UPPSALA UNIVERSITET

Accelerator development

RECFA Meeting Lund 20 May 2016

Tord Ekelof, Uppsala University

Prologue

The accelerator technology has now reached a very wide use in society, similarly to e.g. detector technology or IT technology.

The accelerator technology, like particle detectors and, lately, massive parallel computing and www, originates from fundamental research into the structure of the nucleus and of the elementary particles and fields. This is why we report our activities in particlee physics to the Committee for Future **Accelerators** created by Eduardo Amaldi and others in the early 1960s.

Accelerator development remains at the forefront of the development of particle physics, for which the next generation of accelerators, like LHC HL, CLIC, ILC and FCC, are decisive.

At the same time these new accelerator developments, like the detector and IT developments, very soon find new, most often unexpected, applications within other Sciences and in Society at large.

In my view, we high energy physicists, have all - both scientific an civic reasons - to develop the tools of our science, in addition to analyzing the data they give rise to.

The use of Accelerators

The development of state of the art accelerators is essential for many many fields of science (fundamental, applied or industrial)

Research accelerators

- **Particle Physics**
- **Nuclear Physics**
- **Research fields using light source (condensed matter, biology, geophysics, human sciences…)**
- **Research fields using spallation neutron sources (material sciences...)**
- **Study of material for fusion**
- **Study of transmutation**

In past 50 years, about 1/3 of Physics Nobel Prizes are rewarding work based on or carried out with accelerators

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Clinical accelerators

- radiotherapy
- electron therapy
- hadron (proton/ion)therapy

Industrial accelerators

- ion implanters
- electron cutting&welding
- electron beam and X-ray irradiators
- radioisotope production
- …

Application	Total systems (2007) approx.	System sold/yr	Sales/yr ($M)	System price ($M)
Cancer Therapy	9100	500	1800	2.0 - 5.0
Ion Implantation	9500	500	1400	1.5 - 2.5
Electron cutting and welding	4500	100	150	0.5 - 2.5
Electron beam and X-ray irradiators	2000	75	130	0.2 - 8.0
Radioisotope production (incl. PET)	550	50	70	1.0 - 30
Non-destructive testing (incl. security)	650	100	70	0.3 - 2.0
Ion beam analysis (incl. AMS)	200	25	30	0.4 - 1.5
Neutron generators (incl. sealed tubes)	1000	50	30	0.1 - 3.0
Total	**27500**	**1400**	**3680**	

Courtesy: R. Hamm

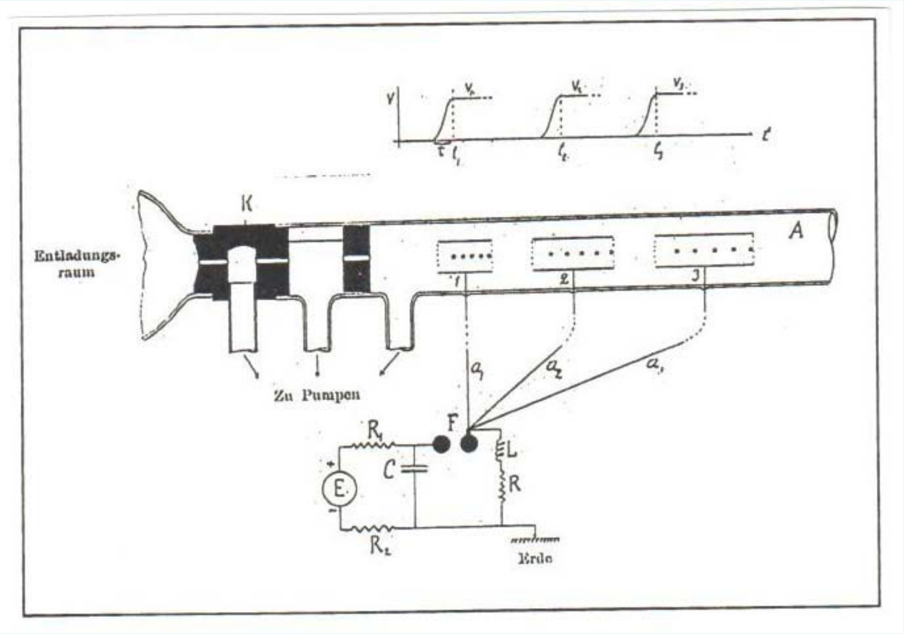
2011-05-16 Tord Ekelöf Uppsala University 4

Accelerator design, development and 'construction in Sweden

Gustav Ising

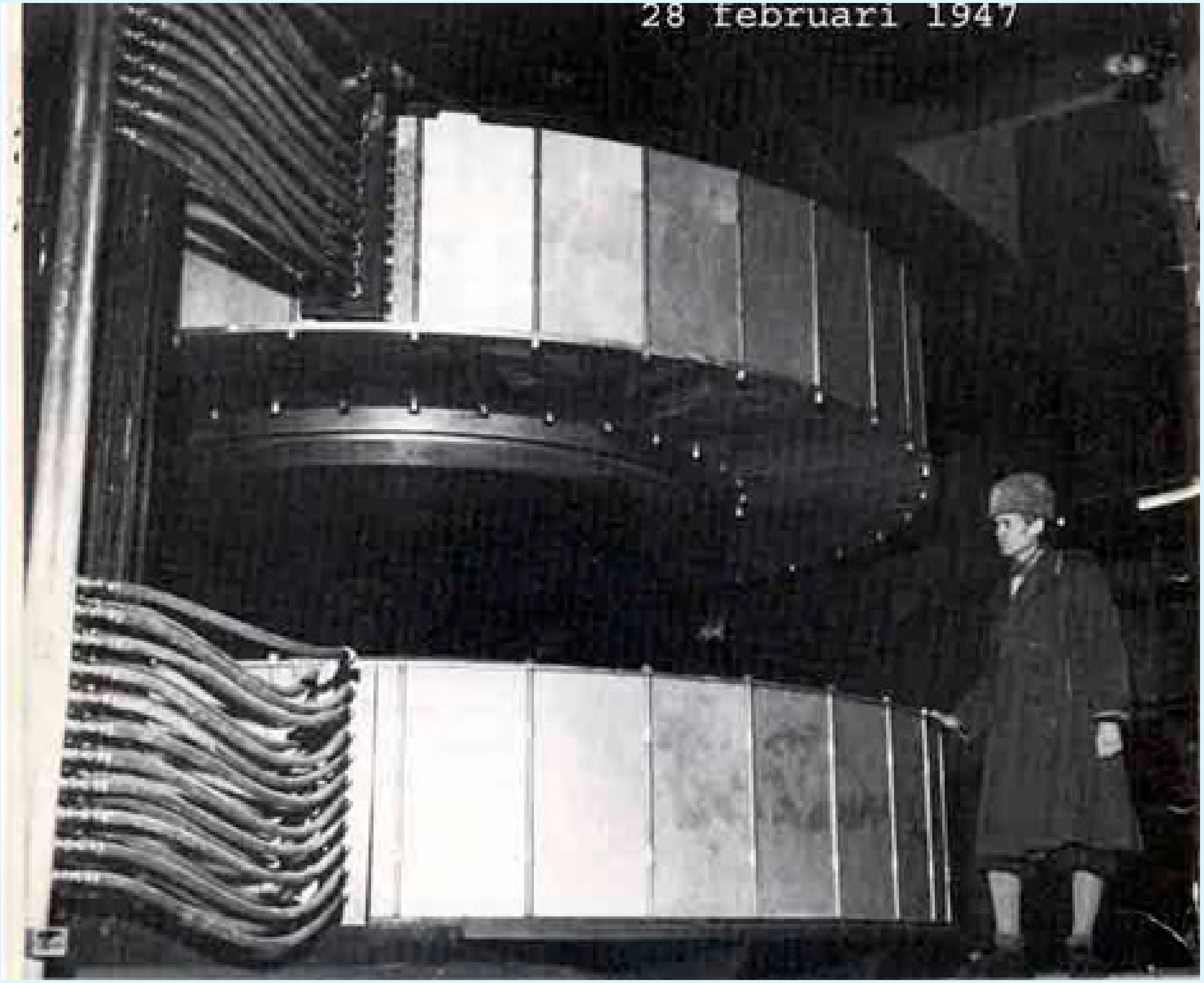
Fil. Kand. Uppsala 1903
Fil. Dr. Stockholm 1919
published in the 1920's an accelerator concept with voltage waves propagating from a spark discharge to an array of drift tubes.

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!

The Gustaf Werner 180 MeV Synchrocyclotron was in 1947 the first SC in Europe and the highest energy accelerator in Europe when it was taken into operation
- It served as a model when building the first CERN accelerator, the 600 MeV SC



The Svedberg

MAX IV

Awaiting the inauguration on 21 June 2016

The European Spallation Source

Construction started in autumn 2014
The linac tunnel terminated spring 2016
Full 5 MW power in 2023

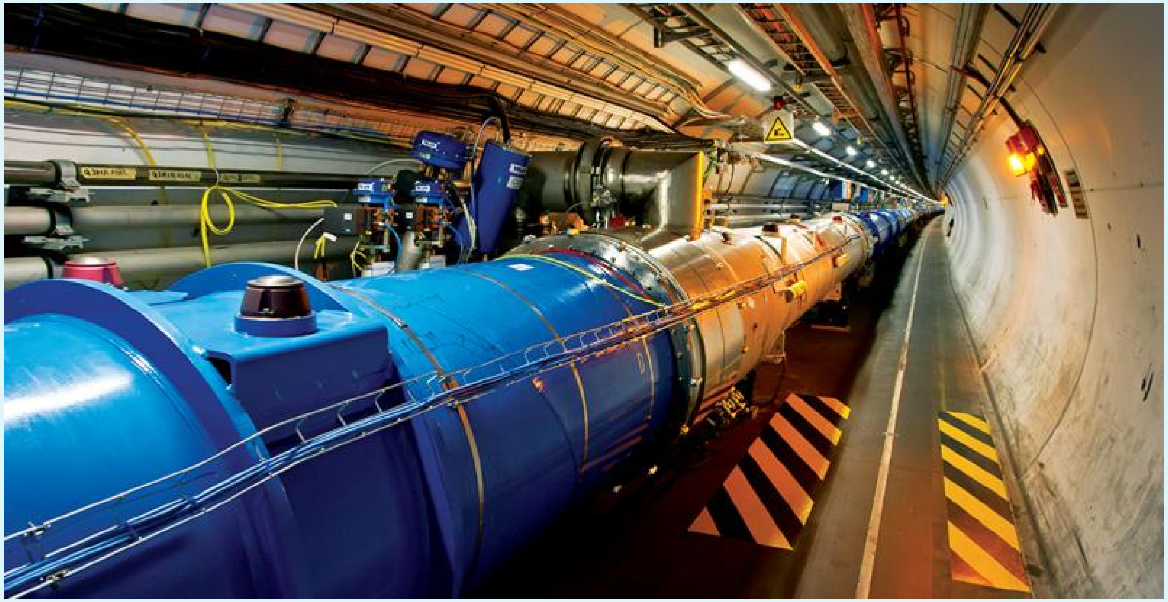
I will here focus on
<u>Current accelerator development projects in Sweden for High Energy Physics</u>

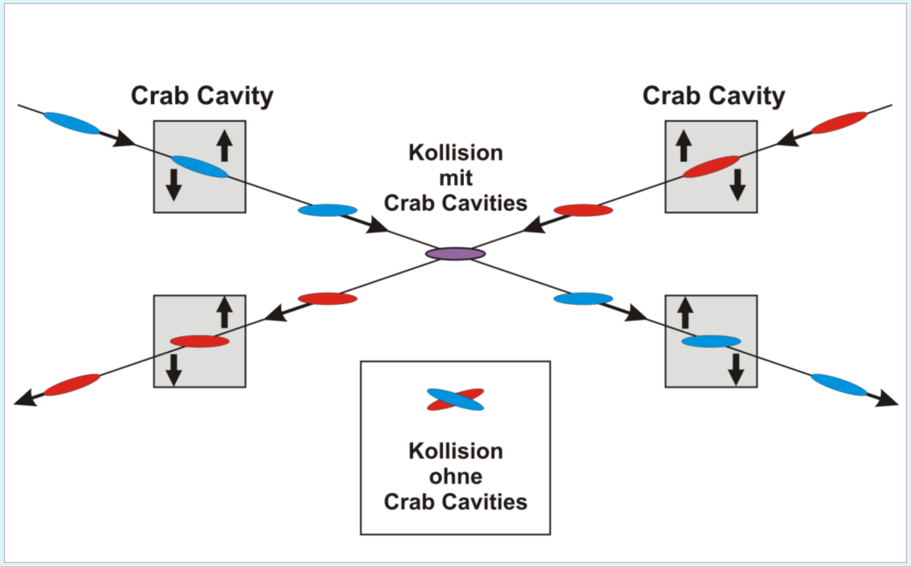
1. Testing crab cavities and orbit corrector dipoles for LHC luminosity upgrade -> discovery of new high mass particles, new symmetries – competitor CEPS

2. Testing and developing high gradient accelerator structures for CLIC -> high precision studies of recently discovered high mass particles, like top and H^0 – competitor ILC

3. Upgrading the ESS linac to produce a neutrino Super Beam of world unique intensity -> neutrino physics, leptonic CP violation, sterile neutrinos – competitors DUNE and Hyper-K

High Luminosity LHC to be in operation 2025



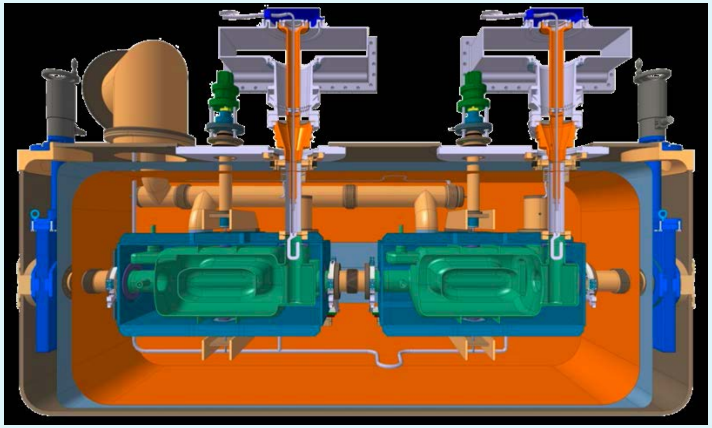


Principle of Crab Cavity: bunch rotation needed to boost the luminosity to 10^{25} $cm^{-2}s^{-1}$

FRAMEWORK COLLABORATION AGREEMENT KN1914/DG
between
THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)
and
UPPSALA UNIVERSITY (the "University")
concerning
Collaboration in cold testing of superconducting orbit corrector magnets and superconducting crab cavities in the framework of the High Luminosity upgrade for the LHC at CERN

K-contract about to be signed by CERN and UU. This development and test work will be carried out in the FREIA Laboratory in Uppsala 2017-2020.

