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UHE ν_τ Search in IceCube

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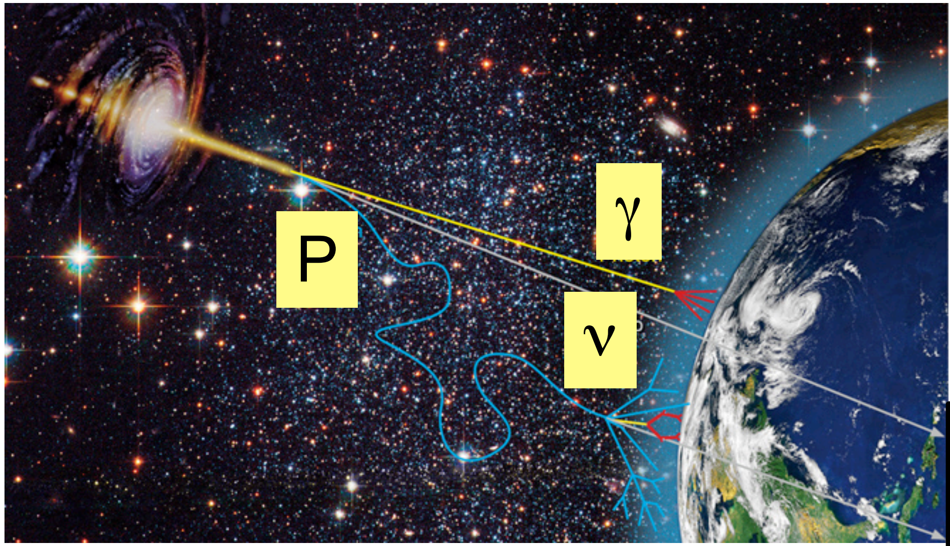
for IceCube

<u>Outline</u>

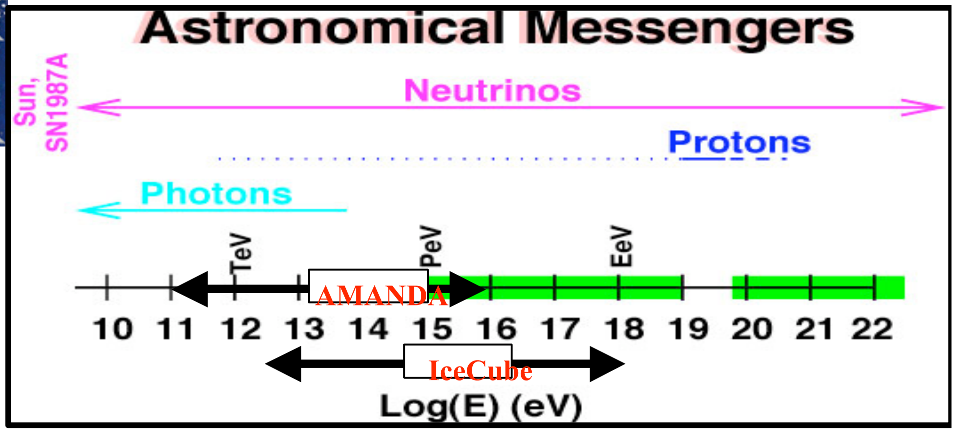
1. General: astro. / atm. ν
2. IceCube
3. UHE ν_τ search in IceCube (IC22)

Why "Neutrinos" from Sky?



(image source: DESY-Zeuthen web)

We observe γ, ν and cosmic-rays (~ 80% protons) on earth as a result of cosmological activity/phenomena.



1 PeV = 10^{15} eV
1 EeV = 10^{18} eV

Pros & Cons:

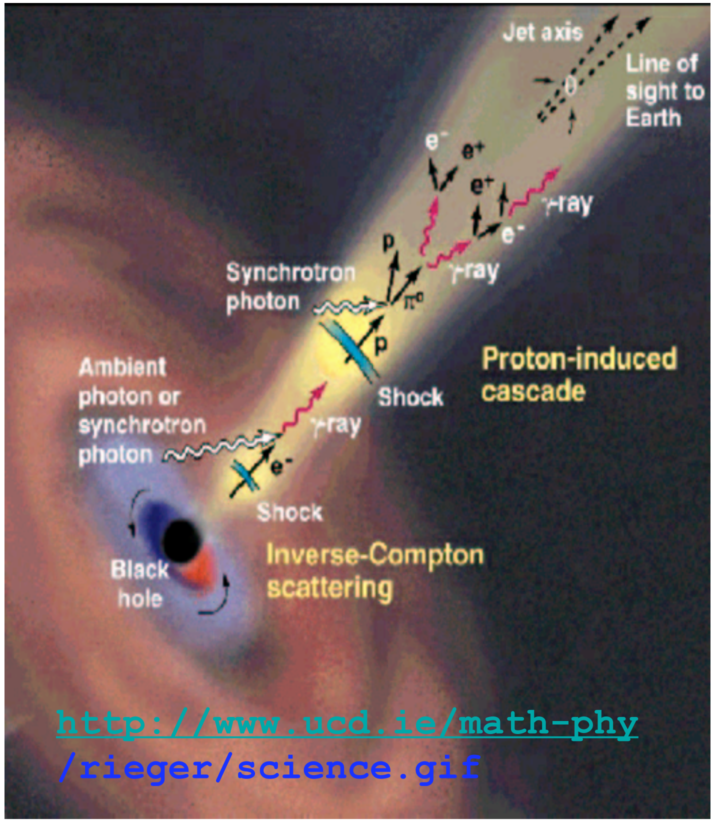
- Protons get bent below 10 EeV.
- Protons are strongly attenuated above 50 EeV (GZK cut-off).
- Photons get absorbed (or pair-production) above 50 TeV.
- Neutrinos cover all energy range, point back, but hard to detect.

--> need very large (Km^3 scale) "Neutrino Telescope"

Astrophysical Neutrinos

Km^3 scale neutrino telescopes are especially targeted for
Galactic & extra-galactic sources: SNRs, AGNs, GRBs, etc…
and GZK (induced) neutrinos

Production mechanism:

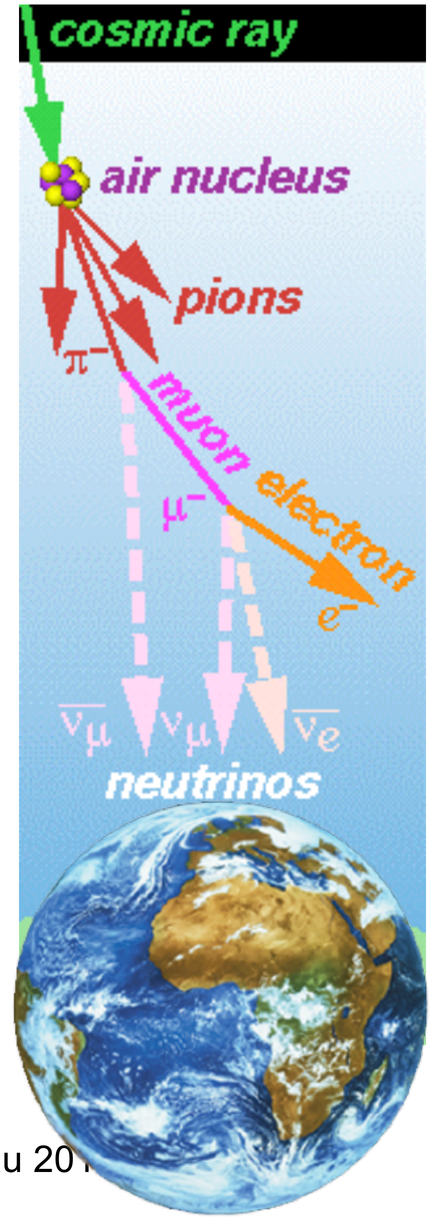


-- Astrophysical engine powers jets
-- Shock waves propagate through surrounding medium
-- Particles scatter repeatedly off shocks
--> Fermi acceleration
--> very efficient, universal power law

$$dN/dE \sim E^{-2}$$

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

Atmospheric Neutrinos



Background for astrophysical neutrinos!

