Status of the ESSnuSB Design Study

J-PARC Symposium in Tsukuba

26 September 2019

Tord Ekelöf

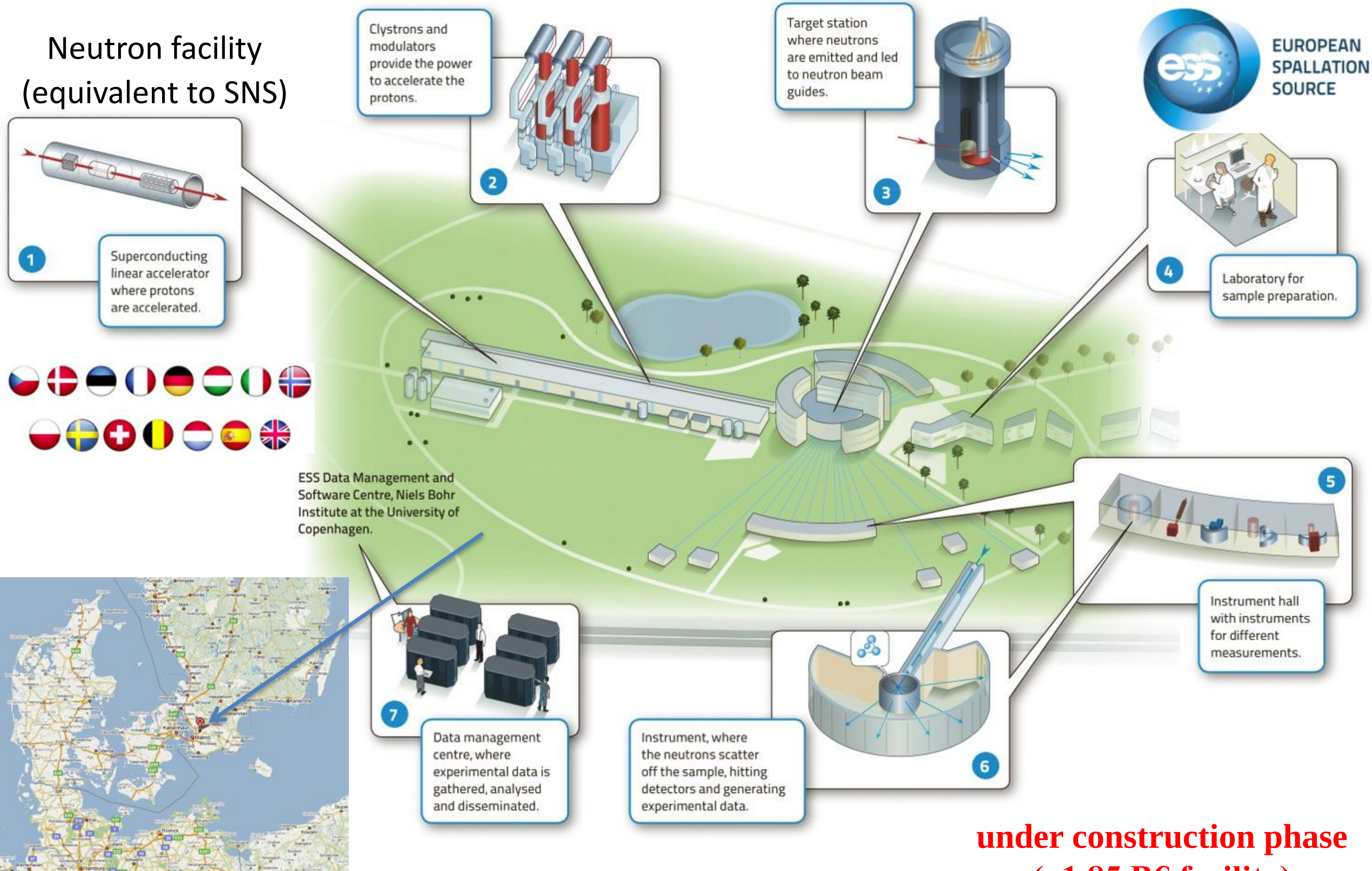
Uppsala University

MANY CONGRATULATIONS TO
J-PARC
AND WISHES FOR AT GREAT FUTURE
FROM UPPSALA UNIVERSITY

UPPSALA
UNIVERSITET

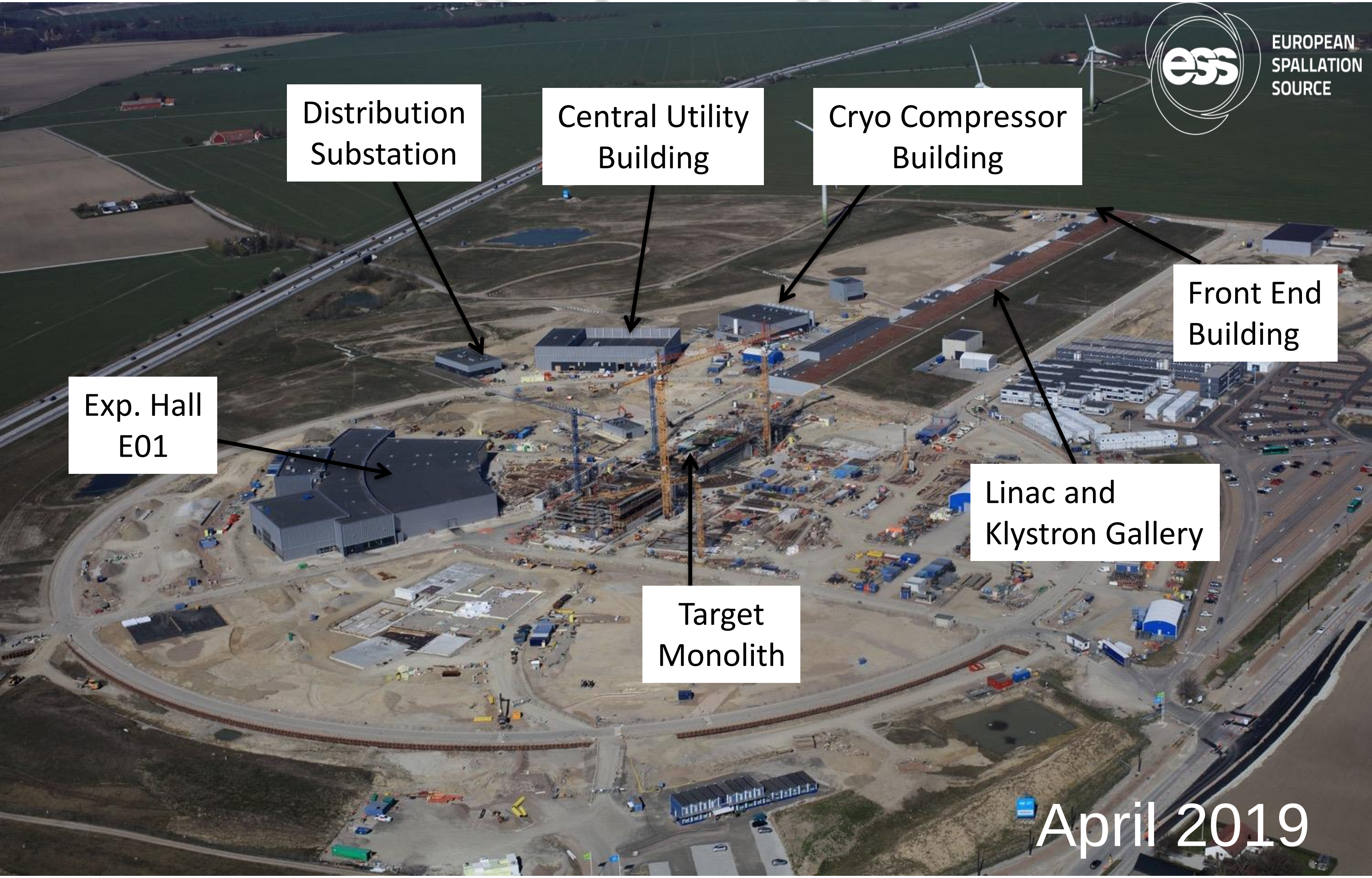
European Spallation Source

Neutron facility
(equivalent to SNS)

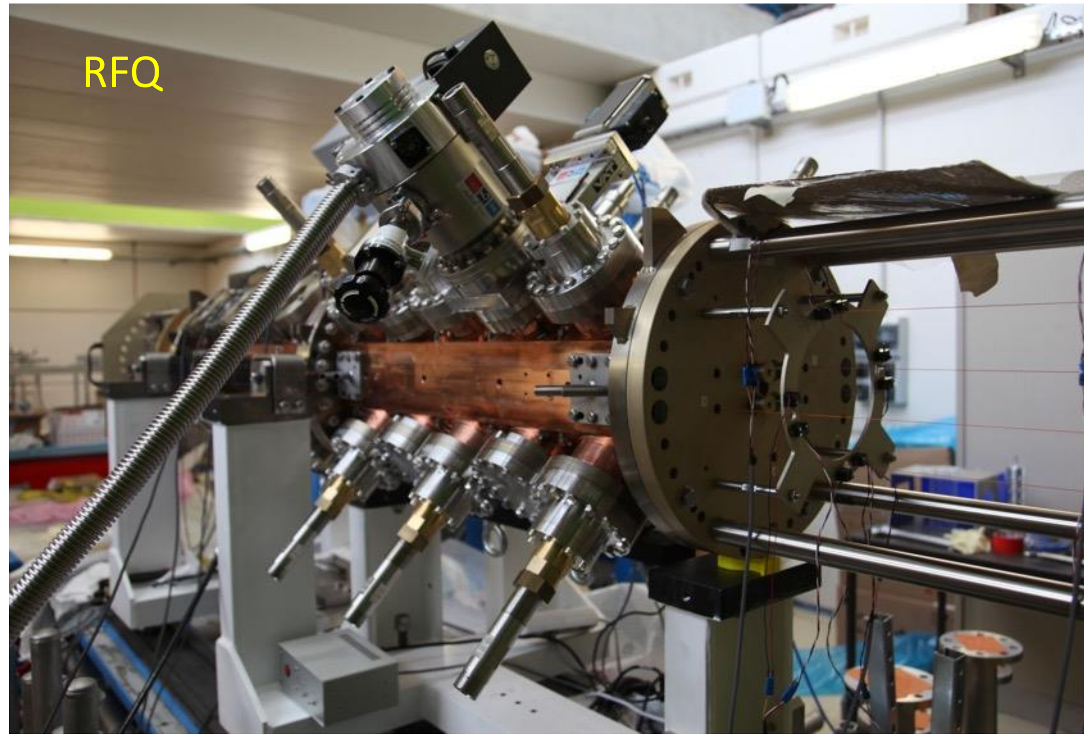


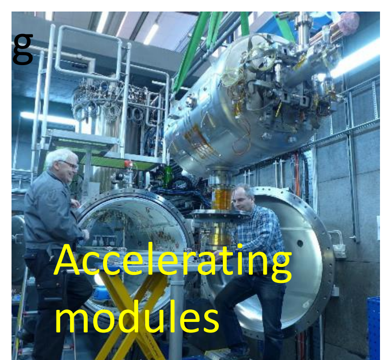
under construction phase
(~1.85 B€ facility)

