Towards Future Neutrino Activities

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NEU2012 : AB, Fanny Dufour

AIDA : A.B., Sandro Bravar, Etam Noah, Yordan Karadhzov, Ruslan Asfandiyarov

LBNO : AB, Yordan Karadhzov + everybody

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

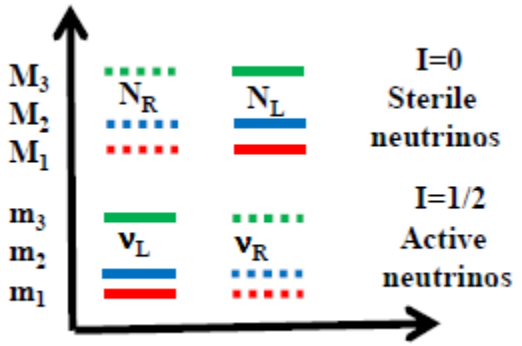
-- baryon asymmetry of the universe

-- 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!

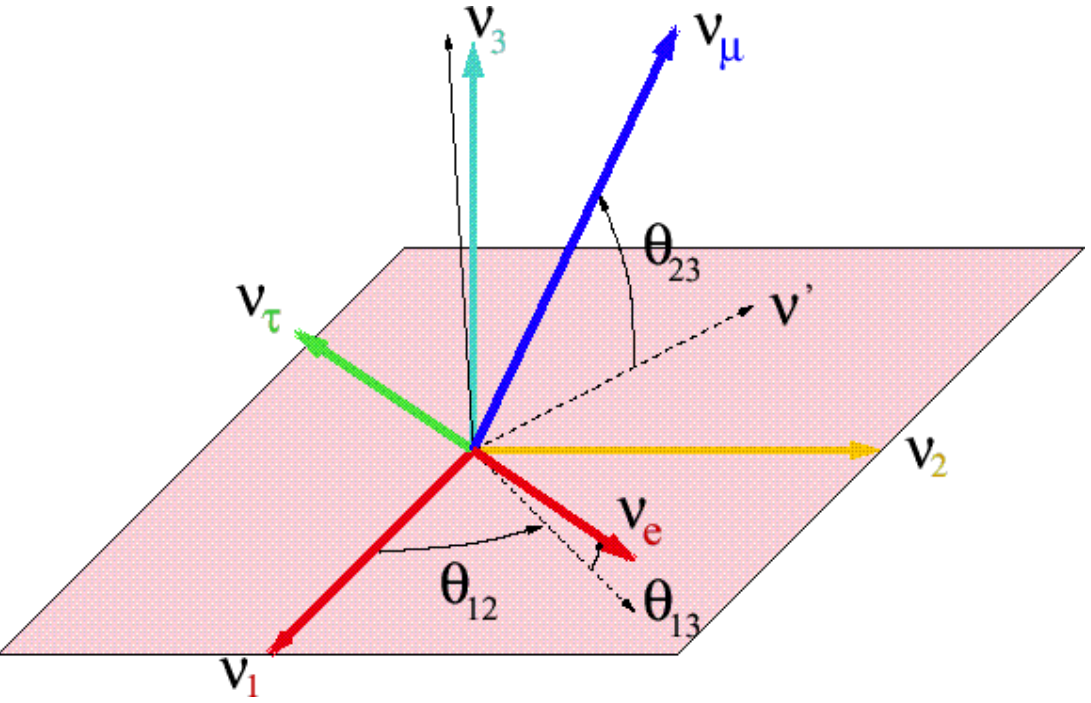
SM	Dirac mass term only	Majorana mass term only	Dirac AND Majorana Mass terms
mass spectrum of each family of mass eigenstates:			
ν_L $\bar{\nu}_R$ I= $\frac{1}{2}$ $\frac{1}{2}$	ν_L ν_R $\bar{\nu}_R$ $\bar{\nu}_L$ $\frac{1}{2}$ 0 $\frac{1}{2}$ 0	ν_L ν_R $\frac{1}{2}$ $\frac{1}{2}$ (a.k.a. $\bar{\nu}$)	
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 0νββ	6 masses 12 states 6 active states 6 sterile neutrinos… More mixing angles and CPV phases 0νββ ➔ Leptogenesis and Dark matter

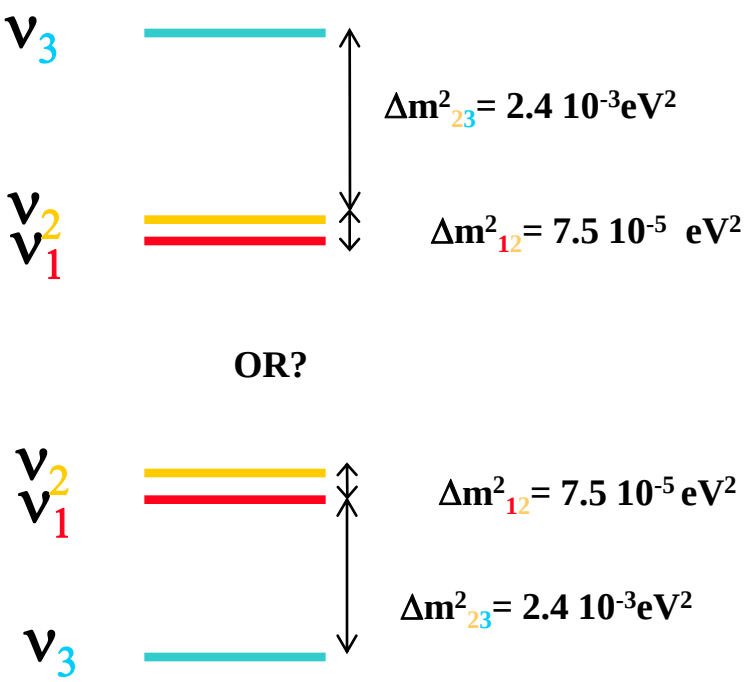
Mass hierarchies are all unknown except $m_1 < m_2$

Preferred scenario has both Dirac and Majorana terms …

… extreme experimental challenges

The neutrino mixing matrix: 3 angles and a phase δ





θ_{23} (atmospheric) ~ 45^0, θ_{12} (solar) ~ 32^0, θ_{13} ~ 9^0

$\sin^2 2\theta_{13}$ ~ 0.097 ± 0.012 is no longer 'unknown' and is quite large

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

Unknown

sign of Δm_{32} and phase δ ,

-2012

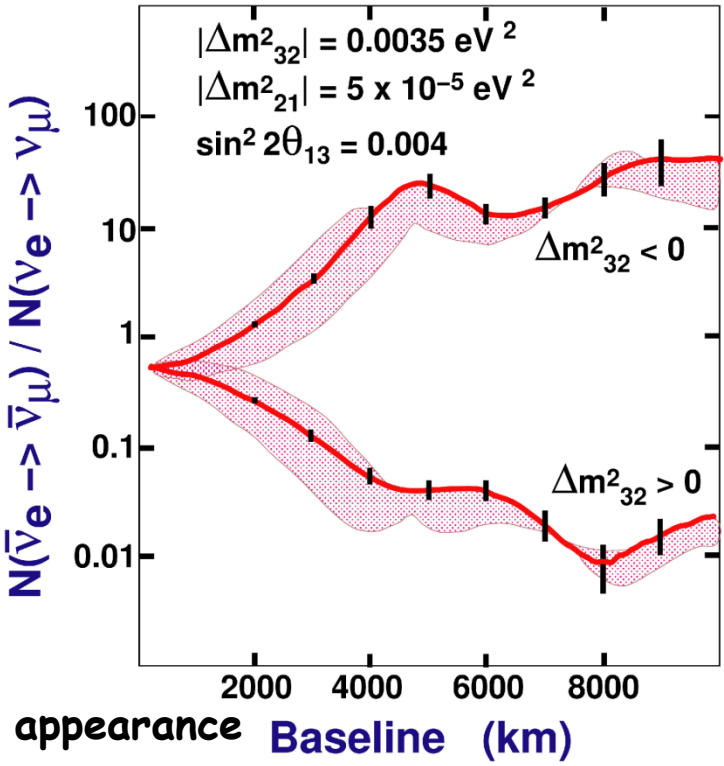
1998	Atmospheric neutrinos	$\|\Delta m^2_{32}\| = \|m^2_3 - m^2_2\|$, θ_{23}.
2002	Solar neutrinos (SNO) reactor (KAMLAND)	$\Delta m^2_{21} = m^2_2 - m^2_1$, θ_{12}
2011/12	Accelerator (T2K (06/2011, MINOS 07/2011) and reactors (Dchooz 12/2011, DayaBay 03/2012, Reno 04/2012)	θ_{13}

NOW

Depth = exoticity or perhaps time

Do neutrinos follow the same *mass hierarchy* as all other fermions?	Oscillations sign(Δm^2_{32})
Do ν's and $\bar{\nu}$'s oscillate the same? (CP violation)	Oscillations δ_{CP}
what is the absolute mass of neutrinos?	KATRIN, Cosmology
Do neutrinos have a Majorana mass term?	$\beta\beta0\nu > 0$
Do sterile neutrinos exist? What are their masses ? (anywhere from ≤~eV to ~10^{19}eV!)	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

Accessing Mass Hierarchy and CP violation in neutrino oscillations



both produce and asymmetry between neutrino and antineutrino
+ distortion of the oscillation
different dependence on baseline and energy → (mass hierarchy intervenes through matter effect)

Golden Channel :

$\nu_\mu \to \nu_e$ (conventional $h \to \nu_\mu$ beam) electron appearance

$\nu_e \to \nu_\mu$ (neutrino factory $\mu \to \nu_e\ \bar{\nu}_\mu$) wrong sign muon appearance

--Oscillation maximum is such that $\sin^2(1.27\ \Delta m^2\ L/E) = \pi/2$ ➔ L/E = 500 km/GeV
--number of events per ton of detector and MW of proton beam power scales like E_ν

2 good places to do the experiment:
1. E~600 MeV (T2K) → good energy for Water Cherenkov (highest E below π treshold) sensitive to δ_{CP} only
2. E>2000km and either high energy conventional beam (with FGD) or Neutrino Factory very sensitive to sign (Δm^2_{32}) and then to δ_{CP} , also allows ν_τ studies

There *may be* ways to determine the mass hierarchy from non-accelerator sources and some are under study (none for a definitive 5σ or even 3) (Melody's talk)

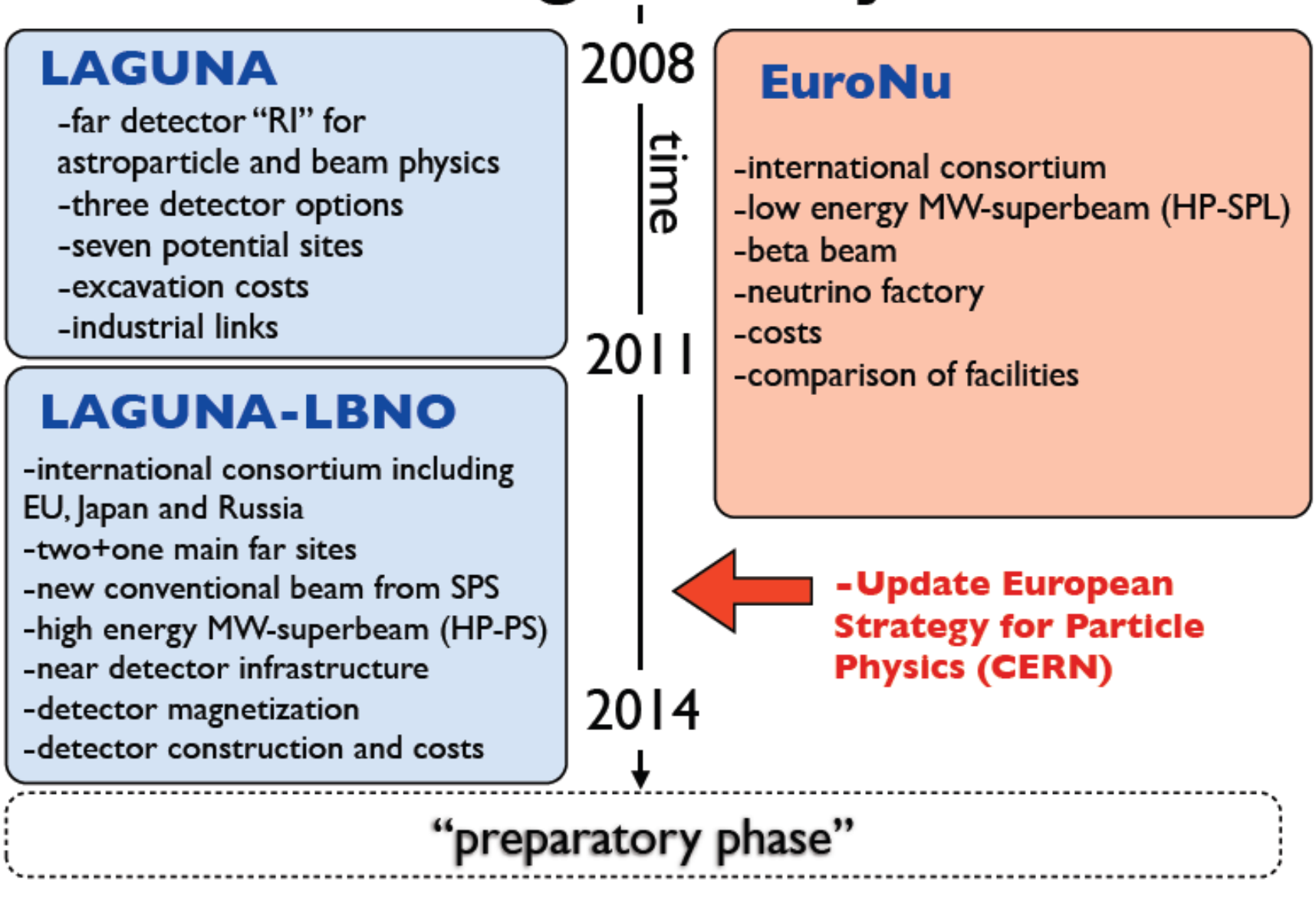
However CP violation needs to be seen in appearance experiment
$P(\nu_x \rightarrow \nu_x)$ is time reversal symmetric
and in an experiment that differentiates neutrino and antineutrinos.

