LAGUNA/LBNO

on behalf of CH-Neutrino groups
(NOMAD, K2K, ICARUS, OPERA, T2K, MicroBOONE,.... LBNO)

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CHIPP Plenary meeting 2013
Campus Sursee, June 24-26th, 2013

ETH
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v3

Where is Godot ? (A. Signer)

Sheldon Lee Glashow

"Unless the SM fails, there is no real hope for progress in particle physics. Forbidden decay modes? NONE; neutrino masses? NO; neutrino mixing? NO; neutrino-less double beta decay ? NO; new particles? NO; magnetic monopoles? NO; fractional charges? NO; new stable forms of matter? NO; proton decay? NO; n-nbar oscillations? NO; axions? NO... there is exactly zero evidence for a failure of the SM. The [CERN p-pbar] collider, operating at an energy which is the world highest, is the only realistic hope for something really new & exciting."

S.L. Glashow, St-Vincent workshop, March 1985

Neutrinos at the frontier

- Discovery of the Higgs boson confirms/reinforces the “invincible” Standard Model. What are properties of the Higgs field Φ ?
- **Neutrino masses and oscillations give us an experimental evidence of physics Beyond the Standard Model (BSM)**

“neutrino masses and mixings”

$$V(\phi) = -\mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2 + Y^{ij}\Psi^i_L\Psi^j_R\phi + \frac{g^{ij}}{\Lambda}\Psi^i_L\Psi^{T,j}_L\phi\phi^T$$

Dirac term involving LH+RH — contact Majorana mass term

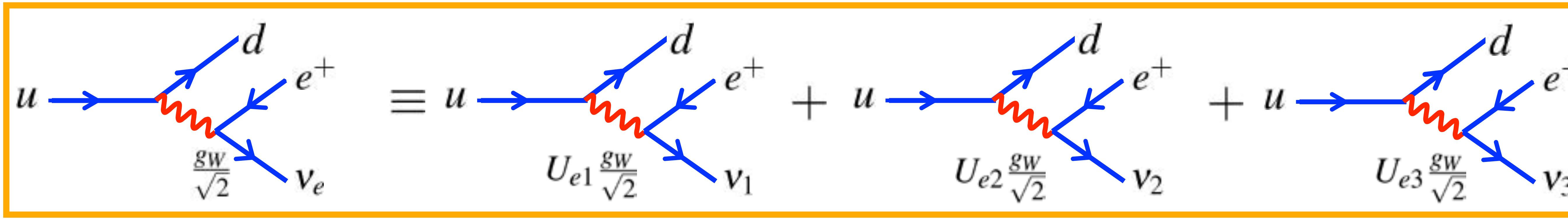
$$Y^{ij} = \text{Yukawa's}, g^{ij} = \text{couplings}, \Lambda = \text{new physics scale}$$

- Neutrinos are the only fermions whose properties remain largely unknown, and these could bring further our knowledge beyond the present SM. They could offer a window to the “Dark Sectors”.
- Past and present measurements have significantly clarified the neutrino picture and helped focus our efforts towards future quests.

The 3νSM paradigm (PMNS)

- Neutrinos are produced and interact as weak eigenstates.
- The weak eigenstates are coherent superposition of the fundamental mass eigenstates. The mass eigenstates are the solutions of the free Hamiltonian and represent the propagation of the neutrinos in space.

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



★ **The 3x3 Unitary matrix U is known as the Pontecorvo-Maki-Nakagawa-Sakata matrix, usually abbreviated PMNS**

★ **The PMNS matrix is usually expressed in terms of 3 rotation angles $\theta_{12}, \theta_{23}, \theta_{13}$ and a complex phase δ, using the notation** $s_{ij} = \sin\theta_{ij}, \quad c_{ij} = \cos\theta_{ij}$

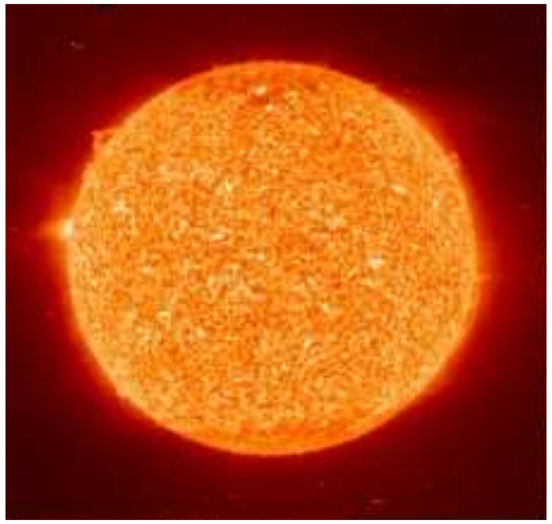
$$\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Dominates: "Atmospheric" "subleading" "Solar"

Global data on neutrinos...

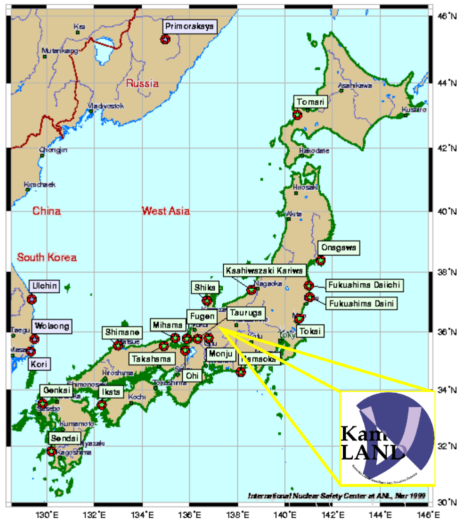
from various neutrino sources and
vastly different energy and distance scales:

sun



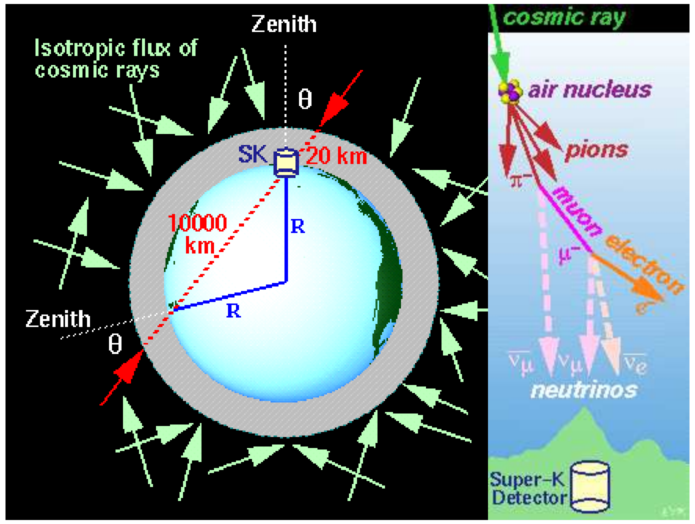
Homestake,SAGE,GALLEX
SuperK, SNO, Borexino

reactors



KamLAND, CHOOZ

atmosphere



SuperKamiokande

accelerators

K2K, MINOS, T2K

- global data fits nicely with the 3 neutrinos from the SM
- a few “anomalies” at 2-3 σ: LSND, MiniBooNE, reactor anomaly, no LMA MSW up-turn of solar neutrino spectrum
  - *Sterile* states conceivable, would imply PMNS matrix non-unitary

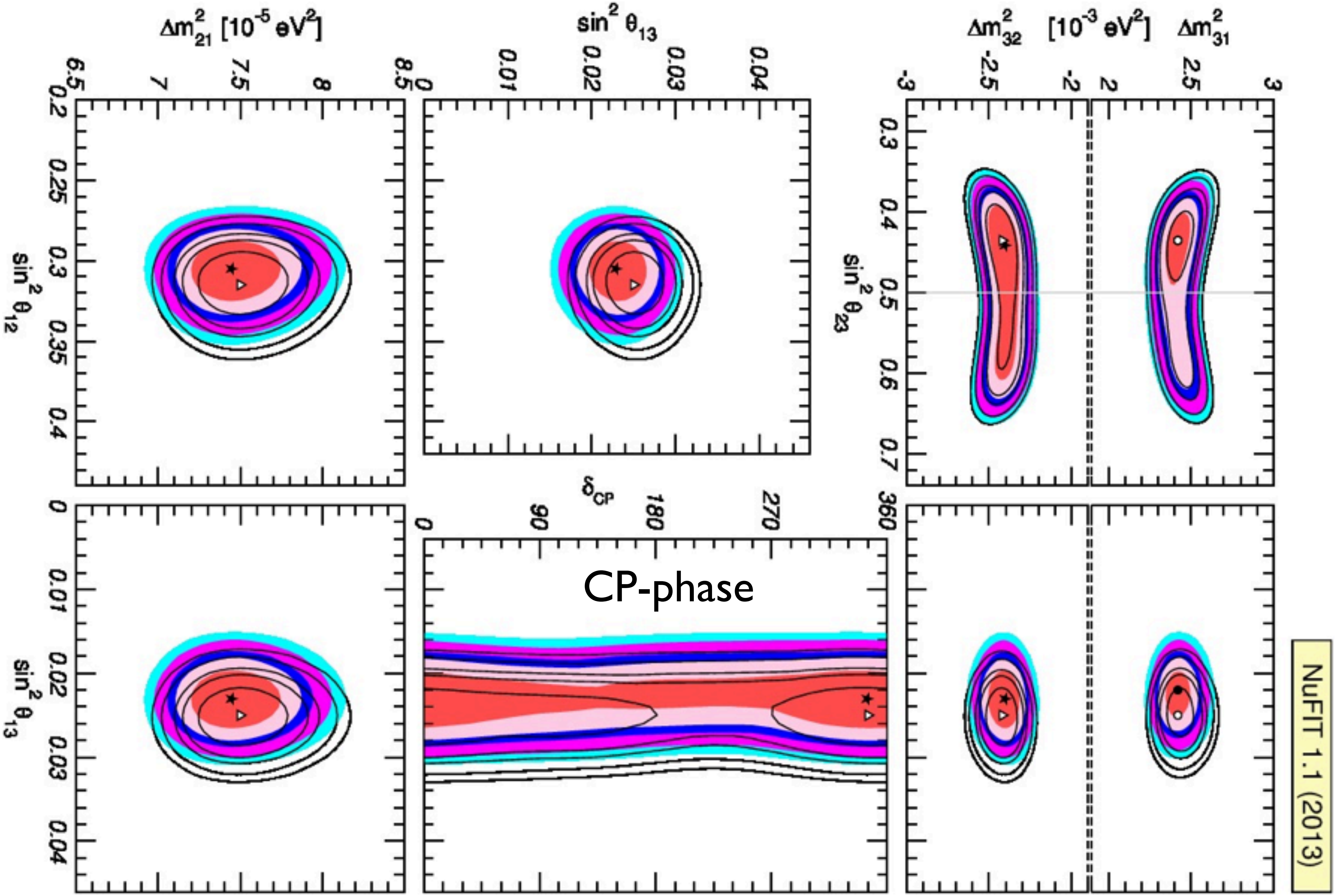
The 3νSM paradigm: global fit

	Free Fluxes + RSBL	
	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	$0.306^{+0.012}_{-0.012}$	$0.271 \to 0.346$
$\theta_{12}/^\circ$	$33.57^{+0.77}_{-0.75}$	$31.38 \to 36.01$
$\sin^2\theta_{23}$	$0.437^{+0.061}_{-0.031}$	$0.357 \to 0.654$
$\theta_{23}/^\circ$	$41.4^{+3.5}_{-1.8}$	$36.7 \to 54.0$
$\sin^2\theta_{13}$	$0.0231^{+0.0023}_{-0.0022}$	$0.0161 \to 0.0299$
$\theta_{13}/^\circ$	$8.75^{+0.42}_{-0.44}$	$7.29 \to 9.96$
$\delta_{\mathrm{CP}}/^\circ$	341^{+58}_{-46}	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.45^{+0.19}_{-0.16}$	$6.98 \to 8.05$
$\frac{\Delta m^2_{31}}{10^{-3}\ \mathrm{eV}^2}$ (N)	$+2.421^{+0.022}_{-0.023}$	$+2.248 \to +2.612$
$\frac{\Delta m^2_{32}}{10^{-3}\ \mathrm{eV}^2}$ (I)	$-2.410^{+0.062}_{-0.063}$	$-2.603 \to -2.226$

- **Current precision: $\delta(\theta_{12})\approx 2\%$, $\delta(\theta_{23})\approx 8\%$, $\delta(\theta_{13})\approx 5\%$, $\delta(\Delta m^2_{21})\approx 3\%$, $\delta(\Delta m^2_{31})\approx 1\%$(NH)-3%(IH)**
- **No hints for neutrino mass hierarchy (MH)**
- Both NH and IH solutions are allowed
- **All values of CP-phase δ are allowed at 3σ C.L.**

Gonzalez-Garcia, Maltoni, Salvado, Schwetz, arXiv:1209.3023

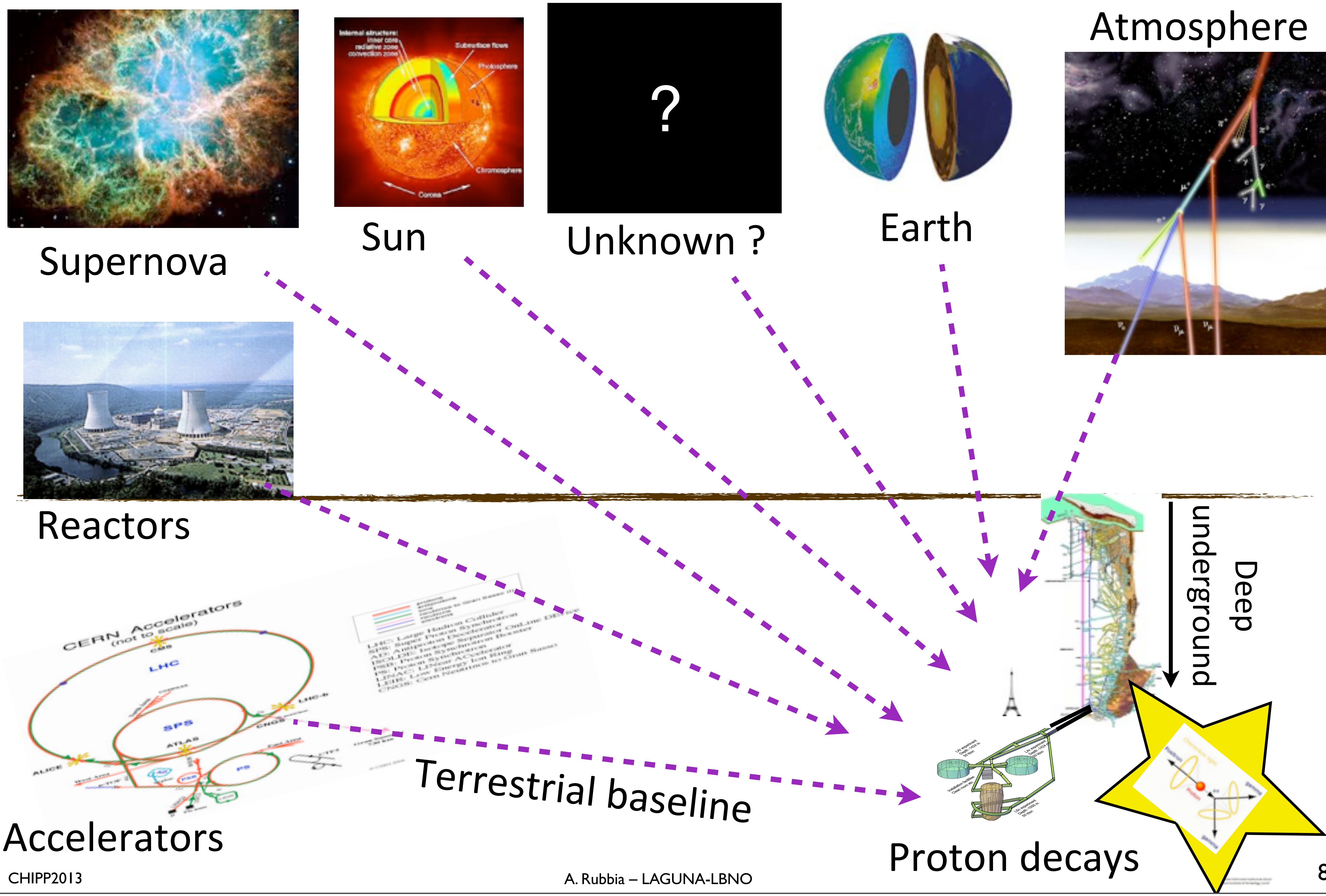
The 3νSM paradigm: global fit



coloured regions = reactors norm. free

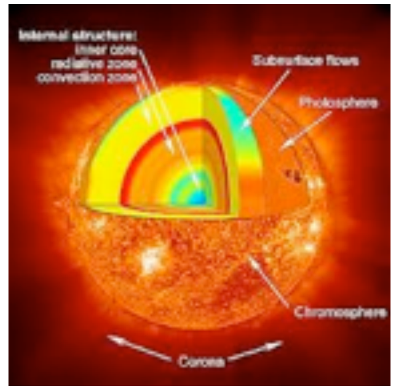
Continuously updated results at www.nu-fit.org

Goal: next underground observatory?

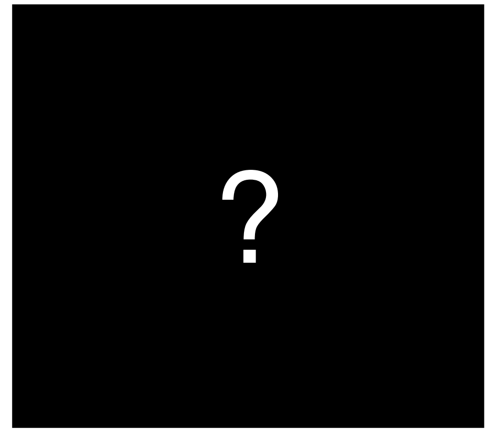


Goal: next underground observatory?

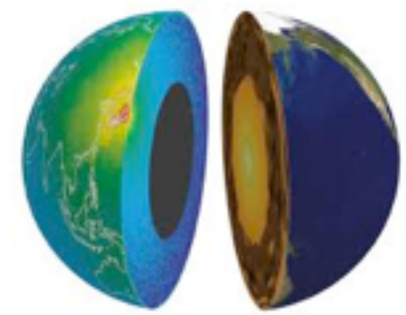
Supernova



Sun

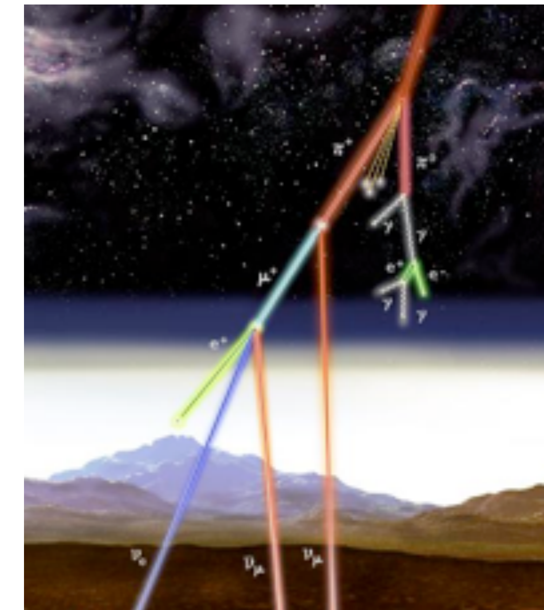


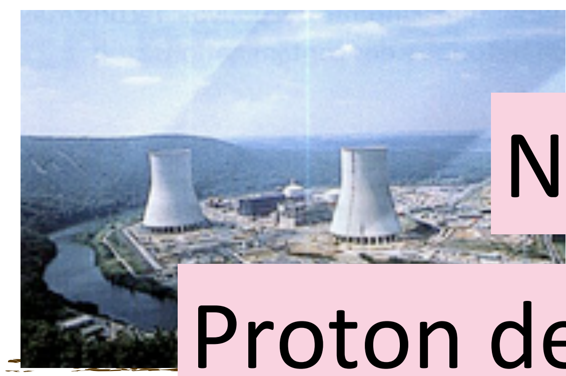
Unknown ?



