LBNO: neutrino oscillations and facility

Etam NOAH (UniGe) - on behalf of the LBNO collaboration

December 5, 2012

LBNO motivation — the background

- Discovery of the Higgs confirms/reinforces the Standard Model;
- Neutrino masses and oscillations are the only experimental evidence of physics Beyond the Standard Model (BSM);
- Neutrinos are the only fermions whose properties remain largely unknown.. and these are sought to further our knowledge of the SM;
- Past quests and recent results have significantly clarified the picture and help focus our efforts towards the future precision measurements required.

LBNO motivation

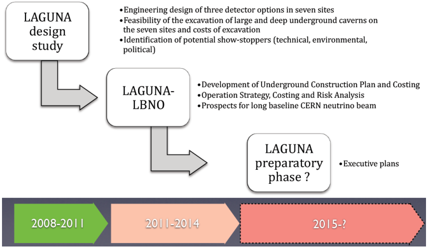
- Next generation long baseline experiment aiming at significantly better sensitivity than achievable at combined T2K, NOνA and reactor experiments;
- LBNO will explicitly observe MH induced matter effects and CP-violation - c.f. extraction of hierarchy or δ_{CP} from global fits of all available data;
- Extend nucleon decay searches, a unique probe for BSM up to the Grand Unification Scale,
- Perform very compelling and complementary atmospheric and astrophysical neutrino detection programmes, accessible since detector is deep underground.

2100 km from RAL, 1500 km from DESY, and 1160 km from Protvino.

- CUPP : Centre for Underground Physics in Pyhäsalmi (www.cupp.fi)
- Location: 63° 39' 31"N – 26° 02' 48"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

Being extensively investigated in LAGUNA DS since 2008

2300 km baseline is suitable for Neutrino Factory



[1]

- 2010: Site selection;
- 2012: Submission of LBNO EoI to CERN;
- 2014: Technical design;
- 2015: Critical decision;
- 2016-2021: Excavation-construction;
- 2023: LBL physics start.

[1] Timescale pending approval and funding

LBNO EOI

- Expression of Interest for a very long baseline neutrino oscillation experiment (LBNO) - SPSC-EOI-007-LBNO: submitted June 2012;
- Presentation to the SPS committee 26 June 2012;
- SPSC favourable:
  - Encouraged collaboration to prepare a TDR.

LBNO Collaboration

~230 authors, 51 institutions

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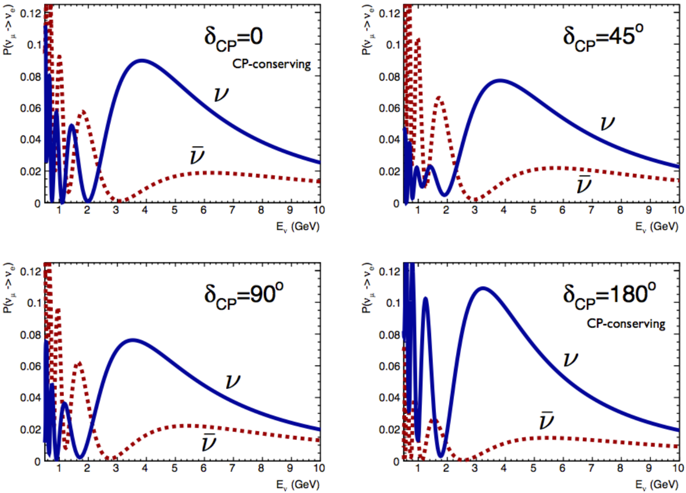
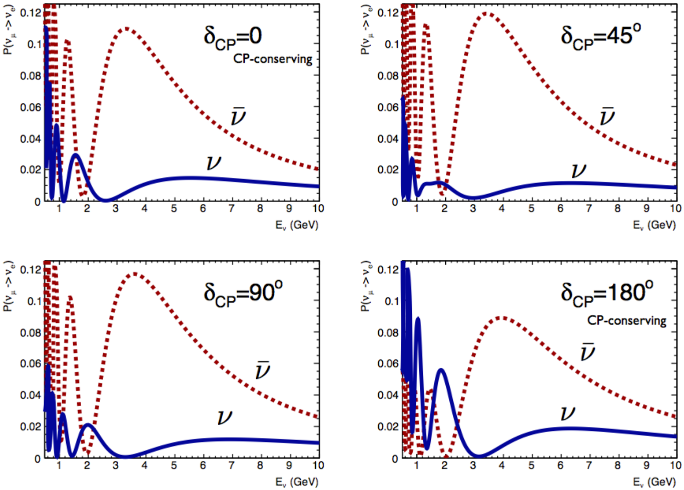
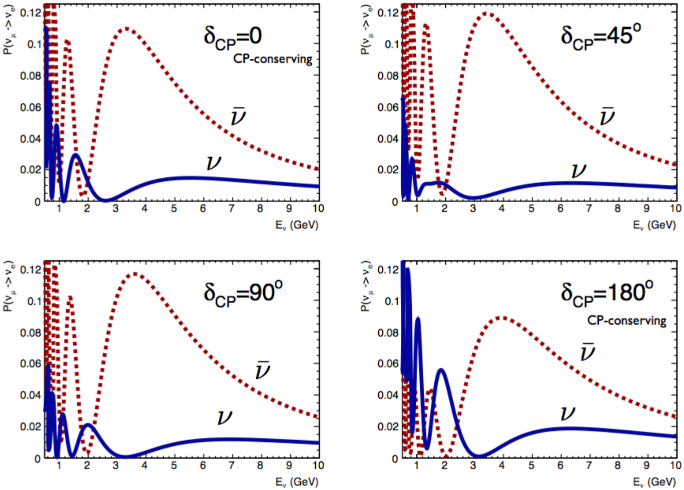
Normal mass hierarchy: spectral information: $\nu_\mu \to \nu_e$



