UPPSALA UNIVERSITET

ESSνSB

Measuring δ_{CP} at the second ν oscillation maximum

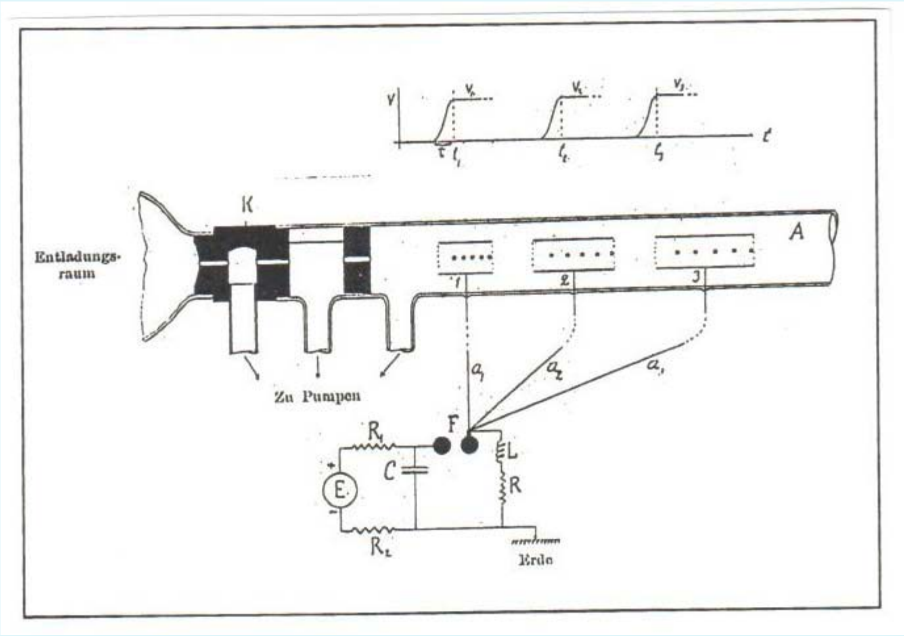
Second International Meeting for Large Neutrino Infrastructures
Fermilab 20-21 April 2015

Tord Ekelöf, Uppsala University

90 year anniversary

Gustav Ising

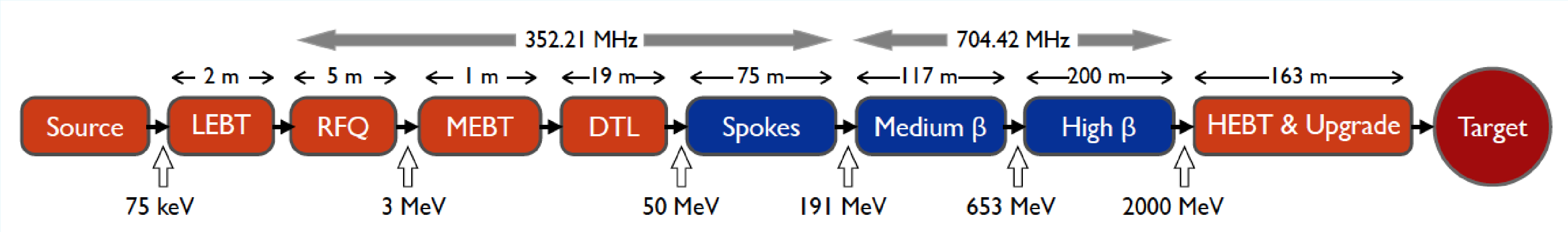
Fil. Kand. Uppsala 1903
Fil. Dr. Stockholm 1919
published in the 1920's an accelerator concept with voltage waves propagating from a spark discharge to an array of drift tubes.



Voltage pulses arriving sequentially at the drift tubes produce accelerating fields in the sequence of gaps.

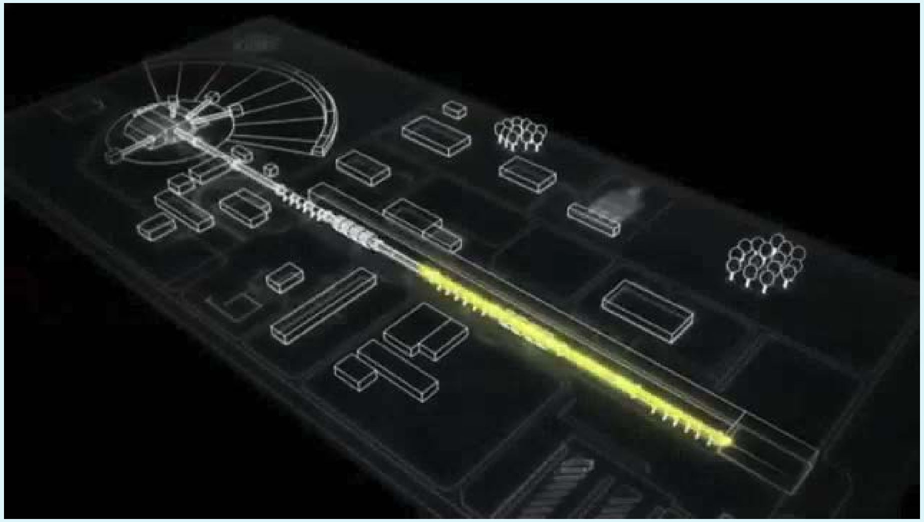
The 5 MW ESS linac is the hitherto most powerful realization of this visionary proposal made 90 years ago!

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 long pulses each of 10^{15} protons)
- 2.0 GeV protons (up to 3.5 GeV with linac upgrades)
- **>2.7x10^{23} p.o.t/year**

HEBT & upgrade: 2.5 GeV+68 m,
3.0 GeV +60 m,
3.5 GeV +66 m,



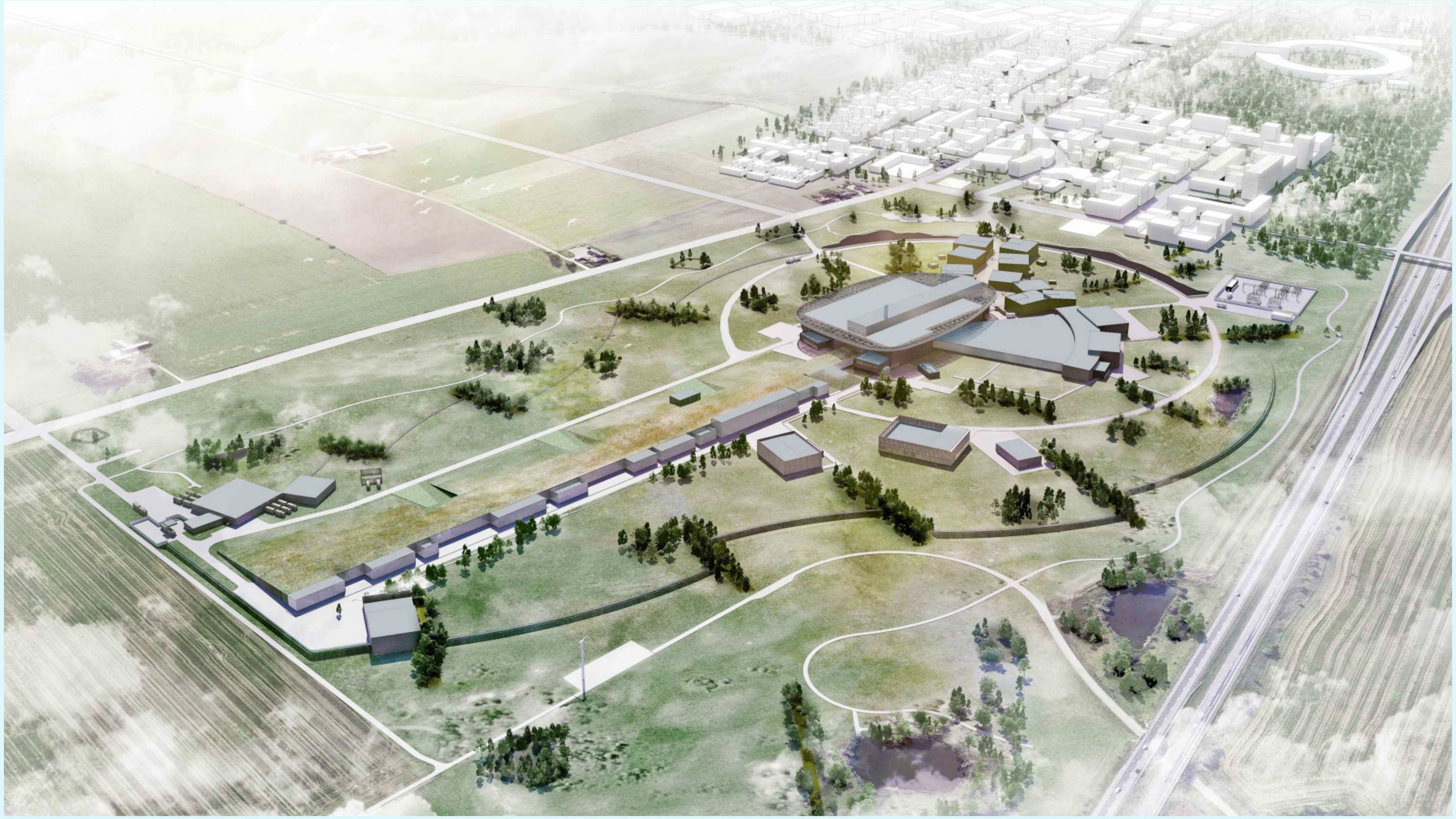
Linac ready by 2023 (full power and energy)

The construction of ESS is underway

ESS groundbreaking
Lund, September 2, 2014

Swedish science minister
discussing ESSnuSB

Artists view of the future ESS site



ESS construction site 10 April 2015

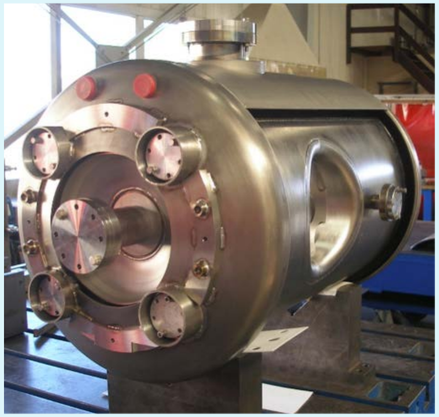
The linac tunnel on 10 april 2015

Casting of the cryo-transfer line base concrete slab

Accelerator tunnel concrete base slab casting and reinforcement

The first accelerating cavity prototypes have been designed and fabricated and are being tested this and next year. Series production will start in 2017

Double spoke cavity
352 MHz



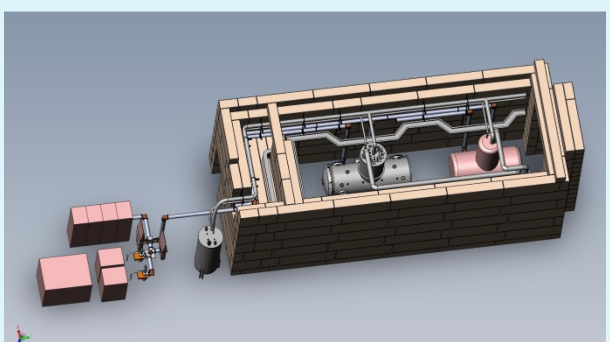
Has been low power tested at IPN Orsay and will be high power tested in FREIA Lab in Uppsala in 2015

Fivefold elliptical cavity
704 MHz

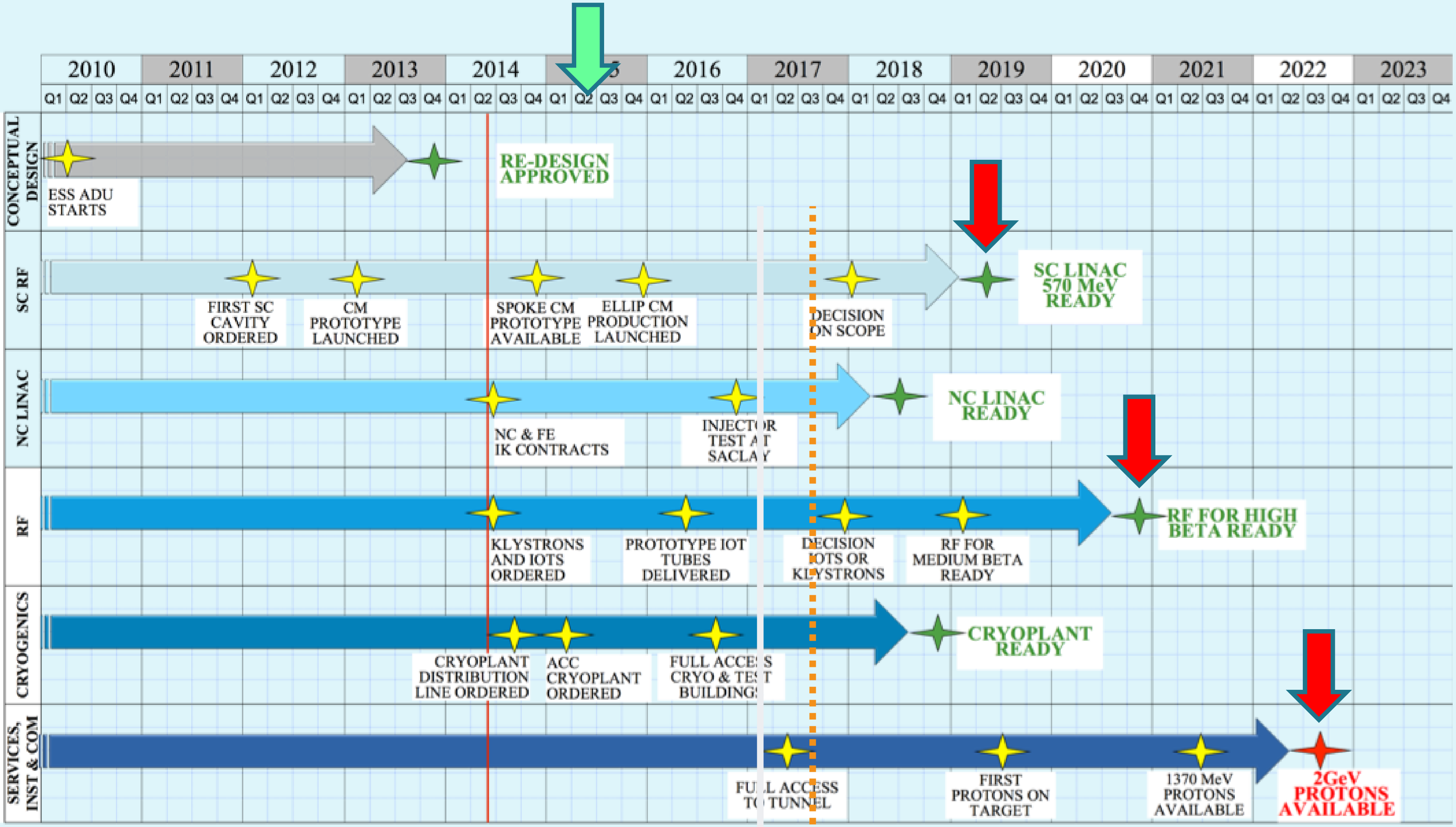
Has been low power tested at CEA Saclay and will be high power tested in Lund in 2016

