NEU2012

Accelerator-based neutrino experiments

Towards a coherent proposal by the neutrino community?

Disclaimer: the recommandations by the « neutrino community » are not there to replace the scientific committees, which always have the last word but to provide input to the CERN strategy upgrade process.

Massive neutrinos: THE NEW PHYSICS there is

Since neutrino oscillations have been demonstrated in 1998 …
-- SuperKamiokande atmospheric neutrinos 8σ

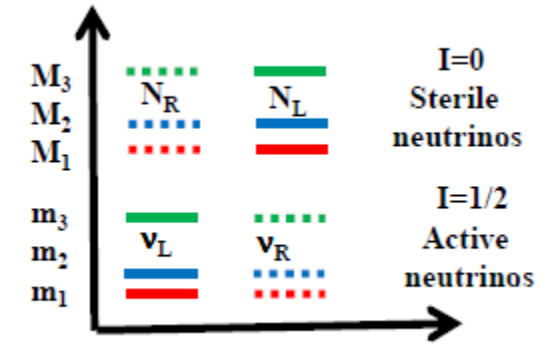
neutrino masses constitute a new question which has no unique answer in the Standard Model

-- while all other charged fermions receive 'Dirac' masses
neutrinos are neutral and could *also* receive 'Majorana' masses
which alllow a transition between neutrinos and antineutrinos
i.e. matter and anti-matter

As a consequence, massive neutrinos could quite naturally have 'sterile' brothers … and contribute to the solution of several well known observations
-- baryon asymmetry of the universe
-- dark matter
-- ($N_\nu^{eff} \approx 4$ instead of 3) the apparent need for an additional degree of freedom in the early universe (CMB)

which have no explanation within the Standard Model.

Neutrinos : the New Physics there is… and a lot of it!

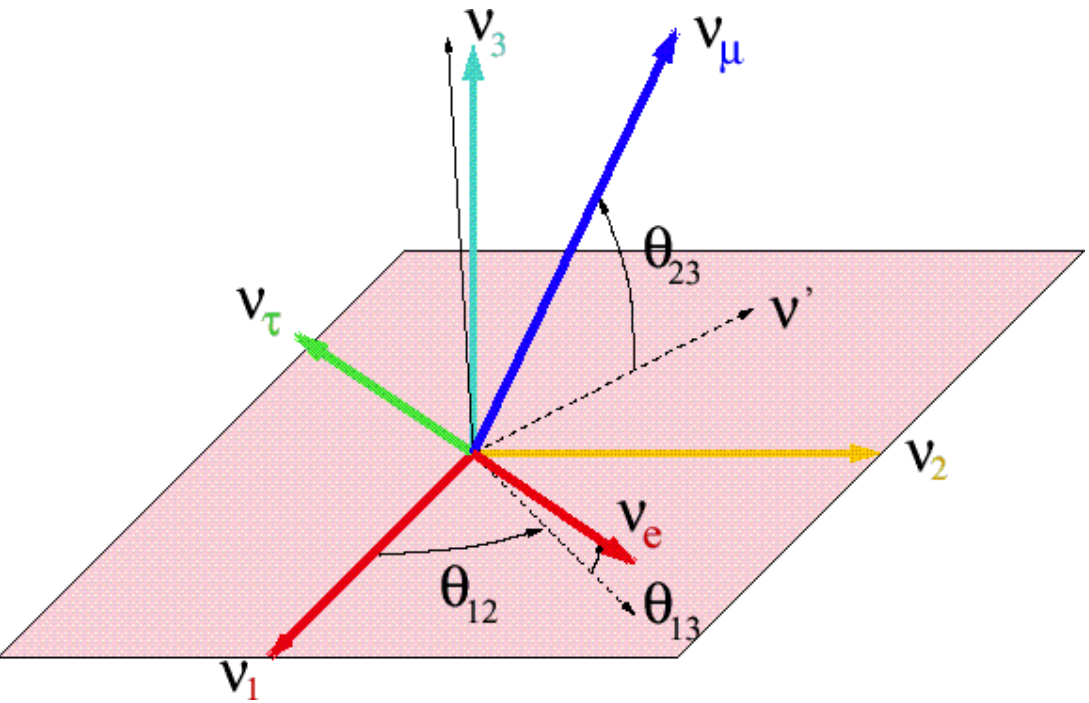
SM	Dirac mass term only	Majorana mass term only	Dirac AND Majorana Mass terms
ν_L $\bar{\nu}_R$ $I = \frac{1}{2}$ $\frac{1}{2}$	ν_L ν_R $\bar{\nu}_R$ $\bar{\nu}_L$ $\frac{1}{2}$ 0 $\frac{1}{2}$ 0	ν_L ν_R $\frac{1}{2}$ $\frac{1}{2}$ (a.k.a. $\bar{\nu}$)	
X 3 Families	X 3 Families	X 3 Families	
6 massless states	3 masses 12 states 3 active neutrinos 3 active antinu's 6 sterile neutrinos… 3 mixing angles 1 CP violating phase	3 masses 6 active states No steriles 3 mixing angles 3 CP violating phases $0\nu\beta\beta$	6 masses 12 states 6 active states 6 sterile neutrinos… More mixing angles and CPV phases $0\nu\beta\beta$ ➔ Leptogenesis and Dark matter

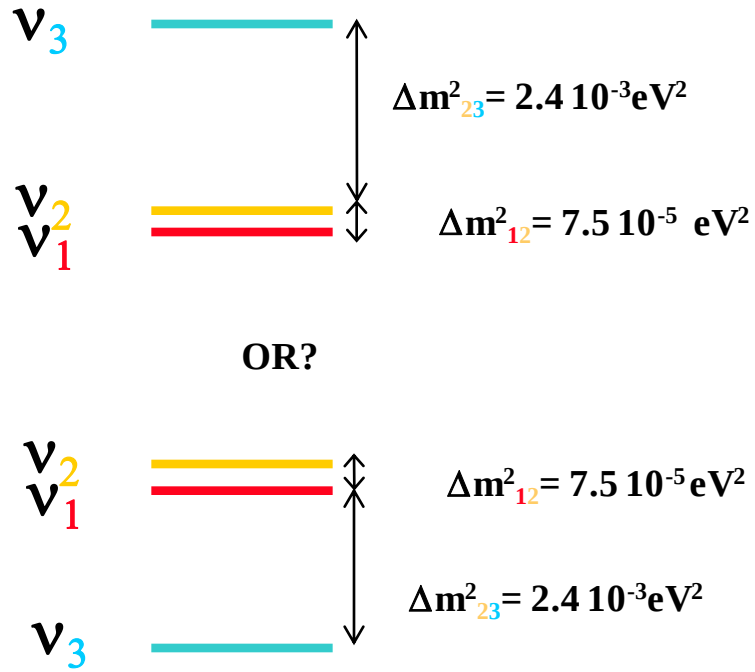
Mass hierarchies are all unknown except $m_1 < m_2$

Preferred scenario has both Dirac and Majorana terms …

… a bonanza of extreme experimental challenges

The neutrino mixing matrix: 3 angles and a phase δ





θ_{23} (atmospheric) $\sim 45^0$, θ_{12} (solar) $\sim 32^0$, $\theta_{13} \sim 9^0$

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

Unknown

sign of Δm_{32} and phase δ ,

1998	Atmospheric neutrinos	$\lvert\Delta m^2_{32}\rvert = \lvert m^2_3 - m^2_2\rvert$, θ_{23}.
2002	Solar neutrinos (SNO) reactor (KAMLAND)	$\Delta m^2_{21} = m^2_2 - m^2_1$, θ_{12}
2011-12	Accelerator (T2K (06/2011, MINOS 07/2011) and rectors (Dchooz 12/2011, DayaBay 03/2012, Reno 04/2012)	θ_{13}

NOW

Depth = exoticity or perhaps time

Do neutrinos follow the same *mass hierarchy* as all other fermions?	sign(Δm^2_{32})
Do ν's and $\bar{\nu}$'s oscillate the same? (CP violation)	δ_{CP}
Do neutrinos have a Majorana mass term?	$\beta\beta 0\nu > 0$
Do sterile neutrinos exist?	Precision measts of all the above, new oscillations or new neutral objects that interact only with gravity. except for small mixing with active ν's
What are their masses (anywhere from $\leq$~eV to ~10^{19}eV!)	

