The Diffuse Supernova Neutrino Flux

Cecilia Lunardini
Institute for Nuclear Theory
University of Washington - Seattle

NOW2006 - Conca Specchiulla - 09/14/2006

Abstract

- Diffuse = integrated over sky
- O(1) question: Seen?
  - Not yet (limits)
  - BUT: *will be seen* at next generation detectors -> *transition to fast(er)-moving field*
- O(ε) question: *What can we learn?*
  - original ν spectrum? *YES! (decouple from cosmology)*
  - SN population (rate)? *..no.. (unlikely)*

Diffuse = integrated over whole sky $\sum_{\star} \Phi_\nu^{\star}$

$$\frac{d\Phi}{dE} = \frac{c}{H_0}\int_0^{z_{max}} R_{SN}(z) \sum_{w=e,\mu,\tau} \frac{dN_w(E')}{dE'} P_{we}(E,z) \frac{dz}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

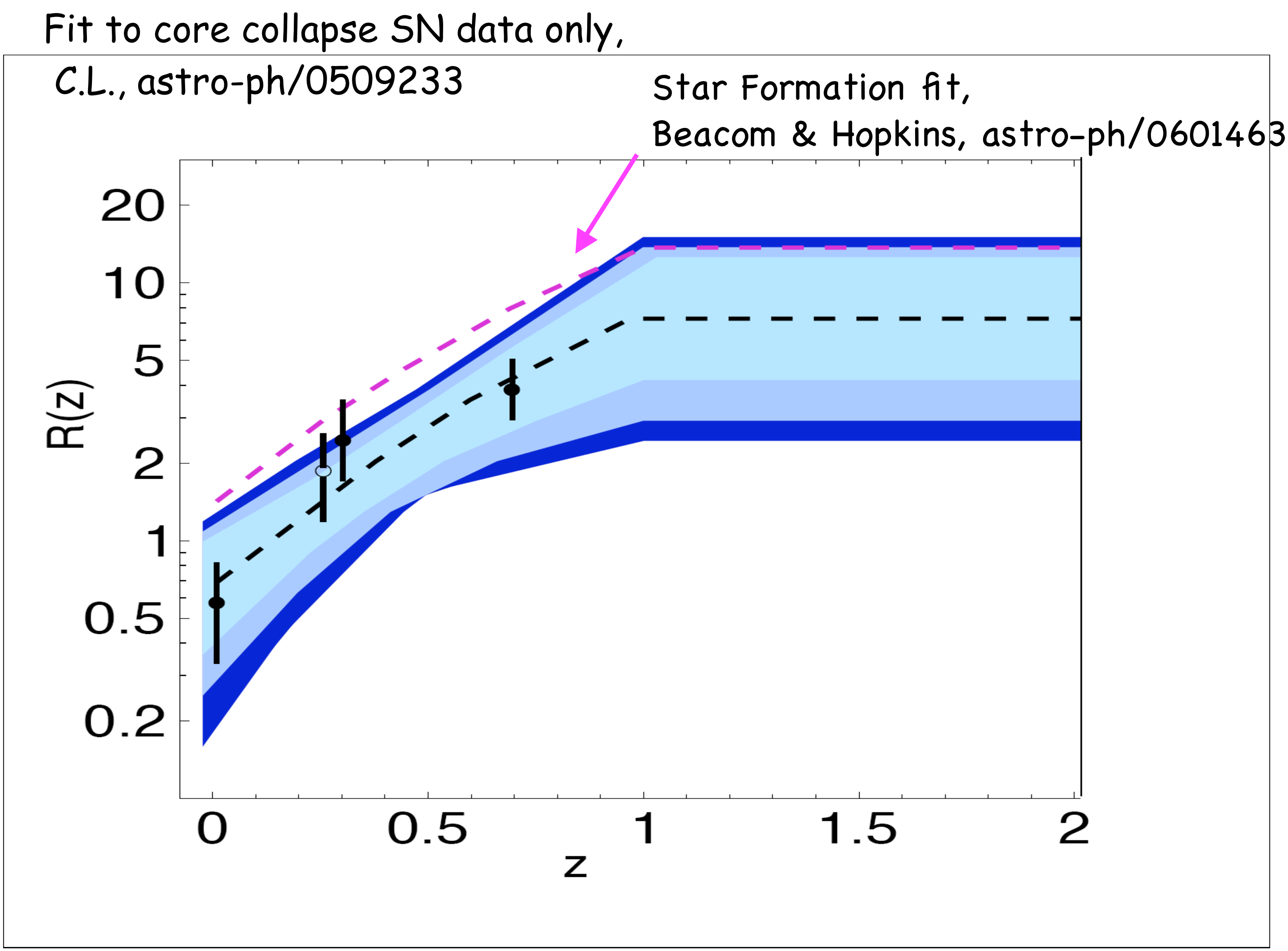
$$E' = (1+z)E$$

$$H_0 = 70\, Km/(s\cdot Mpc), \quad \Omega_m = 0.3, \quad \Omega_\Lambda = 0.7, \quad z_{max} \approx 5$$

- Cosmological SN rate: $R_{SN}(0) \sim 10^{-4}\ Mpc^{-3}yr^{-1}$

$$R_{SN}(z) = R_{SN}(0)\,(1+z)^\beta \qquad z<1, \beta \approx 3$$

$$= R_{SN}(0)\,2^\beta \qquad z>1$$



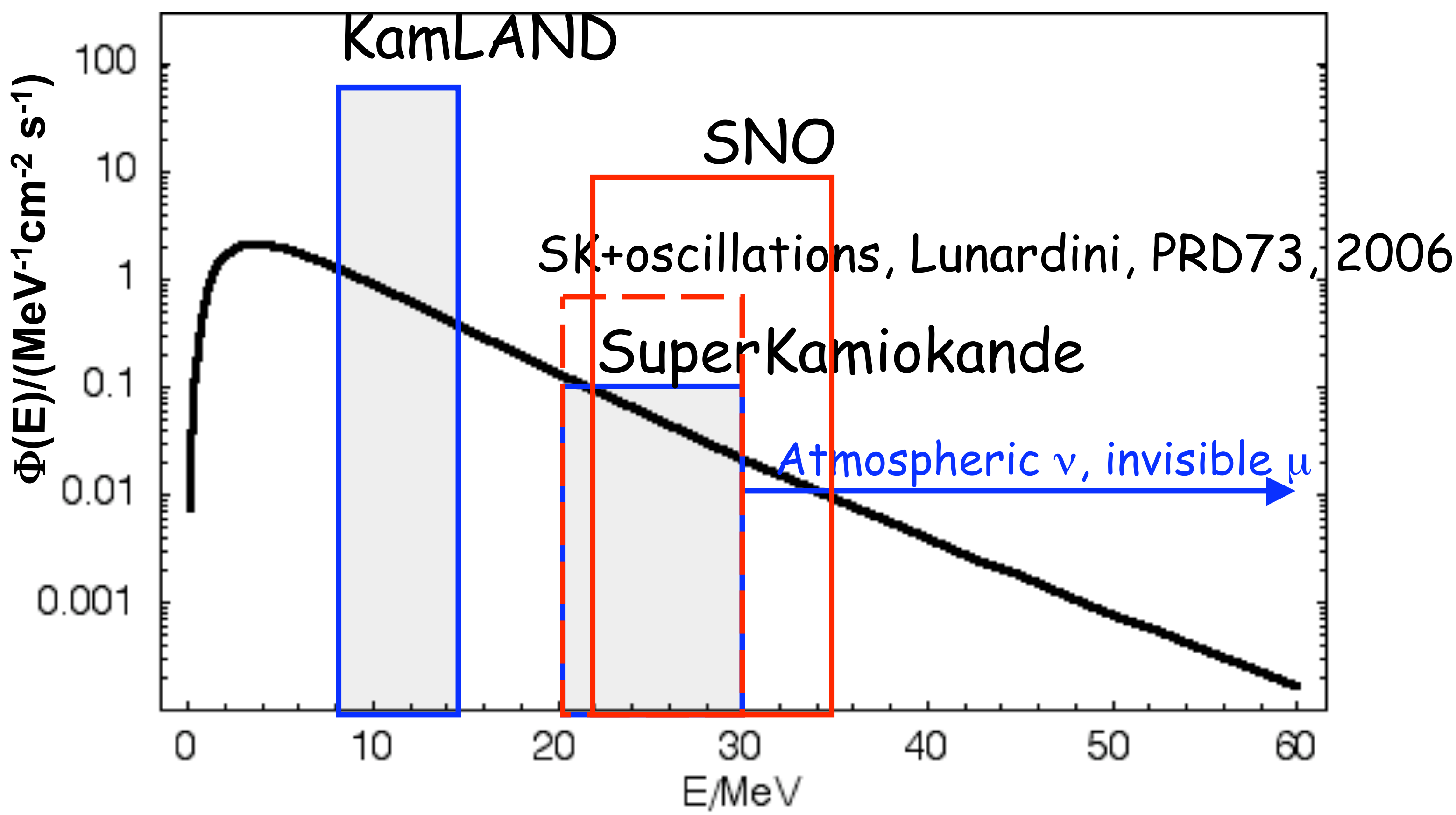
Fit to core collapse SN data only,
C.L., astro-ph/0509233
Star Formation fit,
Beacom & Hopkins, astro-ph/0601463
R(z)
20
10
5
2
1
0.5
0.2
0
0.5
1
1.5
2
z

