Search for Muon Decays in KM3NeT/ORCA6

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Muon Decays in ANTARES/KM3NeT

- Discussed by Juergen Brunner for ANTARES

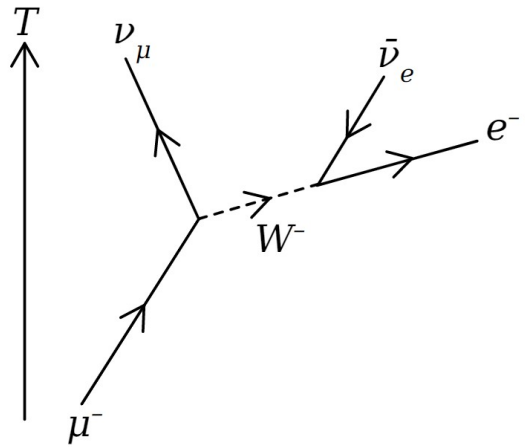
  Several possible applications for physics (calibration)

- Study for KM3NeT/ARCA by Dimitry Zaborov (Bari meeting, 2017)

  Michel electrons from muon decay: a feasibility study using ARCA data

Search for a time difference for 2 multiple hits group in the same KM3NeT DOM

Muon Decays

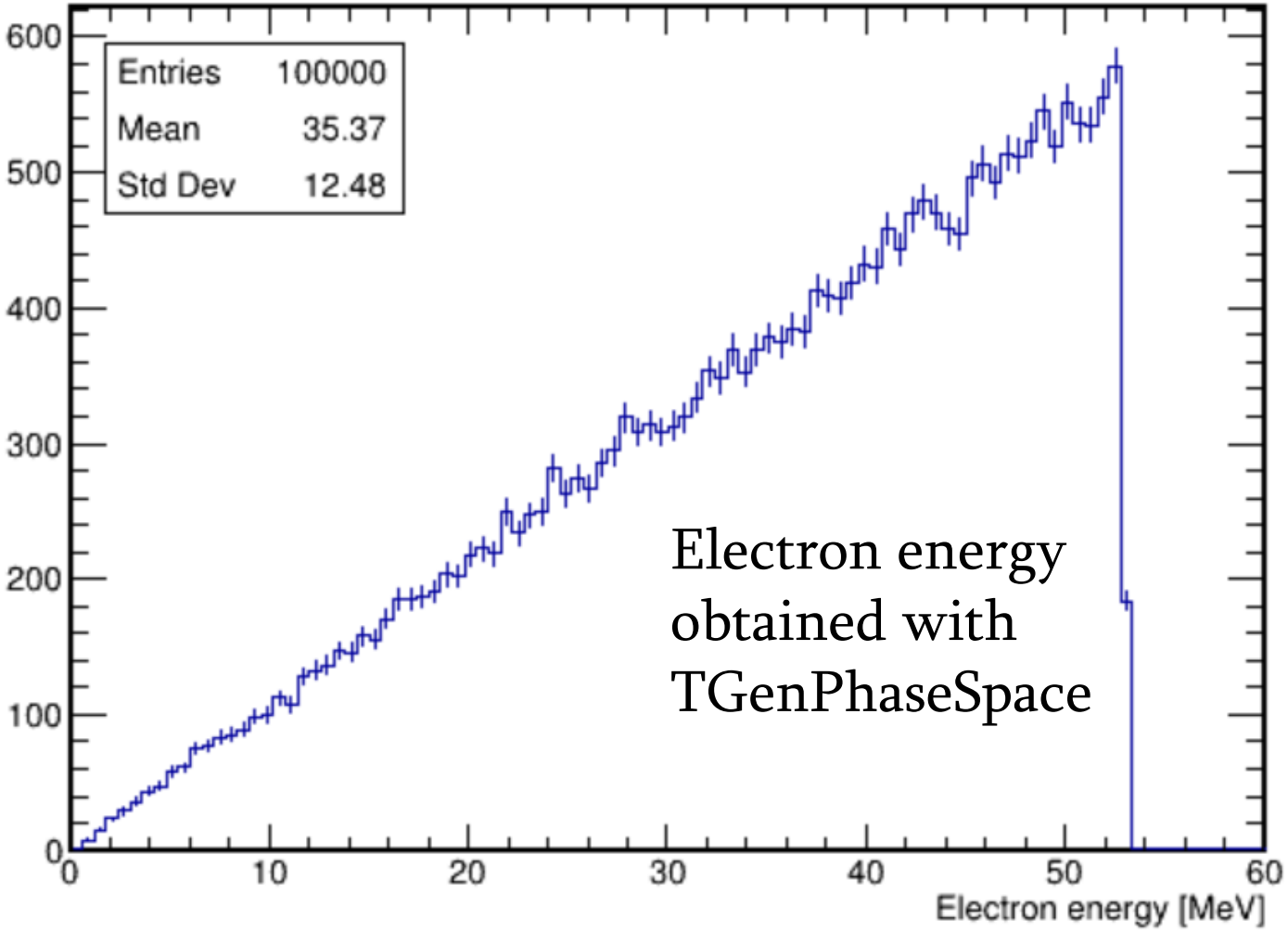


$$\mu \rightarrow e + \nu_\mu + \nu_e \qquad 100\%$$

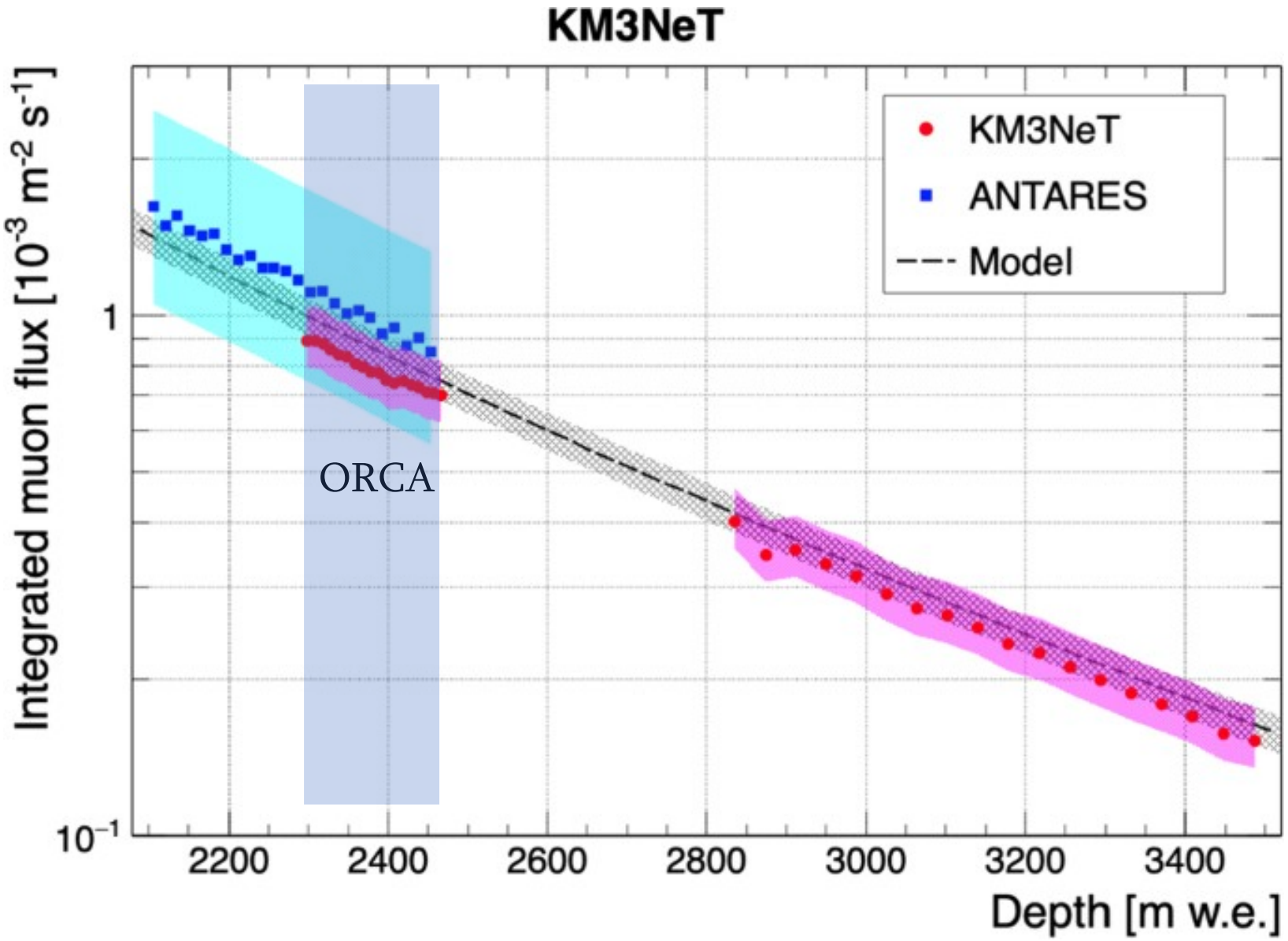
$m_\mu = 105.6583745 \pm 0.0000024$ MeV

$\tau_\mu = (2.1969811 \pm 0.0000022)$ μsec

$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$



Muons in KM3NeT (Muon Flux Dependence on Seawater Depth)



$$I_\mu(d) = \frac{I_\mu(d, \theta = 0)}{C(d)} = \frac{A_1 \cdot e^{A_2 \cdot d} + A_3 \cdot e^{A_4 \cdot d}}{B_1 + B_2 \cdot d},$$

