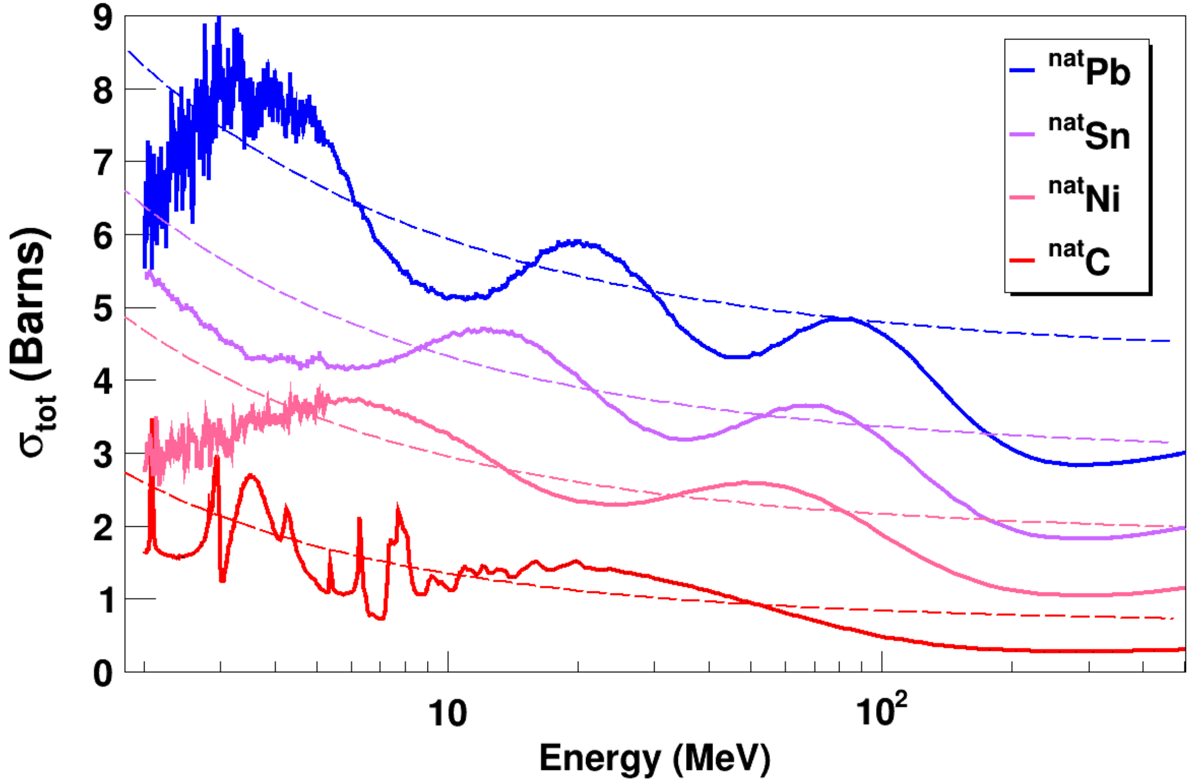
Using Neutron σ_{tot}(E) to Constrain the Asymmetry Dependence of Optical Potentials



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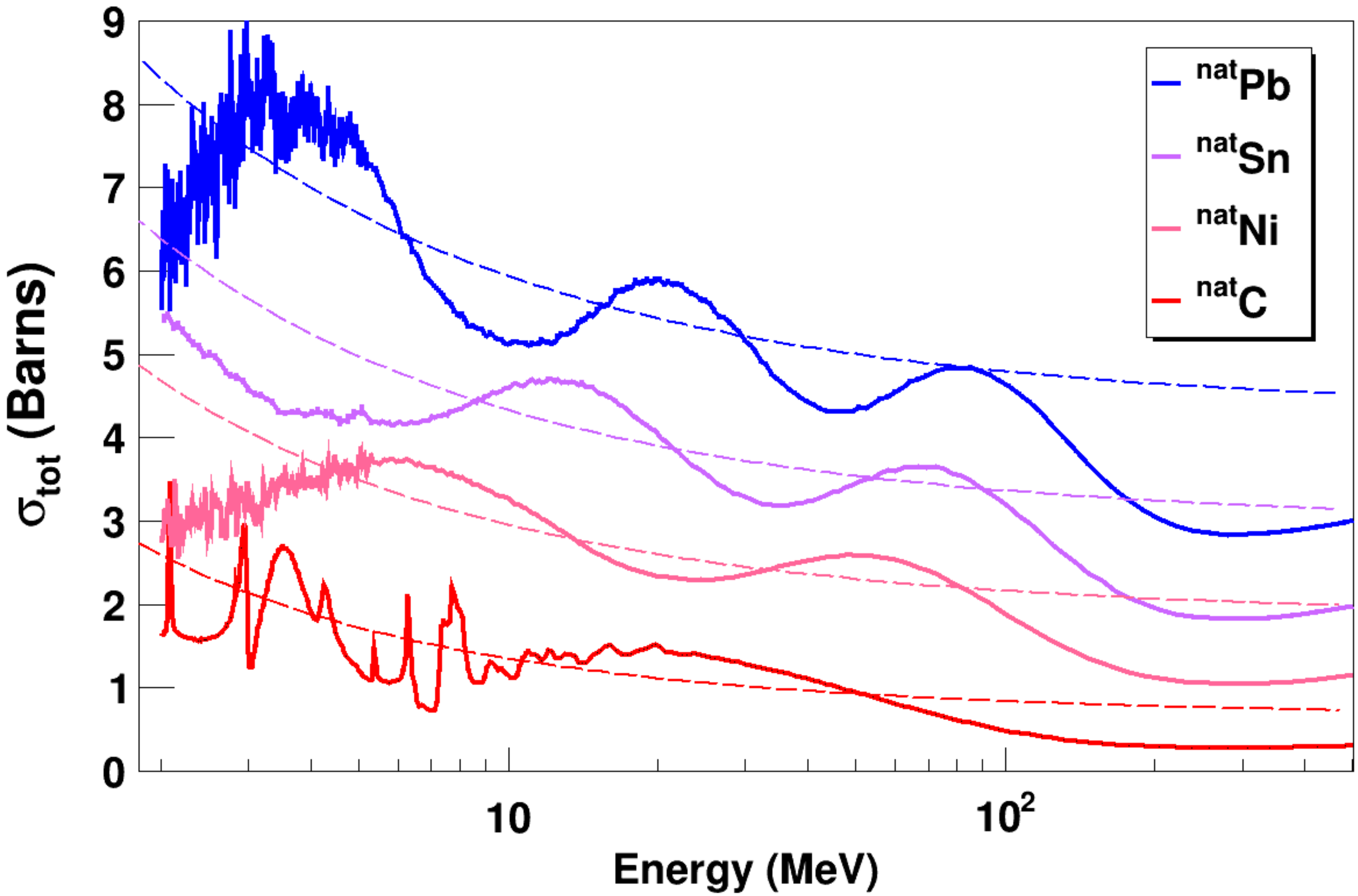
PhD candidate in Chemistry
Washington University in St Louis

Outline

The state of neutron σ_{tot} data

σ_{tot} experimental results:
$^{16,18}O$, $^{58,64}Ni$, $^{112,124}Sn$

DOM improvement and fit status:
$^{16,18}O$



$$\sigma_{tot}(E) = 2\pi(R + \lambda\!\!\!^{-})^2 [1 - \rho \cos(\delta)]$$

"SAS"