- "Effective" neutrino spectrum *after oscillations:*
  - α ("pinching")~ 2-4 , E_0 ~ 12 - 20 MeV

$$\sum_{w=e,\mu\tau} \frac{dN_w}{dE} P_{we} \simeq \frac{(1+\alpha)^{1+\alpha} L}{\Gamma(1+\alpha) {E_0}^2} \left(\frac{E}{E_0}\right)^{\alpha} e^{-(1+\alpha)E/E_0}$$

SN1987A-motivated,
Mirizzi & Raffelt, PRD72, 2005

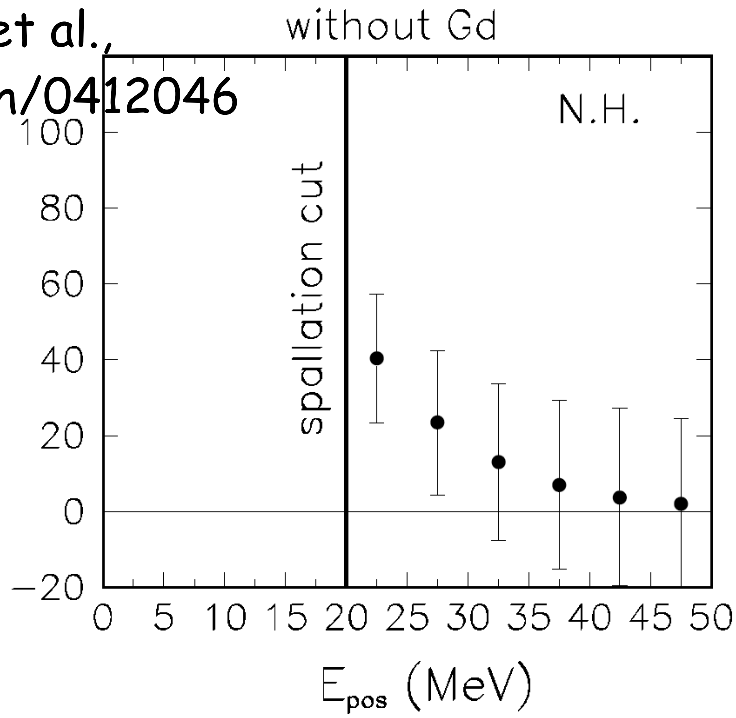
Seen? Not yet! Limits: anti-ν_e, ν_e



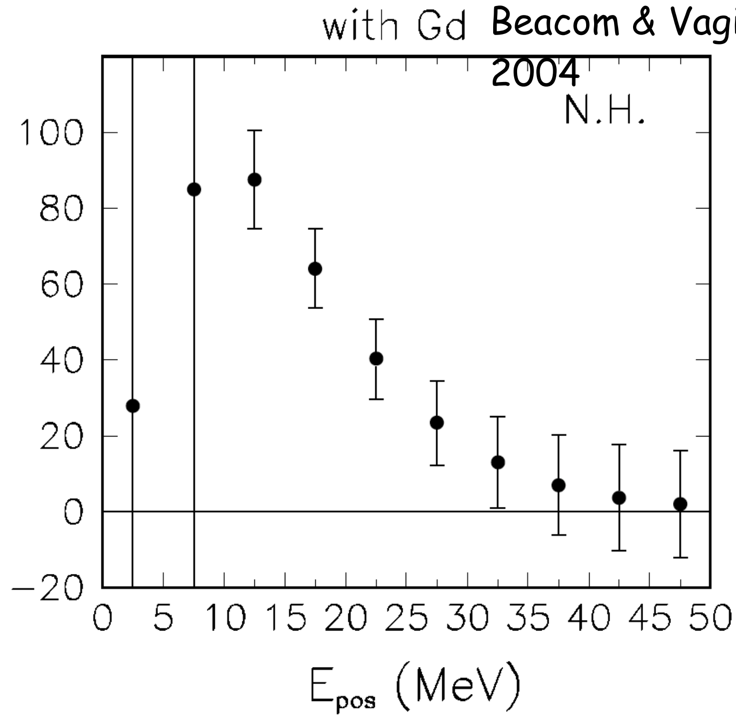
Zhang et al. (Kamiokande) PRL61, 1988; Eguchi et al. (KamLAND), PRL92, 2004; Malek et al. (SK), PRL90, 2003; Aharmim et al., (SNO), PRD70, 2004; Aglietta et al. (LSD), Astrop. Phys. 1, 1992, Aharmim et al., (SNO), hep-ex/0607010, 2006

