^

Wednesday, December 3, 2003

We have already got annus mirabilis

Chairman: S.Bilenky (JINR,Dubna)

A.Y.Smirnov *(INR of RAS, Moscow & ICTP,Trieste)*	*Neutrinos:"...annus mirabilis"*
V.Rusu *(University of Pennsylvania)*	*The Impact of the SNO Results*
G.A. Horton-Smith *(California Institute of Tech., Pasadena)*	*KamLAND Status and Prospects*
V. Koshio *(University of Tokyo)*	*Solar Neutrinos in SK*

Chairman: Chairman: J.Schneps *(Tufts University)*

E.Bellotti *(University of Milano)*	The Gallium Observatory (ppt, pdf)
G.P.Bellini *(University of Milano)*	*The Status and the Physics Expectations of the Borexino Experiment*
D.O. Caldwell *(University of California, Santa Barbara)*	*Solar Neutrino Flux Variability*
V.Berezinsky *(LNGS)*	*Oscillation of Mirror Neutrinos in Solar and High Energy Physics*

What comes next?

Chairman: E.Coccia *(LNGS)*

S. Petcov *(SISSA/INFN & INRNE, Sofia)*	*Neutrino Masses and Mixing and the Nature of Massive Neutrinos*
F.T.Avignone *(University of South Carolina)*	*Double Beta Decay: Selected Next Generation Proposals*
K. Okumura *(University of Tokyo)*	*SK Atmospheric Neutrinos Results*
P. Lipari *(INFN, Roma La Sapienza)*	*Atmospheric Neutrino Oscillations and Accelerator Experiments*

Chairman: Y.Déclais *(LAPP,Annecy-le-Vieux)*

I.Kreslo *(University of Bern)*	*OPERA*
R.Dolfini *(University of Pavia)*	ICARUS (ppt, pdf)
N.Tagg *(University of Oxford)*	*MINOS*
R. Voss *(CERN)*	*Gulf of Taranto*

Thursday, December 4, 2003

Which way?

Chairman: D.Haidt *(DESY)*

M. Lindner *(University of Munich)*	*The Path to Measuring θ_{13}, Matter Effects and Leptonic CP Violation*
J.Bouchez *(CEA/DAPNIA)*	*New Experimental Options on the θ_{13} Measurements*
G. Feldman *(HarvardUniversity)*	*NuMI off-axis*
K. Nishikawa *(KyotoUniversity)*	*Neutrino Experiment at J-PARC*

Chairman: S.Katsanevas (*IN2P3/CNRS)*

H. deKerret *(PCC - Collège de France)*	*Reactor Experiments: Systematic Errors and Background*
L.Oberauer *(TechnicalUniversityMunich)*	*LENA Low Energy Neutrino Astronomy*
S.Choubey *(SISSA)*	Solar Neutrino Oscillation Parameters in Experiments with Reactor Anti-Neutrinos
P.Migliozzi *(INFN,Napoli)*	Complementarity of Terrestrial Neutrino Experiments in Searching for θ_{13}

An ultimate goal?

Chairman: E. Iarocci *(University of Roma, La Sapienza)*

H. Minakata *(Tokyo Metropolitan University)*	New Views on the Problem of CP Violation
A.Rubbia *(ETH,Zurich)*	Accelerator Experiments for CP Violation
H.Haseroth *(CERN)*	Superbeam and Neutrino Factories. Status of R&D and Plans for Technological Selections
A.Marchionni *(FERMILAB)*	About Detectors

Chairman: M. Aguilar-Benítez *(CIEMAT)*

A.Blondel *(University of Geneva)*	MICE
R. Raja *(FNAL)*	Status of Neutrino Factory R&D
M. Mezzetto *(INFN, Padova)*	*Beta Beams*
N.Mavromatos *(King's College,London)*	*CPT Violation: Cosmological and Quantum Gravity Effects and their Phenomenology*

Friday, December 5, 2003

What can we learn?

Chairman: J.Panman *(CERN)*

W.G. Scott *(Rutherford Appleton Laboratory)*	Status of Tri-Bimaximal Mixing
E. Ma *(University ofCalifornia,Riverside)*	*Neutrinos with Z_3 Symmetry and New Charged-Lepton Interactions*
C.Bemporad *(University of Pisa)*	Lepton Number Violation and Neutrino Oscillations
A.Bottino *(University of Torino)*	Neutrinos and Dark Matter

Chairman: J. Fry *(University of Wisconsin)*

S. Pascoli1G *(UCLA)*	*On the Connection between Leptogenesis and Low-Energy CPV*
P. Di Bari *(IFAE, University Autonoma of Barcelona)*	*Leptogenesis and Neutrino Mixing Data*
S.Bludman *(DESY)*	*Energy: Cosmological Constant or Quintessence?*
A.Vilenkin *(Tufts University)*	Anthropic Prediction for Neutrino Masses

Finding the way

Round Table on: Workshop Conclusion and Plans for Future Work

Chairman: N.Cabibbo

H.Haseroth, M. Lindner,L.Maiani, H.Minakata,K. Nishikawa, K. Peach, M. Spiro and S. Wojcicki

(Video)

"... annus mirabilis"

- December 4, 2002 — K2K: ``Indication of neutrino oscillations in a 250 km ...''
- December 6, 2002 — ``First Results from KamLAND: Evidence for Reactor ...''
- December 10, 2002 — Ceremony of the Nobel Prize award: ``for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos''

  Raymond Davis Jr. Masatoshi Koshiba

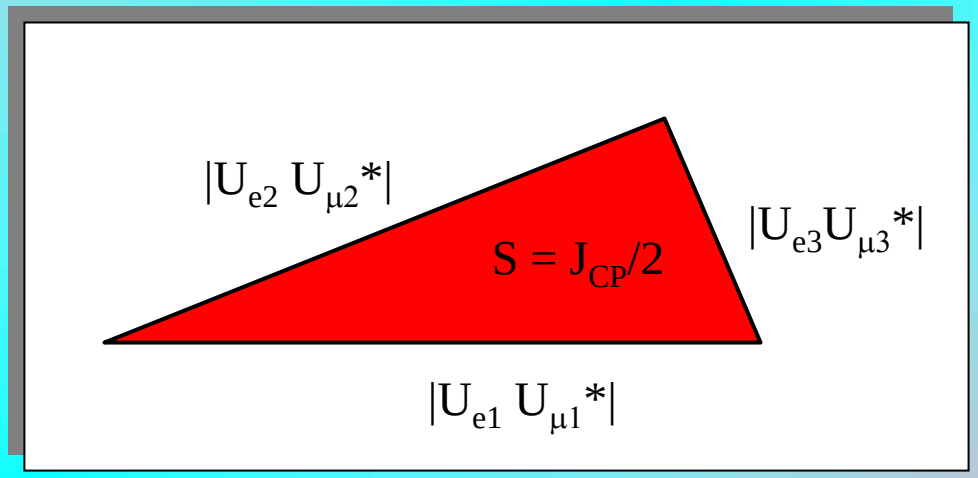
- February 11, 2003 — WMAP: First year Wilkinson microwave anisotropy probe observations: determination of cosmological parameters
- September 3, 2003 — ``Precise measurement of the solar neutrino Day/Night and seasonal variations in Super-Kamiokande-1''
- September 7, 2003 — SNO salt phase results: ``Measurements of the Total...''
- October 27, 2003 — Sloan Digital Sky Survey: ``Cosmological parameters...''
- December ??, 2003 — ...?

Leptonic Unitarity Triangle

$$U_{PMNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} 0.79 - 0.86 & 0.50 - 0.61 & 0.0 - 0.16 \\ 0.24 - 0.52 & 0.44 - 0.69 & 0.63 - 0.79 \\ 0.26 - 0.52 & 0.47 - 0.71 & 0.60 - 0.77 \end{pmatrix}$$

Global fit of the oscillation data 1σ

M.C. Gonzalez-Garcia , C. Pena-Garay



- $|U_{e3}| = 0.16$
- nearly best fit values of other angles

Can we reconstruct the triangle?
Can we use it to determine the CP-violating phase? Y. Farsan, A.S.

Problem: coherence (we deal with coherent states and not mass eigenstates of neutrinos)

Main features

- Heaviest mass: $m_h > \sqrt{\Delta m_{23}^2} > 0.04$ eV → $m_h \sim (0.04 - 0.4)$ eV

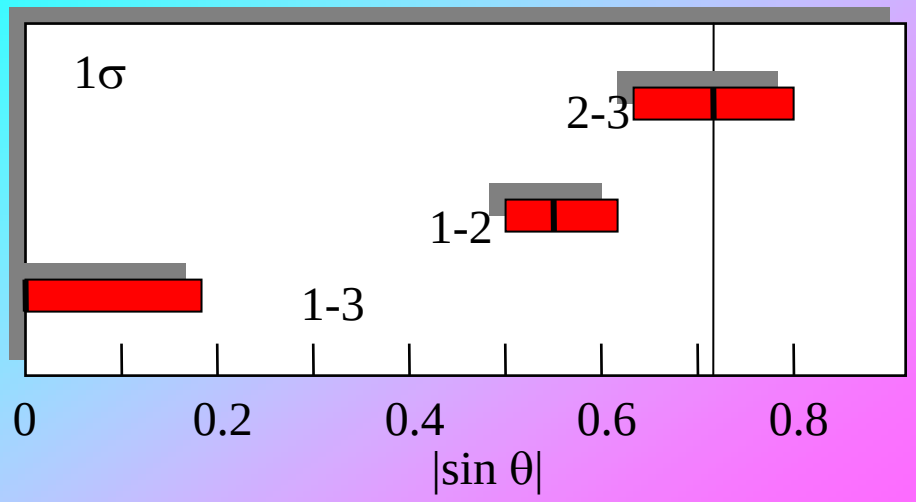
- Hierarchy of mass squared differences: $|\Delta m_{12}^2 / \Delta m_{23}^2| = 0.01 - 0.15$

- No strong hierarchy of masses: $|m_2/m_3| > \sqrt{|\Delta m_{12}^2 / \Delta m_{23}^2|} = 0.18 \begin{smallmatrix} +0.22 \\ -0.08 \end{smallmatrix}$

- Bi-large or large-maximal mixing between neighboring families (1- 2) (2- 3):

$$\theta_{12} + \theta_C = \theta_{23} \sim 45^o$$

- bi-maximal + corrections?



NEUTRINO MASSES AND MIXING AND

THE NATURE OF MASSIVE NEUTRINOS

S. T. Petcov

SISSA/INFN - sezione di Trieste, Trieste, Italy, and
INRNE, Bulgarian Academy of Sciences, Sofia,
Bulgaria

NO-VE
December 3 - 5, 2003
Venice

HIGHEST PRIORITY : θ_{13}

- CONTROLS THE SUB-DOMINANT $\overset{(-)}{\nu}_\mu \rightleftarrows \overset{(-)}{\nu}_e$ OSCILLATIONS
  - OF THE ATMOSPHERIC $\overset{(-)}{\nu}_\mu$, $\overset{(-)}{\nu}_e$
  - IN LBL EXPERIMENTS (MINOS, OPERA, ICARUS ...)
  - IN VLBL EXPERIMENTS AT ν-FACTORIS
- CONTROLS (TOGETHER WITH $\sin\delta$) THE MAGNITUDE OF CP- AND T-VIOLATING EFFECTS IN ν-OSCILLATIONS
- $|\langle m \rangle|$ IN $(\beta\beta)_{0\nu}$ NH
- THE KNOWLEDGE OF THE VALUE OF θ_{13} IS CRUCIAL FOR THE SEARCHES FOR CORRECT THEORY OF ν-MASSES AND MIXING

$$\Delta m^2_{\odot} = \Delta m^2_{21}, \quad \theta_{\odot} = \theta_{12}$$

$\nu_{\odot}$ - EXPERIMENTS

CAN RESTRICT FURTHER THE ALLOWED RANGES

SNO: $A_{D-N} < 6\%$

WOULD RESTRIC FURTHER Δm^2_{21} FROM BELOW

$R_{CC/NC} = 0.306 \pm 0.035$

IMPROVING THE PRECISION WILL RESTRICT
- Δm^2_{21} FROM ABOVE FURTHER
- THE RANGE OF ALLOWED VALUES OF $\sin^2\theta_{12}$

BOREXINO

LOWNU (pp - NEUTRINOS)

THE QUESTIONS OF

- THE NATURE OF MASSIVE ν's (DIRAC OR MAJORAN
- THE TYPE OF ν-MASS SPECTRUM
- THE ABSOLUTE NEUTRINO MASS SCALE

ARE AMONG THE FUNDAMENTAL QUESTIONS IN THE STUDIES OF ν-MIXING.

THE NATURE OF MASSIVE ν'S IS RELATED TO THE BASIC SYMMETRIES OF THE PARTIC INTERACTION

MASSIVE DIRAC ν'S

$$L = L_e + L_\mu + L_\tau = \text{CONST.}$$
$$L(\nu) \neq L(\bar{\nu})$$

MASSIVE MAJORANA ν'S:

$$\Delta L \neq 0, \ldots$$

TRUELY NEUTRAL PARTICLES $\equiv$ ANTIPARTICLE

$$\nu \equiv \bar{\nu}$$

SEE-SAW MECHANISM $\rightarrow$ ν_i - MASSIVE MAJORAN ν's

IF ν_j - MAJORANA PARTICLES,

U_{PMNS} - CONTAINS 3ν MIXING

δ - DIRAC

α_{21}, α_{31} - MAJORANA PHYSICAL CP PHASES

ν - OSCILLATIONS $\overset{(-)}{\nu}_l \rightleftarrows \overset{(-)}{\nu}_{l'}$, $l, l' = e, \mu, \tau$

- ARE NOT SENSITIVE TO THE NATURE OF ν_j.

BILENKY, HOSEK, STP '80
LANGACKER ET AL. '87

- PROVIDE INFORMATION ON $\Delta m^2_{jk} = m_j^2 - m_k^2$, BUT NOT ON THE ABSOLUTE VALUES OF NEUTRINO MASSES ν_j.

THE MAJORANA NATURE OF ν_j CAN MANIFEST ITSELF IN THE EXISTANCE OF PROCESSES

$\Delta L = \pm 2$: $K^+ \to \pi^- \mu^+ \mu^+$

$\mu^- + (A, Z) \to \mu^+ + (A, Z-2)$

THE MOST SENSITIVE PROCESS -

$(\beta\beta)_{0\nu}$ - DECAY OF CERTAIN EVEN-EVEN NUCLE

CONCLUSIONS:

FUTURE $(\beta\beta)_{0\nu}$ - DECAY EXPERIMENTS HAVE A REMARKABLE PHYSICS POTENTIAL:

- CAN ESTABLISH THE MAJORANA NATURE
- CAN DETERMINE THE TYPE OF ν-MASS SPE
- CAN PROVIDE UNIQUE INFORMATION ON THE ABSOLUTE ν-MASS SCALE (M_1)
- CAN PROVIDE UNIQUE INFORMATION ON T MAJORANA CP-VIOLATING PHASES.

J. BOUCHEZ
CEA - DAPNIA
SACLAY

NO-VE
4/12/2003

θ_{13} measurements experimental options

- disappearance expts
  - Reactor
  - Tritium
- Appearance at accelerators

THE MIXING MATRIX

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13} e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13} e^{-i\delta} & 0 & c_{13} \end{pmatrix}} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\nu_\mu \leftrightarrow \nu_\tau$ at atm. frequency (Δm^2_{23}) $\theta_{23} \sim 45°$

GEVERA'S ν_e oscillations at atmospheric frequency

Solar ν_e disappearance (LMA) $\theta_{12} \sim 35°$

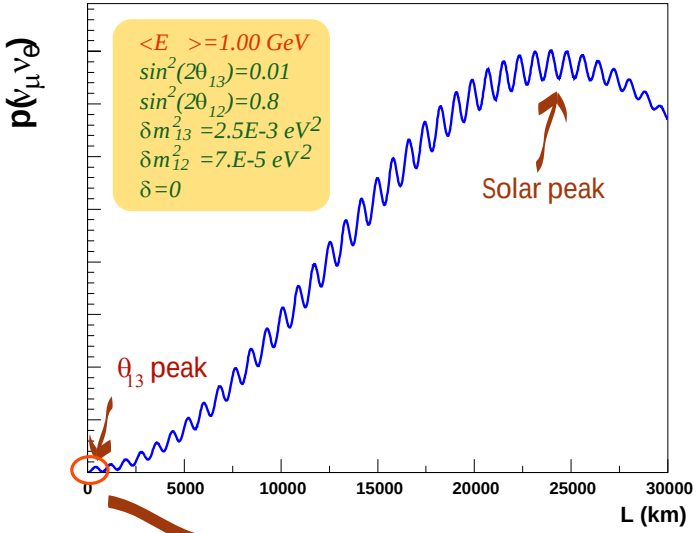
CHOOZ = $\theta_{13} \lesssim 12°$ [finite depends upon actual Δm^2_{23} value]

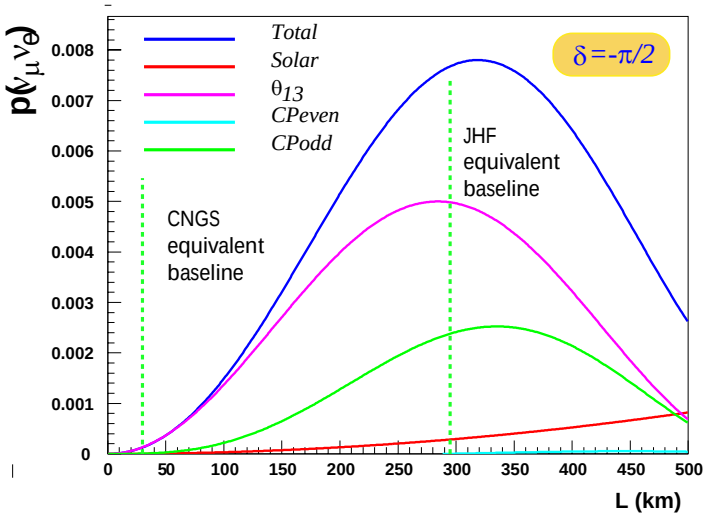
To best determine θ_{13} =
Get to the maximum of atmospheric oscillation ($L/E \sim 500$ km/GeV)

→ look for ν_e disappearance

→ look for ν_e appearance from ν_μ
or ν_μ appearance from ν_e
(or ν_τ appearance from ν_e)

Sub leading $\nu_\mu - \nu_e$ oscillations





$p(\nu_\mu \to \nu_e)$ developed at the first order of matter effects

$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \qquad \theta_{13} \text{ driven}$$

$$+ 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

$$- 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{solar driven}$$

$$- 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) \qquad \text{matter effect (CP odd)}$$

where $a = \pm 2\sqrt{2} G_F n_e E_\nu = 7.6 \cdot 10^{-5} \rho[g/cm^3] E_\nu [GeV] \quad [eV^2]$

$\nu_\mu \leftrightarrow \nu_e$ APPEARANCE EXP^{TS} USING ACCELERATORS

4 phases :

- **Phase 1** : Use "existing" facilities & detectors (optimized for ν_μ disappearance and/or ν_τ appearance)

  $\theta_{13} > 5^\circ$

  - MINOS, ICARUS, OPERA
  - Gulf of Taranto, horizontal showers

- Phase 2 : 1st generation of superbeams

  $\theta_{13} > 2.5^\circ$ + CP ?

