UNIVERSITÄT BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

ArgonCube

Light Readout for Neutron Tagging in DUNE Near-Detector

Patrick Koller

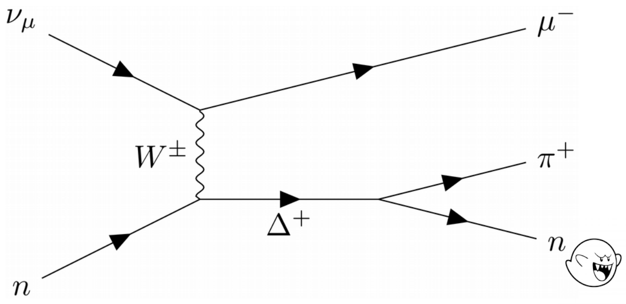
Motivation for n-Tagging

- Neutrino energy reconstruction (calorimetric method):

$$E_{\nu,reco} = \underbrace{E_\mu}_{leptonic} + \underbrace{\sum_{i=p,\pi^\pm} E_i}_{hadronic} + \underbrace{\sum_{i=\pi^0,e,\gamma} E_i}_{EM-showers} + \underbrace{\sum E_n}_{neutrons}$$

neutrons not visible in traditional LAr TPCs

- Interaction modes which produce neutrons are dominant in DUNE



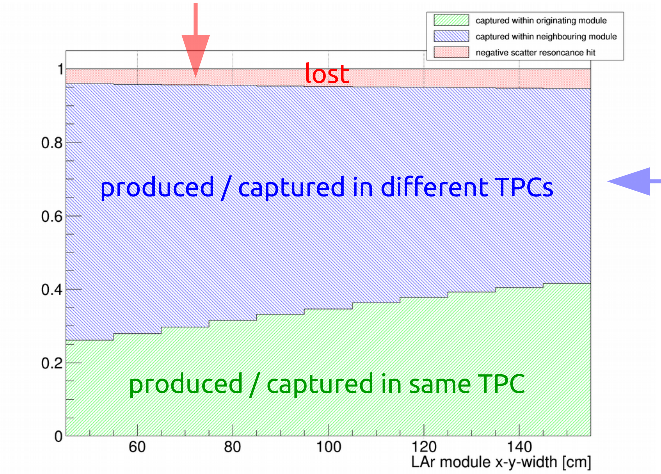
→ **mis-reconstructed neutrino energy!**

- Hadronic showers can fluctuate to neutrons → detached energy deposits (up to 10s MeV)

Slow vs. Fast Neutrons

Slow Neutrons [O(keV)]:

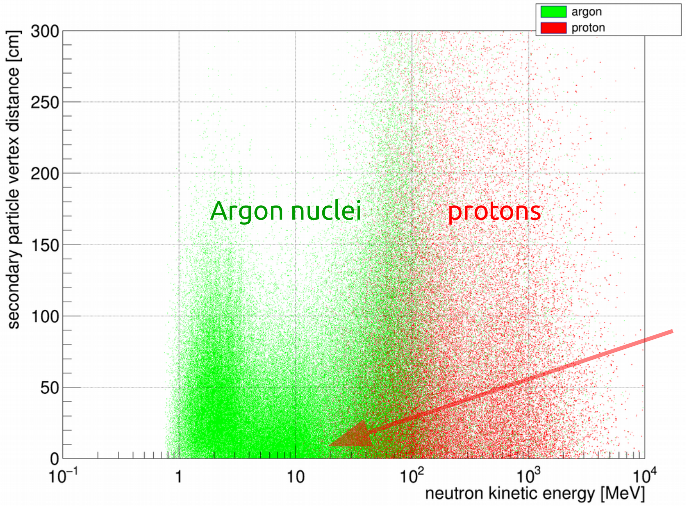
- cross several TPCs during thermalization (blue fraction)
- LAr has negative neutron-scatter resonance at ~50 keV (red fraction)



→ vertex association impossible!

Fast Neutrons [O(MeV)]:

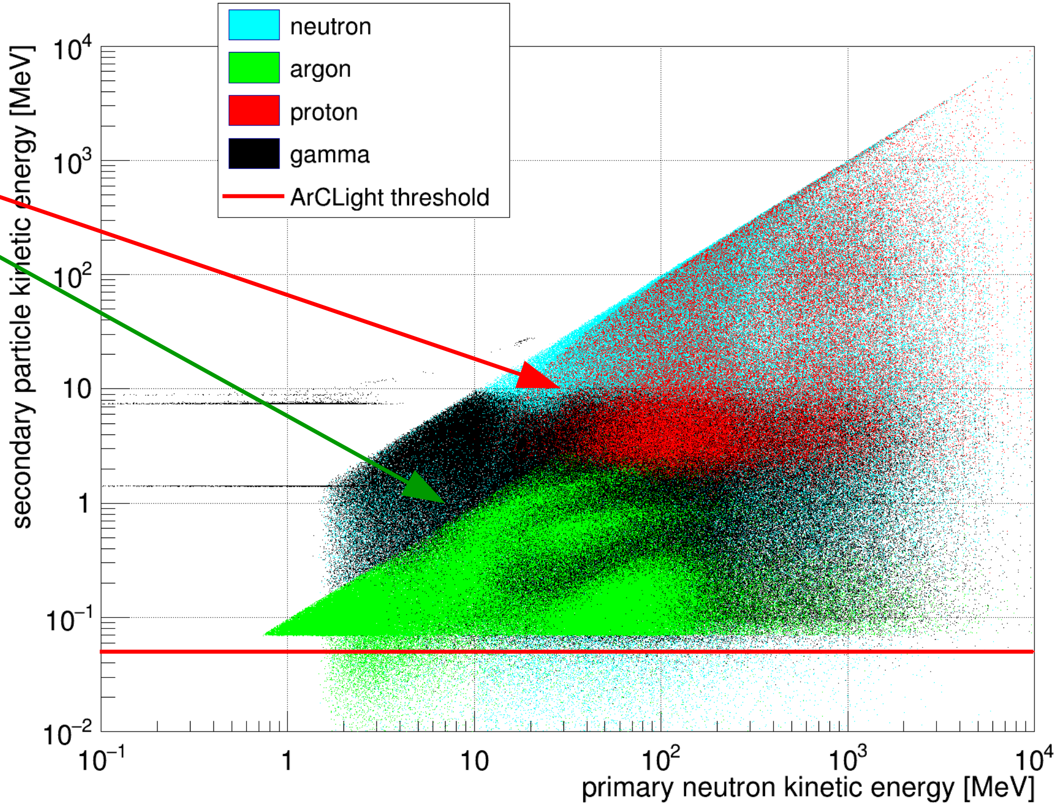
- can interact with an atomic nucleus
- mainly recoiling Argon nuclei and protons



→ these particles are visible in LAr!

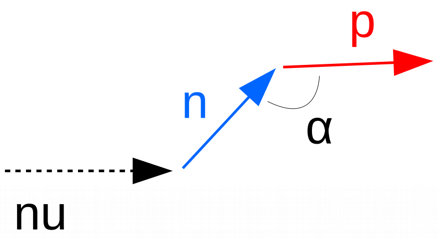
Properties of Recoiling Particles

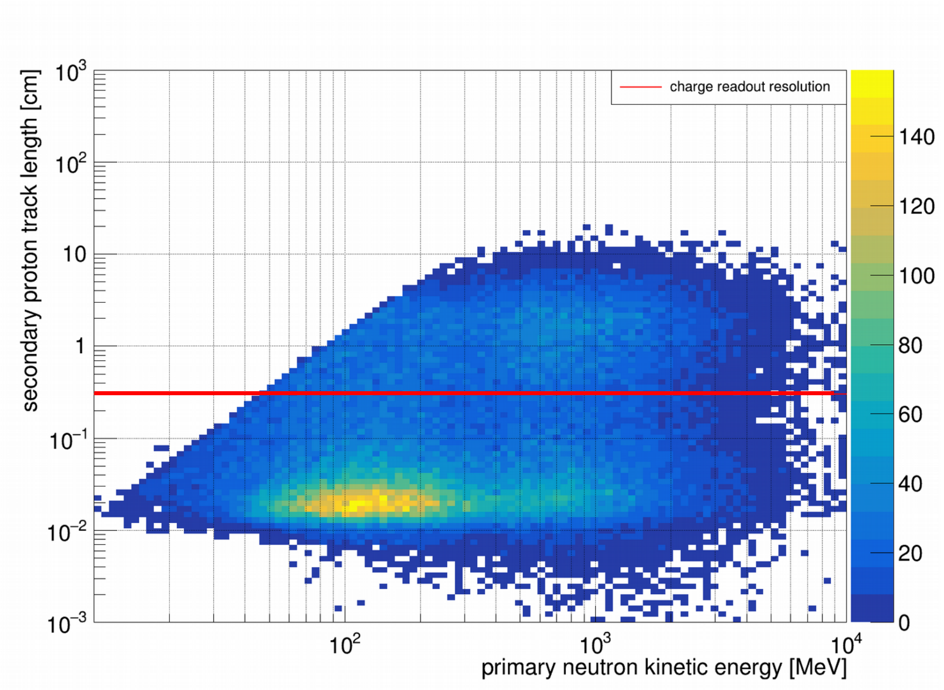
- Clear energy-separation between recoiling Argon nuclei and protons
- Signatures in pixel-readout:
  - Argon nuclei only single blips
    - → difficult
  - Protons deposit 30 MeV/cm
    - → short tracks

