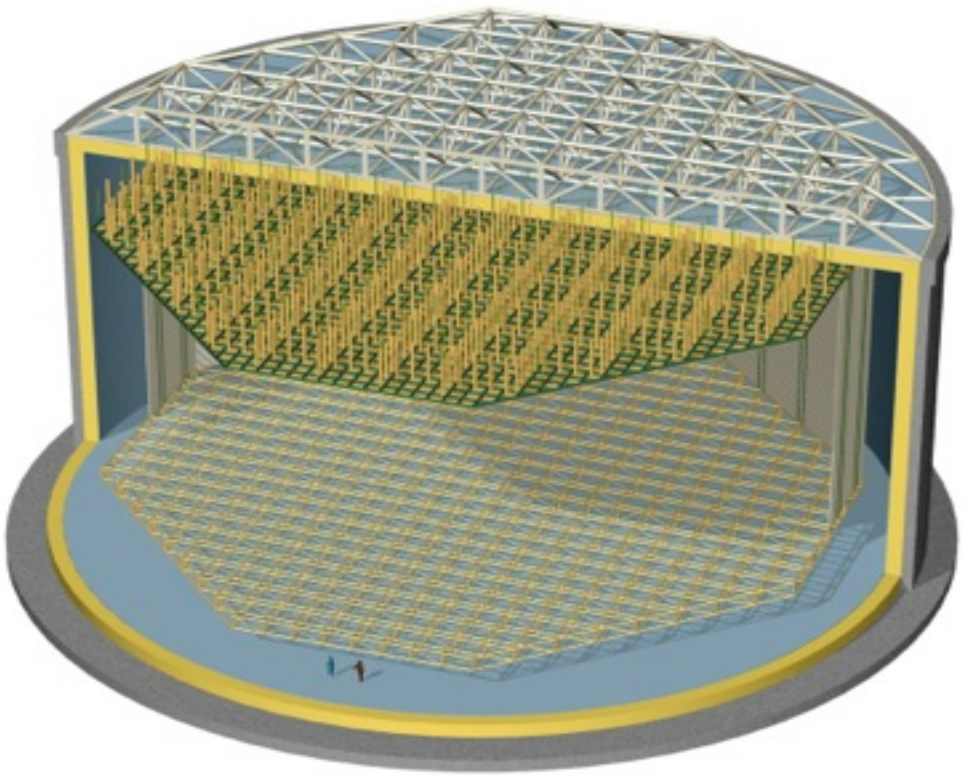


The LAGUNA/ LBNO project

André Rubbia (ETH Zürich)

APPEC

International Meeting for Large Neutrino Infrastructures

23-24 June 2014
Ecole Architecture Paris Val de Seine
Europe/Paris timezone

Search

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

v3

More than an idea…

- After several years of R&D and very detailed EC funded studies (**≈17M€ investment**), we have **a clear end-to-end path** solution for LBNO, a liquid argon TPC based experiment capable to
  - Determine **unambiguously (>5 σ) the neutrino MH** and
  - Cover **80% of the CPV phase space at 3σ and 65 % at 5σ** with realistic systematic error assumptions (**"HEPAP P5 requirement" satisfied**)
- **Designed for deep underground location**, it offers a comprehensive:
  - Astrophysics program
  - p-decay searches

  } **Complementary to WCD**
- **A full Conceptual Design Report is available**, developed in collaboration with industrial partners leading to: Underground facility, construction sequence, well defined costs, deployment in Europe,…
- The next-step is **a 1:20-scale LBNO-DEMO demonstrator @ CERN (WA105).**
- **LBNE and LBNO held executive-level phone meetings every two weeks.**

LBNO: A steadily maturing process

- **GLACIER** (Giant Liquid Argon Charge Imaging ExpeRiment, **2003**)
  - **New concept** of Double Phase Liquid Argon TPC for CP-violation and future deep underground detector, up to 100 kton mass (hep-ph/0402110)
- **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
  - Fully engineered conceptual designs (20/50 kton LAr, 50 kton LSc, 540 kton WCD)
  - Extended site investigation at Pyhäsalmi mine
- **LBNO** (CERN SPSC EoI for a very long baseline neutrino oscillation experiment, **June 2012**) – CERN-SPSC-2012-021 ; SPSC-EOI-007
  - 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
- **WA105** (CERN experiment, **August 2013**)
  - Kton-scale demonstrators for LBNO@CERN: engineering and charged particles calibration.

Large **A**pparatus for **G**rand **U**nification and **N**eutrino **A**strophysics - **L**ong **B**aseline **N**eutrino **O**scillations

Sustained funding led to a carefully developed LBNO proposal with accurate plans and cost estimates

Question #1 for LBNO

Q1. (Theoretical relevance) What is according to you the theoretical relative urgency of the determination of the

- *neutrino mass hierarchy,*
- *PMNS CP violating phase δ,*
- *θ_{23} octant*
- *existence of sterile neutrinos*
- *Dirac vs Majorana nature of the neutrino*

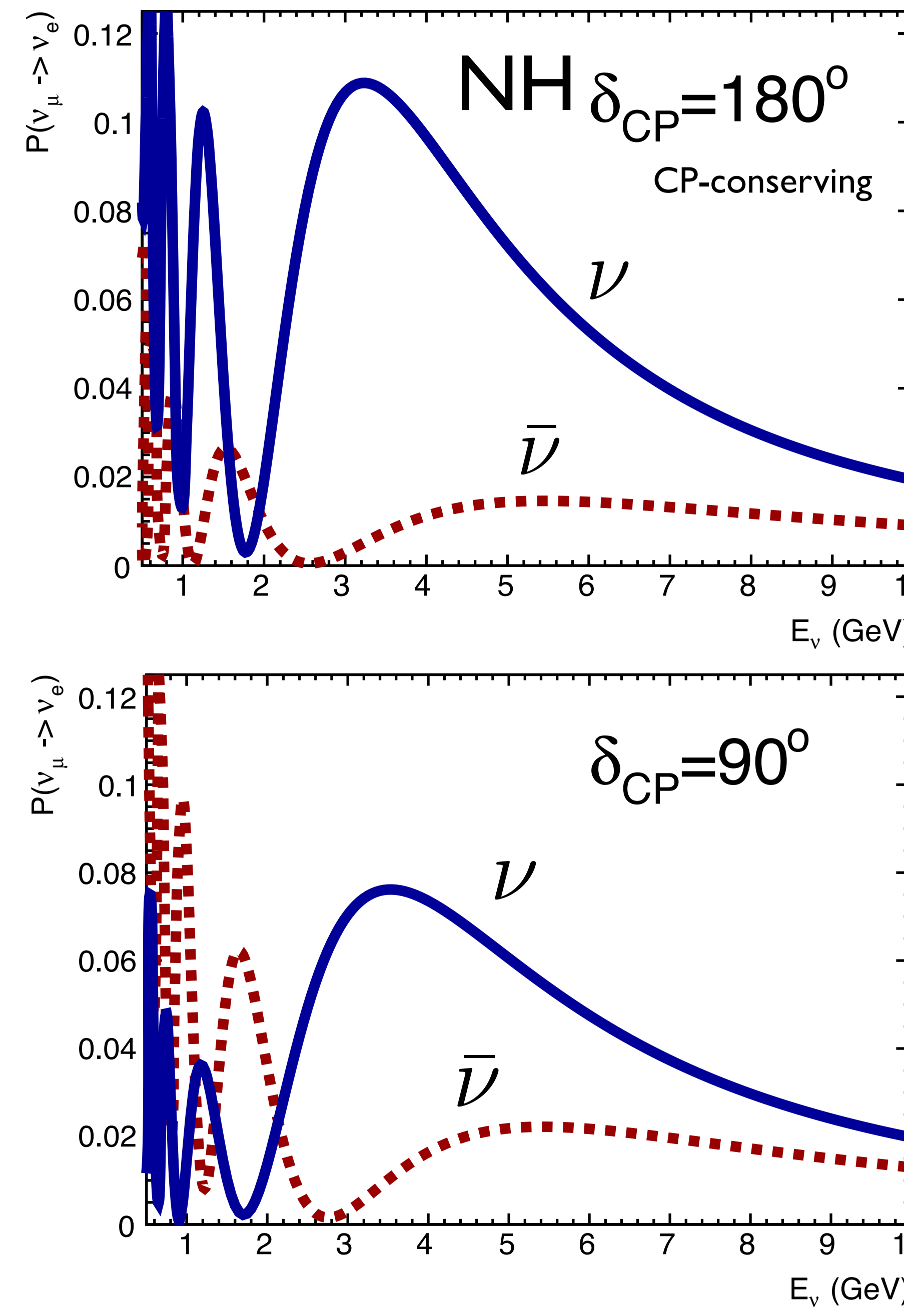
Compare, if relevant, to other attempts of measurement direct or indirect (e.g. in cosmology). Describe also synergies with other topics of science e.g. proton decay or neutrino astrophysics (supernova burst and relic, solar neutrinos,…).

- **GOAL: Achieve 80% coverage of the δ_{CP} for CPV at 3σ, incrementally**, measurement $\delta(\delta_{CP}) < \pm 20$deg uncertainty
- **Matter effects and MH guaranteed during first years of running**. Are prerequisites for CPV; don't rely on or expect someone else to provide them.
- **Theta_23** (and it's octant) impacts visibly the CPV sensitivity.
- **Exotic scenarios:** Measure cleanly all oscillation channels:
  νμ→ νe & νμ→ ντ & νμ→ νμ & νNC
  Test sterile / non-standard models / propagation through matter
- **Proton decay, atmospheric neutrinos (SubGeV), SN ν_e (neutronisation),…**

LBNO main physics goals

LBNO EoI, SPSC-EOI-007, June 2012

- **Long baseline neutrino oscillations**
  - All: **$\nu\mu \rightarrow \nu e$ & $\nu\mu \rightarrow \nu\tau$ & $\nu\mu \rightarrow \nu\mu$ & 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
  - Mass hierarchy determination median sensitivity >5σ C.L. in first two years of running
  - CP-phase measurement and CPV “discovery” (⇒ 5σ C.L.), covering 1st and 2nd oscillation maxima
  - 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

Broad physics accelerator and non-accelerator based programme

How to test CPV in neutrino sector?

- If PMNS matrix is complex, then neutrino and antineutrinos will behave differently in their flavour oscillations. CP and T will be violated (CPT conserved). This excludes disappearance channels (e.g. $\nu_e \rightarrow \nu_e$).

  → **Main channel of investigation: the appearance channel $\nu\mu \rightarrow \nu e$**

- **Neutrino/antineutrino difference:**

$$P(\nu_\mu \rightarrow \nu_e; E) \neq P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e; E)$$

  ➡ Sensitive to any origin (in principle not only induced by δ_{CP})

- **Energy dependence of oscillation probability, independently for neutrinos and antineutrinos:**

$$\begin{aligned} P(\nu_\mu \rightarrow \nu_{\mathrm{e}}; L) \simeq\ & 4c_{13}^2 s_{13}^2 s_{23}^2 \left\{1 + \frac{a}{\delta m_{31}^2} \cdot 2(1 - 2s_{13}^2)\right\} \sin^2 \frac{\delta m_{31}^2 L}{4E} \\ & + c_{13}^2 s_{13} s_{23} \left\{-\frac{aL}{E} s_{13} s_{23}(1 - 2s_{13}^2) + \frac{\delta m_{21}^2 L}{E} s_{12}(-s_{13} s_{23} s_{12} + c_\delta c_{23} c_{12})\right\} \sin \frac{\delta m_{31}^2 L}{2E} \\ & - 4\frac{\delta m_{21}^2 L}{2E} s_\delta c_{13}^2 s_{13} c_{23} s_{23} c_{12} s_{12} \sin^2 \frac{\delta m_{31}^2 L}{4E} \end{aligned}$$

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

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$$+ c_{13}^2 s_{13} s_{23} \left\{-\frac{aL}{E} s_{13} s_{23} (1 - 2s_{13}^2) + \frac{\delta m_{21}^2 L}{E} s_{12} (-s_{13} s_{23} s_{12} + c_\delta c_{23} c_{12})\right\} \sin \frac{\delta m_{31}^2 L}{2E}$$

$$- 4 \frac{\delta m_{21}^2 L}{2E} s_\delta c_{13}^2 s_{13} c_{23} s_{23} c_{12} s_{12} \sin^2 \frac{\delta m_{31}^2 L}{4E}$$

Matter terms∾a

CP-even

L/E dependence

CP-odd∾sinδ_{CP}

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Matter terms~a

CP-even

CP-odd~sinδ_{CP}

L/E dependence

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

➡ Direct test of δ_{CP} origin of CPV and of matter terms

Enhanced CP effect at 2nd maximum

- **Matter- and pure CP-terms are disentangled by their different L/E dependence and by the growing CP effect with L/E:**

$$\mathcal{A} \equiv P(\nu_\mu \to \nu_e) - P(\bar\nu_\mu \to \bar\nu_e) =$$

$$16\frac{a}{\delta m^2_{31}}\sin^2\frac{\delta m^2_{31}L}{4E}c^2_{13}s^2_{13}s^2_{23}(1-2s^2_{13})$$

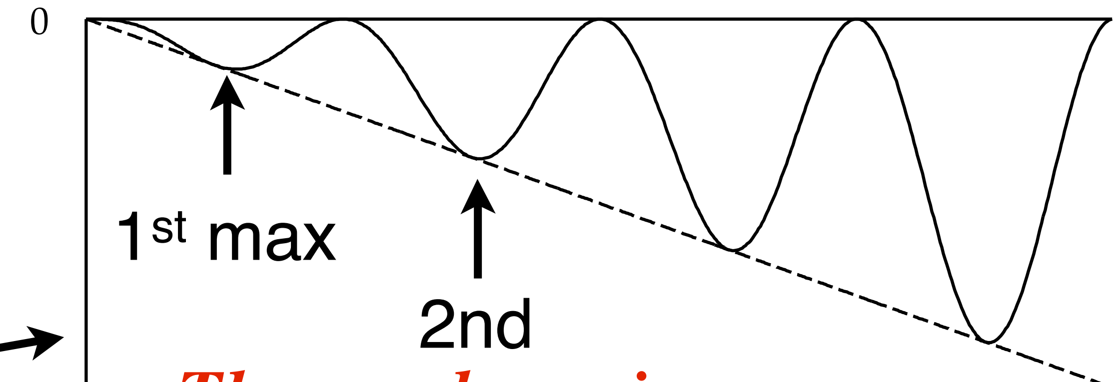
$$-4\frac{aL}{2E}\sin\frac{\delta m^2_{31}L}{2E}c^2_{13}s^2_{13}s^2_{23}(1-2s^2_{13})$$

Matter terms

$$-8\frac{\delta m^2_{21}L}{2E}\sin^2\frac{\delta m^2_{31}L}{4E}s_\delta c^2_{13}s_{13}c_{23}s_{23}c_{12}s_{12}$$

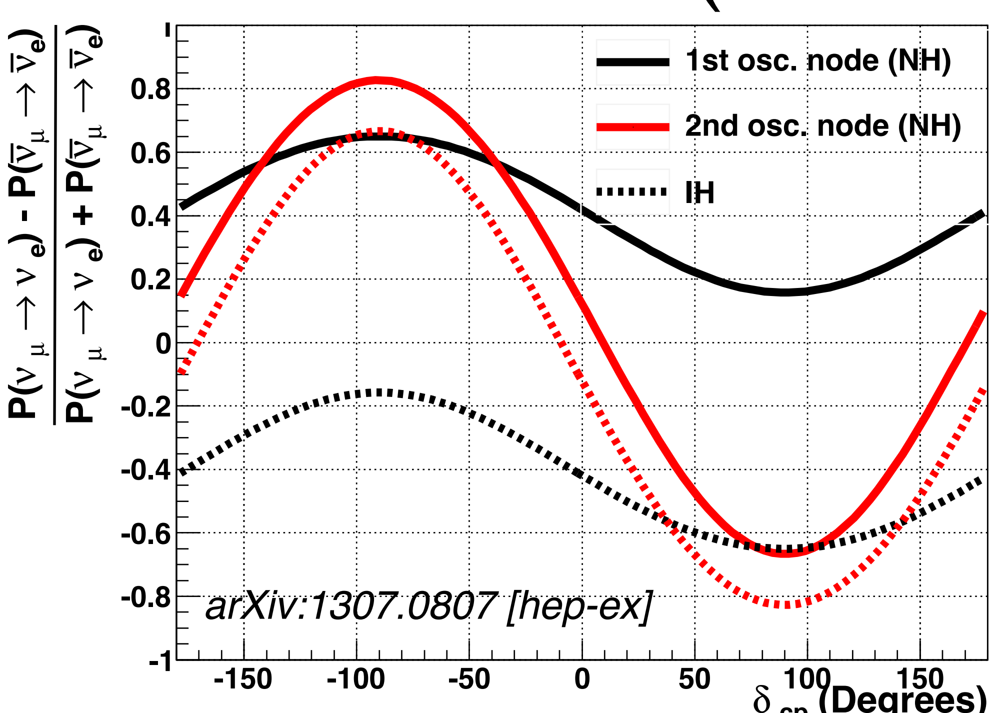
Pure CP-term

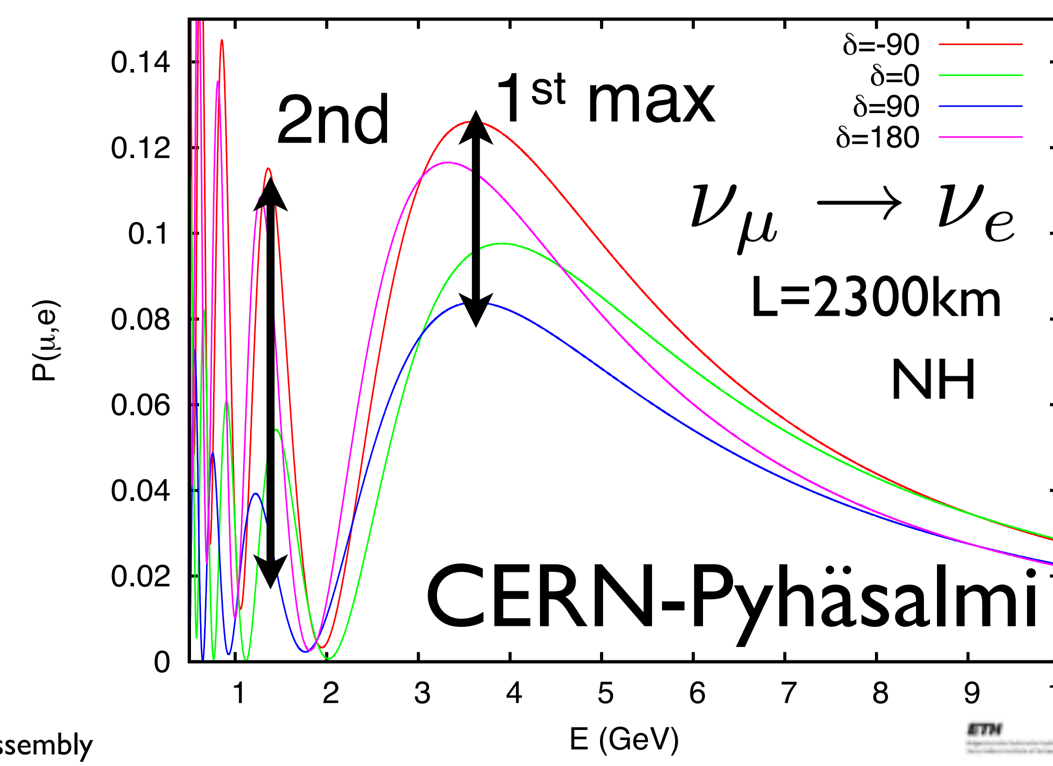
$$\left.\frac{P(\nu)-P(\bar\nu)}{P(\nu)+P(\bar\nu)}\right|_{a=0} \approx -\frac{2s_\delta c_{12}s_{12}}{s_{13}}\cot\theta_{23}\frac{\delta m^2_{21}L}{2E}$$



The enveloppe increases linearly with L/E

FNAL-Homestake (L=1300km)





The LBNO Experimental strategy

- We select a very long baseline (2300 km) to explore the L/E oscillation pattern predicted by the 3 flavour mixing paradigm over the 1st and 2nd max
- We propose a phased experiment to adjust the beam and detector mass with respect to the findings of phase n-1 to use resources in the most efficient way ("*incremental approach*") – Nature might have chosen maximal CP violation !
- Assume two complementary long baseline experiments, one measuring nu-vs-anti-nu (300km), the other focused on the L/E dependence (2300km) to guarantee MH 5sigma C.L., incremental CPV exploration reaching P5 requirement.
- **Phase I (LBNO20):**
  - 24 kt fid. DLAr + SPS beam (750 kW, Ep = 400 GeV)
  - Guaranteed 5 σ MH determination + 46 % δCP coverage at 3 σ + p-decay + astroparticle physics
  - Estimated cost (excavation + detector + infrastructure + contingency): ≈ **210 M€ +/- 10%**
- **Phase II (LBNO70):**
  - 70 kt fid. DLAr + HPPS beam (2 MW, Ep = 50 GeV) or Protvino beam
  - **80% δCP coverage at 3 σ** + p-decay + astroparticle physics

Question #2 for LBNO

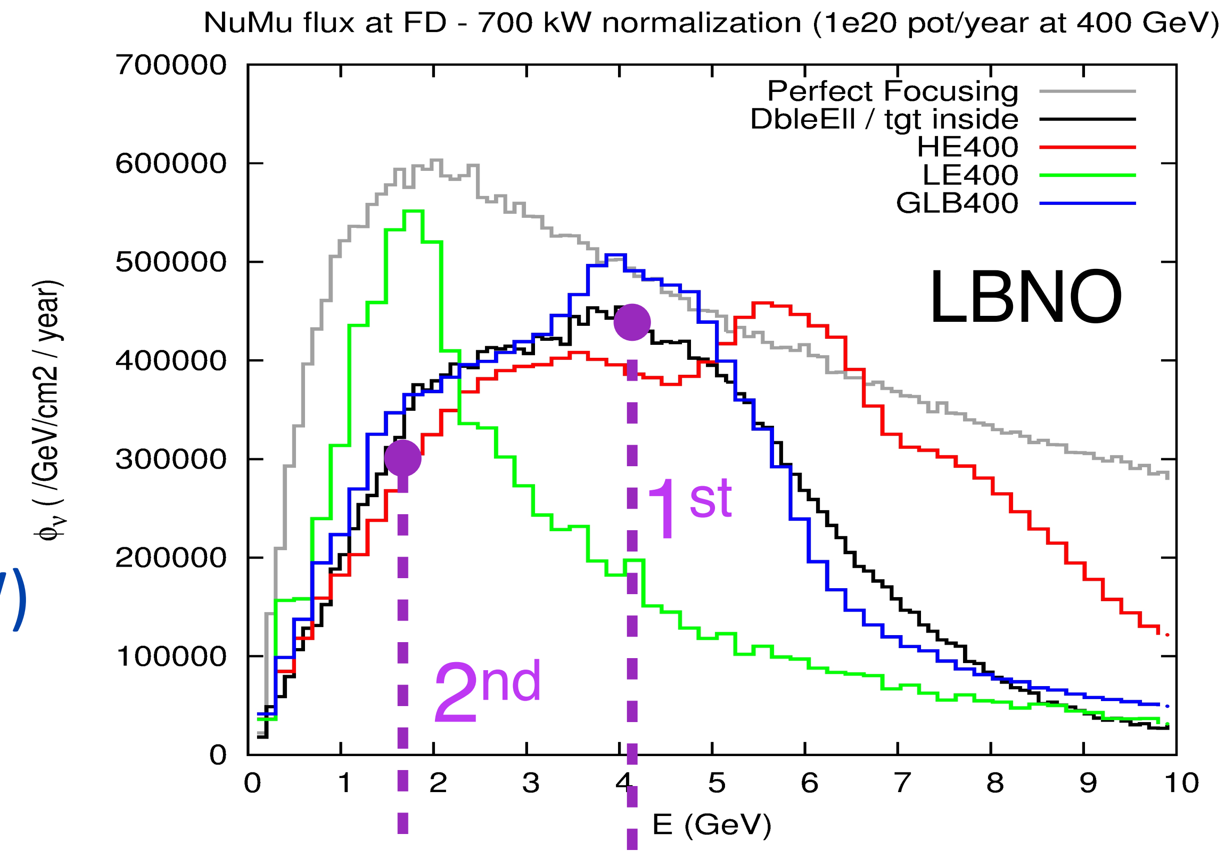
Q2. (Experimental Strategy) What is according to you the experimental strategy that needs to be deployed worldwide in order to answer the above questions? And in particular, how many experiments should there be worldwide, what complementarities or double check features should they exhibit? In this world-wide context describe the phases of your project, its timeline and the expected statistical significance per phase. Discuss the relevant systematics, how well you know them and in particular do you need any supporting measurements to further determine them?