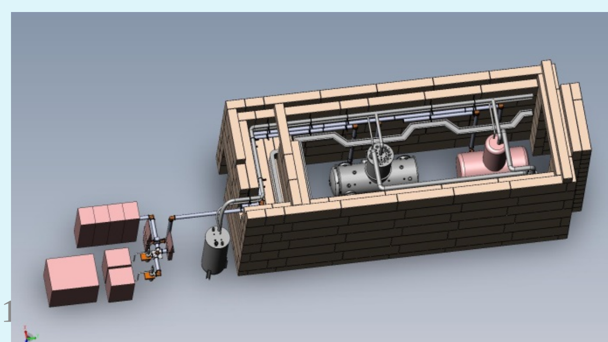
Orbit corrector magnet coil winding
20 magnts to be tested



A cryomodule containing 2 Crab Cavities
12 cavities to be tested

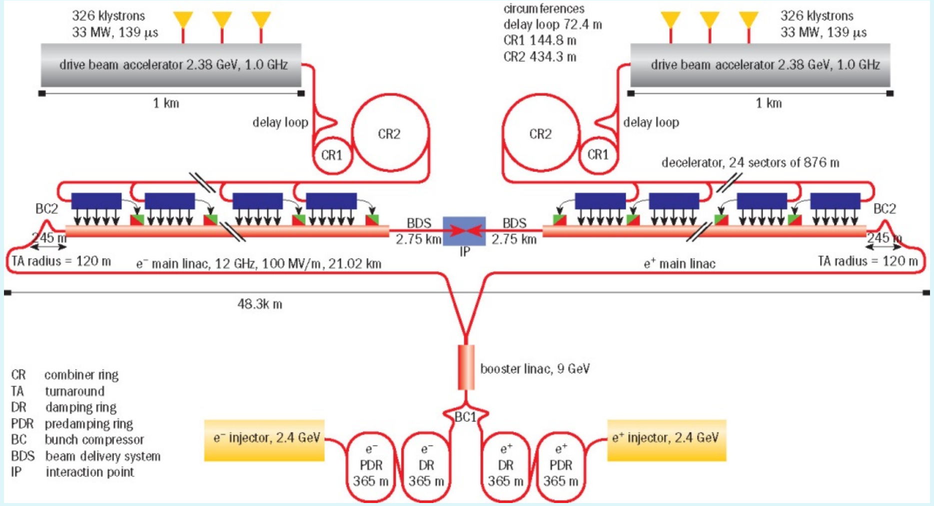
FREIA

The picture shows the cryostat and test bunker at the FREIA Laboratory in Uppsala where a first prototype of the ESS 352 MHz spoke accelerating cavity is currently under test and which will be used for LHC Crab cavity quench studies. A new vertical cryostat is under construction for the test of the corrector magnets.

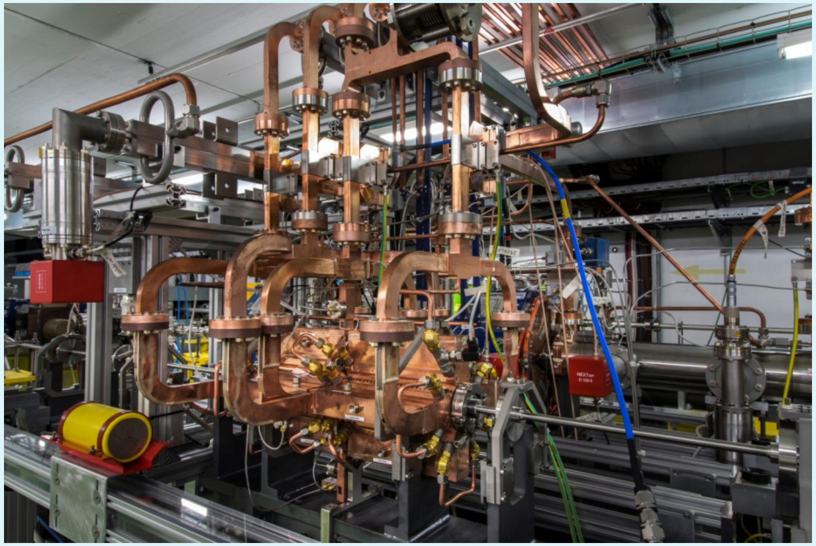


CLIC

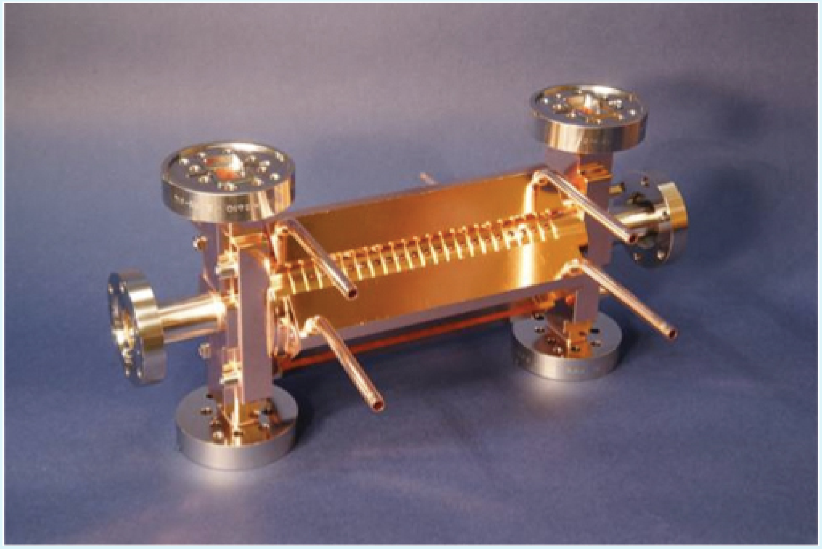
CLIC Two Beam Acceleration
Electron-Positron Collider
Accelerating frequency 12 GHz
Accelerating gradient 100 MV/m



Lay-out of 3 TeV CLIC



Two Beam Test Stand at CTF3
100 MV/m first demonstrated



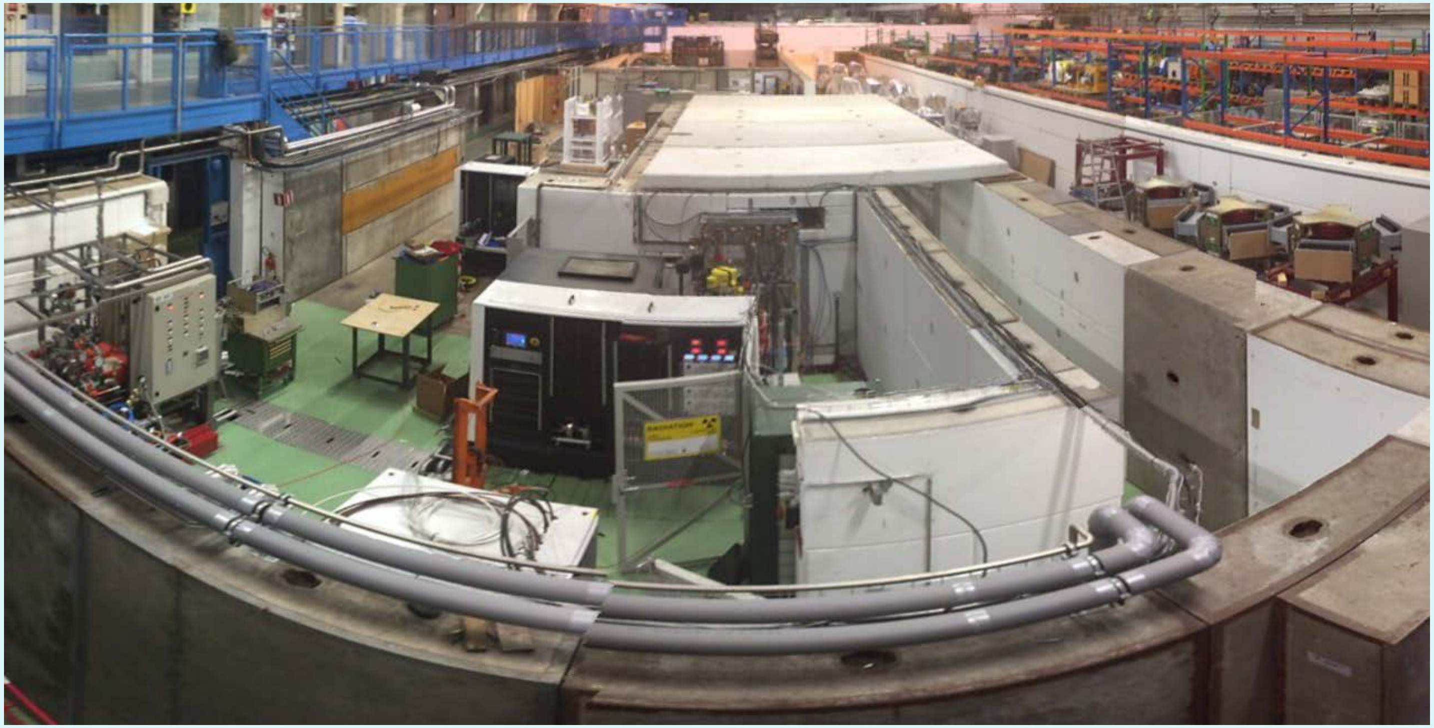
CLIC 12 GHz accelerating structure
Discharge studies under way

Spectrometers for RF breakdown studies for CLIC

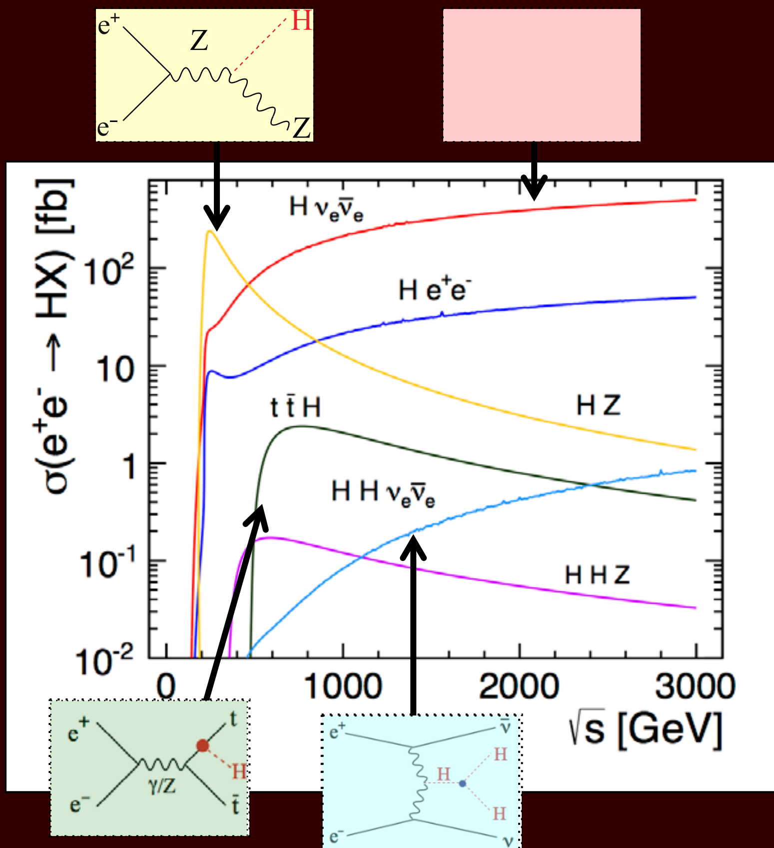
M. Jacewicz[a], V. Ziemann[a], T. Ekelöf[a], A. Dubrovskiy[b], R. Ruber[a]

