

The CERN to Pyhasalmi long baseline experiment (LBNO): expression of interest

Marco Zito
GDR, Paris, 20 juin 2012

Slides from A. Rubbia, A. Blondel, P. Huber ...

Expression of Interest
for a very long baseline neutrino oscillation experiment
(LBNO)

AUTHOR LIST NOT YET COMPLETE,¹ A. M. Guler,¹ M. Kamiscioglu,¹ R. Sever,¹ A.U. Yilmazer,² C. Gunes,² D. Yilmaz,² P. Del Amo Sanchez,³ D. Duscheneau,³ H. Pessard,³ E. Marcoulaki,⁴ I. A. Papazoglou,⁴ V. Berardi,⁵ F. Cafagna,⁵ M.G. Catanesi,⁵ L. Magaletti,⁵ A. Mercadante,⁵ M. Quinto,⁵ E. Radicioni,⁵ A. Ereditato,⁶ I. Kreslo,⁶ C. Pistillo,⁶ M. Weber,⁶ A. Ariga,⁶ T. Ariga,⁶ T. Strauss,⁶ M. Hierholzer,⁶ J. Kawada,⁶ C. Hsu,⁶ S. Haug,⁶ A. Jipa,⁷ I. Lazanu,⁷ M. Prest,⁸ Y.A. Gornushkin,⁹ S. Pascoli,¹⁰ R. Collins,¹¹ M. Haworth,¹¹ J. Thompson,¹¹ A. Blondel,¹² A. Bravar,¹² F. Dufour,¹² Y. Karadzhov,¹² A. Korzenev,¹² E. Noah,¹² M. Ravonel,¹² M. Rayner,¹² R. Asfandiyarov,¹² A. Haesler,¹² C. Martin,¹² E. Scantamburlo,¹² F. Cadoux,¹² R. Bayes,¹³ F.J.P. Soler,¹³ L. Aalto-Setälä,¹⁴ K. Enqvist,¹⁴ K. Huitu,¹⁴ K. Rummukainen,¹⁴ G. Nuijten,¹⁵ M. Manninen,¹⁶ J. Maalampi,¹⁶ K.J. Eskola,¹⁶ K. Kainulainen,¹⁶ T. Kalliokoski,¹⁶ K. Loo,¹⁶ J. Suhonen,¹⁶ W.H. Trzaska,¹⁶ K. Tuominen,¹⁶ A. Vrtanen,¹⁶ I. Bertram,¹⁷ A. Finch,¹⁷ N. Grant,¹⁷ L.L. Kormos,¹⁷ P. Ratoff,¹⁷ J. Coleman,¹⁸ C. Touramanis,¹⁸ K. Mavrokoridis,¹⁸ N. McCauley,¹⁸ D. Payne,¹⁸ P. Jonsson,¹⁹ A. Kaboth,¹⁹ K. Long,¹⁹ M. Malek,¹⁹ Y. Uchida,¹⁹ M.O. Wascko,¹⁹ F. Di Lodovico,²⁰ J.R. Wilson,²⁰ B. Still,²⁰ R. Sacco,²⁰ R. Terri,²⁰ A. Izmaylov,²¹ M. Khabibullin,²¹ A. Khotjantsev,²¹ Y. Kudenko,²¹ V. Matveev,²¹ O. Mineev,²¹ N. Yershov,²¹ V. Palladino,²² T. Pihlajaniemi,²³ M. Weckström,²³ K. Mursula,²³ T. Enqvist,²³ P. Kuusiniemi,²³ T. Räihä,²³ J. Sarkamo,²³ M. Slupecki,²³ J. Hissa,²³ E. Kokko,²³ M. Aittola,²³ G. Barr,²⁴ J. de Jong,²⁴ A. Weber,^{24,25} H. O'Keeffe,²⁴ J. Ilic,²⁵ D. Wark,²⁵ A. Longhin,²⁶ A. Robert,²⁷ B. Andrieu,²⁷ B. Popov,²⁷ C. Giganti,²⁷ J.-M. Levy,²⁷ J. Dumarchez,²⁷ M. Buizza-Avanzini,²⁸ A. Cabrera,²⁸ J. Dawson,²⁸ D. Franco,²⁸ D. Krym,²⁸ M. Obolensky,²⁸ T. Patzak,²⁸ A. Tonazzo,²⁸ F. Vanucci,²⁸ M. Bonesini,²⁹ D. Orestano,³⁰ B. Di Micco,³⁰ L. Tortora,³¹ O. Bésida,³² A. Delbart,³² S. Emery,³² V. Galymov,³² E. Mazzucato,³² G. Vasseur,³² M. Zito,³² V. Kudryavtsev,³³ L. Thompson,³³ R. Tsenev,³⁴ D. Kolev,³⁴ I. Rusinov,³⁴ M. Bogomilov,³⁴ G. Vankova,³⁴ R. Matev,³⁴ A. Vorobьев,³⁵ Yu. Novikov,³⁵ S. Kosyanenko,³⁵ V. Suvorov,³⁵ G. Gavrilov,³⁵ E. Vallazza,³⁶ S. Agarwalla,³⁷ D. Autiero,³⁸ L. Chaussard,³⁸ Y. Déclais,³⁸ J. Marteau,³⁸ E. Pennacchio,³⁸



1. PHYSICS CASE

The existence of massive neutrinos is, today, the only existing demonstration of new physics beyond the standard model of particle physics (SM)

It requires extension of the SM in a way that is yet unknown.

- Dirac or/and Majorana mass terms
- spectrum of masses, mixing angles and phases
- new particles: right-handed (a.k.a. sterile) neutrinos

This opens a deep and promising field of research, with a large potential for discoveries of considerable consequences.

discoveries:

Mass hierarchy, CP violation, $O\nu\beta\beta$, sterile neutrinos, violation of unitarity, etc

consequences:

Insight in the nature of particle masses and the question of flavour

Baryon asymmetry of the Universe

Evolution of early Universe

Dark matter

Europe should place neutrino physics at highest level of priority.

A decade after CHOOZ: the θ_{13} revolution

- T2K (Jun 2011):
 $\sin^2 2\theta_{13} = 0.03 - 0.34$ (90% CL).

T2K Collaboration, Phys.Rev.Lett. 107 (2011) 041801

See talk by GL Fogli

- MINOS (July 2011):
 $\sin^2 2\theta_{13} \neq 0$ at 89% CL.

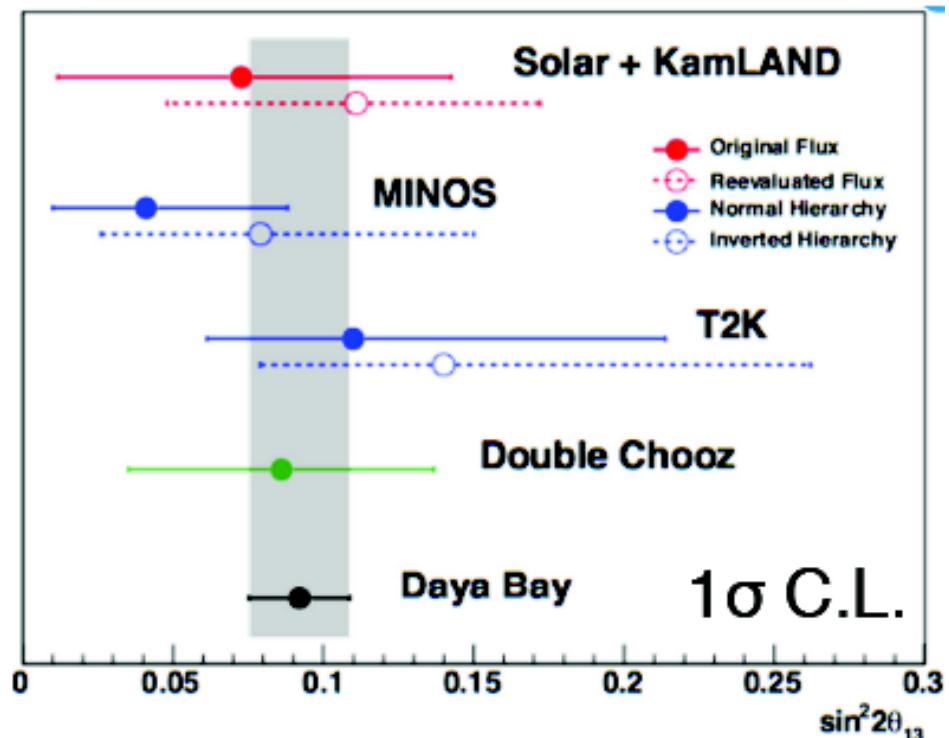
MINOS Collaboration, Phys.Rev.Lett. 107 (2011) 181802

- Double CHOOZ (Dec 2011):
 $\sin^2 2\theta_{13} = 0.017 - 0.16$ (90% CL).

Double CHOOZ Collaboration, arXiv: 1112.6353 [hep-ex].

- Daya Bay (Mar 2012):
 $\sin^2 2\theta_{13} \neq 0$ at 5.2σ (!),
best-fit = 0.092.

Daya Bay Collaboration, arXiv: 1203.1669 [hep-ex].



$$\sin^2(2\theta_{13}) = 0.092 \pm 0.016(stat) \pm 0.005(syst)$$

- Reno (April 2012):
exclude no oscillations at 4.9σ \longrightarrow $\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat) \pm 0.019(syst)$

Next steps

- Theta13 observation opens an exciting possibility in the study of the mixing matrix PMNS
- CP violation phase delta, matter hierarchy, theta23 can be explored at a long baseline neutrino experiment
- The CP violation phase delta could help explaining the matter-antimatter asymmetry (and mystery)
- In the end, we would like to explore PMNS to the same level of accuracy as CKM (eg. Unitarity, cf new physics potential of $Bs \rightarrow \mu\mu$)

What we want to learn

In the context of long baseline neutrino experiments

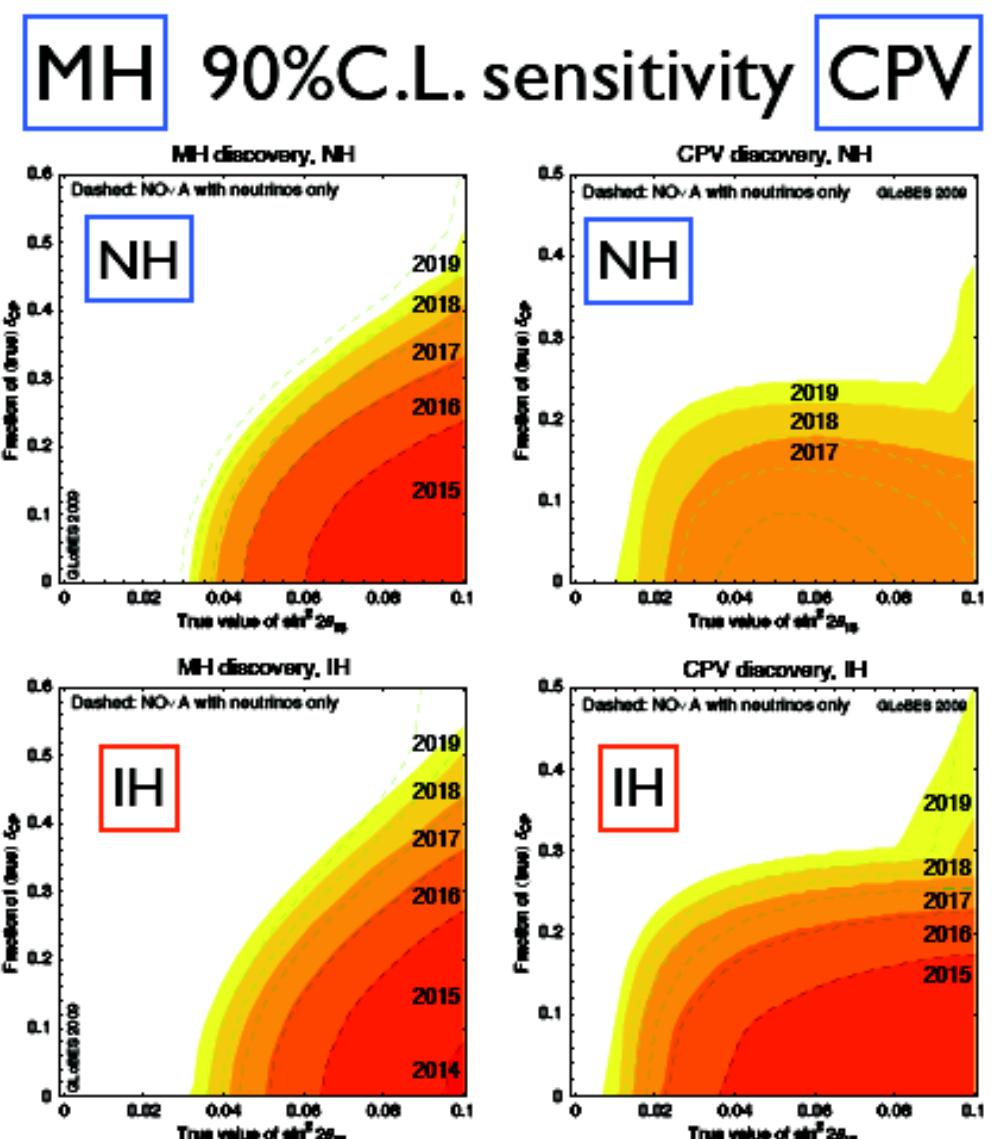
- δ_{CP}
- mass hierarchy
- $\theta_{23} = \pi/4$, $\theta_{23} < \pi/4$ or $\theta_{23} > \pi/4$?
- New physics?

It is very difficult to rank those measurements in their relative importance

Given the current state of the theory of neutrinos we can not say with confidence that any one quantity is more fundamental than any other.

T2K and NOvA: in the future

- Preliminary estimation of sensitivity of T2K and NOvA *See talk by Schwetz*
- Nominal beam power scenarios (750kW). Need to check beam power assumptions.
- For $\sin^2 2\theta_{13} = 0.1$, approximately (at 90% C.L.):
 - MH: $\approx 50\%$ coverage
 - CPV: $\approx 30\text{-}40\%$ coverage (robustness vs MH ?)
- Is 90% C.L. enough ? at 3σ C.L. sensitivity is highly reduced even with largely increased statistics.
- Atmospherics to the rescue ?
- Official curves to be produced by experiments with revised projections.



Huber et al., JHEP 0911:044, 2009

Oscillation phenomenology

Approximate formula (M. Freund)

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 \theta_{23} \frac{\sin^2 2\theta_{13}}{(\hat{A} - 1)^2} \sin^2((\hat{A} - 1)\Delta) + \alpha \frac{8J_{CP}}{\hat{A}(1 - \hat{A})} \sin(\Delta) \sin(\hat{A}\Delta) \sin((1 - \hat{A})\Delta) + \alpha \frac{8I_{CP}}{\hat{A}(1 - \hat{A})} \cos(\Delta) \sin(\hat{A}\Delta) \sin((1 - \hat{A})\Delta) + \alpha^2 \frac{\cos^2 \theta_{23} \sin^2 2\theta_{12}}{\hat{A}^2} \sin^2(\hat{A}\Delta)$$

quadratic dep. on θ_{13}
matter effect $\sim E$

~ 7500 km
magic bln

~ 2540 kr
magic blr

solar

term

linear dep. on θ_{13}

CPV term
approximate dependence

$\sim L/E$

$$J_{CP} = 1/8 \sin \delta_{CP} \cos \theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}$$

$$I_{CP} = 1/8 \cos \delta_{CP} \cos \theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}$$

$$\alpha = \Delta m_{21}^2 / \Delta m_{31}^2, \Delta = \Delta m_{31}^2 L / 4E$$

$$\hat{A} = 2VE / \Delta m_{31}^2 \approx (E_\nu / \text{GeV}) / 11 \text{ For Earth's crust.}$$

CP asymmetry grows as
 θ_{13} becomes smaller !

