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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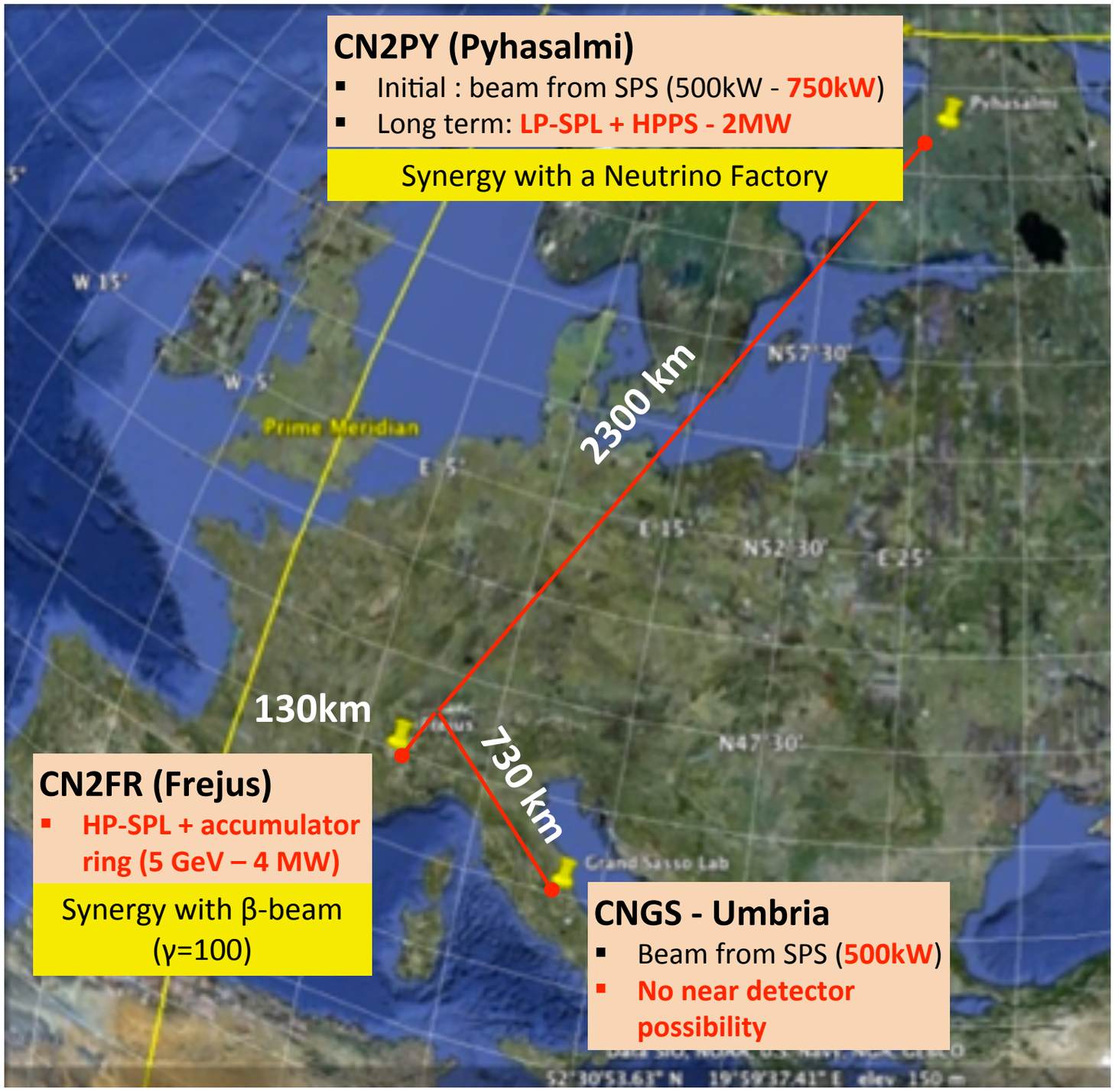
~350 authors
51 institutions

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 ν detector
  - accelerator + other ν 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 ν-beam options
    - CN2FR : β-beam
    - CN2PY : Neutrino Factory
- Pyhäsalmi selected as top priority site that combines several optimal conditions --> **CN2PY beam study**



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 10^{13} protons every 6 sec, **~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 10^{14} ppp, **2 MW** nominal beam power, 4 μs pulse
  - alternative option: upgradedSPS
  - CN2PY also compatible with a NF option

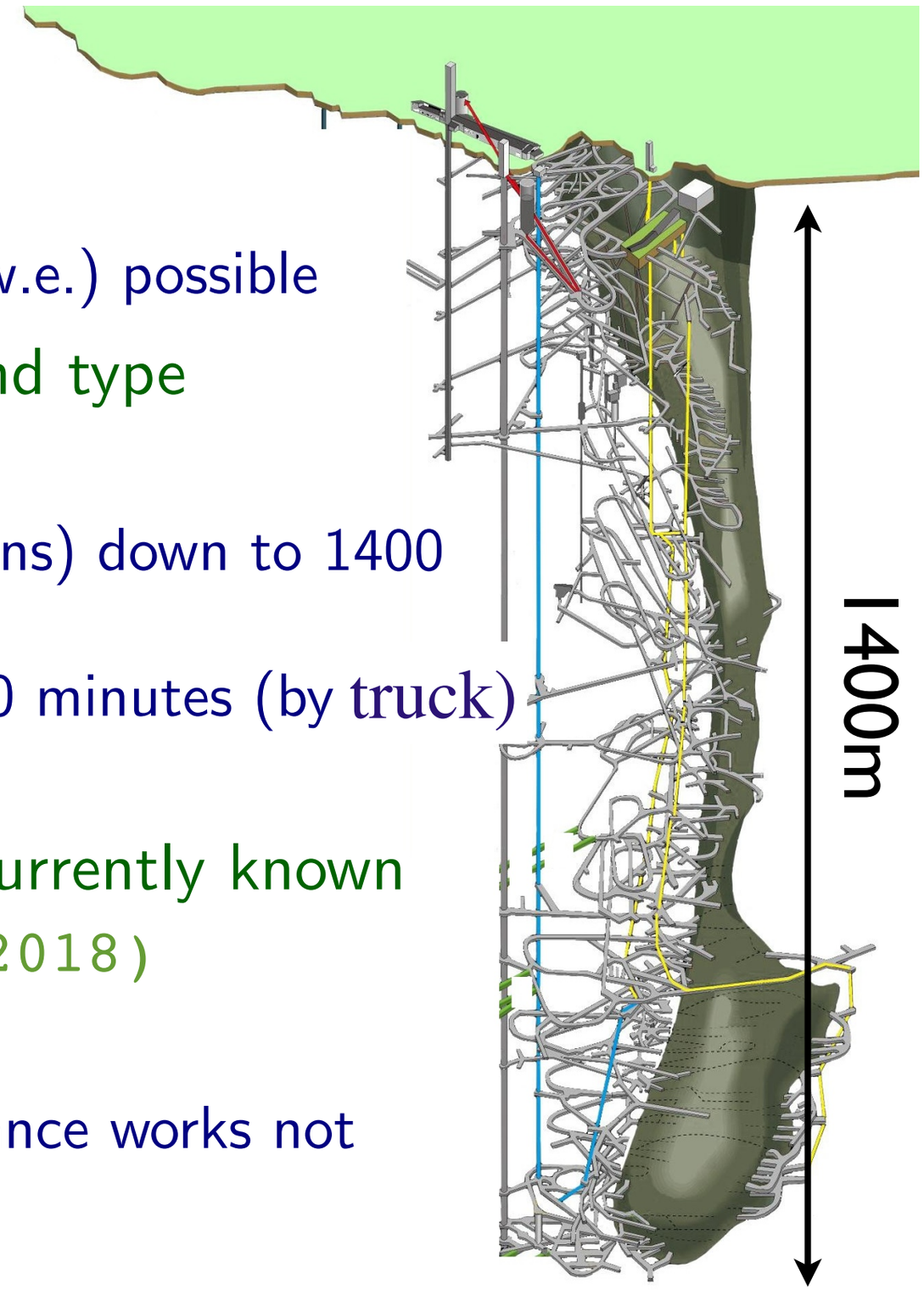
Beam parameters

- **400 GeV** protons from SPS (initial)
- Survey info:
  - CERN (TCC2 target station -NA) 46°15'26.27"N, 6° 3'8.19"E
  - Inmet 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 ($\theta_{max} \approx 30$ MeV/E_ν) : **14÷34 Km** for Eν 2÷5 GeV

