A study of the Absorption Cross Section of Iron using Two Techniques

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1. Pulsed Sphere
   1. A pair of iron spheres were pulsed with 1, 6 , 8, and 10 MeV neutrons.
   2. Output Neutrons measured at 8 angles from 0^{o} to 135^{o} .
   3. Due to Multiple scattering the flight path is uncertain.
   4. A Monte Carlo code and cross section library are used to calculate the arrival time of the neutrons.

2. Two types of information:
    a. Pass through peak
        1. Good statistics
        2. Depends on the nonelastic cross section
        3. Some have one elastic scattering.

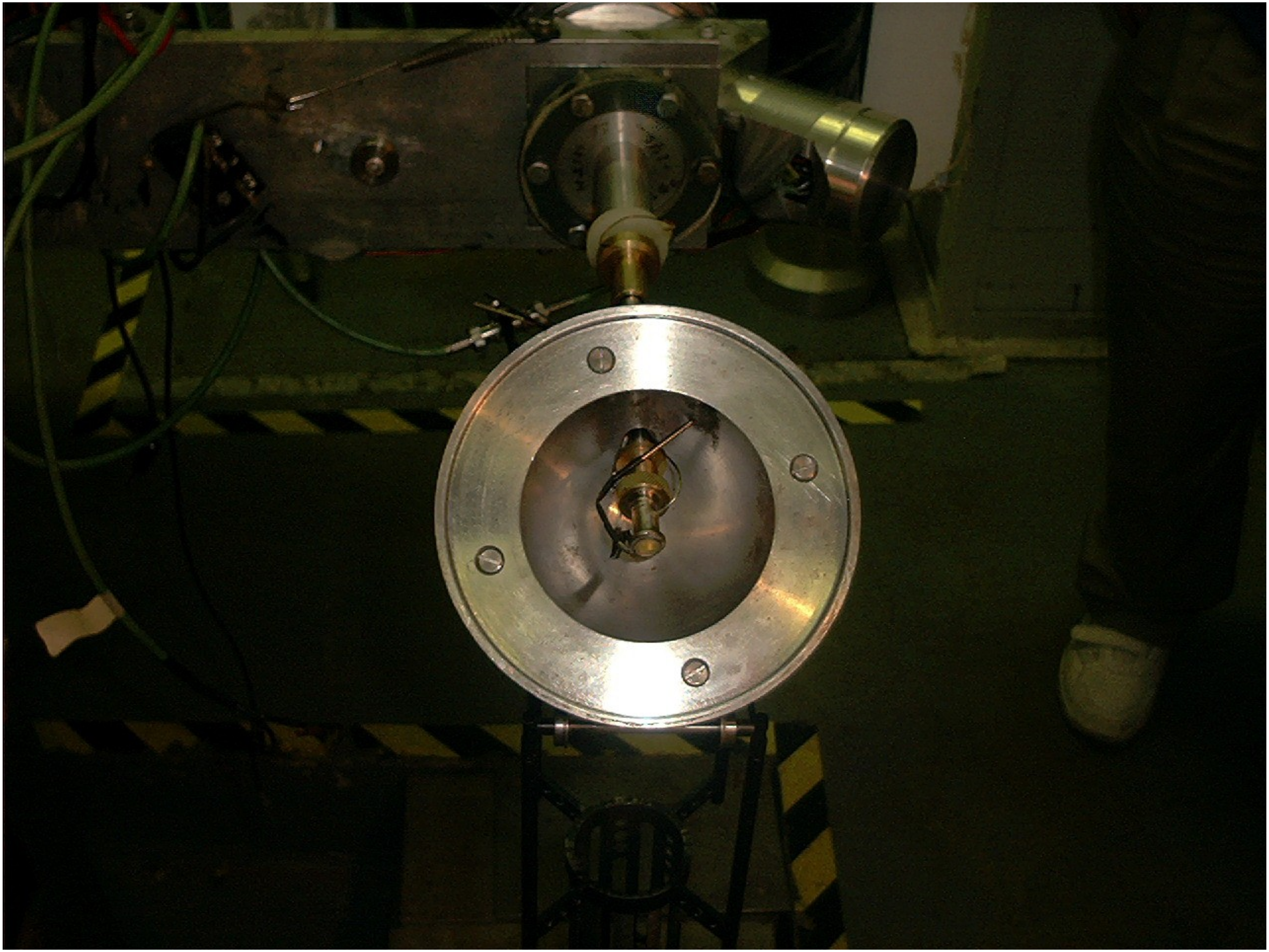
    b. Have lower energy continuum resulting from (n,n’), (n,2n), (n,pn), (n,αn).

