Challenges for the determination of the Atmospheric Mass Ordering using electron antineutrinos from reactors

Stephen Parke

Fermilab Theory

- See Atmospheric (31/32) wiggles:
  - Resolution
- Know were the wiggles are:
  - Linearity of nu energy reconstruction

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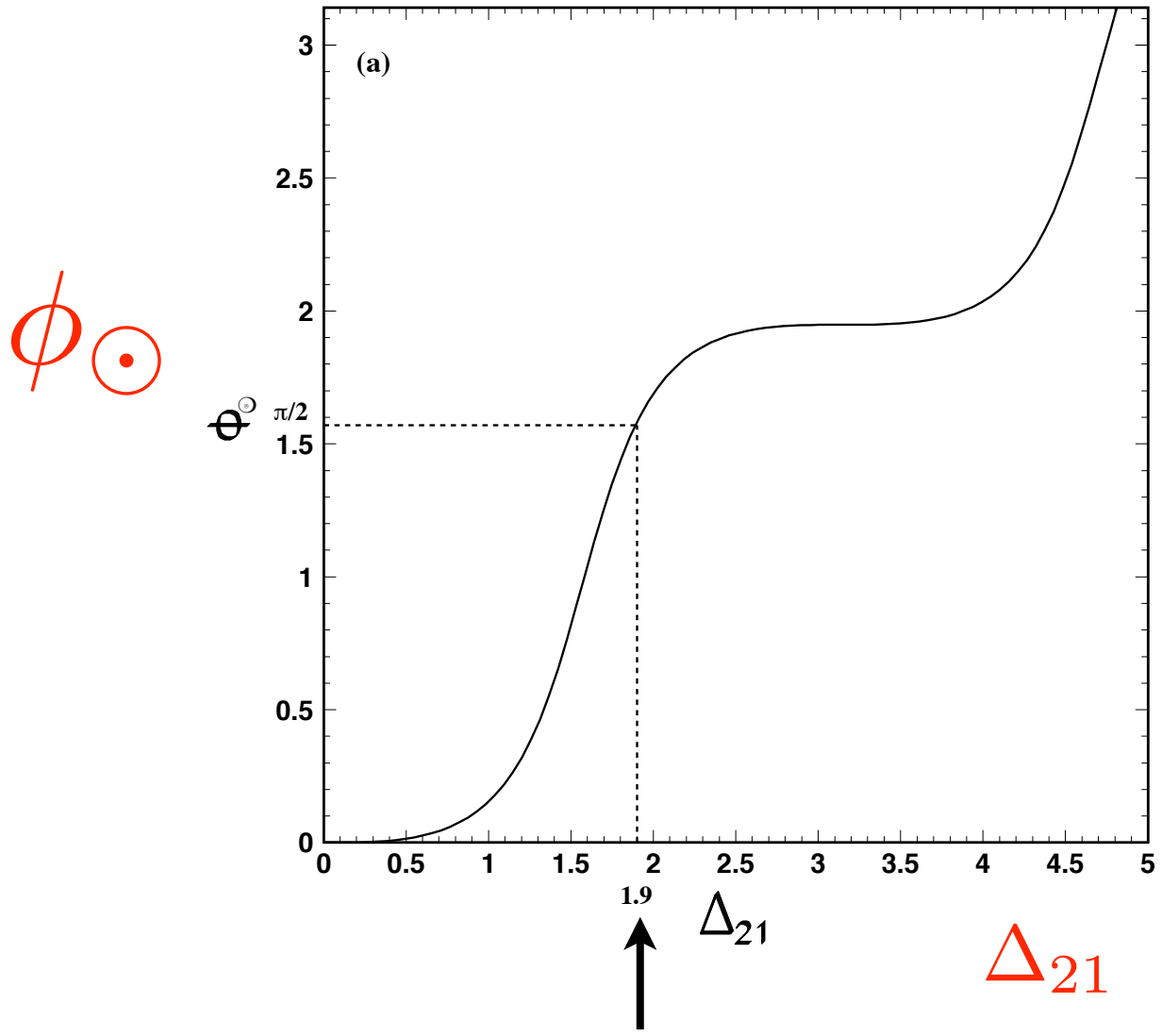
Phase Advance or Retardation

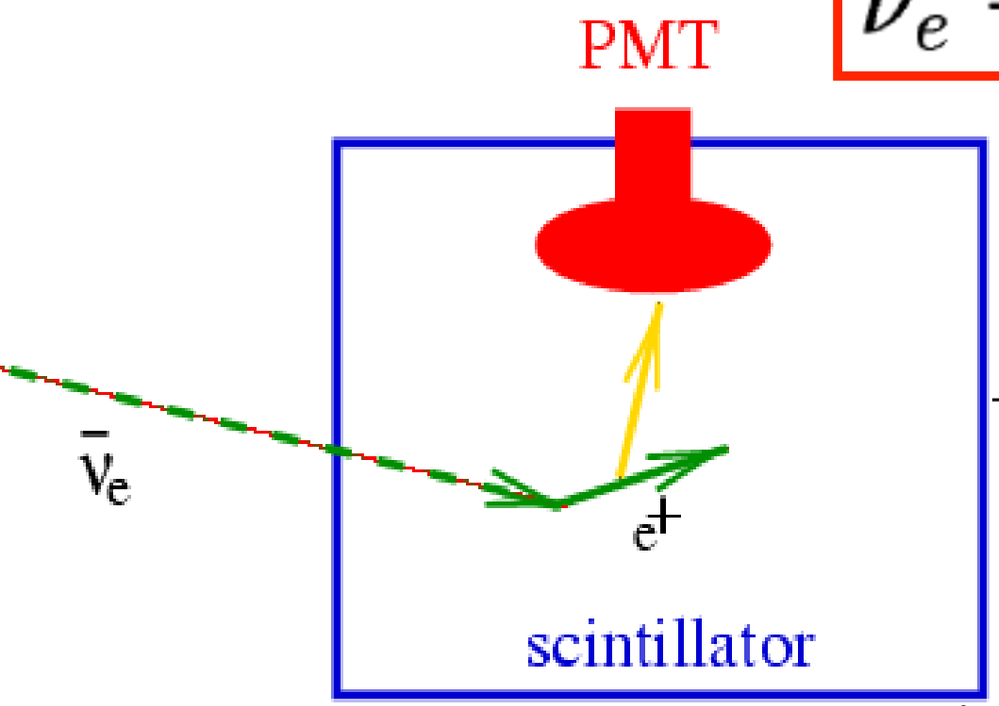


- $\phi_\odot = \arctan(\cos 2\theta_{12} \tan \Delta_{21}) - \Delta_{21} \cos 2\theta_{12}$

$$\phi_\odot(\Delta_{21} + \pi) = \phi_\odot(\Delta_{21}) + 2\pi \sin^2 \theta_{12},$$

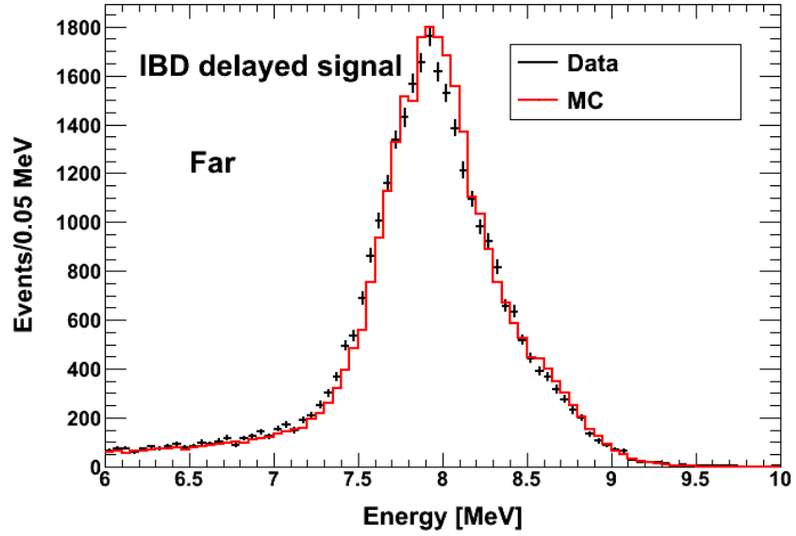
REACTOR NEUTRINOS:

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

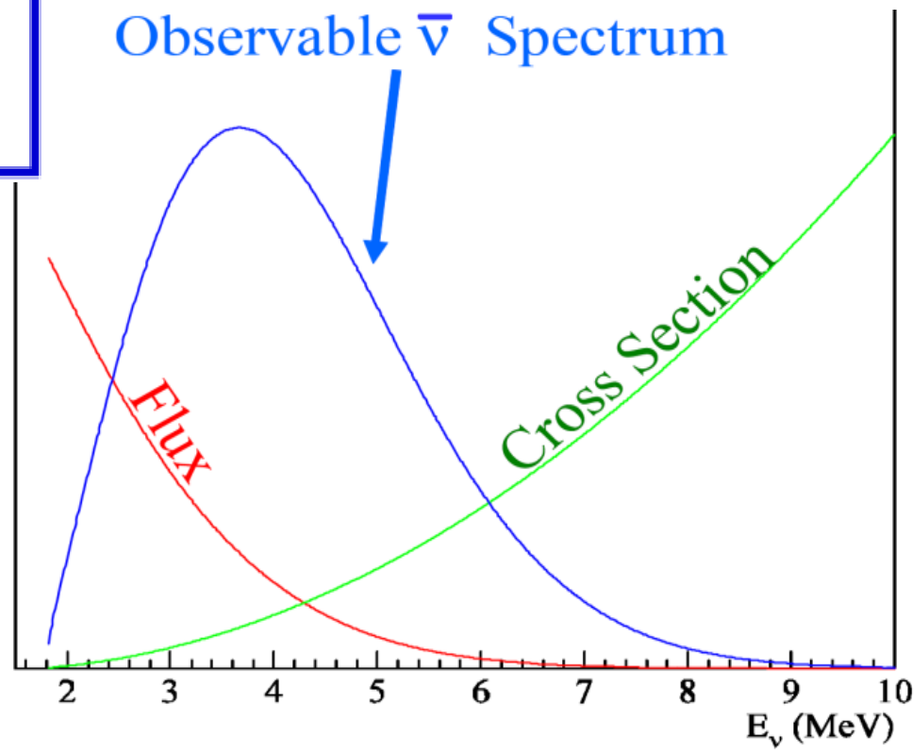


Prompt signal

delayed signal



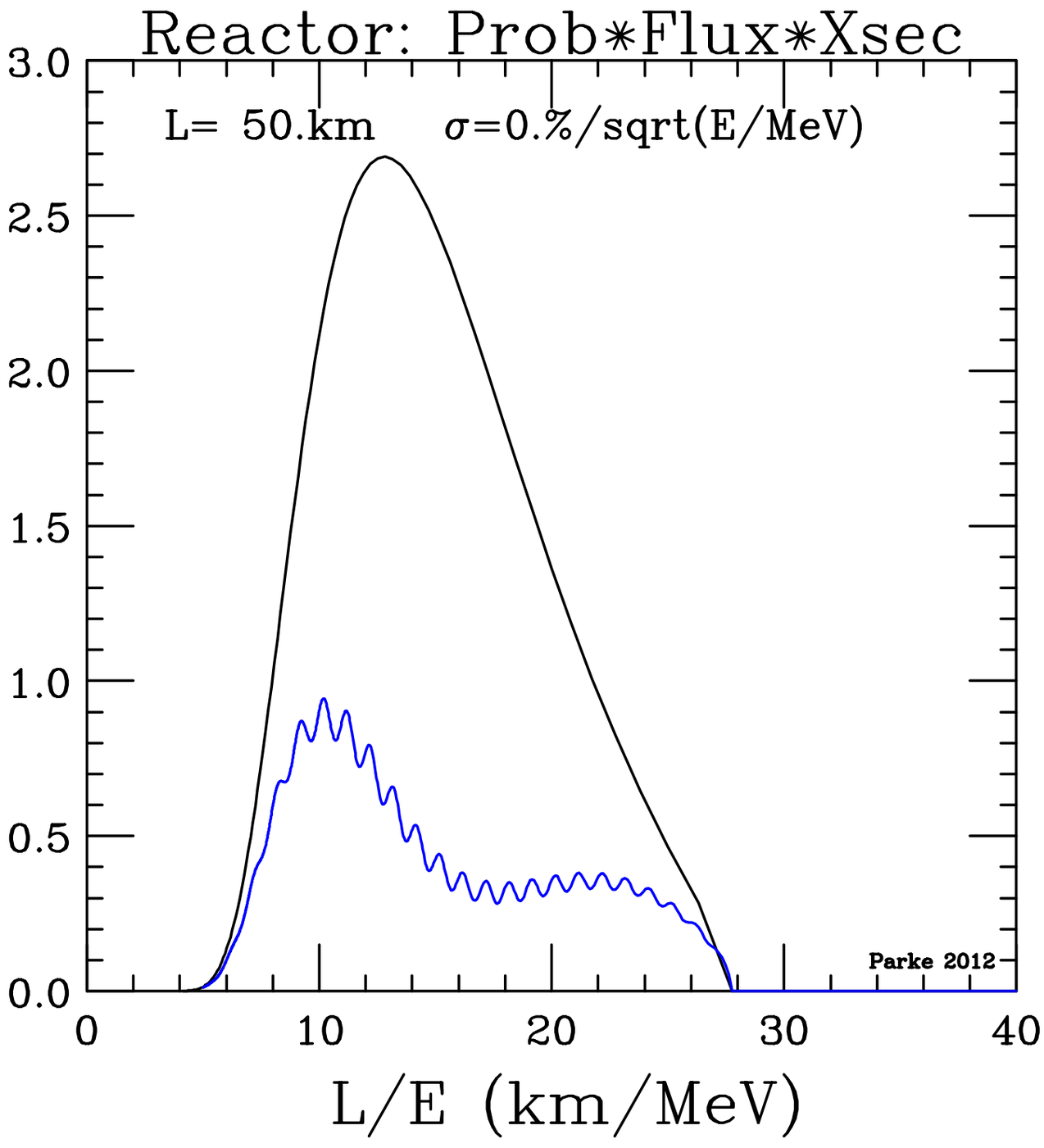
From Bemporad, Gratta and Vogel



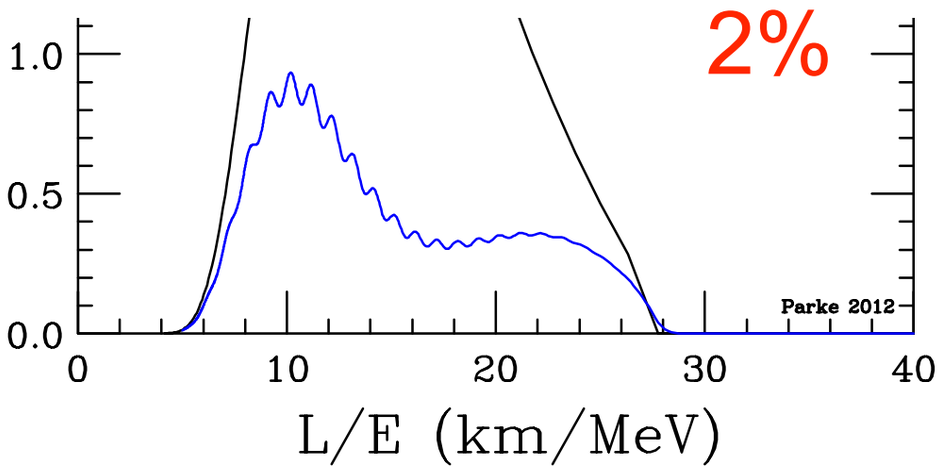
$$E_{\bar{\nu}} \cong T_{e^+} + T_n + (M_n - M_p) + m_{e^+}$$

10-40 keV *1.8 MeV*

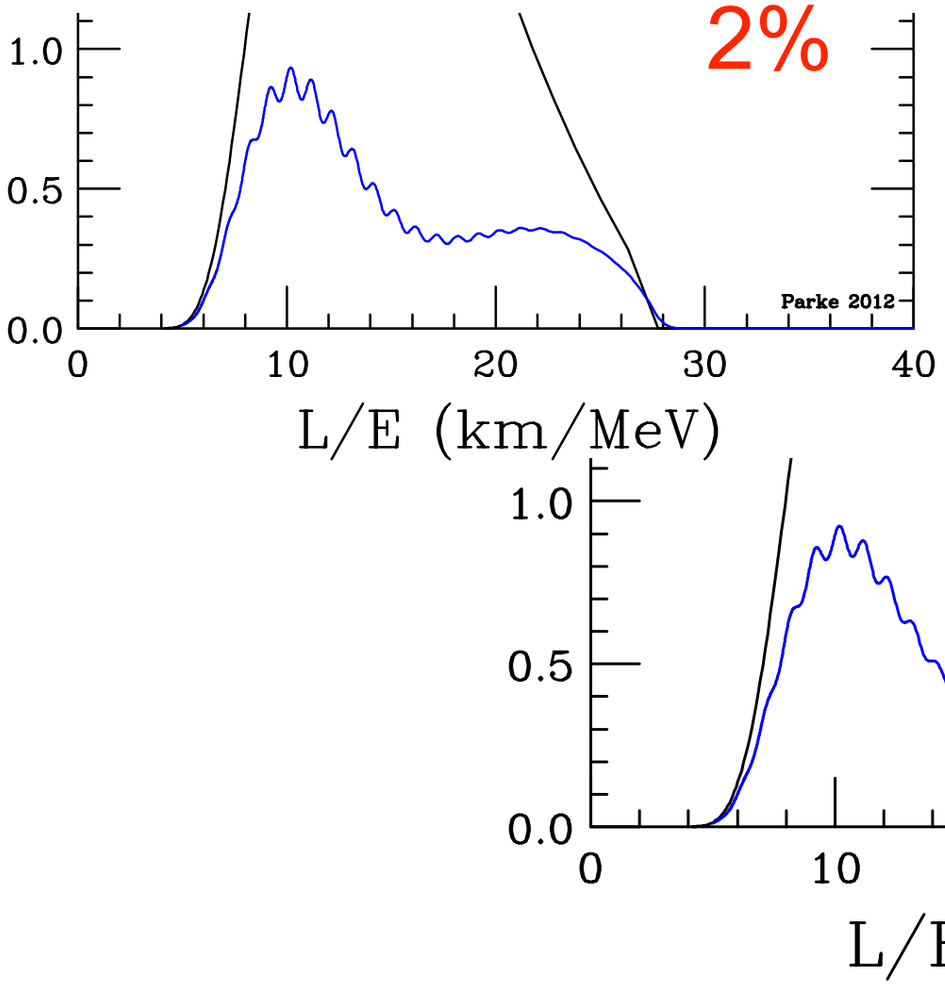
Perfect Energy Resolution:

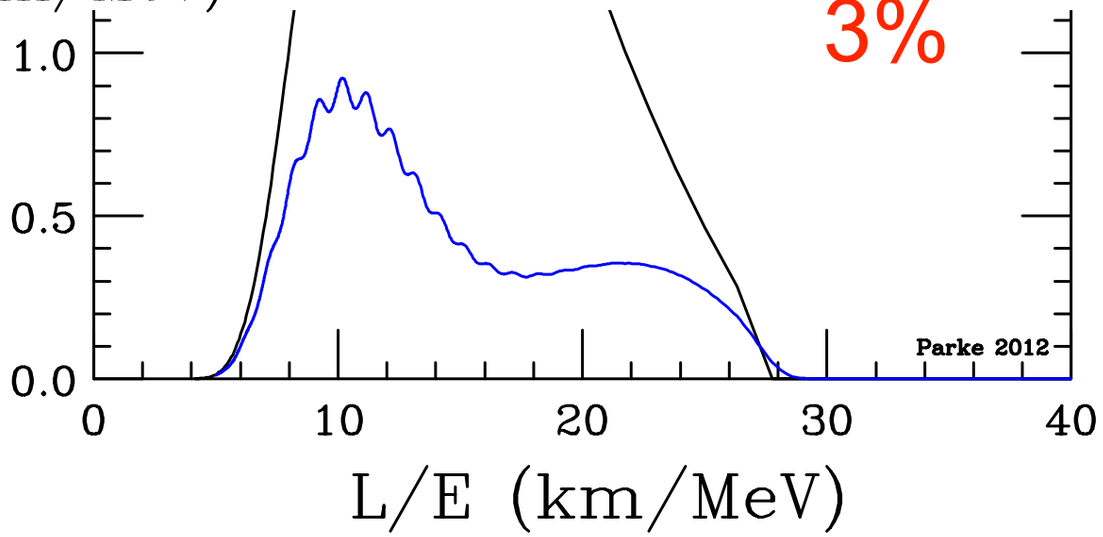


Finite Energy Resolution:

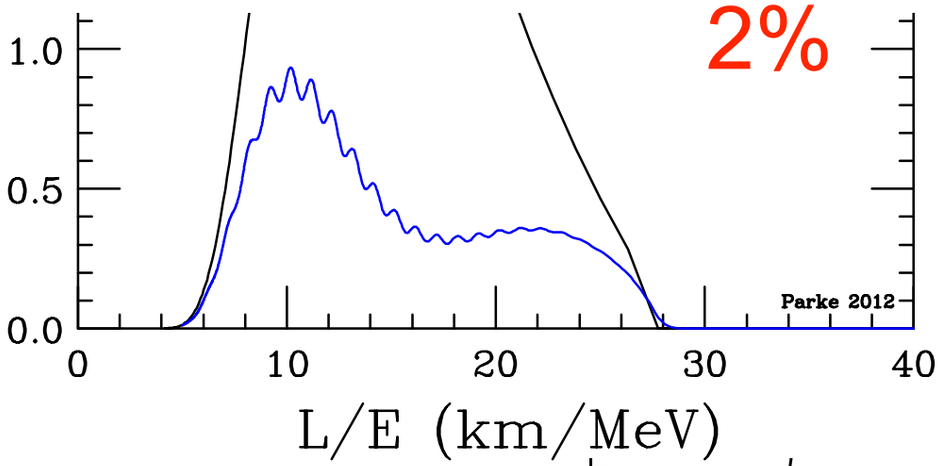


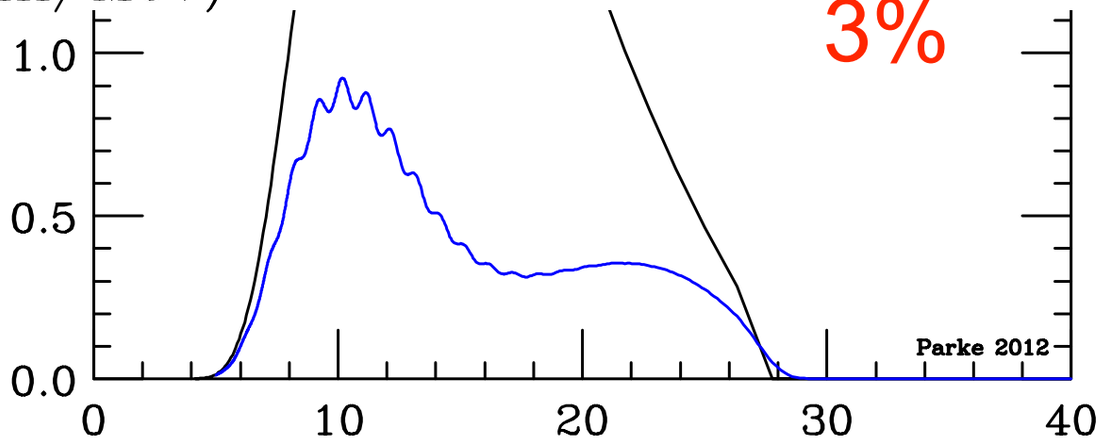
Finite Energy Resolution:

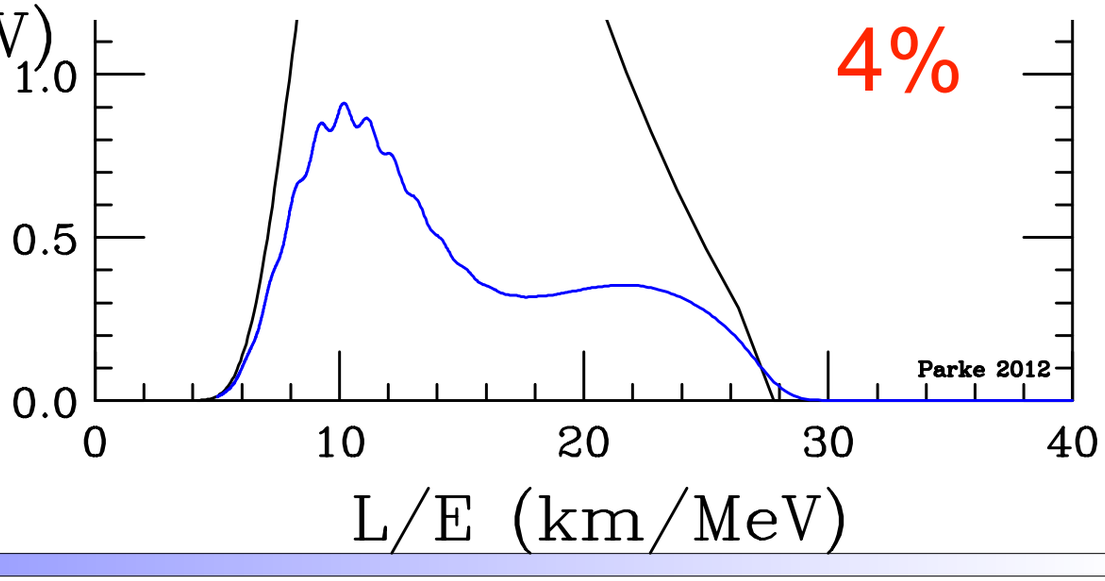




Finite Energy Resolution:

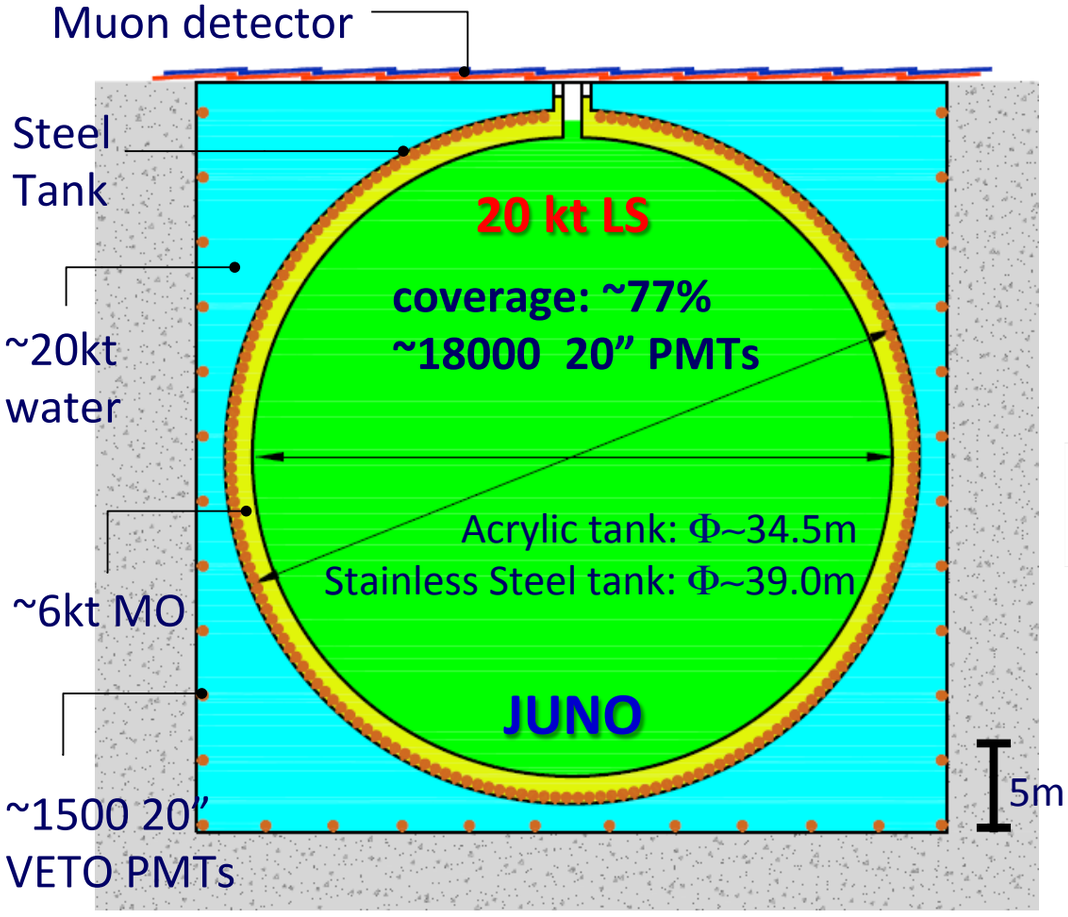




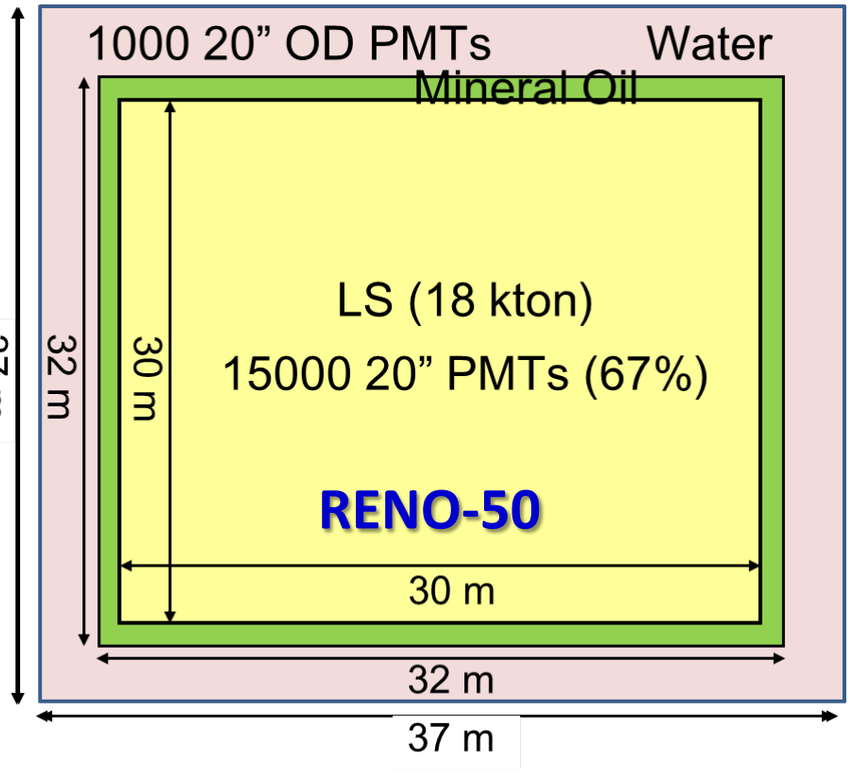


Experiments: (SK class exp.)