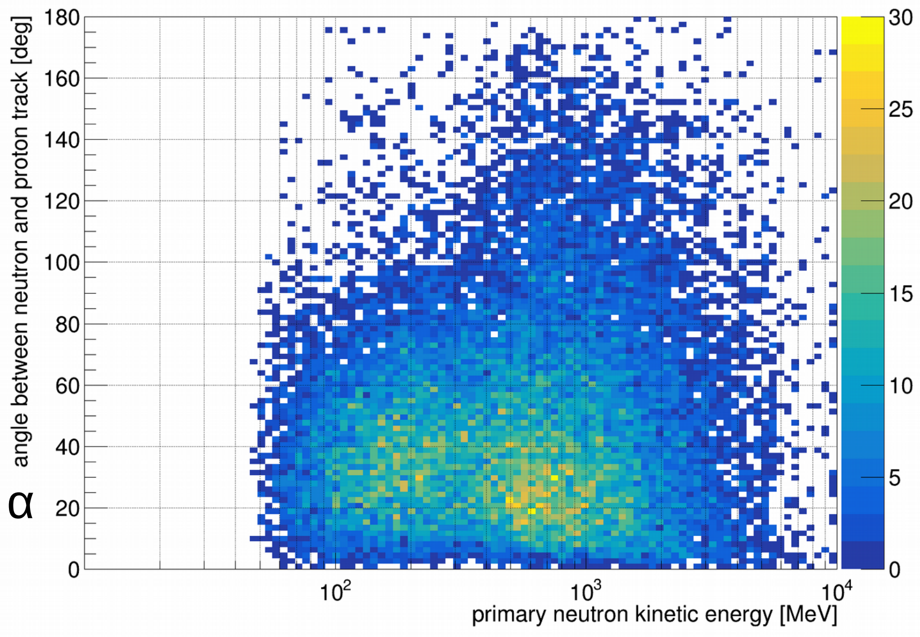


→ **focus on recoiling protons**

Recoiling Protons







→ start to see tracks from recoiling protons at neutron energies > 50 MeV

→ directional information

→ no correlation between angle and neutron energy

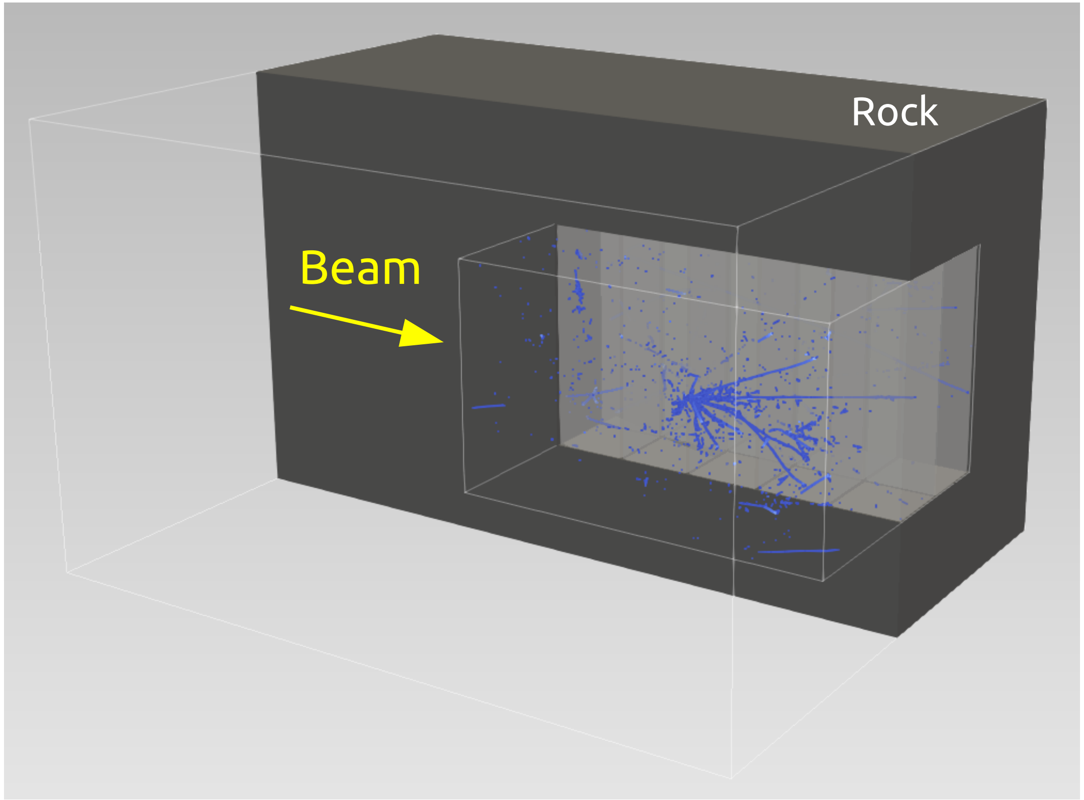
→ no point-back / **no energy reconstruction**

→ **only option:** **n-tagging with protons**

Track-Pileup Simulation

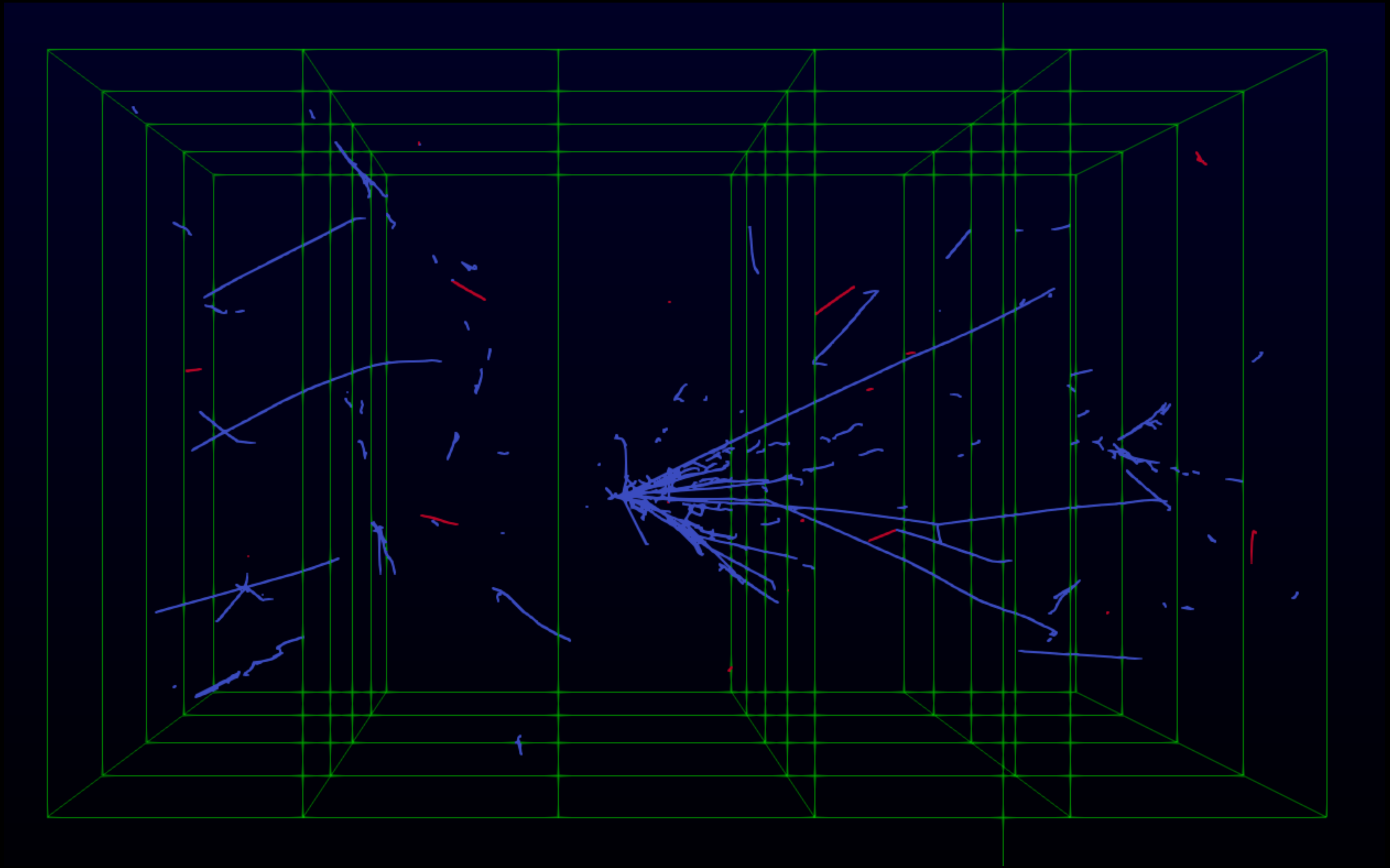
- Full spill simulation in ArgonBox (GEANT4 LAr simulation by Dan Dwyer)
- 4 x 5 ArgonCube modules
- Module dimensions: 1m x 3.5m x 1m
- TPC dimensions: 0.5m x 3m x 1m
- Additional LAr volume to emulate rock interactions (mainly muons):
  - 5m upstream,
  - 2m at the sides,
  - 1.5m above/below the detector
- **At 1MW: ~70 interactions per spill**

