Physics Laboratory
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A reconstruction method for neutrino induced muon tracks taking into account the apriori knowledge of the neutrino source

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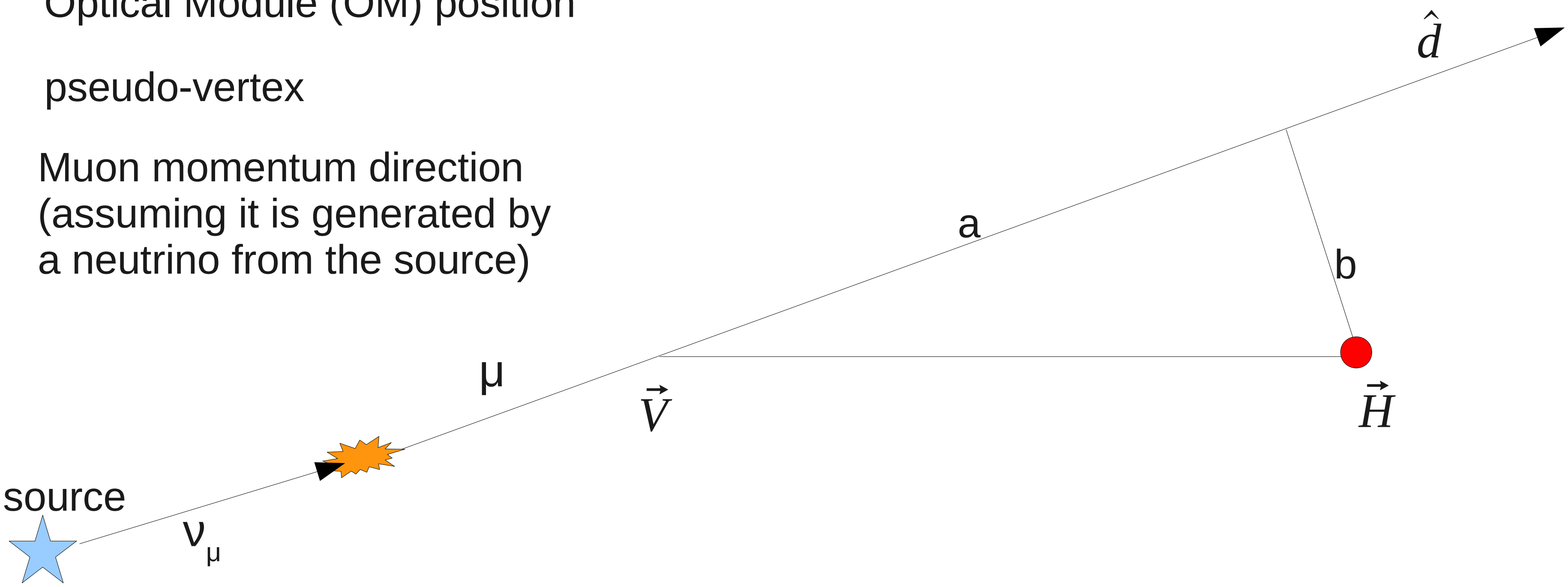
- Background filtering technique using the apriori known neutrino point source
- Prefit and triggering technique
- First results
  - Reconstruction efficiency and angular resolution
  - Estimation of fake signal

Background filtering technique using the apriori known neutrino point source
Causality criterion

$\vec{H}$ Optical Module (OM) position

$\vec{V}$ pseudo-vertex

$\hat{d}$ Muon momentum direction (assuming it is generated by a neutrino from the source)



Expected arrival time to OM of a photon emitted by the muon with the Cherenkov angle, θ_c (direct photon):

$$ct_{expected} = a + b\tan\theta_c$$

$$a = \hat{d}\cdot(\vec{H} - \vec{V})$$

$$b = \left|\vec{H} - \vec{V} - a\hat{d}\right|$$ The vertical distance of OM to the muon track

Background filtering technique using the apriori known neutrino point source

Causality criterion

Two direct photons with arrival times t_1, t_2 on the OMs with positions $\vec{H}_1$, $\vec{H}_2$ should satisfy:

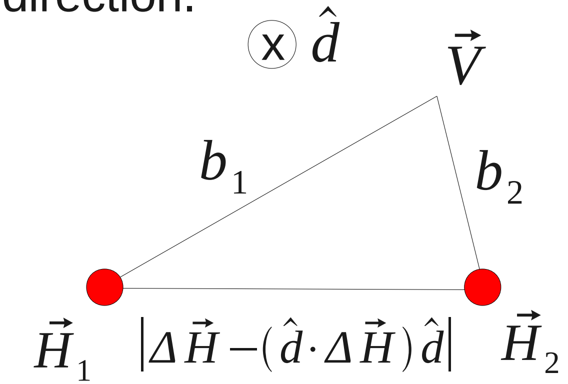
$$\frac{c\Delta t - \hat{d}\cdot\Delta\vec{H}}{\tan\theta_c} = \Delta b$$

$$\Delta t = t_1 - t_2$$

$$\Delta\vec{H} = \vec{H}_1 - \vec{H}_2$$

$$\Delta b = b_1 - b_2$$

Project the hits position and vertex on a plane perpendicular to the known direction.



Then from simple geometry:

$$|\Delta b| = \left|\frac{c\Delta t - \hat{d}\cdot\Delta\vec{H}}{\tan\theta_c}\right| < |\Delta\vec{H} - (\hat{d}\cdot\Delta\vec{H})\hat{d}|$$

Background filtering technique using the apriori known neutrino point source
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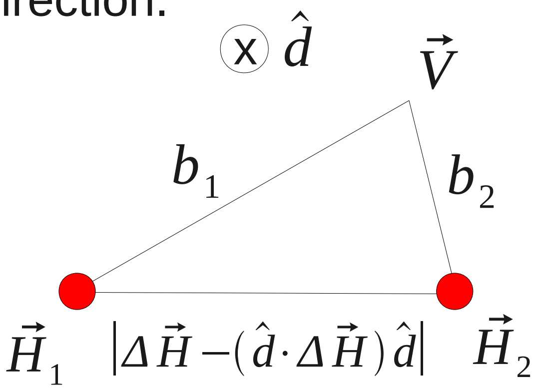

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Causality criterion between two hits using the known direction of the source

$$|c\Delta t - \hat{d}\cdot\Delta\vec{H}| < \tan\theta_c|\Delta\vec{H} - (\hat{d}\cdot\Delta\vec{H})\hat{d}| + ct_s$$ $$t_s = 10\mathrm{ns}$$

Relax the criterion
(light dispersion, time jitter)

$$|\Delta\vec{H}\cdot\hat{d}| < 800\mathrm{m}$$

Longitudinal distance between the two OMs to the direction of the muon track

$$|\Delta\vec{H} - (\hat{d}\cdot\Delta\vec{H})\hat{d}| < 67.5\mathrm{m}\,(\textit{one absorption length})$$

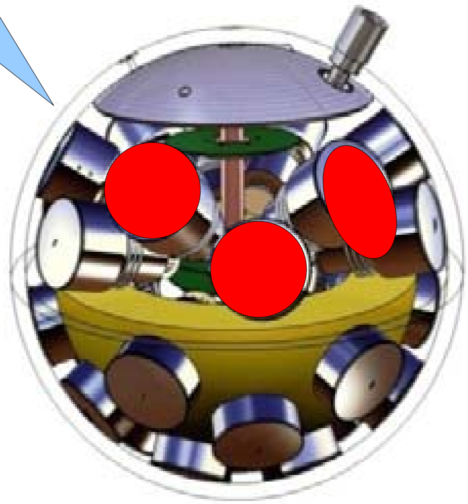
Lateral distance

Background filtering technique using the apriori known neutrino point source
Causality criterion used as background filtering

31 3” PMTs inside a 17” glass sphere

OM Multiplicity (m): the number of active small pmts of an OM within a time window of 10ns

L1 coincidence trigger: m>1



OMhit $H_i(t_i, \vec{H}_i, m_i)$ described by:
the first photon arrival time, t_i
the OMs position $\vec{H}_i$ and
the multiplicity, m_i

For every OMhit H_0 require the sum of the OMhit multiplicities of all OMhits H_i (that satisfy the causality criterion with respect to H_0) to be >=5

>90% of signal hits survive
<0.3% of noise hits survive (~0-3 L1s)

