Hunting the tachyon

and finding three unicorns and a herd of elephants

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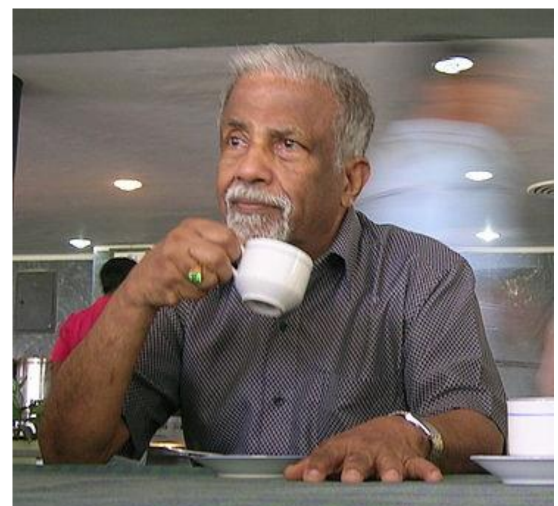
"Speeds greater than light have no possibility of existence"

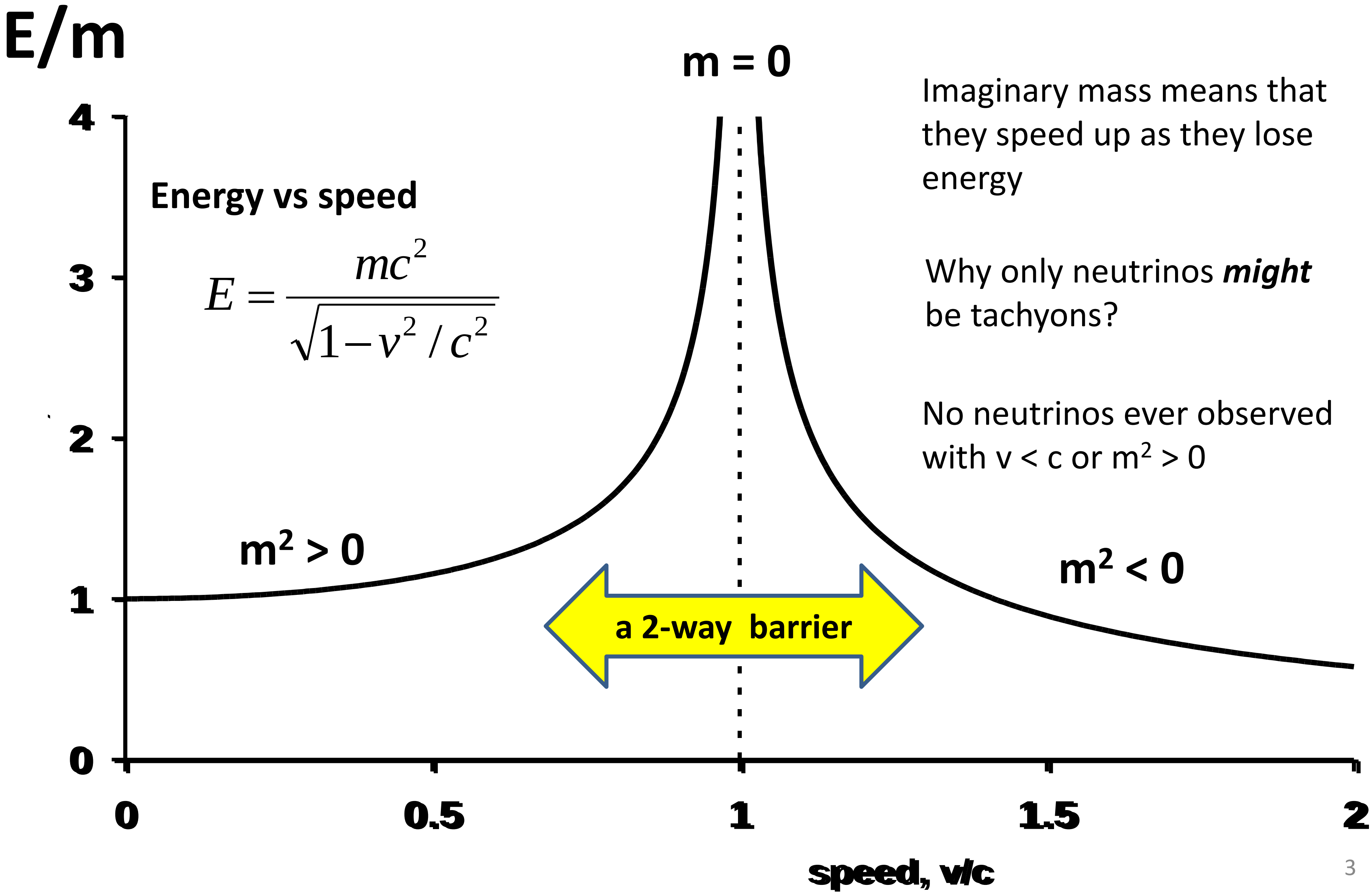
1905

But he only ruled out FTL Speeds for particles initially having sub-light speed



1962

Dependence of energy on speed



$$E = \frac{mc^2}{\sqrt{1 - v^2/c^2}}$$

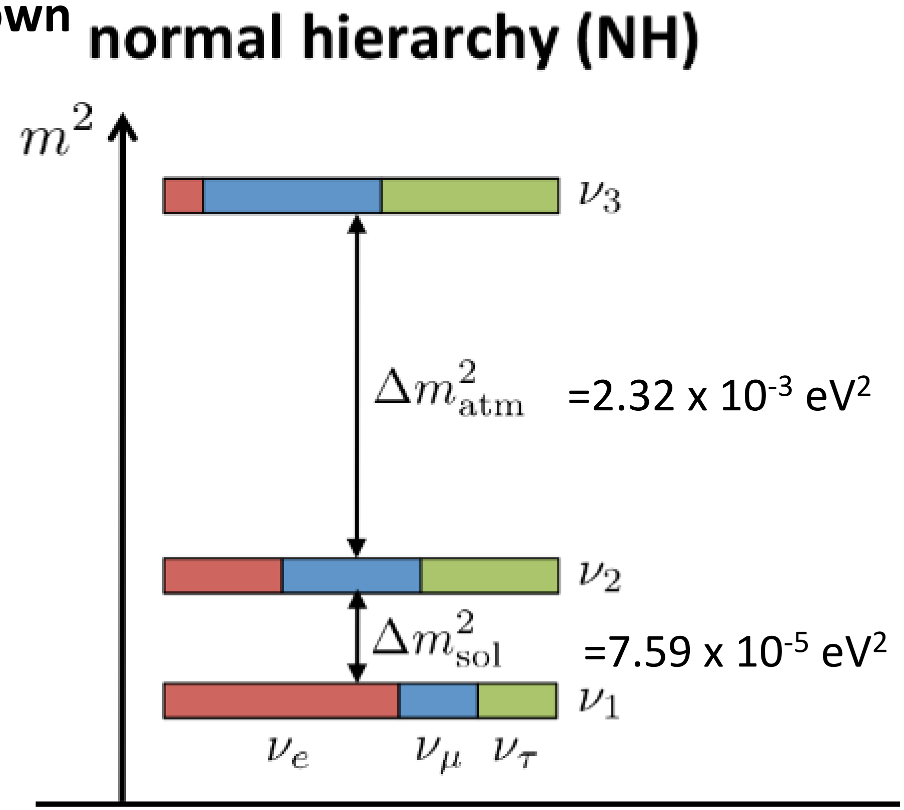
Imaginary mass means that they speed up as they lose energy

Why only neutrinos ***might*** be tachyons?

No neutrinos ever observed with $v < c$ or $m^2 > 0$

Conventional view of neutrino mass states

Absolute scale unknown



?

3 nearly equal masses & same for inverted hierarchy

What is the basis for this conventional view?

Origin of 3 + 3 Model

based on neutrinos from SN 1987A

R. Ehrlich, Astropart. Phys., 35, 625-628 (2012)
& R. Ehrlich, Astropart. Phys., 41 , 16 (2013)
First noted in 1987 (Huzita) & 1988 (Cowsik)

Neutrino “burst” from SN 1987A

Of 10^{58} neutrinos emitted 25 were detected:

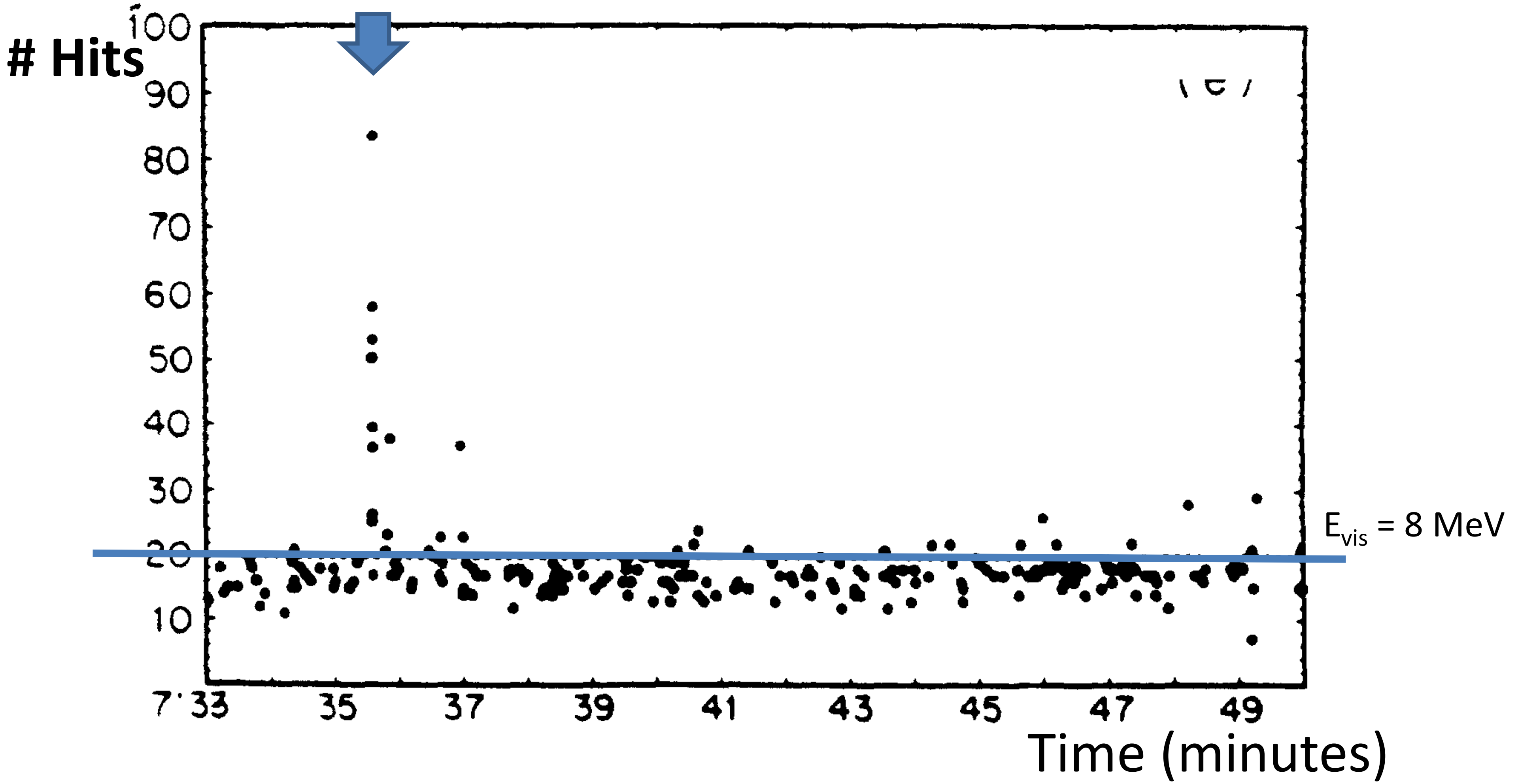
Kamiokande II	12
IMB	8
BAKSAN	5

Also: Mont Blanc detector saw 5 events
(*almost 5 hr early*) usually ignored

12 event neutrino burst

in Kamiokande detector on Feb 24, 1987

publication included 7 other such plots from the same day



Finding the neutrino mass from SN 1987A

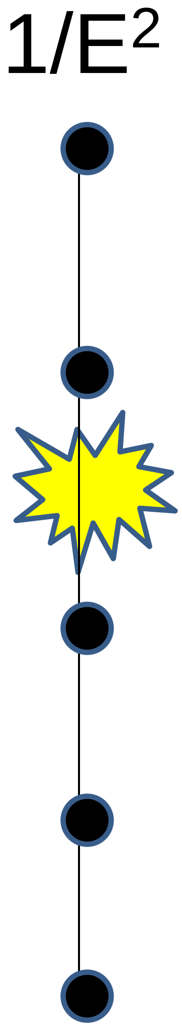
Standard approach: Assume nearly equal m's & get only an upper limit m < 5.7 eV.[1]

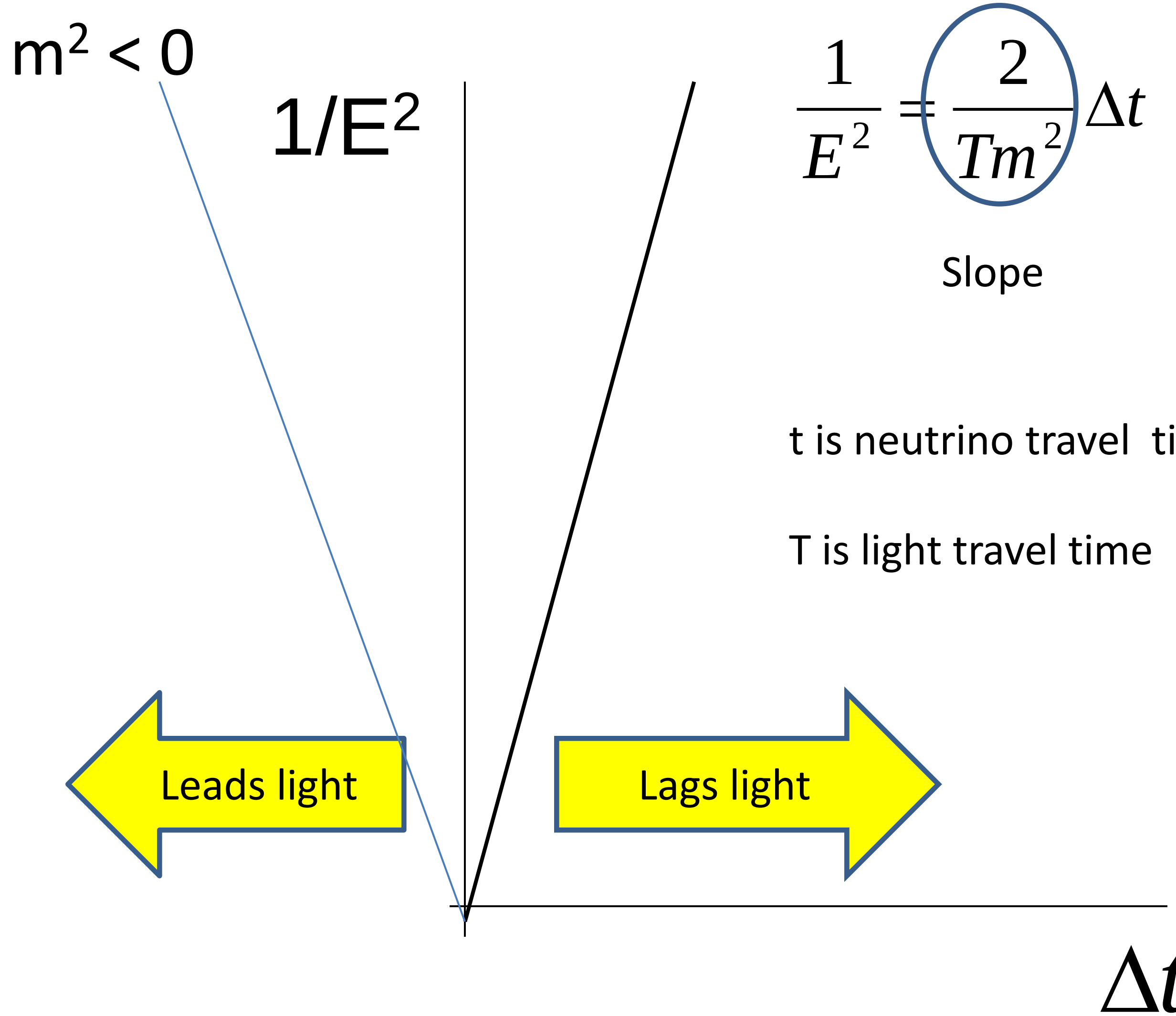
My 2012 analysis[2]: Remain agnostic on whether masses nearly equal and assume emissions are nearly simultaneous.

This assumption allows you to find masses of <u>*individual*</u> neutrinos based on their arrival times (using E & t)

[1]Loredo and Lamb, Phys. Rev. D65 (2002) 063002
[2] R. Cowsik, Phys. Rev. D 37, 16851687 (1988);
R. Ehrlich, Astropart. Phys., 35, 625-628 (2012)