  (~9 in active volume)



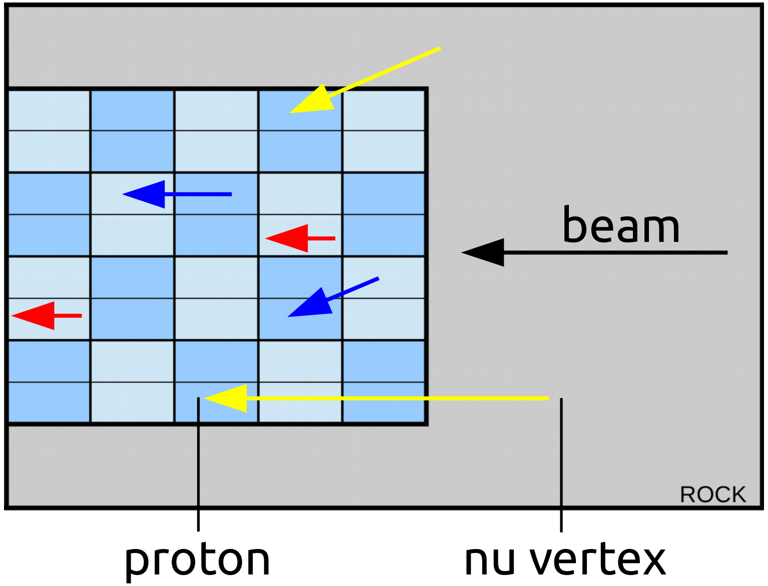
made with Paraview

energy deposits from proton recoils: red, everything else: blue ($E_{th,tracks}$ = 10 MeV)

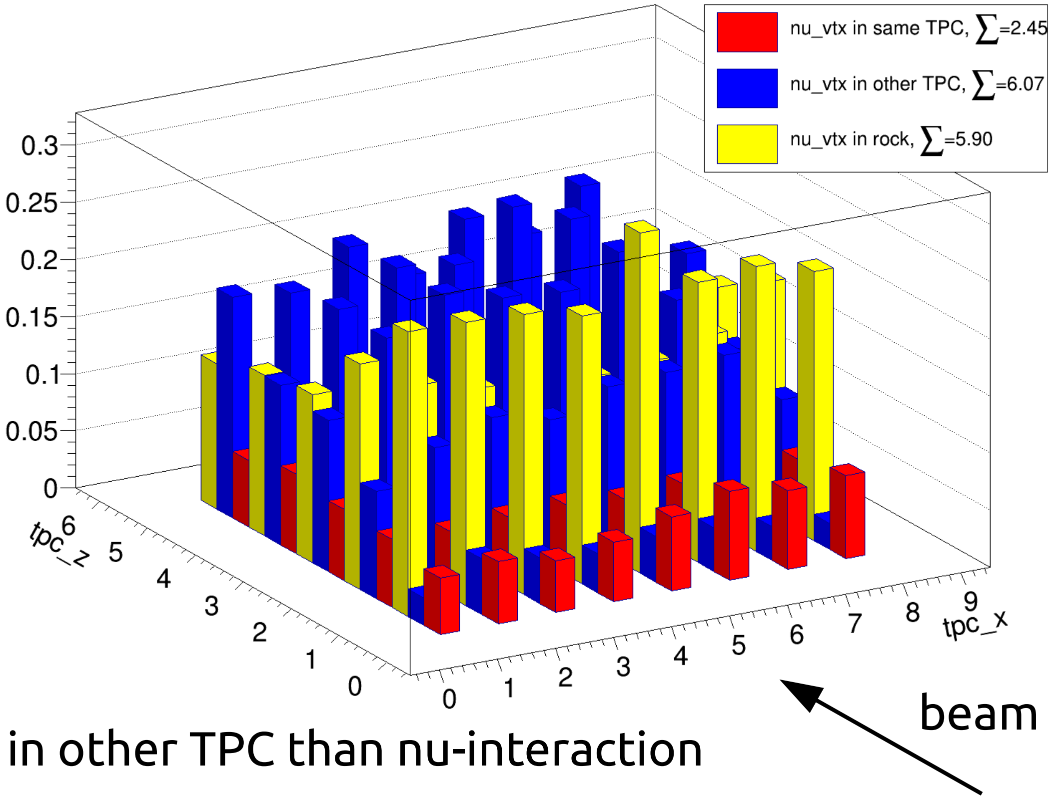


Proton-Track Pileup Results

3 topological categories:



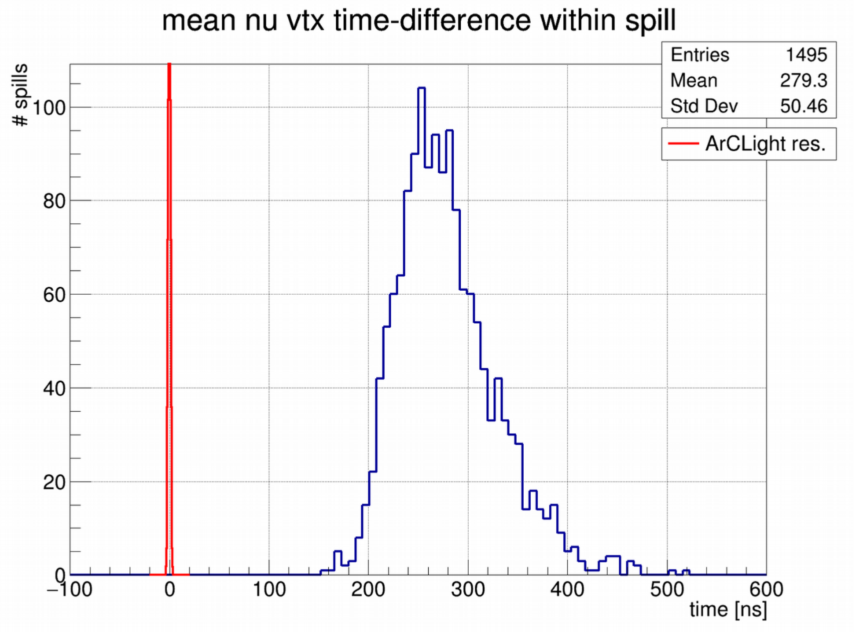
spill multiplicity of recoiling protons > 10 MeV

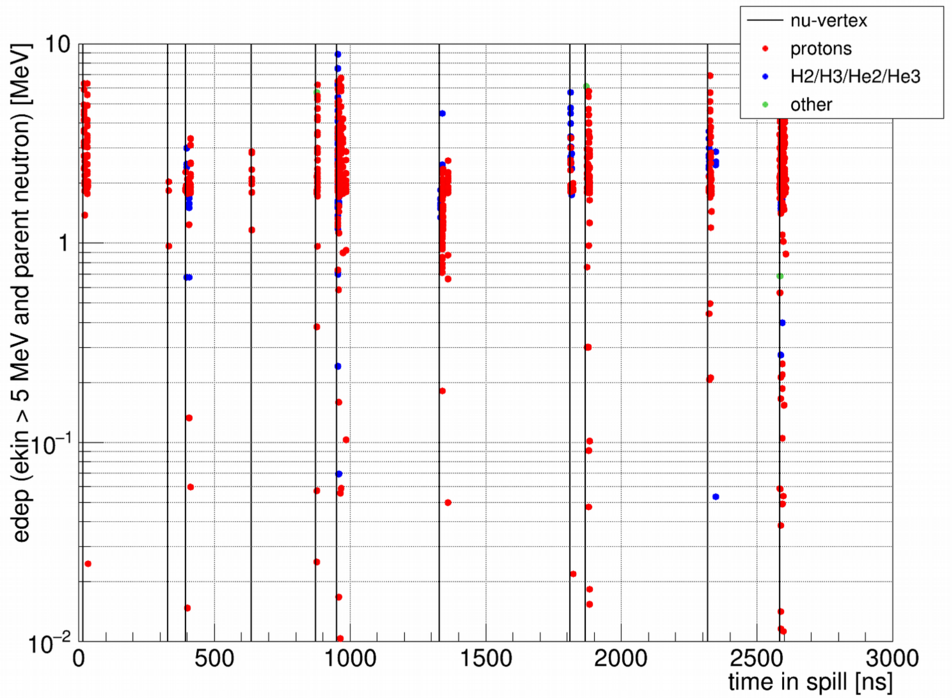


~15 recoil proton tracks per spill, mostly in other TPC than nu-interaction

Neutron ↔ Neutrino Association

- Spill length: 10 us, Spill frequency: ~1 Hz
- Average drift time at 1 kV/cm: ~100 us
- ArCLight pulse resolution: ~6 ns

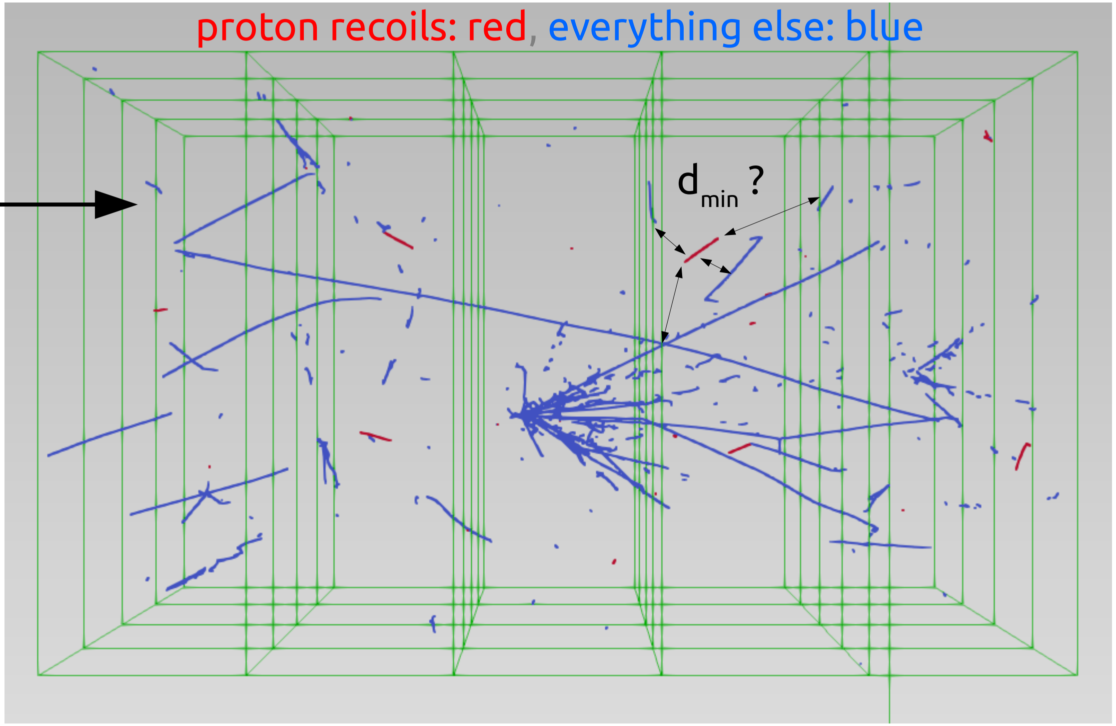




→ use prompt light from protons and neutrino interaction vertex to associate tagged neutrons with neutrino-interactions

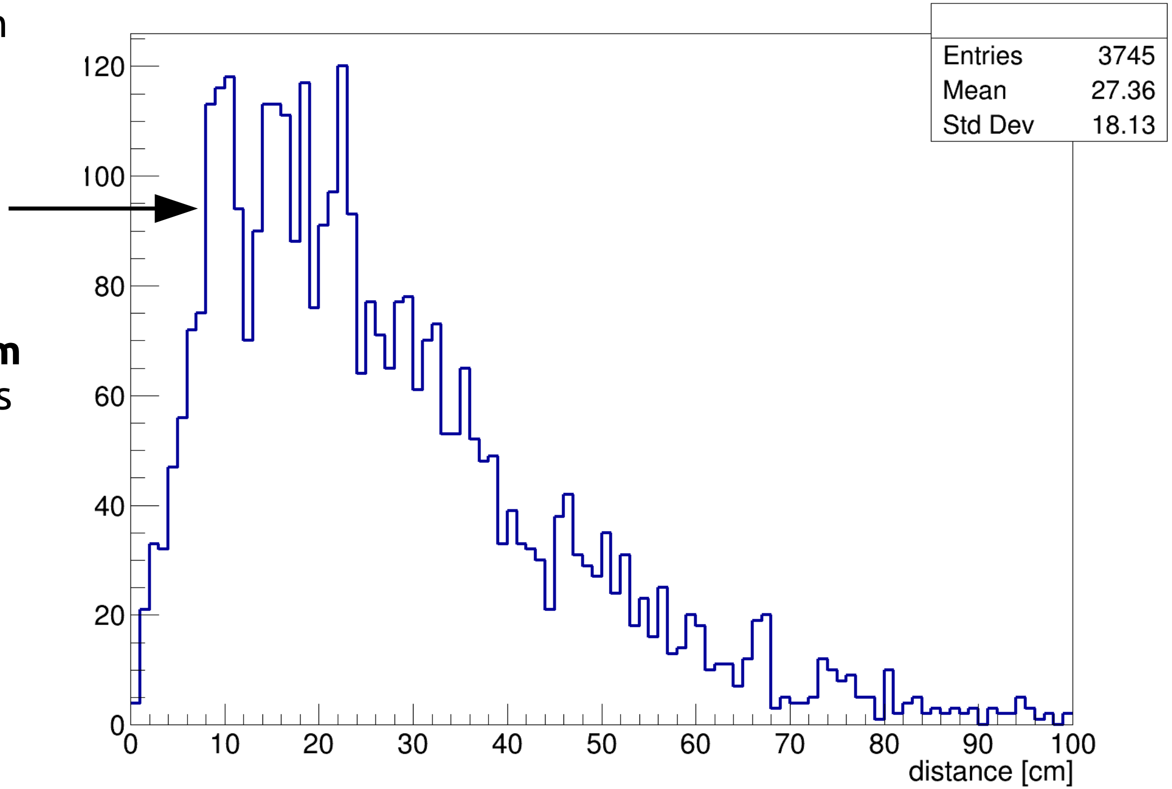
ArcLight – Spatial Resolution

- Pileup → need spatial information from light readout together with timing information
- What is the distance from a recoiling proton to any activity above 0.1 MeV from other interactions?
  - → with a spacial resolution of ~**30 cm** possible to separate proton tracks from other activities
  - → Can we do this with ArCLight?



ArcLight – Spatial Resolution

- Pileup → need spatial information from light readout together with timing information
- What is the distance from a recoiling proton to any activity above 0.1 MeV from other interactions?
  - → with a spacial resolution of ~**30 cm** possible to separate proton tracks from other activities
  - → Can we do this with ArCLight?



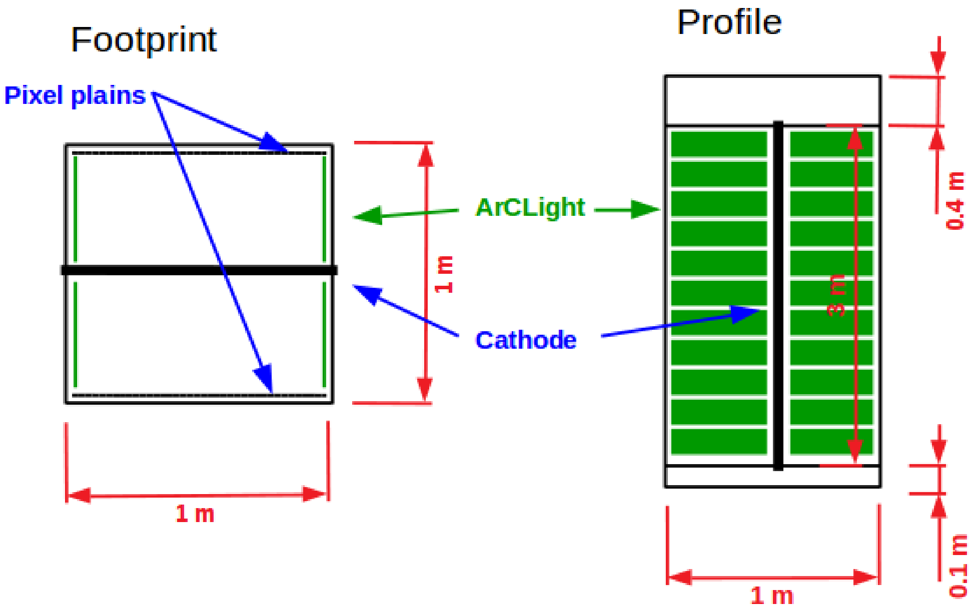
ArCLight – Spatial Resolution

- ArCLight modules line the inner fieldcage
- Stacked vertically in horizontal strips
- How many modules at each side do we need to achieve a spatial resolution of ~**30 cm**?