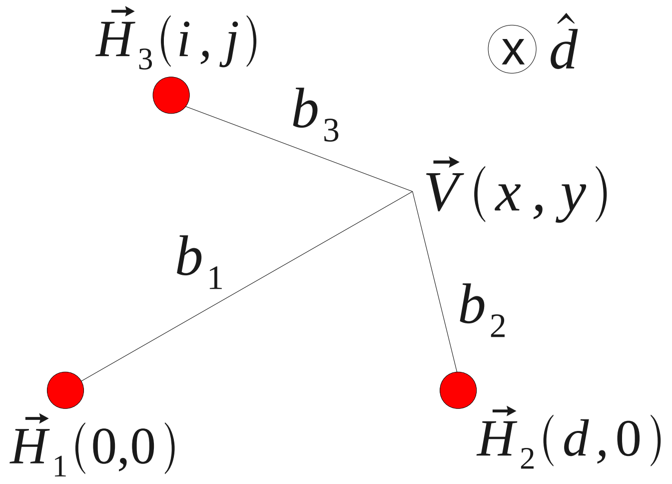
Prefit and triggering technique using the known neutrino direction

For every three OMhits (on different OMs) that satisfy the causality criterion a pseudovertex, V, can be found analytically:

$$ct_i = \hat{d} \cdot (\vec{H}_i - \vec{V}) + b_i \tan\theta_c \qquad \text{(i=1..3)}$$

$$\Rightarrow c_i + z = b_i \qquad z = \frac{\hat{d} \cdot \vec{V}}{\tan\theta_c} \qquad c_i = \frac{ct_i - \hat{d} \cdot \vec{H}_i}{\tan\theta_c}$$

- Project the hits and the vertex on a plane perpendicular to the known direction.
- Assume that this plane is the x-y plane in a new coordinate system.
- The x-axis is along the projected H_1H_2 line
- Then the problem becomes solving the equations (like trilateration used in GPSs) for x,y,z:



$$b_1^2 = (c_1 + z)^2 = x^2 + y^2$$
$$b_2^2 = (c_2 + z)^2 = (x-d)^2 + y^2 \qquad d, j \neq 0$$
$$b_3^2 = (c_3 + z)^2 = (x-i)^2 + (y-j)^2$$

$$\vec{V} = \vec{H}_1 + \hat{d} \cdot [z\tan\theta_c - \hat{d} \cdot \vec{H}_1 - \frac{x}{d} \hat{d} \cdot (\vec{H}_2 - \vec{H}_1)] + \frac{y}{d} \hat{d} \times (\vec{H}_2 - \vec{H}_1) + \frac{x}{d} (\vec{H}_2 - \vec{H}_1)$$

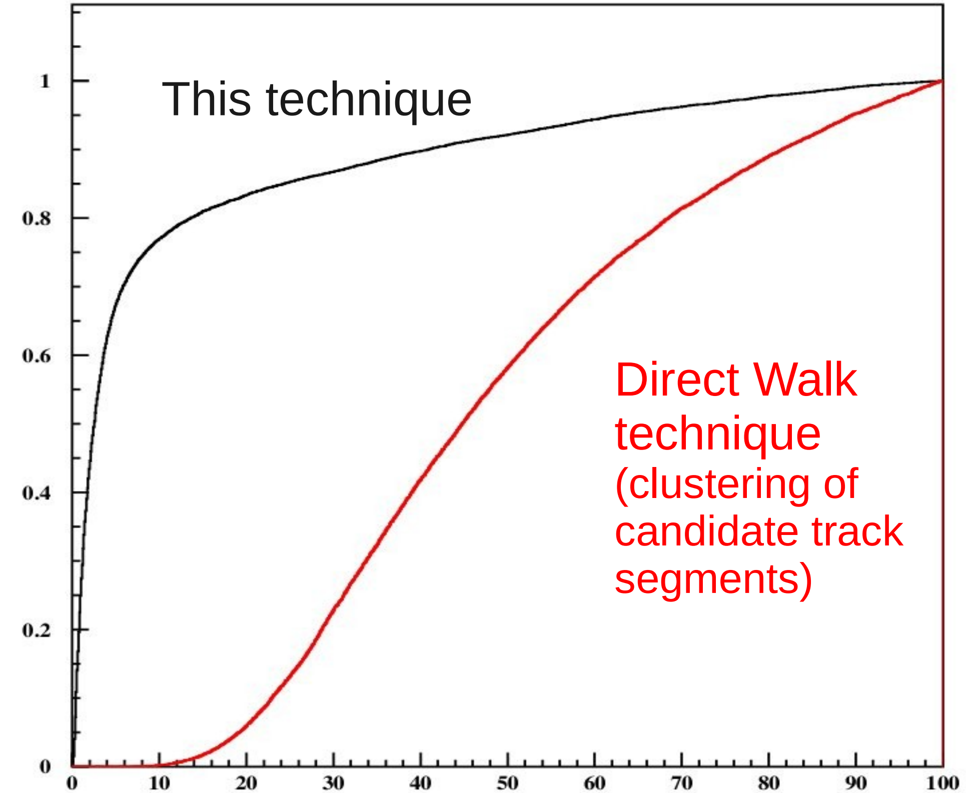
Prefit and triggering technique using the known neutrino direction

For every three OMhits (on different OMs) that satisfy the causality criterion a pseudo-vertex, $\vec{V}$, can be found analytically.

