ESSνSB

An ESS Based Super Beam for Lepton CP violation discovery

Tord Ekelof, Uppsala University
of behalf of the ESSνSB Collaboration

The ESS 2 GeV proton linac as proton driver for a neutrino Super Beam

EUROPEAN SPALLATION SOURCE

The European Spallation Source (ESS), which is being built in Lund, Sweden, will have a

5 MW

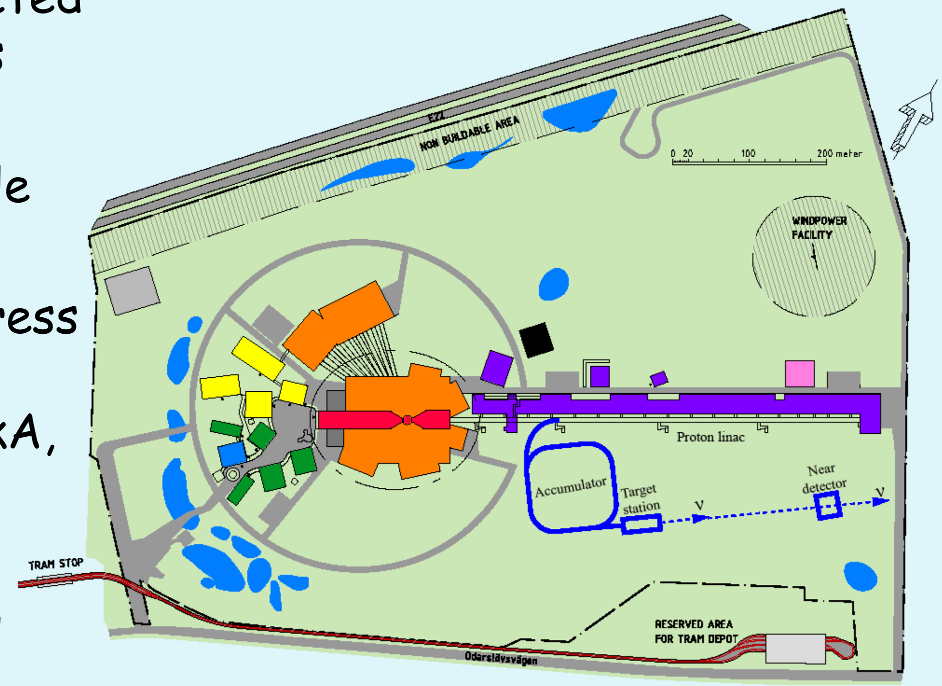
2 GeV,
1.6×10^{16} protons on target/second (!),
4% duty cycle (under-used),
superconducting linac (high efficiency).

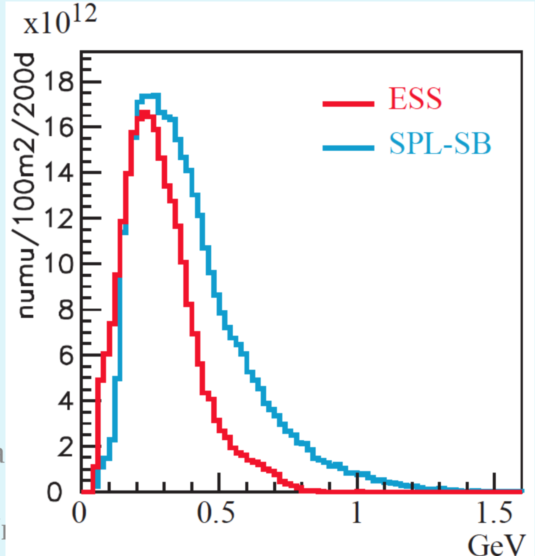
This is an order of magnitude more power than any other proton driver planned in near time
First beams 2019
Full power linac operation 2022

Has the potential to run at 8% duty cycle producing 5+5 MW, 5 MW for neutrons and 5 MW for neutrinos

How to add the neutrino facility?

- The neutron program must not be affected and if possible synergetic modifications
- Linac modifications: increase the pulse rate (14 Hz → 70 Hz) and the duty cycle from 4% to 8%.
- Accumulator (ø 143 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 effects to be studied
- ~300 MeV neutrinos
- Target station (studied in EUROnu)
- Underground detector (studied in LAGUNA)
- Short pulses (~μs) will also allow DAR experiments
- Linac and accumulator could be the first step towards the Neutrino Factory



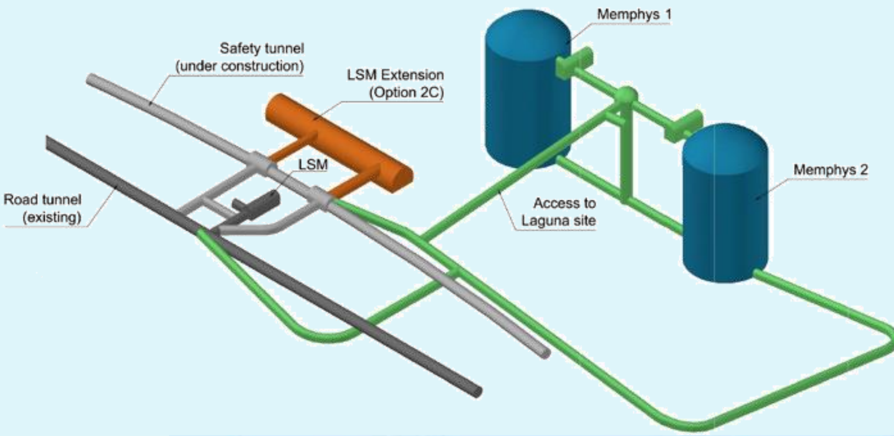


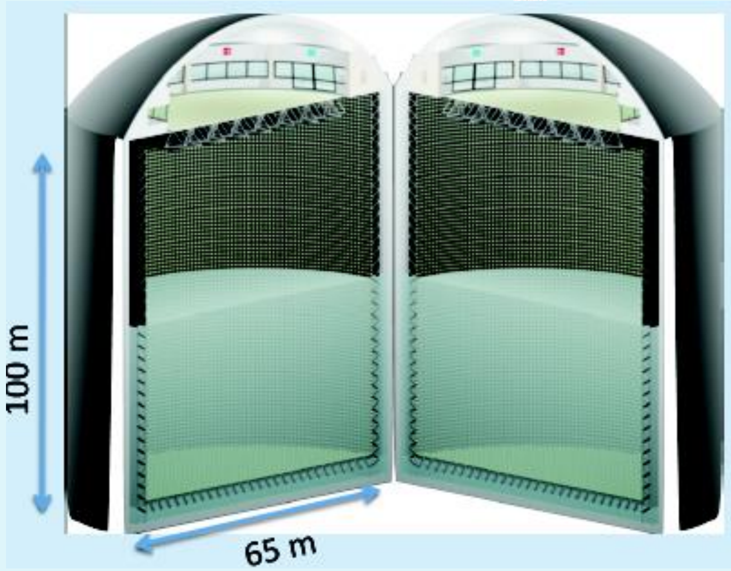
neutrino flux at 100 km (similar spectrum than for EUROnu SPL SB)

The MEMPHYS WC Detector
(MEgaton Mass PHYSics)

- **Neutrino Oscillations**
- Proton decay
- Astroparticles
- Detection of galactic SuperNova ν
- Supernovae "relics"
- Solar Neutrinos
- Atmospheric Neutrinos

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



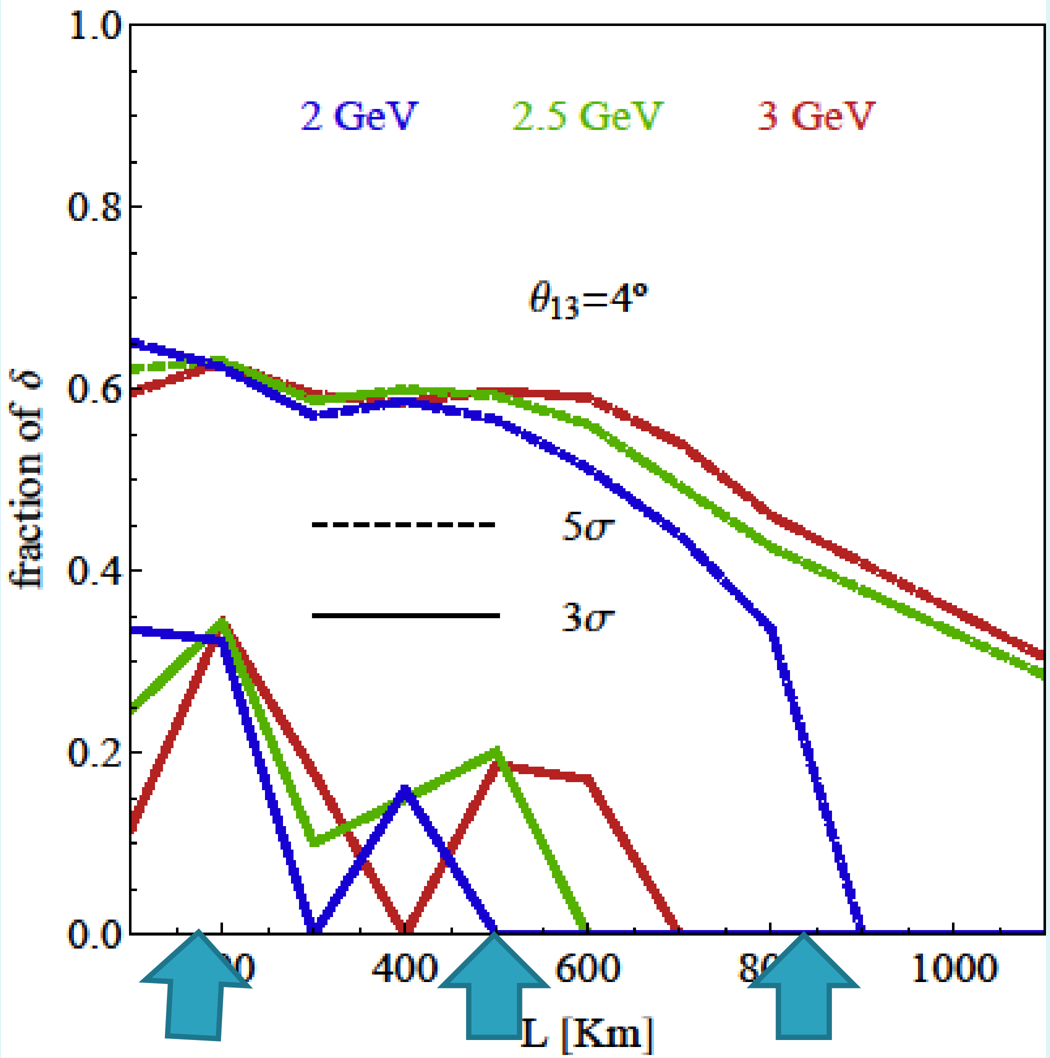


(arXiv: hep-ex/0607026)

The depth and distance from ESS/ Lund of different mines in Scandinavia

Reminder of the situation before 2012 at which time LBNE, Hyper-K and LBNO were designed – the optimum for CP violation discovery was clearly at the first maximum