2010 Solar + reactors		$\sin^2 2\theta_{13} \simeq 0.08 \pm 0.04$	2σ
06/2011 T2K	Accelerator	$\sin^2 2\theta_{13} \simeq 0.11(0.14) \pm$ NH(IH)	2.5σ
08/2011 MINOS	Accelerator	$2\sin^2\theta_{23} \sin^2 2\theta_{13} \simeq 0.041^{+0.11\ (0.13)}_{-0.05\ (0.06)}$ NH $2\sin^2\theta_{23} \sin^2 2\theta_{13} \simeq 0.079 \pm^{0.047}_{0.031}$ IH	1.3σ
12/2011 DChooz	Reactor	$\sin^2 2\theta_{13} = 0.086 \pm 0.041^{+0.071}_{-0.053}$ (stat) $\pm$ 0.030 (syst)	1.7σ
03/2012 Daya Bay	Reactor	$\sin^2 2\theta_{13} = 0.092 \pm 0.016$ (stat) $\pm$ 0.005 (syst)	5.2σ
04/2012 Reno	Reactor	$\sin^2 2\theta_{13} = 0.113 \pm 0.013$(stat) $\pm$ 0.019(syst)	4.9σ

$\sin^2 2\theta_{13} \sim 0.097 \pm 0.012$ is no longer 'unknown' and is LARGE

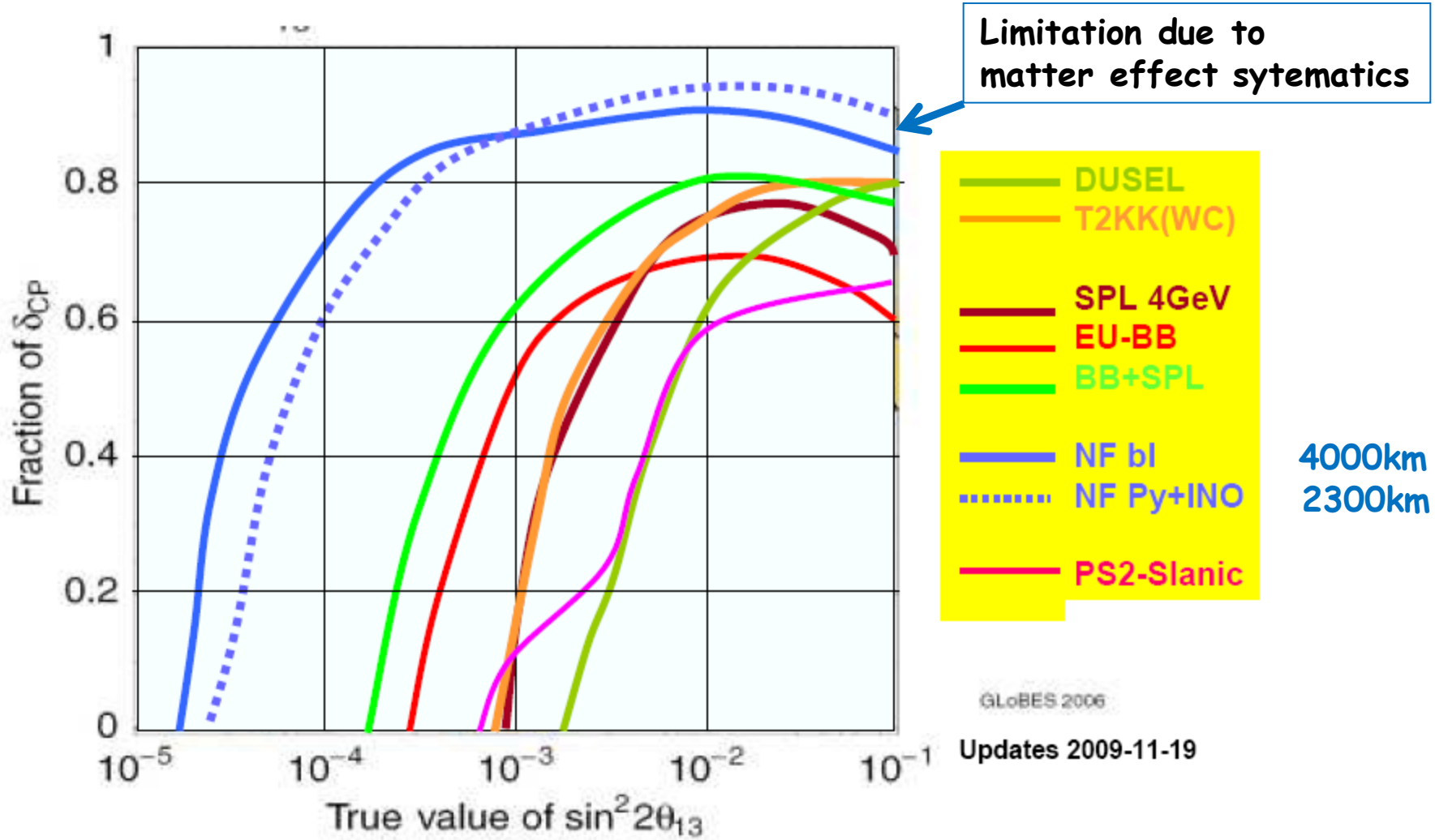
Next: sensitivity to Mass Hierarchy (MH)
and next: to CP Violation (CPV)

Discussion will come up 'what is the next step'?

-- T2K + NOvA + reactors will not get 3 nor 5 sigma on MH or CPV

-- systematic errors will be important

Sensitivity plot from the SPC panel report (2009): published in CERN 2010-03
work from EUROnu, Laguna, IDS-NF, DUSEL, T2KK etc…



$\sin^2 2\theta_{13} \sim 0.097 \pm 0.012$ is no longer 'unknown' and is LARGE

Next: sensitivity to Mass Hierarchy (MH)
and next: CP Violation (CPV)

This is a turning point for which we have been preparing since 1998
ECFA study groups,
BENE in CARE, (2004-2008)
NEU2012 in EUCARD, (2009-2013)
Beta-beam in EURISOL, (2005-2009)
superbeam, beta beam and neutrino factory in EURONU (2008-2012)
LAGUNA (detectors for astroparticle physics and beam experiments) (2008-2010)
LAGUNA-LBNO (focuses on beam experiments from CERN) (2011-2014)

HOW DO WE GO ABOUT IT ?

GLOBAL or EUROPEAN?

Small steps or a big step?