FREIA

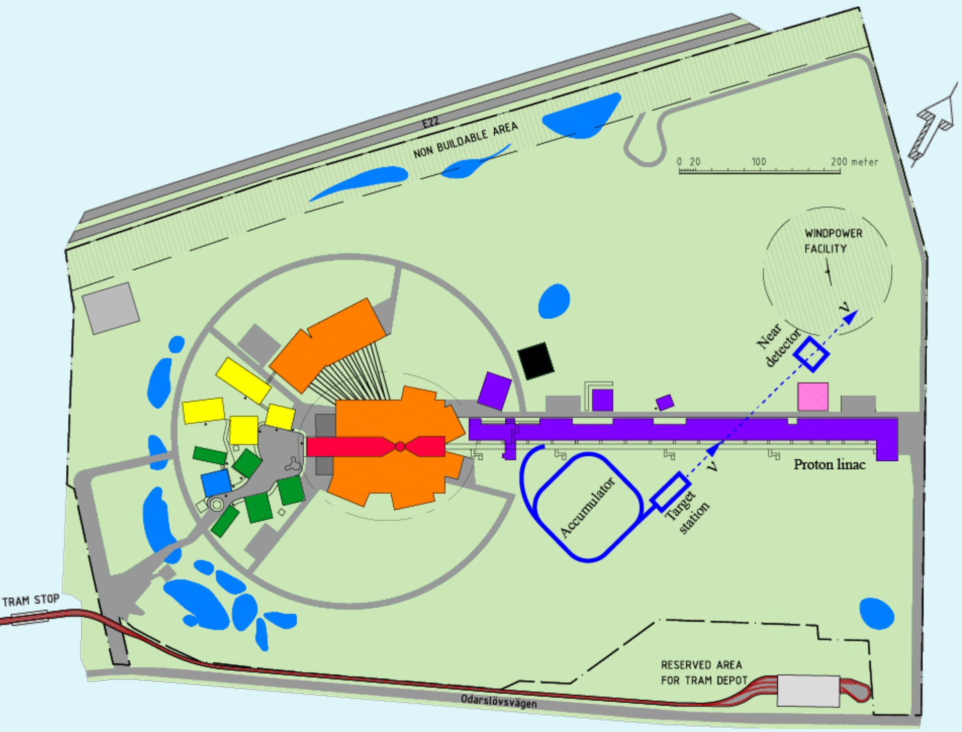
The picture shows the cryostat and test bunker at the FREIA Lab in Uppsala where a first prototype of the ESS 352 MHz spoke accelerating cavity is currently under test



ESS LINAC PROJECT SCHEDULE

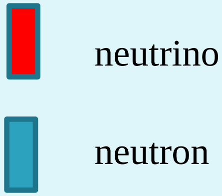


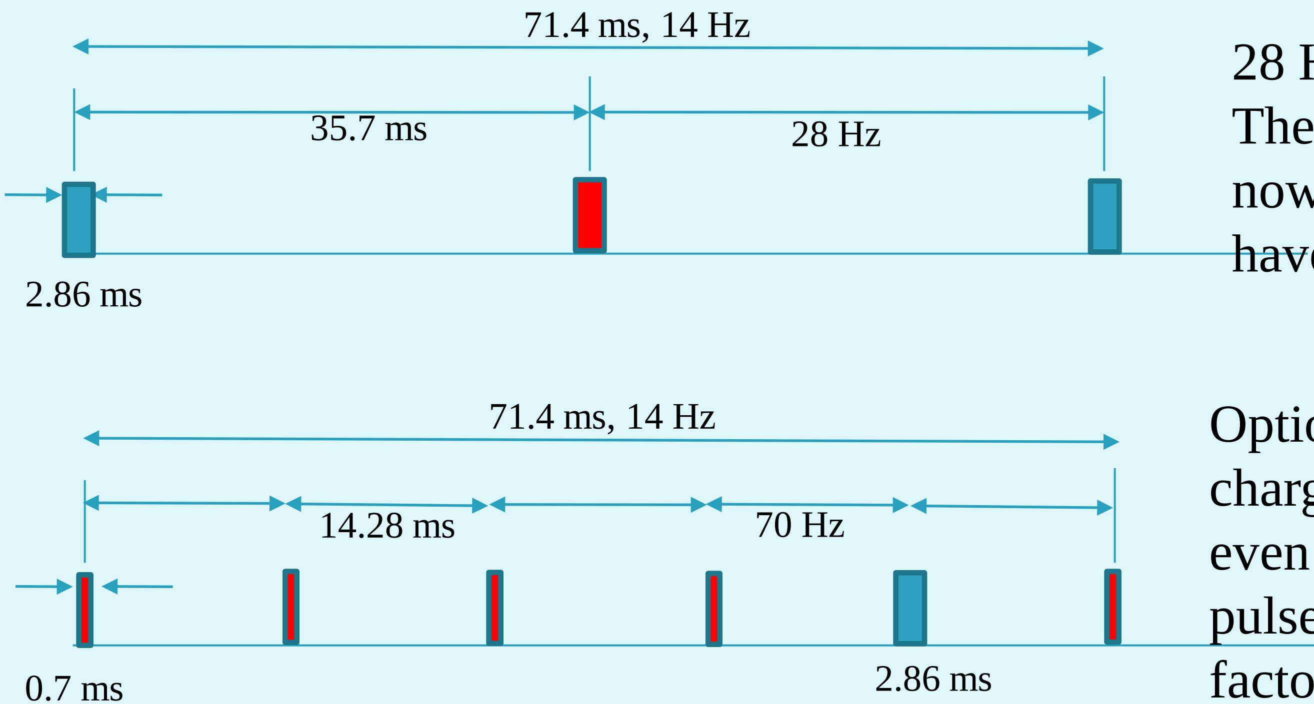
How to add a neutrino facility to ESS?



- Increase the linac average power from 5 MW to 10 MW by increasing the linac pulse rate from 14 Hz to 28 Hz, implying that the linac duty cycle increases from 4% to 8%.
- Inject into an accumulator ring circumference ca 400 m) to compress the 3 ms proton pulse length to 1.5 μs, which is required by the operation of the neutrino horn (fed with 350 kA current pulses). The injection in the ring requires H^- pulses to be accelerated in the linac.
- Add a neutrino target station (studied in EUROν)
- Build near and far neutrino detectors (studied in LAGUNA)

Increasing the linac average power from 5 MW to 10 MW by increasing the rate of proton pulses



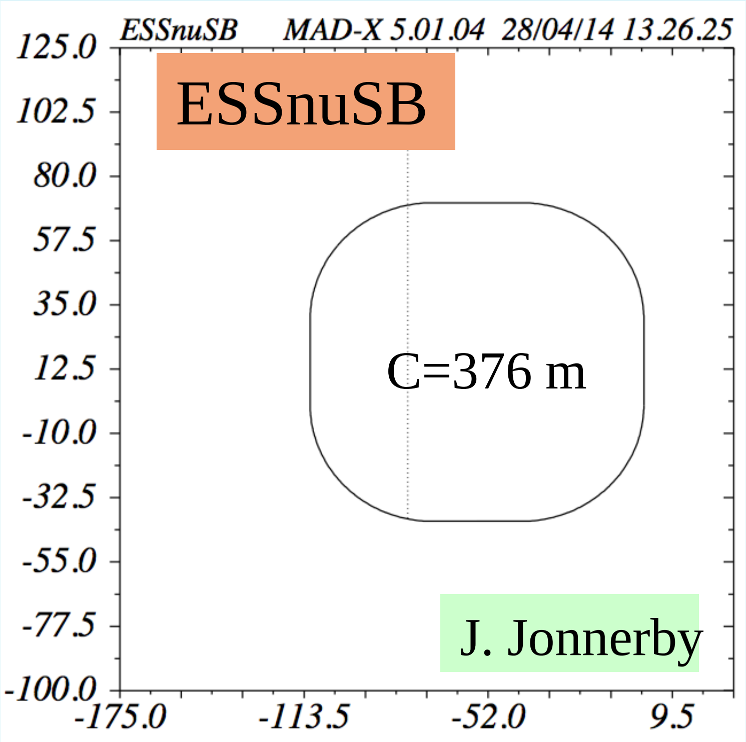


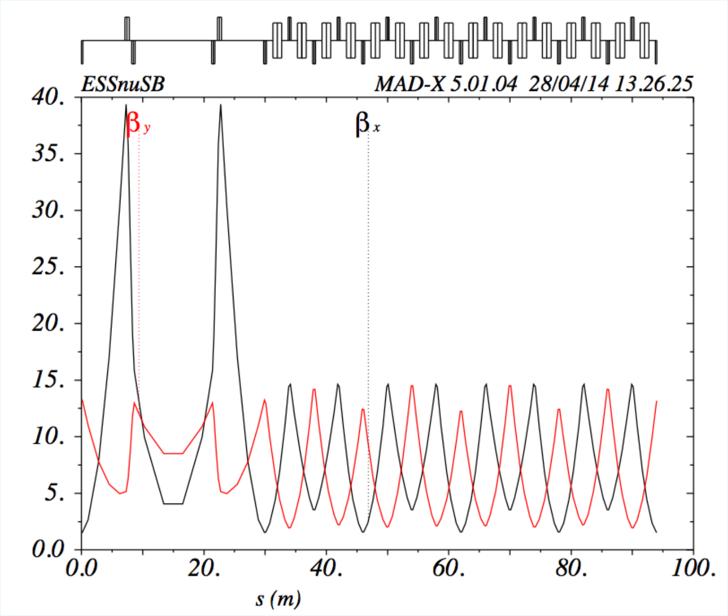
28 Hz pulsing
The accumulator ring, now under design, may have space charge problems

Option in case of space charge problems: 42 Hz or even 70 Hz pulsing, reducing pulse charge and length by factors 2 and 4, respectively

The linac instantaneous power 125 MW remains unchanged

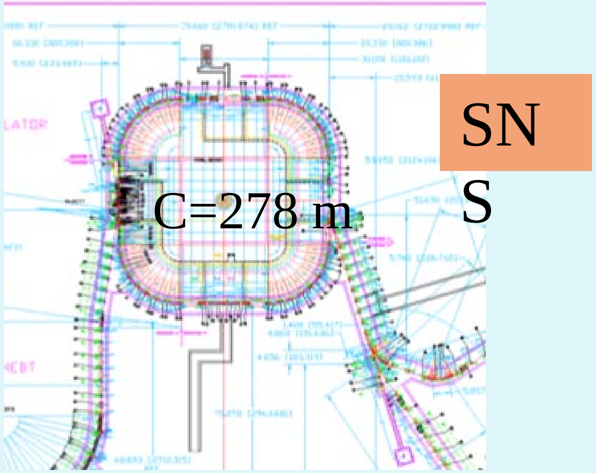
ESSnuSB Accumulator Ring Lattice





Straight Arc

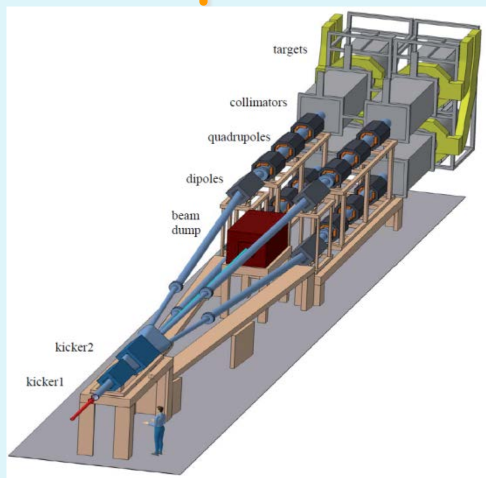
Circumference	376 m
Dipole field	0.635 T
# Dipoles	64
# Quads	84
Bending radius	14.6 m
Injection region	12.5 m
Revolution time	1.32 μs