  - JHF 1, NuMI off axis

- Phase 3 : 2nd generation of superbeam

  $\theta_{13} > 1^\circ$ + CP

  - JHF 2, NuMI 2, BNL
  - CERN → Fréjus = Superbeam and betabeam

- Phase 4 : ν factories, HE β-beams

  $\theta_{13} > 0.1^\circ$ + CP

SUPER BEAMS

Conventional ν_μ beams produced by high intensity proton drivers.

20 kT detectors	• NuMI	400 kW	2005
	• JHF1	750 kW	2008
500 kT detectors	• JHF2	4 MW	2012
	• SPL-SB	4 MW	$\geq$ 2012

$\Rightarrow$ look for $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ appearance at 1st maximum ($L_{opt} \sim 600$ km/GeV)

Beam requirements

- Low ν_e contamination
- Good knowledge of $\frac{\nu_e}{\nu_\mu}$
- Good understanding of the beam (near $\to$ far extrapol.)

Detector requirements

- Good e^- efficiency
- Good π^0 rejection
- Good understanding of background

θ_{13} issue

- The measurement of θ_{13} is made complicated by the fact that oscillation probability is affected by matter effects and possible CP violation
- Because of this, <u>there is not a unique</u> mathematical relationship between oscillation probability and θ_{13}
- Especially for low values of θ_{13}, sensitivity of an experiment to seeing $\nu_\mu \rightarrow \nu_e$ <u>depends very much</u> on δ
- Several experiments with different conditions and <u>with both ν and anti-ν</u> will be necessary to disentangle these effects

APPEARANCE AND θ_{13} SENSITIVITY

Appearance amplitudes depend upon θ_{13} and δ (correlations)

θ_{13} upper limit if no signal
θ_{13} value if significant signal } will

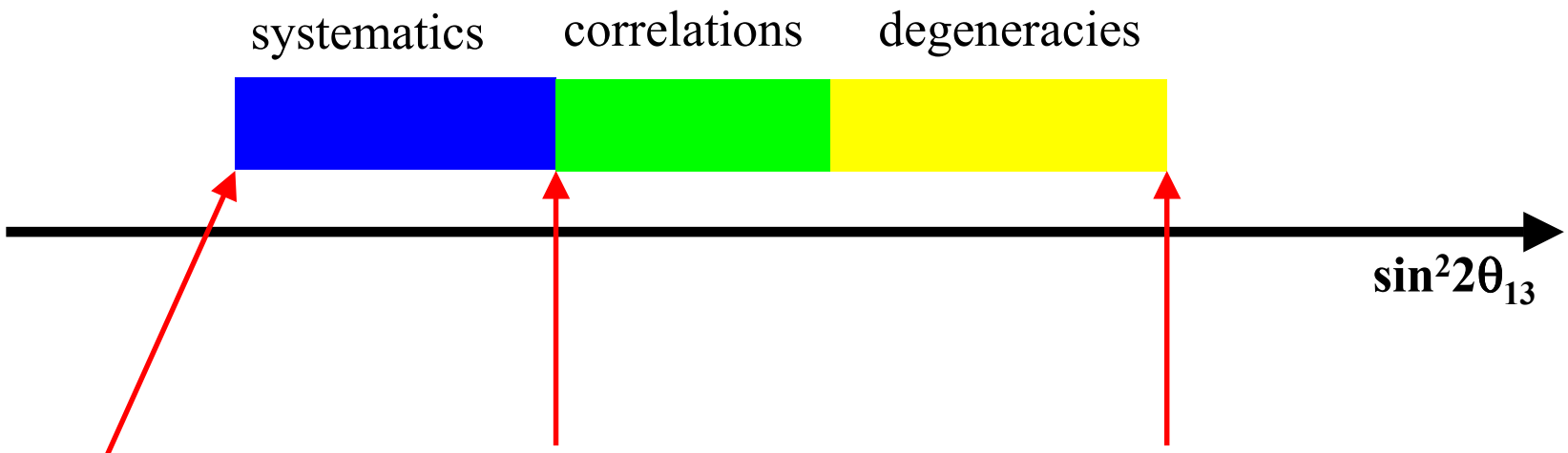
depend upon the value of δ

This does not limit θ_{13} sensitivity, but θ_{13} determination.

$\Rightarrow$ Appearance sensitivity should be shown in θ_{13}, δ plane

δ is not a nuisance parameter, it is a physical quantity!

Sensitivitiy Plots



statistical limit
(all parameters fixed)

limit for $(\sin^2 2\theta_{13})_{eff}$

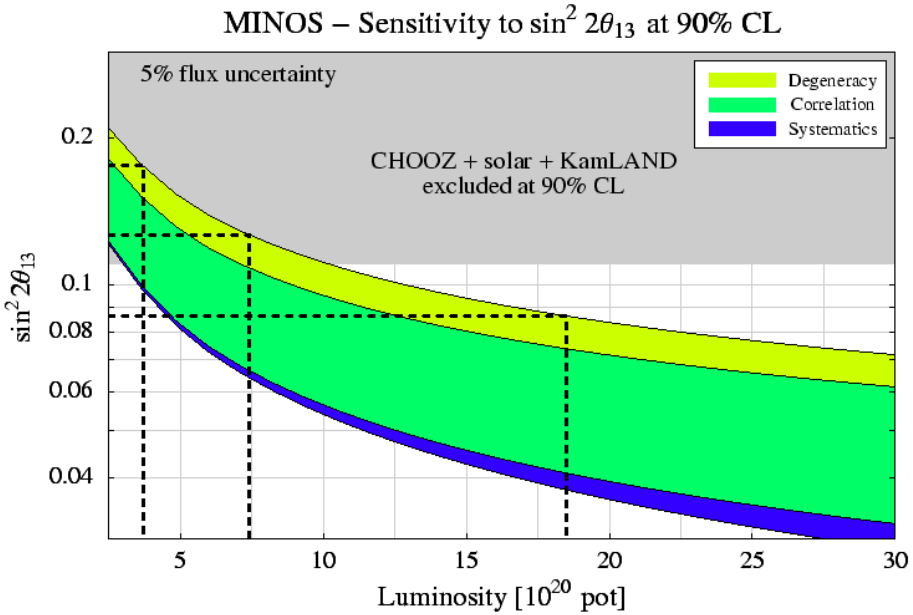
limit for $\sin^2 2\theta_{13}$ from *THIS* experiment only

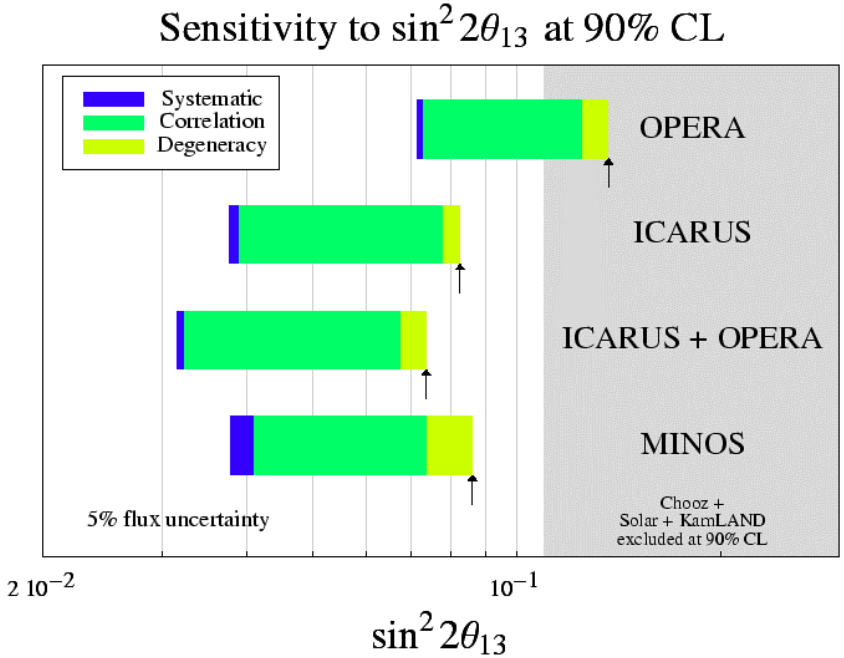
precise knowledge of some parameter combination = precision of the experiment

synergies = combine with other experiments
➔ gain more than statistics

„Current“ generation long baseline experiments

Huber, ML, Rolinec





MINOS sensitivity as a funtion of time:

– MINOS: $3.7 \cdot 10^{20}$ pot/y

– 1,2,5 years

Compare: 5 years, 5% flux uncertainty

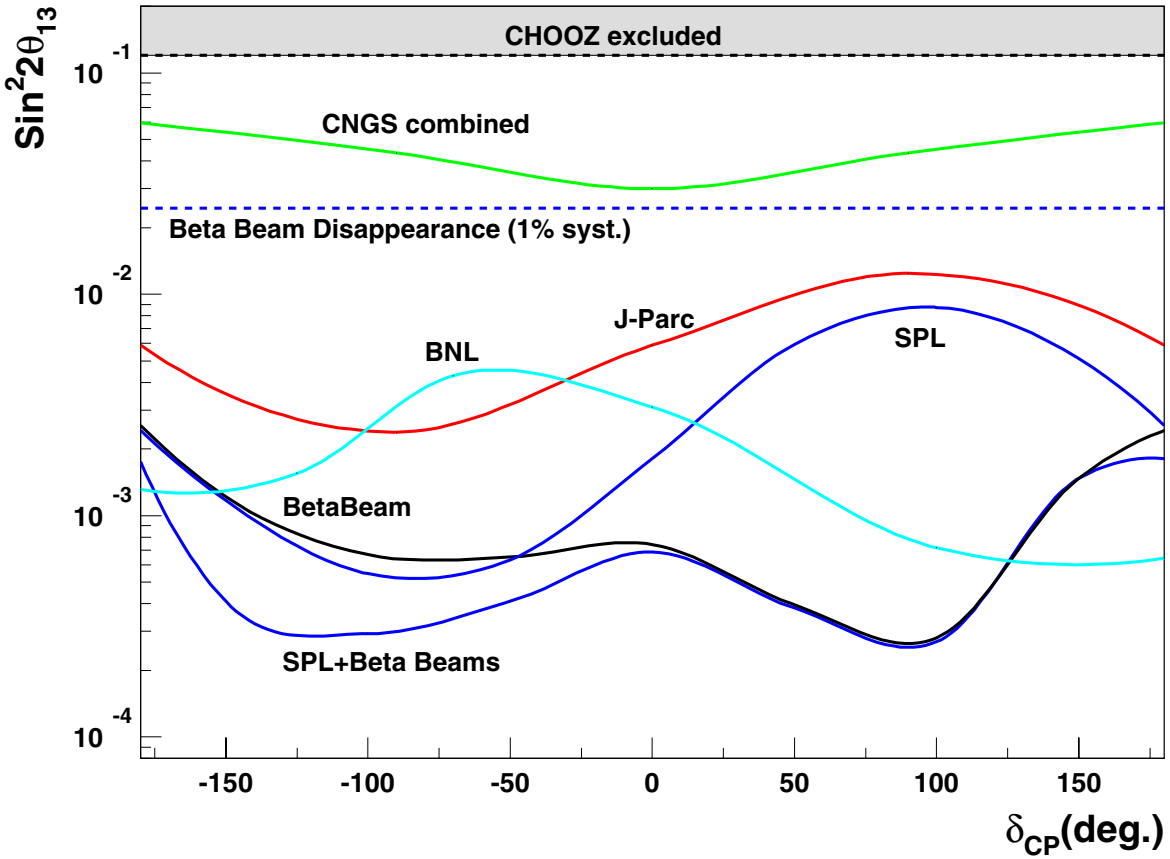
– CNGS: $4.5 \cdot 10^{19}$ pot/y

- **only modest improvements for θ_{13}**
- **other objectives...**

The SuperBeam - BetaBeam synergy: a benchmark on θ_{13} sensitivity

Computed for $\delta_{CP} = 0$, sign$(\Delta m^2) = +1$ and 5 years running.

- No way to disentangle θ_{13} from δ in a high sensitivity experiment.
- The full information of experiment sensitivity is given by a bidimensional θ_{13} vs δ plot.
- **Beta Beam can measure θ_{13} both in appearance and in disappearance mode. All the ambiguities can be removed for $\theta_{13} \geq 3.4°$**



Adding a new reactor experiment

$\overset{\overline{\nu}_e}{\Longrightarrow}$ **near detector (150m)** $\overset{\overline{\nu}_e}{\Longrightarrow}$ **far detector (2000m)**

identical detectors ➔ many errors cancel

- **The survival probability:**
  - expand in small quantities

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m^2_{31} L}{4E_\nu} + \left(\frac{\Delta m^2_{21} L}{4E_\nu}\right)^2 \cos^4\theta_{13} \sin^2 2\theta_{12}$$

  - last term negligible for $\frac{\Delta m^2_{31} L}{4E_\nu} \sim \pi/2$ and $\sin^2 2\theta_{13} \gtrsim 10^{-3}$
  - atmospheric frequency is dominant
  - most important:

- **No degeneracies!**
- **Practically no correlations!**
- **No matter effects!**

REACTOR EXPERIMENT

CHOOZ = Single detector

⇒ relies on predicted flux

Active mass

Absolute efficiency

SYSTEMATICS = 2.8%

⇒ USE 2 IDENTICAL DETECTORS TO LOWER SYSTEMATICS AT 1% BY COMPARING NEAR AND FAR MEAS

<u>Remarks</u>

- 2 detectors are never "identical"
  - Background rates will be different (⇒ dead times will be ≠)
  - S/N will be different

BUGEY3 1.7%

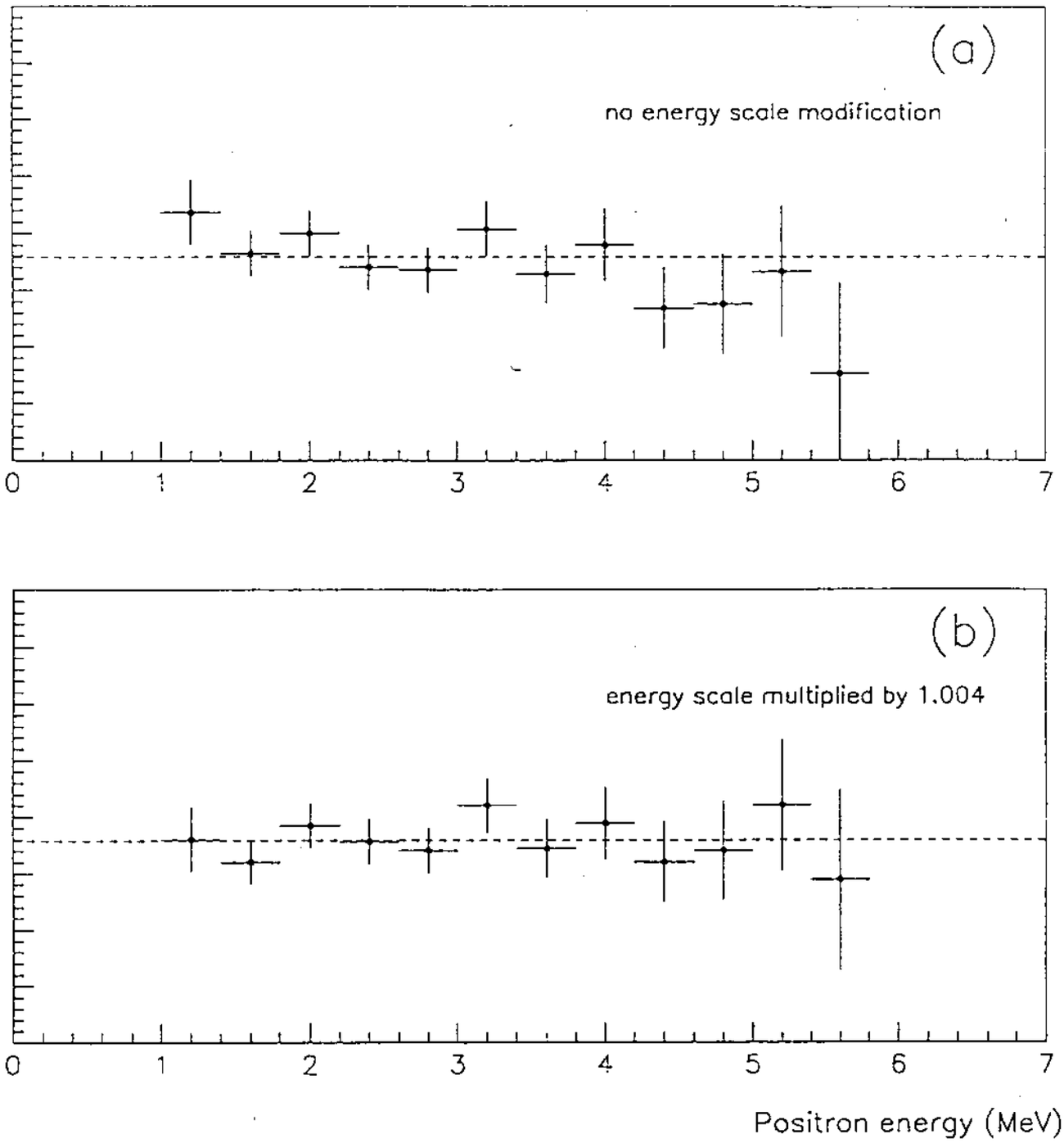
Better design to decrease background.

- Energy scale is very important (scale + non linearities)

See H. de KERRET's talk

BUGEY 3 : Comparisons DATA / PREDICTIONS

Phys. Letters B 374 (1996) 243



Effect of a 0.4% change on energy scale (syst uncertainty = 0.8%)

TWO COMPETING PHILOSOPHIES

1 - Go fast, to start before or at the same time as LBL (JHF1, NuMI off-axis)

EUROPE
JAPAN

⇒ Detectors at fixed locations
Reuse if possible existing infrastructures (CHOOZ)

2 - No need to hurry, reactors are complementary to LBL appearance expts

⇒ More sophisticated design
(movable detectors)

USA

But more expensive and later start

There is matter for debate.

TRITIUM SOURCE

- Idea = Use a strong tritium source

  20 kg ⇒ 200 MCi. ($7\ 10^{18}\ \bar{\nu}_e$ /s)

  $E^{\nu}_{max} = 18.6$ keV

  Diffusion on e^- $E^{max}_{e^-} \sim 1.3$ keV !

  $E_\nu = 14$ keV $\langle E_{e^-} \rangle = 360$ eV

- Detector = spherical TPC with MicroMegas readout

- $\bar{\nu}_e$ osc.

