# Status of the neutron detector prototype for Xe run

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on behalf of INR RAS, Moscow



9th Collaboration Meeting of the BM@N Experiment at the NICA Facility

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VBLHEP JINR

Outline:

1) Neutron detectors in heavy-ion collision experiments

- first neutron detectors at GSI
- LAND and neuLAND multilayer detectors

2) Prototype of proposed neutron detector (nDet) for BM@N:

- installation at BM@N
- results of MC simulations of nDet performance

3) Front-end and readout electronics development for nDet:

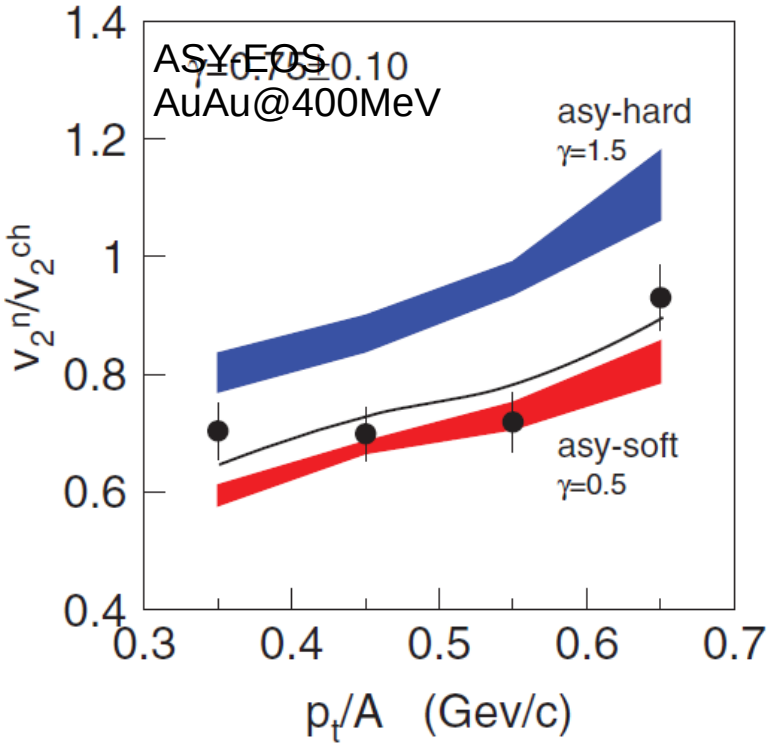
(will be presented by Alexander Makhnev)

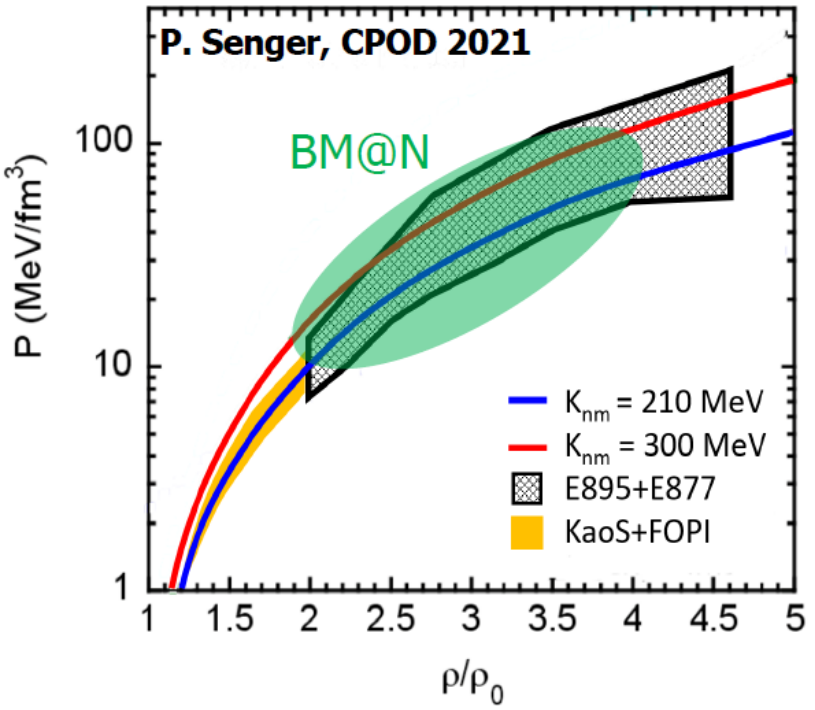
- detector development and construction at INR (Troitsk)
- light readout, signal readout electronics
- results of tests of scintillator detectors for nDet (cosmics and beam tests)

# Flow as probe of the high-density EOS

EoS – relation describes the relation between density, pressure, energy, temperature and the isospin asymmetry

The neutron-proton elliptic flow ratio - sensitive probe of the high density behavior of the nuclear symmetry energy



# Neutron flow measurements at GSI

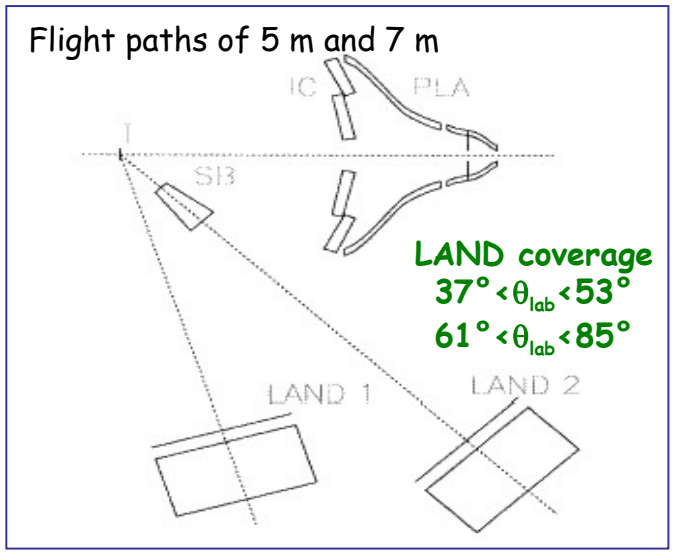
## FOPI/LAND

**Au+Au, 400 AMeV**

Y. Leifels *et al.* Phys. Rev. Lett. 71, 963 (1993)

**Au+Au, 400-800 AMeV**

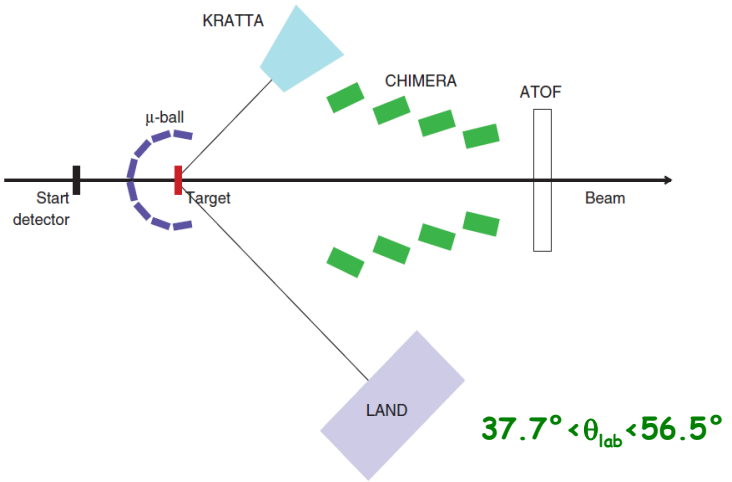
D. Lambrecht et al., Z. Phys. A 350, 115-120 (1994)