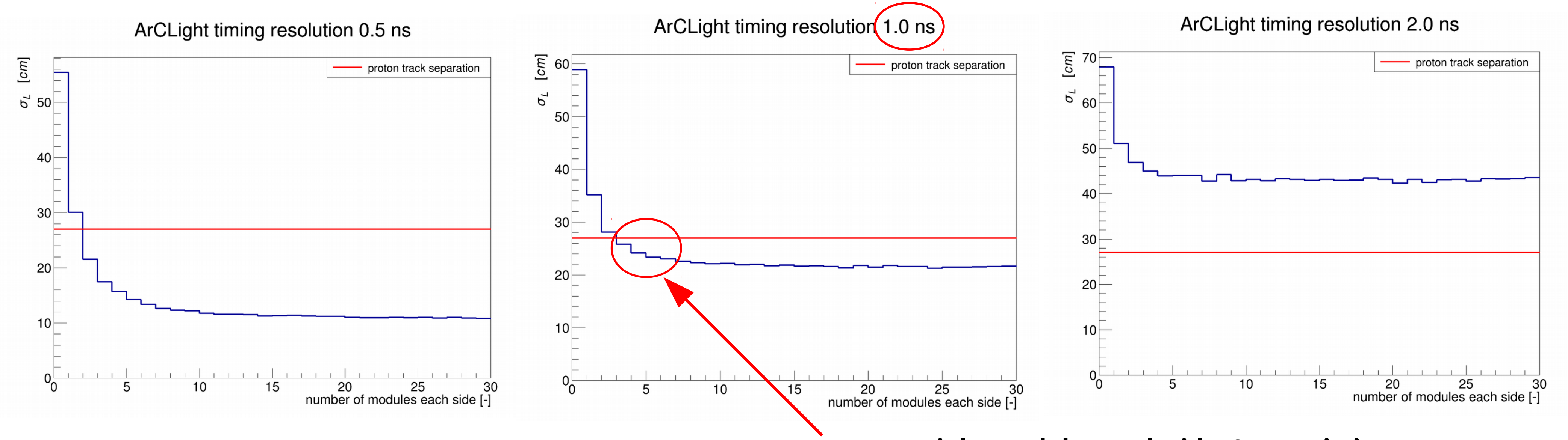
→ simulate isotropically distributed photon emission from random recombination points

→ calculate time uncertainty from residuals

(→ use pulse shape of ArCLight signal (TAC) to increase timing resolution)

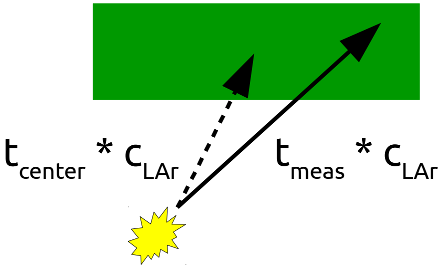


ArcLight – Required Dimensions



~6 ArCLight modules each side @ 1 ns timing accuracy

$$\sigma_t = \sqrt{\sum_{i=1}^{n} \frac{\left(t^i_{meas} - t_{center}\right)^2}{n}} \quad \text{and} \quad \sigma_{pos} = \sigma_t \cdot c_{LAr}$$



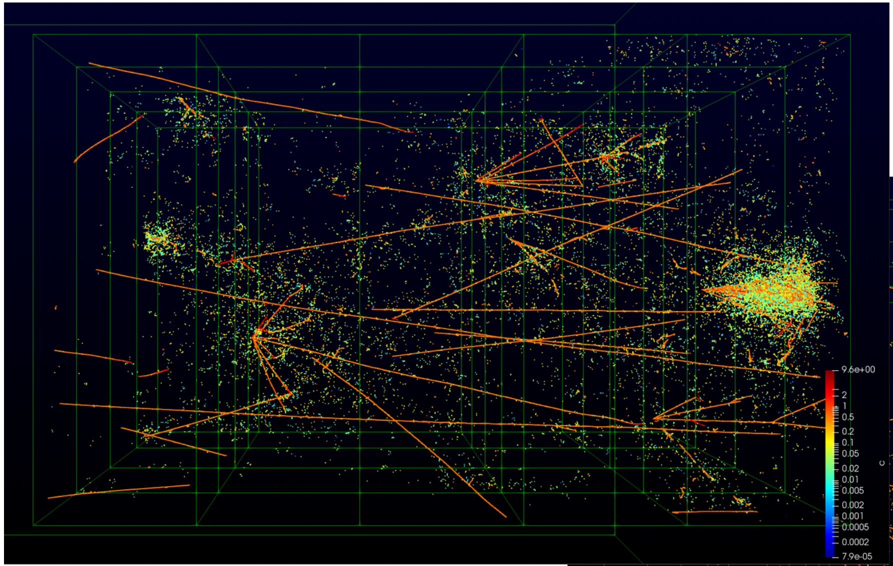
Conclusions and Outlook

- Neutron induced proton recoil is the best indicator to flag events with mis-reconstructed neutrino energy
- Pixel readout can resolve proton tracks > 10 MeV
- Light readout can handle event multiplicity with time from prompt light
- Light readout with good timing (~ 1ns) provides necessary spatial resolution to separate proton recoils from other activities

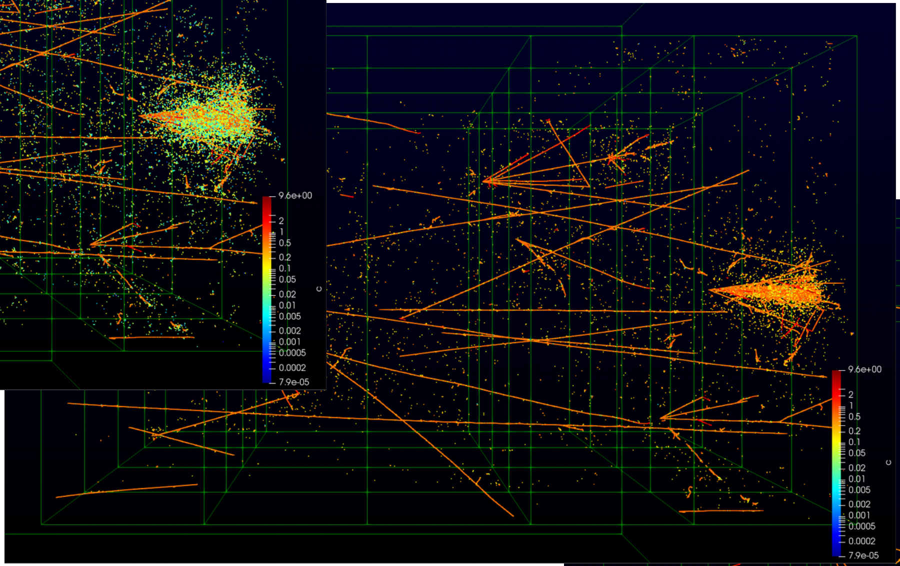
Next:

- ArCLight intensity study
- GEANT4 simulation for light propagation in ArgonCube