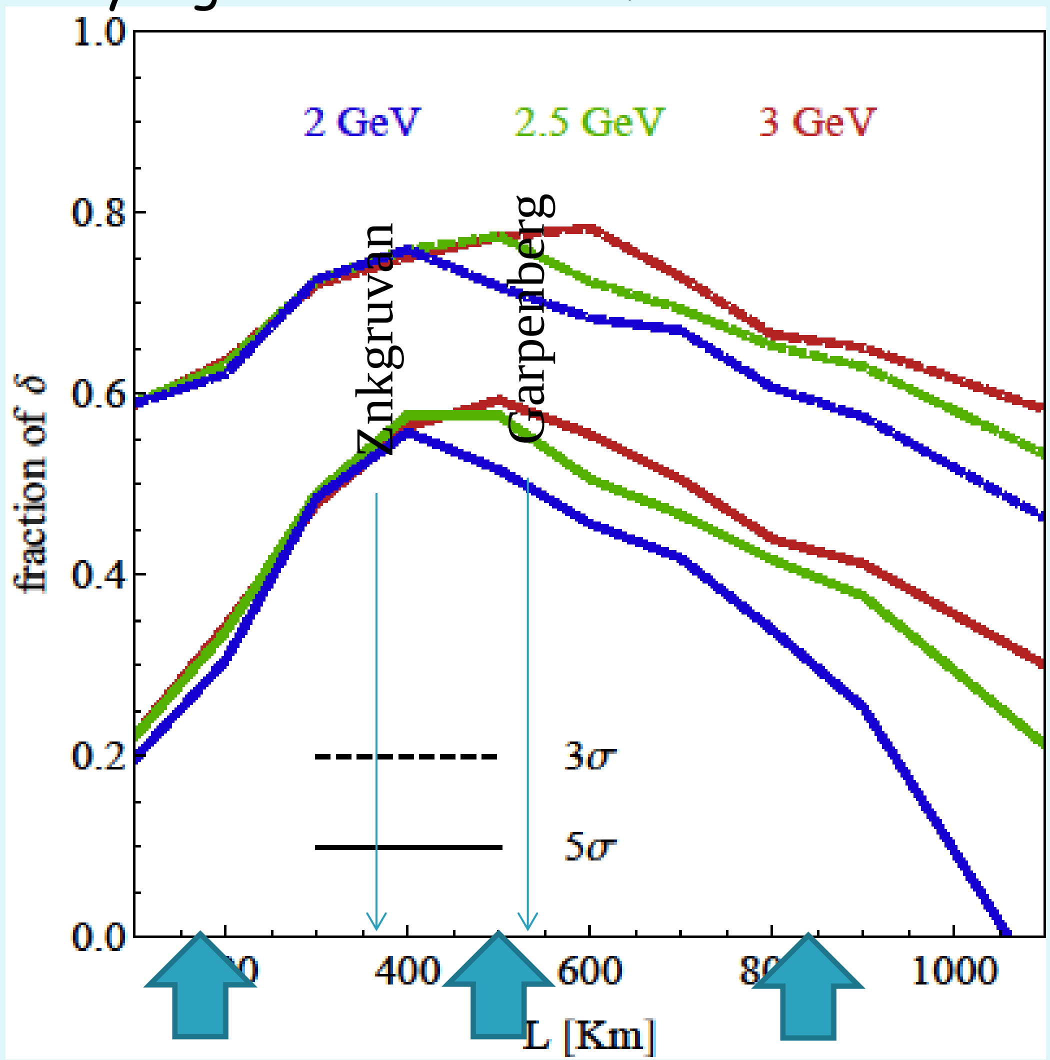
$\Theta_{13}=4^o$



1st osc. max 2nd osc. max 3rd osc. max

After the spring 2012, when Θ_{13} had been measured and ESSnuSB was designed, CP violation discovery probability did not increased at the first maximum – at the second maximum it however increased drastically and became significantly higher than at the first

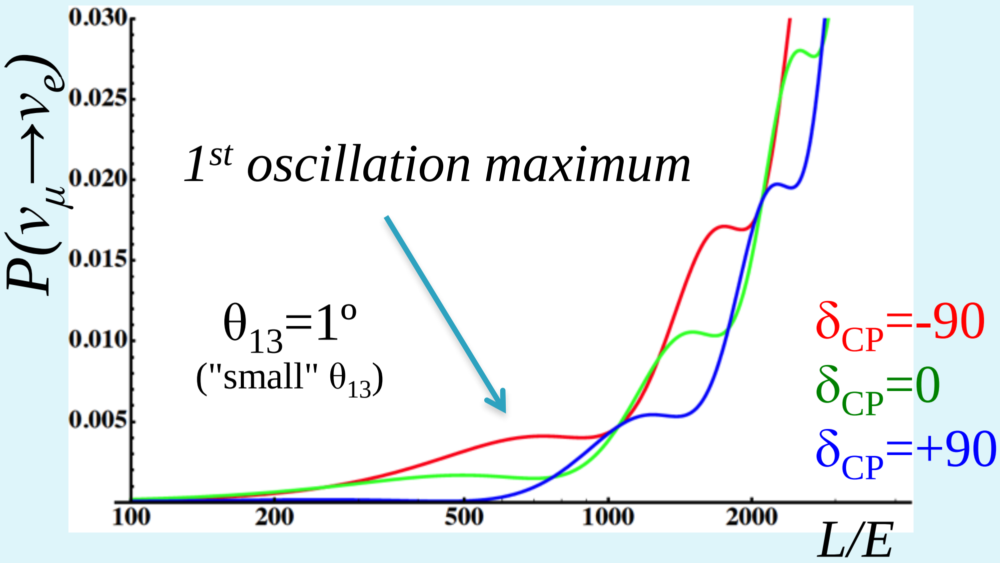
$\Theta_{13}=8.73^o$

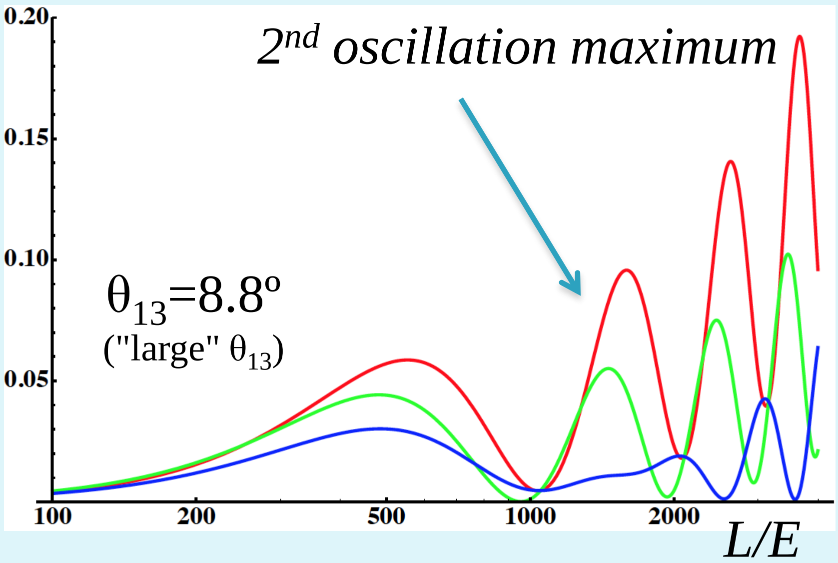


1st osc. max 2nd osc. max 3rd osc. max

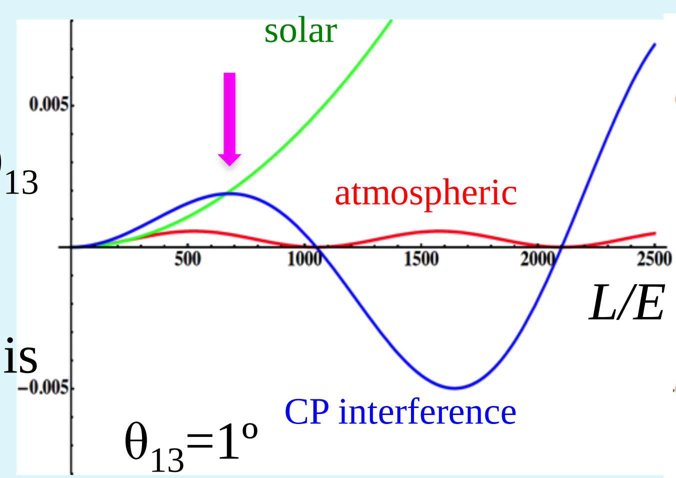
Tord Ekelöf Uppsala University

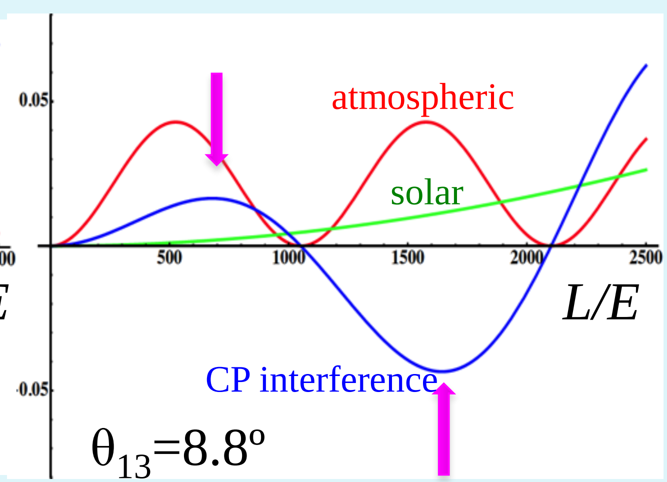
Neutrino Oscillations with "large" θ_{13}





for small θ_{13} 1st oscillation maximum is better





for "large" θ_{13} 1st oscillation maximum is dominated by atmospheric term,

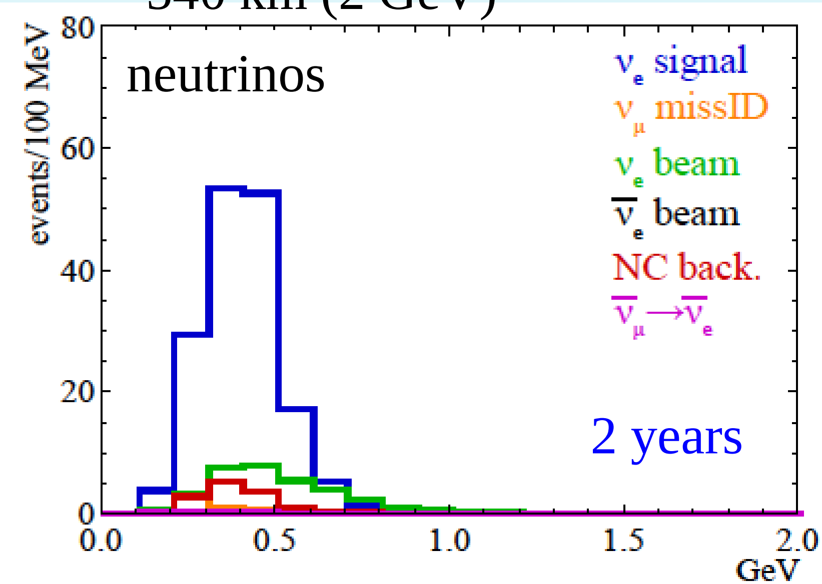
(arXiv:1110.4583)

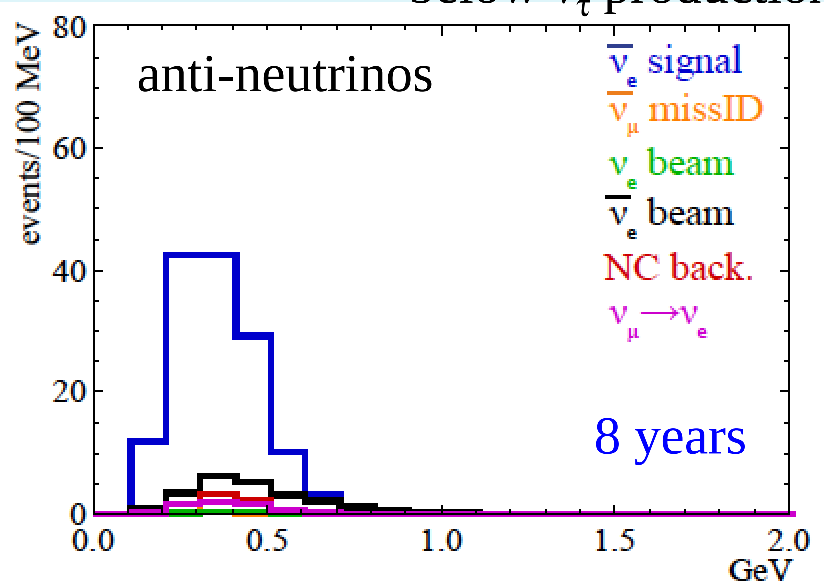
2nd oscillation maximum is better (less affected by systematic errors)

