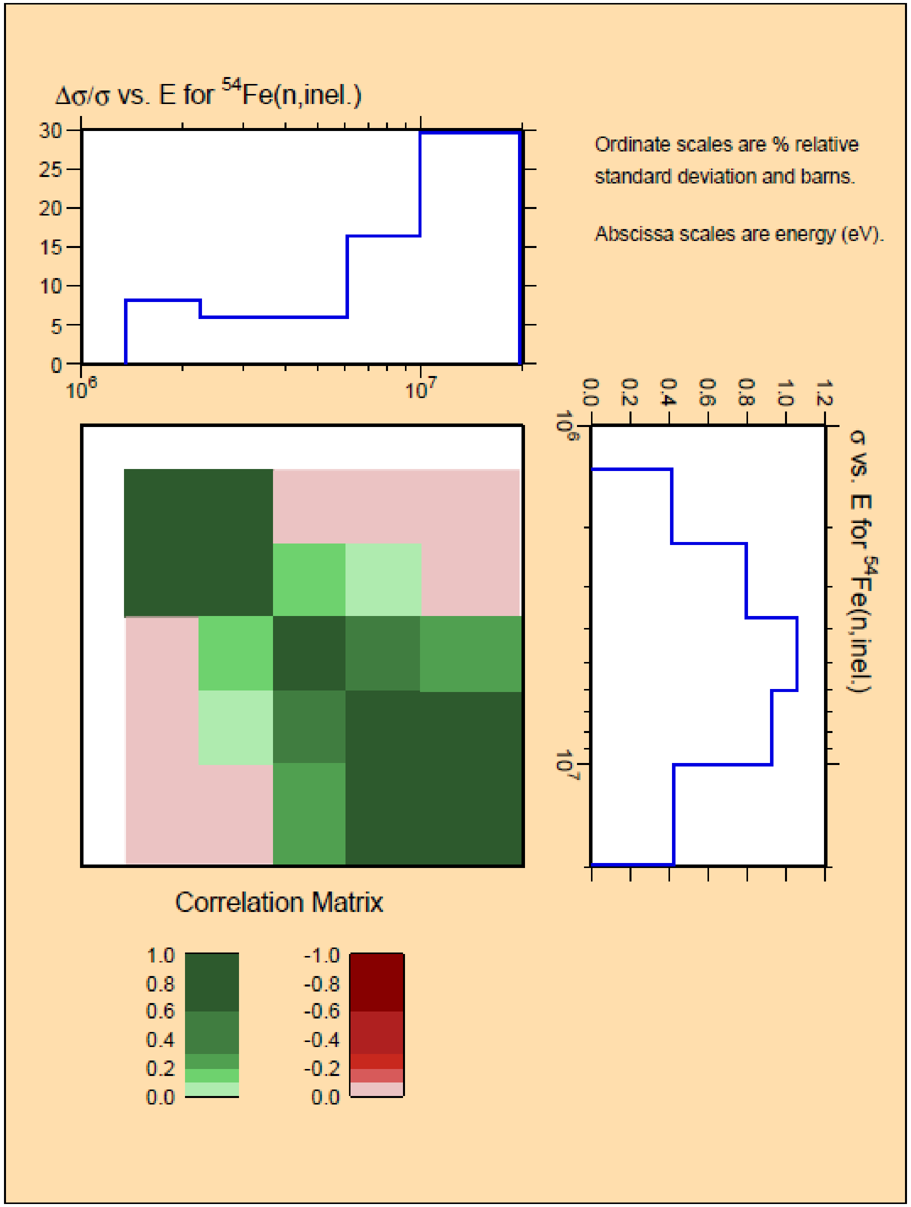

Δσ/σ vs. E for ^{52}Cr(n,inel.)

Ordinate scales are % relative standard deviation and barns.

Abscissa scales are energy (eV).

Correlation Matrix

σ vs. E for ^{52}Cr(n,inel.)

