Simulating the DESCANT Neutron Detection Array with the Geant4 Monte Carlo Toolkit

WNPPC 2017

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TRIUMF

GRIFFIN

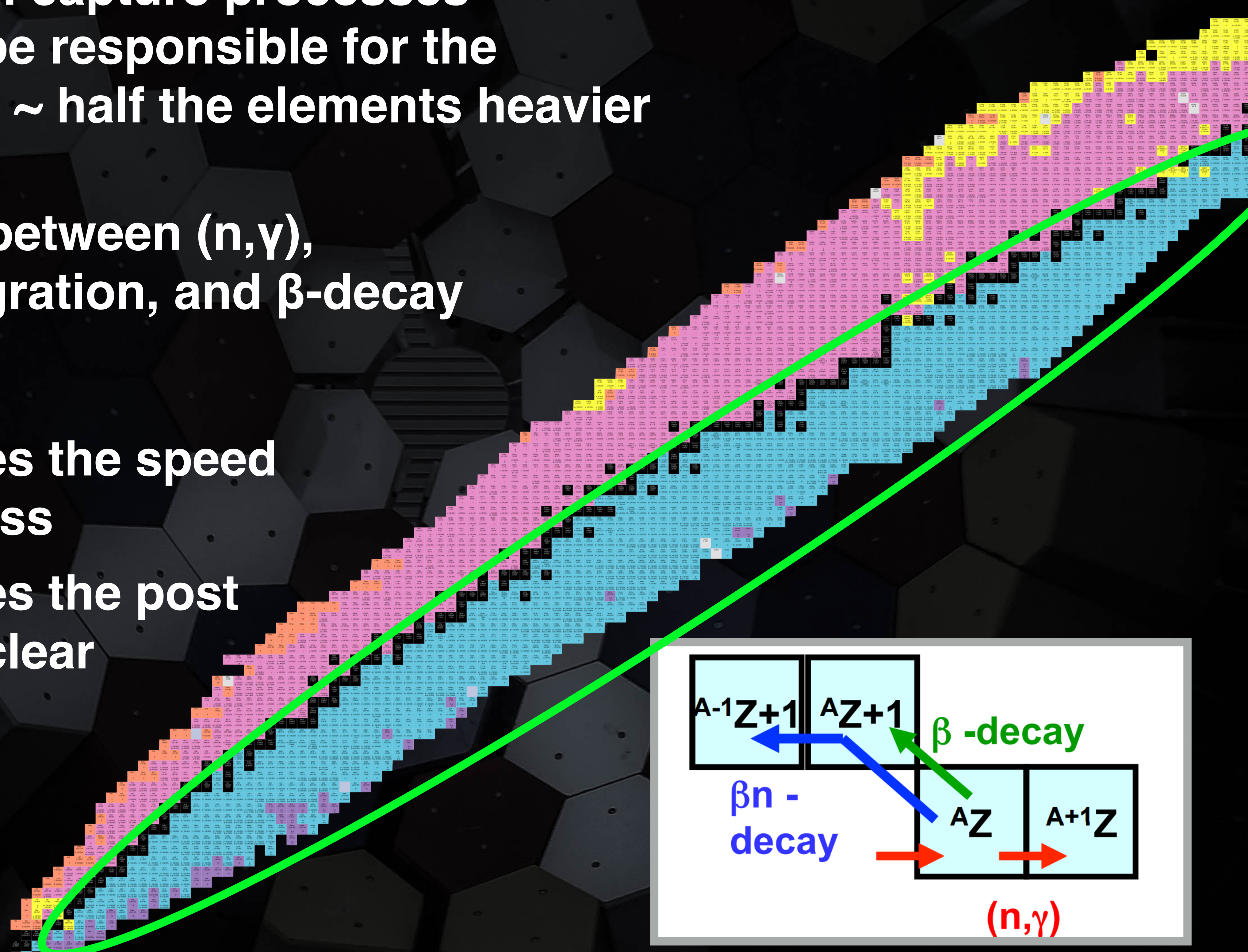
Motivation

Rapid neutron capture processes predicted to be responsible for the production of ~ half the elements heavier than ^{56}Fe

Competition between (n,γ), photodisintegration, and β-decay processes

$t_{1/2}$ influences the speed of the r-process

$P_{\beta n}$ influences the post r-process nuclear abundances



DESCANT

DEuterated SCintillator Array for Neutron Tagging

Located at TRIUMF, in Vancouver, BC

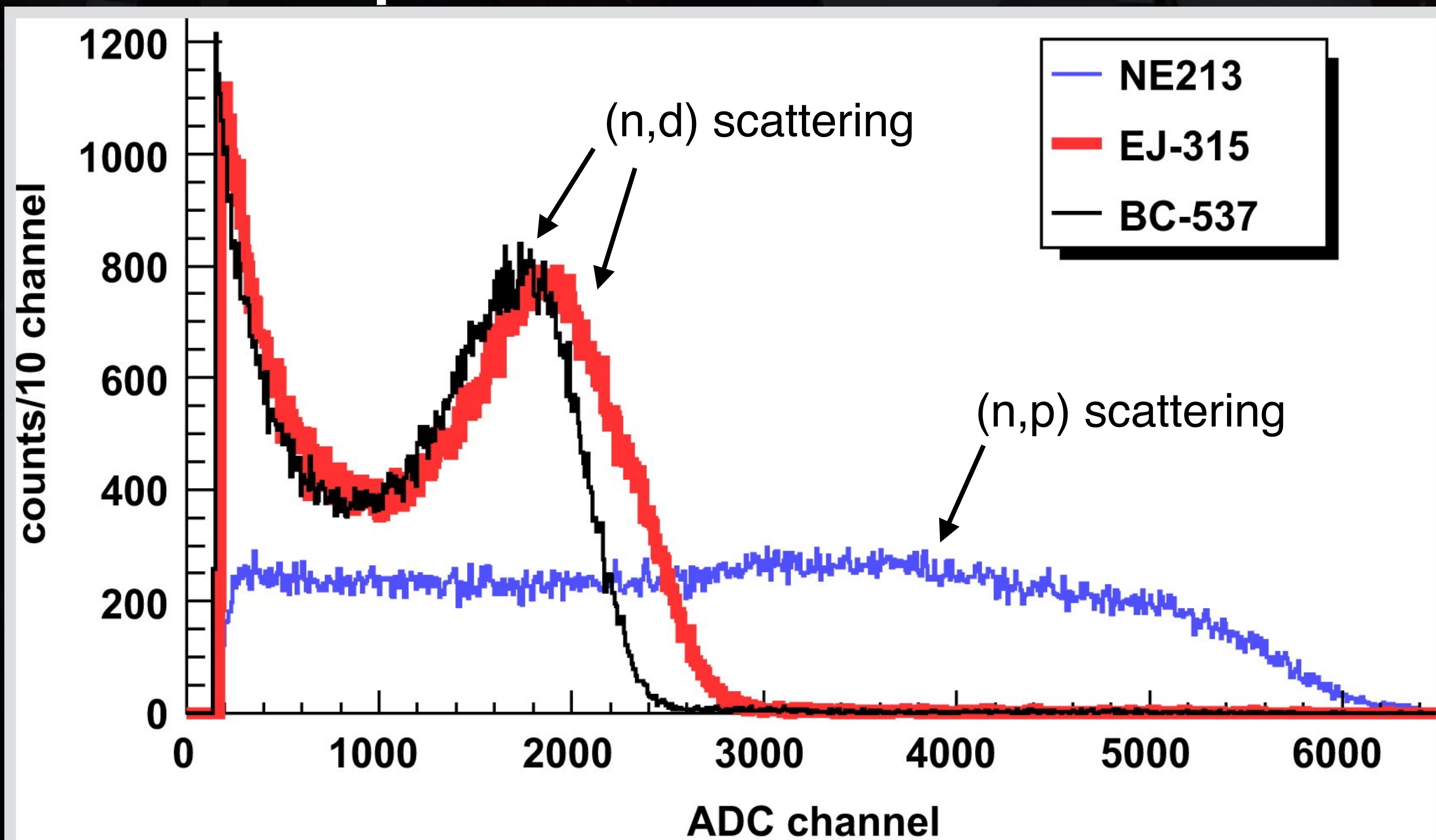
70 close-packed hexagonal deuterated benzene scintillators form array to replace downstream lampshade of either GRIFFIN or TIGRESS

New ancillary detector to GRIFFIN / TIGRESS γ -ray spectrometers for neutron tagging

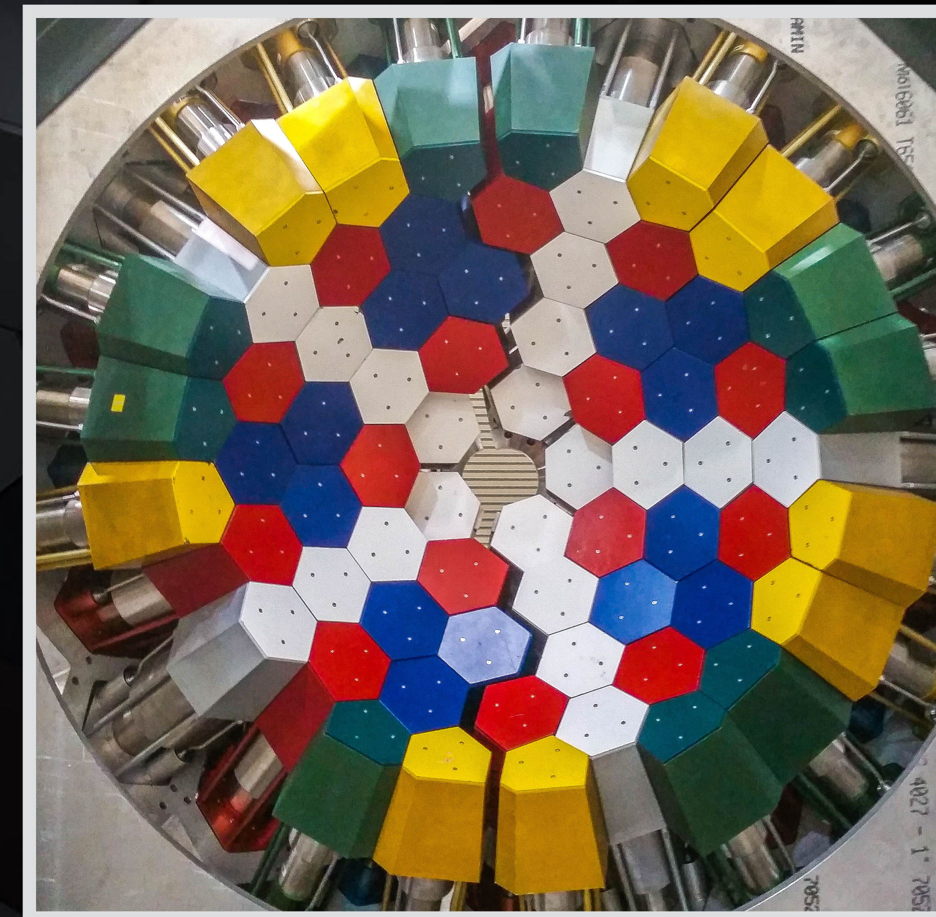
DESCANT

DEuterated SCintillator Array for Neutron Tagging

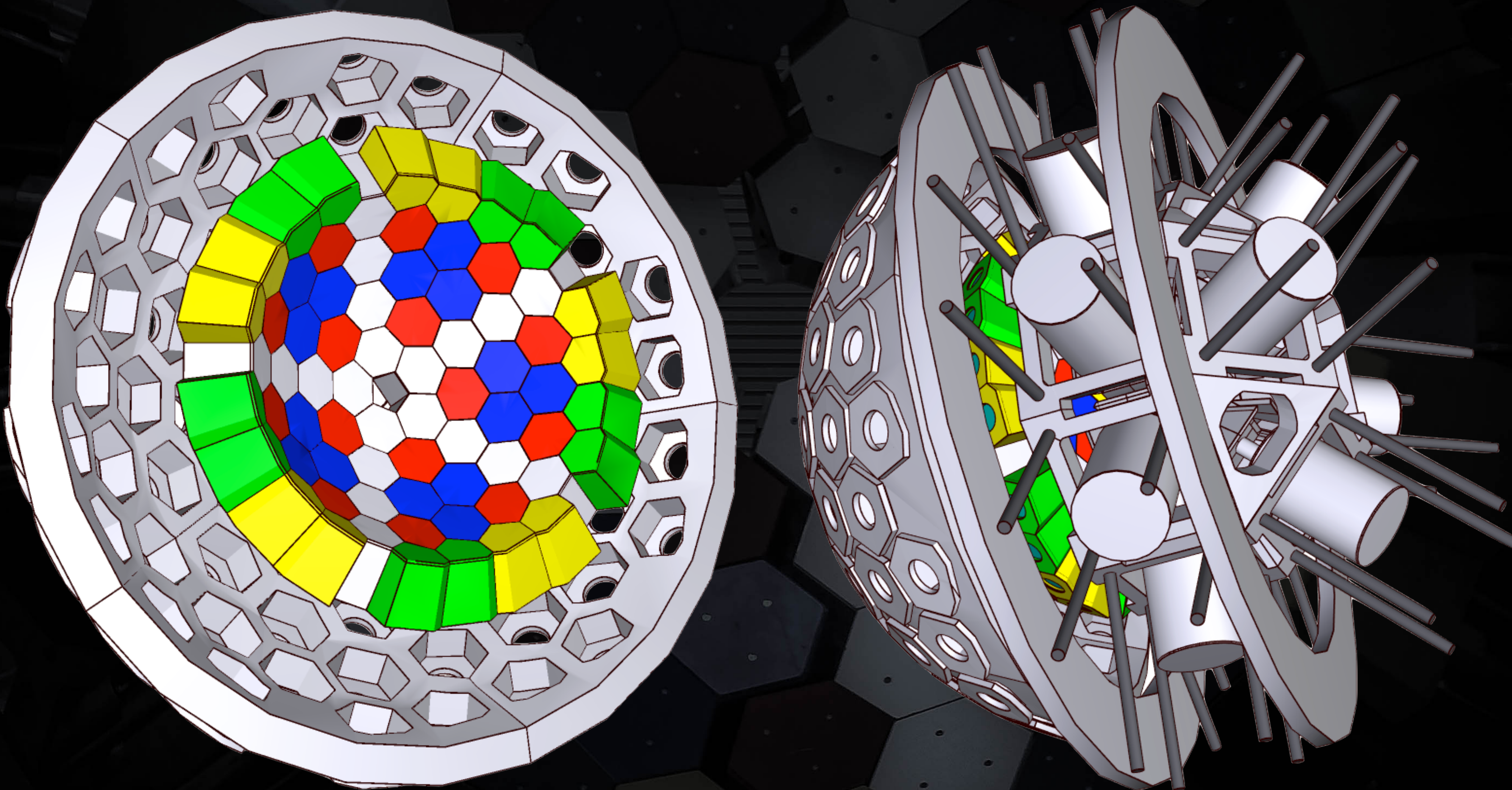
Response to 2.4 MeV Neutrons



V Bildstein. *et al,* Nuclear Instruments and Methods in Physics Research A 729 (2013) 118