Earth

Atmosphere





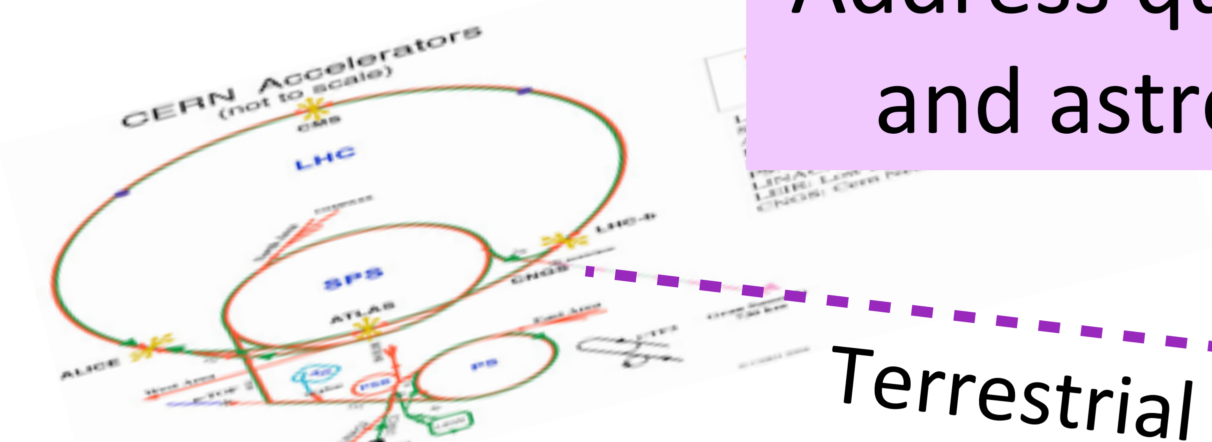
Reactors

Neutrinos from MeV to 10's GeV

Neutrino oscillations → MH, CPV, precision

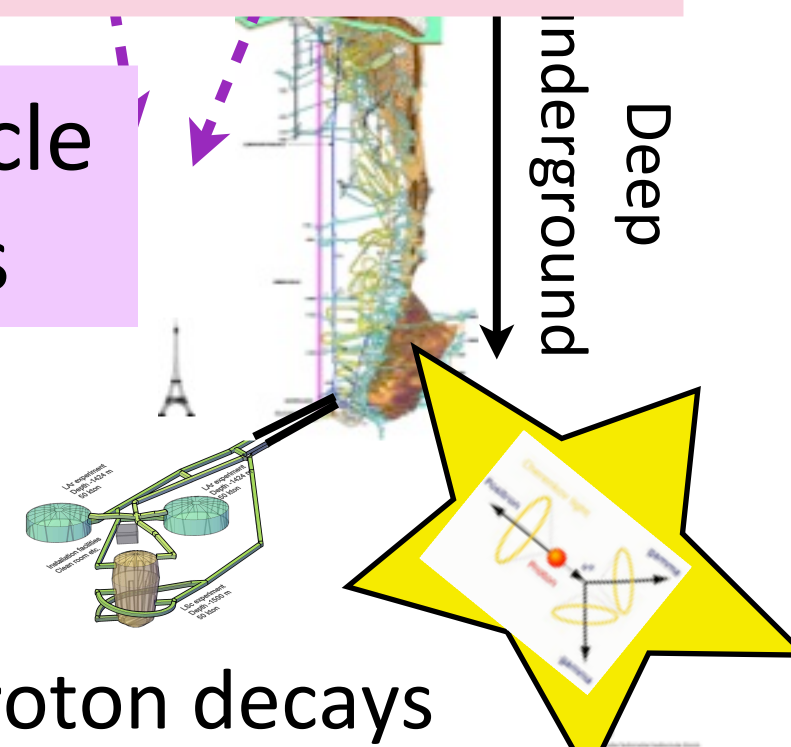
Proton decay → GUT (charge cancellation quarks-leptons)

Address questions of particle and astroparticle physics



Accelerators

Terrestrial baseline



Proton decays

LAGUNA-LBNO overview

Large Apparatus for Grand Unification and Neutrino Astrophysics - Long Baseline Neutrino Oscillations

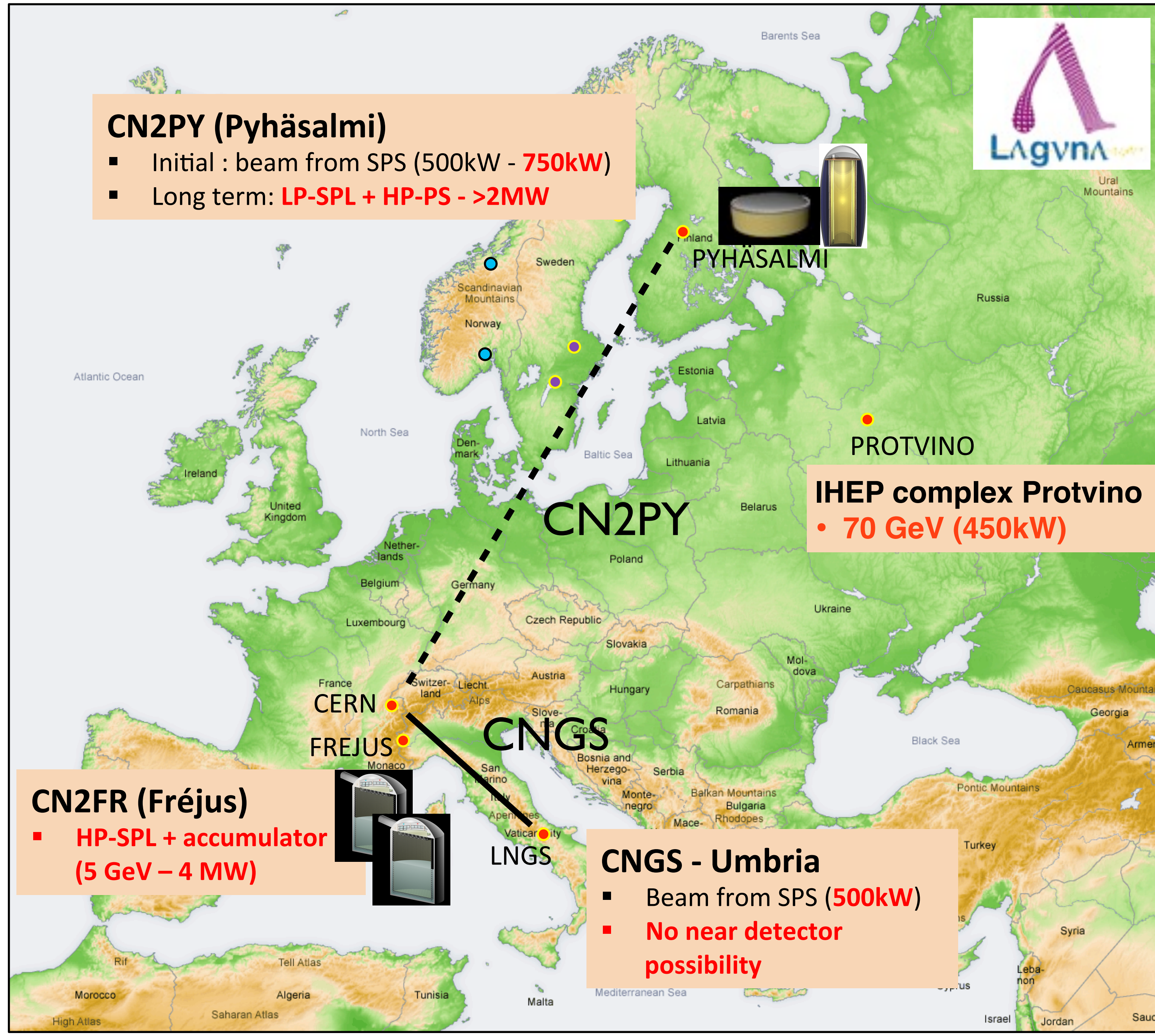
- **LAGUNA DS** (FP7 Design Study 2008-2011)
  - ~100 members; 10 countries
  - 3 detector technologies ⊗ 7 sites, different baselines (130 → 2300km)
- **LAGUNA-LBNO DS** (FP7 DS Long Baseline Neutrino Oscillations, 2011-2014)
  - ~300 members; 14 countries + CERN
  - Down selection of sites & detectors
- **LBNO** (CERN SPSC EoI for a very long baseline neutrino oscillation experiment, June 2012)
  - Consensus towards full long baseline physics + full astroparticle as mandatory physics drivers
  - An incremental approach with clear phase 1 physics capabilities
  - ~230 authors; 51 institutions
  - CERN-SPSC-2012-021 ; SPSC-EOI-007, under review
  - European Strategy → high priority for long baseline neutrino physics; explore USA/Japan

LAGUNA-LBNO: sites overview

Three far sites considered in details

arXiv:1003.1921 [hep-ph]

- **Option 1: Pyhäsalmi mine** (privately owned), 4000 m.w.e overburden, excellent infrastructure for deep underground access
- **Option 2: Fréjus**, nearby road tunnel, 4800 m.w.e. overburden, horizontal access
- **Option 3: Umbria** (LNGS extension), green site with horizontal access, 2000 m.w.e., CNGS off-axis beam
- **Protons and beams:**
  - Design of new CERN conventional neutrino beam to Finland (CN2PY) Baseline = 2300 km
  - Upgrades of CERN SPS to 700kW
  - New CERN HP-PS (2MW@50 GeV)
  - Recently: assessment of a new conventional beam coupled to accelerator upgrade at Protvino, Russia (OMEGA project) – Baseline = 1160 km

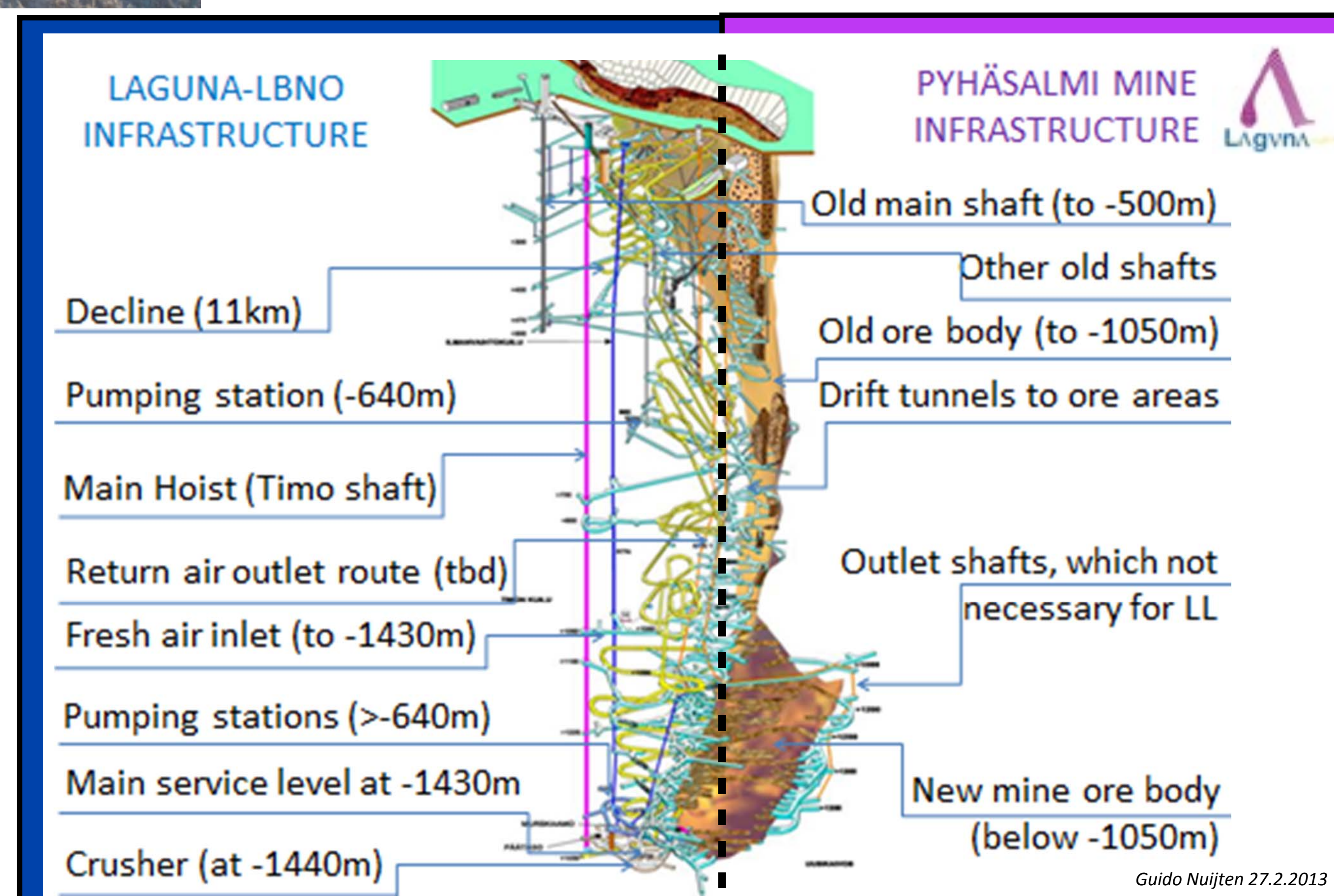


- **Detector options:** 20, 50, 100 kton LAr; 50 kton LSc and 540 kton WCD

Pyhäsalmi mine (Inmet/PM Oy)

- Inmet Mining Corporation acquired by First Quantum Minerals Ltd (March 2013)
- Underground mining activities lifetime estimated until 2019. On-surface activities would continue afterwards.
- **Extended site investigation**
  - Assess rock where LAGUNA caverns would be excavated
  - So far 750m drilled. Final report expected in 2014.

- Only those parts that are necessary for LAGUNA/ LBNO during construction and operation would be transferred to the LAGUNA lab's entity.
  - The decline (length about 11km)
  - The main hoist (Timo shaft, from surface to -1440m)
  - The fresh air inlet shaft (from surface to -1440m)
  - An return air outlet route
  - Pumping stations (the main pump at -640m and the pumps on deeper levels down to -1440m)
  - The Main service level at -1410m
  - The crusher at -1440m
- Yearly operational costs for LAGUNA are found to be similar to those for MINOS in the Soudan mine.

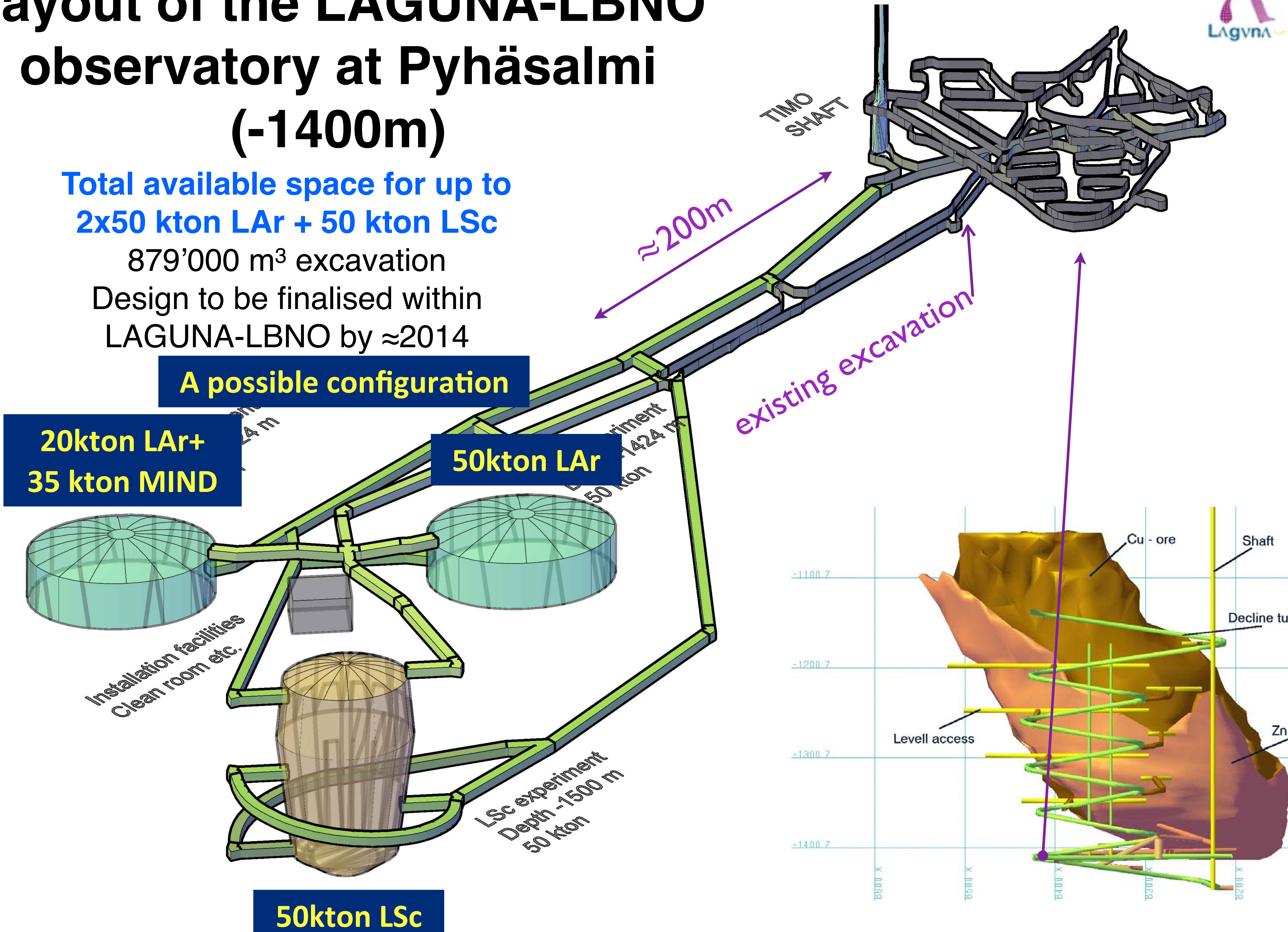


Layout of the LAGUNA-LBNO observatory at Pyhäsalmi (-1400m)

