WNPPC 2020

SIMULATING A COMPLEMENTARY DETECTOR FOR DESCANT:

TO DETERMINE NEUTRON ENERGIES

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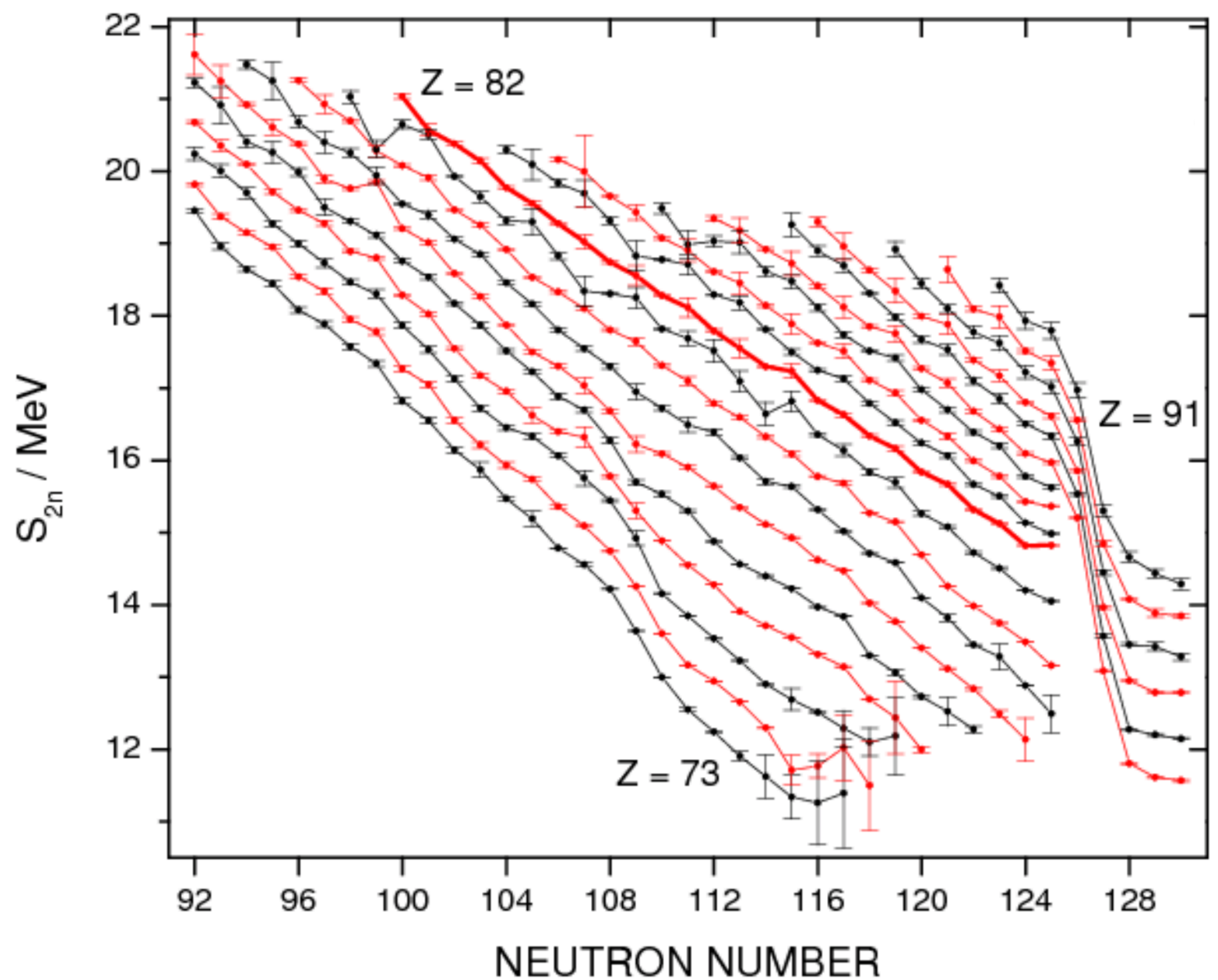
TRIUMF

UNIVERSITY of GUELPH

BACKGROUND

- Studying neutron rich nuclei is the at the forefront of nuclear physics research using radioactive beam experiments

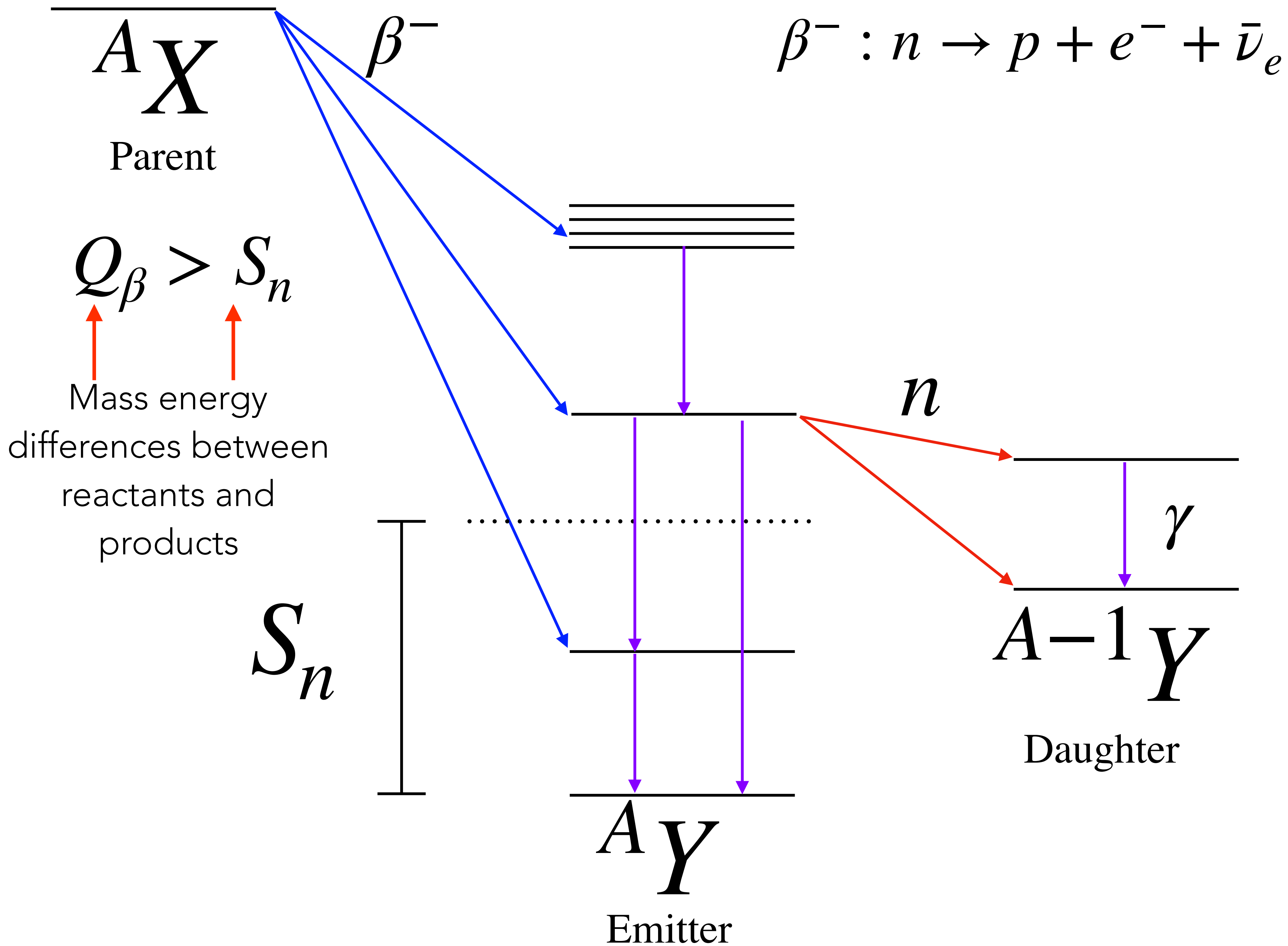
- As the ratio of neutrons (N) to protons (Z) increases, the valence neutrons become less bound



C. Weber et al., Nuclear Physics A 803, 1 (2008)

BACKGROUND

Beta Delayed Neutron Emission



BACKGROUND

Astrophysical Processes

Many r-process nuclei are beta delayed neutron emitters

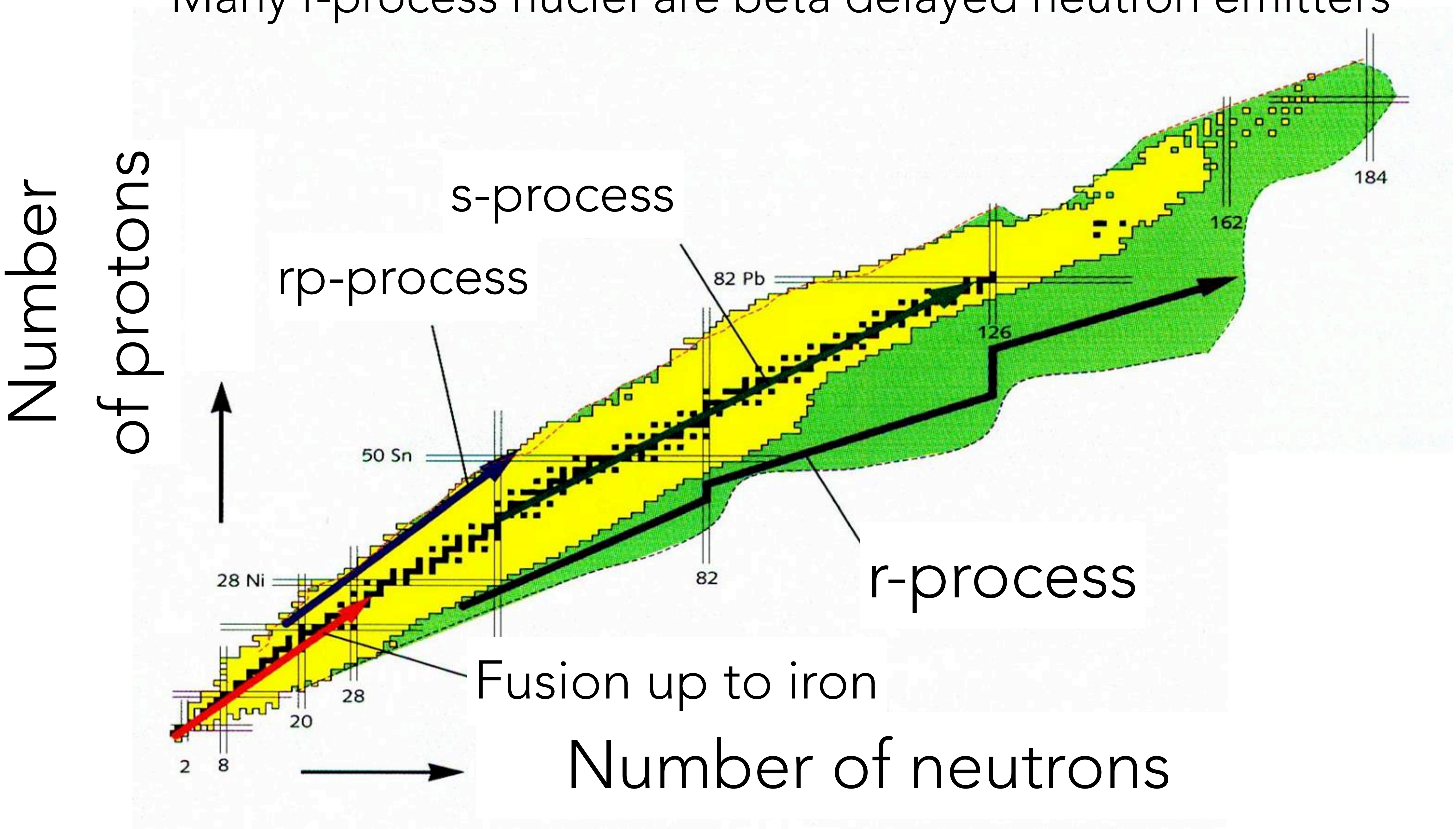
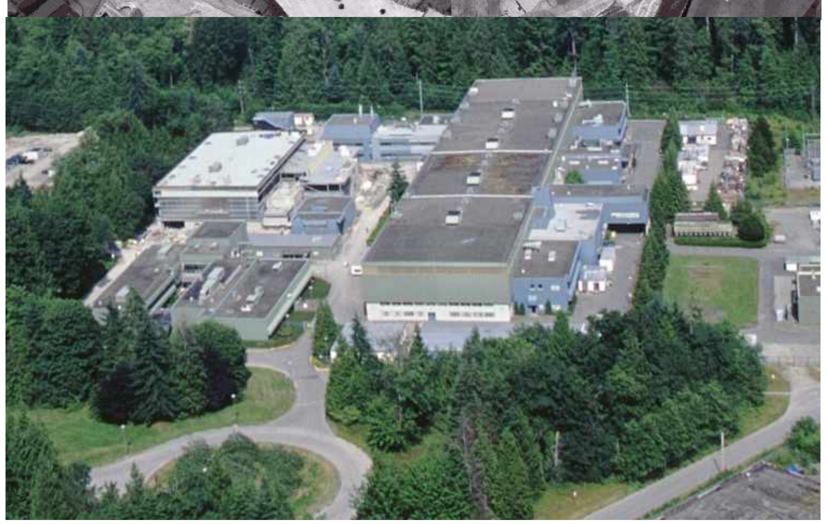
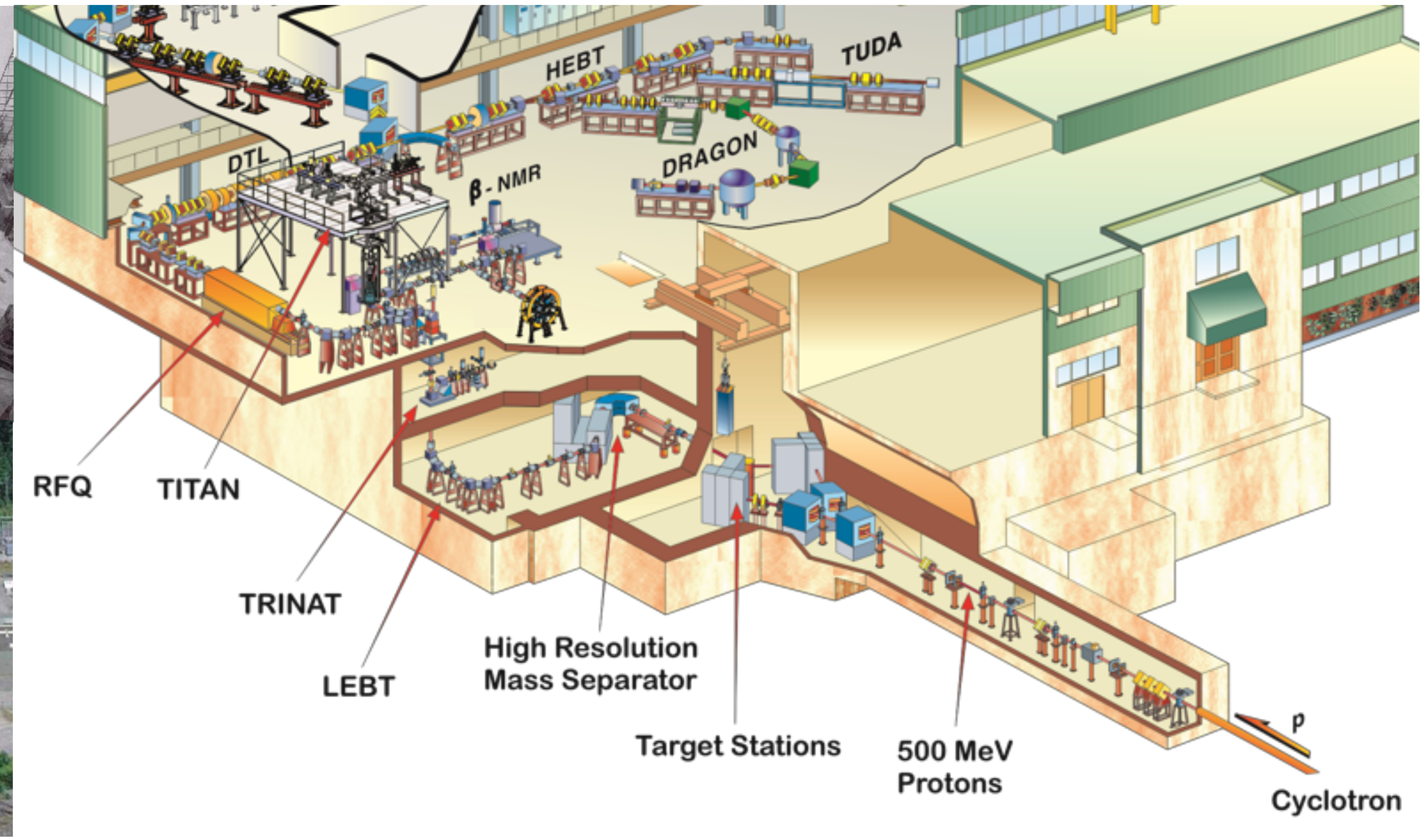


