Summary of systematic uncertainties

Guang Yang
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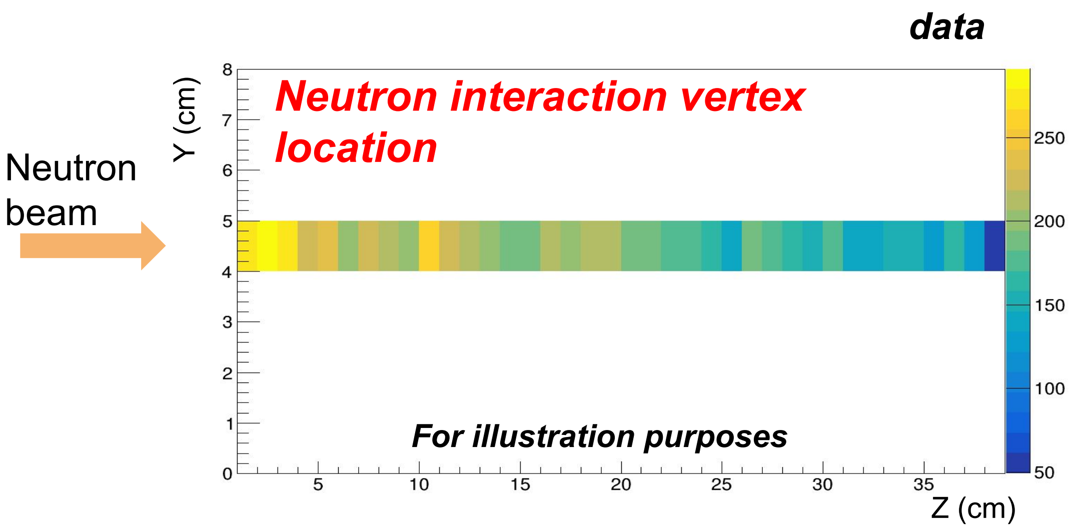
A total cross-section measurement



The "extinction method" needs a relative measurement of event rate at each layer along the beam.

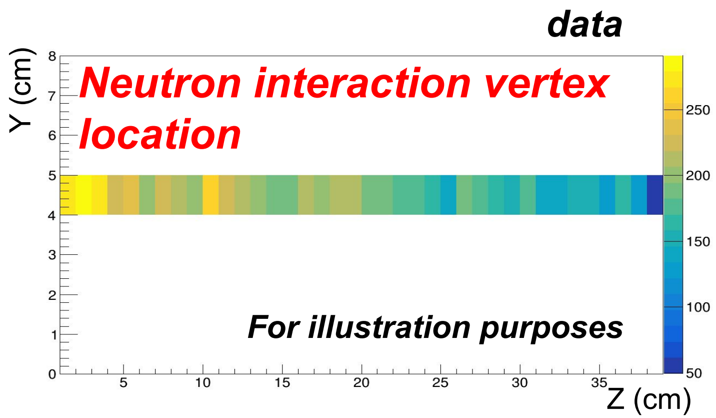
$$N(z) = N_0 \cdot \exp(-T \cdot \sigma_{total} \cdot z)$$

→ Measurement of event rate at each layer indicates a total cross section

- T: Nuclear density
- σ_{total}: total xsec
- z: depth along the beam, i.e. layer

A total cross-section measurement

Neutron beam



Event rate ratio for any two layers with certain topology (e.g. single-track) is equal to the event rate ratio for any two layers with all topologies-> any topology can be used

$$N_{e,z} = \sum \begin{pmatrix} N_{single\text{-}track,e,z} \\ N_{invisible,e,z} \\ N_{two\text{-}track,e,z} \\ .. \\ N_{100\text{-}track,e,z} \end{pmatrix} = \sum \begin{pmatrix} N_{single\text{-}track,\ e,z} \\ N_{single\text{-}track,\ e,z} \times r_e \end{pmatrix}$$

Energy Layer

r is the cross section
Ratio between "non-single-track" and single-track, it only depends on energy, regardless of layer

$$N_{e,l} / N_{e,m} = N_{single\text{-}track,e,l} / N_{single\text{-}track,e,m}$$

Layer l Layer m

Single track attenuation indicates a total cross-section

Single track defined as a single temporal and spatial cluster with at least three voxels and good linearity

