Future Neutrino Oscillation Experiments: Physics studies

Towards a comparison of options on equal footing
Defining the next steps (short term aim is about NUFACT05)

Aim of this presentation is to trigger discussion

I Questions from JJ Gomez-Cadenas et al.

T2K-II

- Needs a very serious upgrade of proton driver, to 4 MW. It is unclear today how feasible/easy/costly is to do that. It requires a MTON class detector.
- Cannot "move" before T2K-I sees a signal. Building the detector will take 5 years at least. Cannot start before 2020, probably
- It is still a conventional beam, affected by the usual systematics on intrinsic background, beam shape and normalization.
- Lifefime: 2020-?

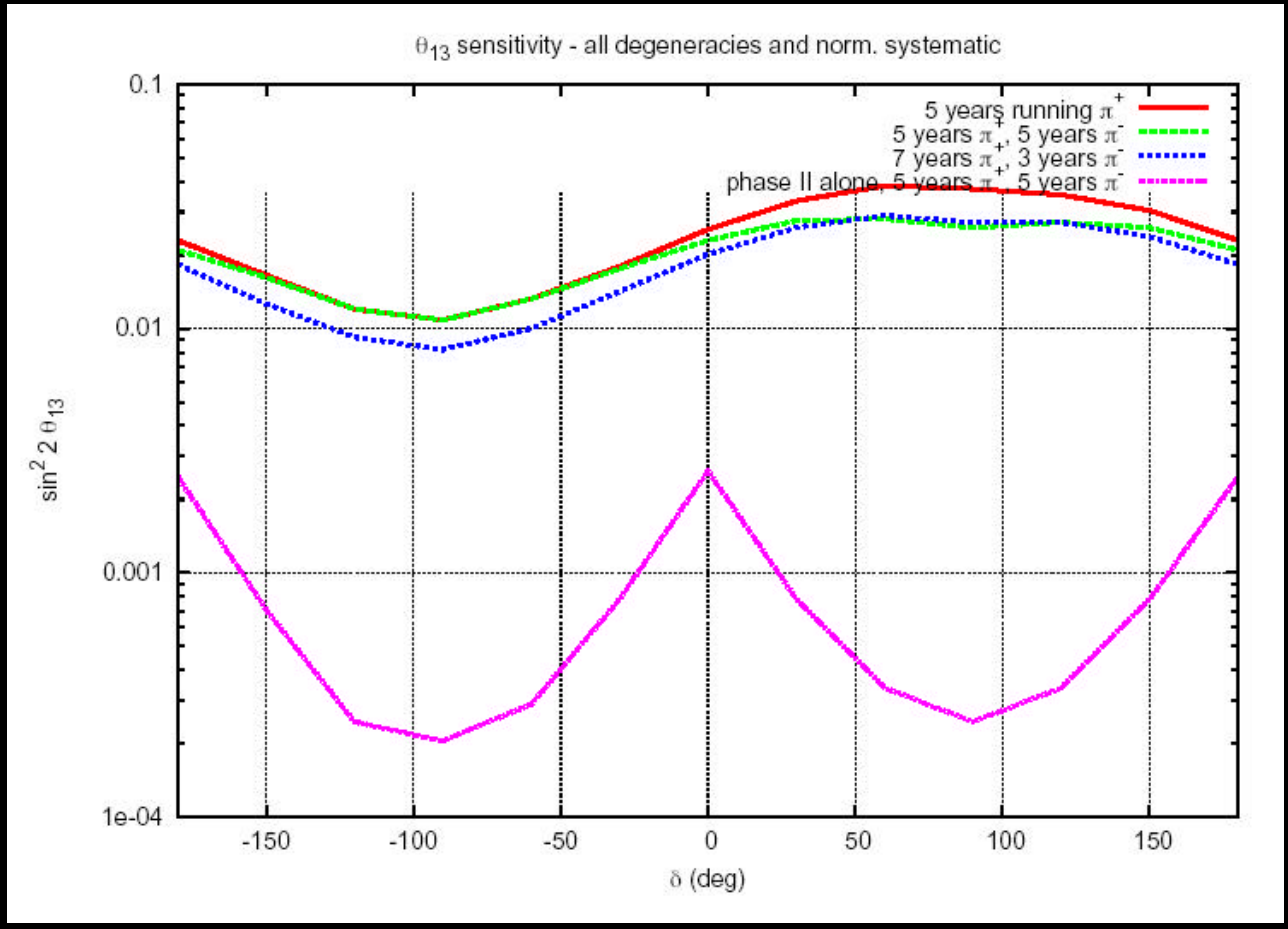
Beta-Beam

- A design based on low gamma has been studied over the last 1-2 years.
- A design that uses the SPS has a limit on gamma 150 (He6) and 250 (Ne18). Perhaps some further acceleration possible in storage ring.
- A design based on the Tevatron can reach a gamma of about 500
- Requires Mton class detector.
- It does not need to wait for T2K-I to start. Experiment could start as early as 2015, about 10 years from now.