Total available space for up to 2x50 kton LAr + 50 kton LSc

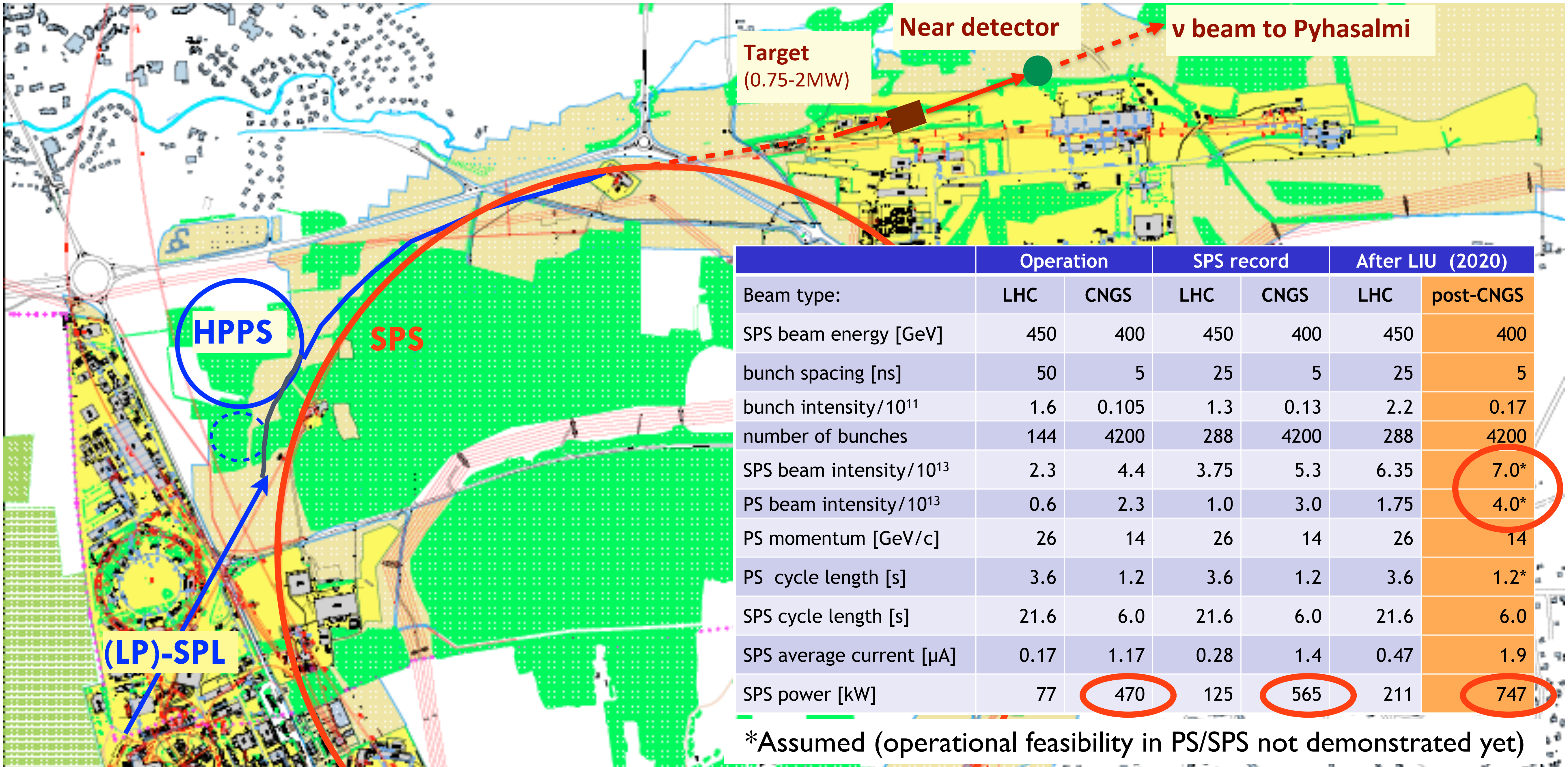
879’000 m^3 excavation

Design to be finalised within LAGUNA-LBNO by ≈2014



The CN2PY beam

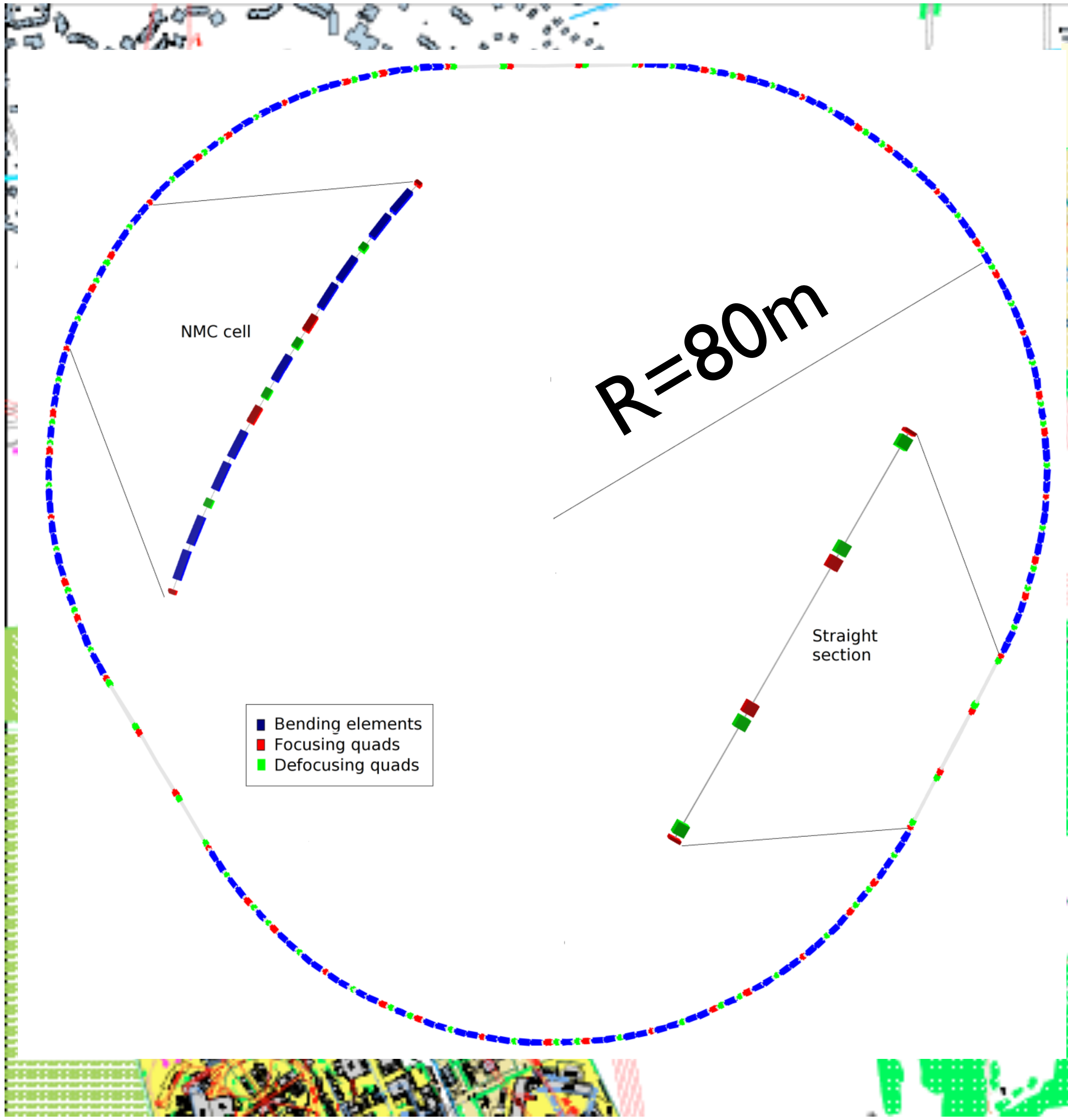
- **Phase 1** : use the proton beam extracted beam from SPS
  - **400 GeV**, max 7.0 10^{13} protons every 6 sec, **750 kW** nominal beam power, 10 µs pulse
  - Yearly integrated pot = (8–13)e19 pot / yr depending on “sharing” with other fixed target programmes.
- **Phase 2** : use the proton beam from the new HP-PS
  - **50**(70) GeV, 1 Hz, 2.5e14 ppp, **2 MW** nominal beam power, 4 µs pulse

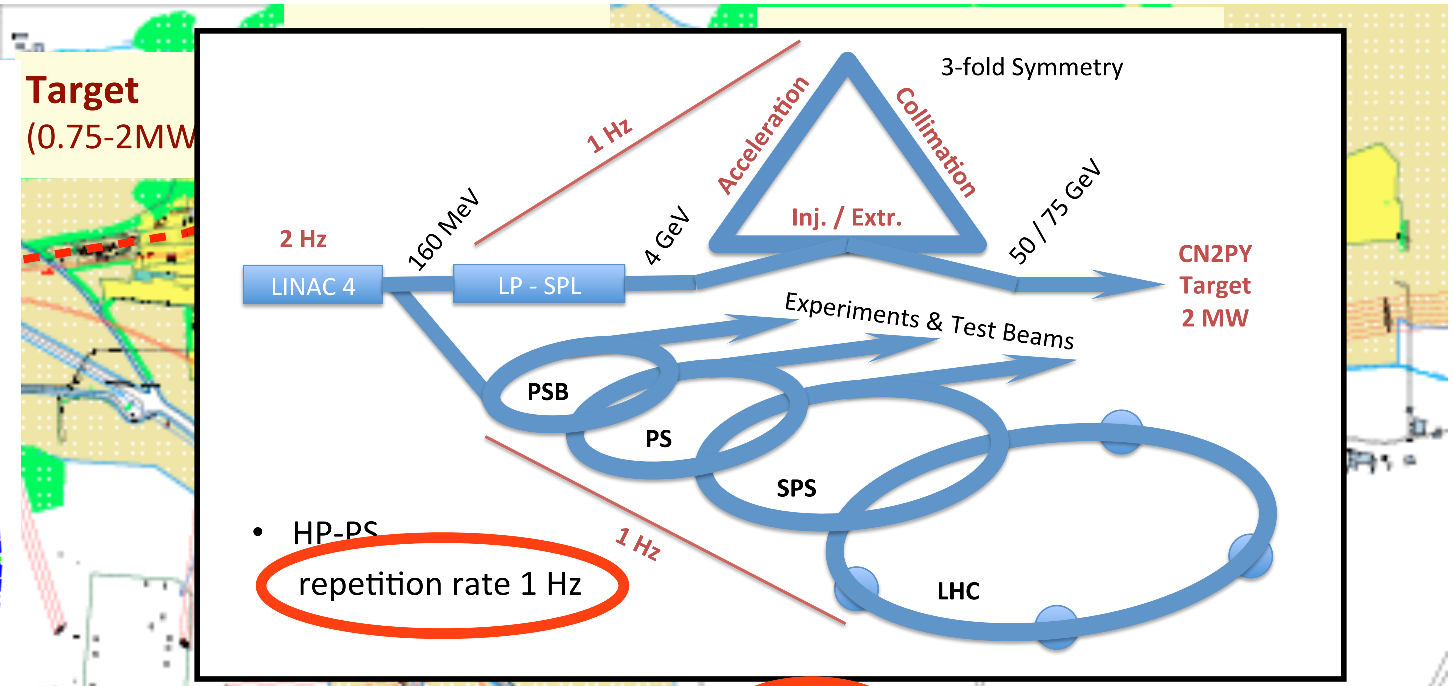


	Operation		SPS record		After LIU (2020)	
Beam type:	LHC	CNGS	LHC	CNGS	LHC	post-CNGS
SPS beam energy [GeV]	450	400	450	400	450	400
bunch spacing [ns]	50	5	25	5	25	5
bunch intensity/10^{11}	1.6	0.105	1.3	0.13	2.2	0.17
number of bunches	144	4200	288	4200	288	4200
SPS beam intensity/10^{13}	2.3	4.4	3.75	5.3	6.35	7.0*
PS beam intensity/10^{13}	0.6	2.3	1.0	3.0	1.75	4.0*
PS momentum [GeV/c]	26	14	26	14	26	14
PS cycle length [s]	3.6	1.2	3.6	1.2	3.6	1.2*
SPS cycle length [s]	21.6	6.0	21.6	6.0	21.6	6.0
SPS average current [µA]	0.17	1.17	0.28	1.4	0.47	1.9
SPS power [kW]	77	470	125	565	211	747

*Assumed (operational feasibility in PS/SPS not demonstrated yet)

High power HP-PS study





Parameter	50 GeV	75 GeV	Units
Inj. / Extr. Kinetic Energy	4 / 50	4 / 75	[GeV]
Beam power	2		[MW]
Repetition rate	1		[Hz]
f_{rev} / f_{RF} @ inj.	0.248 / 38.97		[MHz]
RF harmonic	157		-
f_{rev} / f_{RF} @ extr.	0.255 / 40.08	0.255 / 40.09	[MHz]
Bunch spacing @ extr.	25		[ns]
Total beam intensity	2.5×10^{14}	1.7×10^{14}	-
Number of bunches	147		-
Intensity per bunch	1.7×10^{12}	1.25×10^{12}	-
Main dipole field inj. / extr.	0.17 / 2.1	0.17 / 3.13	[T]
Ramp time	500	500	[ms]
Dipole field rate dB/dt (acc. ramp)	3.9	5.9	[T/s]

- Basic design well underway and main parameters available
- Optics design well advanced
- Injection and extraction concepts are available
- Basic ideas about accelerating RF system
- Basic ideas about collimation
- Consolidate optics and establish set of requirements for different magnet families.
- Design of magnet foreseen.

LBNO (CERN SPSC-EOI-007)

- **In June 2012, an enlarged LAGUNA-LBNO Consortium has put forward an Expression of Interested focused on neutrino Mass Hierarchy determination and CPV discovery coupled to a full astrophysics programme to CERN**
  - Initial positive feedback from SPSC (108^{th} minutes, January 2013)
  - Physics case supported by European Strategy as High-priority large-scale scientific activities: "*Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector.*"

- **An incremental long-baseline program with a competitive 1st stage guaranteeing high level physics performance from the beginning.**
  - LBNO Stage 1 is based on a 20 kt fid. LAr detector (double phase) and a conventional beam from the CERN SPS of 700 kW at 2300 km.
  - If the findings from Stage 1 require, the detector and the beam will be upgraded to 70 kton mass and 2 MW proton power.

- **The costs, possible implementation schemes and physics potentials will be further studied until the end of 2014.**

- **Proposed next step: Large-scale detector prototyping with CERN support, with priority emphasis on a large double-phase LAr demonstrator, using charged-particle test beams (2014-2017).**

Rich MH & CP phenomenology

- **First order approximation in expansion (Sato et al.):**

$$P(\nu_\mu \to \nu_e; L) \simeq 4c_{13}^2 s_{13}^2 s_{23}^2 \left\{1 + \frac{a}{\delta m_{31}^2} \cdot 2(1-2s_{13}^2)\right\} \sin^2 \frac{\delta m_{31}^2 L}{4E}$$
$$+ c_{13}^2 s_{13} s_{23} \left\{ -\frac{aL}{E} s_{13} s_{23} (1-2s_{13}^2) + \frac{\delta m_{21}^2 L}{E} s_{12}(-s_{13}s_{23}s_{12} + c_\delta c_{23} c_{12}) \right\} \sin \frac{\delta m_{31}^2 L}{2E}$$
$$- 4 \frac{\delta m_{21}^2 L}{2E} s_\delta c_{13}^2 s_{13} c_{23} s_{23} c_{12} s_{12} \sin^2 \frac{\delta m_{31}^2 L}{4E}$$

Matter terms∾a

CP-even

L/E dependence

CP-odd∾sinδ

$$a \equiv 2\sqrt{2} G_F n_e E = 7.56 \times 10^{-5} \mathrm{eV}^2 \frac{\rho}{\mathrm{g\,cm}^{-3}} \frac{E}{\mathrm{GeV}}$$

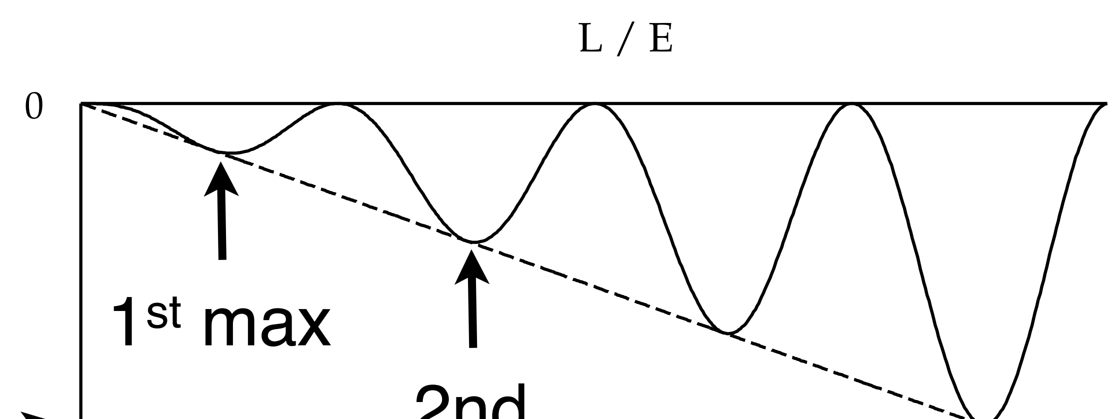
- **Difference between neutrinos and antineutrinos:**

$$\mathcal{A} \equiv P(\nu_\mu \to \nu_e) - P(\bar\nu_\mu \to \bar\nu_e) =$$
$$16 \frac{a}{\delta m_{31}^2} \sin^2 \frac{\delta m_{31}^2 L}{4E} c_{13}^2 s_{13}^2 s_{23}^2 (1-2s_{13}^2)$$
$$-4 \frac{aL}{2E} \sin \frac{\delta m_{31}^2 L}{2E} c_{13}^2 s_{13}^2 s_{23}^2 (1-2s_{13}^2)$$
$$-8 \frac{\delta m_{21}^2 L}{2E} \sin^2 \frac{\delta m_{31}^2 L}{4E} s_\delta c_{13}^2 s_{13} c_{23} s_{23} c_{12} s_{12}$$

Matter terms

Pure CP-term

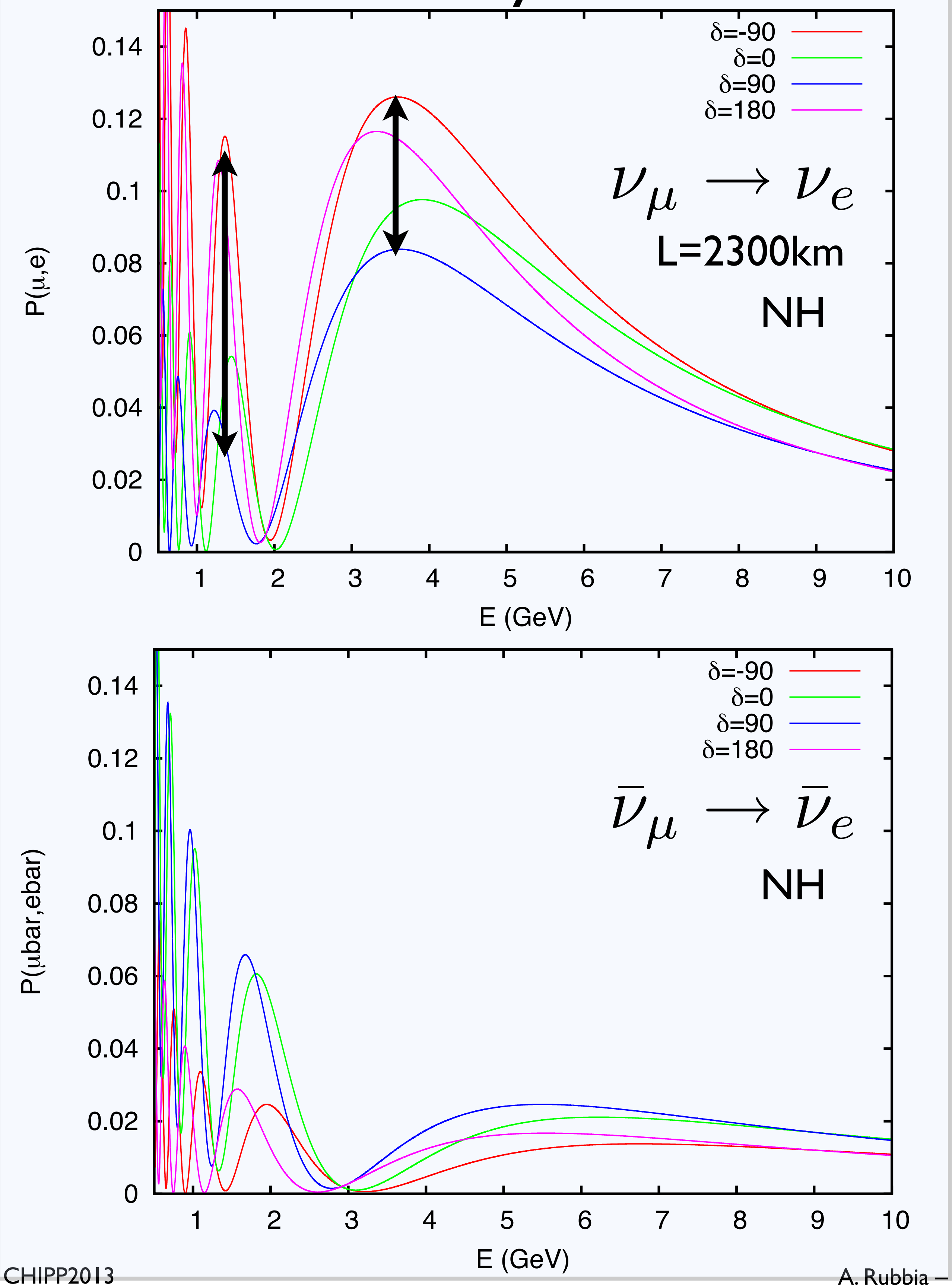
$$\left.\frac{P(\nu) - P(\bar\nu)}{P(\nu) + P(\bar\nu)}\right|_{a=0} \approx -\frac{2 s_\delta c_{12} s_{12}}{s_{13}} \cot\theta_{23} \frac{\delta m_{21}^2 L}{2E}$$