Geant4 Simulation of DESCANT

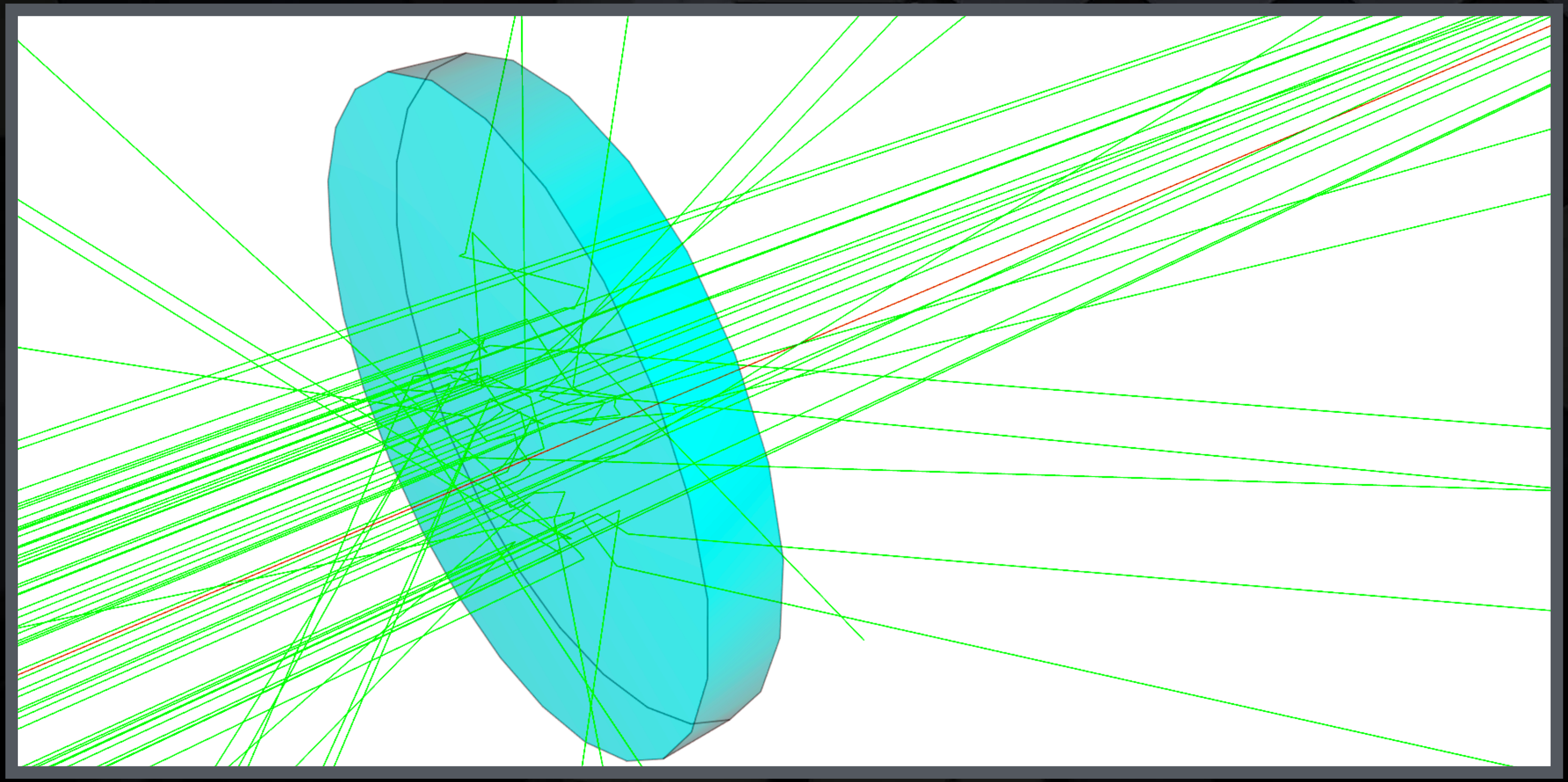


Geant4 Neutron Physics

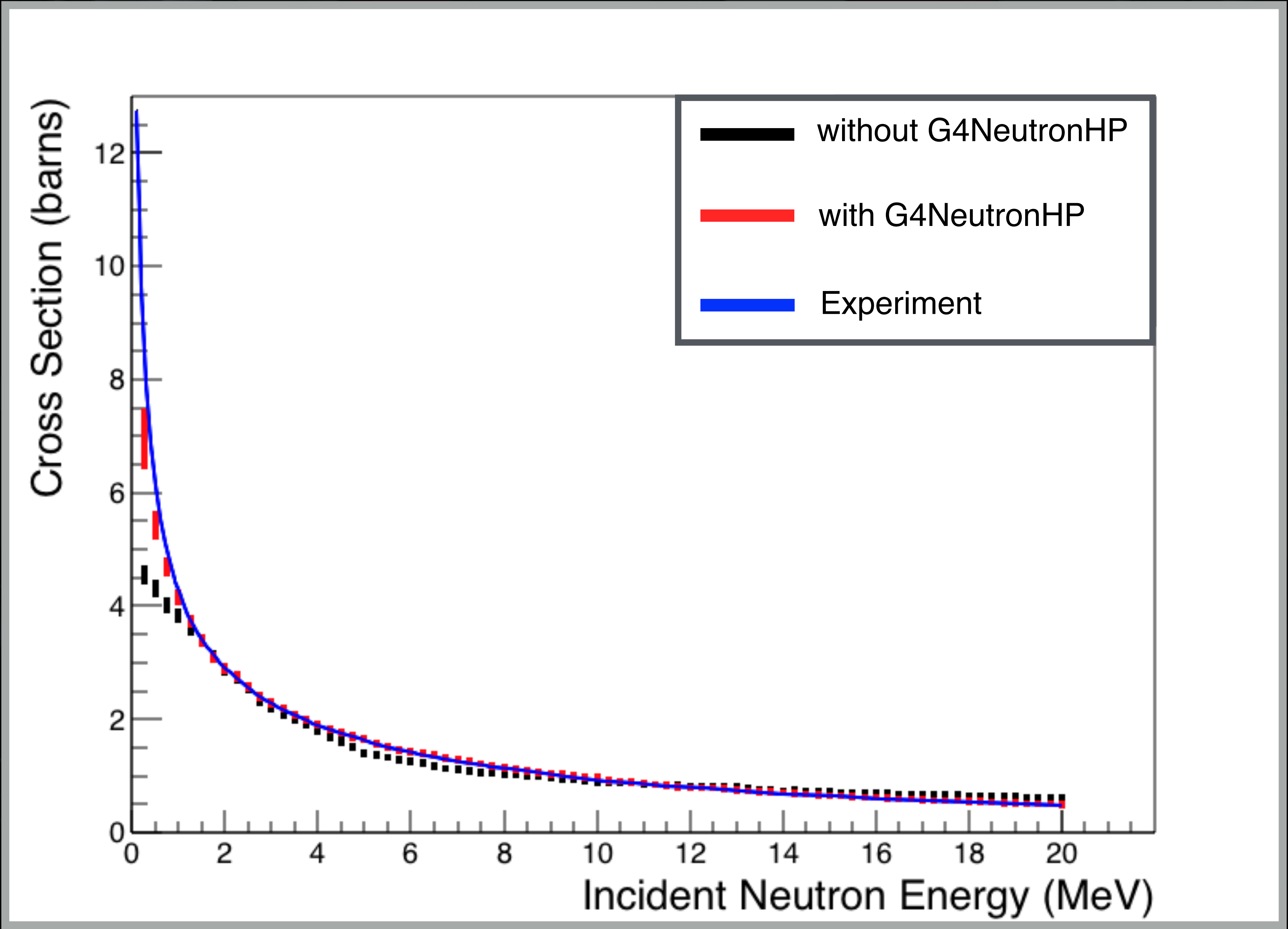
To validate the use of the Geant4 code, a simple cylindrical detector was simulated to verify the fast-neutron cross sections of ^{1}H, ^{2}H, and ^{12}C

The total and differential cross-sections were calculated in Geant4 and compared to experimental results from ENDF

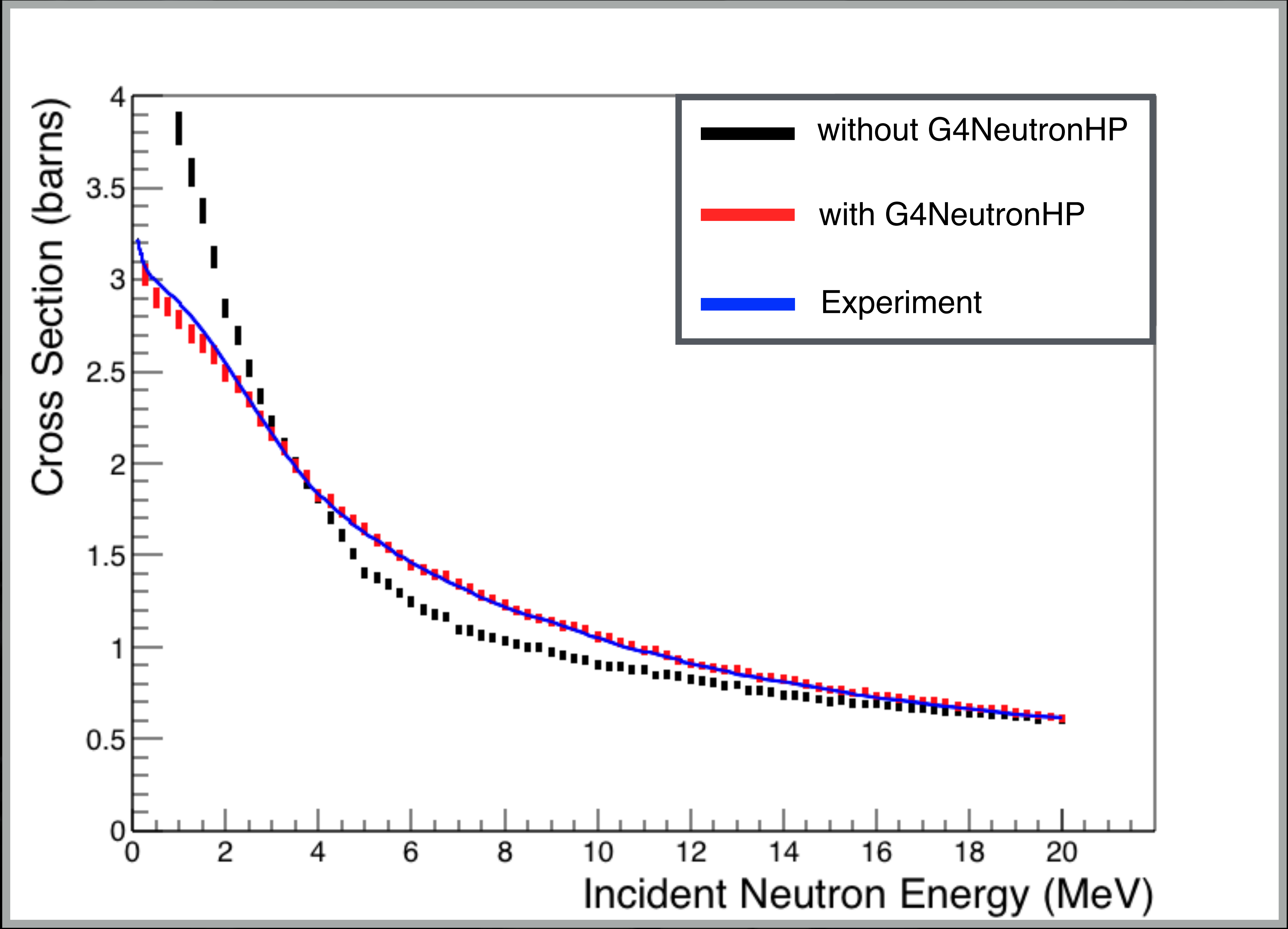
Validation of G4NeutronHP data-driven models



