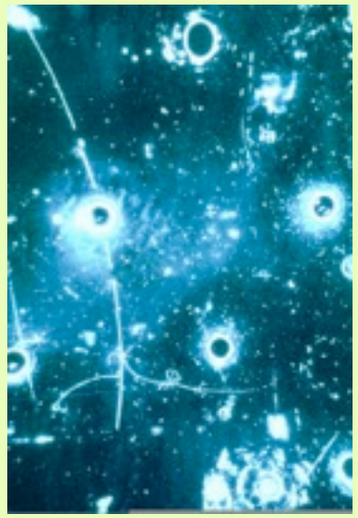
Opportunities for ν-beams at CERN

...with feedback from many colleagues - **thanks!**

ν-beams at CERN

ν-beams at CERN

The Legacy



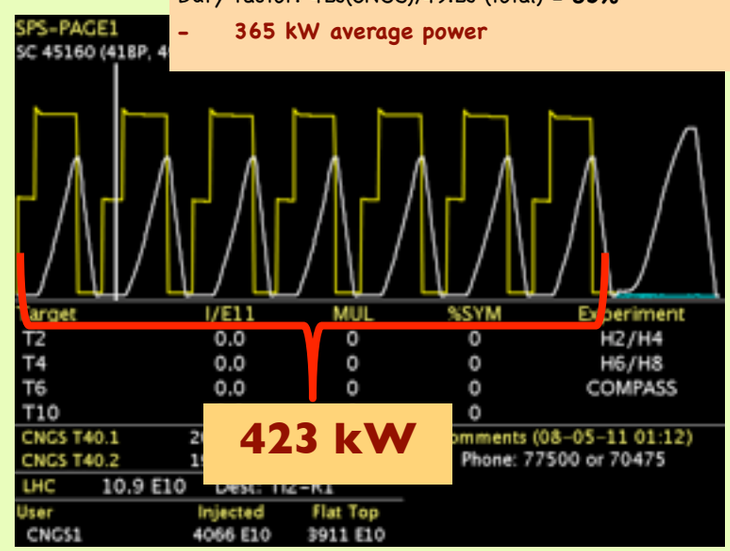
ν-beams at CERN

The Legacy

The Present

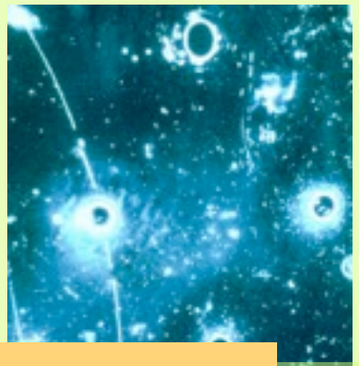
Duty factor: 42s(CNGS)/49.2s (total) = **85%**

- **365 kW average power**

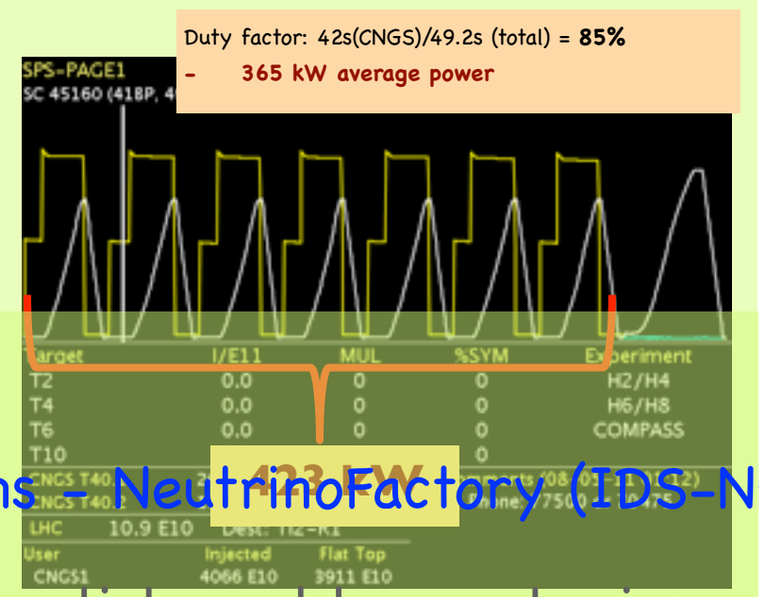


ν-beams at CERN

The Legacy



The Present

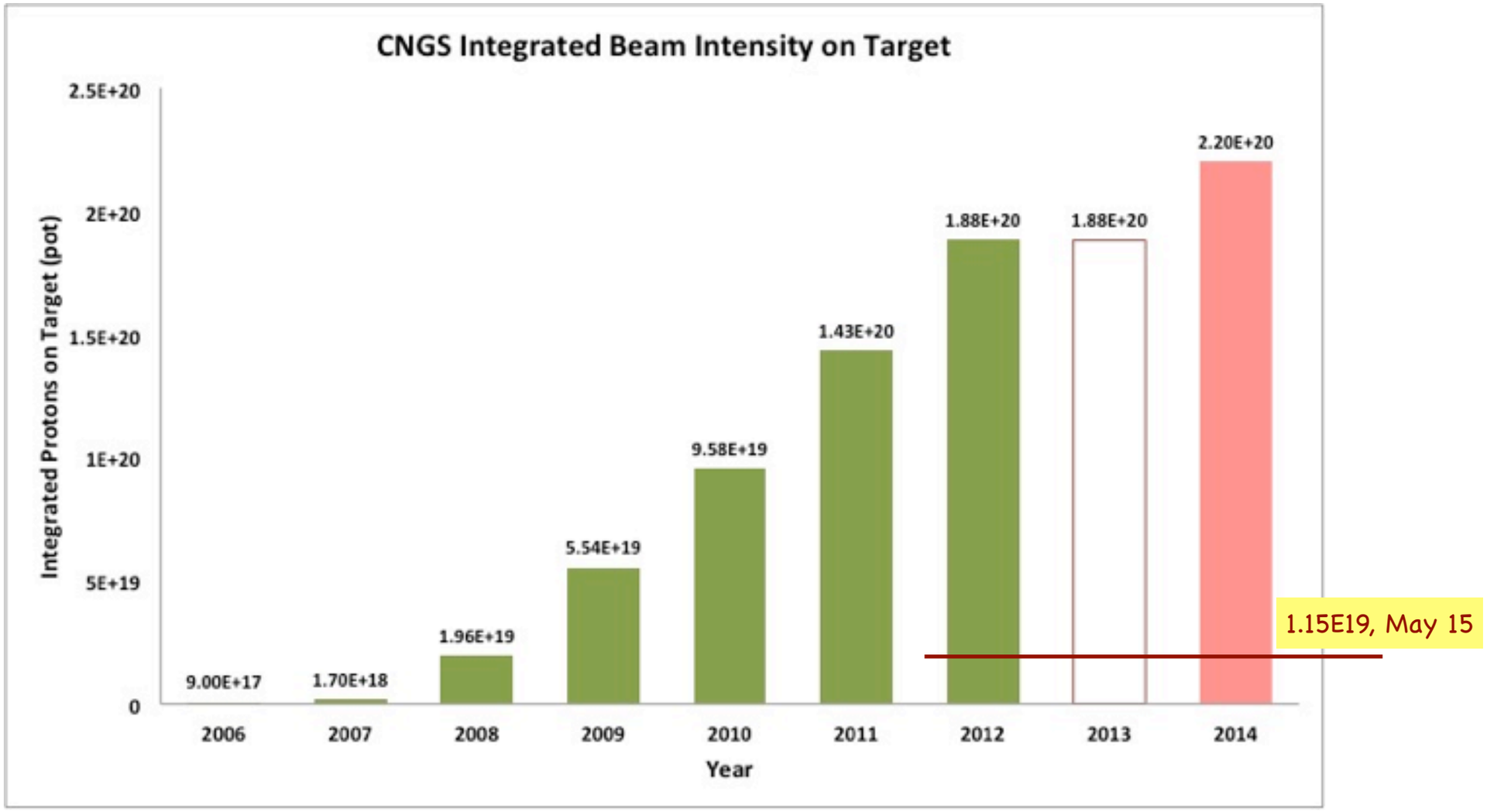


The Future

- Design Studies
  - **EUROν**/FP7 (2008-2012) : SuperBeams - BetaBeams - NeutrinoFactory (IDS-NF)
  - **LAGUNA**/FP7 (2008-2011) : Far detector for astroparticle and beam physics
  - **LAGUNA_LBNO**/FP7 (20011-2014) : LAGUNA + Beam from CERN
    - Incremental Approach towards a ~2MW LBL ν-beam facility ⇒ LBNO LoI in preparation
- ν-experiment proposal
  - **Short-baseline** neutrino Beam at CERN/SPS - sterile neutrinos

The CNGS ν-beam - Status & Plans

- At the end of 2012 CNGS should reach **1.88 × 10^{20} pot**
  - to complete the presently approved program **(5y × 4.5 10^{19} pot/y = 2.2 10^{20} pot)** running in 2014 will be required
- decision to continue or not beyond LS1 still pending



CNGS Technology - Lessons learned

- The design and operation of a high-intensity, high-power beam facility is always very challenging

- **Design**
  - choice of **materials**, **layout**, **shielding**, **radiation** environment
  - technical challenges during **construction**

- **Operation**
  - possibility for **early repairs** must be included in the design
  - radiation effects on **proximity electronics** should not be ignored
  - the target area **ventilation system** is a key element with double challenge:
    - temperature/humidity control and management of the radioactive air
  - **H-3 creation** (air, water) should not be forgotten
    - **civil engineering & layout** are key elements for the operation of the facility

- **Important experience, in view of future facilities with (M)MW of beam power**

CNGS Technology - Upgrades?

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Today :

- **SPS a key asset for CERN**
  - 450 kW nominal beam power today
    - 4.0 10^{13} prot @ 400 GeV, 6s cycle
    - 4.5÷4.7 10^{19} pot/y achieved

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Future-I (>LS2, ~2018) :

- **SPS upgrade potential**
  - 750 kW nominal beam power
    - 7.0 10^{13} prot @ 400 GeV, 6s cycle
    - 0.8÷1.3 10^{20} pot/year

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- **SPS upgrade potential**
  - 750 kW nominal beam power
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    - 0.8÷1.3 10^{20} pot/year

Future-II (>2025?)

- **HP-PS: a dedicated proton source**
  - provide 1.6 MW @ 30-50 GeV

Beam Intensity Upgrades - Injectors (PSB, PS, SPS)

E. Shaposhnikova, R. Garoby - LiU-LLBNO/CERN

- **Present limitations:**
  - PSB-to-PS injection, losses
    - controls
  - PS-to-SPS extraction, losses
    - MTE, bunch to bucket injection
  - SPS RF power
    - additional RF cavities
    - injection beyond transition
  - Shielding in PS
    - ongoing

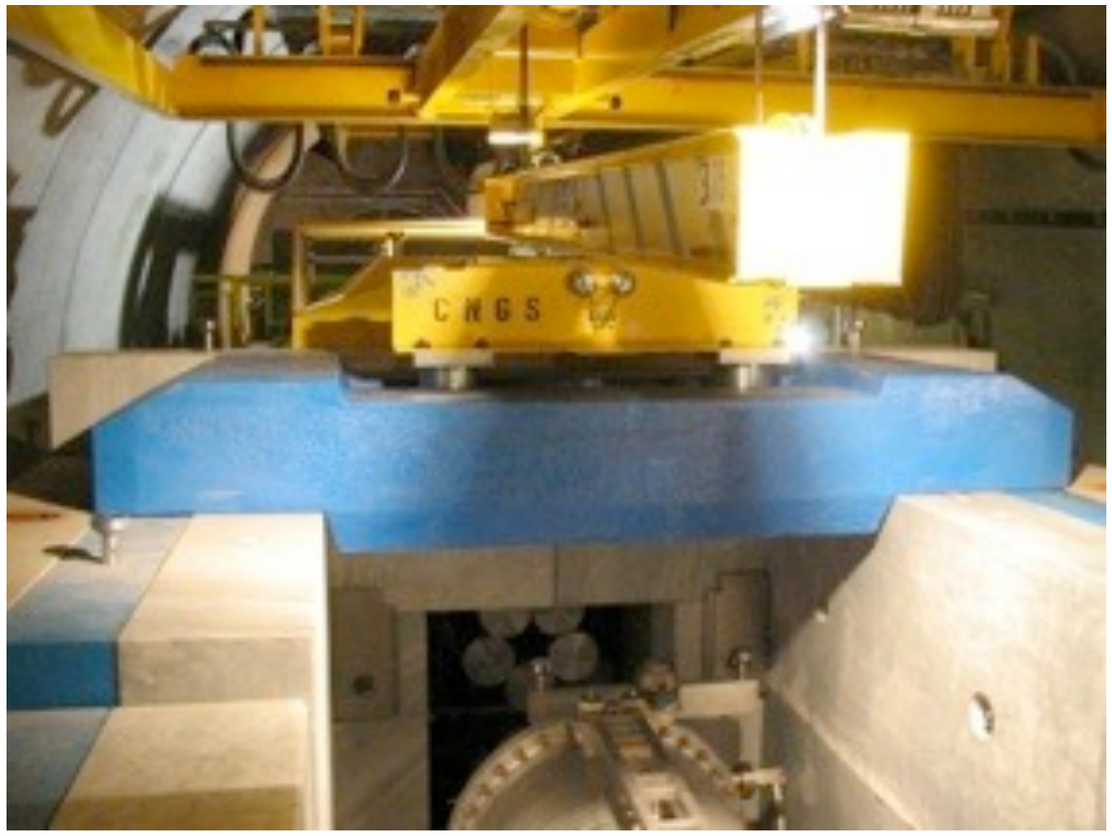
Parameters	SPS record at 450 GeV		HL-LHC at 450 GeV	
	LHC	CNGS	I	II
bunch spacing [ns]	25	5	25	50
bunch intensity /10^{11}	1.3	0.13	2.2	3.6
number of bunches	288	4200	288	144
total intensity /10^{13}	3.7	**5.3**	**6.3**	5.2
long. emittance [eVs]	0.7	0.8	0.8	0.9
norm. H/V emitt. [μm]	3.0	8/5	2.5	3.0