European Spallation Source

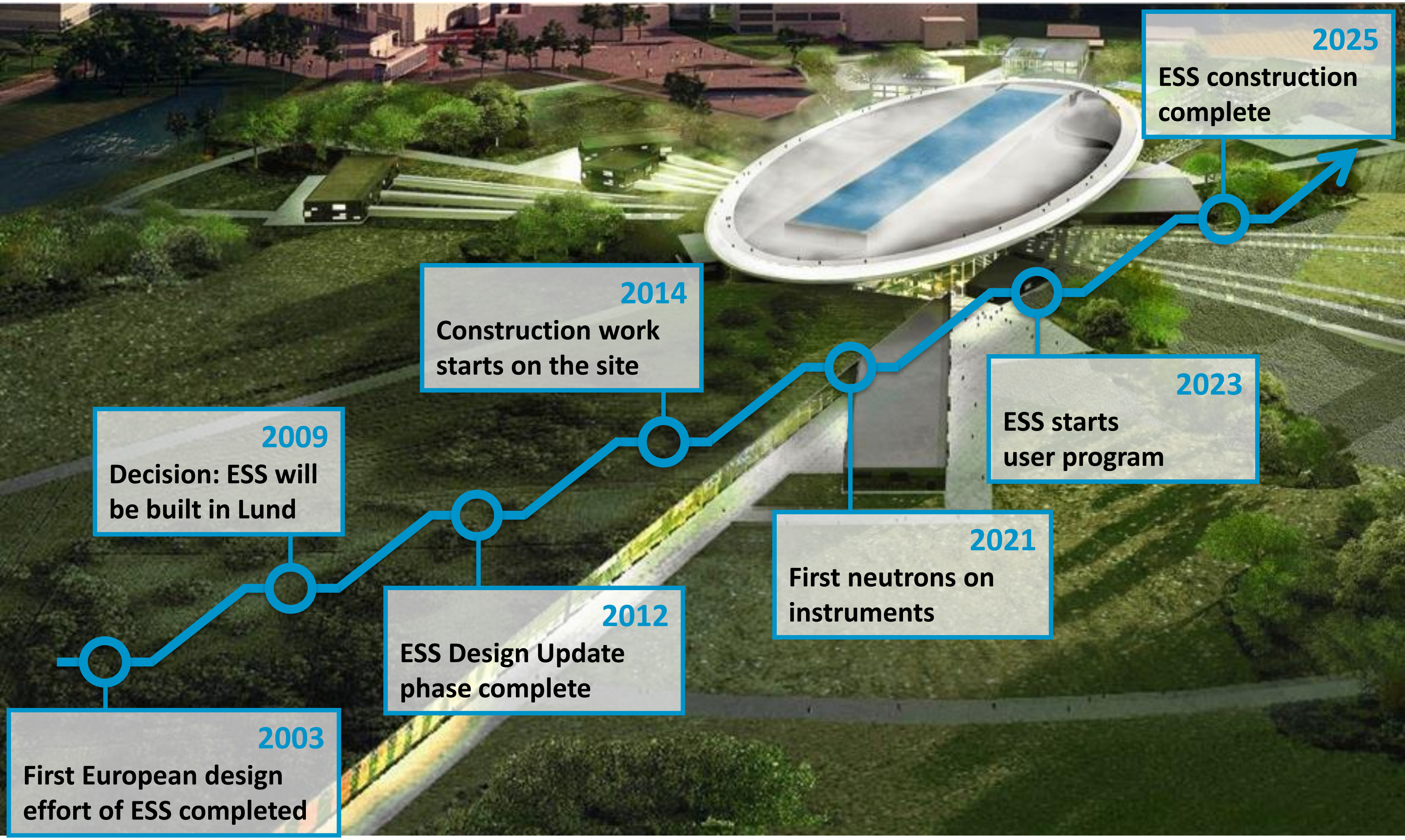


European Spallation Source

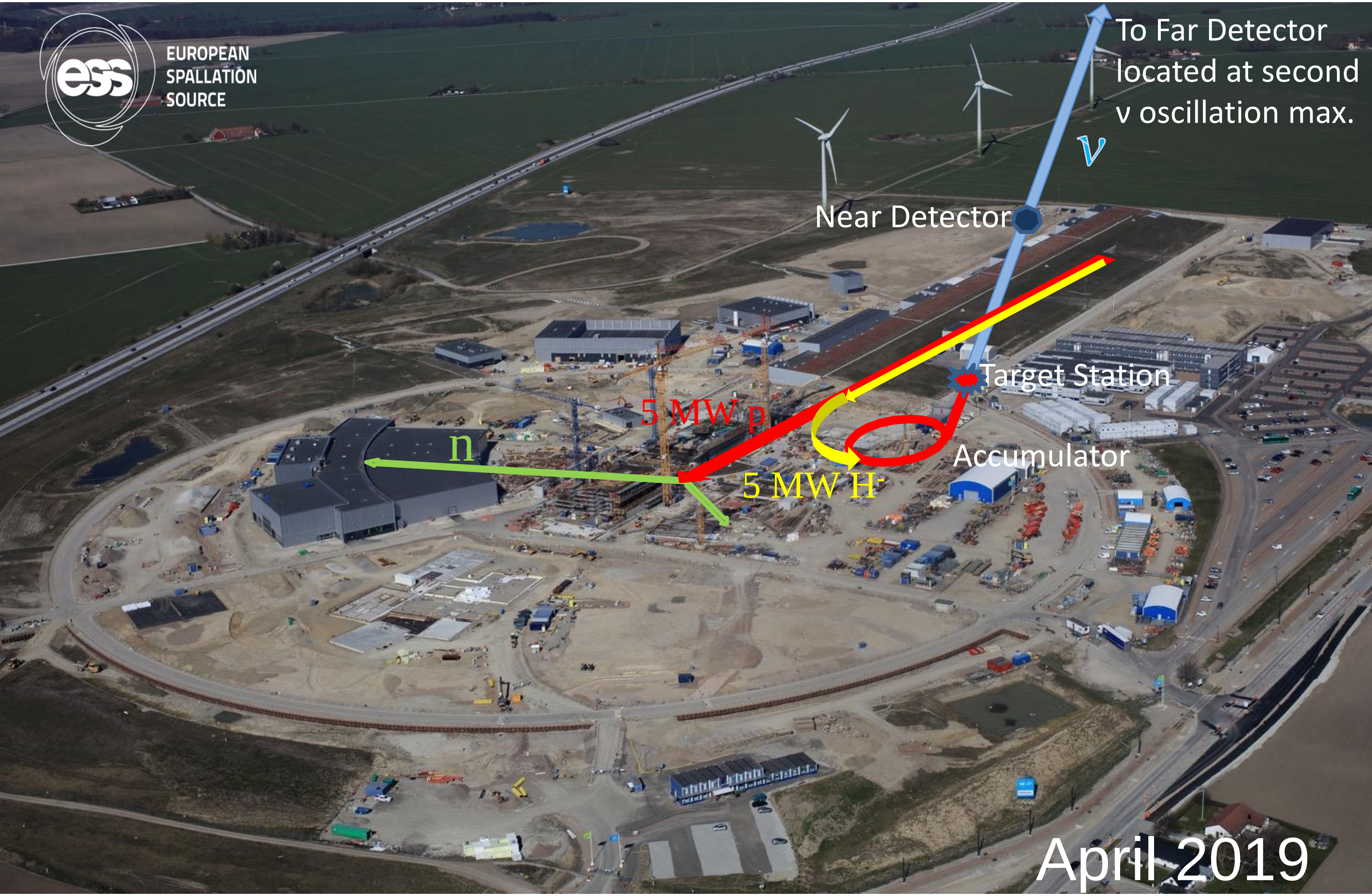




ESS schedule

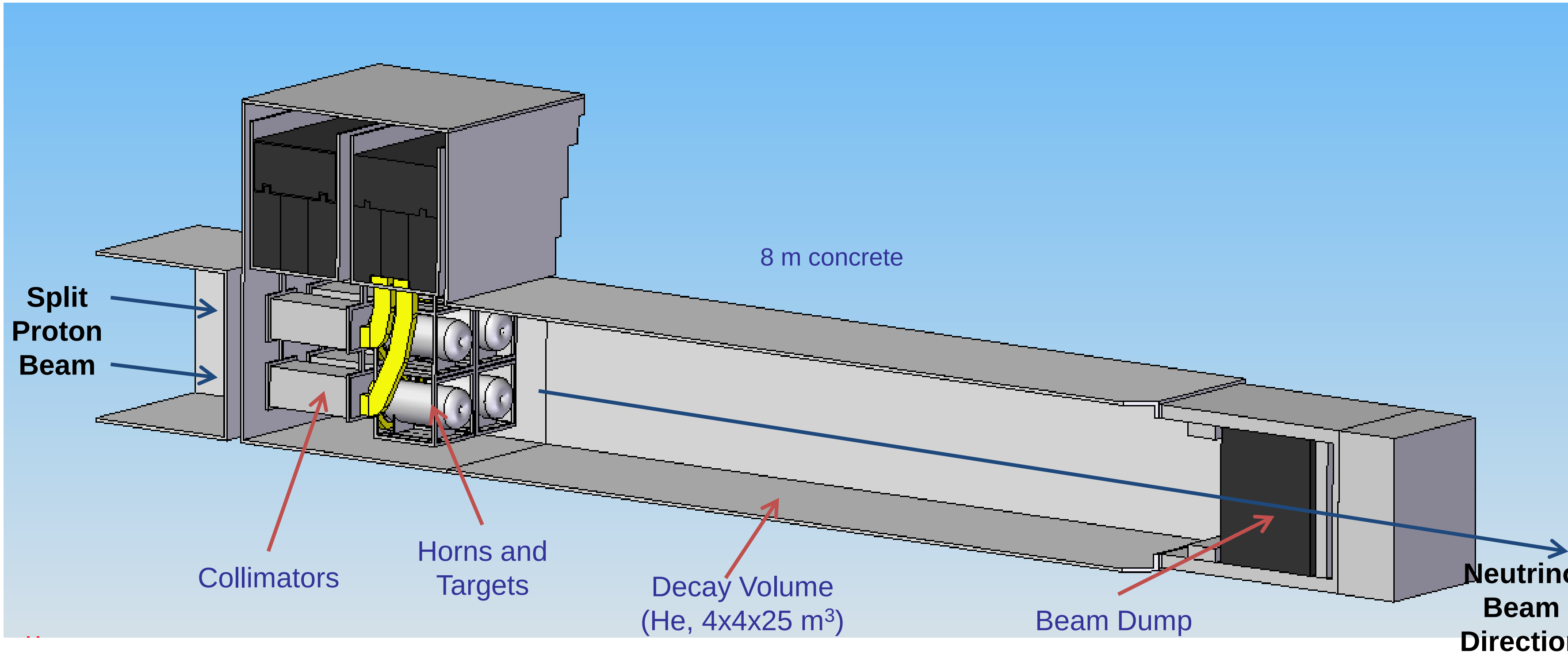


ESS ν Super Beam

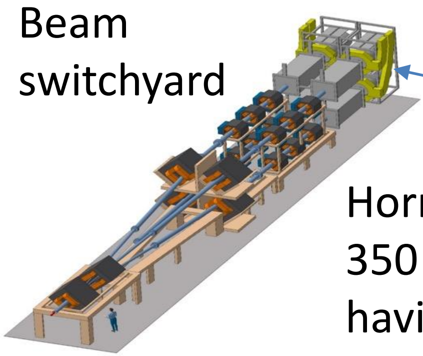


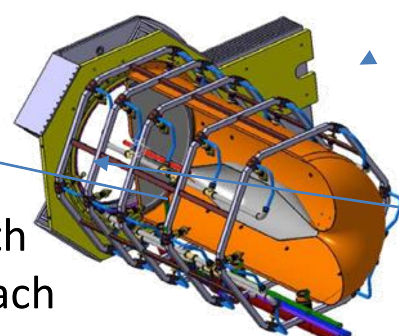
General Layout of the 5 MW target station

The proton beam is split up om 4 targets, each receiving a 1.25 MW beam



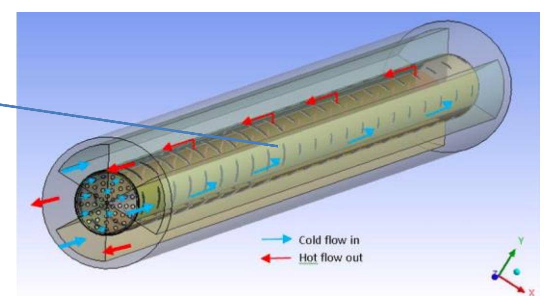
Beam switchyard





Horn excided with 350 kA pulses, each having a 1.3 flat top