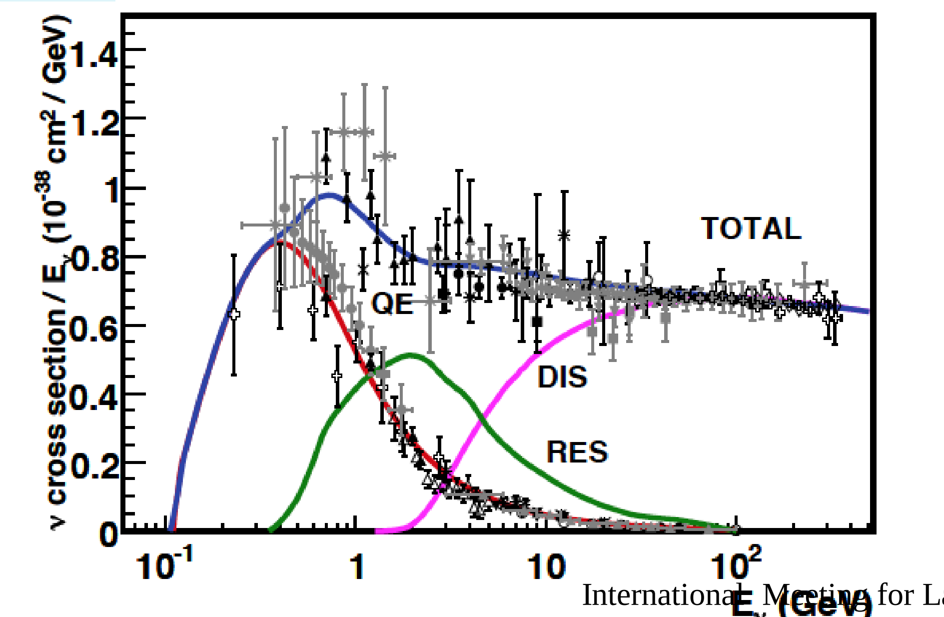
Neutrino spectra and statistics

540 km (2 GeV)

below ν_τ production







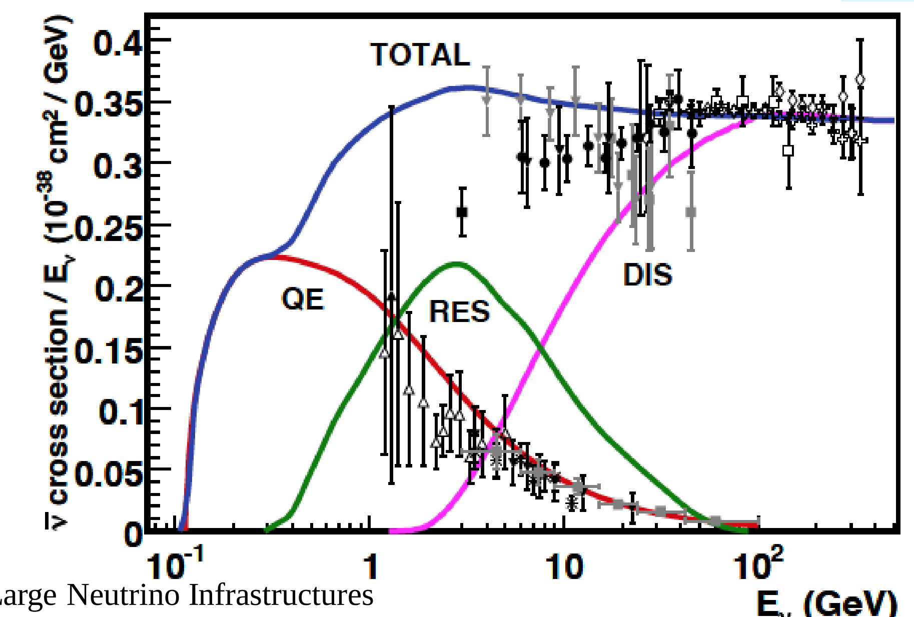


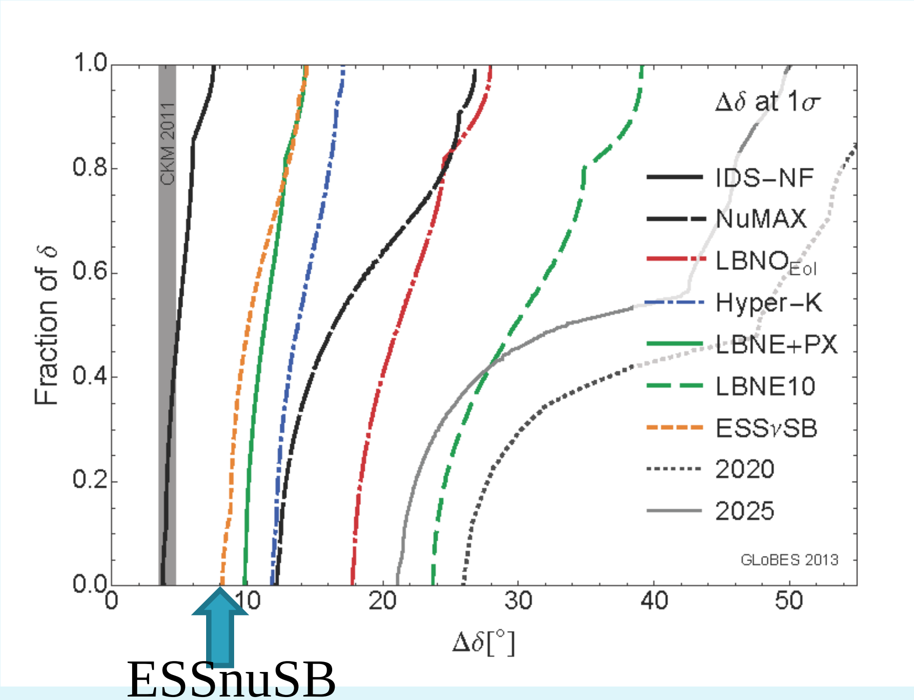
Figure 11 on page 34 in the Snowmass "Neutrinos" report arXiv:1310.4340v1 [hep-ex] 16 Oct 2013

arXiv:1310.4340v1 [hep-ex] 16 Oct 2013

Neutrinos

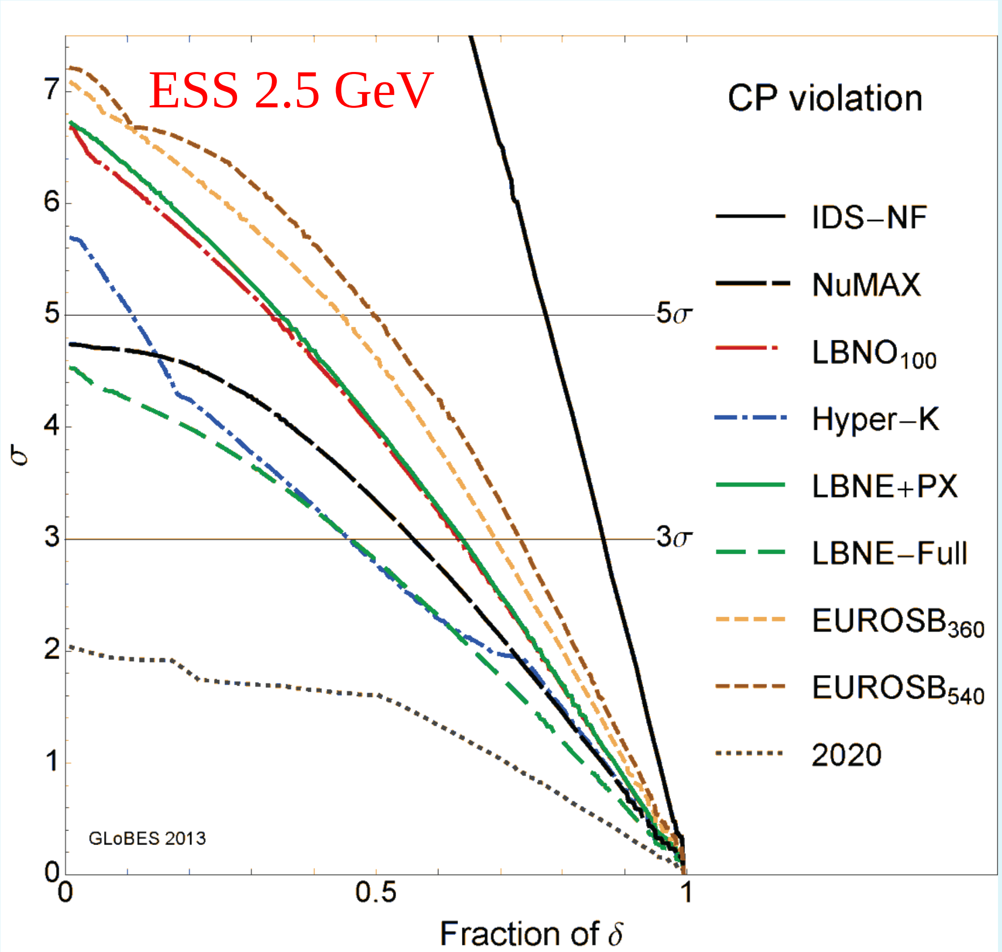
Conveners: A. de Gouvêa[50], K. Pitts[32], K. Scholberg[26], G.P. Zeller[27]

Subgroup Conveners: J. Alonso[46], A. Bernstein[41], M. Bishai[8], S. Elliott[42], K. Heeger[78], K. Hoffman[43], P. Huber[74], L.J. Kaufman[35], B. Kayser[27], J. Link[74], C. Lunardini[4], B. Monreal[15], J.G. Morfín[27], H. Robertson[75], R. Tayloe[35], N. Tolich[75]



"Figure 11: ……ESSνSB corresponds to the performance of a 500-kt water Cherenkov detector placed at 360 km from the source; see [117]. The beam would be obtained from 2-GeV protons accelerated at the ESS proton linac. Migration matrices fromRefs. [98, 118] have been used for the detector response…"

CPV Discovery Performance for Future SB projects, MH unknown, Snowmass comparison



- IDS-NF Neutrino Factory
- NuMAX are: 10 kton magnetized LAr detector, Baseline is 1300 km, and the parent muon energy is 5 GeV
- LBNO100: 100 kt LAr, 0.8 MW, 2300 km
- Hyper-K: 3+7 years, 0.75 MW, 500 kt WC
- LBNE-Full 34 kt, 0.72 MW, 5/5 years ~ 250 MW*kt*yrs.
- LBNE-PX 34 kt, 2.2 MW, 5/5 years ~750 MW*kt*yrs.
- **ESSnuSB, in the figure called EUROSB: 2+8 years, 5 MW, 500 kt WC (2.5 GeV, 360 (upper)/540 km (lower))**
- 2020 currently running experiments by 2020