➔ $\nu_\mu \rightarrow \nu_e$ at any energy or $\nu_e \rightarrow \nu_\mu$ above muon threshold.

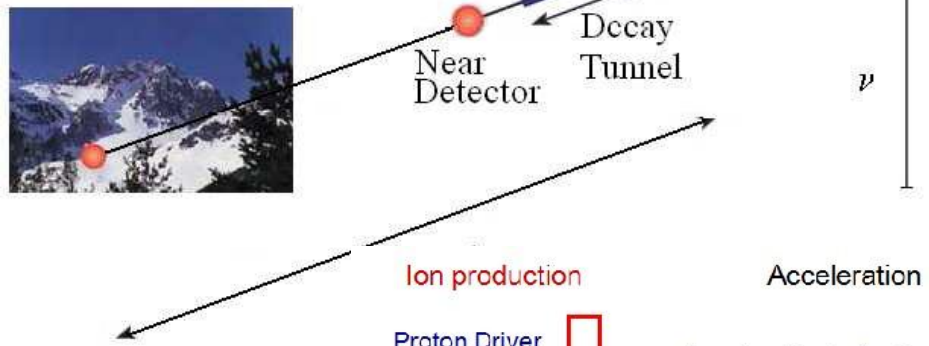
Observation and study of CP violation require accelerator-based neutrino beams

At given beam power, rate increases with energy (thus distance)
because of cross-sections.

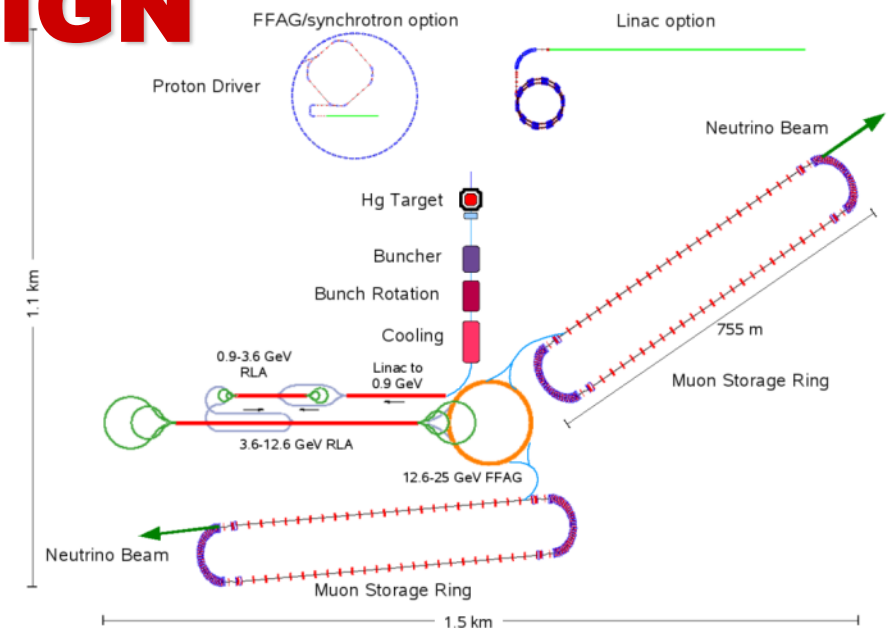
The EU design study "menu"



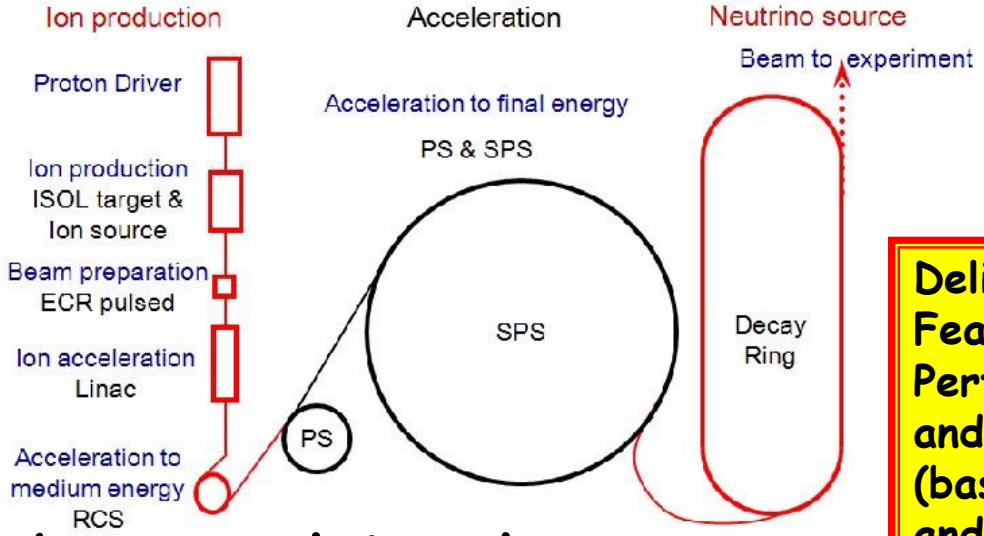
EUROν DESIGN STUDY



superbeam (pion decay)



Neutrino Factory (muon decay)

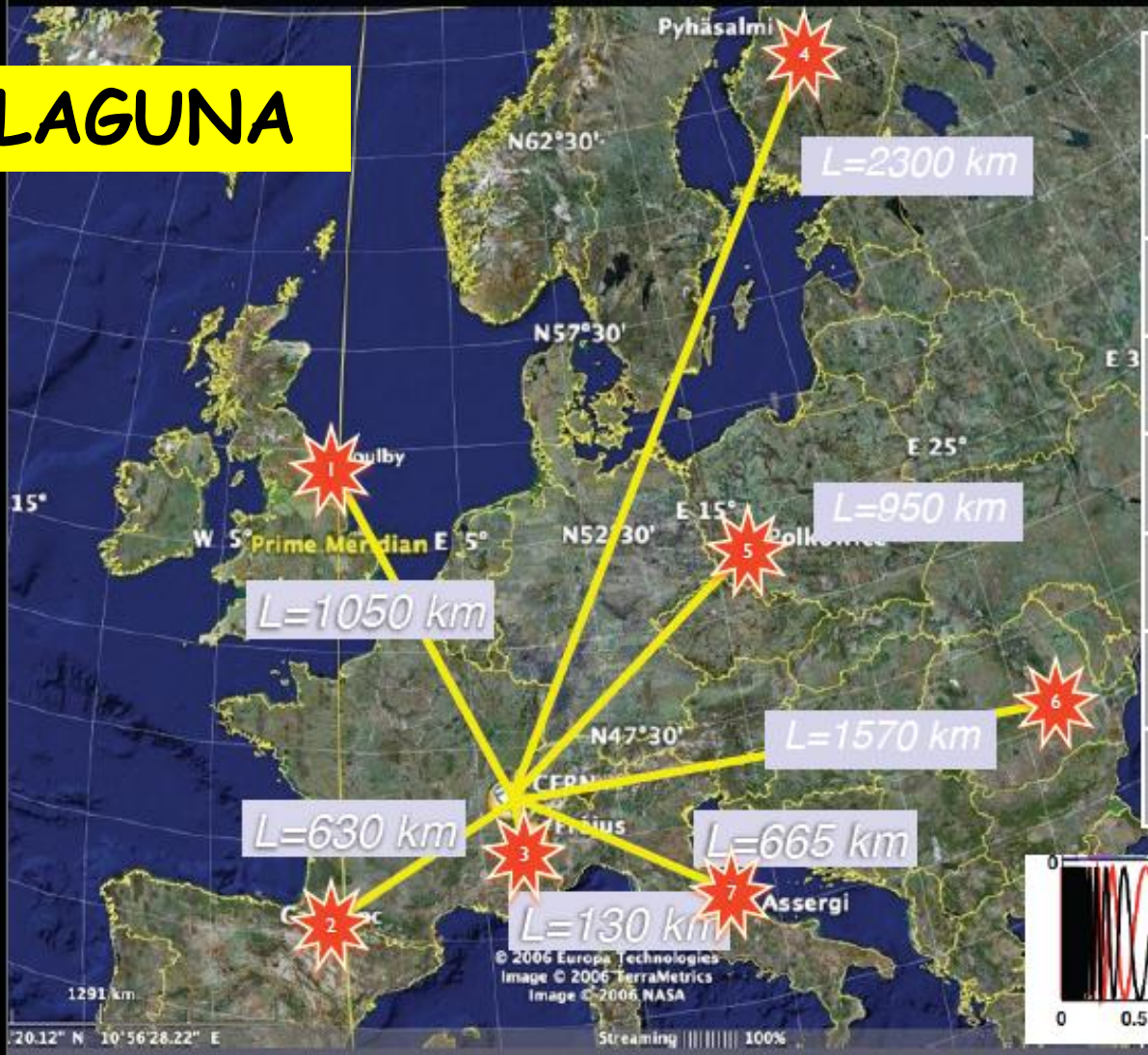


Beta-beam rad-ion decay

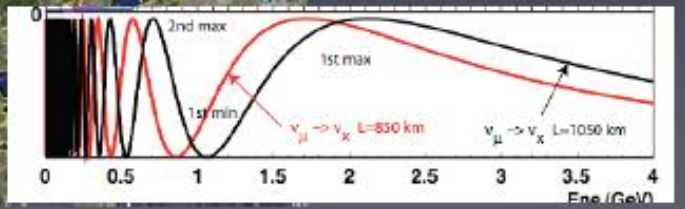
Deliverable Summer 2012:
Feasibility
Performance
and cost evaluations
(based on cost at CERN)
and choice

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

Getting our feet on (under) the ground:

LAGUNA –LBNO
new FP7 design study
2011-2014

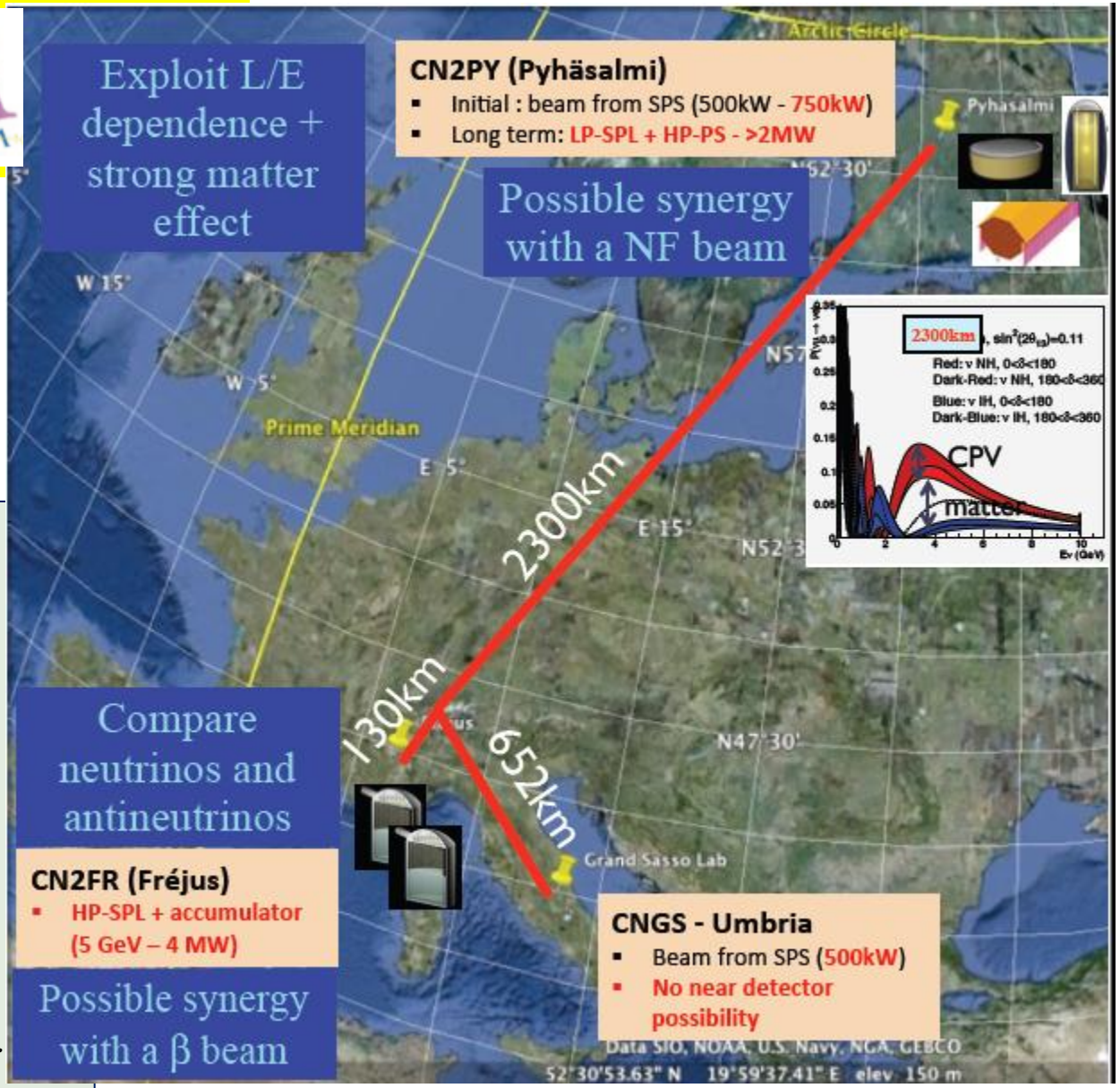
A. Rubbia

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



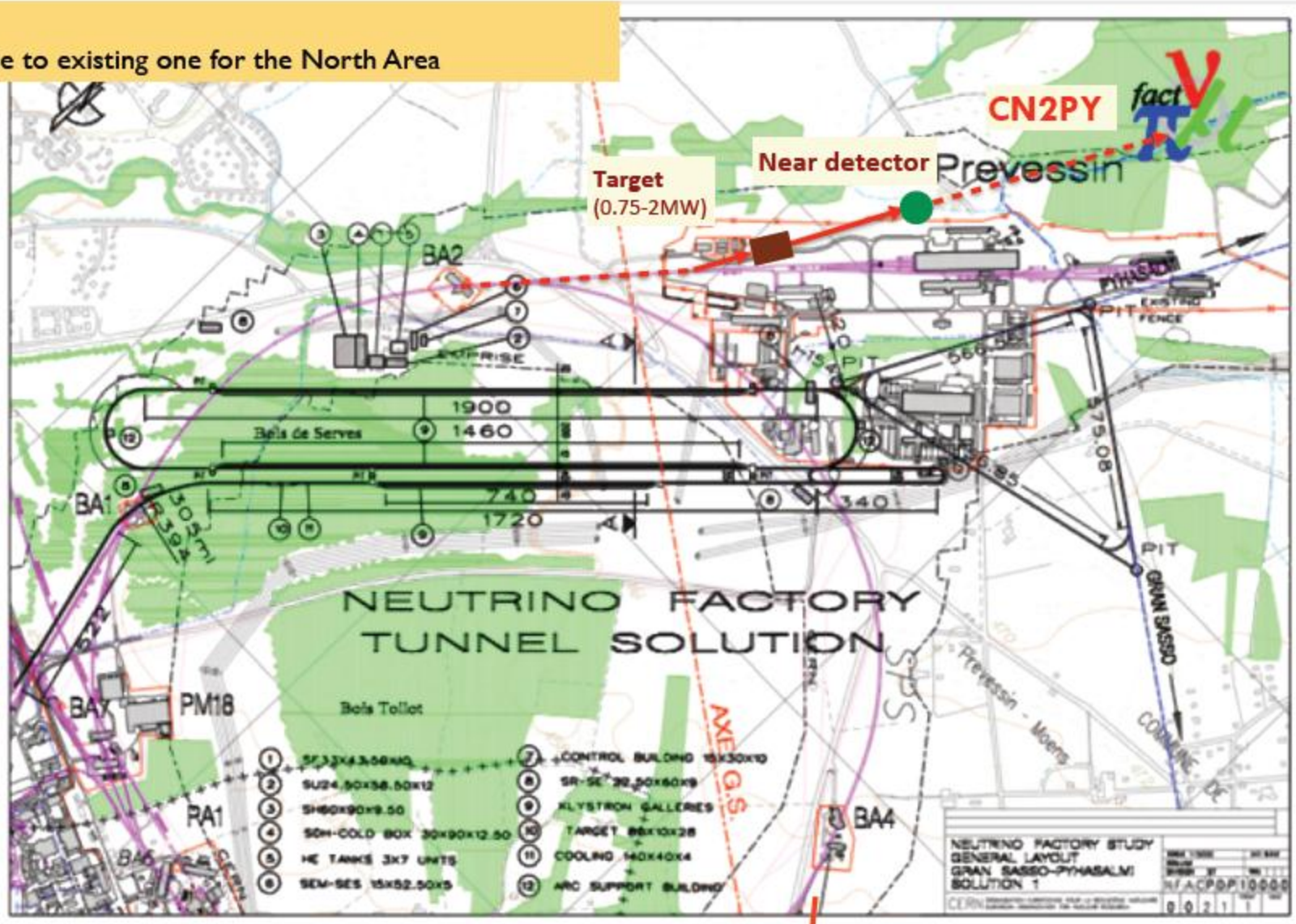
Medium term plans include long term plans!

Alain Blondel reflection DPNC 18-06-2012

Alain Blondel HIF

CERN ν-beam to Pyhasalmi - CN2PY

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



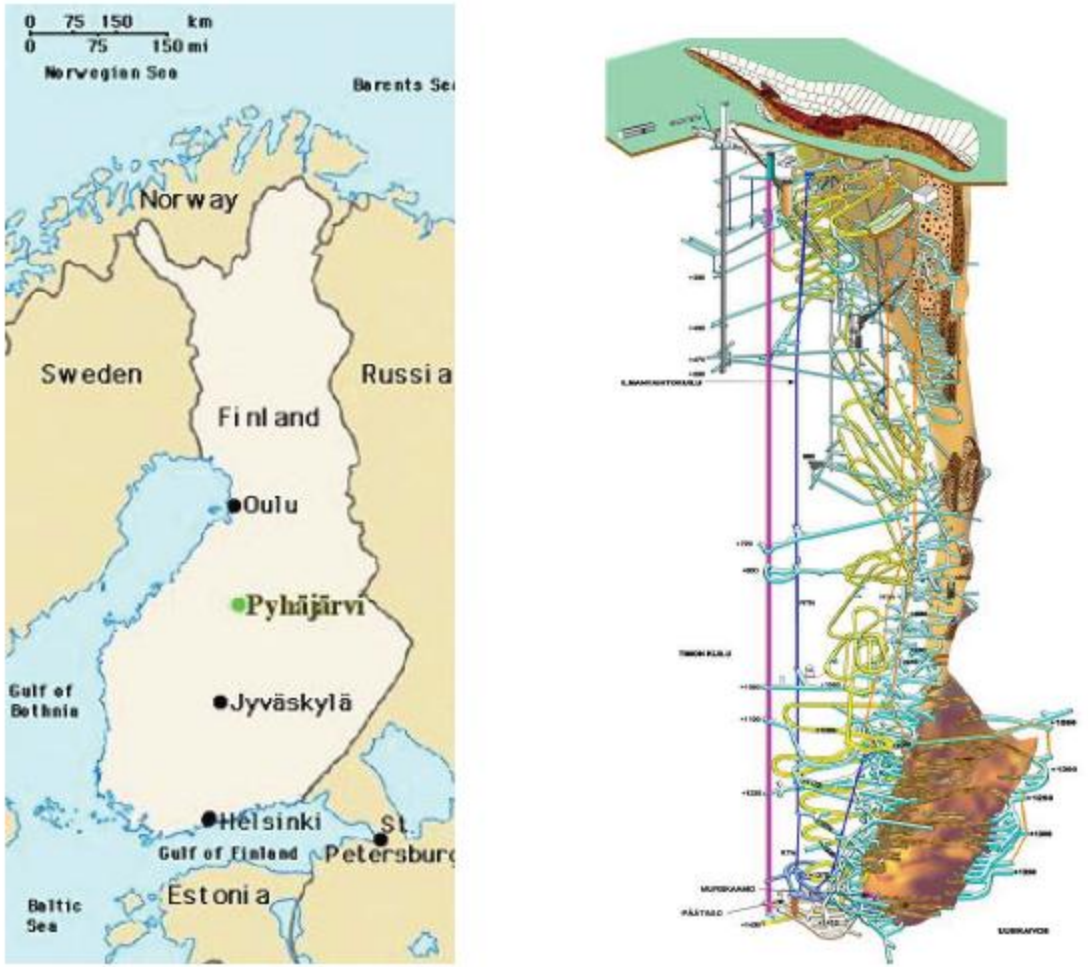
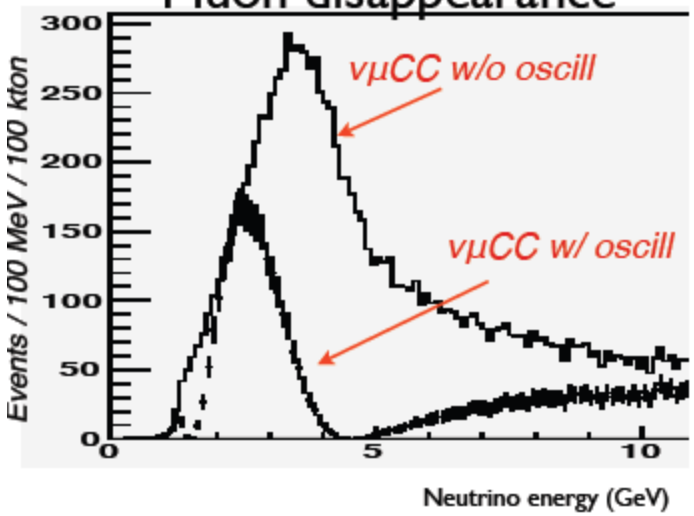


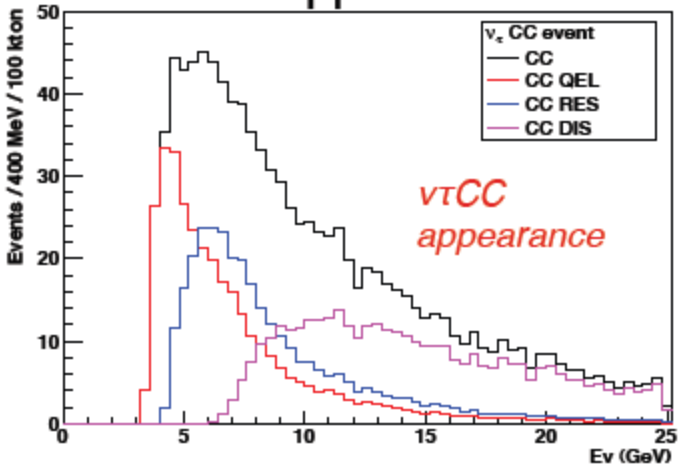
FIG. 7: (left) Far site location; (right) present layout of the Pyhäsalmi Mine.

Muons, electrons and taus

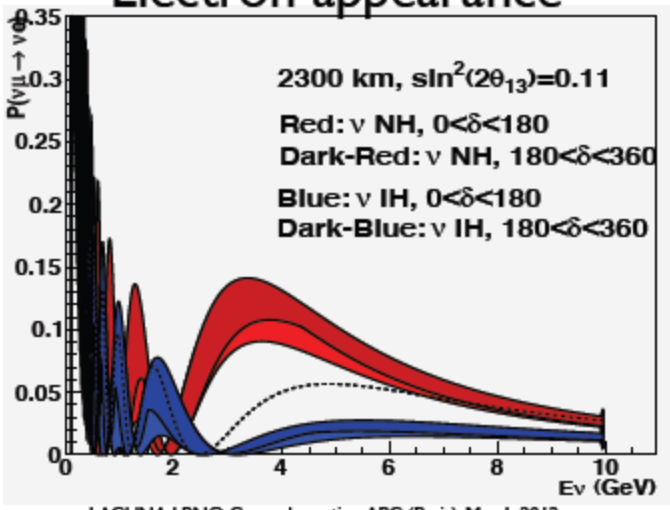
Muon disappearance



Tau appearance

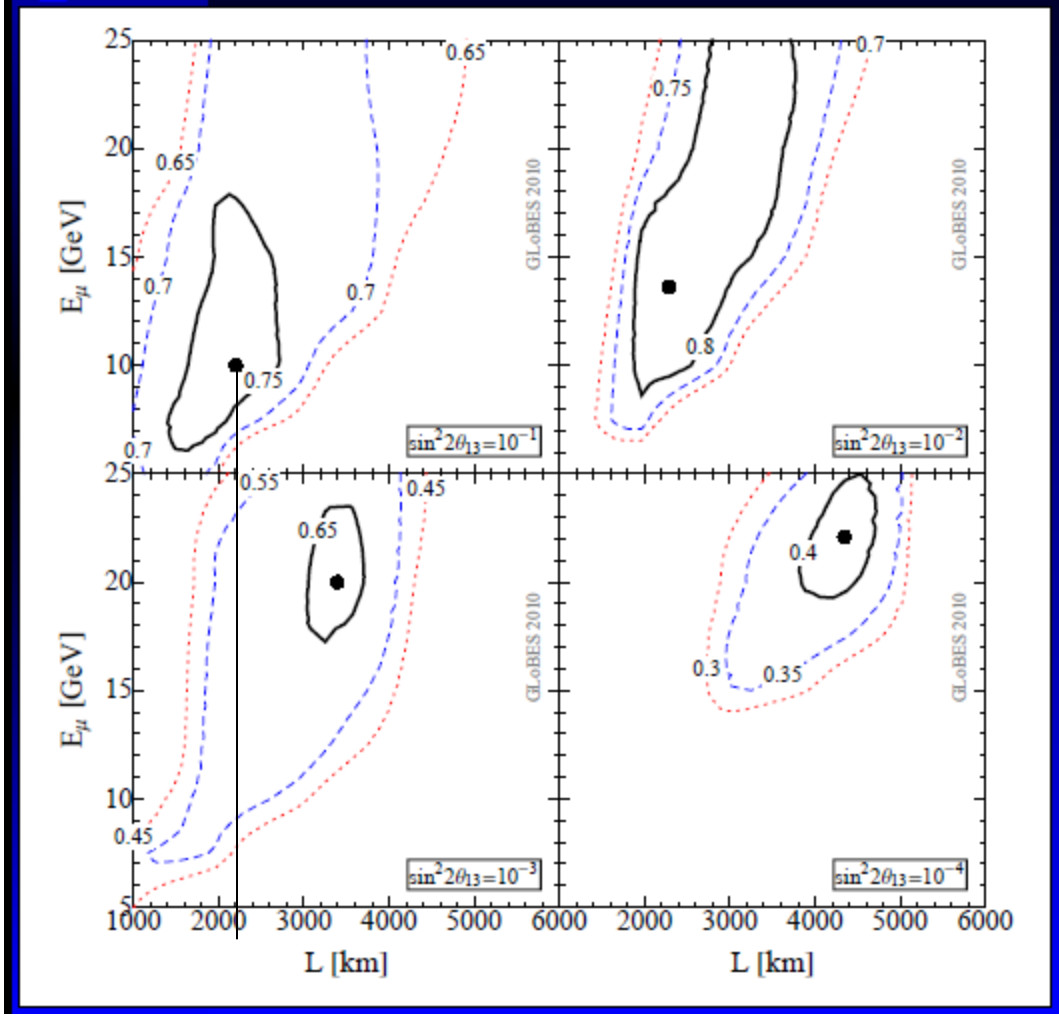


Electron appearance



Rich oscillation physics

Optimization – one baseline



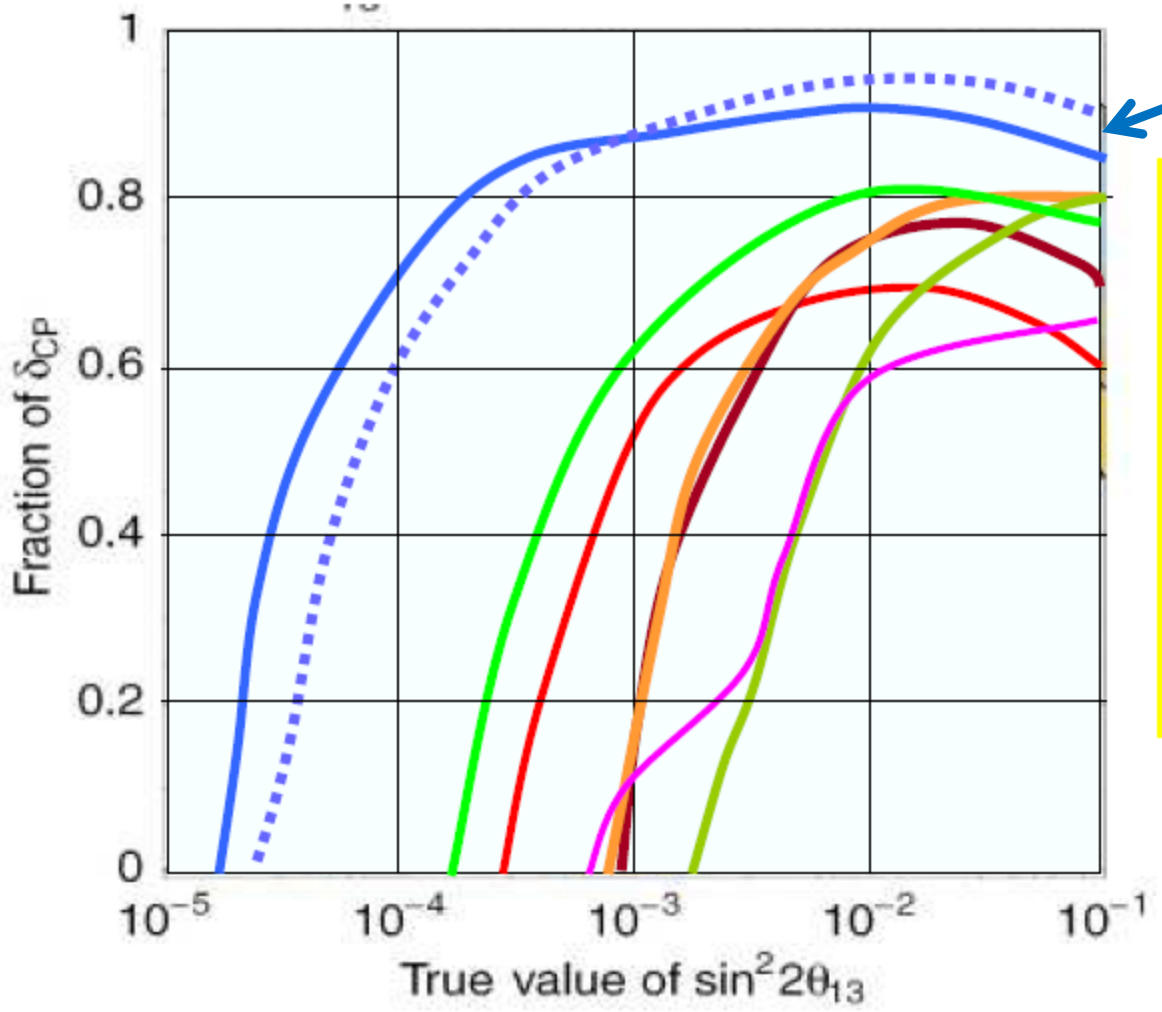
At large θ_{13}, using MIND and one baseline, optimum is at 2200-2300 km and 10-14 GeV.

CPF 0.77-0.84

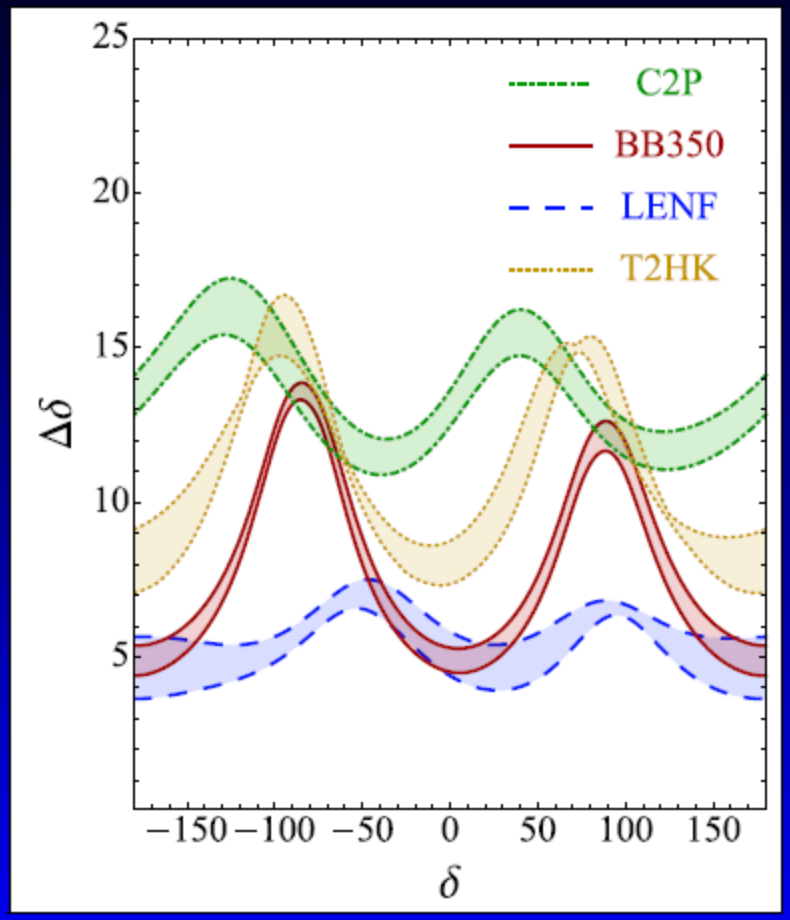
S. Agarwalla, PH, J. Tang, W. Winter JHEP 1101 120 (2011).

P. Huber – VT-CNP – p. 16

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



CP precision



P. Coloma, A. Donini, E. Fernandez-Martinez, P. Hernandez, ar-Xiv:1203:5651

CONVERGENCE

LAGUNA decided to propose with higher priority the
CERN to Pyhasalmi Long Baseline Neutrino Oscillation experiment @2285 km

EUROnu decided to focus future studies on the Neutrino Factory
because of better performance on CP violation and tests of the 3X3 mixing
The optimum distance is ~2200-2300 km !

➔ we can initiate a long term program with a large underground laboratory
where also proton decay, solar, atmospheric and supernova neutrinos can be studied
and prepare the ultimate study of neutrino oscillations

NB: NEU2012 was very instrumental in this convergence

A Coherent Line …

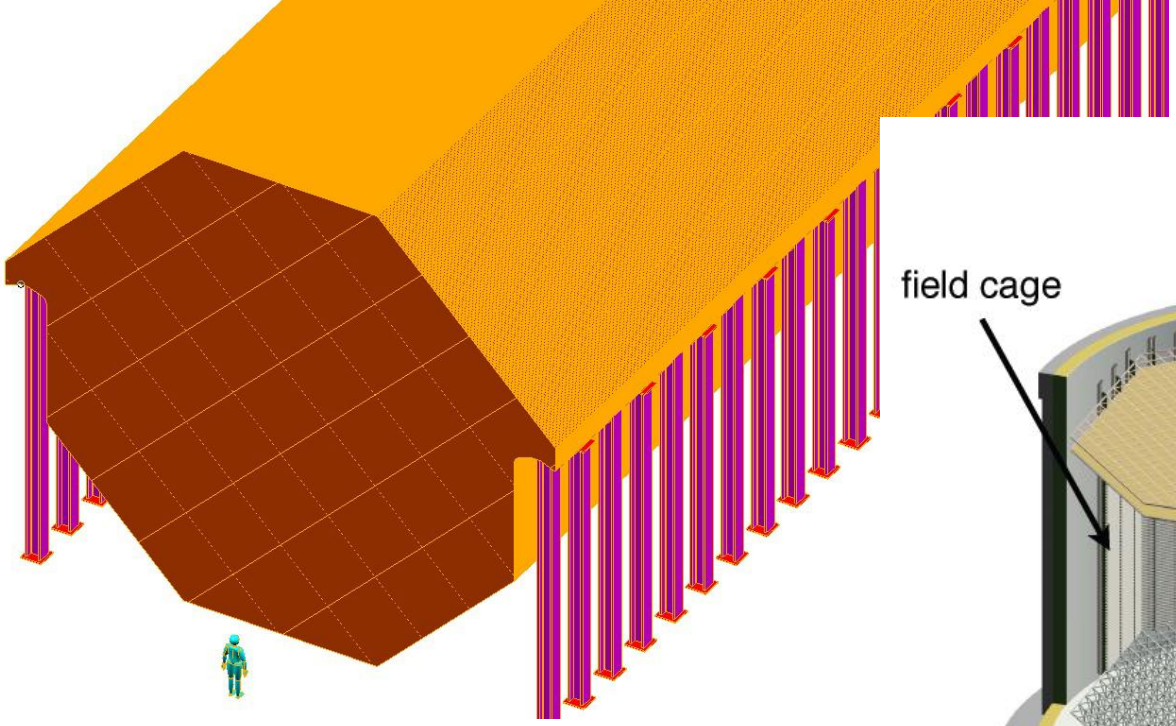
0. SBNF is a proposal (ICARUS + OPERA magnet) to study the LSND anomaly by $\nu_\mu \to \nu_e$ apppearance in the $\Delta m^2 \sim$ eV^2 region. SPS beam in the CERN North Area Neutrino Facility NANF

1. CN2PY « modest » SPS conventional beam line in North Area NANF
from CERN to Pyhasalmi (Finland, 2300km) (dip =~-10^0)
Far detector = 20kton Larg TPC + Magnetized Iron Neutrino Detector (MIND)
near detector = gas argon TPC + plastic scintillator and MIND

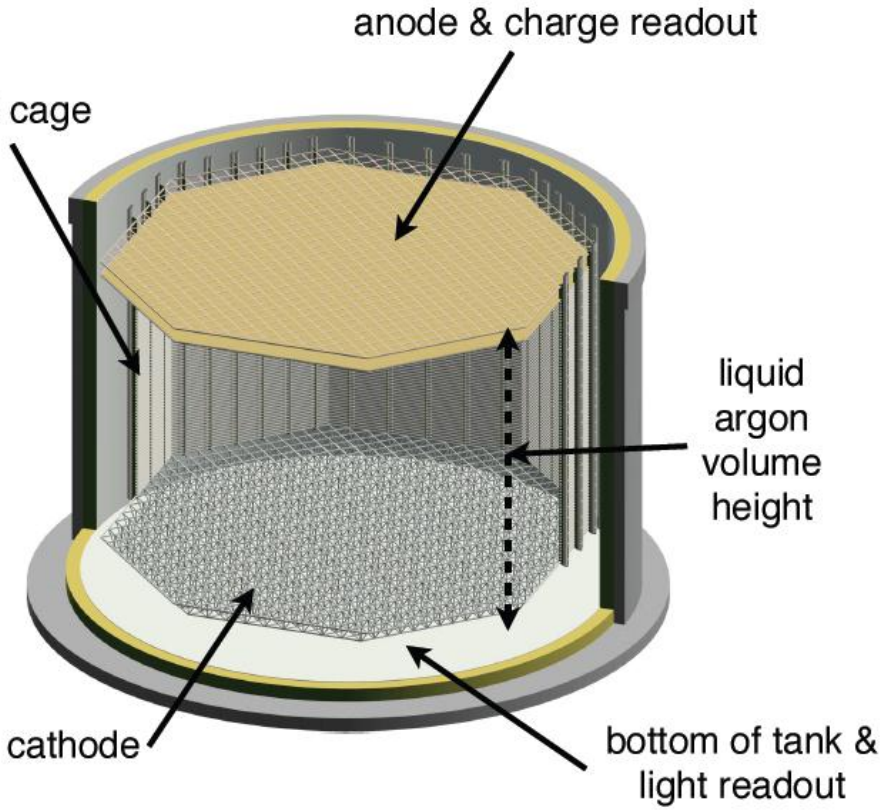
$\nu_\mu \to \nu_e$ a definitive mass hierarchy determination in 2-3 years (ν_μ beam)
+ more precision on $\nu_\mu \to \nu_\mu$ disappearance, $\nu_\mu \to \nu_\tau$ appearance.

Expression of interest in June 2012
Full proposal in 2014,
beam and cavern construction start in 2017
data taking starts 2023
UNIGE role: near detector, MIND

2. NF2PY design study of Neutrino Factory (definitely best ultimate solution)
towards full proposal in 2017
Far detector 100kton MIND
Ultimate meaasurement of CPV and test of 3X3 mixing
UNIGE role : MICE, near detector, MIND

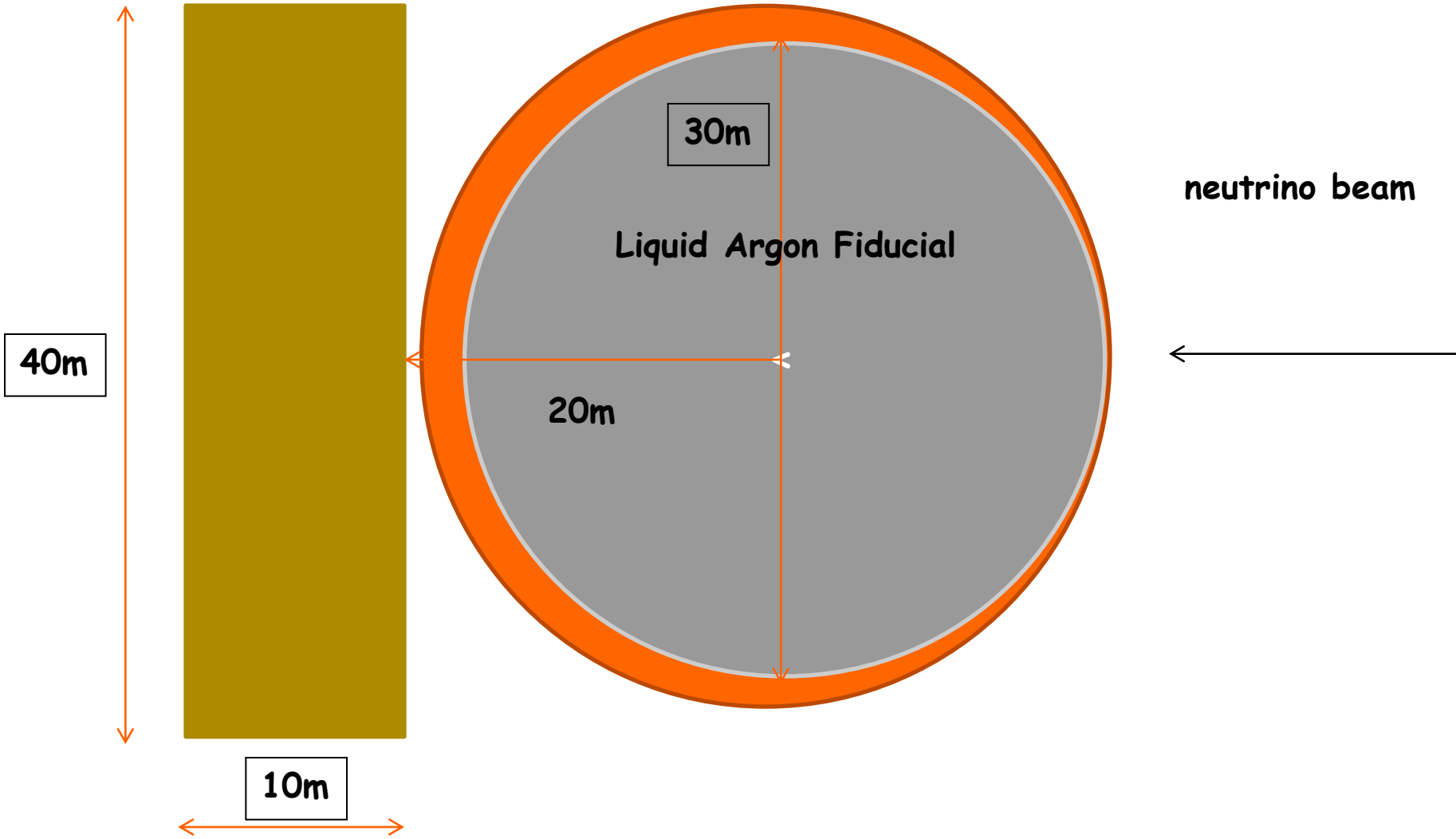


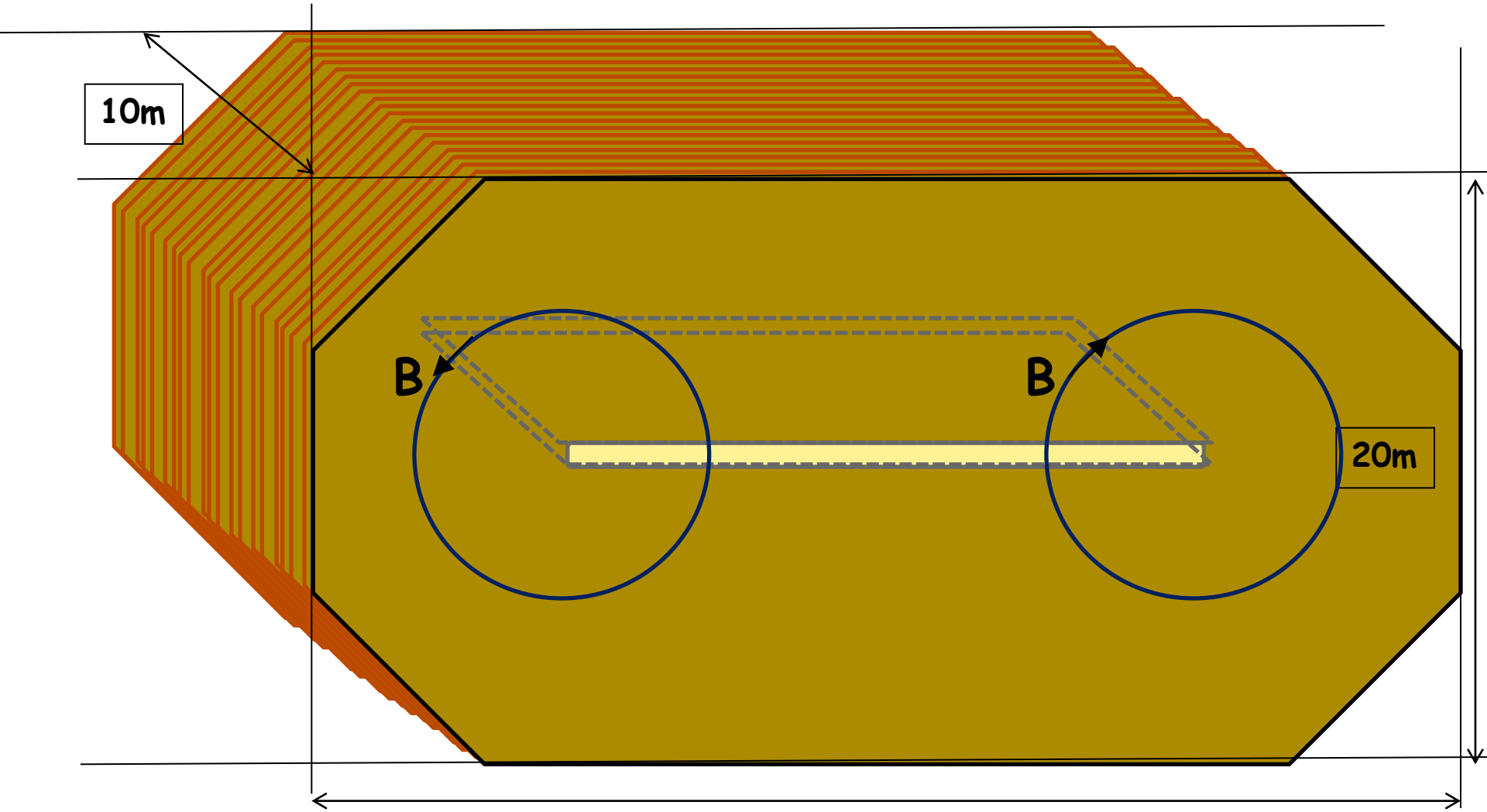
MIND detector =
Neutrino Factory baseline detector
as of the NF-IDR
(Interim Design Report)
100kton Magnetized Iron detector
(1.5 T toroidal field)
Scintillator read out with
Wave Length Shifting fibers and SiPMTs



20kton Glacier detector
Liquid Argon TPC
with 2-phase readout (LEM)

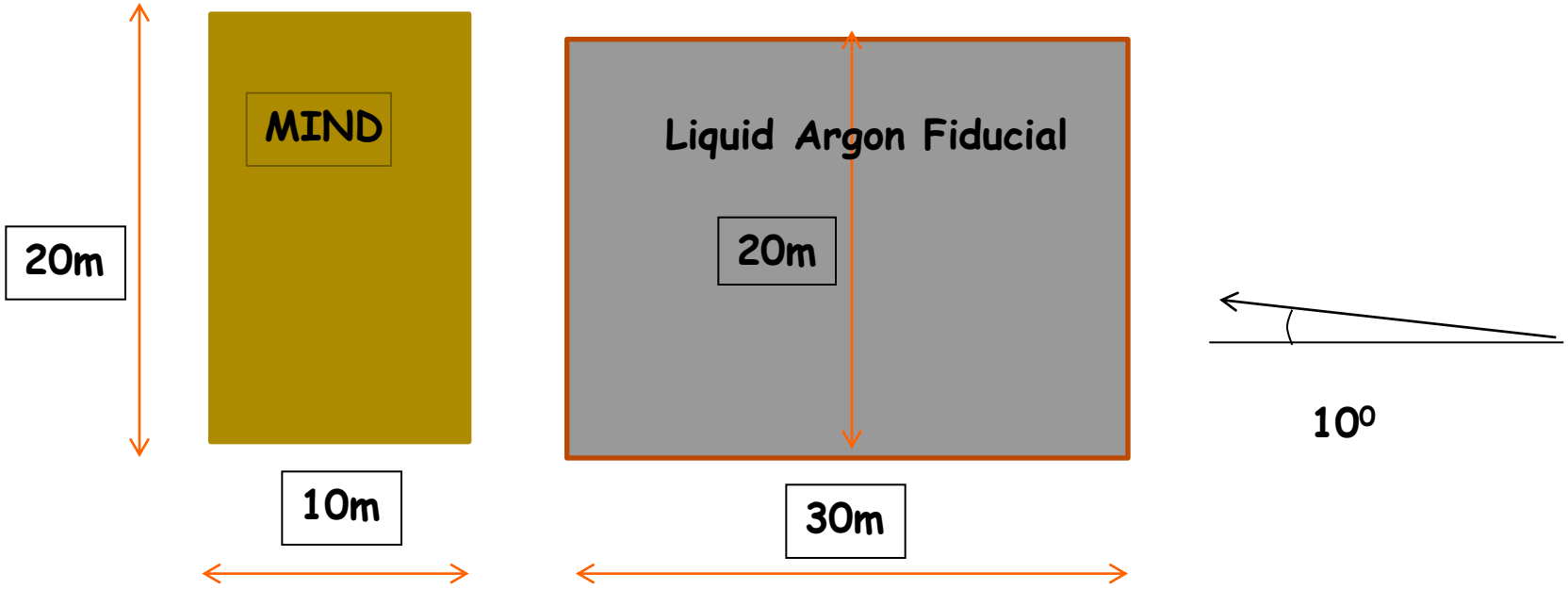
top view

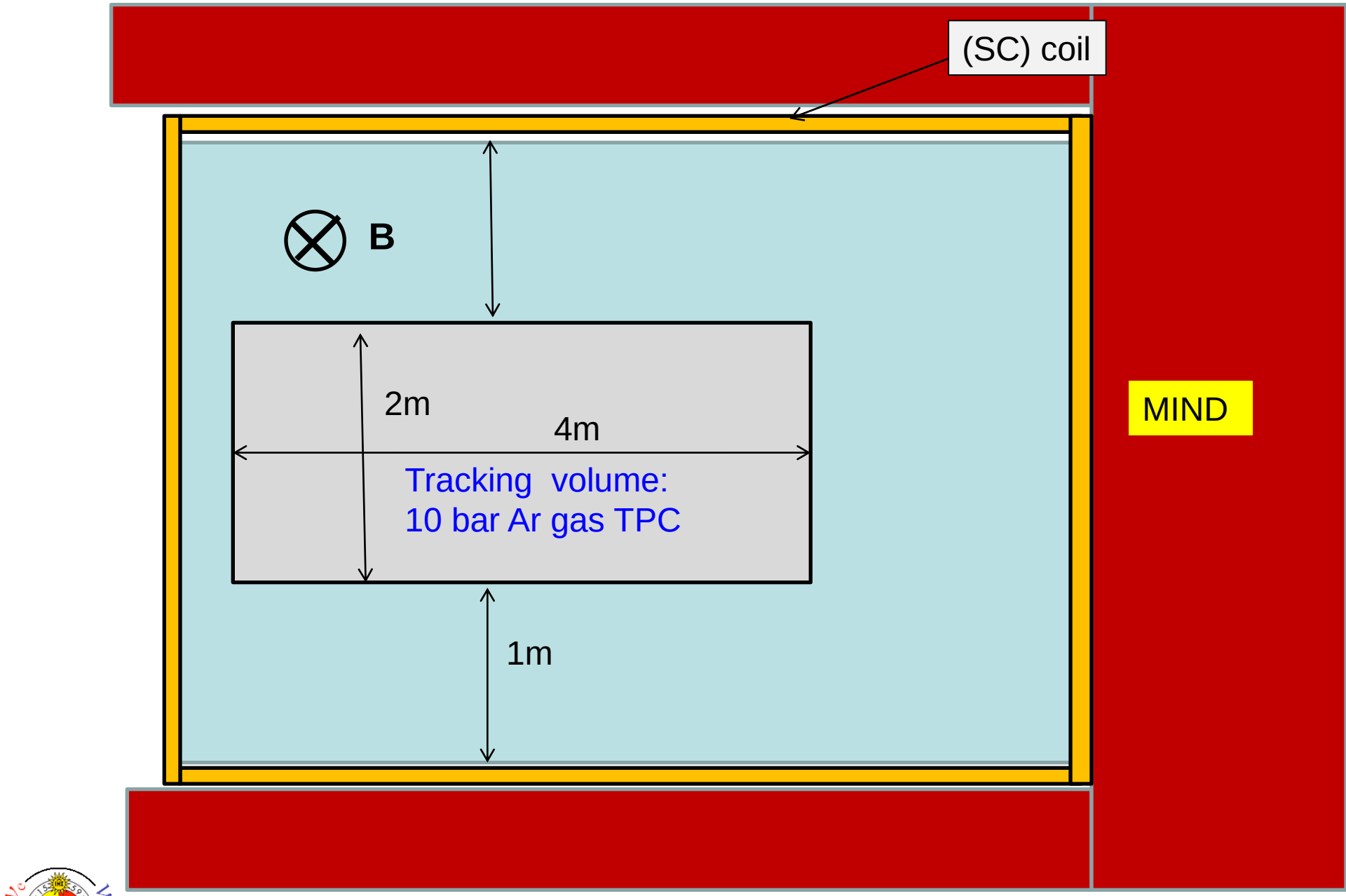




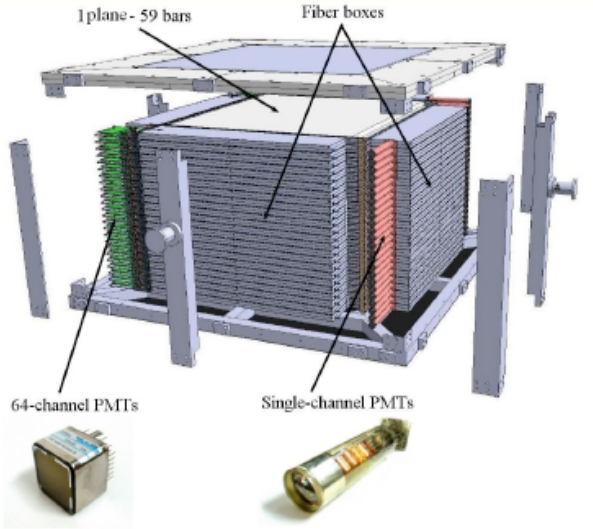
Alain Blondel reflection DPNC 18-06-2012

side view




(SC) coil
B
2m
4m
Tracking volume:
10 bar Ar gas TPC
1m
MIND

EMR Design

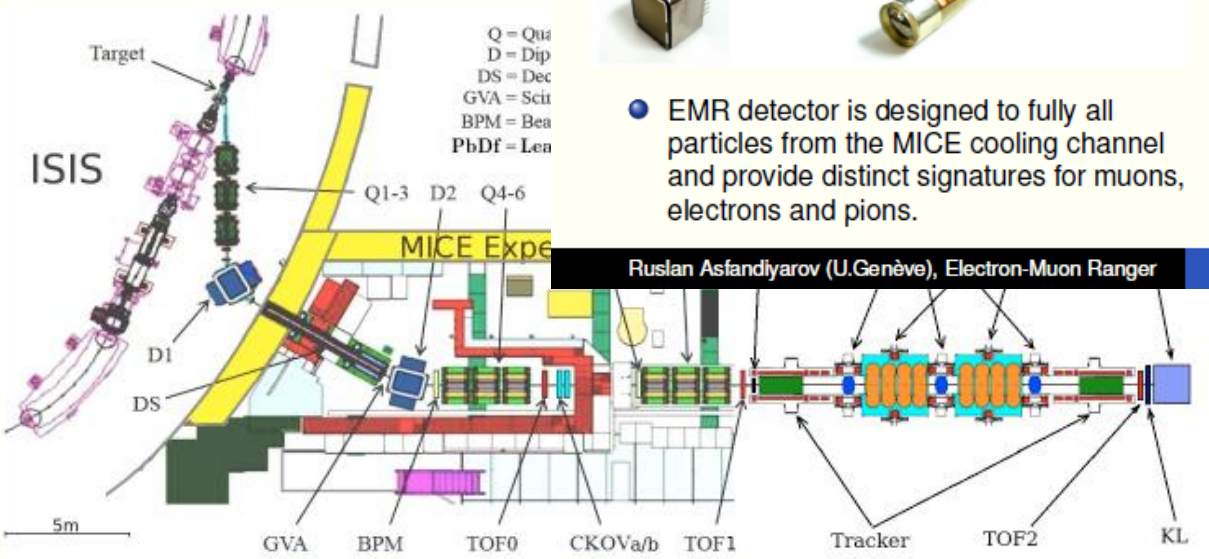


- EMR detector is designed to fully all particles from the MICE cooling channel and provide distinct signatures for muons, electrons and pions.

Characteristics

- 24 modules (module=X&Y planes)
- 59 triangular scintillator bars per plane → 2832 bars
- WLS fiber inside each bar glued and coupled to clear fiber
- total energy per plane detected by single-channel PMT (PHILIPS)
- energy in every bar detected by 64-channel PMT (HAMAMATSU)
- custom made electronics based on MAROC/FPGA ISICs and integrated with CAEN boards
- signal from every channel amplified, shaped and discriminated on-line
- pulse hight and time-over-threshold measured on-line

EMR in MICE

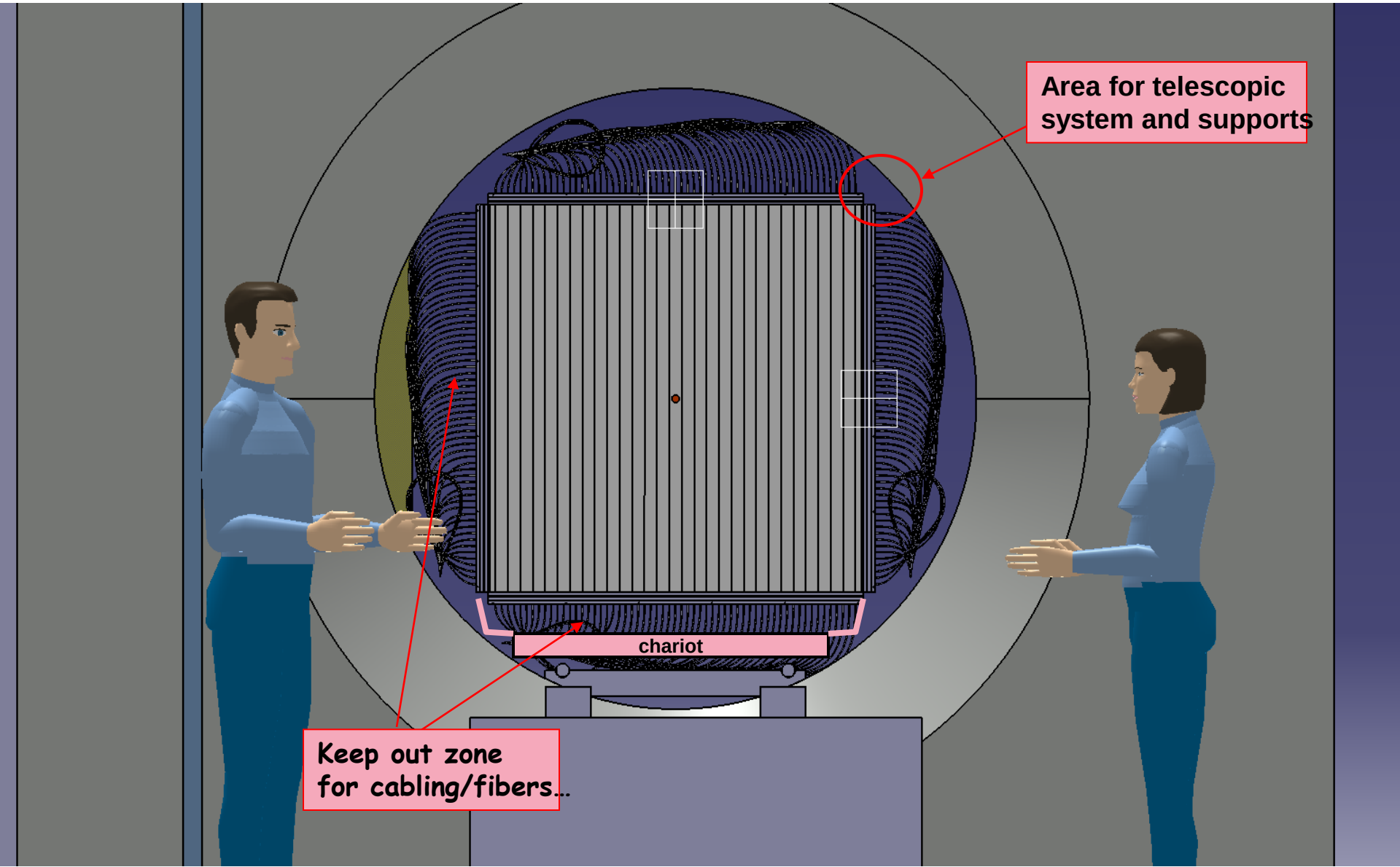


- MICE is designed to produce a 10% cooling effect on the muon beam with momentum 140-240 MeV/c and different selected emittances
- EMR is located at the very end of cooling channel and will stop and measure all outgoing particles