Finding neutrino mass for simultaneous emissions





$$\frac{1}{E^2} = \frac{2}{Tm^2}\Delta t$$

Slope

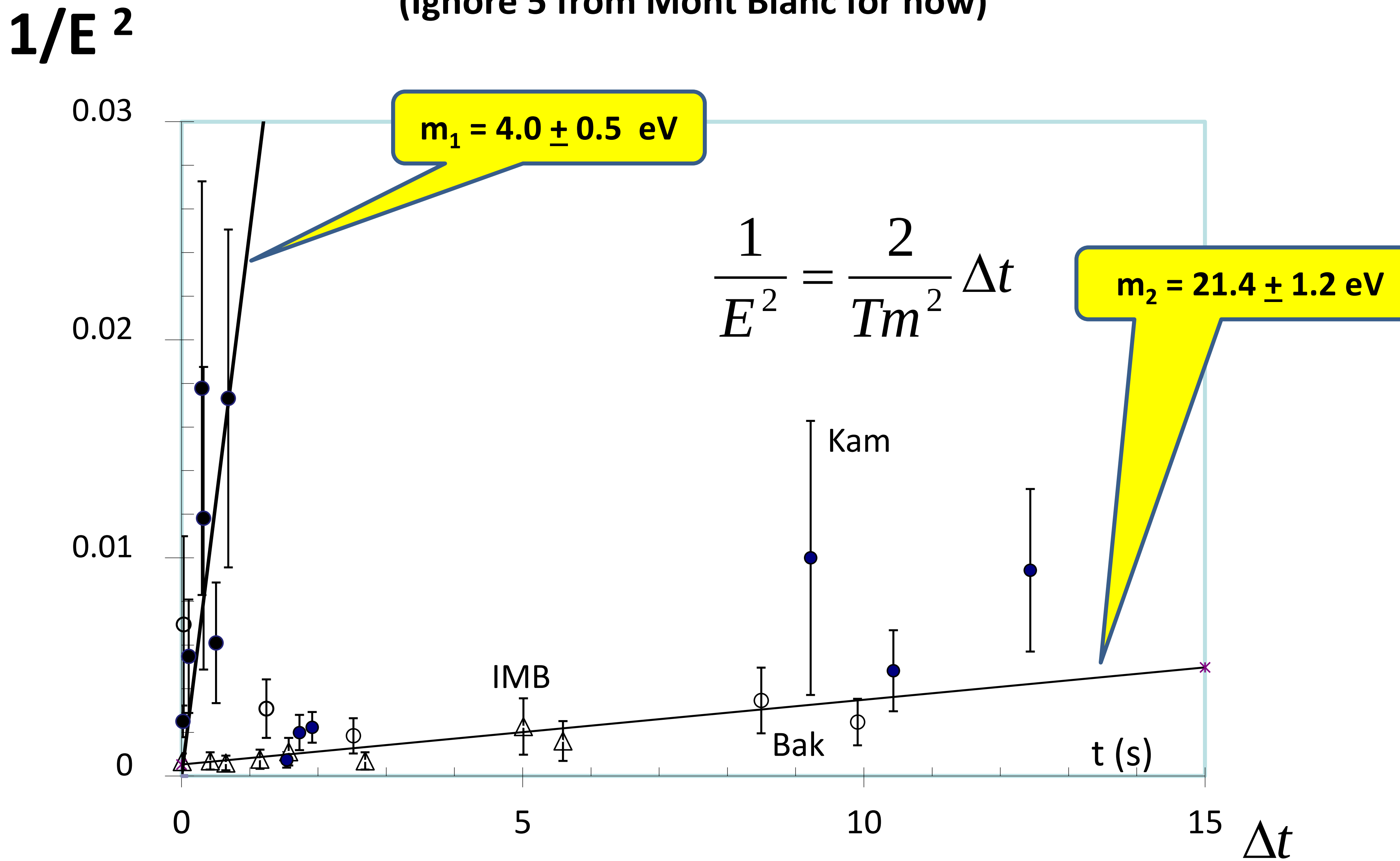
t is neutrino travel time

T is light travel time

$$\Delta t = t - T$$

25 Neutrinos from SN 1987A fits 2 m's

(Ignore 5 from Mont Blanc for now)



R. Ehrlich, Evidence for two neutrino mass eigenstates from SN 1987A and the possibility of superluminal neutrinos, Robert Ehrlich, Astroparticle Physics 35 , 625–628 (2012)

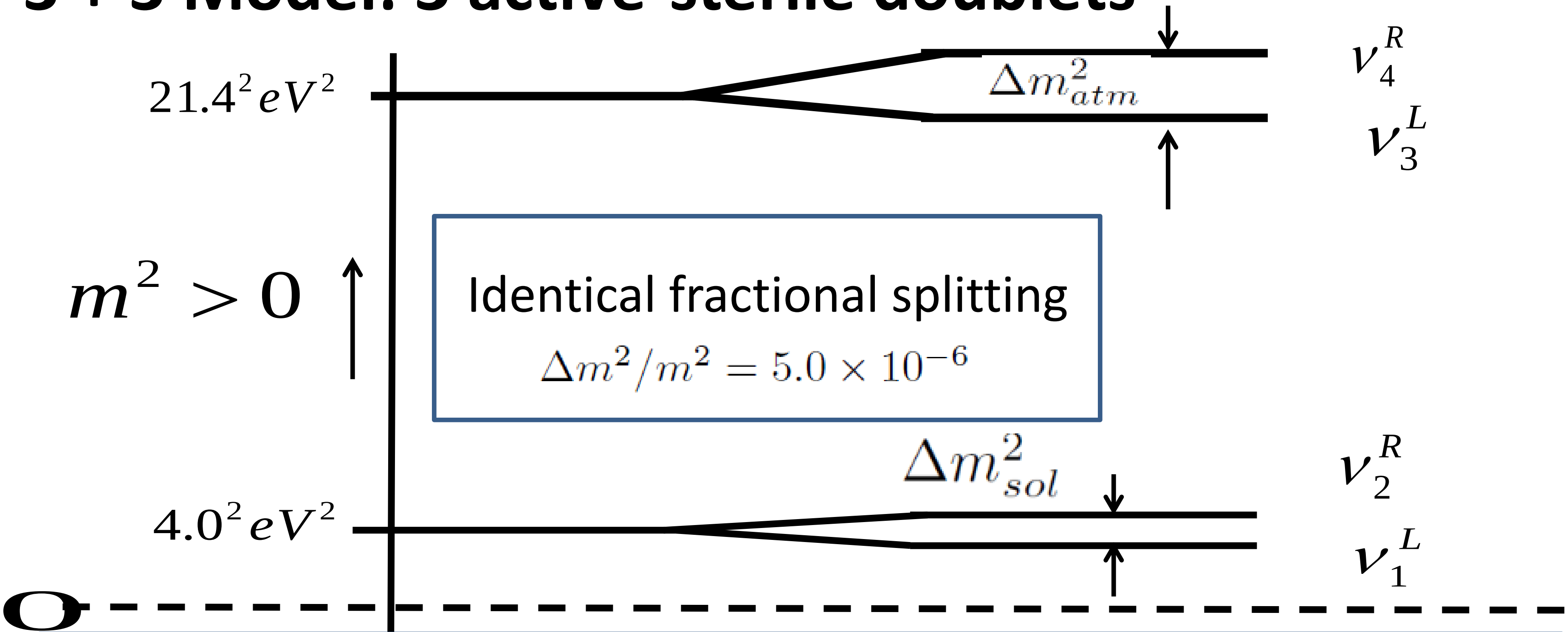
Conclusions

The 25 neutrinos all cluster about 2 specific masses 4.0 eV & 21.4 eV

Inconsistent with conventional neutrino mass hierarchy

Not the only reason why conventional neutrino model is suspect

3 + 3 Model: 3 active-sterile doublets



A 3rd doublet having $m^2 < 0$ is needed to keep the effective flavor state masses small

