Benchmark Parameters for Future km3 Detectors

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VLVNT Workshop Amsterdam
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- According to which physics goals should a km3 detector be optimized ?
- According to which physics goals should a site selection be made ?
- Which benchmark parameters should be used to judge the performance (into which parameters should the performance be „casted“?)

Main physics goals proposed as basis for benchmarking procedure

→ Point source search (excluding WIMPs) **+**
- steady sources ? **+**
- transient sources **-**
- muons **+**
- cascades **-**
- energy range **?**

→ WIMPs
- Earth WIMPs not competitive with direct searches **-**
- Solar WIMPs **+**
- energy range go as low as possible

Main physics goals proposed as basis for benchmarking procedure (cont‘d)

→ Atm.neutrino oscillations -

- not competitive with SK & K2K if not the spacing is made unreasonably small
- nested array a la NESTOR 7-tower ?
- proposal: → no optimization goal
  → no benchmark goal

→ Oscillation studies with accelerators -

- too exotic to be included now

Main physics goals proposed as basis for benchmarking procedure (cont'd)

→ Diffuse fluxes

- muons up and down **+**
- cascades **+**

→ Others

- downgoing muons
  - → physics **-**
  - → calibration **?**
- monopoles **-**
- slowly moving particles **-**
- ...

Benchmark Parameters

Eff area / volume after bg rejection $A_{eff\text{-}bg}(E)/V_{eff\text{-}bg}(E)$

Angular resolution after bg rejection angres(E)

Energy resolution after bg rejection delta E(E)

Eff area / volume after cuts yielding the best sensitivity $A_{eff\text{-}s}(E) / V_{eff\text{-}s}(E)$

Time

Average upper flux limit & sensitivity

90% C.L. interval $m_{90} = \langle m_1, m_2 \rangle$

is a function of number of observed events n_{obs} and of expected background n_b

$$m_{90}(n_{obs}, n_b)$$

Feldman-Cousins sensitivity (average upper event limit) for no true signal ($n_s = 0$)

$$\overline{m}_{90}(n_b) = \sum_{n_{obs}=0}^{\infty} m_{90}(n_{obs}, n_b) \frac{(n_b)^{n^{obs}}}{(n_{obs})!} \exp(-n_b)$$

Minimize „model rejection factor“ $mrf = \frac{\bar{m}_{90}}{n_s}$

and hence the **average upper flux limit**

$$\boxed{\Phi(E,\Theta)_{90} = \Phi(E,\Theta) \cdot \bar{m}_{90} / n_s}$$

→ 90% C.L. exclusion limit ?

→ 5σ detection sensitivity ?

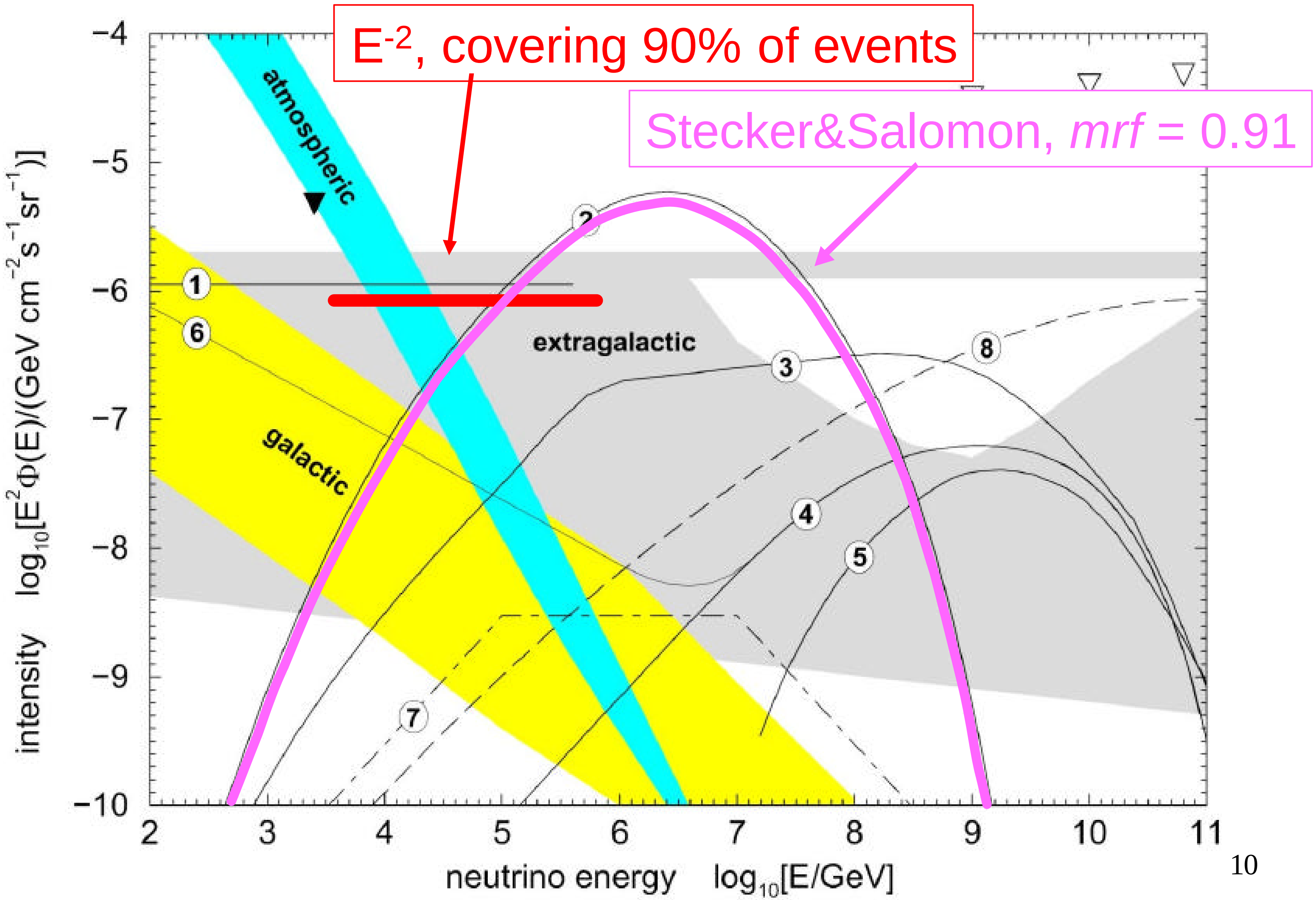
→ for which models ?

