# DarkSide-20k : Cosmogenic backgrounds

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Total simulation lifetime ~ 158.2 years

Within protodune-style cryostat , 5 nested volumes (from inside to outside)
- LAr TPC/sensitive volume ( ~ 50 tons of LAr)
- Acrylic TPC wall (5 cm all directions)
- Inner LAr Veto (40 cm thick around the vessel)
- Gd-doped acrylic veto (10 cm thick around the inner veto, Gd at 1 % mass fraction)
- Outer LAr Veto ( 40 cm thick around Gd-doped acrylic veto)
- LAr Bath ( ~ 700 tons)
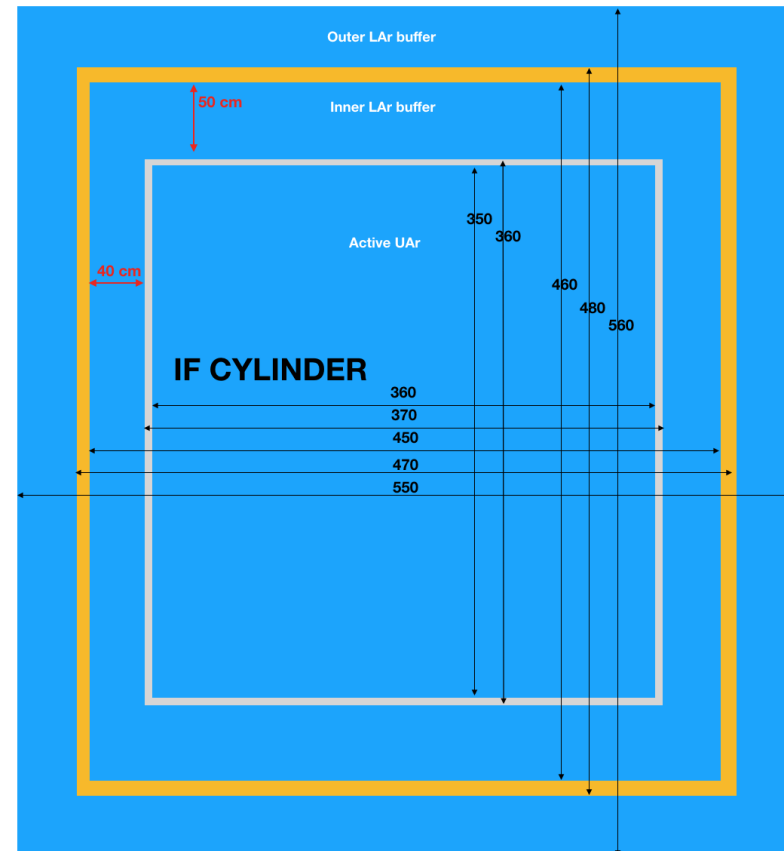
# Implemented design and geometry
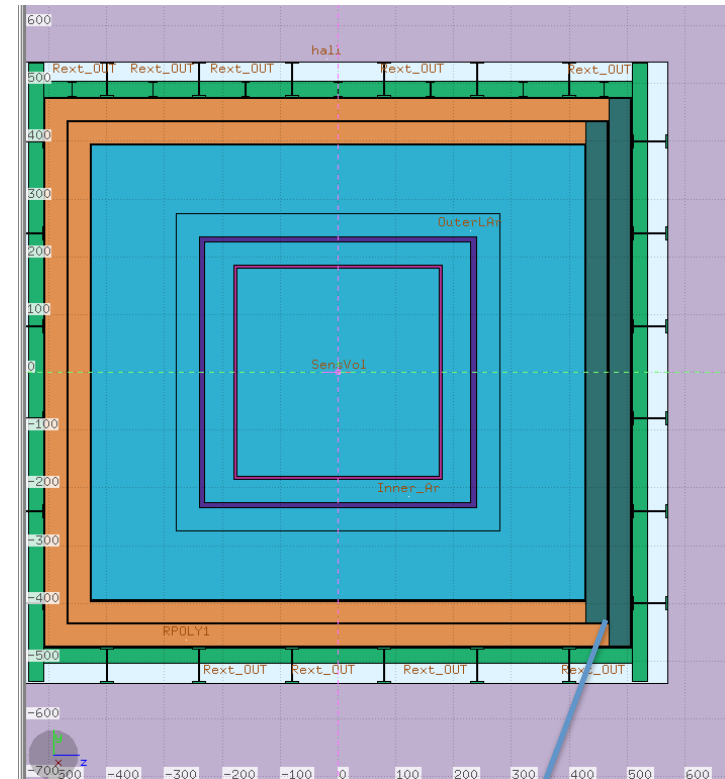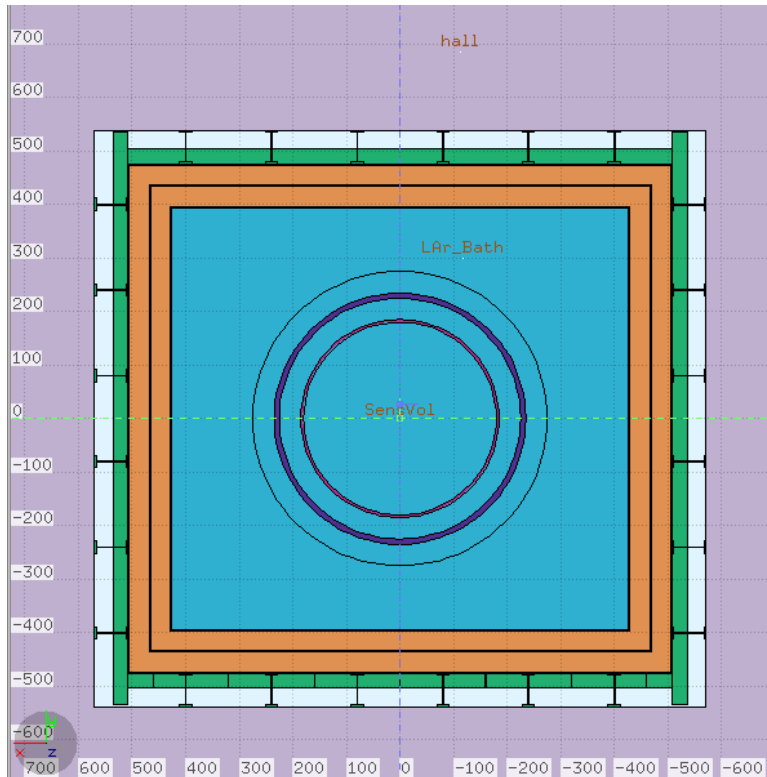