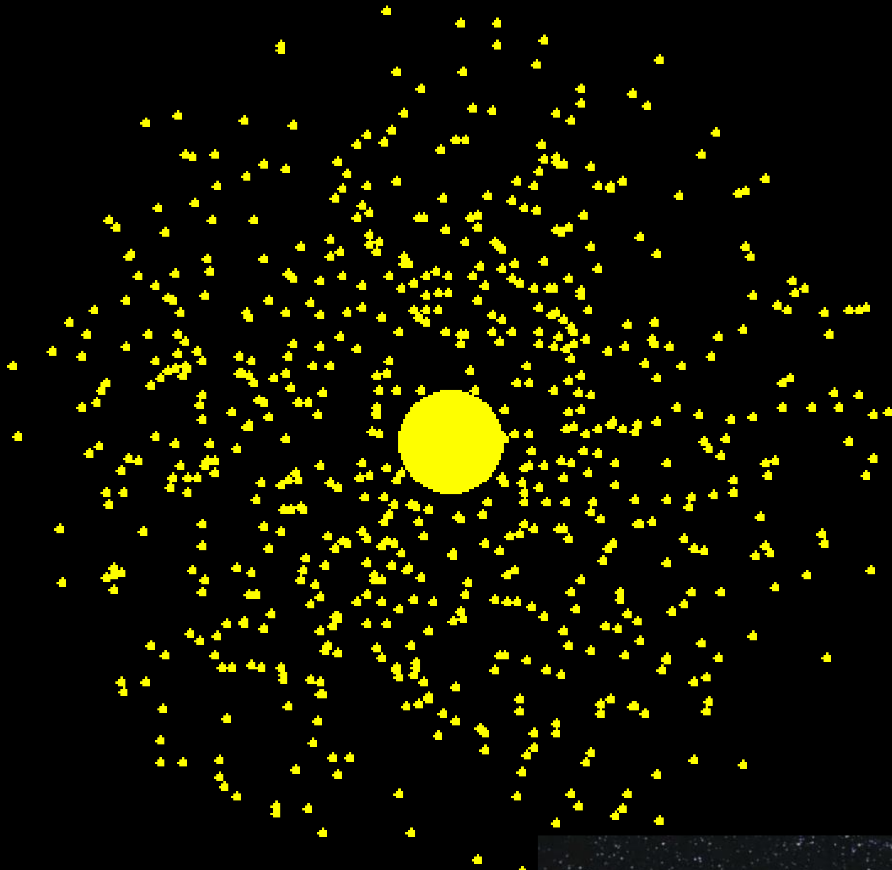
Effective flavor state mass

$$m_i^2 = \Sigma |U_{i,j}|^2 m_j^2$$

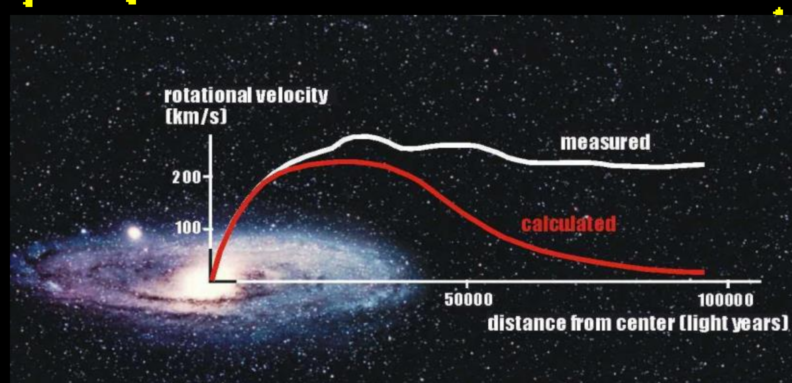
Other evidence for 3 + 3 model masses

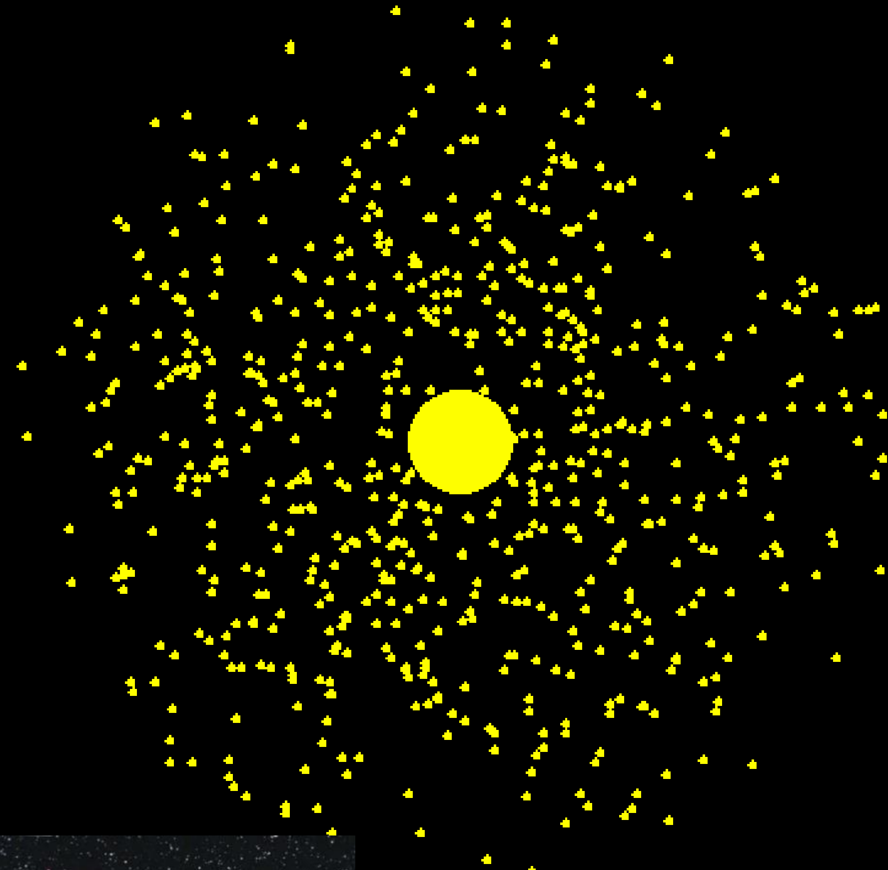
Sterile neutrinos are a good candidate for dark matter

Why dark matter in galaxy?



No DM





Observed

Find neutrino mass by fit to DM radial profile

(1) Deduce ``observed” dark matter halo profile from rotation curve

(2) Derive Equation of state for slightly degenerate neutrinos

$$P(r) = n(r)kT_s + \frac{n^2(r)h^3}{16\pi^{3/2}g_s}(m_s kT_s)^{-3/2}(kT_s)^{-1/2}.$$

(3) Set neutrino mass density n(r) at r = 0 to ``observed” value & integrate outward using Eq. for hydrostatic equilibrium in order to find M(r):

$$\frac{dP(r)}{dr} = -\frac{Gm_sM(r)n(r)}{r^2},$$

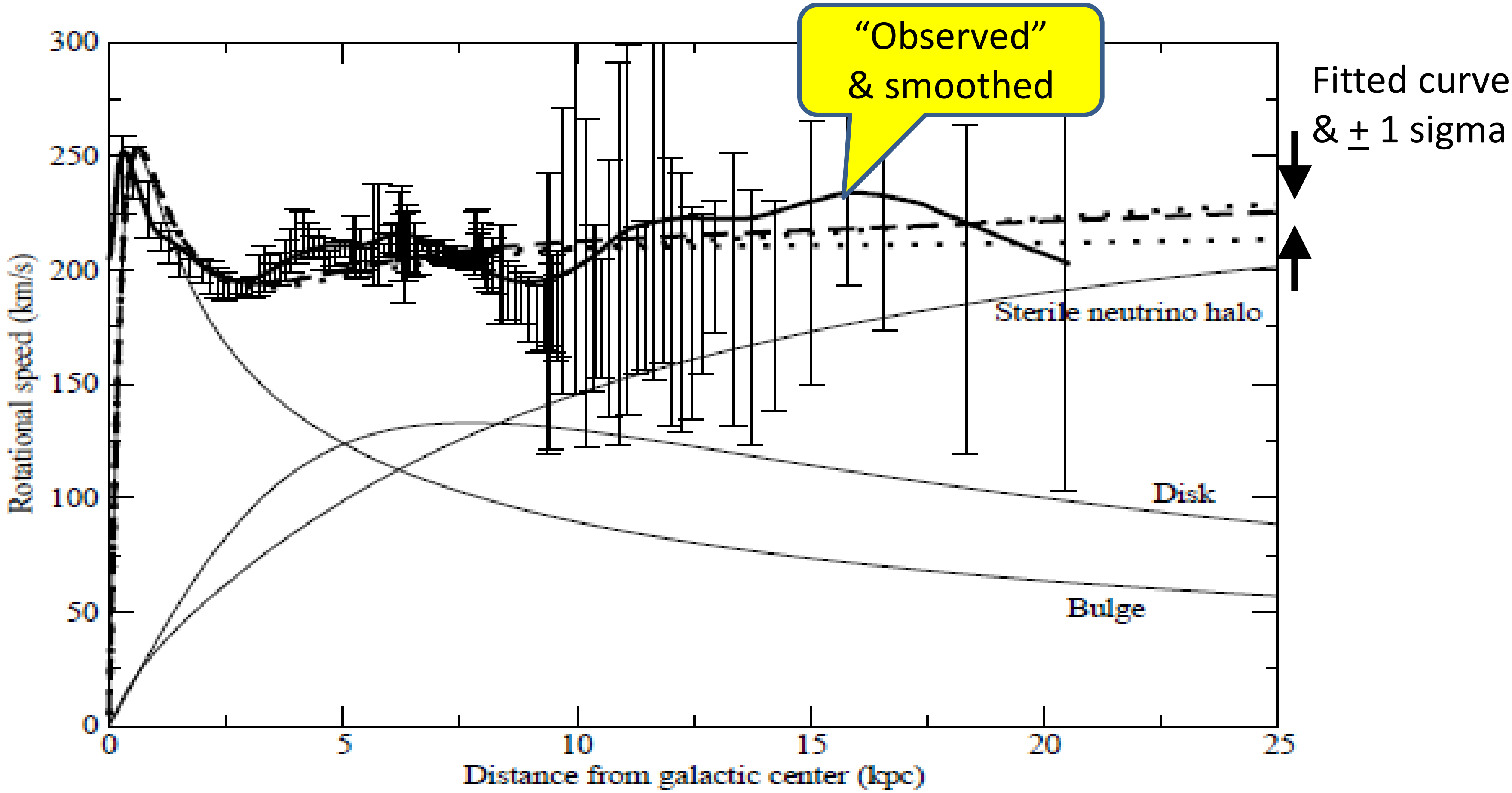
$$M(r) = M_D(r) + M_B(r)$$

(4) Find v(r) = $(2GM(r)/r)^{1/2}$

Chan, M .H. and Ehrlich, R., Astrophys. and Space Sci., 3, 49, (1), 407-413, (2014)

Observed and fitted rotation curve for Milky Way

with m = 21.4 + 1.2 eV neutrinos



Chan, M .H. and Ehrlich, R., Astrophys. and Space Sci., 3, 49, (1), 407-413, (2014)

Clusters of galaxies

Properties:

The largest known gravitationally-bound structures containing 100 to 1,000 galaxies (only 1% of total mass)

the rest: hot gas (9%) and dark matter (90%)

Dark matter fits:

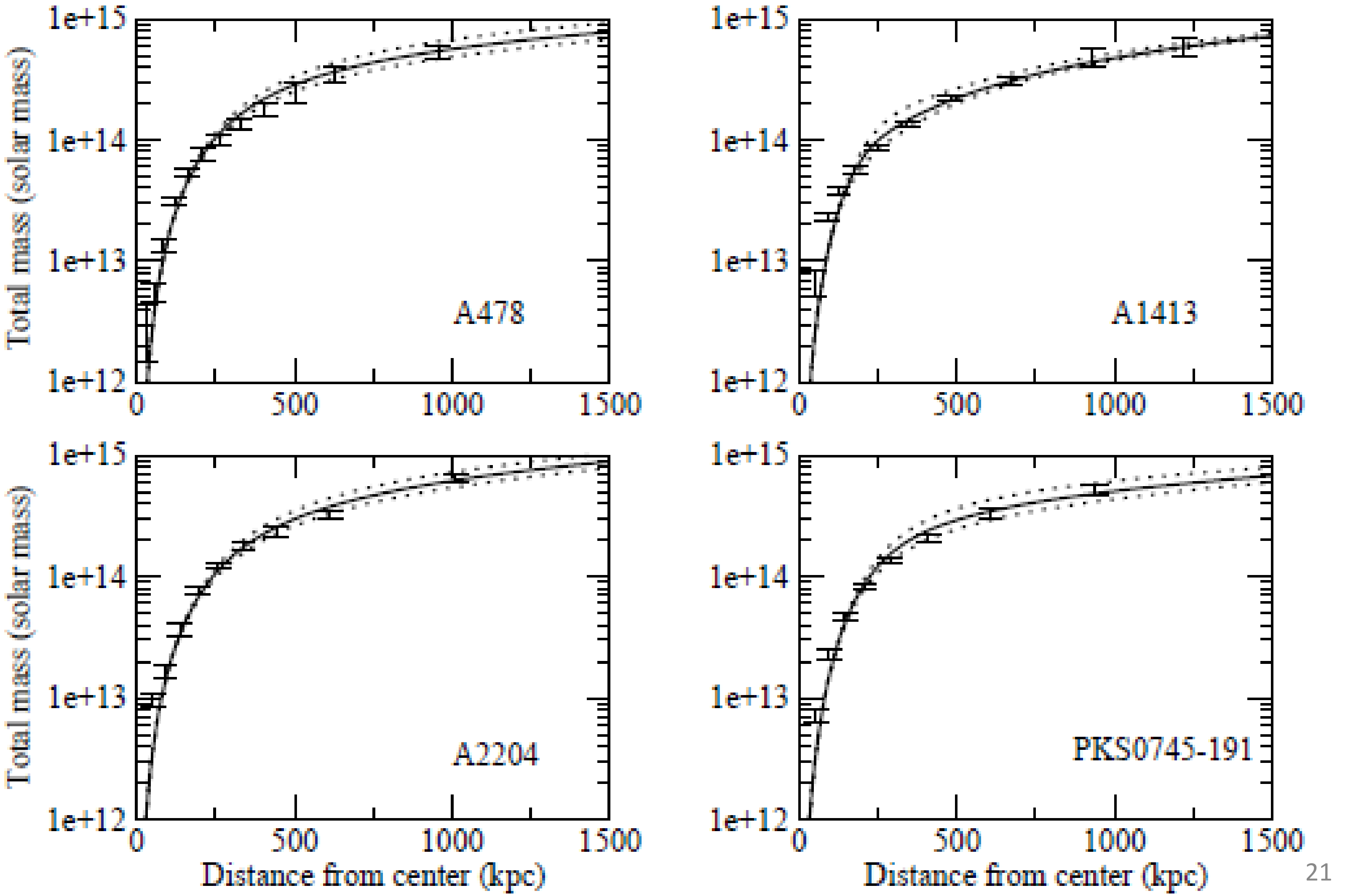
Can infer DM profile from v of individual galaxies using the Virial Theorem

Only measure v along line of sight

Observed and fitted mass profiles for 4 clusters of galaxies with m = 4.0 + 0.5 eV neutrinos

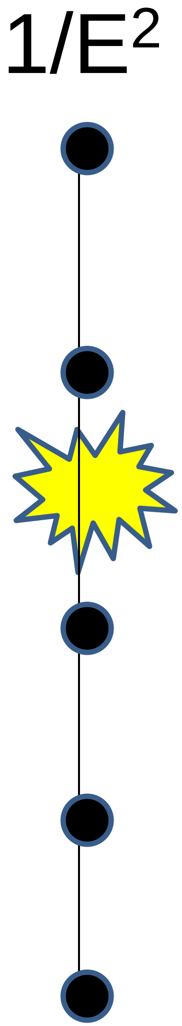
Observed uncertainty (Error bars) due to limited numbers of galaxies in cluster

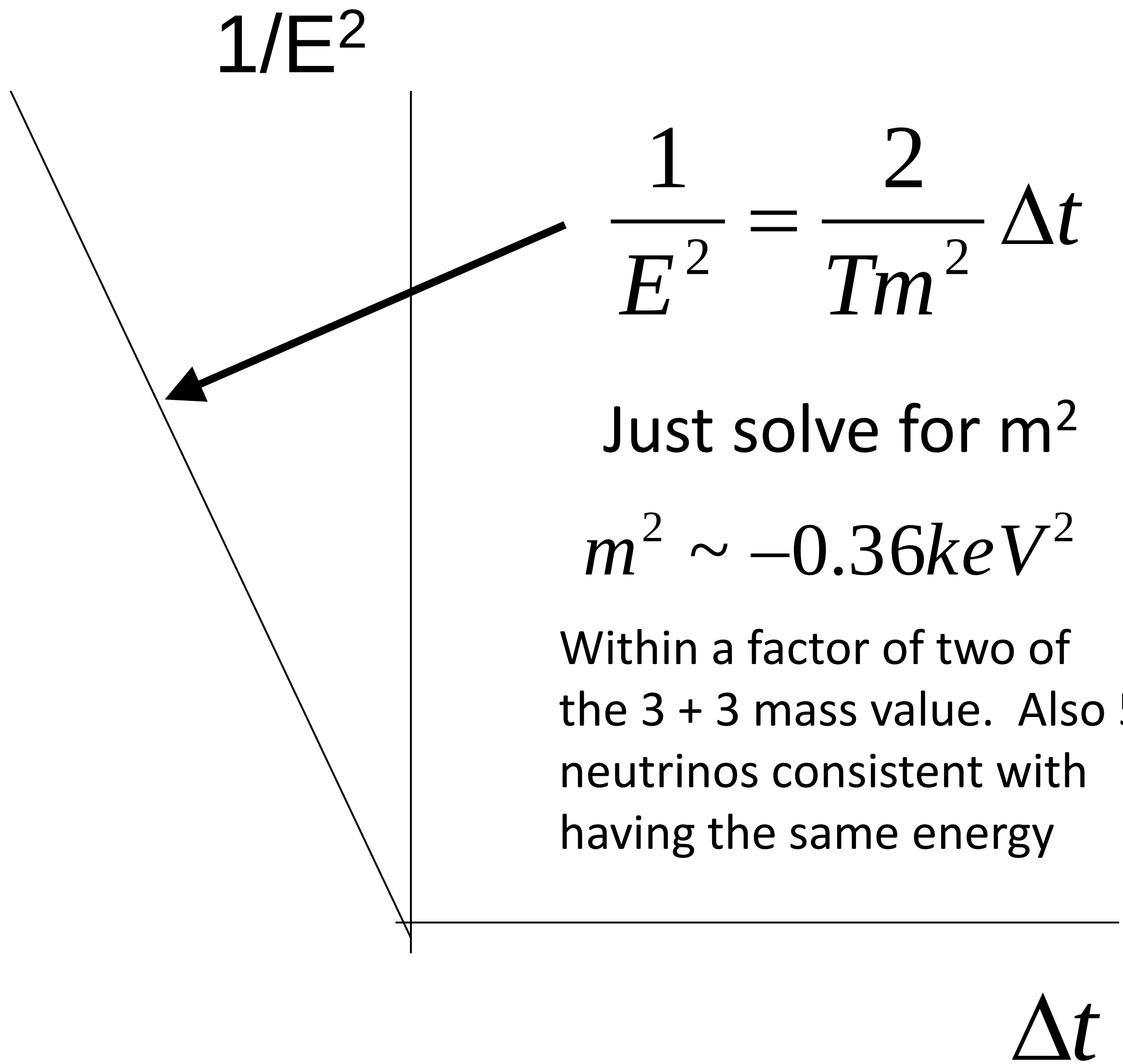
Uncertainty in fitted profiles (Dotted curves) for +/- 1 sigma in neutrino mass



What about the $m^2 < 0$ mass?

