Neutrino physics: an introduction

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Outline

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What are neutrinos

- Particles that accompany radioactive β decay
- Byproducts of nuclear reactions
- The most abundant particles
- The lightest massive particles
- The most weakly interacting particles
- Particles that break left-right (mirror) symmetry maximally
- Particles that may be their own antiparticles
- Particles that have always given unexpected new results

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Current excitement in neutrinos

- Solar neutrino problem
- Atmospheric neutrino problem
- Cosmology: structure formation, CMBR anisotropy
- Matter-antimatter asymmetry

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Aspects of neutrino physics

- Postulation of neutrino: β decay kinematics
- Discoveries of the three neutrinos ν_e, ν_μ, ν_τ
- Direct measurement of neutrino mass
- Violation of left-right symmetry: Wu's experiment
- Atmospheric neutrino problem:
  quantum mechanics of neutrino oscillations
- Solar neutrino problem:
  matter effects on neutrino oscillations
- Open questions in neutrino physics
- Current activities in neutrino physics

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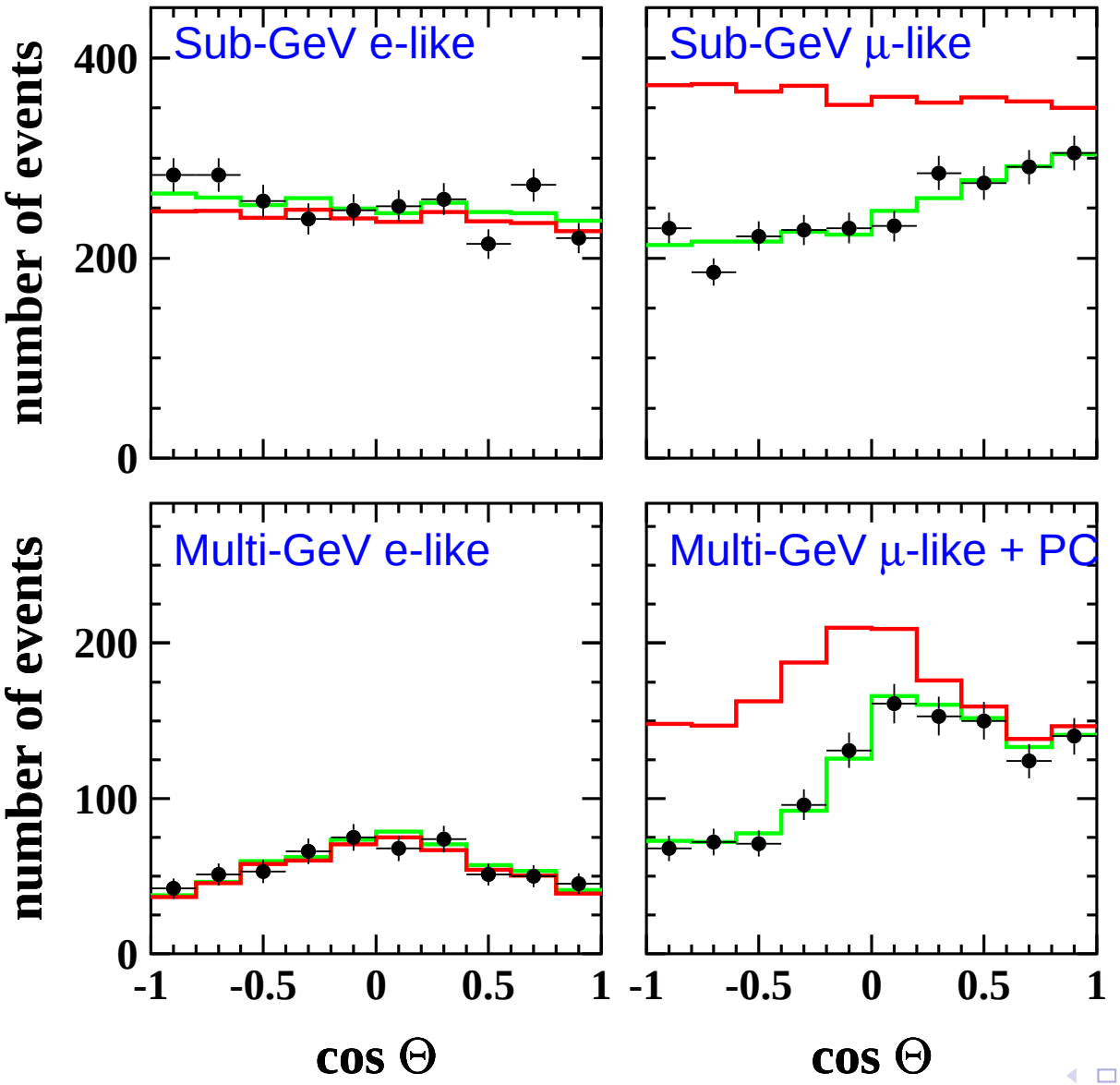
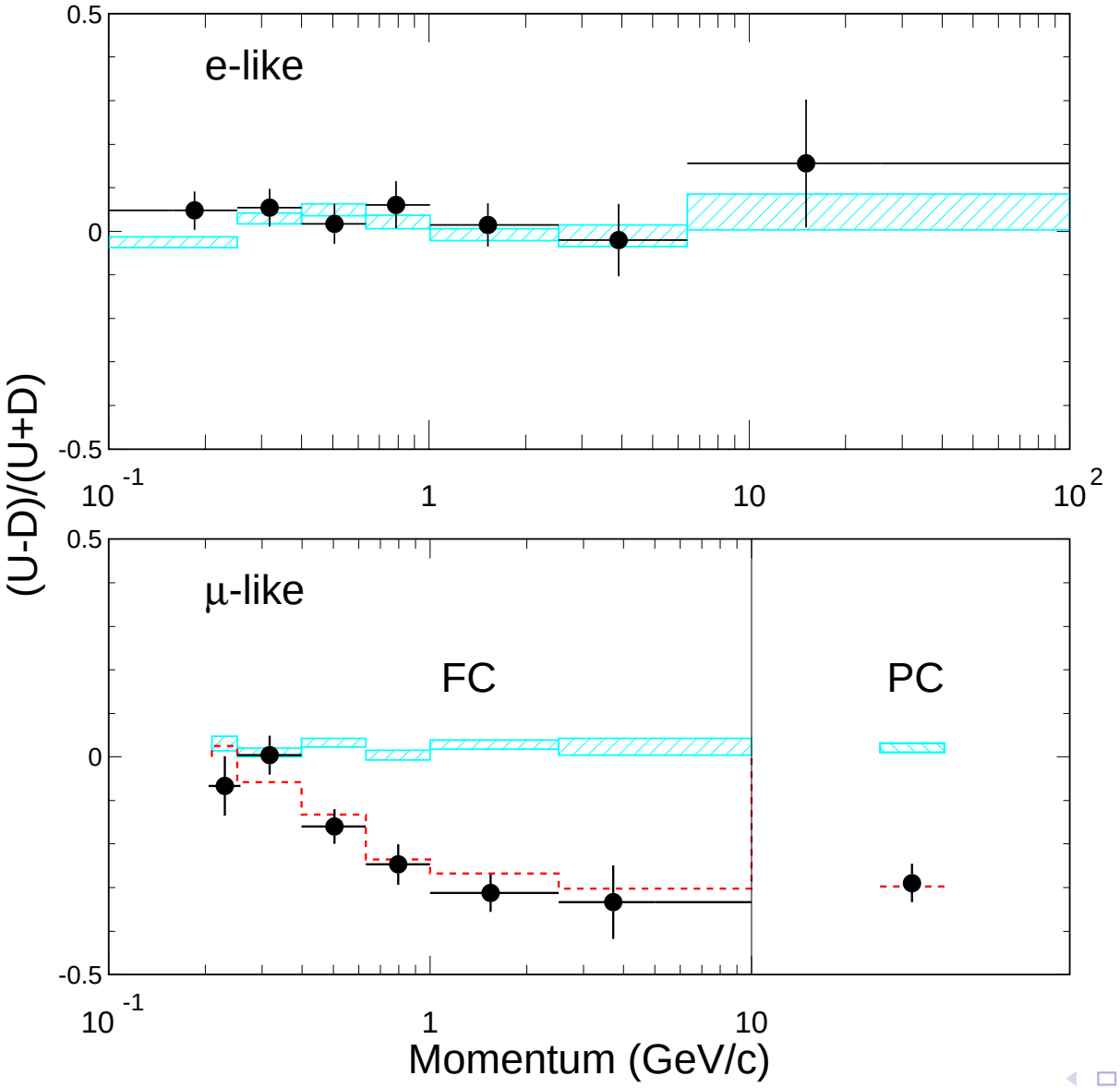
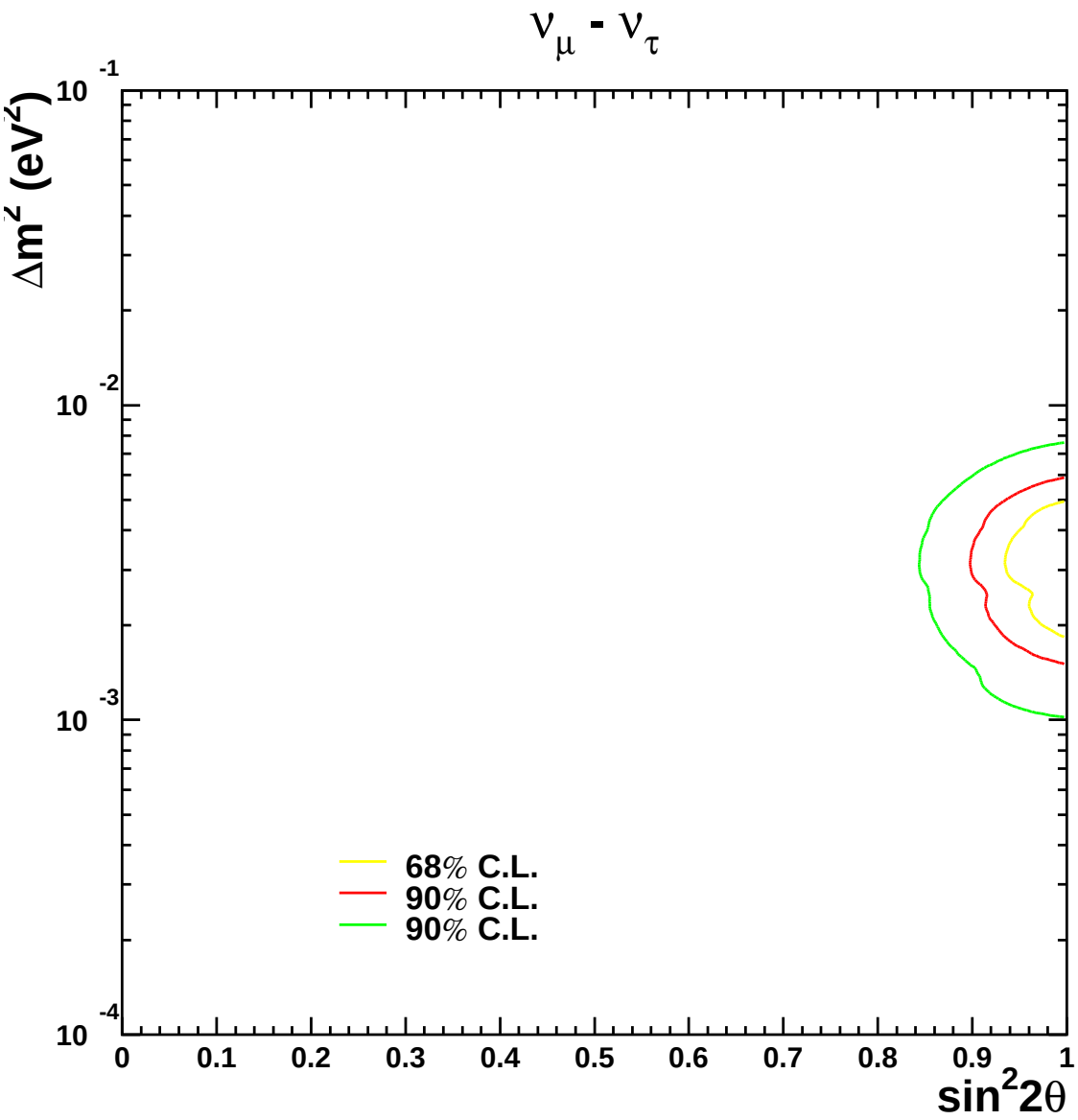
Zenith angle dependence