Double-layered polyure foam at the cryostat roof (reduced density now)

## Physics cards

PRECISIO - activates most of the physics processes relevant to cosmogenic muon interactions, while threshold for transport of the various particles can be set by user.

PHOTONUC - Photo-nuclear interactions (activated on all materials)

EVAPORAT and COALESCE – needed to allow nuclear-deexcitation

RADDECAY – simulate radioactive decays

IONTRANS – Activate nucleus-nucleus interactions and transport.

To allow nucleus-nucleus interactions at higher energies (above 125 MeV/n), FLUKA requires linking of external event generators DPMJET and RQMD creating ldpmqmd executable.
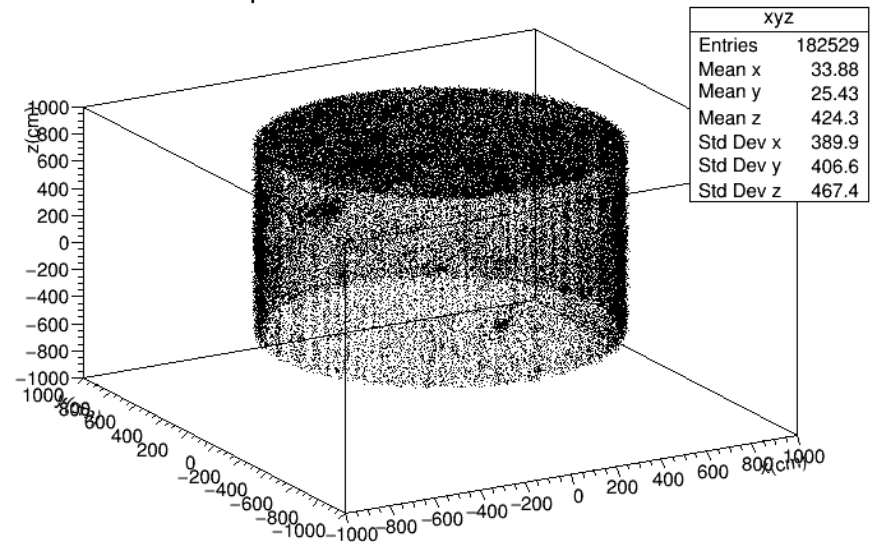
Low energy neutron are transported down to thermal energies.

FLUKA version used
2011.2x.8 from November 2019

- Full muon and muon-induced particle field at Hall-C propagated and stored on virtual cylinder 14 m height and 14 m diameter (carried out by Anton Empl)

- Present DarkSide-20k cryostat corners stick out of the cylinder, pulled back events by 78 cm to propagate the events in.

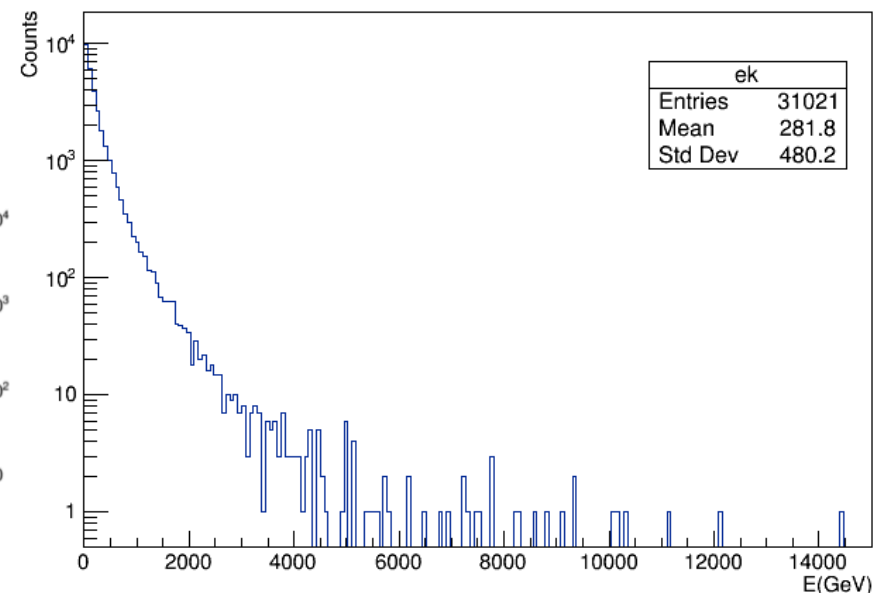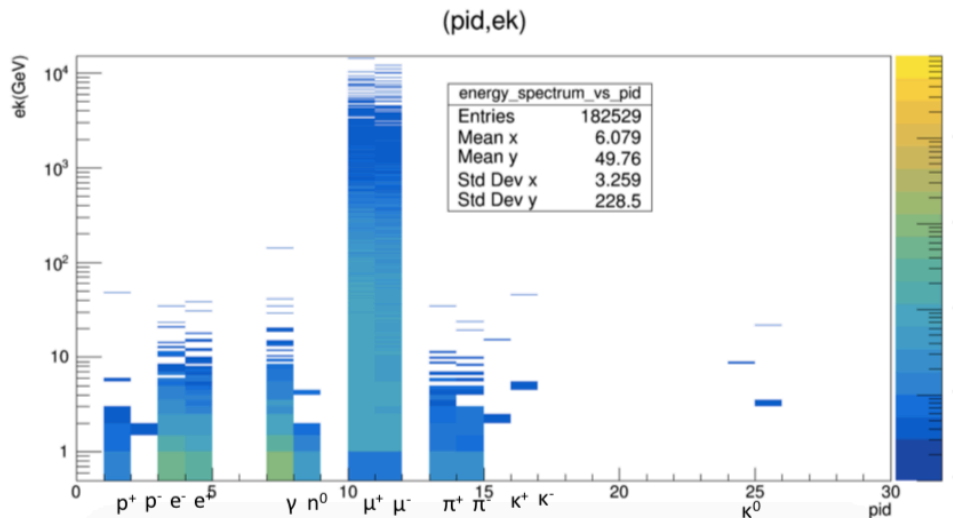- Need to read the events in using source.f (FLUKA)