Five early neutrinos seen in the Mont Blanc detector





$$\frac{1}{E^2} = \frac{2}{Tm^2}\Delta t$$

Just solve for m^2

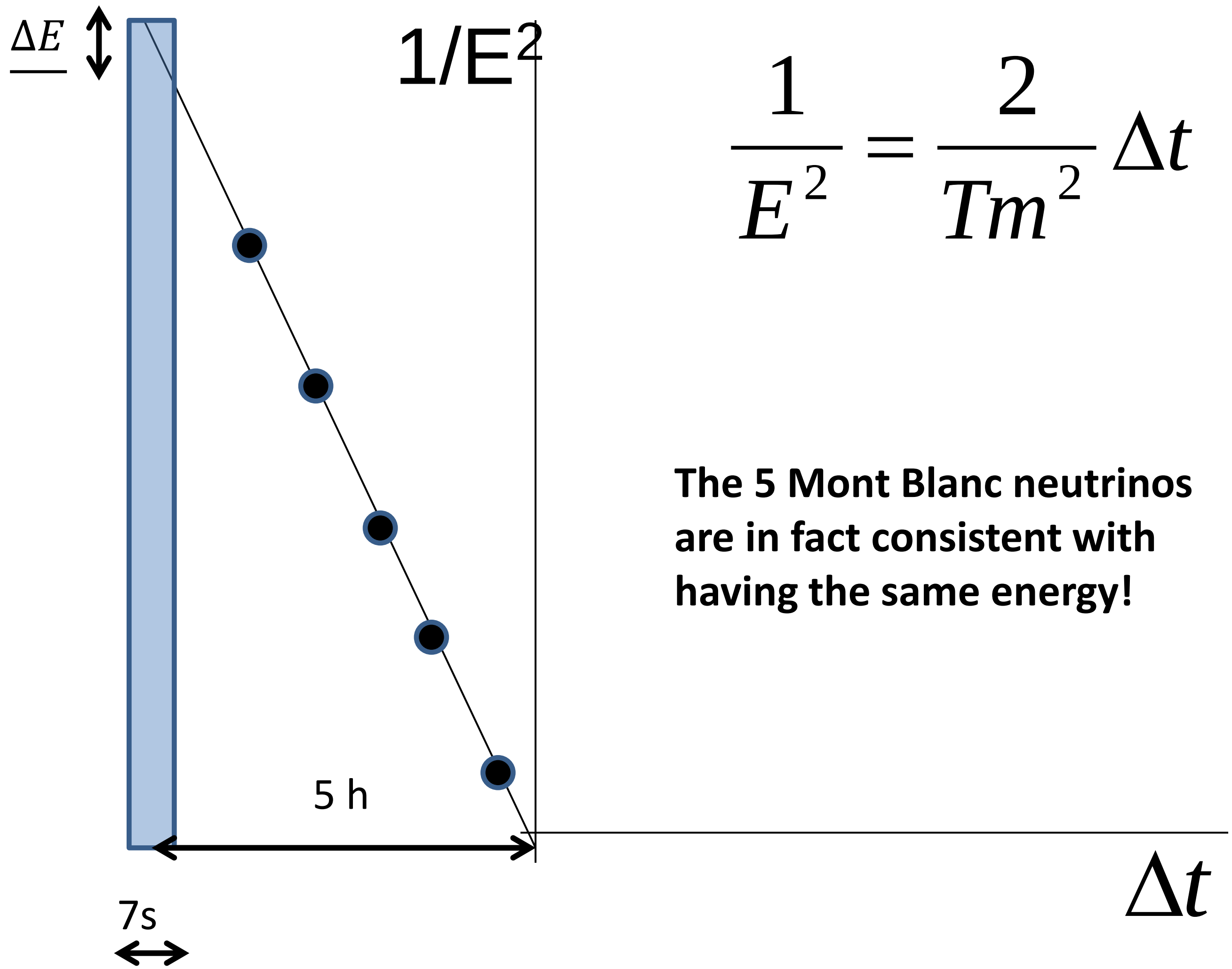
$$m^2 \sim -0.36 keV^2$$

Within a factor of two of the 3 + 3 mass value. Also 5 neutrinos consistent with having the same energy

Suppose the 5 Mont Blanc neutrinos have $m^2 < 0$

Requires an 8 MeV spectral line???

$$\frac{\Delta E}{E} = 0.02\%$$

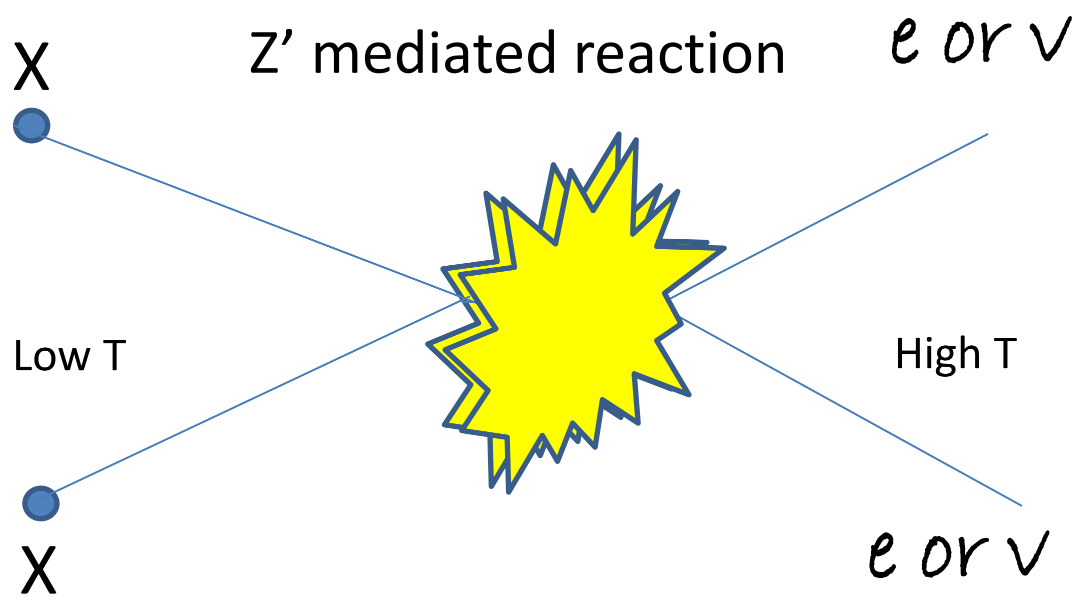


$$\frac{1}{E^2} = \frac{2}{Tm^2}\Delta t$$

The 5 Mont Blanc neutrinos are in fact consistent with having the same energy!

How to get monochromatic 8 MeV SN neutrinos?

Assume DM X-particles in stellar core



Z' = 16.7± 0.6 MeV boson Krasznahorkay (2016)

X = COLD dark matter particles of mass 8.4 MeV

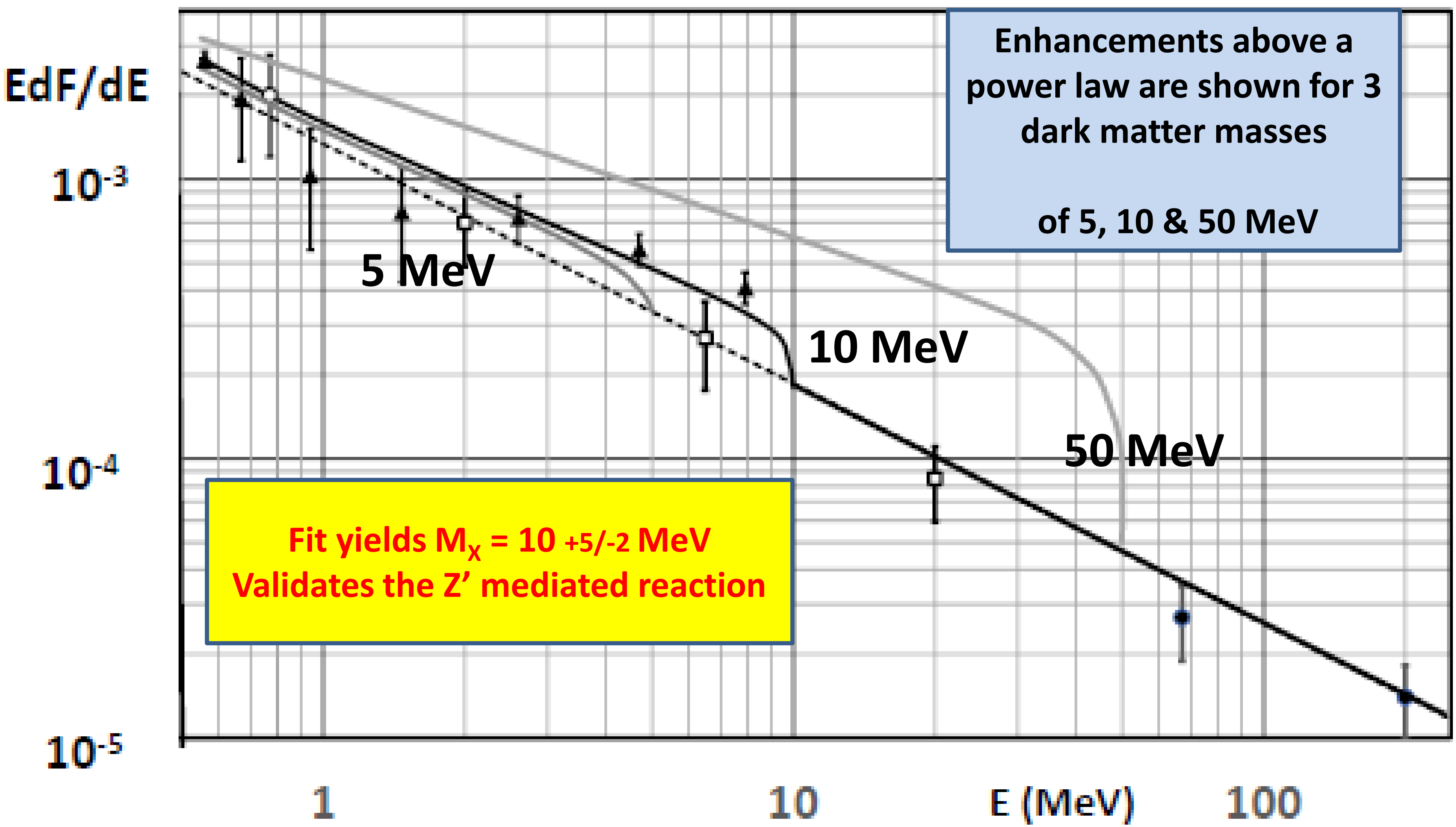
Reaction yields *monochromatic* ~8 MeV neutrinos & $e^+ e^-$ pairs

Test of this model: Wait for next supernova?

Maybe 8.4 MeV dark matter X particles also exists near galactic center

Impact on spectrum of galactic center gamma rays

Gamma ray spectrum from GC



Recall the main idea here:

Mont Blanc neutrinos were tachyons → **An 8 MeV neutrino line from SN 1987A**

Shouldn't we also see an 8 MeV spectral line for the m > 0 neutrinos?