Image from: http://www.phys.utk.edu/expnuclear/nucastro.html

TRIUMF

Canada's particle accelerator centre

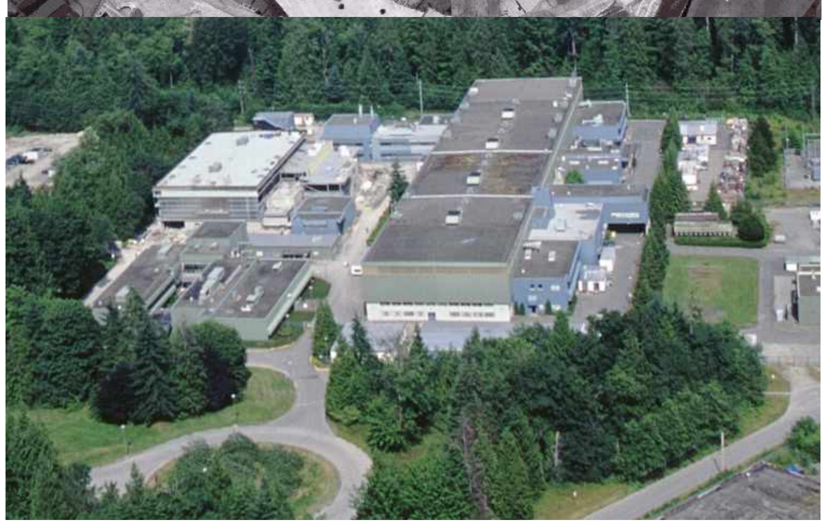


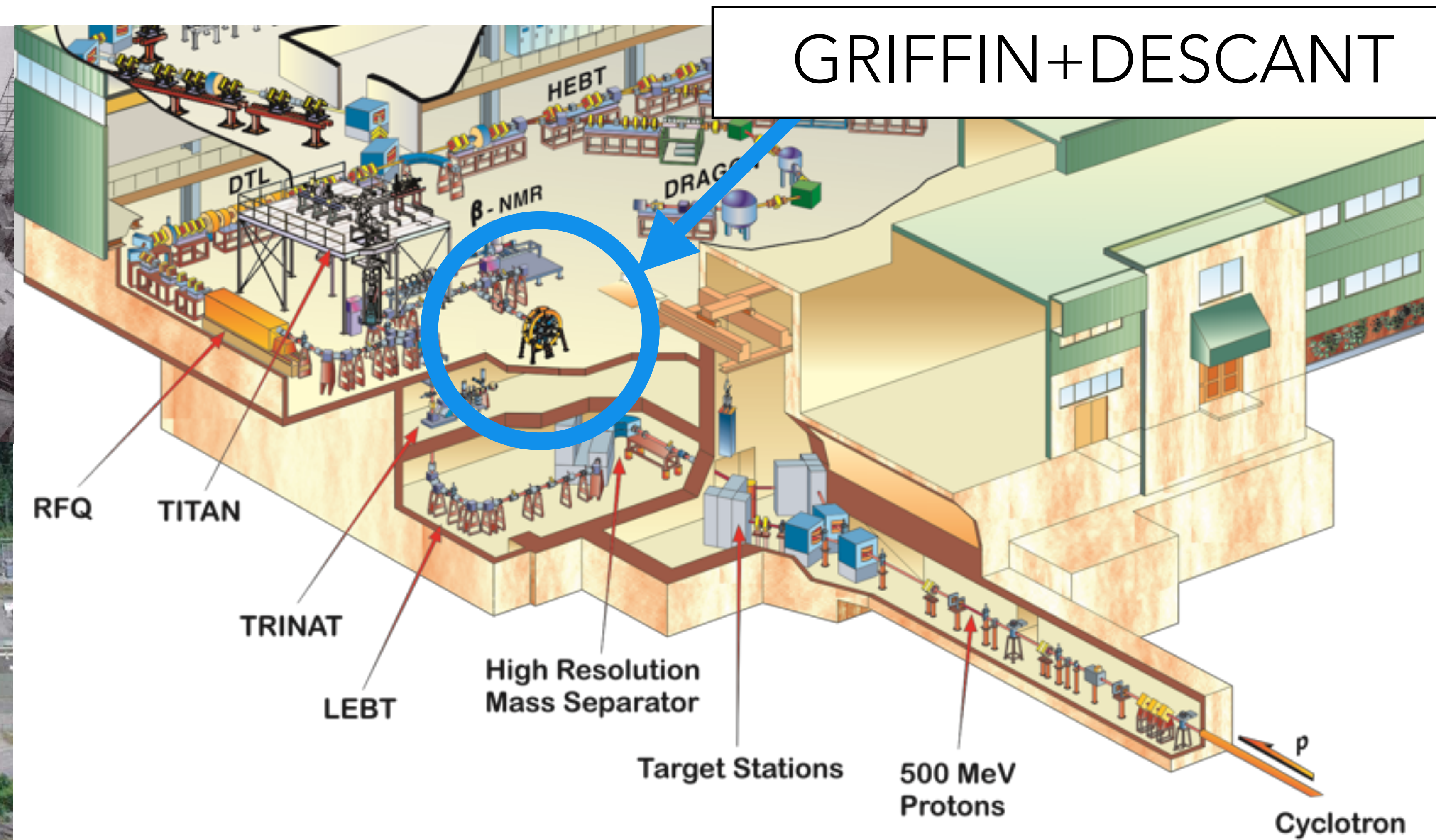


- Strong campaign studying neutron rich nuclei at TRIUMF
  - Via beta decay and beta delayed neutron spectroscopy

TRIUMF

Canada's particle accelerator centre



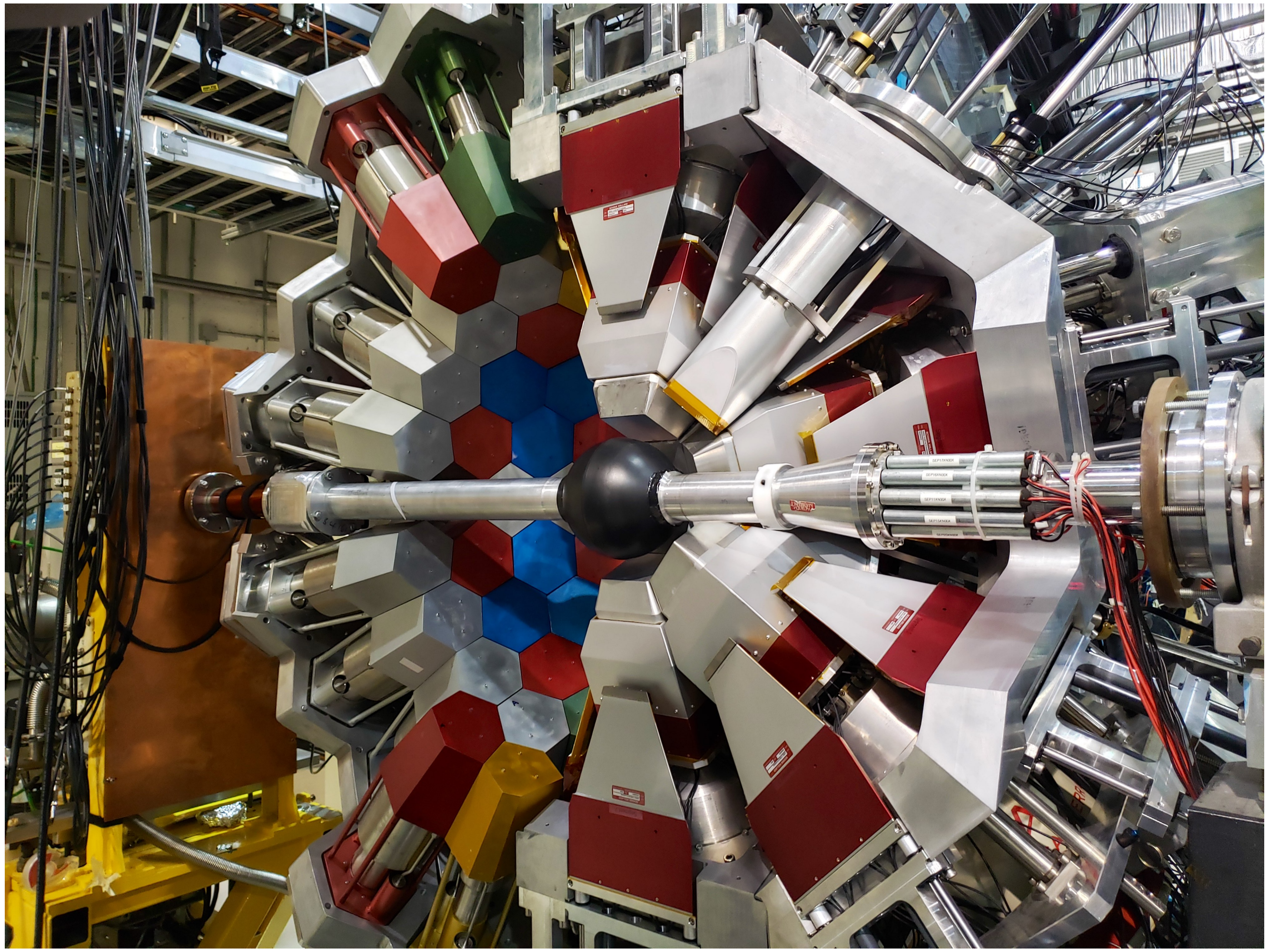


- Strong campaign studying neutron rich nuclei at TRIUMF
  - Via beta decay and beta delayed neutron spectroscopy

GRIFFIN+DESCANT

Experimental Setup

- GRIFFIN (Gamma-Ray Infrastructure For Fundamental Investigation of Nuclei)
- DESCANT (DEuterated SCintillator Array for Neutron Tagging)
- In addition there are beta particle detectors and available position for other ancillary devices



GRIFFIN+DESCANT

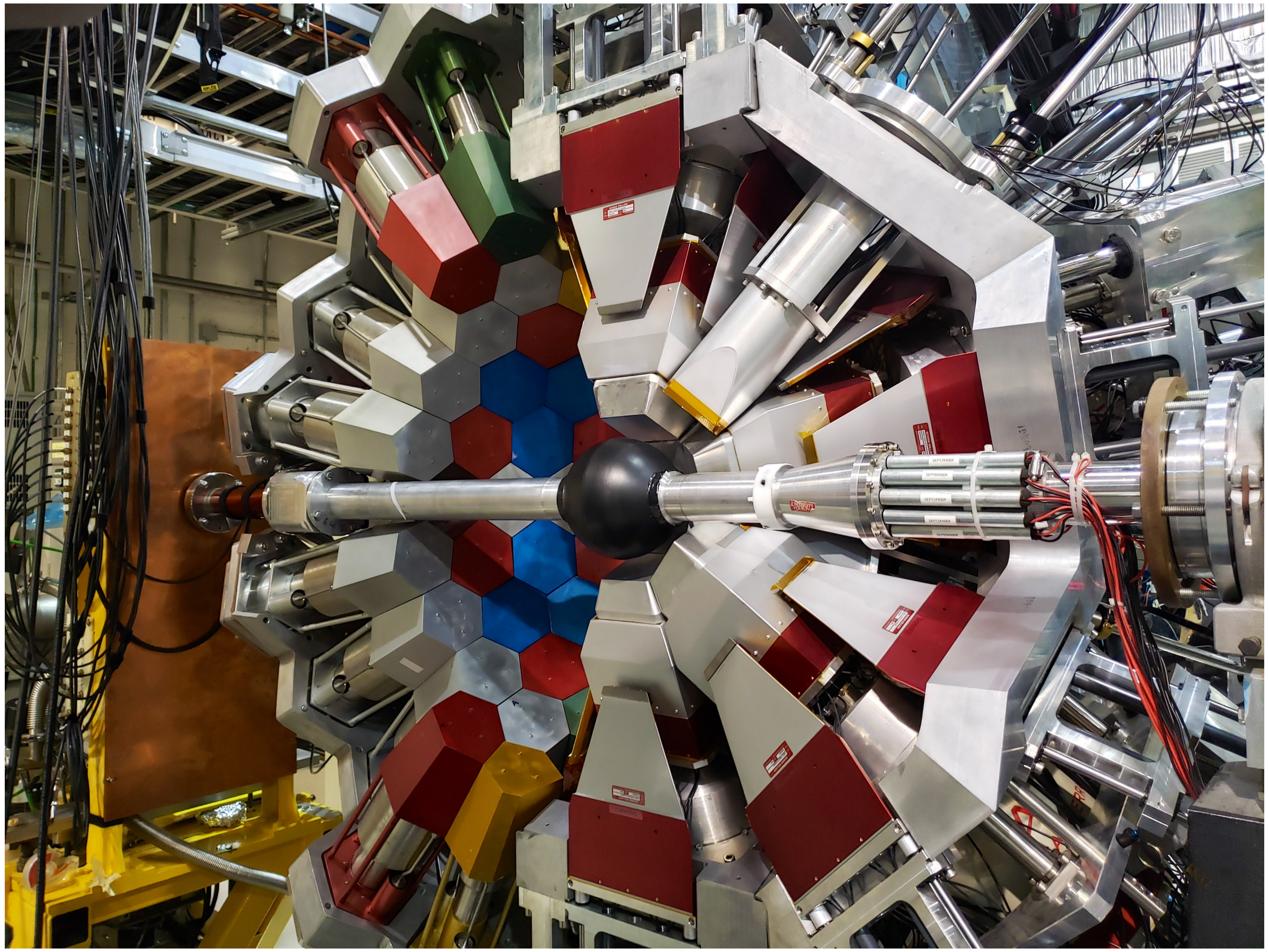
Experimental Setup

- DESCANT has good neutron detection efficiency, but at the expense of precision on the neutron kinetic energy

- Good energy resolution could be obtained through the addition of an array of plastic scintillators potentially placed in front of DESCANT