Correlations !

The degeneracies problem

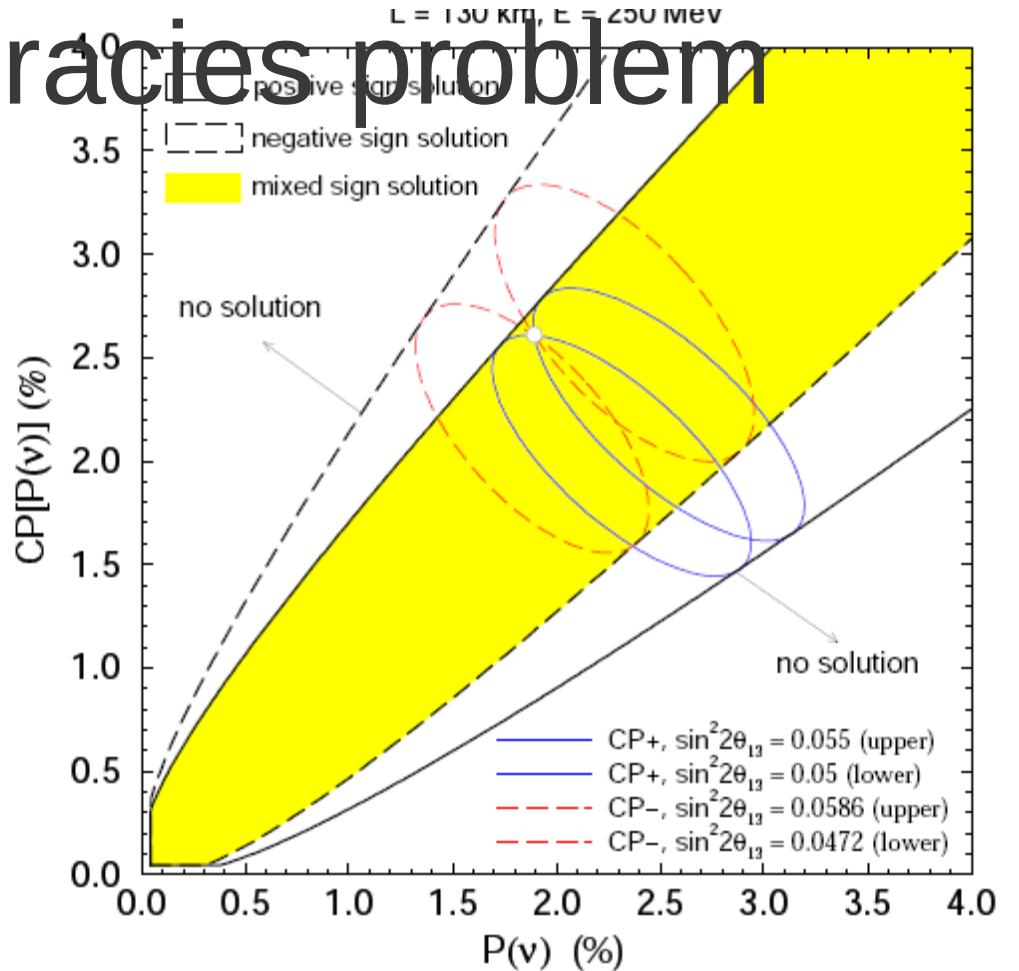


FIG. 1. An example of the degenerate solutions for the CERN-Frejus project in the $P(\nu) \equiv P(\nu_\mu \rightarrow \nu_e)$ versus $CP[P(\nu)] \equiv P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ plane. Between the solid (dashed) lines is the allowed region for positive (negative) Δm_{13}^2 and the shaded region is where solution for both signs are allowed. The solid (dashed) ellipses are for positive (negative) Δm_{13}^2 and they all meet at a single point. This is the CP parameter degeneracy problem. We have used a fixed neutrino energy of 250 MeV and a baseline of 130 km. The mixing parameters are fixed to be $|\Delta m_{13}^2| = 3 \times 10^{-3} eV^2$, $\sin^2 2\theta_{23} = 1.0$, $\Delta m_{32}^2 = +5 \times 10^{-5} eV^2$, $\sin^2 2\theta_{12} = 0.8$ and $Y_e \rho = 1.5 \text{ g cm}^{-3}$.

The Super Beam magic baseline

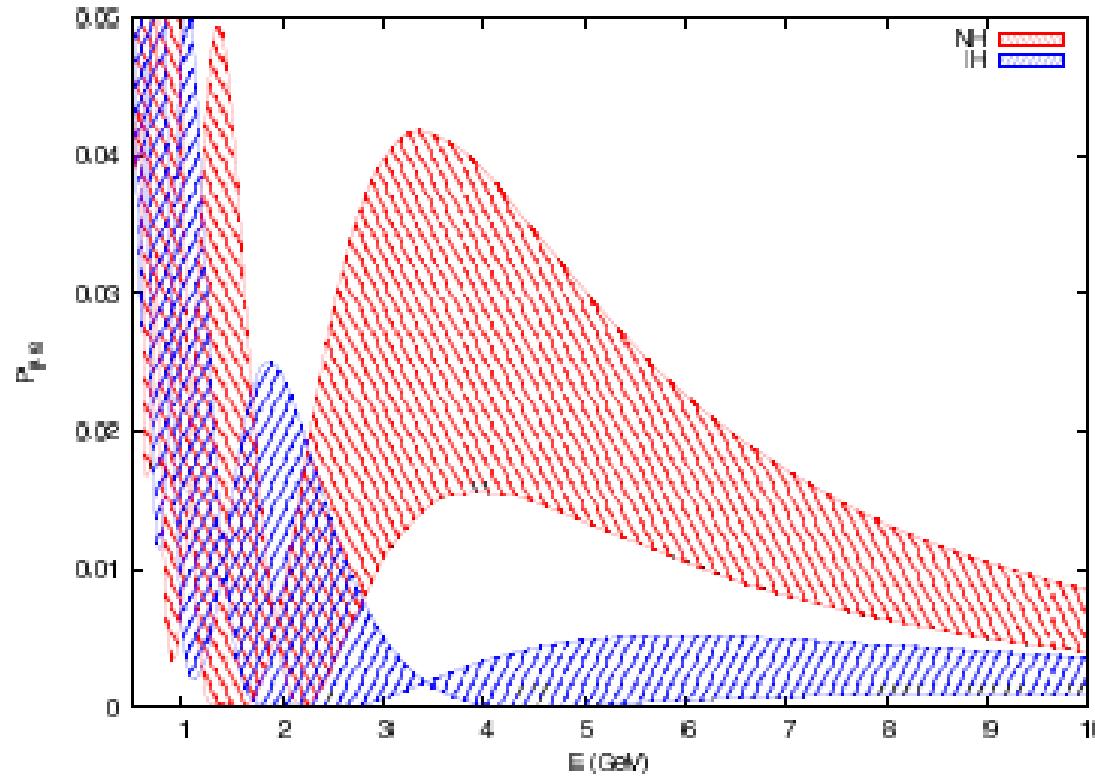


FIG. 1: $P_{\mu\tau}$ as function of E for $L = 2540$ km and $\sin^2 2\theta_{13} = 0.02$. It is plotted for both NH and IH, in each case as a band. Within each band, δ_{CP} varies in the range $0^\circ - 360^\circ$.

Requirement of $\sin((1-A)\Delta) = 0$ for IH and maximum for NH gives $L=2500$ km and $E = 3.3$ GeV

Marco Zito

GDR 20 Juin 2012

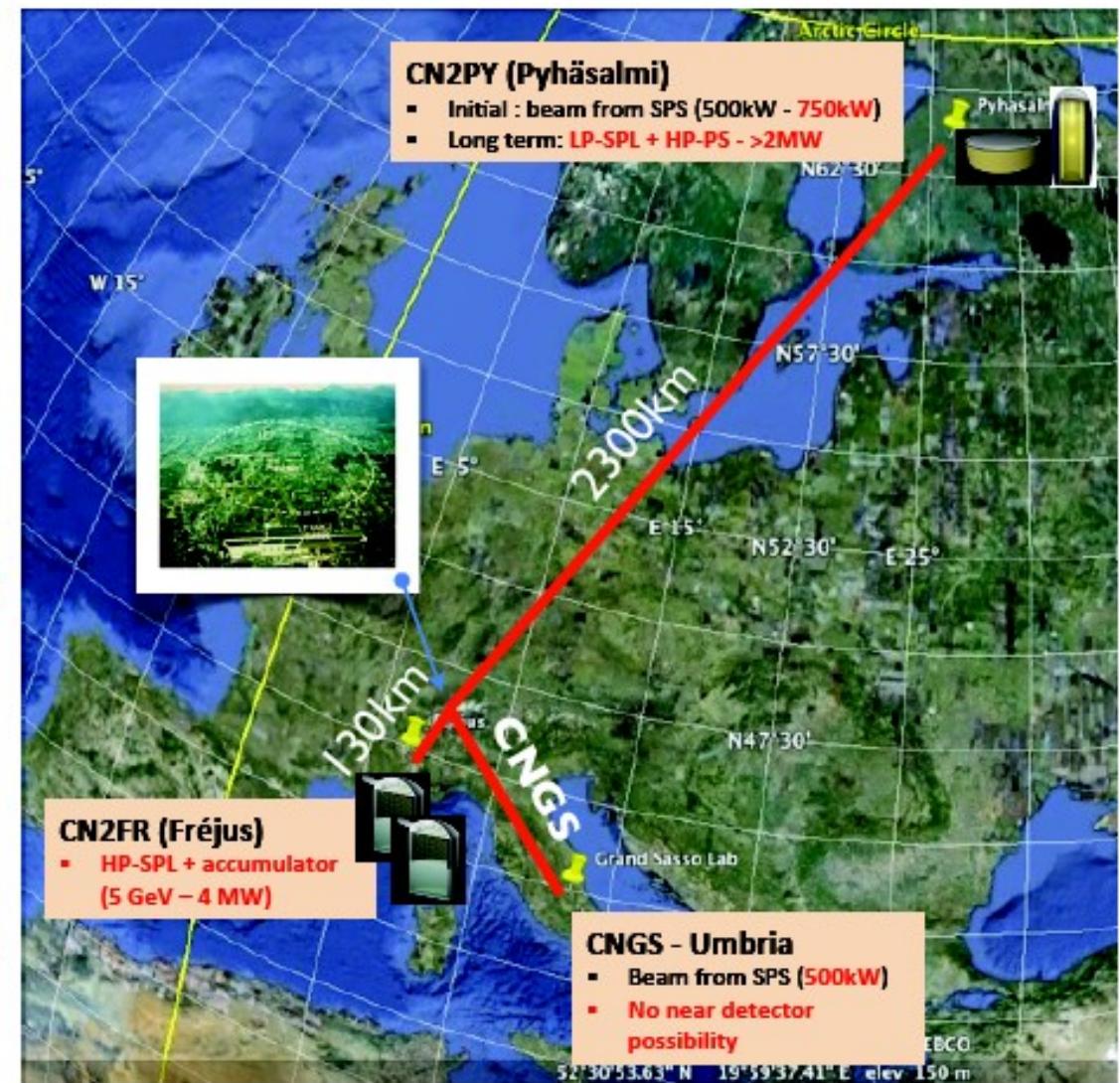
European sites: LAGUNA-LBNO



arXiv:1003.1921 [hep-ph]

Three far sites considered in details

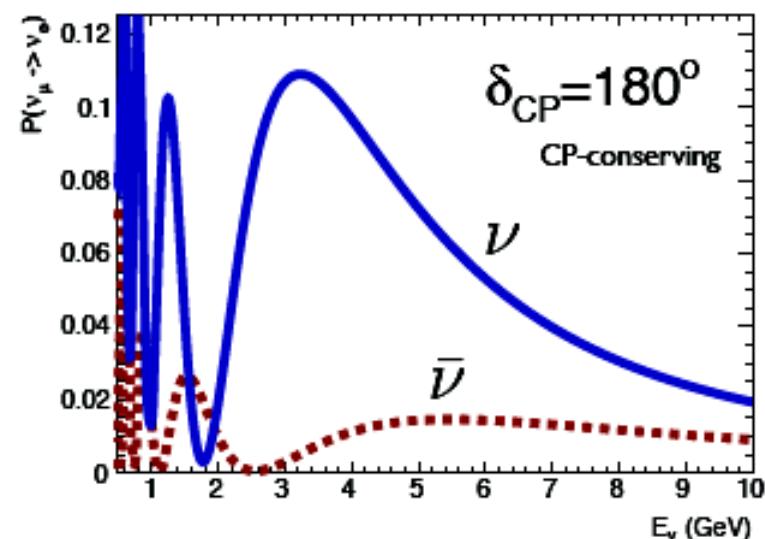
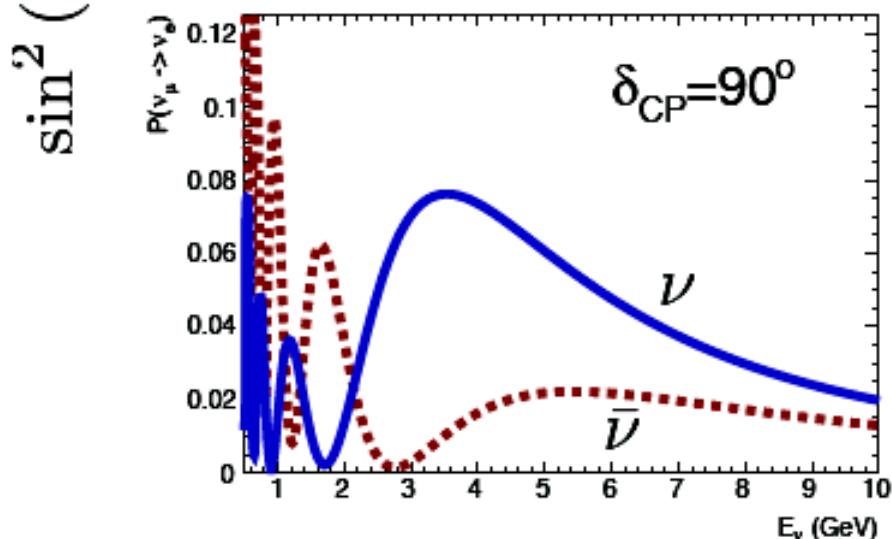
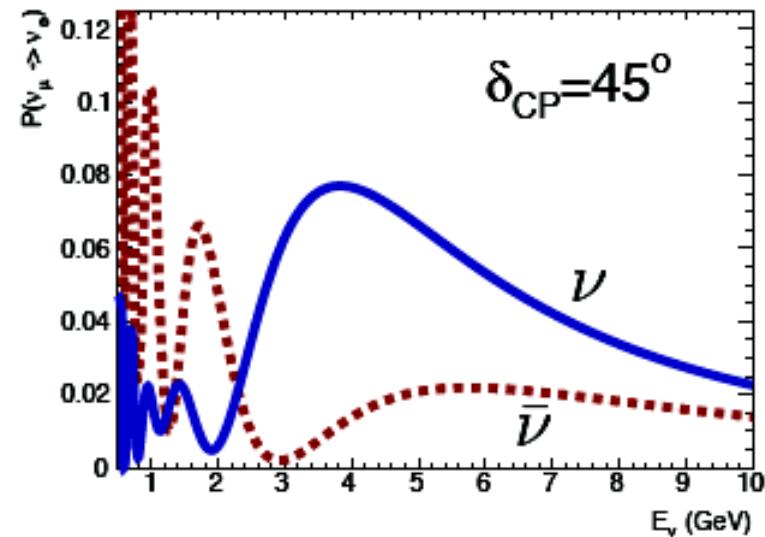
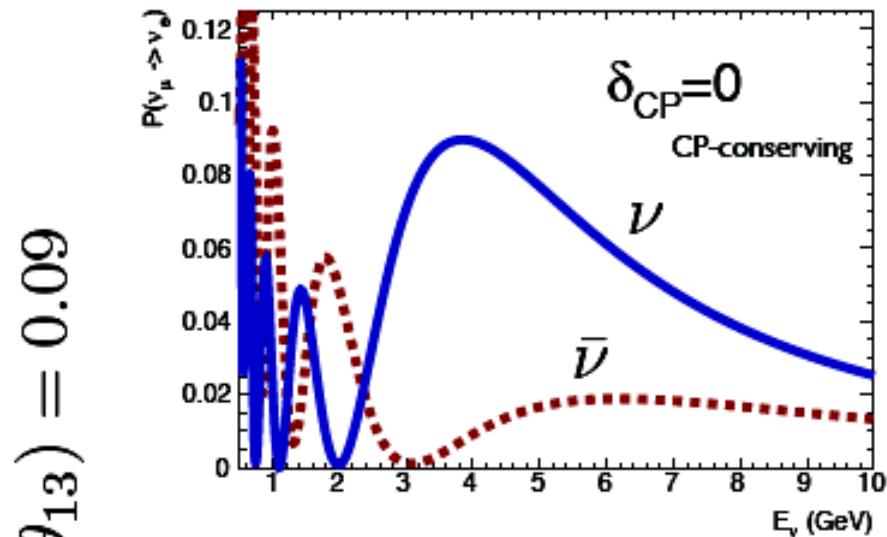
- ▶ Large Water Cerenkov Detector.
CERN-Fréjus is a short baseline.
It offers good synergy for
enhanced physics reach with β -
beam at $\gamma=100$
- ▶ Liquid Argon TPC & magnetized
iron + Liquid Scintillator detectors
CERN-Pyhäsalmi is the longest
baseline. It offers good synergy
for enhanced physics reach with
a NF
- ▶ [CNGS is an existing beam but is
considered at lower priority
(missing near detector, limited
power upgrade scenarios)]