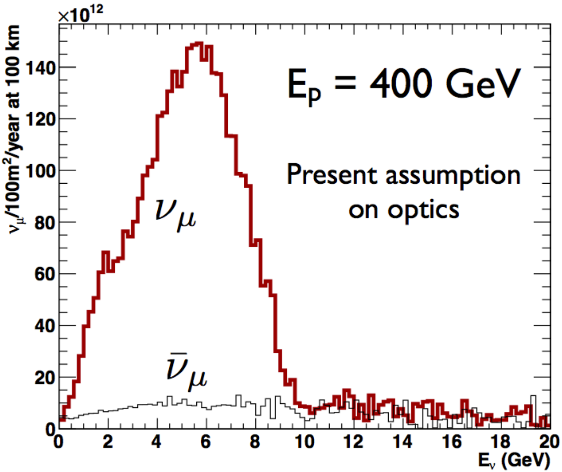
Inverted mass hierarchy: spectral information: $\nu_\mu \to \nu_e$



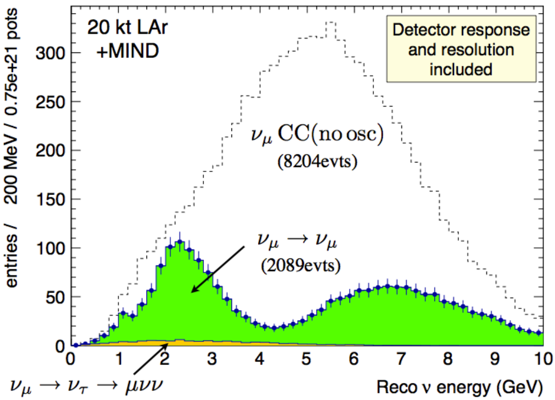
Inverted mass hierarchy: spectral information: $\nu_\mu \rightarrow \nu_e$



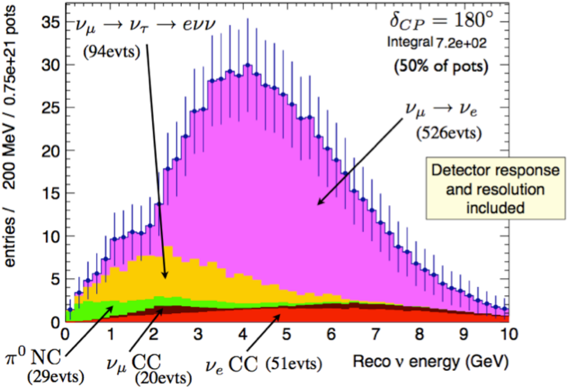
Beam composition



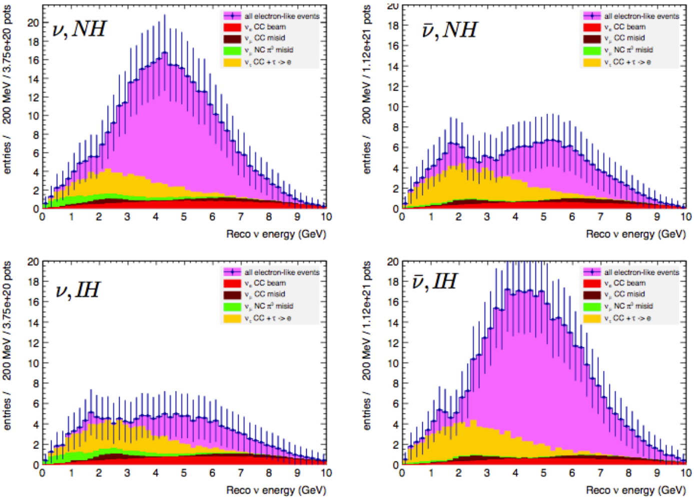
μ-like CC sample



e-like CC sample

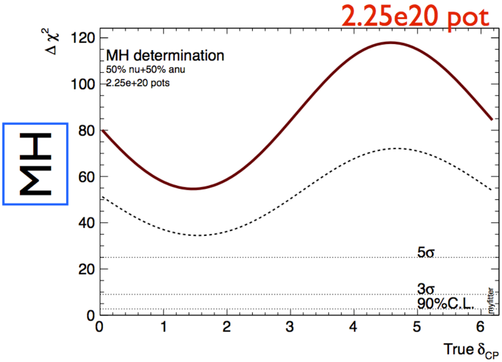


$\nu/\overline{\nu}$ and MH



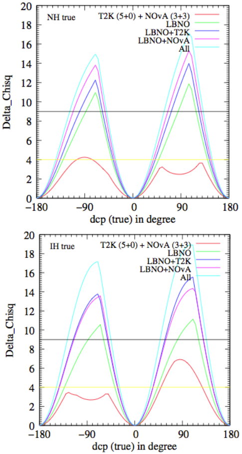
MH sensitivity

- Nominal beam power scenarios (700kW);
- MH: 100% coverage above 5σ in a few years of running.