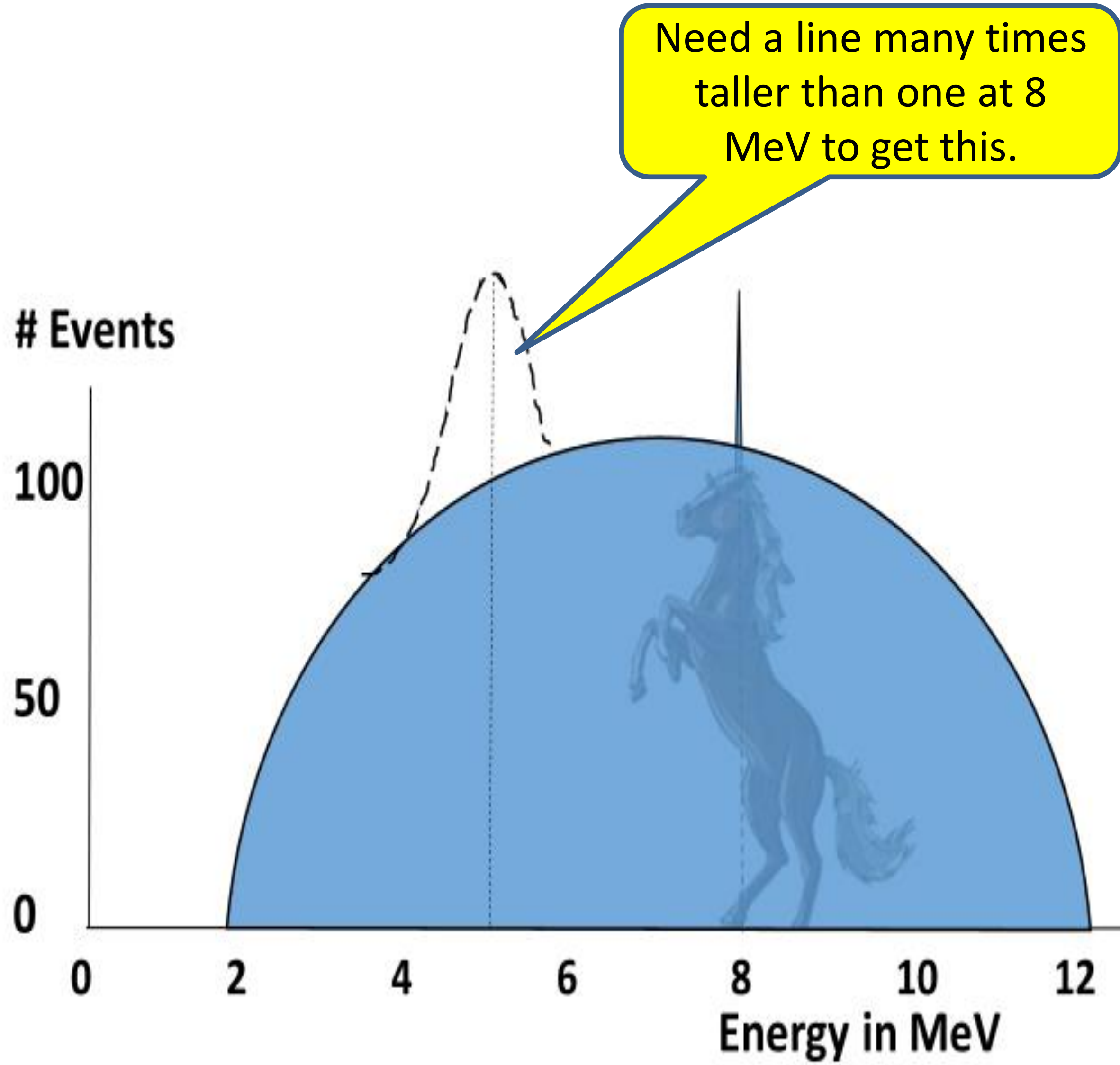
Might an 8 MeV neutrino line be hiding in plain sight in the SN 1987A data?

Recall the 7 extra data plots from Kamiokande (~1000 events over 136 min)

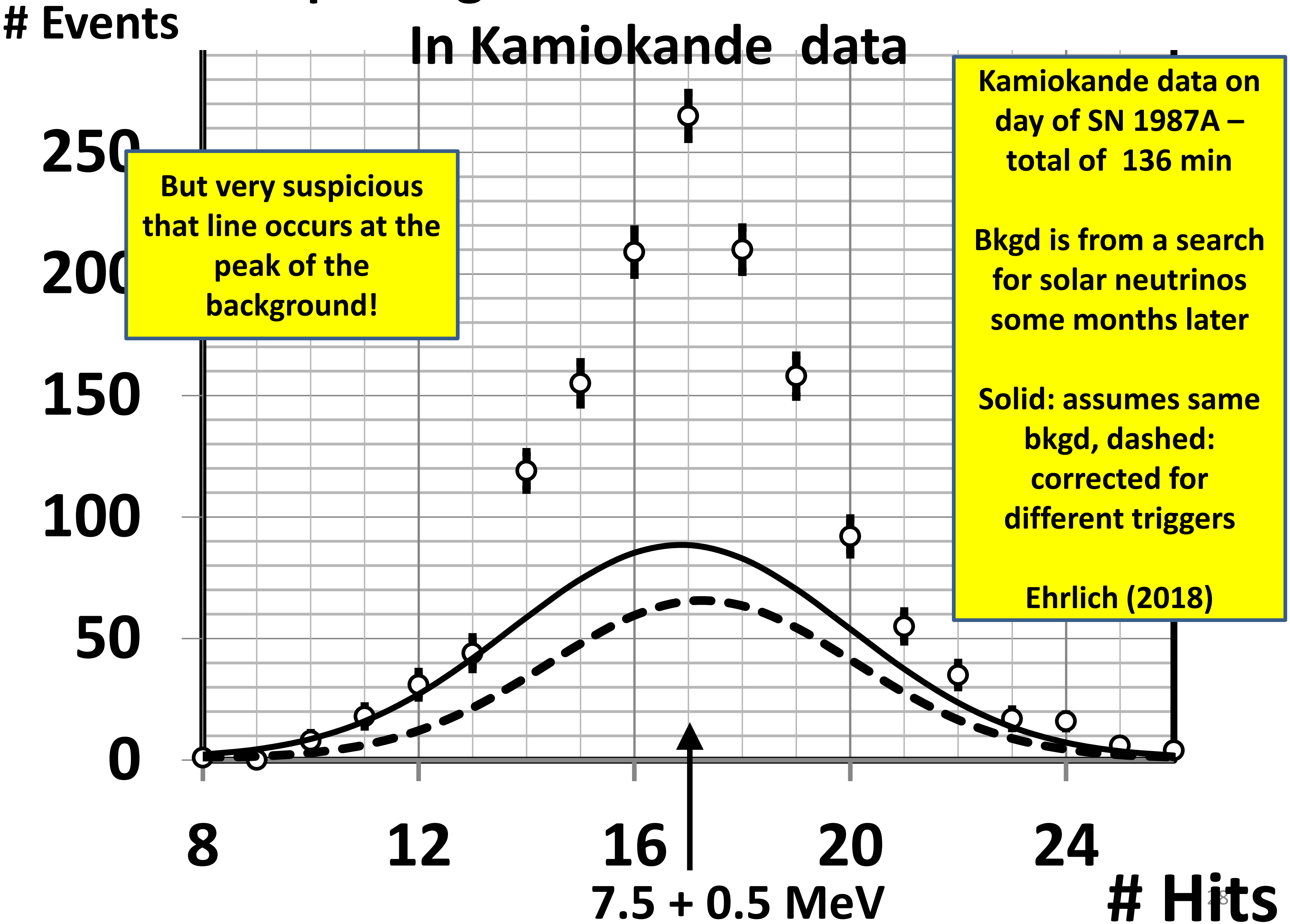
Difficulty of spotting a neutrino line

Not like spotting visible spectral lines. Any neutrino line will be considerably broadened

Need large enough amplitude or it will fade into the background



Spotting the hidden 8 MeV line In Kamiokande data



But very suspicious that line occurs at the peak of the background!

Kamiokande data on day of SN 1987A – total of 136 min

Bkgd is from a search for solar neutrinos some months later

Solid: assumes same bkgd, dashed: corrected for different triggers

Ehrlich (2018)

The 3 unicorns?

