Miami 2010 conference
14-19 December 2010

Astrophysical ν_τ search in IceCube.

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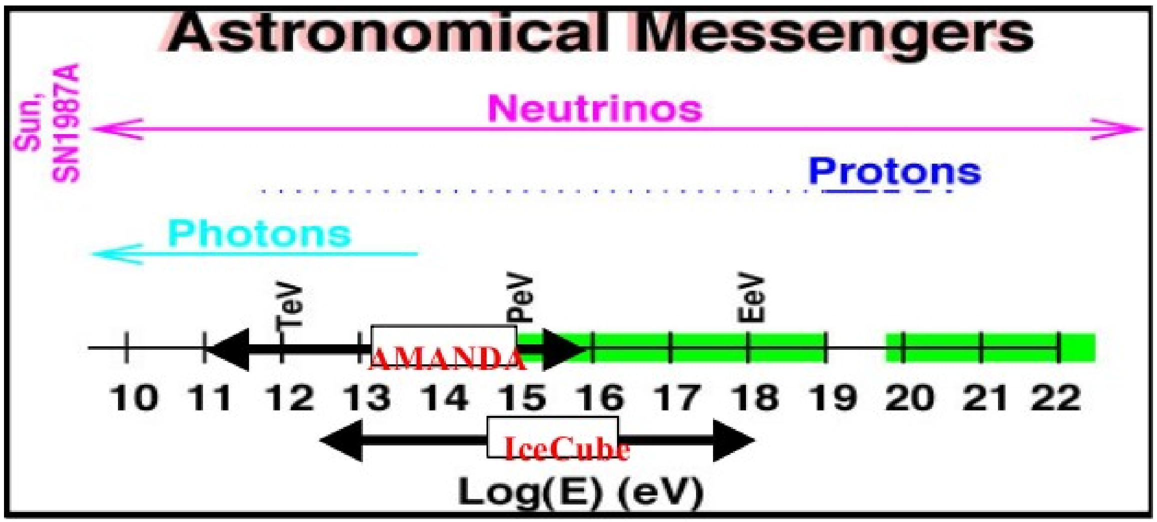
on behalf of the IceCube Collaboration

Astronomical messengers



- photons: absorbed above 10 TeV.
- protons: deflected below 10 EeV and attenuated above 50 EeV.
- neutrinos: cover all energy range.
- neutrinos are hard to detect -> very large detector is needed ($\sim 1km^3$) IceCube detector.

Astrophysical neutrino

Possible astrophysical neutrino sources are:

- active galactic nuclei
- gamma ray bursts
- supernova remnants
- ...

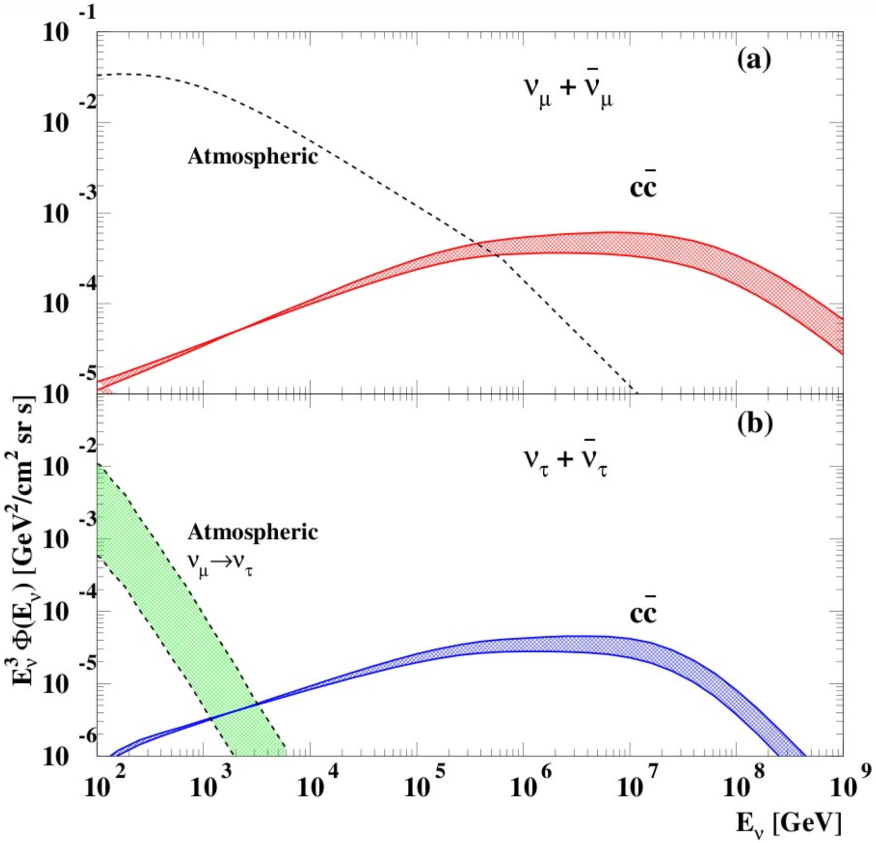
Production mechanism:

$$p+p(\text{or } \gamma) \rightarrow \pi^0 \rightarrow \gamma$$
$$\hookrightarrow \pi^\pm \rightarrow \mu^\pm + \nu_\mu$$
$$\hookrightarrow e^\pm + \nu_\mu + \nu_e$$

ν's initial flavor ratio is (1:2:0) $\rightarrow$ (1:1:1) ratio due to oscillation. There is a prediction of (1:1.8:1.8) flavor ratio at high energies.

$dN/dE \sim E^{-2}$ - astrophysical neutrino spectrum.

Why ν_τ ?



Martin, Ryskin, Stasto hep-ph/0302140v2

Atmospheric ν's are background for astrophysical ν's.

Production mechanism:

conventional:

$$p+p(\text{or } \gamma) \to \pi^0 \to \gamma$$

$$\hookrightarrow \pi^\pm \to \mu^\pm + \nu_\mu$$

$$\hookrightarrow e^\pm + \nu_\mu + \nu_e$$

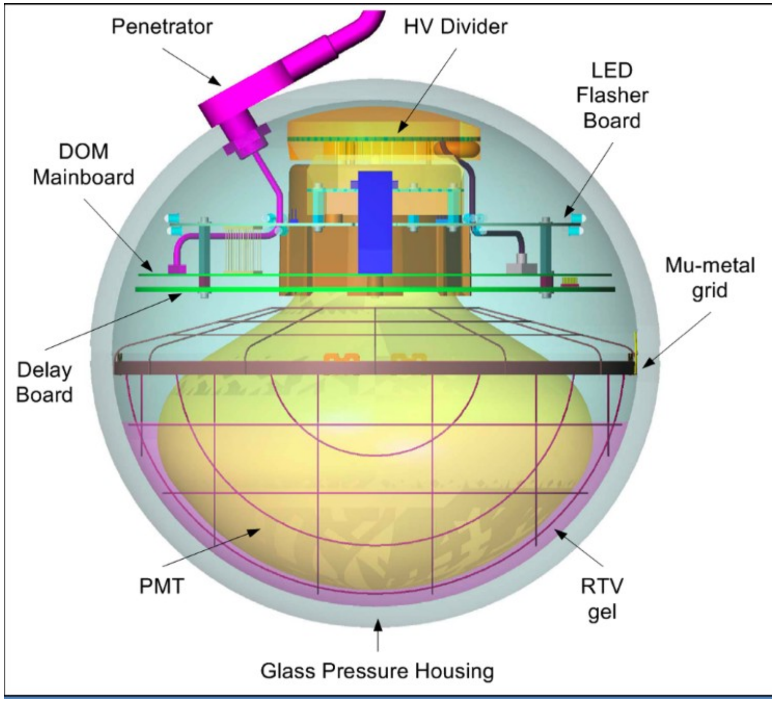
(1:2:0) flavor ratio.