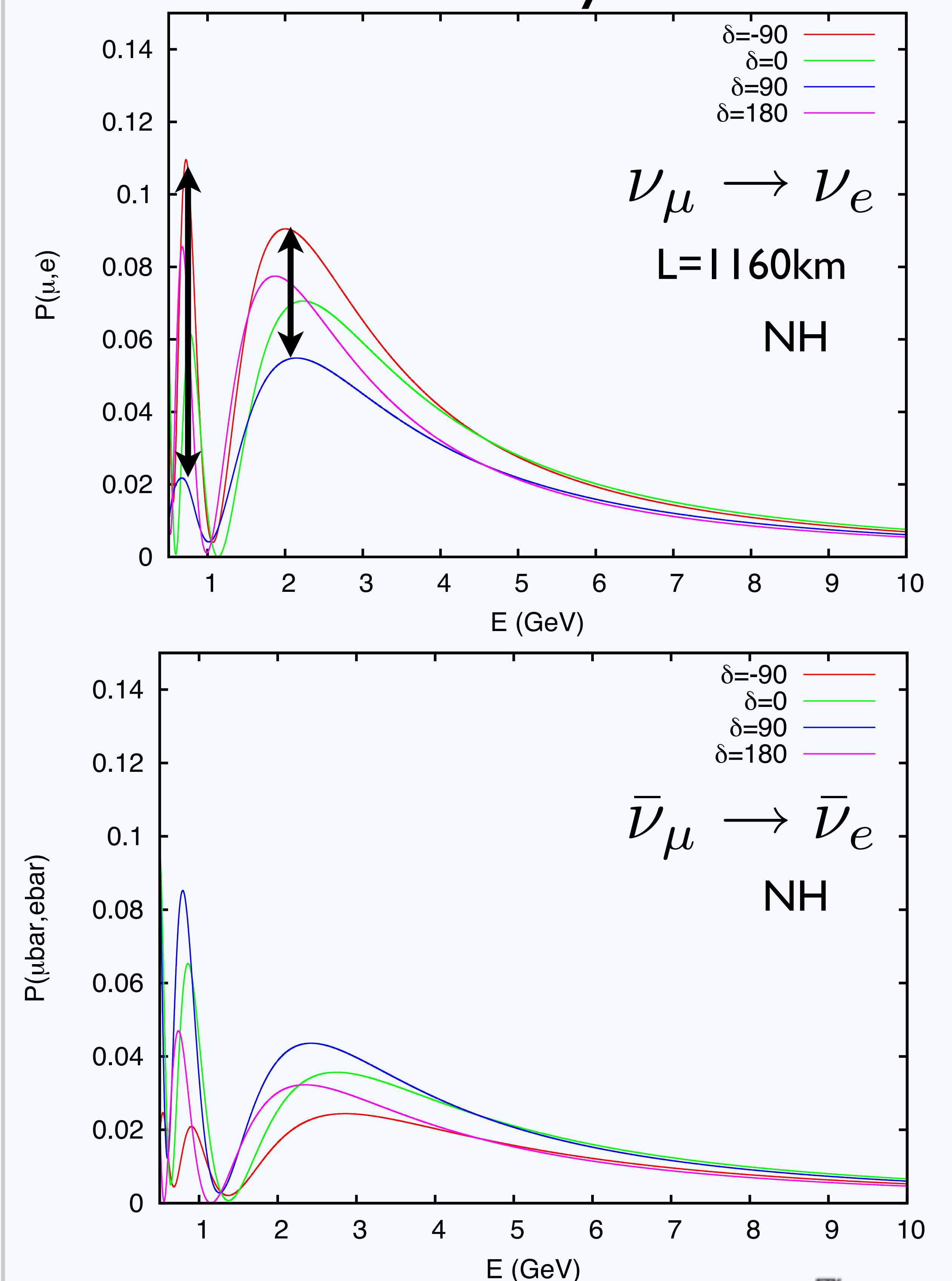
The enveloppe increases linearly with L/E

Expected oscillation probability

CERN-Pyhäsalmi

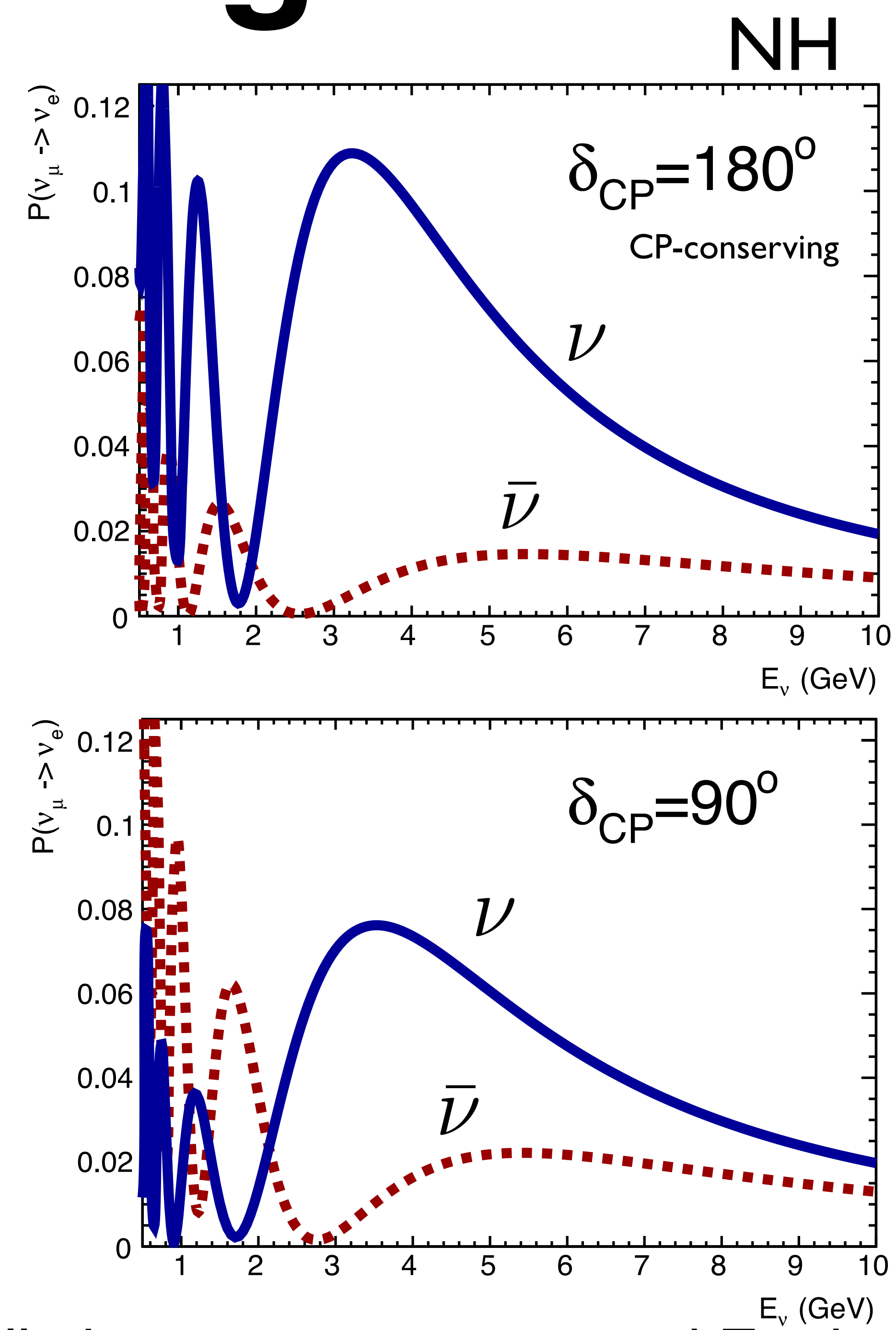


Protvino-Pyhäsalmi



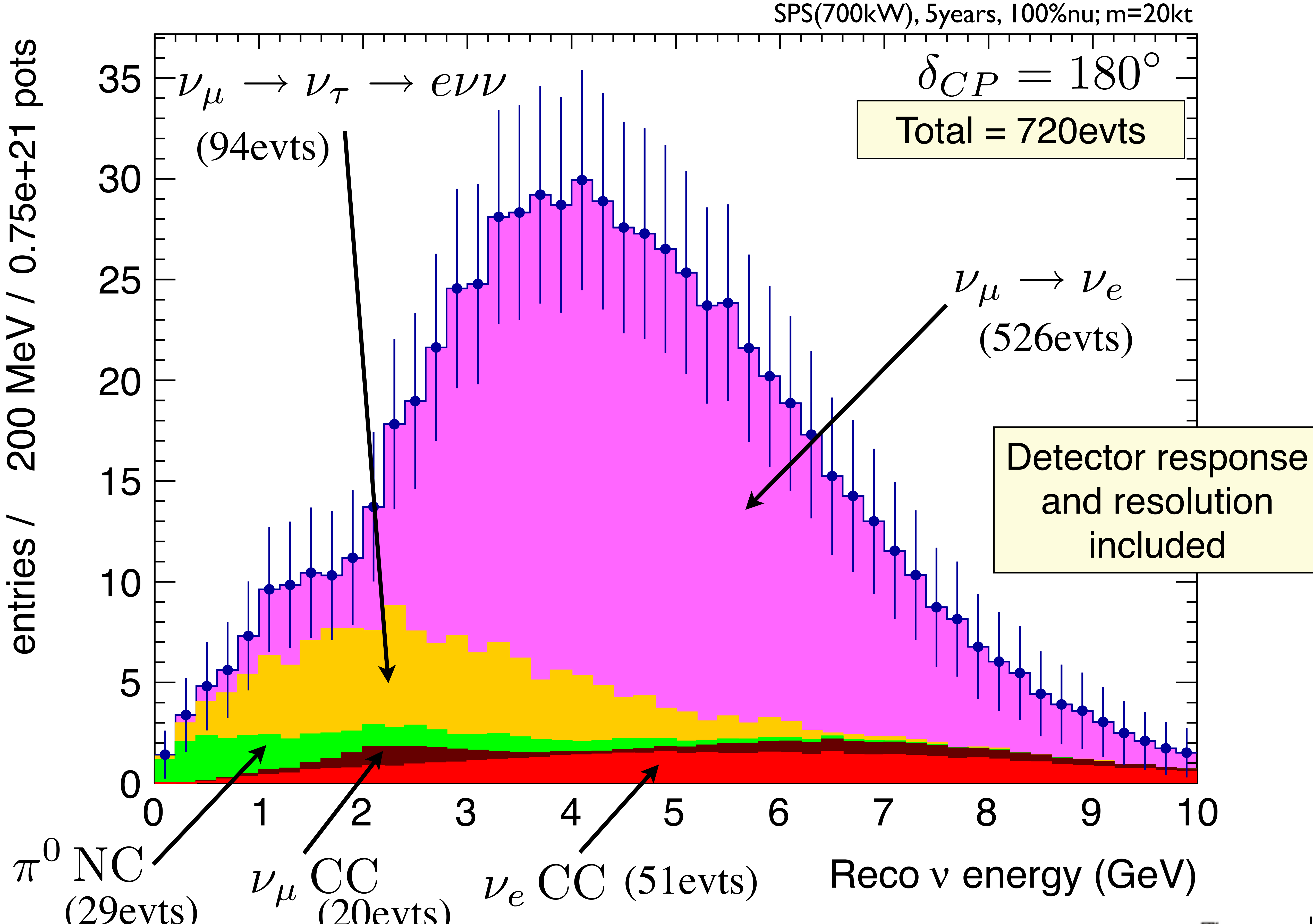
LBNO main physics goals

- **Long baseline neutrino oscillations**
  - $\nu_\mu \rightarrow \nu_e$ & $\nu_\mu \rightarrow \nu_\tau$ & $\nu_\mu \rightarrow \nu_\mu$ & νNC
  - Direct measurement of the energy dependence (L/E behaviour) induced by matter effects and CP-phase terms, independently for ν and anti-ν, by direct measurement of event spectrum, in particular covering 1st and 2nd oscillation maxima
  - Mass hierarchy determination at >5σ C.L. in first two years of running
  - CP-phase measurement and CPV "discovery" (⇒ 5σ C.L.)
  - Test of three generation mixing paradigm



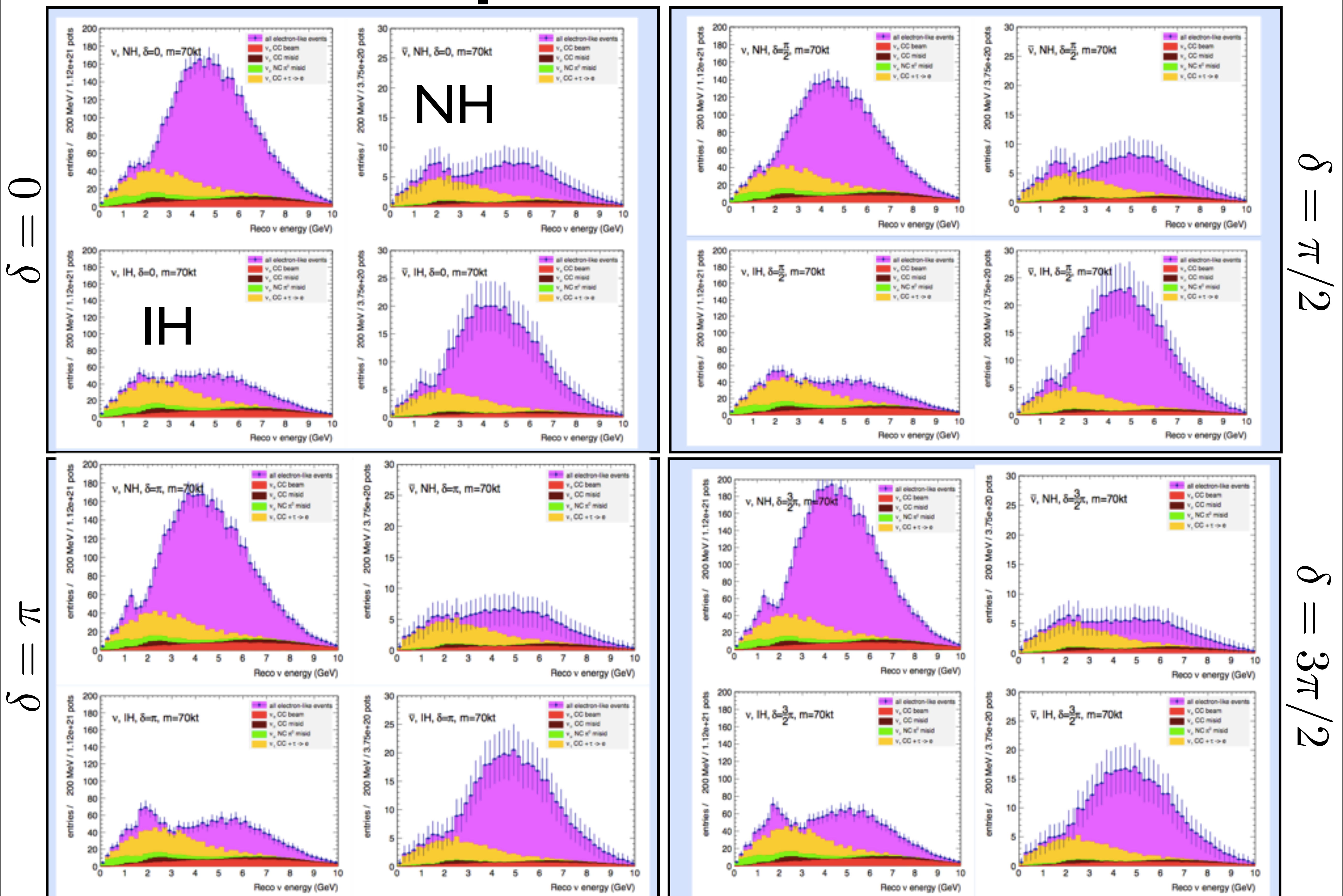
- **A full astrophysics programme**
  - Nucleon decays (direct GUT evidence)
  - Atmospheric neutrino detection with complementary oscillation measurements and Earth spectroscopy
  - Astrophysical neutrino detection and searches for new sources of neutrinos
- **Near detector measurements**
  - Exclusive neutrino cross-sections, rare neutrino processes, oscillations at short baseline