→ for which time - 3 years, 5 years ?

How to present energy dependence of limits ? Integral, quasi-differential, differential ?

- E^{-2} line extending over range which contains 90% of events expected
- Limits on specific models (giving *model rejection factor, mrf*)
- Envelope to series of benchmark models
- Greens function
- differential limit per decade

Integral Limits



Quasi-Differential Limits

1. Envelope along a series of benchmark spectra

e.g. E^{-1} with an exponential cut-off (like MPR did for their limit)

$$F \approx \exp(E / E_{\max}) \cdot E^{-1}$$

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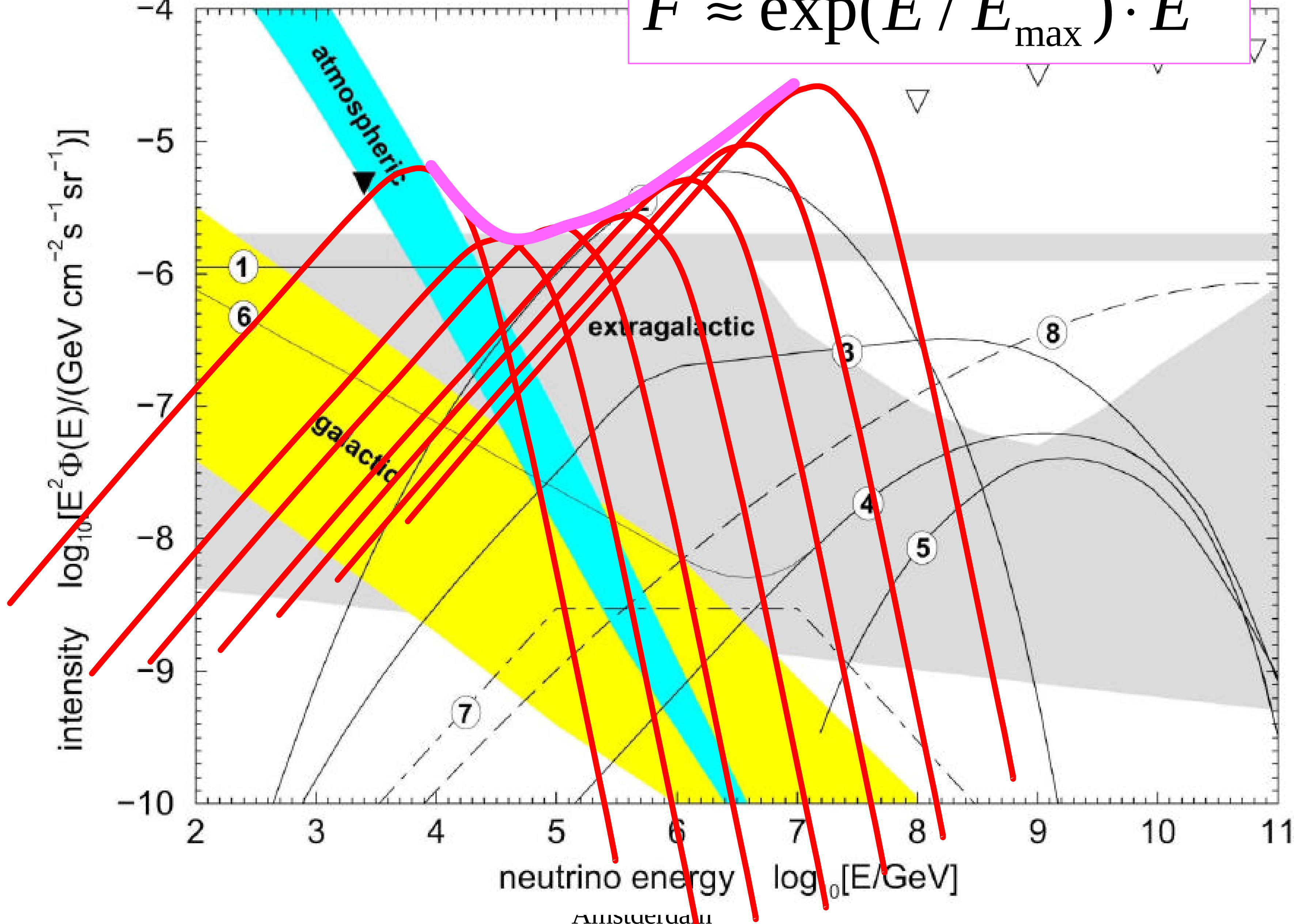
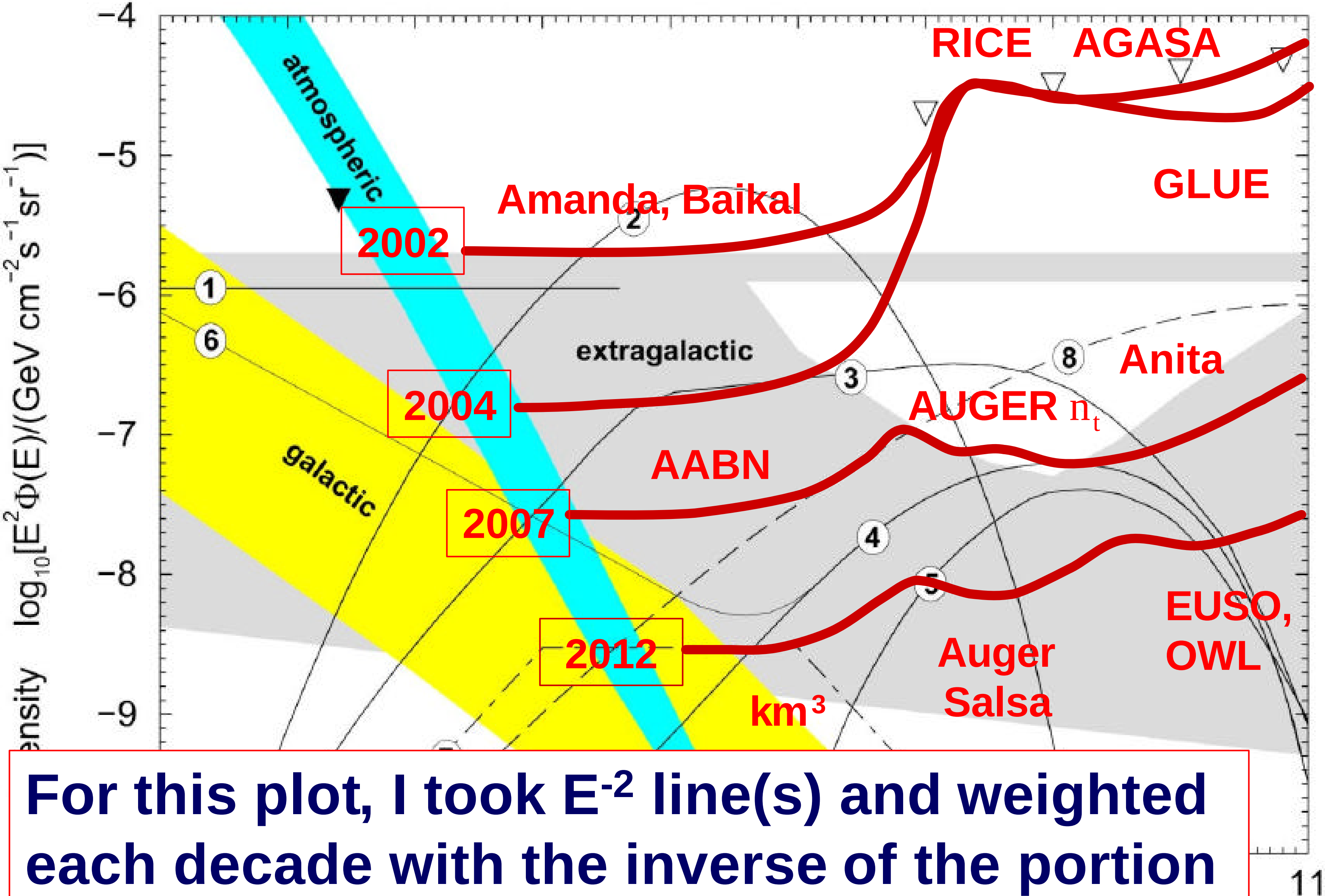