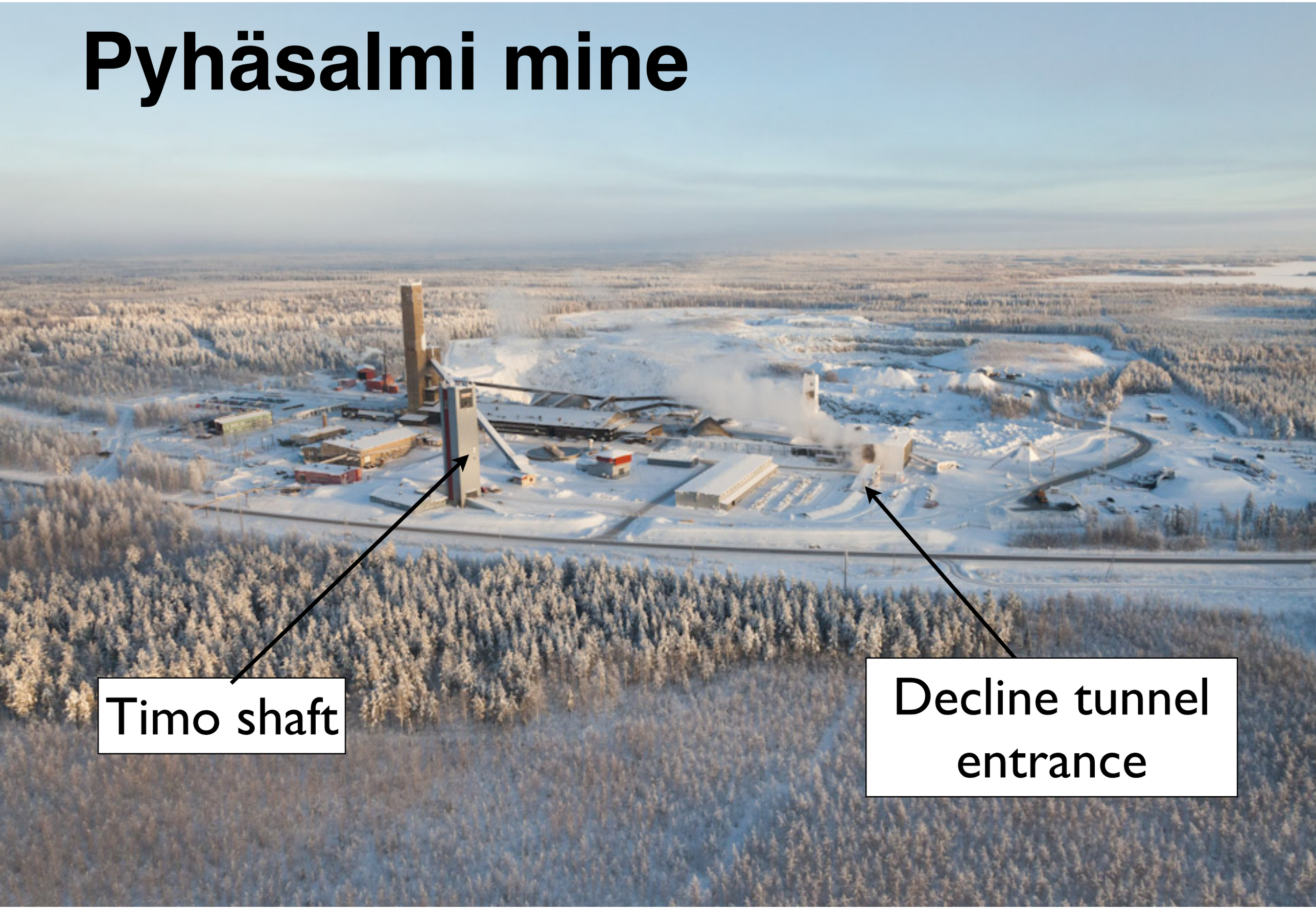
Present state of mine

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

- Produces Cu, Zn, and FeS_2
- The deepest mine in Europe
  - Depths down to 1400 m (4000 m.w.e.) 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



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

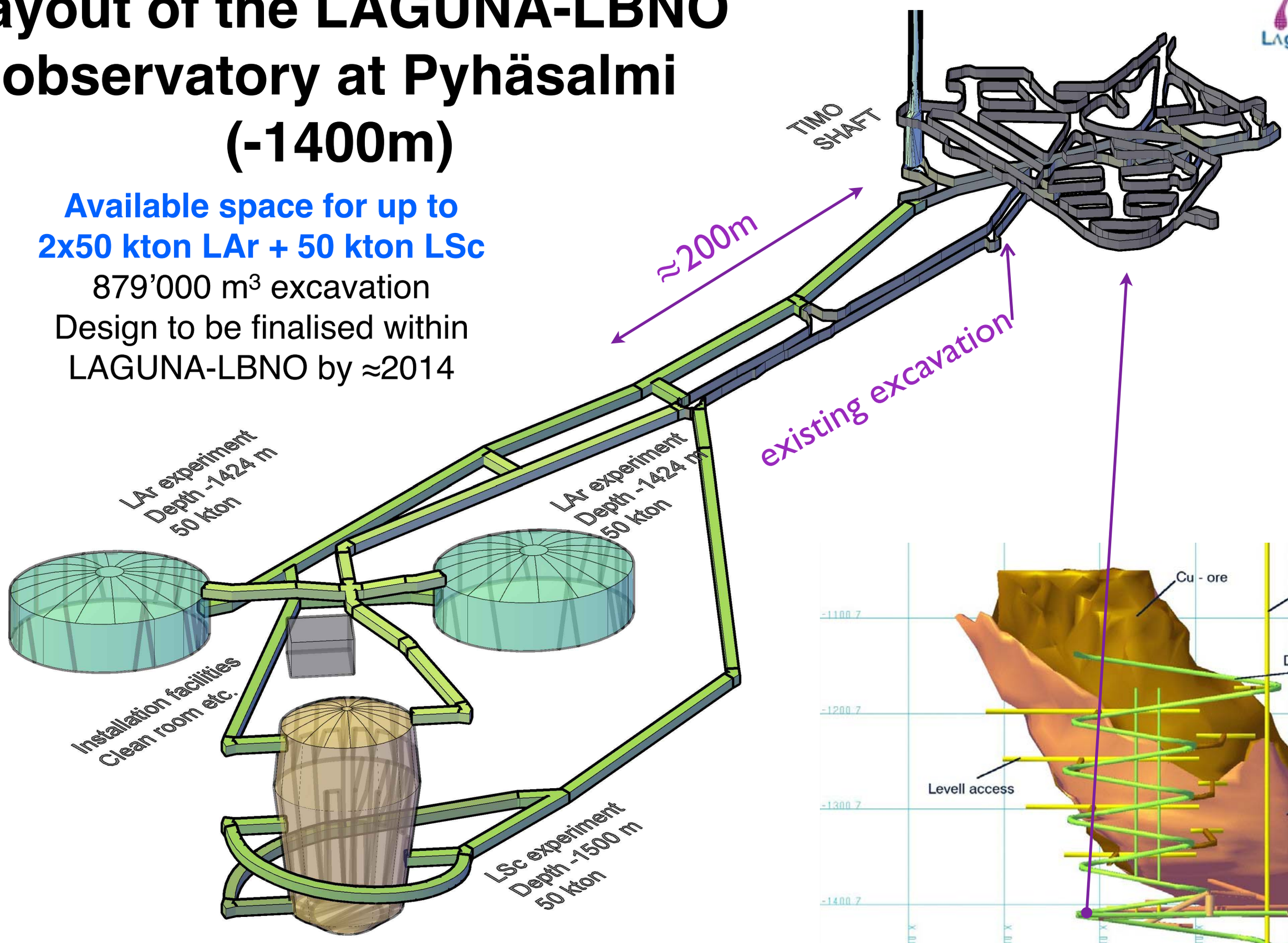
Mobile phones work and internet available also at 1400 m

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

Available space for up to 2x50 kton LAr + 50 kton LSc

879’000 m³ excavation

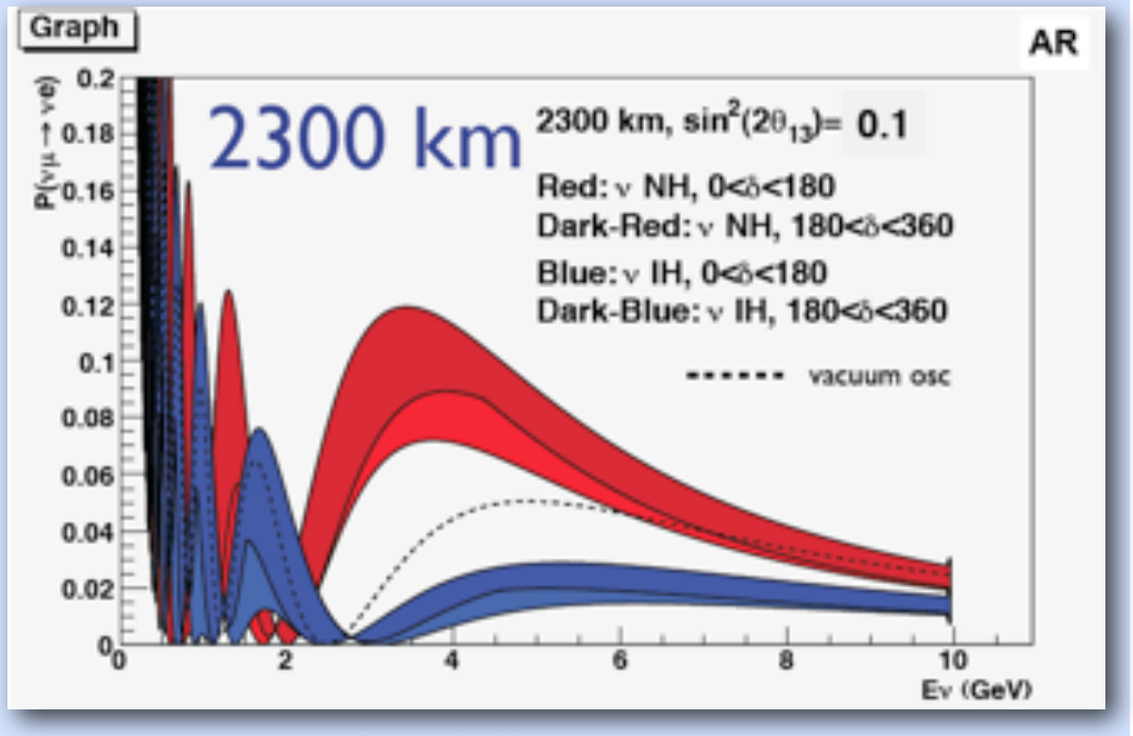
Design to be finalised within LAGUNA-LBNO by ≈2014



CERN ν-beam to Pyhäsalmi - CN2PY

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_ν]
  - 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