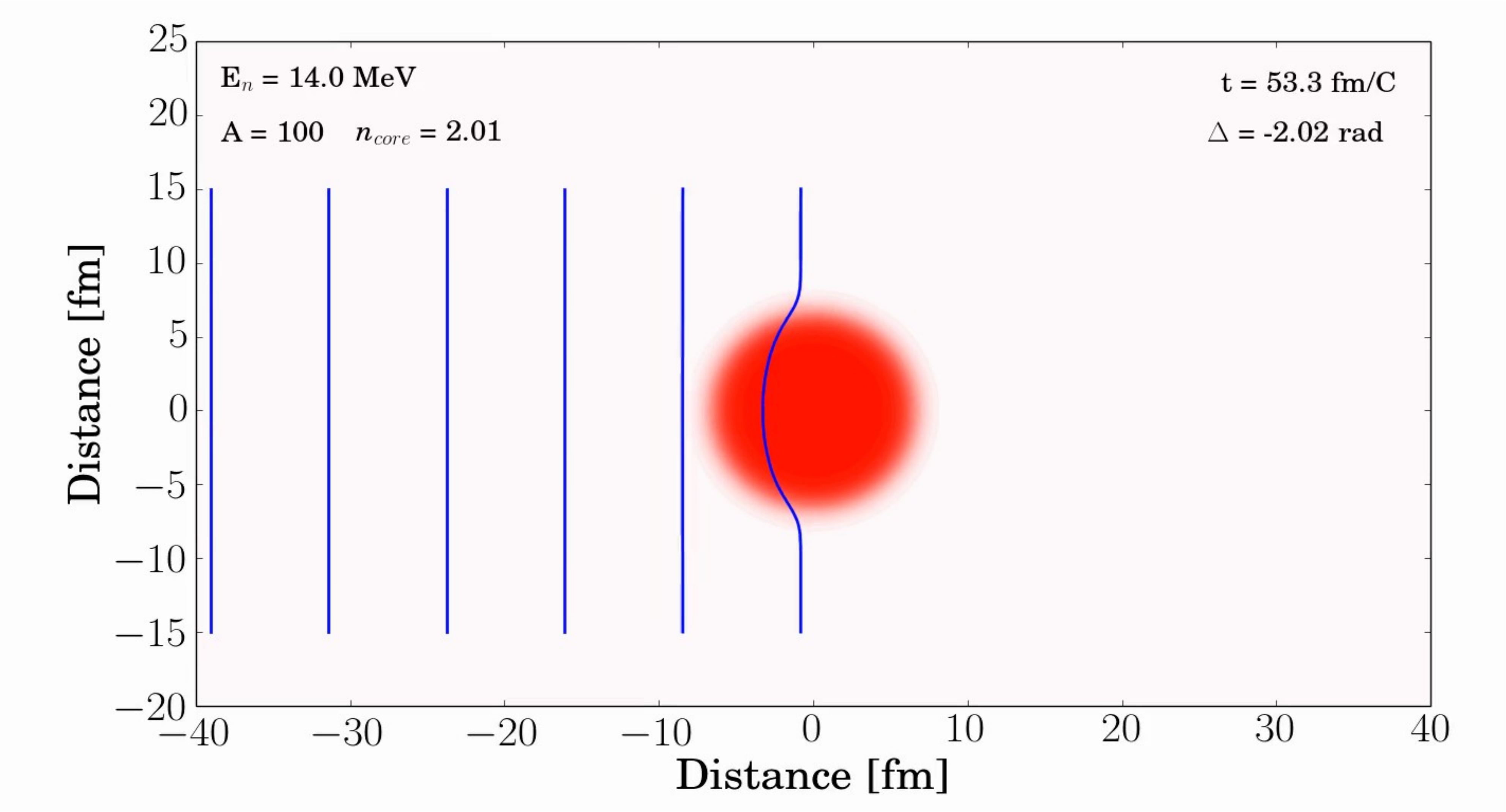
$r_0 A^{1/3}$ $E^{-1/2}$

$e^{-Im(\mathbf{\Delta})}$ $Re(\mathbf{\Delta})$

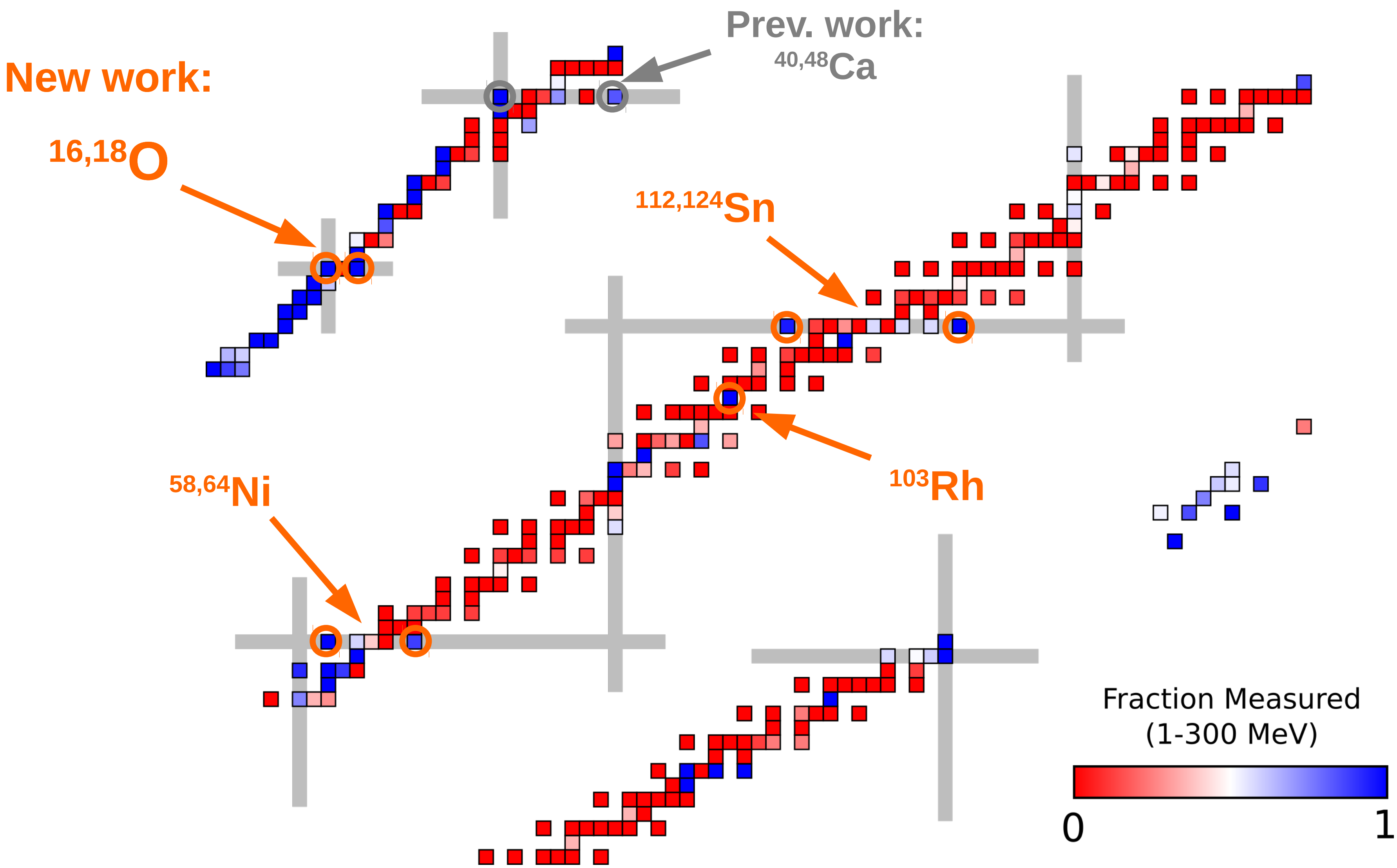
"Nuclear Ramsauer Effect"

Angeli and Csikai, *Nucl. Phys. A* **158**, 389 (1970)

σ_{tot} oscillations: “nuclear Ramsauer effect”



Intermediate-energy $\sigma_{tot}(E)$



Takeaway: tons of missing σ_{tot} data, especially isotopically resolved!

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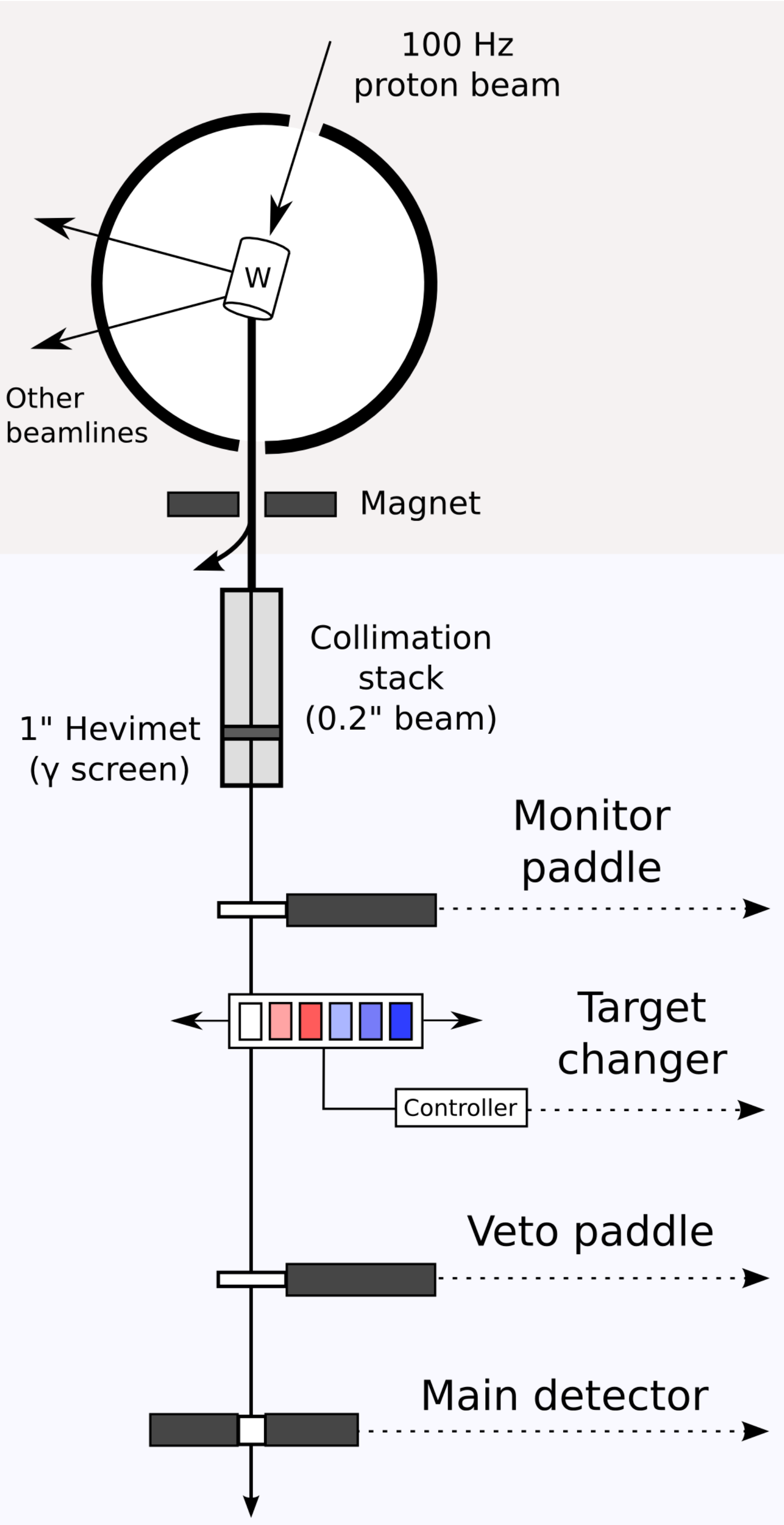


Measuring σ_{tot} for isotopically-enriched targets

Targets:

$^{16,18}O$ (as H_2O), $^{58,64}Ni$, ^{103}Rh, $^{112,124}Sn$

Goal:

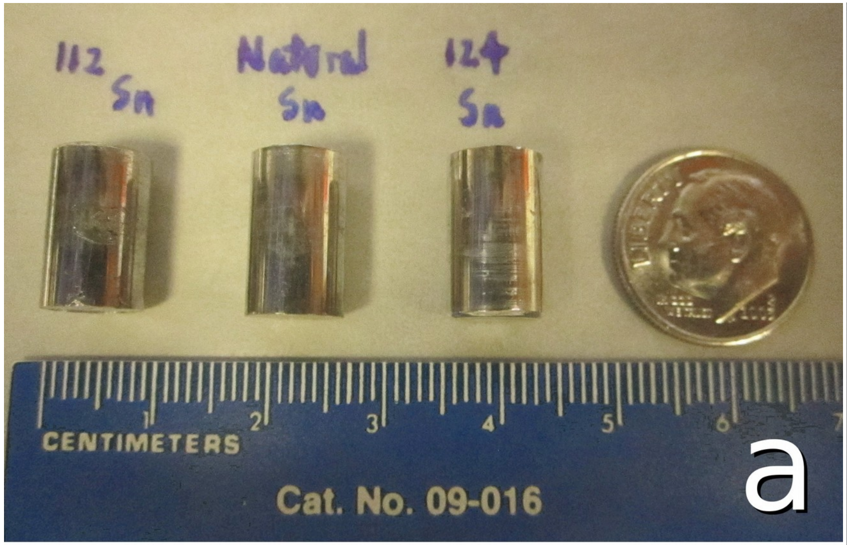
To achieve 1% statistical accuracy for a 1% difference between isotopes

