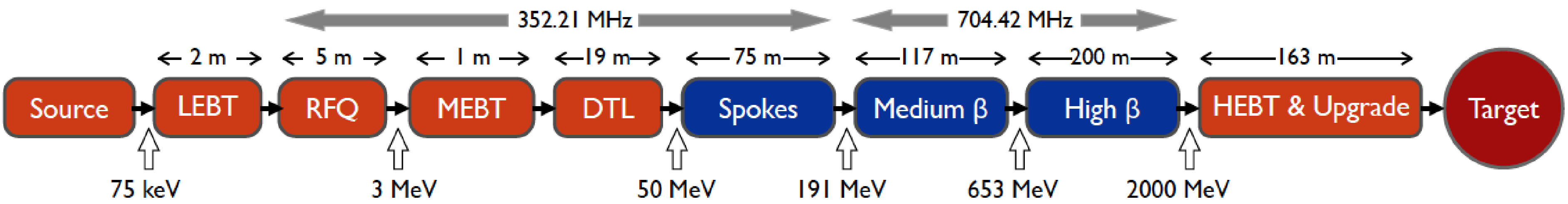
Euopean Spallation Source neutrino Super Beam project 'ESSnuSB' - project status

NOW 2018 Workshop 2018-09-11

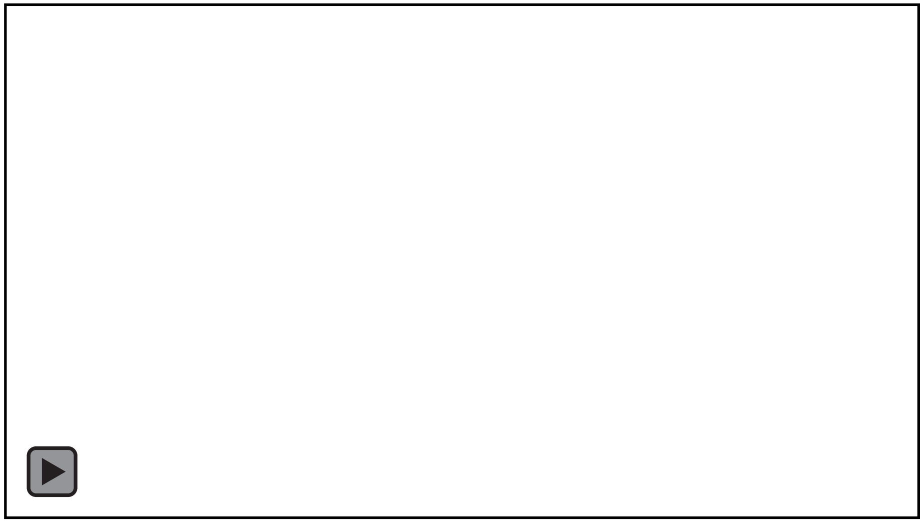
Tord Ekelöf

Uppsala University

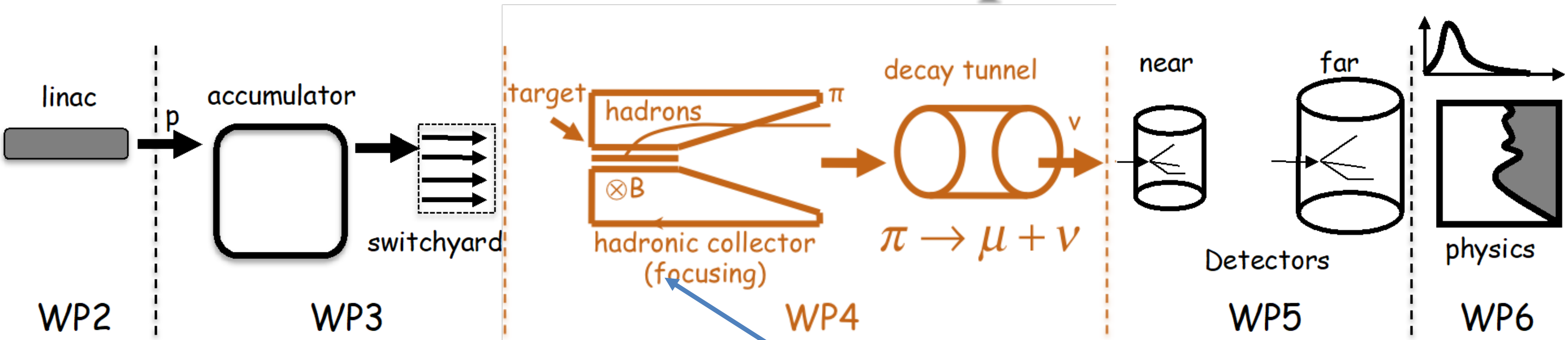
ESS proton linac

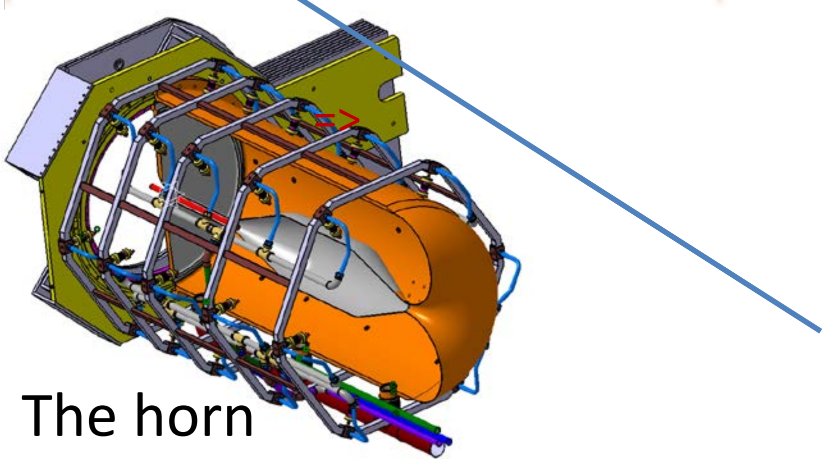


- The ESS will be a copious source of spallation neutrons.
- 5 MW average beam power.
- 125 MW peak power.
- 14 Hz repetition rate (2.86 ms pulse duration, 10^{15} protons).
- Duty cycle 4%.
- 2.0 GeV protons
  - up to 3.5 GeV with linac upgrades
- **>2.7x10^{23} p.o.t/year.**



ESSnuSB neutrino production





The horn

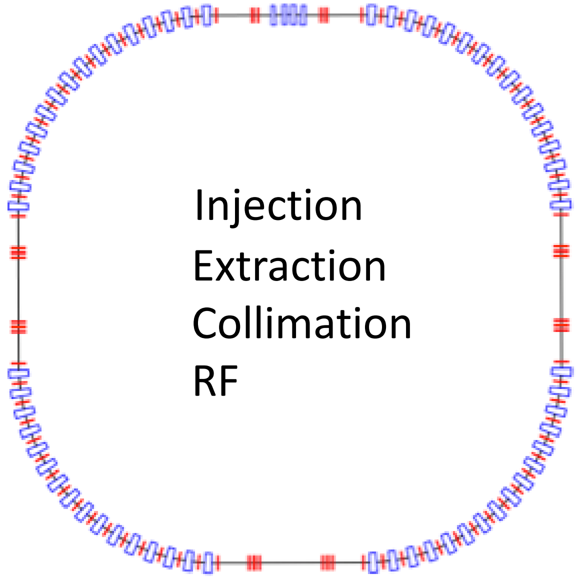
The horn 350 kA current supply can have maximum ~1 μs flat top =>

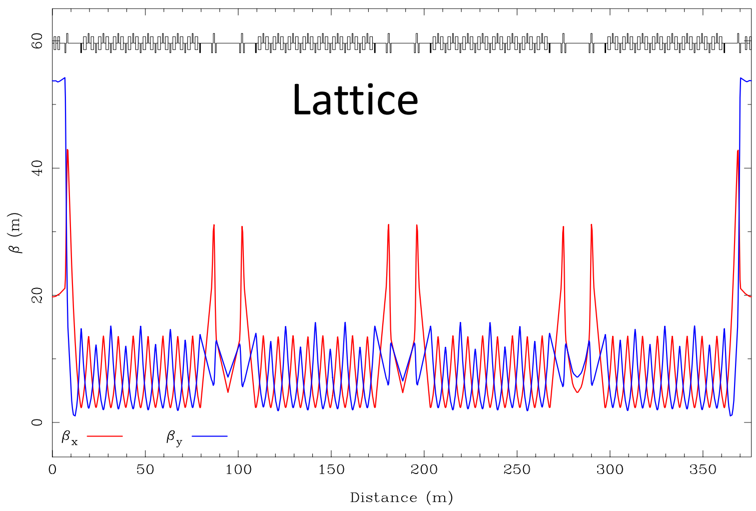
The 3 ms long ESS linac pulse needs to be compresse to ~1 μs =>

Accumulator ring need

Accumulation Ring

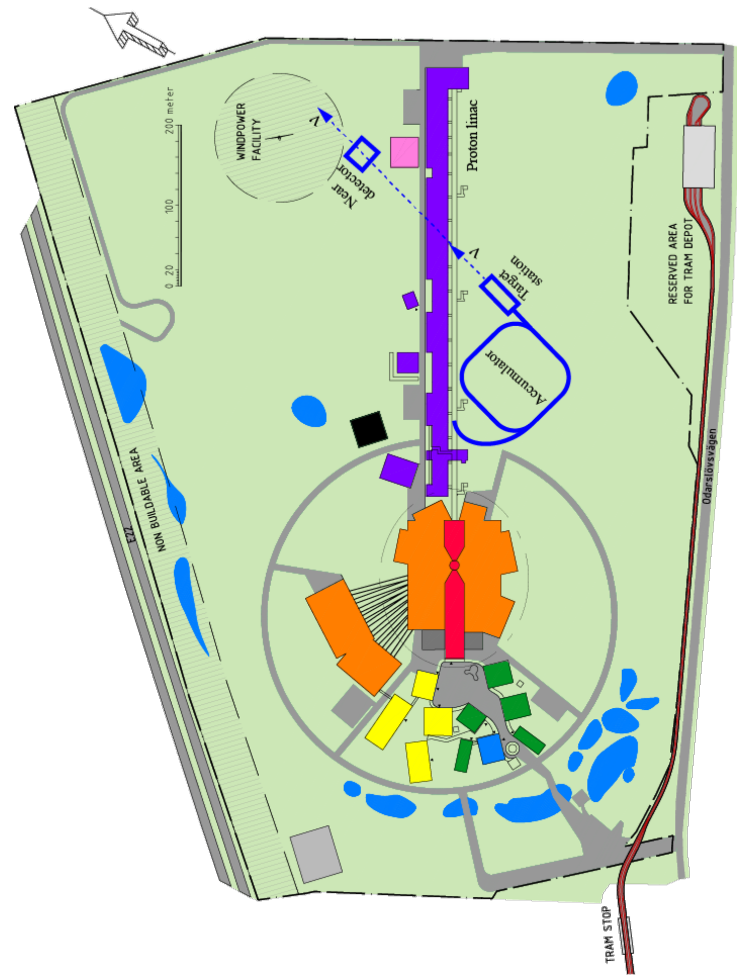
- **Baseline**: **single-ring accumulator**
  - Current studies give a **376 m** circumference accumulator ring 1.32μs pulse lengh.
  - Injecting the 10^{15} protons of one ESS linac pulse in the ring leads to a large space–charge **tune–shift** of about **0.75** .