Submitted to NIM

[a]Uppsala University, Uppsala, Sweden 3
[b]CERN, Geneva, Switzerland

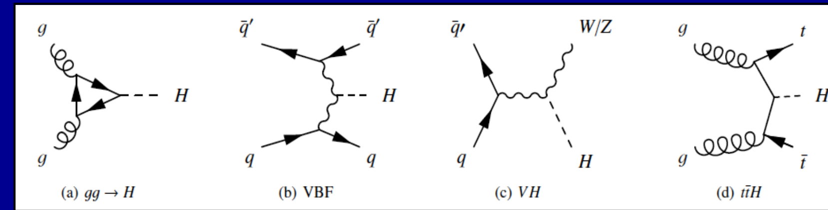


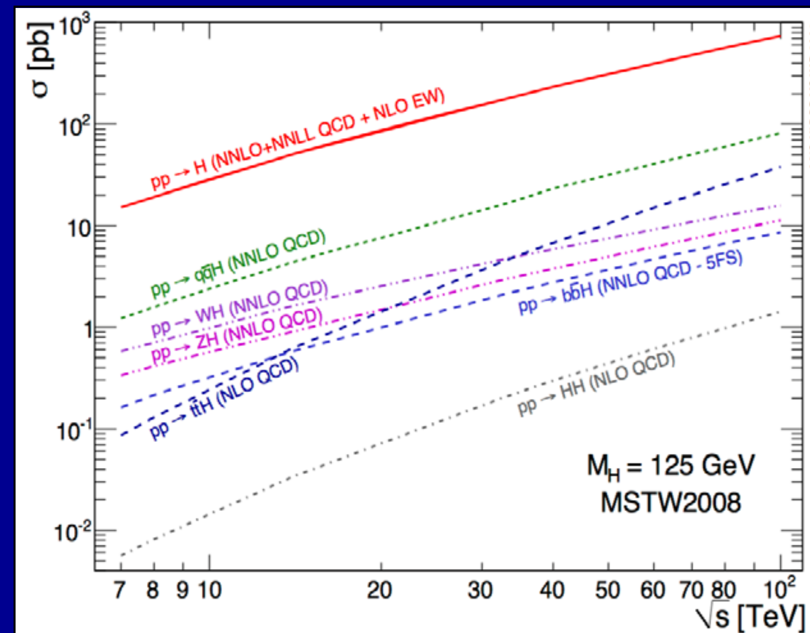
e^+e^- colliders



- ❑ Low backgrounds → all decay modes (hadronic, invisible, exotic) accessible
- ❑ Model-indep. coupling measurements: σ(HZ) and Γ_H from data (ZH → μμ/qq+X recoil, Hνν →bbνν)
- ❑ ttH and HH require $\sqrt{s} \geq 500$ GeV

pp colliders





- ❑ High energy, huge cross-sections → optimal for (clean) rare decays and heavy final states (ttH, HH)
- ❑ Huge backgrounds → not all channels accessible
- ❑ Model-dep. coupling measurements: Γ_H and σ (H) from SM

Units are %

Coupling √s (TeV) → L (fb^{-1}) →	LHC 14 3000(1 expt)	CepC 0.24 5000	FCC-ee 0.24 +0.35 13000	ILC 0.25+0.5 6000	CLIC 0.38+1.4+3 4000	FCC-hh 100 40000
K_W	2-5	1.2	0.19	0.4	0.9	
K_Z	2-4	0.26	0.15	0.3	0.8	
K_g	3-5	1.5	0.8	1.0	1.2	
K_γ	2-5	4.7	1.5	3.4	3.2	< 1
K_μ	~8	8.6	6.2	9.2	5.6	
K_c	--	1.7	0.7	1.2	1.1	
K_τ	2-5	1.4	0.5	0.9	1.5	
K_b	4-7	1.3	0.4	0.7	0.9	
$K_{Z\gamma}$	10-12	n.a.	n.a.	n.a.	n.a.	
Γ_h	n.a.	2.8	1%	1.8	3.4	
BR_{invis}	<10	<0.28	<0.19%	<0.29	<1%	

Few preliminary estimates available
SppC : similar reach

← from K_γ/K_Z, using K_Z from FCC-ee

rare decays → pp competitive/better

← from ttH/ttZ, using ttZ and H BR from FCC-ee

- ❑ LHC: ~20% today → ~ 10% by 2023 (14 TeV, 300 fb^{-1}) → ~ 5% HL-LHC
- ❑ HL-LHC: -- first direct observation of couplings to 2nd generation (H→ μμ)
  -- model-independent ratios of couplings to 2-5%
- ❑ Best precision (few 0.1%) at FCC-ee (luminosity !), except for heavy states (ttH and HH) where high energy needed → linear colliders, high-E pp colliders

Theory uncertainties (presently few percent e.g. on BR) need to be improved to

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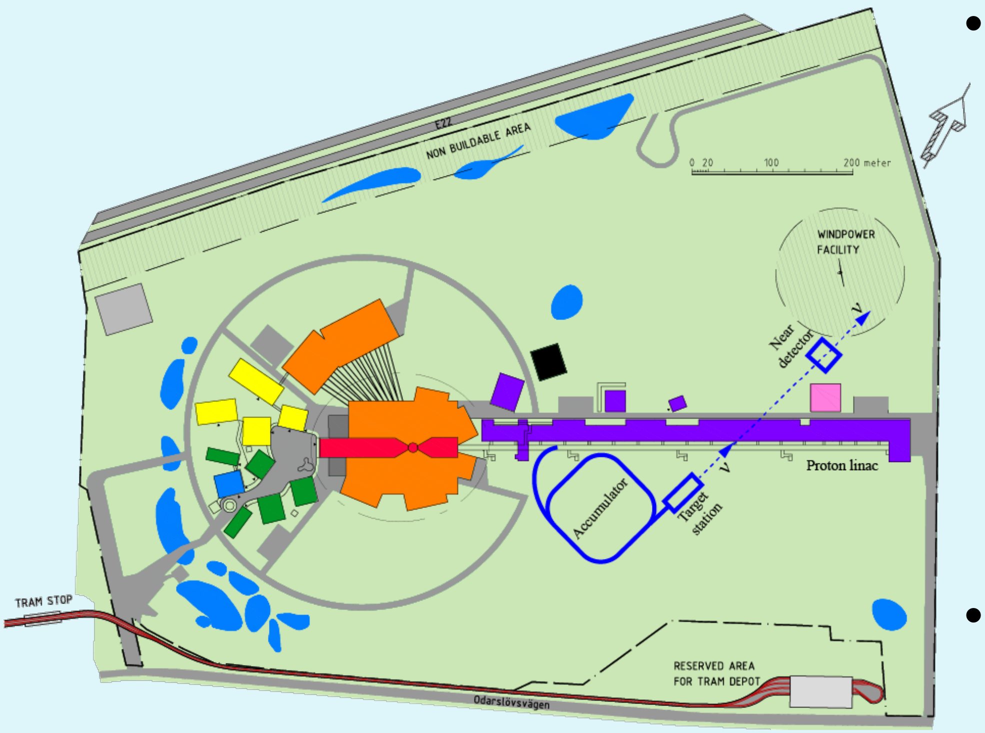
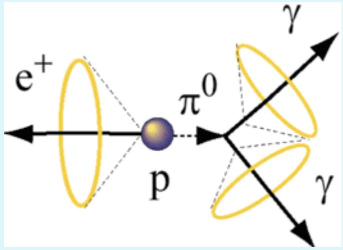
How make a neutrino facility of the ESS linac?



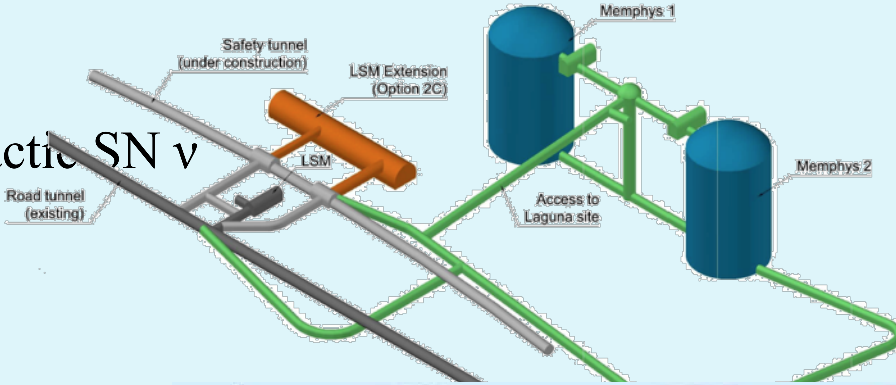
- Increase the linac average power from 5 MW to 10 MW by increasing the linac pulse rate from 14 Hz to 28 Hz, implying that the linac duty cycle increases from 4% to 8%.
- Inject into an accumulator ring circumference ca 400 m) to compress the 3 ms proton pulse length to 1.5 μs, which is required by 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)

ESS construction site February 2016

The MEMPHYS WC Detector in Garpenberg
(MEgaton Mass PHYSics)

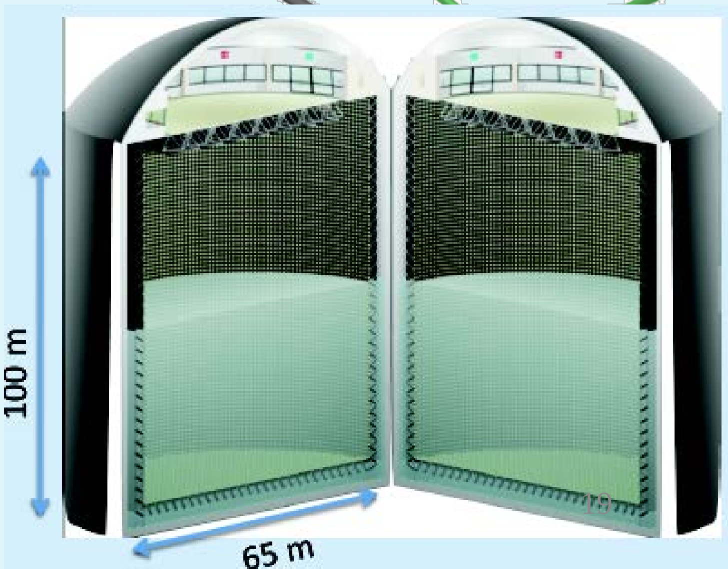


- **Neutrino Oscillations (Super Beam from ESS)**
- **Proton decay**
- **Astroparticles**
- Understand the gravitational collapsing: galactic SN ν
- Supernovae "relics"
- Solar Neutrinos
- Atmospheric Neutrinos



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

(arXiv: hep-ex/0607026)



European COST Action: ESSnuNet

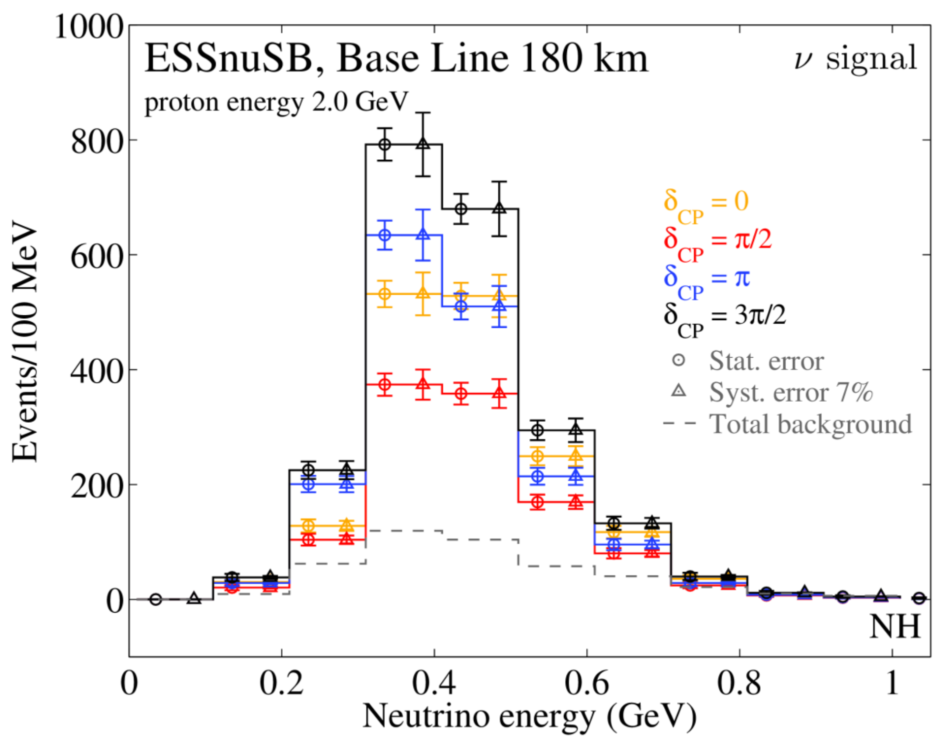
Joining forces to discover neutrino CP violation using ESS (ESSnuNet)

