LBNO Project Overview

CERN-SPSC-2012-021
SPSC-EOI-007, 2012

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Expression of Interest

for a very long baseline neutrino oscillation experiment

(LBNO)

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On behalf of LAGUNA-LBNO, WP4
LAGUNA_LBNO / FP7 Design Study (2011-2014)

- New design study, extending that of LAGUNA, including the neutrino beams from CERN

- **LAGUNA**: search for optimal site in Europe for an underground $\nu$ detector
  - accelerator + other $\nu$ sources

- **LAGUNA-LBNO**: beam options for unique physics opportunities in Europe
  - Profit from experience gained with the CNGS operation
  - Incremental approach with competitive physics goals at each stage
  - Synergy with other $\nu$-beam options
    - CN2FR : $\beta$-beam
    - CN2PY : Neutrino Factory

- Pyhäsalmi selected as top priority site that combines several optimal conditions --> CN2PY beam study

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CN2PY (Pyhasalmi)
- Initial : beam from SPS (500kW - 750kW)
- Long term: LP-SPL + HPPS - 2MW

Synergy with a Neutrino Factory

CN2FR (Frejus)
- HP-SPL + accumulator ring (5 GeV - 4 MW)

Synergy with $\beta$-beam ($\gamma=100$)

CNGS - Umbria
- Beam from SPS (500kW)
- No near detector possibility
The LBNO Proposal – CN2PY LBL ν-beam

CERN Neutrinos 2 PYhasalmi beam

- **Phase 1**: proton beam extracted beam from SPS
  - 400 GeV, max $7.0 \times 10^{13}$ protons every 6 sec,
  - $\sim 750$ kW nominal beam power, 10 μs pulse

- **Phase 2**: use the proton beam from a new HP-PS
  - 50(30,70) GeV, 1.33 Hz, $1.9 \times 10^{14}$ ppp, 2 MW
    nominal beam power, 4 μs pulse
  - alternative option: upgradedSPS
  - CN2PY also compatible with a NF option

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**Beam parameters**

- **400 GeV** protons from SPS (initial)
  - Survey info:
    - CERN (TCC2 target station –NA) 46°15'26.27"N, 6° 3'8.19"E
    - Innet Mine (Finland): 63°39'30.92"N, 26° 2'47.65"E
    - distance: 2296 km
  - dip angle: 10.4 deg, 181 mrad
  - Neutrino beam at Pyhäsalmi ($\theta_{max} = 30$ MeV/$E_{\nu}$): $14\pm34$ Km for $E_{\nu} > 2\pm5$ GeV
Present state of mine

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

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

- Timo shaft
- Decline tunnel entrance
This pump alone takes all the water from 645 m to the surface

250 m long tunnel and a cavern at 1400m excavated for LAGUNA R&D

Cafeteria, meeting room and sauna at 1400 m below ground

Mobile phones work and internet available also at 1400 m
Layout of the LAGUNA-LBNO observatory at Pyhäsalmi (-1400m)

Available space for up to 2x50 kton LAr + 50 kton LSc
879’000 m³ excavation
Design to be finalised within LAGUNA-LBNO by ≈2014
Requirements - design challenges for the beam

- **Primary beam**
  - match of the beam parameters to the target for both beams, same final focusing elements

- **Secondary beam elements [400 ↔ ~30 GeV beam]**
  - focusing system design for both 1st and 2nd maximum [~4 GeV $E_\nu$]
  - sufficient shielding to contain the produced radiation
    - including muons, water and soil activation (H3 and NA22 production)
  - beam elements: target and horn(s)
    - similar size to fit in the same infrastructure
    - same relative positions? or allow variations already from the design phase
    - remote handling possibilities ↔ flexibility in the design

- **Decay volume, dump, muon monitoring and near detector**
  - same length or intermediate dump?
  - dump length vs muon monitoring and near detector location

- Determine CP-violation and mass degeneracy by spectrum measurement and resolve degeneracies and so called “π-transit” effect
- arXiv:0908.3741.v1 for “Magic distance” A. Rubbia, LAGUNA

Work is progressing, highlights of present studies in the next slides....
CERN ν-beam to Pyhäsalmi - CN2PY Layout
Target station and ND in the North Area, use existing TT20 line and TI2 or LSS2 extraction
Phase-II: HP-PS using (LP)-SPL as injector
CERN ν-beam to Pyhäsalmi - CN2PY Layout