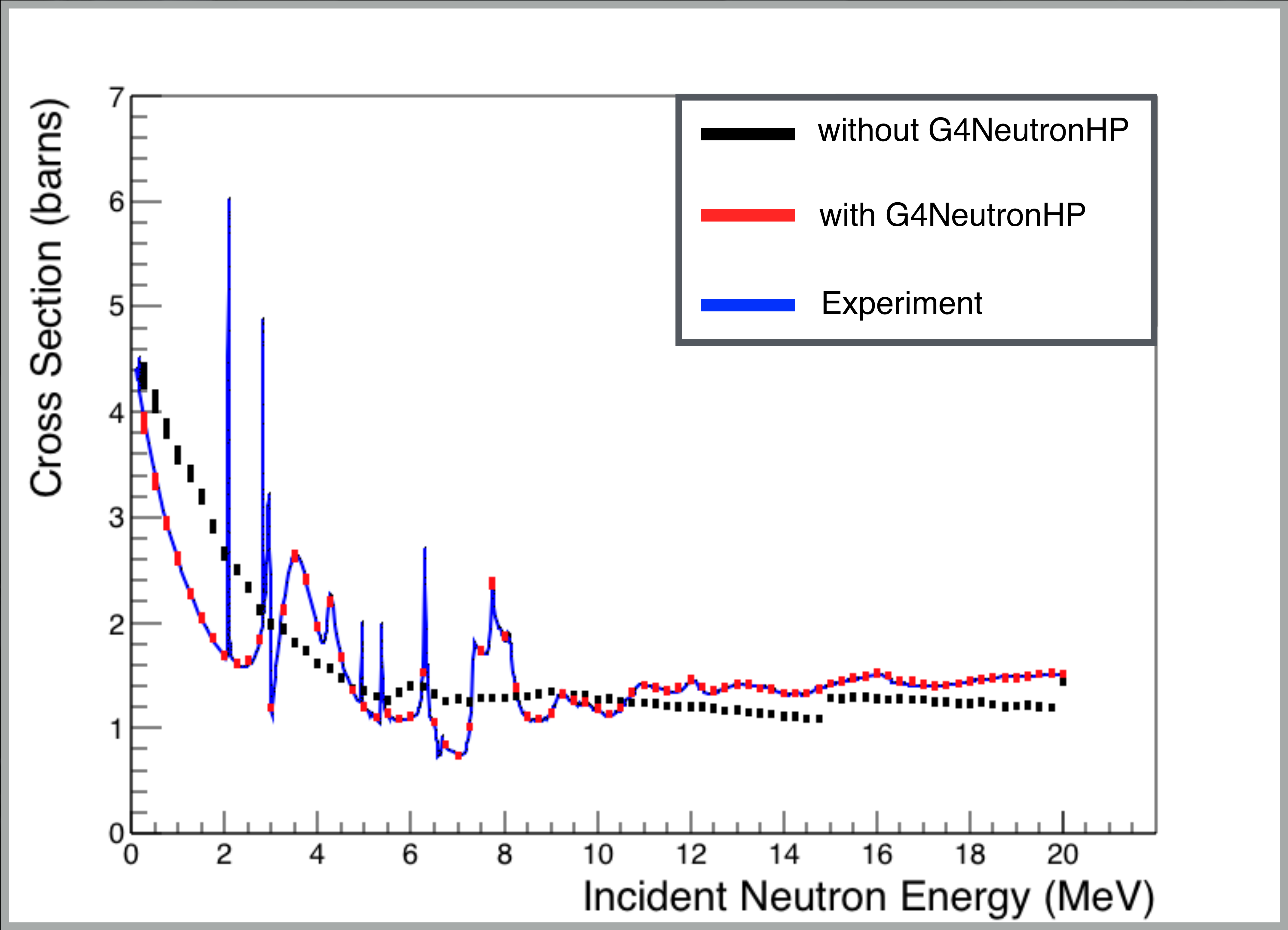
^{1}H Total Cross Section



^2H Total Cross Section



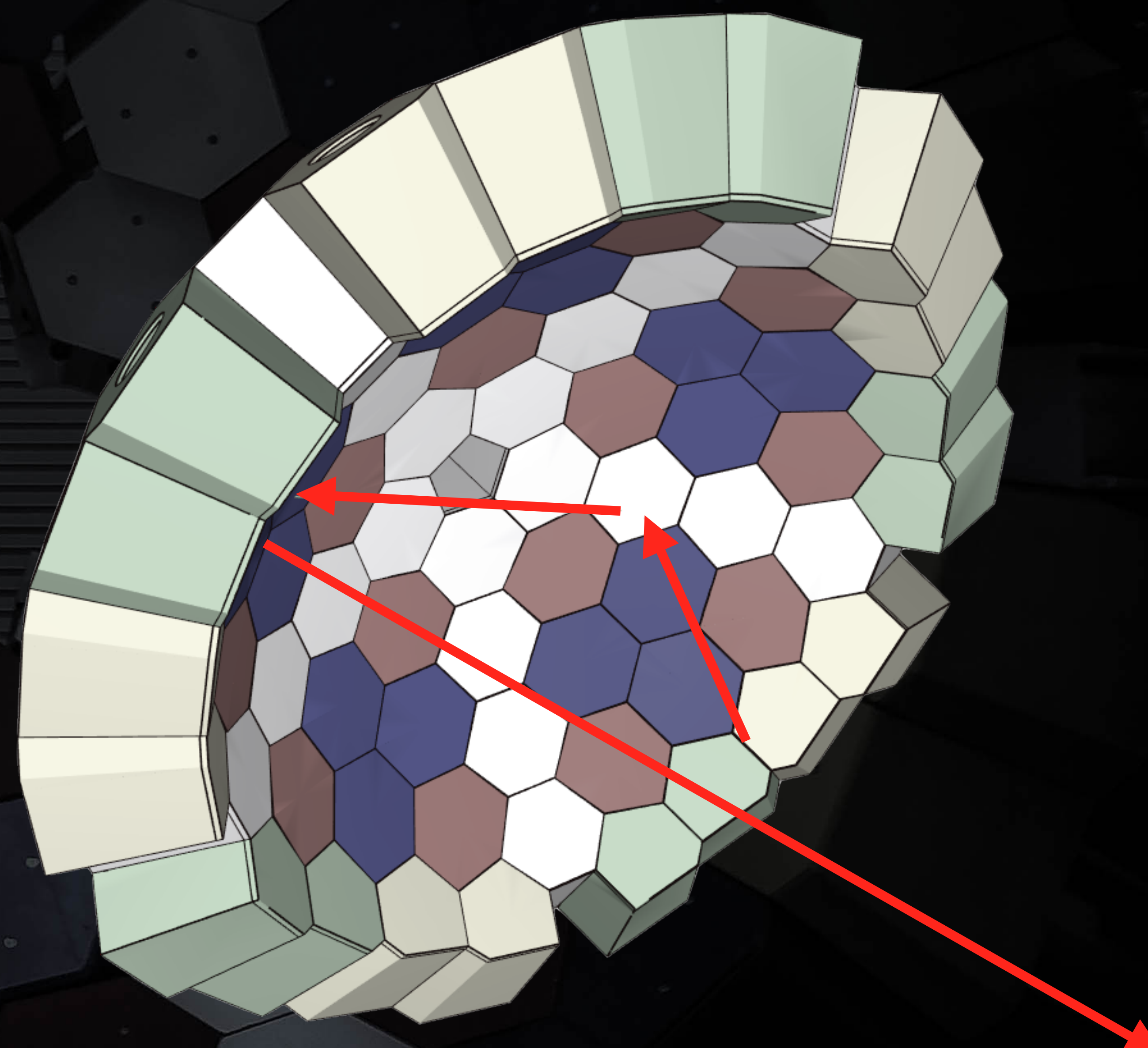
^{12}C Total Cross Section



Differential Cross Sections

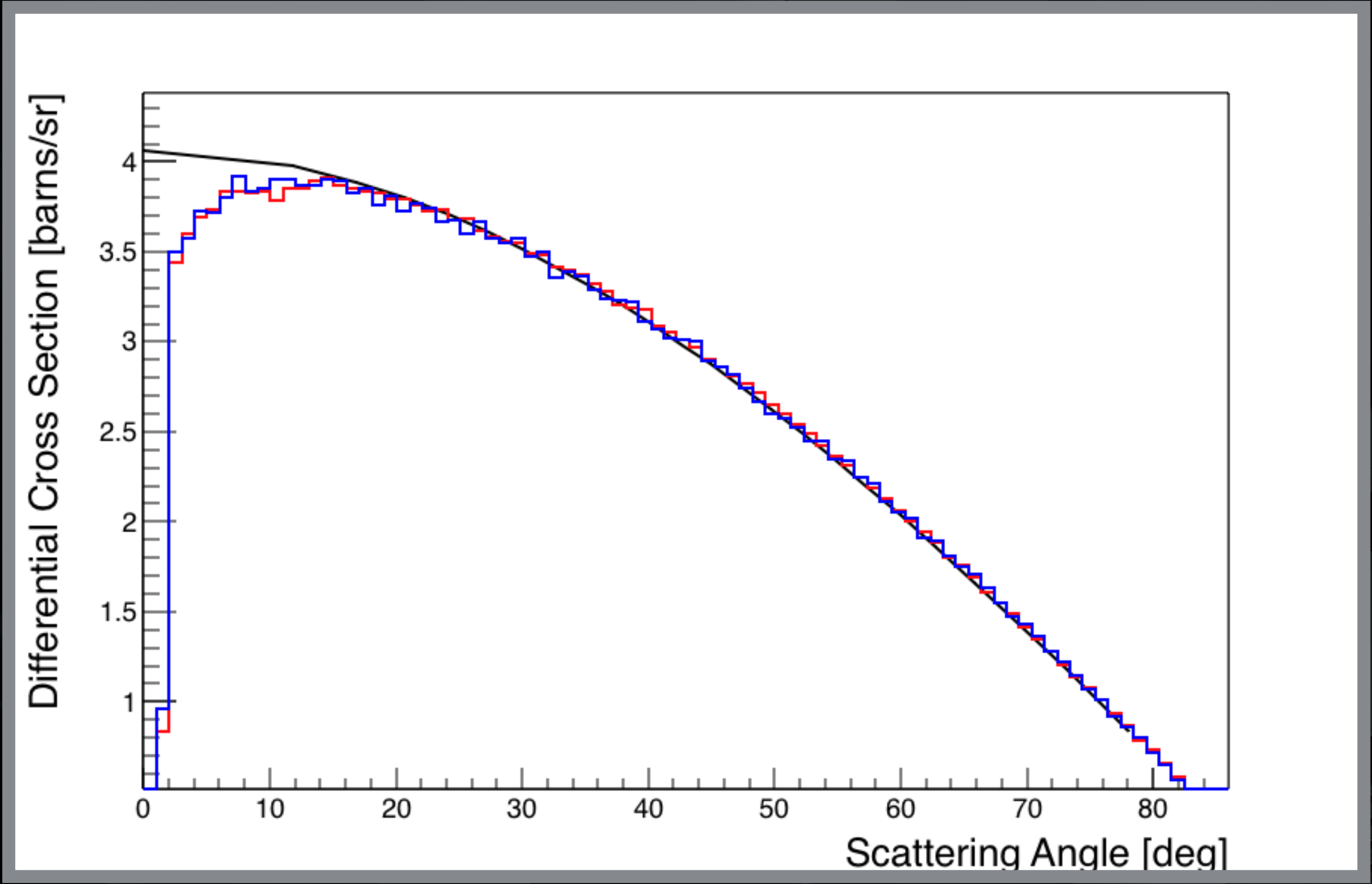
Differential cross sections were calculated by comparing the incoming and outgoing momenta of the first elastic scattering interaction of mono-energetic neutrons

Very important quantity to verify - Geant4 will be used to develop data-rejection algorithms for multiple scattering interactions between detectors