LBNO 20kton LAr: e-like CC sample



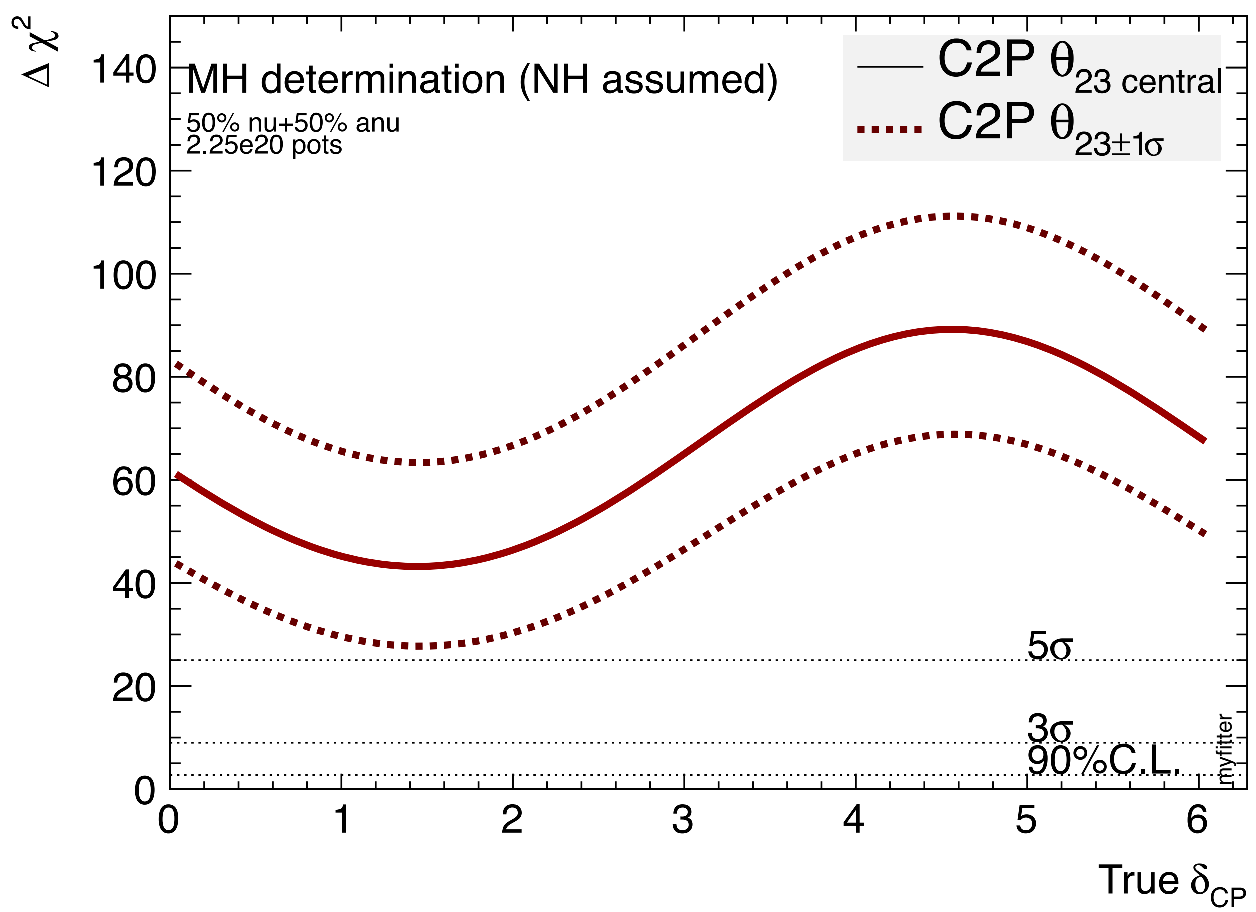
δ_{CP} & MH dependence

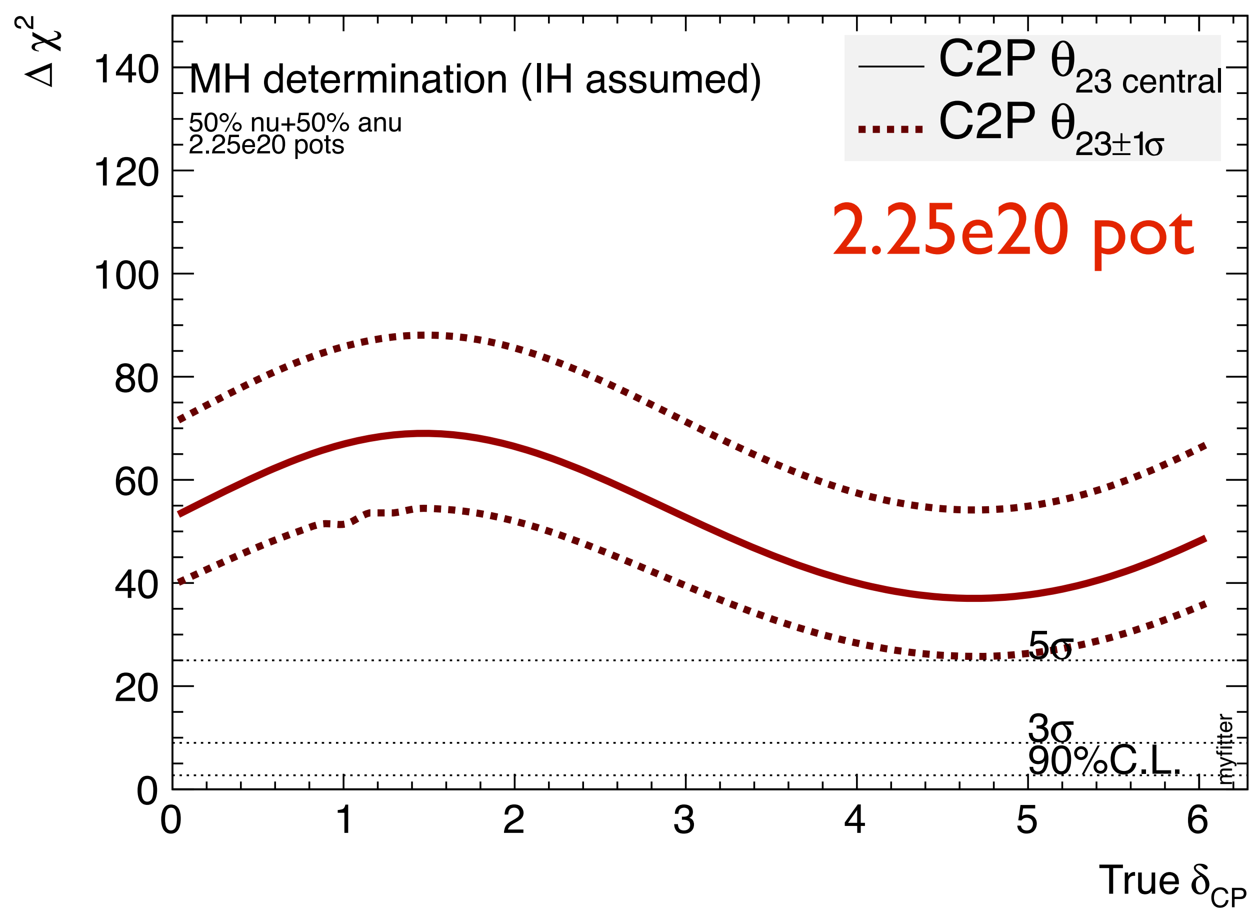
SPS(700kW), 10y, 75%nu-25%antinu; m=70kt



Sensitivity to mass hierarchy

Extracting MH from global fits can not replace a direct 5σ measurement from a direct measurement !

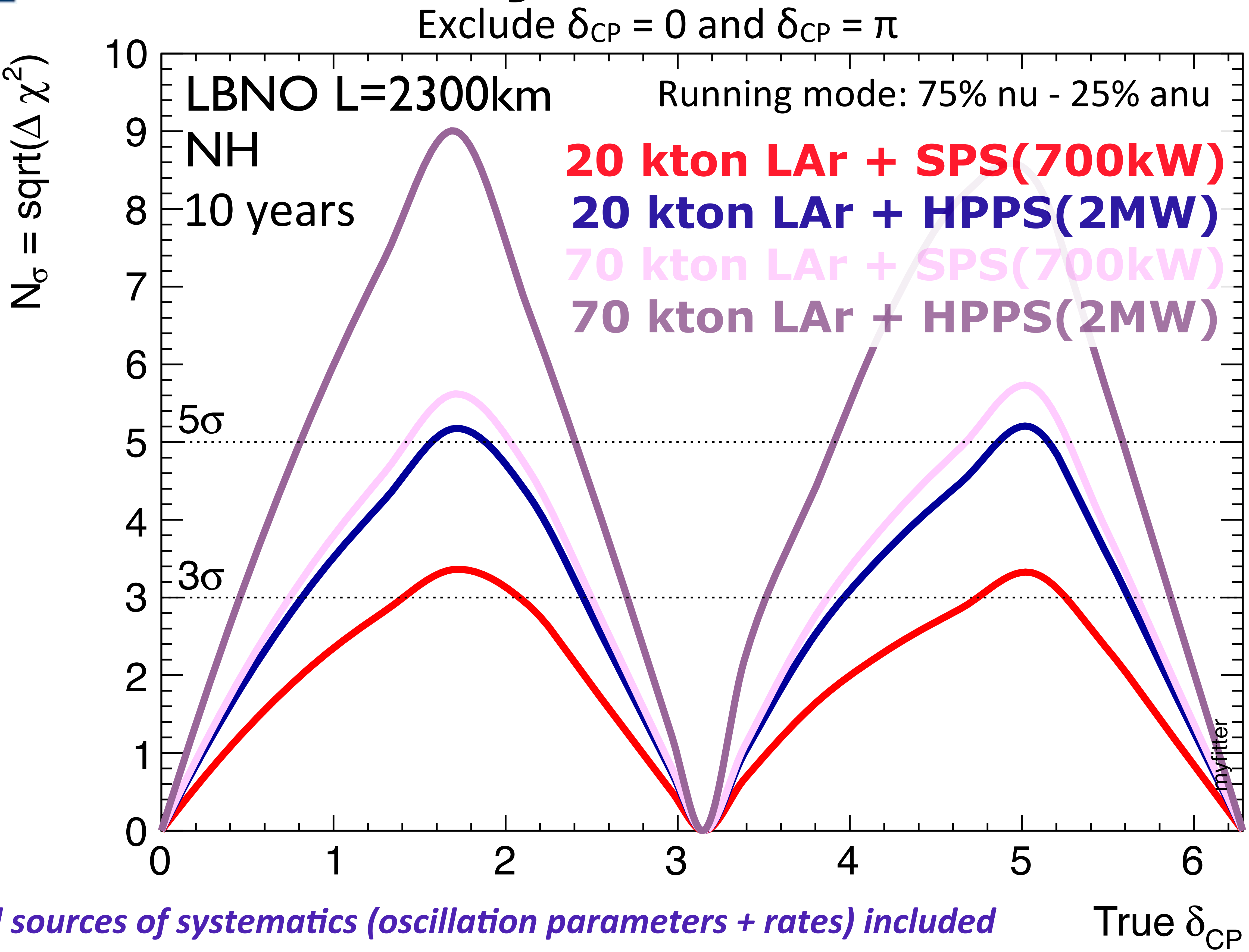




Provide a >5σ direct determination of MH independent of the values of θ_{23} & δ_{CP} in ≈2 years of running

Other methods proposed (atmospheric neutrinos, reactors) do not provide such a level of sensitivity and could be prone to irreducible systematic errors

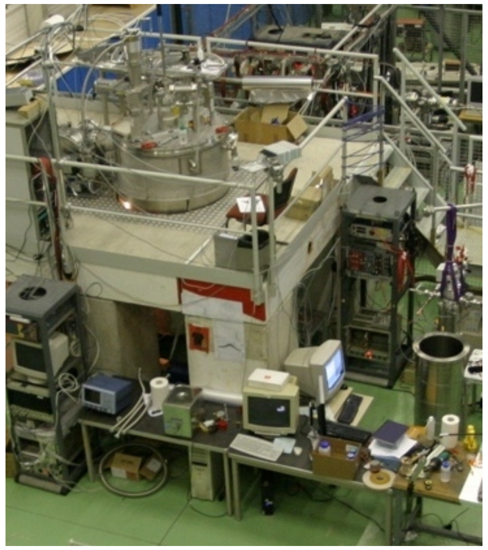
Sensitivity to CP violation



All sources of systematics (oscillation parameters + rates) included

LAr detector prototyping efforts

ETHZ & University Bern detector R&D



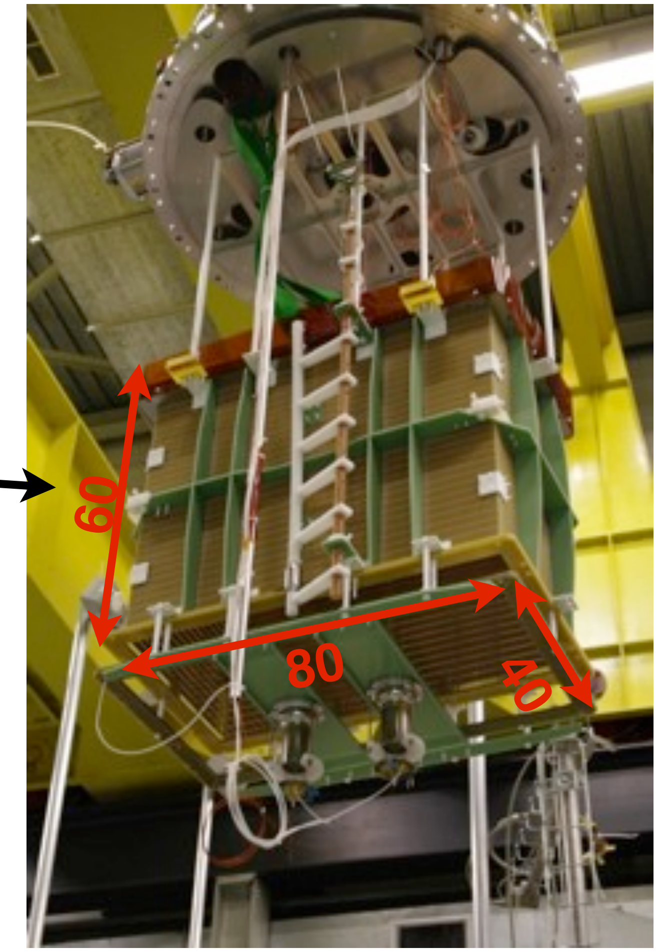
(1) ArDM-1t @ CERN

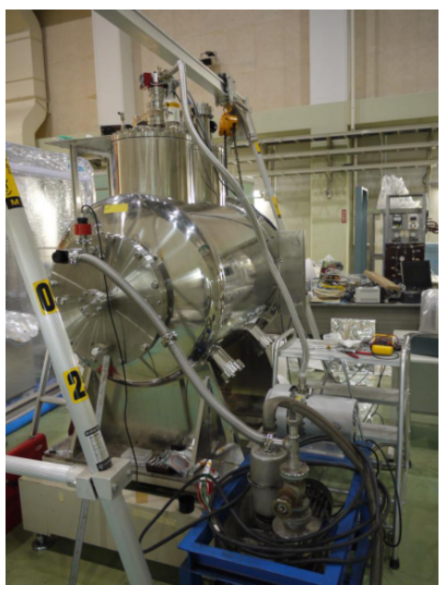
J.Phys.Conf.Ser. 39 (2006) 129-132

World's first double phase liquid argon LEM-TPC successfully operated

40x80cm2

JINST 7 (2012) P08026
JINST 8 (2013) P04012



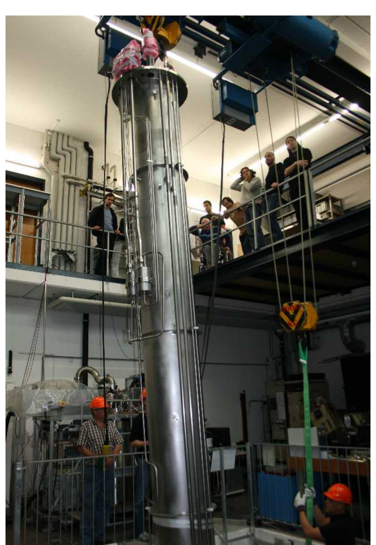


(2) J-PARC T32

J.Phys.Conf.Ser. 308 (2011) 012008

0.4 ton LAr TPC

World's largest sample of charged particles events ever collected



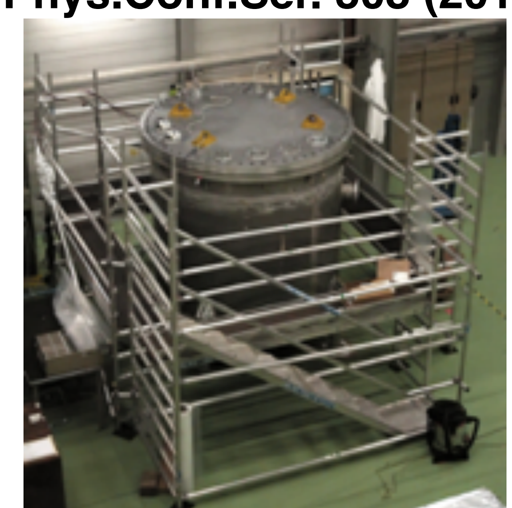
(3) ArgonTube @ Bern

Nucl.Phys.Proc.Suppl. 139 (2005) 301-310

Aim to demonstrate world's longest electron drift path

(4) 10T @ CERN

J.Phys.Conf.Ser. 308 (2011) 012024

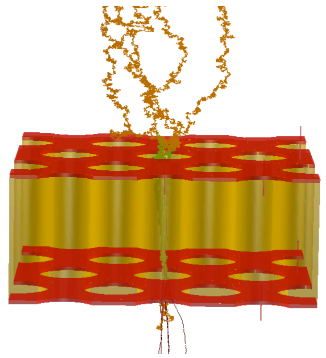


Purity by flushing w/o evacuation

Reminder: Double phase concept

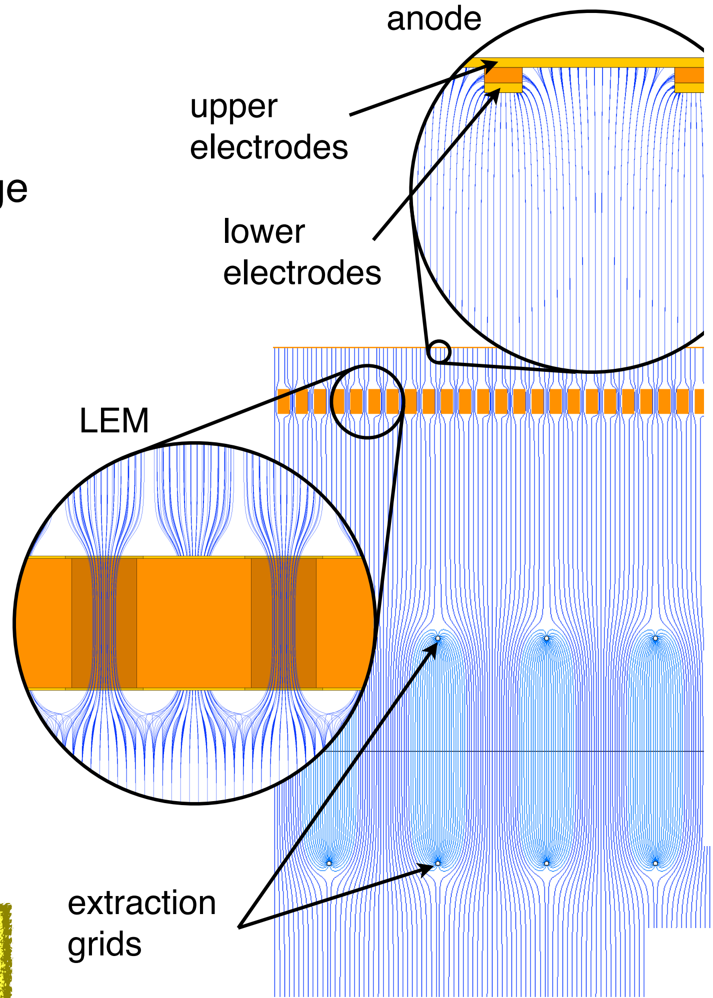
4.) Charge collection on a 2D anode readout (symmetric unipolar signals with two orthogonal views)

3.) Charge multiplication in the holes of the Large Electron Multiplier (LEM)