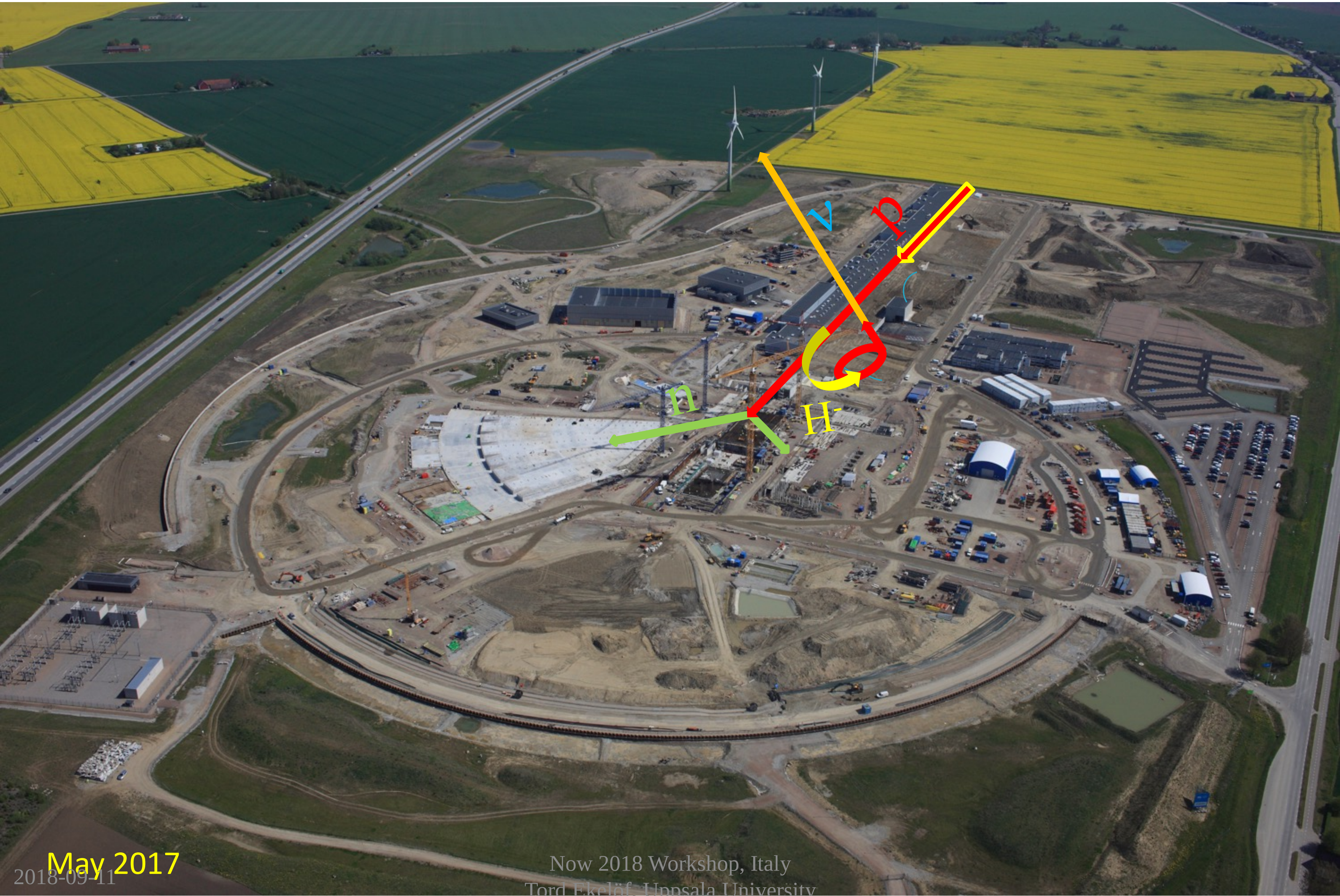


How to add a neutrino facility?

- The neutron program must not be affected and if possible synergetic modifications.
- Linac modifications: double the rate (14 Hz → 28 Hz), from 4% duty cycle to 8%.
- Accumulator (C~400 m) needed to compress to few μs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA, power consumption, Joule effect)
  - H^- source (instead of protons),
  - space charge problems to be solved.
- ~300 MeV neutrinos.
- Target station (studied in EUROν).
- Underground detector (studied in LAGUNA).



The neutron and neutrino beams

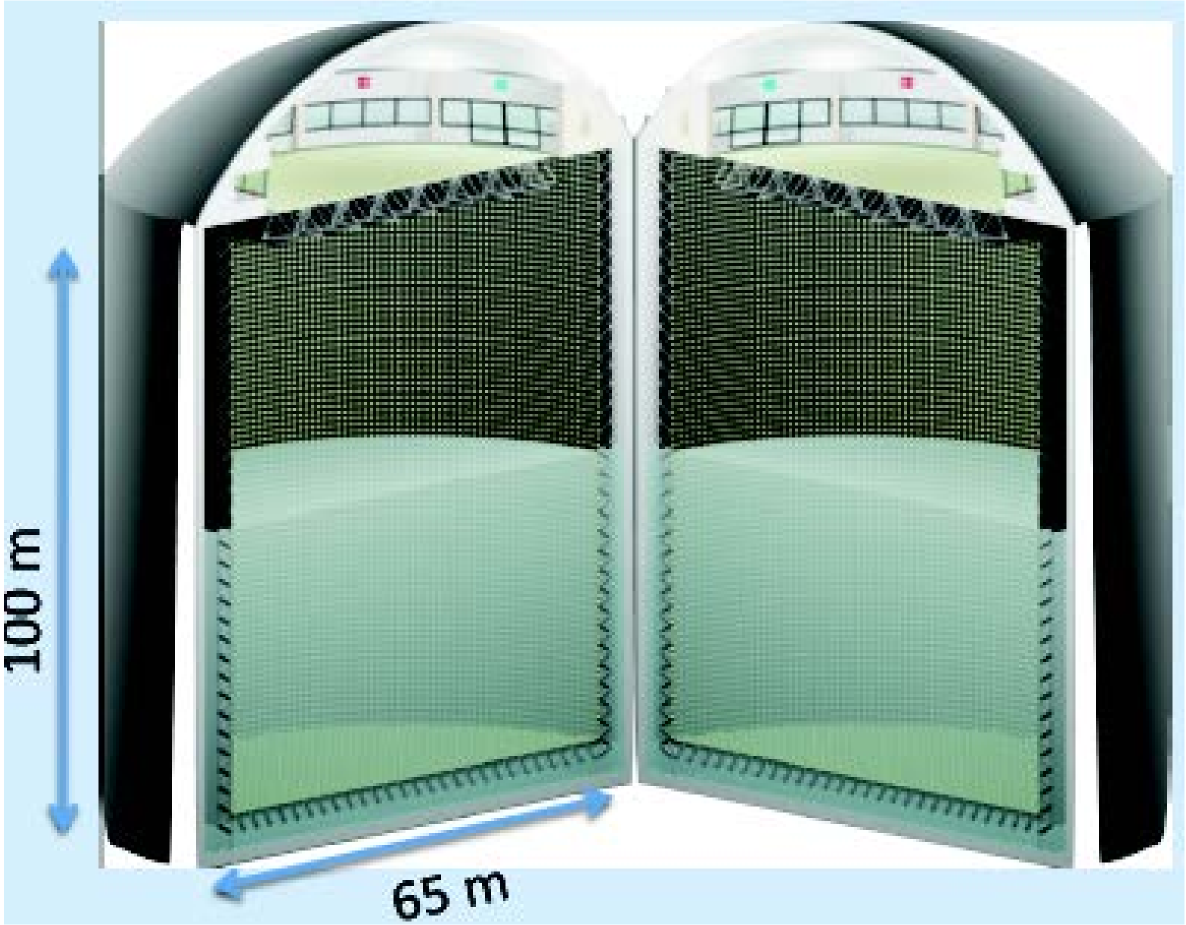


The Megaton Water Cherenkov neutrino detector

MEMPHYS like Cherenkov detector(MEgaton Mass PHYSics studied by LAGUNA)

- 500 kt fiducial volume (~20xSuperK)
- Readout: ~240k 8” PMTs
- 30% optical coverage

(arXiv: hep-ex/0607026)