Situation Simple at 14 MeV

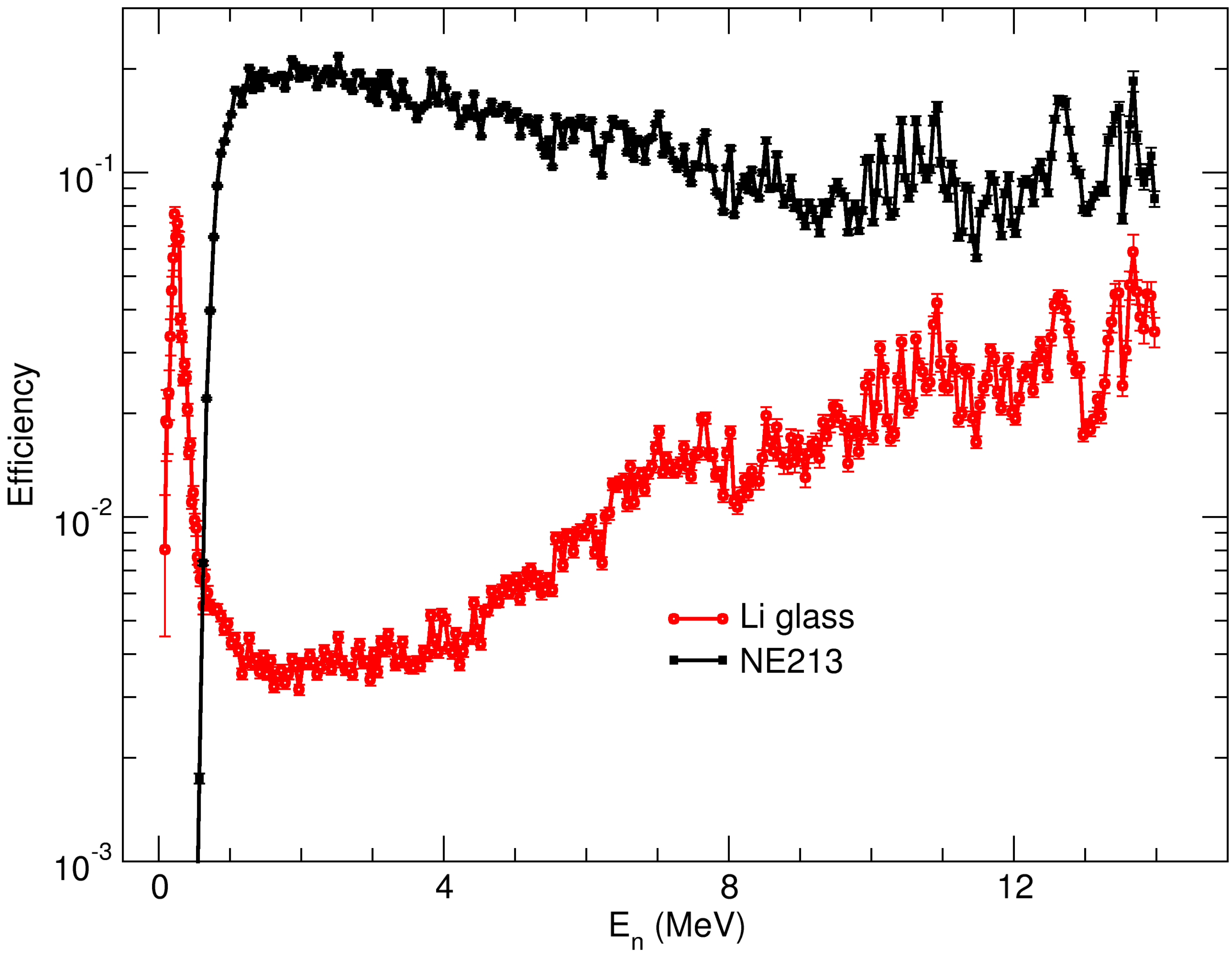
A. Cross Section for T(d,n) almost isotropic