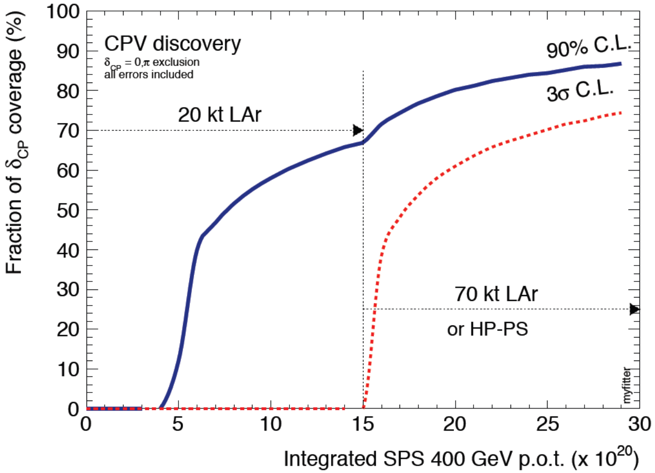


CPV sensitivity

- Nominal beam power scenarios (700 kW);
- CPV: 60% coverage and evidence for maximal CP ($\pi/2$, $3\pi/2$) at 2.9σ in 10 years;
- Reduce systematics with near detector, hadron prod. meas...;
- sensitivity also improved by:
  - higher beam power;
  - larger far detector;



Incremental approach with conventional beams



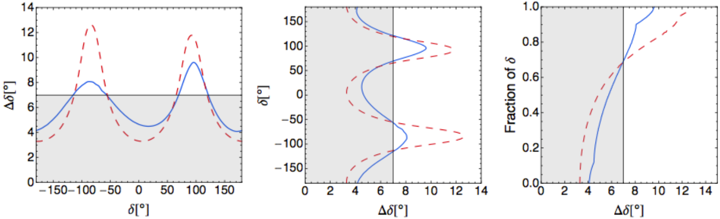
Facilities compared in P. Huber et al. arXiV 1209.5973

	Setup	E_ν^{peak}	L	OA	Detector	kt	MW	Decays/yr	$(t_\nu, t_{\bar{\nu}})$
Benchmark	BB350	1.2	650	–	WC	500	–	$1.1(2.8)\times10^{18}$	(5,5)
	NF10	5.0	2 000	–	MIND	100	–	7×10^{20}	(10,10)
	WBB	4.5	2 300	–	LAr	100	0.8	–	(5,5)
	T2HK	0.6	295	2.5°	WC	560	1.66	–	(1.5,3.5)
Alternative	BB100	0.3	130	–	WC	500	–	$1.1(2.8)\times10^{18}$	(5,5)
	+ SPL			–			4	–	(2,8)
	NF5	2.5	1 290	–	MIND	100	–	7×10^{20}	(10,10)
	$LBNE_{mini}$	4.0	1 290	–	LAr	10	0.7	–	(5,5)
	$NO\nu A^+$	2.0	810	0.8°	LAr	30	0.7	–	(5,5)
2020	T2K	0.6	295	2.5°	WC	22.5	0.75	–	(5,5)
	$NO\nu A$	2.0	810	0.8°	TASD	15	0.7	–	(4,4)

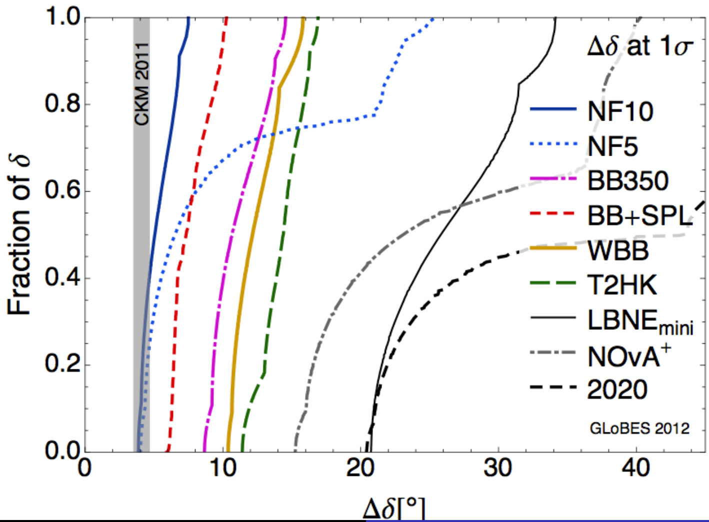
Systematics: arXiV 1209.5973

	SB			BB			NF		
Systematics	Opt.	Def.	Cons.	Opt.	Def.	Cons.	Opt.	Def.	Cons.
Fiducial volume ND	0.2%	0.5%	1%	0.2%	0.5%	1%	0.2%	0.5%	1%
Fiducial volume FD (incl. near-far extrap.)	1%	2.5%	5%	1%	2.5%	5%	1%	2.5%	5%
Flux error signal ν	5%	7.5%	10%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background ν	10%	15%	20%	correlated			correlated		
Flux error signal $\bar{\nu}$	10%	15%	20%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background $\bar{\nu}$	20%	30%	40%	correlated			correlated		
Background uncertainty	5%	7.5%	10%	5%	7.5%	10%	10%	15%	20%
Cross secs $\times$ eff. QE†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs $\times$ eff. RES†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs $\times$ eff. DIS†	5%	7.5%	10%	5%	7.5%	10%	5%	7.5%	10%
Effec. ratio ν_e/ν_μ QE*	3.5%	11%	–	3.5%	11%	–	–	–	–
Effec. ratio ν_e/ν_μ RES*	2.7%	5.4%	–	2.7%	5.4%	–	–	–	–
Effec. ratio ν_e/ν_μ DIS*	2.5%	5.1%	–	2.5%	5.1%	–	–	–	–
Matter density	1%	2%	5%	1%	2%	5%	1%	2%	5%

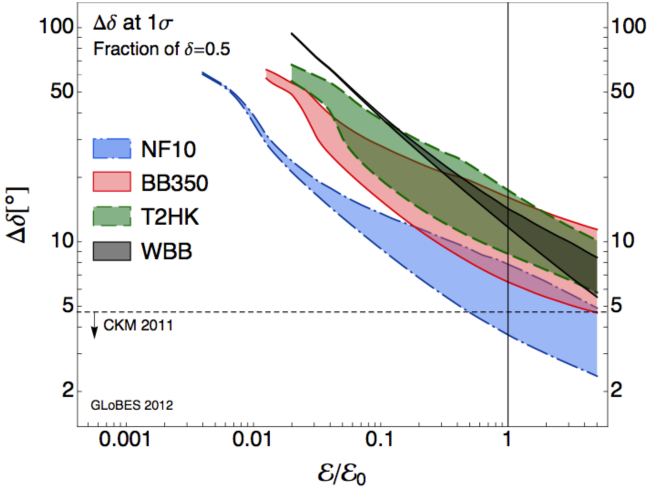
"Fraction of δ" as performance indicator: arXiV 1209.5973