Advantages:

- shape not so far from „typical“ spectra
- gives a realistic impression how a model peaking at that energy would be constrained (gives *mrf* within < factor 2 except for exotic models
- easy, agreeable as standard

Disadvantages:

- artificial spectrum



For this plot, I took E^{-2} line(s) and weighted each decade with the inverse of the portion of E^{-2} events falling into this decade.

Green‘s Function Approach

(see Lehtinen et al, astro-ph/0309656 , also Fukuda et al, SK, astro-ph/0205304)

Be $\lambda(E)$ the expected number of events for unit monoenergetic flux at different energies *E.*

Expected number of events for differential flux $\Phi(E)$ is

$$n_{\exp} = \int l\,(E) \cdot \Phi(E)\, dE$$

No events detected, no background:

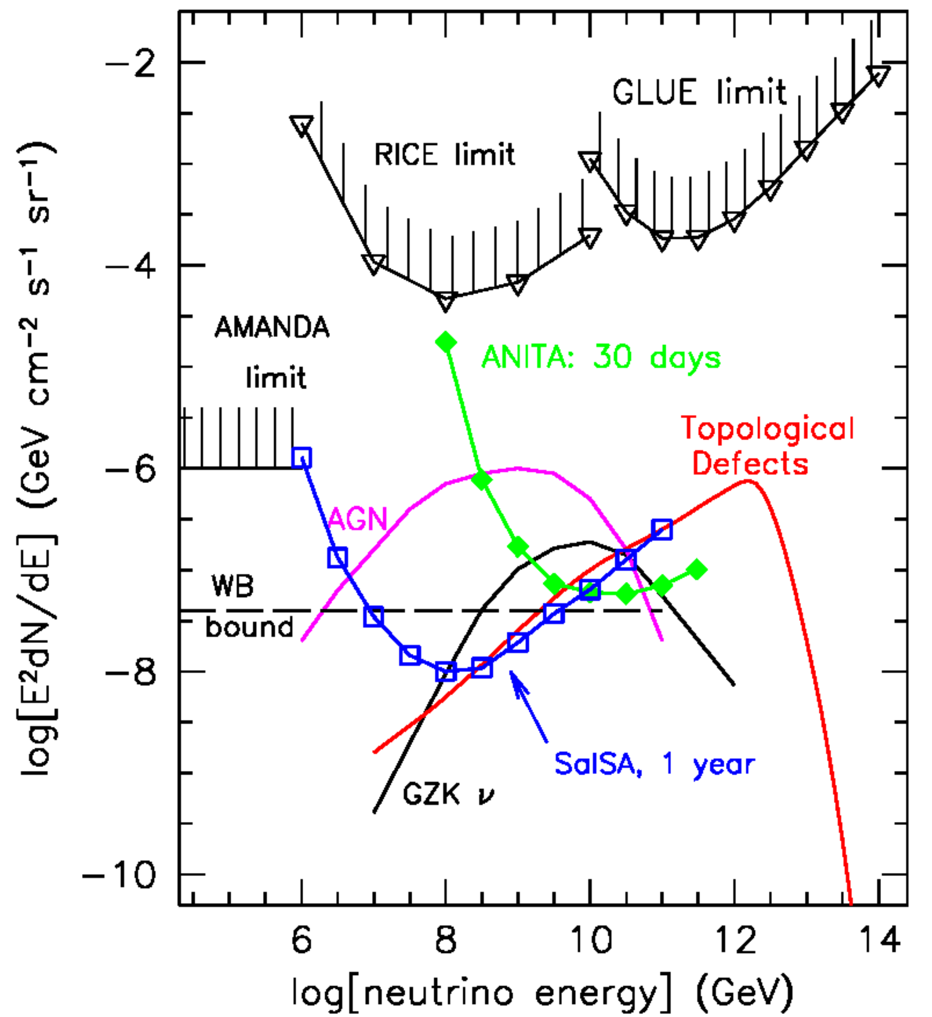
$$\int l\,(E) \cdot \Phi(E)\, dE \leq 2.4 = m_{90}$$

Green's Function Approach (cont'd)

$$\Phi(E_n) \le \frac{m_{90}}{E_n \cdot l(E_n)}$$

Anita limit for 30 days.
Green's function limit
(is about factor 2.3 above
the decadal limit as
used by Kowalski /Auger)

from a 2002-talk
of Peter Gorham



Green‘s function: advantages and drawbacks

Advantages:

- Really differential information
- Allows everybody to convolute with his/her own spectrum
- Could be the „exchange format“ for limits between different experiments

Drawback:

- Not so intuitive like other methods

Decadal limit (M. Kowalski)

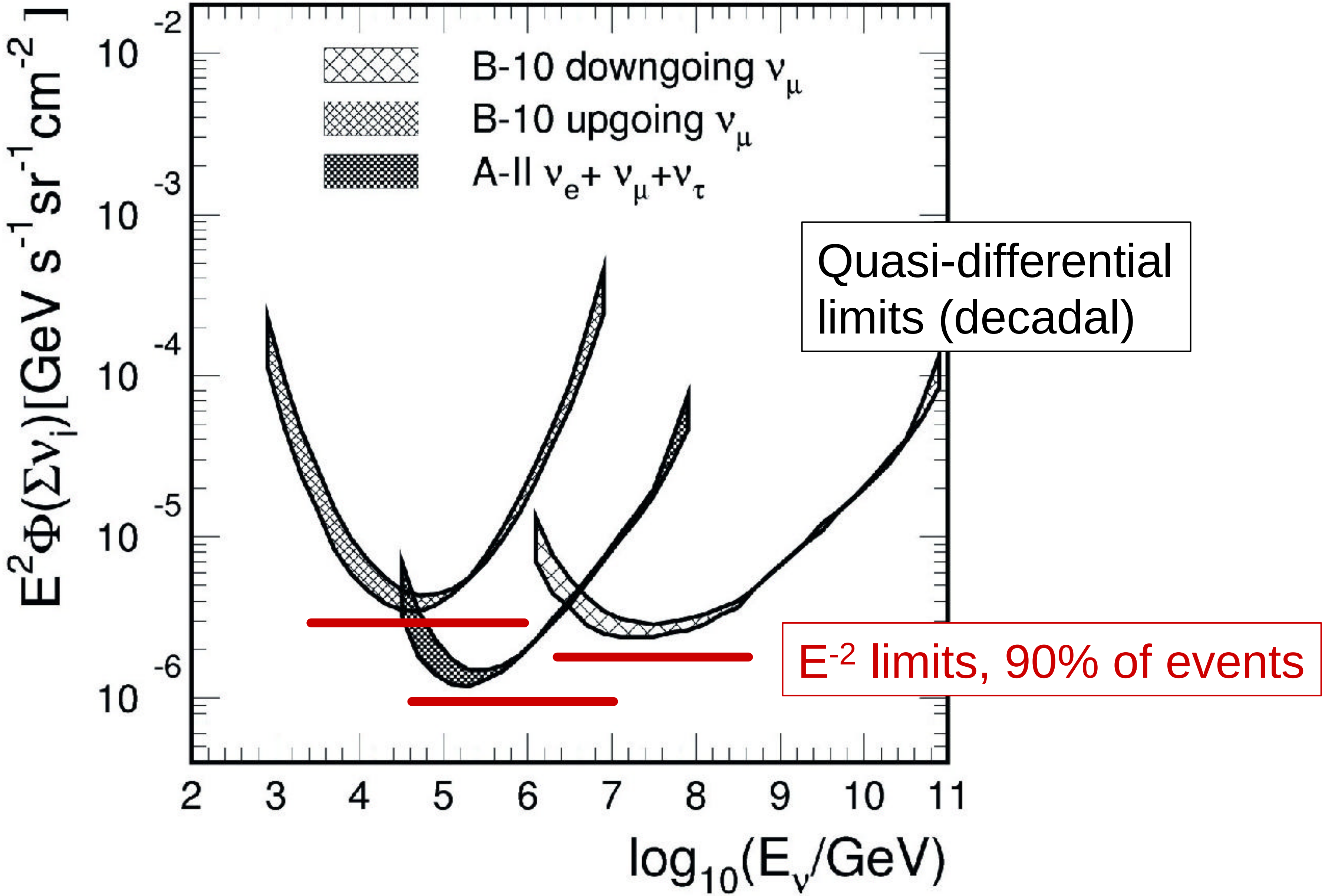
Calculate the differential limit on the flux at energy E_0 from moving average of number of expected events:

$$N(E_0) \propto \int_{E-}^{E+} \Phi_0 (E / E_0)^{-g} \cdot A_{eff}(E)\, dE$$

$$E\pm = 10^{(\log E_0 \pm 0.5)}$$

→ Upper limit on the flux of neutrinos:

$$\boxed{\Phi_{90}(E_0) = m_{90} / N(E_0) \times \Phi_0}$$


B-10 downgoing ν_μ
B-10 upgoing ν_μ
A-II $\nu_e + \nu_\mu + \nu_\tau$
Quasi-differential limits (decadal)
E^{-2} limits, 90% of events
$E^2\Phi(\Sigma\nu_i)$ [GeV s^{-1}sr^{-1}cm^{-2}]
$\log_{10}(E_\nu/\mathrm{GeV})$

End of Talk

Which units for diffuse flux ?

- $E^2 \times dF/dE$ [$cm^{-2}\ s^{-1}\ sr^{-1}$ GeV]
- $\log \{dF/(d \ln E)\}$ [$cm^{-2}\ s^{-1}\ sr^{-1}$]

$dF/d(\ln E) = E\, dF/dE \rightarrow \nu F_\nu$

(as commonly used in astrophysics)

$E^2\, dF/dE$ does not reflect the integral spectrum reasonably well and is misleading.

