Discovery Potential of KM3NeT to Galactic Sources

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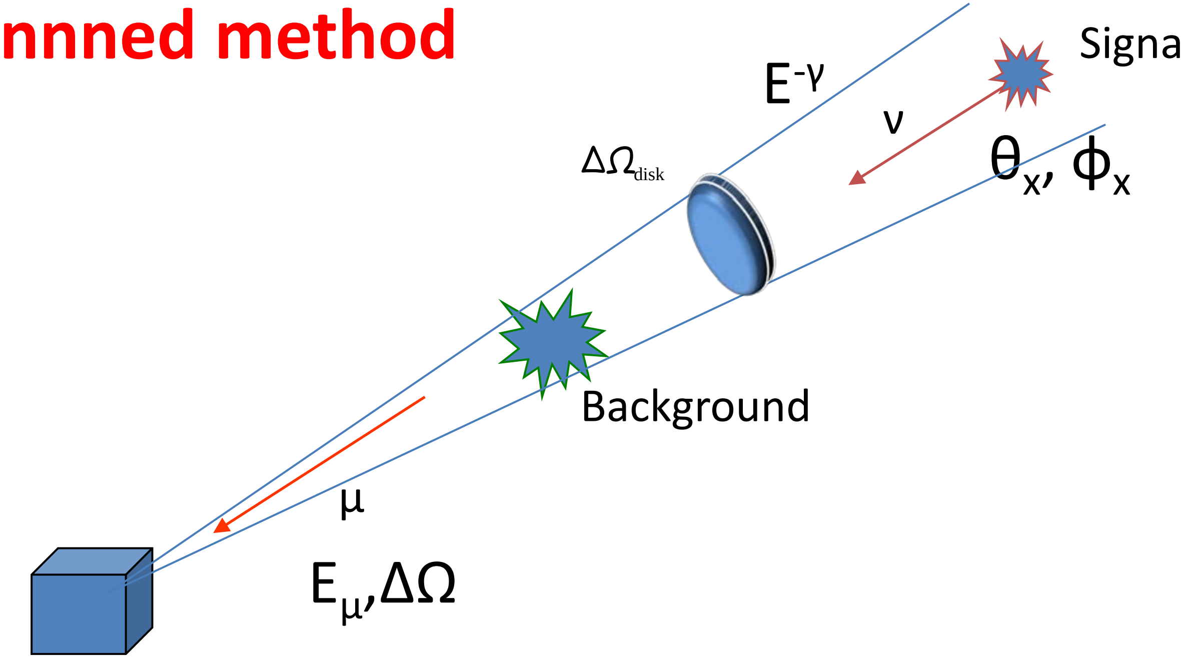
Outline

- The UnBinned method for estimating the DP
- KM3NeT (DU:strings) DP for RXJ1713 & Vela X sources
- Estimation taking into account the known source direction

KM3NeT Phase-1 Meeting
29-31 January 2013
Marseille

Reminder of the Unbinnned method



$$P_{signal} = \frac{N_s}{N_{total}}$$

$$P_{bck} = \left(1 - \frac{N_s}{N_{total}}\right)$$

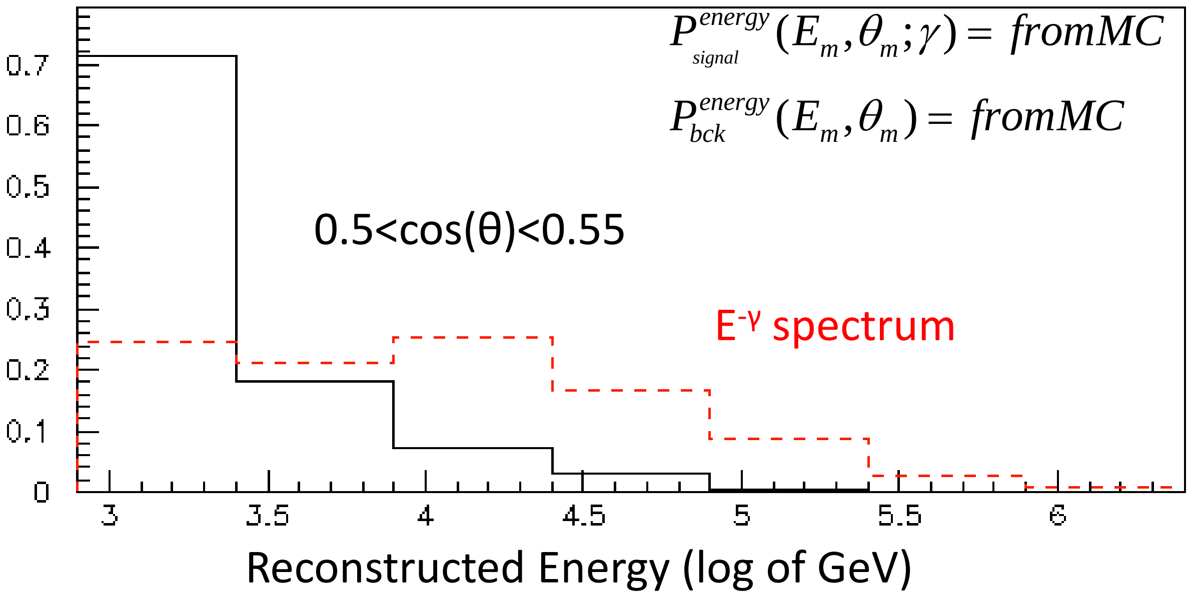
$$P(E_\mu, \Delta\Omega_{disk}) = P(E_\mu, \Delta\Omega_{disk} / signal) \cdot P_{signal} + P(E_\mu, \Delta\Omega_{disk} / bck) \cdot P_{bck}$$

$$P(E_\mu, \Delta\Omega_{disk} / signal) = P^{angle}_{signal}(\Delta\Omega_{disk}, \theta_x, \varphi_y) \cdot P^{energy}_{signal}(E_m, \theta_m; \gamma)$$

$$P(E_\mu, \Delta\Omega_{disk} / bck) = P^{angle}_{bck}(\Delta\Omega_{disk}, \theta_x, \varphi_y) \cdot P^{energy}_{bck}(E_m, \theta_m) = \frac{1}{\Delta\Omega_{disk}} \cdot P^{energy}_{atmospheric}(E_m, \theta_m)$$

Energy and Angular distributions

Reconstructed Energy Distributions for **Signal (E^{-2} spectrum)** and **Atm. Neutrino Background**



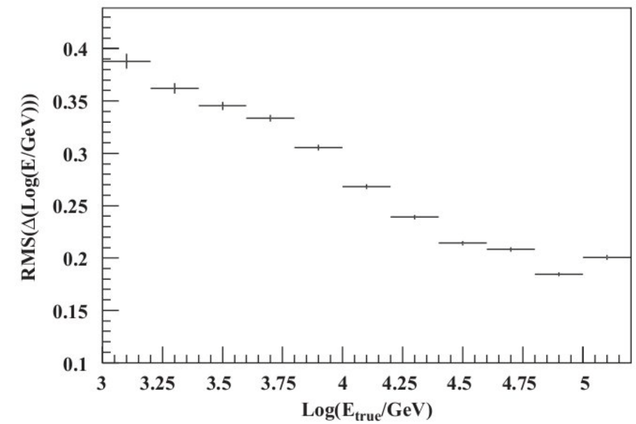
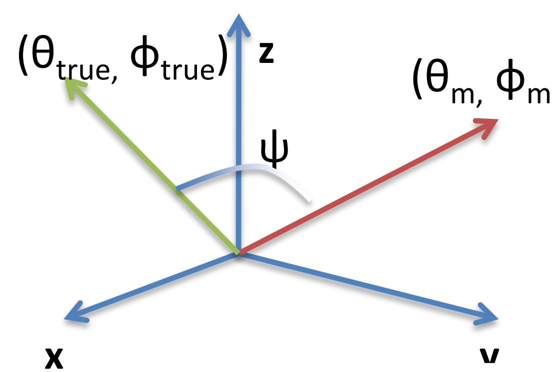


Fig. 2. The muon energy estimation resolution as a function of the true muon energy at the impact point to the center of the detector.