Event reconstruction

2D hits → **3D voxels** → **Clustering and vertex**

2D hits

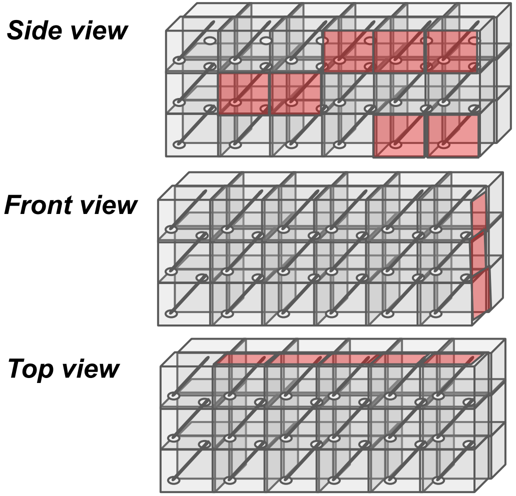
1. Time range selection
2. Gain calibration
3. PE cut
4. Time-walk correction
5. Time clustering

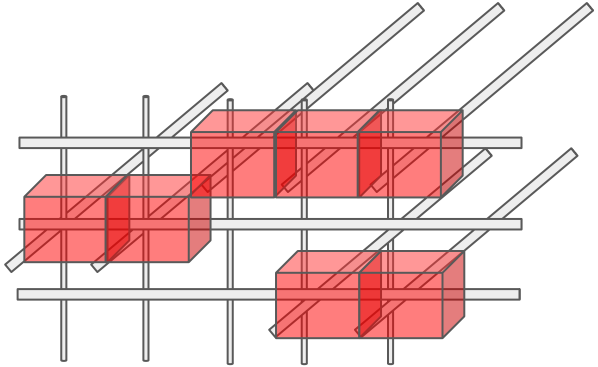
3D voxels

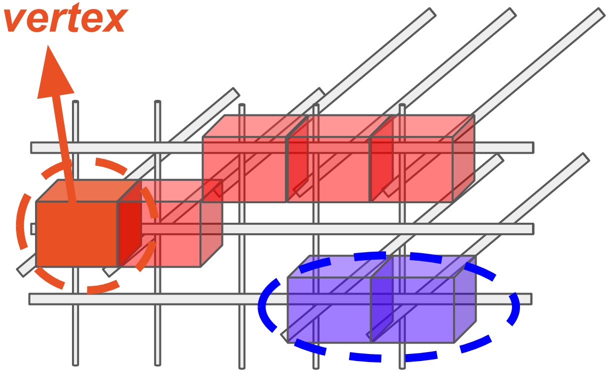
1. 3D voxel matching
2. Hit number
3. Attenuation corr.

Clustering and vertex

1. Spatial clustering
2. Vertex: first voxel in z in fiducial volume



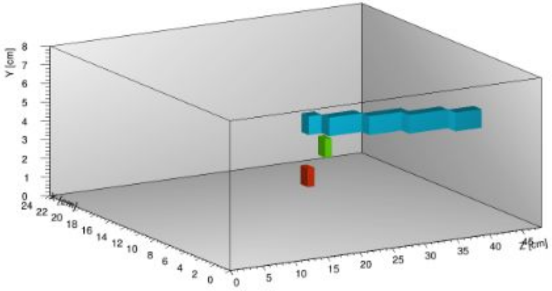




Single-track event selection

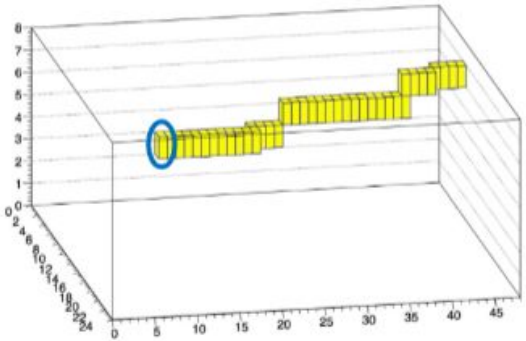
Single cluster in time and space

1. Single time cluster
2. Single spatial cluster with DBSCAN
3. 3-8 number of voxels in single cluster



Linear track

1. Not in first layer
2. Linearity > 0.70
3. Cluster width < 1.4 and max-vox-line < 1.2
4. Vertex in fiducial volume (1.5 cm radius around beam center)



Systematic uncertainty included

Dominating !

Detection systematic: Cube, MPPC and passive material non-uniformity

Invisible scattering: If the first interaction is **elastic scattering or inelastic scatterings below the threshold**, we can't see the primary vertex.