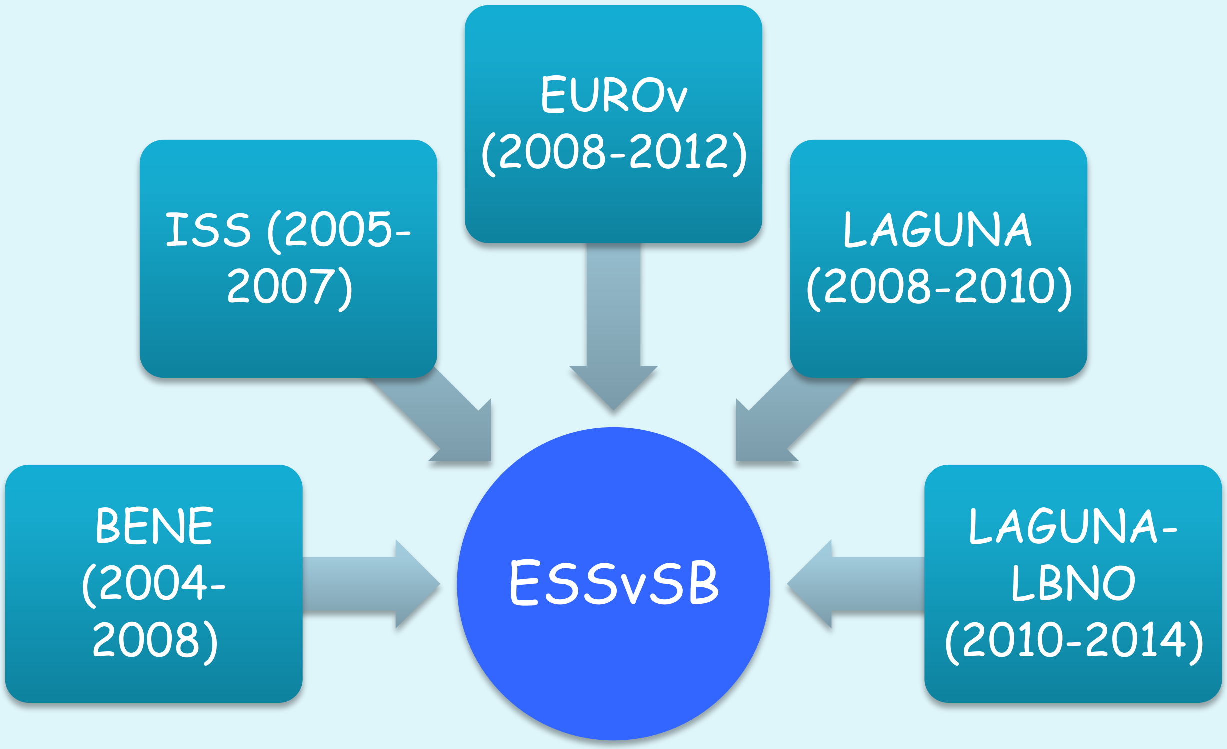
Pilar Coloma

The systematic errors used by the Snowmass Group

Pilar Coloma et al arXiv:1209.5973

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 $\times$ eff. QE†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs $\times$ eff. RES†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs $\times$ 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%

Previous experience



ESS Neutrino Super Beam (ESSνSB) proposal

A Very Intense Neutrino Super Beam Experiment for Leptonic CP Violation Discovery based on the European Spallation Source Linac: A Snowmass 2013 White Paper

E. Baussan,[m] M. Blennow,[l] M. Bogomilov,[k] E. Bouquerel,[m] J. Cederkäll,[f] P. Christiansen,[f] P. Coloma,[b] P. Cupial,[e] H. Danared,[g] C. Densham,[c] M. Dracos,[m,*] T. Ekelöf,[n,*] M. Eshraqi,[g] E. Fernandez Martinez,[h] G. Gaudiot,[m] R. Hall–Wilton,[g] J.–P. Koutchouk,[n,d] M. Lindroos,[g] R. Matev,[k] D. McGinnis,[g] M. Mezzetto,[j] R. Miyamoto,[g] L. Mosca,[i] T. Ohlsson,[l] H. Öhman,[n] F. Osswald,[m] S. Peggs,[g] P. Poussot,[m] R. Ruber,[n] J.Y. Tang,[a] R. Tsenov,[k] G. Vankova–Kirilova,[k] N. Vassilopoulos,[m] E. Wildner,[d] and J. Wurtz.[m]

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14 participating institutes form 10 different countries, among them ESS and CERN

Answers to the questions asked by the conference organizers

Q1. (Theoretical relevance) What is according to you the theoretical relative urgency of the determination of the
- neutrino mass hierarchy,
- PMNS CP violating phase δ,
- θ_{23} octant
- existence of sterile neutrinos
- Dirac vs Majorana nature of the neutrino

From a theoretical point of view we see the fundamental questions to be those of the existence of leptonic CP violation, and, if so, the value of the PMNS CP violating phase δ, and the establishment of whether the neutrino is Dirac or Majorana particle.

The establishment of which is the octant of θ_{23} and of the neutrino mass hierarchy can in part be seen as important steps on the way, to which ESSnuSB can contribute, but which are not crucial to ESSnuSB for the CP violation discovery. These measurements will be, if not yet done, a byproduct of the next generation leptonic CP Violation projects.

The existence of sterile neutrinos would, on the one hand, open completely new perspectives but is, on the other hand, a more speculative possibility.

Q1". Compare, if relevant, to other attempts of measurement direct or indirect (e.g. in cosmology). Describe also synergies with other topics of science e.g. proton decay or neutrino astrophysics (supernova burst and relic, solar neutrinos,…).

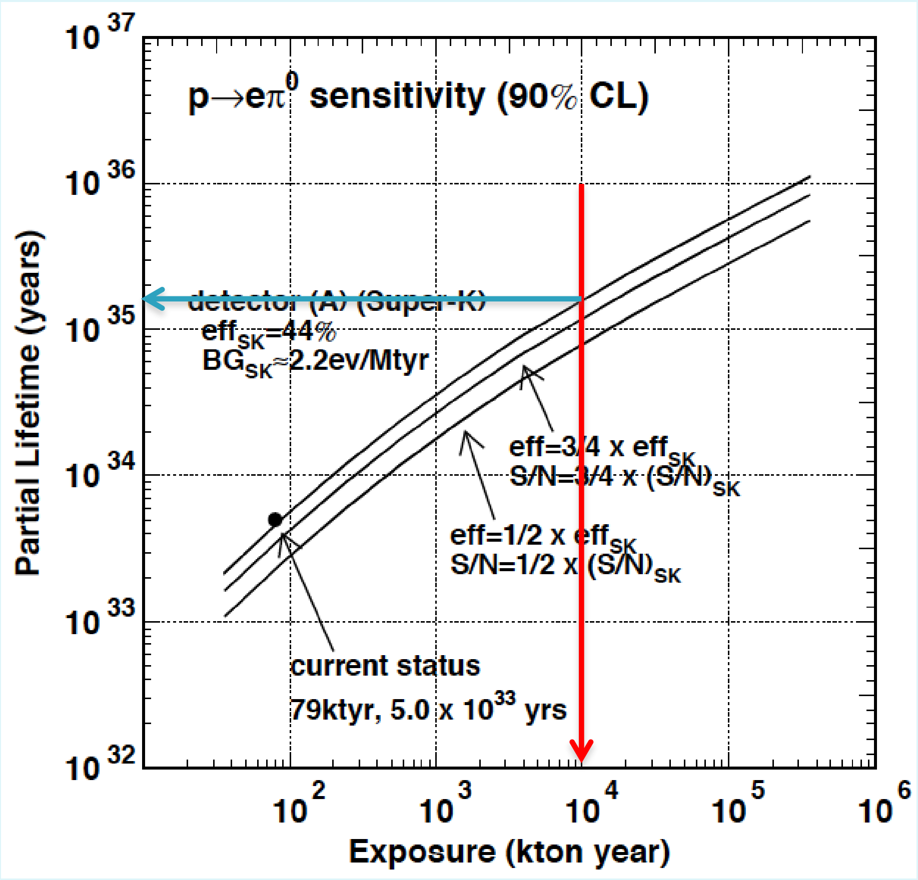
The discovery and measurement of leptonic CP violation can only be made with a neutrino Super Beam experiment.

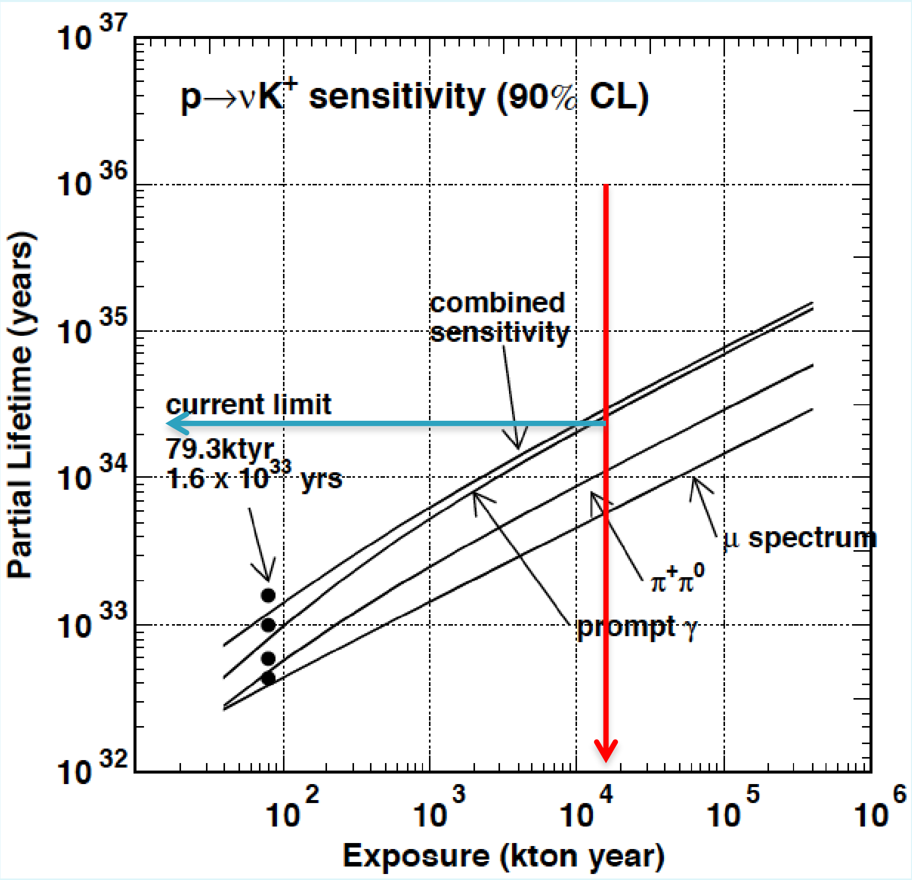
As the ESSnuSB far detector is a Megaton water Cherenkov detector it will, with its huge mass and relatively low energy threshold, have substantial reach for proton life time measurements (10^{35} years) and neutrino astrophysics (10^{5} Supernova explosion neutrinos detected, can attempt detection of relic neutrinos, high statistics solar neutrino measurements).

We are currently in contact with APPEC for the planning of the latter measurements.