- To complete our understanding there should be **two complementary** long baseline experiments, **(A) one measuring nu/anti-nu asymmetry at the 1st maximum, and (B) the other focused on the L/E dependence covering the 1st and 2nd maximum. Water Cerenkov is adequate for (A); LAr TPC (much smaller than HK) is unique for (B).**
- **The 2300km baseline with 1st/2nd max is the way to meet the P5 requirements on CPV. It is the only proposal that can guarantee 5sigma C.L. on the MH, and the accelerator beam is the only systematic free method (change of horn polarity). Europe is the only place (so far?) where such a solution was developed and accurately quoted (±10% cost estimates) after 6 years of sustained EC funded DStudies.**
- **Systematics: conservative ≈3% and we rely on 2nd maximum for CPV when 1st maximum become systematic dominated**
- **Calibration of event energy reconstruction in a charged particle test beam of relevant energies (1-10 GeV) is mandatory to reduce several systematic errors (e.g E-scale, hadronic showers, …)**

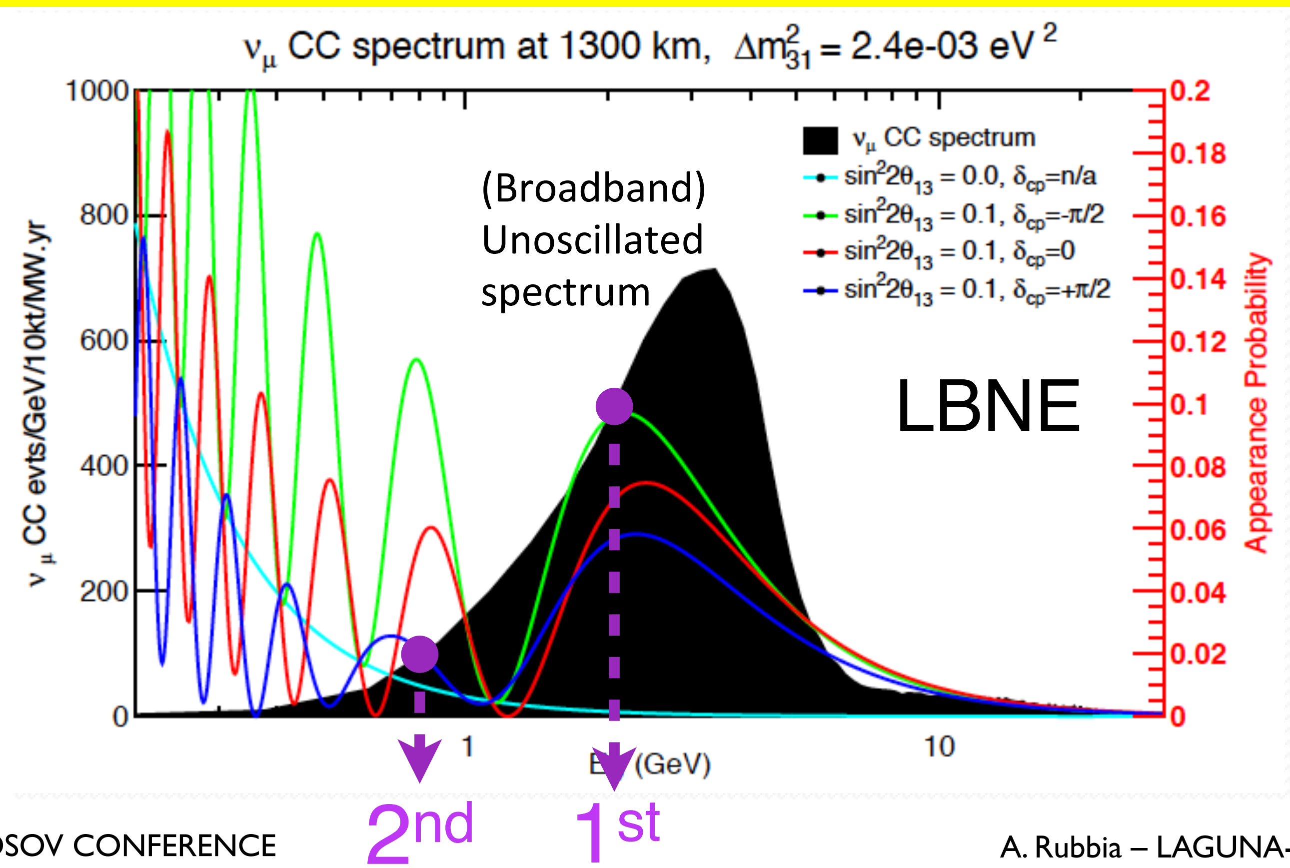
LBNO baseline beam optimisation

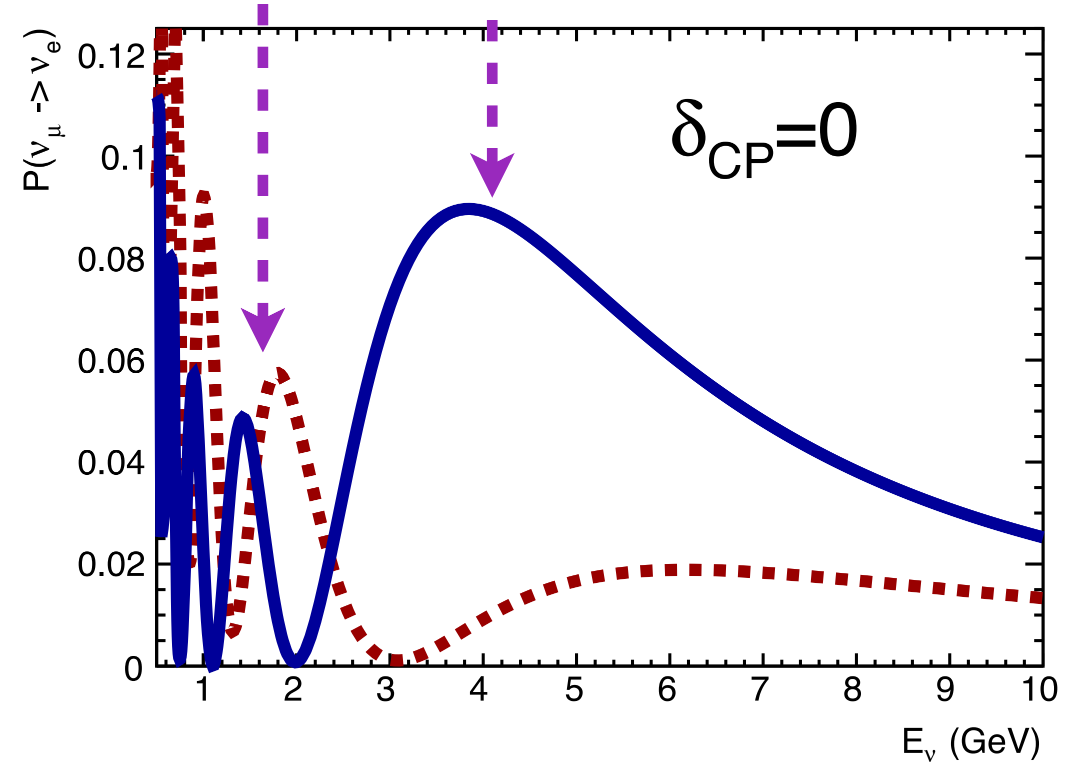
2300 km is optimal for covering 1st&2nd max

- Conventional beam, horn focused
- Medium energy to cover at $E_\nu \approx 4$ GeV (1^{st} max) and $E_\nu \approx 1.5$ GeV (2^{nd} max)
- Wide band covering 1^{st} and 2^{nd} maximum
- Small tail at high energy
- Positive and negative focus (ν and anti-ν modes)
- High beam power (initially 700 kW then 2MW)
- Angle 10deg dip angle (distance = 2300km)



1300 km is far from optimal to cover 1&2nd max





Recent update of the LBL physics program:

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The mass-hierarchy and CP-violation discovery reach of the LBNO long-baseline neutrino experiment

The LAGUNA-LBNO collaboration

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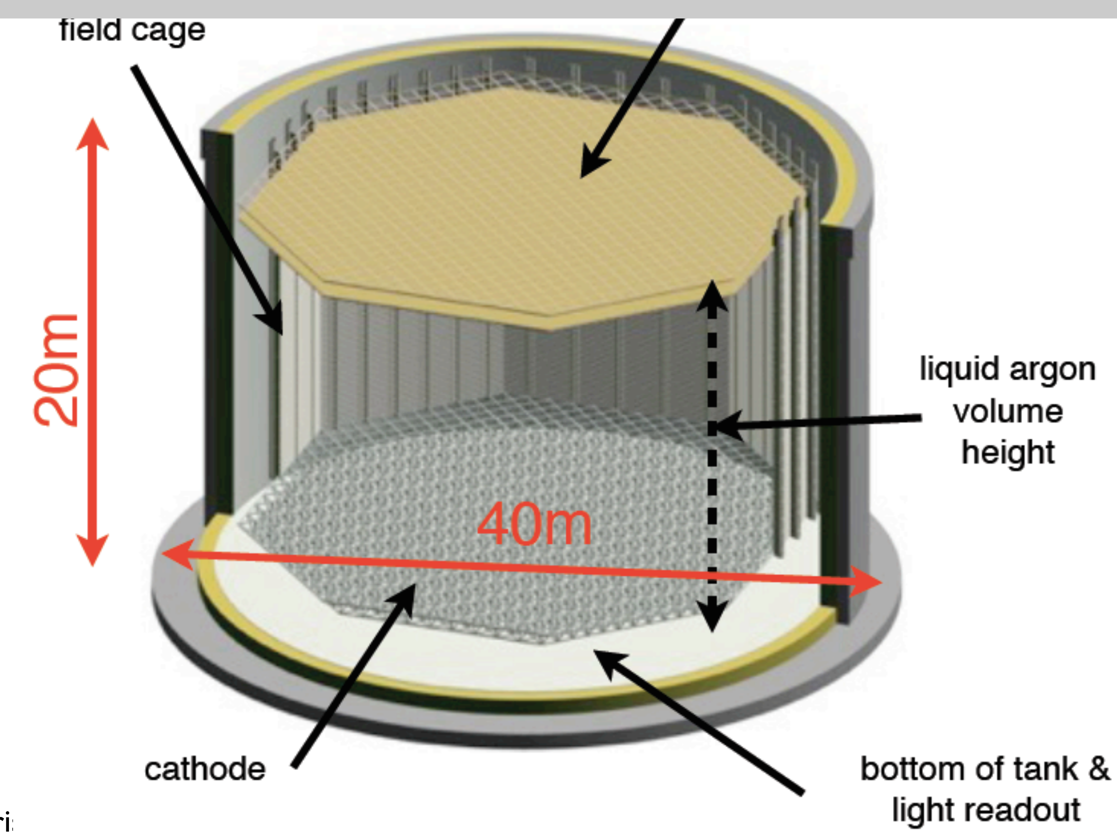
Basic assumptions :

- Realistic systematics
- 2300 km baseline
- SPS 400 GeV protons – 750 kW beam
- HPPS 50 GeV protons – 2 MW beam
- Liquid Argon double phase detector GLACIER :
  LBNO20 -> LBNO70

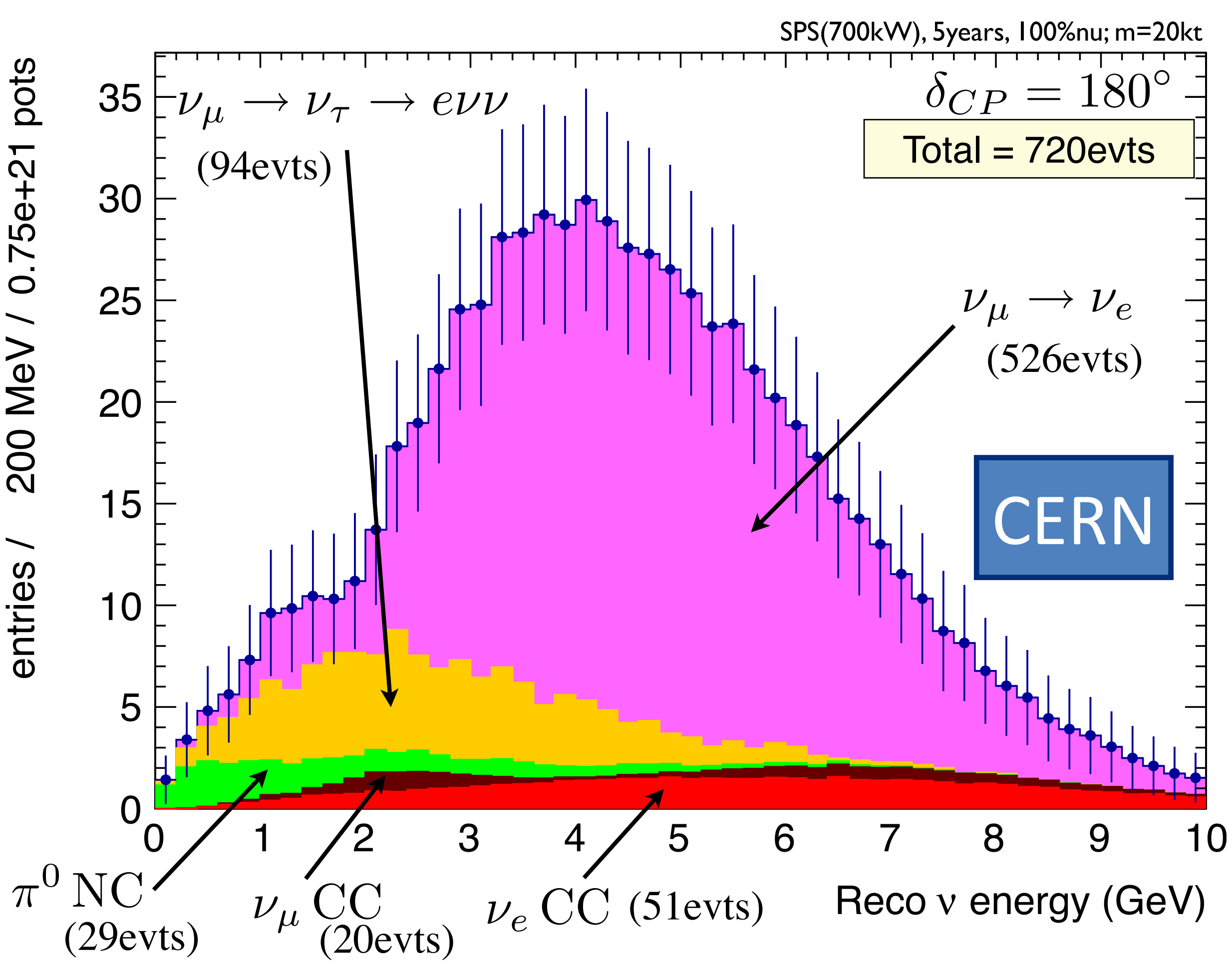


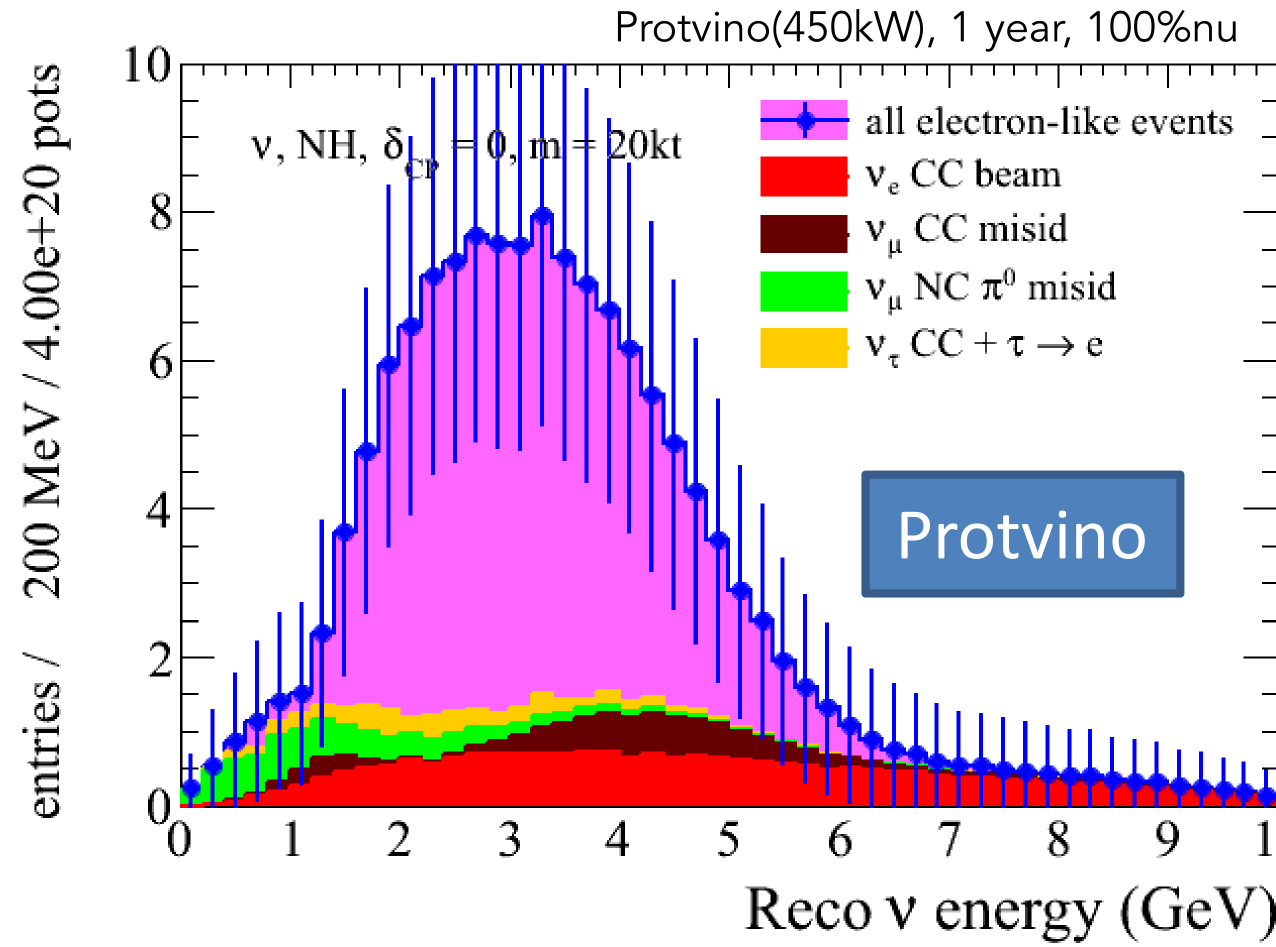
Event rates/year for LBNO20

POT normalisation
(corresponds events/1 year):

Protvino: 4e20 pot @ 70 GeV
CERN: SPS 1.5e20 pot @ 400GeV and HP-PS 3.5e21 pot @ 50 GeV

Nu beam	CERN SPS 700kW		CERN HP-PS 2MW		Protvino 450kW	
	ν	$\bar{\nu}$	ν	$\bar{\nu}$	ν	$\bar{\nu}$
NEUT					2056	21
GENIE	**1428**	10	**4007**	26	**1805**	18
GLOBES	1426	10	3975	26	1756	18



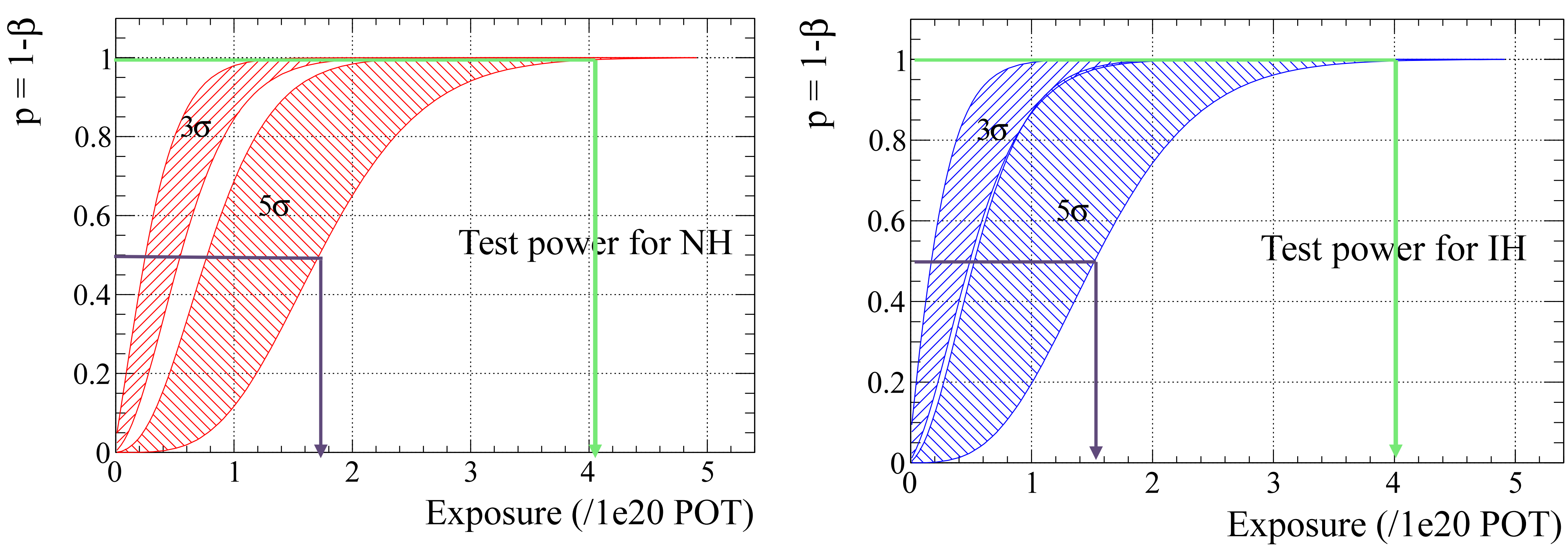


Neutrino mass hierarchy (MH)

- Explore and resolve the mass hierarchy and the CP-phase problem by observing clear signatures and ascertaining their L/E dependence.
- To guarantee the measure MH on the > 5σ level one need to go to very long baselines > 2000 km, ~ 1000 km gives not enough MSW to measure the full phase space.
- The median 5σ C.L. (p = 0.5) for LBNO is reached within 2 years of SPS at 750kW.
- The guaranteed 5σ C.L. (p = 1) for LBNO is reached within 5 years of SPS at 750kW.

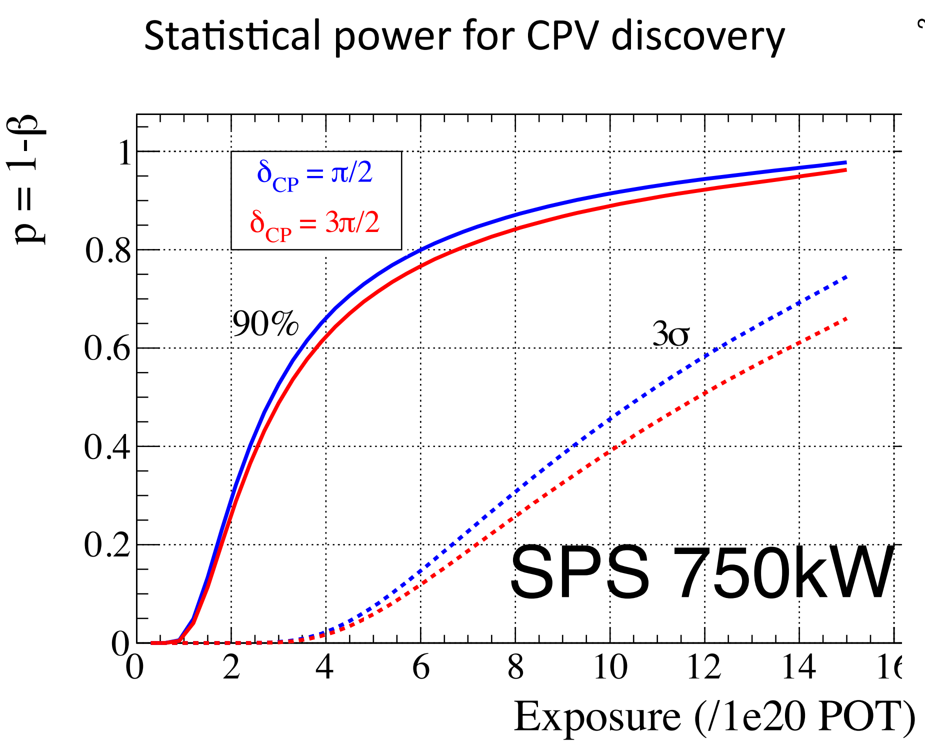
  - Power vs exposure for all values of δ_{CP} (shaded bands)

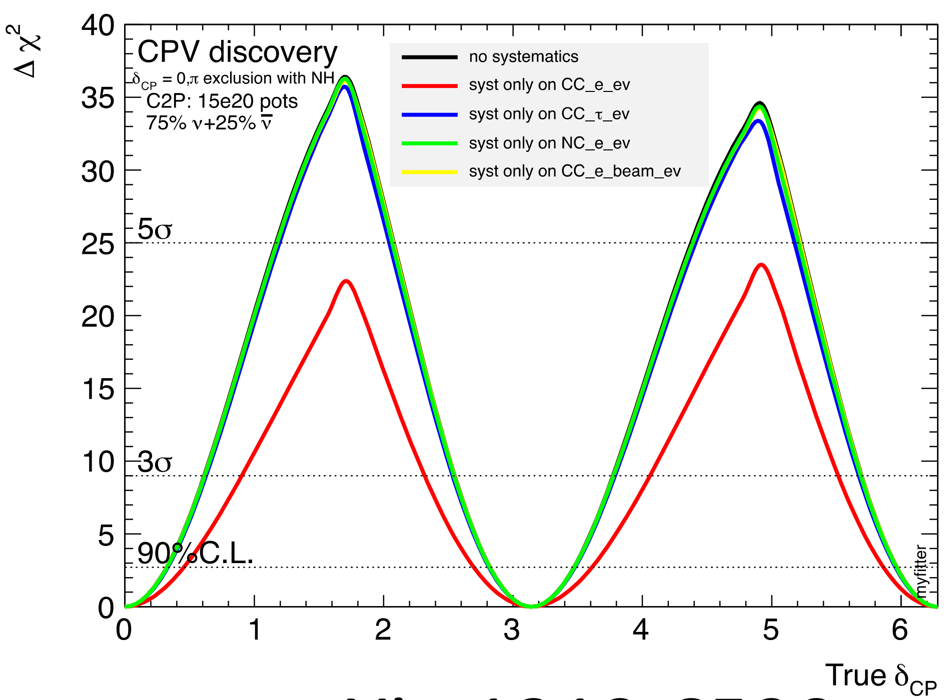
arXiv:1312.6520



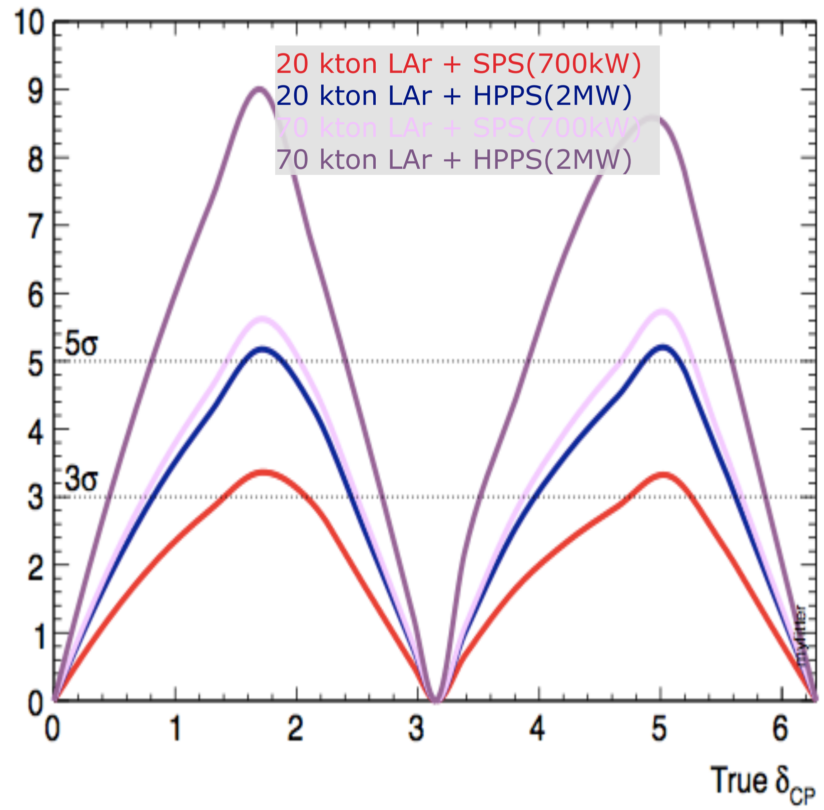
CP-violation in leptonic sector

- MH determination and the understanding of matter effects is a prerequisite to study leptonic CPV. Once MH determined run more years to cover the most possible phase space in δ_{CP}.
- **Upgrading mass to 70 kton** and/or the beam from the SPS to HP-PS increases the coverage way above 5σ C.L. for a large fraction of phase space.
- **Systematic errors are a limiting factor for the CPV reach.** The most important oscillation parameters are θ_{23} and θ_{13} and the most important systematics is the knowledge of the absolute rate of ve CC events.
- Our strategy was to present conservative estimates with realistic systematic errors (5%/10%). Very detailed work (based on the expertise gain in T2K with the ND280/NA61) has begun to assess potential improvements in systematic errors.