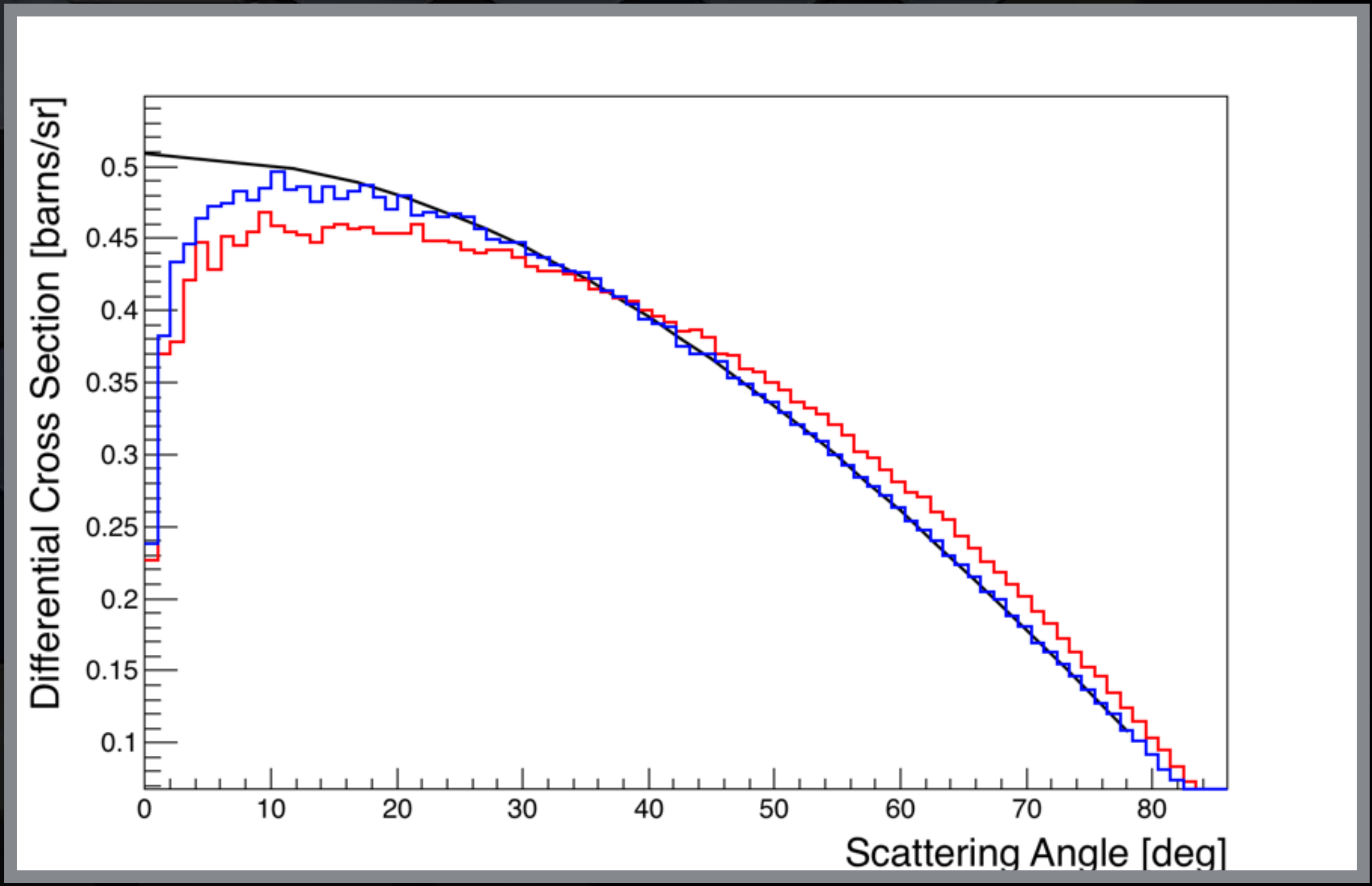


Differential Cross-sections of ^{1}H

1 MeV



5 MeV



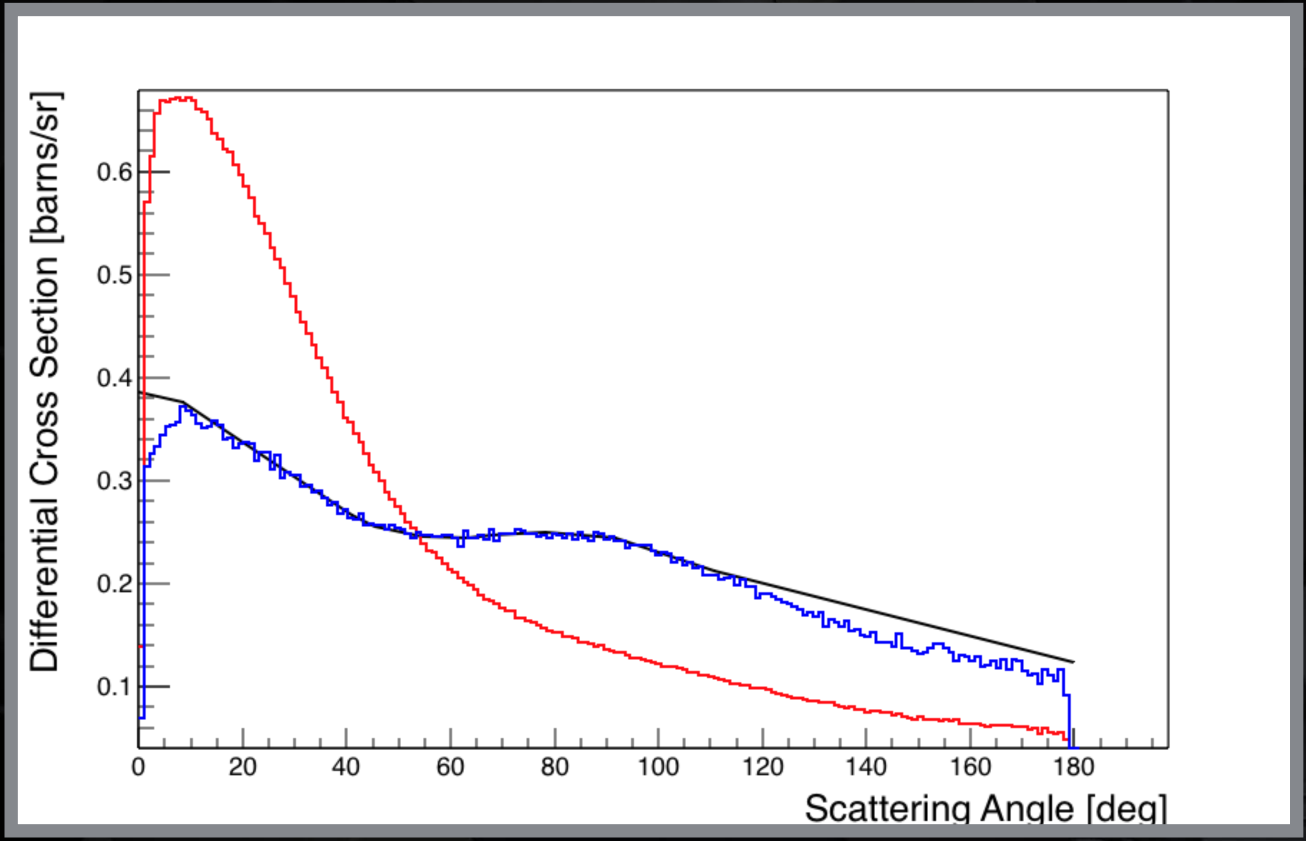
without G4NeutronHP

with G4NeutronHP

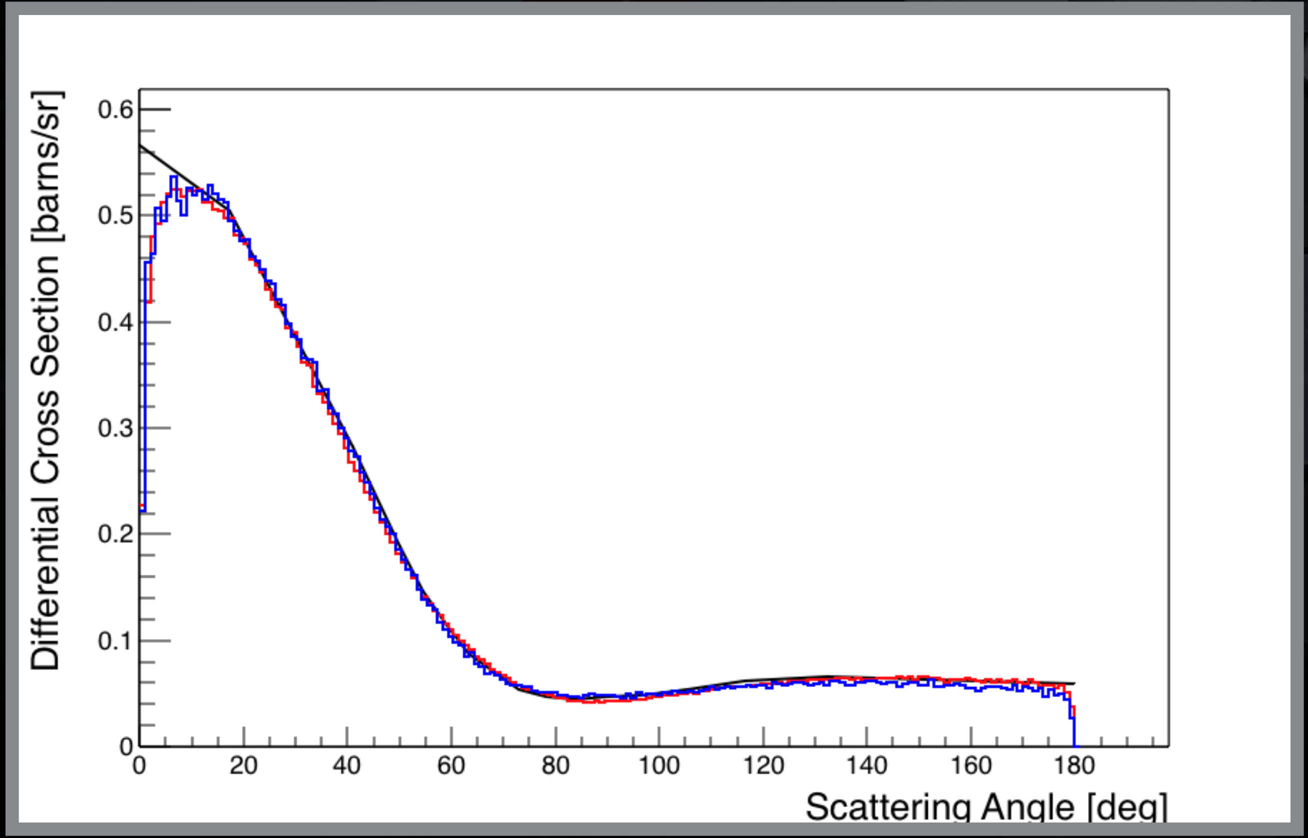
Experiment

Differential Cross-sections of ^2H

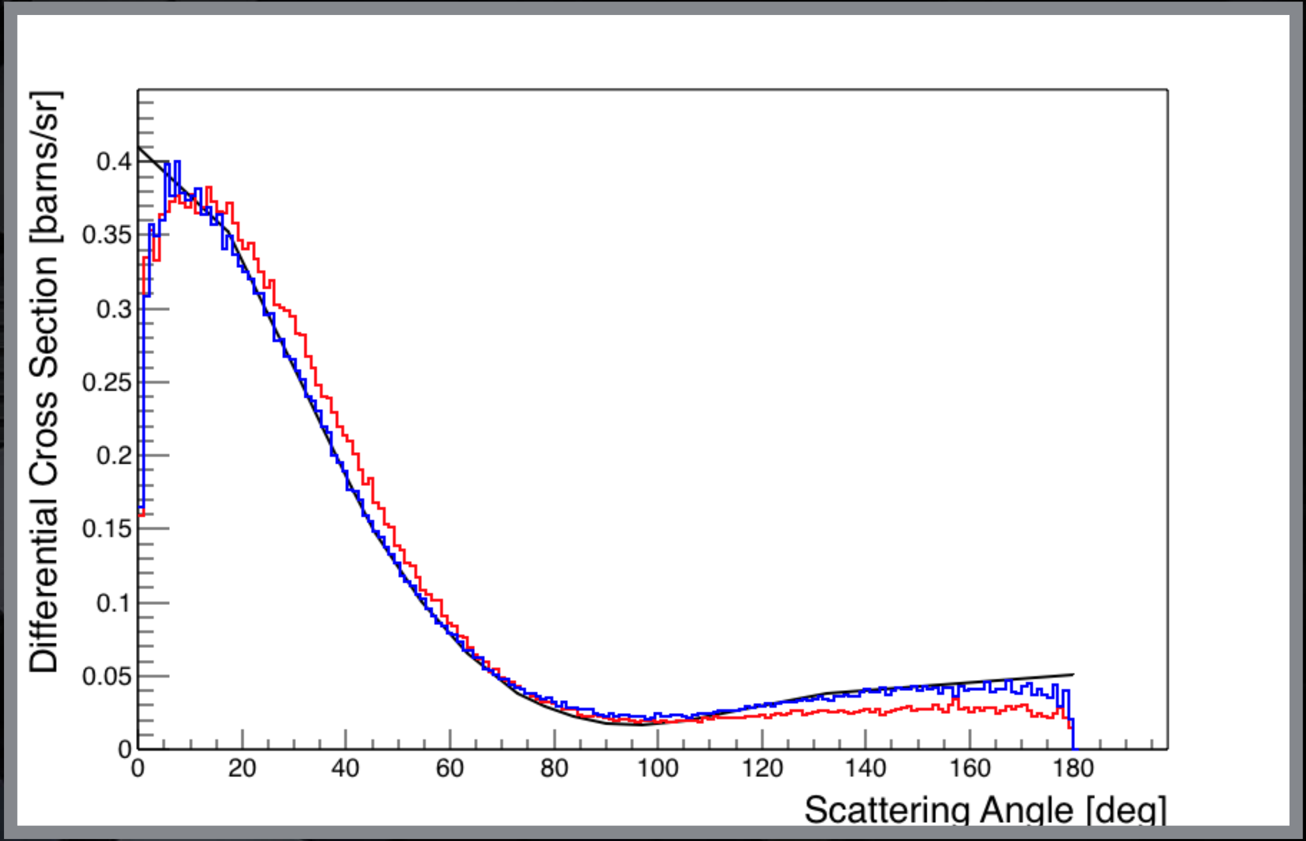
1 MeV



5.5 MeV



9.7 MeV



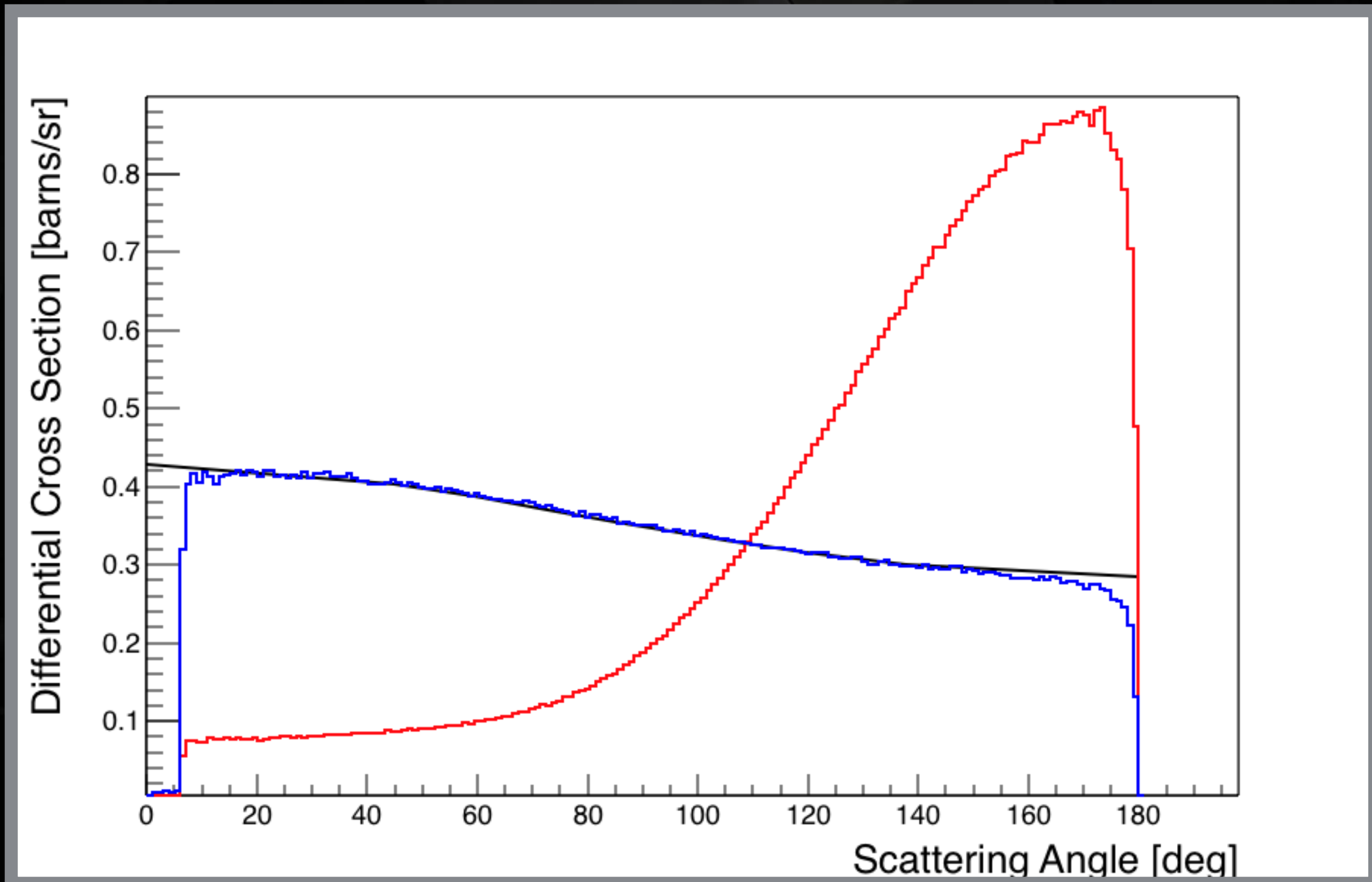
without G4NeutronHP

with G4NeutronHP

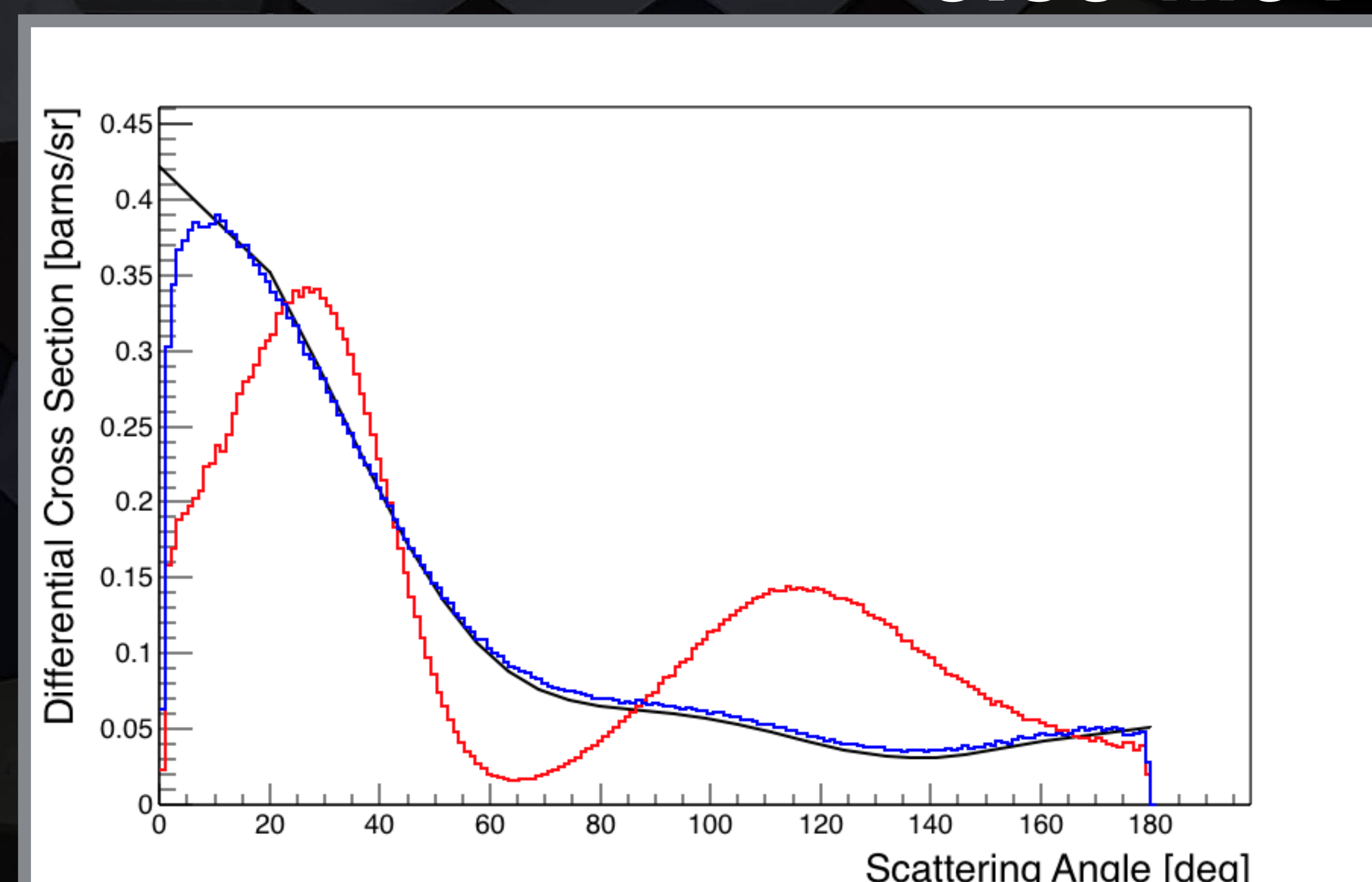
Experiment

Differential Cross-sections of ^{12}C

0.1 MeV



5.35 MeV



without G4NeutronHP

with G4NeutronHP

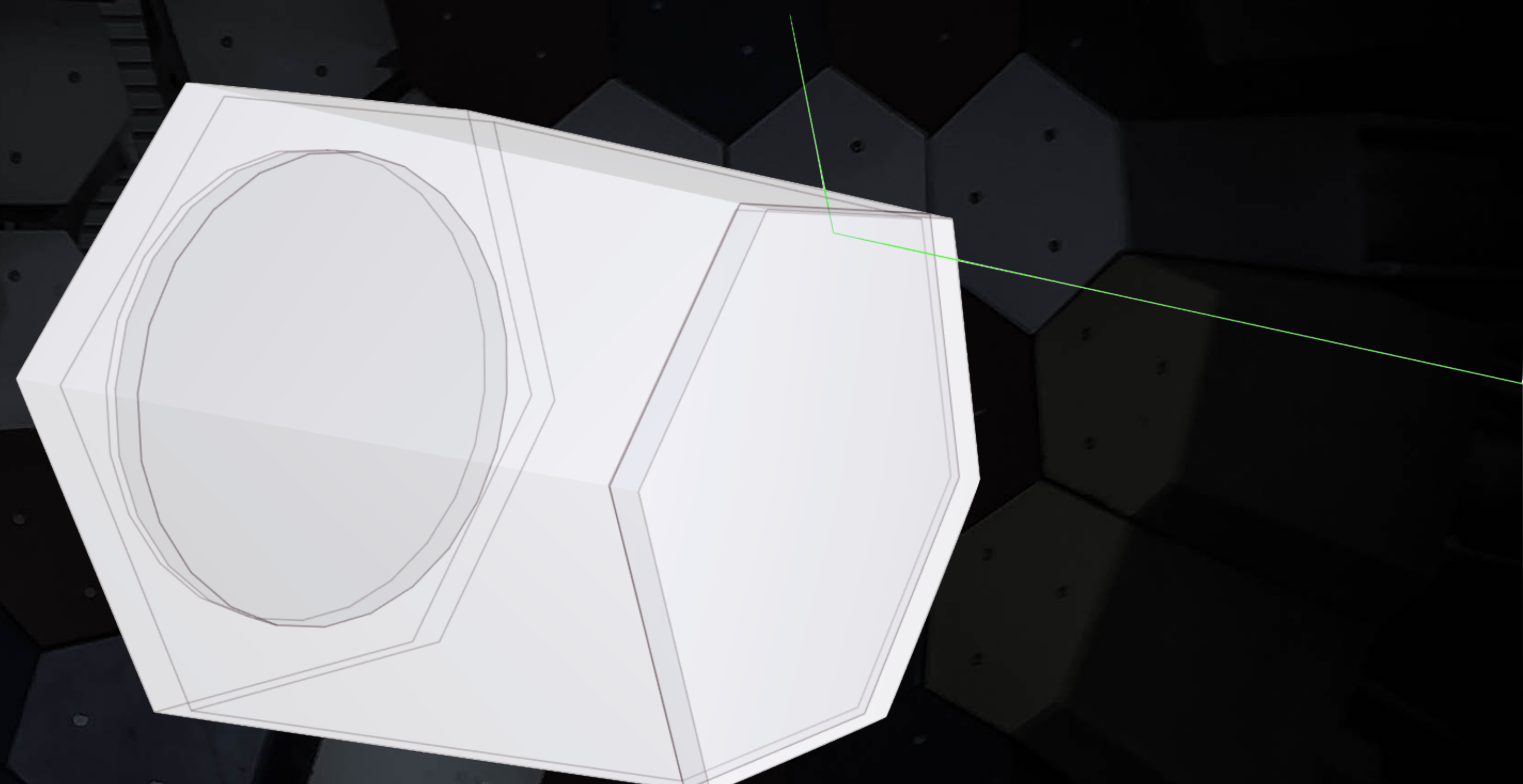
Experiment

