Development of the method of reconstruction of neutron energy spectrum with HGND in the BM@N experiment

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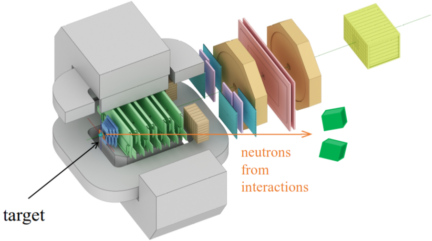
Outlook

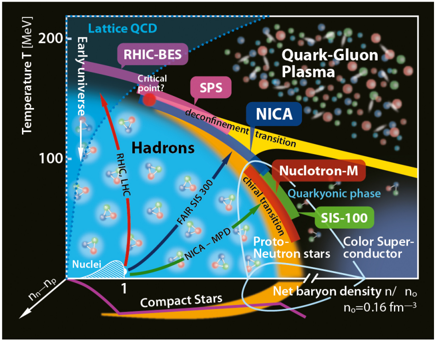
Baryonic Matter at Nuclotron

- Fixed target heavy-ion experiment at Nuclotron in Dubna, Russia
- Beam energy $2 - 6 \cdot A$ GeV
    - Study of hadronic matter at high baryonic densities



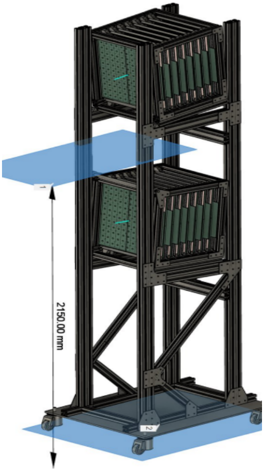
Physical motivation

- Need to study isospin degree of freedom of baryonic matter equation of state
- Neutrons are sensitive to isospin
- Absence of data on neutron yields at $1 - 10 \cdot A$ GeV



Highly Granular Neutron Detector

- New time-of-flight detector for measurements of neutrons with kinetic energy $T_n \lesssim 4$ GeV
- Alternating plastic scintillator/copper layers
- MPPC directly connected to scintillators
- Time resolution $\sim 150ps$
- High granularity enables precise neutron tracking

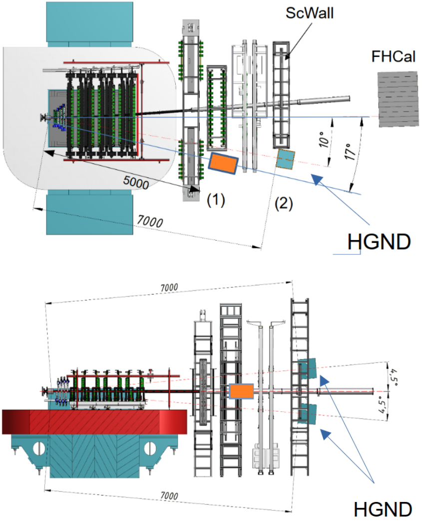


MC Simulation

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

Simulation parameters

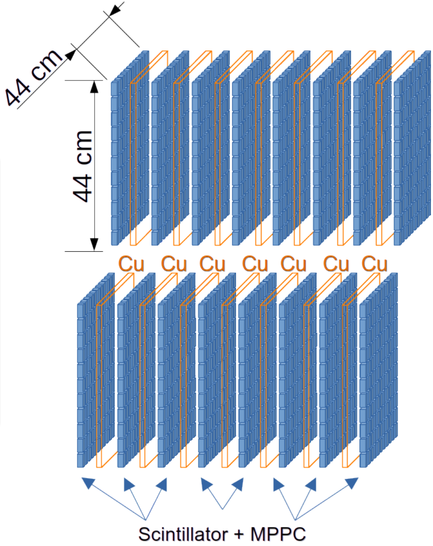
- Bi+Bi at $3 \cdot A$ GeV
- 200 000 events
- DCM-QGSM-SMM model
- Full BM@N geometry



HGND configuration

HGND parameters in simulation

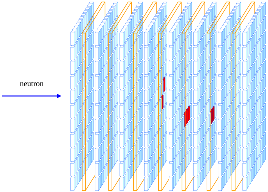
- Two parts mode
- 8 layers of scintillator 11x11 cells
- 7 layers of Cu convertor in between of scintillator layers
- Time resolution 130ps