Geometric acceptance: Limited detector size

Light yield: Light yield variation for each channel

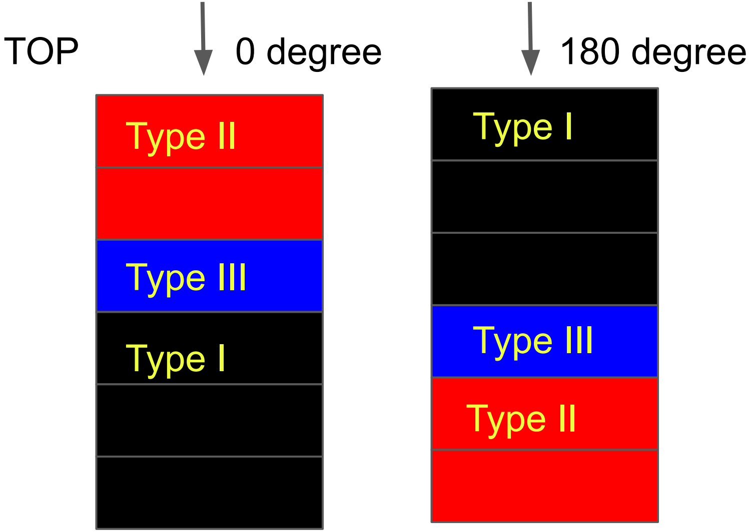
Time resolution: Events shifting across different energy bins

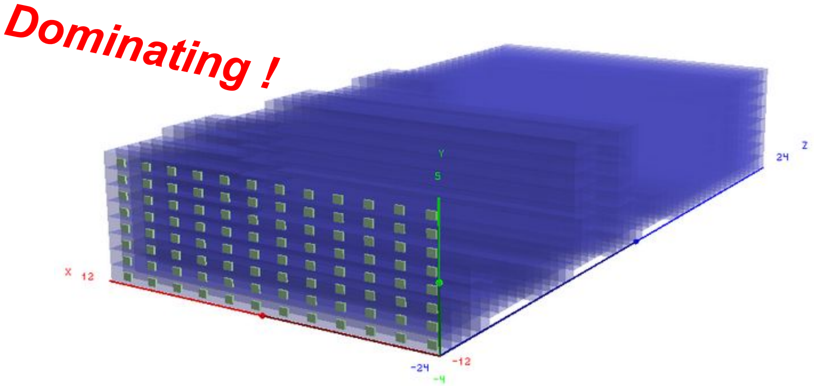
Collimator interaction: Events interacting with the collimator before entering the detector

Major Systematics: Detection

- When compare the event rates of 0 degree and 180 degree configurations, the difference is up to 10% across the z layers.
- **MPPC anisotropy:** Relatively small as the results without the top view are very similar.
- Ruled out the hypothetical reasons of **calibration, beam tilting and reconstruction**.
- **Cube misalignment:** In simulation, systematically shifting every 5 layers by 1 mm makes the events rate at z changes up to 10% -> **this is the culprit of our best understanding.**

Guessing but can be realistic





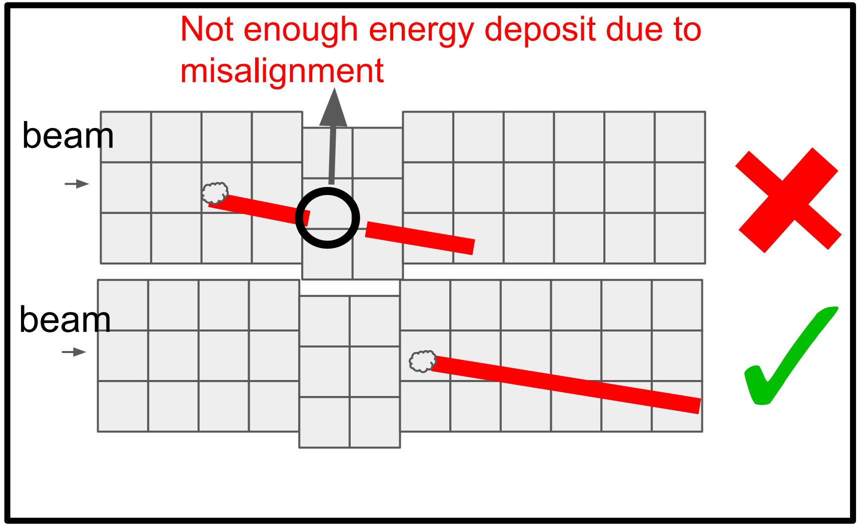
Major Systematics: Detection

Dominating !

A certain topology along z results in a total cross section measurement, compare

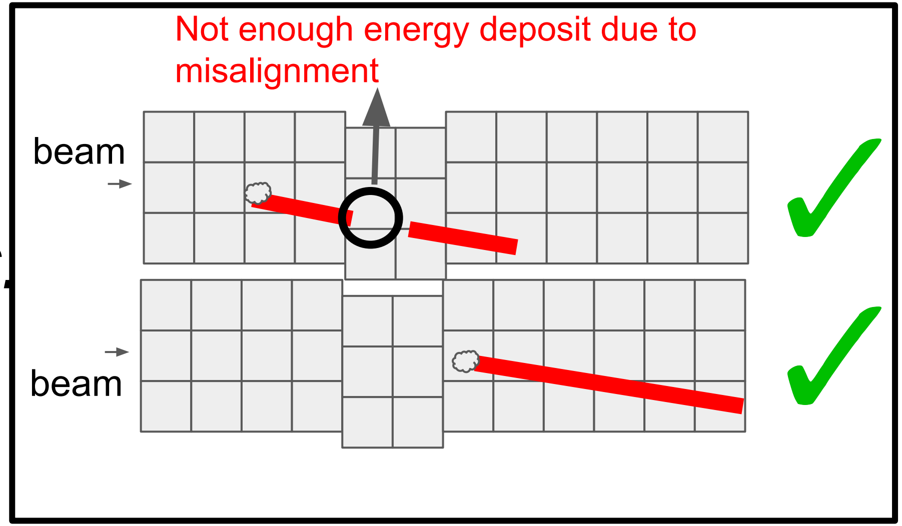
- Single-track
- Everything above threshold