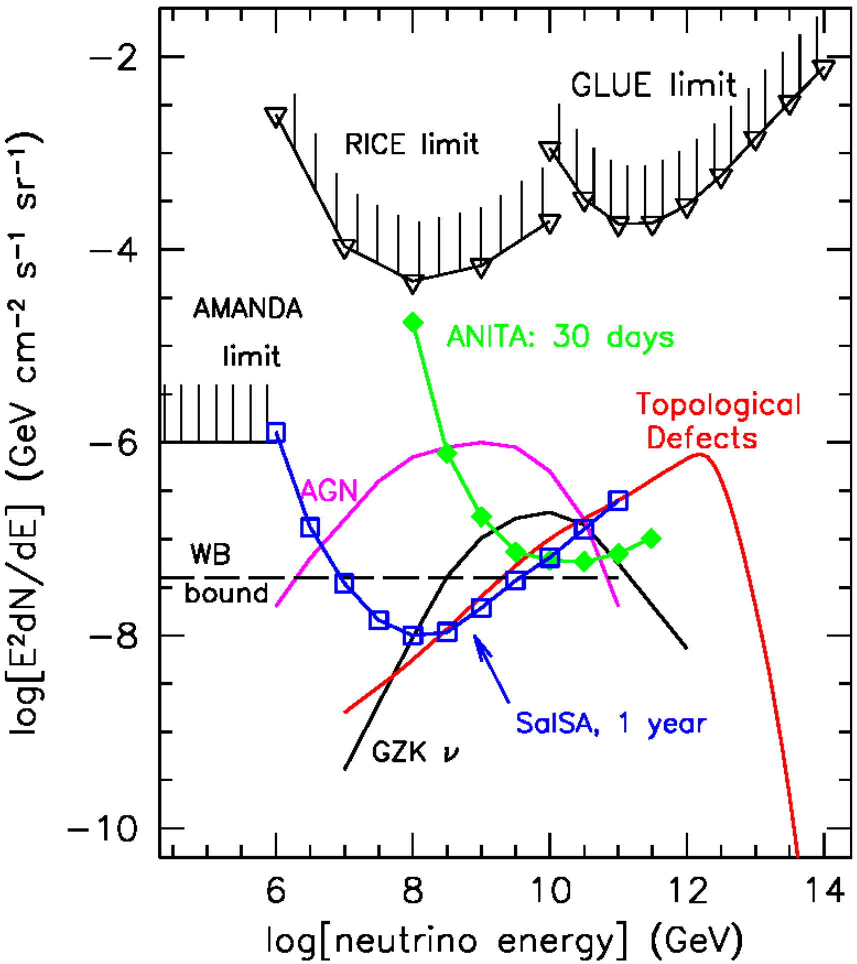
e.g. GZK

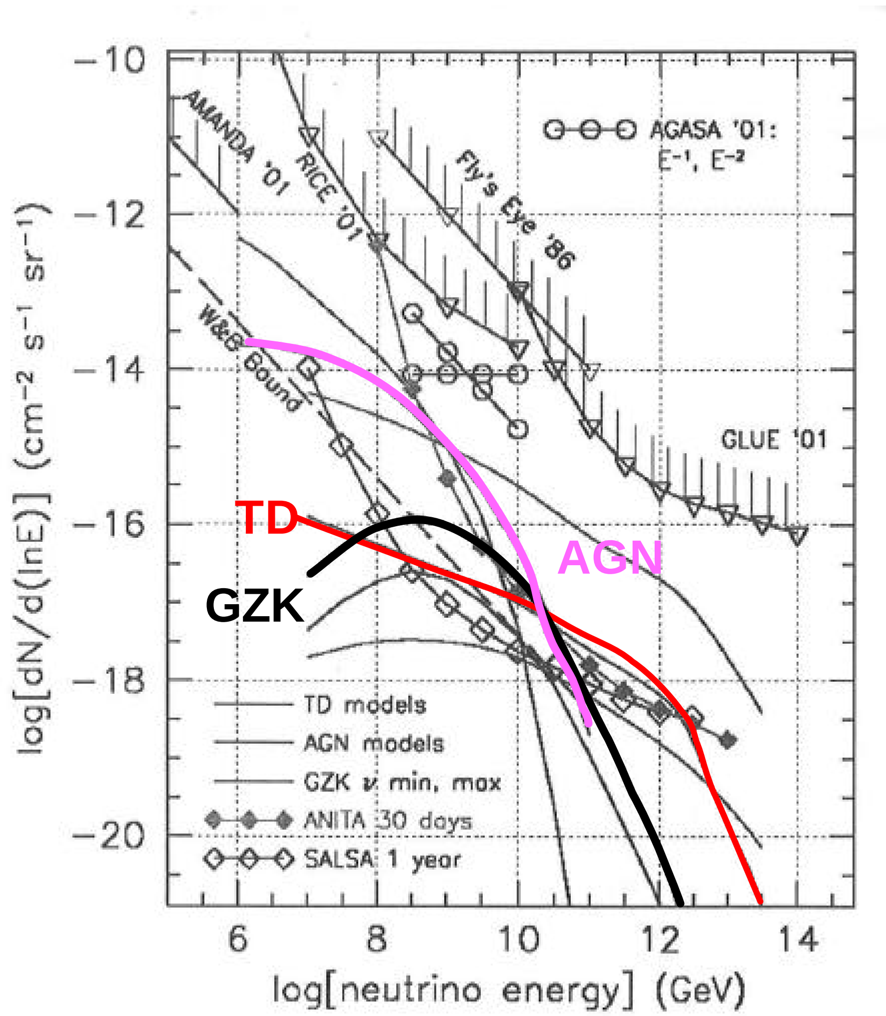
- peak in $E^2\, dF/dE$ at 10^{10} GeV
- peak in $dF/d(\ln E)$ at 10^9 GeV
- max. particle flux at 10^8 GeV

$E^2\, dF/dE$ is „easier“, looks „nicer“ for most models