Challenge: high-precision, giant LS detector



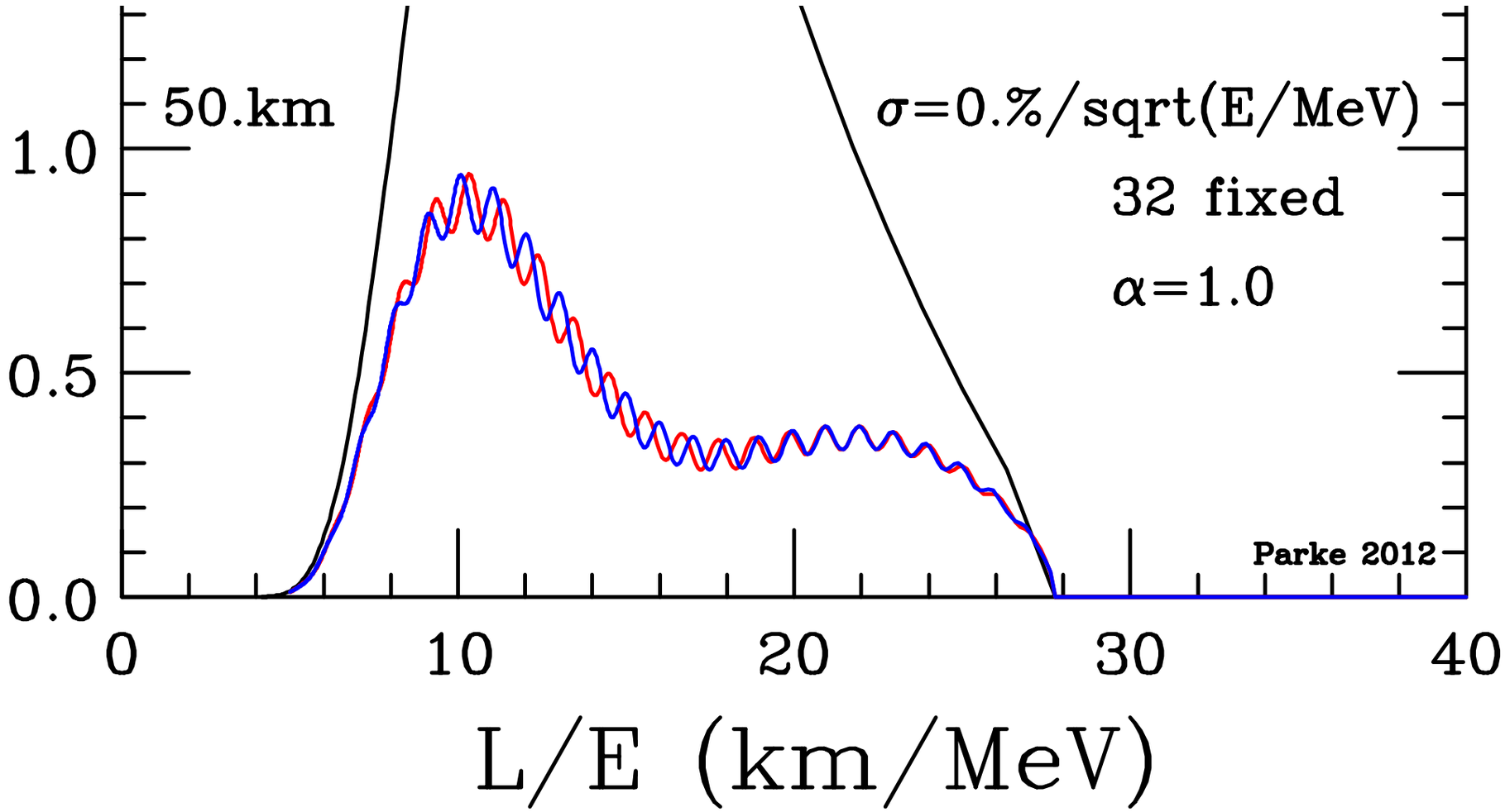
@Neutrino 2014



	KamLAND	JUNO	RENO-50
LS mass	~1 kt	20 kt	18 kt
Energy Resolution	6%/	~3%/	~3%/
Light yield	250 p.e./MeV	1200 p.e./MeV	>1000 p.e./MeV

44

Mass Hierarchy:



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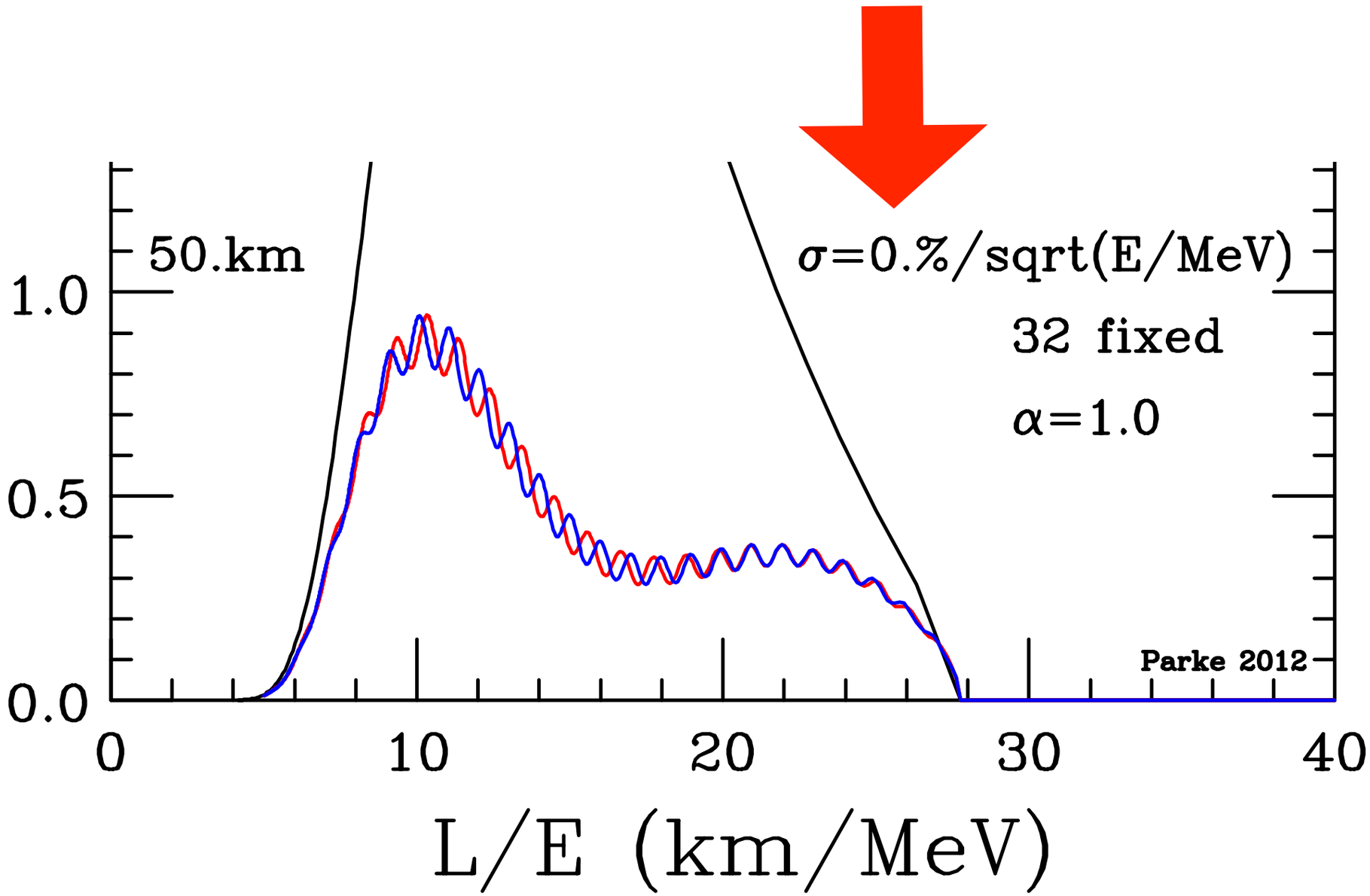