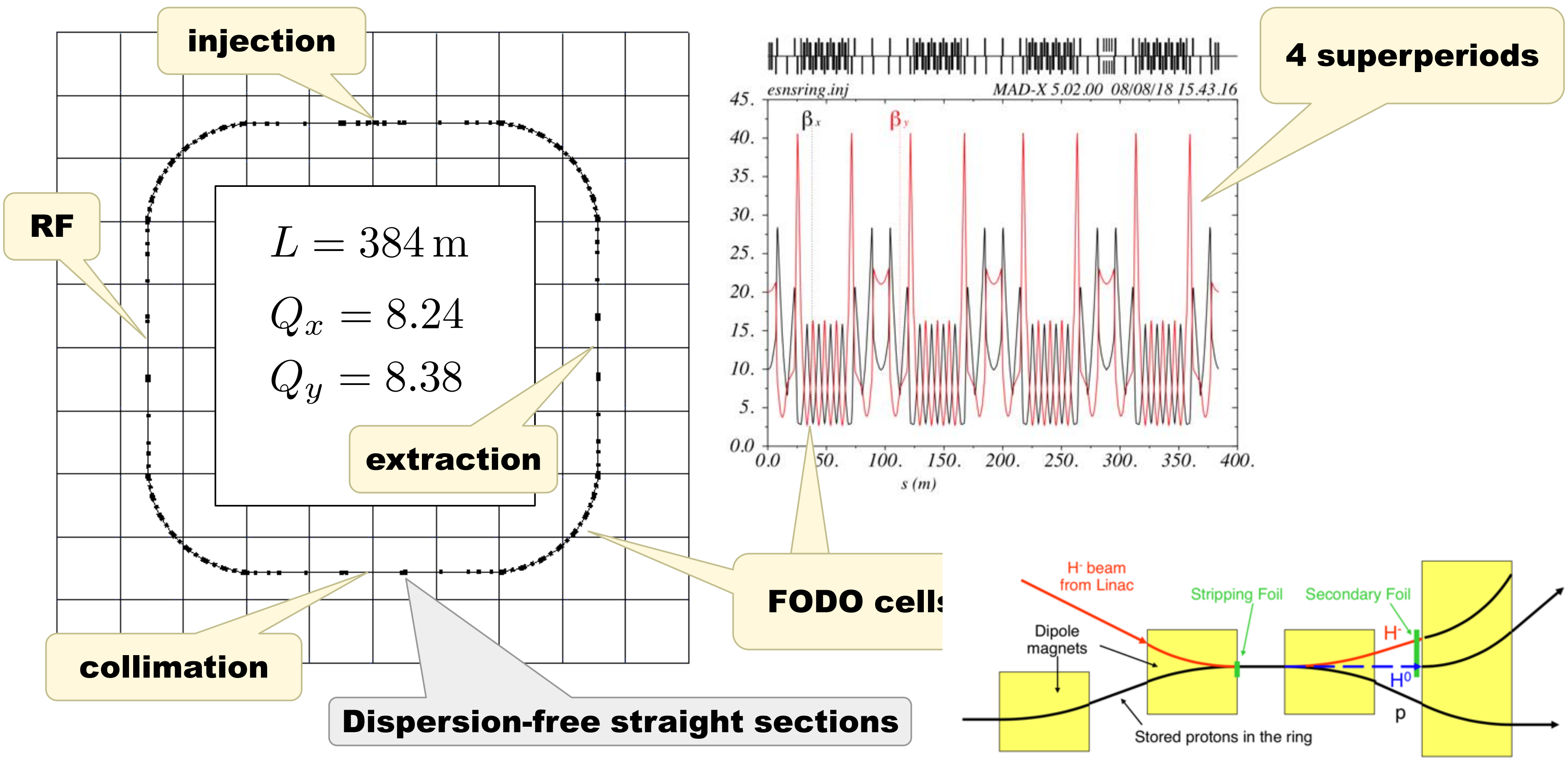
Granular Ti target with He gas cooling for a 1.25 MW beam



The Accumulator Ring

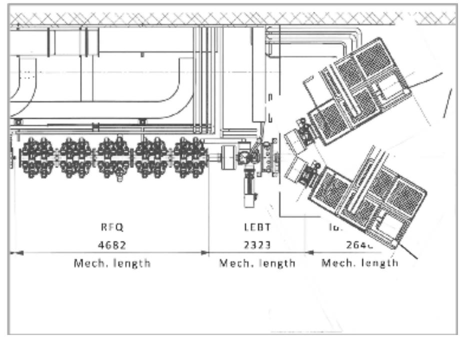
which compresses each 0.65 ms pulse of 2.5×10^{14} protons from the ESS linac to 1.3 μs

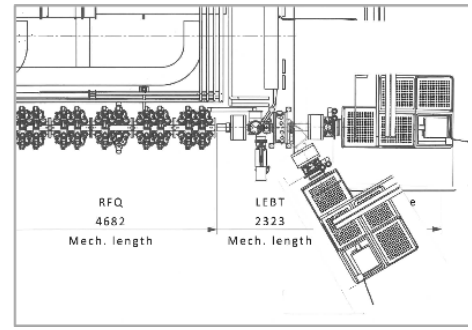
To inject such a high charge in the accumulator ring, H^- injection with stripping is required

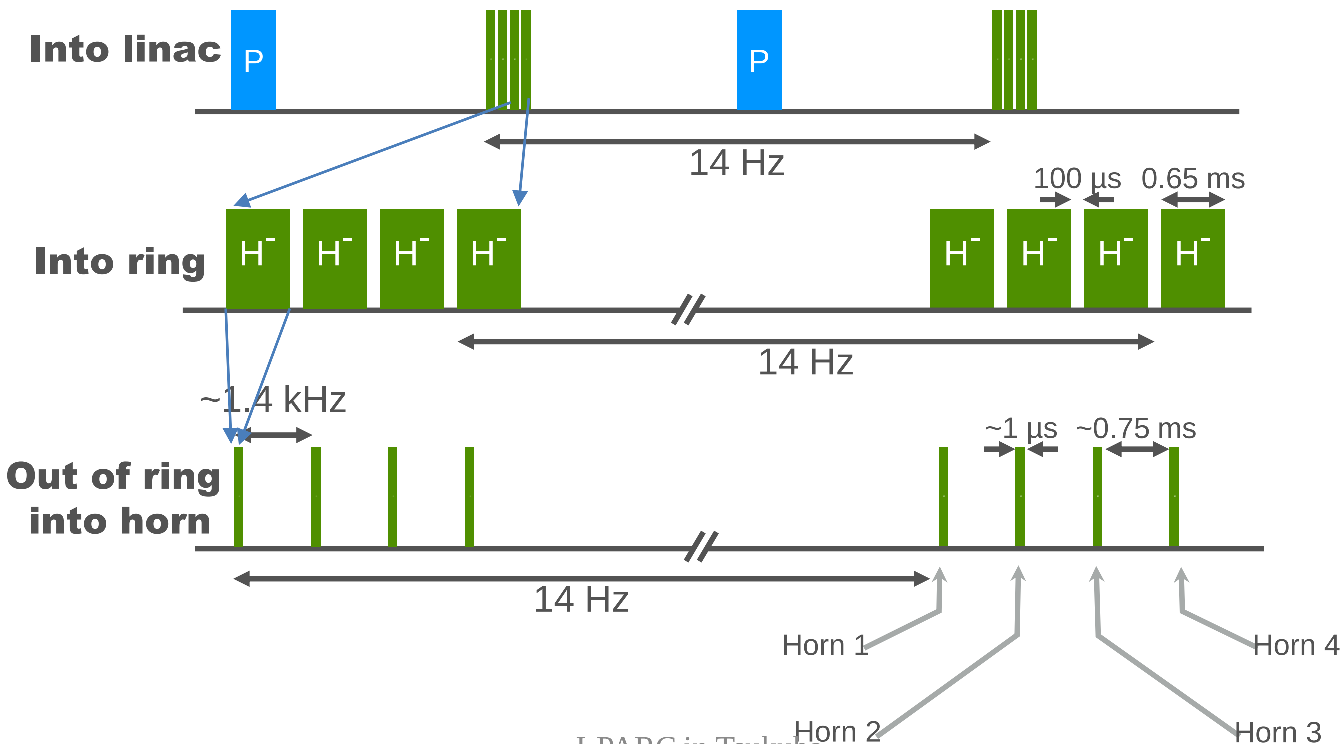


The Linac modifications and operation

H^- source options







Required modifications of the ESS accelerator for adding a 5 MW H^- beam for ESSnuSB