- Studies ongoing to understand the limits and identify possible upgrade options
  - constraint : maintain the machine performance for LHC beams

- Aim to reach **~750kW** of nominal beam power (7.0E13, 6s cycle)

CNGS Beam Upgrades ? (1)

- Target station design with large cavern
- Optimized shielding and services (crane, etc.)
- However difficult to imagine could suffice for MW class beams
  - air volume around the target --> H3 production
  - still lot of equipment in a very "hot" environment



CNGS Beam Upgrades ? (2)

- **Limitations:**
  - key elements of the secondary beam line to increased beam power: **target**, **horns**, **beam windows**
  - **layout** and **RP** considerations (impact to environment - beam permit?), SPS RF and beam extraction system

- **Considerations** - to be further studied depending on physics program:
  - new target/horn optimization for new (lower) energy
  - near detector, optimized(?) decay pipe length, beam dump

Int. per PS batch	# PS batches	Int. per SPS cycle	200 days, 100% efficiency, no sharing	200 days, 55% efficiency, no sharing	200 days, 55% efficiency, 60% CNGS sharing
		[prot./6s cycle]	[pot/year]	[pot/year]	[pot/year]
2.4×10^{13} - Nominal CNGS	2	4.8×10^{13}	**1.38×10^{20}**	**7.6×10^{19}**	**4.56×10^{19}**
3.5×10^{13} - Ultimate CNGS	2	**7.0×10^{13}**	2.02×10^{20}	1.11×10^{20}	6.65×10^{19}

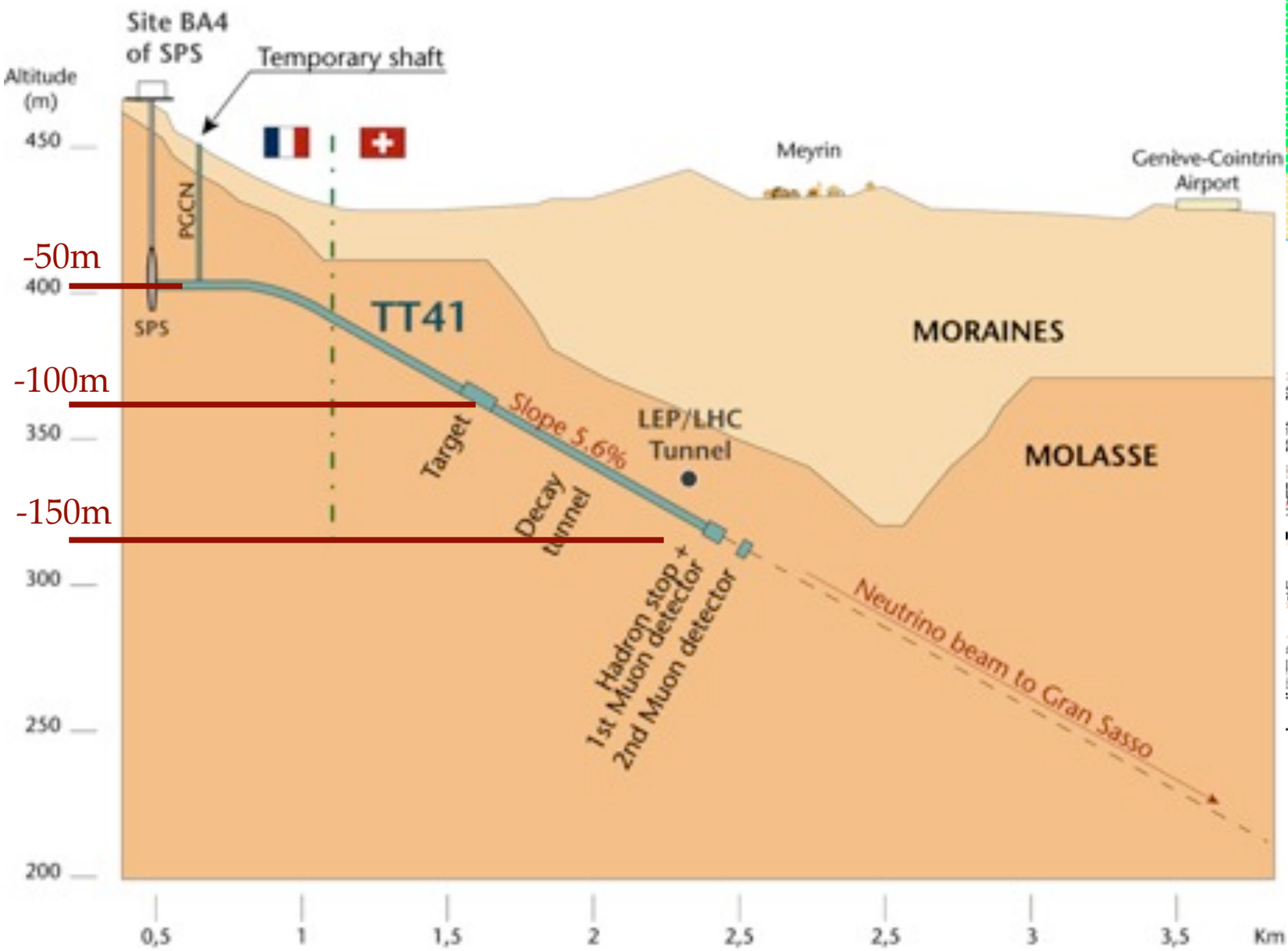
M.Meddahi, E.Schaposnicova - CERN-AB-2007-013 PAF

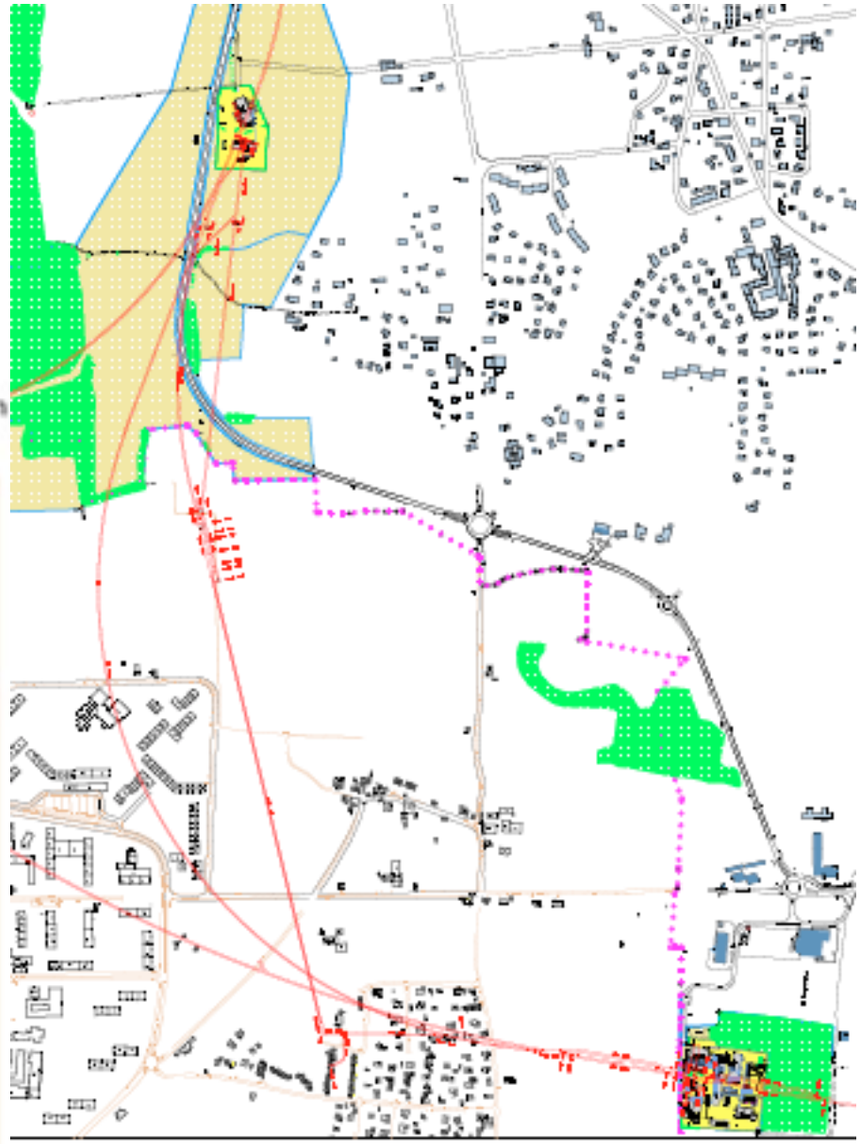
750kW design limit for the target head

working hypothesis for RP calculations

CNGS Beam Upgrades ? (3)

- Near detector location under Meyrin/Airport
- Access via LHC/Point-8





CNGS Beam Upgrades ? (4)

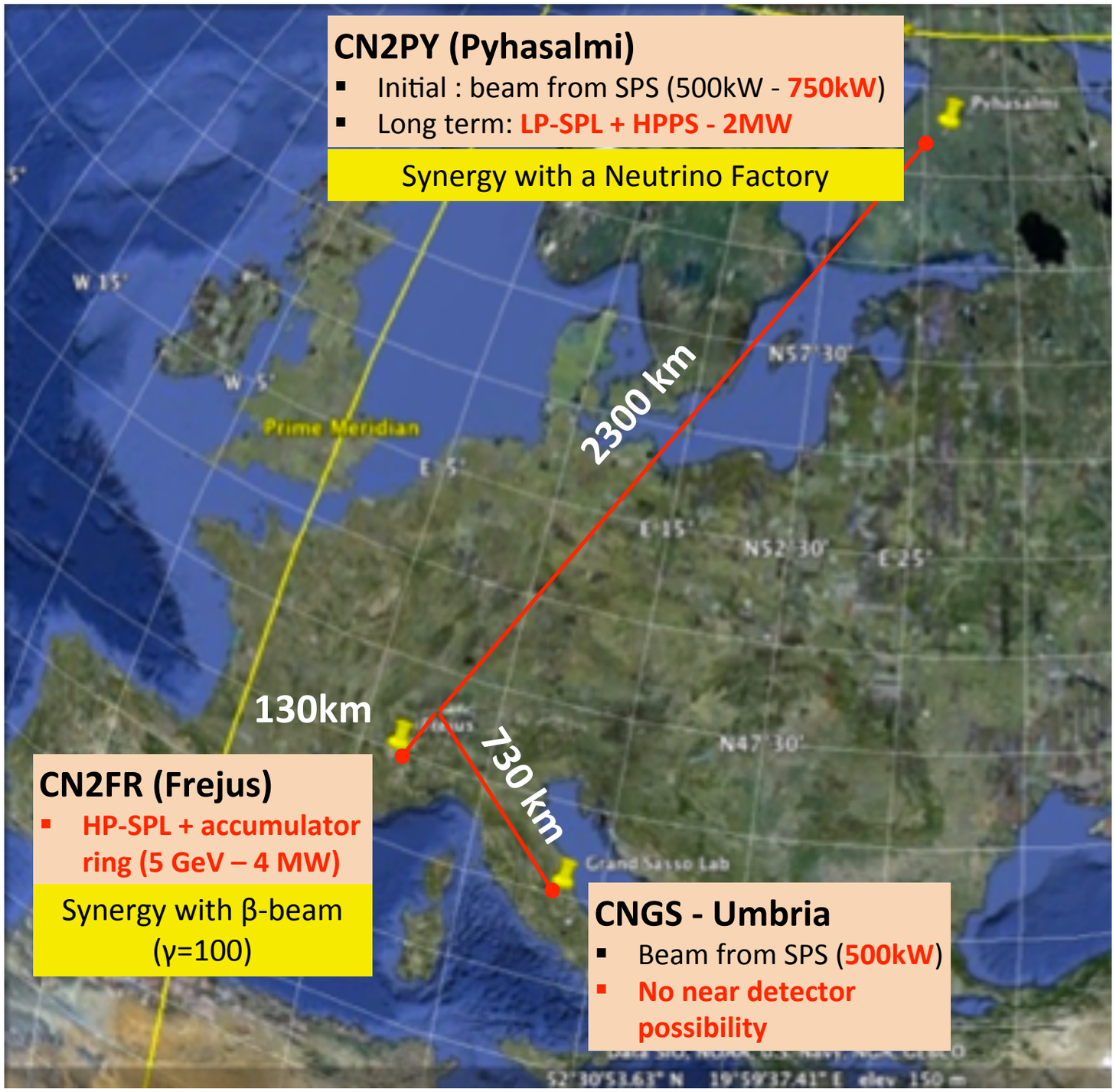
- Extending the lifetime of present CNGS looks tempting
  - at the same time
    - difficult to modify the layout (if requested) of highly radioactive facilities not designed to retrofit; it will be costly in dose and money, and will take time
    - the present installation may reach its limits (H3, environment impact) even before the intensity limits (~700kW) from SPS !!
    - in all cases would be a single step upgrade (~700kW) without long-term (MW) possibilities