Scintillation Physics

New release Geant4.10 contains optical physics packages to handle scintillation processes

Many input parameters required to accurately handle scintillation light emission:

- **Resolution scale for the scintillating material**
- **Reflection and refraction coefficients of all materials**
- **Absorption lengths of all materials**
- **Fast and slow scintillation light emission components**
- **Light yield of various recoiling nuclei**
- **Etc…**



Many of these parameters are not available for the DESCANT scintillator!

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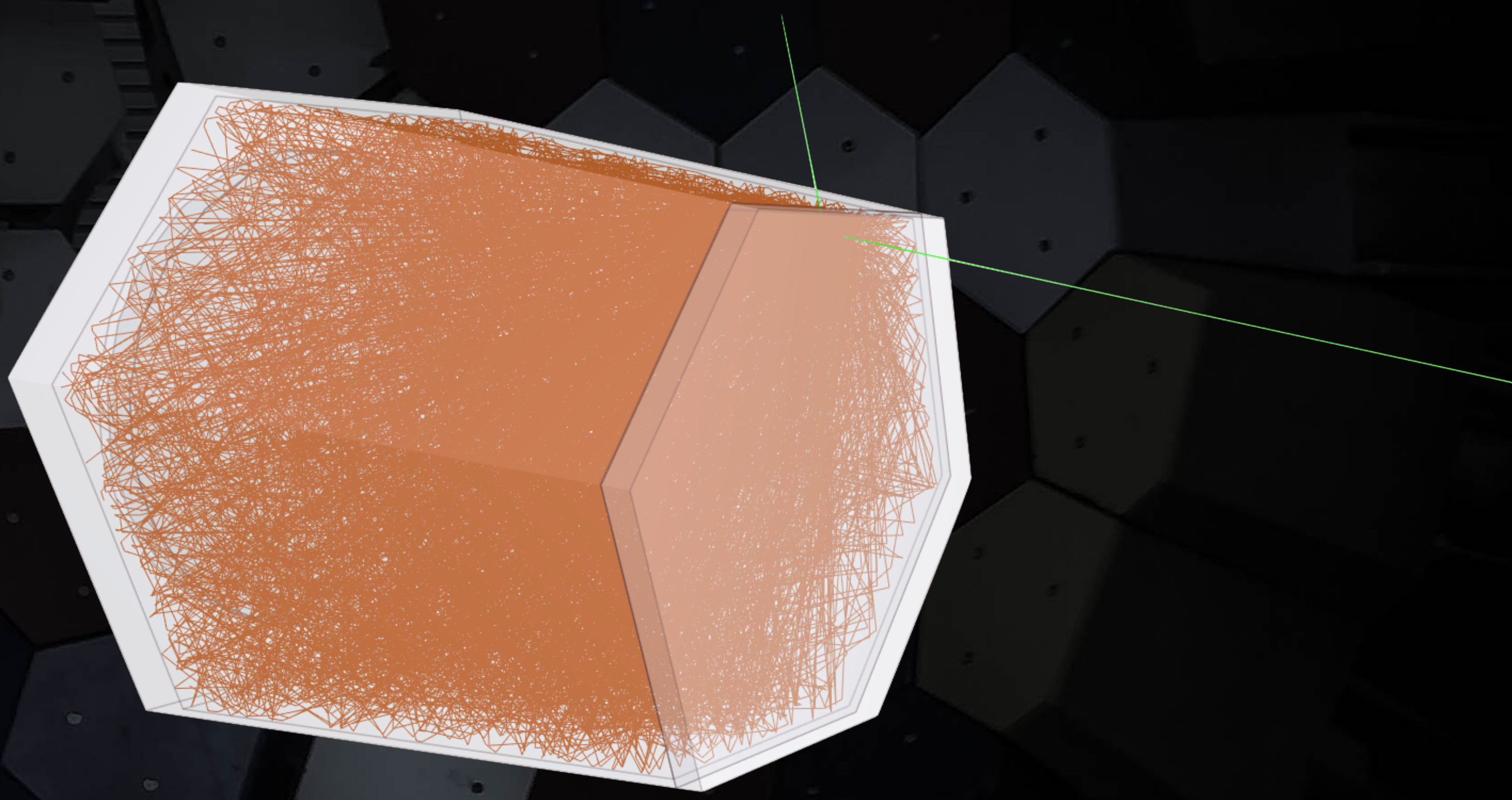