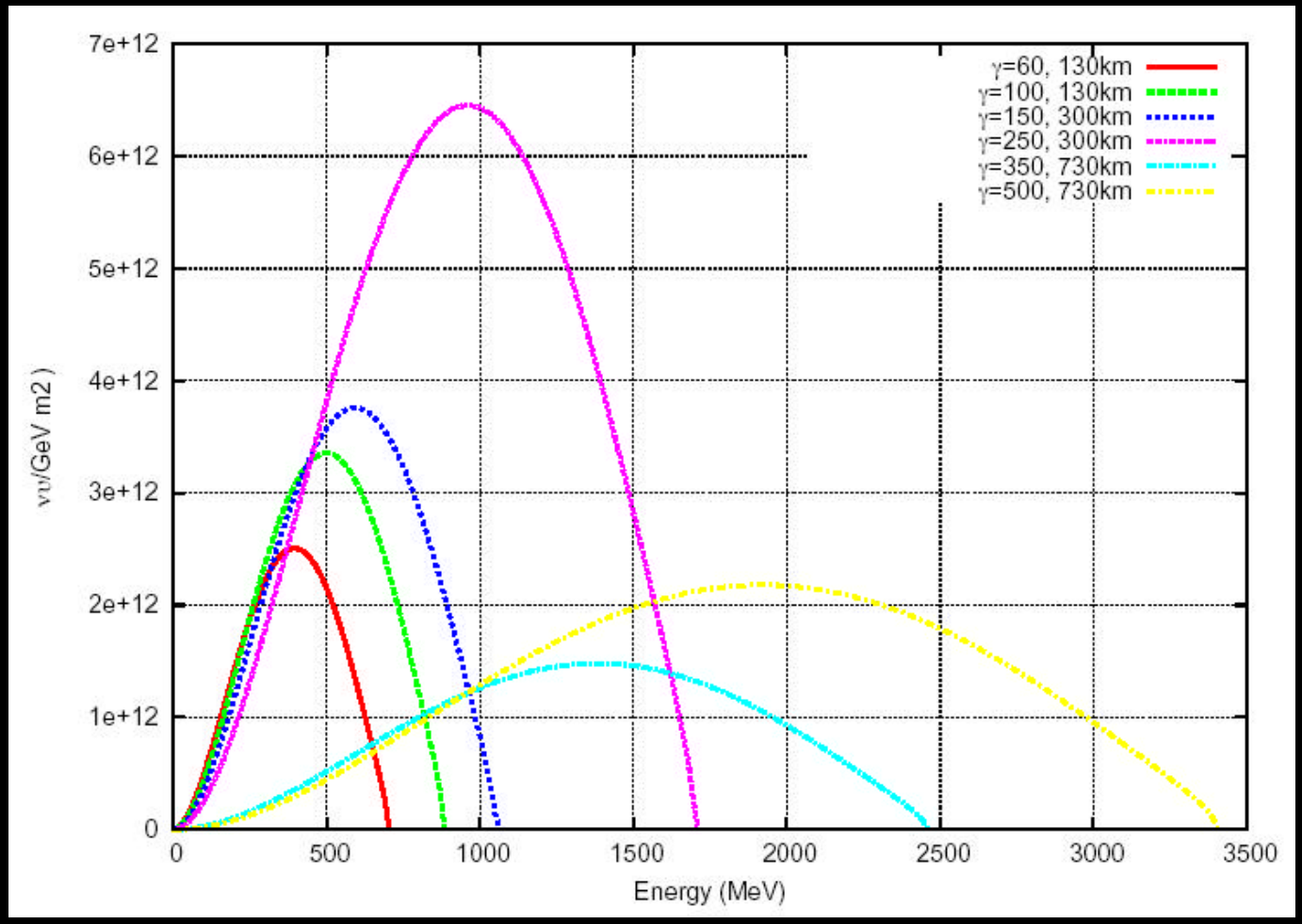
Neutrino Factory

- Design improving with time, but always challenging
- Needs “only” “conventional” detectors (Minos x 10, Opera x 2-5)
- Tau and muon appearance + energy binning. Best tools against degeneracies.
- Measures with great precision atmospheric parameters. Can also measure matter effects
- It still seems the best neutrino machine around. But what is the realistic time scale?

T2K-II Sensitivity to θ_{13}



BB: Scenarios

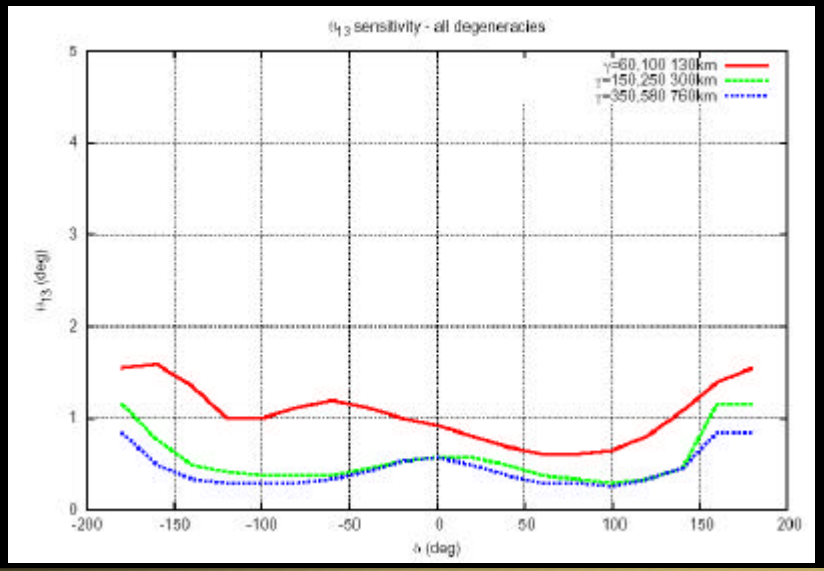


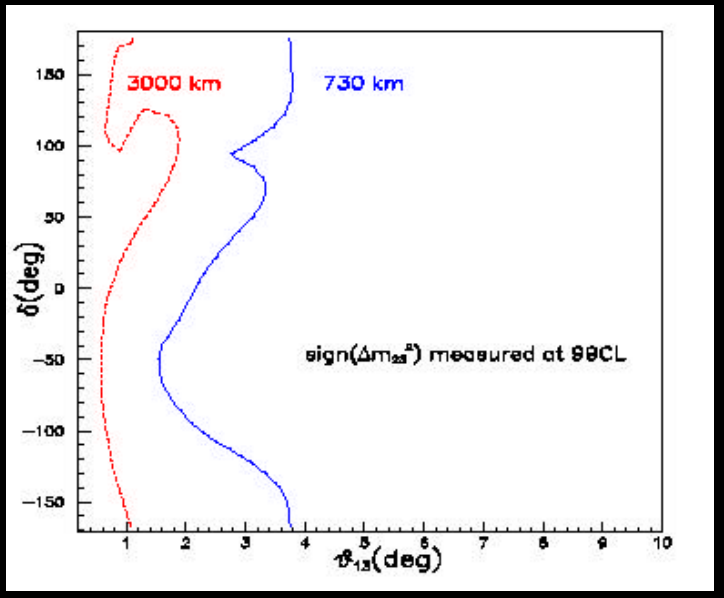
Option a: SPS-Frejus gamma 60 ($^{6}He^{2+}$)/100 ($^{18}Ne^{10+}$)