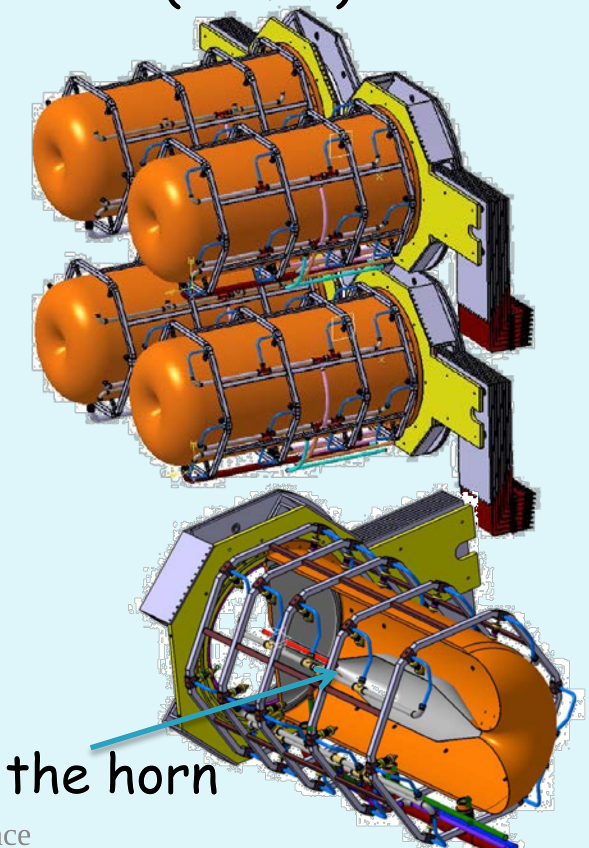
SNS straight section for injection used "as is" for simulations of foil stripping

Mitigation of high power effects in the neutrino production target

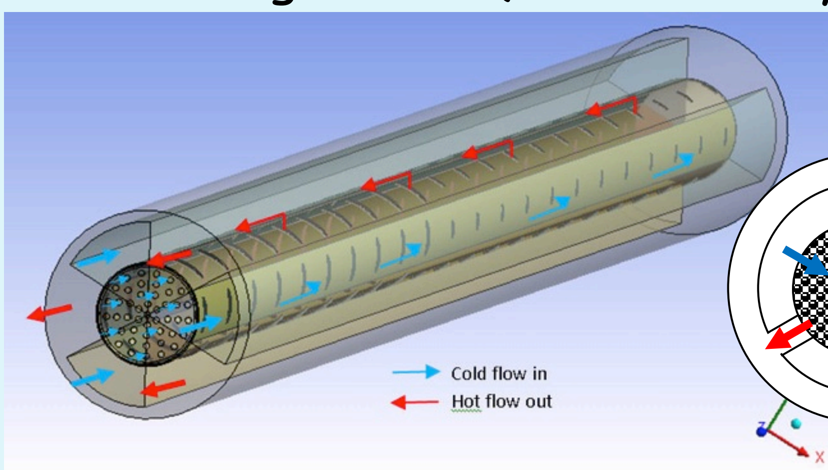
Downstream of the accumulator ring the beam pulses are distributed in sequence on the four targets

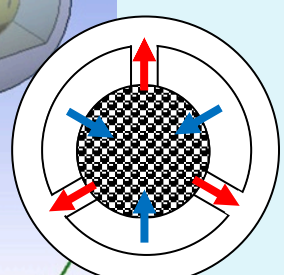


Four-target/horn system to mitigate the high proton beam power (5 MW) and rate (70 Hz)



Packed bed canister in symmetrical transverse flow configuration (titanium alloy spheres)

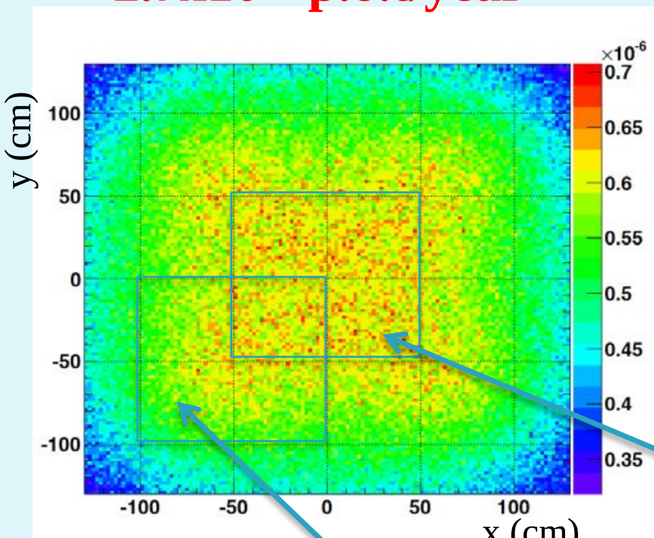




Target inside the horn

Muon at the level of the beam dump

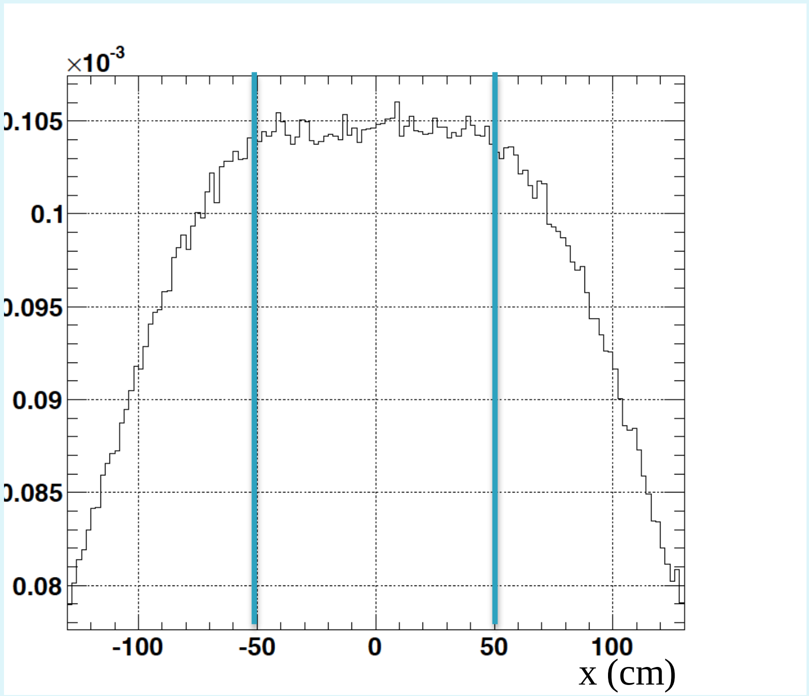
2.7x10^{23} p.o.t/year



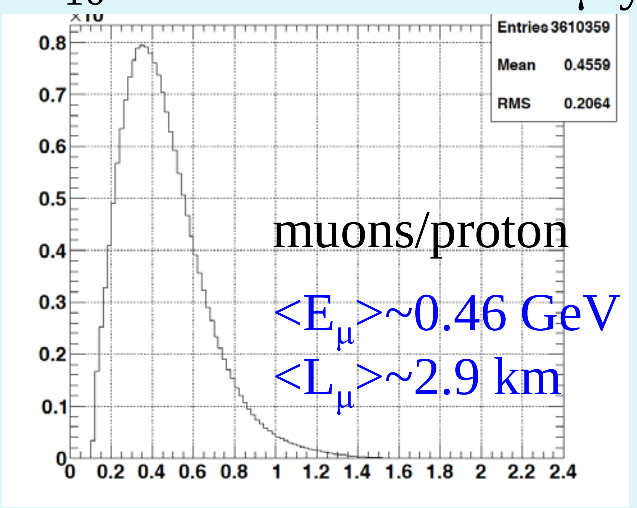
muons at the level of the beam dump (per proton)

4.2x10^{20} μ/year (16.3x10^{20} for 4 m^2)

4.1x10^{20} μ/year



10^{-3}



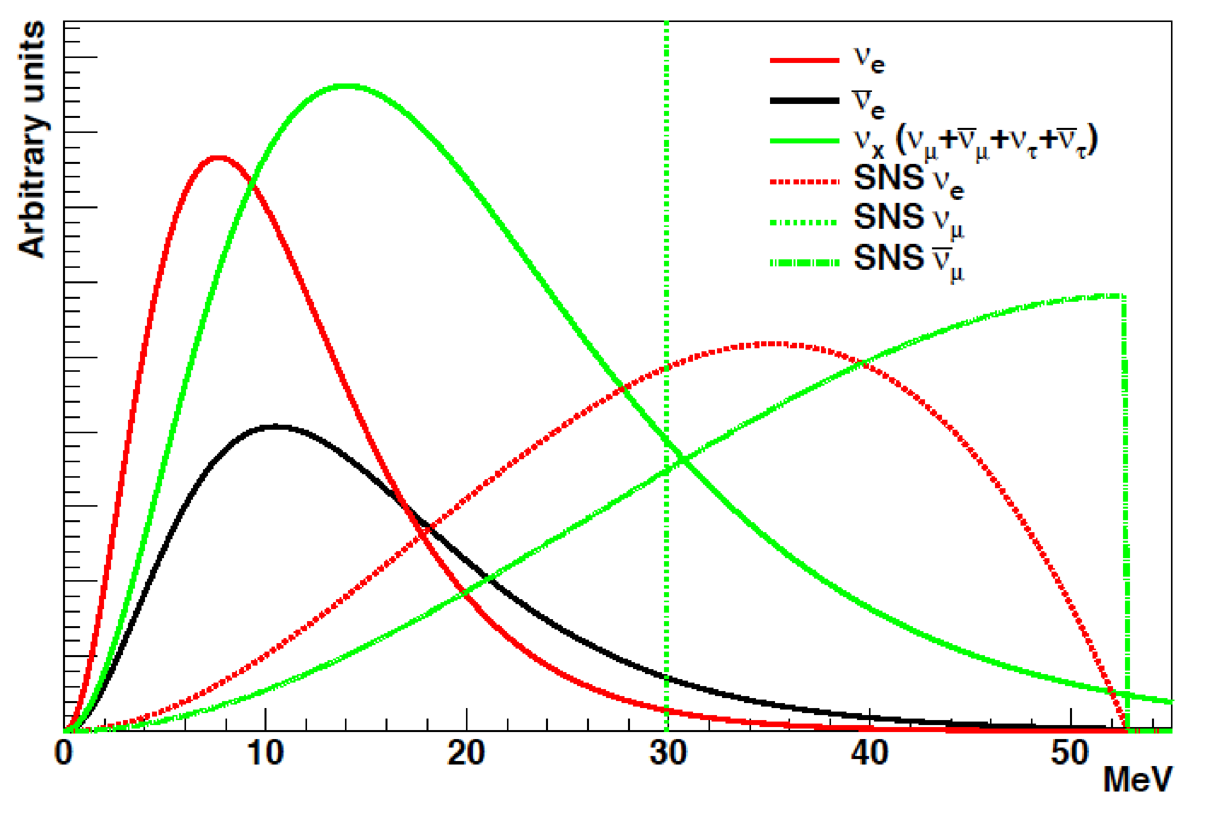
muons/proton

$\langle E_\mu \rangle \sim 0.46$ GeV

$\langle L_\mu \rangle \sim 2.9$ km

- input beam for future 6D μ cooling experiments (for muon collider)
- good to measure neutrino x-sections (ν_μ, ν_e) around 200-300 MeV (low energy nuSTORM)

DAR experiments (ESS/SNS)

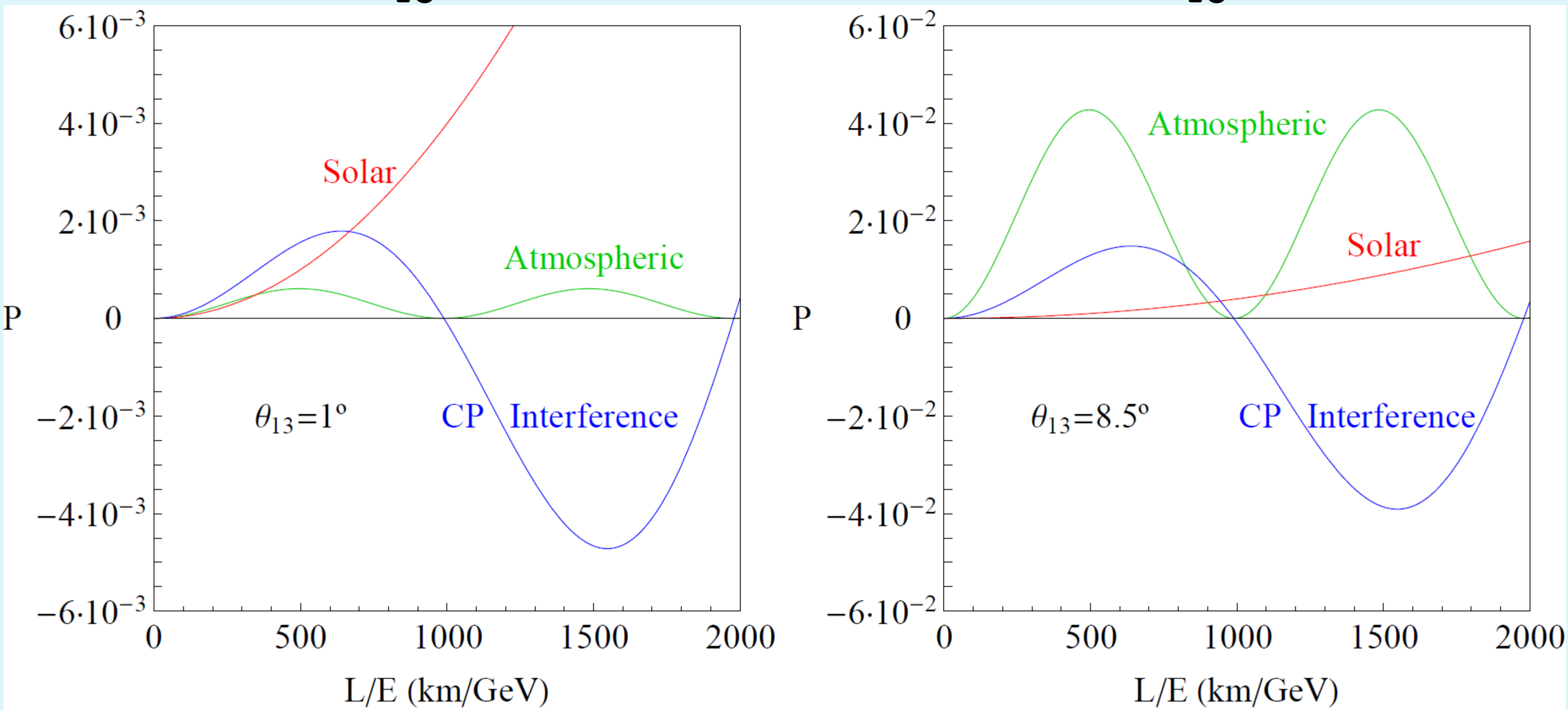


Typical expected supernova neutrino spectrum for different flavours (solid lines) and SNS/ESS neutrino spectrum (dashed and dotted lines)