F. Gerigk and E. Montesinos **CERN-ACC-NOTE-2016-0050 8 July 2016**

- The identified major modifications for the doubling of the beam power via a higher repetition rate and higher beam energy are (in no particular order):
  - Three new electrical substations along the RF gallery.
  - A third main electrical station, alongside the 2 existing ones.
  - HV cable trenches and pulling of additional HV cables from the main station towards the new substations. New HV cables between the substations and the modulators in the RF gallery.
  - Installation of 8 new cryo modules and associated RF stations. To accelerate to 2.5 GeV.
  - Change of klystron collectors, so that 60% more average power can be produced. If klystrons are at the end of their lifetime, they could be exchanged against more powerful models.
  - Installation of additional capacitor chargers to allow faster pulsing of the modulators. This is only possible if the modular design developed in-house is adopted.
  - Installation of a H- source + RFQ + MEBT + beam funnel alongside the existing protons source.
  - Exchange trim magnets and associated power supplies against pulsed versions

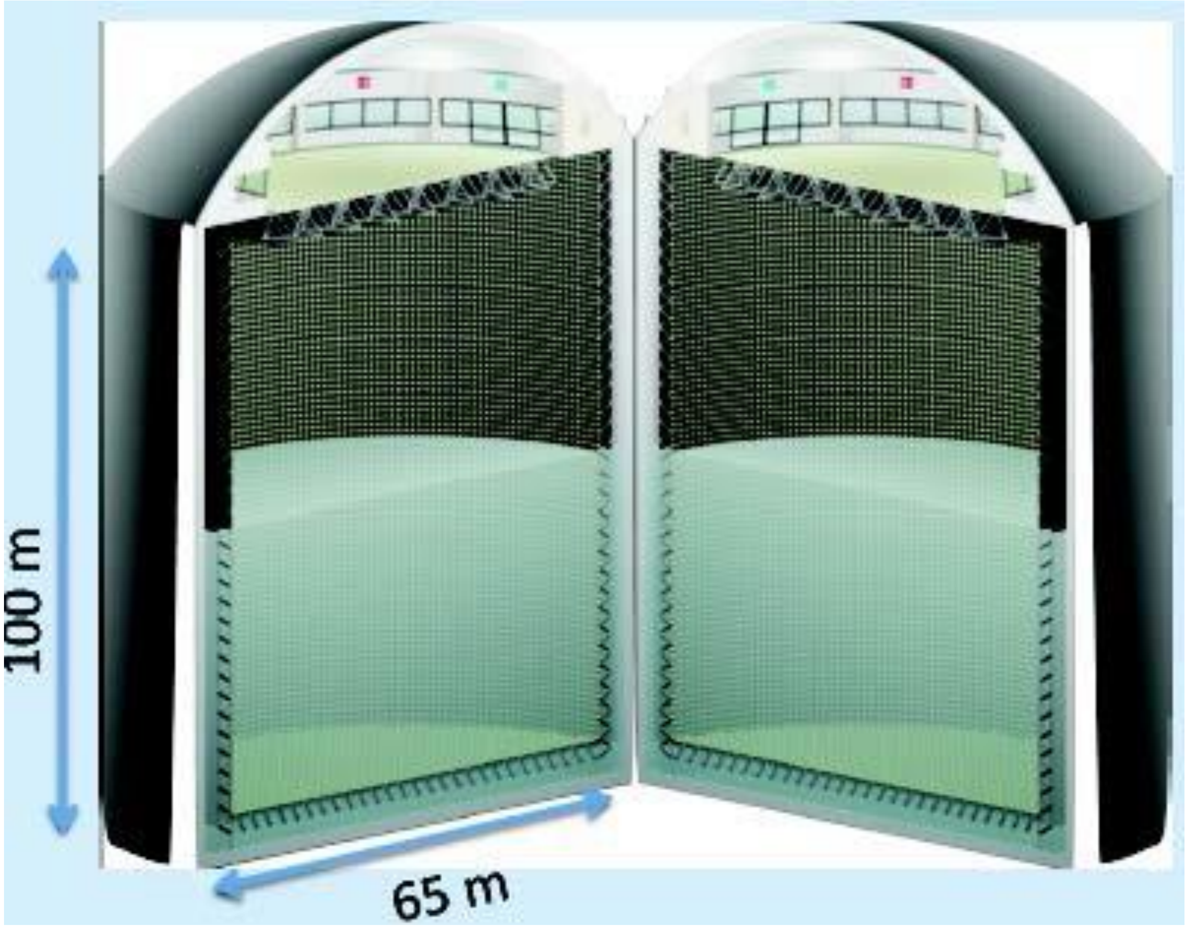
"No show stoppers have been identified for a possible future addition of the capability of a 5 MW H- beam to the 5 MW H+ beam of the ESS linac built as presently foreseen. Its additional cost is roughly estimated at 250 MEuros."
Cf total cost of the ESS 5 MW linac of ca 1000 MEuros

The Megaton Water Cherenkov neutrino detector

MEMPHYS-like Cherenkov detector (MEgaton Mass PHYSics) studied the EUROν and LAGUNA EU Design Studies

- Two cylindrical tanks
- Total fiducial volume 500 kt (~20xSuperK)
- Readout: latest type of high efficiency PMTs

(arXiv: hep-ex/0607026)



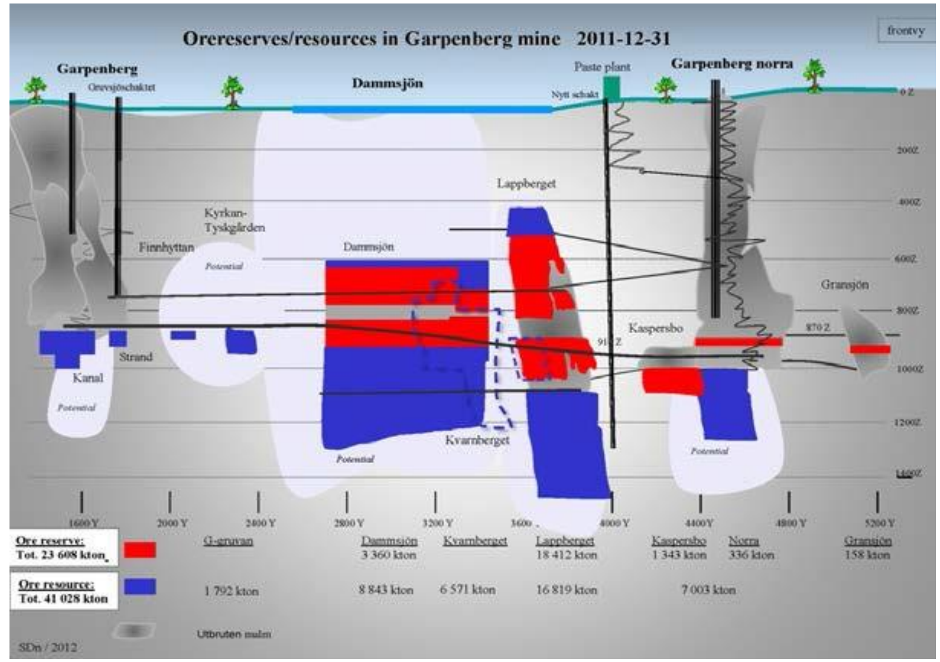
Garpenberg Mine 540 km from ESS

The MEMPHYS type detector to be located 1000 m down in a mine

Garpenberg mine depth 1200 m

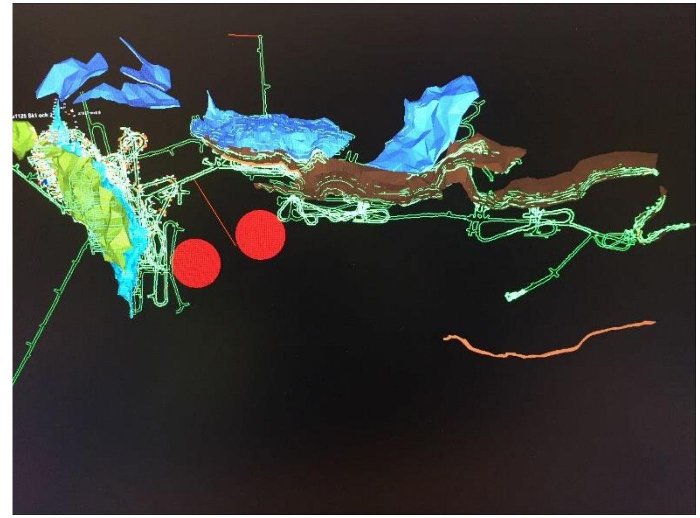
Truck access tunnel

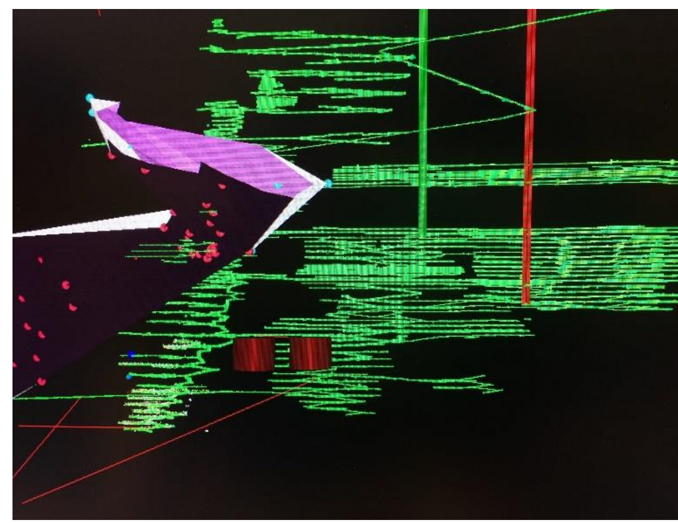
A new ore-hoist shaft has been taken into operation, **leaving an older shaft free to use for transport of ESSnuSB-detector cavern excavation-debris**