    - Plastic scintillators are inexpensive neutron detectors

    - Time-of-flight technique



TIME OF FLIGHT TECHNIQUE

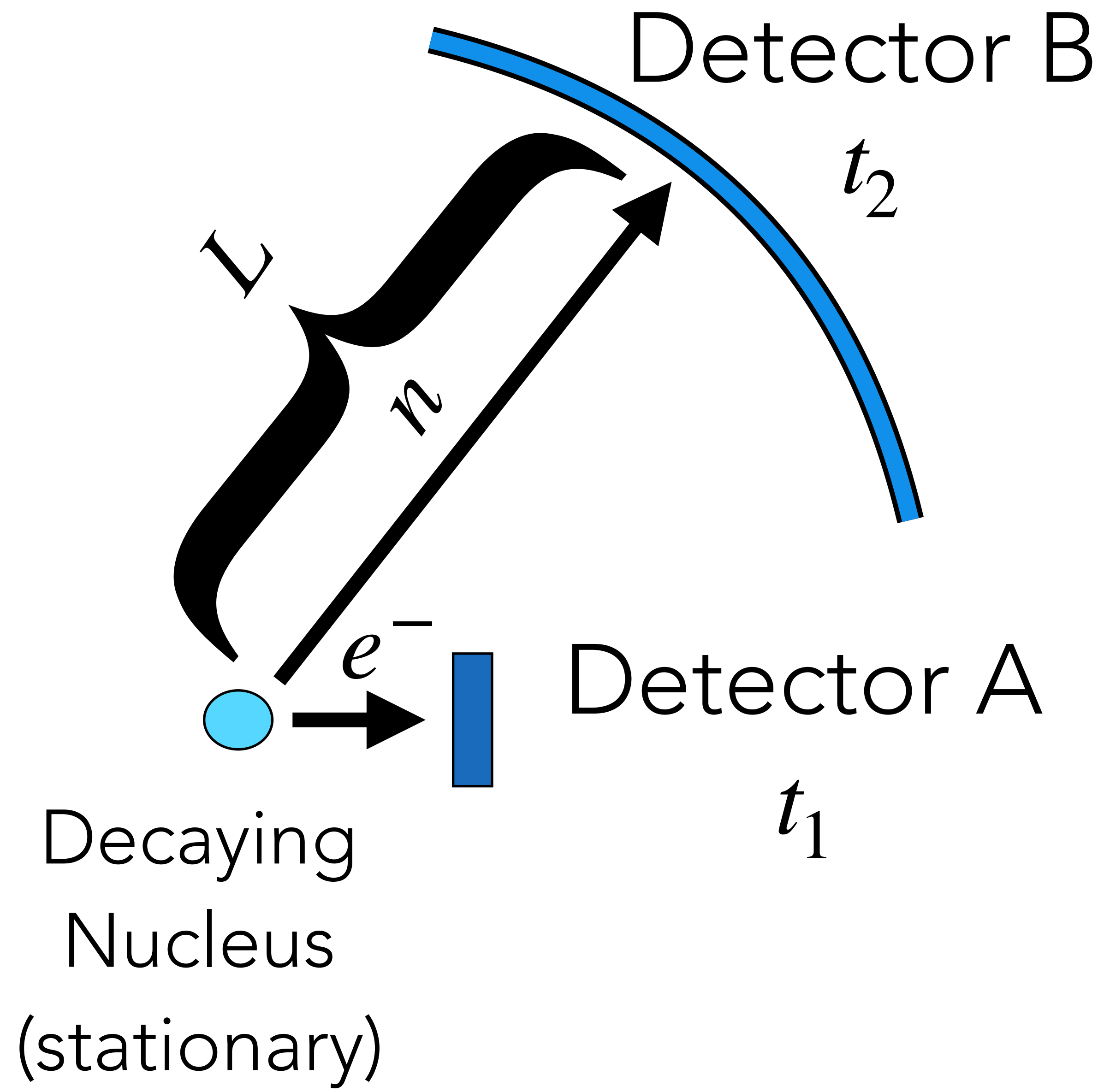
$$E = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{L^2}{TOF^2}$$

- Get TOF from 2 separate detectors that act as a stopwatch

- Beta and neutron emitted "simultaneously"

$$TOF = t_2 - t_1$$

- Distance L can be measured



TIME OF FLIGHT TECHNIQUE

Non relativistic neutron energy

$$E = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{L^2}{TOF^2}$$

L ← Distance travelled

TOF ← Time of Flight

Energy Resolution

Determined by detector thickness

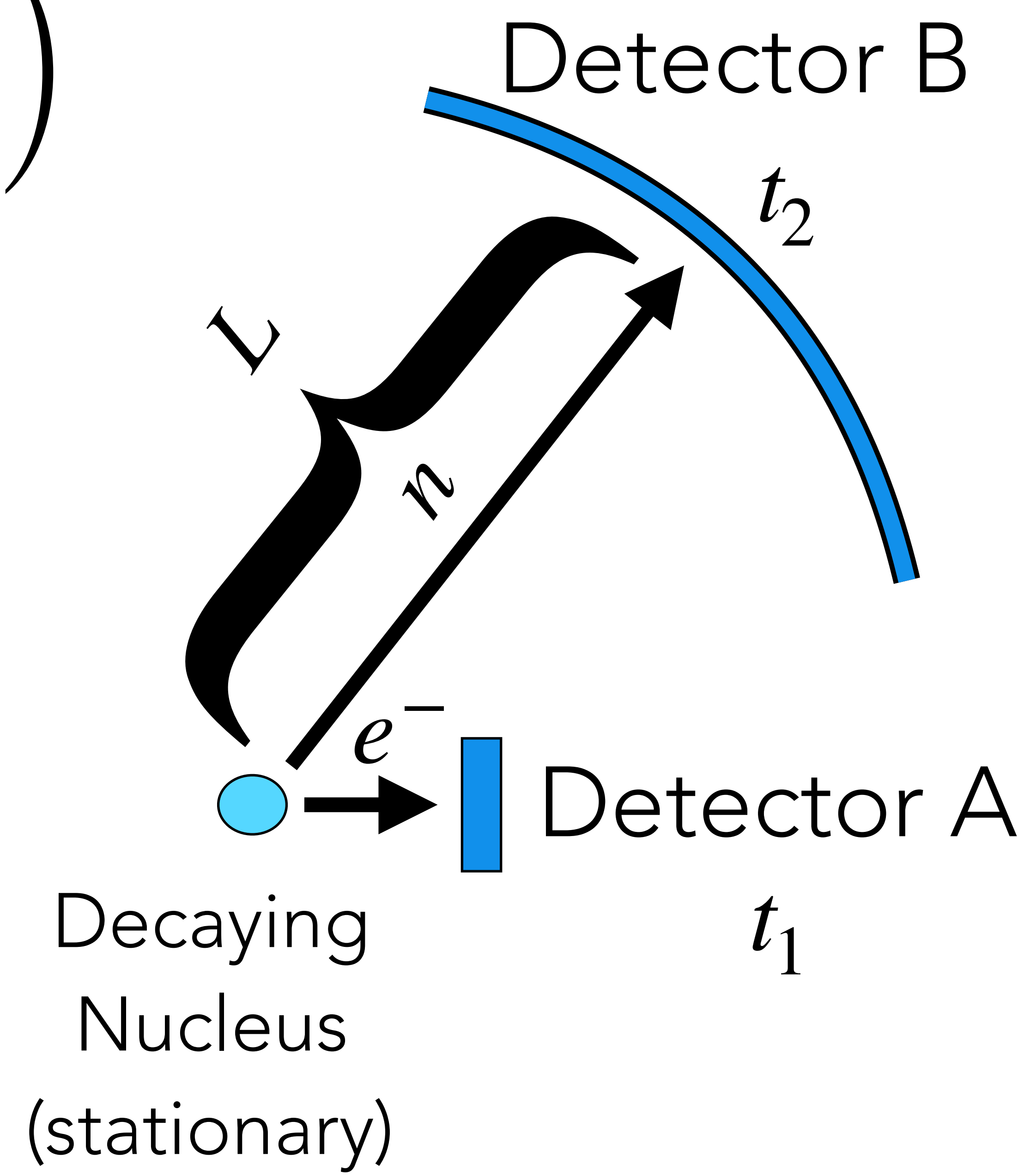
Determined by detector properties

$$\left(\frac{\Delta E}{E}\right)^2 = \left(\frac{2\Delta L}{L}\right)^2 + \left(\frac{2\Delta TOF}{TOF}\right)^2$$

TIME OF FLIGHT TECHNIQUE

$$\left(\frac{\Delta E}{E}\right)^2 = \left(\frac{2\Delta L}{L}\right)^2 + \left(\frac{2\Delta TOF}{TOF}\right)^2$$

- Good TOF energy resolution requires thin detectors
- Good efficiency requires thick detectors
- Detector geometry must be optimized

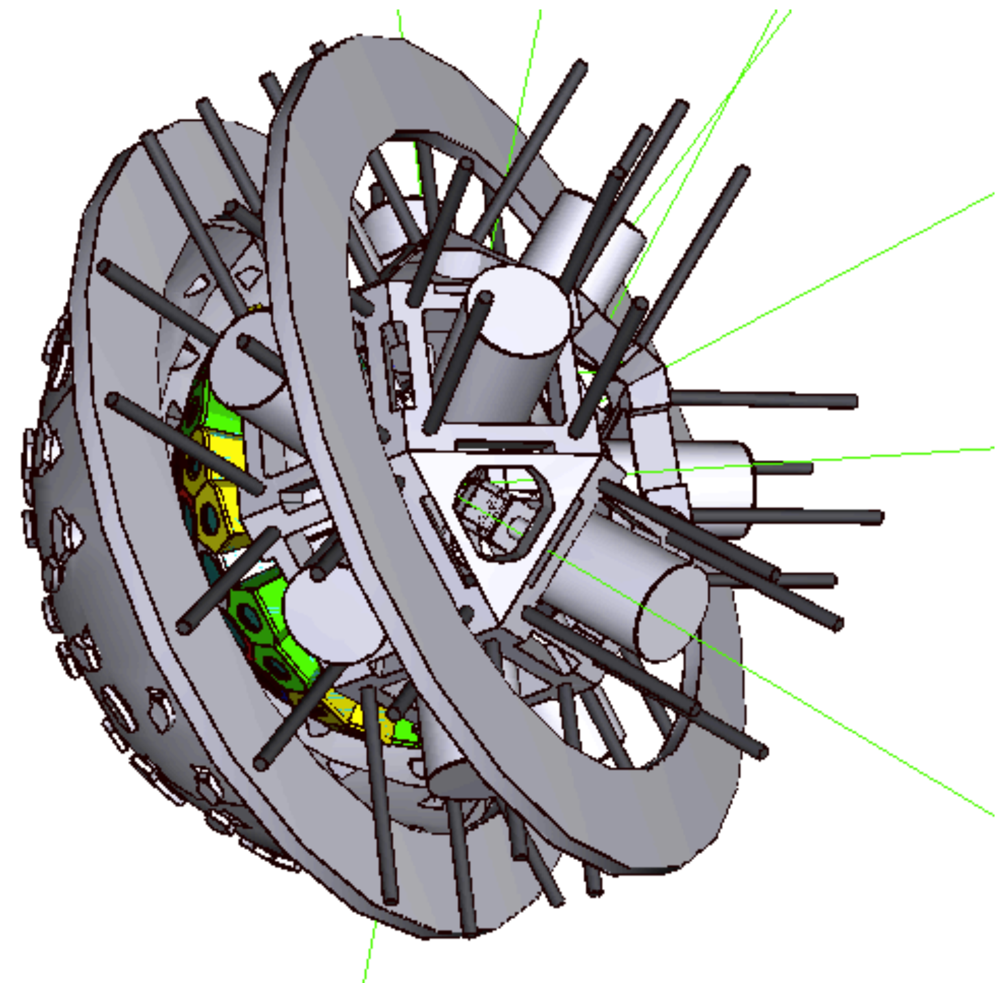


$$TOF = t_2 - t_1$$

GEANT4 SIMULATIONS

Detector Geometry

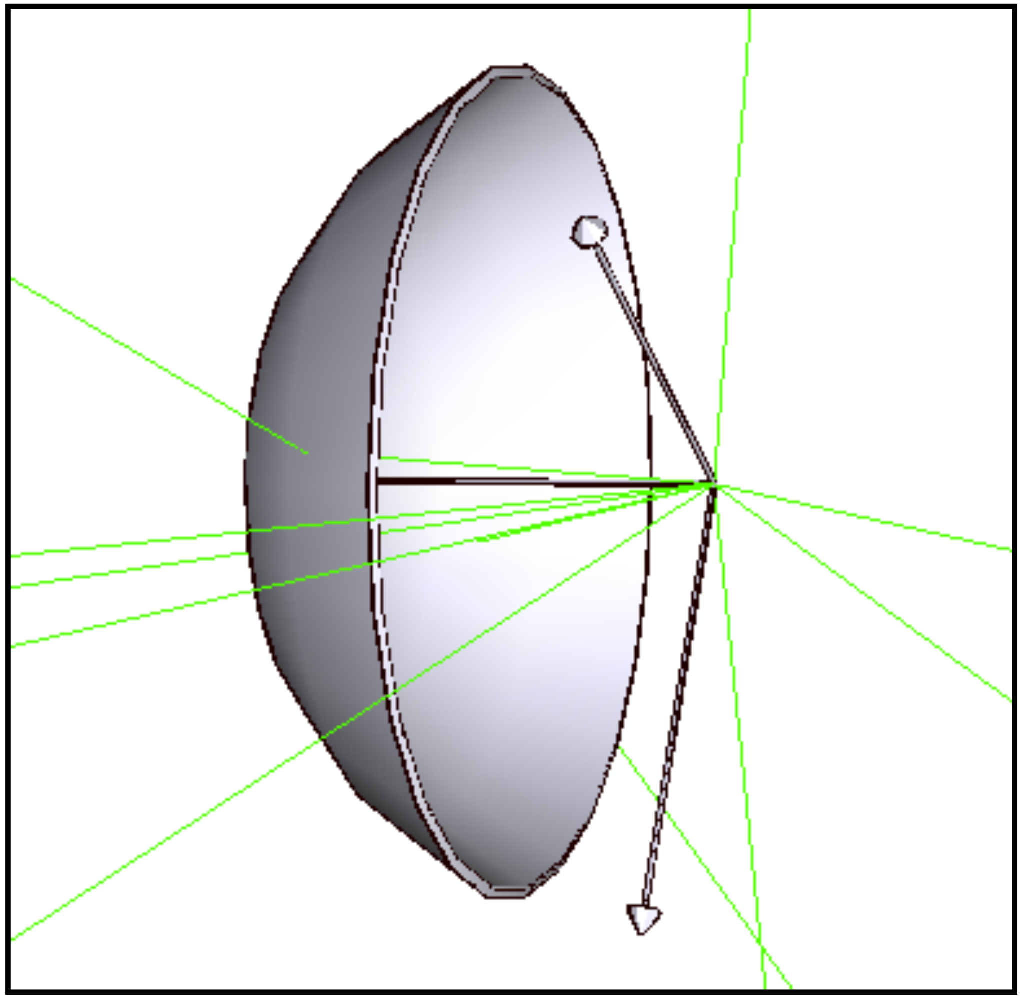
- GEANT4 is a toolkit for simulating particles passing through matter
  - Monte-Carlo technique
  - Ideal for designing and optimizing new detector concepts