Many people in our community are used to $E^2\, dF/dE$
(for a counter example see:
Albuquerque/Lamoureux/Smoot, hep-ph/0109177 !)

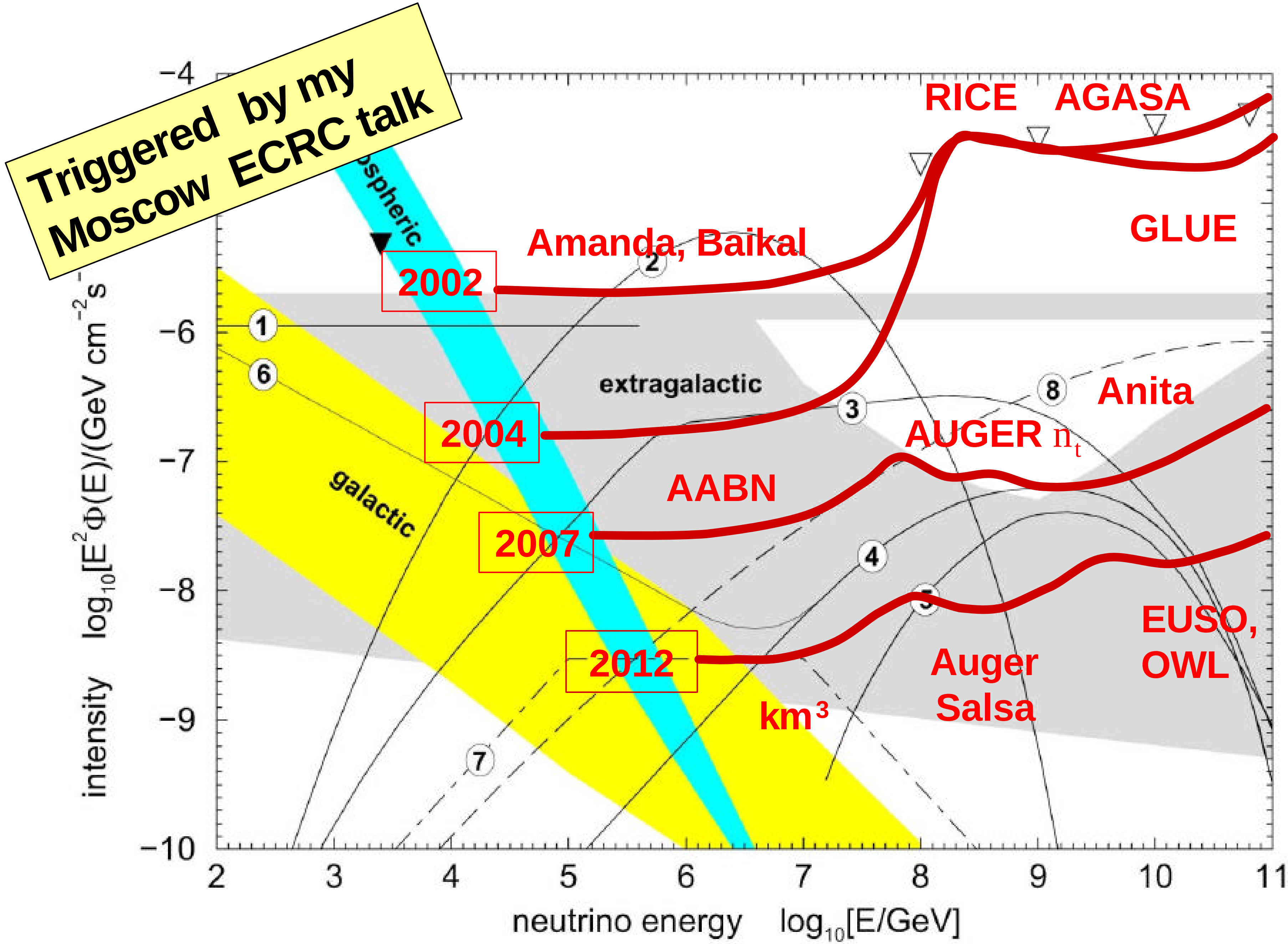
$E^2 \times dF/dE$ *versus* $\log \{dF/(d \ln E)\}$