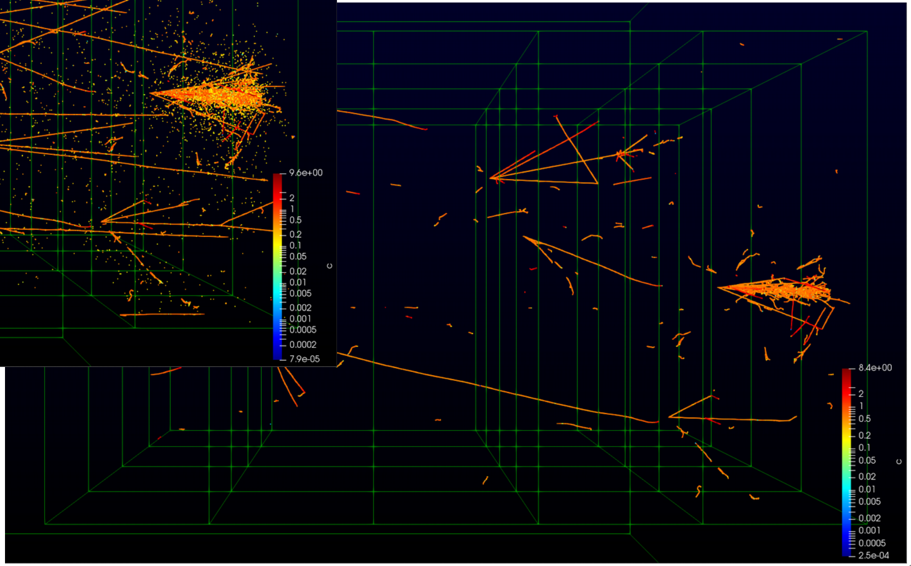
Event Display – Track Energy Threshold



no threshold

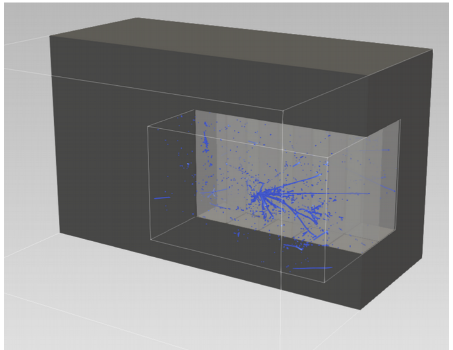


0.1 MeV



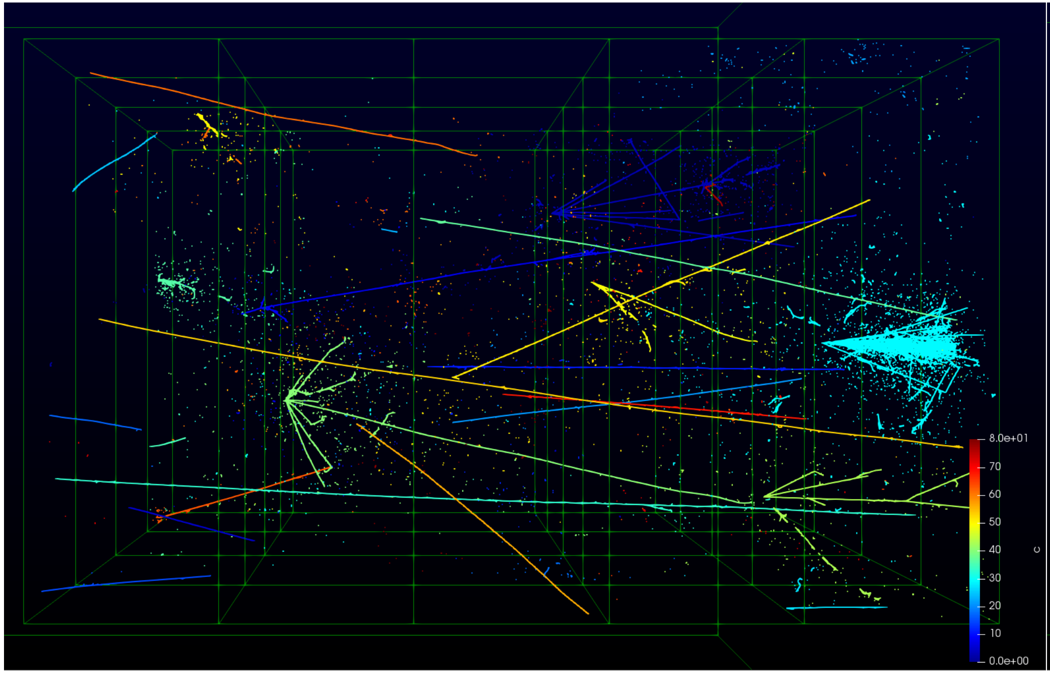
10 MeV

full spill simulation including rock events →

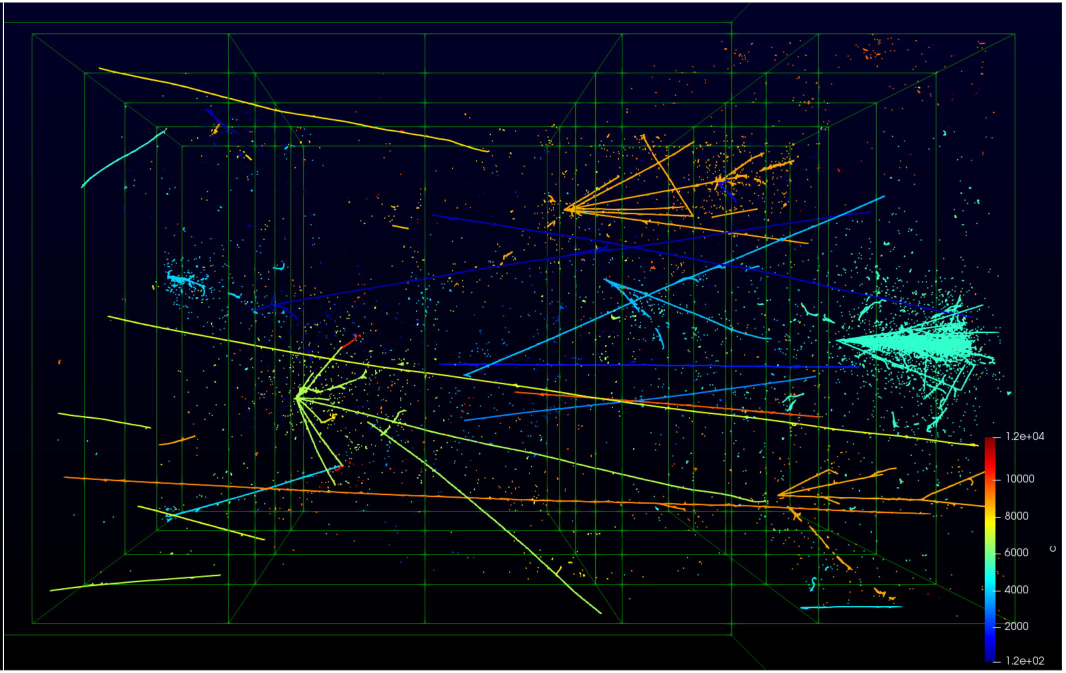


Event Display – Pileup Studies

color by eventID



color by tq (time of energy deposits)

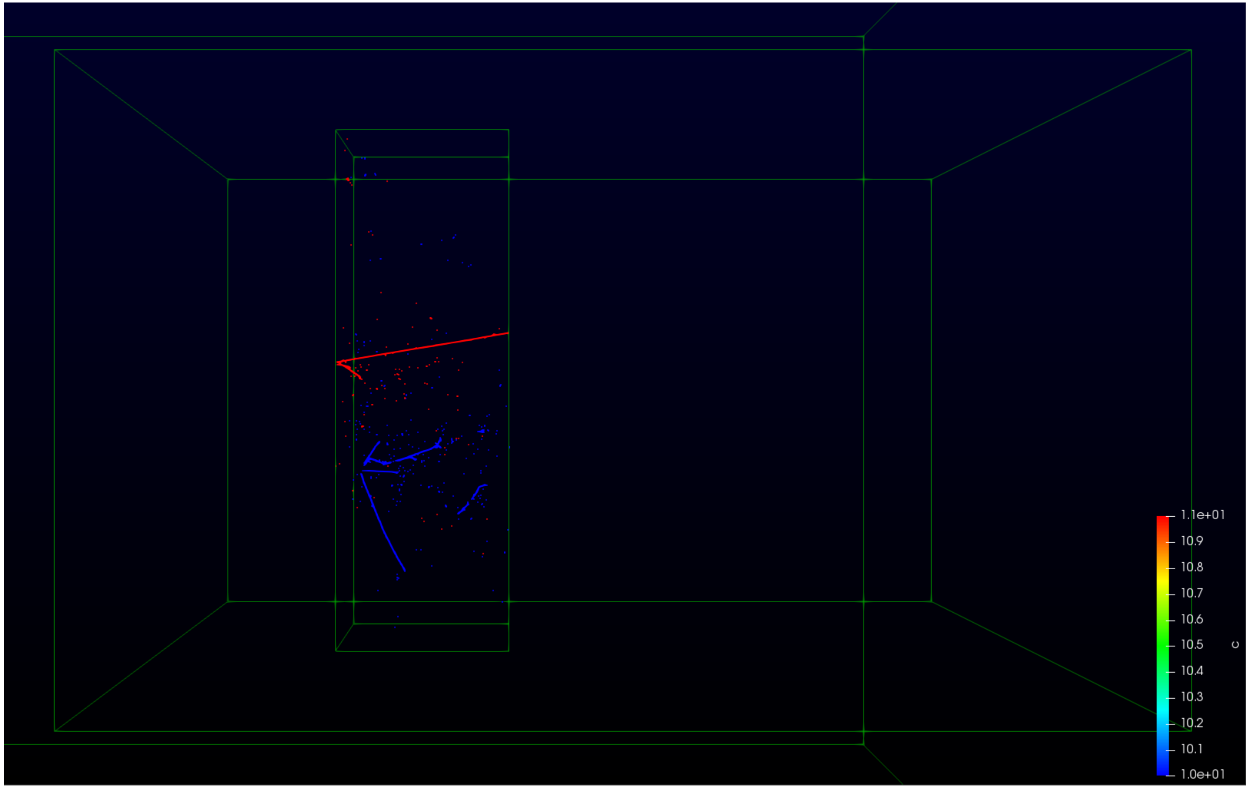


Event Display – Single Modules/TPCs

What is seen by a single module / TPC?