B. Energy almost independent of angle

C. Very small production of neutrons with $E_n <$ 14 MeV

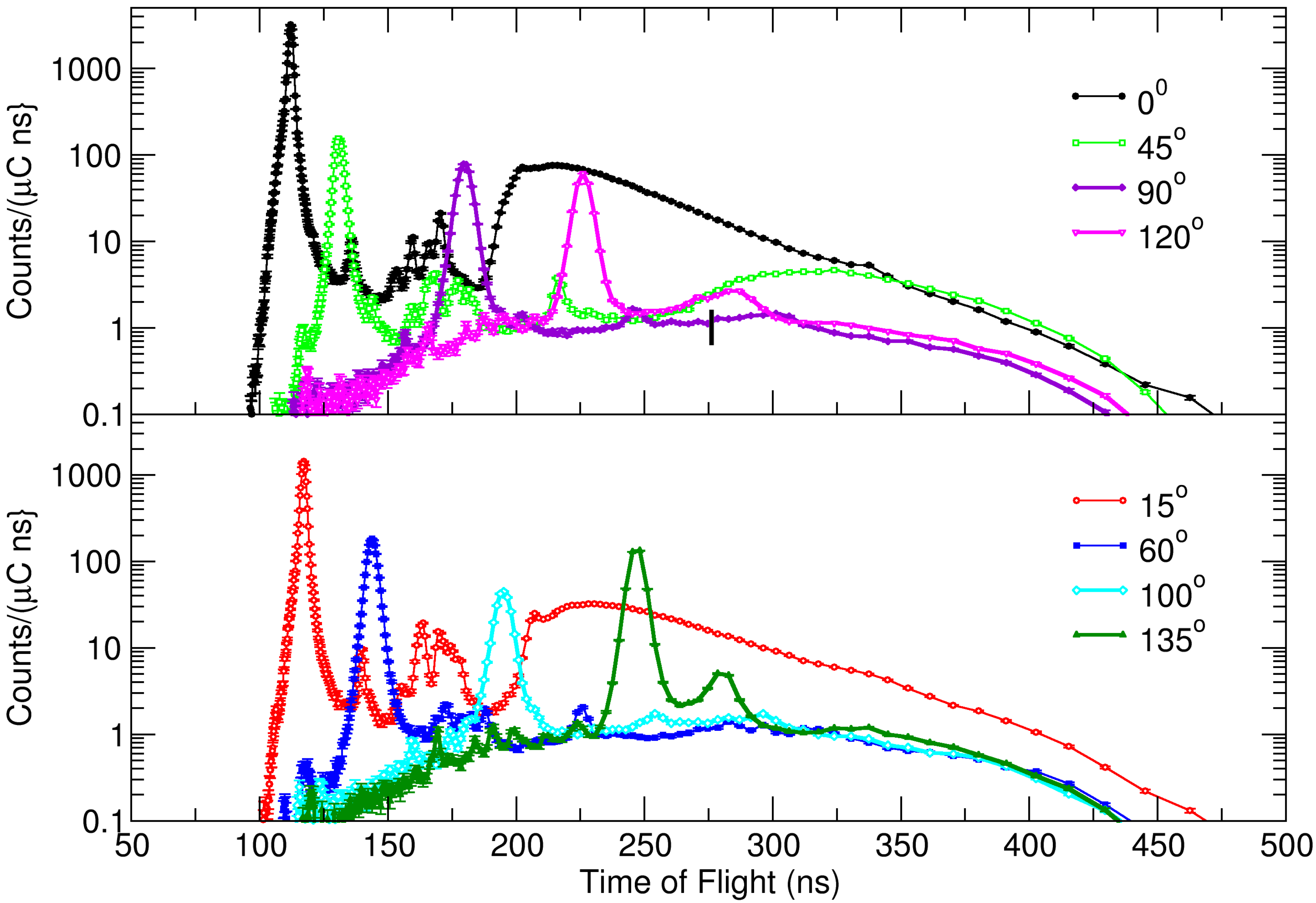


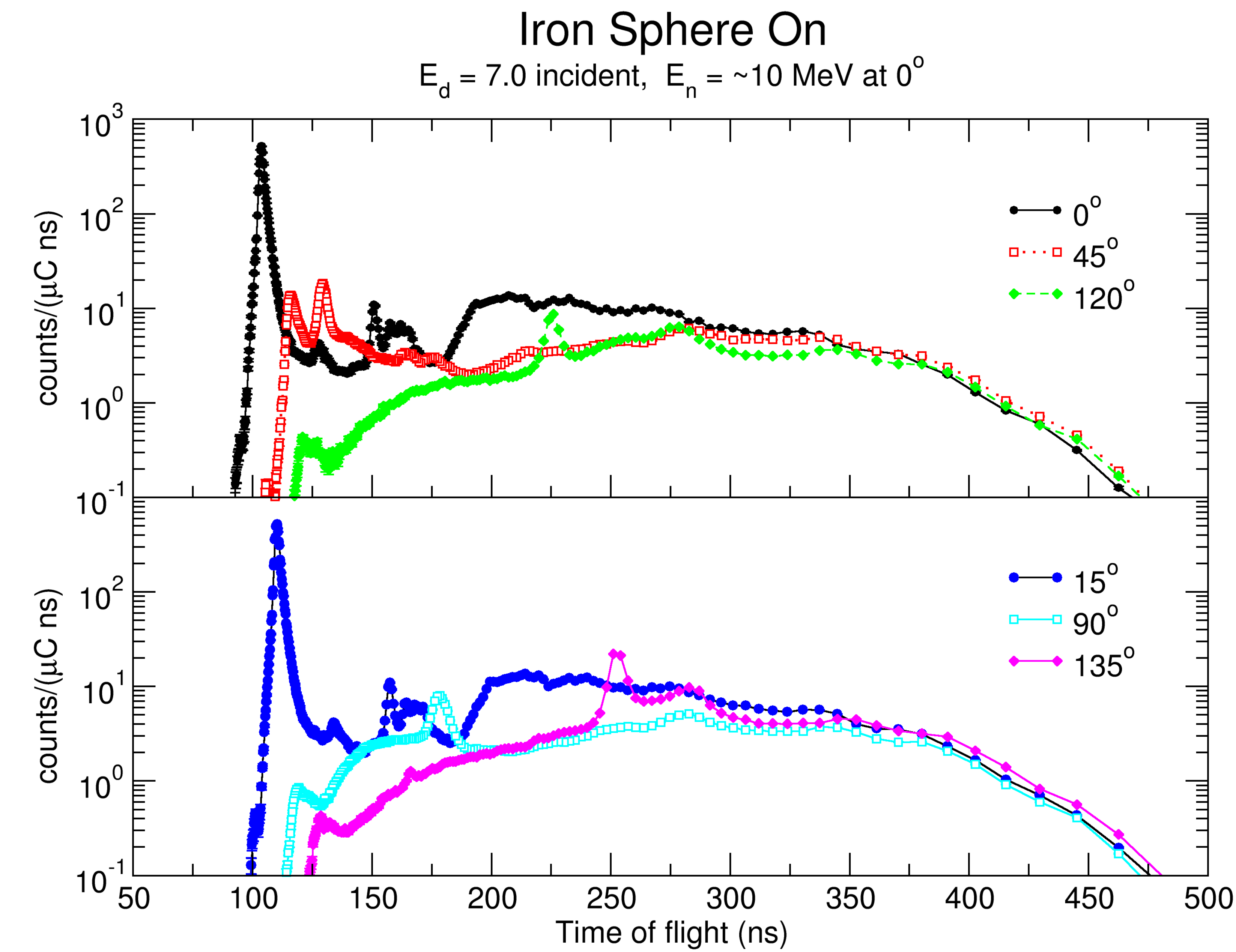
Detector Efficiencies



Iron Sphere Off (Source Spectrum)

E_d = 7.0 incident, E_n = ~10 MeV at 0^o





Iron Sphere On
E_d = 7.0 incident, E_n = ~10 MeV at 0^o
counts/(μC ns)
Time of flight (ns)
0^o
45^o
120^o
15^o
90^o
135^o

Present Results

A. 1 MeV: used $^{15}N(p,n)$ small cross section except for primary peak.
B. 6, 8, 10 MeV: used D(d,n) source
   I. large change in σ with angle,
   II. large change in E_n with angle,
   III. significant break-up in forward direction,
   IV. Sphere Off (source spectrum) measured for 12 angles.

Present Results: continued

V. Subsequently found angular interpolation method not unambiguous,
VI. Needed more angles on sphere off or better physics ,
VII. Makes "inelastic" comparison more uncertain
VIII. Does not have substantial effect on pass-through peak,
IX. Range of energies tested is substantial,
X. For 10 MeV, range was from 2.5 MeV (back angles) to 10 MeV 0^{o} .