- If a new **CERN-LNGS** long-term physics program is proposed, the option of building a new optimized target station and secondary beam including possibly a ND, maximizing the use of existing infrastructure should also be evaluated

- Alternatively, the **experience gained** by CNGS in the design and operation of high-power neutrino beams (and **detectors**), can be **capitalized** in future projects

LAGUNA_LBNO / FP7 Design Study (2011-2014)

- New design study, extending that of LAGUNA, **including the neutrino beams from CERN**
- 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
- Collaboration in a **global** scale, profit from know-how in other ν-beam facilities in US and Japan



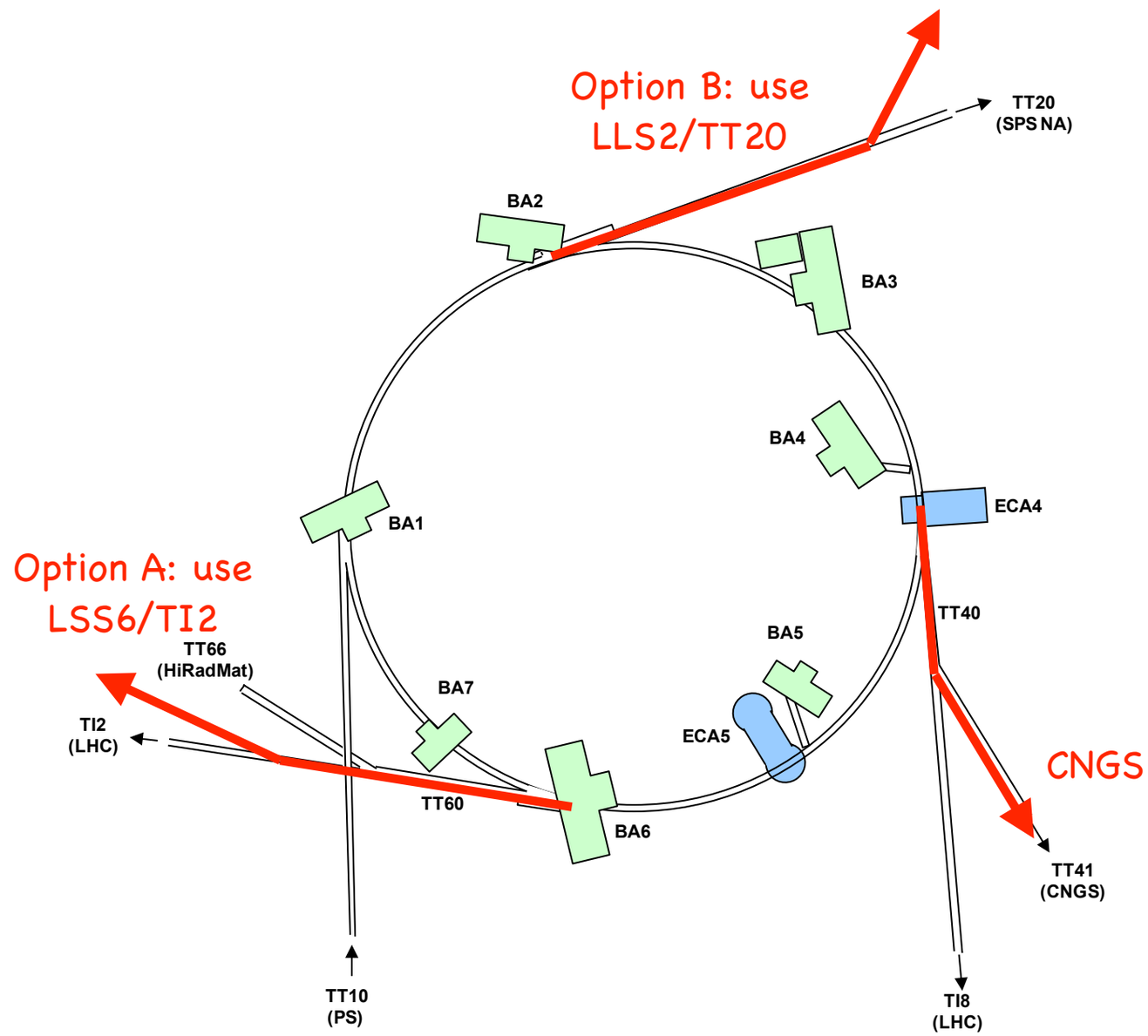
CERN ν-beam to Pyhasalmi - CN2PY

- Phase 1 layout using the 400 GeV beam from SPS

Possibilities:

- **Option A**: LSS6 extraction, target near BA2
  - LSS6 fast extraction and TT60 beam line exists
  - New switch to direct the proton beam towards North
  - Long (~1.6km) proton tunnel to bring the beam towards BA2

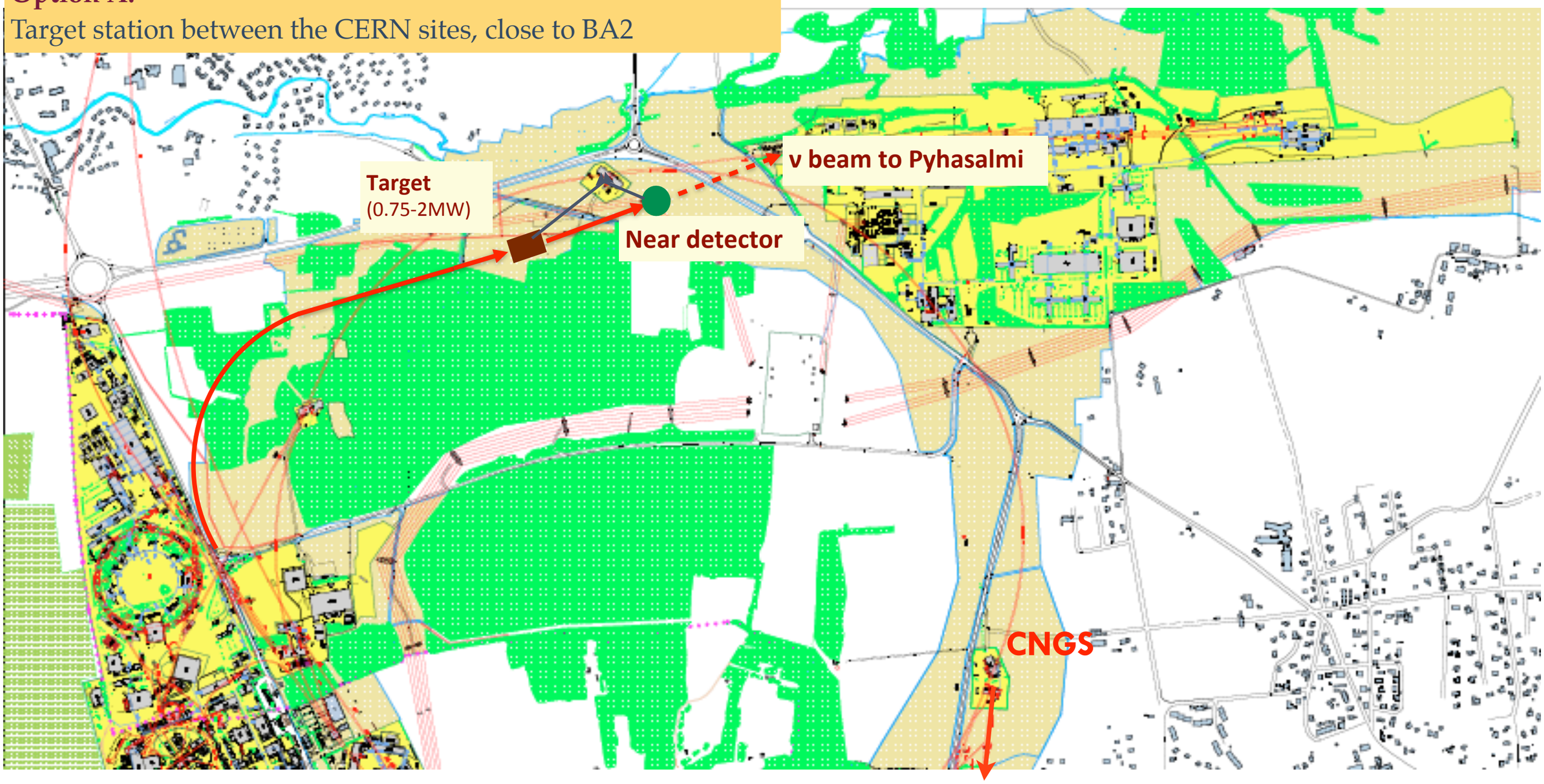
- **Option B** : LSS2 extraction, target near TCC2
  - new fast extraction system in LSS2
  - TT20 beam line exists
  - Target area near existing TCC2



