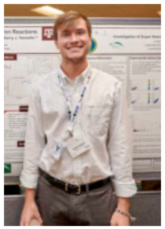
DAPPER
+
triton beams

A.B. McIntosh
Texas A&M University Cyclotron Institute

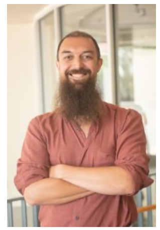
DAPPER

TEXAS A&M UNIVERSITY
Cyclotron Institute



Austin Abbott

Maxwell Sorensen



Alan McIntosh

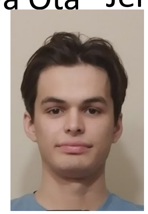
Shuya Ota

Jerome Gauthier

Kris Hagel

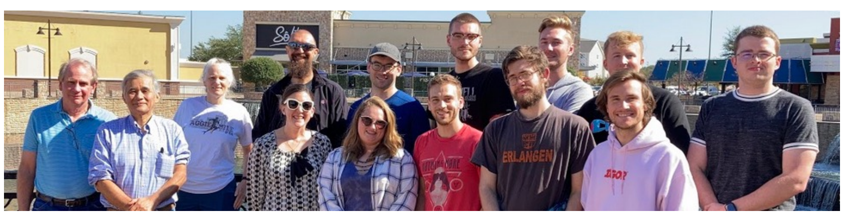
Aaron Couture

Grigory Potel
Andrea Richard



Sebastian Regener

Arthur Alvarez



Yennello Research Group

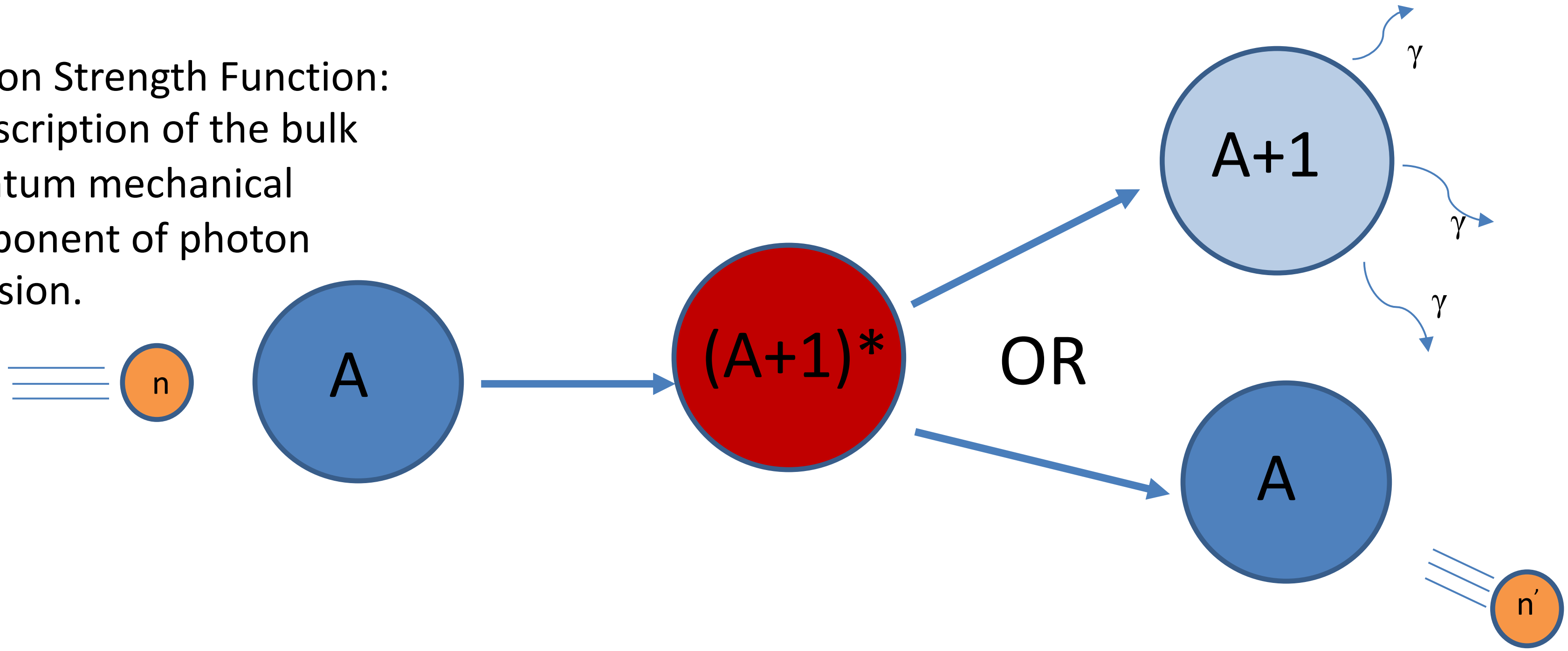
CENTER FOR EXCELLENCE
CENTAUR
IN NUCLEAR TRAINING AND UNIVERSITY-BASED RESEARCH

U.S. DEPARTMENT OF ENERGY

This research is possible thanks to the NNSA Grant #DE-NA0003841, and Department of Energy Grant #DE-FG02-93ER40773.

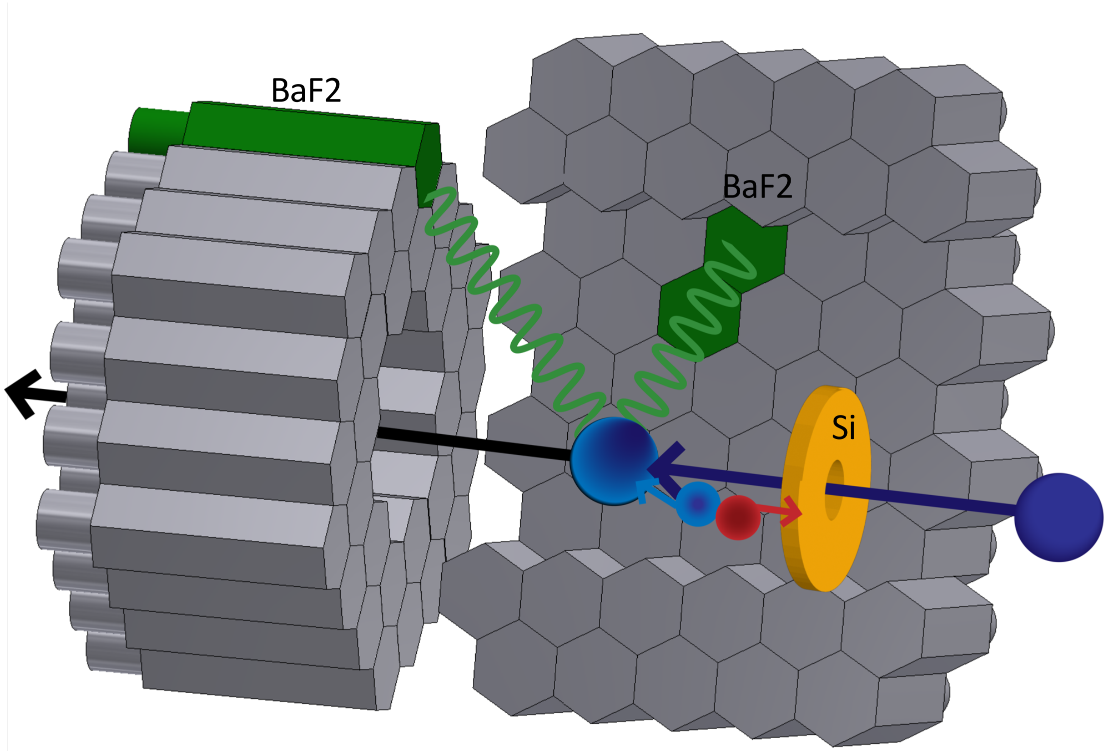
Why Photon Strength Function Matters: Radiative Neutron Capture

Photon Strength Function:
A description of the bulk quantum mechanical component of photon emission.