Plots from a talk given by Peter Gorham

Backup Slides


Triggered by my
Moscow ECRC talk
RICE
AGASA
GLUE
Amanda, Baikal
2002
2004
2007
2012
extragalactic
galactic
Anita
AUGER n_t
AABN
EUSO,
OWL
Auger
Salsa
km^3
-4
-6
-7
-8
-9
-10
2
3
4
5
6
7
8
9
10
11
intensity $\log_{10}[E^2\Phi(E)/(GeV\ cm^{-2}s^{-1}$
neutrino energy $\log_{10}[E/GeV]$

Amsterdam

Green's Function Approach

(see Lehtinen et al, astro-ph/0309656)

$$Flux = \frac{N_{ev}}{N_T \int \sigma(E_\nu)\varepsilon(E_\nu)\Phi(E_\nu)dE_\nu}$$

- N_T - nb. of nucleons
- σ - cross section
- ε - detector efficiency
- Φ - energy spectrum (norm. to 1)

replace spectrum $\Phi(E)$ by delta function

Green's function

for contained events

$$G(E_\nu) = \frac{N_{ev}}{N_T \int \sigma(E_\nu')\varepsilon(E_\nu')\delta(E_\nu - E_\nu')dE_\nu'}$$

Green‘s Function Approach

(see Fukuda et al, SK, astro-ph/0205304)

Fluence limit F_{90} [cm^{-2}] $$F_{90} = \frac{m_{90}}{N_T \int s\,(E_n)\,e\,(E_n)\,l\,(E_n)\,dE_n}$$

- N_T - nb. of nucleons
- ε - detector efficiency
- σ - cross section
- λ - energy spectrum (norm. to 1)

replace spectrum l(E) by delta function

Green‘s function

for contained events

$$G(E_n) = \frac{m_{90}}{N_T \int s\,(E_n^{'})\,e\,(E_n^{'})\,d\,(E_n - E_n^{'})\,dE_n^{'}}$$

Green's function for μ-tracks

$$G(E_?) = \frac{N_{ev}}{AN_a \int \left[\int_{E_{th}}^{E'_?} \frac{ds(E'_?)}{dE_\mu} r(E_\mu)\, dE_\mu \right] d(E_? - E'_?)\, dE'_?}$$

Expected number of events

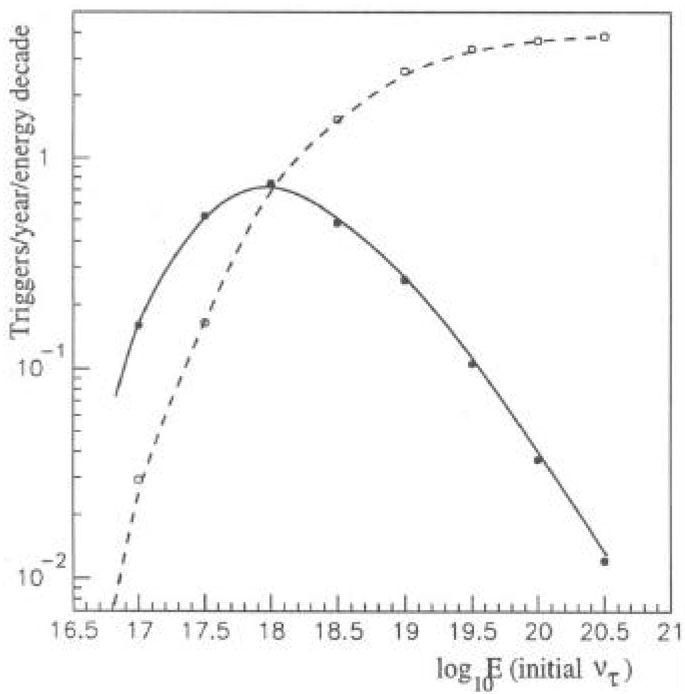
$$N_{ev} = \int l(E_n)\Phi(E_n)\, dE_n$$

Single event sensitivity (SES) per decade

(see e.g. AUGER paper, Bertou et al., astro-ph/0104452)

„Event rate per decade“

$$I_{10}(E) = \lim_{e \to 0} \frac{\int_{E-e}^{E+e} f(e) \cdot A_{eff}(e)\, de}{\log_{10}\left(\frac{E+e}{E-e}\right)}$$



$$= \ln 10\, E \cdot f(E) \cdot A_{eff}(E)$$

AUGER $I_{10}(E)$ for 2 spectral shapes E^{-2} (solid line) and E^{-1} (dashed line)

SK Green's function
for HE contained and
upward muons coincident
with a GRB.

