Looking forward

Luciano MAIANI. CERN. Geneva

Parliamo dei Neutrini

Accademia Nazionale dei Lincei.

Roma, March 7, 2003

Solar neutrinos

- $\Delta m_{12}^2 \approx 5.5\ 10^{-5}\ eV^2$
- $\sin^2 2\theta_{12} \approx 0.8$
- Spectrum deformation of CC events seen: Homestake, Kamioka, Gallex/Sage; BOREXINO will complete the picture
- SNO:
  - shows that neutrinos are fully active for NC
  - “appearance” of new flavours proved (as far as possible)

Atmospheric neutrinos

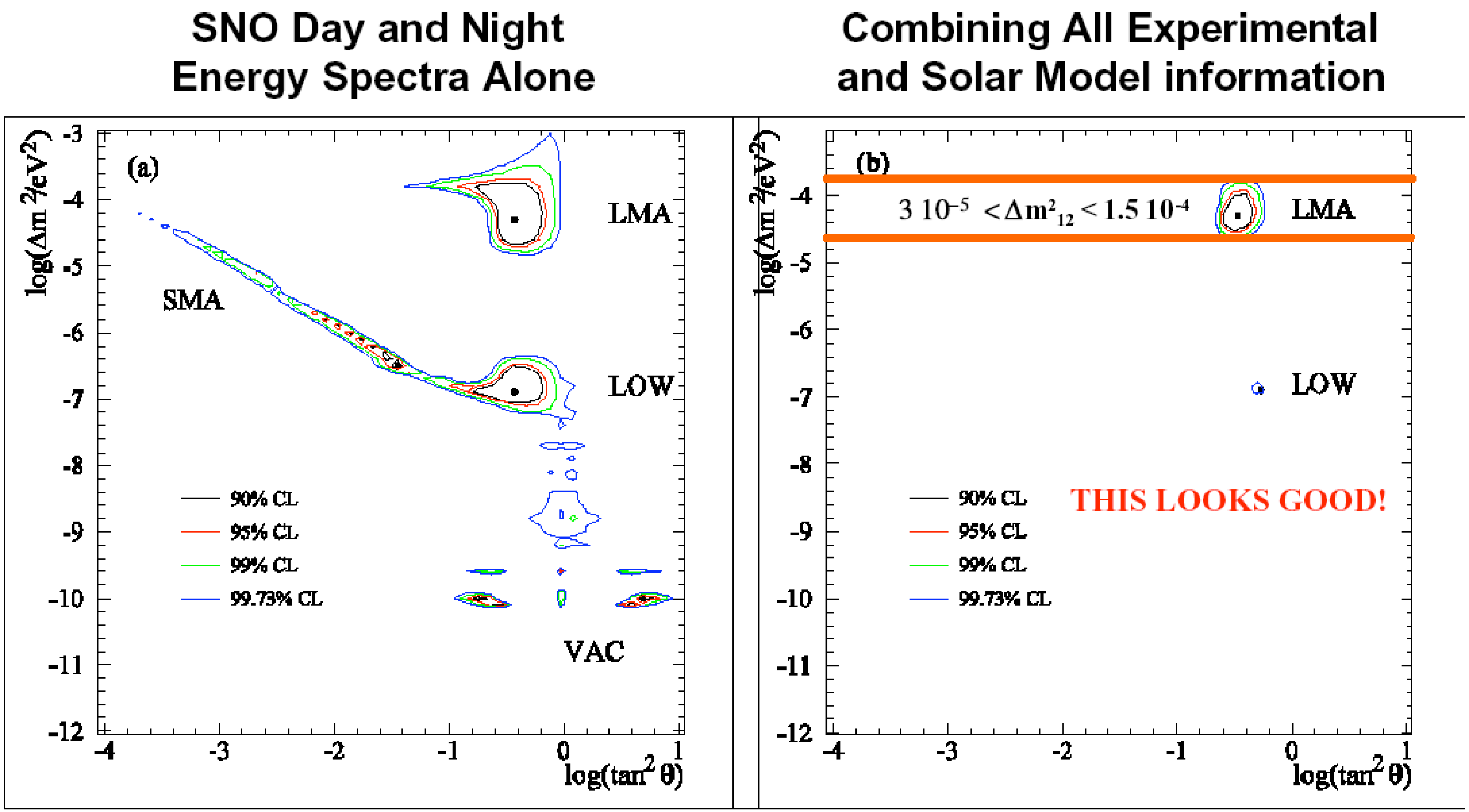
- $\Delta m_{23}^2 \approx 2.4\ 10^{-3}\ eV^2$
- $\sin^2 2\theta_{12} \approx 1$

- Spectrum deformation indicated by K2K
- $\nu_\mu \rightarrow \nu_\tau$ gives best fit to atmospheric neutrinos, but…
- Next generation long-baseline neutrino beams:
  - Spectrum deformation
  - NC/CC
  - ν_τ appearance

NuMI-Minos

CNGS- OPERA and later ICARUS

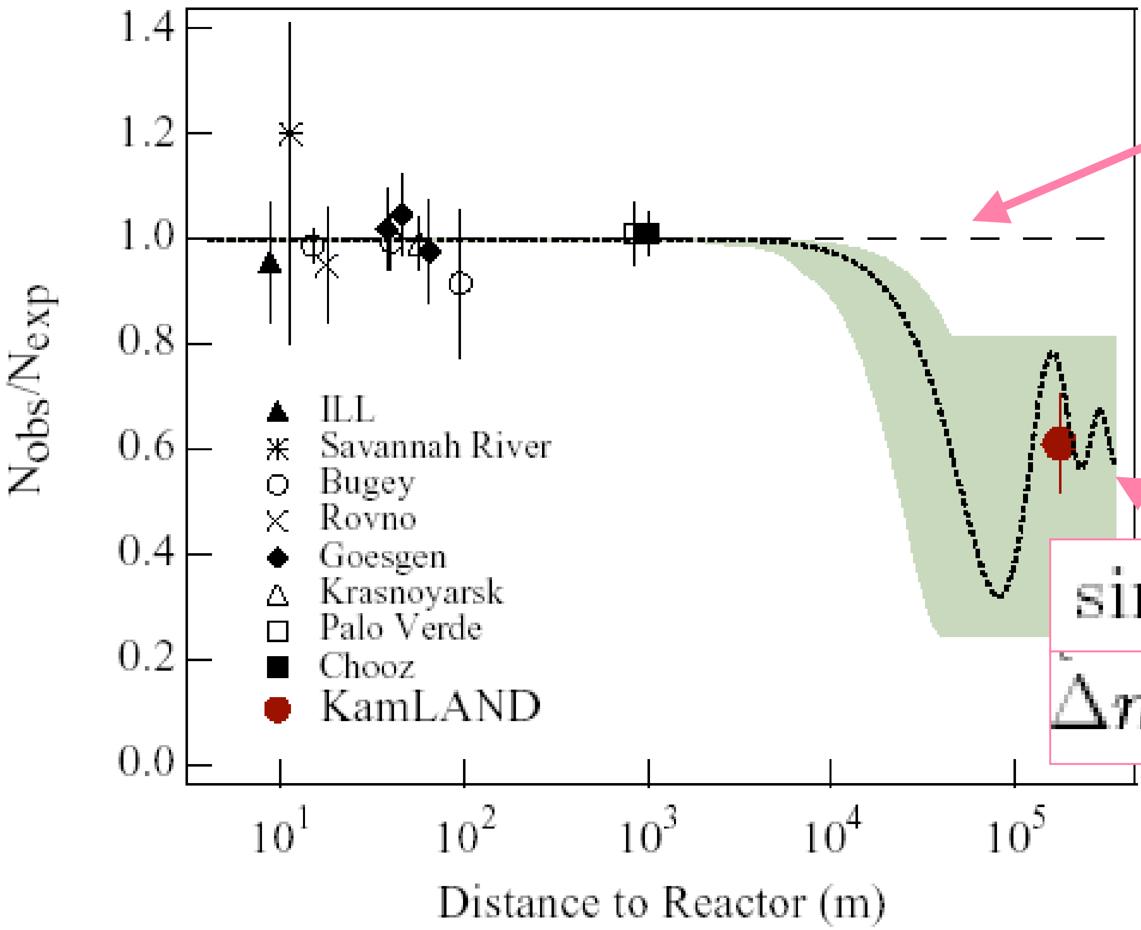
Solar neutrino oscillation parameters



This will be confirmed and Δm^2_{12} measured precisely by e.g. KAMLAND in next 2-4 yrs

Alain Blondel, ICFA @cern - 2002

KAMLAND !!