On the higher sensitivity to δ_{CP} at the second oscillation maximum

Optimization of facilities for large Θ_{13}

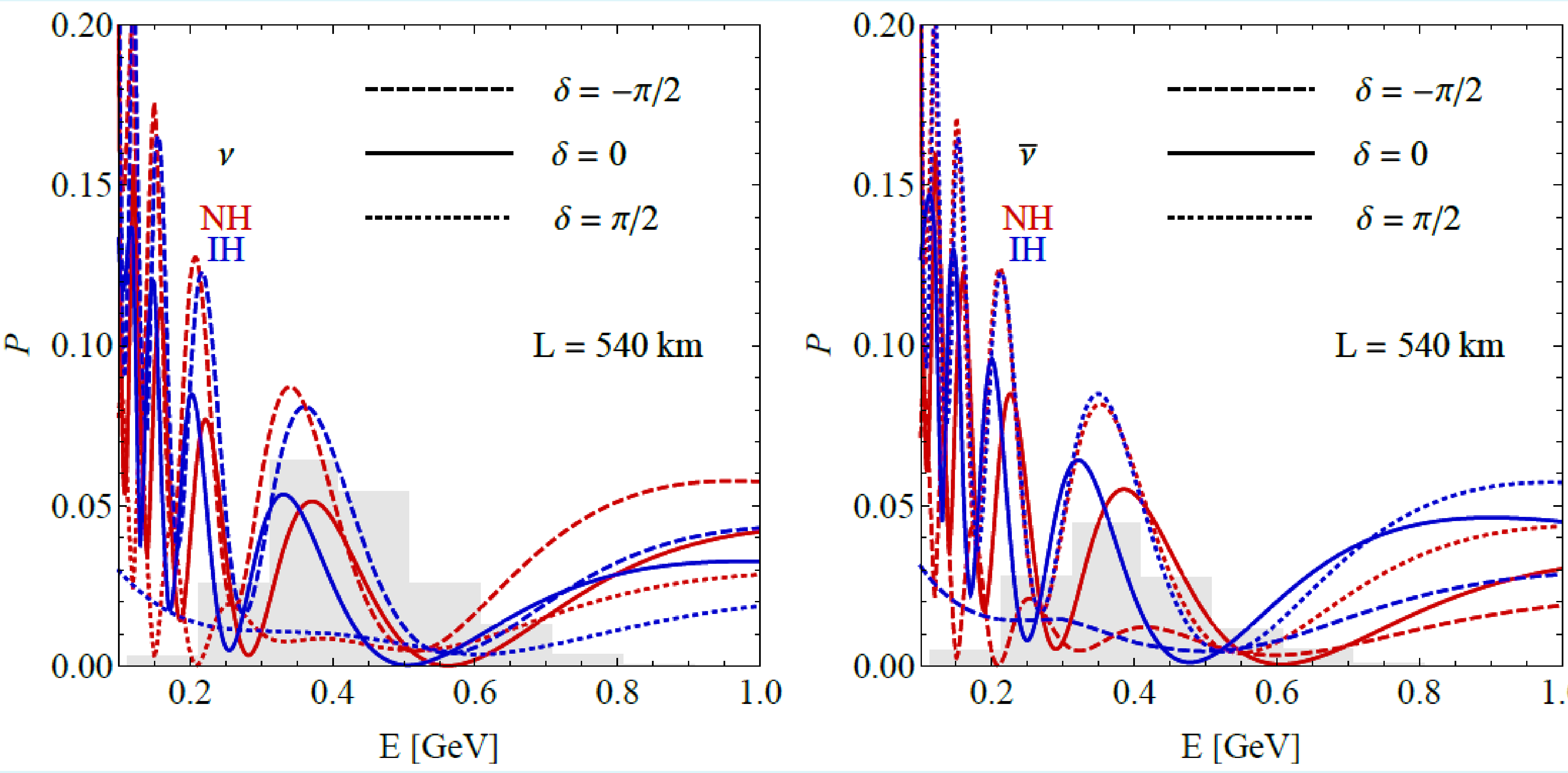
$\Theta_{13}=1°$ $\Theta_{13}=8.5°$



Signal systematics and not statistics is the bottleneck for large θ_{13}, explore second peak

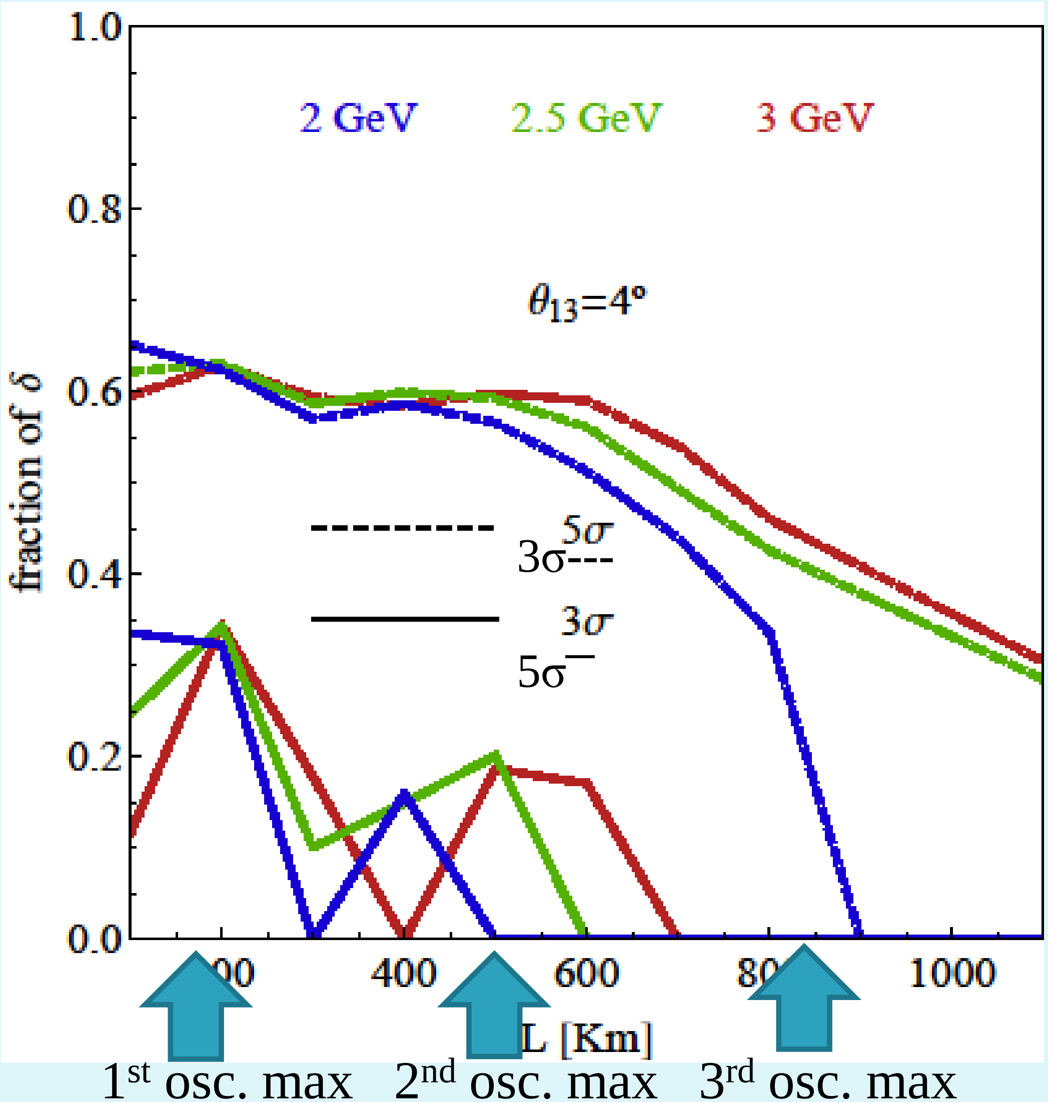
P. Coloma and EFM 1110.4583

The ESSnuSB neutrino-energy distribution has its peak at 2nd max



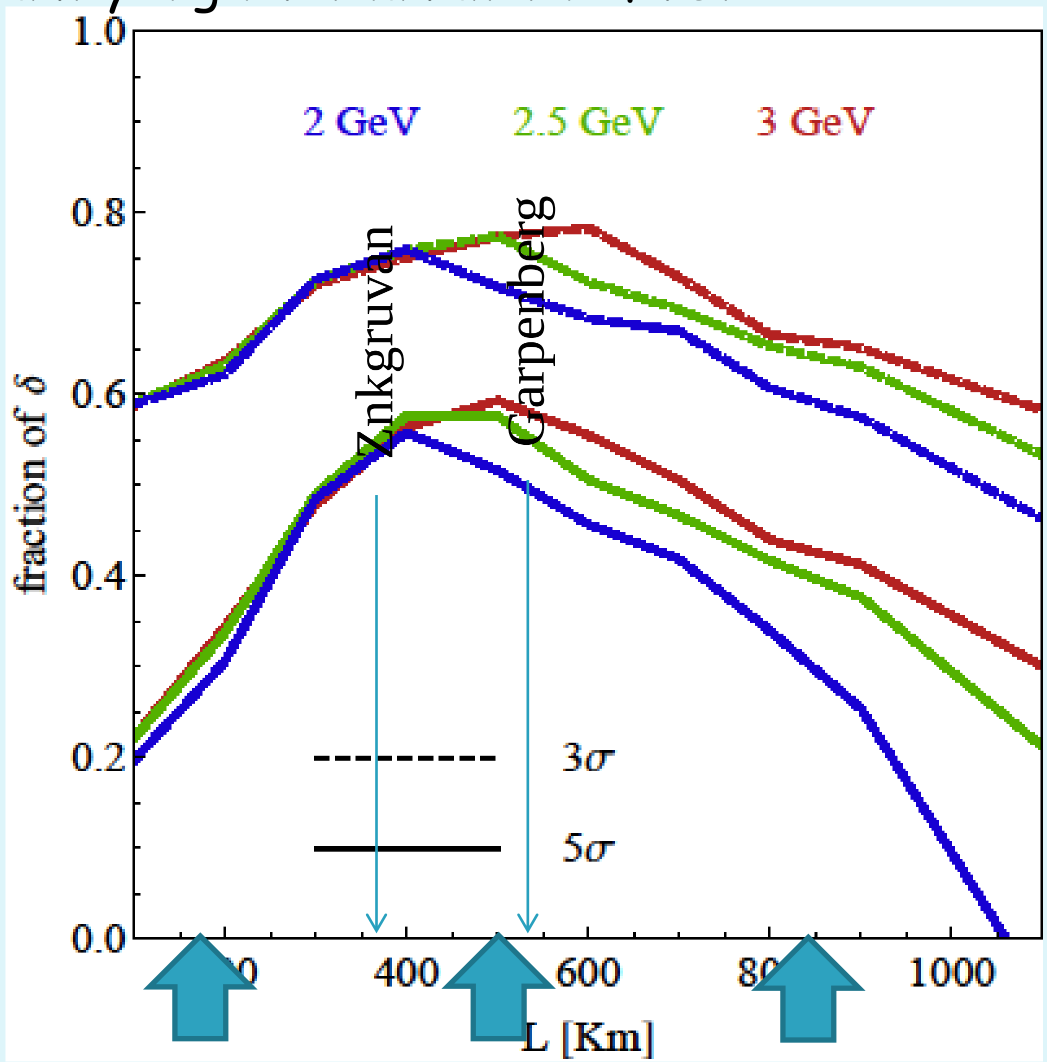
Reminder of the situation before 2012 at which time LBNE, Hyper-K and LBNO were designed – the optimum for CP violation discovery was clearly at the first maximum