NEU2012 activities

-- Kickoff meeting 18 Mar 2009

-- European strategy for future neutrino physics I (1-3 Oct 2009)
round table, proceedings (CERN 2010-03)

shortly after, SPL was removed from LHC upgrade plans.

-- Neutrino detector studies and possible experiment at CERN PS (17-18 Mar 2010)

-- NEU2012 -- Doing the best of existing infrastructures in Europe and at CERN
27-28 Sept 2010
discussions and minutes bring together
LAGUNA, EUROnu, CNGS &T2K community → LEGUNA-LBNO

-- NUFACT11 XIII international workshop on
superbeams, betabeams and neutrino factories 1-6 Aug 2011
round table, proceedings in preparation

Coming:
-- European strategy for neutrino oscillation physics II (14-16 May 2012)

Neutrino Studies in Europe :
EUROnu, IDS-NF, Neutrino R&D experiments

Present neutrino beam: CNGS 500kW 730 km
-- the most 'super' of todays superbeams

Future neutrino beams
-- EUROnu Superbeam: 4MW, to Fréjus
Betabeam design and R&D experiments
Neutrino Factory design study
-- R&D experiments: MERIT, MICE, EMMA, Bbeam…

An approach with a feasible first step
-- CN2PY

Outlook: the CERN strategy process

The EU design study "menu"

LAGUNA

-far detector "RI" for astroparticle and beam physics
-three detector options
-seven potential sites
-excavation costs
-industrial links

LAGUNA-LBNO

-international consortium including EU, Japan and Russia
-two+one main far sites
-new conventional beam from SPS
-high energy MW-superbeam (HP-PS)
-near detector infrastructure
-detector magnetization
-detector construction and costs

2008

time

2011

2014

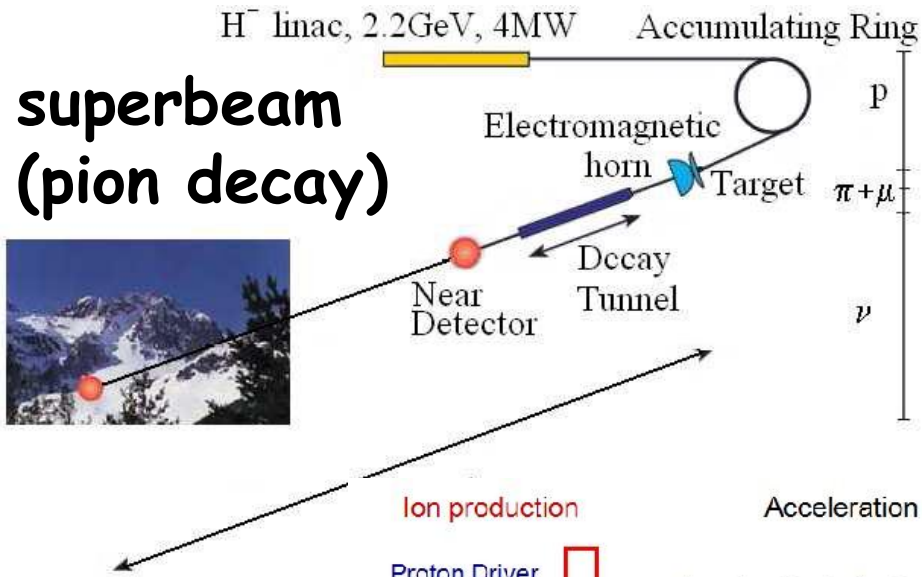
EuroNu

-international consortium
-low energy MW-superbeam (HP-SPL)
-beta beam
-neutrino factory
-costs
-comparison of facilities

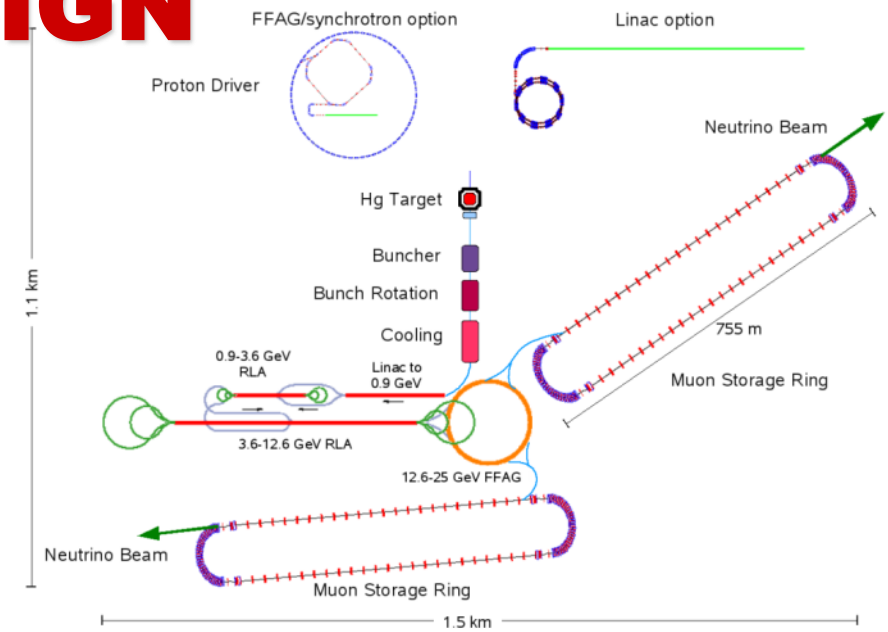
-Update European Strategy for Particle Physics (CERN)

"preparatory phase"

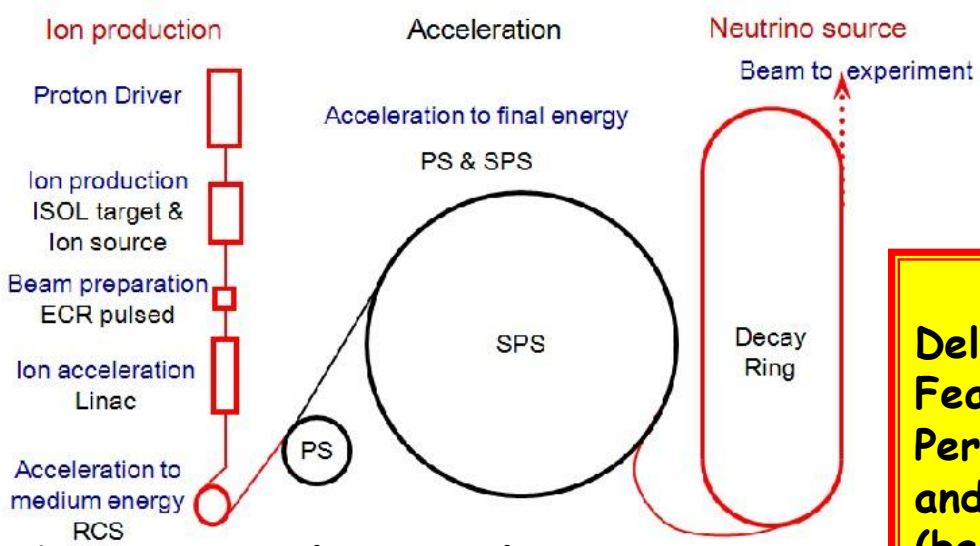
EUROν DESIGN STUDY



superbeam (pion decay)



Neutrino Factory (muon decay)