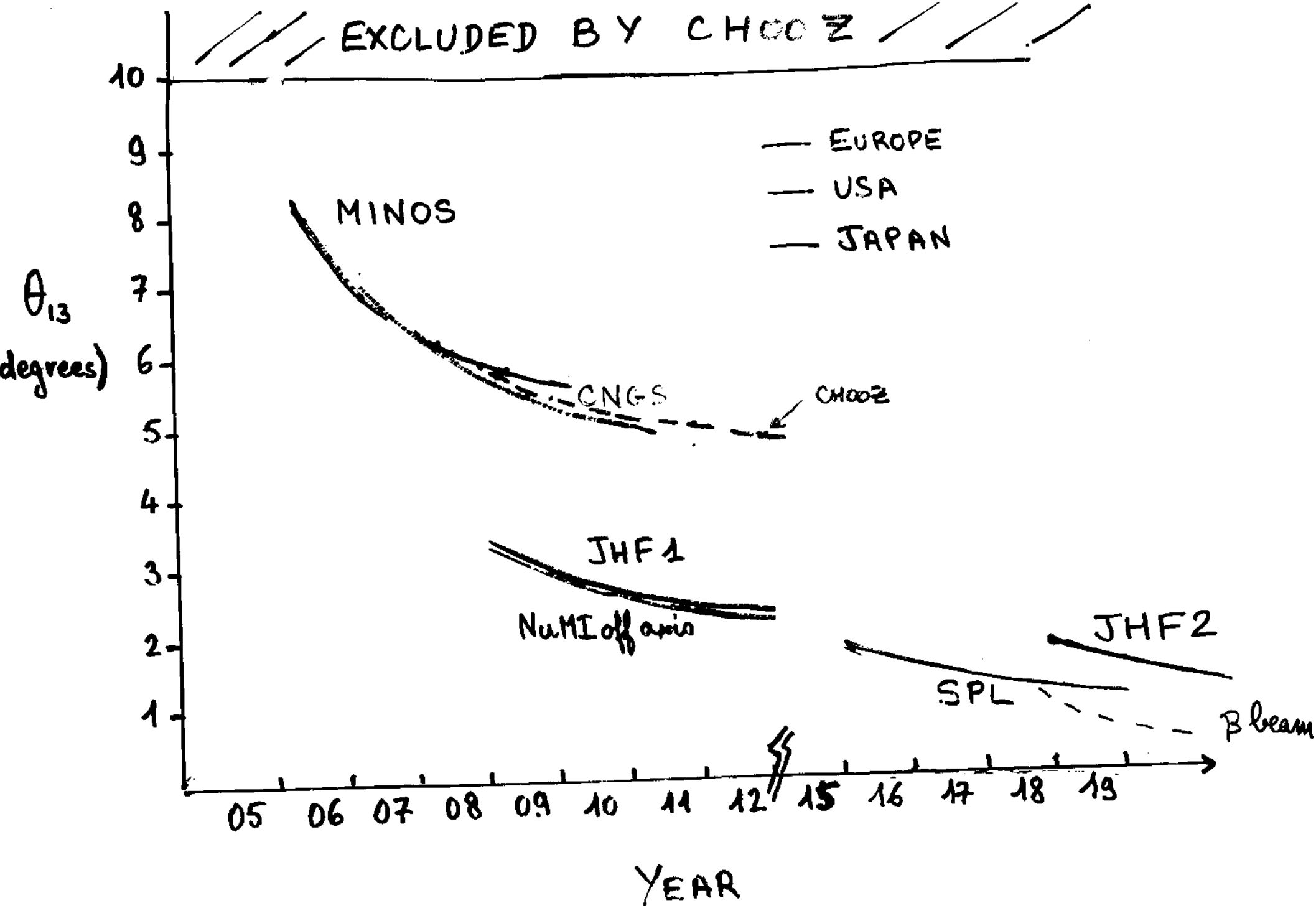
  L_{osc} (14 keV) = 14 m ($2.5\ 10^{-3}$ eV^2)

  17.5 m ($2\ 10^{-3}$ eV^2)

- μ_{ν_e} at $10^{-12}\ \mu_B$ level

- $\bar{\nu}_e\ e^-$ scattering at low energy
  - $\sin^2\theta_W$ at large distances
  - Atomic binding effects.

MAIN QUESTION = What will be the background level ?


EXCLUDED BY CHOOZ
EUROPE
USA
JAPAN
MINOS
CNGS
CHOOZ
JHF1
NuMI off axis
JHF2
SPL
β beam
θ_{13} (degrees)
10
9
8
7
6
5
4
3
2
1
05
06
07
08
09
10
11
12
15
16
17
18
19
YEAR

Comparing different scenarios in a two families scheme

Limits at 90% C.L. on $\sin^2 2\theta_{13}$ and θ_{13}
($\Delta m^2_{23}=2.5\times10^{-3}$ eV^2; $\sin^2\theta_{23}=1$)

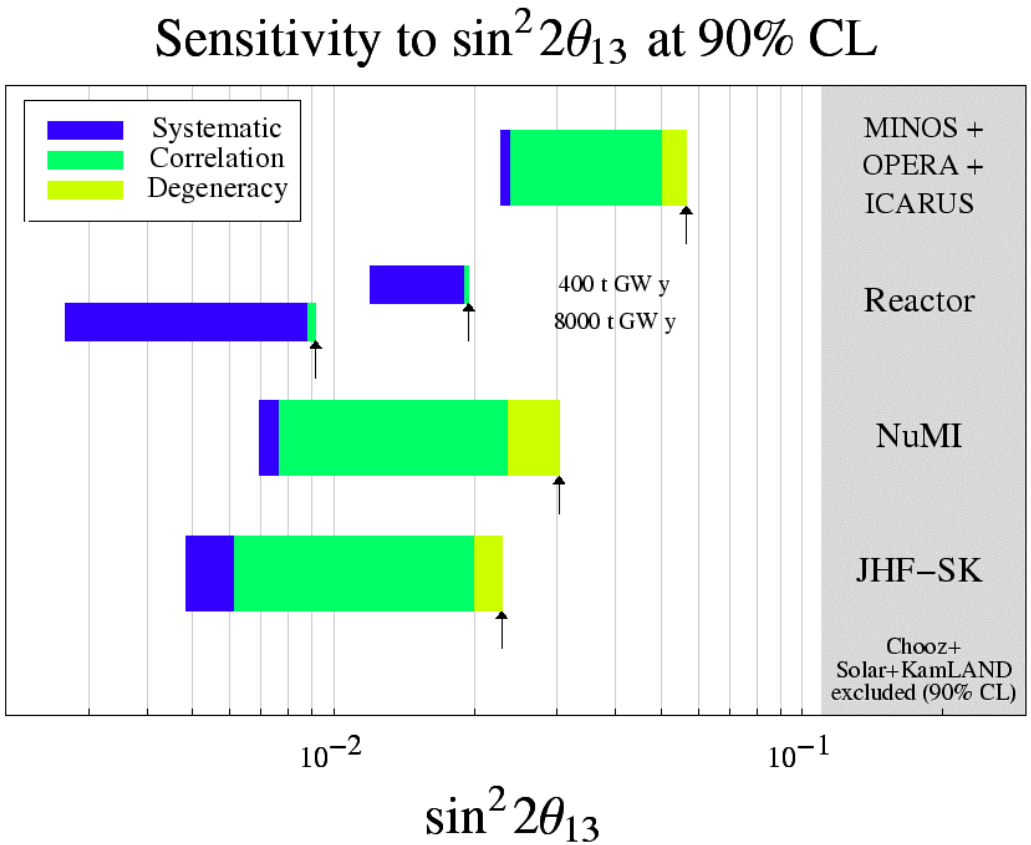
Experiment	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	<0.14	<11º
MINOS 2yr	<0.06	<7.1º
ICARUS 5yr	<0.04 (LI) <0.03(HI)	<5.8º <5.0º
OPERA 5yr ≡ CNGS	<0.06(LI) <0.05(HI)	<7.1º <6.4º
ICARUS+OPERA 5yr	<0.03(LI) <0.025(HI)	<5.0º <4.5º
JHF 5yr	<0.006	<2.5º

LI = nominal CNGS; HI = nominal CNGS x 1.5

Phase I exps

NB The CNGS sensitivity is limited by statistics
⇒ very important high intensity proton beam

The next generation: JHF-SK , NuMI-OA , reactor

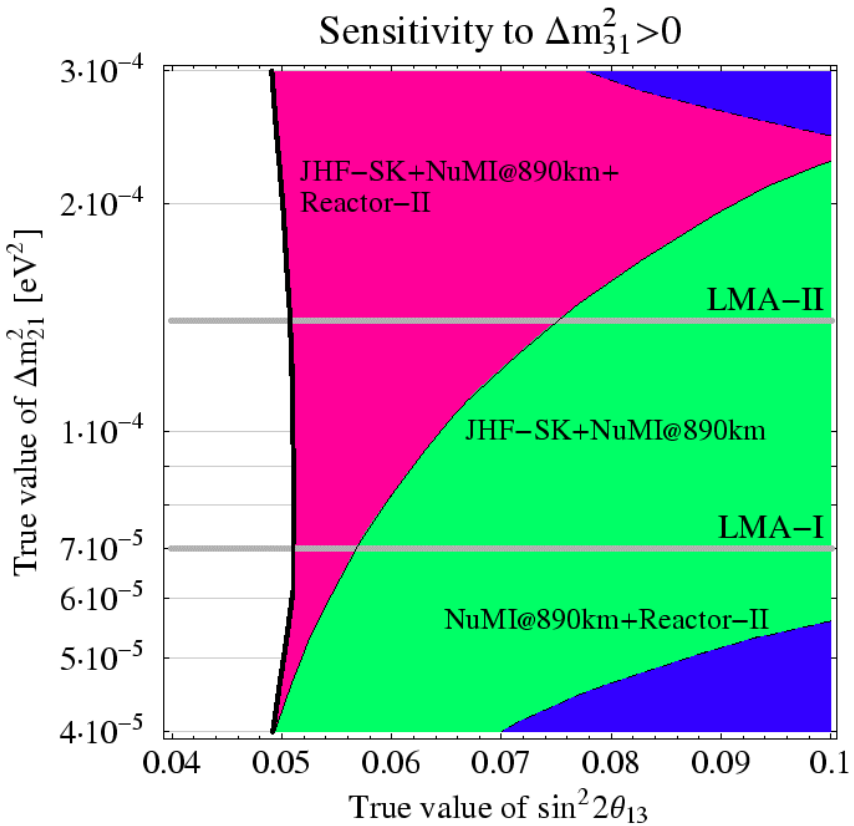


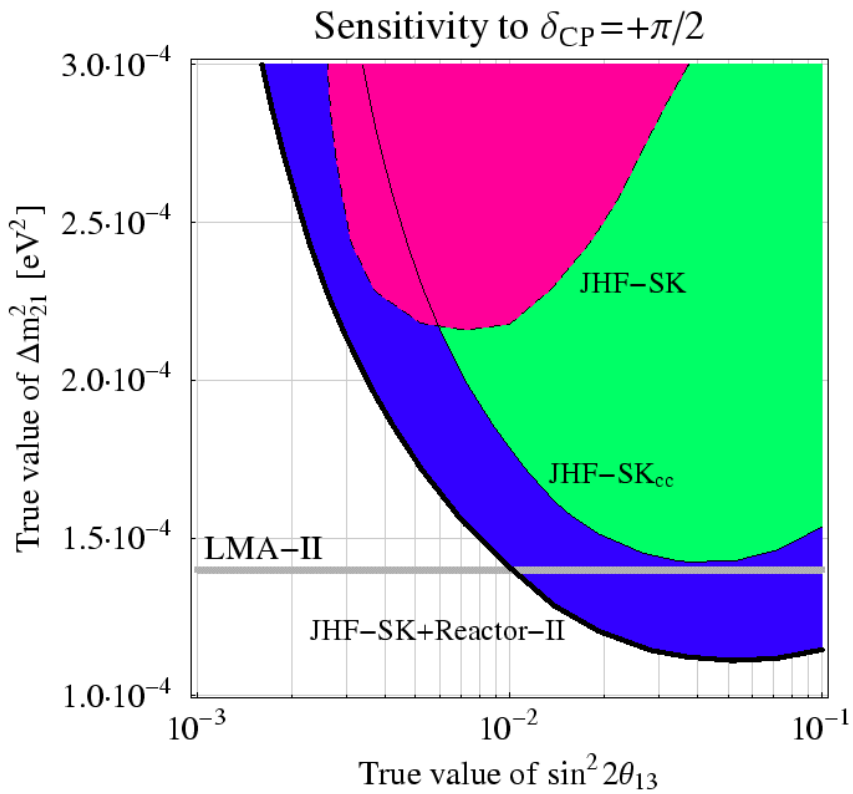
Compare:
- 5 years each
- 5% flux uncertainty

Huber, ML, Rolinec, Winter

- one order of magnitude improvement for θ_{13}
- synergies between reactor and accelerator experiments
  - reactor anti-neutrinos $\Rightarrow$ only neutrino beams (x-section)
  - reactor: uncorrelated θ_{13} $\Rightarrow$ combine with beams & resolve correlations
- synergy between beams $\Rightarrow$ NuMI at larges baseline $\Rightarrow$ matter effects

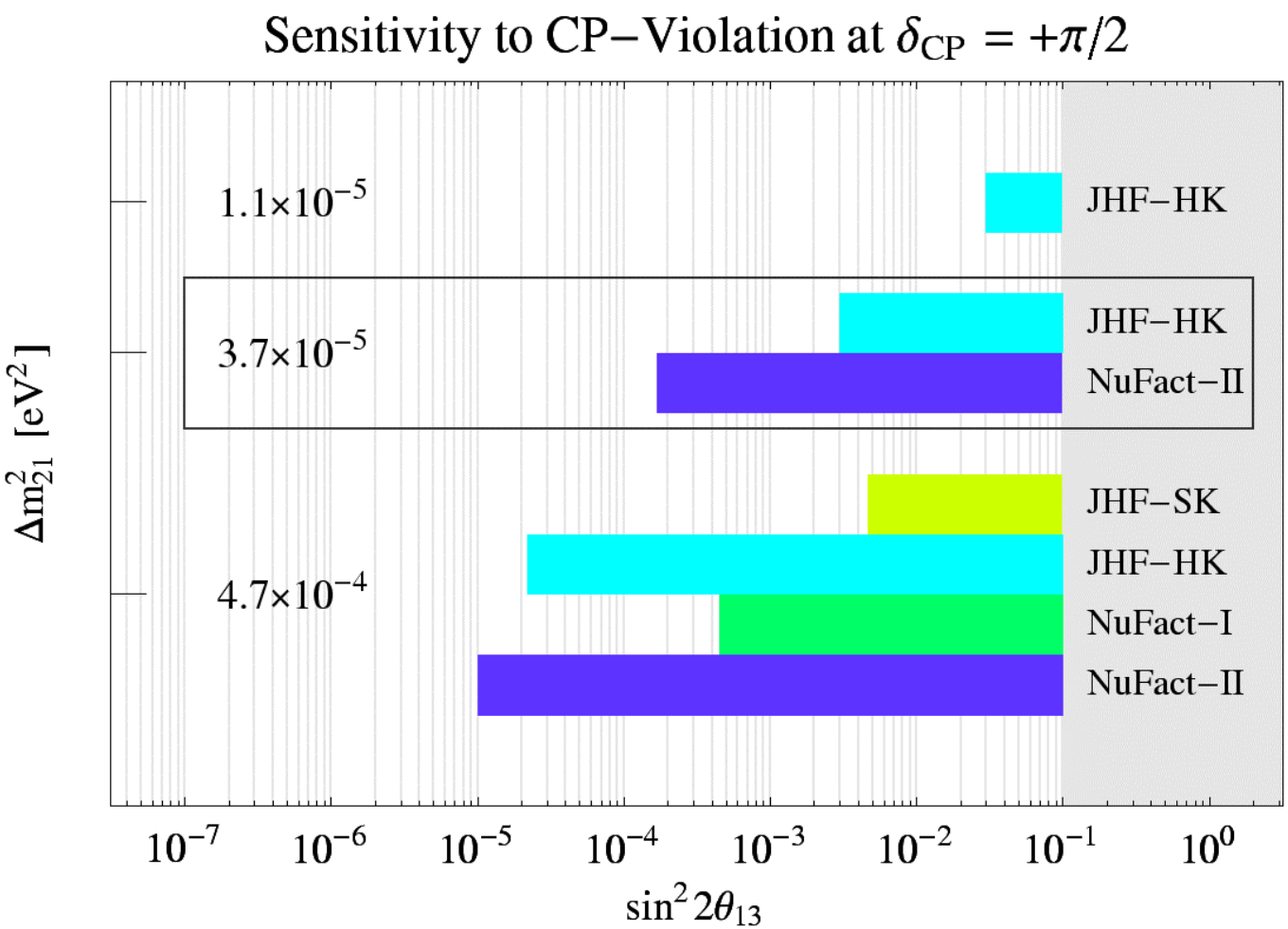
Synergies for other quantities Huber, ML, Schwetz, Winter





- $sign(\Delta m^2_{31})$ **possible for** $\sin^2 2\theta_{13} > 0.05$
- **leptonic CP violation close, but for LMA-I not yet possible**

Measurements of CP-violation



- CP violation with high luminosity superbeams feasable
- sensitivity is δ_{CP} dependent

Huber, ML, Winter, hep-ph/0204352

Why should we measure neutrino parametrers so precisely?

$\Downarrow$

- Impact on physics beyond the Standard Model
- Very good precison possible $\Leftrightarrow$ flavour structure
- Connection to leptogenesis $\Leftrightarrow$ baryon asymetry of the universe

Measurement of θ_{13} with reactor neutrinos: systematics and background

The Double-Chooz project

H de Kerret – PCC College de France and APC

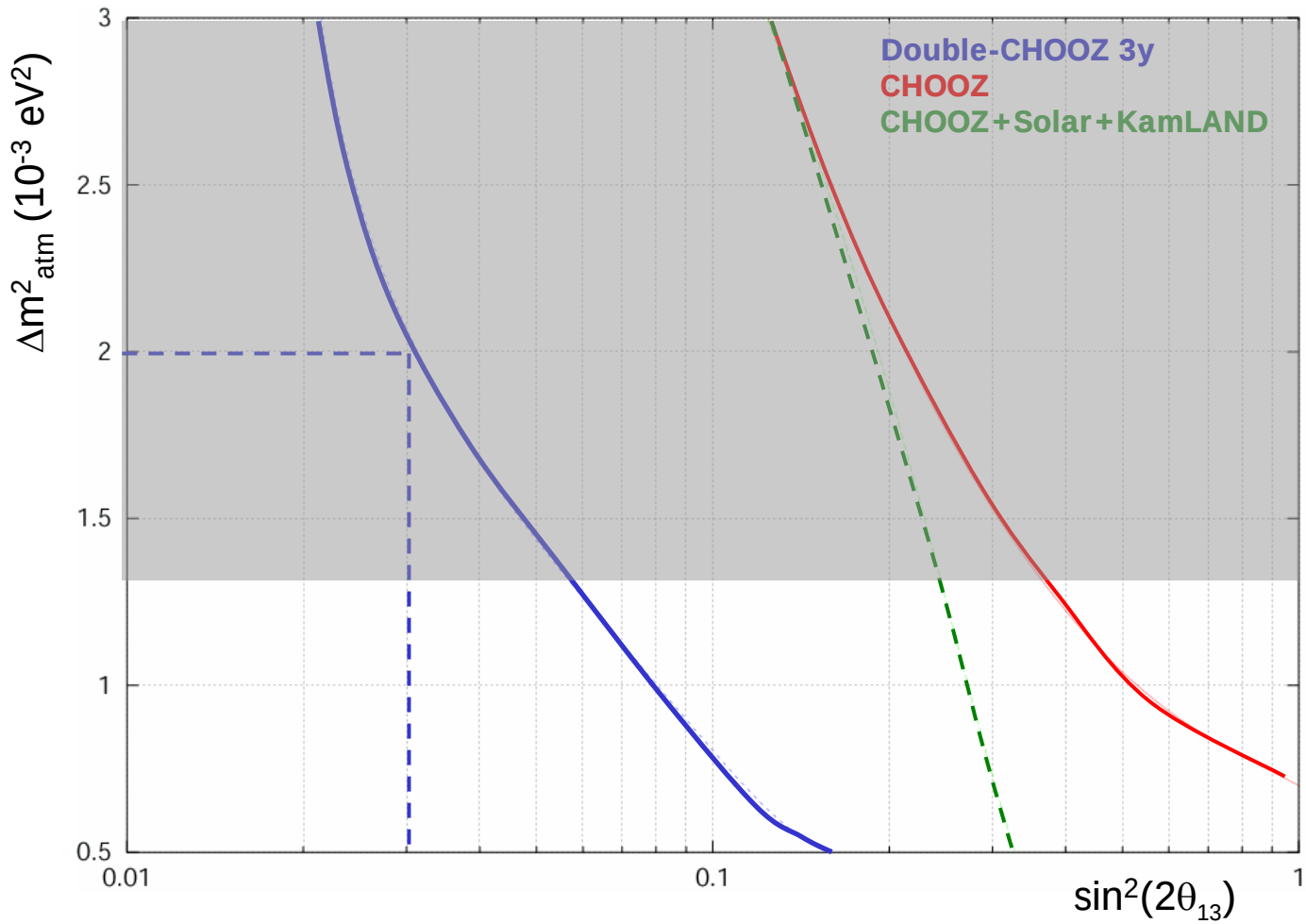
World wide community

- Workshops: Alabama, Munich (09/03)
- White book : first draft written (M.Goodman)
- Studied experimental site: Kashiwasaki (japan), Diablo canyon,.. (USA), Brazil, Taiwan .. And in europe: Penly, Cruas and Chooz

As an example: the double-Chooz project

- 2 identical detectors (12.6 m^3)
  - at 150 m. (artificial overburden)
  - at 1050 m. (use the pit of the Chooz experiment)
- Reach .03 in $\sin(2\theta_{13})^2$ (.05 in 1 year)
- 25 physicists of 4 European countries

Contours


Double-CHOOZ 3y
CHOOZ
CHOOZ+Solar+KamLAND
Δm^2_{atm} (10^{-3} eV^2)
3
2.5
2
1.5
1
0.5
0.01
0.1
1
$\sin^2(2\theta_{13})$

systematics

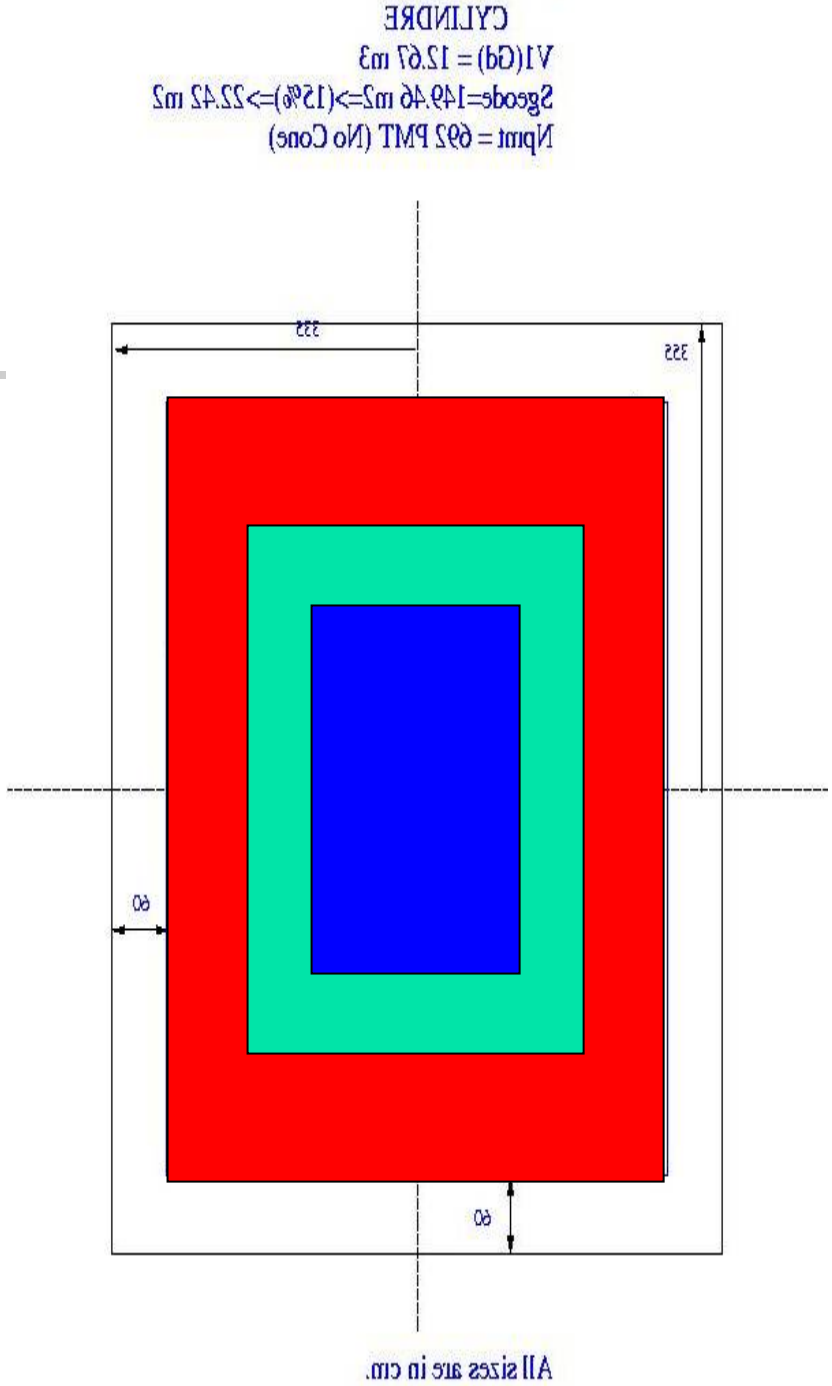
- 2 detectors (suppress the physical uncertainties)
- detector design to control the effect of some calibration uncertainties

  ➔Less accidentals → less cuts
- Address the few remaining source of uncertainties

→ .5% on the relative normalisation of the 2 detectors

Detector design

- A scintillating buffer around the target (to see the gammas from positron capture and Gd decays) ~60 cm
- A non scintillating buffer in front of pmts (reduce the single rates) ~ 1m
- Increase as much as possible the active buffer for the fast neutrons coming from outside



2 detectors: the solution

- Reactor uncertainties
- Distances (distance between detectors rather than to the core)
- Physics of the target (% of free protons, spectrum of Gd capture, neutronics at the detector frontier) if we use the same liquid in both detectors
- Physical cuts (time positron-neutron, gammas from GD not well known)

2 detector: the problem

- Relative target size (volume and density)
- Neutron identification → 6MeV cut on the products of Gd capture
- Live time → 0.1%
- Energy scale → shape of the nu spectrum

  - linearity
  - work in measured energy (no correction)
  - MC: allowed range of differences (light yield, attenuation length , etc..)

Neutrino experiments backgrounds

- Accidentals
  - “e^+” : gammas from pmts , etc..
  - “n” : 0.04 Hz from cosmics
- Correlated events

muons → spallation fast neutrons→ recoil protons + capture of n

- Cosmogenics: Li^9,etc..

FAR detector: improve the Chooz S/B

- Target volume * 2.2 (cylindrical target)
- Background /3

  - non-scintillating buffer for pmts's gammas

  - thicker active buffer for fast neutrons (coming from outside) + outer veto (over the detector)

→ S/B increased by 6

→ Cost of the detector by 2

NEAR detector

- Shallow overburden: 55 mwe at 150 meters → 500 Hz of muons, 25% dead time (with 500 microsec. Gate)
- Important signal : 3000 evts /day
- Expected correlated background :

  - 20 ^{9}Li (upper limit : gives 1/d at Chooz: not observed)

  - 15 fast neutrons

  .5/d at FAR * muon ratio (30), but better buffers

schedule

- Far detector : install end of 2006
- NEAR “ : 2007

→ FIRST RESULT 2008

→ Detectors cost <10 Meuros

conclusion

- Improve the current limit on θ_{13} (which is sin 2 θ_{13})^2=.2) for the more recent atmospheric mass) by an order of magnitude is possible with nuclear reactors
- The European project Double-Chooz is the most advanced→ a first result to be expected end of 2008

Off Axis

The NuMI Off-Axis Experiment

NO-VE Workshop

Venice

4 December 2003

Gary Feldman

Off Axis

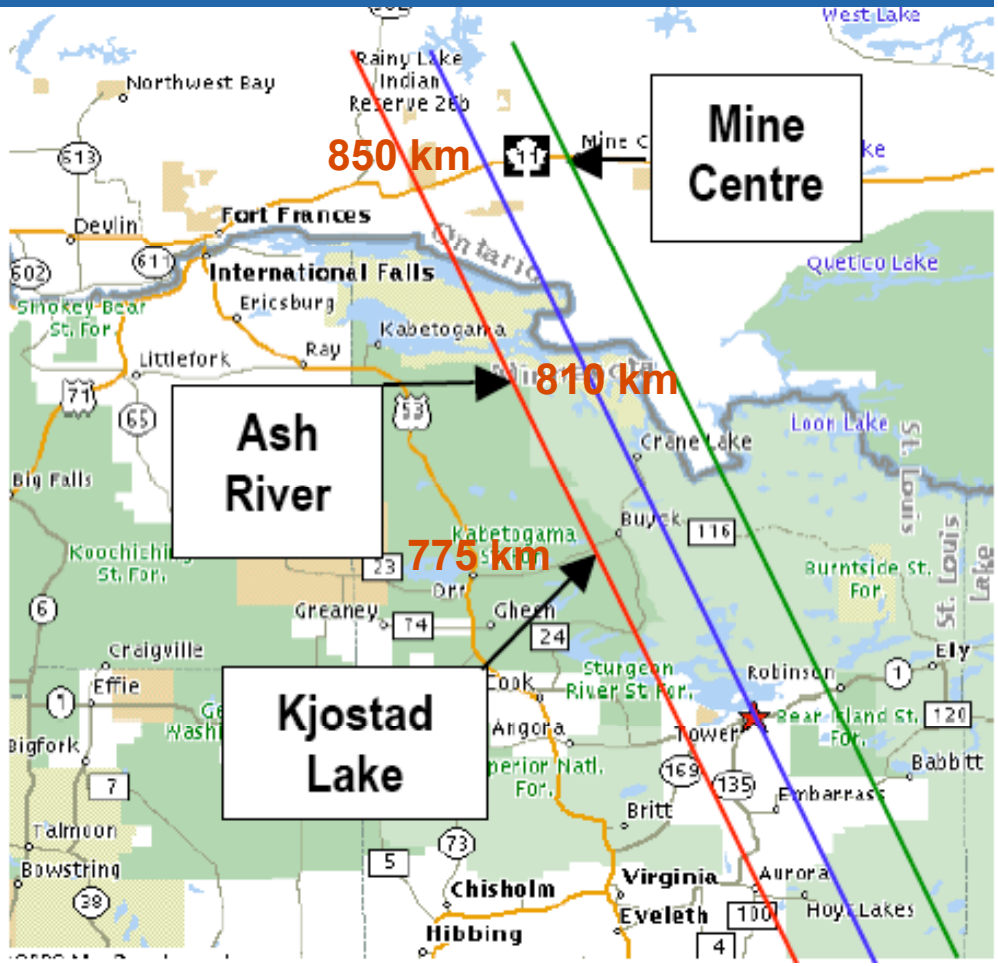
NuMI Off-Axis Proposal

- The Off-Axis experiment is proposed to be
  - 50 kT
  - Medium-Z sandwich detector
    - Particle board absorber
    - Liquid scintillator strip detectors with APD readout
    - Glass RPC detectors backup option
    - We will re-evaluate the technology decision in a year.
  - 810 km baseline, about 12 km off-axis (Ash River, MN)
  - Current cost estimate about 170 M$
  - Collaboration of 33 institutions from 8 countries; seeking additional collaborators
    - One day meeting in Cambridge, England, January 12

Off Axis

Possible Sites

We are now focusing on the Ash River site.



$P(\nu_1 \to \nu_e)$ (in Matter)

- In matter, P_1 will be approximately multiplied by $(1 \pm 2E/E_R)$ and P_3 and P_4 will be approximately multiplied by $(1 \pm E/E_R)$, where the top sign is for neutrinos with normal mass hierarchy and antineutrinos with inverted mass hierarchy.

$$E_R = \frac{\Delta m_{13}^2}{2\sqrt{2}G_F N_e} \approx 11 \text{ GeV for the earth's crust.}$$

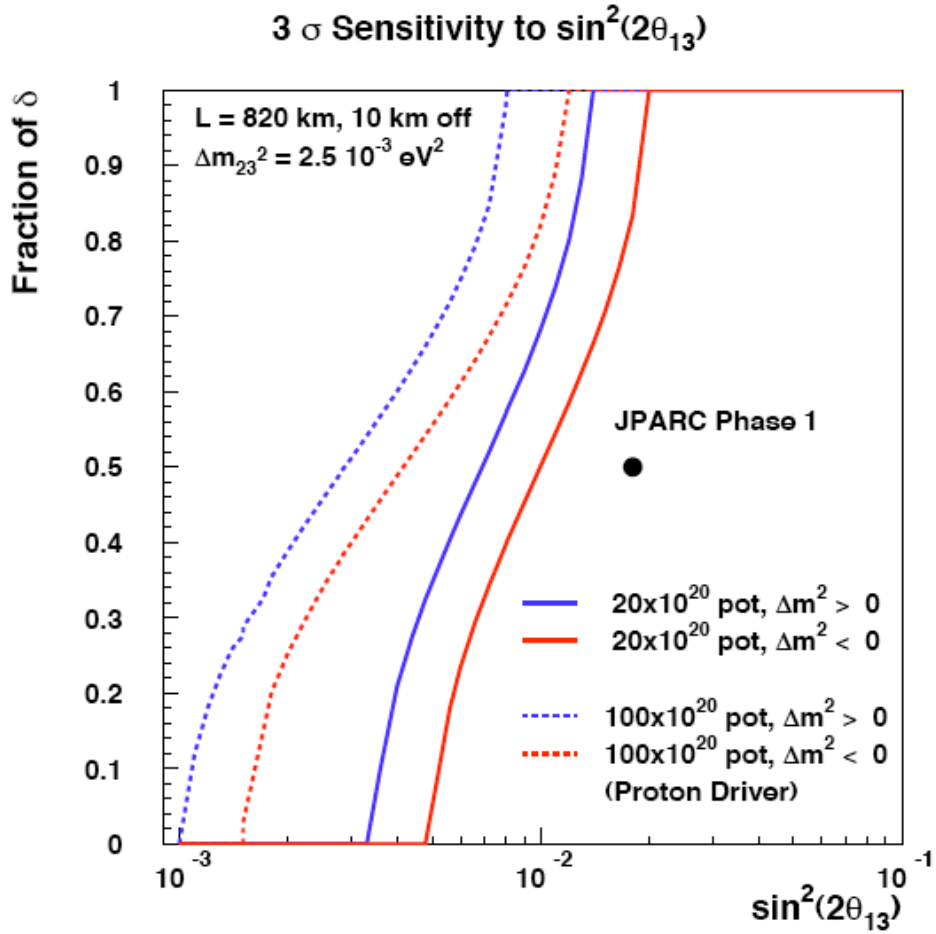
About a ±23% effect for NuMI, but only a ±10% effect for JPARC .

Goals of the Off-Axis Experiment

- **Primary goal: Find evidence for $\nu_\mu \to \nu_e$, determining $\sin^2(2\theta_{13})$ to a factor of 2.**
- **Longer term goal: Determine the mass hierarchy.**
- **Ultimate goal: Precision measurement of the CP-violating phase δ.**

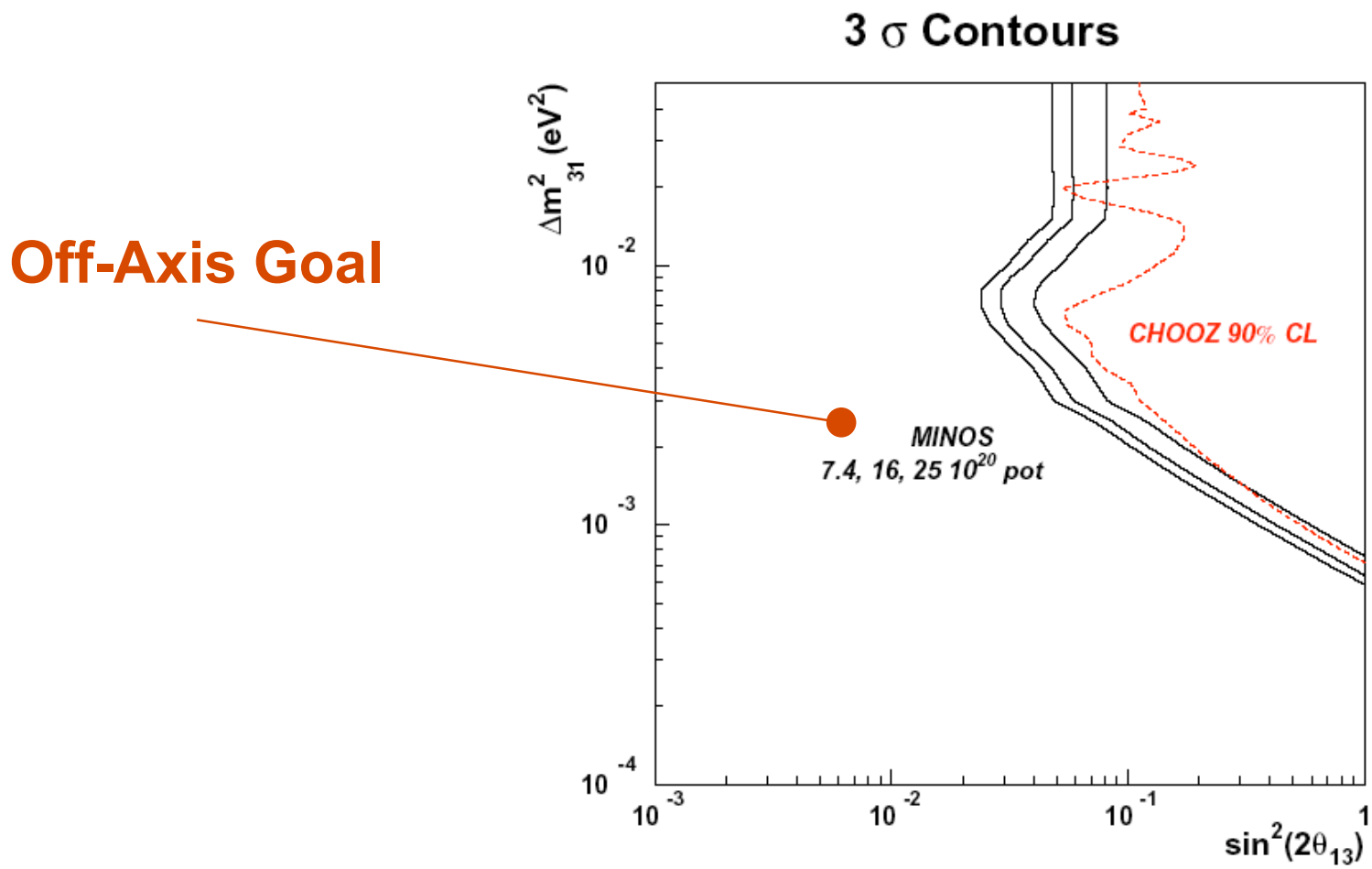
Off Axis

3 σ Discovery Potential for $\nu_\mu \to \nu_e$



Off Axis

MINOS Sensitivity to $\nu_\mu \to \nu_e$ at 3σ Discovery



Off Axis

Status and Prospects

- **Proposal**
  - **Letter of Intent Submitted 2002**
  - **Progress Report just submitted this week**
  - **Full proposal will be submitted in March 2004**
- **Interest in neutrino oscillations has greatly increased during the past year**
  - **HEPAP request APS study beginning next week**
  - **Fermilab Long-Range Planning committee sees neutrino oscillations as a major part of Fermilab's future program**
  - **Secretary of Energy lists a neutrino superbeam as one of four high-energy projects in "Facilities for the Future of Science."**