(E spectrum: softer in high energy region)

Conventional ν:

$$p + p \rightarrow \pi^- / \pi^+ \rightarrow \mu\, \nu_\mu \rightarrow (e)\, \nu_e\, \nu_\mu \nu_\mu$$

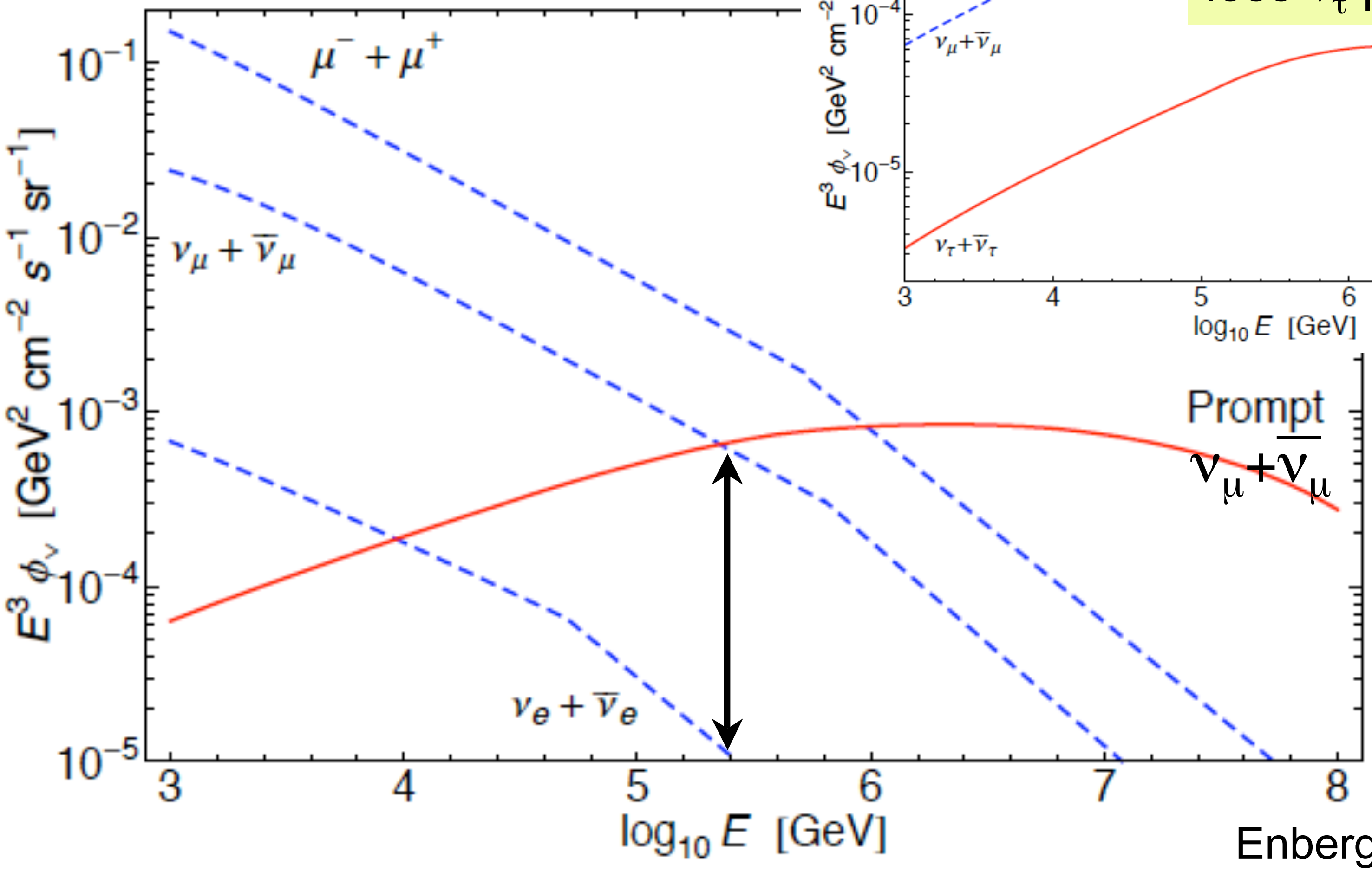
$$\nu_e : \nu_\mu : \nu_\tau \;=\; 1 : 2 : 0$$

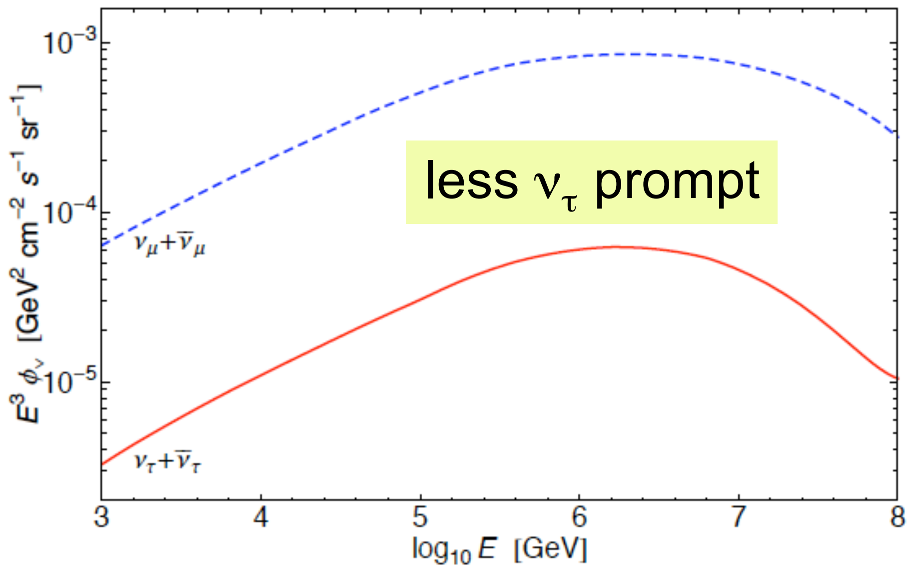
Prompt ν:

Prompt decay of charmed hadrons

$$D^+ \rightarrow \overline{K^0} + l^+ + \nu_l$$
$$D^0 \rightarrow K^- + l^+ + \nu_l$$
$$\Lambda_c \rightarrow \Lambda_0 + l^+ + \nu_l.$$

Atmospheric Neutrinos

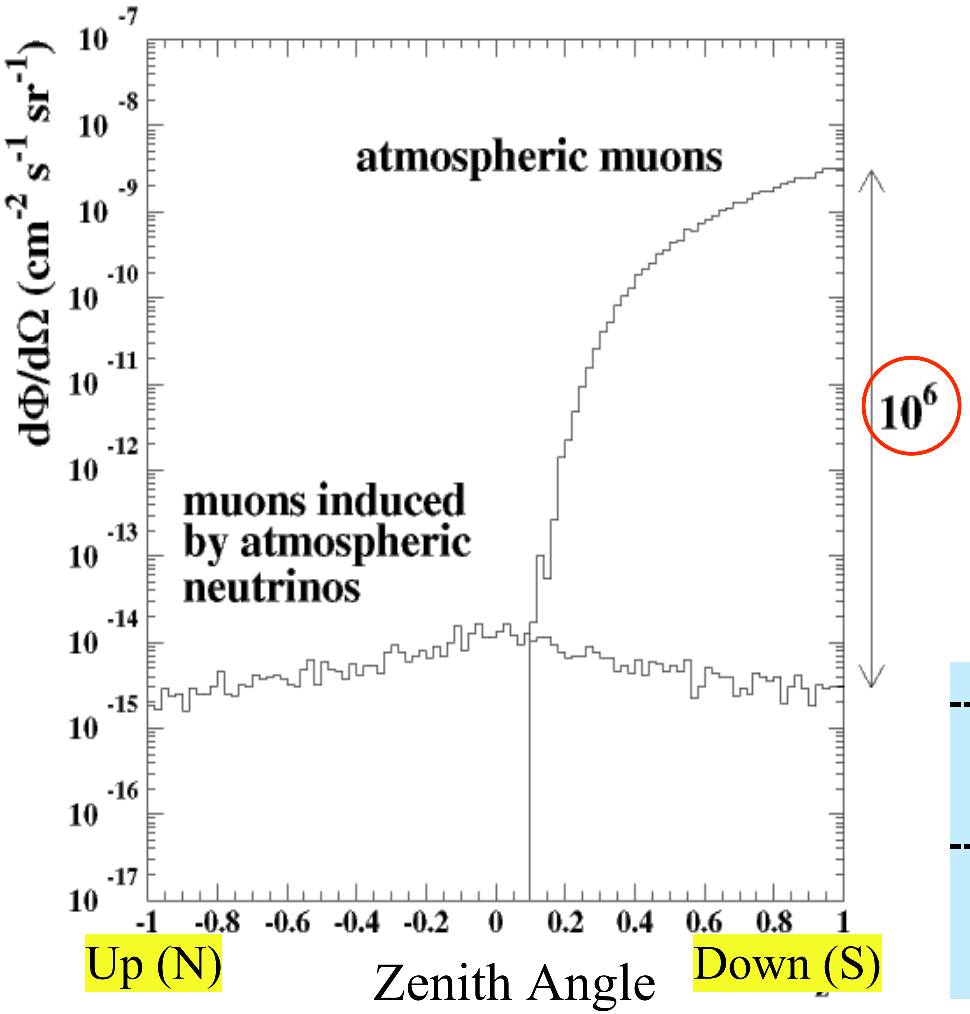


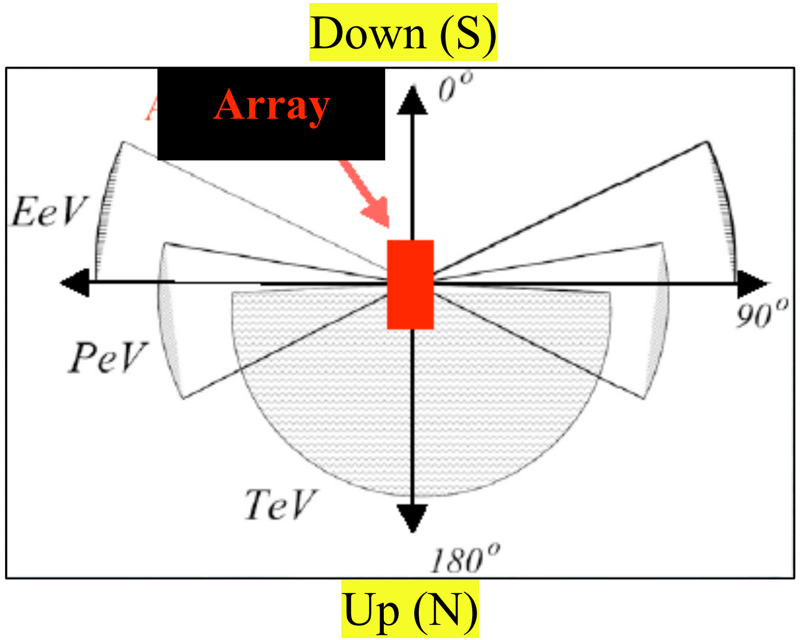


Enberg et al. (2008)

