Algorithm of reconstruction of neutron spectra with HGND

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Outlook

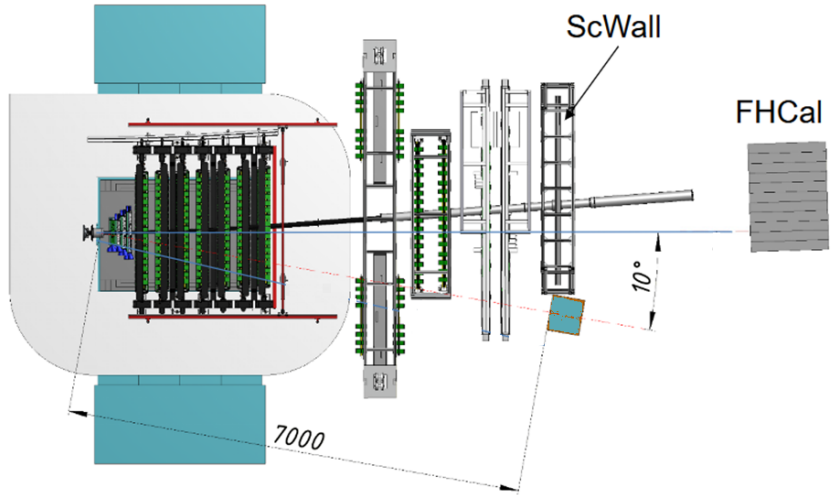
1. HGND
2. Analysis flow
3. Clusterization
4. Background subtraction
5. Spectrum corrections
   - Deconvolution
   - Efficiency correction
6. Conclusions

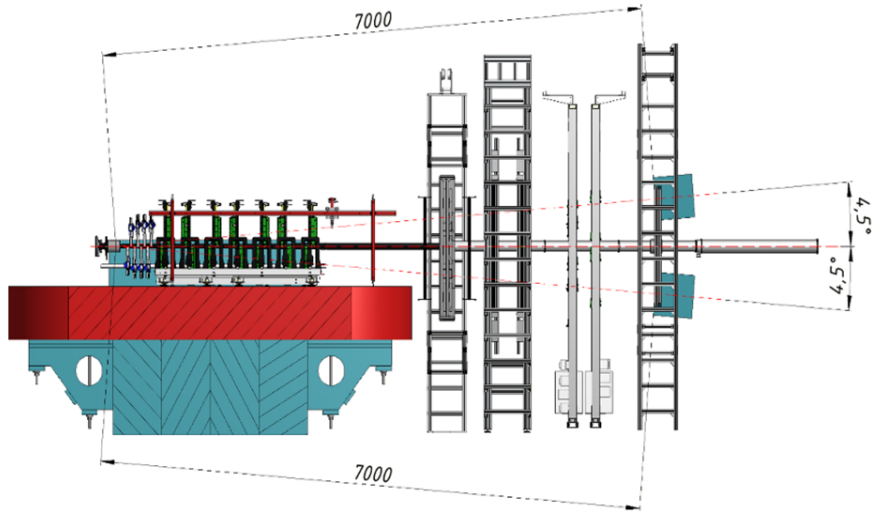
MC Simulation

In order to develop and check the algorithm of neutron identification the MC simulation was performed

Simulation parameters

- Xe+Cs at $\sqrt{s} = 3.26 \cdot A$ GeV
- 500 000 events
- DCM-QGSM-SMM model
- Full BM@N geometry