Complementarity of Terrestrial Neutrino Experiments in Searching for θ_{13}

Pasquale Migliozzi

INFN - Napoli

P.M., F. Terranova Phys. Lett. B 563 (2003) 73
M. Komatsu, P.M., F. Terranova J. Phys. G. 29 (2003) 443

Δm^2 versus YEAR

Atmospheric exps

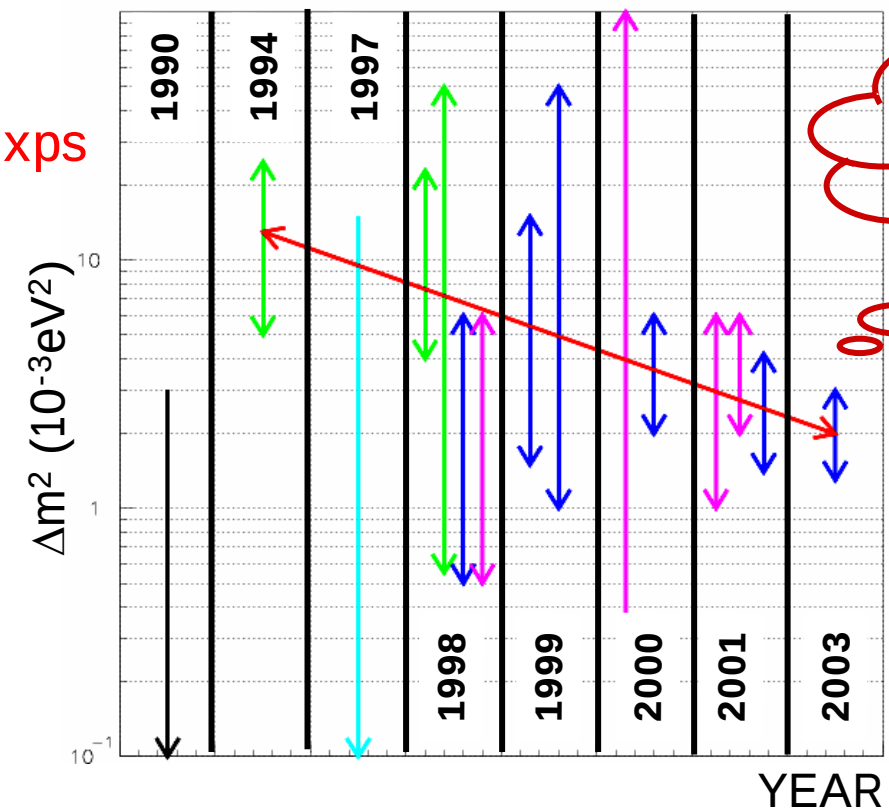
Frejus

Kamiokande

IMB

Super-K

Macro



90% allowed regions for different exps as a function of the time

NB

P_{osc} goes like $(\Delta m^2)^2$

From '94 to '03 it decreased by a factor 100!!

Very difficult the tuning at the atmospheric mass scale!

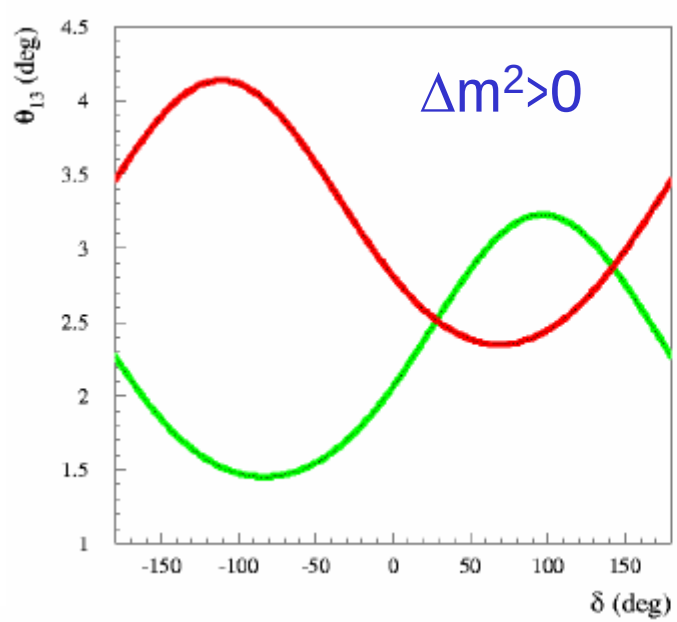
Impact both on $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$ oscillation searches

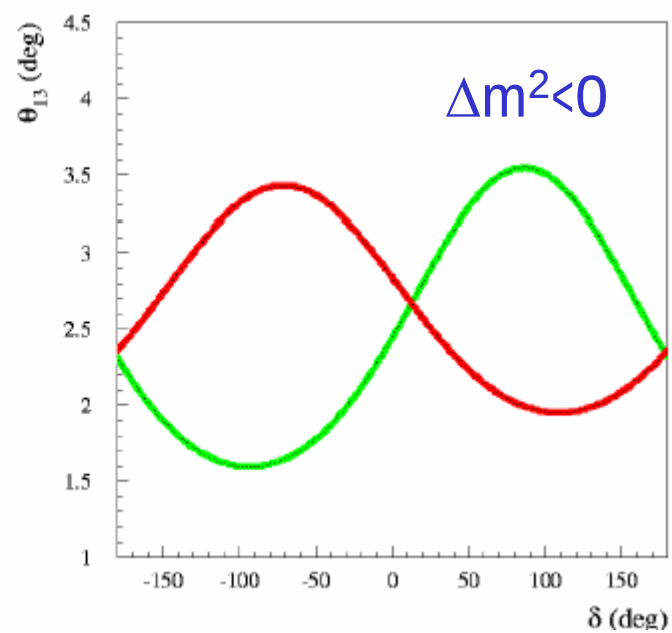
What happens if an exp decides to start with anti-neutrinos?

At the present NuMI-OA is supposed to start data-taking with ν

BAD CHOICE: results similar to JHF, no synergies

GOOD CHOICE: would be data-taking with anti-ν, <u>synergies</u>!





NUMI-OA in anti-ν mode (5y). Yield corrected for σ(anti-n) and π-/π+ yield

JPARC-Ph1 in ν mode (5y)

Conclusion

- Null result at Phase I exps : **WARNING!** δ_{CP} could be huge but hidden by the choice of the neutrino run. A dangerous manifestation of the (δ-θ_{13}) correlation!

- The anti-ν choice (done after the ν run or in parallel by NUMI-OA) is mandatory to take decisions about the Phase II

- Positive result at MINOS or CNGS: **Great time for oscillation physics!** Synergic use of MINOS+ CNGS + JHF + NuMI-OA:
  - to constrain (δ-θ_{13})
  - to determine the sign of Δm^2_{atm}

- $4° < \theta_{13} < 7°$ **Another great season for Japanese neutrino physics!** Signal seen at JPARC. NuMI-OA contribute to precision measurement of (δ-θ_{13}) in anti-ν mode, sign Δm^2_{atm} in neutrino mode

Final remark

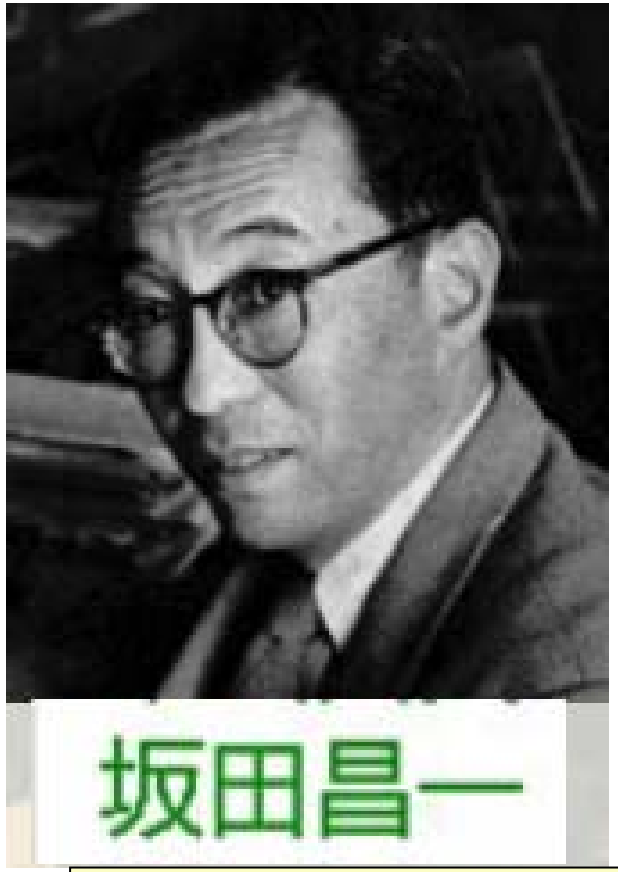
For a successful future one should first exploit and optimise the present

Why do we look for leptonic CP violation?

Lepton-quark correspondence

- Quantum anomaly tells us that leptons and quarks are related with each other in a deeper level => we want to know if leptonic KM phase is unsuppressed

"lepton-quark correspondence" in the spirit of Nagoya model (Sakata et al., '60th)



Shoichi Sakata

Leptogenesis

- Lepton # asymmetry generated by Majorana ν converted to baryon # asym. by "spharelon"
- => standard model for baryogenesis?
- Need CP violating phases
- Related with leptonic KM phase δ ?

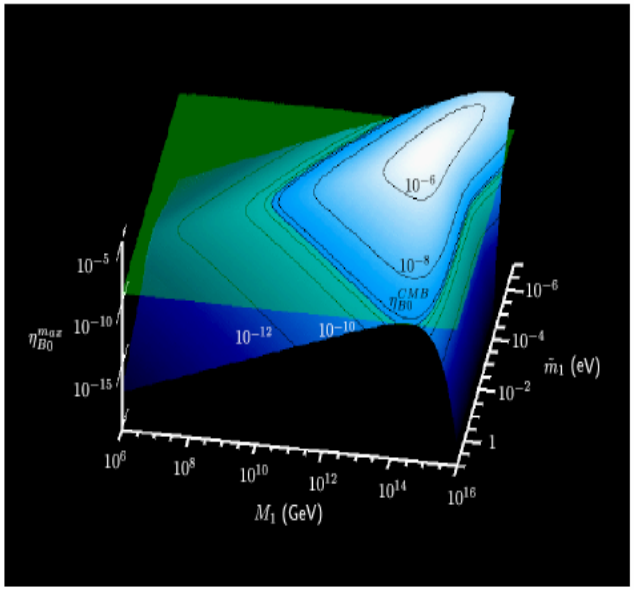
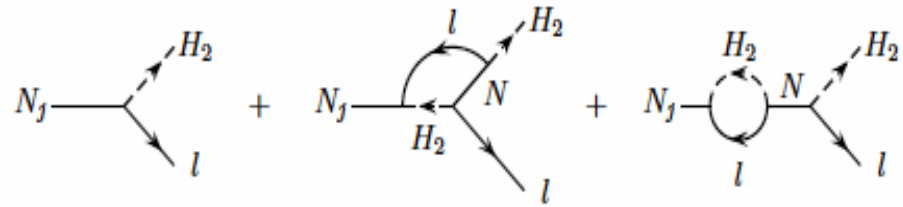


Figure 2: *Maximal baryon asymmetry* $\eta_{B0}^{\max}$ *(blue) as function of* $\tilde{m}_1$ *and* M_1 *for* $\overline{m}$ = 0.05 *eV. The black lines are curves of constant baryon asymmetry with the value indicated. The lines around the intersection with the green plane correspond to the measured value and the upper/lower limits at* 3σ.

(Buchmuller et al.)

(Fukugita-Yanagida '86)



Main problems in a Neutrino Factory:

(Proton driver)

Target

Collection

Cooling (Phase rotation)

Acceleration

Main problems with a superbeam:

High intensity linacs **NOT** a basic problem:

Work at Los Alamos, ESS, TRISPAL, CONCERT, EURISOL and SNS (the only one being build…)

Except for cost, halo and hands-on maintenance

You may (?) need an accumulator (+stripper foil!)…

But target and collection need experiments

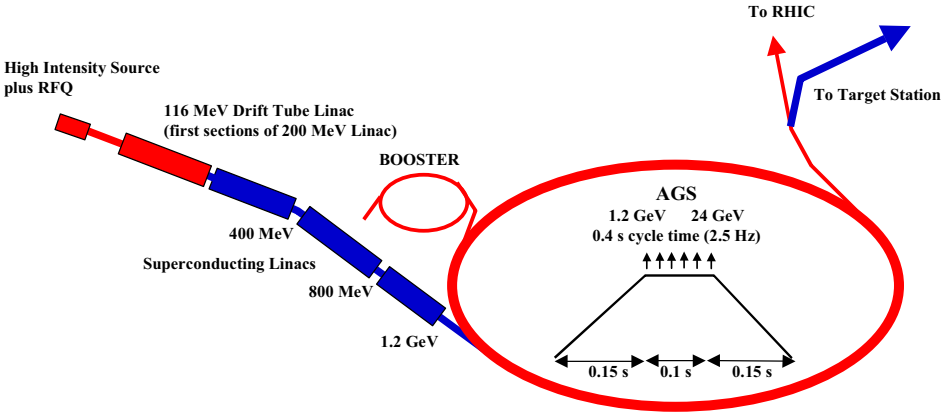
especially for a low energy proton beam (high Z target material required)

(Of course we are waiting for the detailed analysis of the HARP experiment)

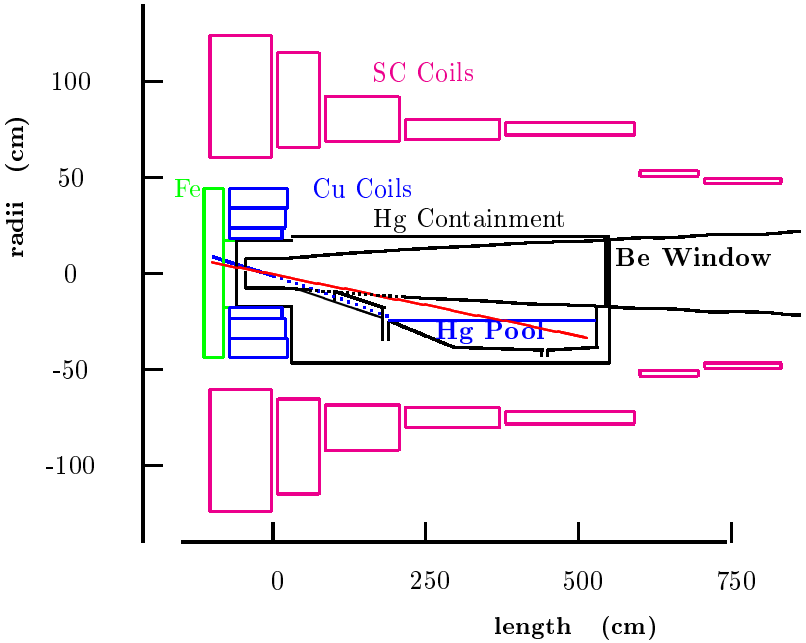
Stage-1 Proton Driver

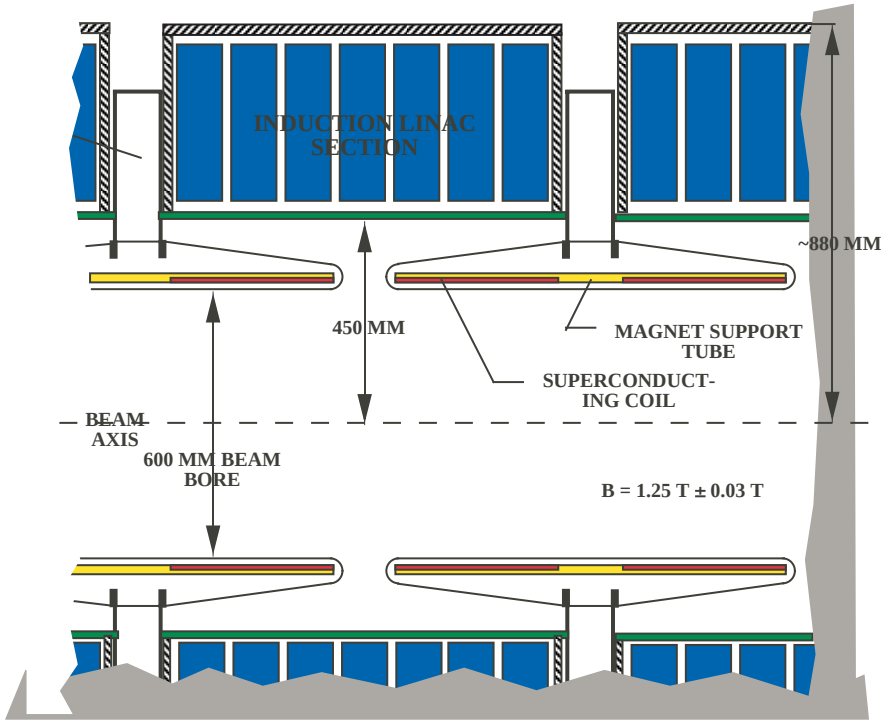
- Costs $250M-330M (1MW), $330M-410M(4MW)
- FNAL scheme

BNL scheme

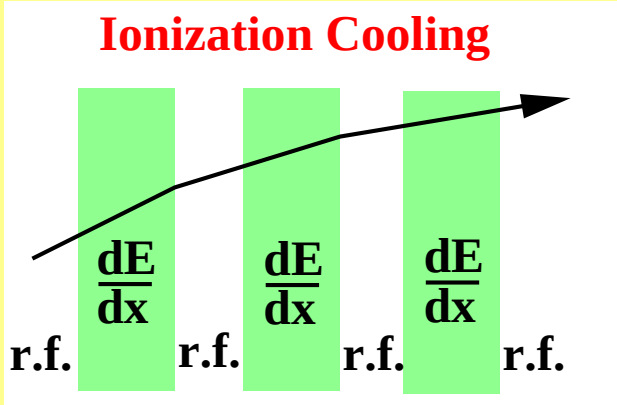


Stage 2 collection , phase rotation





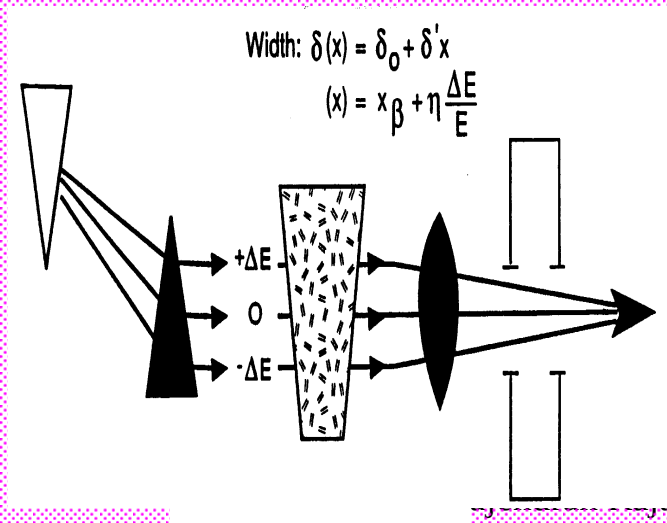
Ionization Cooling



Transverse Cooling

Muons lose energy by dE/dx and long−itudinal momentum replaced by r.f.

- **To Minimize heating from Coulomb Scattering:**
  - **Small $\beta_\perp$ (strong focusing) : High−field solenoids or Lithium Lenses**
  - **Large L_R (low−Z absorber) : Liquid H_2**



Energy "Cooling"

Ionization cooling using a wedge plus dispersion.