GEANT4 SIMULATIONS

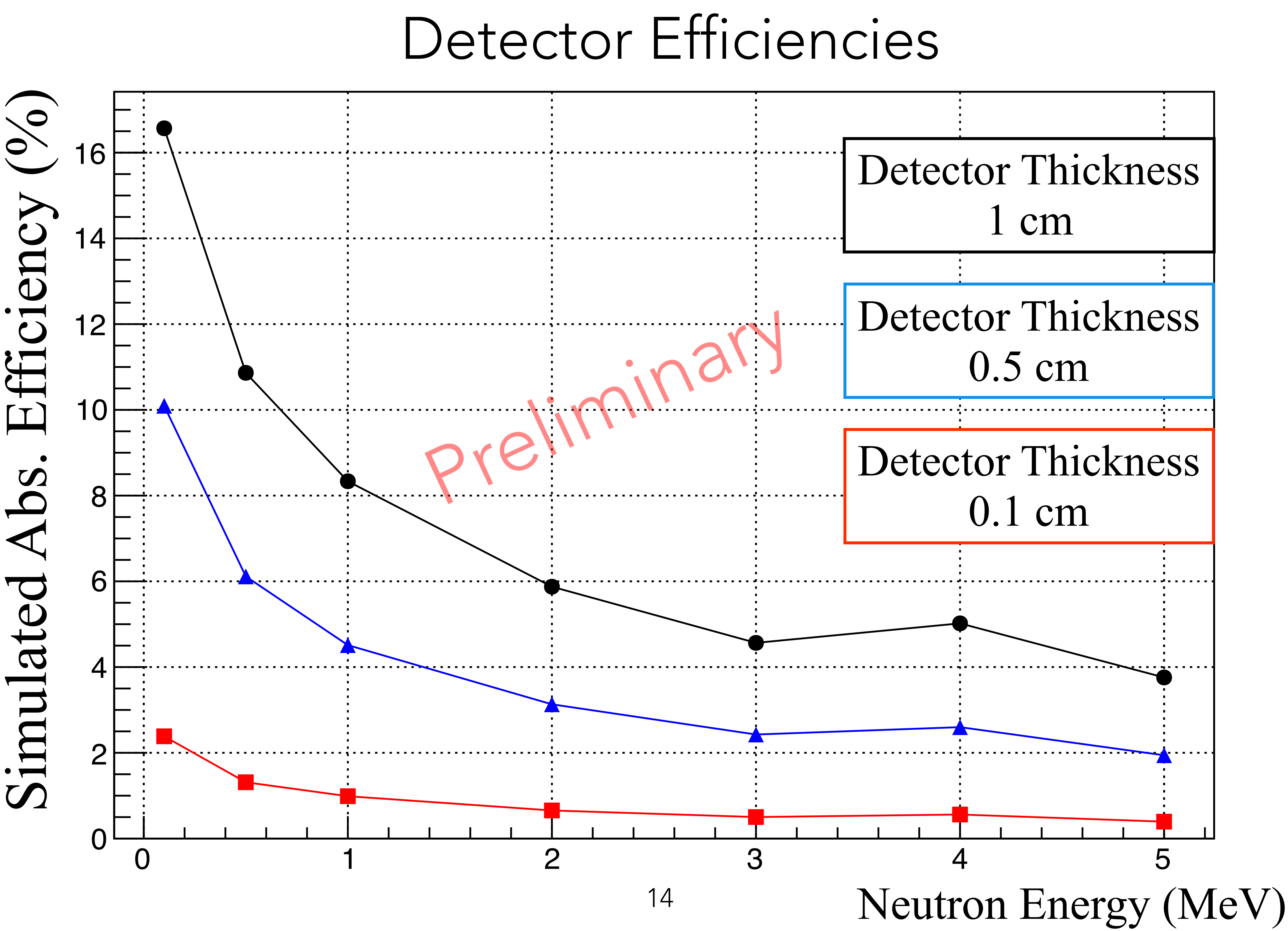
Detector Geometry

- Simplified geometry
  - Hollow plastic sphere that fits inside DESCANT - roughly 30% solid angle coverage
  - Useful for extracting basic information like efficiencies and scattering effects
- Look at absolute efficiencies of neutrons scattering in plastics for different detector thicknesses



Based on BC408 plastic scintillators

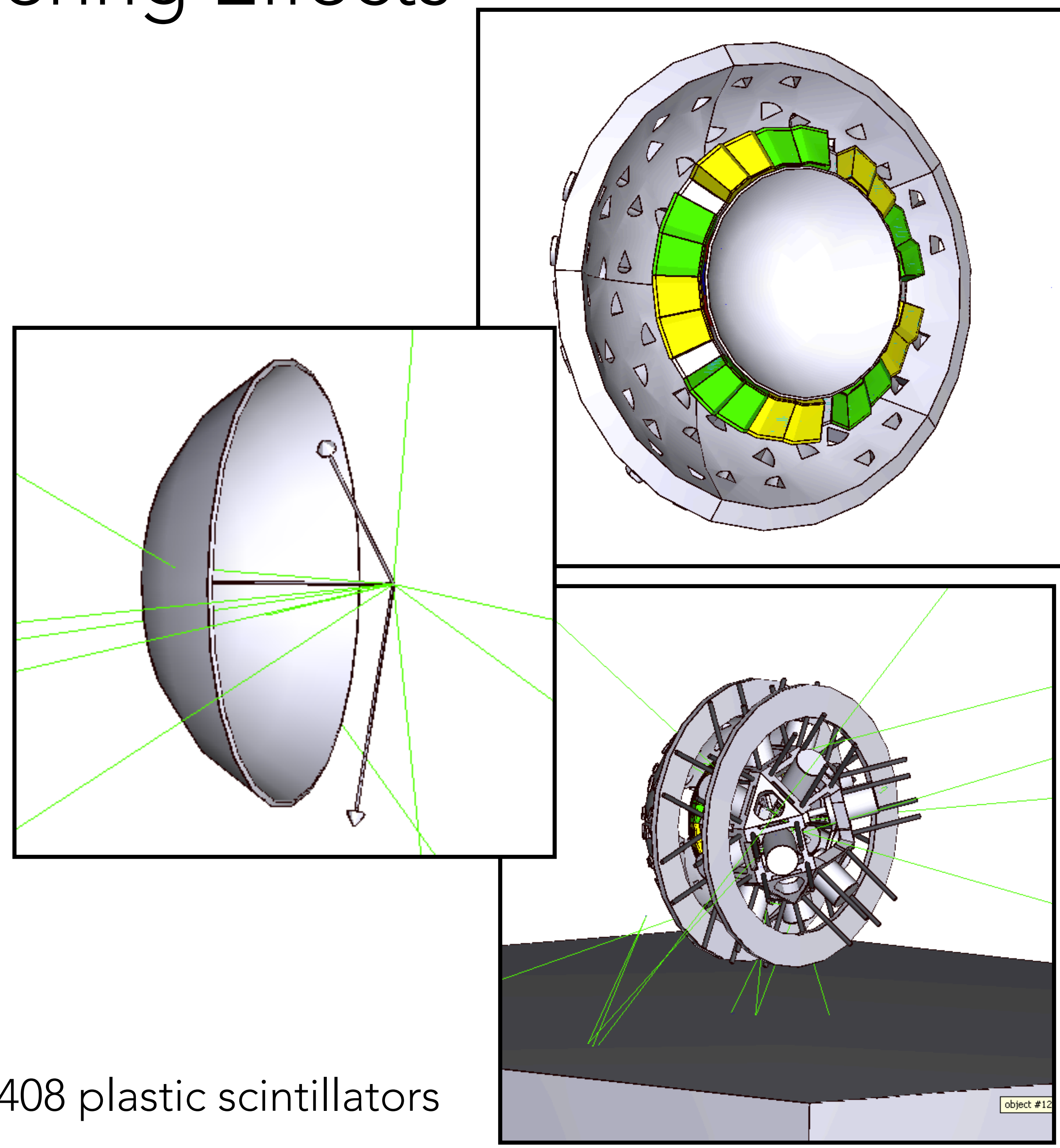
GEANT4 SIMULATIONS



GEANT4 SIMULATIONS

Scattering Effects

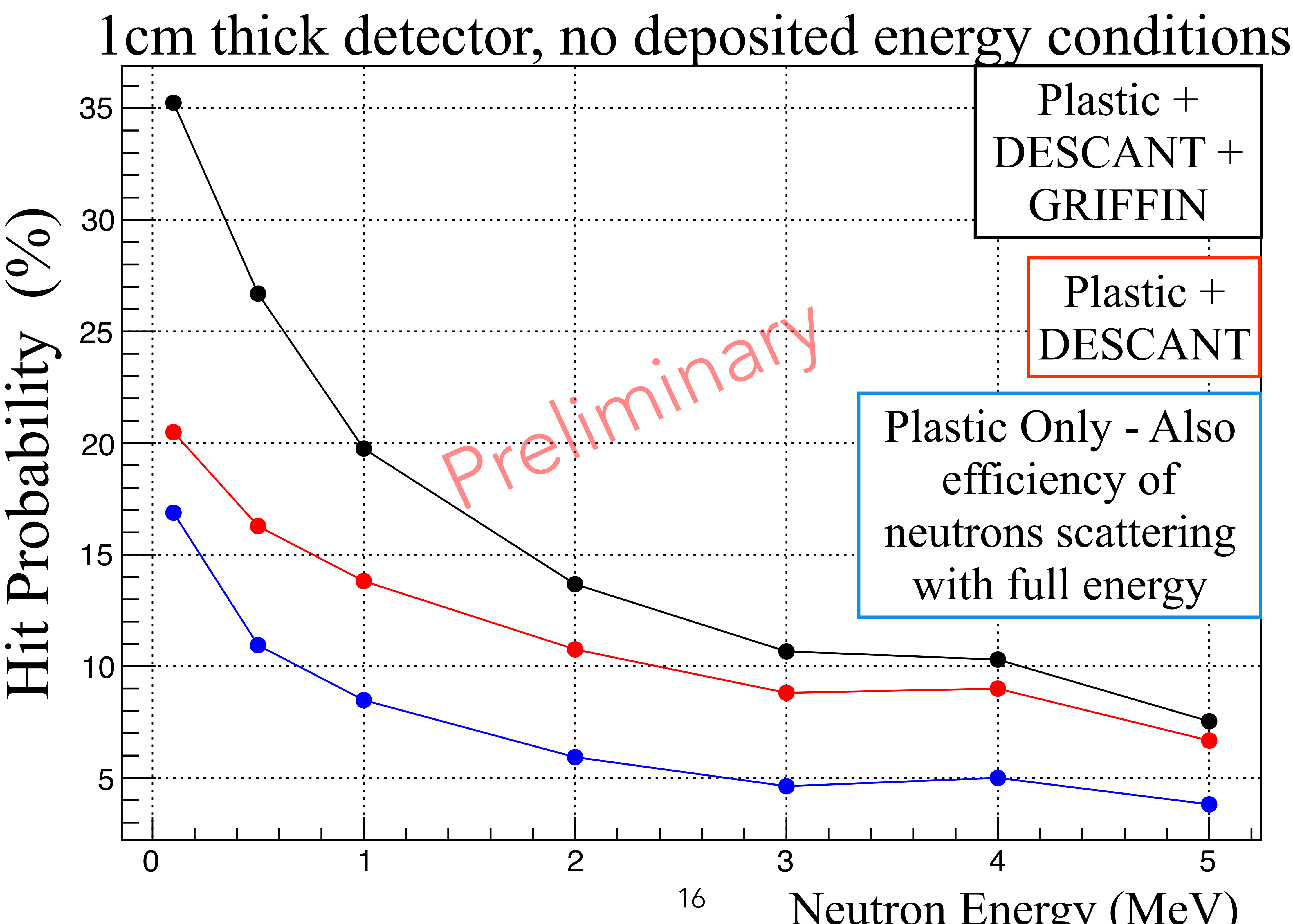
- Compare 3 configurations
  - Plastic only - Corresponds to neutrons scattering with full energy
  - Plastic + DESCANT
  - Plastic + DESCANT + GRIFFIN (Full Setup)
- Look at hit probabilities as we add detectors to the simulation to see background levels