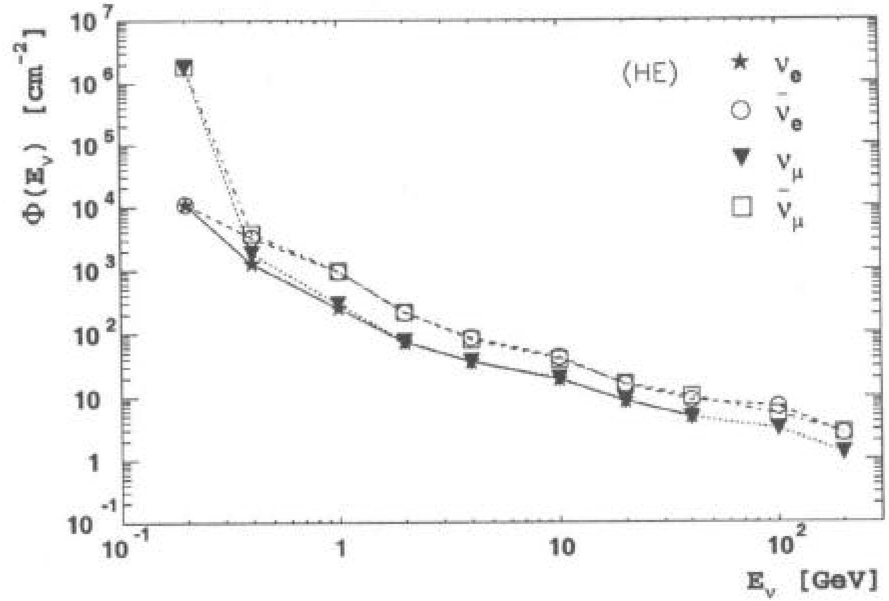
Convolution with an E^{-2}
spectrum gives, e.g.

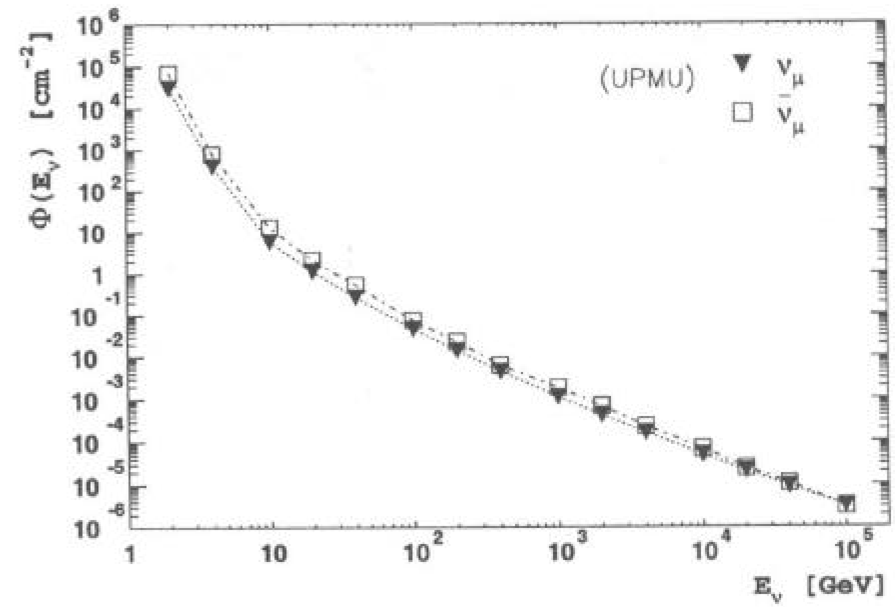
$F_{90}(\nu_\mu)$ =

$2.7 \cdot 10^8$ cm^{-2} for 7-80 MeV

$1.4 \cdot 10^2$ cm^{-2} for 0.2-200 GeV

$3.8 \cdot 10^{-2}$ cm^{-2} for 2 GeV–100TeV





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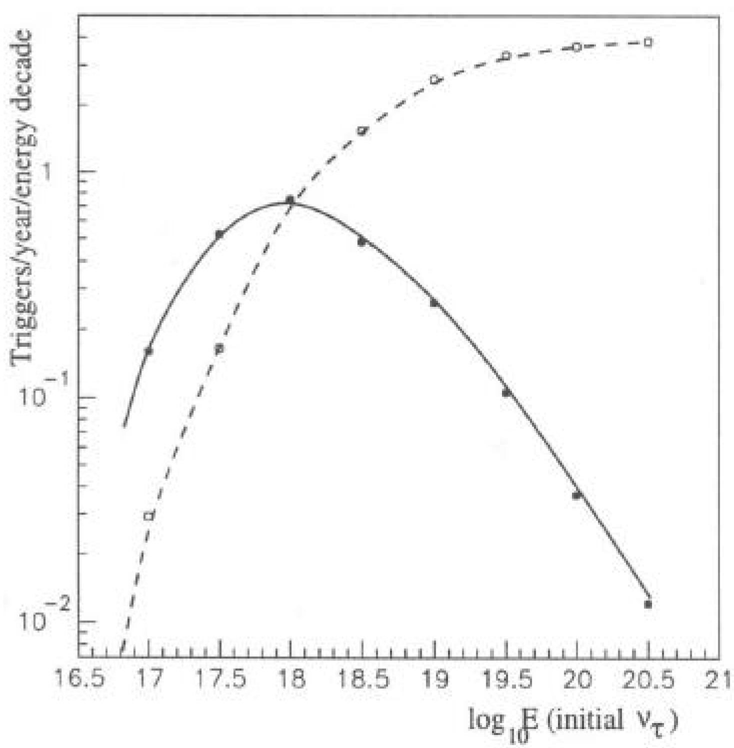

AUGER $I_{10}(E)$
for 2 spectral shapes $\lambda(E)$:

E^{-2} (solid line) and E^{-1} (dashed line)

AUGER $I_{10}(E)$ = 1 curves (1 event per year and decade)