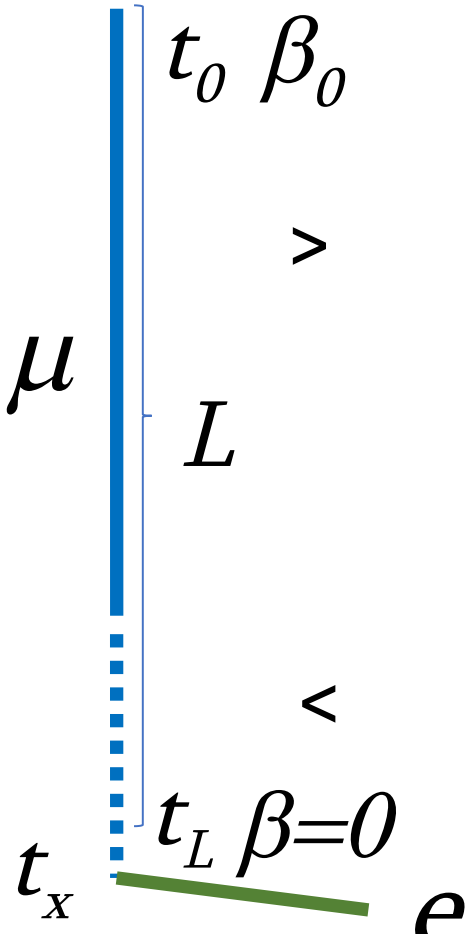
$A_1 = 1.31 \times 10^{-5}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}}$, $A_2 = -2.91 \times 10^{-3}\,\mathrm{m^{-1}}$,
$A_3 = 7.31 \times 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}}$, $A_4 = -1.17 \times 10^{-3}\,\mathrm{m^{-1}}$,
$B_1 = 4.16 \times 10^{-1}\,\mathrm{sr^{-1}}$, $B_2 = 1.07 \times 10^{-4}\,\mathrm{m^{-1}\,sr^{-1}}$.

The KM3NeT Collaboration
EPJ C80(2020), 99

Dependence of atmospheric muon flux on seawater depth measured with the first KM3NeT detection units

Muons are detected with a single DOM – rate difference vs depth indicates muon decays.

Muon Decays



$\mu \rightarrow e + \nu_\mu + \nu_e$

Muon propagation time: $= \frac{2}{\quad}$ $_0$

Muon decay time: $- \quad = \Delta \quad = \exp\left(-\frac{\Delta}{\quad}\right)$

$\tau = 2.1969811(22)\ \mu sec$

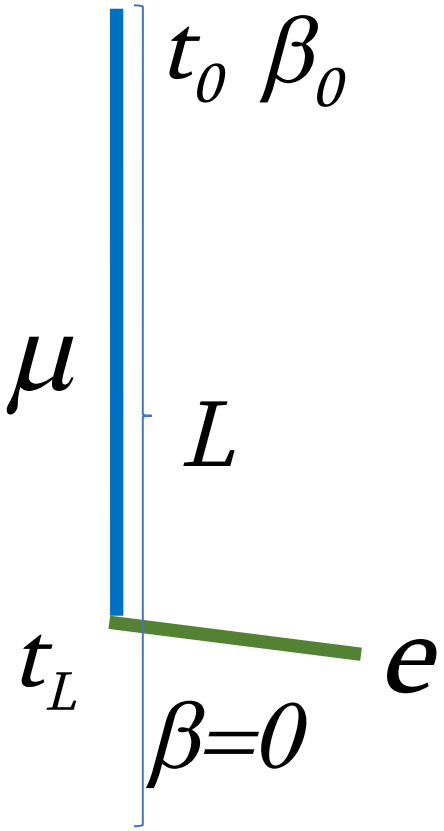
Cherenkov condition:

$\geq \frac{1}{\quad} \quad = \left(\frac{\quad}{\sqrt{\quad^2 - 1}} - 1\right) \quad = 1.35$

$E_k(\mu) = 52\ MeV$ $E_k(e) = 0.25\ MeV$

E_k _ *kinetic energy*

Decays at Rest vs. Decays in Flight



Muon time of flight: $= \frac{2}{0}$

For L=200 m, and $\beta_0 \approx 1$ (E_μ>10 GeV) $t_L \approx 1.3$ μsec

Probability of muon decay for: $t < t_L$

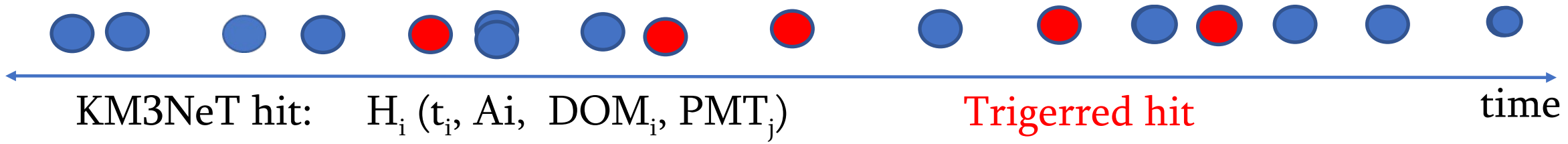
$\approx$

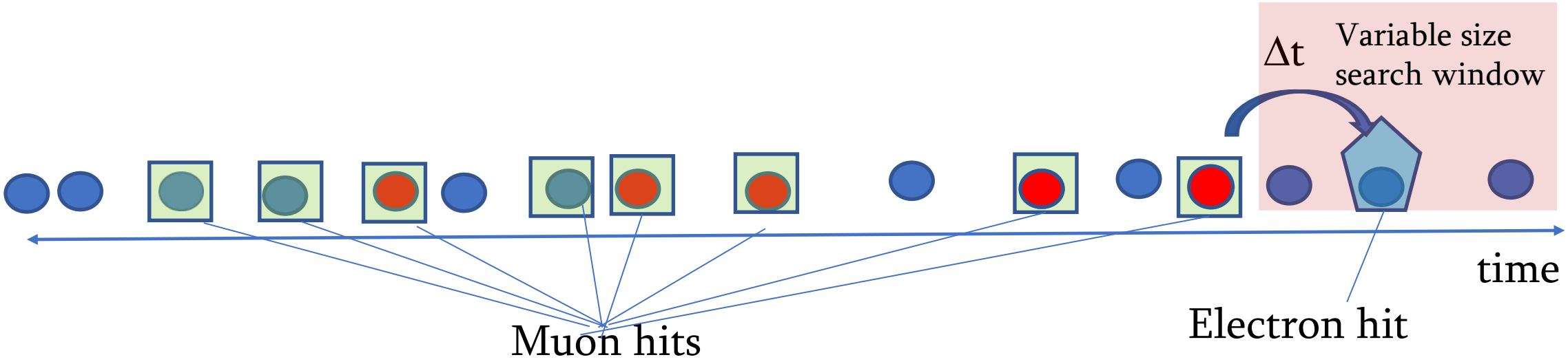
$\mu \rightarrow e + \nu_\mu + \nu_e$

$\tau = 2.2\ \mu sec$

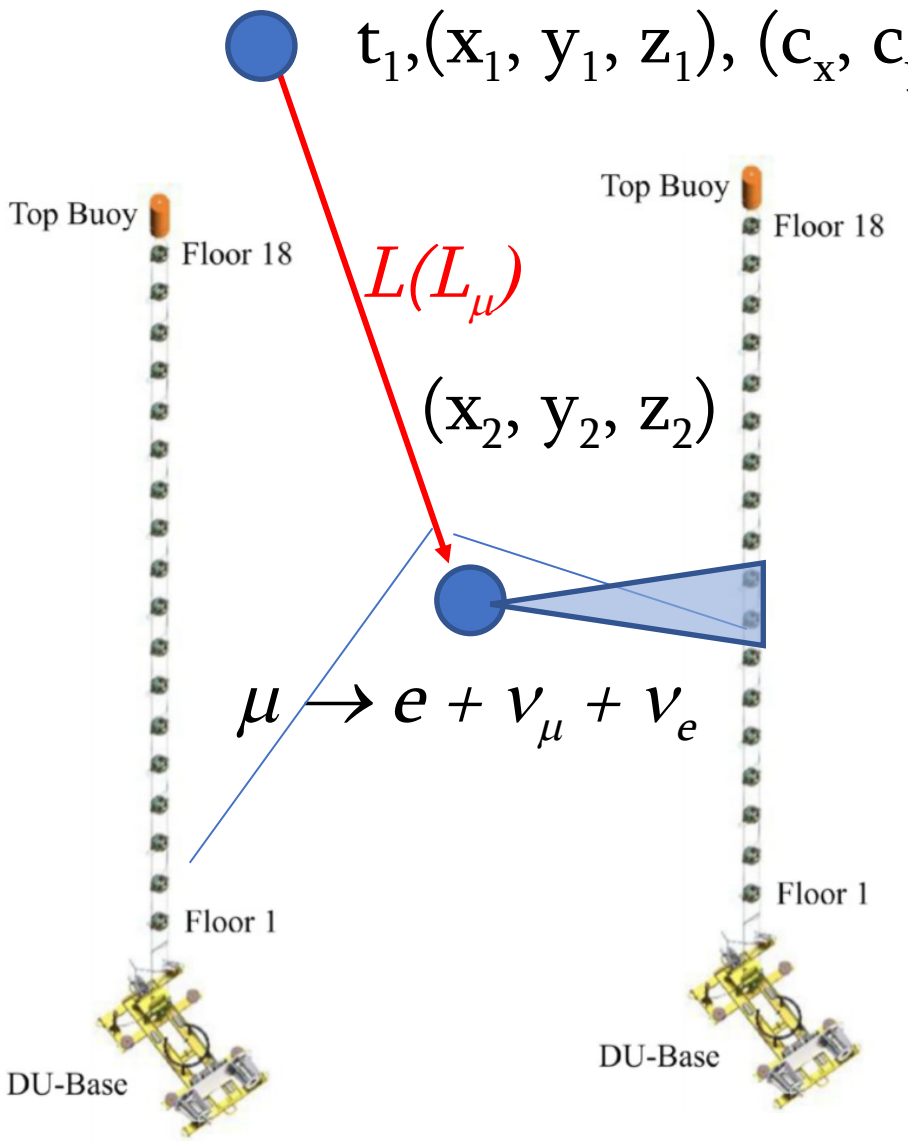
KM3NeT Event

KM3NeT events is a collection of the hits (PMT signals) in the selected time interval