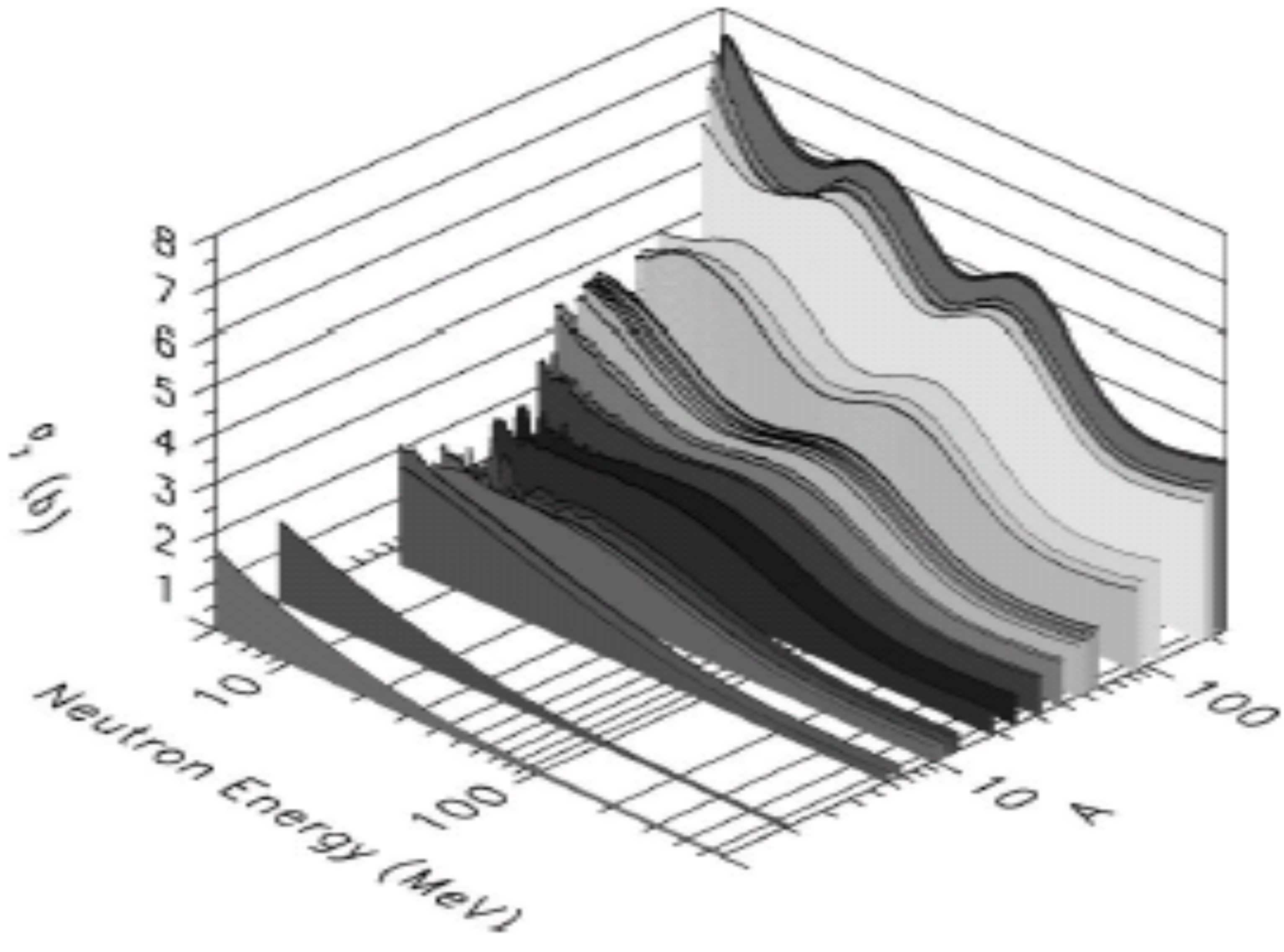
Findings:

- The description good for 1 MeV, only has elastic and 2^+ inelastic.
- Capture small (n,p) and (n,α) small or zero
- Description poor at 6, 8 and 10 MeV.
- Indicates need to lower σ_{abs} for Fe by more than 10%.
- Measurements are being repeated with more detailed Sphere-Off (source spectra) characterization.

Ramsauer Analysis

- σ_T was measured for ~25 samples from $5 \leq En \leq 400\ MeV$ at WNR.
- These studies of σ_T for neutrons find oscillations with a large period (~ 10 MeV).
- The change in position with E and A are not consistent with single particle resonances.
- There is a correspondence to interference maximum and minima between wave passing through and around the nucleus.
- The model is not applicable for $E_n \leq 5$ MeV
- Get good fits from ~5 to 100 MeV

Total Cross Sections at WNR



Ramsauer Form

- $\square T = 2\square (R + \square)^{2} (1 - \alpha \cos \square)$

$\alpha \approx 0.1$

$\square = c A^{1/3} \left(\sqrt{a + bE} - \sqrt{E}\right)$

- Consistently fit to 3%.
- R.W. Bauer et al., N.S.E. **130** 348 (1998)
- Ramsauer is equivalent to a single phase shift assumption.

- Particularly useful for estimation of ^{90}Zr, ^{91}Zr, ^{92}Zr, ^{94}Zr ^{96}Zr T, for $E_n > 6$ MeV from natural Zirconium T
- Could also be used to determine T for nuclei off the line of stability such as fission products.

- Interference effects come from elastic scattering.
- Possible decomposition of the equation:
- $\square T = 2\square (R + \square)2(1 - \alpha\cos\square\ )$
- Into:
- $\square elastic = 2\square (R + \square)2(1 - \alpha\cos\square\ )$
- $\square nonelastic = 2\square (R + \square)2$
- Comparison with elastic model indicates 10% consistency on $\square elastic$ - $\square nonelastic$ breakdown.