Target station and ND in the North Area, use existing TT20 line and TI2 or LSS2 extraction
Phase-II: HP-PS using (LP)-SPL as injector
All installations in CERN reserved territory
- CN2PY sharing or infrastructure with TCC2/NA
  - further optimization possible

Primary beam
Target cavern
Beam dump
Near detector (500m)
Near detector (800m)
CN2PY Layout - Beam extraction

Target station and ND in the North Area, use existing TT20 line and TI2 or LSS2 extraction
Phase-II: HP-PS using (LP)-SPL as injector

- 400 GeV beam extraction using existing kickers at LSS6 & LSS2 of SPS
- Feasibility test at SPS with positive results

B. Goddard et. al, LAGUNA-LBNO, WP4
Layout drawing

- Use the existing extraction from SPS (LLS2)
  - same extraction point from TT20 line to the new beams
  - **CN2PY**: 400 GeV beam, 10.4 deg down dip, **SBL2NA**: 100 GeV beam, 5 mrad upwards
The depth for the installations is the major concern -18% slope compared to 5.6% for CNGS.

Starting the beam from the SPS level adds ~50 m to the depth of the installations.

Here we gain as we start from the end of TT20 line that is ~11 m deep.

The target may be at the limit of the moraines/molasse layer.

Staying in the molasse layer has quite some advantages for the CE (stability) and radiation to environment (underground water activation issues) issues.

Note:
- The deepest shaft presently at CERN is ~140 m (LHC/P4)
- these are preliminary numbers
- The exact values will be determined once the study of the proton line is finalized.
CN2PY - Layout considerations

- CNGS Secondary Beam Layout

\[ p + C \rightarrow (interactions) \rightarrow \pi^+, \ K^+ \rightarrow (decay) \rightarrow \mu^+ + \nu_\mu \]

- CN2PY Layout
CN2PY Target Cavern Layout

Target station building & services
(C&V, hot cell, cranes, power supplies, etc.)
(can be underground – no access during operation)

Movable concrete blocks

Movable steel plates

Air volume for structural support services

~3 m (if access needed)

~2 m Fe

Target horn reflector

DP collimator

Primary beam zone

Beam window

~5 m

<25 meters (CNGs is ~100 m)

10 m

He container (?)

TS and DP unique volume?

Decay pipe (DP)
target cavern layout

- single or step-wise solution?
- horizontal or vertical access?

talk of D. Wilcox
Design guidelines from our experience in CNGS and other ν-beam lines (T2K, NuMI)

Adopt the chase or rather “champignon” design for the target cavern

- for T2K H=\sim16m
- How much shielding we would need in the chase? RP !!!
- The logistics of the opening/closing in the cavern in the slope must be worked out!
Effect of relative distance between horn/reflectors

Horn configuration:
- $d_{TH} = 0$ cm
- $I_H = 220$ kA

Both peaks optimization

Effect of relative distance between target/horn

Reflector configuration:
- $d_{HR} = 10$ m
- $I_R = 220$ kA

With a fixed inner conductor shape

M. Calviani, P. Velten - CN2PY neutrino beam line design
2 October 2012
Higher $\nu_\mu$ fluence for longer DP (~saturation for $r>1.5$ m)

The longer the DP, the larger the fraction of high-energy $\nu$

DP length partly imposed by the $\mu$ fluence in the ND!

...And by costs!

Potential DP configuration

$\rho_D = 1.5$ m, $L_D \leq 300$ m

CNGS

$\rho_D = 1.2$ m, $L_D = 1100$ m
**Present and future SPS performance**  
(in terms of beam power)

<table>
<thead>
<tr>
<th>Operation</th>
<th>SPS record</th>
<th>After LIU (2020)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>LHC</td>
<td>CNGS</td>
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<tr>
<td>SPS beam energy</td>
<td>450</td>
<td>400</td>
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<tr>
<td>bunch spacing</td>
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<tr>
<td>bunch intensity/10^{11}</td>
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<td>number of bunches</td>
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<td>PS beam intensity/10^{13}</td>
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<tr>
<td>PS momentum</td>
<td>26</td>
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<tr>
<td>PS cycle length</td>
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<td>SPS cycle length</td>
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<td>SPS average current</td>
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<td>1.17</td>
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<tr>
<td>SPS power</td>
<td>77</td>
<td>470</td>
</tr>
</tbody>
</table>

*Feasibility including operational viability (especially in the PS) remains to be demonstrated*
### Present and future SPS performance (in terms of beam power)