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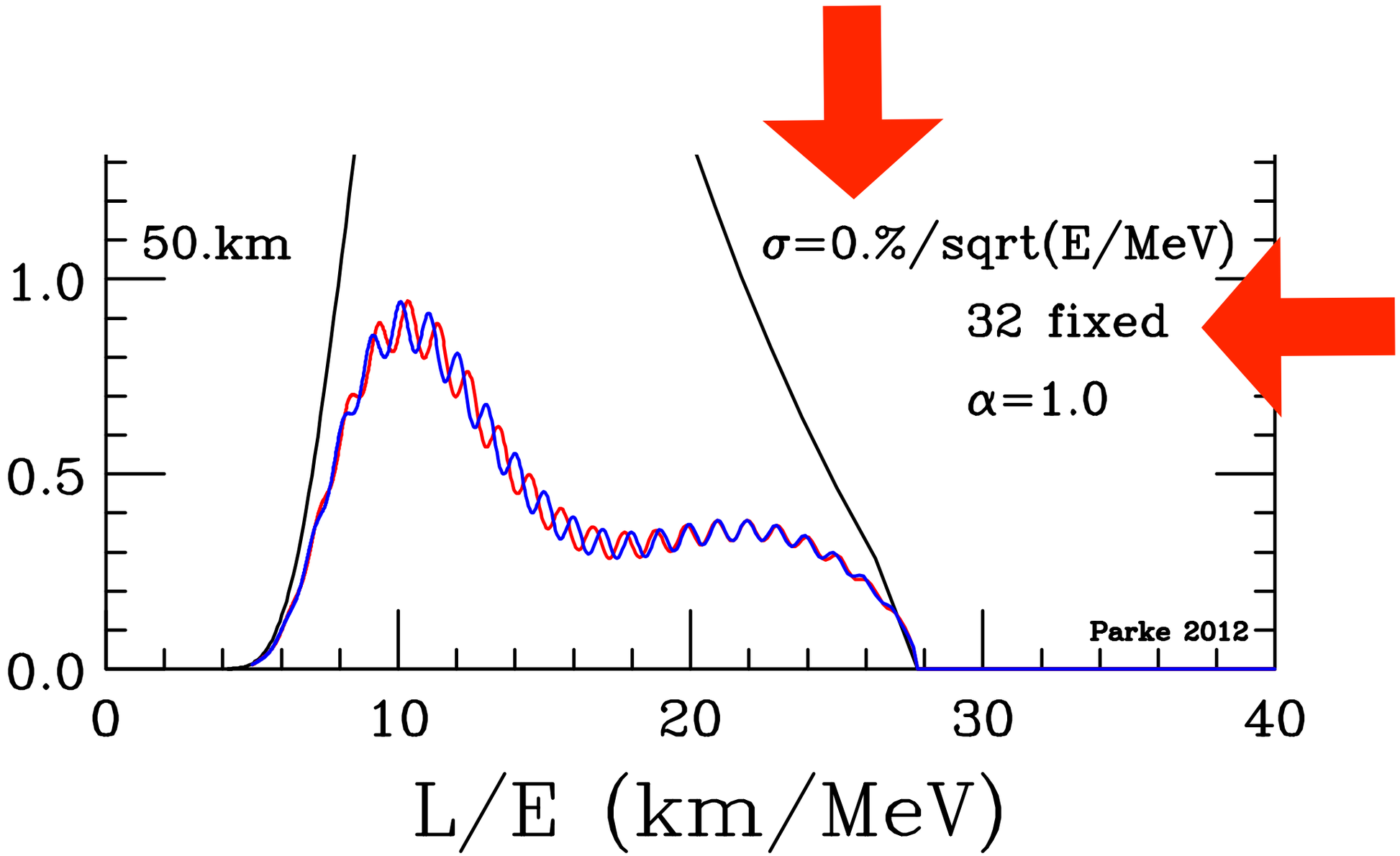
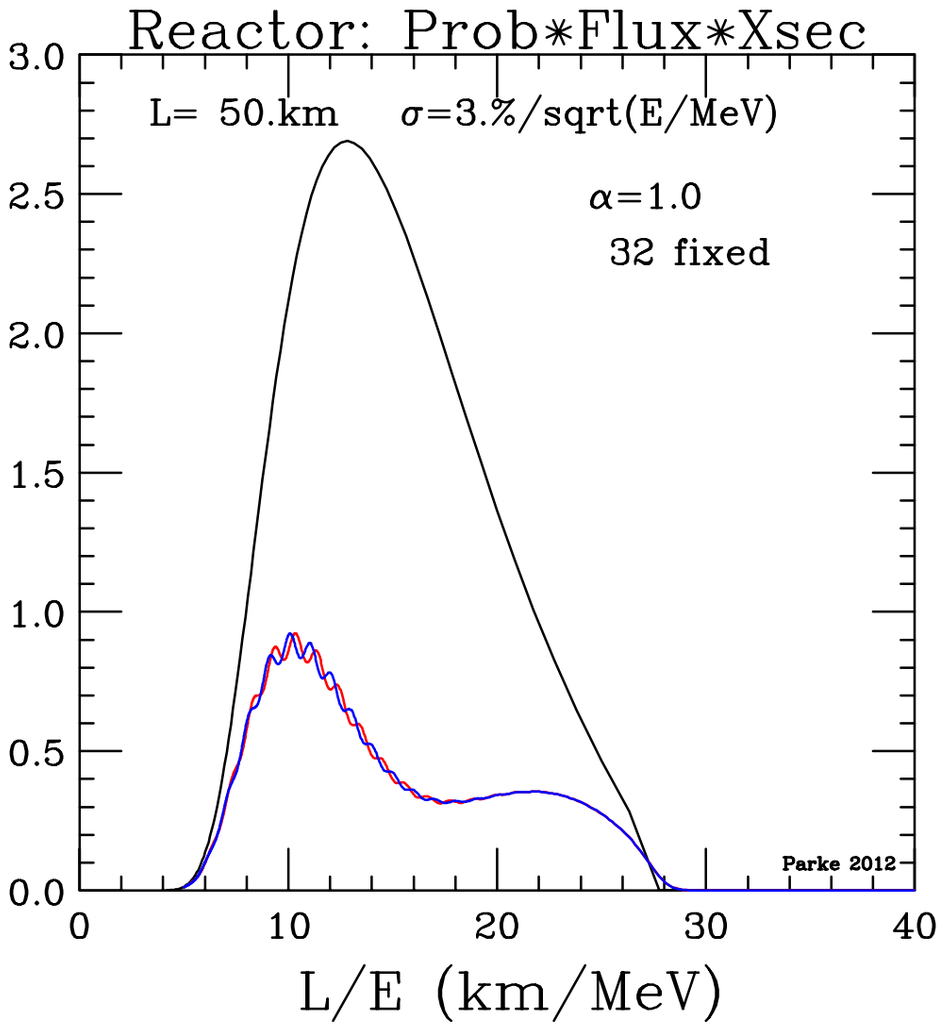
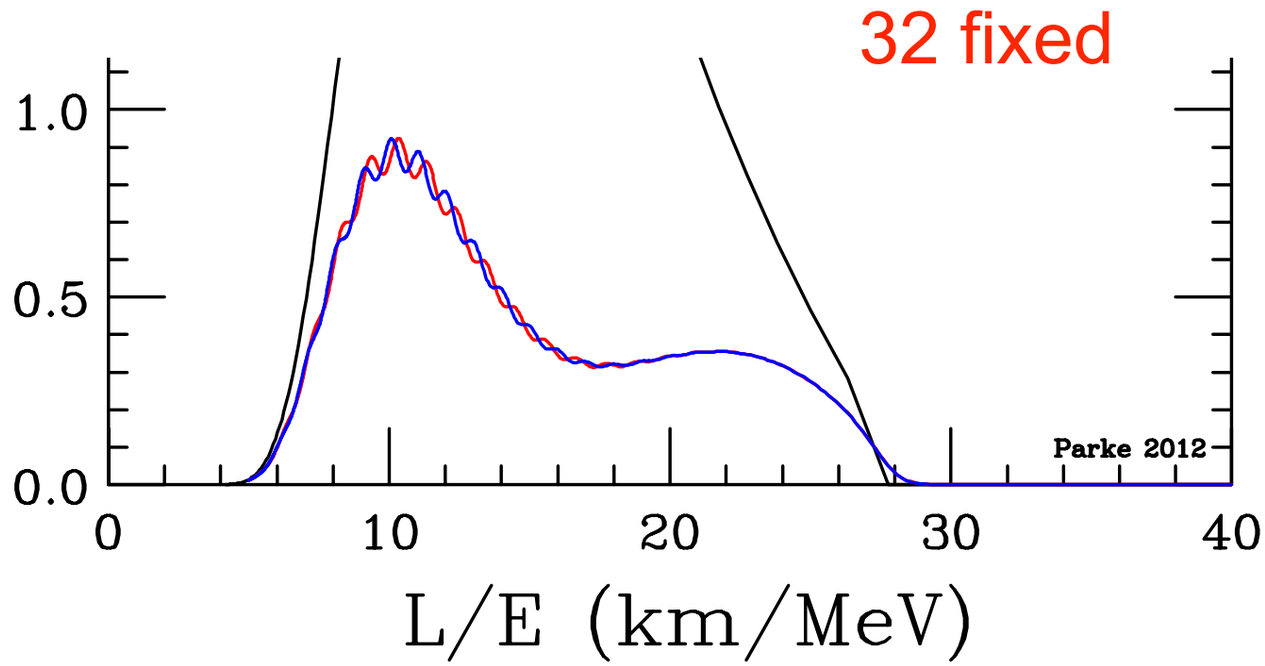
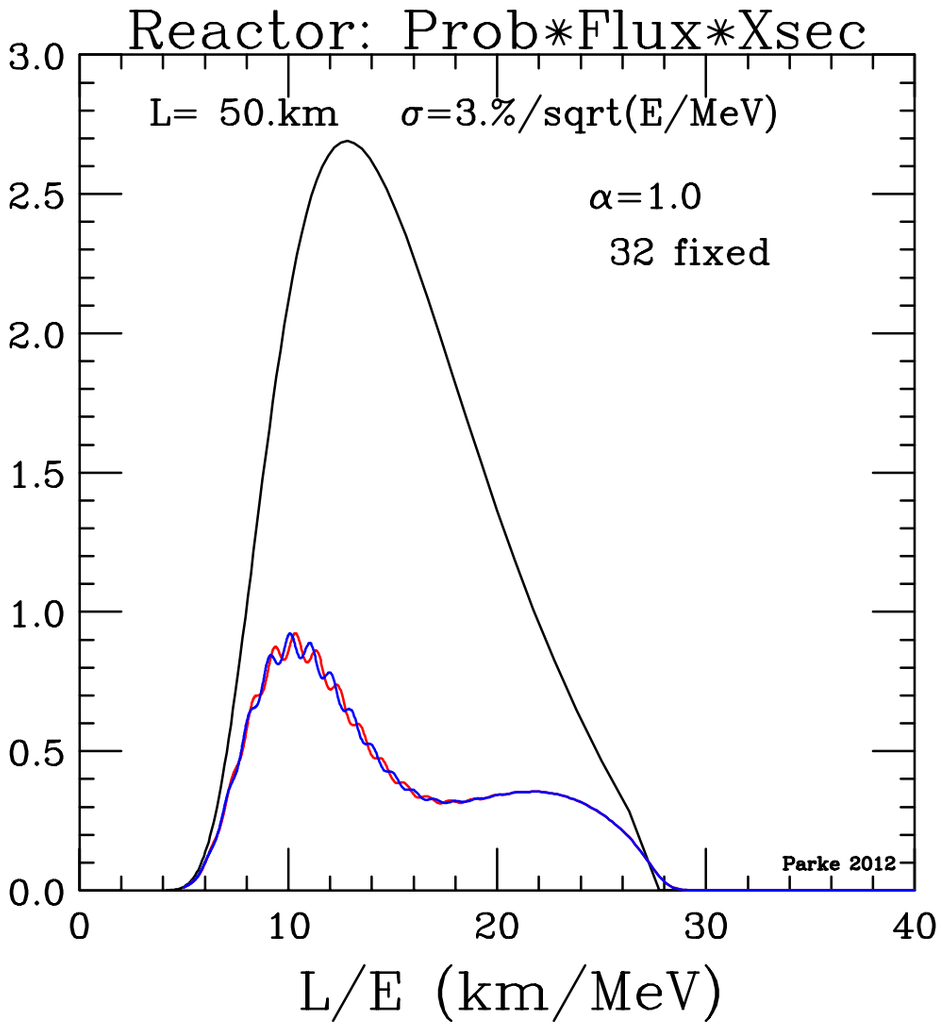


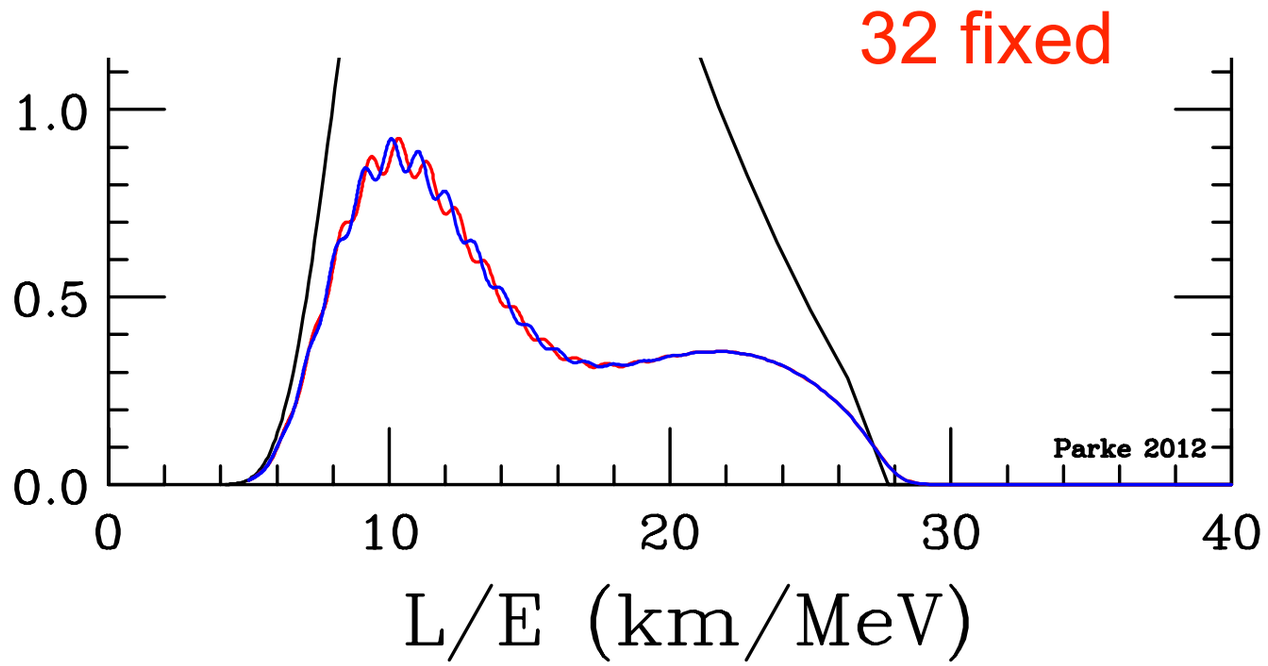
Mass Hierarchy:

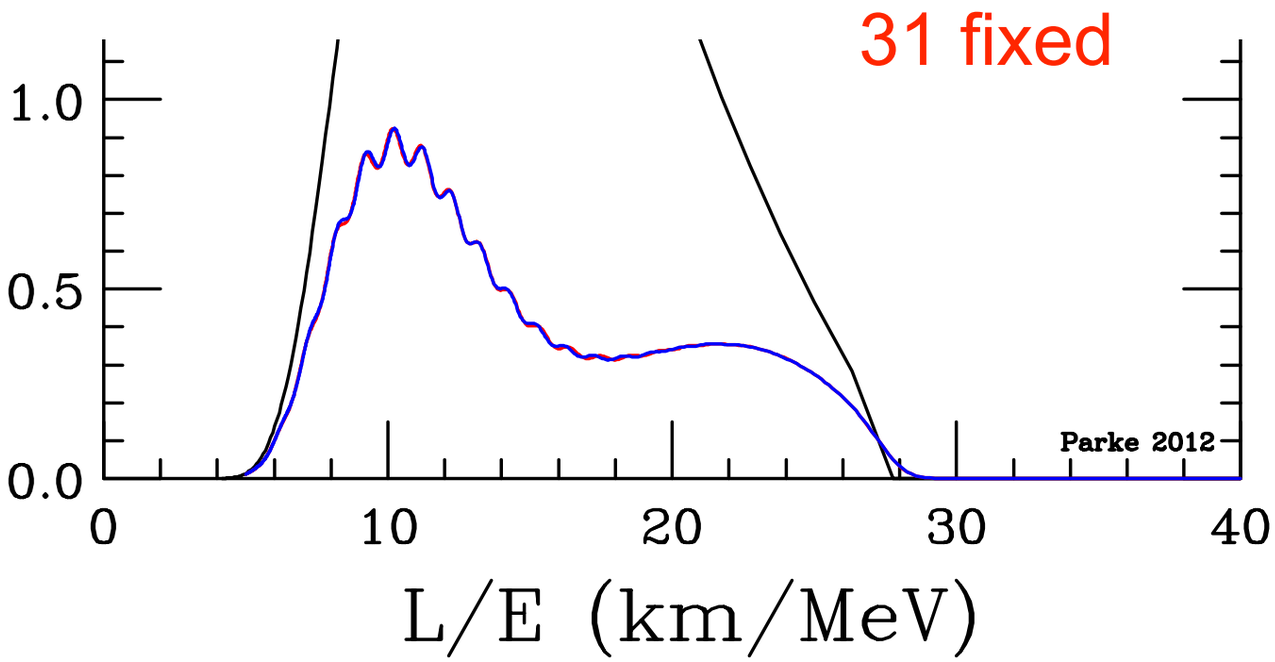




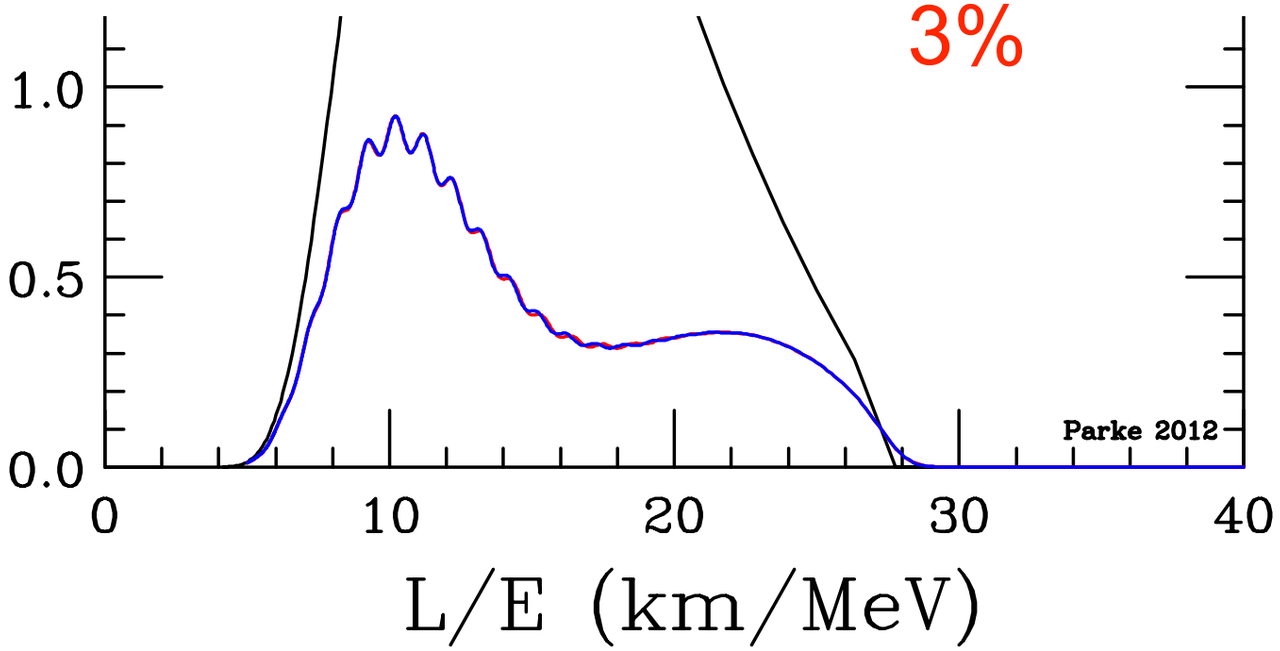
Mass Hierarchy:







Floating the delta m^2



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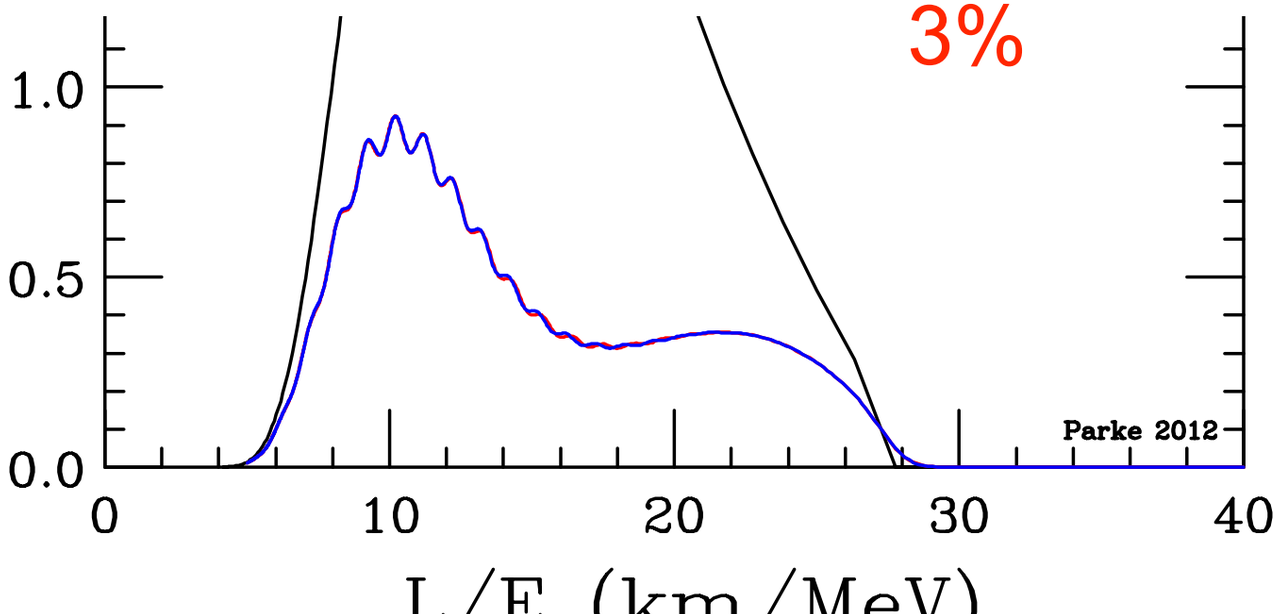

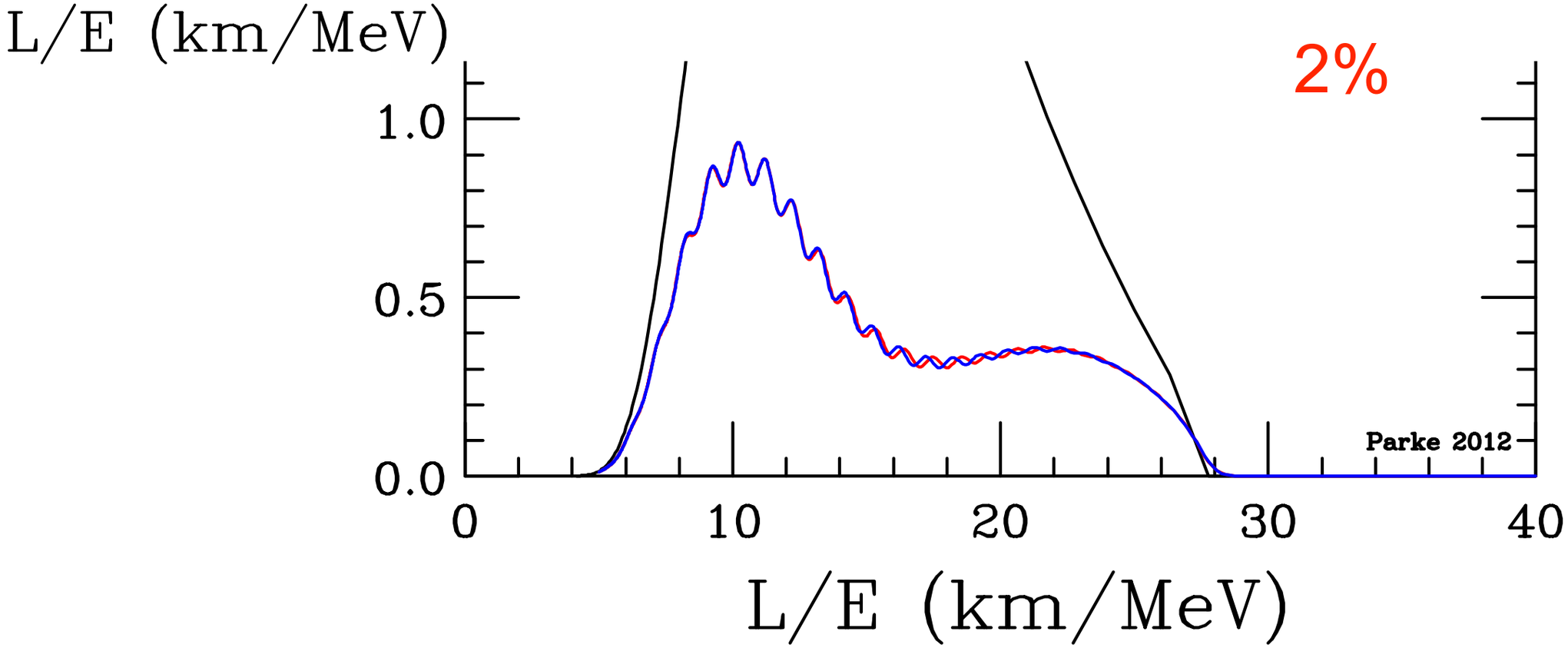

Mass Hierarchy Resolution in Reactor Anti-neutrino Experiments: Parameter Degeneracies and Detector Energy Response

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[3] *Brookhaven National Laboratory, Upton, NY*

(Dated: August 16, 2012)

arXiv:1208.1551

Determination of the neutrino mass hierarchy using a reactor neutrino experiment at ∼60 km is analyzed. Such a measurement is challenging due to the finite detector resolution, the absolute energy scale calibration, as well as the degeneracies caused by current experimental uncertainty of $|\Delta m^2_{32}|$. The standard χ^2 method is compared with a proposed Fourier transformation method. In