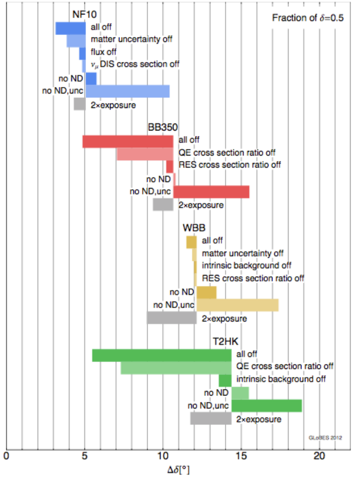
Comparing facilities: arXiV 1209.5973

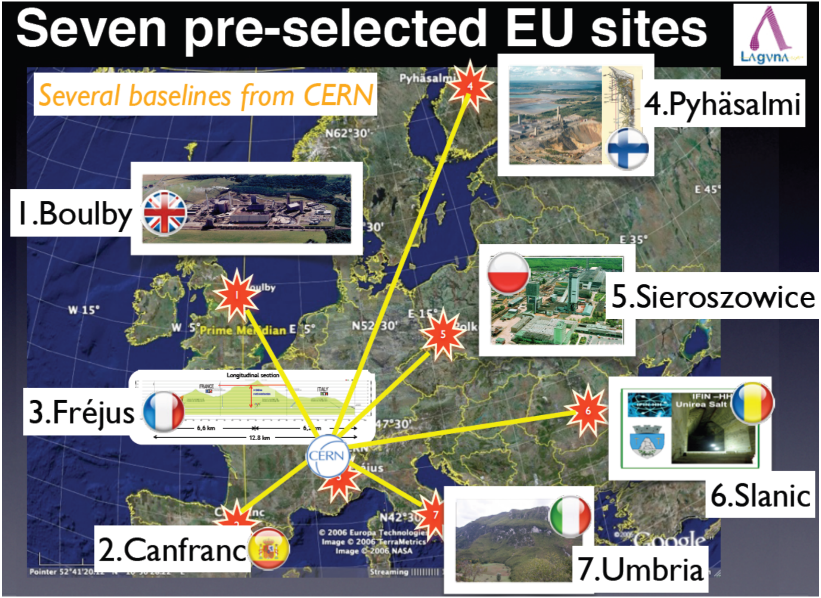


Varying systematics: arXiV 1209.5973



"Switching off" systematics: arXiV 1209.5973




Seven pre-selected EU sites
LAGUNA
Several baselines from CERN
1.Boulby
2.Canfranc
3.Fréjus
4.Pyhäsalmi
5.Sieroszowice
6.Slanic
7.Umbria
CERN
Longitudinal section
FRANCE
ITALY
6,6 km
12.8 km
IFIN -HH
Unirea Salt
Prime Meridian
W 15°
W 5°
E 5°
E 15°
E 35°
E 45°
N62°30'
N52°30'
N42°30'
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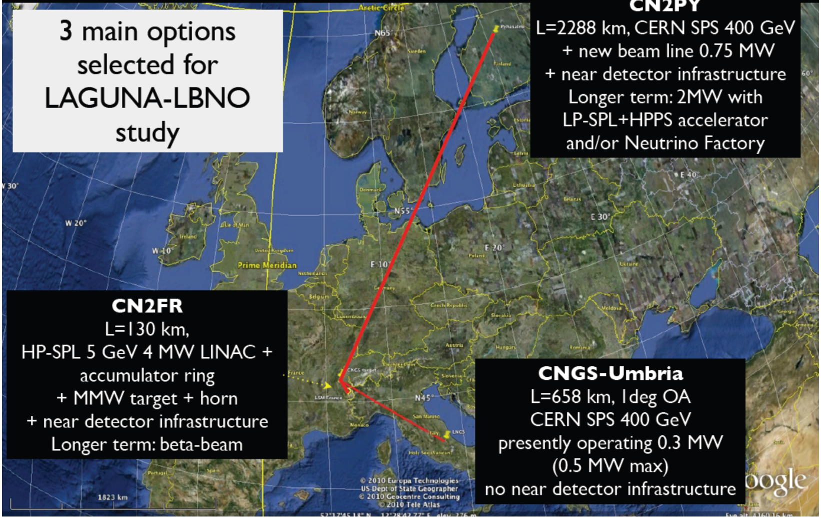
2540 km – bimagic value
7250 km – magic value

Location Baseline (km)	CERN 2540	J-PARC 7250	Fermilab 7250
Pyhäsalmi	2290 (90%)	7090 (98%)	6630 (91%)
Boulby	1050 (41%)	8480 (117%)	5980 (82%)
Canfranc	650 (26%)	9280 (128%)	6550 (90%)
Frejus	130 (5%)	8900 (123%)	6840 (94%)
Sieroszowice	940 (37%)	8180 (113%)	6960 (96%)
Slanic	1540 (61%)	8150 (112%)	7780 (107%)
Umbria	670 (26%)	8850 (122%)	7300 (101%)

LAGUNA-LBNO study cases



3 main options selected for LAGUNA-LBNO study

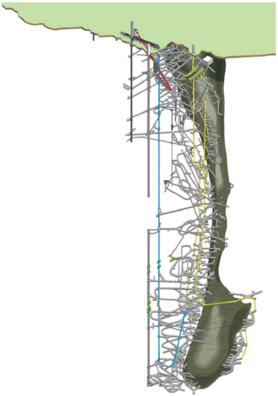
CN2PY
L=2288 km, CERN SPS 400 GeV
+ new beam line 0.75 MW
+ near detector infrastructure
Longer term: 2MW with
LP-SPL+HPPS accelerator
and/or Neutrino Factory