Members Sweden (UU, LU, KTH), France, Spain, Italy, UK, Poland, Bulgaria, Greece, Croatia

500 kEURO granted for worlshops, travel, missions

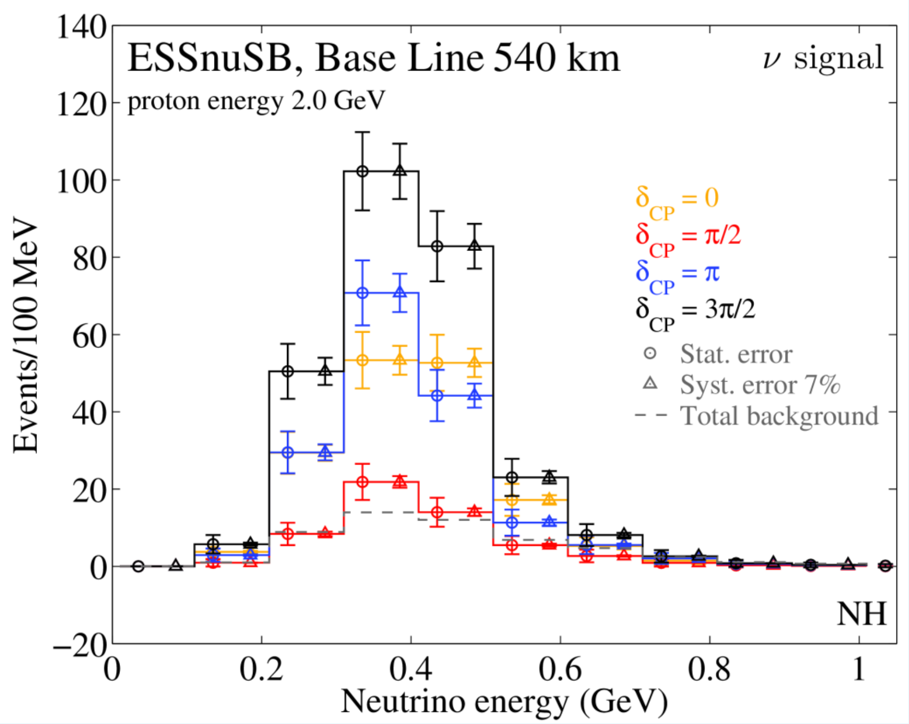
The ESSnuSB electron neutrino energy distribution from the ESS 2 GeV proton beam at the first and second maximum for Θ_{13}=8.5° and different δ_{CP} values

First maximum



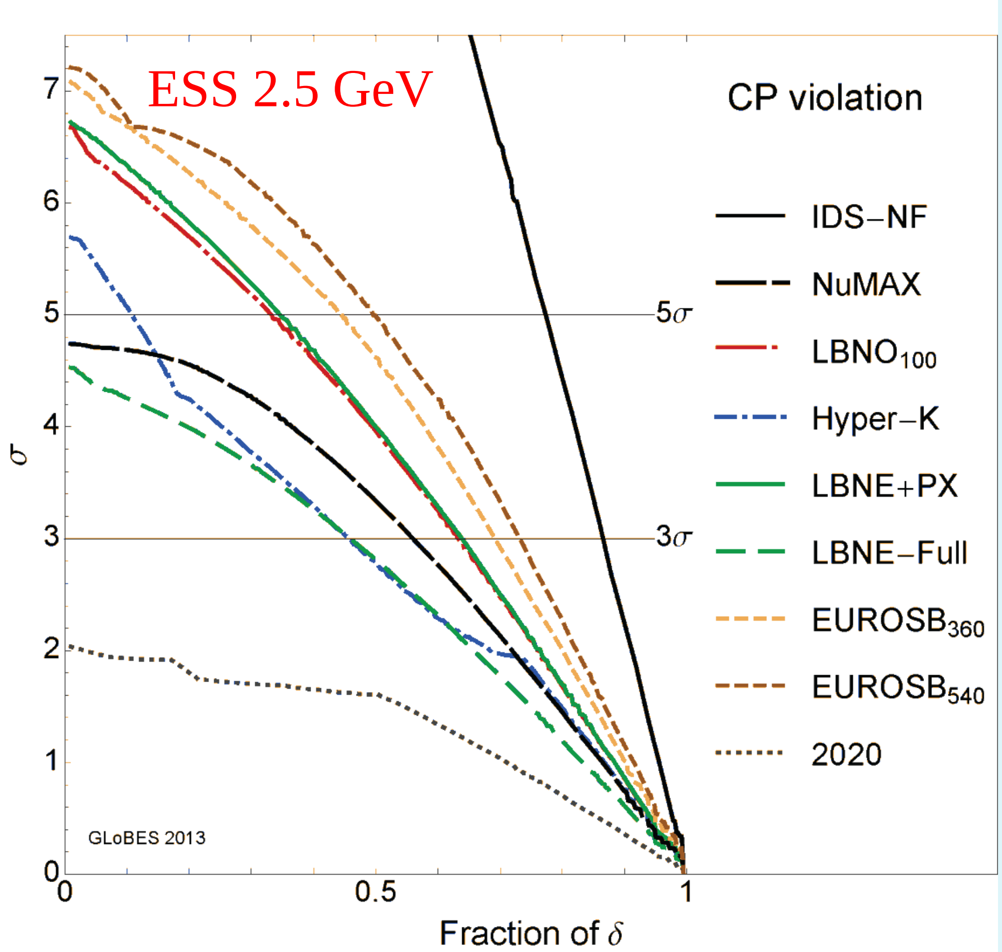
Limited discrimination between different δ_{CP} values due to systematic errors

Second maximum



Three timesetter discrimination between the different δ_{CP} values

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

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These three developments of LHC crab cavities, CLIC accelerating structures and ESS upgrade for a neutrinos are driven by the FREIA Laboratory in Uppsala

Facility for Research Instrumentation and Accelerator Development

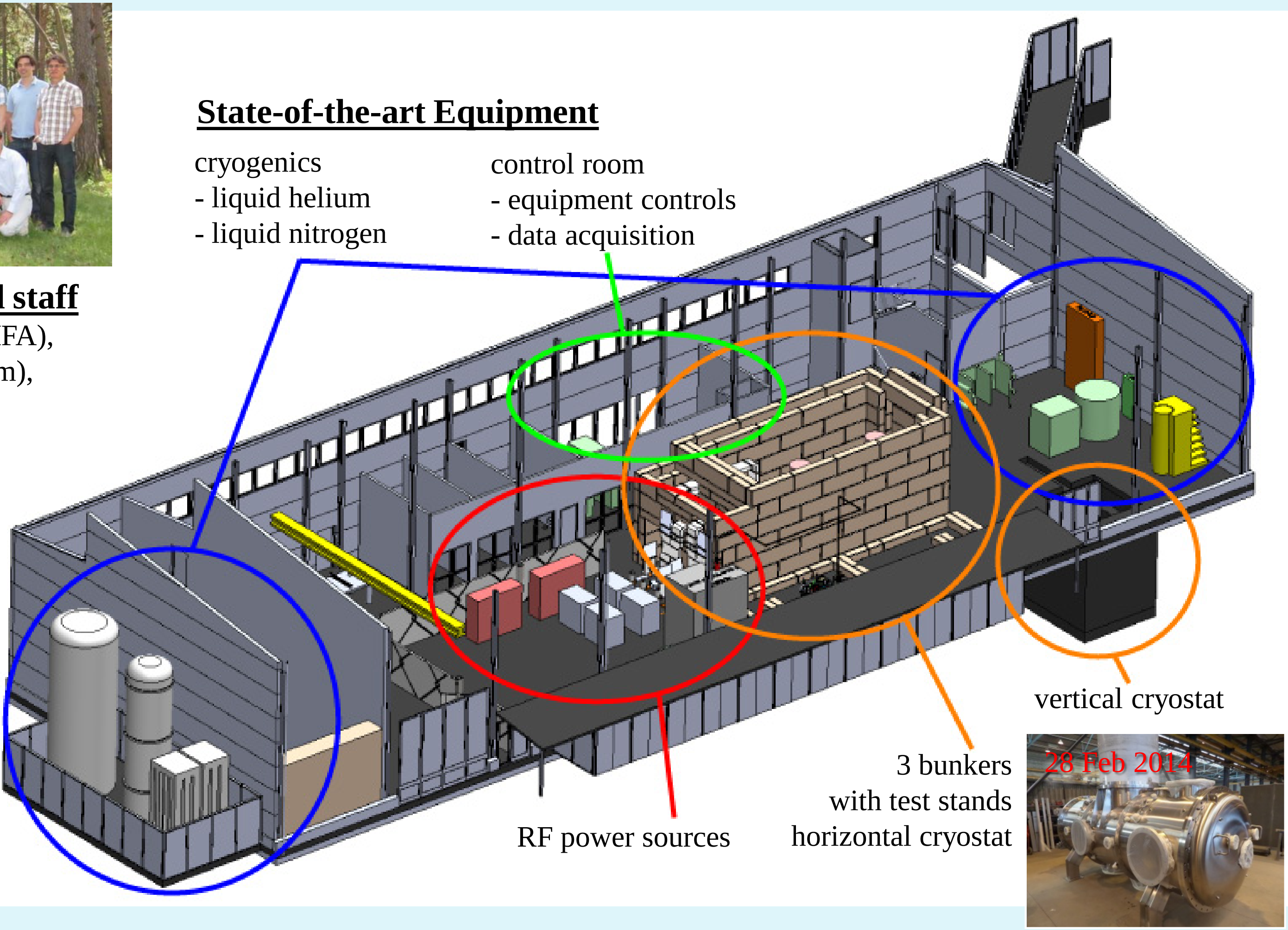
Competent and motivated staff
collaboration with HEP & NP (IFA),
solid-state electronics (Teknikum),
Ångström workshop and TSL

Funded by
KAWS,
Government,
Uppsala Univ.

State-of-the-art Equipment

cryogenics
- liquid helium
- liquid nitrogen

control room
- equipment controls
- data acquisition



vertical cryostat

3 bunkers
with test stands
horizontal cryostat

RF power sources

In addition FREIA is developing and testing accelerating cavities and radiofrequency power sources for ESS

Other planned FREIA projects:

1. Design and construction of superconducting cyclotrons for radioisotope production and light-ion cancer therapy

2. Insertion device for the upgrade Inner Detector in ATLAS

3. TeraHerz laser design and construction

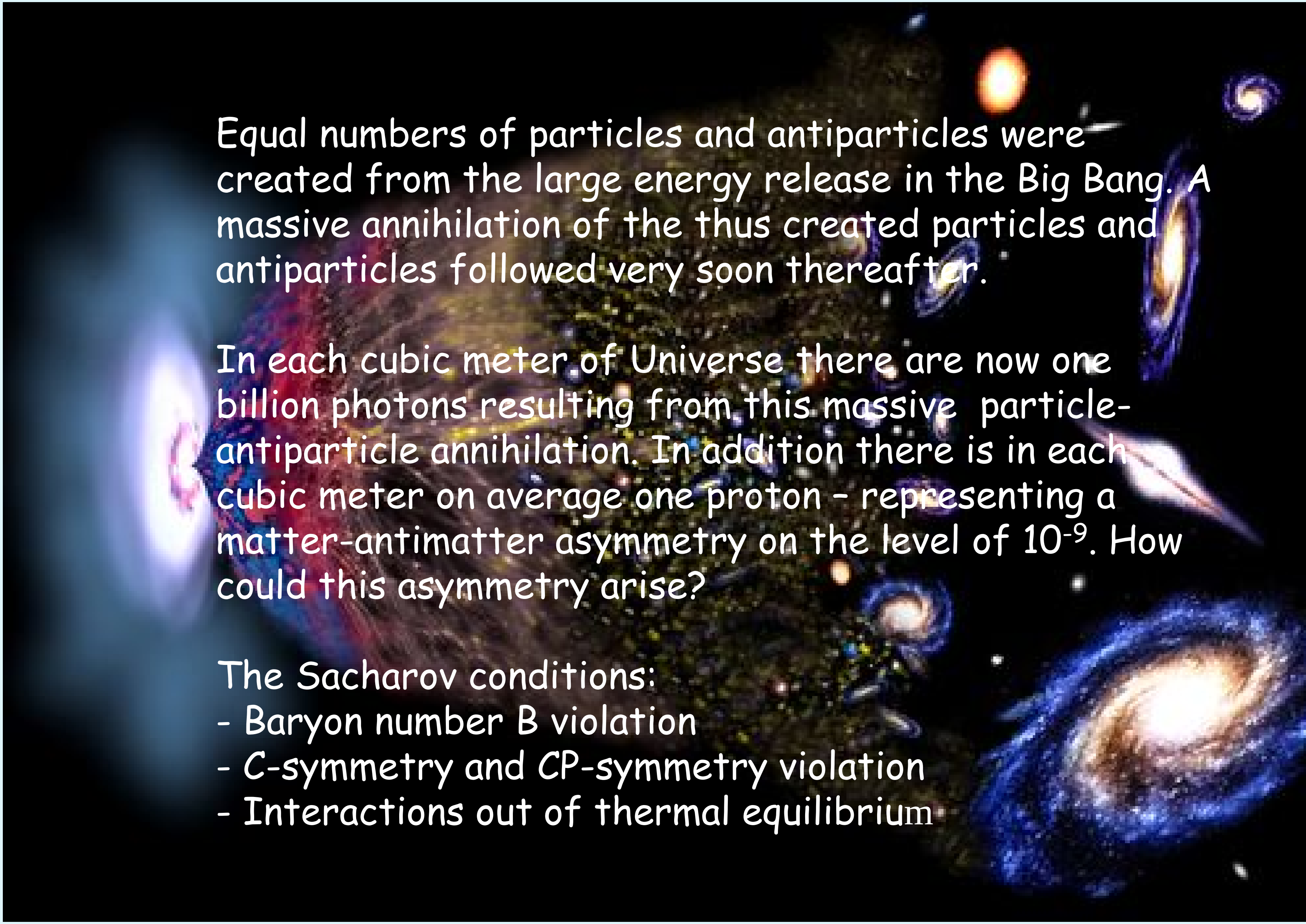
4. A superconducting undulator for a beam line at MAX IV

5. A neutron instrument for ESS

Conclusion

The FREIA Laboratory is complementing the data analysis research activities in Swedish High Energy Physics by giving significant contributions to the development of new accelerator facilities for HEP and also for other Sciences and for Society

Back-up slides



Equal numbers of particles and antiparticles were created from the large energy release in the Big Bang. A massive annihilation of the thus created particles and antiparticles followed very soon thereafter.