prompt decay:

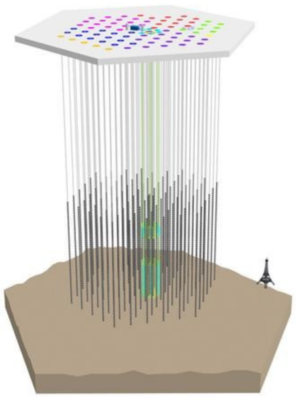
$$c \to s + l + \nu_l$$

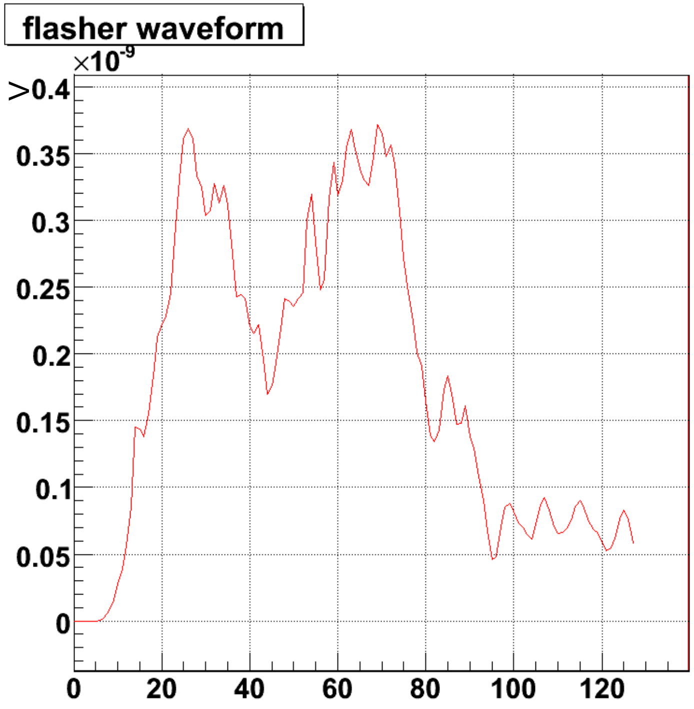
Atmospheric ν_τ background is almost negligible.

Digital Optical Module (DOM)



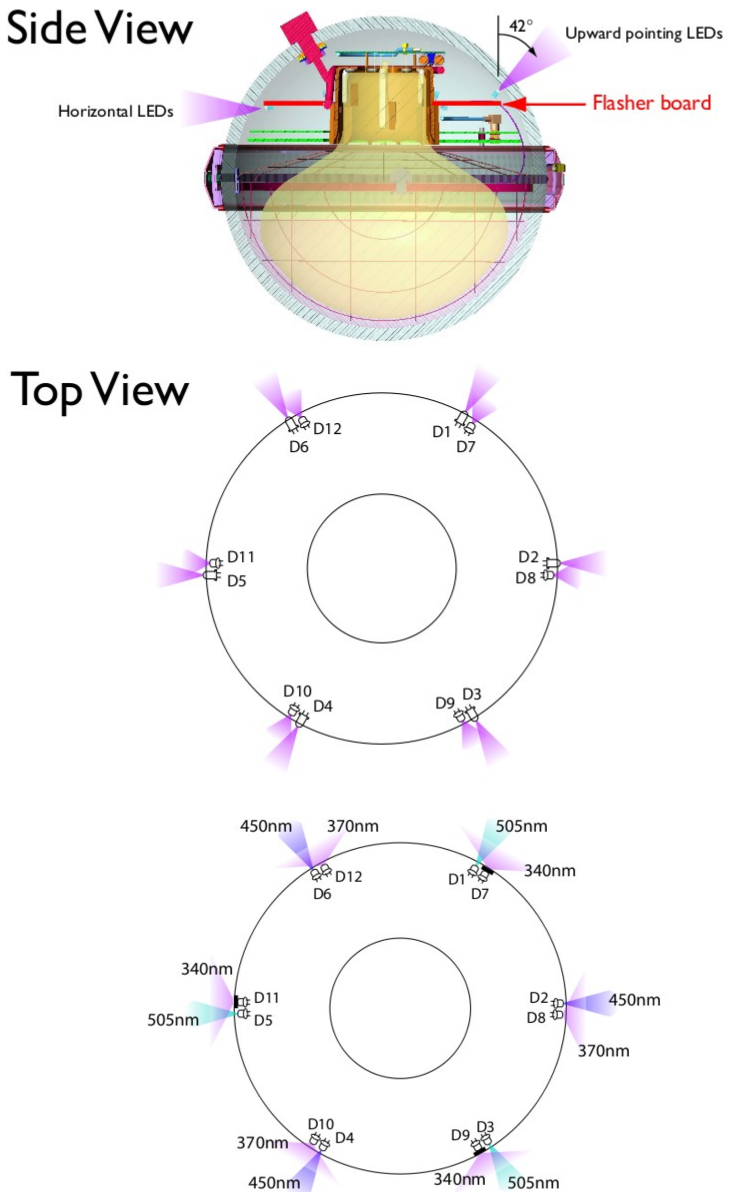
- detect cherenkov light
- convert and amplify light signal with PMT
- digitize the voltage signal and makes a waveform
- each waveform bin correspond to 3 ns
- contain flasher board with 12 LED's





Waveform example

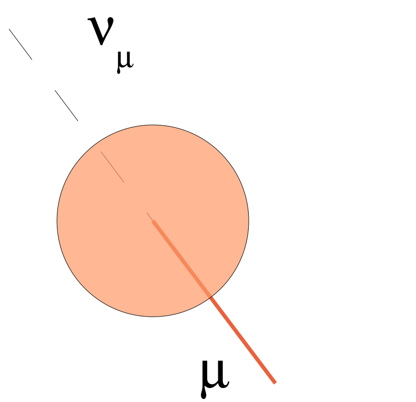
Flasher board



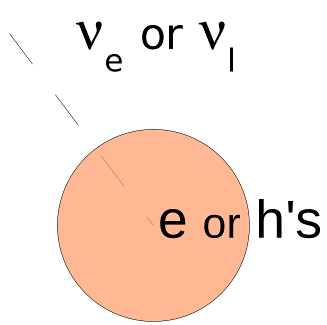
Plots from Chris Wendt's talk

- contain 12 405 nm LED's
- 6 horizontal and 6 tilted at ~40 degrees upward
- LED's can be flashed separately with different brightness
- each LED produces a pulse from 5-65 ns
- 16+1 boards have LED's with different wavelength (cDOMs), all horizontal