Courtesy : B. Goddard - LLBNO

CERN ν-beam to Pyhasalmi - CN2PY

Option A:
Target station between the CERN sites, close to BA2



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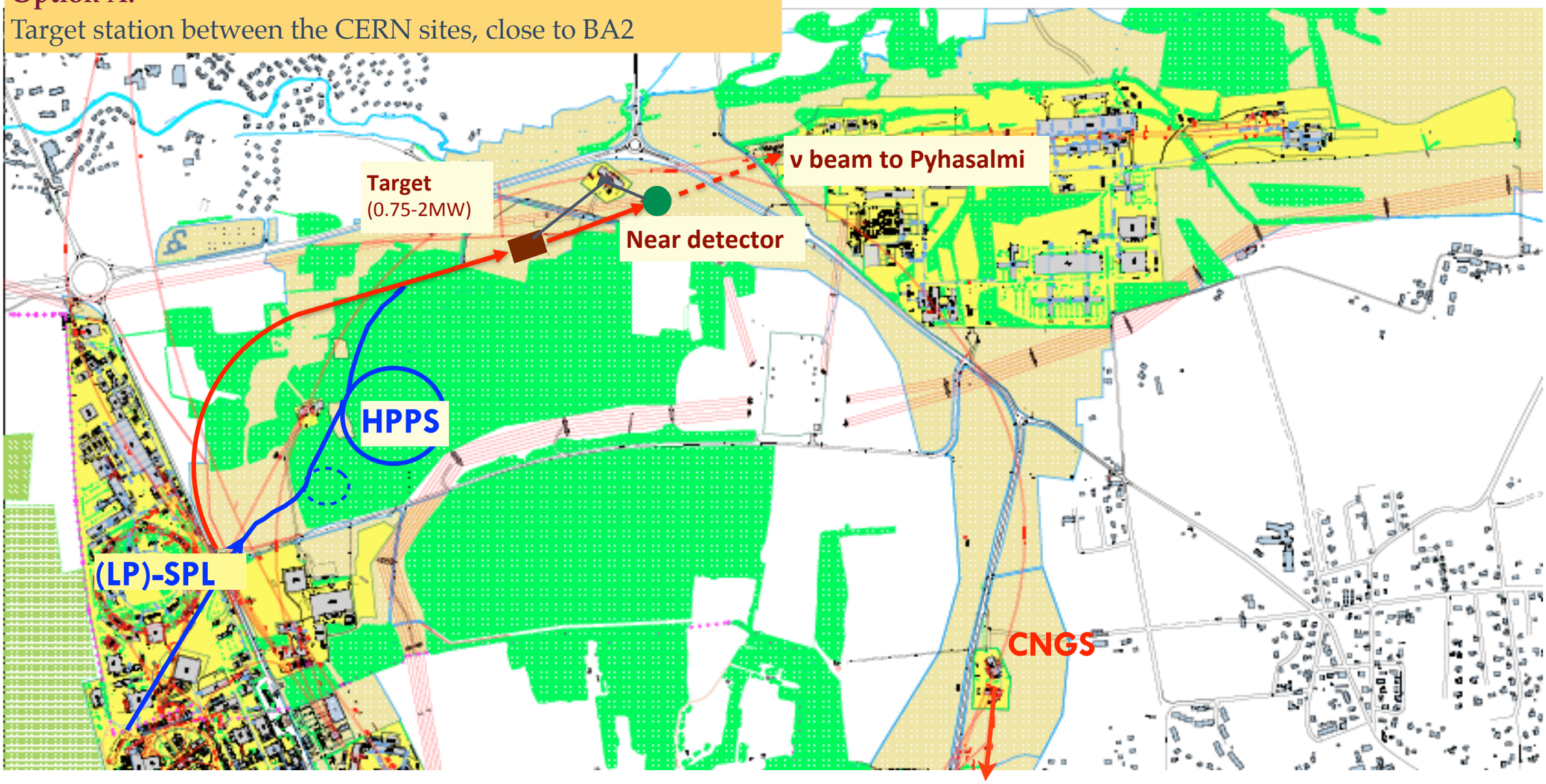
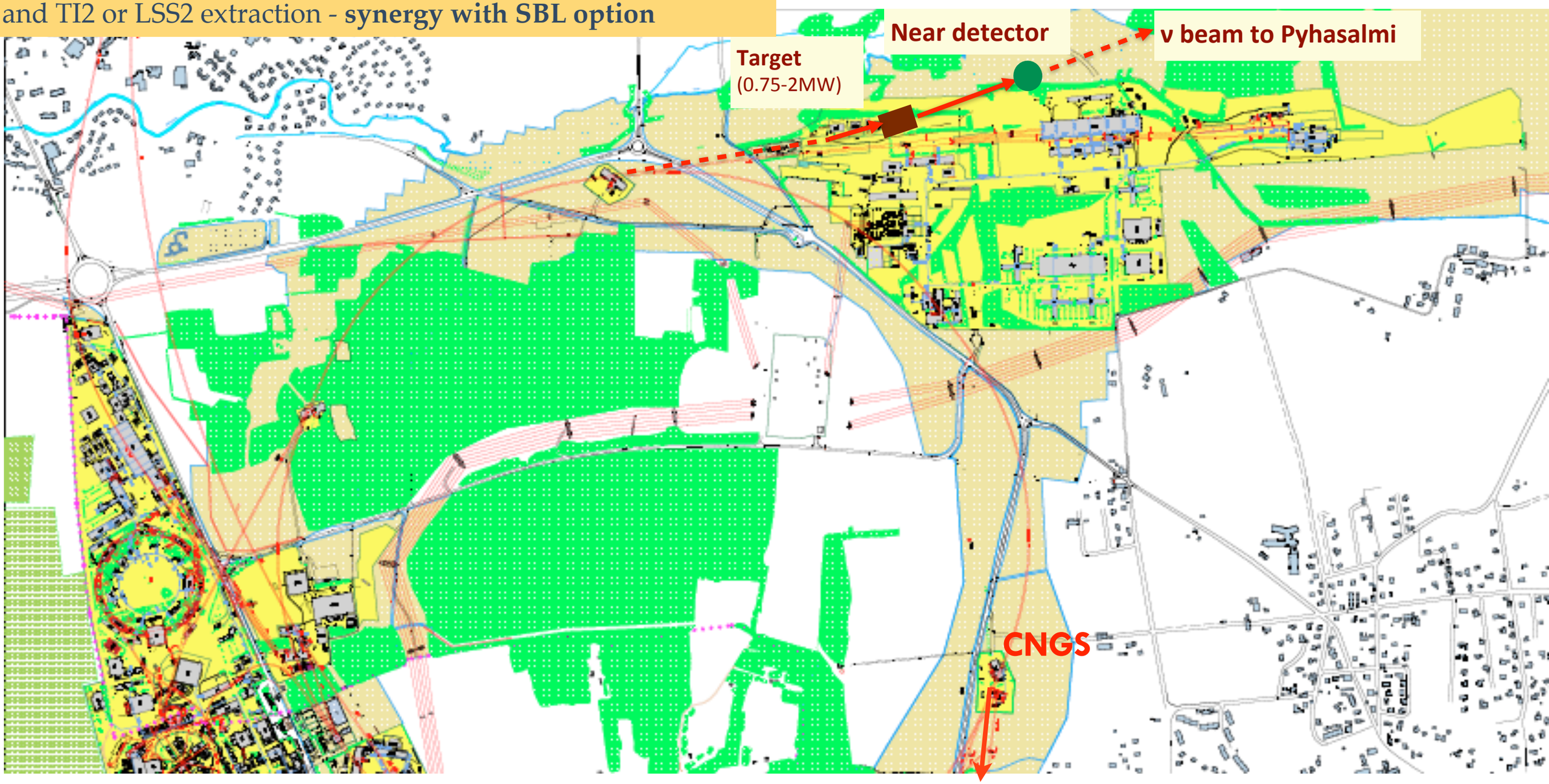


CERN ν-beam to Pyhasalmi - CN2PY

Option B:
Target station and ND in the North Area, use existing TT20 line and TI2 or LSS2 extraction - **synergy with SBL option**



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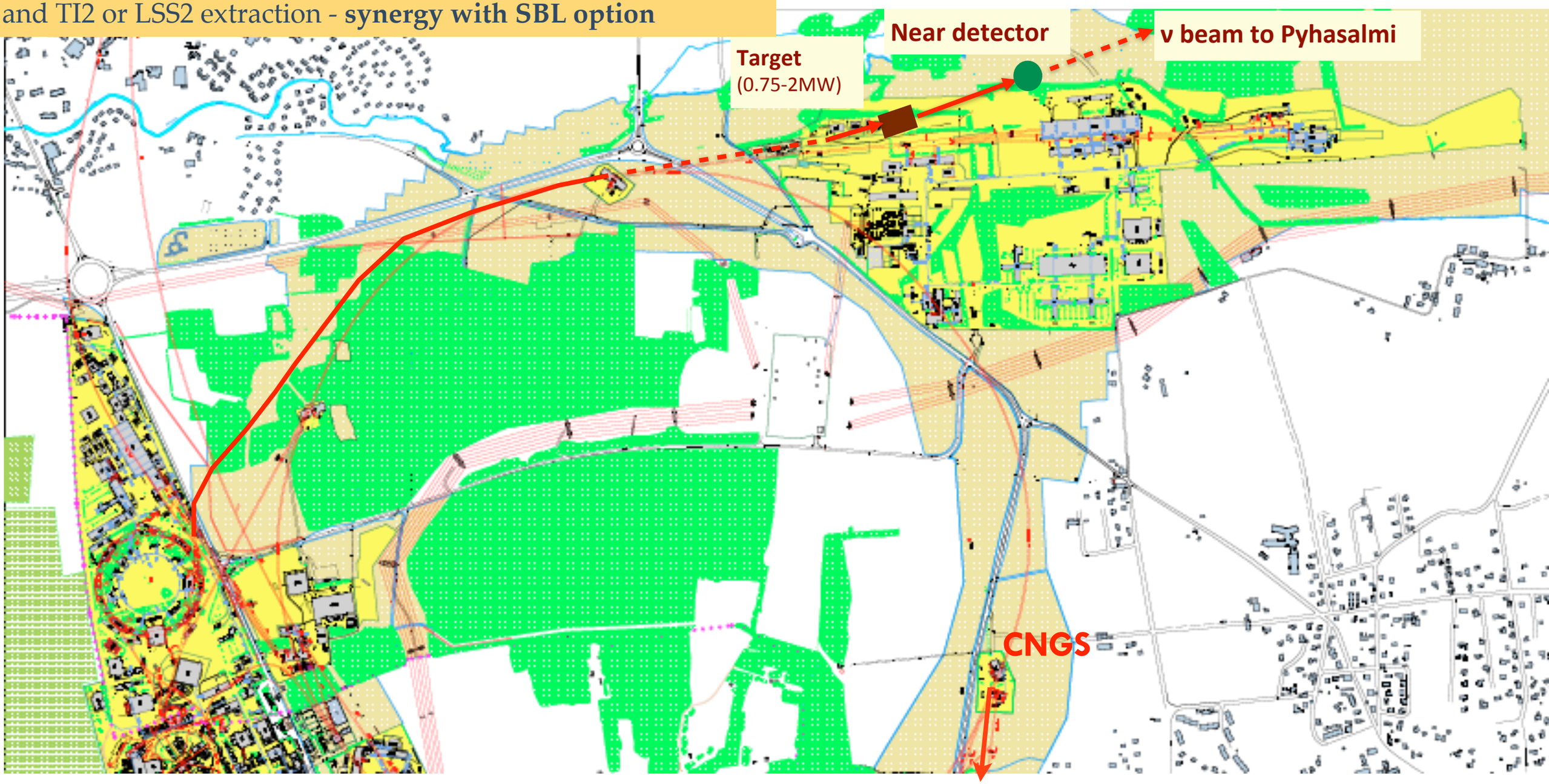