Single-track



VS.

Everything above threshold (called "no-cut")



Major Systematics: Detection

Technote available
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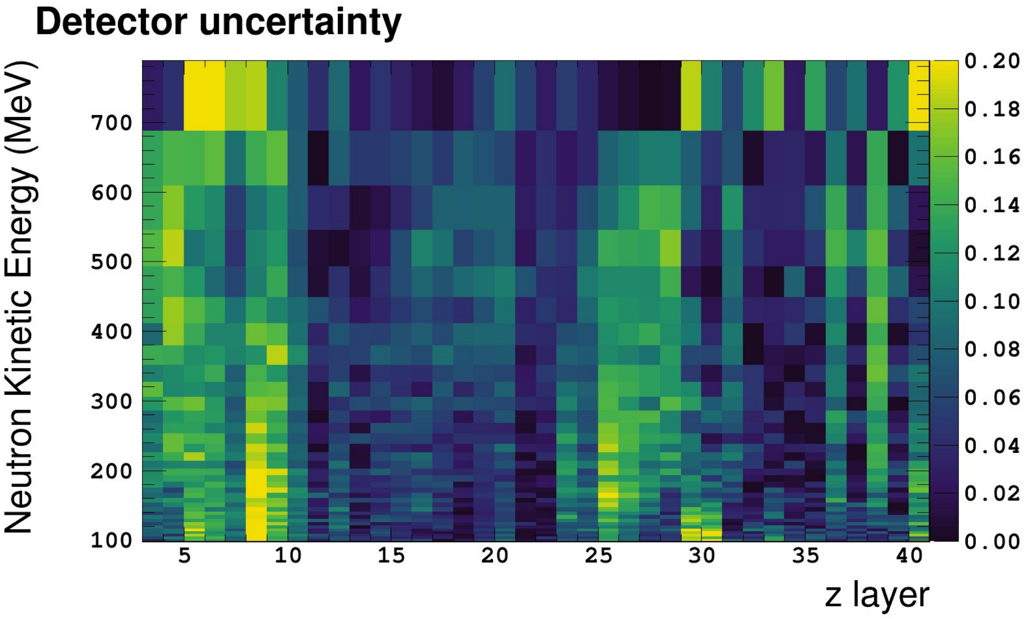
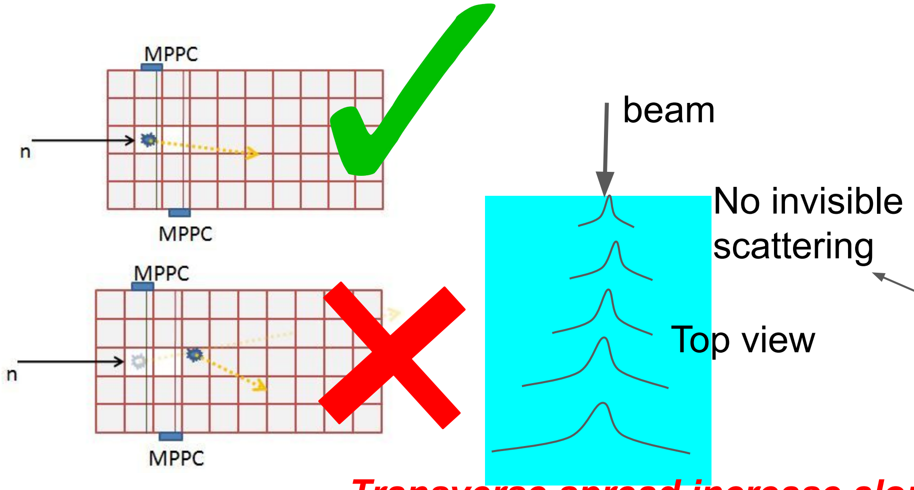
Re-emphasize:
Cube mis-alignment plays a big role:vertical shift of every 5 cube layers by 1 mm causes up 10% difference in event rate between Z layers