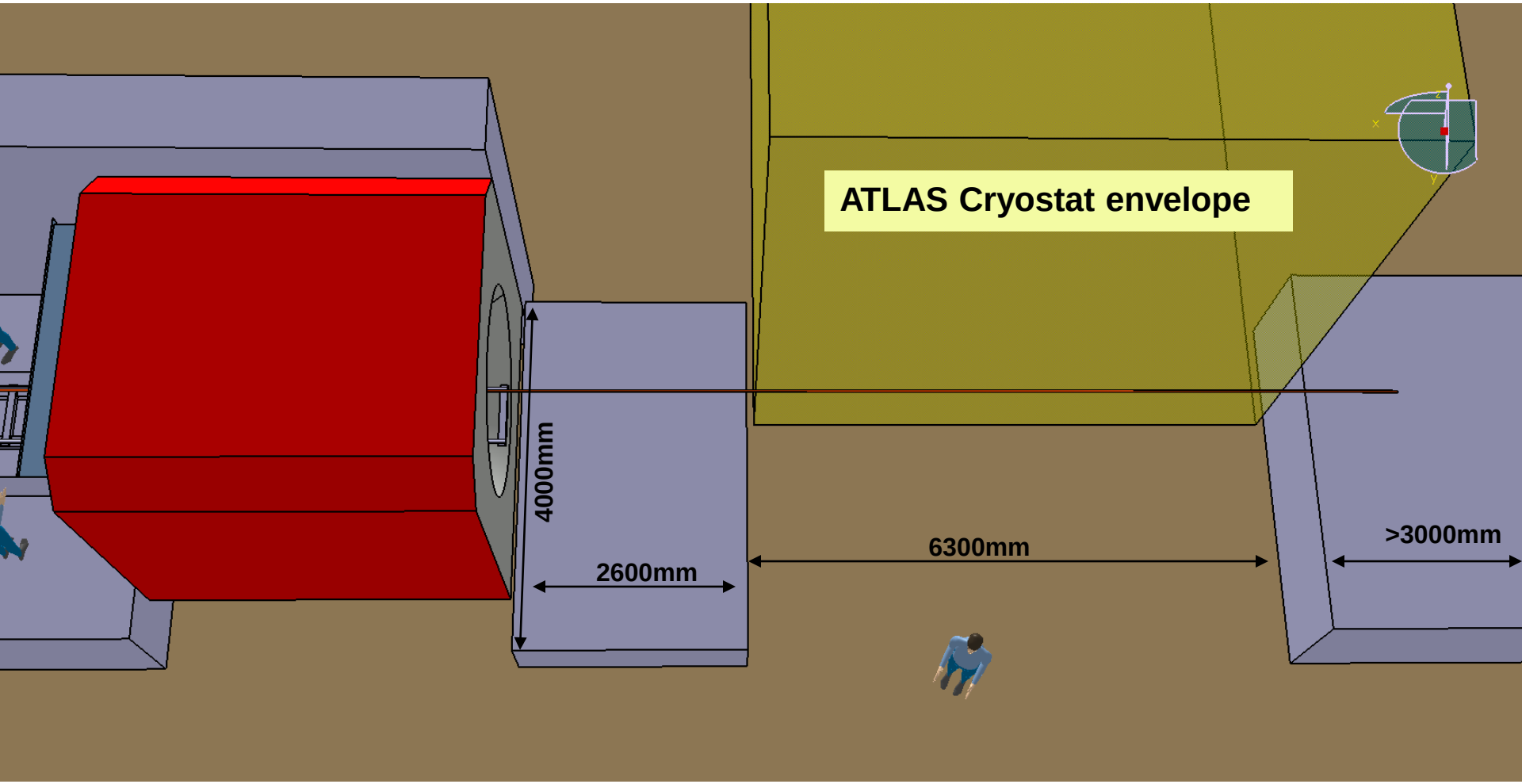
MIND Positioning

TASD proposal

Based on EMR…new bar length to fit in…(1000mm)



MIND possible location
(on the back side of Morpurgo)



The future of the neutrino group at DPNC

with the caveat that many things can happen!

1. T2K will continue data taking until 2017-2020
   -- and may be followed by T2HK….

2. NA61/SHINE will remain the world's best hadroproduction experiment
   --T2K and then NUMI

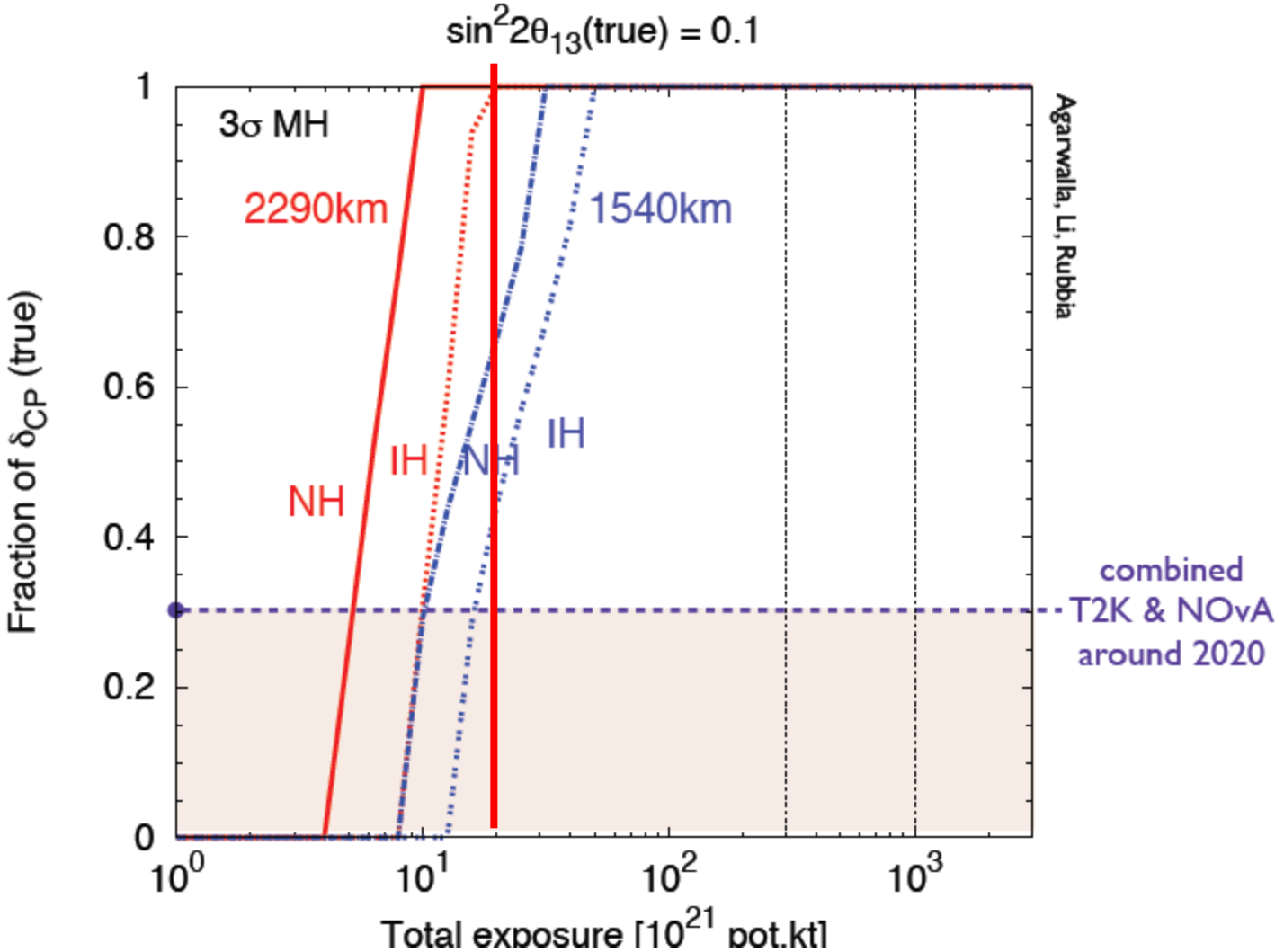
1+2 Physics: $\nu_\mu \rightarrow \nu_e$ appearance → sensitivity to δ_{CP}
$\nu_\mu \rightarrow \nu_\mu$ disappearance → Δm^2_{23} , θ_{23}
cross-section measts (< 1GeV in T2K, 1-10 GeV in MINERvA)

3. The future as we would like it:
   -- North Area Neutrino Facility at CERN
   possibilities : -- Short baseline neutrino experiment (2017?)
   participation straightforward through NA61/SHINE
   -- Long baseline neutrino experiment (CN2PY LBNO)
   (proposal 2014, beam 2023)
   Near detector, MIND
   -- Neutrino Factory (proposal 2017, beam 2030)