Based on BC408 plastic scintillators

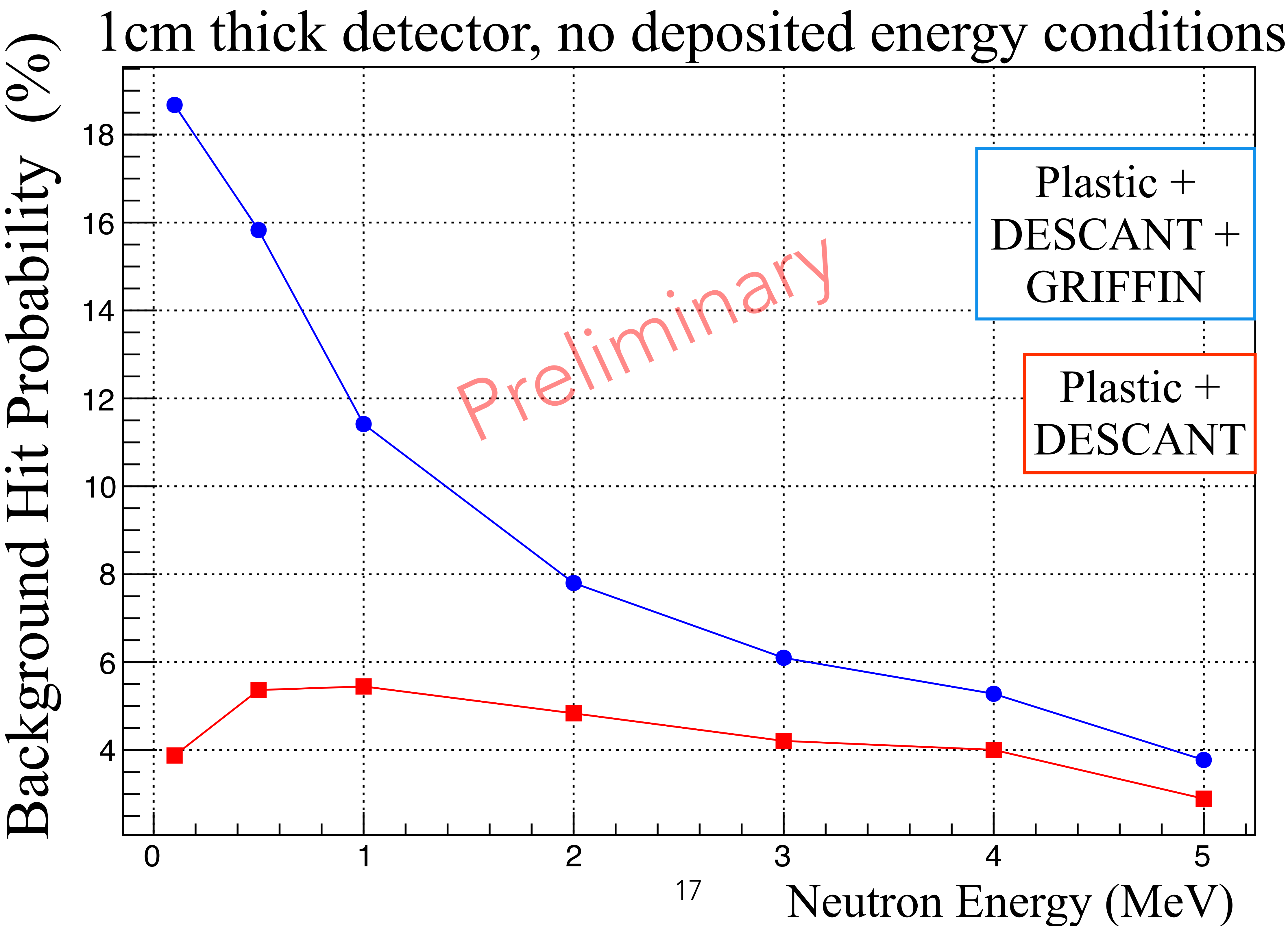
GEANT4 SIMULATIONS

Scattering Effects



GEANT4 SIMULATIONS

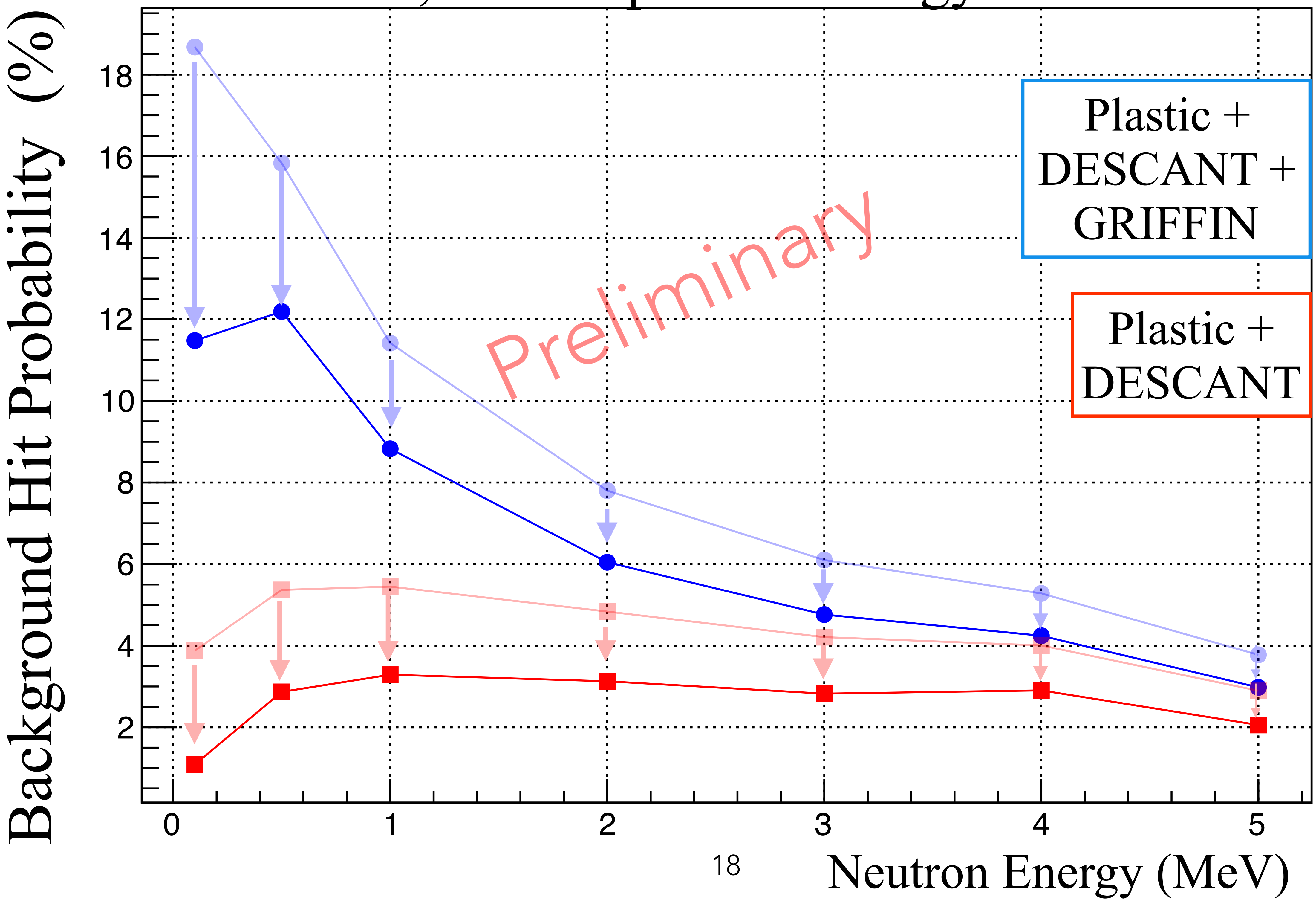
Scattering Effects



GEANT4 SIMULATIONS

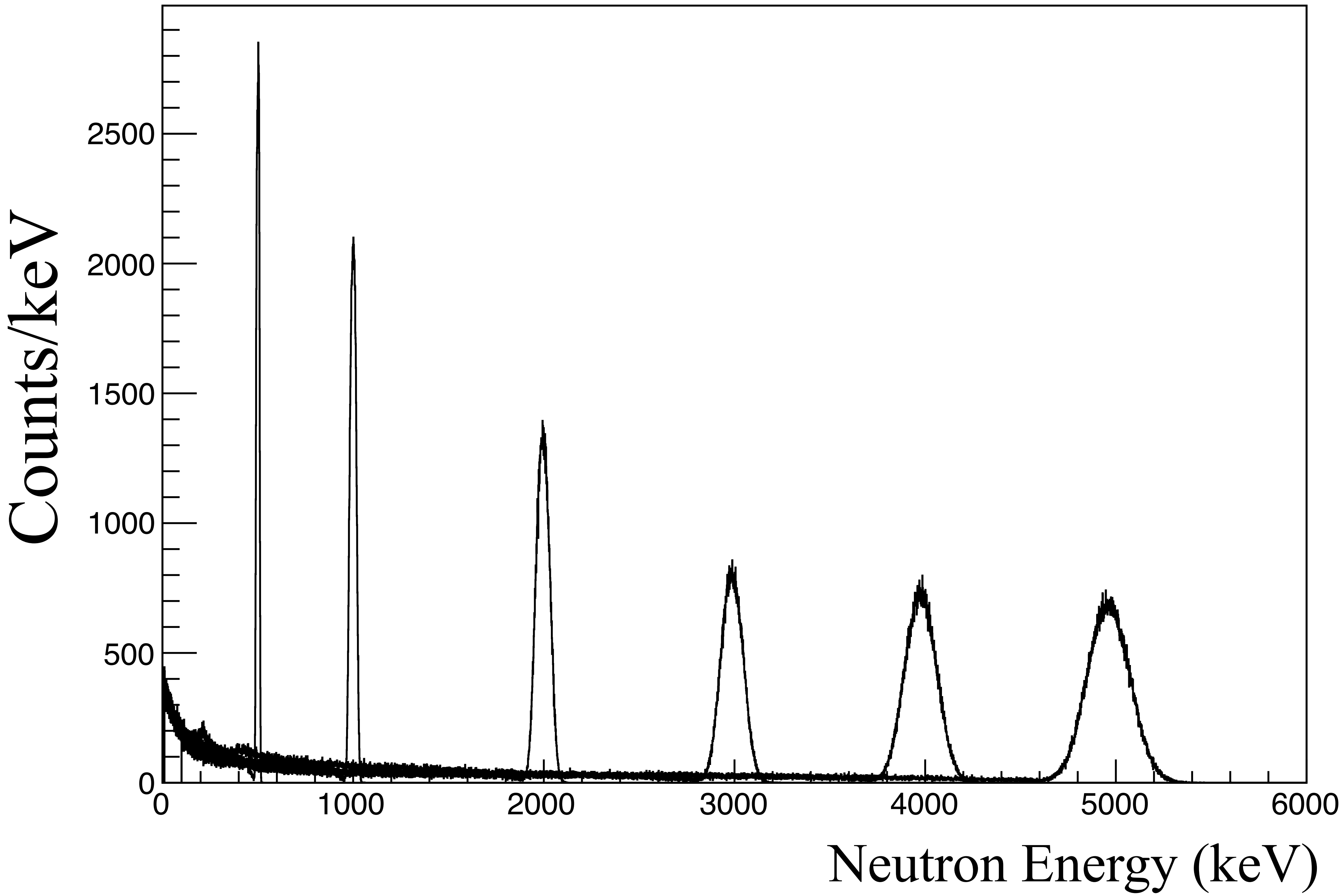
Scattering Effects

1cm thick detector, with deposited energy conditions > 30 keV



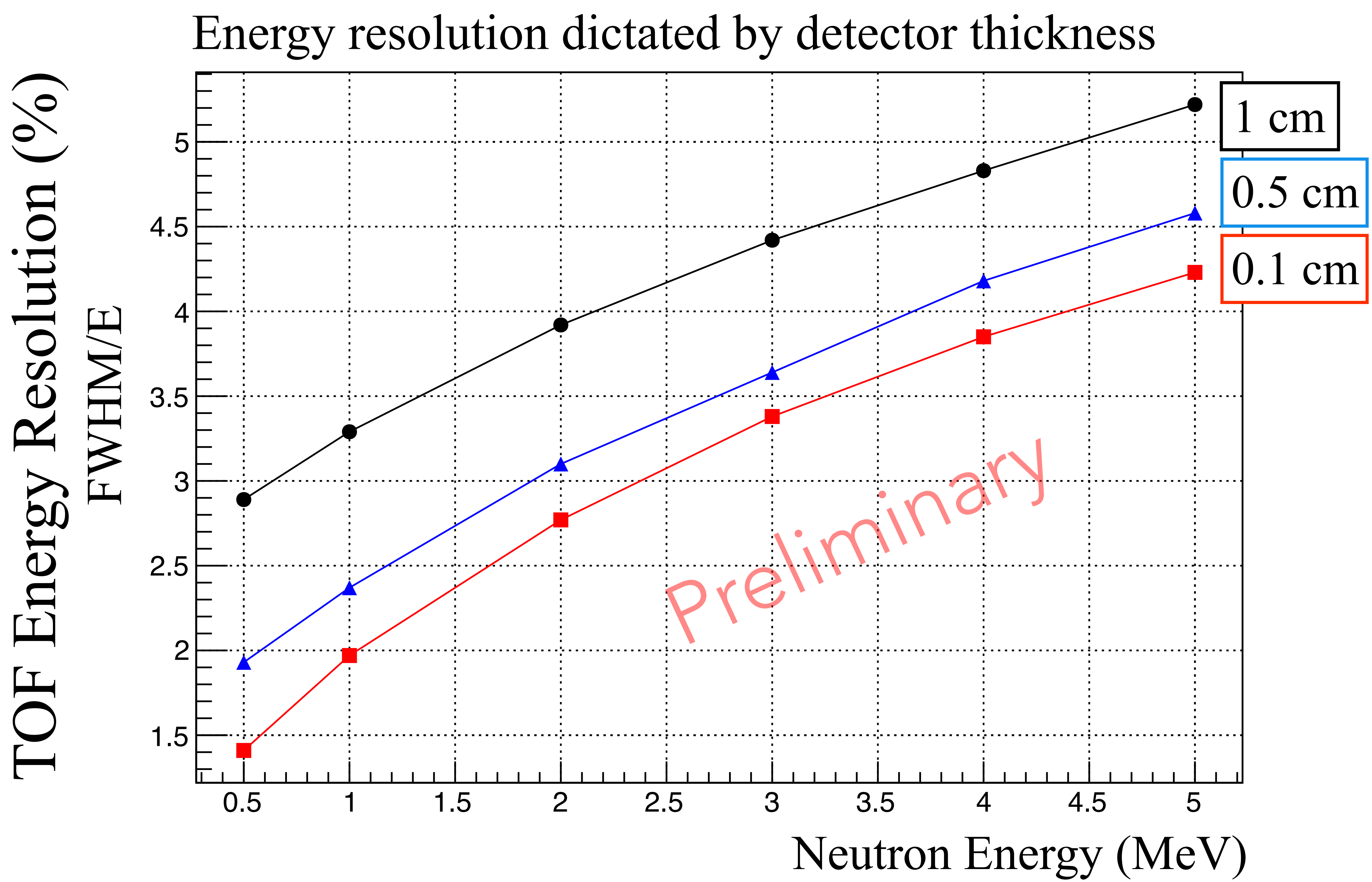
GEANT4 SIMULATIONS

TOF is scatter time taken straight from simulation



1 cm thick detector, coincidence timing uncertainty: Gaussian with of 350 ps FWHM

