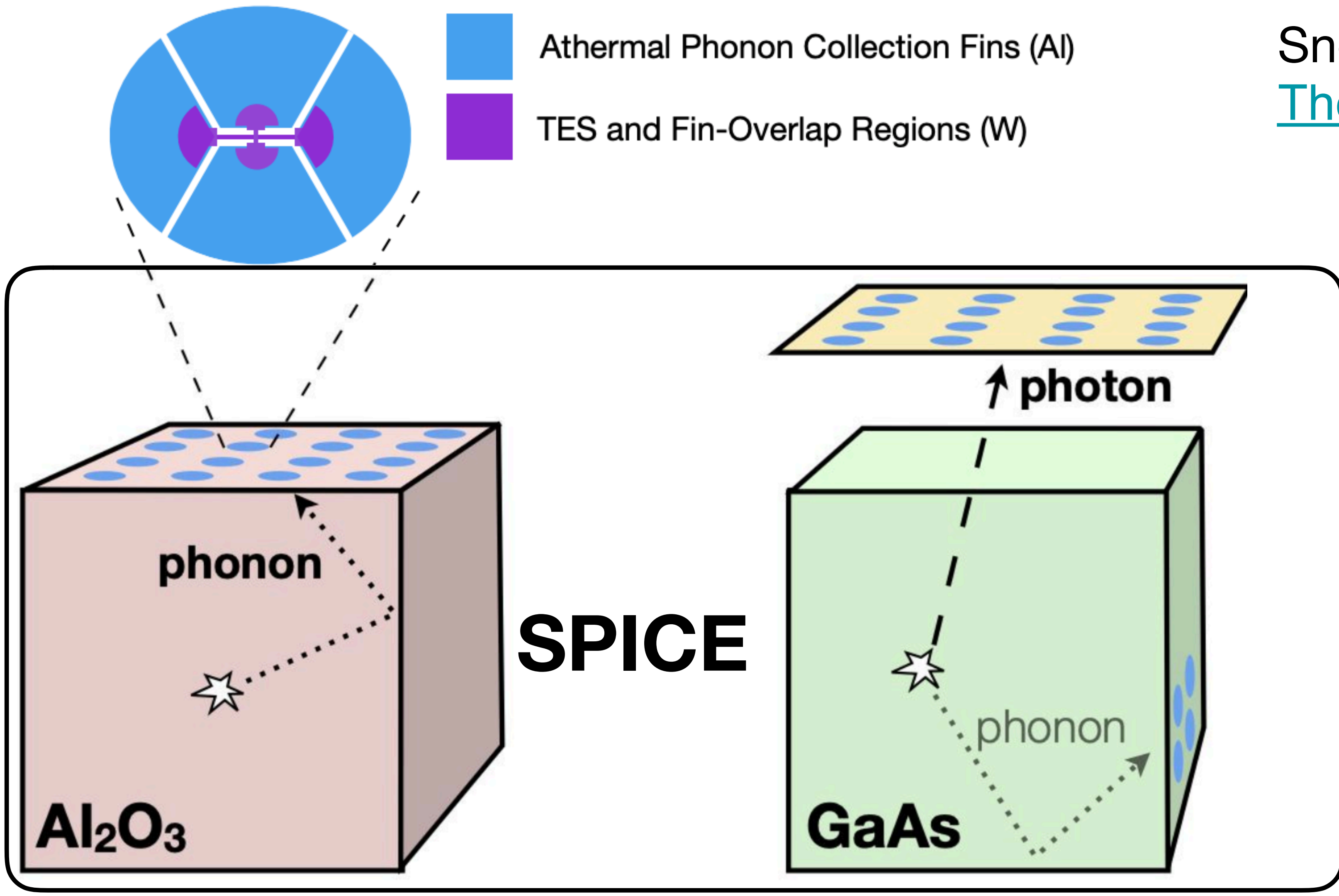
Progress towards sub-keV *Nuclear* Recoil calibration

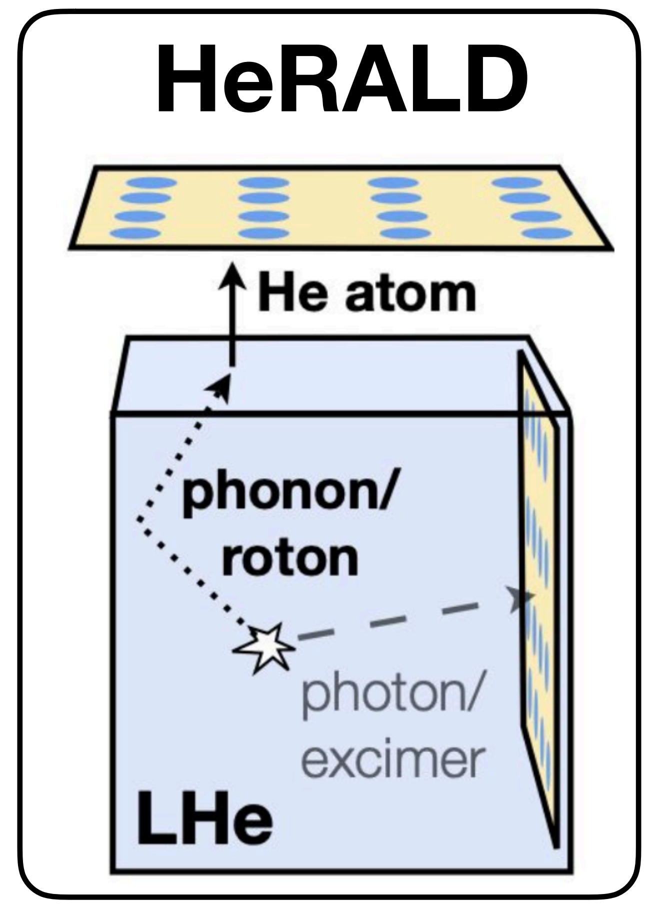
Pratyush Patel (University of Massachusetts, Amherst)

For the SPICE/HeRALD Collaboration

SPICE/HeRALD Collaboration

Snowmass2021 - Letter of Interest
The TESSERACT Dark Matter Project





SPICE/HeRALD at CPAD 2022

Roger Romani: **Stress Induced Backgrounds**

Doug Pinckney: **Progress Towards HeRALD**

Xinran Li: **Transition Edge Sensor developments**

David Osterman: **Quasiparticle Diffusion in Superconducting Al Films**

Outline

- Introduction to Nuclear Recoil (NR) calibration
- Tools for sub-keV NR calibration (<1keV in LHe):

    1. Low energy neutron:

        - Portable 24 keV neutrons from ^{124}SbBe
        - Pulsed 2 keV neutrons from Sc filtered DT neutron
        - Further lowering NR calibration threshold (<20 eV in LHe)

    2. Low energy neutron detector

- Summary

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  2. Neutron detector aka Backing detector
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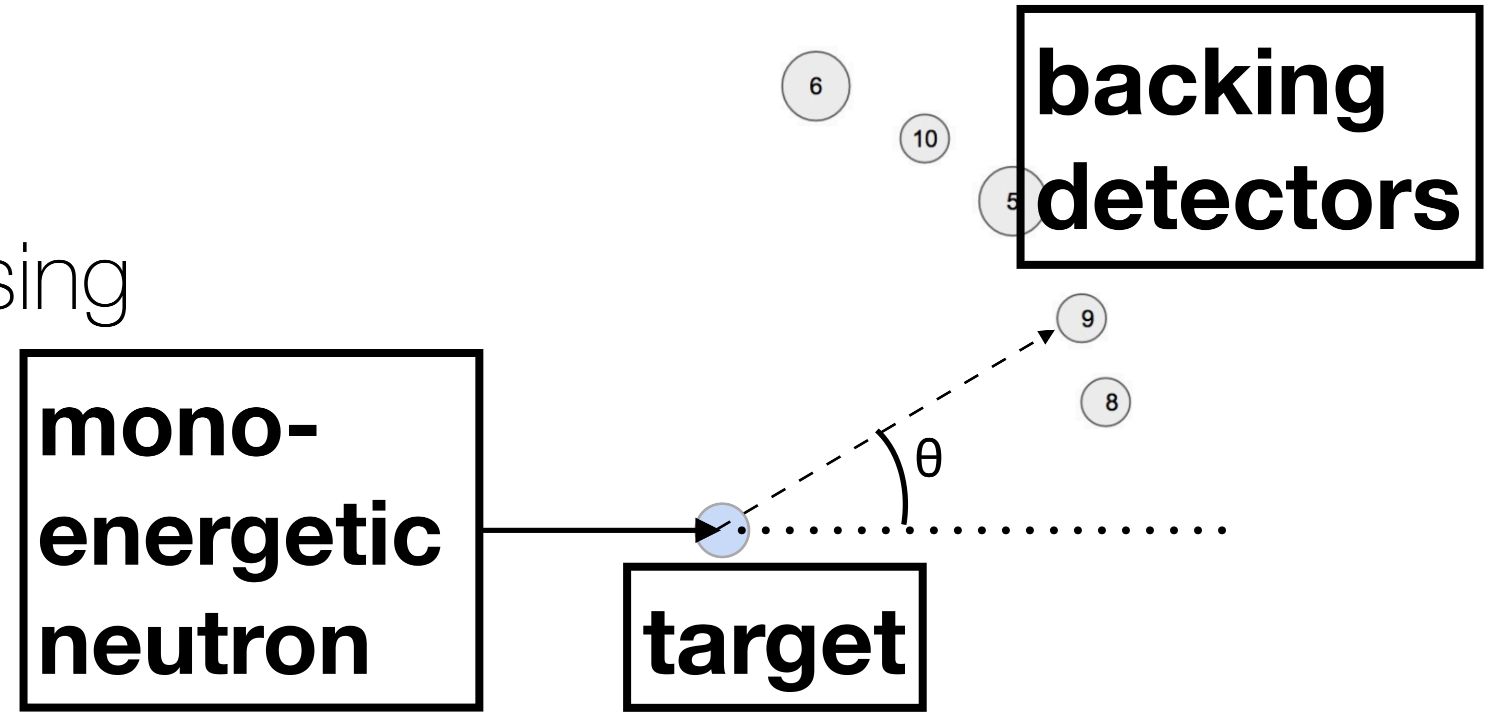
- Summary

Introduction to Nuclear Recoil (NR) calibration

- Big Picture:

  - Mimic dark matter signal using neutrons



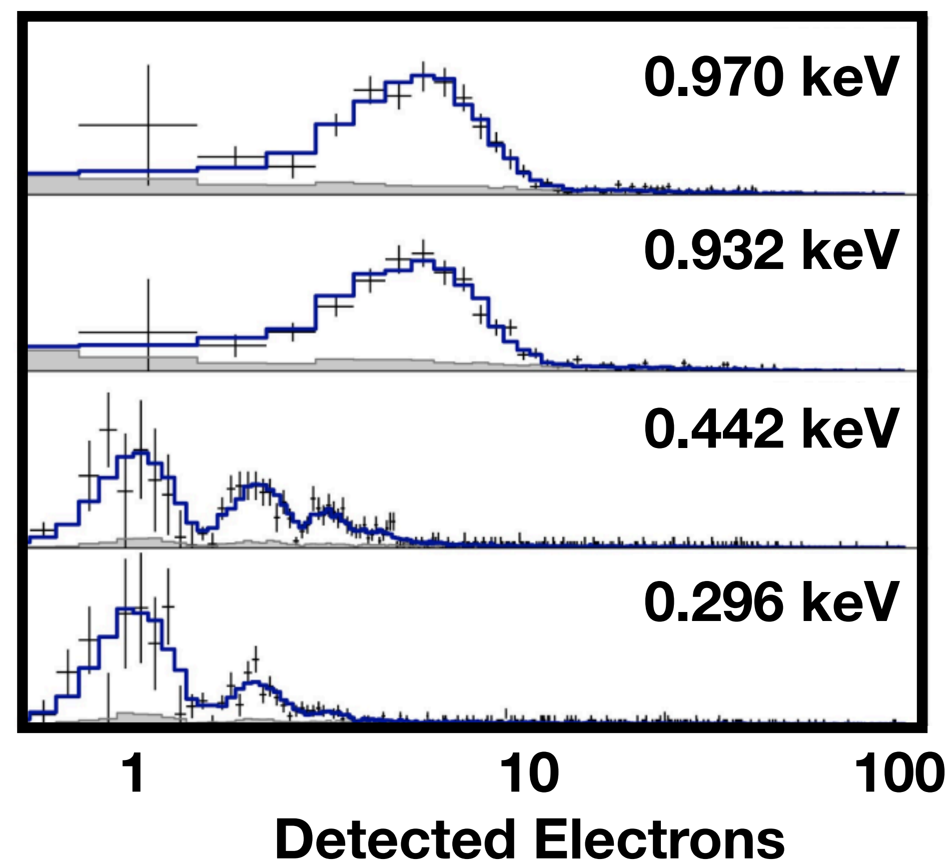
- Goal:

  - Produce a NR of known energy using neutron

- Primary strategy:

  - Given a neutron of known energy, tag its scattering angle

Lenardo et. al. ***for LXe TPC***



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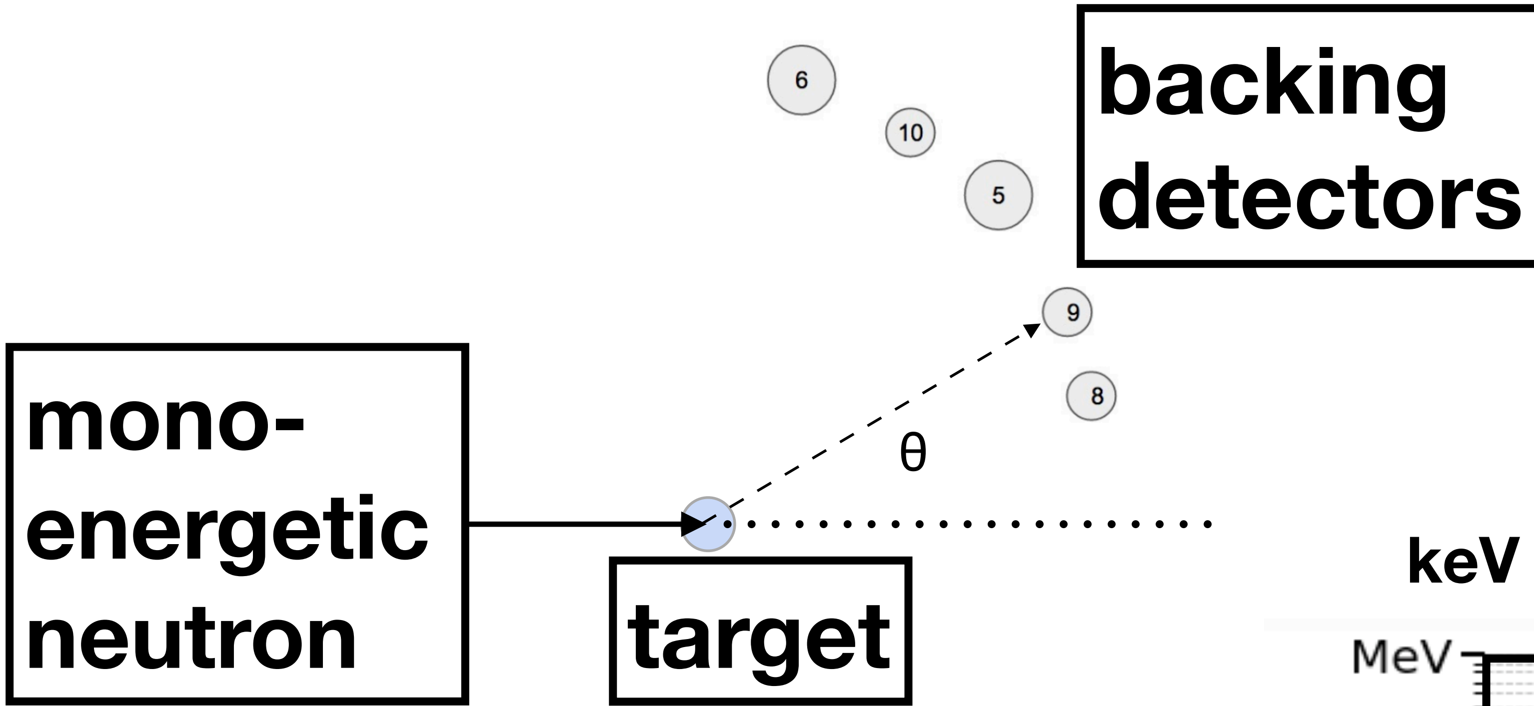
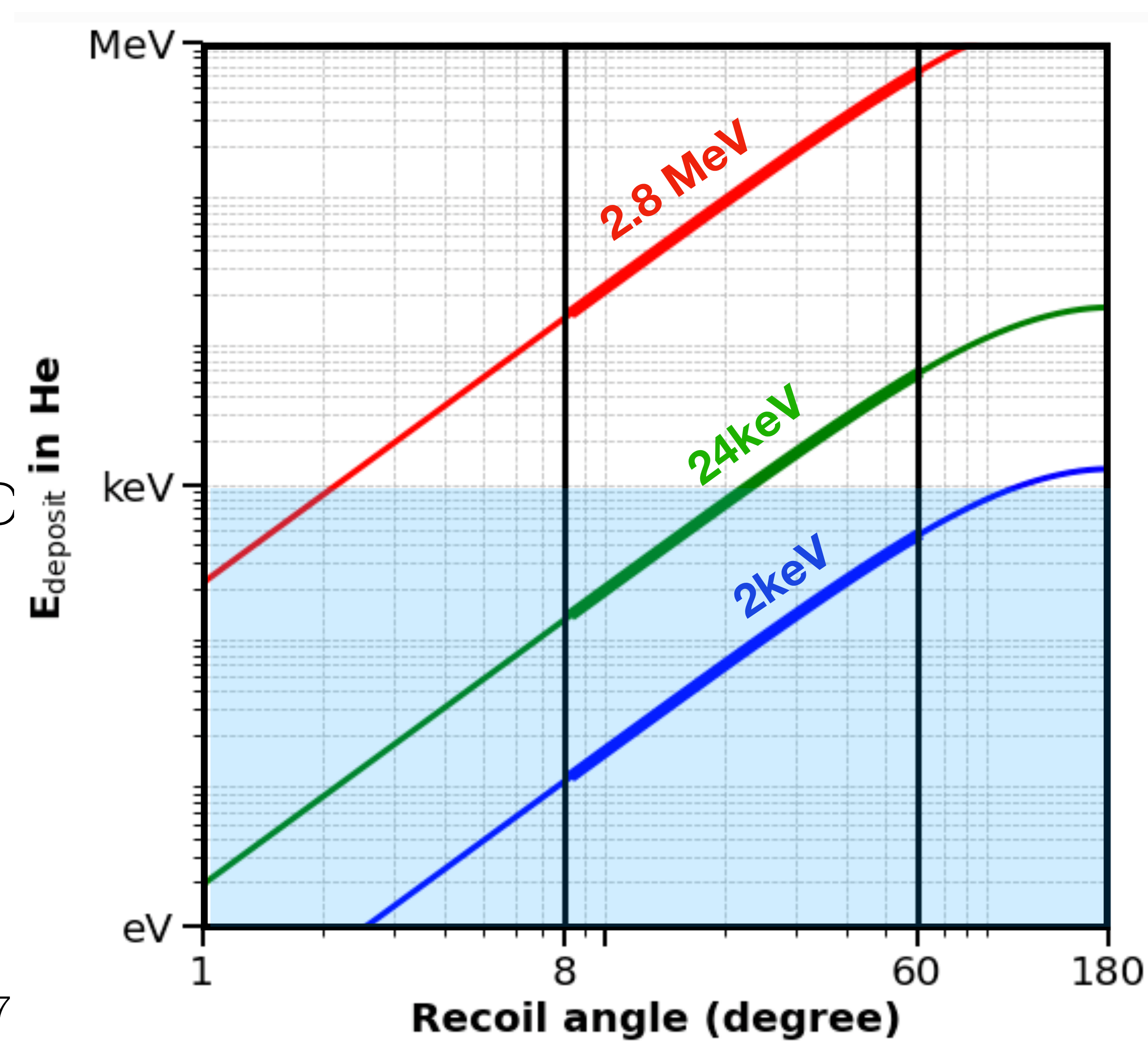
Tools for sub-keV NR calibration (<1keV in LHe)