$\Theta_{13}=4^o$



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

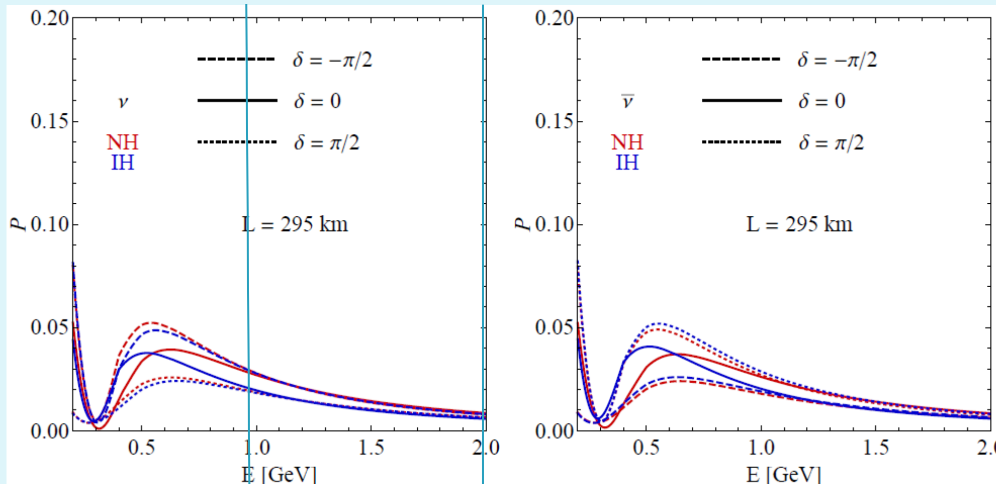
Θ_{13}=8.73°



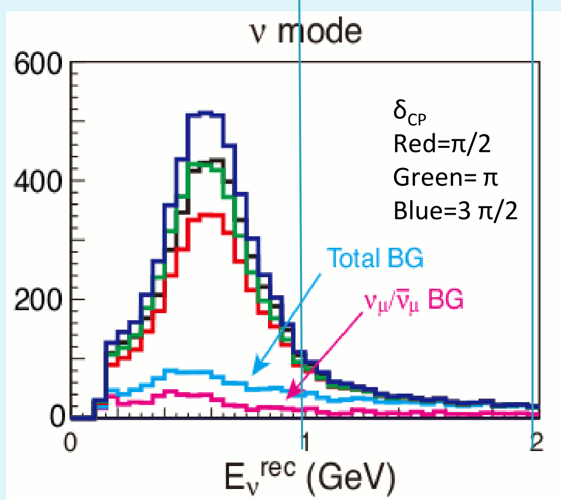
1st osc. max   2nd osc. max   3rd osc. max

The T2K/T2HK neutrino energy distribution peaked at the first max

Plot from the Physics Briefing Book: Input for the Strategy Group to the European Strategy for Particle Physics



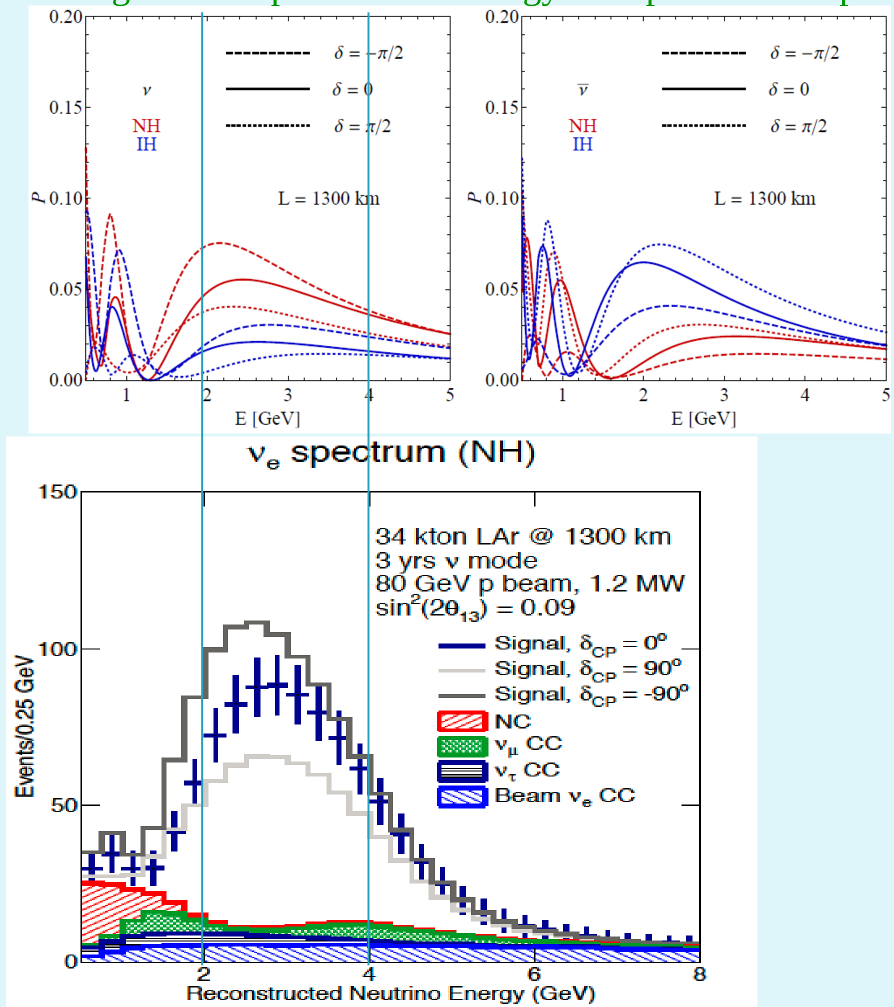
T2K/T2HK



The DUNE/LBNF neutrino energy distribution peaked at the 1st max

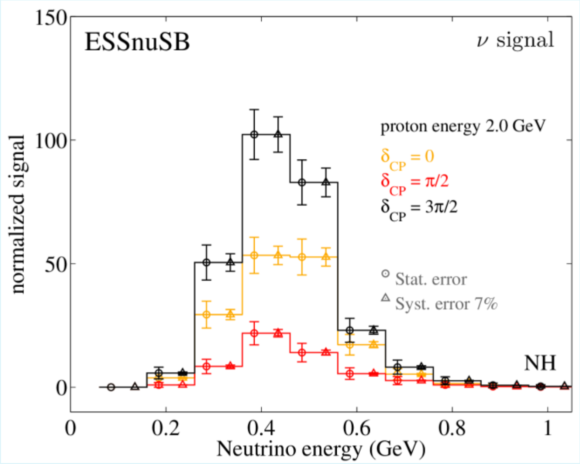
Plot from the Physics Briefing Book: Input for the Strategy Group to the European Strategy for Particle Physics

DUNE/LBNF

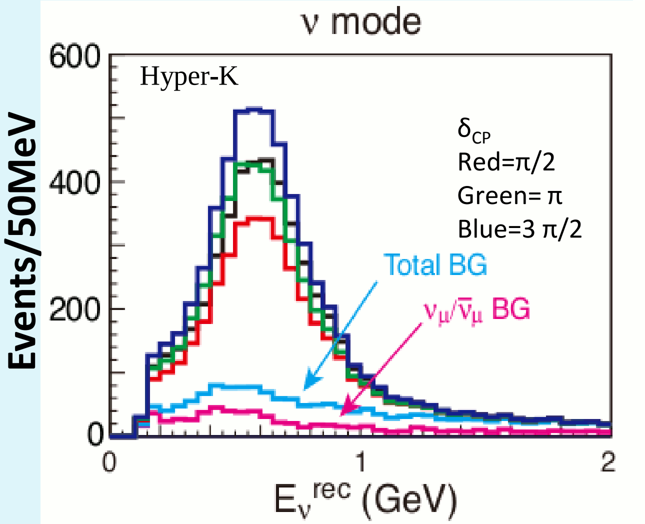


The sensitivity of the neutrino energy distribution to δ_{CP}

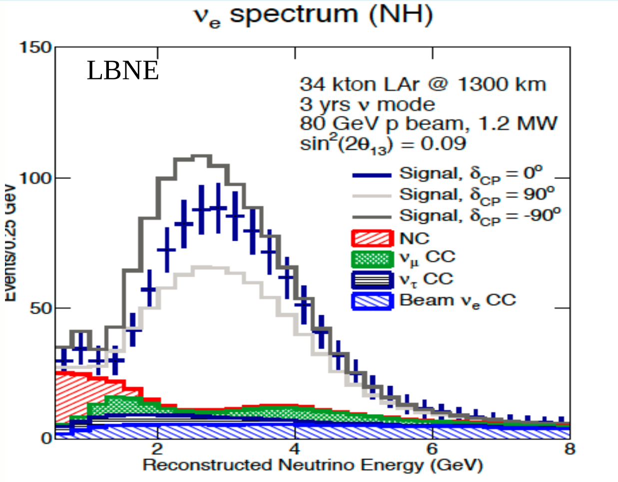
ESSnuSB second maximum



Hyper-K first maximum



LBNE first maximum

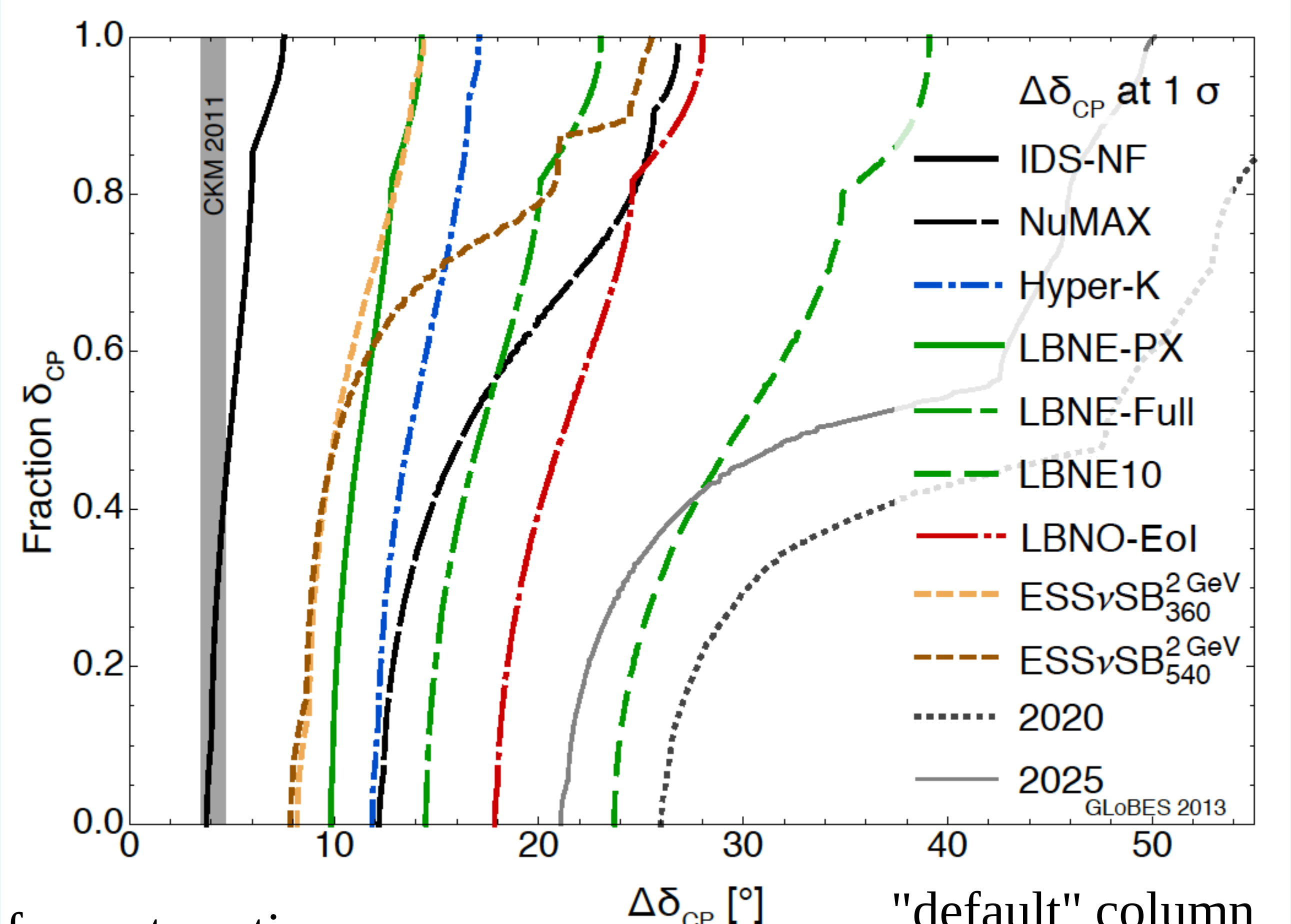


Relative difference in counts at maximum between $\delta_{CP} = 3\pi/2$ and $\pi/2$:

105/22 = 4.8 510/340 = 1.5 110/65 = 1.5

δ_{CP} accuracy performance

(USA snowmass process, P. Coloma)