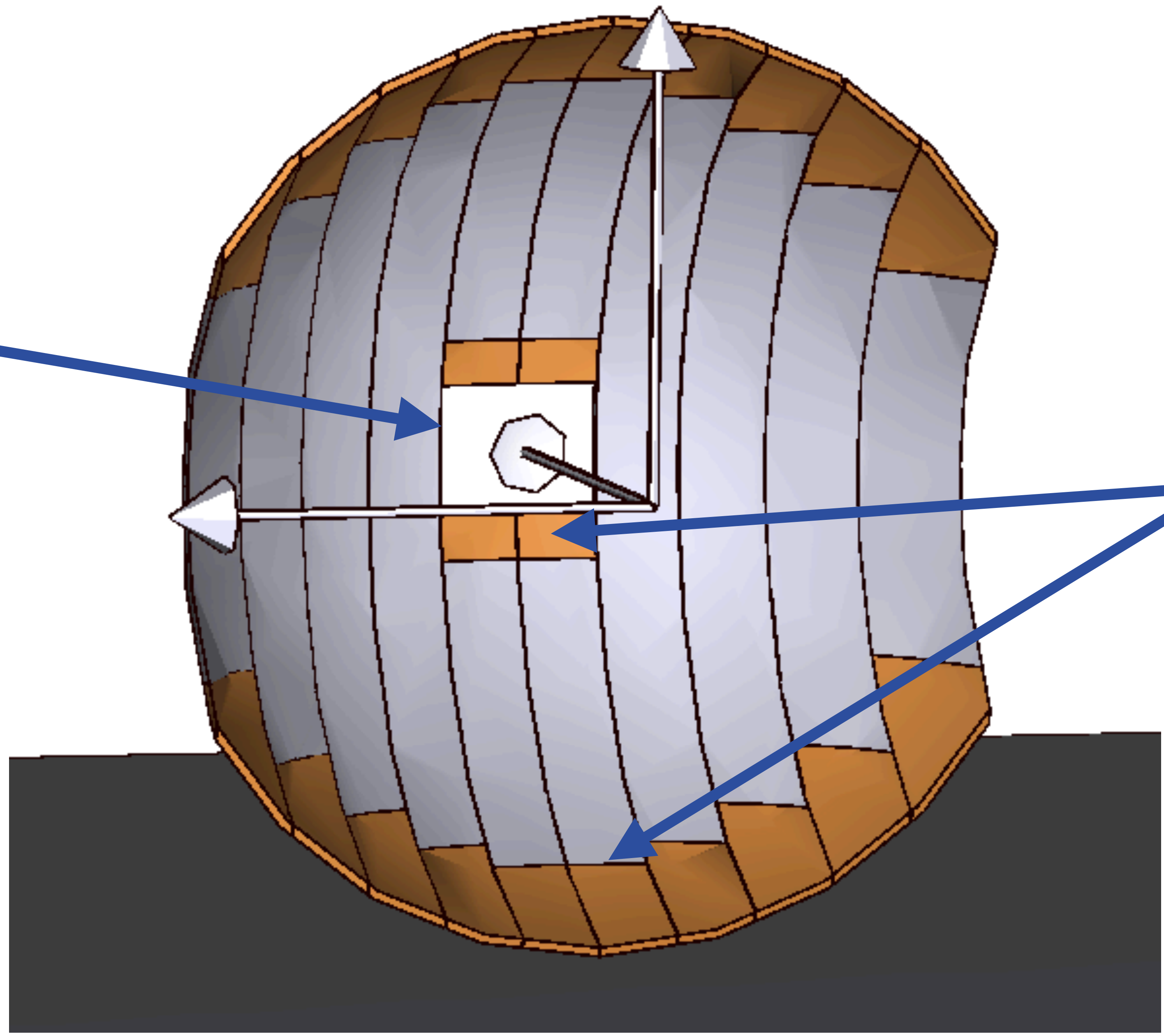
GEANT4 SIMULATIONS



1 cm thick detector, timing uncertainty: Gaussian with of 350 ps FWHM

GEANT4 SIMULATIONS

More realistic geometry

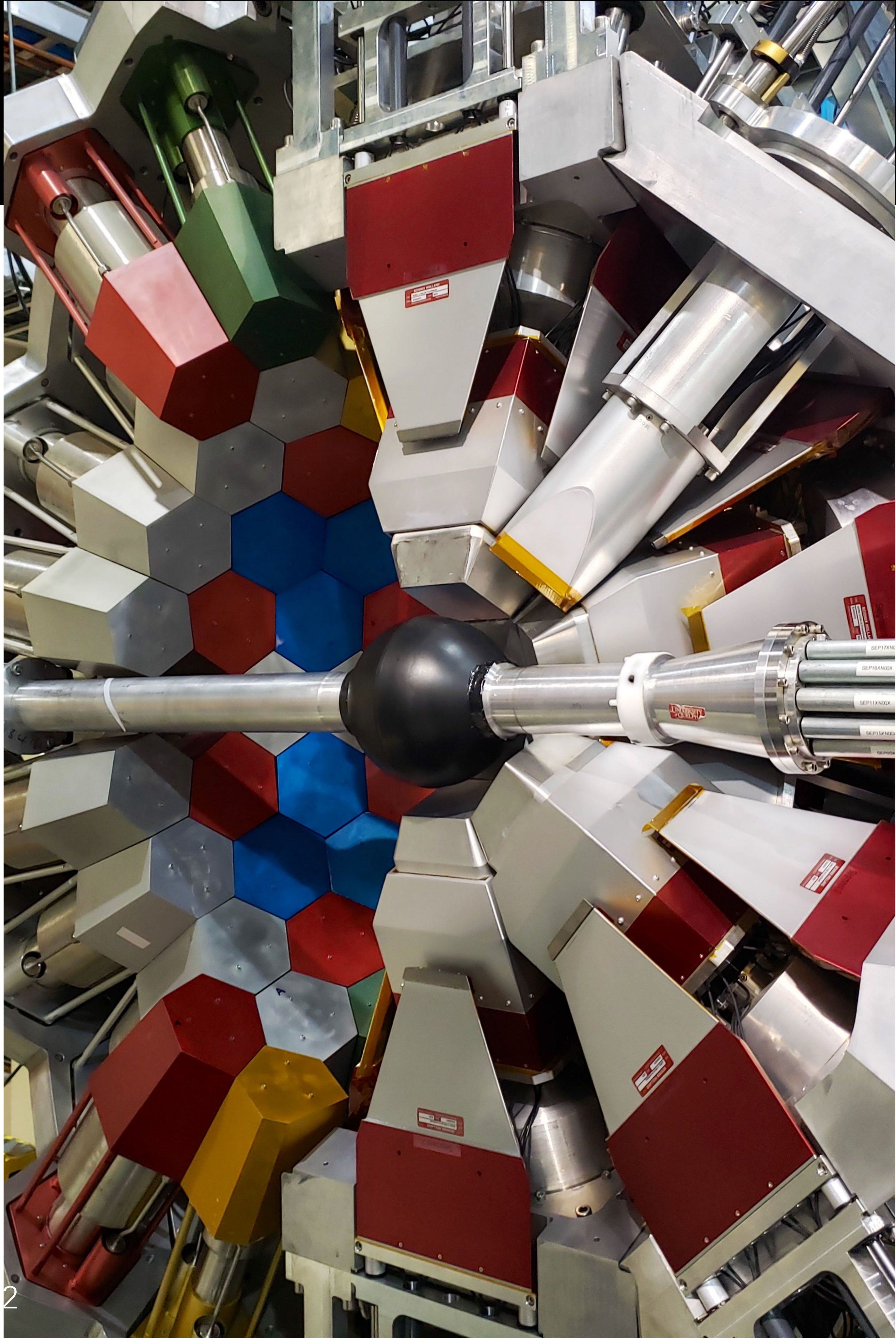


Hole for beam line

Each distinct detector has its own top and bottom PMT

NEXT STEPS

- Implement optical physics
    - Extract time and position of scatter
- Other geometries will continue to be investigated
- External frame required?
- Cost?



THANK YOU

Collaborators

University of Guelph

Paul Garrett

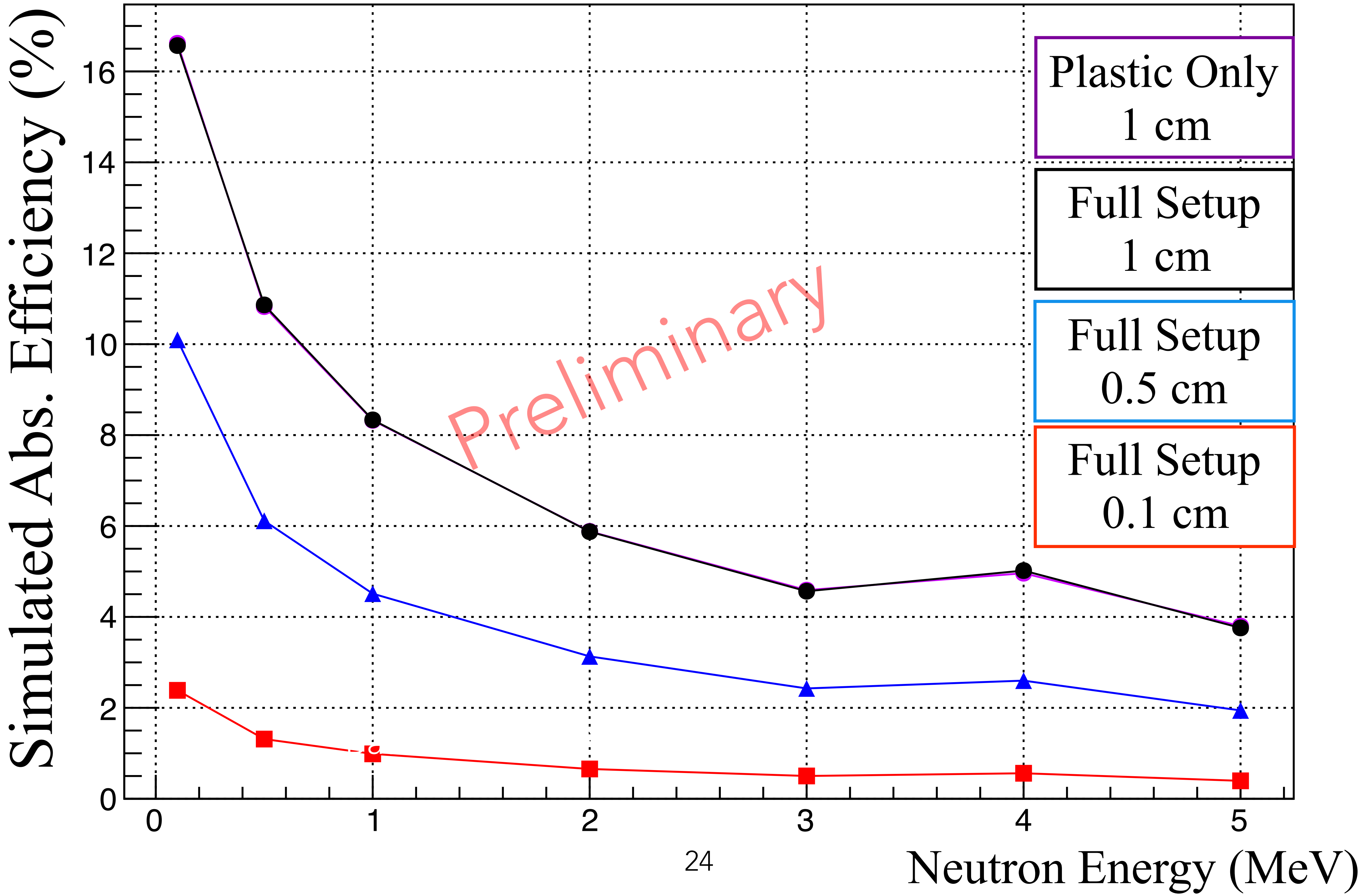
Vinzenz Bildstein

Allison Radich

UNIVERSITY of GUELPH

GEANT4 SIMULATIONS
DETECTOR THICKNESS: EFFICIENCIES

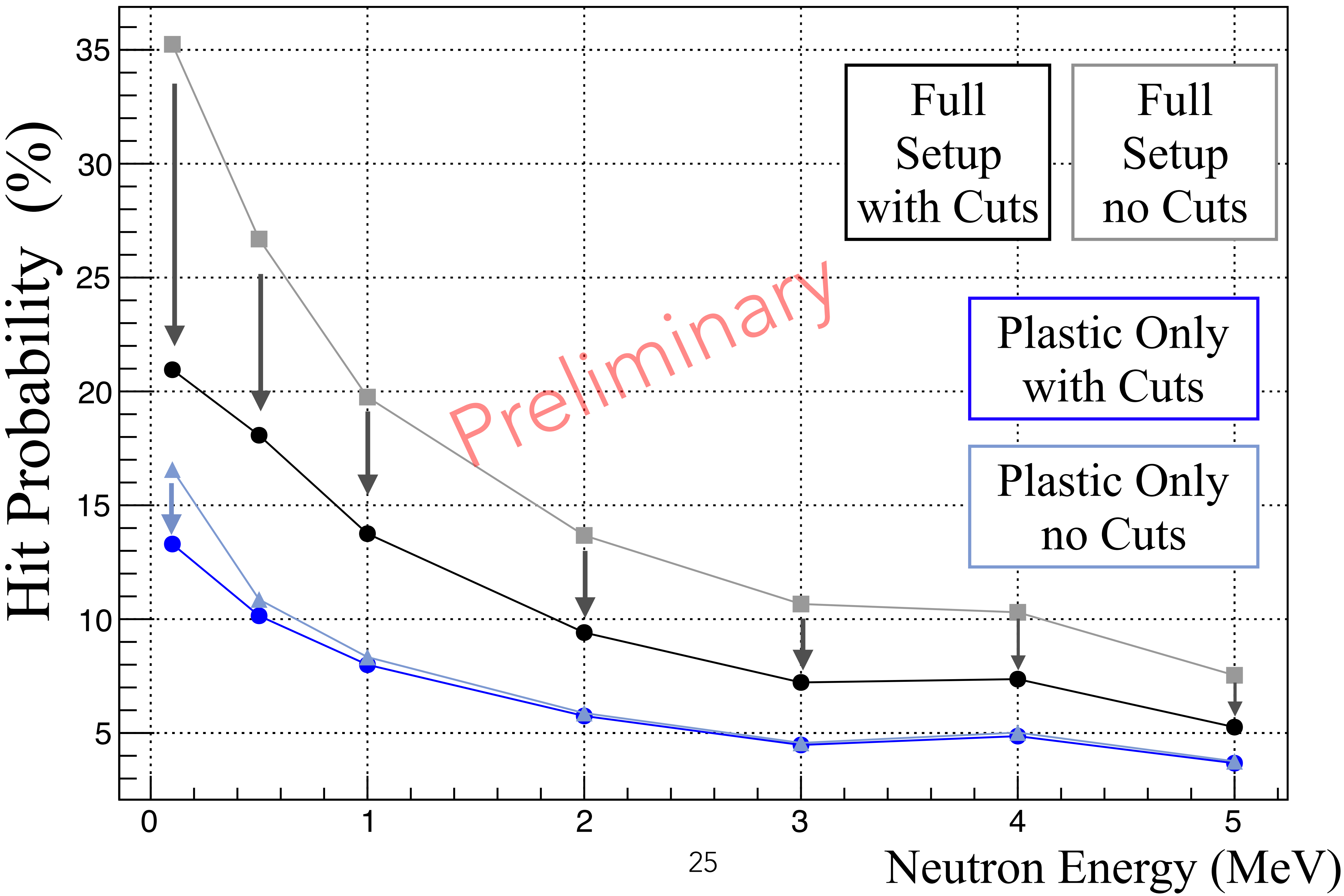
Full energy neutrons that scatter in Plastic
(No prior scattering before arriving at plastic detector)



GEANT4 SIMULATIONS

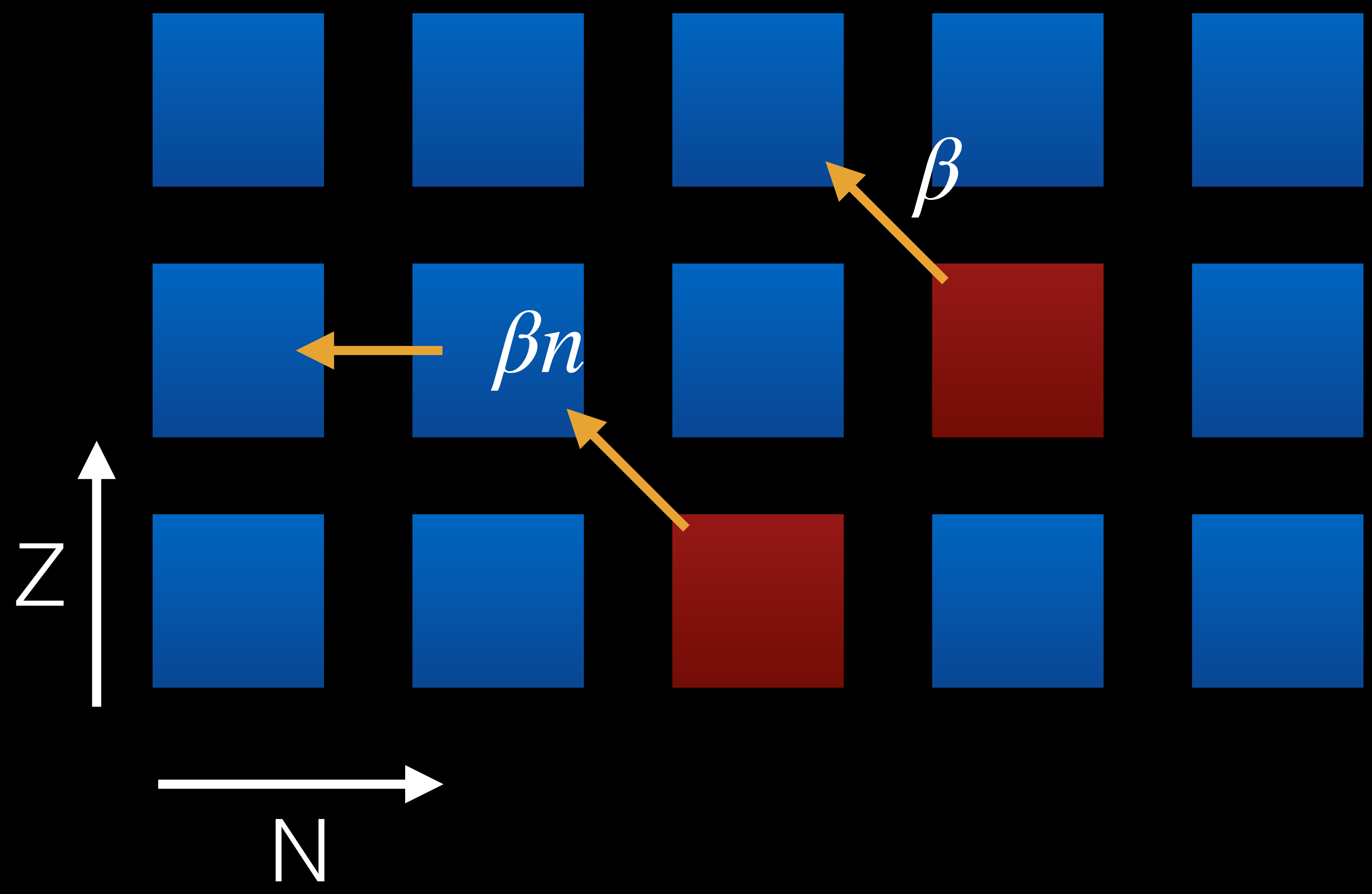
Scattering Effects

1cm thick detector, with deposited energy conditions > 30 keV



BACKGROUND

- Many of the nuclei found in the astrophysical rapid neutron capture process are beta delayed neutron emitters