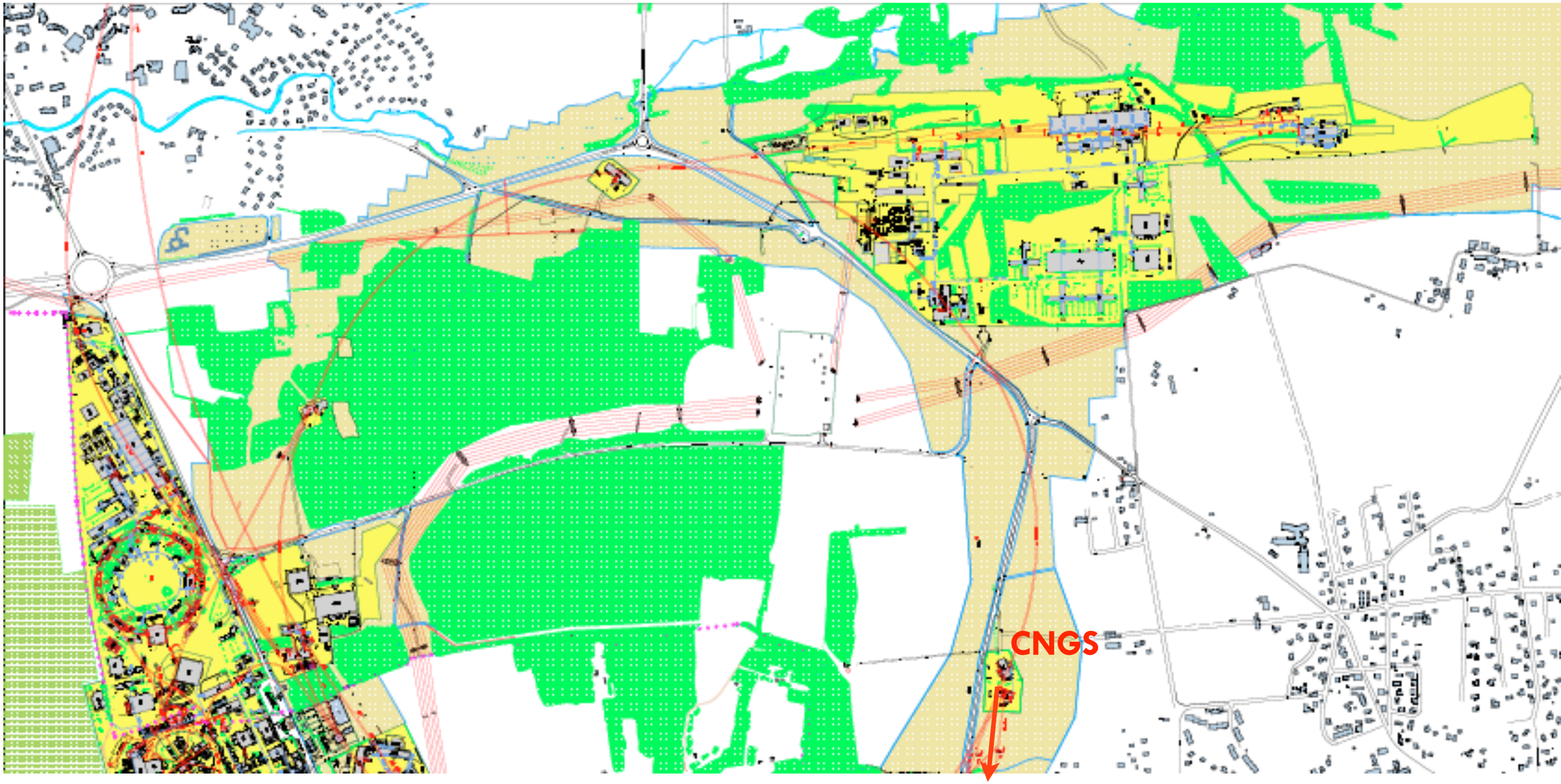


- Determine CP-violation and mass degeneracy by spectrum measurement and resolve degeneracies and so called "π-transit" effect
- arXiv:0908.3741.v1 for "Magic distance"

A. Rubbia, LAGUNA

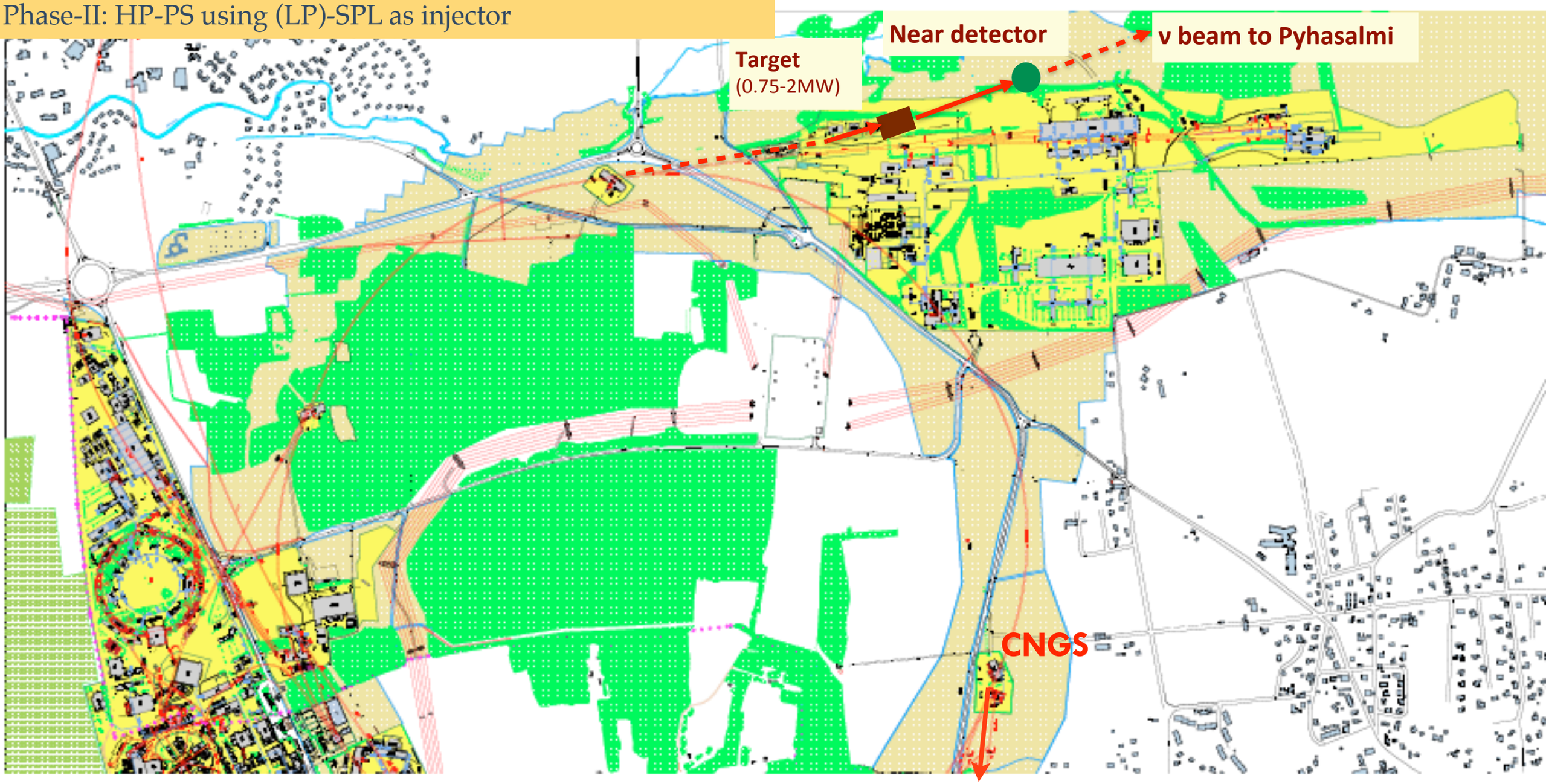
Work is progressing, highlights of present studies in the next slides....

CERN ν-beam to Pyhäsalmi - CN2PY Layout



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



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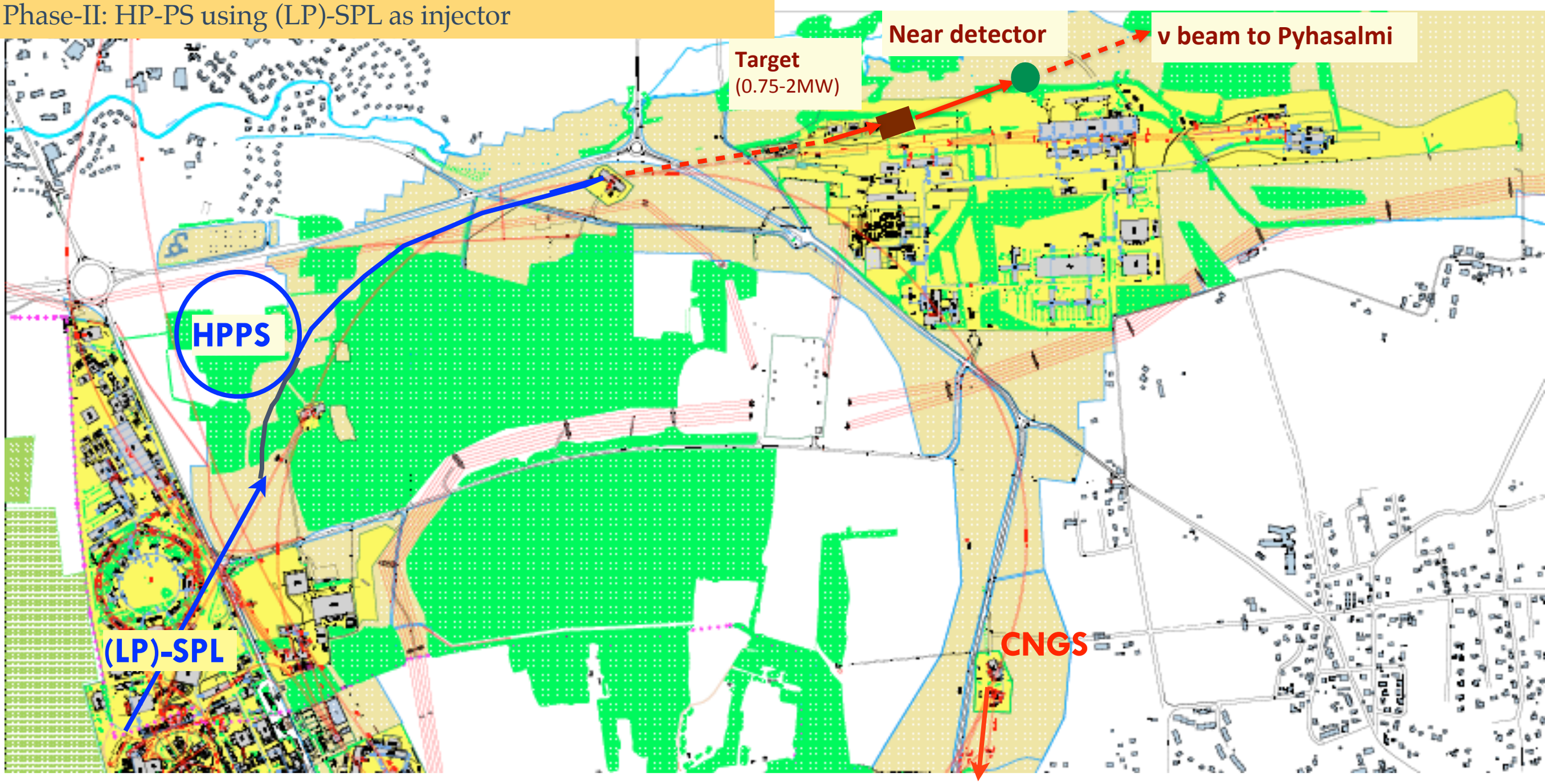
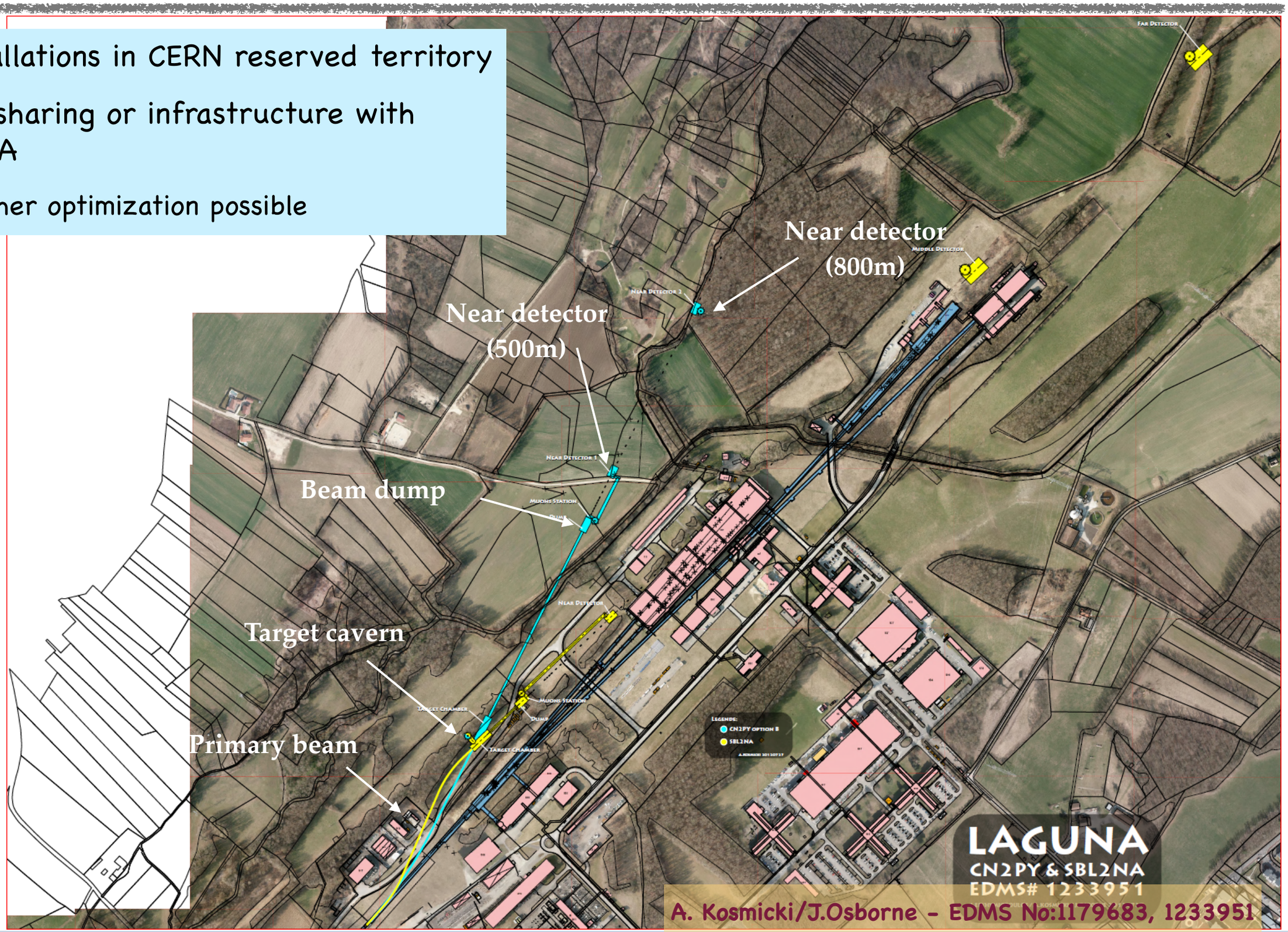