PDF of a reconstructed track to differ by θx and ϕx from the direction of a point source

$$P^{angle}_{signal}(\theta_x, \phi_y) = \frac{1}{1 - e^{-\frac{R^2_{max}}{s_x^2 + s_y^2}}} \frac{1}{2\pi s_x s_y} e^{-\frac{1}{2}\left(\frac{\theta_x^2}{s_x^2} + \frac{\phi_y^2}{s_y^2}\right)}$$

$$P^{angle}_{bck}(\theta_x, \phi_y) = \frac{1}{\Delta\Omega} = \frac{1}{\pi R^2_{max}}$$

Estimating the angular resolution of tracks in neutrino telescopes based on a likelihood analysis

Till Neunhöffer

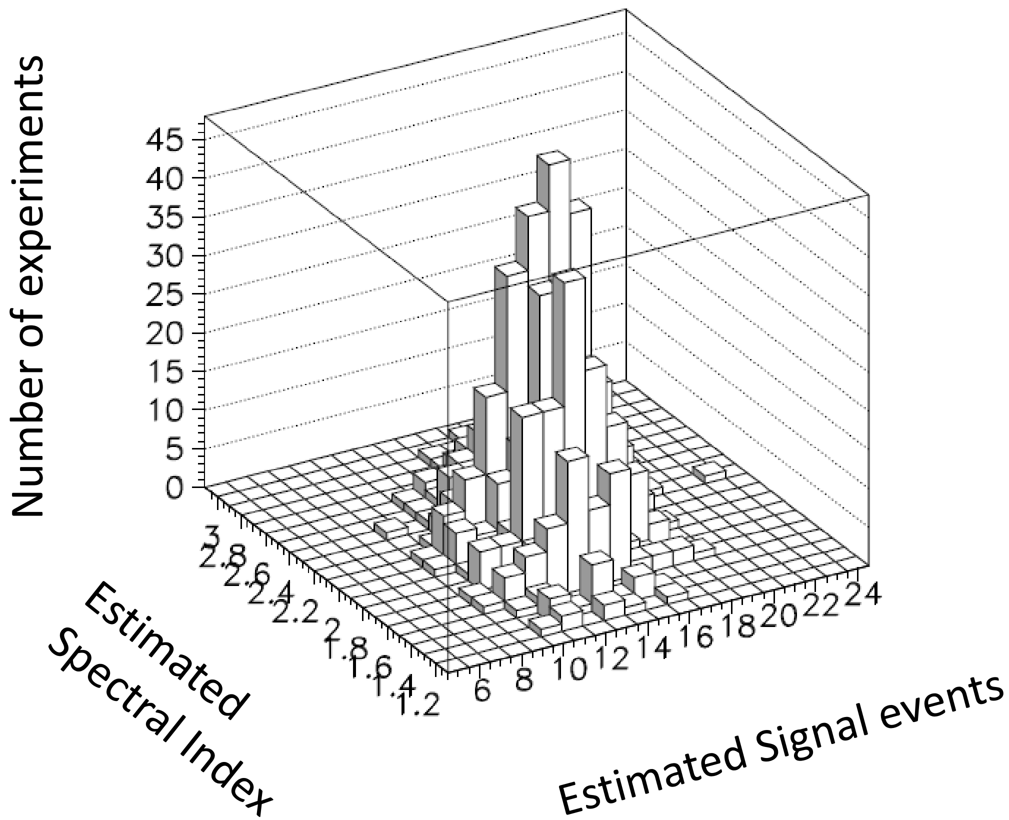
Where s_x s_y incorporate the uncertainty of the angle between the ν-μ

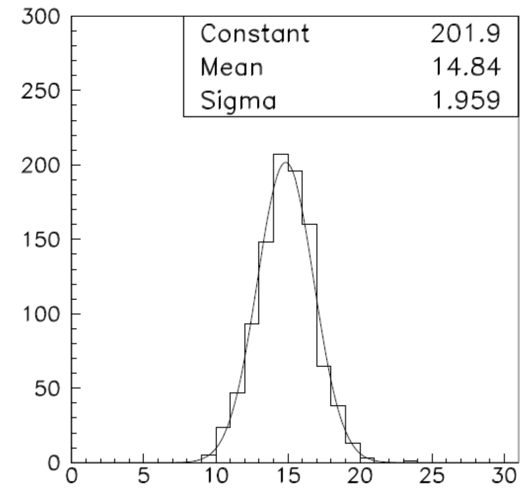
Likelihood estimations

$$L(\gamma, N_s) = \prod_{i=1}^{N_{total}} P_i(\theta_x, \varphi_y, E_m, \theta_m; \gamma, N_s)$$

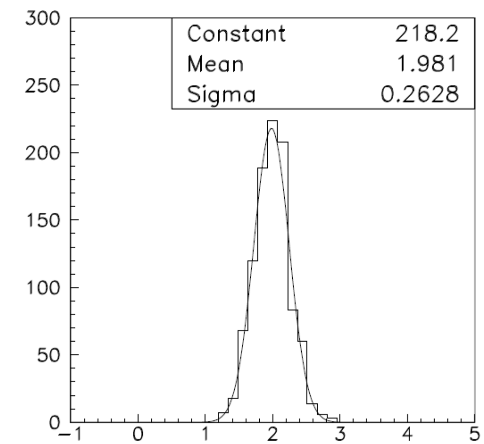
Point source d=-60^0 and R_{max}=0.6^0 Detector: 308 Towers-180m distance

True Values: 15 Signal Events on top of 15 background events with γ=2





Estimated Signal events



Estimated Spectral Index

Discovery potential determination

$$P_{signal}\left(\theta_x,\phi_y,E_m,\theta_m;\gamma\right)=P^{angle}_{signal}(\theta_x,\phi_y)\cdot P^{energy}_{signal}(E_m,\theta_m;\gamma)$$

$$P_{bck}=P^{angle}_{bck}(\theta_x,\phi_y)\cdot P^{energy}_{bck}(E_m,\theta_m)$$

$$P_i\left(\theta_x,\phi_y,E_m,\theta_m;\gamma,N_s\right)=\frac{N_s}{N_{total}}\cdot P_{signal}\left(\theta_x,\phi_y,E_m,\theta_m;\gamma\right)+\left(1-\frac{N_s}{N_{total}}\right)P_{bck}\left(\theta_x,\phi_y,E_m,\theta_m\right)$$

$$L\left(\gamma,N_s\right)=\frac{\left(m_B\right)^{\left(N_{total}-N_s\right)}e^{-m_B}}{\left(N_{total}-N_s\right)!}\cdot\prod_{i=1}^{N_{total}}P_i\left(\theta_x,\phi_y,E_m,\theta_m;\gamma,N_s\right)$$

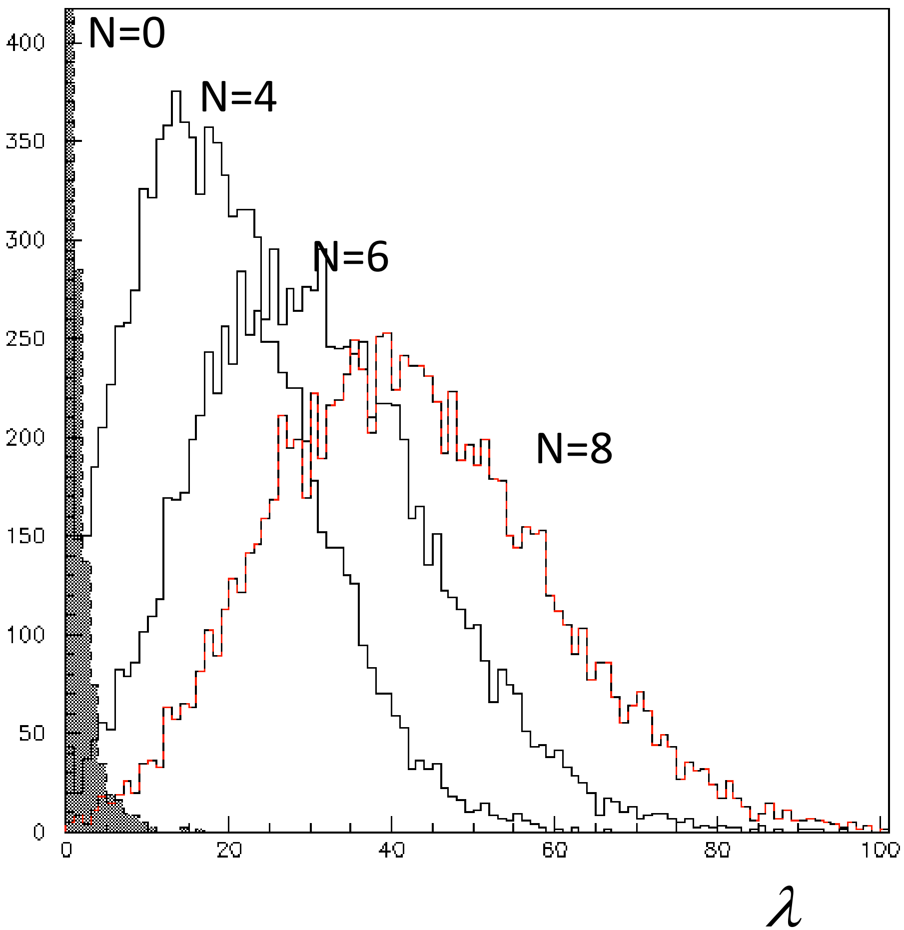
Two hypotheses:

- the data sample is only background (null hypothesis)
- The data sample contains signal events (discovery)

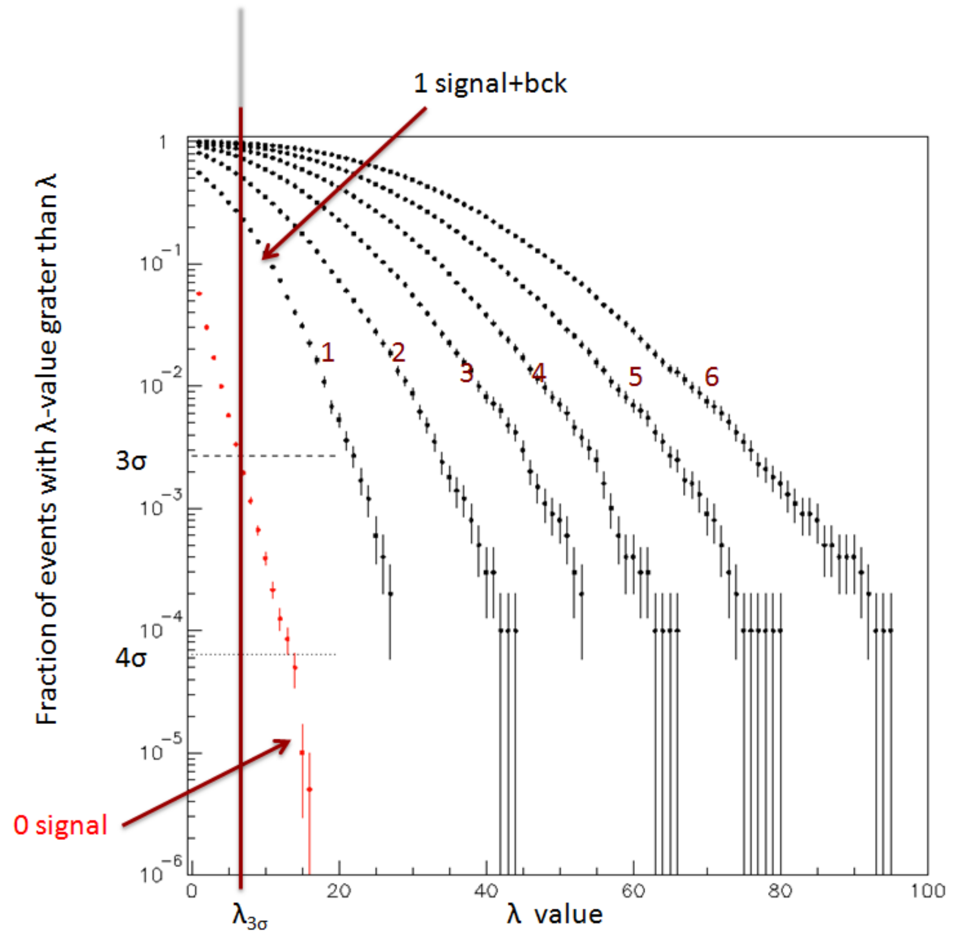
Test statistic: $$\lambda=-2\cdot\ln\frac{L_0\left(N_s=0\right)}{L\left(\gamma=2,N_s\right)}$$

Distribution of λ and Discovery probability

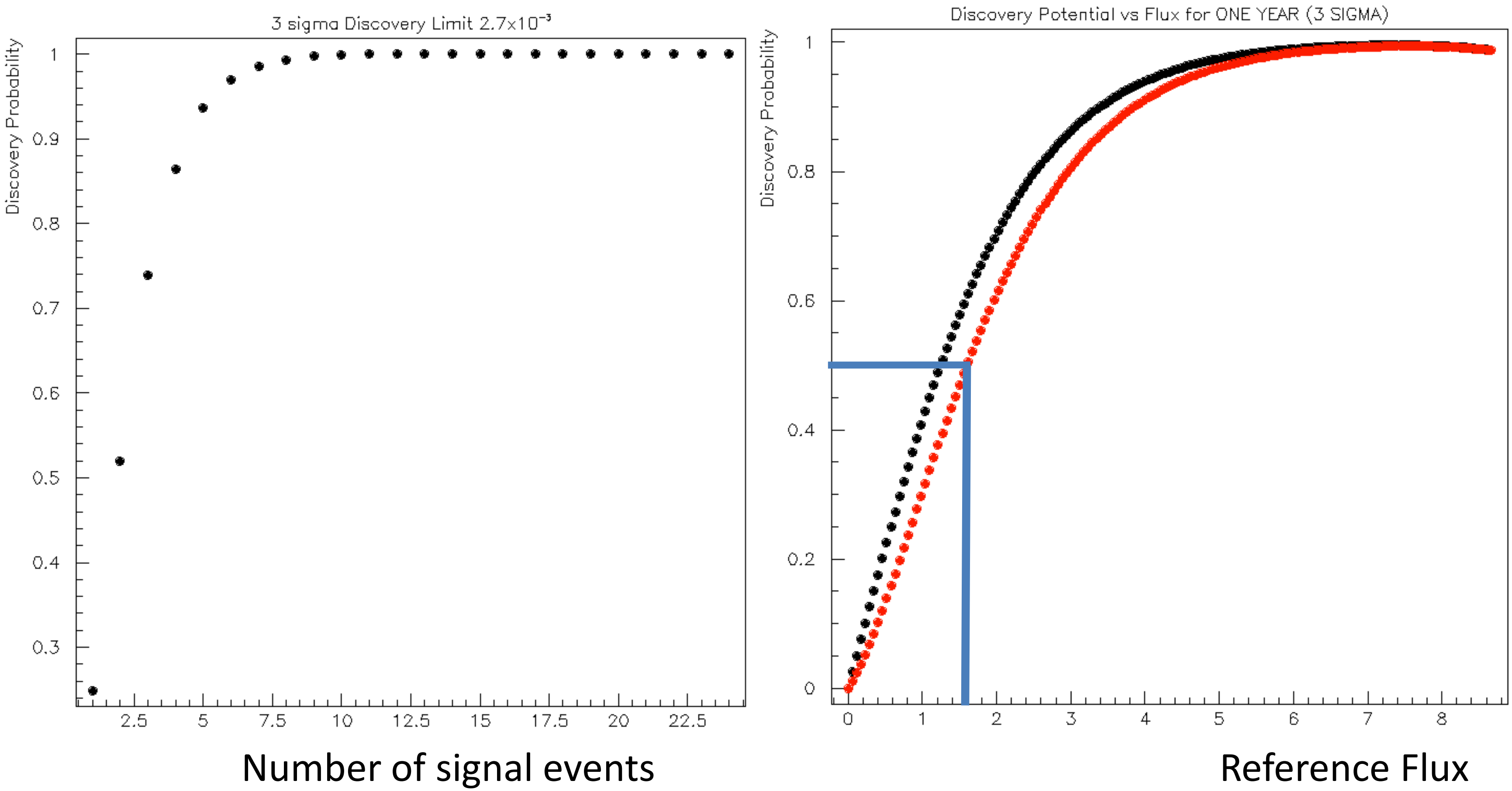
Distribution of λ when N signal events are present on top of background



Fraction of events with λ greater than a λ value



Discovery probability and integrated flux



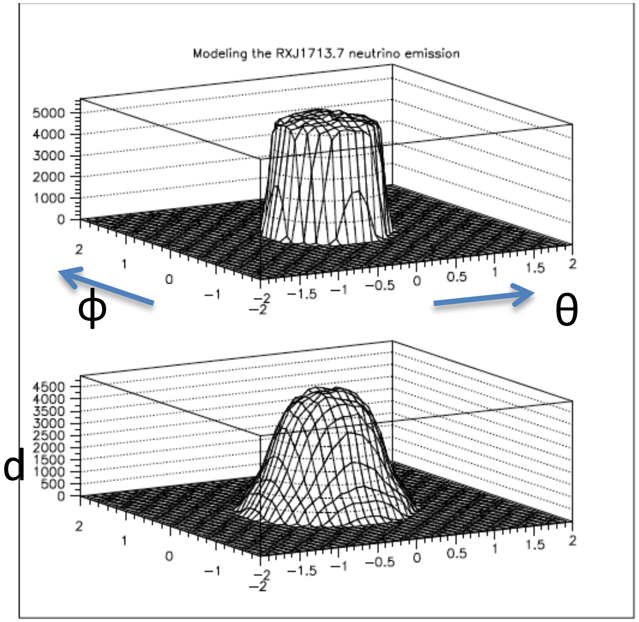
If r is the mean number of expected signal from a source then we expect 0, 1, 2, 3, 4,… tracks to be observed with probabilities according to the Poissonian probability function P(n;r).