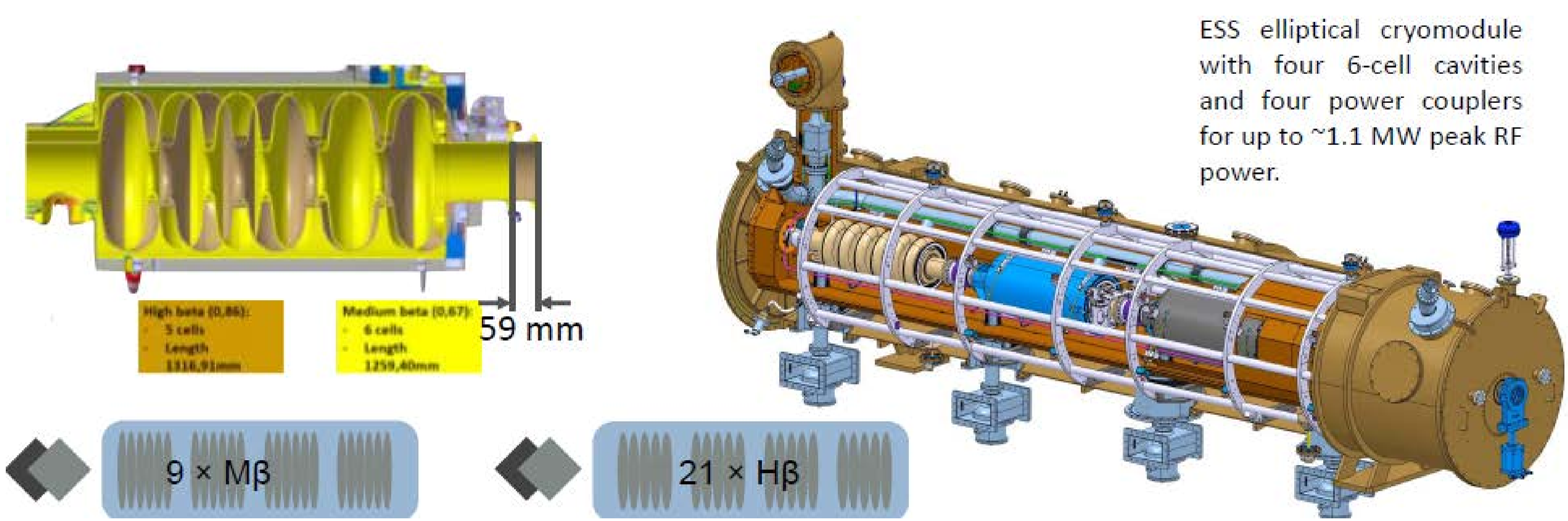


Status of accelerator upgrade to 10 MW

• The identified major modifications for the doubling of the beam power via a higher repetition rate and higher beam energy are according to Frank Gerigk's and Eric Montesinos' CERN-ADD-NOTE-2016-0050 :

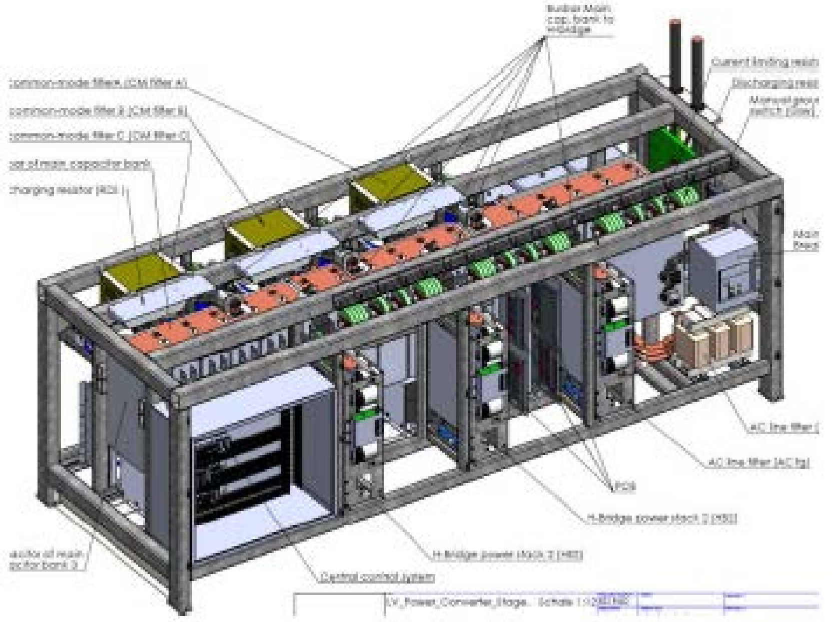
‣ Three new electrical substations along the RF gallery.
‣ A third main electrical station, alongside the 2 existing ones.
‣ HV cable trenches and pulling of additional HV cables from the main station towards the new substations. New HV cables between the substations and the modulators in the RF gallery.

‣ Installation of 8 new cryo modules and associated RF stations to increase energy to 2.5 GeV.



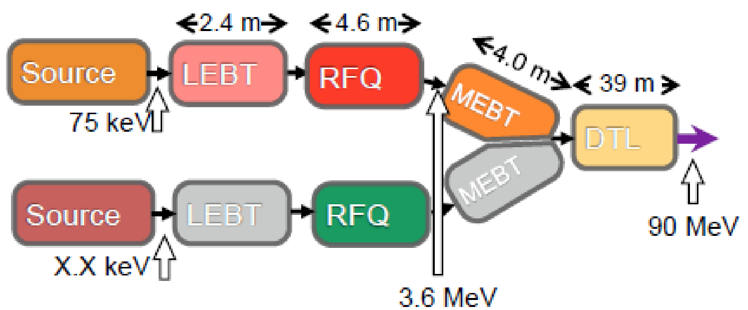
Status of accelerator upgrade to 10 MW

- 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 possible with the modulator design now adopted by ESS.

- Installation of a H- source + RFQ + MEBT + beam funnel alongside the existing protons source.



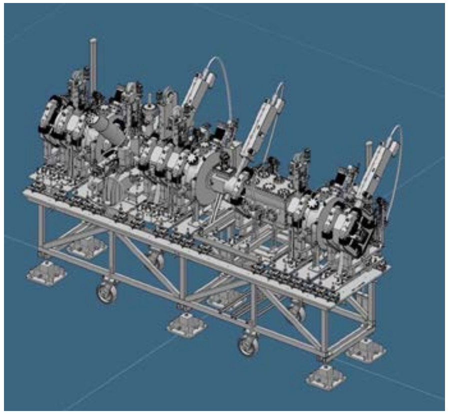
- Exchange trim magnets and associated power supplies against pulsed versions

Status of accelerator upgrade to 10 MW

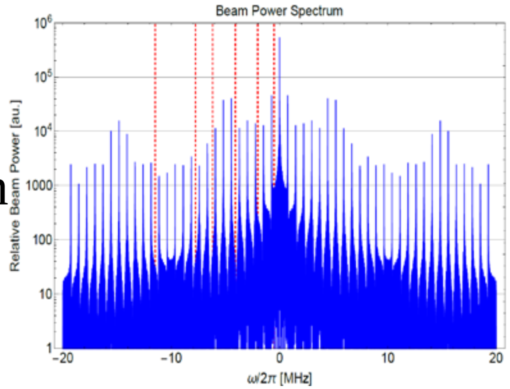
The following linac problems are currently being studied in particular:

- Beam losses due to H- intrabeam stripping may lead to a high irradiation of the accelerator components and therefore needs to be considered in detail.

- 100 ns time gaps need to be generated every 1.4 μs in the 3 ms long proton pulses, using a beam chopper, such that the gaps will overlap in the pulse compressor ring and allow the extraction kicker of the ring to rise to full field during 100 ns time gap. The effects on the proton beam of the excitation of Higher Order Modes (HOMS) by these gaps in the linac acceleratig cavities needs to be studied in detail.



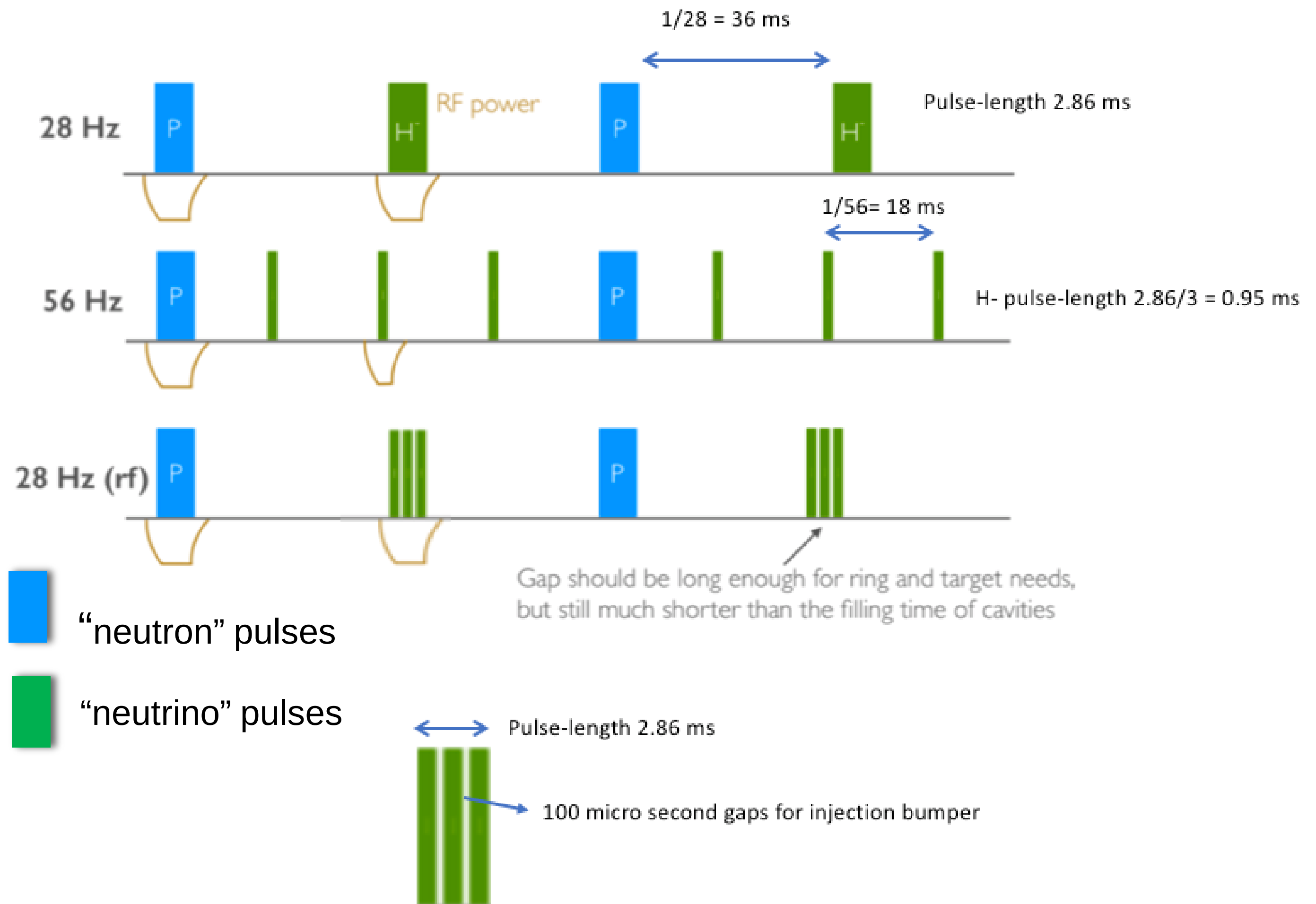
MEBT chopper will be used to create the gaps



Extraction gap excitation of side bands. Preliminary results show that the closest side band is damped by a factor of 20.