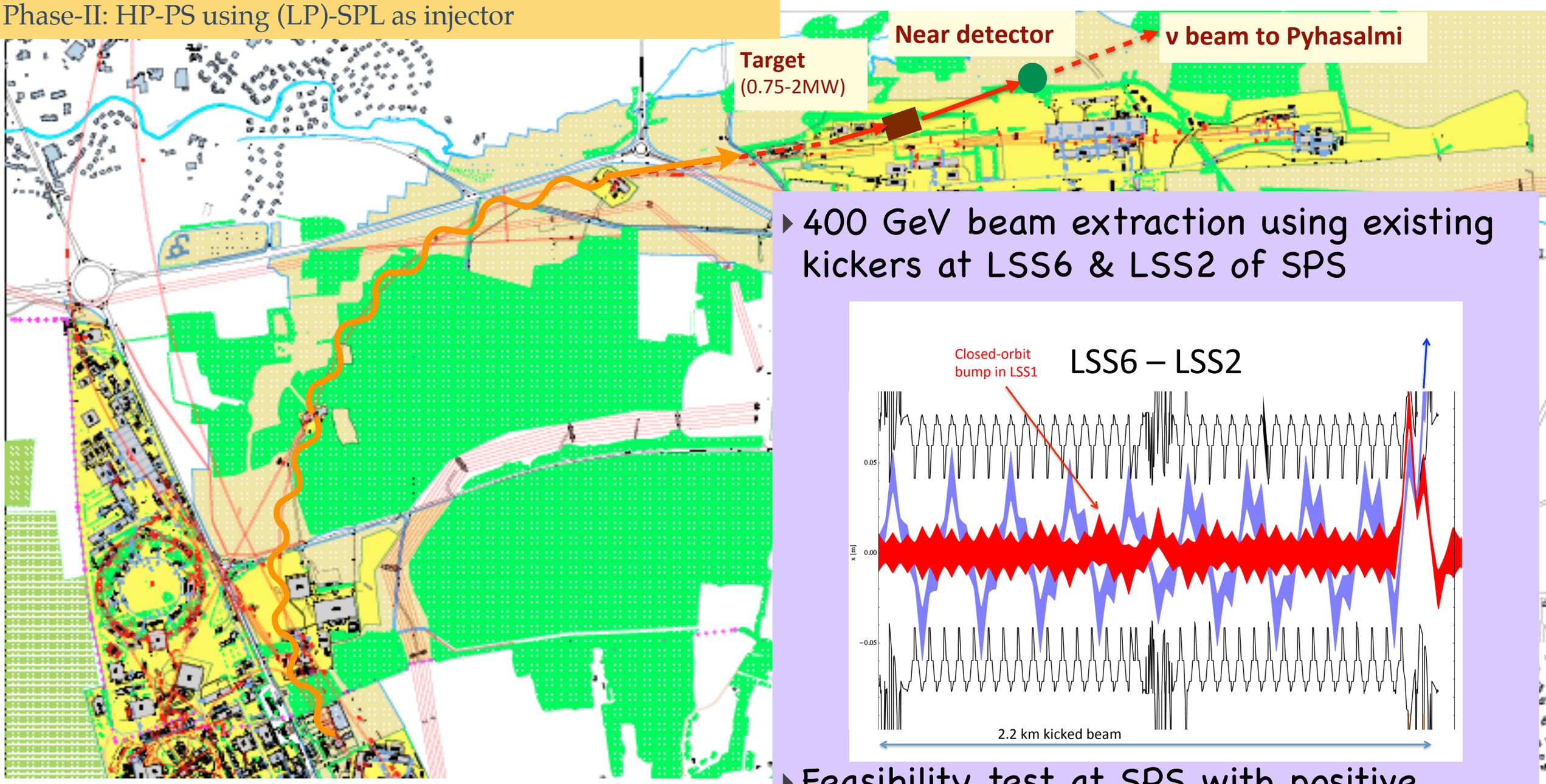
CN2PY (and SBL2NA) Layout in SPS North Area

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



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



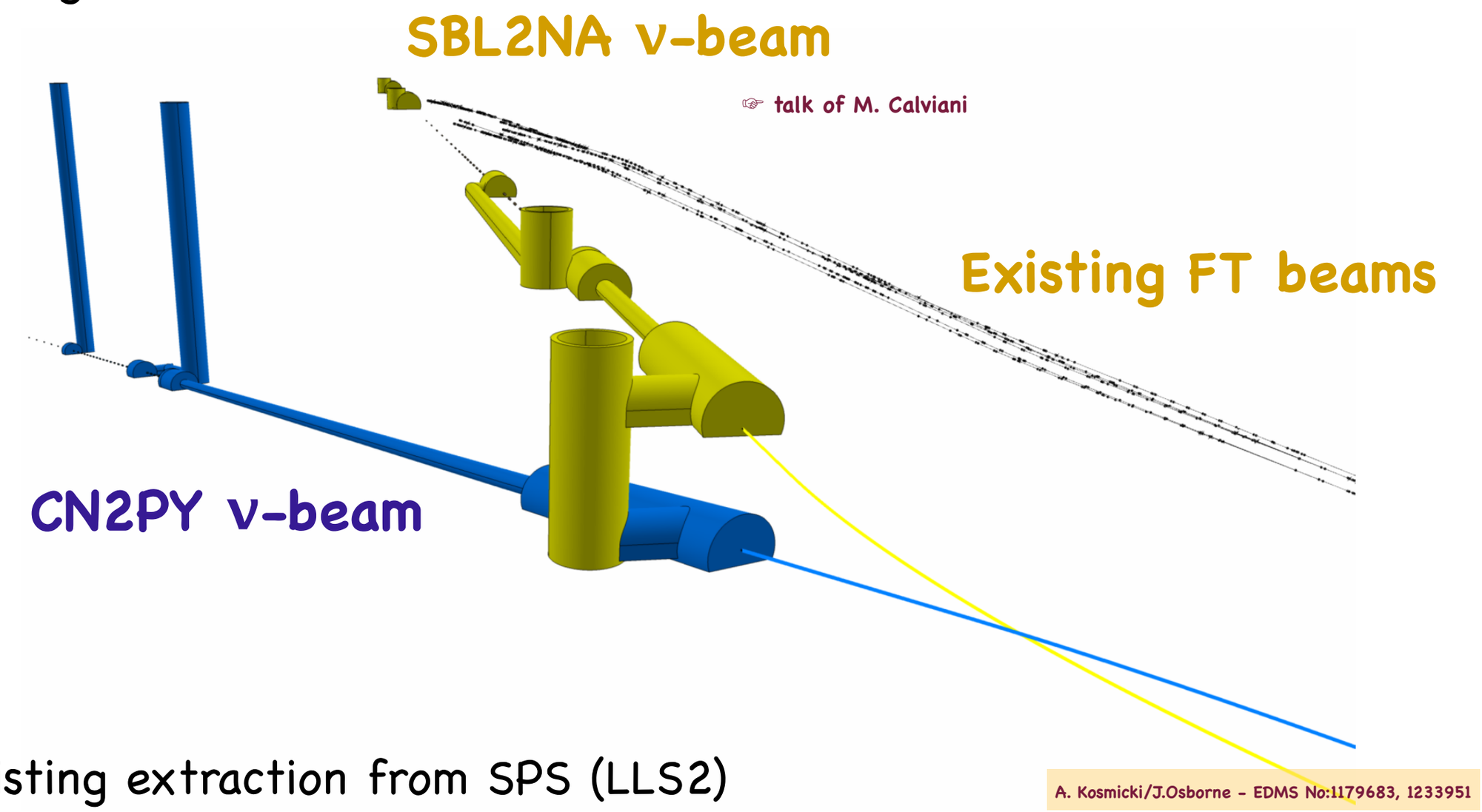
- 400 GeV beam extraction using existing kickers at LSS6 & LSS2 of SPS