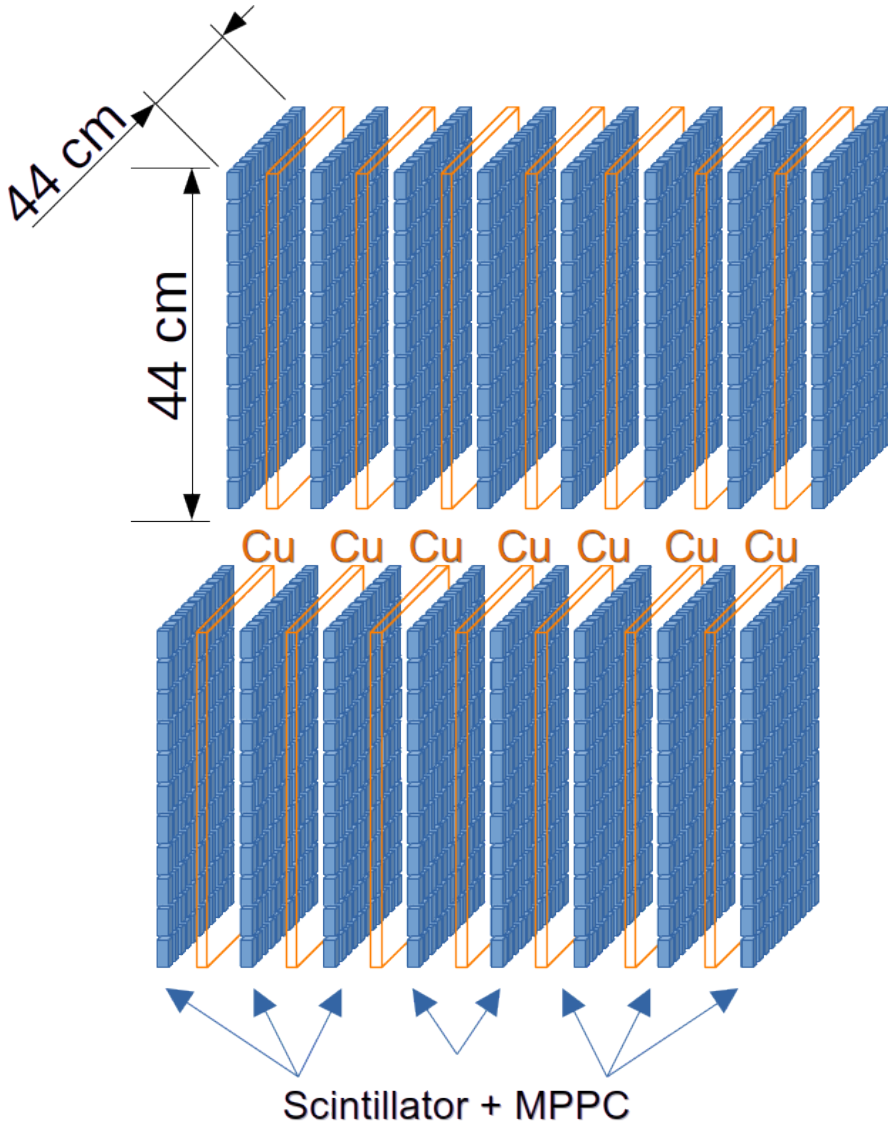




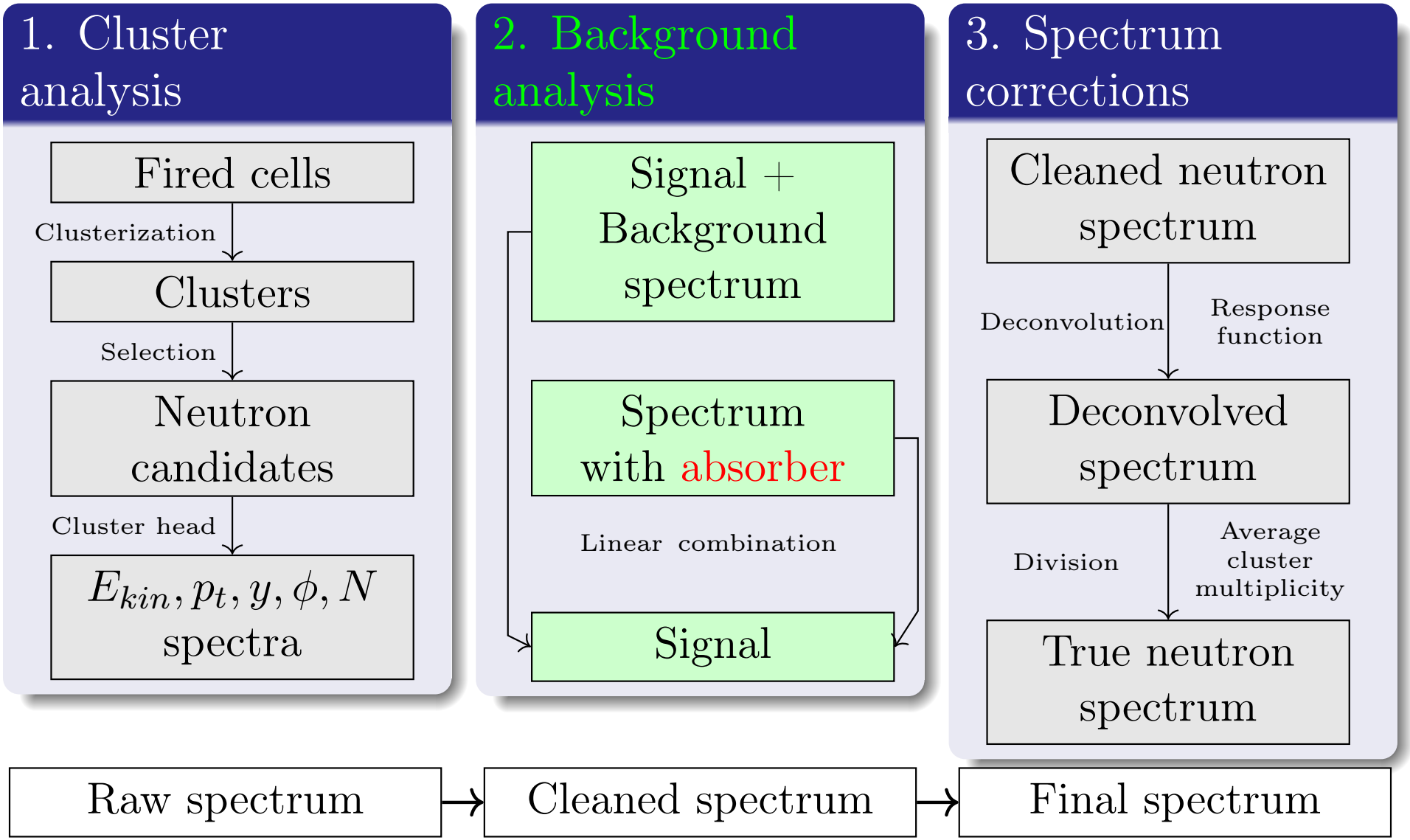
HGND configuration

HGND parameters in simulation

- Two arms mode
- 8 layers of scintillator 11x11 cells
- 7 layers of Cu convertor in between of scintillator layers
- Time resolution 130ps



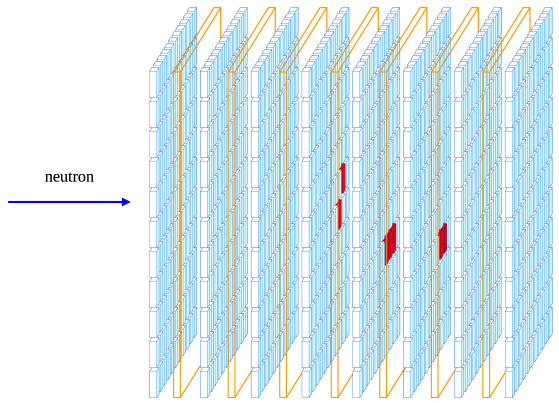
Analysis flow



Cluster analysis

Algorithm

1. Select cells with $E_{kin} > 3MeV$ (noise rejection)
2. Merge neighboring cells into clusters
3. Calculate $\beta = \frac{1}{c} d/t$ for each cell; the cell with the highest β is labeled as the cluster "head"
4. Apply selection criteria



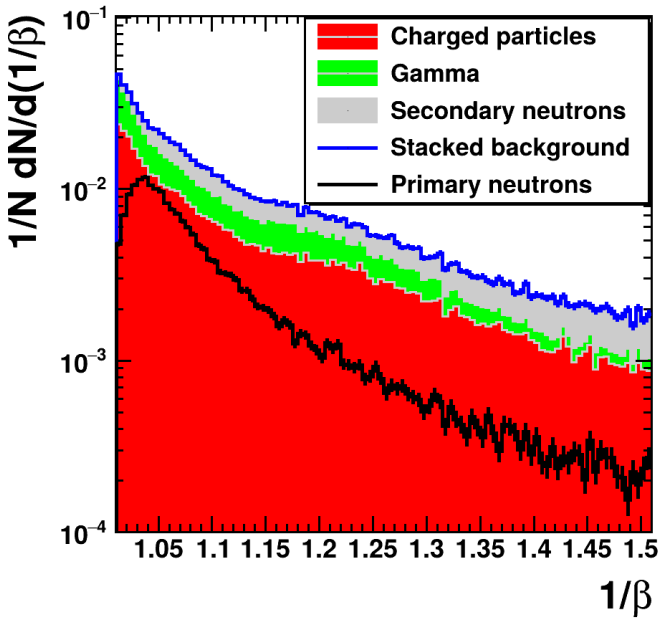
Selection criteria

- No hit in layer 0 (charged particles rejection)
- No hit in layer 1 (γ rejection)
- $\beta < 0.9$ (fast e^+, e^-, γ rejection)
- $T_{reconstructed} > 300$ MeV (secondary neutrons suppression)
- Cluster size $N_{cells} \geq 2$

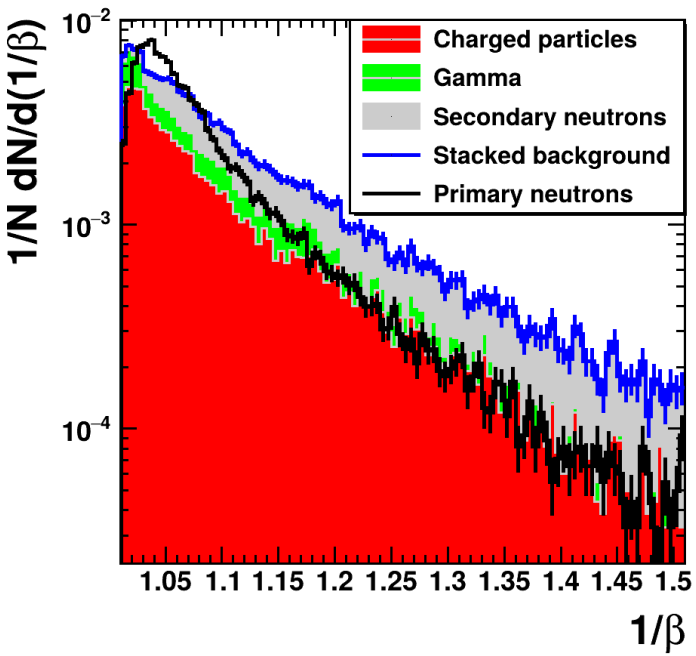
Suppression of the background with cluster selection

The number of the **background particles** producing a hit in HGND is much higher than the number of **neutrons** with a hit.

Before selection



After selection



Cluster selection improves S/B ratio ~ 10 times.

After all cuts background remains comparable to signal

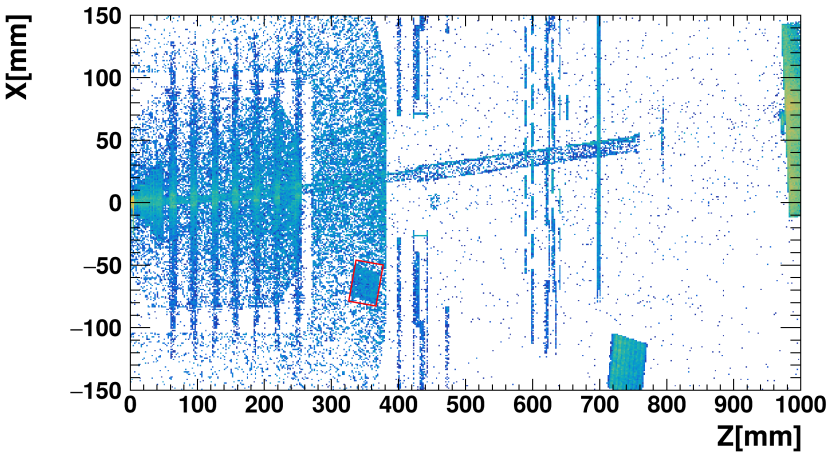
$1/\beta \sim TOF$ (time of flight) – the main value measured by the HGND

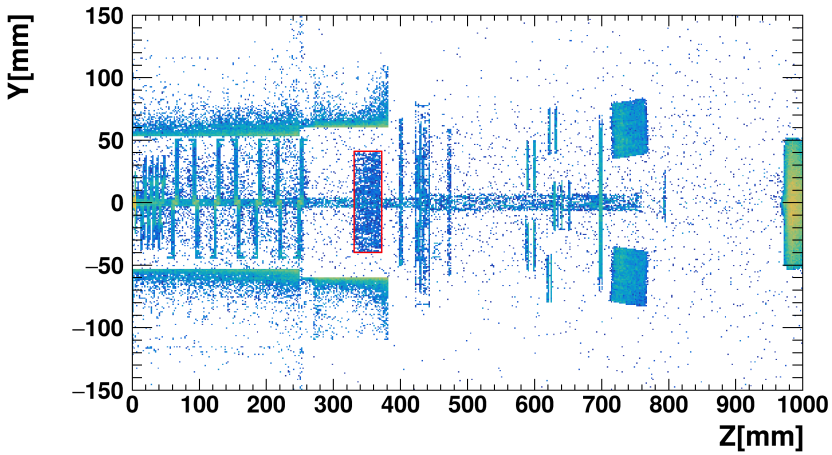
Usage of plastic absorber for subtraction of the background

Special run with absorber is suggested:

- Xe+Cs at $\sqrt{s} = 3.26 \cdot A$ GeV
- 500 000 events
- DCM-QGSM-SMM model
- Full BM@N geometry

- plastic absorber, 40 cm thik
- 320 cm from target, in between of target and HGND