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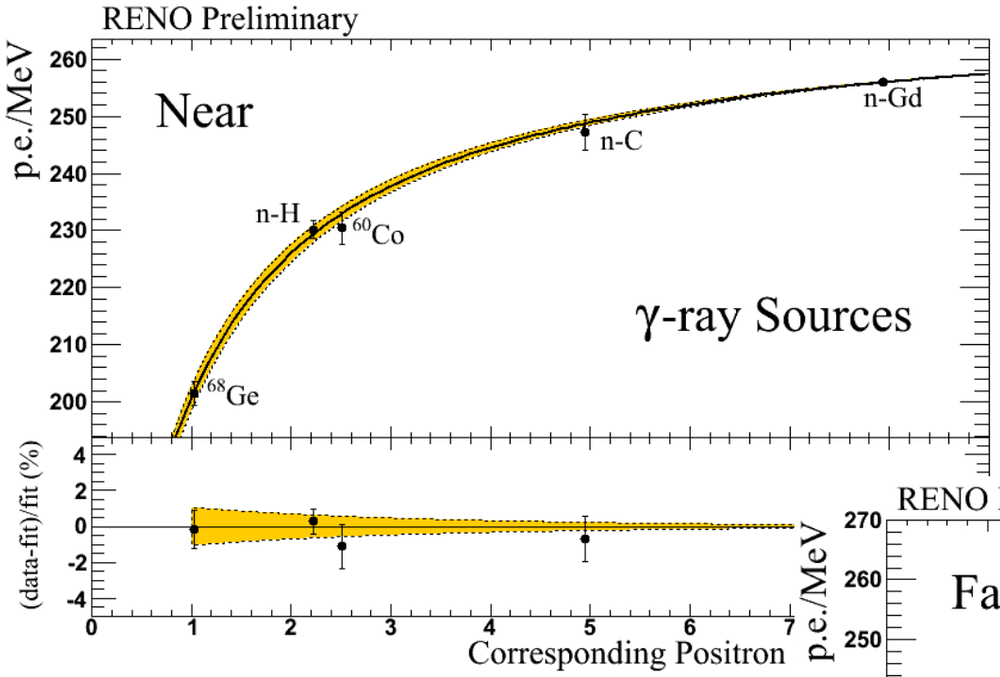
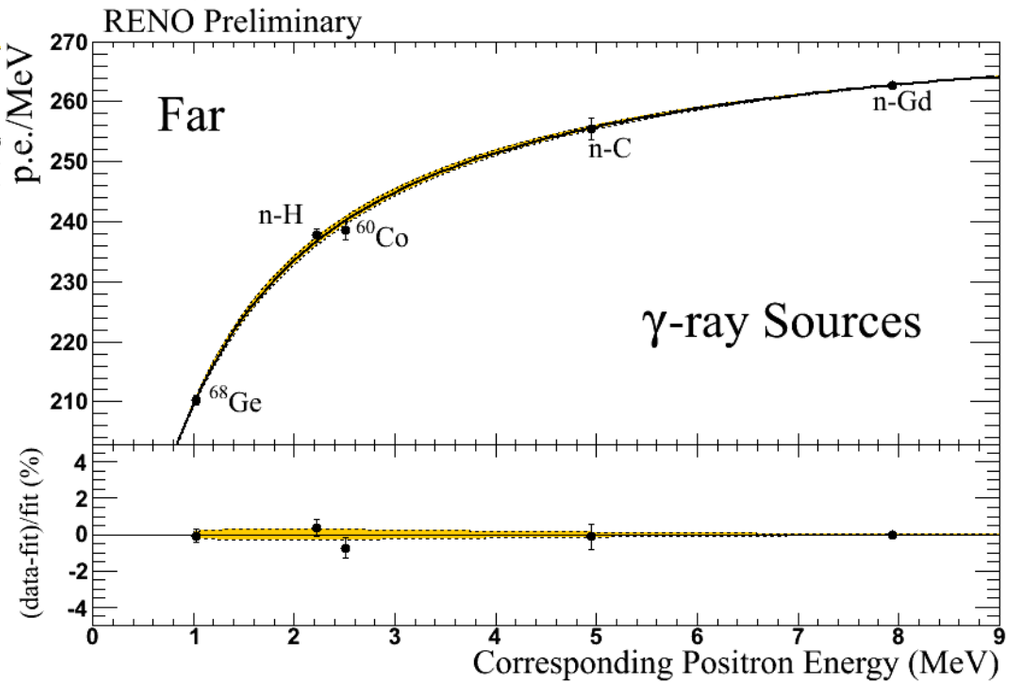
KamLAND achieved 1.9%

Energy Calibration:

Energy Calibration from γ-ray Sources



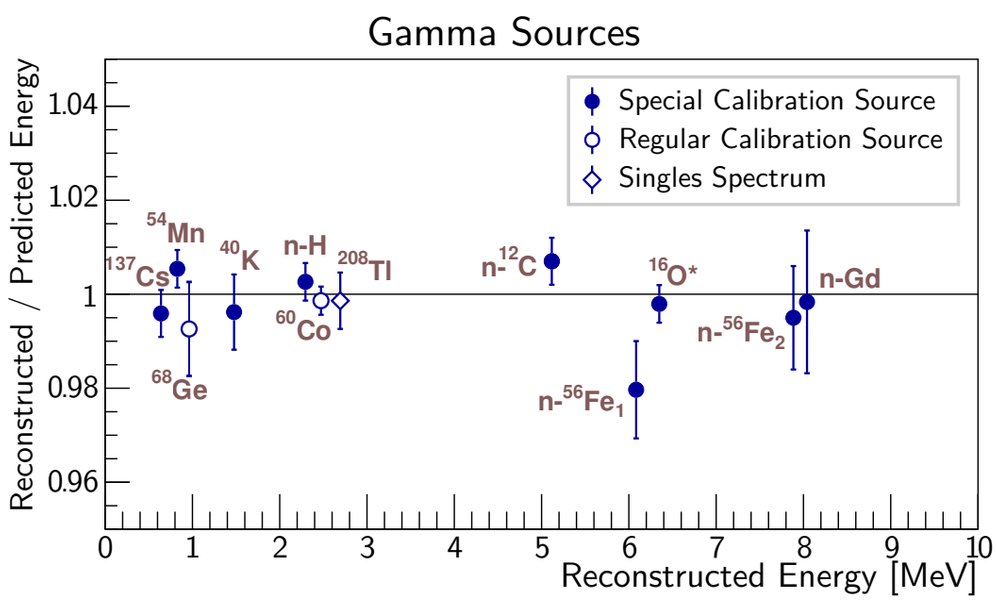


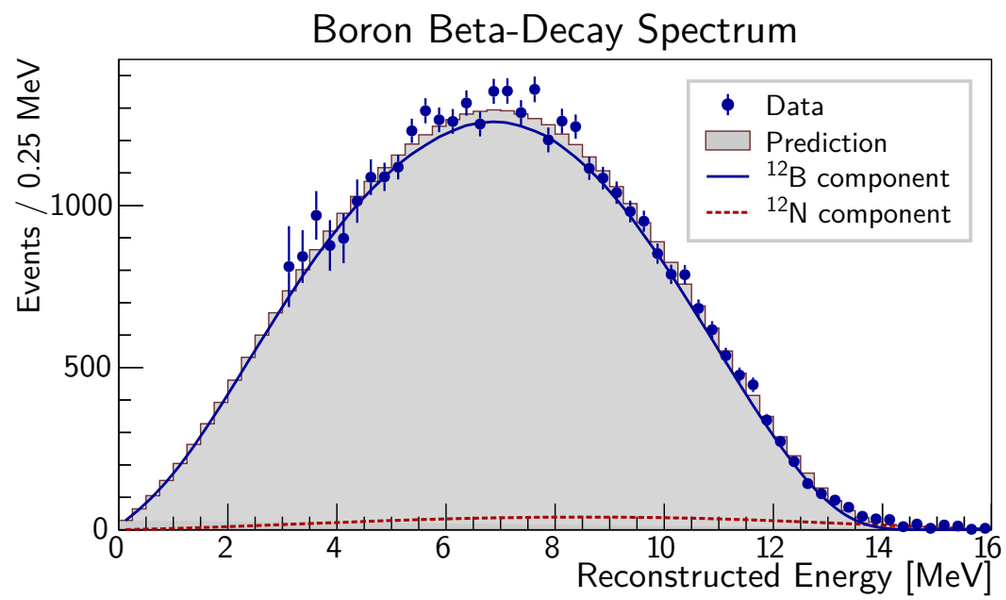
RENO

→ Obtain p.e. to MeV Conversion function

Daya Bay

Constraining Non-Linearity Parameters





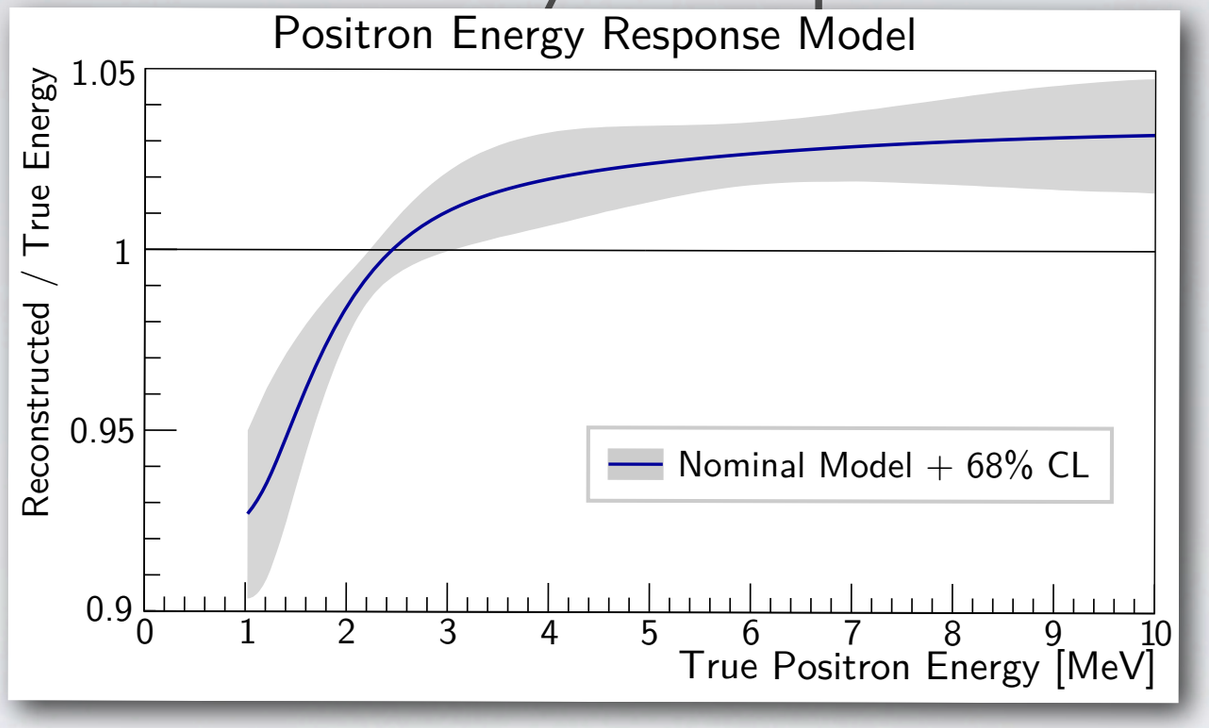
Full detector calibration data

1. Monoenergetic gamma lines from various sources
   - Radioactive calibration sources, employed regularly: ^{68}Ge, ^{60}Co, ^{241}Am-^{13}C and during special calibration periods: ^{137}Cs, ^{54}Mn, ^{40}K, ^{241}Am-^{9}Be, Pu-^{13}C
   - Singles and correlated spectra in regular physics runs (^{40}K, ^{208}Tl, n capture on H)
2. Continuous spectrum from ^{12}B produced by muon spallation inside the scintillator