Relatively small contribution from MPPC type differences

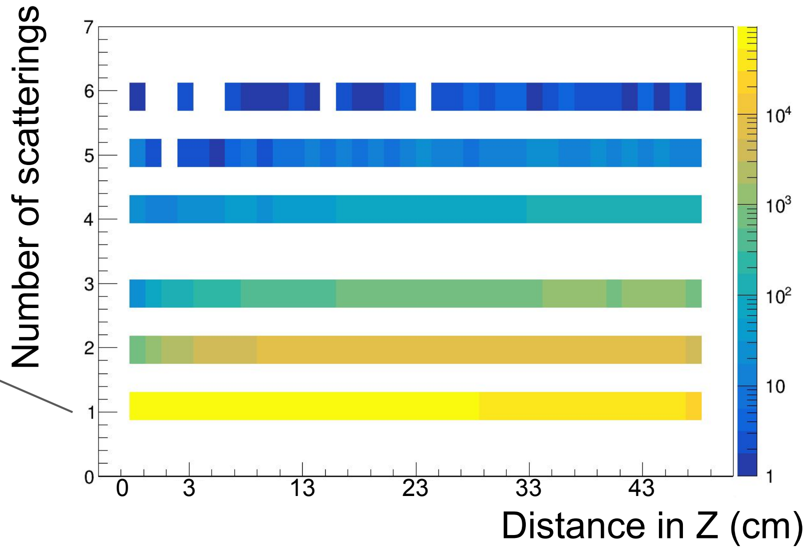


Major Systematics: Invisible scattering

What we want to measure:
neutron-induced single track as the first interaction => requiring no invisible scattering before the visible one



Simulation



Transverse spread increase along beam caused by invisible scattering

Major Systematics: Invisible scattering

Technote available
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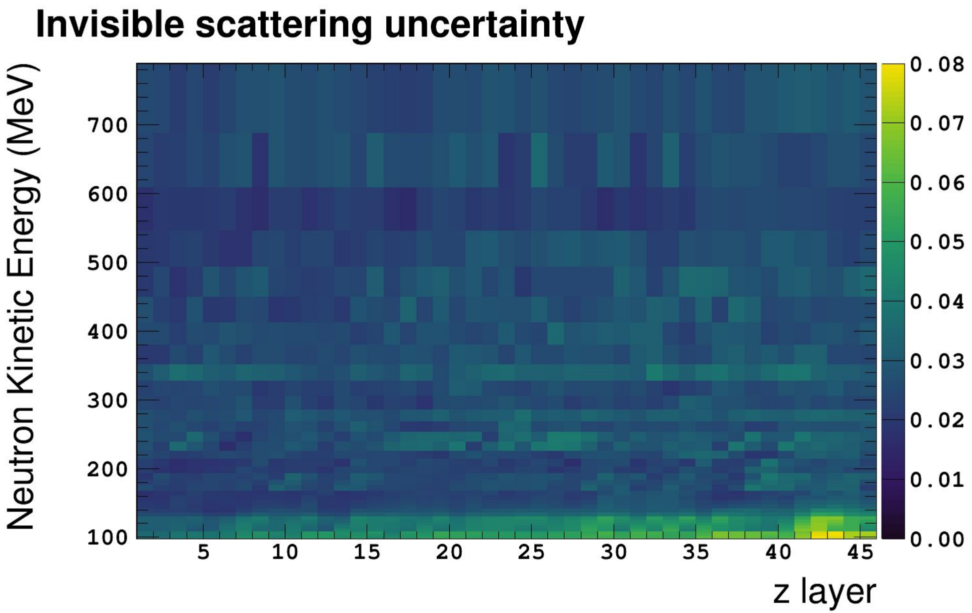
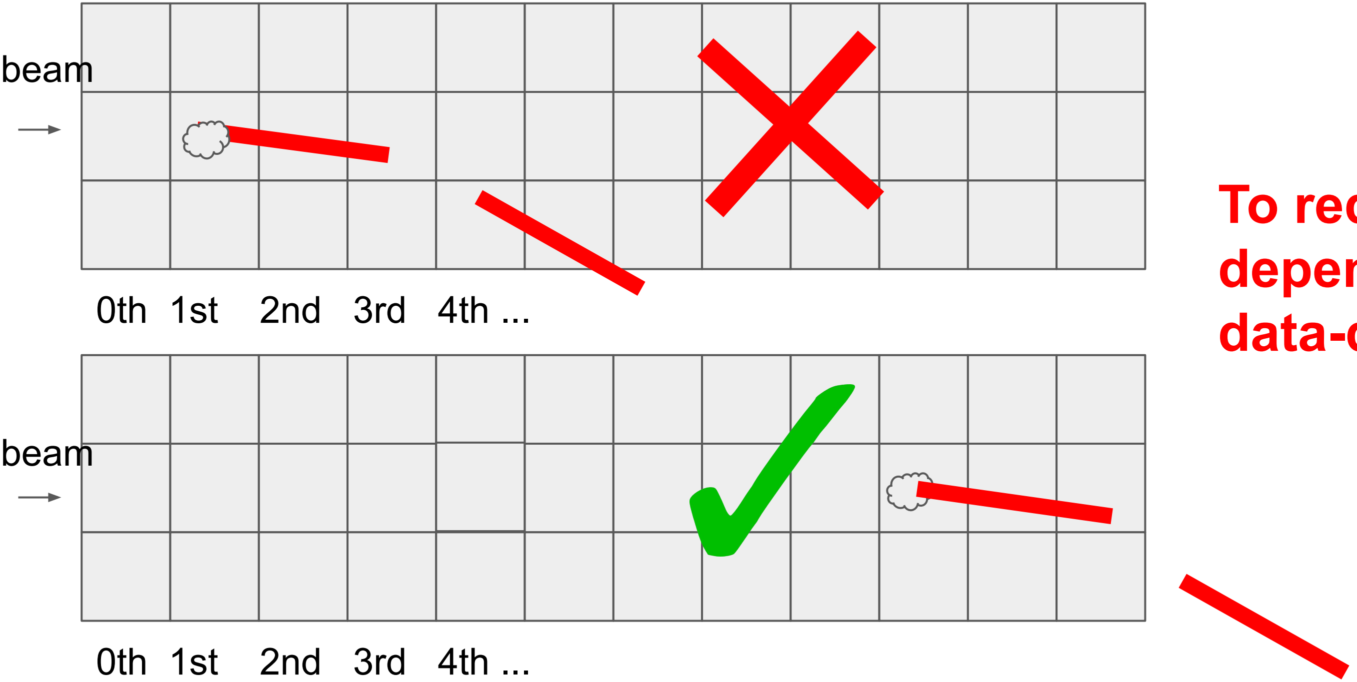
1. ***Tune MC transverse spread to data by weighting invisible scattering.***
2. ***Invisible scattering fraction can be extracted from the tuned MC -> It is taken as the systematic uncertainty.***