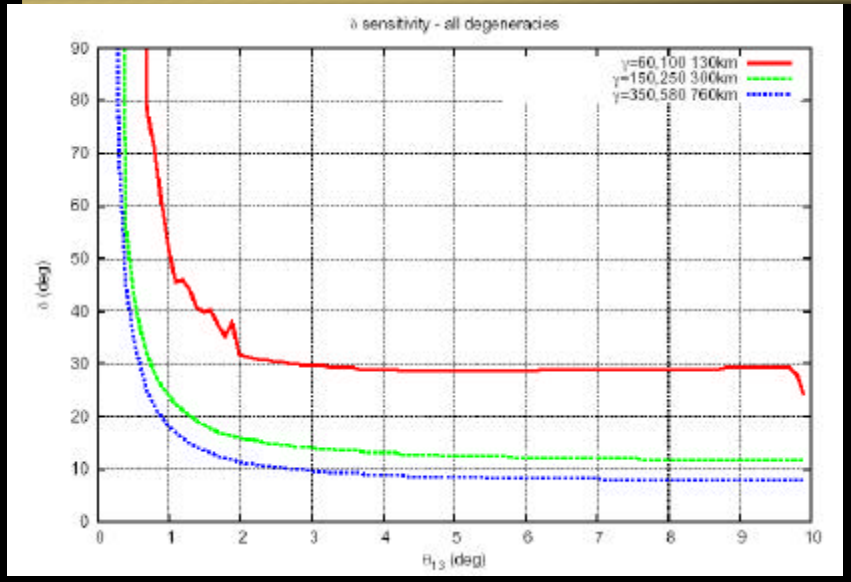
Option b: SPS-limit gamma 150/250 at 300 km

