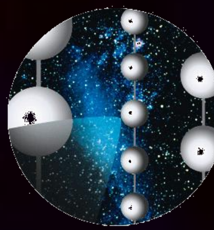
„ A Hitchhiker`s guide to the IceCube - Detector "

JIGSAW10

(Joint-Indo-German-Supernova Astroparticlephysics-Workshop)

Timo Griesel



02/25/2010 Mumbai, India

Outline

Part I – IceCube & South Pole (Entertaining part)

- A km³ Detector at the South Pole - IceCube
- DOMS and Deployment
- Scientists at the South Pole

Part II – Model Dependent SN Detection (Physics part)

- Detecting the Deleptonizaton Peak with I³
- QCD Phase Transition in I³
- SN signatures for multiple hierarchies

IceCube Collaborators

http://icecube.wisc.edu
http://www.etap.physik.uni-mainz.de/icecube

USA (14)

- IAS, Princeton, USA
- University of Wisconsin-Madison, USA
- University of Wisconsin-River Falls, USA
- LBNL, Berkeley, USA
- University of Kansas, USA
- Southern University and A&M College, Baton Rouge, USA
- Alabama University, USA
- Bartol Research Institute, Delaware, USA
- Pennsylvania State University, USA
- UC Berkeley, USA
- UC Irvine, USA
- Clark-Atlanta University, USA
- University of Alaska, Anchorage, USA
- Univ. of Maryland, USA

Europe (15)

- Universite Libre de Bruxelles, Belgium
- Vrije Universiteit Brussel, Belgium
- Université de Mons-Hainaut, Belgium
- Universiteit Gent, Belgium
- Humboldt Universität, Germany
- Universität Mainz, Germany
- DESY Zeuthen, Germany
- Universität Dortmund, Germany
- Universität Wuppertal, Germany
- MPI Heidelberg, Germany
- Uppsala University, Sweden
- Stockholm University, Sweden
- Imperial College, London, UK
- Oxford University, UK
- Utrecht University, Netherlands

Japan (1)

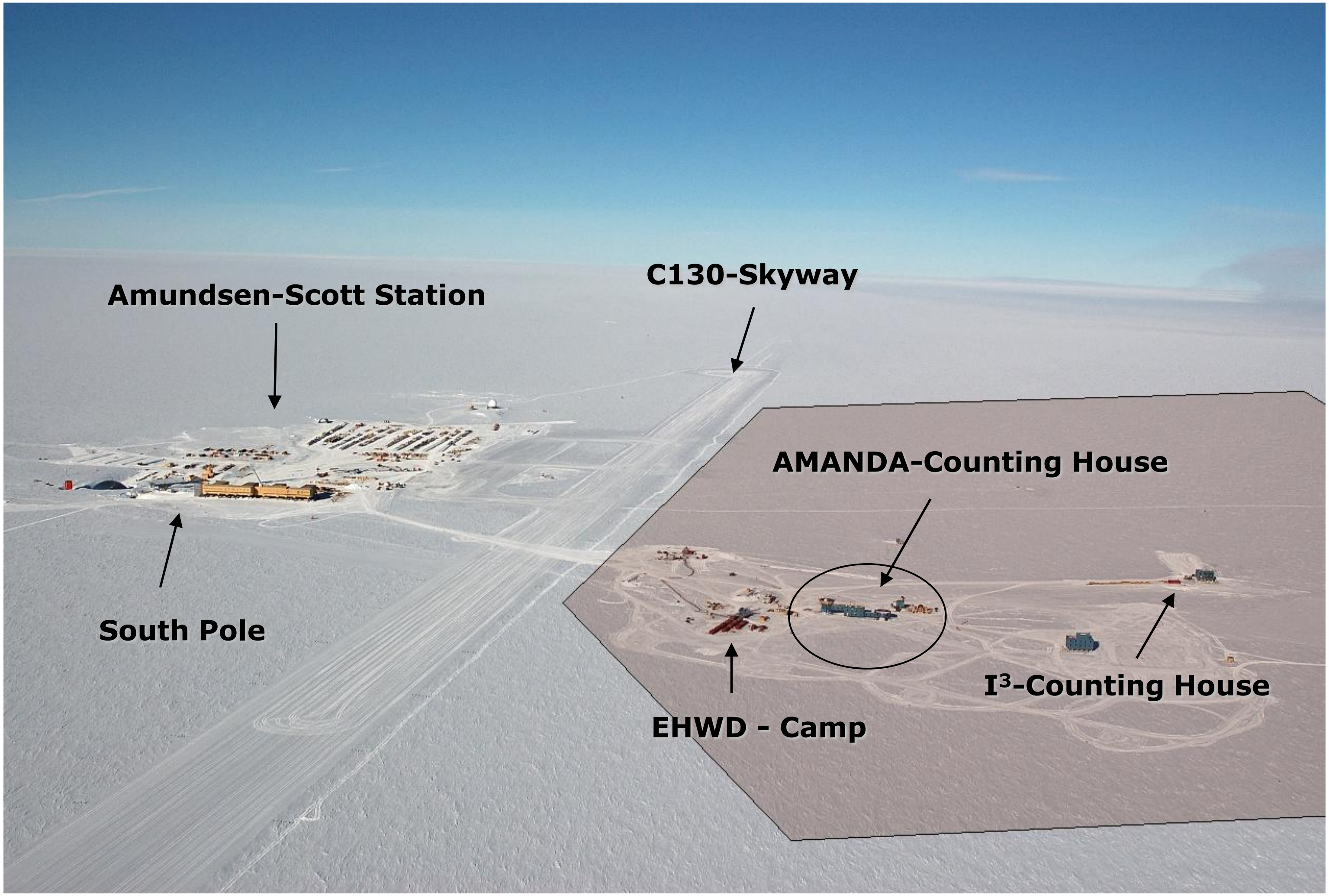
- Chiba University, Japan

New Zealand (1)