- For K^{40} events the probability to find three L1 OMhits producing a pseudovertex ~10^{-5}
  - Dedicated Trigger : Require at least one pseudo-vertex using the L1 Hits (<10ms CPU time/event for K^{40} events)

- Many candidate pseudo-vertexes are found using different triplets of hits
  - Cluster the candidates in space and choose the cluster with the maximum participants (within 5 meters).
  - The estimated pseudo-vertex is defined as the mean of the participants of the best cluster
  - For signal events (E_ν>100GeV) the clustering in space of all the candidate pseudo-vertexes can estimate the MC-true pseudo-vertex with accuracy ~ 2m

Cumulative distribution of the distance between the estimated pseudo-vertex and the MC-true pseudo-vertex



Prefit and reconstruction technique using the known neutrino direction

- The estimated pseudo-vertex and the known direction is used to further reduce the number of noise hits
  - ~ 3 noise hits survive (0.03% of the initial noise hits)
  - ~90% good signal hits survive
    - (good = residual with respect to the MC true track <100ns)

- Combination of χ^2 minimization and Kalman Filter is used to produce many candidate tracks
  - Take all the hits that pass the last filtering stage
  - To avoid fake signal do not constrain the fit to the known direction

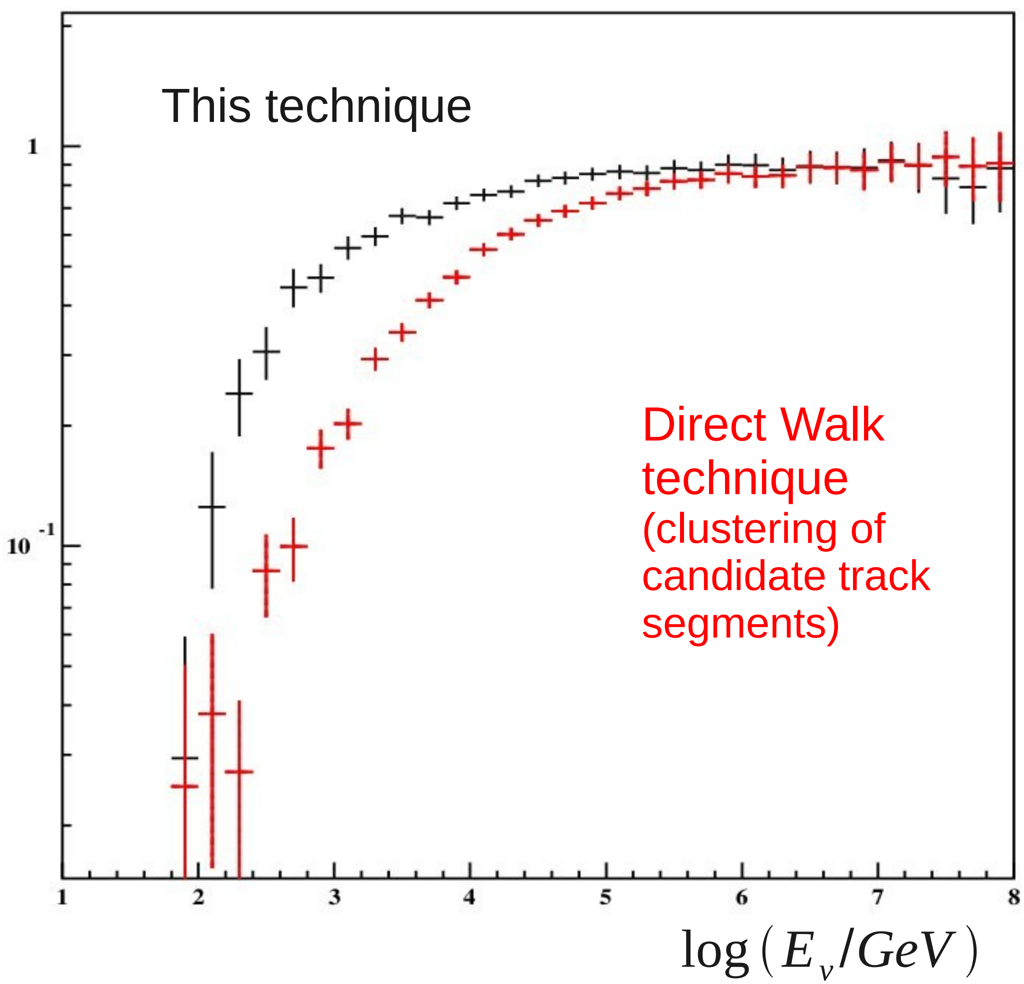
- The best candidate is chosen using the timing and Multi-PMT direction Likelihood