CN2FR
L=130 km,
HP-SPL 5 GeV 4 MW LINAC +
accumulator ring
+ MMW target + horn
+ near detector infrastructure
Longer term: beta-beam

CNGS-Umbria
L=658 km, 1deg OA
CERN SPS 400 GeV
presently operating 0.3 MW
(0.5 MW max)
no near detector infrastructure

Current status of the Pyhäsalmi mine (Inmet Mining Ltd., Canada)

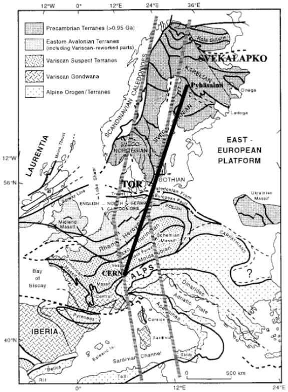
- Produces Cu, Zn, and FeS_2;
- The deepest mine in Europe:
  - depths down to 1400 m (4000 m.w.e.).
- The most efficient mine of its size and type;
- Very modern infrastructure:
  - lift down to 1400 m: 3 minutes;
  - 11-km long decline: 40 minutes by truck;
  - good communication systems.
- Operation time still 7-8 years with currently known ore reserves (until 2018);
- Compact mine, small foot print.



Unique features of Pyhäsalmi

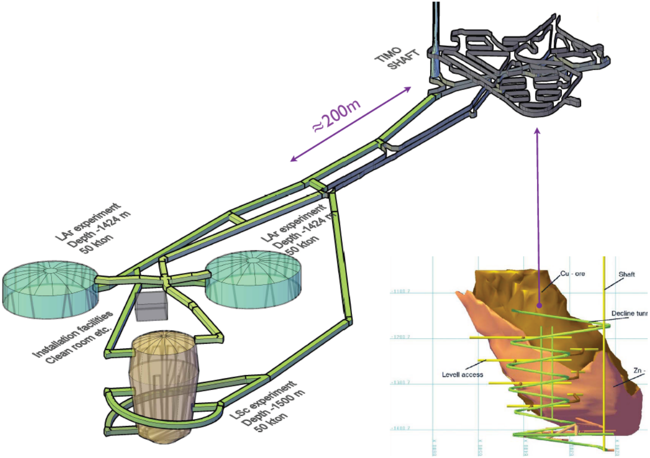
- Many optimal conditions satisfied simultaneously:
  - Infrastructure is ultra modern and in perfect state since mine is still operational;
  - Very little environmental water;
  - Could be dedicated to science when mine closes in 2018.
- One of the deepest locations in Europe (4000 m.w.e);
- Lowest reactor neutrino background in Europe, relevant for v. low MeV ν;
- Extensive site investigation planned 2012-2014 (Finnish contribution).

CERN to Pyhäsalmi



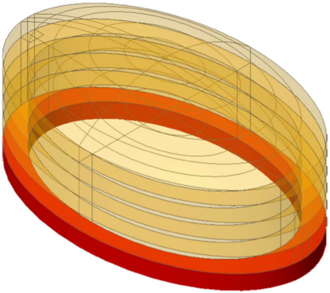
- Distance CERN Pyhäsalmi = 2288 km;
- Deepest point = 103.8 km;
- Abundant geophysical data about crust and upper mantle available;
- Remaining uncertainty has small effect on neutrino oscillations (assumed equivalent to $\pm 4\%$ global change in matter density).

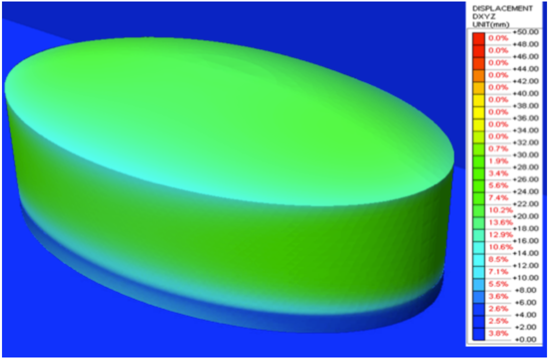
Layout of the LAGUNA-LBNO observatory at Pyhäsalmi