Granite drill cores

Zinkgruvan Mine 360 km from ESS





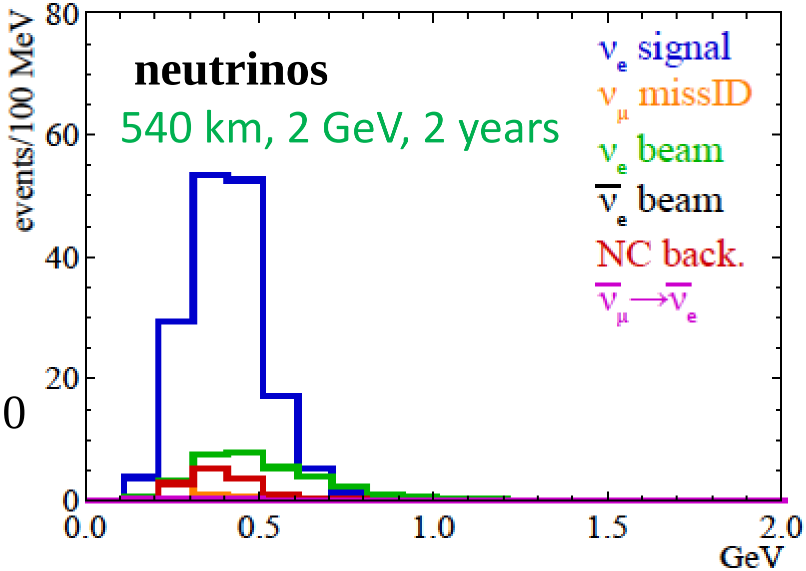
Zinggruvan mine depth 1500 m

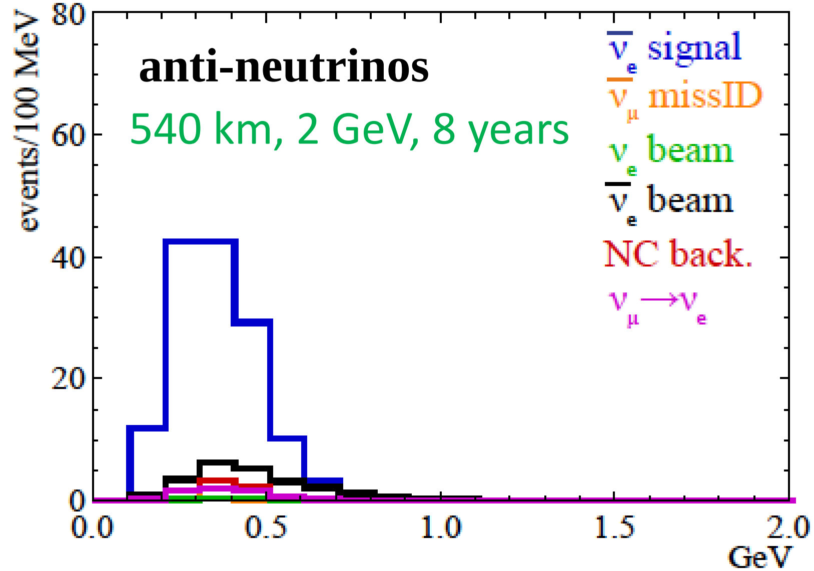
Truck access tunnel

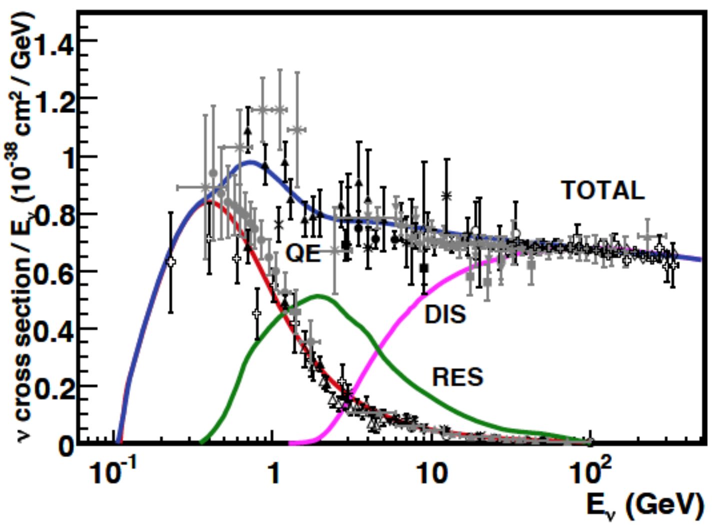
The main ore transport-shaft hoist has a capacity of 6000 tons per 24 hours of which only 2/3 is used. **To bring up the 2.5 Mton of cruched rock will take order 3 years.**

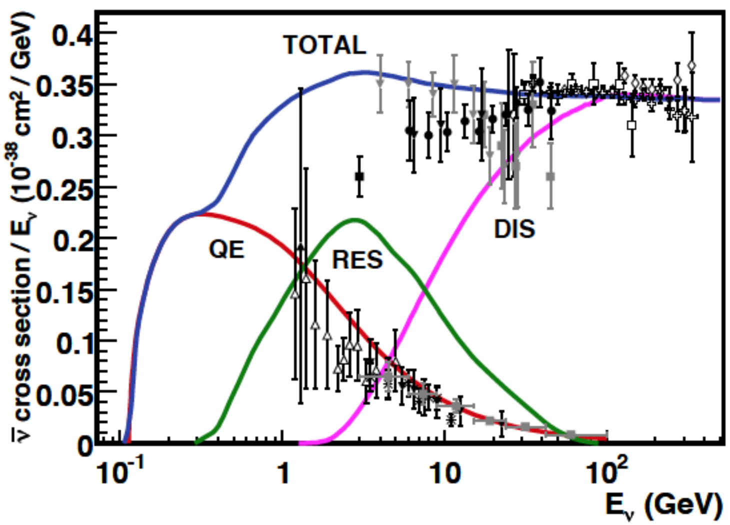
Neutrinos in the far detector

$\delta_{CP}=0$



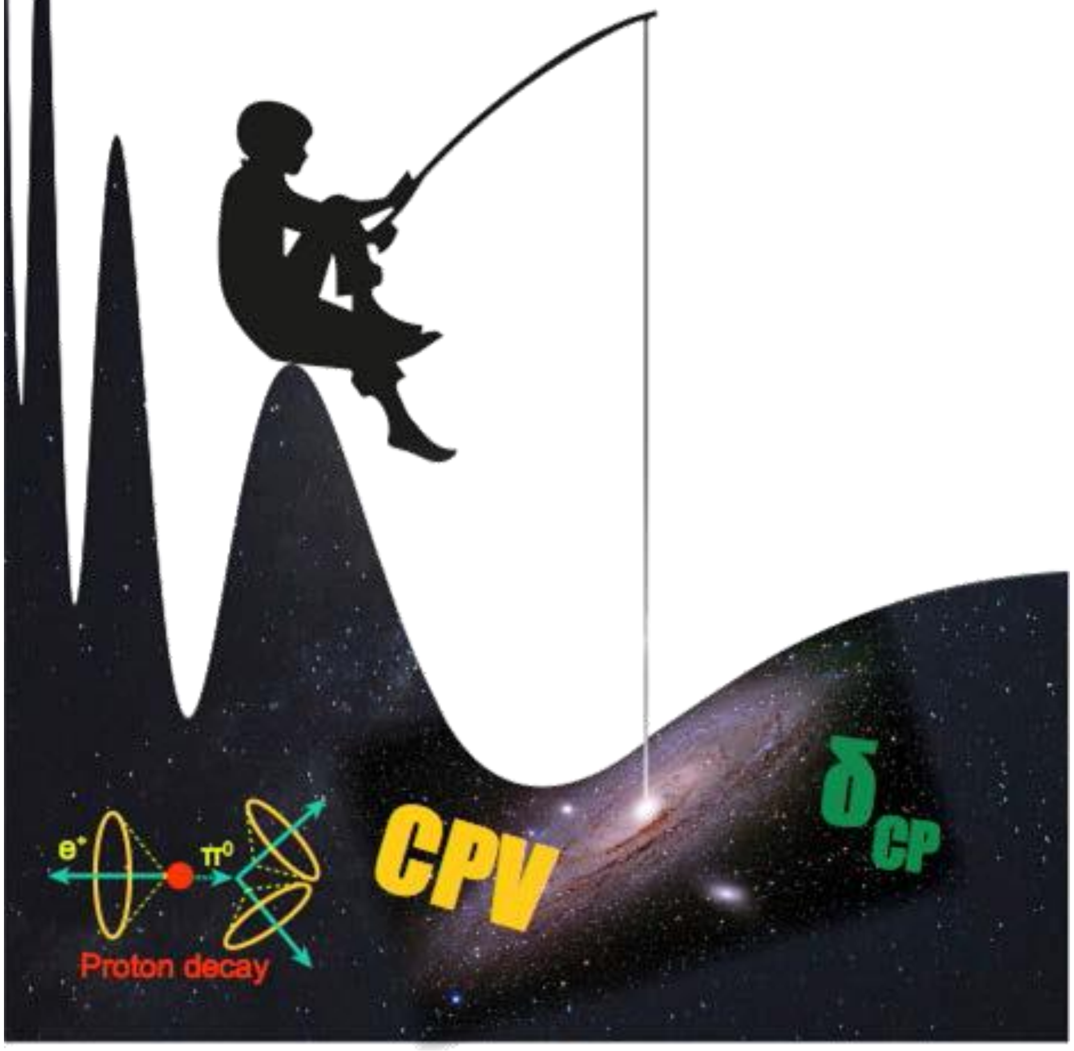






Almost only QE events, very little RES background and no DIS background

The second ν oscillation maximum



The ultimate precision in the determination of the leptonic CP violating angle δ_{CP} from neutrinos oscillation measurements will be set by **systematic errors**.

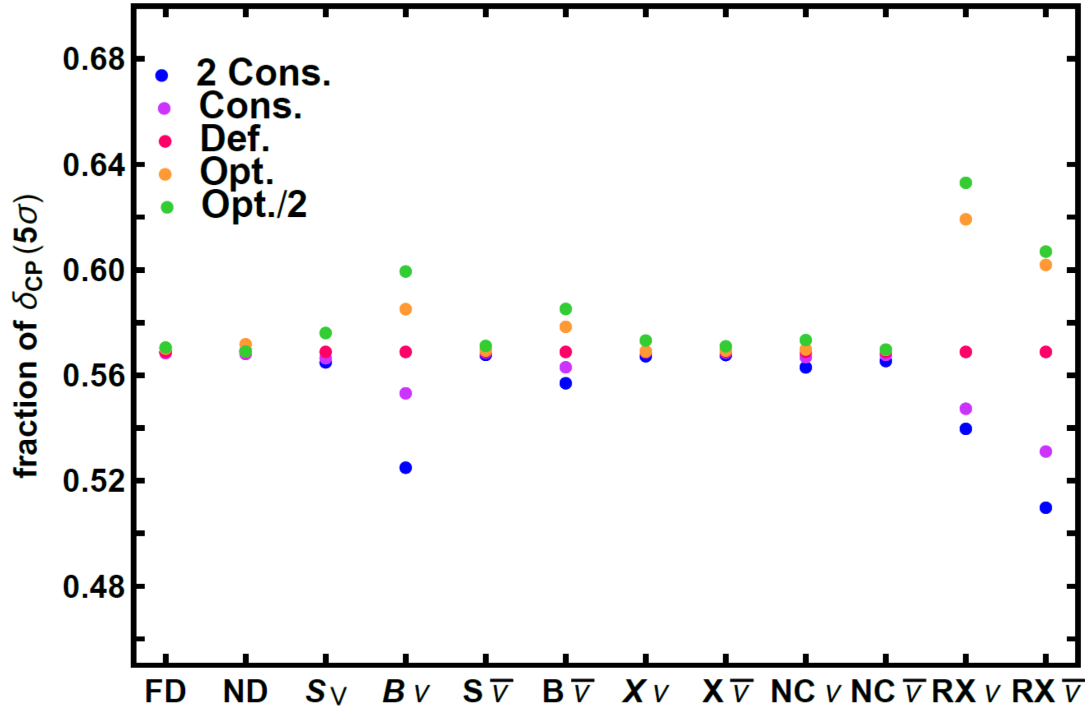
The motivation for the effort to generate a world-uniquely intense neutrino beam using the ESS 5 MW linac is to have enough statistics to reach the second maximum where the CP signal is 3 times higher than at the first maximum, thus **reducing the uncertainty in δ_{CP} due to systematic errors by a factor 3**.