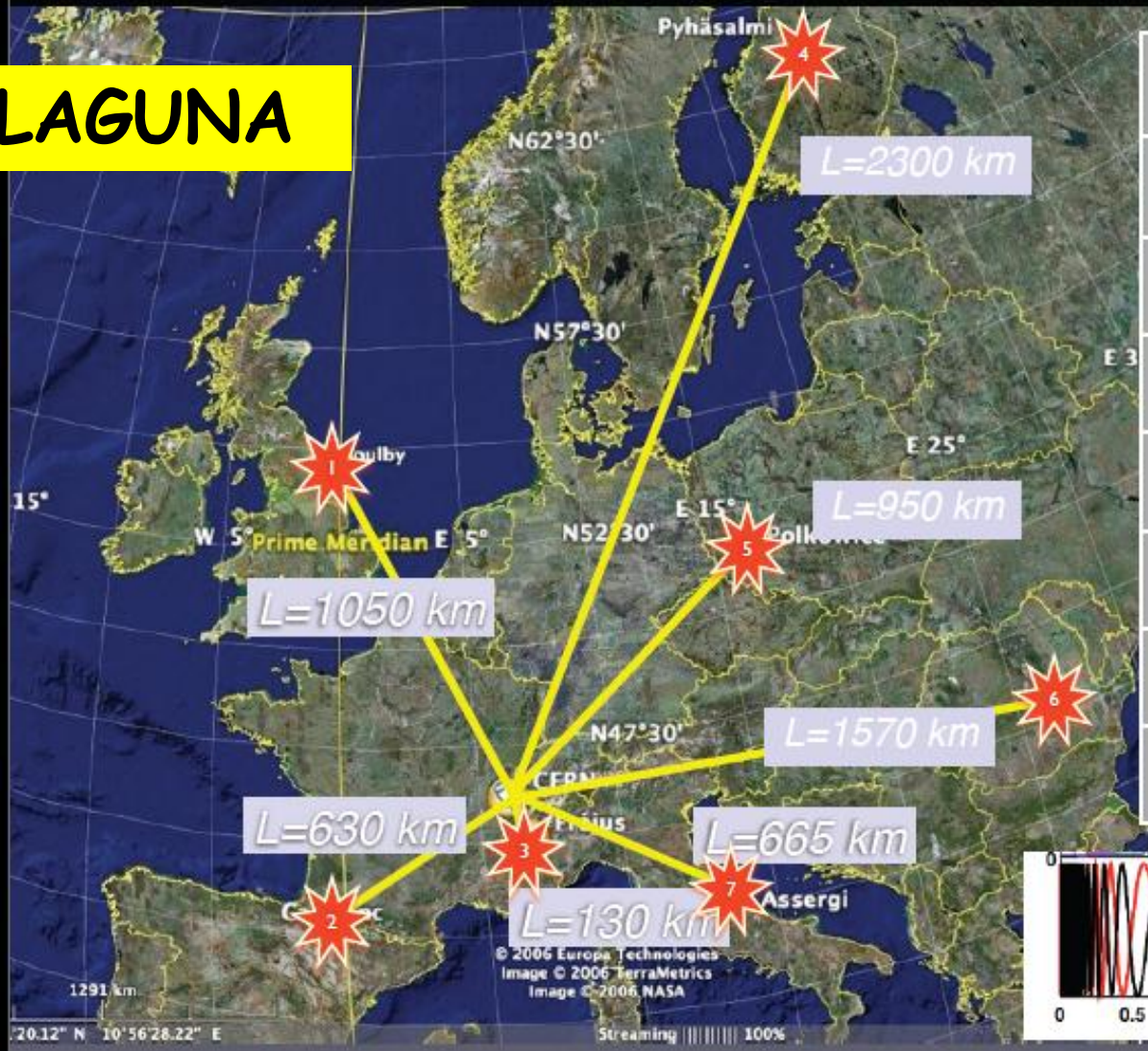


Beta-beam rad-ion decay

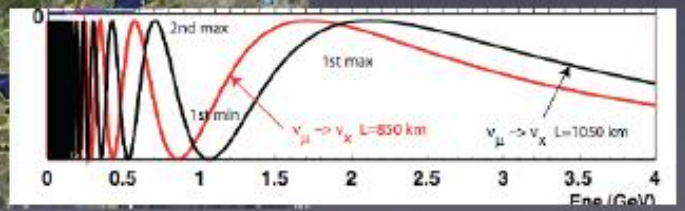
Deliverable Summer 2012:
Feasibility
Performance
and cost evaluations
(based on cost at CERN)

Criteria: distance from CERN

LAGUNA



Distance/km	1st oscillation max (GeV)
130	0.26
630	1.27
665	1.34
950	1.92
1050	2.12
1570	3.18
2300	4.65



A. Rubbia NEU2012, 18 March 2009, CERN 43

Global or not global ?

of course we are in a global, competitve environment.
Should we decide on facilities through a global collaborative process like ILC?
This was discussed at NUFACT11 round table
Community consensus:
there is not so much to gain here
-- host has to put down ~2/3 of investment anyway
-- there are so many aspects of neutrino physics…
and they cannot all be solved with the same technique
-- competition gives better physics/money.

ONE BIG STEP or small steps?

The neutrino oscillation community in Europe is not small (~700, some double count)
OPERA (~180) ICARUS(~60) DChooz(~170) T2K(~250) MINOS (~25)
but it has shrunk to 0 at CERN.

We need a small step to get restarted
BUT make sure steps have a small term top level result and a long term view

➔ Small steps

The facilities considered in EUROnu are all very exciting !

Although the costing is not complete at this point,
they involve one or several of the following:

-- SPL 4MW + accumulator (Superbeam)
" " " + compressor (Neutrino Factory)
-- SPL >100kW (beta-beam)

-- a 4MW target area (Superbeam or Neutrino Factory)

-- 440 kton fiducial Water Cherenkov detector (Beta-beam and superbeam)

-- a very large storage ring of rigidity ~SPS (beta beam)

-- a new and complex muon accelerator (Neutrino Factory)

➔too large to be the next step (+no SPL!)

On the long term for precision measts a well known source for all disappearance and appearance channels will be required (NUFACT, Beta-Beam)

The next step should be an experiment which is feasible in a reasonable time (less than ~10 years), maintains the community healthy, with a real chance of discovery and long term upgrade possibilities.

The existence of a possible long baseline in Europe
CERN → Pyhasalmi = 2300 km is unique in this regard.

As a first step a conventional neutrino beam (ala CNGS) in the north area aims at 20kton of fine grain detector (Larg) followed by a magnetized iron detector (MIND) at Pyhasalmi.

This can achieve a definitive ($\geq 3\sigma$) determination of the neutrino mass hierarchy quite rapidly (2.5 years at present CNGS intensity) . The deep underground location allows non accelerator applications (LENA project)

Both the local situation and the distance make it such that it can evolve into a larger detector and a more powerful beam (NF)
and thus, offers a long term vision.

This project, called LBNO, is the first priority of the LAGUNA-LBNO consortium and is endorsed by the NF community. It will be proposed as next step at the workshop in May (and to the SPSC etc..)