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<td></td>
<td>LHC</td>
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<td>number of bunches</td>
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<td>SPS beam intensity/10^{13}</td>
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<tr>
<td>PS momentum [GeV/c]</td>
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<td>14</td>
<td>26</td>
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<td>PS cycle length [s]</td>
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<tr>
<td>SPS cycle length [s]</td>
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<td>SPS average current [µA]</td>
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<td>SPS power [kW]</td>
<td>77</td>
<td>470</td>
<td>125</td>
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</table>

*Feasibility including operational viability (especially in the PS) remains to be demonstrated*

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R. Garoby, S. Gilardoni, E. Shaposhnikova,– LiU-LLBNO/CERN

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![Graph showing integrated pot vs years of running](image)
### Beam Intensity Upgrades - HP-PS

\[ P = q_f r N_p E_k \]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PS2</th>
<th>HP-PSa</th>
<th>HP-PSb</th>
<th>HP-PSc</th>
<th>HP-PSd</th>
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<tbody>
<tr>
<td>Circumference [m]</td>
<td>1346.4</td>
<td>1256</td>
<td>1009</td>
<td>763</td>
<td>1256</td>
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<tr>
<td>Symmetry</td>
<td>2-fold</td>
<td>3 / 4-fold</td>
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<tr>
<td>Beam Power [MW]</td>
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<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
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<td>Repetition rate [Hz]</td>
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<td>2</td>
<td>2.6</td>
<td>1.3</td>
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<tr>
<td>Kinetic Energy @ inj./ext. [GeV]</td>
<td>4/50</td>
<td>4/50</td>
<td>4/40</td>
<td>4/30</td>
<td>4/50</td>
</tr>
<tr>
<td>Protons/pulse [10^{14}]</td>
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<td>1.25</td>
<td>1.6</td>
<td>1.6</td>
<td>1.9</td>
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<tr>
<td>Dipole ramp rate [T/s]</td>
<td>1.4</td>
<td>6.1</td>
<td>6.0</td>
<td>7.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Bending field @ inj/ext. [T]</td>
<td>0.17/1.7</td>
<td>0.17/1.7</td>
<td>0.21/1.7</td>
<td>0.27/1.7</td>
<td>0.17/1.7</td>
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<tr>
<td>Fractional beam loss [10^{-4}]</td>
<td>35.1</td>
<td>6.5</td>
<td>5.0</td>
<td>4.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Space-charge tune-shift H/V</td>
<td>-0.13/-0.2</td>
<td>6.5</td>
<td>5.0</td>
<td>4.0</td>
<td>6.5</td>
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<tr>
<td>Lattice type</td>
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<td>Resonant NMC arc, doublet LSS</td>
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<td></td>
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<tr>
<td>Max. beta H/V [m]</td>
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<td>60/60</td>
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<tr>
<td>Max. dispersion [m]</td>
<td>3.2</td>
<td></td>
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</tbody>
</table>

- Getting 2MW of beam power is not straight-forward
- ramp rate, space-charge, losses, acceptance, space(circumference), cost!
Design guidelines

- Design adapted from PS2 studies
- 3-4 fold symmetric ring to accommodate in separate LSS injection/extraction collimation and RF
- NMC lattice necessary to avoid transition and reduce losses
- Use resonant NMC cells to increase filling factor (no DS)
- Doubles LSS leave space for BT equipment, collimation and RF
- Layout considerations with existing machines and constraints

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SF HP-PS</th>
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<tbody>
<tr>
<td>Circumference [m]</td>
<td>1093</td>
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<tr>
<td>Symmetry</td>
<td>3 / 4-fold</td>
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<tr>
<td>Beam Power [MW]</td>
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<tr>
<td>Repetition rate [Hz]</td>
<td>1.3</td>
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<tr>
<td>Kinetic Energy @ inj./ext. [GeV]</td>
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<tr>
<td>Protons/pulse [$10^{14}$]</td>
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<td>Dipole ramp rate [T/s]</td>
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<td>Bending field @ inj./ext. [T]</td>
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<tr>
<td>Max. dispersion [m]</td>
<td>4.3</td>
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</tbody>
</table>
CN2PY – Upgrade option HP-PS

Design guidelines

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- 3–4 fold symmetric ring to accommodate in separate LSS injection/extraction collimation and RF
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Summary

- After CNGS may be is now time to go...
Summary

‣ After CNGS may be is now time to go...

from South ...
After CNGS may be is now time to go... to North?

from South...