Standalone measurements

- Scintillator quenching measurements using neutron beams and Compton e^-
- Calibration of readout electronics with flash ADC

Final Positron Energy Non-Linearity response

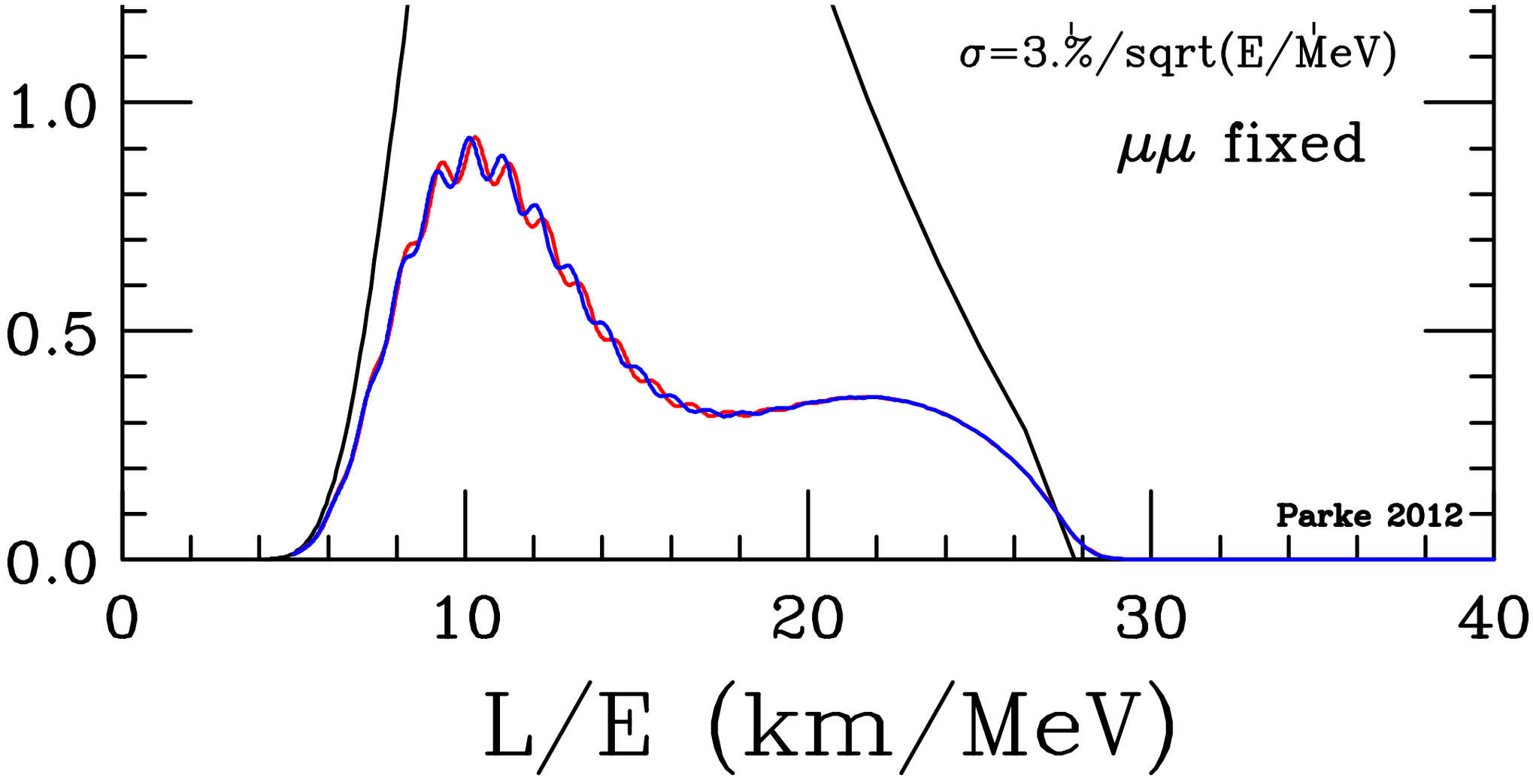


Several validated models

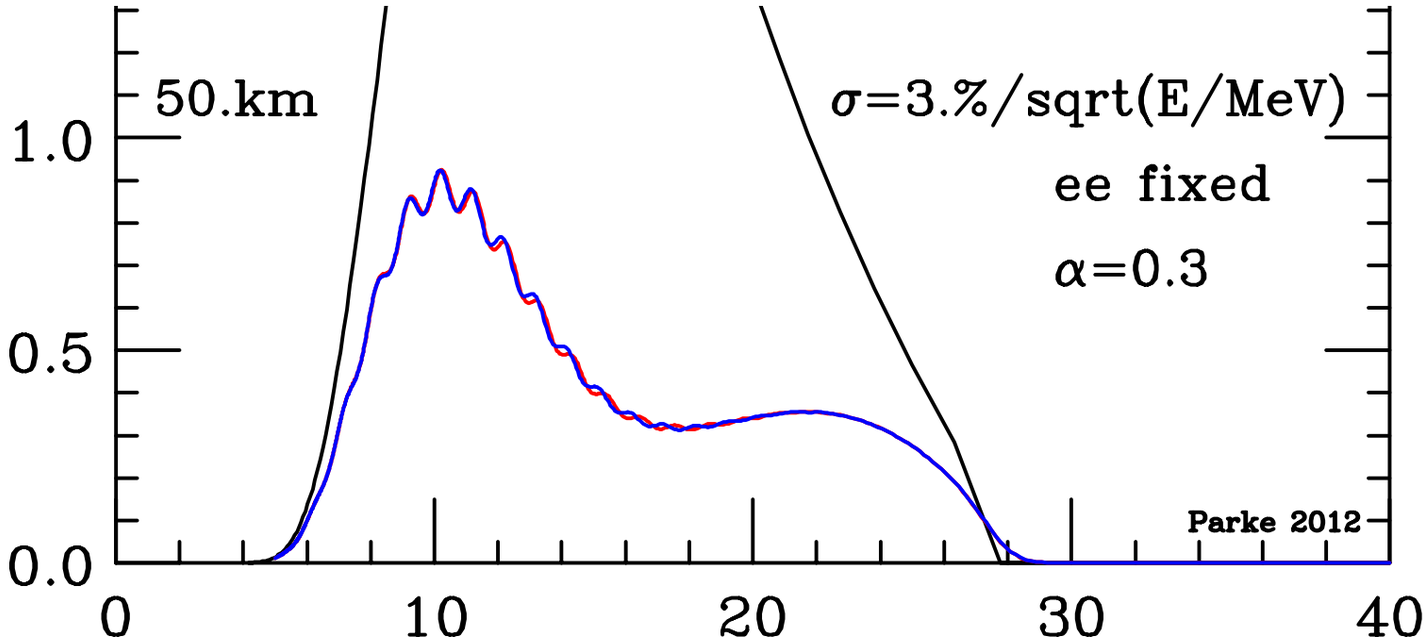
- Constructed based on different parameterizations/weighting of data constraints
- All models in good agreement with detector calibration data
- Resulting positron non-linearity curves consistent within $\sim 1.5\%$ uncertainty

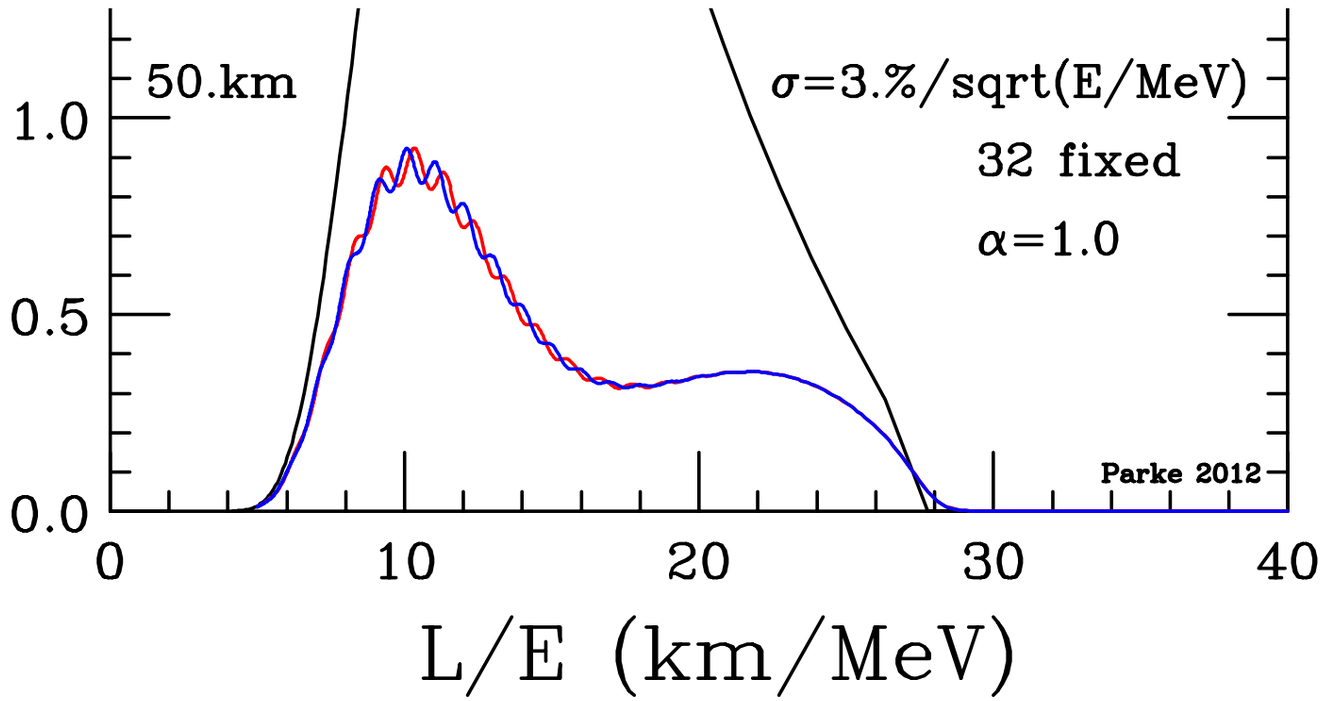
Used combination of 5 models to conservatively estimate uncertainty

Other Constraints:



-/+ 1 %


50.km
σ=3.%/sqrt(E/MeV)
ee fixed
α=0.3
Parke 2012
1.0
0.5
0.0
0
10
20
30
40
L/E (km/MeV)


50.km
σ=3.%/sqrt(E/MeV)
32 fixed
α=1.0
Parke 2012
1.0
0.5
0.0
0
10
20
30
40
L/E (km/MeV)

R&D needed

- Energy Resolution to 3% or lower at 1 MeV
- Linearity to sub 1% precision for the reconstructed neutrino energy

	KamLAND	JUNO	RENO-50	
LS mass	~1 kt	20 kt	18 kt	20 x
Energy Resolution	6%/	~3%/	~3%/	
Light yield	250 p.e./MeV	1200 p.e./MeV	>1000 p.e./MeV	4 x
Linearity	1.9%	< 0.5%	< 0.5%	> 4 x

Resolution/Linearity Seesaw:

Resolution/Linearity Seesaw:

RESOLUTION

LINEARITY