The accumulator ring – pulse schemes

How reduce the charge of the beam pulse to be stored in the accumulator ring such that a tune shift below 0.2 can be obtained?
Several proton beam pulse configurations are under investigation:



Original concept
28 Hz RF pulsing

So far studied
56 Hz RF pulsing

New base-line
28 Hz RF pulsing

The accumulator ring – lattice design

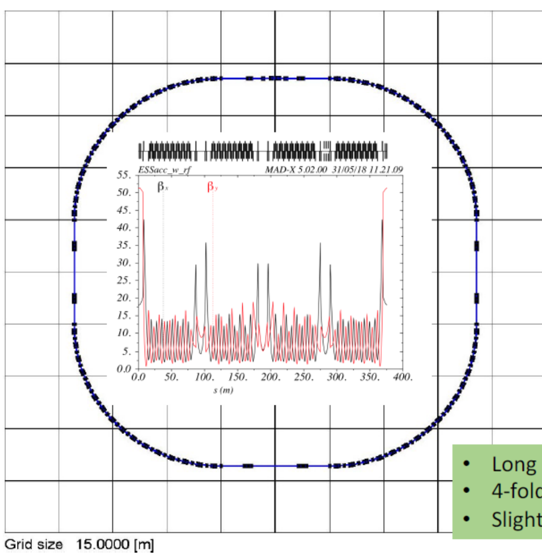
To design an accumulator which can accommodate 5 MW average beam power, the primary concern is the radiation activation caused by excessive uncontrolled beam loss, which can limit a machine's availability and maintainability

Uncontrolled beam loss usually attributed to:

- A high space charge tune shift (> 0.25) at injection
- Beam injection: not fully stripped H^- and H^0 and electrons and injection foil scattering
- Limited transverse and momentum acceptance
- Instabilities

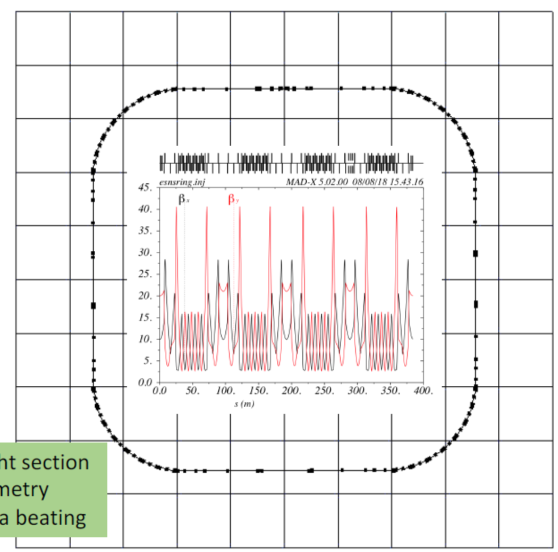
The lattice development

Horst Schönauer



First design

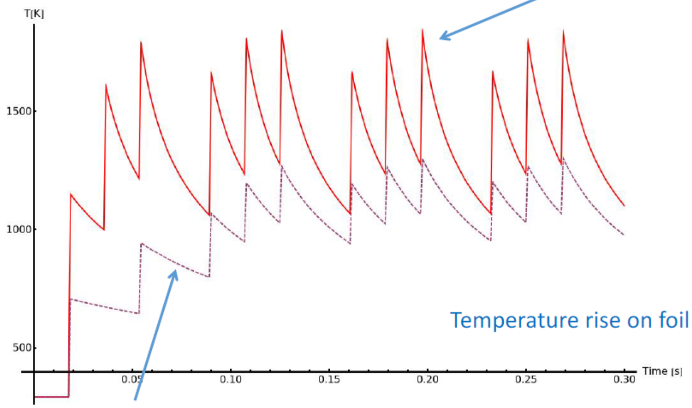
- Long straight section
- 4-fold symmetry
- Slightly beta beating



Second design

The accumulator ring – H^- stripping

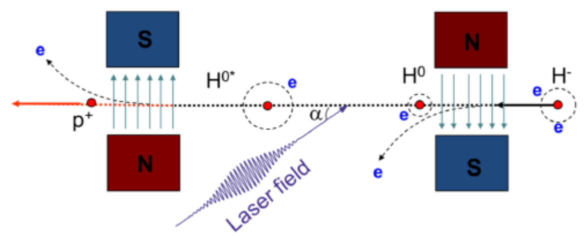
Injection H- stripping with foil – simulation of foil temperaturr



- So far, laser stripping is the most promising foil-free alternative stripping scheme
- Latest demonstration of laser stripping for microsecond pulse (11 μs) at SNS (stripping efficiency comparable with foil-based stripping) Sarah Cousineau et al., PRL 118, 074801 (2017)
- How to reduce the required average laser power is the key issue for longer pulse
- Possible for millisecond pulse: using cavity to recycle the laser power

Laser stripping scheme

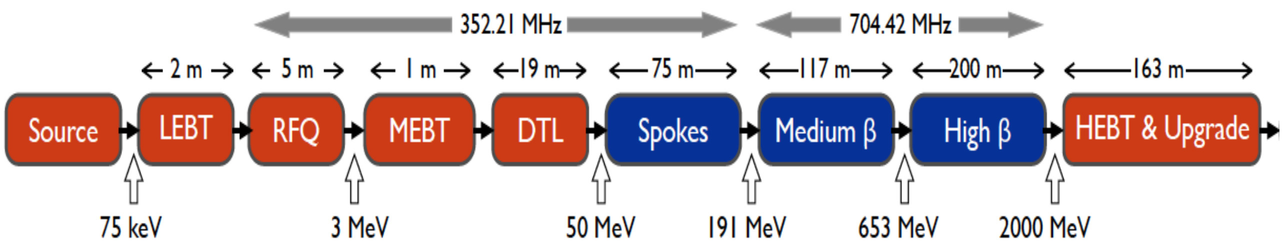
Sarah Cousineau



Lorentz stripping of the first electron by a dipole magnet in the first step, resonant excitation of the second electron by the laser in the second step, and, finally, stripping of the excited electron by the second dipole magnet

The target station

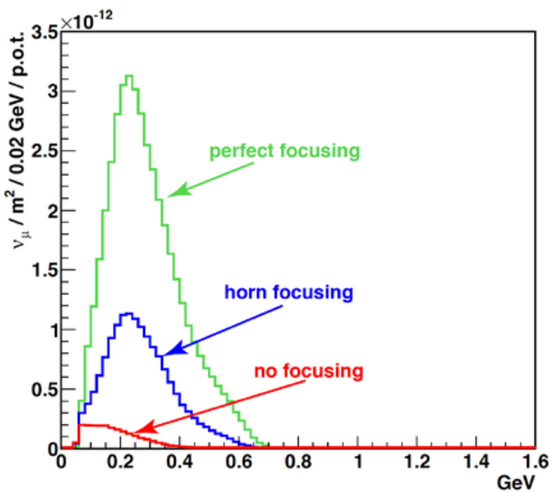
ESS Proton Beam LINAC



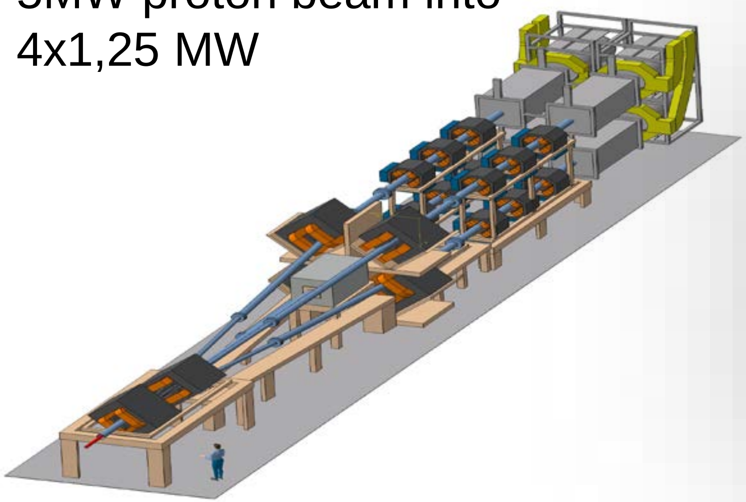
5 MW proton beam for neutron users (2.86 ms pulse width)

5 MW proton beam for neutrino users
1 µs pulse width =>
Accumulator required

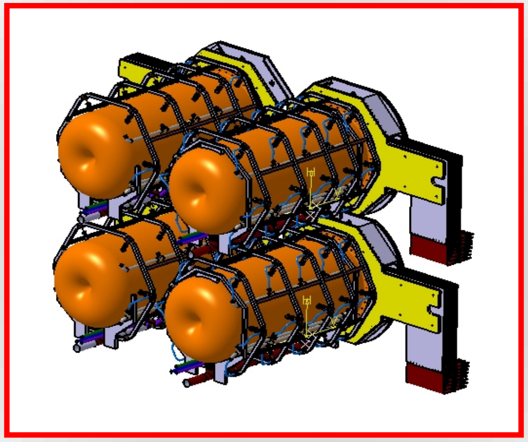
Effect of focusing



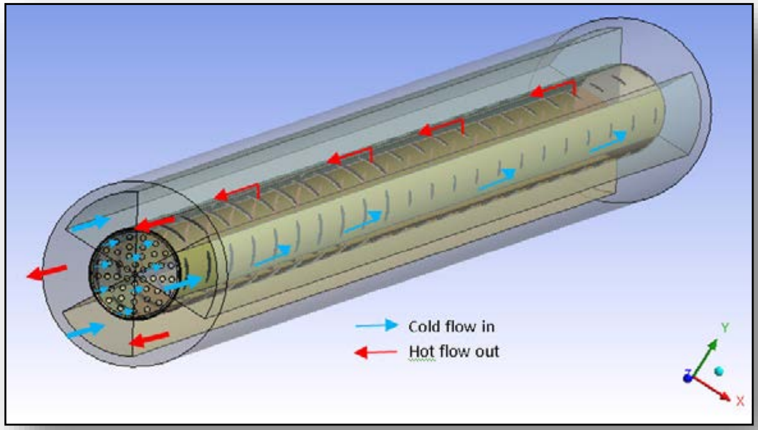
5 MW on one target is too much. Beam Switchyard to split the 5MW proton beam into 4x1,25 MW