Muon Track Selection



$$x_2 = x_1 + L\cos(x)$$

$$y_2 = y_1 + L\cos(y)$$

$$z_2 = z_1 + L\cos(z)$$

$$t_2 = t_1 + 2L/v_\mu$$

$$v_\mu = c$$

$$\Delta t_\mu = t_e - t_\mu$$

Muon track selection

Containment condition

Muon stops (t_μ)

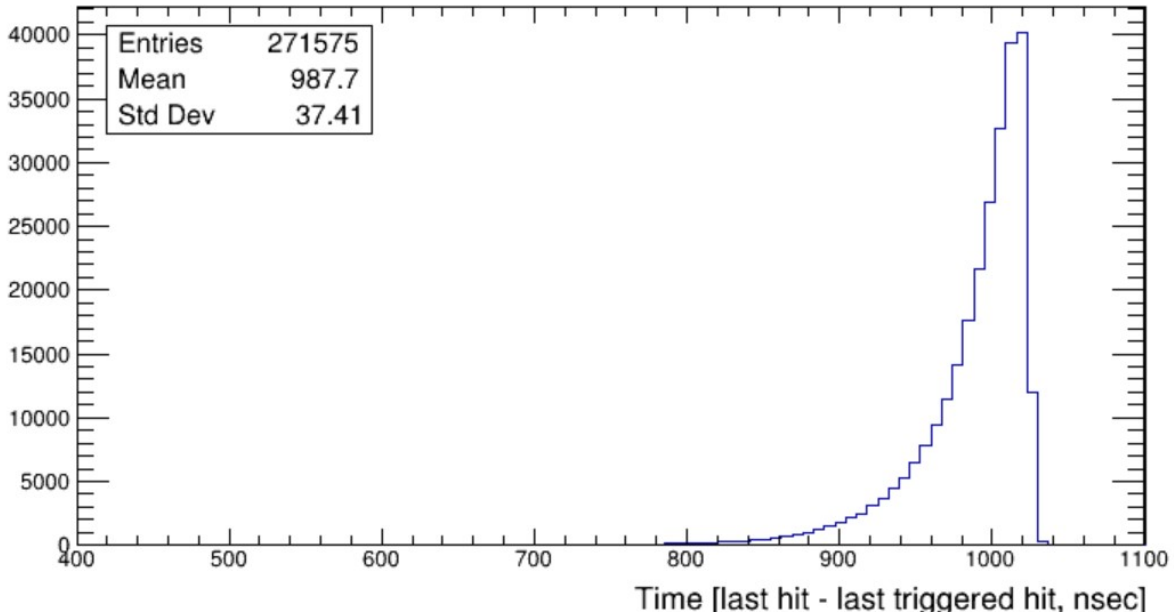
Electron-hit (t_e)

