Estimate of background from beam induced external interactions for SAND detector

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Sources of background for SAND detector

The background events for SAND detector have three possible sources:

1) Cosmic radiation

2) Environment radioactivity

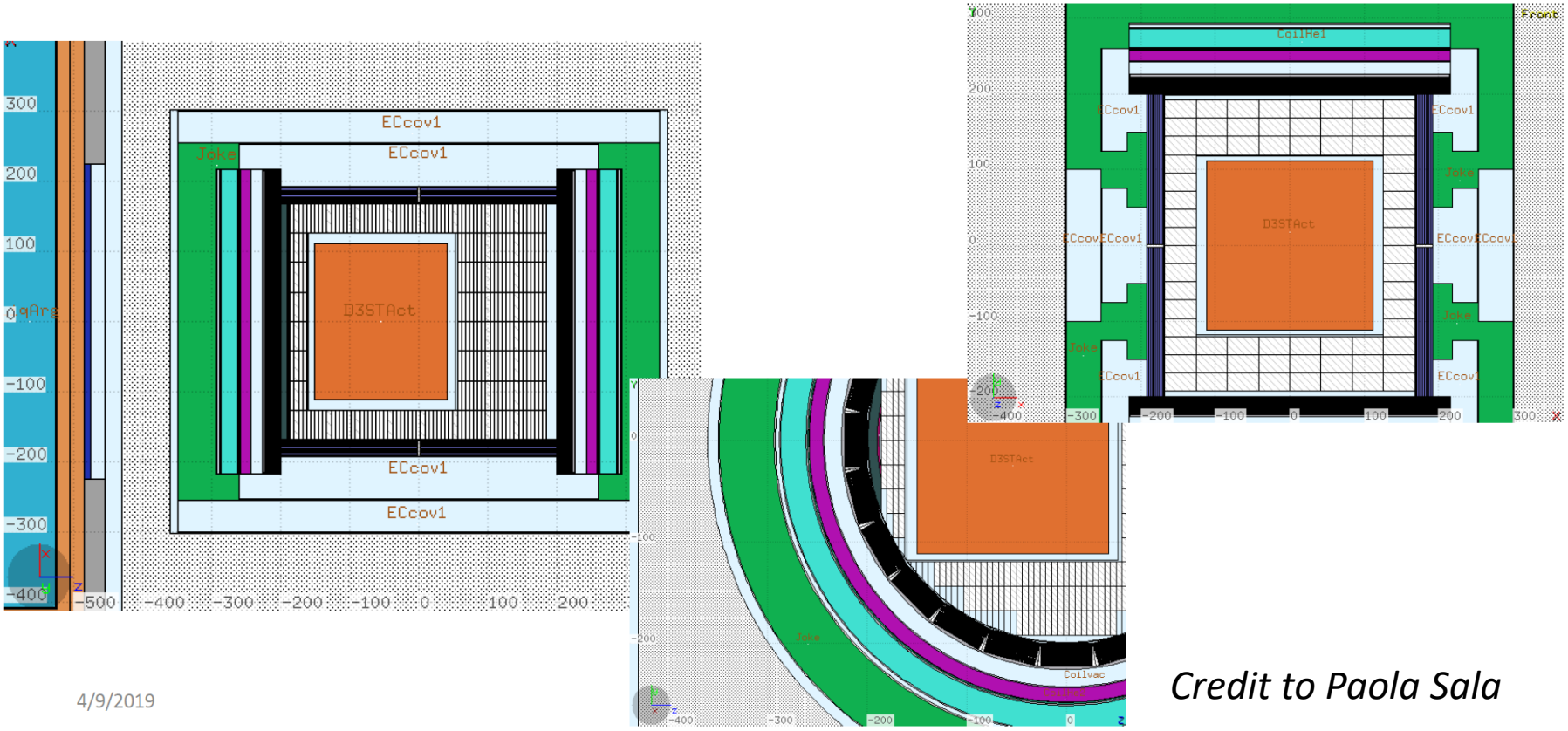
3) Beam-related netrino external interactions

The first two can be reduced to ~0 through the time coincidence with beam spill

The last one is the most critical

FLUKA simulation of SAND detector

Integration of 3DST, surrounded by tracking devices (STT)



Credit to Paola Sala

MC samples

✓ "Internal" events: ν_μ (CC) interactions inside 3DST

Target mass:

10.6 tons

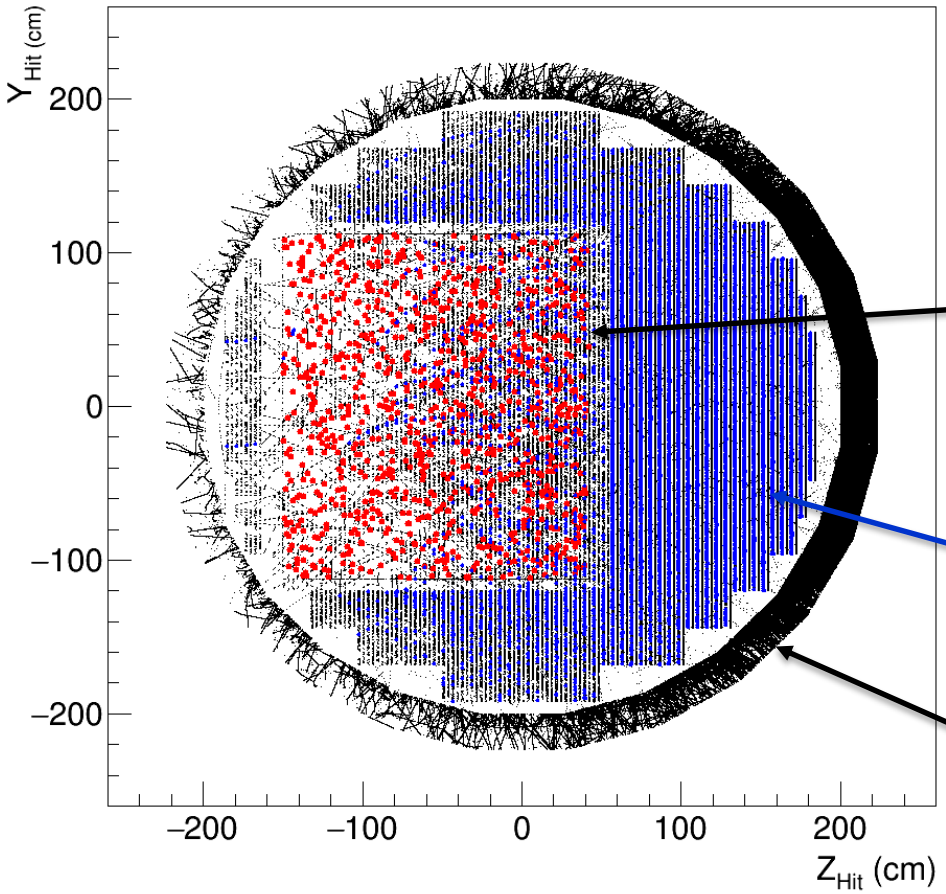
Active volume: 2.24x2.24x2 m^3
10,637,312 tons (1.06 g/cm^3)
139,776 channels ($1cm^3$ cube)

✓ "External" events: ν_μ (CC and NC) interactions inside SAND magnet+Calorimeter (ECal)

Target mass: **611 tons**

MC sample of internal events (CC)

10,000 ν_μ-CC interactions in the 3DST



● Interaction vertices in 3DST

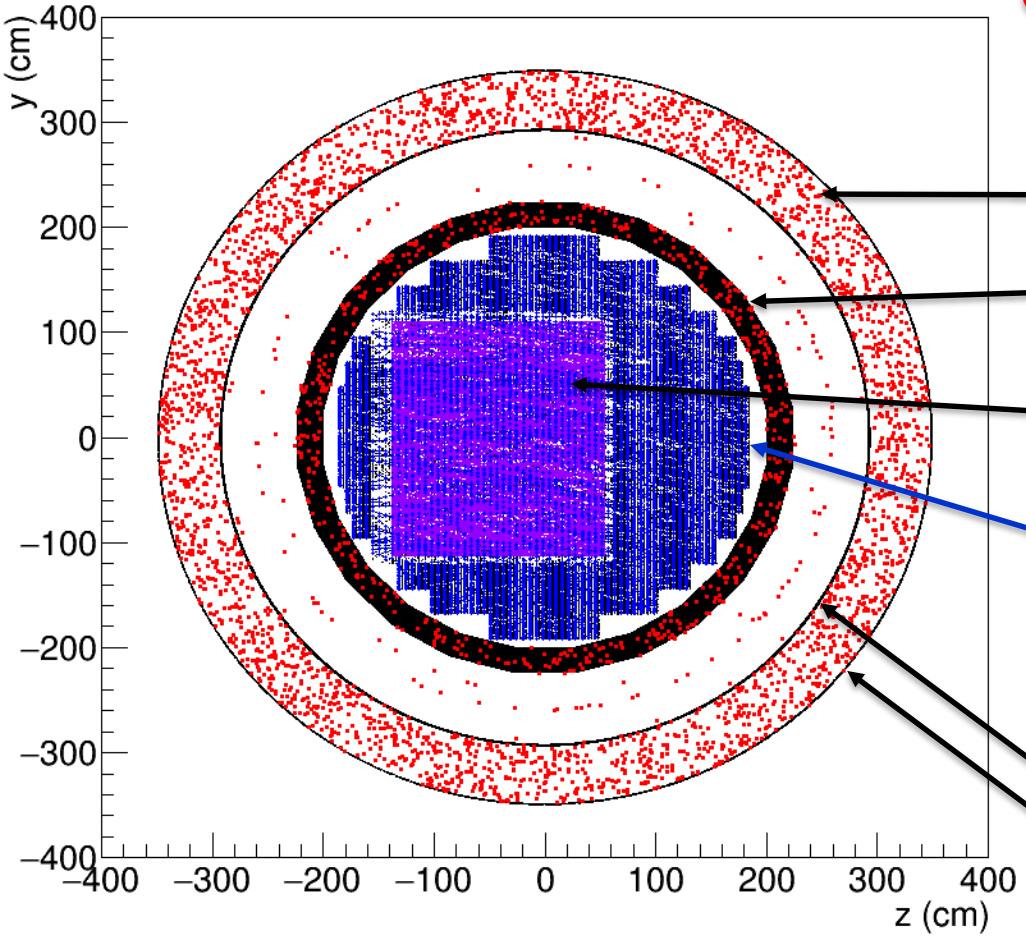
3DST
(2.24 x 2.24 x 2.4 m^3)