## ASY EOS

**Au+Au, 400 AMeV**

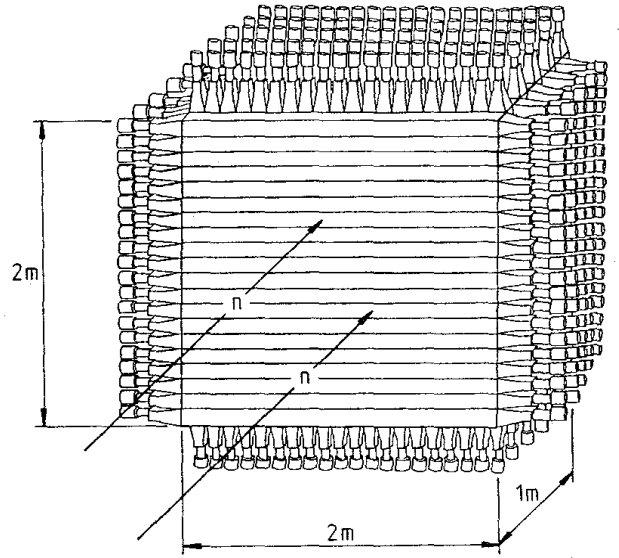
P .Russotto et al., Physics Letters B 697 (2011) 471–476




- the multiple-hit resolving capability is limited
- at 1 AGeV only the first two detector layers was used for the data analysis
- for a single layer the efficiency reduces to 0.19 (200 MeV) and 0.265 (1.05 GeV)

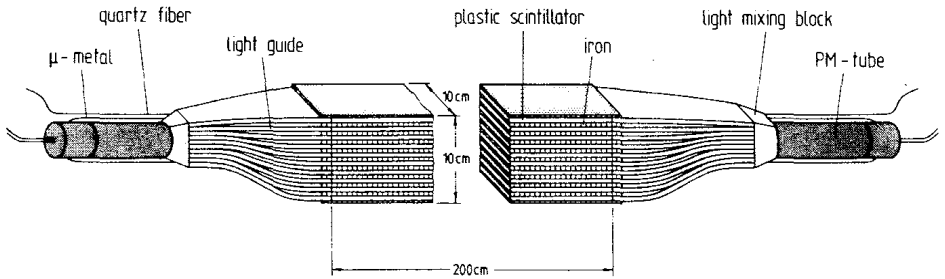
LAND - a TOF neutron spectrometer with the precise determination of the position and arrival time of identified neutrons (constructed in 1990).

T. Blaich, et al., NIM. A 314 (1992) 136.




- total volume 2.0x2.0x1 $m^3$
  200 modules (plastic scint/Fe bars 200x10x10 $cm^3$
- 10 mutually perpendicular planes with 20 bars in each,
- two PMT for each bar readout (400 readout channels)
- $\sigma_t \approx 250$ ps,
- $\sigma_{x,y,z} \leq 3$ cm
- one-neutron efficiency > 80% for energies > 400 MeV
- multi-neutron detection capability
- without 1,2,3H isotopic discriminations

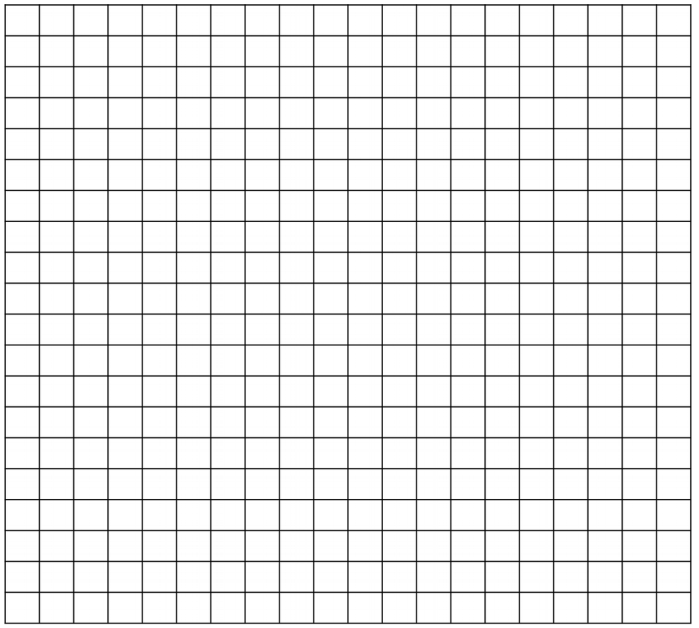
P. Pawłowski et al., ‚Neutron recognition in the LAND detector for large neutron multiplicity, arXiv.org > nucl-ex > arXiv:1203.5608v3

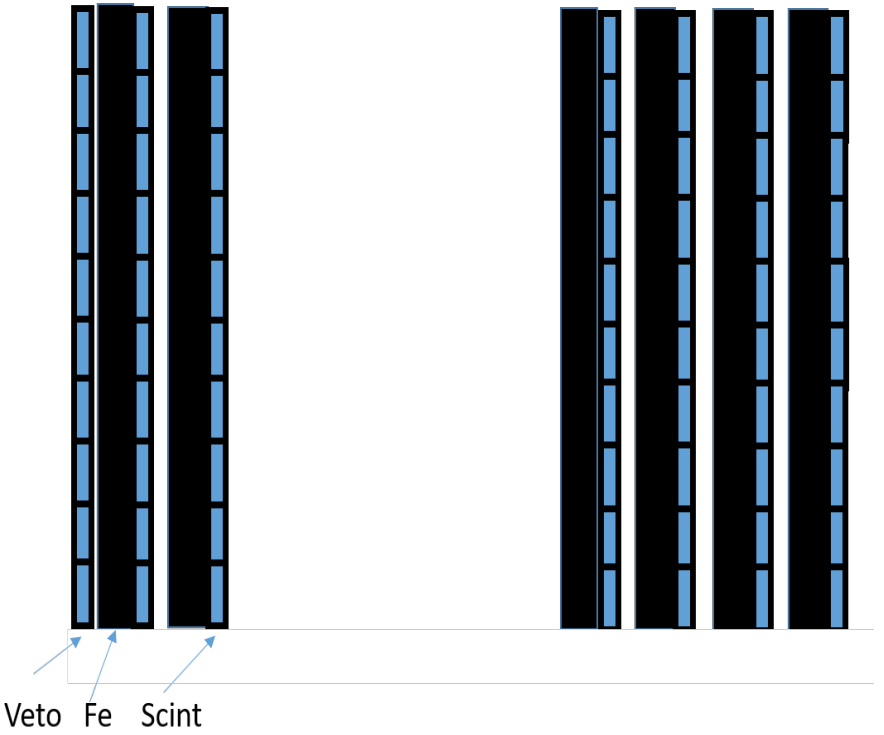



- primary neutron hit: event-by-event identification of the first hit generated by the neutron.
- hit location and time is used to determine the velocity vector of the incident neutron.
- the multiplicity of detected neutrons:
  calorimetric observables:
  1) hit multiplicity $N_{hit}$
  2) total visible energy $E_{vis}$