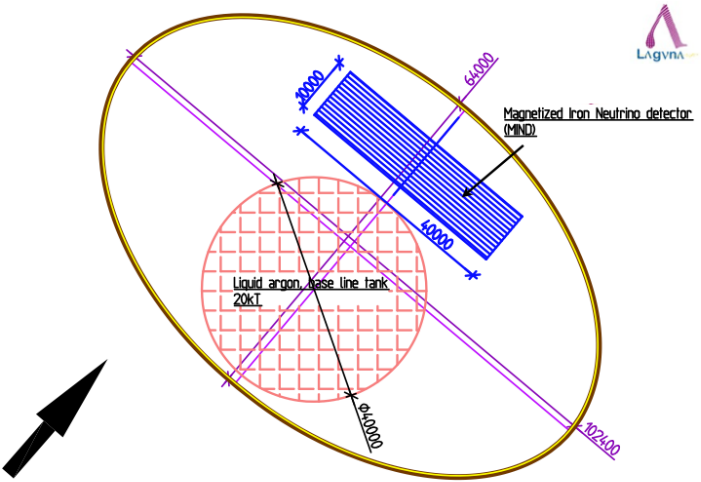
Dome excavation simulations by ROCKPLAN

Stage 10



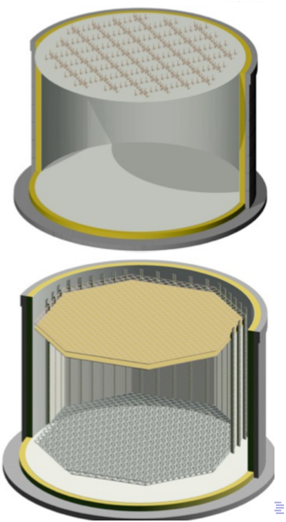


Top view of far detector cavern

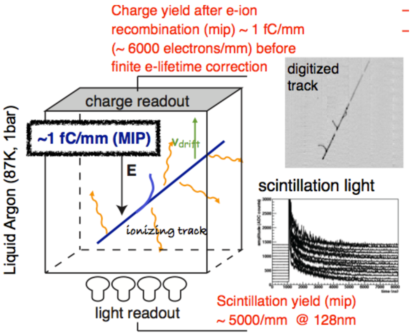


GLACIER detector parameters

		20 KT	50 KT	100 KT
Liquid argon density at 1.2 bar	[T/m³]	1.38346		
Liquid argon volume height	[m]	22		
Active liquid argon height	[m]	20		
Pressure on the bottom due to LAr	[T/m²]	30.4 (≈ 0.3 MPa ≈ 3 bar)		
Inner vessel diameter	[m]	37	55	76
Inner vessel base surface	[m²]	1075.2	2375.8	4536.5
Liquid argon volume	[m³]	23654.6	52268.2	99802.1
Total liquid argon mass	[T]	32525.6	71869.8	137229.9
Active LAr area (percentage)	[m²]	824 (76.6%)	1854 (78%)	3634 (80.1%)
Active (instrumented) mass	[KT]	22.799	51.299	100.550
Charge readout square panels (1m×1m)		804	1824	3596
Charge readout triangular panels (1m×1m)		40	60	72
Number of signal feedthroughs (666 channels/FT)		416	1028	1872
Number of readout channels		277056	660672	1246752
Number of PMT (area for 1 PMT)		804 (1m×1m)	1288 (1.2m×1.2m)	909 (2m×2m)
Number of field shaping electrode supports (with suspension SS ropes linked to the outer deck)		44	64	92

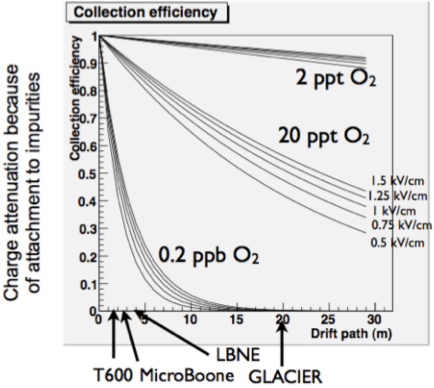


Liquid argon pros



- High density, cheap medium;
- Quasi free *e* from ionising tracks are drifted in LAr (87K, 1bar) by E_{drift}
- *e* drift velocity 2 mm/μs at 1 kV/cm;
- *e* cloud diffusion is small:
  - $\sigma = \sqrt{2Dx/v_{drift}}$ after several meters;
- High scintillation light yield (at 128 nm) can be used for;
  - T_0, trigger,....

Liquid argon challenges



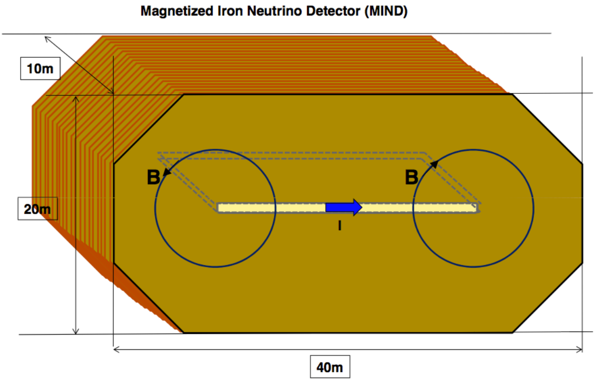
- Long drift requires ultra high purity, Goal:
  - $\ll$ 100 ppt O_2 equiv....
- Large wire chambers at cryogenic T;
- No charge amplification in liquid: fC sens. preamp;
- Large number of readout channels;
- Large cryogenic systems.

Future LAr detectors

Project	LAr mass (tons)	Goal	Baseline (km)	Where	Status
MicroBOONE	170 (70 fid.)	short baseline	0.47	FNAL BNB	Under construction
LAr1	≈1'000	2nd detector for short baseline	≈0.7	FNAL BNB	Proposal submitted
ICARUS-NESSIE	150 + 478	two-detectors short baseline	0.3 + 1.6	CERN + new SBL beam	Proposal submitted
MODULAr	5'000 unit	shallow depth far detector	730	Italy, new lab nearby LNGS	plan
GLADE	5000	surface	810	NUMI off-axis	Letter of Intent
LBNE LAr (*)	2x17'000(*)	underground(*) far detector	1300(*)	Homestake(*) + new FNAL beam(*)	CD-0
GLACIER LAGUNA-LBNO	initially 20'000 (incremental)	underground far detector	2300	Finland + new CERN LBL beam	Expression of interest in preparation
GLACIER Okinoshima	up to 100'000	underground far detector	665	Japan + JPARC neutrino beam	R&D proposal at JPARC

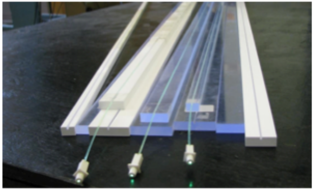
Magnetised Iron Neutrino Detector (MIND)

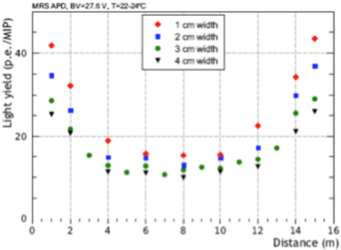
- μ momentum and charge identification;
- 35 kton;
- $B = 1.5$ to 2.5 T;
- 3 cm Fe plates;
- 1×0.7 cm^2 scintillator bars;



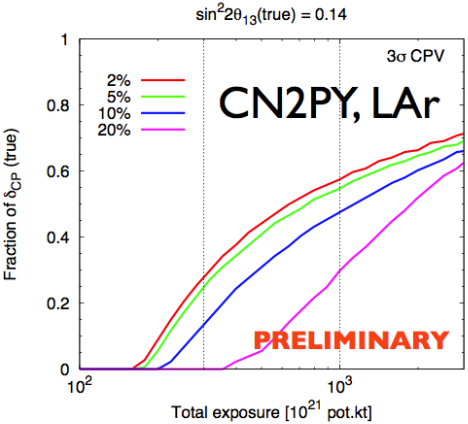
MIND readout with scintillator bars

- Extruded scintillator slabs produced by Uniplast;
- Polysterene, 1.5% paraterphenyl (PTP), 0.01% POPOP;
- Used in T2K SMRD detector;
- Surface etched with chemical agent to create 30-100 μm layer that works as diffusive reflector;
- Grooves milled for wavelength shifting fibres;
- Photosensor is silicon photomultiplier.

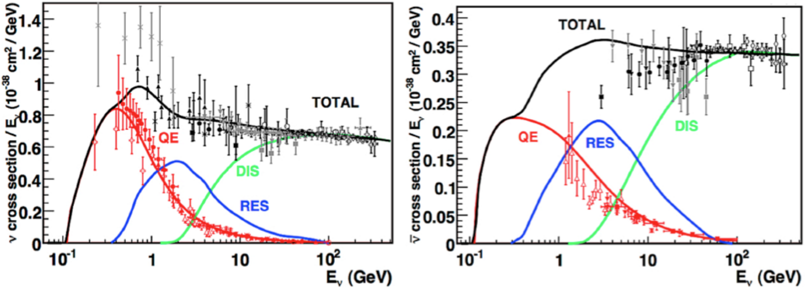




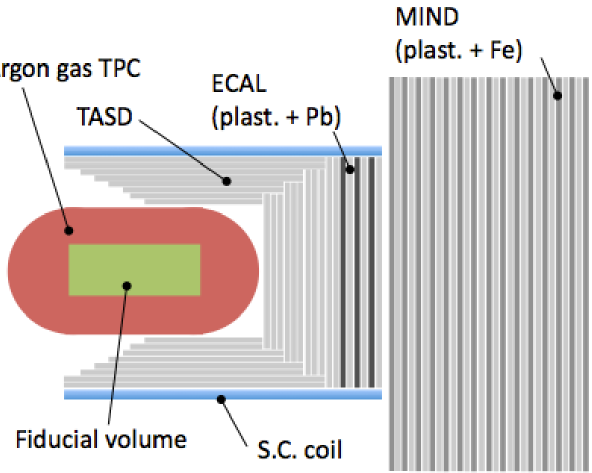
Near detector - motivation I: 5% syst. requirement



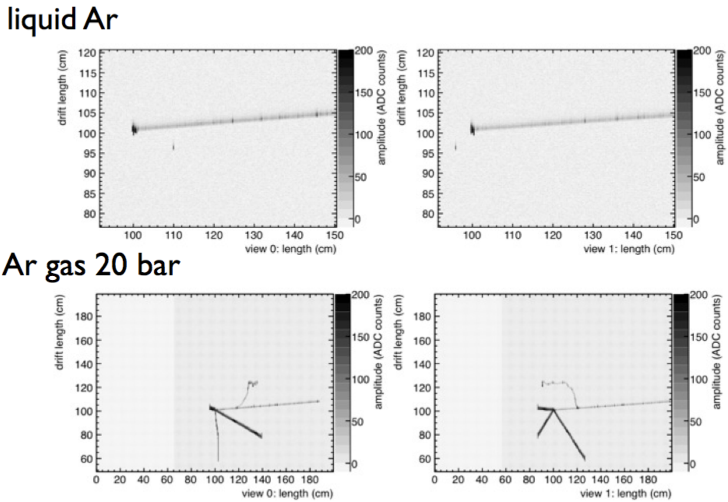
Near detector - motivation II: 10-40% xsec uncertainties