BUT: will be seen at Mton (and/or Gd) detectors

Fogli et al., hep-ph/0412046



Beacom & Vagins, PRL93, 2004



- 0.4 Mt fiducial water, 4 years:
  - 7 - 60 events (most conservative) *C.L., astro-ph/0509233*

BUT: will be seen at Mton (and/or Gd) detectors

	UNO/HyperK: Water, 0.4 Mton fiducial, E_ν > 19.3 MeV	GADZOOKS Water+Gd, 20 Kt fiducial, E_ν>11.3 MeV
Anti-ν_e + p Events/4 yr (99% CL, from SN1987A)	7 - 60	1.1 - 6.4

Most conservative, C.L., astro-ph/0509233

See also Ando & Sato, New J. Phys., 2004; Fogli et al., JCAP, 2005; Marrodan Undagoitia et al., Prog. Part. Nucl. Phys. 57, 2006 ; Cocco et al. JCAP 0412:002,2004

What can we learn?

- Spectrum of e^+:
  - E_0 , α ("pinching"), β (SNR power)
- Number of e^+ events:
  - L_e , $R_{SN}(0)$, E_0, α , β

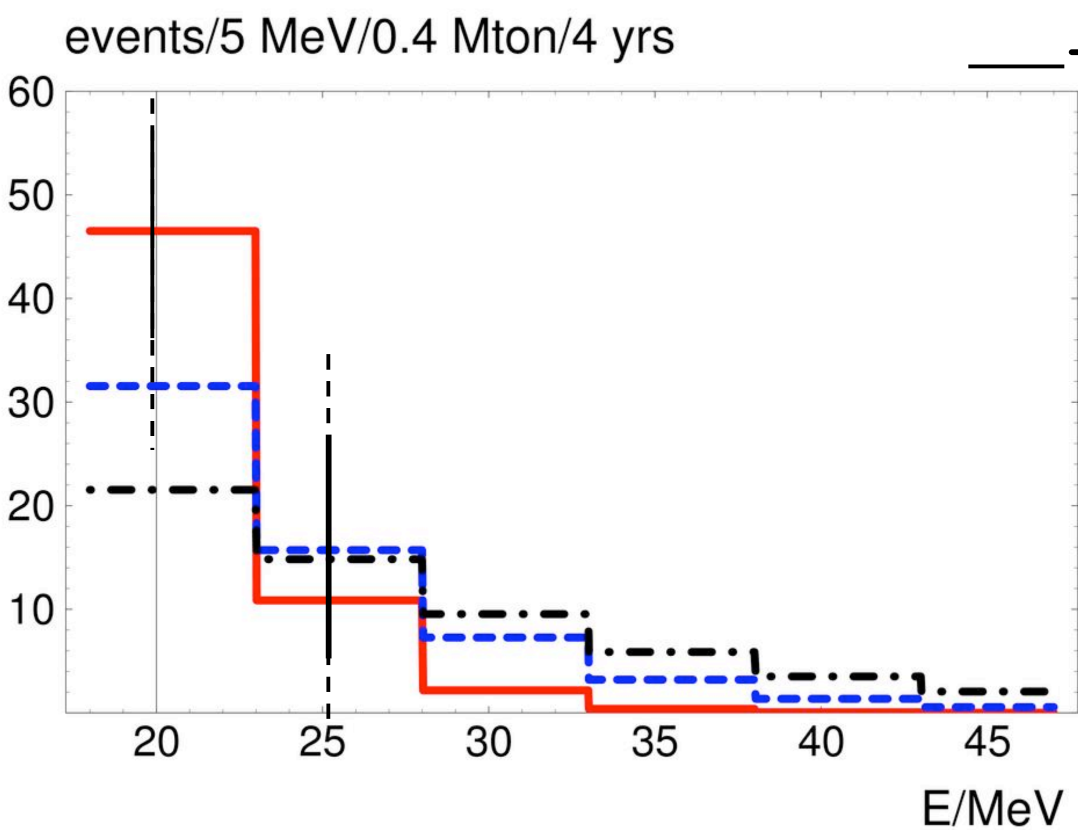
Original ν spectrum? YES!

C.L., in preparation

Normalized to 60 events, β=3.28

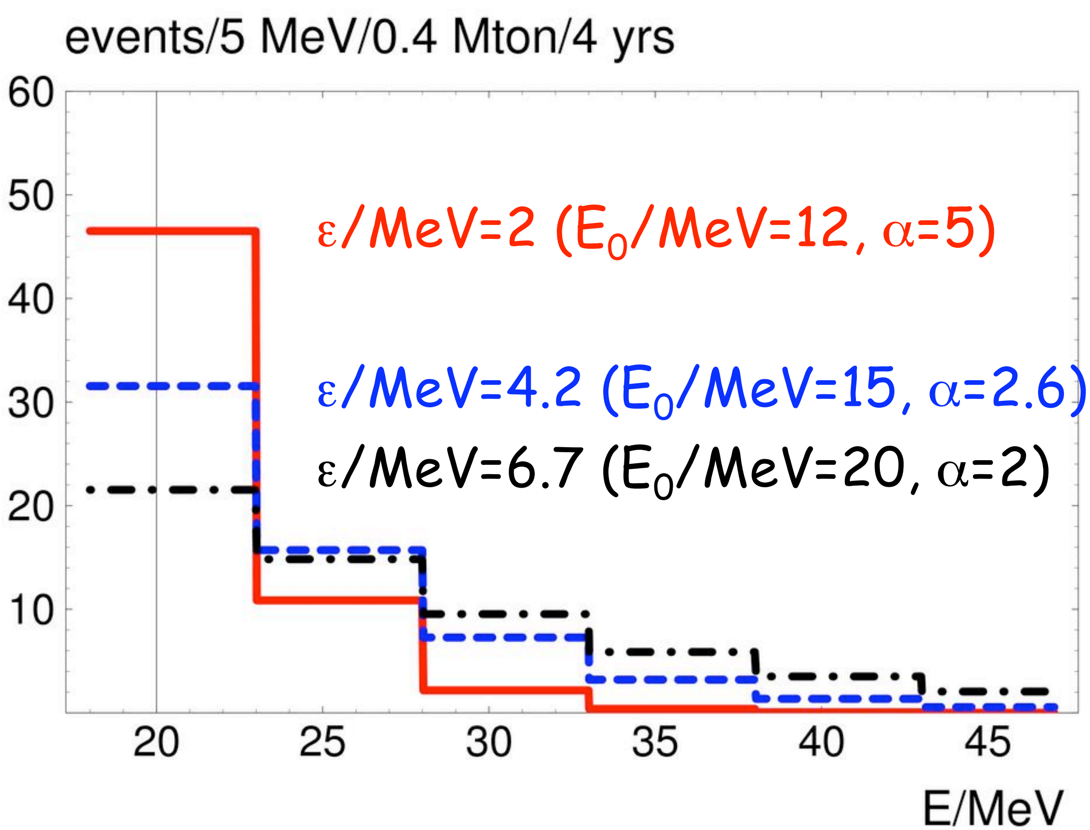
----Total error, no Gd

——Total error, with Gd



Original ν spectrum? YES!

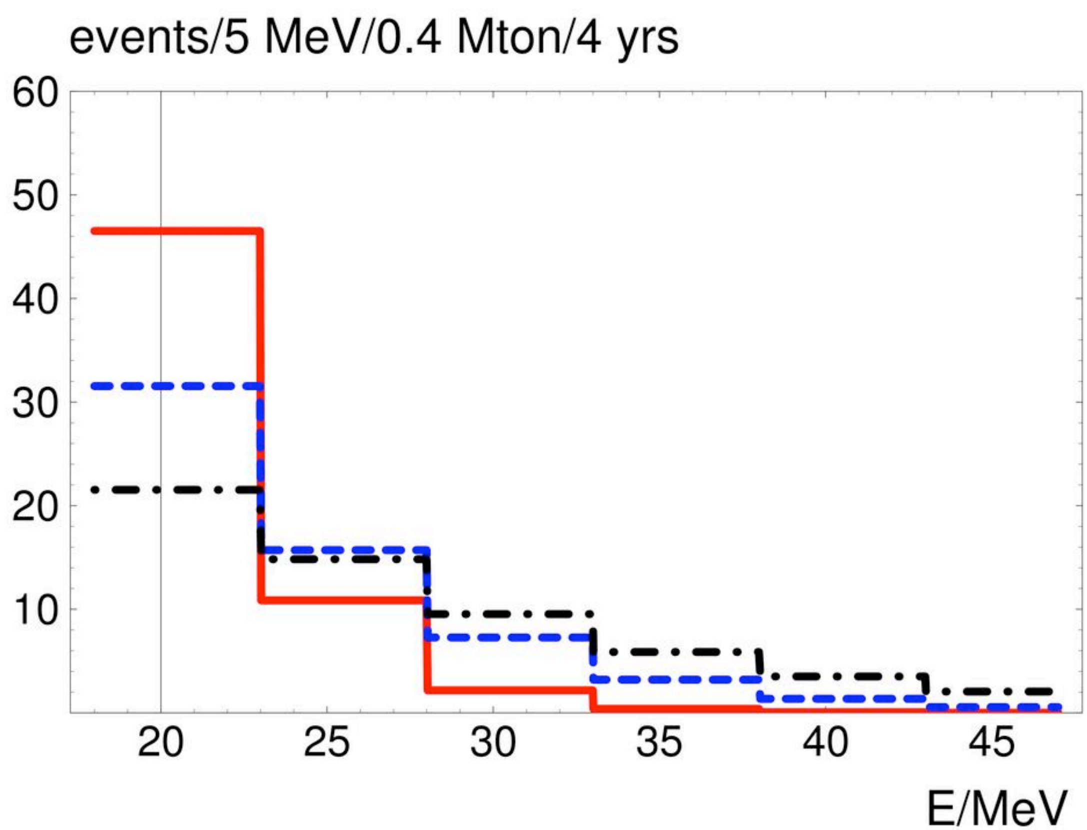
Normalized to 60 events, β=3.28



- **Depends on $\varepsilon = E_0/(1+\alpha)$**

Original ν spectrum? YES!