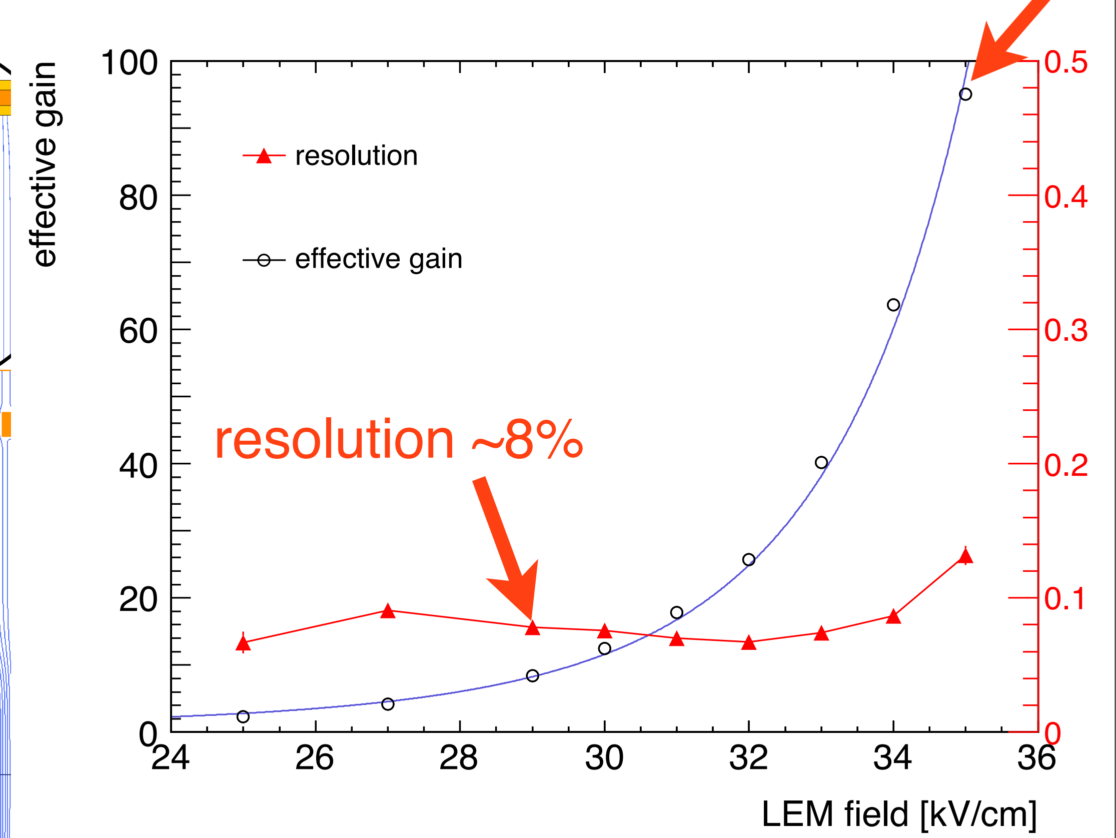
2.) Drift electrons are efficiently emitted into the gas phase

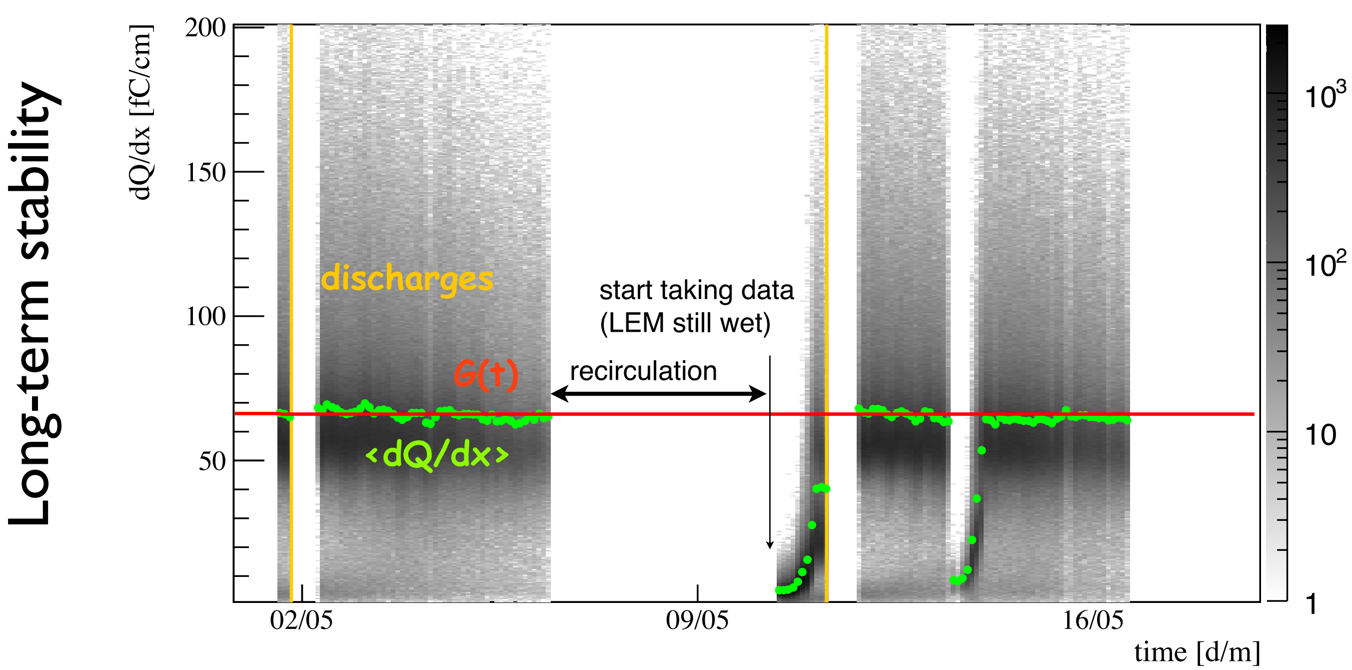
1.) Ionization electrons drift towards the liquid argon surface



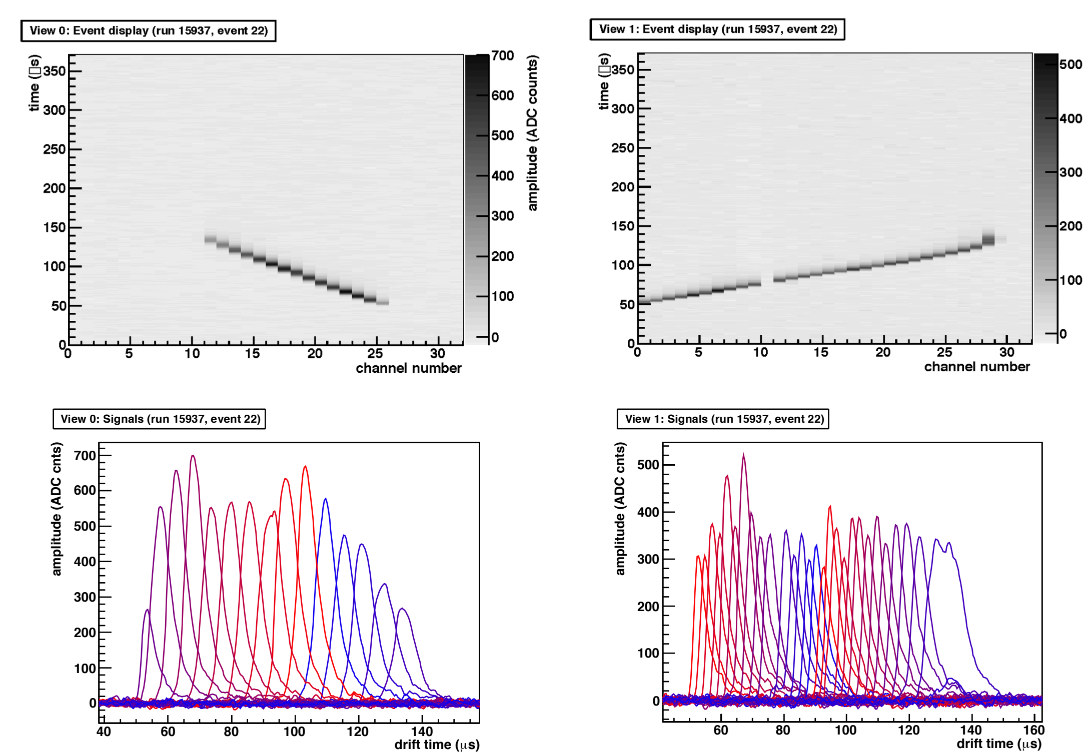
Single Compact readout module of square meter doing extraction, amplification and readout

gain and resolution for diff. LEM fields



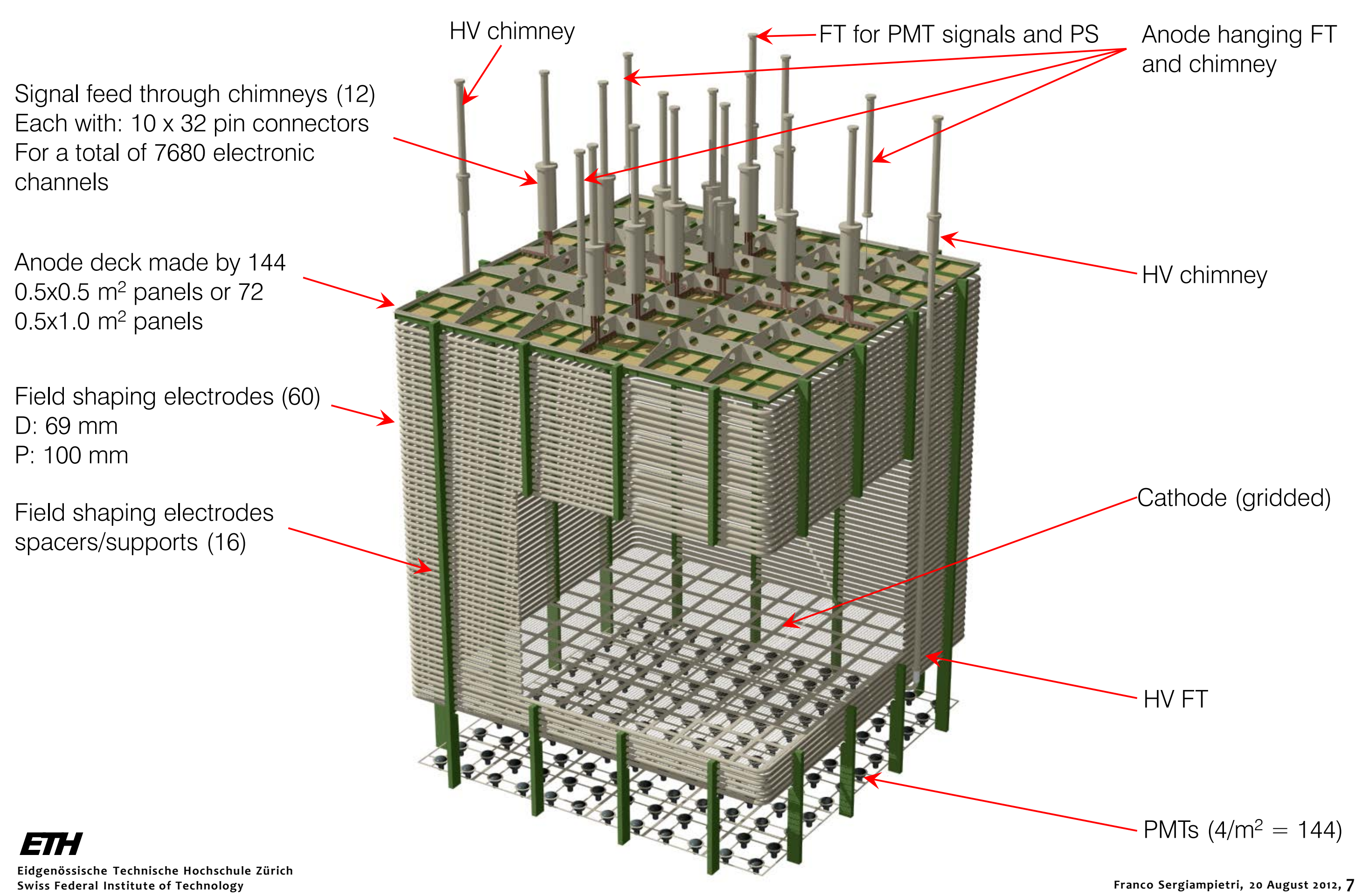


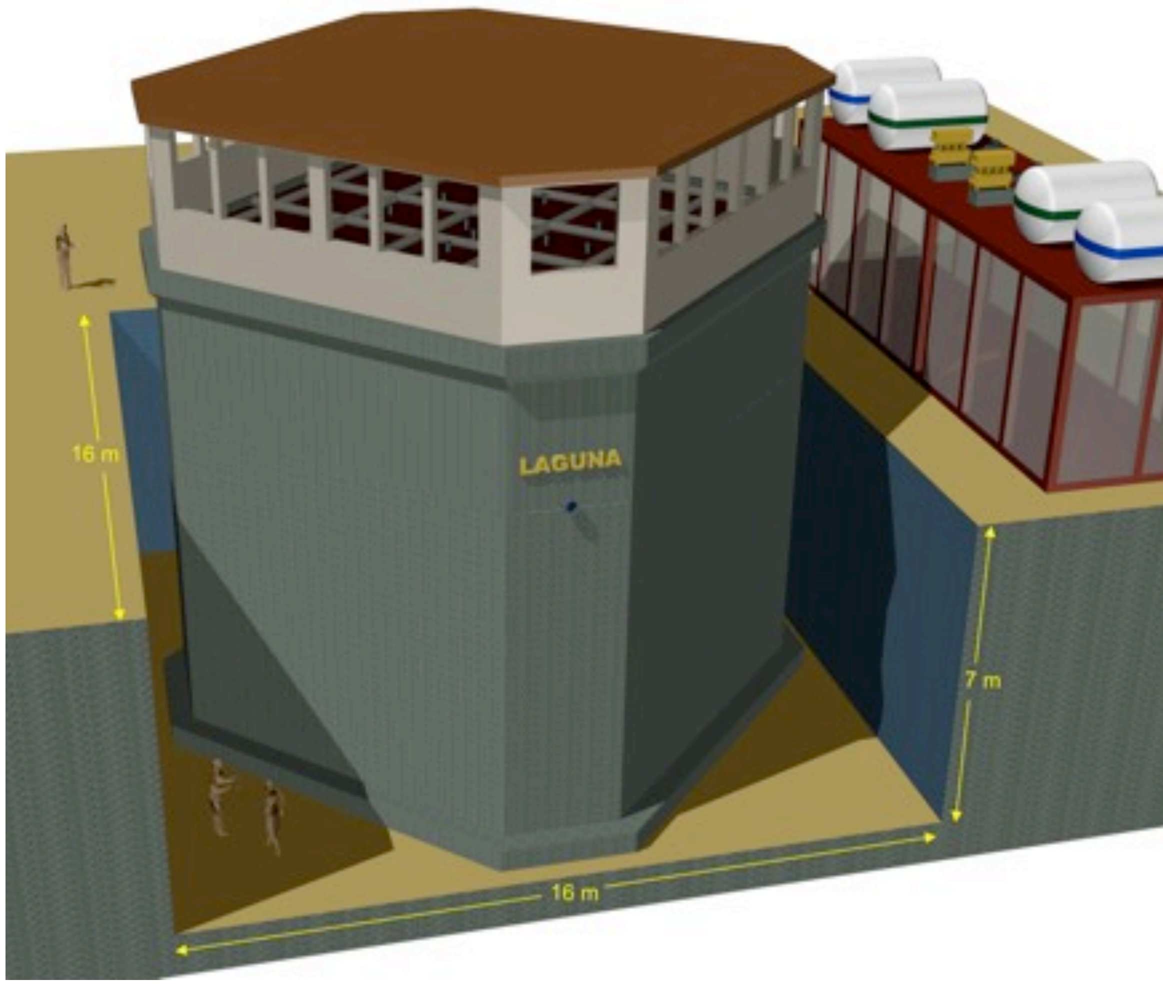
LEM: 31 kV/cm, induction: 5 kV/cm, extraction: 2 kV/cm, drift: 0.5 kV/cm



Double phase LAr demonstrator

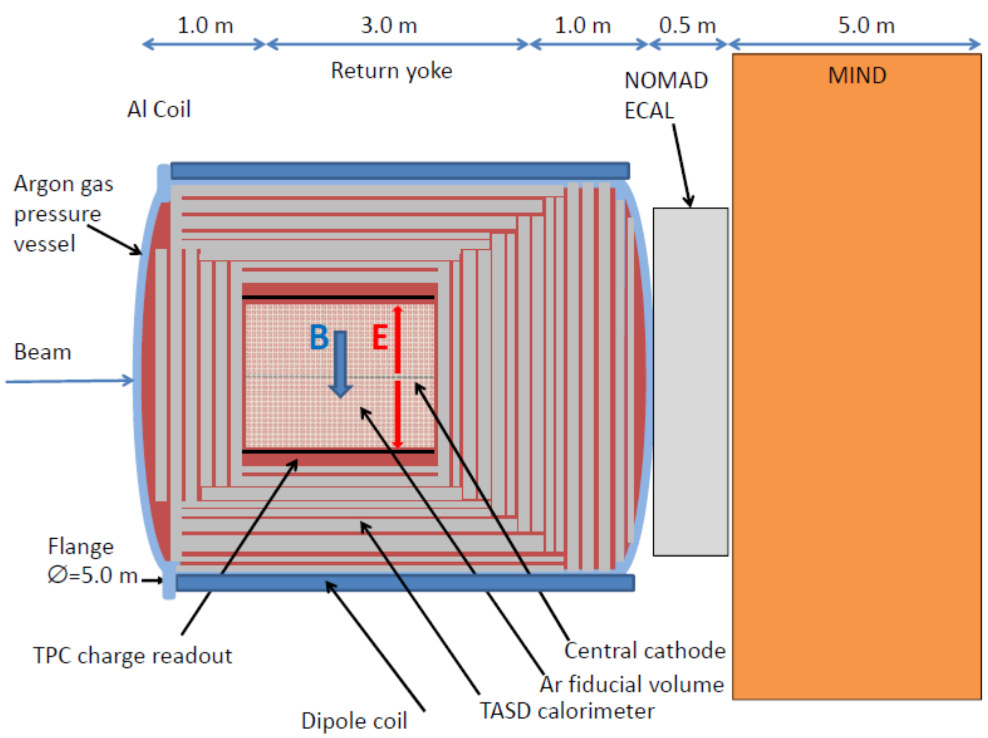
- We are proposing a **6x6x6 = 216 m³ active volume double phase LAr detector** to be constructed and operated at CERN
- Charged test beams to collect the large controlled data set allowing **electromagnetic** and **hadronic calorimetry** and general **detector performance** (PID, ...) to be measured, **simulation and reconstruction** to be improved and validated.
- **Proposal under submission to CERN SPSC committee (June 2013)**



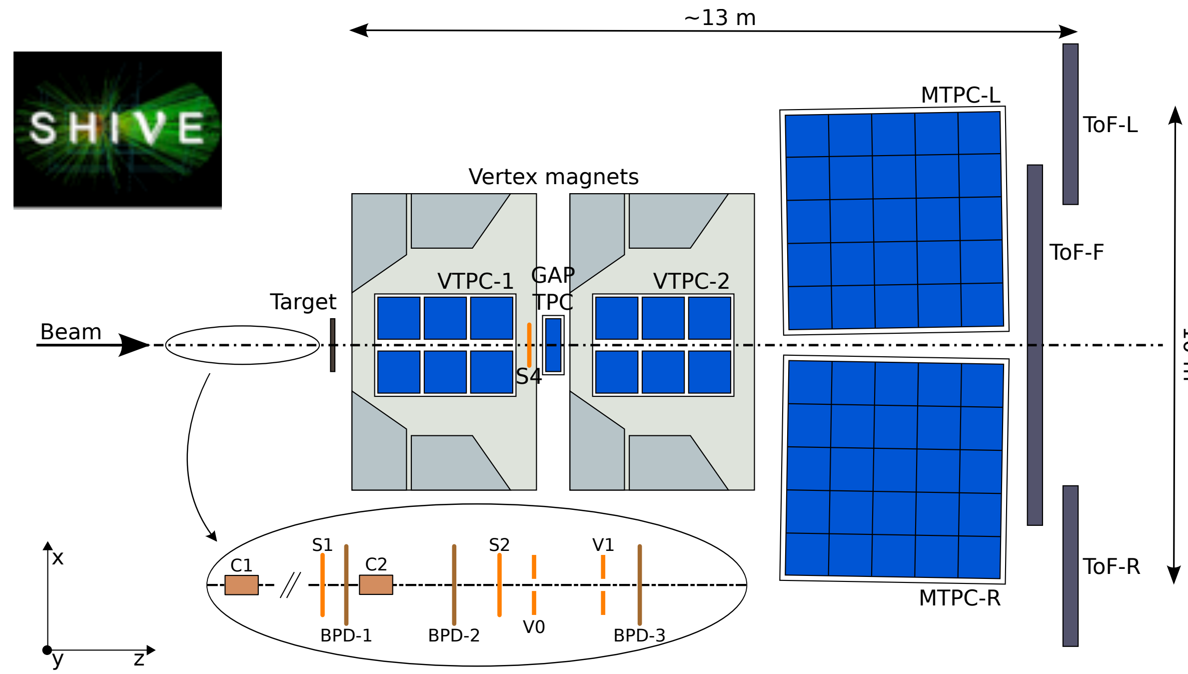


LBNO near detector and hadroproduction

- **Aim**: systematic errors for signal and backgrounds in the far detectors below ±5%, possibly at the level of ±2% ⇒ control of fluxes, cross-sections, efficiencies,...



