Potential Effects of Accretion-Disk Neutrinos on High-Energy Neutrinos Produced in Gamma-Ray Bursts and Core-Collapse Supernovae

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work done mostly by
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Institute for Nuclear Theory Workshop on
Flavor Observations with Supernova Neutrinos
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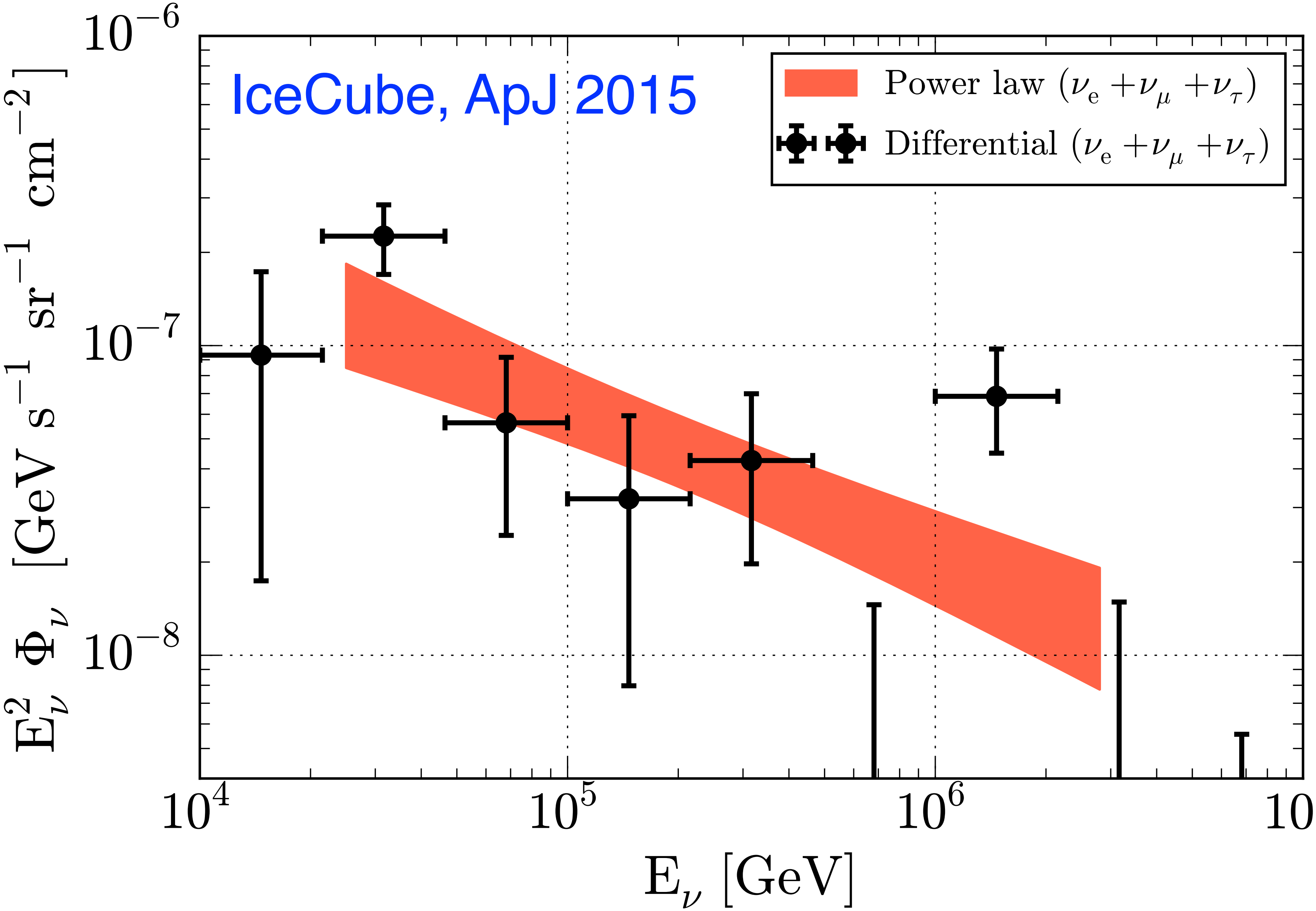
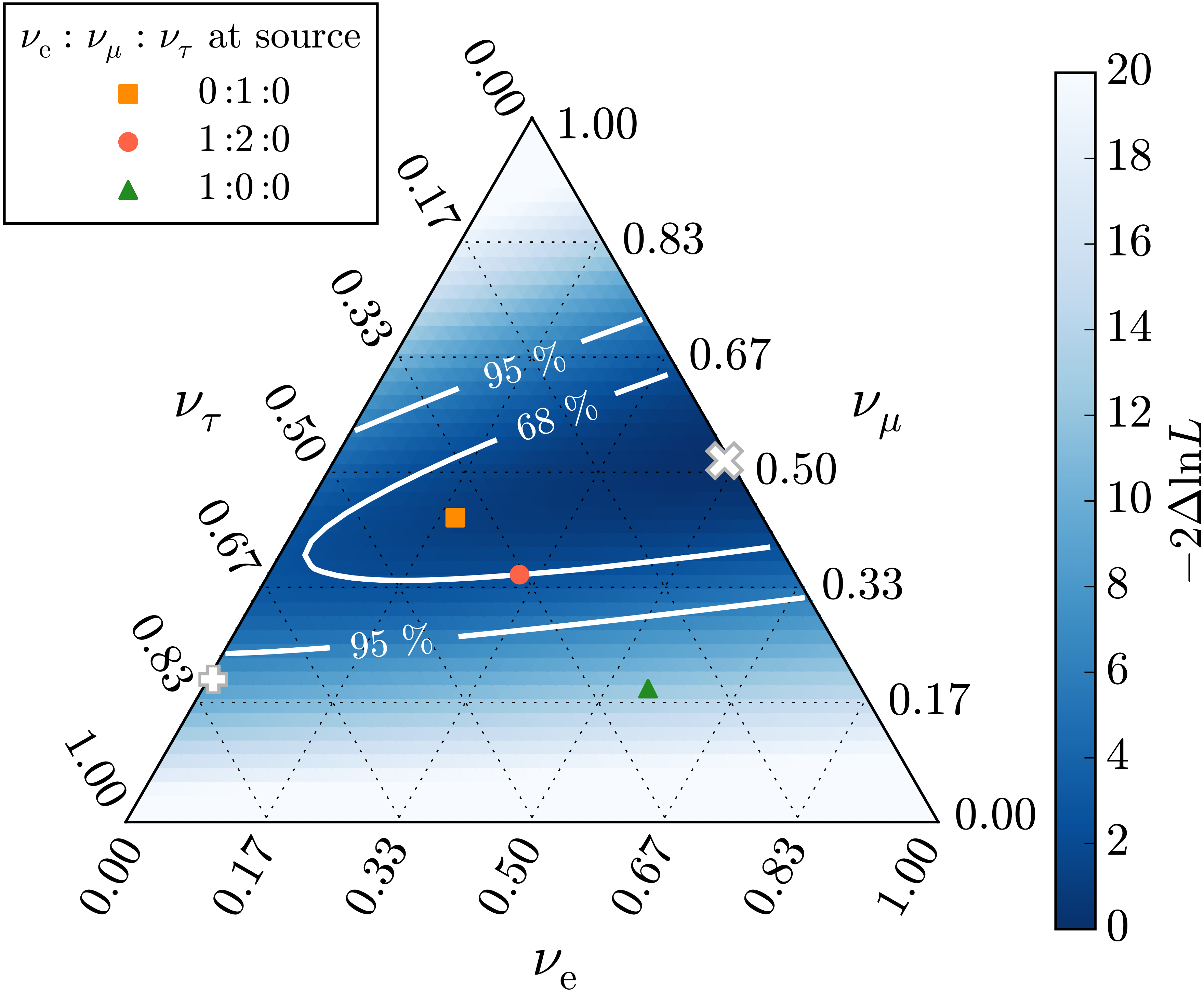


$$\phi(E) = \frac{\left(6.7^{+1.1}_{-1.2}\right) \times 10^{-18}}{\mathrm{GeV} \cdot \mathrm{s} \cdot \mathrm{sr} \cdot \mathrm{cm}^2} \left(\frac{100\ \mathrm{TeV}}{E}\right)^{2.50 \pm 0.09}$$