  (talk "Reconstruction efficiency and discovery potential of a Mediterranean neutrino telescope: A simulation study using the Hellenic Open University Simulation & Reconstruction (HOURS) package", by A.Tsirigotis)
  - Accept the event if the angular difference between the known direction and the reconstructed muon direction < 1^o

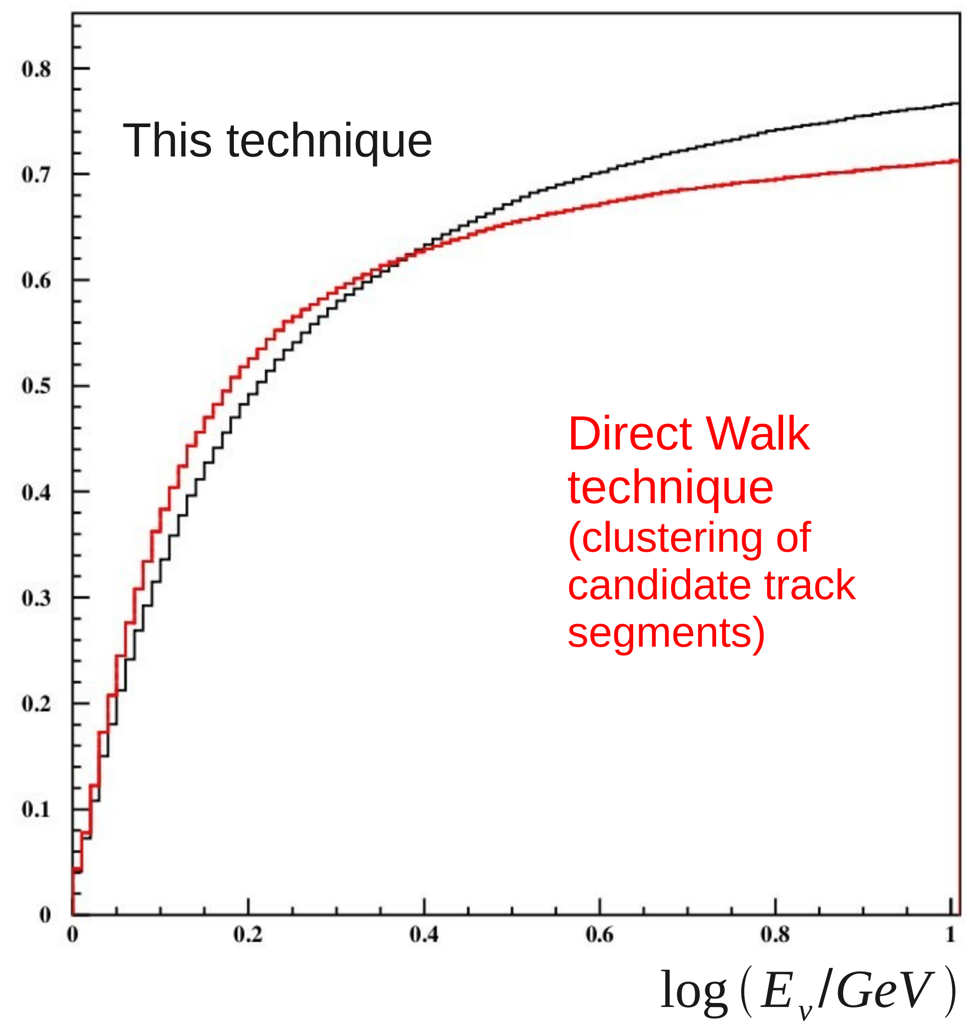
Prefit and reconstruction technique using the known neutrino direction
Reconstruction efficiency and angular resolution

- E^{-2} neutrino generated spectrum (15GeV – 100PeV)
- 2.9km^3 neutrino detector with 6160 Multi-PMT OMs (arranged in 154 Detection Units (Towers))
- Reconstructed tracks with at least 8 hits on different OMs