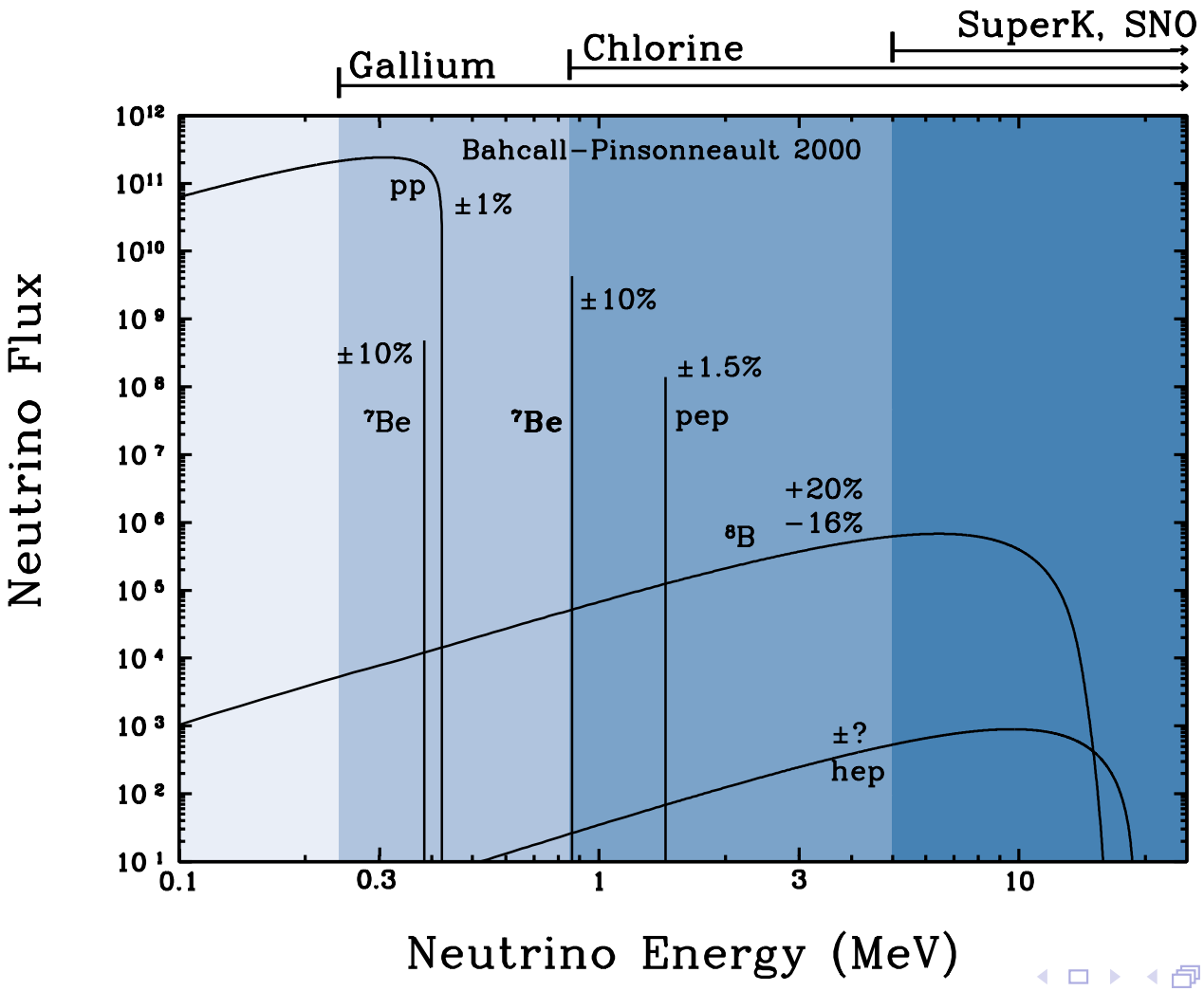
Up-down asymmetry