- Feasibility test at SPS with positive results

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

CN2PY Layout in SPS North Area

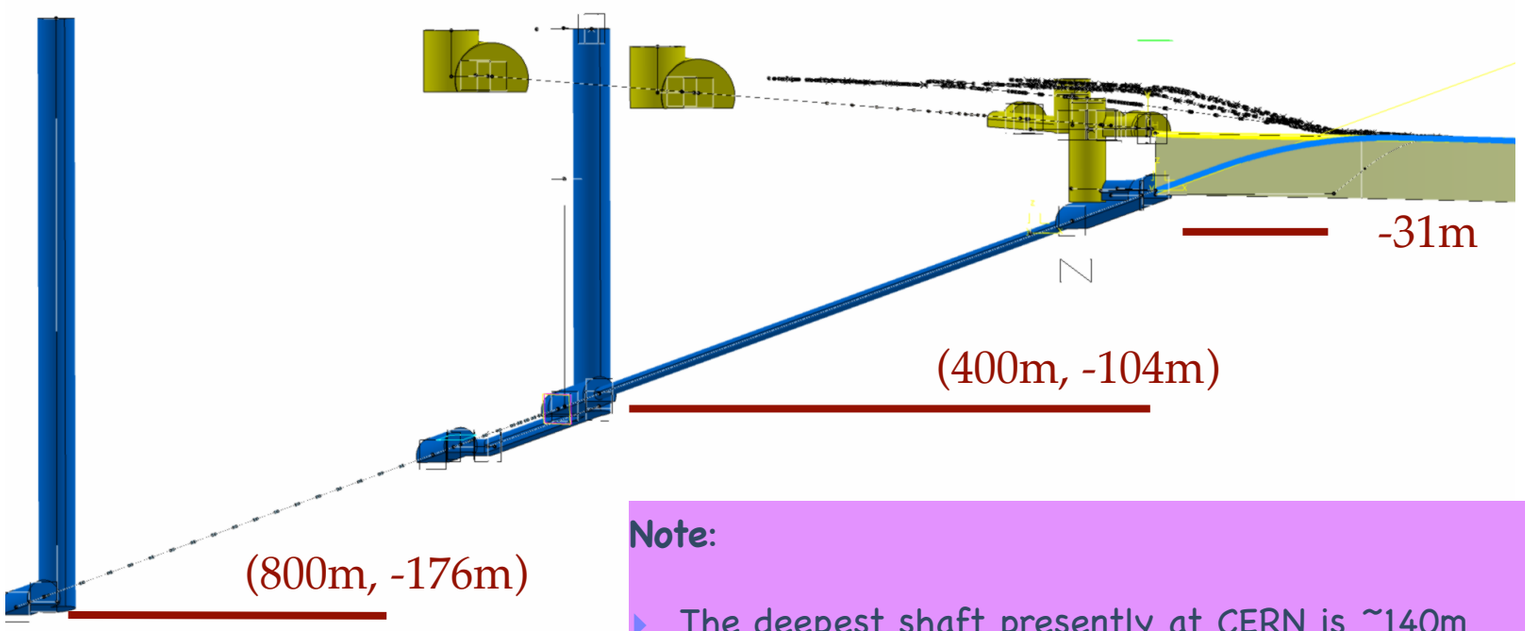
- Layout drawing



- 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, 5mrad upwards

CN2PY - Layout considerations

- The depth for the installations is the major concern
  - 18% slope compared to 5.6% for CNGS



CN2PY Beam - Generic Layout		
	Distance	Depth
Target	-	-31 m
Hadron stop	400 m	-104 m
Muon station	450 m	-113 m
Near detector	500 m	-122 m
Middle detector	830 m	-176 m

Note:

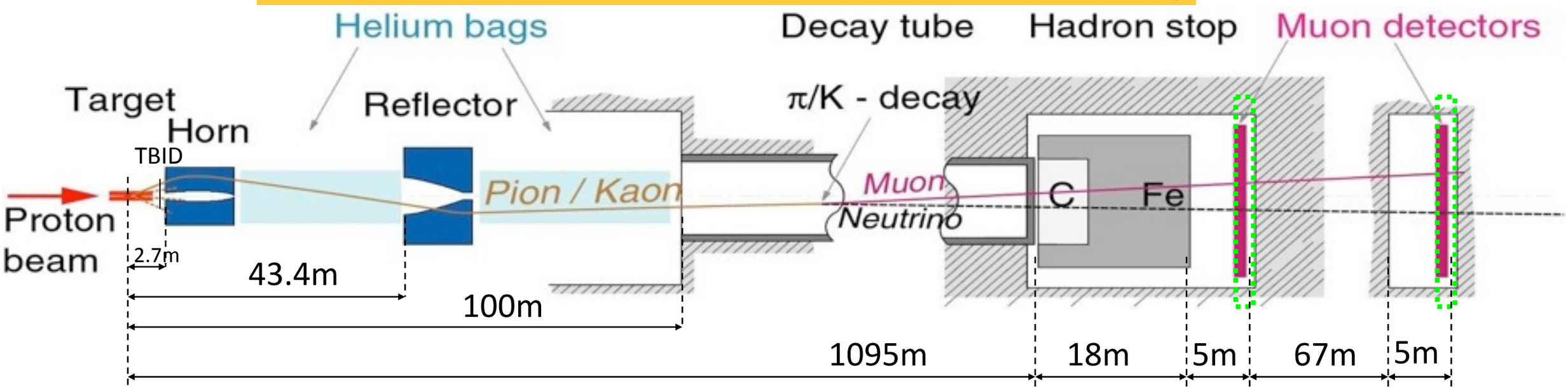
- The deepest shaft presently at CERN is ~140m (LHC/P4)
- these are **preliminary numbers**
- The exact values will be determined once the study of the proton line is finalized

- Starting the beam from the SPS level adds **~50m** to the depth of the installations
- Here we gain as we start from the end of TT20 line that is **~11m** 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

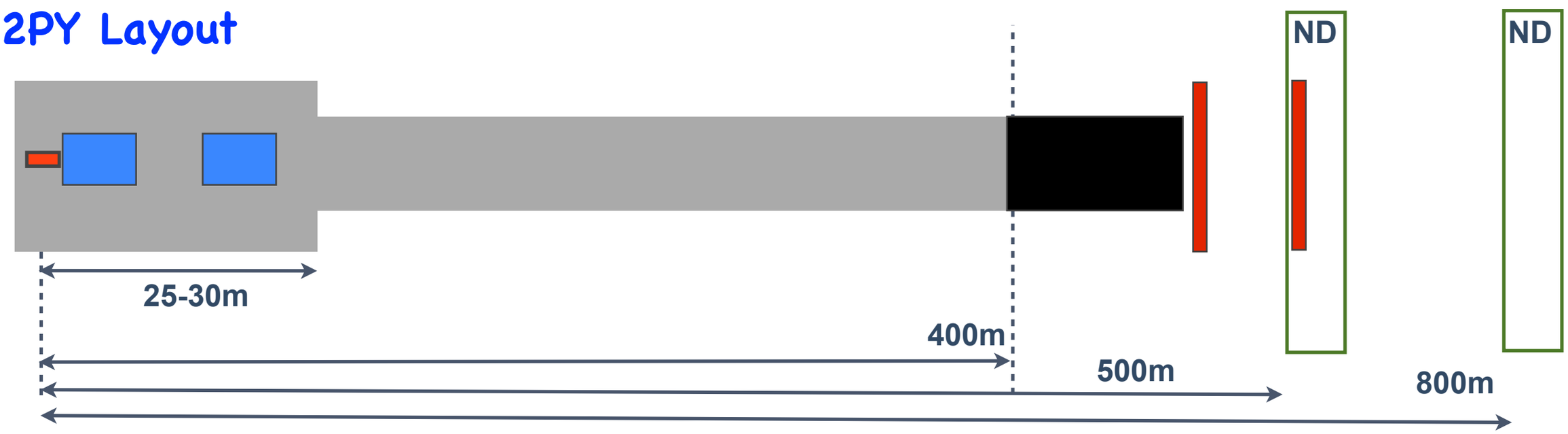
CN2PY - Layout considerations

CNGS Secondary Beam Layout

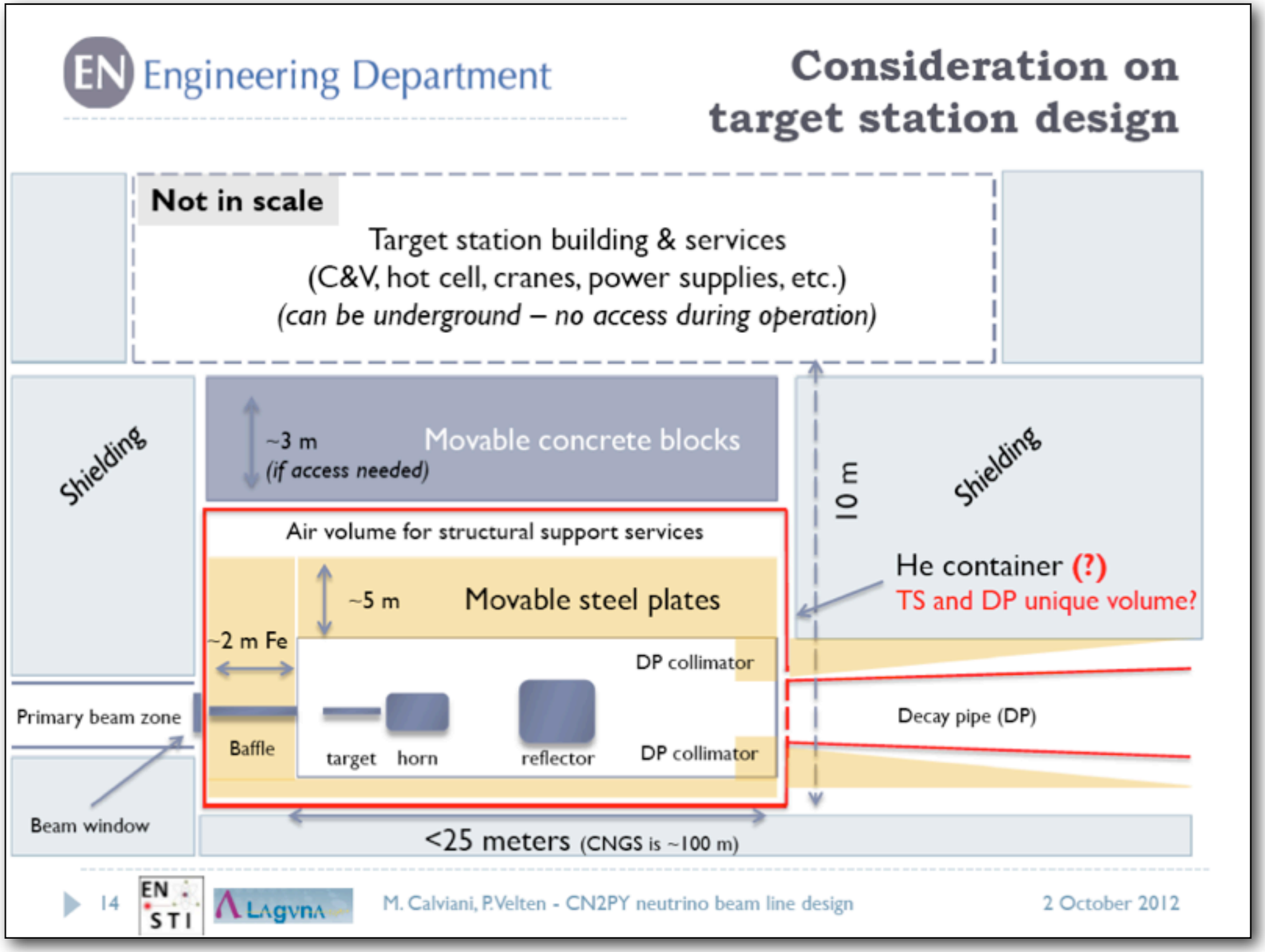
$p + C \rightarrow$ (interactions) $\rightarrow \pi^+, K^+ \rightarrow$ (decay) $\rightarrow \mu^+ + \nu_\mu$