Option c: Tevatron-Soudan gamma=350/500

Options Compared





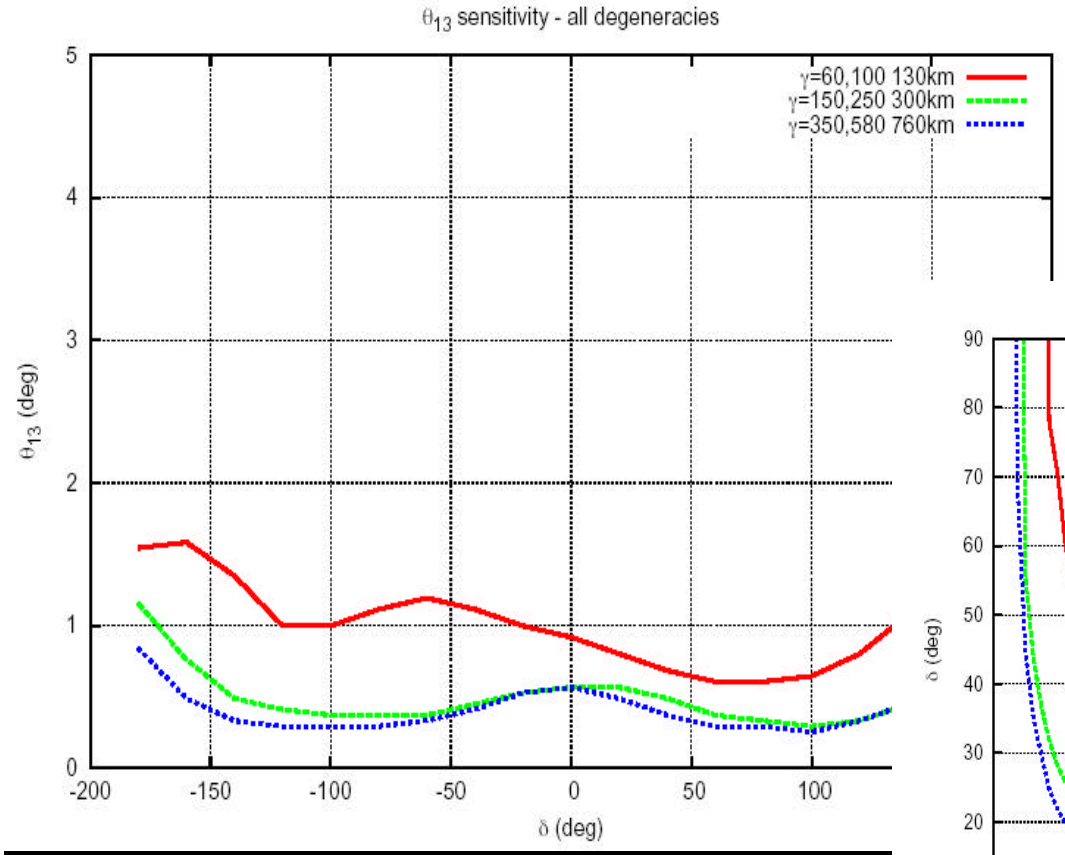


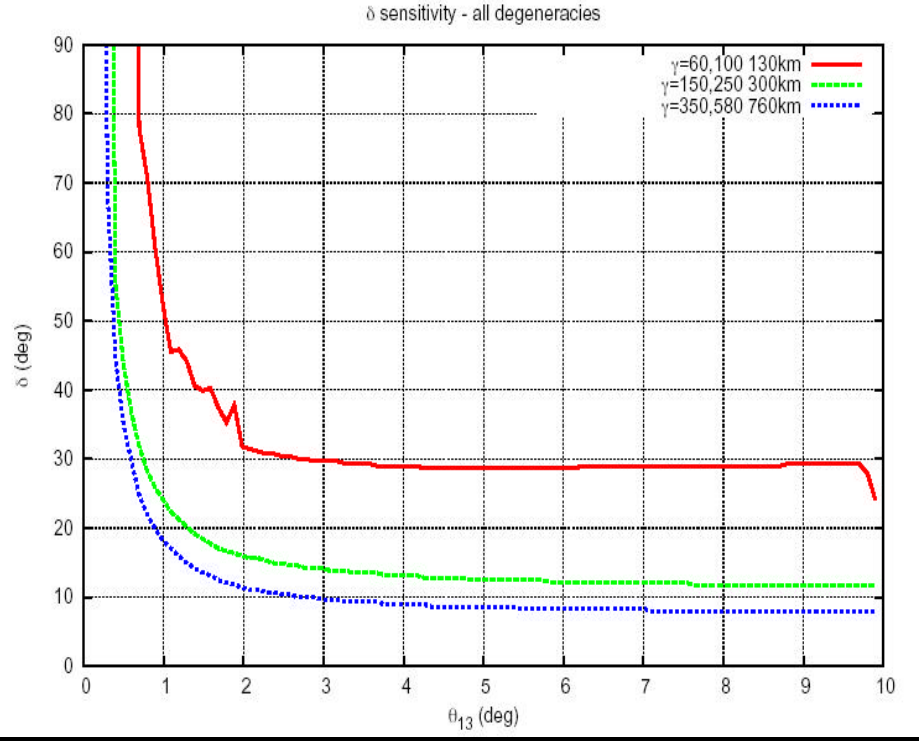
Option b and c always much better than option a

Option b and c very similar for q_{13} d sensitivity

Option c sees matter effects

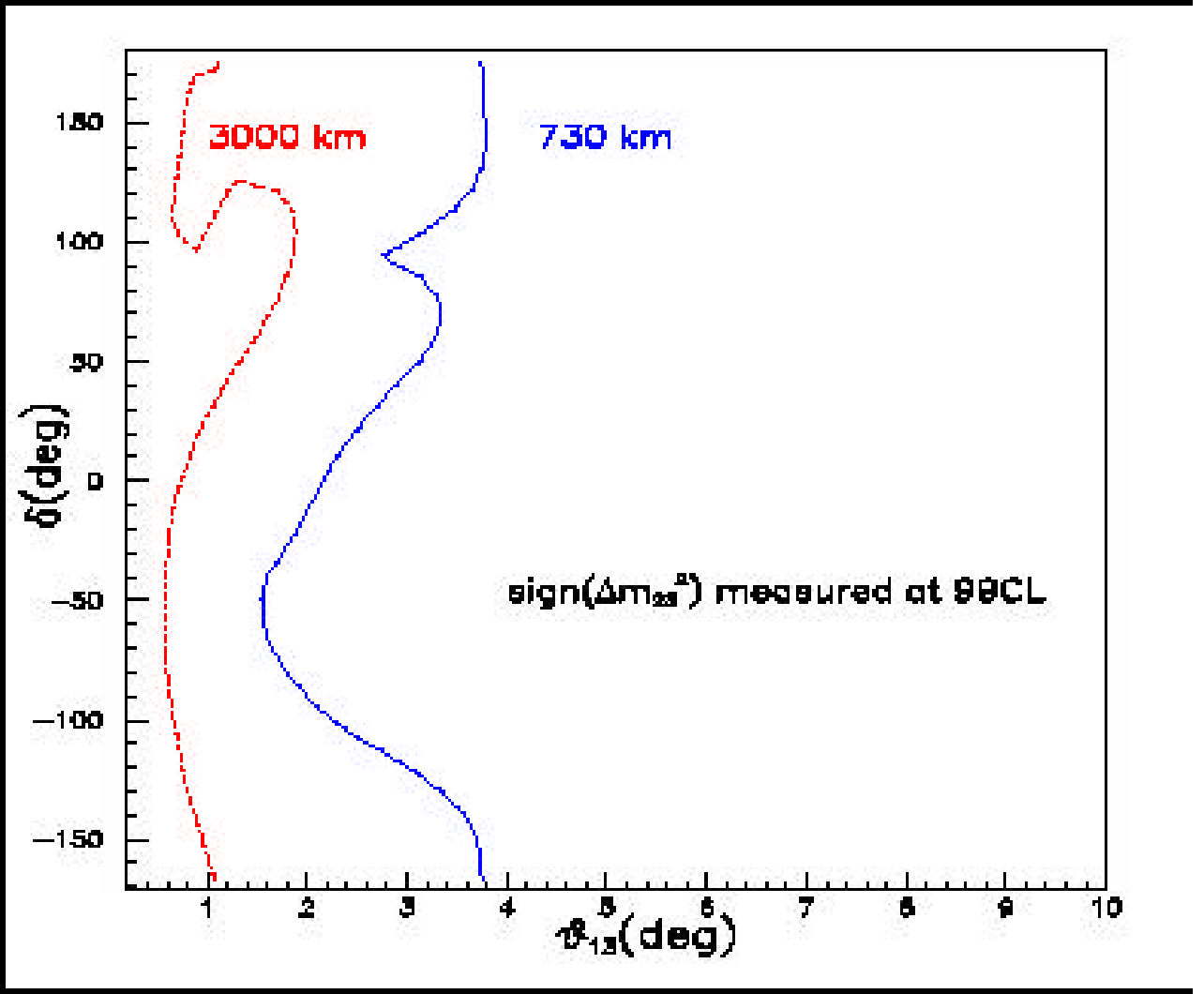
Options Compared (I)





Option b and c always much better than option a

Option b and c very similar for q_{13} d sensitivity



Option c (gamma 500) sees matter effects

Conclusions (from JJ)

First generation Super-Beams (T2K-I) will hopefully observe the subleading transition, measuring or setting a lower bound to θ_{13}. T2K-II will only happen if a signal is observed in T2K-I.