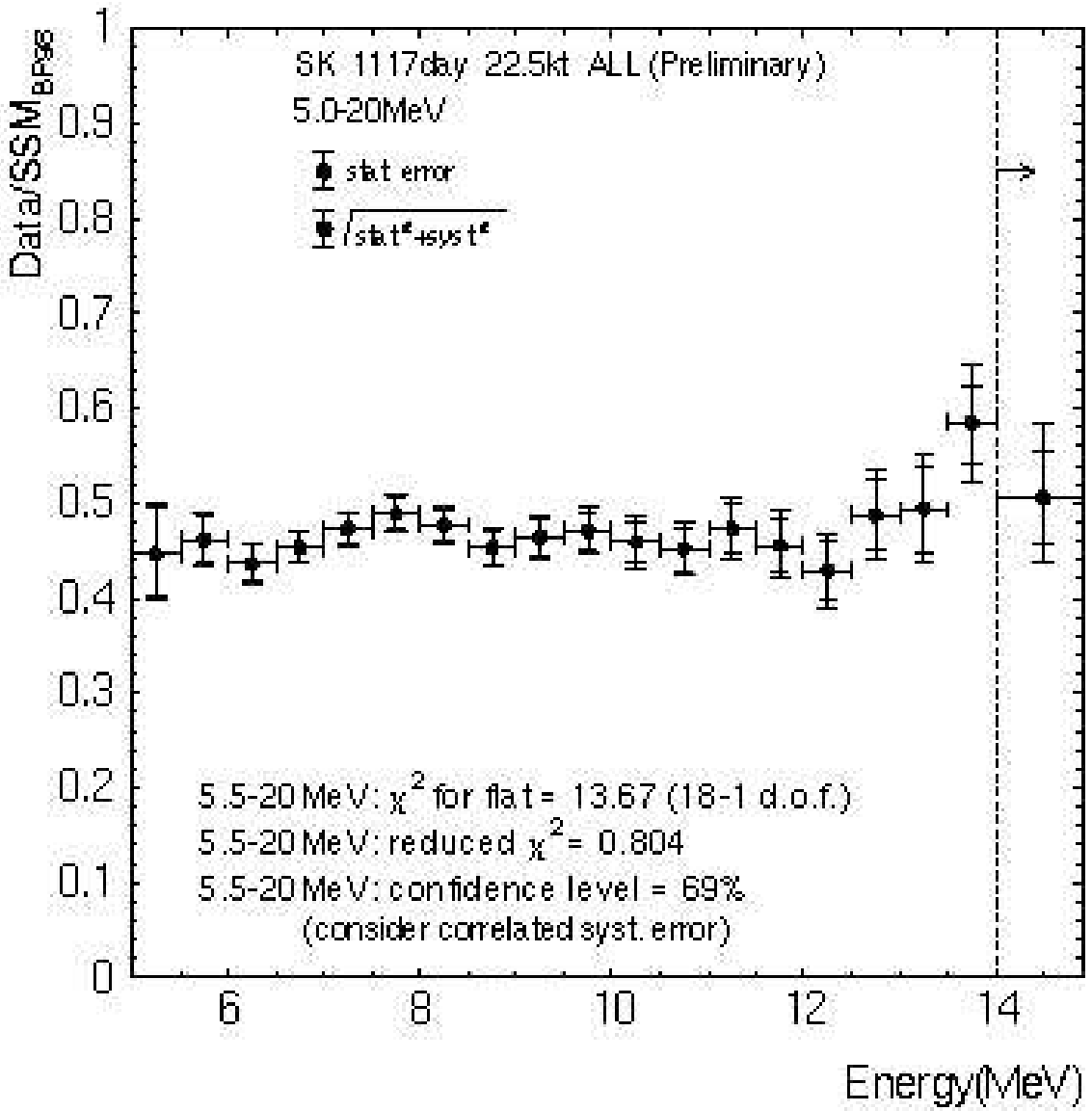
Solution to the atmospheric neutrino problem