Prompt neutrino flux takes over between 10^5 - 10^6 GeV, and harder.
The cross-over energy increases with zenith angle.

Neutrino Detection Window





-- Large background from above (Southern sky) for E_ν < O(100 TeV)

-- Earth is opaque to ν with E_ν > 100 TeV due to ν cross section and earth density.

Tau Neutrino Properties

Halzen and Saltzberg
PRL 81, 4305

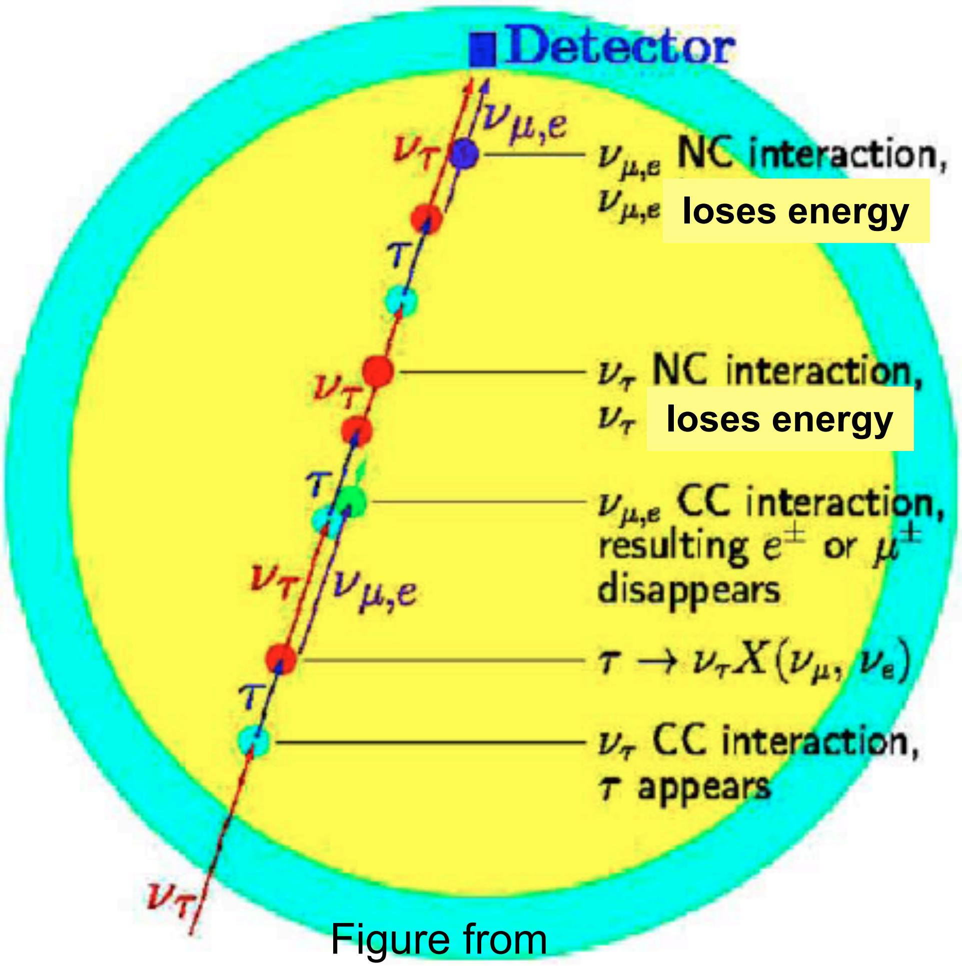


Figure from
Bugaev et al. (2004)

Regeneration:

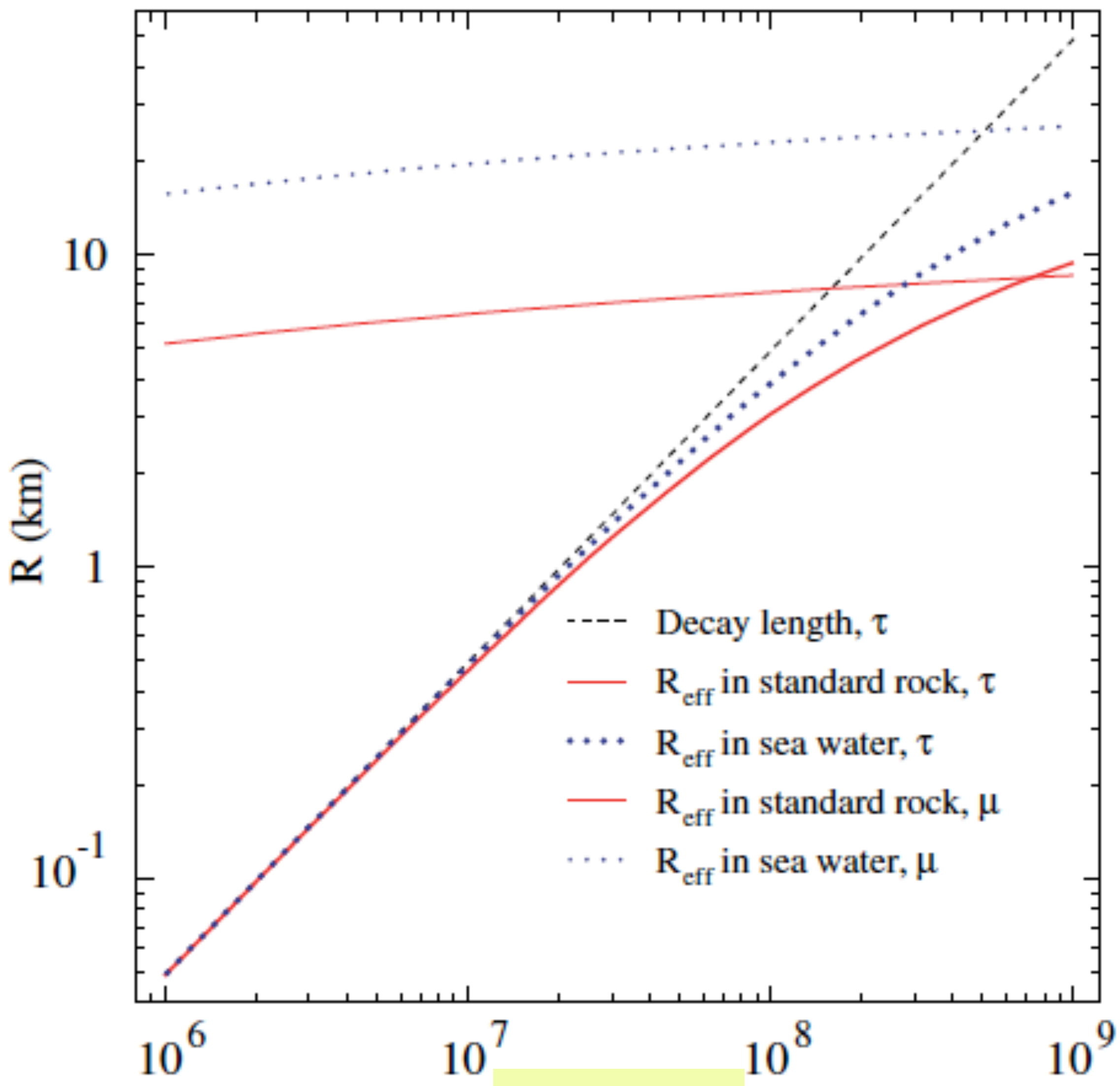
due to short lifetime of tau
(~ 3×10^{-13} sec)

Tau decay modes:

τ --> ν_τ X (~65%)
τ --> $\nu_\tau \nu_e$ e (~18%)
τ --> $\nu_\tau \nu_\mu \mu$ (~17%)