- Small Mixing Angle
- Vacuum Oscillations

$$\sin^2 2\theta = 0.833$$

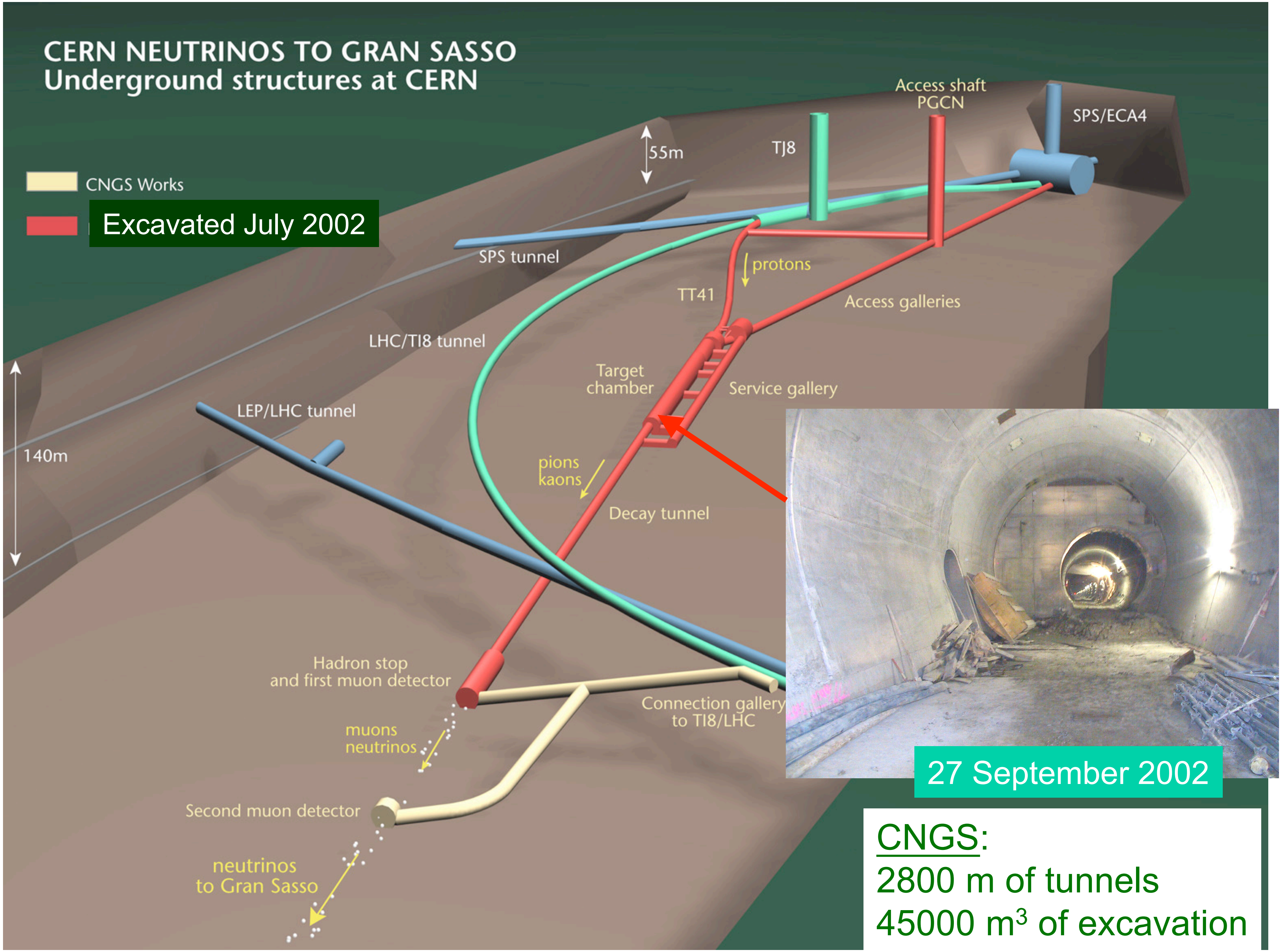
$$\Delta m^2 = 5.5 \times 10^{-5}\ eV^2$$

What's Next ?

Summary

- The next Long-Baseline Experiments
- The third mixing angle
  - Off axis beams
  - Superbeams
- CP violation:
  - Neutrino factory
  - Beta Beams
- Looking further
- Conclusions

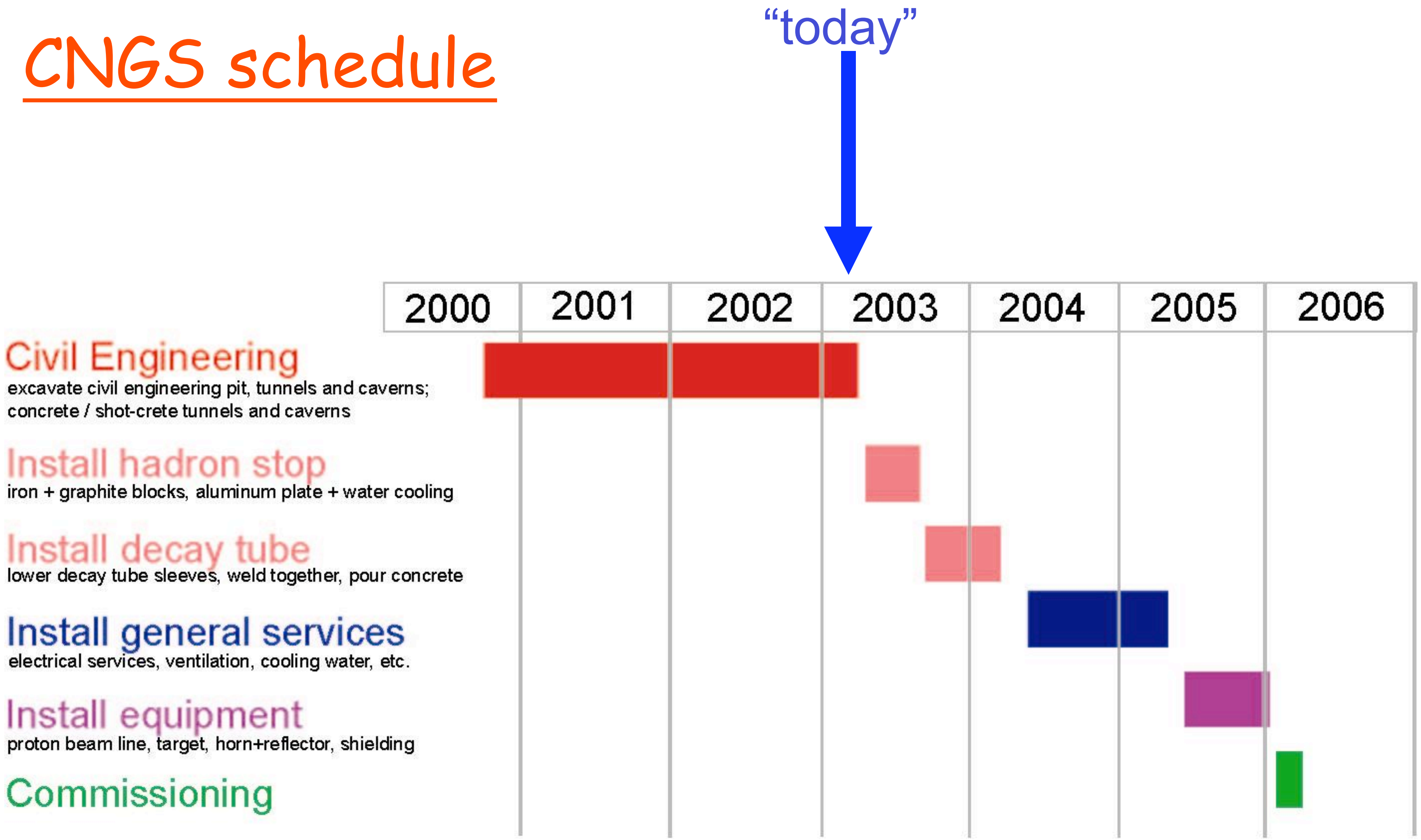
Very personal considerations
A systematic survey:
A. Blondel at ICFA Seminar, CERN, Oct. 2002