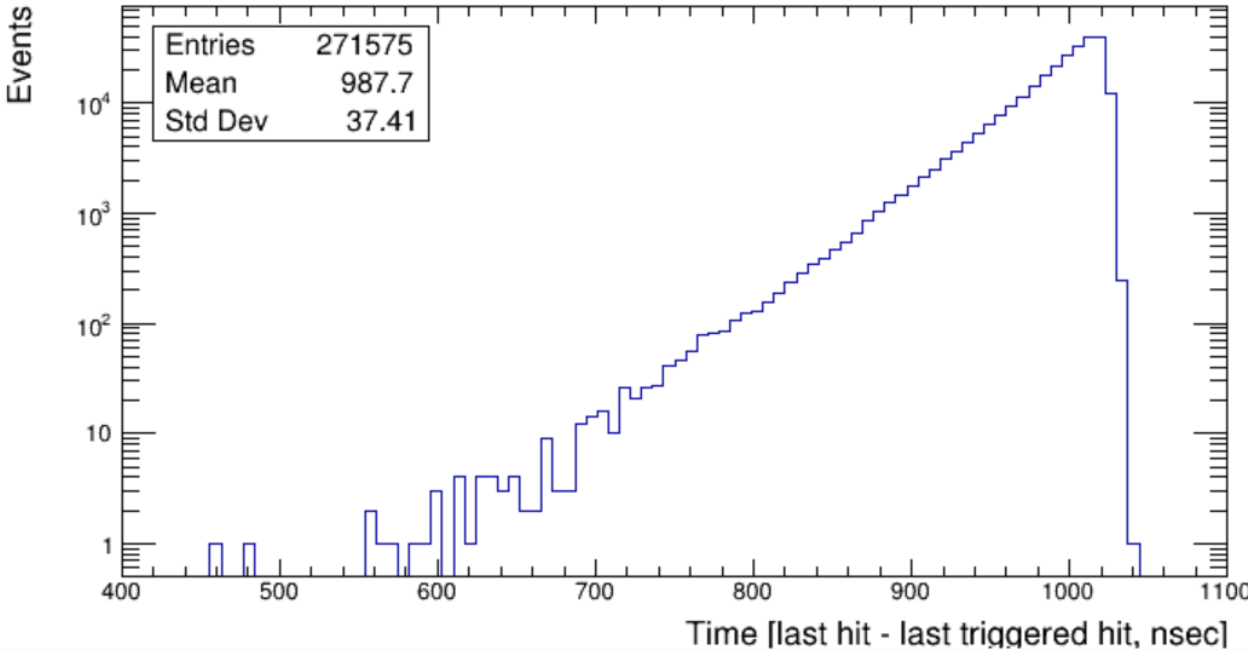
Cherenkov corrections

$\Delta t = t_e - t_\mu$ distribution

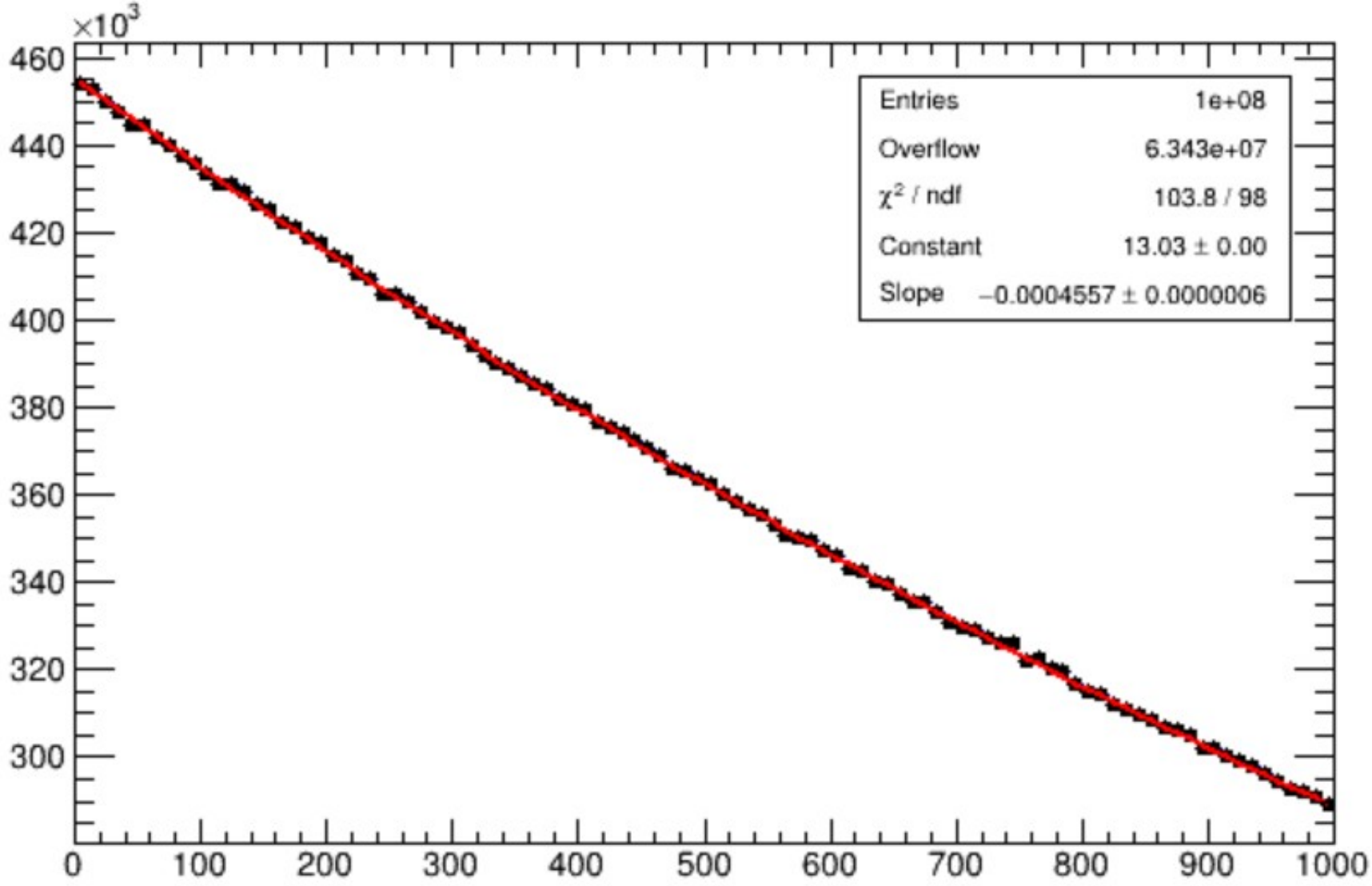
Muon Decay Search Window

Time interval for μ-decay search: difference last hit - last triggered hit





MC: Muon Decay distribution (10^8 decays)



MC: Δt-distribution (No bkg)

with τ_μ =2196. 98 nsec

Fit value:

τ_μ = 2194.26

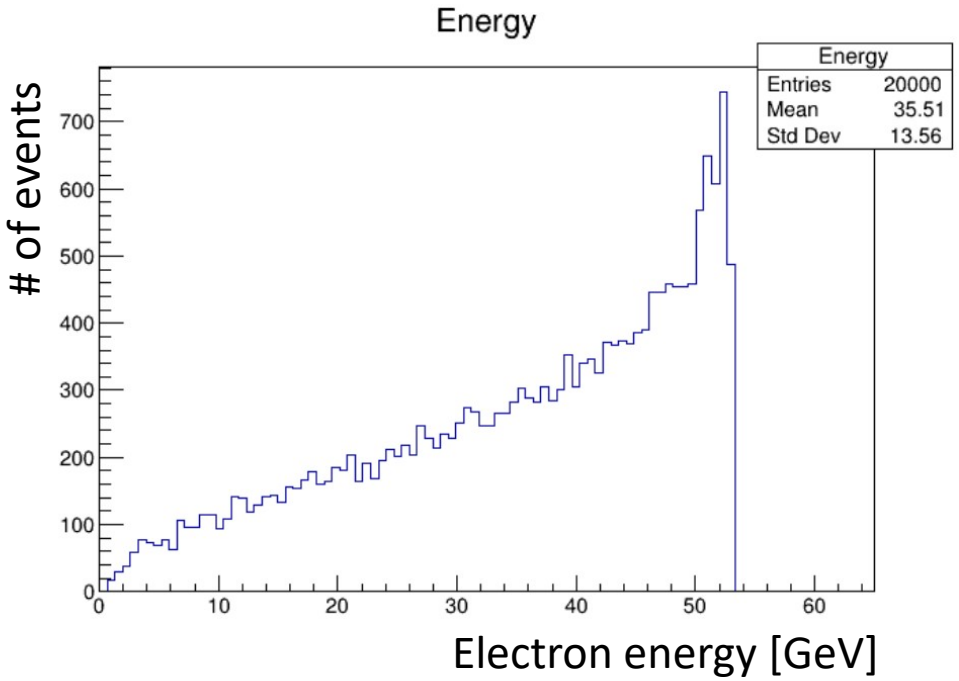
Fit interval:

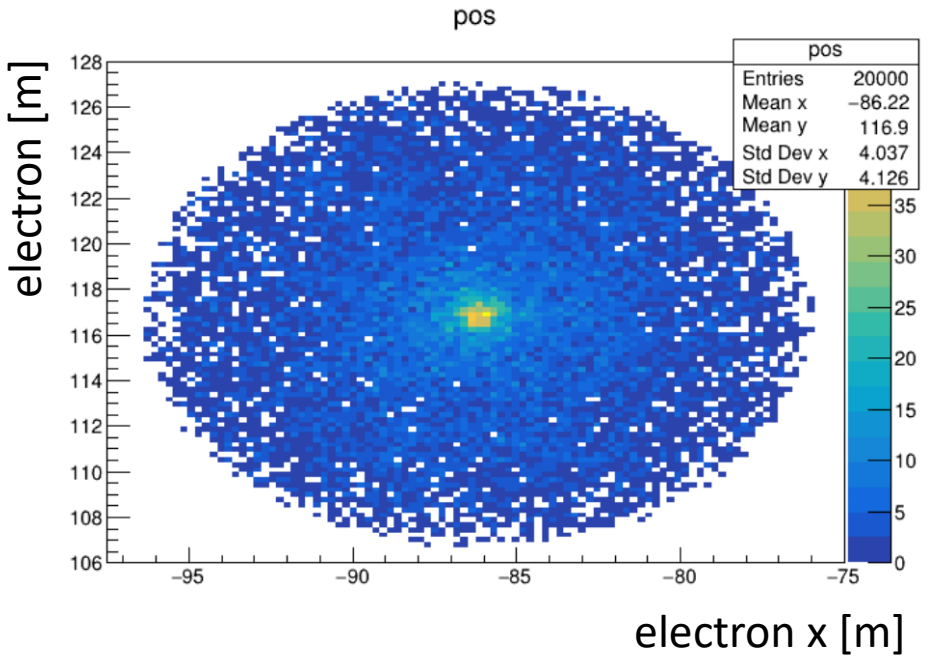
$0 < t_\mu < 1$ μsec

36.6% statistics in 0-1000 nsec

Muon decay MC

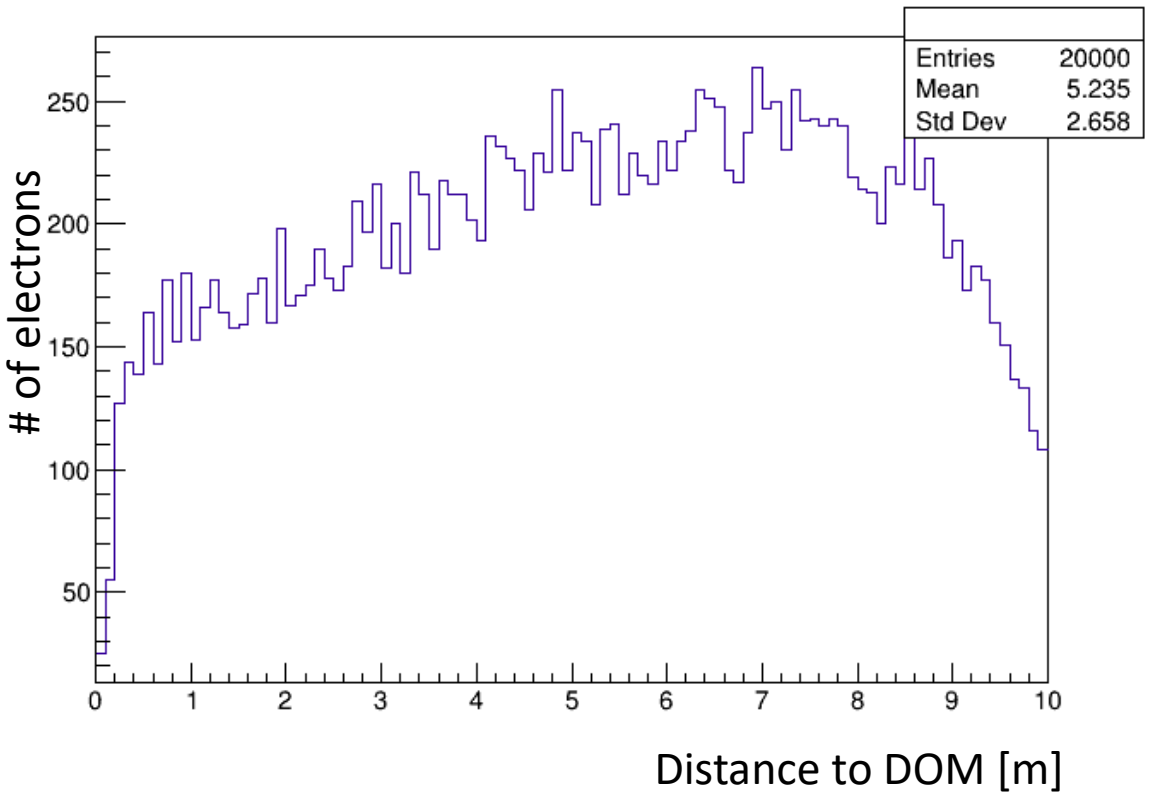
- $2x10^4$ muon decays MC is done using ROOT TGenPhaseSpace
- Michel electrons are distributed around a DOM, inside 10 meter radius sphere