In Europe we don't have such restriction. A Beta-Beam at SPS-limit energies seems to provide a very good physics case and it also seems feasible technically. Such an experiment could operate whether T2K sees a signal or not, explore θ_{13} to less than 1 degree and δ to about 10 degrees.

Conclusions II (From JJ)

The Beta-Beam offers and alternative/complement to the Neutrino Factory. Different technology, different systematic errors and different E/L.

It needs for ultimate sensitivity 1Mton class detector. Such a detector has a great physics potential (proton decay, supernova observatory) of their own, but it is extraordinarily challenging to build

It cannot provide by itself measurement of atmospheric parameters, and the lower-gamma options cannot measure matter effects. No tau appearance.

A careful assessment of the relative merits of the Beta-Beam versus NUFACT is necessary

Personnal view

The strategic situation as I see it is as follows.

In 2011 LHC will be running and paid, and CERN does not have a credible plan.
CLIC is not going to happen so soon and the sub-TeV linear collider will happen elsewhere.
If the sub-TeV linear collider happens CLIC will not begin serioulsy until the other one has already been exploited;
and if the sub-TeV linear collider does not happen it may mean that CLIC is not worth building either (although it can be rescued in some scenarios).

Conclusion: there is a gap at CERN in the years 2011-20XX where my middle estimate for XX is >20.

The leading contender for filling this gap is a high intensity neutrino programme.

Which one?

Package 1: neutrino factory
Package(s) 2: superbeam + beta beam + large water Cherenkov

A bit of explanation:

Why is it that now we are placing these options as alternative and not in sequence? (→decisions are more painful)

A. The time window is limited
B. We may not have another shot
C. The cost estimate for Neutrino factory has been reduced considerably (and design simplified, and flux doubled)
(See Zisman's presentation later today)
D. The timeline has shifted somewhat

Caveats:

the fact that either a neutrino factory or a 1 Mton Water Cherenkov is ready to be built in 2011 is highly non-trivial! (not to mention the Large Liquid Argon detector)

These aspects of feasibility need demonstration

$$$$$ ... COST ... $$$$$

Why we are optimistic:

	Study 2	Now	Factor
PHASE ROTATION			
Beam Line (m)	328	166	51 %
Acceleration (m)	269	35	13 %
Acc Type	Induction	Warm RF	
COOLING			
Beam Line (m)	108	51	47 %
Acceleration (m)	74	34	46 %
Absorbers	Liquid Hydrogen	Solid Li or LiH	
ACCELERATION			
Beam Line (m)	3261	$\approx$ 700	$\approx$ 21 %
Tun Length	1494	$\approx$ 700	$\approx$ 47 %
Acc Length	288	$\approx$ 130	$\approx$ 45 %

In the previous design ~ ¾ of the cost came from these 3 equally expensive sub-systems.

New design has similar performance to Study 2 performance and keeps both μ^+ and μ^- ! (RF phase rotation)

NUFACT 2004: cost can be reduced by at least 1/3
= proton driver + 1 B €

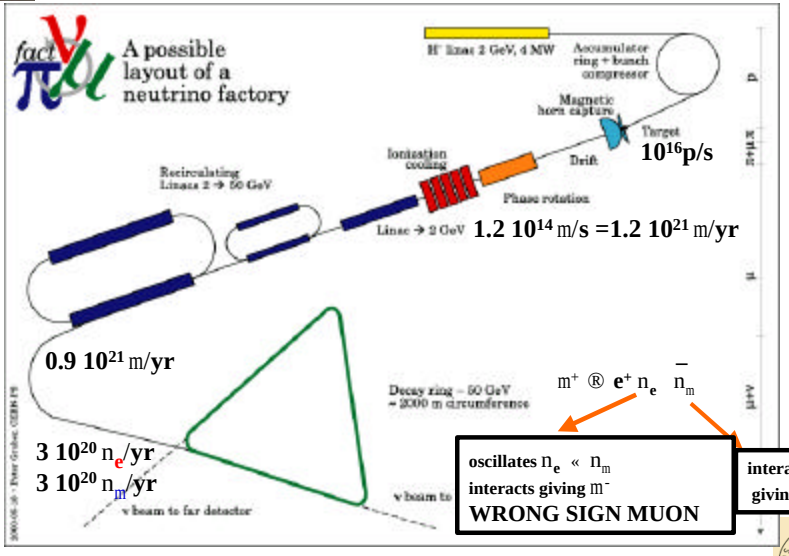
MAYBE the Neutrino Factory is not so far in the future after all….