Systematic errors

Systematics	SB Opt.	SB Def.	SB Cons.	BB Opt.	BB Def.	BB Cons.	NF Opt.	NF Def.	NF Cons.
Fiducial volume ND	0.2%	0.5%	1%	0.2%	0.5%	1%	0.2%	0.5%	1%
Fiducial volume FD	1%	2.5%	5%	1%	2.5%	5%	1%	2.5%	5%
(incl. near-far extrap.)									
Flux error signal ν	5%	7.5%	10%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background ν	10%	15%	20%		correlated			correlated	
Flux error signal $\bar{\nu}$	10%	15%	20%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background $\bar{\nu}$	20%	30%	40%		correlated			correlated	
Background uncertainty	5%	7.5%	10%	5%	7.5%	10%	10%	15%	20%
Cross secs × eff. QE†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs × eff. RES†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs × eff. DIS†	5%	7.5%	10%	5%	7.5%	10%	5%	7.5%	10%
Effec. ratio ν_e/ν_μ QE*	3.5%	11%	–	3.5%	11%	–	–	–	–
Effec. ratio ν_e/ν_μ RES*	2.7%	5.4%	–	2.7%	5.4%	–	–	–	–
Effec. ratio ν_e/ν_μ DIS*	2.5%	5.1%	–	2.5%	5.1%	–	–	–	–
Matter density	1%	2%	5%	1%	2%	5%	1%	2%	5%

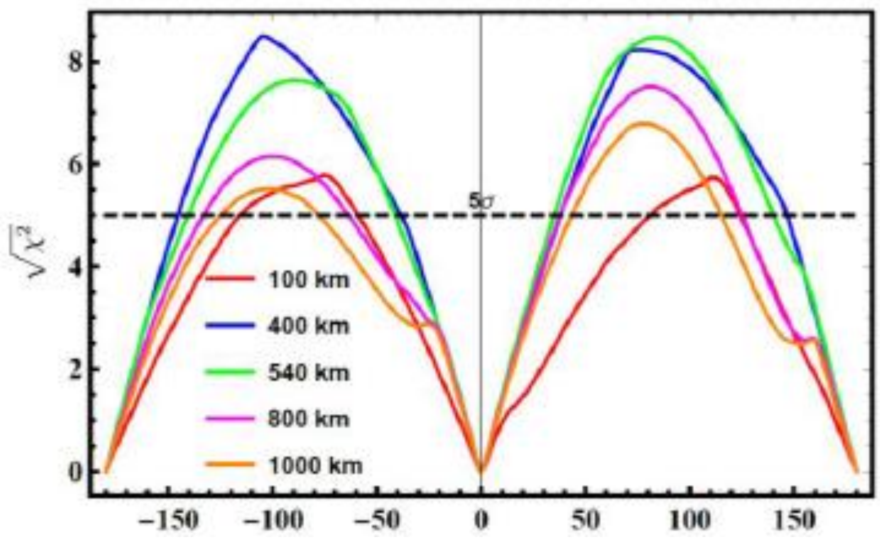
Systematic uncertainties in long-baseline neutrino oscillations for large θ_{13}
Pilar Coloma, Patrick Huber, Joachim Kopp, and Walter Winter
Phys. Rev. D 87, 033004 – Published 11 February 2013

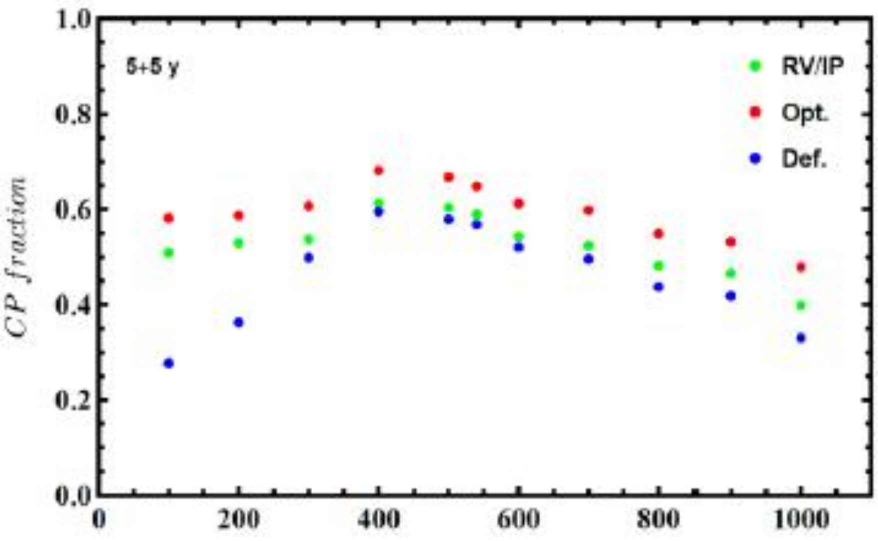
Sensitivity to the different error types



Fraction of values of δ_{CP} for which a 5σ discovery would be possible is shown when each of the systematic errors from table is varied individually between one half of the "optimistic" values and twice the "pessimistic" ones. A 540 km baseline and 5 yrs in neutrino and antineutrino mode have been assumed. The different systematics studied in the plot are the far and near detector fiducial volumes (FD and ND), the signal and background components of the beam running in neutrino and antineutrino modes (S ν , B ν , S ν , and B ν), the cross section uncertainties for neutrinos and antineutrinos (X ν and X ν) as well as for the NC interactions (NC ν and NC ν) and the ratio of the muon to electron neutrino cross sections (RX ν and RX ν).