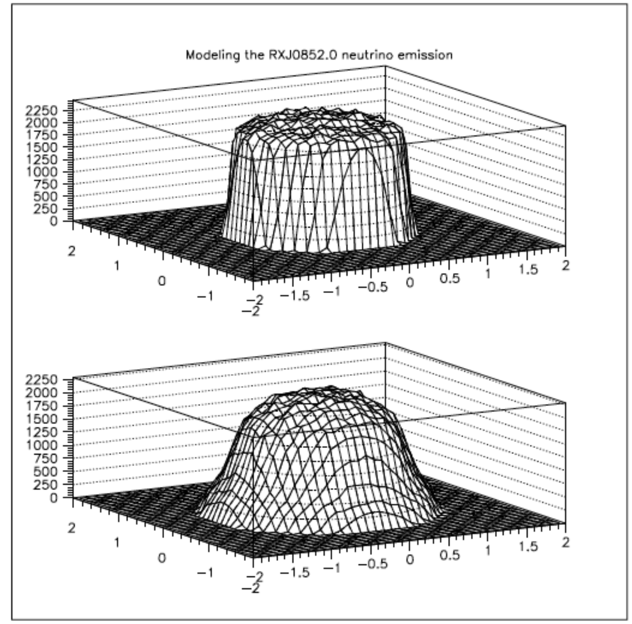
Consequently, the Discovery Potential for r expected signal tracks is the convolution of the discovery probabilities for certain number of tracks with the corresponding Poissonian probabilities for mean equals to r

Modeling the Spatial Distribution of the Sources

generated neutrinos

Reconstructed neutrino directions





generated neutrinos

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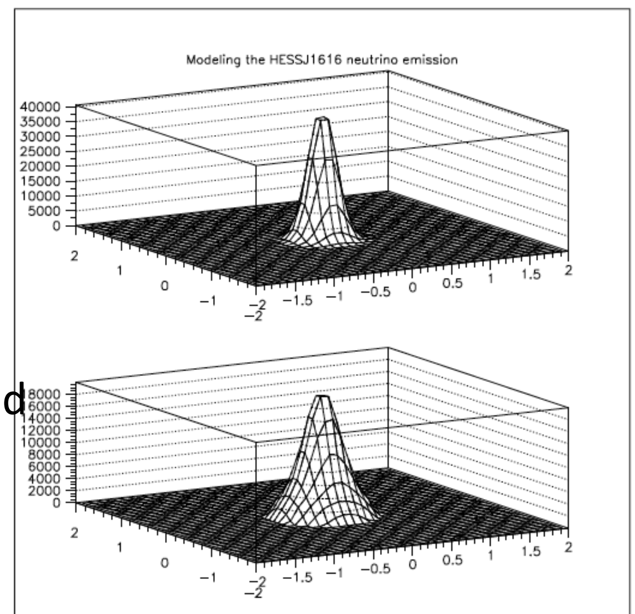
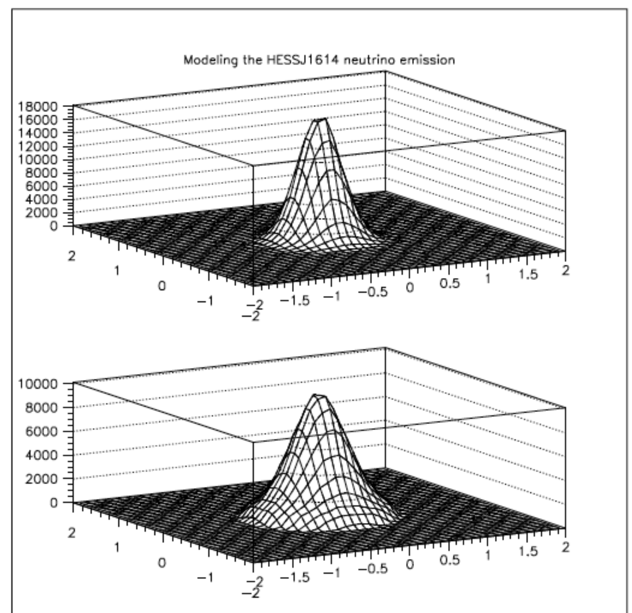


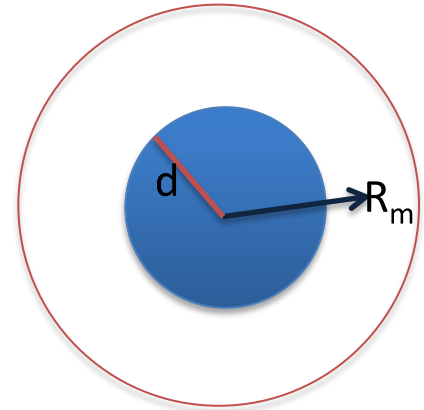


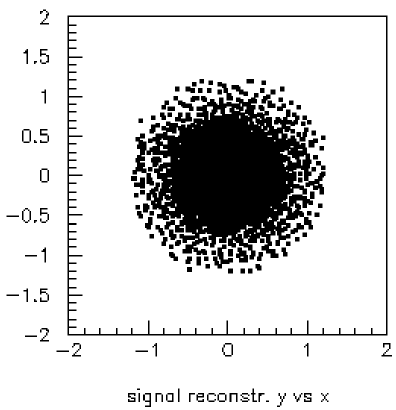
Flat disk treatment

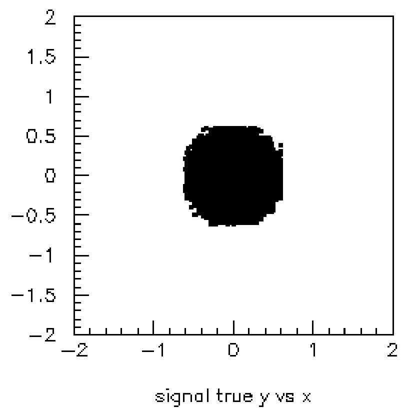
Point source →

$$P^{angle}_{signal}(\theta_x,\varphi_y)=\frac{1}{1-e^{-\frac{R_{max}}{s_x^2+s_y^2}}}\frac{1}{2\pi\sigma_x\sigma_y}e^{-\frac{1}{2}\left(\frac{\theta_x^2}{s_x^2}+\frac{\varphi_y^2}{s_y^2}\right)}$$

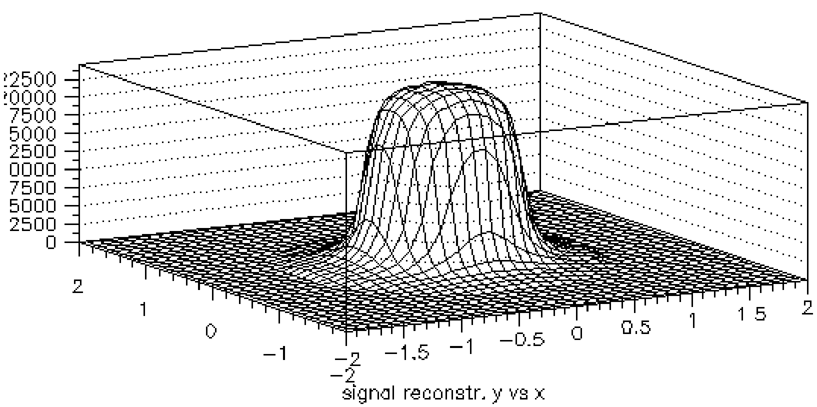
$$P^{angle}_{signal}(\theta_x,\phi_y)=\frac{1}{1-e^{-\frac{d}{s_x^2+s_y^2}}}\frac{1}{2\pi\sigma_x\sigma_y}\iint_{\Delta} e^{-\frac{1}{2}\left(\frac{(\theta_x-\theta_t)^2}{s_x^2}+\frac{(\phi_y-\varphi_t)^2}{s_y^2}\right)}\frac{1}{\pi d^2}d\theta_t\, d\phi_t$$