CERN-Pyhäsalmi: oscillations

★ Normal mass hierarchy

L=2300 km

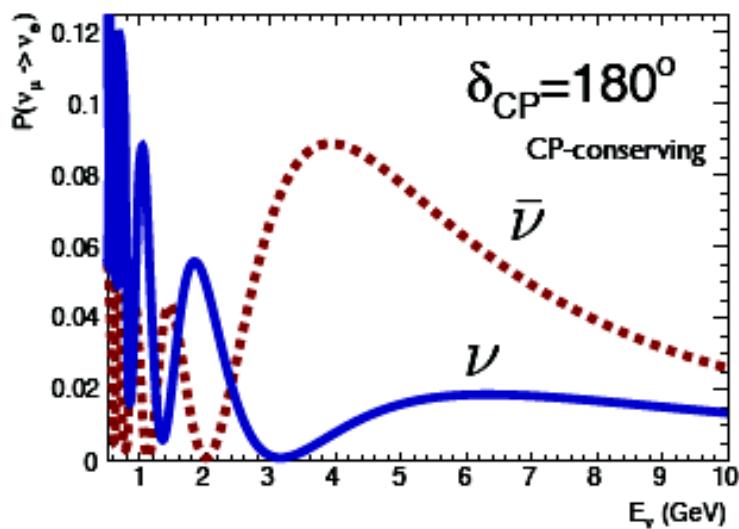
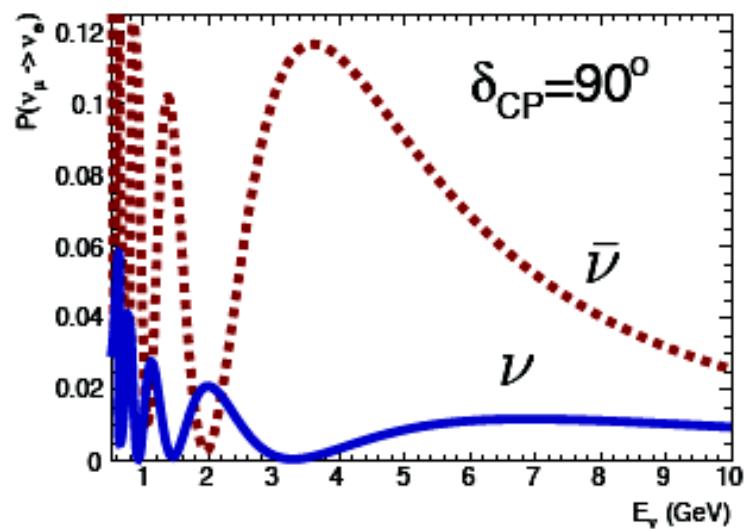
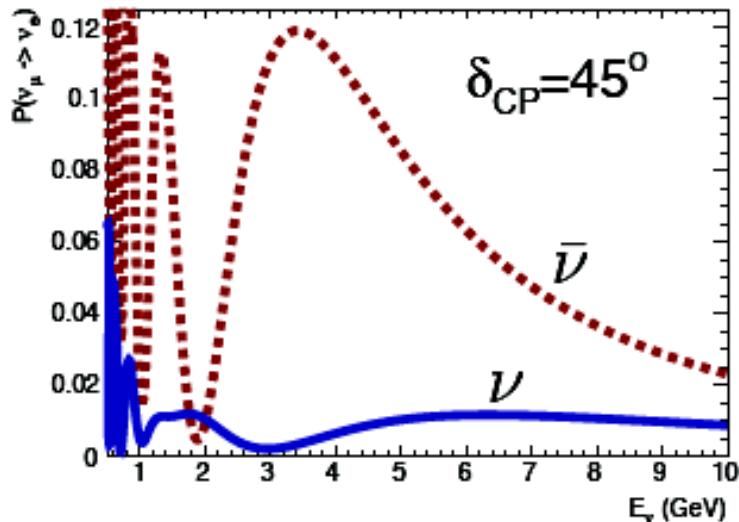
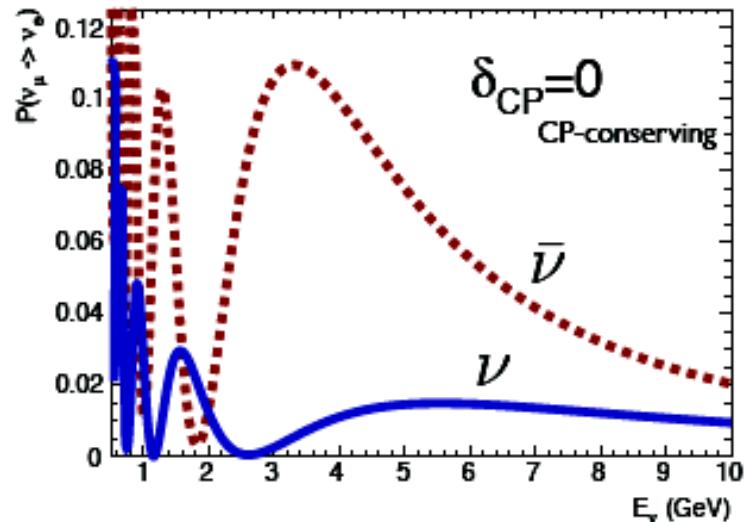


CERN-Pyhäsalmi: oscillations

★ Inverted mass hierarchy

L=2300 km

$$\sin^2(2\theta_{13}) = 0.09$$



From magic baseline to an experiment

- We need a Wide Band Beam (1st and 2nd maximum)
- Need good energy resolution also at 2nd maximum to use L/E for CP extraction
- $E_{\text{osc}} \sim 5 \text{ GeV}$: no water Cherenkov
- A detector with better eff. and background rejection than SK or NOVA but similar mass as first step : 20 kT fine sampling tracking detector
- We consider a Liquid Argon Detector
- Underground : astrophysics and proton decay
- Use of a conventional beam
- Performances can improve in steps : larger mass, beam power

New LBNO neutrino beam

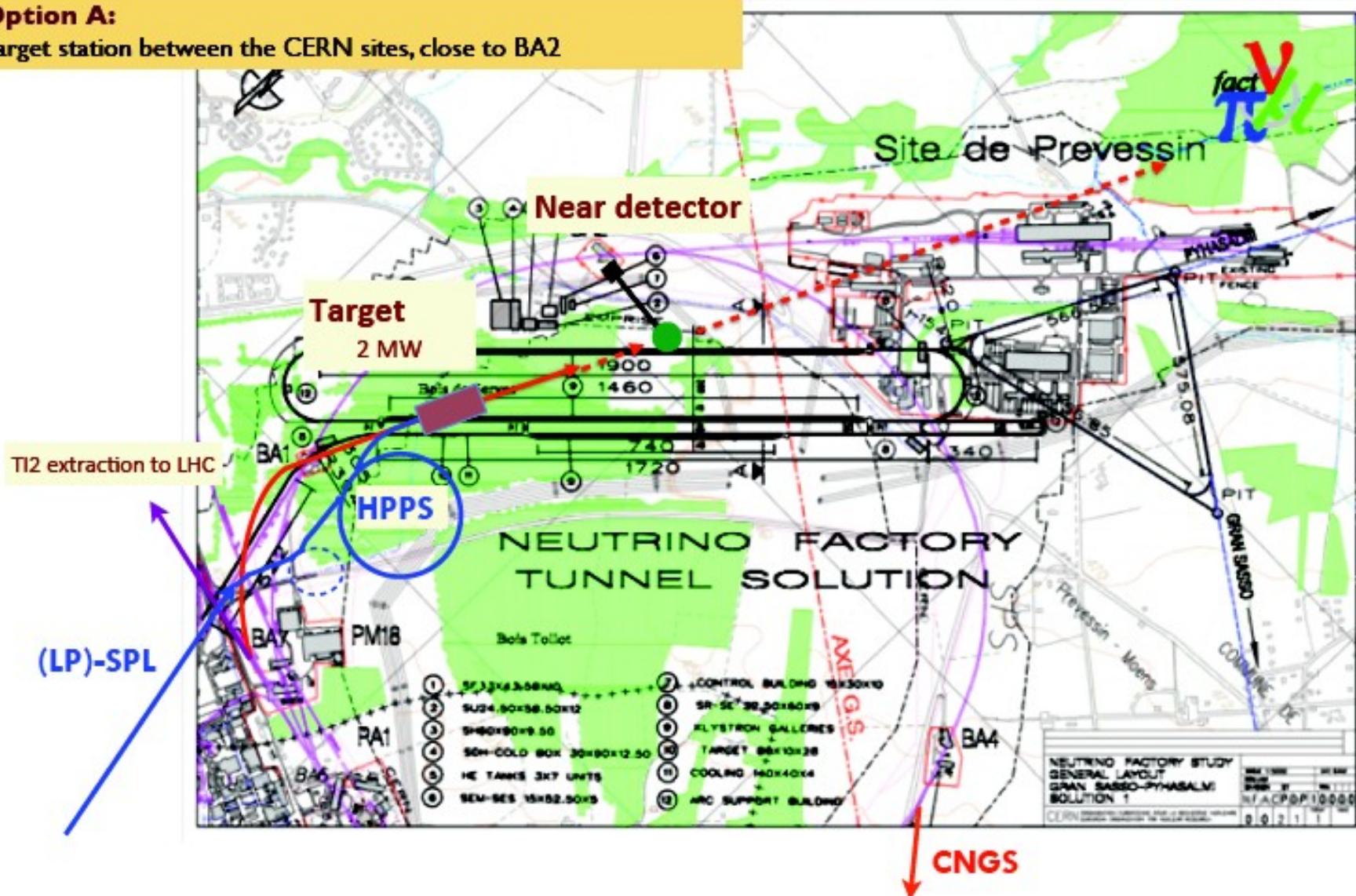
See talk by I Efthymiopoulos

- **CN2PY horn focused neutrino beam towards Pyhäsalmi/FI**
 - Starting point is SPS and CNGS operation (achieved 420kW)
 - Protons extraction, transfer & secondary beam lines
 - Target, horn focusing systems, beam monitors design
 - Decay tunnel ≈300m, 10deg dip angle
 - Low energy optimization; WBB covering $0.5 \rightarrow 5$ GeV
- **Benefit from improved performance of SPS+injectors; consider further options to upgrade power of SPS (LAGUNA-LBNO WP4)**
- **Upgrade path: HP-PS accelerator (50 GeV) with significant power improvement compared to SPS complex (\rightarrow “MW” beam). Exploit synergies with the NF R&D.**

CN2PY layout (option A)

Option A:

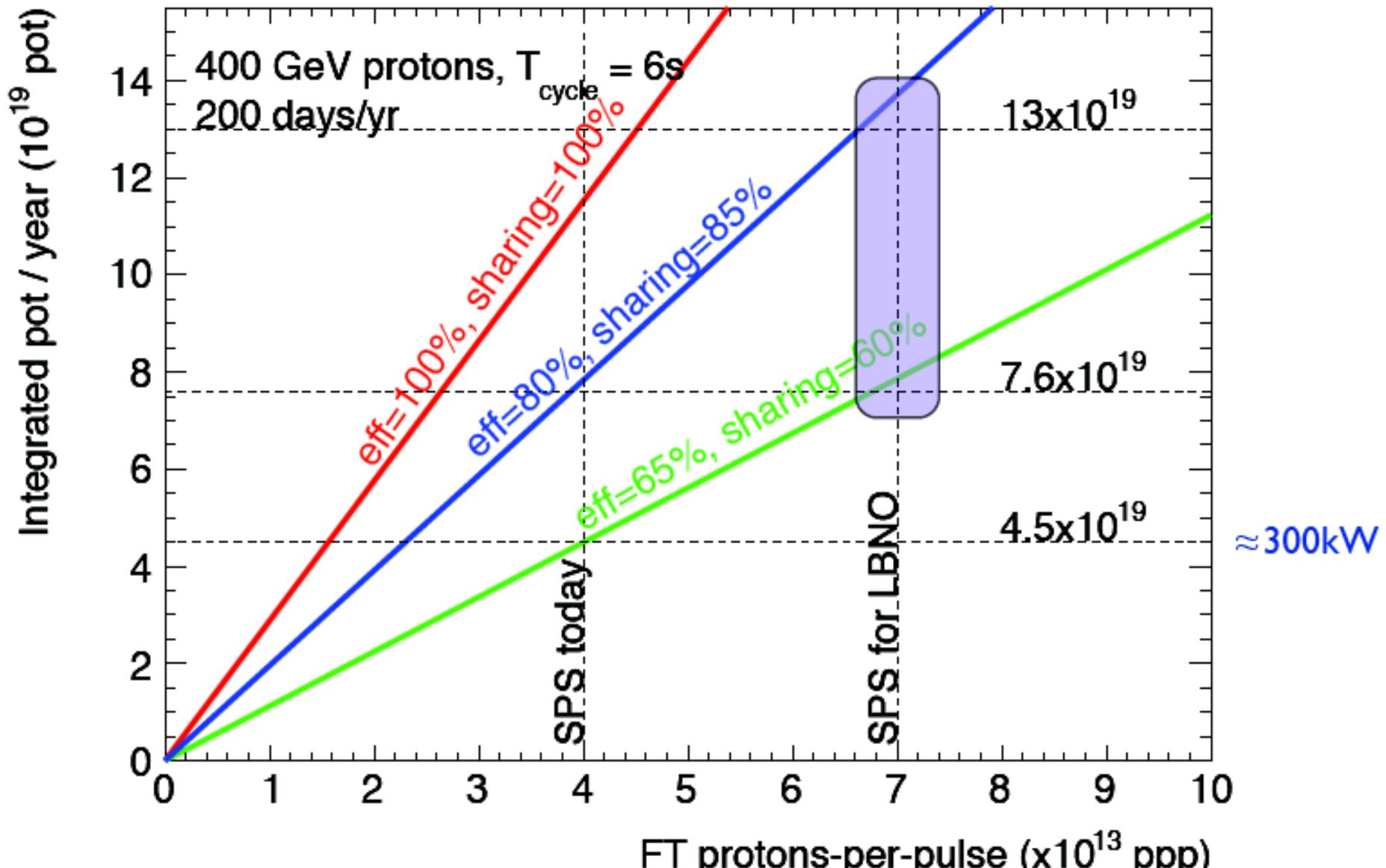
Target station between the CERN sites, close to BA2



Realistic SPS proton intensity for LBNO

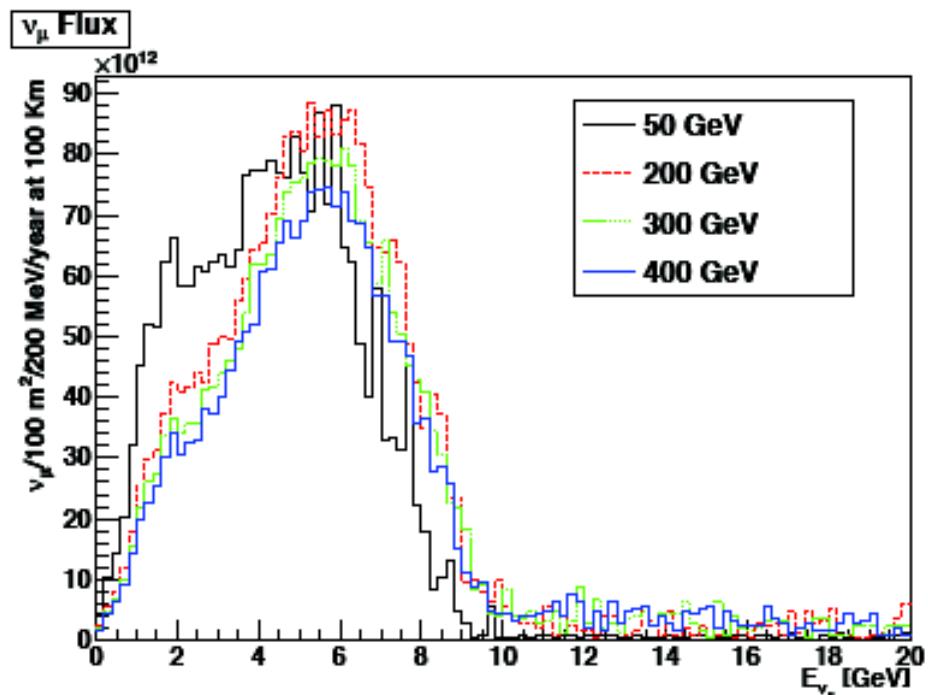
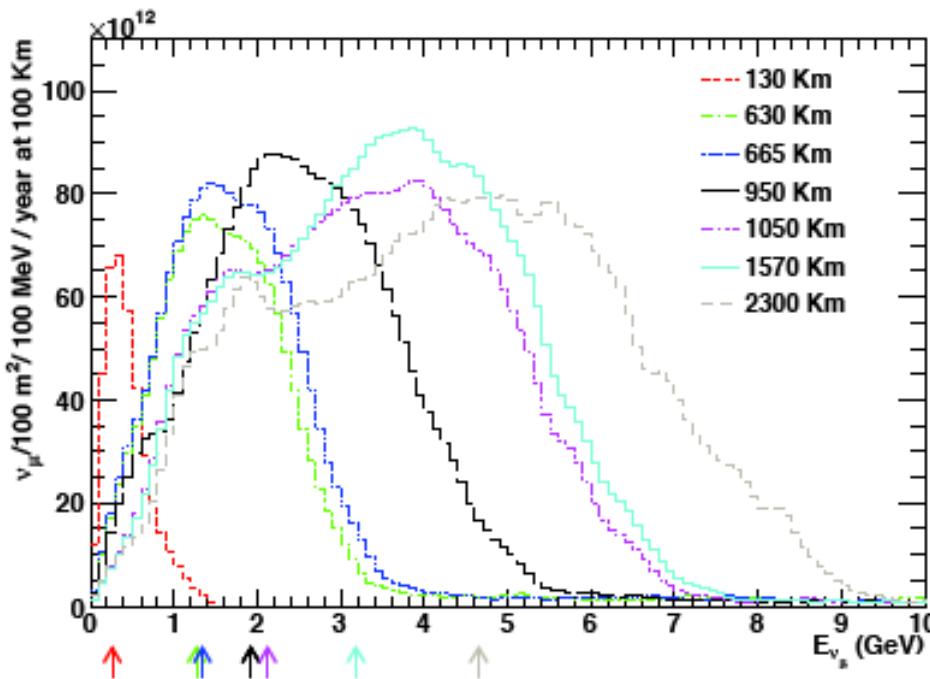
- We consider the CERN SPS 400 GeV as the only realistic accelerator for the initial LBNO phase. Then, we assume:
 - ★ 85% SPS “sharing” by taking 2 hours/day out for LHC filling
 - ★ 80% efficiency for the accelerators
- Today: SPS intensity is $4\text{e}13 \text{ ppp}$ and factor 61% from SPS sharing (situation of today, likely can change within the timescale of LBNO when NA62 or COMPASS physics is completed).
- **In the context of LBNO (>2018)**: the SPS intensity is upgraded (also thanks to LIU project) to $7\text{e}13 \text{ ppp}$ at 400 GeV with cycle time = 6 seconds.
 - ★ yearly integrated pot = $(0.8\text{--}1.3)\times 1\text{e}20 \text{ pot / yr}$
 - ★ total integrated (12 years) = $(1\text{--}1.5)\times 1\text{e}21 \text{ pot}$
 - ★ range corresponds to sharing 60–85%
 - ★ studies ongoing within CERN accelerator team in LAGUNA-LBNO WP4

SPS 400 GeV p.o.t / year



Target, optics optimization

- Preliminary optimization done within LAGUNA DS for various baselines to maximize θ_{13} sensitivity, and assuming 50 GeV protons from HP-PS
- Present activities within LAGUNA-LBNO WP4:
 - Optimization for 50 HP-PS vs 200, 300 and 400 GeV SPS protons
 - Focusing optimization to maximize MH&CPV physics reach.
 - Target optimization.



Near detector concept

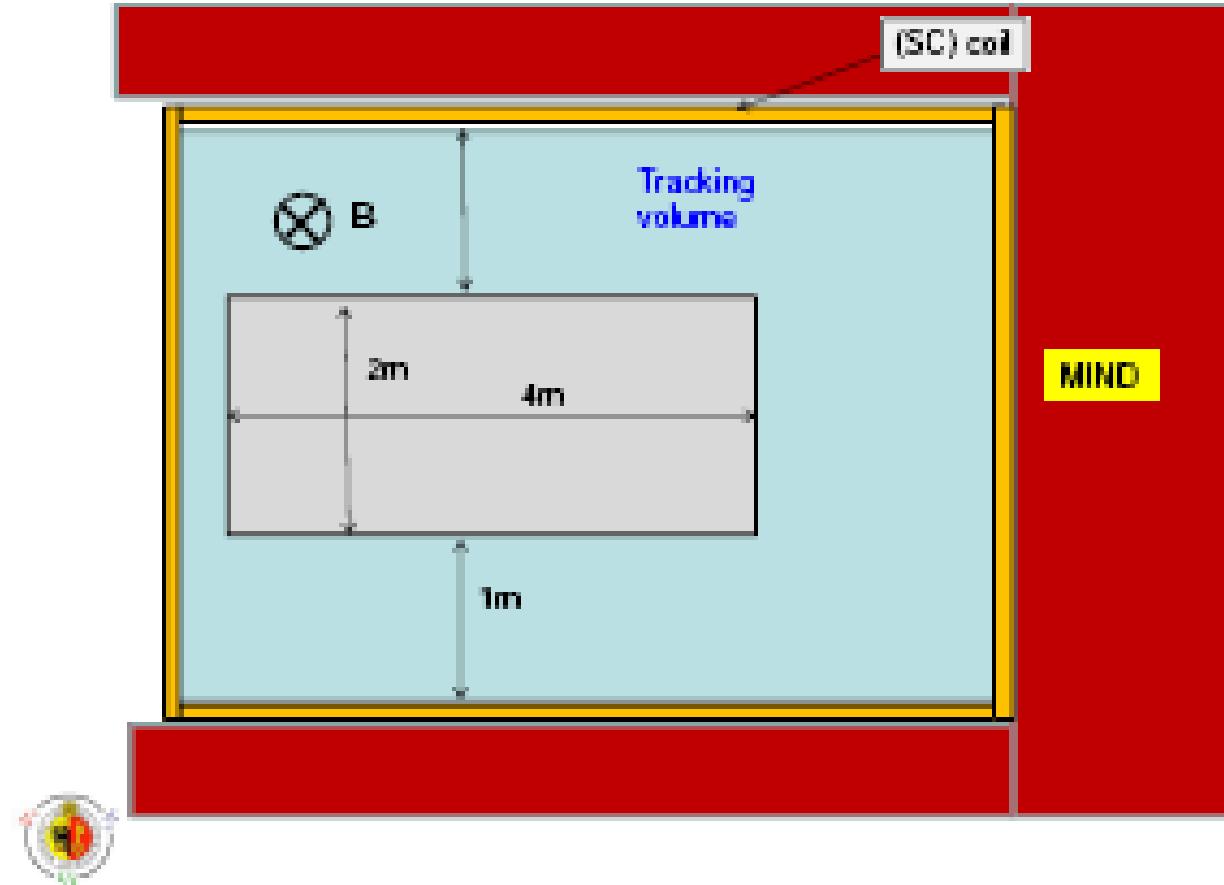


FIG. 17: Sketch of the considered near detector design: in the center (gray) a 16 m^3 , 10 bar Argon gas TPC. It is surrounded by a fully active segmented scintillator detector for hadronic shower containment. The detector is embedded in a 0.4 T magnet with instrumented return yoke catching the tails of hadronic and electromagnetic interactions. Behind sits a Magnetized Iron Detector with a depth of 5m of iron.

Some unique features of Pyhäsalmi



- ▶ **Many optimal conditions satisfied simultaneously:**
 - ▶ Infrastructure in **perfect state** because of current exploitation of the mine
 - ▶ **Unique assets available** (shafts, decline, services, sufficient ventilation, water pumping station, pipes for liquids, underground repair shop...)
 - ▶ **Very little environmental water**
 - ▶ Could be **dedicated to science activities** after the mine exploitation ends (around 2018)
- ▶ One of the deepest location in Europe (4000 m.w.e.)
- ▶ The distance from CERN (2300 km) offers unique long baseline opportunities.
- ▶ The site has the lowest reactor neutrino background in Europe, important for the observation of very low energy MeV neutrinos.

Pyhäsalmi site location

See talk by T Enqvist

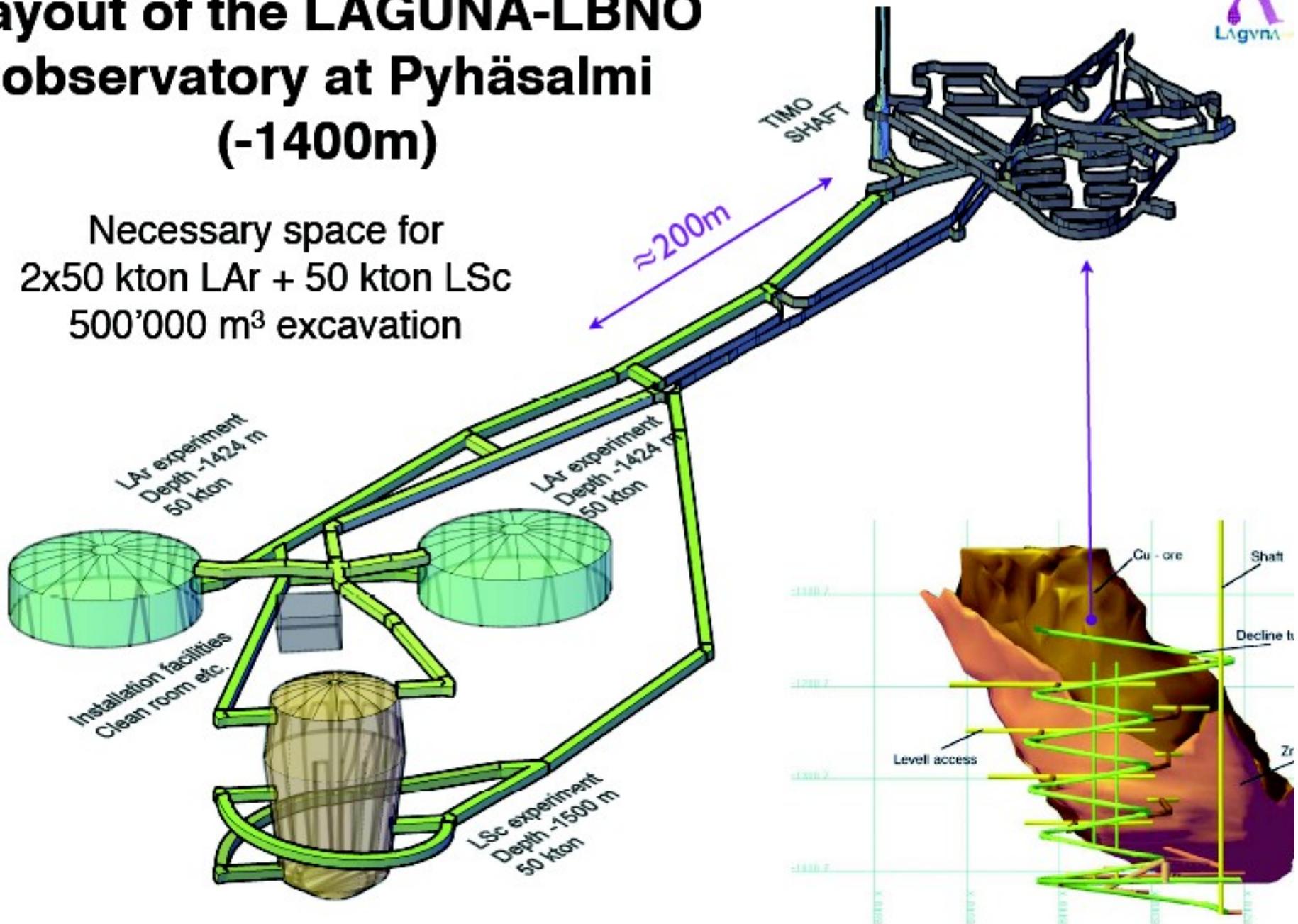


- ▶ CUPP : Centre for Underground Physics in Pyhäsalmi (www.cupp.fi)
- ▶ Location: $63^{\circ} 39' 31''\text{N}$ – $26^{\circ} 02' 48''\text{E}$
- ▶ Distances (by roads)
 - ▶ Oulu – 165 km
 - ▶ Jyväskylä – 180 km
 - ▶ Helsinki – 450 km
- ▶ Distance to CERN 2300 km
- ▶ Good traffic connections
 - ▶ the main highway:
Helsinki – Jyväskylä – Oulu – ...
 - ▶ the second busiest airport in Oulu
 - ▶ rail yard at the mine
- ▶ Inhabitants: ~ 6000

Layout of the LAGUNA-LBNO observatory at Pyhäsalmi (-1400m)



Necessary space for
2x50 kton LAr + 50 kton LSc
500'000 m³ excavation



Far detectors for long baseline

- **Double phase LAr LEM TPC (GLACIER): best detector for electron appearance measurements with excellent energy resolution and small systematic errors**
 - ▶ Exclusive final states, low energy threshold on all particles
 - ▶ Excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
 - Suitable for spectrum measurement with needed wide energy coverage
 - ▶ Excellent π^0 /electron discrimination
 - Wide band On-Axis beam is tolerable
- **Magnetized Muon Detector (MIND): conventional and well-proven detector for muon CC, and NC**
 - ▶ muon momentum & charge determination, inclusive total neutrino energy
 - ▶ compatible with NF

Far detector concept

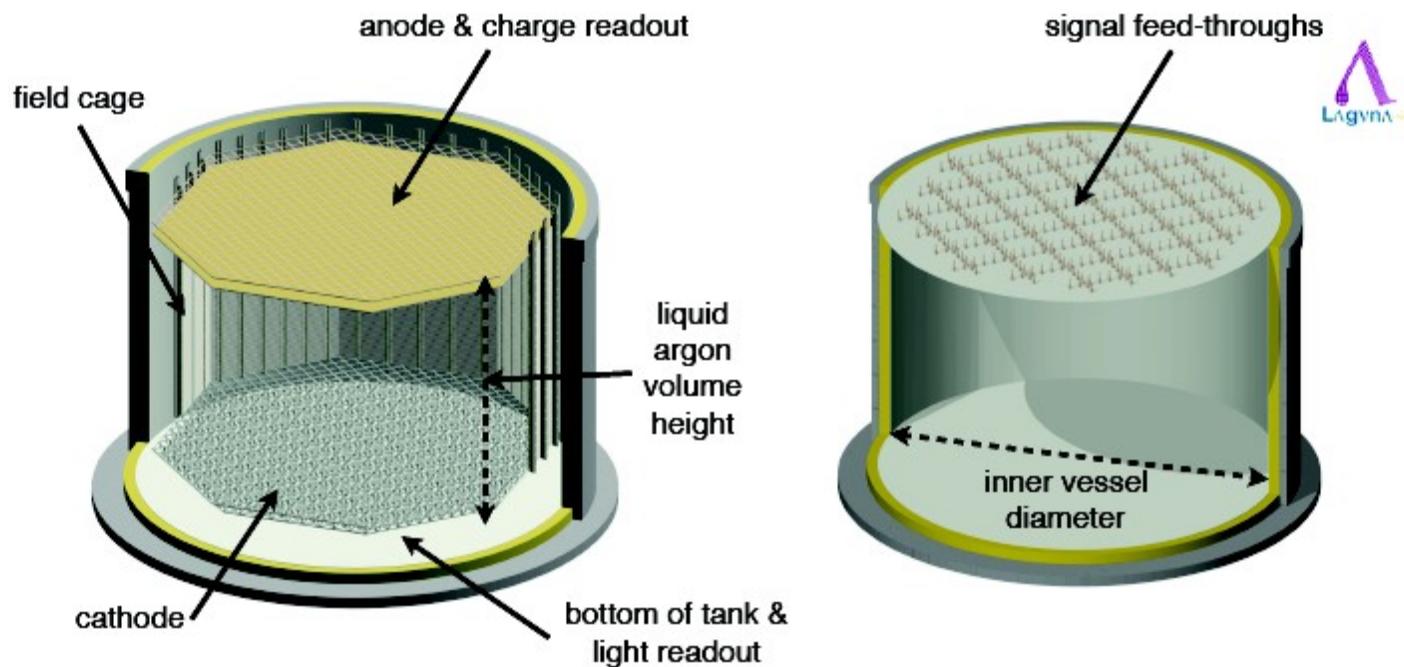


FIG. 12: (left) Cut view showing the inner detector; (right) Cut view showing the inner vessel and the top roof with the signal feed-throughs.

The far detector concept

FIG. 13: Top view of the anode and charge readout plane.

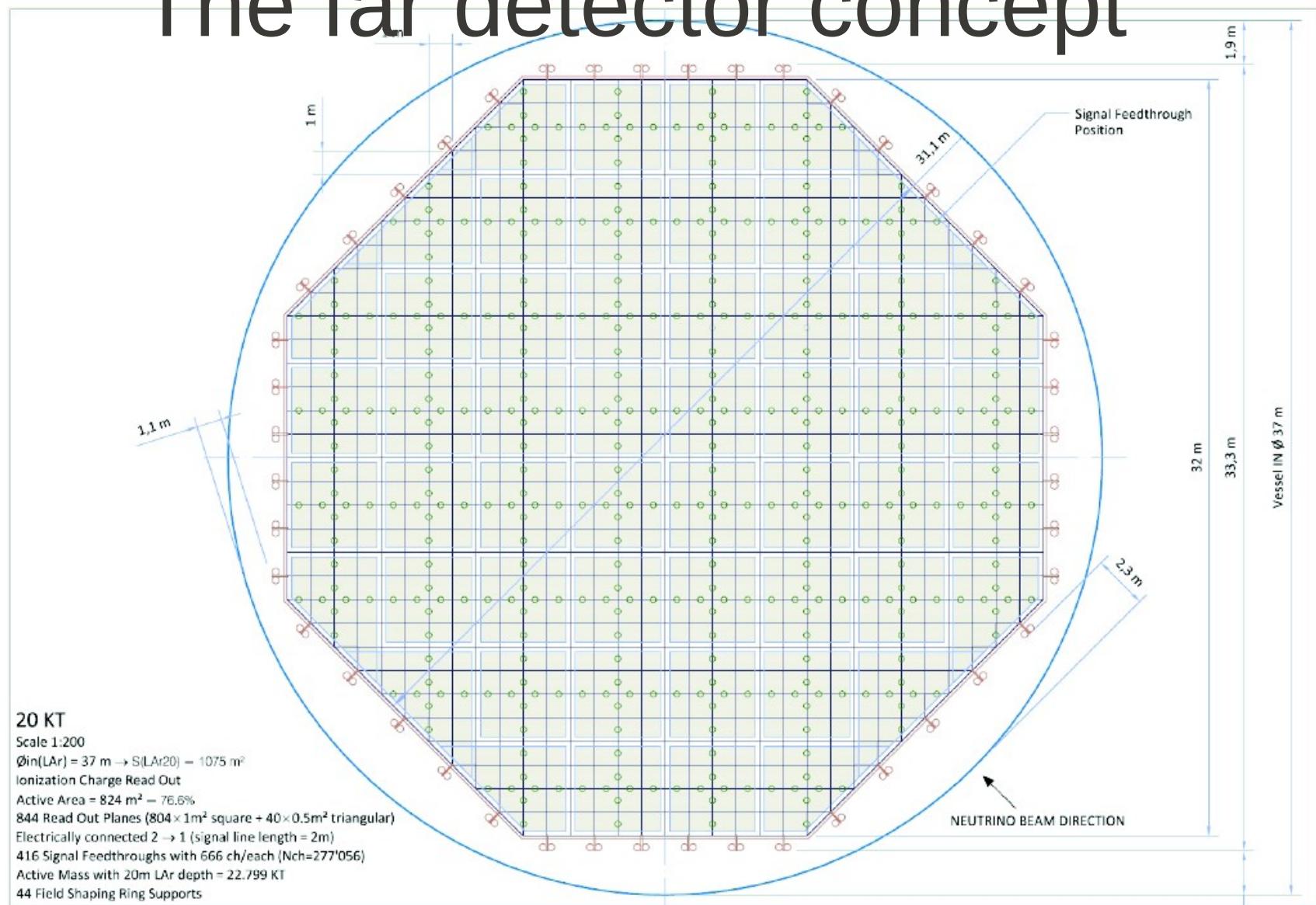
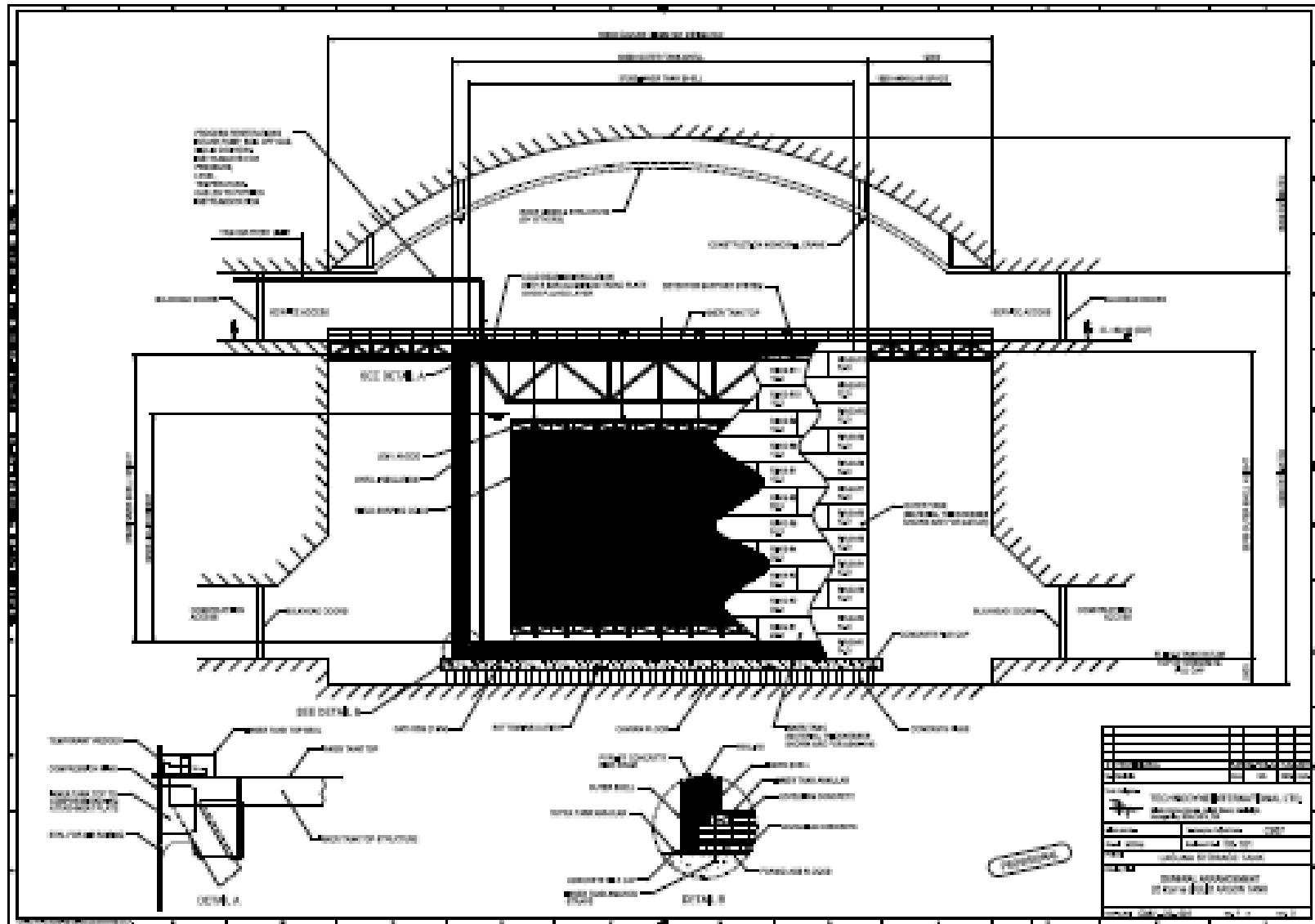


FIG. 1&: Engineering design of the storage 20 kton tank for the 55-9% nickel option.



Liquid argon : ~ bubble chamber detector

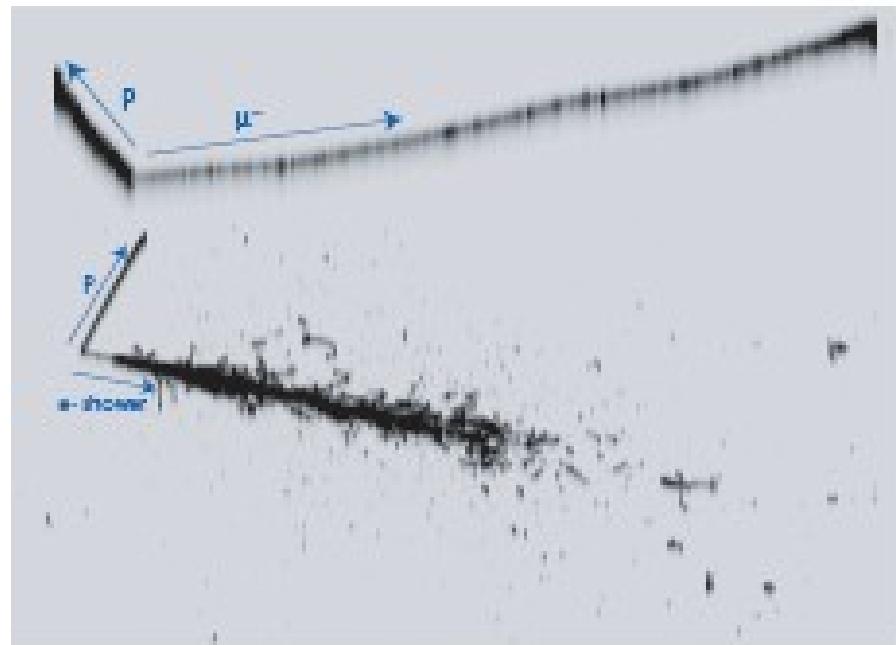
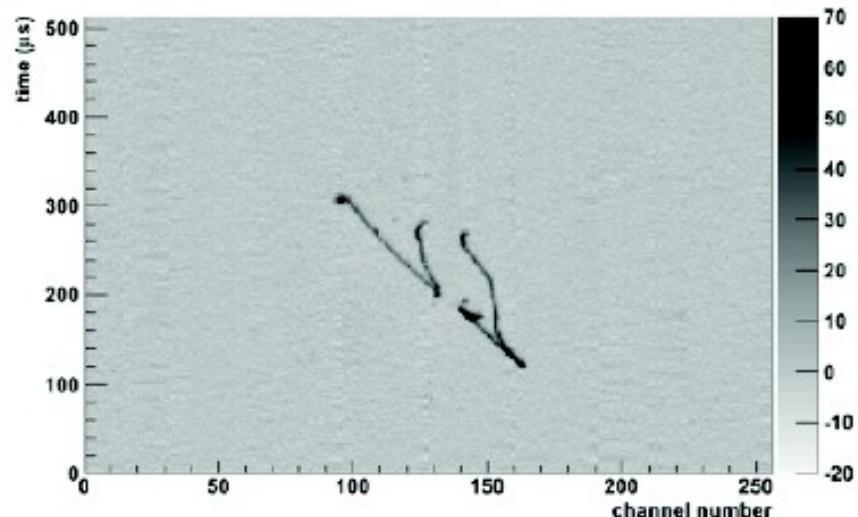


FIG. 38: Typical atmospheric ν_μ and ν_e QE event in liquid Argon detector ($\nu_\mu + n \rightarrow p + \mu^-$ and $\nu_e + n \rightarrow p + e^-$).

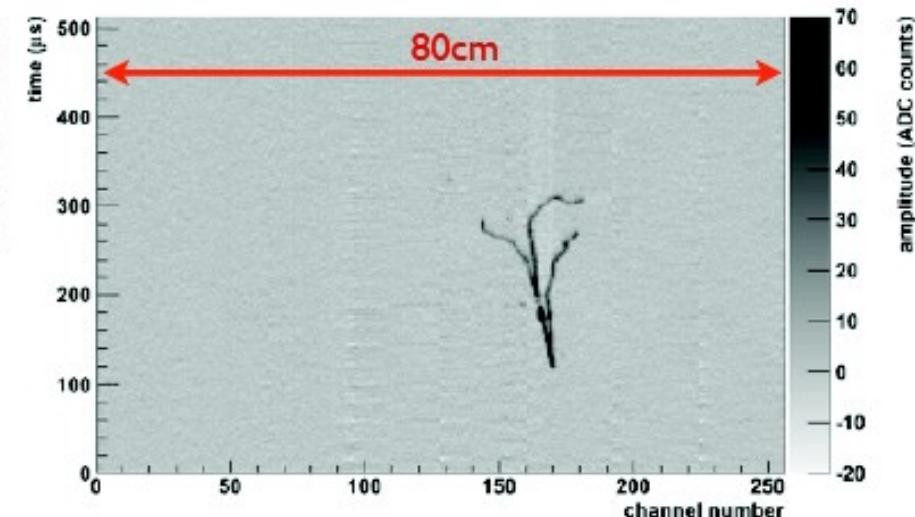
Real cosmic rays in LAr LEM-TPC

Cosmic track in double phase 80x40cm² LAr-LEM TPC with adjustable gain : S/N > 100 for m.i.p !!

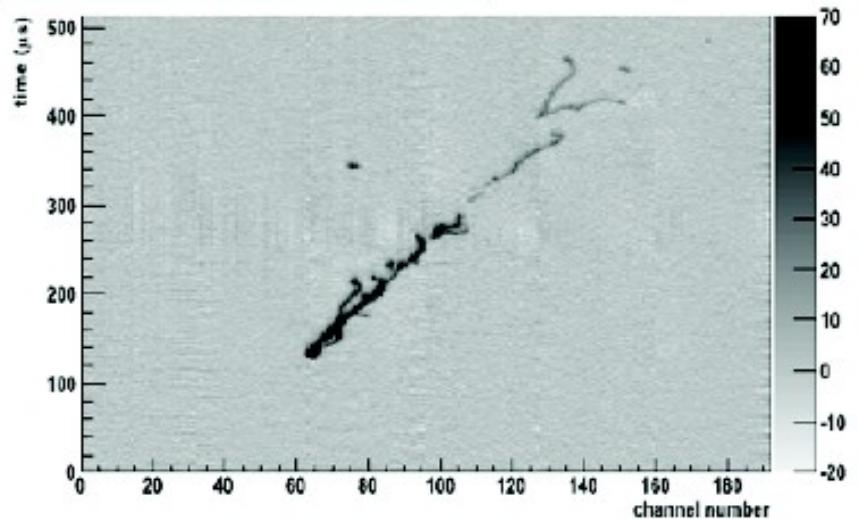
View 0: Event display (run 14456, event 8044)



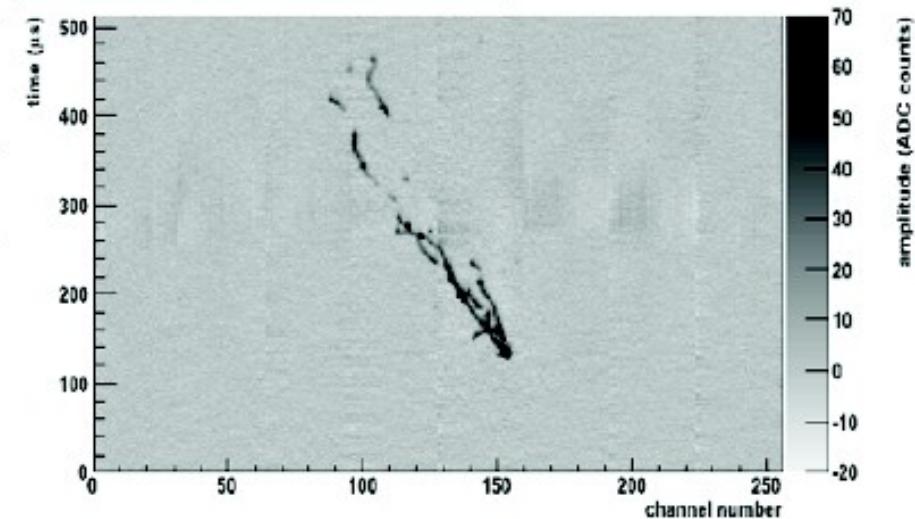
View 1: Event display (run 14456, event 8044)



View 0: Event display (run 14450, event 1511)



View 1: Event display (run 14450, event 1511)



Electron pi0 separation

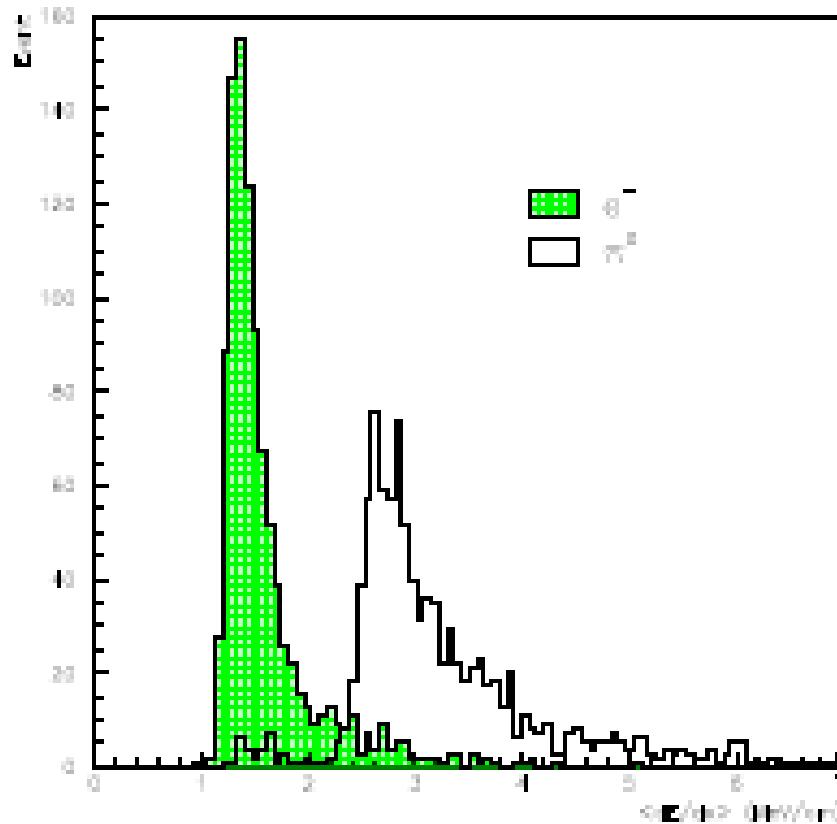
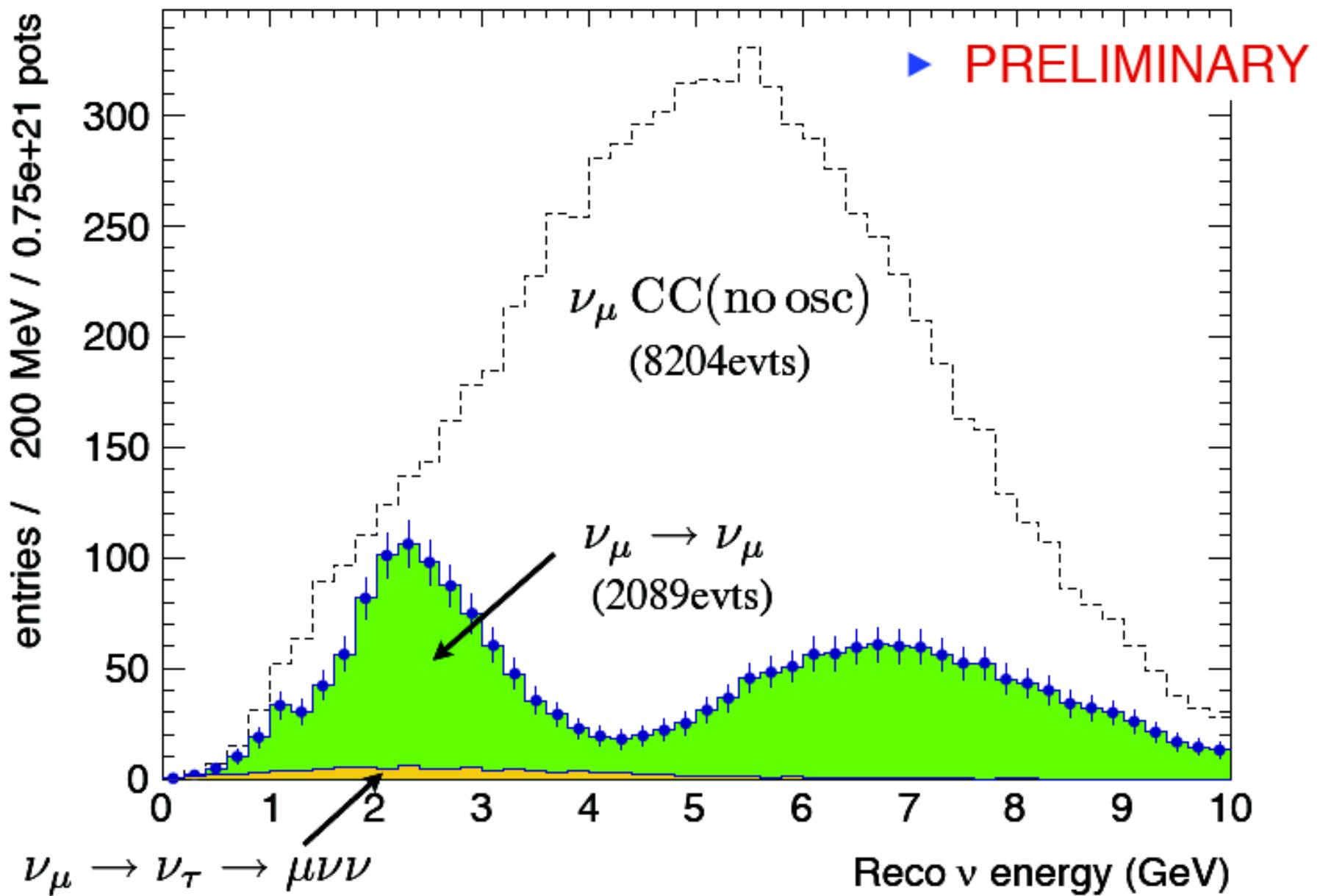


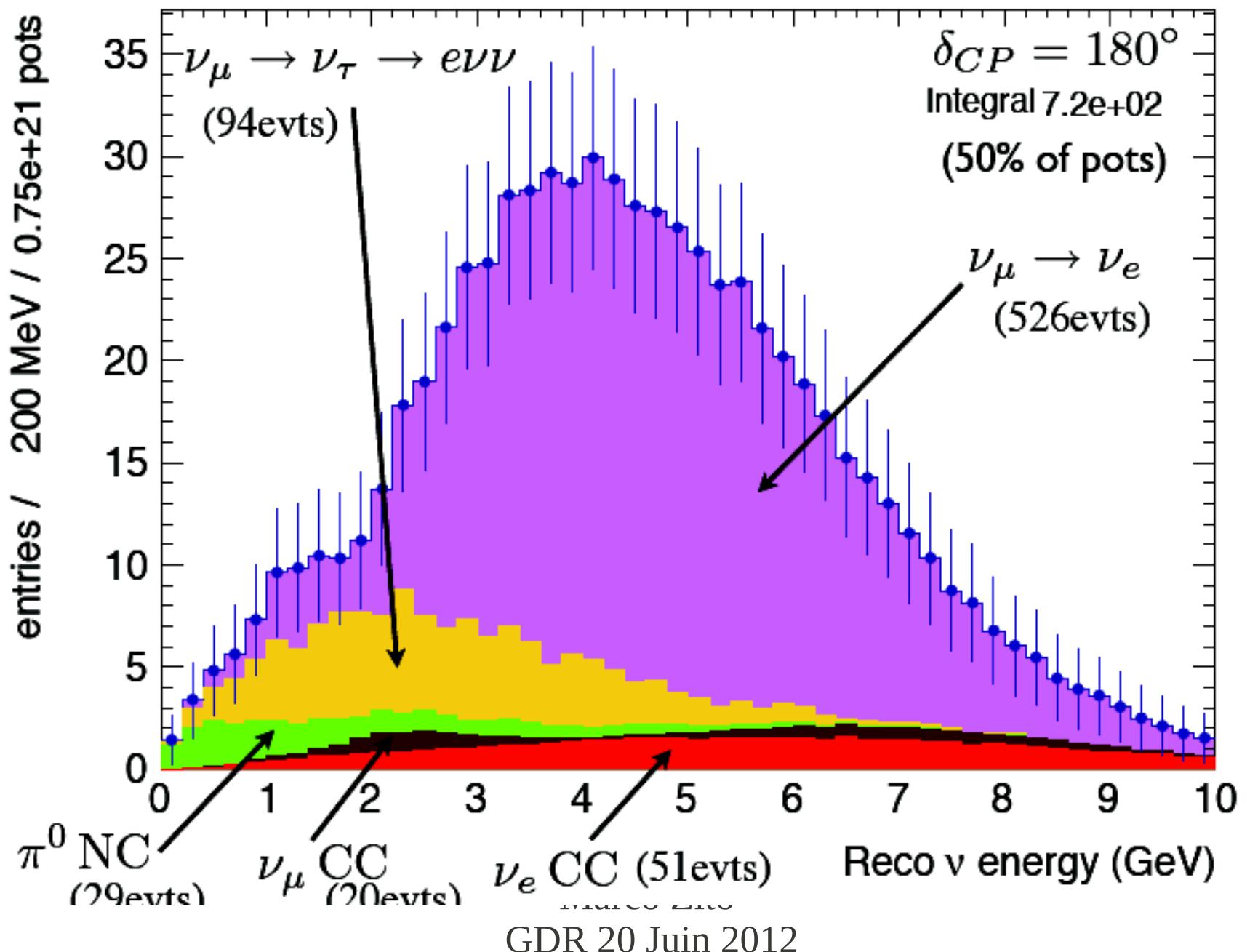
FIG. 29: The e^- (hatched area) and π^0 (blank area) can be separated with 90% e^- identification efficiency and 3.7% of π^0 contamination by a $\langle dE/dx \rangle$ cut at 2.21 MeV/cm. The $\langle dE/dx \rangle$ is the average over the first 8 successive wires.