Alternate Method

- F. S. Dietrich et al., Phys. Rev. C **68,** 064608 (2003).
- Wick's Limit $Im(f(0^o)) = k/4\square \; \square_{total}$
- $\square_{elastic}(0^o) = |Re(f(0^o))|^2 + |Im(f(0^o))|^2$
- $\square_{elastic}(0^o) \geq |Im(f(0^o))|^2$
- $\square_{elastic}(0^o) \geq (k/4\square \; \square_{total})^2$
- $f(0^o) = ik(1 - e^{i\square})/2$
- Using the $f(0^o)$ equation we recover the Ramsauer Equation
- $\square_{total} = 2\square(R + \square)^2 \; (1 - \alpha\cos\square)$

- Can now calculate σ_T and *im f(0º)* to directly check Wick's Limit
- Use best fit α and β parameters and look at $6 \leq E\downarrow n \leq 60\ MeV$
- Find deviation between 0 and 1.5% over this range
- Can also use the optical Model (Koning and Delaroche) to calculate $\sigma_{elastic}$ (0º) and compare to Wick's Limit

- For ^{56}Fe the deviation is
  - $\leq 1\%$ for 7-10 MeV
  - $\geq 5\%$ for $E_n \leq 5\ MeV$ or $E_n \geq 50\ MeV$
- If we have σ_{total} accurately over an energy range and find energy where Wick's limit is an equality, we can get $\sigma_{elastic}(0^o)$

  - Renormalize $\int^{\square} \square_{elastic}(0^{o})\sin\square\ d\square$ with

h = $\sigma_{elastic}(0^o)_{optical}/\sigma_{elastic}(0^o)_{Wick's\_Limit}$

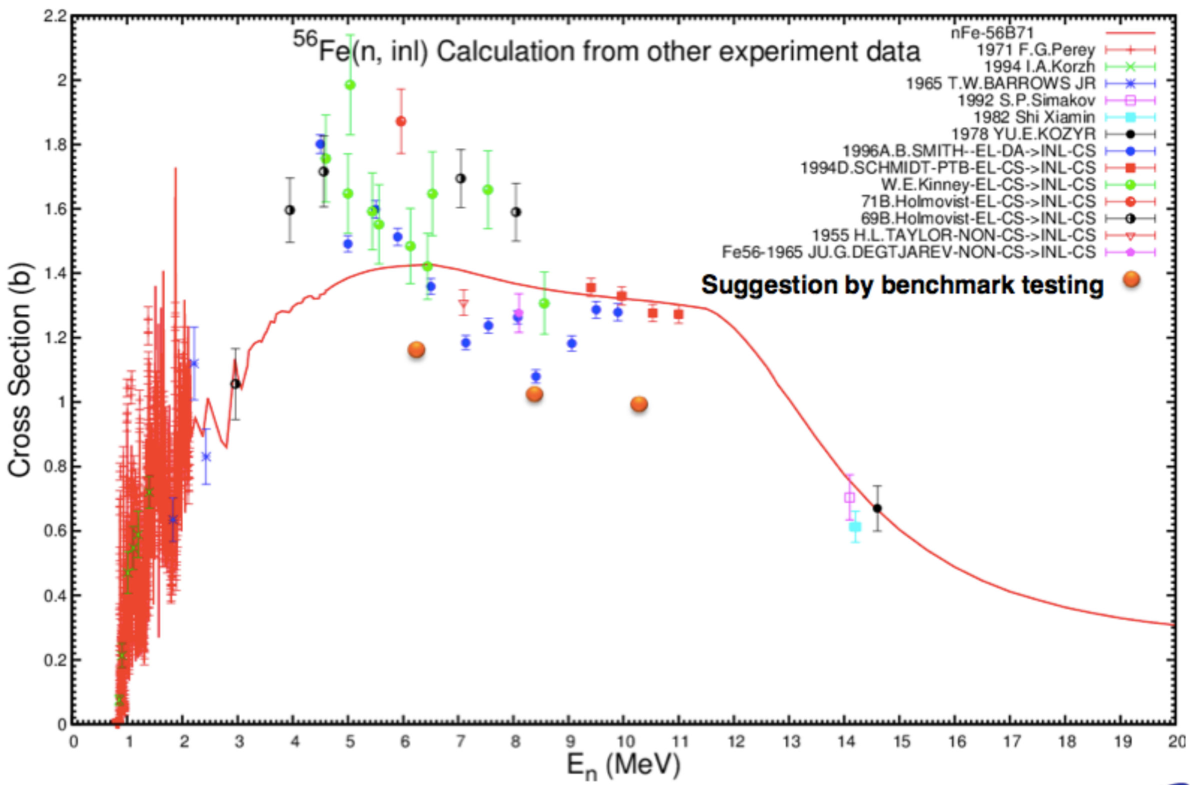
Conclusion

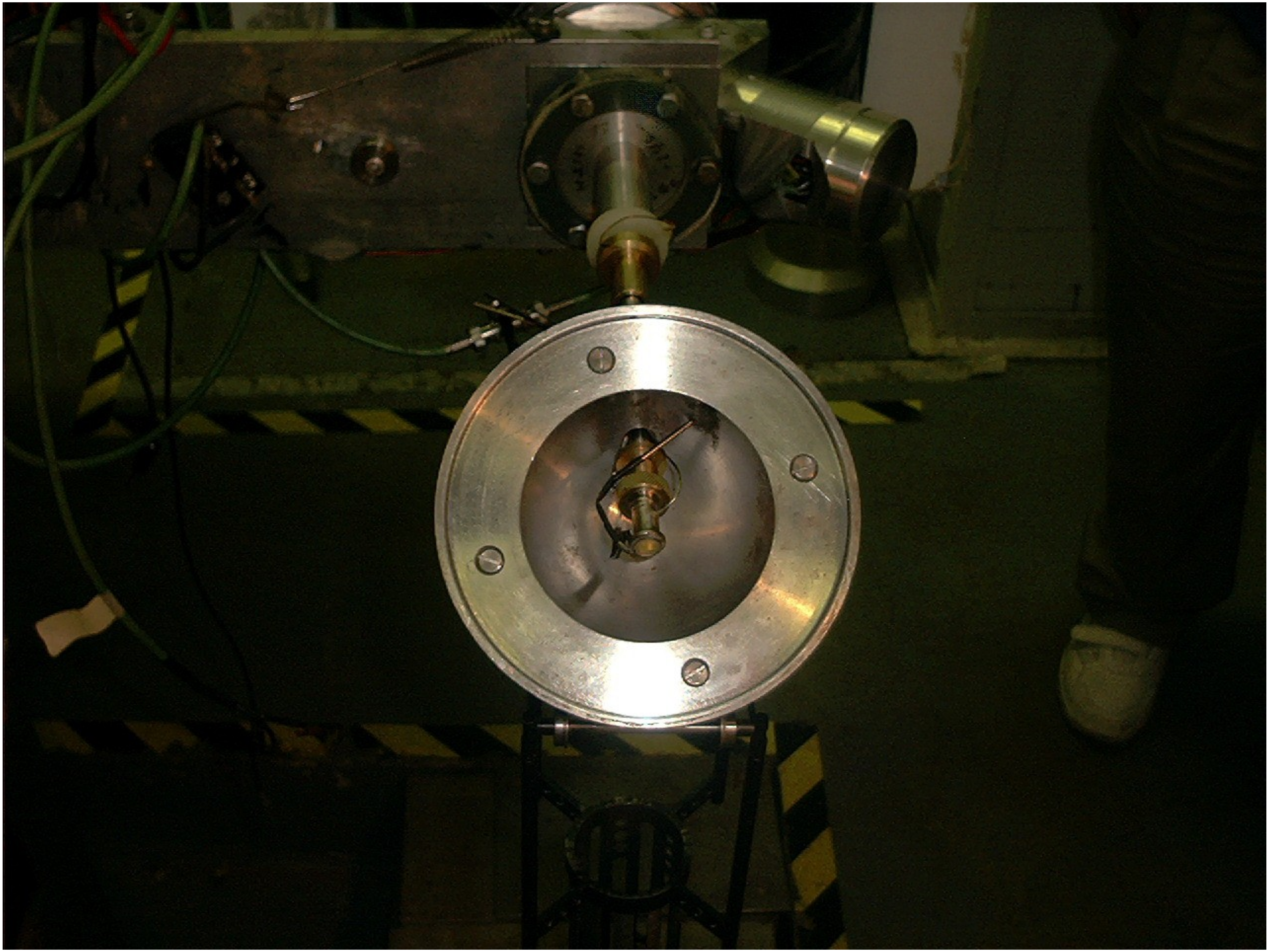
- Now get
- $\sigma_{abs} = \sigma_{total} - h\sigma_{elastic}^{optical}$
- This value is lower than σ_{abs} from ENDFB/VII by approximately 10% for $6 \leq E_n \leq 10$ MeV.