27 September 2002

CNGS:
2800 m of tunnels
45000 m^3 of excavation

CNGS schedule



First beam to Gran Sasso: May 2006

Sensitivity to $\nu_\mu \rightarrow \nu_\tau$ oscillations

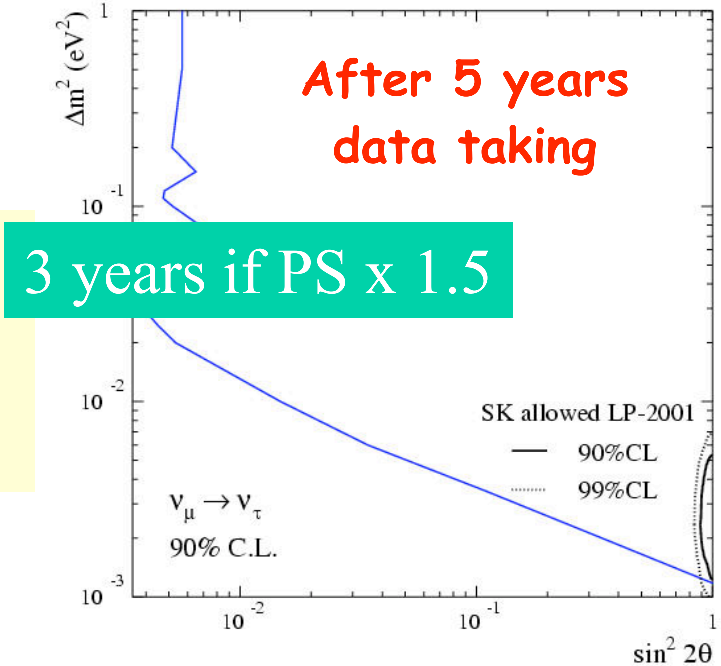
(5 year run with 1.8 kton average target mass)

Decay mode	*Signal* 1.2×10^{-3}	*Signal* 2.4*10-3	*Signal* 5.4*10-3	*Bkgnd.*
$\tau \rightarrow$ e long	**0.8**	**3.1**	**15.4**	**0.15**
$\tau \rightarrow \mu$ long	**0.7**	**2.9**	**14.5**	**0.29**
$\tau \rightarrow$ h long	**0.9**	**3.4**	**16.8**	**0.24**
$\tau \rightarrow$ e short	**0.2**	**0.9**	**4.5**	**0.03**
$\tau \rightarrow \mu$ short	**0.1**	**0.5**	**2.3**	**0.04**
Total	**2.7**	**10.8**	**53.5**	**0.75**

Signal events
$\mu \; (\Delta m^2)^2$

90 % CL upper limit obtained on average by a large ensemble of experiments:

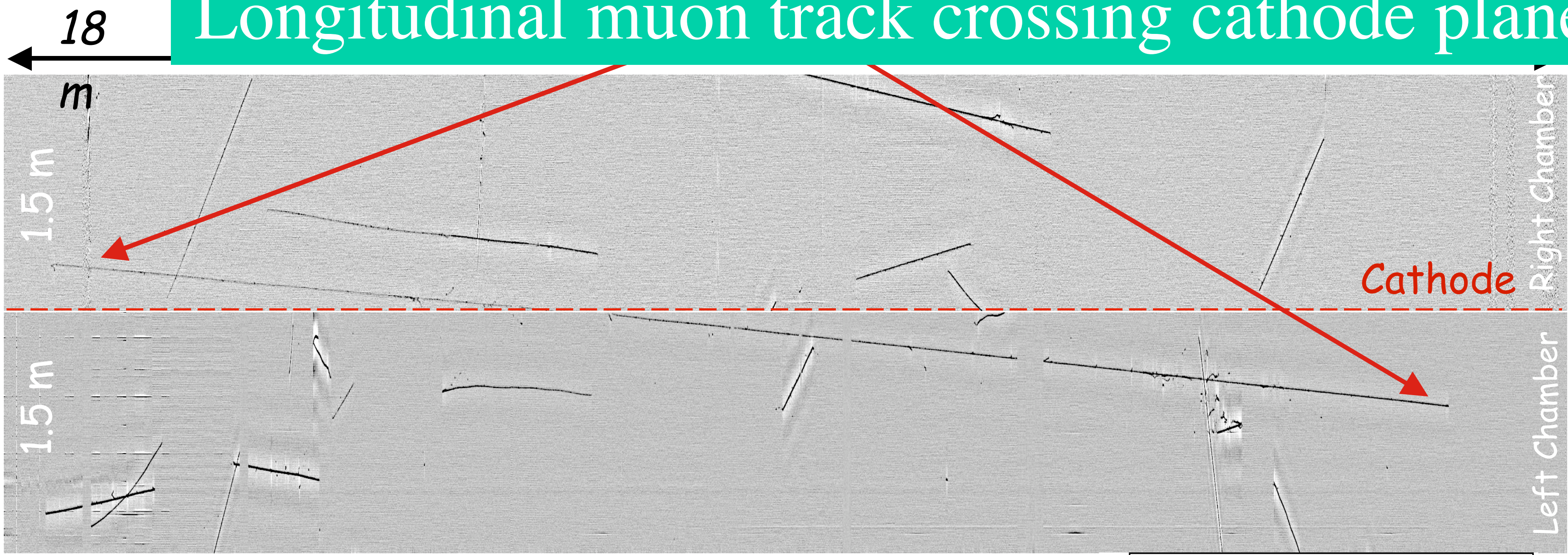
Δm^2	$< 1.2 \times 10^{-3}$ eV^2 at full mixing
$\sin^2(2\theta)$	$< 5.7 \times 10^{-3}$ at large Δm^2

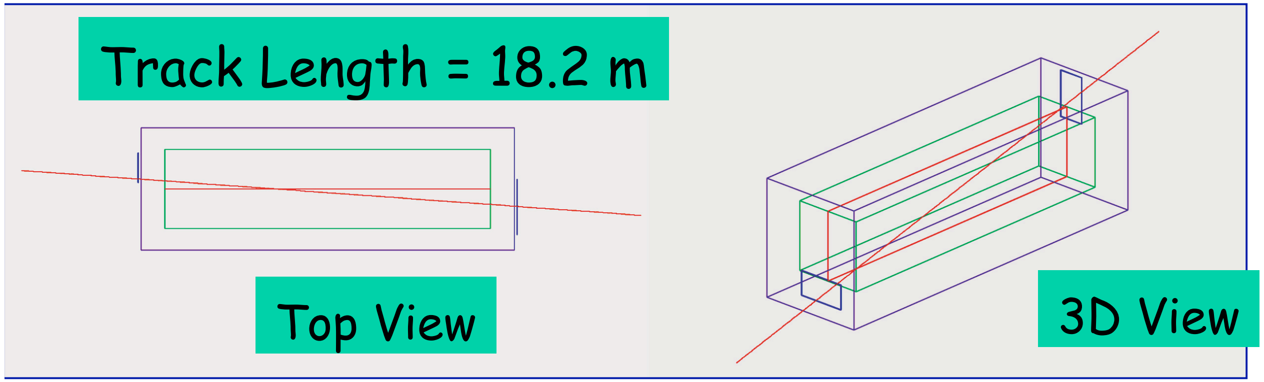


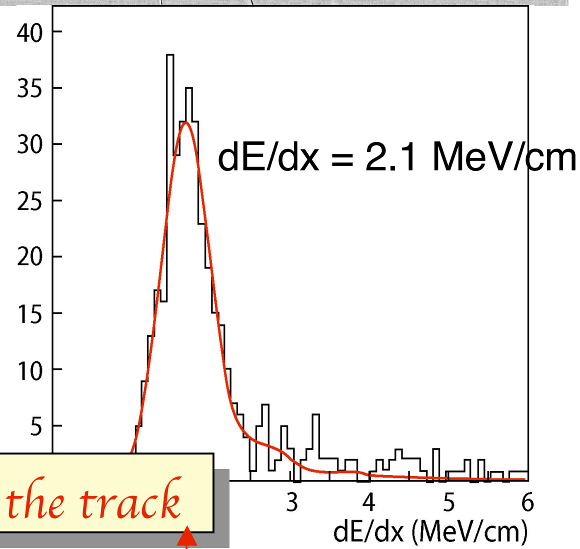
Accounted uncertainties: on background (±33%) and on efficiencies (±15%)

ICARUS T300 cryostat (1 out of 2)