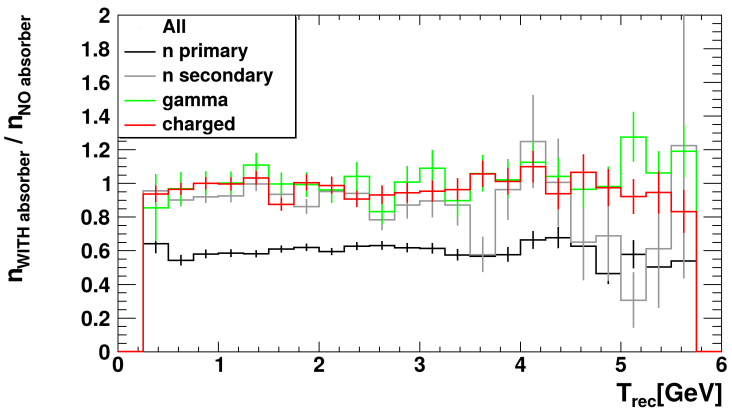


Absorber impact on signal and background

Signal - intact primary neutrons from target
Background - scatterred and produced in material neutrons, charged particles, photons

Spectrum without absorber

$N_{NOAbs} = N_S + N_B$



Spectrum with absorber

$N_{Abs} = k_S \cdot N_S + k_B \cdot N_B$

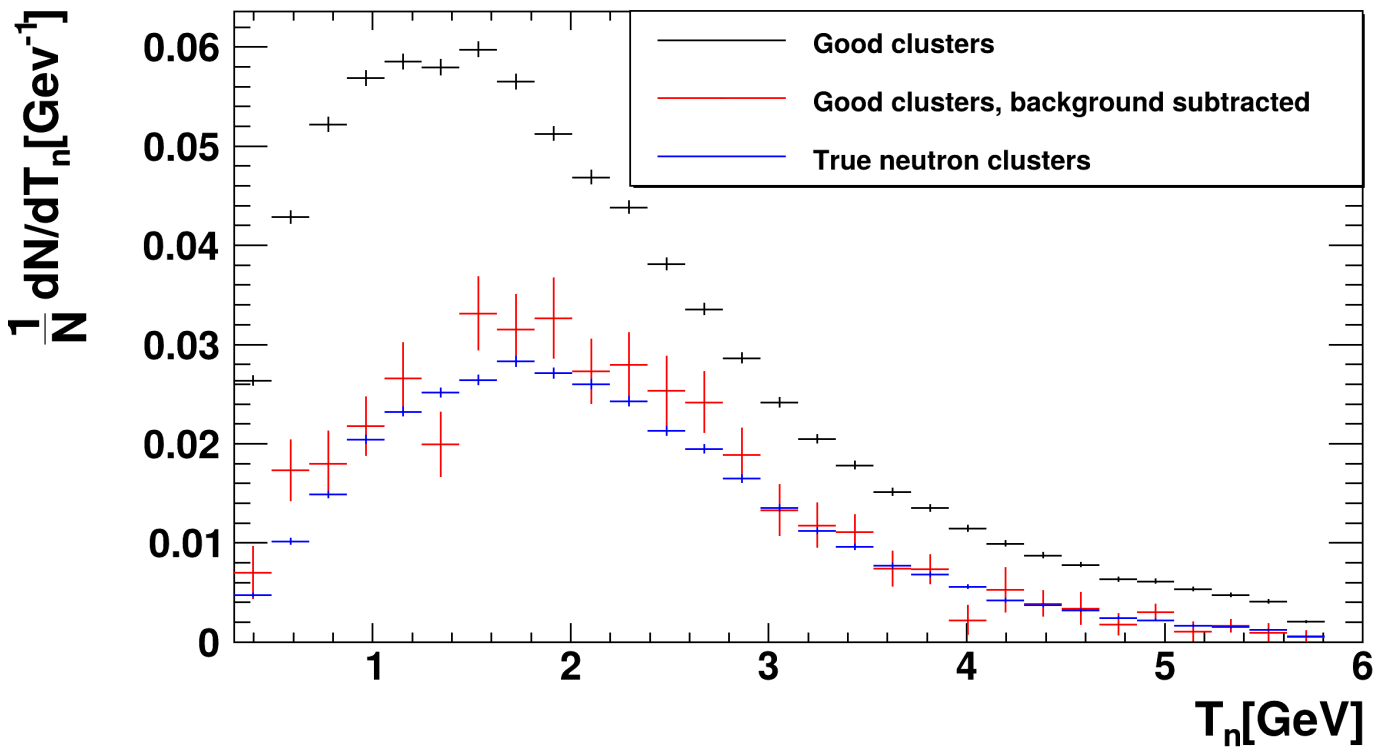
Background
$k_B \simeq 1$
Absorber doesn't affect backgroung

Signal
$k_S \simeq 0.6$
Absorber reduces flux of primary neutrons

Background subtraction

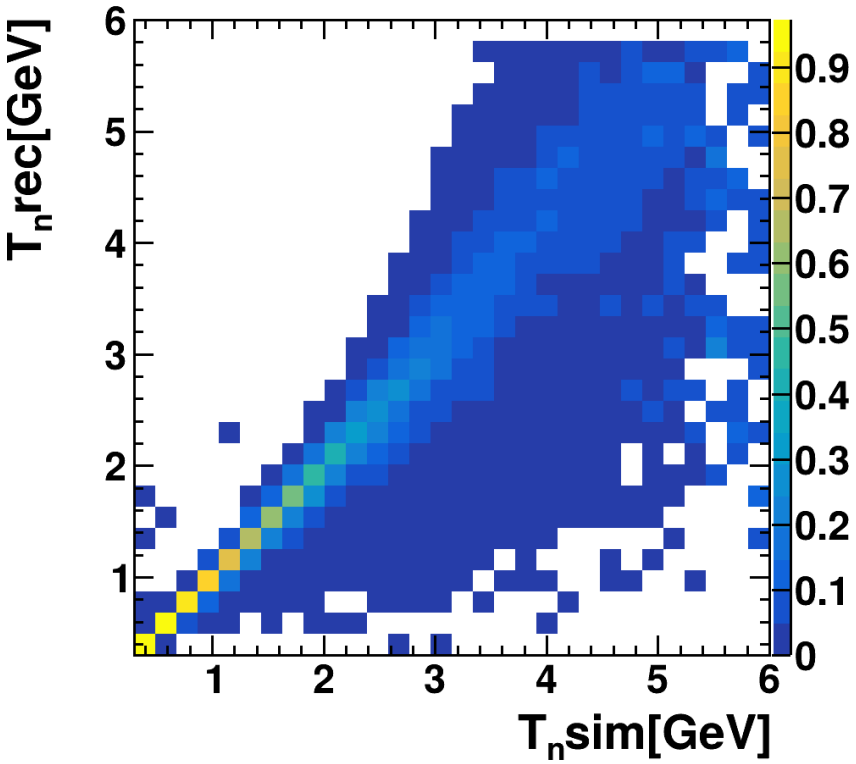
Linear combination of spectra with absorber and without absorber gives pure signal

$$N_S = \frac{N_{\text{NO abs}} - N_{Abs}}{1 - k_S}$$



Deconvolution

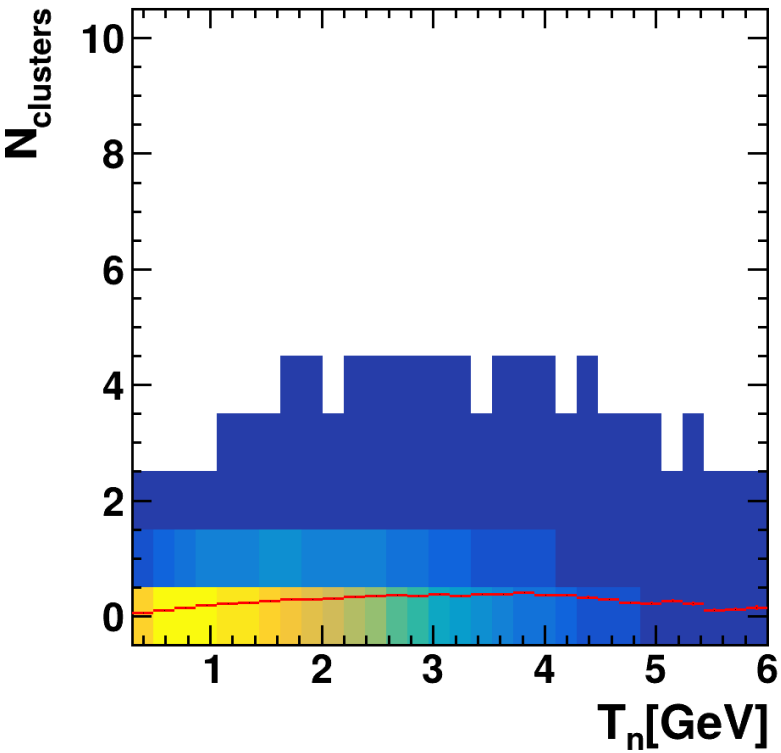
Response function for primary neutrons



The **Richardson-Lucy** algorithm deconvolves spectrum using known response function