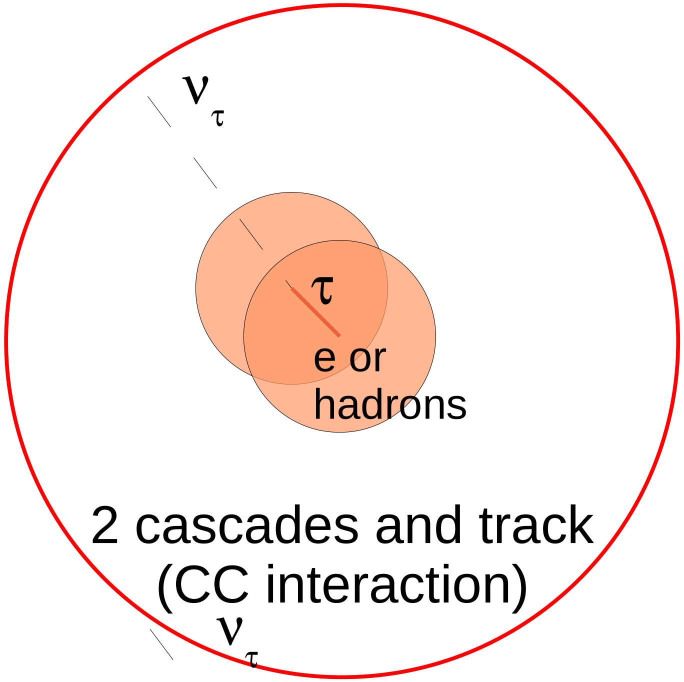
ν signals in IceCube



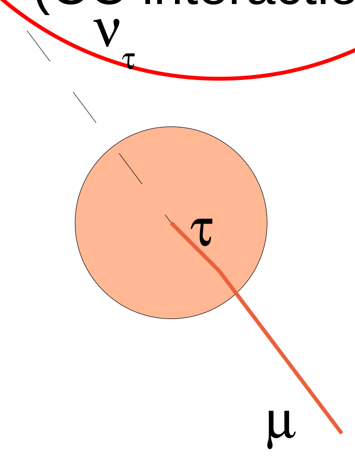
cascade and track
(CC interaction)



e-m cascade
(CC interaction)
or hadron cascade (NC interaction)

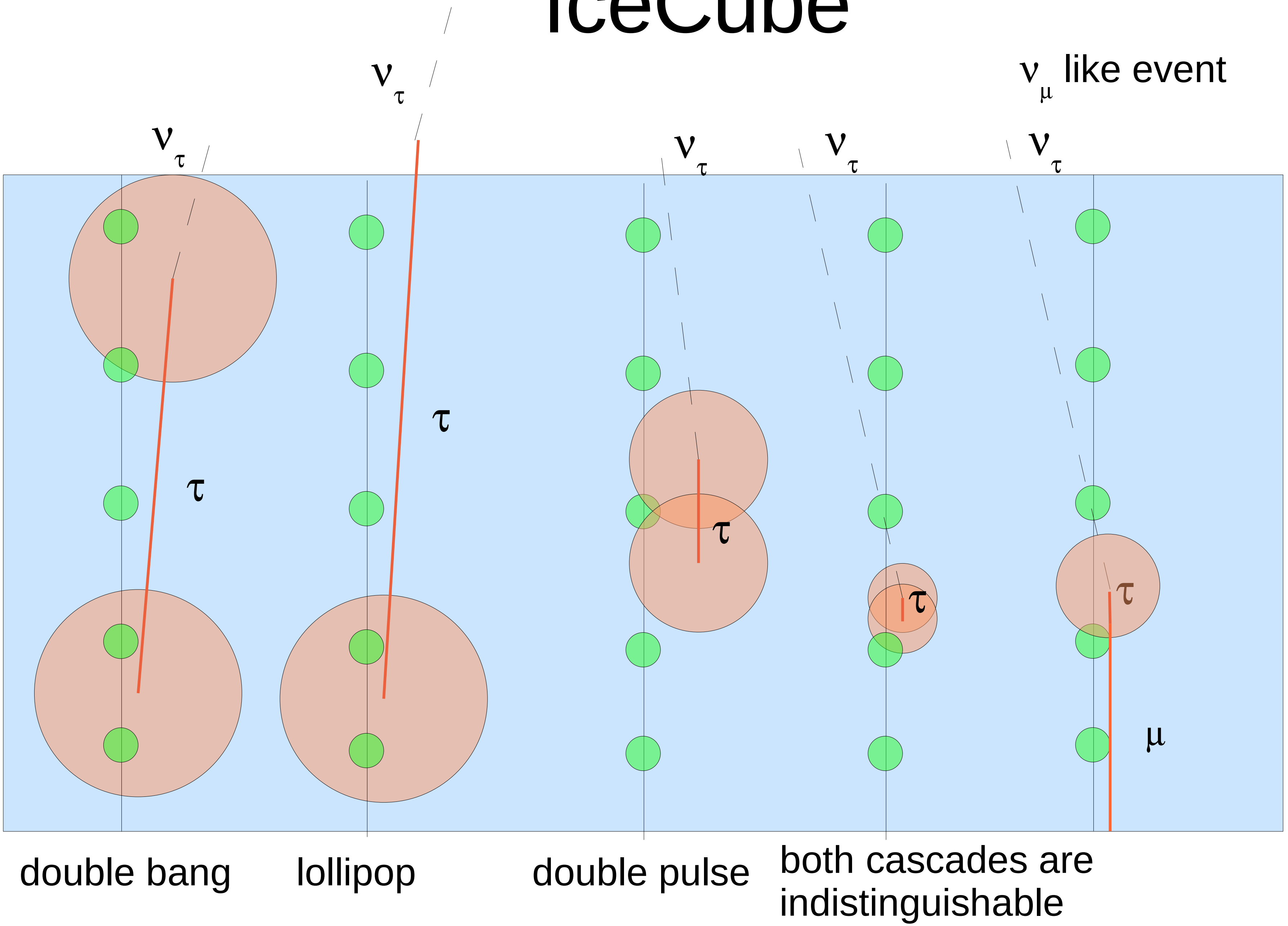


2 cascades and track
(CC interaction)



cascade and track
(CC interaction)