# Proposed structure of nDet for the BM@N (INR RAS + ITEP + JINR)

One layer: map of scintillator cells






- transverse size: 30 x 30 – 40 x 40 cm

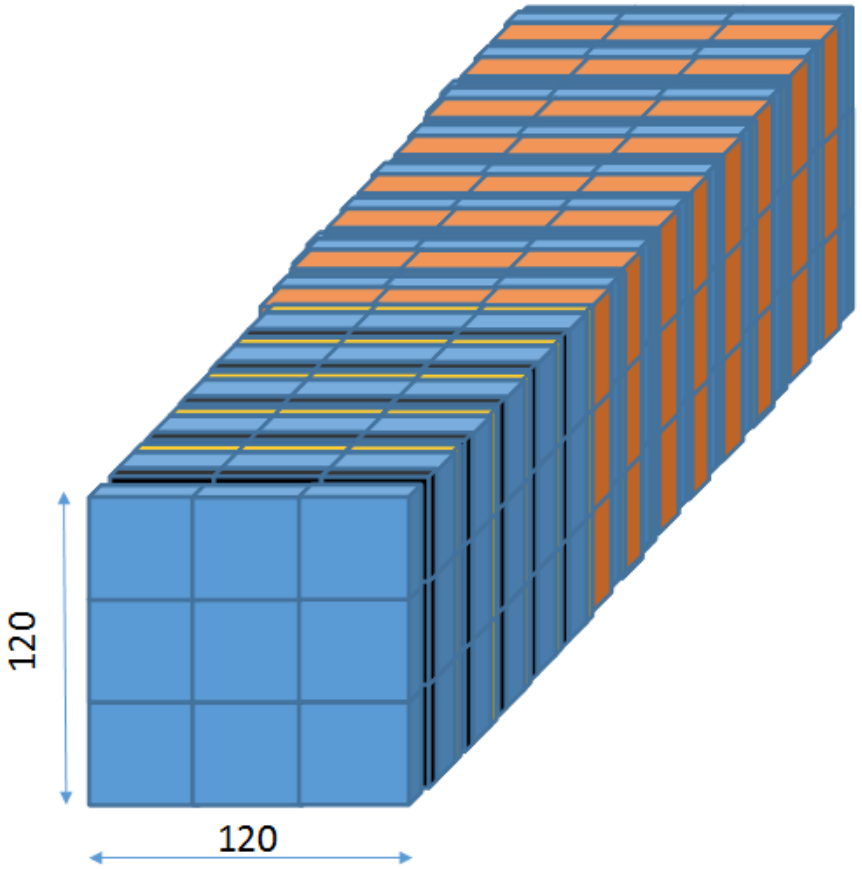
- number of layers: (Fe/Cu) + Scintillator + Plastic (for electronics) – under optimization (15 - 20)

- length of nDet ~ 100 cm (3 - 4 $\lambda_{in}$)

- scintillation detectors (cells):
  size: 3x3 – 4x4 cm, number of cells ~ 2000 – 3000
  light readout: SiPM (6x6 mm), time resolution ~ 100 – 150 ps

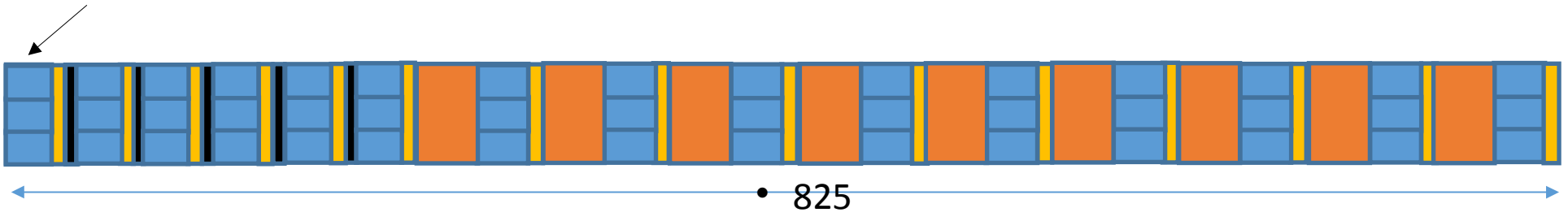
Final parameters are still discussed (based on MC simulations and future results from nDet prototype)