Physics performances

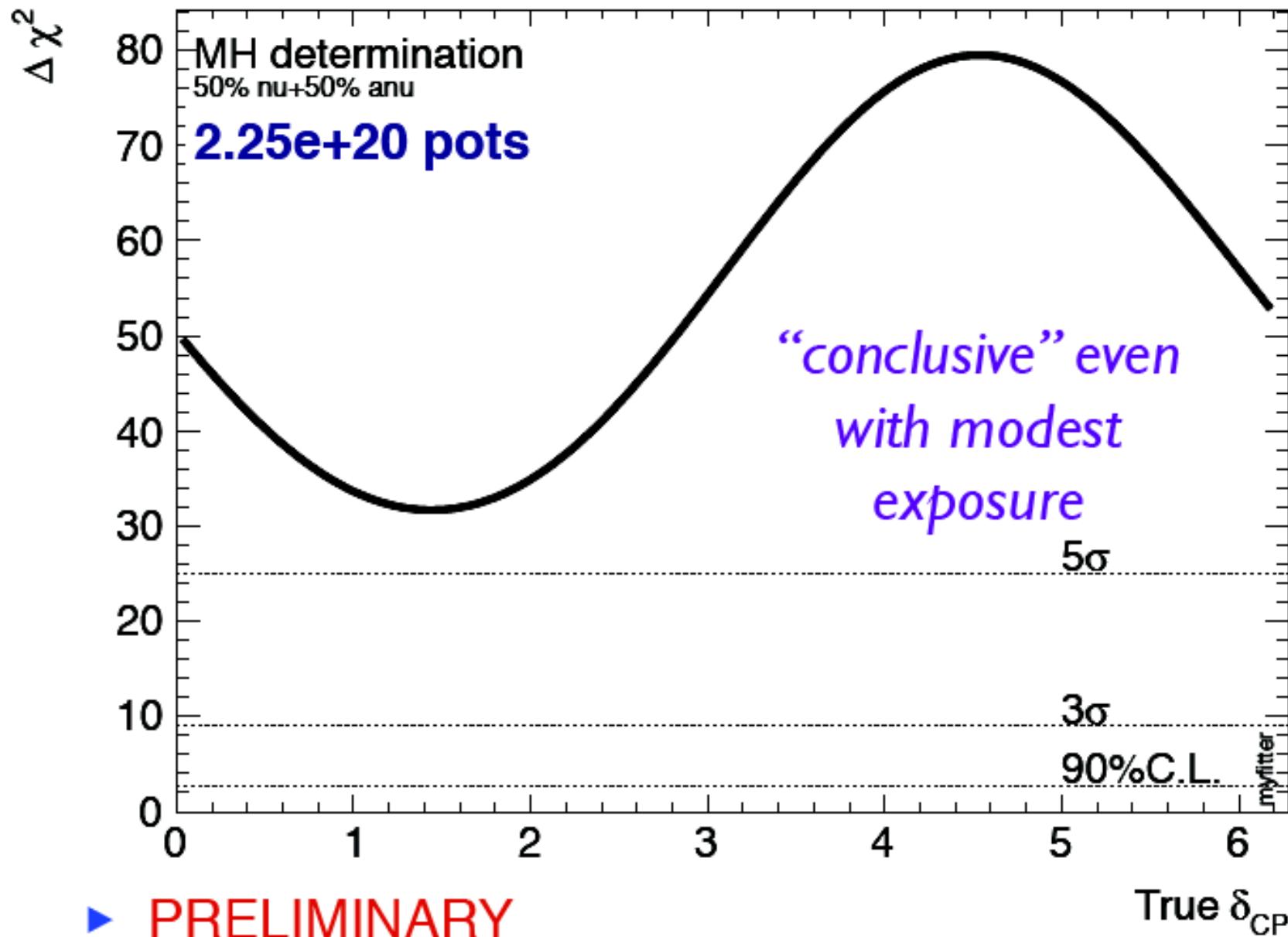
μ -like sample



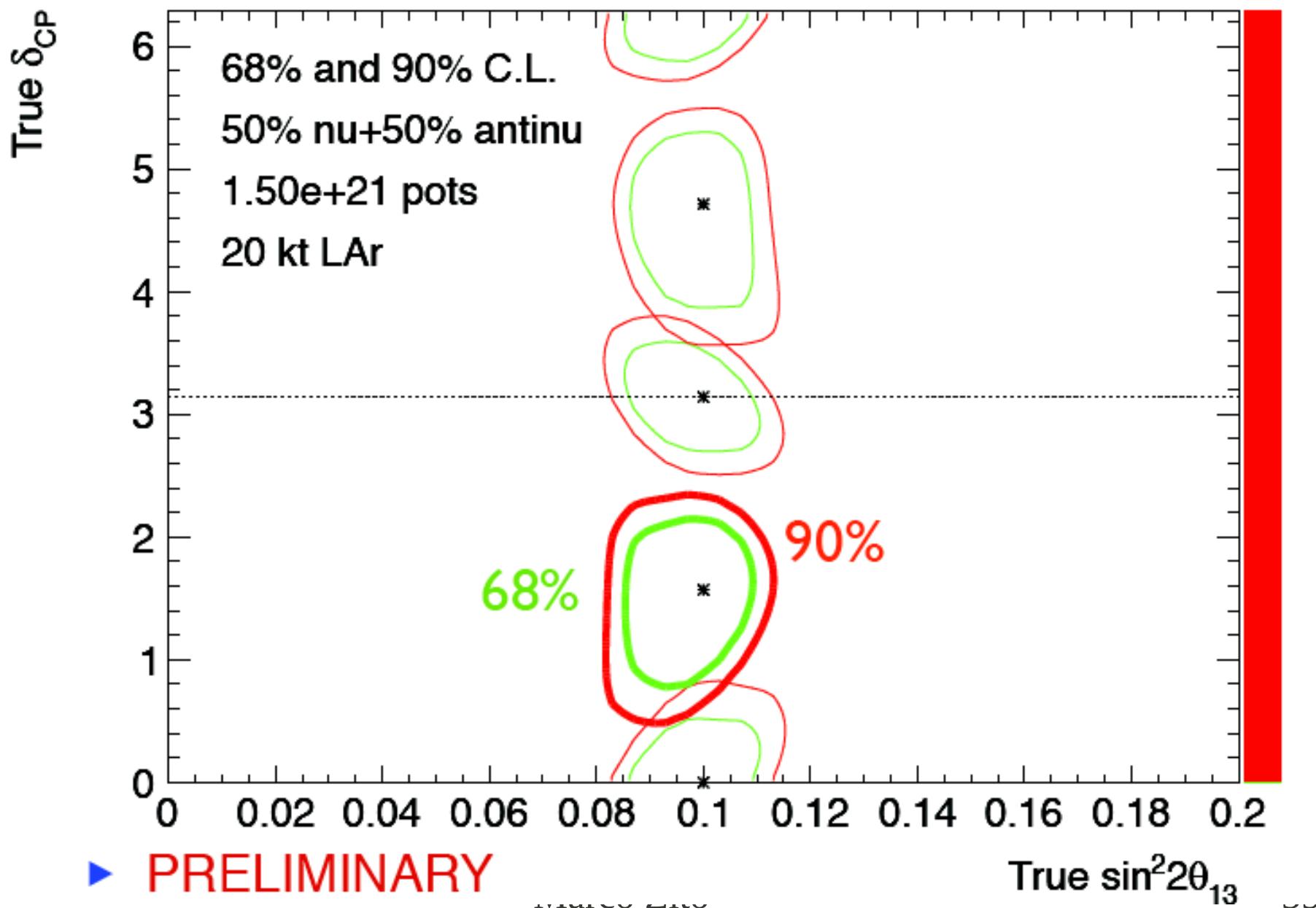
e-like sample



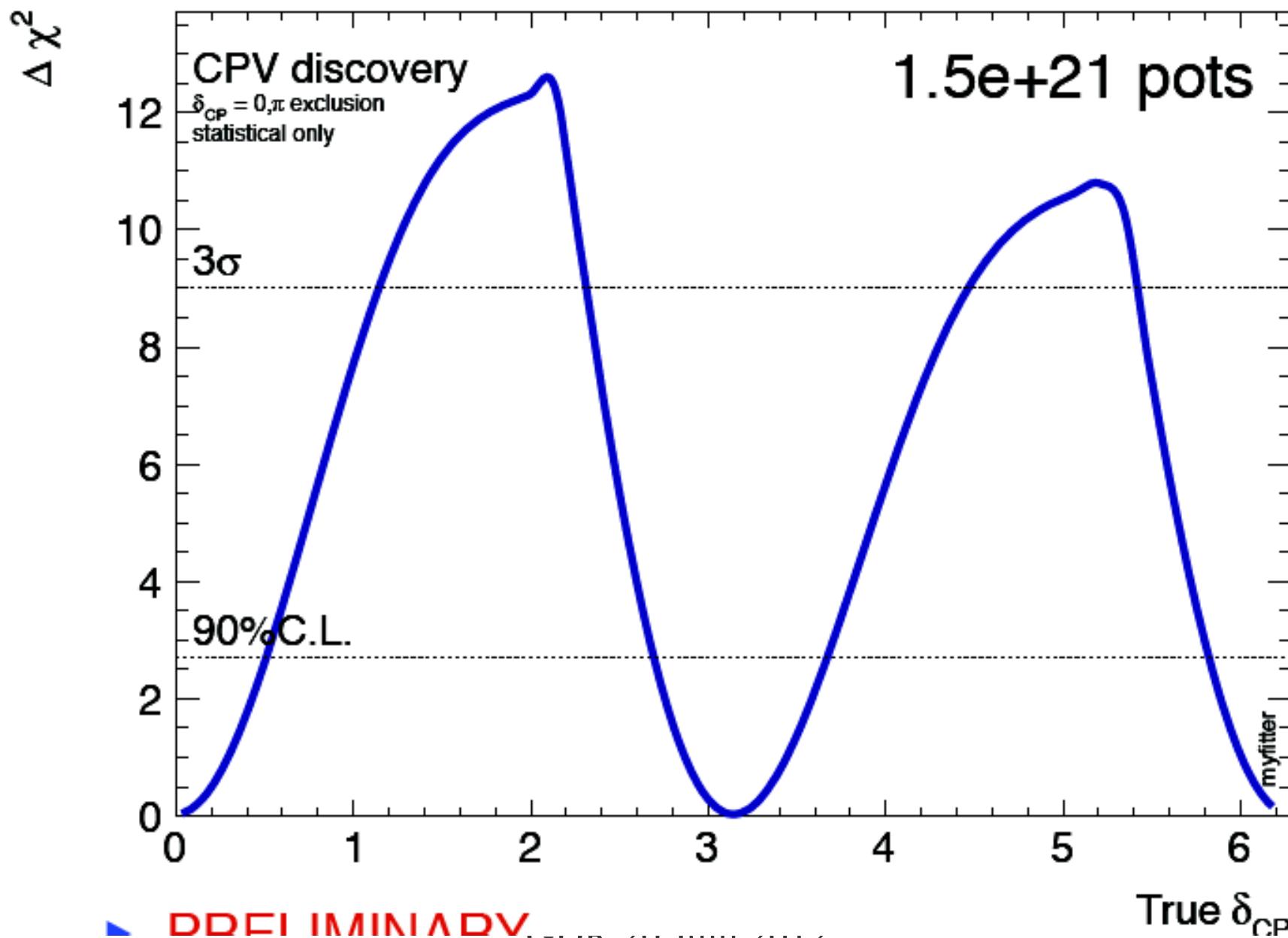
MH determination



CP-phase determination

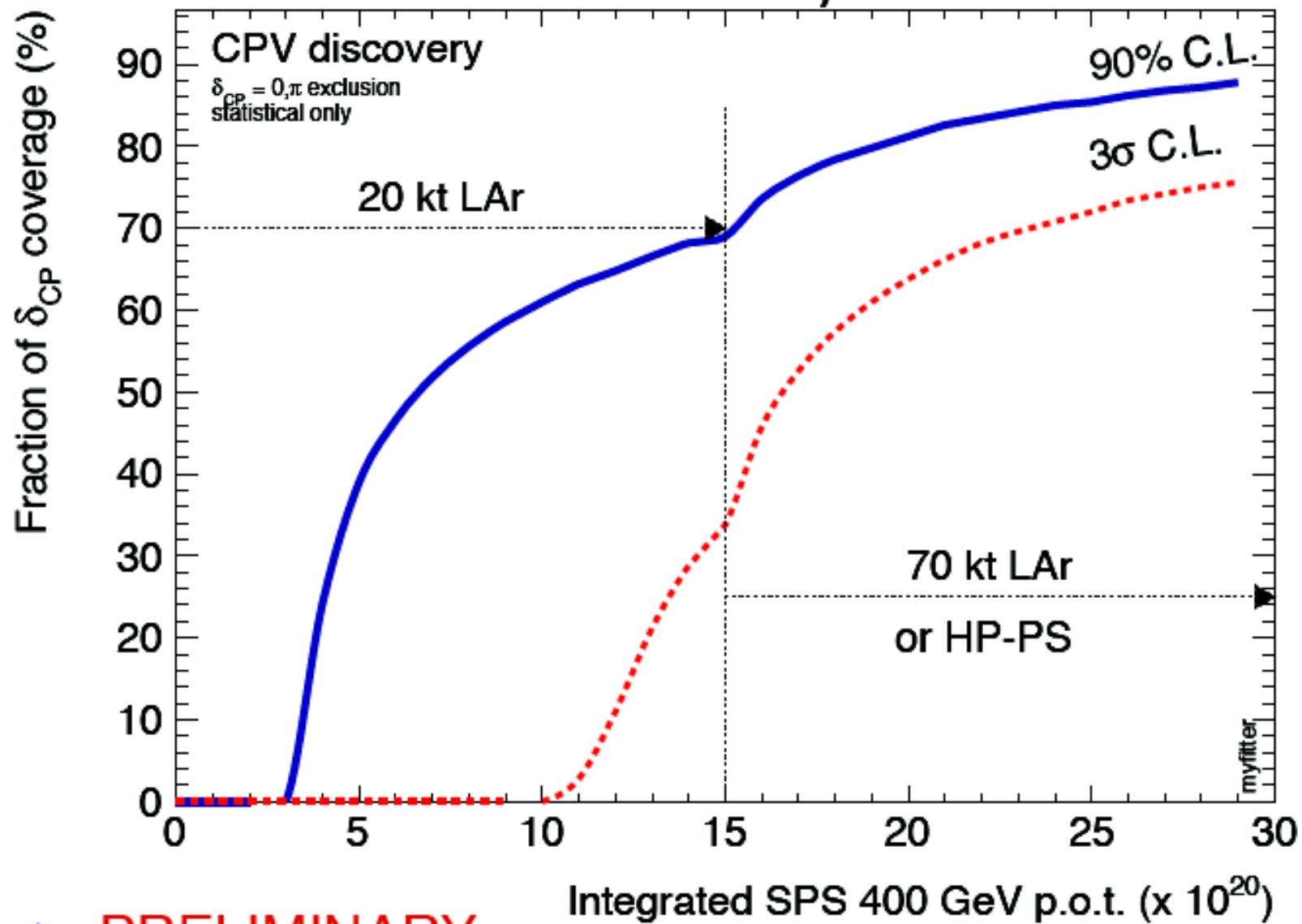


CPV discovery



CPV discovery as function of p.o.t.