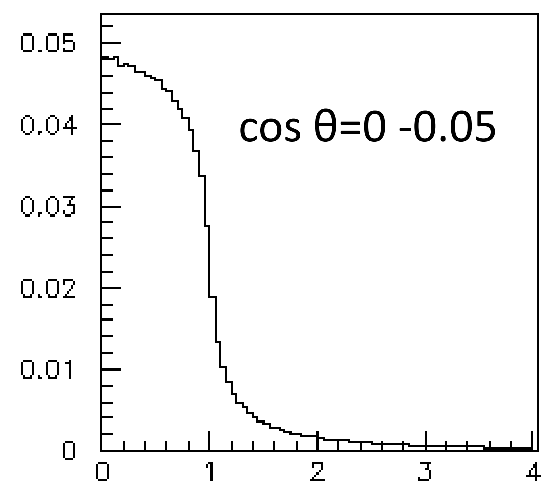




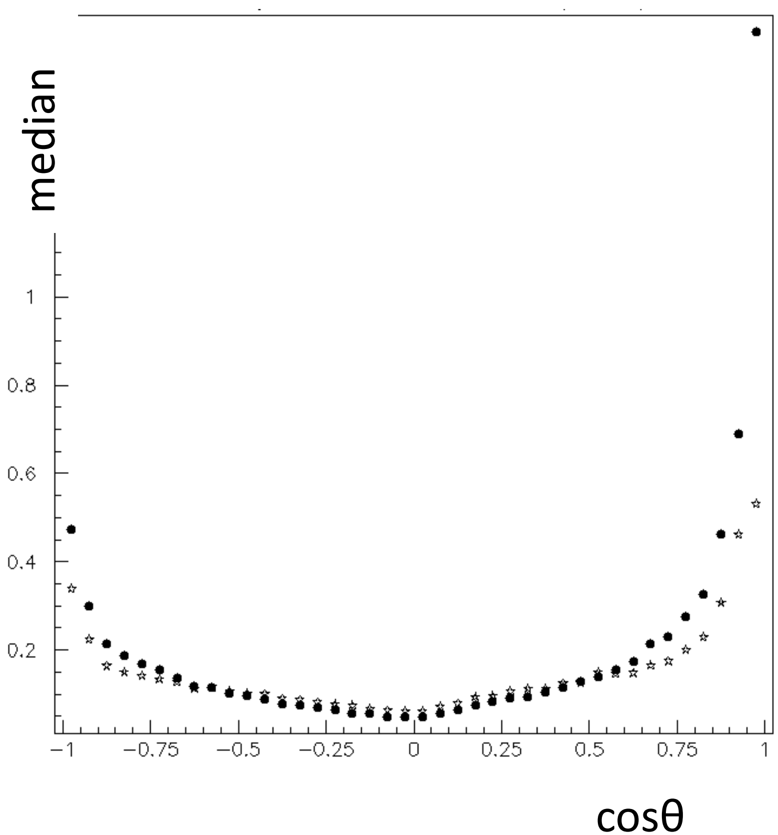


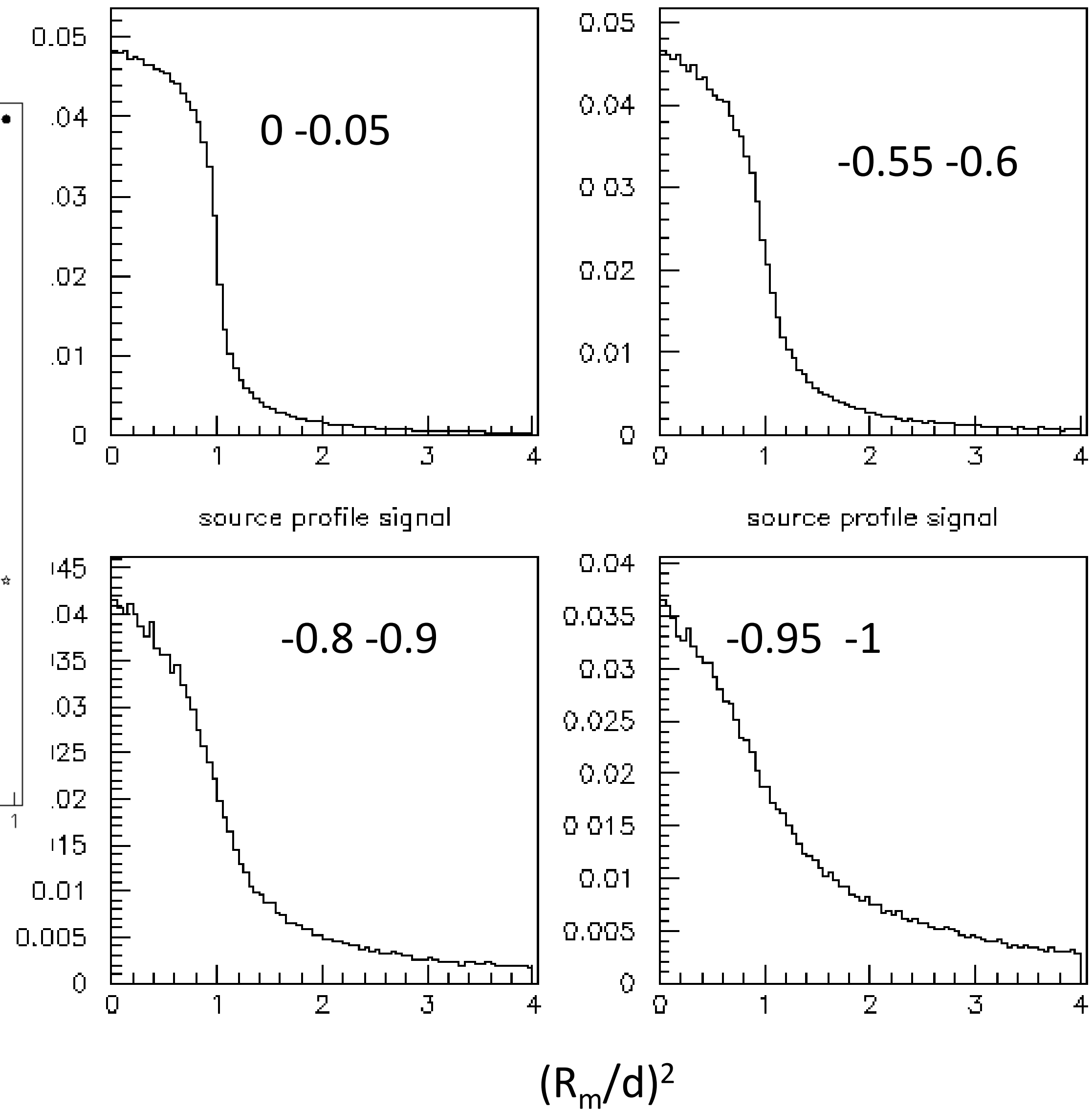
$$P^{angle}_{signal}(\theta_x,\phi_y)\rightarrow P^{angle}_{signal}\left(\left(\frac{R_m}{d}\right)^2,\cos\theta_t\right)$$





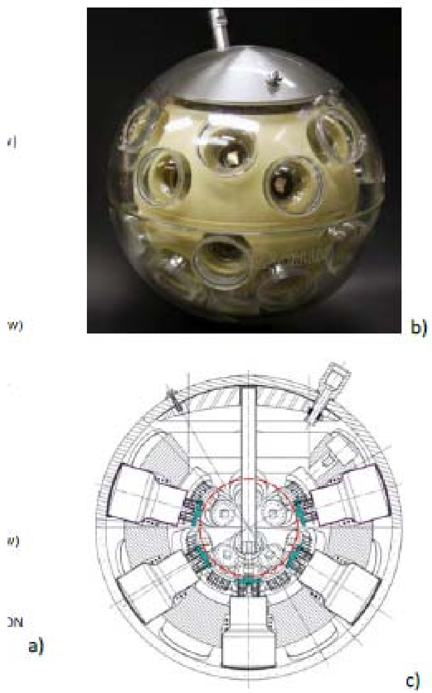
$$P_{signal}^{angle}(\theta_x,\phi_y) \rightarrow P_{signal}^{angle}\left(\left(\frac{R_m}{d}\right)^2,\cos\theta_t\right)$$



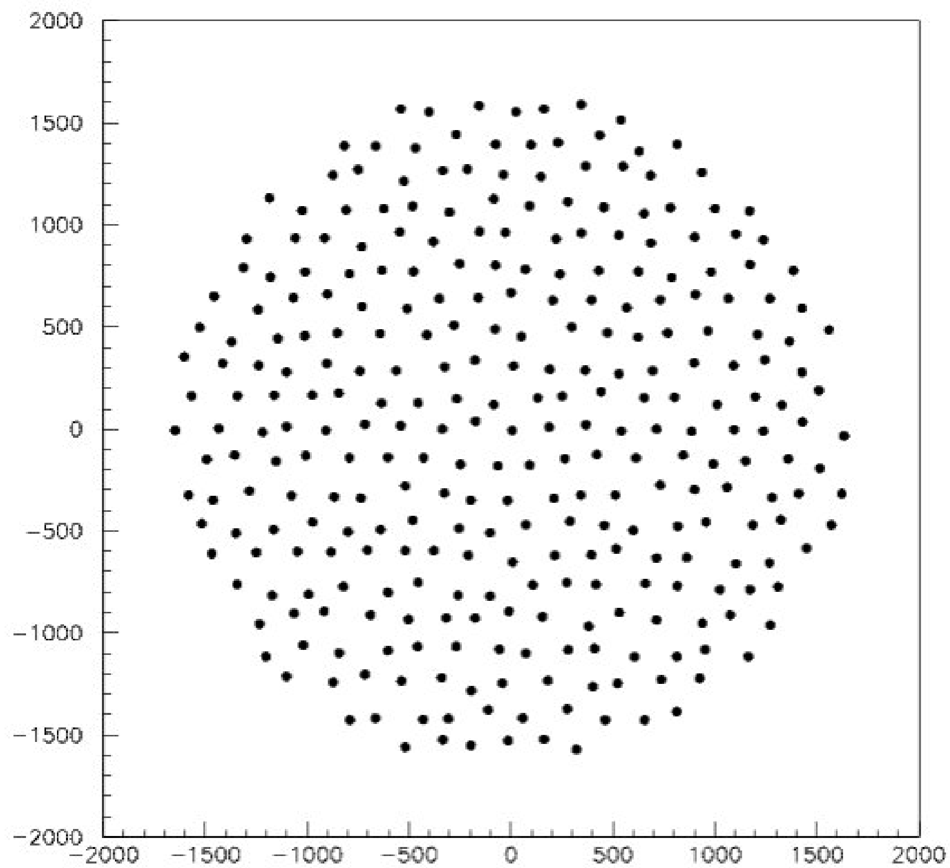


Detector Geometrical Layout

Strings: 616 strings with 100m inter string distance. Each string comprise 20 Multi PMTs, 40 m apart.