Tau range

Bugaev et al. (2004)



Eτ (GeV)

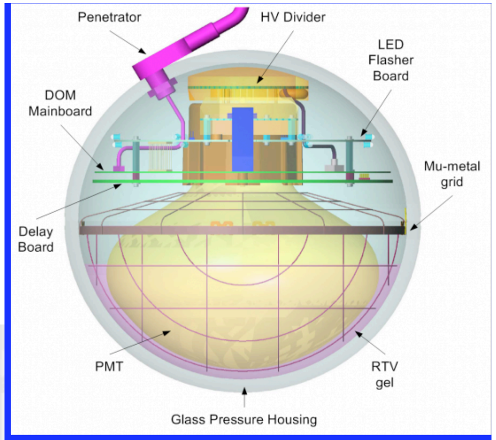
Tau decay length
≠
Tau range

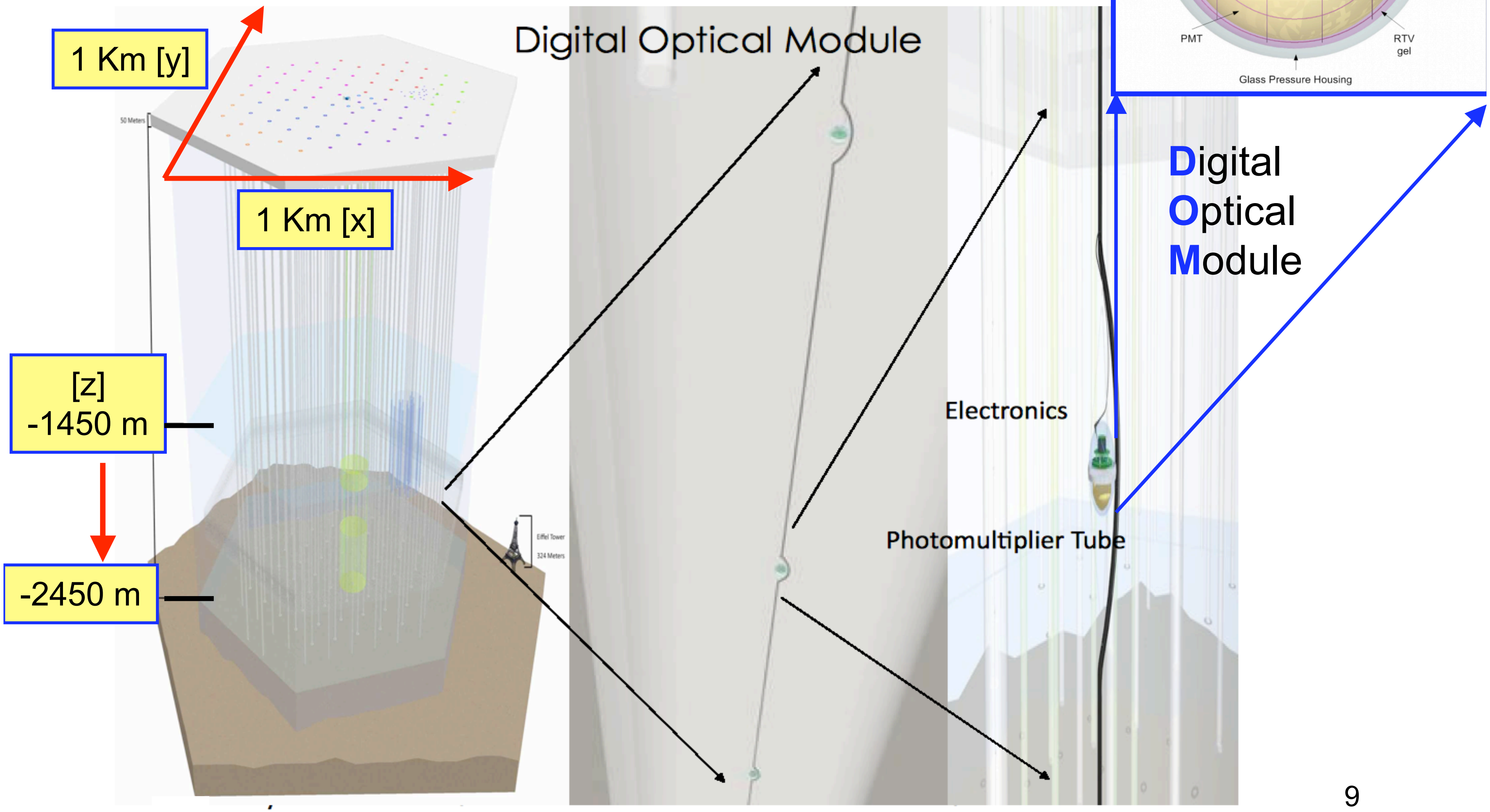
✯ Due to
tau energy loss
while passing
through material

More dense
(more E loss),
Less τ/μ range

The IceCube: neutrino telescope

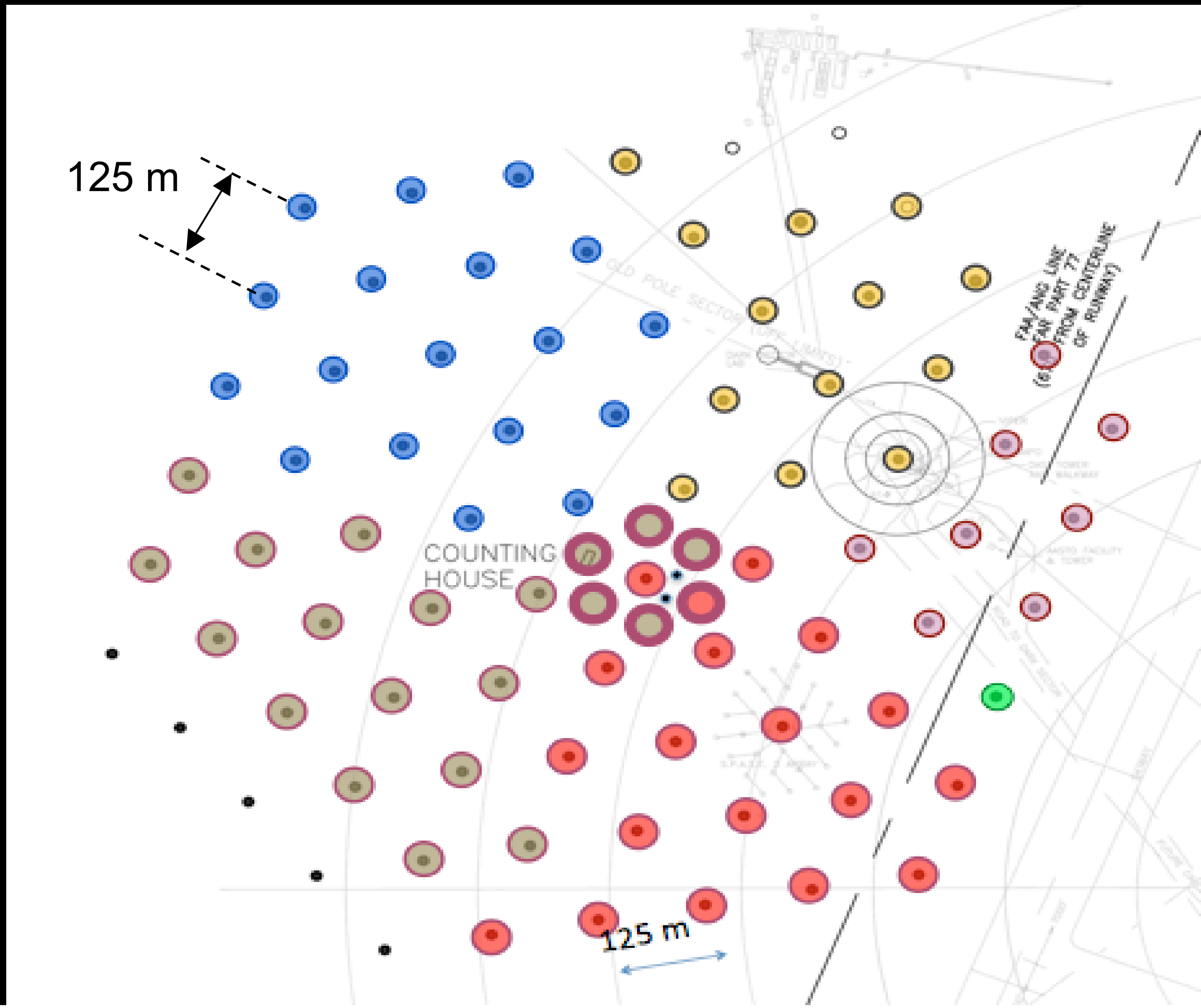
World largest:
~ 1 Km^3
~ 1 Gton





IceCube Construction Status

79 strings deployed (total 86) & taking data!