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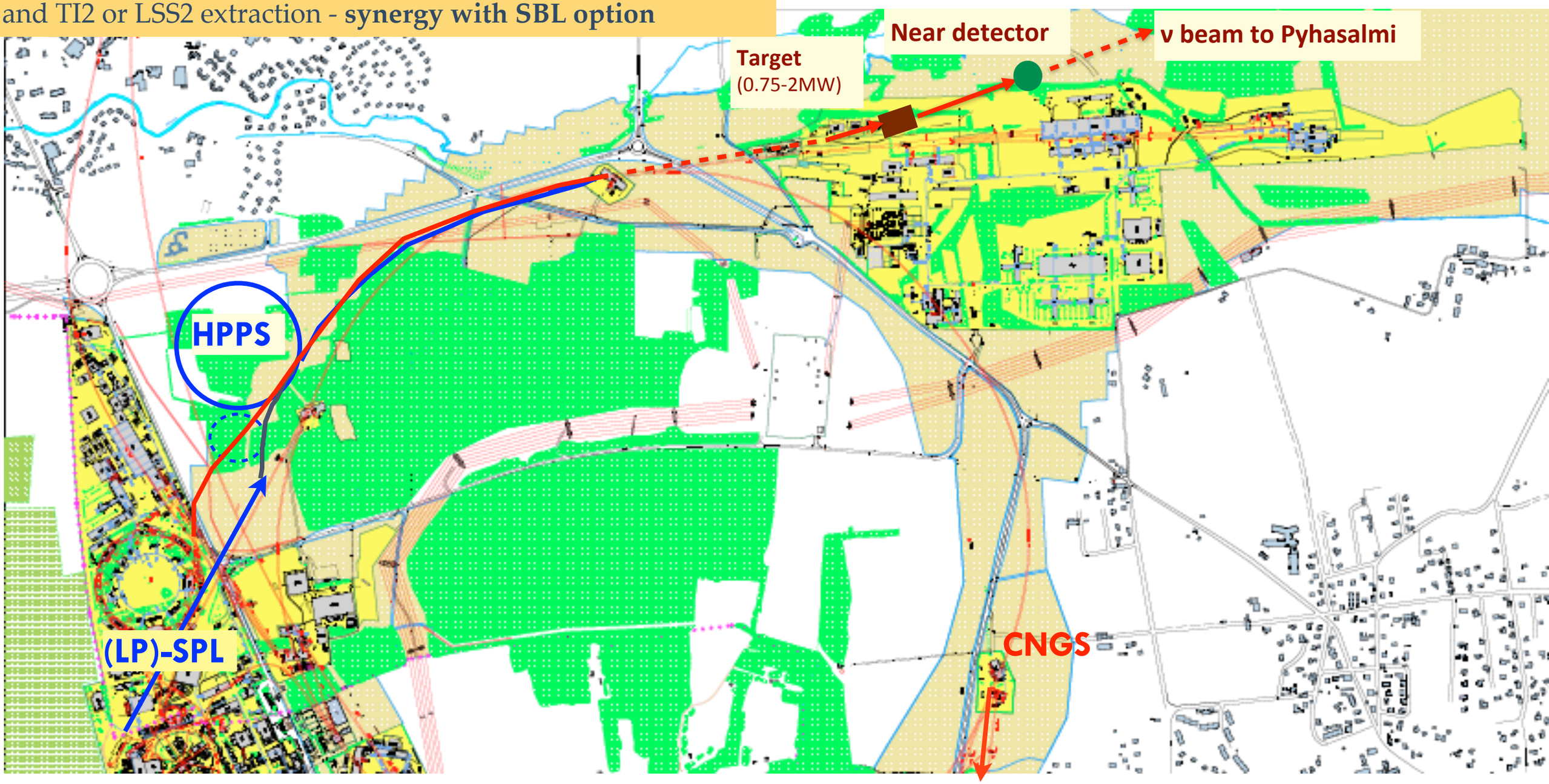
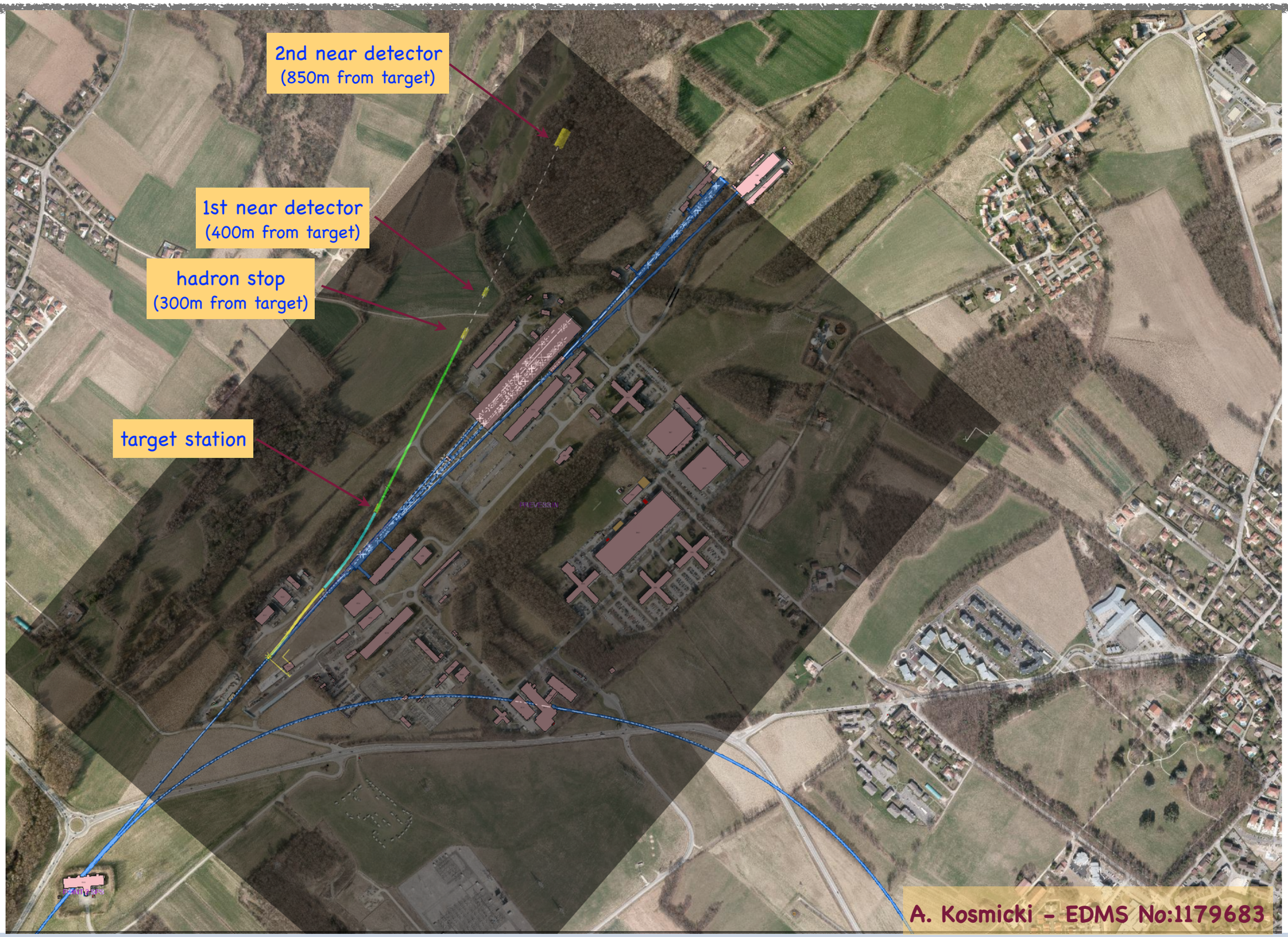
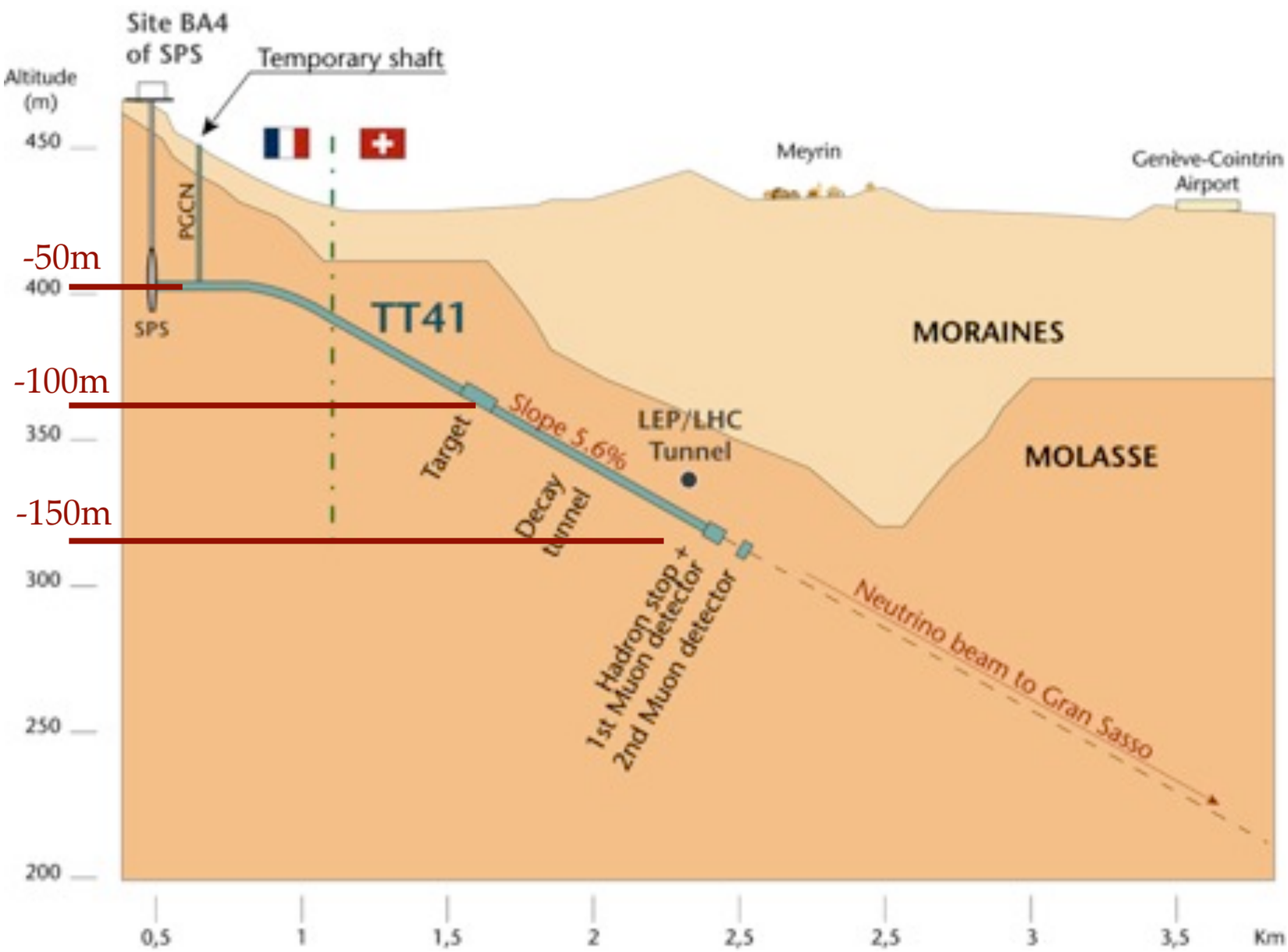


CN2PY Option-B Layout study



CN2PY - Layout considerations

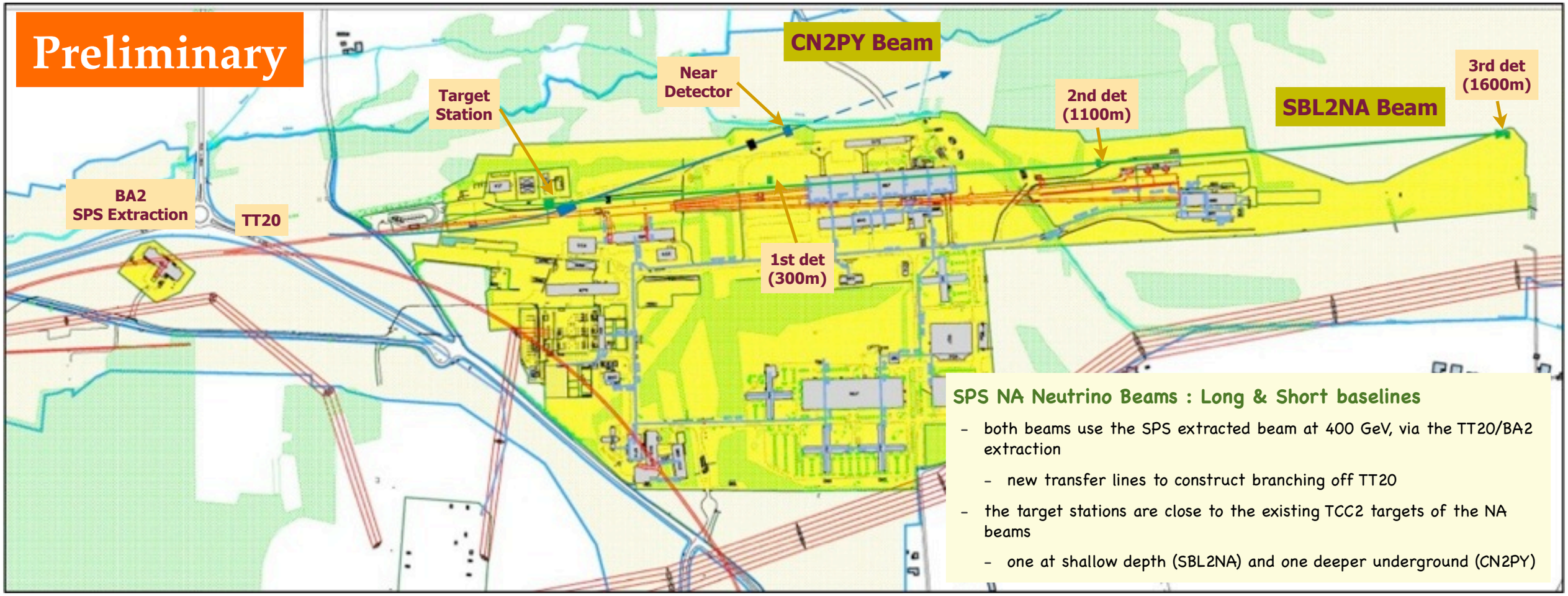
- The depth for the installations is the major concern
  - 18% slope compared to 5.6% for CNGS



CN2PY Beam - Generic Layout		
	Distance	Depth
Target	-	0 m
Hadron stop	300 m	-54.3 m
Muon station	330 m	-59.8 m
Near detector	400 m	-72.6 m
Middle detector	830 m	-150.6 m

- Starting the beam from the SPS level adds **~100m** to the depth of the installations
- Staying in the **molasse layer** has quite some advantages for the CE (stability) and radiation to environment (underground water activation issues) issues

NA Long & Short Baseline ν beams



- **CN2PY Beam layout parameters**
  - 10.4 deg downwards slope to point to Finland
  - 15.1 deg angle wrt North Area beams
  - target station at ~34m underground
    - 20 m deeper than the existing TCC2 targets
    - ~6m of concrete shielding around to allow 2MW operation
  - decay pipe ~300-400m long
  - near detector at ~500m, 116m underground, within the CERN area

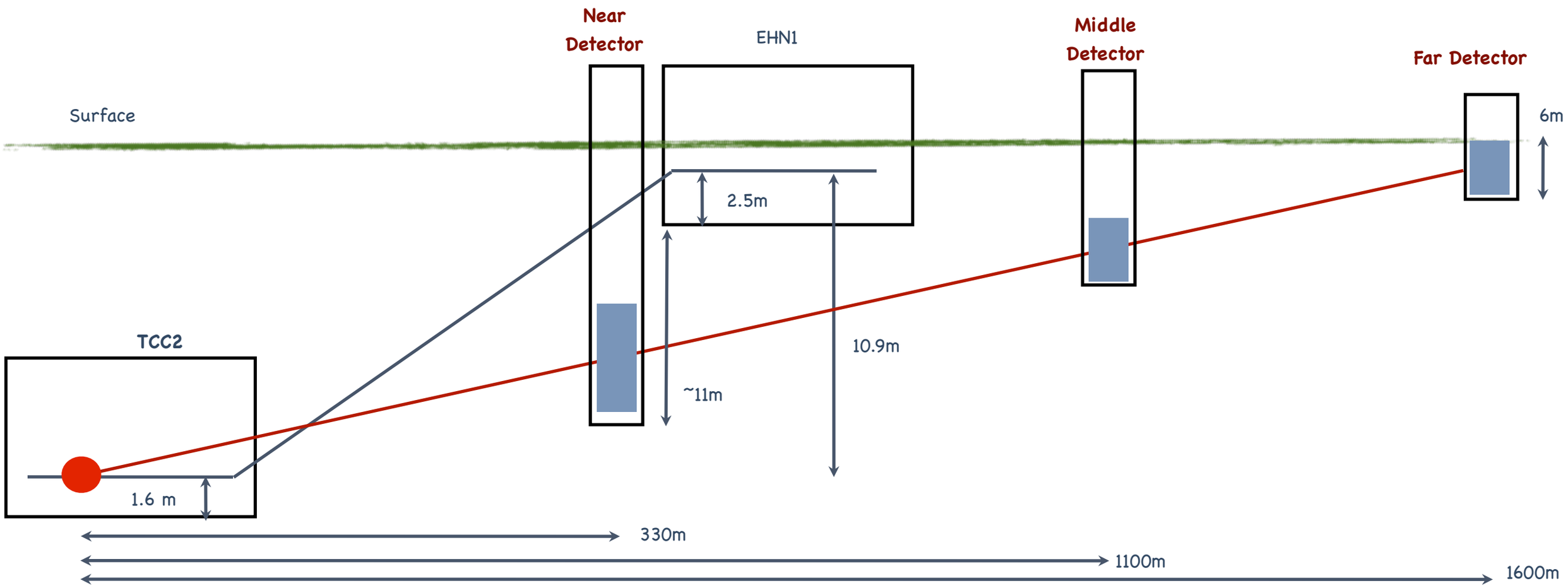
- **Short-Baseline beam (SBL2NA)**
  - horizontal (or slightly upwards) beam line
  - short decay pipe (~50m) followed by the beam dump
  - target station at ~10m underground, adjacent to existing TCC2 target station
  - possibilities for detectors at 300, 1100, or 1600m
    - profit from existing infrastructure, including cryogenics
  - detector position and on/off axis location depending on physics