- Proposed structure of nDet prototype for Xe run

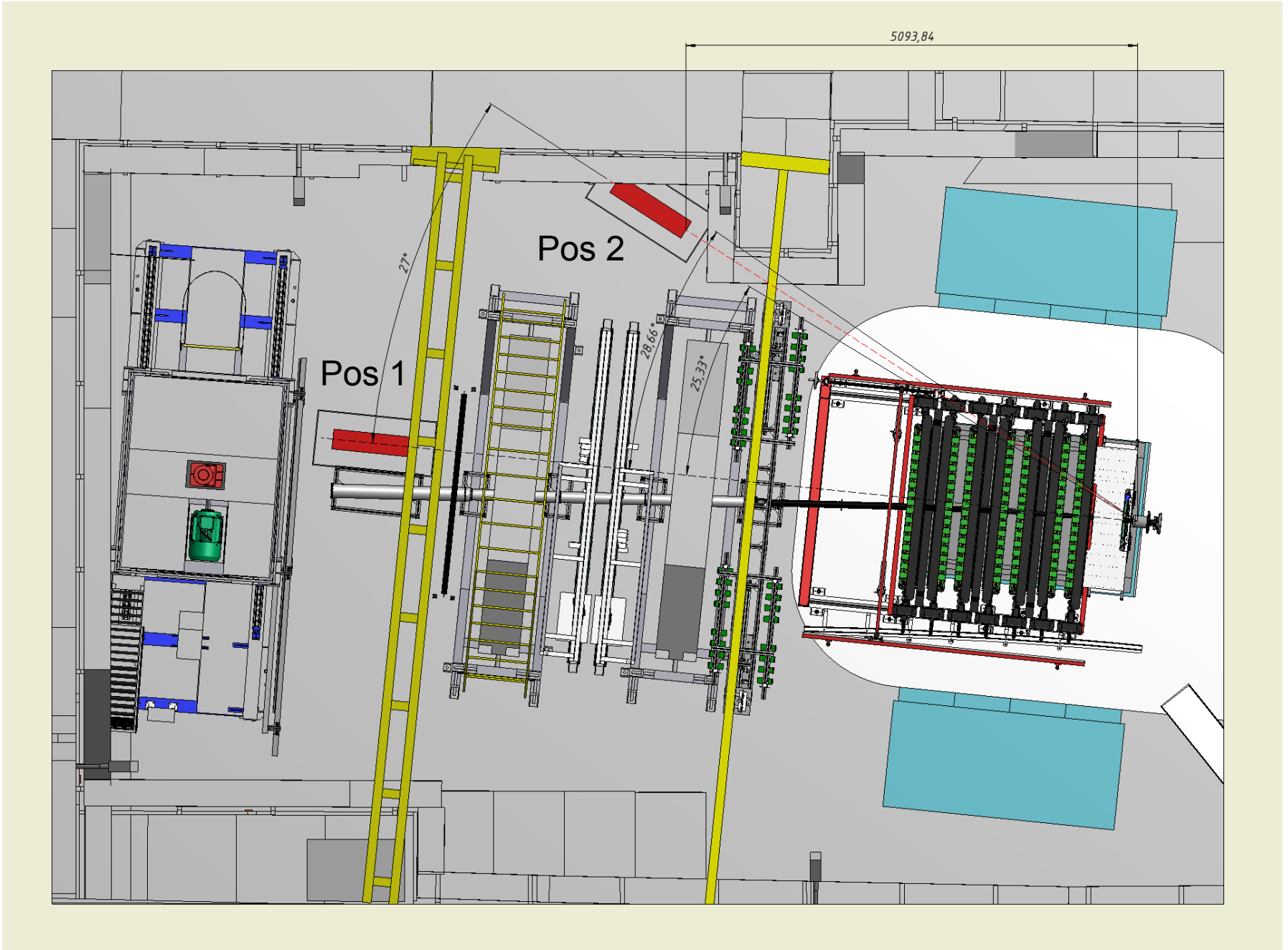



- First layer as Veto detector

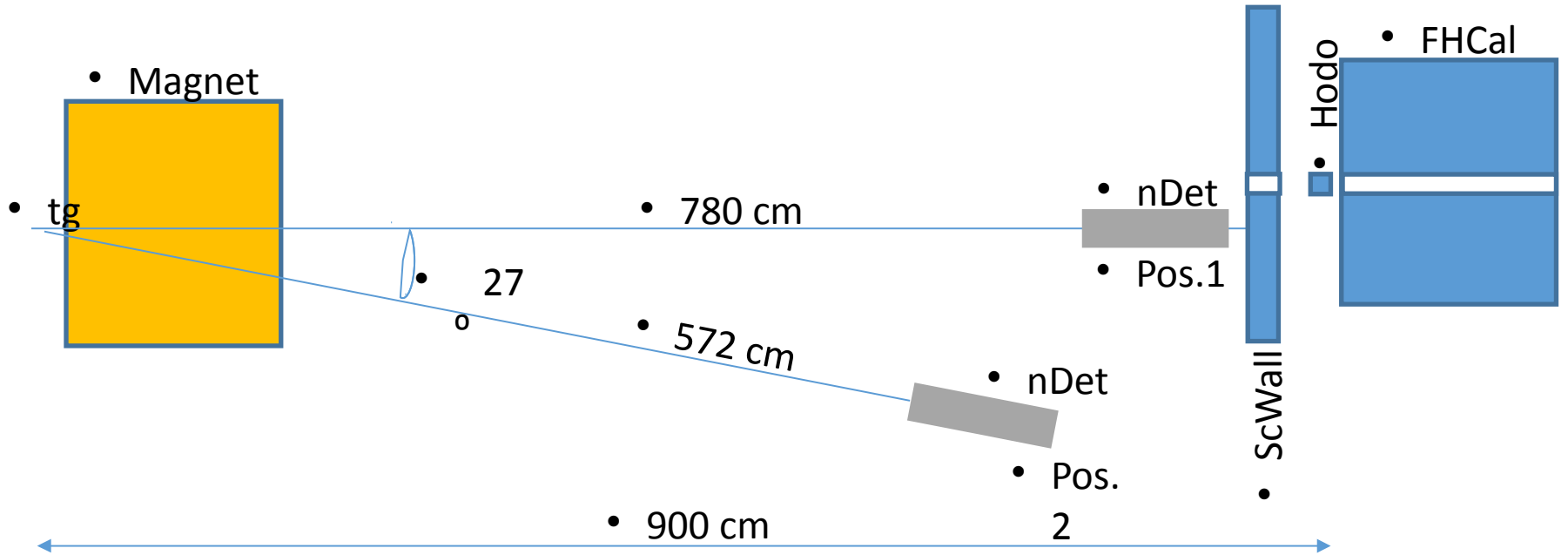
- - Veto scintillator layer 120x120x25 (mm)
- - First (electromagnetic) part:
  5 layers: Lead (8mm) + Scintillator (25mm)
- + PCB(5mm) +air(5mm)
- - Second (hadronic) part:
- 9 layers: Cu (30mm) + Scintillator (25mm)
- + (PCB(5mm) +air(5mm)
- 
- Scintillator cell – 40 x 40 x 25 $mm^3$
- Total readout channels 9+45+81 = 135
- Total size – 12 x 12 x 82.5 $cm^3$
- Total nuclear interaction length ~ 3.
- Total weight: 7(Pb) + 35(Cu) + 6 (Sc) + 2(el.) ~ 50 kg



# Proposed positions of nDet prototype for Xe run an BM@N



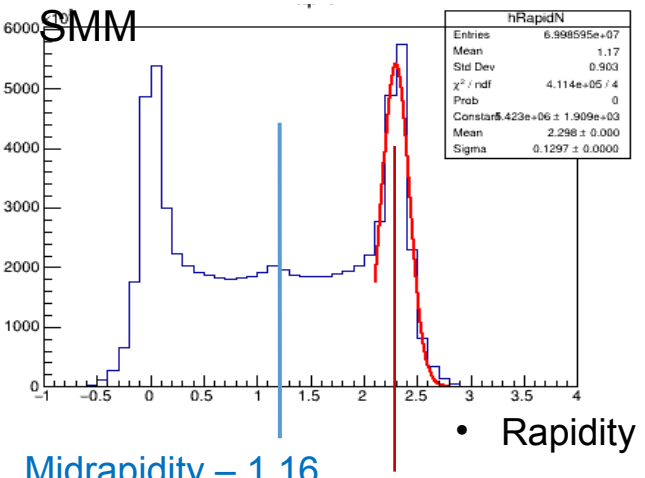
## Proposed positions of nDet prototype for Xe run an BM@N




- Position of nDet at 0 deg.
- - to test of nDet with known neutron energy
- (beam energy of neutron-spectators)

- Position of nDet at 27 deg.
- - measurements of neutron spectra at ~ midrapidity.

XeCsI@3.9A GeV, DCM-SMM



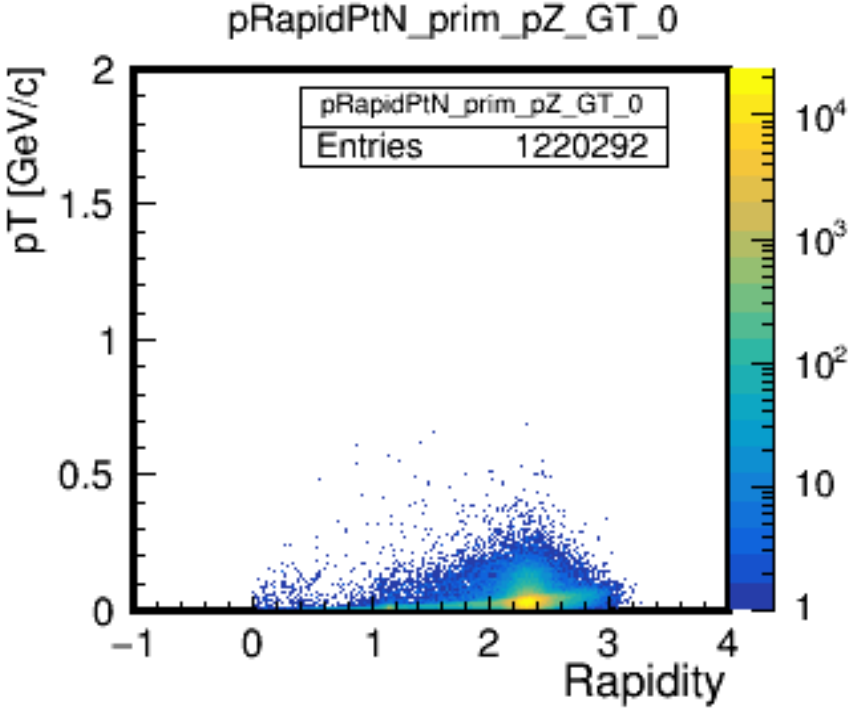

Midrapidity – 1.16

Spectator rapidity - 2.3

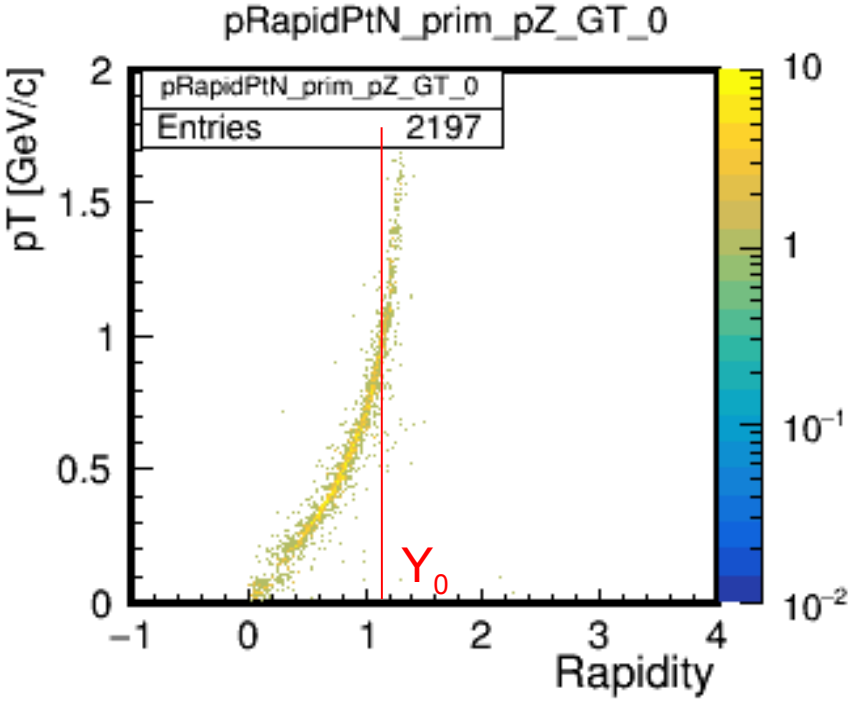
XeCsI@3.9A GeV, DCM-SMM

- pT vs rapidity distributions on nDet surface for primary neutrons

- *nDet at* 0 deg.
- (1196586 generated MB ev.)



