CP violation at Neutrino Factories and future neutrino beams

Neutrino Factory overview

Low energy Super-beam … and beta-beam

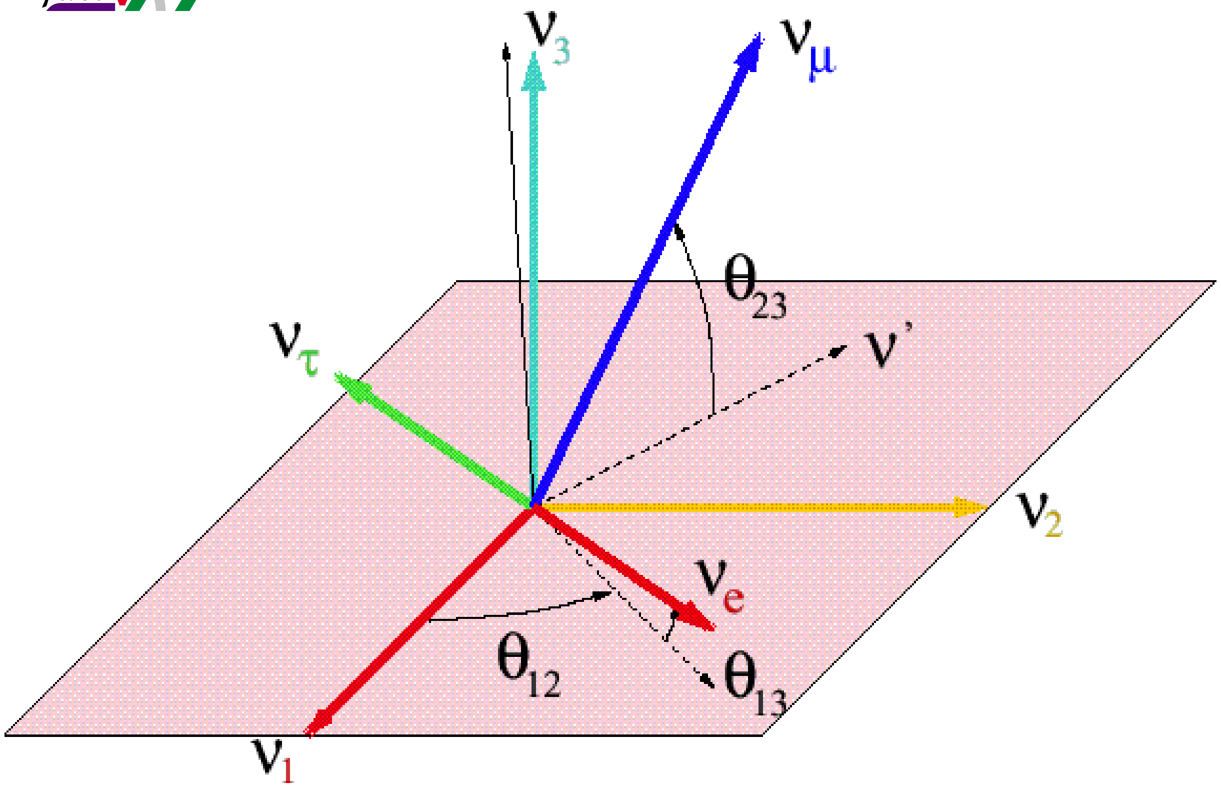
Neutrino Factory R&D

New developments: EMCOG, MICE, ring cooler

Conclusions

Alain Blondel

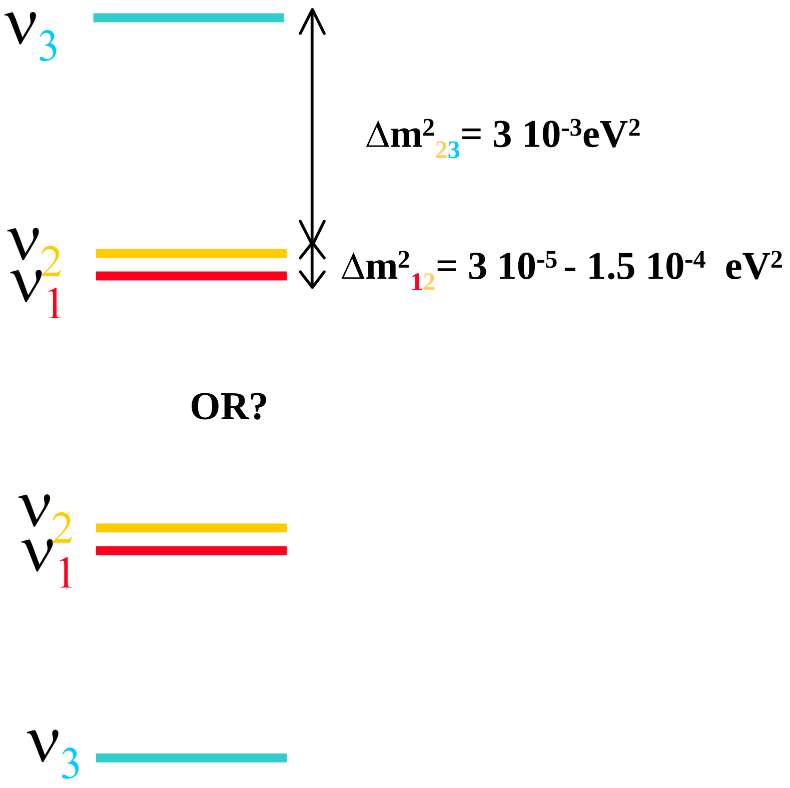
The neutrino mixing matrix (LMA)



θ_{23} **(atmospheric) = 45^0**

θ_{12} **(solar) = 30^0**

θ_{13} **(Chooz) < 13^0**



$$\mathrm{U_{MNS}} : \begin{pmatrix} \sim \frac{\sqrt{2}}{2} & \sim -\frac{\sqrt{2}}{2} & \sin\theta_{13}\, e^{i\delta} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim -\frac{\sqrt{2}}{2} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim \frac{\sqrt{2}}{2} \end{pmatrix}$$

Unknown or very poorly known even after approved program:

θ_{13} , **phase δ , sign of Δm_{13}**

$$
\begin{aligned}
p(\nu_\mu \to \nu_e) = \\
& 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} && \theta_{13}\ \text{driven} \\
& + 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} && \text{CP} - \text{even} \\
& - 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} && \text{CP} - \text{odd} \\
& + 4s_{12}^2 c_{13}^2 \{ c_{12}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2 c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta \} \sin \frac{\Delta m_{12}^2 L}{4E} && \text{solar driven} \\
& - 8c_{13}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) && \text{matter effect (CP odd)}
\end{aligned}
\tag{1}
$$

$$
\frac{P(\nu_e \to \nu_\mu) - P(\overline{\nu}_e \to \overline{\nu}_\mu)}{P(\nu_e \to \nu_\mu) + P(\overline{\nu}_e \to \overline{\nu}_\mu)} = A_{CP} \ \alpha \ \frac{\sin\delta \quad \sin(\Delta m^2_{12}\, L/4E) \quad \sin\theta_{12}}{\sin\theta_{13} + \text{solar term}\ldots}
$$

… need large values of sin θ_{12}, Δm^2_{12} (LMA) but not large $\sin^2\theta_{13}$

… need APPEARANCE … $P(\nu_e \to \nu_e)$ is time reversal symmetric (reactors or sun are out)

… can be large (30%) for suppressed channel (one small angle vs two large)

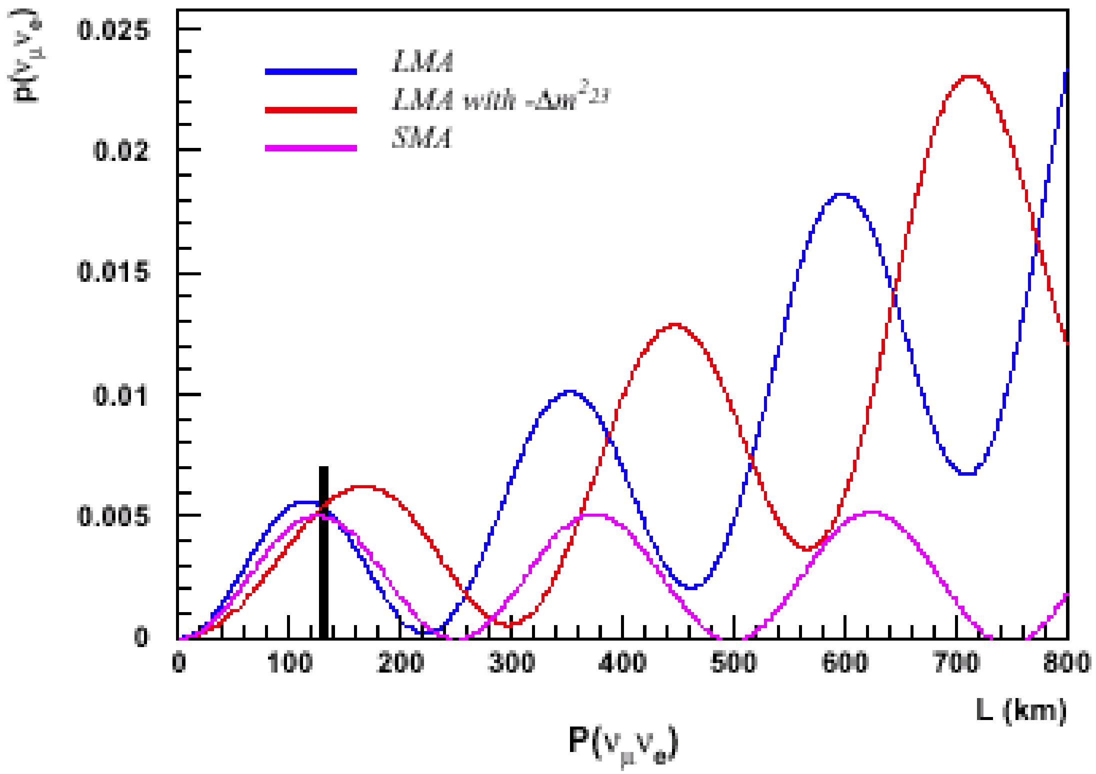
at wavelength at which ‘solar’ = ‘atmospheric’ and for $\nu_e \to \nu_\mu$, ν_τ

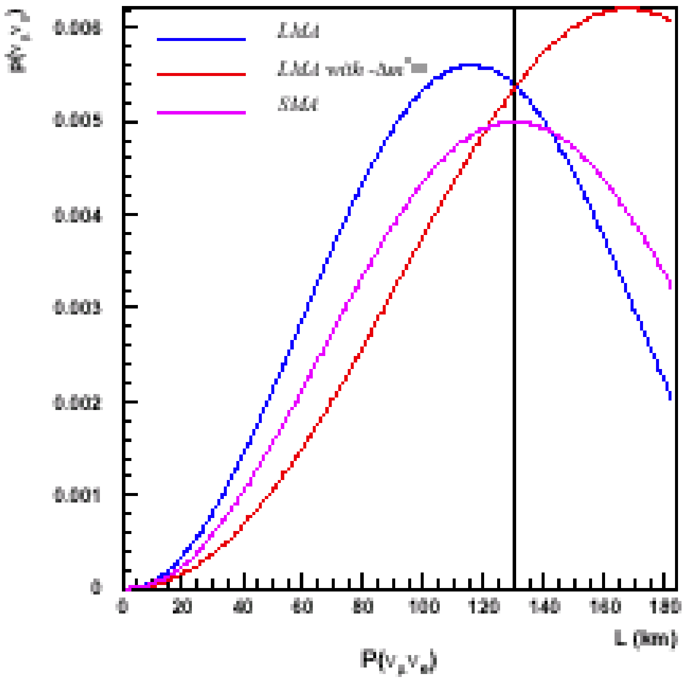
… asymmetry is opposite for $\nu_e \to \nu_\mu$ and $\nu_e \to \nu_\tau$

Regarding the parameters' choice.

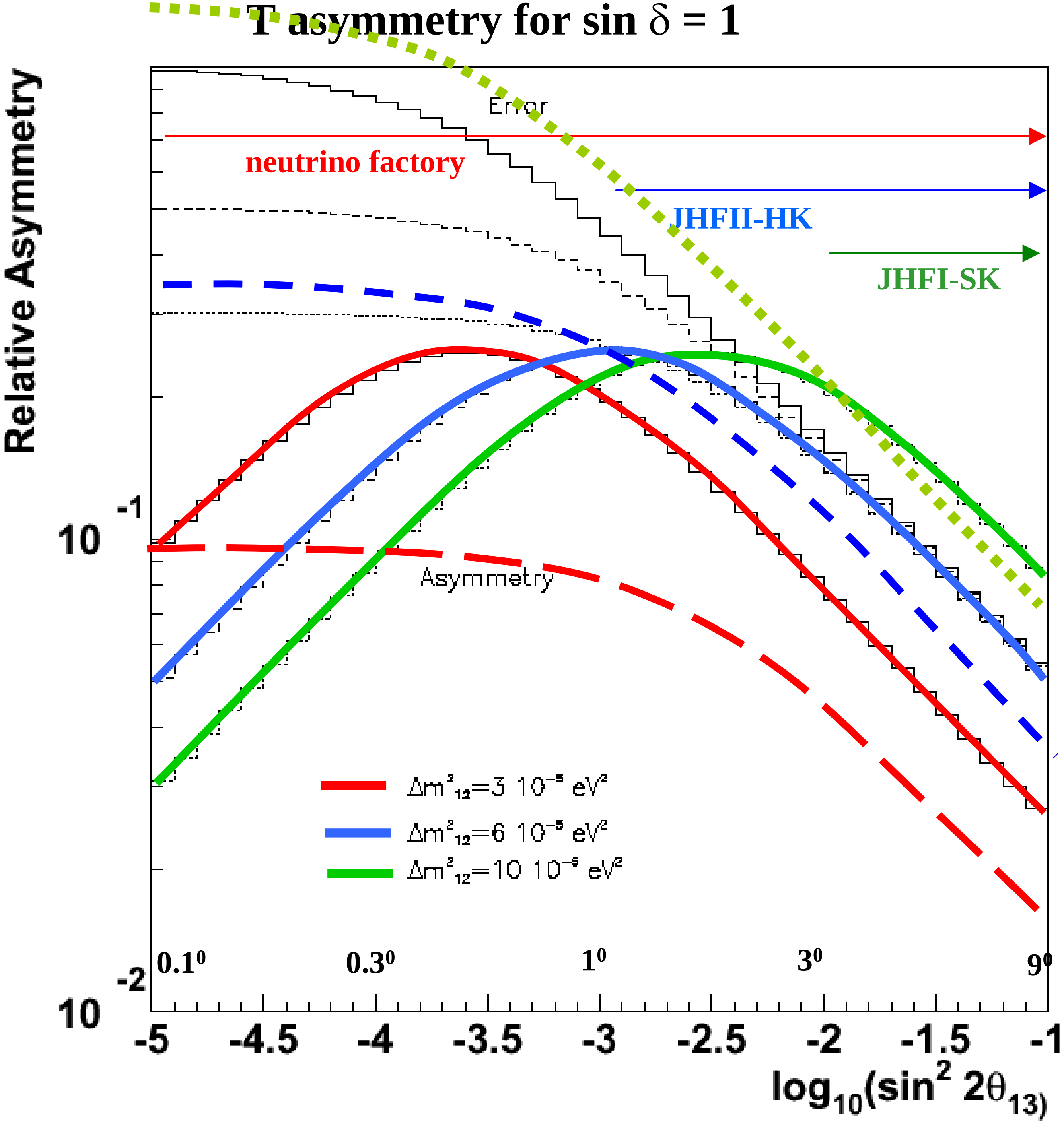
- Amplitude is driven by $\sin^2(2\theta_{13})$
- Wavelength is driven by δm^2_{23}

- But also δm^2_{12}, its sign, δ, $\sin^2 2\theta_{23}$, $\sin^2 2\theta_{12}$ have sizable effects





T asymmetry for sin δ = 1



!

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

!