Showing only the module of interest and color defined by TPC number:

→ allows to see the content of single TPCs



Backup - Event Display

Tree converter:

ArgonBox raw files → Event Display format

Each entry in the Event Display format represents a track containing the information shown here →

Event Display commands:

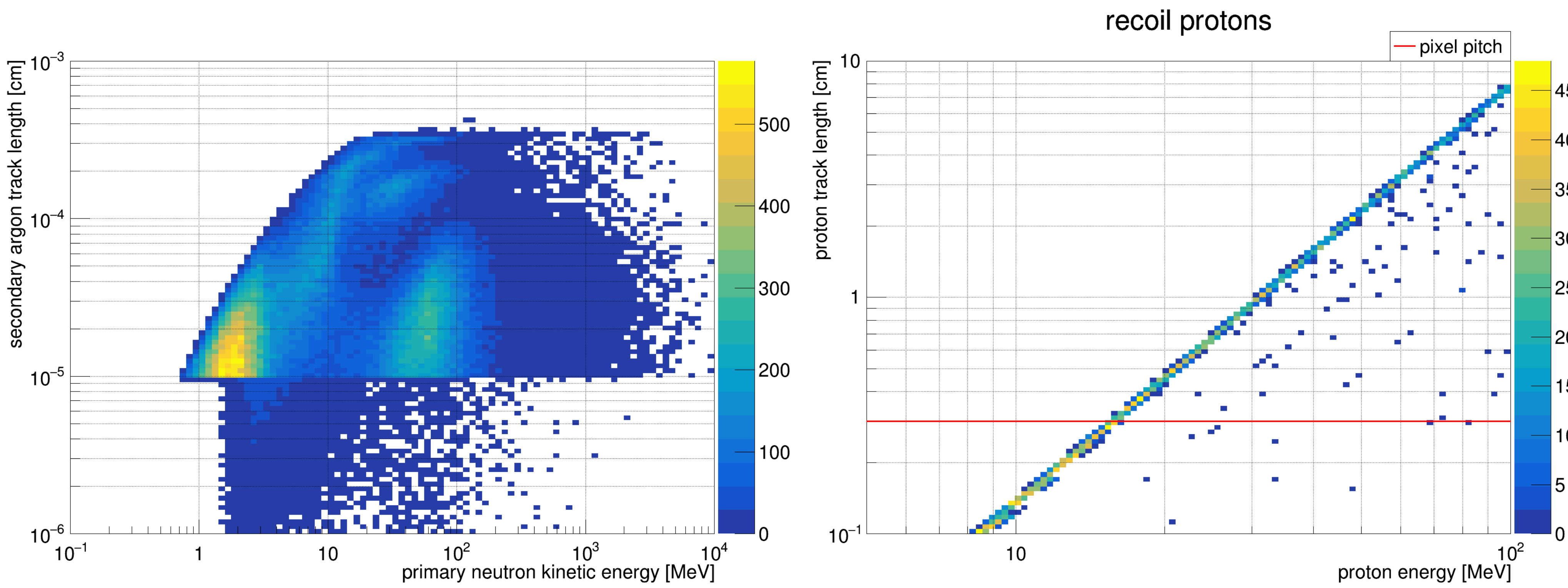
- `python event_display.py ArCube*.root`

  options:

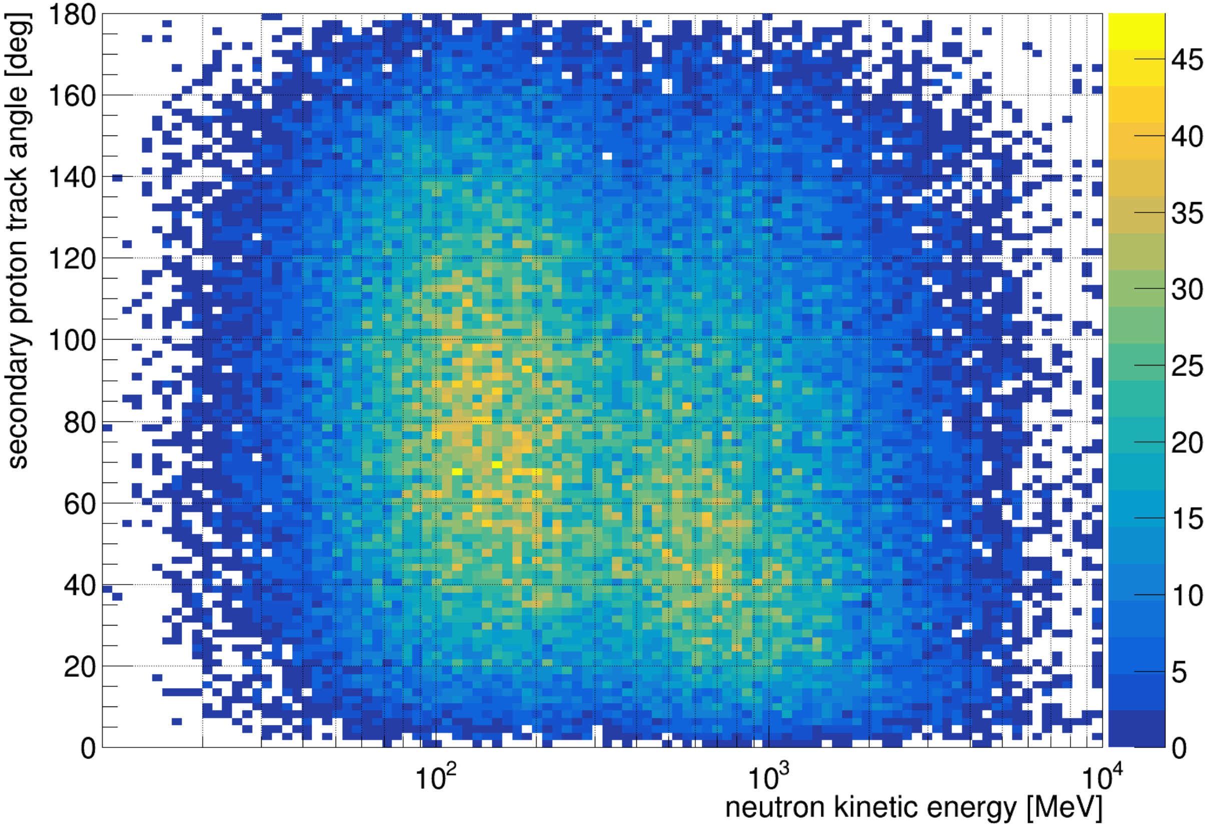
- ```
  -h:  help
  -a:  show 360° orbit animation
  -c:  set coloring style (any variable in tree)
  -m:  module number (default: 0 = all modules)
  -s:  spill number in the tree (1, 2, ...)
  -t:  kinetic energy threshold for tracks (GeV)
  ```