- University of Canterbury, Christchurch, NZ

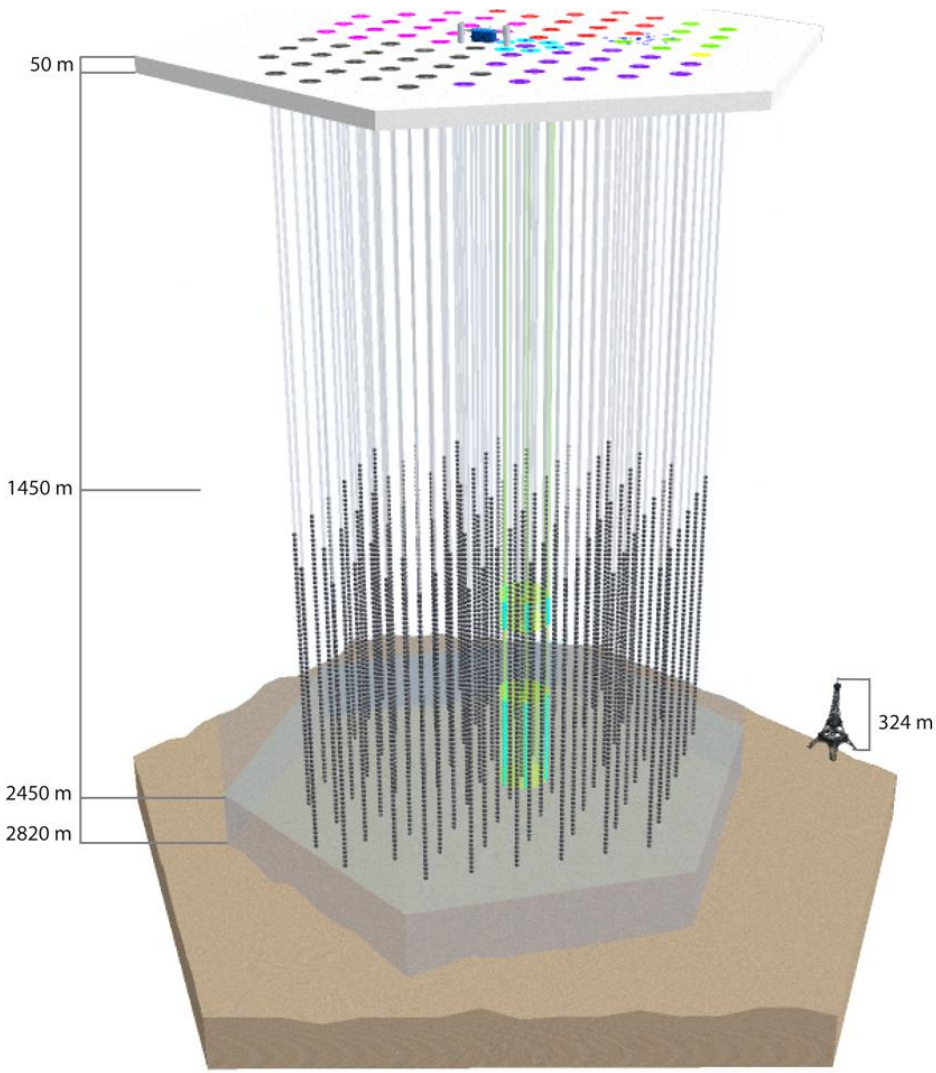

ANTARCTICA
AND THE SOUTHERN OCEAN
Mainz–Mombach
15534 km
ANTARCTIC PENINSULA STATIONS
URUGUAY
Polar Stereographic Projection
Scale : 1:35,000,000 at 71°S
Winter station
AUSTRALIA

The site


Amundsen-Scott Station
C130-Skyway
AMANDA-Counting House
South Pole
I³-Counting House
EHWD - Camp


21094
NEW YORK AIR GUARD
edrik Sörqvist

IceCube Detector

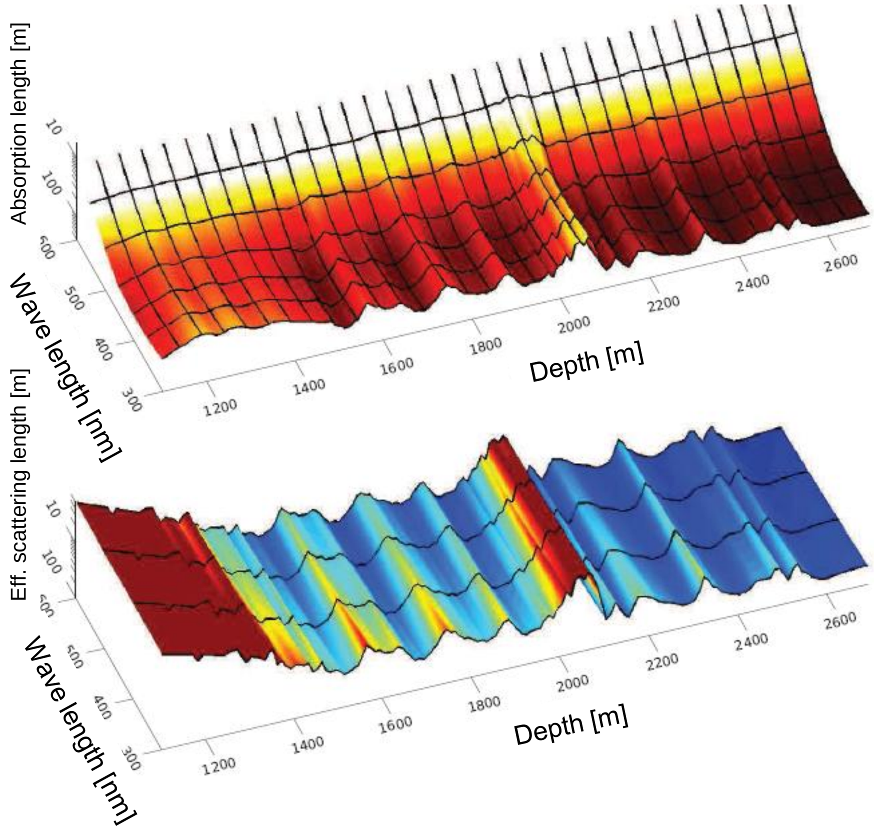


Design Specifications

- **Fully digital detector concept.**
- **Number of strings – 86**
- **Number of surface tanks – 140**
- **Number of DOMs – 5160**
- **Instrumented volume – 1 km^3**
- **Angular resolution of in-ice array < 1.0°**

Current Status

- **79 strings, 138 surface stations**
- **4740 deployed DOMs,**
- **Instrumented volume ~ 0.98 km^3**
- **Work still in progress**
- **Collecting physics data**



average photon absorption length:

$$\overline{\Lambda}_A \approx 96m$$

Ice Properties

- **Clearest natural medium on earth**
- **No Bioluminescence, no radioactivity**
- **Scatter and Absorption length is influenced by:**
  Dust layers
  Bubbles
- **Pole ice cap still growing**
- **Upper glacier is moving with 10.2 m/a**