Efficiency correction

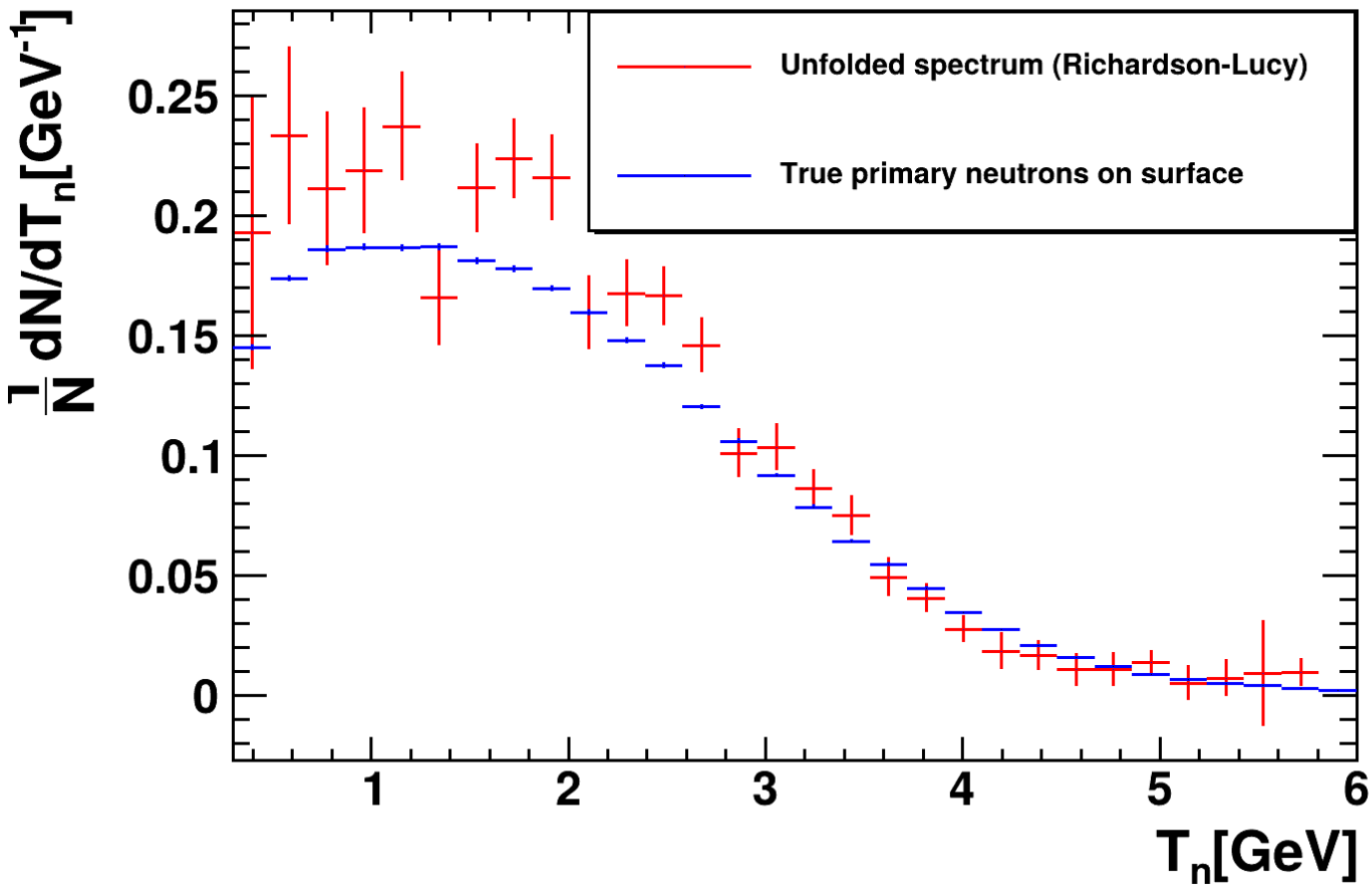
Number of clusters produced by a neutron



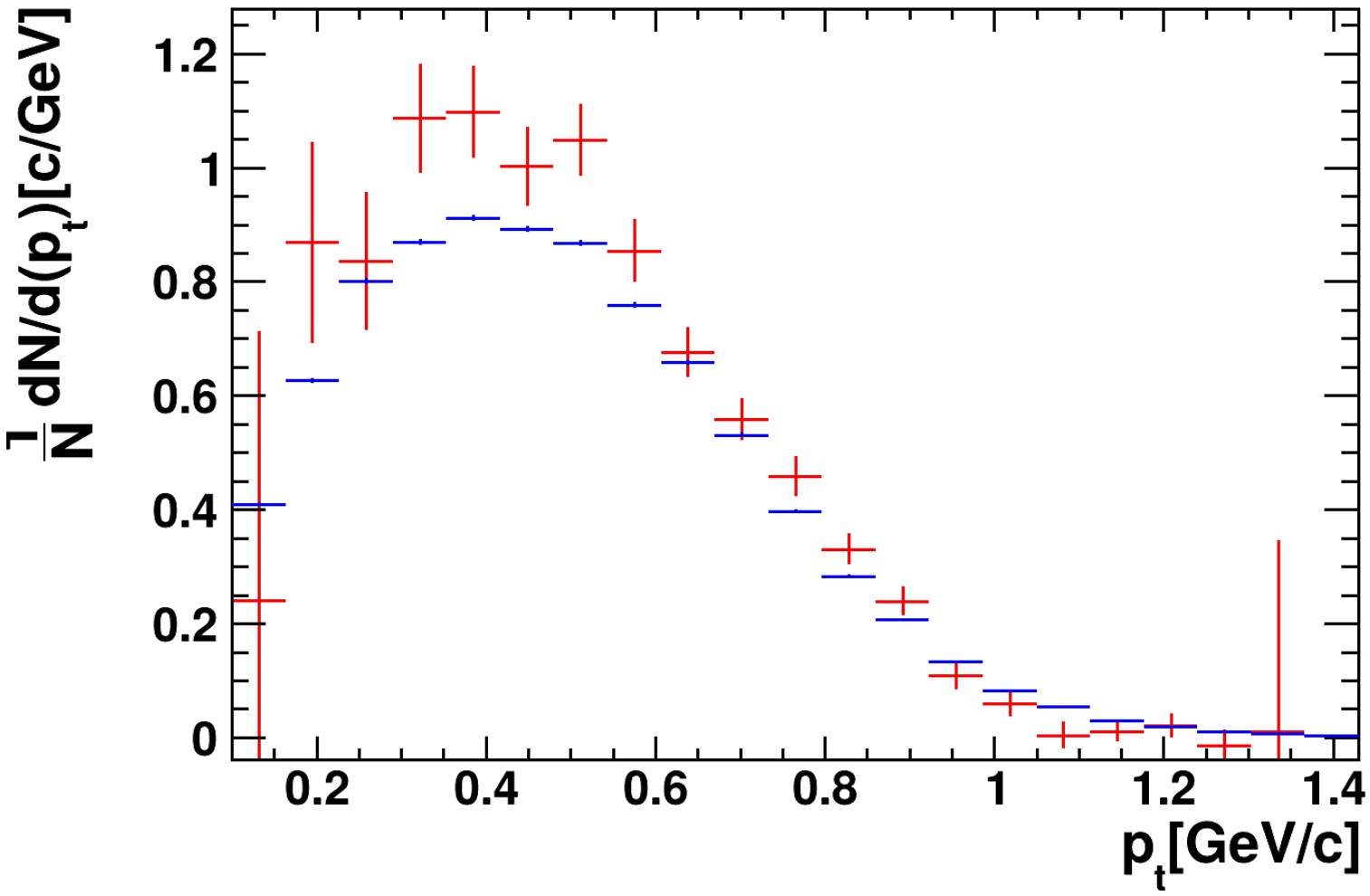
The spectrum must be divided by the average number of clusters per neutron