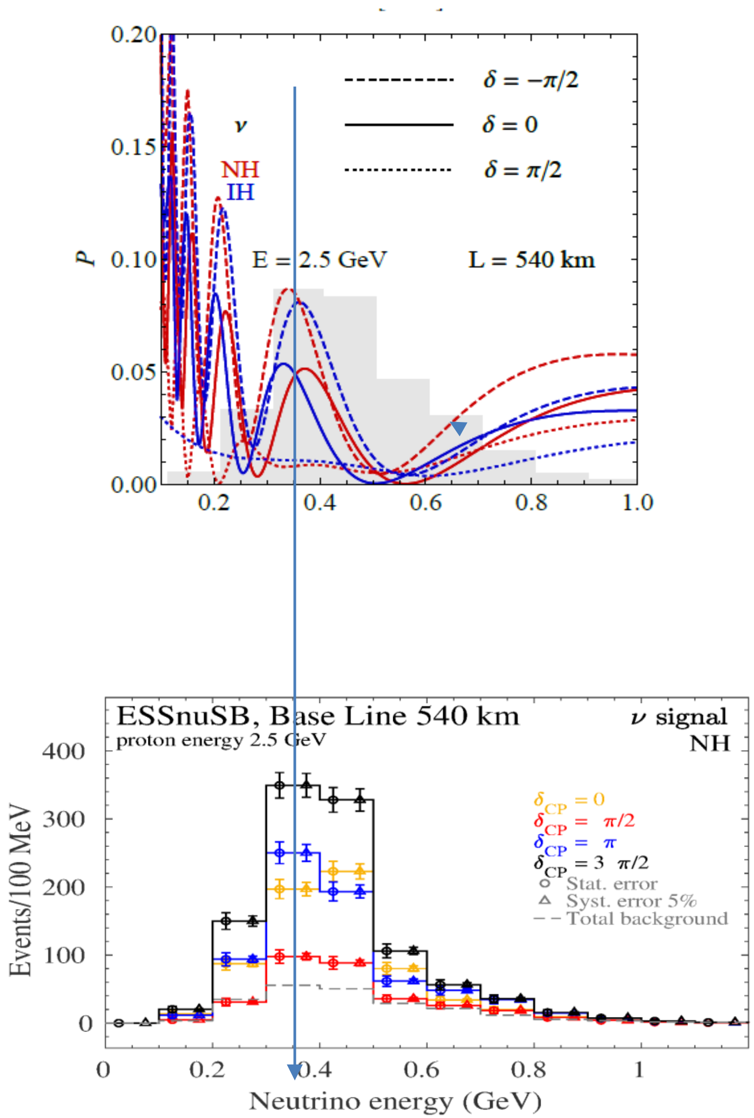
Copmarison of different baselines



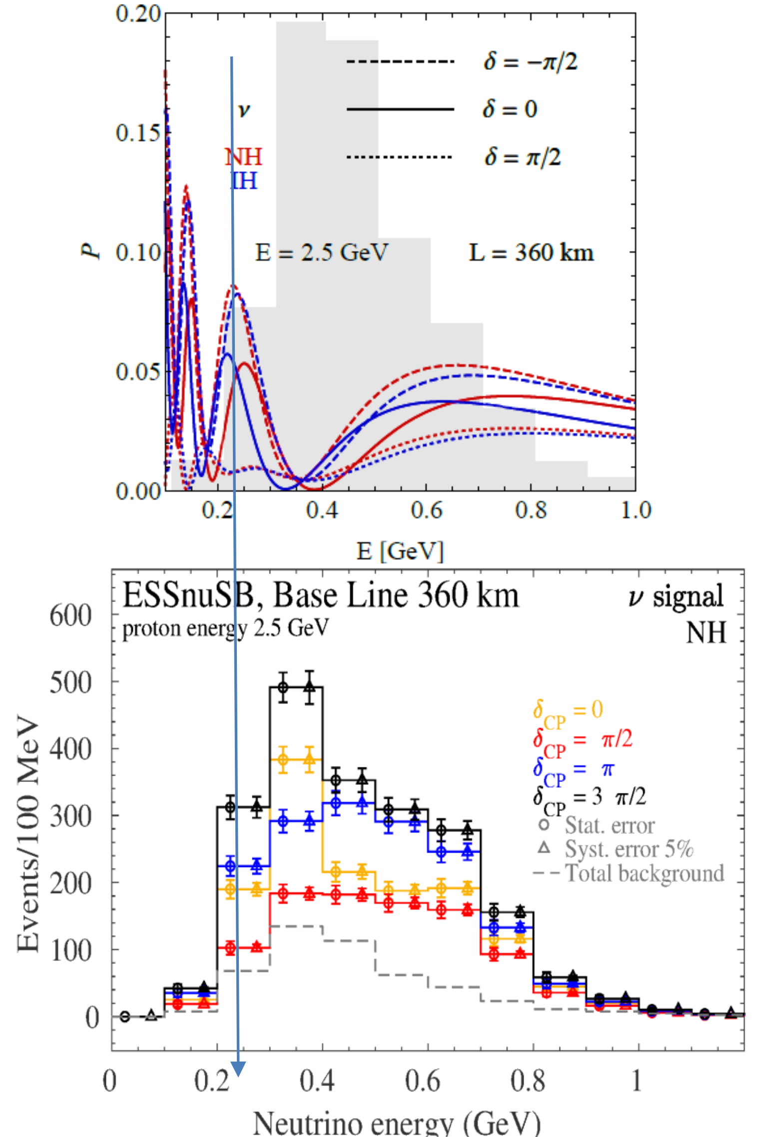


Comparison of the two mines

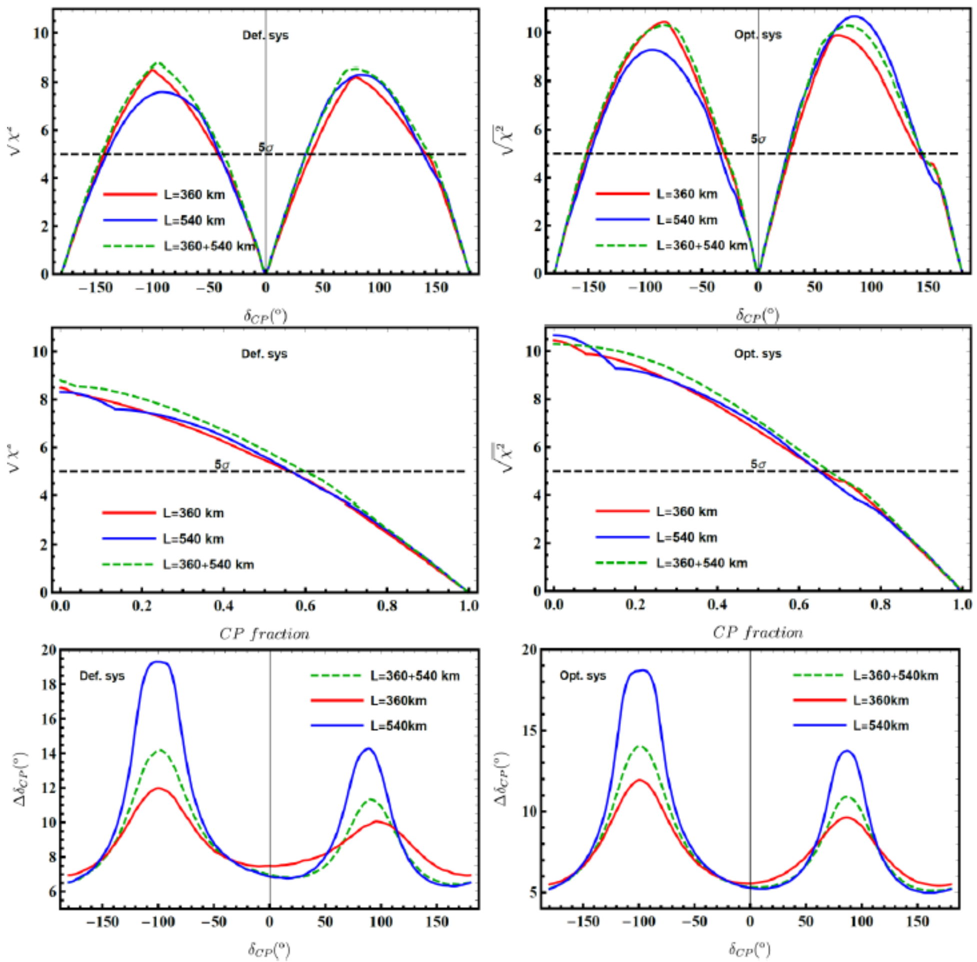
Garpenberg 540 km



Zinkgruvan 360 km

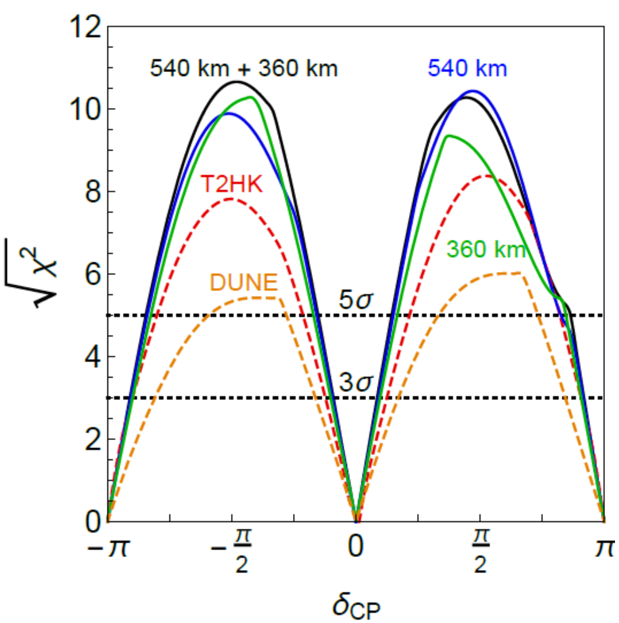


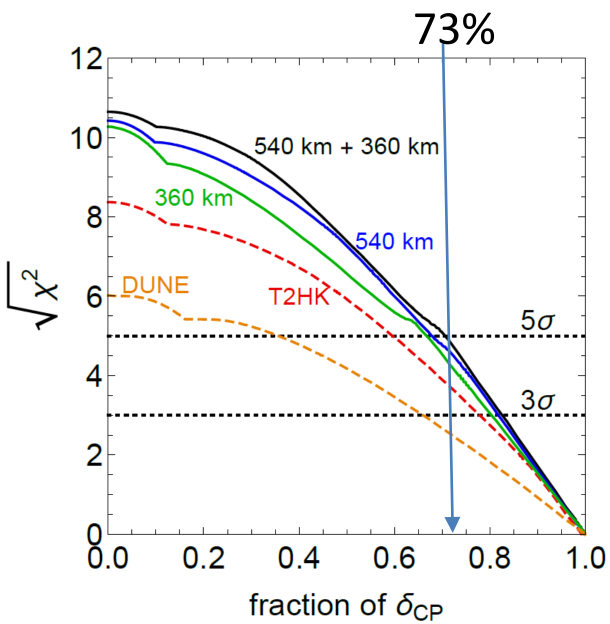
ESSnuSB performance at Garpenberg (blue) and Zinkgruvan (red) and the two error sets ‘Def.’ and ‘ Opt’

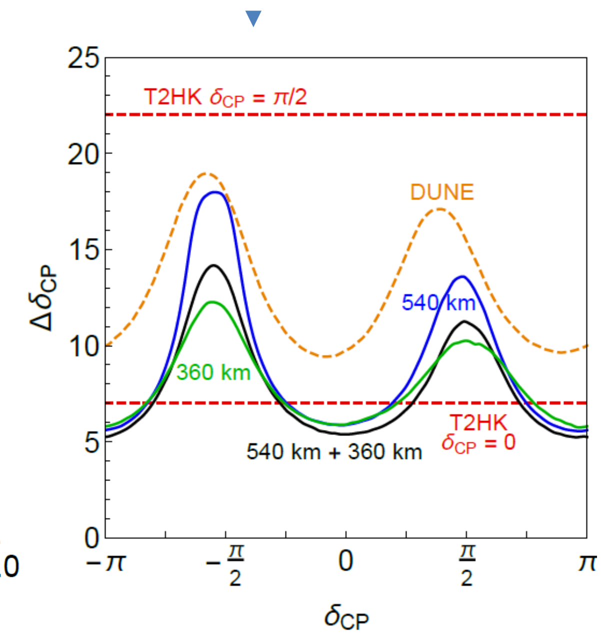


The performances of ESSnuSB, DUNE and Hyper-K

The performance of ESSnuSB, DUNE and Hyper-K assuming *the same* systematic error 3% for all three experiments to compare them on the same footing (detailed explanation on the next slide)







Courtesy Enrique F. Martinez

Explanation of the figures in slide 18

In these figures are shown results for two 250 kt detectors in the Garpenberg mine (540 km baseline, blue curves), two 250 kt detectors in the Zinkgruvan mine (360 km baseline, green curves) and one 250 kt detector in the Garpenberg mine and one in the Zinkgruvan mine (black curves).

The Hyper-K curve in the middle and right plots and the two resolution values in the left plot for $\delta_{CP} = 0$ and $\delta_{CP} = \pi/2$, indicated by the two dotted horizontal lines, are those presented by Hyper-K at the Neutrino 2018 conference.

The DUNE curves have been derived using the public GLoBES file released by the DUNE collaboration with its Conceptual Design Report in 2016. Performance predictions for DUNE, assuming 7 years of data taking, were shown by the DUNE collaboration at the Neutrino 2018 conference. For the comparison, in this plot the same simulations were repeated, assuming 10 years of data taking to be in line with the assumptions made for the Hyper-K simulations.

The ESSνSB curves have been derived setting the systematic errors to 3% to be in line with the systematic error levels set by DUNE and Hyper-K. The θ_{13} and θ_{23} values for DUNE and ESSνSS have been set to the same values as those used by Hyper-K, again to compare the three experiments on the same footing.

The interest of measuring δ_{CP} precisly

Test of flavor models

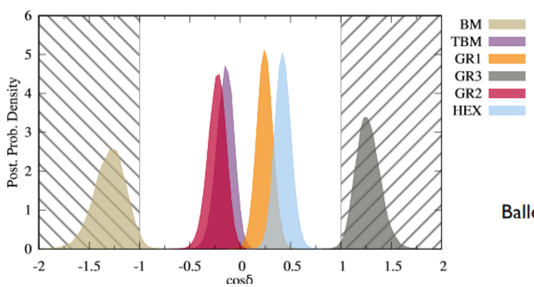
Tests of flavour models

Typically, the models considered have a reduced number of parameters, leading to relations between the masses and/or mixing angles.