Possible types of ν_τ signals in IceCube

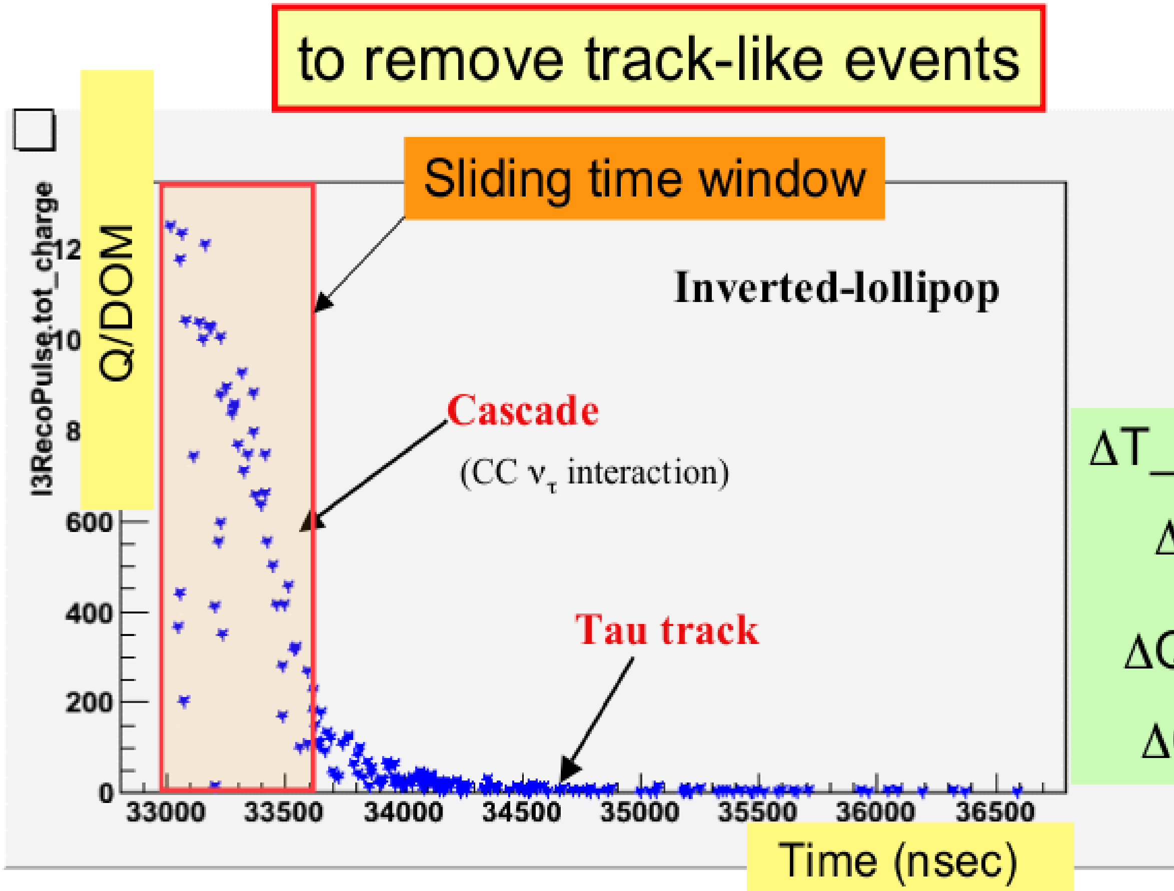


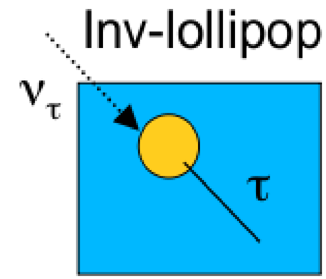
Double bang analysis (intro)

Double bang analysis (Seon-Hee Seo)

- it was done for IC22 detector configuration
- targeted energy range is $E_\nu > 1$ PeV
- the analysis is based on the event topology:
  - Signal: ν_τ event contains one or two cascades and a track
  - BG: μ event contains only a track
  - BG: NC or ν_e event contains just a cascade

Double bang analysis (1)





ΔT_on = sliding time window

ΔT_off = T_tot - ΔT_on

ΔQ_on = Q_inside ΔT_on

ΔQ_off = Q_tot - ΔQ_on

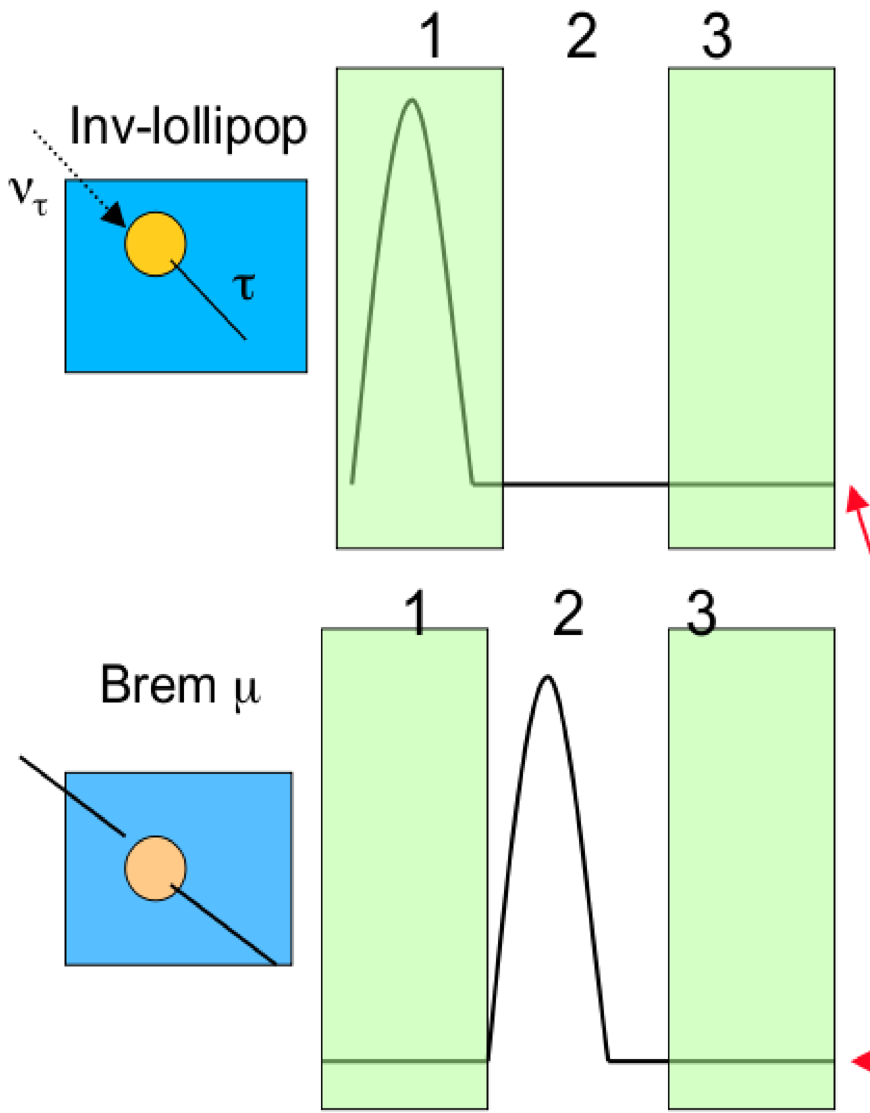
$$\textbf{Current ratio} = \left|\frac{\text{Current\_on} \; (= \Delta\text{Q\_on}/\Delta\text{T\_on})}{\text{Current\_off} \; (= \Delta\text{Q\_off}/\Delta\text{T\_off})}\right|_{\max}$$

> 1 (for ν_τ)

~ 1 (for μ)

Double bang analysis (2)

to remove certain brem μ



--- Local charge densities in two regions $(Q/T)_1$, $(Q/T)_3$

--- choose maximum between 1^{st} and 3^{rd}

$(Q/T)_1^{signal} > (Q/T)_1^{BG}$

To be selected by this cut.

Not to be selected.

Double bang analysis (3)