In each cubic meter of Universe there are now one billion photons resulting from this massive particle-antiparticle annihilation. In addition there is in each cubic meter on average one proton – representing a matter-antimatter asymmetry on the level of 10^{-9}. How could this asymmetry arise?

The Sacharov conditions:

- Baryon number B violation
- C-symmetry and CP-symmetry violation
- Interactions out of thermal equilibrium

CP violation in strong interaction suppressed. Axions, however not yet discovered, could explain that

CP violation in weak interaction among quarks discovered in 1962. However this CP violation is too small as it could only explain matter-antimatter asymmetry on the level of 10^{-18}

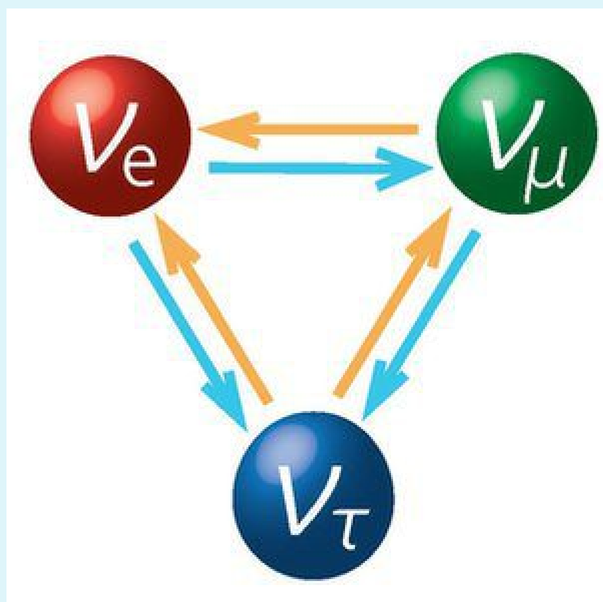
So this is why we are so interested in finding a CP violation in the leptonic sector that would be big enough to be compatible with the matter-antimatter asymmetry that we observe on the level of 10^{-9}

Three neutrino mixing.

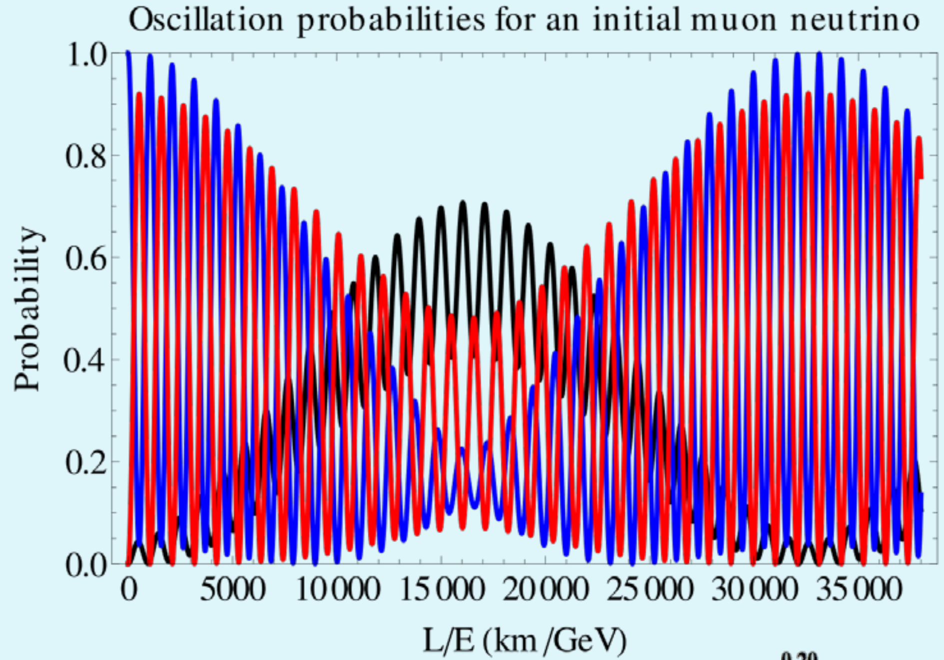
If neutrinos have mass: $|\nu_l\rangle = \sum U_{li} |\nu_i\rangle$

$$U_{li} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

where $c_{ij} = \cos\theta_{ij}$, *and* $s_{ij} = \sin\theta_{ij}$

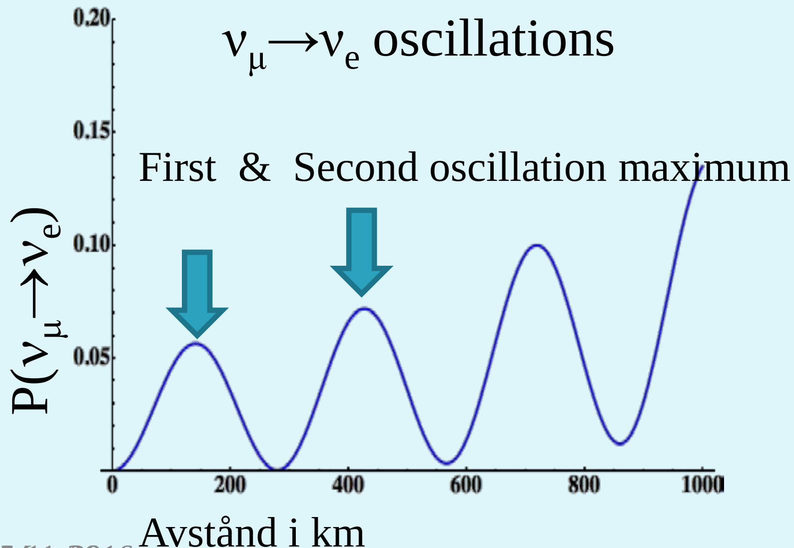


Neutrino oscillations



Blue=ν_μ
Red=ν_τ
Black=ν_e

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2} \ (1 - 2S_{13}^2)\right)$$
$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$
$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$
$$+4S_{12}^2 C_{13}^2 \{C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta\} \sin^2 \frac{\Delta m_{21}^2 L}{4E}$$
$$-8C_{13}^2 S_{13}^2 S_{23}^2 \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \frac{aL}{4E} \ (1 - 2S_{13}^2)$$



Grouping the $P(\nu_\mu \rightarrow \nu_e)$ expression into three terms:

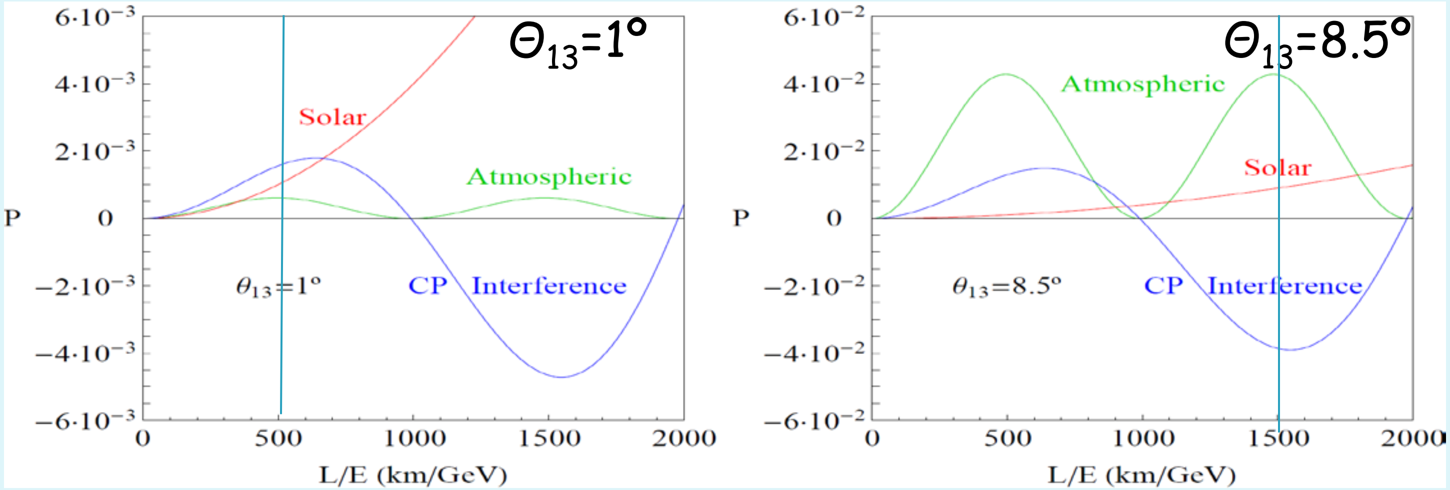
$$P(\nu_\mu \rightarrow \nu_e) = \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta_{31}L}{2}\right)$$ atmospheric

$$+ \cos^2\theta_{23}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta_{21}L}{2}\right)$$ solar

$$+ \widetilde{J}\cos\left(\delta_{cp} - \frac{\Delta_{31}L}{2}\right)\sin\left(\frac{\Delta_{21}L}{2}\right)\sin\left(\frac{\Delta_{31}L}{2}\right)$$ interference

where $\widetilde{J} \equiv \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13}$ and $\Delta_{ij} \equiv \frac{\Delta m^2_{ij}}{2E_\nu}$. The sign of δ_{cp} is the opposite for antineutrinos.

Optimization δ_{CP} for the large Θ_{13} measured in 2012



First oscillation maximum at L/E= 500Km/GeV and the second maximum at **L/E=1500 km/ GeV**

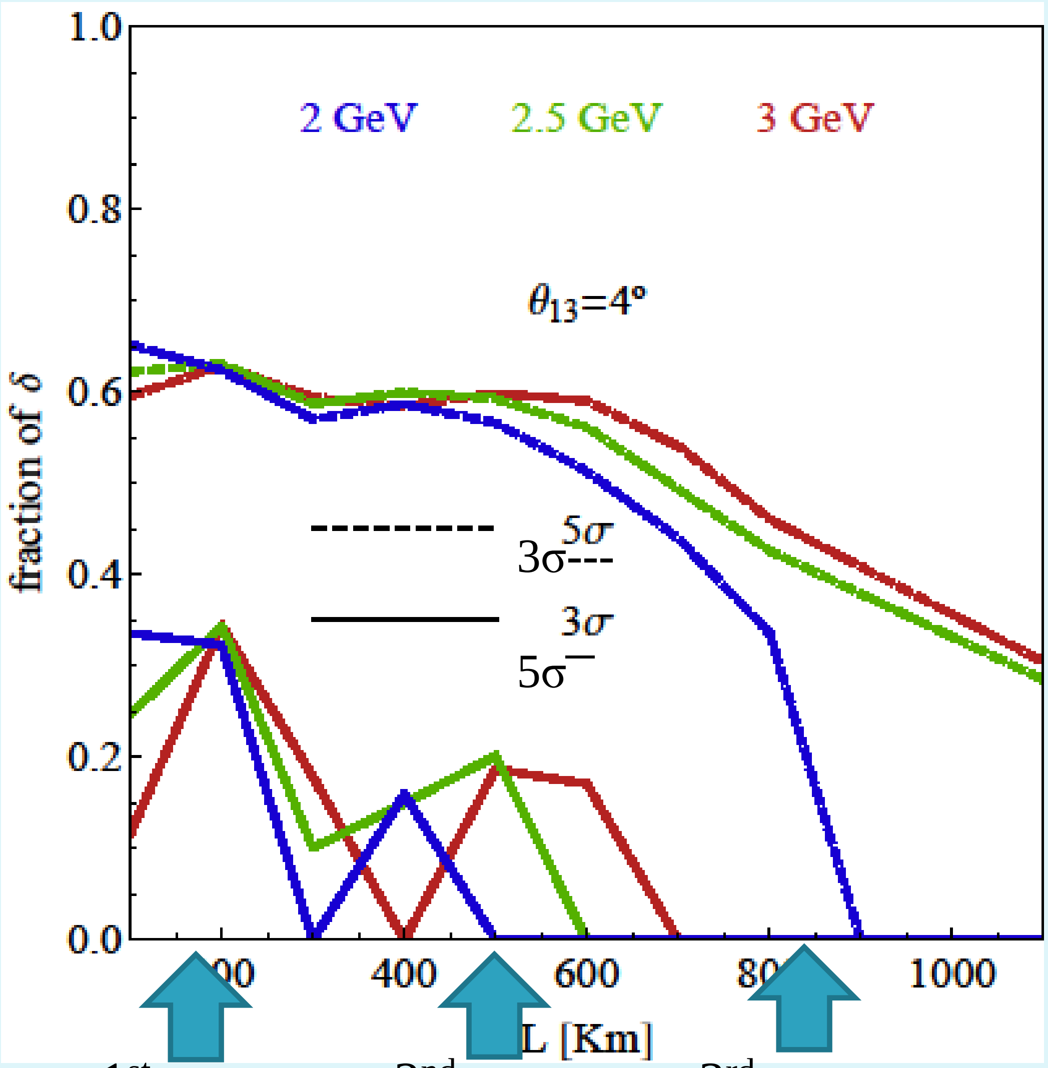
Signal systematics and not statistics is the bottleneck for large Θ_{13}, explore second maximum