$\nu_e : \nu_\mu : \nu_\tau$ at source
0 :1 :0
1 :2 :0
1 :0 :0
95 %
68 %
95 %
ν_τ
ν_μ
ν_e
0.00
0.17
0.33
0.50
0.67
0.83
1.00
0
2
4
6
8
10
12
14
16
18
20
$-2\Delta \ln L$

Production of High-Energy (HE) Neutrinos

$$p + p \rightarrow \pi^{\pm} + \cdots$$

$$p + \gamma \rightarrow \pi^{\pm} + \cdots$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}, \; \mu^{+} \rightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}$$

$$\pi^{-} \rightarrow \mu^{-} + \bar{\nu}_{\mu}, \; \mu^{-} \rightarrow e^{-} + \bar{\nu}_{e} + \nu_{\mu}$$

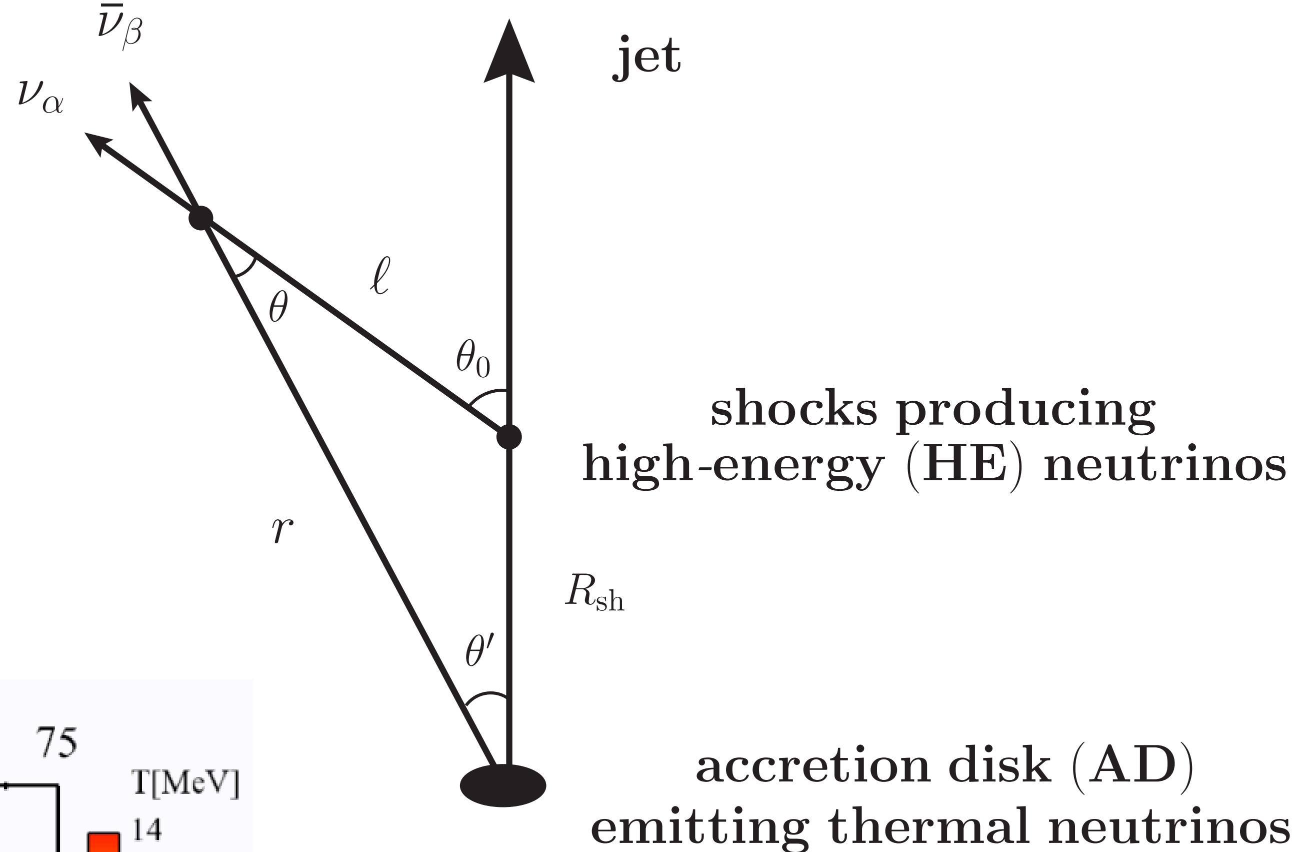
$$n \rightarrow p + e^{-} + \bar{\nu}_{e}$$

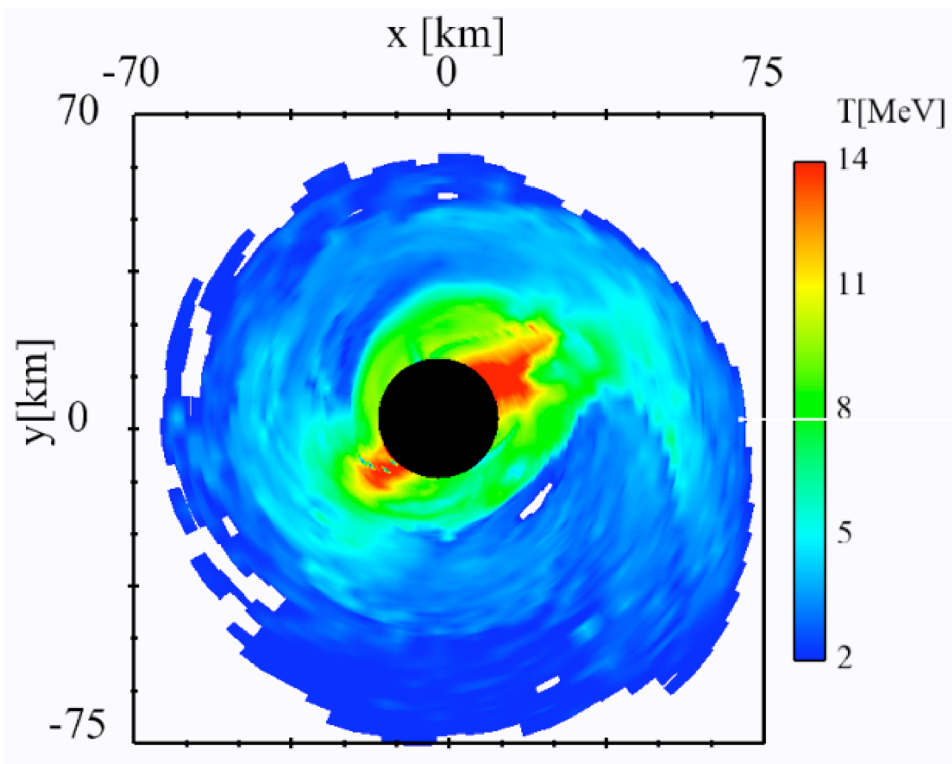
→ need HE protons!