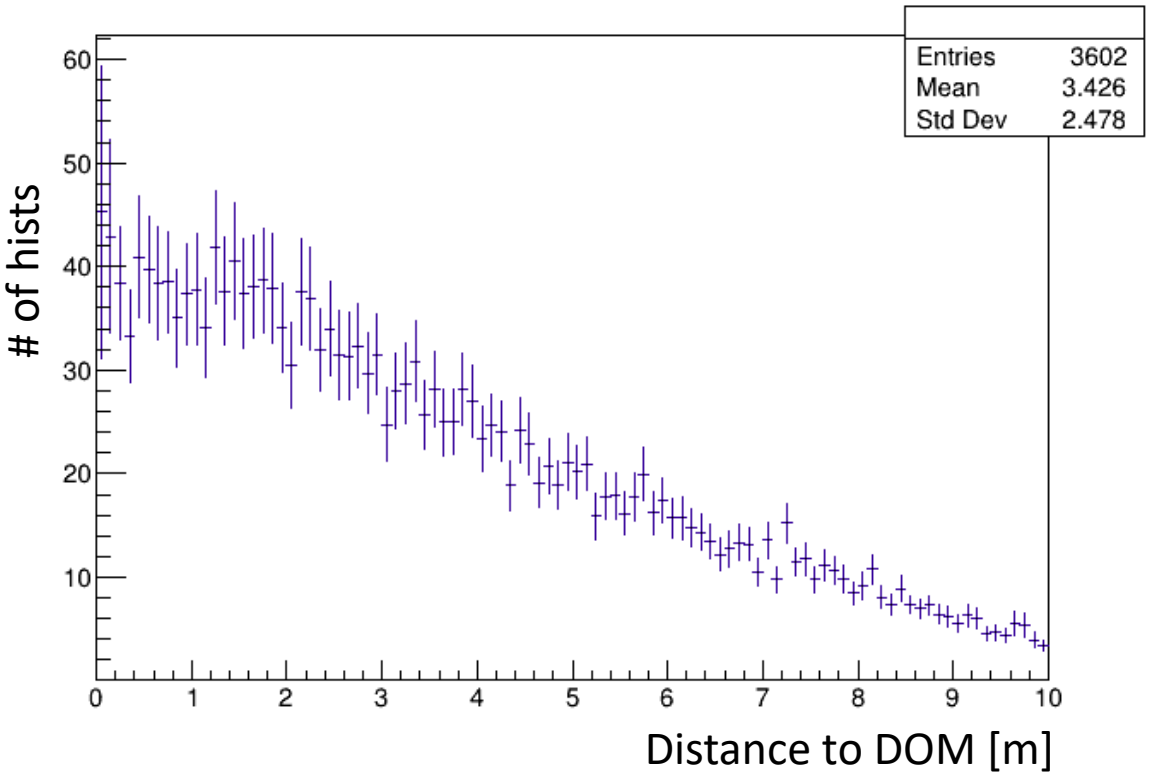




Michel electron MC

- Michel electron propagation and light is simulated with KM3Sim





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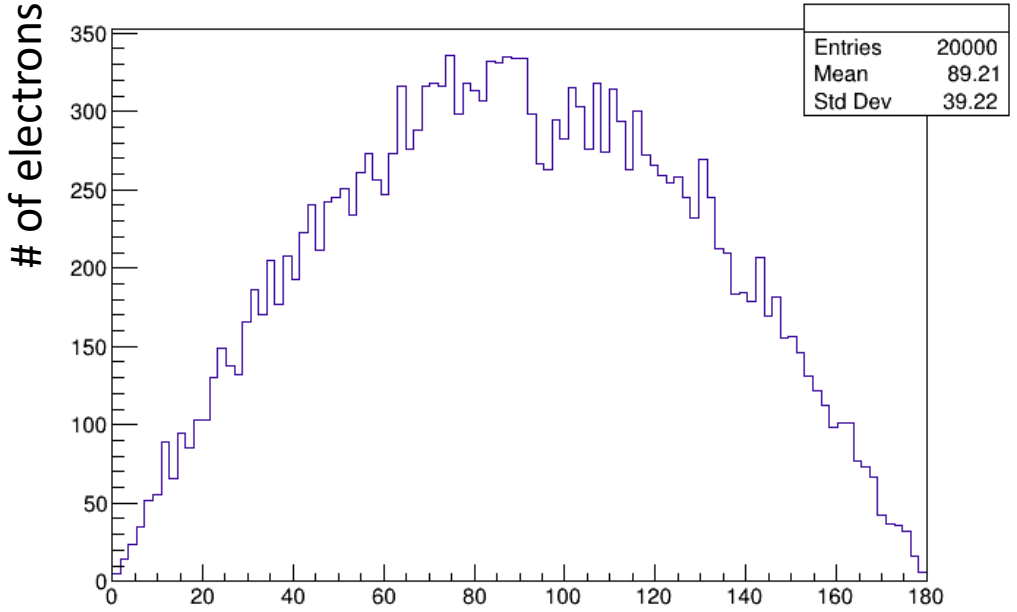
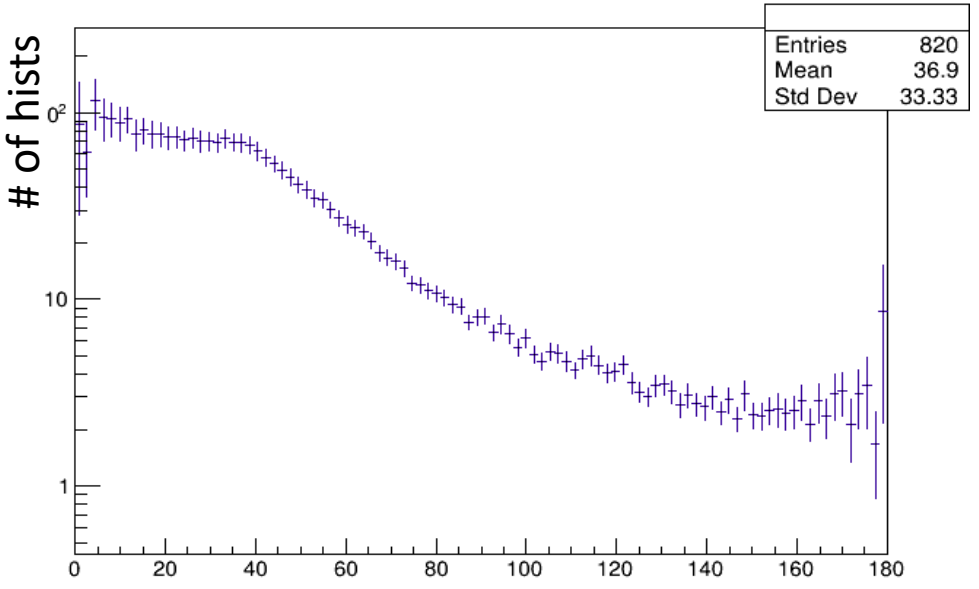
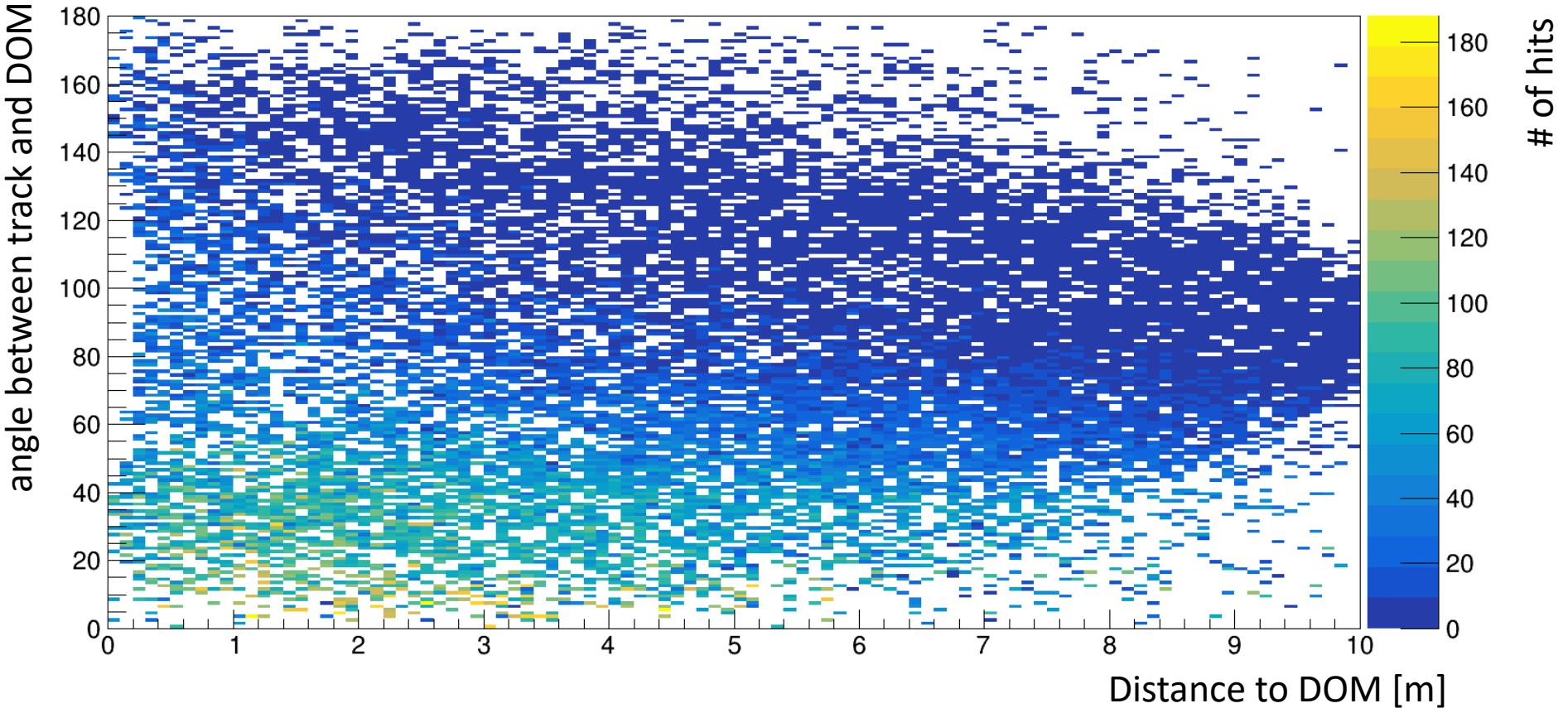