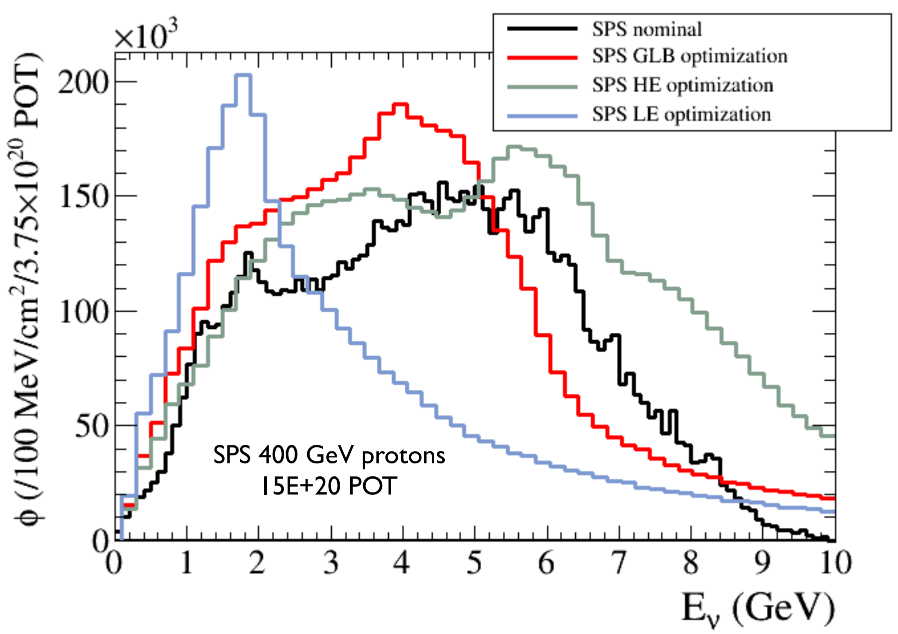
arXiv:1312.6520

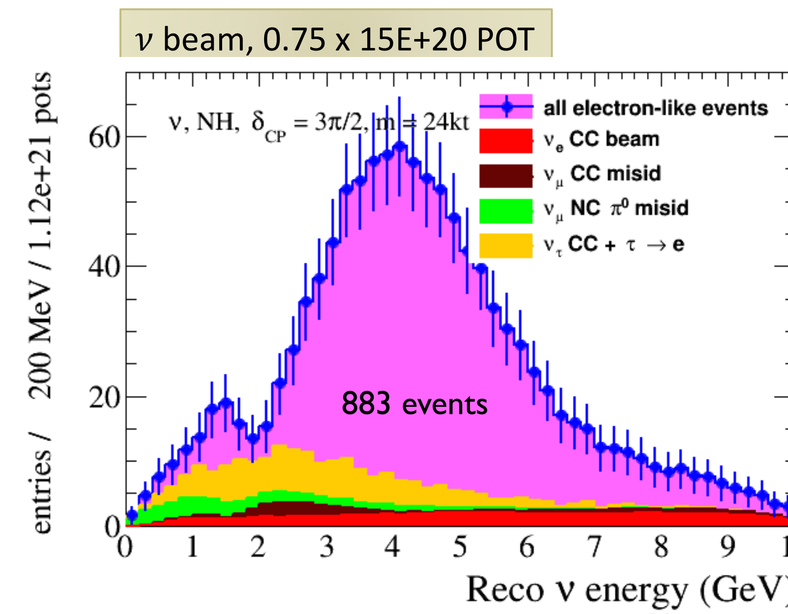


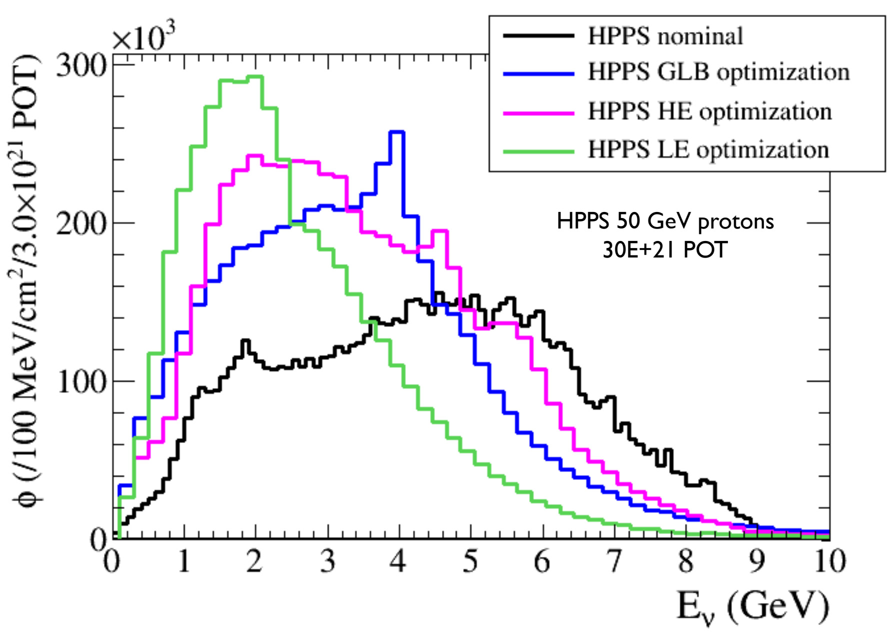
Optimised CPV with LBNO

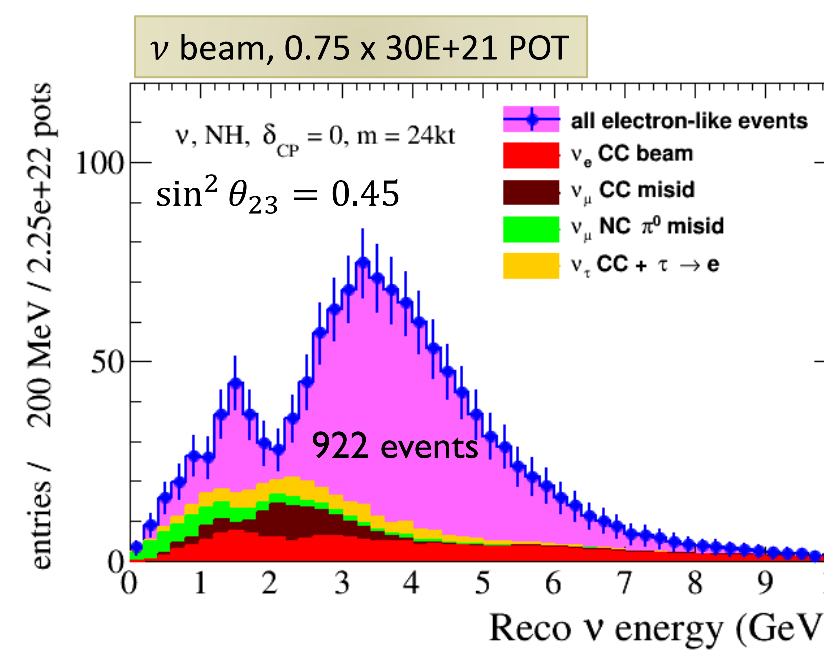
Measure δ_{CP} by measuring the energy dependence of the neutrino spectrum, the **L/E behavior**, and the **2nd maximum**, this is fully complementary to the HK proposal which measures the asymmetry between nu and anti-nu oscillation probabilities at the first maximum.

Continuous effort to optimize the beam to enhance the CPV coverage of the experiment:









Best CPV coverage is obtained for "SPS GLB" and "HPPS LEOPT"

Optimised CPV with LBNO

Assumed values and errors for oscillation parameters and systematics

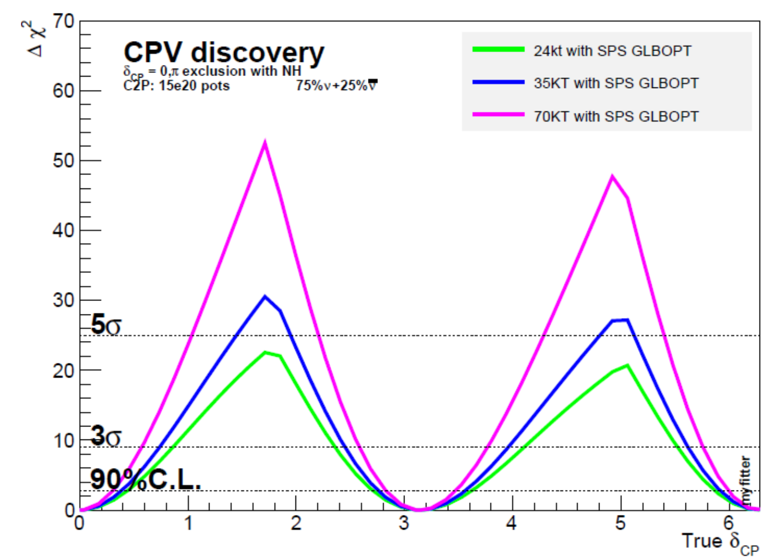
www.nu-fit.org

After TAUP 2013

Parameter	Value	Error
L	2300 km	exact
Δm^2_{21}	7.45×10^{-5} eV^2	fixed
Δm^2_{31}	2.42×10^{-3} eV^2	2 %
$\sin^2\theta_{12}$	0.306	fixed
$\sin^2\theta_{23}$	0.446	5 %
$\sin^2\theta_{13}$	0.09	3 %
ρ	3.20 g/cm^3	4 %

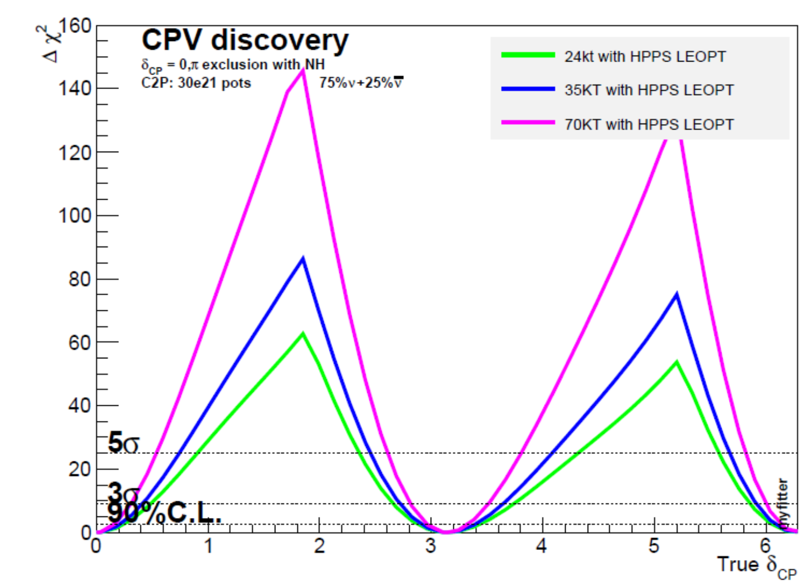
Parameter	Value	Error
Signal normalization (f_{sig})	1	3 %
Beam electron contamination normalization ($f_{\nu e}$)	1	5 %
Tau normalization ($f_{\nu \tau}$)	1	20 %
ν NC and $\nu\mu$ CC background (f_{NC})	1	10 %

LBNO Phase I (24 kt) with Optimized SPS beam: Covers 47 % CPV space at 3σ



Remark: Similar results are obtained with LBNO @ Garpenberg

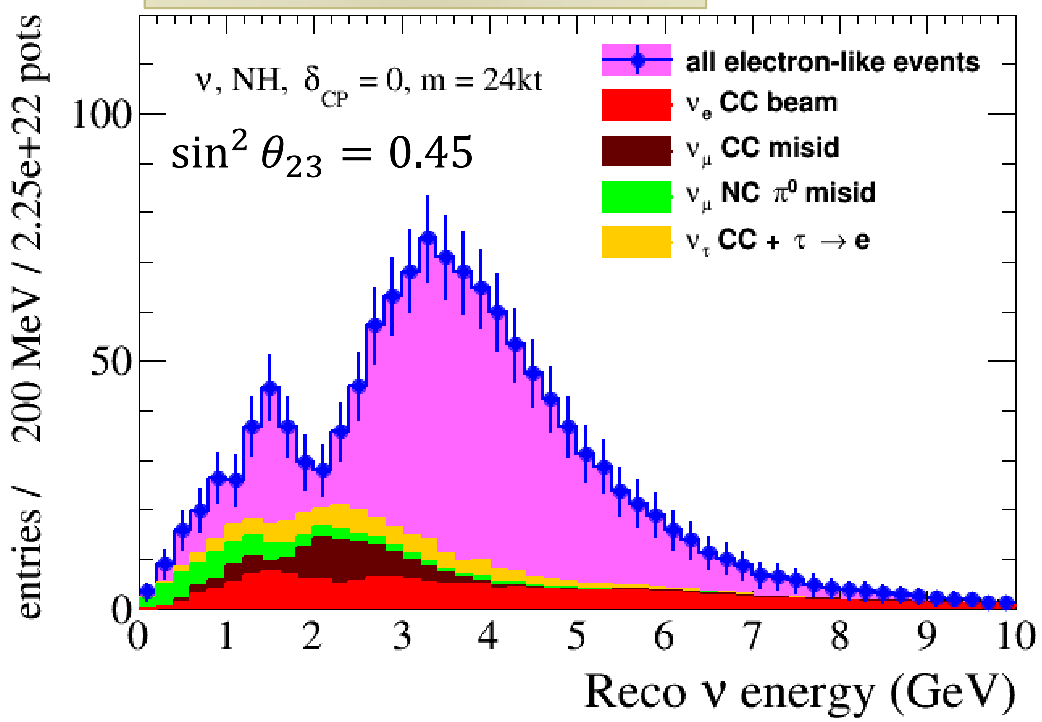
LBNO Phase II (70kt) with Optimized HPPS beam: Covers 80 % CPV space at 3σ



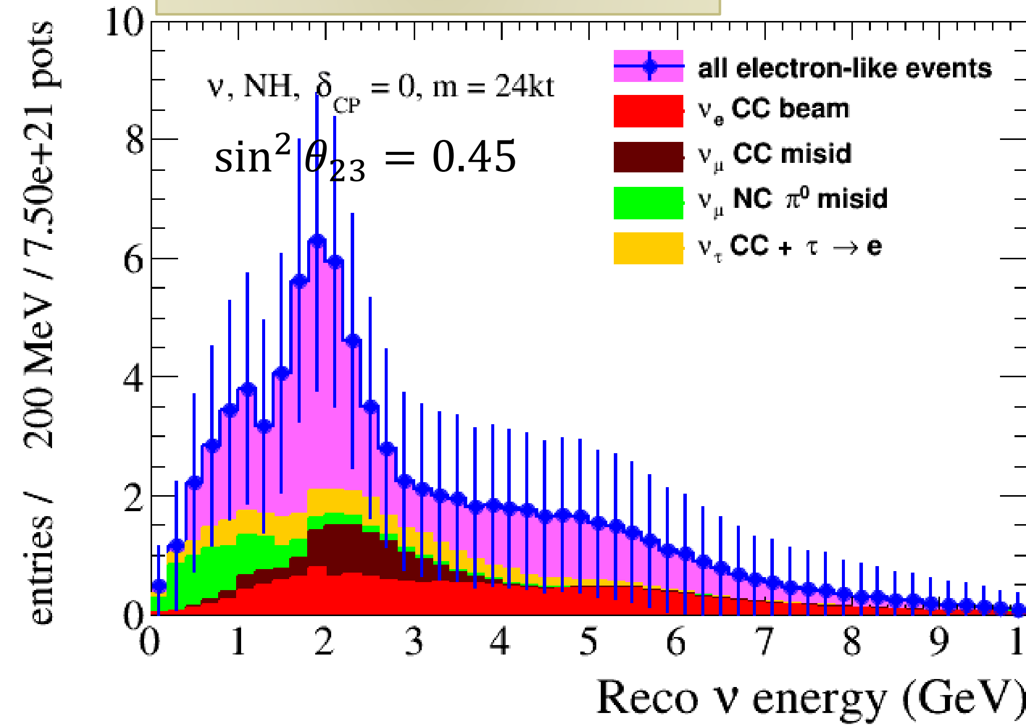
Remark: Alternatively an additional beam from Protvino instead of HPPS

Expected event rates: HPPS ν beam

ν beam, 0.75 x 30E+21 POT



$\bar{\nu}$ beam, 0.25 x 30E+21 POT



Beam	Sig ν_e	Beam ν_e	ν_μ NC	ν_τ CC
HPPS ν nominal	1711	195	109	365
HPPS ν optimized	922	162	58	80

Beam	Sig ν_e	Beam ν_e	ν_μ NC	ν_τ CC
HPPS $\bar{\nu}$ nominal	71	16	15	56
HPPS $\bar{\nu}$ optimized	48	15	7	8

For SPS:

Median coverage

	$F_{3\sigma}$	$F_{5\sigma}$
24 kton	45% → 34%	--
70 kton	63% → 53%	35% → 16%

Although the contribution of signal events below 2.5 GeV appears to be low (~5% of the total), the impact these events have on the sensitivity to CP is not negligible

For HPPS:

Median coverage

	$F_{3\sigma}$	$F_{5\sigma}$
24 kton	69% → 41%	43% → 0%

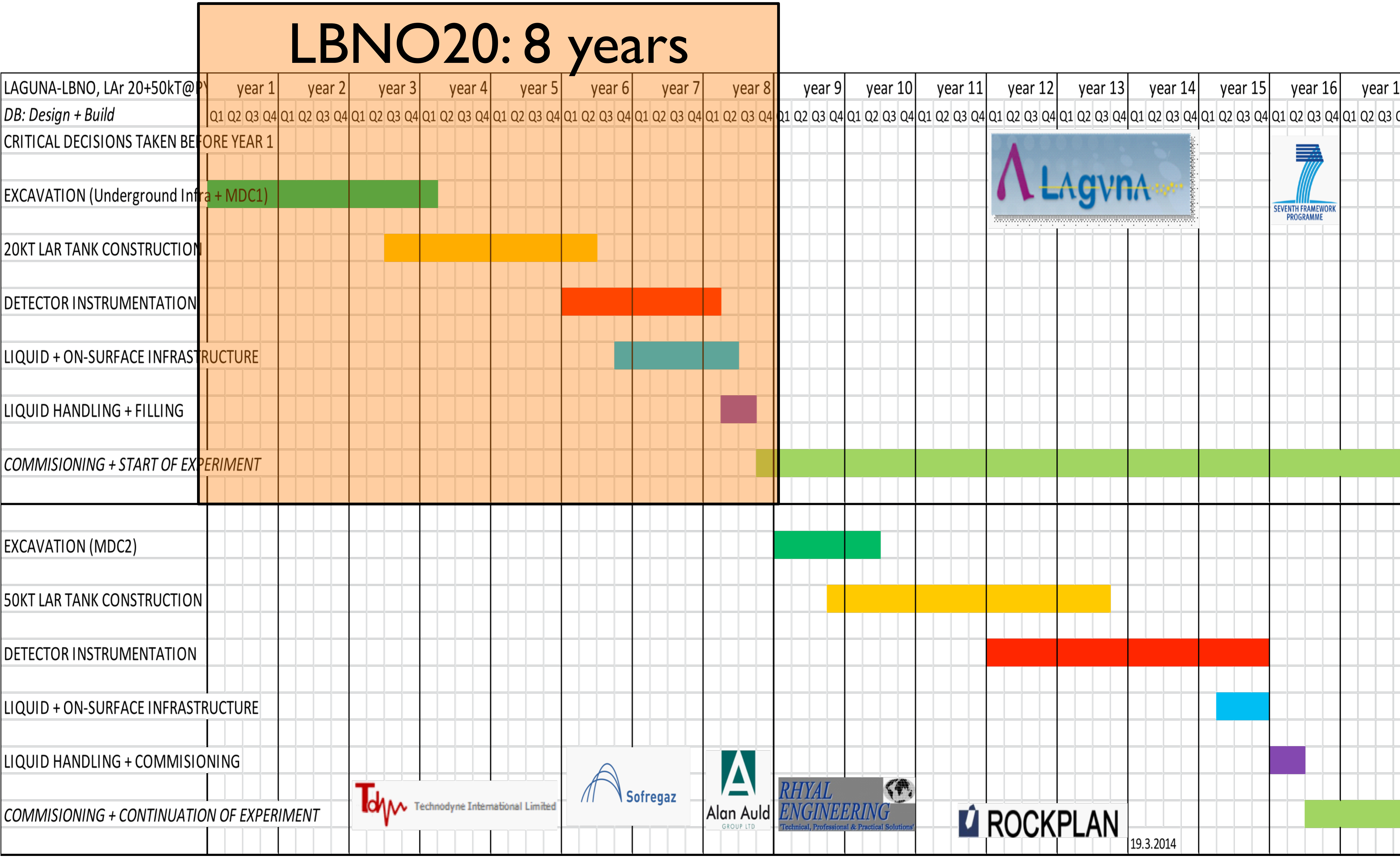
The effect is more dramatic. The cut results in complete loss of sensitivity for CPV discovery

Question #2 for LBNO

Q2. (Experimental Strategy) What is according to you the experimental strategy that needs to be deployed worldwide in order to answer the above questions? And in particular, how many experiments should there be worldwide, what complementarities or double check features should they exhibit? In this world-wide context describe the phases of your project, its timeline and the expected statistical significance per phase. Discuss the relevant systematics, how well you know them and in particular do you need any supporting measurements to further determine them?

- **Timeline**:
  - **August 2014 : LBNO CDR is finished and ready**
  - **2015-2018: LBNO-DEMO (WA105) demonstrator**
  - 2020 : Underground Pilot Project (5kton-scale) astrophysics and proton decay
  - 202X : LBNO20 Phase I commissioning (24kton)
  - 203X : LBNO70 Phase II commissioning (70kton)

Technical timescale for construction LAGUNA-LBNO 20+50kT



Question #3 for LBNO

Q3. (Experimental readiness) Evaluate the readiness of the technology you are planning to use. Describe the phases (or R&D) towards its final validation. What are the risks associated. Is there place for global sharing and coordination of the R&D or validation effort? Are there industrial issues e.g. in procurement?