Ice Model Simulation

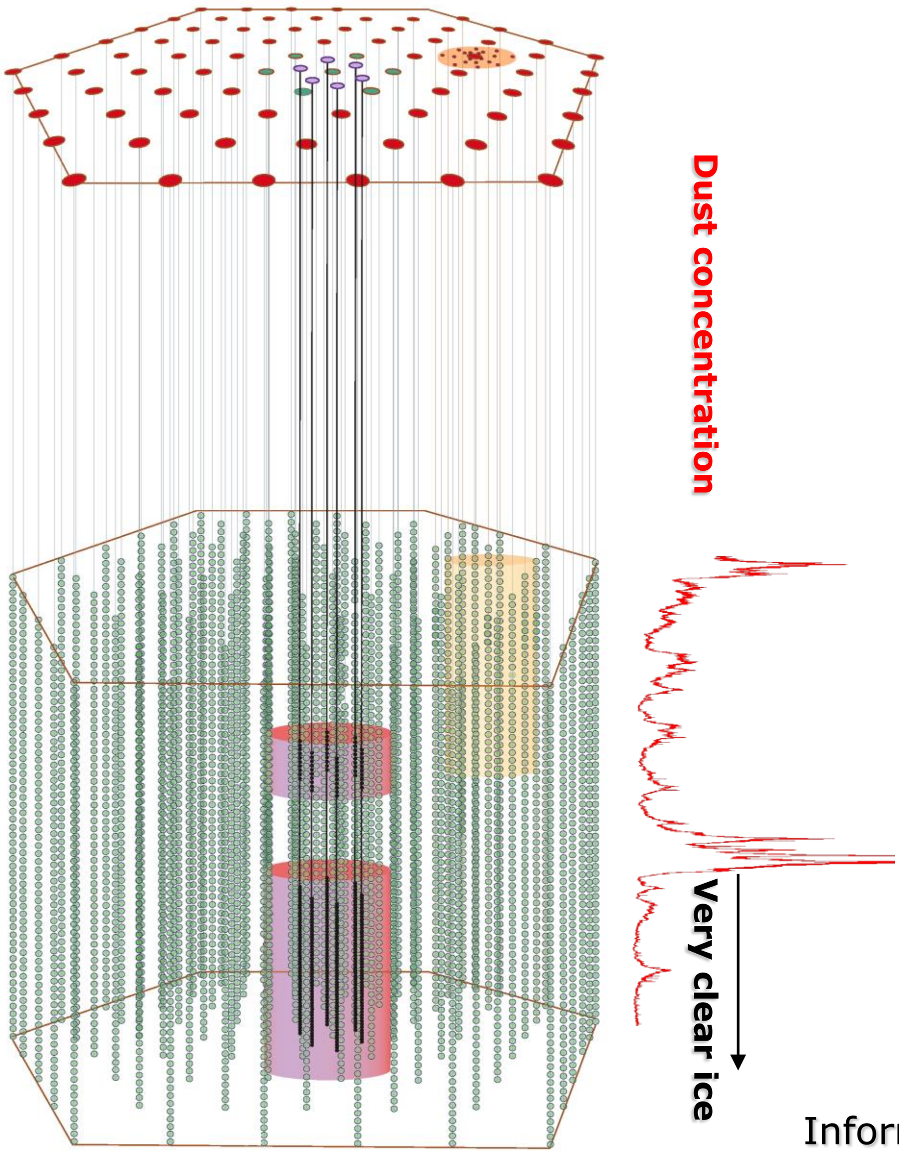
- **GEANT4 and Photonics simulation leads to a couple of slightly different Ice Models**

average track length:

$$\bar{x}(E_e) = (0.579 \pm 0.017) cm \cdot E_e / MeV$$

IC/DC – Deep Core

http://icecube.wisc.edu
http://www.etap.physik.uni-mainz.de/icecube

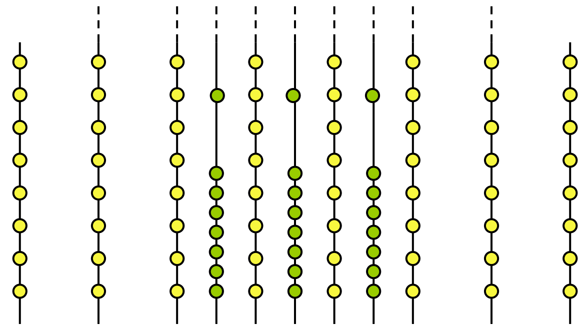


Layout

- 6 new strings
- 60 high quantum efficiency PMTs each concentrated in the very clear ice below 2100 m
- Seamlessly integrated with standard IceCube strings and modules

Low energy threshold

- Eth(n) < ~10 GeV due to ice clarity, high Q.E. PMTs (~18%→~25%) and closer spacing
- Energy overlap at low end with SuperK; IceCube at high end



Information taken from D.Cowen Neutrino 2008 Poster

Digital Optic Module (DOM)

Effective Volume

DOM acceptance :

$$a(\lambda,\theta) = \frac{N_{PE}}{N_\gamma(\lambda,\theta)}$$

No. of Photoelectrons

No. of photons hitting the Module

Effective Volume for Photons :

$$V_{eff}^{\gamma}(a) = \iiint p_\gamma(r,a)\,dV = A_{eff}\Lambda_A \approx 0.1811 \pm 0.0023\, m^3$$

No of Cherenkov Photons using Frank-Tamms Formula :