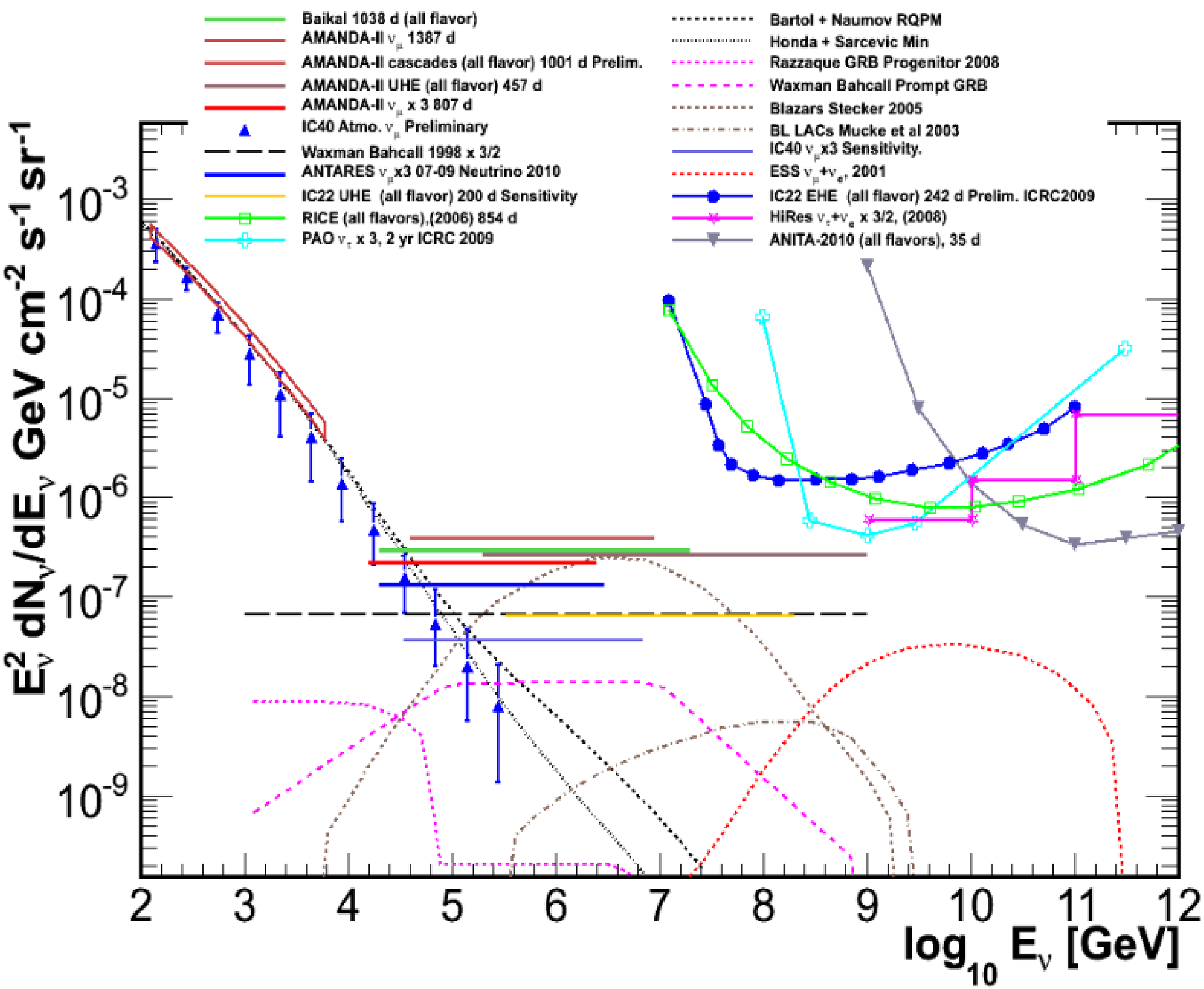
Signal (all flavor): 3.18 events in 200 live days (WB)
BG (atm. μ, atm. ν): 0.76 events in 200 live days

Event type	E spectrum	Flux model	Live time	#. Events at final cut
NuTau	E-2	WB	200 d	0.97
NuMu	E-2	WB	200 d	0.64
NuE	E-2	WB	200 d	1.57
All Nu		prompt	200 d	0.25
NuMu + NuE		Bartol	200 d	0.05
Atm. muons			200 d	0.46
S.Pole (30%)	---	---	82.4 d	0

Double bang analysis (4)

$E^2 \Phi_\nu < 6.54 \times 10^{-8}$ GeVcm^{-2}s^{-1}st^{-1} (all flavor, preliminary)

$5.53 < \mathrm{Log10(E/GeV)}_{90\%} < 8.30$

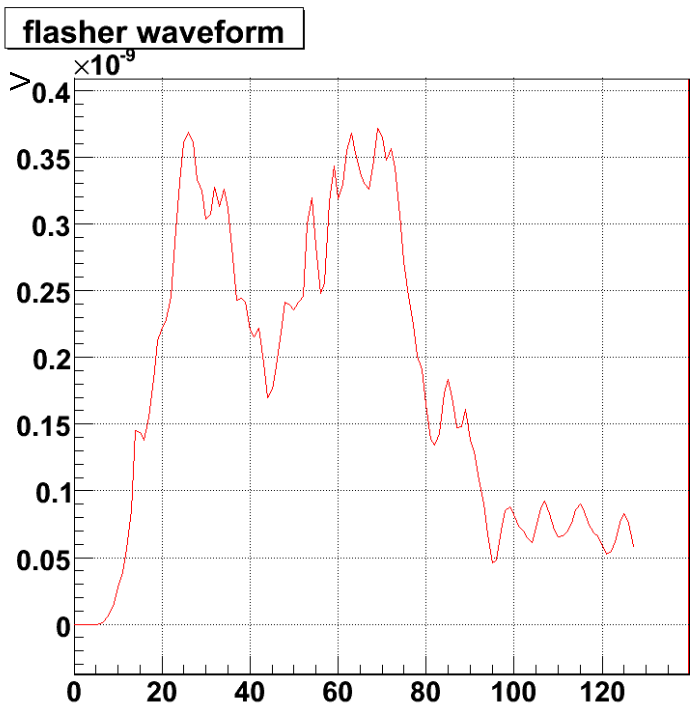


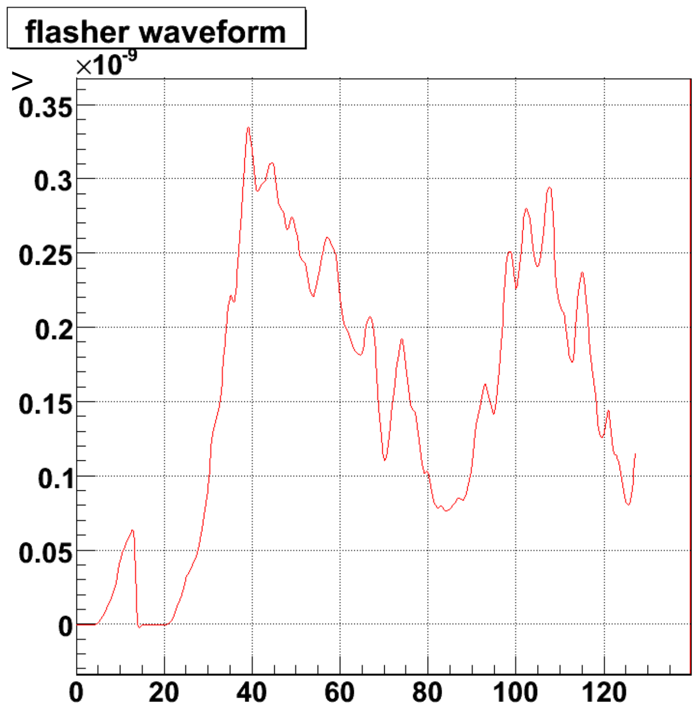
Double pulse analysis

Double pulse analysis

- energy range 10 PeV > E_ν > 0.1 PeV.
- assuming E^{-2} spectrum, double pulse must have more events than double bang.
- based on analyzing single waveform shape
- or based on analyzing shower shape using likelihood method (Patrick Toale)
- double pulse waveform finding algorithm was tested using flasher and toy simulation data.

Flasher waveform





An example of two flasher double pulse waveforms registered at DOM 39-12 and generated by DOMs 39-11 and 39-14. Each light pulse contained ~$8*10^8$ photons (~8 TeV cascade).

There is a plan to have a large flasher run in January 2011.

Toy double pulse generator

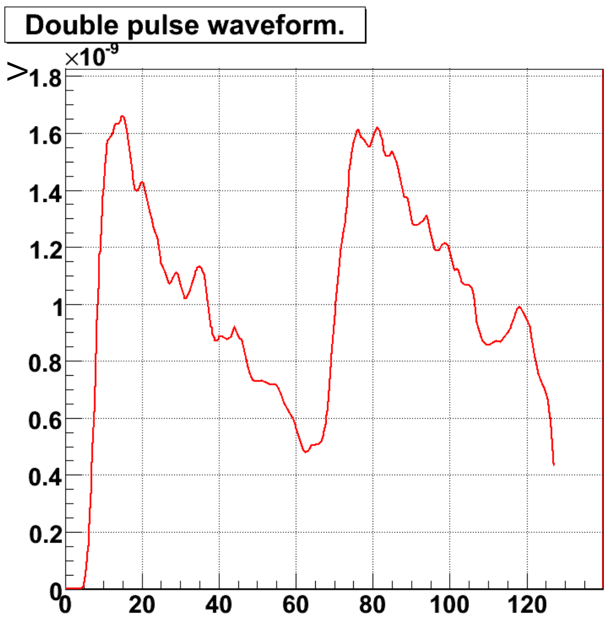
Toy double pulse generator:

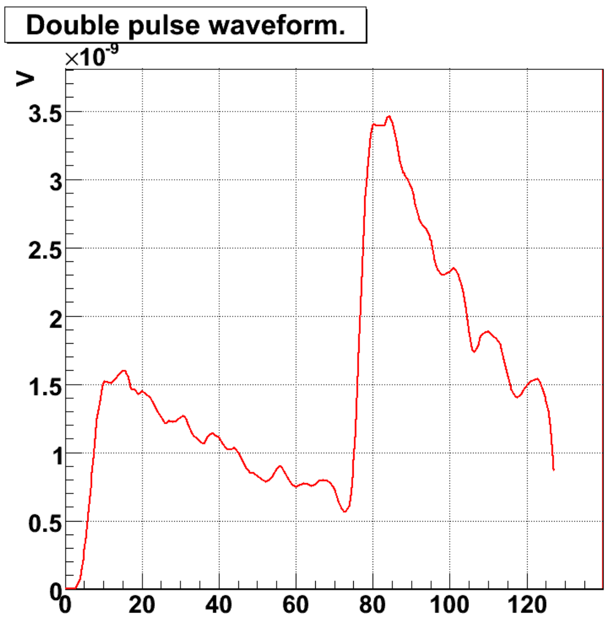
- two hadronic cascades (one mimics ν_τ interaction, the other mimics τ decay); this event is called double pulse event later
- event can be anywhere with any direction
- each cascade gets 50% energy
- “track length” can be set
- no τ track simulation
- if only one cascade produced with all energy, the event is called single pulse event (used for bg estimate)

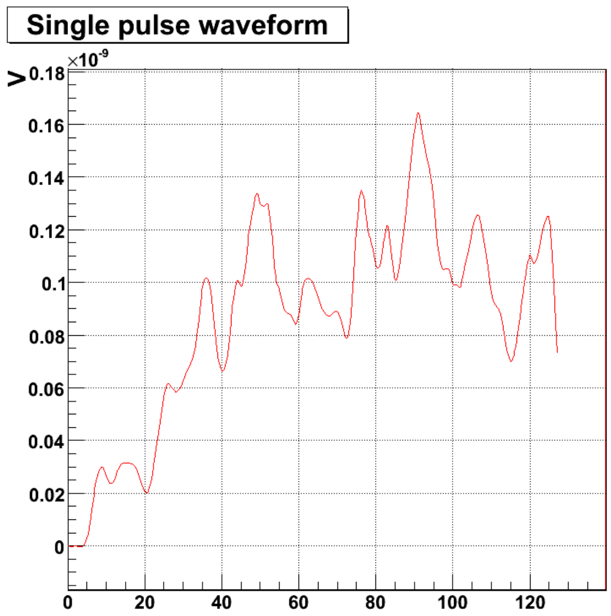
Event sample:

- contain 1000 double and single pulse events
- each event has energy within 0.1-10 PeV
- ν_τ interaction point is close to DOM 63-51 ($\pm$100 m in x and y, $\pm$17 m in z)
- angular distribution is uniform in ϕ from 0 to 360 and in θ from 0 to 90

Double pulse waveforms



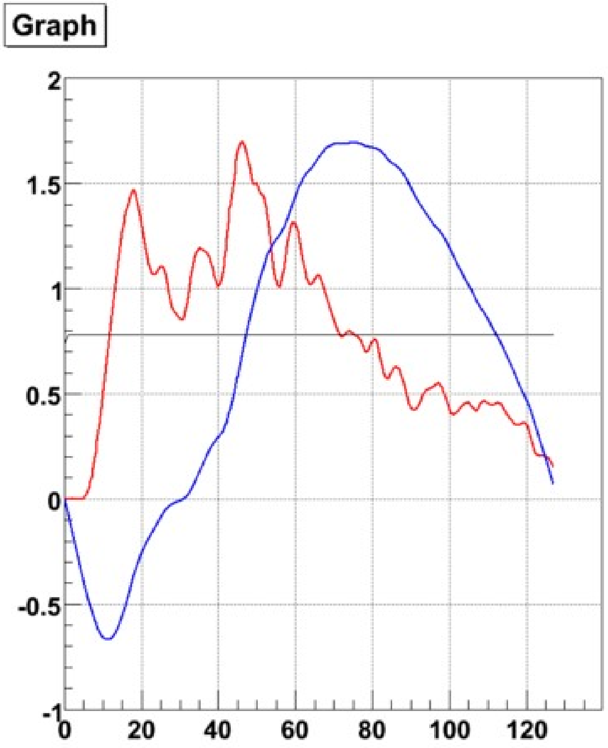


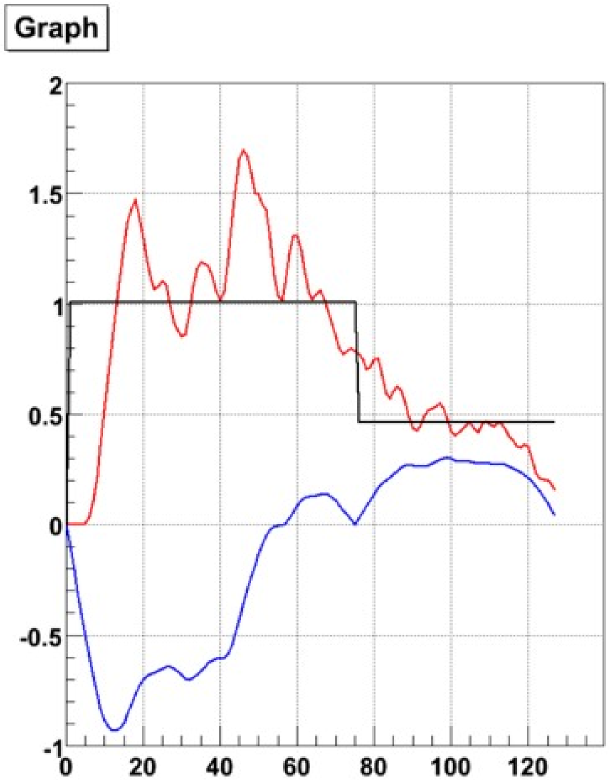


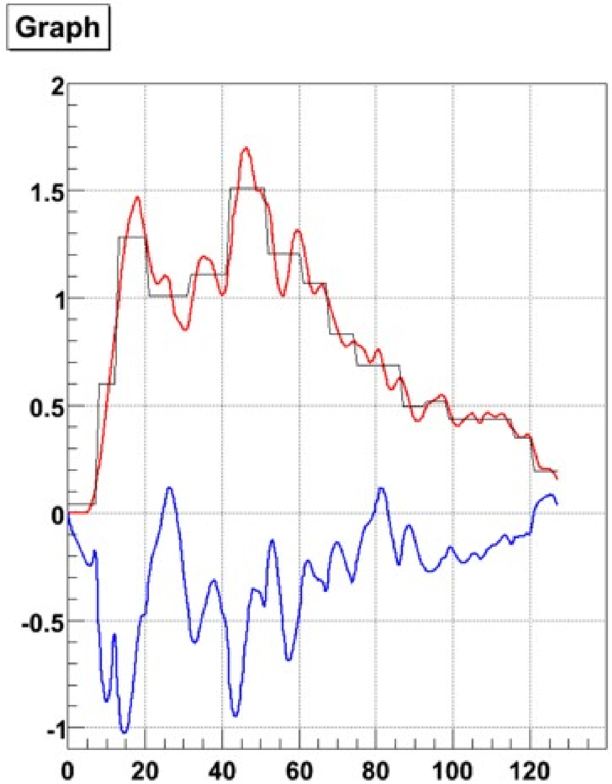
Energy, track length and possible delay time between first and second pulses

E, PeV	0.2	0.5	1	1.5	2	3	4	5	6
L_{track}, m	10	25	50	75	100	150	200	250	300
dt, ns	13-80	33-200	66 - 400	99-600	131-800	197-1200	262-1600	328-2000	394-2400

Change point algorithm

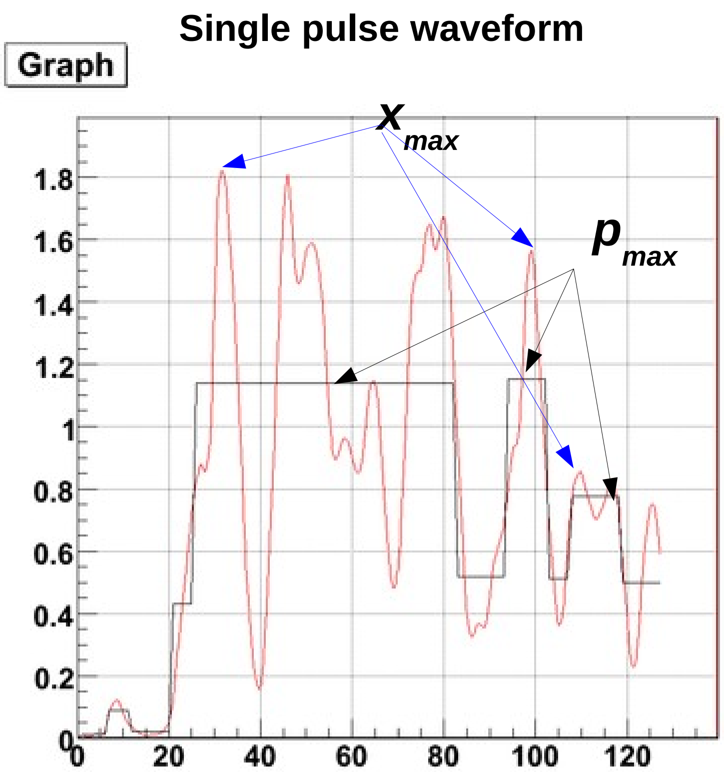


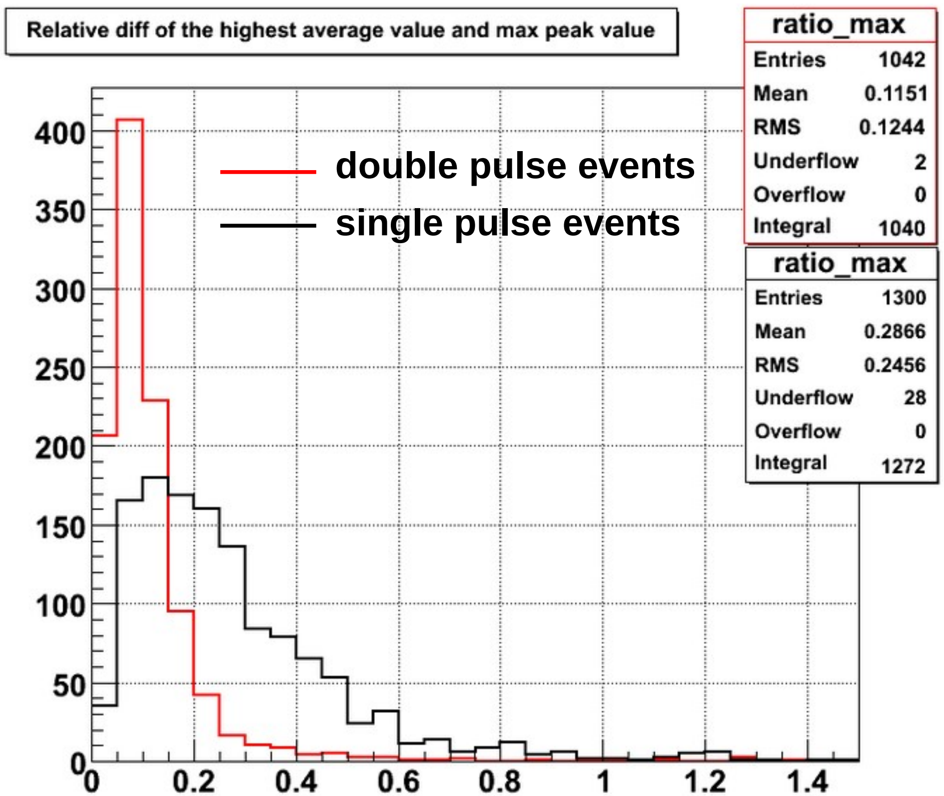




- based on cumulative sum $S(i) = S(i-1) + x_i + \langle x \rangle$, where $S(0) = 0$, x_i is a current value of the waveform, $\langle x \rangle$ is waveform average.
- iterative algorithm
- provides set of points and tell if waveform is rising or falling at this point.

Peak quality



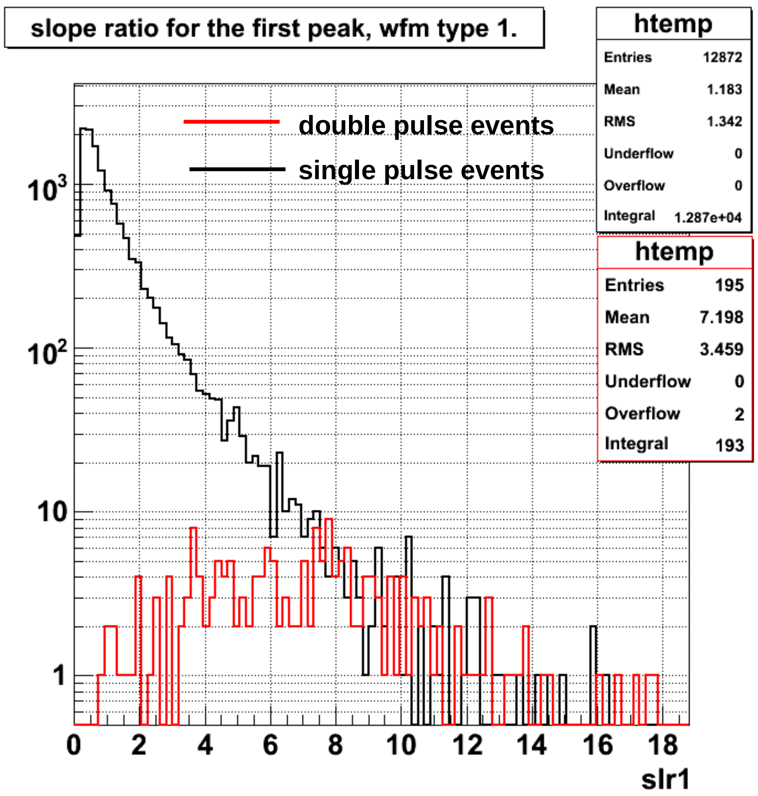


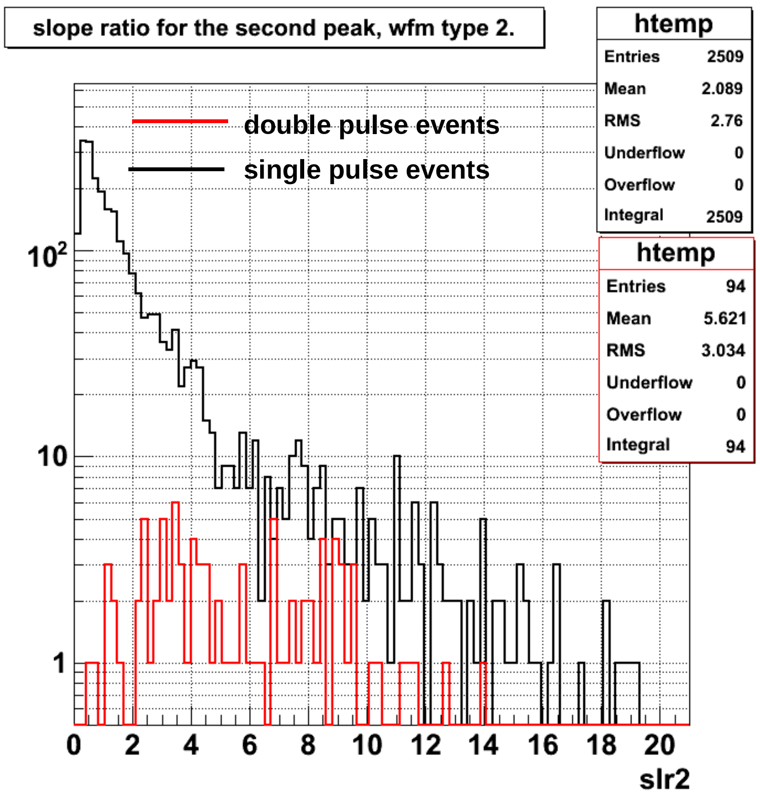
$R_{max} = (x_{max} - p_{max})/p_{max}$

Cut selected:

$R_{max} < 0.2$

Waveform parameters





Type 1, $p_{max1}/p_{max2} > 0.7$:

cut value: slr1 > 2

Signal eff. - 0.685

BG eff. - 0.132

Type 2, $p_{max1}/p_{max2} < 0.7$:

cut value: slr2 > 2

Signal eff. - 0.258

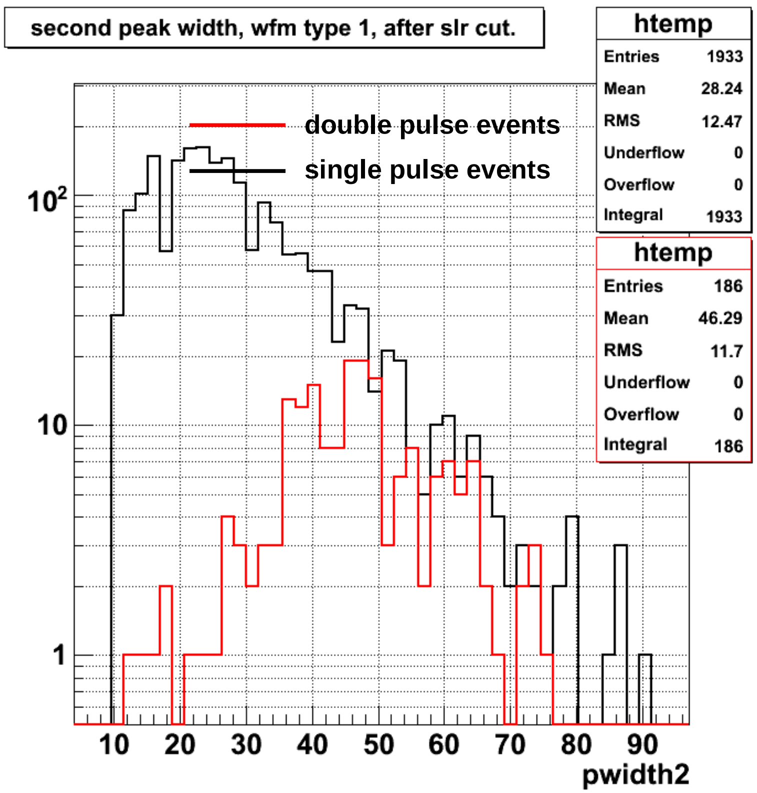
BG eff. - 0.058

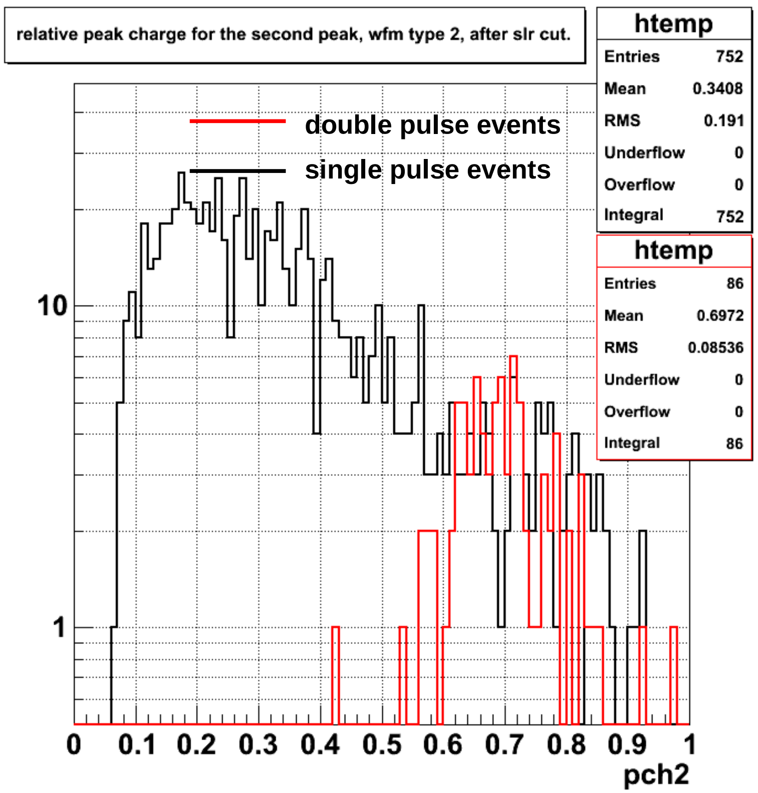
Combined:

Signal eff. - 0.943

BG eff. - 0.190

Waveform parameters





Type 1:

cut value: $pwidth_2 > 25$

Signal eff. - 0.663

BG eff. - 0.068

Type 2:

cut value: $pch_2 > 0.5$

signal eff. - 0.251

BG eff. - 0.009

Combined:

Signal eff. - 0.914

BG eff. - 0.077

Double pulse waveform selection

Selection strategy:

- **Charge cut**
  - *relatively high energy events*
  - *dp waveform is wider (two peaks)*
- **Pulse selection**
  - *change point algorithm*
  - *peak quality check*
- **Waveform selection**
  - *individual waveform properties cuts (slope ratio, peak width, peak charge,...)*
- **Event selection**
  - *number of double pulse waveforms in event*
  - *???*

Summary

- Astrophysical ν_τ search in IceCube is pursued in both ultra high (double-bangs) and low energies (double pulses).
- Double-bang search with IC22 resulted in good upper limit on all flavors compared to AMANDA, ANTARES.
- Triggering online double-pulse ν_τ events in IceCube is intended as multi-wavelength analysis with other exp.
- Real double pulse waveforms (from flashers) can be registered in IceCube.
- Toy MC gives a promising result for finding double pulse waveforms.
- Further MC studies are need, especially for backgrounds.