^{56}Fe: Fast Range - BNL and collaborators….

Many issues to work, as a new high energy evaluation is developed

Jing Qian: Conclusions from Ohio experiment on inelastic problematic?





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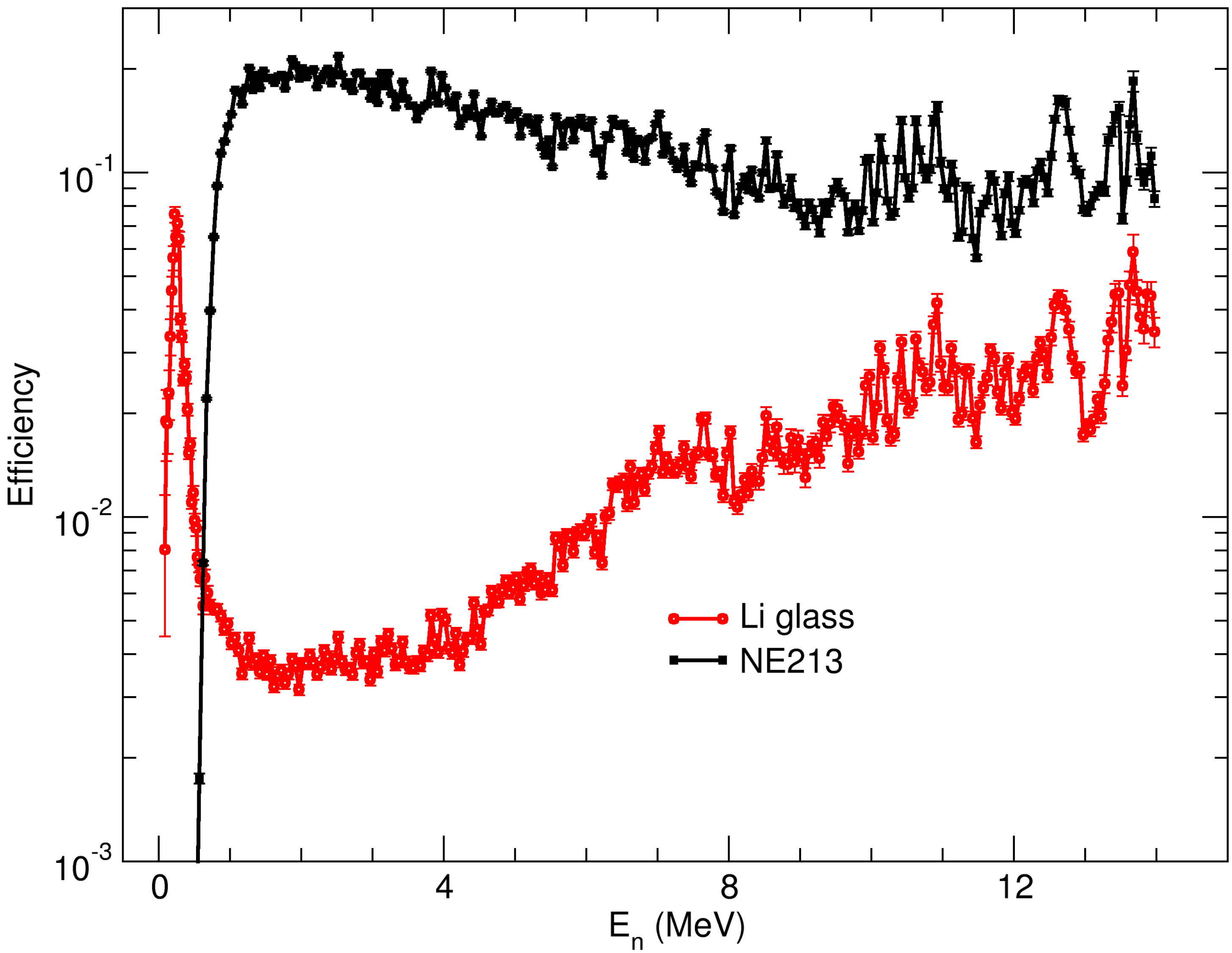
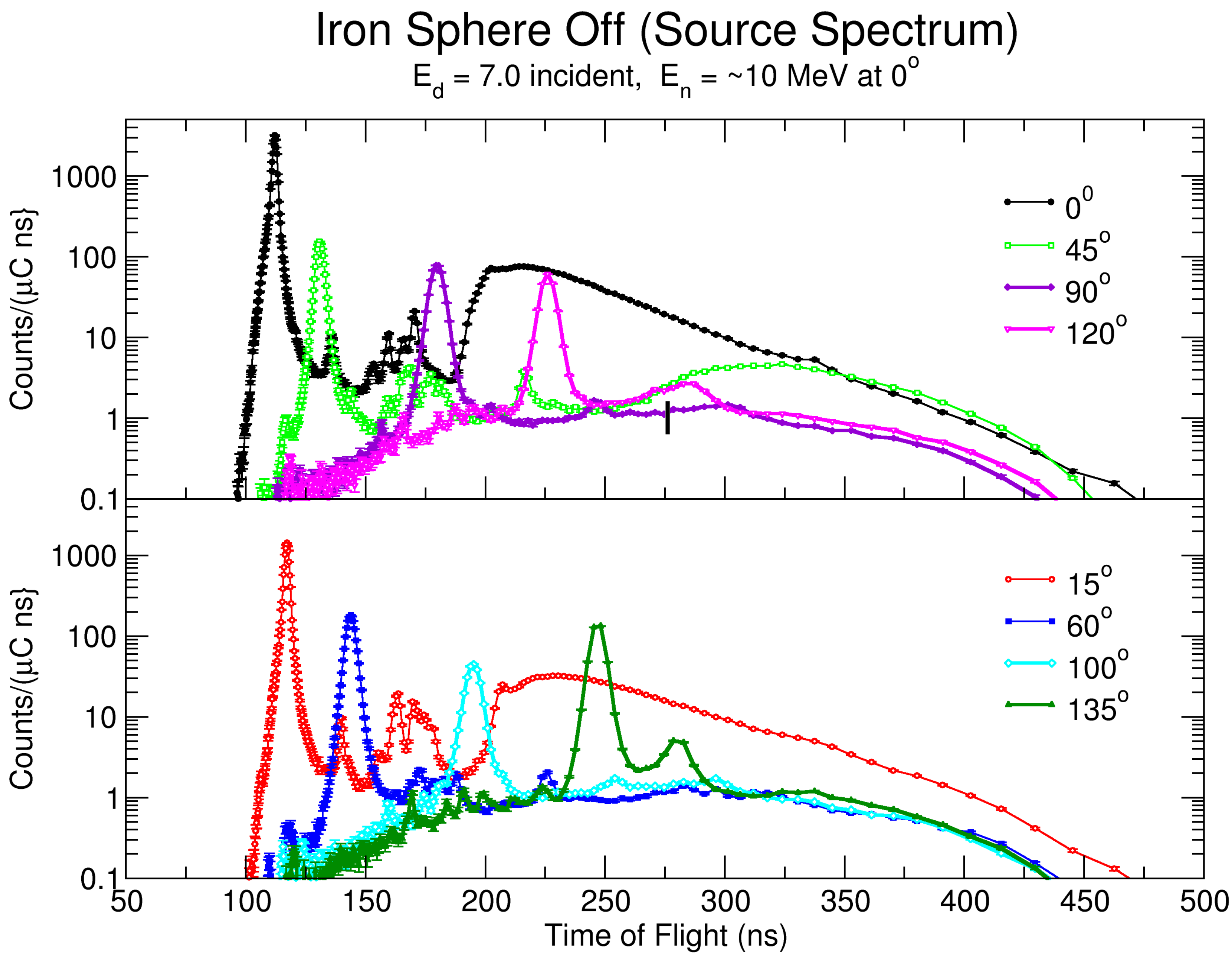
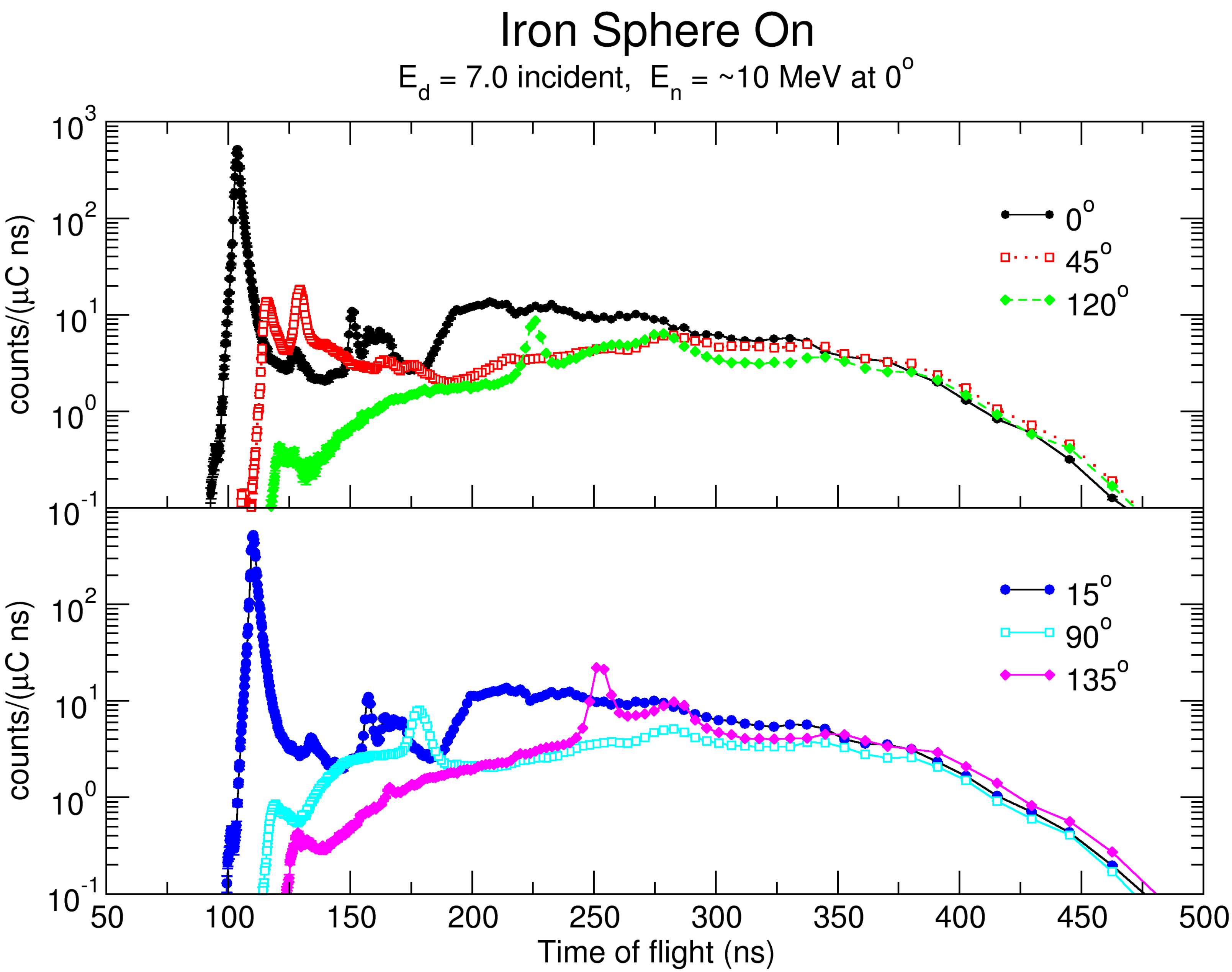