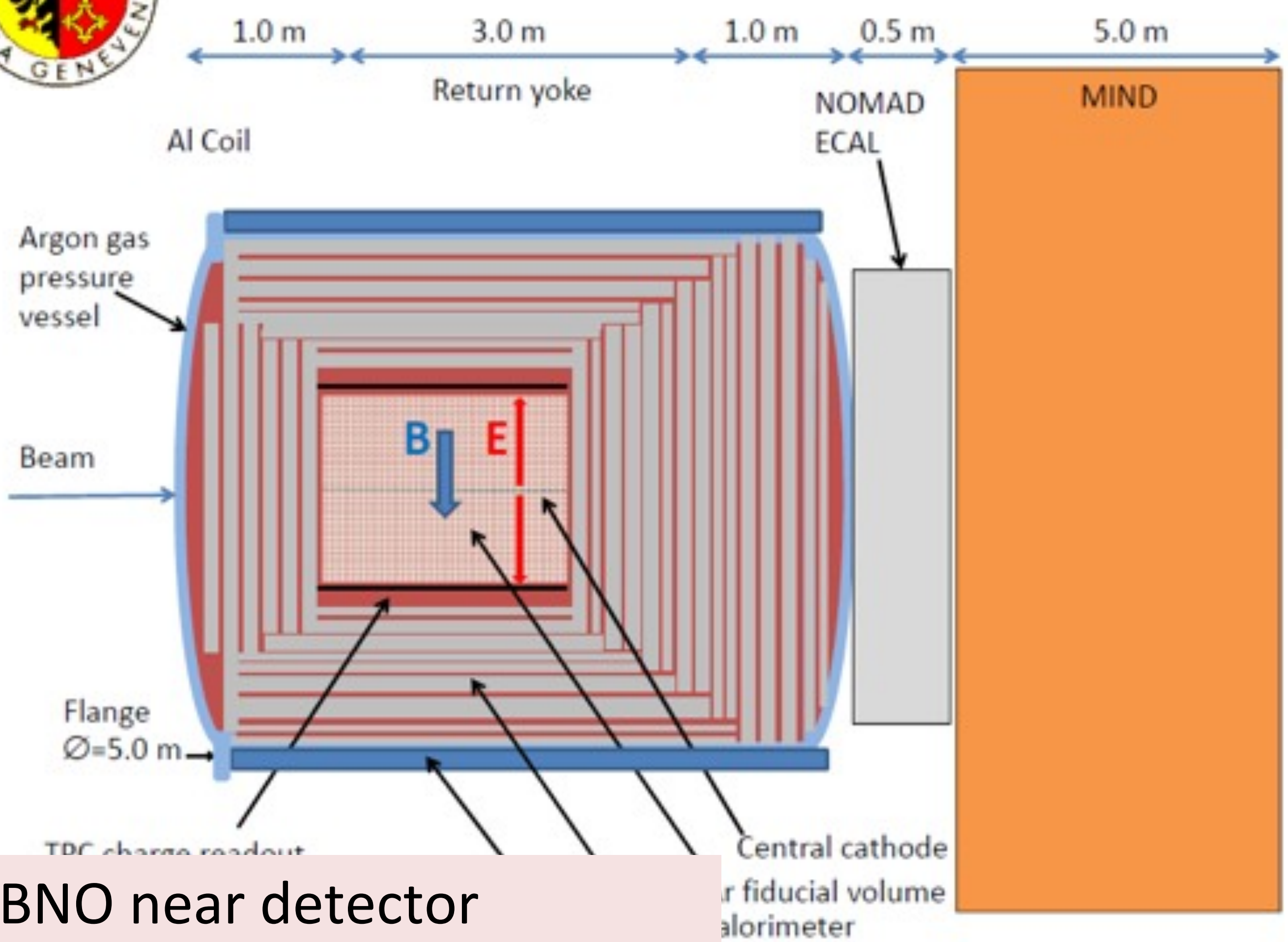
- Concept: 20 bar gas argon-mixture TPC (2.4 m × 2.4 m × 3 m) surrounded by scintillator bar tracker embedded in an instrumented magnet with field 0.5T
- 600 kg argon mass in TPC
- 0.2 event/spill @ 7e13 ppp 400 GeV
- O(100’000) events/year



- It is widely recognized that hadro-production measurements with thin or replica target are really crucial for precision neutrino experiments (eg. K2K, T2K, MINOS).
- CERN NA61 upgrade needed for 400 GeV incident protons

- Precision neutrino cross-section measurements: e.g. MINERVA, T2K-ND280, also nuSTORM

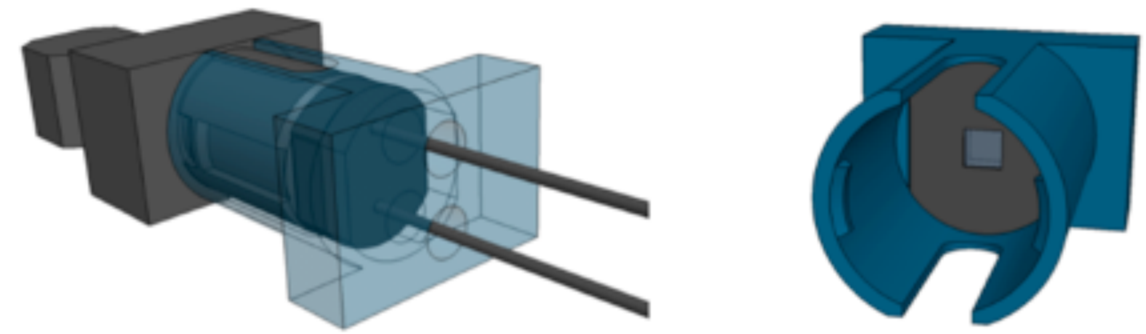
University Geneva detector R&D

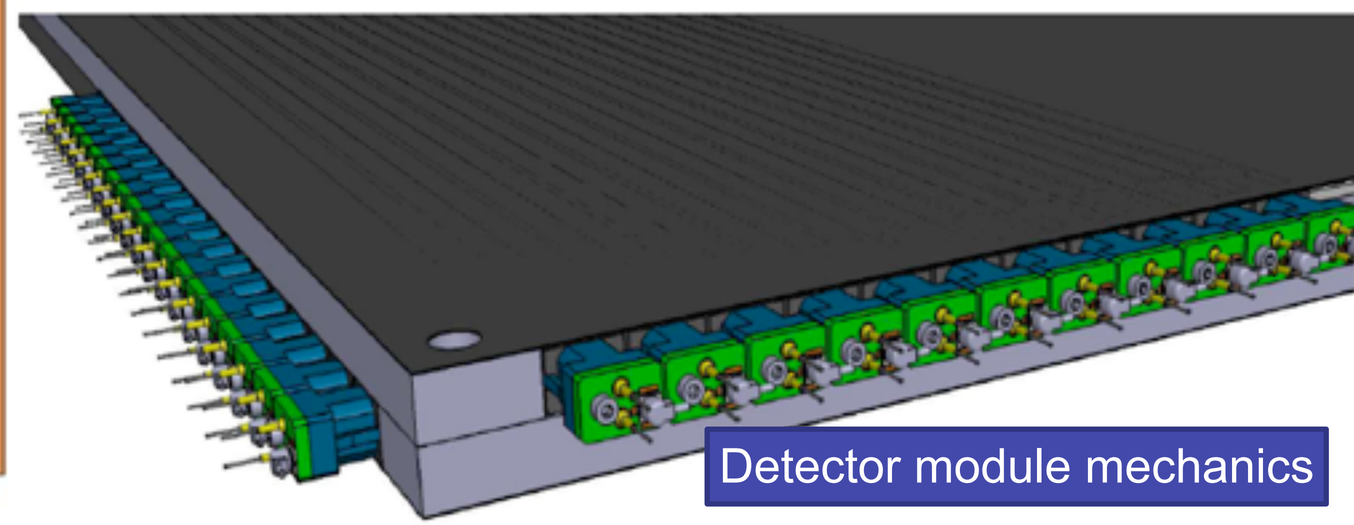


LBNO near detector
High Pressure Ar Gas TPC
+ scintillator based detectors
(avoid pile-up)

AIDA

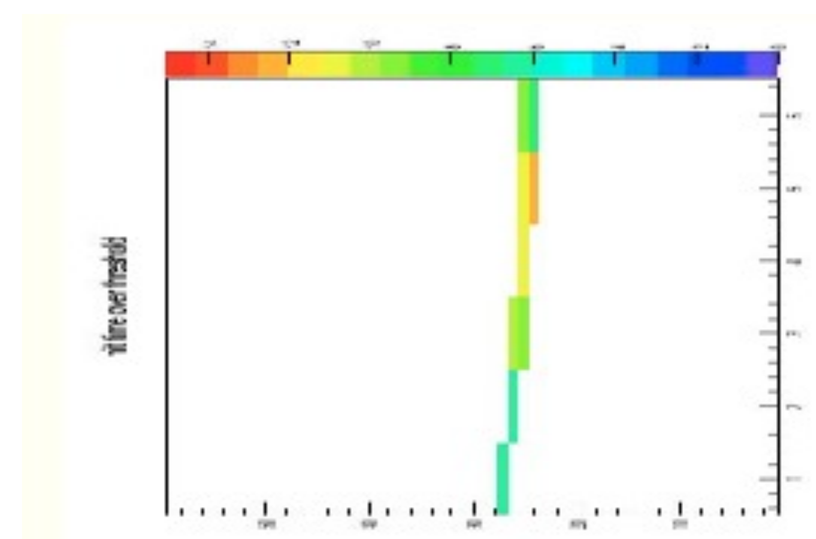
Photosensor connector design





Detector module mechanics

MICE calorimeter
($1\ m^3$ fully active scintillator
as in MIND)

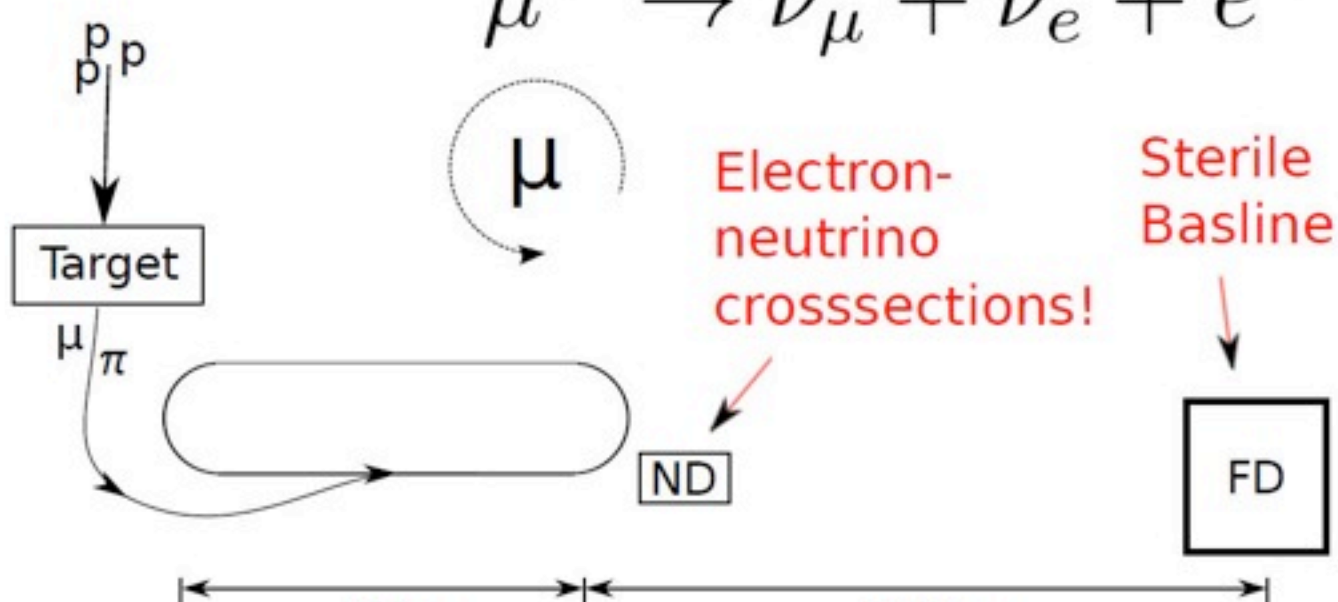


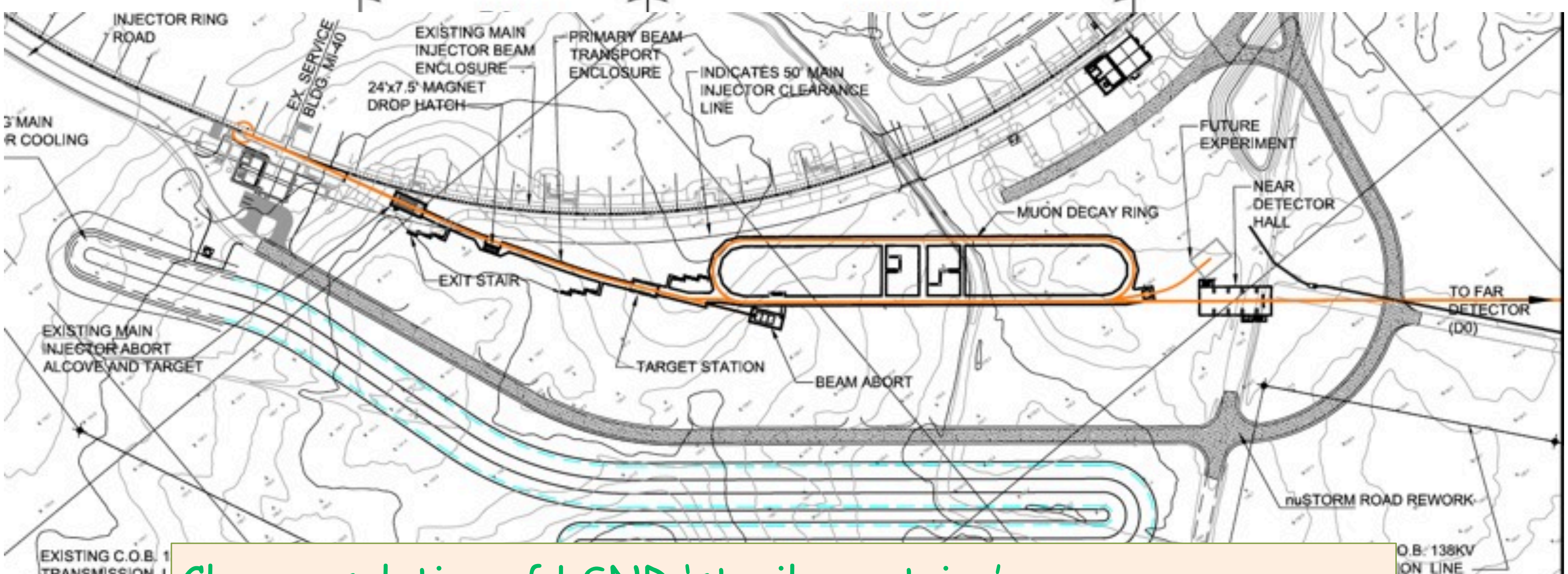
First cosmic
tracks!

vSTORM: neutrinos from stored muons

➔ first step towards neutrino factory and muon collider

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





Clean resolution of LSND 'sterile neutrino'

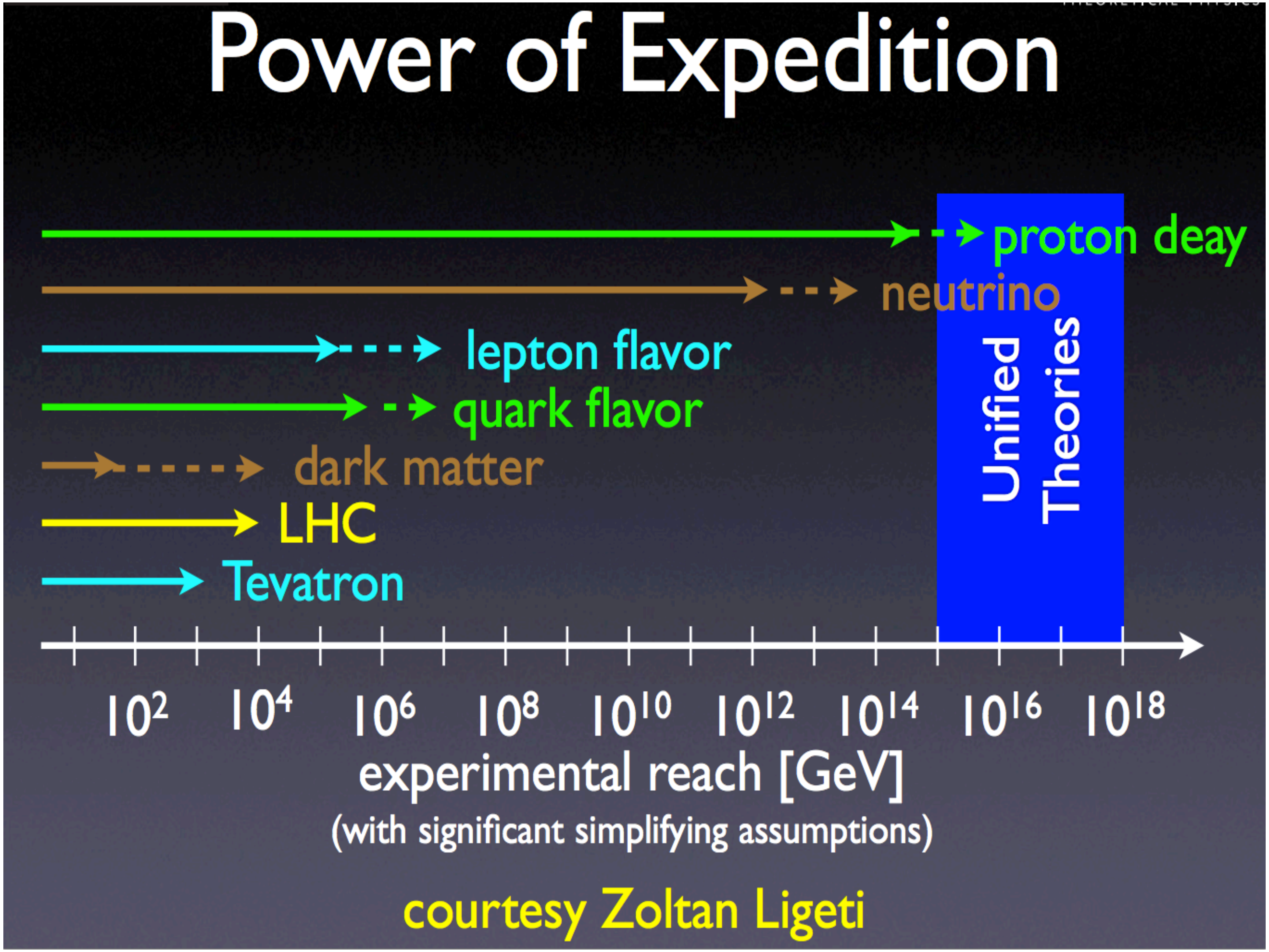
Precision measurements of cross-sections (E=0.5-3 GeV)

Proposal at Fermilab 5 June and at CERN 25 June (yesterday)

Conclusion

- The SM, despite huge successes, has still some drawbacks. The further investigation of the neutrino sector and the search for proton decays with very large underground observatories is a promising way to make progress in some of these areas.
- The LAGUNA/LBNO design study, led by Swiss groups, has made significant progress at designing and optimising a next generation deep underground neutrino observatory in Europe.
- LBNO has been put forward to CERN with unique physics potentials, including astro-particle physics and proton decay search. It is conceived as an incremental approach starting with an underground LAr detector, a clear stage 1 physics goal (>2023) and well-defined upgrade plan (>2030).
- Physics case strongly endorsed by European Strategy.
- Swiss groups are heavily involved in the definition of the project and performing intense detector R&D. We are now proposing a demonstrator for the double phase LAr technology at a relevant scale (216m^3) to be built at CERN during the period 2014-2017.