Mont Blanc neutrinos are tachyons

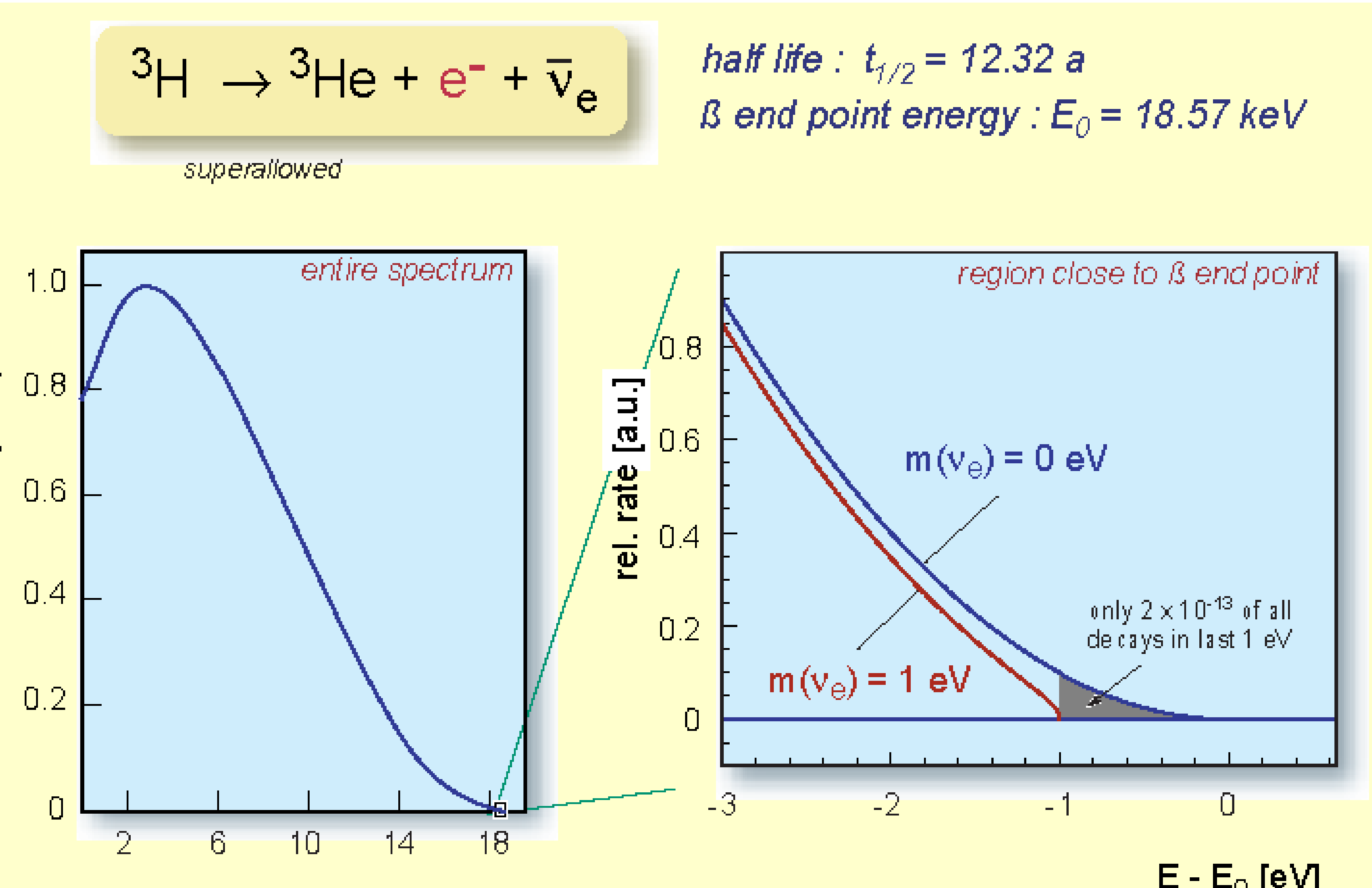
8 MeV neutrino line

8 MeV mass dark matter particles

Unicorn definition

1. a mythical animal with a single straight horn.
2. something that is highly desirable but difficult to find.

Wouldn't 3 + 3 masses be seen in Lab experiments?



Determination of m_ν^2 from spectrum shape

Fit the region of the spectrum near E_0, using 4 free parameters:

Neutrino mass squared
Endpoint energy
Signal amplitude
Background amplitude

John von Neumann famous quote about fitting data using four free parameters:

"With four parameters I can fit an elephant, and with five I can make him wiggle his trunk."

KATRIN Experiment

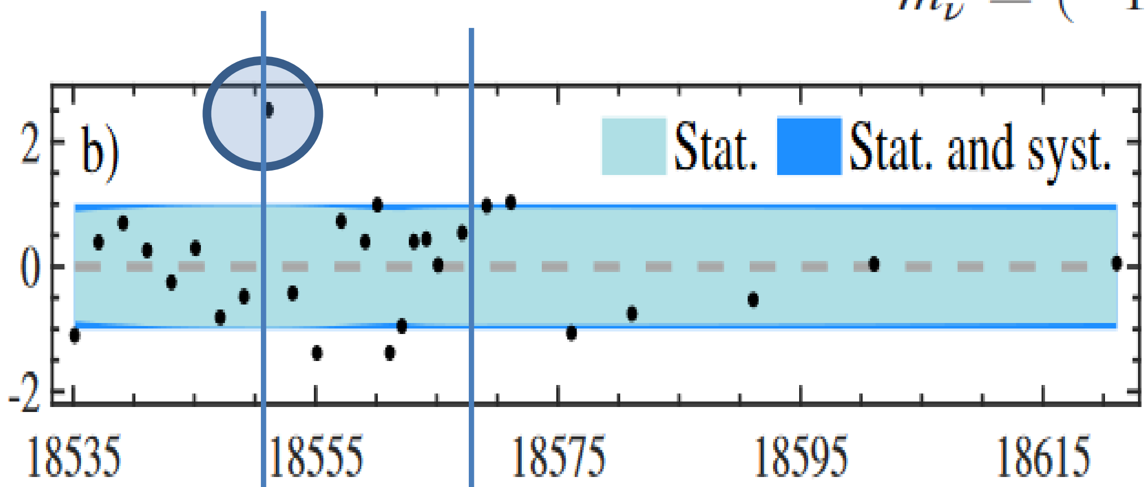
Should be a factor of ten improvement on previous results

Started taking data in 2019 & published initial results then

KATRIN 2019 results: Fit to spectrum using 4 free parameters

$$m_\nu^2 = (-1.0^{+0.9}_{-1.1})\ \text{eV}^2$$

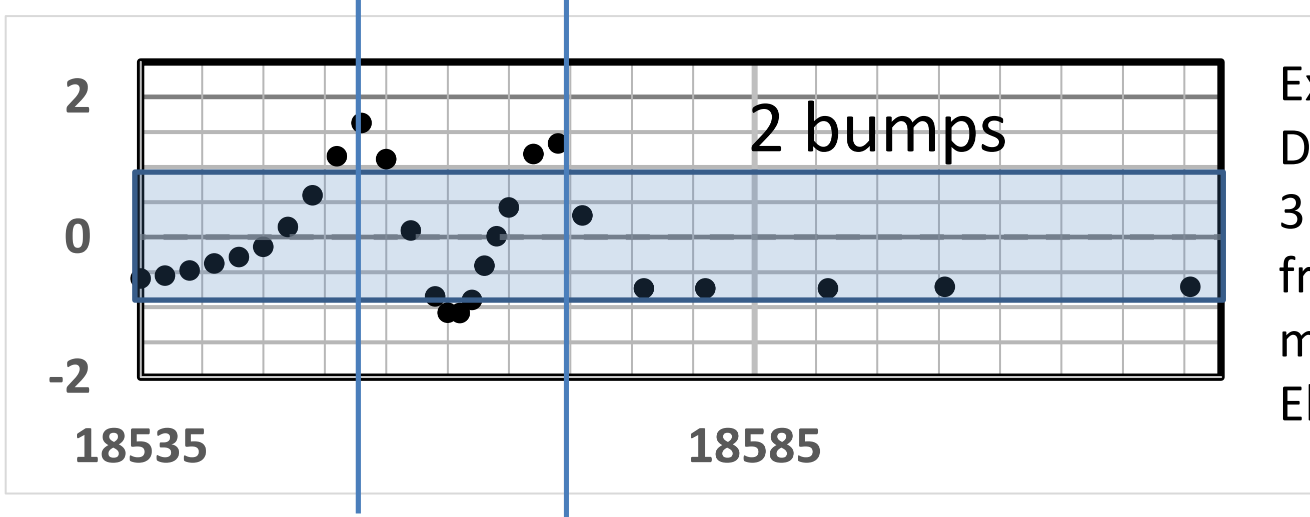
#Sigma



Residuals

Retarding energy, E_n (eV)

#Sigma



Expected Departure of 3 + 3 model from single mass spectrum Ehrlich (2019)

First results from KATRIN in 2019 fit the 3 + 3 model better than a single mass

The “herd of elephants”

KATRIN 2021 results

From their paper:

In addition to the neutrino mass squared, m_ν^2, the parameters $A_s(r_j)$, $R_{bg}(r_j)$, and the effective endpoint $E_0(r_j)$ are treated as independent parameters for the 12 detector rings, leading to a total number of free parameters of $1 + 3 \times 12 = 37$ in the fit. The introduction of ring-dependent parameters was chosen to allow for possible unaccounted radial effects. In particular, the effective

“Don’t worry guys. With 37 free parameters the hunters will never spot us.”

Questions about KATRIN's results

Why did KATRIN fit their 2019 initial spectrum using four free parameters, but then resort to 37 free parameters for their 2021 data?

What were those 37 parameters?

Might they have first done a four free parameter fit & found it a very poor one?

Was it a poor fit because of two "bumps" like 3 + 3 model predicts?

Summary of talk

FTL particles OK if mass imaginary or $m^2 < 0$: Sudarshan (1962)

Neutrinos are the only candidates among known particles: Chodos (1985)

3+3 model of neutrino masses from SN 1987A: Ehrlich (2013)

Many separate data sets support the 3+3 model: Ehrlich (2018)

1st KATRIN results (2019) -- neutrino m < 1 eV (a ***four*** free parameter fit); they also fit 3 + 3 model. Ehrlich (2019]

2021 KATRIN results do their fit with 37 free parameters "the herd of elephants" → 3 + 3 still lives. Ehrlich(2021)

New book expected in 2022

Hunting the Faster-than-light Tachyon:
Finding three unicorns and a herd of elephants

CRC Press, Taylor & Francis Group

Ehrlich.physics.gmu.edu