STT hits (charged particles)

Calorimeter (ECal)

MC sample of external events (CC)

86,000 ν_μ-CC interactions in the Magnet+Calorimeter



Interaction vertexes in magnet yoke and Ecal

Yoke

ECal

Hits in 3DST

STT hits (charged particles)

Muon Catchers:

Internal layers

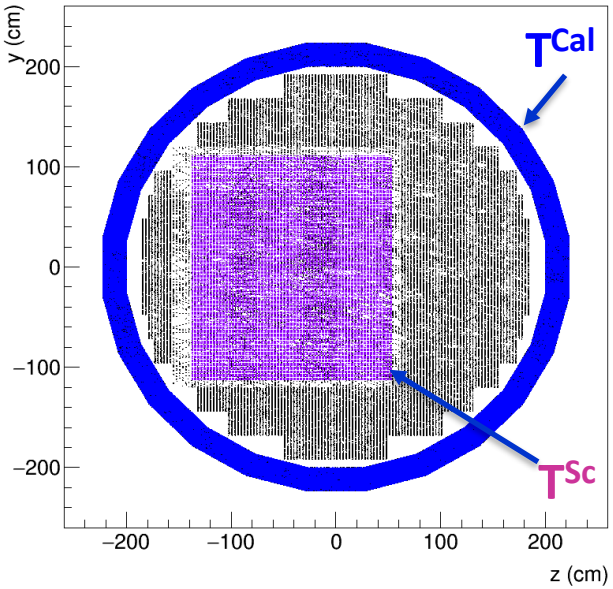
External layers

Selection of internal events

Based on time difference between ECal and 3DST

For each event in both (internal and external) samples:

- 1st time in Ecal ⇒ T_{1st}^{Cal} evaluated on Calo-Cells
- 1st time in 3DST ⇒ T_{1st}^{Sc} evaluated on 3D-Cells



In general:

$T_{1st}^{Cal} > T_{1st}^{Sc}$ ⇒ **internal event**

$T_{1st}^{Cal} < T_{1st}^{Sc}$ ⇒ **external event**

Simulation of ECal and 3DST

➢ ECal

- Cell-time: average of single fiber times weighted with $E_{dep,i}$
- Energy threshold: E_{th}^{Cal}=150keV (→ ~58% hit-surviving) (A)
  E_{th}^{Cal}=20MeV (→ ~19% hit-surviving) (B)
- Time resolution: gaussian spread with σ_t=54ps/√(E/GeV) ⊕ 50ps

➢ 3DST

- Cell energy: Σ of energies deposited by all particles in the event
- Energy threshold: E_{th}^{Sc}=0.5MeV (→ ~35% hit-surviving)
- Time resolution: gaussian spread with σ_t=500ps (3 fibers readout)

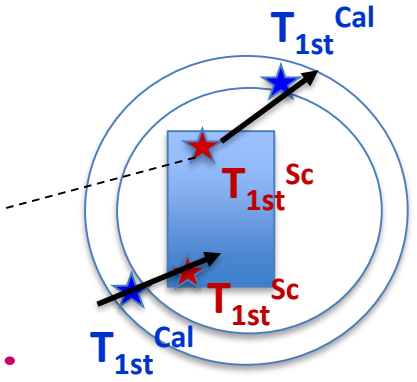
(… next step: use of σ_t=(0.95/√3)*√(2/E(MeV))ns, σ_t>200ps)

Background from external events

Two kinds of background expected:

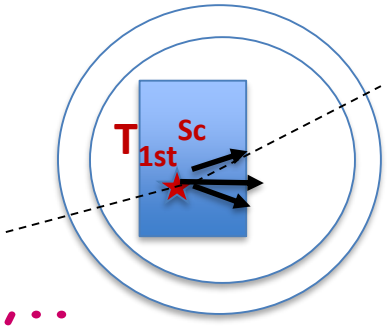
- Bck_1 → Time " reversal" ($T_{1st}^{Cal} > T_{1st}^{Sc}$)

  ... due to limited time resolution, neutrons giving delayed signals in ECal, ..

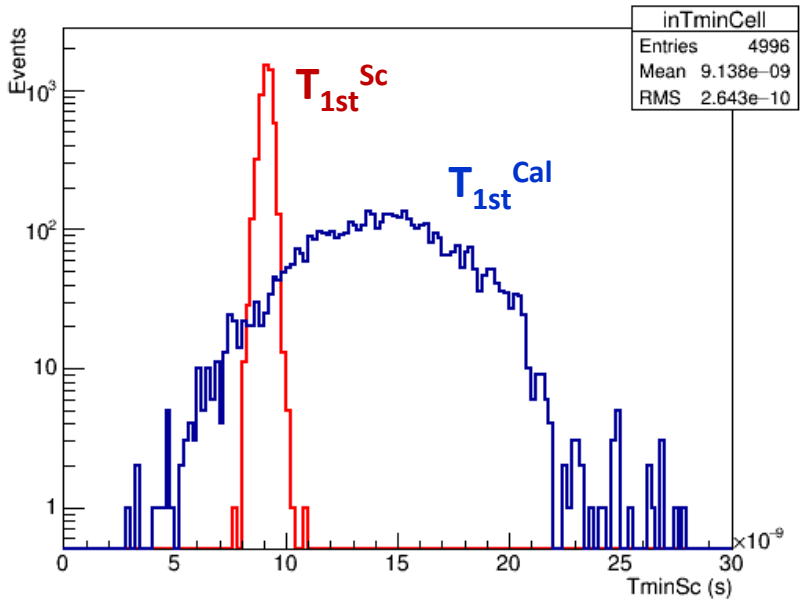


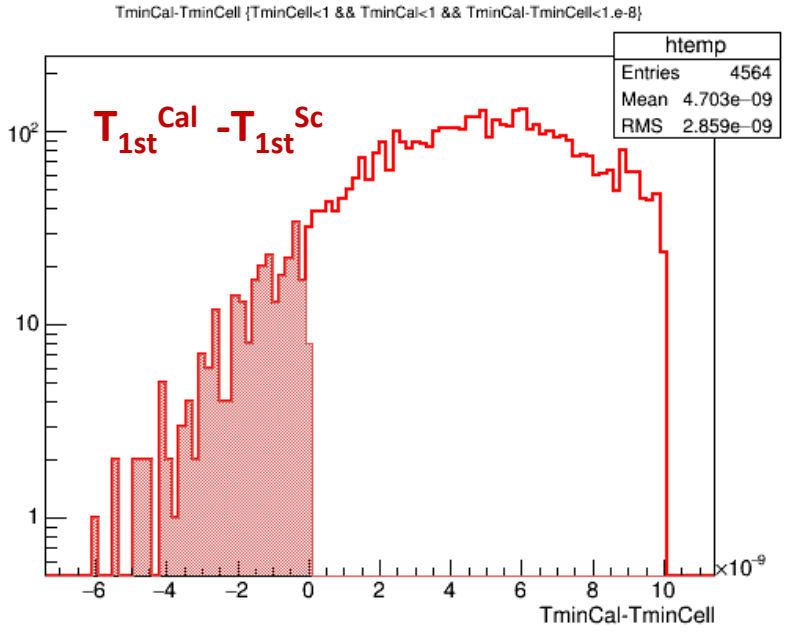
- Bck_2 → T^{Cal} missing in the event

  ... due to absence of ECal-cells with $E_{dep} > E_{th}^{Cal}$, ..