Clustering method

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



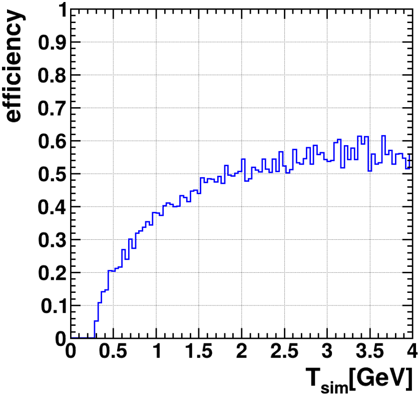
Selection criteria

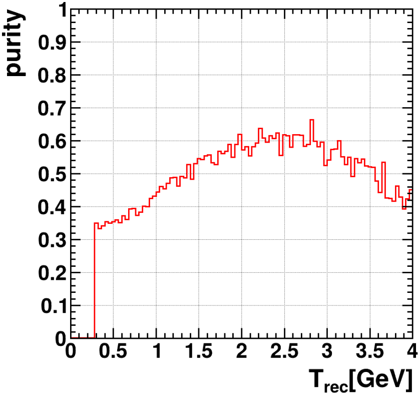
- No hit in layer 0 (charged particles rejection)
- No hit in layer 1 (γ rejection)
- $\beta < 0.9$ (fast e^+, e^-, γ rejection)
- $T_{reconstructed} > 300$ MeV (secondary neutrons suppression)
- Cluster size $N_{cells} \geq 2$

Reconstruction Quality

Performance Metrics

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

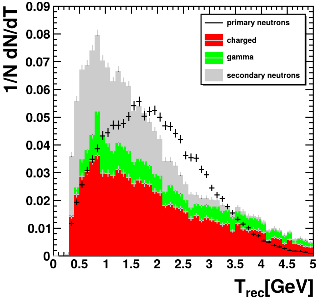




Background contribution to the reconstructed energy spectrum

Background composition

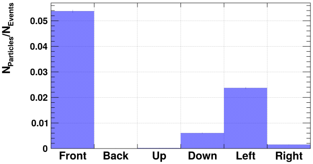
- Charged particles (mostly p, $\pi^{\pm}$)
- γ
- $n_{secondary}$ (produced or scattered in material)

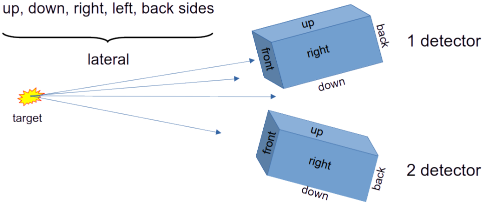


Reconstructed energy spectrum of background particles vs. primary neutrons

Charged particles

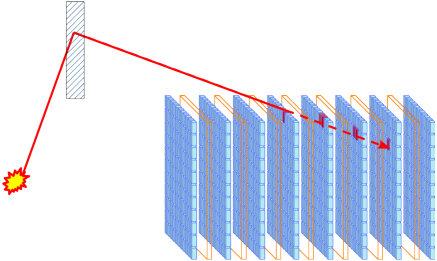
Charged particles produce clusters despite veto applied. Where do they come from?

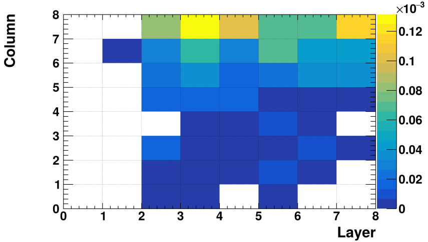


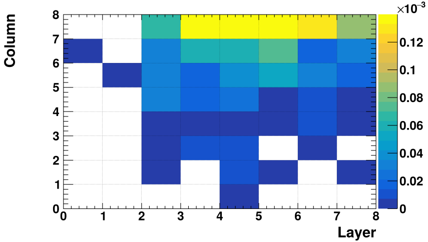


1. Charged particles come through lateral sides
2. Charged particles produce secondary clusters

1. Lateral hit



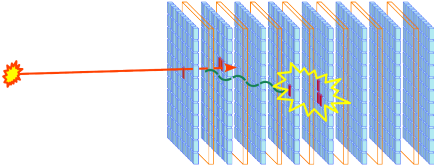




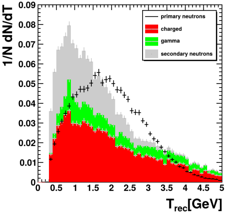
- The particle comes to the HGND through lateral surface
- First cell in cluster lies on border of HGND
- If cluster starts on border, we can reject it