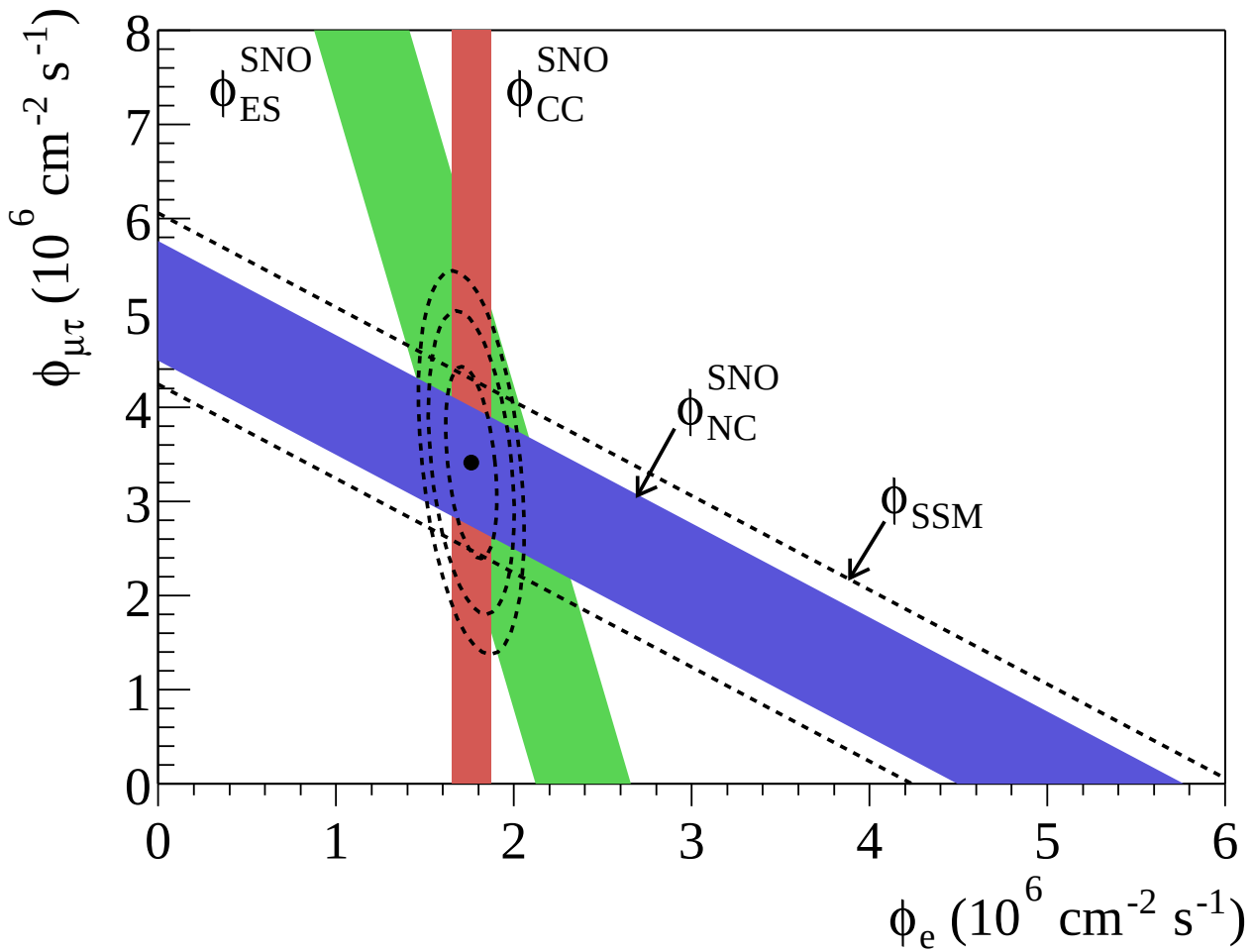
Spectra of solar neutrinos



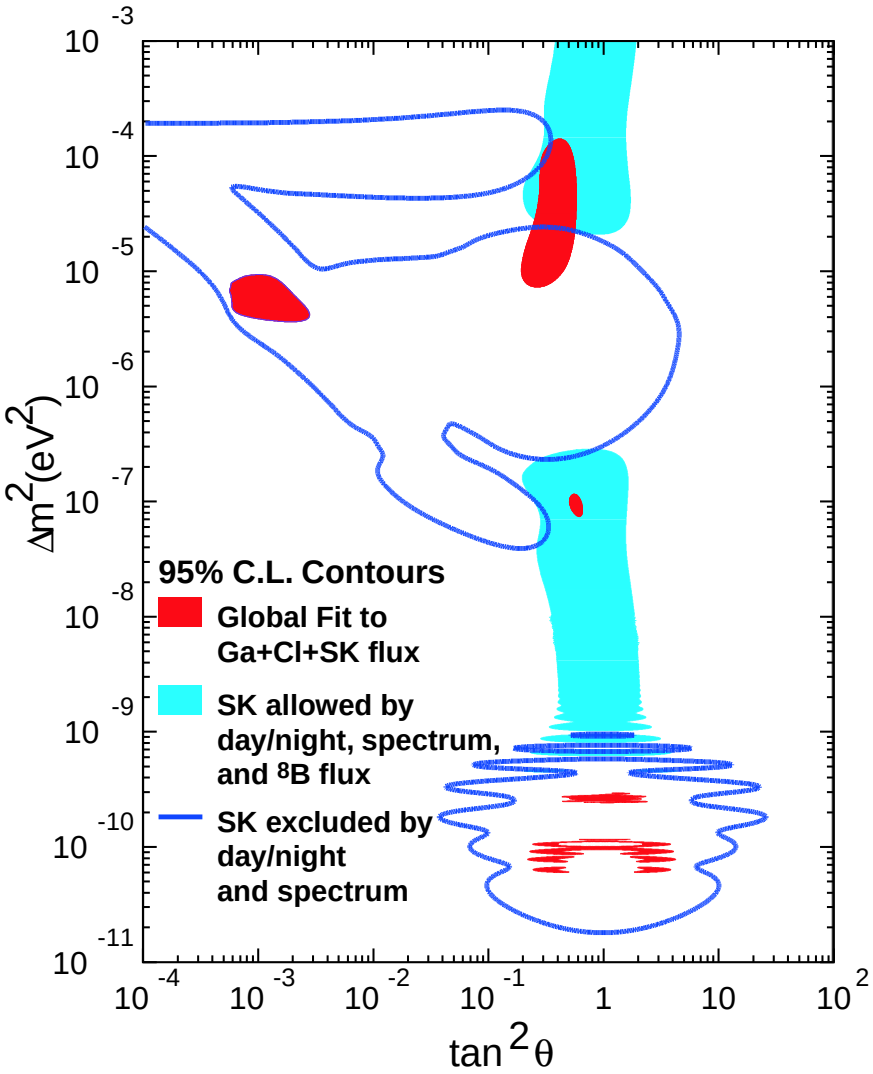
Survival probabilty of solar neutrinos



Solar ν_e convert to ν_μ and ν_τ



Solar neutrino parameters



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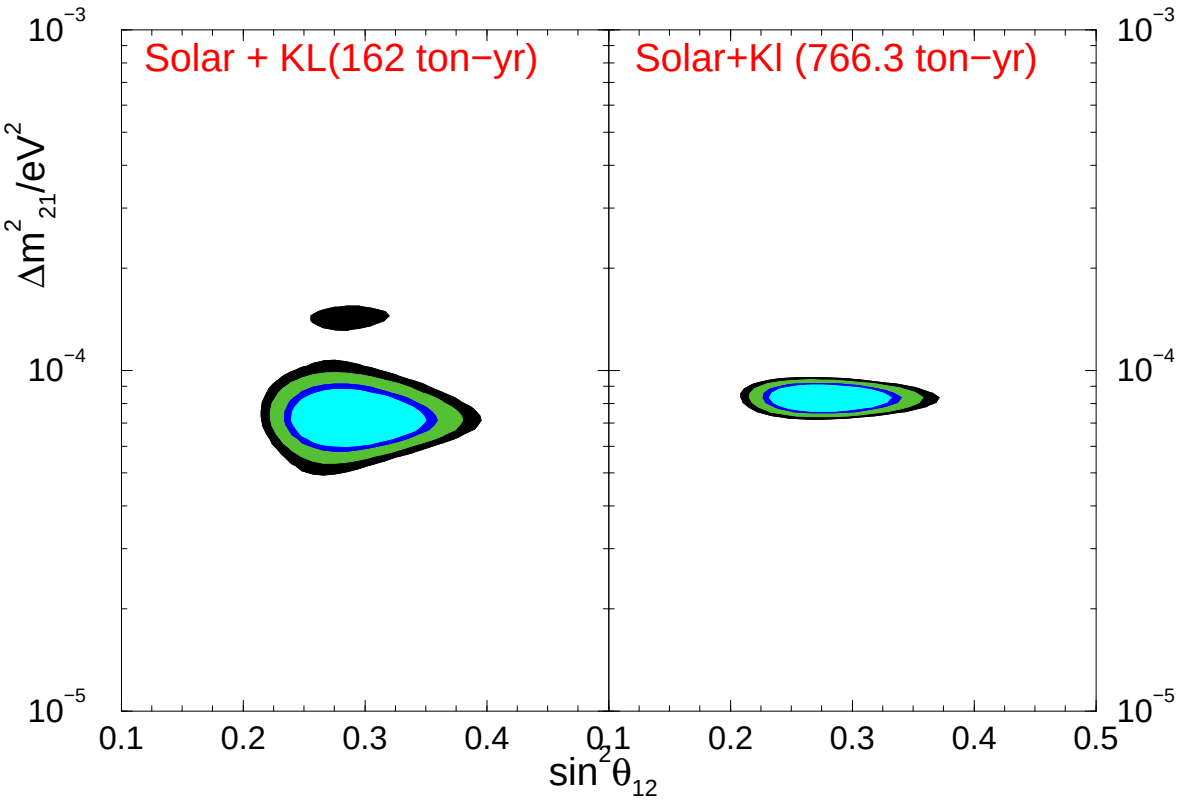

What we know about neutrinos

$$(\nu_e, \nu_\mu, \nu_\tau) \leftrightarrow (\nu_1, \nu_2, \nu_3)$$

Solar, Atmospheric and Reactor neutrino experiments $\Rightarrow$

- Mass squared differences: $\Delta m^2_{21} \ll \Delta m^2_{31} \approx \Delta m^2_{32}$

$$\Delta m^2_{\odot} \approx (7.2 - 9.5) \times 10^{-5}\text{eV}^2 \ , \ \Delta m^2_{\text{atm}} \approx (1.3 - 3.4) \times 10^{-3}\text{eV}^2$$

- Mixing matrix: $U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$

$$|U_{e1}|^2 \approx 0.7 \ , \ |U_{e2}|^2 \approx 0.3 \ , \ |U_{\mu 3}|^2 \approx 0.5 \ , \ |U_{e3}|^2 < 0.05$$

(Two large angles and one small, possibly vanishing – and hence interesting – angle)

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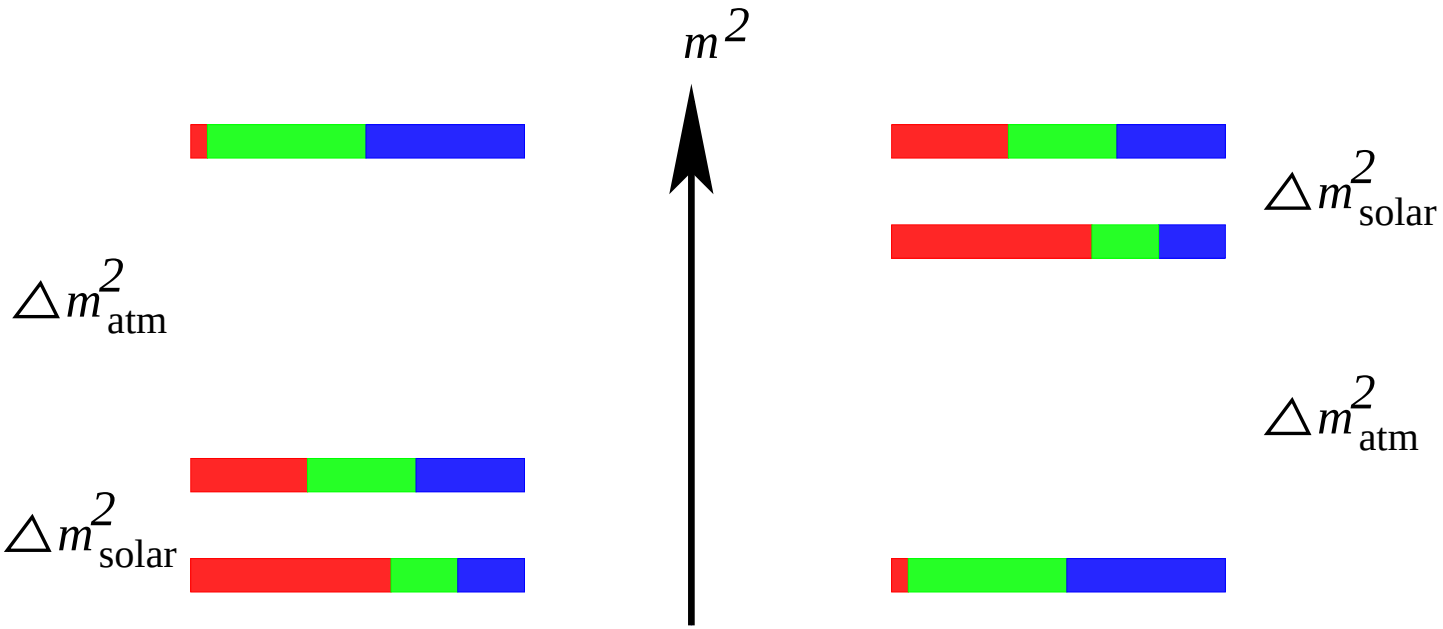
What we do not know

- Mass hierarchy: Normal or Inverted ?
  (red ν_e, green ν_μ, blue ν_τ)



- CP violation
- Absolute neutrino masses

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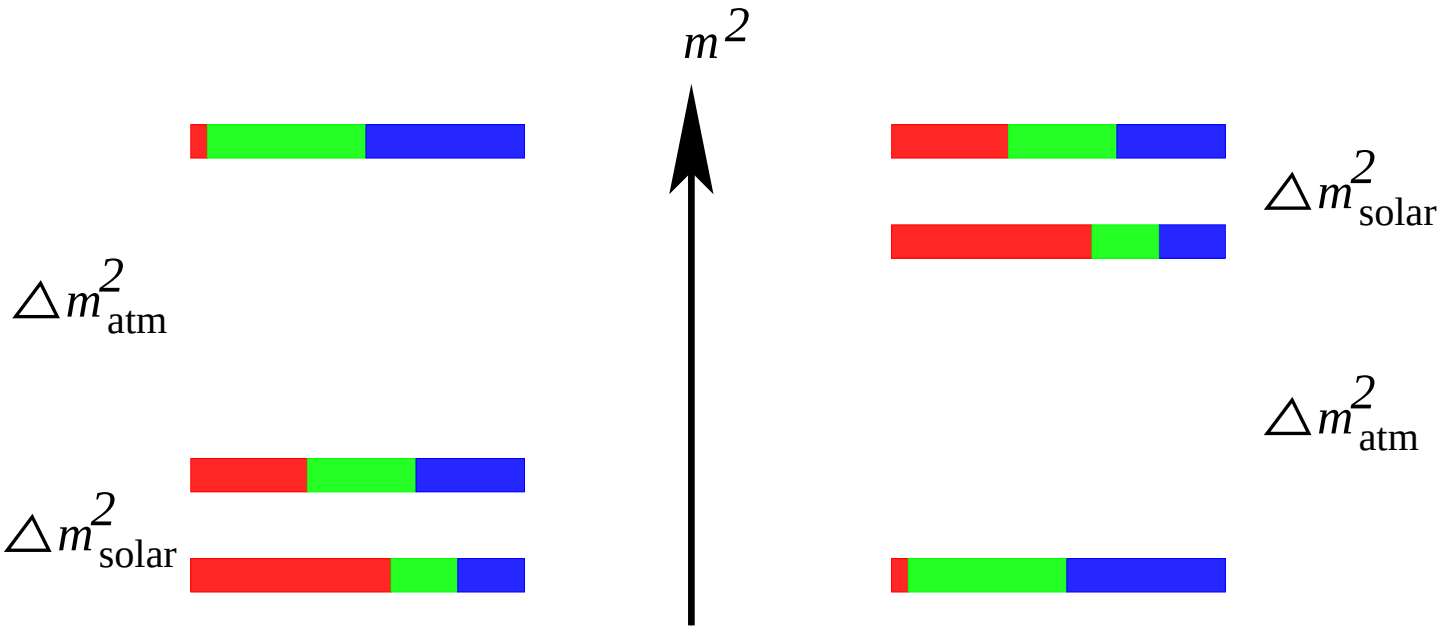

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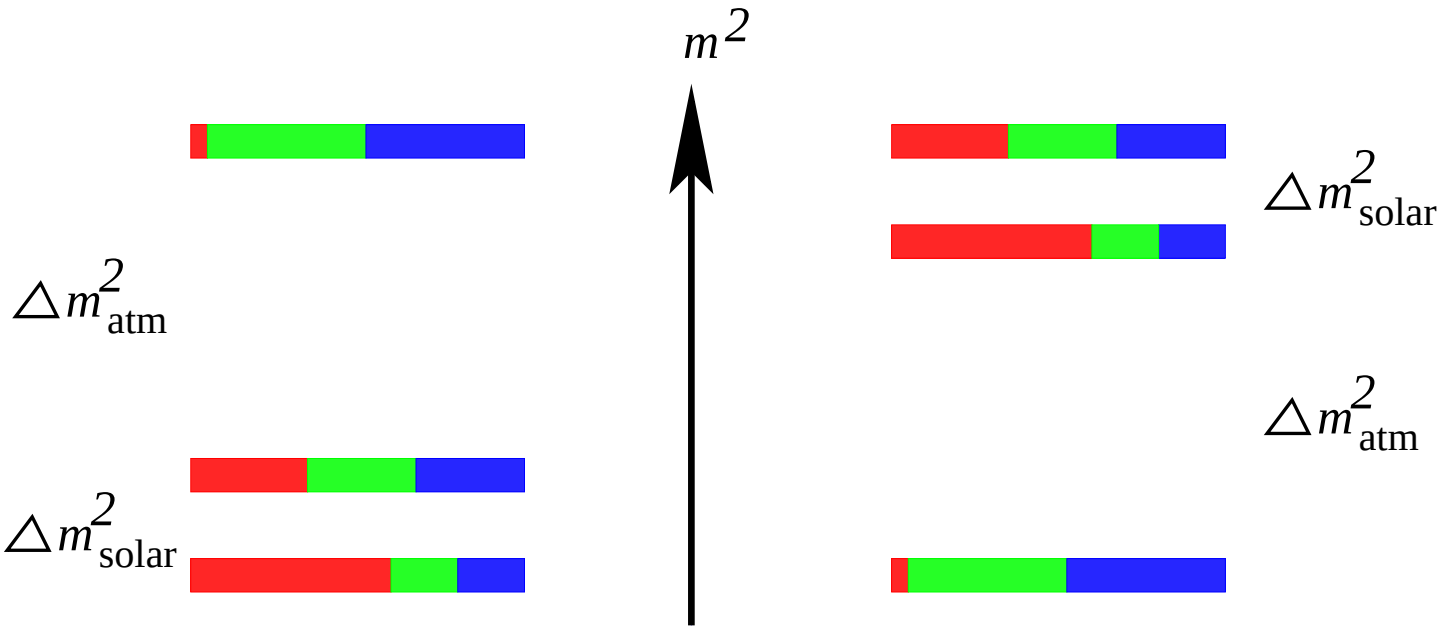

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Current activities in neutrino physics

- Solar experiments:
  measuring the energy of the sun in neutrinos
- Reactor experiments:
  Measuring the small mixing angle
- Short baseline experiments:
  Confirming atmospheric oscillations with known ν fluxes
- "Neutrino factories":
  Long baseline experiments that span the Earth
- Neutrino telescopes: Looking for extremely energetic neutrinos from the cosmic rays
- India-based Neutrino Observatory (INO):
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