Annihilation of HE and AD Neutrinos

$$\nu_\alpha + \bar{\nu}_\alpha \rightarrow f + \bar{f}$$

$$\nu_\alpha + \bar{\nu}_\beta \rightarrow l_\alpha + \bar{l}_\beta$$





neutrino emission from AD

dominantly ν_e and $\bar{\nu}_e$

Caballero+ 2009

Flavor Evolution of AD Neutrinos

No Evolution (NE)

$$f_\beta = \bar{f}_\beta = \delta_{\beta e}$$

Adiabatic Evolution with Normal Mass Hierarchy (NH)

$$f_\beta = |U_{\beta 3}|^2,\ \bar{f}_\beta = |\bar{U}_{\beta 1}|^2$$

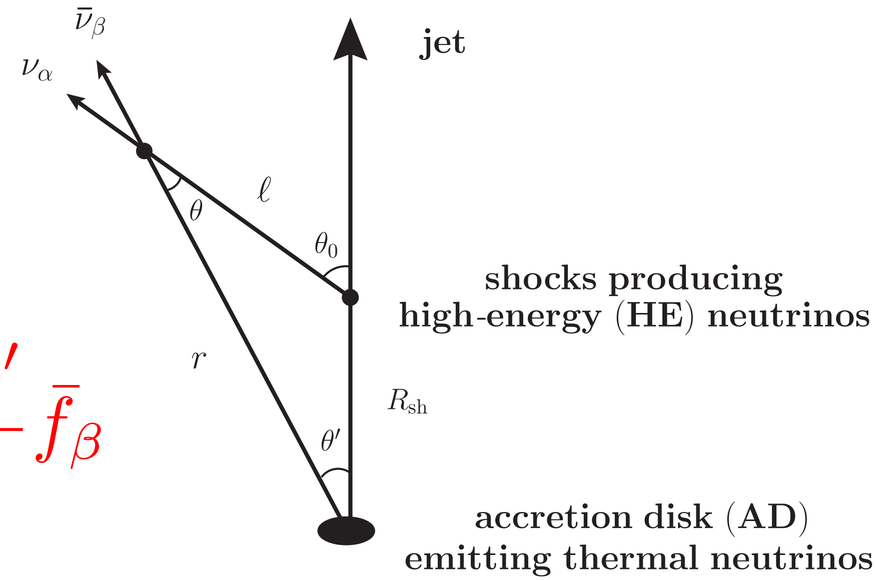
Adiabatic Evolution with Inverted Mass Hierarchy (IH)

$$f_\beta = |U_{\beta 2}|^2,\ \bar{f}_\beta = |\bar{U}_{\beta 3}|^2$$

Exotic Evolution (EE)

$$f_\beta = \bar{f}_\beta = \delta_{\beta \mu}$$

Probability for HE Neutrinos to Survive Annihilation



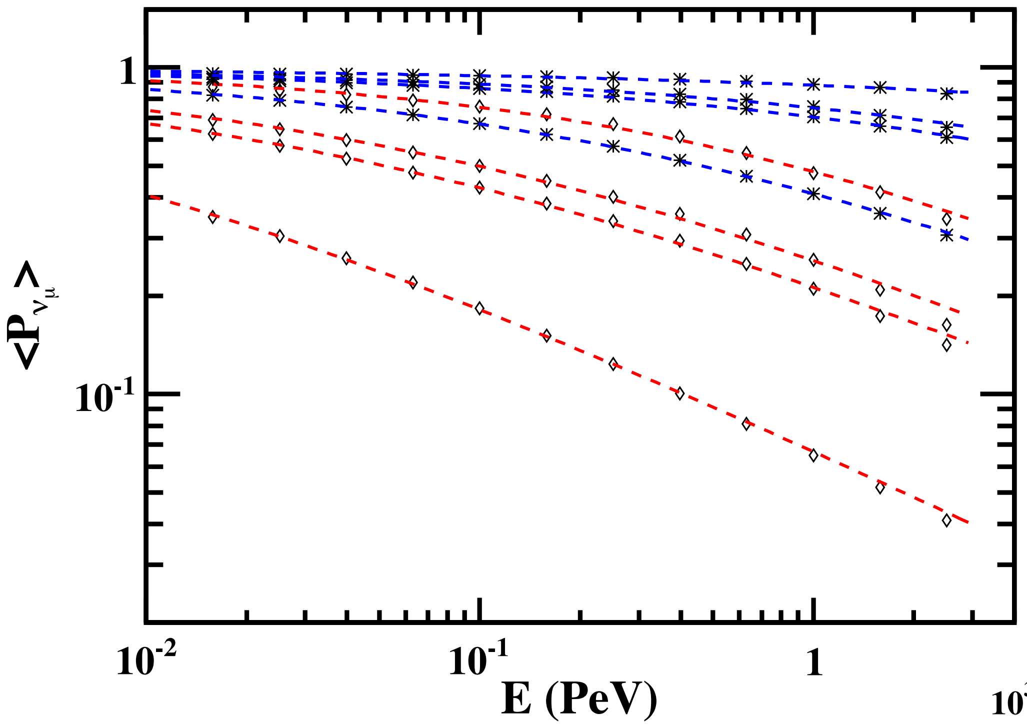
$$\sigma_{\nu_\alpha \bar{\nu}_\beta} \propto s = 2EE'(1 - \cos\theta)$$

$$dn_{\bar{\nu}_\beta} = \frac{E'^2 dE'}{\exp(E'/T_\nu) + 1} \frac{R_\nu^2 \cos\theta'}{8\pi^2 r^2} \bar{f}_\beta$$

$$\tau_{\nu_\alpha}(E, \theta_0) = \sum_\beta \int (1 - \cos\theta) \sigma_{\nu_\alpha \bar{\nu}_\beta}(s) dn_{\bar{\nu}_\beta} d\ell \propto E R_\nu^2 T_\nu^4 \theta_0^4 / R_{\rm sh}$$

$$\langle P_{\nu_\alpha}(E) \rangle = \langle \exp[-\tau_{\nu_\alpha}(E, \theta_0)] \rangle$$

$$\theta_0 \sim \Gamma^{-1} \Rightarrow \eta = R_{\nu,7}^2 T_{\nu,{\rm MeV}}^4 R_{{\rm sh},9}^{-1} \Gamma^{-4}$$



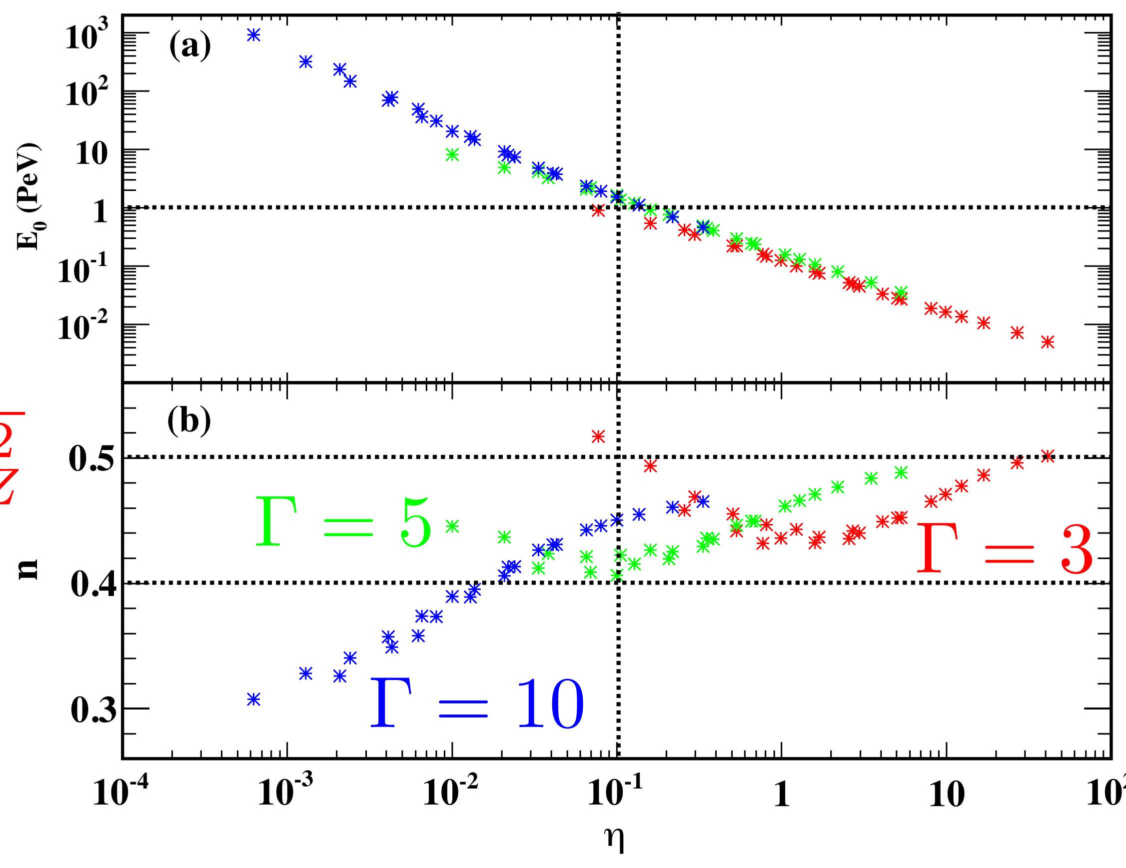
$$\langle P_{\nu_\mu} \rangle = \frac{1}{1 + (E/E_0)^n}$$

$$\eta = \frac{R_{\nu,7}^2 T_{\nu,\mathrm{MeV}}^4}{R_{\mathrm{sh},9}\Gamma^4}$$

Z resonance

$$\sigma_{\nu_\alpha \bar{\nu}_\alpha} \propto \frac{s}{(s - M_Z^2)^2 + \Gamma_Z^2 M_Z^2}$$