Road Map

Experiments to find θ_{13} :

1. search for $\nu_\mu \rightarrow \nu_e$ in conventional ν_μ beam (ICARUS, MINOS)
   limitations: NC π^0 background, intrinsic ν_e component in beam
2. Off-axis beam (JHF-SK, off axis NUMI, off axis CNGS) or
3. low energy superbeam

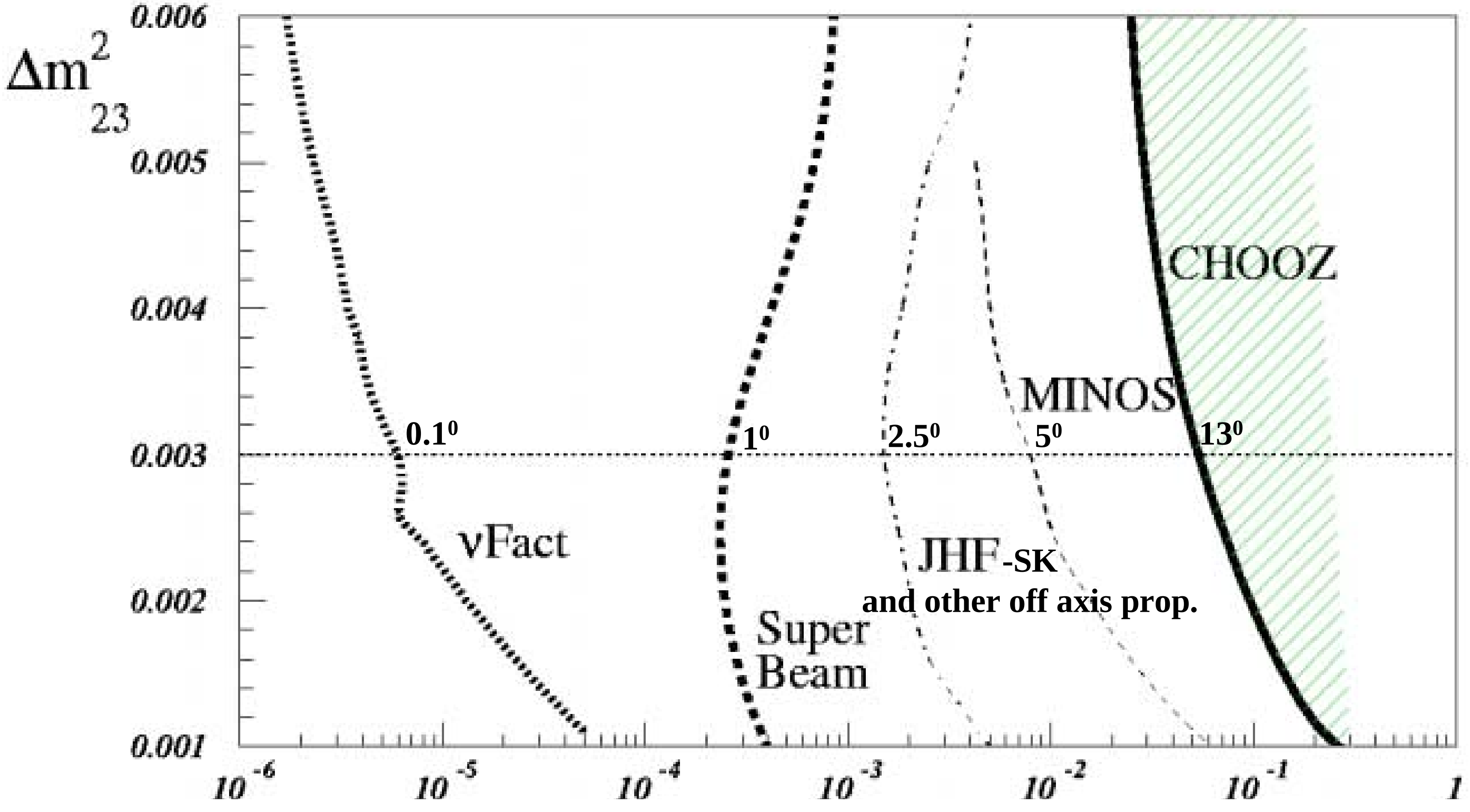
Experiments to find CP violation

1. Neutrino factory with muon storage ring
2. beta-beam

fraction thereof will exist.

Superbeam gets us quite a ways…

European participation in JHK-> SuperK under consideration



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

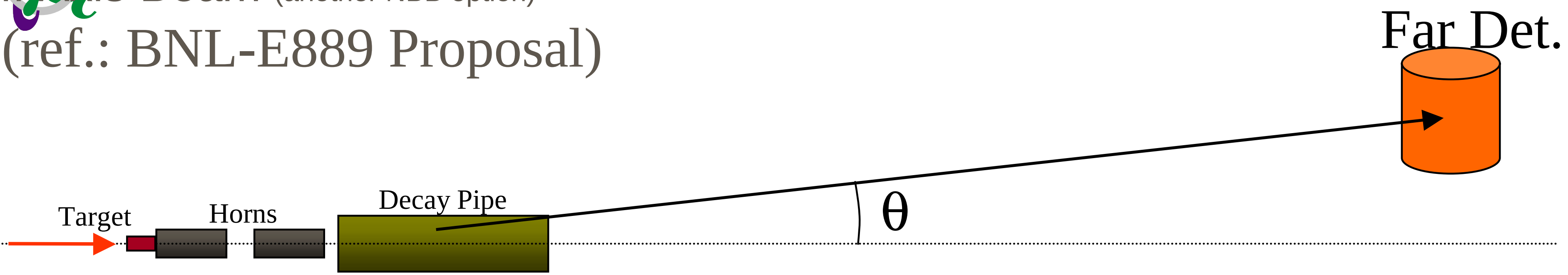
JHF → Super-Kamiokande

- 295 km baseline
- JHF approved
- neutrino beam under discussion but set in first priority by international committee
- Super-Kamiokande:
  - 22.5 kton fiducial
  - Excellent e/μ ID
  - Additional π^0/e ID

- Matter effects small
- need near detector
- European collaboration forming (UK(5)-Italy(5)-Saclay-Gva)

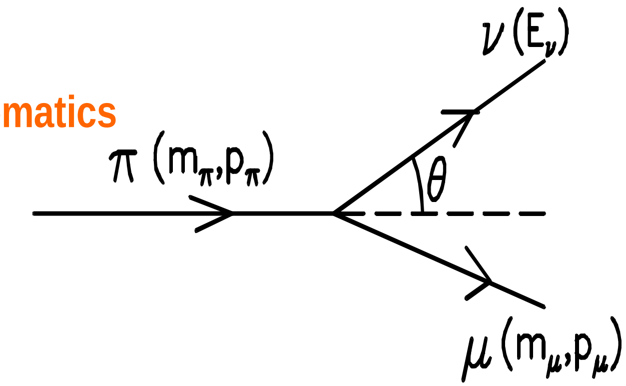
Off Axis Beam (another NBB option)

(ref.: BNL-E889 Proposal)

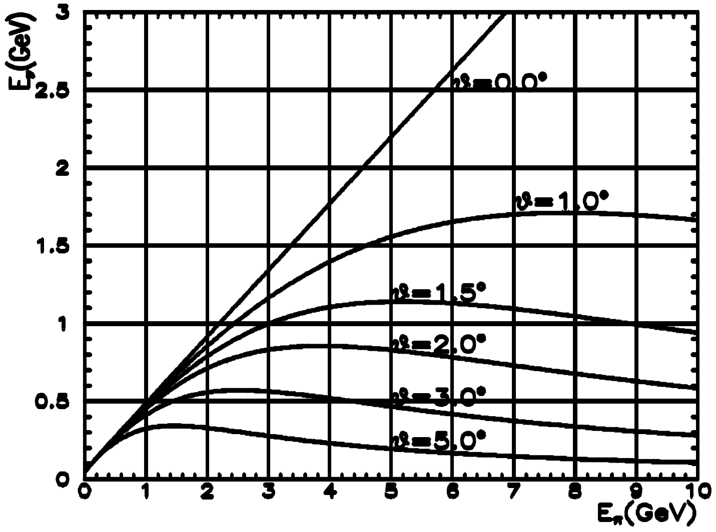


WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\theta)}$$



- **Quasi Monochromatic Beam**
- **x2~3 intense than NBB**

Detectors

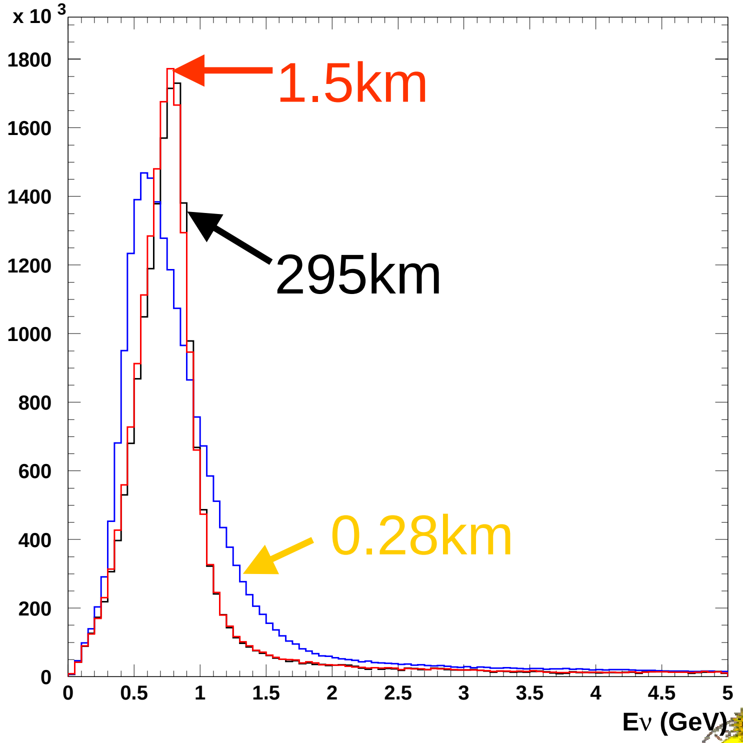
- **Muon monitors @ ~140m**
  - Behind the beam dump
  - Fast (spill-by-spill) monitoring of beam direction/intensity

- **First Front detector** "Neutrino monitor" @280m
  - Neutrino intensity/direction
  - Study of neutrino interactions

- **Second Front Detector @ ~2km**
  - Almost same E_ν spectrum as for SK
  - Absolute neutrino spectrum
  - Precise estimation of background

- **Far detector @ 295km**
  - **Super-Kamiokande (50kt)**
  - Hyper-Kamiokande (~1Mt)

Neutrino spectra at diff. dist

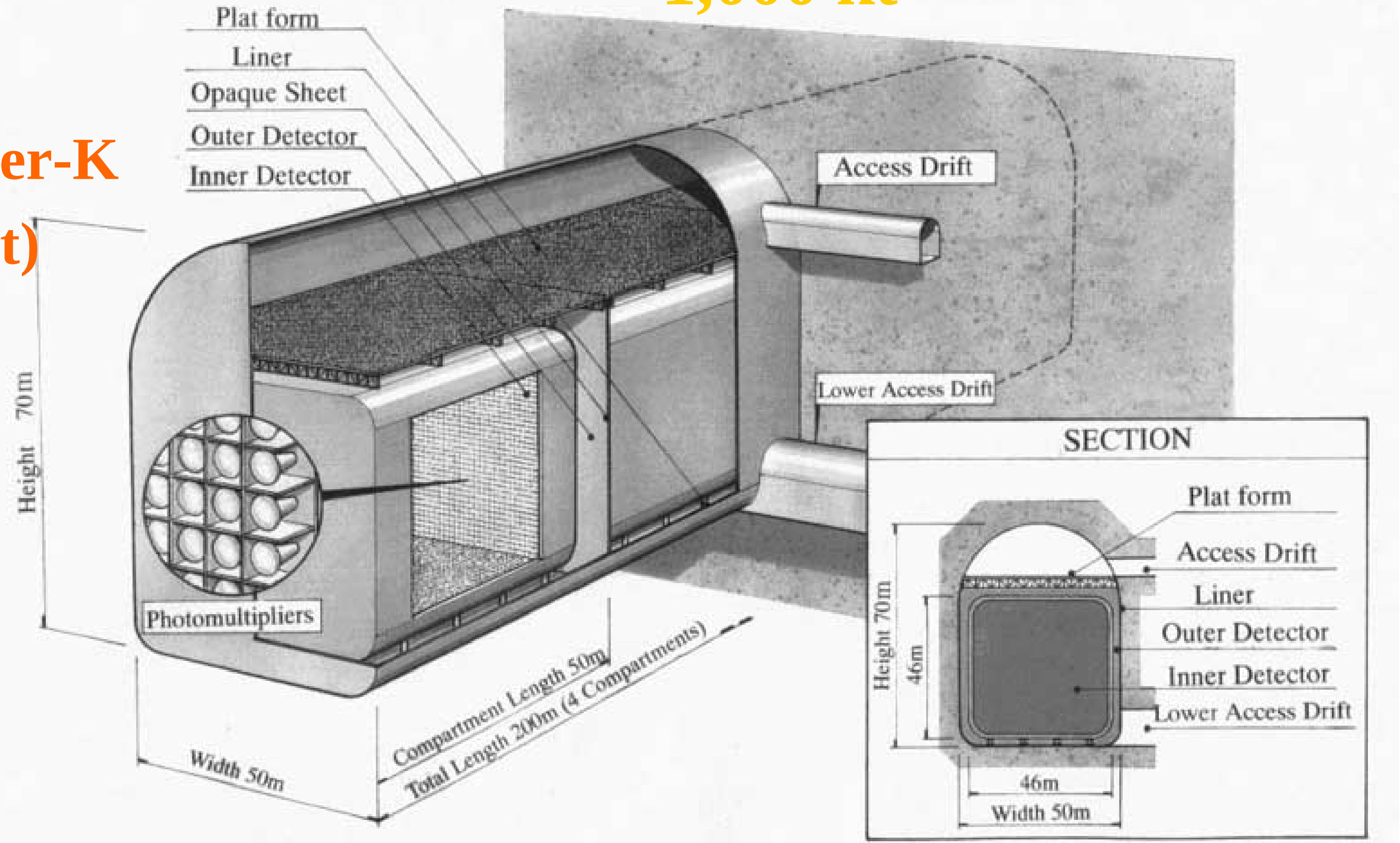


dominant syst. in K2K

Far detector in second phase

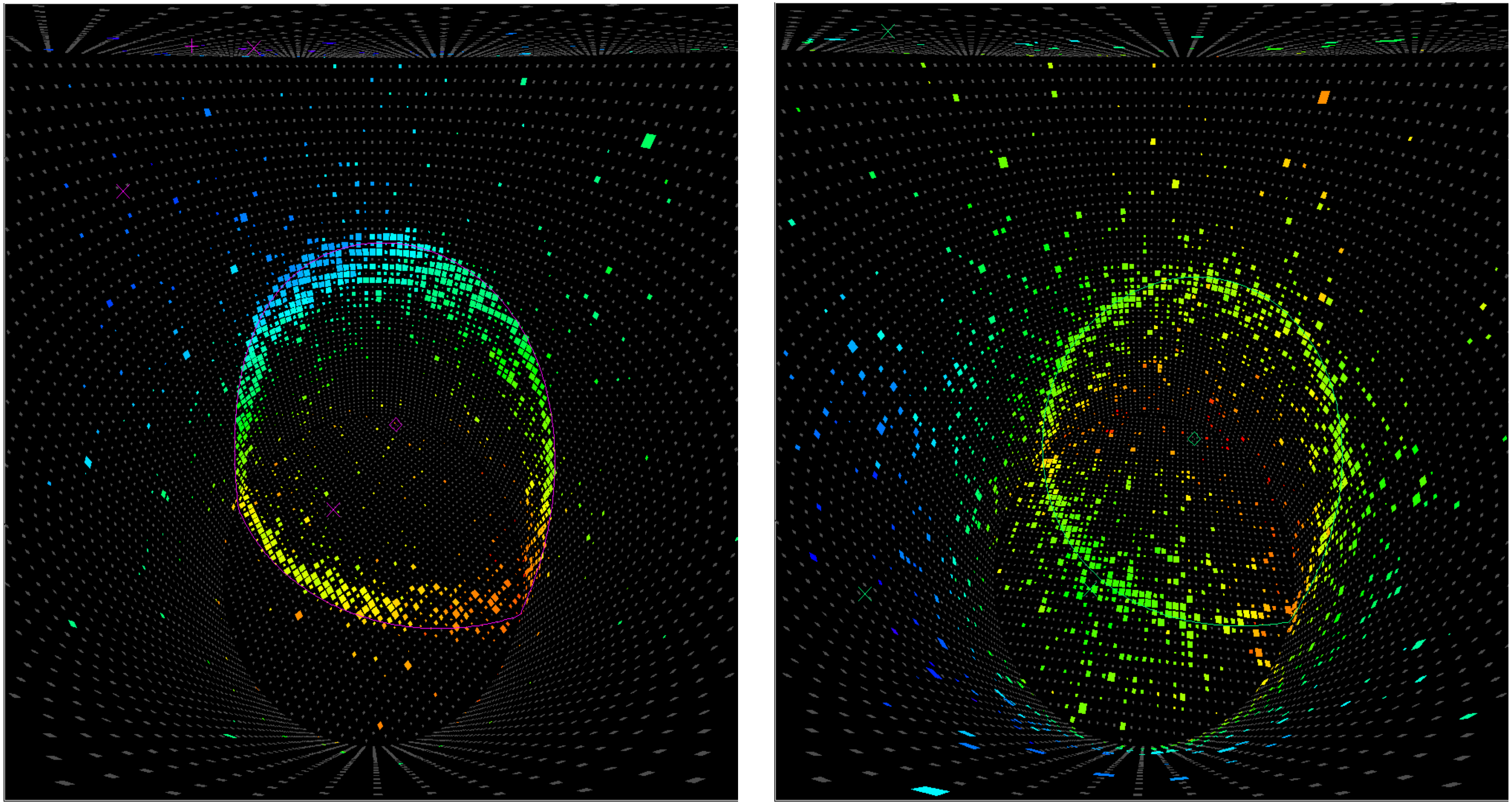
Phase-II: Hyper-K
1,000 kt

Phase-I: Super-K
22.5kt (50kt)