Searching for Godot...



} **LBNO**

LBNO Expression of Interest

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- We are grateful to the CERN Management for supporting the LAGUNA-LBNO design study.
- We thank the CERN staff participating in LAGUNA-LBNO, in particular M.Benedikt, M.Calviani, I.Efthymiopoulos, A.Ferrari, R.Garoby, F.Gerigk, B.Goddard, A.Kosmicki, J.Osborne, Y.Papaphilippou, R.Principe, L.Rossi, E.Shaposhnikova and R.Steerenberg.
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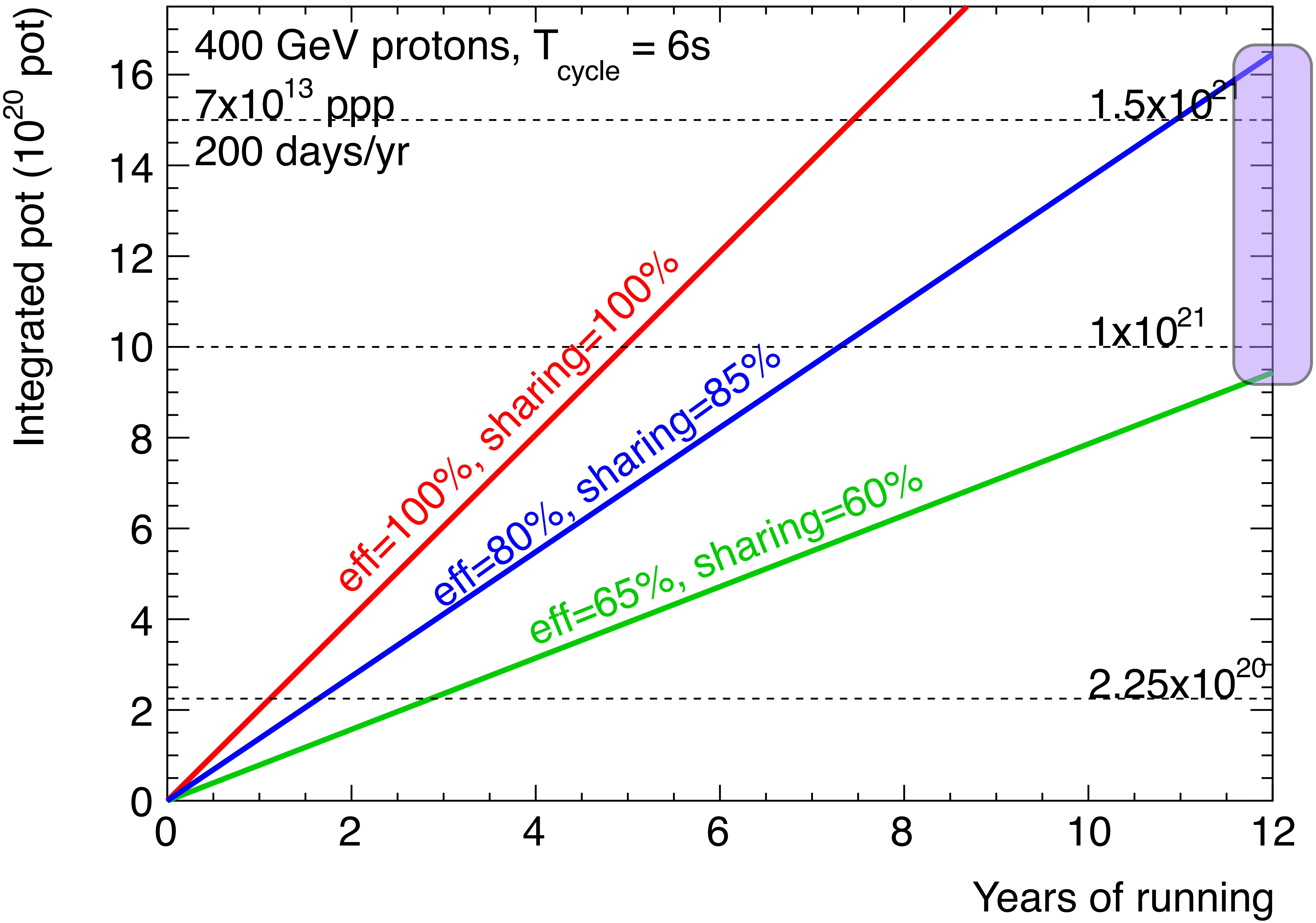
- The contributions of Anselmo Cervera are also recognized.

Backup slides

Courtesy PvZ

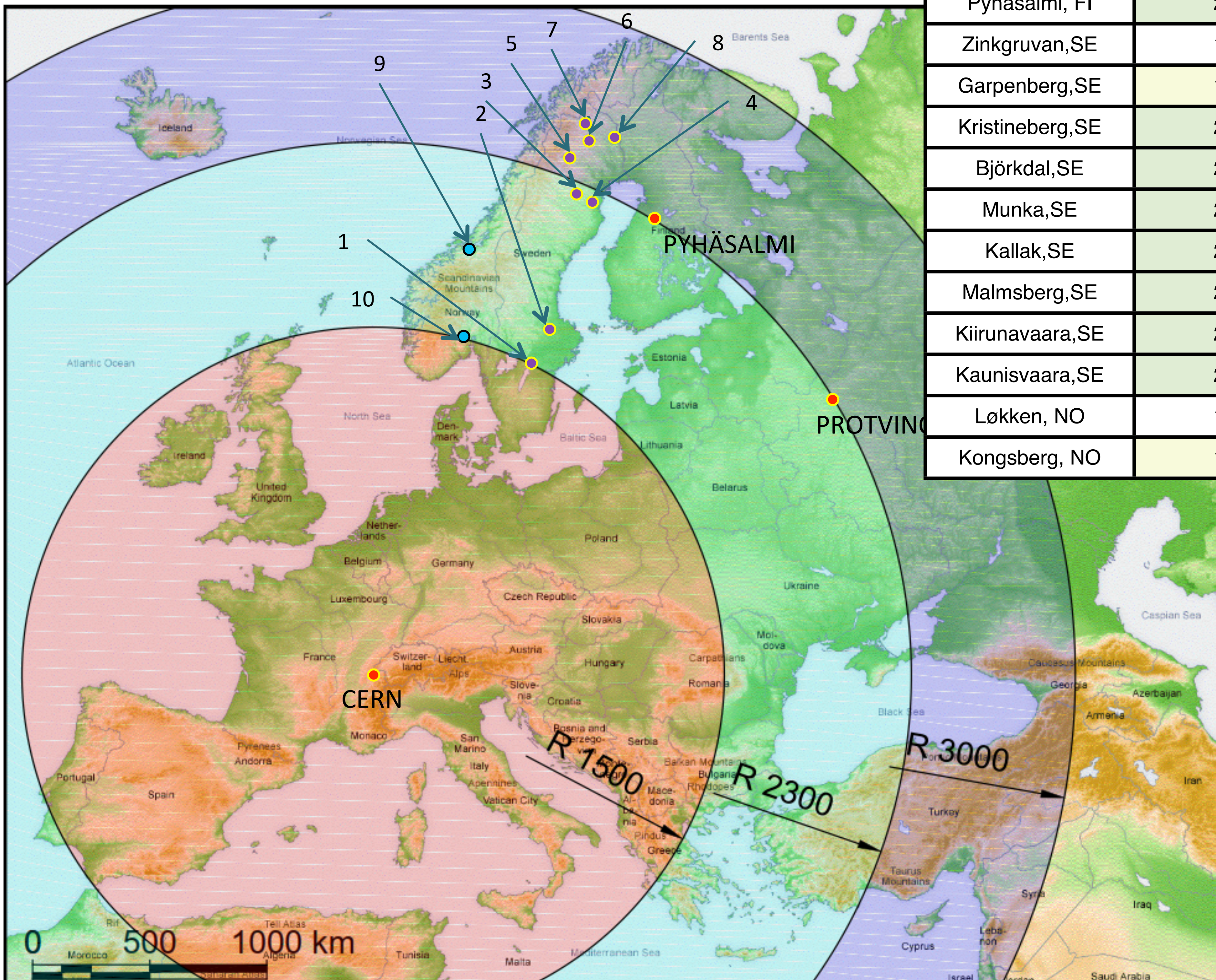
Total integrated p.o.t.



A first look at nearby mines...

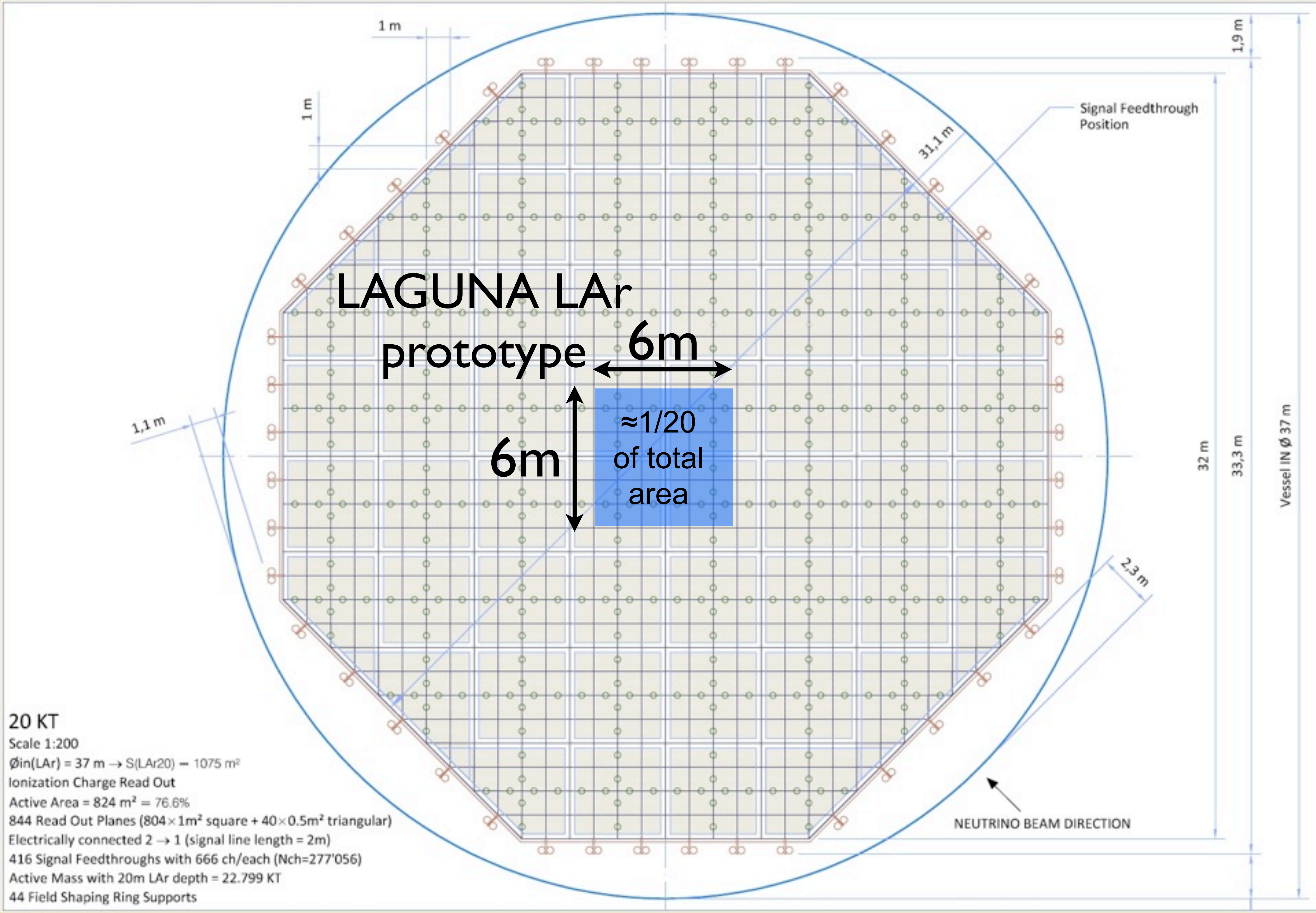
- LAGUNA/LBNO retains Pyhäsalmi as its **first choice** for far site

Location	Baseline from CERN (km)	Baseline from Protvino (km)	Baseline from ESS (km)
Pyhäsalmi, FI	2300	1160	1140
Zinkgruvan,SE	1530	1420	360
Garpenberg,SE	1730	1300	540
Kristineberg,SE	2230	1530	1080
Björkdal,SE	2270	1450	1100
Munka,SE	2310	1620	1160
Kallak,SE	2400	1700	1260
Malmsberg,SE	2480	1620	1320
Kiirunavaara,SE	2530	1700	1380
Kaunisvaara,SE	2552	1580	1390
Løkken, NO	1536	1740	500
Kongsberg, NO	1900	1800	840



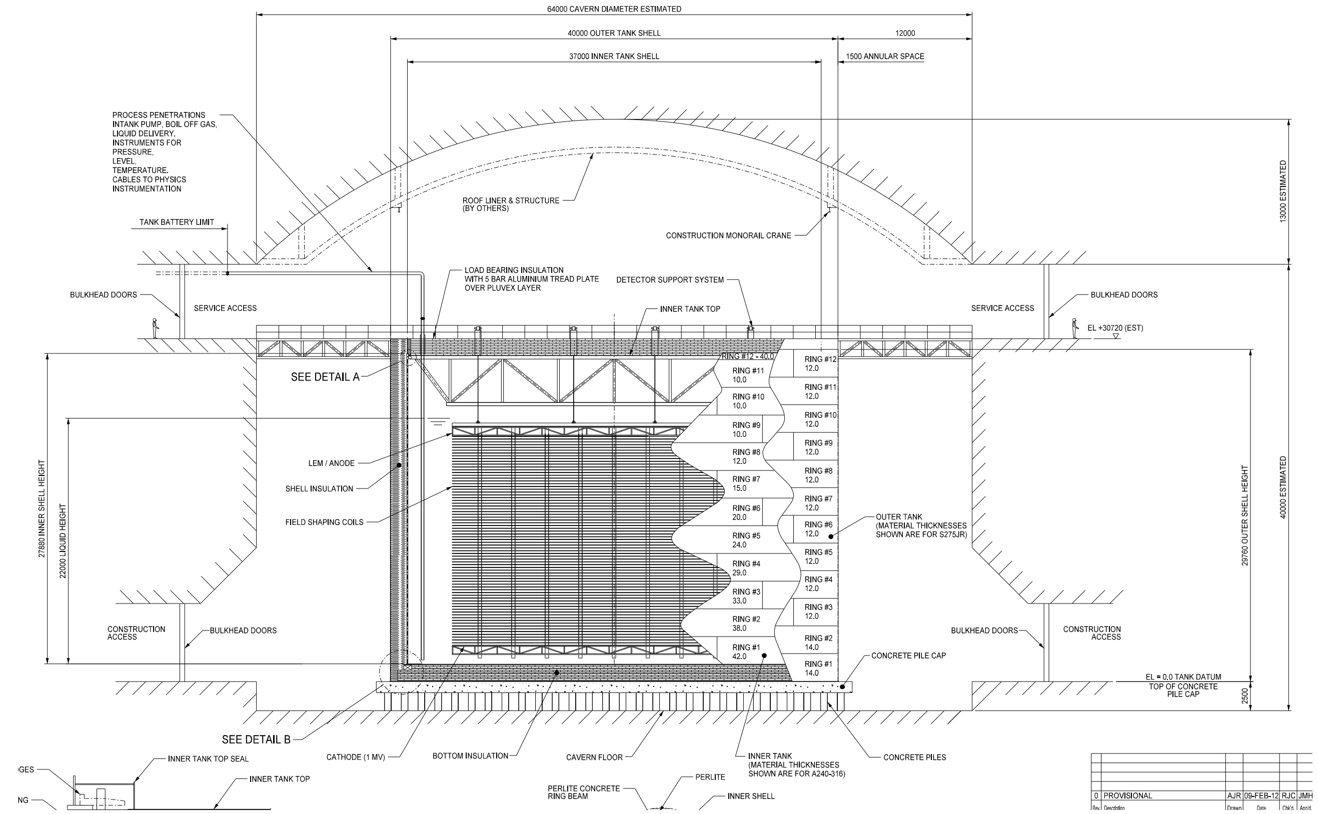
- The concerns that the Finnish government expressed are obviously serious, one cannot exclude that other sites with similar advantages need to be found.
- There are several mines nearby.
- See also talk by Tord Ekelof (next talk)

LAGUNA 6x6x6 m³ prototype compared to 20kton



LAr detector design

- GLACIER concept unchanged since 2003: Simple, scalable detector design, from one up to 100 kton (hep-ph/0402110)
- Single module non-evacuable cryo-tank based on industrial LNG technology
  - industrial conceptual design (Technodyne, AAE, Ryhal engineering, TGE, GTT)
  - two tank options: 9% Ni-steel or membrane (detailed comparison up to costing of assembly in underground cavern)
  - three volumes: 20, 50 and 100 kton
- Liquid filling, purification, and boiloff recondensation
  - industrial conceptual design for liquid argon process (Sofregaz), 70kW total cooling power @ 87 K
  - purity < 10 ppt O_2 equivalent
- Charge readout (e.g. 20 kton fid.)
  - 23'072 kton active, 824 m^2 active area
  - 844 readout planes, 277'056 channels total
  - 20 m drift
- Light readout (trigger)
  - 804 8" PMT (e.g. Hamamatsu R5912-02MOD) WLS coated placed below cathode



Top readout view: