Future prospects in neutrino physics

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Outline

- Open questions
- Superbeams
  - T2KK
  - WBB
  - NOνA*
- Neutrino factories and β-beams
- Summary

Open questions

- Majorana vs Dirac mass – $0\nu\beta\beta$
- Absolute m_ν – Katrin, Cosmology
- How large is θ_{13}? – Oscillation
- Which one is the heaviest neutrino? –$0\nu\beta\beta$, Katrin, Oscillation
- Is θ_{23} maximal? – Oscillation
- Is there leptonic CP violation? – Oscillation
- Are there only 3 light neutrinos? – Oscillation
- Do neutrinos have non-standard interactions? – Oscillation, Scattering

A common, minimal framework for all the neutrino data is oscillation.

- $\Delta m^2_{21} \sim 8 \cdot 10^{-5}\,\mathrm{eV}^2$ and $\theta_{12} \sim 1/2$
- $\Delta m^2_{31} \sim 2.5 \cdot 10^{-3}\,\mathrm{eV}^2$ and $\theta_{23} \sim \pi/4$
- $\theta_{13} \lesssim 0.15$

CAVEAT: I do assume that LSND has a non-oscillation explanation and that neutrinos have only ordinary electro-weak interactions!

What we want to learn

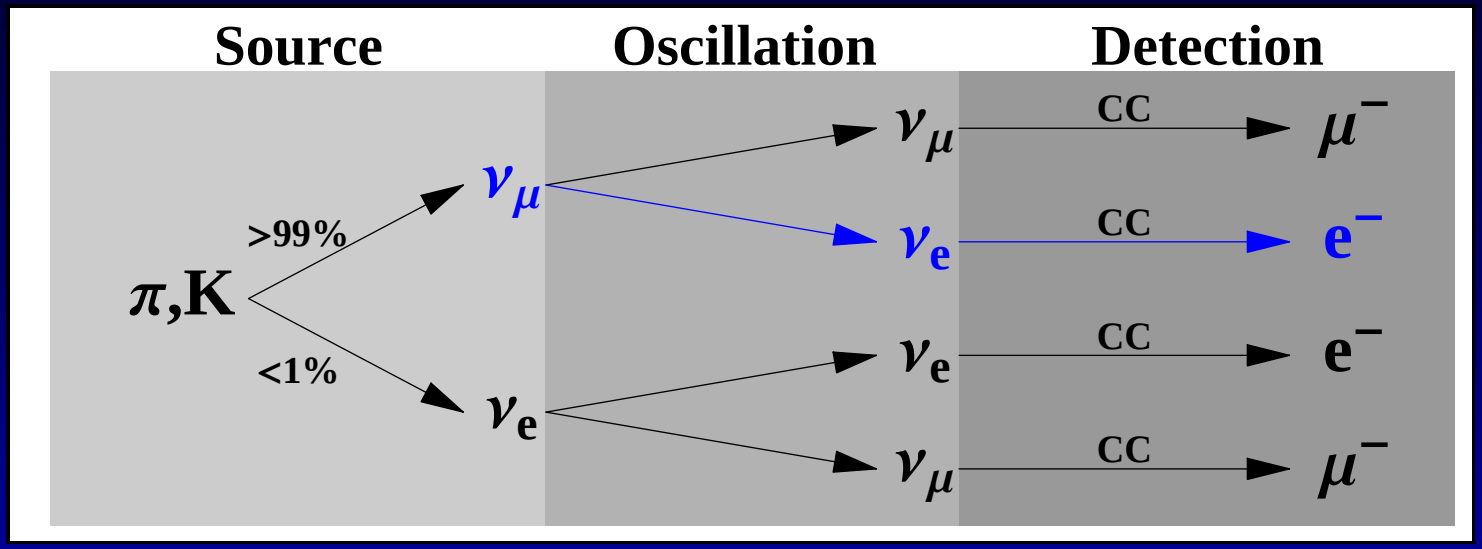
- Size of θ_{13}
- mass hierarchy?
- $\theta_{23} = \pi/4$?
- CP violation in leptons?

The latter three cannot be addressed by currently running (MINOS, OPERA) or planed experiments like DoubleChooz, Reno, Daya Bay, T2K or NOνA.

Hence, the need for a new generation of neutrino oscillation experiments.

Superbeams

Neutrino beam from π-decay



They are called 'super'

- beam power $\sim 1\,\mathrm{MW}$
- detectors mass $\sim 100\,\mathrm{kt}$
- running time of the experiment ~ 10 years
- price

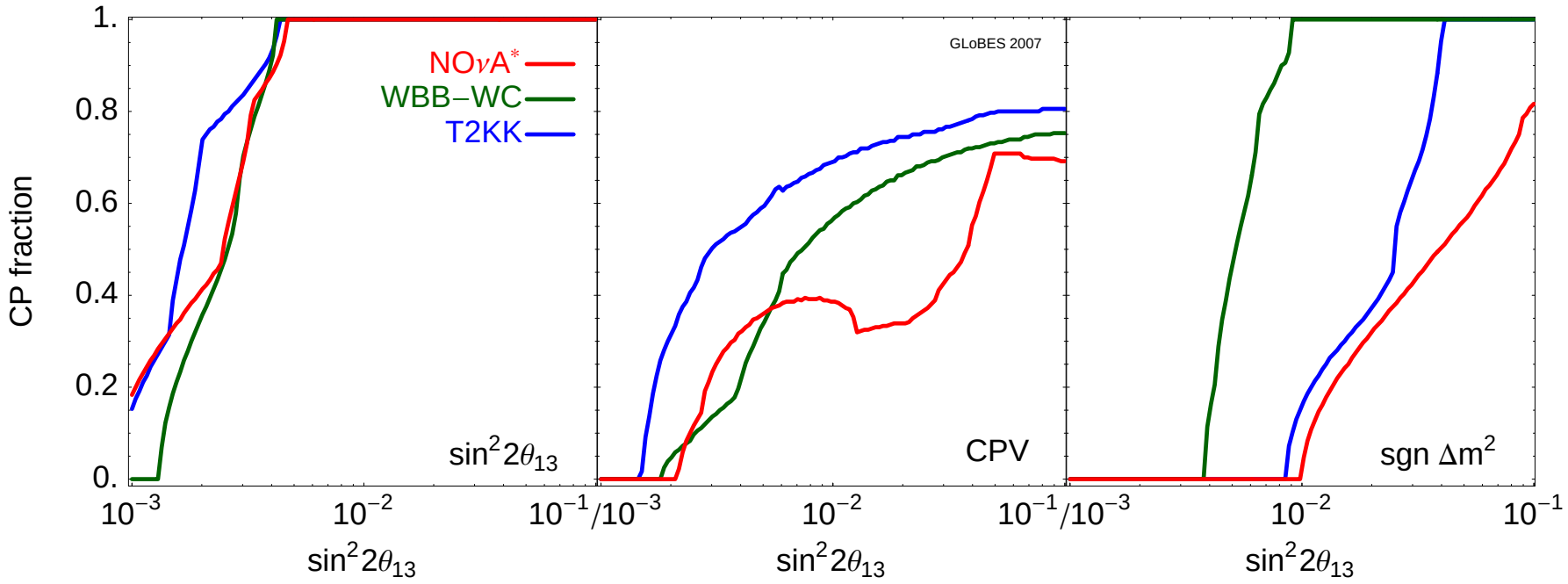
Setups

- T2KK – beam from JAERI, $P = 4\,\mathrm{MW}$, two water Cherenkov detectors at $L = 295\,\mathrm{km}$ and $L = 1050\,\mathrm{km}$ with a fiducial mass of $270\,\mathrm{kt}$, off-axis
- WBB – beam from FNAL, $P = 1.1\,\mathrm{MW}$, one water Cherenkov detector at $L = 1300\,\mathrm{km}$ with a fiducial mass of $300\,\mathrm{kt}$, on-axis
- NOνA* – beam from FNAL, $P = 1.1\,\mathrm{MW}$, one liquid Argon TPC at $L = 810\,\mathrm{km}$ with a fiducial mass of $100\,\mathrm{kt}$, off-axis

Joint BNL-FNAL study group report reviews the US based options

see M. Diwan's talk

Comparison



adapted from Barger, PH, Marfatia, Winter, Phys.Rev.D76:031301,2007.

- $\sin^2 2\theta_{13}$ performances are very similar
- T2KK clearly best for CPV
- WWB clearly best for mass hierarchy

Exposure

Everyone has different assumptions about

- seconds in a year
- number of years
- detector size
- beam power (or pot)

Therefore we introduce the concept of exposure

$$\text{detector mass [Mt]} \times \text{target power [MW]} \times \text{running time} \left[10^7 \text{ s}\right].$$

Exposure and systematics

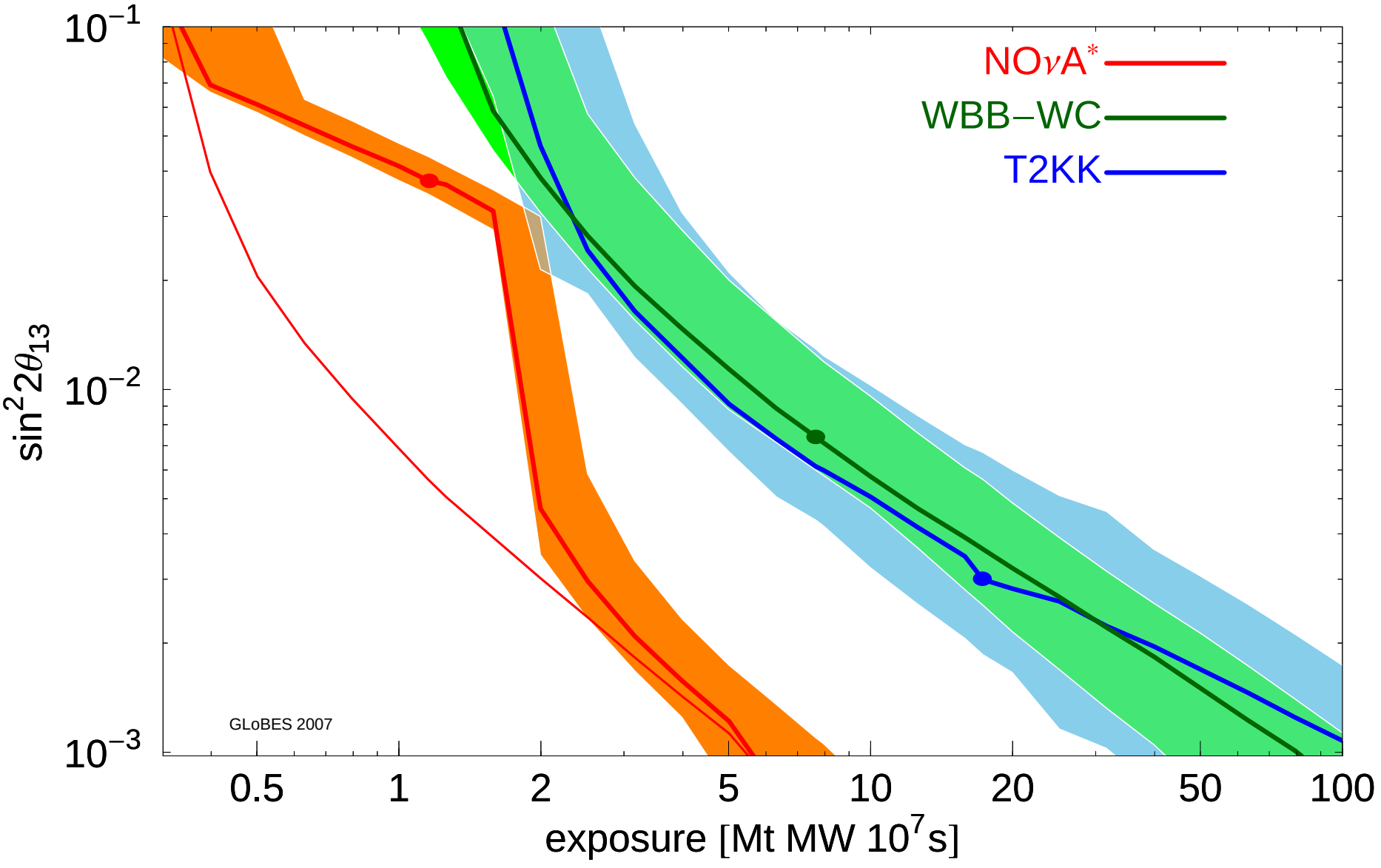
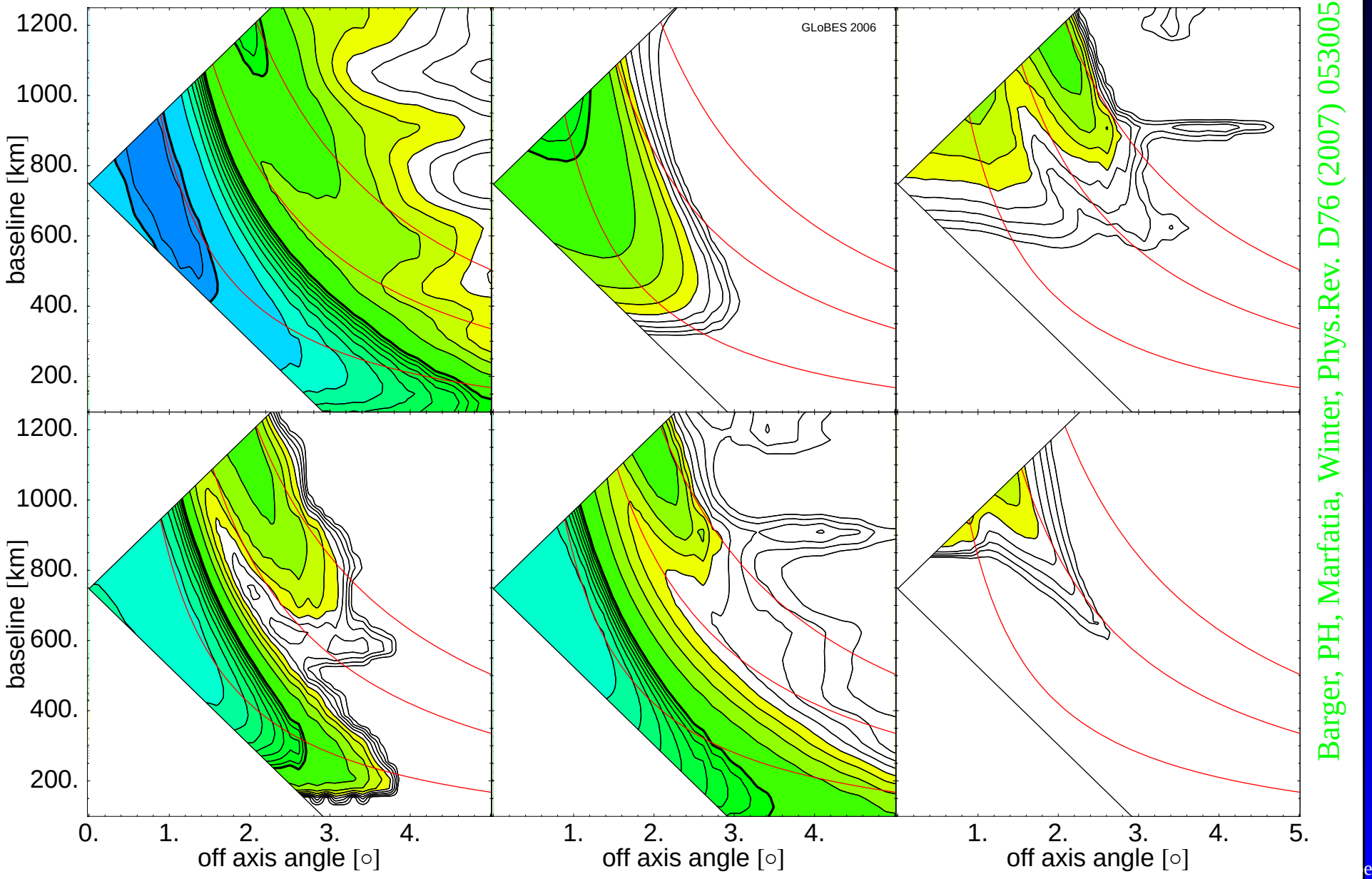
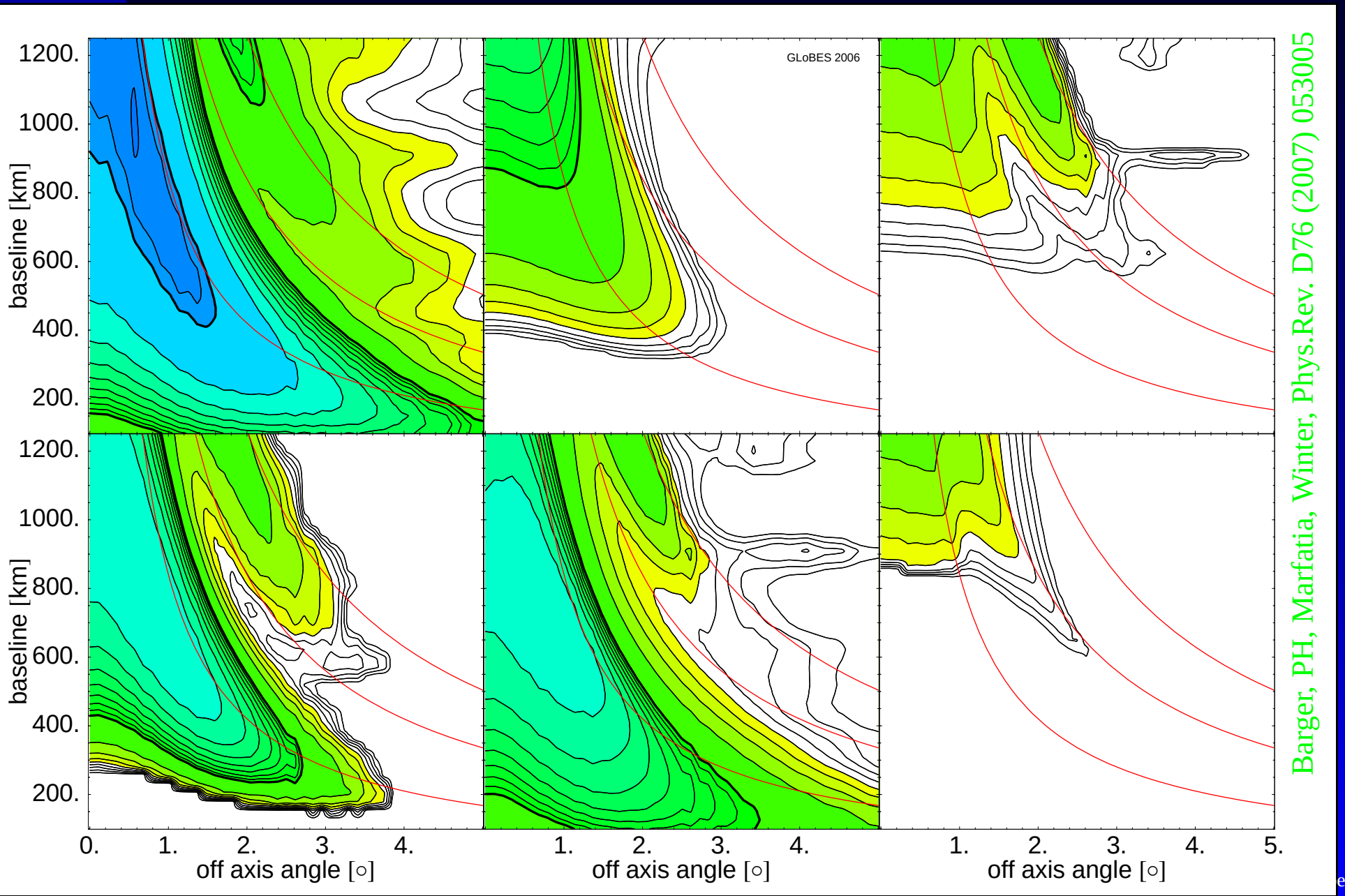


figure adapted from Barger, PH, Marfatia, Winter, Phys.Rev. D76 (2007) 053005

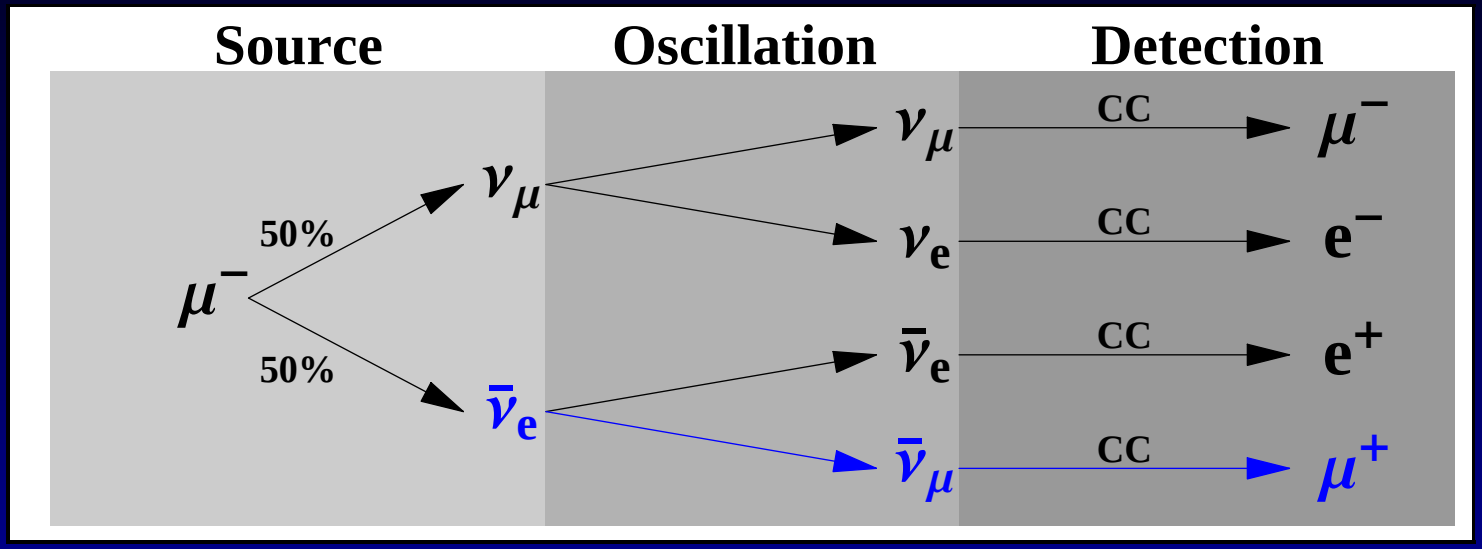
On vs off-axis

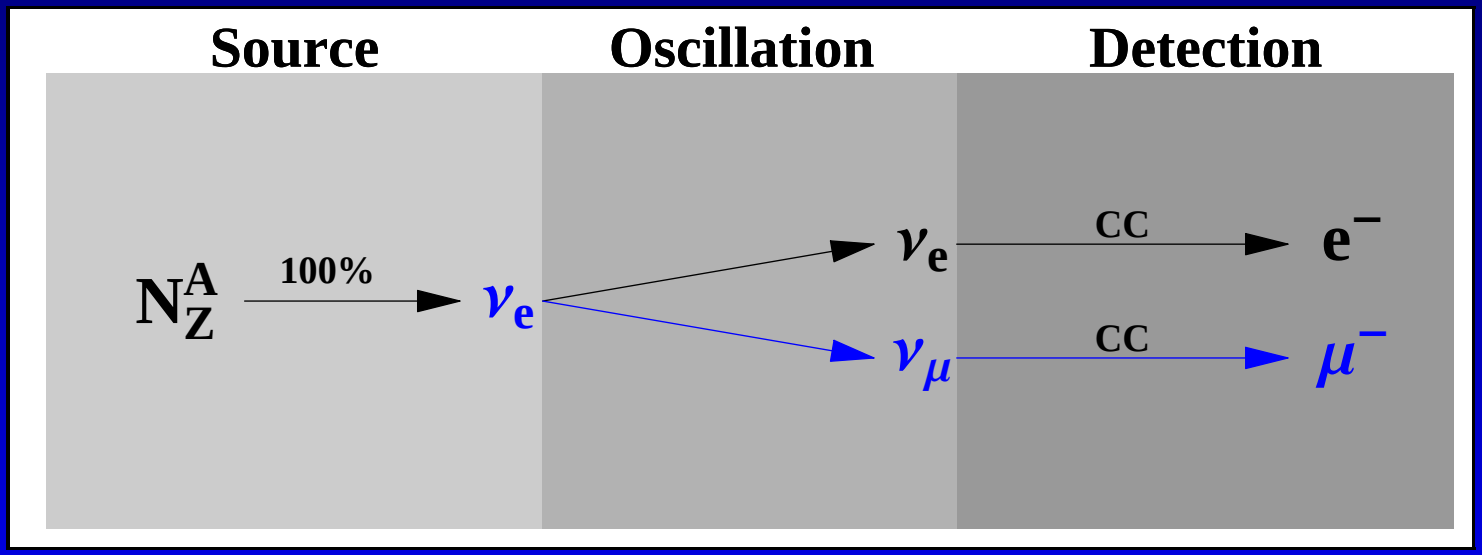


On vs off-axis



Neutrino factories & β-beams





Neutrino factories & β-beams

Challenges for a neutrino factory

- muon production – target power
- muon cooling
- muon acceleration

Challenges for a β-beam

- isotope production
- acceleration – sufficiently high neutrino energies
- radioactive beams – activation of equipment
- storage ring – high ion densities

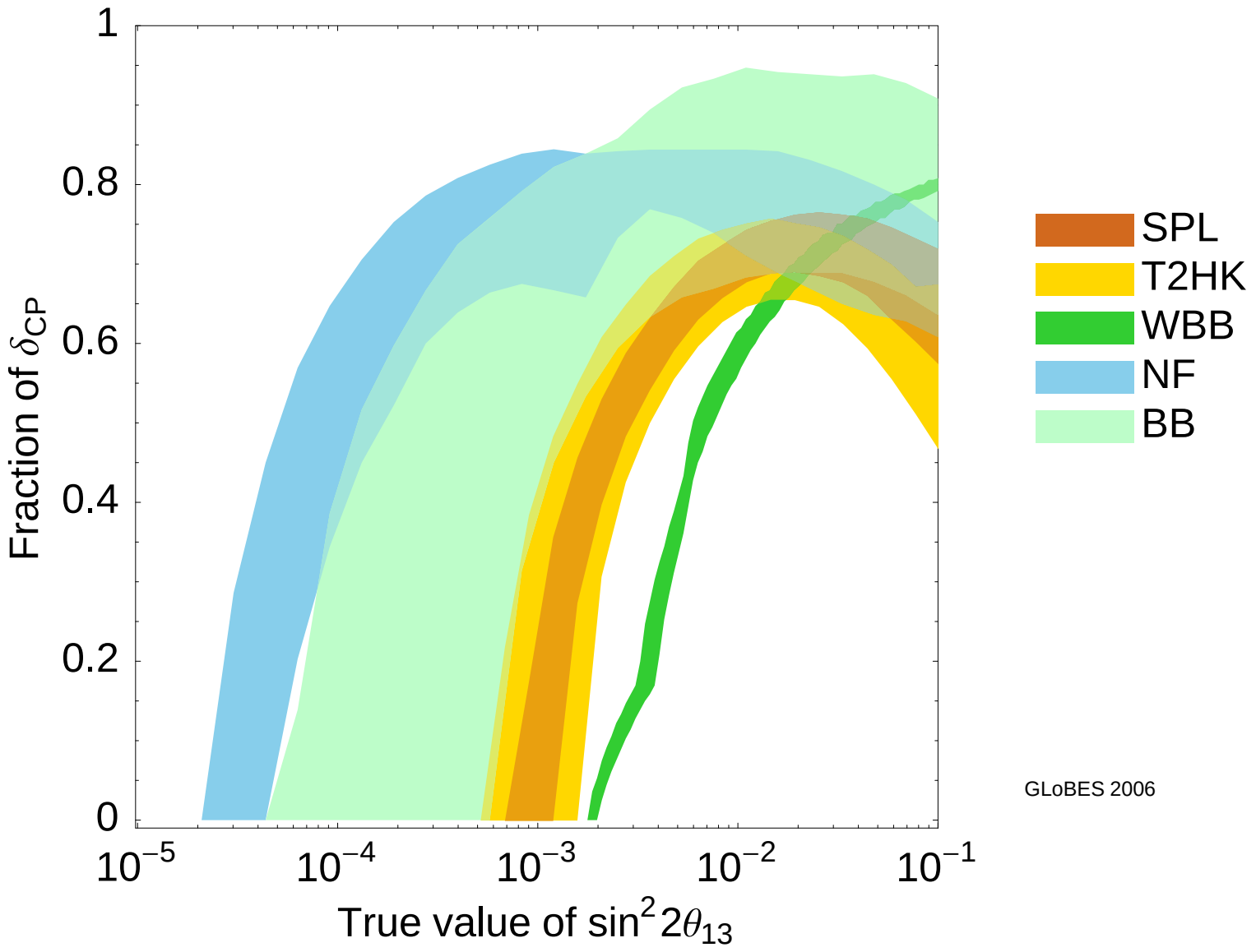
ISS

ISS stands for ’International scoping study of a future Neutrino Factory and super-beam facility’

The scoping study will therefore review the physics reach of the various proposed facilities and make quantitative performance comparisons. These comparisons will be used to define the programme needed to achieve international consensus on the facility or facilities required for an optimal programme of high-precision neutrino-oscillation measurements. This requires that the performance, cost and feasibility of the various proposed facilities, including the detector systems, be evaluated. The conceptual design

Relatively large study, with more than 100 authors, several plenary meetings, many working group meetings. It has ended and is now continued into an ’International Design Study’ (IDS). The IDS aims at providing a CDR for a neutrino factory by 2012.

ISS results in a nutshell



GLoBES 2006

Summary

Superbeams

- Exposure is the key factor – money and physics
- Detector technology plays a big role
- Off vs On-axis decision requires careful analysis
- Short distances ($< 500\,\mathrm{km}$) are disfavored
- Every strategy requires MW beams, 0.1 Mt detectors, 10 years of running

Neutrino factories and β-beams require considerable R&D and may be very difficult to justify if $\sin^2 2\theta_{13}$ is large.

Reactor experiments can find a large $\sin^2 2\theta_{13}$ soon.