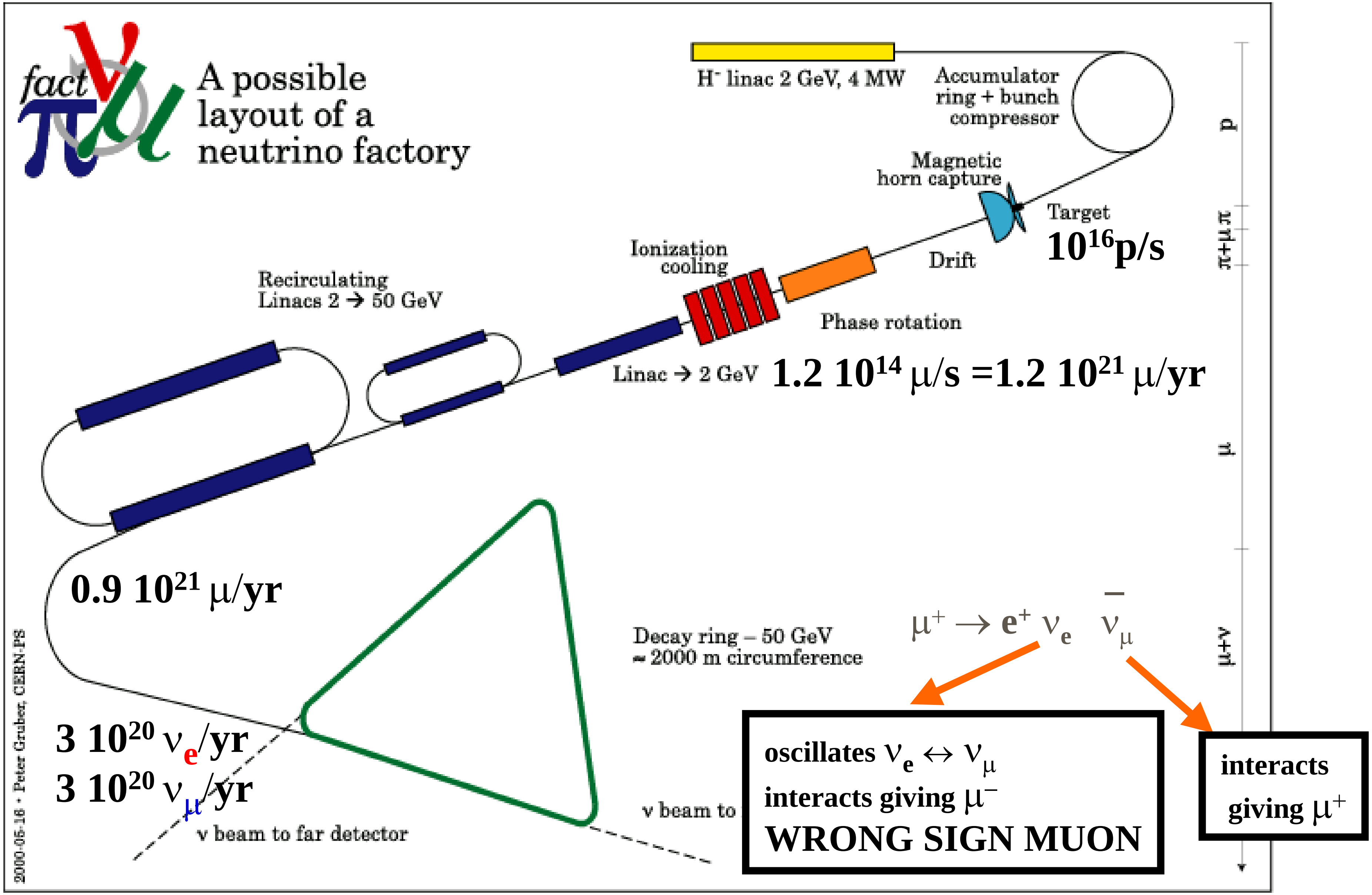
Candidate site in Kamioka

μ/e Background Rejection



separation directly related to granularity of coverage. Limit is around 10^{-3} (mu decay in flight) SKII coverage OK

-- Neutrino Factory -- CERN layout



10^{16}p/s

1.2 10^{14} μ/s =1.2 10^{21} μ/yr

0.9 10^{21} μ/yr

3 10^{20} ν_e/yr

3 10^{20} ν_μ/yr

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

oscillates $\nu_e \leftrightarrow \nu_\mu$

interacts giving μ^-

WRONG SIGN MUON

interacts giving μ^+

Neutrino fluxes μ^+ -> e^+ ν_e ν_μ

ν_μ/ν_e ratio reversed by switching μ^+/μ^-
ν_e ν_μ spectra are different
No high energy tail.

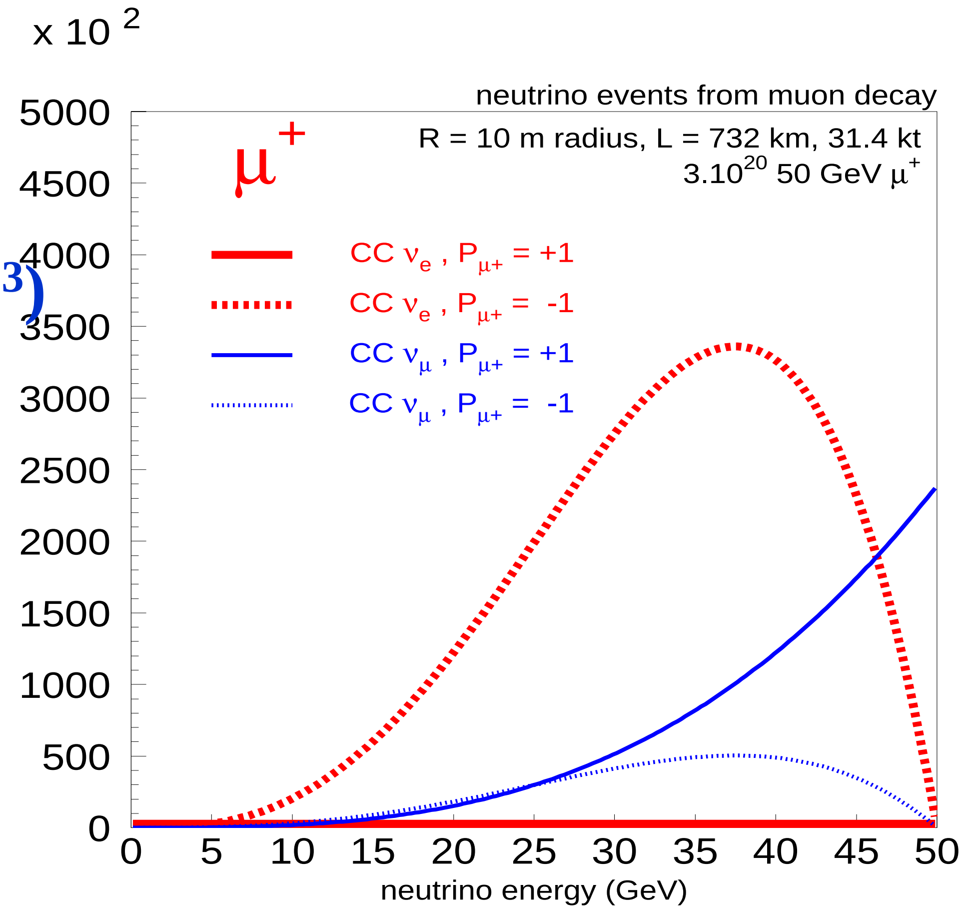
Very well known flux (aim is 10^{-3})

-- E&σ_E calibration from muon spin precession

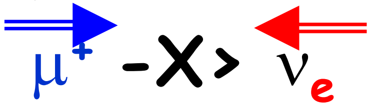
-- angular divergence: small effect if $\theta < 0.2/\gamma$,
-
- absolute flux measured from muon current
or by $\nu_\mu e^- \rightarrow \mu^- \nu_e$ in near expt.

-- in triangle ring,
muon polarization precesses and averages out
(preferred, -> calib of energy, energy spread)

-- in Bow-tie ring,
muon polarization stays constant, no precession
20% easy -> 40% hard
Must be measured!!!! (precision?)



μ polarization controls ν_e flux:


μ^+ -X> ν_e **in forward direction**

Golden MEASUREMENTS at ν- FACTORY

$$\bar{\nu}_e \leftrightarrow \bar{\nu}_{\mu,\tau}$$

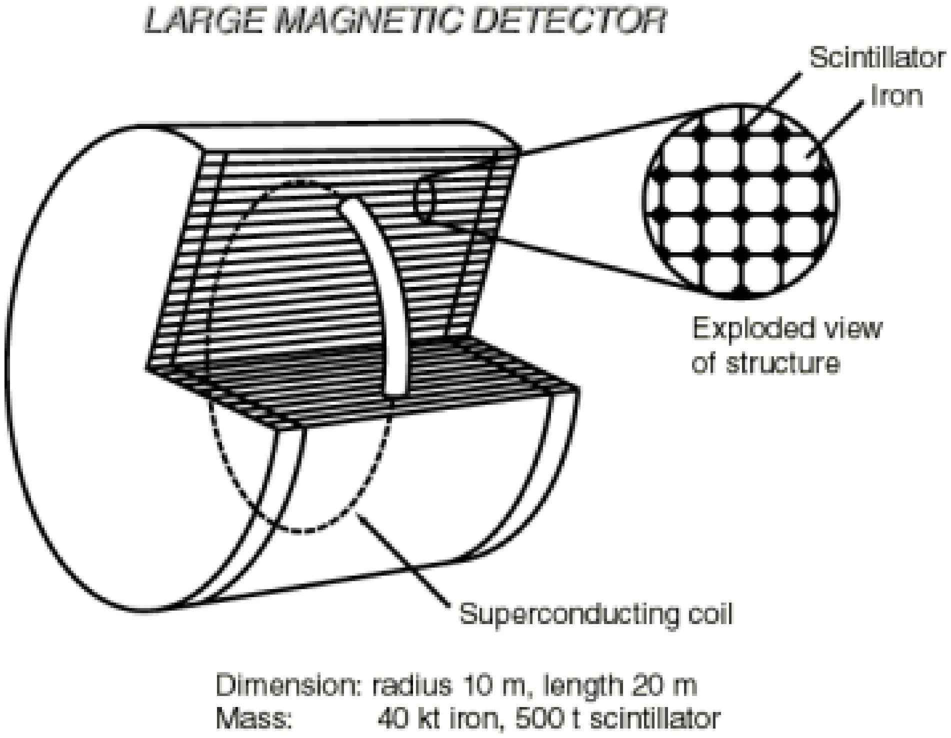
$\bar{\nu}_e \longrightarrow \bar{\nu}_\mu$ is the golden measurement at Nufact:

appearance of wrong-sign muons

$$\begin{array}{llll}
\mu^- \longrightarrow \nu_\mu & \bar{\nu}_e & e^- & \\
 & \downarrow & & \\
 & \bar{\nu}_\mu & \longrightarrow \mu^+ & \\
\mu^+ \longrightarrow \bar{\nu}_\mu & \nu_e & e^+ & \\
 & \downarrow & & \\
 & \nu_\mu & \longrightarrow \mu^- &
\end{array}$$

Detector

- Iron calorimeter
- Magnetized
  - Charge discrimination
  - B = 1 T
- R = 10 m, L = 20 m
- Fiducial mass = 40 kT



Also: L Arg detector: magnetized ICARUS
Wrong sign muons, electrons, taus and NC evts

Events for 1 year

Baseline	$\overline{\nu}_\mu$ CC	ν_e CC	ν_μ signal (sin² θ_{13}=0.01)
732 Km	3.5×10^7	5.9×10^7	1.1×10^5
3500 Km	1.2×10^6	2.4×10^6	1.0×10^5

Event rates

$N_{\mu^+,\mu^-} = 10^{21}$/y, $M_{det} = 40$ KTon y, $E_\mu = 50GeV$

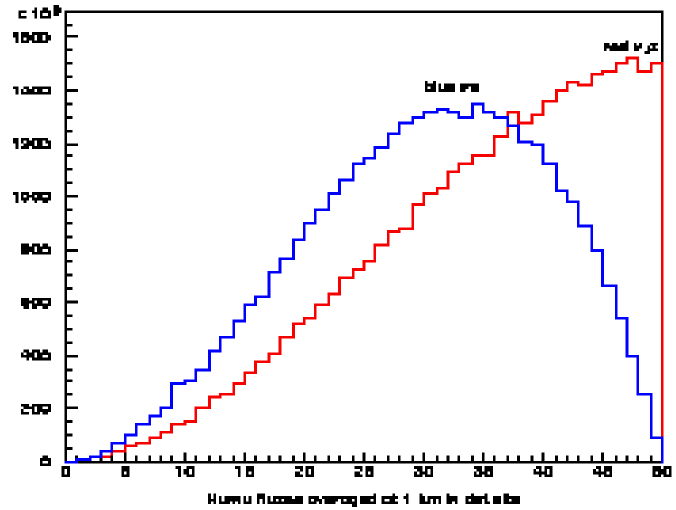
μ^- beam

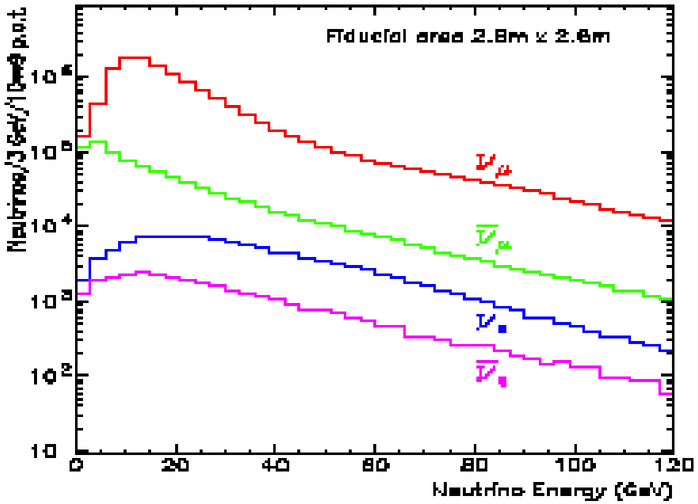
Baseline	$\bar{\nu}_e$ CC	ν_μ CC	$\mu^+(10^o)$	$\mu^+(0.5^o)$
732 Km	$3 \cdot 10^7$	$6.9 \cdot 10^7$	$1.7 \cdot 10^4$	44
3500 Km	$1.3 \cdot 10^6$	$3 \cdot 10^6$	$7 \cdot 10^3$	15
7332 Km	$3 \cdot 10^5$	$6.9 \cdot 10^5$	$2.8 \cdot 10^2$	1

μ^+ beam

Baseline	ν_e CC	$\bar{\nu}_\mu$ CC	$\mu^-(10^o)$	$\mu^-(0.5^o)$
732 Km	$5.9 \cdot 10^7$	$3.5 \cdot 10^7$	$3.6 \cdot 10^4$	94
3500 Km	$2.5 \cdot 10^6$	$1.5 \cdot 10^6$	$3.1 \cdot 10^4$	85
7332 Km	$5.9 \cdot 10^5$	$3.5 \cdot 10^5$	$1.2 \cdot 10^4$	39

NB: oscillation signal is nearly indept of distance





conventional neutrino beam from π, K decay:
long high energy tail,
Bkg from ν_e and NC events