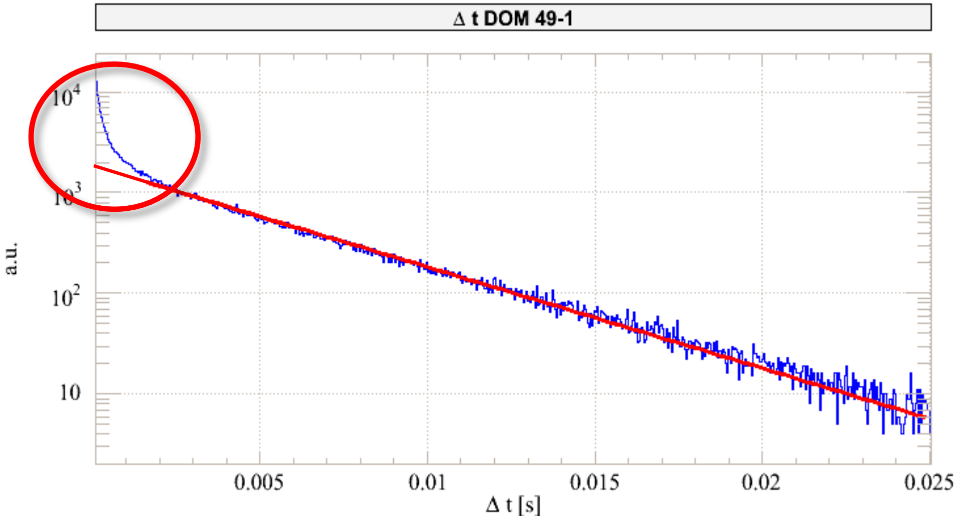
$$\overline{N}_\gamma = 2\pi\alpha\left(1 - \frac{1}{\beta^2\,\overline{n}^2_{Ice}}\right)\overline{x}\int_{300\,nm}^{600\,nm}\frac{d\lambda}{\lambda} = 325.4\,\overline{x}\,/\,cm = 188.3 \pm 5.5\,E_e\,/\,MeV$$

Effective Volume for e :

$$V_{eff}^{e}(E_e) = \overline{N}_\gamma \cdot V_{eff}^{\gamma} \approx (34.1 \pm 2.0)\,m^3 E_e\,/\,MeV$$

Effective Volume is not overlapping – no track information

DOM noise rate



Average raw Rate of a single DOM:

$$R_{raw}^{DOM} = 540 \pm 106\,Hz$$

Applying an artificial Deadtime to the Rate leads to a poissonian noise Rate of:

$$R^{DOM} = 281 \pm 21\,Hz$$

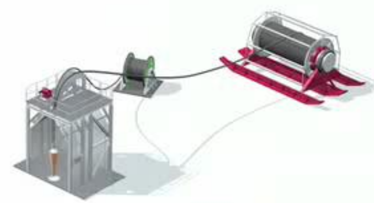
IceCube (IC80) Detector noise rate:

$$R^{IC80} = 1340000 \pm 1800\,Hz$$

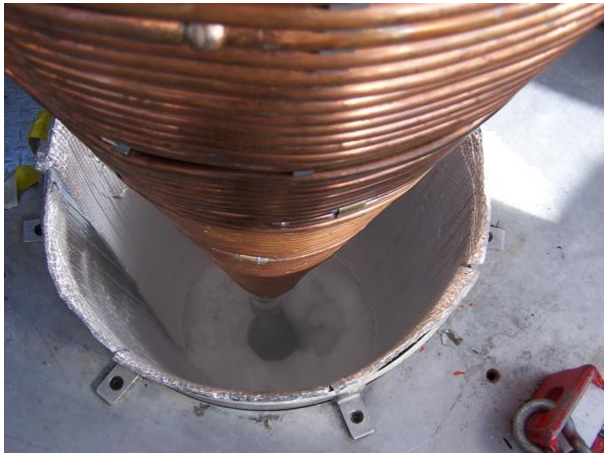
EHWD (Enhanced Hot Water Drill) designed to drill a 2450 m × 60 cm hole in ~30 hr.

Thermal Power: 4.5 Megawatt

Drilling



Drilling

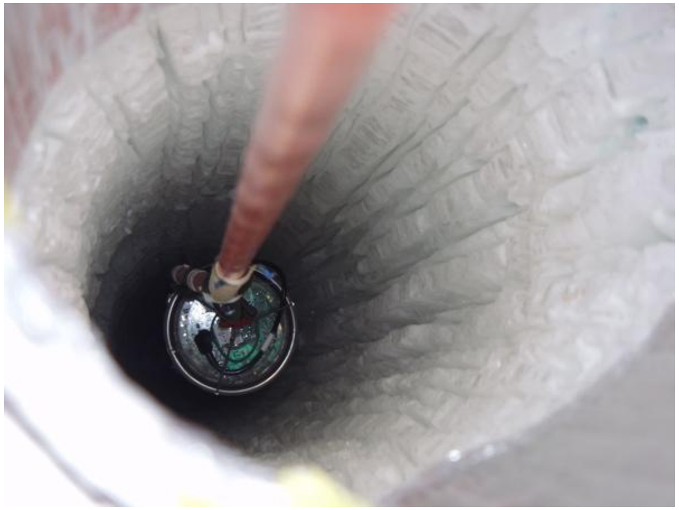


Top layer of packed snow is called *firn*.

Hot water drill designed for ice drilling – it gets starter hole from *firn drill* (lower left).

EHWD drill head entering hole (Top left and top right) .