Mostly, a few percent of invisible scattering uncertainty for energy > 98 MeV is taken as systematic error.

Major Systematics: Geometric acceptance

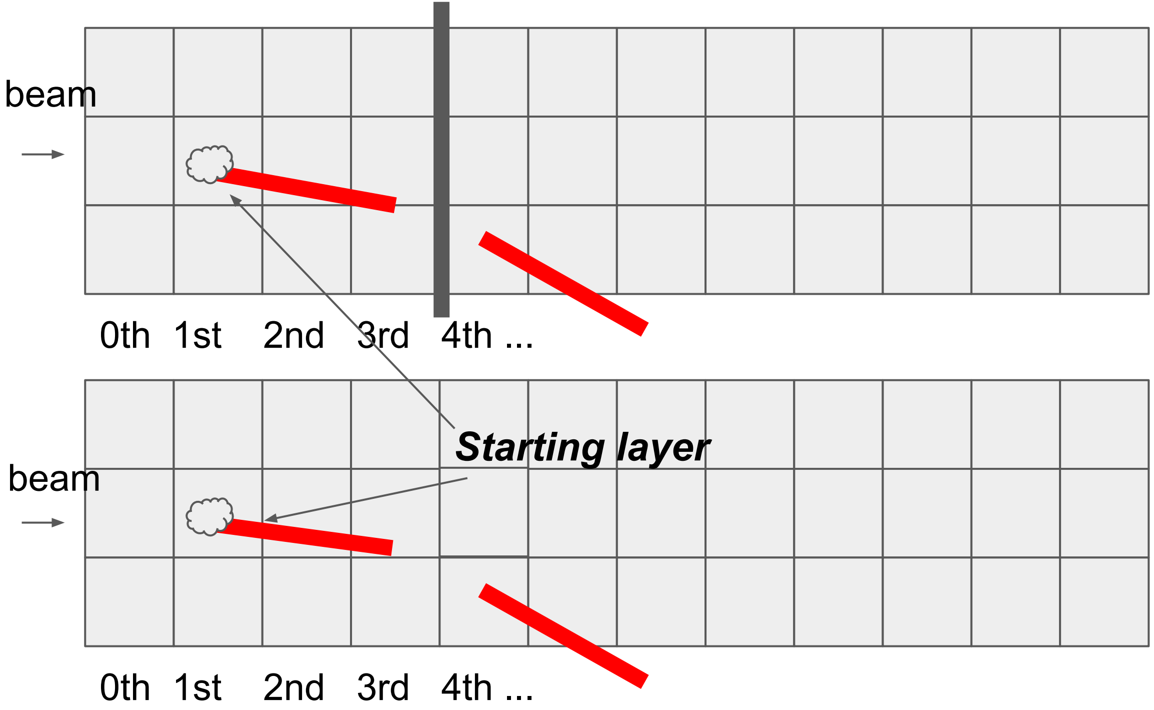
The same topology may have different selection acceptance depending its z location.