60 DOMs / string

125 m horizontal spacing
17 m vertical spacing

IC1 — 2004 - 2005

IC9 — 2005 - 2006

IC22 — 2006 - 2007

IC40 — 2007 - 2008

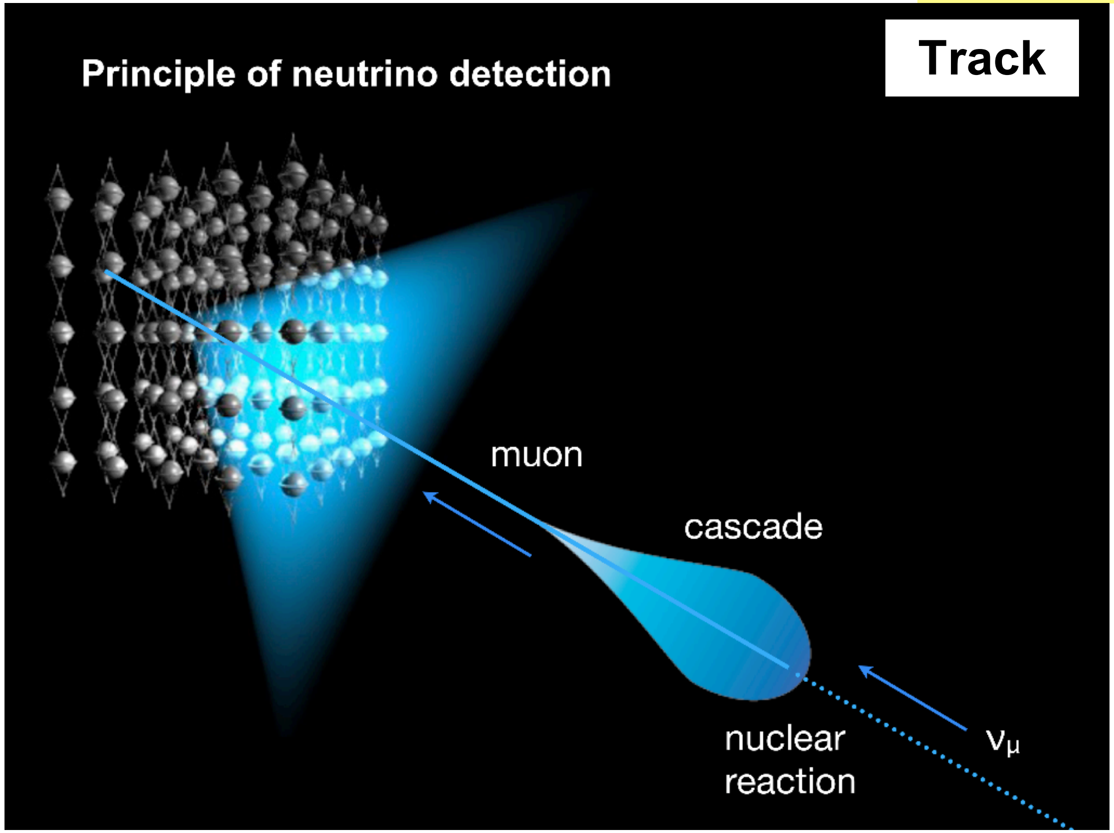
IC59 — 2008 - 2009

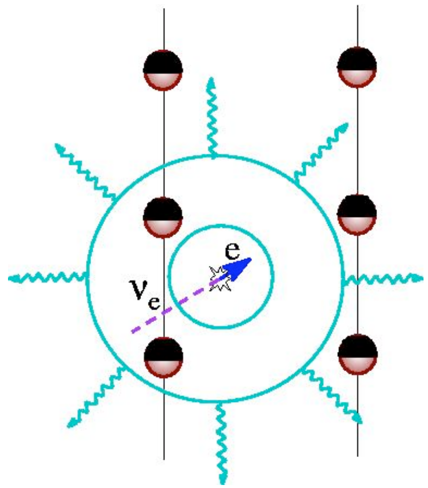
IC79 — 2009 - 2010

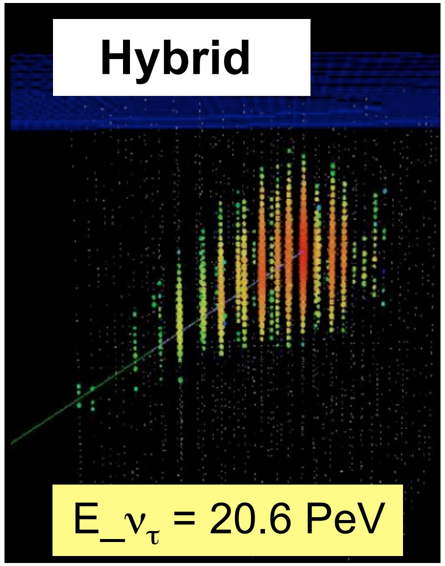
IC86 — To be deployed in Dec. 2010

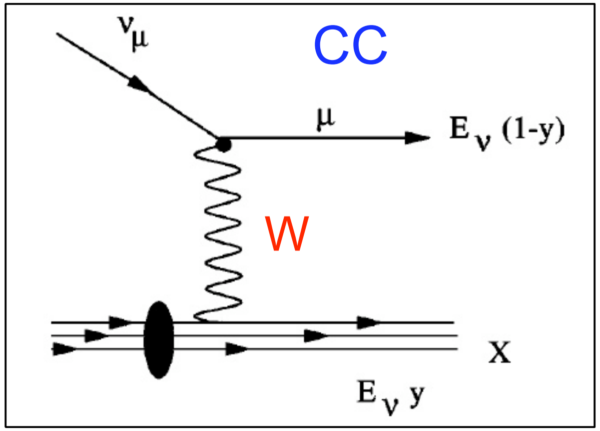
Neutrino detection

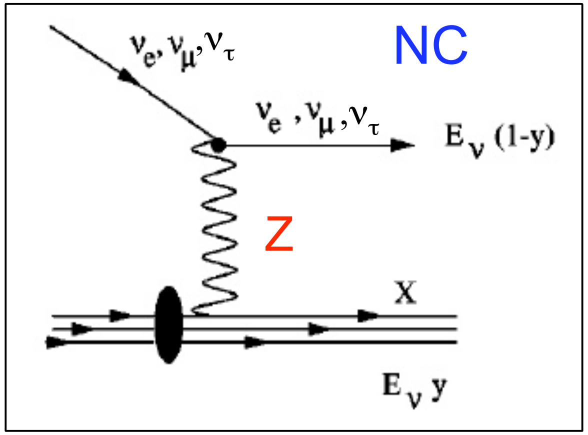
Detect 3 flavors: ν_e, ν_μ, ν_τ











Tau Neutrinos in IceCube

$\nu_e : \nu_\mu : \nu_\tau$

$(1 : 2 : 0)$

$(\text{maximal } \nu_\mu \leftrightarrow \nu_\tau \text{ mixing})$

oscillation

$\nu_e : \nu_\mu : \nu_\tau$

$(1 : 1 : 1)$

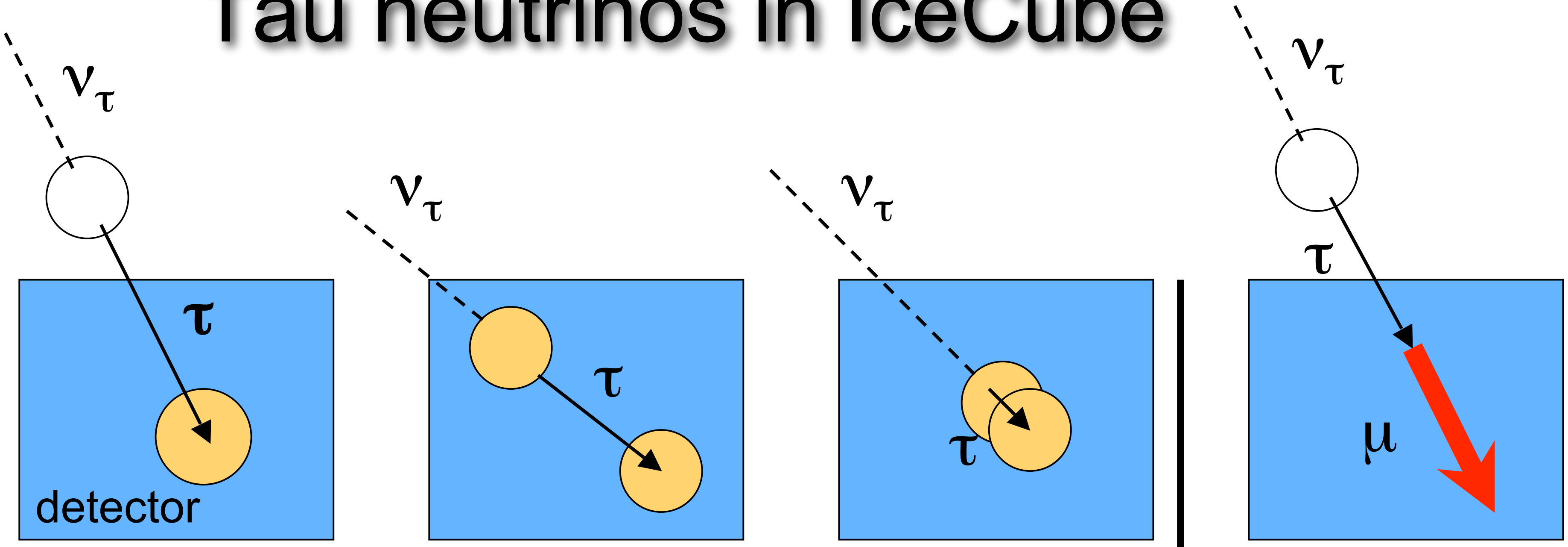
Motivation

+ "Intrinsic" cosmological ν_τ flux is almost negligible,
  but neutrinos should oscillate over cosmological distances:
  look for "oscillated" cosmological ν_τ (add a new window)

+ IceCube's capability to detect all flavors (ν_e, ν_μ, ν_τ)!