LBNO - CERN-Pyhäsalmi



► PRELIMINARY

Integrated SPS 400 GeV p.o.t. ($\times 10^{20}$)

Marco Zito
GDR 20 Juin 2012

37

LBNO EoI: the physics reach

- Initial setup 20 kton LAr LEM TPC + MIND + CERN SPS 700kW upgrade
- **Ultimate** long baseline oscillations measurements:
 - LBNO can measure all transitions ($e/\mu/\tau$) and determine precisely oscillation parameters. It can achieve a **5 σ C.L. determination of the neutrino mass hierarchy** in a few years. In a 10 years run, it explores a **significant part of the CPV parameter space, namely 60% CPV coverage at 90% C.L.**
 - Both the local situation and the distance make it such that it can evolve into larger detector(s) and a more powerful beams (e.g HP-PS and/or NF) and thus, **offers a long term vision**. For example, with a three-fold increase in exposure, **it reaches 75% CPV coverage at 3 σ C.L.** Competitive with T2HK (even more with JPARC MR at 700kW...) and LBNE.
- **Strongly** extended sensitivity to nucleon decay in several channels.
E.g. some channels with sensitivity similar to HK:
$$Br(p \rightarrow \bar{\nu} K) > 2 \times 10^{34} \text{y} (90\% \text{C.L.}) \quad Br(n \rightarrow e^- K^+) > 2 \times 10^{34} \text{y} (90\% \text{C.L.})$$
- **Interesting** astrophysics: LBNO acts as an nu-observatory in the 10 MeV-100 GeV range.
5600 atmospheric events/yr **relic SN, WIMP annihilation, ...**
>10000's events @ SN explosion@10kpc



Milestones - Timescale

LAGUNA Design Study funded for site studies:	2008-2011
Categorize the sites and down-select:	Sept. 2010
LAGUNA-LBNO: detector design, costing and LBL beam options	2011-2014
Submission of LBNO EoI to CERN	2012
Critical decision	2015 ?
Excavation-construction (incremental):	2016-2021 ?
Phase 1 LBL physics start:	2023 ?
Phase 2 incremental step implementation:	>2025 ?

Conclusions

- Unique scientific potential of LBNO CERN to Pyhasalmi with a neutrino beam based on SPS
 - Conclusive mass hierarchy determination
 - Significant exploration of CP phase delta
 - X10 sensitivity for nucleon decay and astrophysics program
- LBNO has a clear upgrade path : larger mass and beam energy up to the ultimate facility the Neutrino Factory
- EOI submitted to SPSC and input to the strategy process

Scientific concerns about the 2300 km baseline (Mauro Mezzetto) (I) ... and my comments (Alain)

1. The close detector must be built 250 m deep, 800 m from the target (decay tunnel is 300 m), severely constraining its design. No way to push down systematic errors.

Estimate size of necessary ND, (Larg+MIND) and make excavation accordingly. We are talking 150 tons of Larg or scintillator and < 1kton of iron, this is <20 times smaller than the far detector. Not cheap, should be evaluated but cant see why this should be a show stopper.

2. Uncertainties in the matter density introduce an additional systematic error that potentially washes out CP sensitivity (i.e. 10% error on matter density changes the 3σ coverage of a 20 kton detector from 30% to 0%)

The matter effect uncertainty on C2PY is estimated to be +/-2% see note by Juha Peltoniemi

3. ν_τ events are a severe background to the second oscillation maximum that potentially destroys its significance.

This is an interesting point and should be studied, but *in fine* I believe that the possibility of producing taus will be turned from a handicap to an advantage. Tau decay into electrons but also muons, pion, rho and a1, and this, independently of the production mode. It is important to understand how well one can monitor/measure the tau production. Remember that the ability to produce taus justified a >200MCHF experiment CNGS+OPERA!

Scientific concerns about the 2300 km baseline (Mauro Mezzetto) (II) ... and my comments (Alain)

4. The second oscillation maximum requires extremely good control of energy reconstruction that has not been demonstrated so far
This is a very good point and should be addressed by simulations, but also with test beam and the near detector. Is there a possibility to expose the detector to a narrow band neutrino beam?

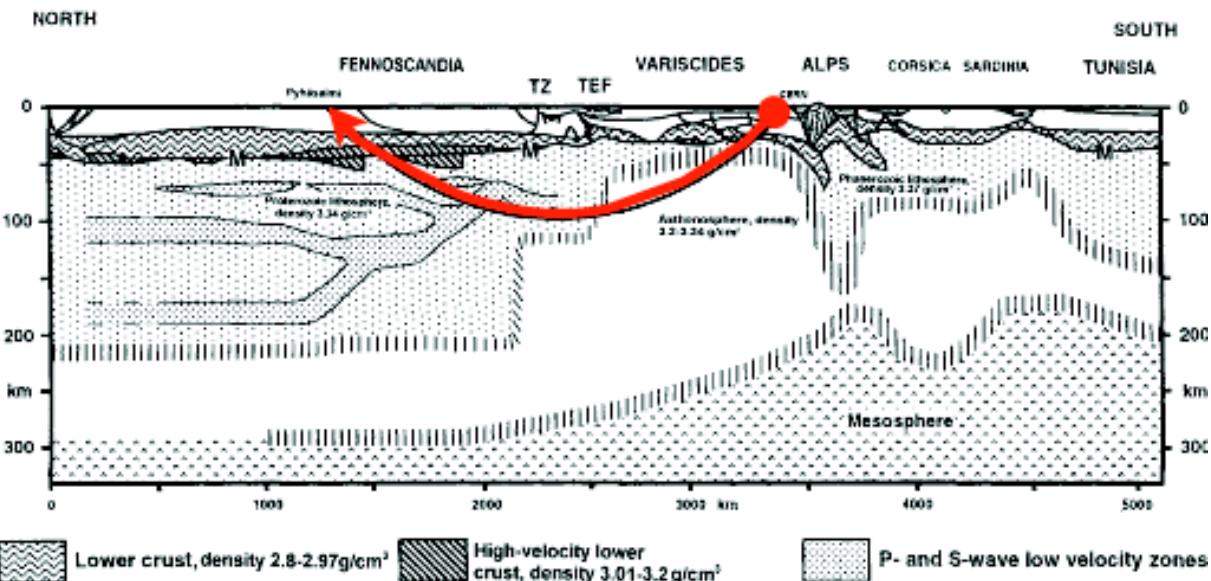
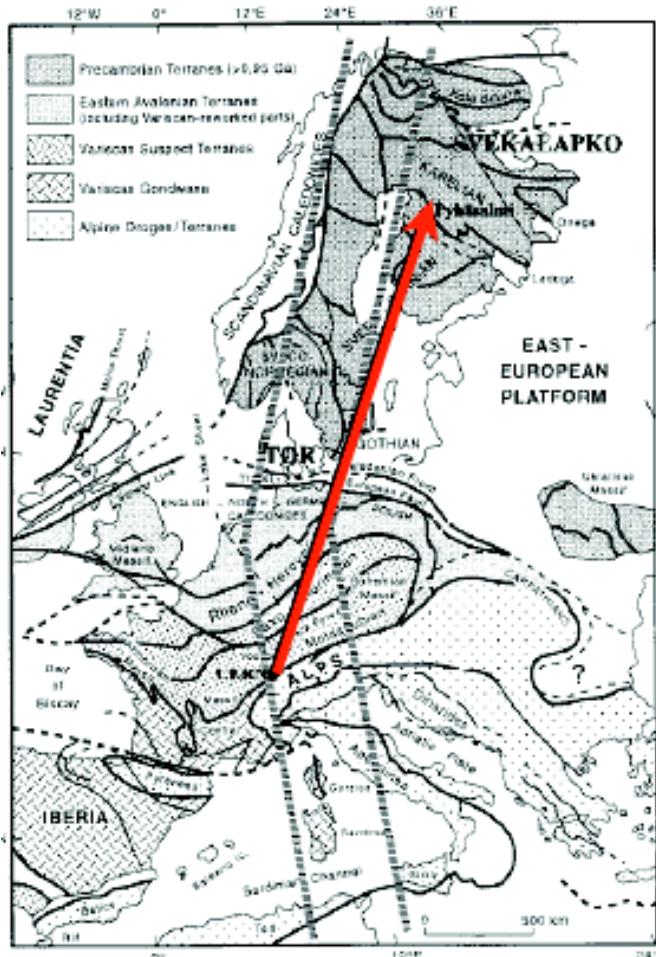
5. Mass hierarchy effects are so big that either the neutrino or the antineutrino beam (depending from the hierarchy) will be almost fully suppressed. CP violation would be extracted from fits to $\sin(\delta)$ and not by $\nu - \bar{\nu}$ asymmetry. Note that even $\nu\mu$ disappearance can provide fits to $\cos(\delta)$.

I find this point somewhat more formal than practical. This will remain a point of discussion for all long baseline experiments in which the matter effect is significant and must be subtracted. Does the subtraction of the matter effect spoil the determination of the difference between neutrino and antineutrino oscillation?

The fact that $\nu\mu$ disappearance can provide fits to $\cos(\delta)$ would be in strong support of the confirmation/test of the scheme with a 3x3 complex matrix. Mauro do you have more info on this?

Neutrinos from CERN to Pyhäsalmi

arXiv:hep-ph/0305042v1



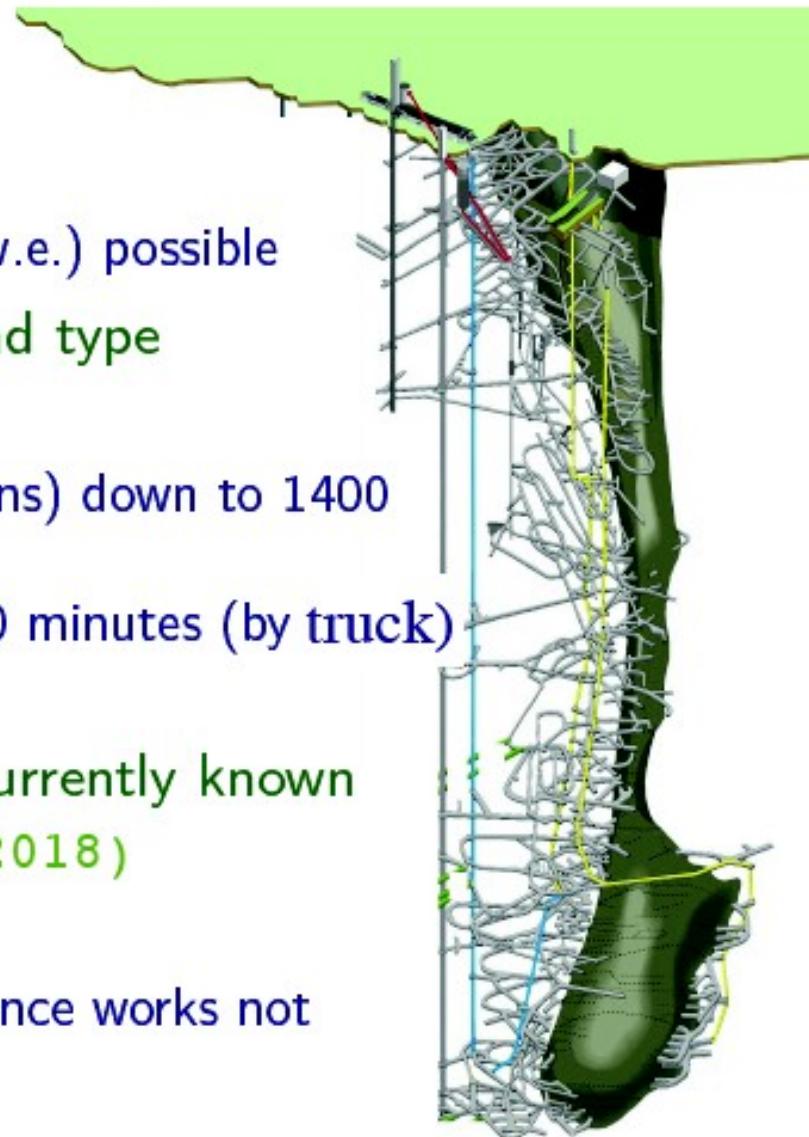
- Distance CERN-Pyhäsalmi = 2288 km
- Deepest point = 103.8 km
- Abundant geophysical data about crust and upper mantle available
- Densities = $2.4\text{-}3.4 \text{ g/cm}^3$
- Remaining uncertainty has small effect on neutrino oscillations

Present state of mine



Present: The Pyhäsalmi mine (Inmet Mining Ltd., Canada)

- ▶ Produces Cu, Zn, and FeS₂
- ▶ The deepest mine in Europe
 - ▶ Depths down to 1400 m (4000 m.w.e.) possible
- ▶ The most efficient mine of its size and type
- ▶ Very modern infrastructure
 - ▶ lift (of 21.5 tons of ore or 20 persons) down to 1400 metres takes ~3 minutes
 - ▶ via 11-km long decline it takes ~40 minutes (by truck)
 - ▶ good communication systems
- ▶ Operation time still 7–8 years with currently known ore reserves (presumably until 2018)
- ▶ Compact mine, small 'foot print'
 - ▶ water pumping and other maintenance works not major issues





2. NEXT STEPS - a neutrino road map

The recent measurement of $\sin^2 2\theta_{13} \sim 0.097 \pm 0.012$ clarifies the next steps to follow. The large value of this parameter will allow a clear-cut determination of the mass hierarchy of neutrinos, and may render observation of CP violation accessible, though not easily, with conventional neutrino beams, within the next 10-20 years depending on the value of parameters

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

A precise study of CP violation, a full verification of the 3x3 mixing of active neutrinos and the search for physics beyond this framework, will require precise determination of all possible flavour transitions of neutrinos for which new, better defined neutrino beams will become necessary (beta beam or neutrino factory)

The search for neutrino Majorana mass terms will require $0\nu\beta\beta$ experiments which cannot be done at accelerators

The search for sterile neutrinos is an extremely broad field as their masses are not constrained between few meV to 10^9 GeV, and can be pursued in a great variety of means.

A good starting point is the clarification of the possible anomalies in nuclear reactor and short baseline experiments, using nuclear sources and short baseline accelerator experiments



4 OPPORTUNITY IN EUROPE FOR THE NEXT STEP

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.

Building on the experience with CNGS and on the pioneering competence in Liquid Argon TPCs, European physicists are in the position to propose a realistic next step: a conventional neutrino beam in CERN north area neutrino facility aiming at 20kton of fine grain detector (Larg) followed by a magnetized iron detector (MIND) at Pyhasalmi. It should be supported by extensive hadroproduction measurements in an upgraded SHINE/NA61.

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, could also contribute to beam)

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 to the SPSC and the European strategy.

LBNO EoI: the priors

- A significantly better sensitivity than the (combined) T2K and NOvA, with an improved method to conclusively determine mass ordering and to explore CP-violation → **exploit L/E dependence with WBB at long baseline** → **spectral information provides unambiguous oscillation parameters sensitivity.**
- A detector with better signal efficiency and better background rejection than T2K & NOvA but with a mass of the same order as T2K/SuperK & NOvA → **>20 kton very fine sampling tracking detector**
- There are compelling ν -astrophysics measurements and nucleon decay searches to be performed → **deep underground location**
- A conventional wide band beam at an energy above 500 MeV is technically achievable and affordable, and enables at long baseline to study L/E dependence of oscillation probability with 1st & 2nd maxima → **new conventional beam aimed at a baseline >1000 km**
- Large sensitivity to mass hierarchy with 100% coverage at $>5\sigma$ and the presently available beam power requires a very long baseline → **baseline >1500 km**
- At a distance suitable for the NF for long term → **baseline >2000 km.**

Jalons et dates de la préparation de la stratégie pour les neutrinos

- Mai Workshop NuTurn au Gran Sasso
- Mai Town Meeting au CERN : input de la communauté
- 12-15 Juin: Réunion finale EURONU
- 20 juin : soumission de l'Expression of Interest pour le faisceau CERN-Pyhasalmi
- 21-22 Juin GDR neutrino: discussion de la stratégie française et de l'executive summary de Giens
- 2-4 Juillet: Meeting Laguna-LBNO : costing du laboratoire et détecteurs à Pyhasalmi
- Fin Juillet: deadline des contributions pour Cracovie
- Septembre : Symposium sur la Stratégie à Cracovie