Exchanges emitt−ance between transverse & long−itudinal directions

Stage 2

- Price tag $660M-$840M. Muon beam is phase rotated and transversely cooled. Central momentum 220MeV/c, transverse normalized emittance of 2.7 mm-rad and an rms energy spread of ~4.5%. 4x 10^{20} muons per year.
- Cold muon physics can start.

Table 3.2: Some current and future tests for new physics with low-energy muons (from [73], [80], and [81]). Note that the "Current prospects" column refers to anticipated sensitivity of experiments currently approved or proposed; "Future" gives estimated sensitivity with Neutrino Factory front end. (The d_μ measurement is still at the Letter of Intent stage and the reach of experiments is not yet entirely clear.)

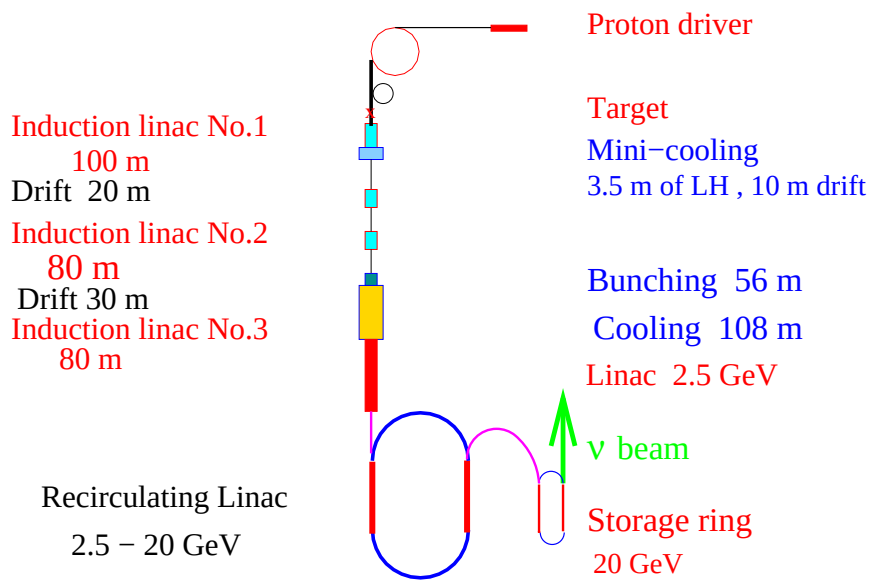
Test	Current bound	Current prospects	Future
$B(\mu^+ \to e^+\gamma)$	$< 1.2 \times 10^{-11}$	$\approx 5 \times 10^{-12}$	$\sim 10^{-14}$
$B(\mu^-\mathrm{Ti} \to e^-\mathrm{Ti})$	$< 4.3 \times 10^{-12}$	$\approx 2 \times 10^{-14}$	$< 10^{-16}$
$B(\mu^-\mathrm{Pb} \to e^-\mathrm{Pb})$	$< 4.6 \times 10^{-11}$		
$B(\mu^-\mathrm{Ti} \to e^+\mathrm{Ca})$	$< 1.7 \times 10^{-12}$		
$B(\mu^+ \to e^+e^-e^+)$	$< 1 \times 10^{-12}$		
d_μ	$(3.7 \pm 3.4) \times 10^{-19}\, e{\cdot}\mathrm{cm}$	$10^{-24}\, e{\cdot}\mathrm{cm}$?	?

Table 3.3: Some examples of new physics probed by the nonobservation of $\mu \to e$ conversion at the 10^{-16} level (from [73]).

New Physics	Limit
Heavy neutrino mixing	$\lvert V^*_{\mu N} V_{eN}\rvert^2 < 10^{-12}$
Induced $Z\mu e$ coupling	$g_{Z_{\mu e}} < 10^{-8}$
Induced $H\mu e$ coupling	$g_{H_{\mu e}} < 4 \times 10^{-8}$
Compositeness	$\Lambda_c > 3,000\,\mathrm{TeV}$

Stage 3, Stage 4

- Stage 3-Accelerate muons to 2.5GeV. $220-250Million.
- g-2, edm of muons can start. (needs 3.1 GeV magic momentum)
- Stage 4- Full neutrino factory 20GeV version costs $550M. 50GeV version costs $1250-1350M.



Neutrino Factory studies and R&D

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

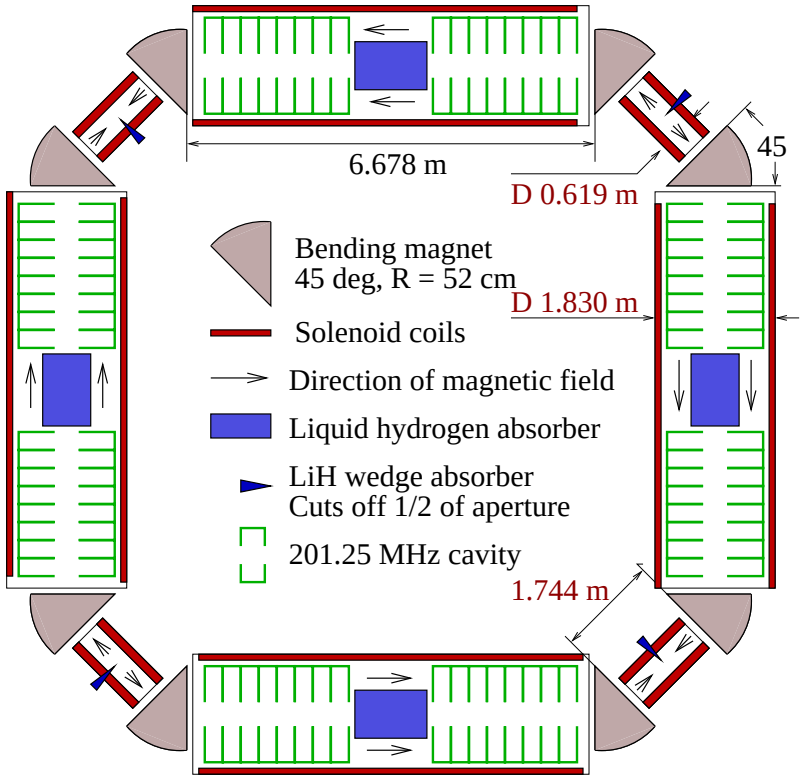
+ detector: MINOS * 10 = about 300 M€ or M$

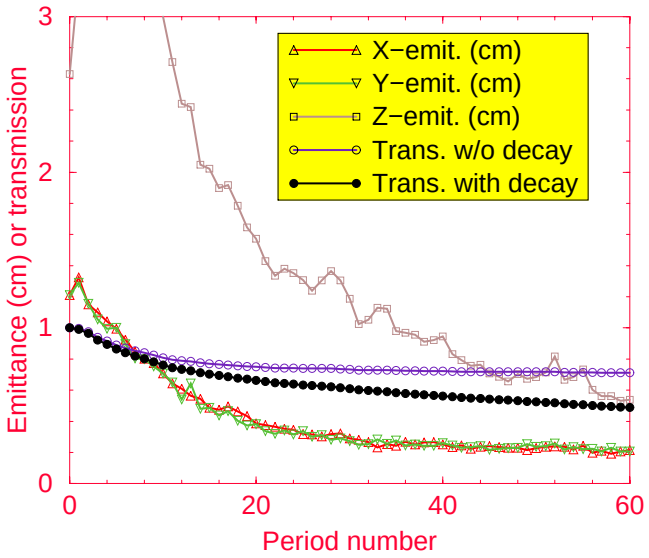
Neutrino Factory CAN be done…..but it is too expensive as is.

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

Stage 5- Muon Collider

- Need to solve emittance exchange problem.
- Ring coolers are a possibility. Injection/extraction, equilibrium emittance are problems.





Hence…

MINOS, OPERA, ICARUS, JHF, reactors

$\theta_{13} \neq 0$!

Super&beta-beams +Giant detectors

And search for $\delta \neq 0$?

$\theta_{13} = 0$?

Symmetry is broken

NF +Large Magnetized detector

And $\delta \neq 0$ detection might be hopeless if $\sin^2 2\theta_{13}$ is $<< \approx 10^{-3}$

The catalog of detectors and their applications

- **Neutrino factory @ E_ν >> GeV**
  - Large Magnetized Fe Sampling Calorimeters **M ≈ 40kt**
  - Large Magnetized Liquid Argon detectors **M ≈ 20kt**
- **Superbeams, beta-beams @ E_ν≈ GeV**
  - Giant Cerenkov detectors **M ≈ 1000 t**
  - Giant Liquid Argon detectors **M ≈ 100 kt**
  - Giant scintillator detectors **M ≈ 30 kt** → ***L. Oberauer***
- **Superbeams @ E_ν ≈ GeV**
  - Large Low Z Sampling Calorimeters **M ≈ 50 kt**

→ ***G. Feldman***

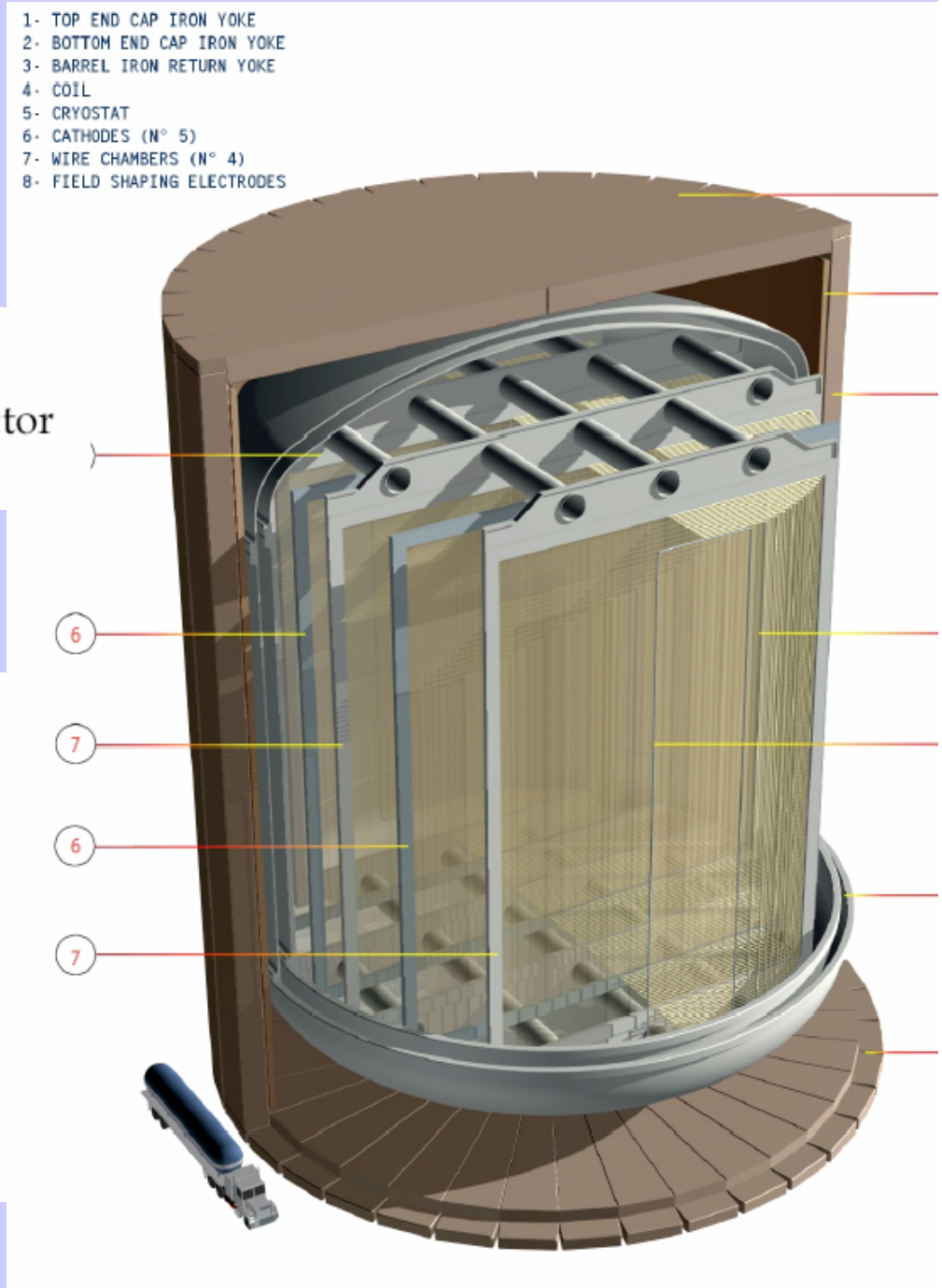
F. Sergiampietri, NUFACT 01 (Tsukuba)
Based on ICARUS

LANNDD

Liquid Argon Neutrino and Nucleon Decay Detector in Magnetic Field

70 kton LAr

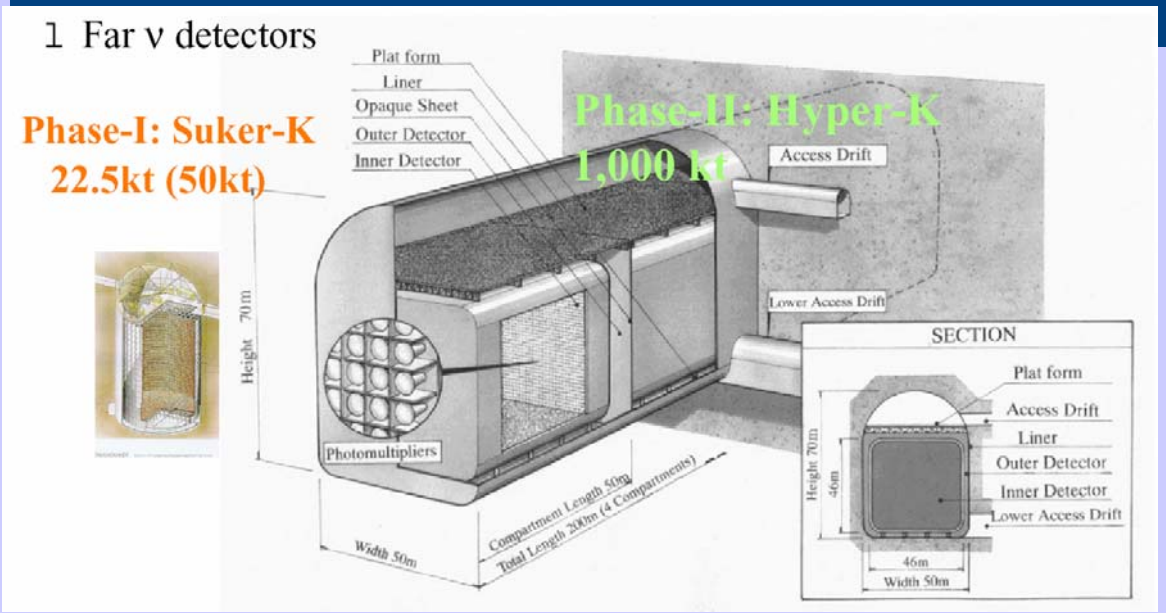
N° OF WIRE CHAMBERS	4
WIRE CHAMBER CH1, CH4	W = 26.8 m ... H = 40 m
CH2, CH3	W = 39.2 m ... H = 40 m
READOUT PLANES / CHAMBER ... [2 at 0°, 2 at 90°]	4
SCREEN-GRID PLANES / CHAMBER	3
TOTAL N° OF WIRES (CHANNELS)	194648
ACTIVE VOLUME	48000 m^3
ACTIVE MASS	67 kT
N° OF CATHODE PLANES	5
MAXIMUM DRIFT	5 m
MAXIMUM HIGH VOLTAGE	250 kV
REQUIRED ELECTRON LIFETIME (PURITY)	15 ÷ 20 ms



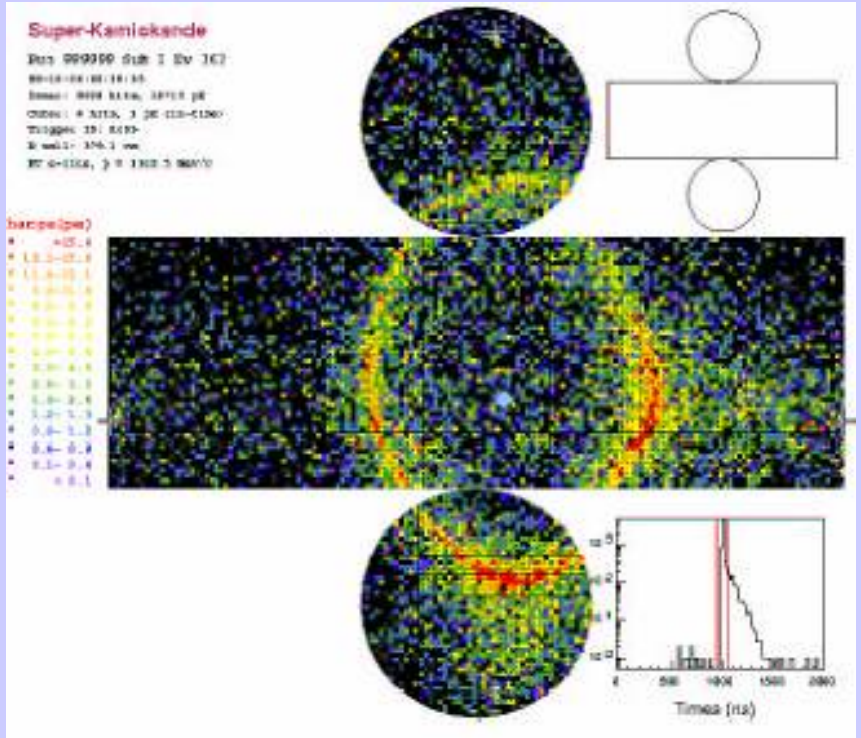
"brute force"