The MEMPHYS Detector

proton decay

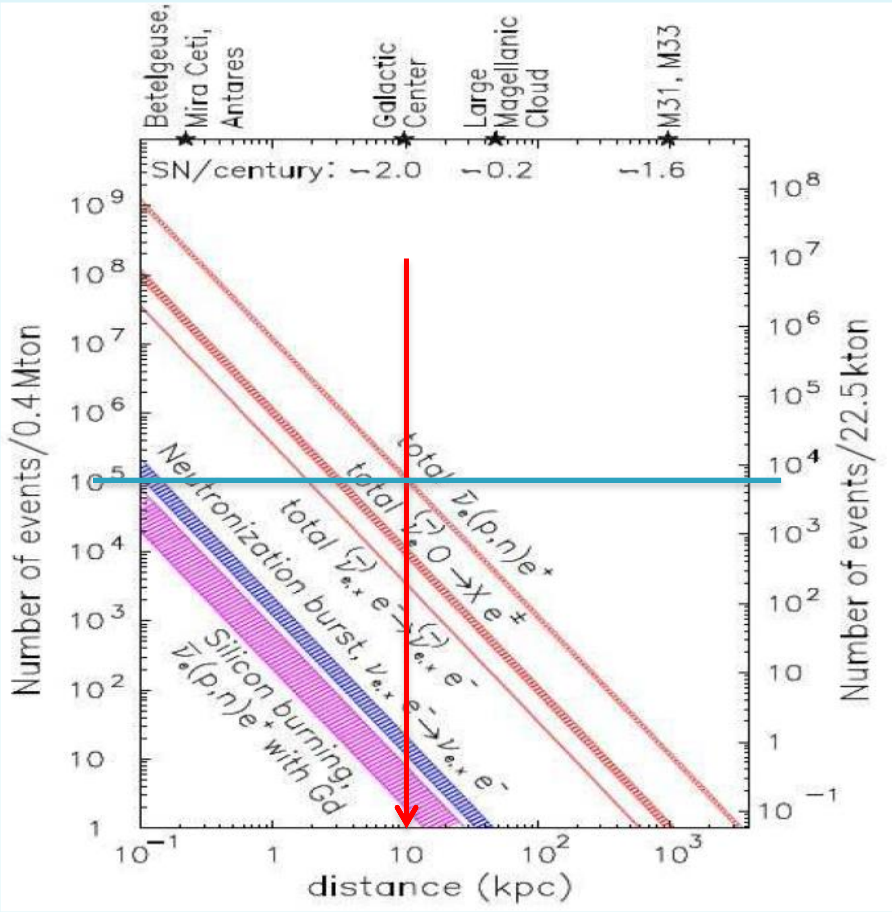




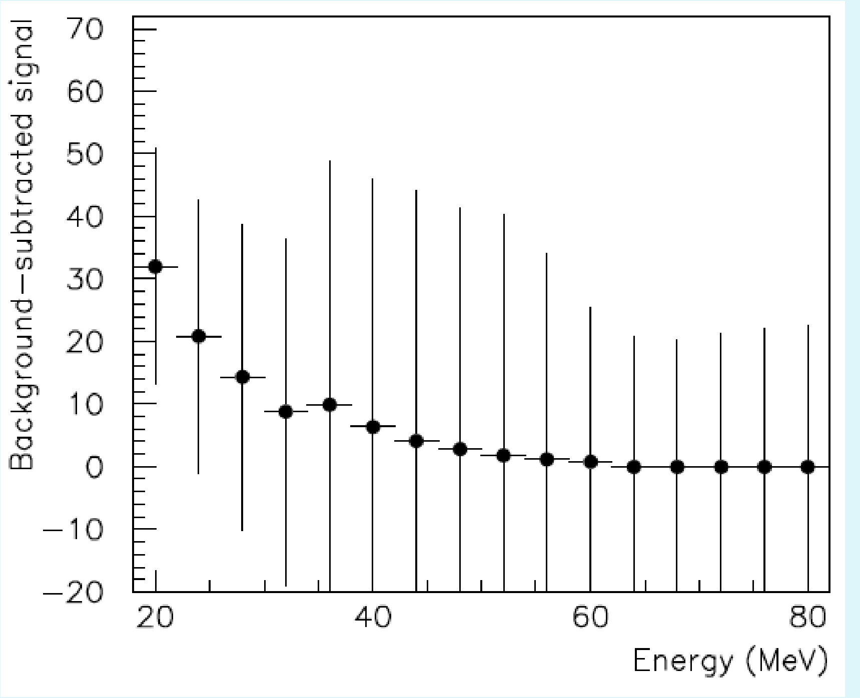
(arXiv: hep-ex/0607026)

The MEMPHYS Detector
Supernova explosion and relics

MEMPHYS



SUPERK



Diffuse Supernova Neutrinos
(10 years, 440 kt)

For 10 kpc: ~10^5 events

Q2.' (Experimental Strategy) What is according to you the experimental strategy that needs to be deployed worldwide in order to answer the above questions?

There are several non-super-beam experiments that aim at determining the θ_{23} octant and the mass hierarchy and which will probably manage to do so before any of the currently planned super-beam experiments will have collected enough data for such determination.

The fundamental question of leptonic CP violation, on the other hand, can only be answered by a super-beam experiment.

Since it is also, in our view, one of the two most fundamental questions in neutrino physics it should, in our view, be the first priority of a super-beam experiment.

As to the second fundamental question, i.e. the Dirac/Majorana question, only a double-beta-decay experiments can provide the answer.

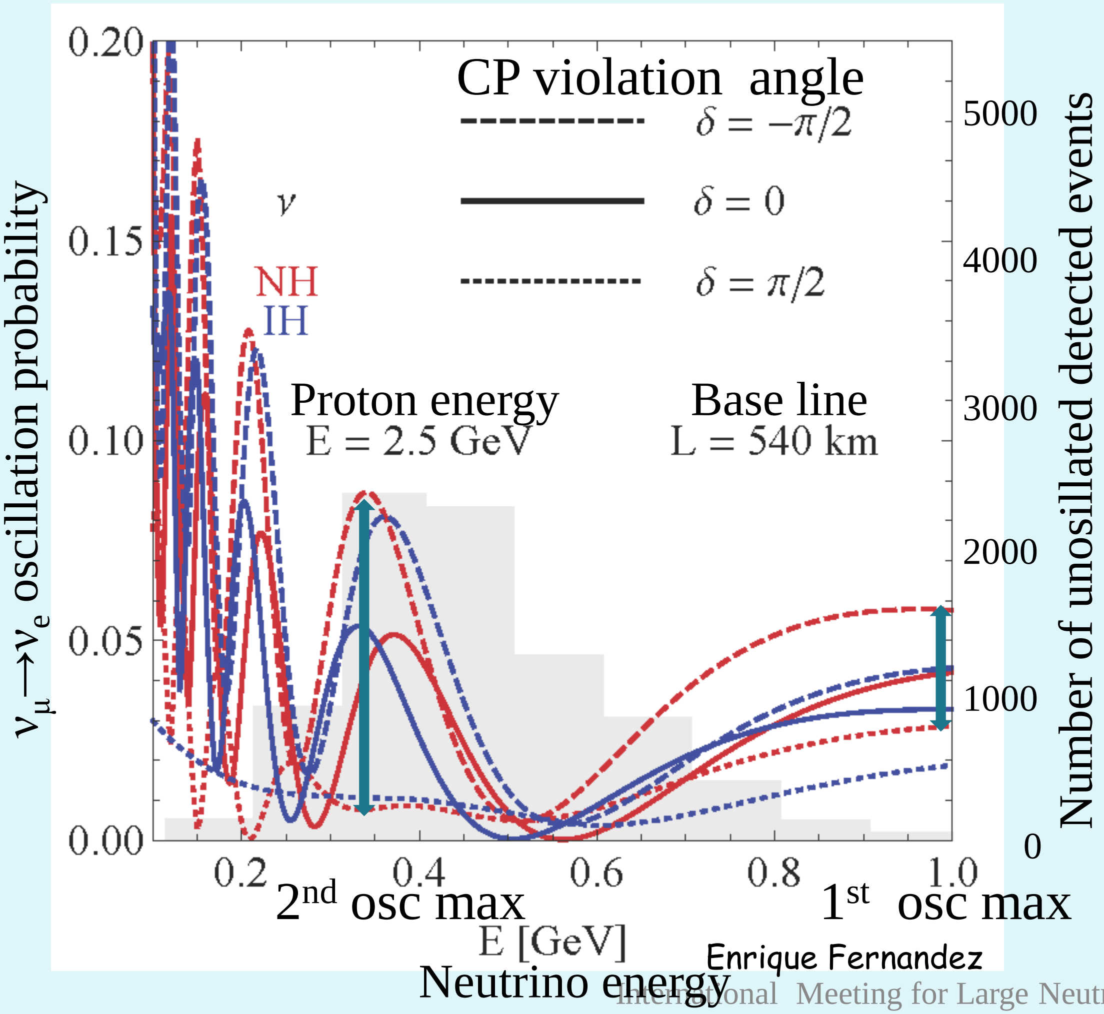
Q2". And in particular, how many experiments should there be worldwide, what complementarities or double check features should they exhibit?

One of the basic requirements for certifying an important discovery is to have confirmation from several experiments, motivating thus at least two neutrino Super Beam experiments.

Another basic requirement when planning experiments for an important discovery is to apply complementarity measurement strategies in order to be sure to attain the goal. LBNE and LBNO propose to use liquid Argon detectors and high energy beams, ESSnuSB and Hyper-K water Cherenkov detectors and low energy beams.

ESSnuSB is the only to collect almost all its statistics at the second maximum, where the CP violating signal is at least 3 times larger that at the first. <u>This is the important complementarity feature of ESSnuSB.</u> The other three proposed Super Beam experiments collect the major part of their statistics at the first oscillation maximum.

Maximum CP violation sensitivity at the 2nd oscillation maximum



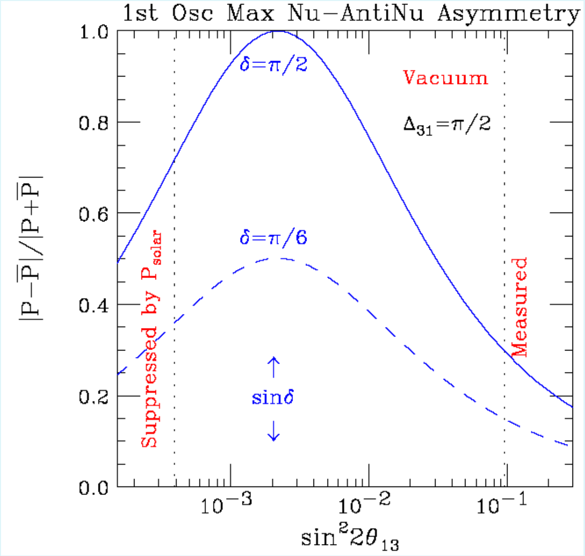
With the newly measured high value of ca 0.1 for $\sin^2 2\theta_{13}$ the CP angle sensitivity is significantly higher at the second $\nu_\mu \to \nu_e$ oscillation maximum than at the first. **With low energy neutrinos the neutrino detector can be placed at the second oscillation maximum.** All other earlier planned experiments have higher neutrino energy and their detector at the first oscillations maximum

From Stephen Parke/ FNAL; "Neutrinos: Theory and Phenomenology"; arXiv:1310.5992v1 [hep-ph] 22 Oct2013, page 12;

"At the **first oscillation maximum** (OM), as is in the running experiments, T2K and NOνA and possible future experiments HyperK and LBNE experiments, the vacuum asymmetry is given by

$A \sim 0.30 * \sin\delta$ at $\Delta_{31} = \pi/2$

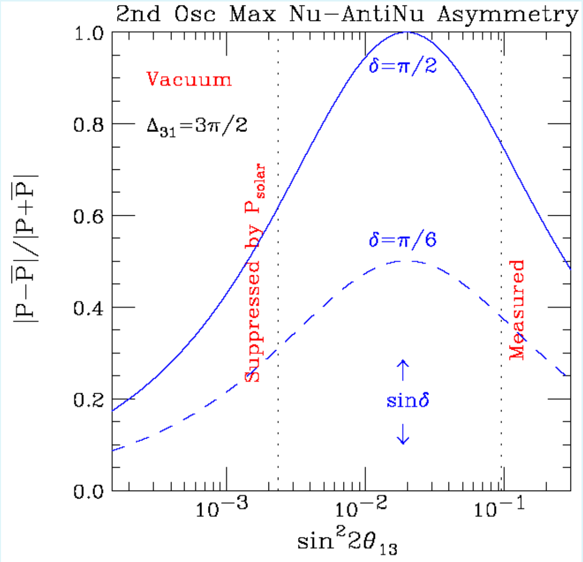
which implies that **$P(\bar{\nu}_\mu \to \bar{\nu}_e)$ is between 1/2 and 2 times $P(\nu_\mu \to \nu_e)$.**



Whereas at the **second oscillation maximum**, the vacuum asymmetry is

$A \sim 0.75 * \sin\delta$ at $\Delta_{31} = 3\pi/2$

which implies **that $P(\bar{\nu}_\mu \to \bar{\nu}_e)$ is between 1/7 and 7 times $P(\nu_\mu \to \nu_e)$.**



So that experiments at the second oscillation maximum, like ESSnuSB [15], have a significantly larger divergence between the neutrino and anti-neutrino channels."

Q2'''. In this world-wide context describe the phases of your project, its timeline and the expected statistical significance per phase.

ESSnuSB is currently in its **Design Study phase**. (It could hardly be in a more advanced phase as its design is based on the discovery of the large value for θ_{13}, published only in spring 2012). The aim is to achieve a Design Report by 2018. This will be possible because of the already extensive **experience existing** from the operation of the US spallation source SNS (which uses H^- acceleration) and from the water Cherenkov detector designs made for Super-K (in operation), Hyper–K, MEMPHYS and LBNE.