Normalized to 60 events, β=3.28

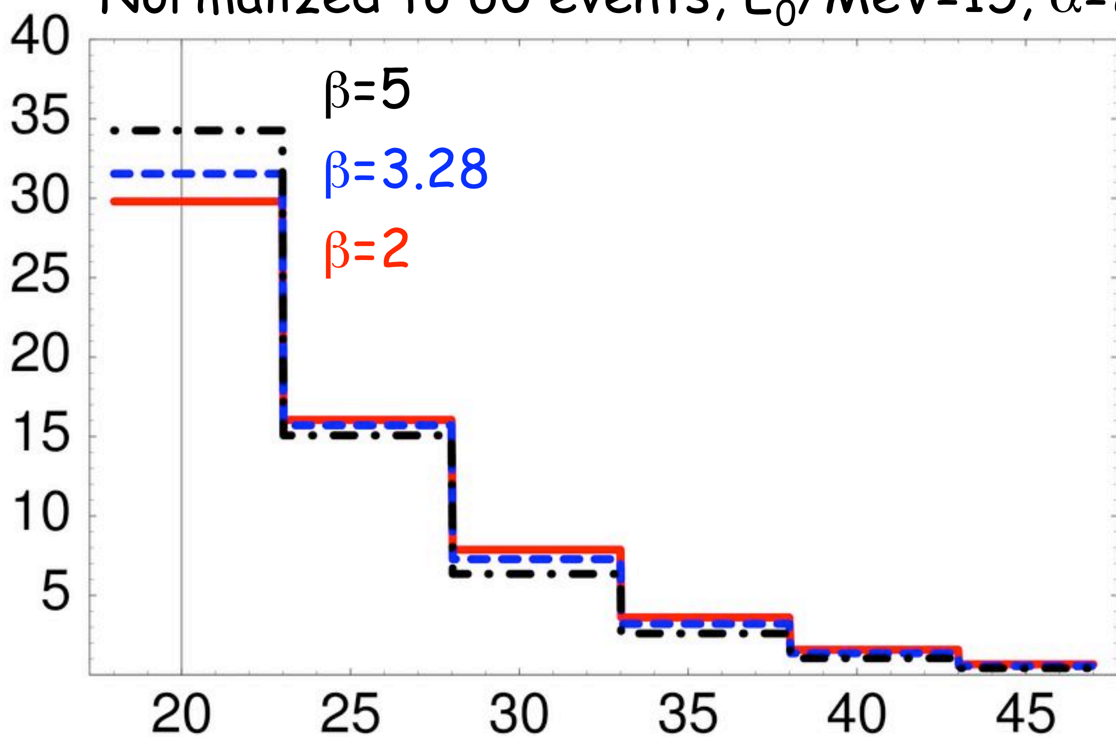


- Useful observable: first bin/rest of data

$$\frac{N(18MeV<E<23MeV)}{N(E>23MeV)} \sim 0.5-5$$

SN population? ..no..

Normalized to 60 events, E_0/MeV=15, α=2.6



To understand: analytics

$$\frac{d\Phi}{dE} = \frac{c}{H_0}\int_0^{z_{\max}} R_{SN}(z) \sum_{w=e,\mu,\tau} \frac{dN_w(E')}{dE'} P_{we}(E,z) \frac{dz}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

$$\sum_{w=e,\mu\tau} \frac{dN_w}{dE} P_{we} \simeq \frac{(1+\alpha)^{1+\alpha} L}{\Gamma(1+\alpha) {E_0}^2} \left(\frac{E}{E_0}\right)^{\alpha} e^{-(1+\alpha)E/E_0}$$

- Approximations: dominated by z<1 at high energy (redshift):
  - $R_{SN}=0$ z>1
  - z<<1 & $\Omega_m + \Omega_\Lambda = 1$:

$$\left[\Omega_m(1+z)^3 + \Omega_\Lambda\right]^{-1/2} \simeq (1+z)^{-\frac{3}{2}\Omega_m}$$

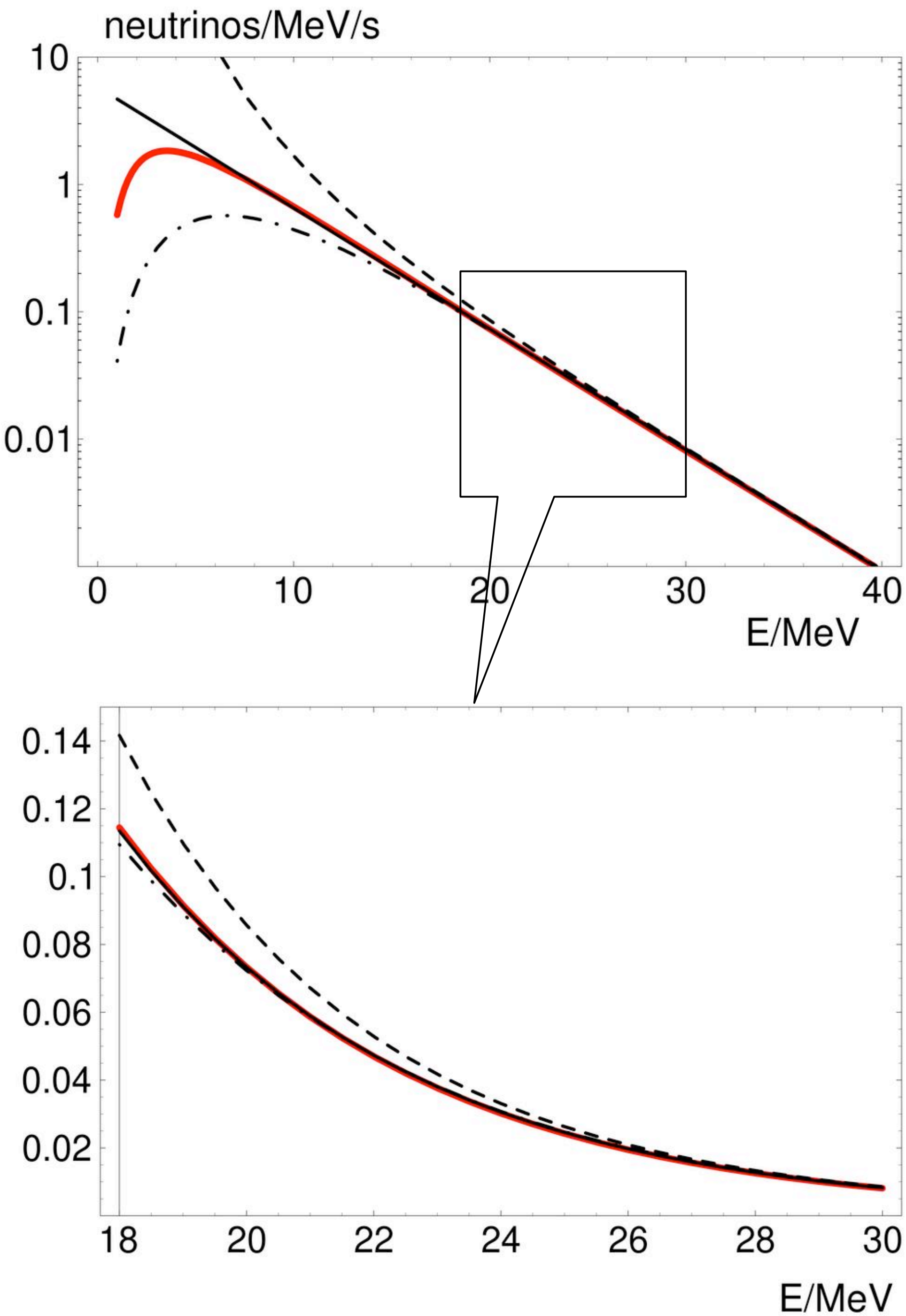
- Result: $\eta = \alpha + \beta - (3/2)\Omega_m$, $z_{max}=1$