Muon event rate at cavern ~ 3.4 x $10^{-4}$ $s^{-1}$ $m^{-2}$

50,000 events



spatial distribution of the events

| xyz | |
|---|---|
| Entries | 182529 |
| Mean x | 33.88 |
| Mean y | 25.43 |
| Mean z | 424.3 |
| Std Dev x | 389.9 |
| Std Dev y | 406.6 |
| Std Dev z | 467.4 |

Sample event file (fort.95)
Information: Event id, pid,age,x,y,z,cxi,cxj,cxk



(pid,ek)

| energy_spectrum_vs_pid | |
|---|---|
| Entries | 182529 |
| Mean x | 6.079 |
| Mean y | 49.76 |
| Std Dev x | 3.259 |
| Std Dev y | 228.5 |

muon energy spectrum

| ek | |
|---|---|
| Entries | 31021 |
| Mean | 281.8 |
| Std Dev | 480.2 |

## Simulation Procedure

### Step1

- Propagated the events , collected the raw energy deposition in
  (LArBath, Outer Lar Veto, Inner LAr Veto, TPC)
- Recorded full information (event id, particle id, KE, age, position and directions)
  for events tracked entering sensitive volume and written to external file

### Step2

- Propagated the events further into the sensitive volume demanding information of
primary event as well as secondaries ( interactions, types, energy deposits)