CN2PY Layout



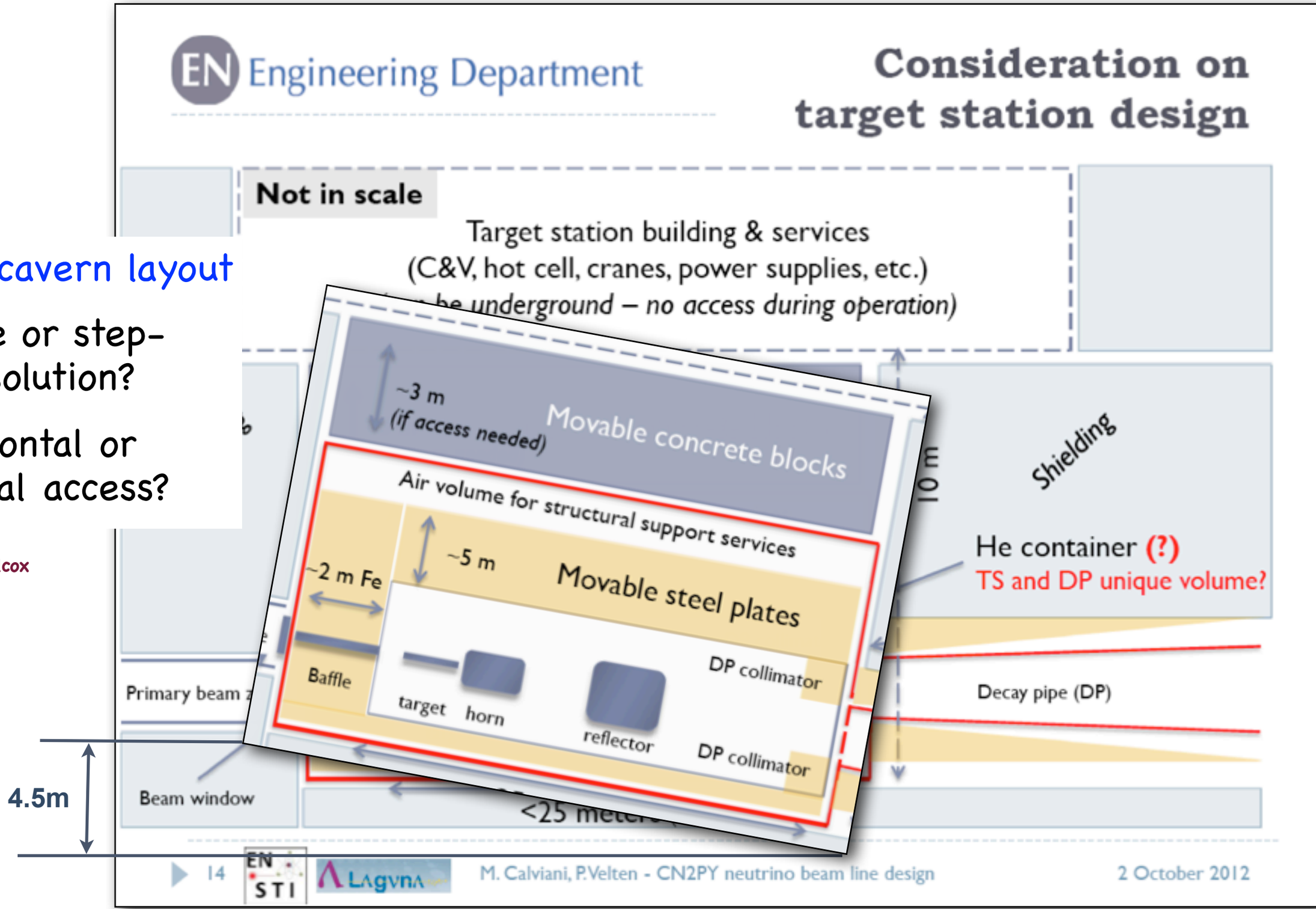
CN2PY Target Cavern Layout



CN2PY Target Cavern Layout

- target cavern layout
  - single or step-wise solution?
  - horizontal or vertical access?

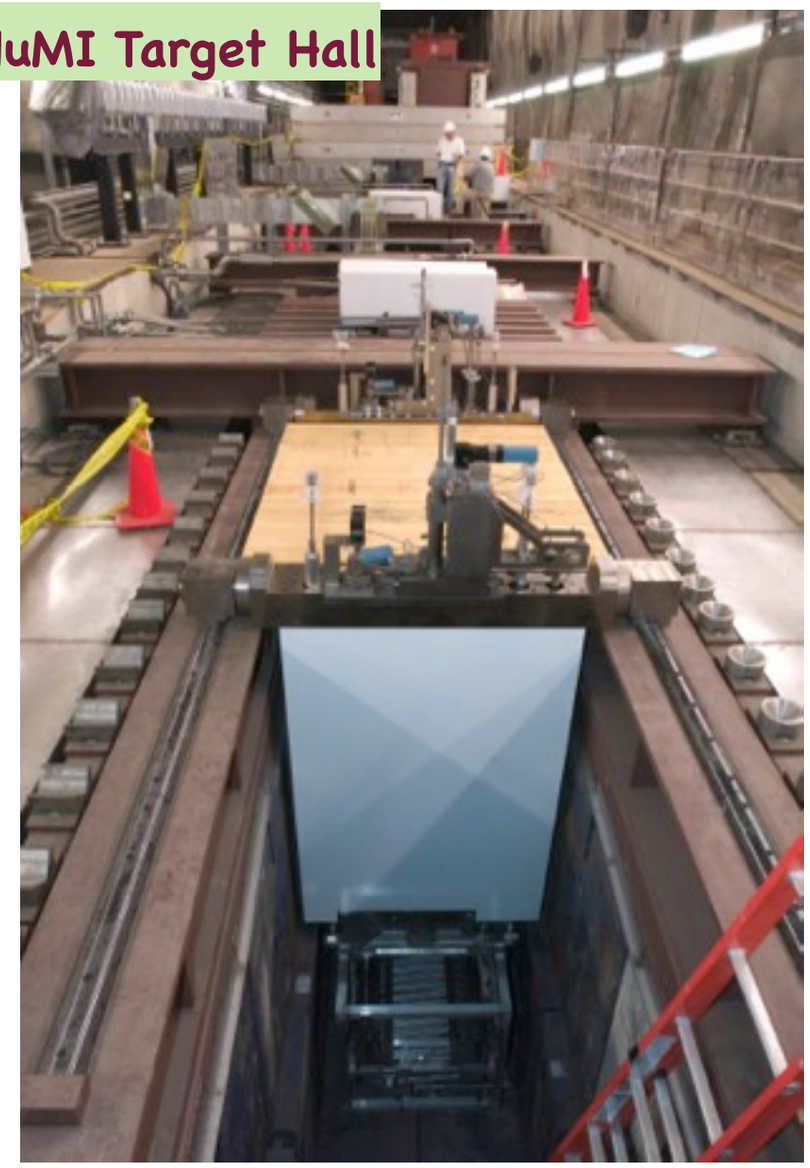
☞ talk of D. Wilcox



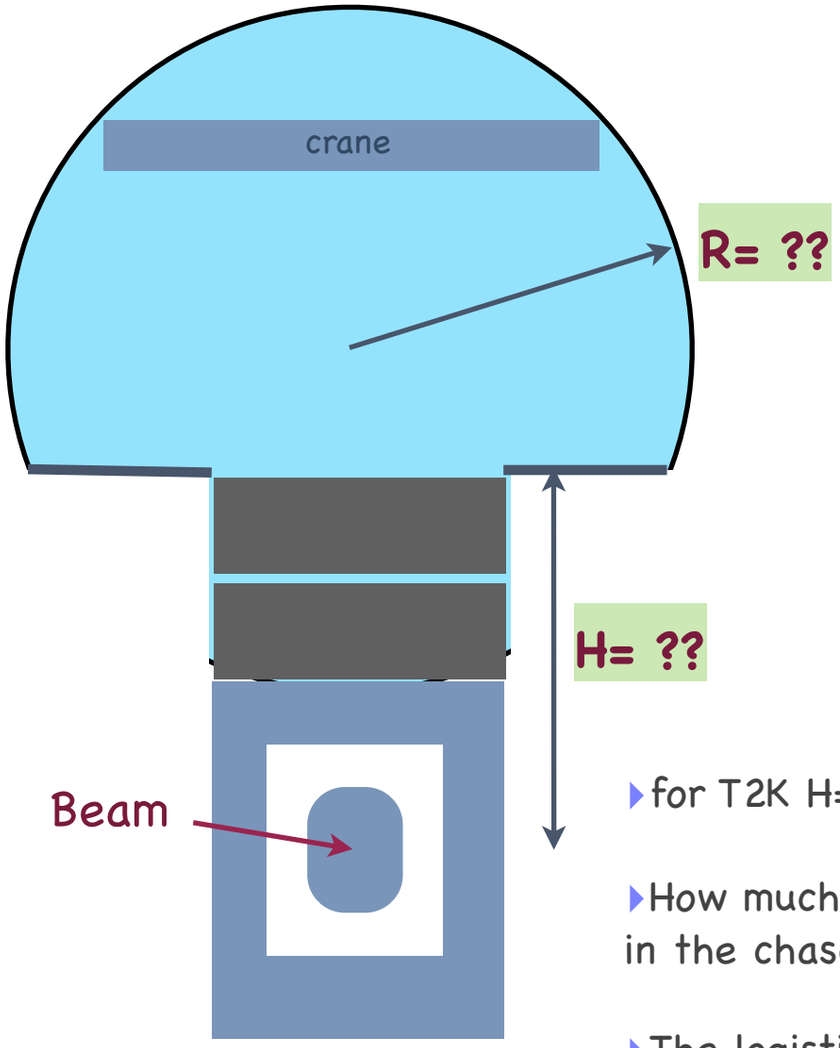
CERN ν-beam to Pyhäsalmi - Layout Considerations

- 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

NuMI Target Hall



J. Hylen/FNAL - NBI10



- for T2K H=~16m
- 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!