$$\Phi_e = R_{SN}(0)\frac{c}{H_0}\frac{(1+\alpha)^{1+\alpha}L}{\Gamma(1+\alpha){E_0}^2}(-)\left(\frac{E}{E_0}\right)^{-1-\beta+3\Omega_m/2}\Gamma[\eta+1,y]\Bigg|_{y=(1+\alpha)\frac{E}{E_0}}^{y=(1+\alpha)(1+z_{max})\frac{E}{E_0}}$$

- Cruder : neglect upper integration limit
  - $\varepsilon = E_0/(1+\alpha)$, *$\beta$ only in the polynomial part!*

$$\begin{aligned}\Phi_e &= R_{SN}(0)\frac{c}{H_0}\frac{L}{\Gamma(2+\alpha)\epsilon^2}\,e^{-\frac{E}{\epsilon}} \\ &\times\left[\left(\frac{E}{\epsilon}\right)^{\alpha-1}+\eta\left(\frac{E}{\epsilon}\right)^{\alpha-2}+\eta(\eta-1)\left(\frac{E}{\epsilon}\right)^{\alpha-3}+\ldots\right]\end{aligned}$$

- Crudest: "fitted" exponential: $\Phi = \Phi_0\, e^{-E/\langle E\rangle}$



$R(0)=10^{-4}$ $Mpc^{-1}yr^{-1}$, $L_e=5\ 10^{52}$ ergs, β = 3.28 , α=2.6 E_0 =15 MeV

- Exact
- Result
- Cruder (20% accuracy above 20 MeV)
  - neglect upper integration limit
- Crudest
  - "fitted" exponential

Number of events add information

$R(0)=10^{-4}$ $Mpc^{-1}yr^{-1}$, $L_e=5\ 10^{52}$ ergs, 0.4 Mt, 4 yr, $E_{th}=18$ MeV

$\beta=3.28$	$E_0/MeV=11$	$E_0/MeV=15$	$E_0/MeV=20$
$\alpha=2$	21.6	71.6	163
$\alpha=4$	7.4	37.5	110

$\varepsilon \sim 7$

$\beta=5$	$E_0/MeV=11$	$E_0/MeV=15$	$E_0/MeV=20$
$\alpha=2$	34	129	326
$\alpha=4$	10	59	200

Conclusions: likely scenario

- Gadzooks and/or LENA and/or HyperK/UNO/MEMPHYS will see the DF
- β known from SN surveys (SNAP, JWST)

  http://snap.lbl.gov/
  http://www.jwst.nasa.gov/,

- DF spectrum -> $\varepsilon = E_0/(1+\alpha)$
  - Test of SN numerical models

- DF number of events -> break degeneracy between E_0, α, L_ν, $R_{SN}(0)$