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Light Production Model

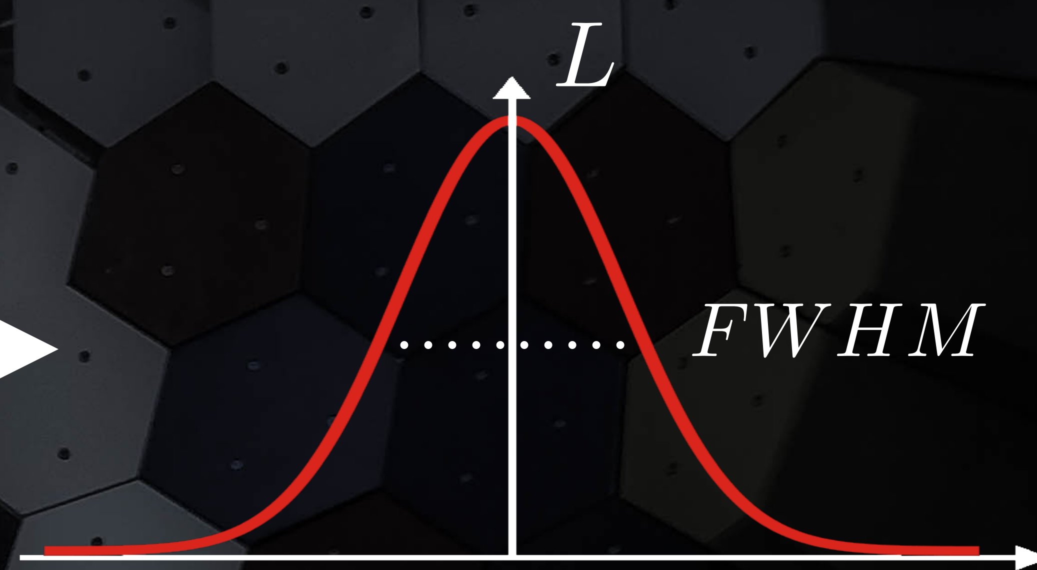
The simulated energy deposition can be then "smeared out" to replicate the experimental spectra

The light yield *L* for each particle in the scintillator can modelled by the function:

$$L(E) = a_1 E - a_2(1 - e^{-a_3 E^{a_4}})$$

This is followed by a Gaussian smearing with centred at *L* with a full-width half maximum given by:

$$FWHM = \sqrt{\alpha^2 + \frac{\beta^2}{L} + \frac{\gamma^2}{L^2}}$$



This is not so easy! All scintillating particles have a separate set of a_i coefficients: protons, deuterons, carbon, alphas, ^{9}Be, and ^{10}B

Gohil M. *et al*, Nuclear Instruments and Methods in Physics Research A 664 (2012) 304

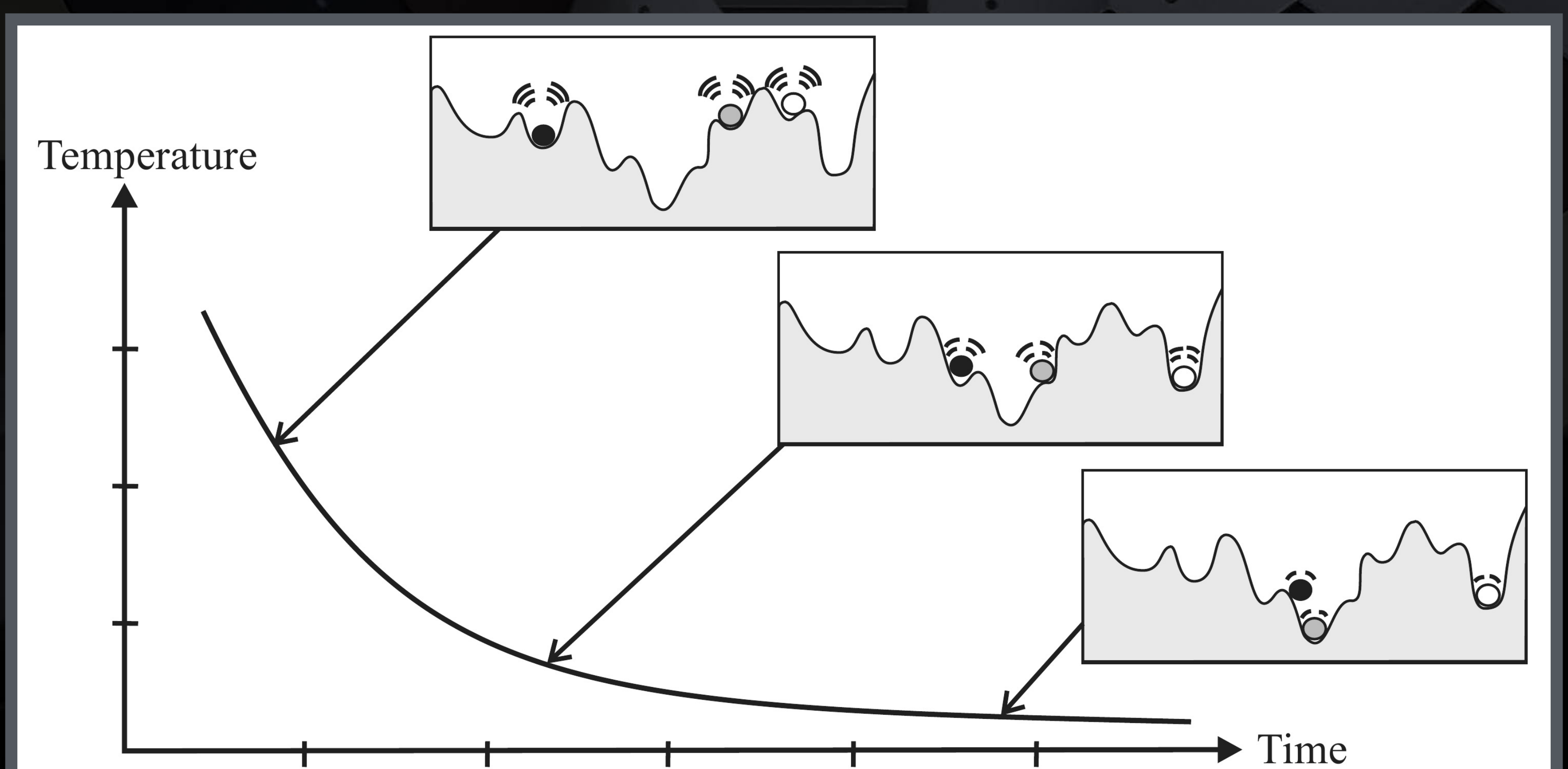
Simulated Annealing

Searching for the best fit over many energies can be very challenging

There are many possible sets of parameters that provide a good fit - which is the best global fit for a large energy range?

Traditional gradient search methods can easily get trapped at local minima near the initial search location - but is this the best global fit?

Simulated annealing is a method to avoid getting trapped at local minima



Light Production Model

Before determining the best coefficients for the deuterated DESCANT detectors, the validity of the model on a simple proton scintillator must be verified

Proof-of-concept experiments comparing a C_6H_6 detector to its C_6D_6 deuterated counterpart were conducted at the University of Kentucky - this data will be analyzed for this component

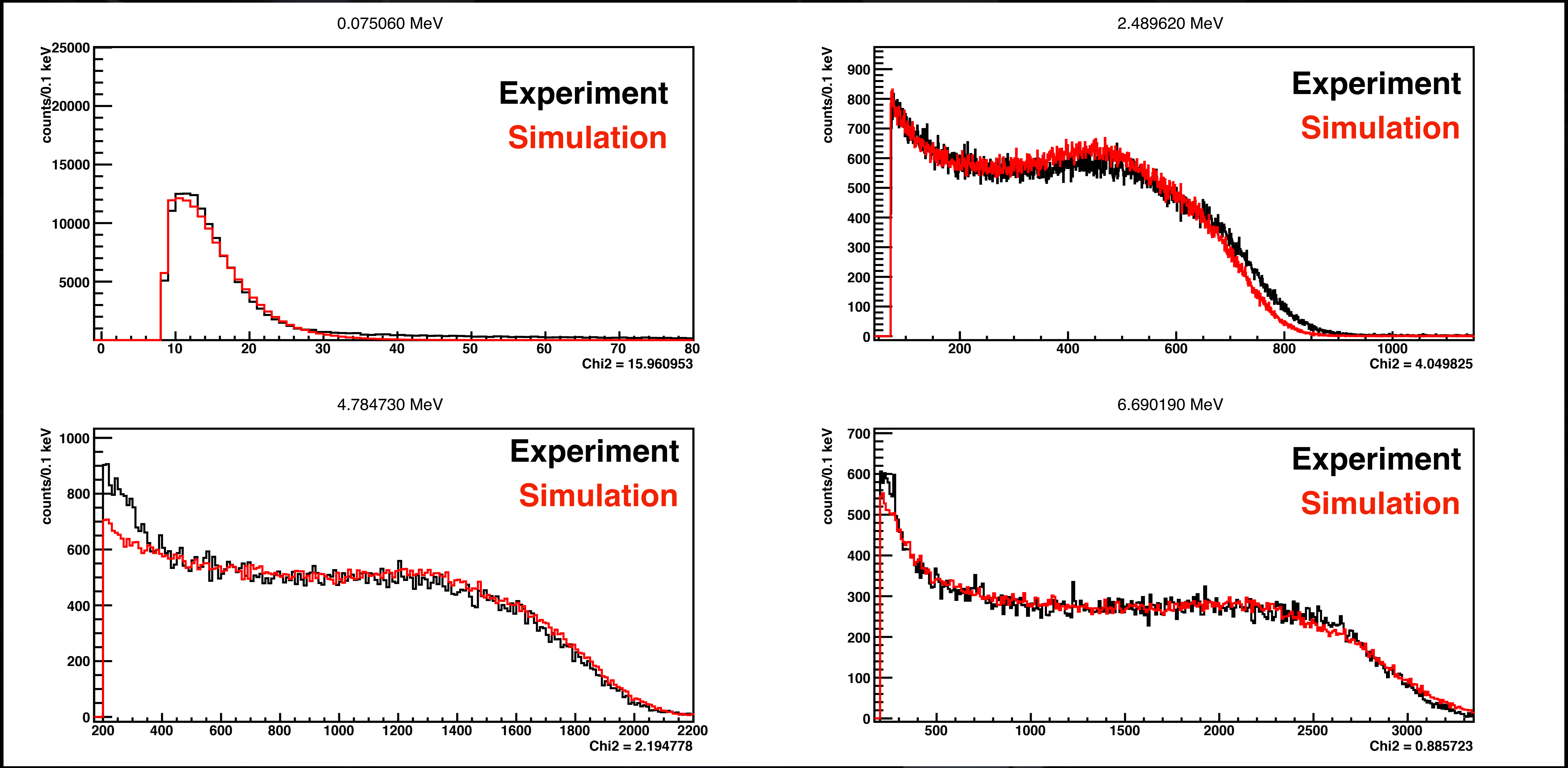
Proton-recoil

	e^-	p^+	α	^{12}C	^{9}Be	^{10}B
a_1	1	0.642	0.41	<0.001	0.0821	0.0375
a_2	0	1.459	0.59	0	0	0
a_3	0	0.373	0.065	0	0	0
a_4	0	0.969	1.01	0	0	0

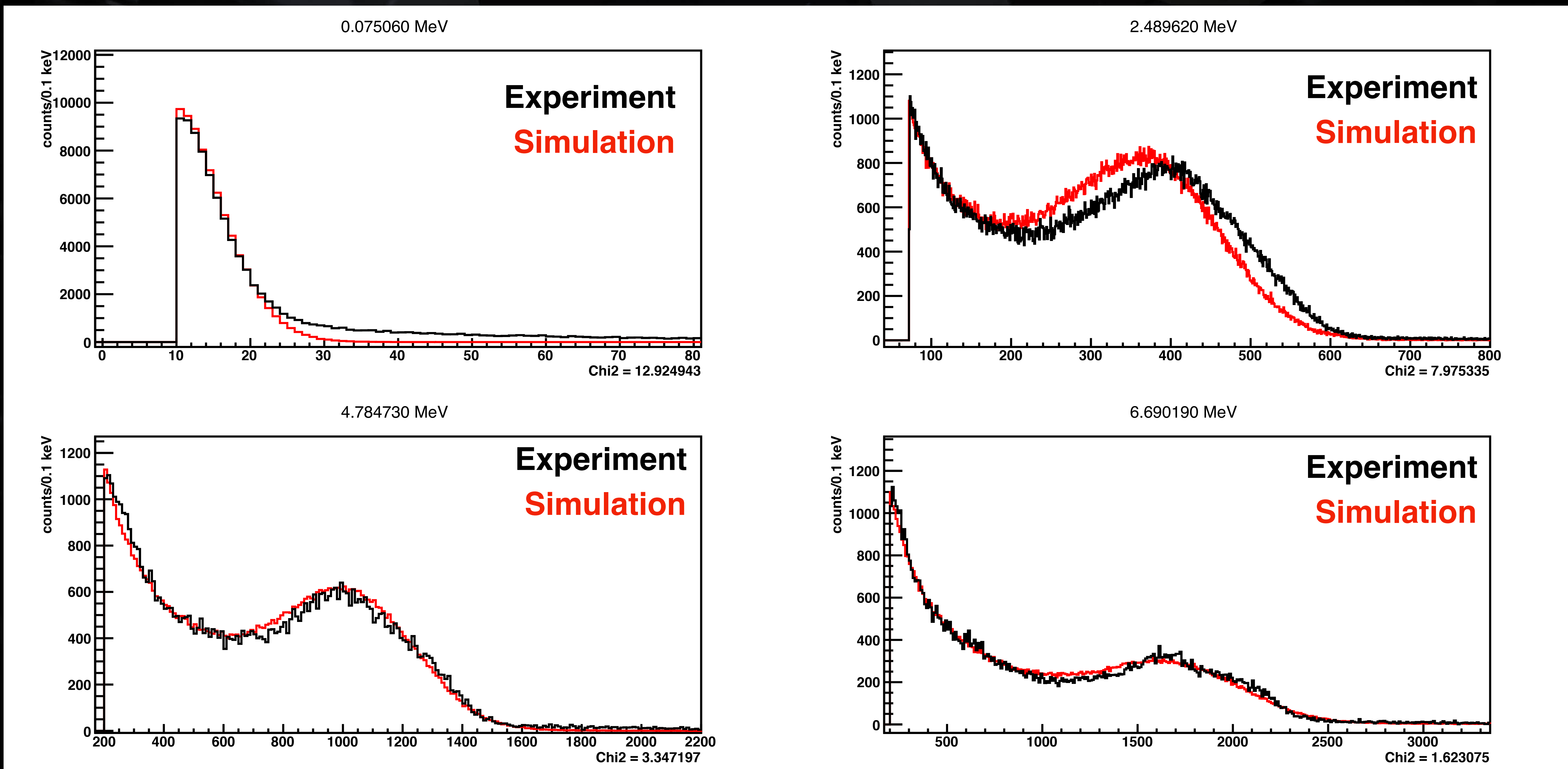
Deuteron-recoil

	e^-	$d+$	α	^{12}C	^{9}Be	^{10}B
a_1	1	0.537	0.41	<0.001	0.0821	0.0375
a_2	0	1.387	0.59	0	0	0
a_3	0	0.338	0.065	0	0	0
a_4	0	1.010	1.01	0	0	0