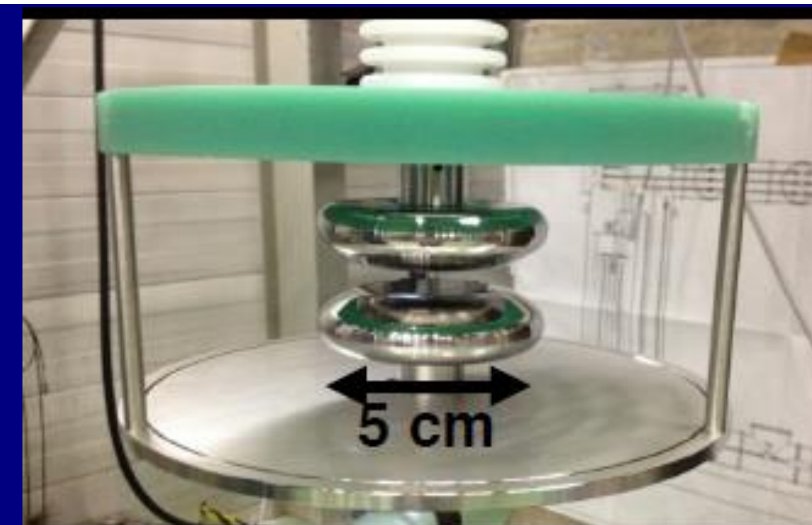
- **Full conceptual design available for 20/50 kton, developed in collaboration with industrial partners leading to: Underground facility, construction sequence, well defined costs,…**
- Risks have been carefully evaluated and available in a Deliverable
- CERN WA105 foresees the construction and operation of a detector of similar size of ICARUS T300. Compare costs. WA105 is an open effort dedicated to the development of cost-effective and affordable underground liquid argon detector scalable up to 50-100 kton scale. Interest from FNAL/LBNE.
- Double phase LAr TPC with adjustable gain provides improved performance, in particular for low energy events such as Supernova neutrinos, etc.

A decade of tests in laboratories

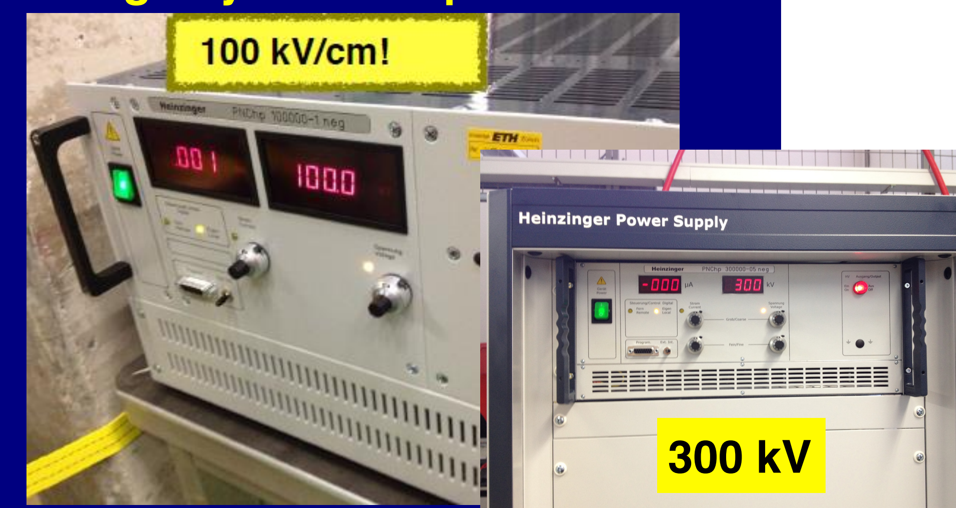
Parallel ongoing technical R&D activities:

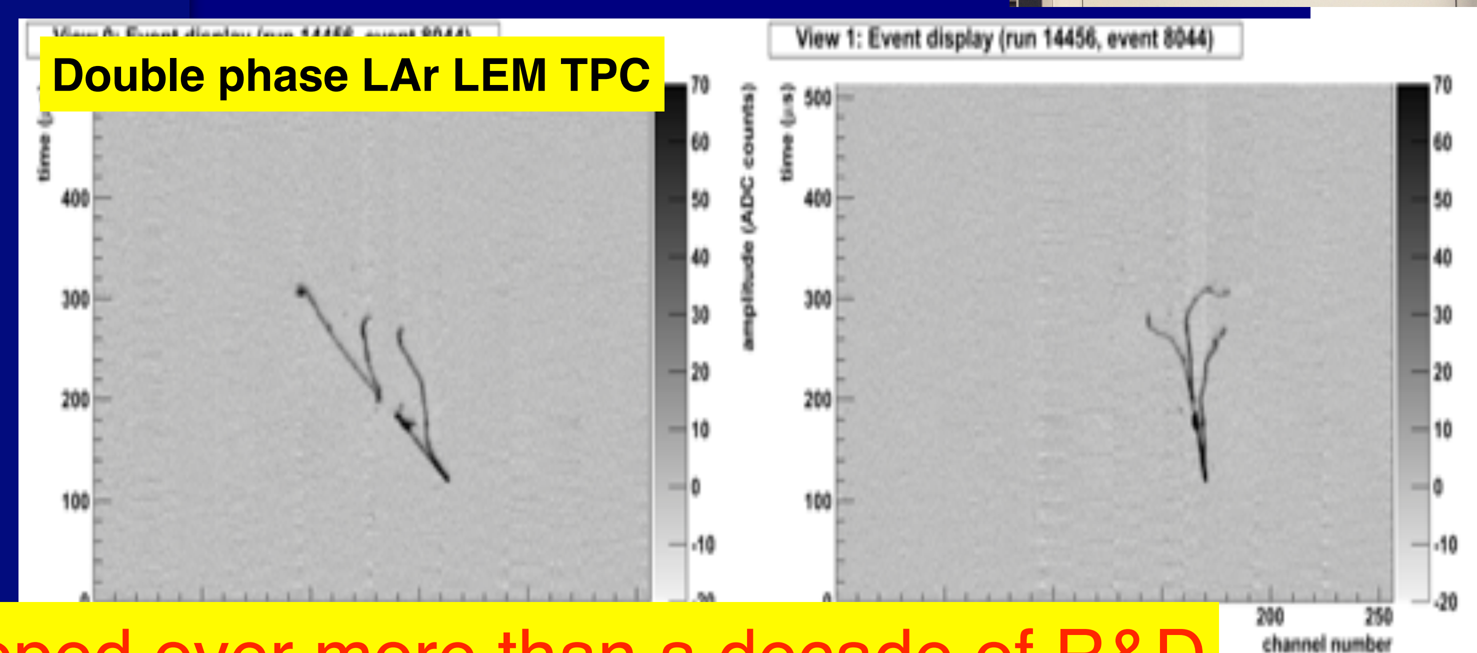
76x40 cm

10x10x20 cm
LEM-anode fast test setup



LAr rigidity test setup





Extensive expertise developed over more than a decade of R&D

LAGUNA-LBNO Design Content

- **FULLY COVERED CONCEPTUAL DESIGN STUDY, INCLUDING:**
  - GENERAL DESIGN
    - COMPLETE AND COHERENT LAYOUT DESIGN OF THE UNDERGROUND
    - DESIGN OF ON-SURFACE INFRASTRUCTURE
    - LOGISTIC DESIGN + EQUIPMENT OF THE DIFFERENT CONSTRUCTION STAGES
    - IMPLEMENTATION INTO CURRECT INFRASTRUCTURE (MINE / ROAD)
    - SAFETY (H&S) DESIGN FOR REALISATION AND OPERATION
  - DESIGN OF INFRASTRUCTURE
    - ROCK ENGINEERING AND EXCAVATION
    - CIVIL WORKS (HVAC + AUXILIARY CONSTRUCTIONS)
  - DESIGN OF EXPERIMENT
    - TANK CONSTRUCTION DESIGN + SCAFFOLDING
    - DETECTOR DESIGN AND INSTRUMENTATION
    - ELECTRONICS
    - LIQUID INFRASTRUCTURE, HANDLING + COMMISSIONING
  - CONSTRUCTION PROGRAMMES OF ALL STAGES
  - RISK ASSESSMENTS + PROJECT RISK REGISTRY + CONTINGENCY
  - CONSTRUCTION + OPERATIONAL COSTINGS

Conceptual Design Report (CDR)





1400 man x months

IN TOTAL 3000 PAGES: Release August 2014

Industrial partners

Industrial partners

France

Sofregaz

UK

Alan Auld

GROUP LTD

Underground excavation
Underground civil engineering
Cryogenic liquid storage
Large-scale mechanical structures
Large-scale industrial liquid process
Electronic industry
Computing, network, telecommunication industry
Risk assessment and analysis methodology
Project Management

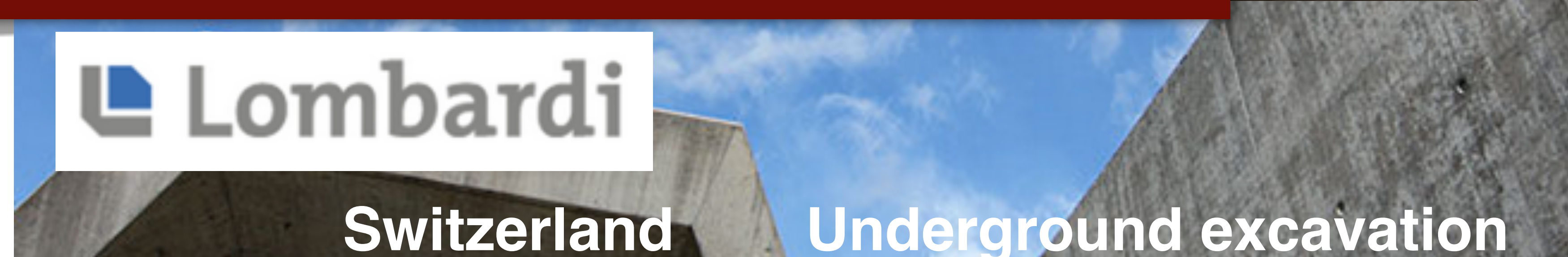
20 m drift

UK

L ENGINEERING

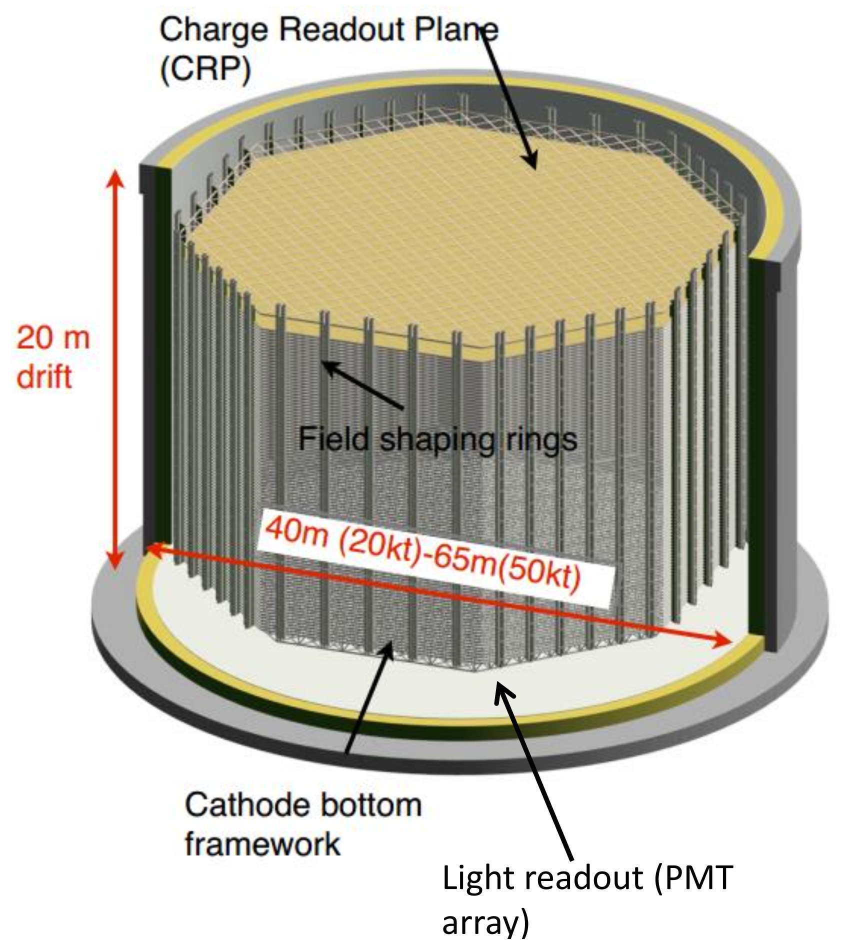
Greece

ΔΗΜΟΚΡΙΤΟΣ



Underground LAr Detector design

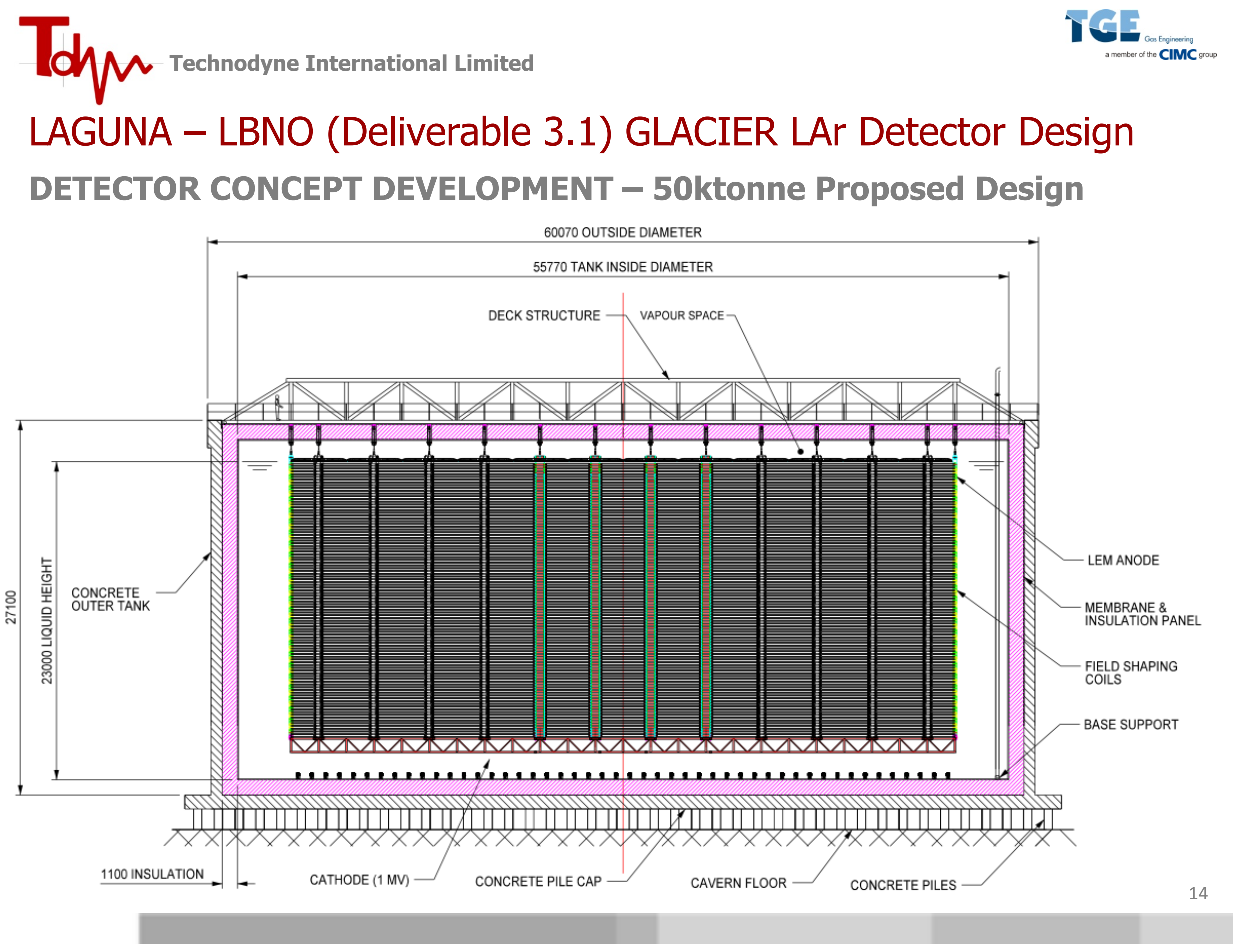
- Baseline design established
- Optimised (design, assembly) for underground location
- Developed with industrial support
- **Detailed costing model**

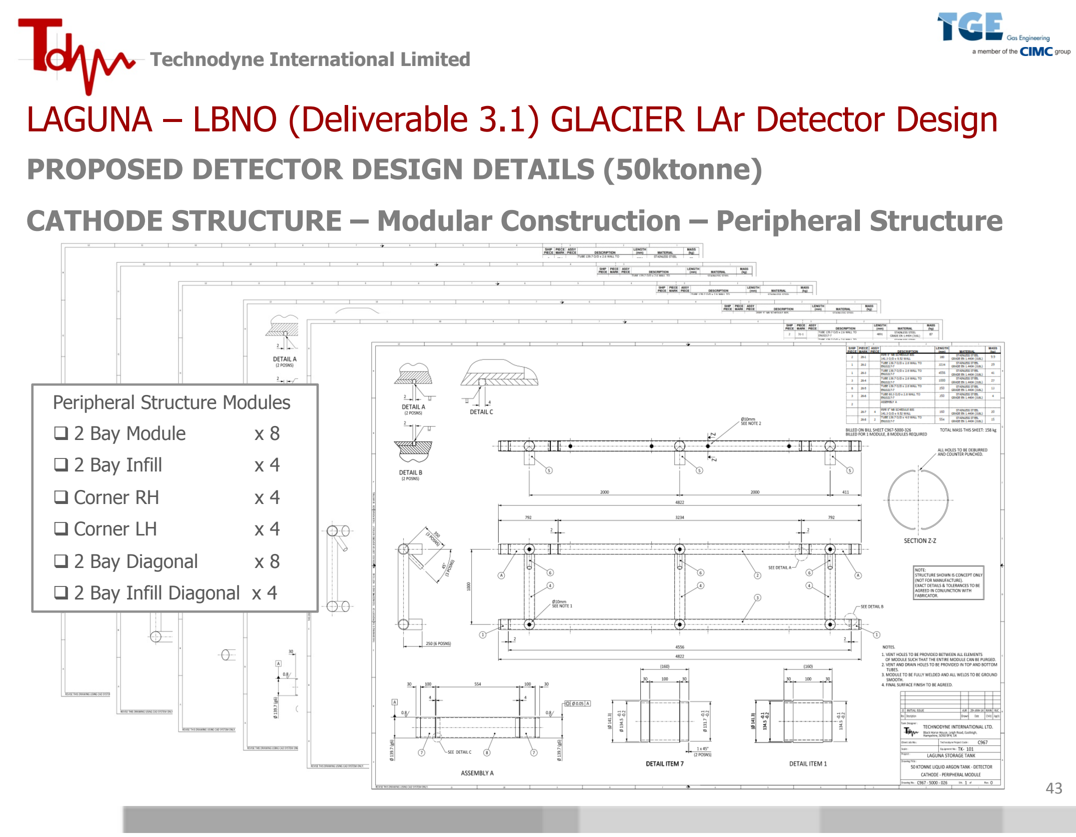


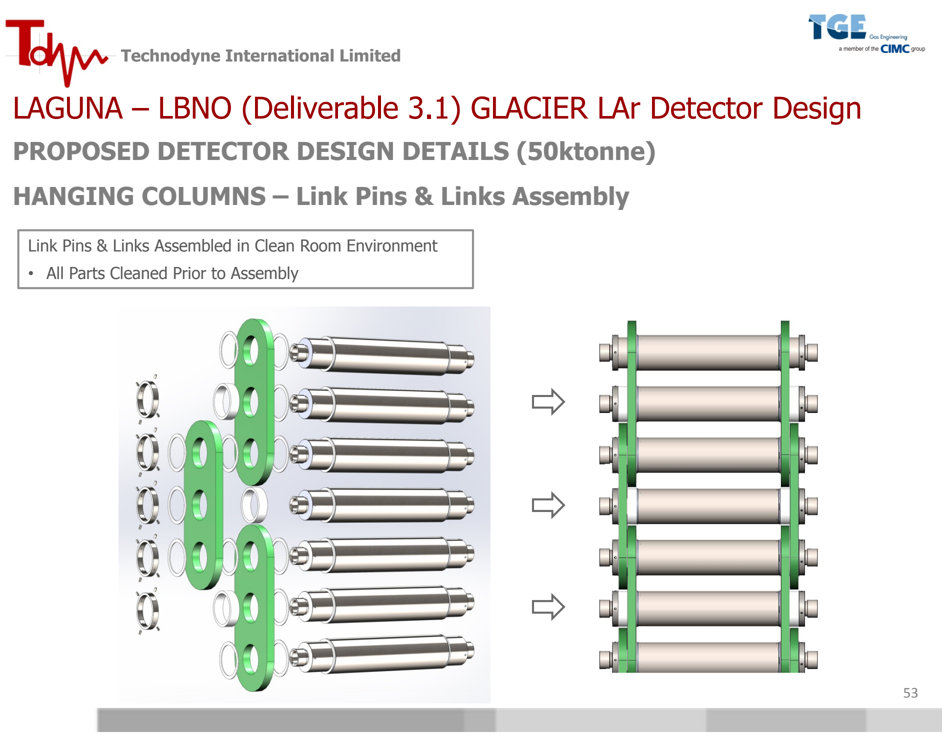
LBNO20+50

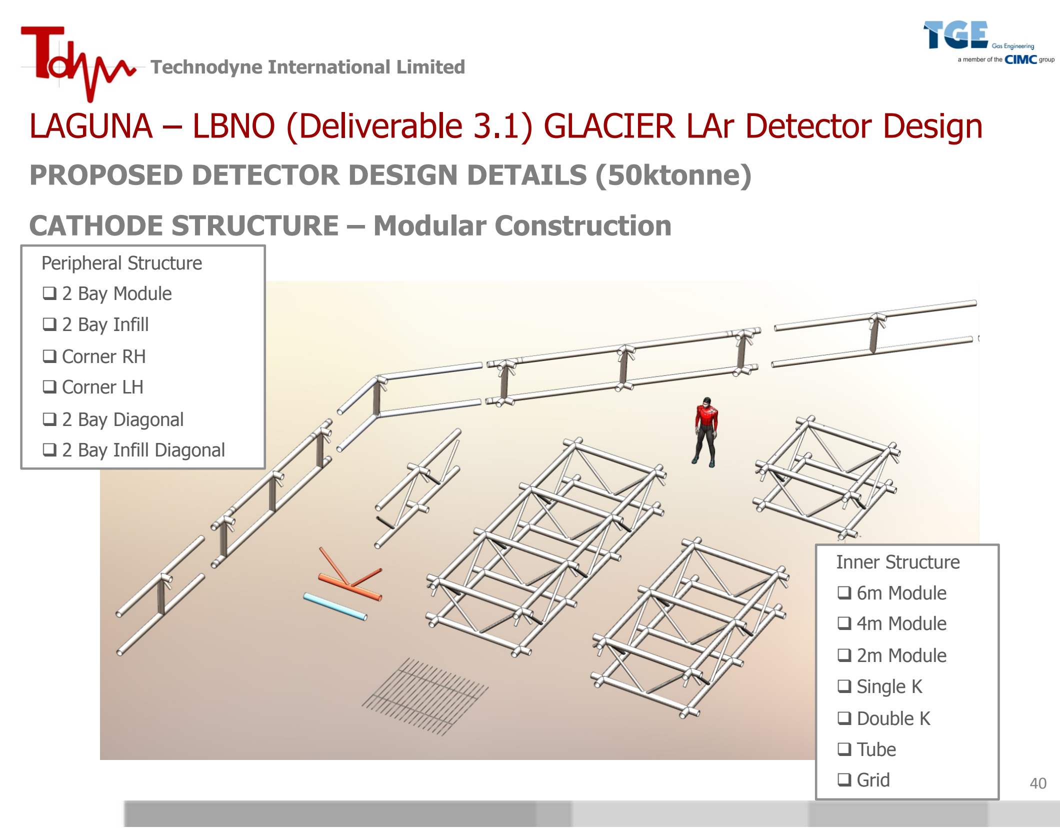
	20kT	50kT
Full LAr height [m]	22	
Instrumented LAr height [m]	20	
Vessel diameter [m]	37	55
Vessel base surface[m^2]	1'075.2	2'375.8
Instrumented LAr area [m^2] (percentage)	824 (76.6%)	1'845 (78%)
Liquid argon volume[m^3]	23'654.6	52'268.2
Instrumented LAr mass [kT]	22.799	51.299
Square charge readout panels (4m×4m)	40	104
Pentagon charge readout panels	12	0
Triangular charge readout panels	8	16
Number of signal feed-throughs (640 ch/FT)	416	896
Number of PMTs (1m × 1m)	~800	~1'850
Number of field shaping rings	100	
Vertical spacing (heart to heart distance)of field shaping rings [mm]	200	

Fully engineered conceptual designs







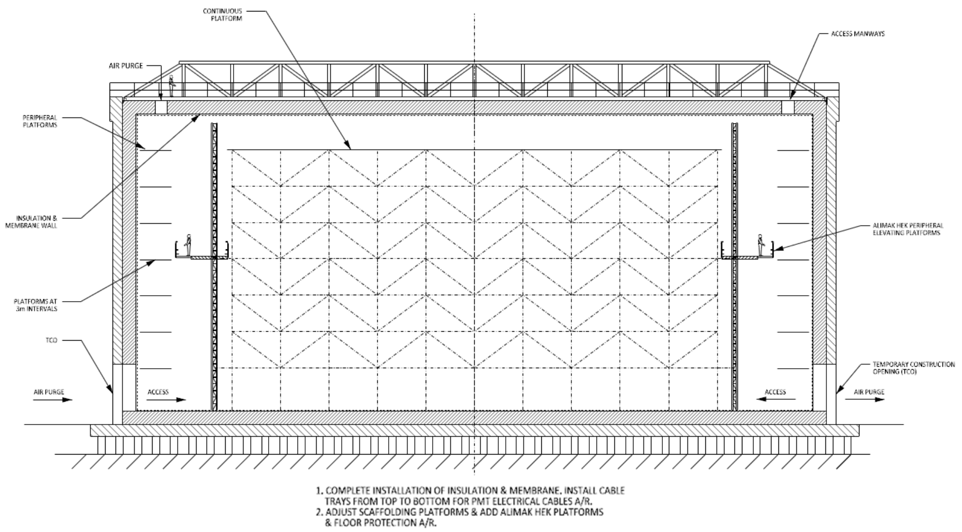


Underground construction sequence

Technodyne International Limited

LAGUNA – LBNO (Deliverable 3.1) GLACIER LAr Detector Design

DETECTOR CONSTRUCTION



Tank membrane complete, internal pipework in place and the cable trays are fitted.

The existing scaffolding will be reworked if necessary to allow the addition of moving access platforms

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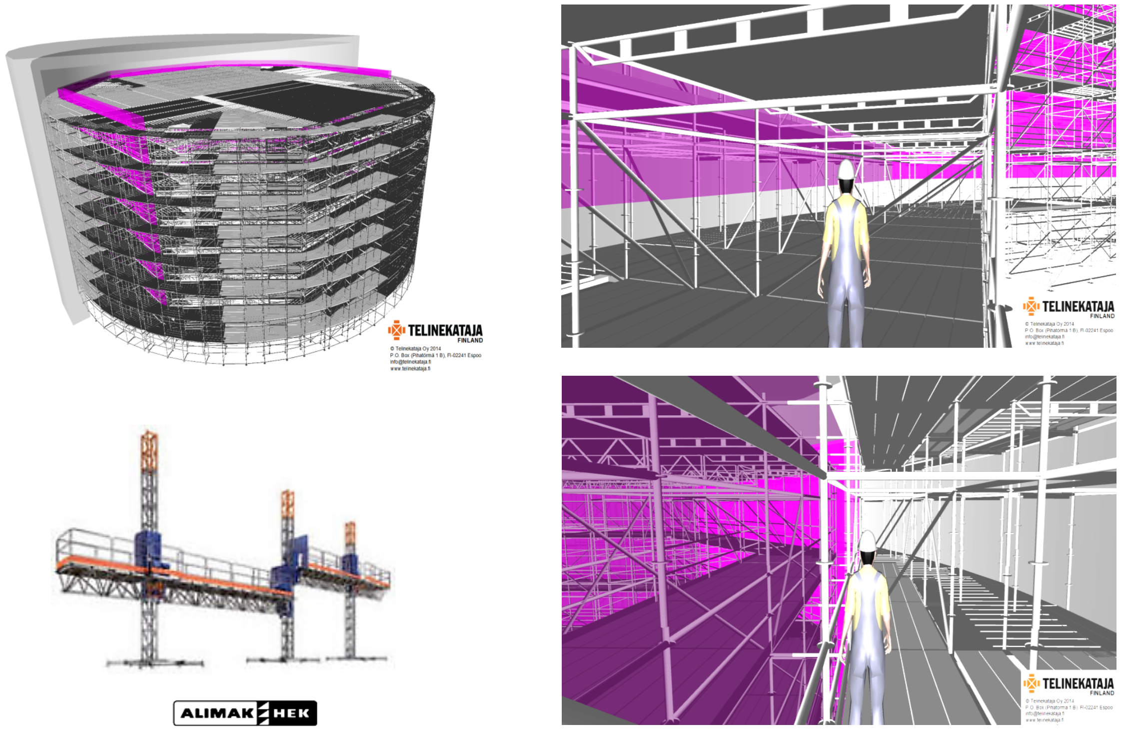
Technodyne International Limited

LAGUNA – LBNO (Deliverable 3.1) GLACIER LAr Detector Design



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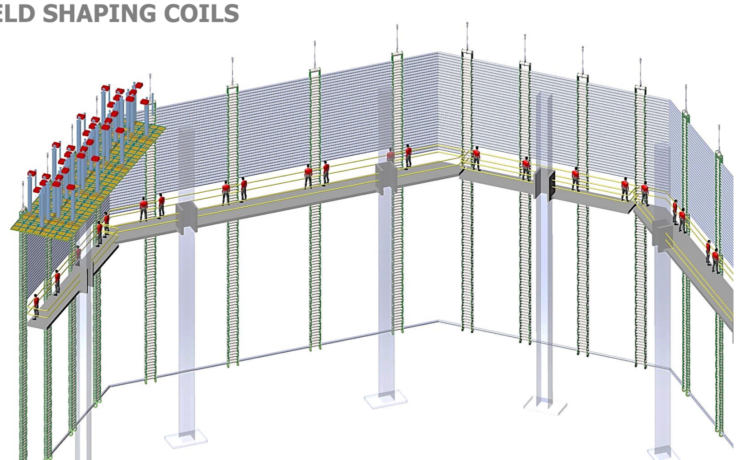
Technodyne International Limited

LAGUNA – LBNO (Deliverable 3.1) GLACIER LAr Detector Design

FIELD SHAPING COILS



Field Shaping Coils will be installed from the top down.
The Alimak platforms can be fitted with assembly aids as necessary to create safe and convenient work stations.
Alimaks will be used to raise materials to the working level.

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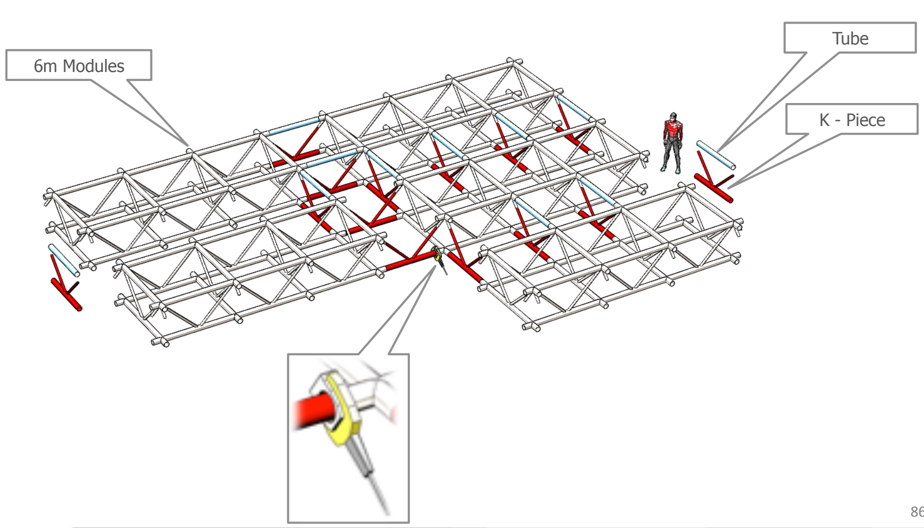
Technodyne International Limited

LAGUNA – LBNO (Deliverable 3.1) GLACIER LAr Detector Design

CATHODE CONSTRUCTION



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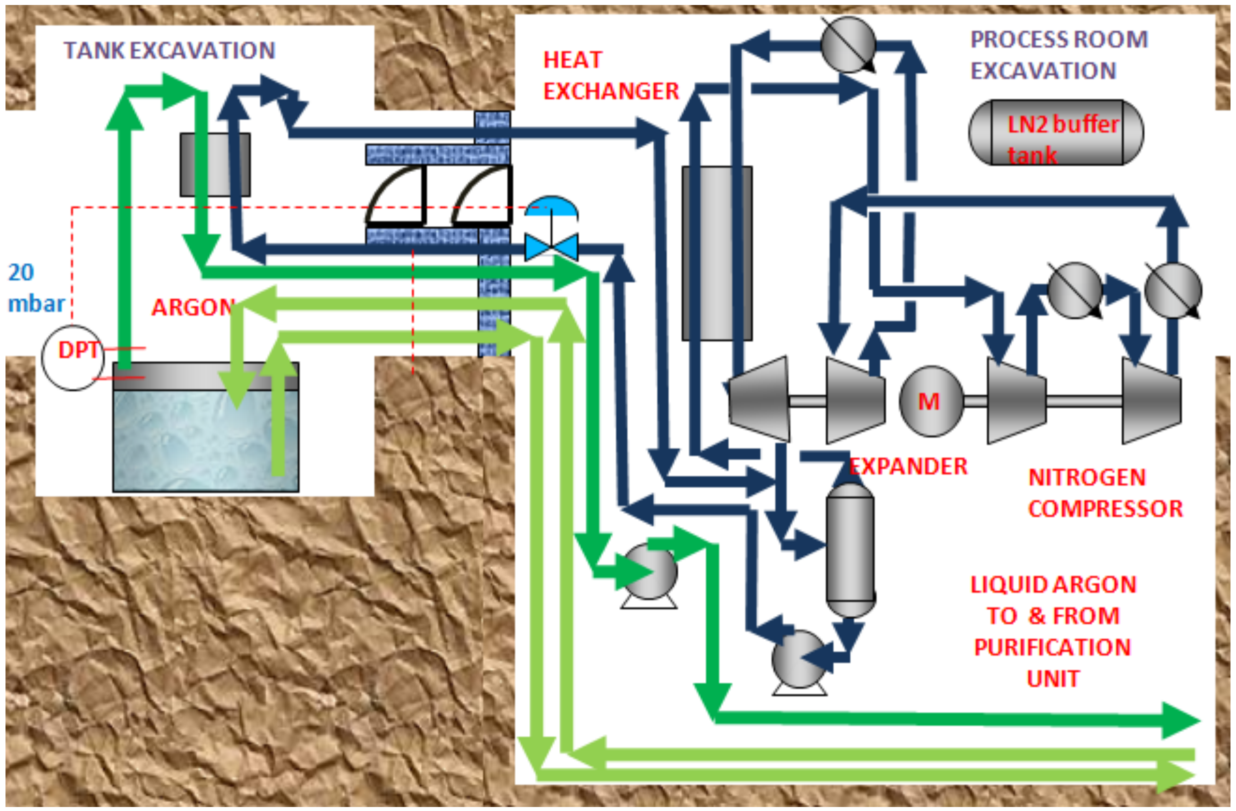
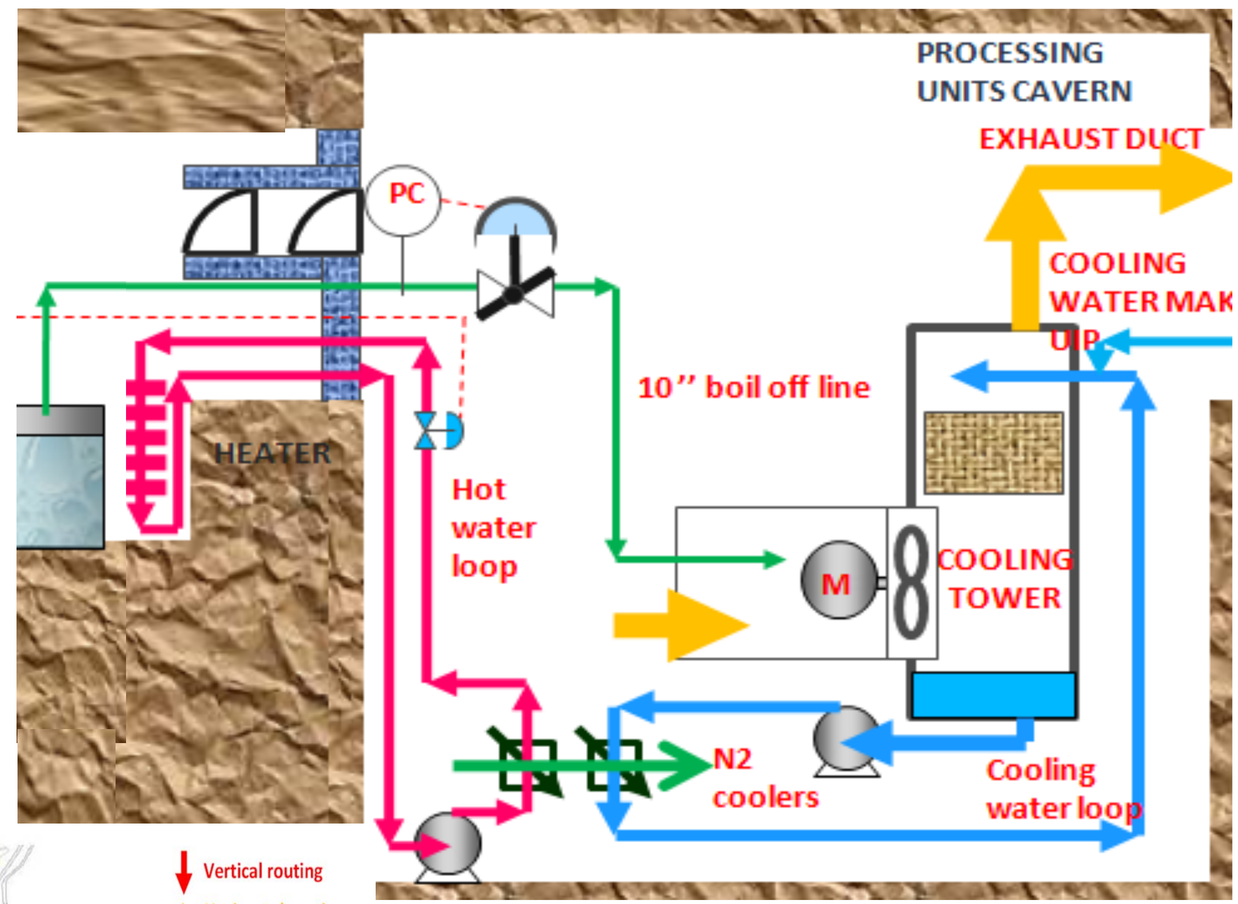
Fully engineered process designs

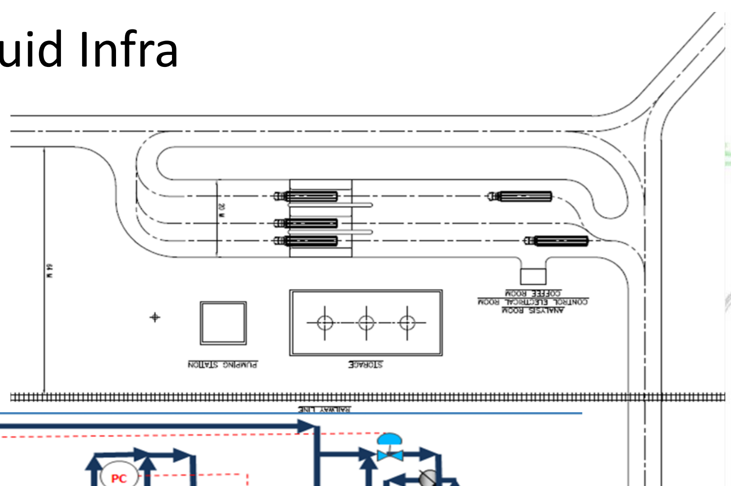


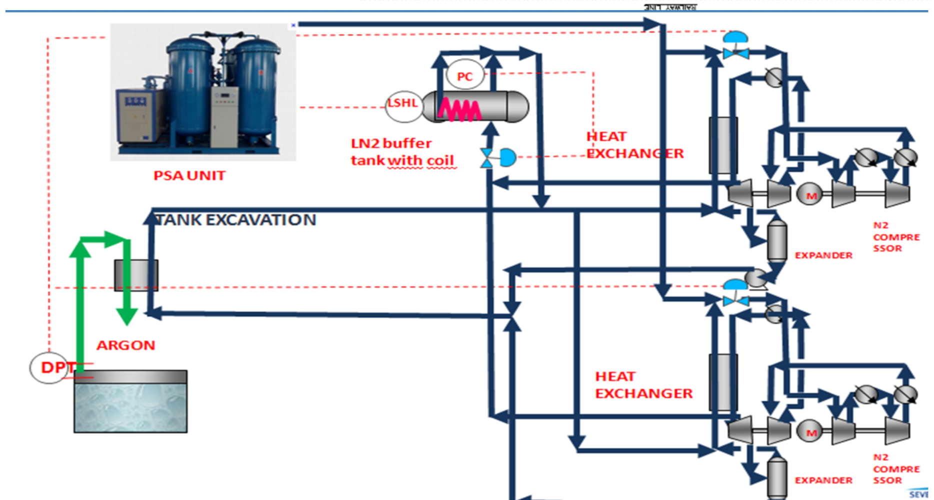


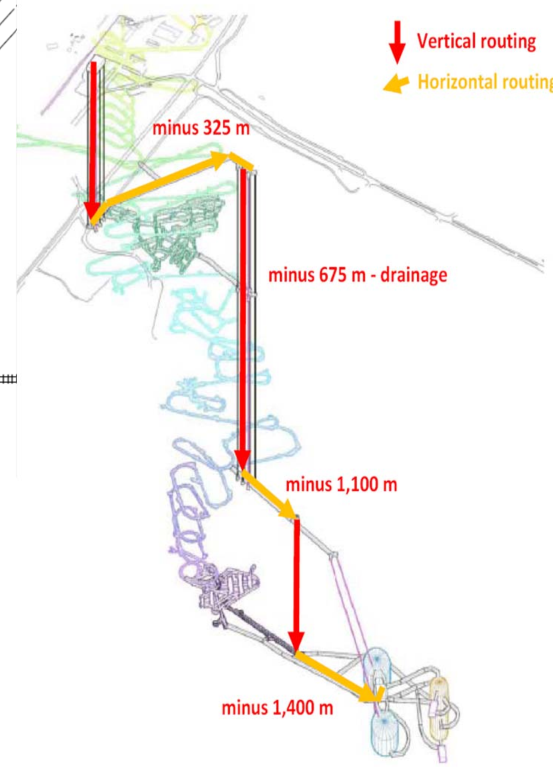
On-surface Liquid Infra

Underground

Liquid Infra





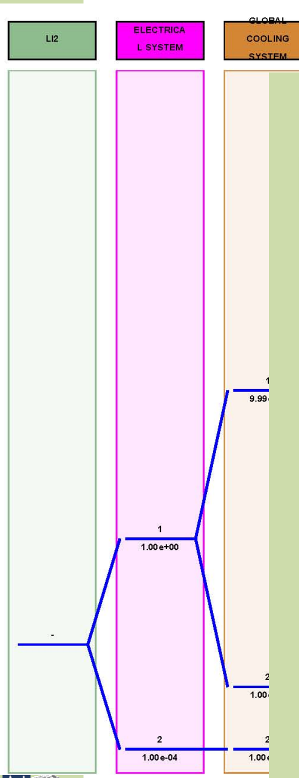


Vertical Intra (LAr pipeline)

Guido Nuijten 11.2.2014

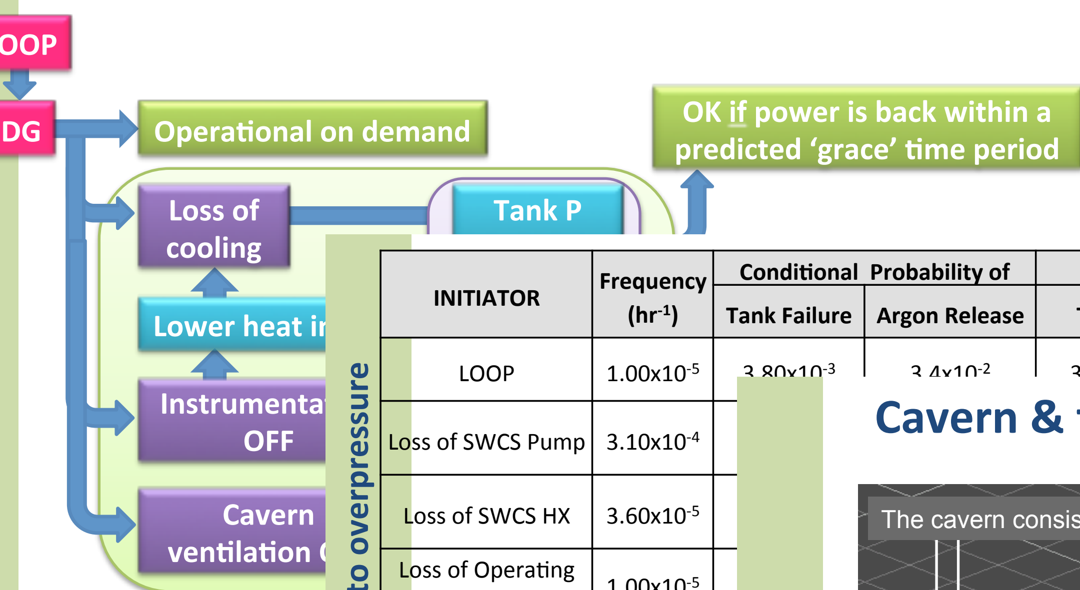
Detailed risk analyses

Reduced Event Tree for Loss of Insulation



NCSR

Ex1: Loss of: Offsite Power + Diesel Generator



Loss of offsite Power (LOO
Mission Duration (grace p
Failure to recover Offsite P
Emergency Diesel Generat
Emergency Diesel Generat
Given that Emergency DG s

Frequencies for LOC owning to overpressure

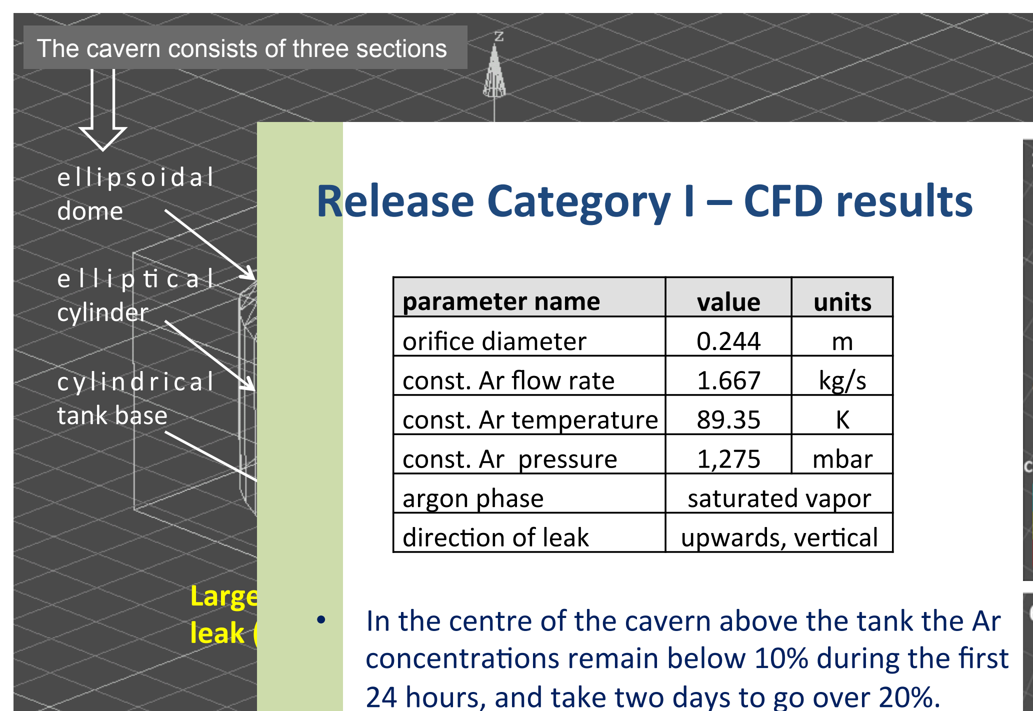
INITIATOR	Frequency (hr^{-1})	Conditional Probability of Tank Failure	Conditional Probability of Argon Release	Frequency of TF (hr^{-1})	Frequency of ArR (hr^{-1})	Contribution of each initiator	
LOOP	1.00×10^{-5}	3.80×10^{-3}	3.4×10^{-2}	3.80×10^{-8}	3.4×10^{-7}	0.013%	0.524%
Loss of SWCS Pump	3.10×10^{-4}						
Loss of SWCS HX	3.60×10^{-5}						
Loss of Operating Pressurizer Train	1.00×10^{-5}						
Loss of Cavern Heating System	3.10×10^{-4}						
Loss of Ar Pump	3.10×10^{-4}						
Loss of Operating N_2 train	5.00×10^{-5}						
Loss of Insulation type LI1	9.12×10^{-7}						
Loss of Insulation type LI2	1.14×10^{-7}						
Loss of Insulation type LI3	7.98×10^{-8}						
Loss of Insulation type LI4	3.42×10^{-8}						
TOTAL							

NCSR DEMOKRITOS –

D3.3 – Final Report
Safety Analysis and Quantitative Risk Assessment of the GLACIER Tank and Underground Processes at Pyhäsalmi

Effie Marcoulaki, Ioannis Papazoglou, Alexandros Venetsanos
nstitute of Nuclear & Radiological Sciences & Technology, Energy & Safety
'or Scientific Research DEMOKRITOS
Greece

Cavern & tank geometry used in CFD simulations



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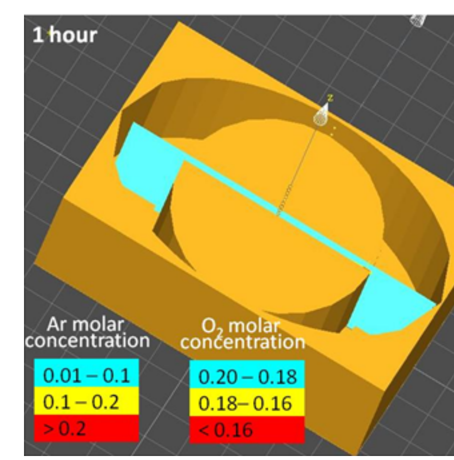
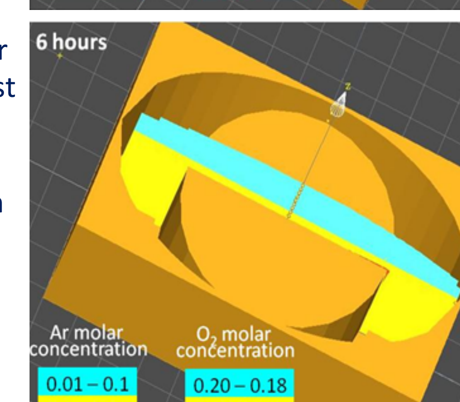
NCSR DEMOKRIT

Release Category I – CFD results

parameter name	value	units
orifice diameter	0.244	m
const. Ar flow rate	1.667	kg/s
const. Ar temperature	89.35	K
const. Ar pressure	1,275	mbar
argon phase	saturated vapor	
direction of leak	upwards, vertical	

- In the centre of the cavern above the tank the Ar concentrations remain below 10% during the first 24 hours, and take two days to go over 20%.
- Near the cavern walls around the tank the concentrations are significantly higher and reach 10% Ar within 5 hours, and 20% within 8 to 10 hours.
- **The CFD predicts O2 concentrations to remain over 18% for a day above the tank and for 5 hours at lower heights.**



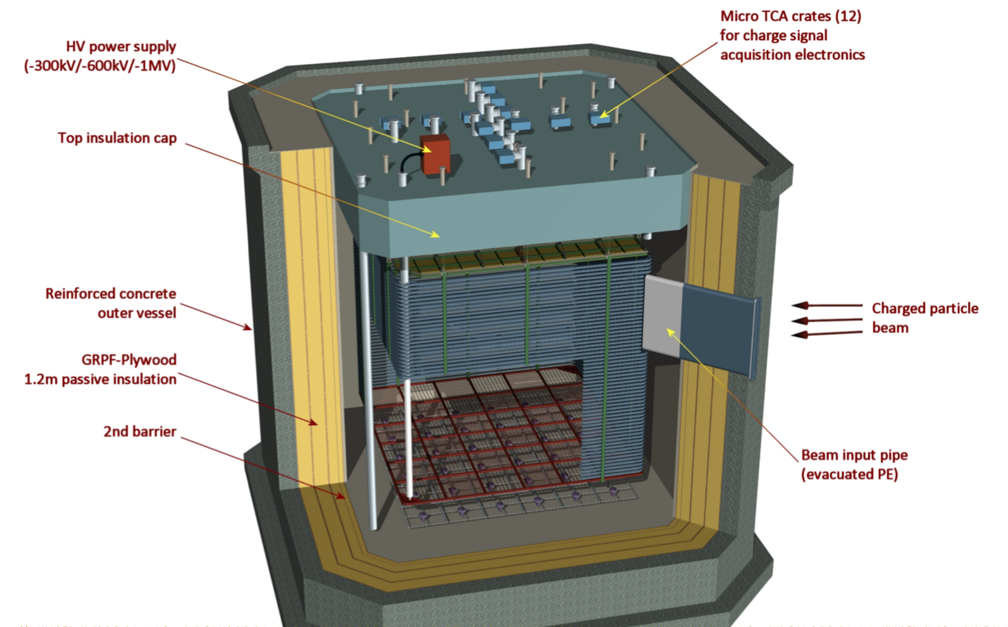


LAGUNA-LBNO and CERN

- In June 2012, we had put forward an "Expression of Interest" to CERN
- Positive feedback from CERN SPSC in January 2013
- 108th SPSC recommendations on new neutrino projects at CERN :
  - The SPSC **supports** the physics cases of both projects and **recognizes** their timely relevance in the rapidly evolving neutrino physics landscape.
  - The SPSC **supports** the focus of the European neutrino community on the LAr TPC technology, for which it has a unique expertise worldwide from the operation of the largest underground LAr detector
  - Concerning LAGUNA-LBNO, the SPSC **supports** the double-phase LAr TPC option as a promising technique to instrument with the very large LAr neutrino detectors in the future. The SPSC therefore **encourages** the LBNO consortium to proceed R&D necessary to validate the technology on a large scale.
- In April 2014, we submitted the TDR for the 6x6x6 m^3 Demonstrator for DLAr in the North Area
- Activity embedded in CERN Neutrino R&D platform

LBNO-DEMO (WA 105)

LBNO-DEMO:Technical demonstrator: Active vol.: 6 x 6 x 6 m³ (0.3 kt)



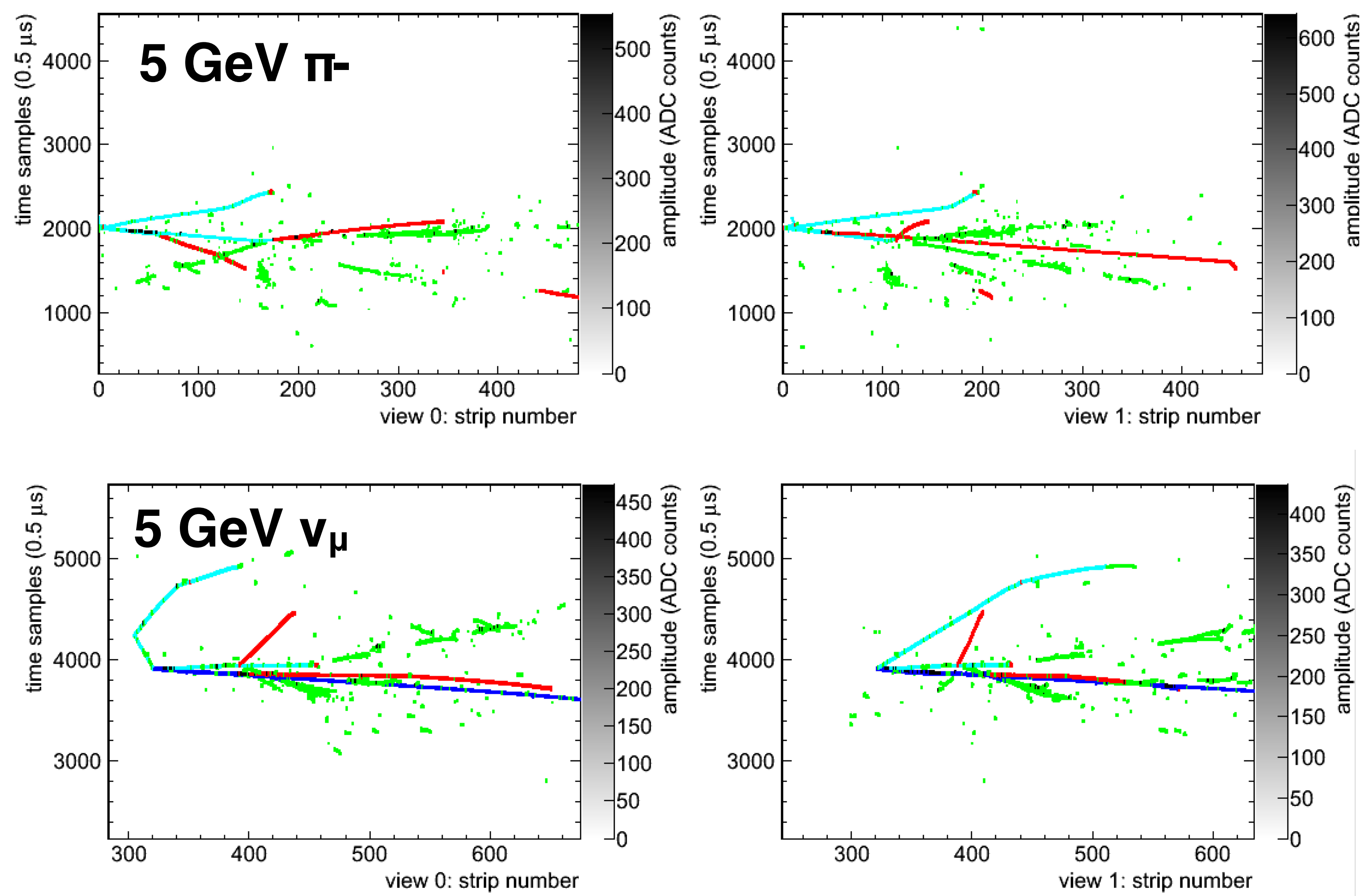
Approved by CERN last year. Asked for a detailed Technical design report

CERN WA105 R&D programme (SPSC-TDR-004-2014).

Some goals

- Development of automatic event **reconstruction**
- **test NC background rejection** algorithms on "ν_e free" events
- Charged **pions** and proton **cross-section** on Argon nuclei. Rate of pion production is important!
- What is the achievable **energy resolution?**
- **Development** and proof-check of industrial solutions

pions, electrons/positrons, protons, muons



Question #4 for LBNO

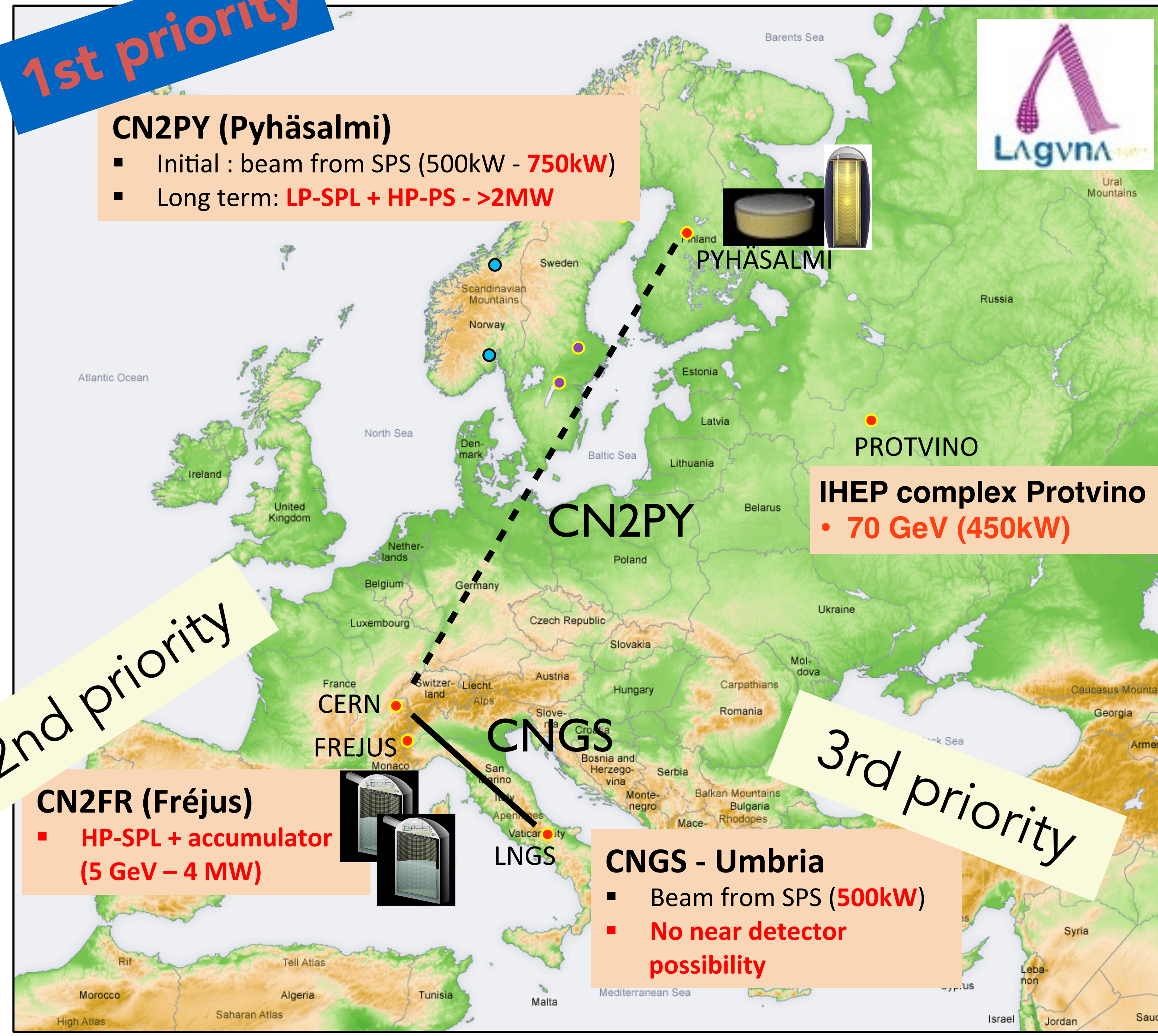
Q4. (Site issues) What are the optimisation criteria for the site you propose? What is the regional support for the site you propose? Is your proposal site specific? Could the same or better performances be obtained in another site in the same continent or some other region?

- **Down-selection of site was done after several years of fully developed studies for 7 sites in Europe: CRITERIA FOR SELECTION: (1) physics – depth + baseline (2) technical feasibility (3) cost of infrastructure (4) maintenance costs**
- **Baseline of 2300 km is optimal for LBNO and for NF (as recommended by the recent ICFA panel report)**
- LBNO20 (Phase I) with SPS provides MH (p≈100%) at 5σ C.L. and 47% coverage for CPV.
- LBNO70 (Phase II) with HP-PS or Protvino beam provides the best sensitivity to CPV (better than HK) : 80% CPV coverage
- CERN-Pyhäsalmi is a fully studied option with 2300km baseline which has been proven feasible and precisely costed (during 6 years of DS).

LAGUNA-LBNO: baseline scrutiny

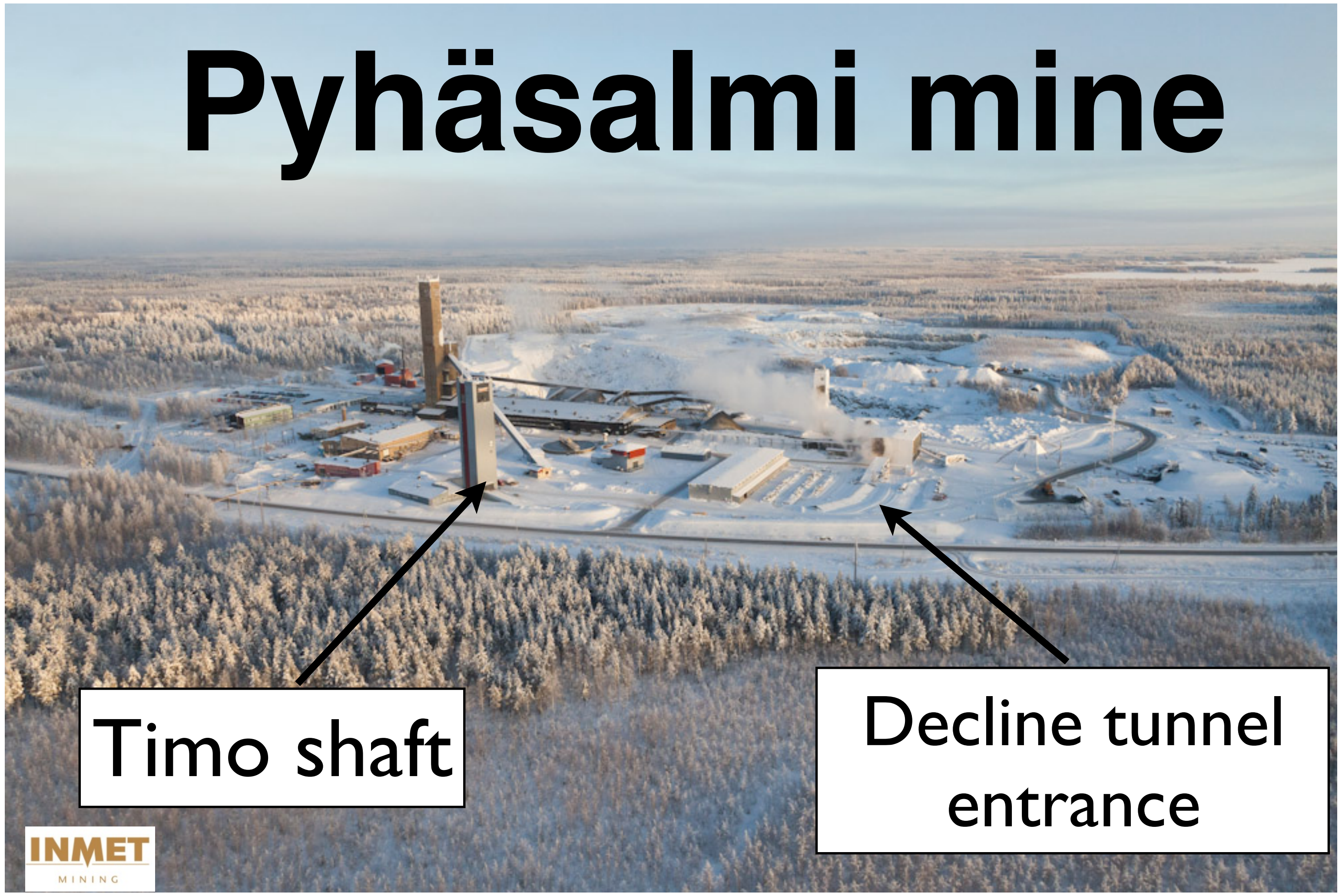
arXiv:1003.1921 [hep-ph]

- **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:**
  - Conventional neutrino beam to Finland (CN2PY) = 2300 km
  - Upgrades of CERN SPS to 700kW
  - HP-PS (2MW@50 GeV)
  - Protvino, Russia (OMEGA project) = 1160 km



- **SITE OPTIMISATION:** A 2300 km baseline is optimal to meet the P5 requirement on CPV and is the only proposal that guarantees 5σ on MH with a systematic free method (change of horn polarity). 2300km is optimal for the long term goal of NF, as recommended by ICFA panel. Pyhälsami offers an unique infrastructure, in excellent state and low running costs.

Pyhäsalmi mine (PMO)

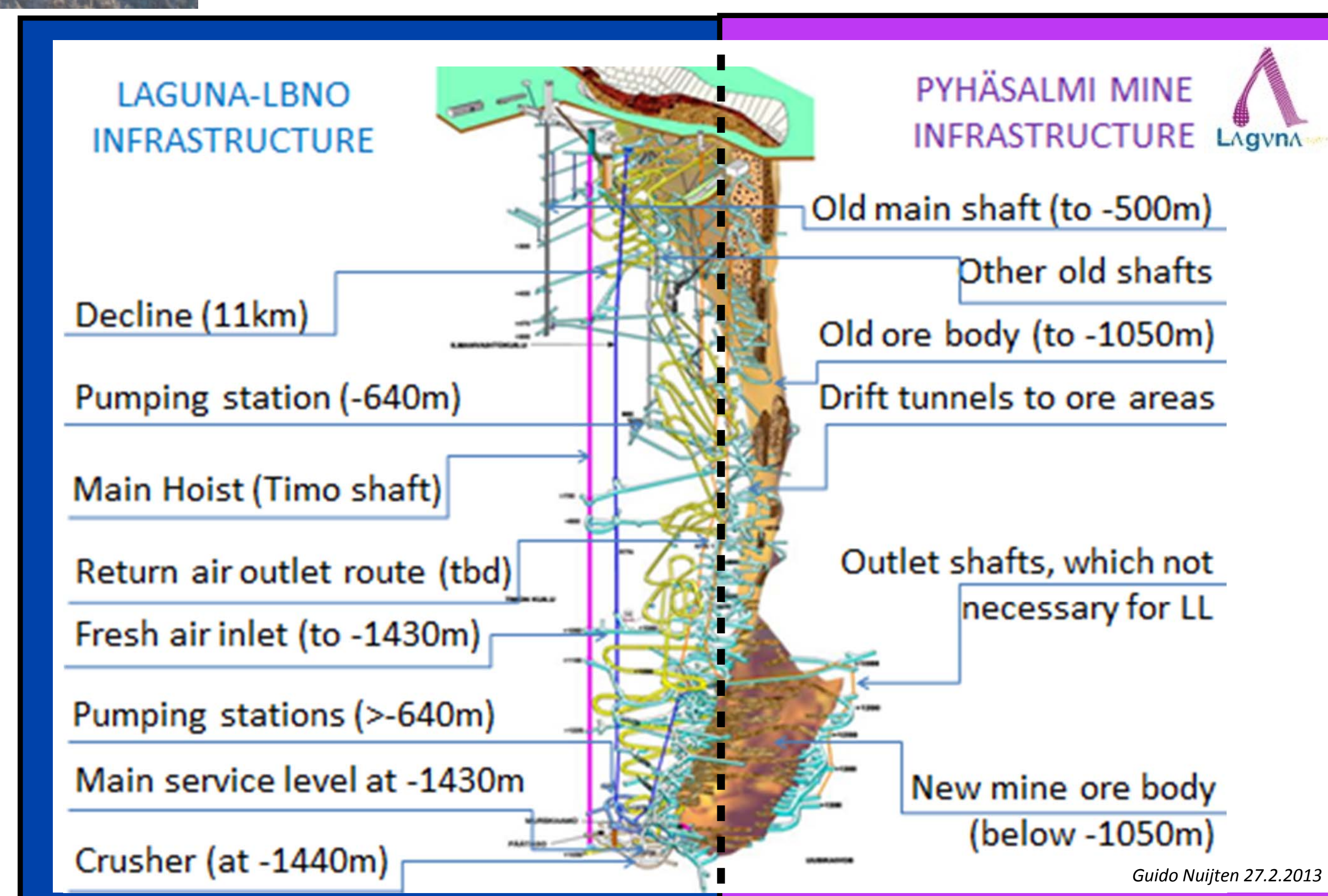


- Inmet Mining Corporation acquired by First Quantum Minerals Ltd (March 2013)
- Underground mining activities lifetime estimated until 2019.
- Tight collaboration between Pyhäsalmi and LAGUNA

WG for reuse of infrastructure:

- Established in March 2014
- Presentatives from
  - Councils of Oulu Region and Central Finland (regional EU funding)
  - the labour unions
  - Confederation of Finnish Industries
  - Centre for Development, Traffic and the Environment (regional research funding for technology)
  - Jyväskylä and Oulu Universities
  - Geological Survey of Finland
  - Energy companies (hydropower plans)
  - Pyhäsalmi Mine
  - Regional development organization NIHAK (local industry and muncipalities)
  - City of Pyhäjärvi

An unique opportunity



Pyhäsalmi site investigation (2013-2014)

- **Extensive field work:**
  - Rock sampling and drilling (about 2000m of drilling !)
  - Core logging
  - Laboratory tests
  - Rock mechanical modelling
  - In-situ stress measurement
- **Laboratory tests:**
  - Samples for the first rock test batch have been selected and analysed
- **Geomechanical modelling:**
  - All the gathered logging-, survey-, and lab test-data is combined into database
  - Geological models are created for example of rock types, foliation, weakness zone,…
  - Accurate geological model is the basis for the rock mechanical calculations

Regional + mine funding

Industrial consortium:

ROCKPLAN

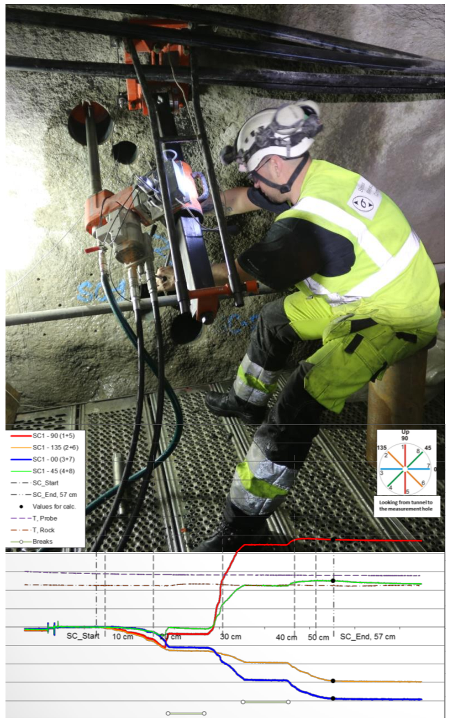
WSP

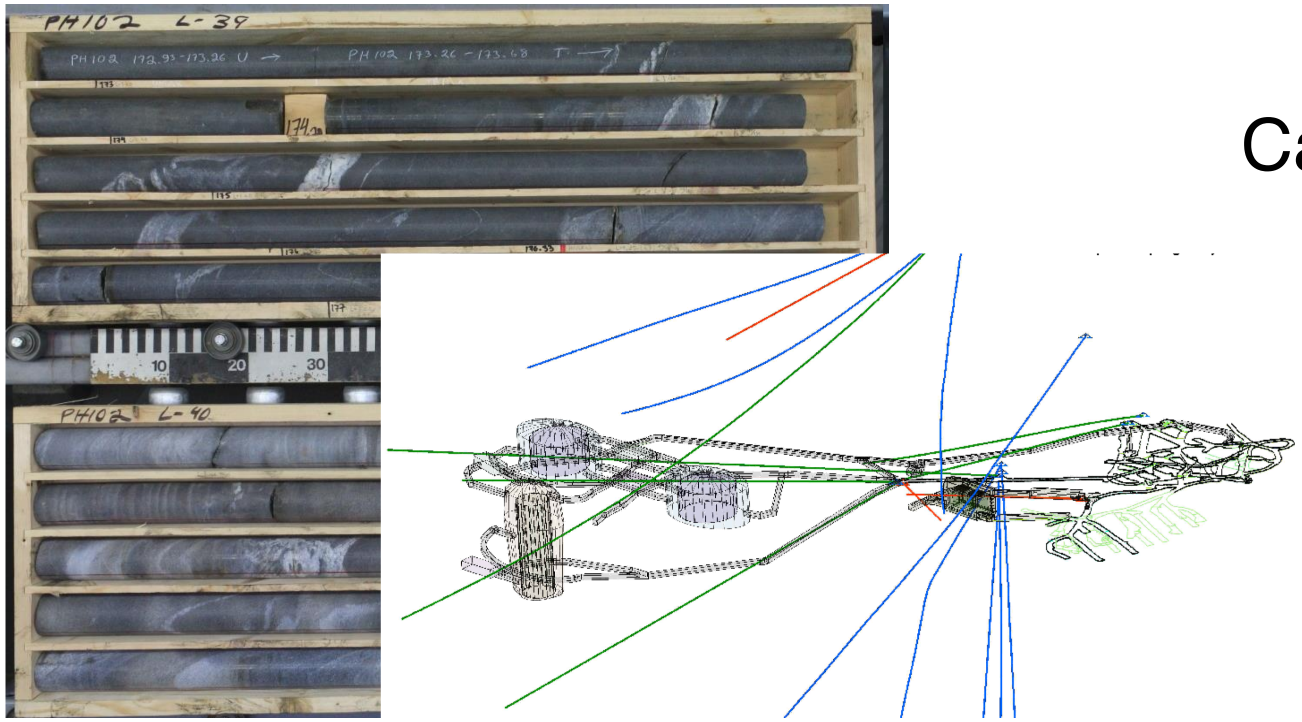
Stress Measurement Company Oy

Drillcon SMOY

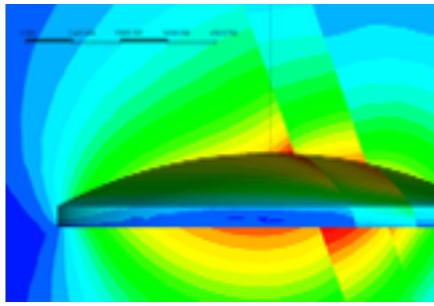
Aalto University

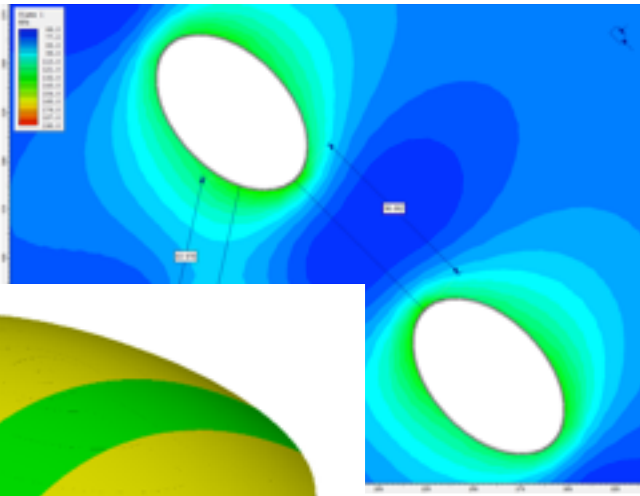
Pyhäsalmi mine Oy

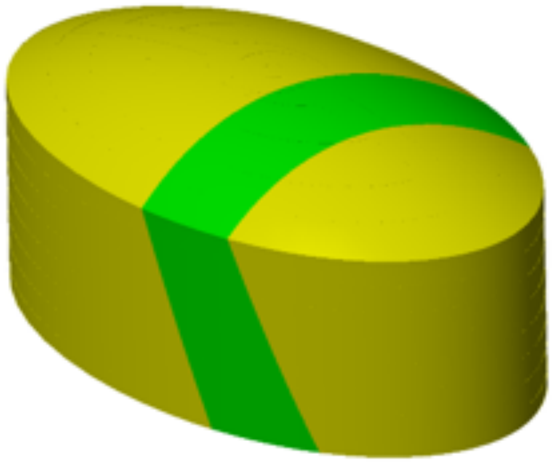




Cavern study







Caverns can be constructed with existing technology.

Political situation in Finland

- **In December 2012, the Finnish Government considered LAGUNA to be scientifically extremely valuable with high impact, but in view of the large predicted costs (900-1600M€, Finnish share:20-50%), it was impossible to commit to host the project.**

- This was unexpected (and inconsistent) with the spirit of the preceding discussions with science administrators.

- Evaluation by panel of Academy of Finland : “the panel sees (LAGUNA) as a very new and positive avenue for future HEP activities both in Finland and on the greater scale.”

- The Dec 2012 statement did not abort activities in Finland: financial support has continued as normal and the funding for the extended site investigation was granted.

- **In March 2013, the Ministry of Education has decided to reconsider the issue once new information is available.**

- In March 2014, a written statement to the Parliament stating that “In such a new situation the definition of the policy of the ministries can be reconsidered.”

Open discussions with the Finnish Government about LAGUNA

Question #5 for LBNO

Q5. (Financial and internationalisation issues) What is the cost of the experimental configuration (beam where relevant and detector)? What is your financial plan? What is the current level of international participation and what level of participation would be necessary to move to a construction decision? What models would you propose for international participation and at which parts of the beam or detectors? What would be the parts of the configuration whose leadership you would be willing to negotiate in exchange of international participation ?

- **LBNO20 (Phase I) : 210M€ (±10%), CN2PY+ND: available in Aug. 2014**
- **Financial plan: European Investment Bank loan**
  ≈15M€ / year needed to accomplish LBNO in Europe
- LAGUNA-LBNO EOI: 14 countries + 42 institutions including CERN
- Models for international participation not yet discussed but likely based on CERN's experience. Likely:
  - hosting country dominant in excavation+civ.eng. (1/4)
  - tank + cryo infrastructure : common project + lab support (1/2)
  - detector instrumentation : international collaboration (1/4)
- No negotiations started yet – present focus on negotiations for CERN WA105 collaboration/commitments.
- WA105 MoU in development (10 countries, 22 institutes)

Detailed costing models

Joint effort between scientific and industry partners

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
CH; detector design, coordinating

Institut de Physique Nucléaire de Lyon
FR; electronics & DAQ

cea SACLAY
FR; charge readout (micromegas), coordinating

CERN
EU: support

FR; Liquid infra design + costs
Sofregaz

Technodyne International Limited
UK; instrumentation & installation design, risk assessment, etc

ROCKPLAN
FIN; coordinating, cost, instrumentation, risk assessment, etc

RHYAL ENGINEERING
UK; cost, programmes, risk assessment

Alan Auld GROUP LTD
UK; cost, programmes, risk assessment

2

Guido Nuijten 5.6.2014

Detailed costing: LBNO20(Phase 1)

24 kton fiducial double phase detector

POTENTIAL REALISATION TIME FRAME 2021 - 2029

Underground infrastructure		**48.1 M€**
Caverns & access tunnels Excavation + Reinforcements	38.7 M€	
HVAC + auxiliary constructions	9.4 M€	
20kT Liquid Argon Experiment		**127.3 M€**
Argon Tank construction	45.4 M€	
Detector instrumentation and installation	41.5 M€	
Cryogenic liquid infrastructure	40.4 M€	
Commissioning Phase + Liquids		**26.3 M€**
Contingency (item by item depending on risk - mitigable)		24.7 M€

FULL COST LBNO 20 kton @ Pyhäsalmi	**226.4 M€**

(site dependent)

Conclusions

- After 2 consecutive DS, the LBNO Collaboration has a clear end-to-end path to propose an experiment capable to
  - Determine unambiguously (>5 σ) MH (no need for external input) and
  - Cover 80% of the CPV phase space at 3σ and 65 % at 5σ with realistic systematic error assumptions -> HEPAP P5 requirement satisfied
  - Deep underground location:
    - Astrophysics program
    - p-decay

    } Complementary to WCD
- Full conceptual design available, developed in collaboration with industrial partners leading to: Underground facility, construction sequence, well defined costs,…
- LAGUNA-LBNO DS final report August 2014, stay tuned!
- **<u>Planned next step</u>: construction and operation of LBNO-DEMO (WA 105)**

LAGUNA-LBNO DS	WA 105	LBNO – PILOT (2.5 – 5 kt)	LBNO Phase I (LBNO20)	LBNO Phase II (LBNO70)
Site selection Full assessment of physics Full engineering costing	DLAr demonstrator Calibration Software development	Underground installation Astro particle physics	MH CPV 3 σ: 46% Proton decay Astrophysics	CPV 3 σ: 80 % Proton decay Astrophysics
2014	2018	202X	202X	203X

Concluding LAGUNA-LBNO DS Meeting

LAGUNA 2014

Open Meeting Marking Completion of the Design Studies and Transition to the Realisation Phase

25 – 27 August 2014, Hanasaari, Finland

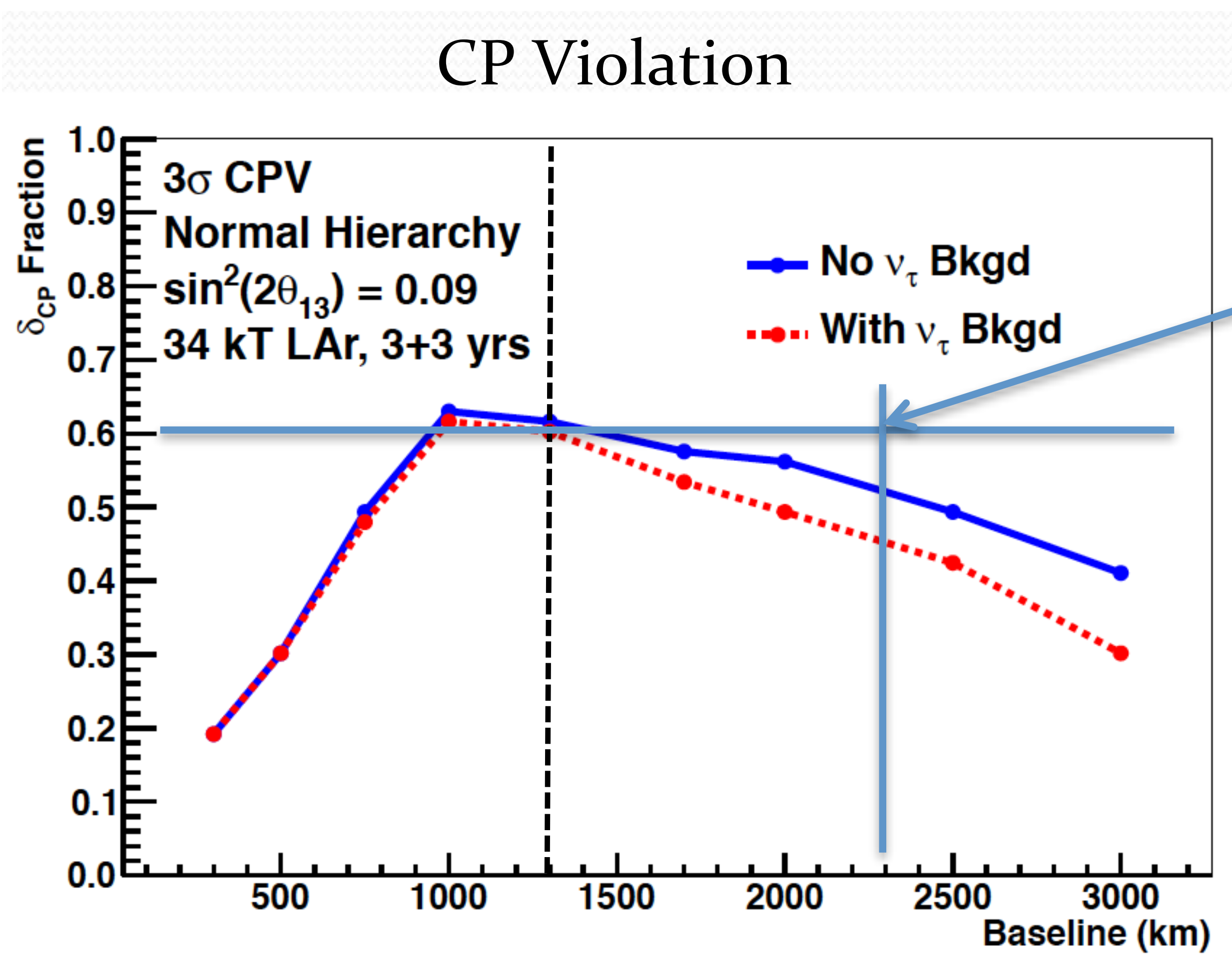
https://www.jyu.fi/fysiikka/en/laguna2014

Backup slides

Courtesy PvZ

Discussion LBNO vs LBNE based on the statement
from Bob Wilson that 1300 km is “nearly optimal for CPV measurements”

We have computed the % of d_{CP} for LBNO at 2300 km for the same exposure as quoted
In the LBNE Neutrino 2014 talk by B. Wilson:
Exposure 245 kt.MW.yr (34 kt x x1.2 MW x (3+3) yr)
1 % signal normalization and q_{23} = 0.39 – the most favorable for CP – 60% coverage



We have made a quick check for LBNO
Using the same exposure: 245 kt.MW.y
Starting from 10 y x 35 kt x 0.75 MW SPS
We downscale the pot to 1.4 E21
We get 60% coverage, as LBNE! Using their
Assumptions (1 % signal normalization and
q_{23} = 0.39) but with tau bg!

This showed that the statement made
by LBNE on the baseline optimization is wrong.

Many more questions arise in p. 11 and p12 of the talk by Wilson, there is mix of
120 GeV and 80 GeV and the **arXiv:1311.0212**

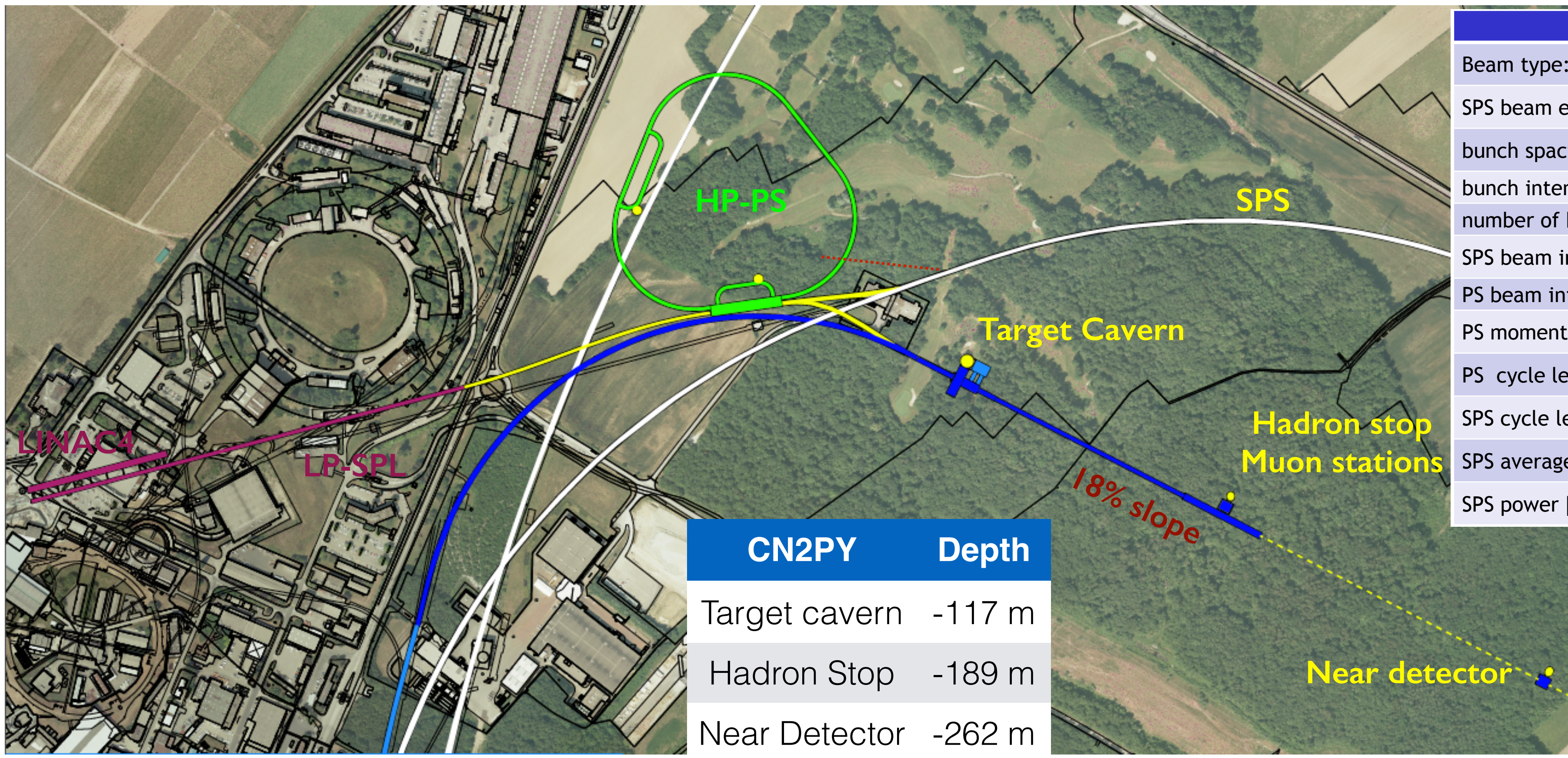
Updated beam LBNO design

Phase 1 : proton beam extracted beam from SPS

400 GeV, max 7.0 10^{13} protons every 6 sec, ~750 kW beam power, 10 μs pulse

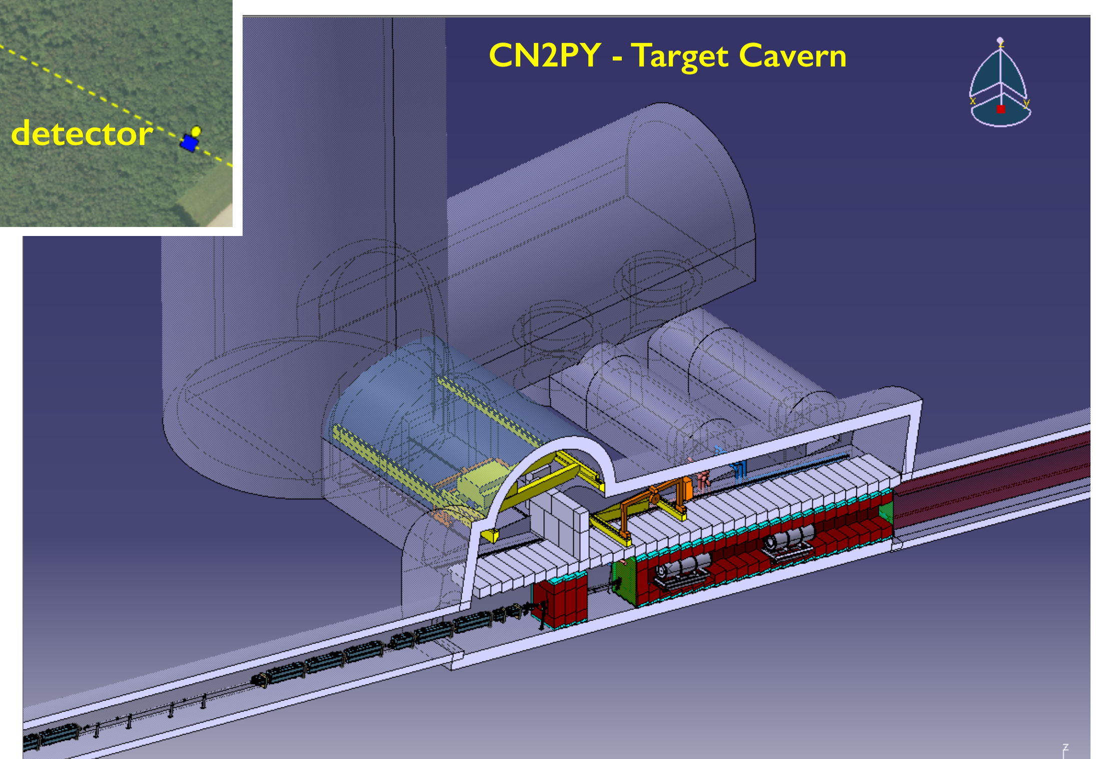
Phase 2 : use the proton beam from a new HP-PS

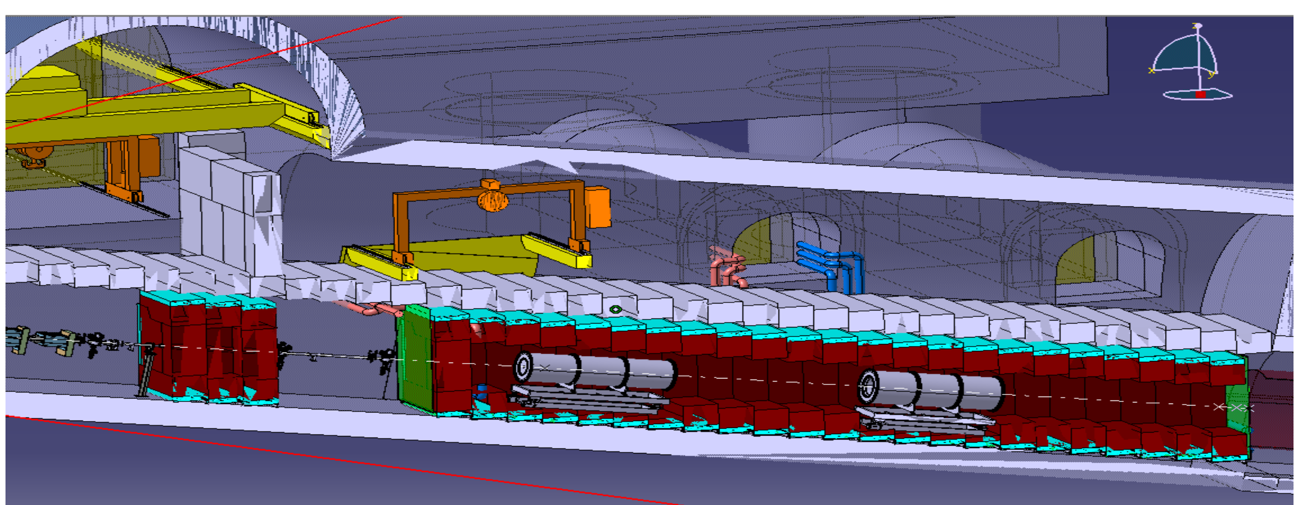
50 GeV, 1 Hz, 2.5 10^{14} ppp, 2 MW beam power, 4 μs pulse



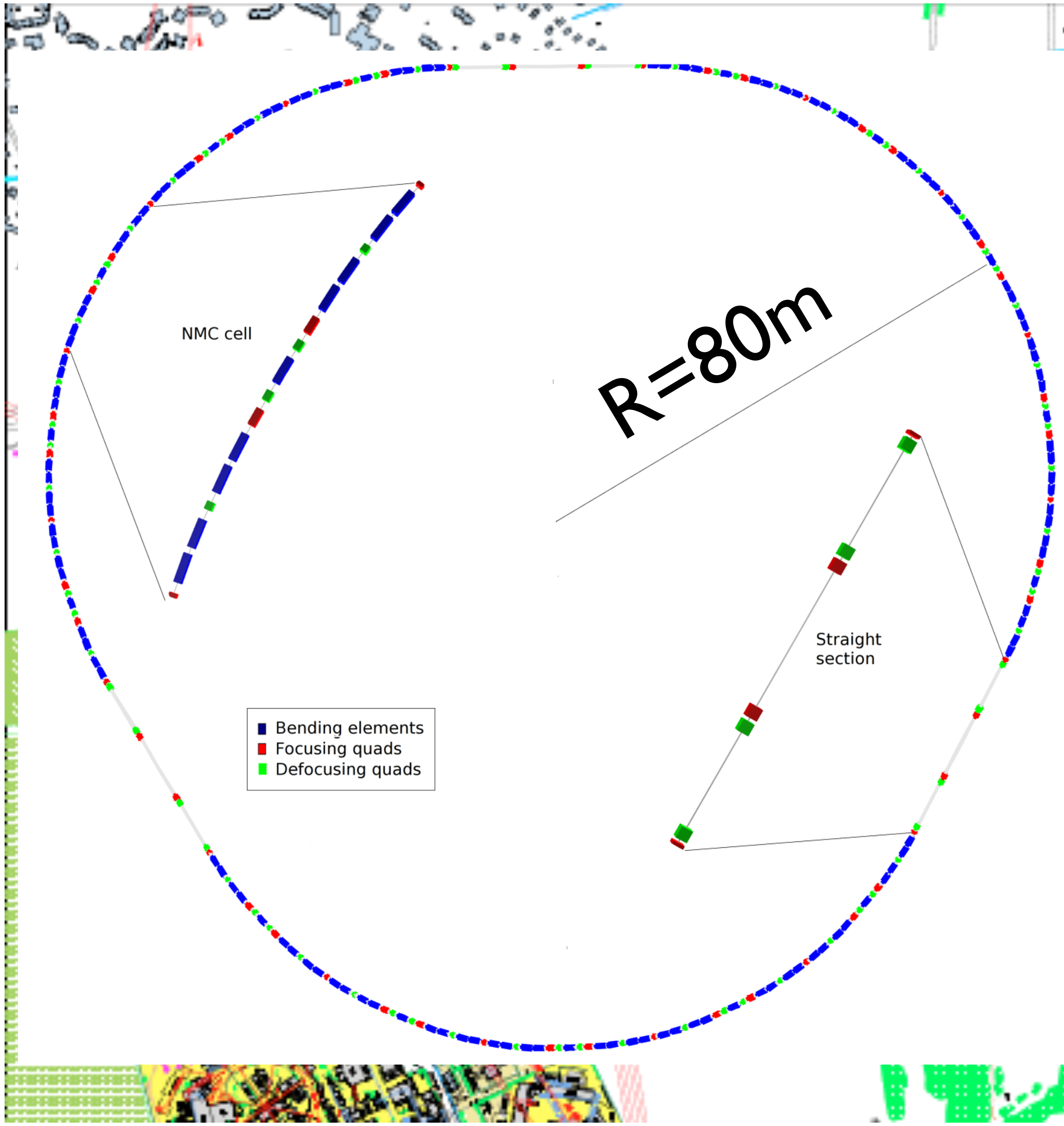
CN2PY	Depth
Target cavern	-117 m
Hadron Stop	-189 m
Near Detector	-262 m

	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

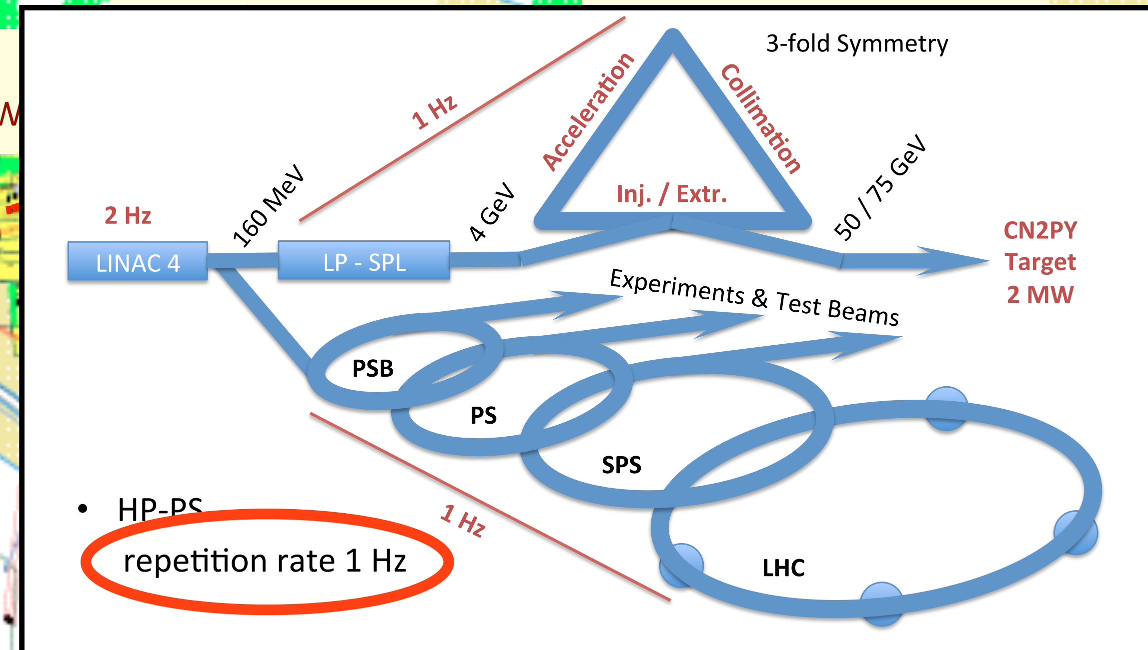




High power HP-PS study



Target
(0.75-2MW

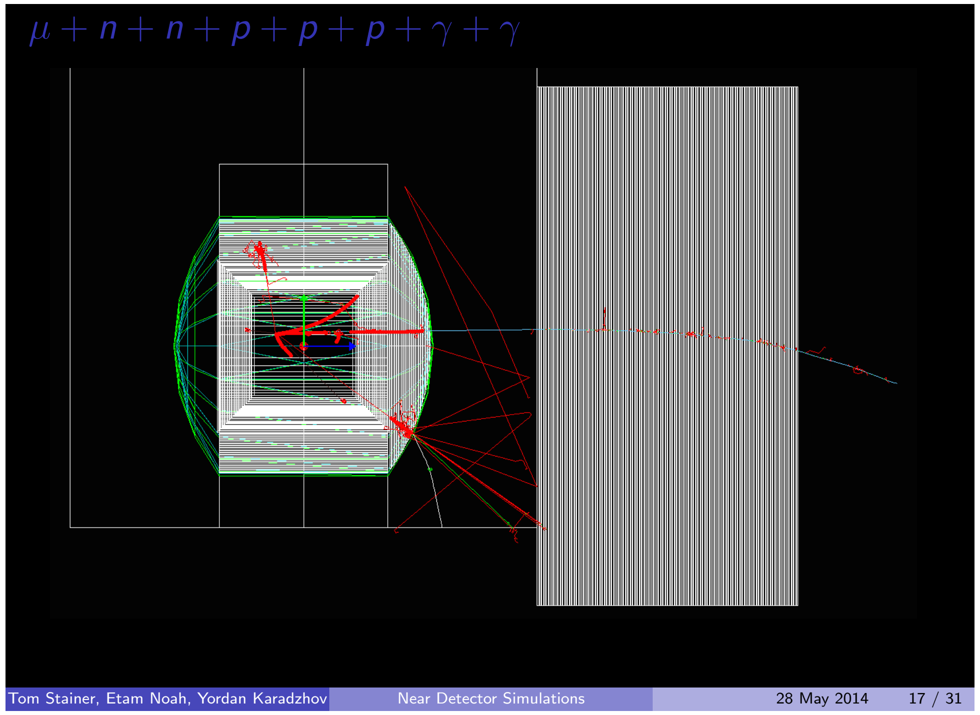


Parameter	50 GeV	75 GeV	Units
Inj. / Extr. Kinetic Energy	4 / 50	4 / 75	[GeV]
Beam power	2		[MW]
Repetition rate	1		[Hz]
f_{rev}	0.248 / 38.97		[MHz]
RF harmonic	157		-
f_{rev}	0.255 / 40.08	0.255 / 40.09	[MHz]
Bunch spacing @ extr.	25		[ns]
Total beam intensity	2.5 x 10	1.7x10	-
Number of bunches	147		-
Intensity per bunch	1.7x10	1.25x10	-
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]

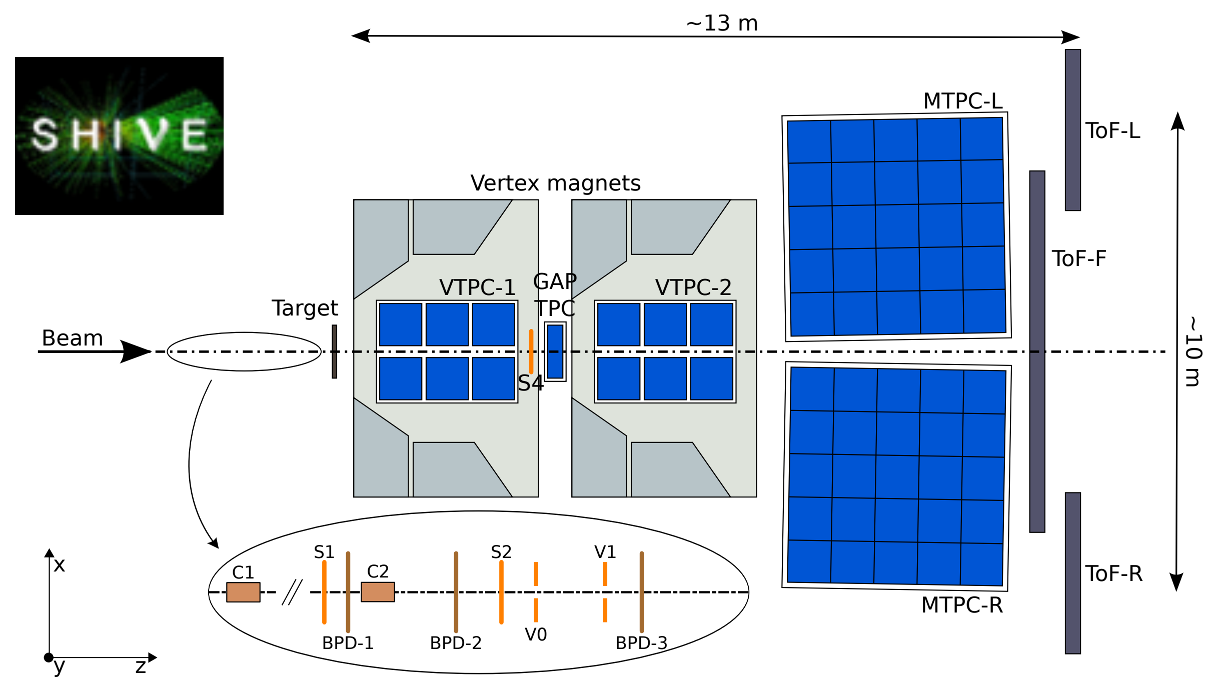
- Basic design well underway and main parameters available
- Optics design well advanced
- Injection and extraction concepts are available
- Basic ideas about accelerating RF system
- Basic ideas about collimation
- Consolidate optics and establish set of requirements for different magnet families.
-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

LBNO near detector and hadroproduction

- **<u>Aim</u>: systematic errors for signal and backgrounds in the far detectors below ±5%, possibly at the level of ±3% ⇒ control of fluxes, cross-sections, efficiencies,...**



- Concept: 20 bar gas argon-mixture TPC (2.0 m × 2.0 m × 2.0 m) surrounded by scintillator bar tracker embedded in an instrumented magnet with field 0.5T
- 300 kg argon mass in TPC
- 0.1 event/spill @ 7e13 ppp 400 GeV
- O(50'000) 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

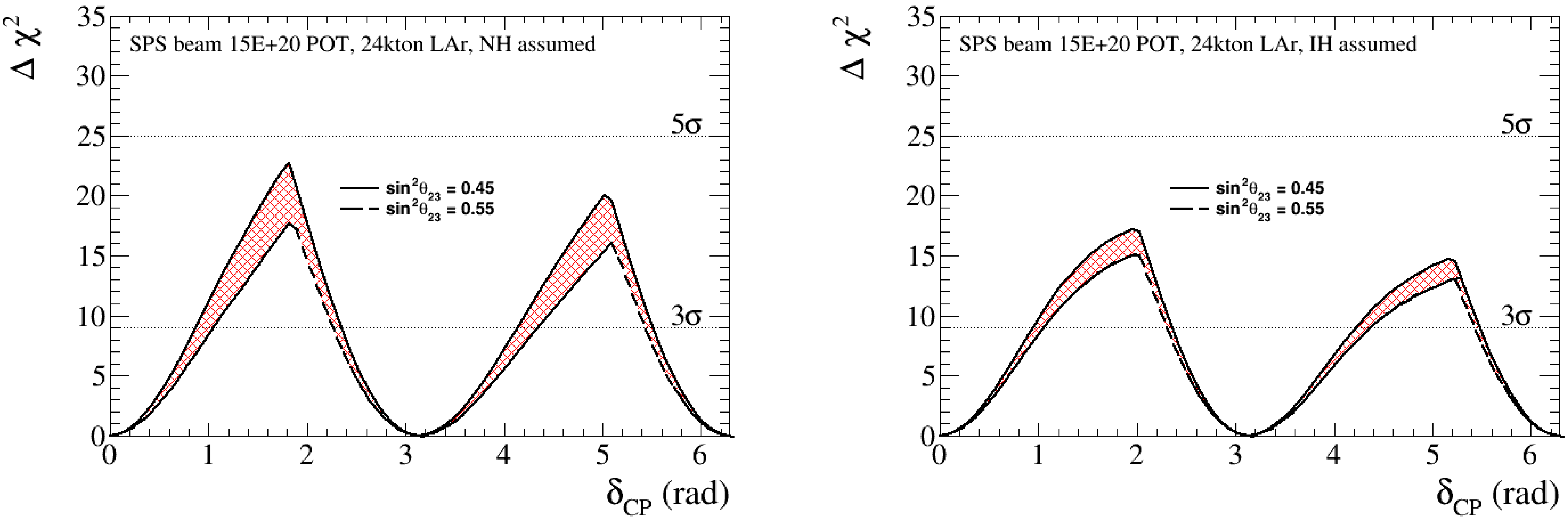
- Precision neutrino cross-section measurements: e.g. MINERVA, T2K-ND280, …

Event rates vs baseline

Beam	ν_μ unosc. CC	ν_μ osc. CC	ν_e beam CC	ν_μ NC	$\nu_\mu \to \nu_\tau$ CC	$\nu_\mu \to \nu_e$ CC $\delta_{CP} = -\pi/2$,	0,	$\pi/2$
LBNO: 2300 km NH 400 GeV, 750 kW 1.5×10^{20} POT/year								
50kt years ν	3447	907	22	1183	215	246	201	162
50kt years $\bar{\nu}$	1284	330	5	543	98	20	27	29
LBNE Low energy beam 120 GeV, 700 kW, NH 6×10^{20} POT/year								
50kt years ν	4882	1765	44	1513	61	217	174	126
50kt years $\bar{\nu}$	2506	890	13	620	22	44	54	56

Total number (1st&2nd) of electron appearance signal events similar at 1300/2300 km
Less muon CC and NC backgrounds at 2300 km
More tau events at 2300 km - handled by kinematical reconstruction

Median sensitivity to CPV with SPS beam



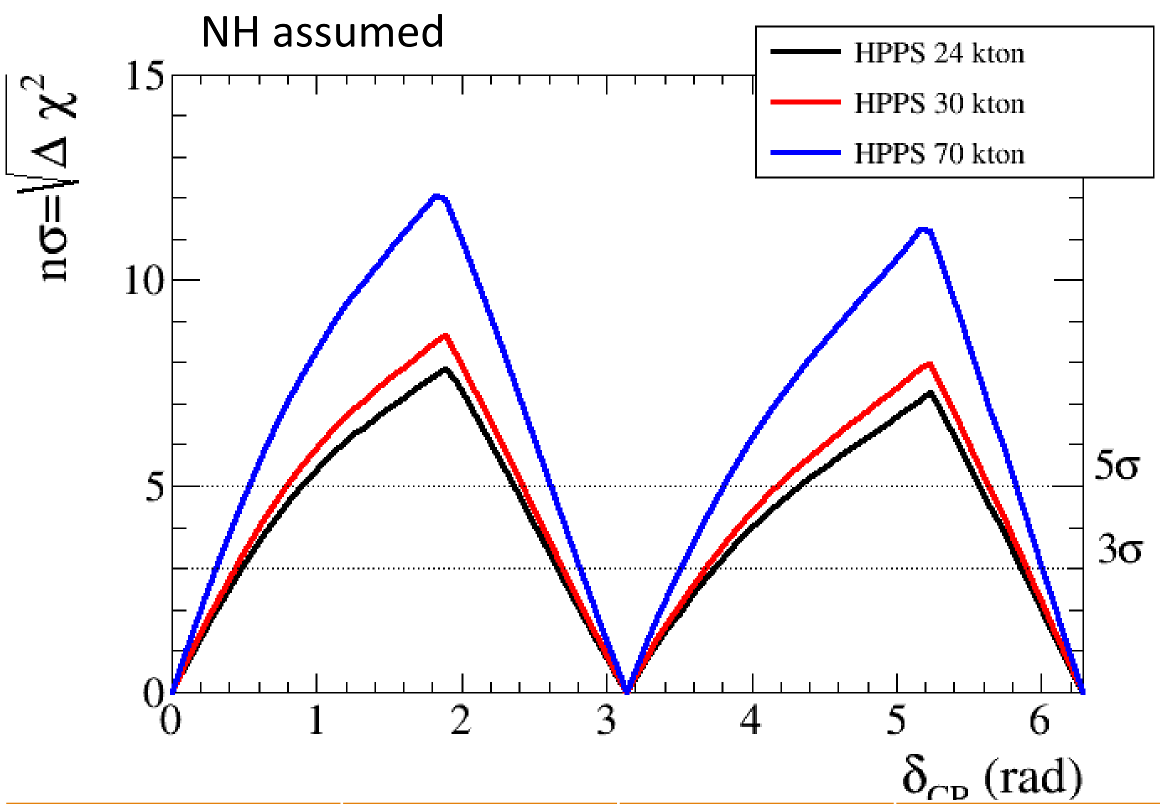
Detector mass	$F_{3\sigma}$ NH	$F_{5\sigma}$ NH	$F_{3\sigma}$ IH	$F_{5\sigma}$ IH
24 kton	45% (36%)	0	43% (36%)	0
30 kton	50% (43%)	3% (0)	49% (44%)	0
70 kton	63% (59%)	35% (26%)	65% (59%)	36% (27%)

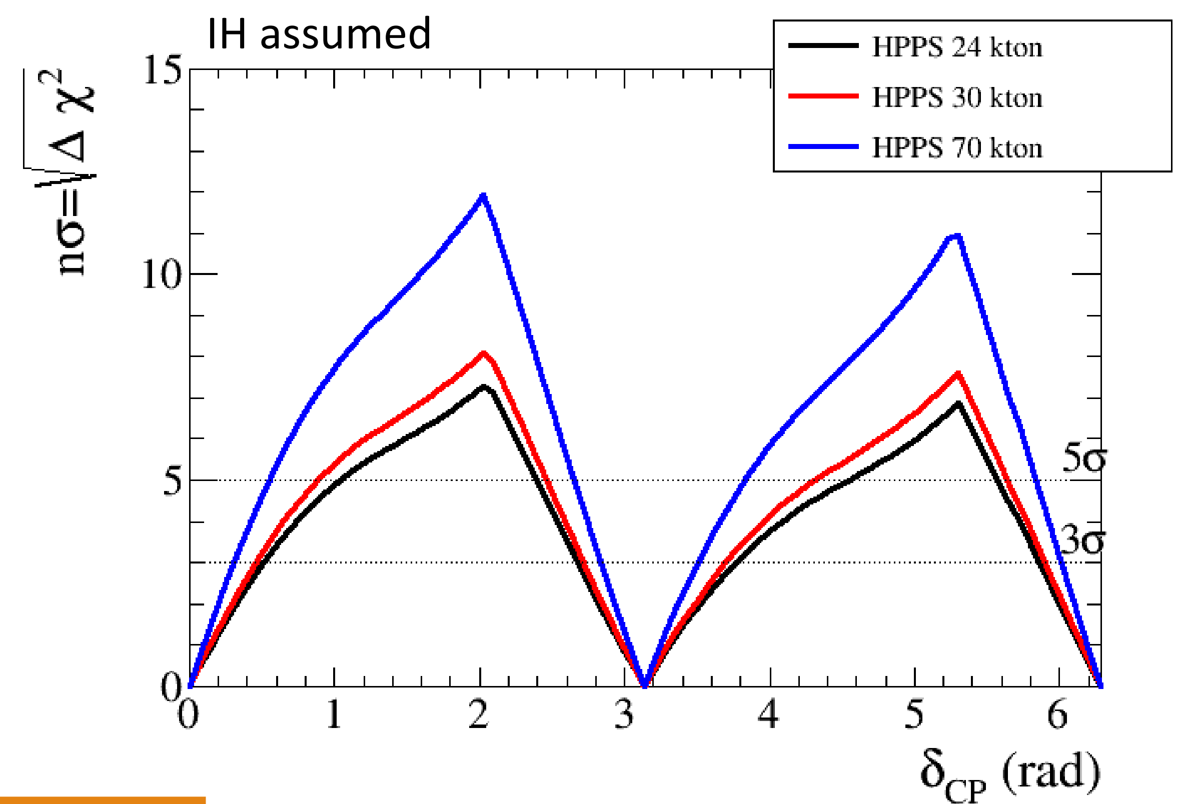
$\sin^2\theta_{23} = 0.45(0.55)$

Galymov

With SPS(750kW): from 45%-65% for 20-70 kton mass

Median significance vs detector mass for HPPS





Detector mass	$F_{3\sigma}$ NH	$F_{5\sigma}$ NH	$F_{3\sigma}$ IH	$F_{5\sigma}$ IH
24 kton	68%	43%	68%	38%
30 kton	71%	49%	71%	46%
70 kton	80%	65%	80%	65%

HPPS exposure: 30E+21 POT, 75%ν: 25%$\bar{\nu}$
$\sin^2\theta_{23} = 0.45$

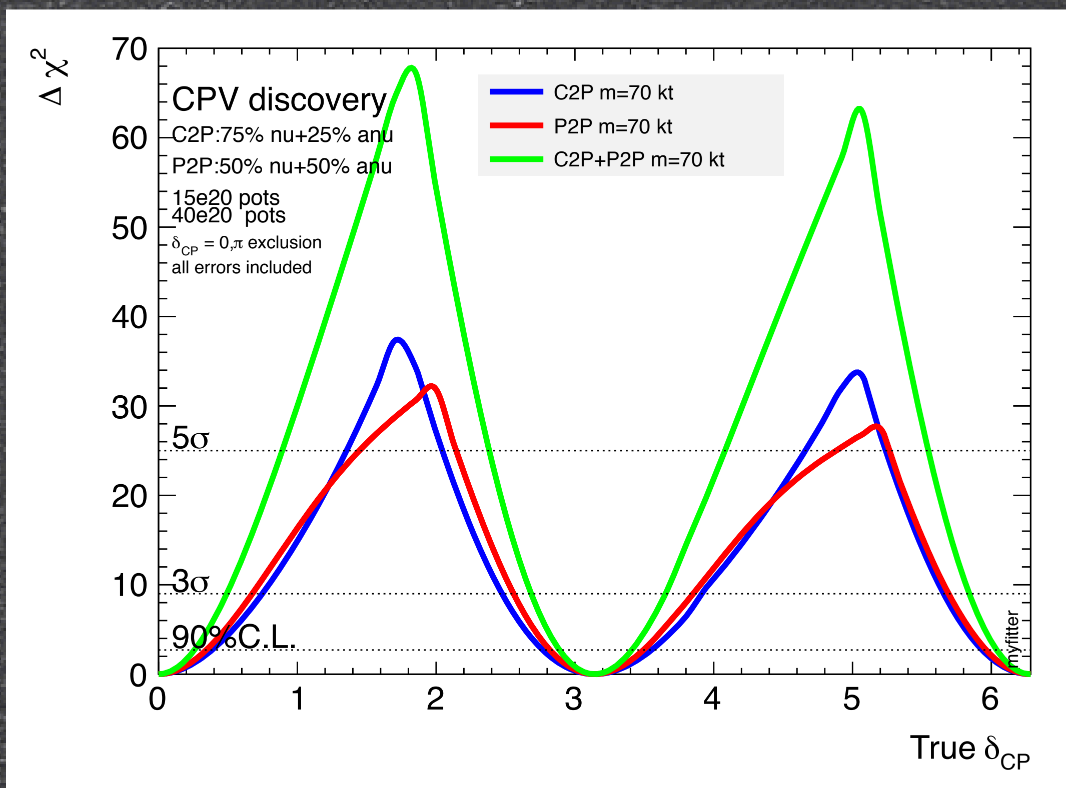
Galymov

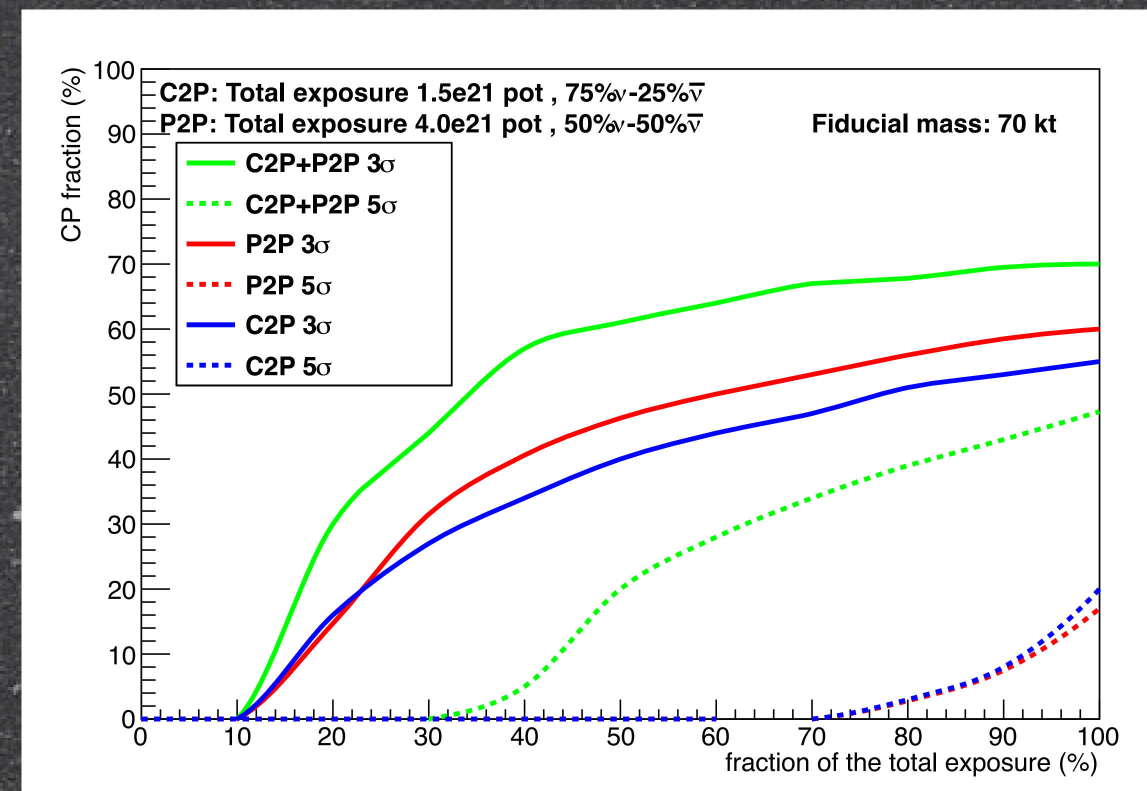
With HPPS(2MW): from 68%-80% for 20-70 kton mass

FULFILS P5 REQUIREMENT ! 👍 👍 👍 👍 👍

Protvino beam

Consider a 2nd 400kW beam at a different baseline – instead of HP-PS





- With the two beams configuration and 70 kton we cover ~70% of δ at 3 σ
- Those plots are obtained with the old CN2PY fluxes

Giganti

FULFILS P5 REQUIREMENT !