Drilling



Upper right: AMANDA OM in -840m

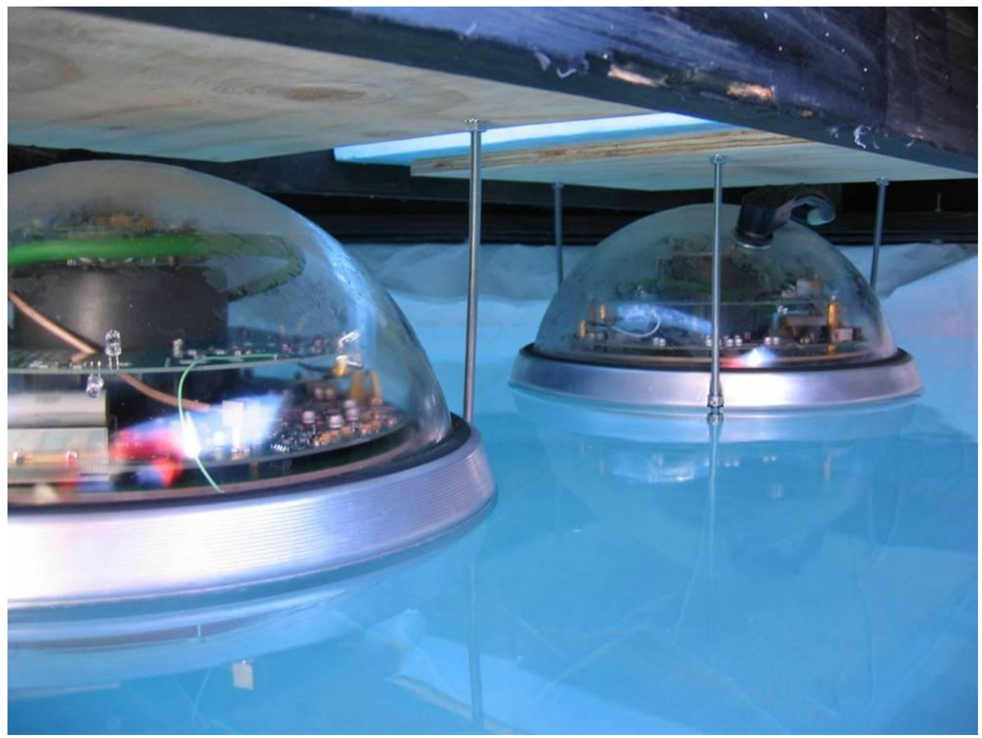
Lower right: DOM low down in the hole

Upper left: DOM hook up right before the low down

Middle: Hooked up DOM

IceTop –

Airshower detector

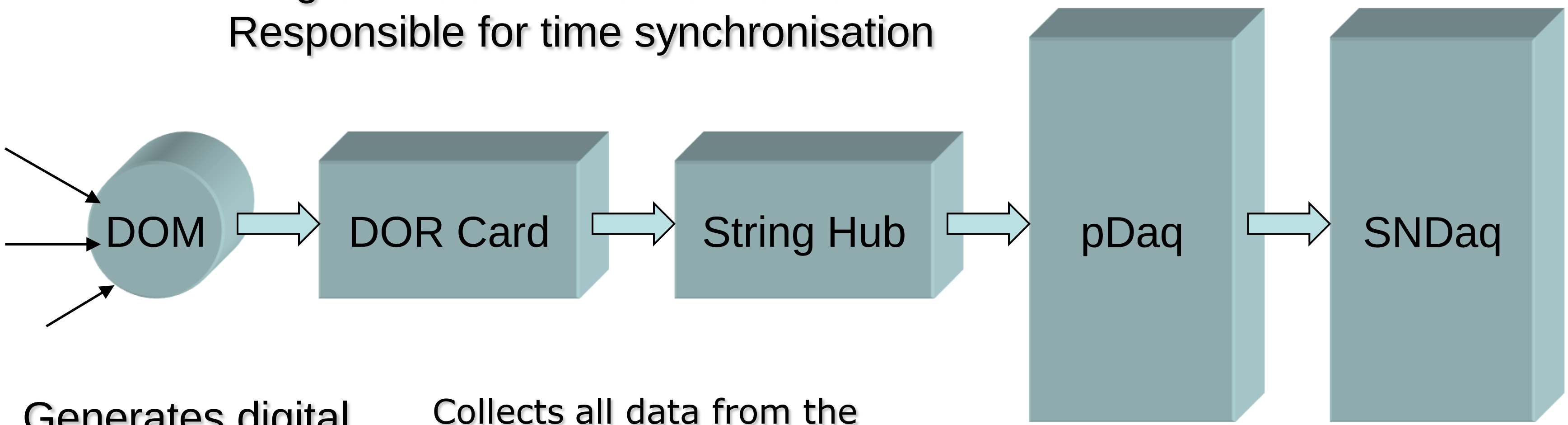


Data Acquisission

Simplified scheme of the IceCube data acquission

Rebins data and performs online analysis

Programms and initialize the DOM.
Responsible for time synchronisation



Generates digital signal

Collects all data from the string and corresponding IceTop station
Sorts and separates Monitoring, Time, Event and SNData

Controlls and Collects data flows
from the complete detector
Assigning tasks to subcomponents

SN Detection-Algorithm

- pDAQ delivers raw rates (DOM-wise, 1.6384ms binning) SNDaq synchronizes and rebins data to 2ms binning >> fine for resolving most interesting structures in ν-signal

- Analytic calculation of the kollektive rate deviation $\Delta\mu$ using Maximum-Likelihood Method (χ^2 -Minimization) in real time.

$$-2\ln L(\Delta\mu) + const. = \chi^2(\Delta\mu) \qquad L(\Delta\mu)\prod_{i=0}^{N_{DOM}} \frac{1}{\sqrt{2\pi\sigma_i}} e^{\frac{(r_i-(\mu_i+\varepsilon_i\Delta\mu))^2}{2\sigma_i^2}}$$

- Estimate significance of collective rate deviation on top of noise $\Delta\mu / \sigma_{\Delta\mu}$

$$\Delta\mu = \left(\sqrt{\sum_{i=0}^{N_{DOM}} \frac{\varepsilon_i^2}{\sigma_i^2}}\right)^{-1} \sum_{i=0}^{N_{DOM}} \frac{\varepsilon_i(r_i-\mu_i)}{\sigma_i^2} \qquad \sigma_{\Delta\mu} = \left(\sqrt{\sum_{i=0}^{N_{DOM}} \frac{\varepsilon_i^2}{\sigma_i^2}}\right)$$

- Estimate homogeneity of illumination over whole detector

$$\chi^2(\Delta\mu) = \sum_i^{N_{DOM}} \left(\frac{r_i - \mu_i - \varepsilon_i\Delta\mu}{\sigma_i}\right)^2$$

- Calculate μ_i and σ_i per DOM from 10‘ data (excluding current position) in multiple binning
- Trigger Conditions. Significance $\Delta\mu / \sigma_{\Delta\mu} > 6.5$ and $p(\chi^2) > 99.9\%$ (for any binning)
- *DOM Disqualification (Per Bin)* on mean value, broadening and skewness of rate distribution

SNEWS – SuperNova Early Warning System

Members: Super-K, LVD, SNO, IceCube…

What happens when IceCube triggers a Supernova event ?

- Take data !
- Send SNEWS alert

SNEWS is the central drop-in center for Supernovae Explosion detections

- A single computer at LBNL collects alarm messages
- In case of a coincidend alam astronomer get informed

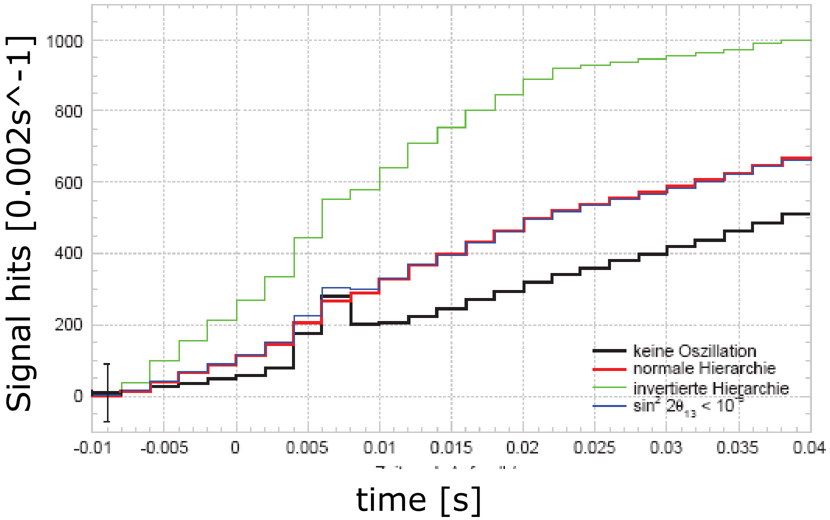
Requirement for the minimization statistcal errors

- Coincidence of two experiments need to be within 10s
- False alarm rate $<0{,}1 d^{-1}$

There were many Supernovae observations - until now – no measurement of the early light curve

Deleptonization Peak

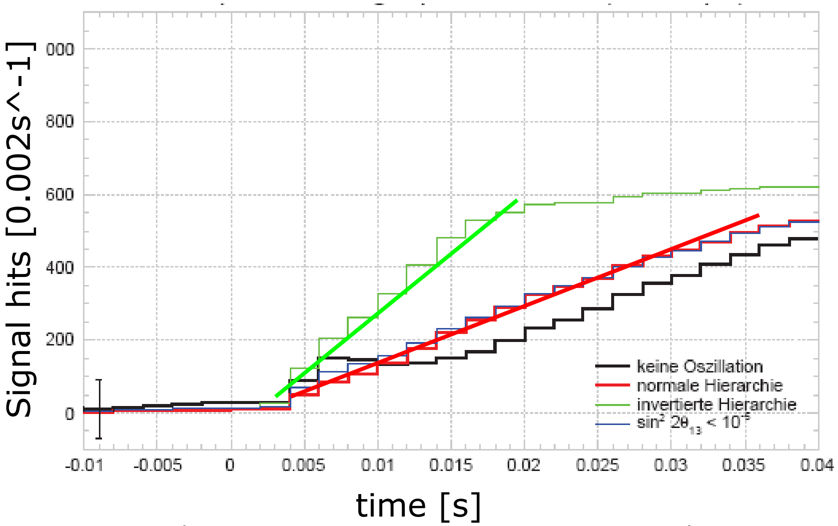
Livermore @ 10kpc



- Generate IceCube detector response for given signal using USSR (see talk Thomas Kowarik)
- switch oscillations on

Deleptonization peak can not be detected for SN at distances >2kpc

Garching @ 10kpc



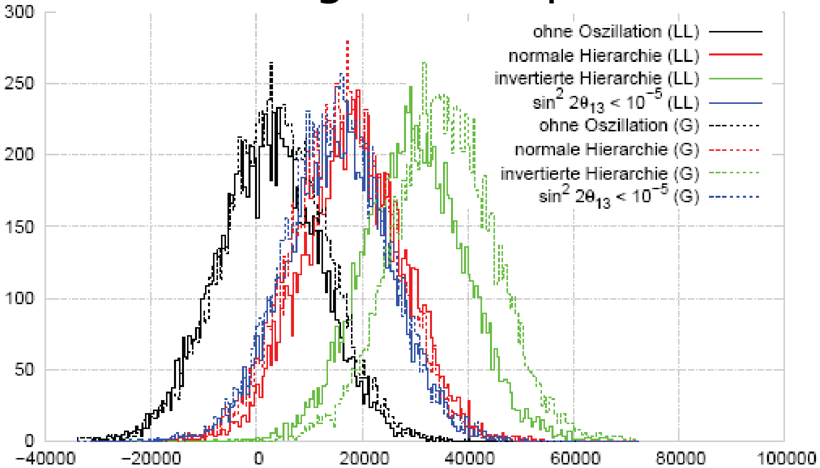
Can we learn something about the hierarchy ?

- Applying linar fits to different scenario signals
- Histogram slopes of fits
- Iterate and change SN distance

Information from Thesis A.Piegsa 2009

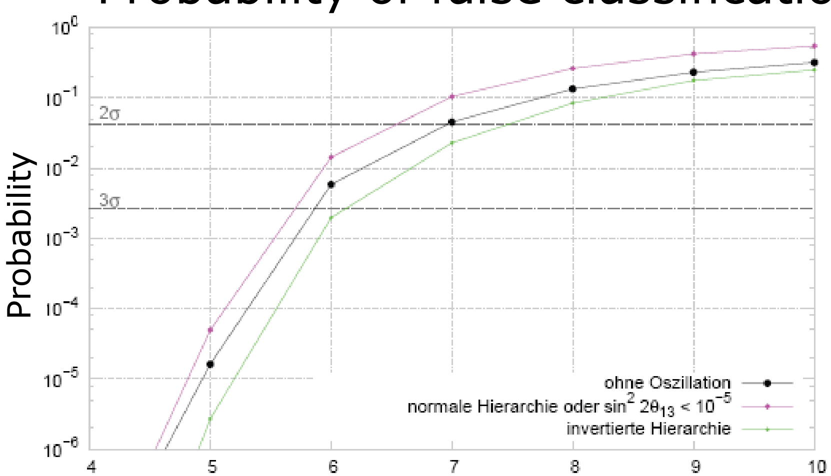
Deleptonization Peak

Rate change @ 10kpc



Slope of the detector rate [hits/ms]

Probability of false classification



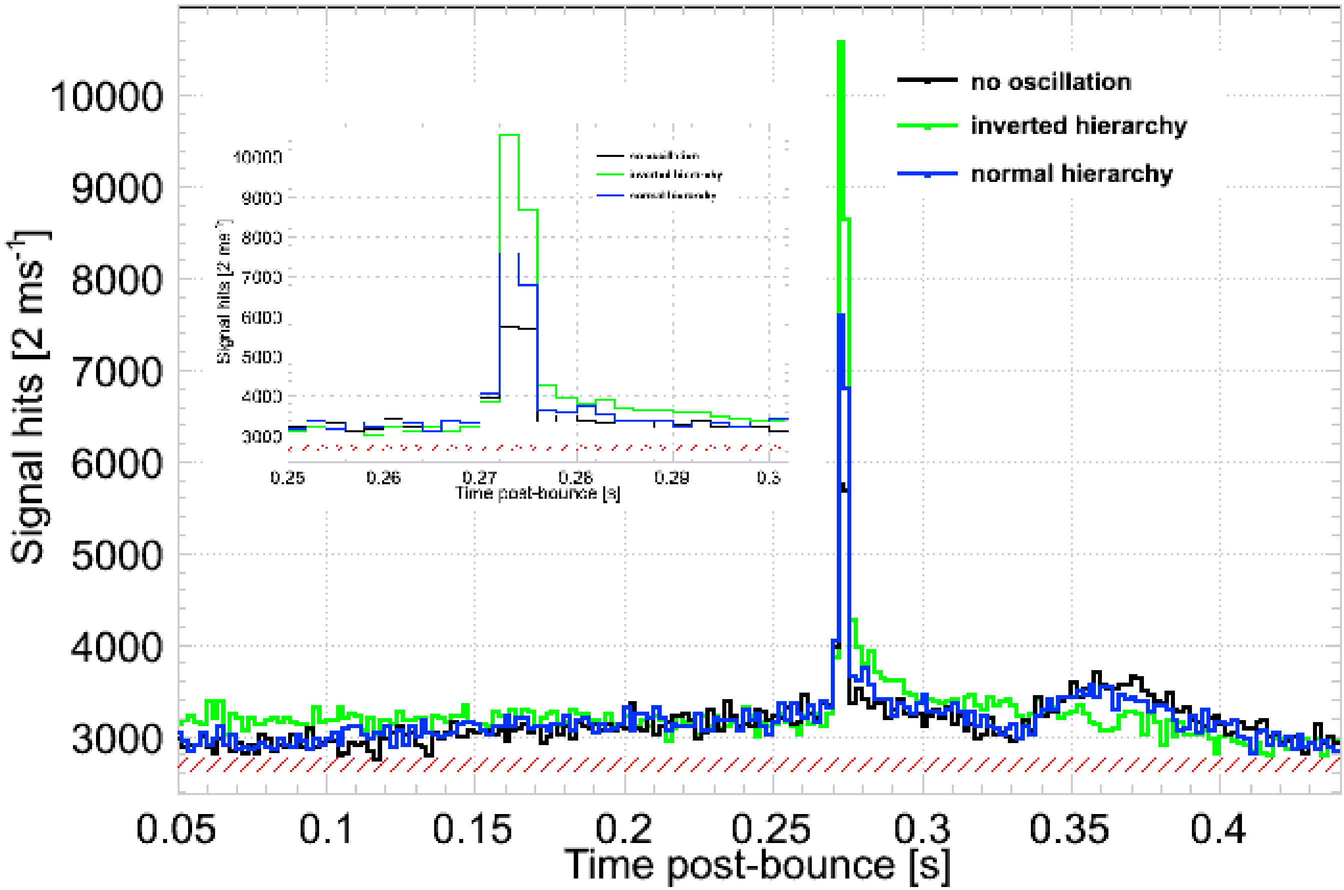
Distance [kpc]

Calculating the 90% quantile and the fraction which leaks into the false scenario leads to the conclusion that hierarchies are capable of being differentiated till:

< 6 kpc (90% C.L.)

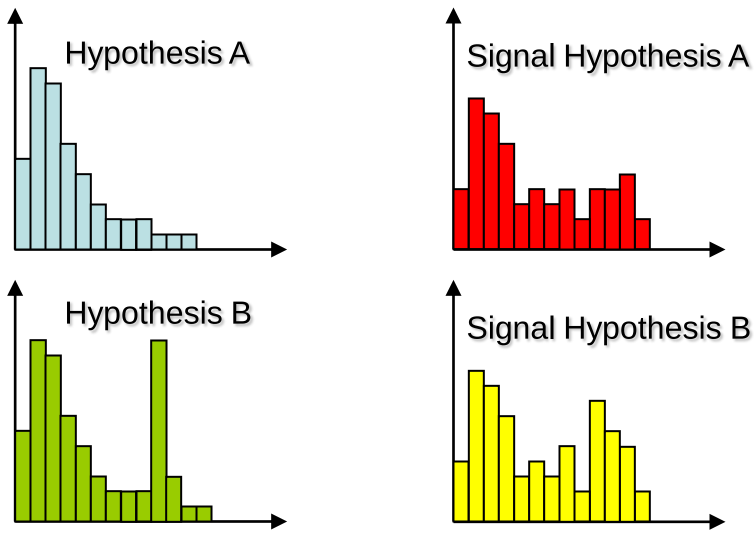
Note: This is only within the erros of the underlying SN Model valid.

IceCube QCD phase transition signal @ 10kpc



Initial signal based on Sagert et al. PRL 102, 081101 (2009)

Using a likelihood Ratio Method as Separator

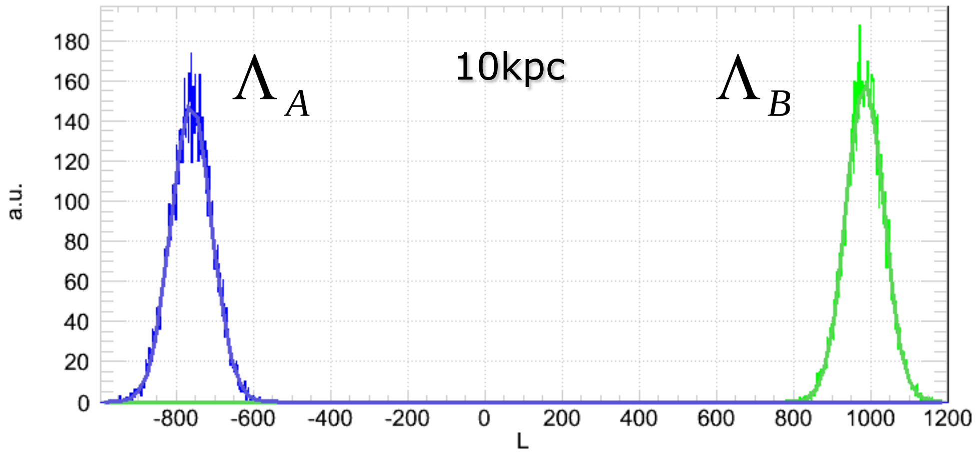


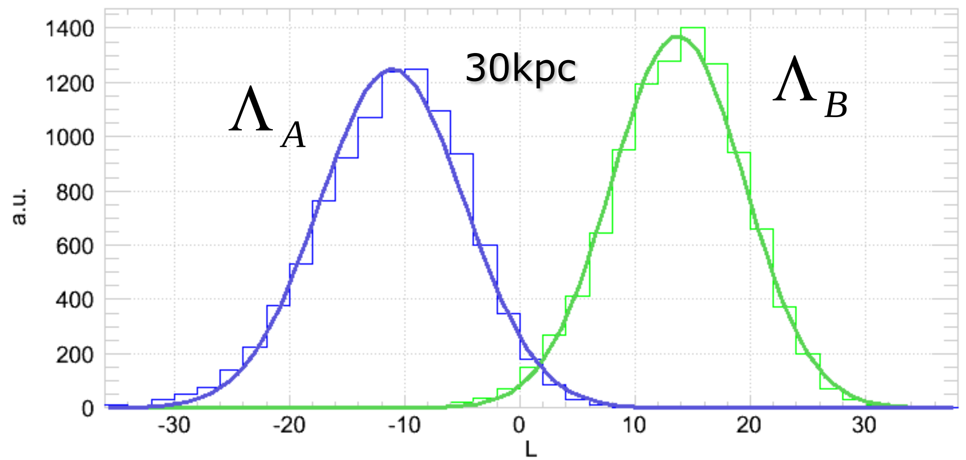
- Theoretical Hypothesis A,B (e.g. SN Models)
- Generate signals based on Hypothesis A,B
- Calculate the Likelihood ratios (only use shape of the signal, no distance information)
- Do this 10000 times

$$\Lambda_A = \frac{L_A}{L_B} = \frac{1}{2\sigma^2}\left((2n_i^A A_i - A_i^2) - (2n_i^A B_i - B_i^2)\right)$$

$$\Lambda_B = \frac{L_B}{L_A} = \frac{1}{2\sigma^2}\left((2n_i^B A_i - A_i^2) - (2n_i^B B_i - B_i^2)\right)$$

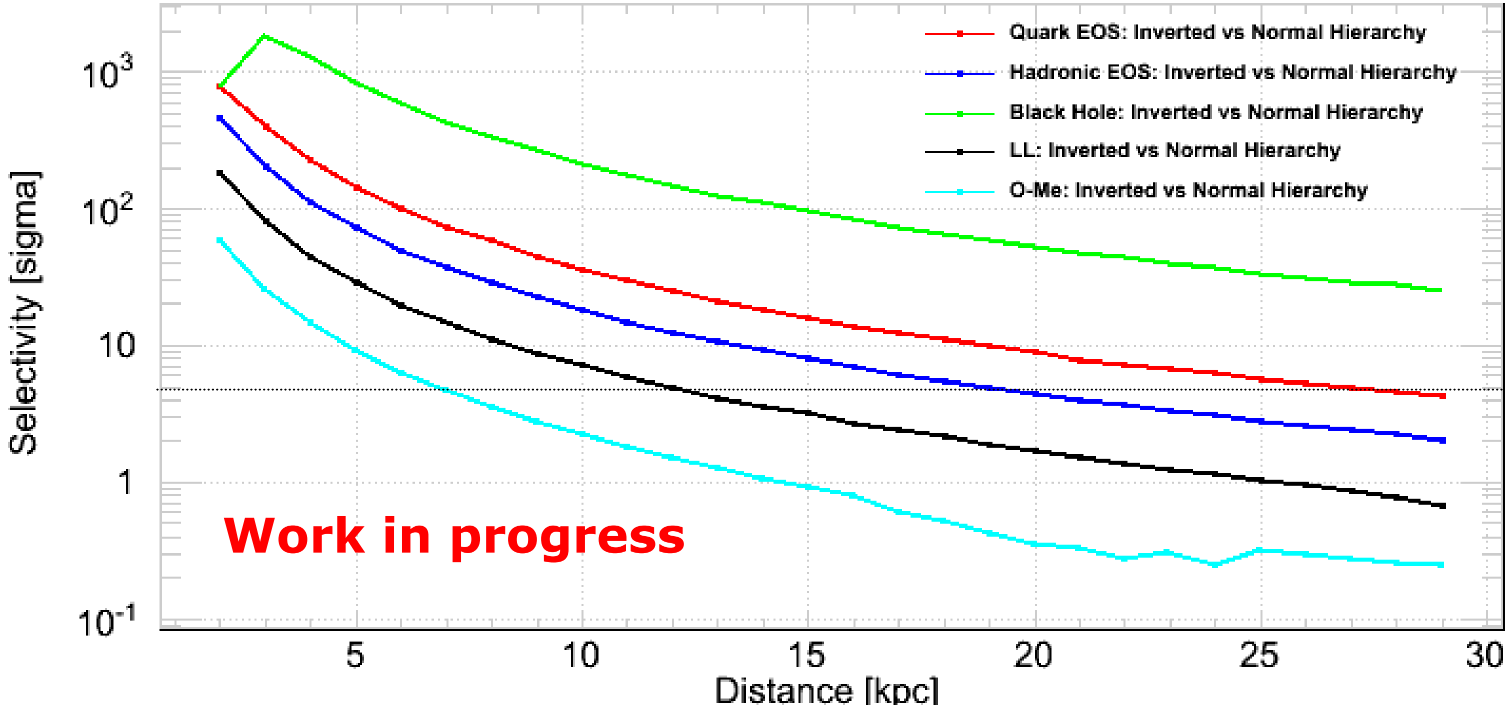
Likelihood Ratio QCD





- Calculate histograms for several distances
- Calculate the selectivity in units of sigma („gap") for each distance

Model Selectivity



QCD: PRL 102, 081101 (2009)
Hadronic: PRL 102, 081101 (2009)
Black Hole: ApJ 667 382-394 (2007)
Livermore: Astrophys. J. 496 (1998) 216-225
ONeMg: arXiv:9012.0260

- Absolute Model shape dependent

Thank you !!!!!!

http://icecube.wisc.edu

http://www.etap.physik.uni-mainz.de/icecube