To speed up the simulation and concentrate on critical events following events were
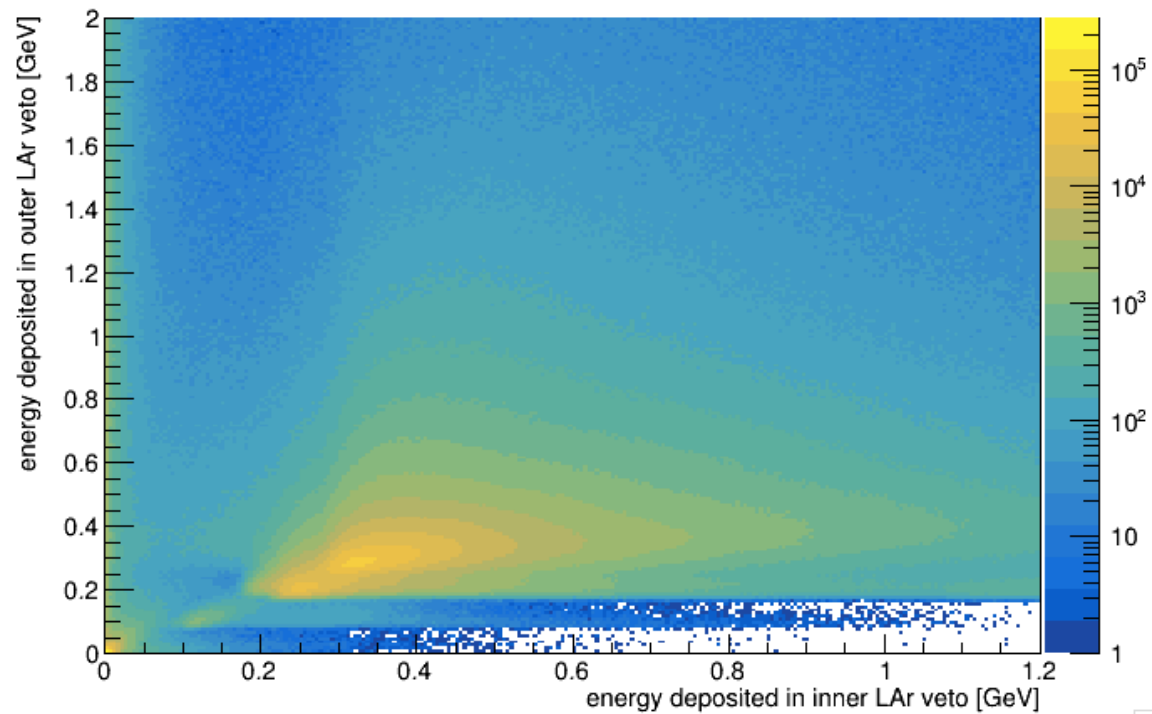rejected after initial studies
  i) Events for which a muon is tracked entering sensitive volume
  ii) Sum energy of particles for an event is greater than 2 GeV
  iii) Number of particles for an event is greater than 50.
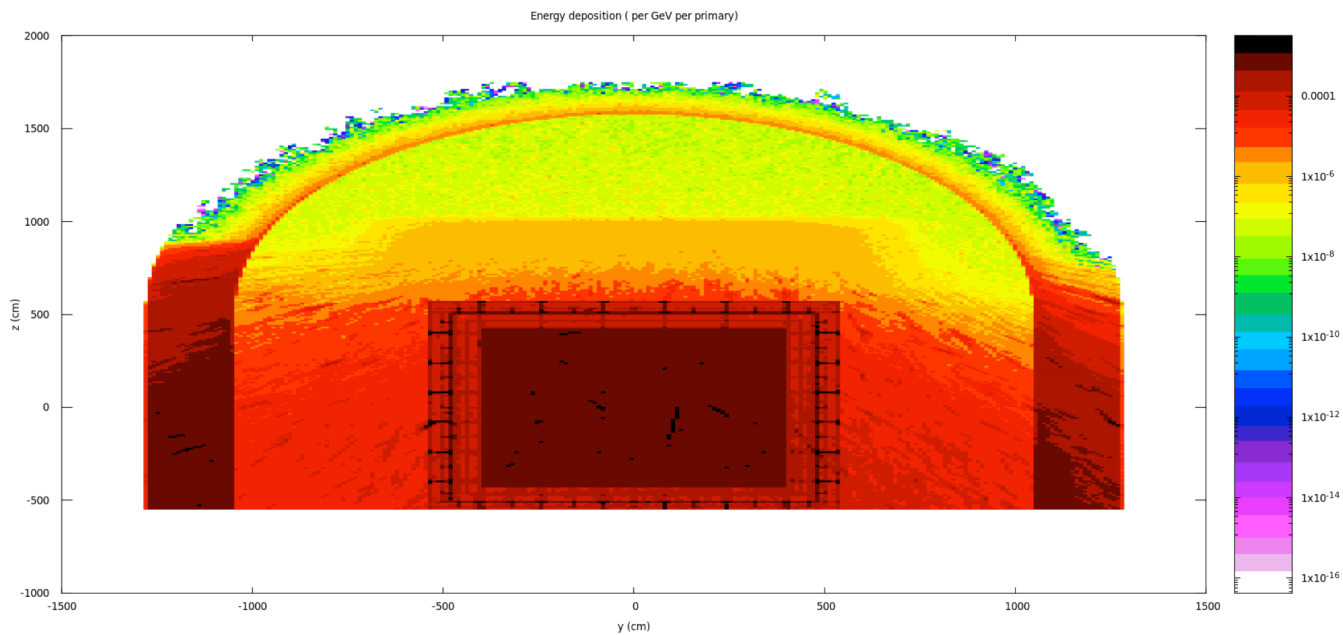
Energy deposition per GeV per primary (Y-Z view (top), X-Y view(bottom))
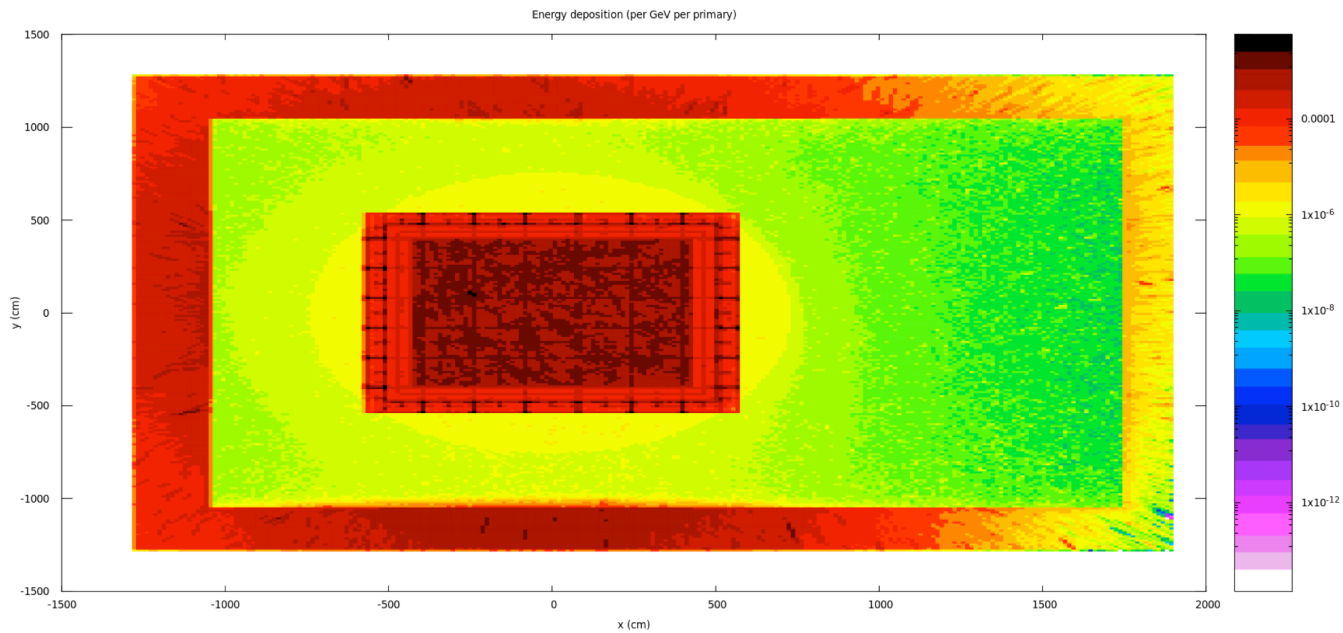
## energy deposition in veto detectors