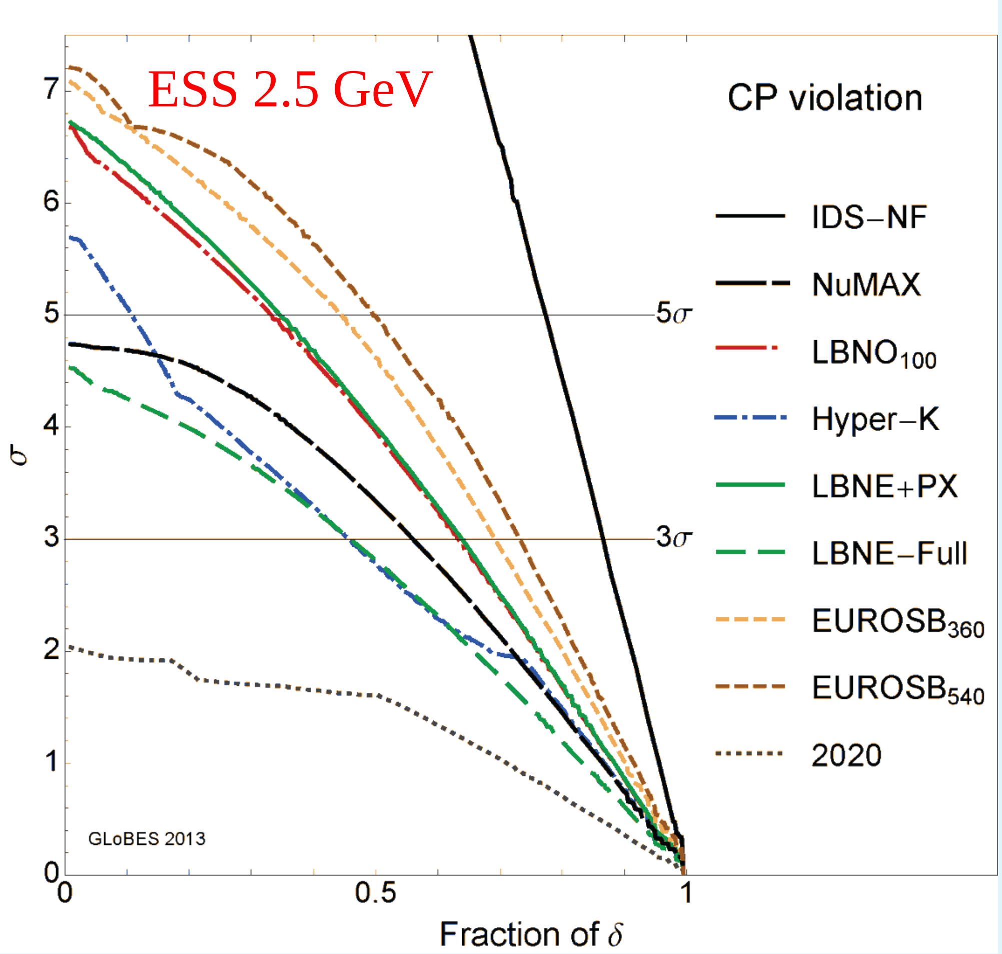


"default" column

for systematic errors see:

- Phys. Rev. D 87 (2013) 3, 033004 [arXiv:1209.5973 [hep-ph]]
- **arXiv:1310.4340 [hep-ex] Neutrino "snowmass" group conclusions**

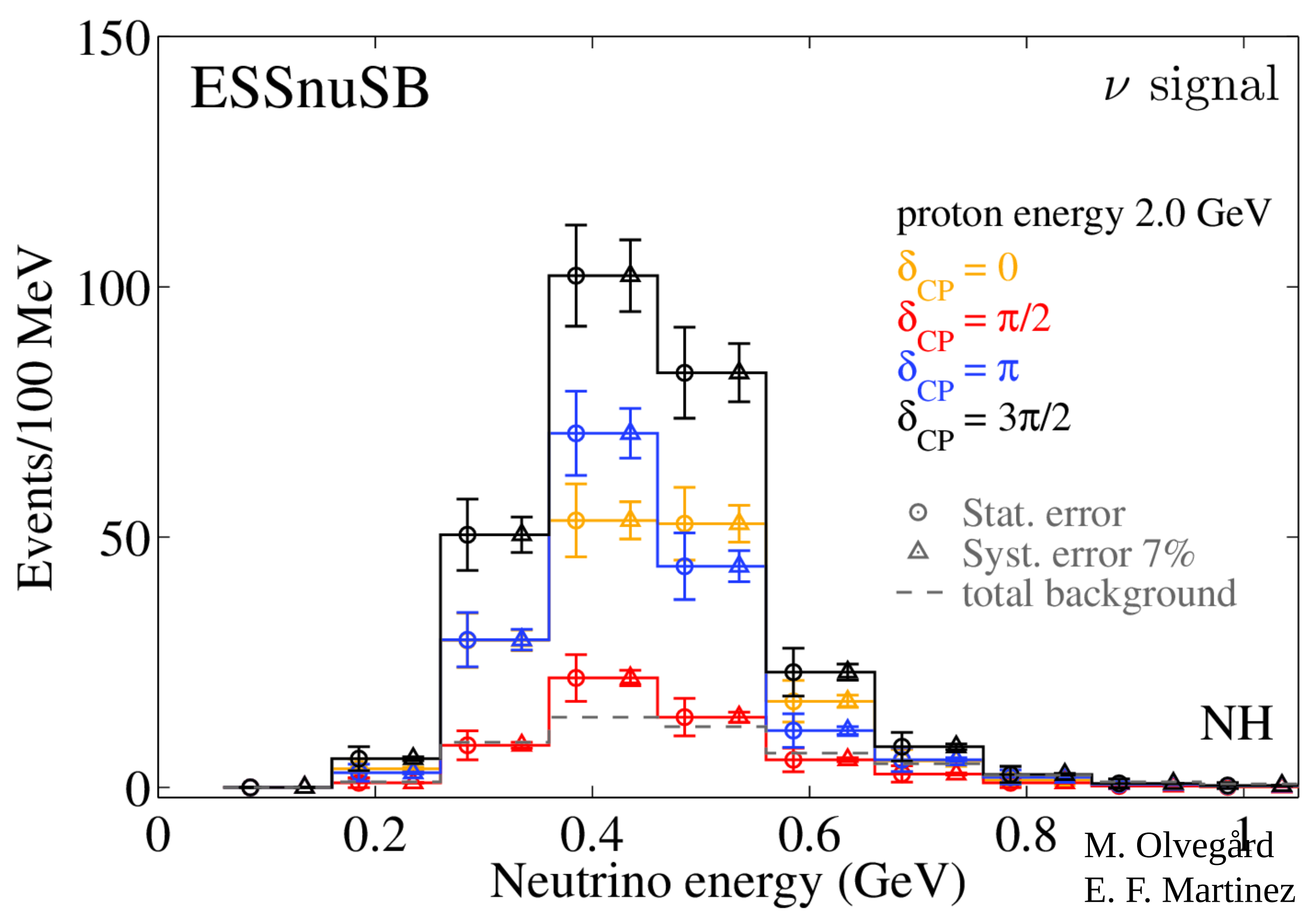
CPV Discovery Performance for Future SB projects, MH unknown, Snowmass comparison



- 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

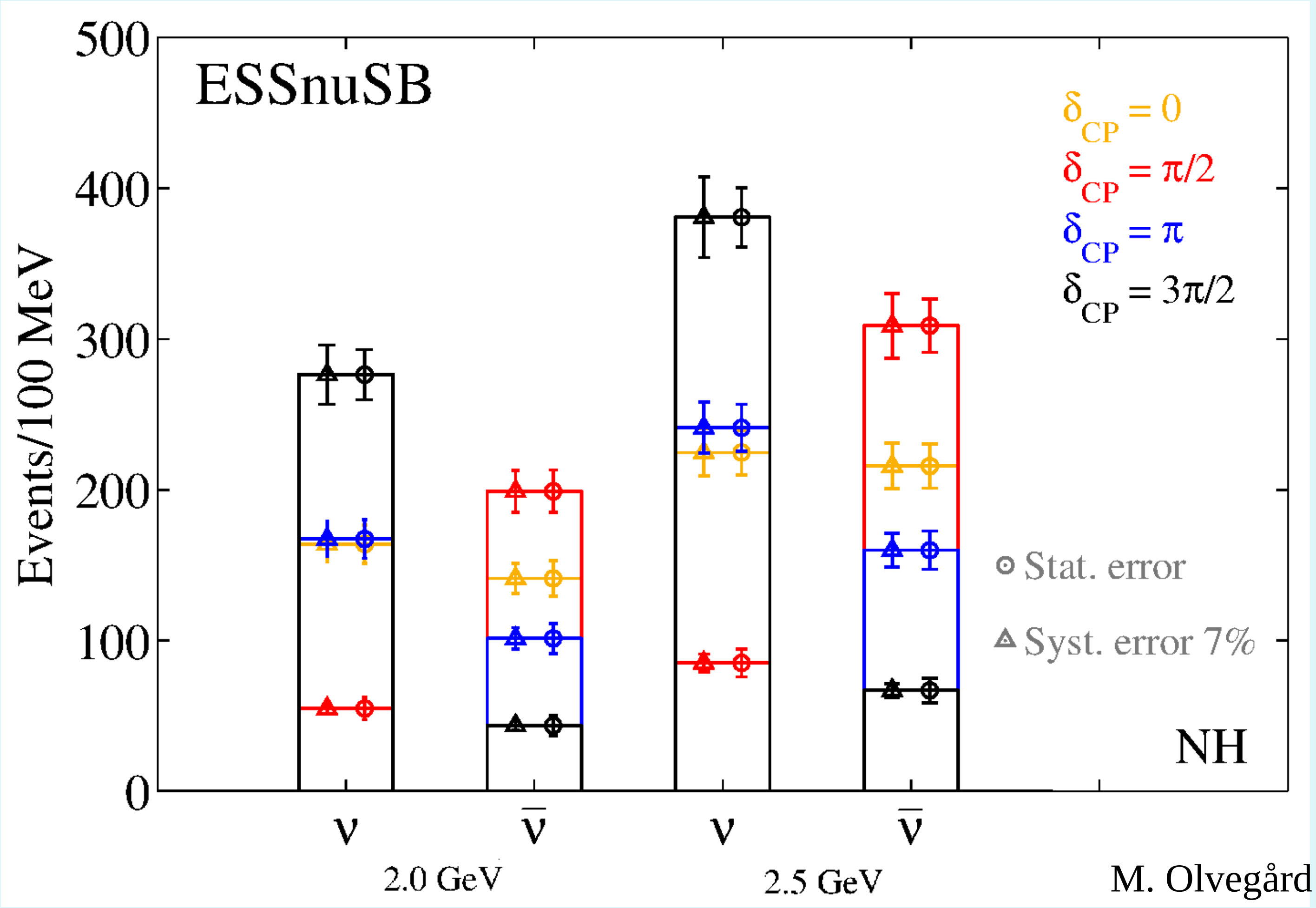
The electron neutrino energy distribution at the ESSnuSB second maximum for different δ_{CP} values