   -- preparations for this future:
   NEU2012
   MICE (NF) and EMR, AIDA

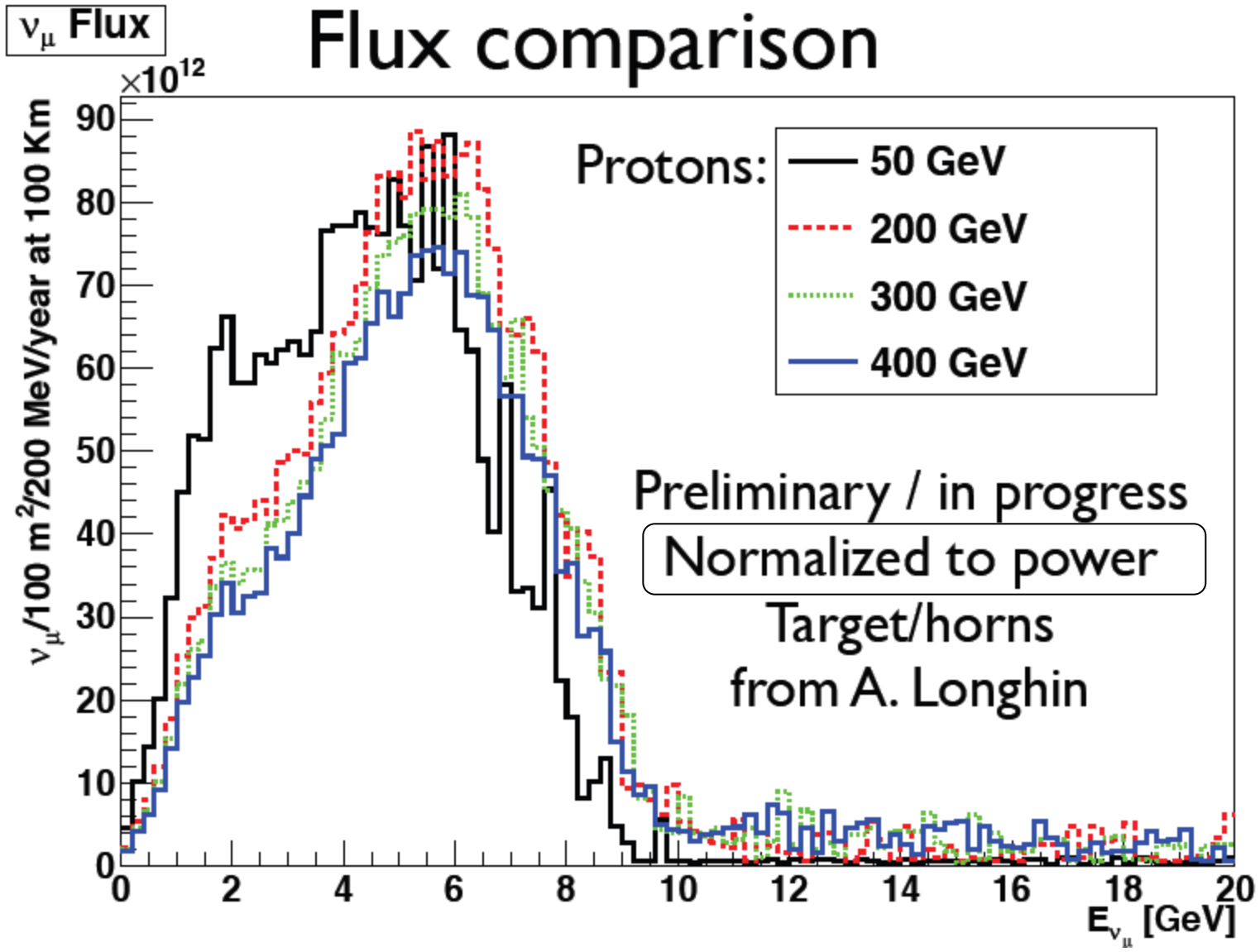
SPARES

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

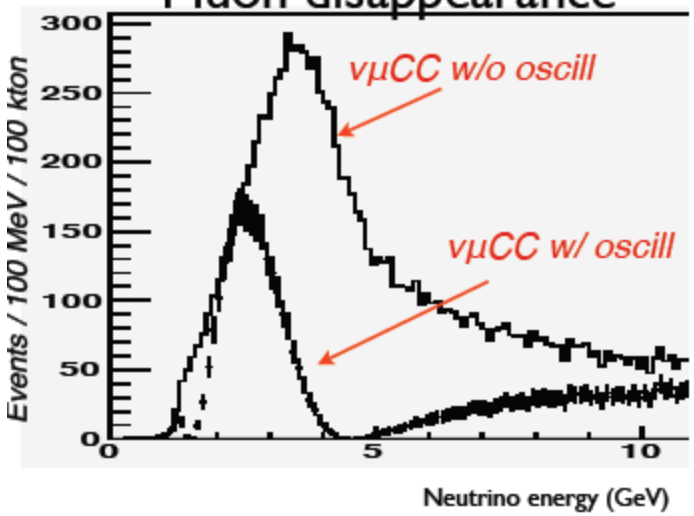
Alain Blondel reflection DPNC 18-06-2012


ν_μ Flux
Flux comparison
$\times 10^{12}$
ν_μ/100 m^2/200 MeV/year at 100 Km
Protons:
50 GeV
200 GeV
300 GeV
400 GeV
Preliminary / in progress
Normalized to power
Target/horns
from A. Longhin
E_{ν_μ} [GeV]

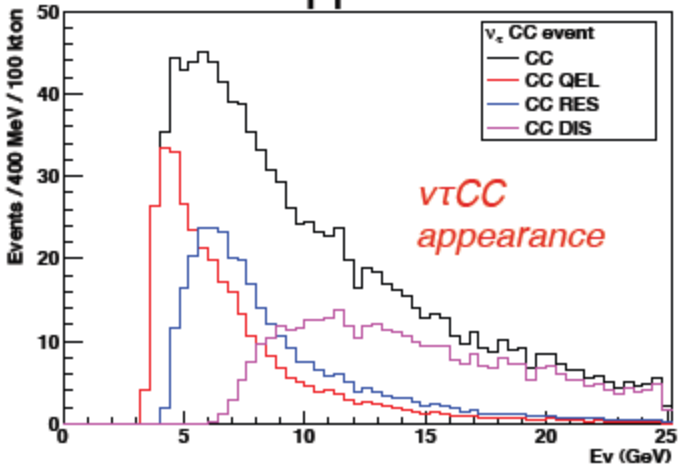
S. Di Luise

Muons, electrons and taus

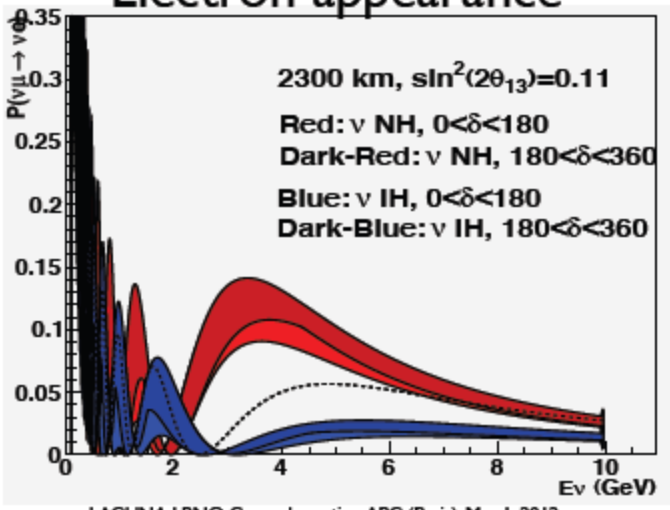
Muon disappearance



Tau appearance

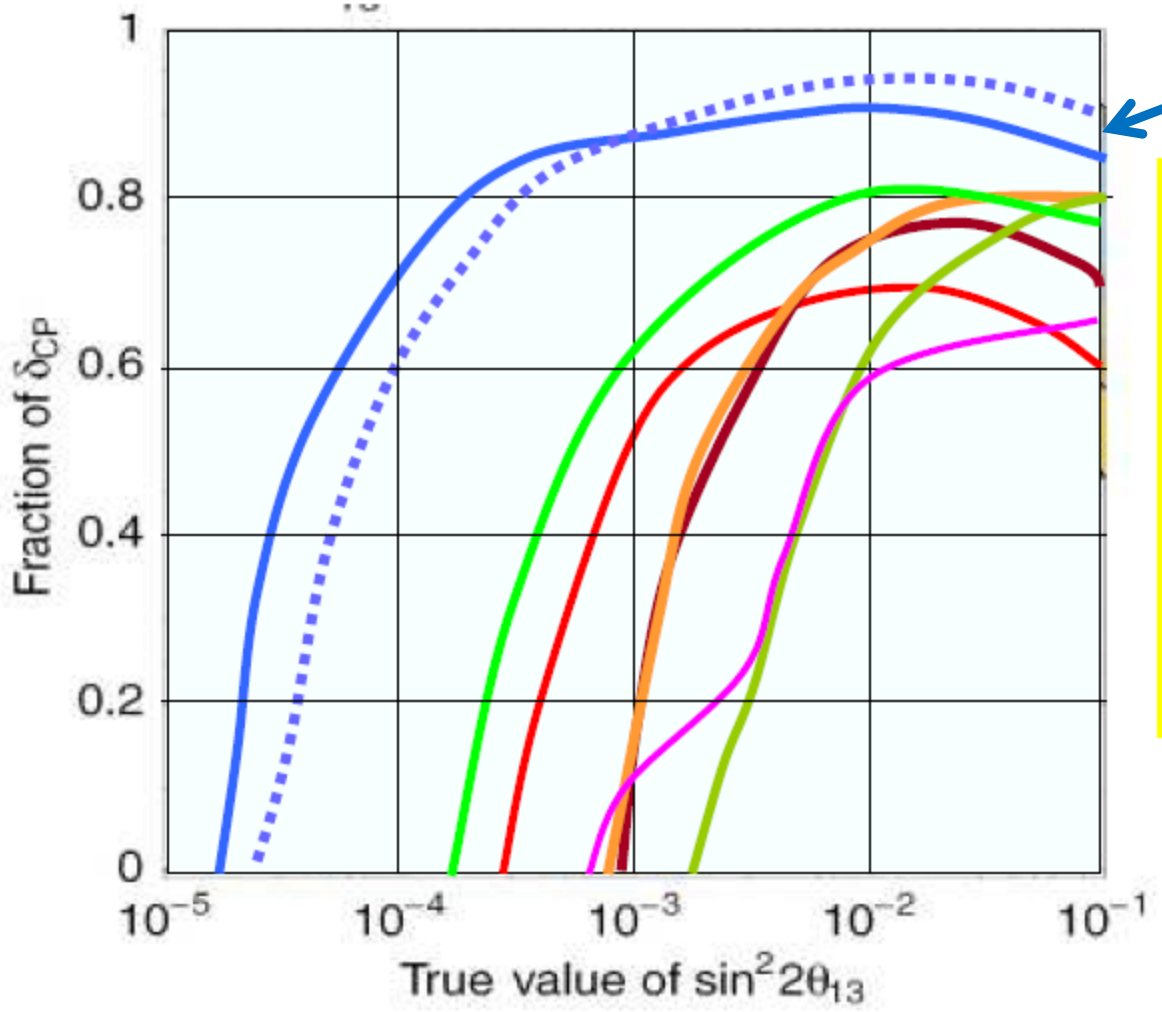


Electron appearance

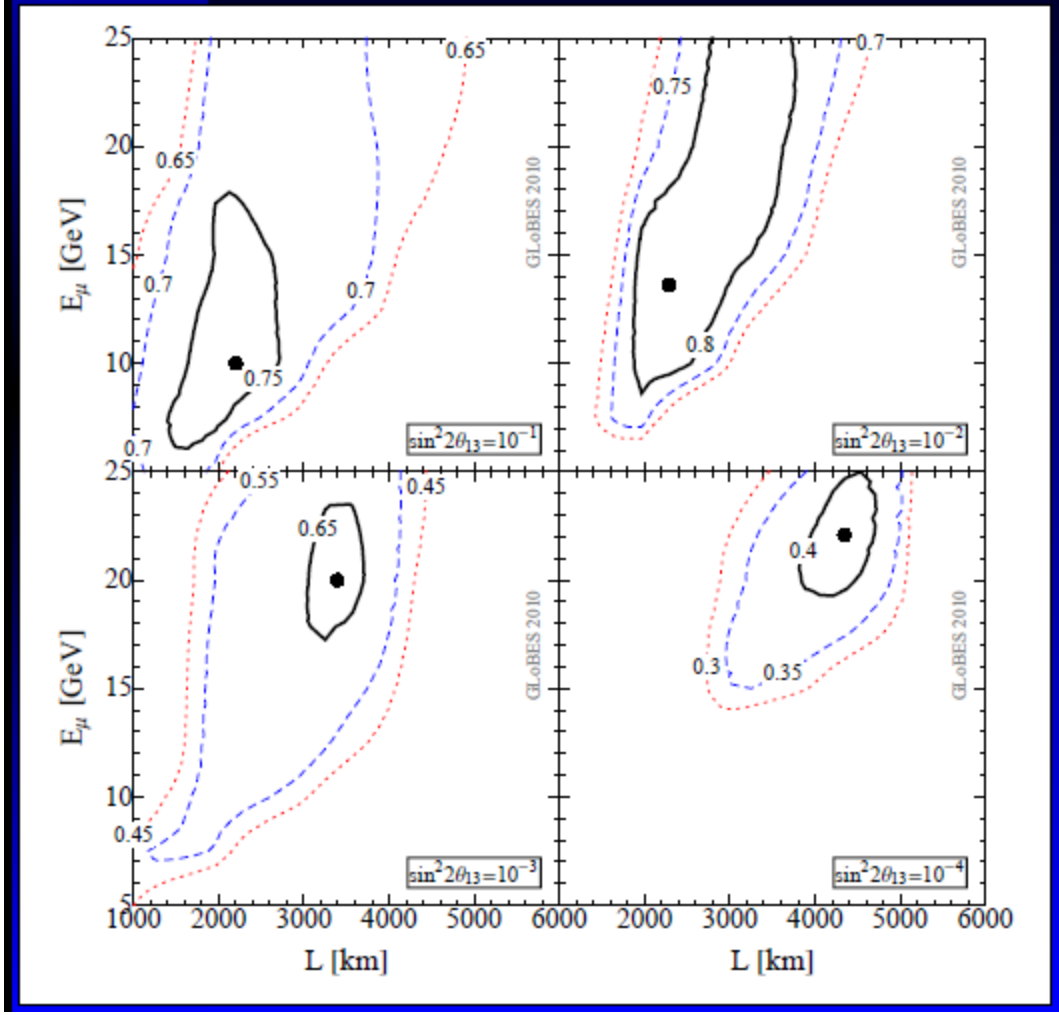


Rich oscillation physics

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.

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	$\sin^2 2\theta_{13} = 0.086 \pm 0.041$ (stat) ± 0.030 (syst)	1.7σ
03/2012 Daya Bay	Reactor	$\sin^2 2\theta_{13} = 0.092 \pm 0.016$ (stat) ± 0.005 (syst)	5.2σ
04/2012 Reno	Reactor	$\sin^2 2\theta_{13} = 0.113 \pm 0.013$(stat) ± 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