Certain **limited modifications** need to be made to the ESS linac during its build-up phase which will start in 2018 (first industrial series orders will be placed already in 2017) with a first low power beam by end 2019 and the final full power beam in 2023. The design and construction of the accumulator (to shorten the linac pulses), the target station (divided up on four target/horn assemblies) and the detector cavern, to be followed by the photodetector installation, can start when the **Design Report will be ready in 2018.**

The construction phase will take about 8 years implying start of data taking in 2026. About the statistics see answer to Q2'''' here below.

Q2""Discuss the relevant systematics, how well you know them and in particular do you need any supporting measurements to further determine them?

The **fundamental distinction** of ESSnuSB, when comparing to other proposed super-beam experiments, is that it will collect nearly all its statistics at the **second oscillation maximum**, where the CP violating signal is at least 3 times larger than at the first. This has radical consequences for its reach for CP discovery.

As the signal is more than 3 times larger than at the first maximum, the requirements on both the systematic and the statistical errors are correspondingly relaxed.

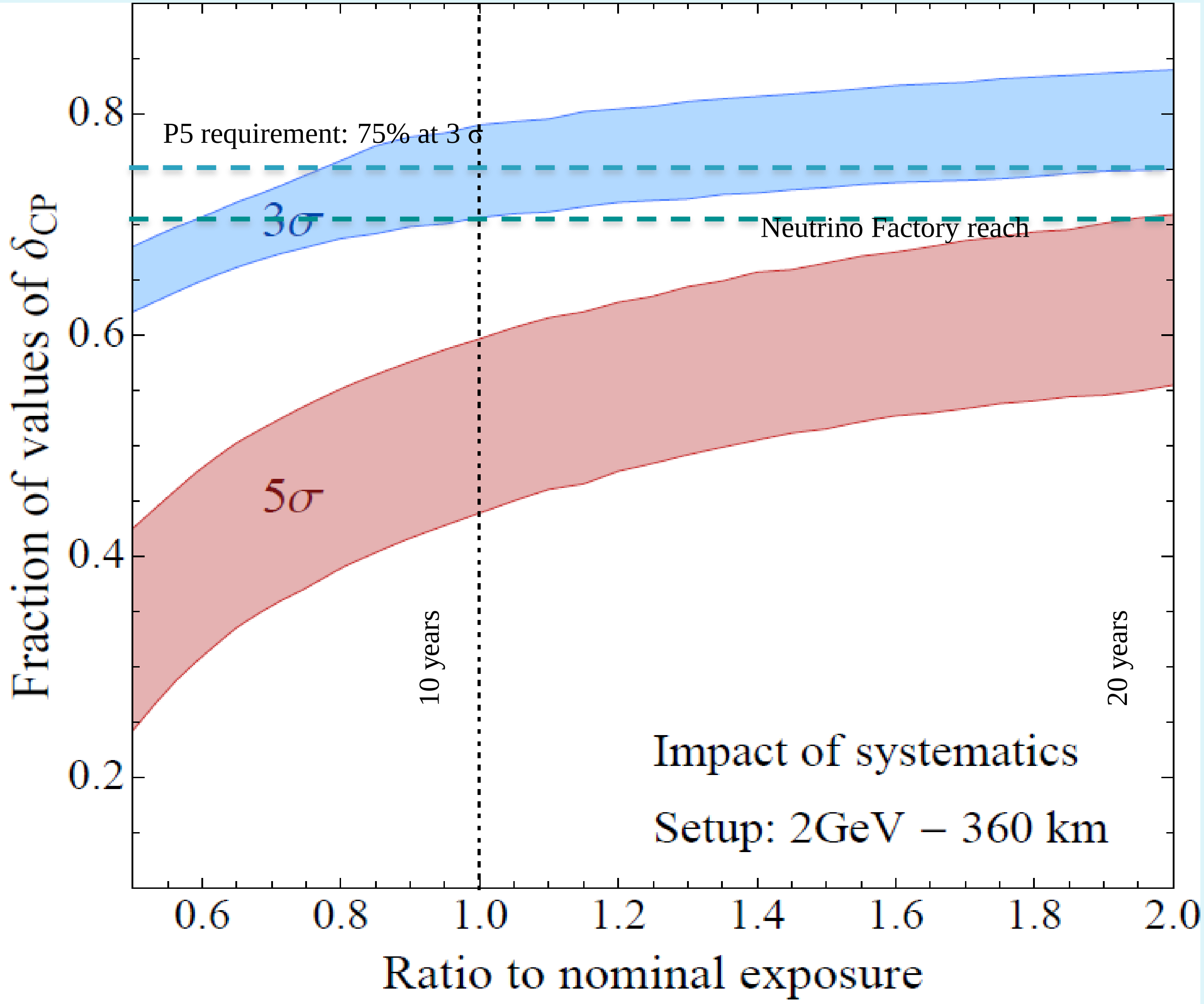
Based on the experience of previous and current neutrino beams and on the feasibility of measuring the electron-neutrino cross-section using the ESSnuSB near detector, we can plan to obtain 5% signal systematic error and 10% background systematic error.

In ESSnuSB we balance the statistic and systematic errors over a running period of 10 years. To achieve this at the second maximum, three times more distant than the first maximum, sufficient event statistics can only be obtained using an exceptionally powerful proton driver.

The next slide shows the interplay between statistics (“exposure”) and the coverage of the CP-phase-angular range for 5 sigma discovery (upper bound curves), implying 60% coverage after 10 years and 72% coverage after 20 years.

The robustness of the CP violation discovery potential is demonstrated by the fact that even under the assumption of as large systematic errors as 10% on the signal and 15% on the background (the lower bound curves), a 25%/ 42%/ 55% coverage with five sigma discovery potential will be attained after 5 years/ 10 years/ 20 years.

This also indicates that after the first few years, before that all systematic uncertainties have been reliably determined, there is a non-negligibel discovery potential for CP violation. One may also conclude that running ESSnuSB for 20 year, we will reach the same performance for CP violation discovery as the Neutrino Factory.



P5 requirement: 75% at 3 σ
3σ
Neutrino Factory reach
5σ
10 years
20 years
Impact of systematics
Setup: 2GeV – 360 km
Fraction of values of δ_{CP}
0.8
0.6
0.4
0.2
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Ratio to nominal exposure

Q3'. (Experimental readiness) Evaluate the readiness of the technology you are planning to use. Describe the phases (or R&D) towards its final validation.

The readiness of ESSnuSB is foremost determined by the design and construction of **the neutrino beam**.

The neutrino **detector technology**, even for the near detector, is sufficiently mature to start build-up of the far and near detectors by the time the far-detector cavern has been constructed.

There have also been studies for several different **underground sites** (Kamioka, Pyhäsalmi, Frejus) made for how to excavate and secure a Megata-ton detector cavern.

Investigation of the specific geological properties at the planned location in Garpenberg, Sweden has already started with promising results. As the rock foreseen for the cavern is **stable and strong granite**, much of earlier cavern design studies are of use in the design of the cavern.

The readiness of ESSnuSB is thus determined by the requirements for the design and construction of the neutrino ESS beam.

We are currently preparing a **fund request to EU** for a ESSnuSB Design Study. This Study will focus on the required upgrade of the linac power from 5 to 10 MW, on the design of the combiner ring needed to shorten the 3 ms long ESS linac pulses and on the target station – we plan to use four target/horn assemblies in parallel so each will receive a 1.25 MW beam .

We already have **support from ESS and CERN accelerator division staff** to study these challenging tasks. Tomorrow and the day after (24-25 June) a team of two CERN accelerator specialists will visit ESS in Lund to work out, in collaboration with ESS accelerator staff, the required modifications to the current base-line ESS linac design to enable 10 MW operation for concurrent neutron and neutrino production.

Program for the visit 24-25 June 2014 of Eric Montesinos and Frank Gerigk of CERN to ESS in Lund

Tuesday June 24

0900-1000: Overview - D. McGinnis, S. Molloy
1000-1100: Beam Physics M. Eshraqi, R. Miyamoto
1100-1200: Front-End - E. Sargsyan, A. Ponton,
1300-1400: Modulators - C Martins
1530-1630: Civil Construction - G. Lanfranco, K. Svendin
1830-2359: Dinner - Pizza, Wine, Beer - Everybody

Wednesday June 25

0900-1000: Power Distribution - F. Jensen
1000-1100: Water Systems - J. Jurns
1100-1200: Cryogenics - X. Wang, P. Arnold
1300-1400: Cryomodules - C. Darve
1400-1500: RF - A. Sunesson, M. Jensen, R Yogi
1500-1600: Wrapup - D. McGinnis, S. Mollo

Q3"What are the risks associated.

There are some design risks associated with the high power of the neutrino beam required to reach the second oscillation maximum.

The power upgrade of the linac using a **H^- beam** (needed for injection in the accumulator ring) should not entail more than 1 W/m beam loss in the linac (to limit activation by irradiation). The beam loss for the current 5 MW proton linac design is for 0.1 W/m and experience from SNS shows that with H^- there may be an increase by a factor up to 10, which is thus still tolerable.

For the accumulator ring the **stripping of the 5 MW H^- beam** using foils or a laser techniques need detailed studies – our current Monte Carlo investigation of foil stripping indicates that we can stay below 1200 K temperature with "painting" of the beam on the foil.

Q3'''. Is there place for global sharing and coordination of the R&D or validation effort?

There is ample, not only place but also need, for global sharing and coordination of the R&D and validation effort.

We already have the collaboration of ESS, CERN and 9 European Universities. As to validation of our project the European Steering Group for Accelerator R&D ESGARD and the ICFA Neutrino Panel are playing an important role.

We welcome new collaborators, in particular also from outside Europe, to share the R&D effort and new external bodies for the validation effort.

Q3''''Are there industrial issues e.g. in procurement?

For the accelerator upgrade the additional devices required should not have neither technical, nor procurement capacity problems. The supply of photo-detectors could have some procurement capacity problems if both Hyper-K and ESSnuSB would order at about the same point in time.

Q4. (Site issues) What are the optimisation criteria for the site you propose? What is the regional support for the site you propose? Is your proposal site specific? Could the same or better performances be obtained in another site in the same continent or some other region?

The optimisation criterion for the accelerator site is that it should house the most intense proton driver in the world in order to make measurements at the second oscillation maximum feasible, thereby significantly decreasing the uncertainty in the prediction of systematic measurement errors. The linear accelerator of ESS with 10 MW, of which 5 MW for neutrinos, will be the worlds most intense pulsed proton source for neutrinos.

To attain a 5 MW proton beam for neutrino production with the Fermilab or Tokai accelerators will most probably not be possible, because these accelerator are circular and therefore substantially more subjected to space charge limitations than a linear accelerator.

As the ESS linac cannot reasonably be moved the ESSnuSB proposal is accelerator site specific.

We have received a letter of support from the ESS AB CEO Jim Yeck.

Letter of support to ESSnuSB by the ESS Management

"Given the high scientific interest in exploring the possibility of using the future ESS linear accelerator for neutrino physics, interesting additional user communities, and a shared commitment to the above mentioned conditions for the Design Study, ESS management agrees to provide information and general support for the ESSnuSB collaboration's ongoing studies."

EUROPEAN SPALLATION SOURCE

Date: 19 May 2014

To the European Commission's Horizon 2020 Research Infrastructure Office

Subject: Support for the ESSnuSB Conceptual Study

ESS notes that the ESSnuSB collaboration is planning a Design Study of ways to increase the average power of the ESS linear accelerator from 5 MW to 10 MW by doubling the duty cycle from 4% to 8%. This collaboration includes an international group of scientists and engineers from a number of research institutions including the universities of Durham, Krakow, Lund, Madrid, Sofia, Stockholm-KTH, Strasbourg and Uppsala and the laboratories of CERN, ESS, Fermilab and RAL. The goal of the collaboration is to determine the best way to produce the highest flux neutrino-beam in the world. An important boundary condition for the conceptual study, according to the ESSnuSB group, is that the ESS mission for neutron production will not be compromised in any way. An additional ESS boundary condition is that any ESS engagement in the study will not divert our staff from their current priorities, i.e., successful delivery of the ESS baseline linear accelerator.

The stated scientific aim of the Design Study is to specify how the high flux neutrino beam would be produced and how the beam would make possible the discovery of CP violation in the neutrino sector. According to the ESSnuSB group, this scientific goal could be achieved by comparing the rates of appearance of electron neutrinos and electron anti-neutrinos at the second neutrino oscillation maximum. The second maximum for the enhanced ESS parameters is approximately 500 km from the ESS site. My understanding is that at this distance there is an appropriate underground location for a large neutrino detector available. New neutrino measurements, published in 2012, imply that the CP violation signal at the second maximum is significantly larger than at the first maximum. Other planned neutrino experiments in the US and Japan, proposed before 2012, is designed to measure neutrino oscillations at the first maximum and will not have access to the second maximum. Statistically significant measurements at the second, more distantly situated maximum would be made possible only by the use of the exceptionally high proton beam flux of the ESS linear accelerator.

Given the high scientific interest in exploring the possibility of using the future ESS linear accelerator for neutrino physics, interesting additional user communities, and a shared commitment to the above mentioned boundary conditions for the Design Study, ESS management agrees to provide information and general support for the ESSnuSB collaboration's ongoing studies.

James Yeck
Director General and CEO

European Spallation Source ESS AB
Visiting address: ESS, Tunavägen 24
P.O. Box 176
SE-221 00 Lund
SWEDEN
www.esss.se

The optimisation criterion for the far detector site is that that it should be located at the second oscillation maximum (around 400-500 km base line for the ESS 350 MeV neutrino beam) and that there should be a ~1 km deep mine there.

There are several different candidate sites for the far ESSnuSB detector possible, among those the Garpenberg (540 km from ESS) and the Zinkgruvan (370 km) mines in Sweden and the Kongsberg (480 km) mine in Norway.

It has so far not been possible to show that mines at approximately the right distance in Poland and Germany fulfil the geological requirements for excavation and detector operation (rock strength, ambient temperature…).

Currently the Garpenberg mine is being investigated in detail as it presents the advantage of having a shaft and rock hoist that will become free for crushing and transportation to the ground level of the ESSnuSB excavation rock debris.

There are Swedish groups at the universities in Lund, Stockholm, KTH and Uppsala forming part of the ESSnuSB Collaboration.

We have had several contacts with the Garpenberg mine management who support our investigation of Garpenberg as detector site

Q5'. (Financial and internationalisation issues) What is the cost of the experimental configuration (beam where relevant and detector)?

As the Design Report will be finished only in 2018 it is difficult to make a precise cost estimate now.

An estimate of 700 MEUR has been made for the detector and its cavern, compatible with the Hyper-K detector and MEMPHYS cost estimates. Our first cost estimate for the accelerator upgrade, the accumulator and the target area is 100 MEUR, 200 MEUR and 200 MEUR, respectively, summing up to a total construction cost of 1200 MEUR. In view of the interest among the ESS neutron users to have also short neutron pulses, there is the prospect of sharing the cost for the accumulator with the neutron community.

Q5". What is your financial plan? What is the current level of international participation and what level of participation would be necessary to move to a construction decision? What models would you propose for international participation and at which parts of the beam or detectors? What would be the parts of the configuration whose leadership you would be willing to negotiate in exchange of international participation ?

We currently have about 30 collaborators from 11 different institutions in Europe. We have been designing ESSnuSB during the 2 years since 2012, when the high value of θ_{13} was discovered, and are currently continuously welcoming new members. We obviously need to welcome many more collaborators, in particular also from outside Europe.

We are continuously informing the ICFA Neutrino Panel, the European Steering Group for Accelerator R&D (ESGARD), the Swedish government, the ESS and CERN Managements, the Garpenberg Mine management, APPEC and the EU Research Directorate about the evolution of our project plans. By 2018, when first funding acquisitions need to start on the basis of the Design Report, we need to be of the order of 200 collaborators from 30-40 institutions in several continents. Collaboration will be both on the accelerator and on the detector side.

ESSnuSB is driven primarily by scientific (not regional) interest and we are therefore ready to negotiate leadership of any part of the project in exchange of international participation.

Conclusions and summary

We conclude that the ESSnuSB project:

has the best physics potential for CP violation studies, compared to the other Super Beam projects in the world,

has a cost smaller than any of the other proposed projects,

is synergetic with the major new European infrastructure ESS,

is sufficiently advanced in its concept, benefitting from the European EUROnu and Laguna-LBNO design studies and from the ESS studies,

has the support of the ICFA Neutrino Panel Paris meeting for a EU Design Study

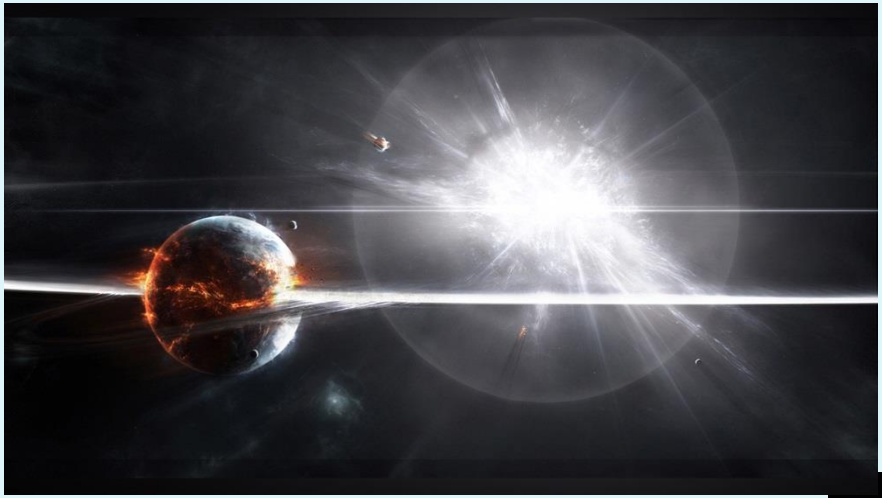
has a strong group of 11 institutes that plan to undertake specific, well planned and prepared tasks to bring the project up to a Design Report for which an EU Design Study grant will be a crucial and decisive source of funding.

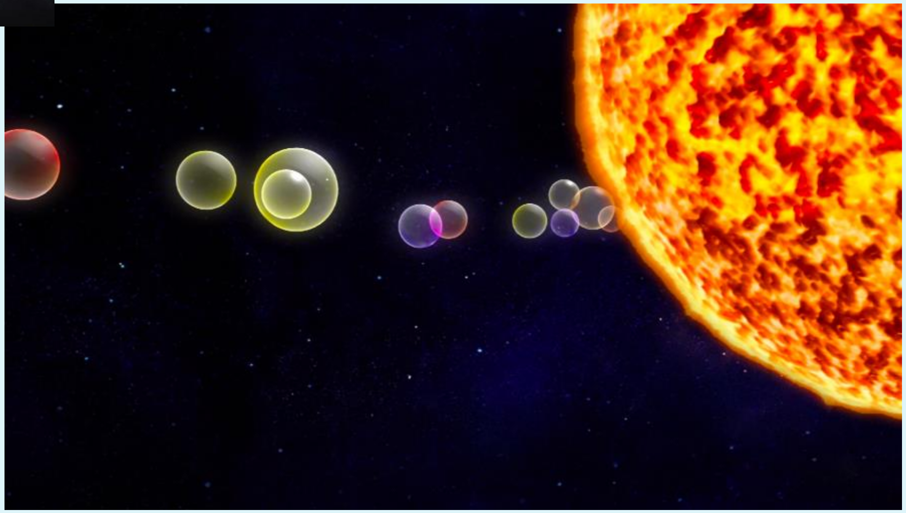
is coherent with the following conclusion of the 'Expert Group on assessment of the ESFRI Roadmap projects' stated in its report published in December 2013: "ESS indicates that the spallation source will offer opportunities for new science for new user communities. It is advisable to start attracting such communities well before the Operational Stage, inter alia in order to strengthen the case for support by funders",

will create cooperation and synergies between ESFRI projects, i.e. between ESS as an accelerator laboratory and CERN as HEP EU center, and, in future, a possible underground detector project for astroparticle physics as detector site, and can profit from the available experience in major accelerator developments labs in Europe like CERN, CEA & CRNS, DESY, RAL and INFN and

has, through its unique feature of providing enough beam power to focus all its statistics at the second maximum and thereby its clear lead for CP violation discovery, the potential to attract collaborators also from the other continents of the world.

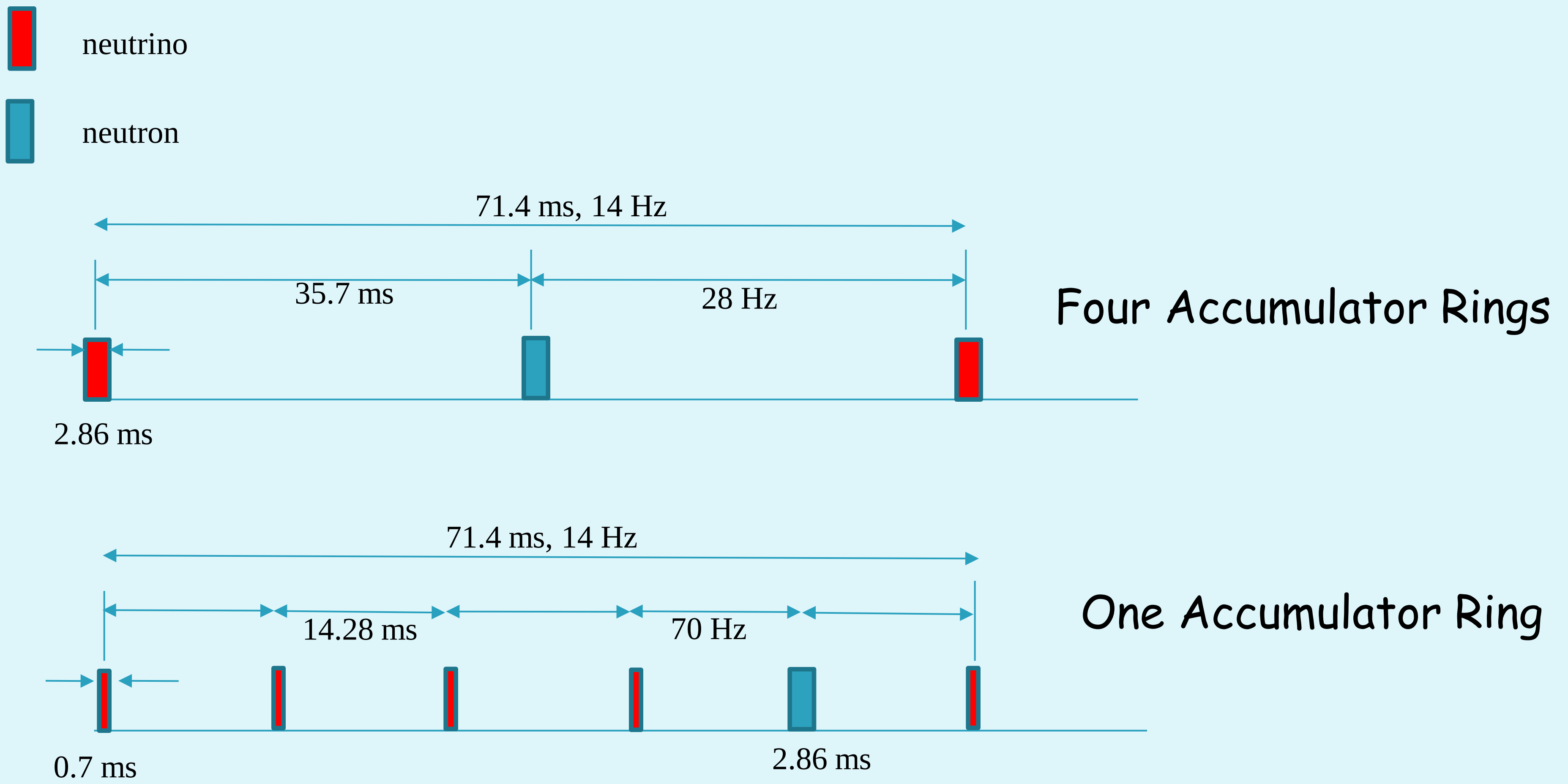
Thanks for your attention





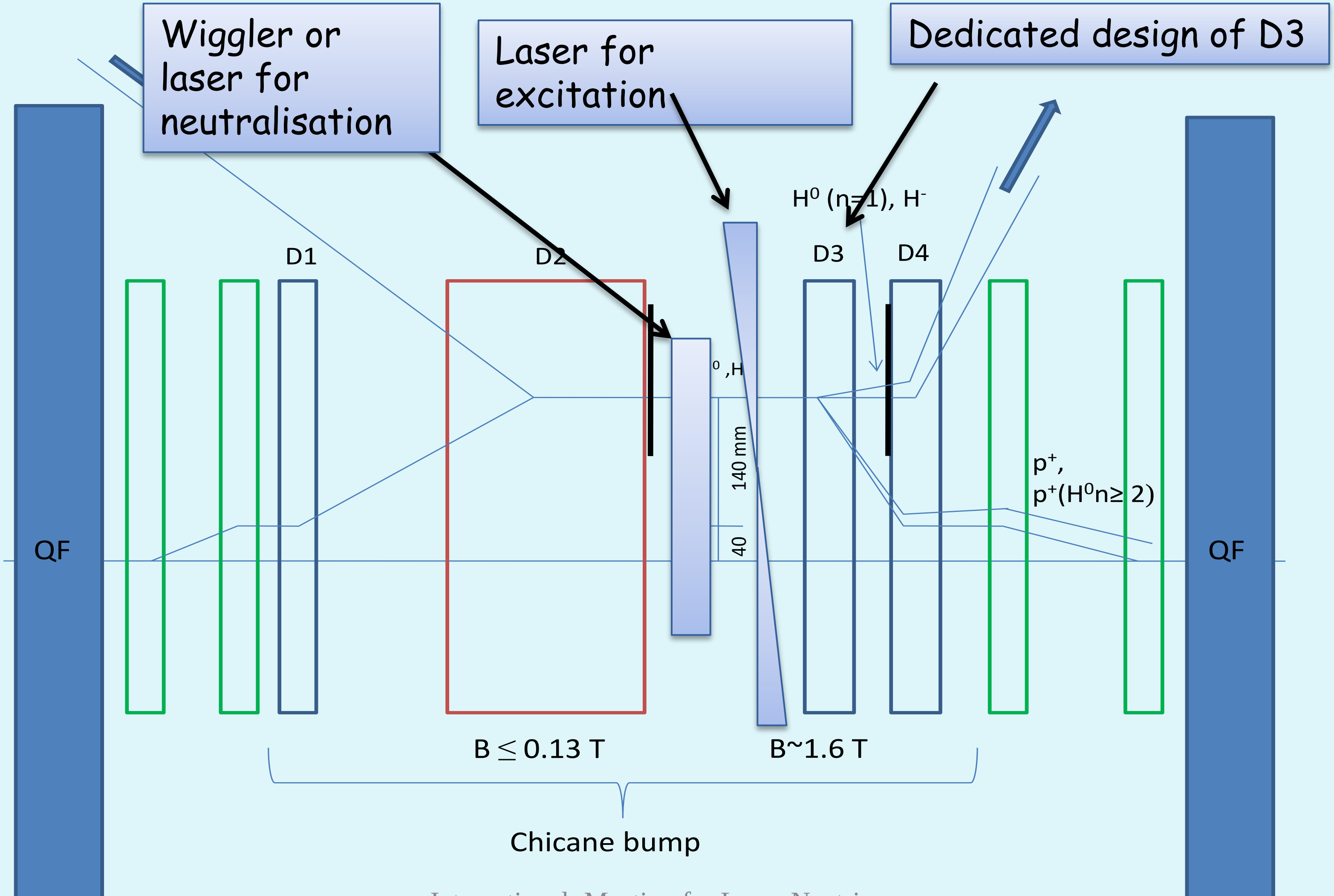
Back-up slides

1 accumulator ring instead of 4



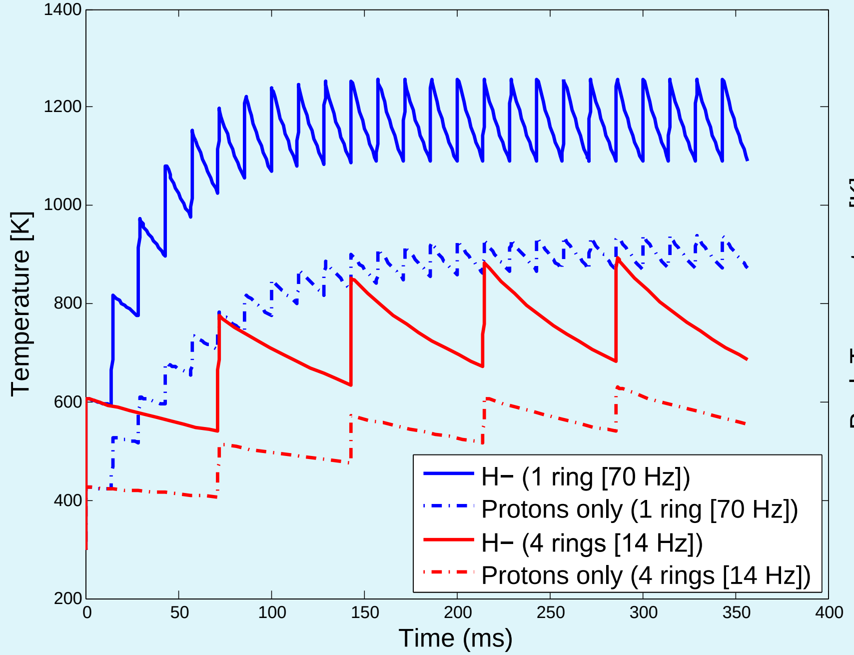
Injection system design of accumulator to be checked (heat deposition and radiation)

Foil or laser stripping



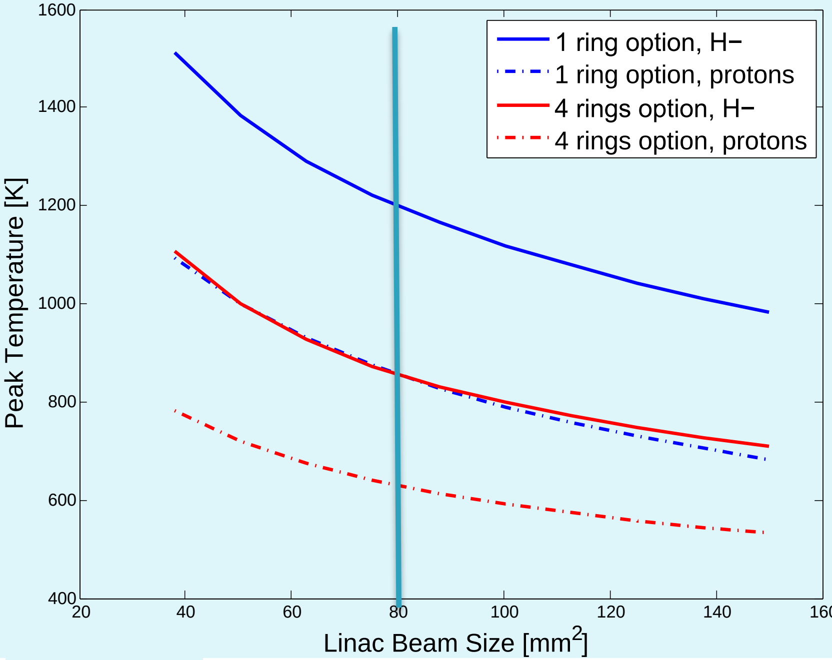
ESSvSB foil temperature

Foil temperature due to the linac beam (1 and 4 rings)



Linac beam size: 8x10 mm^2

Maximum foil temperature (1 and 4 rings)



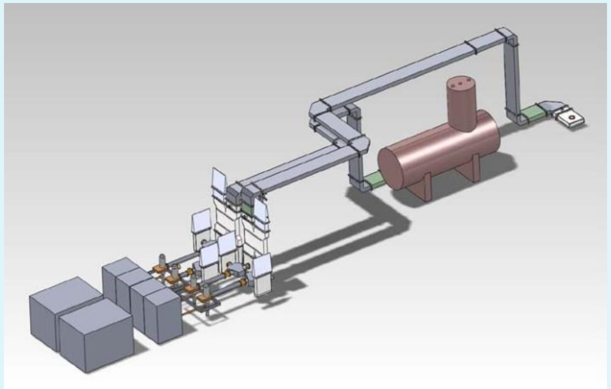
Linac beam size ➔

"Calculation of the maximum temperature on the carbon stripping foil of the spallation neutron source"
C.J.Liaw et al, (BNL),
Proceedings of the 1999 Particle Accelerator Conference, New York

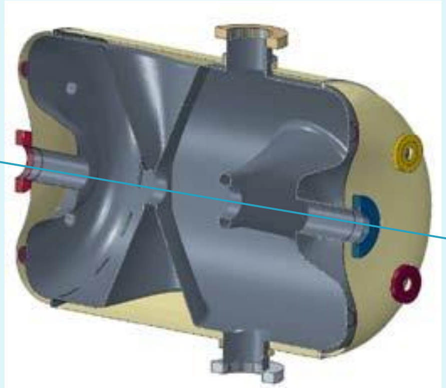
Jakob Jonnerby

Test of operation a RF power source at 28 Hz and 70 Hz

A prototype 352 MHz spoke cavity for the ESS linac will be tested in the FREIA Laboratory at Uppsala University **already as from autumn 2014** in a cryostat at 14 Hz pulse frequency and at the full instantaneous power required for ESS proton acceleration, which is 350 kW. For the generation of the 352 MHz power both a tetrode amplifier and a solid state amplifier will be tried out. As part of the EUROSB project, **the amplifier pulse frequency will be raised to 28 Hz and 70 Hz**, thus doubling the average power to the cavity. The influence of this higher power on the operation of the cavity and on the capacity to cool the cavity itself and, in particular, its RF coupler will be studied.



Lay-out of the 352 MHz RF source, wave guides and test cryostat in the FREIA hall



ESS Spoke 352 MHz Accelerating Cavity

Impact on modulators when upgrading from 14 to 28Hz (C. Martins)

Cost Impact	Per modulator	Total (45 modulators)
1)- Adding extra capacitor charger modules	+ 60 kEURO	+ 3 MEURO
2)- Re-winding HVHF transformers and output filter inductors	+ 100 kEURO	+ 4.5 MEURO
3)- Labour costs (contract follow-up, testing, etc.)		+ 5 MEURO
Total cost increase for modulators' upgrade		**+ 12.5 MEURO (+ 30%)**

Footprint Impact	Per modulator	
Footprint required for additional capacitor chargers	~ 1.2m x 1m	

Impact on the AC distribution grid when upgrading from 14 to 28Hz

Cost Impact		**Total (45 modulators)**
1)- Add additional 10kV/600V distribution transformers (doubling the total quantity, keeping existent ones)		+ 2 MEURO
2)- Add additional LV power cables and switchboards (doubling the total quantity, keeping existent ones)		+ 1.5 MEURO
3)- Labour costs (contract follow-up, testing, etc.)		+ 2 MEURO
Total cost increase for AC grid upgrade *(only for LV grid; new buildings and CF expenses not included)*		**+ 5.5 MEURO (+ 100%)**

Other impacts (to CF)		
New buildings will be required for extra LV transformers and swichboards; Double footprint required.		
An additional HV 120kV/10kV power transformer will be required		
All HV distribution lines and protection devices at 120kV and 10kV levels will be doubled		