BACKGROUND

Start with energy conservation

$$m_{Emitter}c^2 + E_{Emitter} = m_{Daughter}c^2 + E_{Daughter} + m_n c^2 + T_n + T_R$$

Use

$$S_n = m_{Daughter}c^2 + m_n c^2 - m_{Emitter}c^2$$

To get:

$$E_{Emitter} = E_{Daughter} + T_n + T_R + S_n$$

BACKGROUND

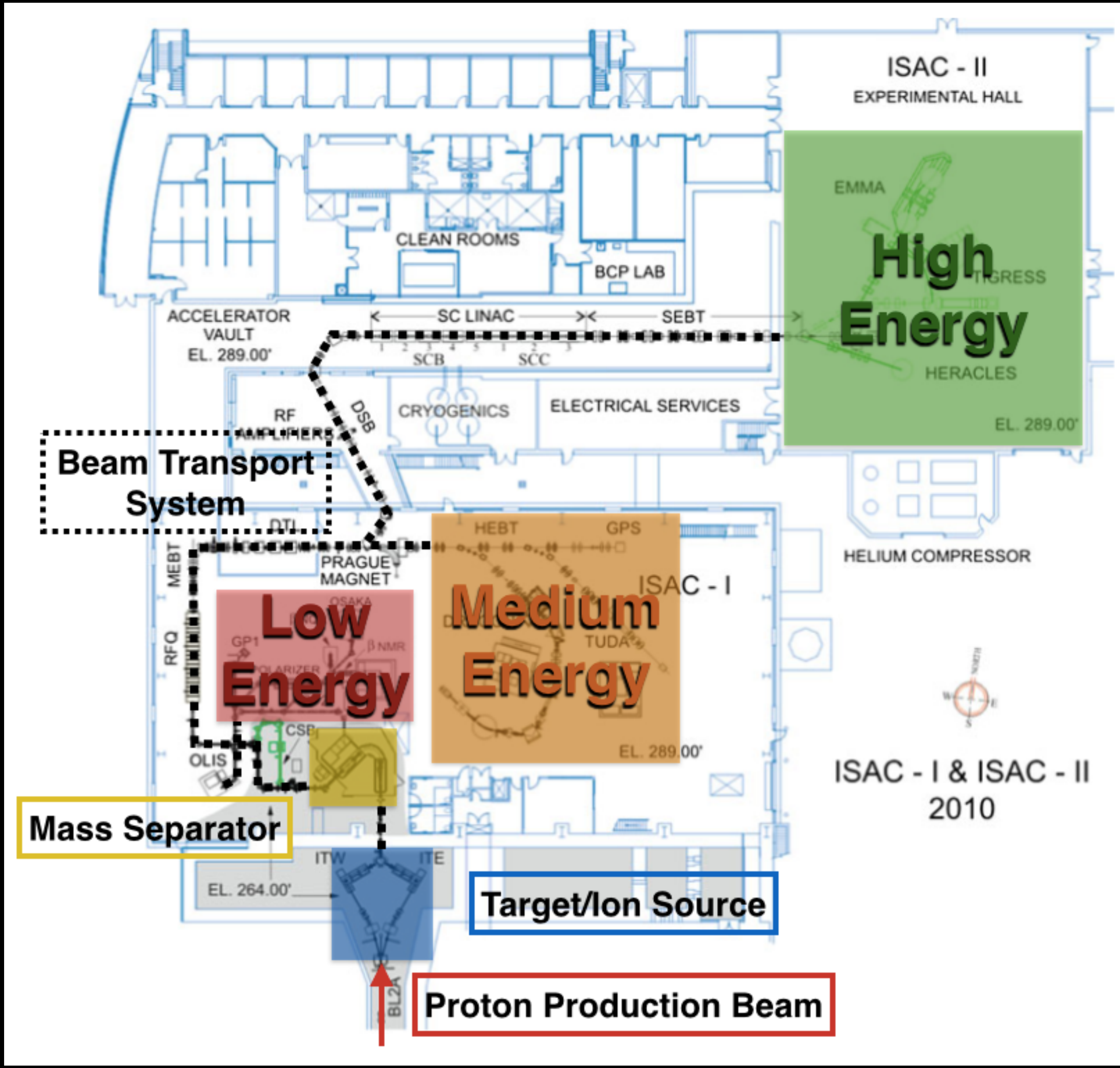
- Beta delayed neutron spectroscopy
  - If the following values are measured precisely, information on excited states can be extracted, which has nuclear structure implications.

$$E_{Emitter} = E_{Daughter} + T_n + T_R + S_n$$

- $E_{Emitter}$: (Excited) State of Emitter
- $E_{Daughter}$: (Excited) State of Daughter
- T_n: Kinetic Energy Neutron
- T_R: Nucleus Recoil Energy
- S_n: Neutron Separation Energy

  - Our goal is to measure neutron energy with good resolution!

TRIUMF



ISAC - II
EXPERIMENTAL HALL
EMMA
High
Energy
TIGRESS
HERACLES
EL. 289.00'
CLEAN ROOMS
BCP LAB
ACCELERATOR
VAULT
EL. 289.00'
SC LINAC
SEBT
SCB
SCC
RF
AMPLIFIERS
DSB
CRYOGENICS
ELECTRICAL SERVICES
Beam Transport
System
DTL
HEBT
GPS
HELIUM COMPRESSOR
MEBT
PRAGUE
MAGNET
ISAC - I
Low
Energy
OSAKA
GP1
β NMR
POLARIZER
Medium
Energy
TUDA
RFQ
CSB
OLIS
EL. 289.00'
ISAC - I & ISAC - II
2010
Mass Separator
ITW
ITE
EL. 264.00'
Target/Ion Source
BL2A
Proton Production Beam

TIME OF FLIGHT TECHNIQUE

$$E = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{L^2}{TOF^2}$$

- DESCANT detectors were never intended to extract neutron energies via Time-of-Flight (TOF) technique
  - Current setup leads to energy resolution ~30% using the TOF technique

$$L = 50cm$$

$$\Delta L \approx 15cm$$

Image from: https://www.physics.uoguelph.ca/Nucweb/descant.html

TIME OF FLIGHT TECHNIQUE

$$E = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{L^2}{TOF^2}$$

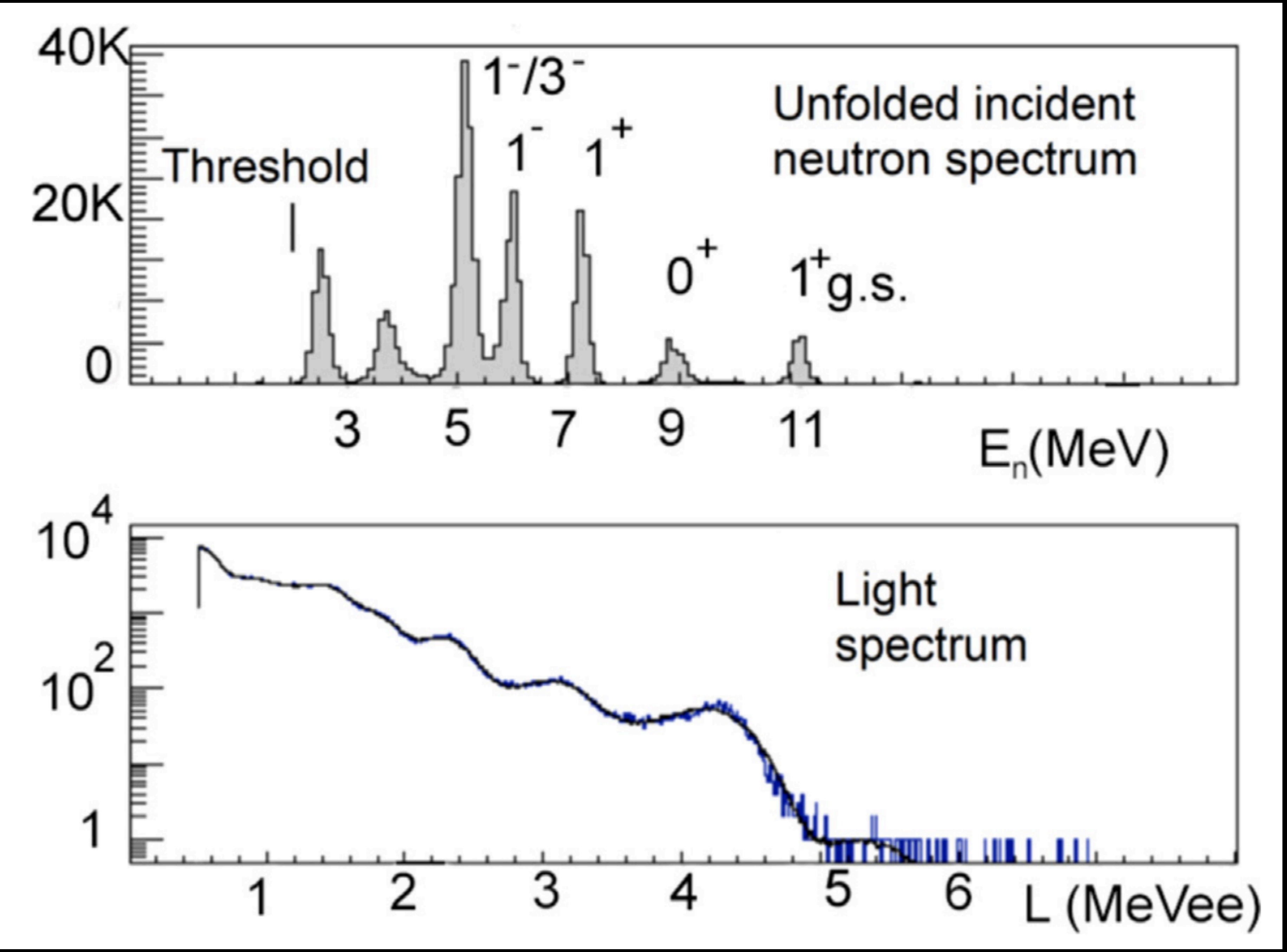
- DESCANT detectors can use light unfolding algorithms to determine neutron energies.
    - Not intended to be used for event by event determination of neutron energies

$$L = 50cm$$

$$\Delta L \approx 15cm$$

Image from: https://www.physics.uoguelph.ca/Nucweb/descant.html

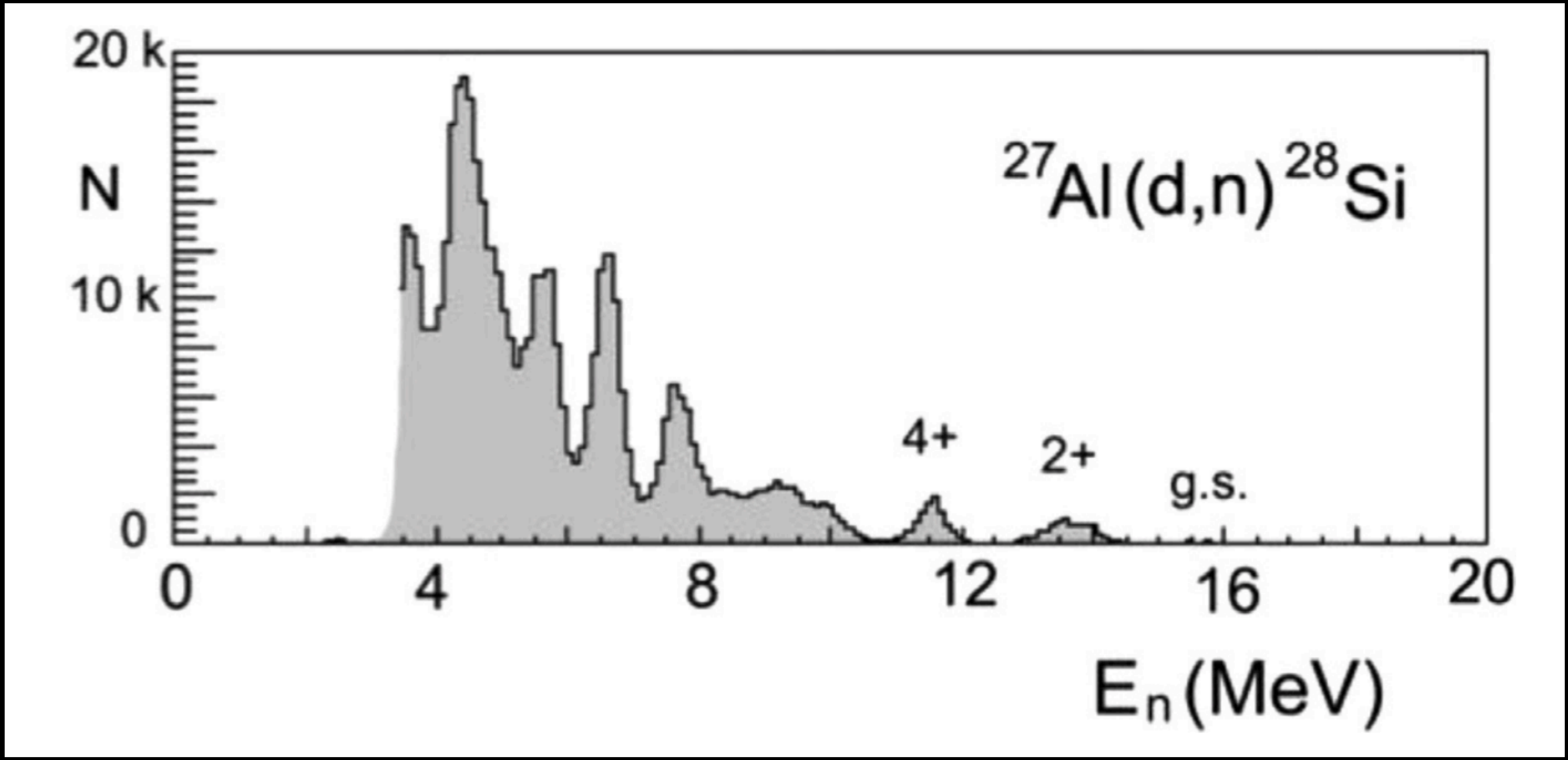
DEUTERATED SCINTILLATORS



$^{13}CH_2$ Target

F.D. Becchetti et al. / Nuclear Instruments and Methods in Physics Research A 820 (2016) 112–120 119