Getting our feet on (under) the ground:

A. Rubbia

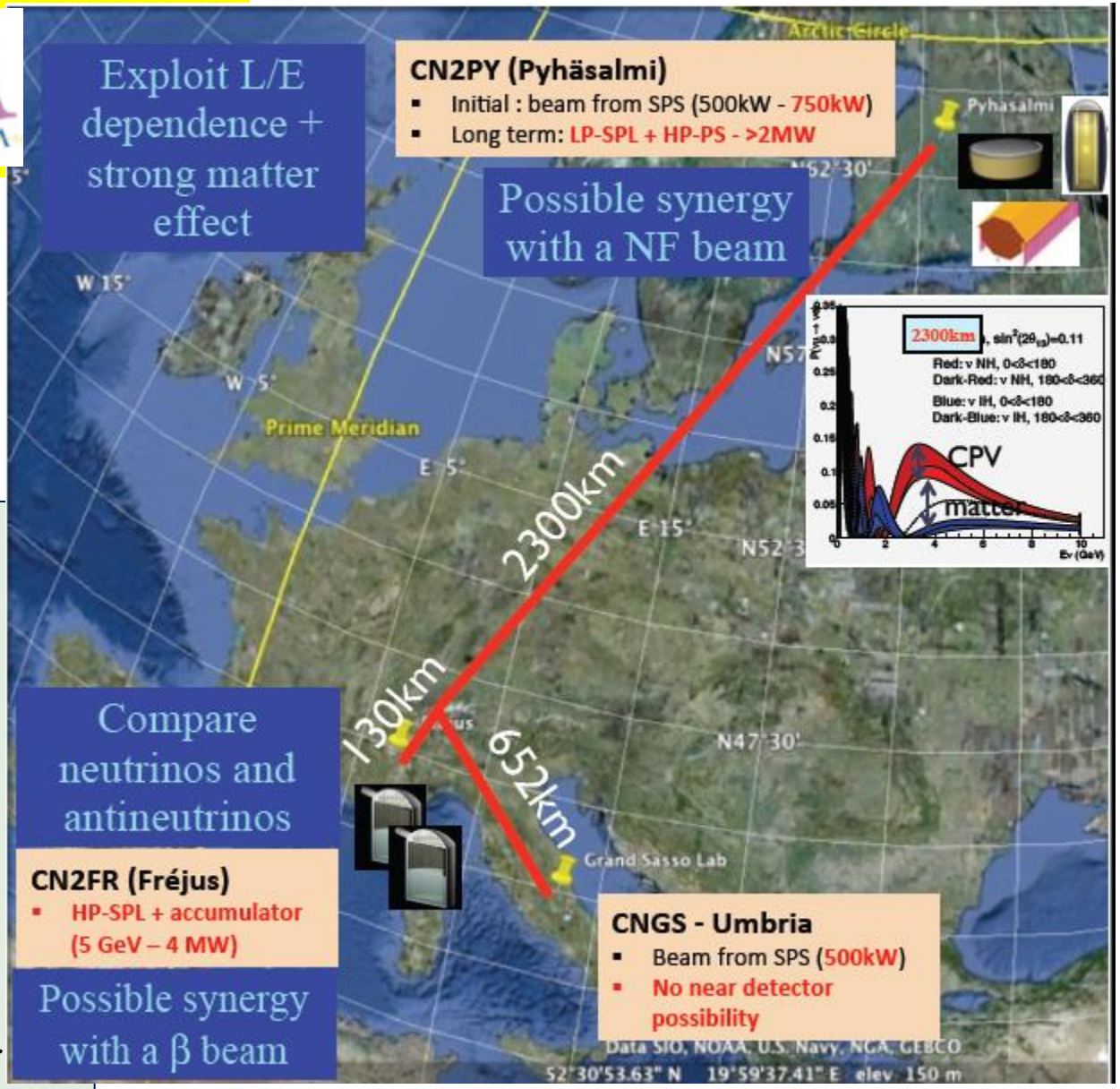
LAGUNA –LBNO
new FP7 design study
2011-2014

2 main options

Short distance: 130km
Memphys at Frejus
SPL+beta beam
CP and T violation

Long distance: 2300km
Pyhasalmi
Fine grain detector
e.g. 20kton fid. Larg
+ Magnetized detector
Long distance allows rapid sensitivity to
sign(Δm^2_{13})

1st step easier: SPS C2PY
➔ consortium 1st priority
Next steps HP 50 GeV PS …
…or neutrino factory



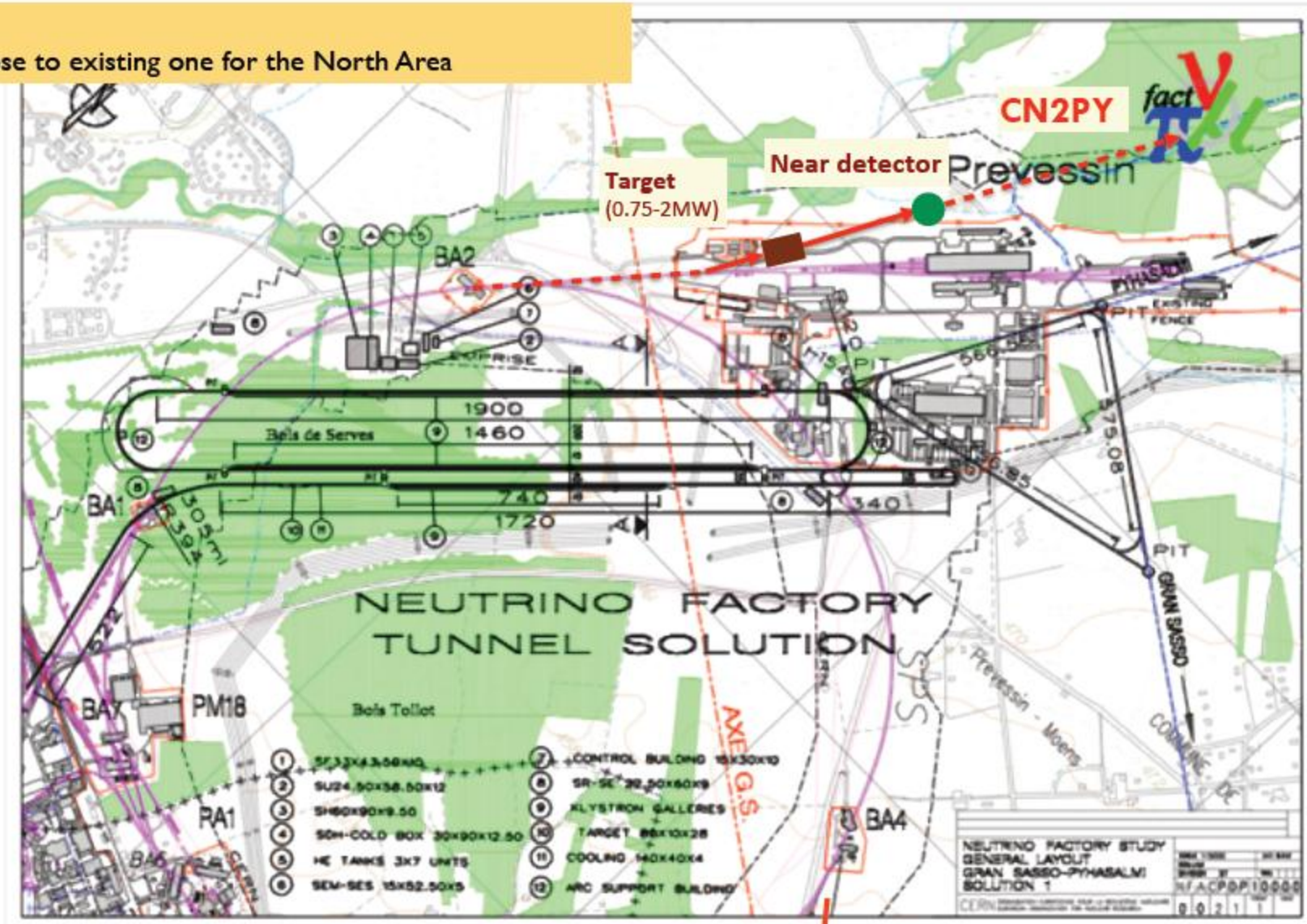
Medium term plans include long term plans!