→ effect of Γ on n



Effects on Source Spectra and Flavor Composition

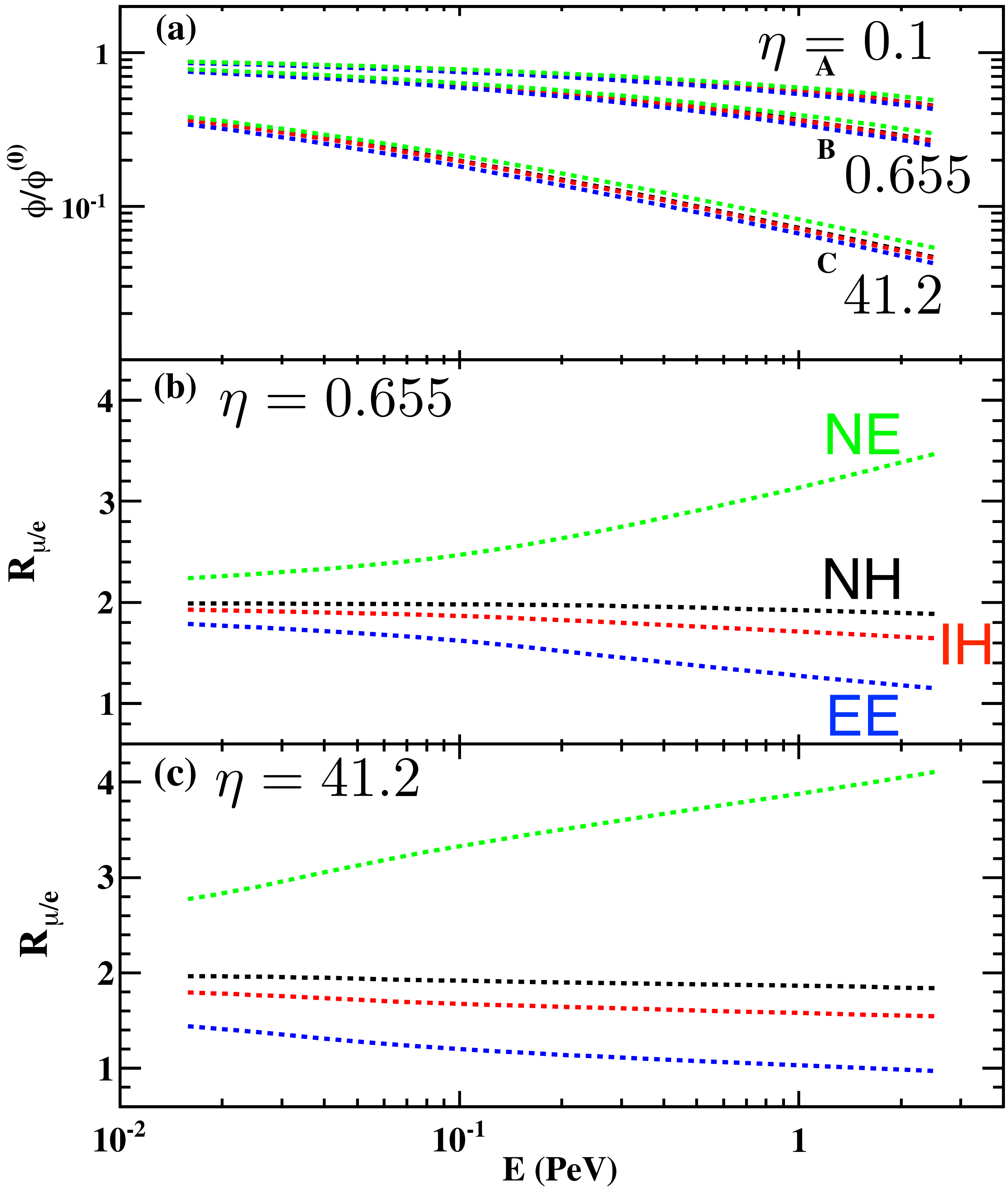
without annihilation

$$\phi^{(0)}_{\nu_e} : \phi^{(0)}_{\bar{\nu}_e} : \phi^{(0)}_{\nu_\mu} : \phi^{(0)}_{\bar{\nu}_\mu} = 1 : 1 : 2 : 2$$

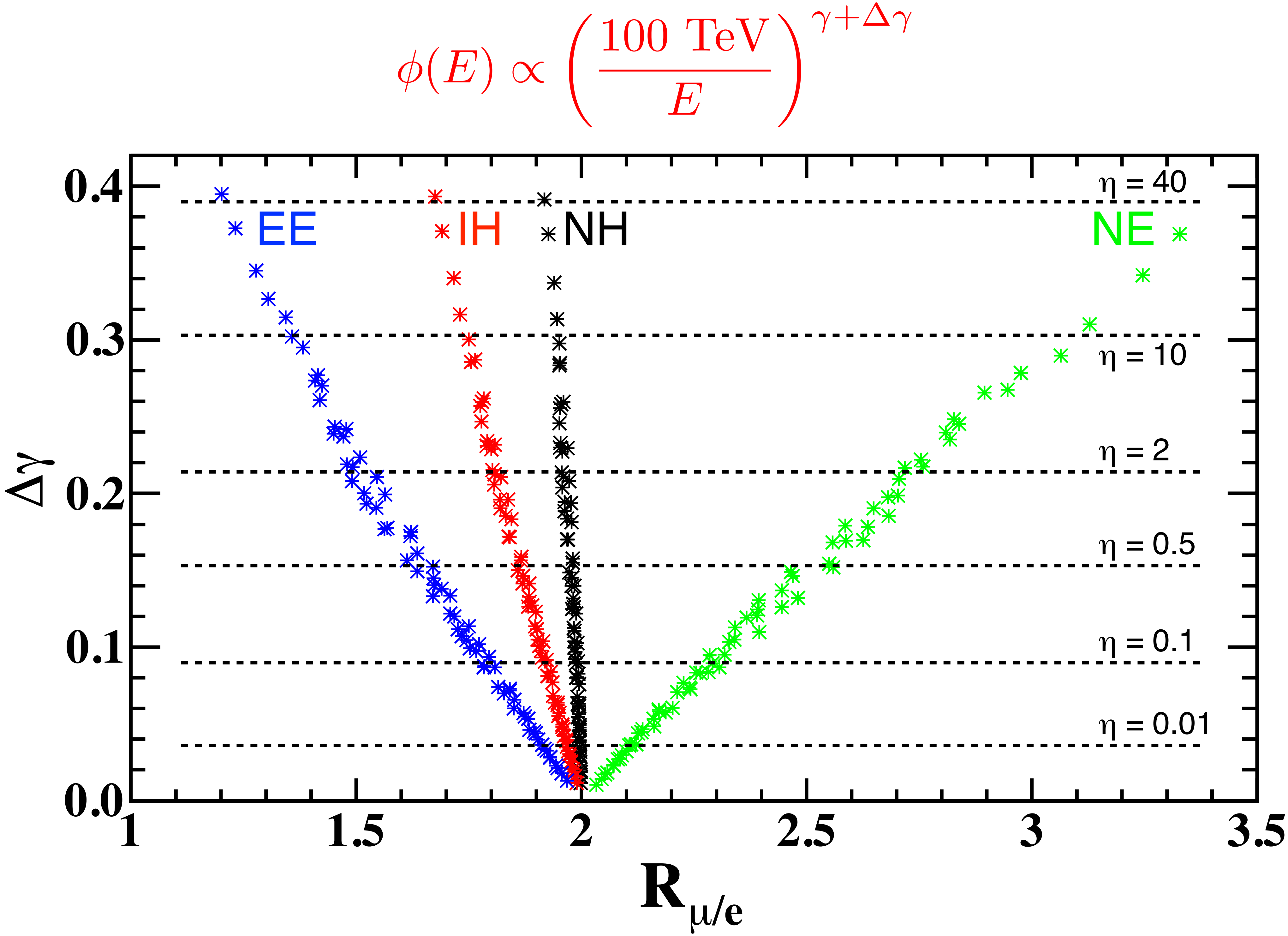
with annihilation

$$\frac{\phi}{\phi^{(0)}} = \frac{\langle P_{\nu_\mu}(E)\rangle + \langle P_{\bar{\nu}_\mu}(E)\rangle}{3} + \frac{\langle P_{\nu_e}(E)\rangle + \langle P_{\bar{\nu}_e}(E)\rangle}{6}$$

$$R_{\mu/e} = \frac{\phi_{\nu_\mu} + \phi_{\bar{\nu}_\mu}}{\phi_{\nu_e} + \phi_{\bar{\nu}_e}} = \frac{2[\langle P_{\nu_\mu}(E)\rangle + \langle P_{\bar{\nu}_\mu}(E)\rangle]}{\langle P_{\nu_e}(E)\rangle + \langle P_{\bar{\nu}_e}(E)\rangle}$$



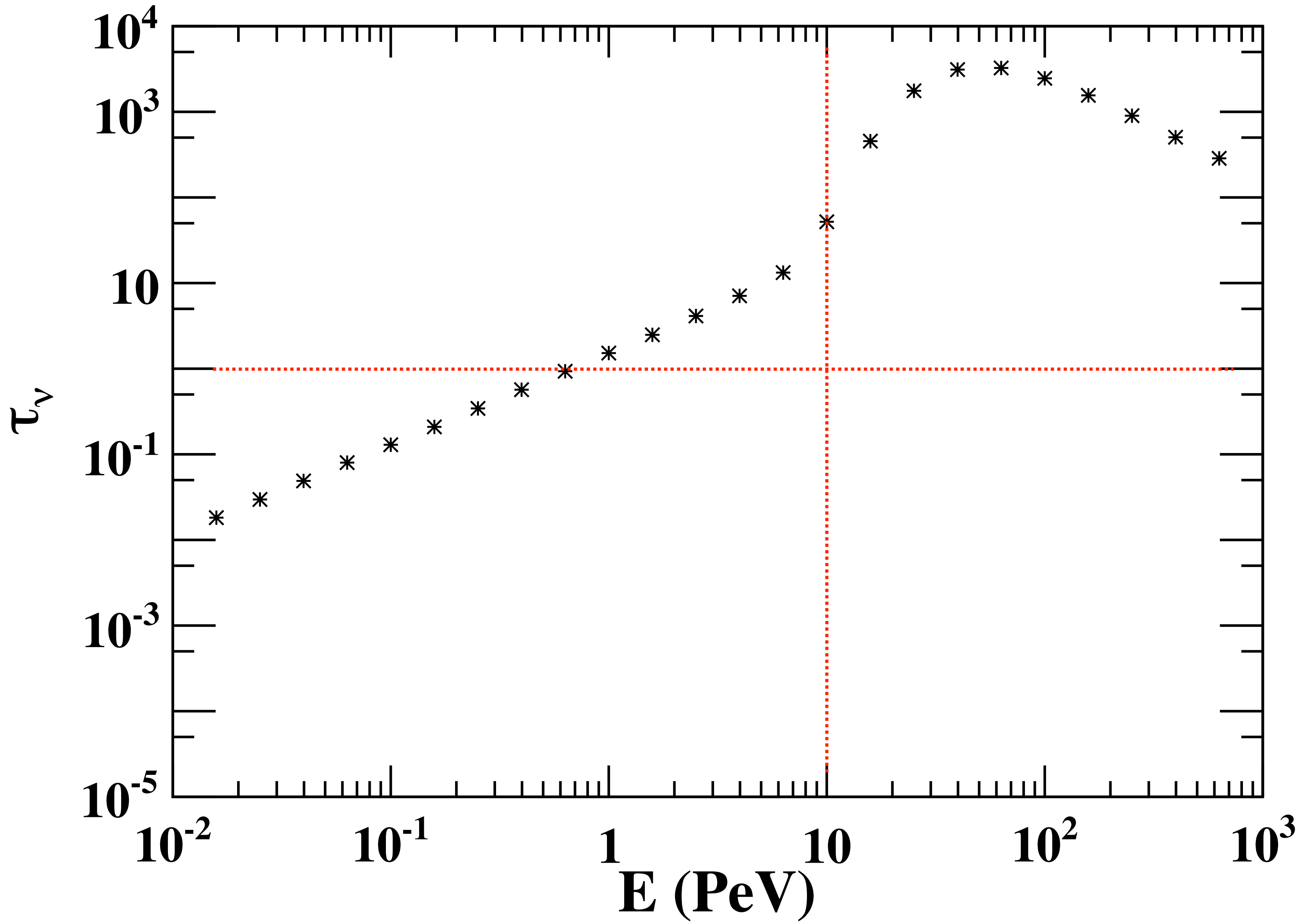
(a)
$\eta = 0.1$
A
B
0.655
C
41.2
$\phi/\phi^{(0)}$
1
10^{-1}
(b) $\eta = 0.655$
NE
NH
IH
EE
$R_{\mu/e}$
4
3
2
1
(c) $\eta = 41.2$
$R_{\mu/e}$
4
3
2
1
10^{-2}
10^{-1}
1
E (PeV)



$\phi(E) \propto \left(\frac{100\ \mathrm{TeV}}{E}\right)^{\gamma+\Delta\gamma}$
EE
IH
NH
NE
η = 40
η = 10
η = 2
η = 0.5
η = 0.1
η = 0.01
Δγ
$R_{\mu/e}$
0.0
0.1
0.2
0.3
0.4
1
1.5
2
2.5
3
3.5

Effect of Z Resonance

$$T_{\nu,\mathrm{MeV}} = 8, \;\; R_{\mathrm{sh},9} = 3, \;\; \theta_0 = 0.1$$



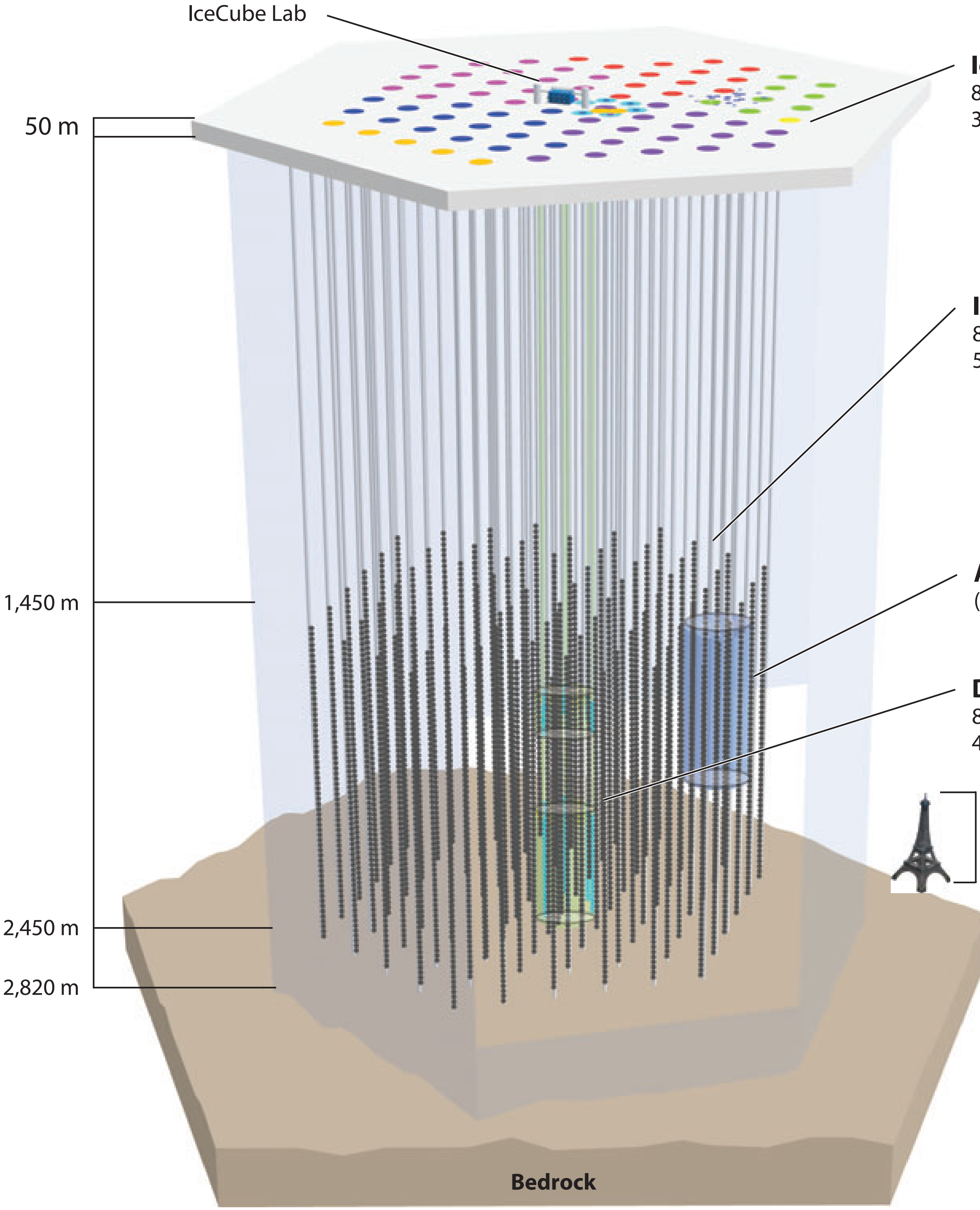
IceCube

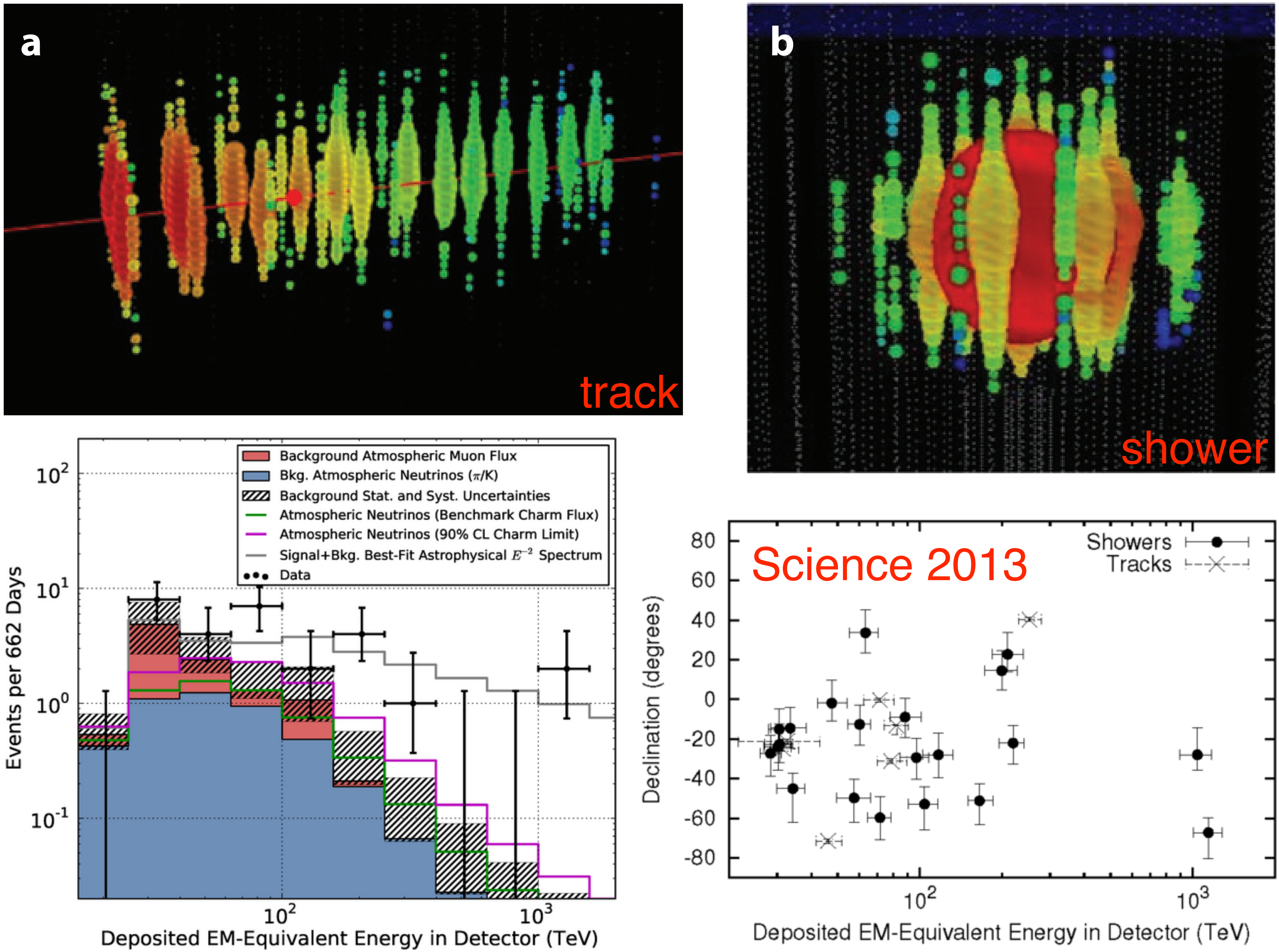
$$\nu_\mu + A \to \mu^- + A' + \cdots$$

$$\nu_e + A \to e^- + A' + \cdots$$

$$\nu_\tau + A \to \tau^- + A' + \cdots$$

$$\nu + A \to \nu' + A' + \cdots$$



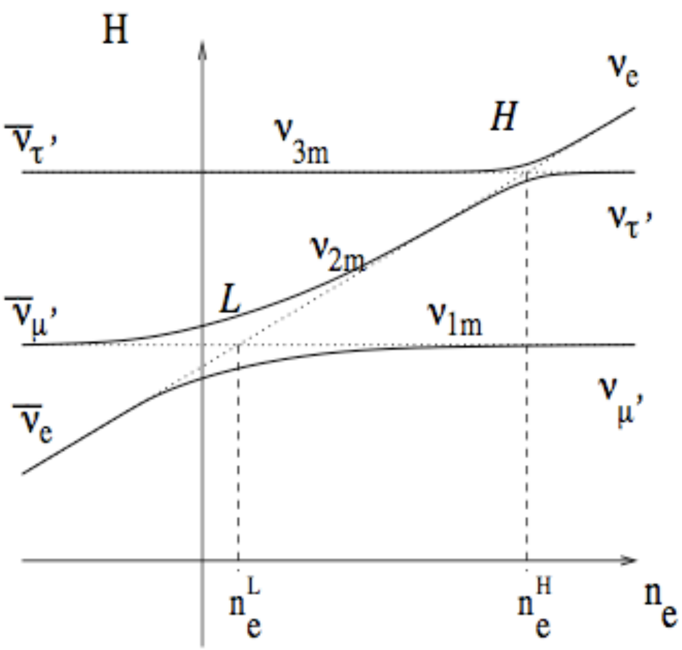


a
track
b
shower
Background Atmospheric Muon Flux
Bkg. Atmospheric Neutrinos (π/K)
Background Stat. and Syst. Uncertainties
Atmospheric Neutrinos (Benchmark Charm Flux)
Atmospheric Neutrinos (90% CL Charm Limit)
Signal+Bkg. Best-Fit Astrophysical E^{-2} Spectrum
Data
Events per 662 Days
10^2
10^1
10^0
10^{-1}
10^2
10^3
Deposited EM-Equivalent Energy in Detector (TeV)
Science 2013
Showers
Tracks
Declination (degrees)
80
60
40
20
0
-20
-40
-60
-80
10^2
10^3
Deposited EM-Equivalent Energy in Detector (TeV)

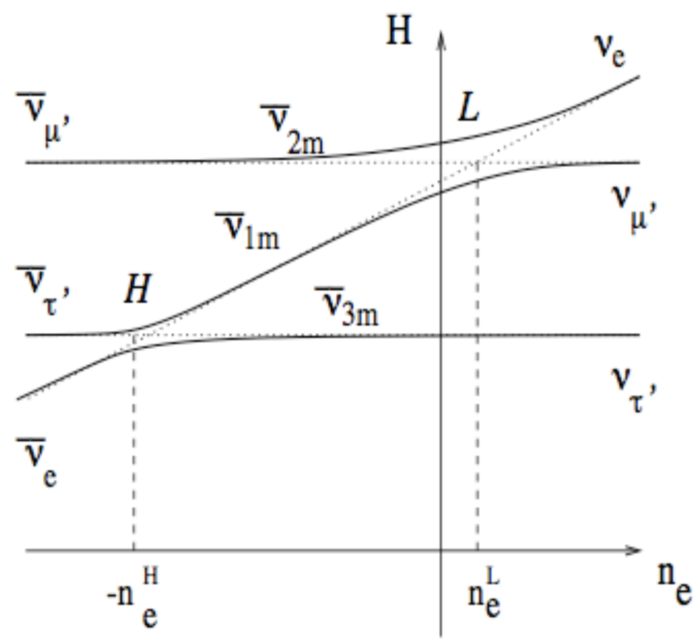
Neutrino Mixing in Vacuum

$$U_{\beta i} = \langle \nu_\beta | \nu_i \rangle, \; \bar{U}_{\beta i} = \langle \bar{\nu}_\beta | \bar{\nu}_i \rangle$$

Neutrino Flavor Evolution in Matter



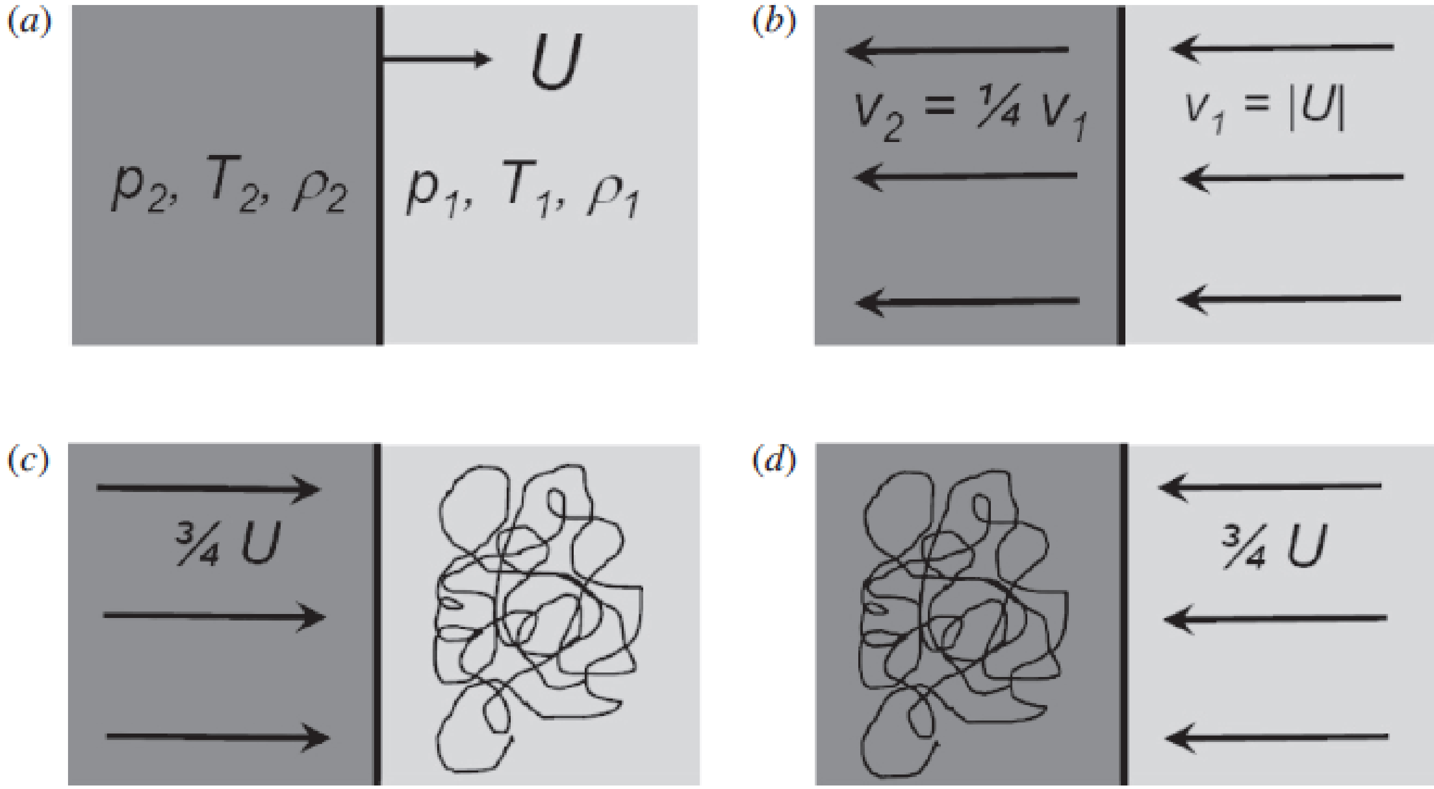
normal mass hierarchy



inverted mass hierarchy

In the pre-shock and post-shock reference frames

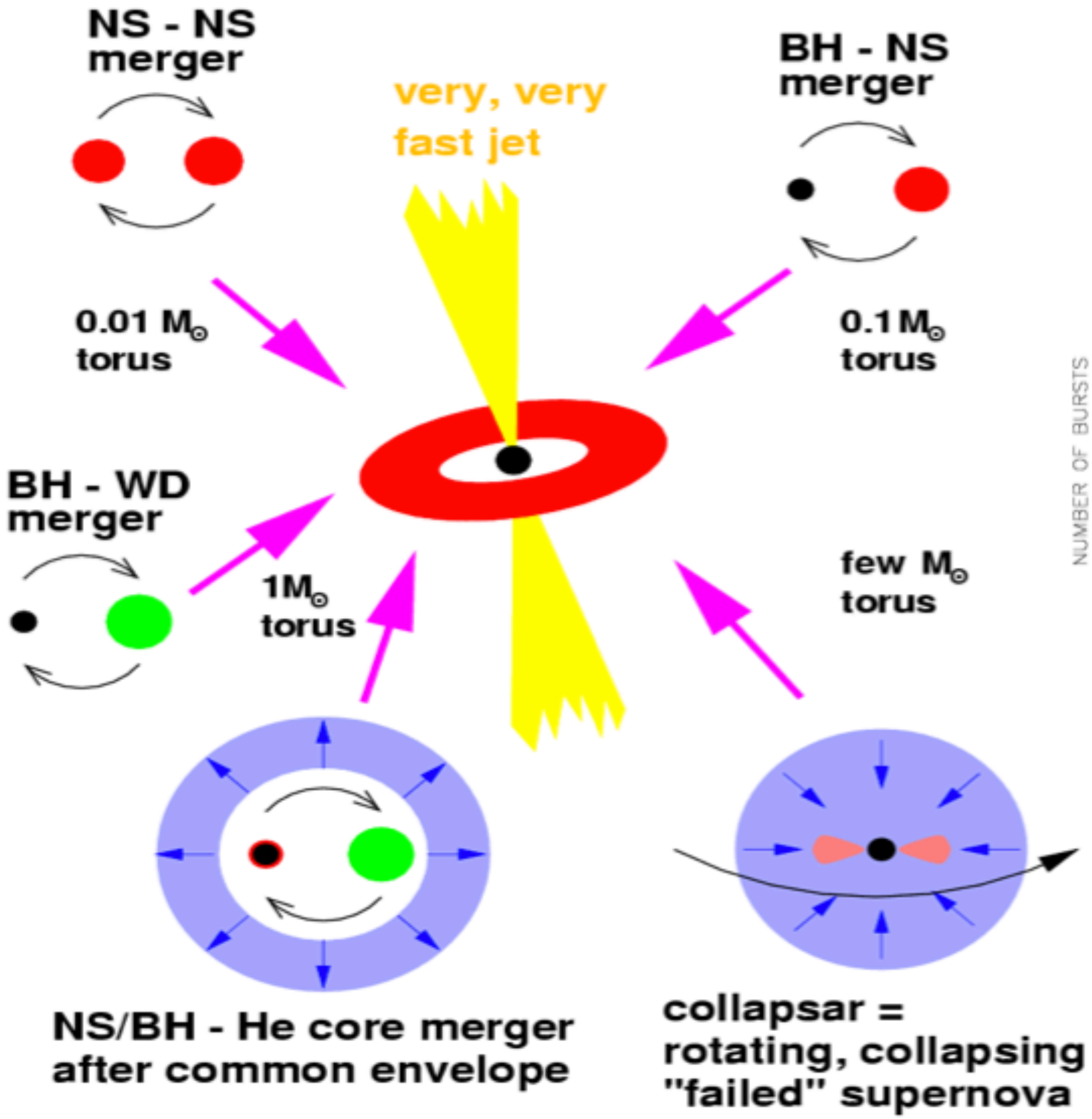
first order Fermi Acceleration



- (a) Observer's frame, (b) reference frame of shock, (c) upstream frame, (d) downstream frame
- When crossing the shock from either side, the particle sees plasma moving toward it at a velocity of $V \equiv \frac{3}{4}U$

GRB: standard paradigm

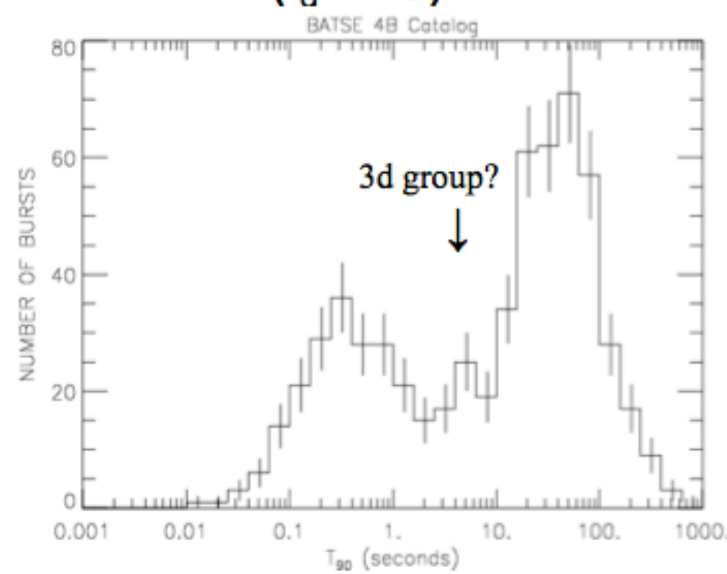
Hyperaccreting Black Holes



Bimodal distribution of t_{γ} duration

←↓**Short**

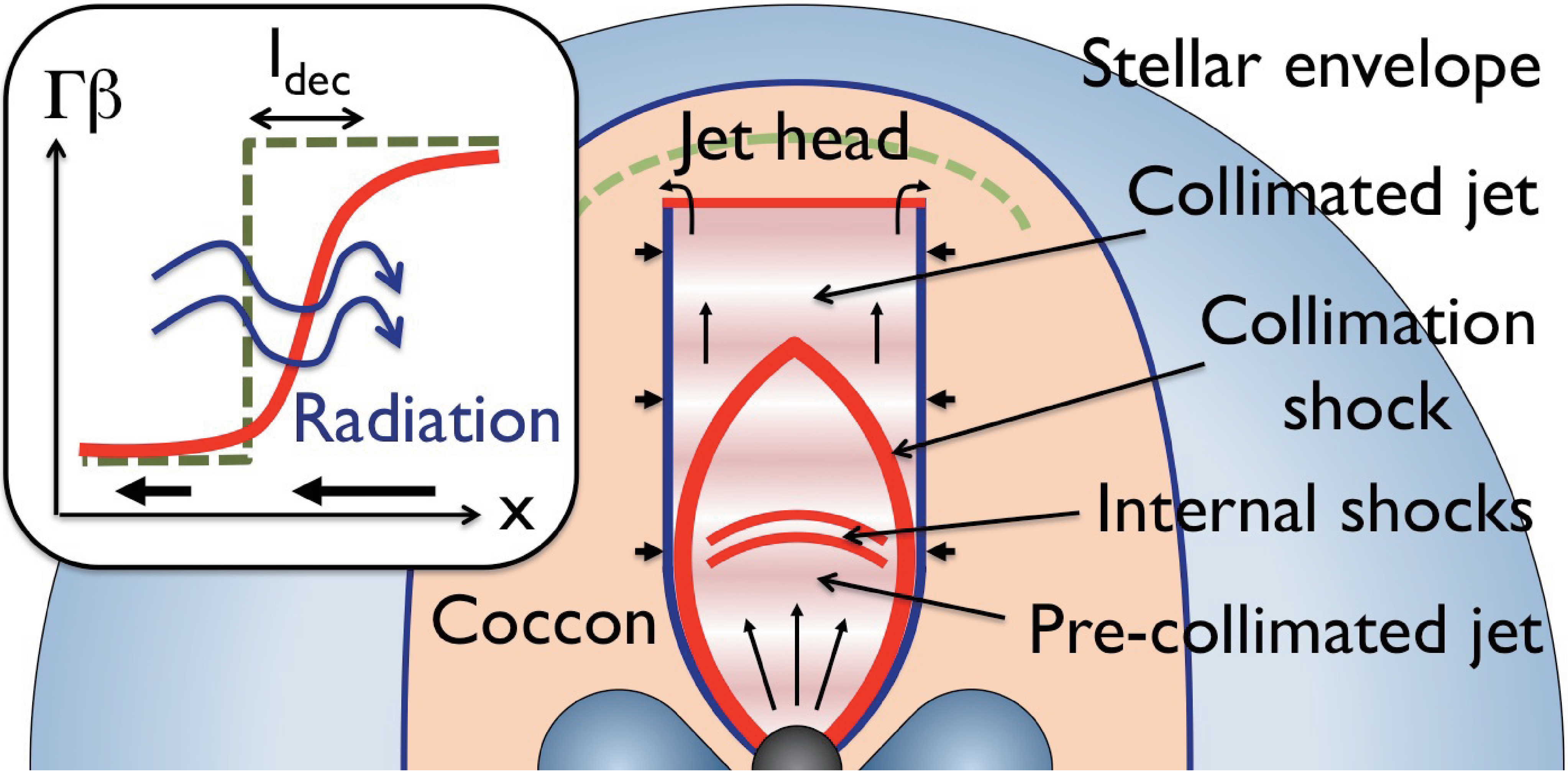
(t_g< 2 s)



→↑**Long**

(t_g >2 s)

Low-Power GRBs



Murase & Ioka 2013

Accretion Disk & Jets in Collapsars

MacFadyen & Woosley 1999