P. Coloma and E. F. Martinez 1110.4583

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

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

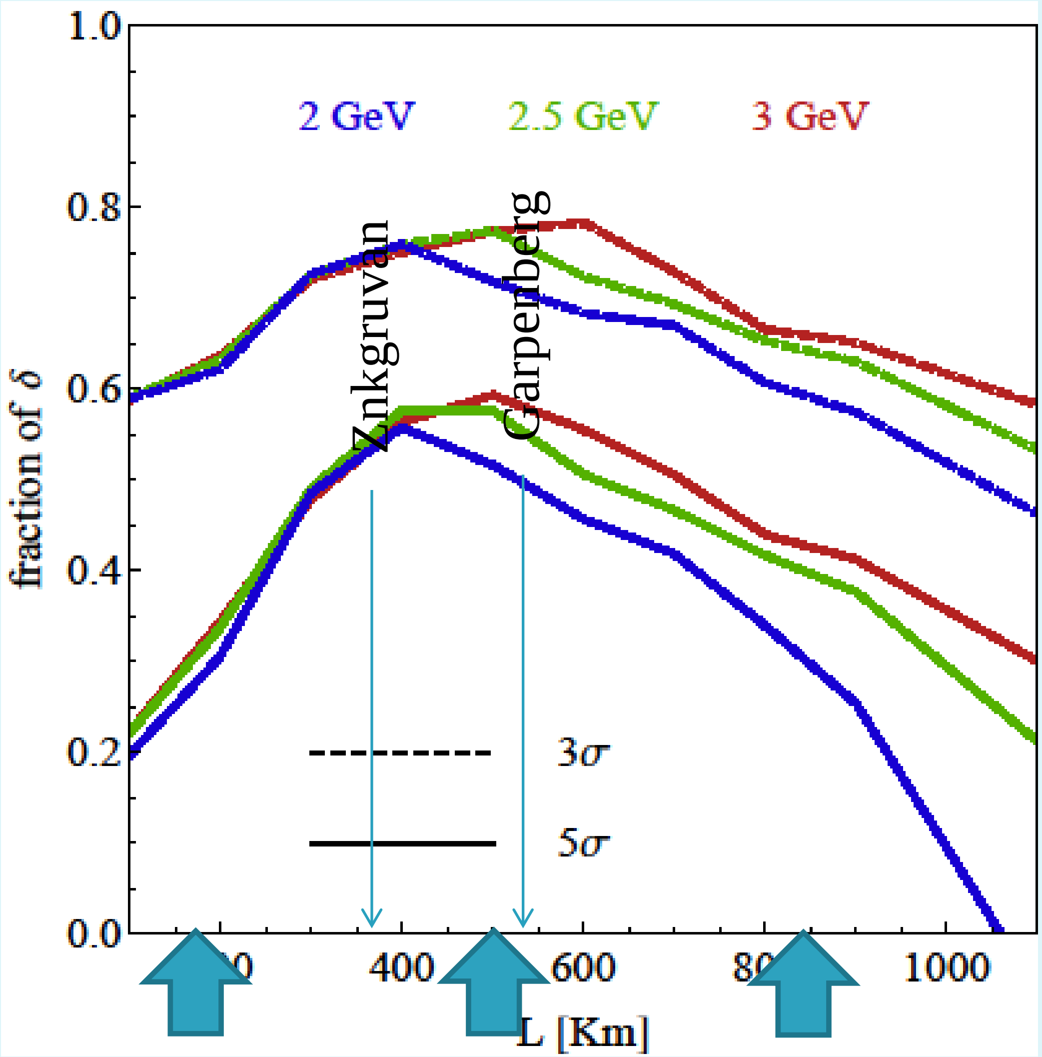
$\Theta_{13}=4^{o}$



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 is considerably larger at the second oscillation maximum as compered to the first

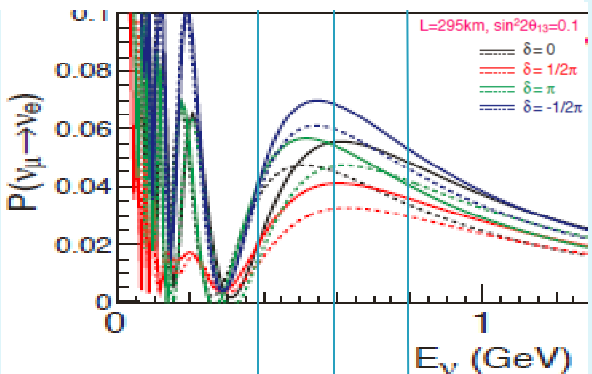
Θ_{13}=8.73^{o}

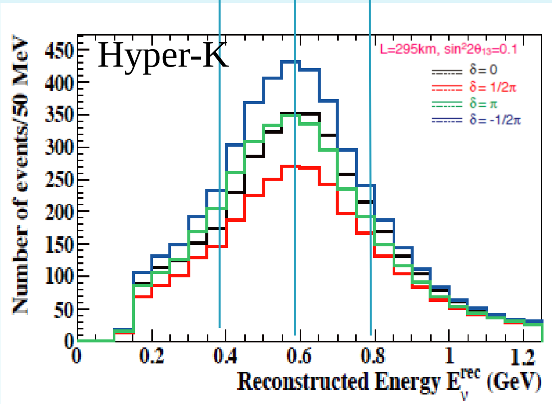


1st osc. max 2nd osc. max 3rd osc. max

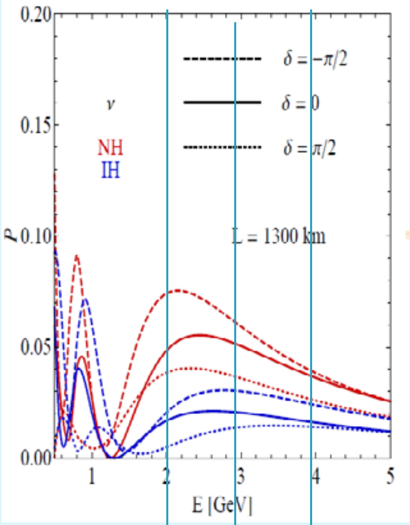
The sensitivity of the neutrino energy distribution to δ_{CP}

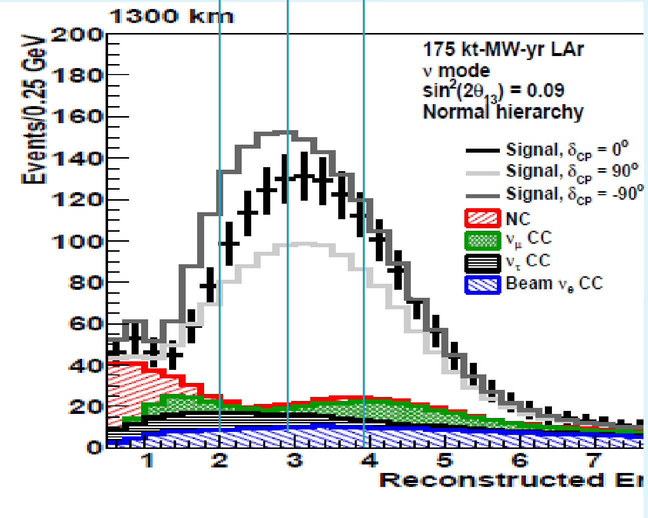
Hyper-K first maximum



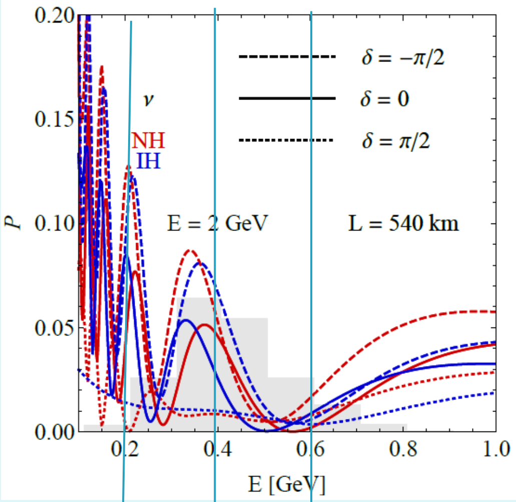


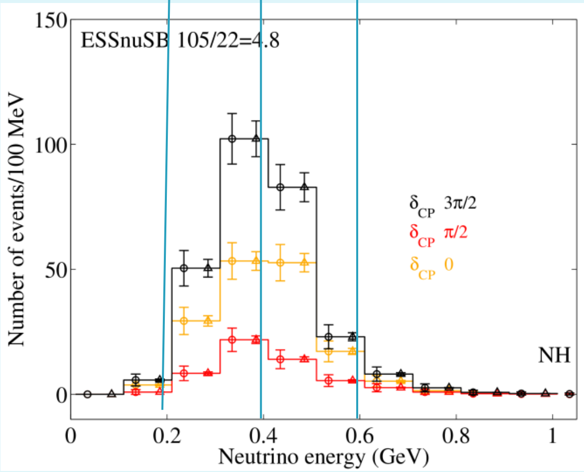
LBNE/DUNE first maximum





ESSnuSB second maximum



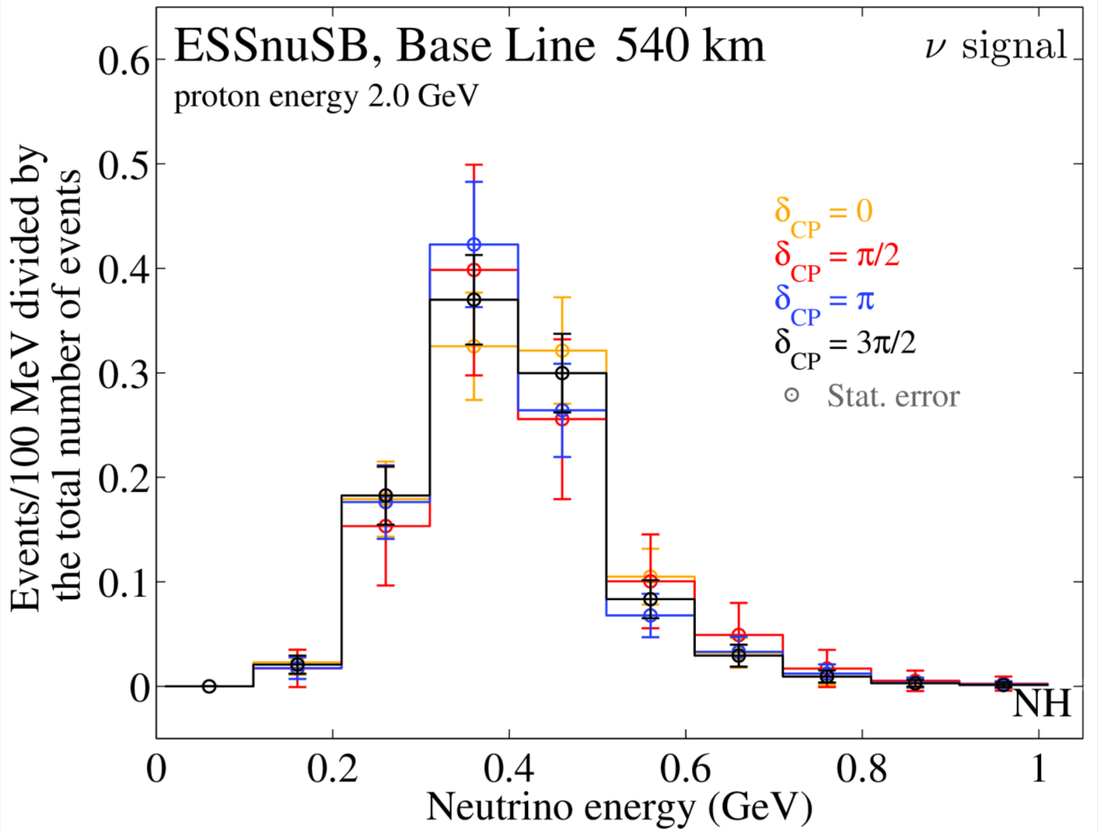


Relative difference in counts at maximum between δ_{CP} = 3π/2 and π/2 :