Stronger Photon Strength Function → More "survivors"

Detector Array for Photons, Protons, and Exotic Residues

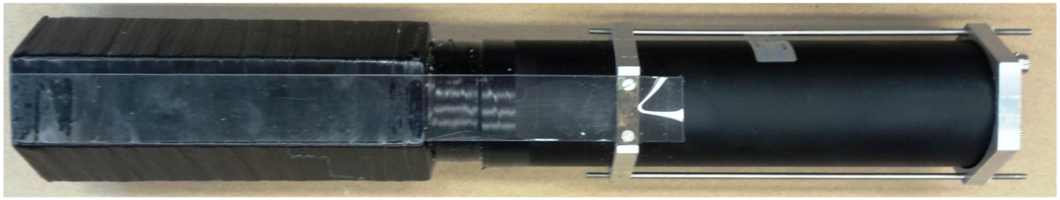


one of two side-packs not shown for clarity

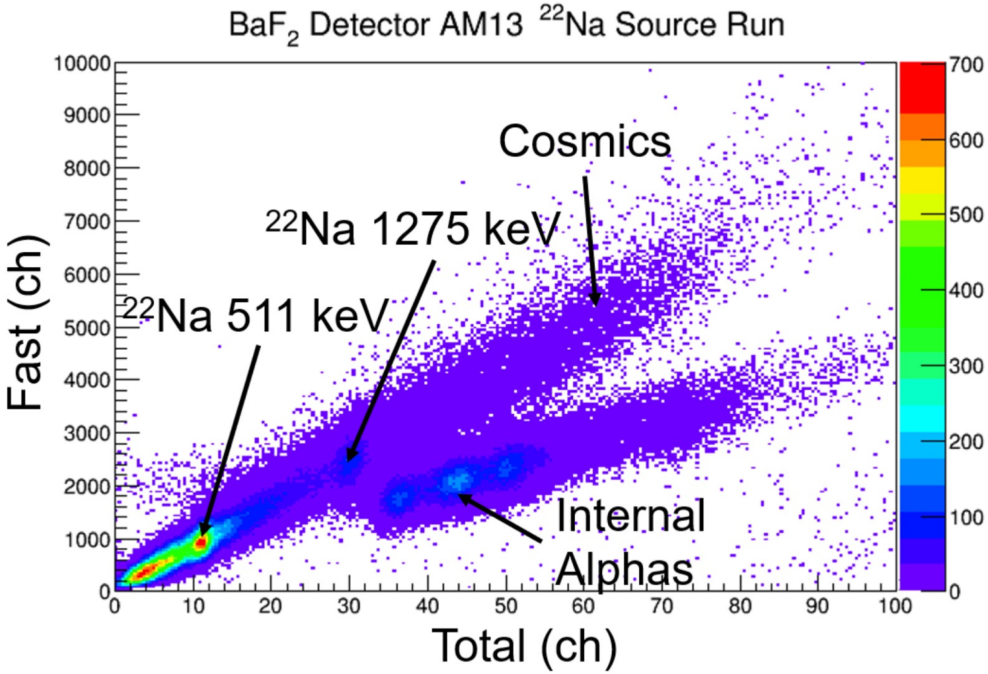
- (d,p) as (n,g) proxy
- Inverse kinematics → RIB
- Highly segmented, high efficiency
  - Excitation energy
  - Gamma multiplicity
  - Total gamma energy
  - Individual gamma energies
- Photon strength function
- Improve neutron capture model predictions

Impacts:

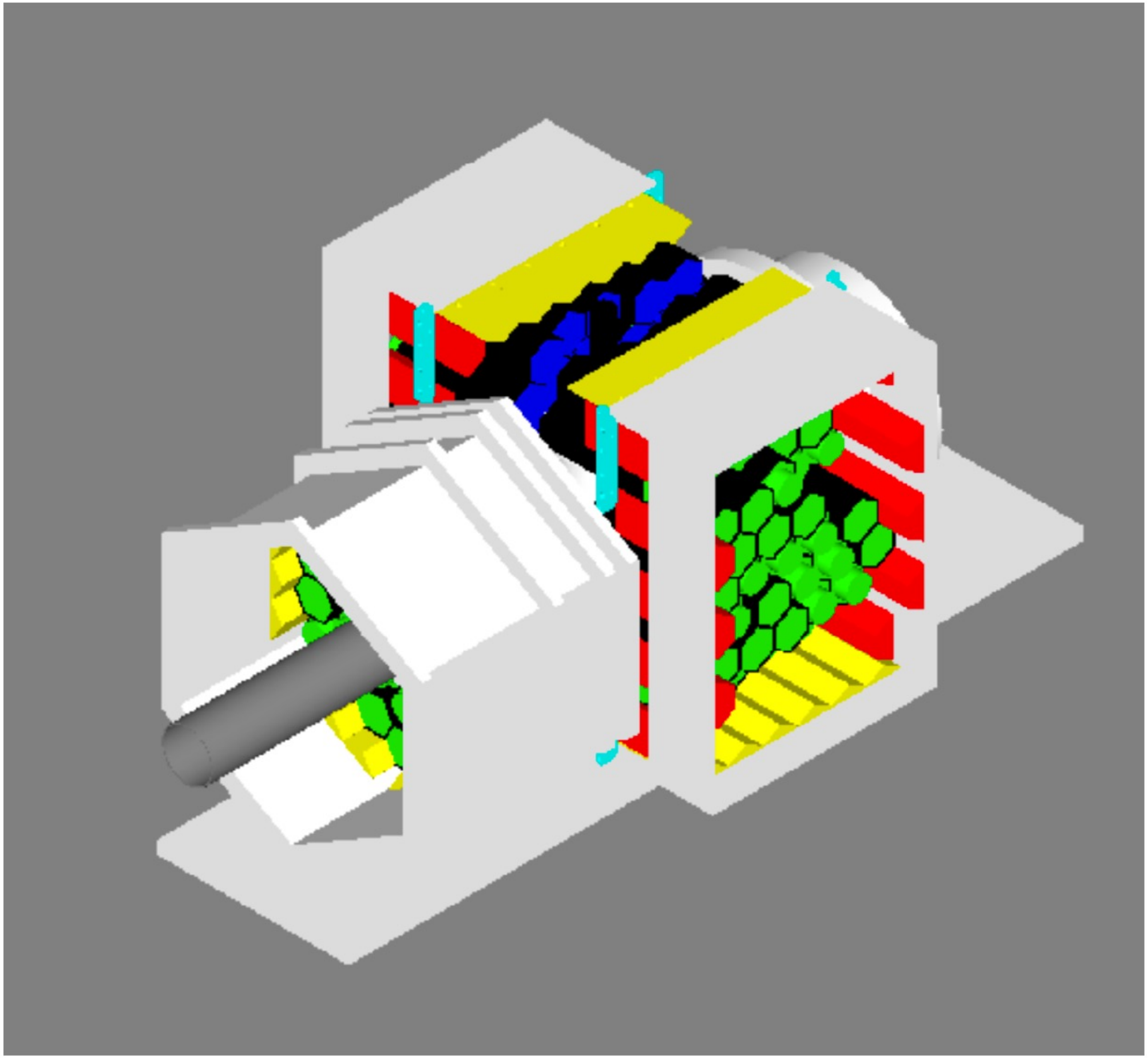
Fundamental Nuclear Science
Nuclear Astrophysics
Stockpile Science
Advanced Reactor Design



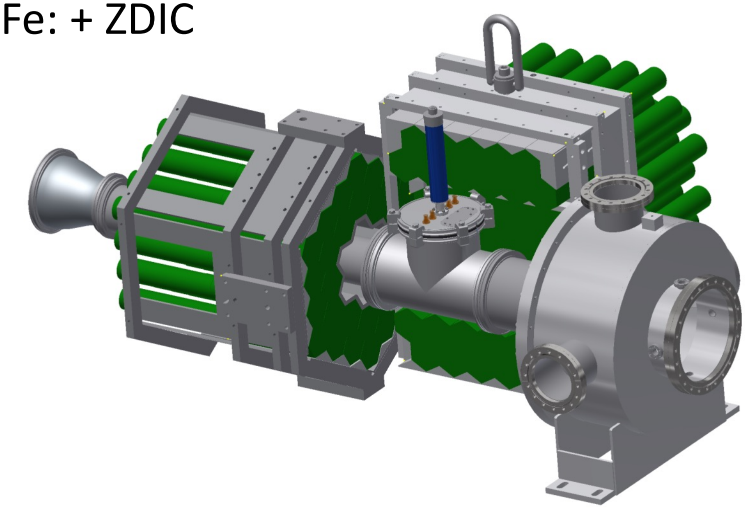
128 BaF2 crystals
6.5 cm face-to-face
20 cm long
~800 lbs for all detectors