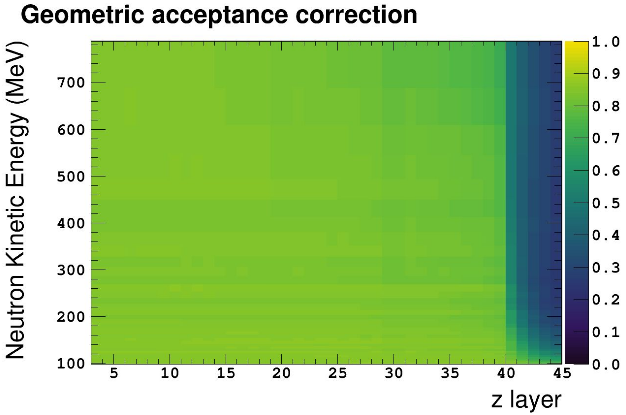


To reduce the model dependency, try to use a data-driven approach.

Major Systematics: Geometric acceptance

Shifting detector z boundary: Remove hit beyond layer m, m is from 47th, 46th to 1st.

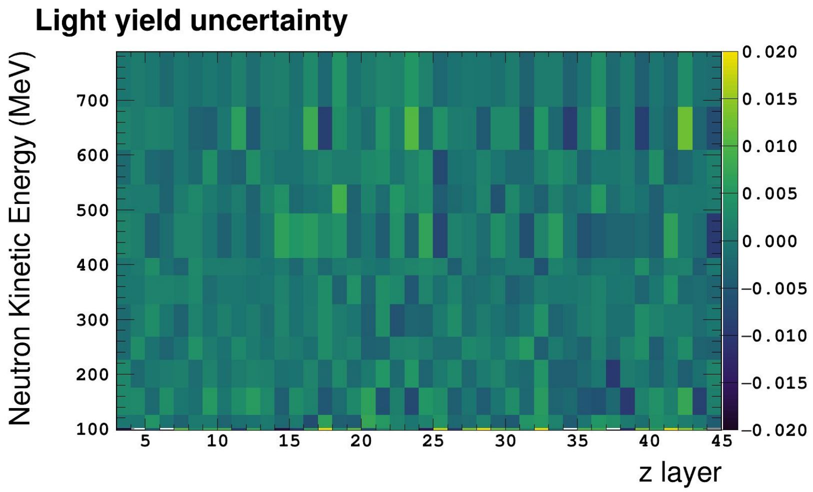


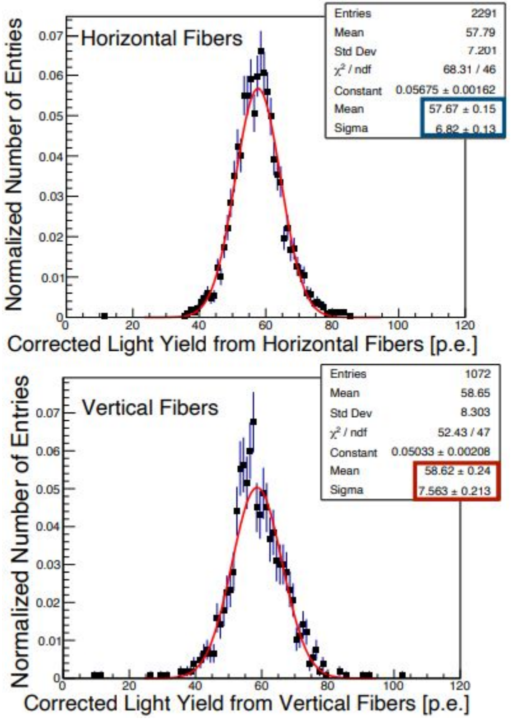


- Ratio between with and without boundary shows the acceptance change due to limited detector size!
- Used 2-8 layers as the starting layers and the variations among them is taken as systematics.

Light yield

Light yield obtained using cosmic data taken at LANL
Random fluctuation of light yield from nominal propagated
as the uncertainty of the event rate in each energy bin and layer