Longitudinal muon track crossing cathode plane







3-D reconstruction of the long track

dE/dx distribution along the track

3. The third mixing angle, θ_{13}

- Needed to further our knowledge of the mixing matrix;
- Determines $\nu_e(\bar{\nu}_e) \leftrightarrow \nu_\mu(\bar{\nu}_\mu)$ oscillations;
- Regulates the size of CP violation in the lepton sector;
- Limits of order 10^{-1} obtained by CHOOZ at $\Delta m^2 \approx 2.4\ 10^{-3}\ eV^2$
- Proposed tools:
  - MINOS, OPERA, ICARUS can improve on CHOOZ by about 1 order of magnitude;
  - Off-axis observation of CNGS or NUMI neutrinos;
  - **Japan Hadron Facility**, the only ongoing programme for a future facility
  - “Neutrino Superbeams”
  - Neutrino beta-beams and Neutrino factories

OPERA sensitivity to θ_{13} (preliminary)

In parallel with appearance search

Cuts

- $E_e > 1$ GeV
- Visible energy < 20 GeV
- Missing p_T of the event < 1.5 GeV

Background

- ν_e beam contamination
- π^0 identified as electrons produced in ν_μNC and ν_μCC with the μ not identified
- $\tau \rightarrow$ e from $\nu_\mu \rightarrow \nu_\tau$ oscillations

Limits at 90% C.L. on $\sin^2 2\theta_{13}$ and θ_{13}
($\Delta m^2_{23}=2.5\text{x}10^{-3}$ eV^2; $\sin^2\theta_{23}=1$)

Experiment	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	<0.14	<11°
MINOS	<0.06	<7.1°
ICARUS	<0.04	<5.8°
OPERA	<0.06	<7.1°
JHF	<0.006	<2.5°

Expected signal and background

θ_{13}	signal	$\tau \rightarrow$ e	ν_μCC	ν_μNC	ν_eCC beam
9°	9.3	4.5	1.0	5.2	18
7°	5.8	4.6	1.0	5.2	18
3°	1.2	4.7	1.0	5.2	18

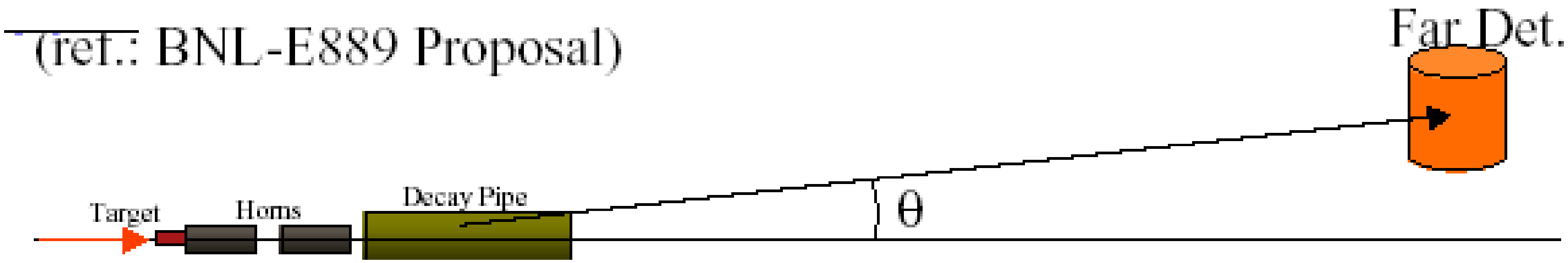
Sensitivity to $\sin^2 2\theta_{13}$ as a function of the year

	2004	2005	2006	2007	2008	2009
CHOOZ	**<0.14**	**<0.14**	**<0.14**	**<0.14**	**<0.14**	**<0.14**
MINOS		→	<0,085	<0,06	<0,049	<0,042
CNGS*			→	<0,067	<0,047	<0,039
CNGSx1,5*			→	<0,056	<0,039	<0,033
Low energy CNGS				? →	<0,040	<0,028
JHF-SK					→	<0,013