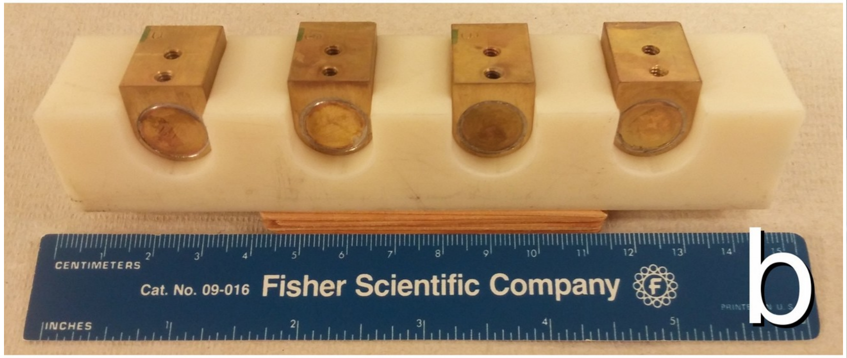
Time:

50+ hours beam per target

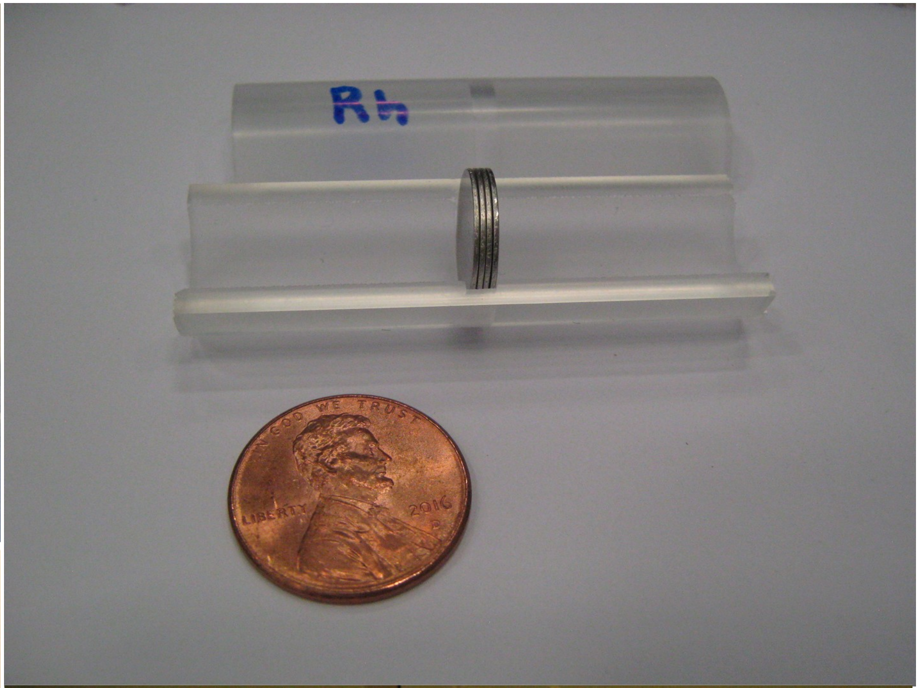
x 10^4 neutrons/sec =

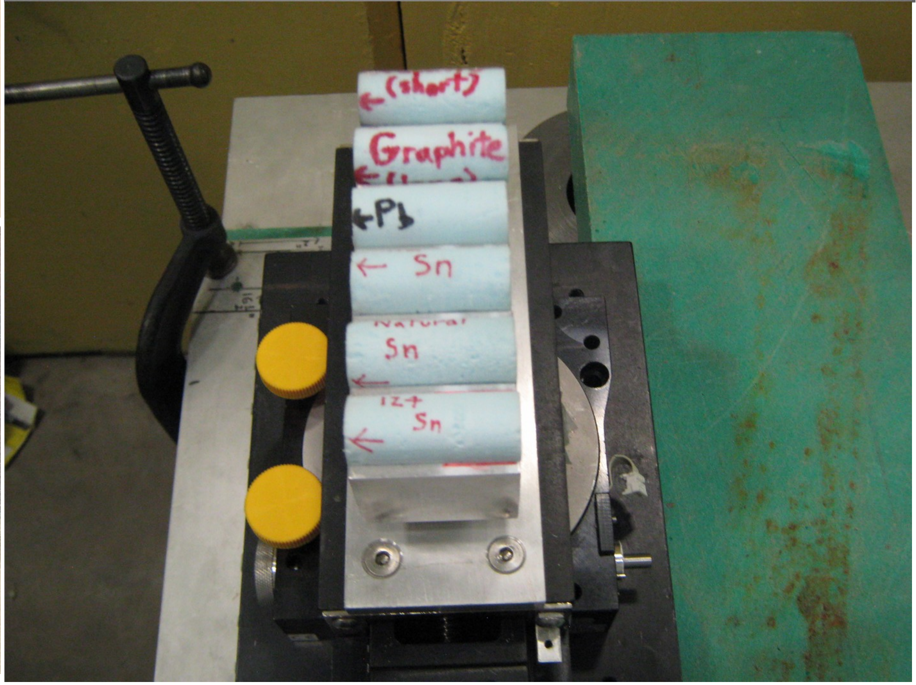
~10^9 neutrons per target

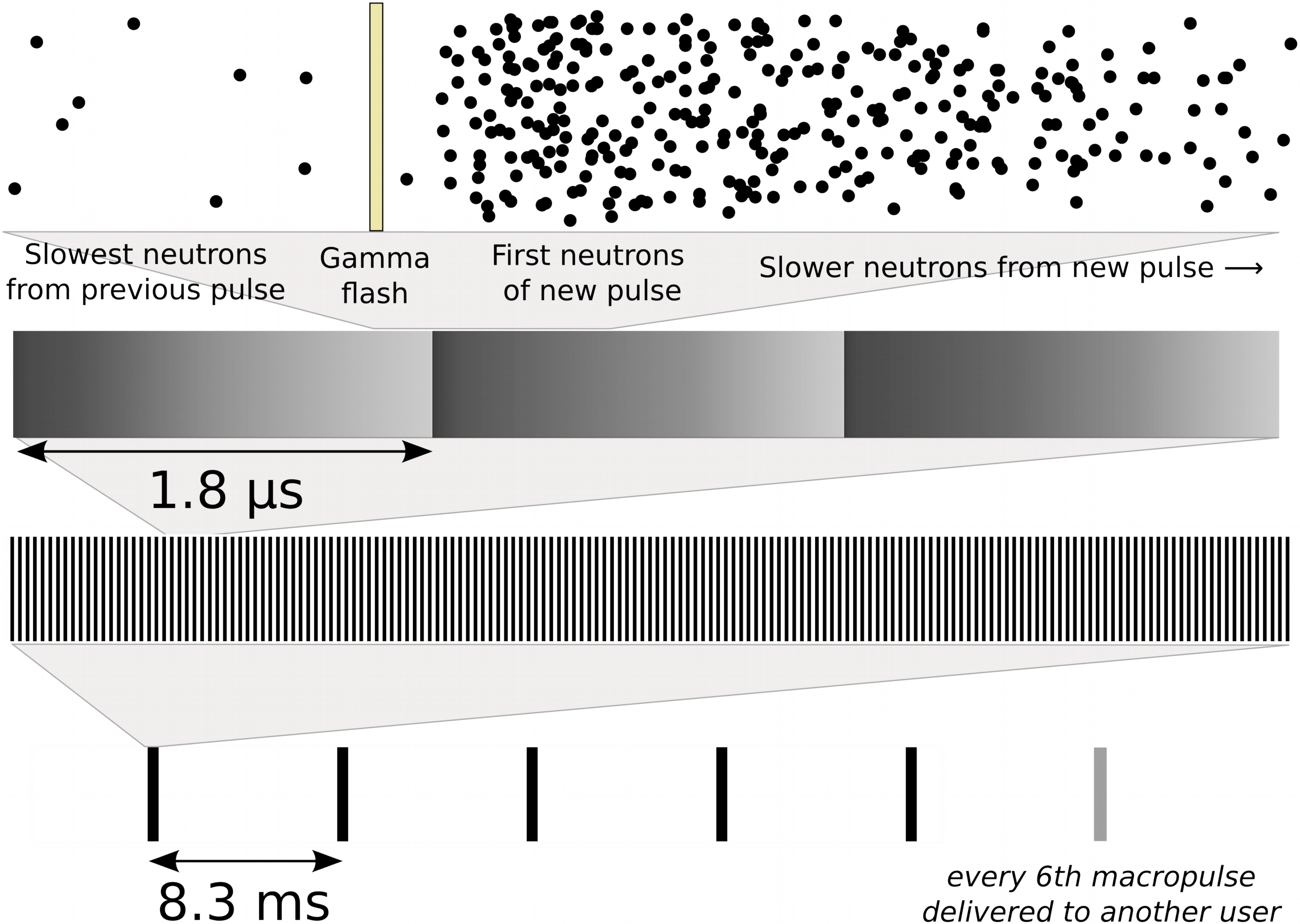

112 Sn
Natural Sn
124 Sn
CENTIMETERS
Cat. No. 09-016
a

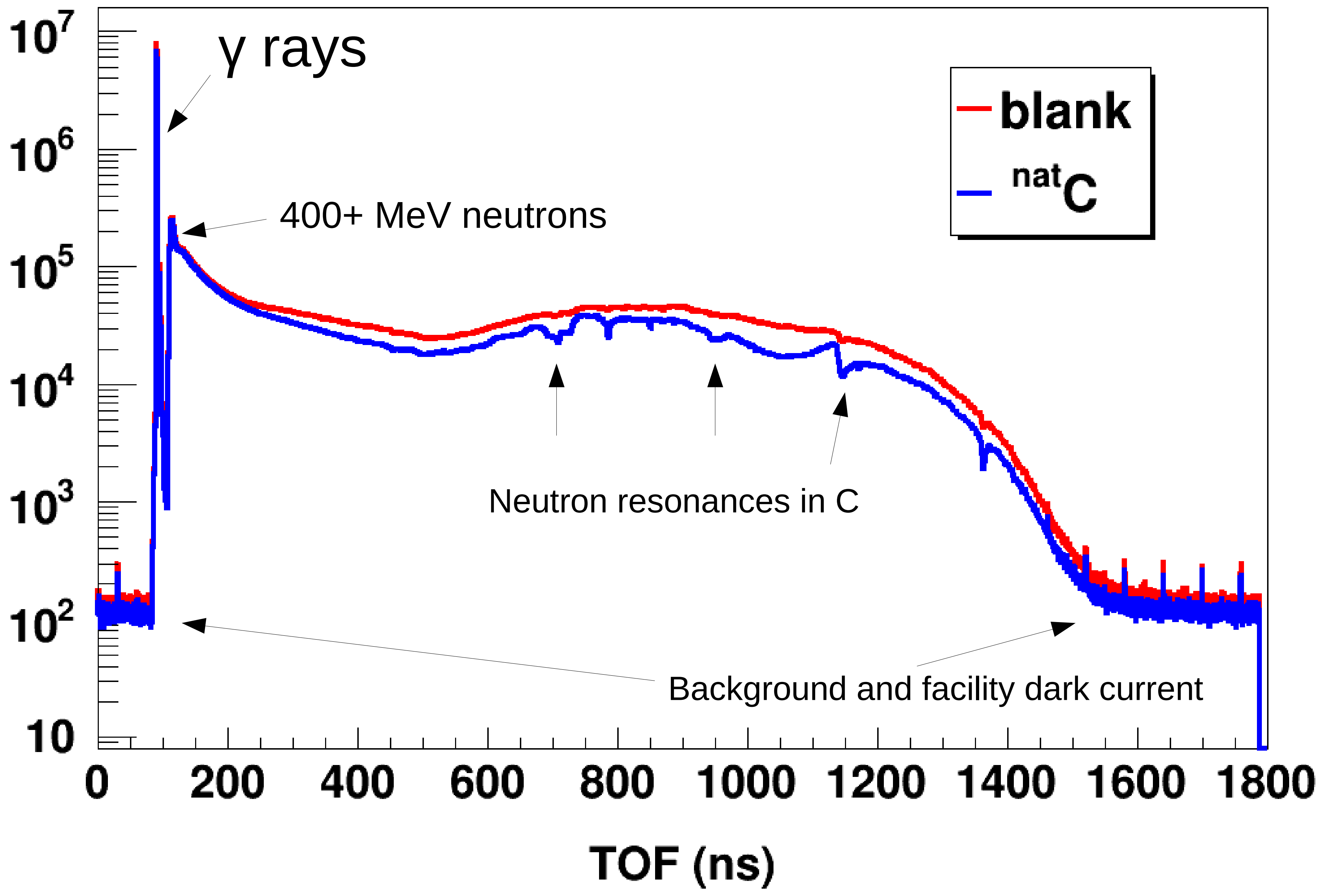

CENTIMETERS
Cat. No. 09-016
Fisher Scientific Company
INCHES
b


Ni-64
3994.2mg
Ni-58
3643.8mg
Nat. Ni
3689.8mg
c


Rh

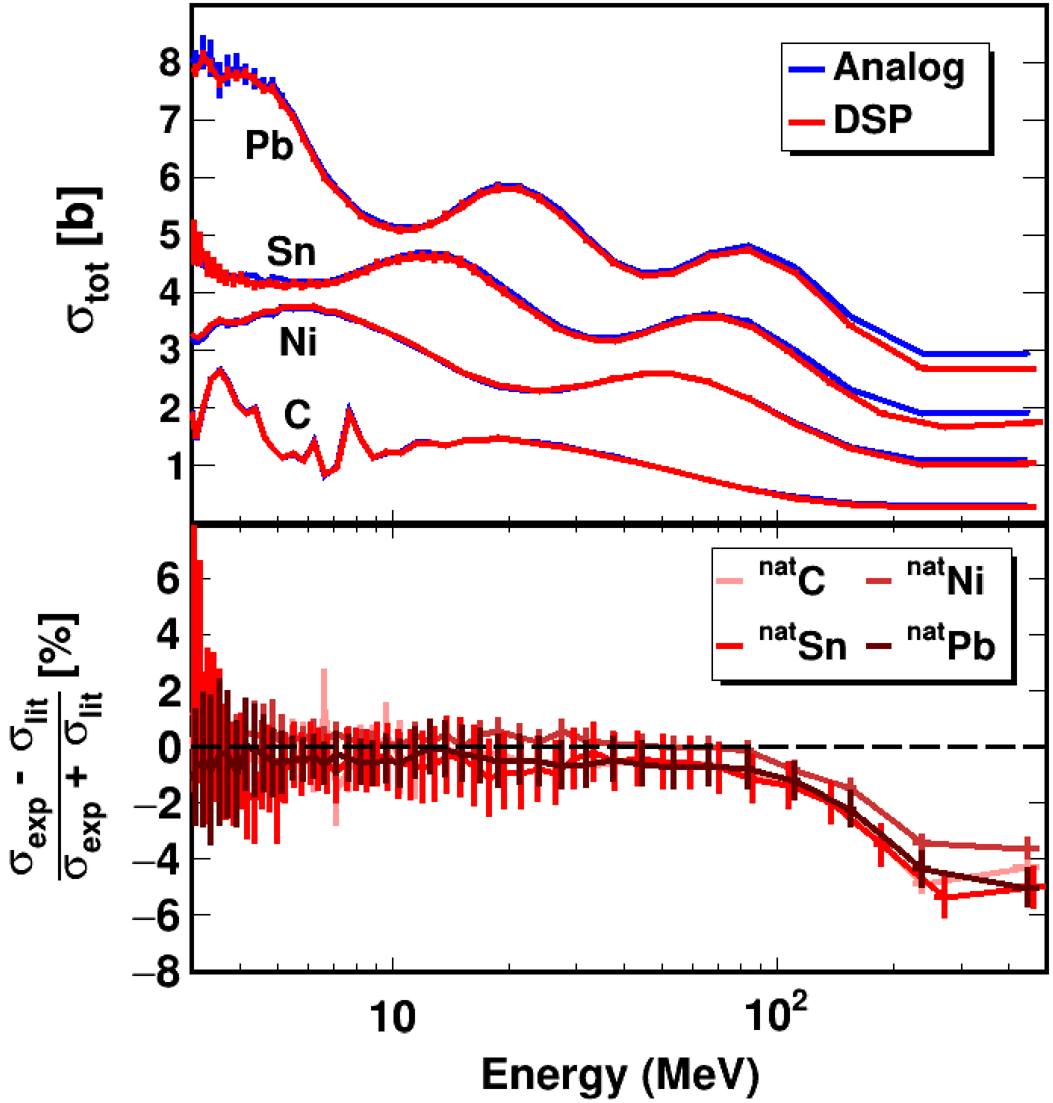

(short)
Graphite
Pb
Sn
Sn
124
Sn