(A) Internal events – E_{th}^{Cal}=150keV





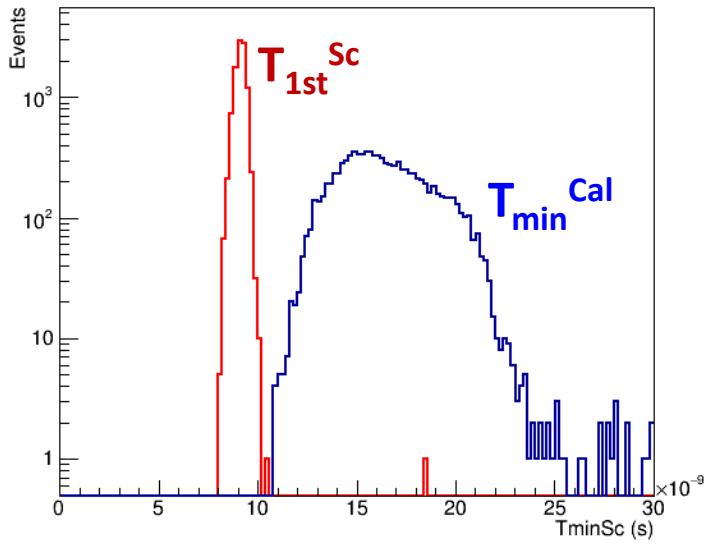
Significant tail with Time Difference < 0 !!!

… caused by lowest ECal-E_{th} (150keV)
and related large time-spread

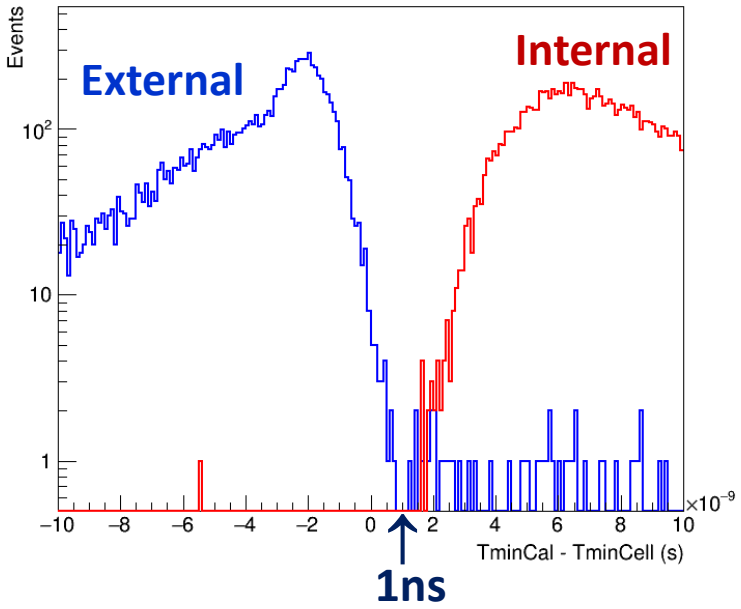
(B) By increasing ECal energy threshold …

✓ Energy threshold: E_{th}^{cal} = 20 MeV ($\Rightarrow \sigma_t$<385ps)

T_{1st} distributions for Internal evts



$\Delta T_{1st}=T_{1st}^{Cal}-T_{1st}^{Sc}$

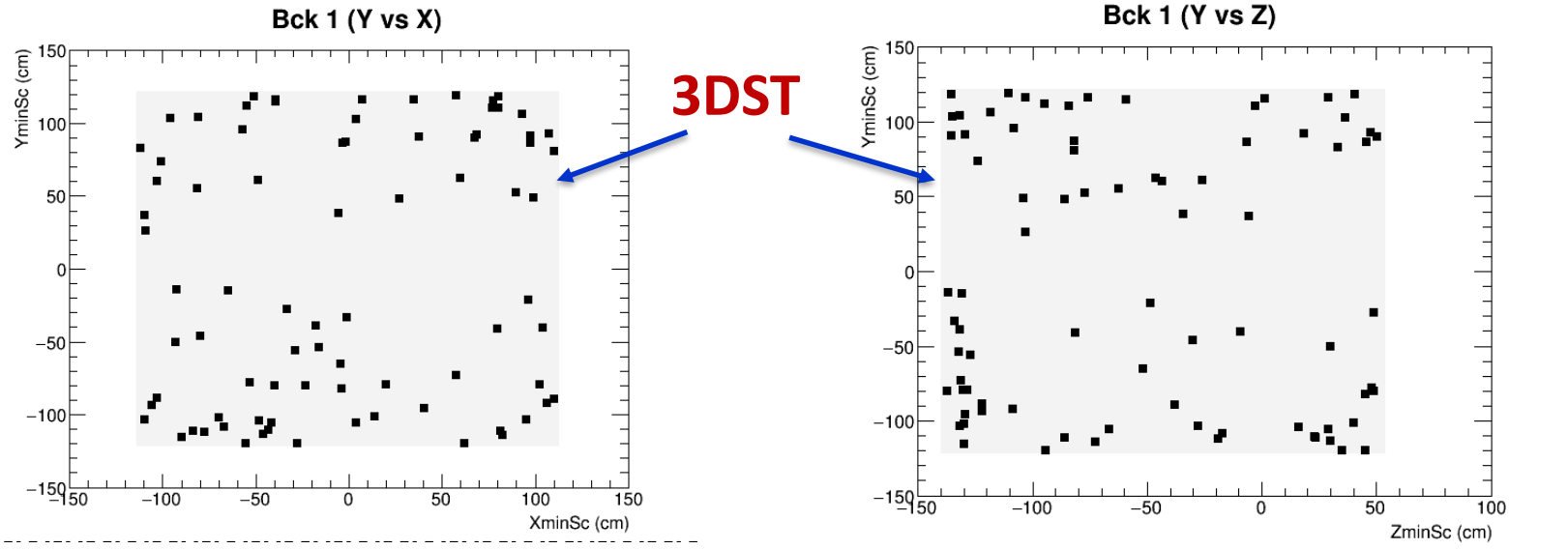


- Internal evts: ΔT_{1st}>1ns (100%, $\eta_{INT} = 1$)
- Bck_1: ~0.09% External evts
- Bck_2: ~1.2% External evts

(η_{EXT}) ⇒ $\frac{S}{N} = \frac{\eta_{INT} \cdot M_{INT}}{\eta_{EXT} \cdot M_{EXT}} \sim 1$

Bck_1 event reduction ($T_{1st}^{Cal} > T_{1st}^{Sc}$)

Distribution of T_{1st} hit positions in 3DST for Bck_1:

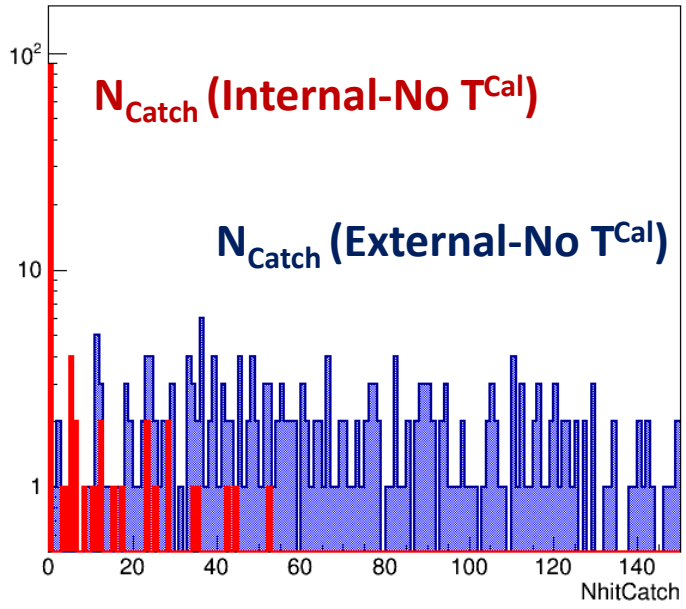


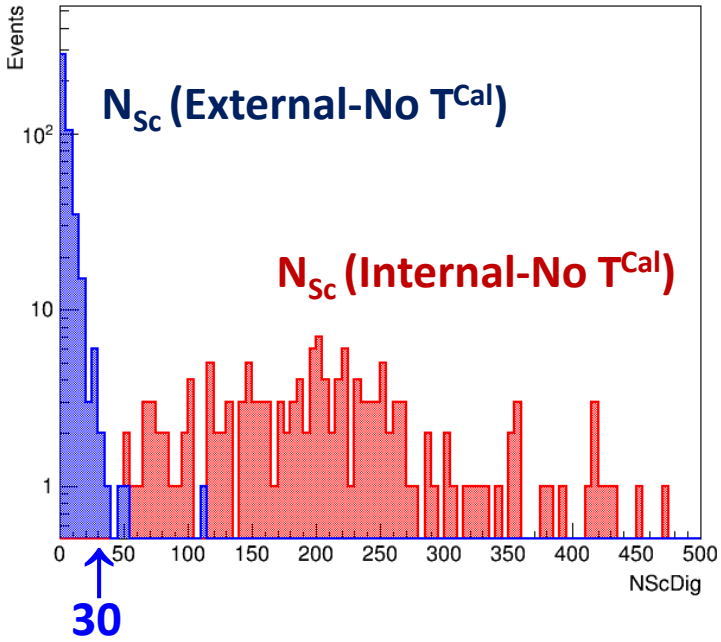
Optimized Fiducial Volume cut:

(10cm cut on X sides) ⊗ (15cm cut on Y sides) ⊗
(20cm cut on Z front side and 10cm cut on Z rear side)

→ Internal event reduction: ~68% (surviving evts)
→ Bck_1 reduction: ~25% (surviving evts)
→ Bck_2 reduction: ~45% (surviving evts)

Bck_2 event reduction (missing T^{Cal})





- Cuts on N_{Scin}, $N_{Catcher}$: $N_{Sc}>2 \otimes N_{Catcher}<3$
- **Alternative cut: $N_{Scin} > 30$** ← applied also to right Δt evts!