Alain Blondel. EUCARD plenary 27-04- 2012

Alain Blondel HIF

CERN ν-beam to Pyhasalmi - CN2PY

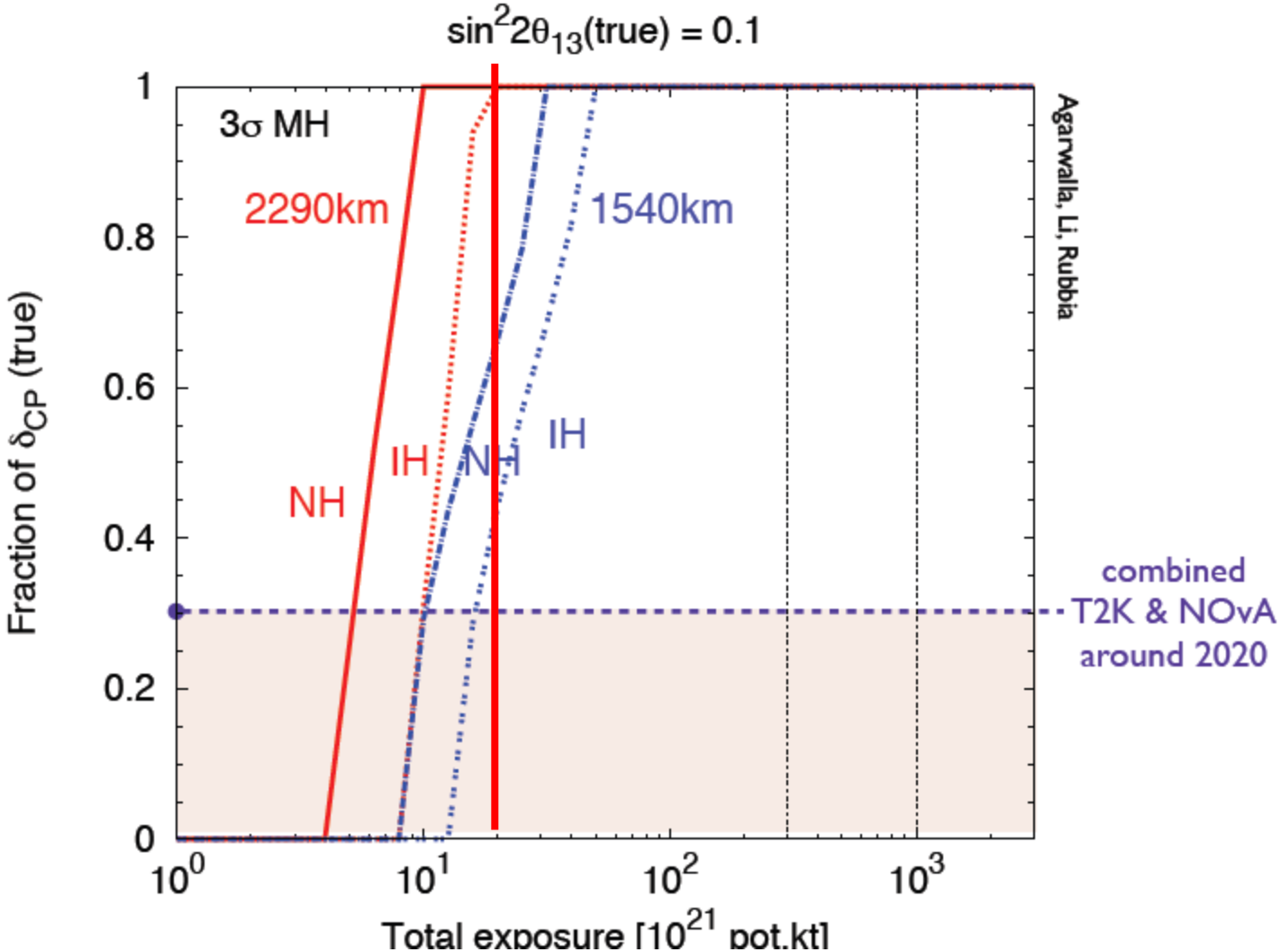
Option B:
Target station close to existing one for the North Area



4. Far detectors

- 4.1 The Pyhäsalmi Site
  - bimagic baseline from CERN
  - unique asset for deep underground access; infrastructure in excellent condition
  - consider “hand-over” in 2018; possibility to initiate excavation in 2016
  - ongoing feasibility and underground layout study (LAGUNA/LAGUNA-LBNO)
  - LAr+Magnetized muon detectors provide the best combination for the GeV beam events given the baseline 2300km; in addition Pyhäsalmi is an excellent location to host a large LSc detector optimized for MeV-neutrino physics
- 4.2 Liquid Argon Detector
  - very fine grain and exclusive final states
  - best detector for GeV neutrinos
  - best for electron and tau CC
- 4.3 Magnetized Muon Detector
  - muon momentum & charge determination, inclusive total neutrino energy
  - simplest for muon CC, and NC
  - compatible with NF

MH determination (3σC.L.)