Slowest neutrons
from previous pulse
Gamma
flash
First neutrons
of new pulse
Slower neutrons from new pulse ⟶
1.8 μs
8.3 ms
every 6th macropulse
delivered to another user



γ rays
400+ MeV neutrons
blank
natC
Neutron resonances in C
Background and facility dark current
10
10^2
10^3
10^4
10^5
10^6
10^7
0
200
400
600
800
1000
1200
1400
1600
1800
TOF (ns)

Benchmarking: literature results on natural samples



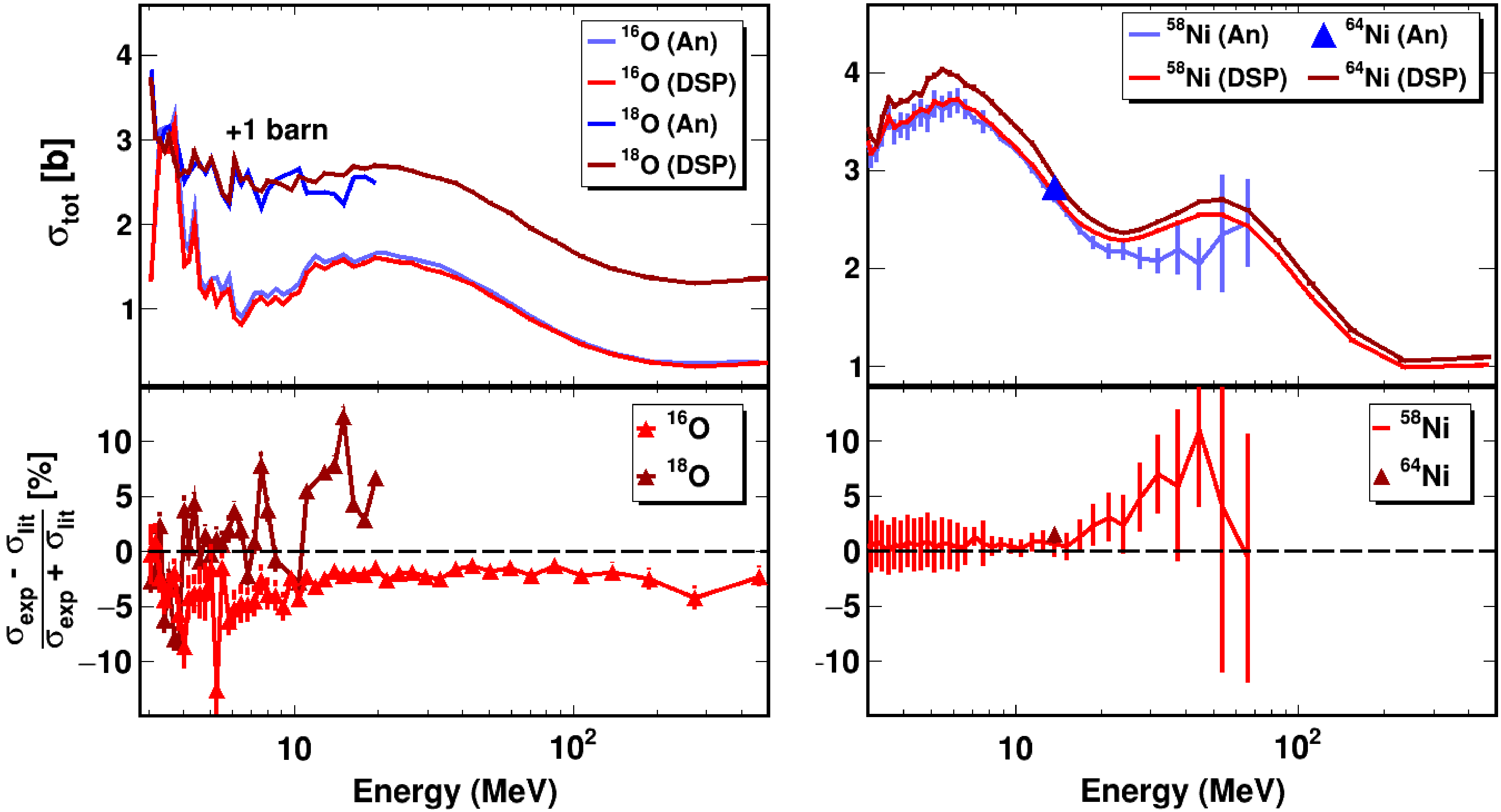
→ *Analog and DSP methods give identical results up to 100 MeV* (within statistical errors)

→ Above, 100 MeV, systematic difference of up to 10%

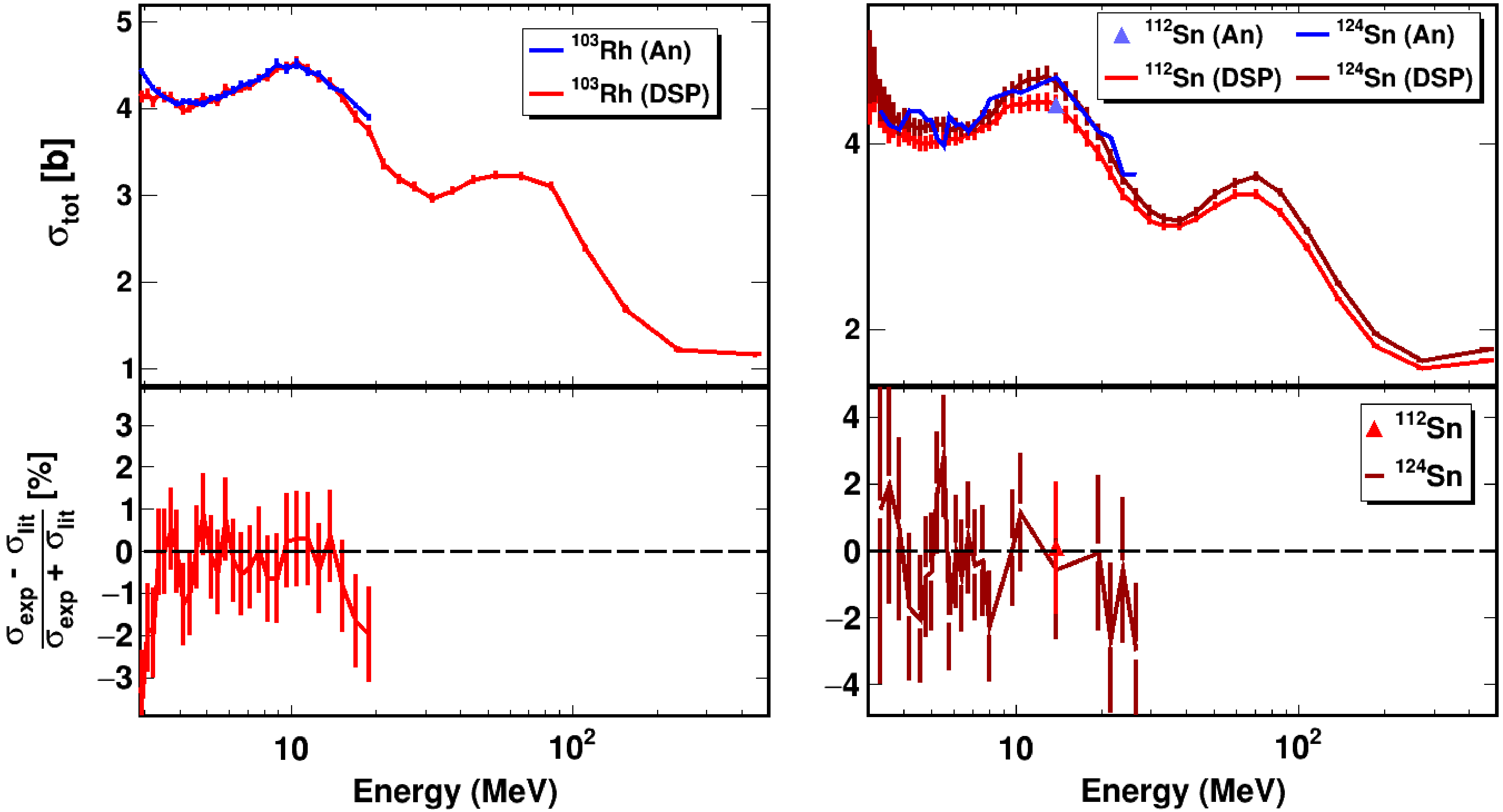
Isotopic relative differences are insensitive to systematic results

For relative differences, achieved ± 1% error over 50 energy bins from 3 to 500 MeV