2. Secondary clusters

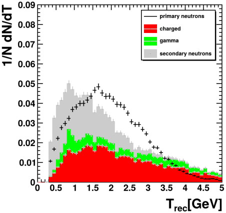
- p, π^+, π^- produce γ, n
- γ, n produce secondary clusters deep inside HGND
- There is a gap between primary and secondary clusters
- Secondary cluster is wrongly recognized as neutron
- The secondary cluster starts in the same (row, column) as hit in veto.
- We can reject such clusters



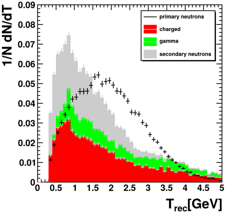
Background after new cuts



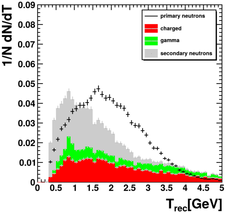
Basic selection



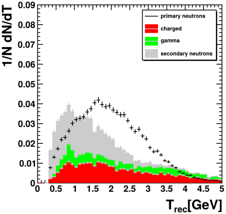
Border cut



Veto coincidence check



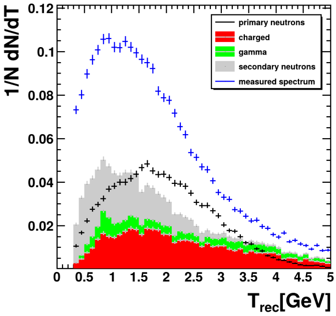
Border cut & veto coincidence check



Best cluster

Challenges

- After all cuts background remains comparable to signal
- Precise measurement of background is needed to subtract it
- Charged background can be measured by HGND itself
- Measurement of secondary neutrons and photons remains problematic
- Multiple corrections are needed:
  - Efficiency corrections
  - Multiple cluster corrections
  - Detector resolution effects



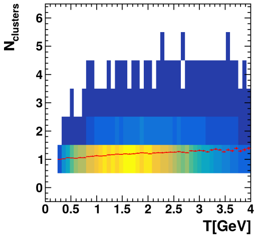
Subtraction of the background

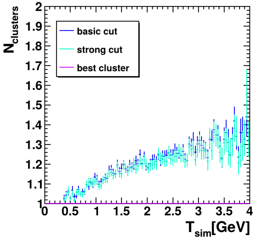
The charged particle spectrum $f(T_{\mathrm{rec}}) \equiv \frac{1}{N}\frac{dN_{\mathrm{charged}}}{dT_{\mathrm{rec}}}$ can be measured using the HGND veto layer.
The probability $p(T_{\mathrm{rec}})$ for a reconstructed cluster to originate from a charged particle can also be determined with HGND by analyzing time correlations between deep and surface clusters.
The charged particle background contribution $c(T_{\mathrm{rec}})$ is then obtained via:

$$c(T_{\mathrm{rec}}) = p(T_{\mathrm{rec}}) \cdot f(T_{\mathrm{rec}}) \quad (1)$$

Multiple clusters correction

- A single neutron interaction can generate multiple reconstructed clusters
- The mean cluster multiplicity $\langle N \rangle (T_n)$ depends on:
  - The clustering algorithm parameters
  - Neutron kinetic energy (T_n)
  - Impact position $(\bar{N}(\theta)), \bar{N}(\phi))$
- This multiplicity distribution must be obtained from simulation





Resulting procedure of spectrum restoration

1. Clustering
2. Cluster selection
3. Distribution building
4. Background subtraction
5. Deconvolution
6. Efficiency correction
7. Comparison of the results obtained with different algorithms to estimate systematic uncertainty