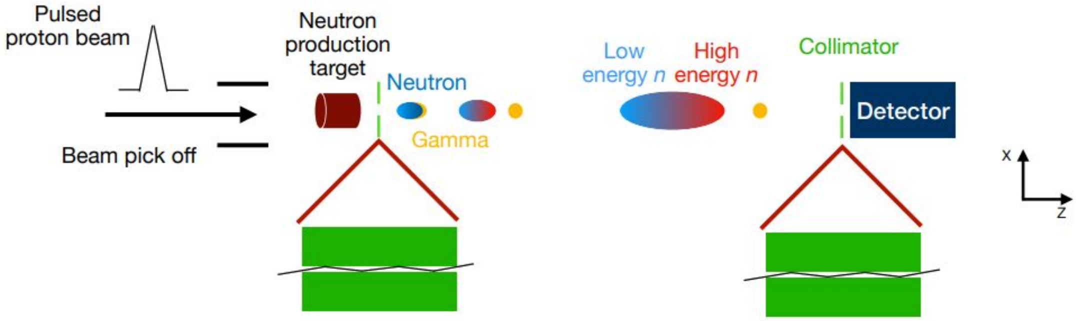


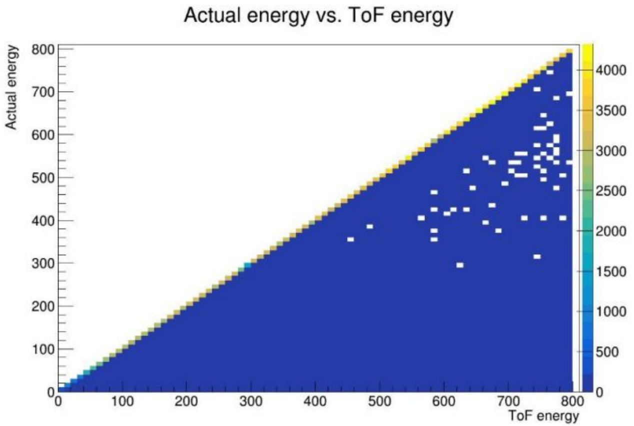
Collimator interaction

Multiple interactions inside the collimators

None of which interacts in first collimator arrive to the detector while the second can contribute to energy smearing (feed-down bias)

Smearing the neutron energy using MC estimations of the energy lost by neutrons showed minimal impact





Comments for the future measurements

Reduction of the total cross-section measurement uncertainty

- Alignment have to be measured with straight tracks along the beam direction. Muons seem to work but we may not have enough statistics -> worth trying though.

Possible major uncertainties for the two major measurements

- Exclusive cross section, fixing some layers and using event rate/flux to extract the cross section: the major uncertainty may be due to the PID. The detection systematic uncertainty, originated from cube misalignment should not present as a major uncertainty.
- Scattering angle measurement, fixing layers also: The statistics may be the main issue. The detection systematic uncertainty should not be a major background.

Comments for the future measurements

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Possible major uncertainties for the two major measurements

- **Exclusive cross section**, fixing some layers and using event rate/flux to extract the cross section: the major uncertainty may be due to the PID. The detection systematic uncertainty, originated from cube misalignment should not present as a major uncertainty.
- **Secondary scattering measurement**, fixing layers also: The statistics may be the main issue. The detection systematic uncertainty should not be a major background.

Comments for the future measurements

Reduction of the total cross-section measurement uncertainty

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Possible major uncertainties for the

Our hope for next USEFUL publications

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- **Secondary scattering measurement**, fixing layers also: The statistics may be the main issue. The detection systematic uncertainty should not be a major background.

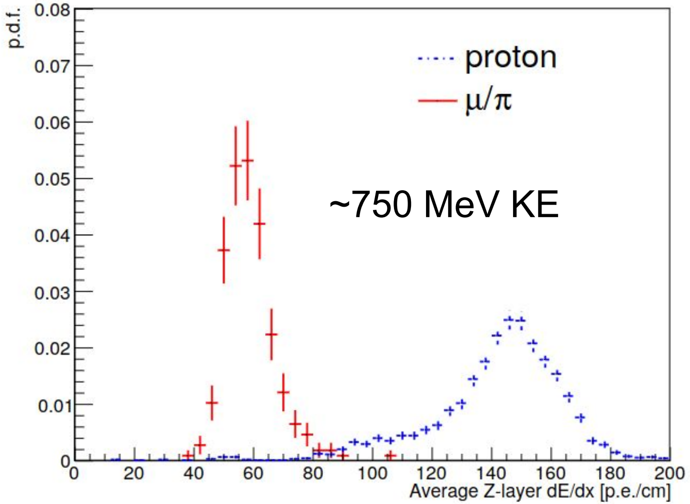
Exclusive cross section

PID systematic: at high energy (> a few hundreds of MeV) a few percent; at low energy (< ~100 MeV), can be as much as tens of percents.

Geometric acceptance: minor but accountable

Light yield, time resolution: take the existing systematic approaches-> same

Detection, invisible, collimator: negligible



Secondary scattering measurement

Geometric acceptance: major background as we are looking at the secondary interactions at the detector edge -> need effort to evaluate with MC, can be > 10% (data-MC neutron scattering discrepancy, only invisible can be a few percents).

Light yield, time resolution: take the existing systematic approaches-> same

Detection, invisible, collimator: negligible