keV neutron produce sub-keV NR in He



- Neutron source:
  1. Pulsed/Portable
  2. keV-scale, mono-energetic

- Neutron detector(Paper):
  1. Fast (~10μs)
  2. Large area

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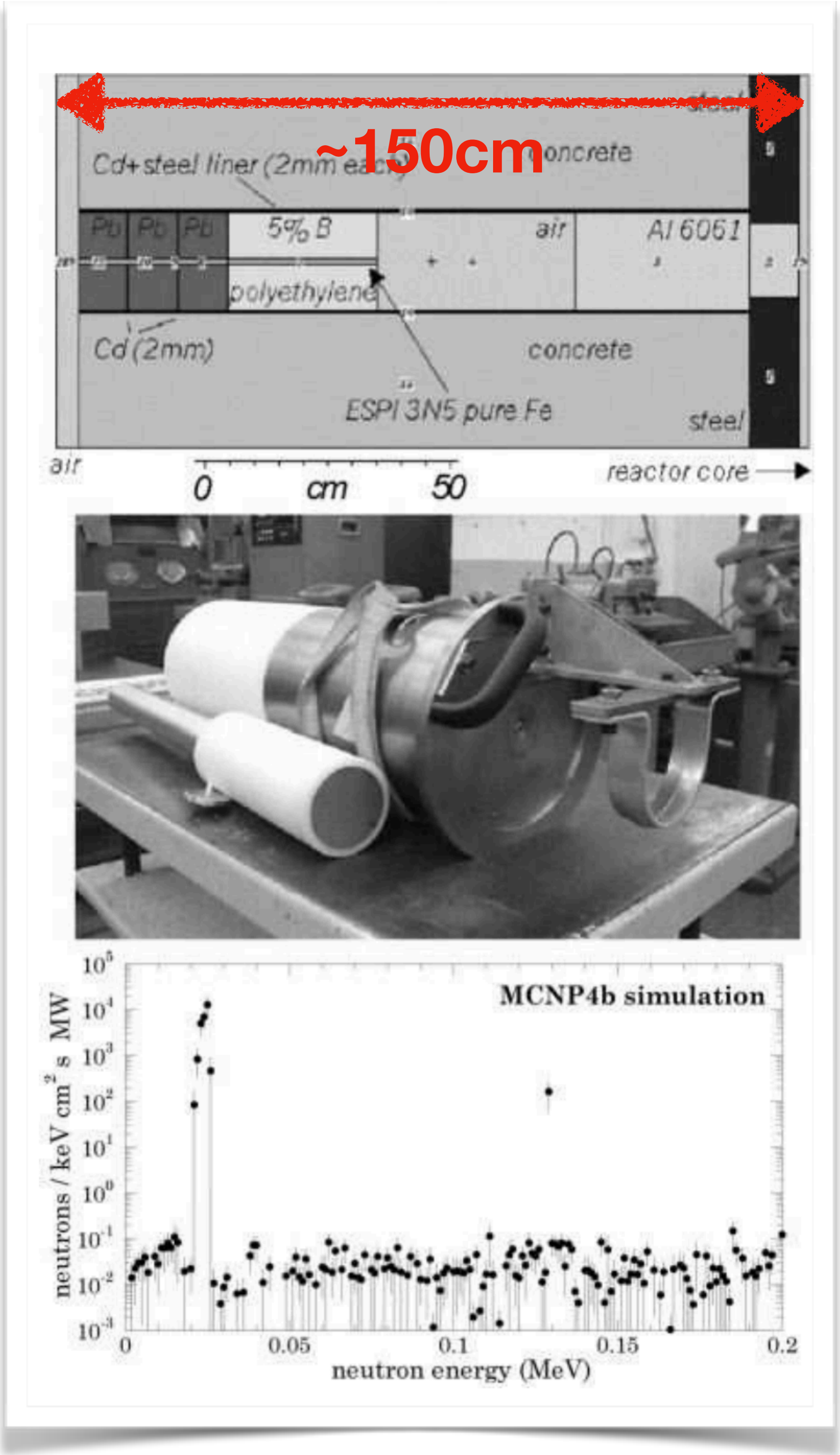
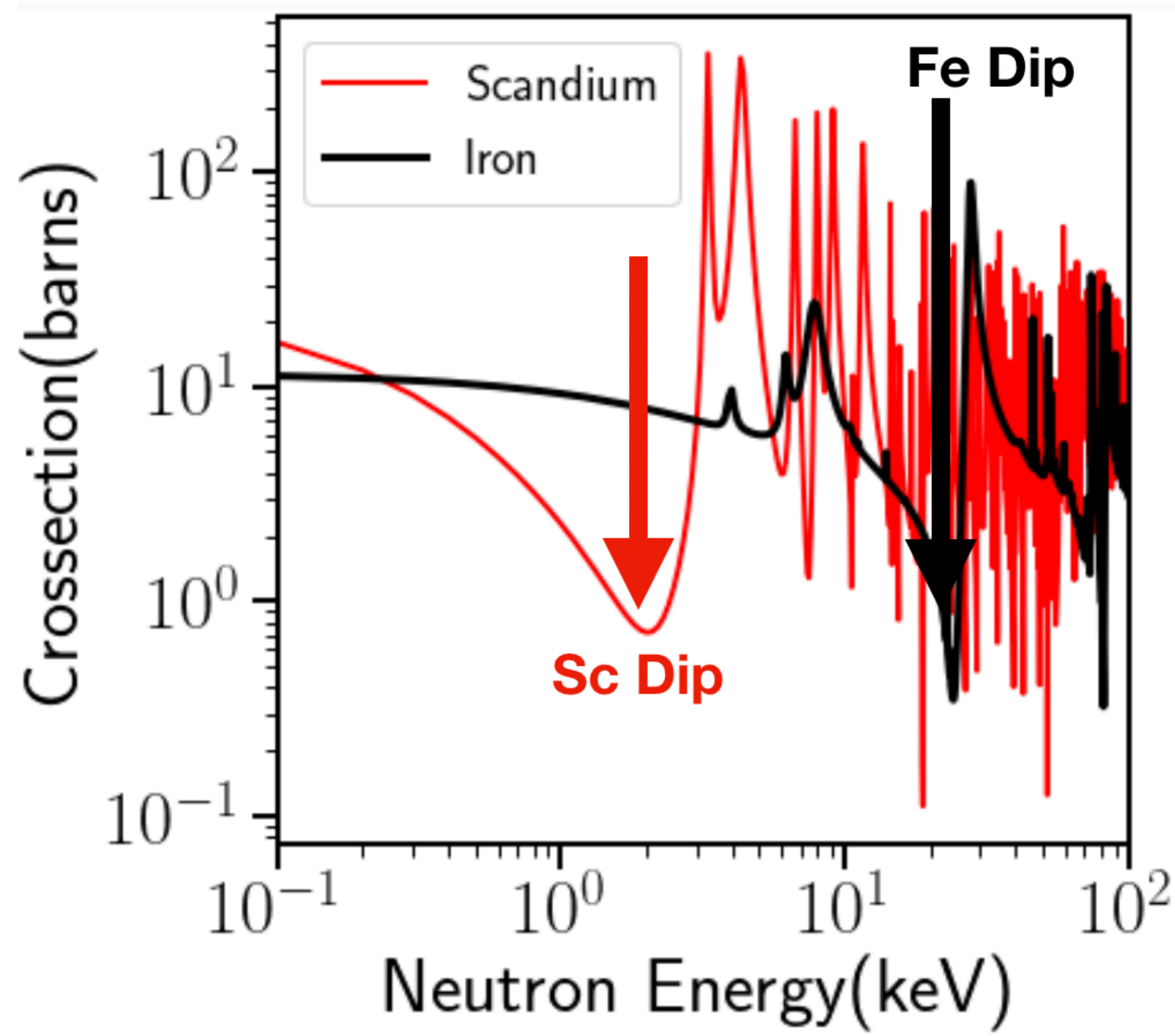
Low energy neutron

One of the way is to use Neutron Filters



[P.S.Barbeau, J.I.Collar, P.M.Whaley]



Using the dips in the neutron-nucleus elastic scattering crossection

Neutron source: Nuclear Reactor

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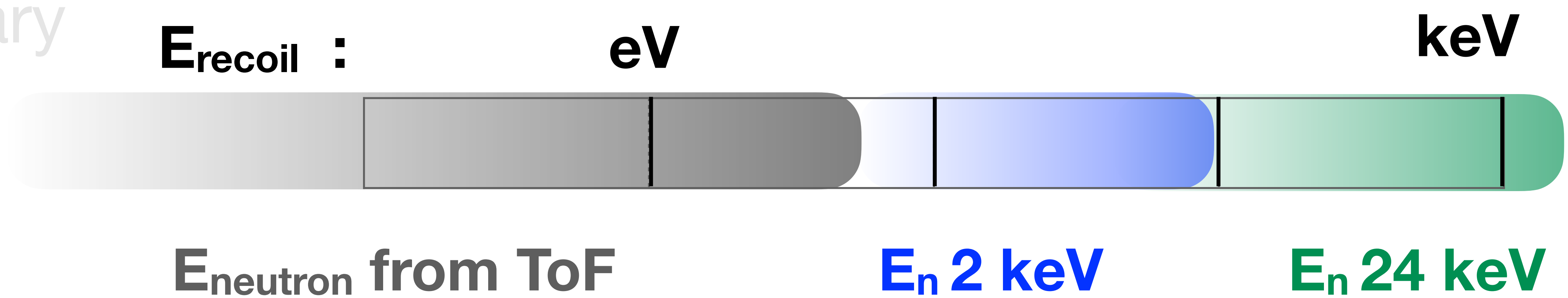


Portable 24 keV neutrons from SbBe at UC, Berkeley

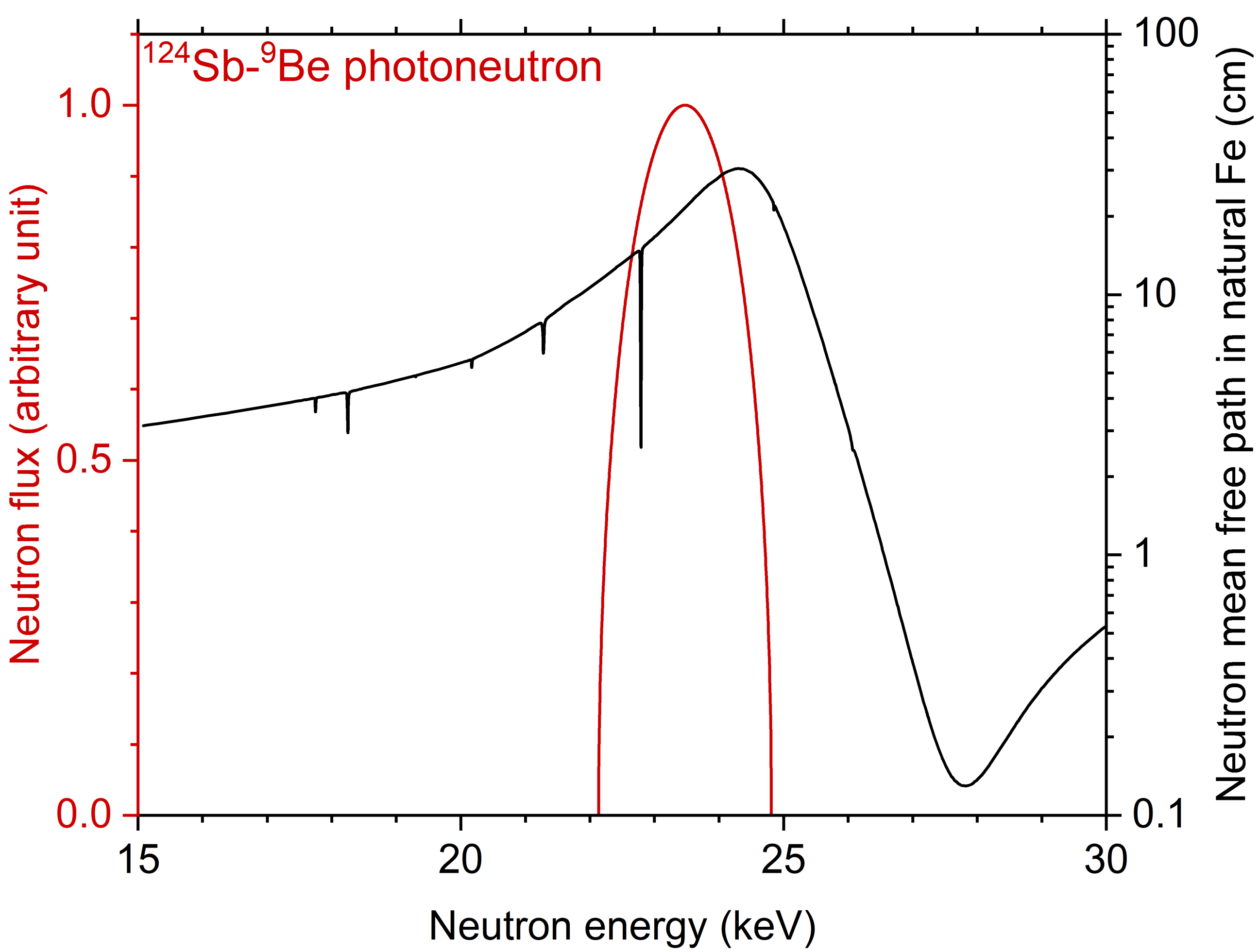
A remarkable coincidence

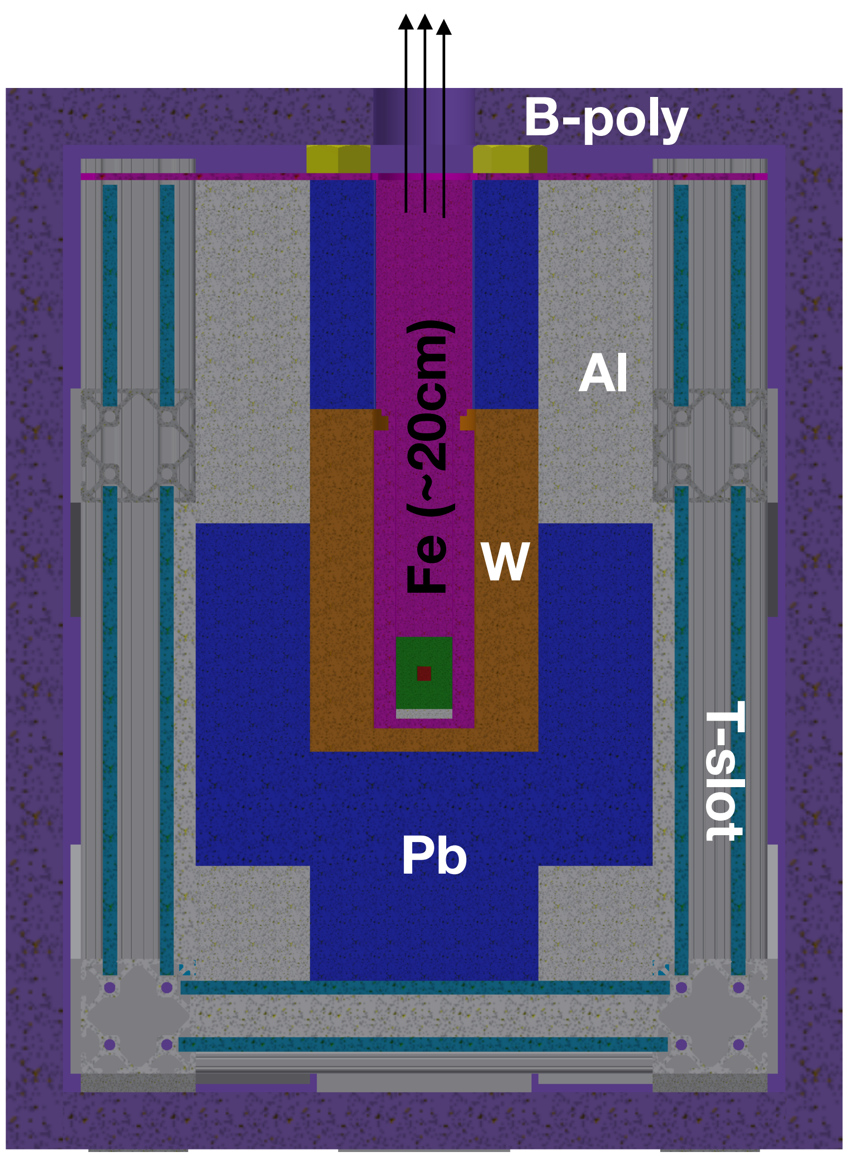
- ^{124}SbBe n energy : 23.47 keV
- Fe resonance : 24.54 keV

Concept:

Use Fe

- ~20cm
- gamma shield (1.7 & 2.1MeV)
- neutron collimator (24 keV)