Reconstruction efficiency vs neutrino energy
for events with at least 3 L1 signal Hits



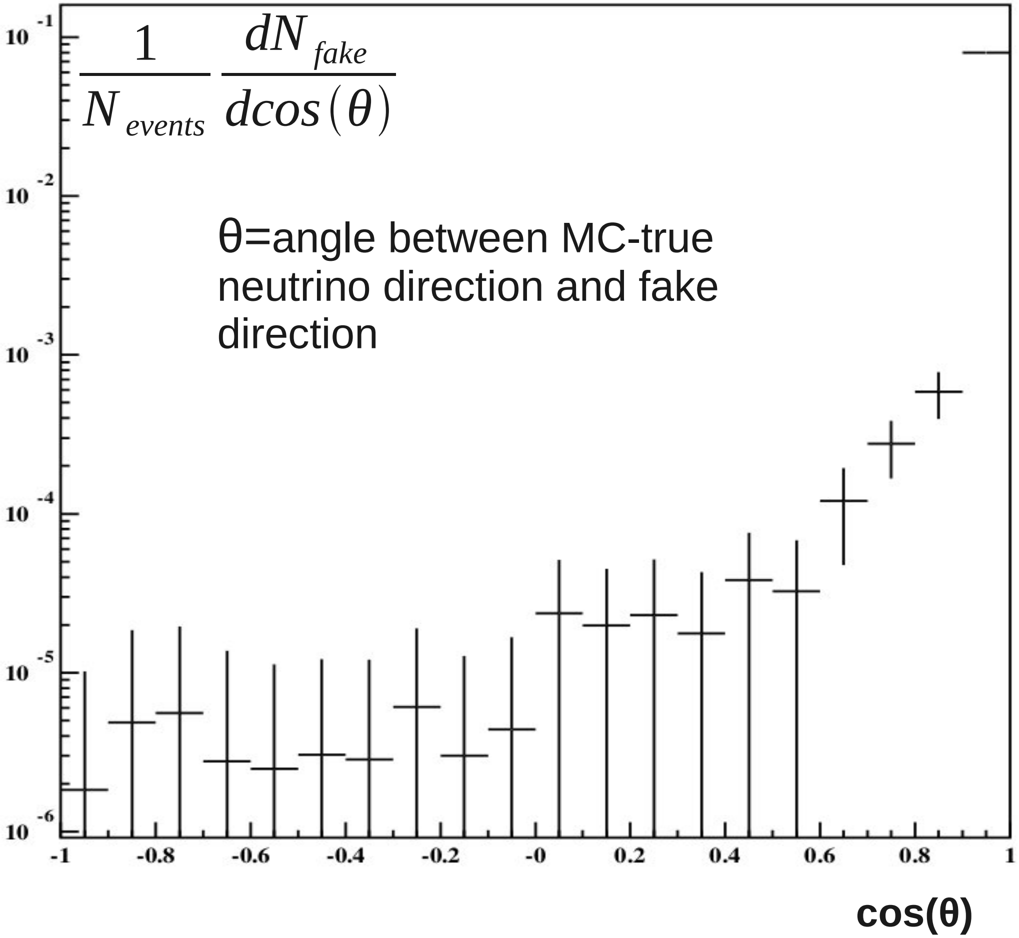
Point spread function for
reconstructed events



Reconstruction technique using the known neutrino direction
Estimation of fake signal

For each event:

- Assume a random (fake) candidate neutrino direction
- Apply filtering and prefit using the fake direction
- Track reconstruction
- Accept the event if the angular difference between the fake direction and the reconstructed muon direction < 1°



- Fake signal can be further reduced by applying tracking quality criteria using the estimated tracking error.
- Fake tracks carry a very small weight in the unbinned method (talk "Evaluation of the discovery potential of an underwater Mediterranean neutrino telescope taking into account the estimated directional resolution and energy of the reconstructed track", by S.E. Tzamarias)

Conclusions and future plans

- We developed a filtering and prefit algorithm taking into account the apriori known direction of the neutrino source. The first results are very encouraging.
- We should study further the elimination of fake signal created by imposing an apriori direction
  - Fake tracks have a low tracking quality which is reflected to the estimated tracking error, i.e. fake tracks carry a very small weight in the unbinned method.
  - We are workings towards combining the known source direction technique with the unbinned method

Acknowledgments
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