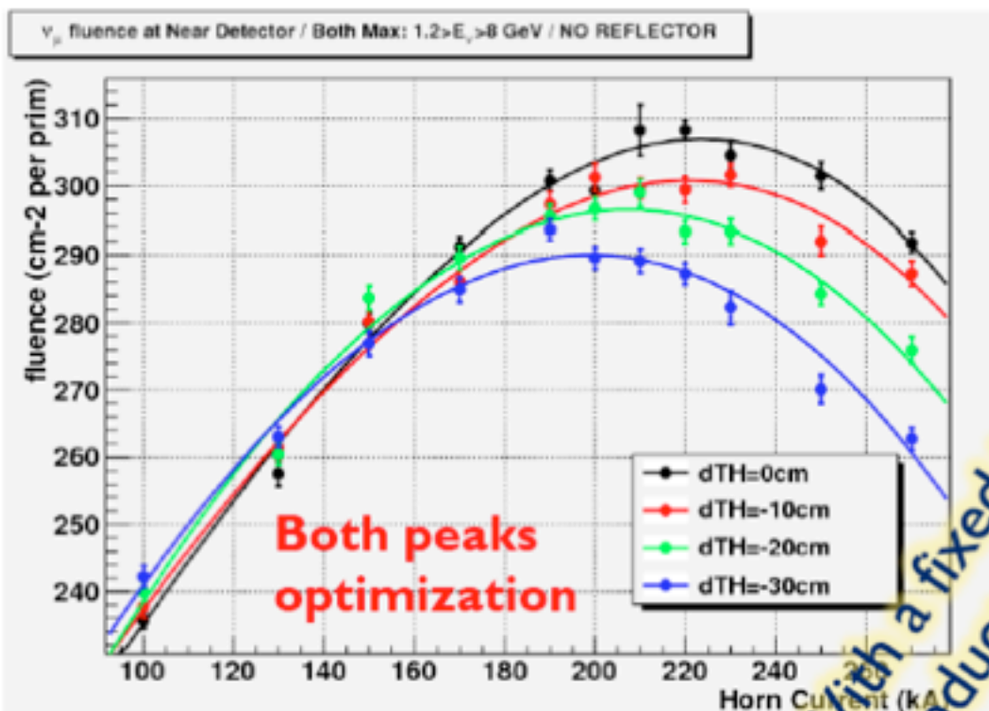
CN2PY - Horn Optimization Studies

EN Engineering Department

Horn/reflector studies

- Effect of relative distance between **target/horn**

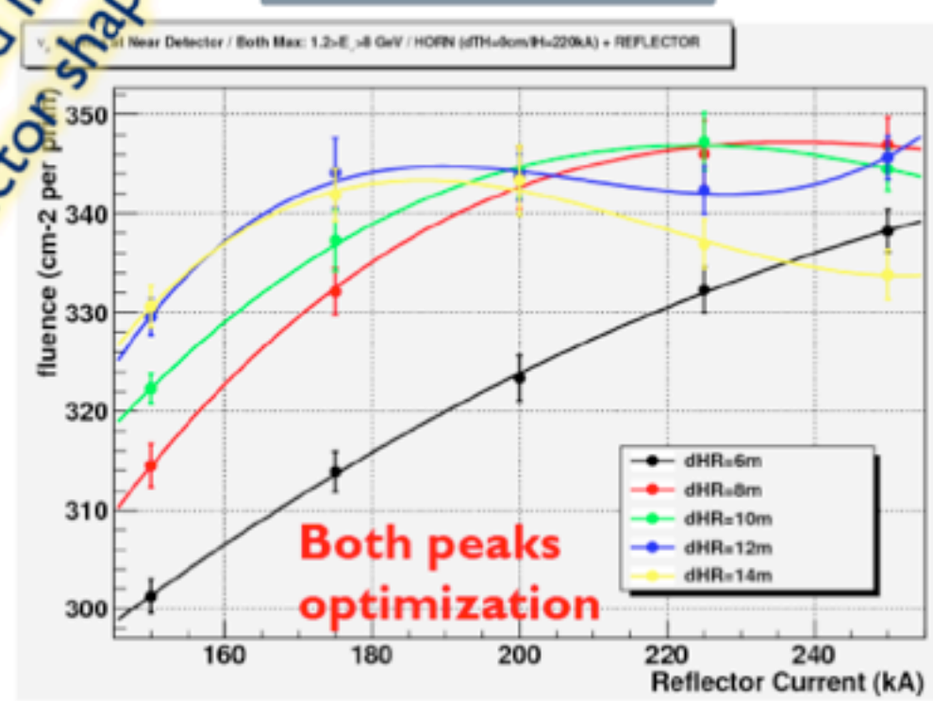
Horn configuration:
d_{TH}=0 cm
I_H=220 kA



With a fixed inner conductor shape

- Effect of relative distance between **horn/reflector**

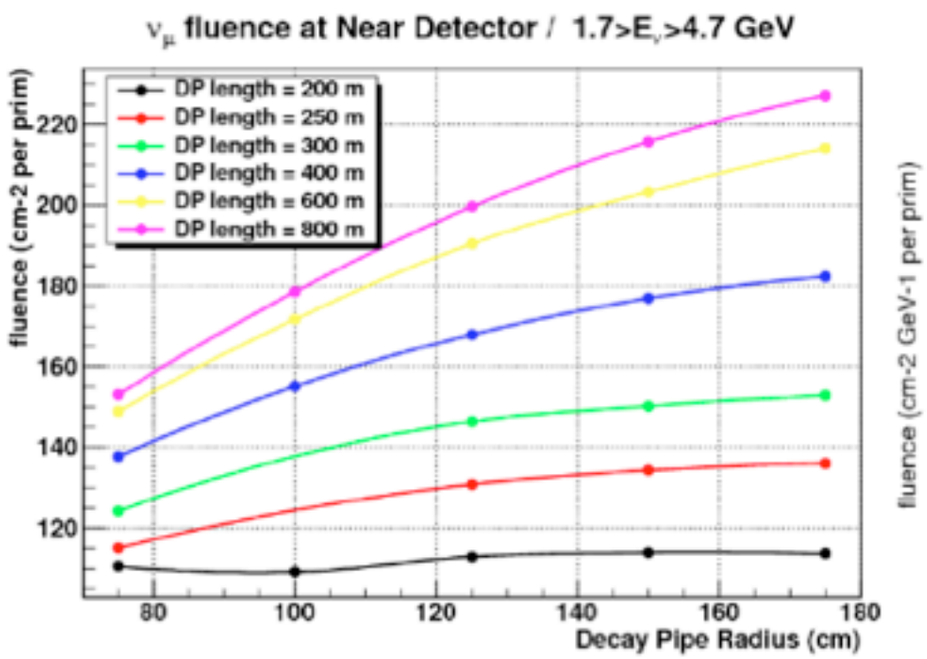
Reflector configuration:
d_{HR}=10 m
I_R=220 kA

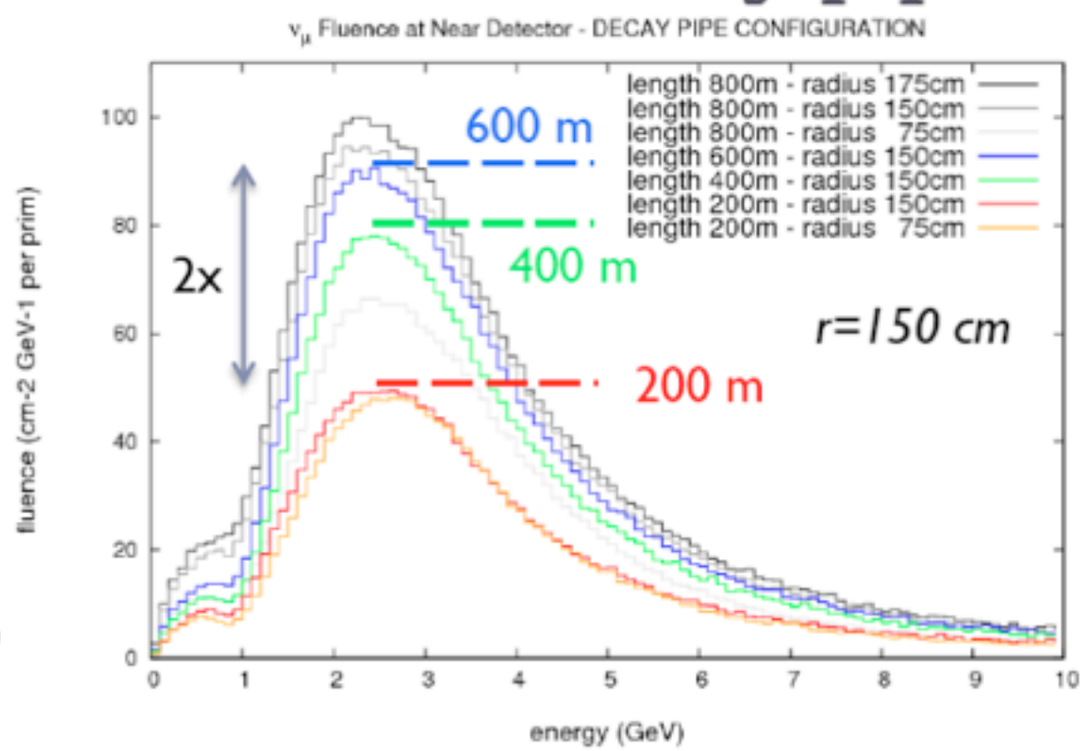


CN2PY - Horn Optimization Studies

EN Engineering Department

Decay pipe





- Higher ν_μ fluence for longer DP (~saturation for r>1.5m)
- The longer the DP, the larger the fraction of high-energy ν
- DP length partly imposed by the μ fluence in the ND!
- ...And by costs!