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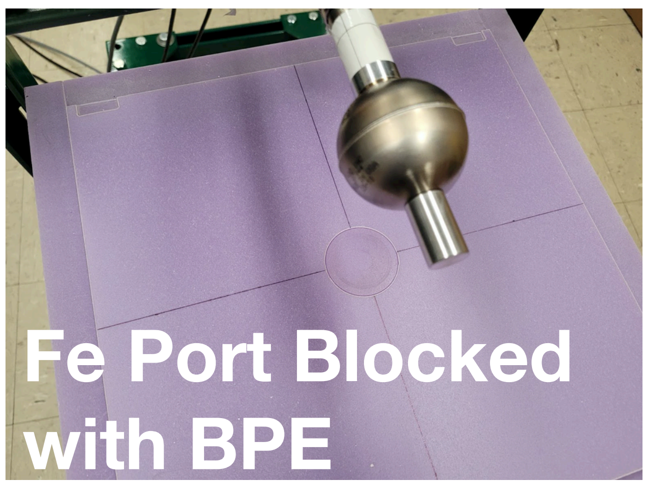
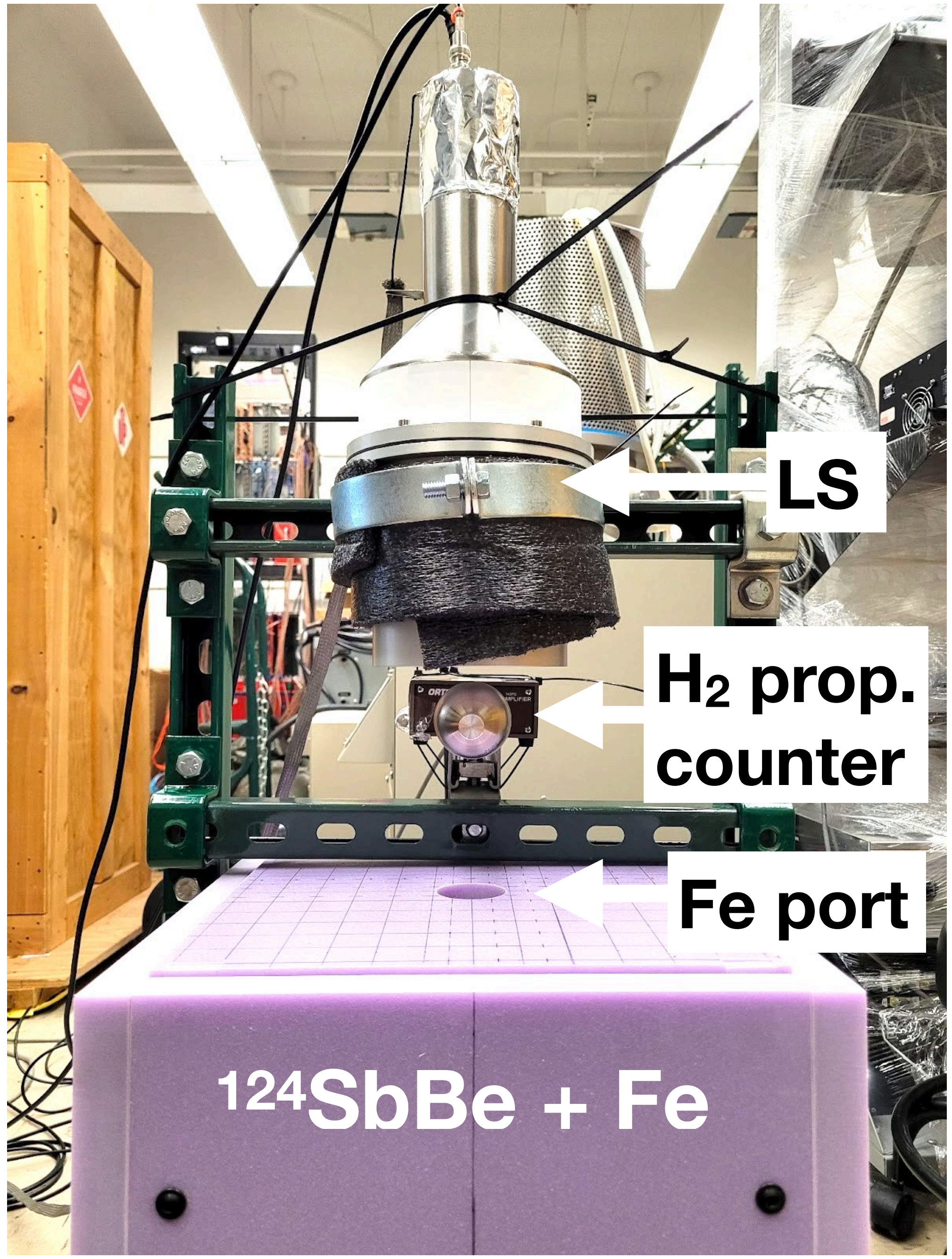
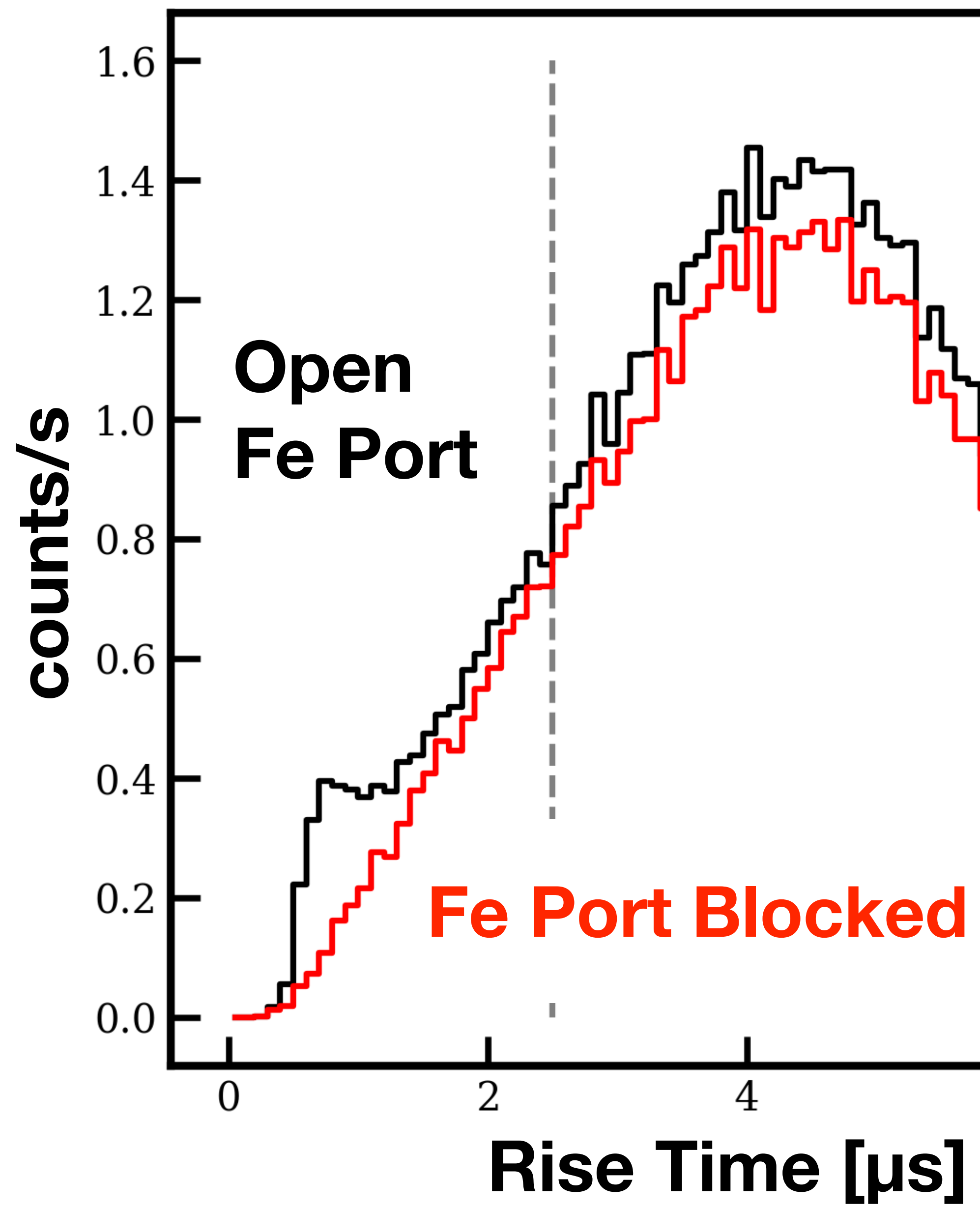


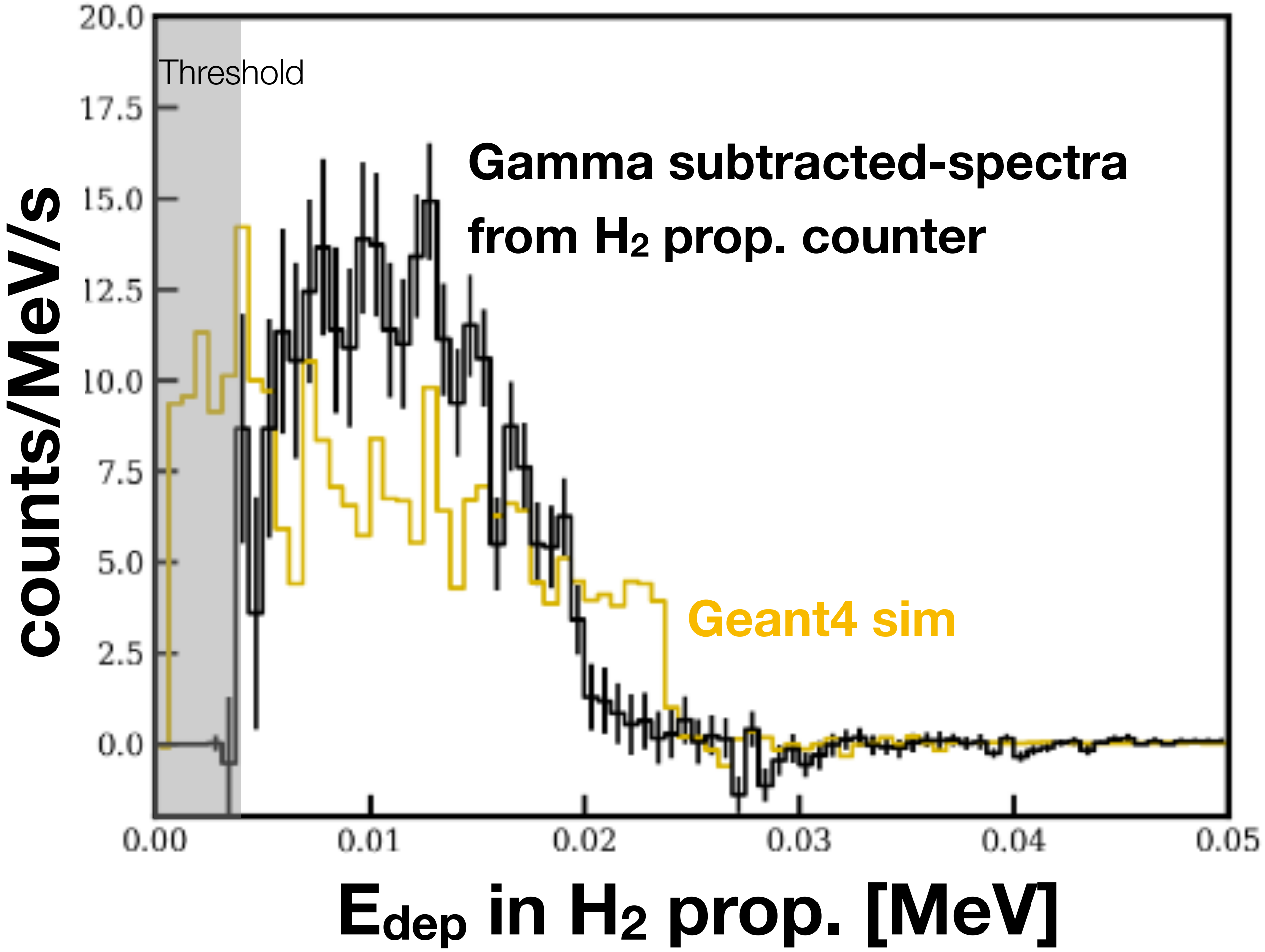


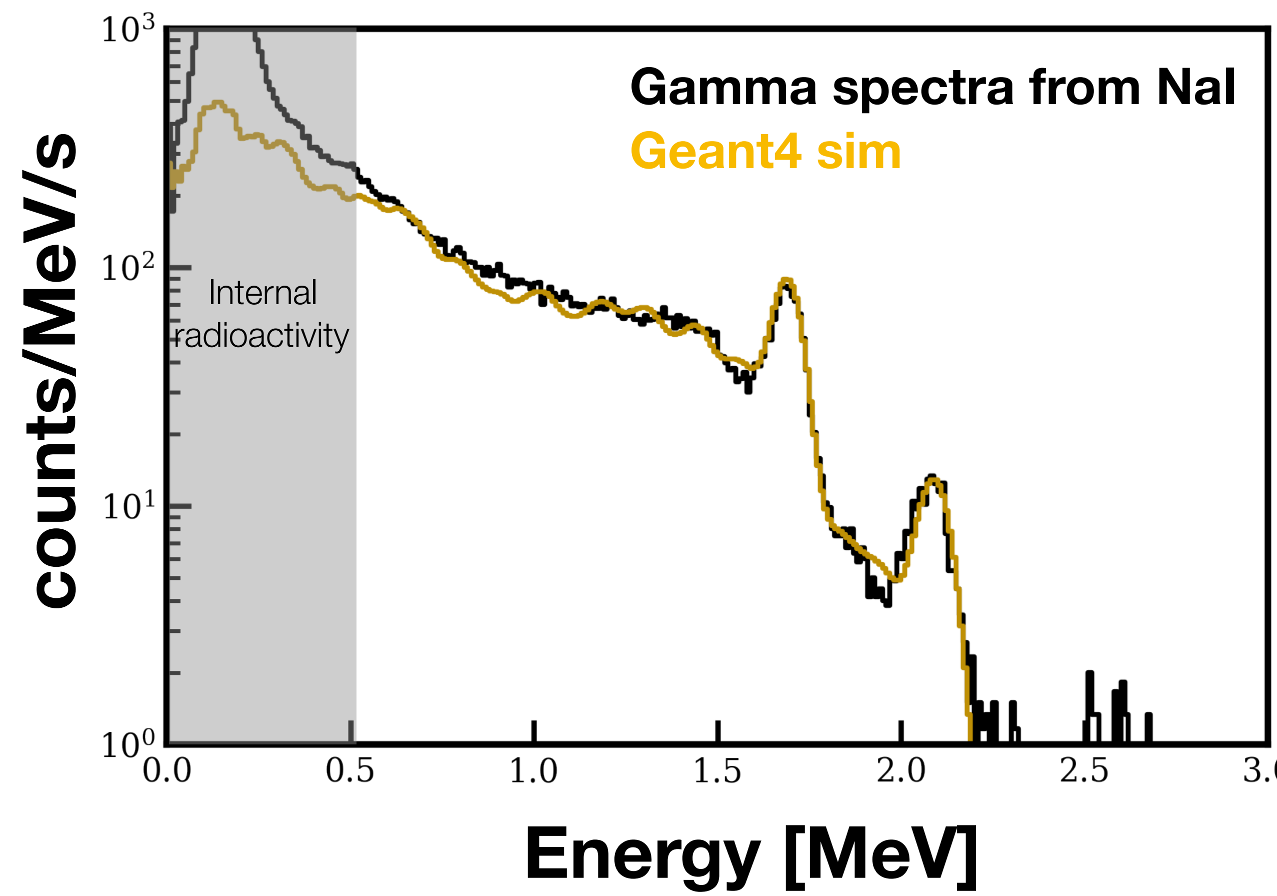


Backgrounds:

- Gammas from ^{124}SbBe and neutron induced gammas
- Gamma tracks ~ cm, high rise time
- Neutron tracks ~ mm, fast rise time

Portable 24 keV neutrons from SbBe at UC, Berkeley





- Neutron rates ~ x2 than rates from simulation
- Gamma rates ~ rates from simulation
- Ongoing plan for calibrating LHe using 24 keV neutrons from ^{124}SbBe

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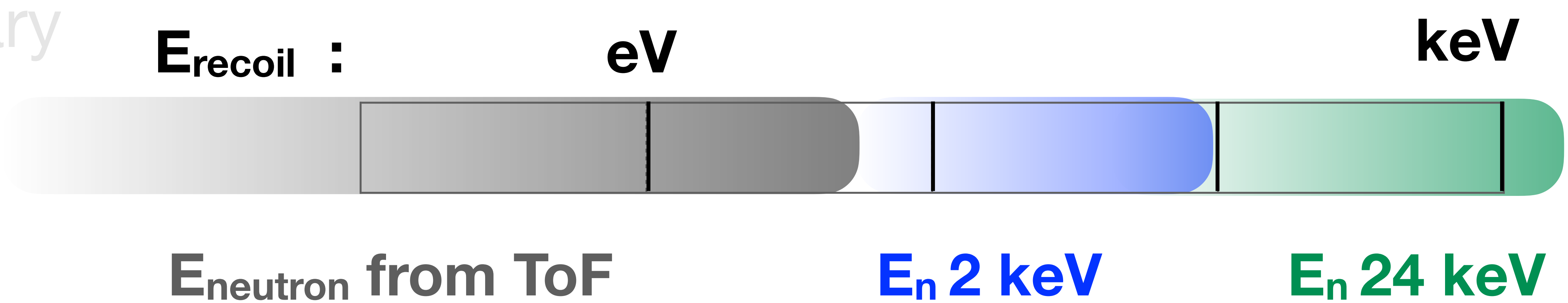
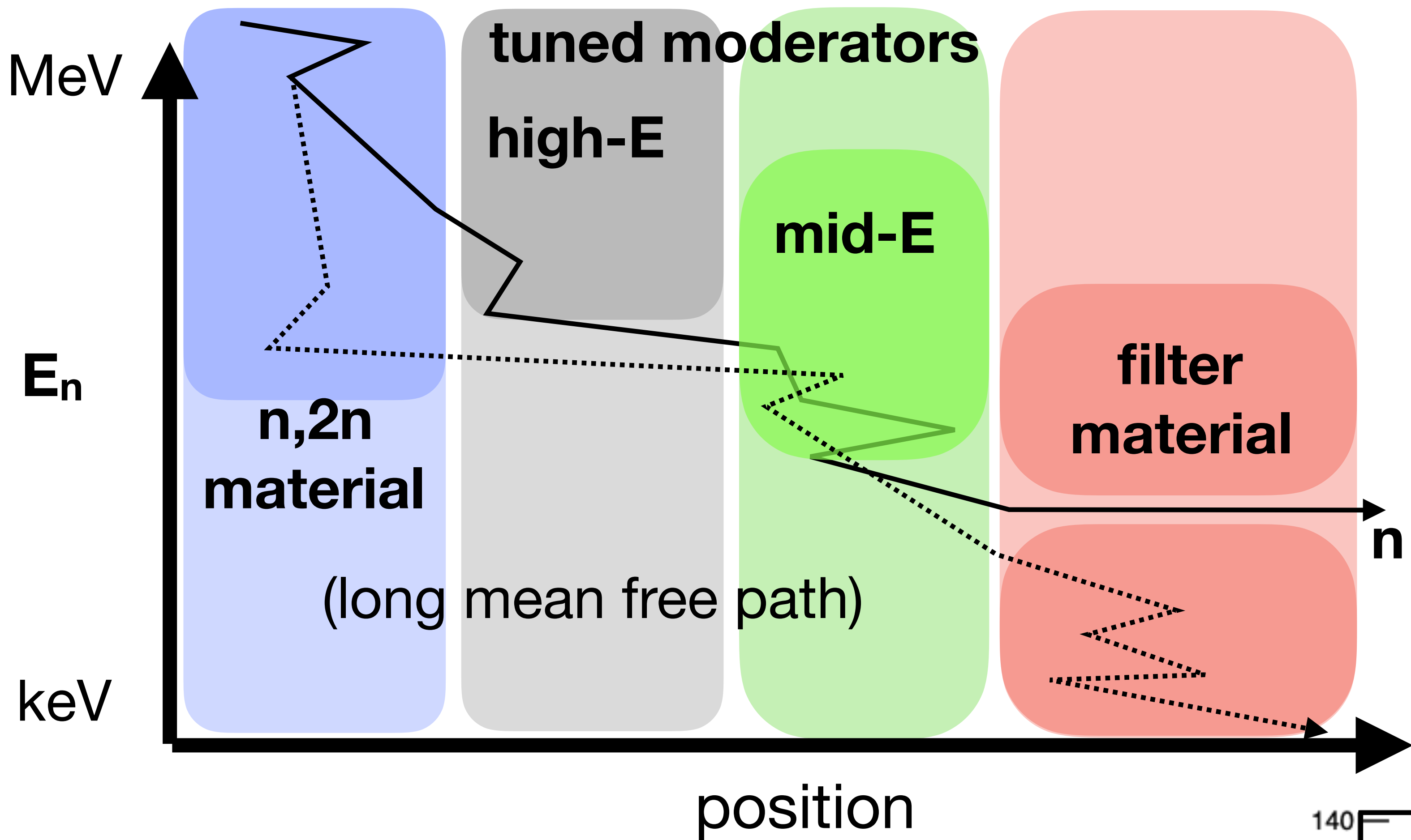
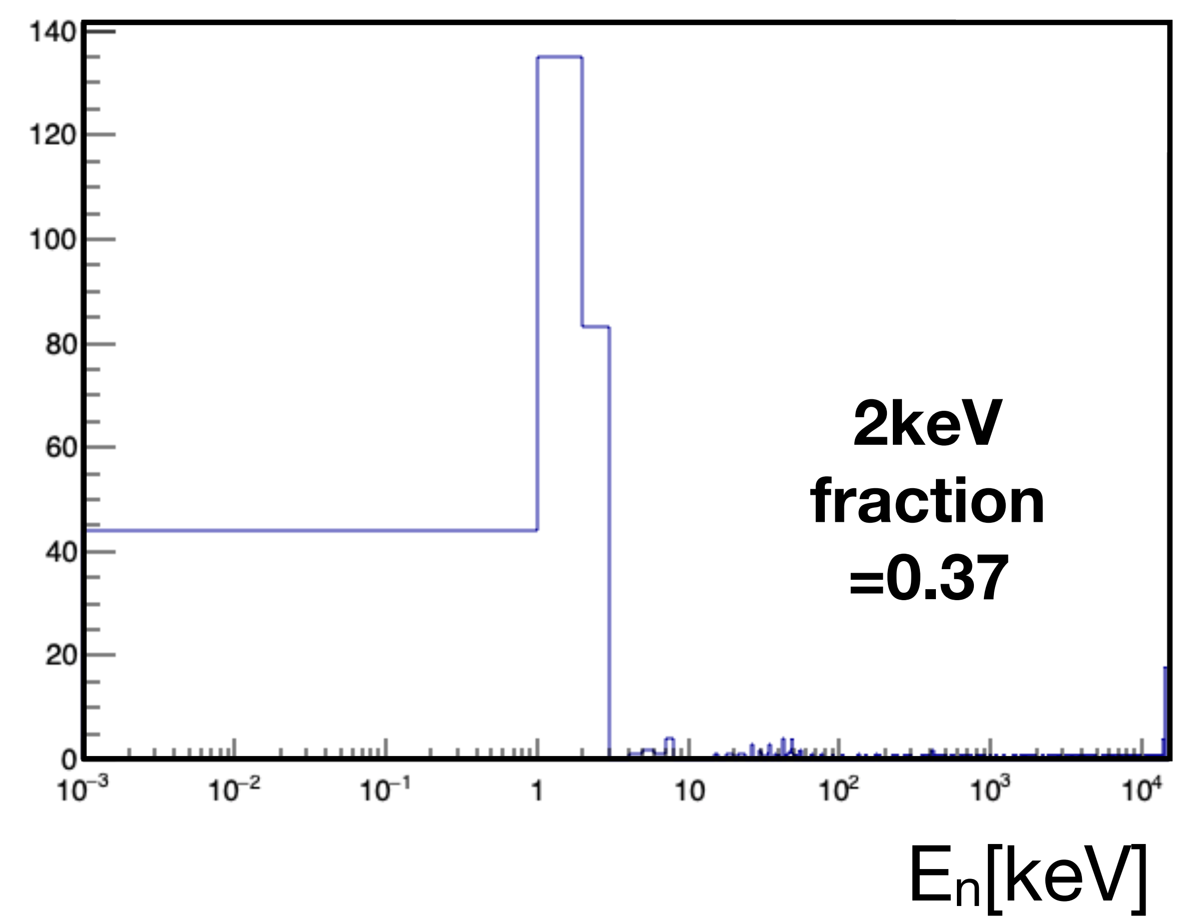


Pulsed 2 keV neutrons from Sc filtered DT neutron



- Start out with 10’s MeV scale neutron
- n-moderators at ~1 MeV energy
- Broad < 10 keV n energy
- Filter materials

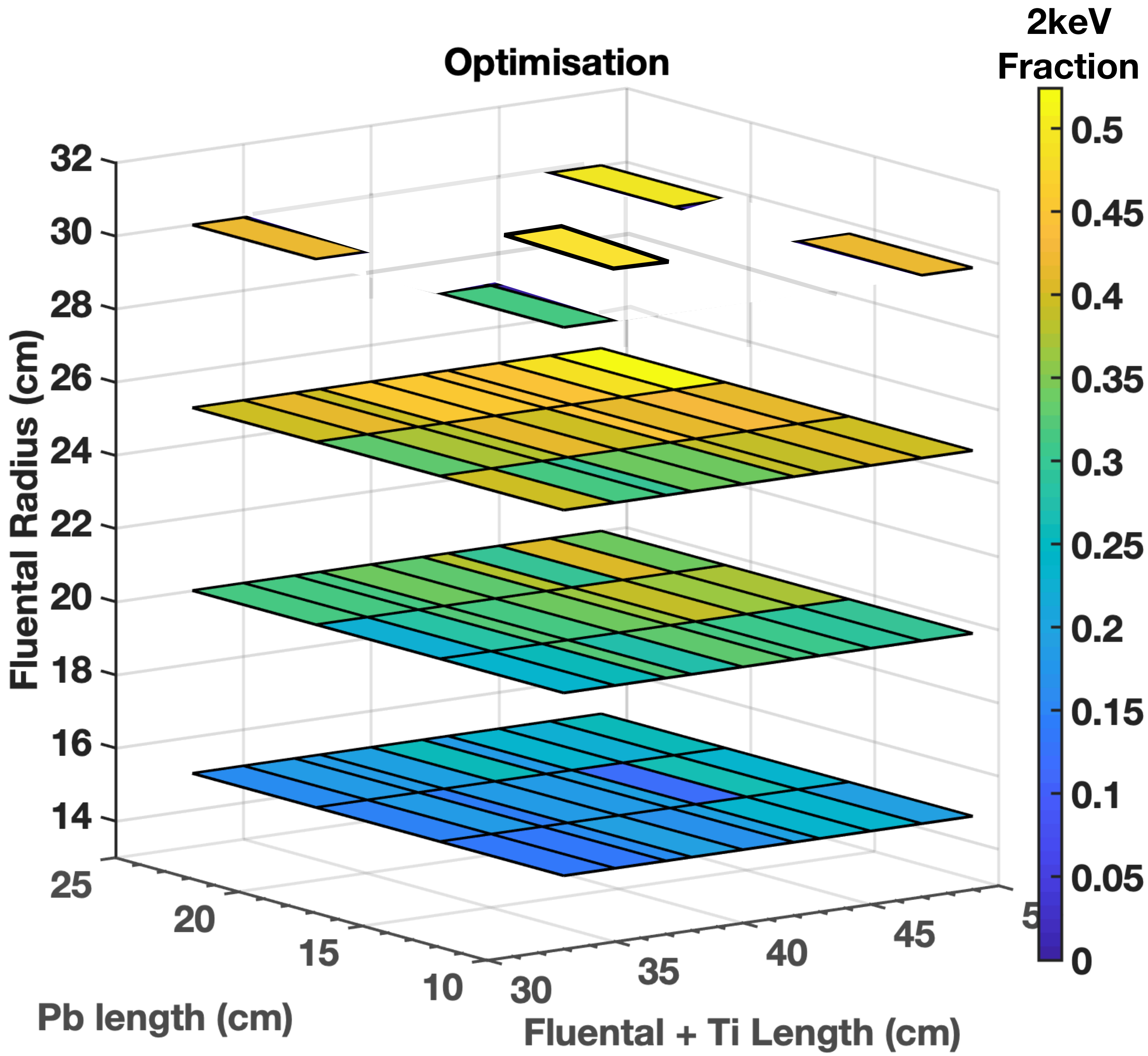
Next step : optimise length and radius of moderators and filter materials, to enchance the 2keV neutron fraction



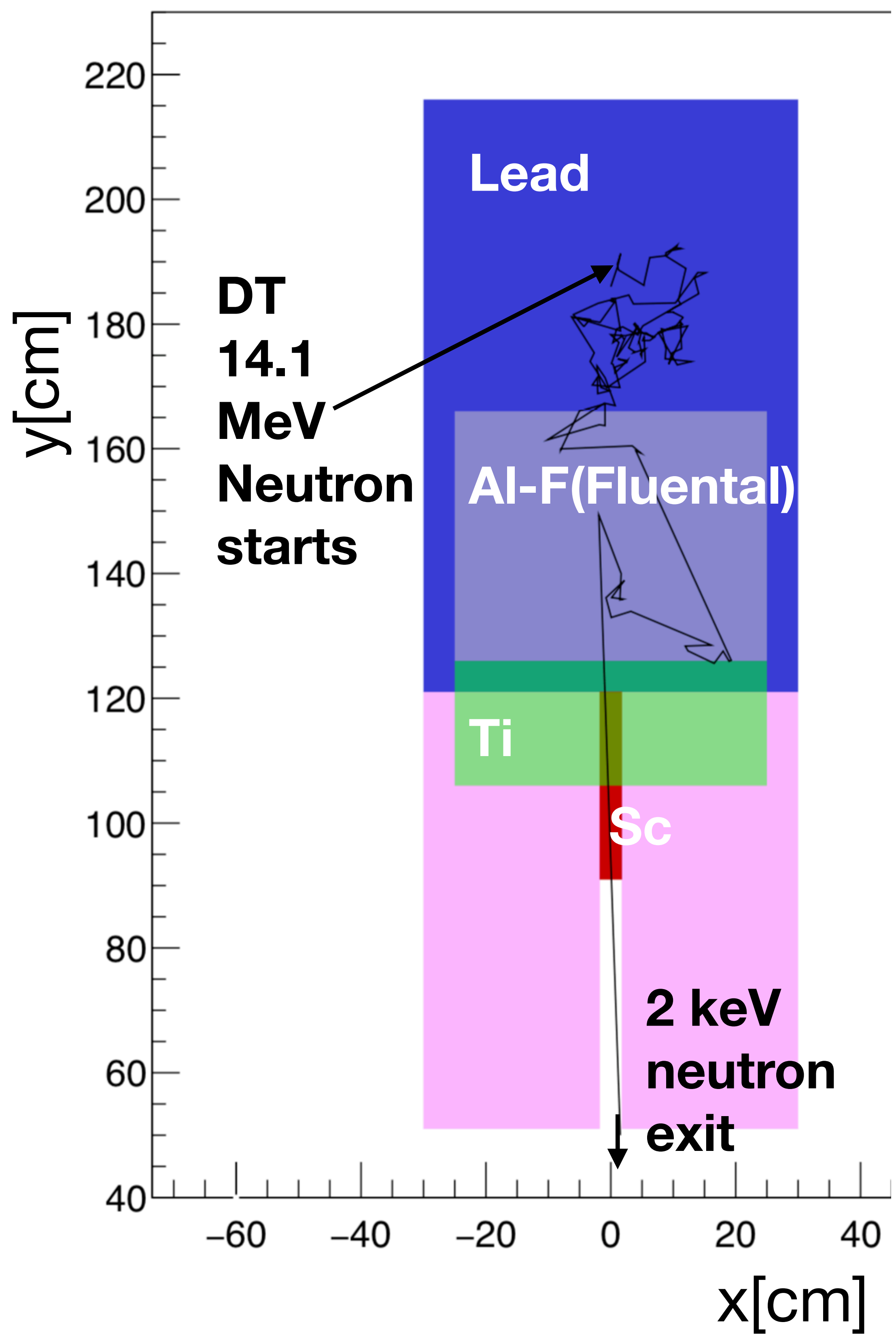
Pulsed 2 keV neutrons from Sc filtered DT neutron

Performed optimisation on:

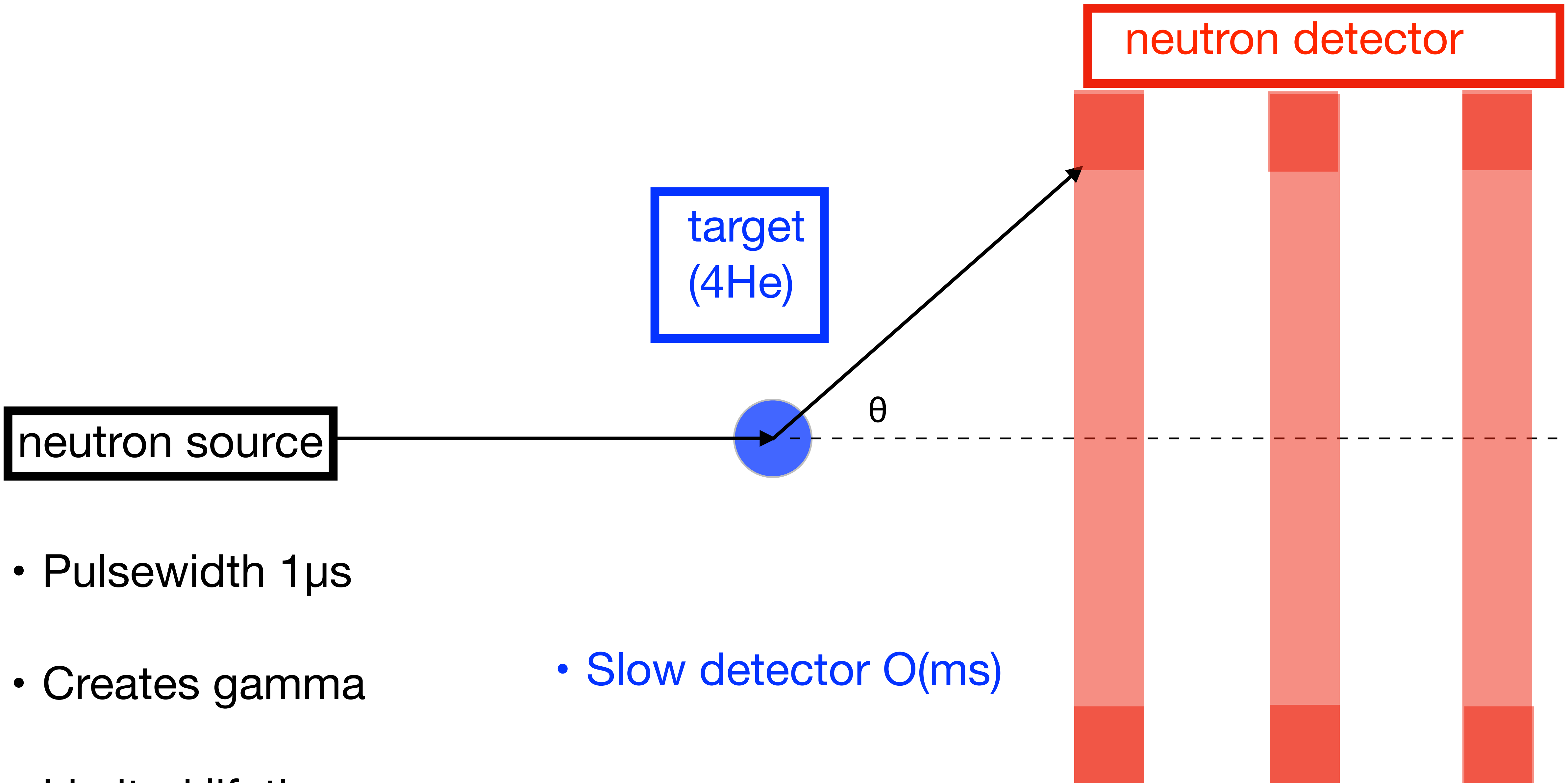
- Fluental Radius
- Pb length
- Fluental+Ti Length



2keV neutron event in geant4



Pulsed 2 keV neutrons from Sc filtered DT neutron

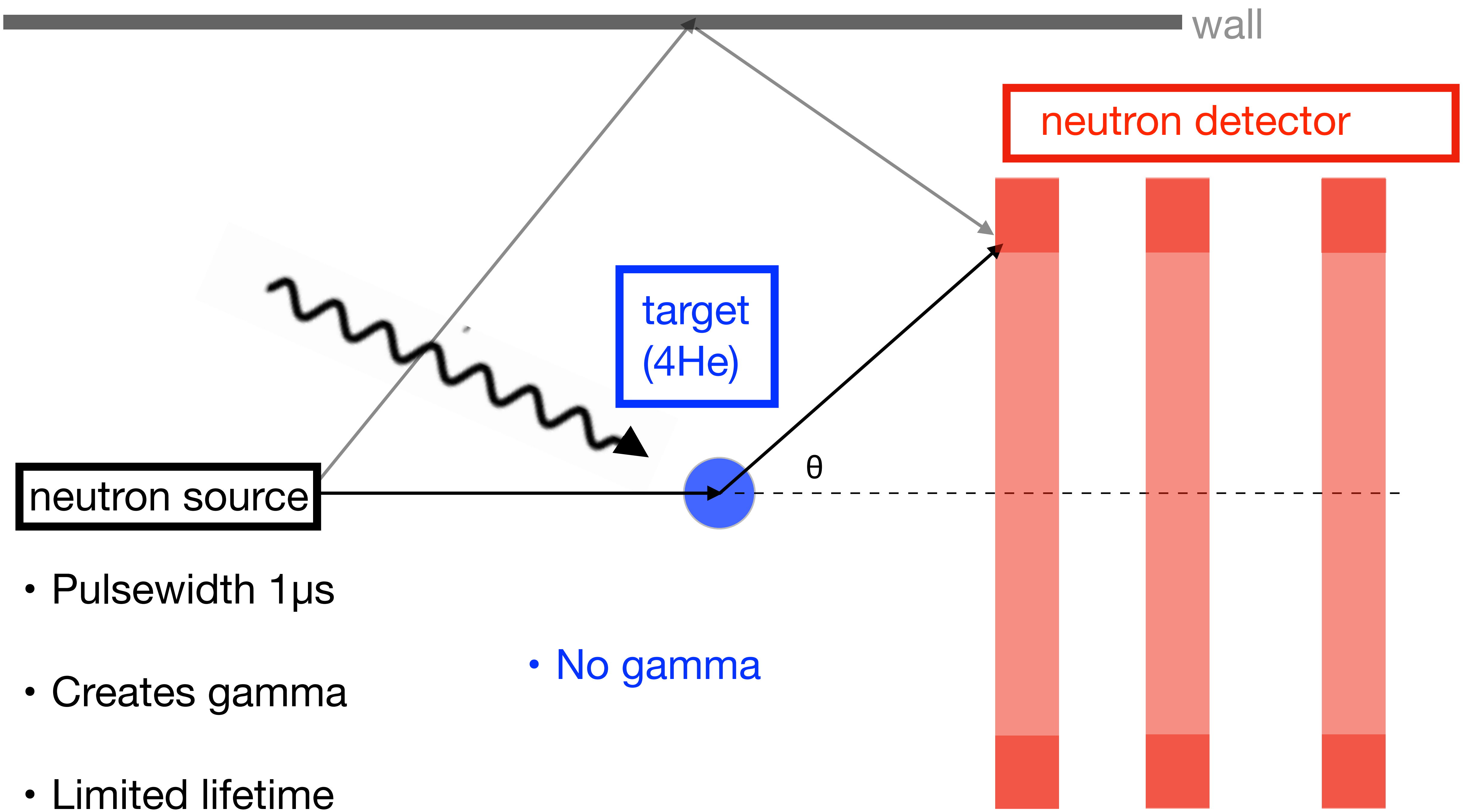


- Pulsewidth 1μs
- Creates gamma
- Limited lifetime

- Slow detector O(ms)

- Avg. detection (capture) time: 10's μs

Pulsed 2 keV neutrons from Sc filtered DT neutron



- Pulsewidth 1μs
- Creates gamma
- Limited lifetime

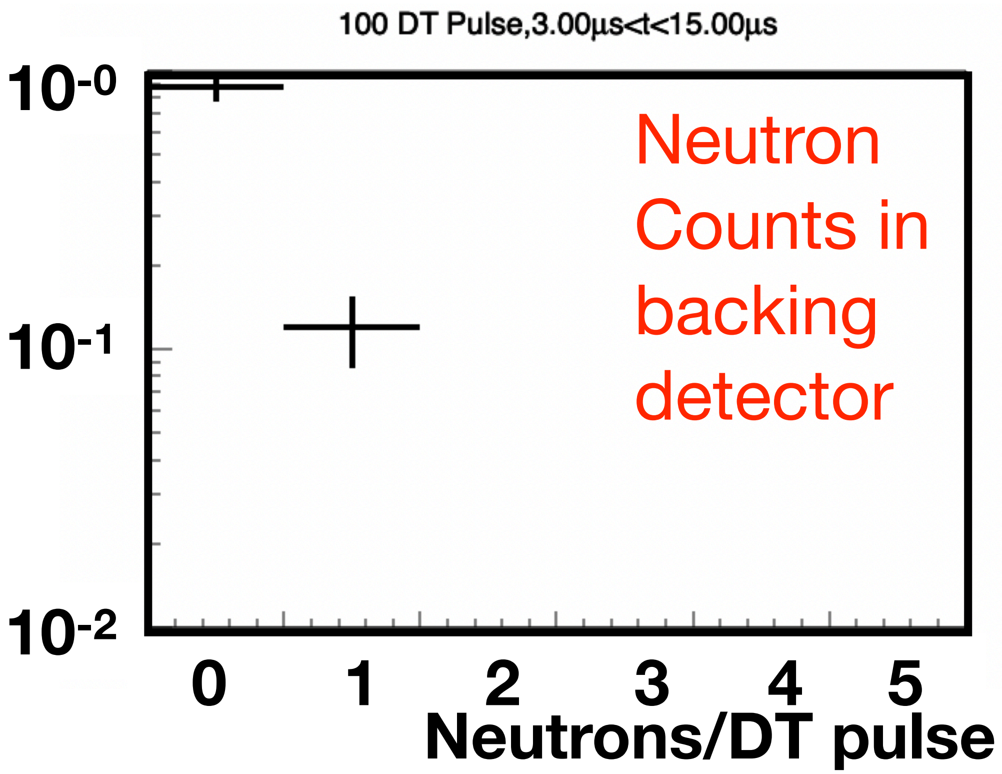
- No gamma

- Useful if only 1 n is tagged per DT pulse in 3μs-15μs window.

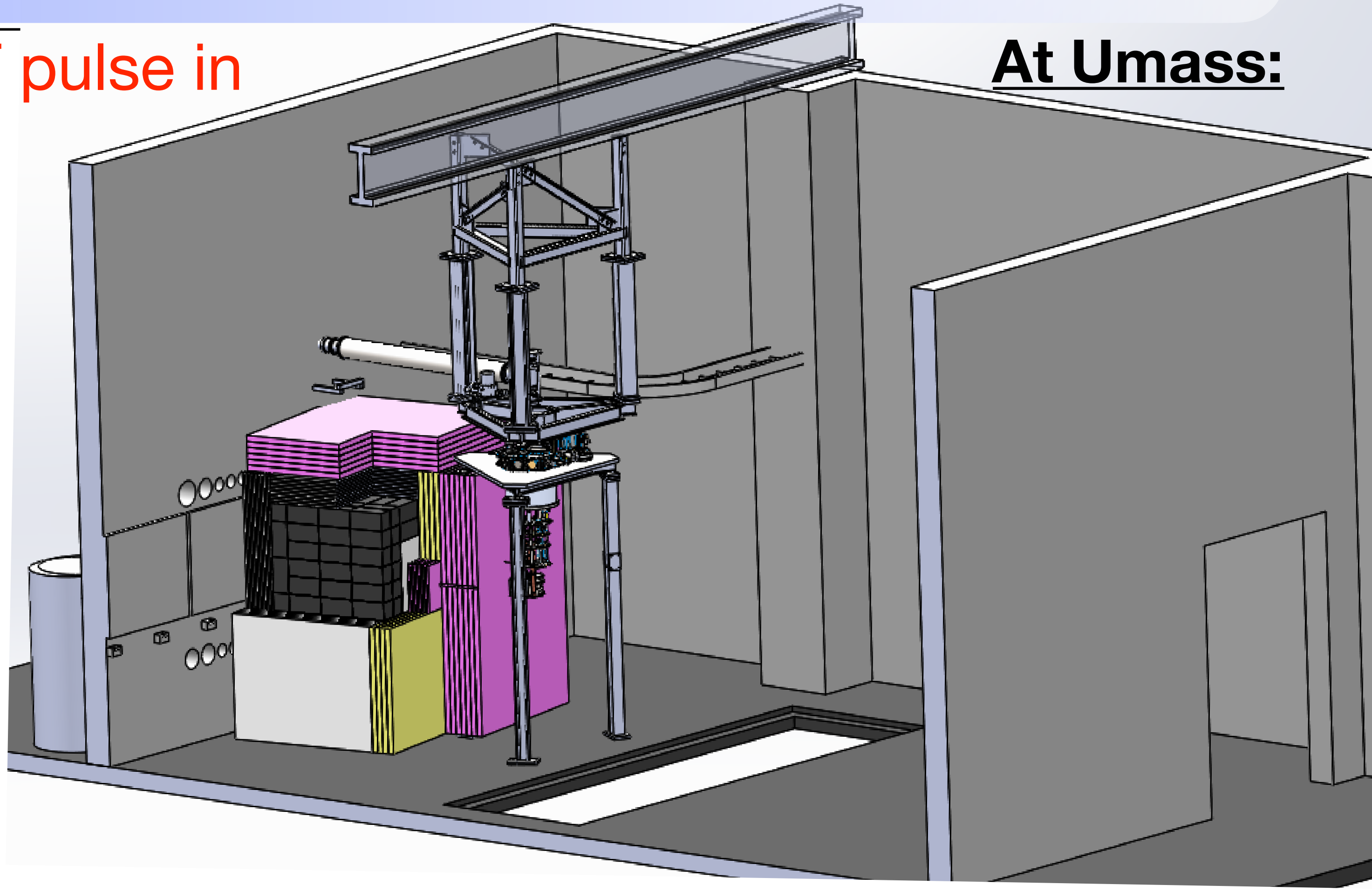
need to reduce n-backgrounds and gamma backgrounds

Pulsed 2 keV neutrons from Sc filtered DT neutron

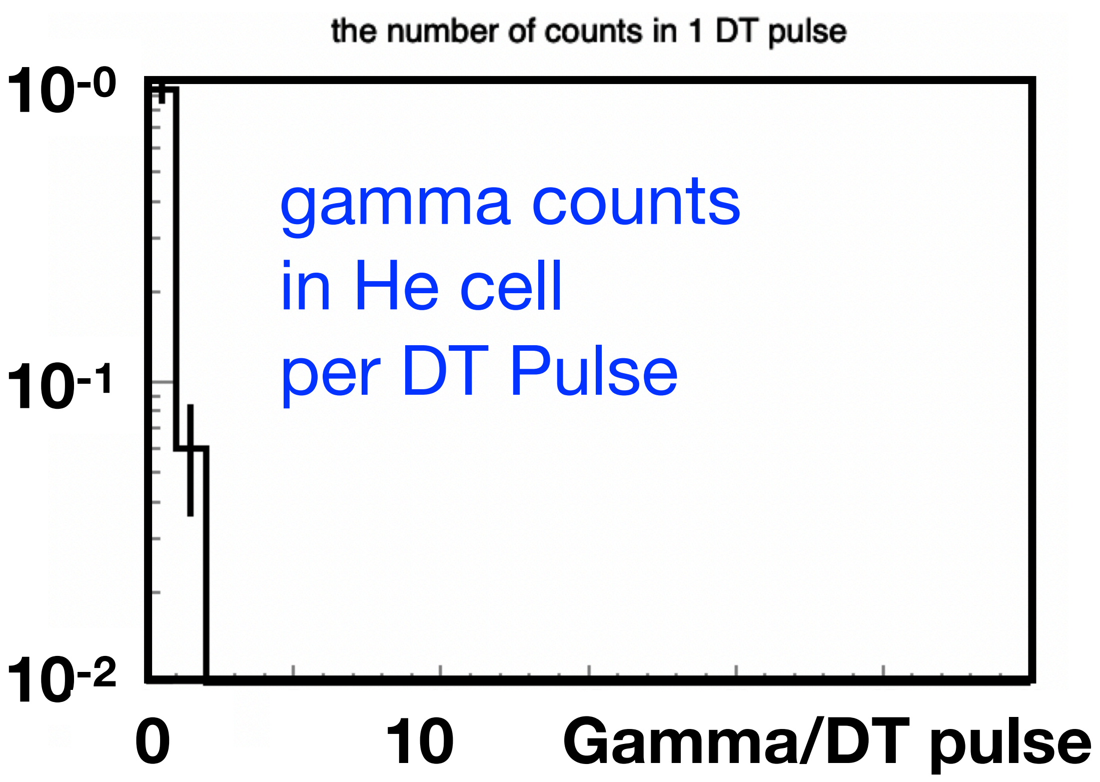
- Useful if only 1 n is tagged per DT pulse in 3μs-15μs window



At Umass:

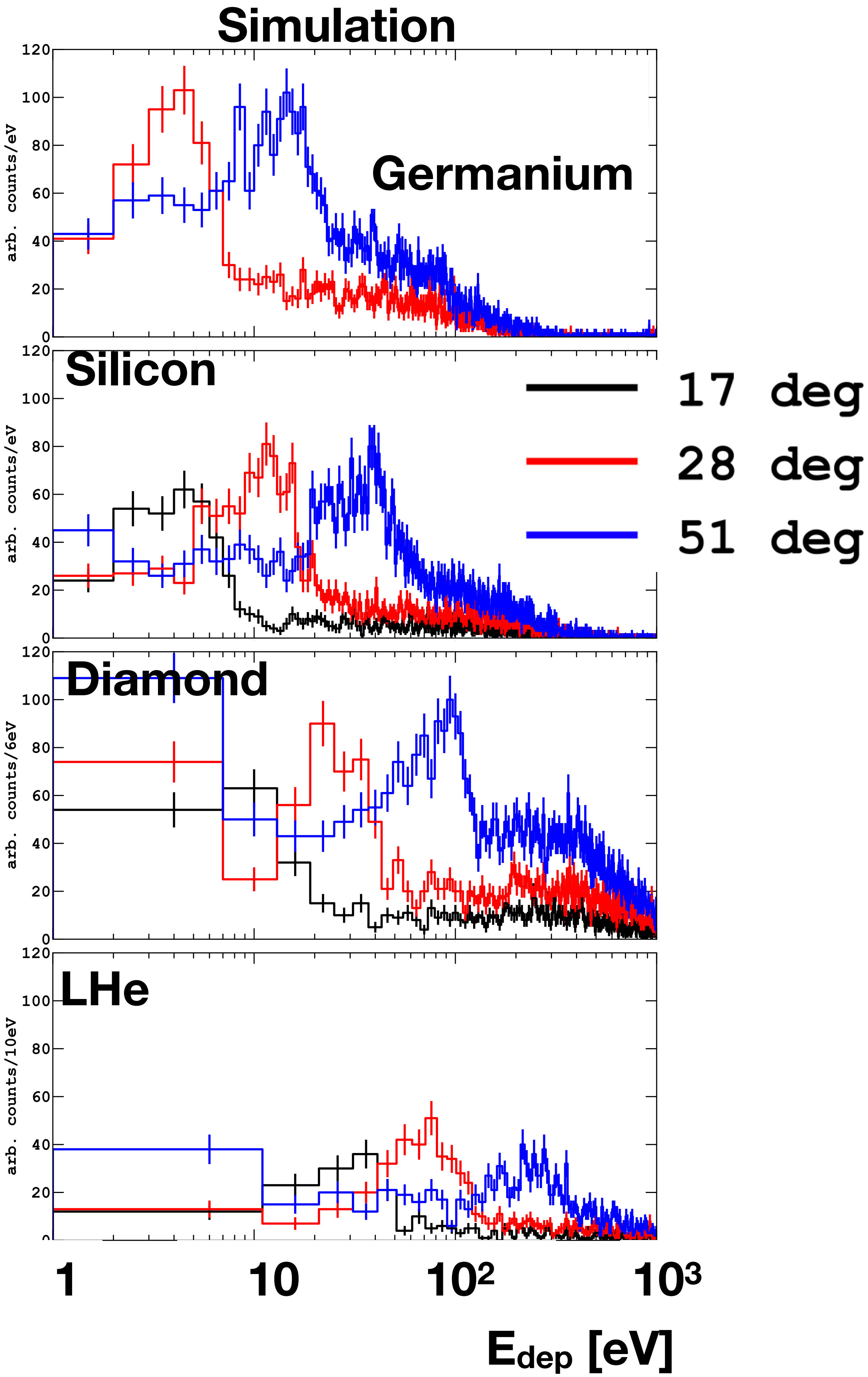


- Useful if only no gamma count in He cell per DT pulse



Gamma rates reduced by placing lead wall infront of the source and Fridge. (not shown in fig)

Pulsed 2 keV neutrons from Sc filtered DT neutron



After :

-Optimising filter geometry parts

-reducing corelated background rates

Now :

-Procurement of various materials

Goal: Turn *on* this low energy calibration facility:

- Diff. targets materials can be calibrated

- Pulsed low energy neutron beam is essential in understanding LHe quasiparticles, triplet kinematics and quenching.

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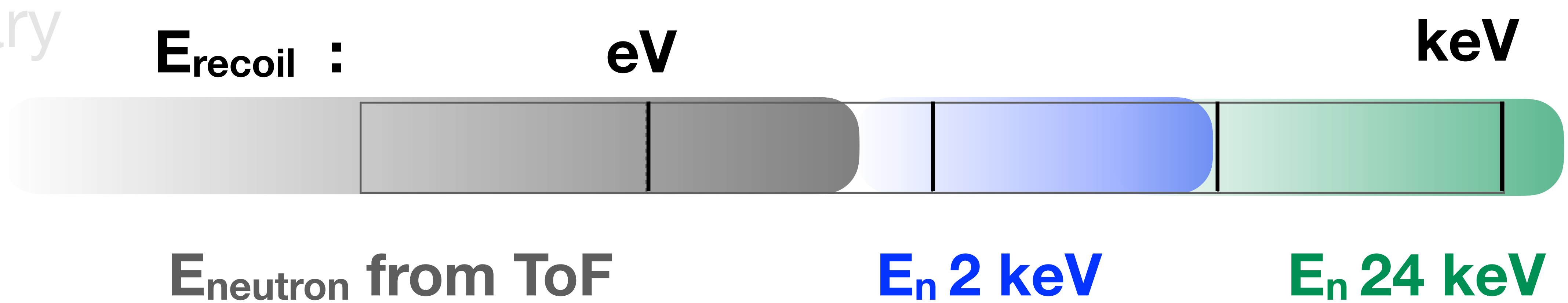
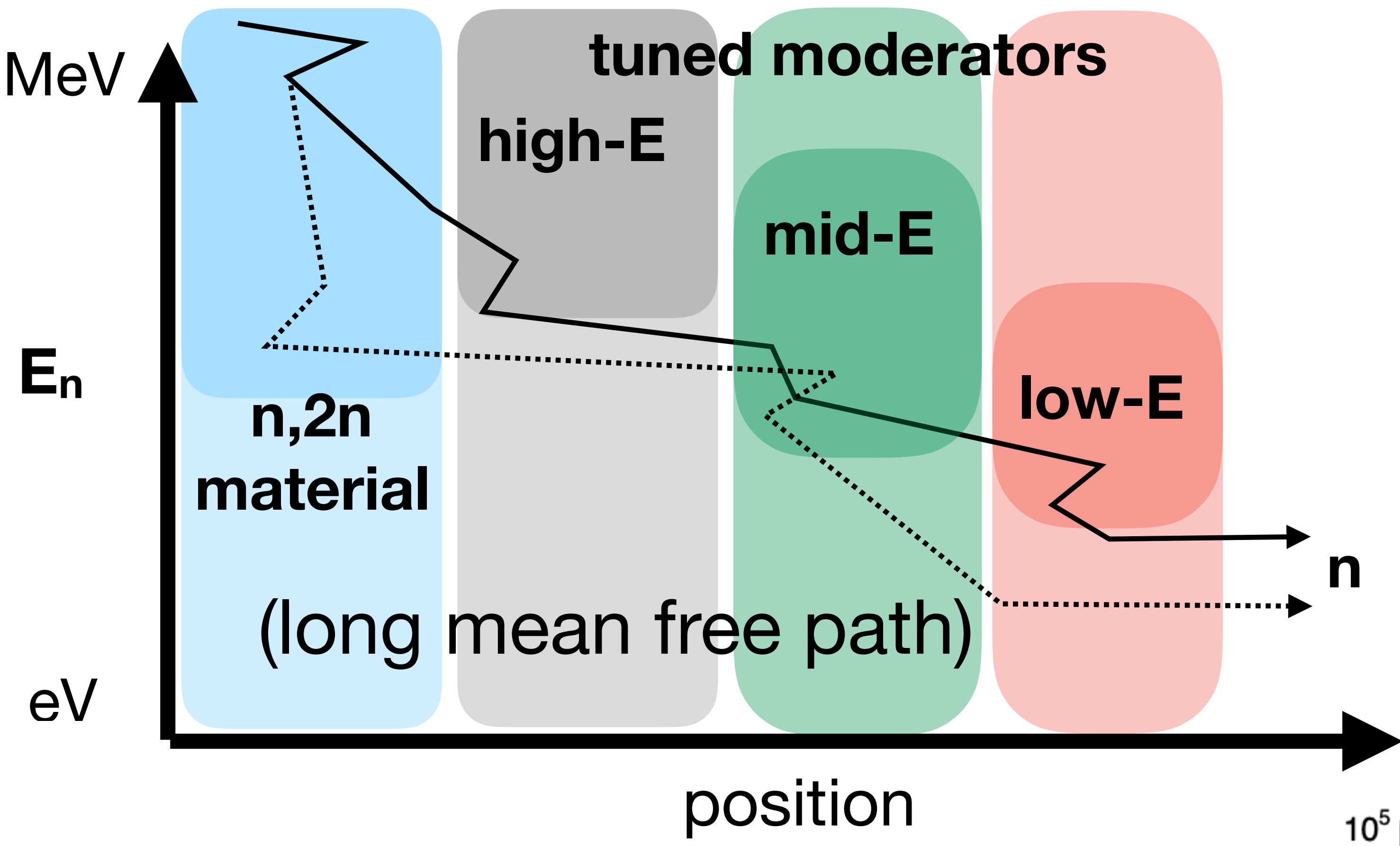
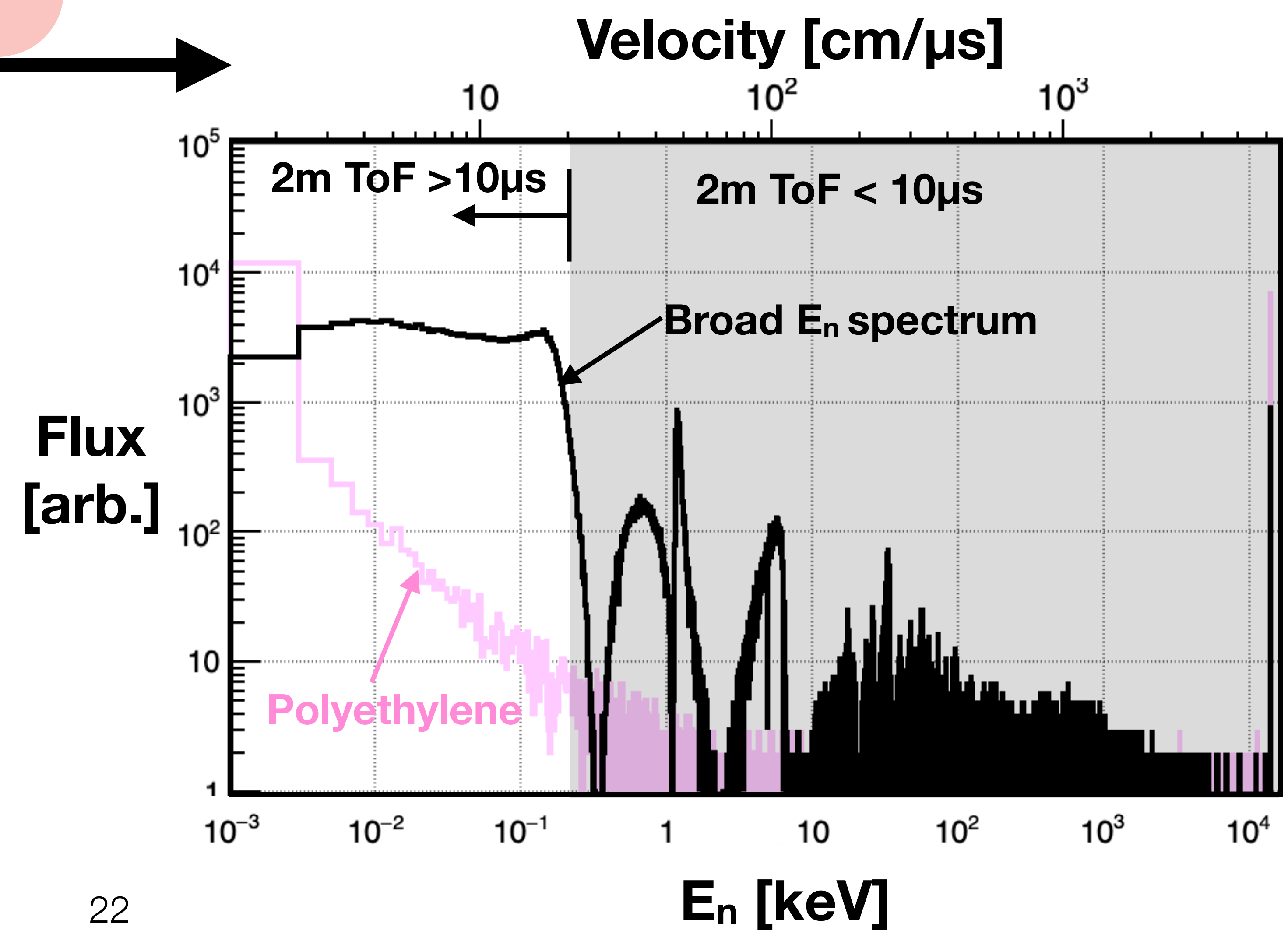


Further lowering NR calibration threshold

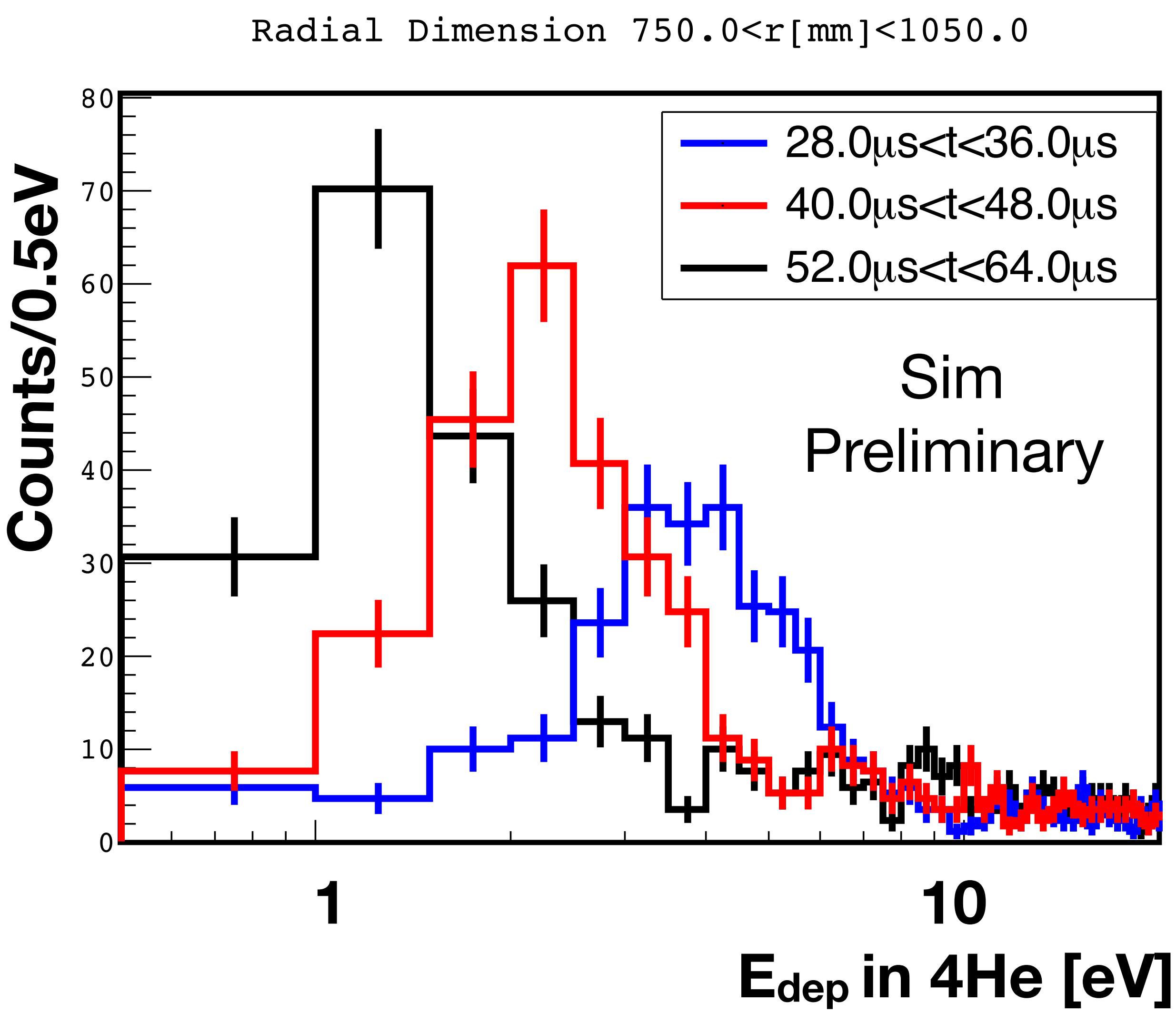


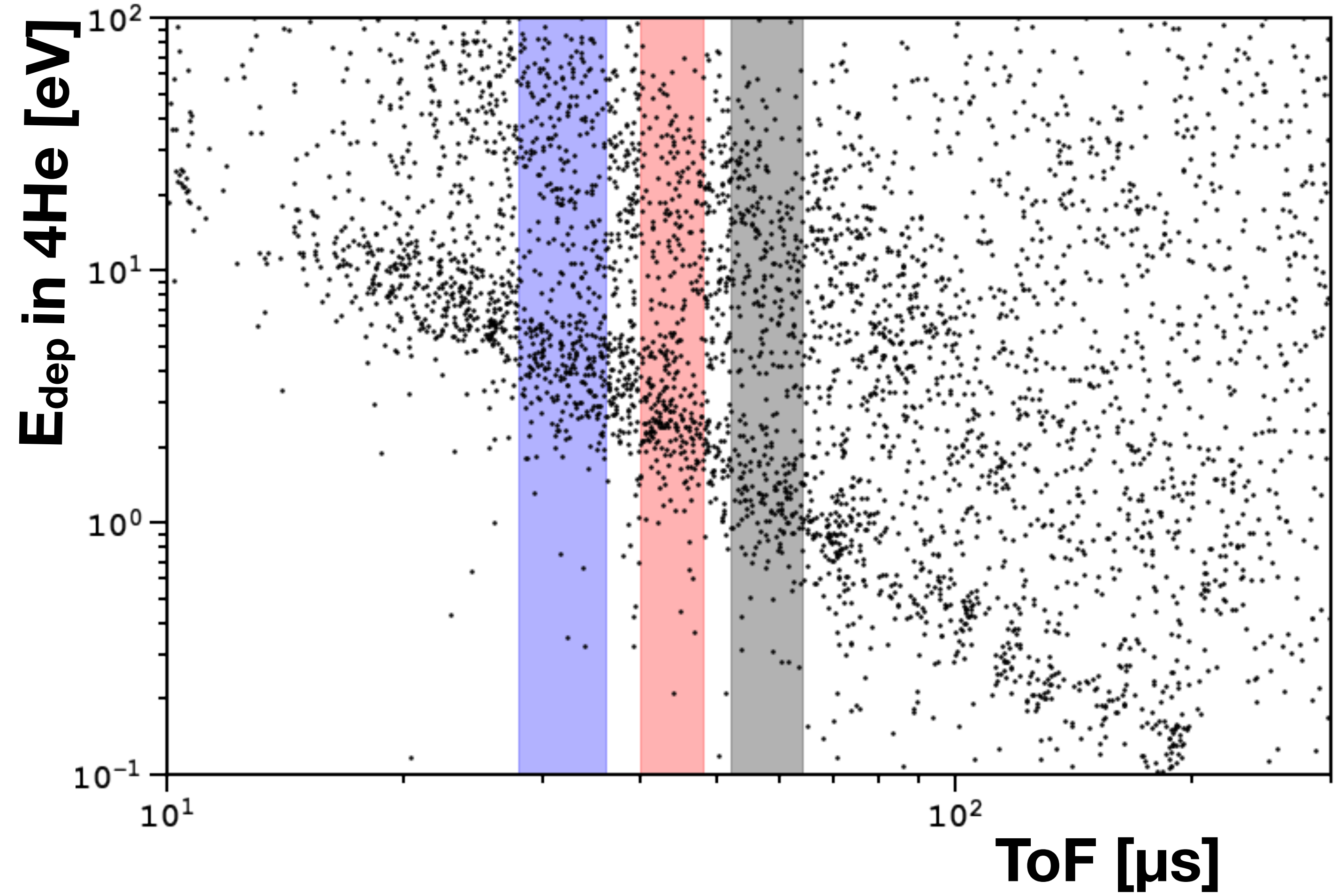
- Concept: replace the Sc filter with additional tuned moderators (including Titanium, Manganese)
- Result: broad E_n spectrum, mostly <200eV

For 1µs timing resolution on backing detetctor, we expect to resolve neutrons based on ToF at a distance of ~2m.



Further lowering NR calibration threshold





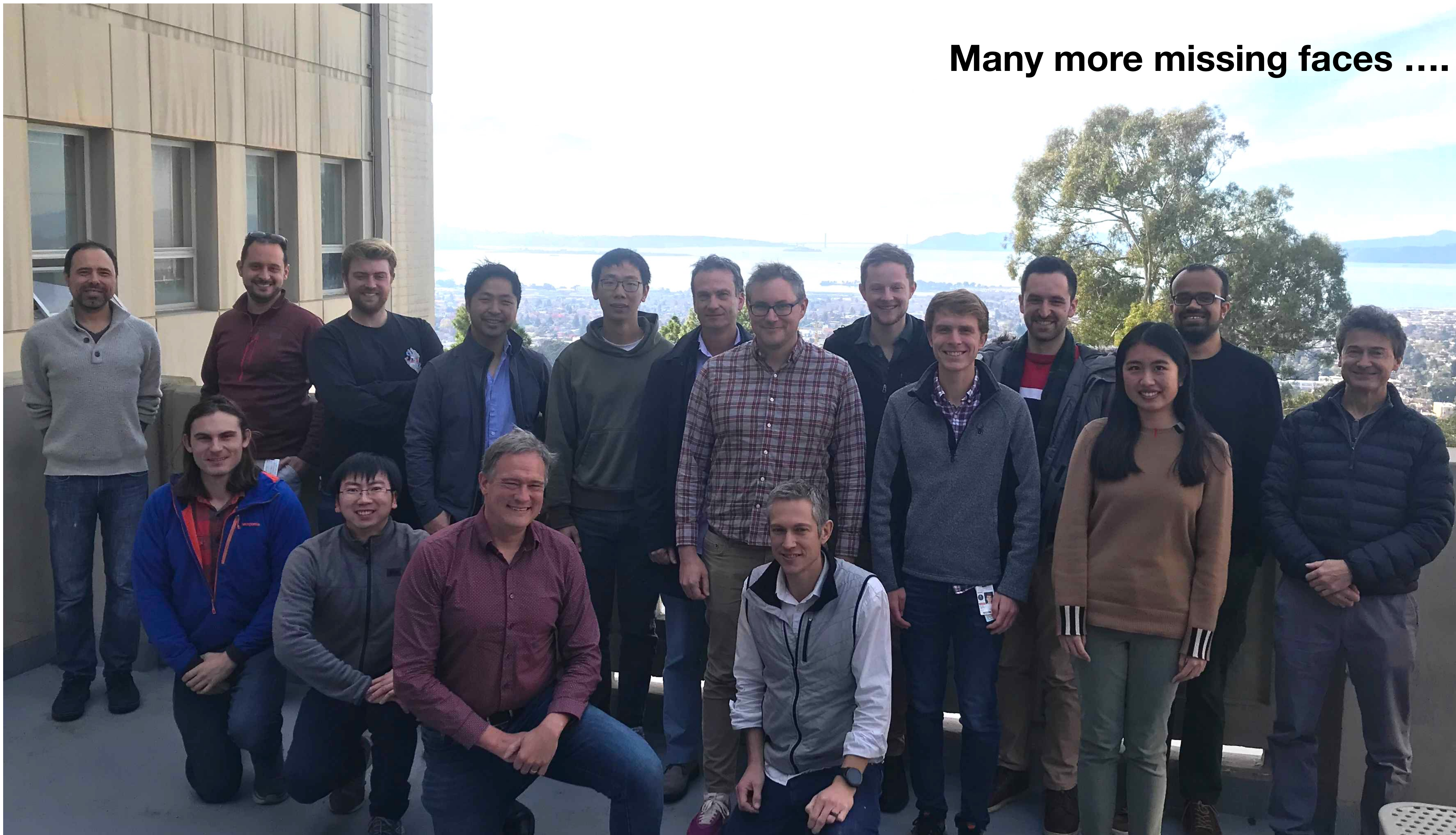
- Clear distinct peaks at 1,3 and 7 eV energy. Helium cell is modeled as a cylinder (r=2.5cm and h =5cm)

- Backing detector angle could be tuned to achieve lower energies in the future sub-eV, one might need to optimize the moderator.

Summary

- Various option for sub-keV NR:
  - demonstrated that we have a working portable 24 keV neutron source from ^{124}SbBe
  - design for Pulsed 2 keV neutrons from Sc filtered DT neutron is ready and we are in process of building it
  - the path of further lowering NR calibration threshold is ready…there could be other interesting ideas too

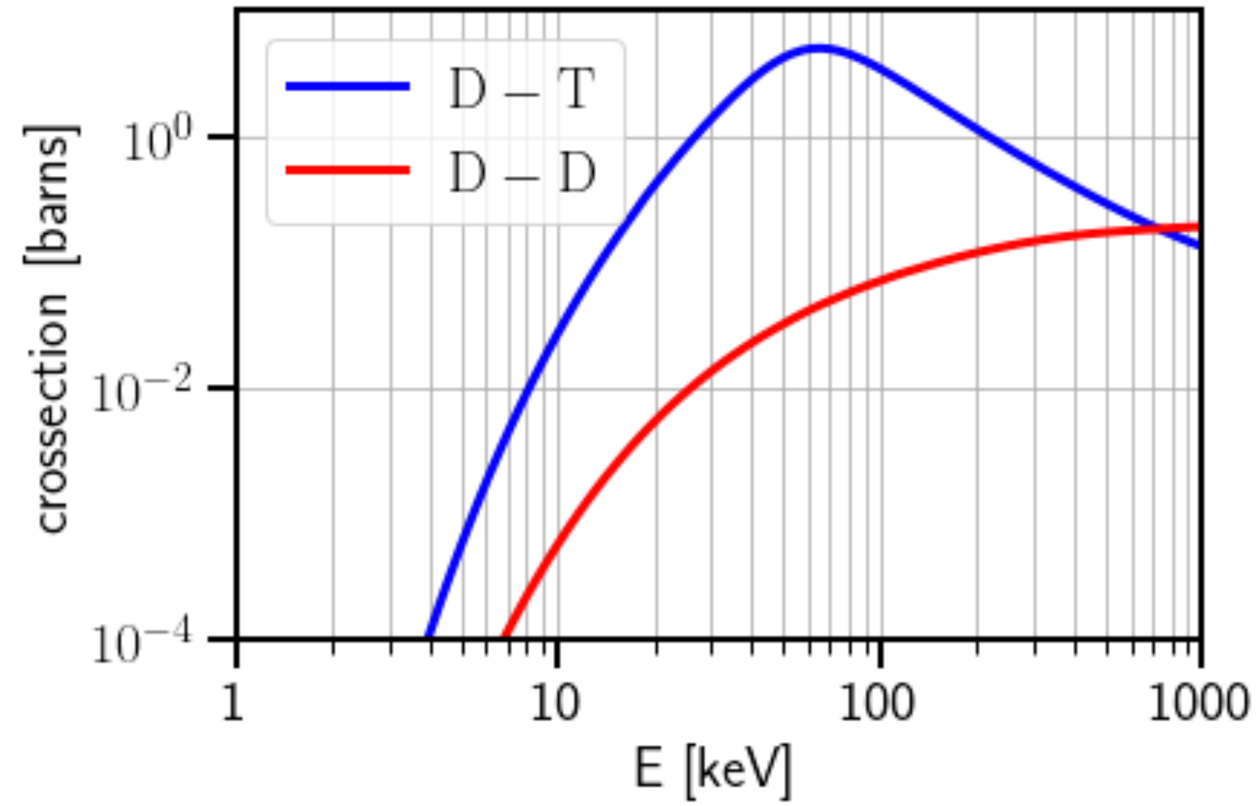
Thank you all for attention!!



Selection of neutron source

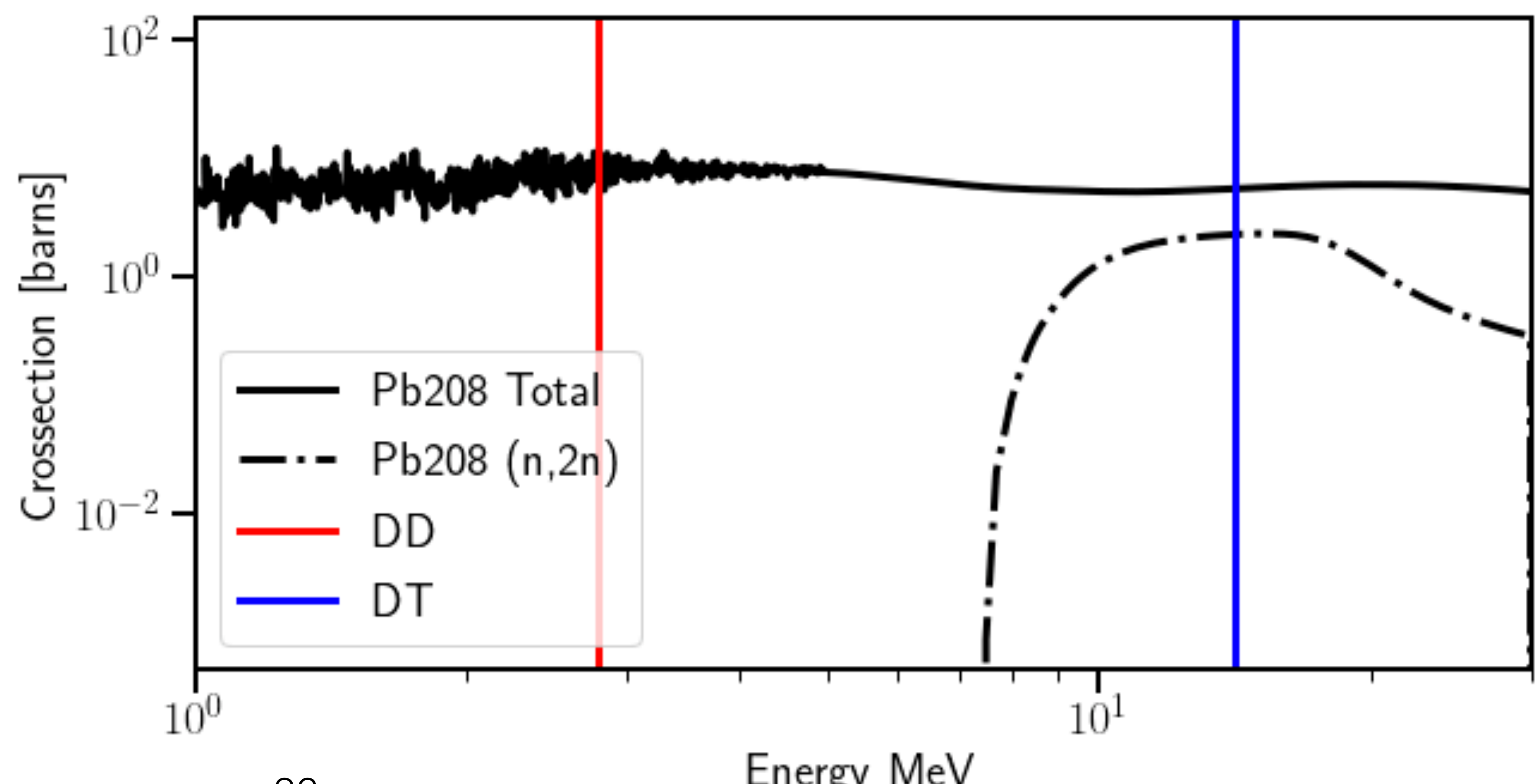
Why DT ?

- DT reaction cross-section is higher
- More neutrons per pulse



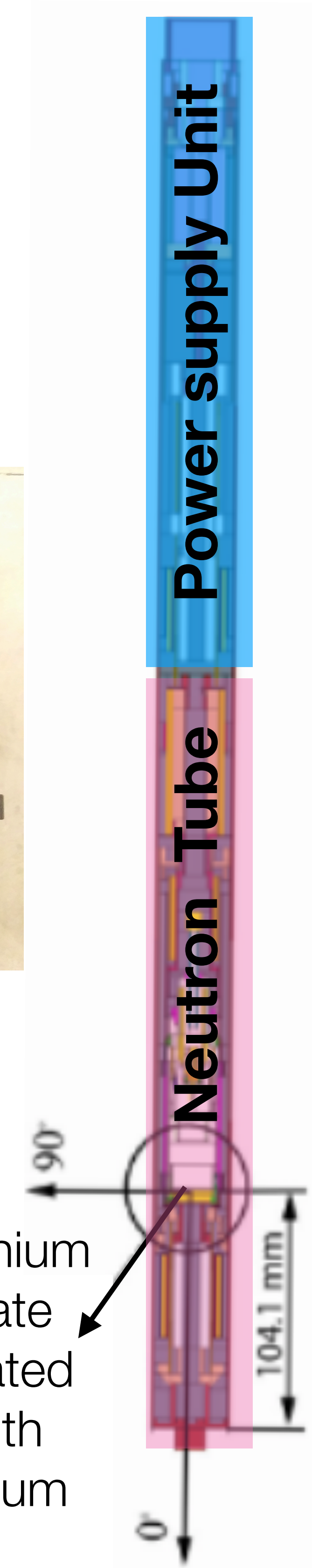
Why Lead?

- n-> 2n cross-section of Pb
- broad < 1 MeV-scale neutron population



- DT reaction: T(d,n)4He, produces neutron of **14.1 MeV**, energy gets smeared.
- Operates in Pulse mode, Pulse width is **0.8µs**.
- Pulse can be trigged externally or internally.
- Maximum pulse generation rate is **50Hz.**
- Cooling period **~ 1hr after 30 min of operation**, if neutron pulse generation rate is > 20Hz.
- Each Pulse has **(1.5+- 0.5)e7** neutrons.
- Lifetime of Neutron generating module: **1e7** pulse.
- Neutron generating module is replaceable

D.Chernikova et al (nima.2014.01.061)

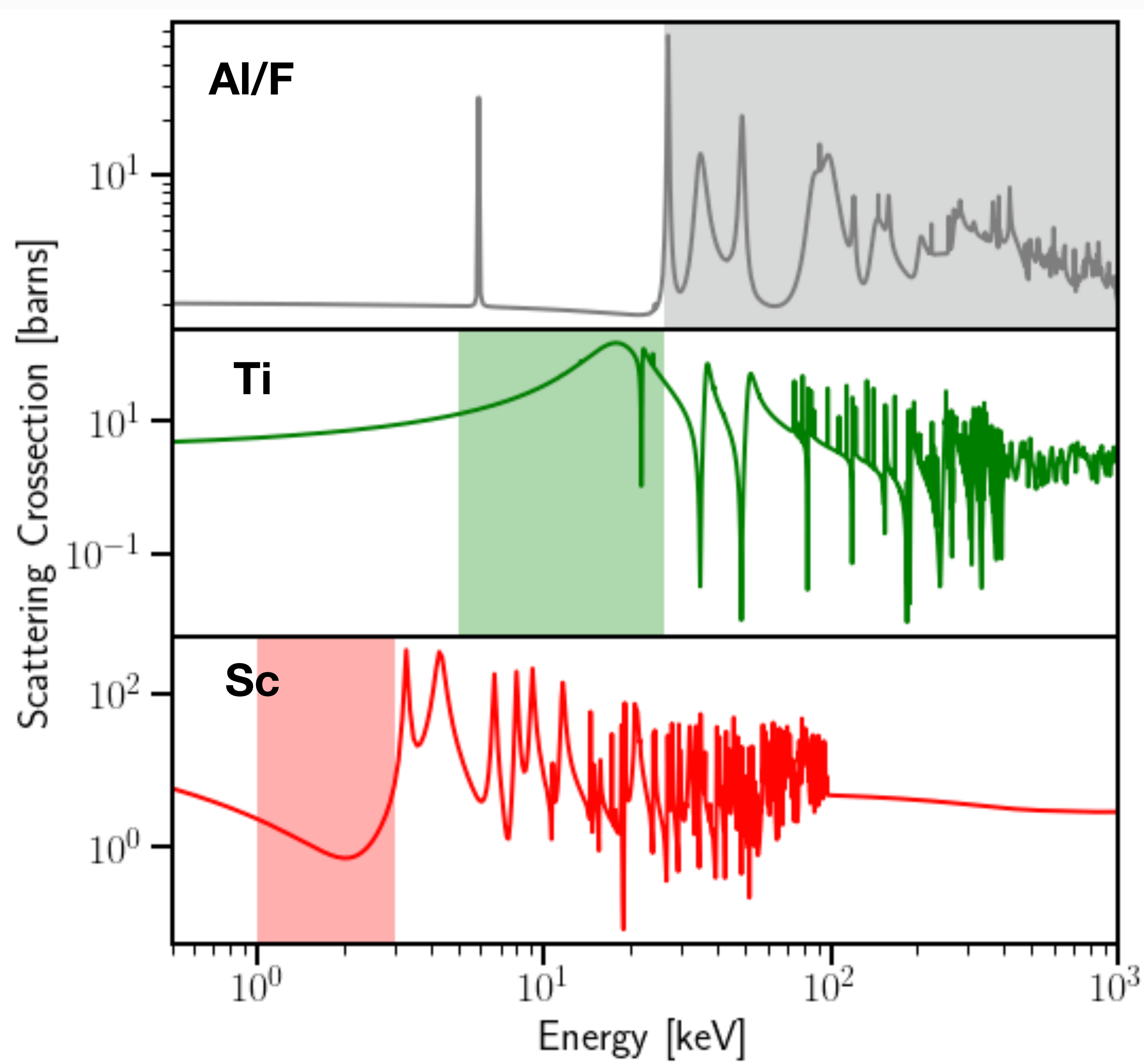


Sacttering Cross-section of various material

- Al/F mixture, with complementary resonances

- Titanium has large scattering cross-section at 20 keV

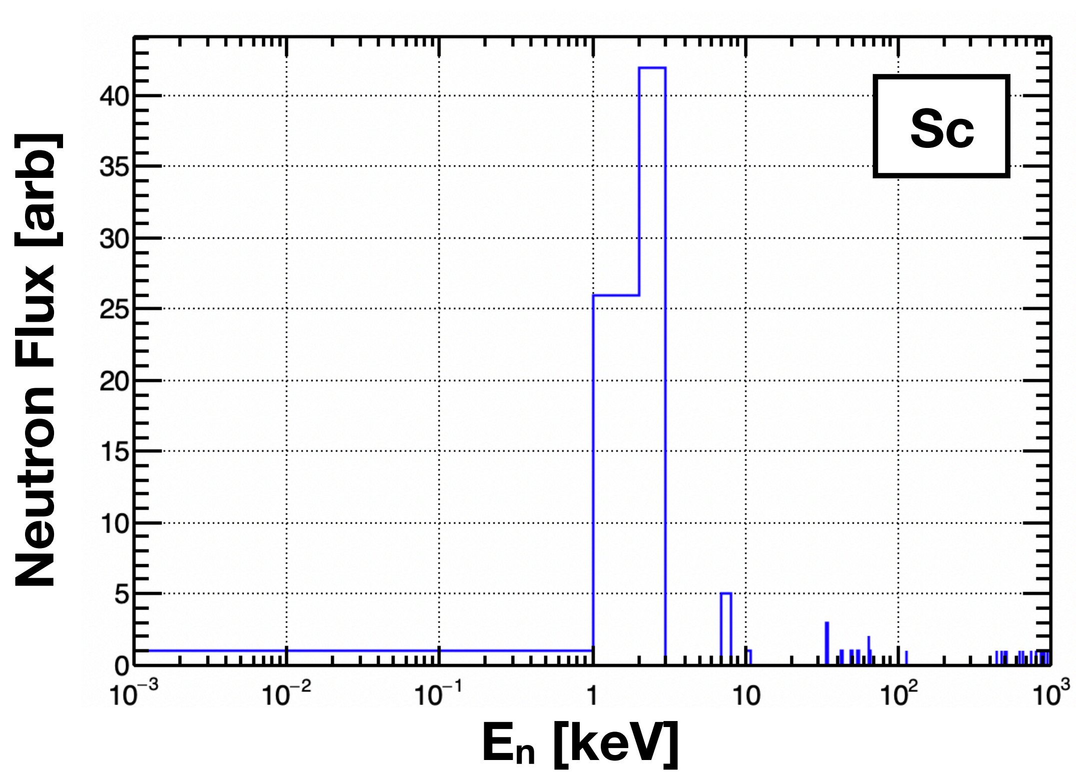
- Sc, has dip in cross-section at 2 keV

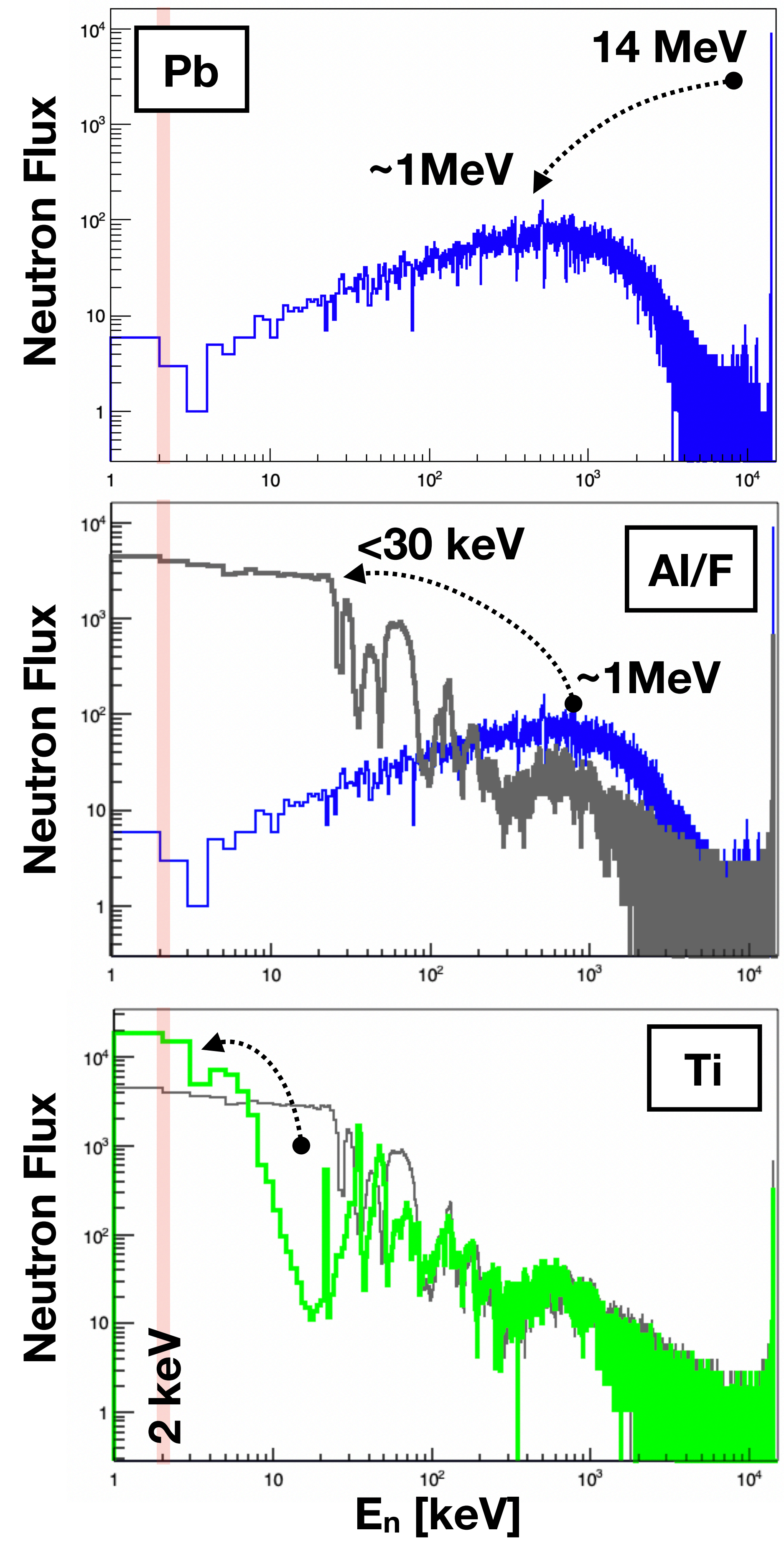


Sc filter (2 keV)

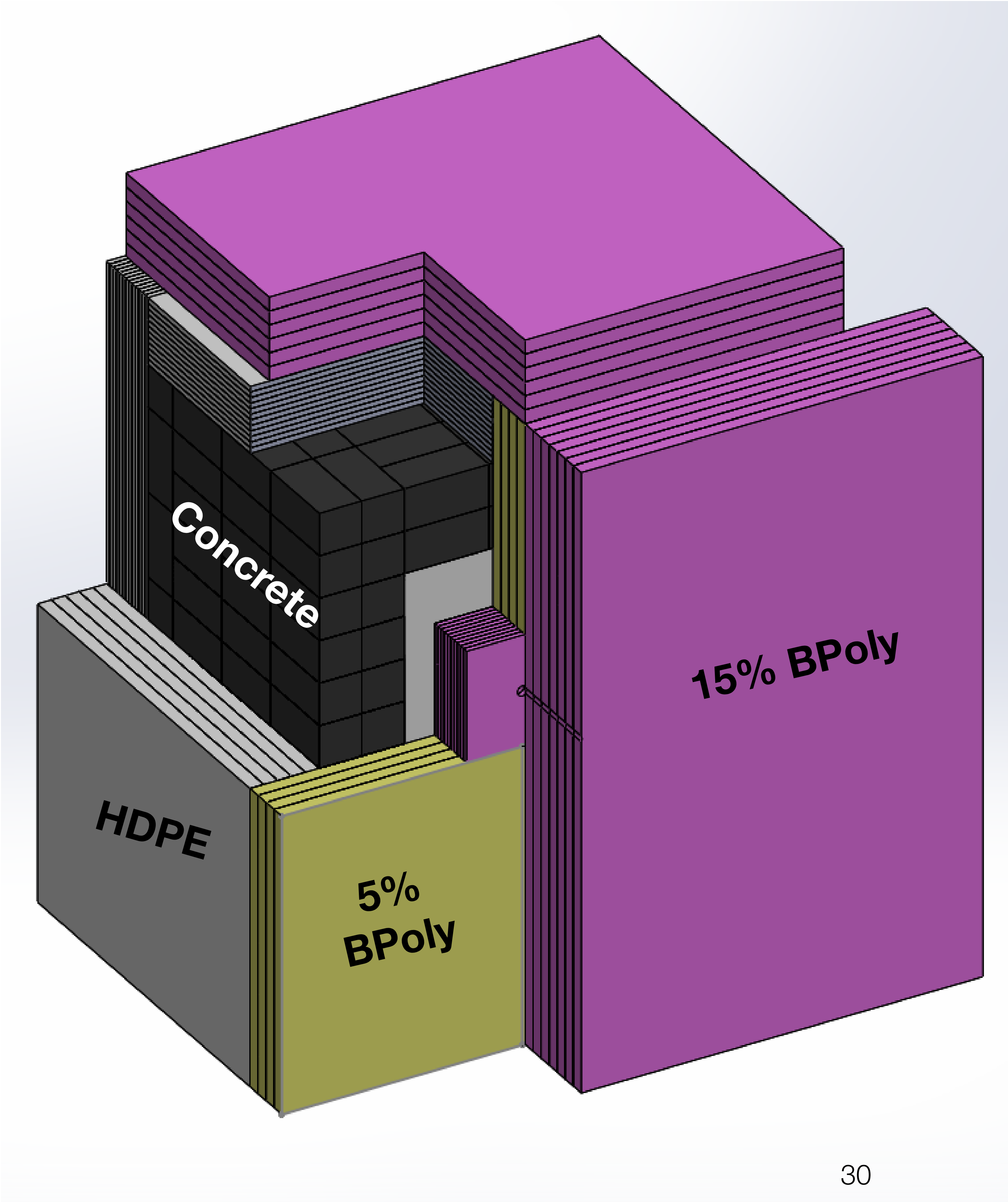
Simulations again show each step performing its role.

Flux is more of a challenge, but sufficient.





Pulsed 2 keV neutrons from Sc filtered DT neutron



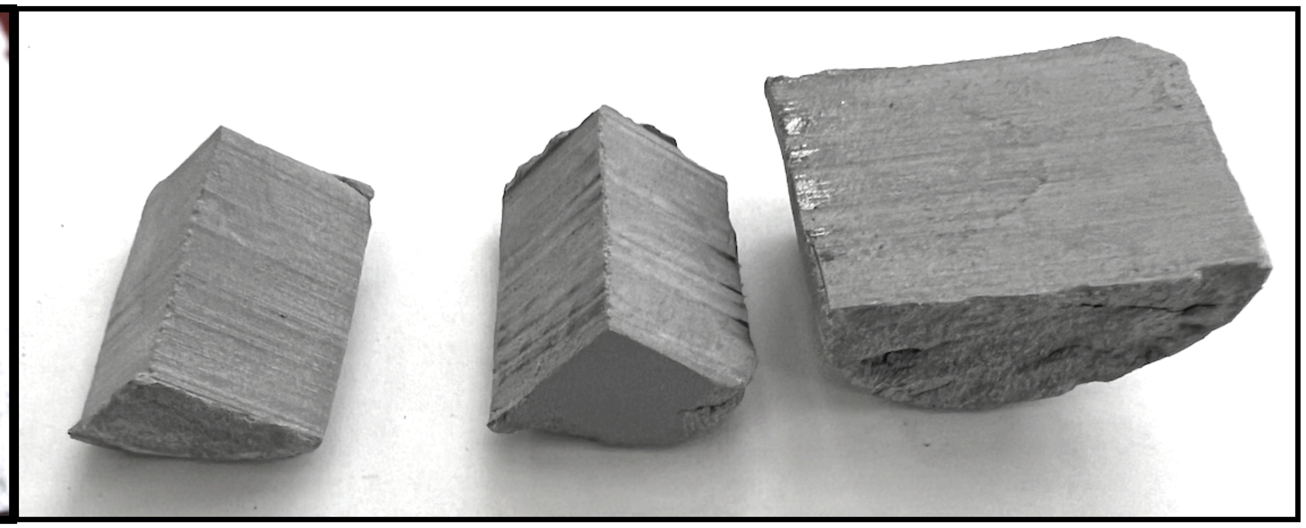
Reiterated various design, but the sandwich of high-z and low-z materials performs better.

Progress made on Fluental side

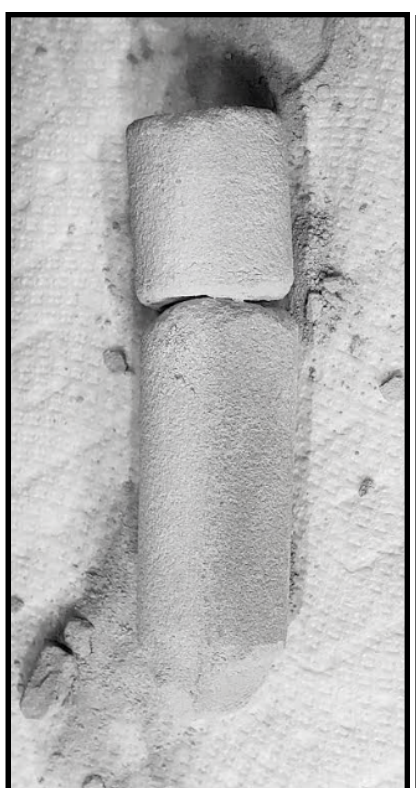
Fluental or Al and F mixture:

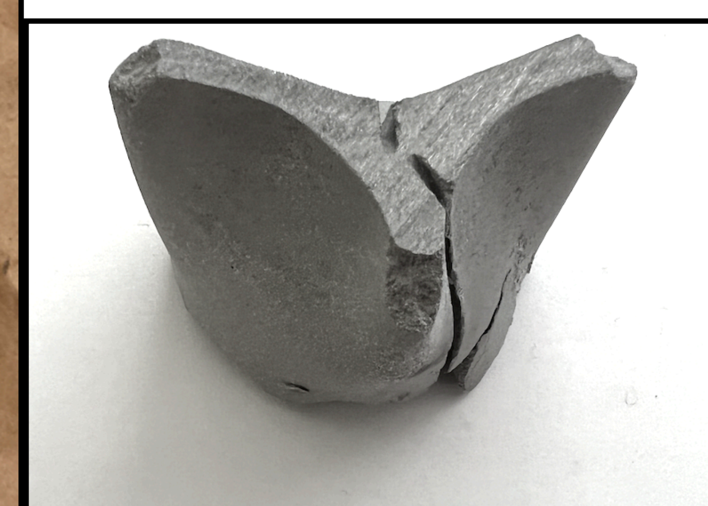
- *our* version of Fluental (roughly 8K for the process+ raw materials+cans):

  - Only HIP part density ~ 2.4 +-0.1 g/cc

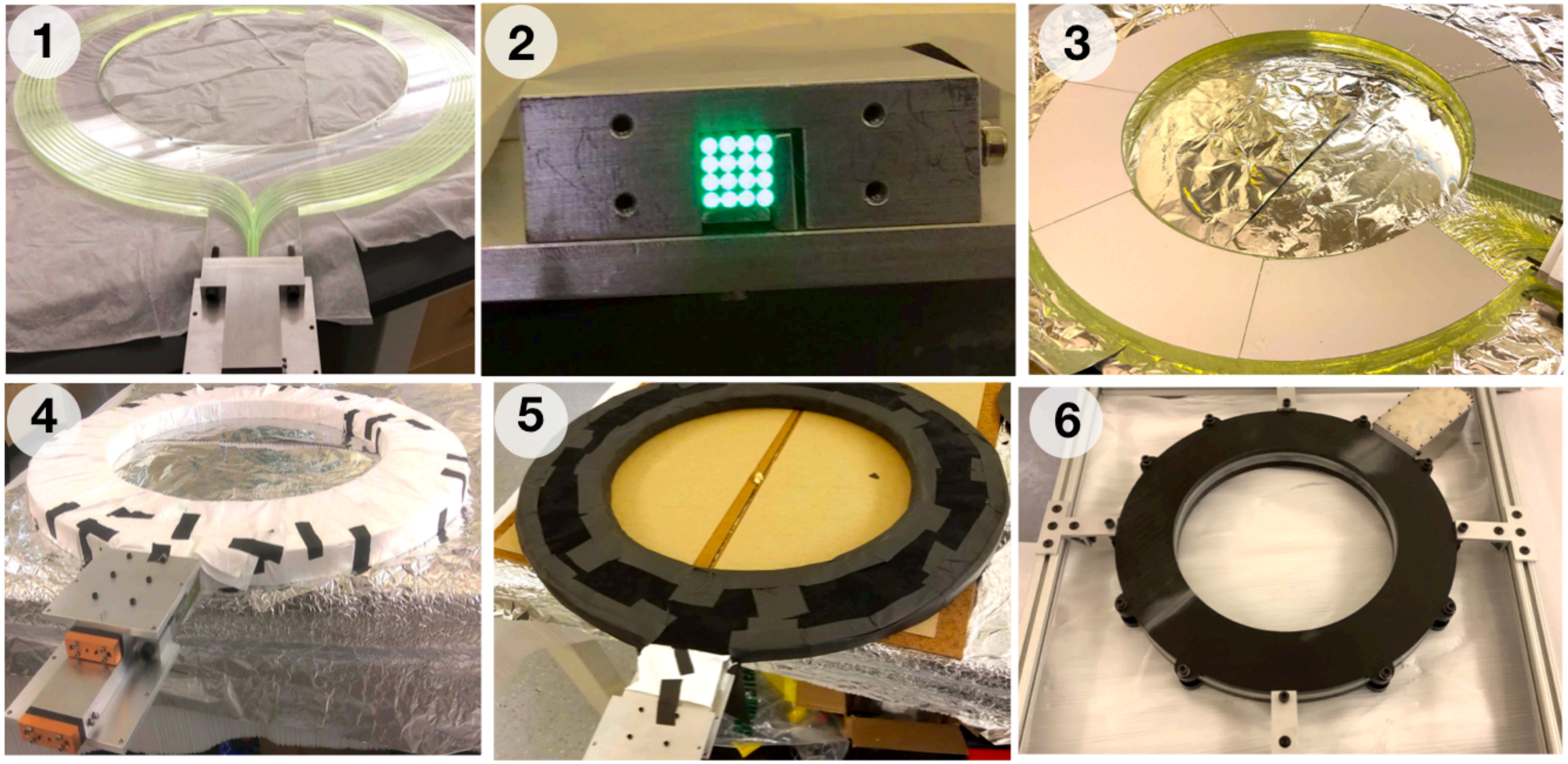



  - CIP+ HIP part density ~ 2.6 +-0.2 g/cc



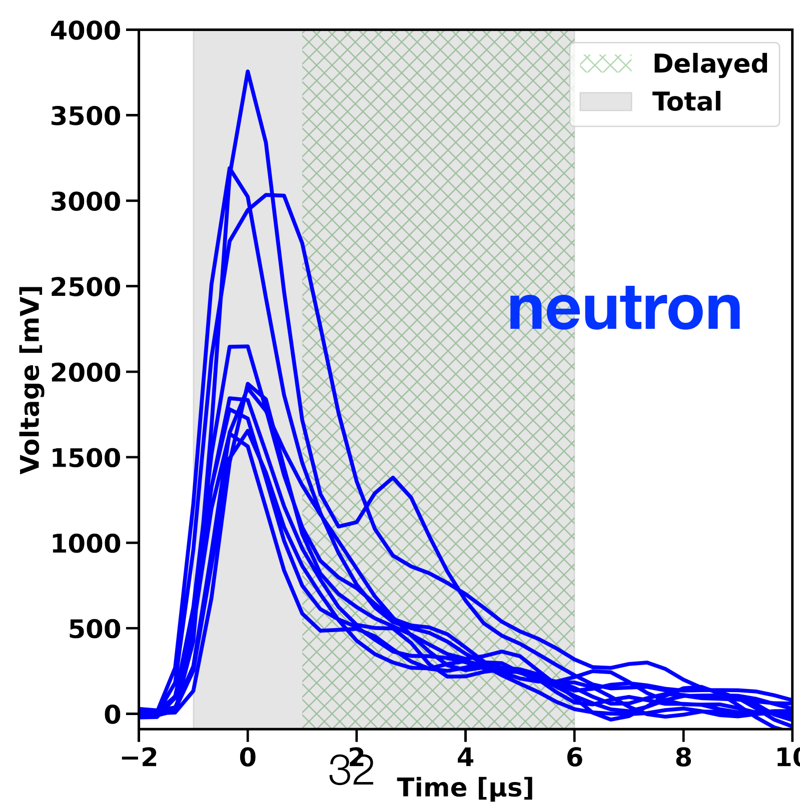



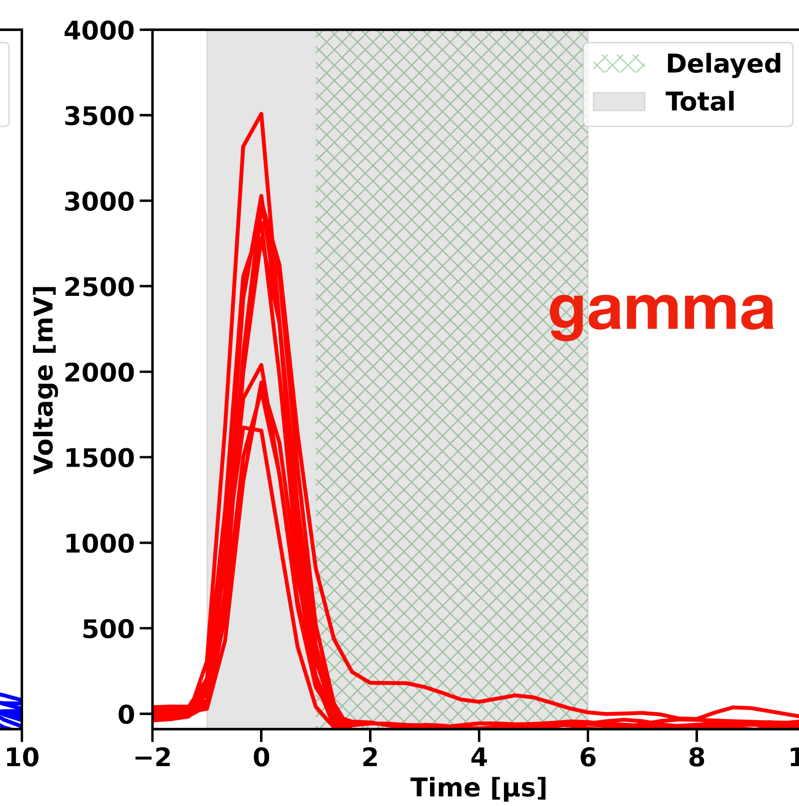
Backing detector



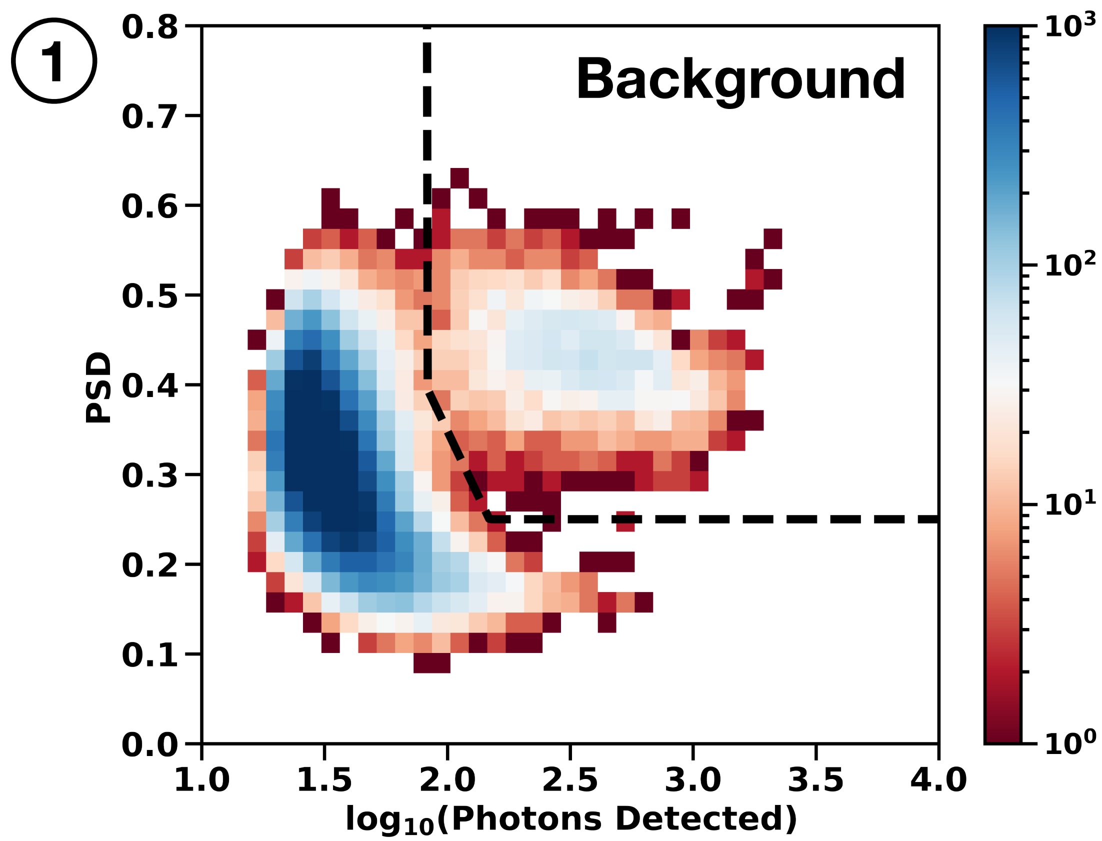
- n-capture on 6Li
 produces alpha and tritium

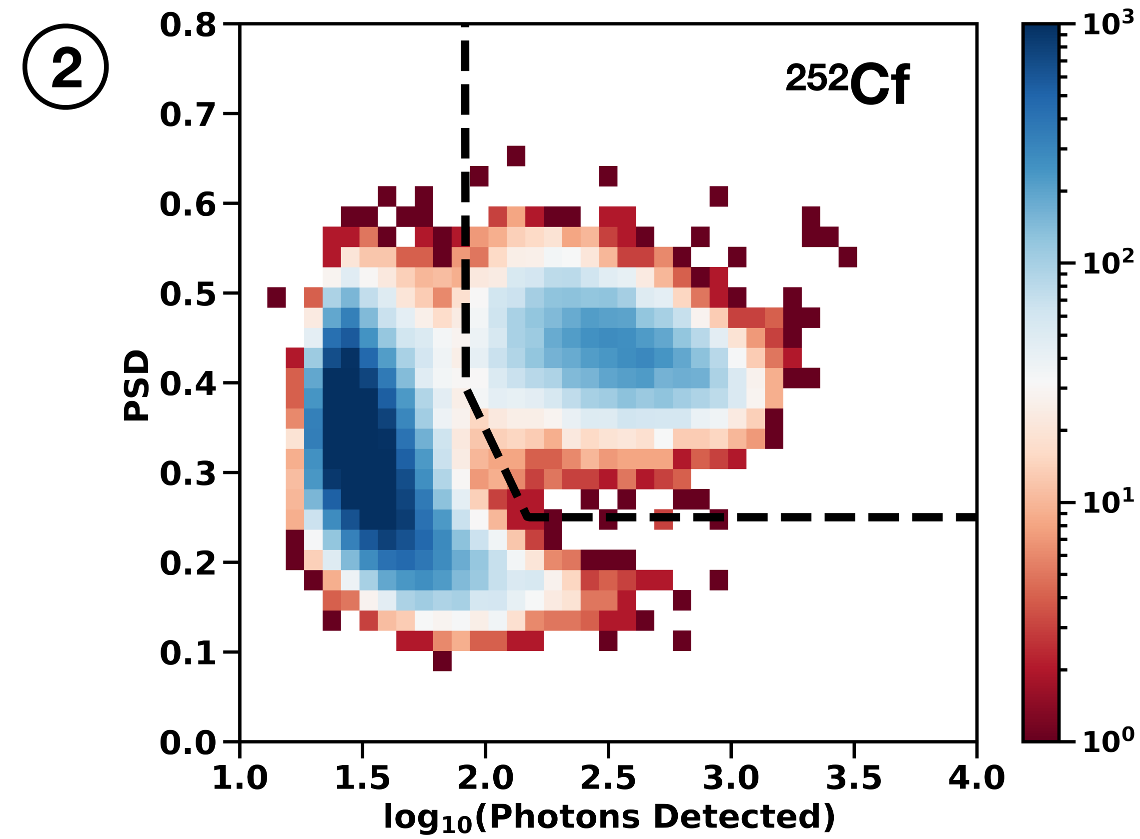
- charged particles than
 produces a relative bright
 and long tailed signal.

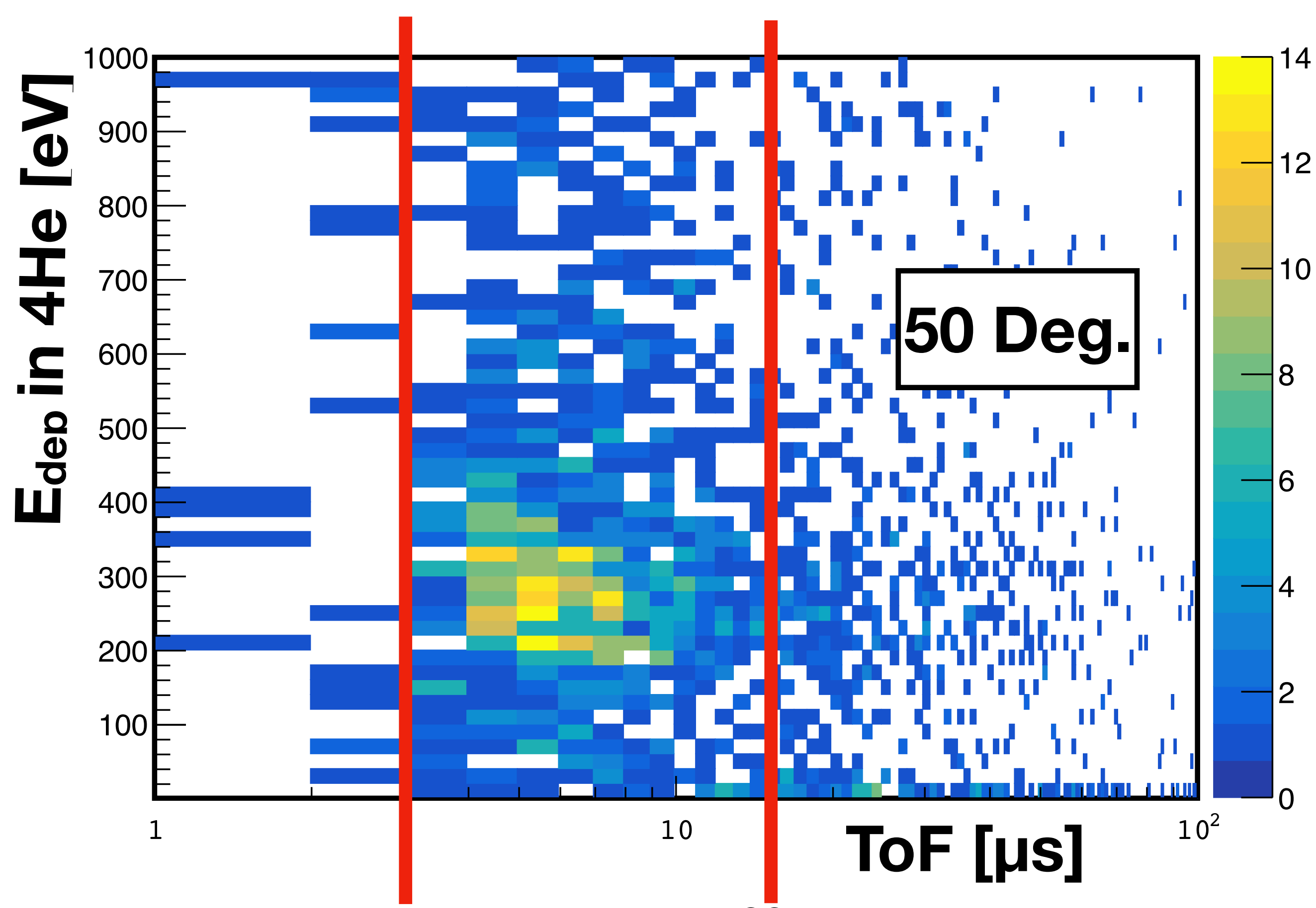




Backing detector PSD and Capture Timing







Capture Timing in Backing detector while calibration