+ Almost (atmospheric ν) background free.

Tau neutrinos in IceCube



Lollipop (LP) | Double-bang (DB) | Double-pulse (DP) | $\tau \rightarrow \mu$

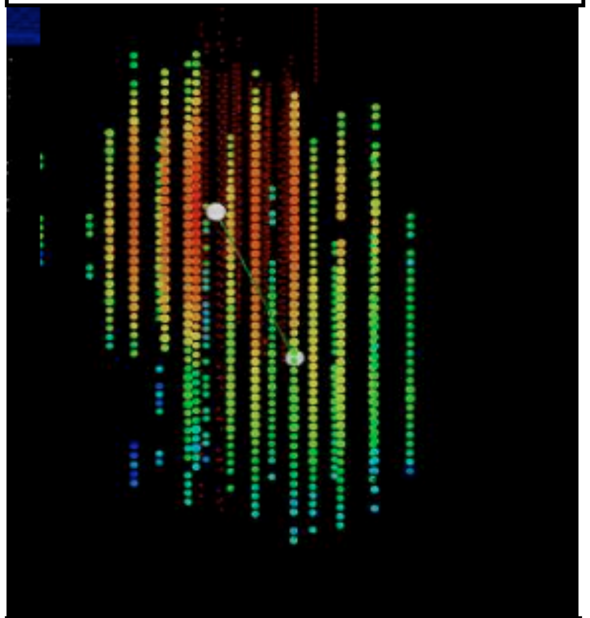
1st bang: hadronic shower by ν_τ CC interaction

2nd bang: hadronic shower by $\tau \rightarrow \nu_\tau X$ (~64%)
EM shower by $\tau \rightarrow \nu_\tau \nu_e e$ (~18%)

$\tau \rightarrow \nu_\tau \nu_\mu \mu$ (~18%)

Simulated Tau neutrinos

Simulated double-bang
IC22



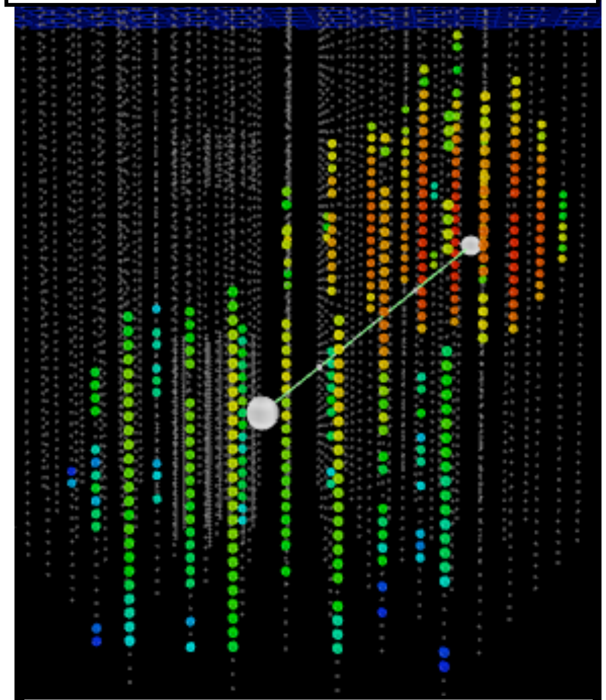
Eν ~47 PeV
Tau track ~332 m

IC22 =
IceCube 22 strings

IC86 =
IceCube 86 strings

(look p. 12
for
the geometry)

Simulated double-bang
IC86



Eν ~6.7 PeV
Tau track ~454 m

IC22 UHE Analysis Strategy

Cut & Count method

Remove atm. BG until signal (UHE ν) gets prominent.

UHE Filter	Offline level 2 filter (NCh > 80)
UHE Cuts	UHE L0, L1, L2, L3

Cuts

UHE L0: remove certain Brem. Muons
localQDensity > 5

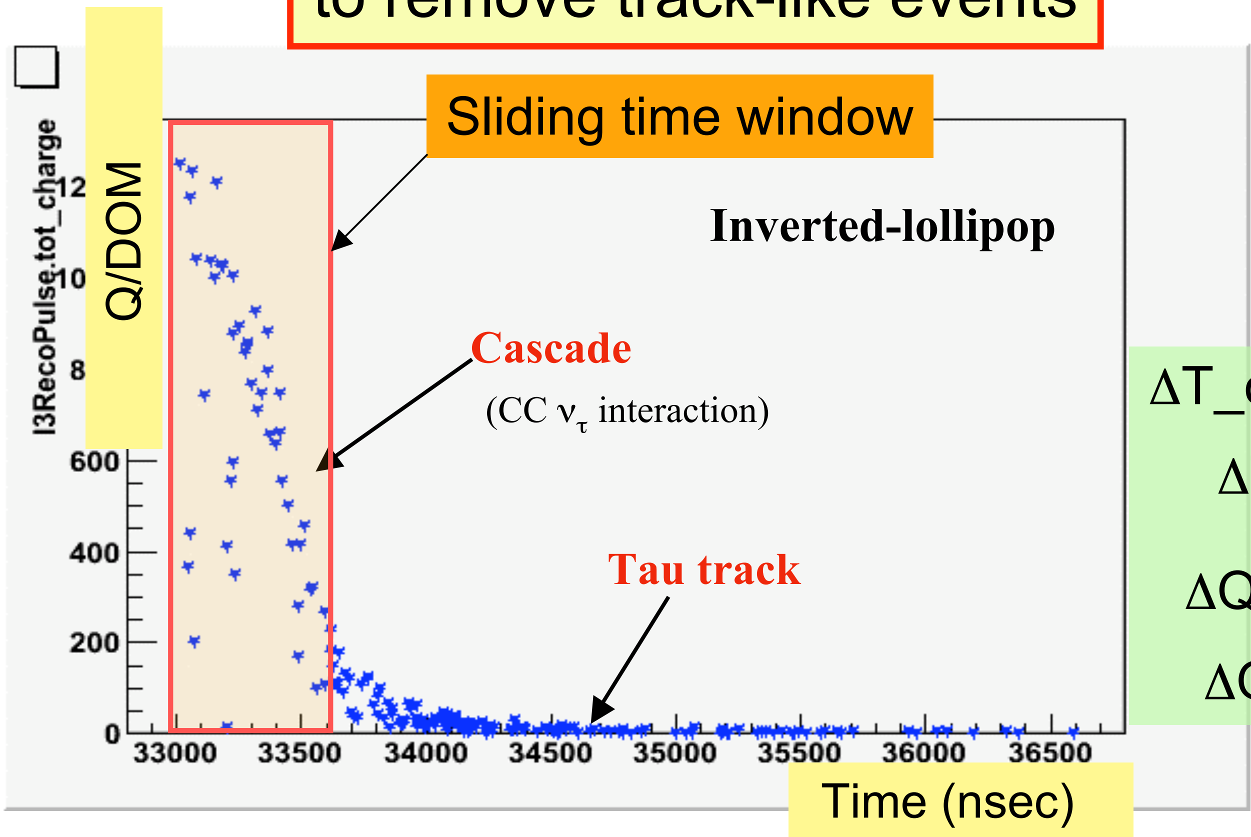
UHE L1: remove down-going events
<Z>init < 450 m & <V>z > -0.1

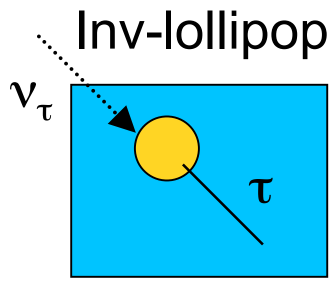
UHE L2: select contained cascade-like events
<Z> > -330 m & TOI_evalratio > 0.1

UHE L3: energy related cut
lRmax >= 200 and log10(npe) > 4.2
(MRF optimized cut)

Cut: IRmax (Current Ratio Max.)