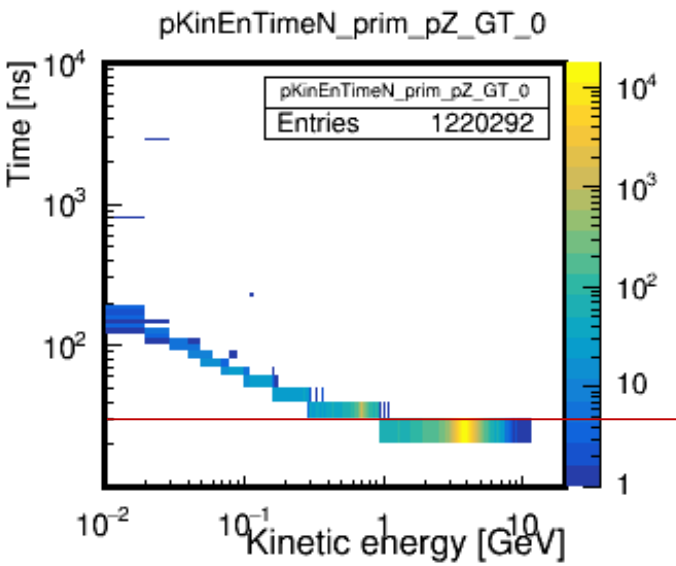

- *nDet at* 27 deg.
- (2242054 generated MB ev.)

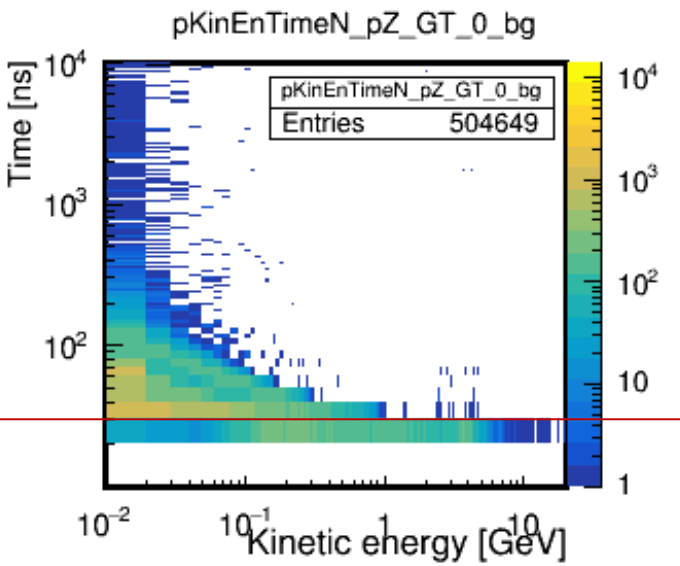


XeCsI@3.9A GeV, DCM-SMM

- Time vs kinetic energy distributions at nDet surface
  - Primary neutrons
  - Background neutrons

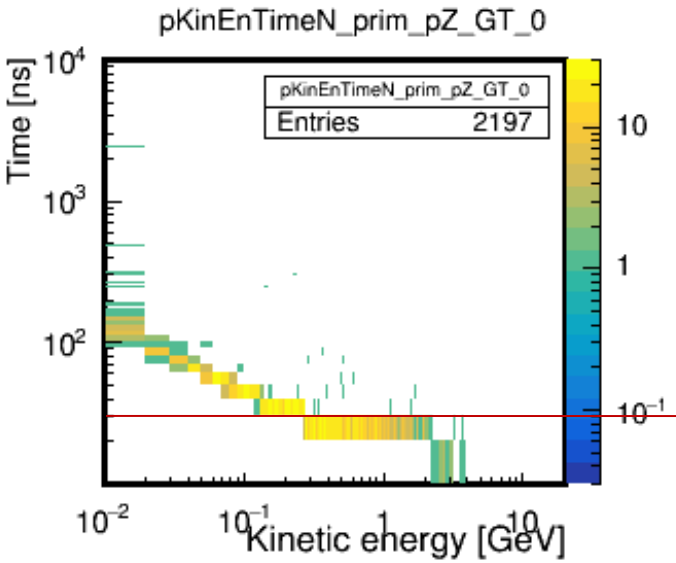
- *nDet at* 0 deg.

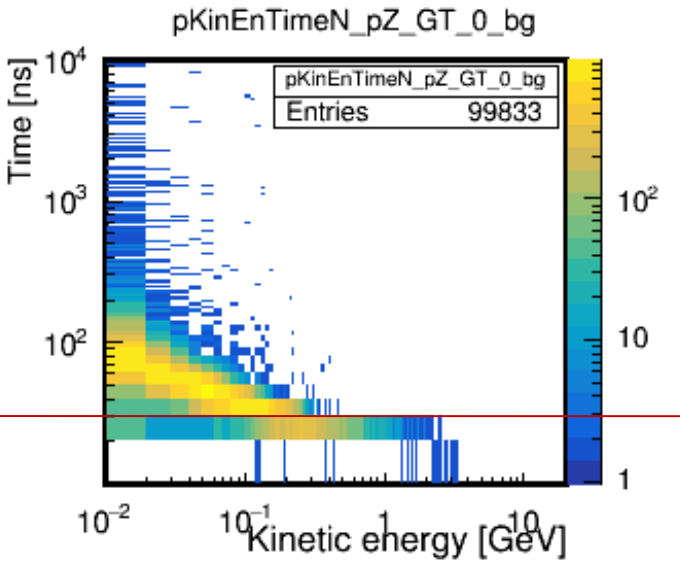



30 nsec

- *nDet at* 27 deg.

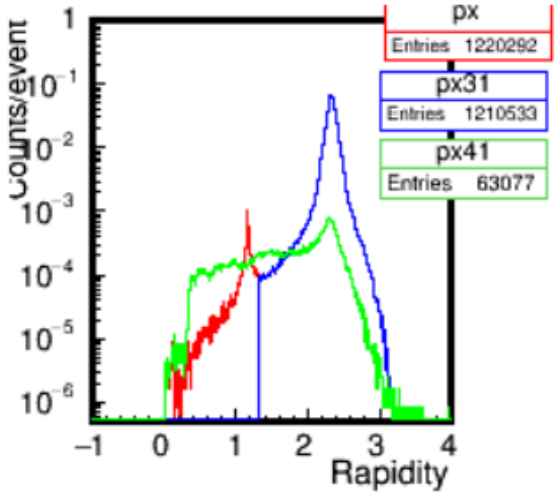


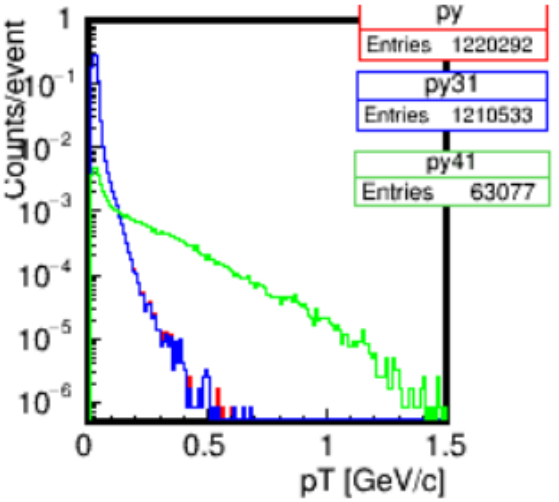

30 nsec

- Neutrons distributions at nDet surface
  - ( **0 deg.** ) normalized to number of events