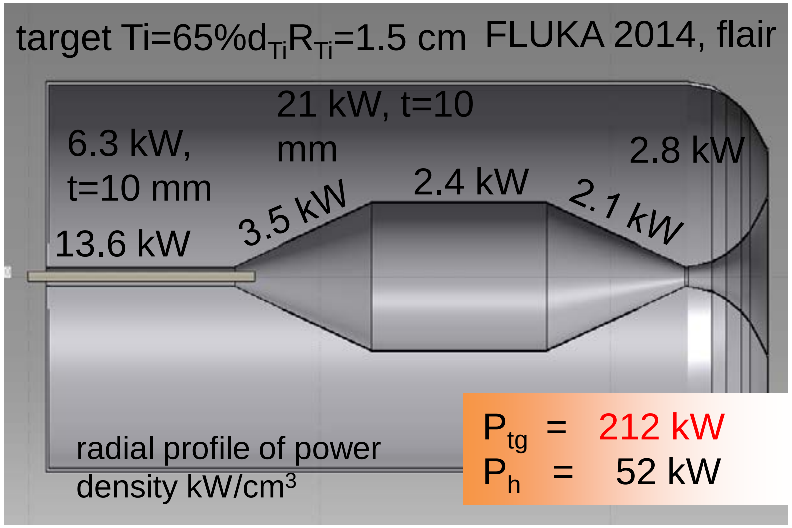


Four target and focusing horn units



The target station





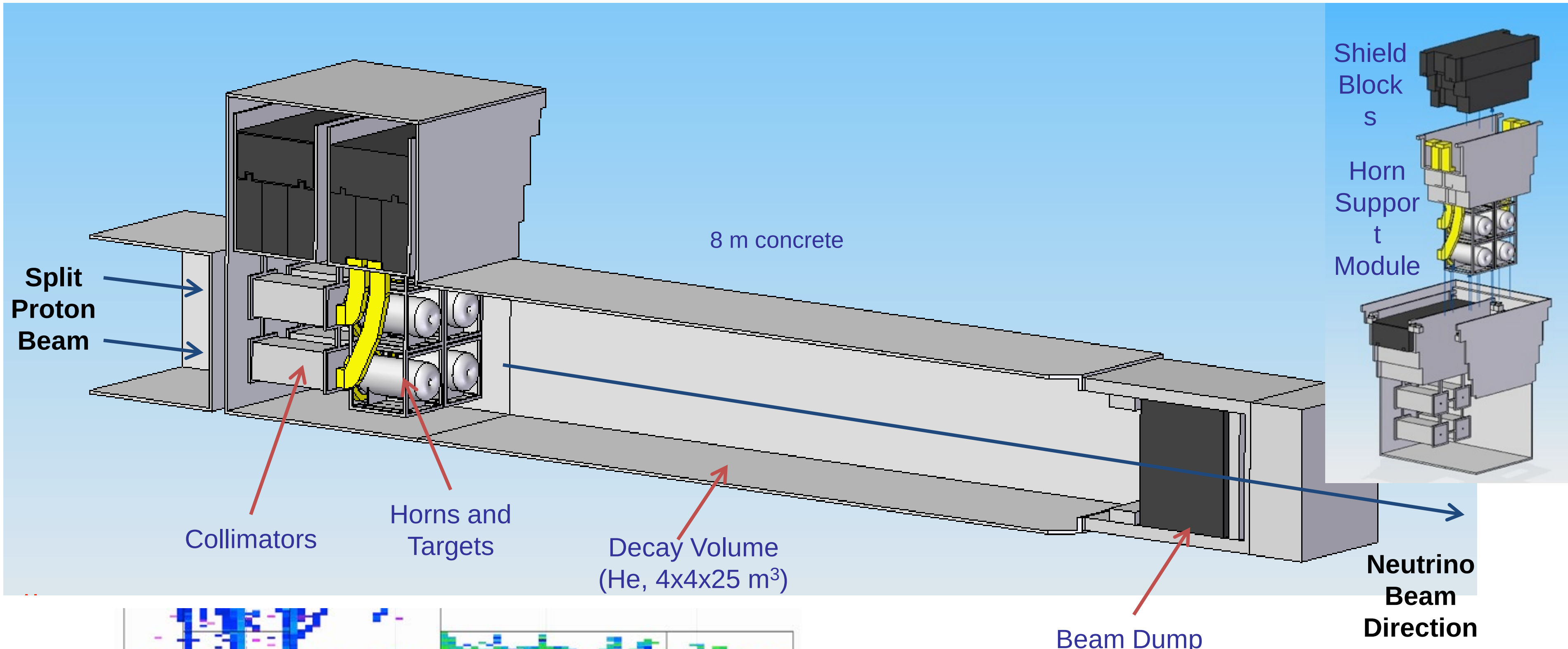
On-going target studies

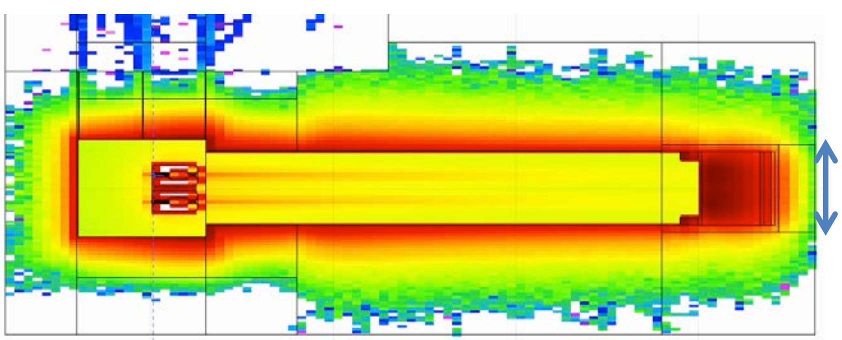
- Detailed analysis of the vibrations of the Titanium spheres
- Thermal stress calculations in the spheres
- Fatigue life estimate of the spheres
- Numerical study of the dynamic and thermal phenomena in the pebble bed target
- Target cooling issues
- Environmental effects (radiation damage, cavitation issues, etc.)

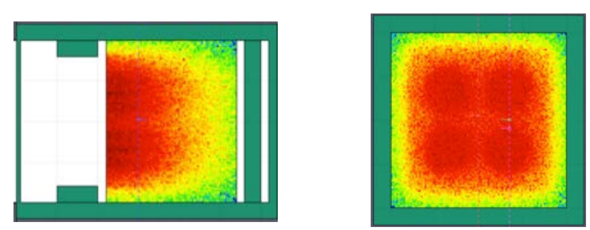
On-going horn studies

- Steady-state temperature determined by the cooling system and the resulting static stress.
- Dynamic stress brought about by short-duration pulses.
- Assessment of the longevity (fatigue) of the horn and its components.
- The performance of the cooling system.

The target station



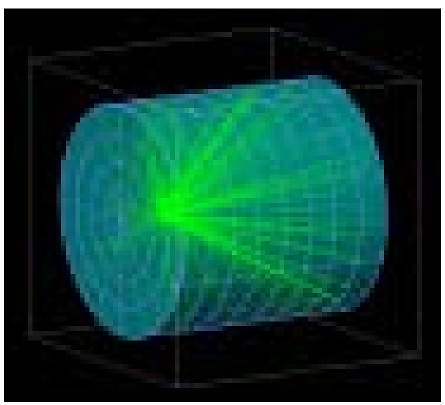


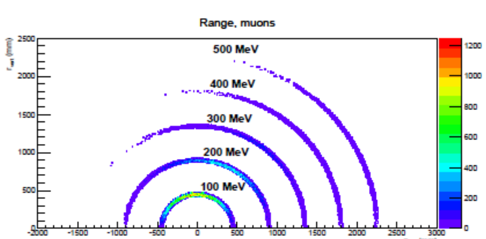


16

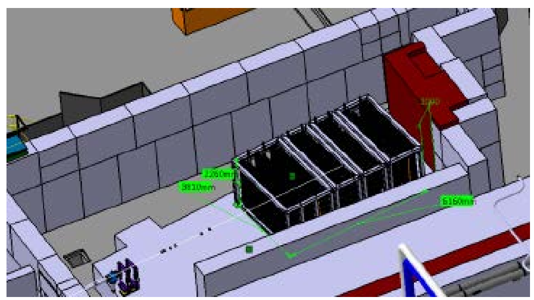
The Near Detector

Simulation study of **Cylindrical kiloton water Cherenkov detector**
Radius ~ 5 m.
Length ~ 10 m.
Lund University report by Alexander Burman

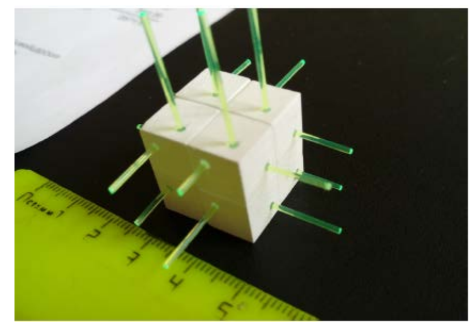


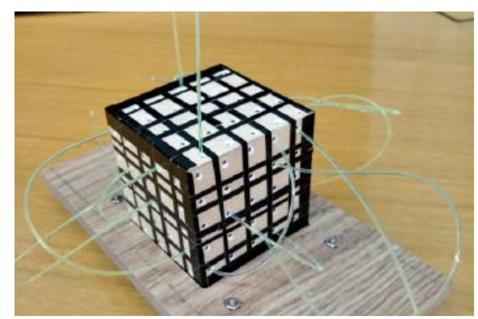


Participation summer 2017 in the PS beam tests of the new T2K Near Detector component **Baby MIND** (magnetize iron tracker) now installed at Tokai



Participation summer 2018 in the PS beam tests of the new T2K Near Detector component **SuperFGD** (scintillating cubes tracker)