S. Geer: *We are working towards a "World Design Study" with an emphasis on cost reduction.*

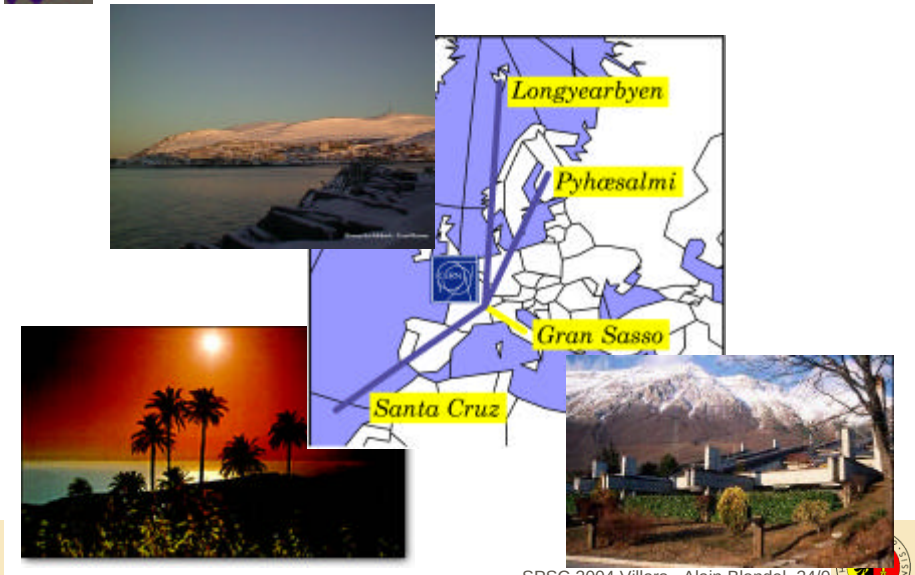
Questions for neutrino factory experiments:

1. Do we REALLY NEED TWO far locations at two different distances?
2. 3000 km = 1st osc. max at 6 GeV 2d max at 2 GeV.
   Muon momentum cut at 4 GeV cuts 2d max info. Can this be improved?
3. Can we really eliminate all degenracies by combination of energy distribution and analysis of different channels (tau, muon, electron, both signs, NC…)
4. What is the optimal energy for the stored muons? Cost of study II was 1500M$ + 400M$*E/20

-- Neutrino Factory --
CERN layout



Where do you prefer to take shifts?



Slide reserved to collect questions and suggestions from the group on neutrino factory

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Superbeam+Betabeam option

1. What is the importance of the superbeam in this scheme?
   T violation?
   increased sensitivity?
   have a (known) source of muon neutrinos for reference?

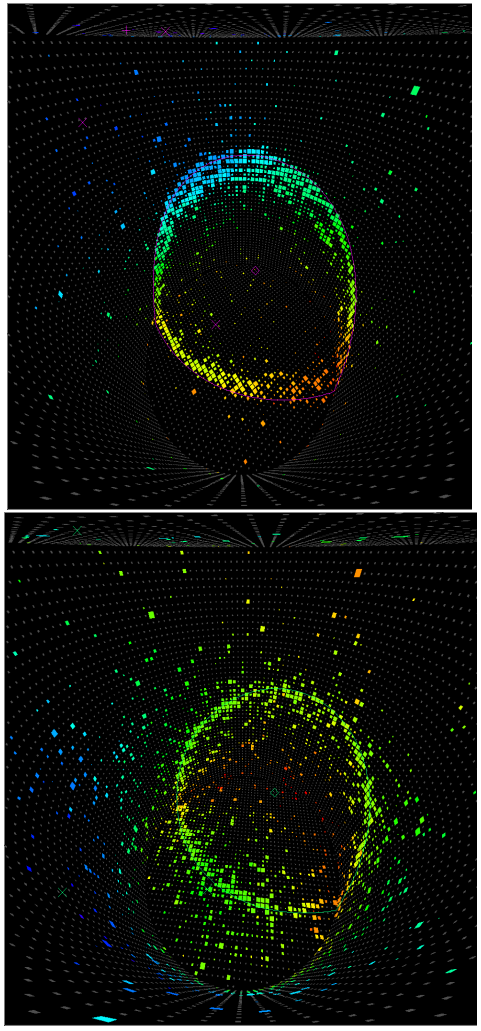
2. At which neutrino energy can one begin to use the event energy distribution?

3. What is the effect of changing the beta-beam and superbeam energy at fixed length? On event rates, backgrounds, ability to use dN/dE_n (is there interest in keeping this parameter variable?)

4, what is the relationship between beta-beam energy vs intensity?

5. What is really the cost of the detector?

Combination of beta beam with low energy super beam



Unique to CERN:

need few 100 GeV accelerator (PS + SPS will do!)
experience in radioactive beams at ISOLDE

many unknowns: what is the duty factor that can be achieved? (needs < 10^{-3})