Rapidity




pT

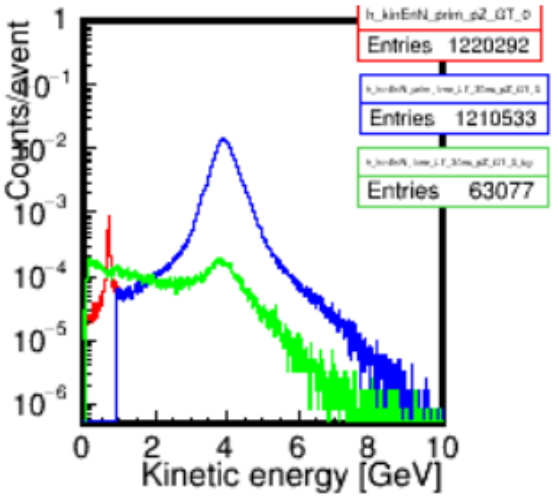



Primary neutrons

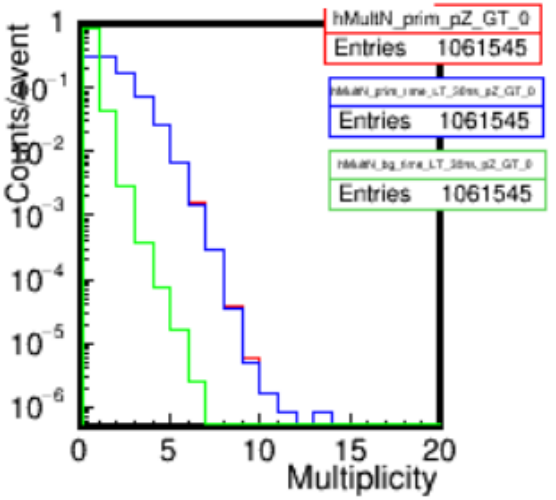
Primary neutrons
with time < 30 nsec.

Background neutrons
with time < 30 nsec.

Kinetic energy



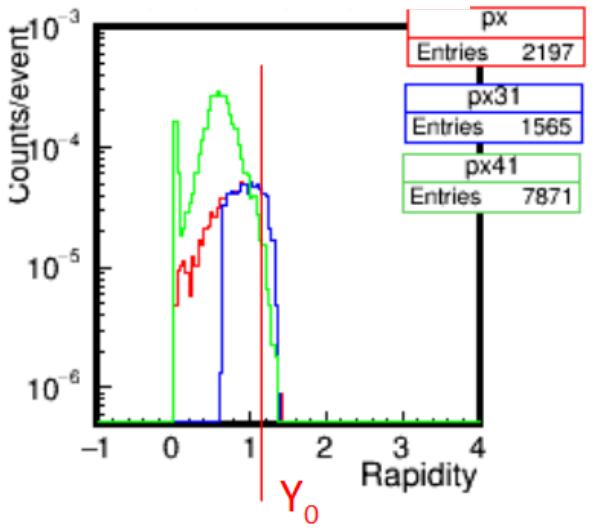

Multiplicity



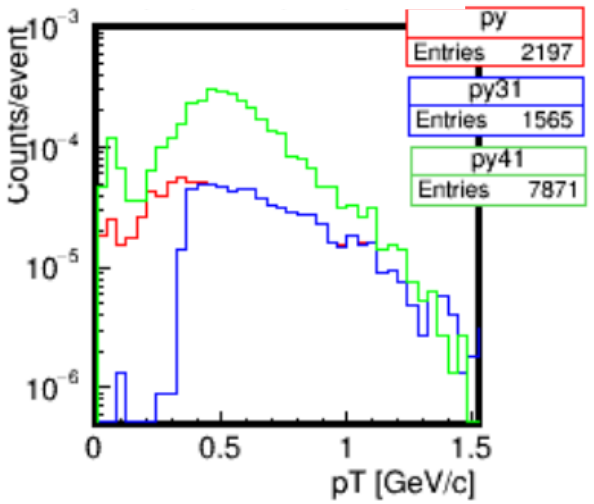

- Neutron yield measured
- with nDet ~ 300 n/sec
- for interaction rate 1kHz

- Neutrons distributions at nDet surface
- ( **27 deg.** ) normalized to number of events

Rapidity




pT

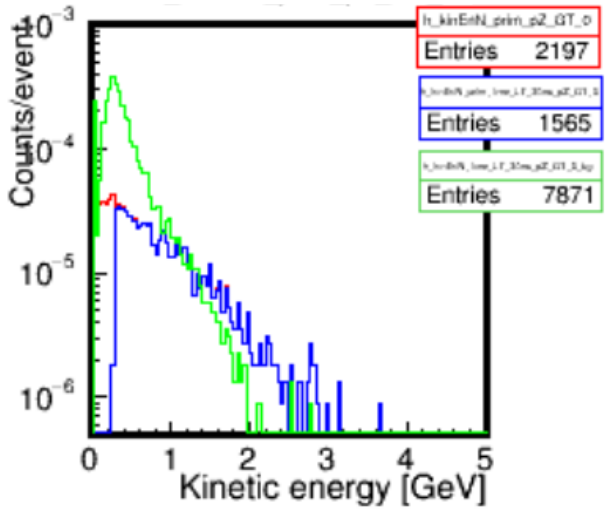



Primary neutrons

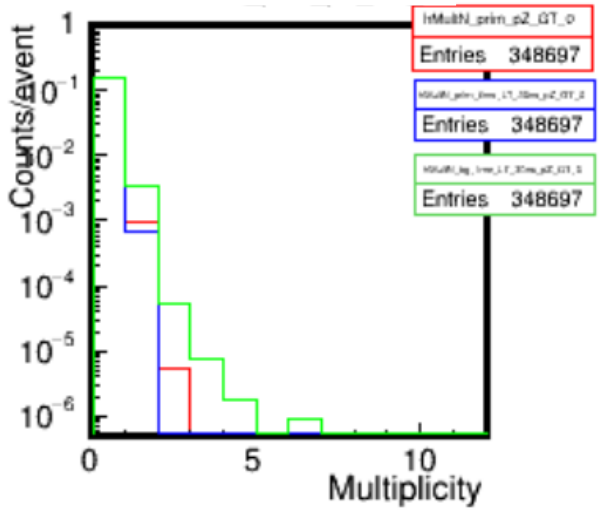
Primary neutrons
with time < 30 nsec.

Background neutrons
with time < 30 nsec.