Short Baseline ν beam in the SPS North Area (SBL2NA)

Layout parameters

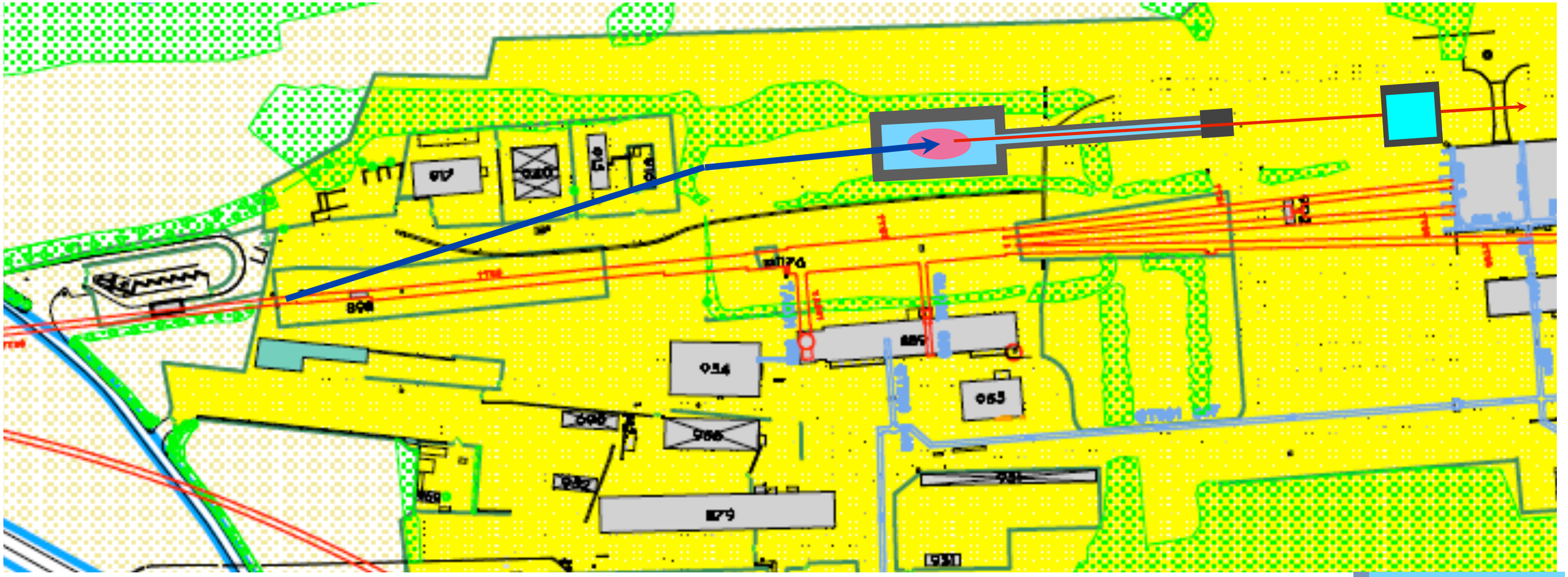
- primary beam : **100 GeV**, ν-beam : **~2 GeV**
- target station at the TCC2 level (**~11m underground**)
  - Lateral distance defined by the location of the near&far detectors
  - sufficient distance from TCC2 to allow works during NA operation
  - not really mandatory but better if we can, at least for civils
  - Cavern design like NuMI (LBNE)
- decay pipe : **80m, 3m** diameter
- beam dump : **15m of Fe** with graphite core, followed by μ stations
- ν-beam angle : pointing upwards
  - at -3m in the far detector --> **~5mrad slope**

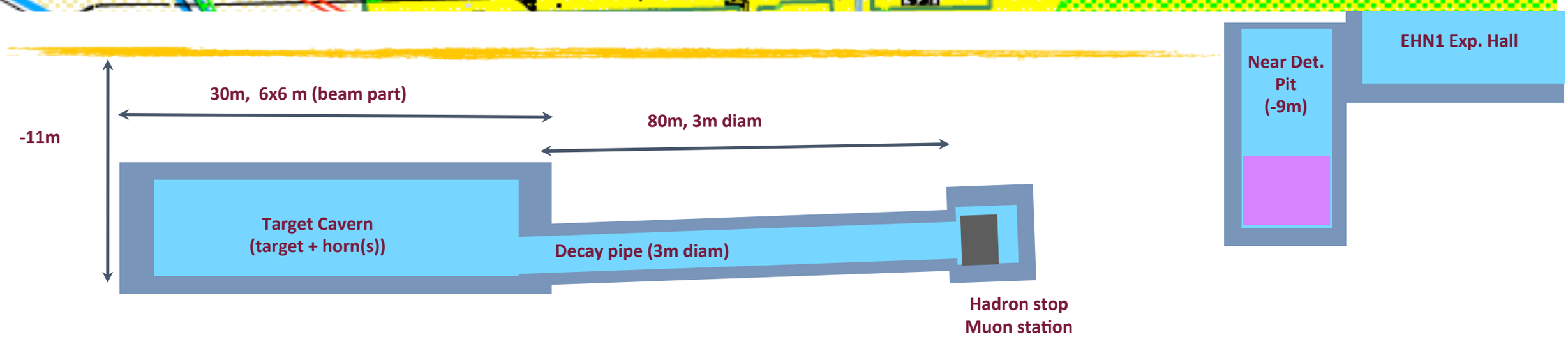
SBL2NA Layout - Vertical plane



- Neutrino beam slope : 8m/1600m = 5mrad
- Depths :
  - near detector : -9.3m, or ~11m below the EHN1 level
  - middle detector : -5.5m
  - far detector : -3m

SBL2NA Layout - Target station and Near Detector

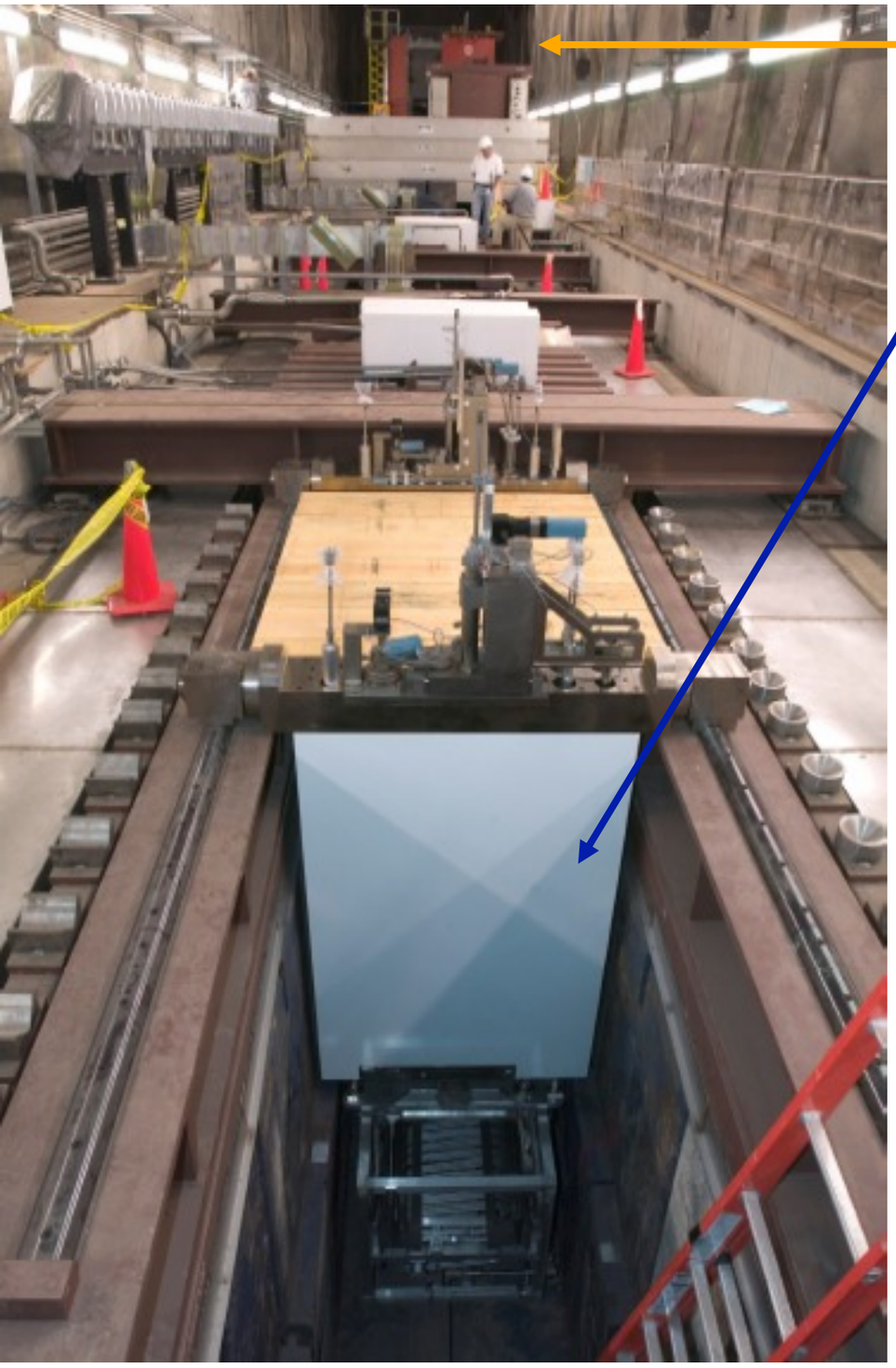




CN2PY/SBL2NA - A 3rd Generation ν-beams

- Profit from the existing experience from the other installations:
  - **CNGS** : radiation, tritium issues, target lifetime/operation
  - **T2K** : high-power design, He vessel for target and decay pipe, remote handling
  - **NuMI** : layout design access and repair of "hot" equipment
- .. and the design options for future projects
  - **LBNE** : target station layout options
  - **Neutrino Factory** : target station design