to remove track-like events





ΔT_on = sliding time window

ΔT_off = T_tot - ΔT_on

ΔQ_on = Q_inside ΔT_on

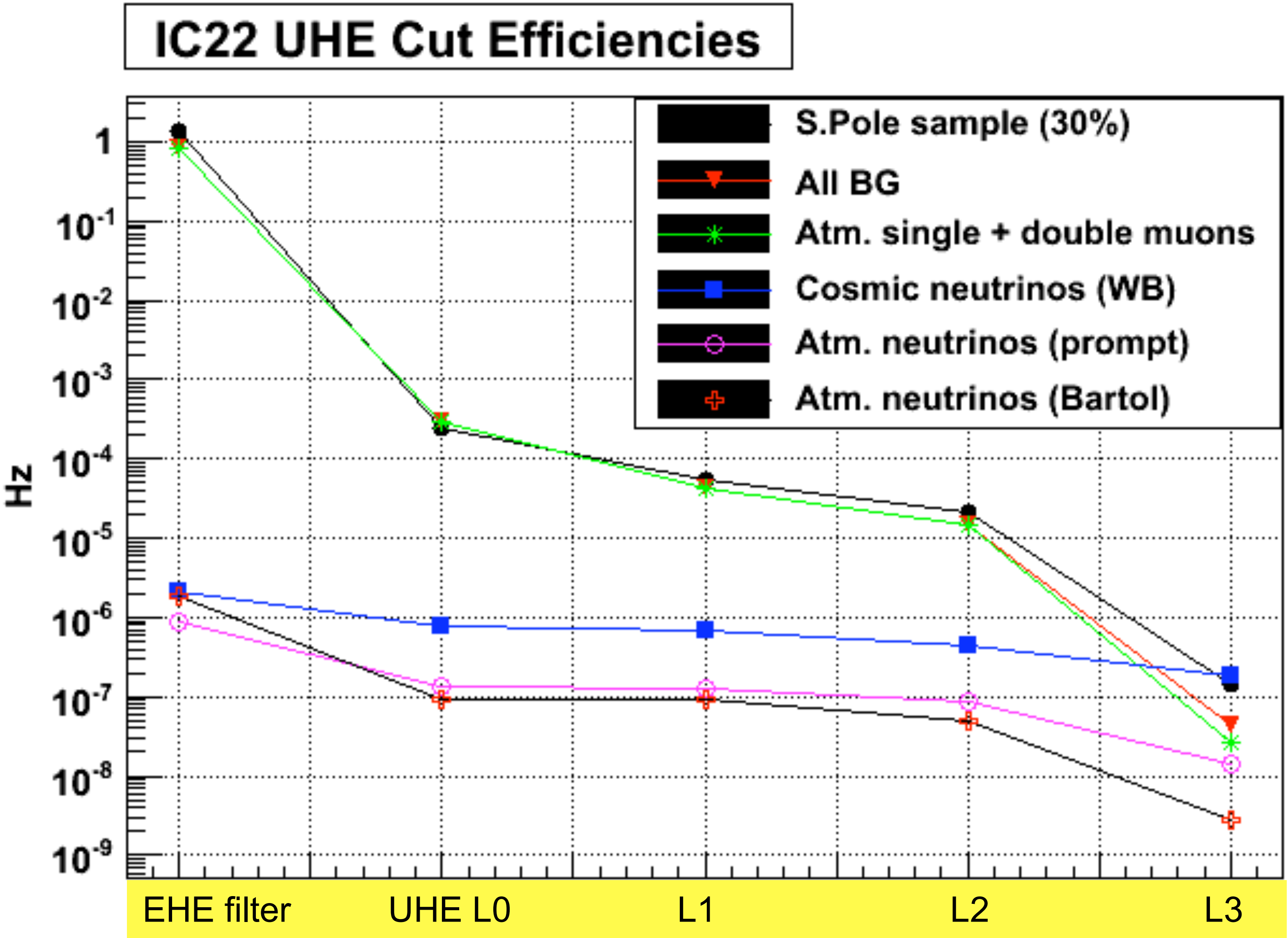
ΔQ_off = Q_tot - ΔQ_on

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

> 1 (for ν_τ)

~ 1 (for μ)

Cut Efficiency



Data and MC agrees relatively well.

Expected Events at Final Cut

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

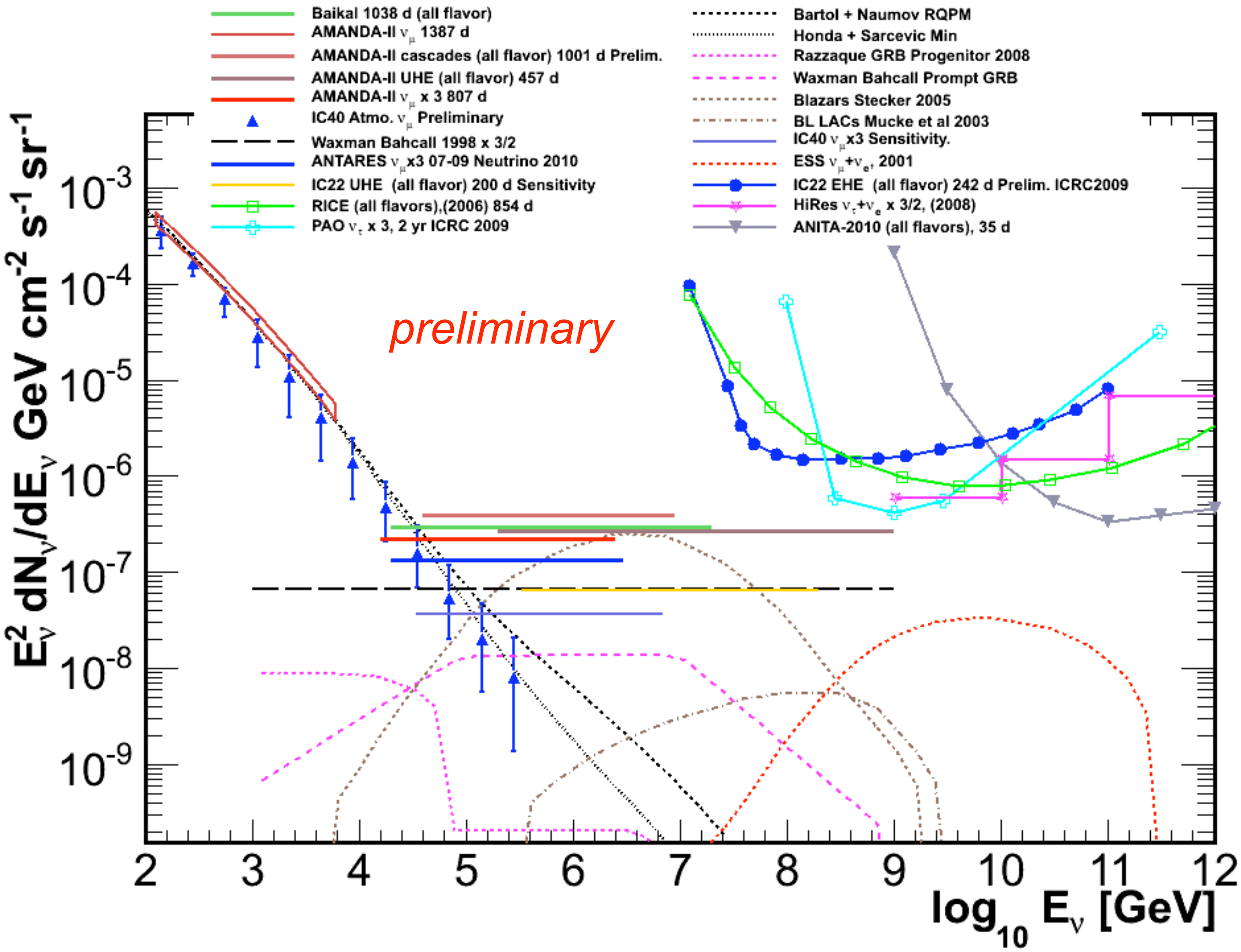
Event type	Spectrum	Flux model	Live time	#. Events at final cut	Efficiency relative to filter
NuTau	$\propto E^{-2}$	WB	200 d	0.97	11 %
NuMu	$\propto E^{-2}$	WB	200 d	0.64	3.1 %
NuE	$\propto E^{-2}$	WB	200 d	1.57	23 %
All Nu		prompt	200 d	0.25	2.2 %
NuMu + NuE		Bartol	200 d	0.05	0.16 %
Atm. muons			200 d	0.46	3.2E-6 %
S.Pole (30%)	---	---	82.4 d	0	

** Signal efficiency will improve as detector gets larger and with sophisticated reconstruction method.

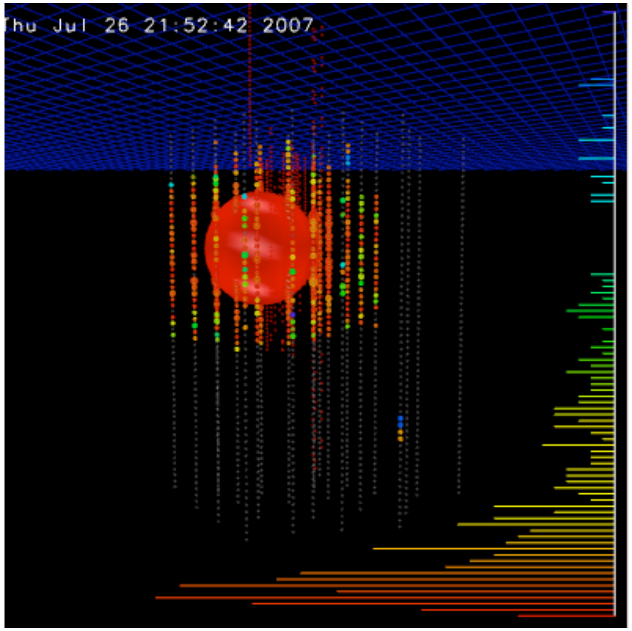
IC22 UHE Sensitivity

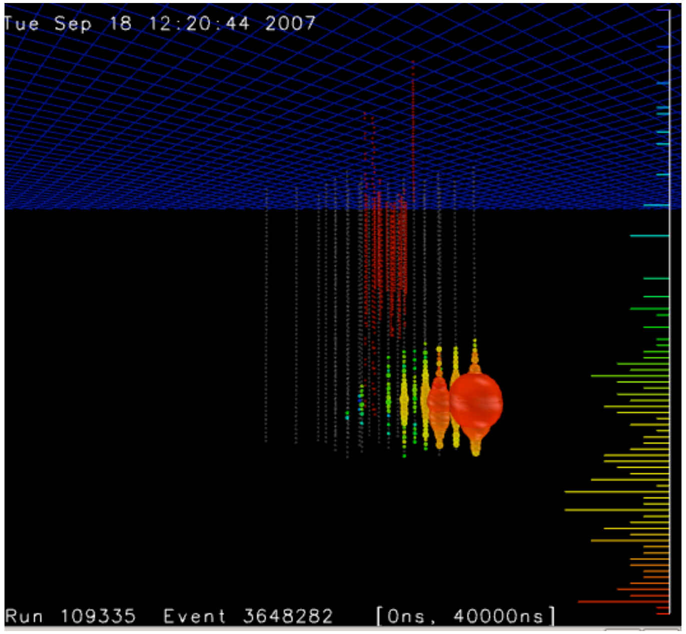
$E^2\,\Phi_\nu < 6.54 \times 10^{-8}$ GeVcm^{-2}s^{-1}st^{-1} (all flavor, preliminary)

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



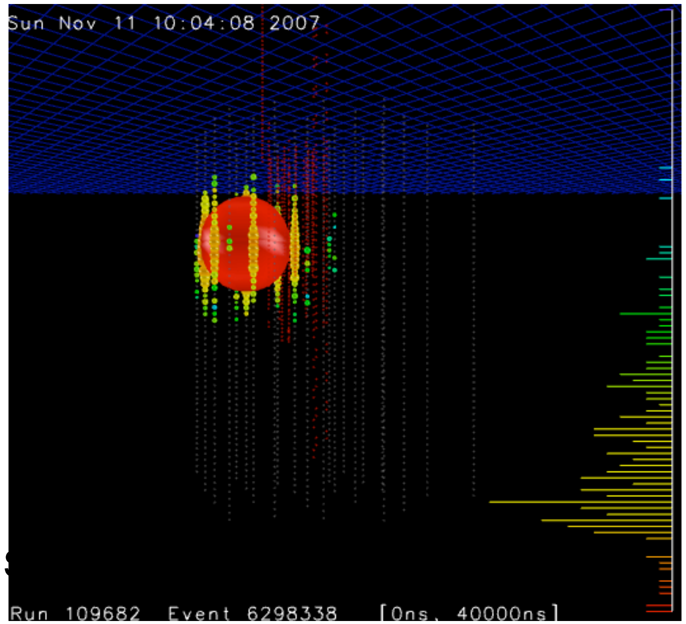
The 3 Events (After unblinding IC22 data)





Looks like a horizontal event?

This event is suspected as detector glitch.
(Amanda flashing OM # 531)



Seen also by other diffuse analyses (good cascade -like event).

-- Systematic study on going.

-- limit will be set soon.

Summary and outlook

* IC22 DB/LP search were based on topology of the events.

* It resulted in almost equally sensitive to all flavors, but with an interesting result.

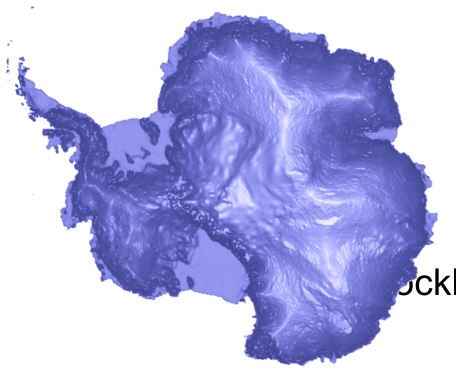
* We will use full reconstruction for future analysis.

* IC86 DB/LP search will be more promising.

* Double pulse, Tau --> mu channels are being under-study.

Thank you!

Oden:
Swedish ice breaker



ckhol

Backup slides

Rough Estimation for IC86

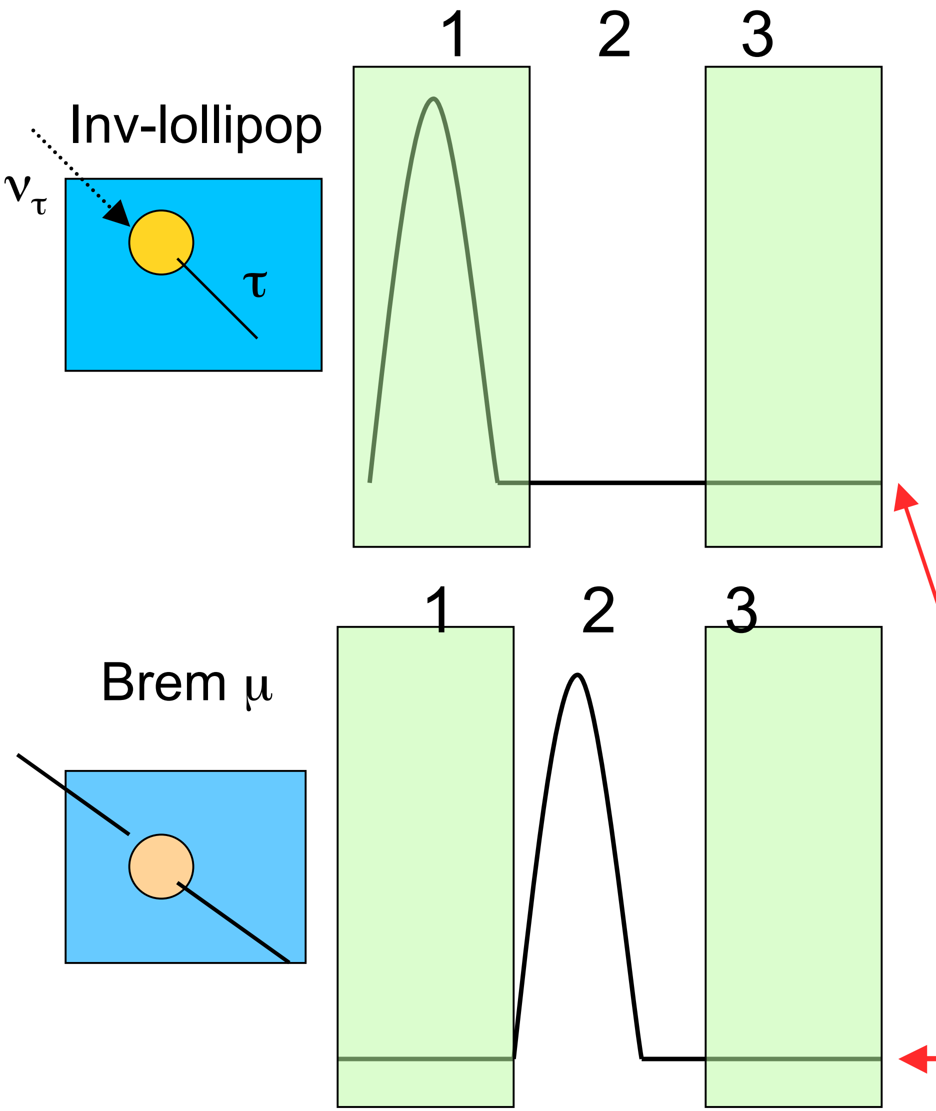
Caution: rough estimation!

Preliminary:

Expected **golden** (DB + LP + ILP) events in **5** years live time

Model	IC22 trigg	IC22 final	IC86 trigg	IC86 final
WB	1.87	0.87	9.44	4.39
SS95 -blaz	38.1	14.5	74.4	28.3

Cut: Local Charge Density



to remove certain brem μ

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

--- choose maximum between 1st and 3rd

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

To be selected by this cut.

Not to be selected.