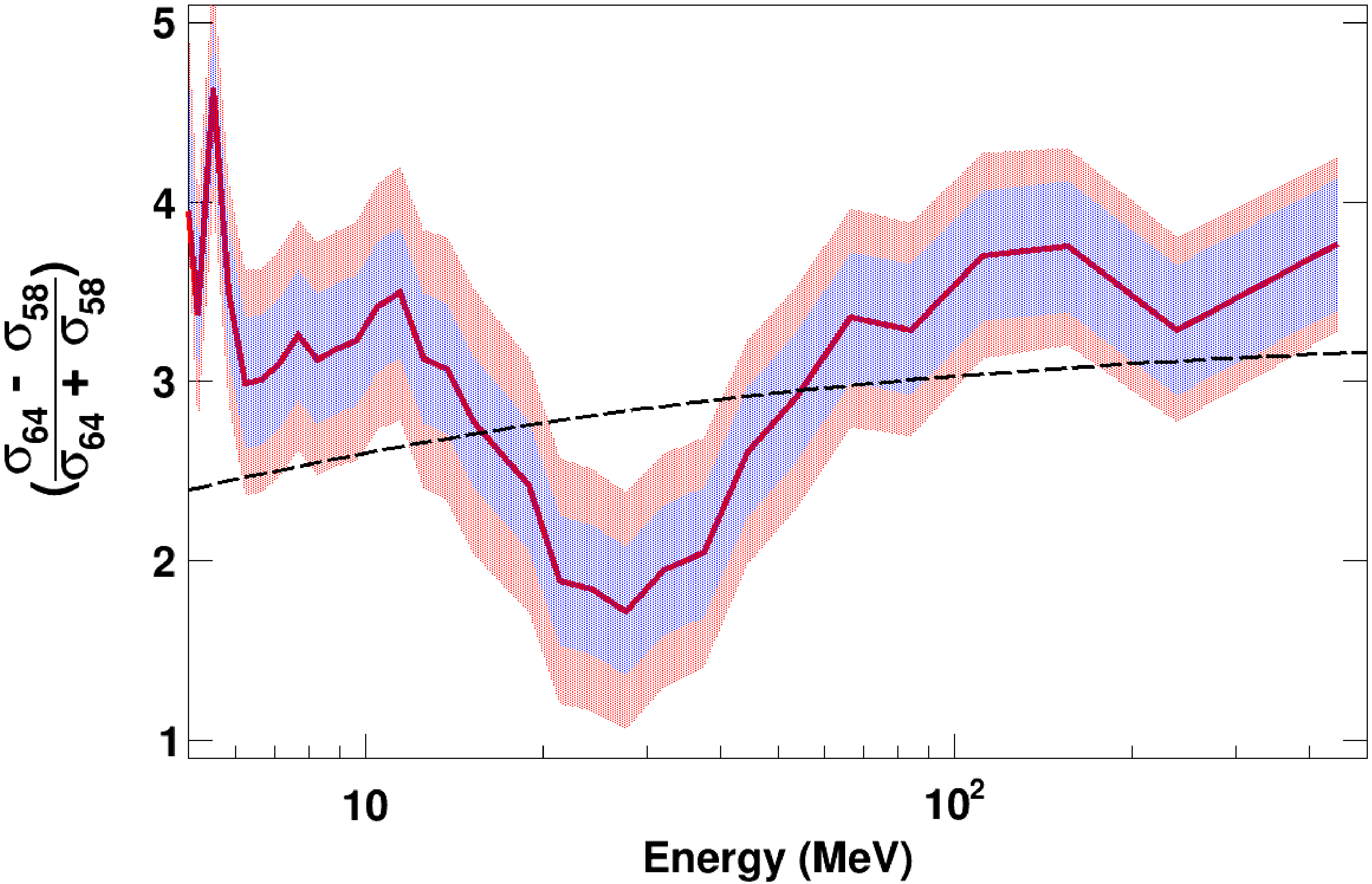
$^{16,18}O$ and $^{58,64}Ni$



^{103}Rh and ^{112,124}Sn



^{58,64}Ni relative difference



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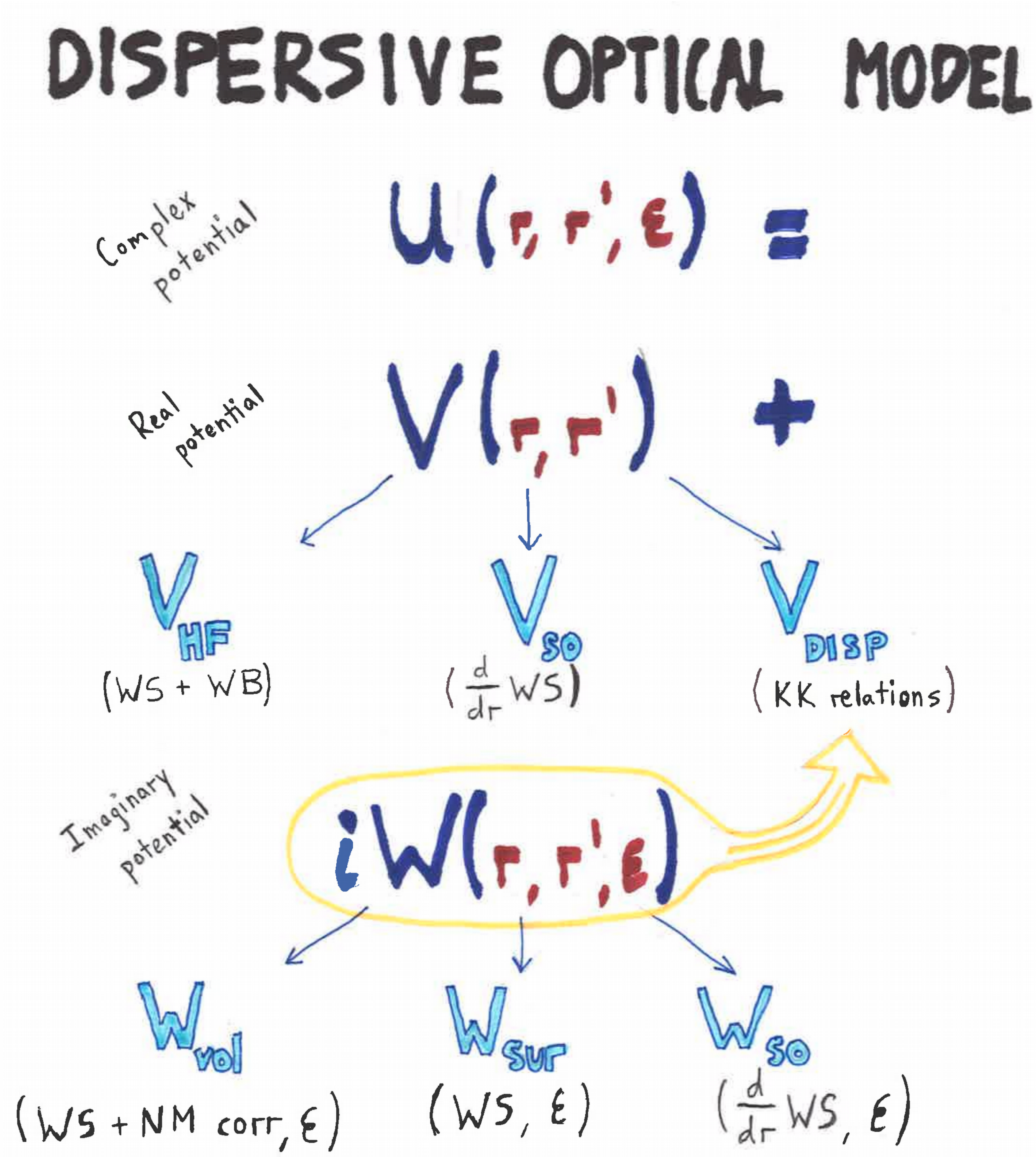
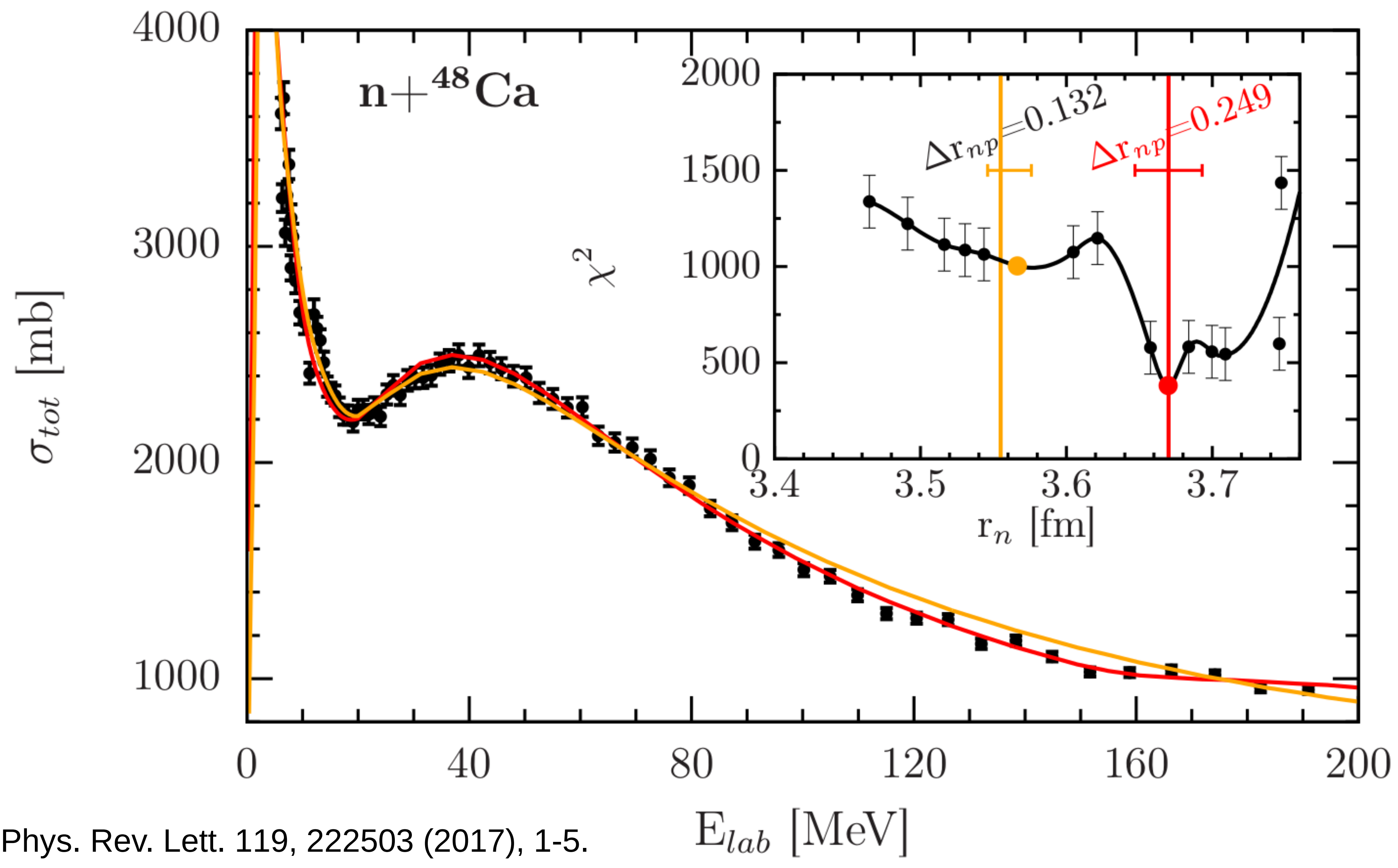
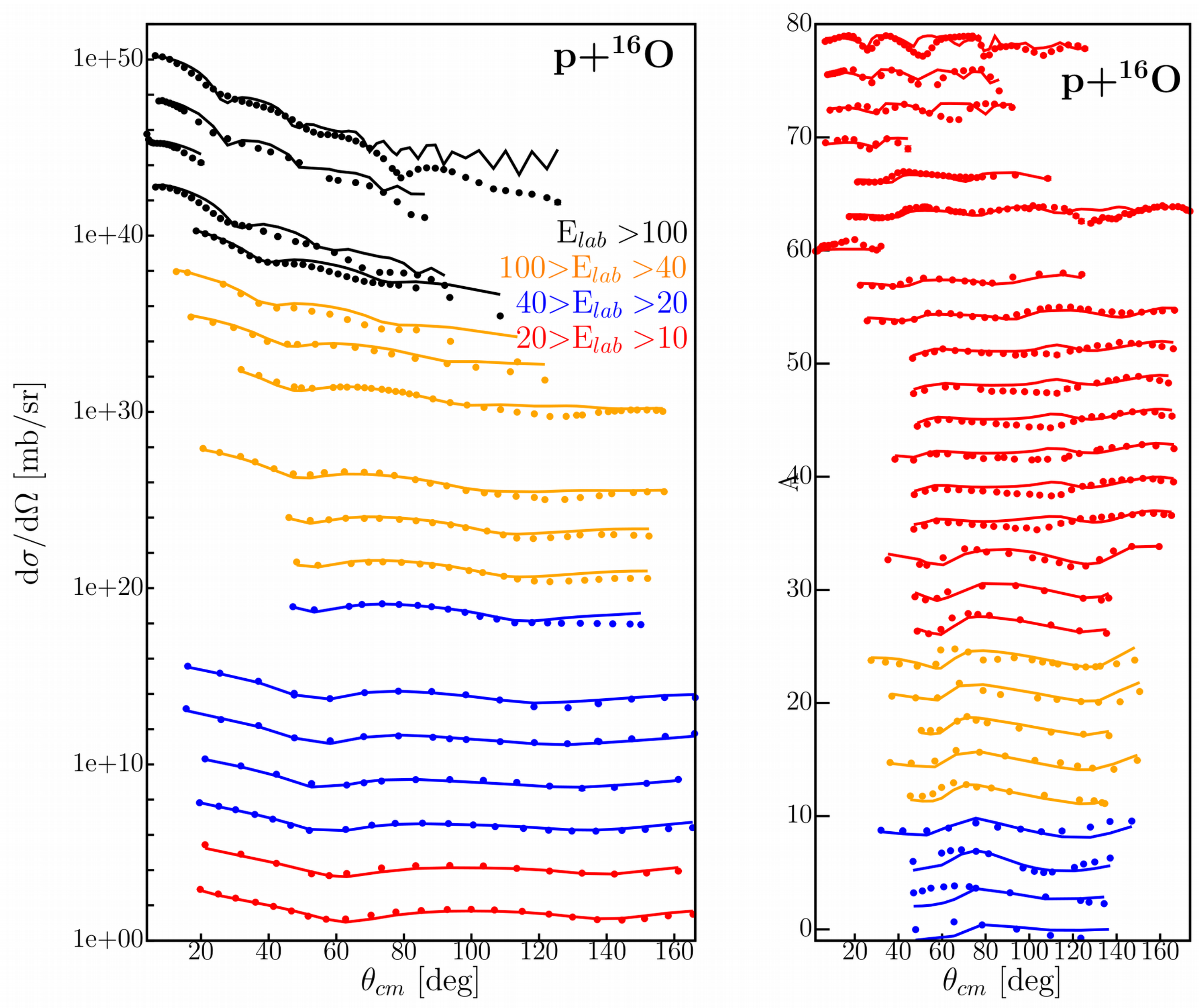

DISPERSIVE OPTICAL MODEL
Complex potential
U(r, r'; ε) =
Real potential
V(r, r') +
V_HF
(WS + WB)
V_SO
(d/dr WS)
V_DISP
(KK relations)
Imaginary potential
iW(r, r'; ε)
W_vol
(WS + NM corr, ε)
W_sur
(WS, ε)
W_SO
(d/dr WS, ε)

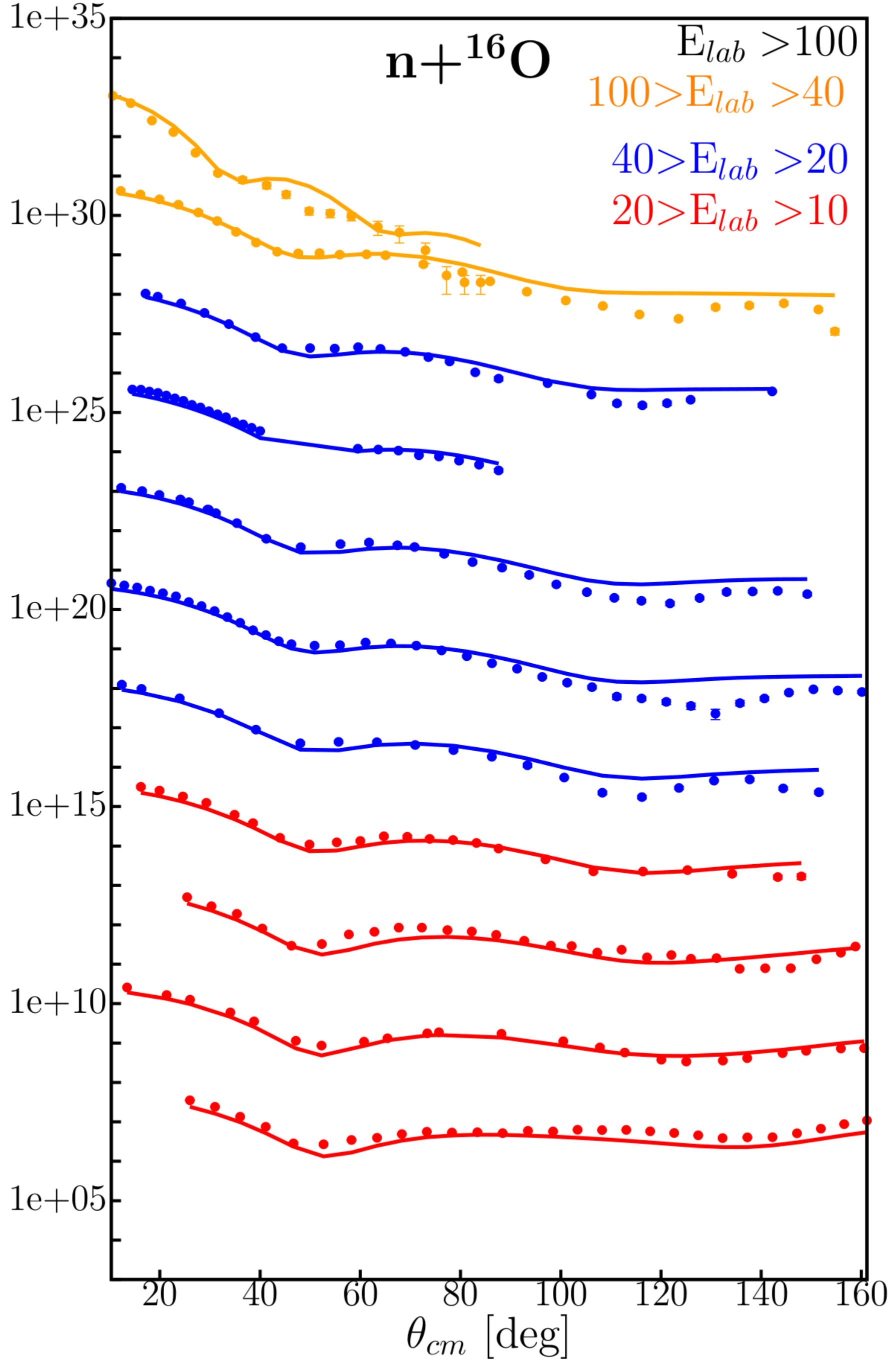
DOM fits: ^{48}Ca neutron skin sensitive to σ_{tot}