MINOS Target Chamber



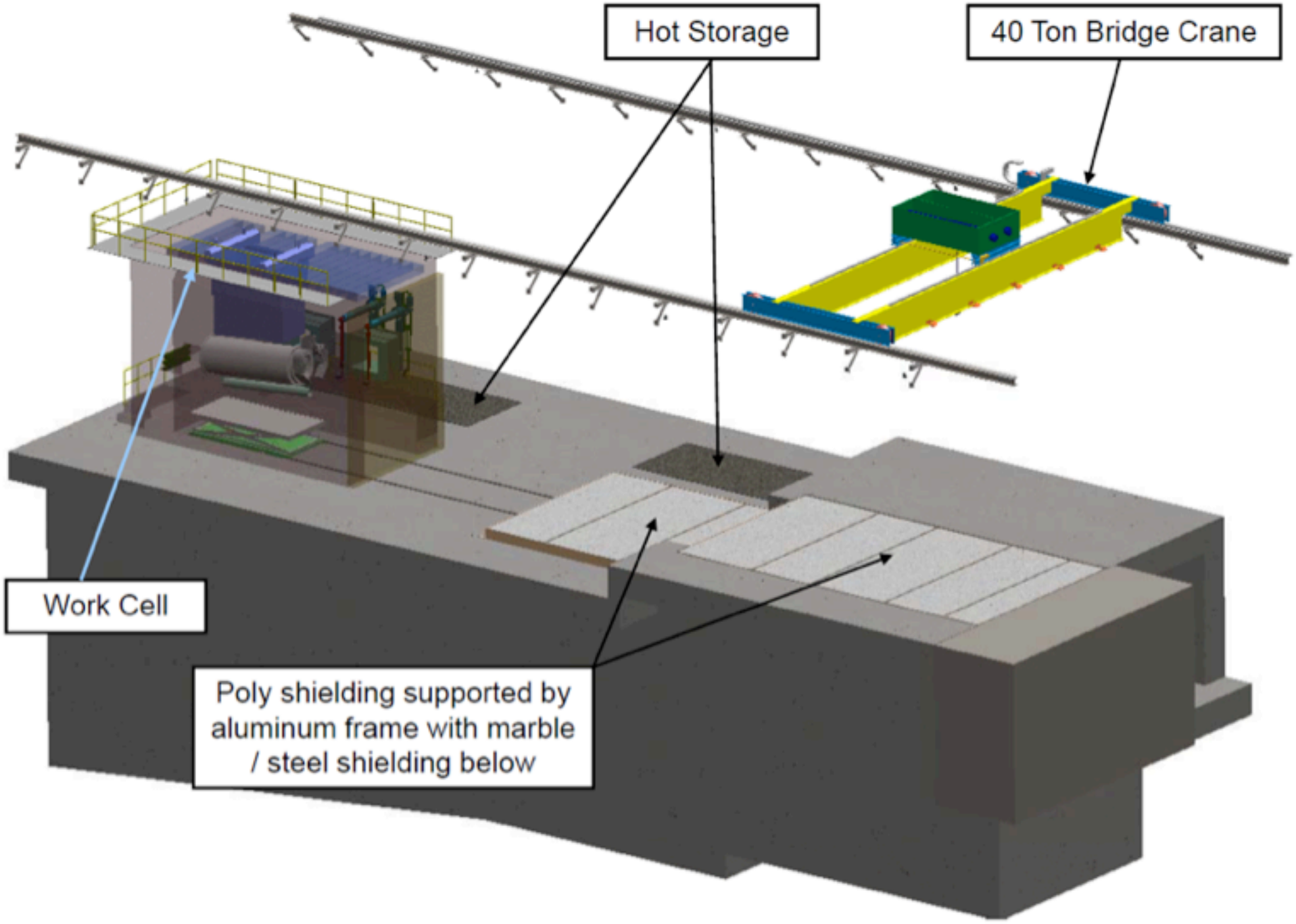
Work cell

Target module in beam-line

1st target being removed

J. Hylen/FNAL - NBI10

LBNE - Target Chamber

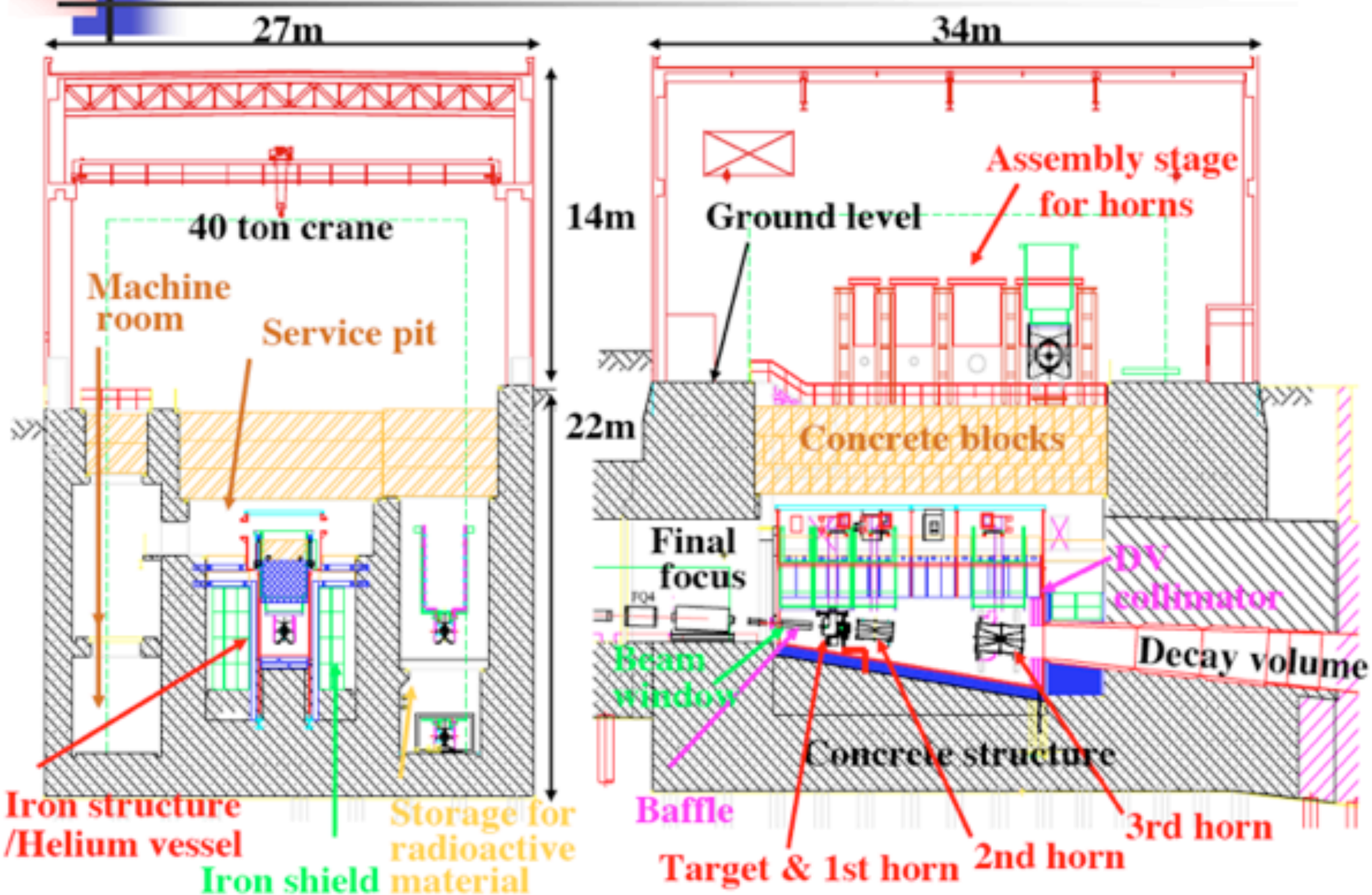


P. Hurh: LBNE Remote Handling Overview for NBI 2010

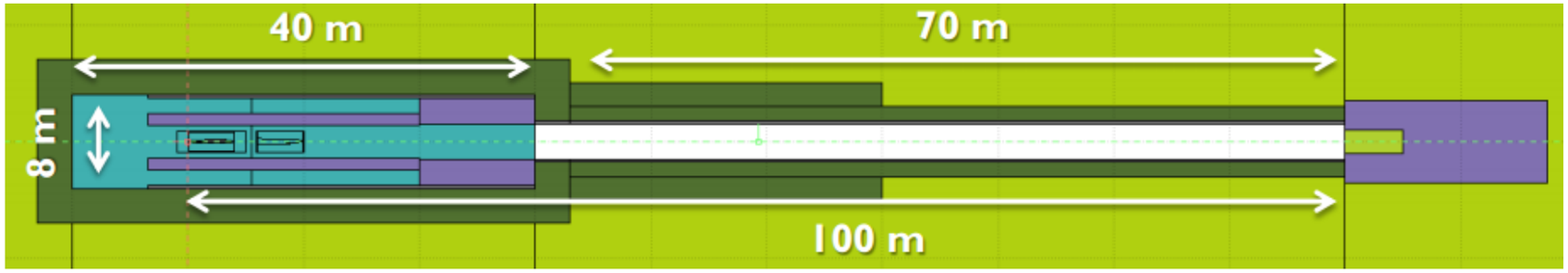
T2K Target Chamber

Y. Yamada/KEK - NBI10

Target station

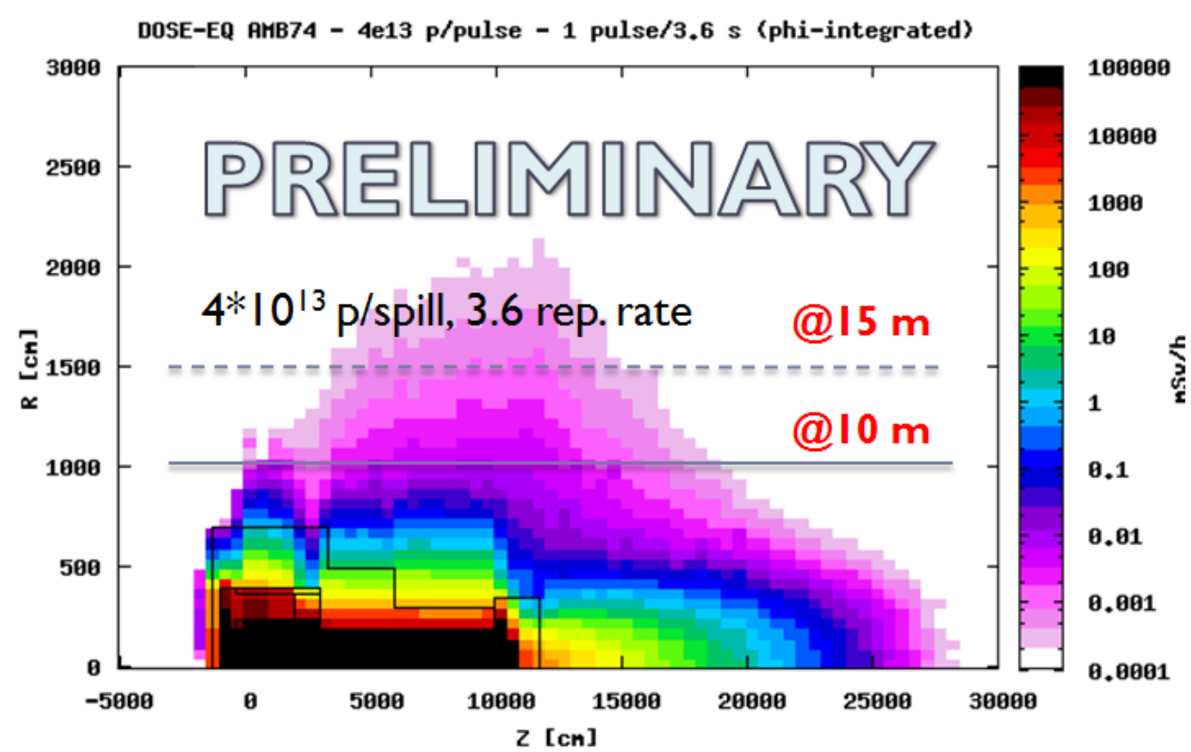


SBL2NA - RP considerations



Element	kJ/spill	kW avg.
Dump core (C)	162.29	45.08
DP inner Fe lining	139.50	38.75
Target Fe sh.	130.15	36.15
Dump (Fe)	79.01	21.95
Target Fe sh. (down)	37.87	10.52
DP upper Fe lining	10.29	2.86
DP concrete shielding	6.40	1.78
Horn inner conductor	2.39	0.66
Target	1.97	0.55
Reflector inner conductor	1.48	0.41

- In a first approximation the SBL2NA beam can receive the same beam intensity presently delivered to CNGS
  - 4÷5 10^{19} pot/year
  - further increase can come as by-product of the SPS upgrades, and a possible shorter SPS cycle (3.6s instead of 6s for CNGS) due to the lower beam energy
- Preliminary FLUKA studies
  - RP issues can be easily mitigated with appropriate shielding
  - Muons rate to near detector (330m) can be kept low: 1 μ/spill
  - Soil activation (^{3}H, ^{22}Na) and RP to environment can be under control with appropriate design



M. Calviani, A. Ferrari - CERN

New fast extraction in SPS LSS2?

B. Goddard - CERN

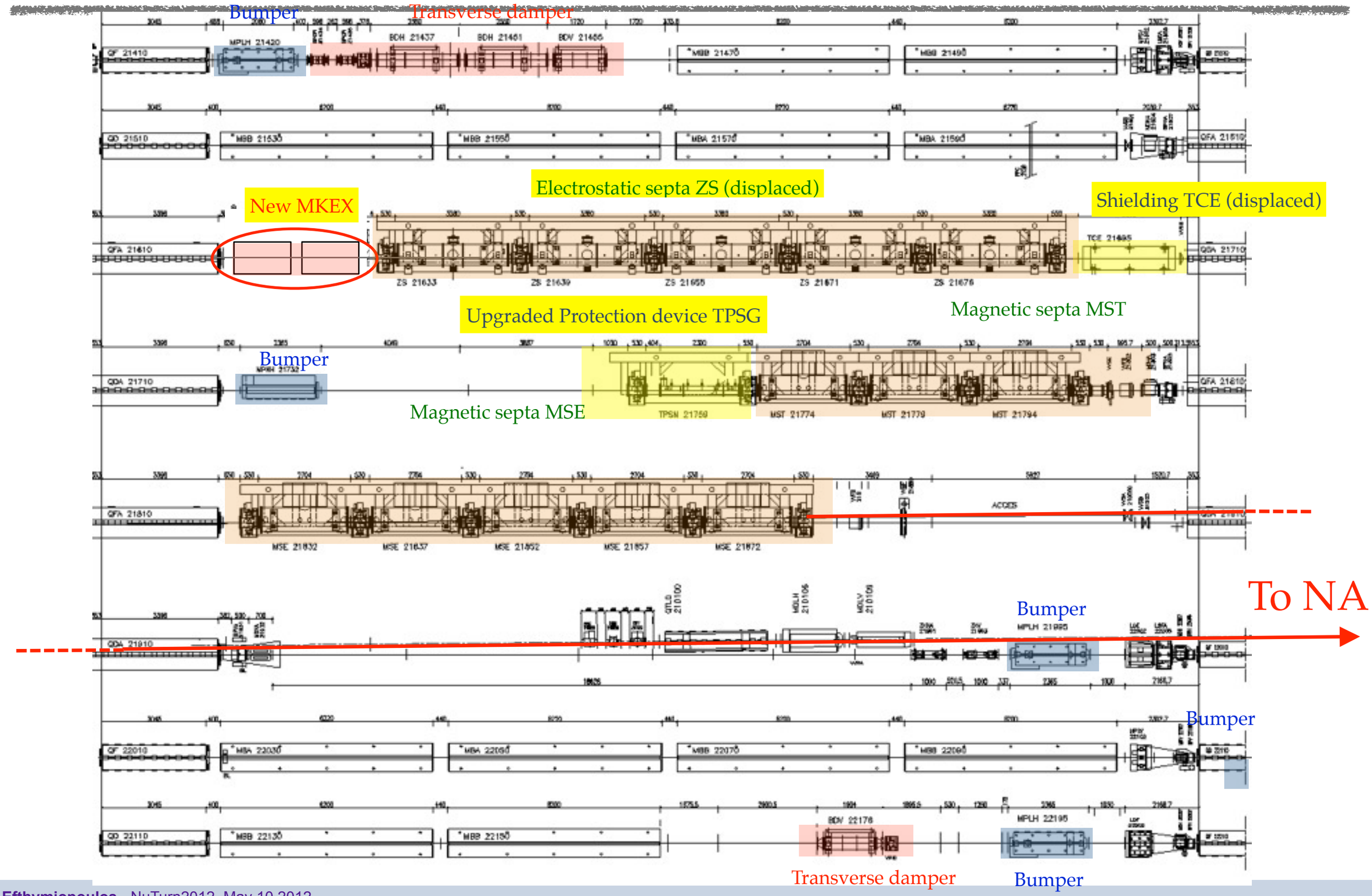
- Constraints : must keep slow extracted beam capability to North Area
  - Hybrid extraction needed for slow and fast extracted beams