* Designed for ν_τ appearance

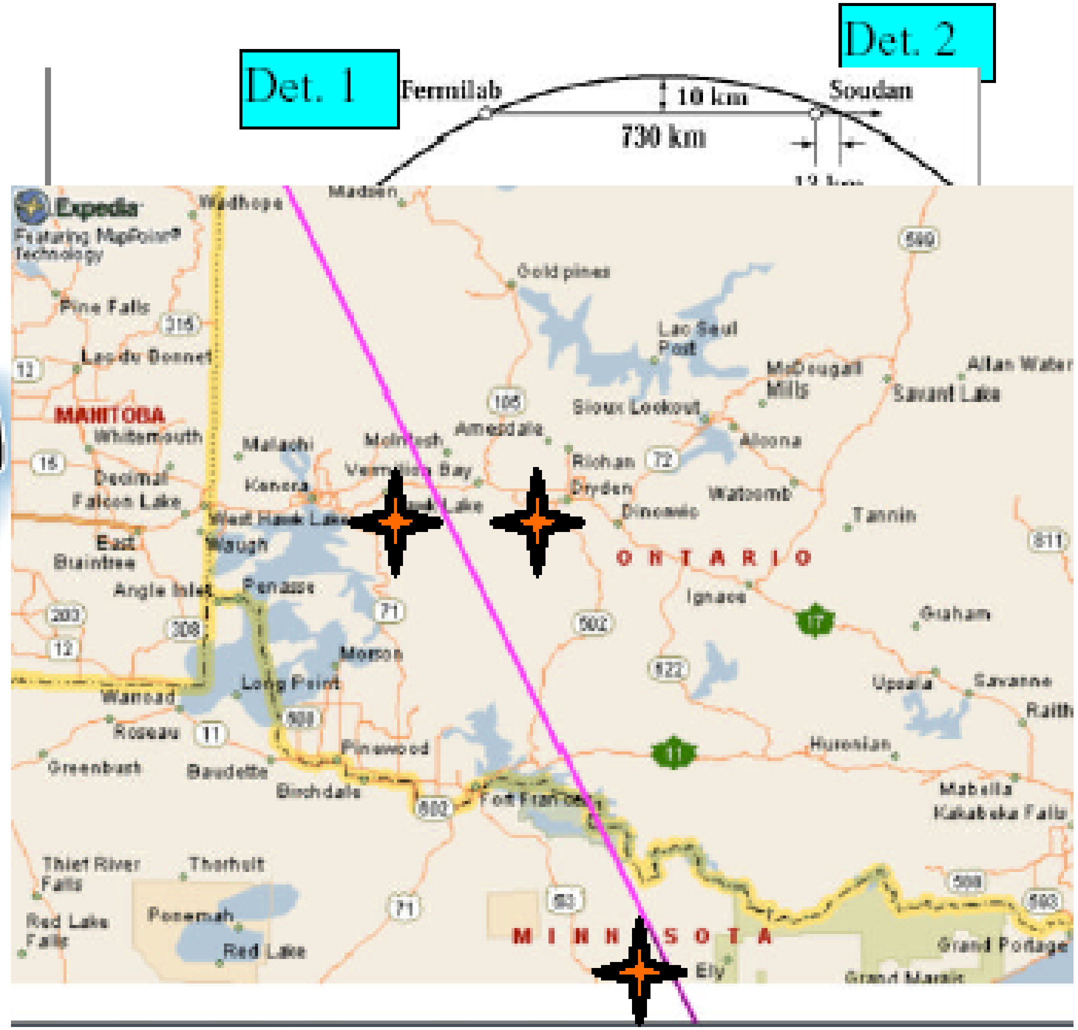
Pasquale Migliozzi ECFA-NOWG, sept 2002

4. OFF-AXIS Beams: NUMI and CNGS



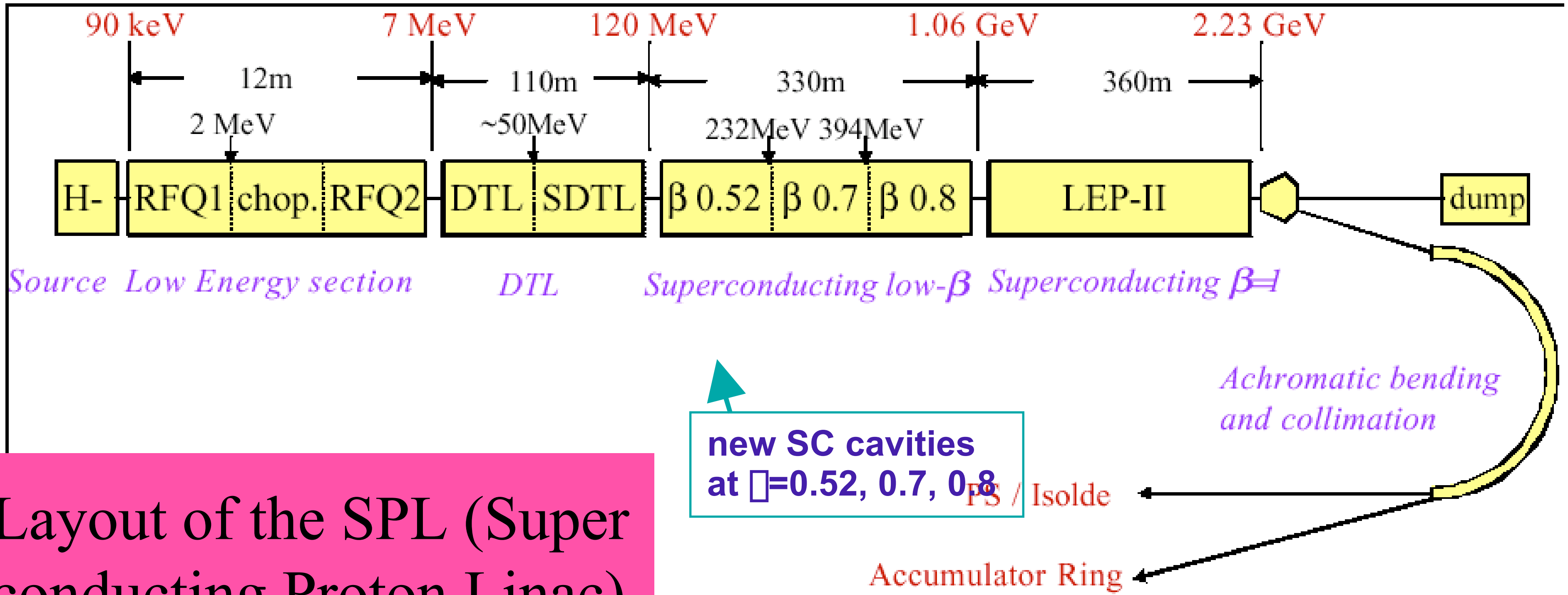
•Almost monochromatic neutrino beam, shows maxima and minima of oscillation!
•US project around first maximum
•similar ideas for Europe:
    •CNGT– Golf of Taranto below the CNGS beam
    •off axis at second minimum 1400 km from CERN, 1 Mton of sea water 1km deep.*F.Dydak, neutrino 2002*

NUMI beam: on and off axis



5. SUPERBEAMS

- Low energy, High intensity, proton drivers to produce pure π beams hence pure ν_μ or anti- ν_μ beams
- no Kaons, ν_e background from μ decay only
- Low energy ν_μ s: for $\Delta m^2 \approx 2\ 10^{-3}\ eV^2$ optimal distance about 100 km (CERN-Frejus??)
- CERN's design is the SPL (Superconducting Proton Linac)
  - E= 2.2 GeV
  - W on target = 4 MW
- The SPL could have many uses! (EURISOL, Beta Beams..)



Layout of the SPL (Super conducting Proton Linac)

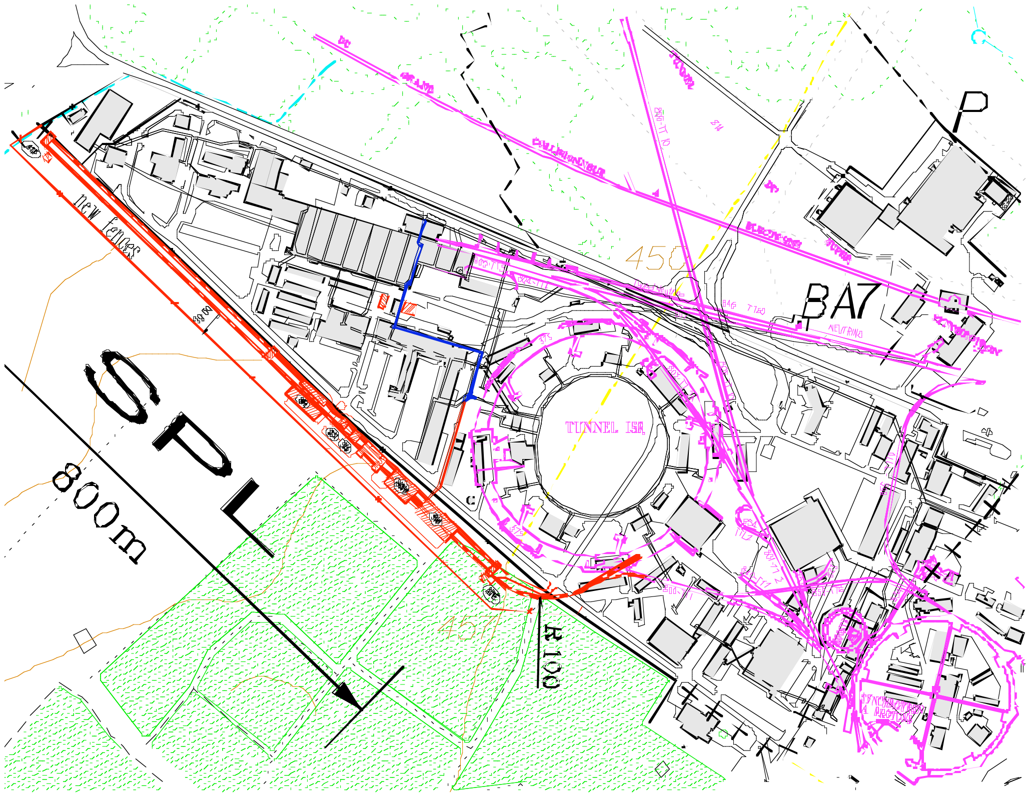
The 2.2 GeV Superconducting H linac parameters in quasi-CW mode

Beam Current, mA	11
Energy (kinetic), GeV	2.2
Invariant transverse rms emittance, μm	0.6
Beam energy spread ($\sqrt{5}\sigma$) MeV	±2
Bunch length (total: $\sqrt{5}\sigma$), ps	24
Linac length, m	800
rf frequency, MHz	352
Overall rf power, MW	31
Number of klystrons	46

We have 53 klys.

Cost 350MCHF (prel.)
good for Isolde, CNGS, LHC.