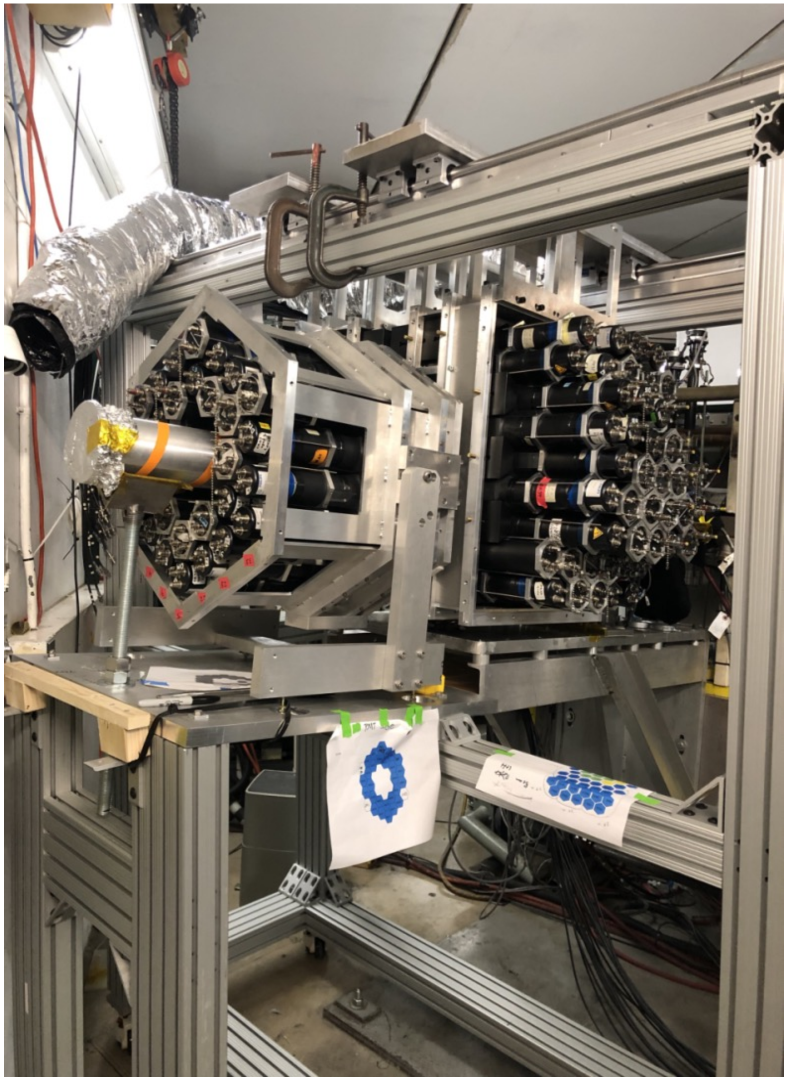


High efficiency
Acceptable energy resolution
Pulse shape discrimination
Fast component (UV) fall: < 20ns
Slow component fall: ~500ns



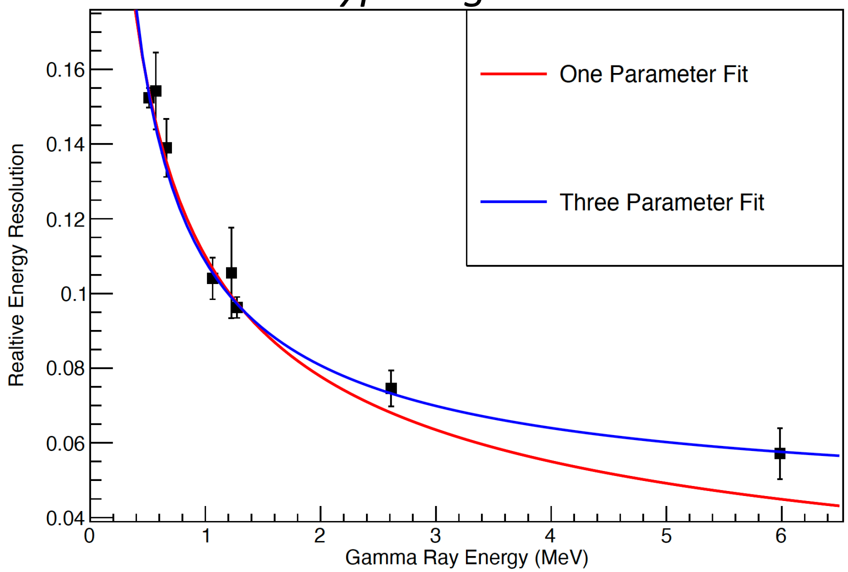
2021: 57Fe(d,pg)58Fe: BaF2, S3
2023: 54Fe(d,pg)55Fe: + ZDIC





Energy Resolution of DAPPER

A typical good detector

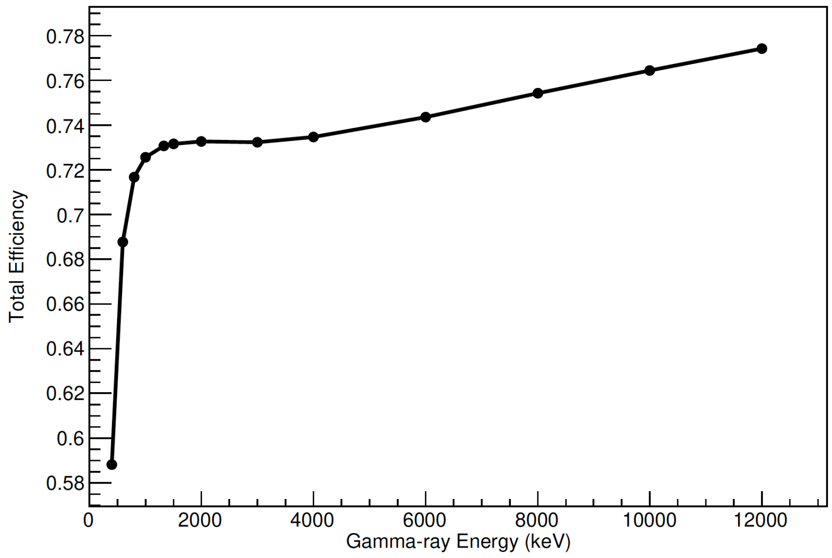


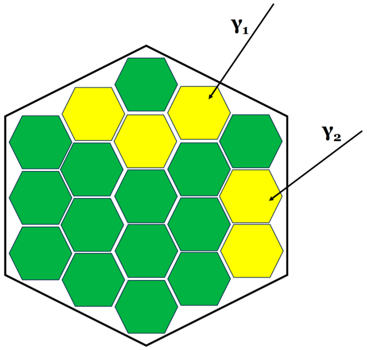
$$\frac{W(E_\gamma)}{E_\gamma} = \frac{\sqrt{aE_\gamma}}{E_\gamma}$$

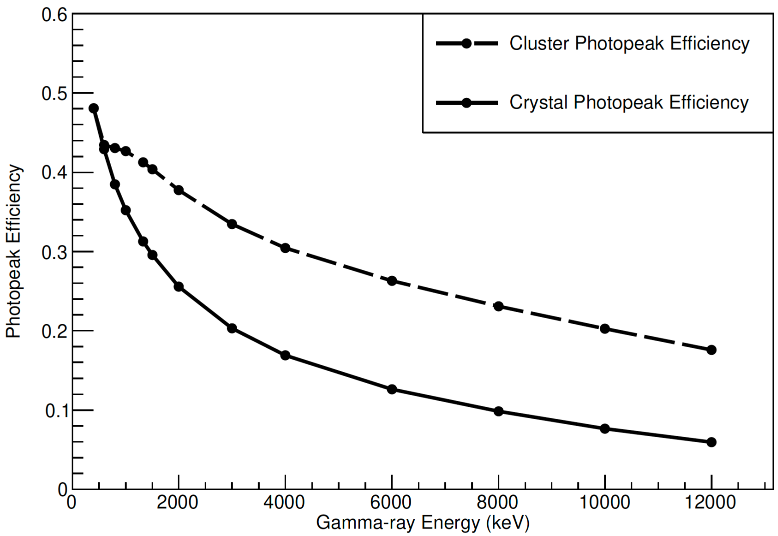
$$\frac{W(E_\gamma)}{E_\gamma} = \frac{\sqrt{a_0 + a_1 E_\gamma + a_2 E_\gamma^2}}{E_\gamma}$$

Nearly all detectors between 10-20% at 1 MeV.

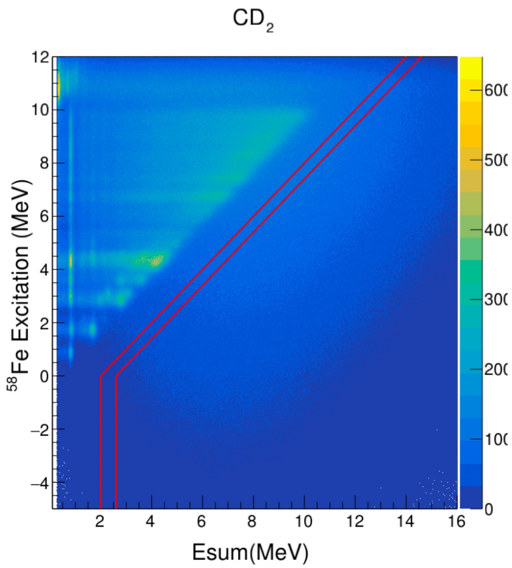
Efficiency of DAPPER

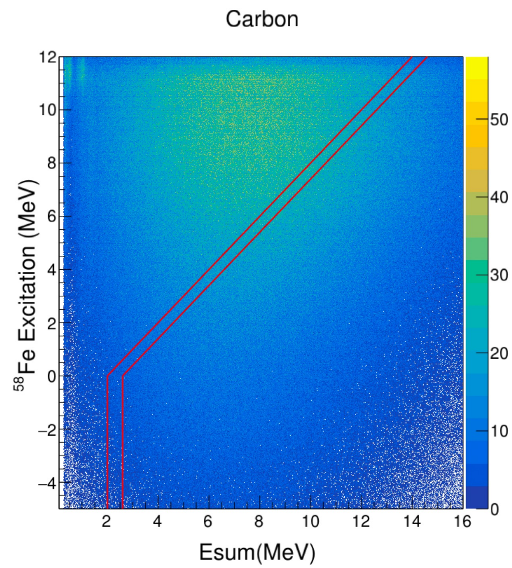


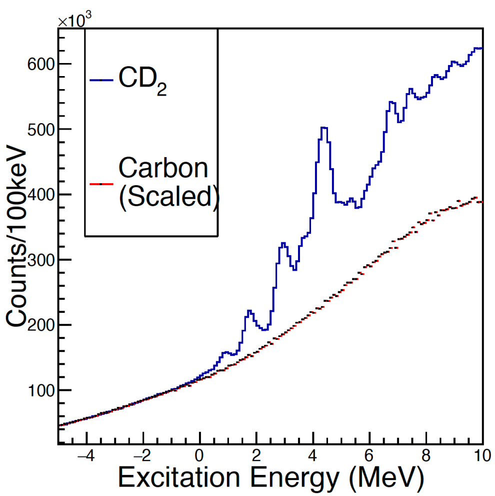


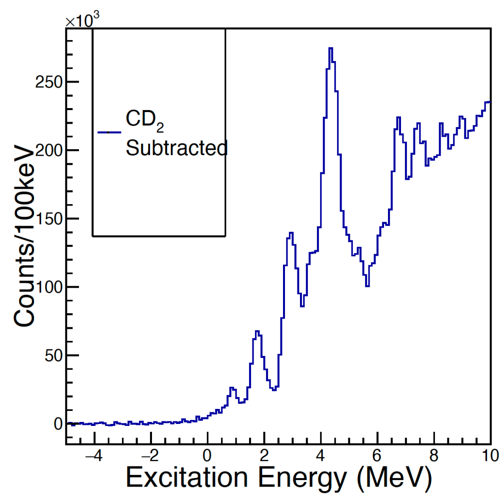


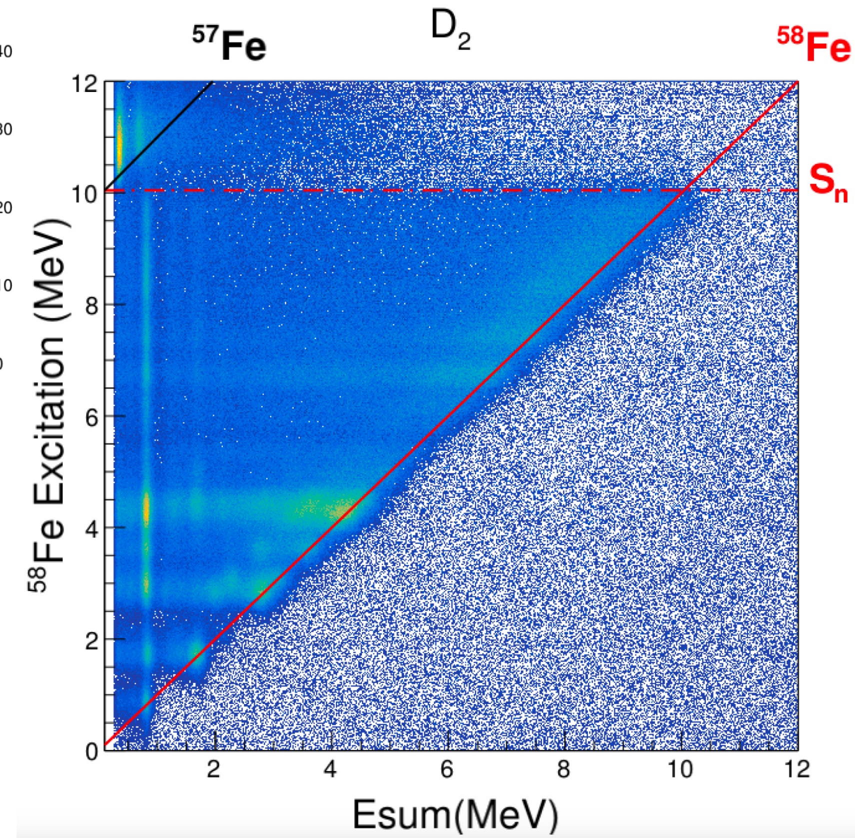
57Fe(d,pg) @ 7.5 MeV/u



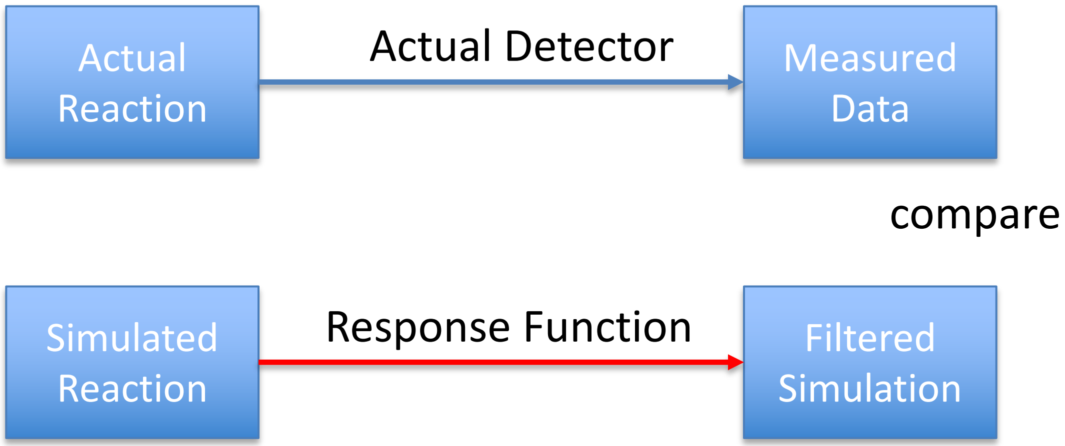




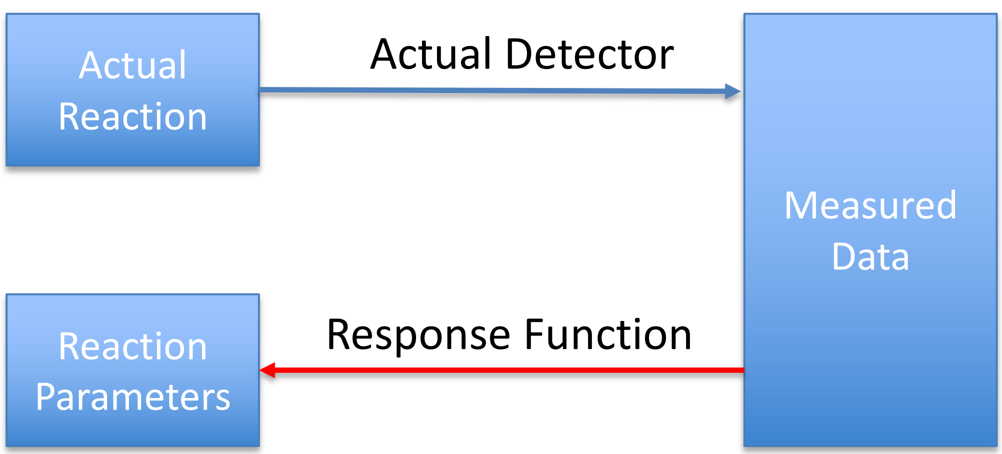




Forward Method

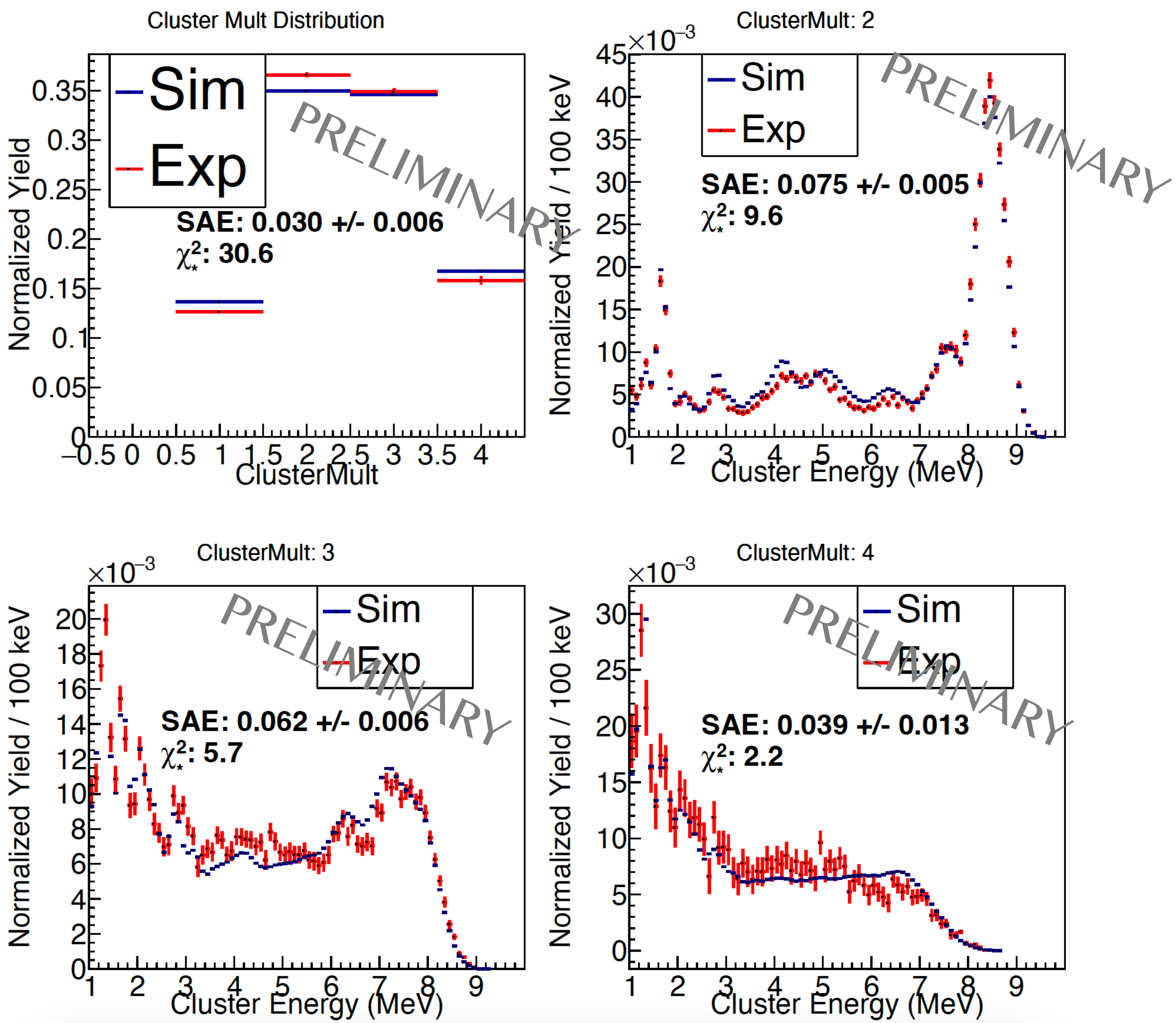


Oslo Method



57Fe(d,pg)58Fe@ 7.5 MeV/u

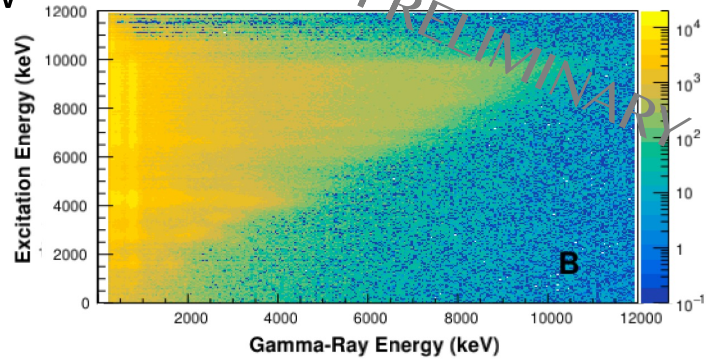
Forward Method



Oslo Method

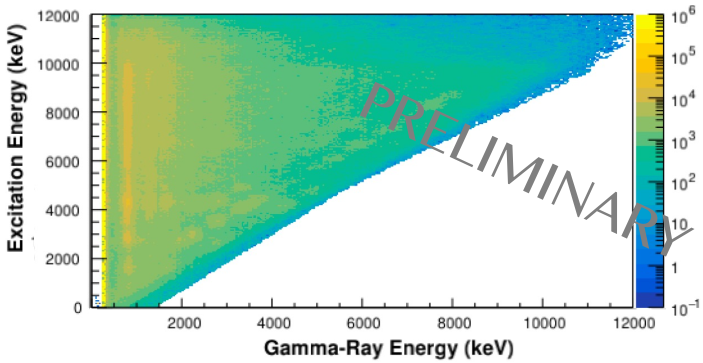
57Fe(d,pg)58Fe@ 7.5 MeV/u

raw

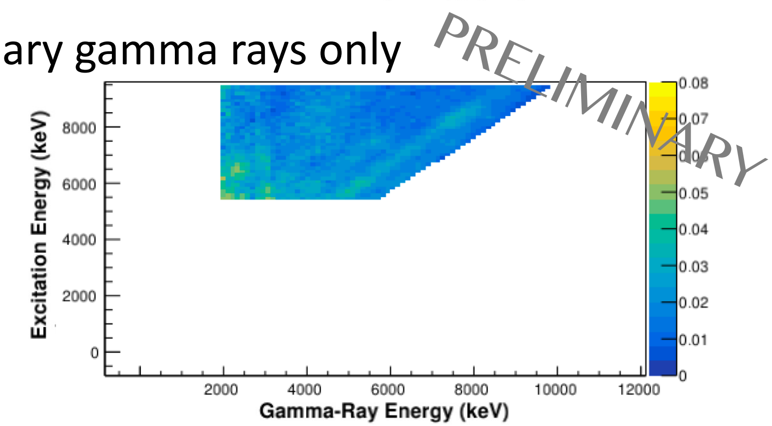


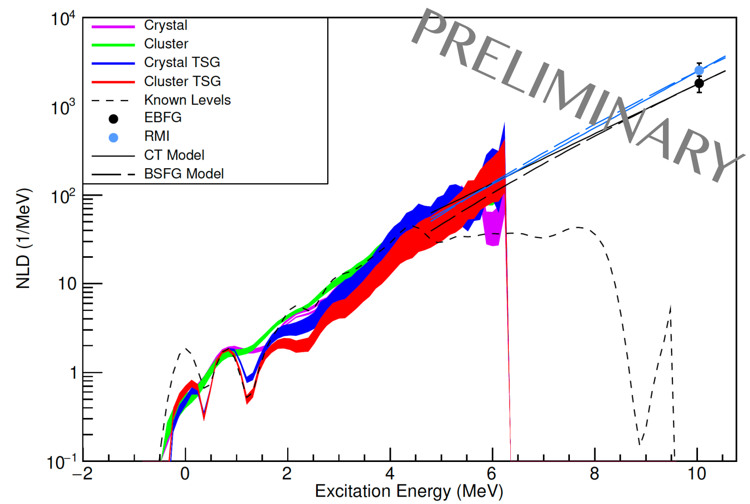
doppler corrected

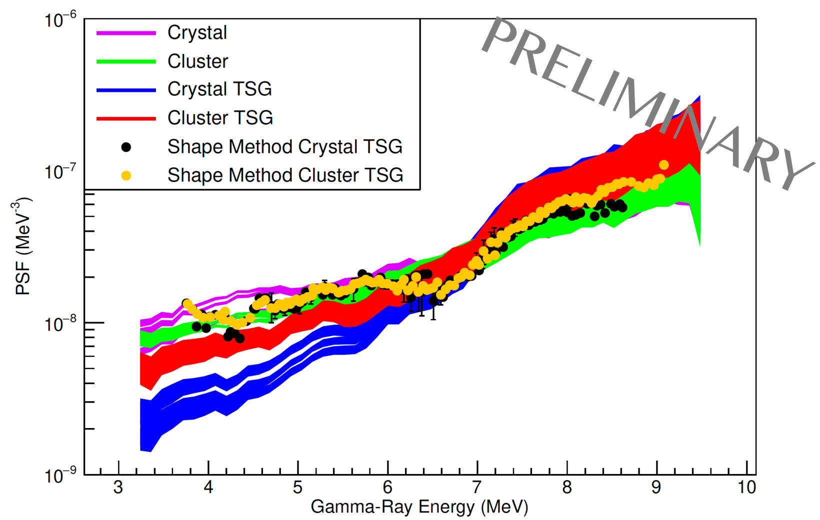
“unfolded” remove detector response



primary gamma rays only







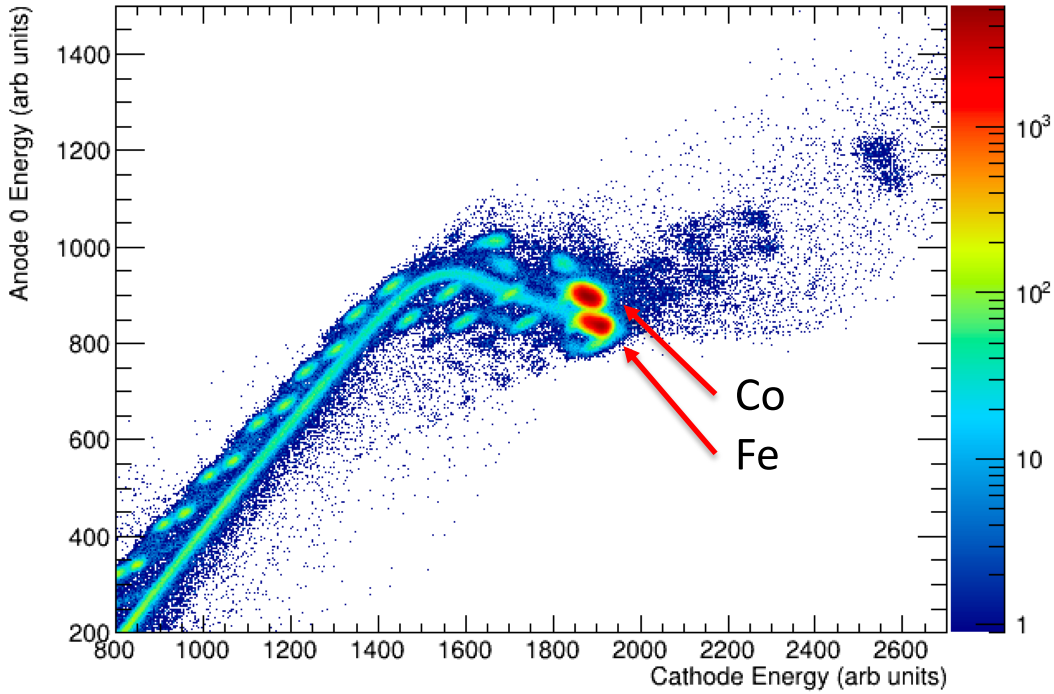
Zero-degree ionization chamber

Collaboration with S. Pain (ORNL) et al.

S. Pain, T.T. King, M. Grinder, S. Balakrishnan, A. Ratkiewicz, R. Ghimire

IC of the GODDESS array

2023 Measurement @ TAMU
Fe/Co cocktail beam

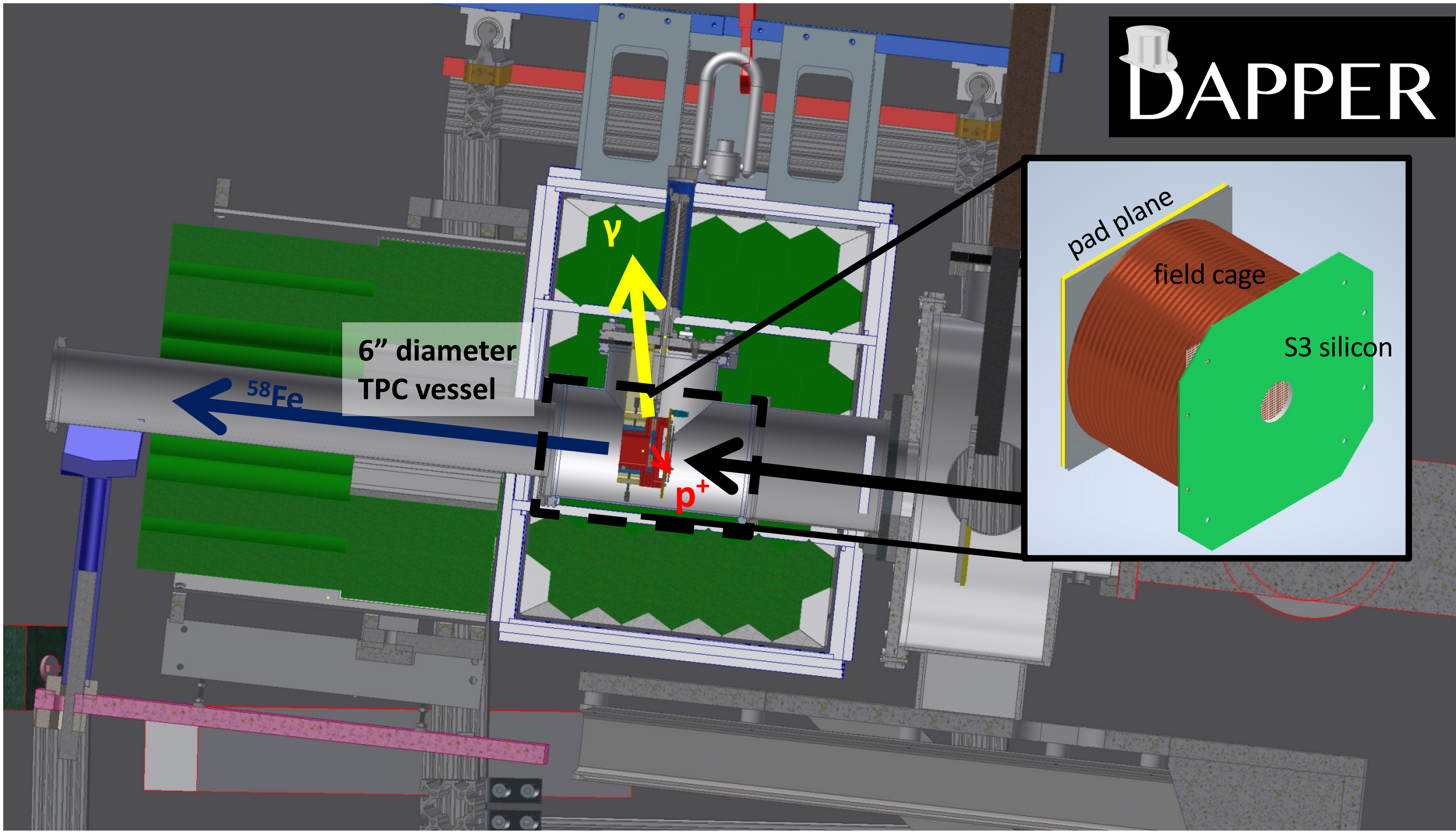


Unit Z separation
> 5e5 pps
dE-E technique

<u>other <= 1% features</u>
slit-scattering
stopping in wires
pile-up
combinations of these