Giant water Cerenkov

- **Perceived widely as a "straightforward" extension of SK (?)**
- **Many "proposals", e.g., Hyper-K, UNO**
- **Many sites, e.g., Frejus, Kamioka, etc.**
- **Physics case is "broad"**
  - ↙ proton decay, neutrino properties, galactic supernovae, …



e or π^0 candidate

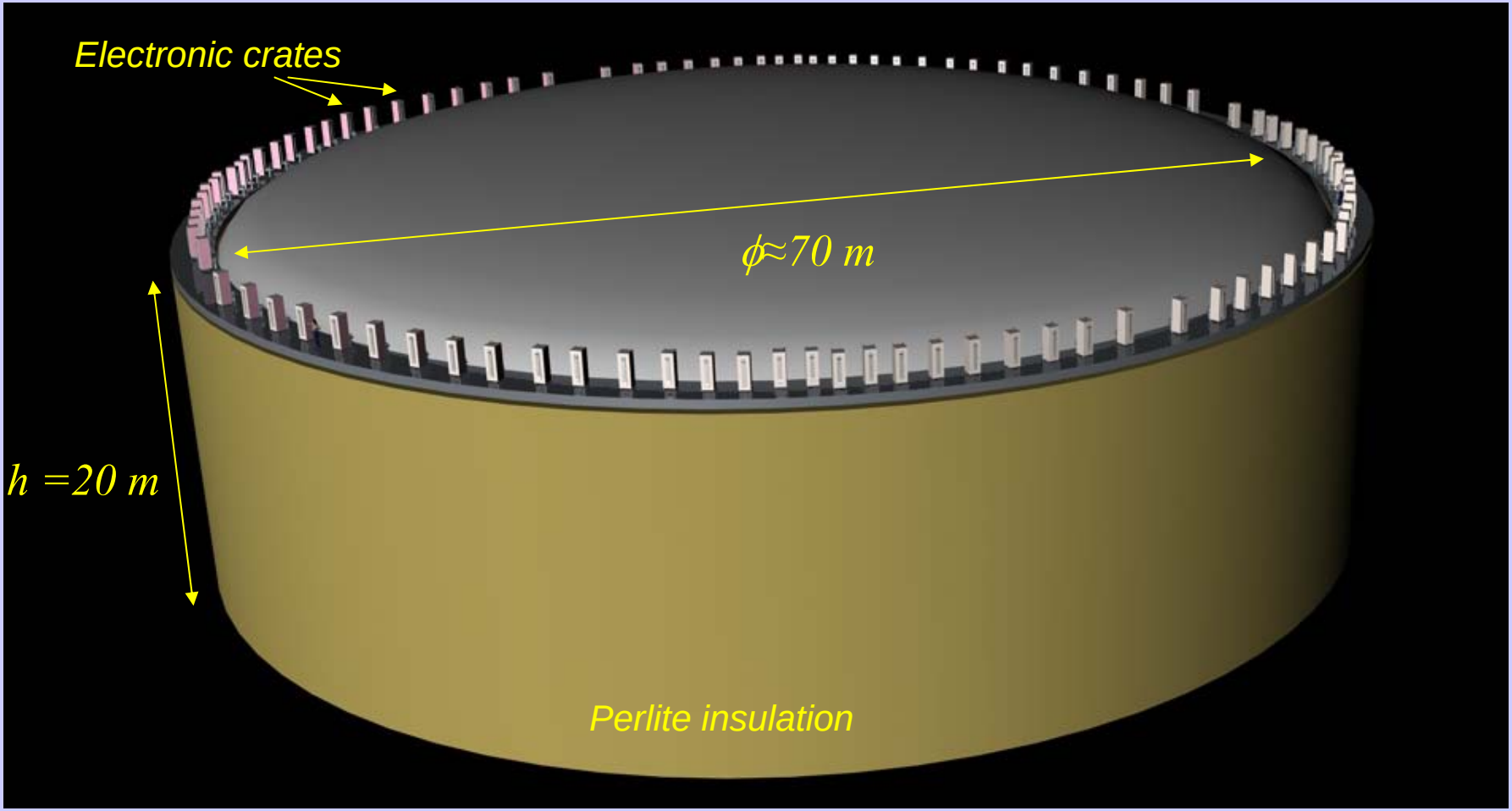


K. Nishikawa

100 kton liquid Argon detector

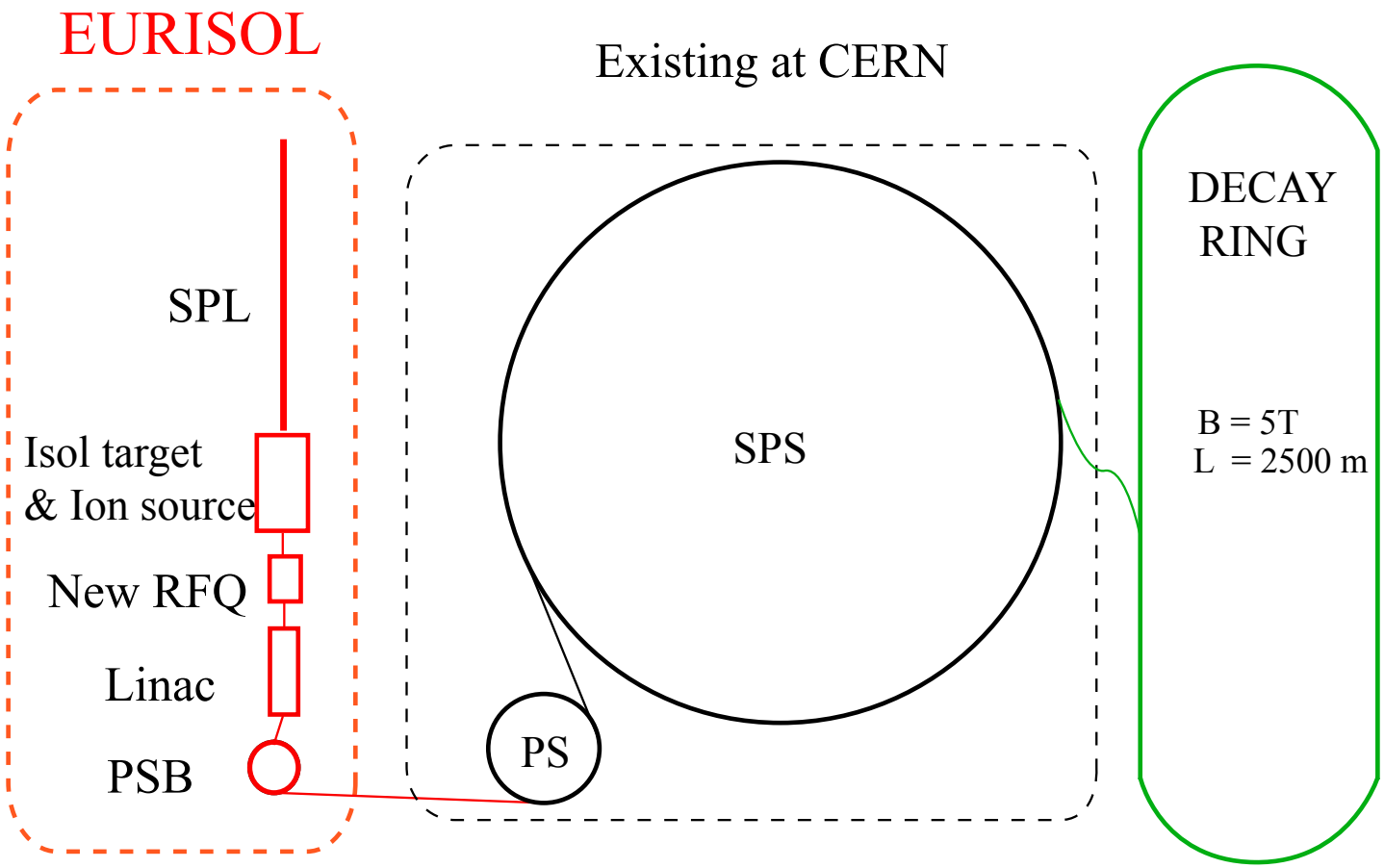
Basic "novelties":

1. Charge imaging + scintillation + Cerenkov light readout for complete event information
2. Charge amplification to allow for extremely long drifts
3. Single 100 kton "boiling" cryogenic tanker with Argon refrigeration



Beta Beam (P. Zucchelli: Phys. Lett. B532:166, 2002)

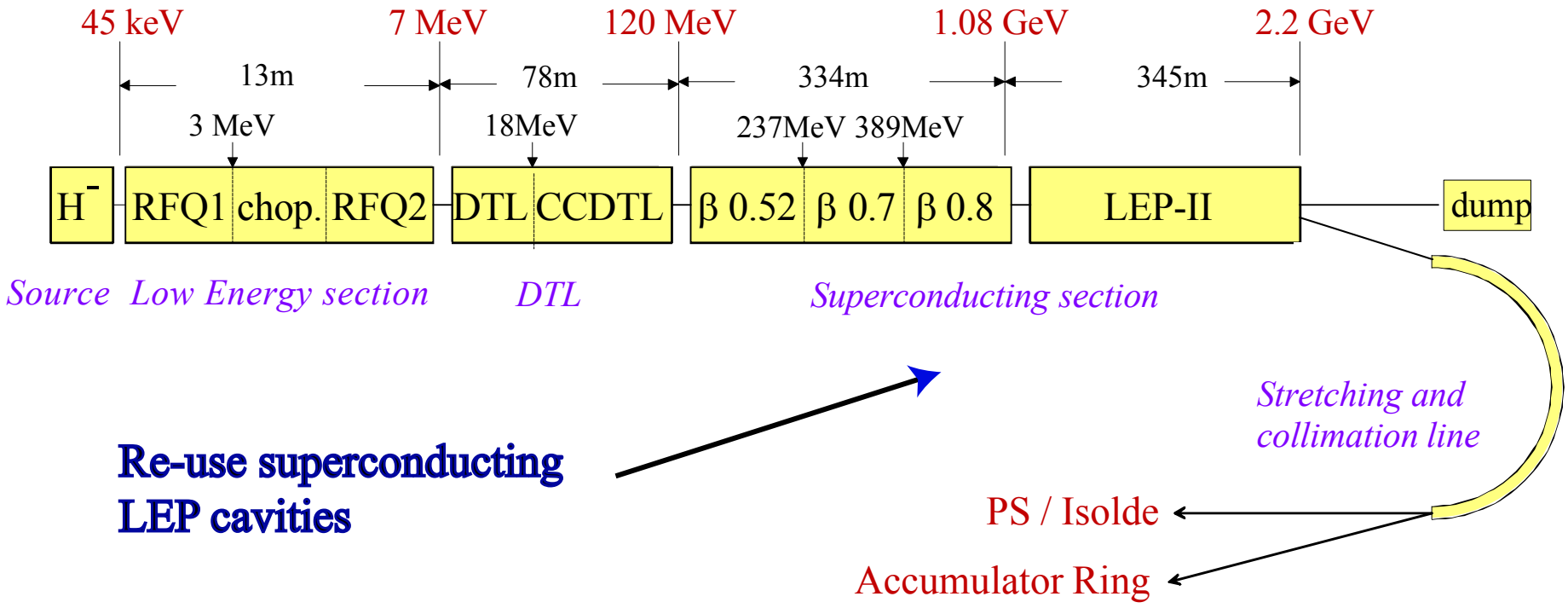
M. Lindroos and collaborators, see http://beta-beam.web.ch/beta-beam



- 1 ISOL target to produce He^6, 100 μA, $\Rightarrow 2.9 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \overline{\nu}_e$.
- 3 ISOL targets to produce Ne^{18}, 100 μA, $\Rightarrow 1.2 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \nu_e$.
- The 4 targets could run in parallel, but the decay ring optics requires:

$$\gamma(Ne^{18}) = 1.67 \cdot \gamma(He^6).$$

MW-Linac: SPL (Superconducting Proton Linac)

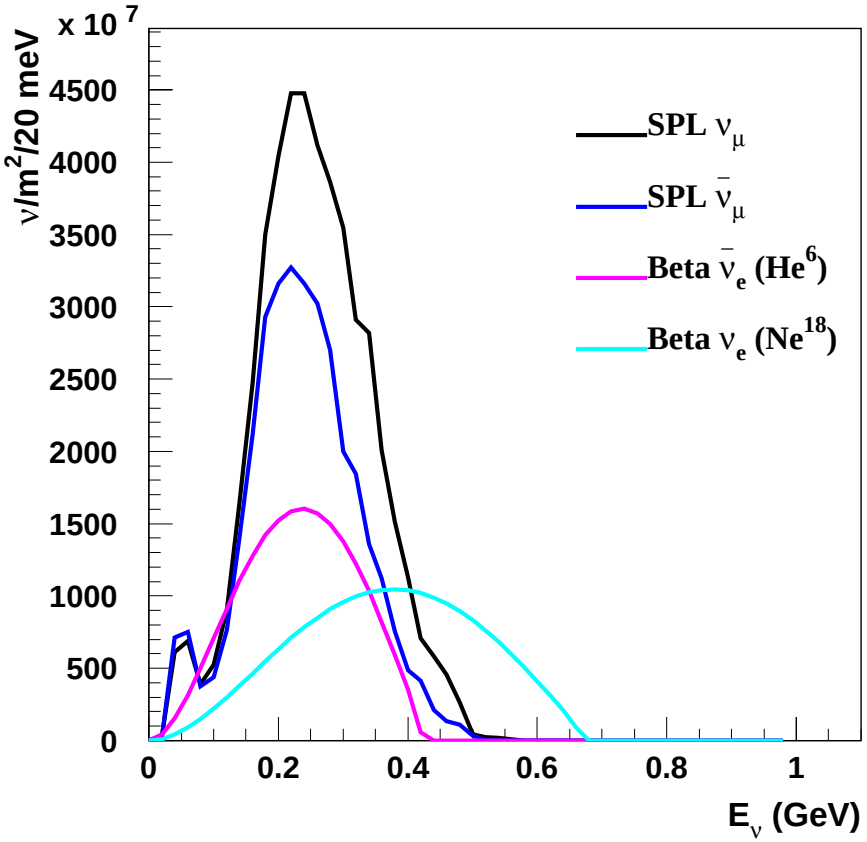


Re-use superconducting LEP cavities

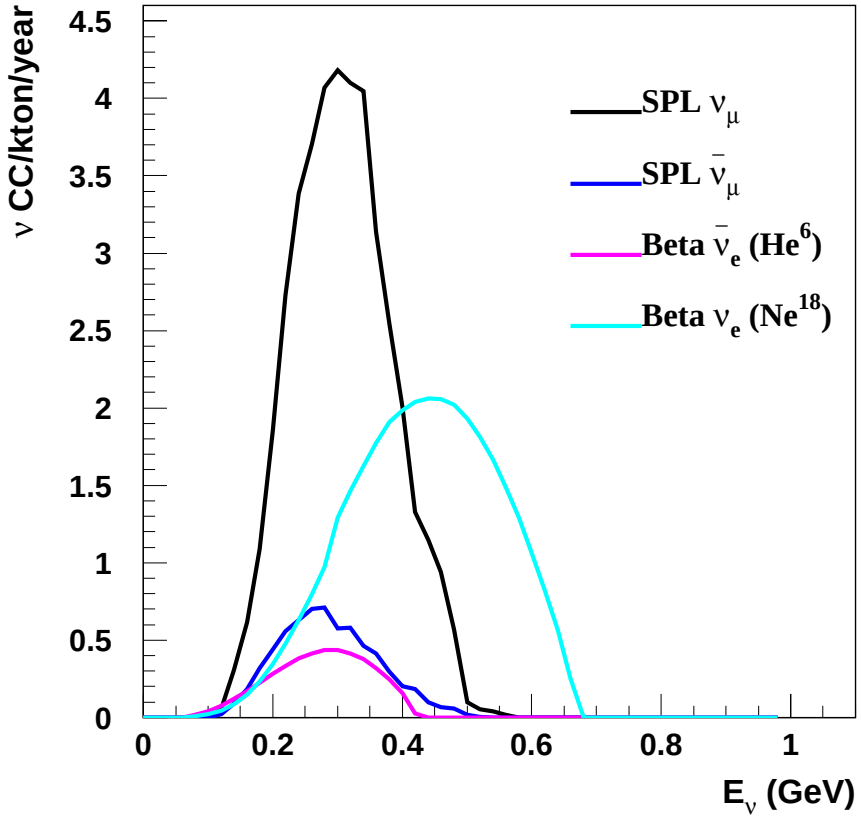
EKIN = 2.2 GeV
Power = 4 MW
Protons/s = 10^{16}

10^{23} protons/year

Fluxes



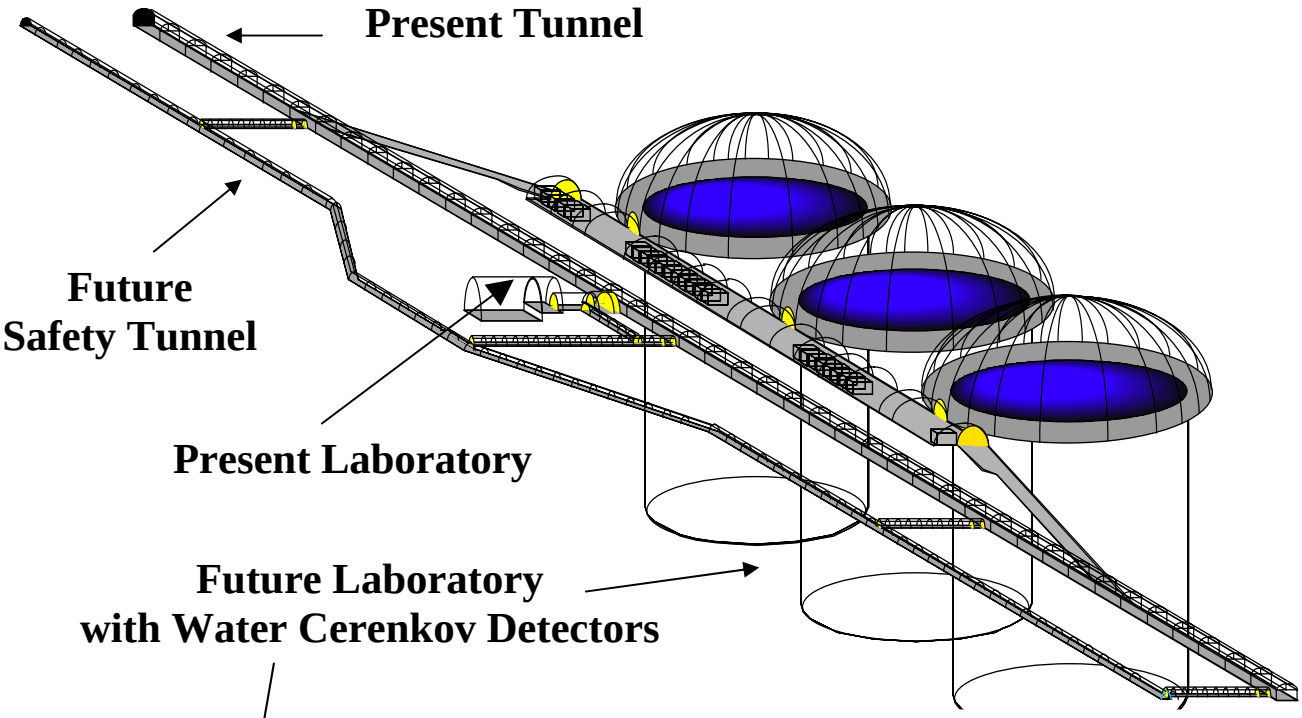
CC Rates

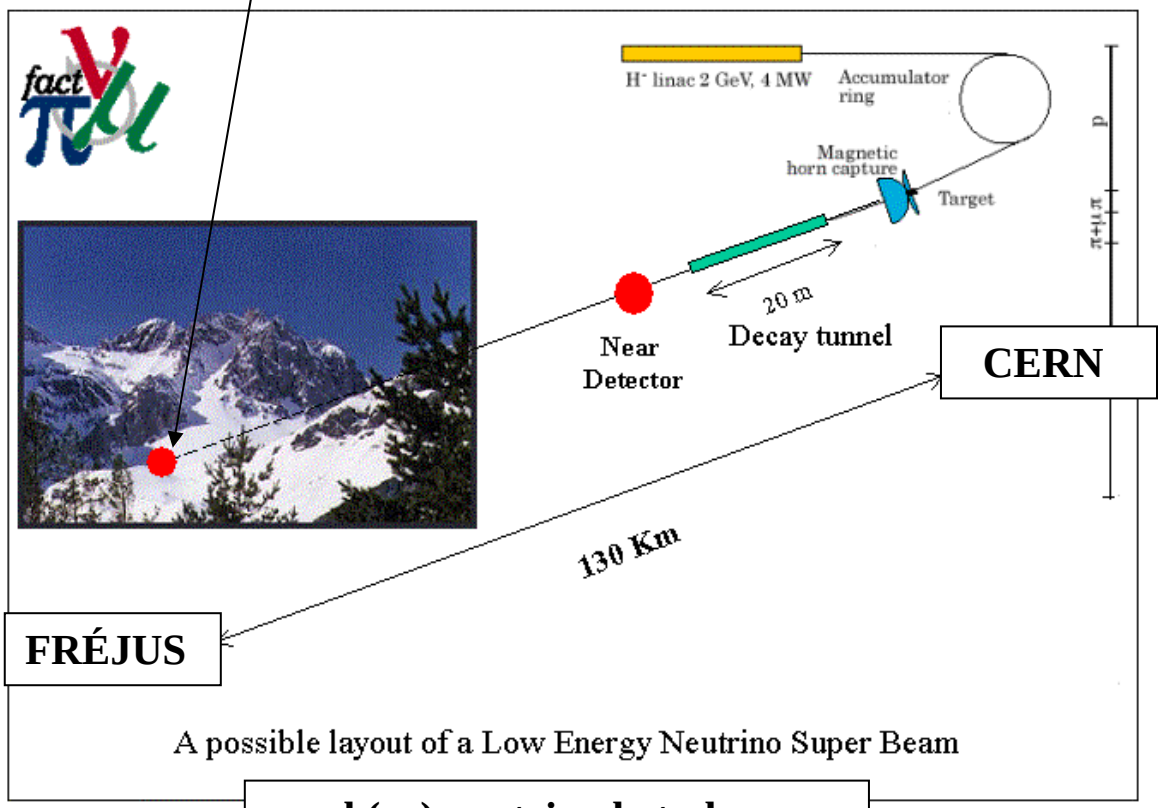


	Fluxes @ 130 km $\nu/m^2/yr$	$< E_\nu >$ (GeV)	CC rate (no osc) events/kton/yr	$< E_\nu >$ (GeV)	Years	Integrated events (440 kton $\times$ 10 years)
SPL Super Beam						
ν_μ	$4.78 \cdot 10^{11}$	0.27	41.7	0.32	2	36698
$\overline{\nu}_\mu$	$3.33 \cdot 10^{11}$	0.25	6.6	0.30	8	23320
Beta Beam						
$\overline{\nu}_e$ $(\gamma = 60)$	$1.97 \cdot 10^{11}$	0.24	4.5	0.28	10	19709
ν_e $(\gamma = 100)$	$1.88 \cdot 10^{11}$	0.36	32.9	0.43	10	144783

2) Components of the Project

-> a **very large Laboratory** to allow the installation of a **Megaton**-scale **Cerenkov** Detector ($\approx 10^6$ m^3)





A possible layout of a Low Energy Neutrino Super Beam

and (or) neutrino beta-beam

Distinctive features of the Beta Beam

Just one neutrino flavour in the beam. No intrinsic contamination.

Short baseline: no subtraction of the fake CP violating matter effects.

Tunable: easy to adapt to the optimal Δm^2_{23}.

In the proposed scheme the $\overline{\nu}_e$ channel is completely background free!

Neutrino fluxes are completely defined by the beta decay properties of the parent ion and by the knowledge of the number of ions in the decay ring. This assures very small systematic errors and a powerful measure of neutrino cross-sections in the close detector.

The ν_e and $\overline{\nu}_e$ beams allow for the disappearance channel with a very good control of the systematics, with a direct access to θ_{13} . Their comparison offers a tool to investigate CPT.

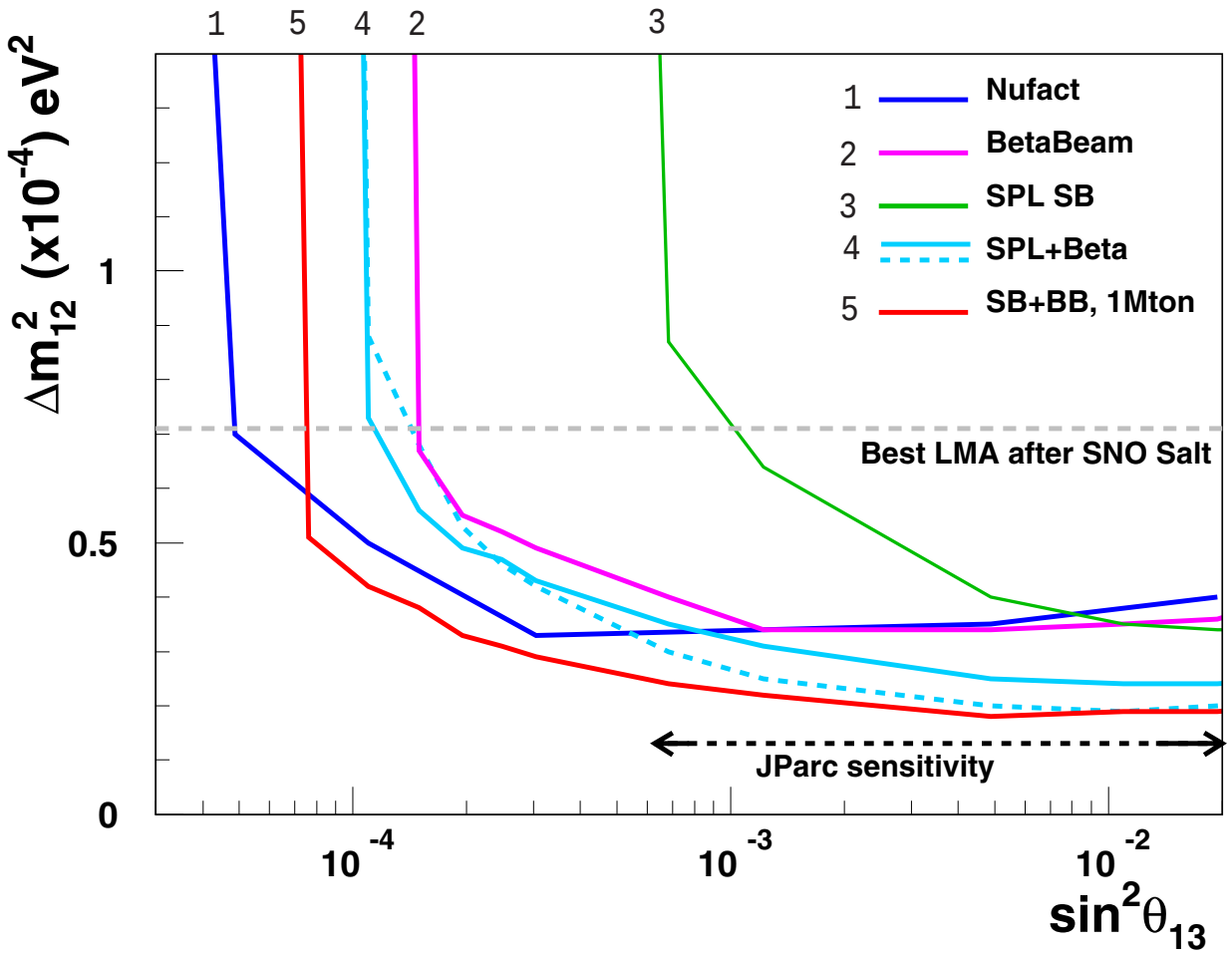
When combined with the ν_μ and $\overline{\nu}_\mu$ SPL beams, the ν_e and $\overline{\nu}_e$ Beta Beams allow for CP, T, and CPT searches.

A comparison of CP sensitivities: Beta Beam vs. Nufact

CP sensitivity, defined as the capacity to separate at 99%CL max CP ($\delta = \pi/2$) from no CP ($\delta = 0$).

Nufact sensitivity as computed in J. Burguet-Castell et al., Nucl. Phys. B **608** (2001) 301:

- 50 GeV/c μ.
- $2 \cdot 10^{20}$ useful μ decays/year.
- 5+5 years.
- 2 iron magnetized detectors, 40 kton, at 3000 and 7000 km.
- Full detector simulation, including backgrounds and systematics.

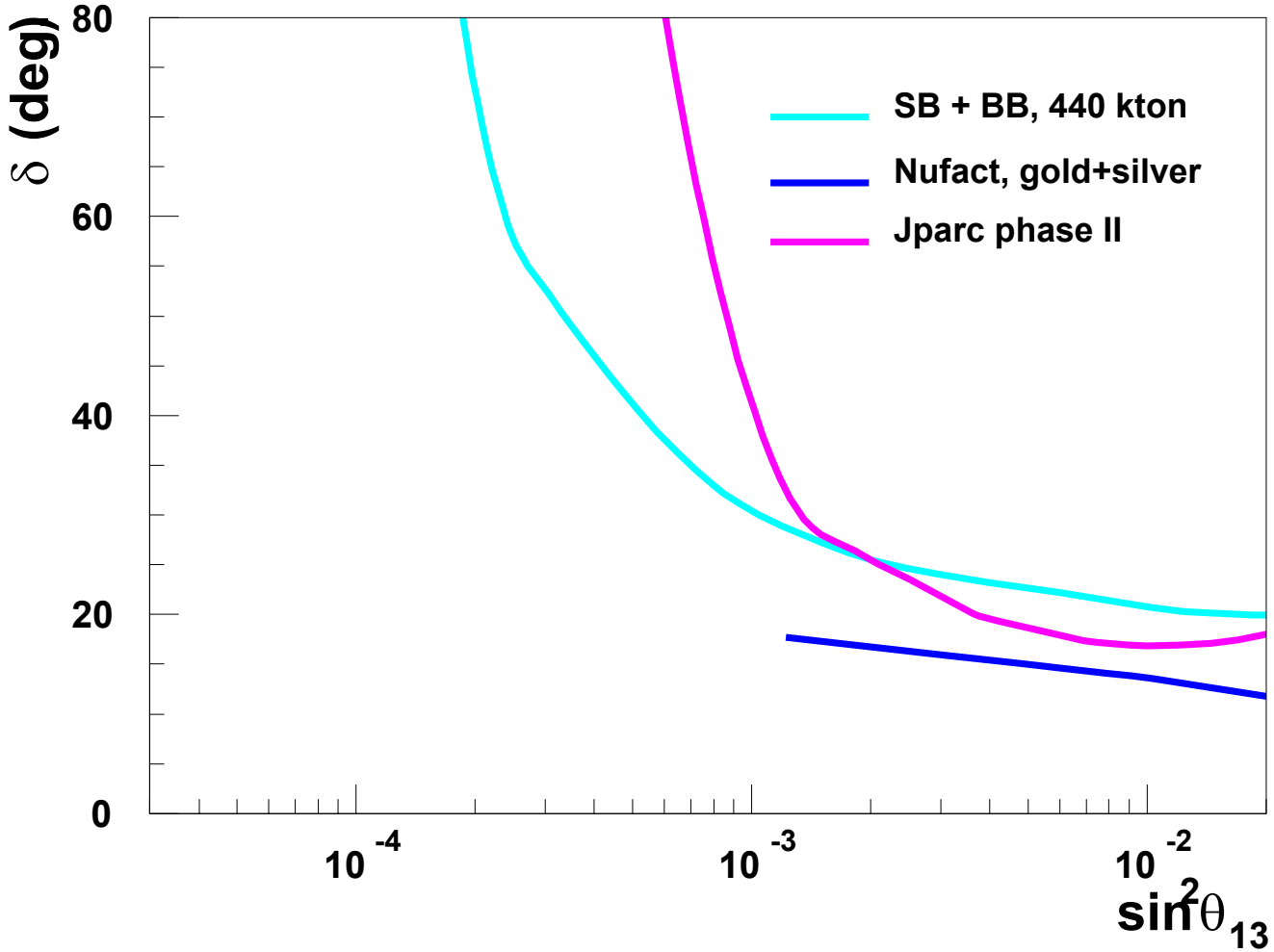


δ sensitivity: Nufact vs SPL SuperBeam + Beta Beam.

Minimum value of δ at 3σ from zero as function of θ_{13} . $\Delta m^2_{12} = 7 \cdot 10^{-3}$ eV^2.

JParc as computed by T. Kobayashi, J.Phys.G29:1493(2003)

Nufact curve is silver+gold, preliminary, courtesy of O. Mena. Its extension below 2° is under investigation.



Conclusions

Beta Beam is a (CERN based) realistic facility that could profit of very deep synergies with:

- Nuclear physicists aiming at a very intense source of radioactive ions.
- A gigantic water Cerenkov detector with great physics potential in its own.

The Super-Beta Beams combination can address δ_{CP} discovery with a sensitivity similar to the Neutrino Factory having the distinctive possibility of:

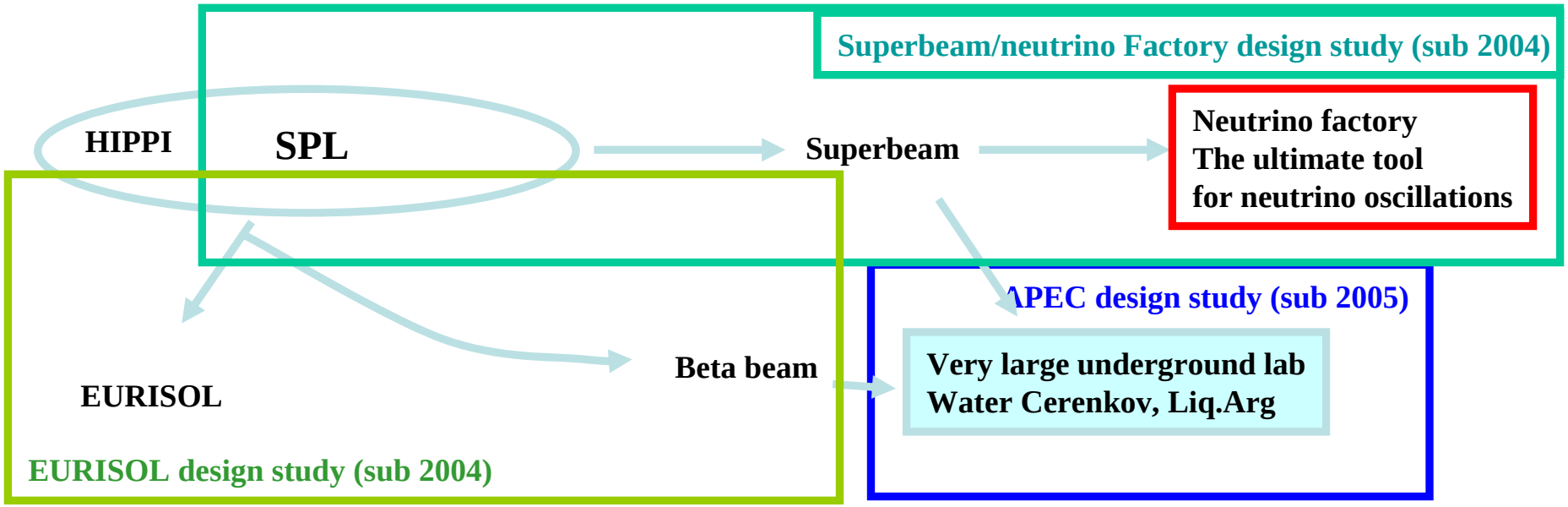
- Combine CP, T and CPT searches
- Use ν_e disappearance to solve all the ambiguities for reasonable large values of θ_{13} .

The Super-Beta Beams combination cannot compete with the Neutrino Factory in measuring sign(Δm^2_{13}).

The possibility to install at Frejus a megaton detector receiving both a super beam and a beta beam offers to Europe a unique opportunity.

Comment on BB cost estimates

Educated guess on possible costs	USD/CHF	1.60
UNO	960	MCHF
SUPERBEAM LINE	100	MCHF
SPL	300	MCHF
PS UPGR.	100	MCHF
SOURCE (EURISOL), STORAGE RING	100	MCHF
SPS	5	MCHF
DECAY RING CIVIL ENG.	400	MCHF
DECAY RING OPTICS	100	MCHF
TOTAL (MCHF)	**2065**	MCHF
TOTAL (MUSD)	**1291**	MUSD
INCREMENTAL COST (MCHF)	705	MCHF
INCREMENTAL COST (MUSD)	441	MUSD



SPL physics workshop: 25-26 May 2004 at CERN

→ CERN SPSC Cogne meeting sept. 2004

HIPPI

R. Garoby

In the frame of the CARE Initiative (ESGARD), *Joint Research Activity* called HIPPI (High Intensity Pulsed proton Injector) (total 6 JRA's)

8 European Laboratories join efforts for a common R&D on high intensity linacs with energy in the range 3-200 MeV (CEA, CERN, ISN-Grenoble, GSI, IAP-Frankfurt, FZ Juelich, RAL, INFN-Mi) to prepare the upgrade of the proton accelerator facilities at CERN, GSI, RAL

4 Work Packages: 1. Normal-conducting accelerating structures
2. Superconducting accelerating structures
3. Beam chopping
4. Beam dynamics

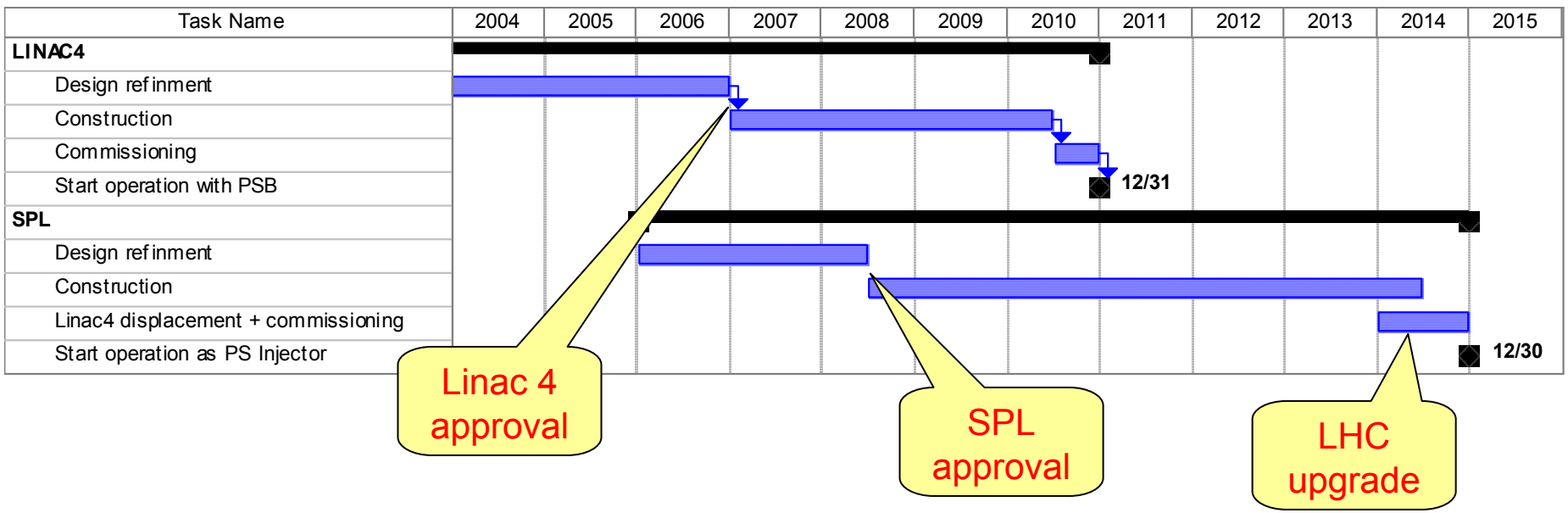
Total investment of some 15 M€ (including lab salaries), request to EU for a contribution of 4 M€ over 5 years (2004-08)

For CERN, this means 130 k€/yr (…).

R. Garoby

Proposed Roadmap

Consistent with the content of a talk by L. Maiani at the “Celebration of the Discovery of the W and Z bosons”. Contribution to a document to be submitted to the December Council *(“CERN Future Projects and Associated R&D”).*

Assumptions:

- construction of Linac4 in 2007/10 *(with complementary resources, before end of LHC payment)*
- construction of SPL in 2008/15 *(after end of LHC payments)*