Statistical errors somewhat larger than the 7% systematic errors

Good discrimination between the different δ_{CP} values

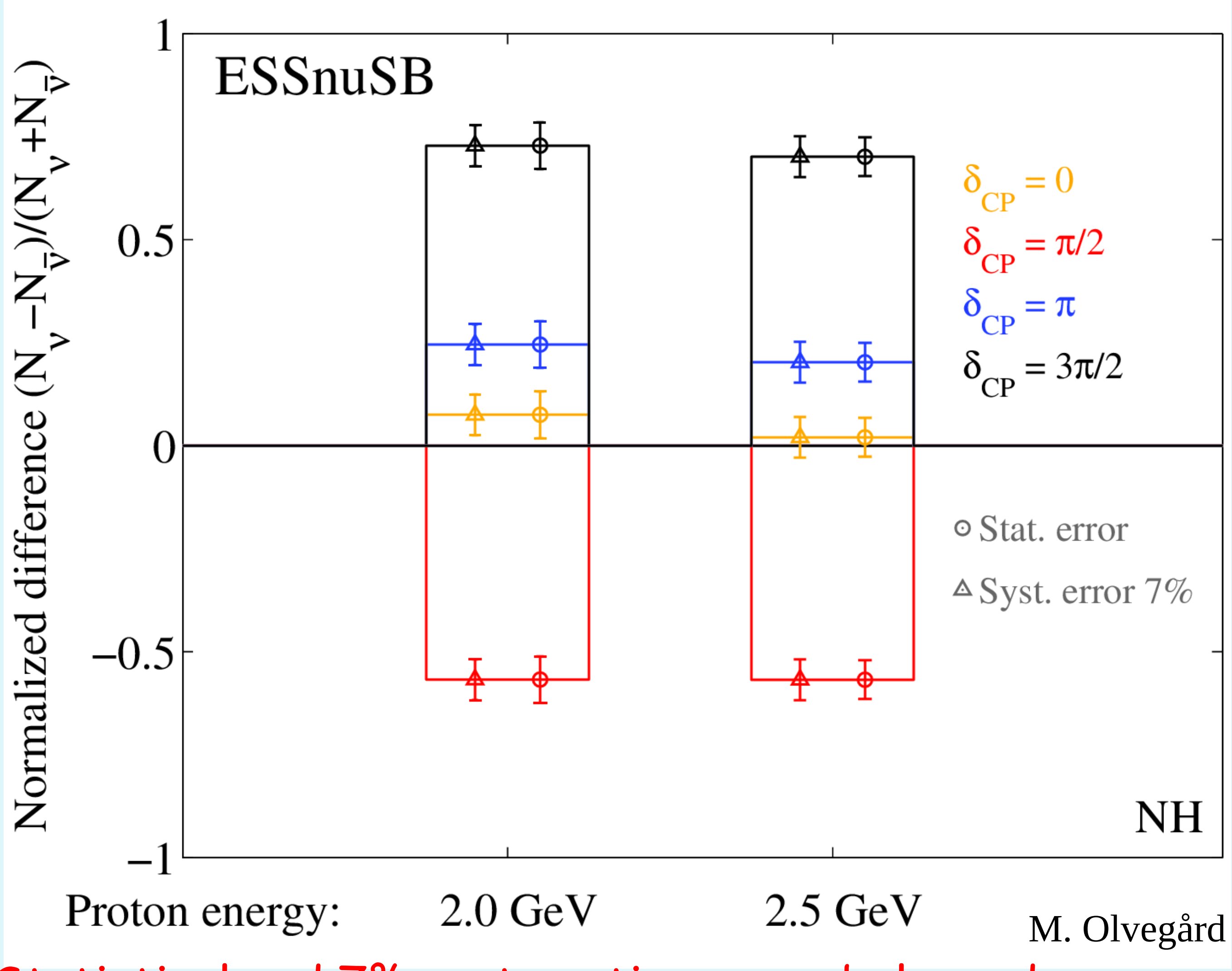
ESSnuSB as counting experiment



Statistical and 7% systematic errors now balanced

Thereby **very good** discrimination between the different δ_{CP} values

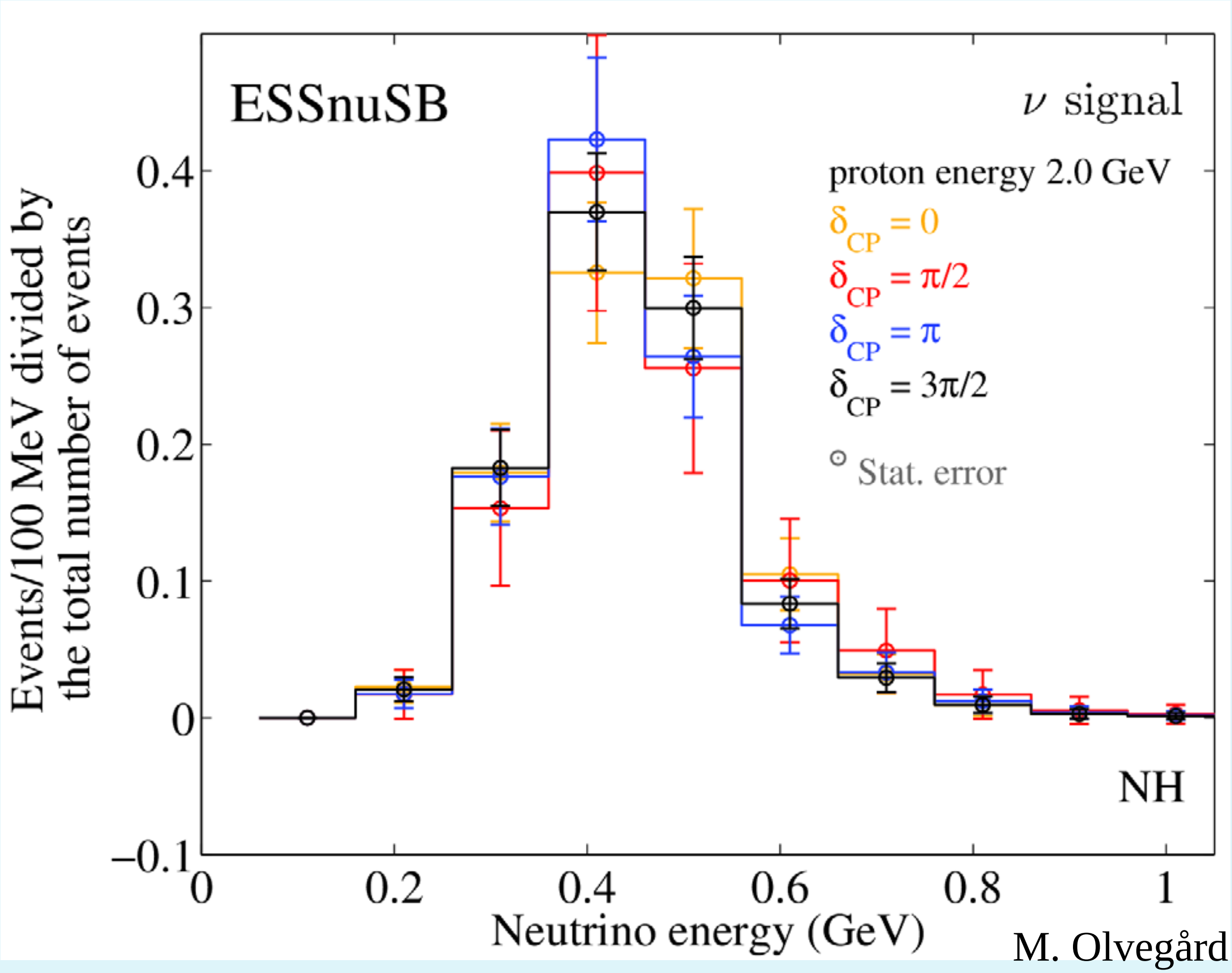
ESSnuSB as neutrino/antineutrino ratio counting expt



Statistical and 7% systematic errors balanced

Even better discrimination between the different δ_{CP} values

ESSnuSB a energy distribution <u>shape</u> measuring experiment



M. Olvegård

Systematic normalization errors suppressed

Only **modest** discrimination between the different δ_{CP} values

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 $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ is between **1/2 and 2** times $P(\nu_\mu \rightarrow \nu_e)$. 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 $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ is between **1/7 and 7** times $P(\nu_\mu \rightarrow \nu_e)$. ***So that experiments at the second oscillation maximum, like ESSnuSB [15], have a significantly larger divergence between the neutrino and anti-neutrino channels."***

So where can we find a deep mine at the second oscillation maximum distance ca 500 km from ESS?

The map shows the depth and distance from ESS/ Lund of different mines in Scandinavia.

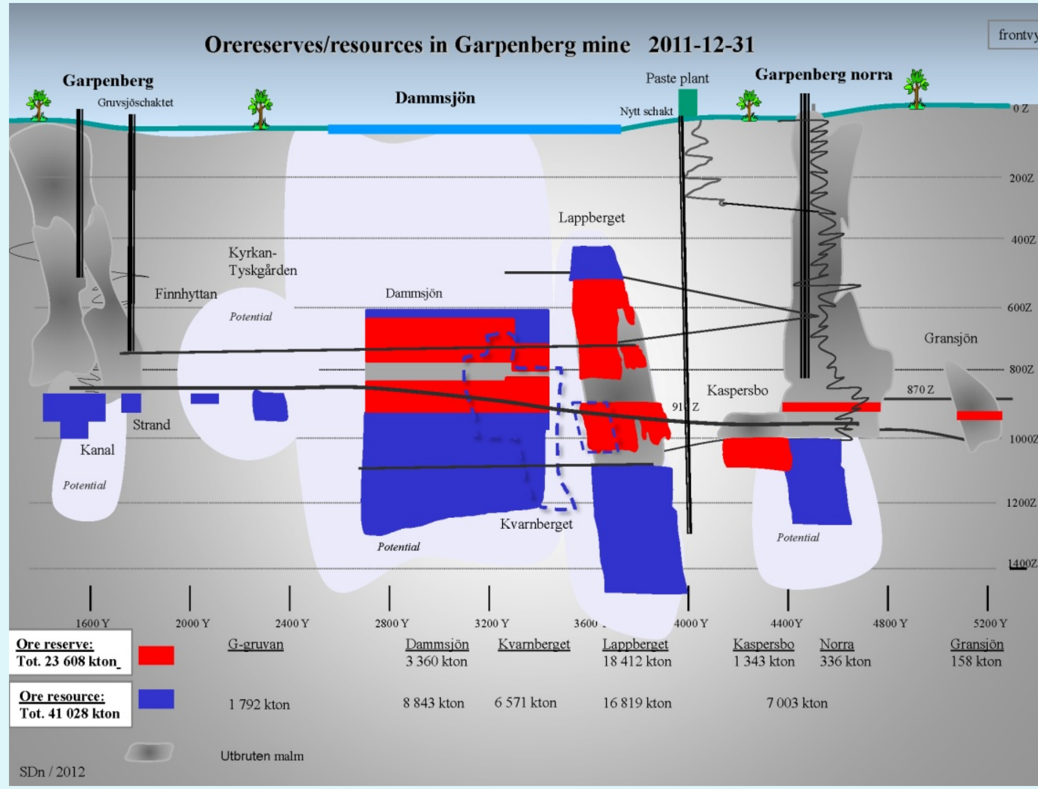
Garpenberg Mine

Distance from ESS Lund **540 km**

Depth 1232 m

Truck access tunnels

Two ore hoist shafts

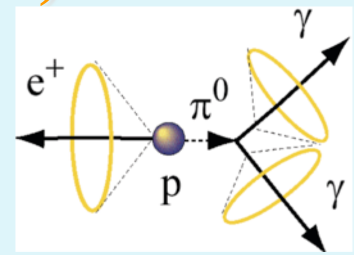


A new ore hoist schaft is planned to be ready i 1 year, **leaving the two existing shafts free for other uses**

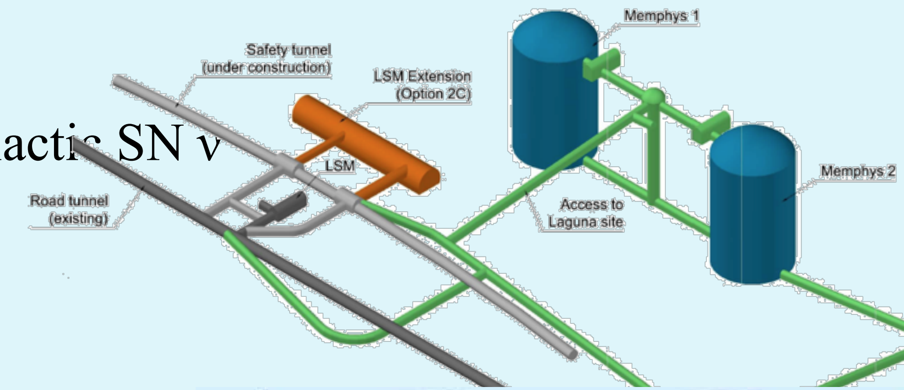
Granite drill cores

The MEMPHYS WC Detector

(MEgaton Mass PHYSics)

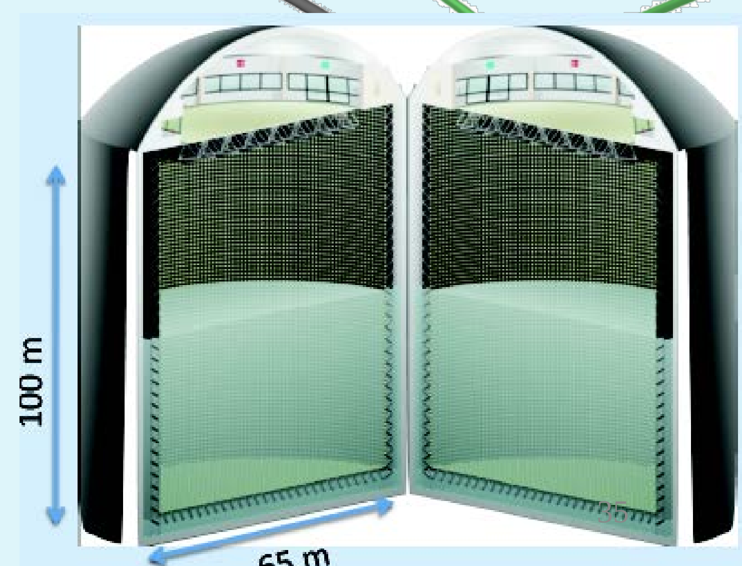


- **Neutrino Oscillations (Super Beam, Beta Beam)**
- **Proton decay**
- **Astroparticles**
- Understand the gravitational collapsing: galactic SN ν
- Supernovae "relics"
- Solar Neutrinos
- Atmospheric Neutrinos



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

(arXiv: hep-ex/0607026)



The ESSnuSB Collaboration

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 885 (2014) 127–149
NUCLEAR PHYSICS B
www.elsevier.com/locate/nuclphysb

A very intense neutrino super beam experiment for leptonic CP violation discovery based on the European spallation source linac

E. Baussan [m], M. Blennow [l], M. Bogomilov [k], E. Bouquerel [m], O. Caretta [c], J. Cederkäll [f], P. Christiansen [f], P. Coloma [b], P. Cupial [e], H. Danared [g], T. Davenne [c], 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], P. Loveridge [c], 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], D. Wilcox [c], E. Wildner [d], J. Wurtz [m]

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40 participating scientists from 11 institutes in Bulgaria, France, Italy, Poland, Spain, Sweden and UK

The ESSnuSB Proposal

published in
Nuclear Physics
B885(2014)127-149

Also available as

arXiv:1309.7022

Letter of support for 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

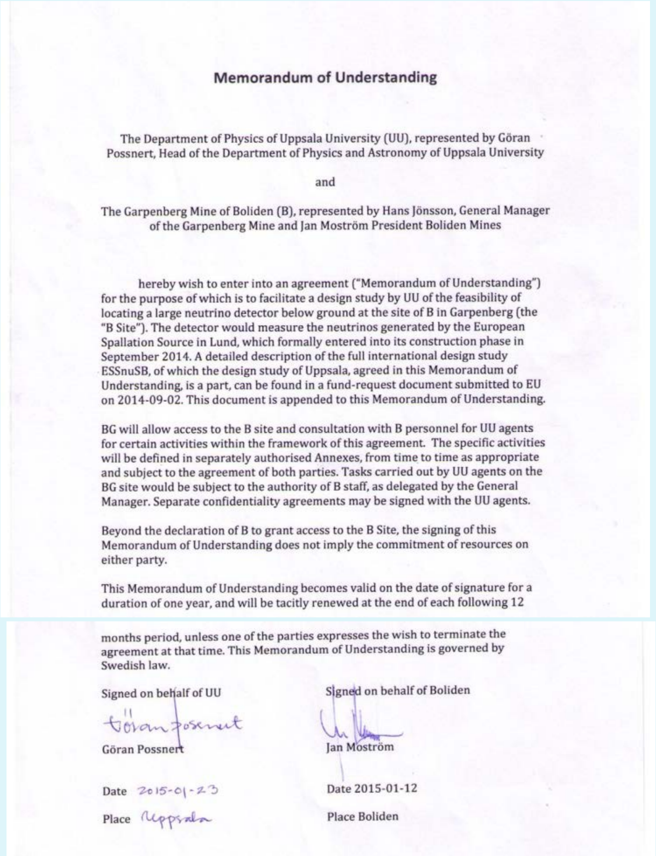
European Spallation Source ESS AB
Visiting address: ESS, Tunavägen 24
P.O. Box 176
SE-221 00 Lund
SWEDEN
www.esss.se

Support by the owner of the mine and of the local authorities

In a memorandum of Understanding the **owner of the Garpenberg Mine, Boliden AB**, authorizes ESSnuSB to access and investigate the mine and to consult with the personnel of its personnel.