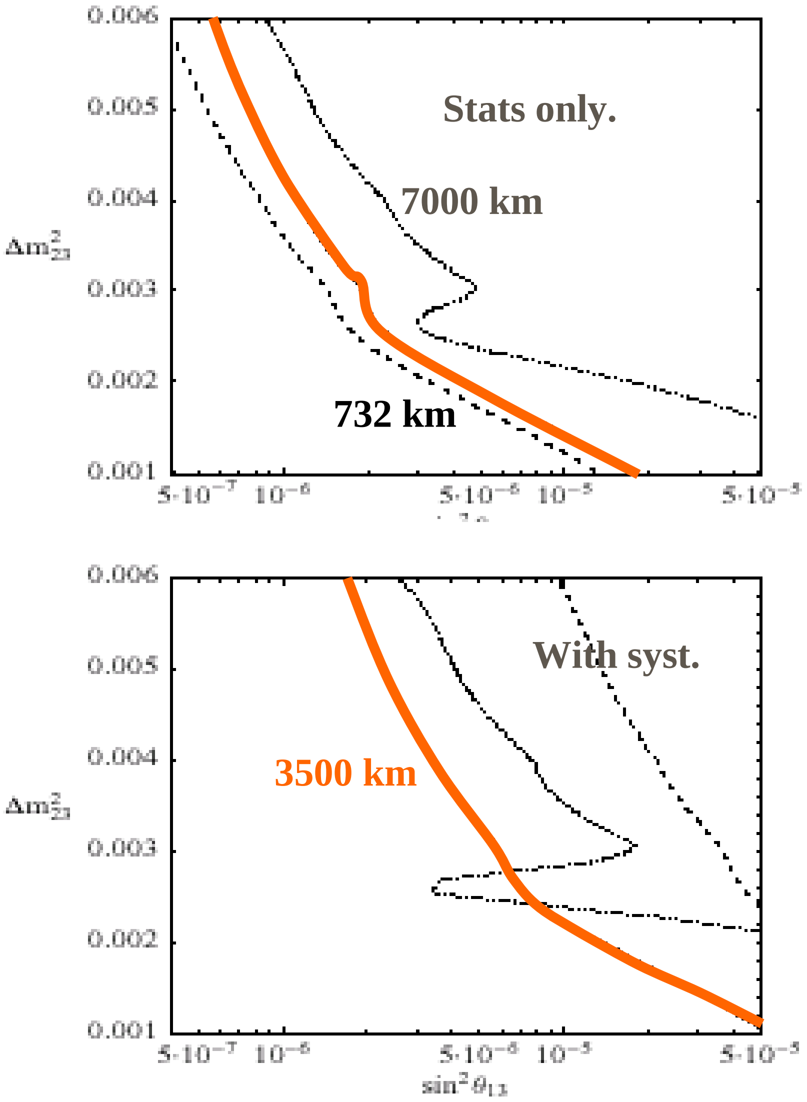
NUFACT = 100 X CNGS with 2 Flavours,

No high energy tail to produce NC with π^0

Alain Blondel

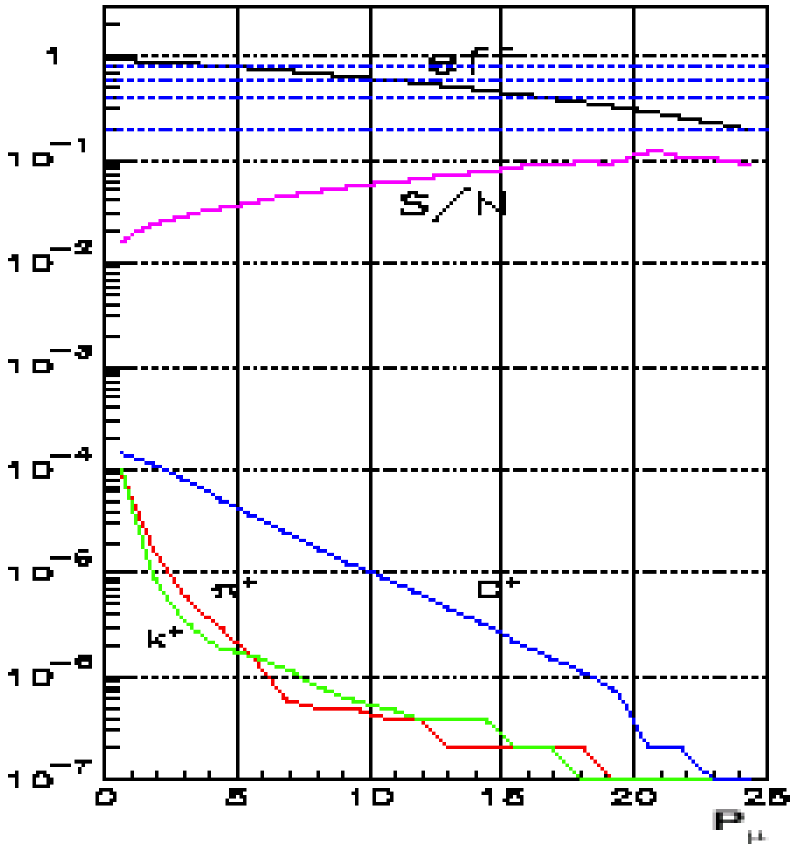
Sensitivity to $\sin^2\theta_{13}$

Appearance of wrong sign muons.
Background very low in dense detector
(mostly comes from very inelastic charm production)
Can be kept at a few 10^{-5} level by cuts on
Muon momentum, Pt, and Pt w.r.t. hadronic shower



$N_{\mu^+,\mu^-} = 10^{21}$/year, $M_{det} = 40$ KTon year

N_{CC} events



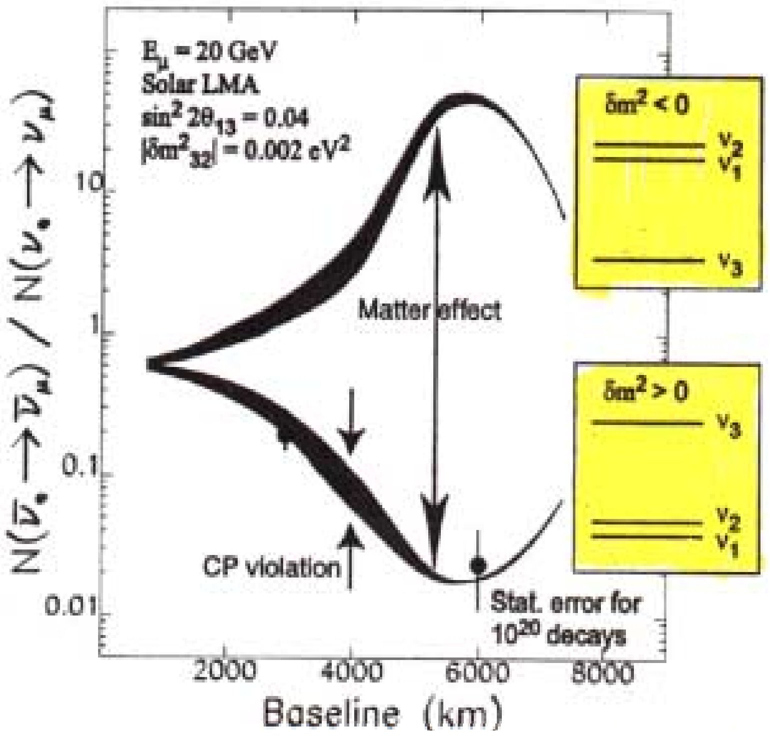
CP asymmetries
compare $\nu_e \rightarrow \nu_\mu$ to $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ probabilities

$$P_{\nu_e\nu_\mu(\bar{\nu}_e\bar{\nu}_\mu)} = \sin^2\theta_{23}\sin^2 2\,\theta_{13}\left(\frac{\Delta m^2_{23}}{B_\pm}\right)^2 \sin^2 B_\pm L$$

with $B_\pm \equiv \sqrt{(\Delta m^2_{23}\cos 2\,\theta_{13} \pm \mu)^2 + (\Delta m^2_{23}\sin 2\,\theta_{13})^2}$

μ is prop matter density, positive for neutrinos, negative for antineutrinos

$$\mathbf{A} = \frac{\mu^- / \nu_e - \mu^+ / \bar{\nu}_e}{\mu^- / \nu_e + \mu^+ / \bar{\nu}_e}$$

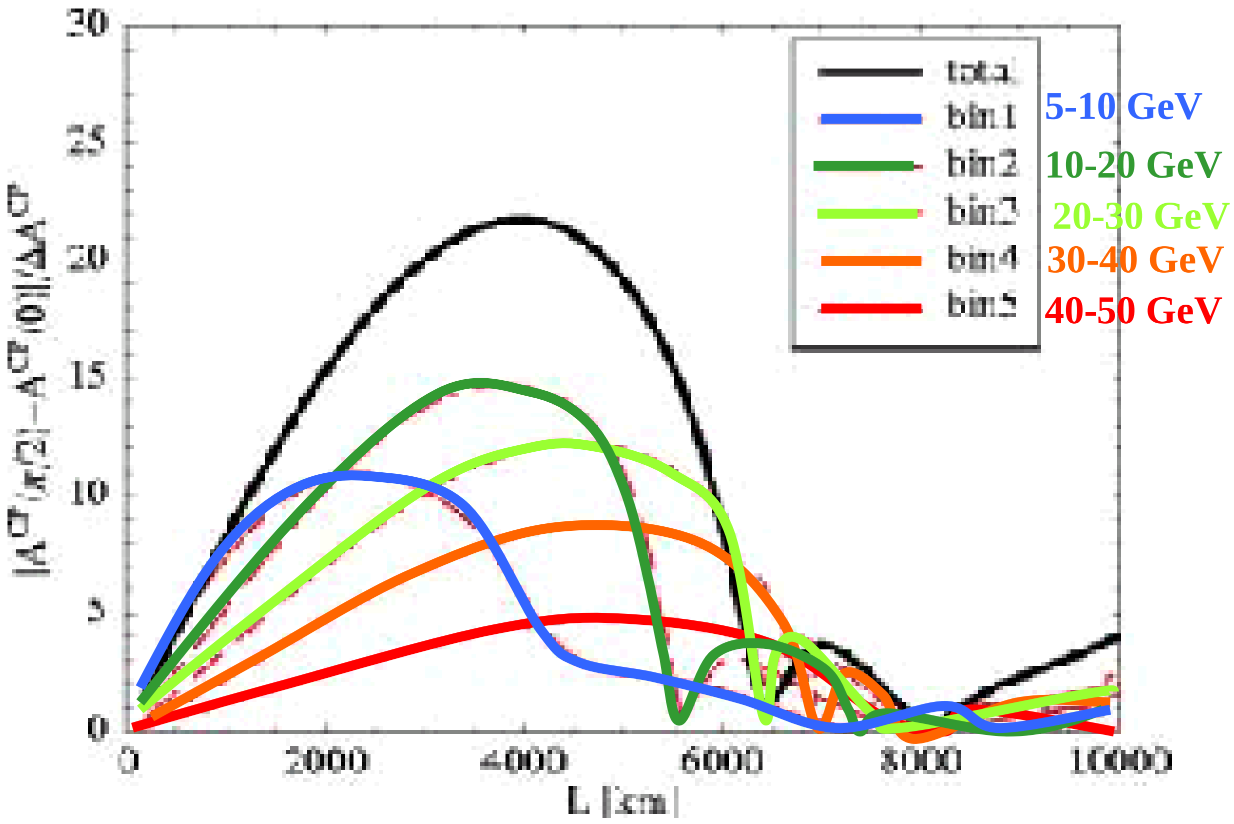


HUGE effect for distance around 6000 km!!
Resonance around 12 GeV when

$\Delta m^2_{23}\cos 2\,\theta_{13} \pm \mu = 0$

CP violation (ctd)

Matter effect must be subtracted. One believes this can be done with uncertainty
Of order 2%. Also spectrum of matter effect and CP violation is different
⇒It is important to subtract in bins of measured energy.
⇒knowledge of spectrum is essential here!



40 kton L M D
50 GeV nufact
5 yrs $10^{21}\mu$ /yr

In fact, 20-30 GeV
Is enough!

Best distance is
2500-3500 km

e.g. Fermilab or BNL
-> west coast or …

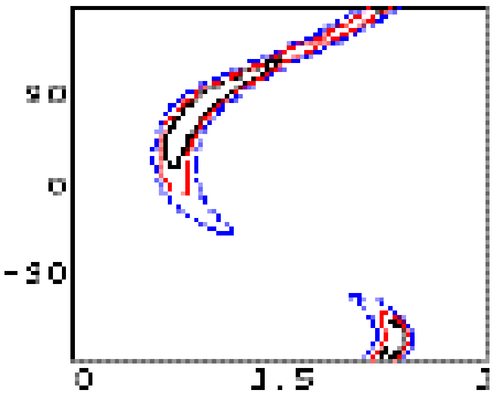
Silver channel at neutrino factory

A. Donini et al
hep-ph/0206034
ROMA-1336/02

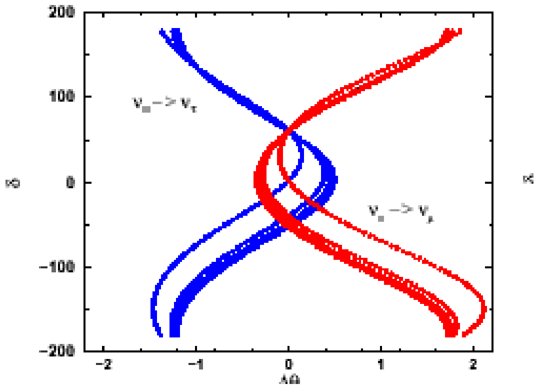
High energy neutrinos at NuFact allow observation of $\nu_e \rightarrow \nu_\tau$
(wrong sign muons with missing energy and P⊥). UNIQUE

Liquid Argon or OPERA-like detector at 3000 km.

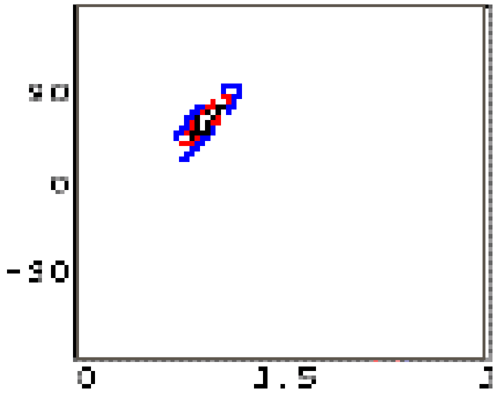
Since the sinδ dependence has opposite sign with the wrong sign muons, this solves ambiguities that will invariably appear if only wrong sign muons are used.



ambiguities with
only wrong sign muons (3500 km)

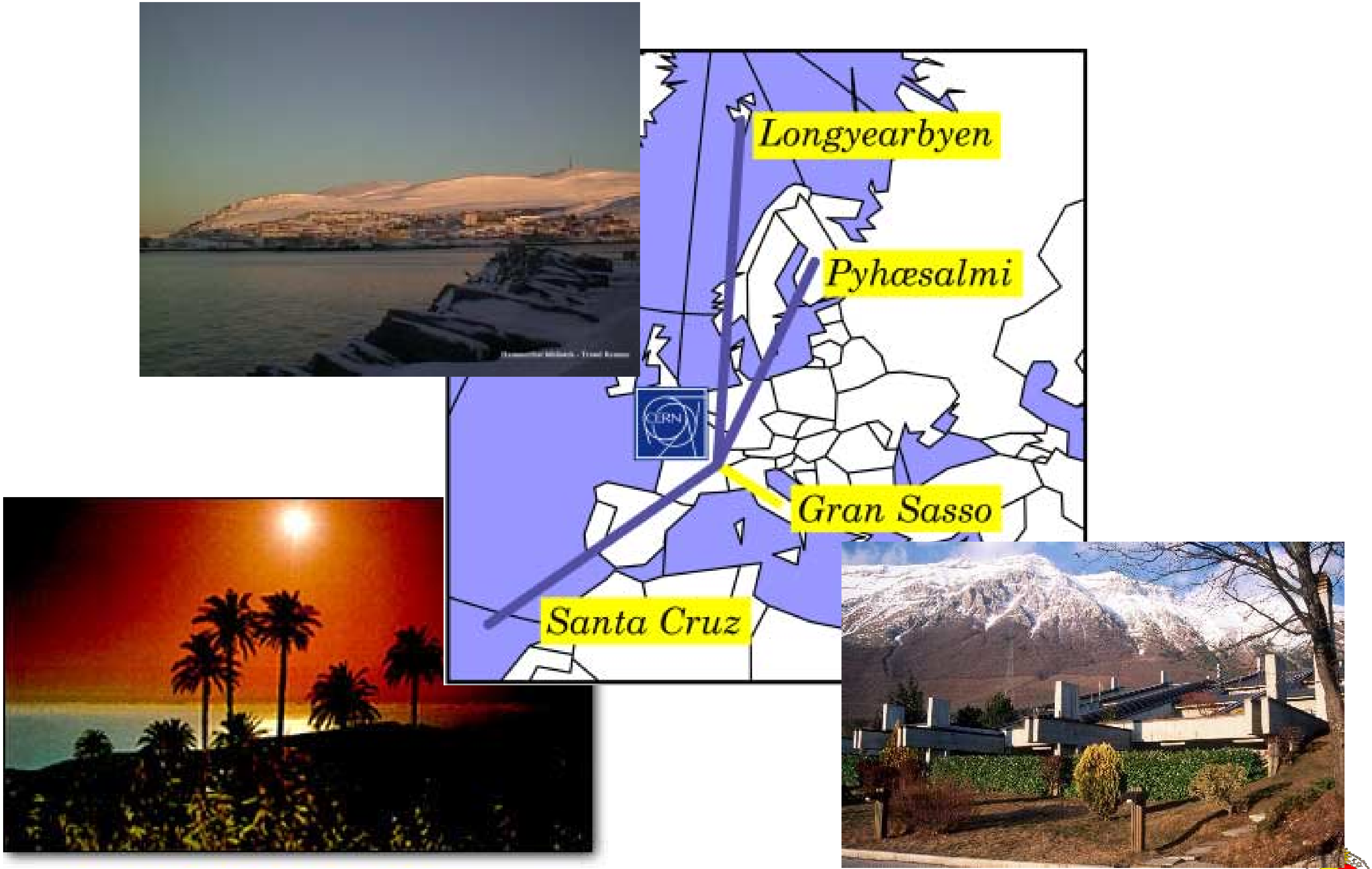


equal event number curves
muon vs taus

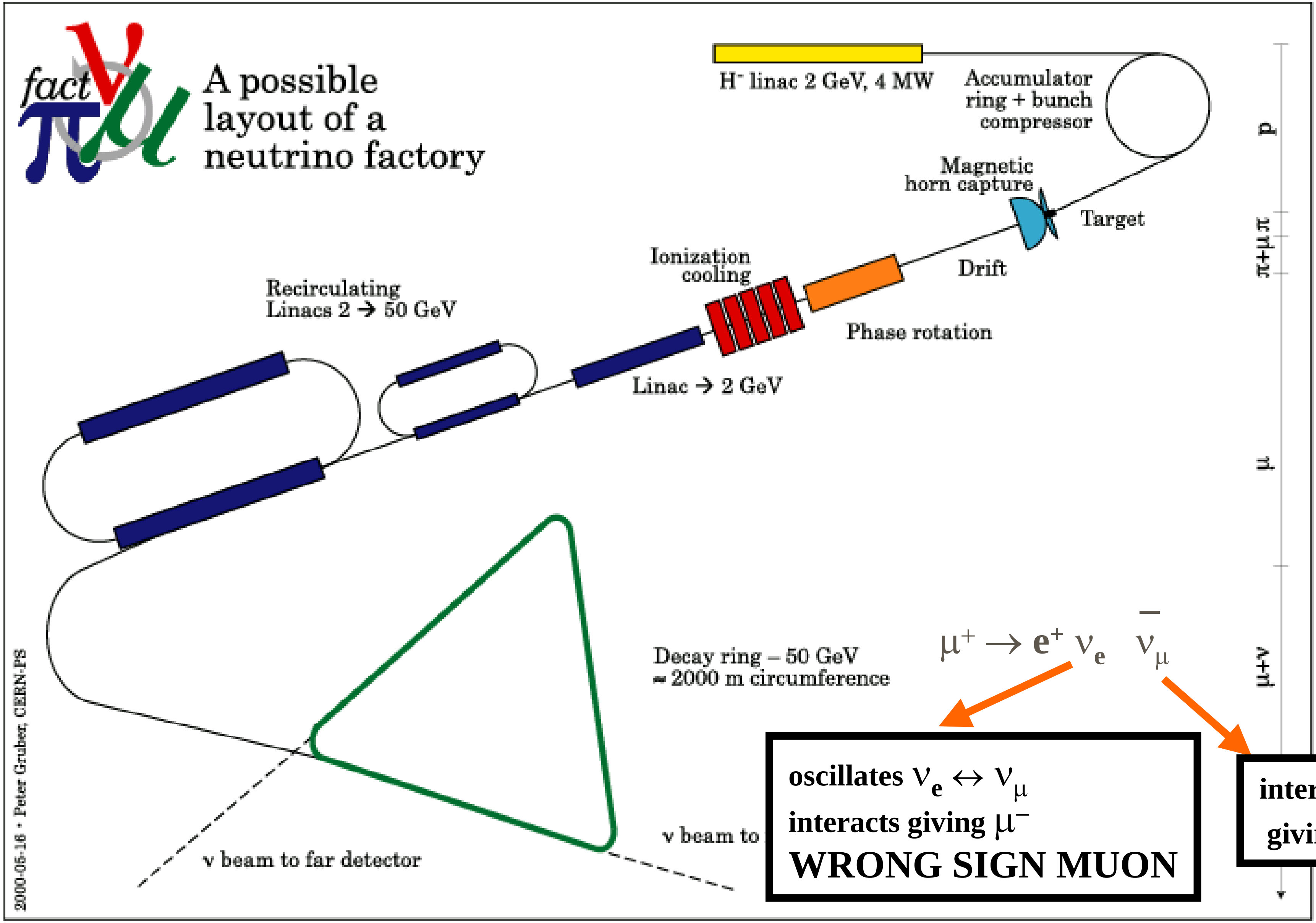


associating taus to muons
(no efficencies, but only OPERA mass)
studies on-going

Where do you prefer to take shifts?



Nufact CERN layout

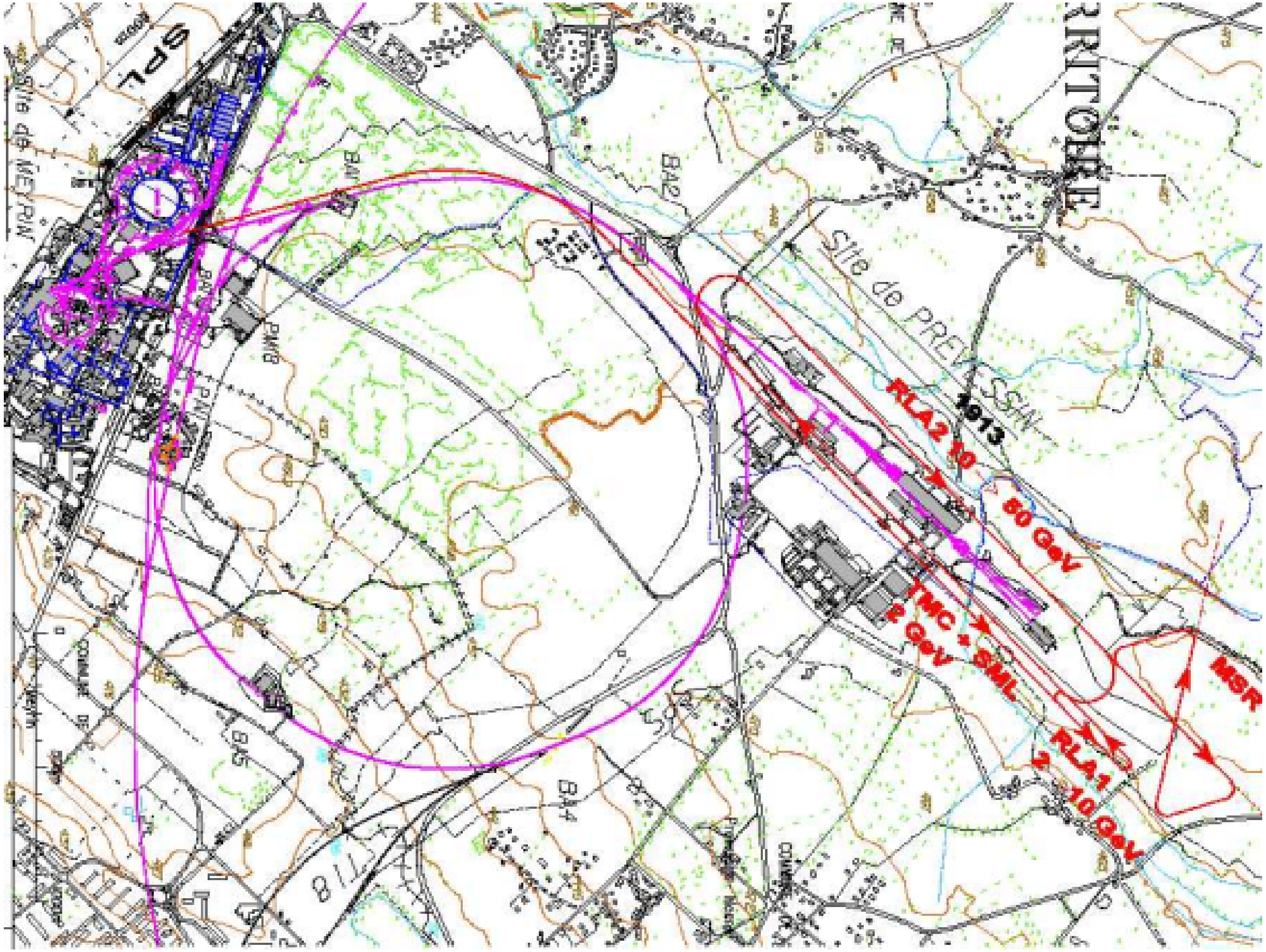


$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

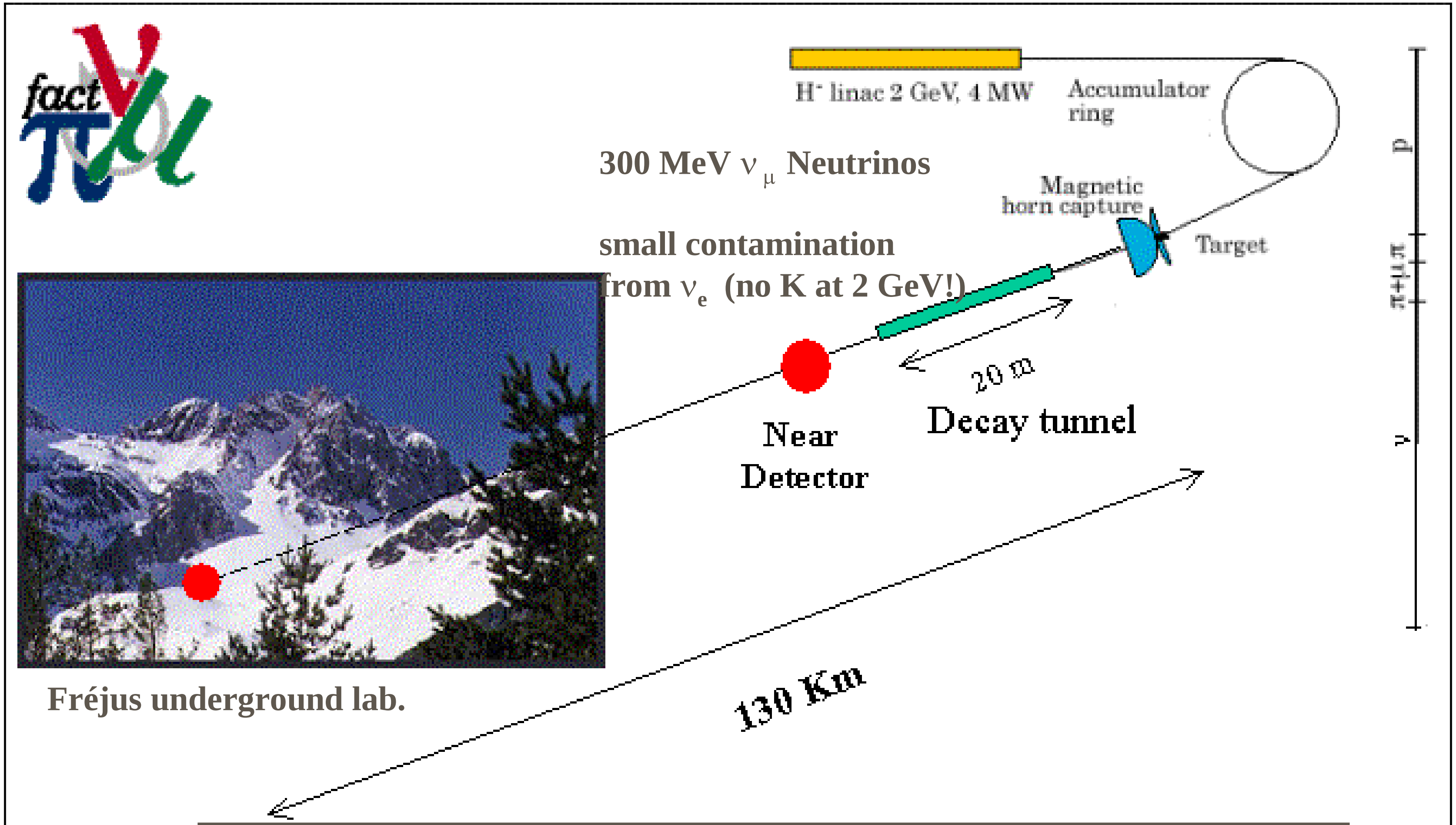
oscillates $\nu_e \leftrightarrow \nu_\mu$
interacts giving μ^-
WRONG SIGN MUON

interacts giving μ^+

Preliminary Layout of Neutrino Factory



Possible step 0: Neutrino SUPERBEAM



300 MeV ν_μ Neutrinos

small contamination from ν_e (no K at 2 GeV!)

Fréjus underground lab.

A large underground water Cerenkov (400 kton)
UNO/HyperK is best choice
also : proton decay search, supernovae events solar and atmospheric neutrinos.

BETA Beam

new idea by P. Zucchelli

produce ^{6}He++, store, accelerate (100 GeV/u), store

$$^{6}\mathrm{He}^{++} \rightarrow {}^{6}\mathrm{Li}^{+++}\ \bar{\nu}_e\ e^{-}$$

Q=3.5078 MeV T/2 = 0.8067 s

pure anti-ν_e beam at ≈ 600 MeV

or:

$$^{18}_{10}\mathrm{Ne} \rightarrow {}^{18}_{9}\mathrm{F}\ \nu_e\ e^{+}$$

pure ν_e beam at ≈ 600 MeV

oscillation signal: appearance of low energy muons

no opposite charge neutrinos=> no need for magnetic detectors

little matter effects at these energies

water Cerenkov excellent for this too, same as for Superbeam.

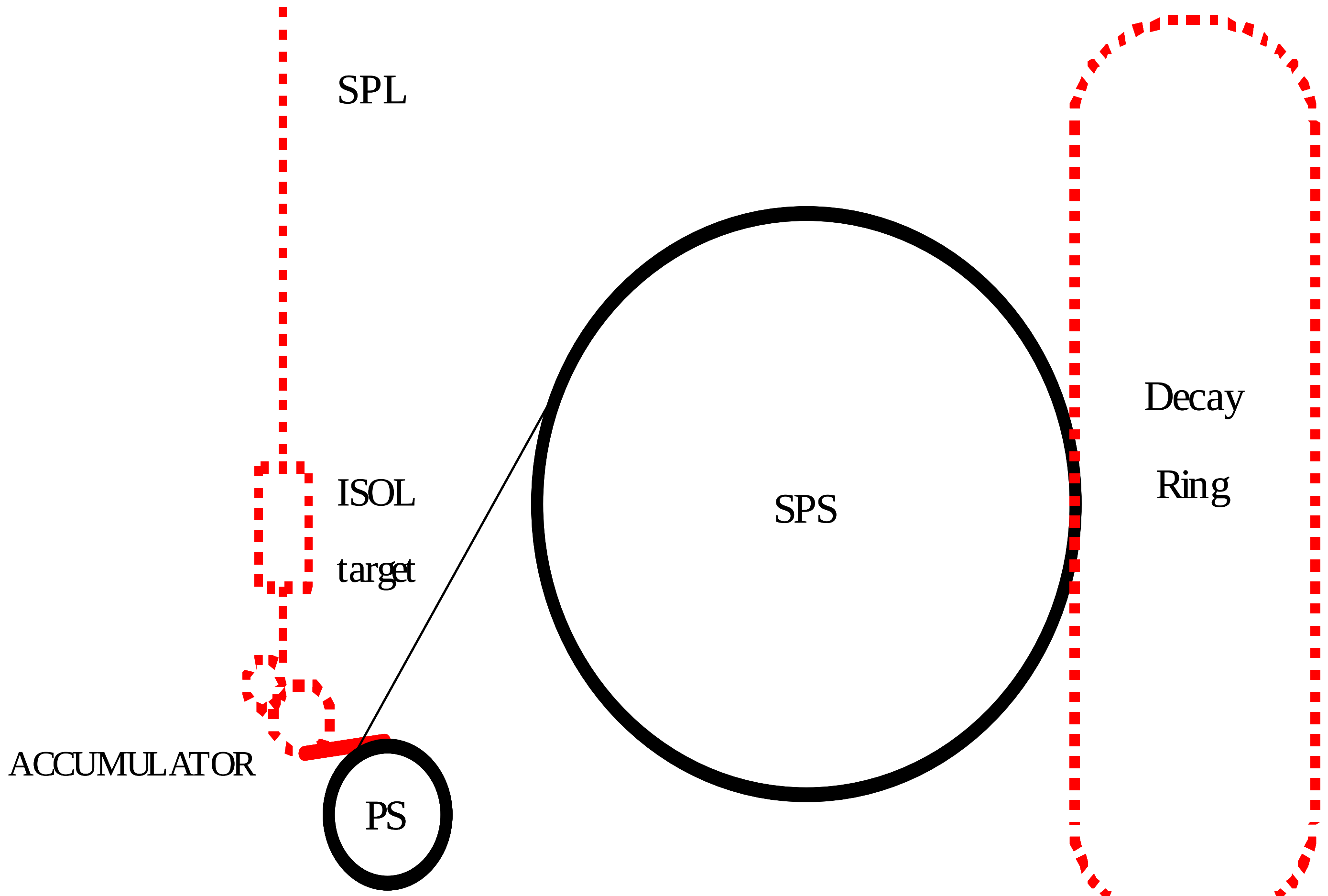
seems feasible; but cost unknown so far.

Critical: duty cycle.

A nice *** idea to be followed up!

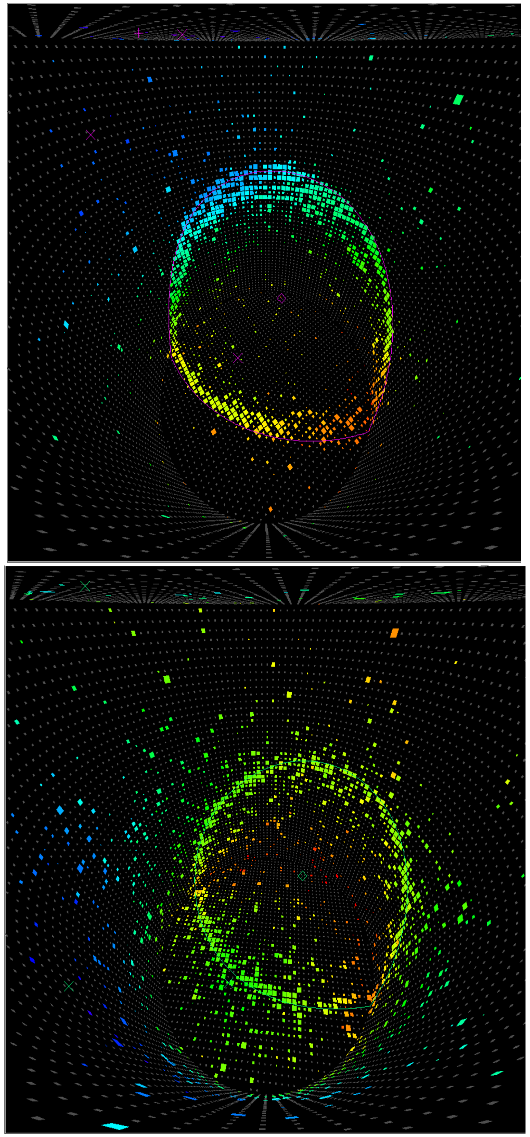
Beta Beam

(P. Zucchelli)



M. Lindroos et al.

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

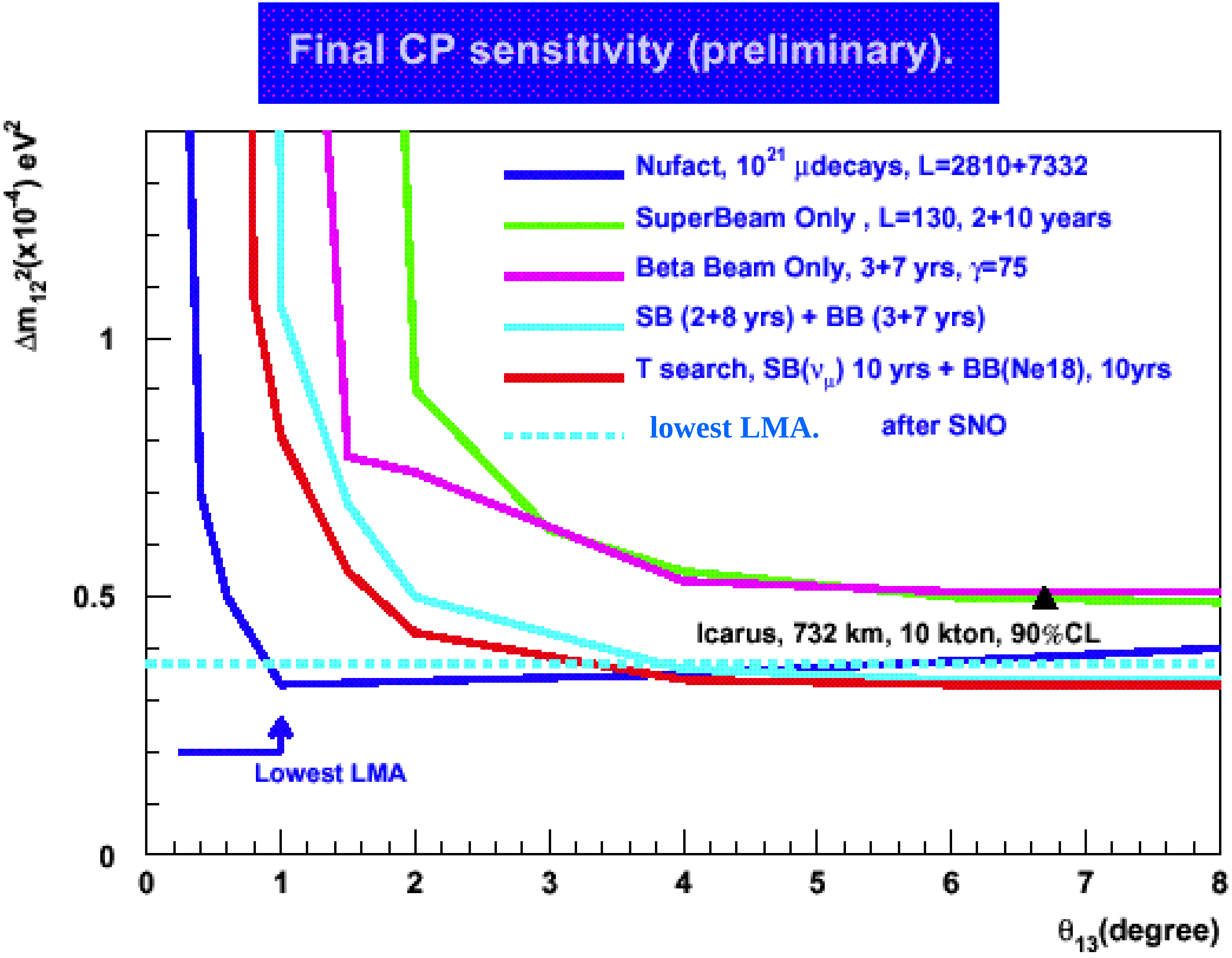
$\nu_e \rightarrow \nu_\mu$ (β+) (T) $\nu_\mu \rightarrow \nu_e$ (π^+)

(CP)

$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ (β-) (T) $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ (π^-)

Can this work???? theoretical studies now on beta beam
+ SPL target and horn R&D revue at NUFACT02 (1-6 July 2002)

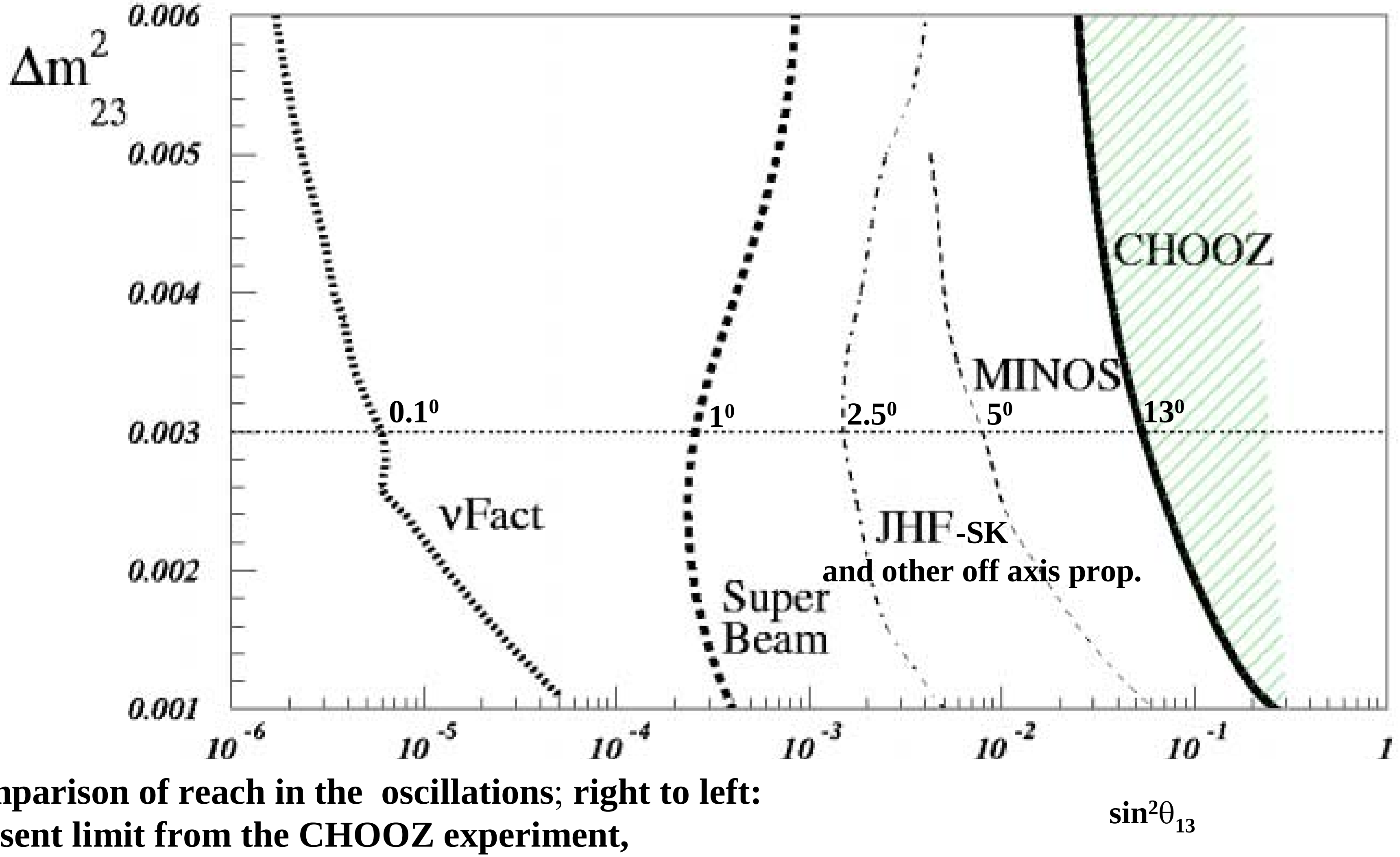
Combination of Beta beam and superbeam is in the same ballpark of performance as neutrino factory …
(bewrare of systematics for low Energy neutrino events, though)



M.Mezzetto, CERN workshop NNN02, january 2002

Superbeam gets us quite a ways…

European participation in JHK-> SuperK under consideration



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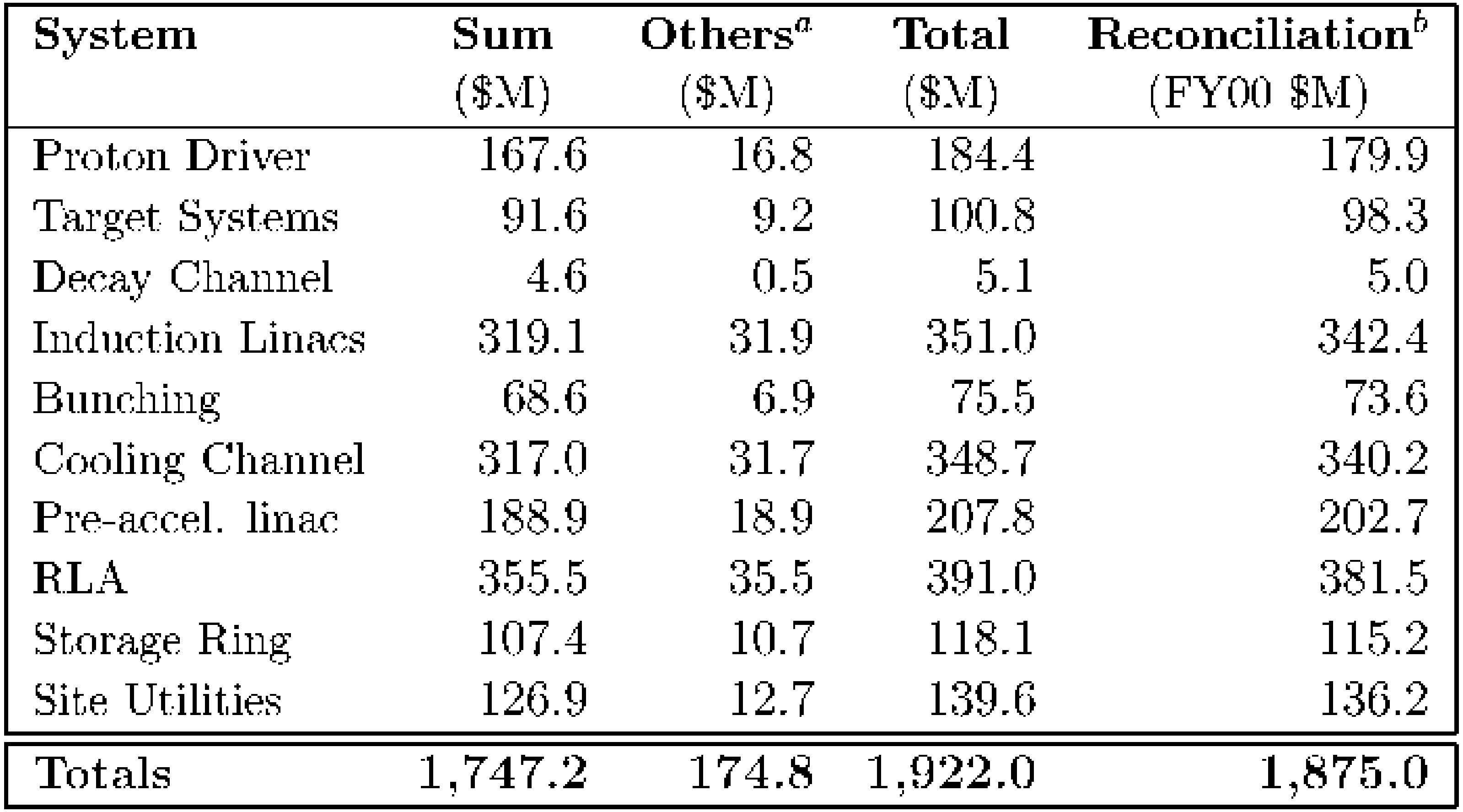
0.75 MW JHF to super Kamiokande with an off-axis narrow-band beam,
Superbeam: 4 MW CERN-SPL to a 400 kton water Cerenkov in Fréjus
from a Neutrino Factory with 40 kton large magnetic detector. INCLUDING SYSTEMATICS

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

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

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

Recent developments

CERN cuts…. and EMCOG initiative

MICE LOI received encouragement at RAL

Cooling rings

European Muon Concertation and Oversight Group (EMCOG)

CERN: Carlo Wyss (chair), Helmut Haseroth, John Ellis
CEA-DAPNIA: Alban Mosnier, François Pierre
IN2P3: Stavros Katsanevas, Marcel Lieuvin
INFN: Marco Napolitano (Napoli), Andrea Pisent (Legnaro)
GSI: Oliver Boine-Frankenheim, Ingo Hofmann
PSI: Ralph Eichler
Geneva: Alain Blondel (secretary)
RAL: Ken Peach

EMCOG (European Muon Concertation and Oversight Group
FIRST SET OF BASIC GOALS

The long-term goal is to have a Conceptual Design Report for a European Neutrino Factory Complex by the time of LHC start-up, so that, by that date, this would be a valid option for the future of CERN.

An earlier construction for the proton driver (SPL + accumulator & compressor rings) is conceivable and, of course, highly desirable.
The SPL, targetry and horn R&D have therefore to be given the highest priority.

Cooling is on the critical path for the neutrino factory itself; there is a consensus that a cooling experiment is a necessity.

The emphasis should be the definition of practical experimental projects with a duration of 2-5 years. Such projects can be seen in the following four areas:

1. **High intensity proton driver**. Activities on the front end are ongoing in many laboratories in Europe, in particular at CERN, CEA, IN2P3, INFN and GSI. Progressive installation of a high intensity injector and of a linear accelerator up to 120 MeV at CERN (R. Garoby et al) would have immediate rewards in the increase of intensity for the CERN fixed target program and for LHC operation. GSI…. EMCOG will invite a specific report on the status of the studies and a proposal for the implementation process.

2. **Target studies**

   . This experimental program is already well underway with liquid metal jet studies. Goal: explore synergies among the following parties involved: CERN, Lausanne, Megapie at PSI, EURISOL, etc…

3. **Horn studies**.

   A first horn prototype has been built and is being equipped for pulsing at low intensity.

   5 year program to reach high intensity, high rep rate pulsing, and study the radiation resistance of horns. Optimisation of horn shape. Explore synergies between CERN, IN2P3 Orsay, PSI (for material research and fatigue under high stress in radiation environment)

4. **MICE**. A collaboration towards and International cooling experiment has been established with the muon collaboration in United States and Japanese groups. There is a large interest from European groups in this experiment. Following the submission of a letter of Intent to PSI and RAL, the collaboration has been encouraged to prepare a full proposal at RAL, with technical help fro RAL. PSI offers a solenoid muon beam line and CERN, which as already made large initial contributions in the concept of the experiment, could earmark some very precious hardware that could be recuperated. A summary of the requests should be presented by the collaboration.

It is noted that the first three items are also essential for a possible initial neutrino program with a high intensity low energy conventional neutrino beam (superbeam).

NUFACT R&D: Target station

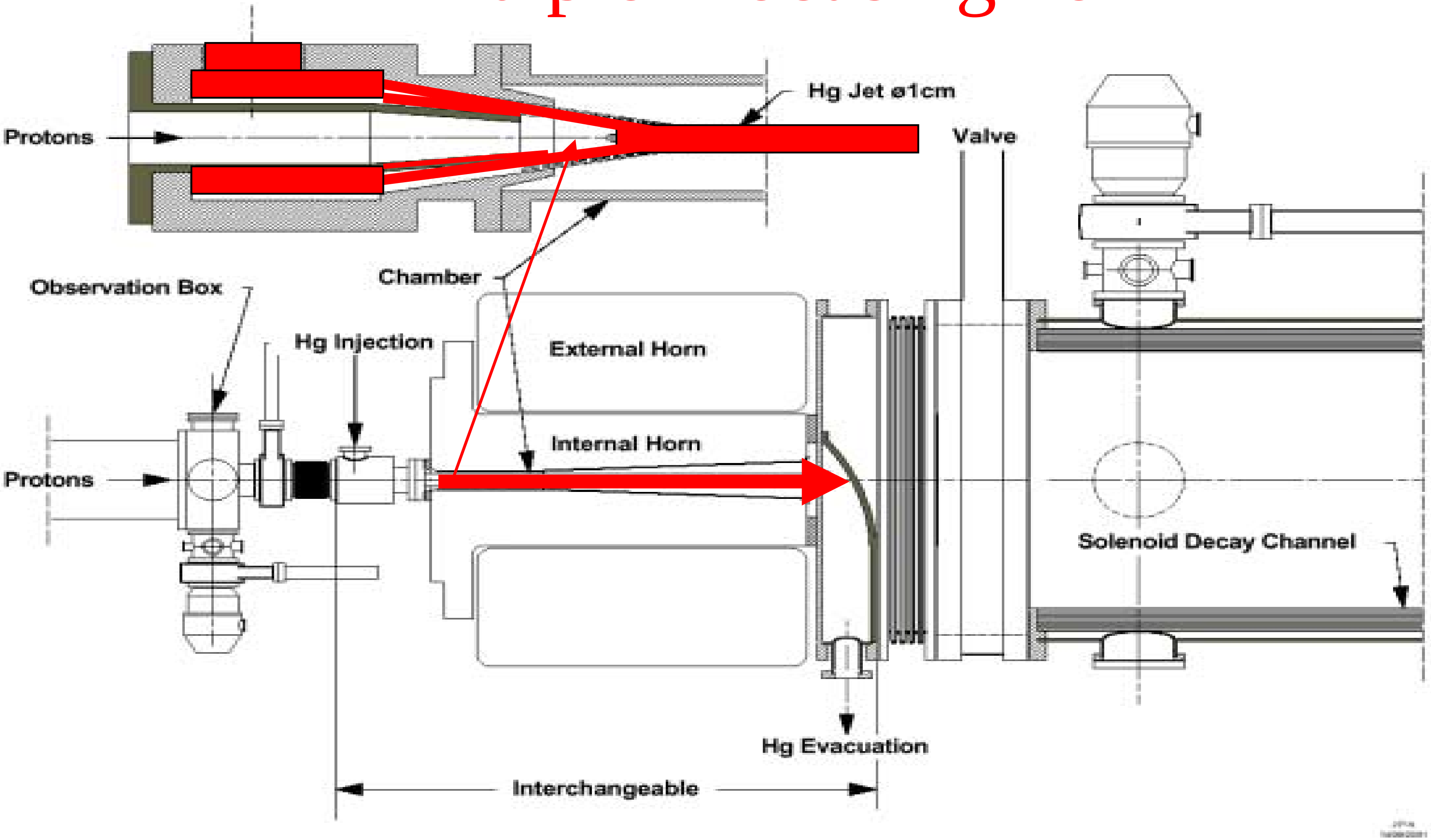
- Target:
  - Dimension: L ≈ 30 cm, R ≈ 1 cm

→ **4 MW proton beam into an expensive cigar…**

→ High Z → small size good for optics

→ Liquid → easy to replace ($v_{//} \approx$ 20 m/s) → Mercury

Hg-jet p-converter target with a pion focusing horn

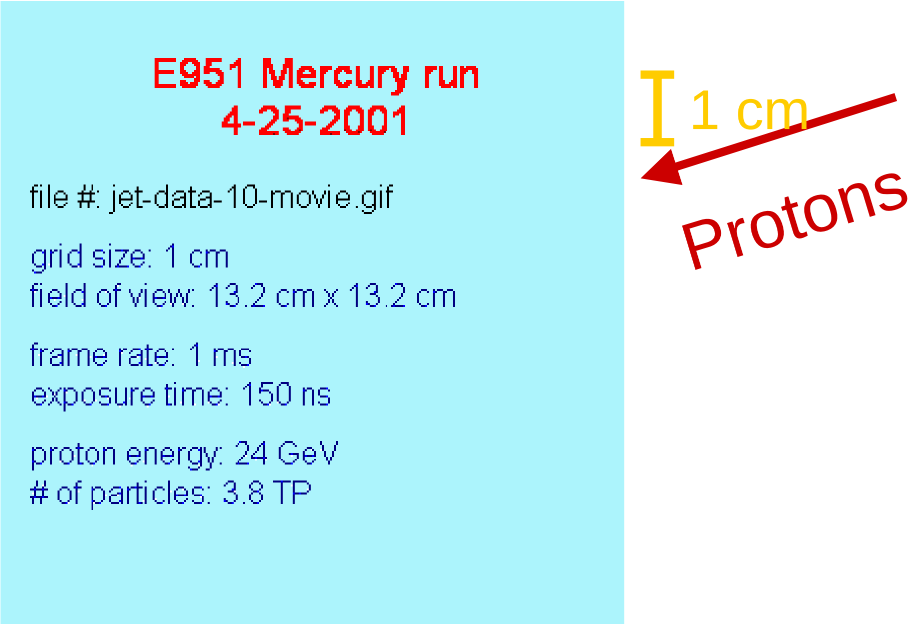


Alain Blondel

NUFACT R&D: Target station

Experiment @BNL and @CERN

- Speed of Hg disruption
- Max $v_\perp \approx$ 20 m/s measured
- $v_{//} \approx 3$ m/s
- jet remains intact for more than 20 microseconds.



E951 Mercury run
4-25-2001

file #: jet-data-10-movie.gif

grid size: 1 cm
field of view: 13.2 cm x 13.2 cm

frame rate: 1 ms
exposure time: 150 ns

proton energy: 24 GeV
# of particles: 3.8 TP

HORN STUDIES

horn is built at CERN
mechanical properties will be measured
(can it be pulsed at 350 KA and 50 Hz?
important for basic choice of proton driver)

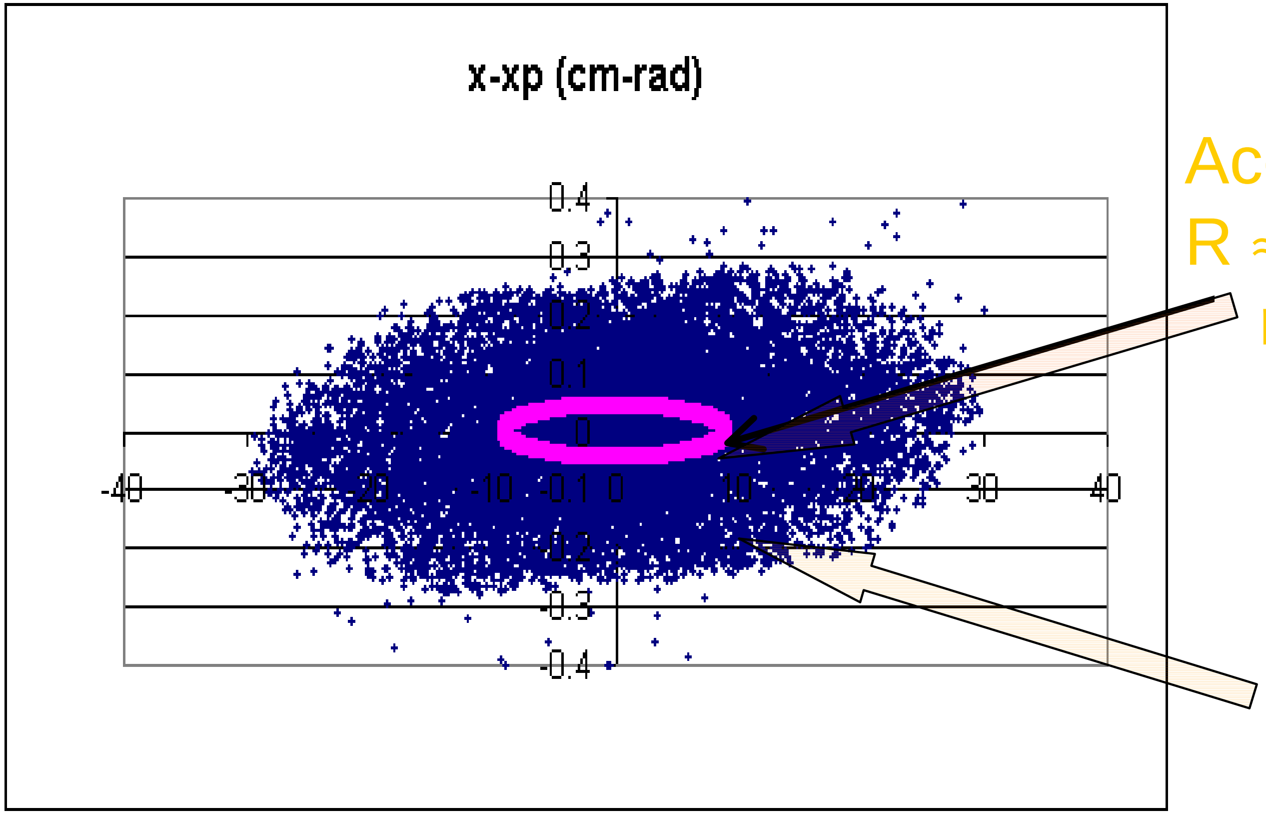
This is the neutrino factory horn,
SPL-superbeam one will have different shape.

J.-M. Maugain, ….(S.Gilardoni, UNiGe) et al

NUFACT R&D; Cooling

- Problem: μ → Beam pipe radius of storage ring

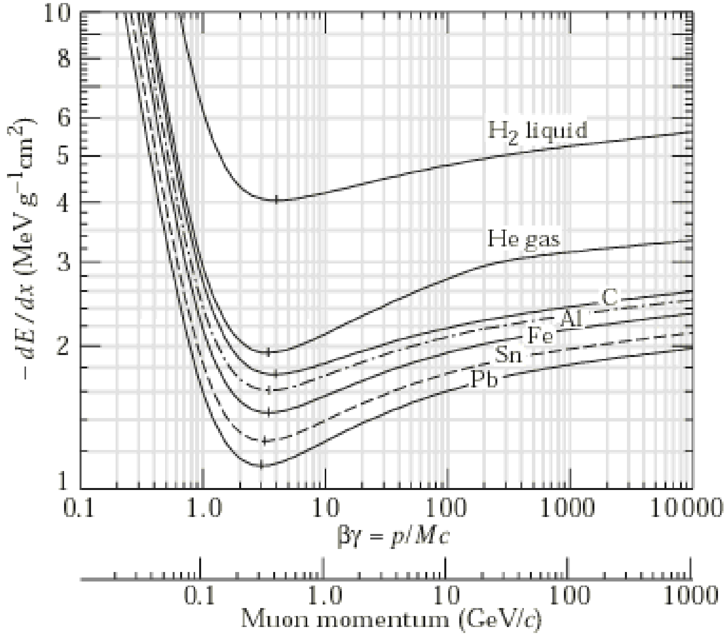
$P_\perp$ or x’ and x reduction needed: COOLING



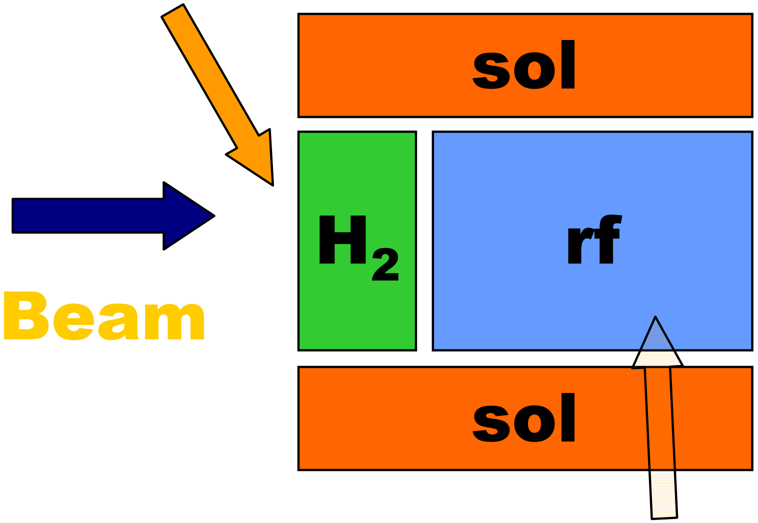
Accelerator acceptance
R ≈ 10 cm, x’ ≈ 0.05 rad
rescaled @ 200 MeV

π and μ after
focusing

Ionization Cooling : the principle



Liquid H_2: dE/dx



sol

H_2

rf

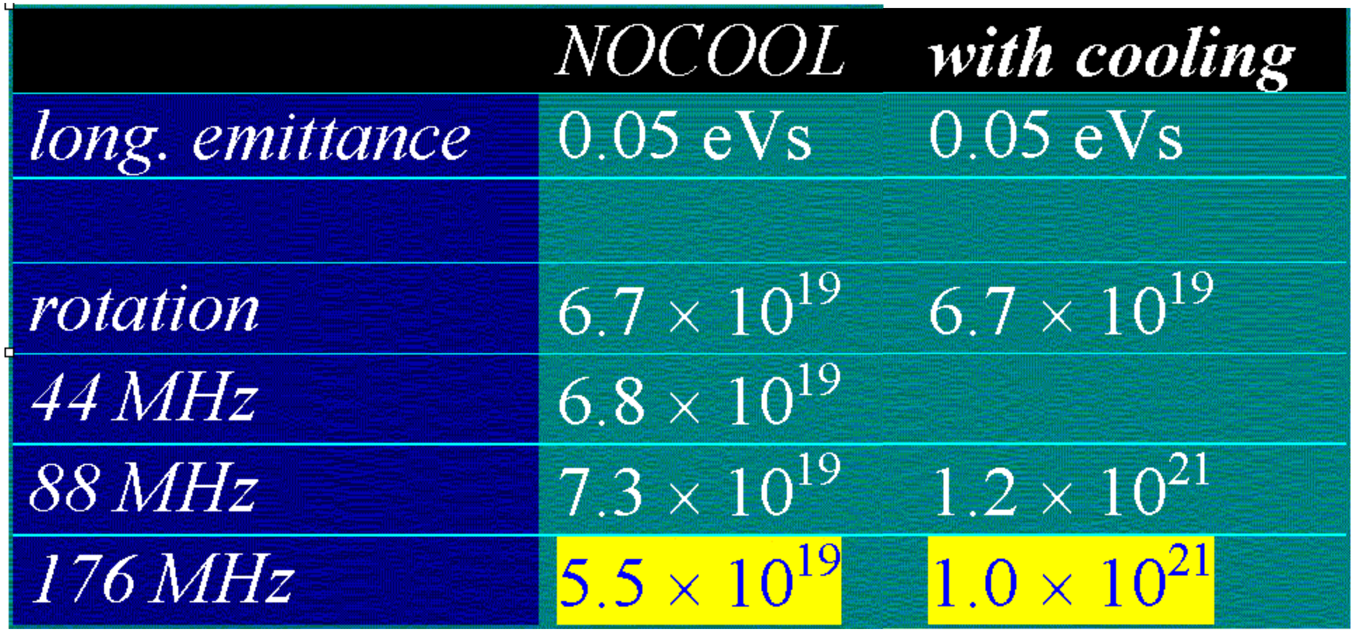
sol

Beam

RF restores only $P_{//}$

What muon cooling buys

MUON Yield without and with Cooling

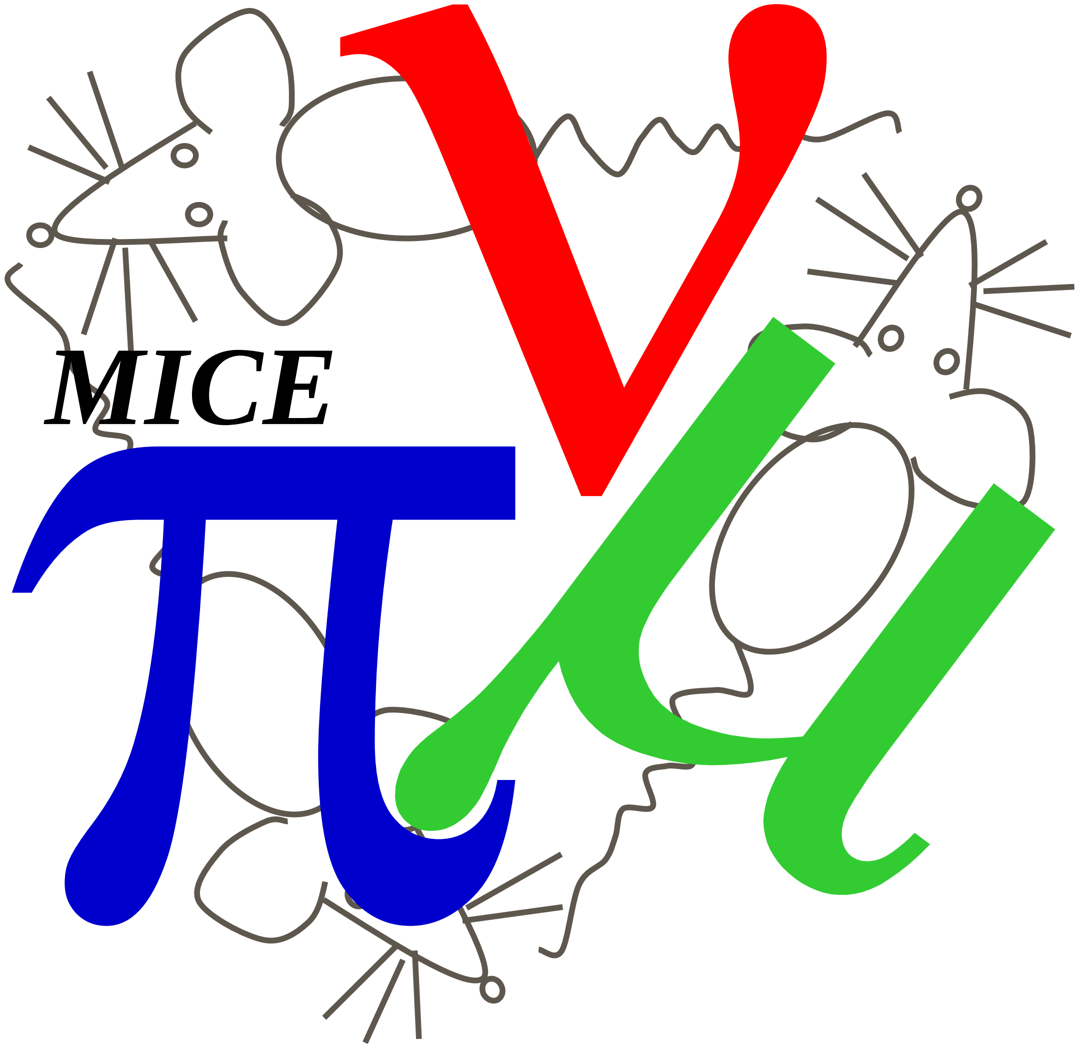


	NOCOOL	with cooling
long. emittance	0.05 eVs	0.05 eVs
rotation	6.7×10^{19}	6.7×10^{19}
44 MHz	6.8×10^{19}	
88 MHz	7.3×10^{19}	1.2×10^{21}
176 MHz	5.5×10^{19}	1.0×10^{21}

exact gain depends on relative amont of phase rotation (monochromatization vs cooling trade off)

cooling of minimum ionizing muons has never been realized in practice
involves RF cavities, Liquid Hydrogen absorbers, all in magnetic field
designs similar in EU and US Nufact concepts

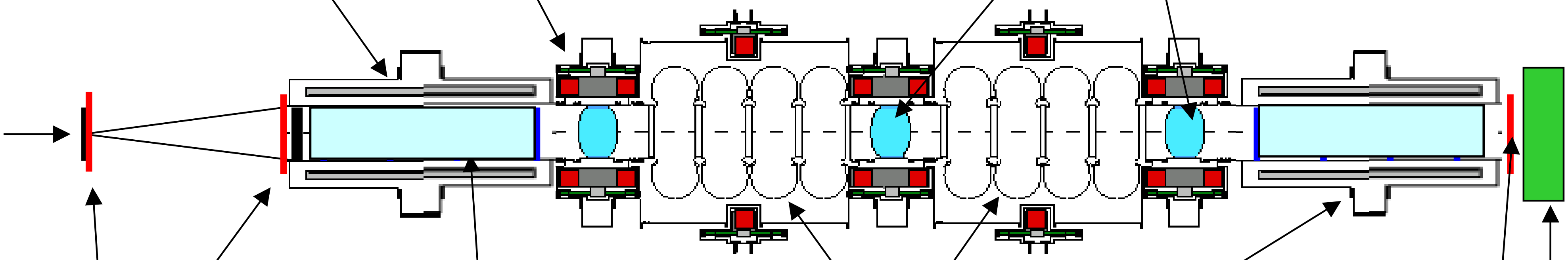
An International **M**uon **I**onization **C**ooling **E**xperiment



10% cooling of 200 MeV muons requires ~ 20 MV of RF

single particle measurements =>

measurement precision can be as good as $\Delta (\varepsilon_{out}/\varepsilon_{in})$ =



SC Solenoids;
Spectrometer, focus pair, compensation coil

Liquid H2 absorbers
or LiH ?

201 MHz RF cavities

T.O.F. I & II
Pion /muon ID
precise timing

Tracking devices:
He filled TPC-GEM (similar to TSLA R&D)
or sci-fi
Measurement of momentum angles and position

T.O.F. III
Precise timing

Electron ID
Eliminate muons that dec

LOI submitted to PSI and RAL.
The two labs agreed to collaborate and RAL encourages submission of proposal. 2002: prepare prop

International Muon Ionization Cooling Experiment

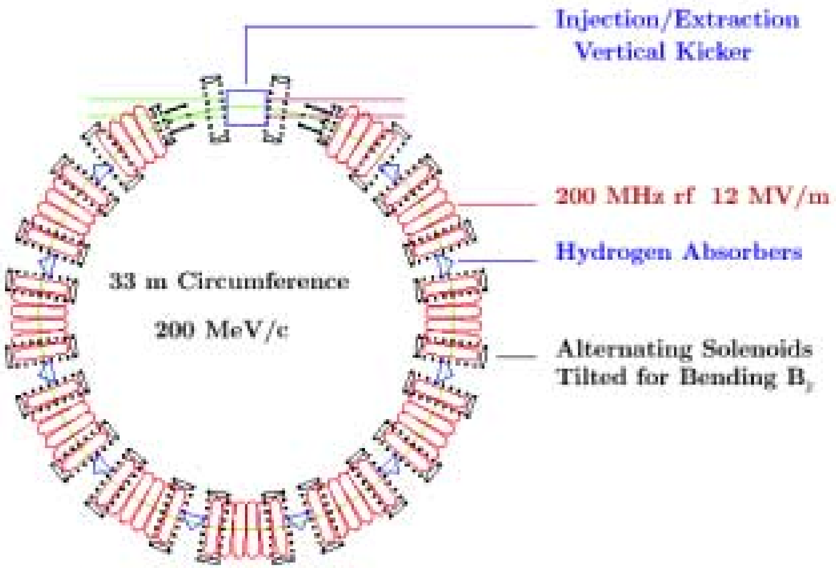
Steering committee:
A. Blondel* (University of Geneva) H. Haseroth (CERN**) R. Edgecock (Rutherford Appleton Laboratory)
Y. Kuno (Osaka University)
S. Geer (FNAL) D. Kaplan (Illinois Institute of Technology) M. Zisman (Lawrence Berkeley Laboratory)
* convener for one year (June 2001-2002)

Conveners of Technical teams:
a) Concept development and simulations: Alessandra Lombardi (CERN **) Panagiotis Spentzouris (FNAL) Robert B Palmer (BNL)
b) Hydrogen absorbers: Shigeru Ishimoto (KEK) Mary-Anne Cummings (Northern Illinois)
c) RF cavities and power sources Bob Rimmer (LBNL) Roland Garoby (CERN**)
d) Magnets Mike Green (LBNL) Jean-Michel Rey (CEA Saclay)
e) Particle detectors Vittorio Palladino (INFN Napoli) Alan Bross (FNAL)
f) Beam lines Rob Edgecock (RAL) Claude Petitjean (PSI)
g) RF radiation Jim Norem (Argonne) Ed McKigney (IC London)

Participating institutes
INFN Bari INFN Milano INFN Padova INFN Napoli INFN LNF Frascati Roma
INFN Trieste INFN Legnaro INFN Roma I Roma II Roma III
Rutherford Appleton Laboratory University of Oxford Imperial College London
DAPNIA, CEA Saclay
Louvain La Neuve
NESTOR institute University of Athens Hellenic Open University
CERN** (H. Haseroth)
** only some limited simulation work and lend of used or refurbished equipment
University of Geneva University of Zurich ETH Zurich PSI
KEK Osaka University
Argonne National Laboratory Brookhaven National Laboratory Fermi National Accelerator Laboratory
Lawrence Berkeley National Laboratory University of California Los Angeles University of Mississippi
University of Indiana/ U.C. Riverside, Princeton University
University of Illinois University of Chicago – Enrico Fermi Institute
Michigan State University Northern Illinois University
Illinois Institute of Technology

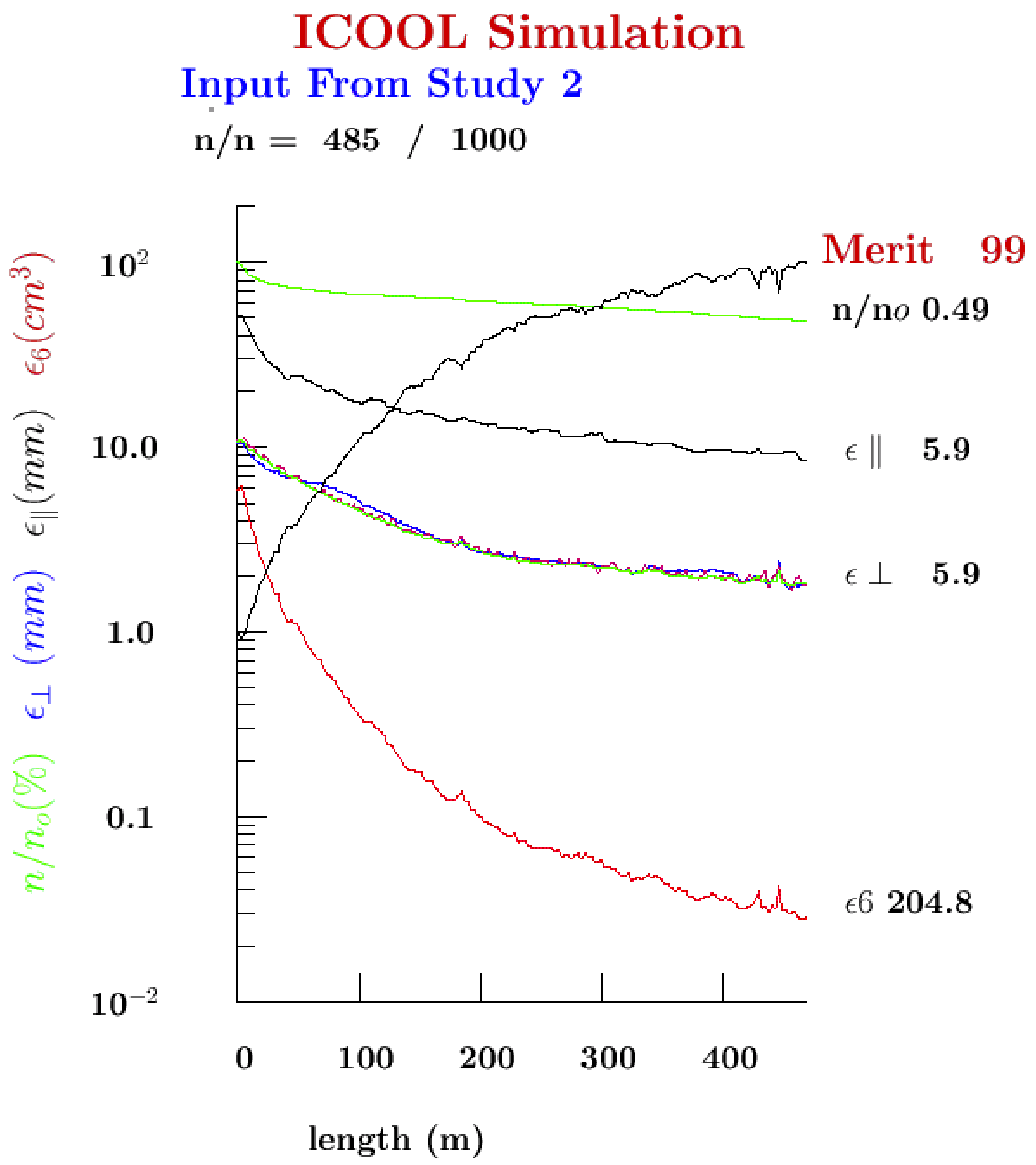
COOLING RINGS

Two goals: 1) Reduce hardware expense on cooling channel
2) Combine with energy spread reduction (longitudinal and transverse cooling)



Simple but Sinful:

- Rf in dispersive location



major problem: Kickers

(Same problem occurs in Japanese acceleration scheme with FFAG)

Conclusions

Neutrinos have mass and they mix.

This is a NEW FORCE, (beyond the SM)
that could also generate proton decay
the baryon asymmetry of the universe,
$\mu \to e\,\gamma$

A Neutrino Factory Complex (and in a first step a high intensity superbeam) would offer the possibility to discover leptonic CP violation and to measure the mass and mixing properties of neutrinos very precisely.
Would offer a very versatile physics program on the side as well.

We know that such a machine can be build and work.
Cost would be too high today and techniques have never been tested in practice.

Requires R&D! Ascertain designs and find new ideas.
Will follow also carefully beta-beam + super-beam combination

Following ECFA recommendations, a coordinated effort is being build in Europe (and across the world), goals and priorities set
-- we will get there, come and help.