Near detector sketch



Near detector argon gas TPC: vertex detector

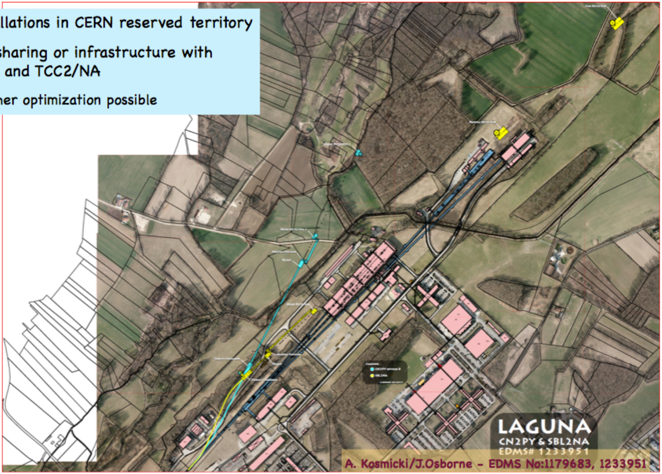


CN2PY beam

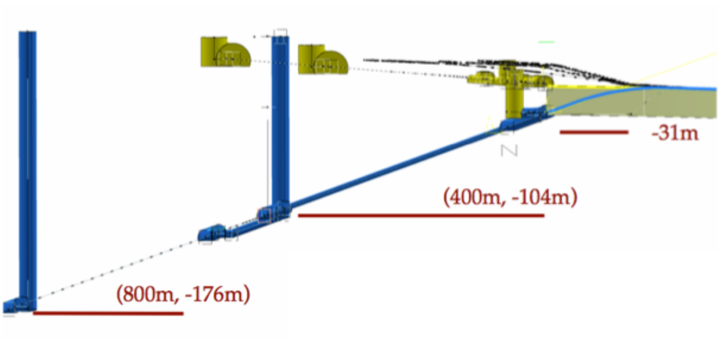
- Phase 1: use proton beam extracted from the SPS:
  - 400 GeV;
  - max. 7.0×10^{13} protons per pulse;
  - 10 μs pulse;
  - 0.167 Hz;
  - 750 kW beam power.
- Phase 2: use proton beam from new HP-PS:
  - 50(30) GeV;
  - 1.9×10^{14} ppp;
  - 4 μs pulse;
  - 1.33 Hz;
  - 2 MW beam power.

Beam layout: surface

- All installations in CERN reserved territory
- CN2PY sharing or infrastructure with SBL2NA and TCC2/NA
  - further optimization possible

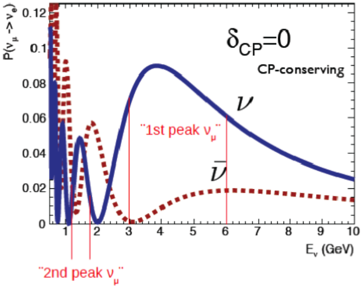


Beam layout: underground

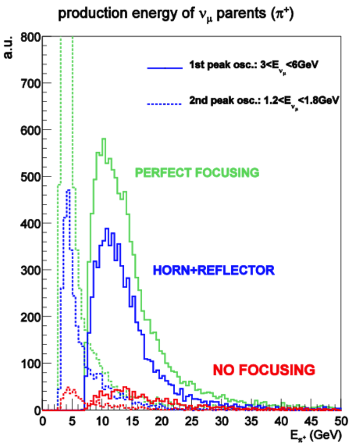


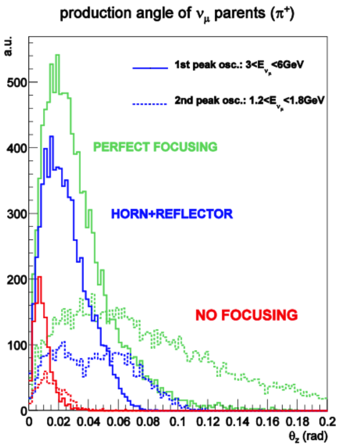
Beam line optimisation

- Maximise π^+ production in energy range of interest;
- Optimize their collection via magnetic horns;
- ν energies of interest:
  - 1^st peak: $3 \rightrightarrows 6$ GeV;
  - $2nd$ peak: $1.2 \rightrightarrows 1.8$ GeV;
- Maximise the total:
  - peak 1+ peak 2;
  - peak 1/total $\sim$ 0.5;

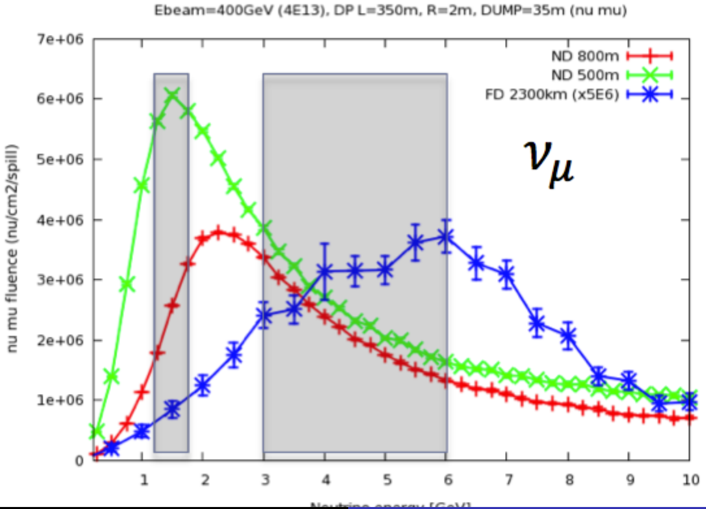


π^+ production





Produced ν_μ at ND and FD



Summary

- LBNO, to be located underground at Pyhäsalmi 2300 km from CERN, has truly unique scientific opportunities;
- One experiment for all transitions (e/μ/τ), can measure separately for ν and $\overline{\nu}$:
  - in appearance: $\nu_\mu \rightarrow \nu_e$
  - in disappearance: $\nu_\mu \rightarrow \nu_\mu$
- Will test three generation mixing paradigm by direct measurement of oscillation probabilities as a function of energy (L/E) - covering 1st and 2nd maxima;
- The direct observation of the energy dependence of the oscillation probabilities induced by matter effects and CP-phase terms, independently for ν and $\overline{\nu}$ will break parameter degeneracy between MH and CP phase and allow a direct determination of mass hierarchy and test of CPV in the lepton sector, different approach to global fits;

Summary - cont'd

- LBNO, is an underground facility geared towards a broad programme;
- detection of several astrophysical sources (SN), and fresh new look at atmph. ν with high granularity and resolution (atm τ app., atm MH, ...);
- $\times 10$ better sensitivity in nucleon decay channels, competitive with HK LoI;
- LBNO defines a clear upgrade path to fully explore CPV. E.g., a three fold exposure yields 75% CPV coverage at 3σ CL, comparable to T2HK LoI - LBNO is a possible first step towards Neutrino Factory.

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- FP7 Research Infrastructure "Design Studies" LAGUNA (Grant Agreement No. 212343 FP7-INFRA-2007-1) and LAGUNA-LBNO (Grant Agreement No. 284518 FP7-INFRA-2011-1);
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