Examples are the so-called sumrules, e.g.:

$$\sin\theta_{23} - \frac{1}{\sqrt{2}} = \sin\theta_{13}\cos\delta$$

$$\cos\delta = \frac{t_{23}s_{12}^2 + s_{13}^2 c_{12}^2/t_{23} - s_{12}^{\nu 2}(t_{23} + s_{13}^2/t_{23})}{\sin 2\theta_{12} s_{13}}$$



Ballet at al., 1410.7573

@Silvia Pascoli

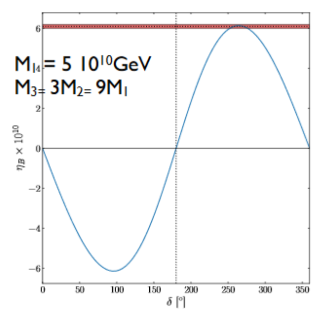
Baryon Asymmetry of the Universe

Does observing low energy CPV imply baryon asymmetry?

In see-saw type I, let's consider the case of low energy CPV, for instance delta (R real). An approximate formula:

$$|Y_B| \cong 2.4 \times 10^{-11} \, |\sin\delta| \left(\frac{s_{13}}{0.15}\right)\left(\frac{M_1}{10^{11}\ \mathrm{GeV}}\right)$$

SP, Petcov, Riotto, PRD and NPB 2007; SP 2014



Intermediate flavour regime:
$10^9\,\mathrm{GeV} < M_1 < 10^{12}\,\mathrm{GeV}$

$$\epsilon_{\tau\tau}^{(1)} = (0.515 - 3.94 c_{13})\, s_{13} \times 10^{-8} \sin\delta$$

$$\epsilon_{\tau\tau}^{(1)} = 3.14 \times 10^{-7} \cos\frac{\alpha_{21}}{2}$$

Moffat, SP, Petcov, Turner, 1804.05066, 1809.08251

A full study shows that delta can give an important (even dominant) contribution to the baryon asymmetry. For Majorana CPV, effects enhanced by a factor of ~10.

ESSnuSB organization and time plan

Call:	H2020-INFRADEV-2017-1
Funding scheme:	RIA
Proposal number:	777419
Proposal acronym:	ESSnuSB
Duration (months):	48
Proposal title:	Feasibility Study for employing the uniquely powerful ESS linear accelerator to generate an intense neutrino beam for leptonic CP violation discovery and measurement.
Activity:	INFRADEV-01-2017

N.	Proposer name	Country
1	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	FR
2	UPPSALA UNIVERSITET	SE
3	KUNGLIGA TEKNISKA HOEGSKOLAN	SE
4	EUROPEAN SPALLATION SOURCE ERIC	SE
5	UNIVERSITY OF CUKUROVA	TR
6	UNIVERSIDAD AUTONOMA DE MADRID	ES
7	NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"	EL
8	ISTITUTO NAZIONALE DI FISICA NUCLEARE	IT
9	RUDER BOSKOVIC INSTITUTE	HR
10	SOFIISKI UNIVERSITET SVETI KLIMENT OHRIDSKI	BG
11	LUNDS UNIVERSITET	SE
12	AKADEMIA GORNICZO-HUTNICZA IM. STANISLAWA STASZICA W KRAKOWIE	PL
13	EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH	CH
14	UNIVERSITE DE GENEVE	CH
15	UNIVERSITY OF DURHAM	UK
	Total:	

Partners: Oslo U, IHEP, BNL, SCK•CEN, SNS, PSI, RAL

- EU grant 3 MEUR/4 years
- Kick-off meeting in January 2018.
- ESSνSB has about 60 members of which 10 are full-time EU-financed postdocs.
- Next ESSnuSB and EuroNuNet annual meeting to be held in Zagreb 21-24 October 2019 – newcomers are most welcome to attend

More information at: http://essnusb.eu/

ESSnuSB organization and time plan

A 2nd generation neutrino Super Beam

ESS NEUTRINO SUPER BEAM

ESFRI

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

2012: Θ_{13} measurement published - inception of the ESSnuSB project

Nucl. Phys. B 885 (2014) 127

2016-2019: beginning of COST Action EuroNuNet

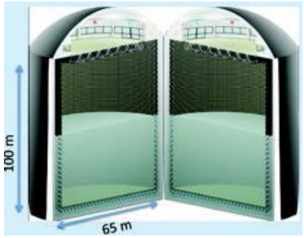
2018: beginning of ESSνSB Design Study (EU-H2020)

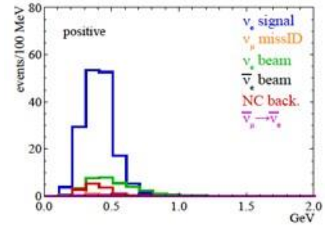
2021: End of ESSνSB Design Study, CDR and preliminary costing

2024:End Preparatory Phase, TDR

2-5 years, International Agreement

EUROPEAN SPALLATION SOURCE

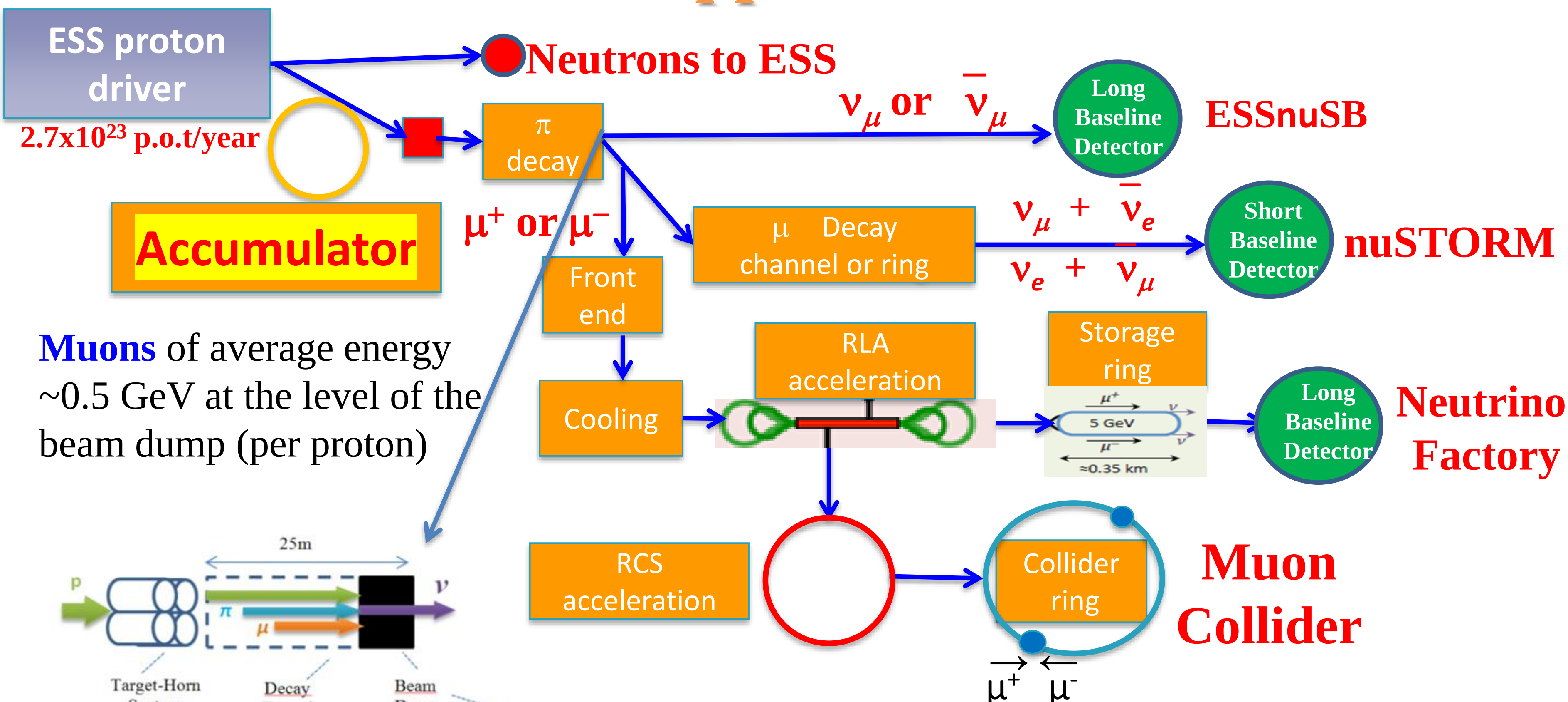




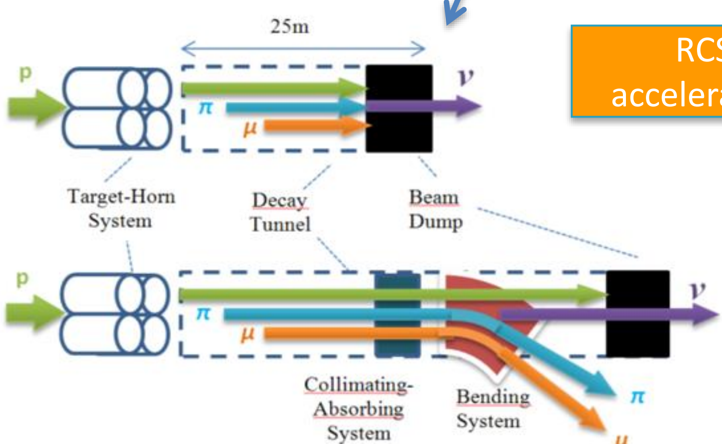
7 years Construction of the facility and detectors, including commissioning

2033-2036: Start Data taking

Open workshop on "Prospects for Intensity Frontier Physics with Compressed Pulses from the ESS Linac" in Uppsala 2-3 March 2020



Muons of average energy ~0.5 GeV at the level of the beam dump (per proton)



more than 4x10^{20} μ/year from ESS

Decay At Rest and Coherent ν scattering also need Compressed pulse and will be included

Sponsors of this project

Funded by the Horizon 2020 Framework Programme of the European Union

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777419.

EuroNuNet

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

This project is supported by the COST Action CA15139 ``Combining forces for a novel European facility for neutrino-antineutrino symmetry-violation discovery'' (EuroNuNet).

A few concluding remarks

ESSnuSB, the design of which is currently being studied, is complementary to other existing and planned super beam experiments by the fact
1. that it focusses at the second maximum where the sensitivity to systematic errors is 3 times lower than at the first maximum and also
2. that the neutrino energy is low enough for the resonant and deep inelastic backgrounds to be strongly suppressed.

If and when the current experimental hints of CP violation will have been confirmed on the level of 5σ, the next important step will be to make an accurate measurement of the CP violating angle δ_{CP}, which will require the CP violation signal to maximized. Accurate measurement of δ_{CP} has the potential to provide decisive information on flavour models and on the baryon asymmetry.

The use of the ESS linac for the producing a world-uniquely intense neutrino beam can pave the way for making use of the concurrent production of an equally intense muon beam to realize the Muon Collider and/or Neutrino Factory project.

Thank you