DEUTERATED SCINTILLATORS

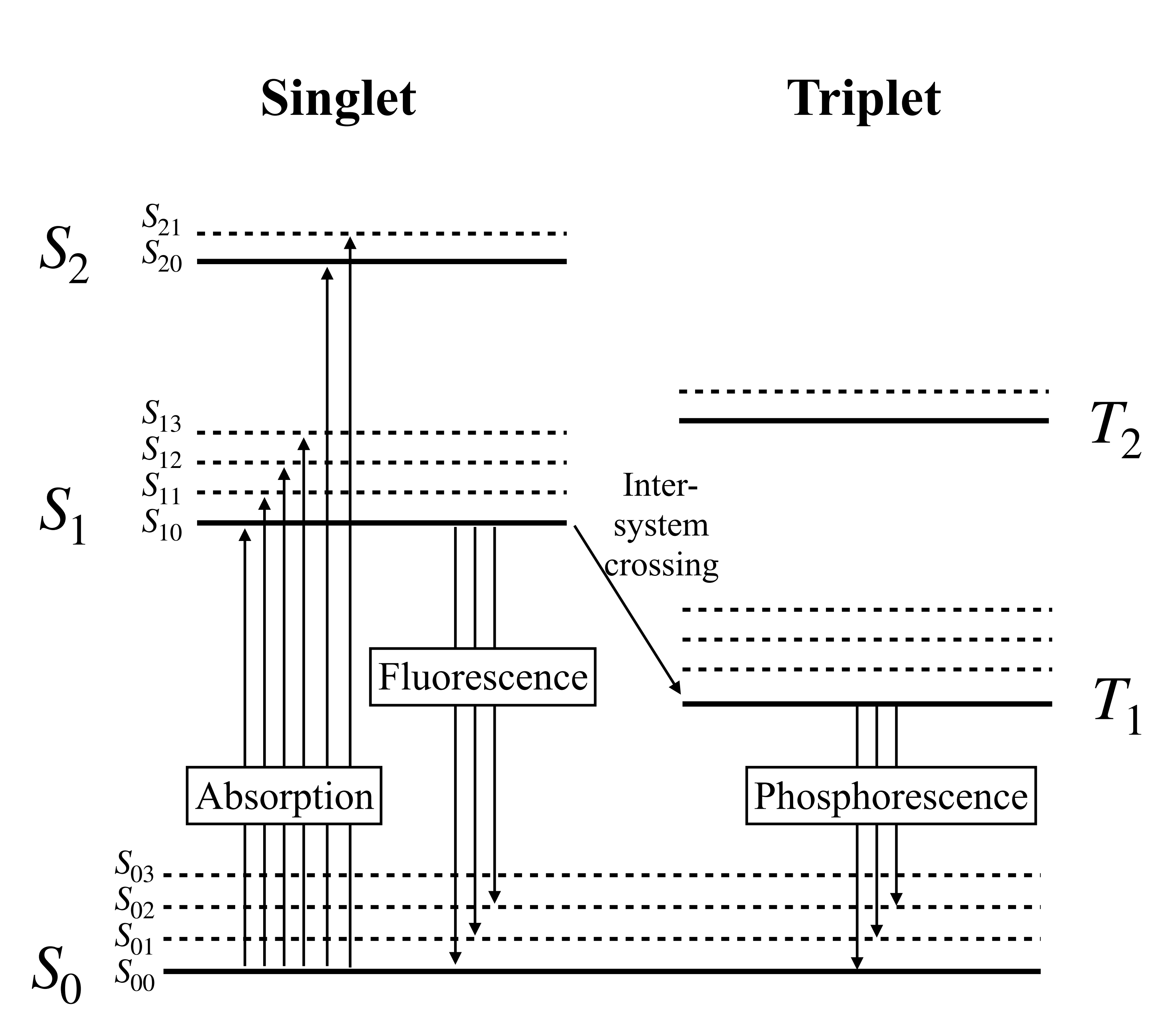


Ideal for lighter nuclei close to closed shells with low level density

F.D. Becchetti et al. / Nuclear Instruments and Methods in Physics Research A 820 (2016) 112–120 119

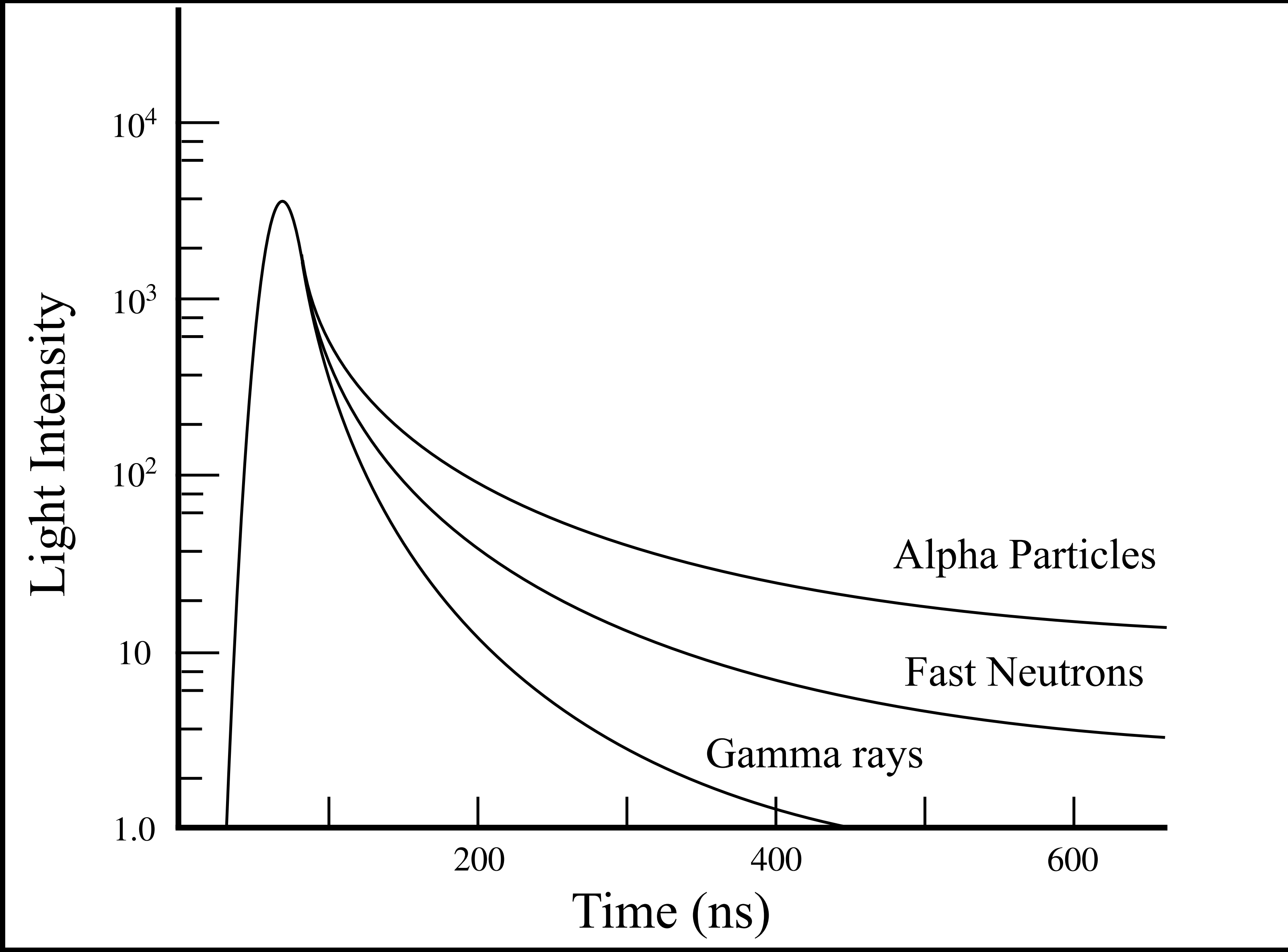
NEUTRON DETECTION SCINTILLATORS

- Extracting neutron energies is slightly more complicated than other radiation due to their lack of charge
- Need special detectors - like scintillators - which can convert kinetic energy of particles into photons for particle detection



NEUTRON DETECTION SCINTILLATORS

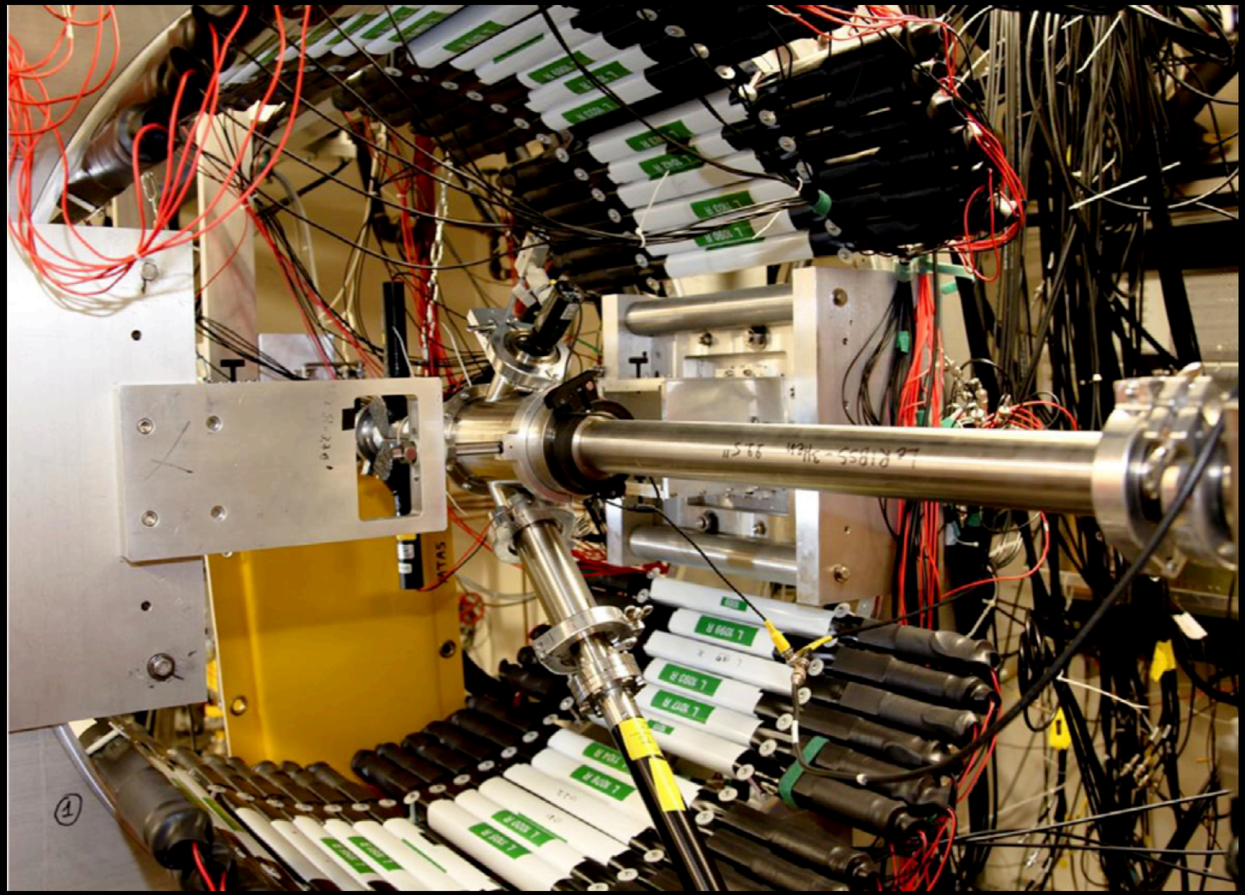
- It is possible to determine the type of radiation incident on a scintillator
  - This can be based on the timing profile of the scintillation light emission



Knoll, G. Radiation and Detection Measurement.

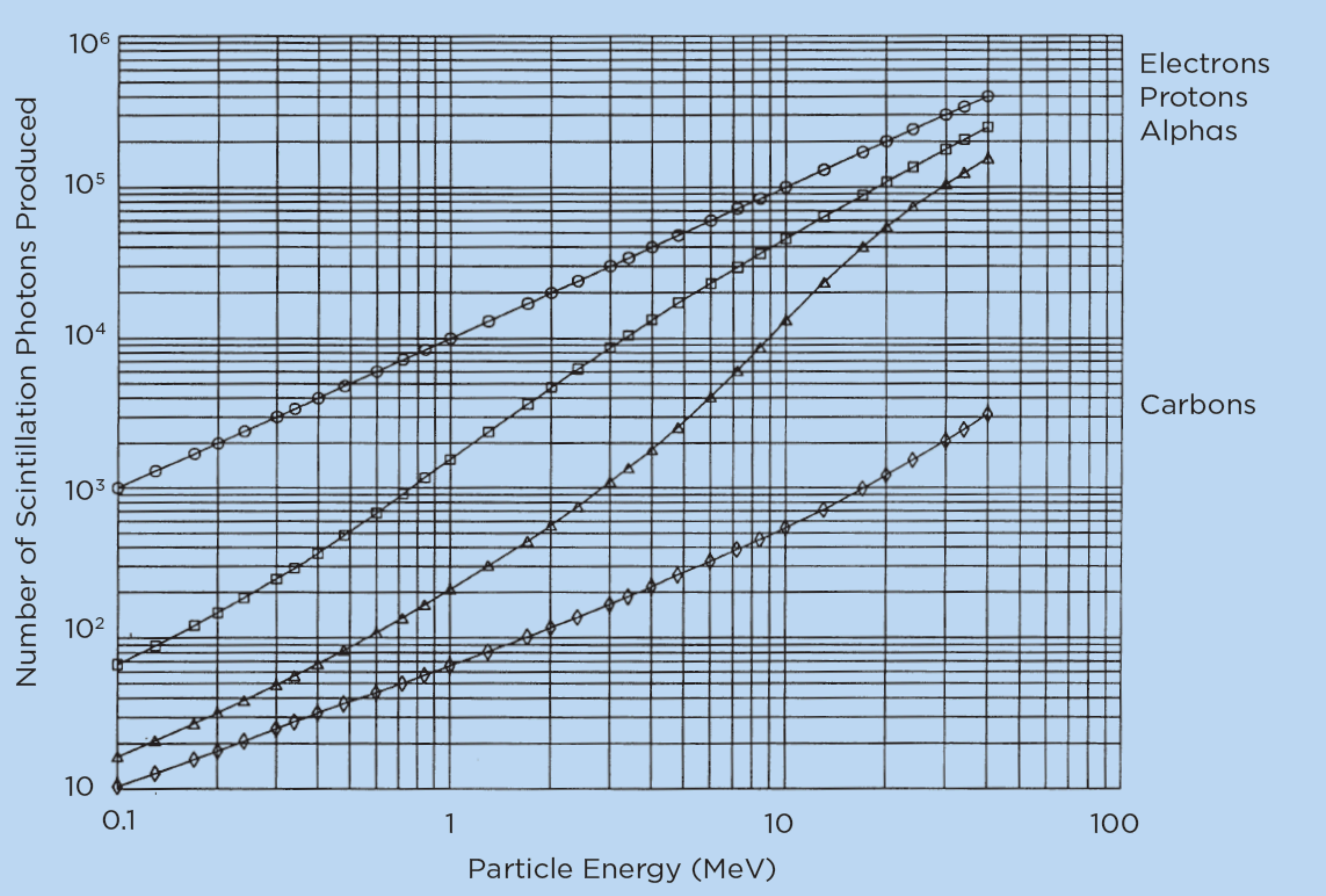
VANDLE AS INSPIRATION

- VANDLE: Versatile Array for Neutron Detection at Low Energies
  - Currently developing NEXT array which has PSD
- Located at Oak Ridge National Laboratory
- Plastic scintillator bars with PMT's on either end
- Plastic used: Bicron BC408
- Three different scintillator sizes:
  - Small(100): 3x3x60 cm^3 – low-energy neutrons
  - Medium(45): 3x6x120 cm^3 – 2-7 MeV neutrons
  - Large(60): 5x5x200 cm^3 – >20 MeV neutrons
- Plastic bars or covers for each DESCANT detector?



W.A.Peters et al. Nuclear Instruments and Methods in Physics Research A 836 (2016) 122–133

GEANT4 SIMULATIONS
OPTICAL PHYSICS



Taken from Saint-Gobain plastic scintillator data sheet