Progress towards production of pulsed 2 keV and 24 keV neutrons, using neutron moderators and filters

Pratyush Patel and Scott Hertel

Photo Credit

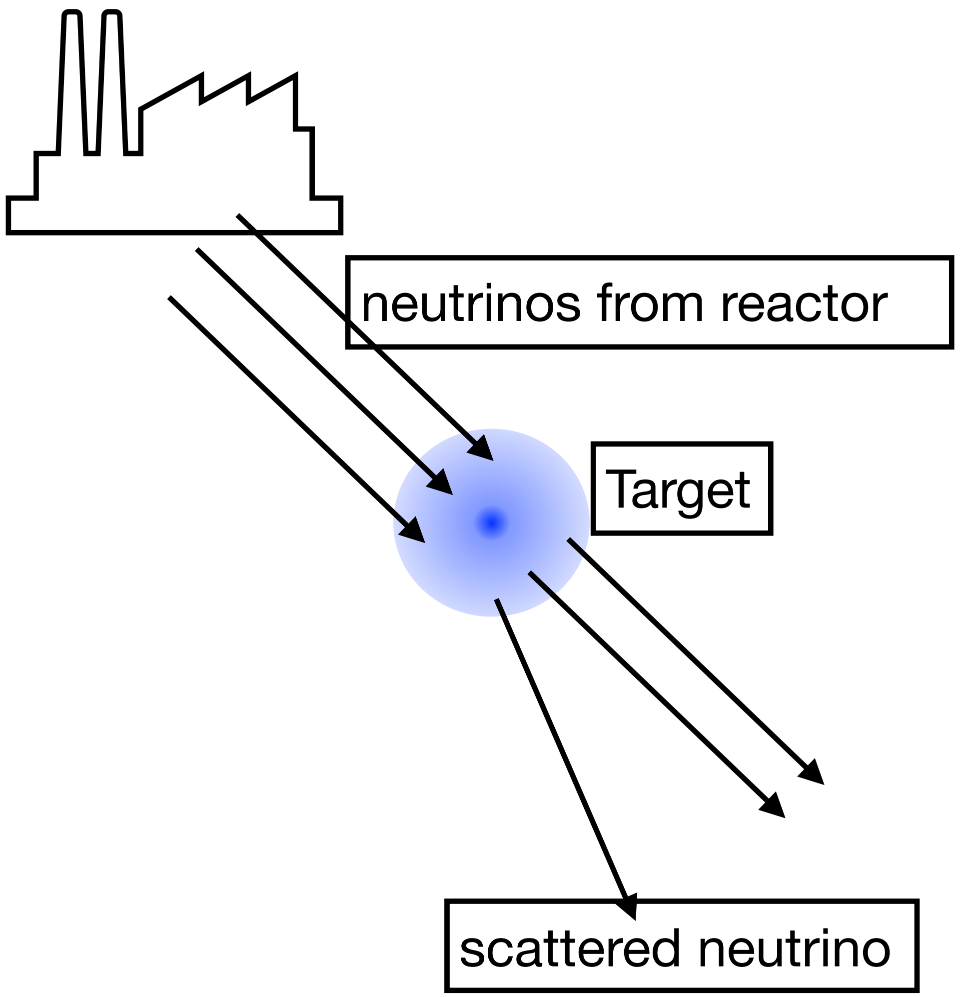
Caveat!!

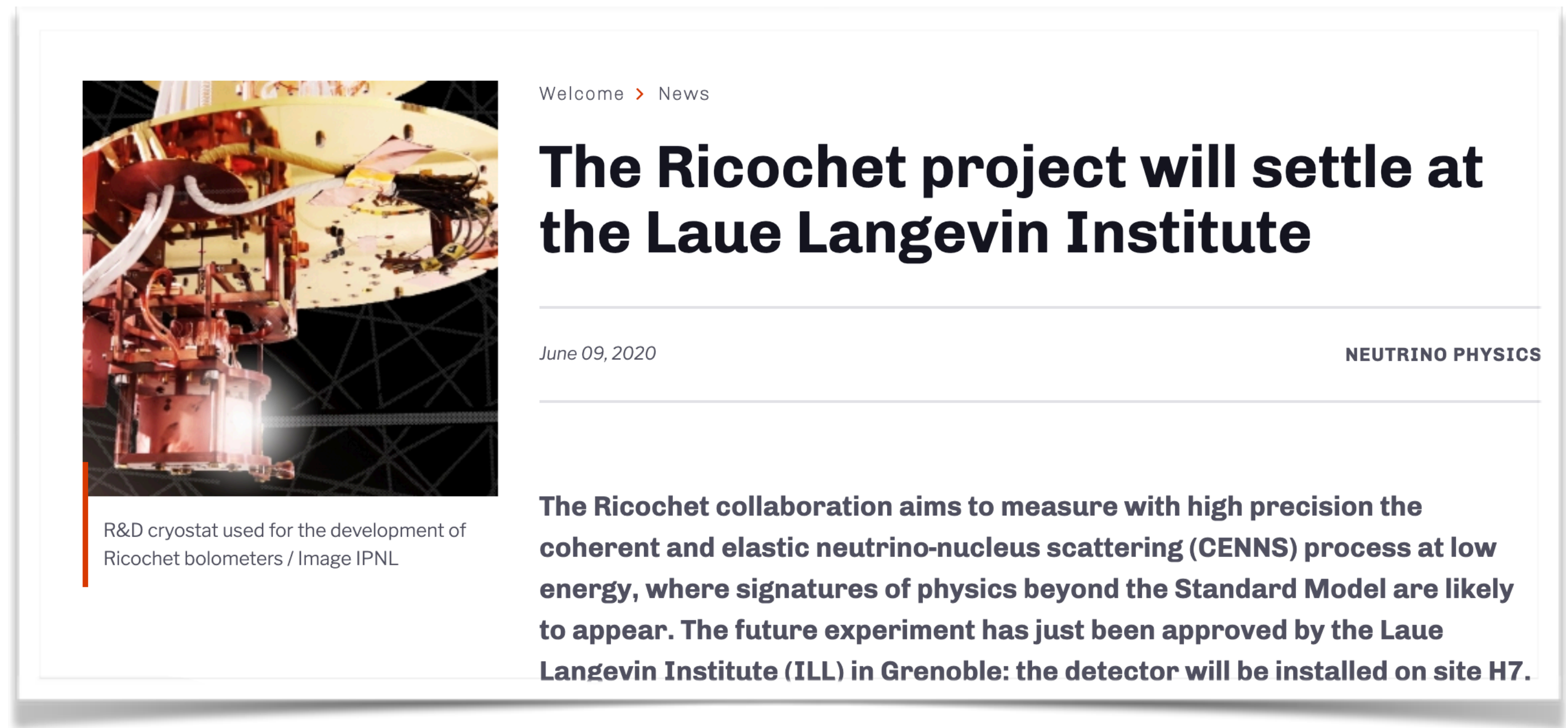
I am not a nuclear engineer or scientist

My background is to look for rare Nuclear Recoil signals from neutrinos or Dark Matter(DM) using diff. target materials

To be very specific: Understand diff. target materials

Neutrinos




Welcome > News

The Ricochet project will settle at the Laue Langevin Institute

June 09, 2020

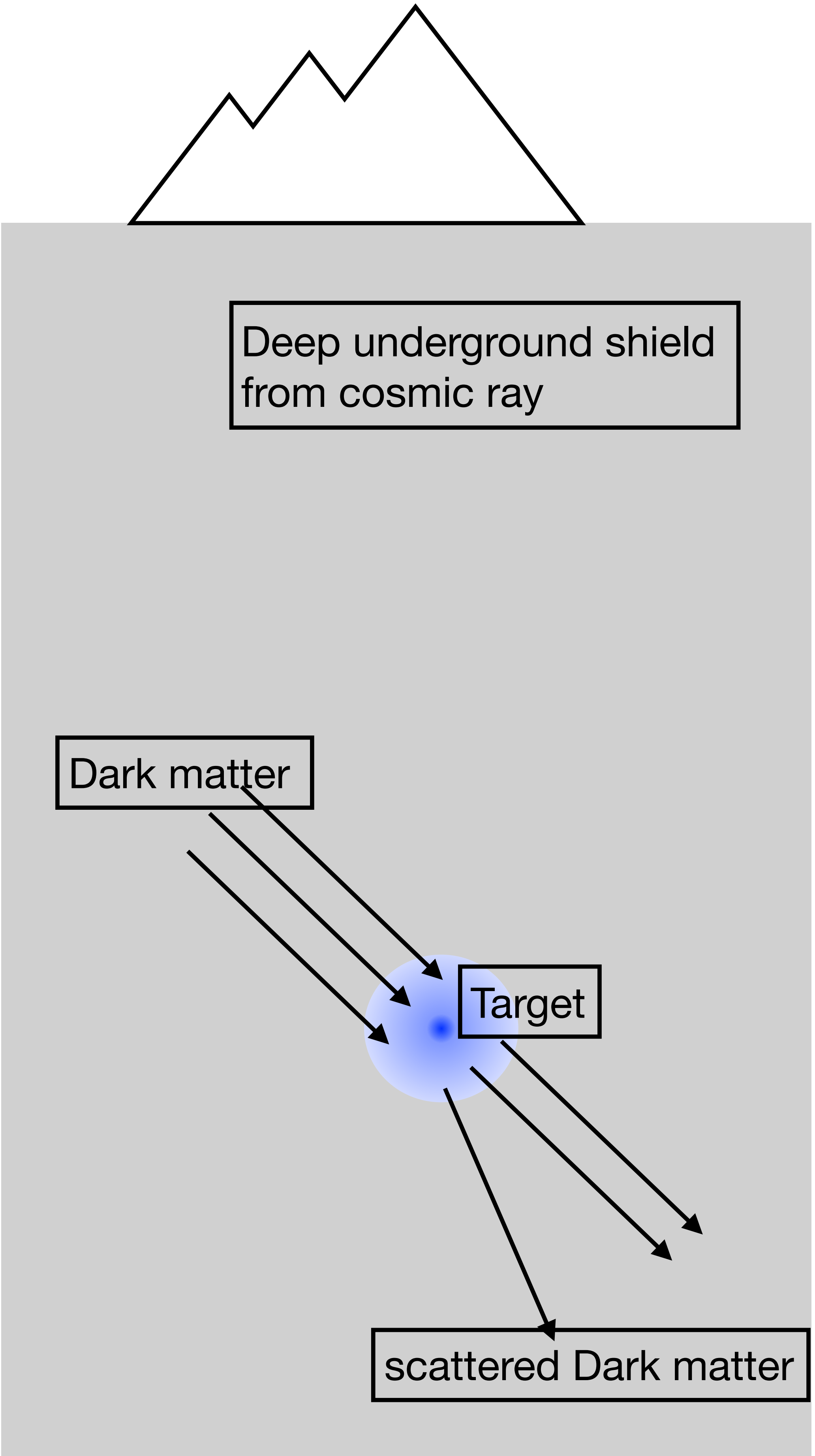
NEUTRINO PHYSICS

R&D cryostat used for the development of Ricochet bolometers / Image IPNL

The Ricochet collaboration aims to measure with high precision the coherent and elastic neutrino-nucleus scattering (CENNS) process at low energy, where signatures of physics beyond the Standard Model are likely to appear. The future experiment has just been approved by the Laue Langevin Institute (ILL) in Grenoble: the detector will be installed on site H7.

Energy deposited by the scattered neutrino is measured via charge and heat signal

Dark Matter



The TESSERACT Dark Matter Project

Thematic Areas:

- IF1 Quantum Sensors
- IF8 Noble Elements
- CF1 Dark Matter: Particle-like
- CF2 Dark Matter: Wavelike

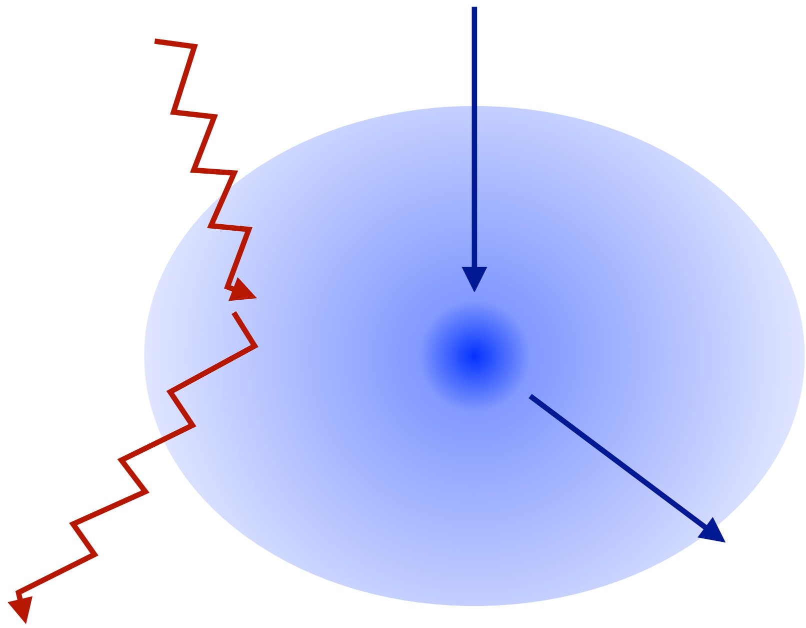
Contact Information:
Dan McKinsey (LBNL and UC Berkeley) [daniel.mckinsey@berkeley.edu]:
TESSERACT Collaboration

Energy deposited by the scattered dark matter is measured via heat signal

Why neutrons?

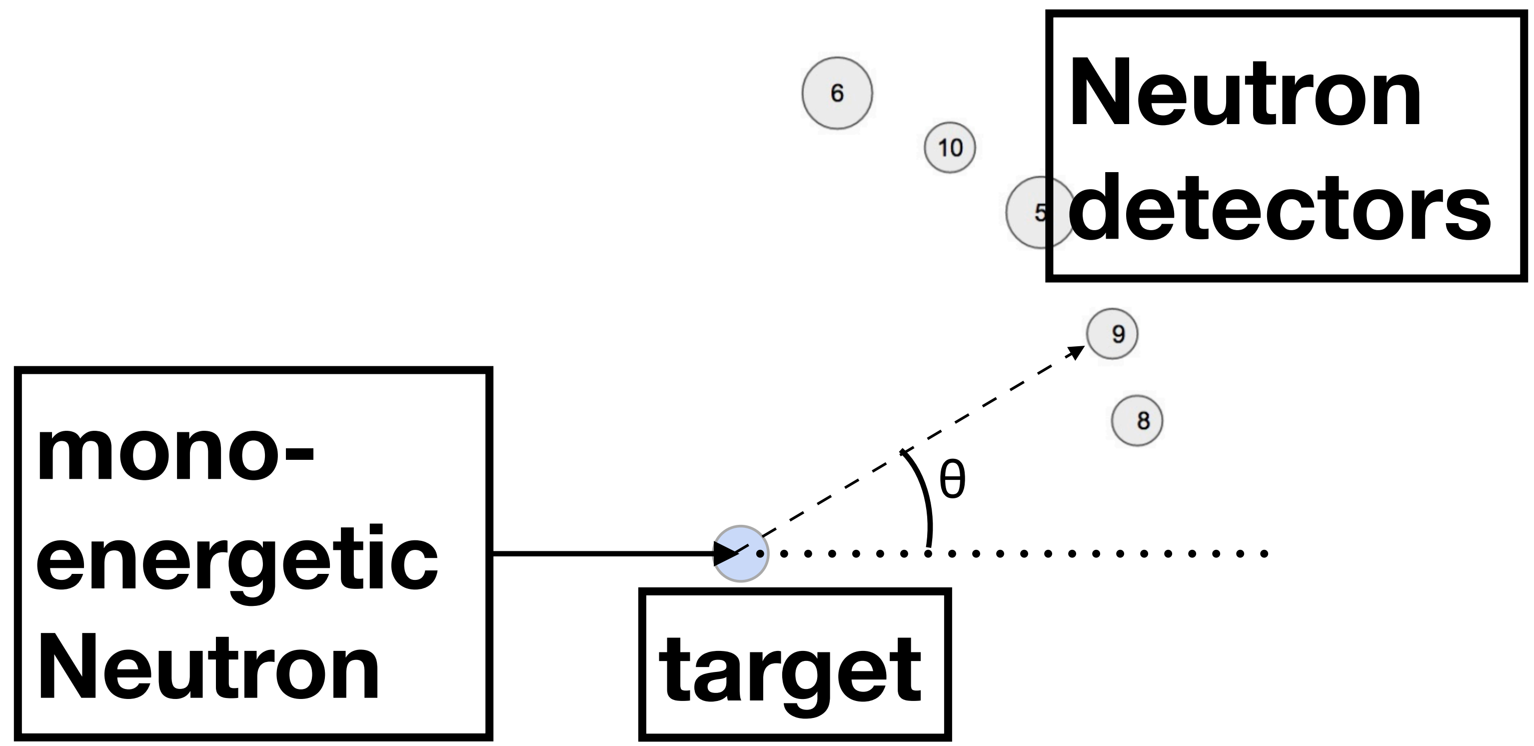
Gamma interacts mostly with electron cloud

Neutron, however interacts mostly with nucleus cloud



Most Dark matter models assume that DM interacts with nucleus, thus a DM signal is imitated with the help of neutrons

Produce a Nuclear Recoil of known energy using neutrons

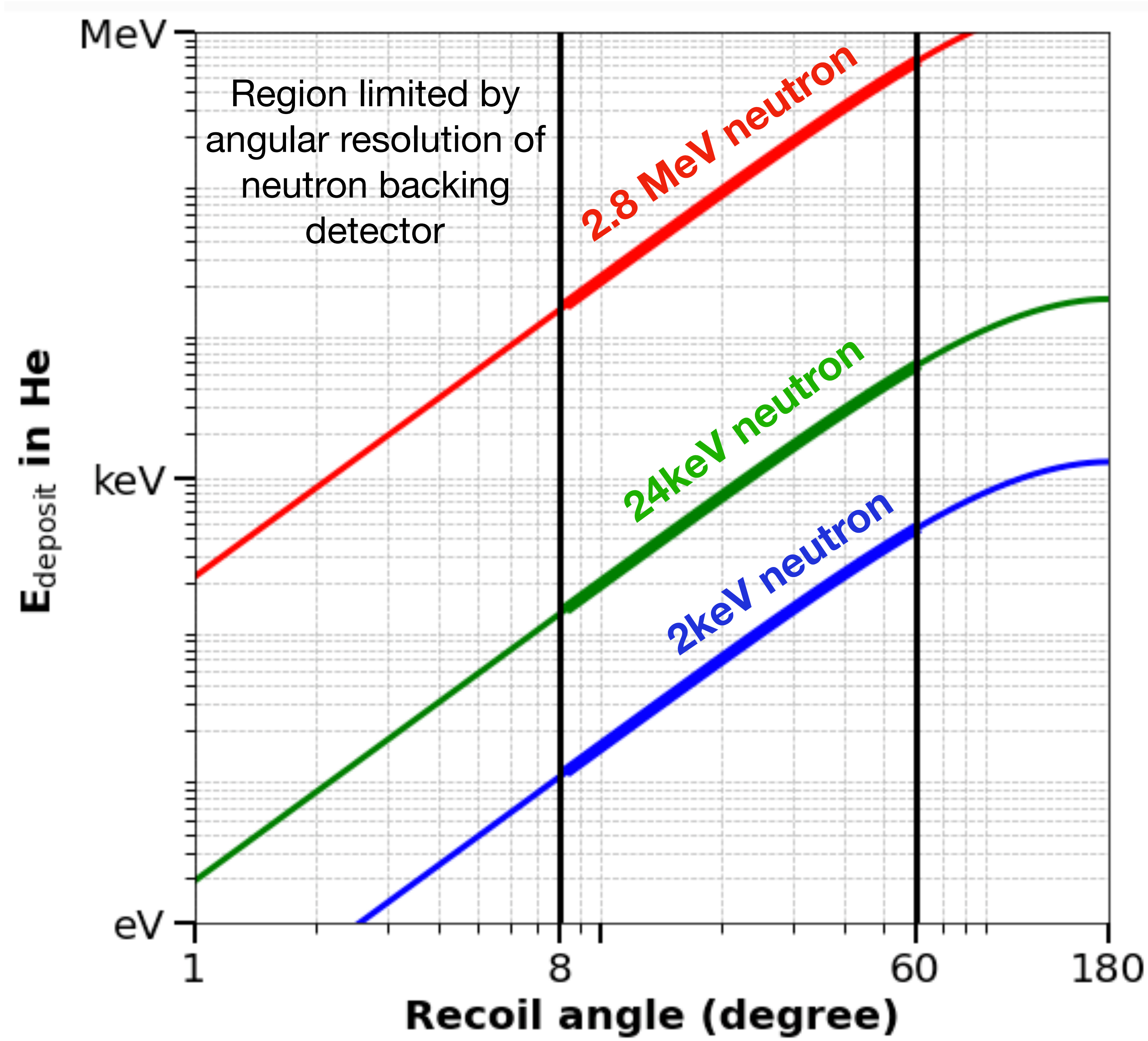


Why keV-scale neutrons?

State of art quantum sensor enable us to sense “eV” scale energy deposit

keV-scale neutrons are suitable to produce eV scale recoil energies in various target

keV neutrons deposit eV Energy in He

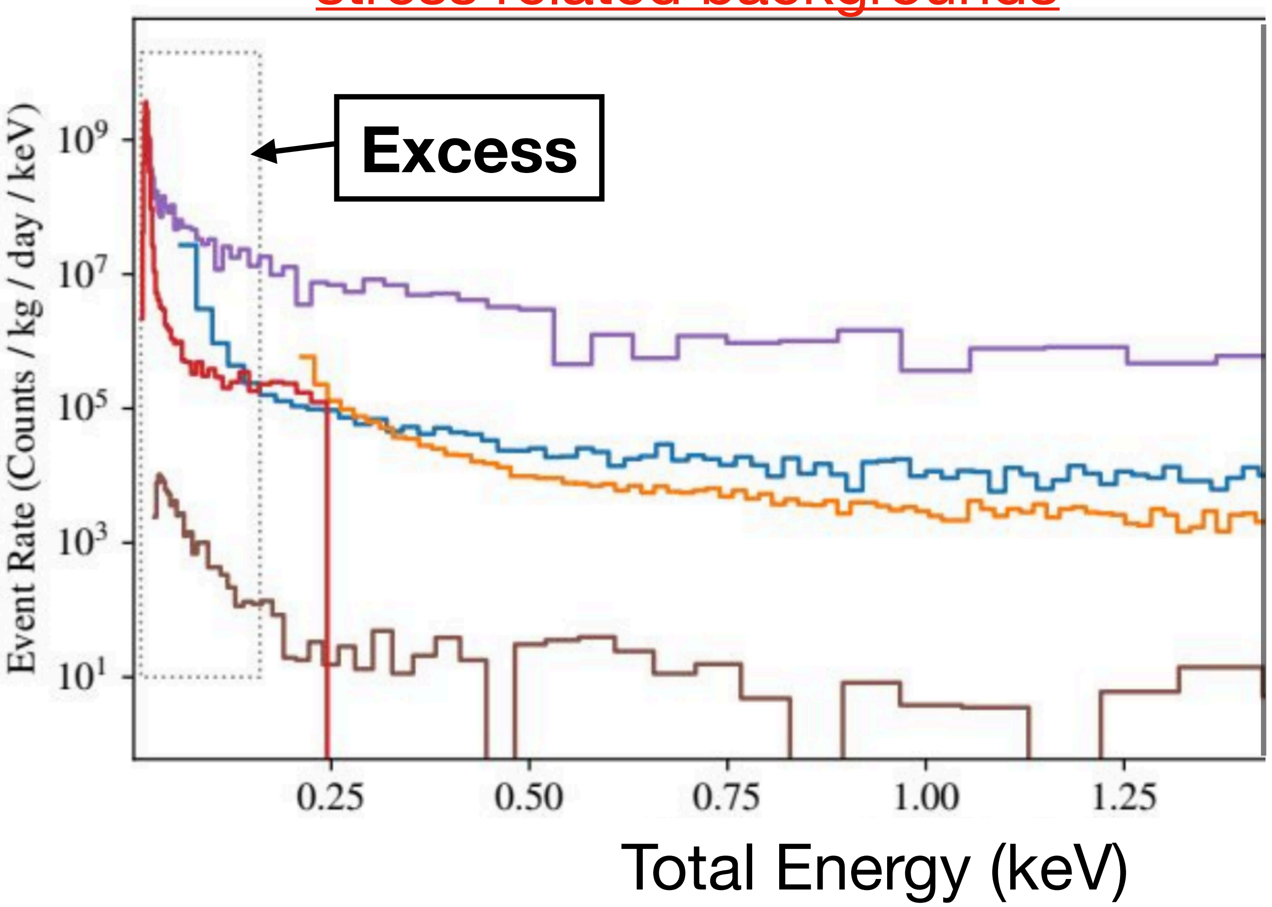


Why a Pulsed source?

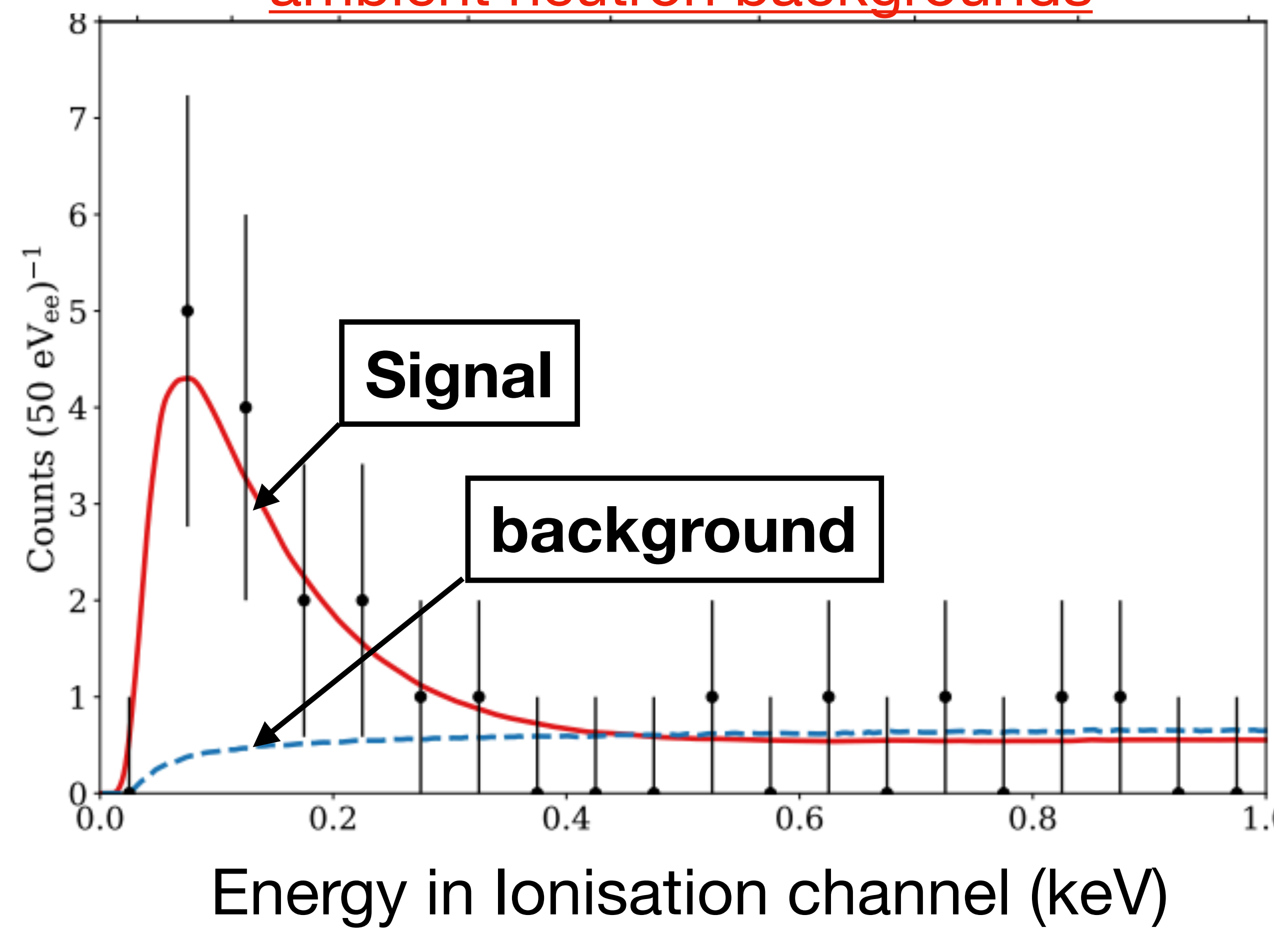
Pulsing:

1. Pulsed neutron source eliminates non-corelated backgrounds
2. Non-corelated Backgrounds < keV is not yet completely understood

stress related backgrounds

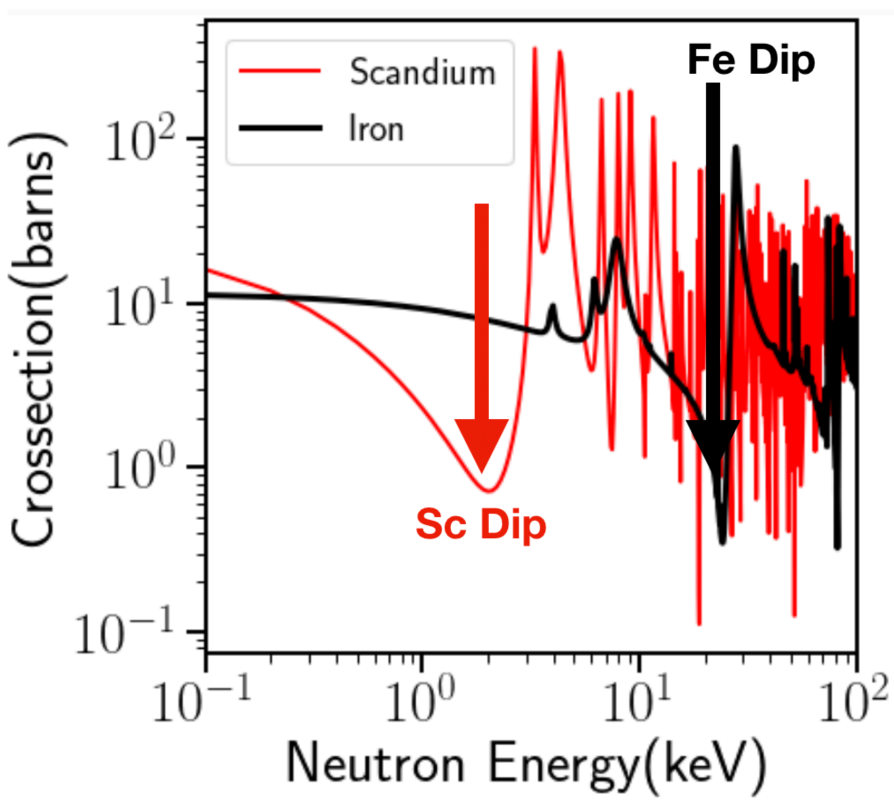


ambient neutron backgrounds



How do we produce keV scale neutron?

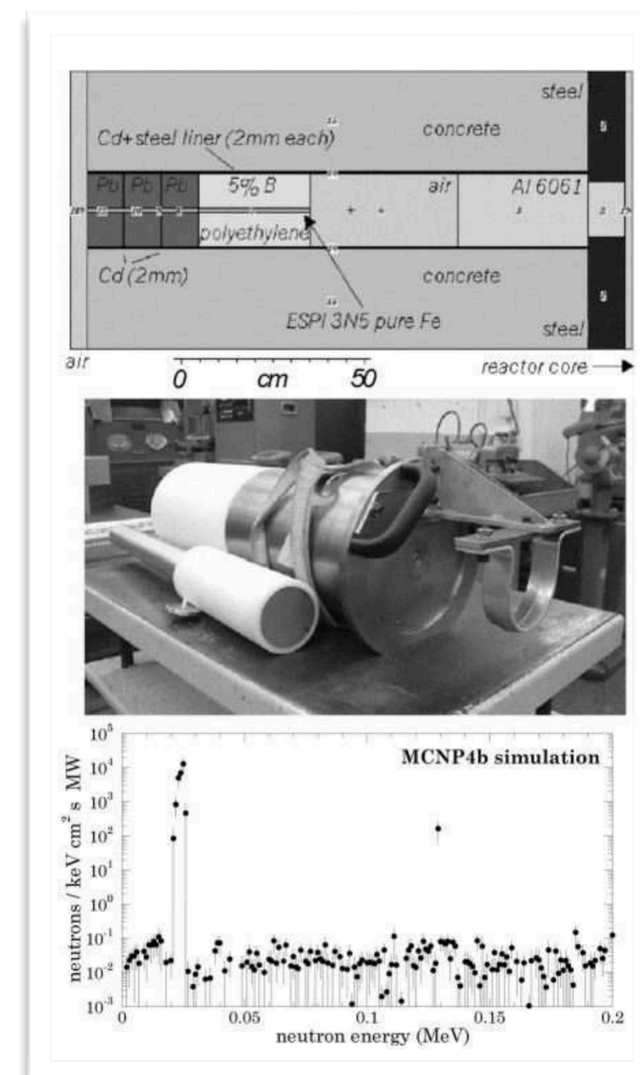
Moderate and filter?



Using the dips in the neutron-nucleus elastic scattering crossection

Neutron source: Nuclear Reactor

~150cm



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

A little history lesson

Idea of neutron Filter is quite old, dates back to 1970s

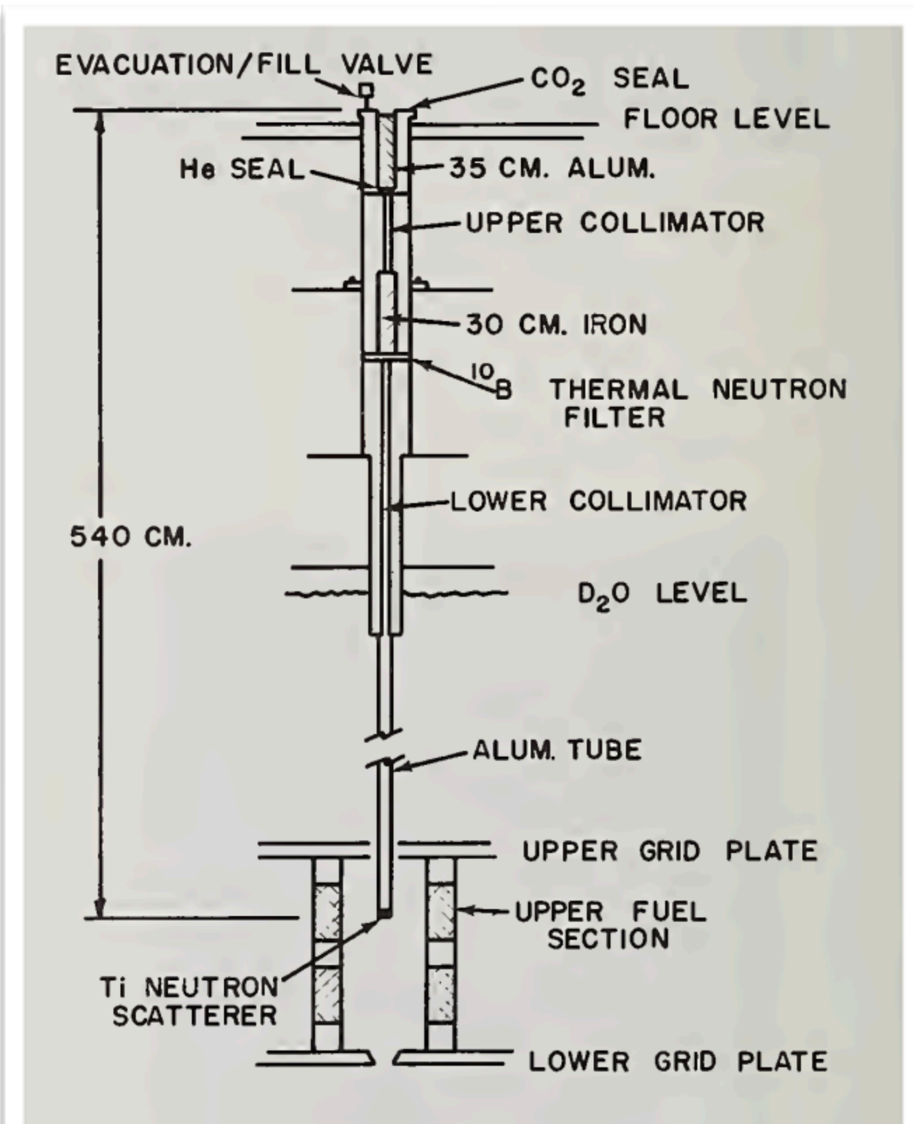
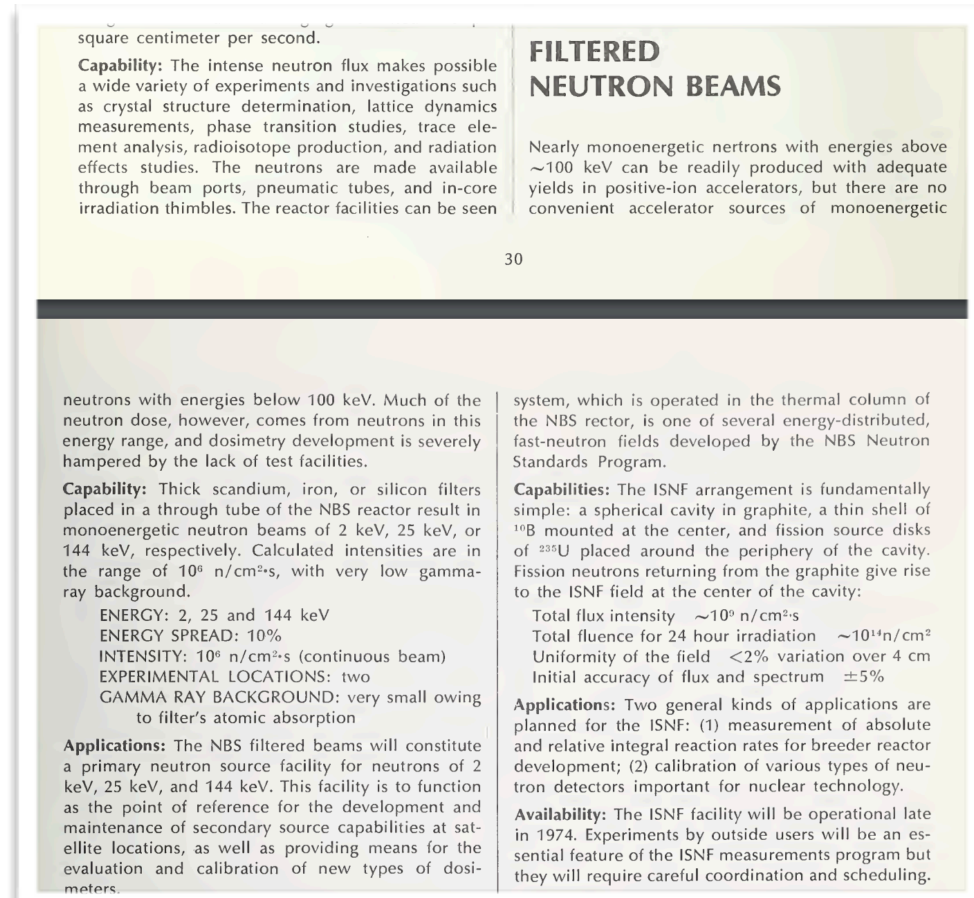


Fig. 1. The 25-keV neutron facility.

McGarry, E D, and Schroder, I G.

link



square centimeter per second.

Capability: The intense neutron flux makes possible a wide variety of experiments and investigations such as crystal structure determination, lattice dynamics measurements, phase transition studies, trace element analysis, radioisotope production, and radiation effects studies. The neutrons are made available through beam ports, pneumatic tubes, and in-core irradiation thimbles. The reactor facilities can be seen

FILTERED NEUTRON BEAMS

Nearly monoenergetic nertrons with energies above ~100 keV can be readily produced with adequate yields in positive-ion accelerators, but there are no convenient accelerator sources of monoenergetic

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neutrons with energies below 100 keV. Much of the neutron dose, however, comes from neutrons in this energy range, and dosimetry development is severely hampered by the lack of test facilities.

Capability: Thick scandium, iron, or silicon filters placed in a through tube of the NBS reactor result in monoenergetic neutron beams of 2 keV, 25 keV, or 144 keV, respectively. Calculated intensities are in the range of 10^6 n/cm^2·s, with very low gamma-ray background.

ENERGY: 2, 25 and 144 keV
ENERGY SPREAD: 10%
INTENSITY: 10^6 n/cm^2·s (continuous beam)
EXPERIMENTAL LOCATIONS: two
GAMMA RAY BACKGROUND: very small owing to filter's atomic absorption

Applications: The NBS filtered beams will constitute a primary neutron source facility for neutrons of 2 keV, 25 keV, and 144 keV. This facility is to function as the point of reference for the development and maintenance of secondary source capabilities at satellite locations, as well as providing means for the evaluation and calibration of new types of dosimeters.

system, which is operated in the thermal column of the NBS rector, is one of several energy-distributed, fast-neutron fields developed by the NBS Neutron Standards Program.

Capabilities: The ISNF arrangement is fundamentally simple: a spherical cavity in graphite, a thin shell of ^{10}B mounted at the center, and fission source disks of ^{235}U placed around the periphery of the cavity. Fission neutrons returning from the graphite give rise to the ISNF field at the center of the cavity:

Total flux intensity ~10^9 n/cm^2·s
Total fluence for 24 hour irradiation ~10^{14}n/cm^2
Uniformity of the field <2% variation over 4 cm
Initial accuracy of flux and spectrum ±5%

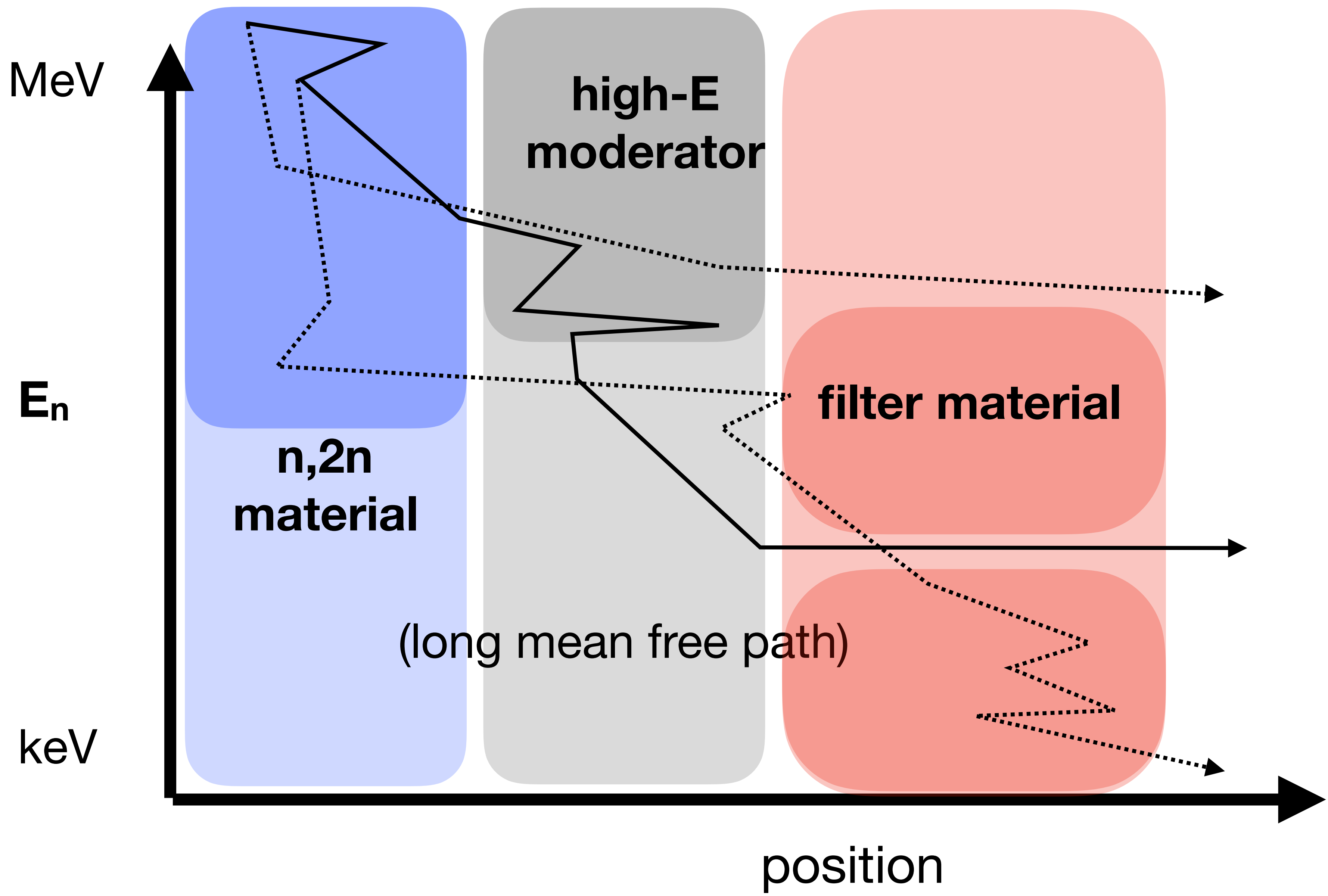
Applications: Two general kinds of applications are planned for the ISNF: (1) measurement of absolute and relative integral reaction rates for breeder reactor development; (2) calibration of various types of neutron detectors important for nuclear technology.

Availability: The ISNF facility will be operational late in 1974. Experiments by outside users will be an essential feature of the ISNF measurements program but they will require careful coordination and scheduling.

Our Novel aspect: **Pulsing** and **moderation**

Working Principle

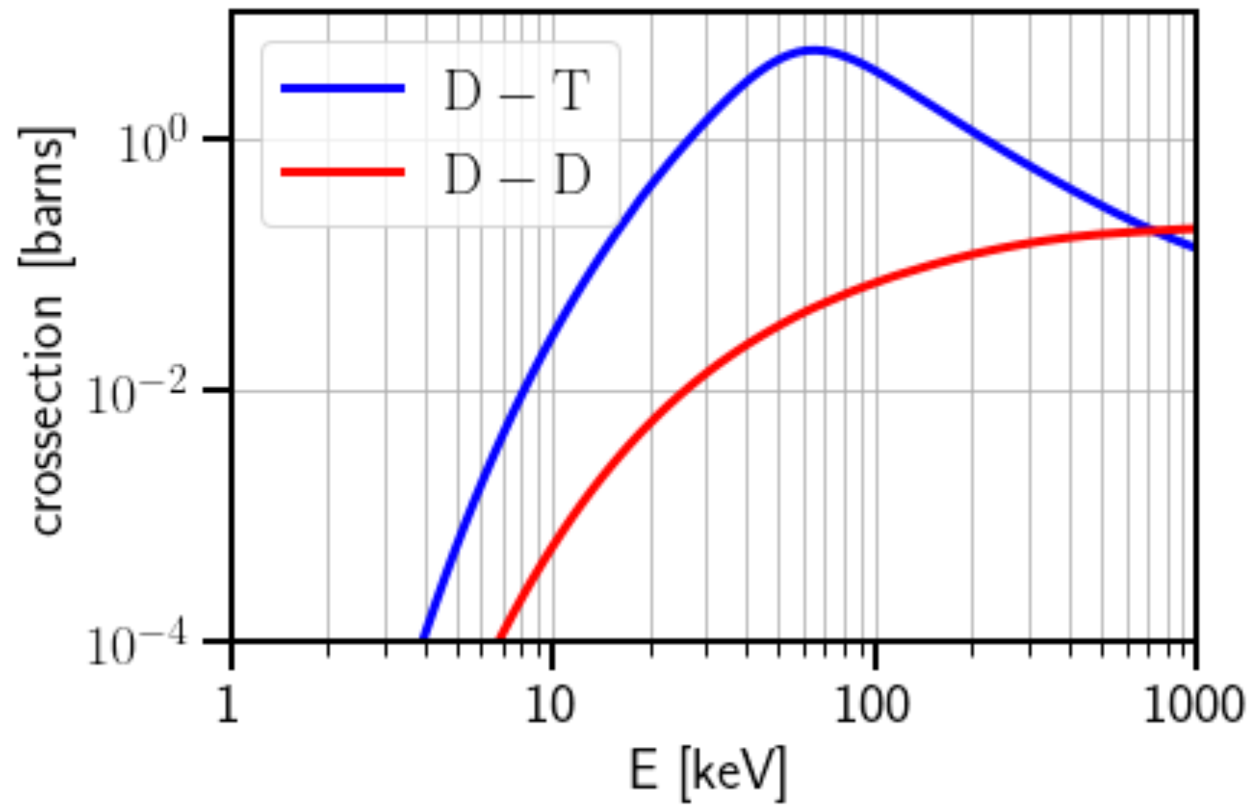
- Start MeV scale neutron
- Find good neutron moderators at these energies
- Create broad < 100 keV-scale n-population
- Filter to select desired neutron energy



Intial Moderation Steps: sub-MeV Moderation

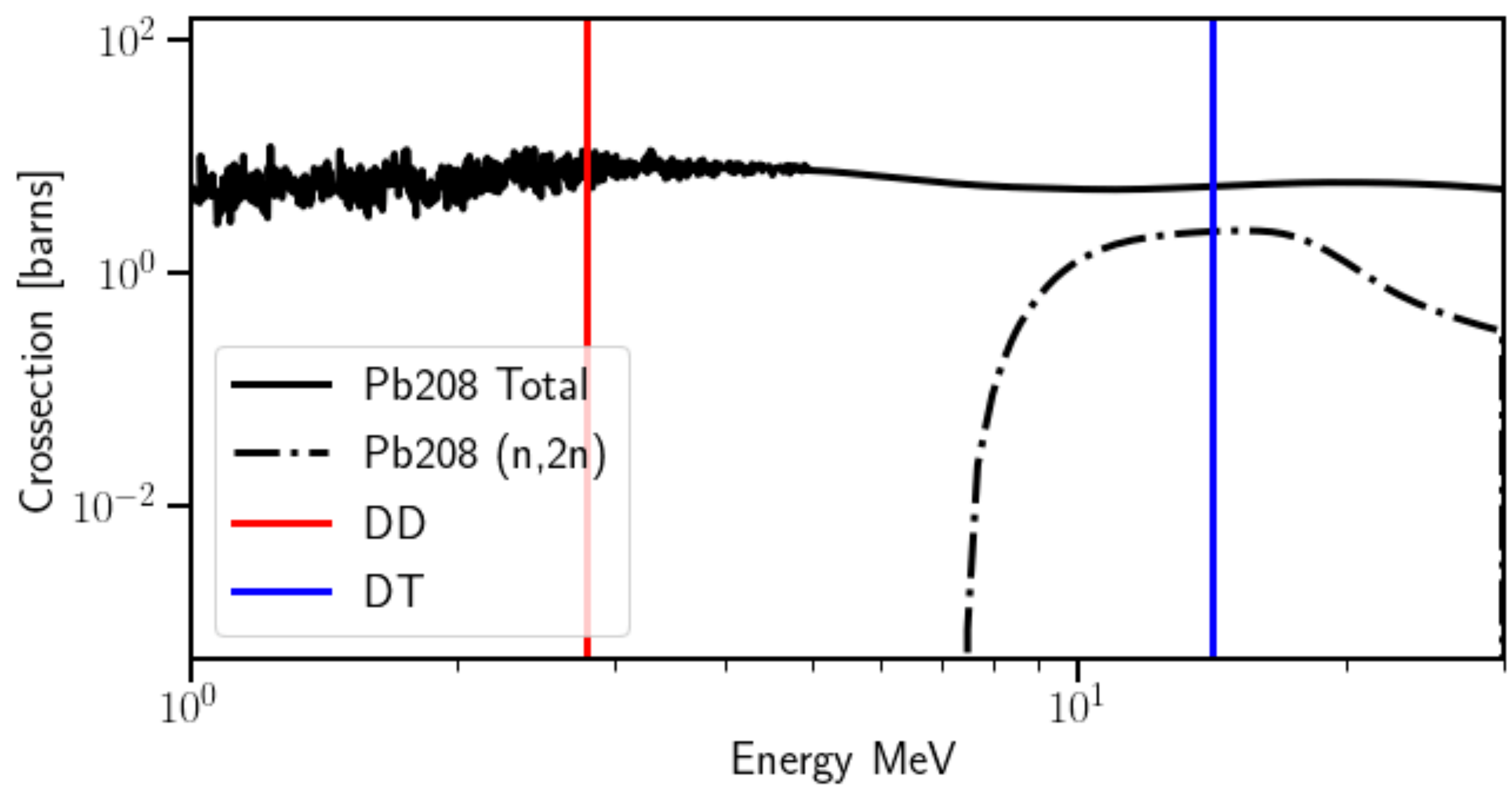
Why DT ?

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

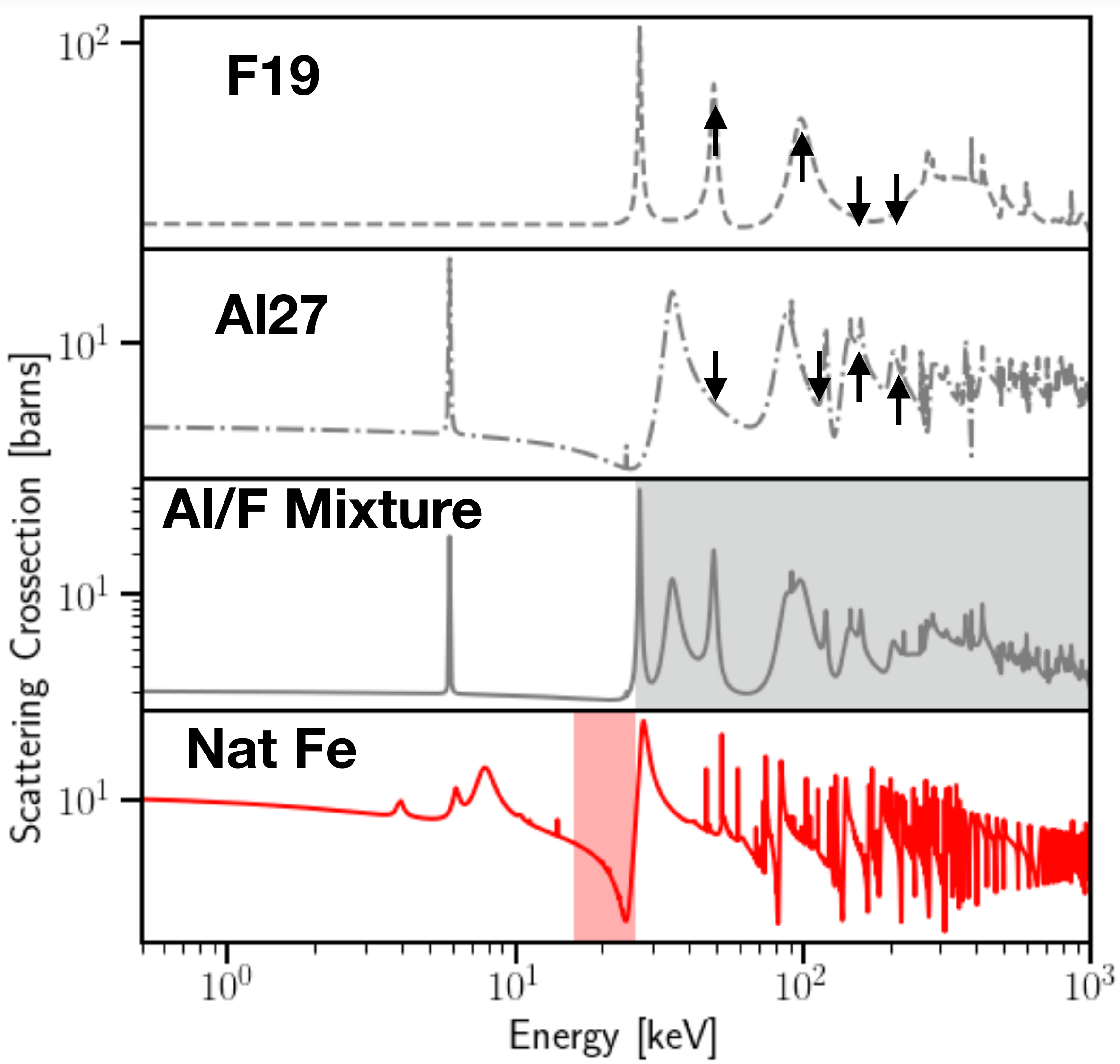


Why Lead?

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



Next Moderation Steps: using Al/F mixture and Ti

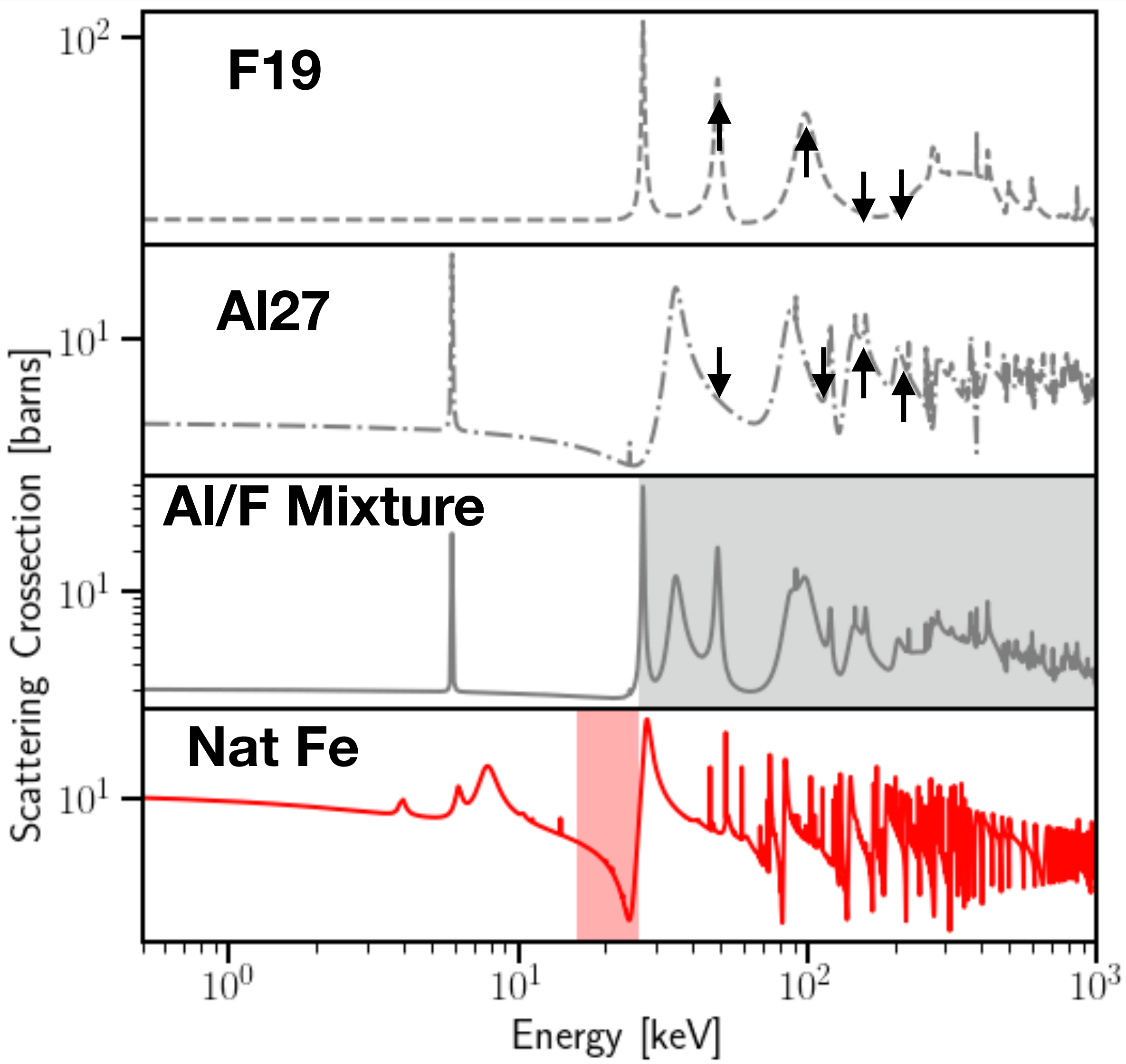


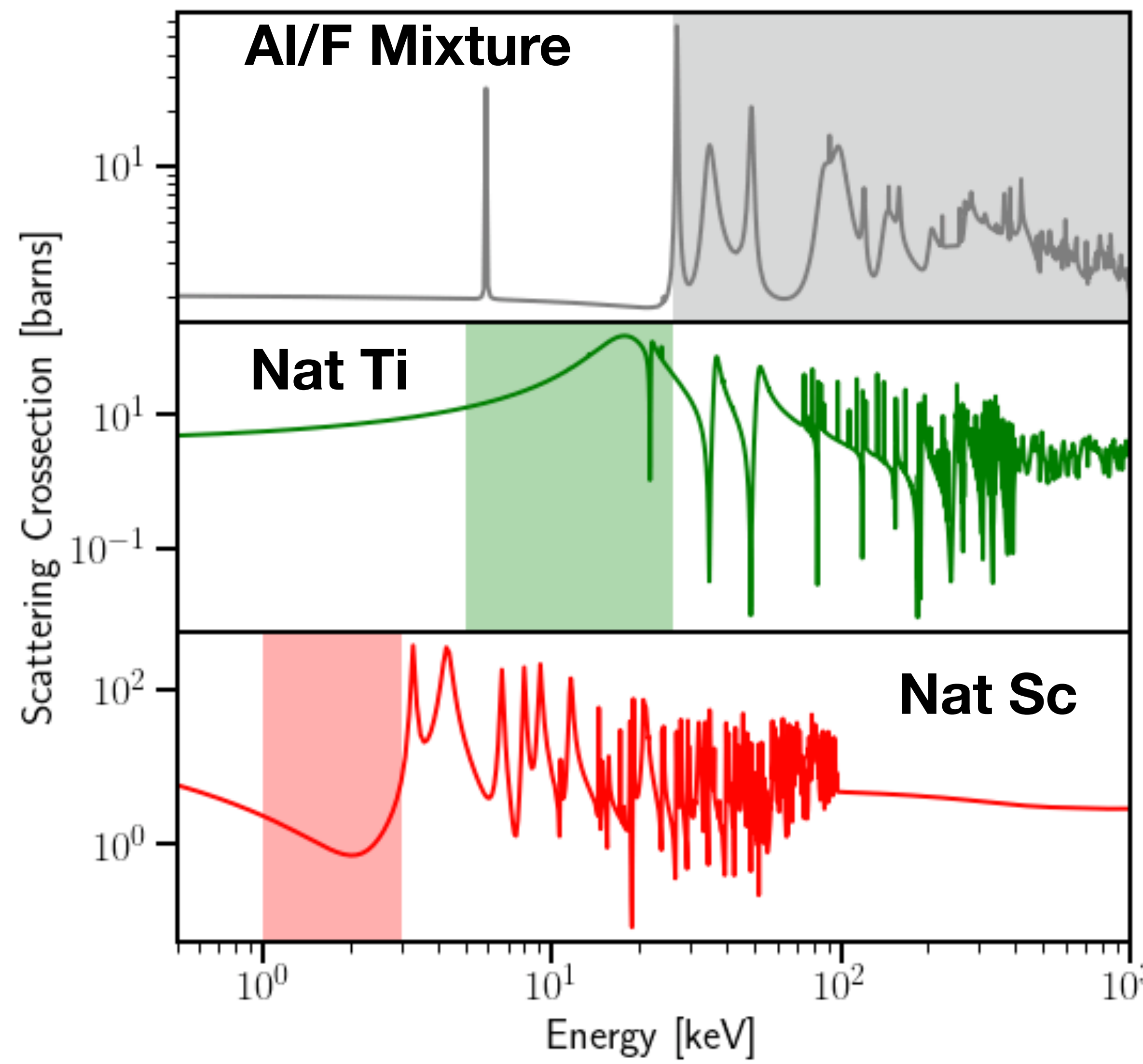
- Complemenatry resonance feature in Al and F helps effective moderation of neutrons doen to 20 keV

- Iron can now filter out 24 keV neutrons

Moderator Al/F invented for boron capture therapy

Next Moderation Steps: using Al/F mixture and Ti

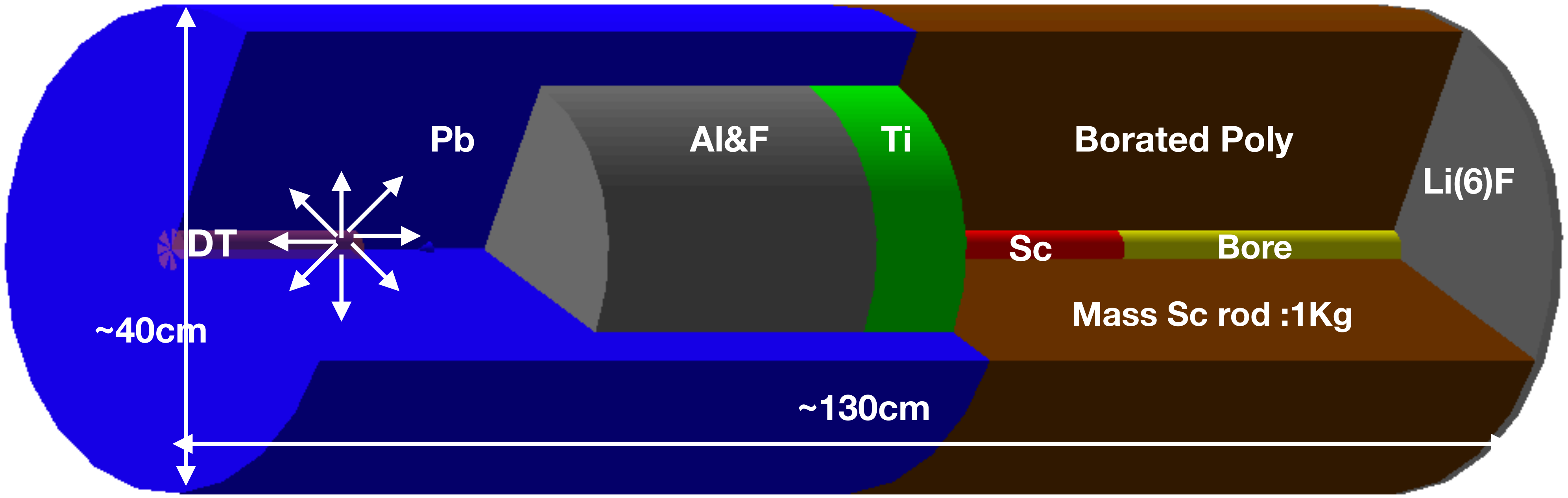


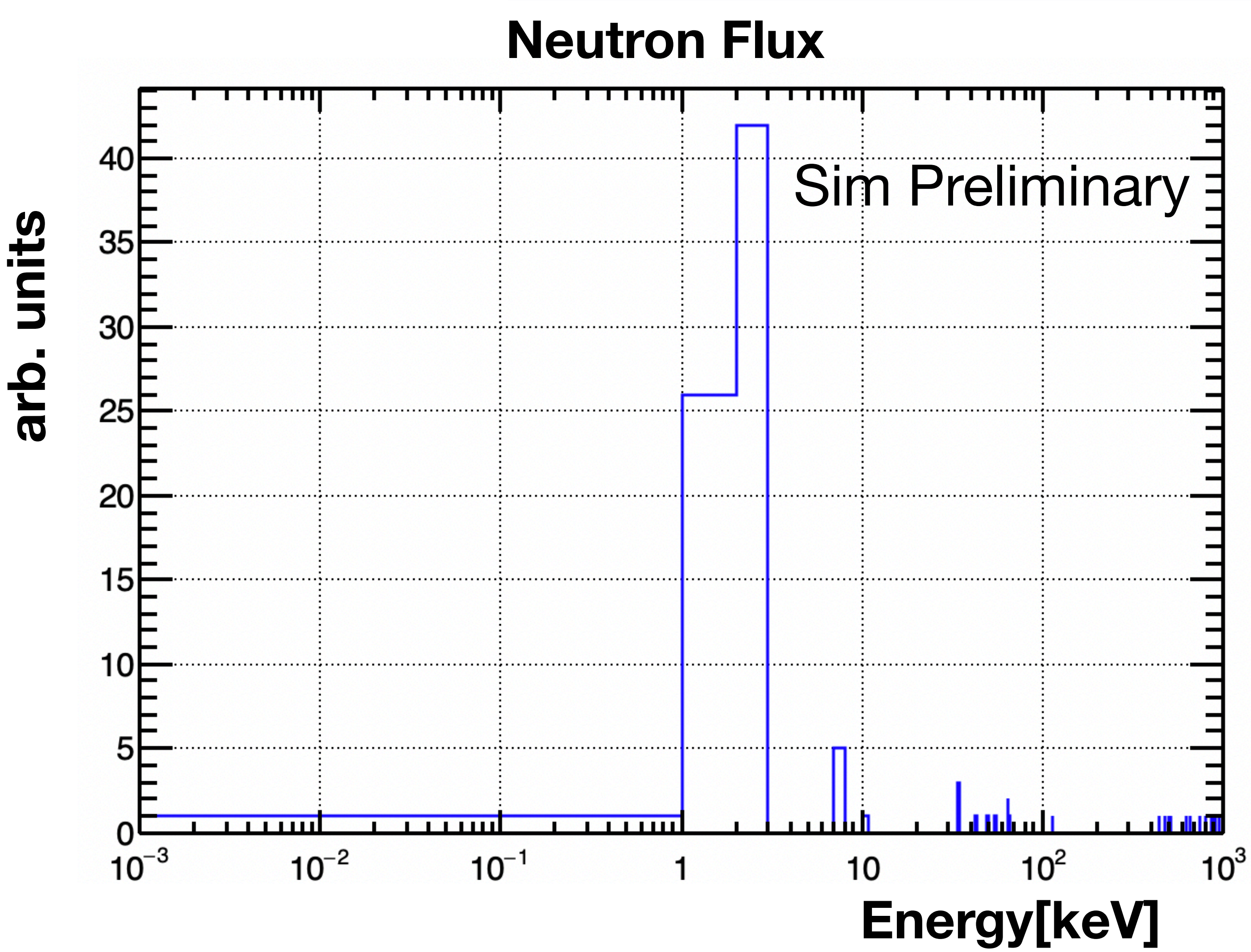


- Complemenatry resonance feature in Al and F helps effective moderation of neutrons doen to 20 keV
- Iron can now filter out 24 keV neutrons

- Another step of moderation of neutrons using Ti is need for 2 keV neutrons
- Ti moderates neutrons down to 1 keV
- Sc can filter out 2 keV neutrons

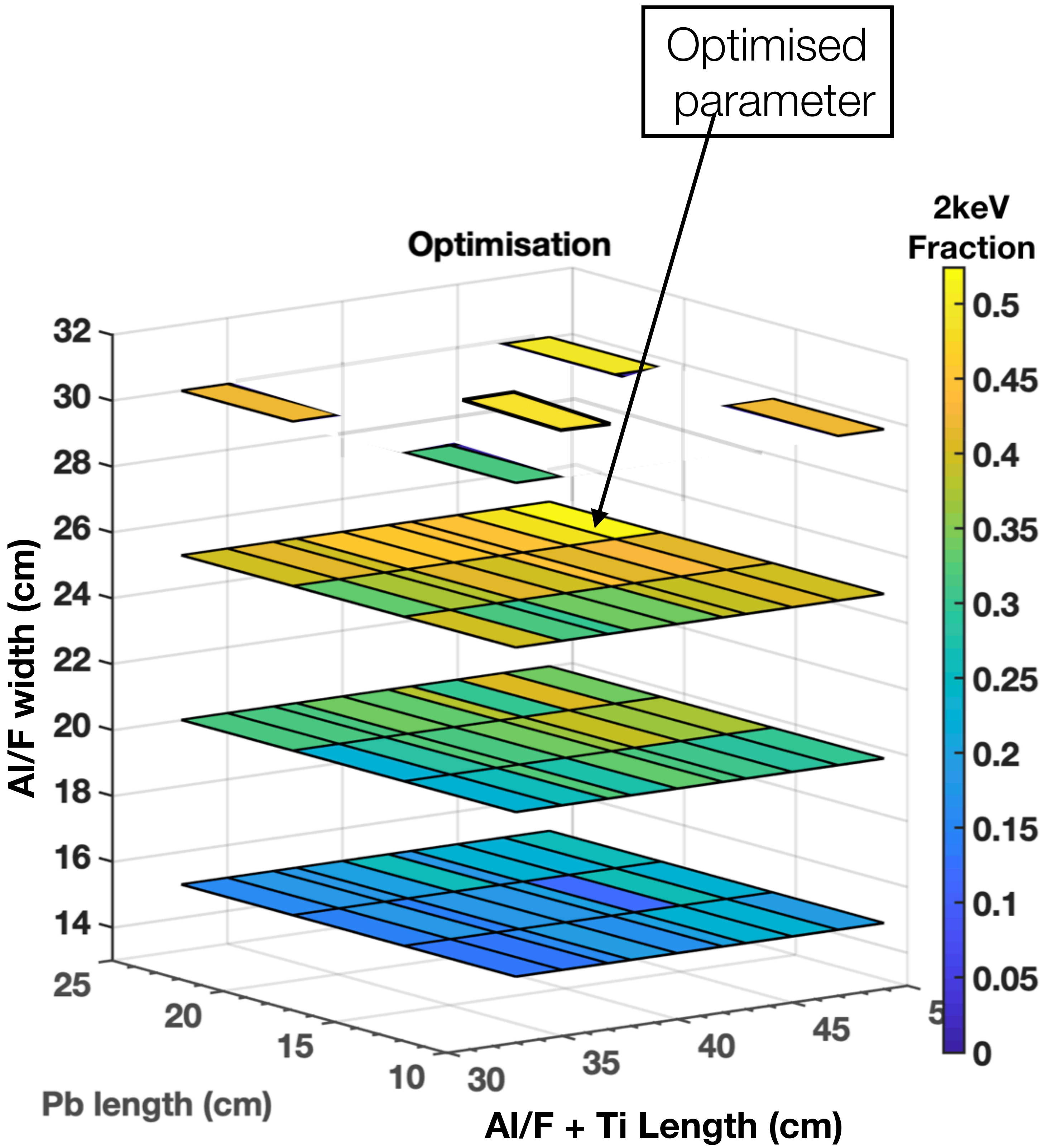
Finally let's put things together



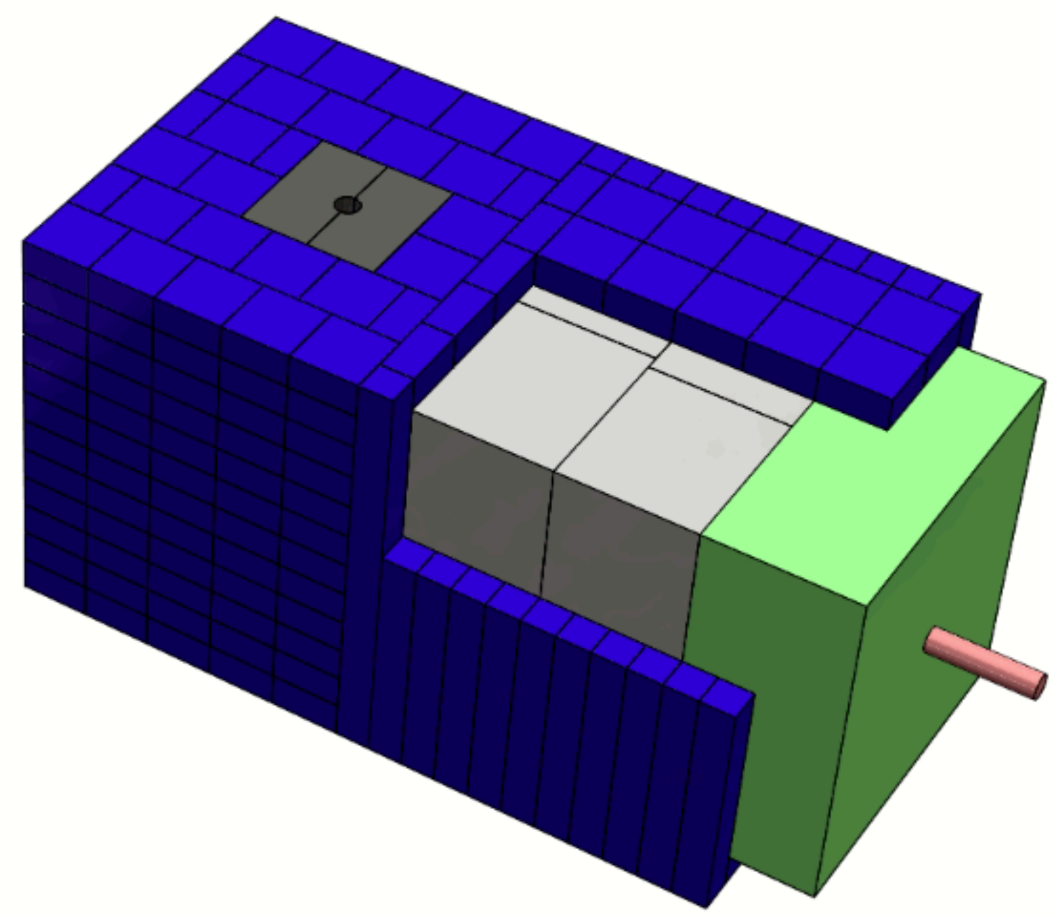


- A fairly monoenergtic peak, with little contaminants
- Needs optimisation of various length scale and also shield neutrons, gamma escaping the assembly from diff. faces

Optimisation using Geant4

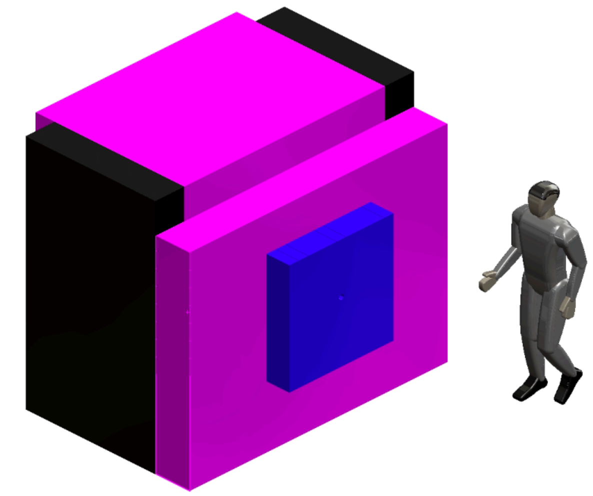


- Al/F - length: 40cm
  - width: 50cm
- Ti - length: 7cm
  - radius same as Al/F
- Lead - length: 25
  - radius of Al/F + 5cm

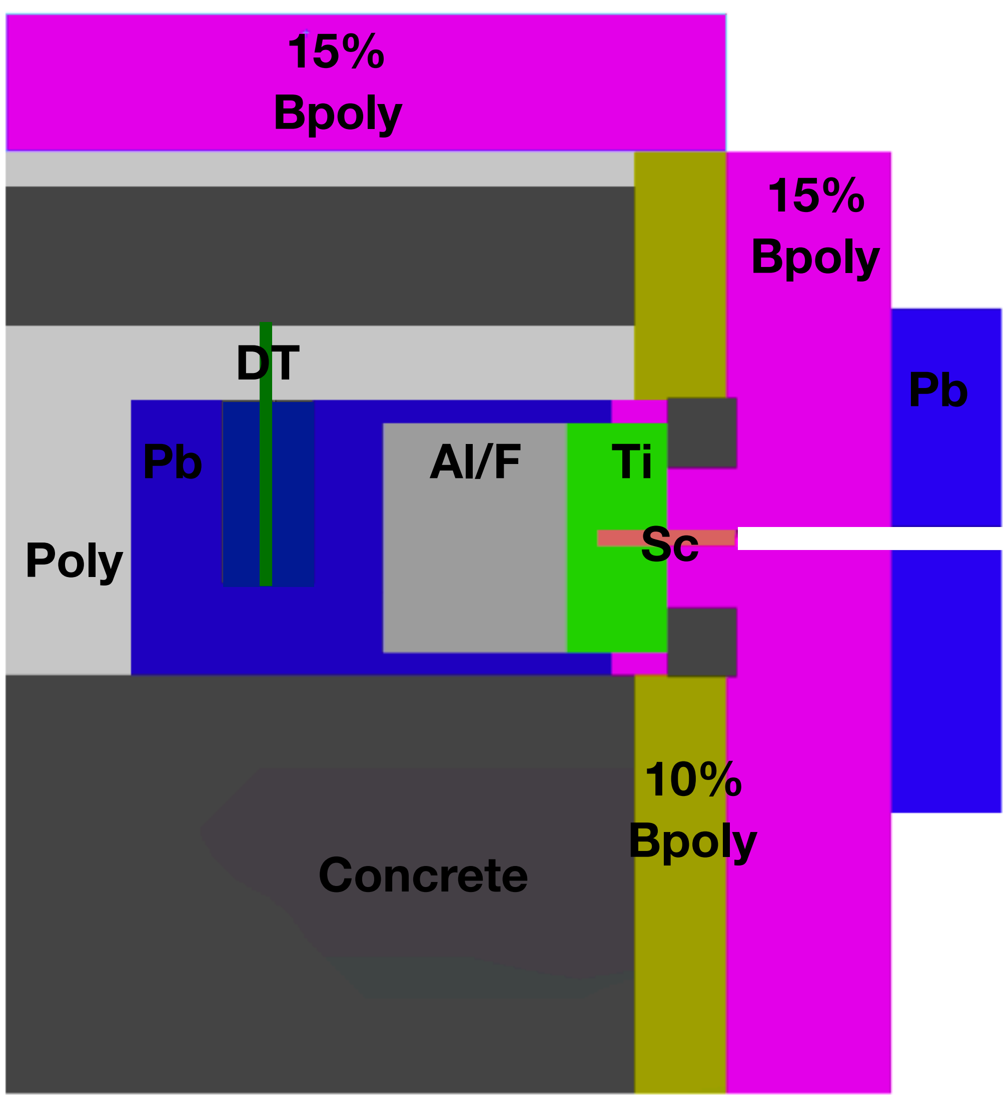


Shielding Challenges

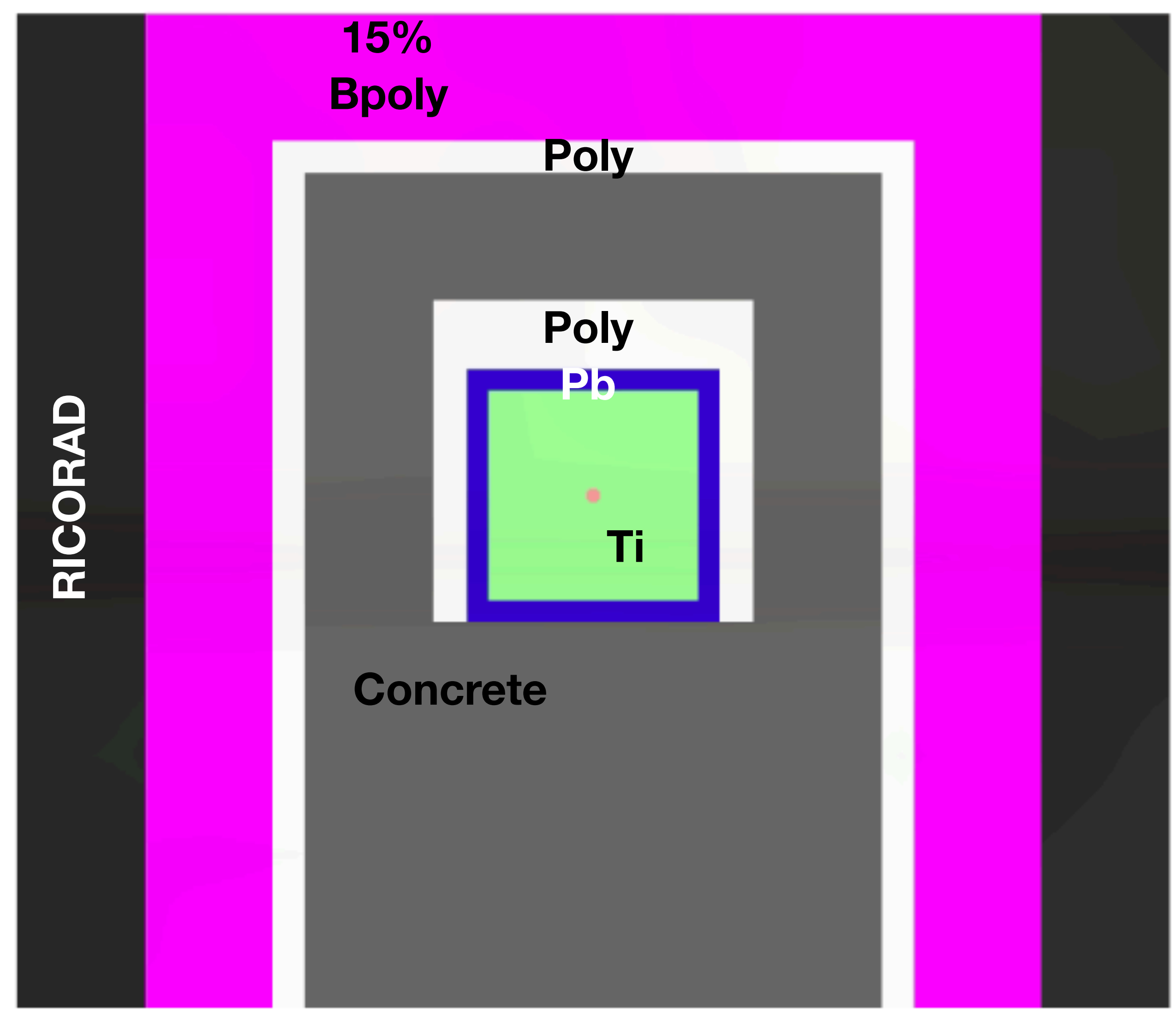
Reiterated various design, but the sandwich layers of high-z (lead and concrete) and low-z materials (poly) performs better



Side View



Front View



Progress in construction

- Lead and Titanium plates have been shipped from China

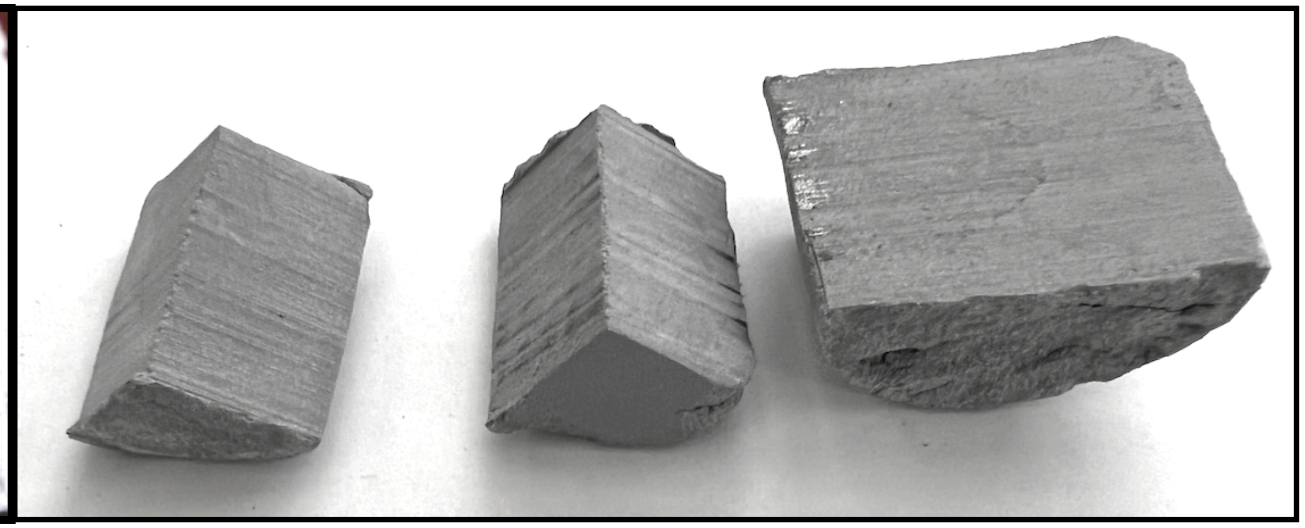
- Recived the interlocking concrete bricks

- Recieved the Sc rod and the DT generator

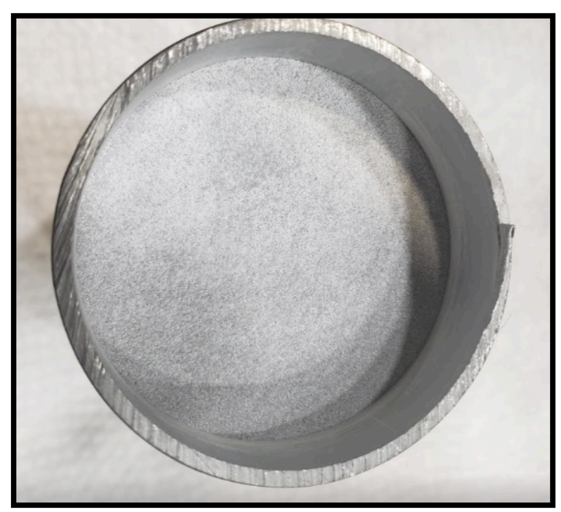
- Al/F mixture is in process of Hot Isotatic Pressing + Cold Isostatic Pressing treatment to achieve density of 2.5g/cc

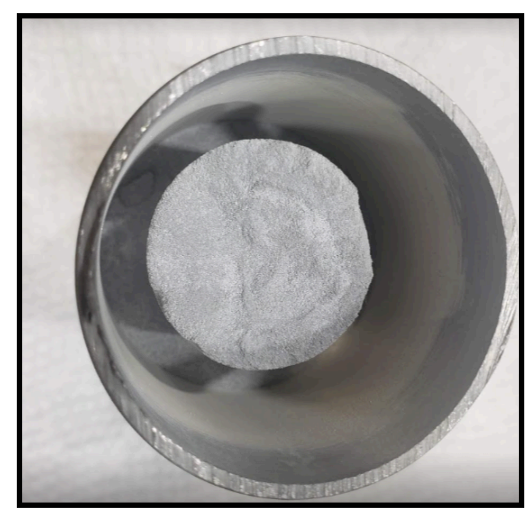
Some Pictures

- Only via Hot Isotatic Pressing obtained density ~ 2.4 +-0.1 g/cc

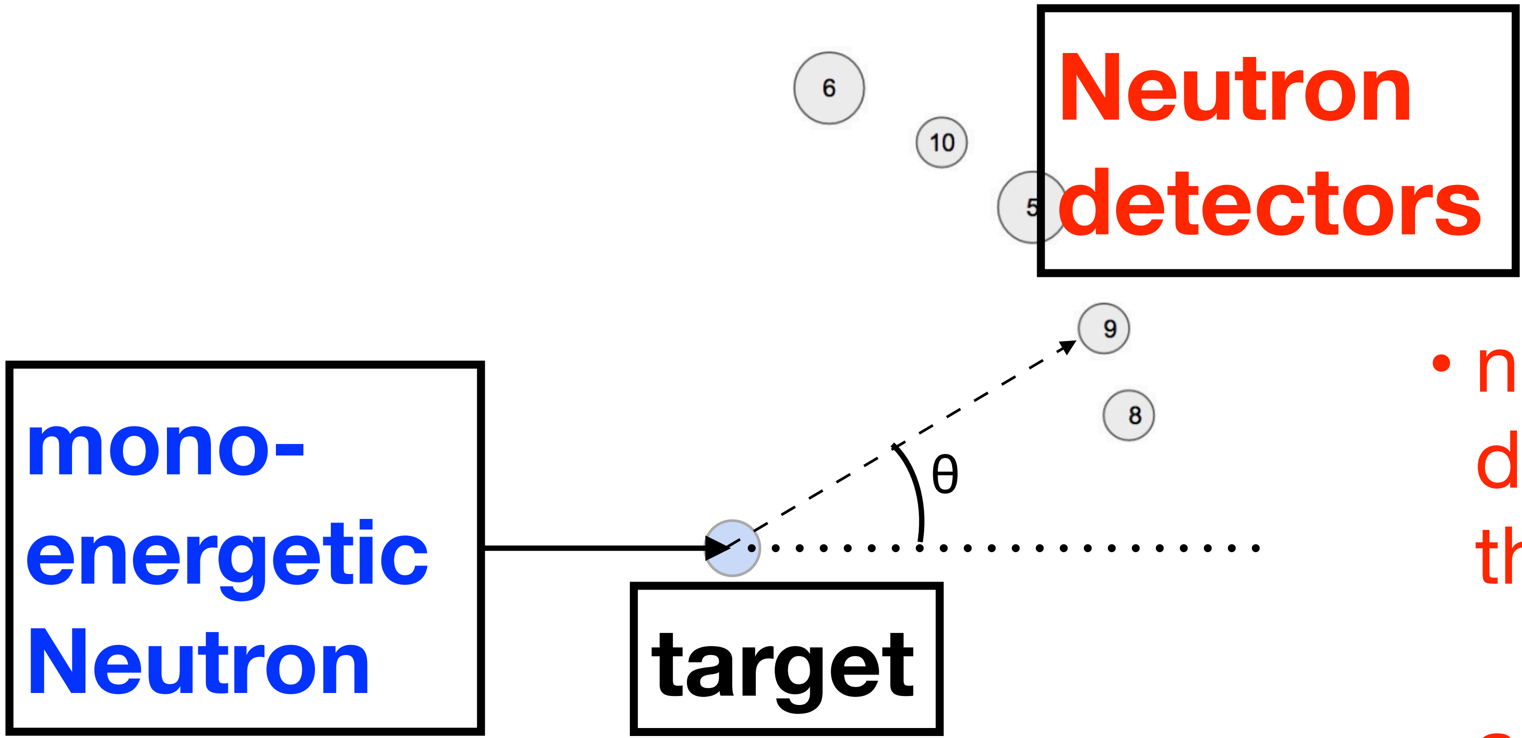


- Cold Isotatic Pressing + HIP part density ~ 2.6 +-0.2 g/cc





Next challenge, large neutron detector



- need large neutron detector, maxmize the solid angle
- also efficient in detecting keV scale neutron

- not entirely monoenergetic
- efficiency of the neutron moderation and filtering idea is too low
- we have finite amount of neutron from DT/DD unit

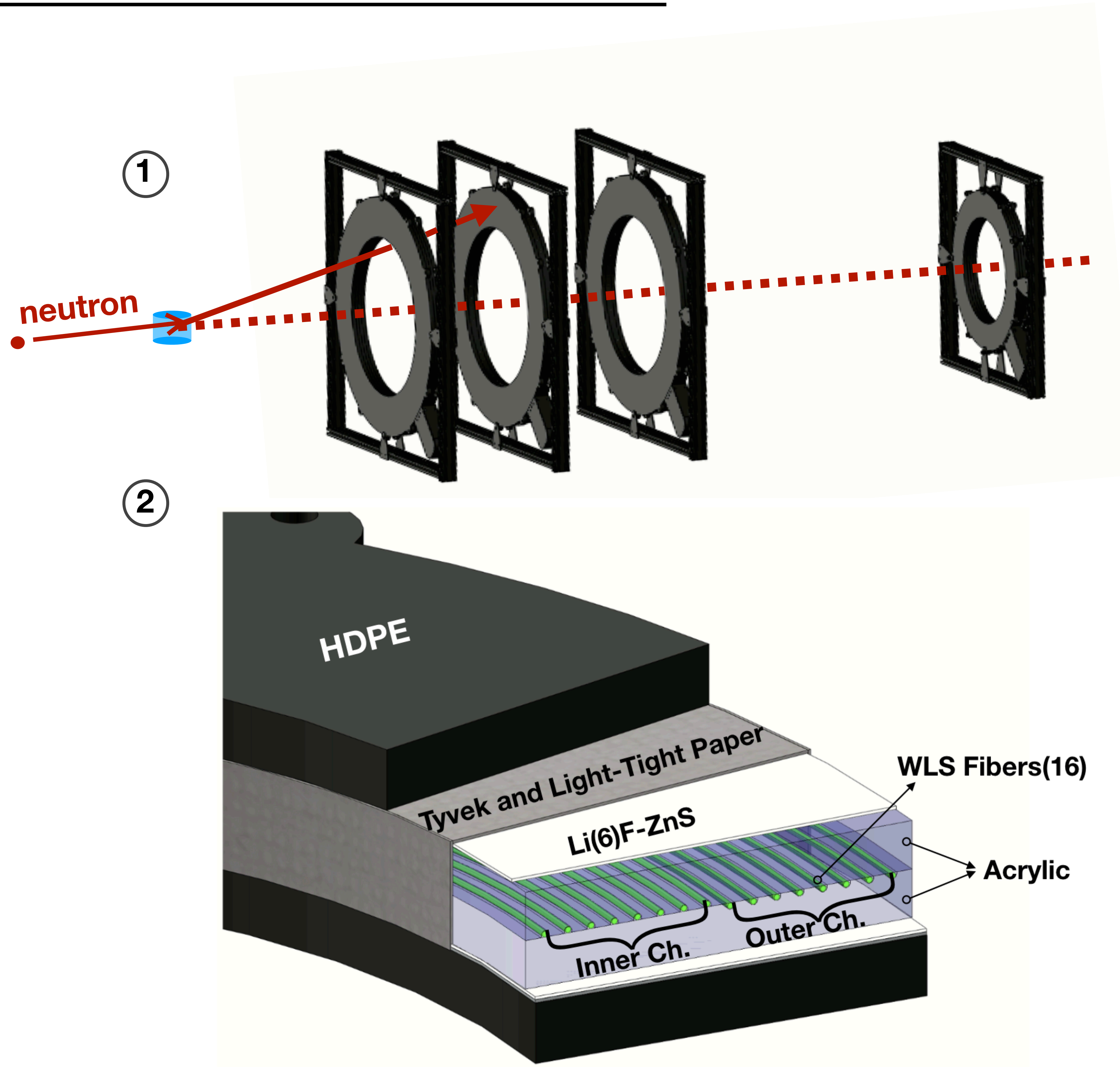
Neutron (Backing) Detector (NIMA 1039)

- Large in area and low in cost/area

- High capture efficiency

- Short capture time (enabling coincidence cut)

- Low in gamma background rate with Pulse Shape Discrimination



Summary

After :

-Optimising filter geometry parts

-reducing corelated background rates

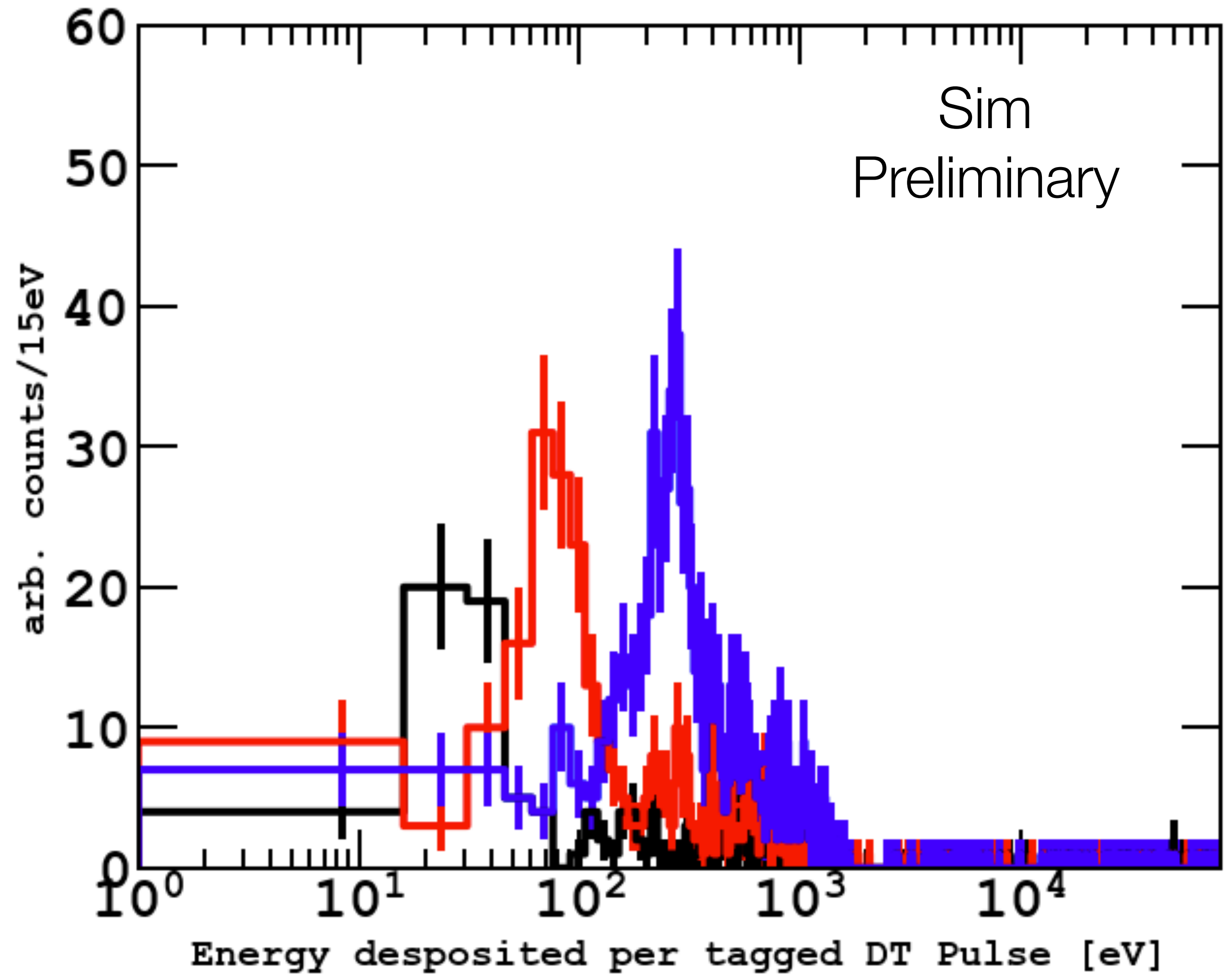
Now :

-Procurement of various materials

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

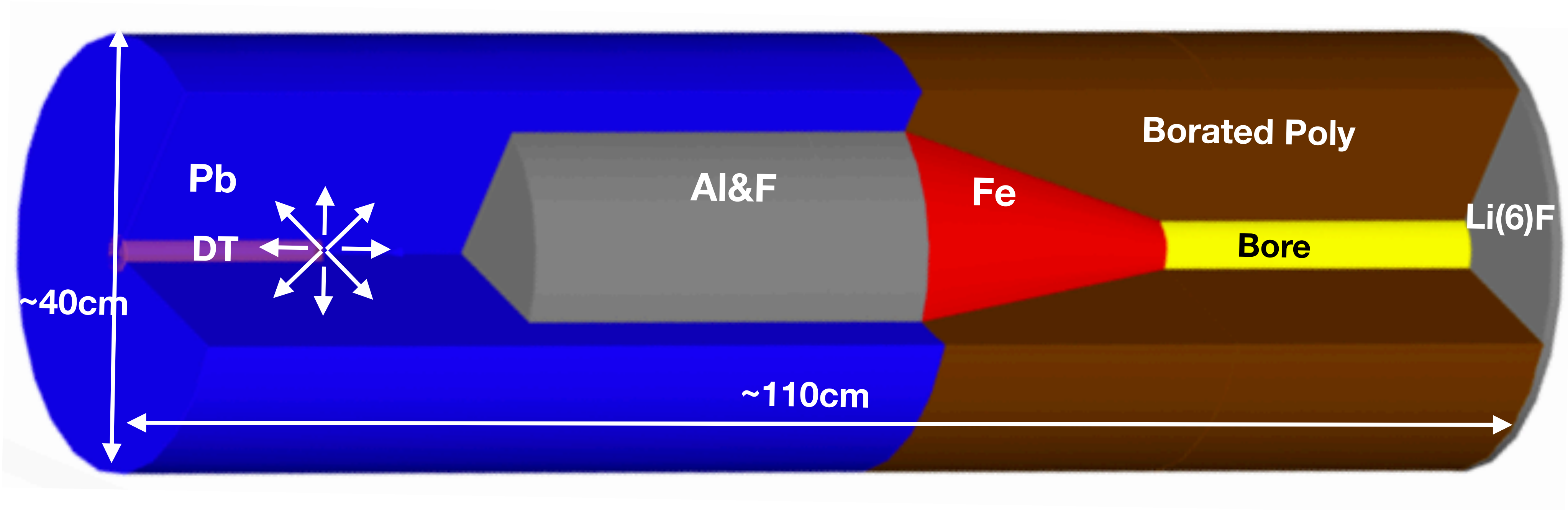
- Diff. targets materials can be calibrated

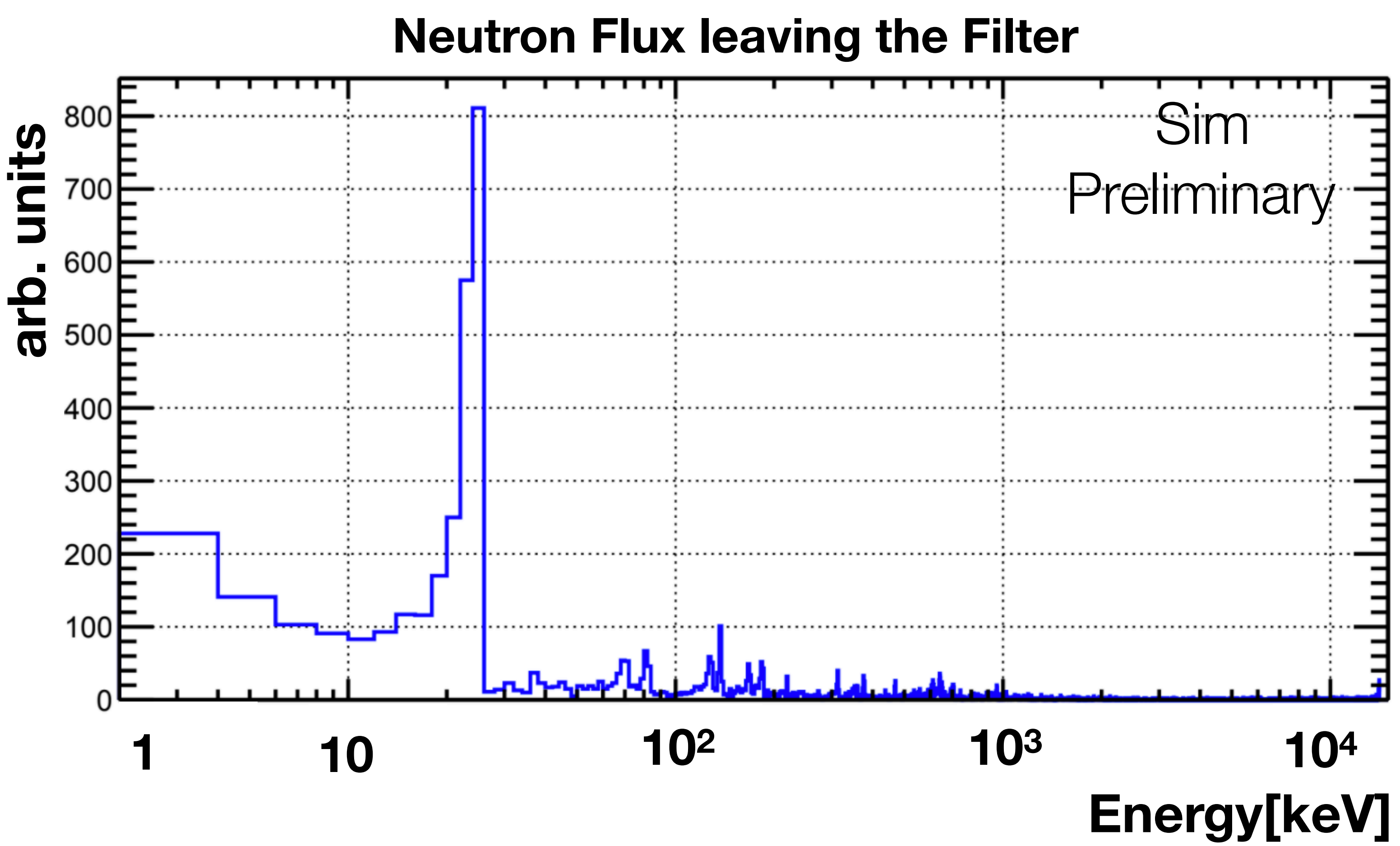
- Pulsed low energy neutron beam is essential in understanding LHe quasiparticles, triplet kinematics and quenching.




Thank you!!!

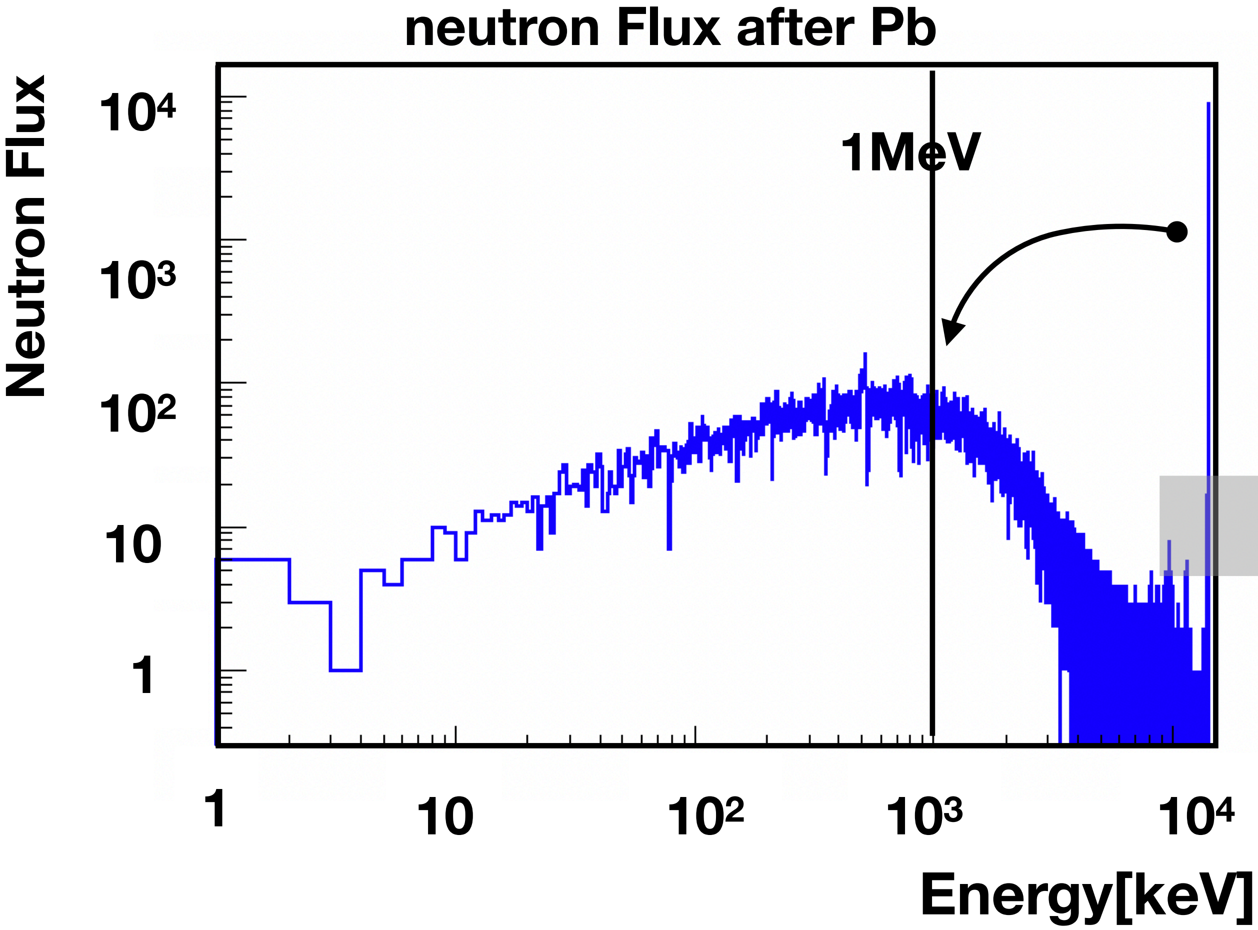
$E_{neutron}$ 24 keV: Final Spectrum

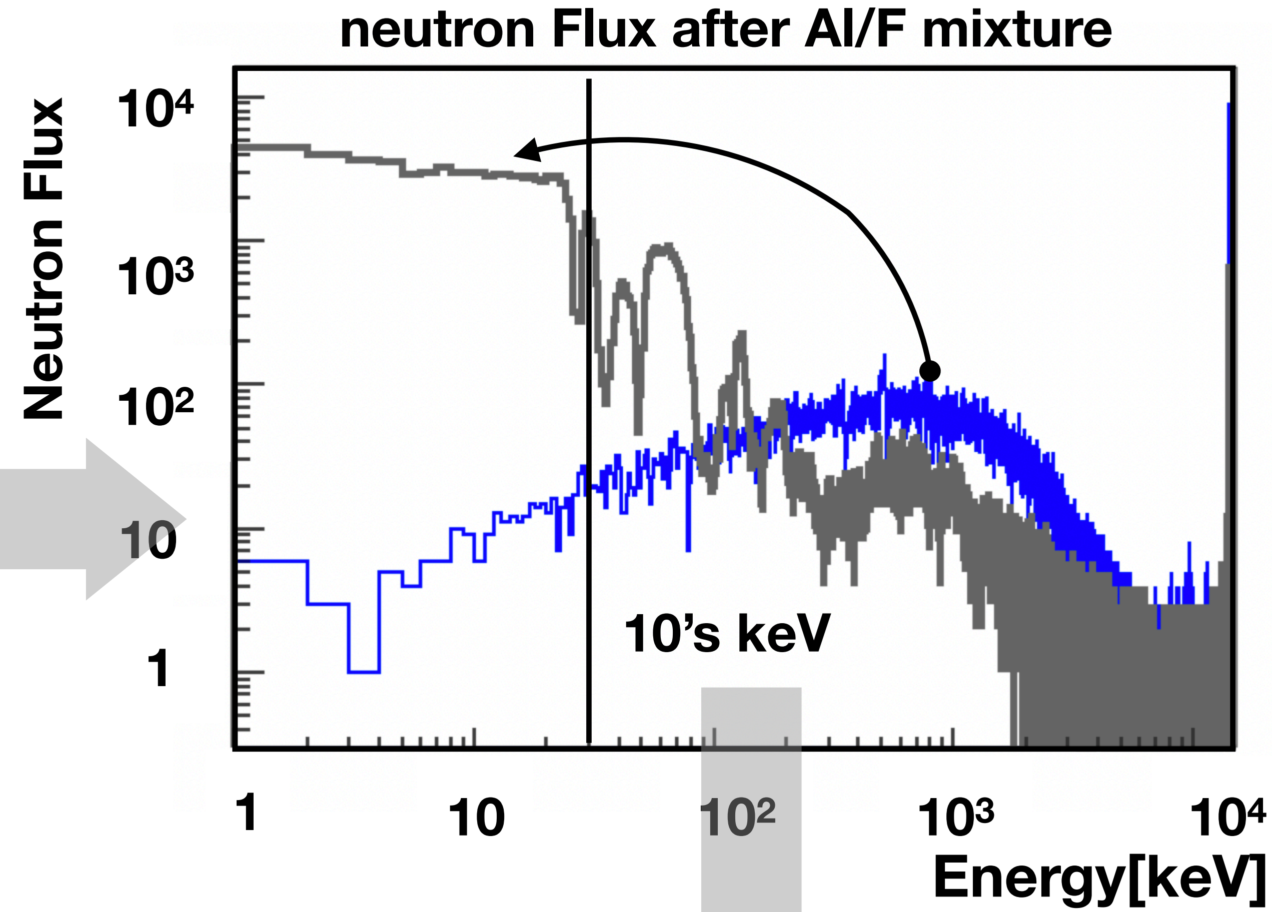


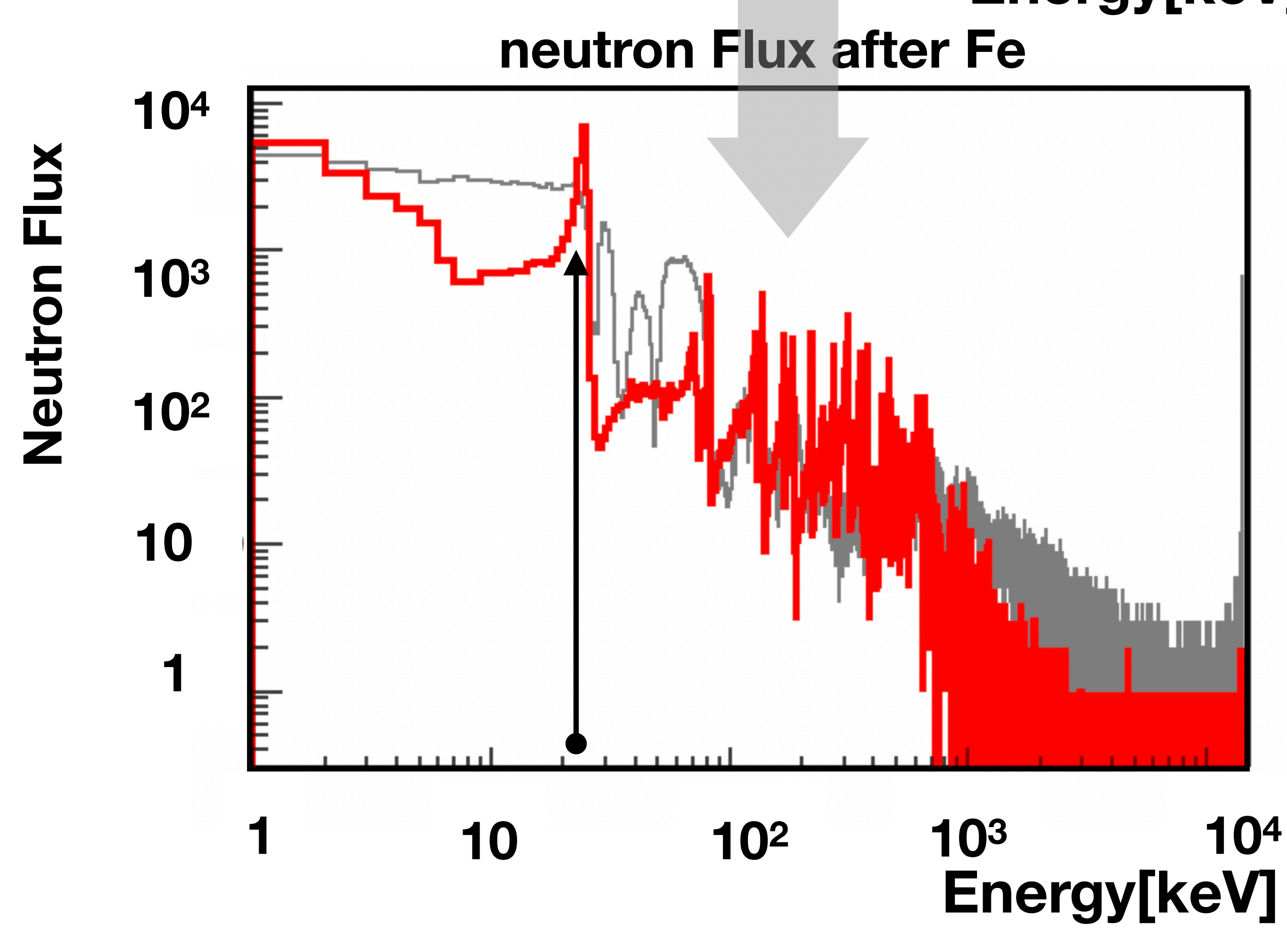


- Clearly we see a 24keV peak, but there are higher energy contaminants….quasi-monoenergetic neutron beam

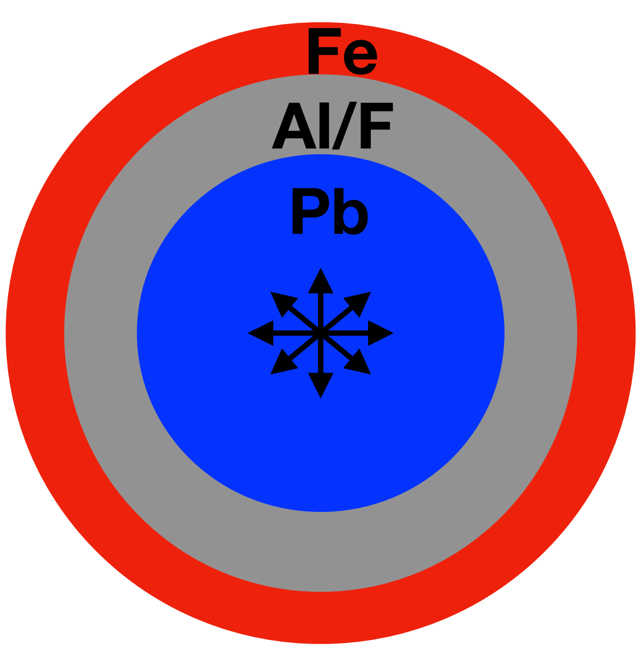
$E_{neutron}$ 24 keV: Initial Toy Model Sim



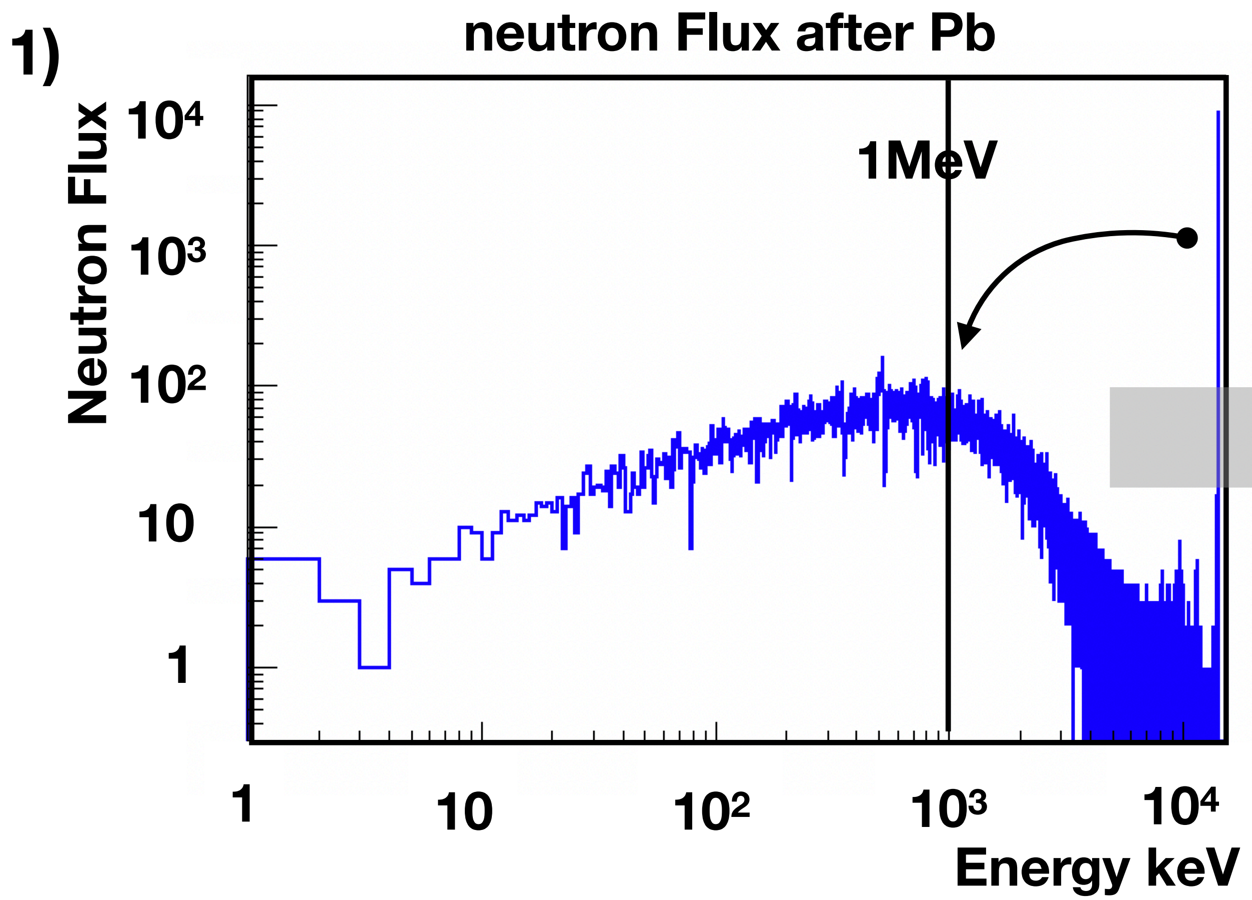


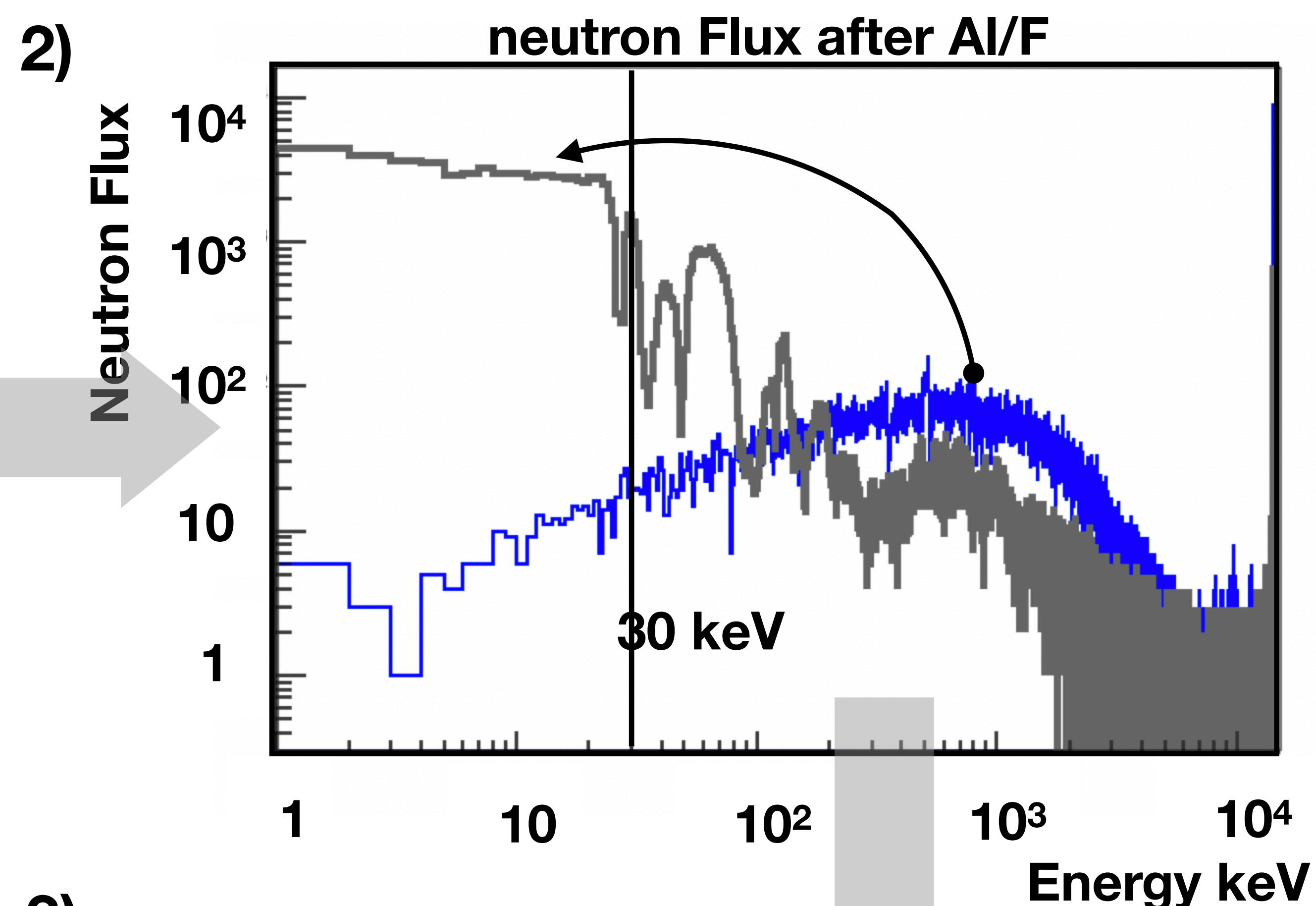


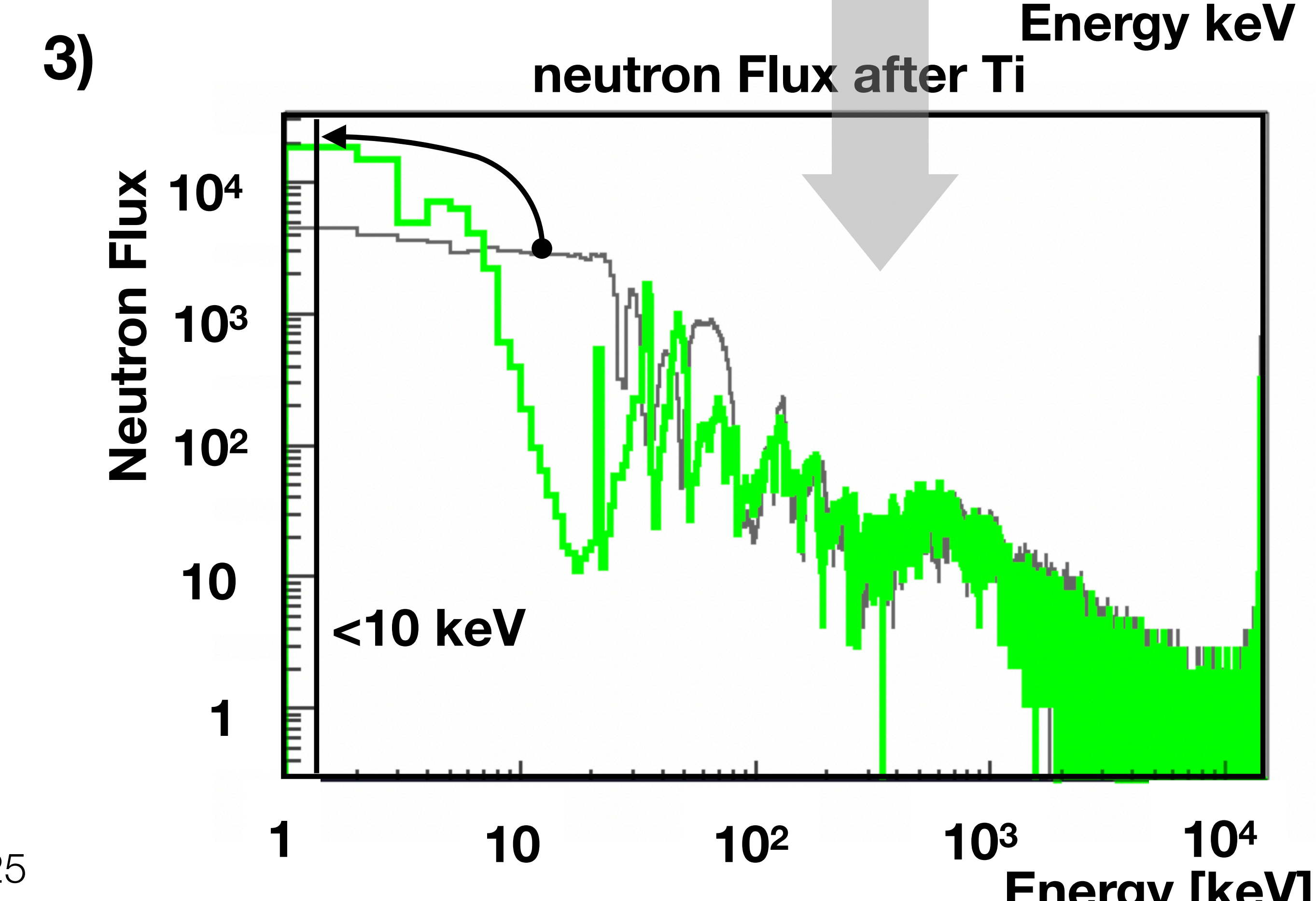
initial spherical sim geometries



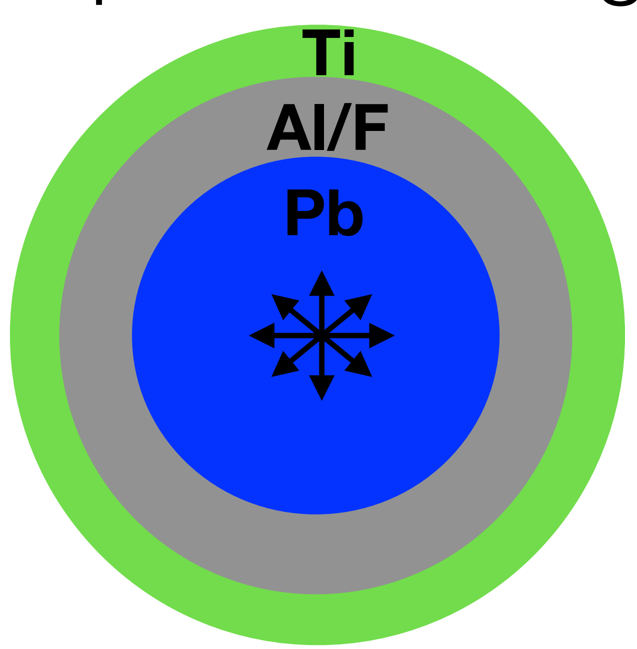
$E_{neutron}$ 2 keV: Initial Toy Model Sim







initial spherical sim geometries



Optimization using GEANT4

- Al/F - length
  - width
- Ti - length
  - width same as Al/F
- Lead - length
  - width of Al/F + 5cm

•Sc length and width is fixed by price!

2keV neutron event in geant4