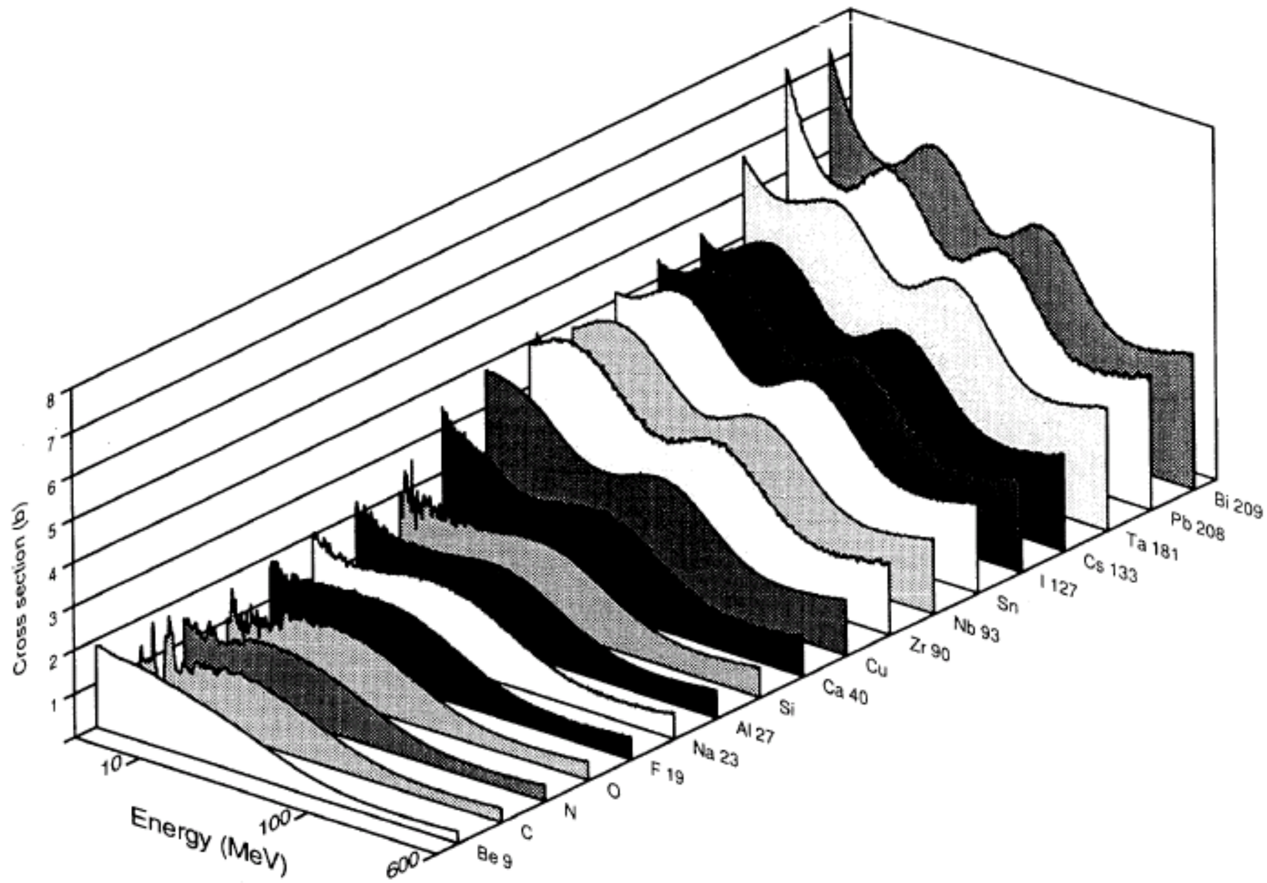
Iron Sphere Off (Source Spectrum)
E_d = 7.0 incident, E_n = ~10 MeV at 0^o
Counts/(μC ns}
0°
45°
90°
120°
15°
60°
100°
135°
Time of Flight (ns)



Iron Sphere On
E_d = 7.0 incident, E_n = ~10 MeV at 0°
counts/(μC ns)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
0°
45°
120°
15°
90°
135°
50
100
150
200
250
300
350
400
450
500
Time of flight (ns)

- High accuracy total cross section measurements.

R. W. Finlay et al., PRC **47, 237(1993)**



Total Cross Sections at WNR