Potential DP configuration
r_{DP}=1.5 m, L_{DP} ≤300 m

CNGS
r_{DP}=1.2 m, L_{DP}=1100 m

21 EN STI LAGUNA M. Calviani, P.Velten - CN2PY neutrino beam line design 2 October 2012

CN2PY Beam - Beam from SPS

Present and future SPS performance
(in terms of beam power)

	Operation		SPS record		After LIU (2020)	
					Aim	Study
	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	1.2/2.4*
SPS cycle length [s]	21.6	6.0	21.6	6.0	21.6	6.0/7.2
SPS average current [μA]	0.17	1.17	0.28	1.4	0.47	1.9/1.6
SPS power [kW]	77	470	125	565	211	747/622

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

2/10/2012 2

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CN2PY Beam - Beam from SPS

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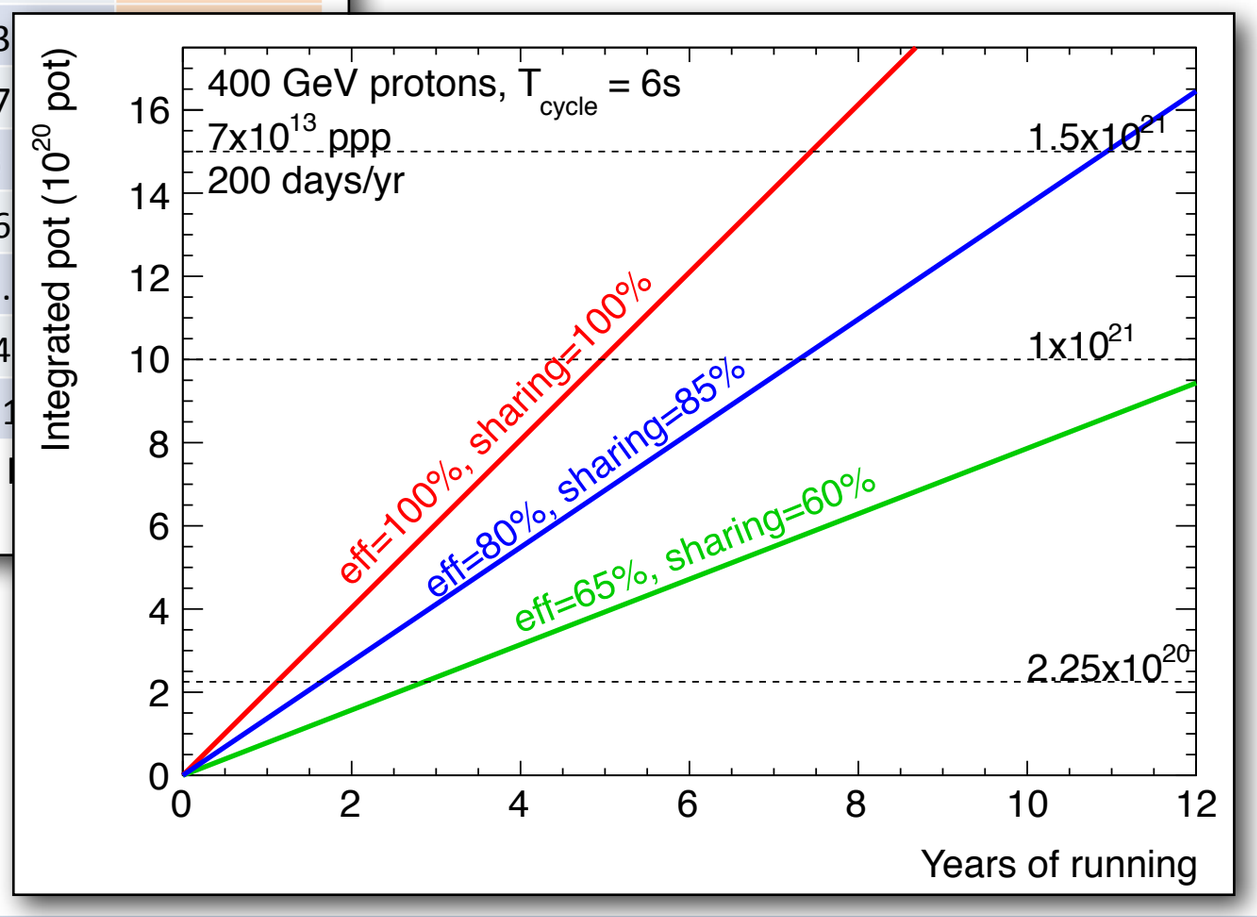
2/10/2012



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Beam Intensity Upgrades - HP-PS

Preliminary !

$$P = q f_r N_p E_k$$

Parameters	PS2	HP-PSa	HP-PSb	HP-PSc	HP-PSd
Circumference [m]	1346.4	**1256**	1009	763	**1256**
Symmetry	2-fold	**3 / 4-fold**			
Beam Power [MW]	0.37	**2.0**			
Repetition rate [Hz]	0.42	**2**	2	2.6	**1.3**
Kinetic Energy @ inj./ext. [GeV]	4/50	**4/50**	4/40	4/30	**4/50**
Protons/pulse [10^{14}]	1.1	**1.25**	1.6	1.6	**1.9**
Dipole ramp rate [T/s]	1.4	**6.1**	6.0	7.5	**4.0**
Bending field @ inj/ext. [T]	0.17/1.7	**0.17/1.7**	0.21/1.7	0.27/1.7	**0.17/1.7**
Fractional beam loss [10^{-4}]	35.1	**6.5**	5.0	4.0	**6.5**
Space-charge tune-shift H/V	-0.13/-0.2	**-0.2/-0.2**			
Lattice type	NMC arc, doublet LSS and DS	**Resonant NMC arc, doublet LSS**			
Norm. emit. H/V [μm]	9/6	**6.8/6.7**	8.6/8.5	11/11	**10.5/10.3**
Max. beta H/V [m]	**60/60**				
Max. dispersion [m]	3.2	**5**			

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

CN2PY - Upgrade option HP-PS

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

Parameters	SF HP-PS
Circumference [m]	1093
Symmetry	3 / 4-fold
Beam Power [MW]	2.0
Repetition rate [Hz]	1.3
Kinetic Energy @ inj./ext. [GeV]	4/50
Protons/pulse [10^{14}]	2.5
Dipole ramp rate [T/s]	3.1
Bending field @ inj/ext. [T]	0.21/2.1
Gamma transition	46.5i
Lattice type	Resonant NMC arc, doublet LSS
Norm. emit. H/V [μm]	TBD
Max. beta H/V [m]	44.6/53.7
Max. dispersion [m]	4.3

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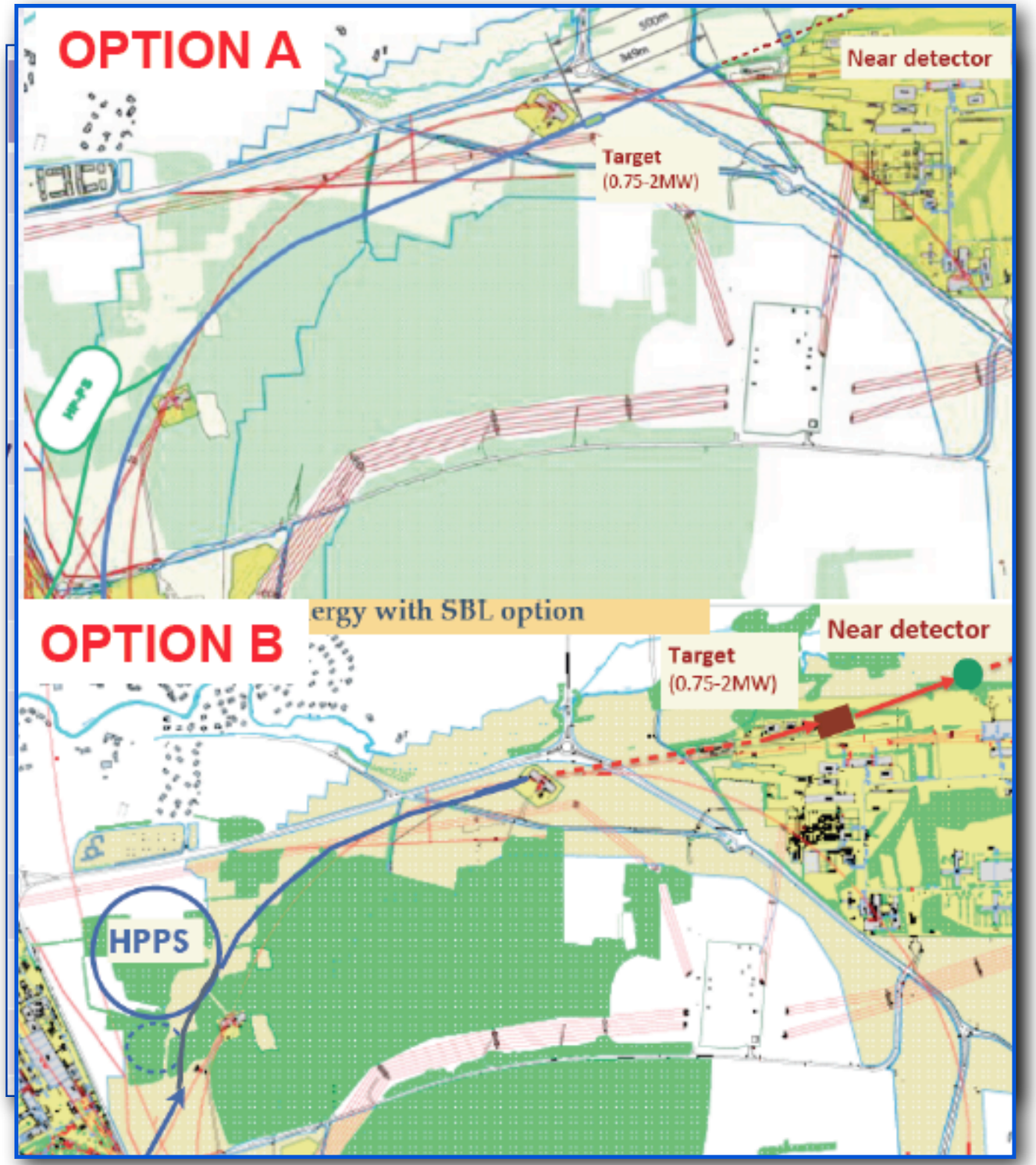

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Summary

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

Summary

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

from South ...

Summary

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

to North?

from South ...