$$N_{true} = \frac{N_{measured}}{\langle N_{clusters} \rangle}$$

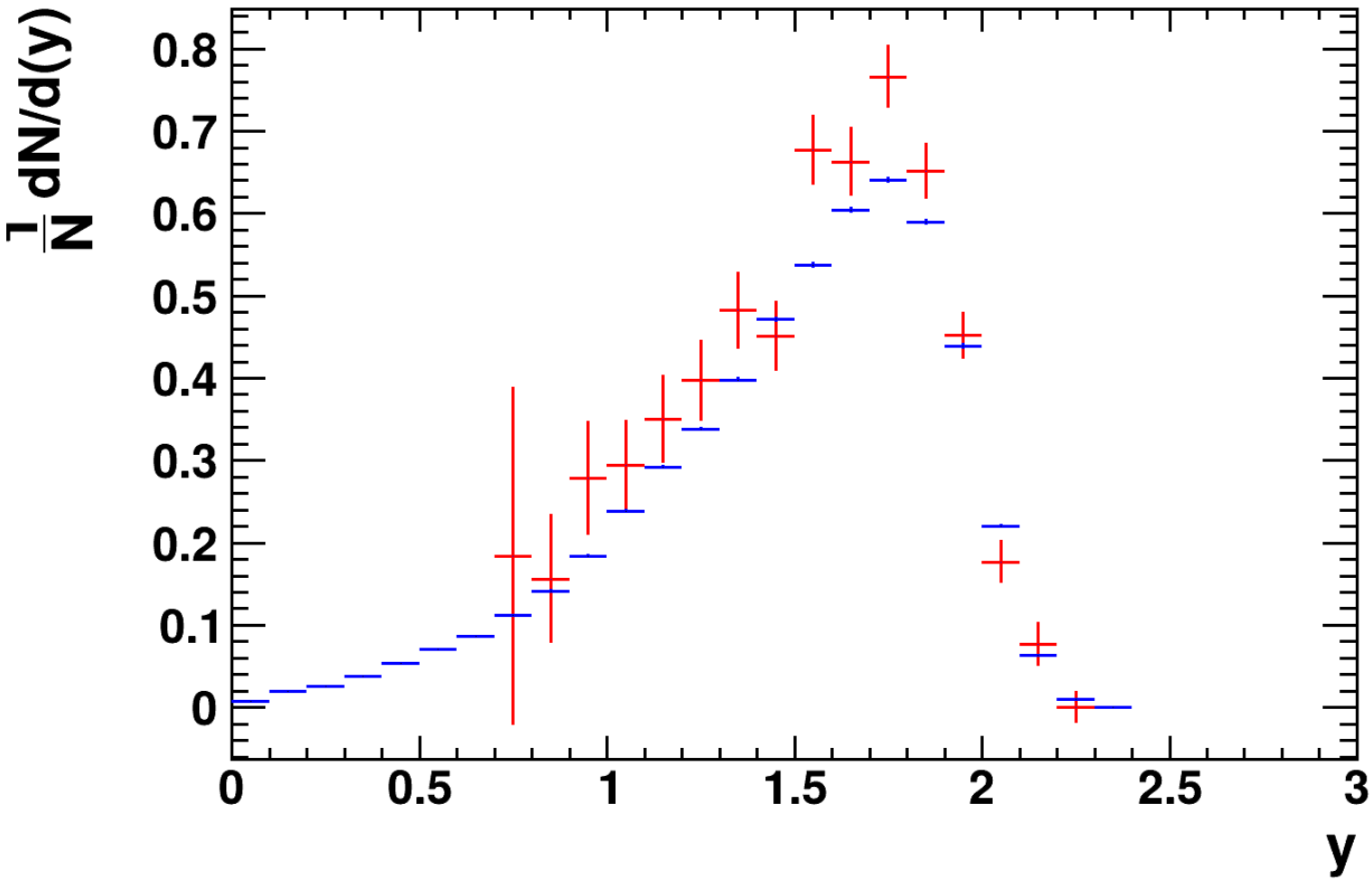
Kinetic energy



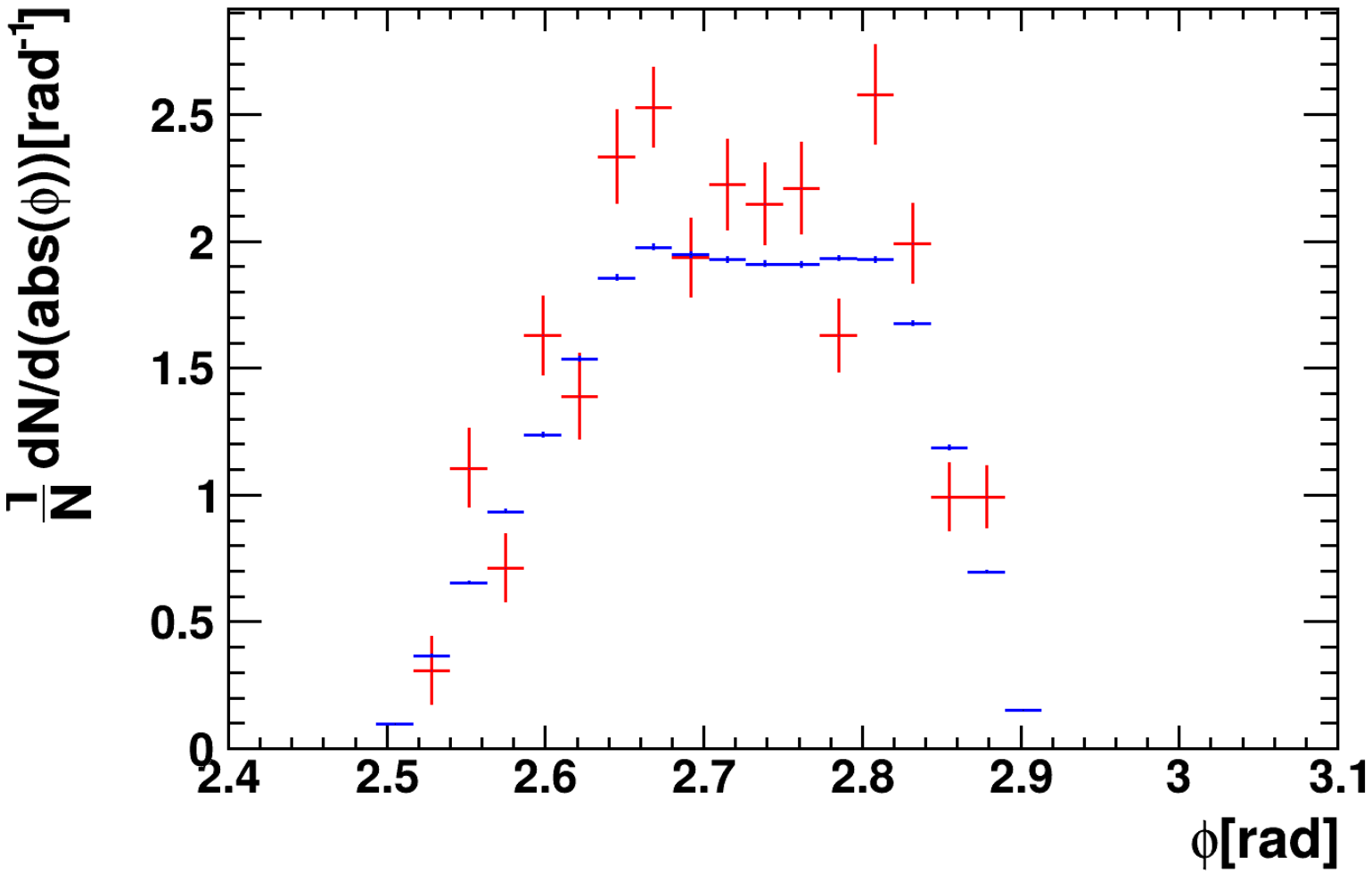
Transverse momentum



Rapidity



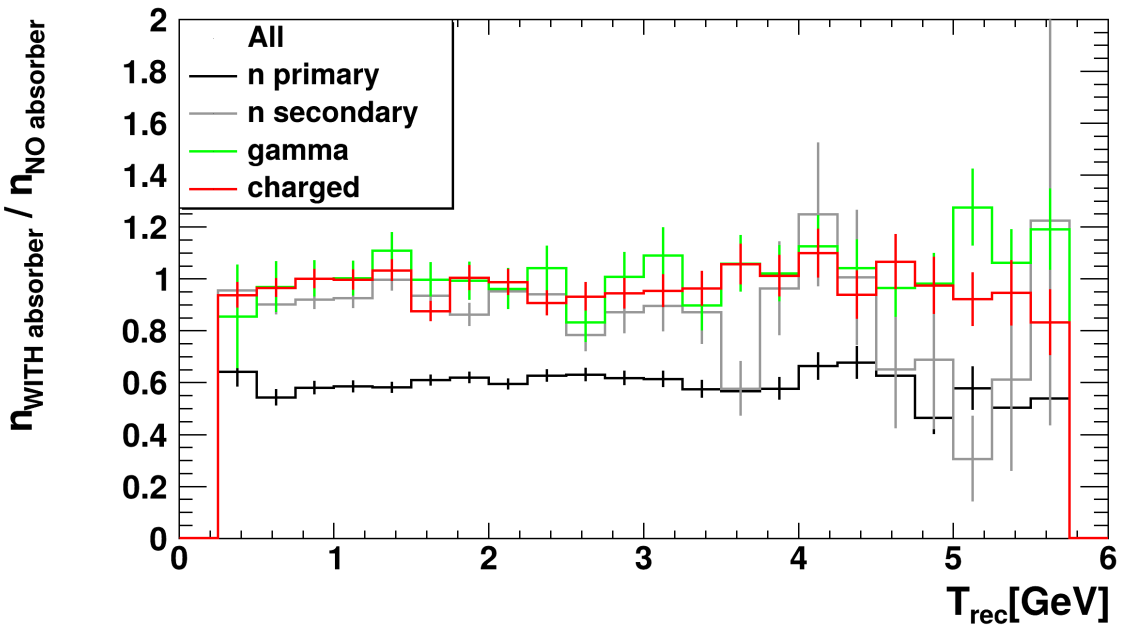
Azimuthal angle



Systematic error due to background subtraction

$$N_S = \frac{N_{\text{NO abs}} - N_{Abs} - N_B \cdot (1 - k_B)}{1 - k_S}$$

$$\left.\begin{array}{l} N_B \simeq N_S \\ k_B \simeq 0.95 \\ 1 - k_S \simeq 0.4 \end{array}\right\} \rightarrow \Delta N_S \simeq +10\%$$



Conclusions

- The algorithm of neutron reconstruction in presense of high background has been developed
- The algorithm includes:
  1. cluster analysis
  2. background rejection
  3. detector response compensation
- Background rejection procedure has been developed. It includes:
  1. measurement of spectrum with plastic absorber
  2. measurement of spectrum without absorber
  3. recalculation of spectrum
- Systematic error due to background subtraction procedure $\Delta N \simeq +10\%$

End

Thank you for your attention!

Problem

- True energy: E
- Measured energy: E'
- True spectrum: $f(E)$
- Measured spectrum: $g(E')$
- Response function: $R(E'|E)$
- Probability of n clusters: $P(n|E)$

$$g(E') = \int n \cdot P(n|E) \cdot R(E'|E) \cdot f(E)\, dE = \langle n \rangle_E \cdot R(E'|E) \cdot f(E)$$

Solution

$$f_{\text{weighted}}(E) = \langle n \rangle_E \cdot f(E)$$

$$g(E') = \int R(E'|E) \cdot f_{\text{weighted}}(E)\, dE$$

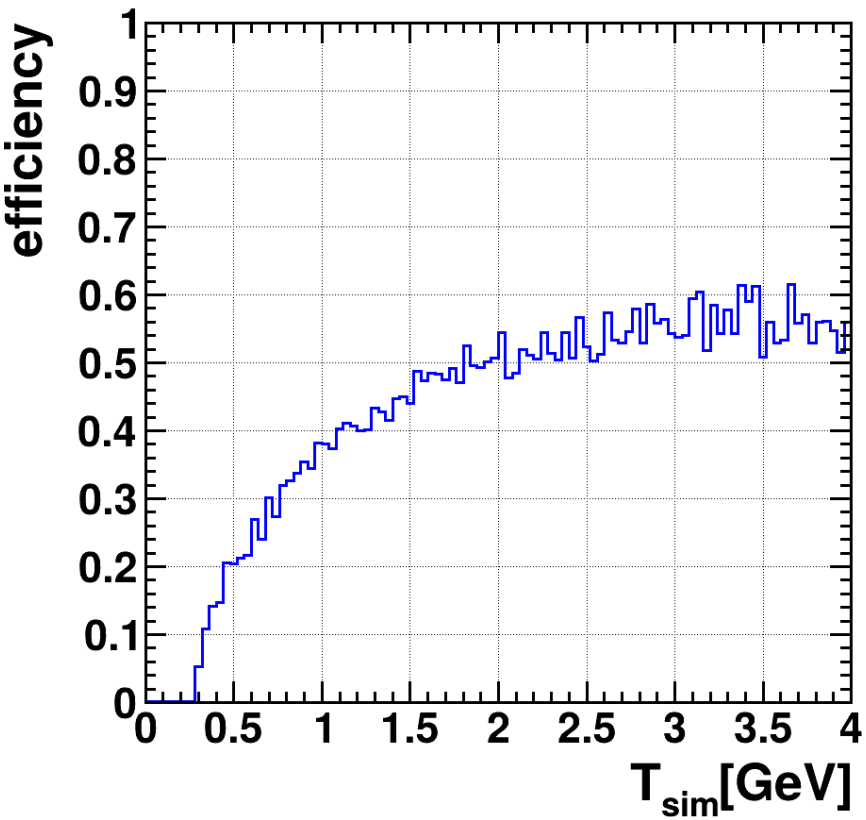
$$f_{\text{weighted}}(E) = \text{Unfolding(}\ \text{g(E')},\ \text{R(E'}\mid\text{E)}\ \text{)}$$

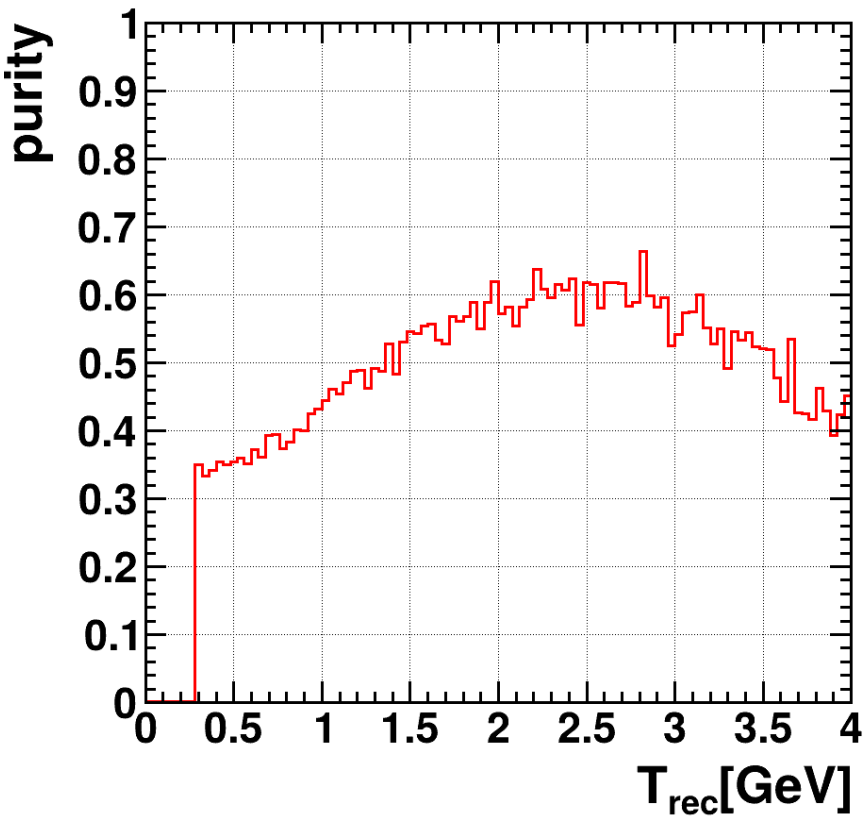
$$f(E) = \frac{f_{\text{weighted}}(E)}{\langle n \rangle_E}$$

Reconstruction Quality

Performance Metrics

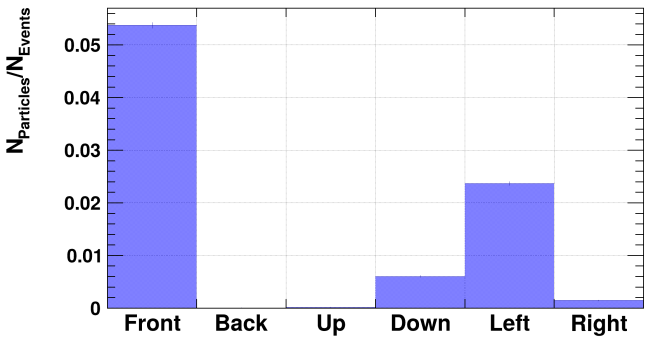
$$\text{Efficiency} = \frac{N_{\text{neutron match}}}{N_{\text{neutrons}}} \qquad \text{Purity} = \frac{N_{\text{cluster match}}}{N_{\text{clusters}}}$$

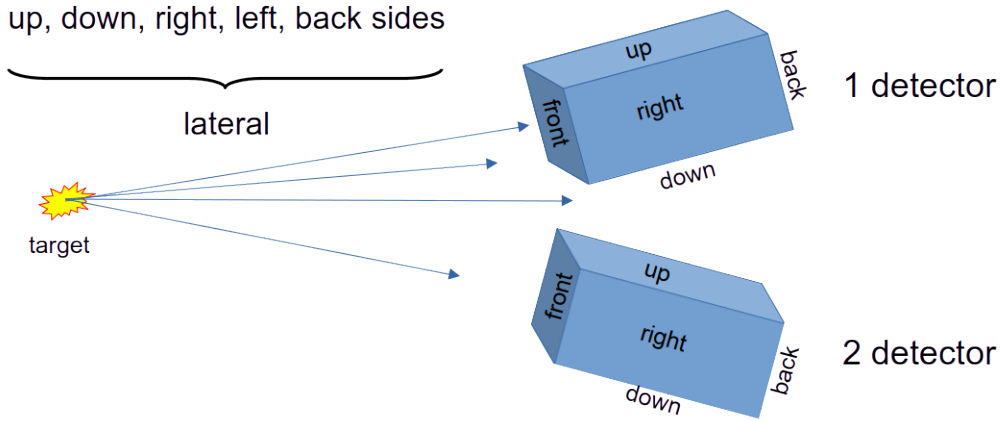




Charged particles

Charged particles produce clusters despite veto applied. Where do they come from?

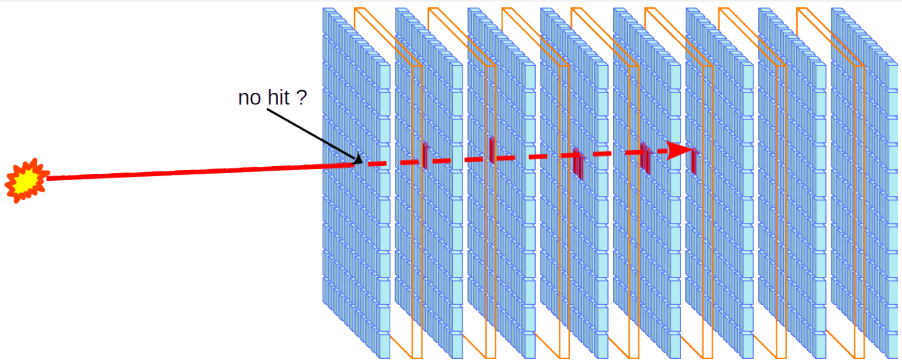




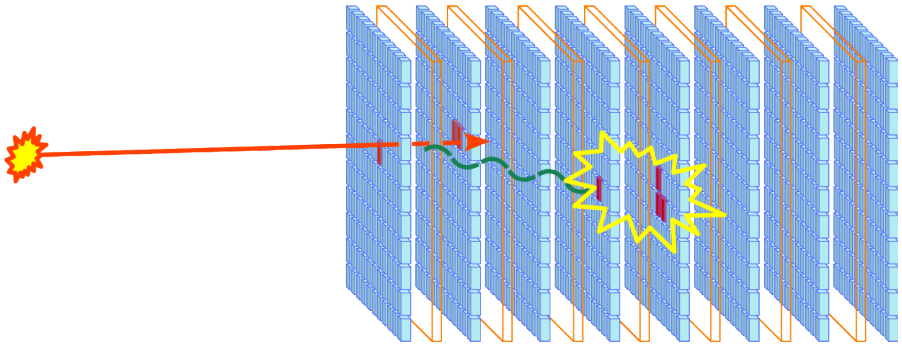
1. Charged particles come through lateral sides
2. Charged particles produce secondary clusters

Reasons of inefficiency of cuts

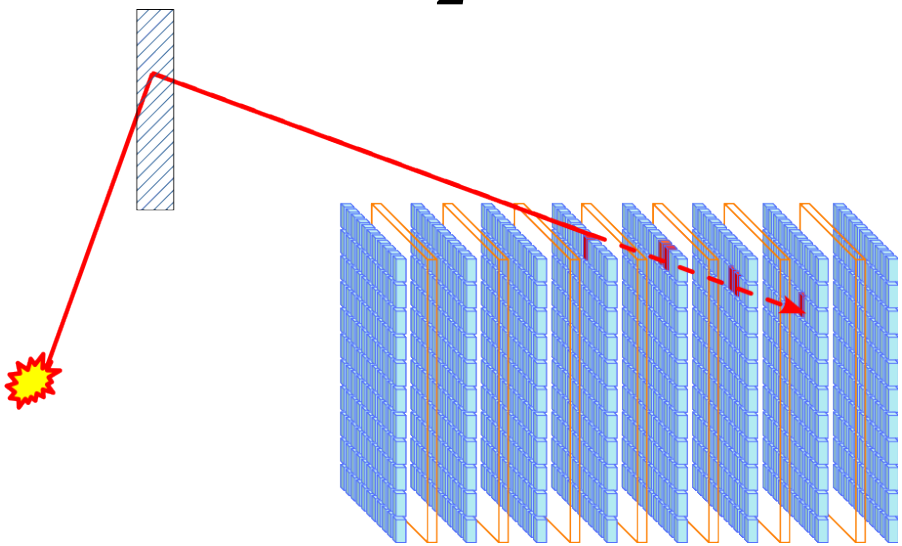
1. No hit in veto
2. Secondary cluster
3. Lateral hit