angle between track and DOM

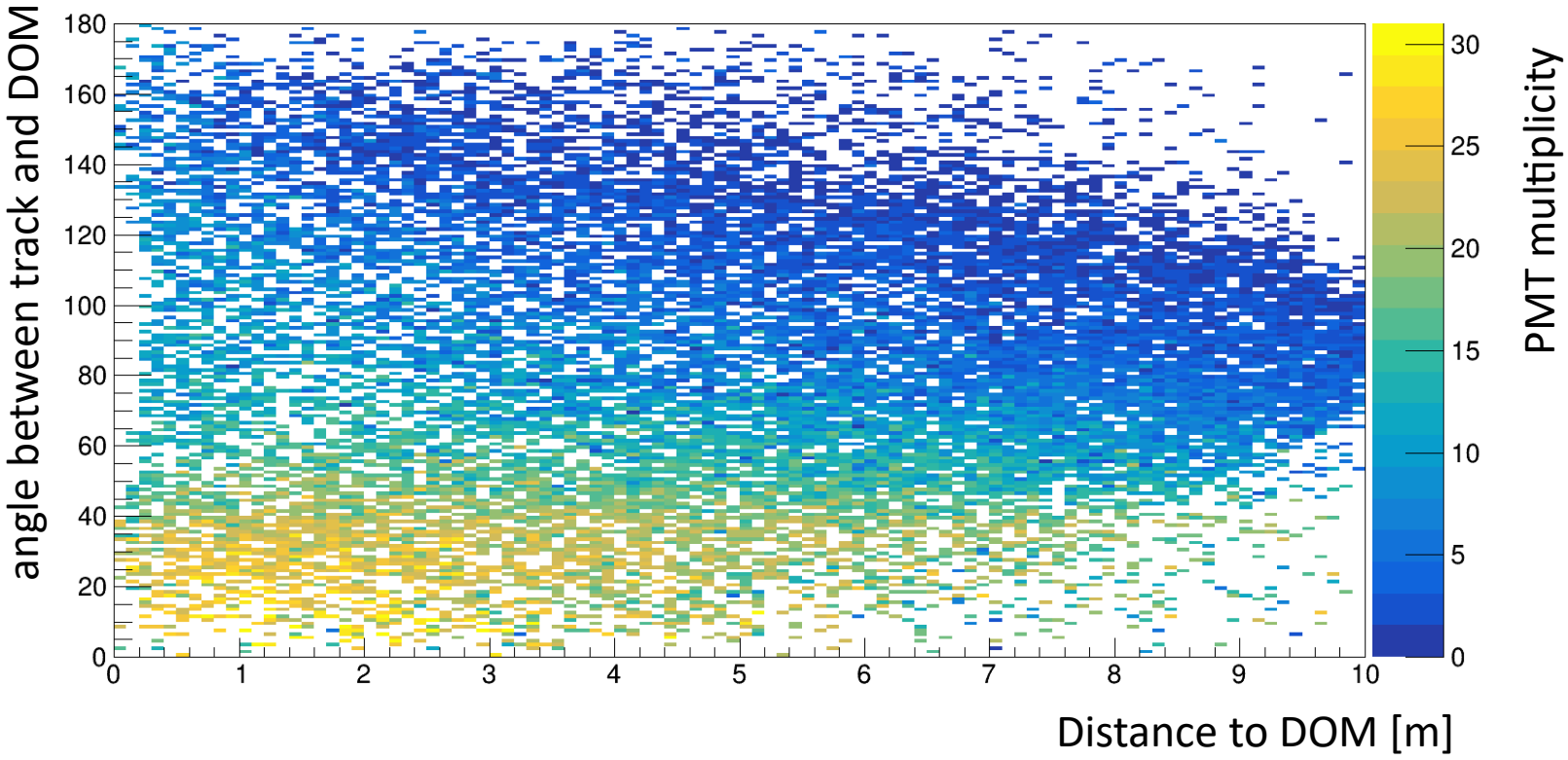


angle between track and DOM

Muon decay MC



Muon decay MC



Summary and Outlook

- Decayed muons could be observed considering ORCA events' time windows and Michel electron energies
- Electrons with corresponding Cherenkov photons are simulated around a single DOM to study hit patterns
- Time windows for searching Michel electron signals should be optimized
- Triggers from background chain should be applied