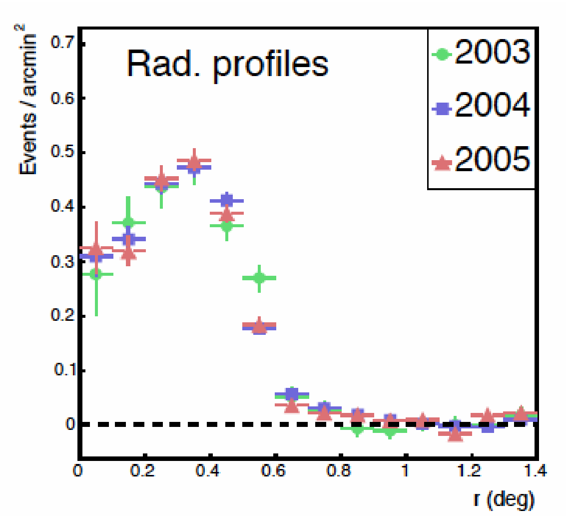


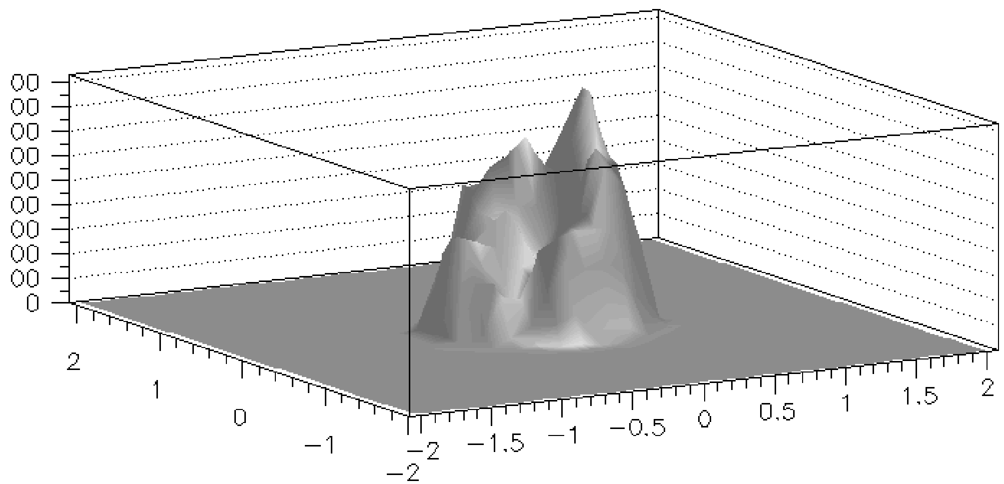
Detectors Footprint



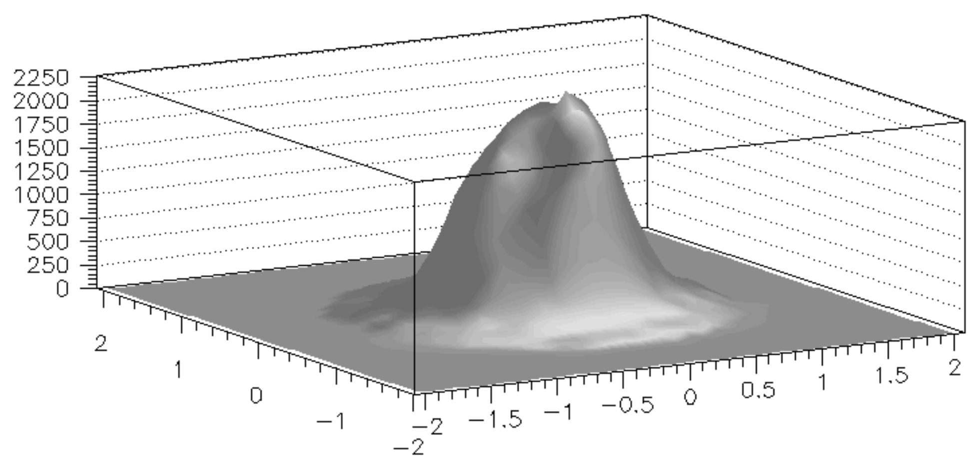
RXJ1713

Simulate the ν emission to follow the (raw) VHE gamma emission topology
(just a toy model)

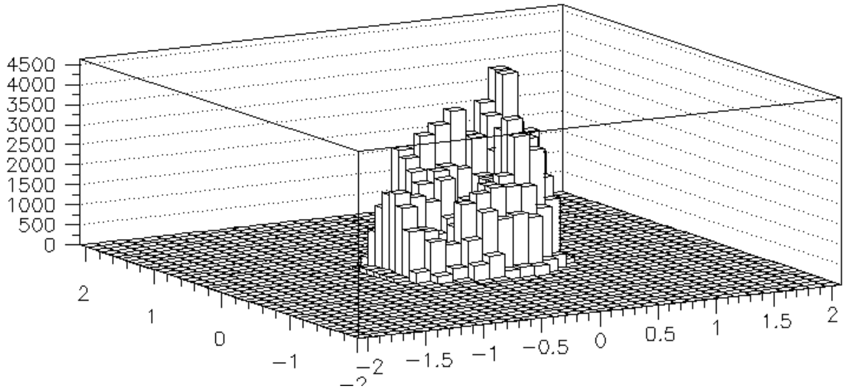




3D angular distribution of the reconstructed (ν) signal induced muons



RXJ1713



Each bin of the source-model contributes as

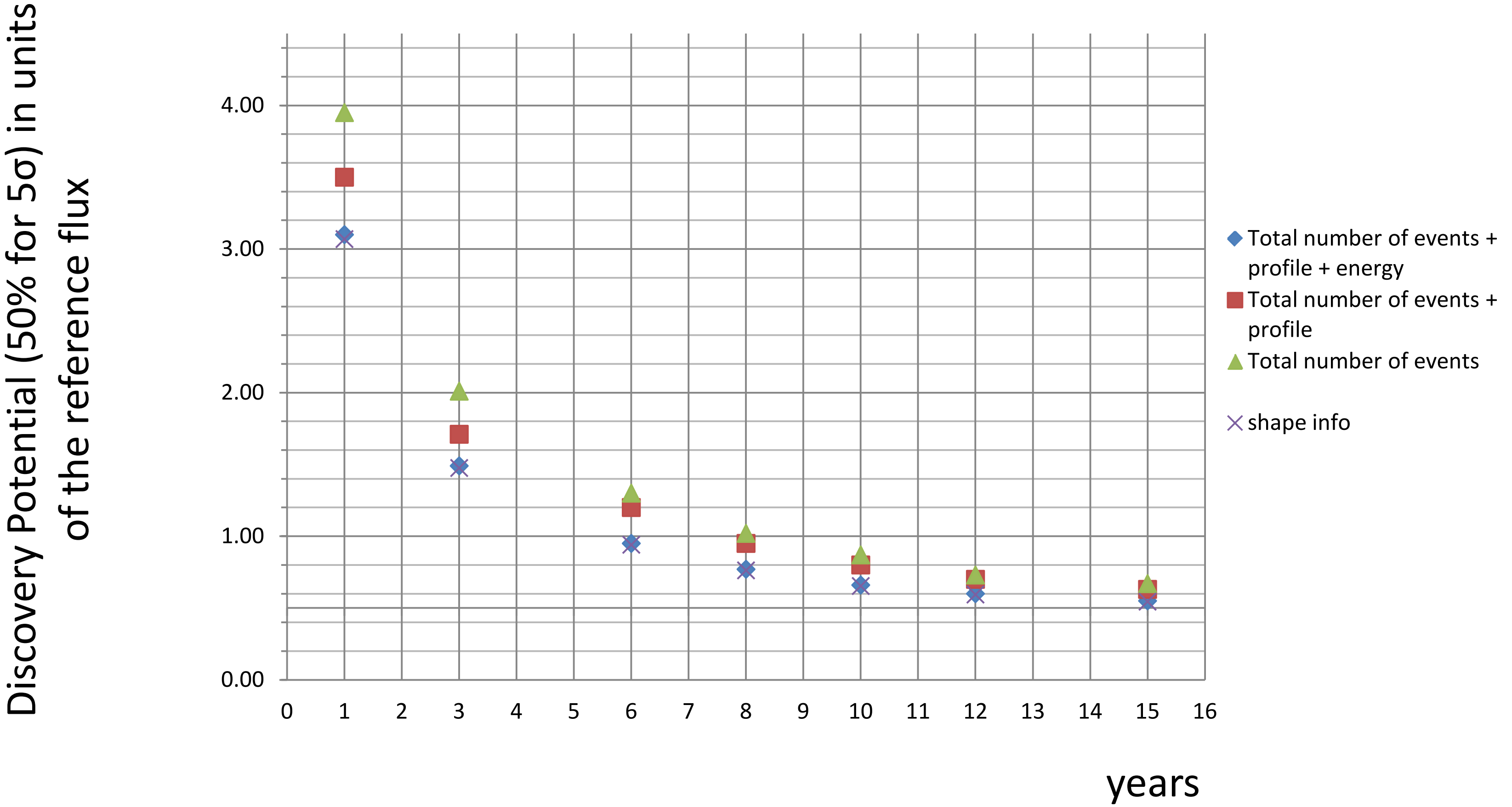
$$P^{angle}_{signal-bin}(\theta_x,\phi_y)=\frac{1}{1-e^{-\frac{R^2_{\max}}{s_x^2+s_y^2}}}\frac{1}{2\pi\sigma_x\sigma_y}\iint_{\Delta} e^{-\frac{1}{2}\left(\frac{(\theta_x-\theta_t)^2}{s_x^2}+\frac{(\phi_y-\varphi_t)^2}{s_y^2}\right)}\frac{1}{\pi d^2}d\theta_x d\phi_y$$

$$P_{signal}(\theta_x,\phi_y,E)=\Pi(E)\cdot\sum_{i=1}^{101}w_i\cdot P^{angle}_{signal-bin-i}(\theta_x,\phi_y)$$

$$P_{total}(\theta_x,\phi_y,E)=\frac{n_s}{N}P_{signal}+\left(1-\frac{n_s}{N}\right)P_{back}$$

RXJ1713

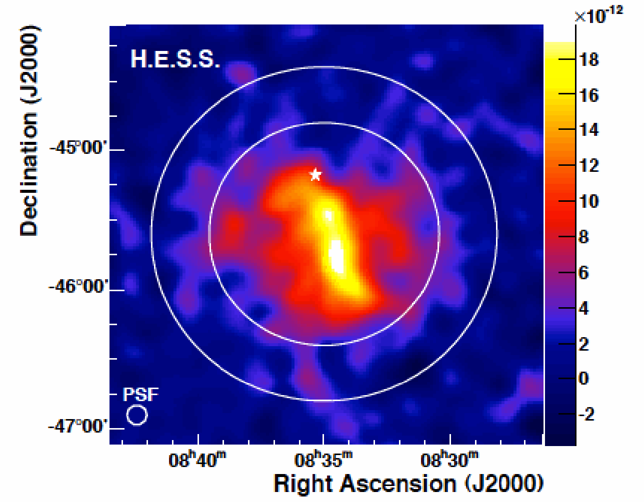
Source	Size (degrees) *	Flux ($TeV^{-1}\ cm^{-2}s^{-1}$), E in TeV
RXJ1713.7-3496	Radius = 0.65°	$1.68*10^{-11}*(E^{-1.72})*exp(-sqrt(E/2.1))$



1% improvement in DP. 50% for 5σ discovery : 5.6 ys → 5.55 ys

DISCOVERY POTENTIAL OF KM3NET FOR THE SNR VELA X

R. Coniglione, P. Sapienza and A. Trovato



Neutrino spectra

	N $(GeV^{-1}s^{-1}cm^{-2})$	Γ	E_{cut} (TeV)	$\Phi_{>1TeV}$ $(s^{-1}cm^{-2})$
RXJ1713 Kelner (Ref.1)*	$1.68\ 10^{-14}$	1.72	2.1	$6.62\ 10^{-12}$
RXJ1713 Vissani** (Ref. 2)	$8.35\ 10^{-15}$	2.04	13.1	$6.12\ 10^{-12}$
VelaX 2006 Vissani** (Ref. 2)	$0.60\ 10^{-14}$	1.45	7.22	$5.76\ 10^{-12}$
VelaX 2012 total Vissani** (Ref. 2)	$0.93\ 10^{-14}$	1.32	8	$10.3\ 10^{-11}$
VelaX 2012 inner Vissani** (Ref. 2)	$0.72\ 10^{-14}$	1.36	7	$7.36\ 10^{-11}$

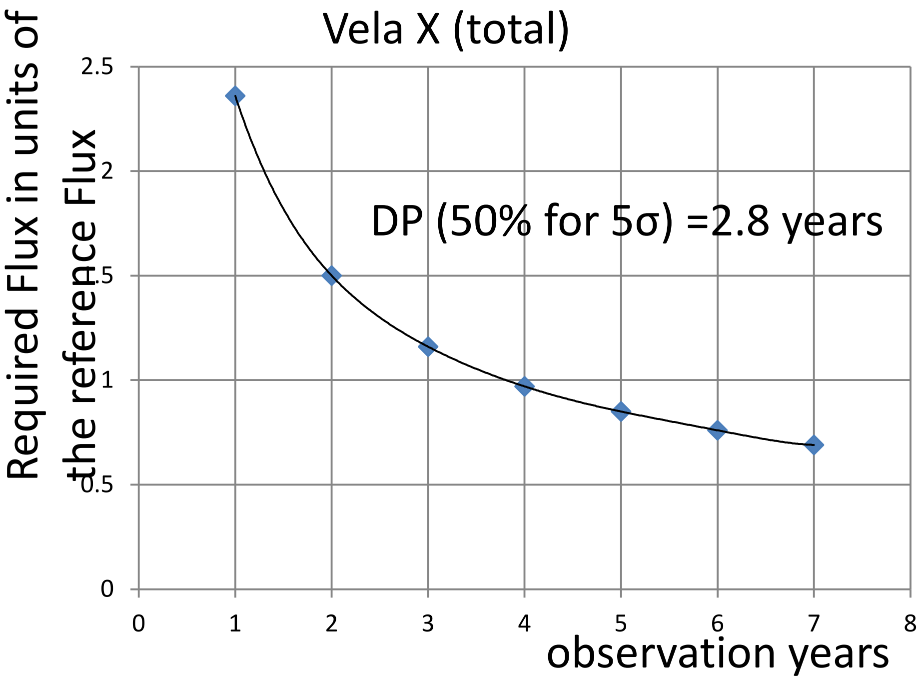
Ref. 1 - S.R. Kelner et al. Phys. Rev. D 74 034018 (2006)
Ref. 2 - From gamma to neutrino spectra following Vissani prescription
F.L.Villante and F.Vissani, Phys. Rev. D 78 (2008) 103007;
F. Vissani and F.L. Villante, Nucl. Inst. Meth. A588 (2008) 123;
F. Vissani, Astropart. Phys. 26 (2006) 310

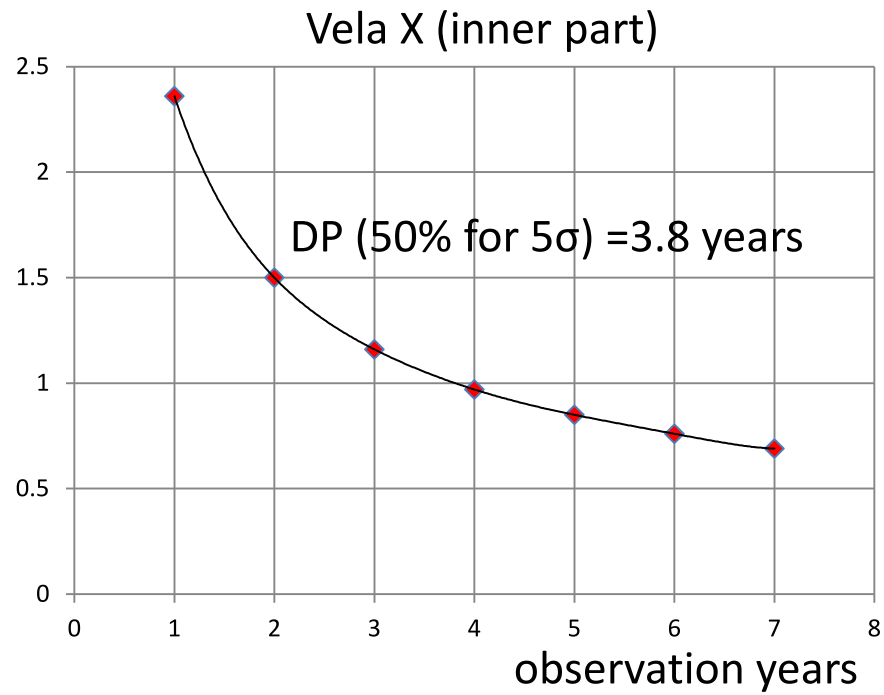
* $$\frac{dN}{dE_\gamma} = N \cdot E_\gamma^{-\Gamma} \cdot \exp(-sqrt(E_\gamma / E_{cut}))$$