First preliminary feasibility study

- Solution found with displacement of ZS girder and TCE downstream by 3m
  - Two new MKEX kickers - [larger H aperture version than MKE]
  - Extraction energy limited to 100 GeV with 1μs kicker rise time
    - Can be later modified to extract 400 GeV, with a rise time 3-4μs
  - Emittance limited to about 8 π.um in H, and 5 π.um in V

LSS2 Possible Layout

B. Goddard - CERN



Beam Intensity Upgrades - HP-PS

Y. Papaphilippou, M. Benedikt, R. Steerenberg - LLBNO/CERN

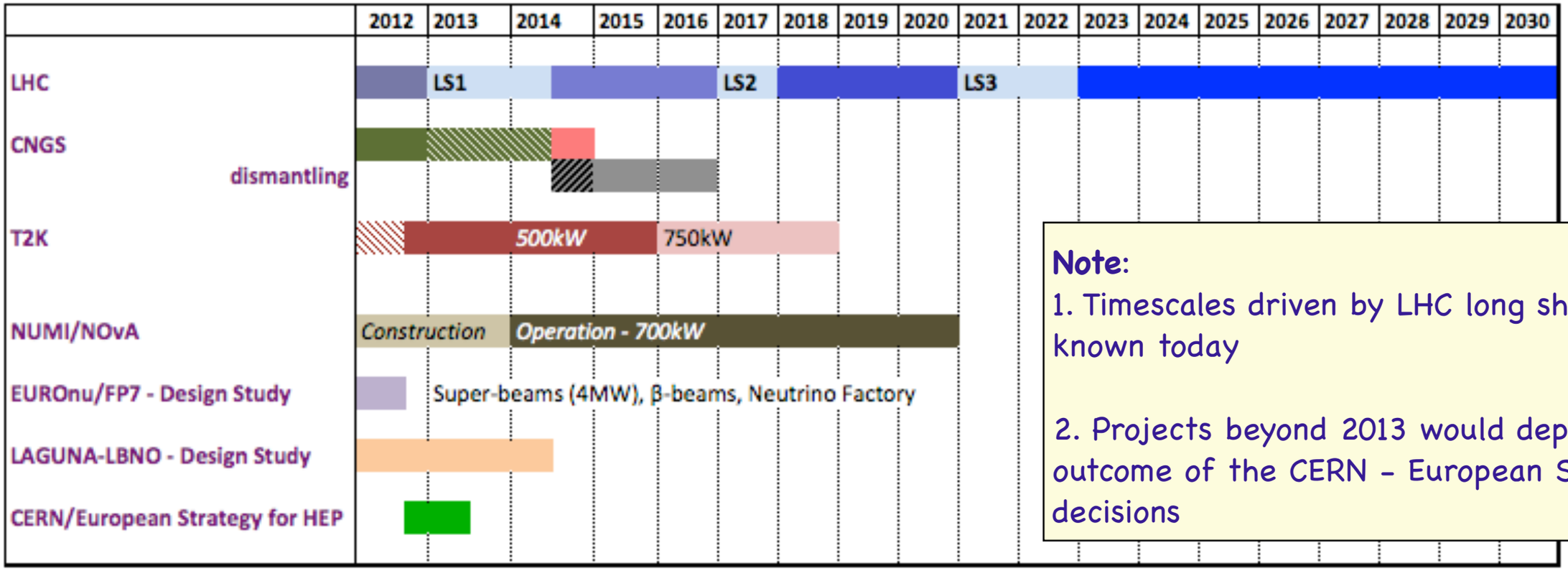
Preliminary !

$$P = q f_r N_p E_k$$

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**			

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

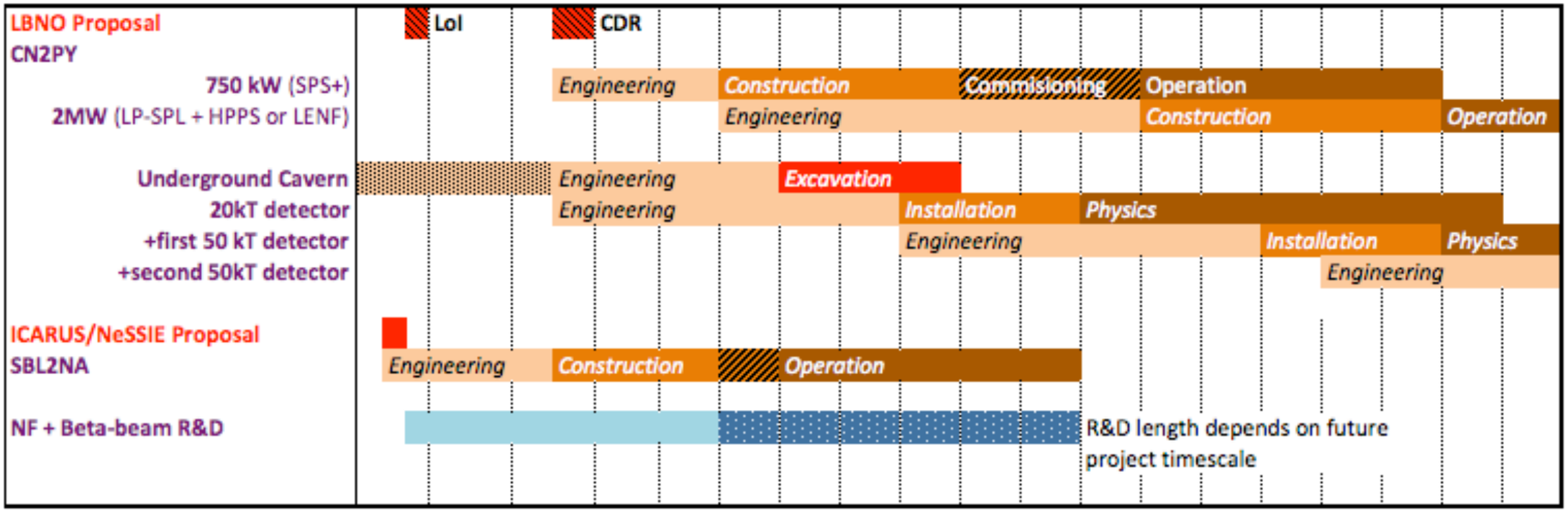
Future Neutrino Beams – possible timeline



Note:

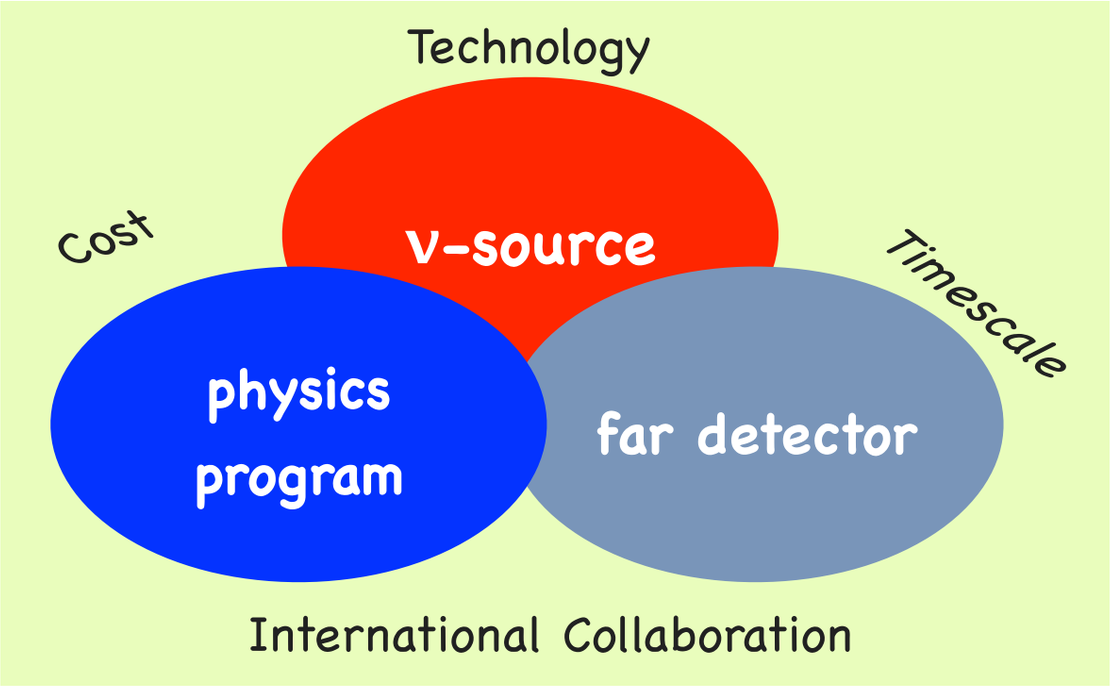
1. Timescales driven by LHC long shutdowns as known today

2. Projects beyond 2013 would depend on the outcome of the CERN – European Strategy decisions



Summary

- The newly obtained results enhanced the interest for ν-physics, changed the landscape and will help to better define a future ν-program among the all possible options currently under study
  - **T2K :** θ_{13} non-zero and **large**
  - **NuMI/MINOS :** θ_{13} , ν ↔ anti-ν results
  - **CNGS:** # ν_τ events
  - **Reactor experiments :**
    - θ_{12}, θ_{13} measurement indeed **very large**!!!



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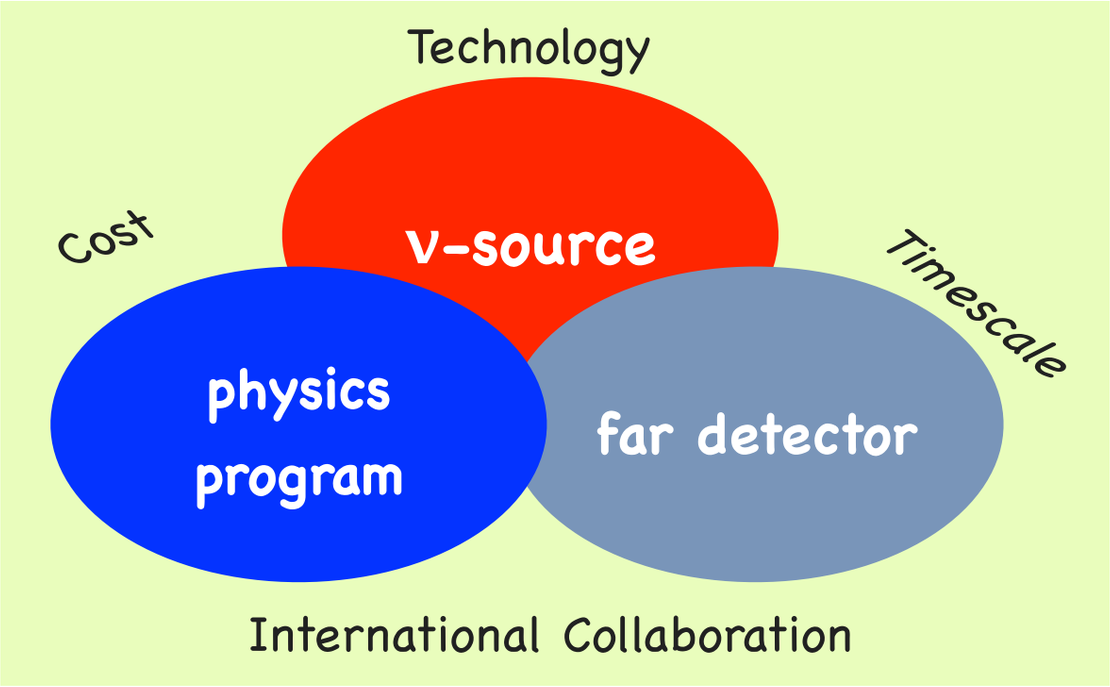

- CERN/Europe has the potential to play an important role in the new experiments
  - Understand possibilities/limitations of CERN-LNGS beam
  - The CN2PY proposal for a future ν-experimental program
    - broad physics potential (CP-violation, mass hierarchy,..)
    - can accommodate different detector technologies, beam options, and synergy with ν-factory
  - The short-baseline option (SBL2NA) can be envisioned as initial step
    - for an independent physics program and detector R&D