A local **mining engineering consultant firm Garpen Gruvkonsult** AB has already studied and written several technical reports for ESSnuSB on the conditions in the mine and the possibilities to excavate and service a water Cherenkov detector in the mine.

We have discussed with the **Chair of the Dalarna Region** and the **Mayor of the local commune,** where the mine is located, and have met a great local enthusiasm for having the detector located in Garpenberg mine.



Memorandum of Understanding

The Department of Physics of Uppsala University (UU), represented by Göran Possnert, Head of the Department of Physics and Astronomy of Uppsala University

and

The Garpenberg Mine of Boliden (B), represented by Hans Jönsson, General Manager of the Garpenberg Mine and Jan Moström President Boliden Mines

hereby wish to enter into an agreement ("Memorandum of Understanding") for the purpose of which is to facilitate a design study by UU of the feasibility of locating a large neutrino detector below ground at the site of B in Garpenberg (the "B Site"). The detector would measure the neutrinos generated by the European Spallation Source in Lund, which formally entered into its construction phase in September 2014. A detailed description of the full international design study ESSnuSB, of which the design study of Uppsala, agreed in this Memorandum of Understanding, is a part, can be found in a fund-request document submitted to EU on 2014-09-02. This document is appended to this Memorandum of Understanding.

BG will allow access to the B site and consultation with B personnel for UU agents for certain activities within the framework of this agreement. The specific activities will be defined in separately authorised Annexes, from time to time as appropriate and subject to the agreement of both parties. Tasks carried out by UU agents on the BG site would be subject to the authority of B staff, as delegated by the General Manager. Separate confidentiality agreements may be signed with the UU agents.

Beyond the declaration of B to grant access to the B Site, the signing of this Memorandum of Understanding does not imply the commitment of resources on either party.

This Memorandum of Understanding becomes valid on the date of signature for a duration of one year, and will be tacitly renewed at the end of each following 12 months period, unless one of the parties expresses the wish to terminate the agreement at that time. This Memorandum of Understanding is governed by Swedish law.

Signed on behalf of UU

Göran Possnert

Date 2015-01-23

Place Uppsala

Signed on behalf of Boliden

Jan Moström

Date 2015-01-12

Place Boliden

Dalahäst

Horse of Dalarna

The Swedish Government

During the two last years we have had three meetings with the Director General of Research at the Swedish Ministry of Research and Education to report on the progress in the planning of ESSnuSB.

On 15 April 2015 we had a very constructive discussion with the State Secretary at the Ministry, thereby **bringing the ESSnuSB project to the agenda of the Swedish government**.

I will report from our meeting here at Fermilab to provide the Swedish government with all facts needed for a **decision on the next step to be taken in the preparation of the Swedish Government's position on the ESSnuSB project**.

Conclusions and summary

We conclude that the ESSnuSB project:

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

has a cost smaller than 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,

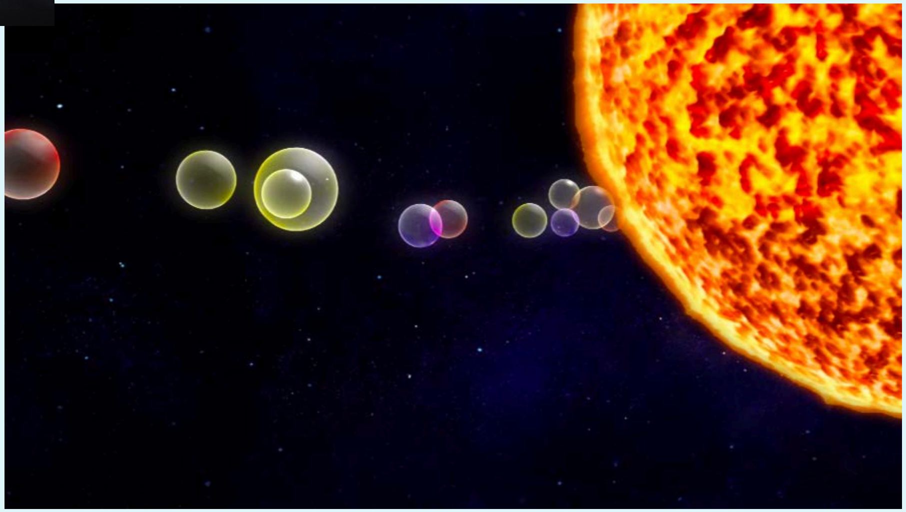
has a strong group of 11 institutes that plan to undertake specific, well planned and prepared tasks to bring the project up to a Design Report

is coherent with the conclusion of the 'Expert Group on assessment of the European 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 new cooperation and synergies between ESS as an accelerator laboratory, CERN as a European HEP center and the major accelerator developments labs in Europe like CEA & CRNS, DESY, RAL and INFN

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

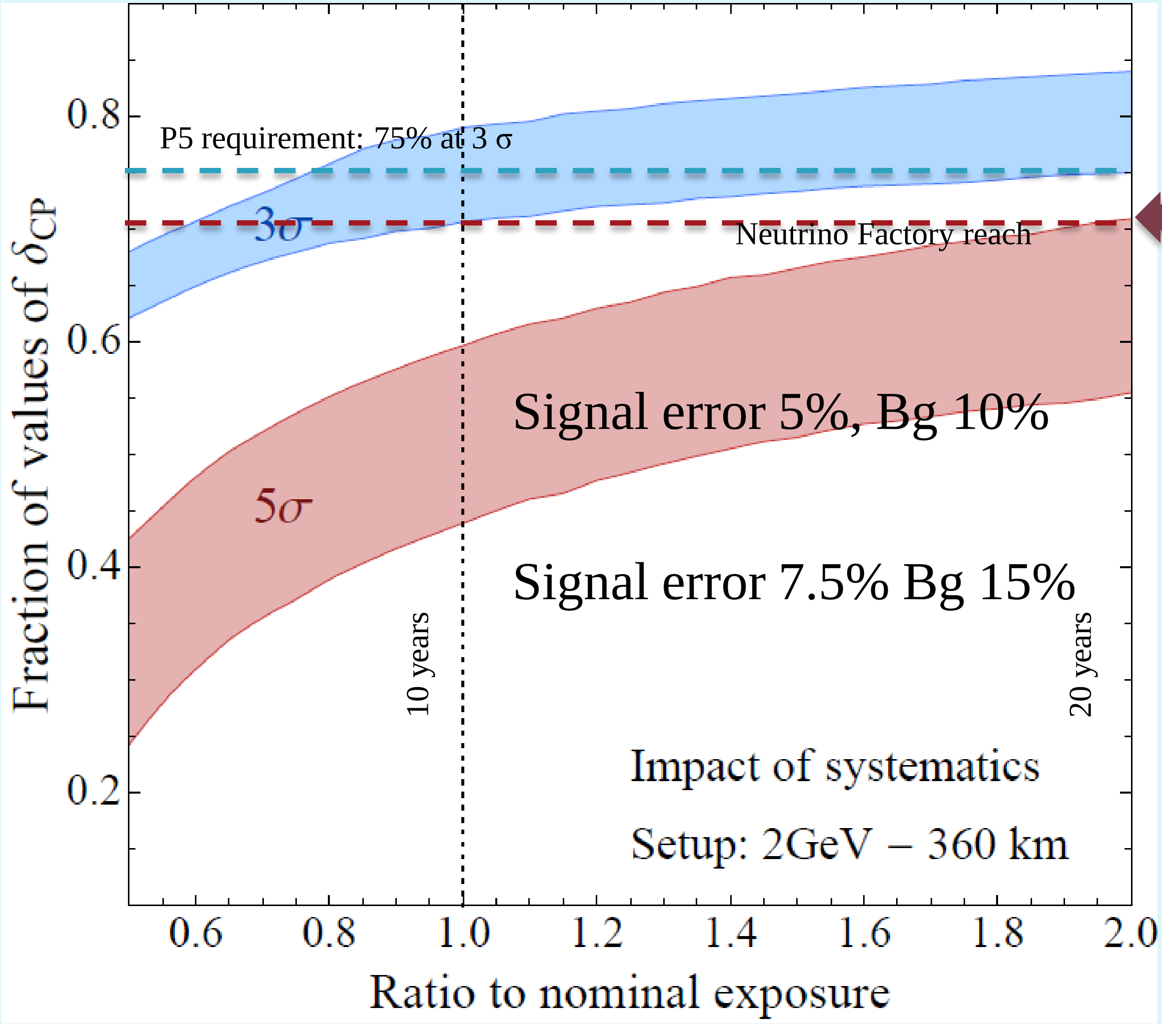
Systematic errors

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%

Phys. Rev. D 87 (2013) 3, 033004 [arXiv:1209.5973 [hep-ph]]

Systematic errors and exposure

for ESSnuSB systematic errors see 1209.5973 [hep-ph] (lower limit "default" case, upper limit "optimistic" case)

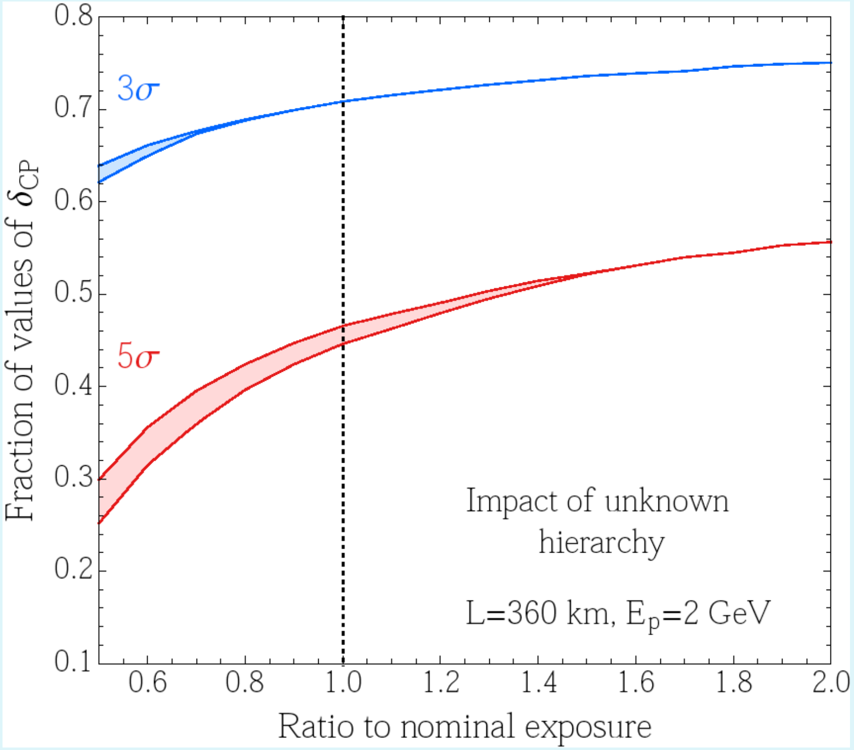


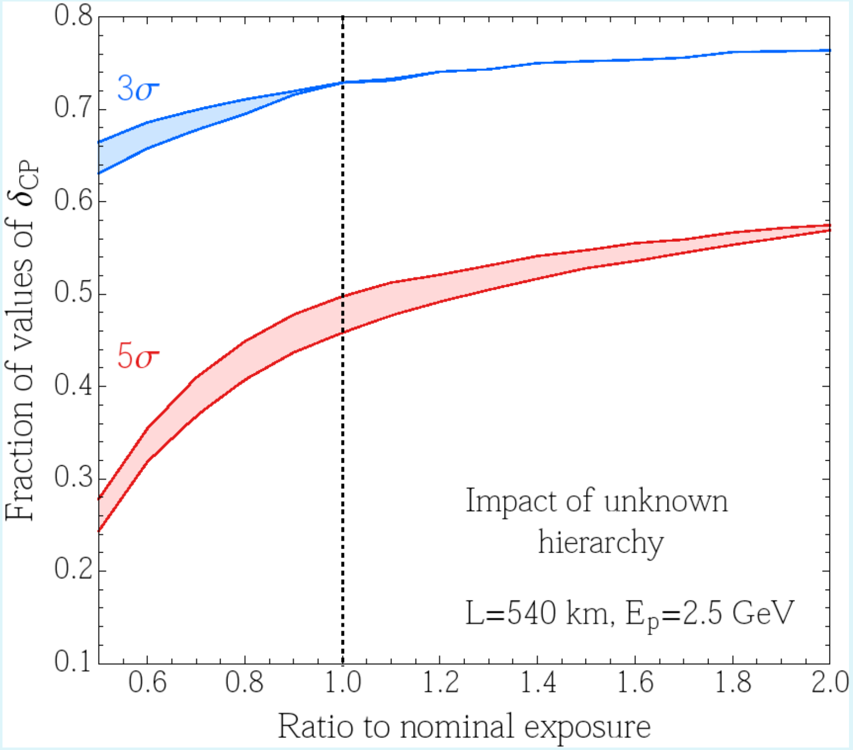
High potentiality

(courtesy P. Coloma)

Effect of the unknown MH on CPV performance

"default" case for systematics





➡ small effect ➡ practically no need to re-optimize when MH will be known