** $$\frac{dN}{dE_\gamma} = N \cdot E_\gamma^{-\Gamma} \cdot \exp(-E_\gamma / E_{cut})$$

Vela X

Source	Size (degrees) *	Flux(TeV^{-1} $cm^{-2}s^{-1}$), E in TeV
Vela X (total)	Radius = 1.2^o	$0.93*10^{-11}*(E^{-1.32})*exp(-(E/8.))$
Vela X (inner part)	Radius = 0.8^o	$0.72*10^{-11}*(E^{-1.36})*exp(-(E/7.))$

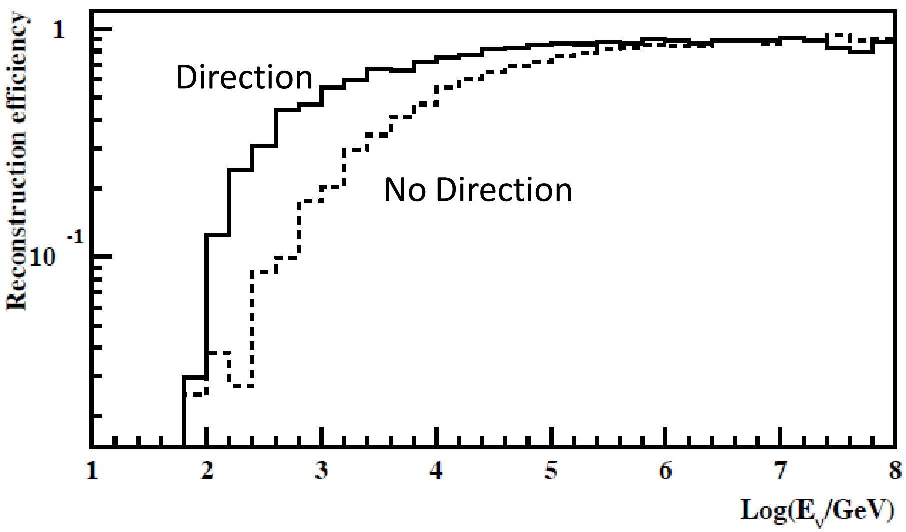




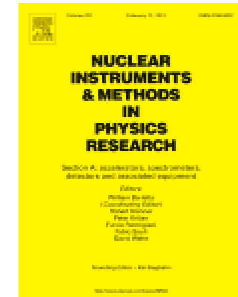
Signal: 7.31/yr Background: 11.10/yr
Extra ring: 0.3^0

Signal: 4.73/yr Background: 5.96/yr
Extra ring: 0.3^0

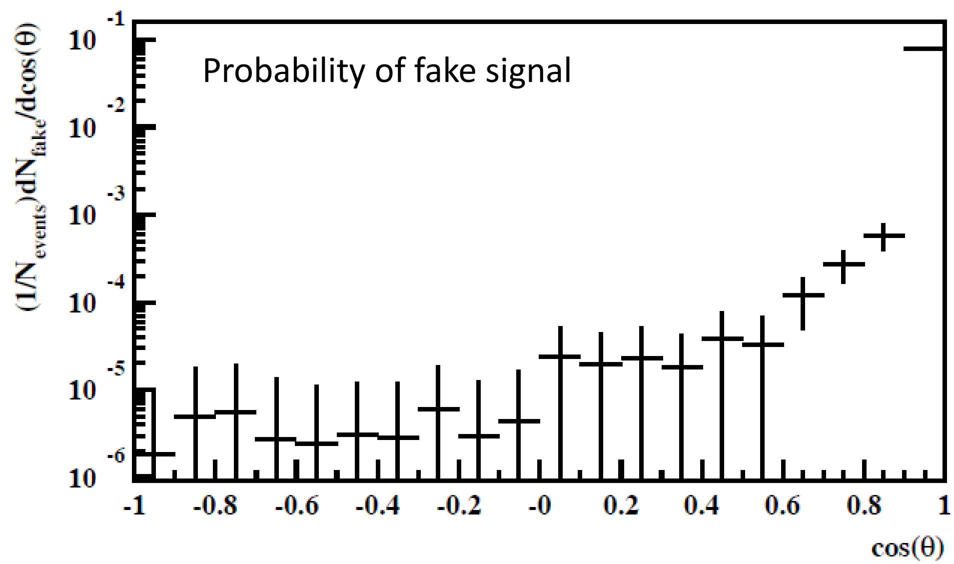
Discovery Potential
using the direction of the galactic source



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



http://dx.doi.org/10.1016/j.nima.2012.11.156



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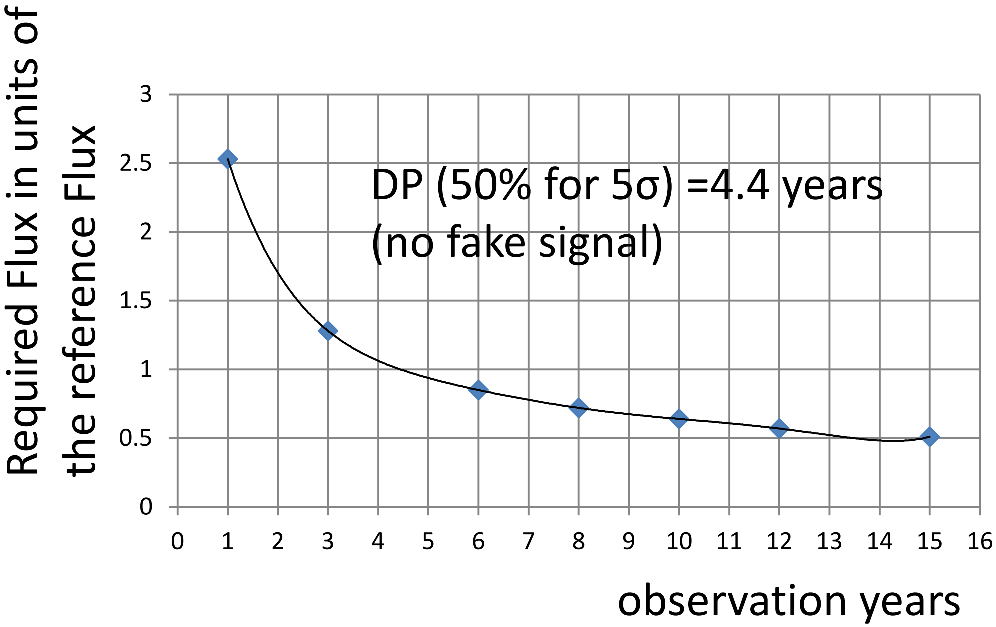

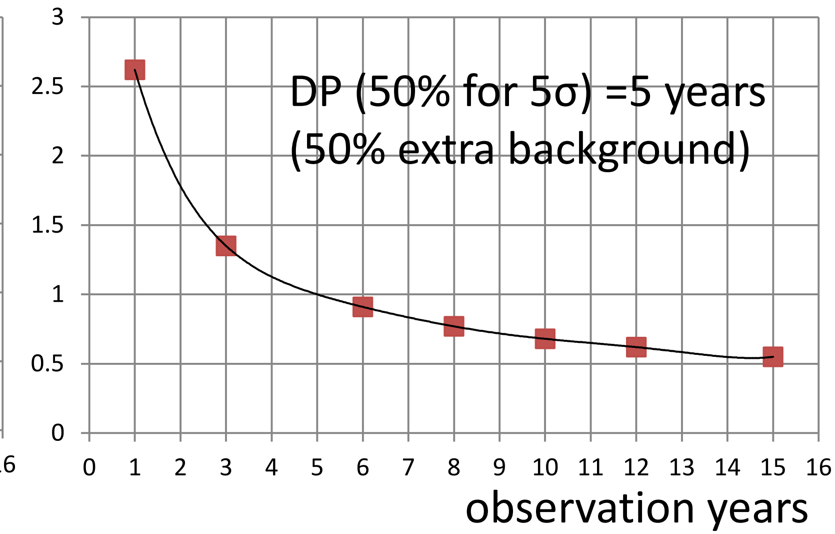

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using the direction of the galactic source

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