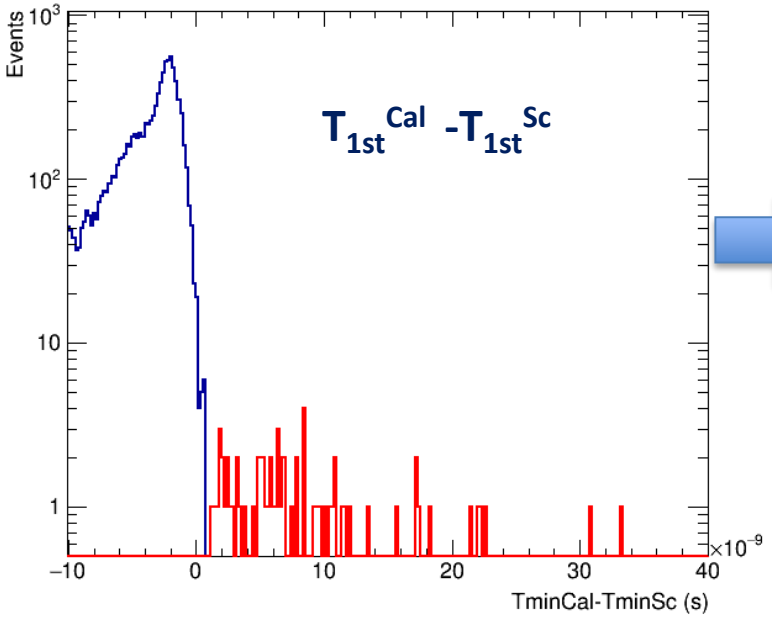
→ Internal event reduction: 99.5%

→ Bck_1 reduction: ~25% (5 evts surviving out of 20)

→ Bck_2 reduction: ~1.3% (6 evts surviving out of 452)

Bck from CC External events (summary)

Results from a sample of 86,000 external events



Bck_1:

($T_{1st}^{Cal} - T_{1st}^{Sc}$) > 1 ns for **81 events (~0.09 %)**

After FV⊗N_{Sc} cut: 5 evts (~0.006%)

Bck_2:

T^{Cal} missing in **1,003 evts (~1.2 %)**

After FV⊗N_{sc} cut: 6 evts (~0.007 %)

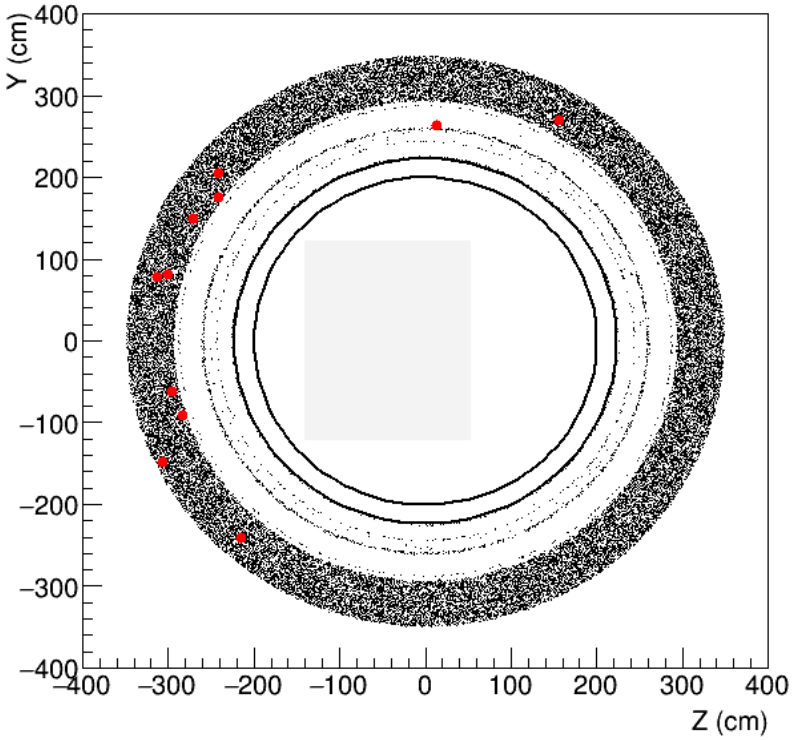
⇒**Residual Bck: 11 events**

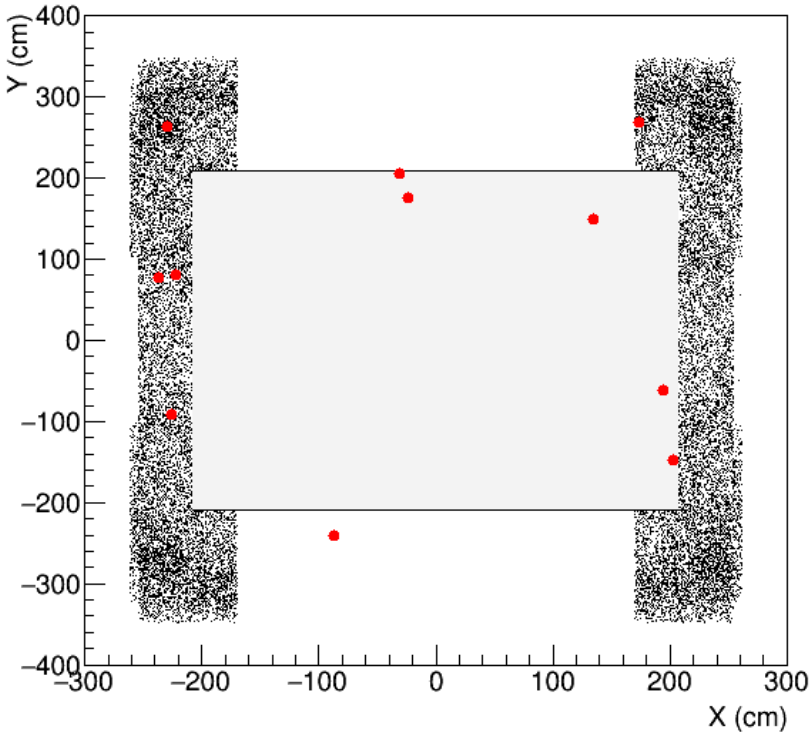
Fraction of events mis-identified as internal: 0.013 %

(surviving factor $\eta_{ext} = 1.3 \cdot 10^{-4}$)

Interaction Vertexes of CC Bck events

After Fiducial Volume and N_{sc} cuts:





Most interaction vertexes of surviving Bck events (11 evts/86,000) are in the yokes

Background from external CC events

(E_{th}^{Cal} = 20 MeV)

- Fiducial Volume cut and (N_{Sc} > 30)

Internal events: surviving 68% (η_{INT}=0.68)

External events: surviving 0.013% (11/86,000 evts)

(η_{EXT}=1.3·10^{-4})

$$\left(\frac{S}{N}\right)_{CC} = \frac{\eta_{INT} \cdot M_{INT}}{\eta_{EXT} \cdot M_{EXT}} = \frac{0.68 \times 10.6\ tons}{1.3 \cdot 10^{-4} \times 611\ tons} = 91 \pm 27$$

→ **$Bck_{beam,CC}$ ~ (1.1 ± 0.3) %**

(from CC interactions in magnet and Calorimeter)

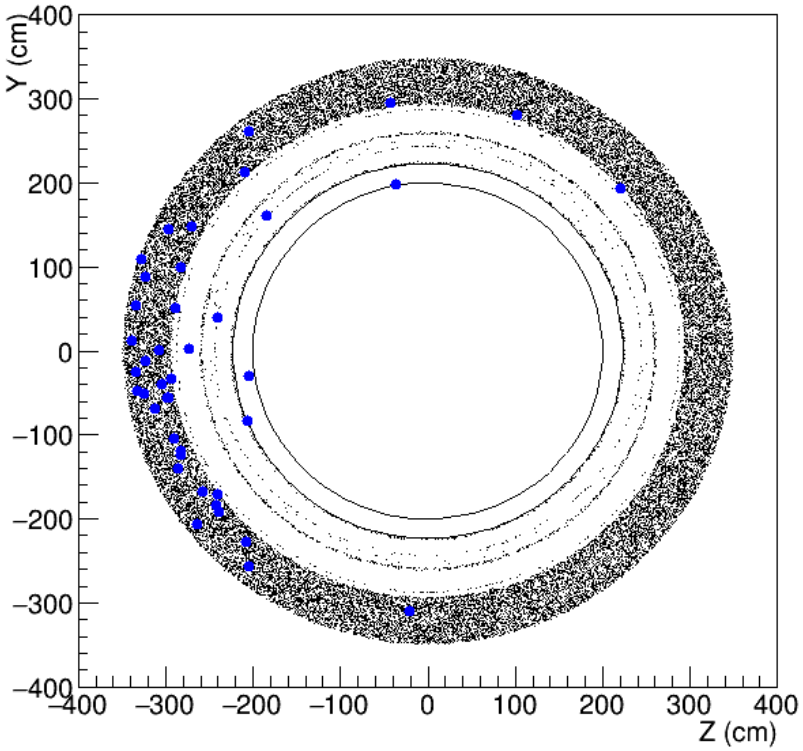
Background from ν_μ-NC external interactions

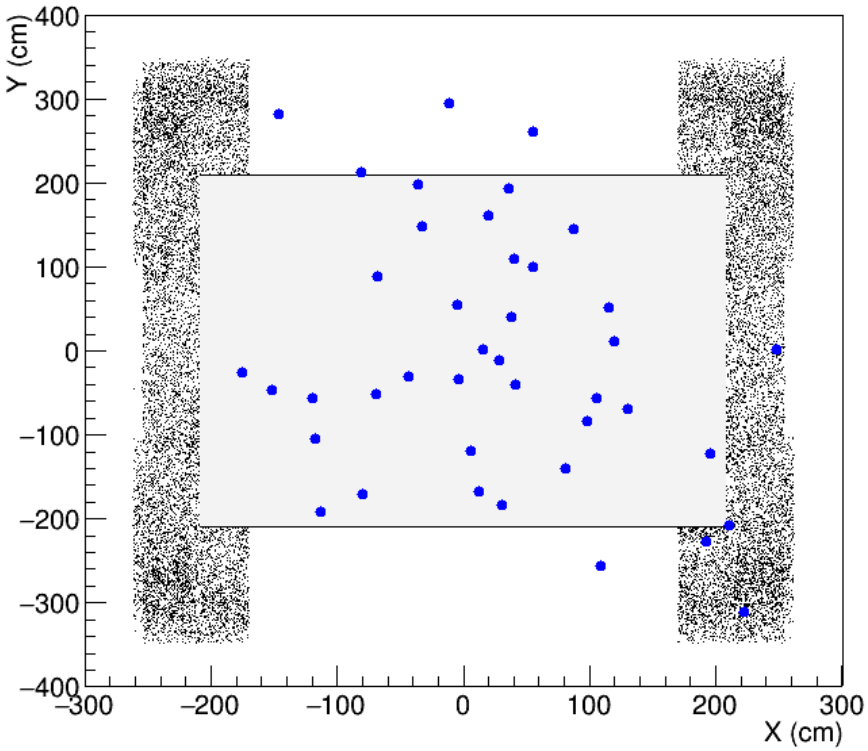
✓ MC sample of 70,000 ν_μ–NC interactions from the beam inside SAND magnet + Calorimeter (ECal)

Target mass: 611 tons

- Event identification based on $\Delta T_{1st} = T_{1st}^{Cal} - T_{1st}^{Sc}$
  (energy threshold on ECal to evaluate T_{1st}^{Cal}: E_{th} = 20 MeV)
- Same selection cuts as for CC:
  1) 3DST Fiducial Volume cut on 1st hit position
  2) Cut on 3DST fired cells (N_{Sc} > 30)
- Assume (η_{INT}=0.68) as for CC Internal events

External events from ν_μ-NC interactions which survive cuts





Most interaction vertexes of surviving Bck events (41 evts/70,000) are in the yokes

Background from external NC events

Bck_1: $(T_{1st}^{Cal} - T_{1st}^{Sc}) > 1$ ns **for 159 evts/70,000 (~0.22 %)**

After FV⊗N_{Sc} cut: 17 evts/70,000 (~0.024%)

Bck_2: T^{Cal} **missing in 1,769 evts/70,000 (~2.5 %)**

After FV⊗N_{sc} cut: 24 evts (~0.034 %)

$\Rightarrow$ **Total background: 41 evts/70,000 ($\eta_{ext} = 5.8\ 10^{-4}$)**

$$\left(\frac{S}{N}\right)_{NC} = \frac{\eta_{INT} \cdot M_{INT}}{\eta_{EXT} \cdot M_{EXT}} = \frac{0.68 \times 10.6\ tons}{5.8 \cdot 10^{-4} \times 611\ tons} = 20 \pm 3$$

$\Rightarrow$ **$Bck_{beam,NC}$ ~ (4.8 ± 0.8) %**

(from NC interactions in magnet + ECal)

Background from beam induced ν_μ-(CC+NC) external interactions

❖ Background from NC more than 4 times that from CC

… probably due to:

- neutrons in NC about 20% more aboundant than in CC ($<N_n/ev>$ ~ 5.1 in NC, $<N_n/ev>$ ~ 4.3 in CC)
- neutrons in NC on average more energetic than in CC ($<E_n>_{NC}$ ~ 0.1 GeV, $<E_n>_{CC}$ ~ 0.06 GeV)

❖ Relative probabilities: CC ~ 80%, NC ~ 20%

Estimated total background: Bck_{beam} ~ 1.8 %

(from CC+NC interactions in magnet + ECal)

based only on Time difference between ECal and 3DST

Conclusions

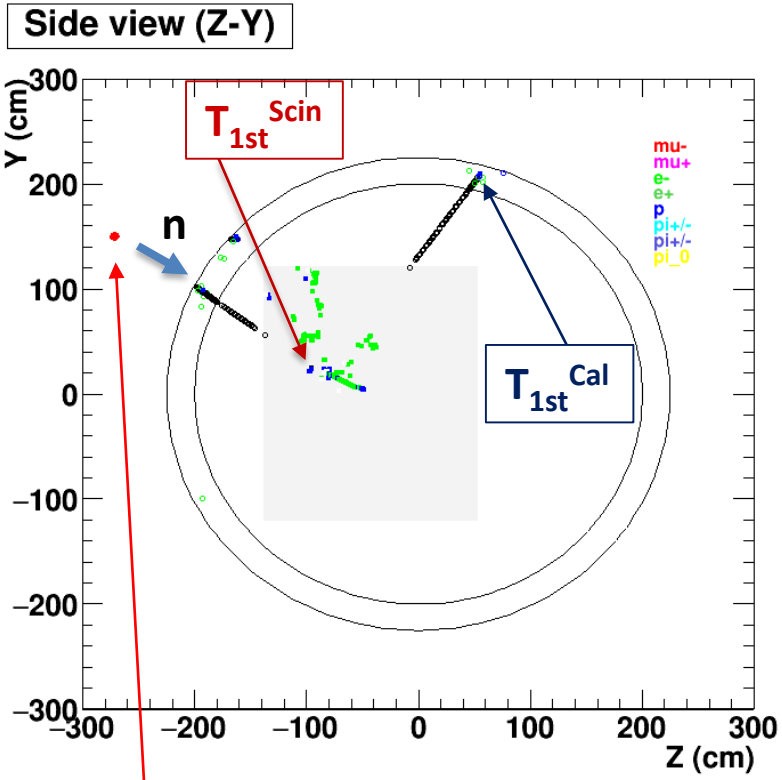
- ✓ The beam induced background from ν_μ interactions in SAND magnet and Calorimeter has been estimated
- ✓ Two separate samples of ν_μ CC and NC interactions by FLUKA have been used for this purpose
- ✓ The evaluation is based only on time information from 3DST and ECal (… correct3DST T-resolution to be used)
- ✓ After a selection based on a 3DST Fiducial Volume cut and a minimum number of 3DST hits, a global residual background is estimated at the level of <2%
- ✓ Further improvements in the background rejection are expected by exploiting event topologies and reconstruction

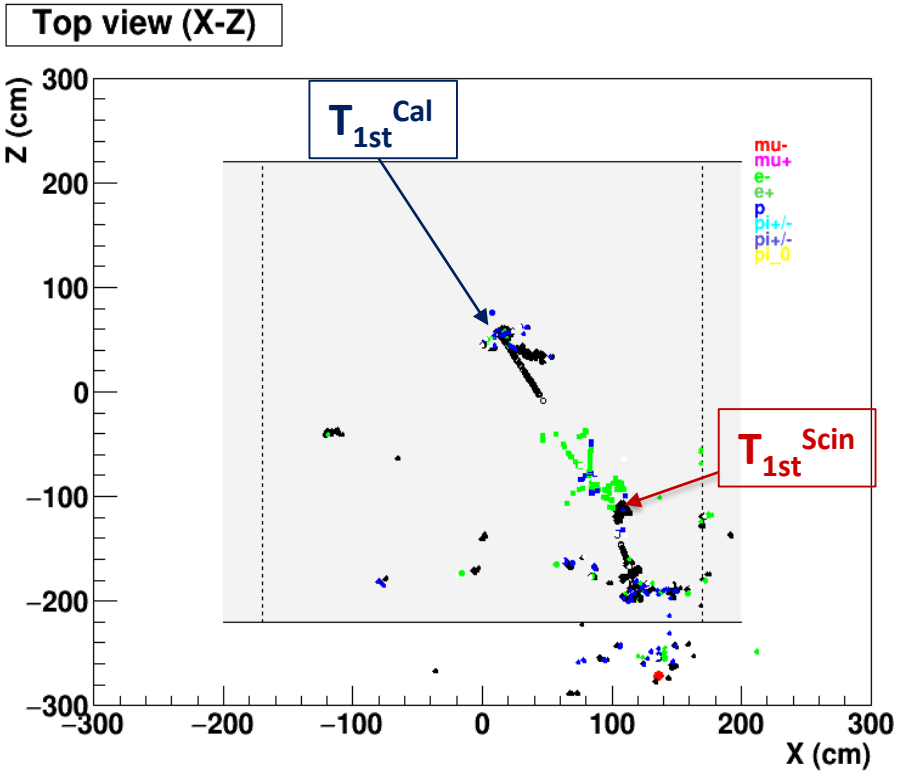
BACKUP

Background Event Display

Example of ν_μ-CC Bck_1 events

External event with Time "reversal" ($T_{1st}^{Cal} > T_{1st}^{Sc}$)

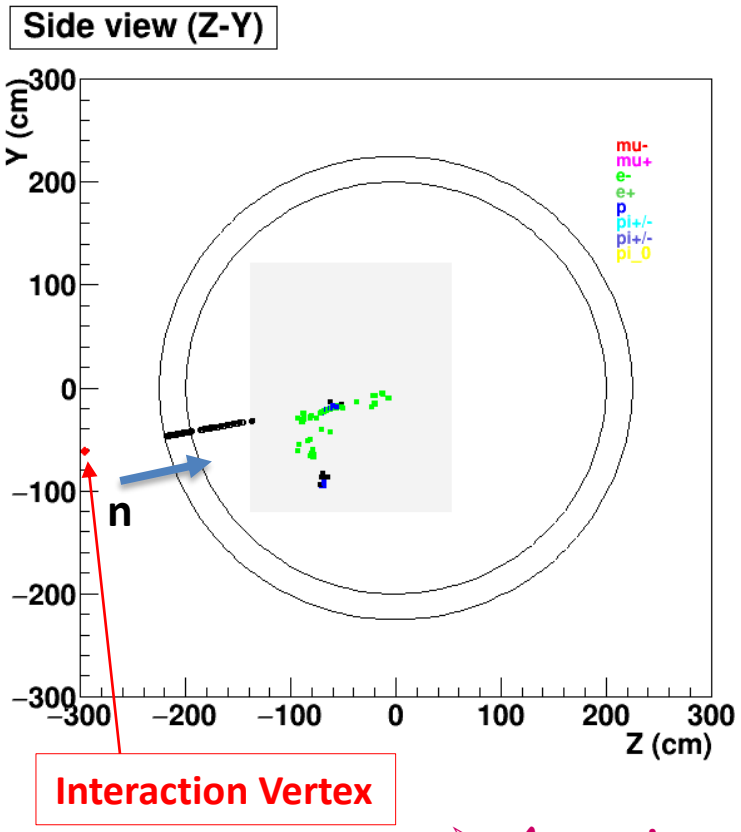


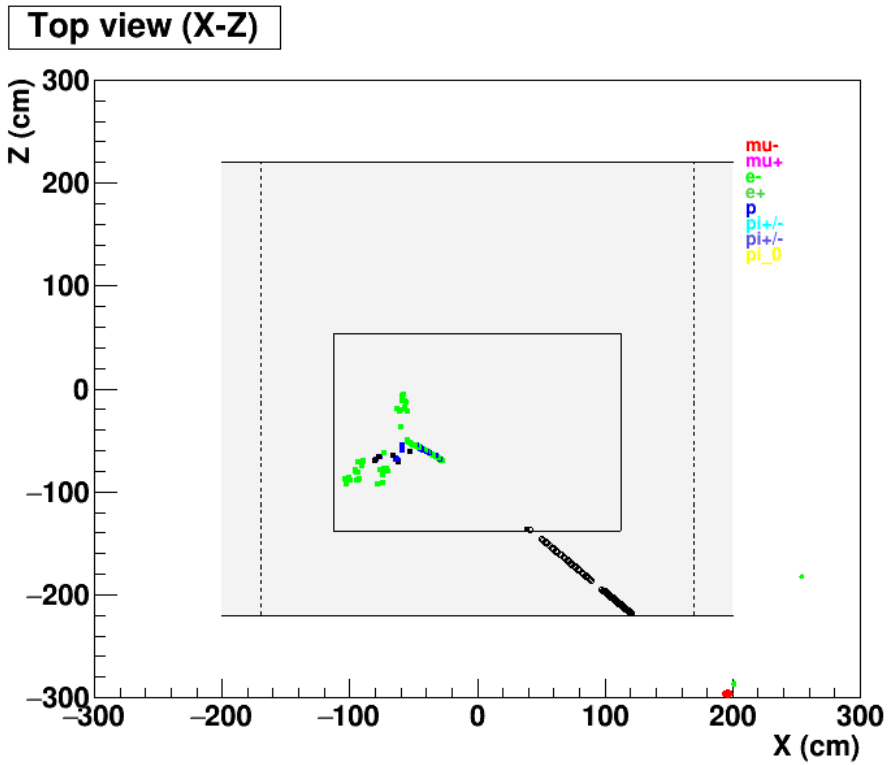


- A neutron crosses ECal without giving hits and enters 3DST (where some hits are produced)
- Subsequent hits in ECal

Example of ν_μ-CC Bck_2 event

External events where T_{cal} is missing

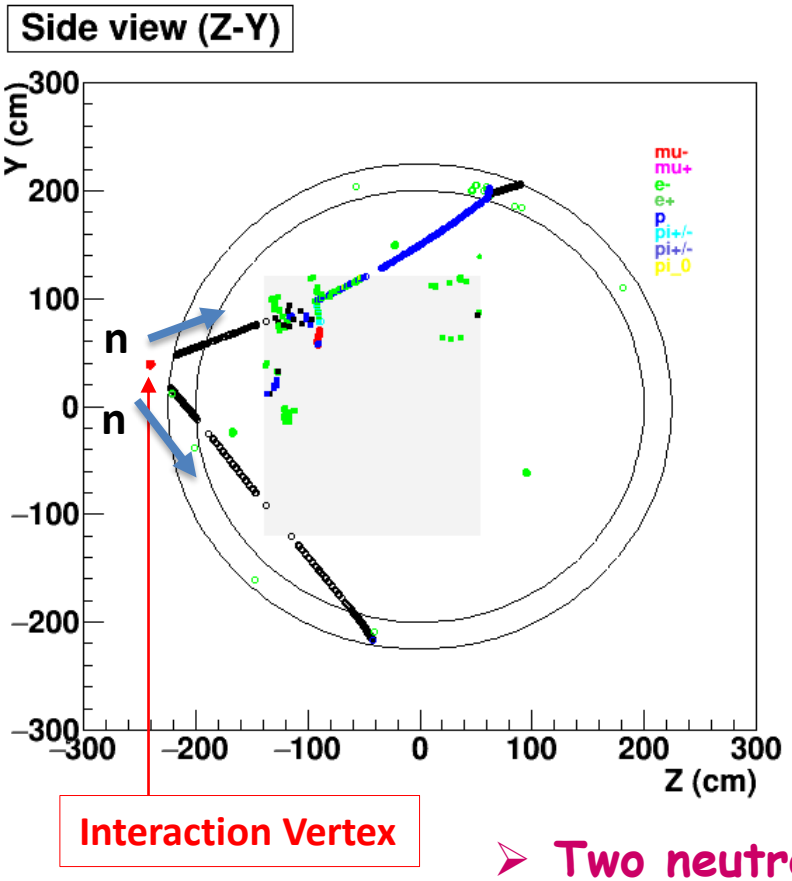


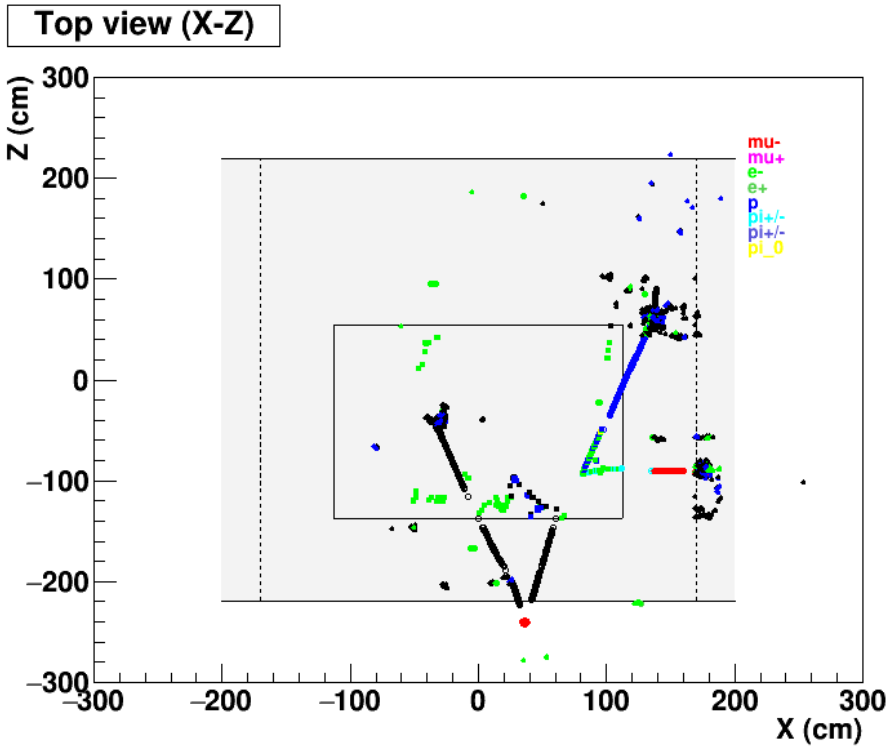


- A neutron crosses ECal without giving hits
  Then enters 3DST, where some hits are produced and remain contained

Example of ν_μ-NC Bck_1 event

External event with Time "reversal" ($T_{1st}^{Cal} > T_{1st}^{Sc}$)

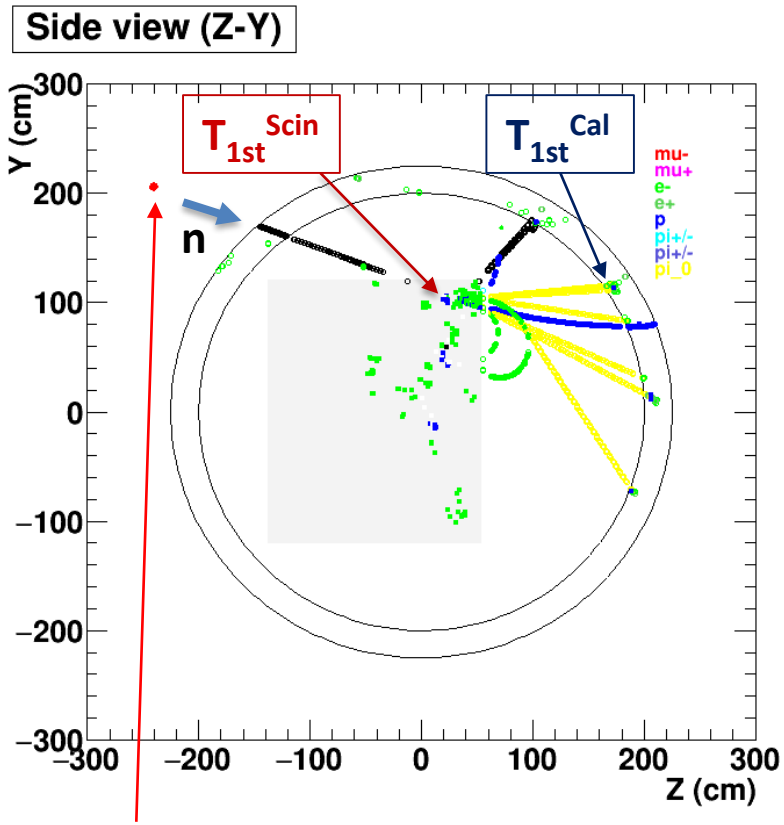


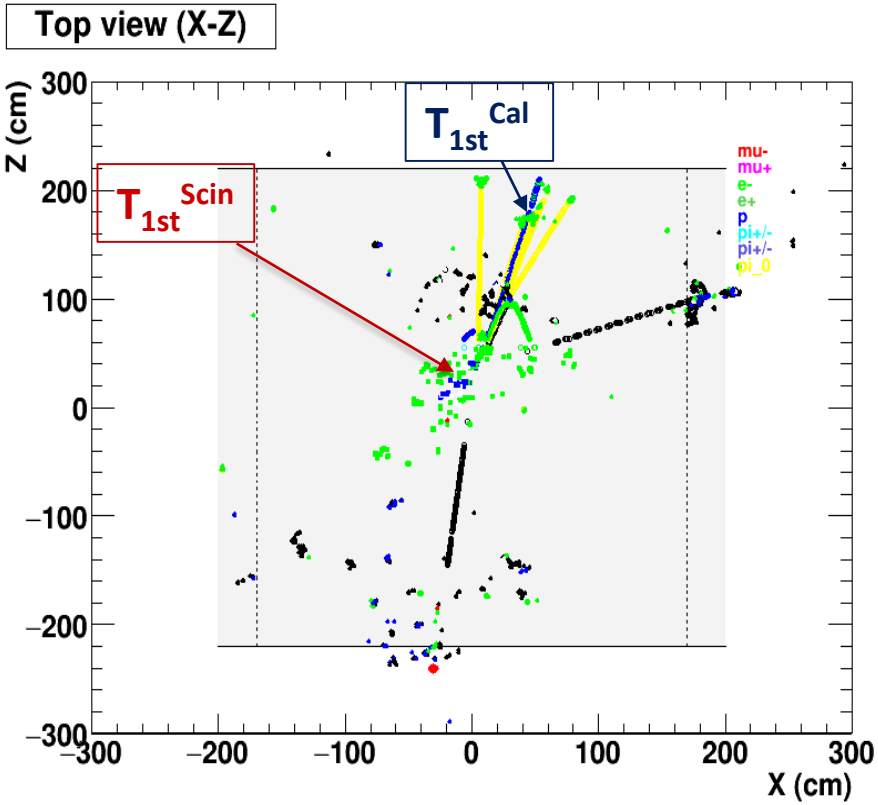


- Two neutrons cross ECal without giving hits, then enter 3DST (where some hits are produced)
- Subsequent hits in ECal

SAND layout: Bck_1 events (3)

External events with Time "reversal" ($T_{1st}^{Cal} > T_{1st}^{Sc}$)



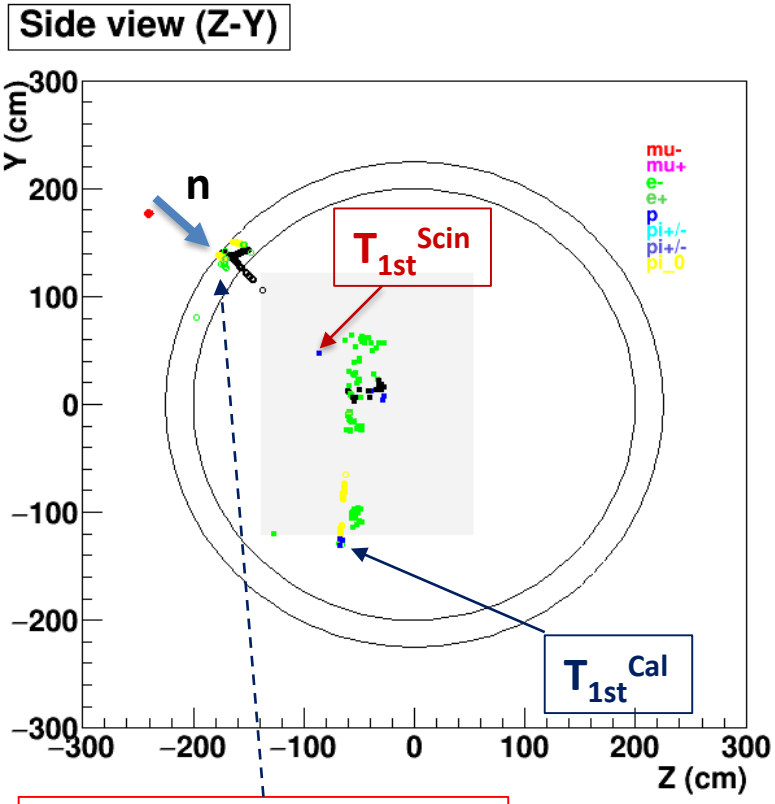


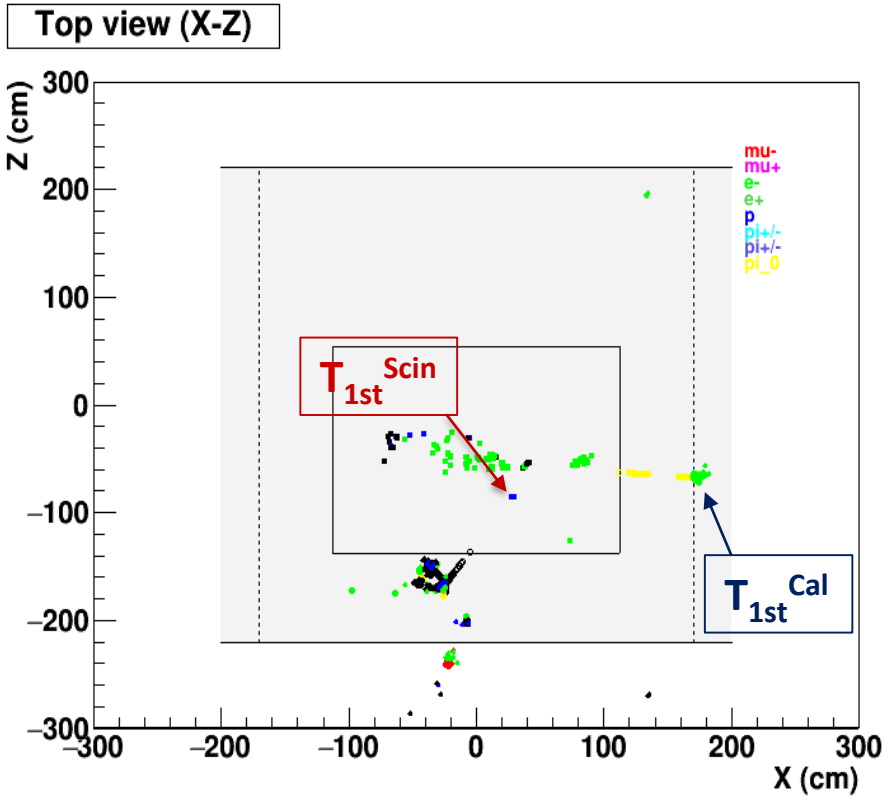
Interaction Vertex

- A neutron crosses ECal without giving hits and enters 3DST (where some hits are produced)
- Subsequent hits in ECal

SAND layout: Bck_1 events (1)

External events with Time "reversal" ($T_{1st}^{Cal} > T_{1st}^{Sc}$)





$10MeV < E_i^{Cal} < 20MeV$

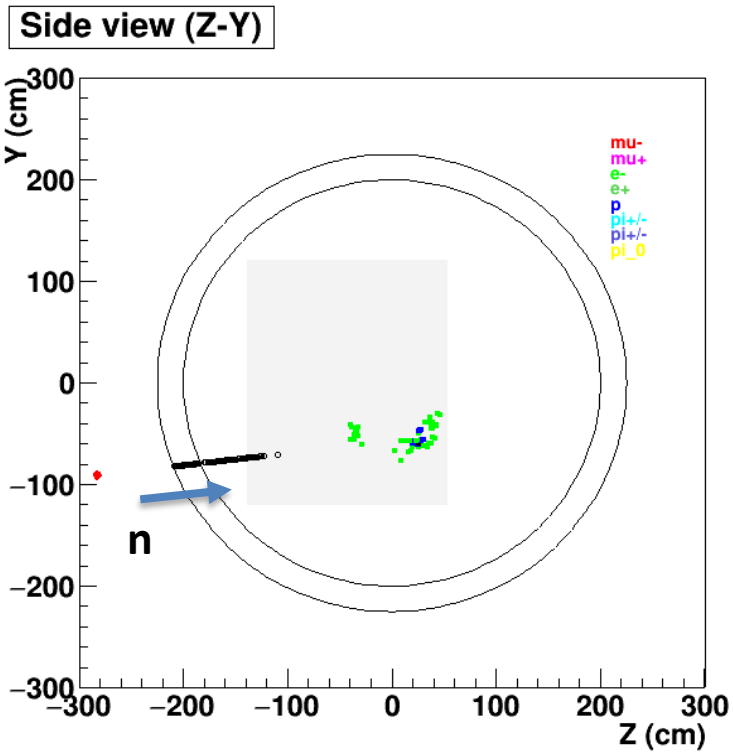
$T_i^{Cal} < T_{1st}^{Scin}$!

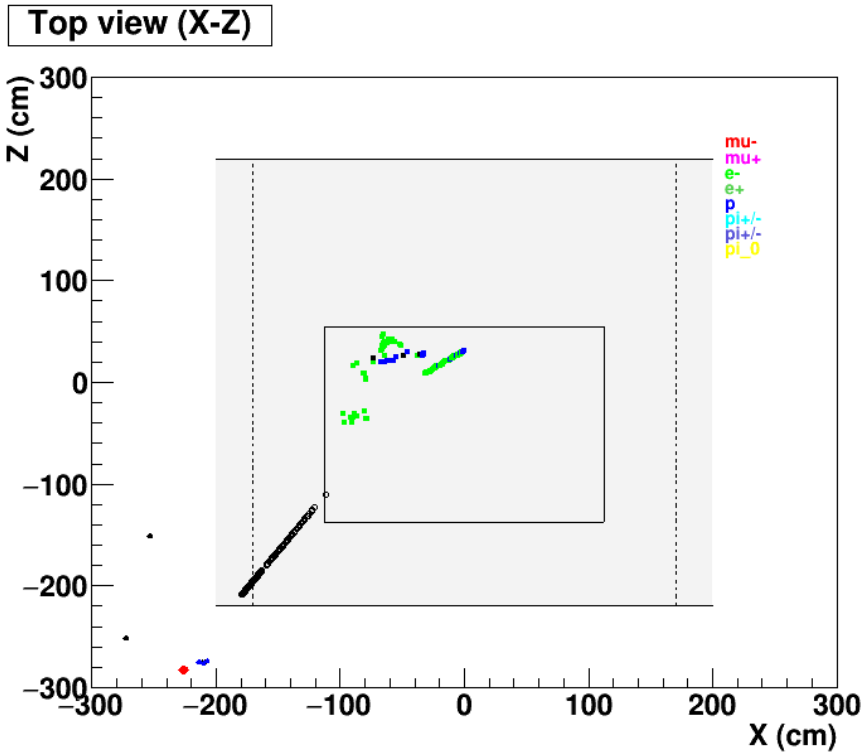
☹ ☺

- Neutron crosses ECal releasing <20 MeV in a cell and enters 3DST (producing some hits)
- Subsequent hit in ECal

SAND layout: Bck_2 events (2)

External events where T_{cal} is missing

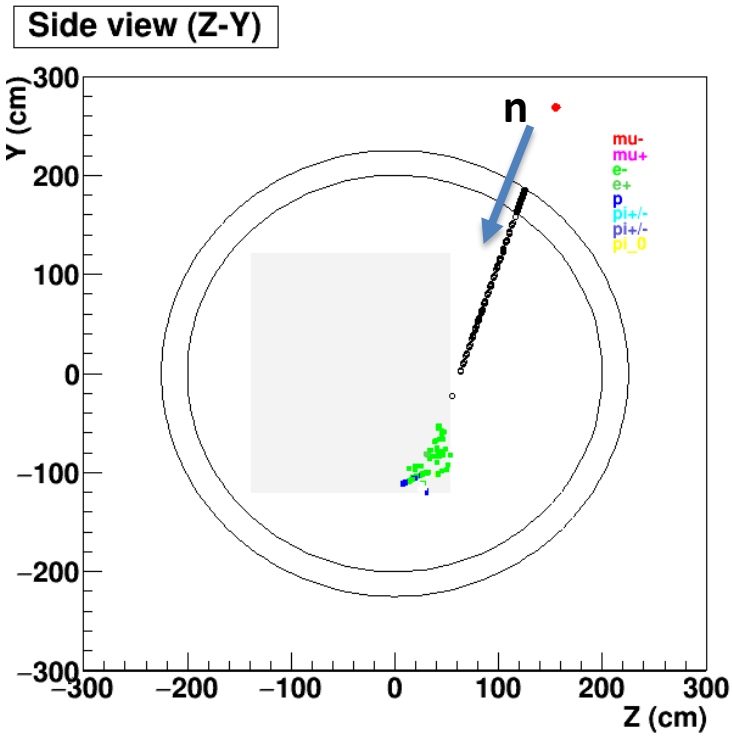


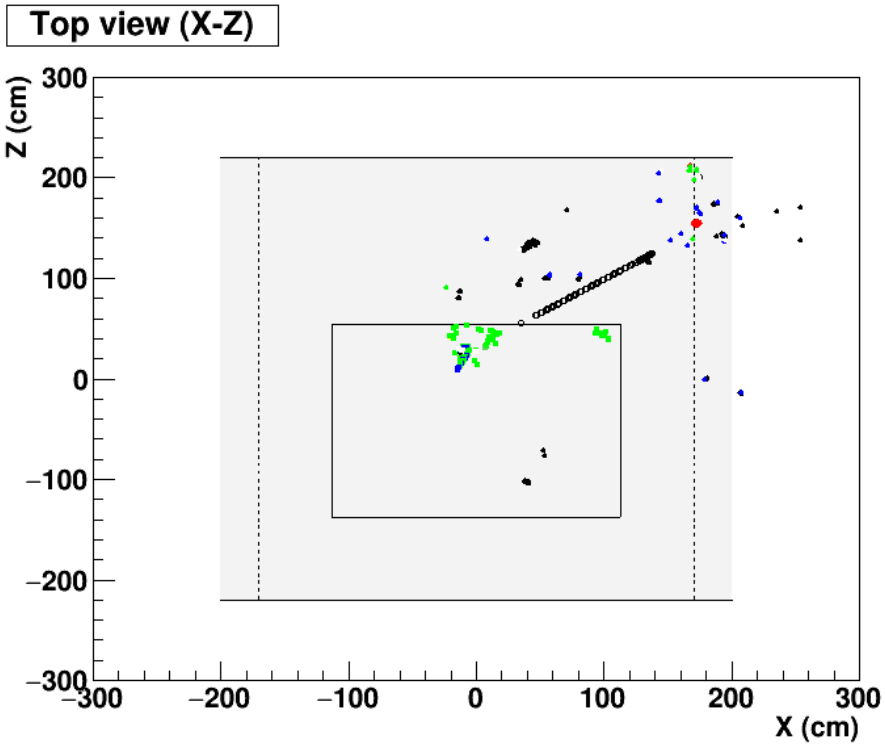


- A neutron crosses ECal without giving hits
  Then enters 3DST, where some hits are produced and remain contained

SAND layout: Bck_2 events (3)

External events where T_{cal} is missing





- A neutron crosses ECal without giving hits
  Then enters 3DST, where some hits are produced and remain contained