Proton-Recoil Scintillator Pulse-Height Spectra



Deuteron-Recoil Scintillator Pulse-Height Spectra



Summary

- Total and differential cross sections in Geant4 were verified for the main isotopic components of BC501A and BC537
- Preliminary pulse height spectra simulated for a simple cylindrical geometry

Next Steps

- Verify light yield parametrization for all energies
- Expand light yield simulation to the DESCANT prototype detectors
- Simulate the entire DESCANT array - investigations of multiple scattering interactions, response with coupling to GRIFFIN, etc…

Acknowledgements

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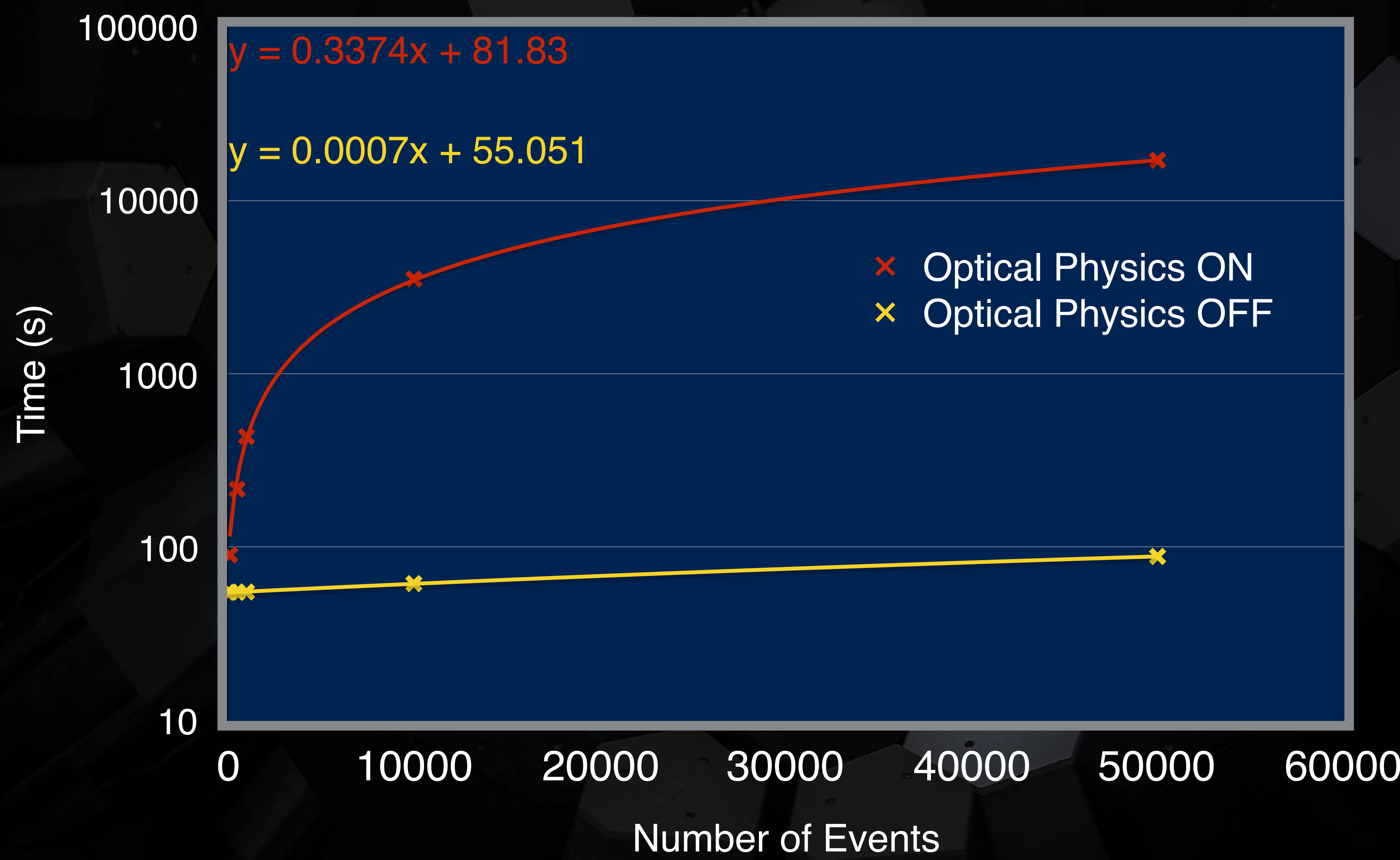
But at what cost?

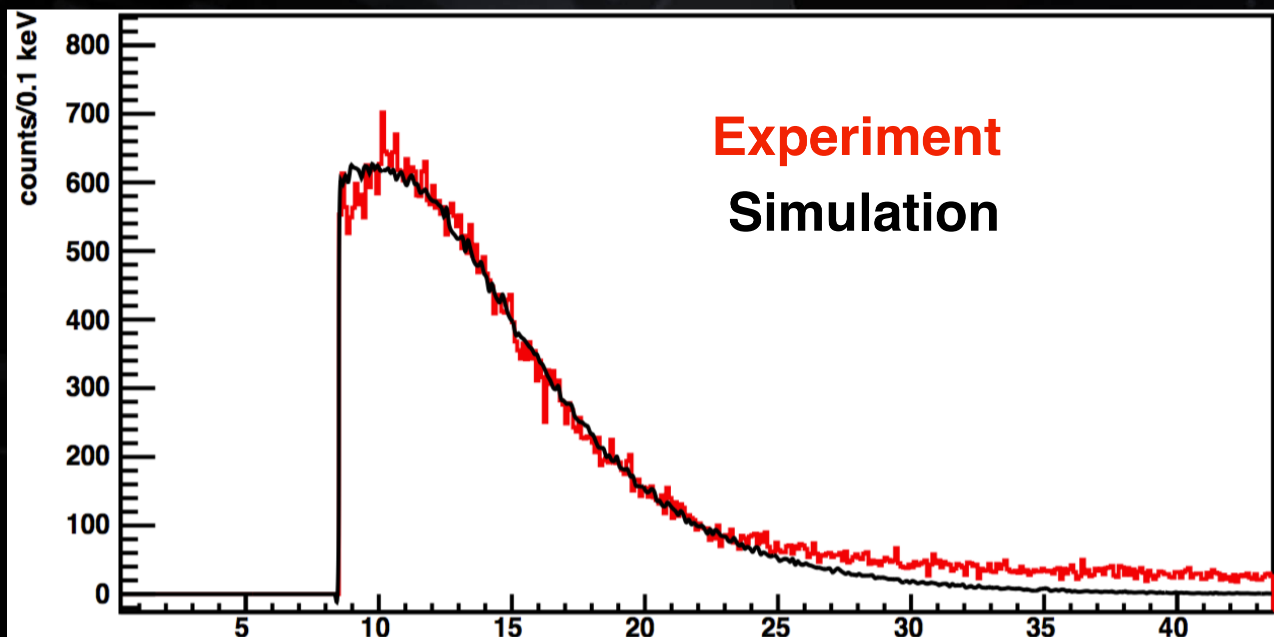
- Optical physics simulations are extremely computationally expensive!
- Assuming a constant event rate, a simulation with 1000 keV neutrons is slowed down by a factor of ~ **500x** !

Simulation Time vs. Number of Events



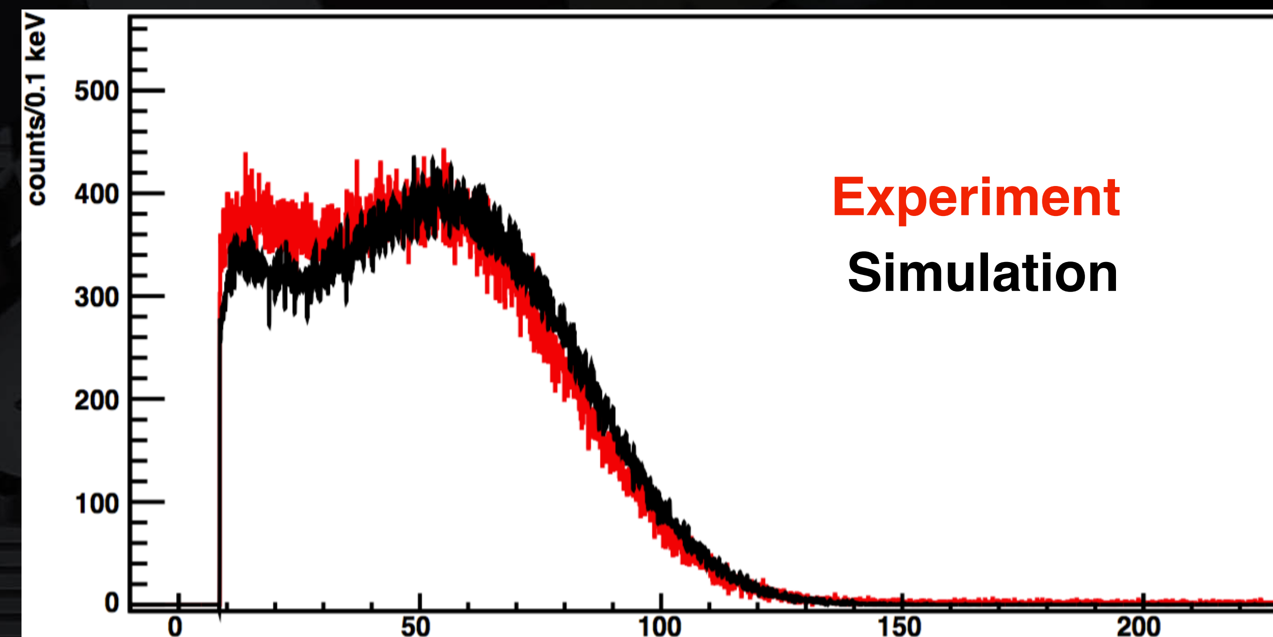
BC501A Pulse-Height Spectra

0.06 MeV



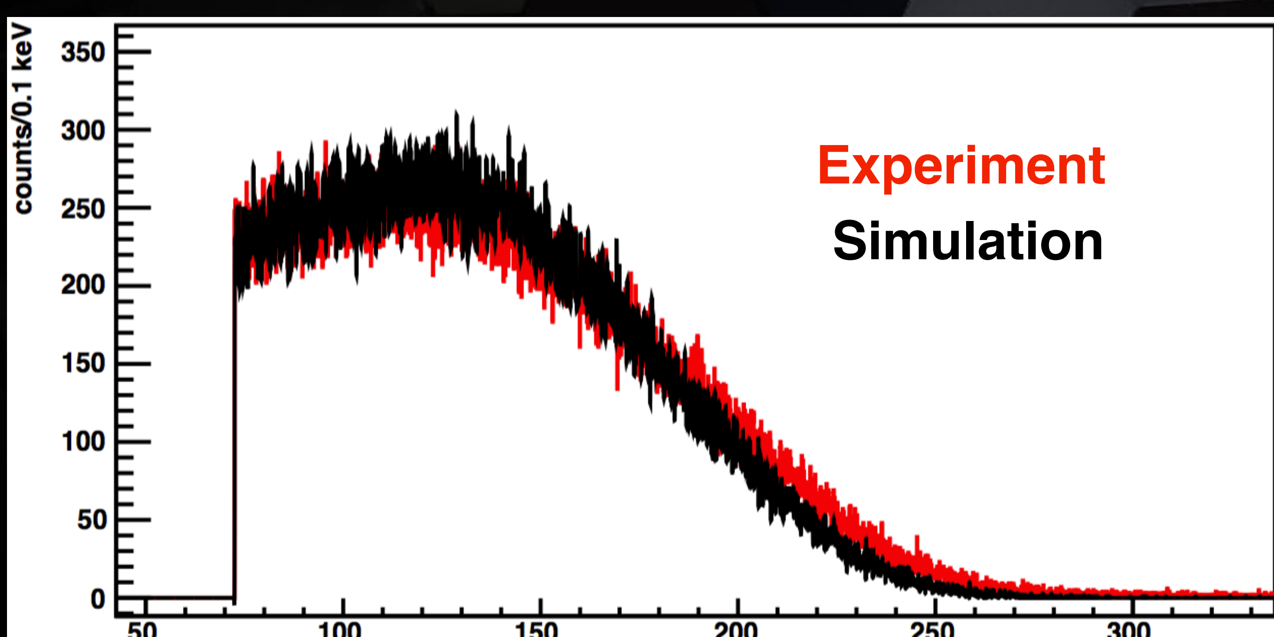
pulse height (keVee)