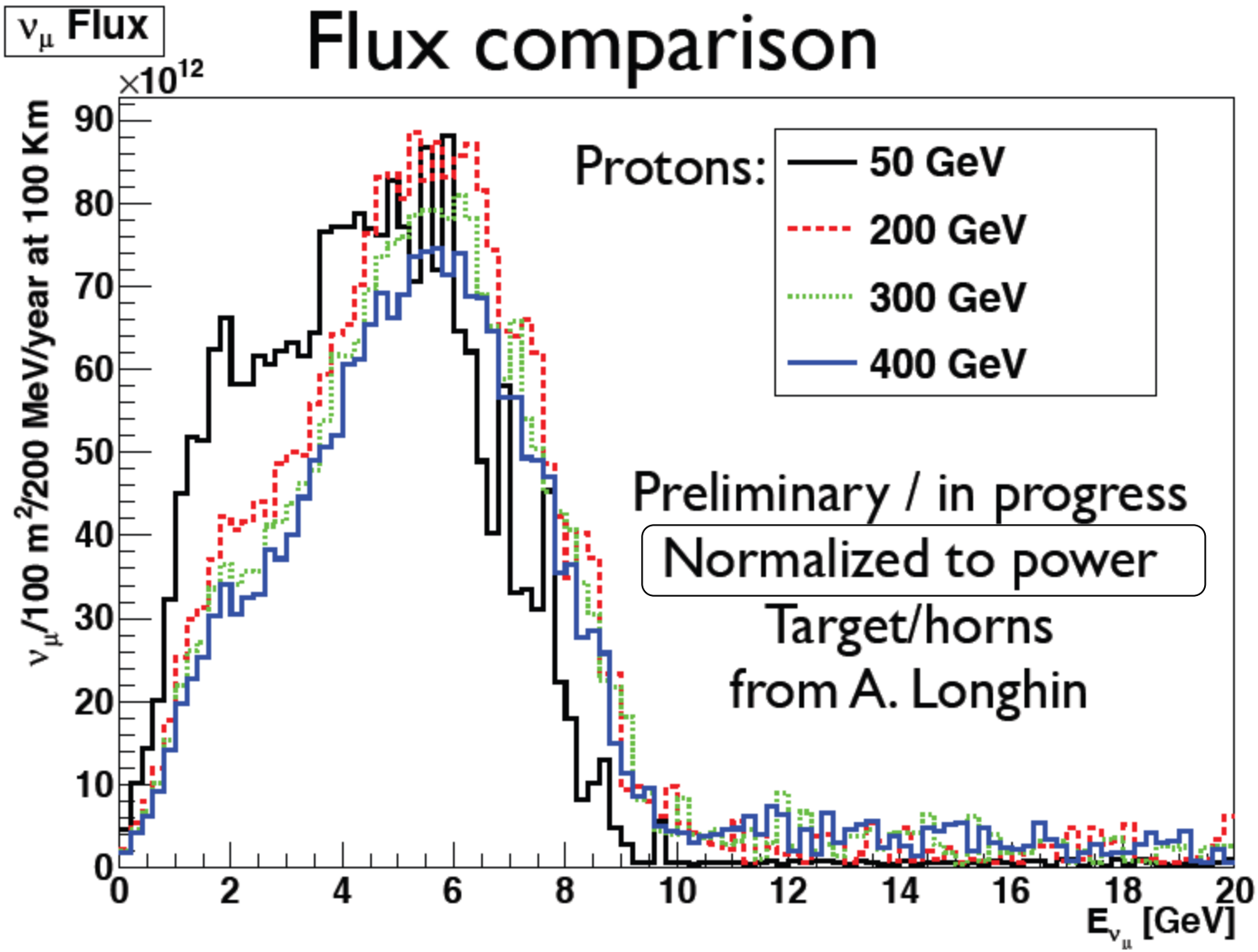


In A.Rubbia's units 20kton.50 GeV 10^21 pots = 25kton.400GeV.10^20 pots

=> 2.5 years of CNGS at present intensity

enough to determine MH at 3sigma for sin2 2theta_13 = 0.1, any value of δ

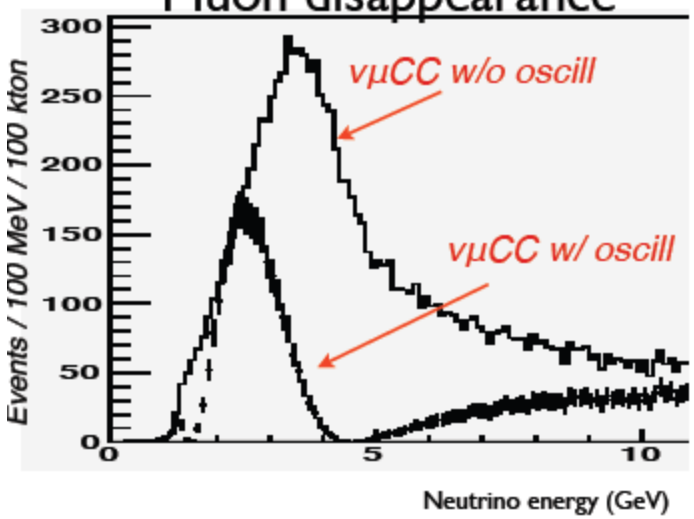
Flux comparison



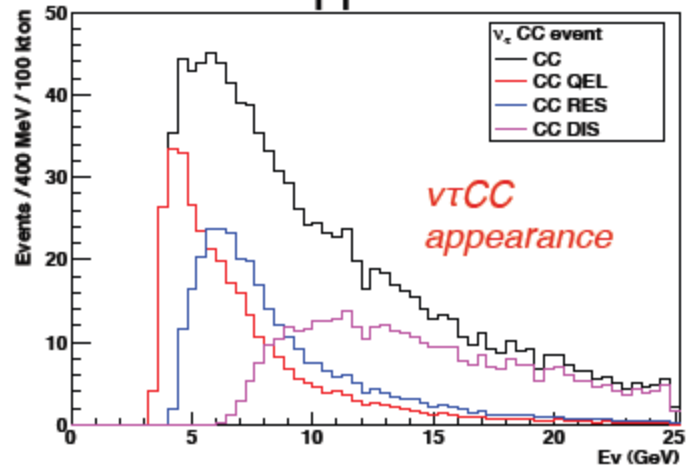
S. Di Luise

Muons, electrons and taus

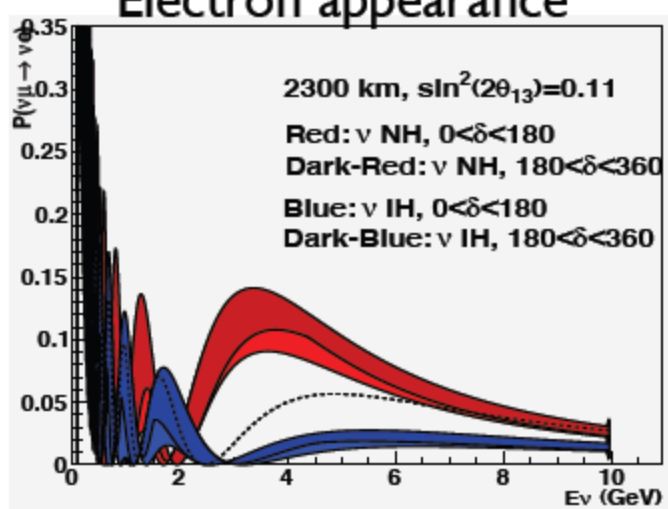
Muon disappearance



Tau appearance



Electron appearance

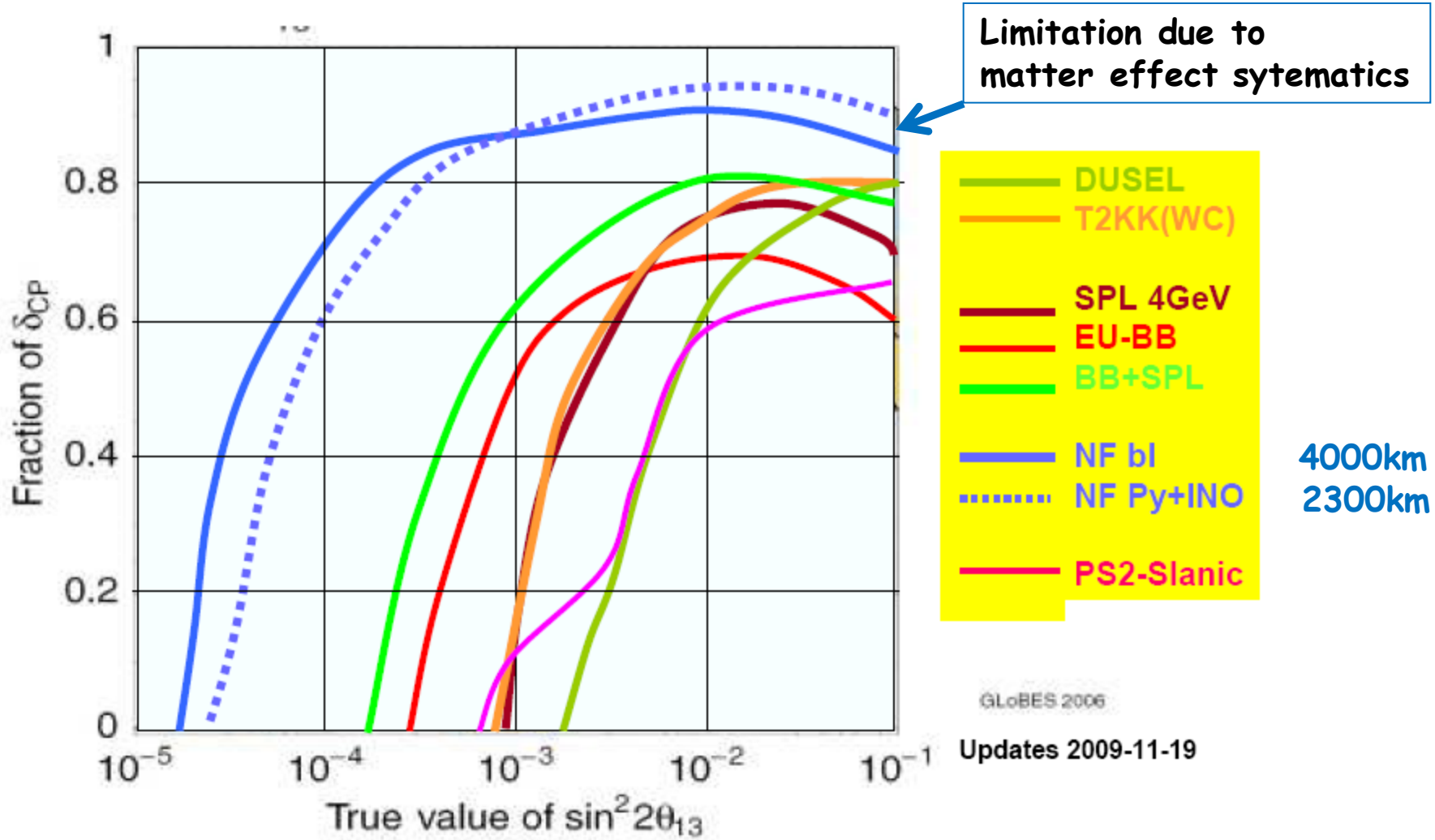


Rich oscillation physics

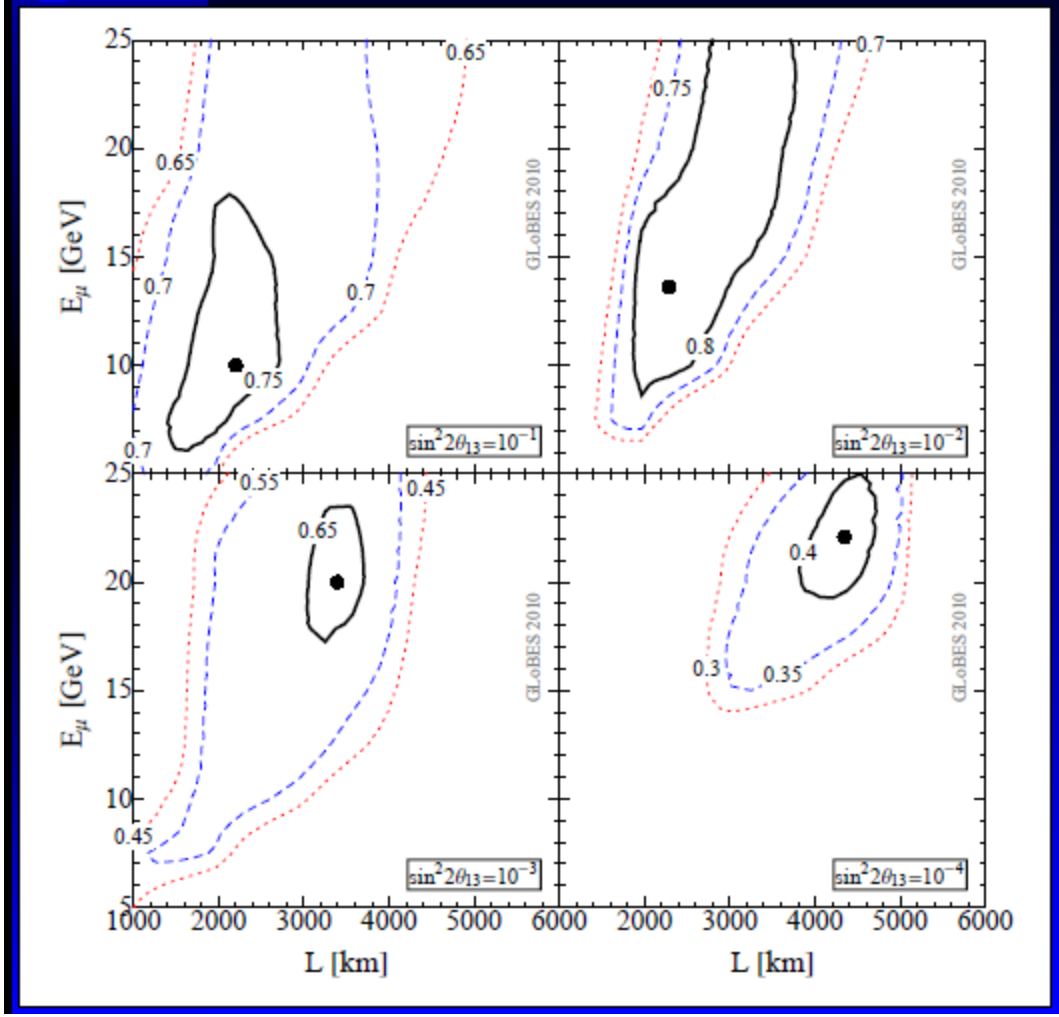
A. Rubbia

LAGUNA LBNO General meeting, APC (Paris), March 2012

Sensitivity plot from the SPC panel report (2009): published in CERN 2010-03
work from EUROnu, Laguna, IDS-NF, DUSEL, T2KK etc…



Optimization – one baseline



At large θ_{13}, using MIND and one baseline, optimum is at 2200-2300 km and 10-14 GeV.

CPF 0.77-0.84

S. Agarwalla, PH, J. Tang, W. Winter JHEP 1101 120 (2011).

P. Huber – VT-CNP – p. 16

Conclusions

1. Massive neutrinos is a most promising field of research in particle physics today, with a large potential for discoveries with considerable consequences.

2. With the recent observations of a large value of θ_{13}, the determination of the neutrino mass hierarchy and the determination of the CP phase are the next steps. These fundamental measurements require and justify dedicated long baseline accelerator-based experiments.

3. By organizing several workshop and dedicated discussion meetings, NEU2012 has brought together the LAGUNA vs EUROnu communities to converge on a realistic strategy, with a first step offering a discovery experiment in ~10 years and a long term vision for CP violation and precision measurements.

4. Europe has a *unique* possibility with the 2300 km baseline to Pyhasalmi which allows great sensitivity to the mass hierarchy by matter effects with a conventional beam and a moderate size detector, while being the optimal Neutrino Factory baseline.

5. The shorter baseline to Frejus with a betabeam is also a longer term possibility and offers interesting CP sensitivity.

6. R&D into high precision facilities (NF and BetaBeam) should be pursued in view of the longer term future.