spillID	# ID of the spill	[%d]	
eventID	# ID of the event	[%d]	
trackID	# ID of the track	[%d]	
vtx_mod	# number of TPC containing nu vtx	[%d]	(1 - 40)
vtx_x	# x-position of nu vtx	[cm]	
vtx_y	# y-position of nu vtx	[cm]	
vtx_z	# z-position of nu vtx	[cm]	
vtx_t	# time of nu vtx	[ns]	
nu_pid	# PDG PID-code of nu	[%d]	
nu_ekin	# kinetic energy of nu	[GeV]	
tid	# track ID	[%d]	
pid	# PDG PID-code of the track	[%d]	
parid	# tid of the parent track	[%d]	
ekin	# initial kinetic energy of the track	[GeV]	
recoil	# flag for recoiling protons	[%d]	(0 or 1)
nq	# number of energy deposits	[%d]	
modq	# number of TPC containing dq	[%d]	(1 - 40)
dq	# deposited energy	[MeV]	
xq	# x-position of energy deposit	[cm]	
yq	# y-position of energy deposit	[cm]	
zq	# z-position of energy deposit	[cm]	
tq	# time of energy deposit	[ns]	
  ```

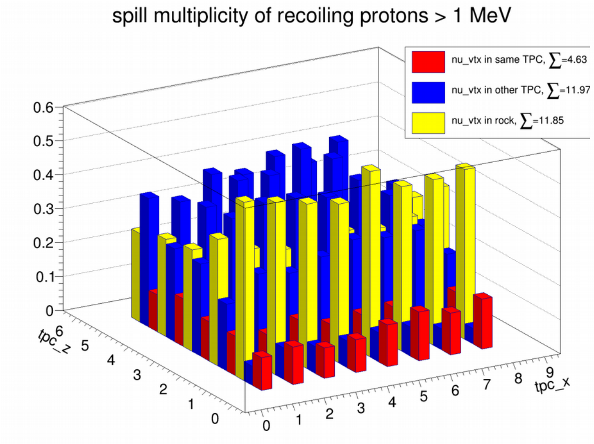
Backup – Track Length

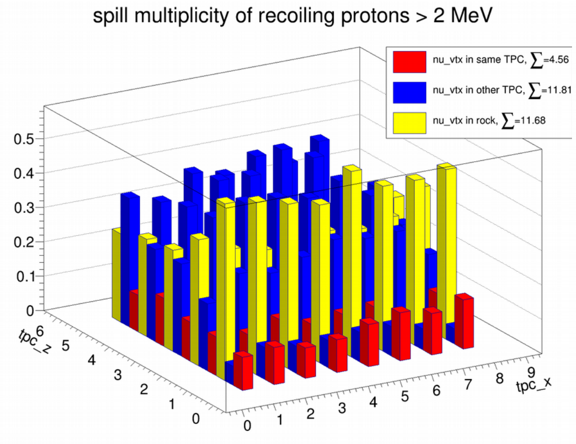


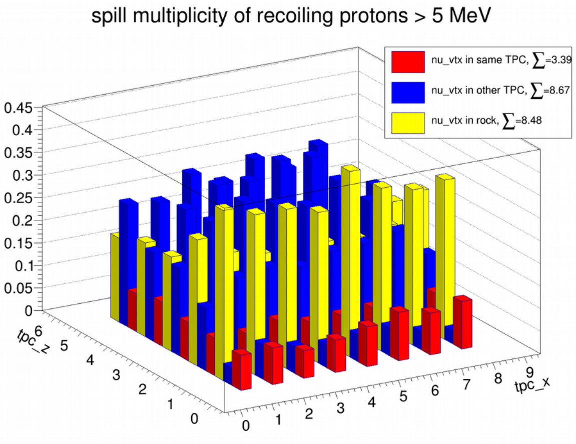
Backup – Neutron Energy Reconstruction

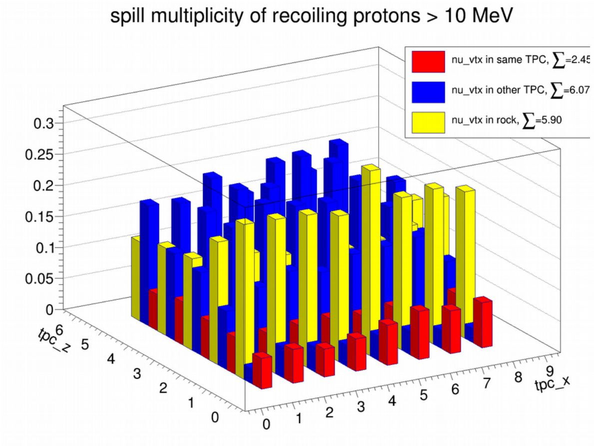


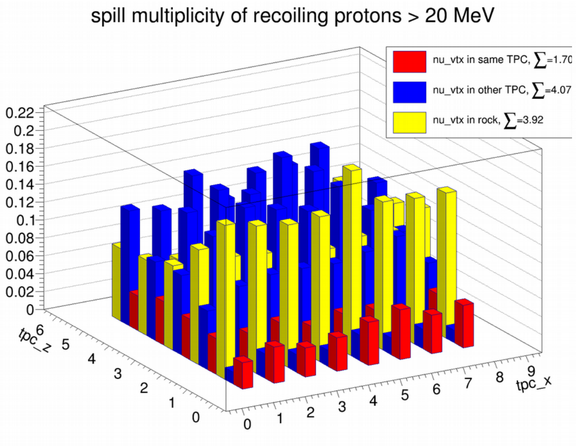
Backup – Proton Pileup Plots

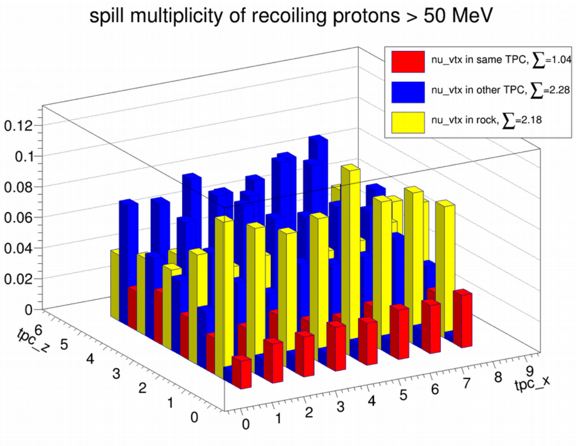




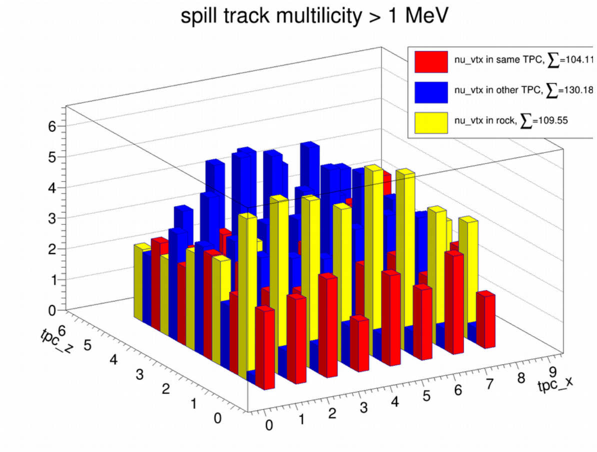


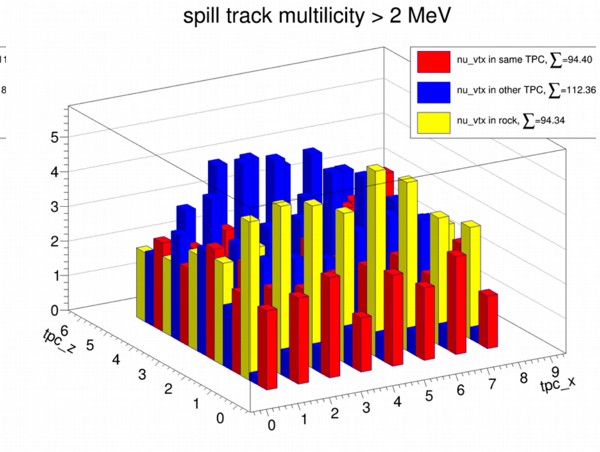


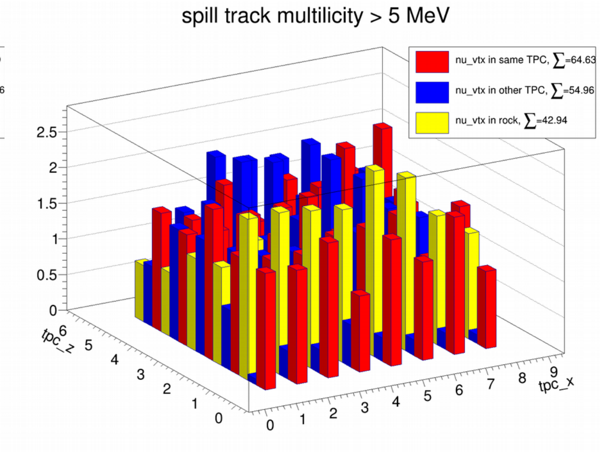


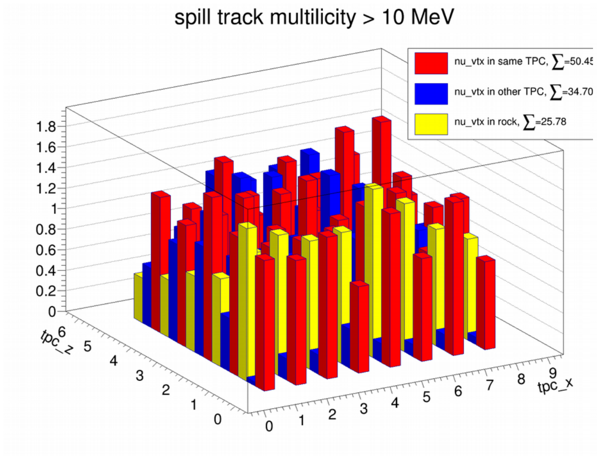


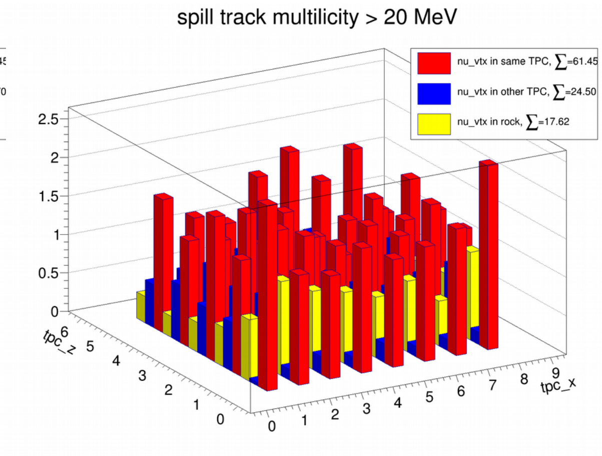
Backup – Track Pileup Plots











Backup – Charge Position Reconstruction