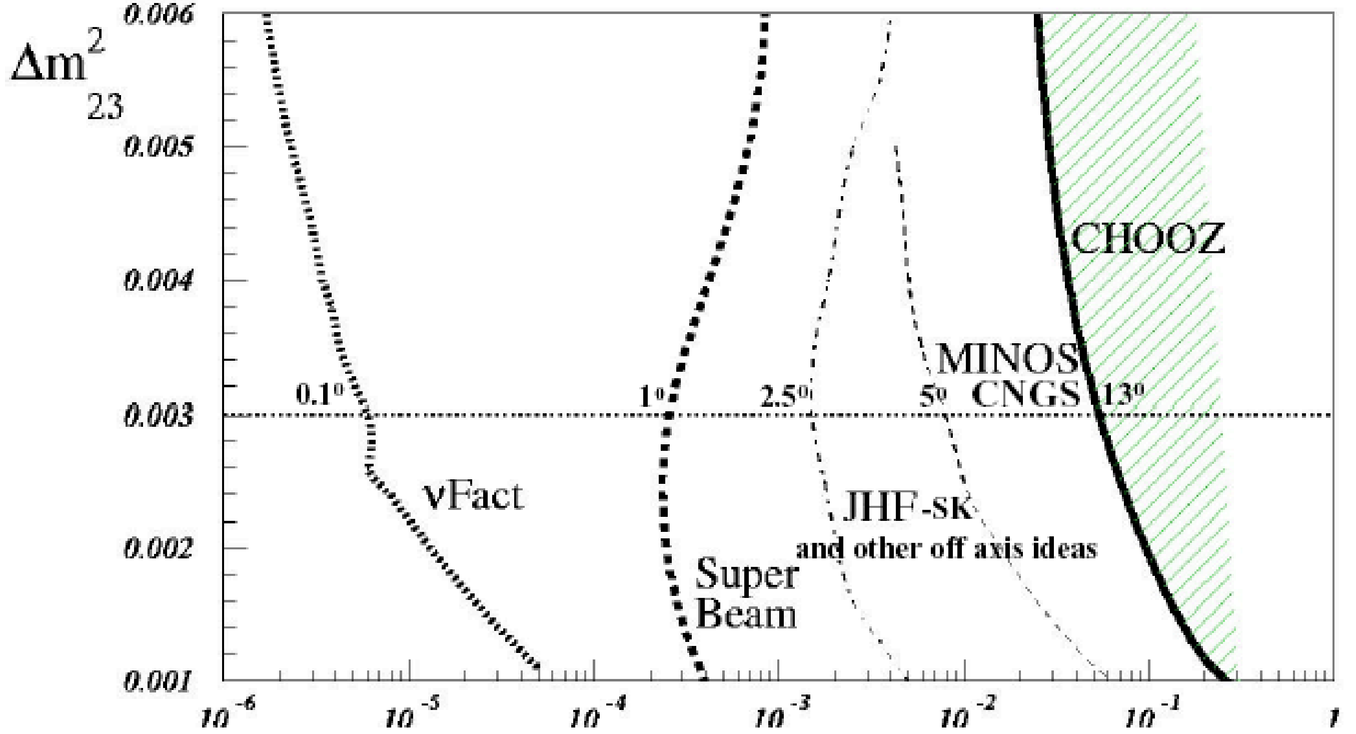
Layout on the CERN site



Linac + klystron gallery parallel to the fence of Meyrin site (Route Gregory)

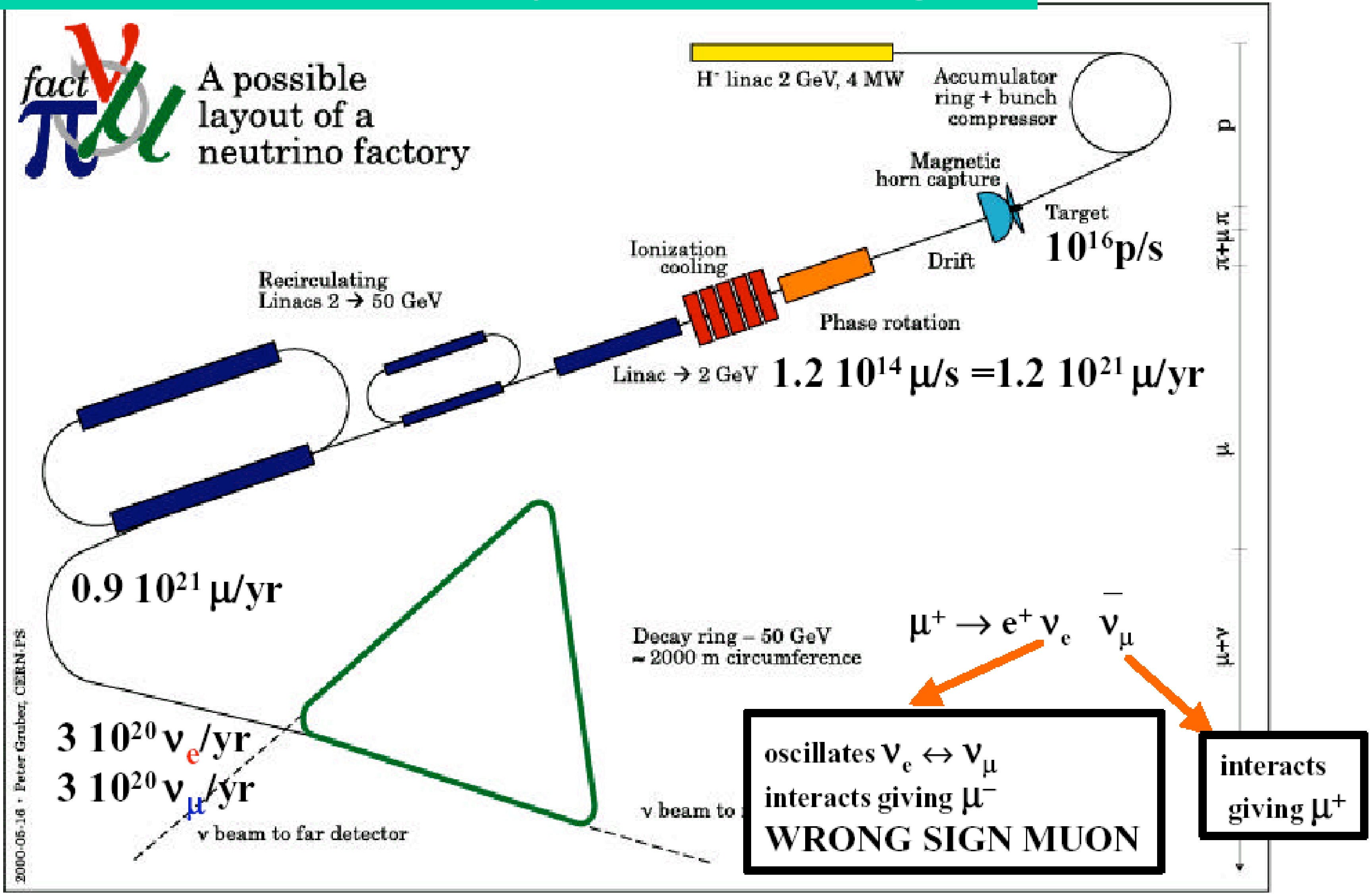
- Economic trench excavation
- Geological advantages (tunnel on“molasse”, no underground water)
- Minimum impact on the environment (empty field)
- Simple connection to PS & ISR via existing tunnels
- Use some of the old ISR infrastructure (electricity, cooling)