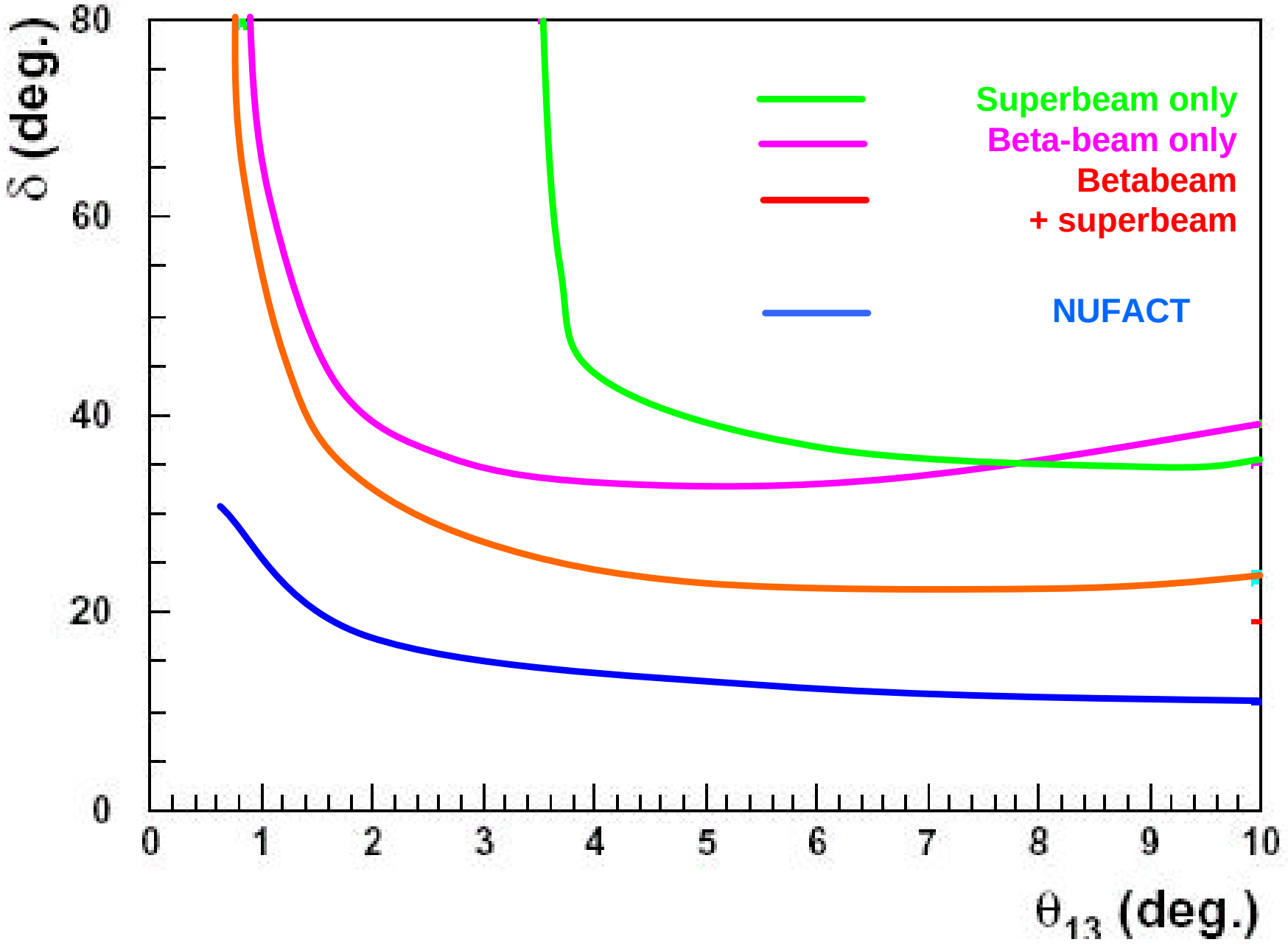
combines CP and T violation tests

$$\nu_e \to \nu_\mu \quad (\beta^+) \quad \mathbf{(T)} \quad \nu_\mu \to \nu_e \quad (p^+)$$

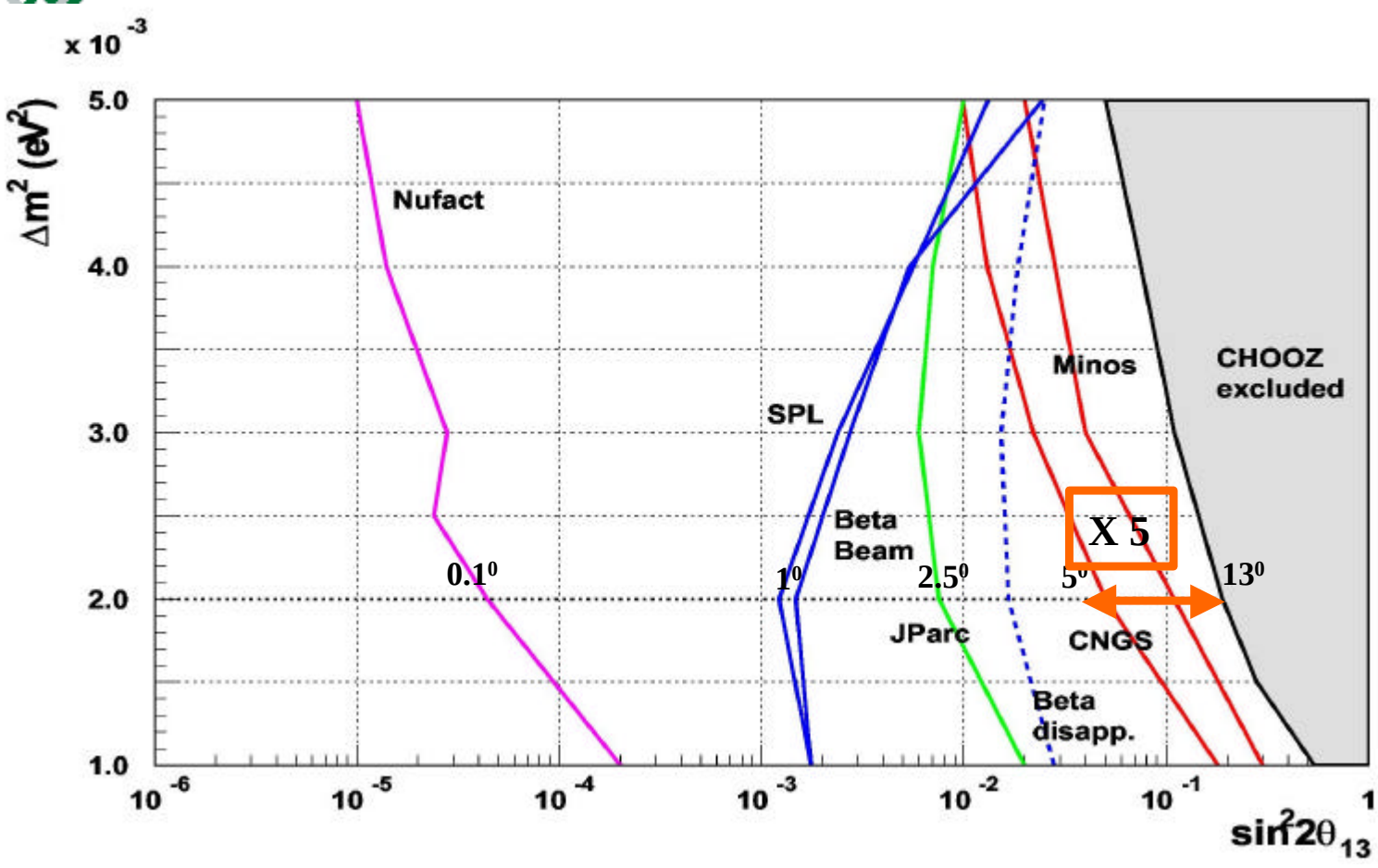
(CP)

$$\bar{\nu}_e \to \bar{\nu}_\mu \quad (\beta^-) \quad \mathbf{(T)} \quad \bar{\nu}_\mu \to \bar{\nu}_e \quad (p^-)$$