0.60 MeV



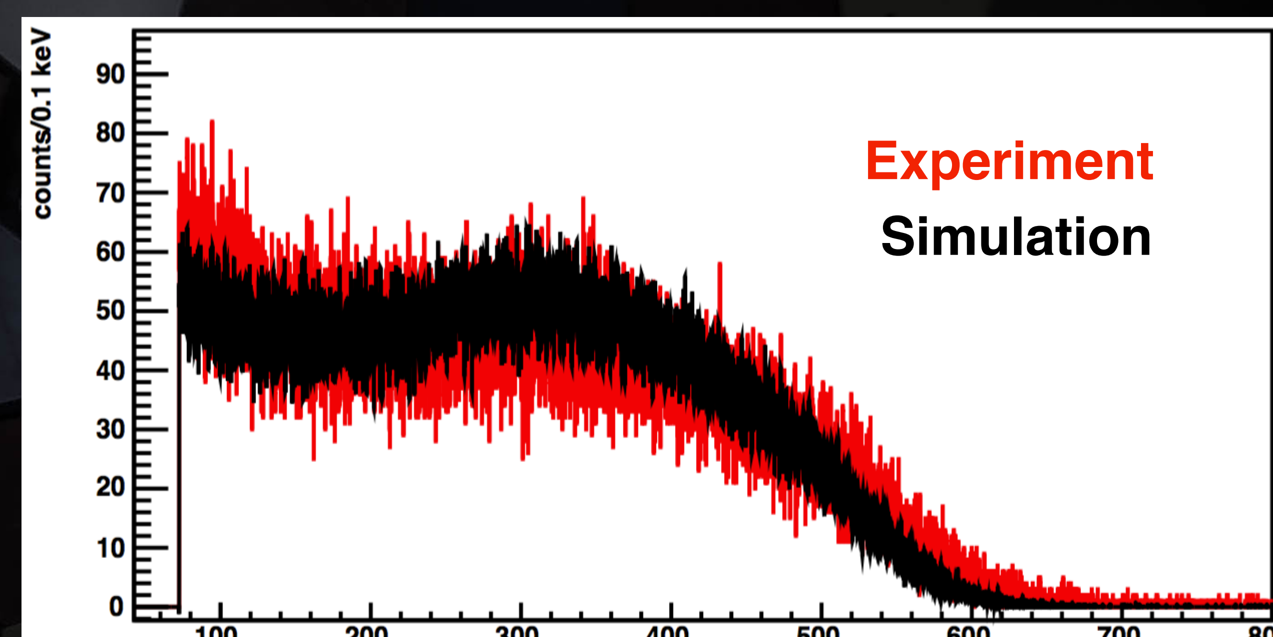
pulse height (keVee)

1.05 MeV



pulse height (keVee)

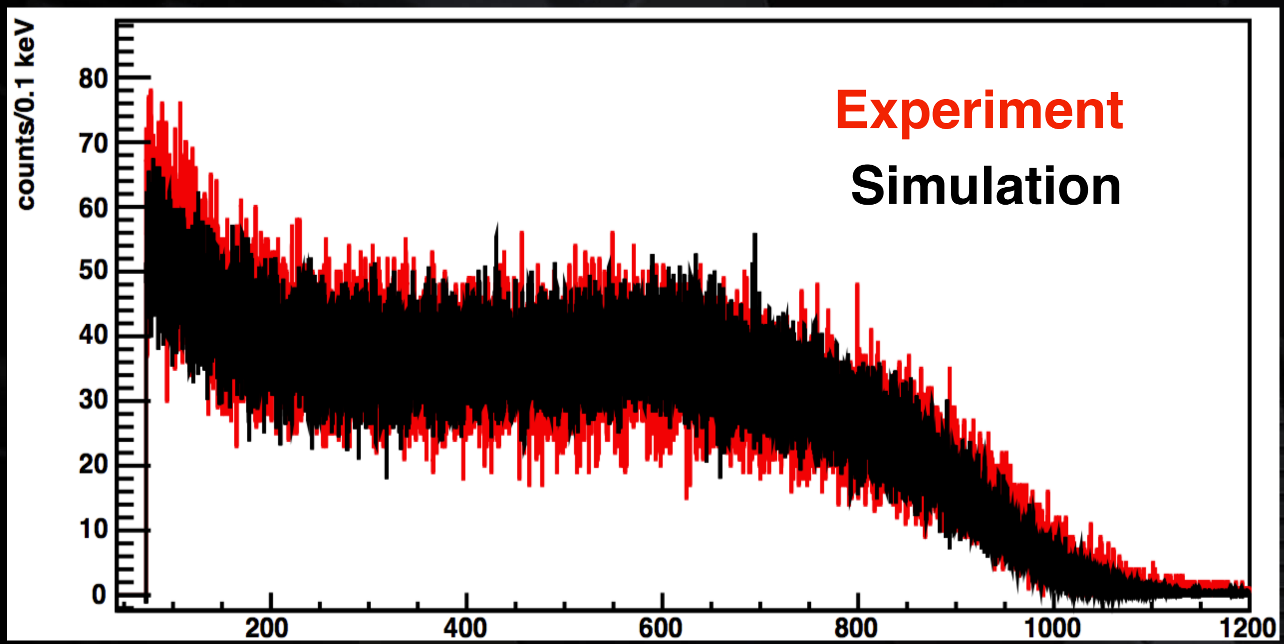
2.00 MeV



pulse height (keVee)

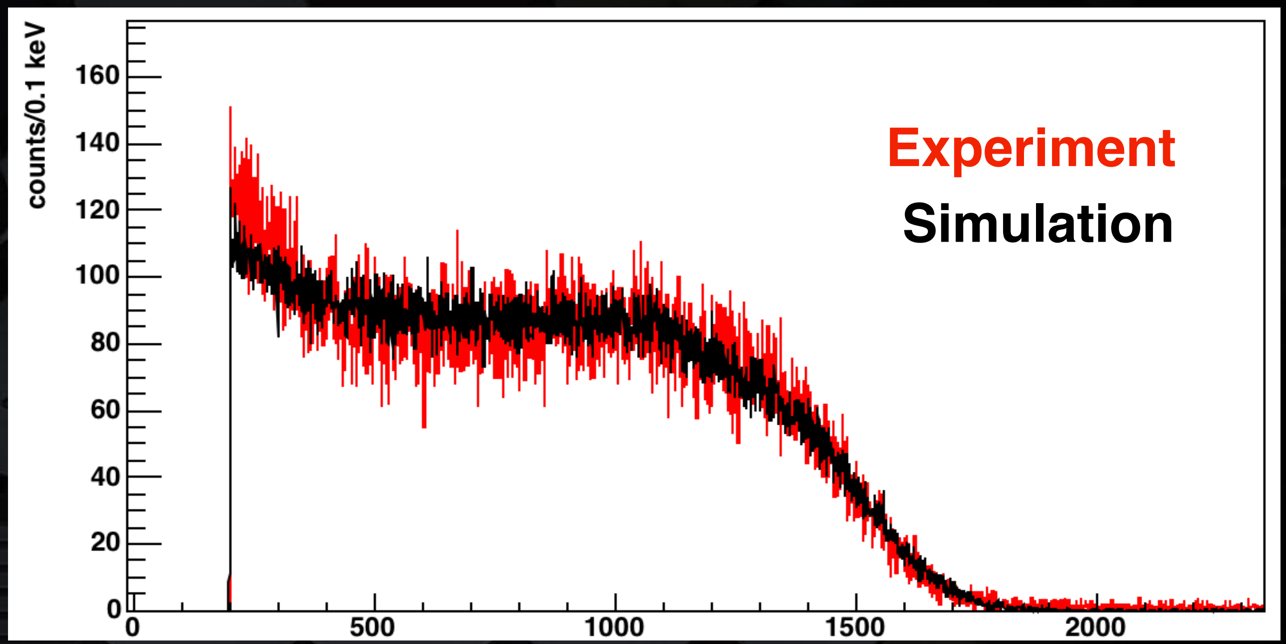
BC501A Pulse-Height Spectra

2.96 MeV



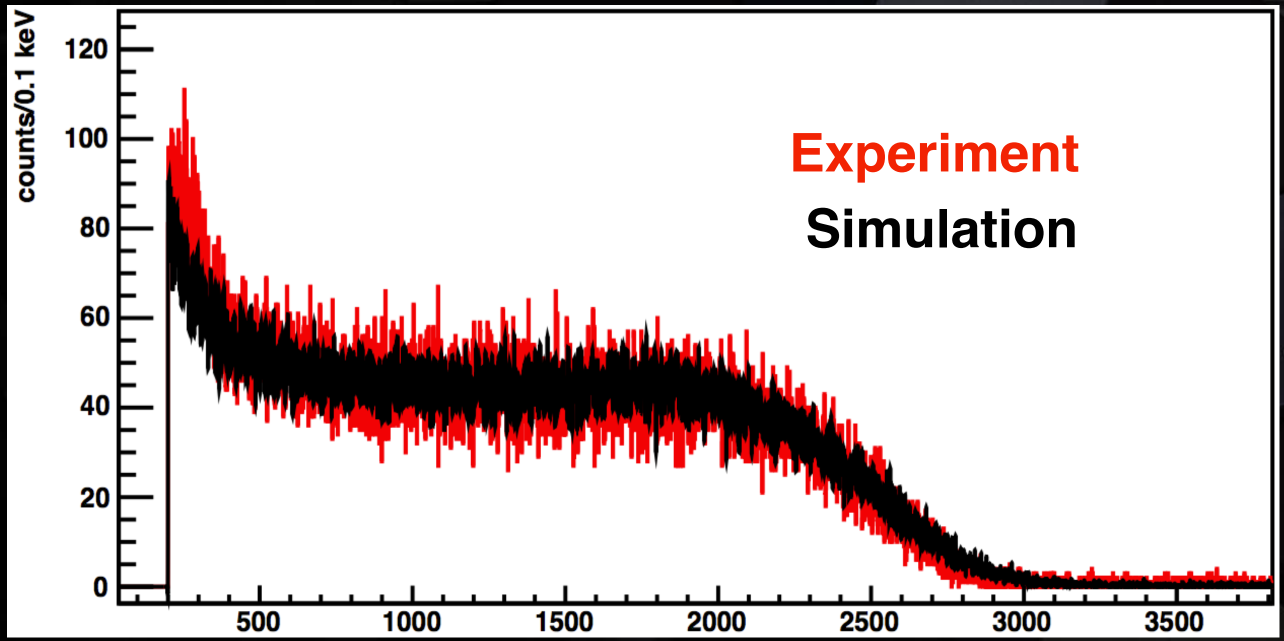
pulse height (keVee)

4.16 MeV



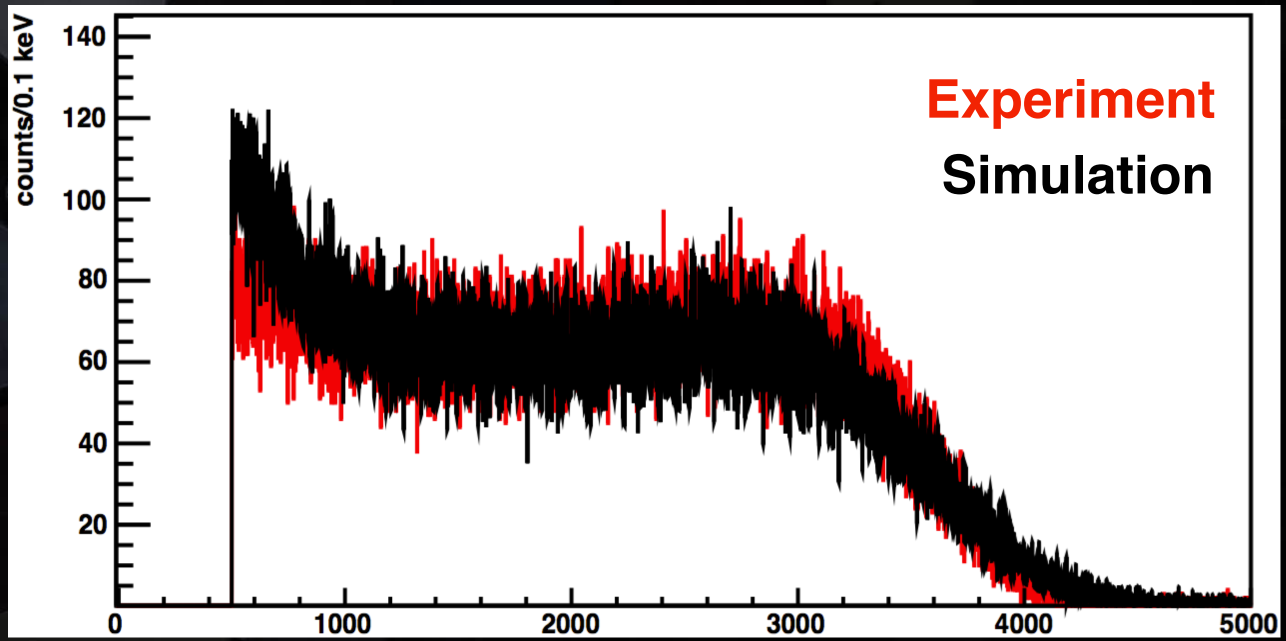
pulse height (keVee)

6.08 MeV



pulse height (keVee)

7.90 MeV



pulse height (keVee)