Where all this will lead us

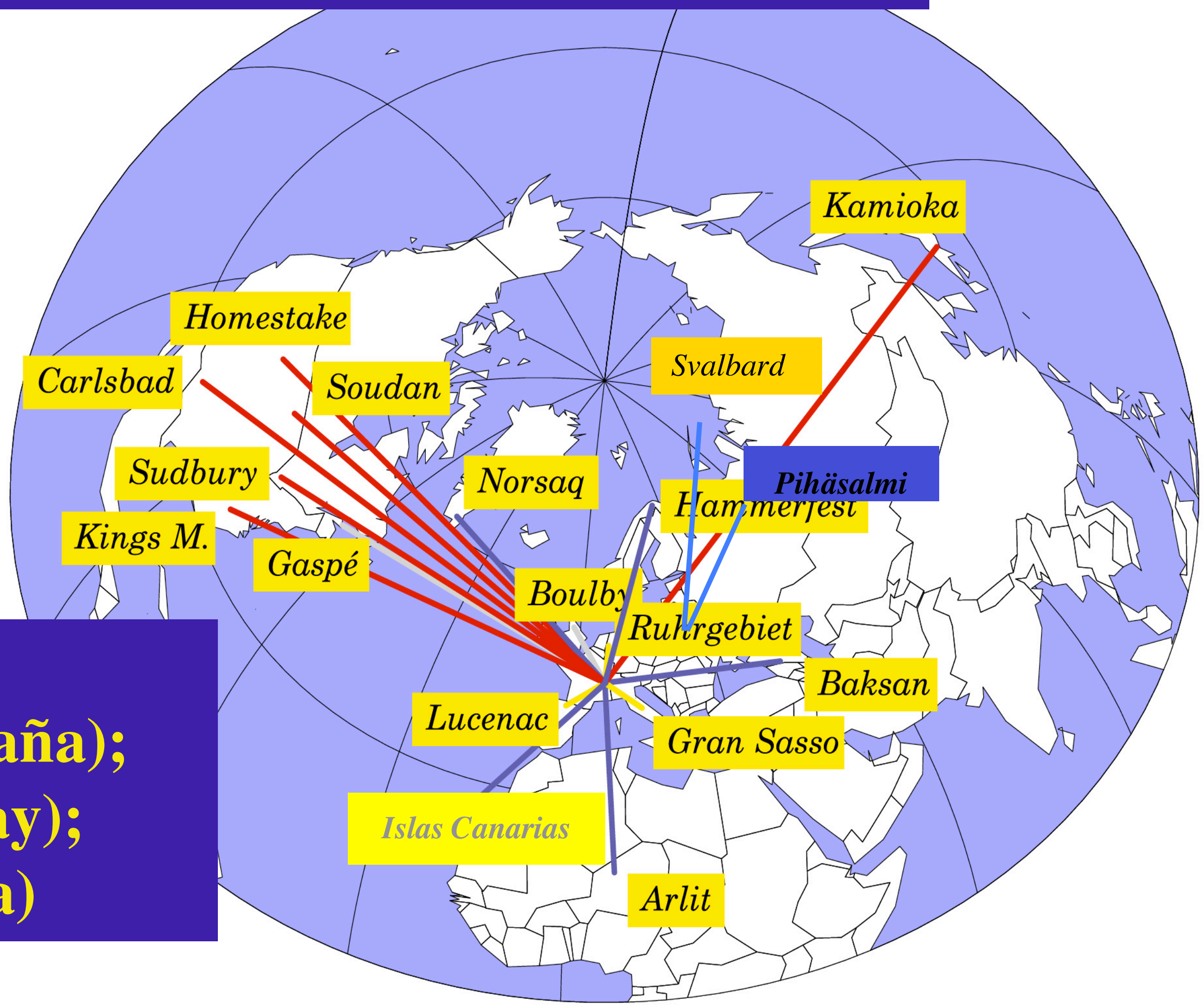


comparison of reach in the oscillations; right to left:
present limit from the CHOOZ experiment,
expected sensitivity from the MINOS experiment,
0.75 MW JHF to super Kamiokande with an off-axis narrow-band beam,
Superbeam: 4 MW CERN-SPL to a 400 kton water Cerenkov in Fréjus
from a Neutrino Factory with 40 kton large magnetic detector. INCLUDING SYSTEMATICS

6. Neutrino factory: CERN design



Perspective locations of Long Baseline neutrino detectors in CERN Member States



Optimal locations:

- Gran Canaria (España);
- Spitzbergen (Norway);
- Pihäsalmi(Finlandia)

Nufact cost studies

USA, Europe, Japan have each their scheme. Only one has been costed, US study II:

System	Sum ($M)	Others[a] ($M)	Total ($M)	Reconciliation[b] (FY00 $M)
Proton Driver	167.6	16.8	184.4	179.9
Target Systems	91.6	9.2	100.8	98.3
Decay Channel	4.6	0.5	5.1	5.0
Induction Linacs	319.1	31.9	351.0	342.4
Bunching	68.6	6.9	75.5	73.6
Cooling Channel	317.0	31.7	348.7	340.2
Pre-accel. linac	188.9	18.9	207.8	202.7
RLA	355.5	35.5	391.0	381.5
Storage Ring	107.4	10.7	118.1	115.2
Site Utilities	126.9	12.7	139.6	136.2
Totals	1,747.2	174.8	1,922.0	1,875.0

Neutrino Factory CAN be done…..but it is too expensive as is.

Aim: ascertain challenges can be met + cut cost in half.

7. Beta-Beams

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Physics Letters B 532 (2002) 166–172

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A novel concept for a $\bar{\nu}_e/\nu_e$ neutrino factory: the beta-beam

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Editor: L. Rolandi

Unstable ions accelerated to □□ 100 and stored to produce neutrino beams by beta decay

Abstract

The evolution of neutrino physics demands new schemes to produce intense, collimated and pure neutrino beams. The current neutrino factory concept implies the production, collection, and storage of muons to produce beams of muon and electron neutrinos at equal intensities at the same time. Research and development addressing its feasibility are ongoing. In the current Letter, a new neutrino factory concept is proposed that could possibly achieve beams of high intensity, known energy spectrum and a single neutrino flavour (electron–antineutrino or electron–neutrino). The scheme relies on existing technology.

Beta-Beams, cont'd

- Absolutely pure ν_e, emitted in a cone of aperture $\approx 1/\gamma$
- Flux at distance L, $\Phi \propto (\dot{N}/L^2)\gamma^2$
- Flux at critical distance, such that $\Delta m^2 L/E \approx 1$ is:

$$\Phi \propto \dot{N}\frac{(\Delta m^2)^2}{E^2}\gamma^2 = \dot{N}\frac{(\Delta m^2)^2}{E_0^{\ 2}}$$

(E$_0$ is the decay energy in the rest frame)

- and the effective flux (flux*energy) is:

$$\Phi\cdot E \propto (\Delta m^2)^2 \frac{\dot{N}}{E}\gamma^2 = (\Delta m^2)^2 \frac{\dot{N}}{E_0}\gamma$$

merit factor

- Possible ν_e, and anti-ν_e ν_e,

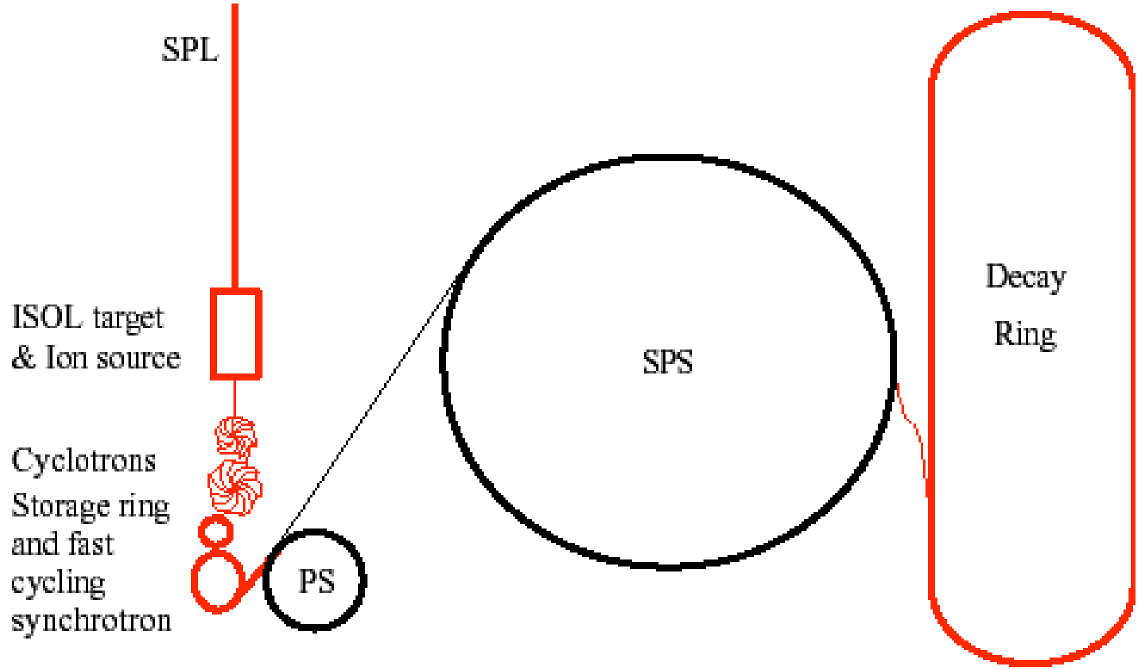
Beta Beams

Decay ring

Brho = 1500 Tm

B = 5 T

L_{ss} = 2500 m



Cost?

Feasibility?