| Just outside of | Cosmogenic event rate |
|---|---|
| Liquid Argon Bath | 2.50 /min |
| Outer Argon Passive Veto | 0.92 /min |
| Inner Argon Active Veto | 0.65 /min |
| Sensitive liquid argon volume | 0.40 /min |

# EVENT RATES

➢ Events for which at least one particle entering sensitive volume
  580 per day      (6.3% of original events)
➢ Events for which a muon is tracked entering sensitive volume
  450 per day      (4.8% of original events)
➢ Events for which at least one neutron is entering sensitive volume
  38 per day         (0.4% of original events)
➢ Events that have at least one neutron interacting on sensitive volume
  and satisfy – Sum vetoes energy < 10 MeV and energy in TPC < 2 MeV
  58.16 per year  ( Loosely , this cosmogenic neutron background event rate )


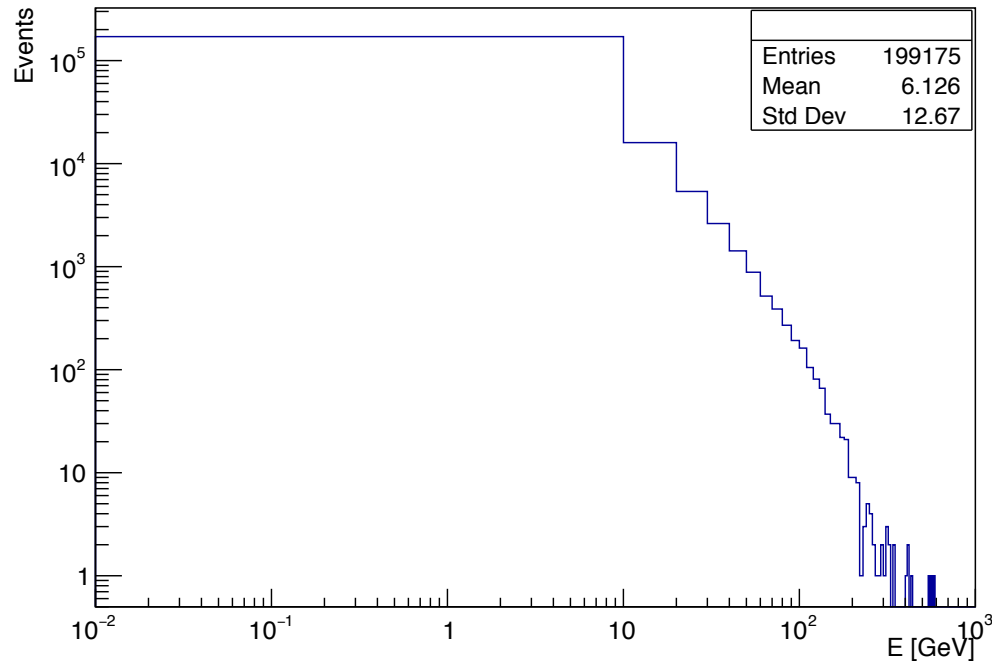
Single-neutron event energy deposition in sensitive volume
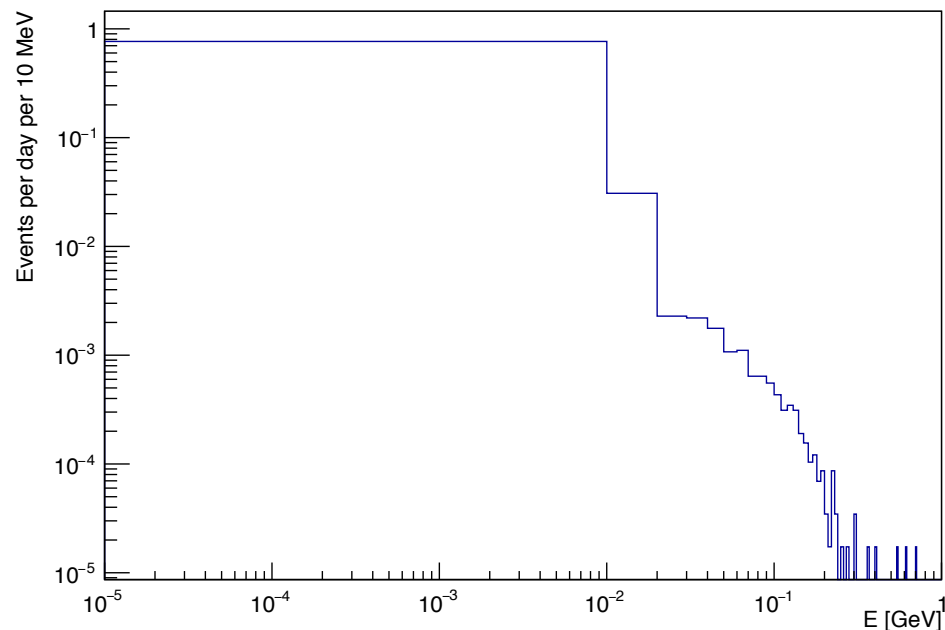
Single neutron entering TPC -> 295 per year