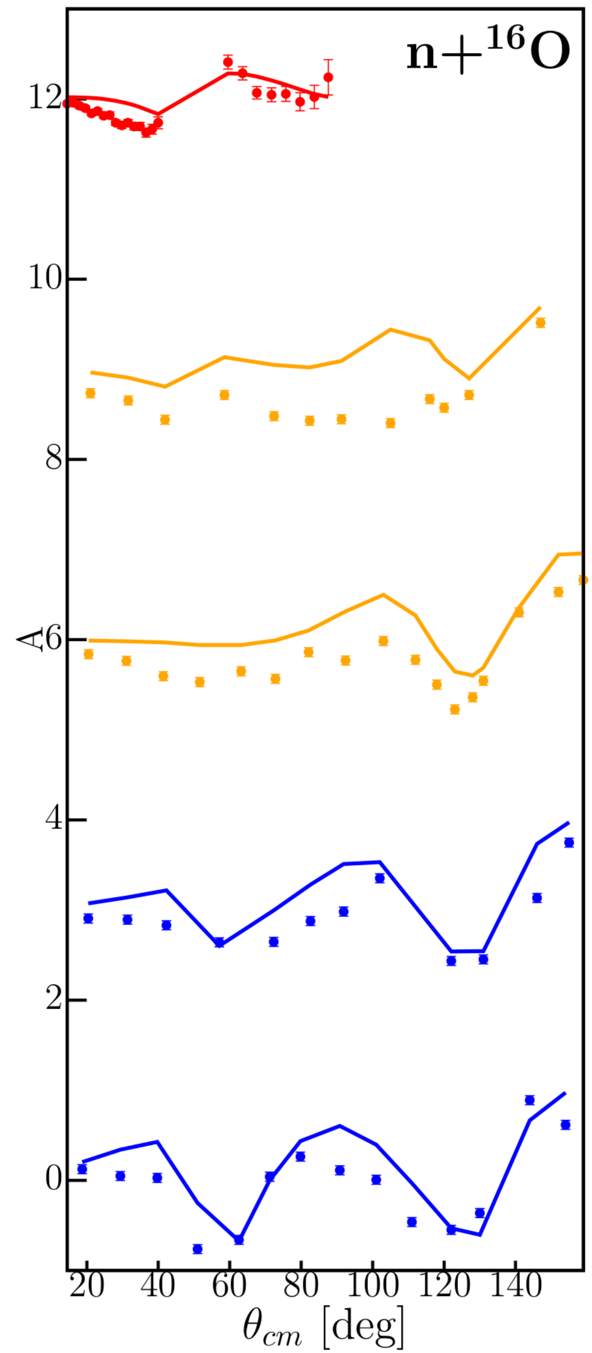
Phys. Rev. Lett. 119, 222503 (2017), 1-5.

Current (preliminary) ^{16}O fit results

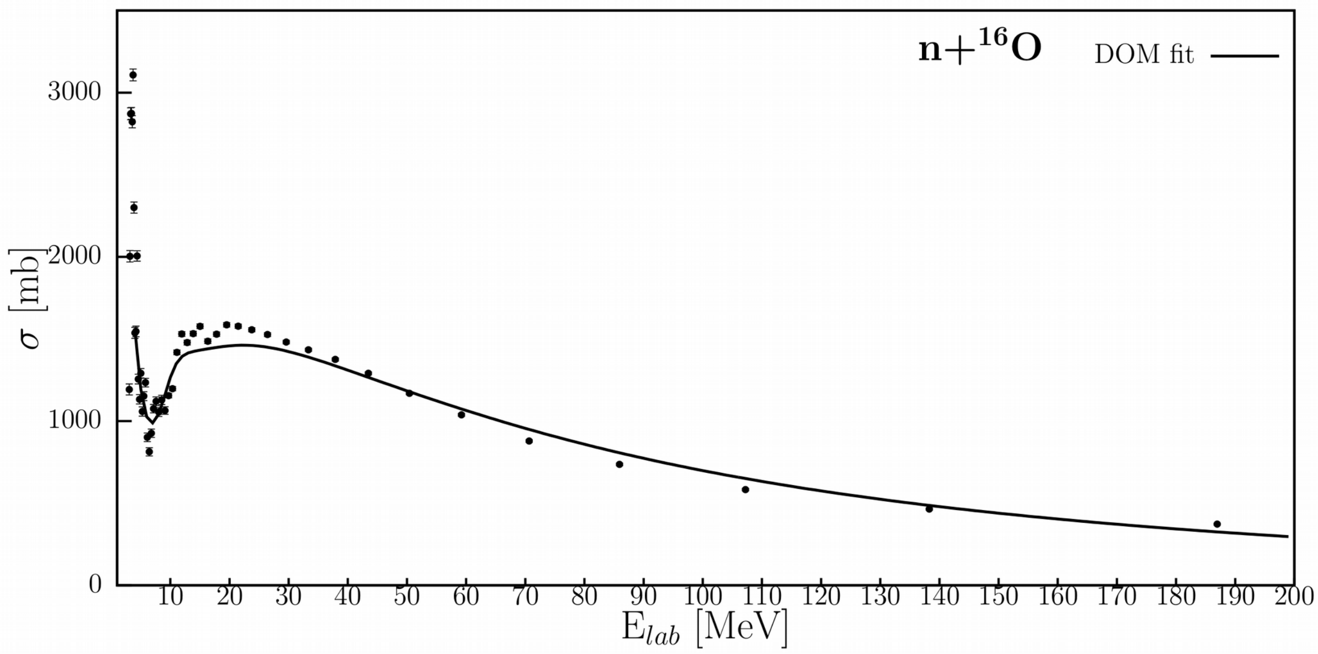


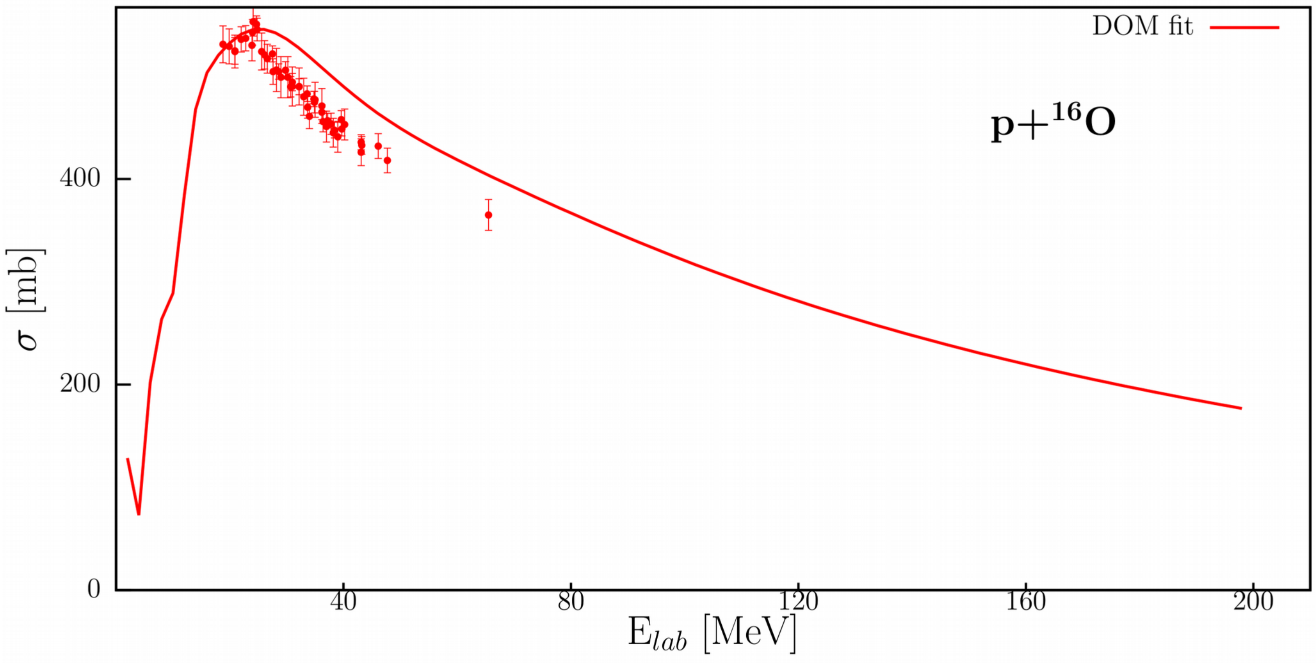


n+^{16}O
E$_{lab}$ >100
100>E$_{lab}$ >40
40>E$_{lab}$ >20
20>E$_{lab}$ >10
1e+35
1e+30
1e+25
1e+20
1e+15
1e+10
1e+05
20 40 60 80 100 120 140 160
θ_{cm} [deg]



n+^{16}O
A
12
10
8
6
4
2
0
20 40 60 80 100 120 140
θ_{cm} [deg]


n+^{16}O
DOM fit
3000
2000
1000
0
σ [mb]
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
E$_{lab}$ [MeV]


DOM fit
p+^{16}O
400
200
0
σ [mb]
40 80 120 160 200
E$_{lab}$ [MeV]

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Radiochemistry Group

Bob Charity
Lee Sobotka
Kyle Brown (GS, now PD at NSCL)
Dan Hoff (GS)
Tyler Webb (GS)