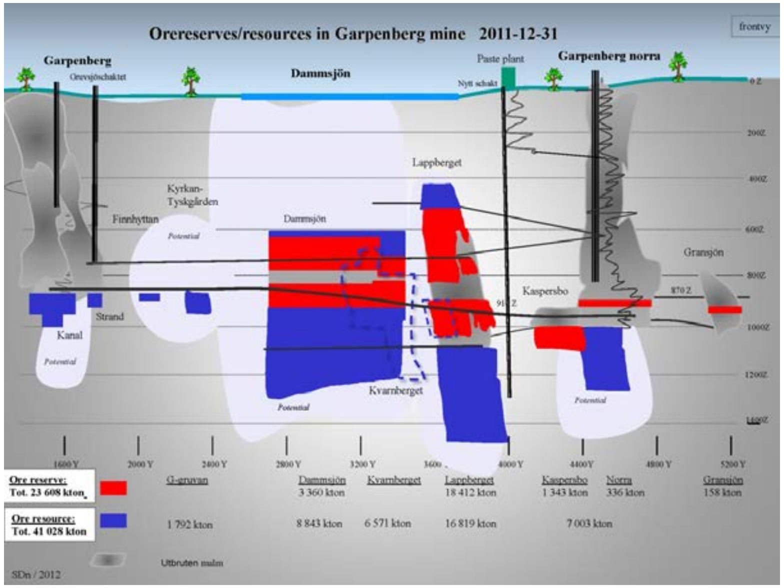




The Far Detector

The MEMPHYS type Detector to be located down in the Garpenberg Mine 540 km north of ESS

Depth 1232 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

The Far Detector

Garpenberg Bed Rock Investigation started by owner company Boliden

Working Team

Morwan Derrien, Geologist, Boliden

Anders Österberg, Bedrock Engineer, Boliden

Lars Norling, Mine Consultant

Kjell Grundström, Coordinator

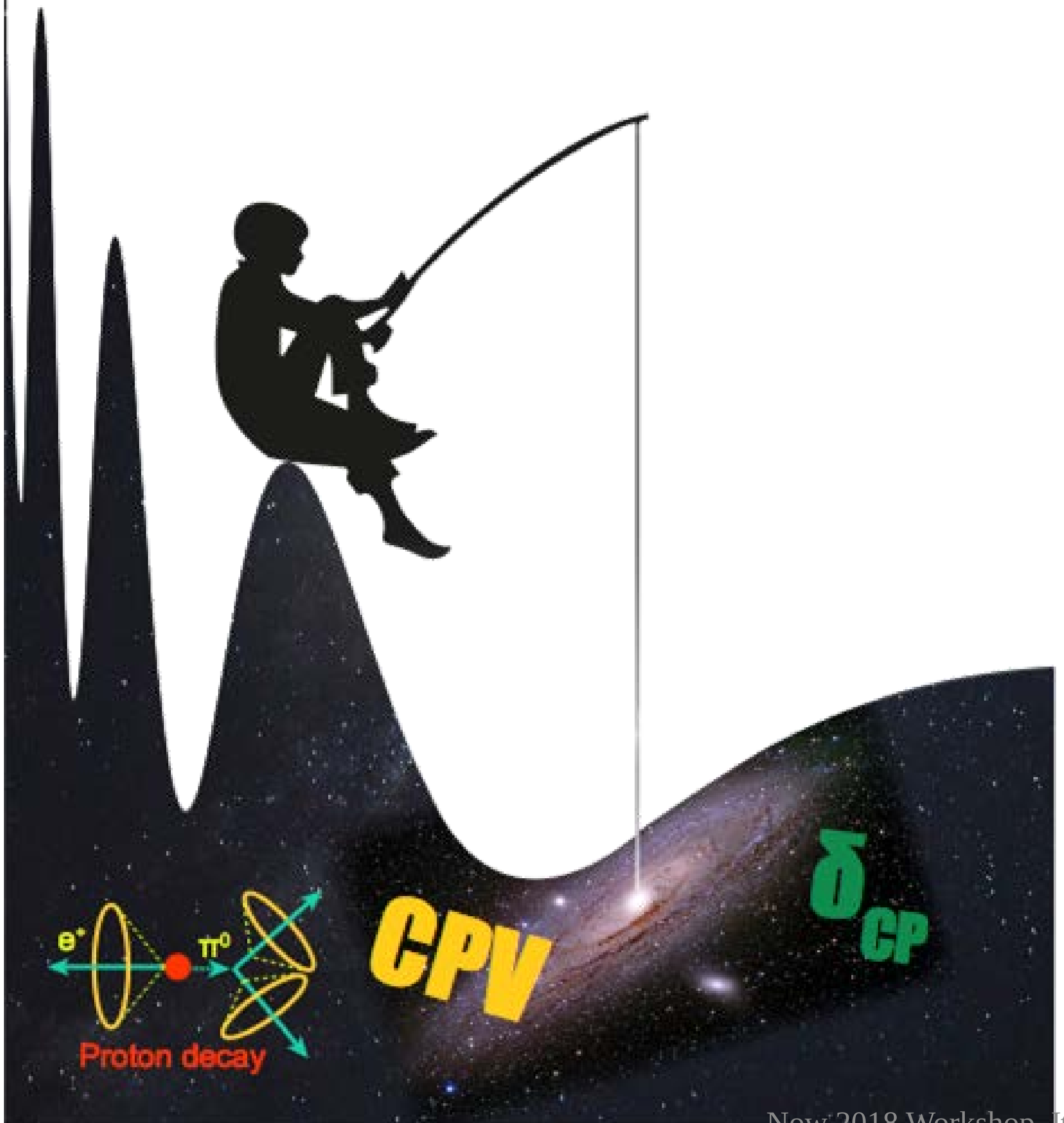
Drill cores from the granite rock

Project Plan

Drill ~20 one km holes into the granite bedrock to measure rock strength and pressure

Using this data to simulate the optimal design of a 500 kt fiducial volume detector cavern in the granite

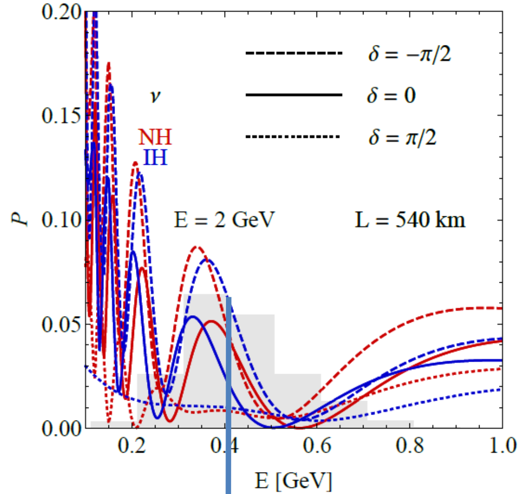
The second ν oscillation maximum

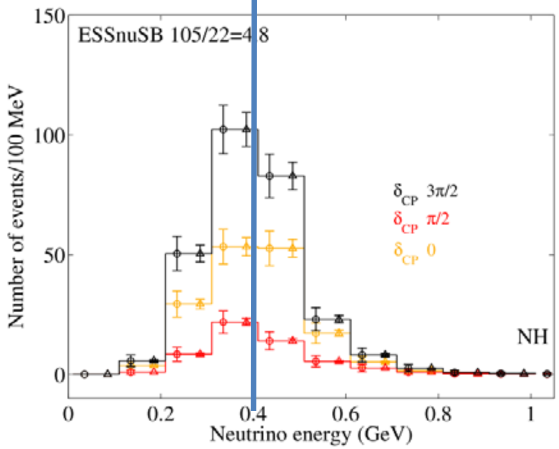


The ultimate precision in the determination of the leptonic CP violating angle δ_{CP} from neutrinos oscillation measurements will be set by **systematic errors**.

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**.

The second ν oscillation maximum

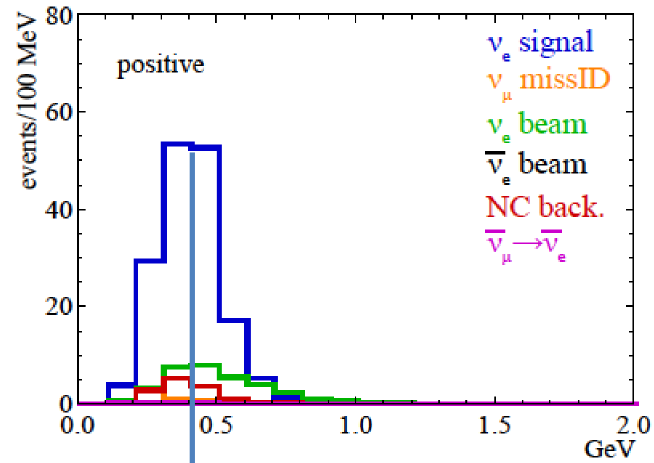


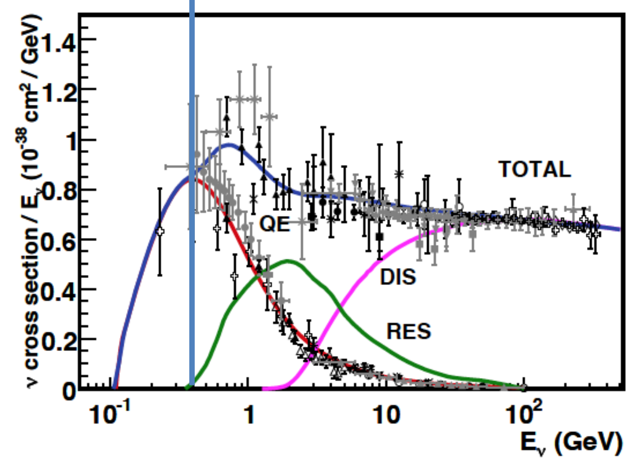


The relative difference in counts at maximum between $\delta_{CP} = 3\pi/2$ and $\delta_{CP} = \pi/2$ is ca 4.8 at the second maximum and ca 1.6 at the first maximum.

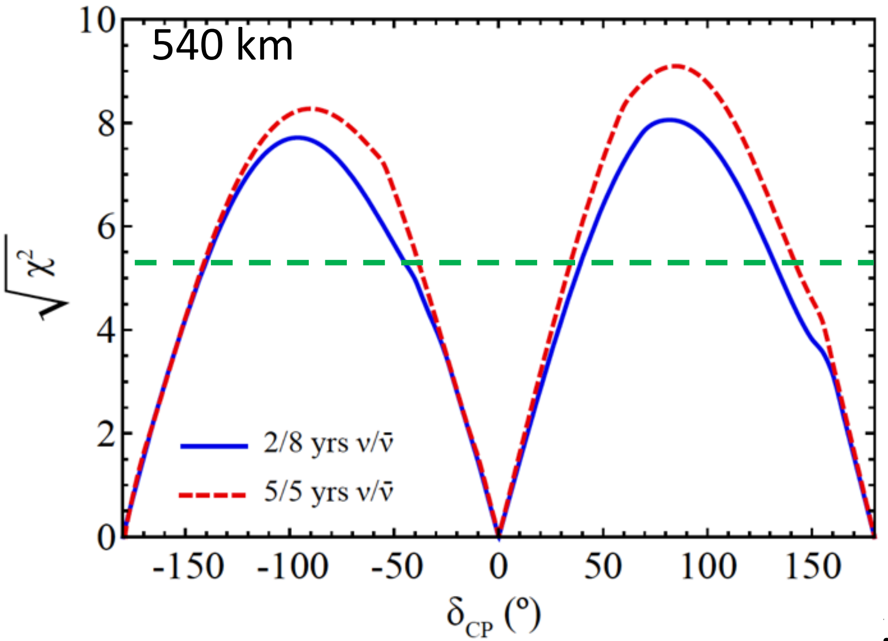
In addition, at the low ν energies of 0.2-0.6 GeV in ESSnuSB the background from RES and DIS is very small.

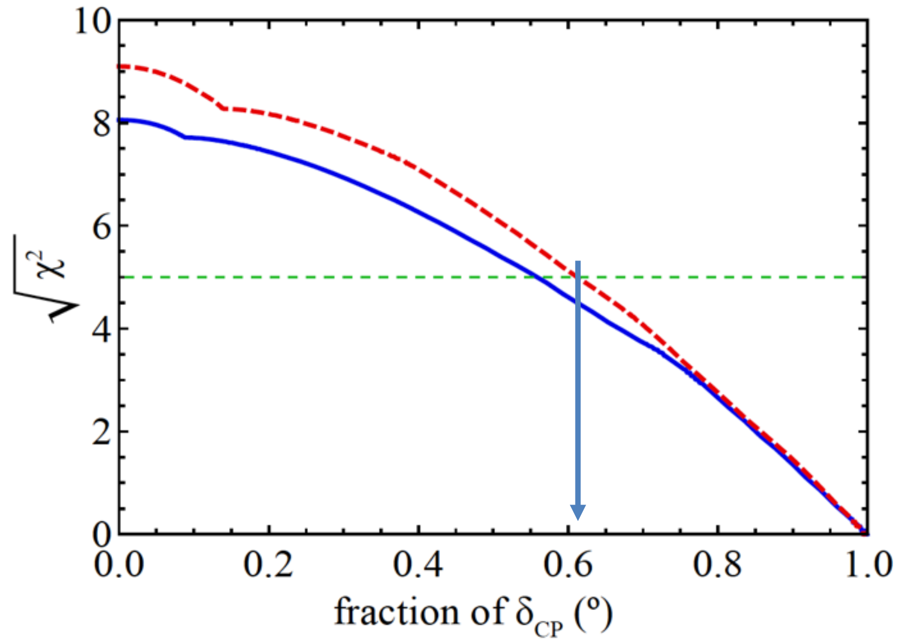
On the other hand, the cross-sections at these low energies is poorly known and must be measured.



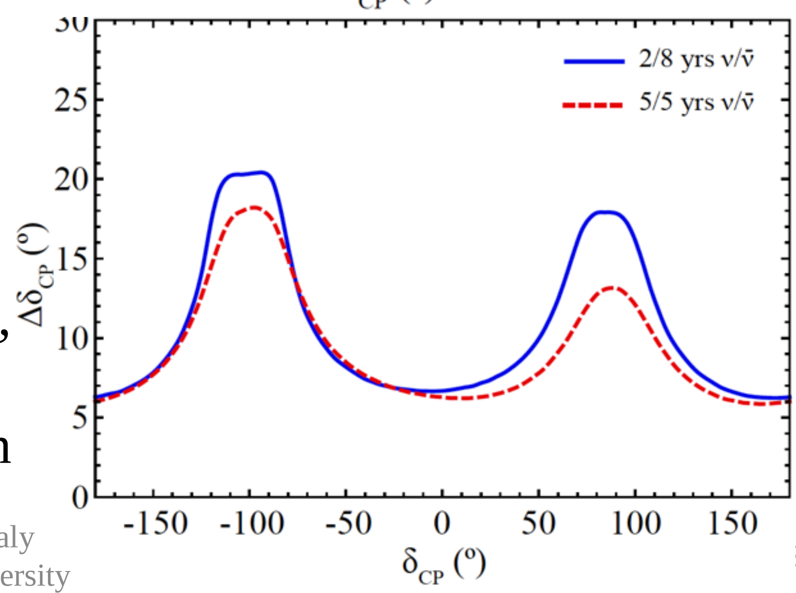


The second ν oscillation maximum





- Little dependence on mass hierarchy,
- δ_{CP} coverage at 5 σ C.L. up to **60%**,
- δ_{CP} accuracy down to **6°** at 0° and 180° and
- systematic errors taken as "Opt." in P.Coloma, P.Huber, J.Kopp, and W.Winter Phys. Rev. D 87(2013) 033004 (**5/10%** systematic errors on signal/background).

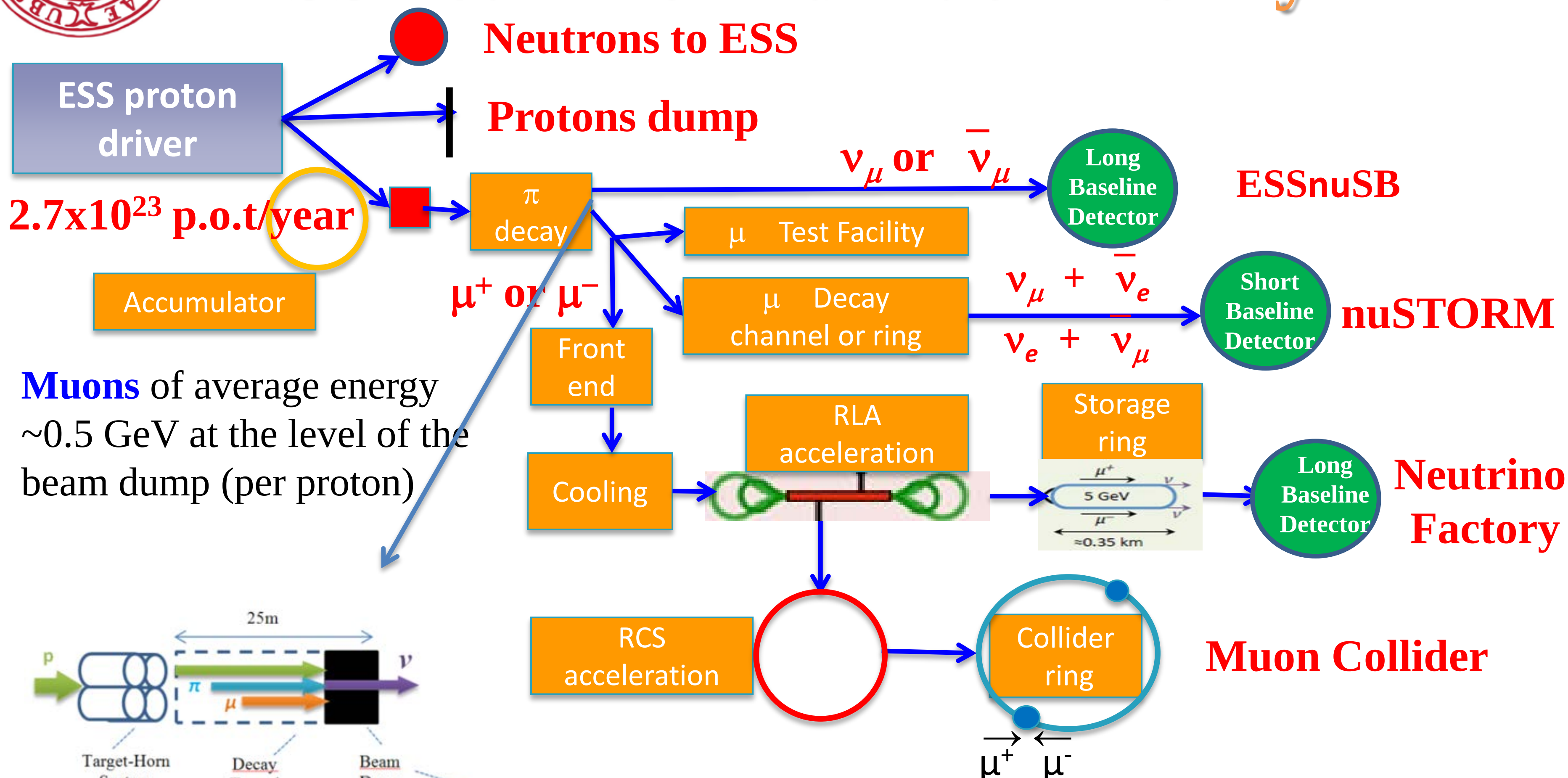


Systematic errors

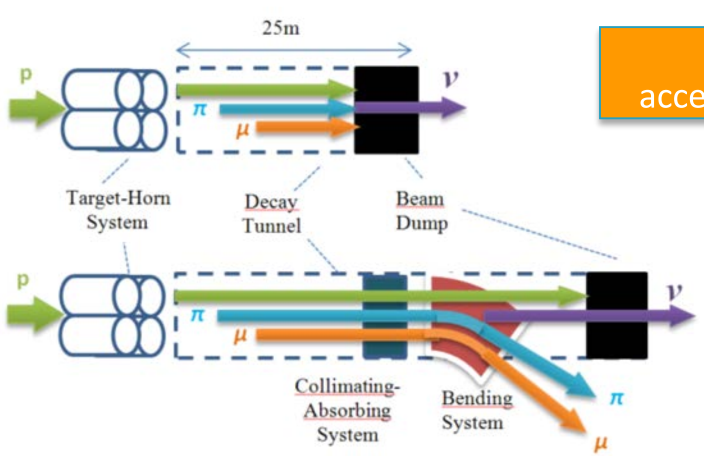
Systematics	SB Opt.	SB Def.	SB Cons.	BB Opt.	BB Def.	BB Cons.	NF Opt.	NF Def.	NF Cons.
Fiducial volume ND	0.2%	0.5%	1%	0.2%	0.5%	1%	0.2%	0.5%	1%
Fiducial volume FD (incl. near-far extrap.)	1%	2.5%	5%	1%	2.5%	5%	1%	2.5%	5%
Flux error signal ν	5%	7.5%	10%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background ν	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 θ13
Pilar Coloma, Patrick Huber, Joachim Kopp, and Walter Winter
Phys. Rev. D 87, 033004 – Published 11 February 2013

Future further option form a ESS neutrino and muon facility



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



more than 4×10^{20} μ/year from ESS compared to 10^{14} μ used by all experiments up to now (10^{18} μ for COMET in the future).

ESSnuSB organization and time plan

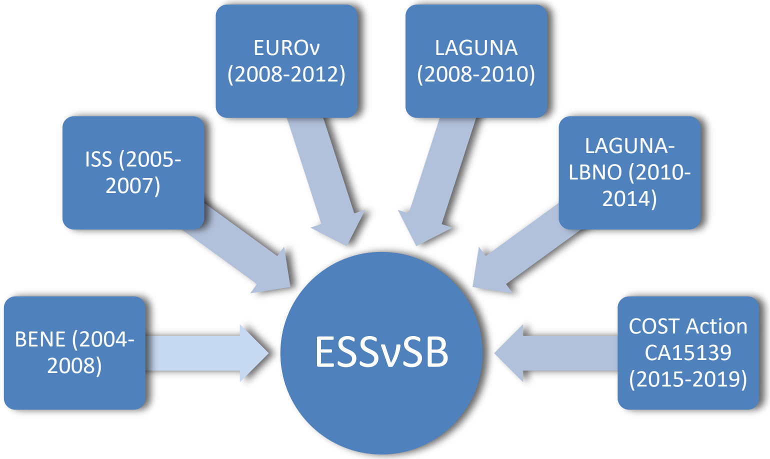
- **COST application for networking: CA15139 (2016-2019)**
  - **EuroNuNet** : *Combining forces for a novel European facility for neutrino-antineutrino symmetry violation discovery* (**http://www.cost.eu/COST_Actions/ca/CA15139**)

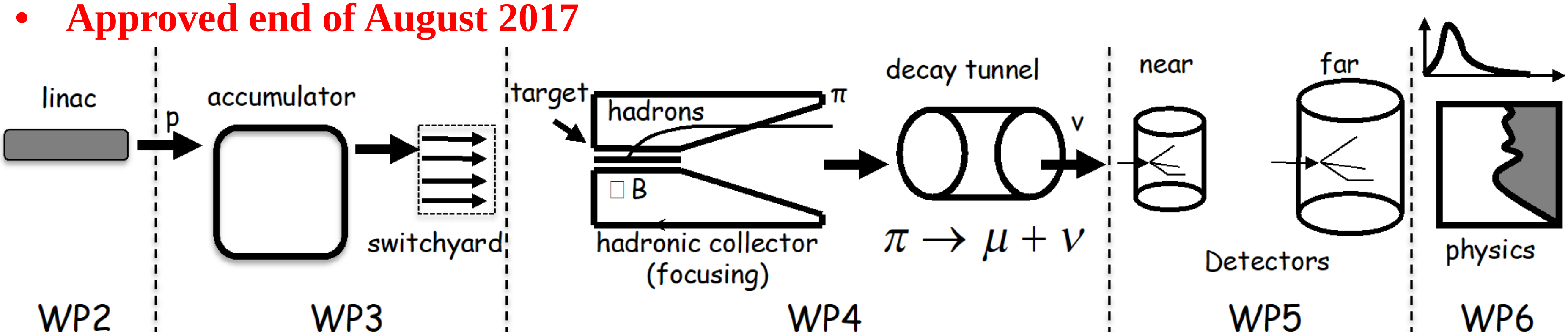
  - **Major goals of EuroNuNet**:
    - to aggregate the community of neutrino physics in Europe to study the ESSνSB concept in a spirit of inclusiveness,
    - to impact the priority list of High Energy Physics policy makers and of funding agencies to this new approach to the measurment of leptonic CP violation.
    - 13 participating countries (network still growing).

http://euronunet.in2p3.fr/

ESSnuSB organization and time plan

- A **H2020** EU **Design Study** (Call INFRADEV-01-2017)
  - **Title of Proposal**: Discovery and measurement of leptonic CP violation using an intensive neutrino Super Beam generated with the exceptionally powerful ESS linear accelerator
  - **Duration: 2018-2021**
  - **Total cost: 4.7 M€**
  - **Requested budget: 3 M€**
  - 15 participating institutes from
    11 European countries including CERN and ESS
  - 6 Work Packages
  - **Approved end of August 2017**





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

Maximum grant amount (proposed amount, after evaluation): **2,999,018.00 EUR**

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:	

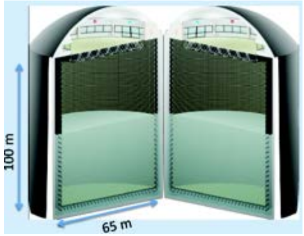
partners: IHEP, BNL, SCK•CEN, SNS, PSI, RAL

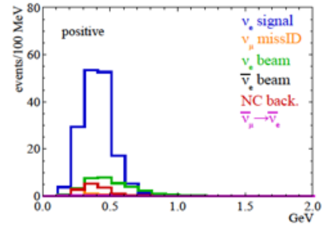
- Kick-off meeting in January 2018.
- ESSνSB is currently engaging 8 postdocs.
- First ESSnuSB and EuroNuNet annual meeting to be held in Strasbourg 22-26 November 2018

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

2022-2024: Preparatory Phase, TDR

2025-2026: Pre-construction Phase, International Agreement

EUROPEAN SPALLATION SOURCE

2027-2035: Construction of the facility and detectors, including commissioning

2036-: Data taking

Conclusions

- ESSnuSB, the design of which is currently being studied, is complementary to other exiting and planned super beam experiments by the fact
1. that it collects almost all its statistics 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 by the currently planned super-beam experiments, the next step will be to make an accurate measurement of the CP violating angle δ_{CP}, which will require relative systematic errors to be minimized.

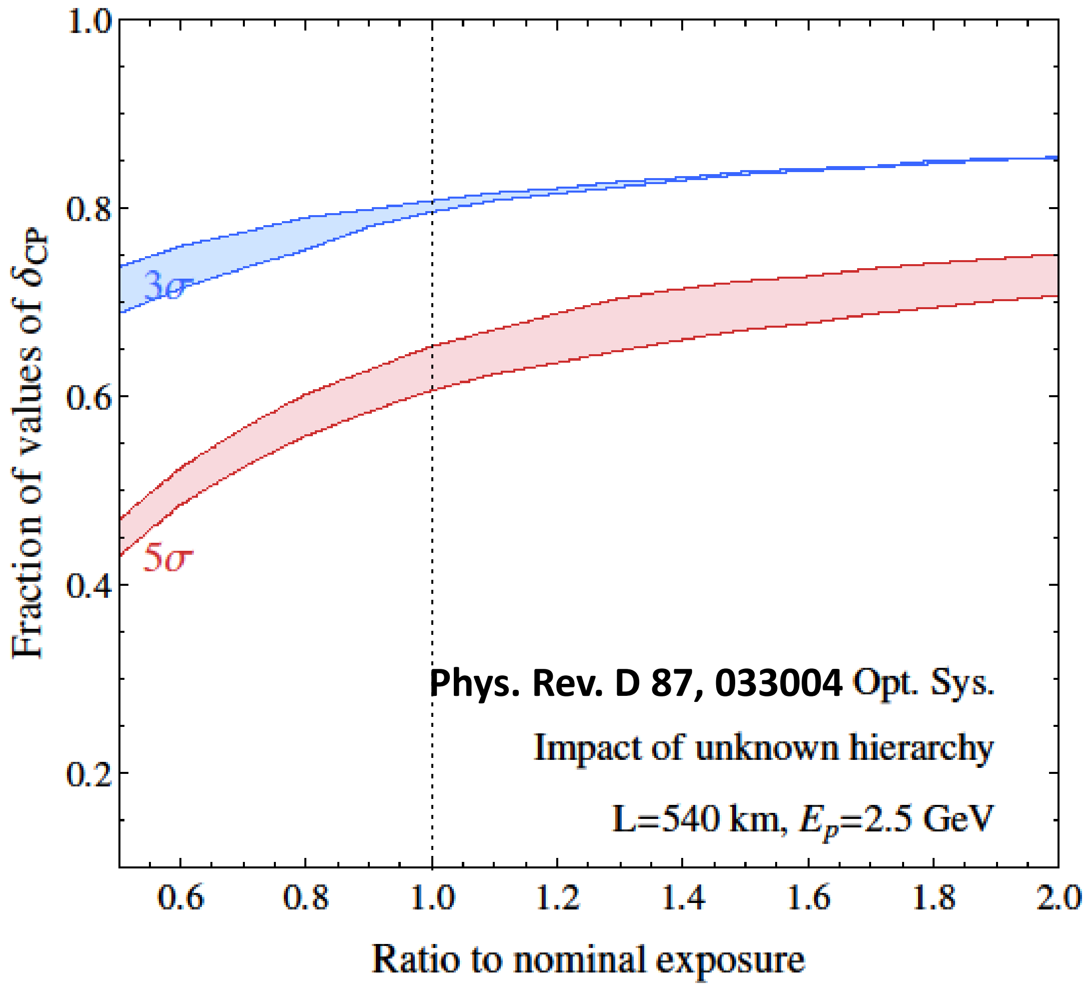
- ESSnuSB is a 2nd generation neutrino Super Beam experiment which will build on the experience on its predecessors.

- The uniquely high power of the ESS linac implies that the muon flux at the level of the beam dump could be used in the longer term to pursue a uniquely high-intensity muon program (i.e. nuStorm, Neutrino Factory, Muon Collider)

- Europe has a long tradition in neutrino physics to be pursued. And there is manifestly a high commitment among the European HEP community for neutrino physics. In view of this and of the exceptional potential for future power upgrades of the ESS proton linac, beyond other accelerators, we argue that Europe should pursue the ESSnuSB Design Study and eventually consider hosting an ESS based neutrino beam experiment in Europe that is complementary to others in the world.

Back-up slides

Systematic errors and exposure



High potentiality

(courtesy P. Coloma)

Comparisons using Phys. Rev. D 87, 033004 Opt. systematic errors and 10 years of data taking for ESSnuSB, Hyper-K and DUNE