Can this work???? **theoretical studies now on beta beam**
+ SPL target and horn R&D → design study together with EURISOL


3 sigma sensitivity of various options
δ (deg.)
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
θ13 (deg.)
Superbeam only
Beta-beam only
Betabeam
+ superbeam
NUFACT

Where will this get us…



Mezzetto

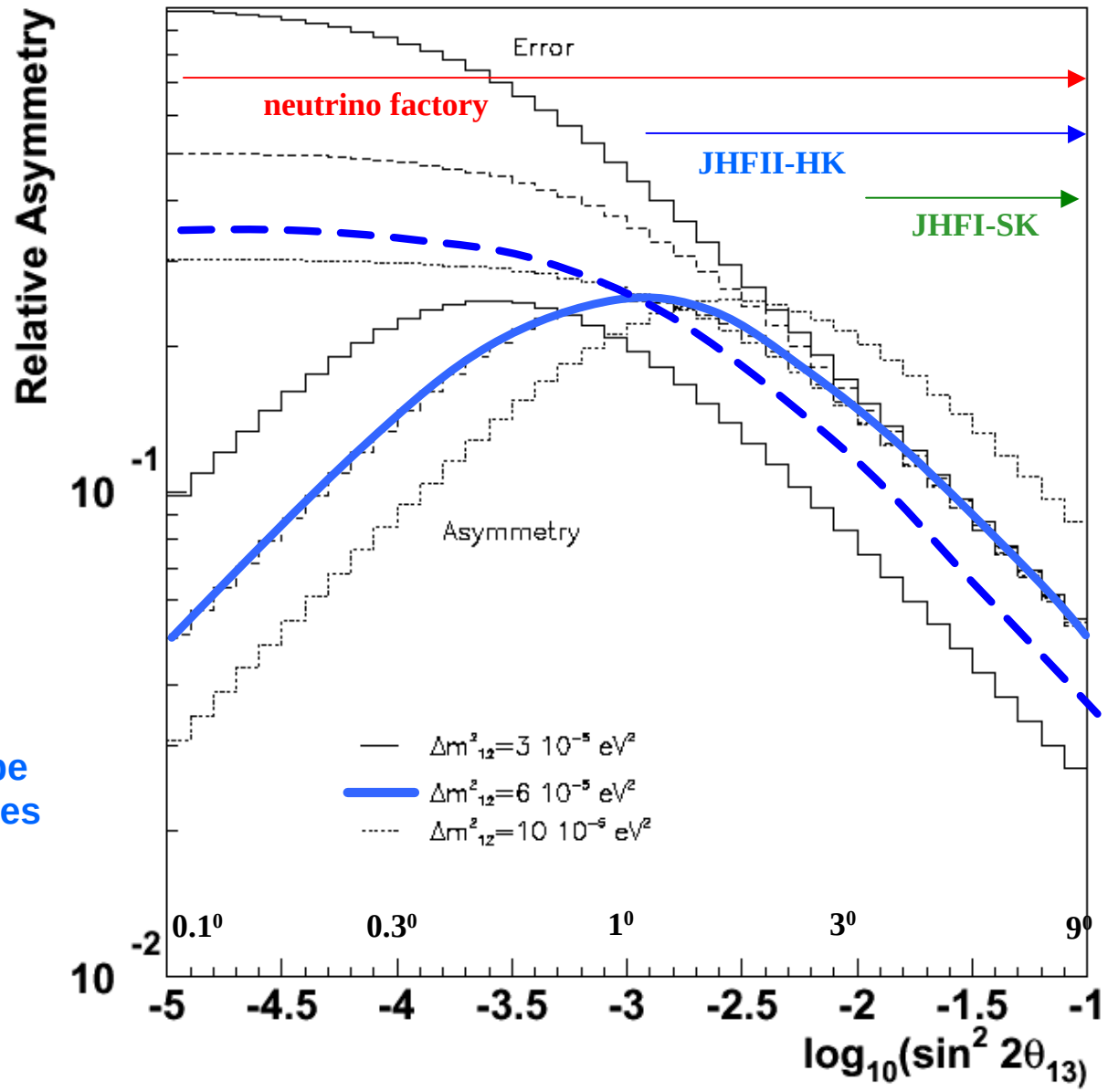
comparison of reach in the oscillations; right to left:
present limit from the CHOOZ experiment,
expected sensitivity from the MINOS experiment, CNGS (OPERA+ICARUS)
0.75 MW JHF to super Kamiokande with an off-axis narrow-band beam,
Superbeam: 4 MW CERN-SPL to a 400 kton water Cerenkov in Fréjus (J-PARC phase II similar)
from a Neutrino Factory with 40 kton large magnetic detector.

!

asymmetry is
a few %
and requires
excellent
flux normalization
(neutrino fact., beta beam
or
off axis beam with
not-too-near
near detector)

NOTE:
This is at first maximum!
Sensitivity at low values of q_{13} is better for short baselines, sensitivity at large values of q_{13} may be better for longer baselines (2d max or 3d max.)
This would desserve a more careful analysis!

T asymmetry for sin d = 1



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