Nuclear Theory Group

Wim Dickhoff
Mack Atkinson (GS)

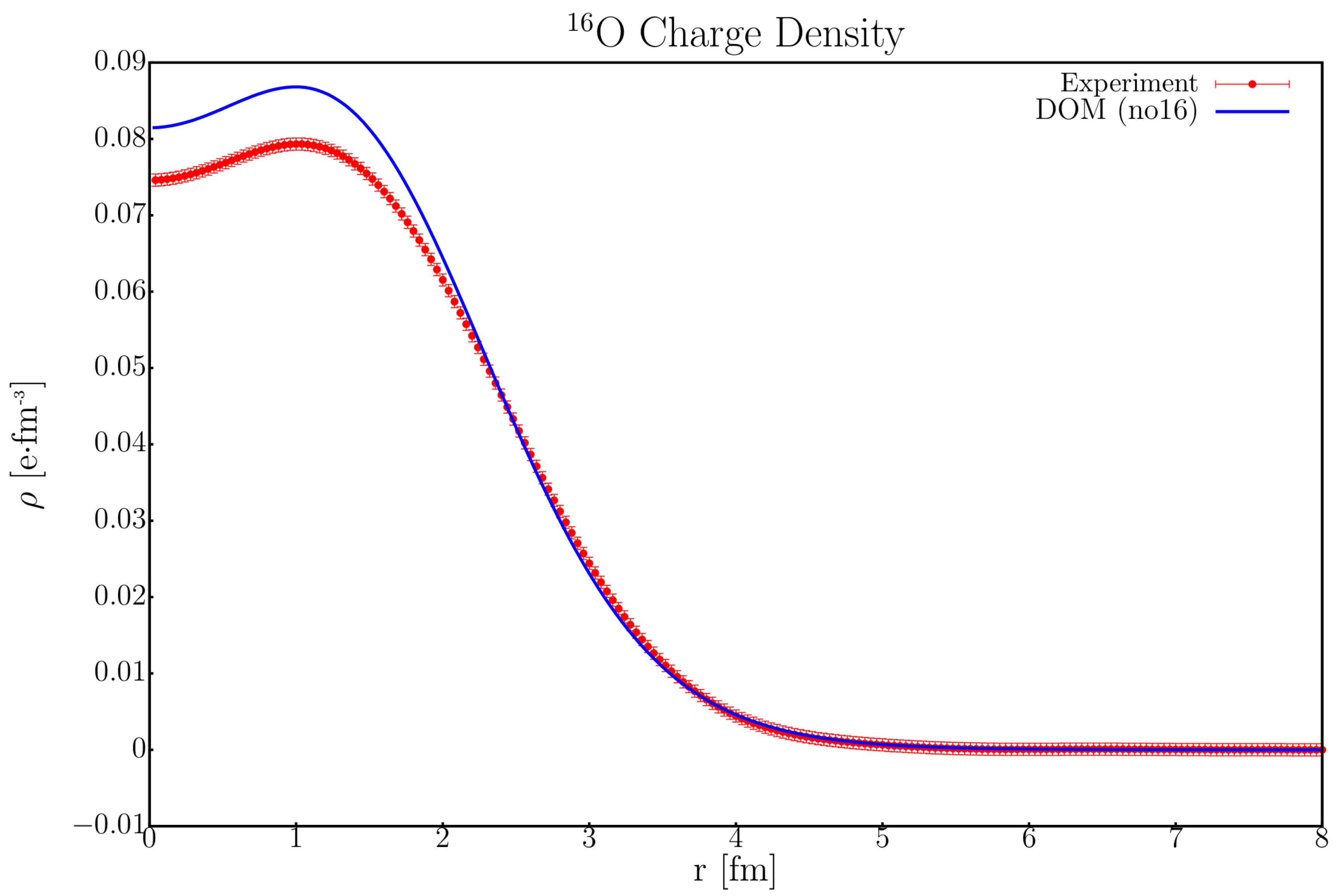
LANSCE
Los Alamos Neutron Science Center

Hye Young Lee
Matt Devlin
Shea Mosby

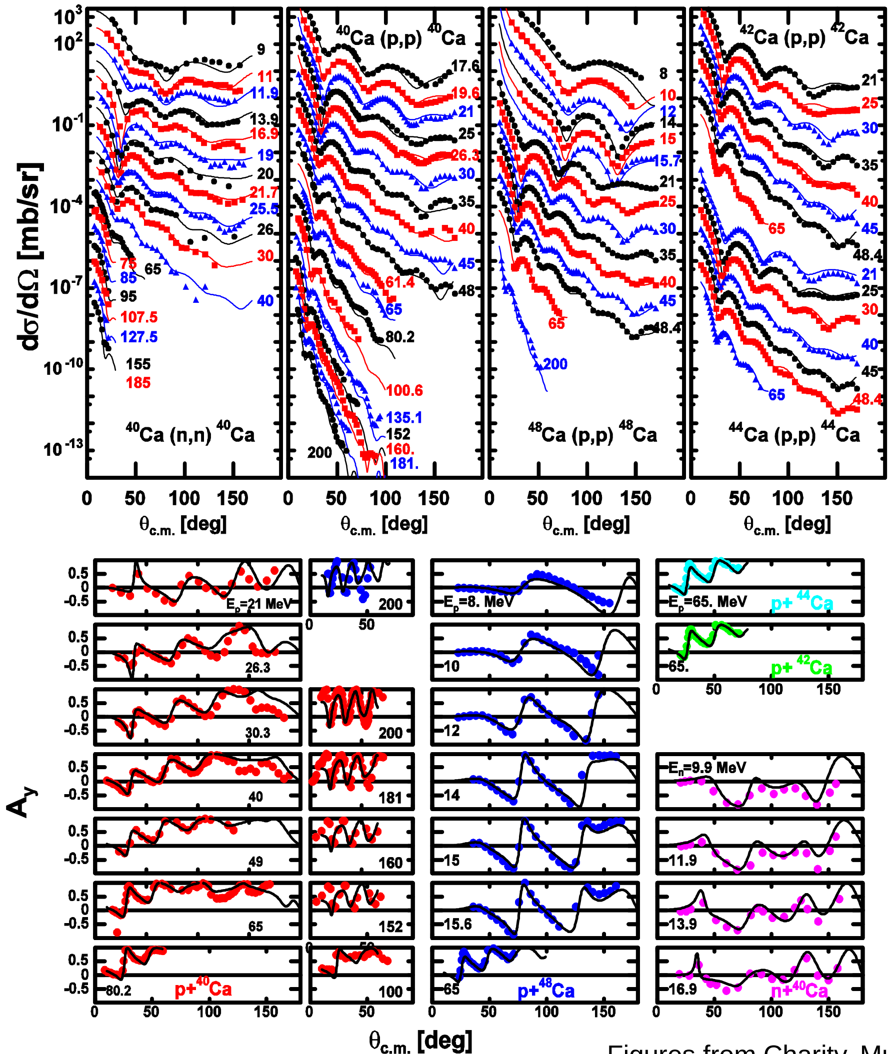
Nikolaos Fotiadis
John O'Donnell

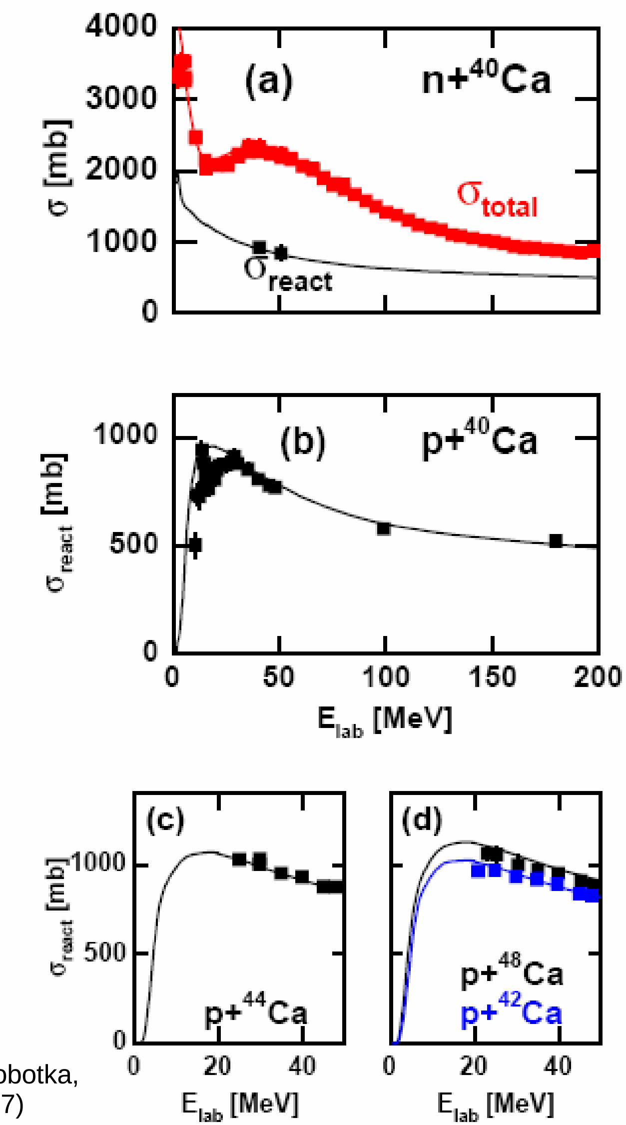
U.S. DEPARTMENT OF ENERGY | Office of Science

For additional detail:
Ramsauer logic: Angeli and Csikai, *Nucl. Phys. A* **158**, 389 (1970)
Literature σ_{tot} data: W. P. Abfalterer et al, PRC **63**, 044608 (2001), R. W. Finlay et al, PRC **47** 237 (1993)
DOM formalism: Dickhoff, Charity, and Mahzoon, J. Phys. G: Nucl. Part. Phys. **44** (2017) 033001, 1-57
^{40,48}Ca σ_{tot}(E): Shane et al, NIM Sect. A **614**, 468 (2010)


^{16}O Charge Density
Experiment
DOM (no16)
ρ [e·fm-3]
r [fm]
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−0.01
0
1
2
3
4
5
6
7
8

Optical potentials are as good as their data





Figures from Charity, Mueller, Sobotka, Dickhoff, Phys. Rev. C (2007)

Neutron star EOS $\Leftrightarrow$ $$S(\rho) \simeq S(\rho_0) - L\left(\frac{\rho_0-\rho}{3\rho_0}\right) + \frac{1}{2}K_{sym}\left(\left(\frac{\rho_0-\rho}{3\rho_0}\right)^2\right)$$

???

"The correlation between **neutron radius of ^{208}Pb and the slope of the symmetry energy L** is by now very well established..."
- F. J. Fattoyev and J. Piekarewicz, PRC 86 015802 (2012)