Kinetic energy



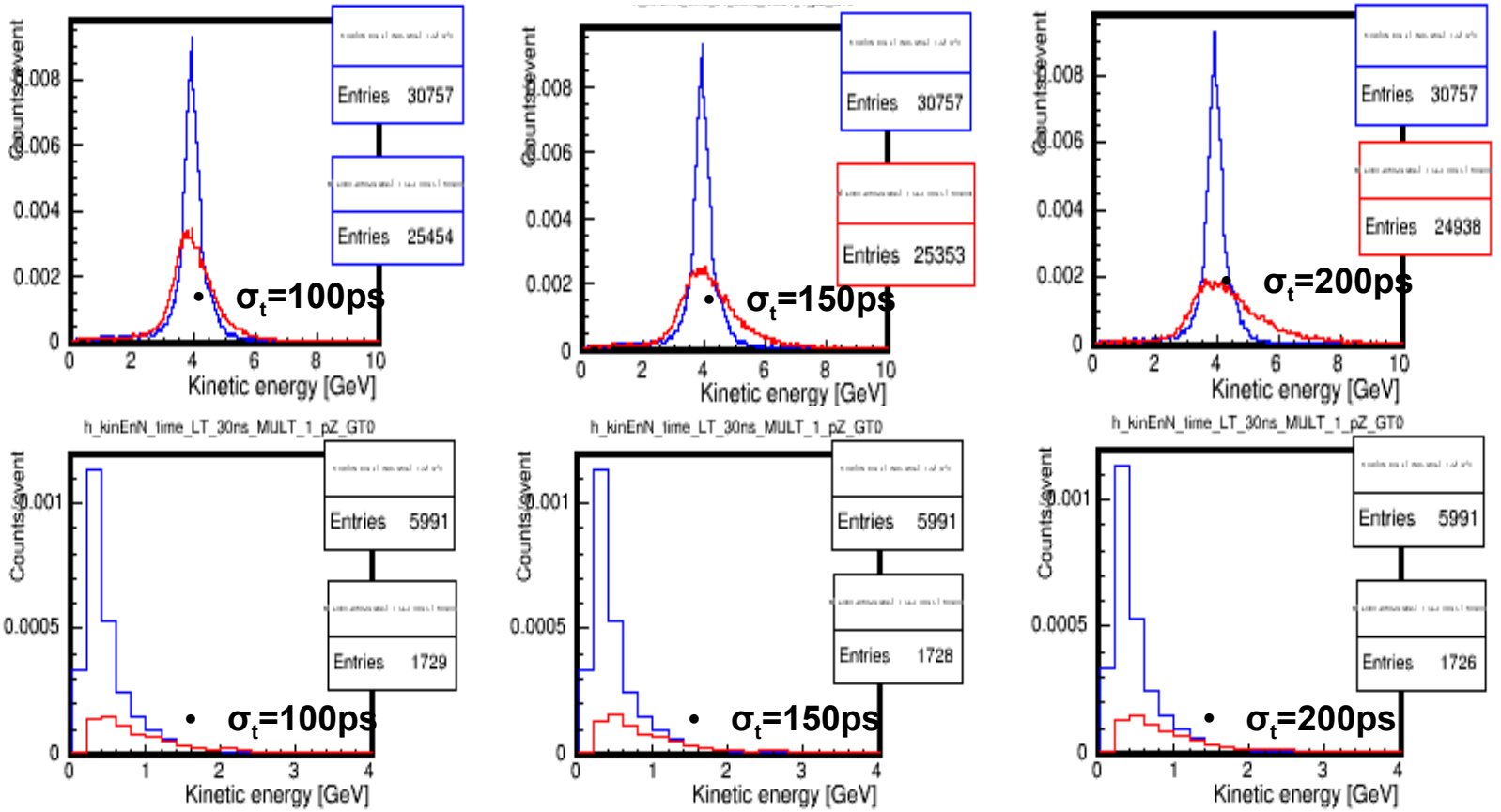

Multiplicity



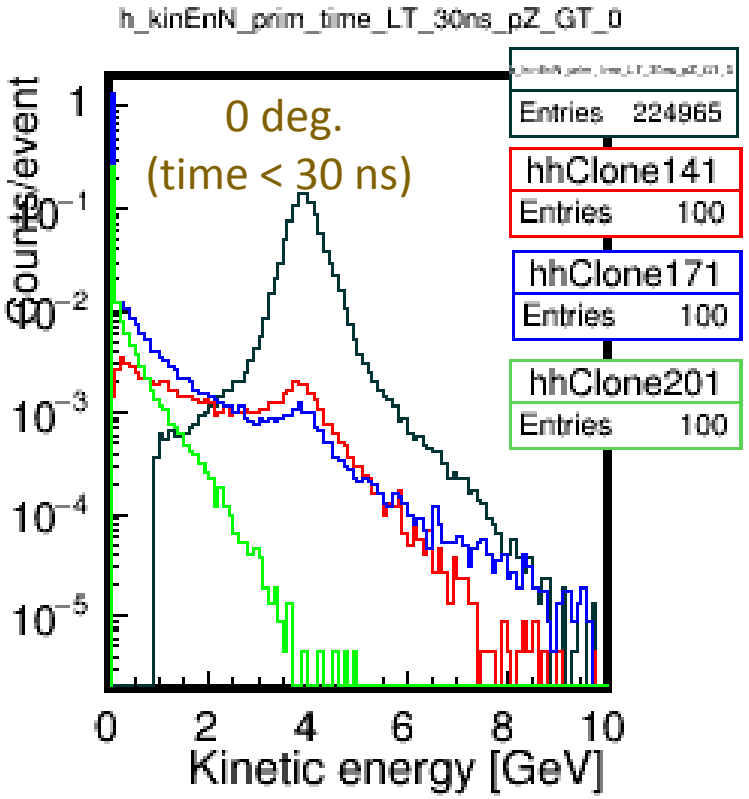

Neutron yield measured
with nDet ~ 1 n/sec
for interaction rate 1kHz

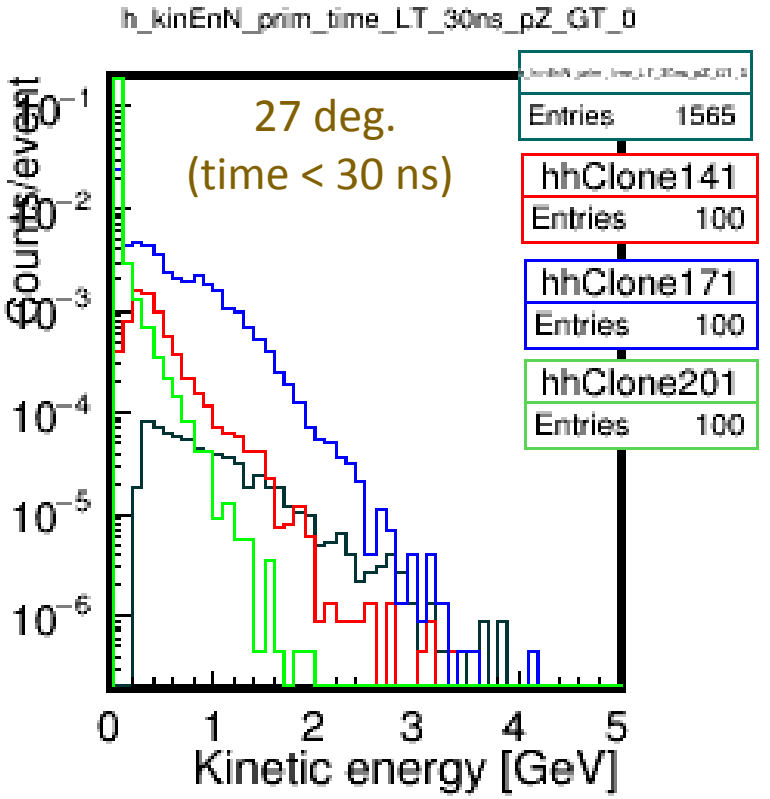
**Reconstruction of kinetic energy spectra for neutrons with multiplicity = 1**
**vs time resolution of scint. Cell** (time < 30 nsec, energy is determined with fastest hit in nDet)

- nDet at 0 deg.
- nDet at 27 deg.




**Neutron kinetic energy at nDet surface**
**Kinetic energy reconstructed in nDet (300MeV – 1 GeV)**




***Primary* neutrons** at nDet entrance surface

Background (before + around):
*Neutrons*
*Charged particles*
**Gamma**

An algorithm of neutron recognition on background is needed!

# Event reconstruction using Graph Neural Networks

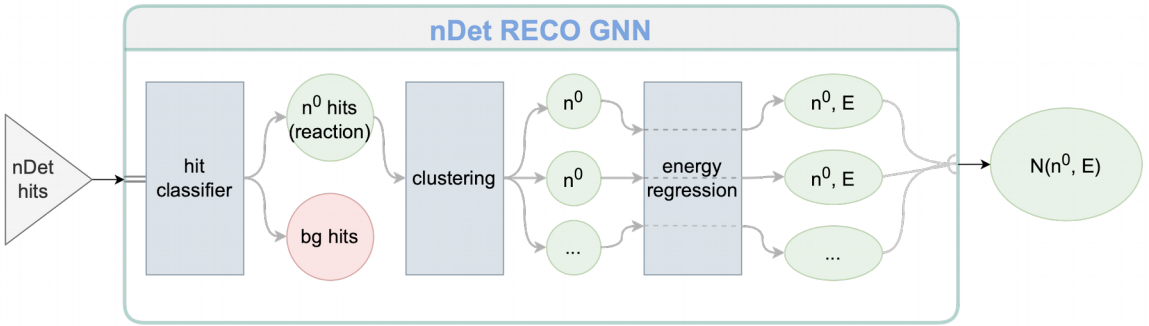
V. Bocharnikov, D. Derkach, F. Ratnikov (LAMBDA Lab., HSE)

Graph Neural Networks (GNNs) - class of deep learning models that are capable to exploit topological structure of data

Graph consists of:

- Nodes - hits (position, deposited energy, time)