1

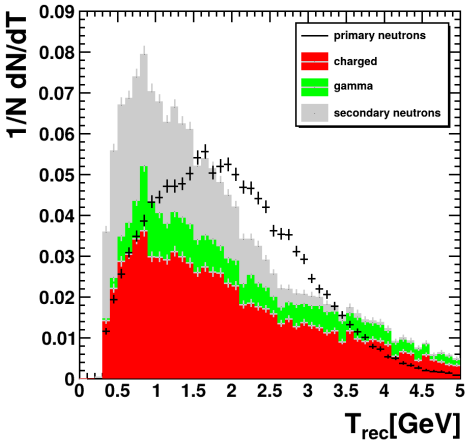


2

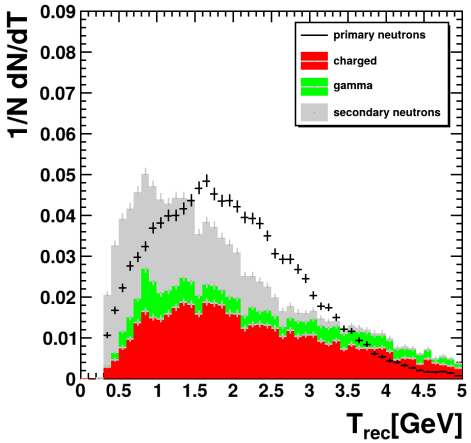


3

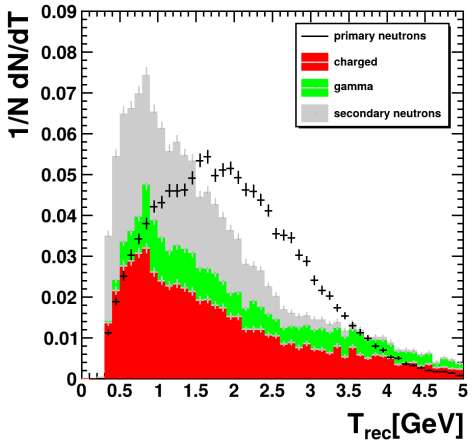
Background after additional cuts



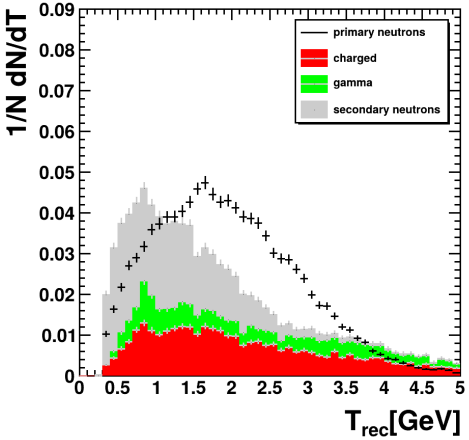
Basic selection



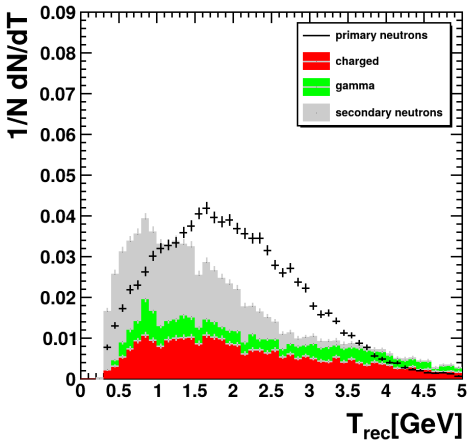
Border cut



Veto coincidence check



Border cut & veto coincidence check



Best cluster

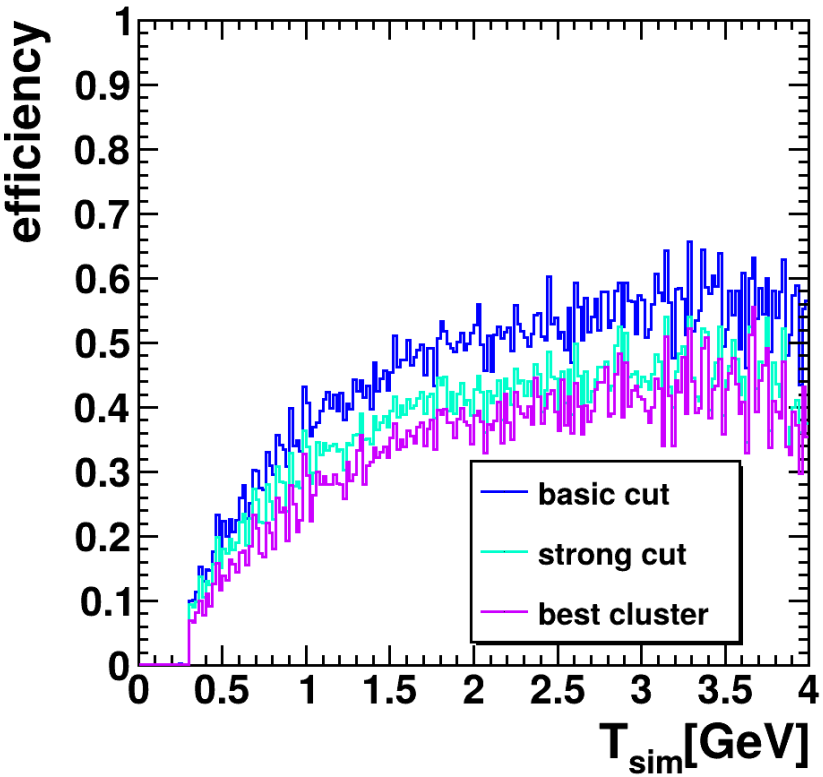
Background composition

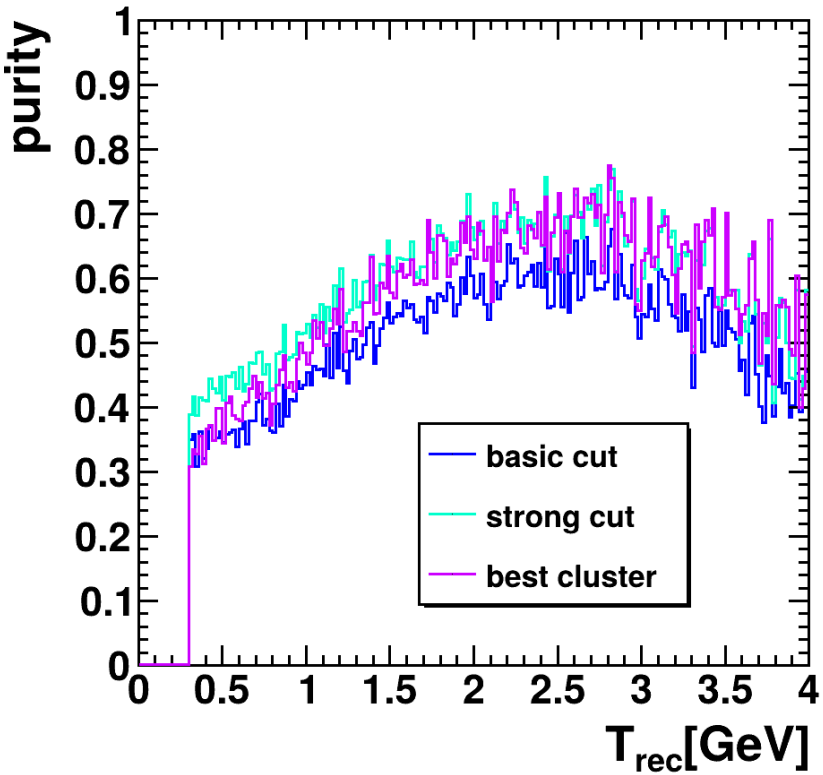
- Charged particles
- Gamma
- Secondary neutrons
- Primary neutrons

Quality after new cuts

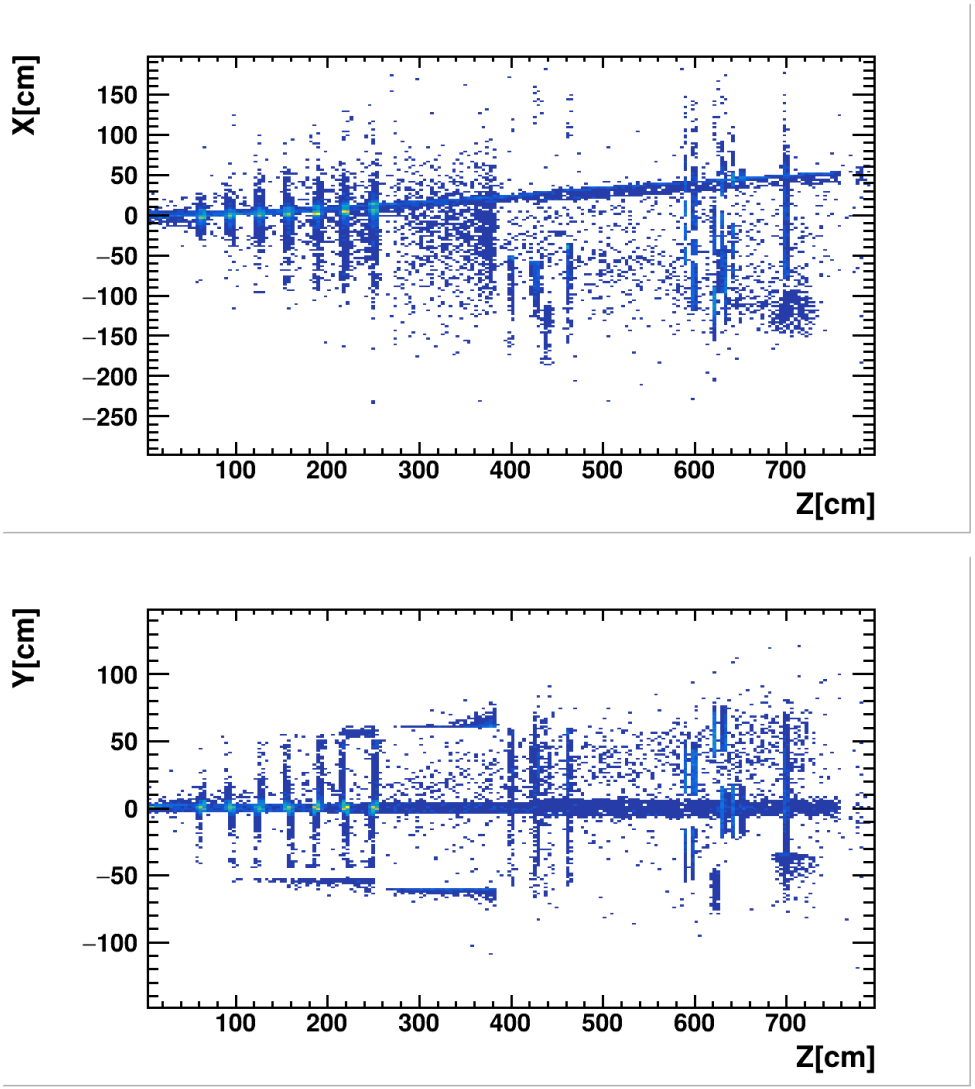
Additional strict criteria improve purity but reduce efficiency. Strong cut:

- Border cell rejection
- Veto layer coincidence check

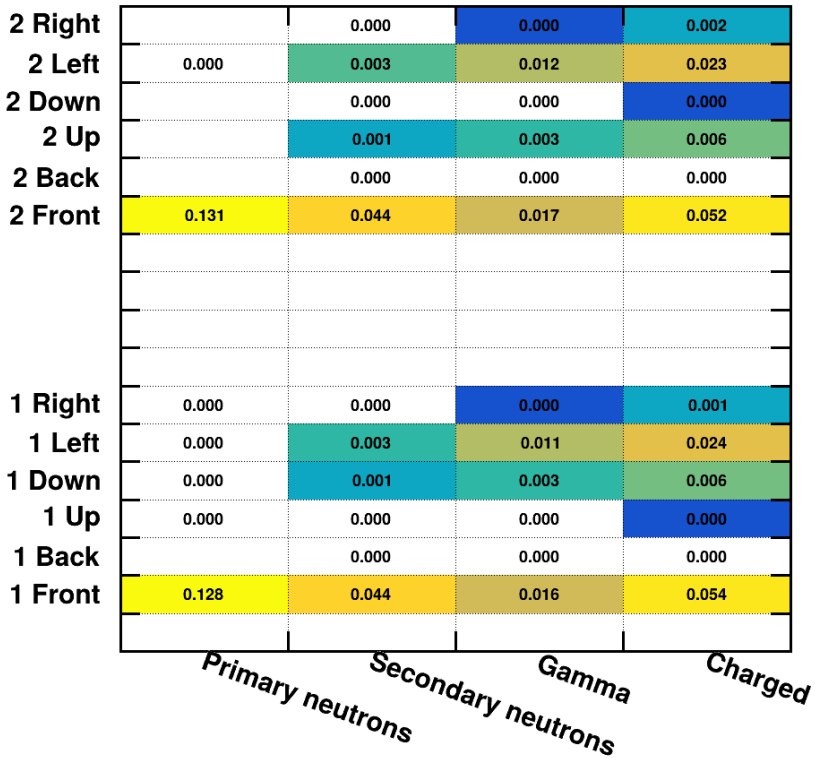




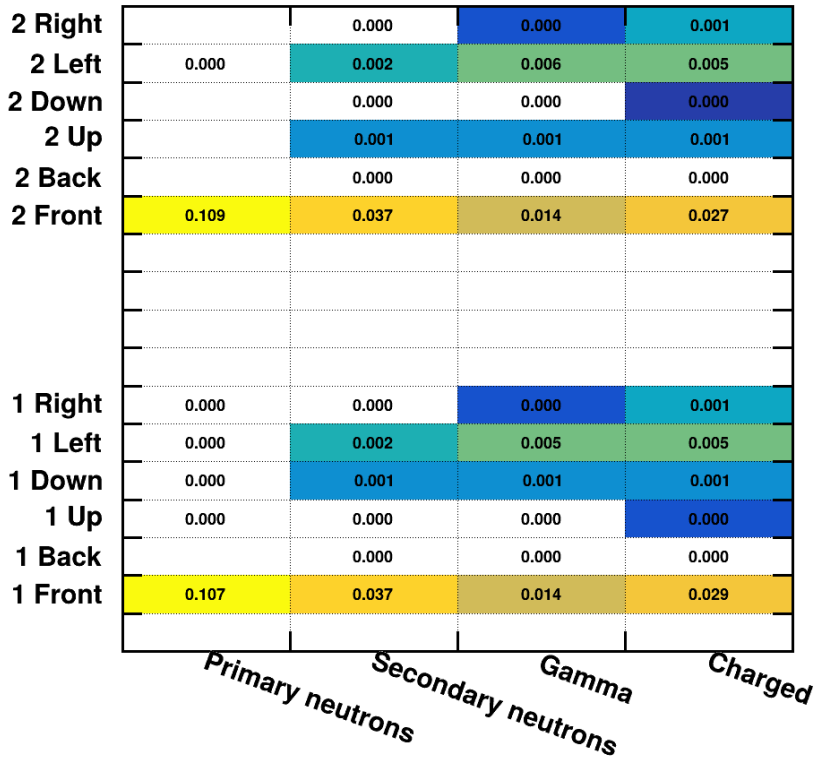
Background sources



Detector side vs. particle species



Basic selection



Border cut