Events for which sum veto energy deposition < 10 MeV and energy deposited in TPC < 2 MeV

- 199175 events in 158.2 years ( 3.449 per day)
( for 13.6 years, 3.41 per day, with no cryostat roof change)

Energy deposition in LAr Bath



| Entries | 199175 |
| Mean | 6.126 |
| Std Dev | 12.67 |

Lot of events that deposit sum veto energy < 10 MeV , but left lot of energy
in LAr bath. Most of > 10 GeV events are  original energetic muons that grazed the LAr bath and
possibly escaped.

- Only 1 event where neutron didn't enter but neutron was created in the interaction (Kaon decay), multiple energy deposits, and scatterings induced by the resulting interaction

- Demand at least one neutron entering , there are 9201 events out of 199175 events.

- Both event-end energy deposit (and interaction kind) and depositions along the track were recorded for all events.

- All the events for which there is some neutron interaction  within the sensitive volume are found multi-sited in principle. It includes all neutron-containing 9201 events.

- There are 194 events for which number of deposition sites <= 5 and single event end nuclear recoil. If restricted to sum veto energy deposition < 2 MeV and ene_tpc < 2 MeV, 29 events remain. But there are 122 events all involving at most two scatterings were event-end deposit is not available. All these events involve neutron with kinetic energy < 2 keV entering sensitive volume.

 - FLUKA low-energy-neutron treatment transports neutrons all the way to thermal energies. 122   events for which neutron with KE < 2 keV enters sensitive volume scatters but does not deposit energy locally in sensitive volume.

- All these event-end deposits induced nuclear recoil in target and were treated with low energy neutron physics models. Need to confirm indeed there were multiple-sited depositions especially for neutron especially for neutron only events.

# Moving forward

- Study the interactions, Look at the track interactions/ scatterings for event-end deposit resulting in a single nuclear recoil

- Propagate selected events sum veto energy< 10 MeV and energy in TPC < 2 MeV events in g4ds.

BACKUP

# Previous Studies

- A Fluka study of underground cosmogenic neutron production (A.Empl et al., 2014)
- Simulations for an alternative veto design   (DarkSide-doc-2361-v11)

- Muon propagated through 700 cm of Gran Sasso rock for full shower development

- Muons and muon induced secondary particles captured at ceiling of Hall-C and further
  propagated and transported on the virtual cylinder of  height 14m and diameter 14m
  (size of original DarkSide-20k baseline design with water tank)
- For our simulation geometry 79.1 years simulation lifetime of data, more statistics created by rotating
  the events by $45^{0.}$

- The events (muon and muon-induced secondaries) are fluka outputs (fortran binary (named fort.94))

- In newer design, the corners of cuboidal cryostat extend  78 cm beyond the curved surface of cylinder

- Pull back the events by 78cm and propagate (incorporated in FLUKA user routine (source.f)

Change in design since Parth worked
- Inner detectors and materials ( AAr veto, Gd-doped acrylic, Size of inner detectors)
- Large LAr sensitive volume ( ~ 50 tons of LAr)
- cryostat roof (reduced polyurethane foam density on the roof)

Muon  flux at cavern ~  $3.4 \times 10^{-4}$ $s^{-1}$ $m^{-2}$