- Edges - spacial connectivity



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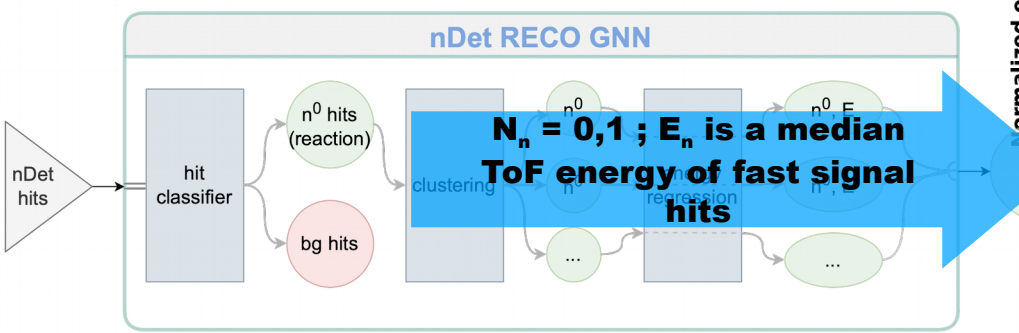
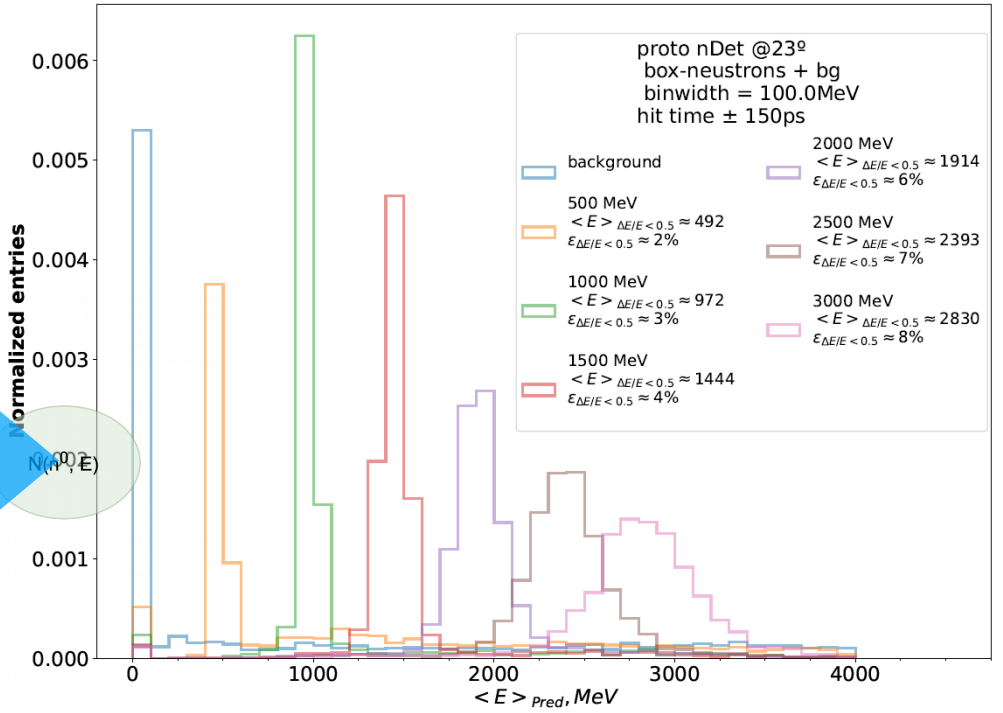



Preliminary performance example for a simplified case of single neutron mixed with background event




Work in progress..

Conclusions & Outlook:

- nDet prototype will be ready and used at Xe run period at BM@N

- scintillation detectors have been studied on cosmics and electron test beam (see Alexander Makhnev presentstion)

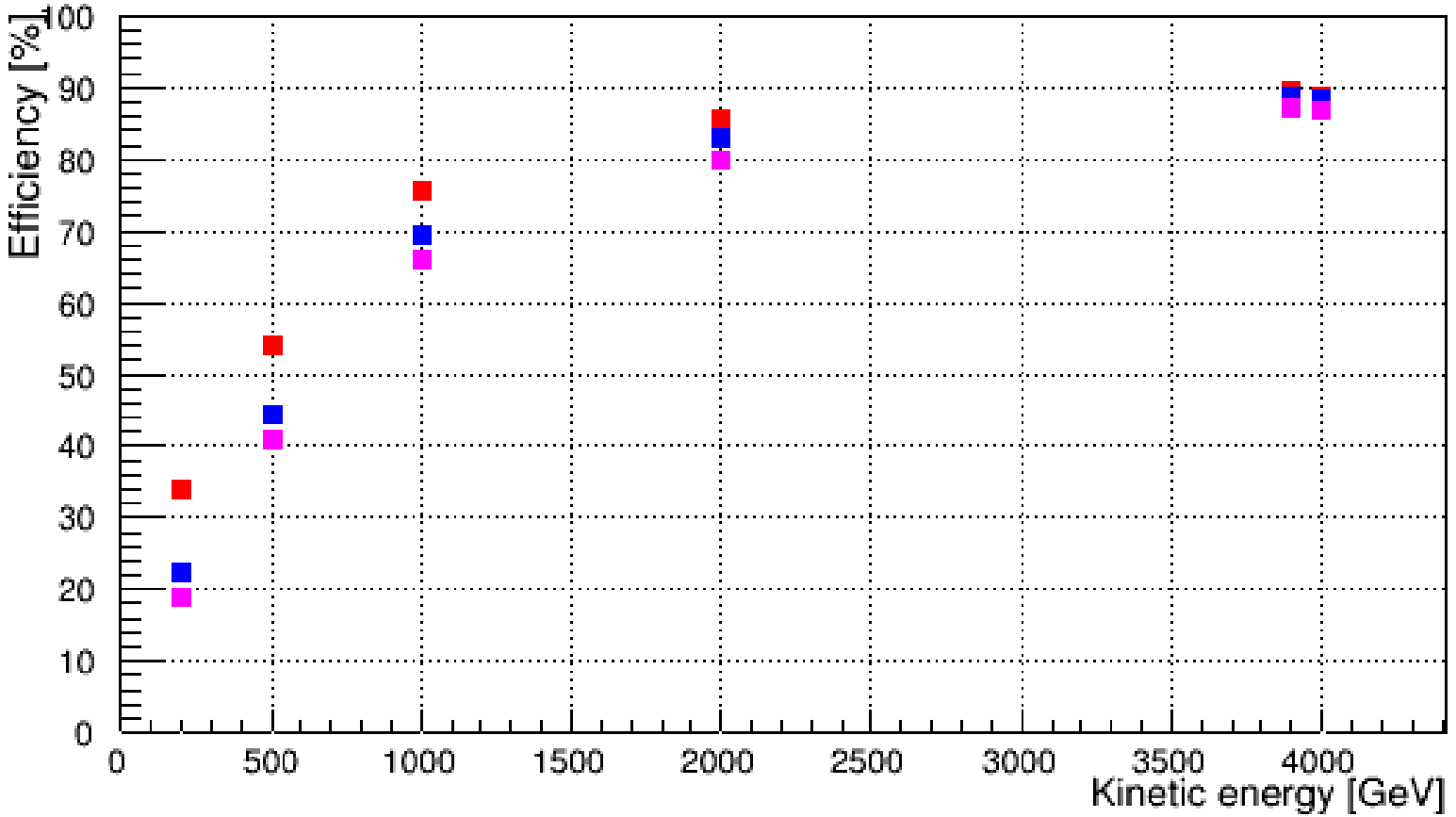
- two positions of nDet prototype has been proposed, 0 deg for test and performance studies and 27 deg for neutron spectra measurements

- neutron reconstruction at high backgrounds is under development

Thank you for your attention!

# Backup slides

# Neutrons efficiency of nDet vs kinetic energy




*Cuts on Edep in slices:*

Edep > 1 MeV
Edep > 3 MeV
Edep > 5 MeV

**Reconstructed neutron kinetic energy and neutron energy resolution of nDet and vs neutron energy on the entrance surface of nDet (for events with neutron multiplicity = 1 and Edep in scint. cells > 3 MeV)**