TPC for DAPPER
Simulations in progress
10cm length x 10cm dia

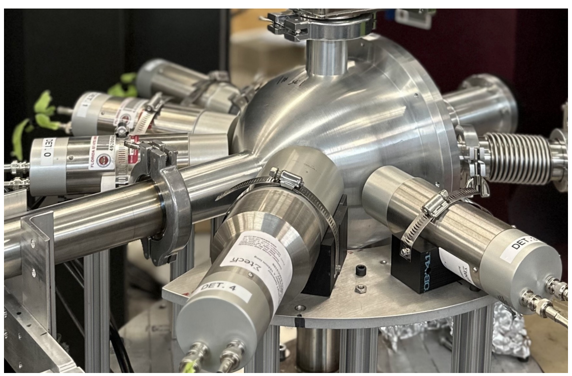
- no fusion-evaporation background
- no target degradation
- higher density of deuterium
- improved E* resolution (energy loss and angle)



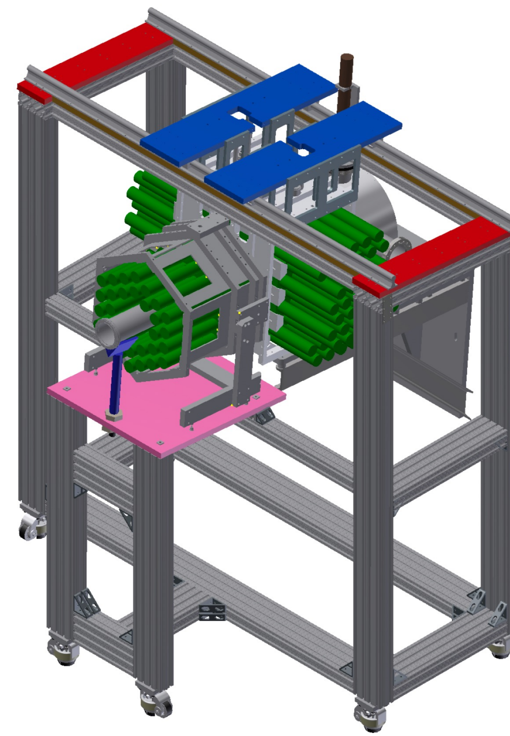
Measurements possible with DAPPER with triton beams may benefit from collaborations involving FSU devices

SPS – could measure protons at some angles

CeBrA – better resolution



DAPPER



weighs ~ 1/2 t

less than 52” x 80” footprint

DAPPER

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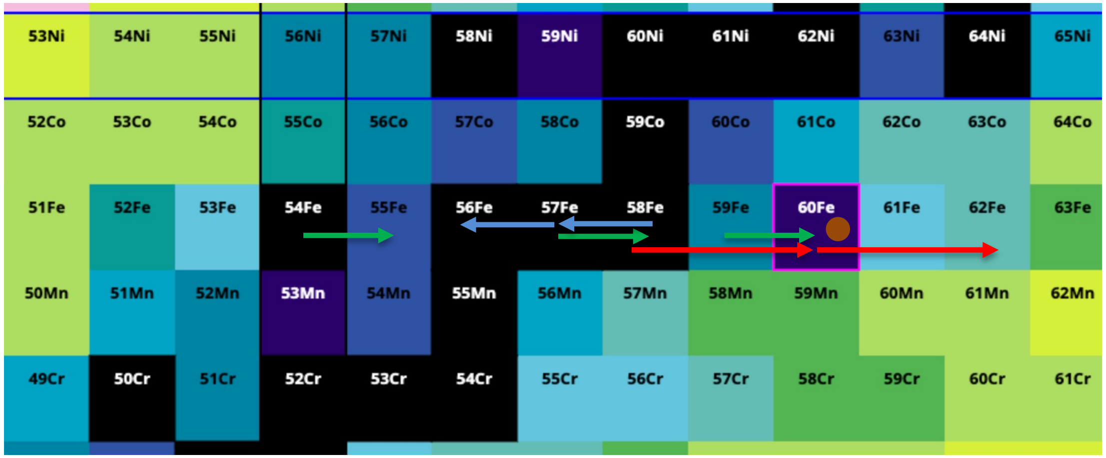
triton beams

Extend Isotopic Chains – Iron Example

59Fe is s-process branch
60Fe is interestingly abundant



PSF measurements for 56Fe, 57Fe exist using (3He,4He)
Analysis for PSF nearly done for 58Fe (DAPPER) using (d,p) (inverse kin)
Data for PSF obtained for 55Fe (DAPPER) using (d,p) (inverse kin)

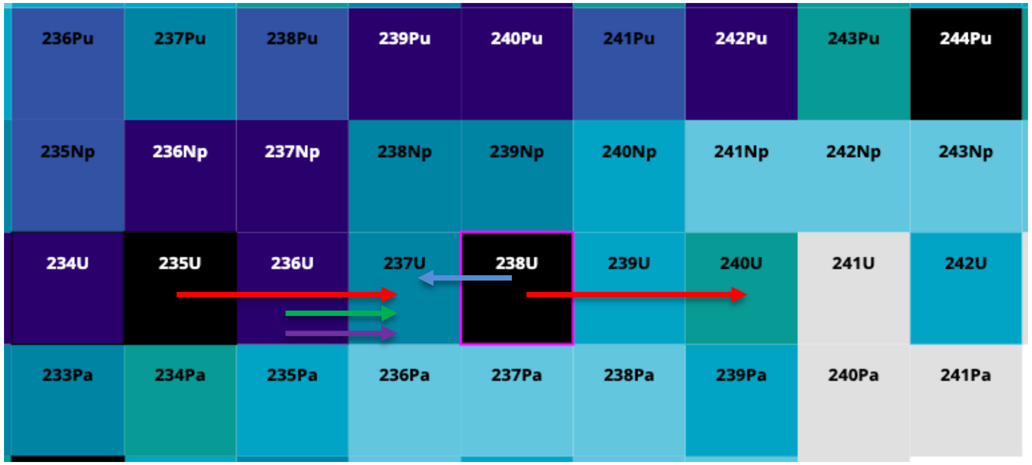
59Fe(d,p)60Fe with DAPPER + RIB (inverse kin)

58Fe(t,p)60Fe with DAPPER + triton beams (normal kin)
60Fe(t,p)62Fe with DAPPER + triton beams (normal kin)
target activity only ~1 uCi
60Fe(p,p’)60Fe with DAPPER

(t,p) cross sections are on the order of 1mb (TENDL2023)

Proxy for neutron capture on actinides

238U(t,p)240U



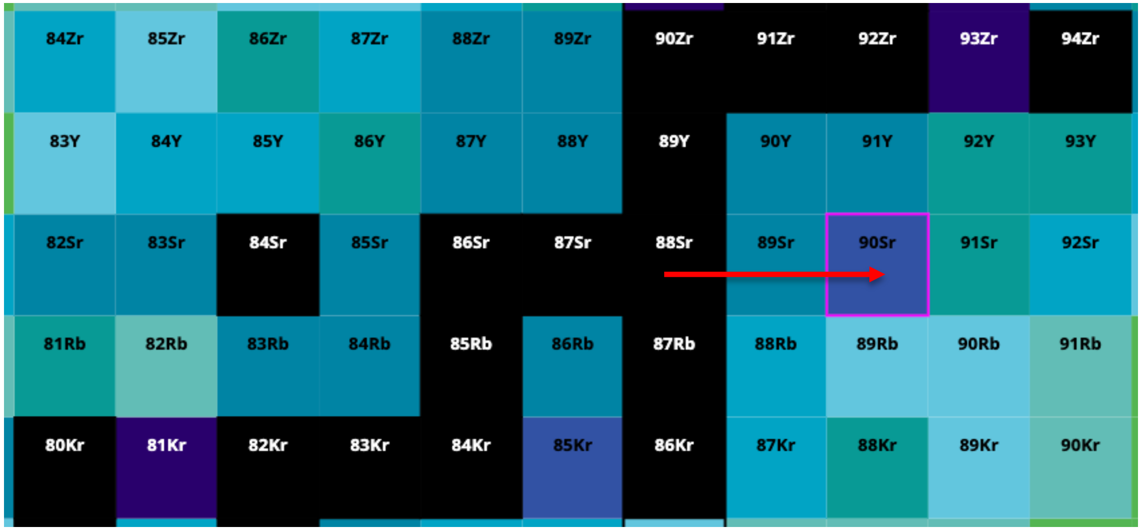
- 239U is produced by neutron capture on 238U in a neutron field
- 239U is short lived (23min) but has a significant (n,F) cross section (~14b) and significant (n,g) cross section (~20b)
- The photon strength function and level density of 240U would be useful to constrain
- Not accessible by (p,p'), (d,p)…