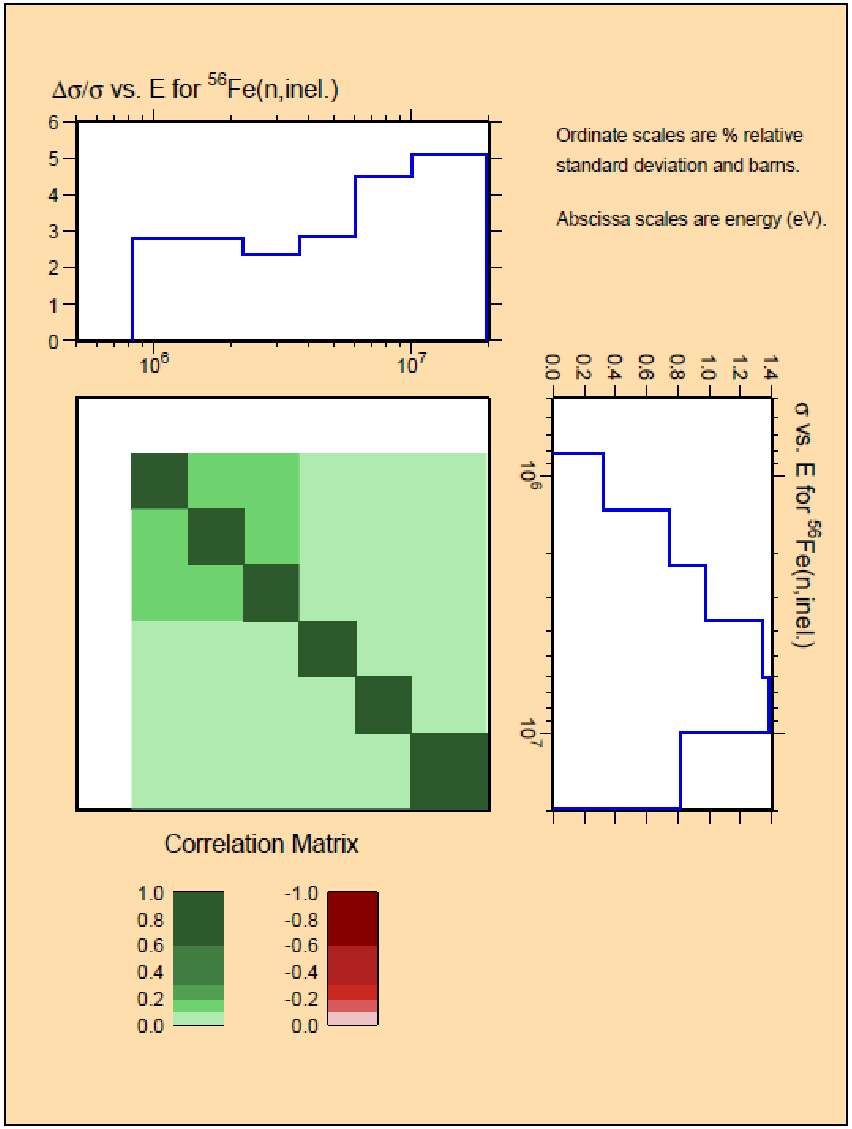

Δσ/σ vs. E for ^{54}Fe(n,inel.)

Ordinate scales are % relative standard deviation and barns.

Abscissa scales are energy (eV).

Correlation Matrix

σ vs. E for ^{54}Fe(n,inel.)



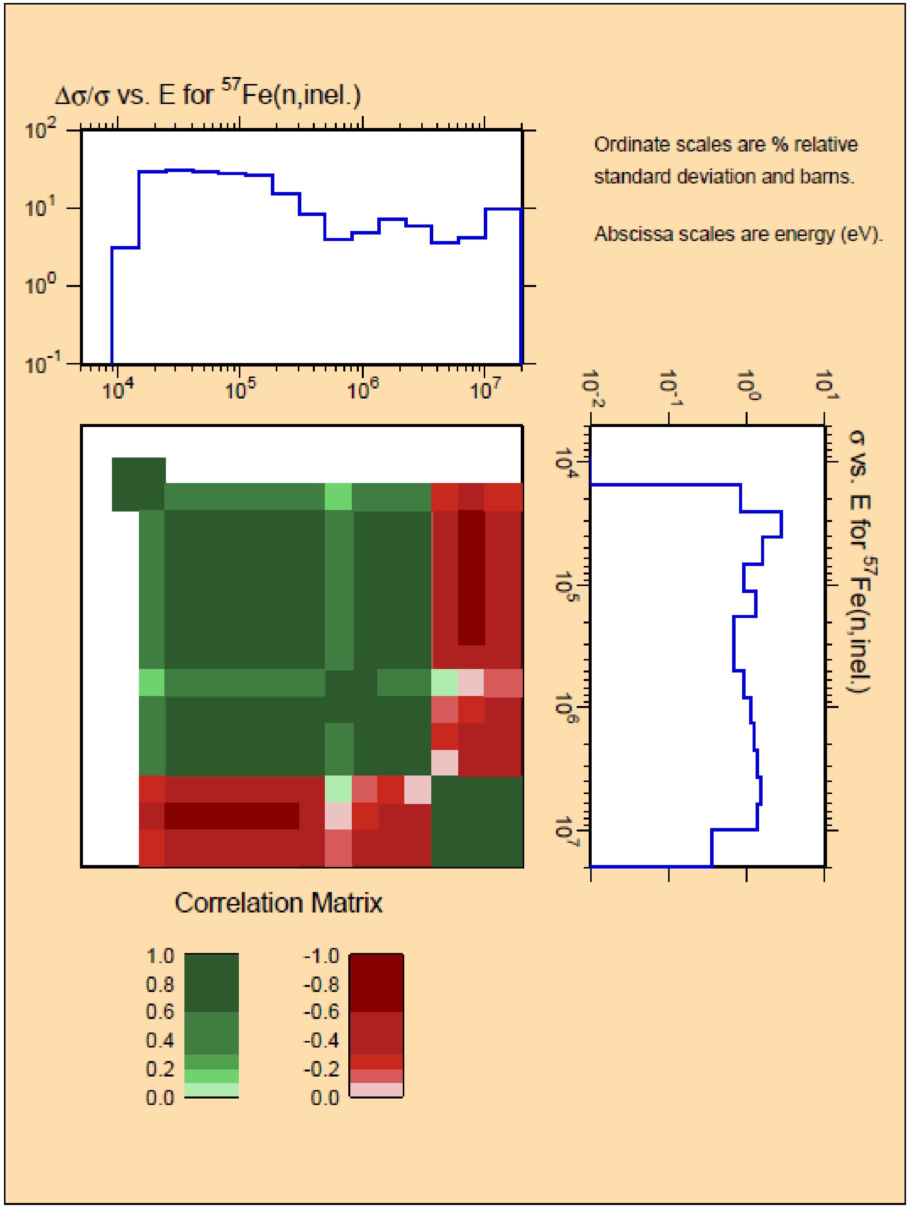
$\Delta\sigma/\sigma$ vs. E for ^{56}Fe(n,inel.)

Ordinate scales are % relative standard deviation and barns.

Abscissa scales are energy (eV).

σ vs. E for ^{56}Fe(n,inel.)

Correlation Matrix



$\Delta\sigma/\sigma$ vs. E for ^{57}Fe(n,inel.)

Ordinate scales are % relative standard deviation and barns.

Abscissa scales are energy (eV).

σ vs. E for ^{57}Fe(n,inel.)

Correlation Matrix