Conclusions

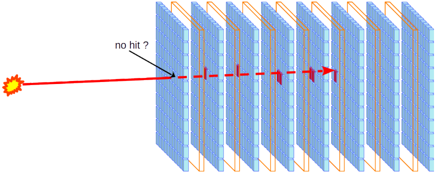
- Clustering algorithm for neutron identification in HGND has been developed
- Background comparable to signal requires sophisticated handling
- Multiple background rejection techniques have been implemented:
  - Basic cluster selection
  - Lateral particles rejection (border cut)
  - Secondary clusters rejection (veto coincidence)
- Afterward spectrum corrections are being developed:
  - Multiple clusters correction
  - Background spectrum subtraction
  - Deconvolution with detector responce function

End

Thank you for your attention!

Front side

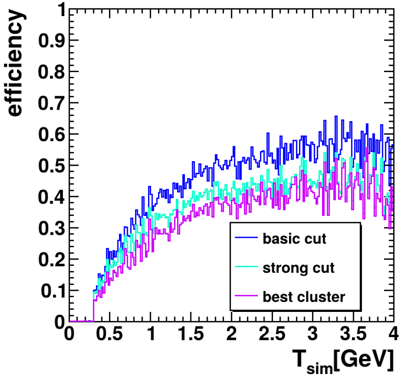
- Deposited energy below threshold (3 MeV)
- Particle pass in between cells, too low energy deposited in each cell
- Charged particle can't avoid hit in both veto and 1st layers, probability is negligible

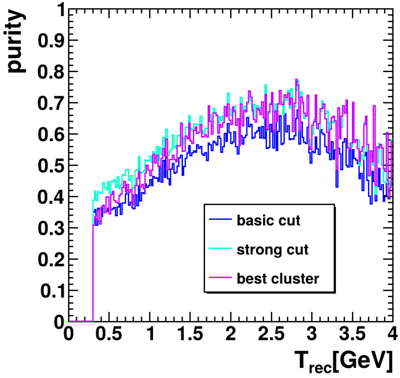


Quality after new cuts

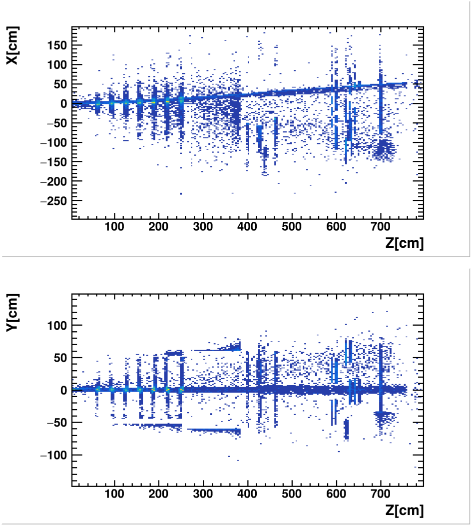
Additional strict criteria improve purity but reduce efficiency. Strong cut:

- Border cell rejection
- Veto layer coincidence check

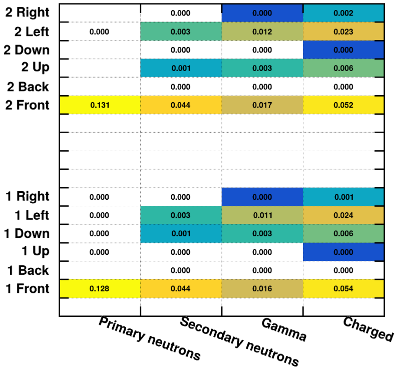




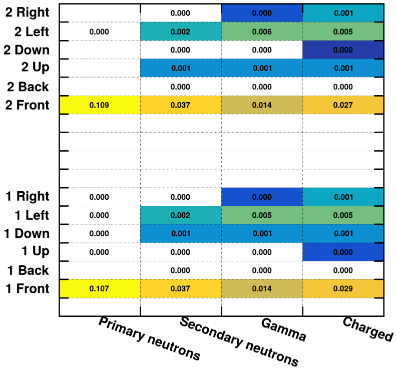
Background sources



Detector side vs. particle species



Basic selection



Border cut