- U236 (23 My) builds up in reactors, neutron poison.
- Capture x-sect for 236U(n,g) desirable, may be sufficiently well known
- 235U(t,p), 236U(d,p), 236U(n,g), 238U(h,a) all possible
- DAPPER can measure charged-particle reactions
- compare cross-section measurements to predictions using PSF; benchmark

90Sr

s-proc branch (89Sr: 51 d)

Fission Prod (90Sr: 29 y)



88Sr(t,p)90Sr

Not accessible by (p,p’), (d,p)…

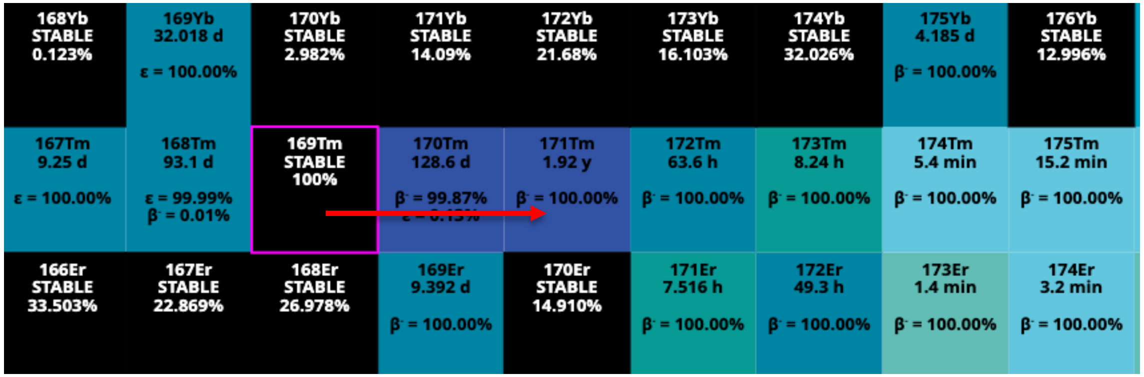
135Xe
strong reactor poison (Mb x-sect)

137Cs
Fiss Prod

134Xe(t,p)136Xe ~1mb
136Xe(p,p')136Xe tens of mb
ice target!

135Cs(t,p)137Cs (4 mb TENDL2023)
133Cs(t,p)135Cs
135Cs(p,p')135Cs
consider also (t,a) ~ 3 mb

169Tm(t,p)



Thulium is naturally monoisotopic (A=169).
170Tm (129d) and 171Tm (1.9y)
Both are LLFP (170 from Pu, and 170&171 from U).
Neutron capture on 170Tm would be useful to constrain.

169Tm(t,p)171Tm ~2 mb
consider (t,a)

Eu

Eu has two only stable isotopes.
152,154,155Eu fission products (4-14y).
Neutron capture on all of these is interesting to constrain.

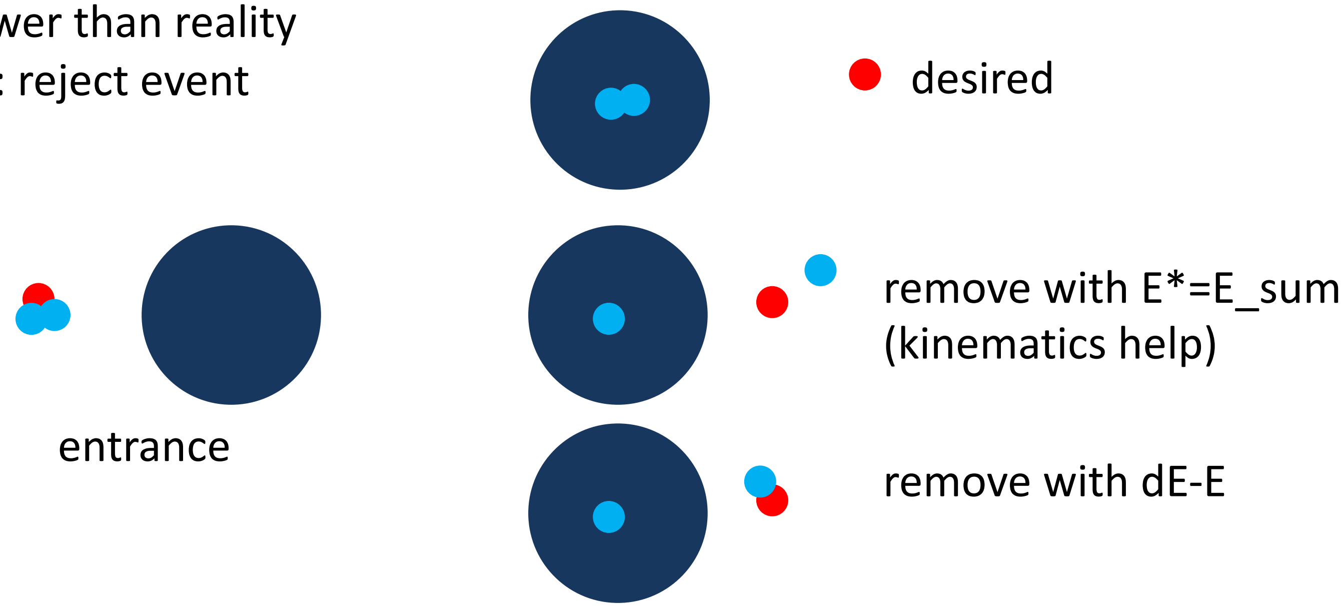
151Eu(t,p)153Eu; can compare to (p,p')
153Eu(t,p)155Eu

BACKGROUND REACTIONS

What about (t,pn) or (t,d) reactions when we want (t,p)?

Note that (t,pn) and (t,d) can be an ~10x higher than for (t,p).

- The (t,p) proton will be kinematically shifted compared to the (t,pn) and (t,d)
- The deuteron can be rejected by dE-E technique
- DAPPER measures E* from proton and E_Sum from gammas
    - (in addition to indiv gamma energies)
    - if rxn is (t,p) and we measure all gamma rays, E* = E_sum
    - if rxn is (t,p) and we measure less than all gamma rays, E* > E_sum: reject
    - if rxn is (t,pn) and we measure all gamma rays, E* < S_sum: reject
    - if rxn is (t,pn) and we measure less than all gamma rays
        - E* from proton is higher than reality
        - E_sum is lower than reality
        - E* > E_sum: reject event



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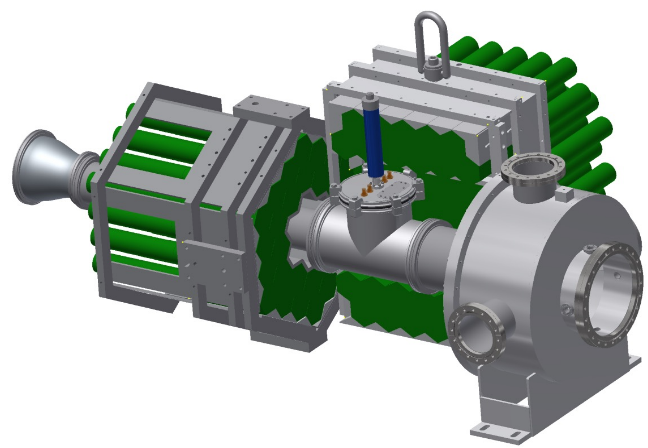
- DAPPER is highly efficient at measuring gamma rays
- Not just E_Sum, but individual energies and multiplicity
- Combined with silicon detectors to determine E* independently
- (Inverse kinematics – short-lived nuclides)
- Charged particle reactions
  - (d,p), (p,p’), (t,p)
- Compare methods where possible
- Use (t,p) to extend reach
  - s-process branch points
  - reactor and stockpile science
  - extend isotopic chains
- Measure Photon Strength Functions
- Constrain predictive models of neutron capture



From Phil Adsley

(t,p) pair transfer

testing pairing prescriptions;
gs->gs if pairing condensate description holds

shape co-existence away from closed shells
e.g. Sm chain – spherical to deformed
SPS well suited