Figure 1: The CERN baseline scenario

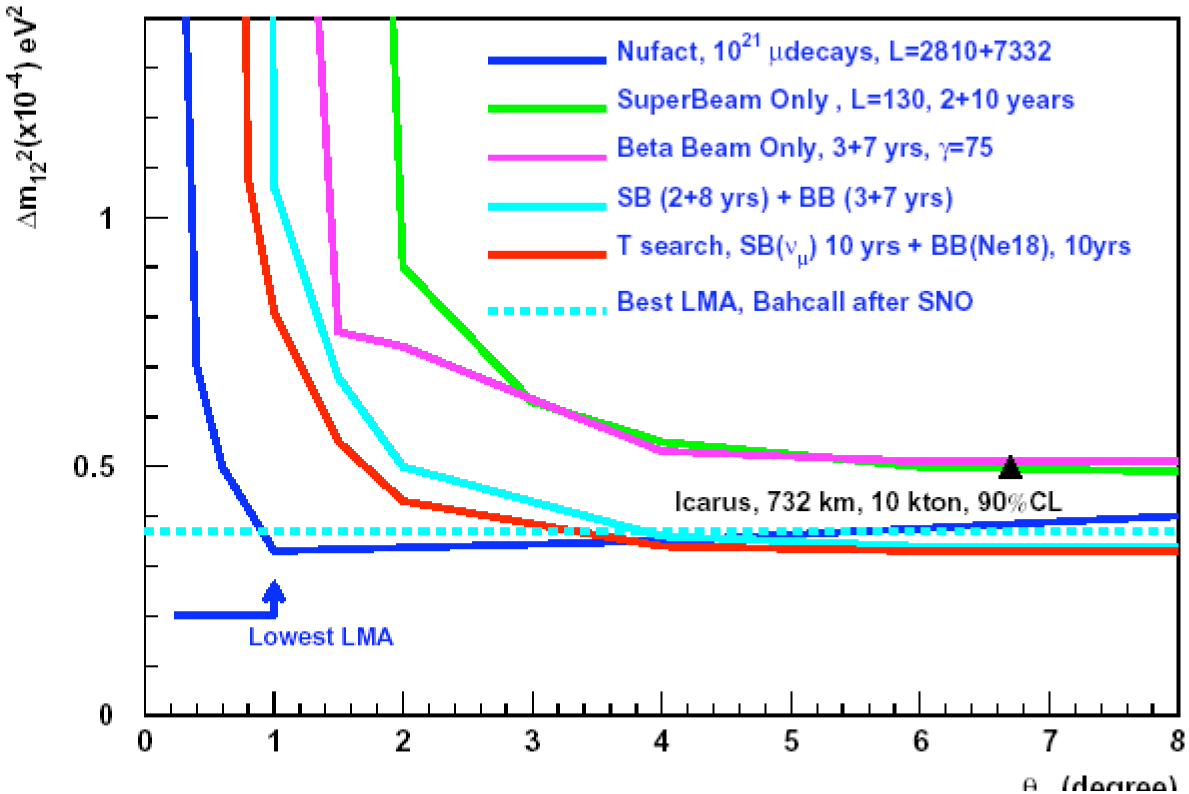
Isotope	A/Z	T ½ (s)	Q_β g.s to g.s (MeV)	Q_β eff (MeV)	E_β av (MeV)	E_ν av (MeV)	Ions/bunch	Decay rate (s^{-1})	rate / $E_{\nu\ av}$ (s^{-1})
^{6}He	3.0	0.80	3.5	3.5	1.57	1.94	$5\cdot10^{12}$	$4\cdot10^{10}$	$2\cdot10^{10}$
^{18}Ne	1.8	1.67	3.3	3.0	1.50	1.52	$1\cdot10^{12}$	$4\cdot10^{9}$	$3\cdot10^{9}$

best □$^-$

best □$^+$

CP sensitivity

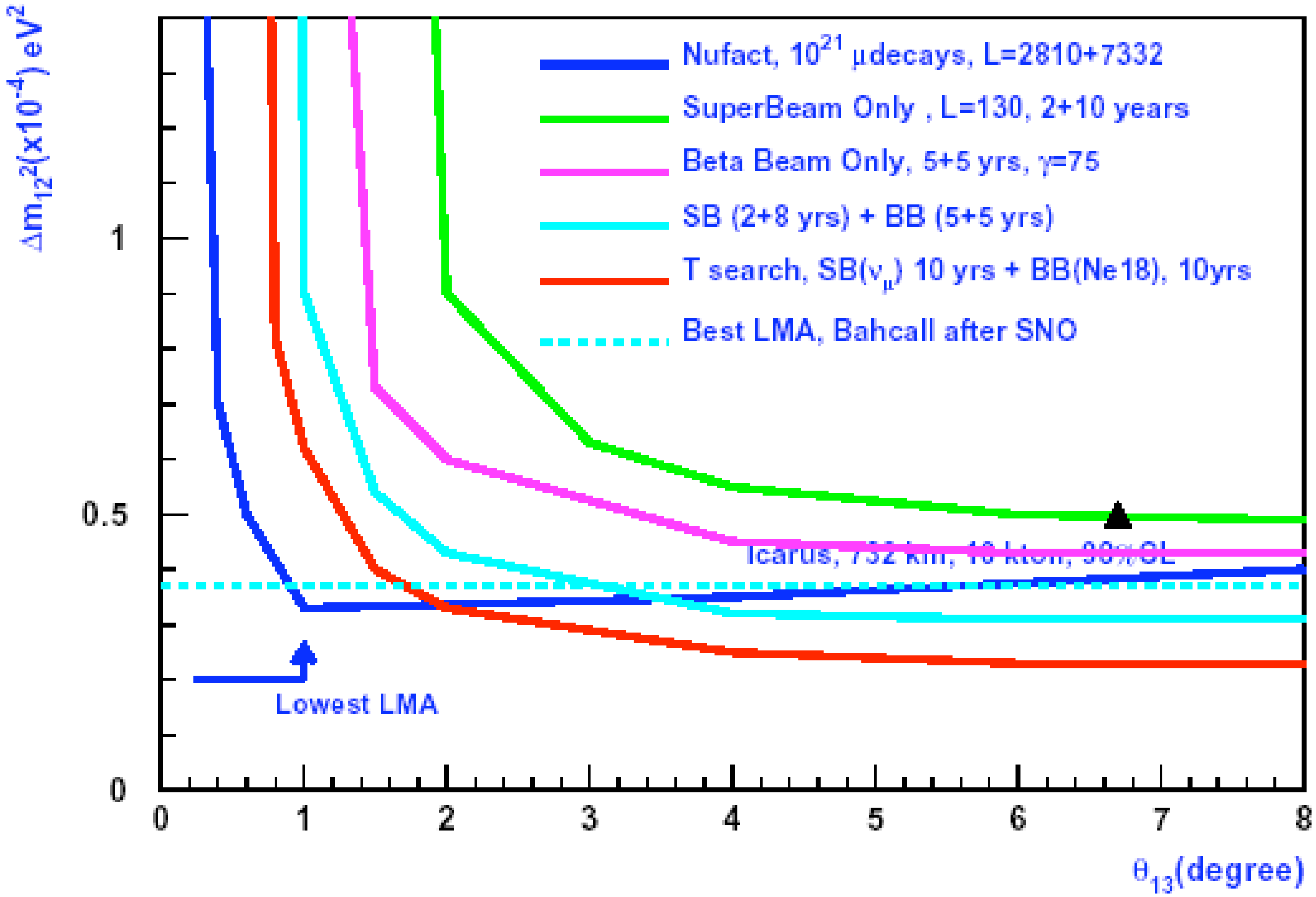
Region in $\Delta m^2 - \theta_{13}$ plane where it is possible to distinguish $\delta = 90^0$ from $\delta = 0^0$



M. Mezzetto, *"Physics reach of Super + Beta Beams"*, NNN02, CERN, 16-18 January 2002

The limiting factor for the Beta Beam is the ^{18}Ne production rate.

Let's see the SuperBeam + Beta Beam performances if a lucky R&D program could rise the ^{18}Ne production rate by a factor 2.



M. Mezzetto, *"Physics reach of Super + Beta Beams"*, NNN02, CERN, 16-18 January 2002

8. Looking further…

- Textures:
  - The see-saw mechanism relates neutrino massess to GUT energy scales or so (all are matrices!):

$$m_\nu \approx \frac{(m_{quark})^2}{M_{GUT}}$$

  - Maybe the reason of so different mixing angles lies in M_{GUT}! Can we guess M_{GUT}?
- Flavour violation in charged lepton processes, induced by neutrino mixing?
  - much too small in Standard Theory, effects are close to present limits in e.g SUSY theories!!
  - Looking for: $\mu \to e\gamma$

$$\mu + \text{Nucleus} \to e + \text{Nucleus}$$

becomes interesting (neutrino factories again…)

Conclusions

- Neutrino mass and oscillations established with "natural neutrinos" (solar, atmospheric): a great success of Underground Laboratories;
- we need to know more: time seems to have come for more controlled (accelerator) sources;
- experiments with first generation long-base neutrino beams are operating (K2K) or well underway (NUMI and CNGS), with very definite goals: spectrum shape, appearance.

Conclusions, cont'd

- There is a long way towards full neutrino factories with muon accumulation rings (cooling, cost…)
- But a lot of interesting ideas and several intermediate steps: off-angle beams, superbeams, □-beams;
- The third mixing angle, $\square_{13}$, and the the CP violating phase, □, are good objectives for progress;
- Texture: finding M_{GUT} from neutrino mass and mixing may prove difficult but not impossible, particularly if coupled to other related observations
- Search for other flavour violations is thus mandatory (□□ e transitions, □□-0□ decays)
- Natural neutrinos at very high energies: the new frontier for "natural neutrinos" (Amanda, Nestor, Antares…).

Neutrino physics is again an exciting, complementary route to the High Energy Frontier (LEP, LHC, Linear Collider?)

WE CANNOT DO WITHOUT IT !