430/275 = 1.6 150/100 = 1.5 105/22 = 4.8

ESSnuSB a energy distribution shape measuring experiment

Second maximum



M. Olvegård

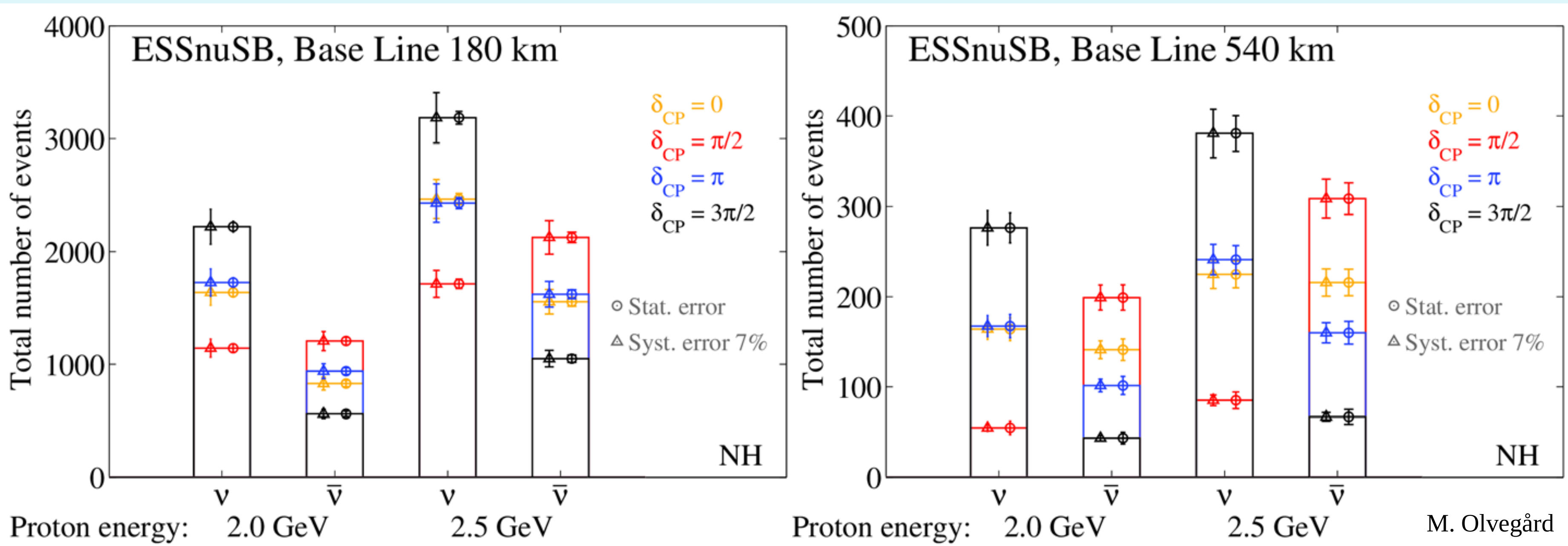
Systematic normalization errors suppressed

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

ESSnuSB as counting experiment

First maximum

Second maximum



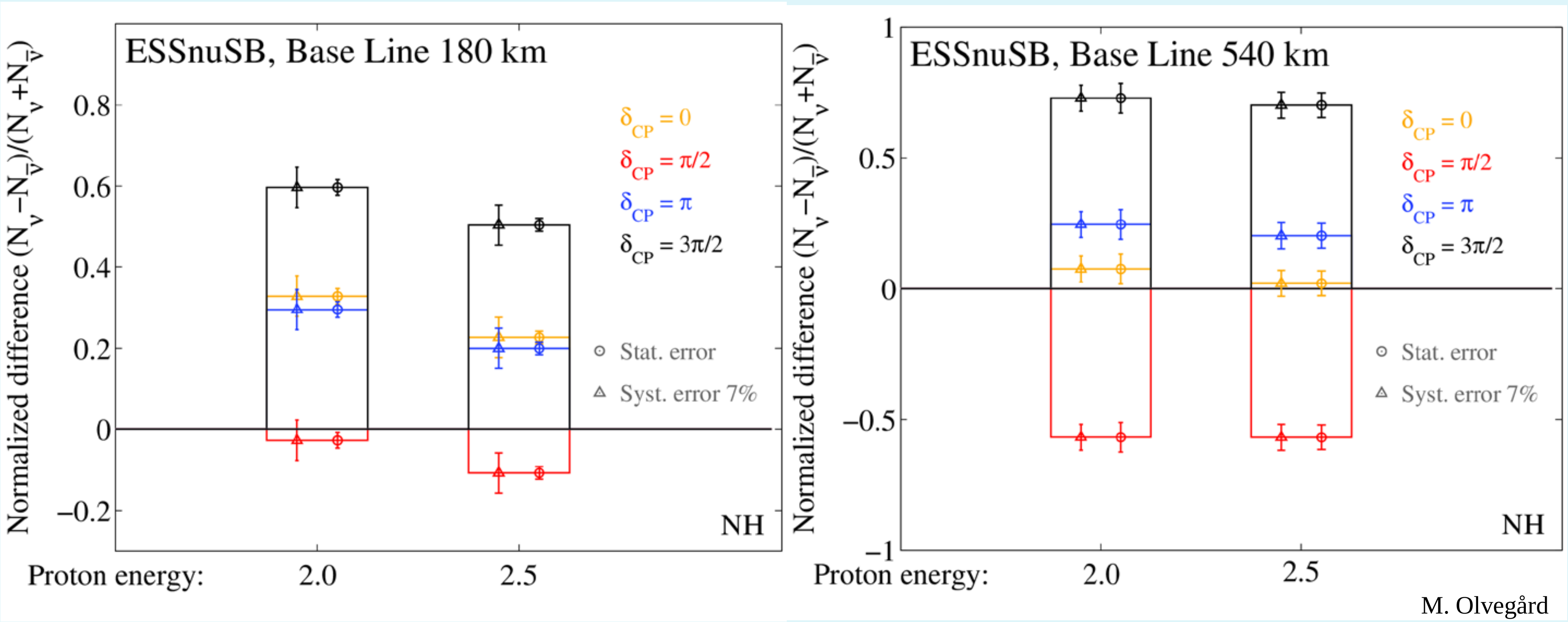
Statistical errors *much* smaller than the 7% systematic errors
Limited discrimination between different δ_{CP} values due to systematic errors

Statistical errors *about equal* to than the 7% systematic errors
Even better discrimination between the different δ_{CP} values

ESSnuSB as neutrino/antineutrino ratio counting expt

First maximum

Second maximum



Syst. and stat. errors not balanced
Range of variation +.06->-0.05
Limited discrimination between the different δ_{CP} values

Syst. and stat. errors balanced
Range of variation +0.75->-0.6
Excellent 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 $\Delta_{31}=\pi/2$

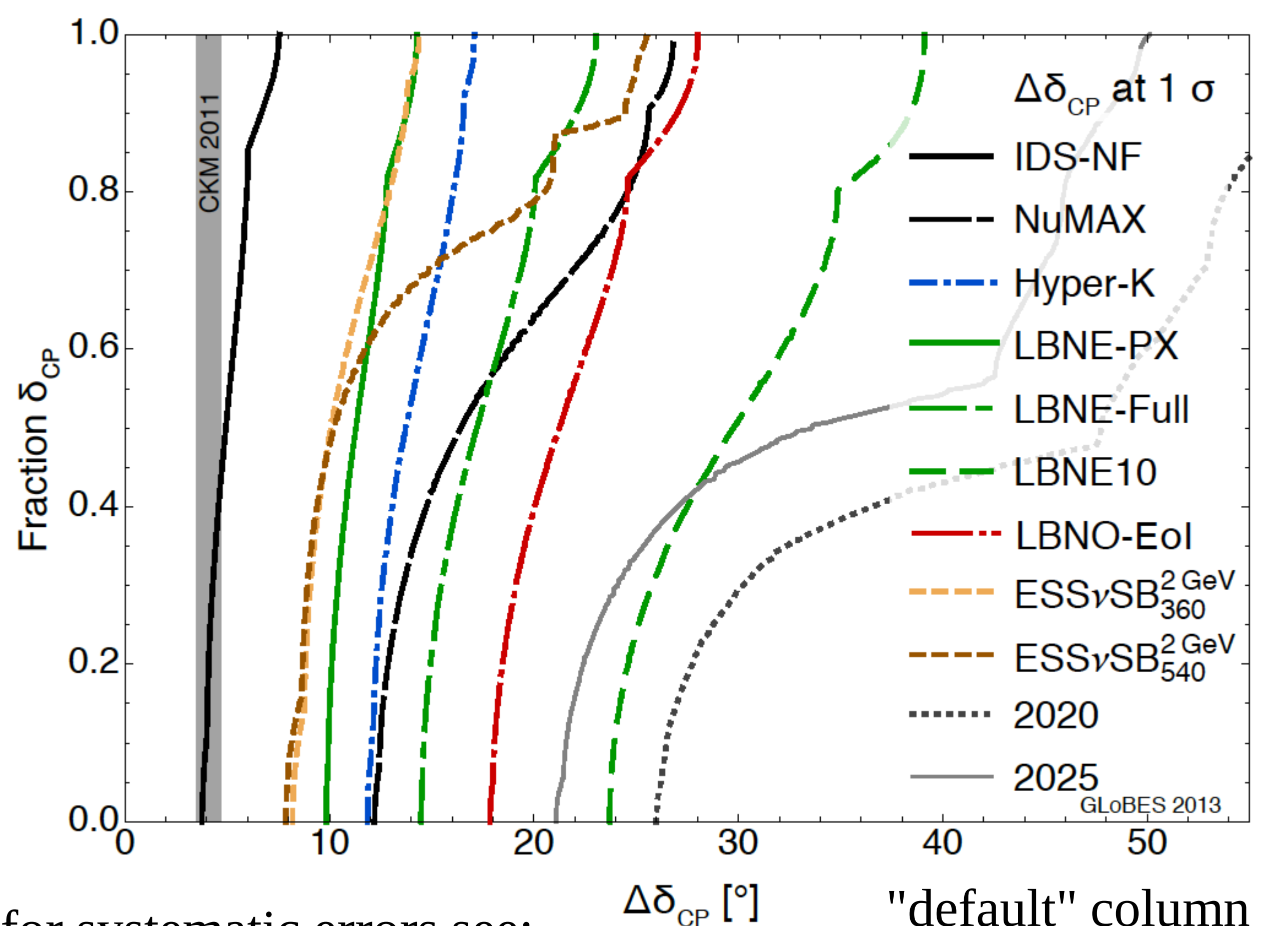
which implies that $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ is between **1/2 and 2** times $P(\nu_\mu \rightarrow \nu_e)$. Whereas at the **second oscillation maximum,** the vacuum **asymmetry** is

$A \sim 0.75 * \sin\delta$ 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."***

δ_{CP} accuracy performance

(USA snowmass process, P. Coloma)



"default" column

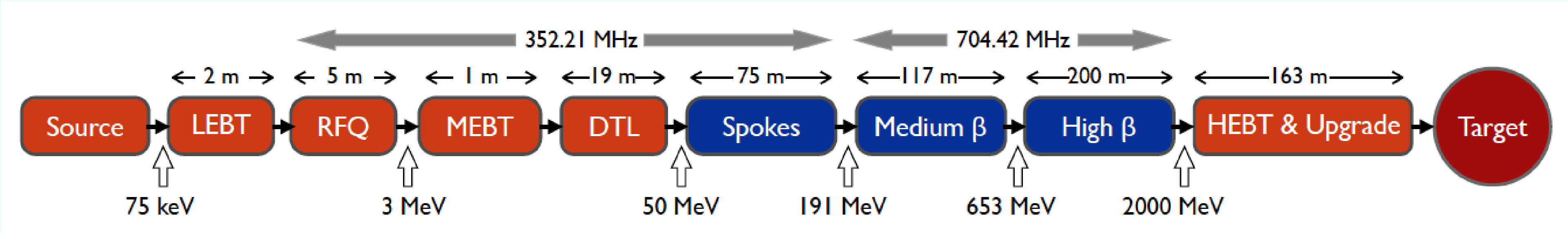
for systematic errors see:

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

So, we should – if the ESS linac can provide enough power (5 MW) and thereby produces enough neutrinos - place the neutrino detector at the **second** oscillation maximum, i.e. at L/E_ν=1500 km/GeV, which for the ESS linac with $\hat{E}_\nu$=0.36 GeV is:

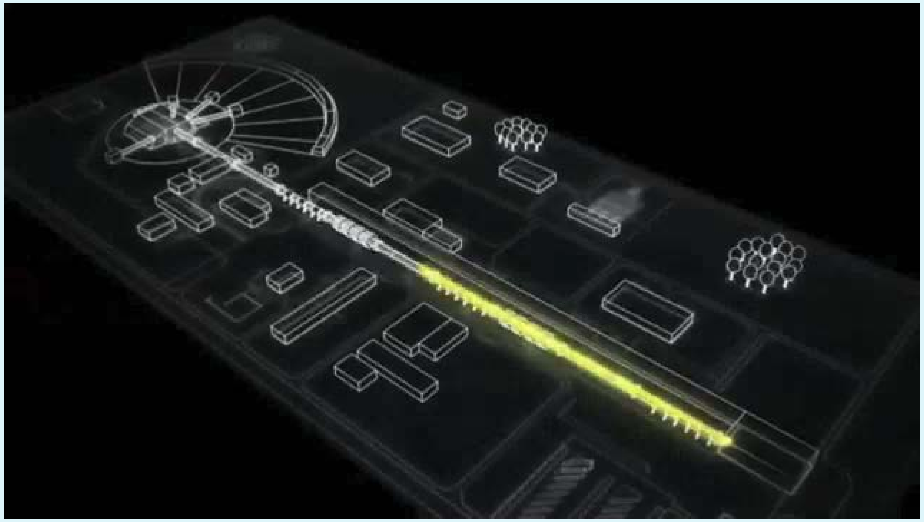
L=0.36*1500=540 km

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)
- **>2.7×10^{23} p.o.t/year**

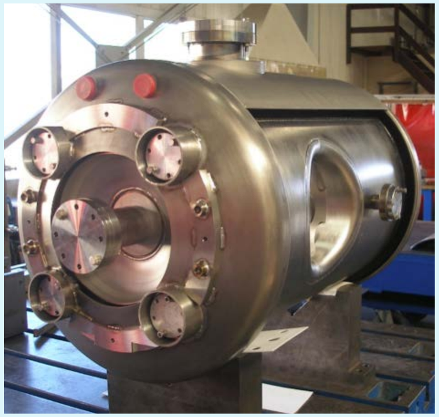
HEBT & upgrade: 2.5 GeV+68 m,
3.0 GeV +60 m,
3.5 GeV +66 m,



Linac ready by 2023 (full power and energy)

The 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

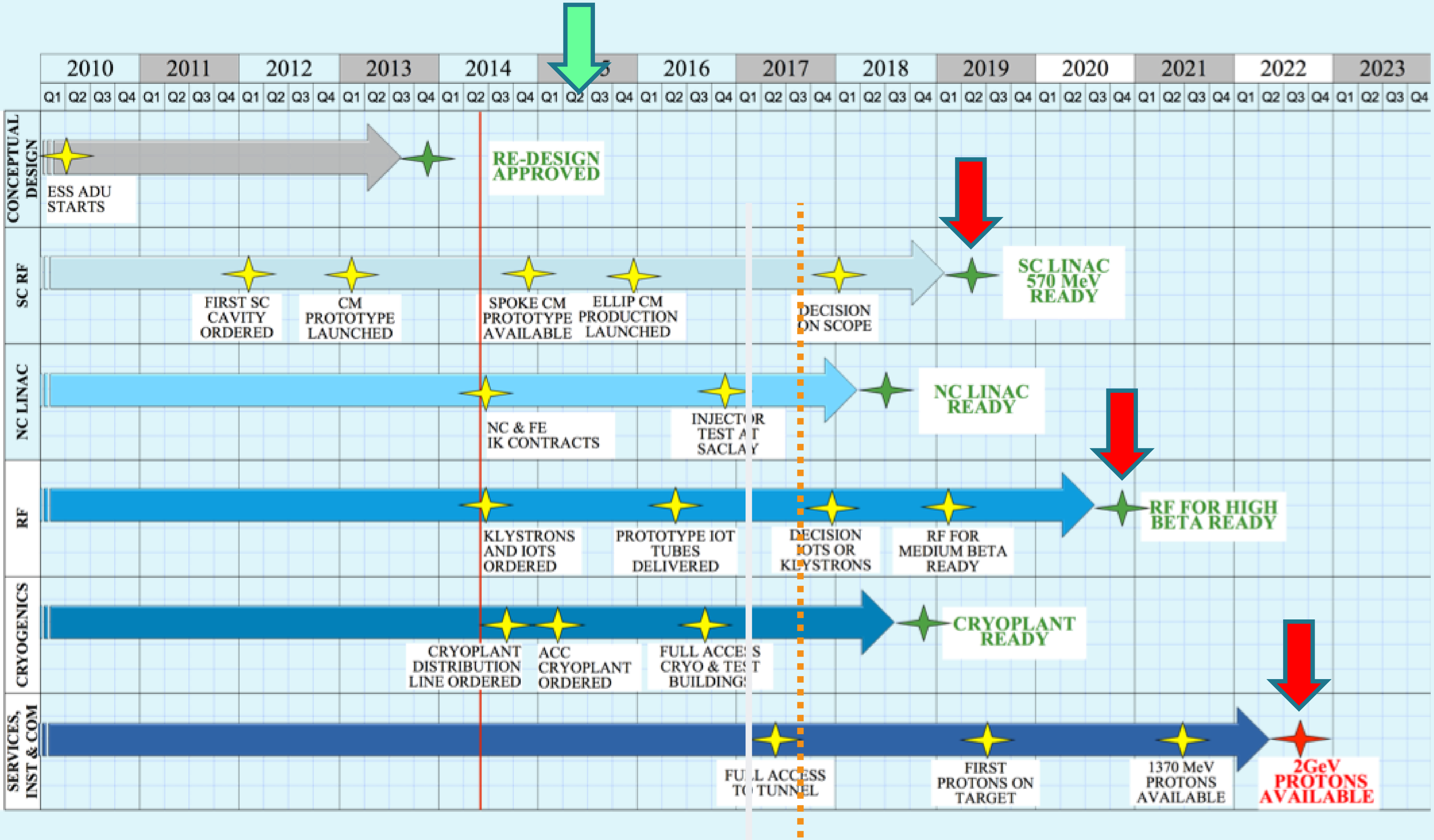


Has been low power tested at IPN Orsay and will be high power tested in FREIA Lab in Uppsala in 2015

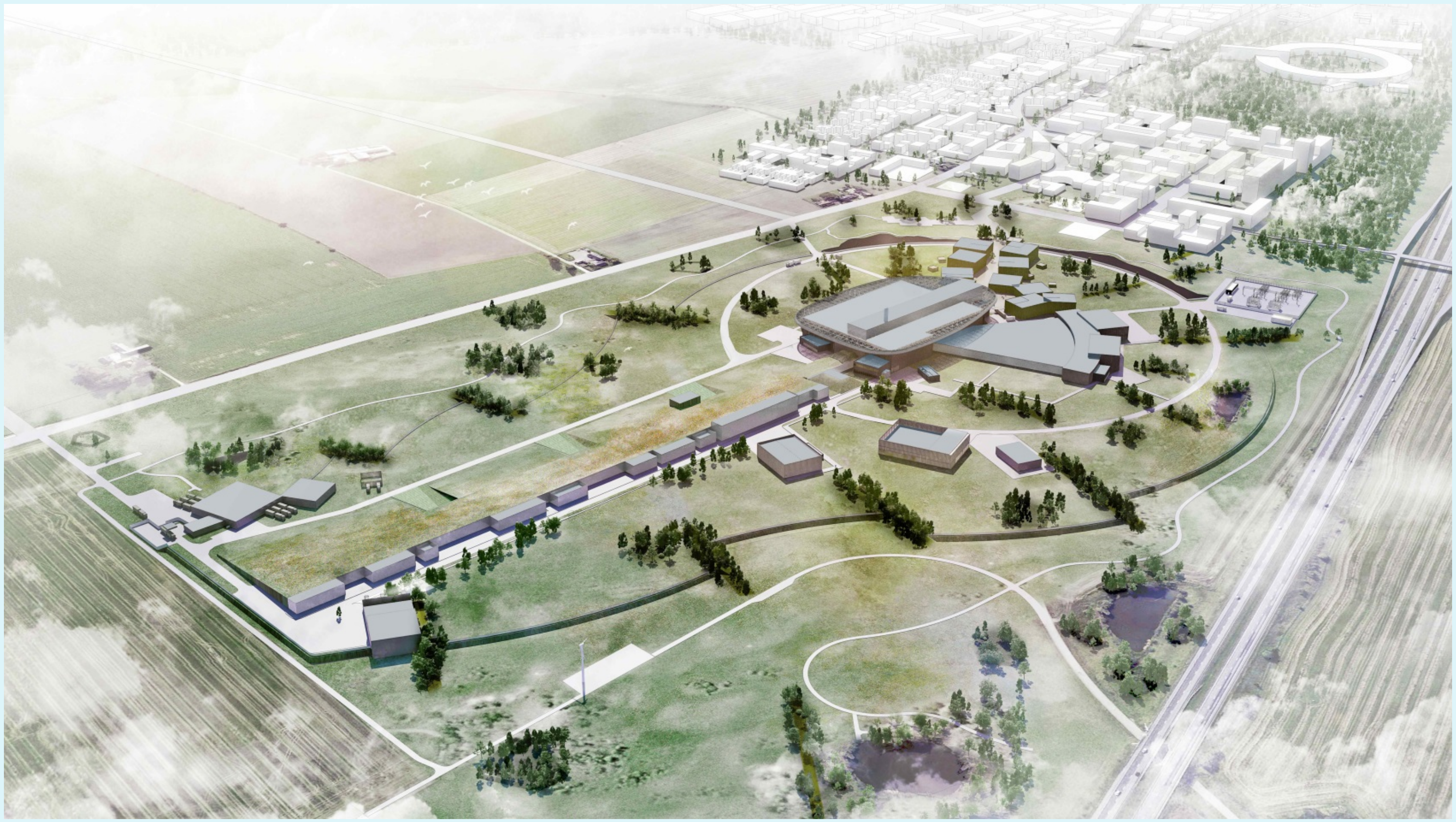
Fivefold elliptical cavity
704 MHz

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

ESS LINAC PROJECT SCHEDULE



Artists view of the future ESS site

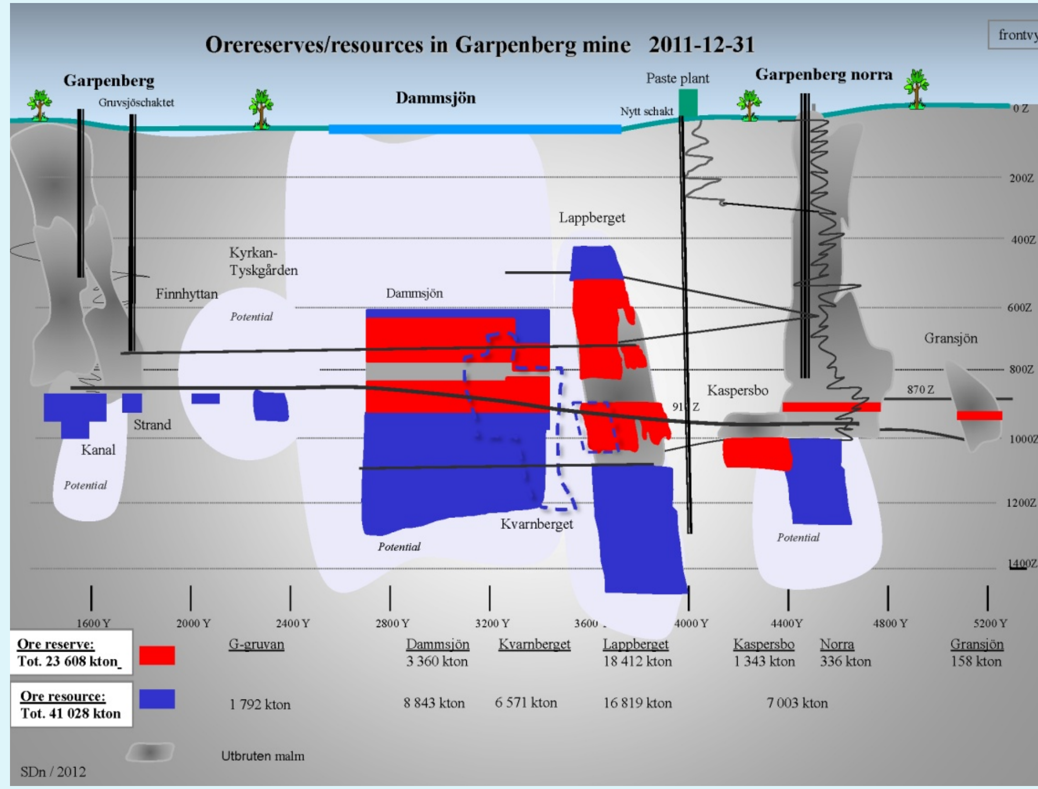


45

Garpenberg Mine

Distance from ESS Lund **540 km**

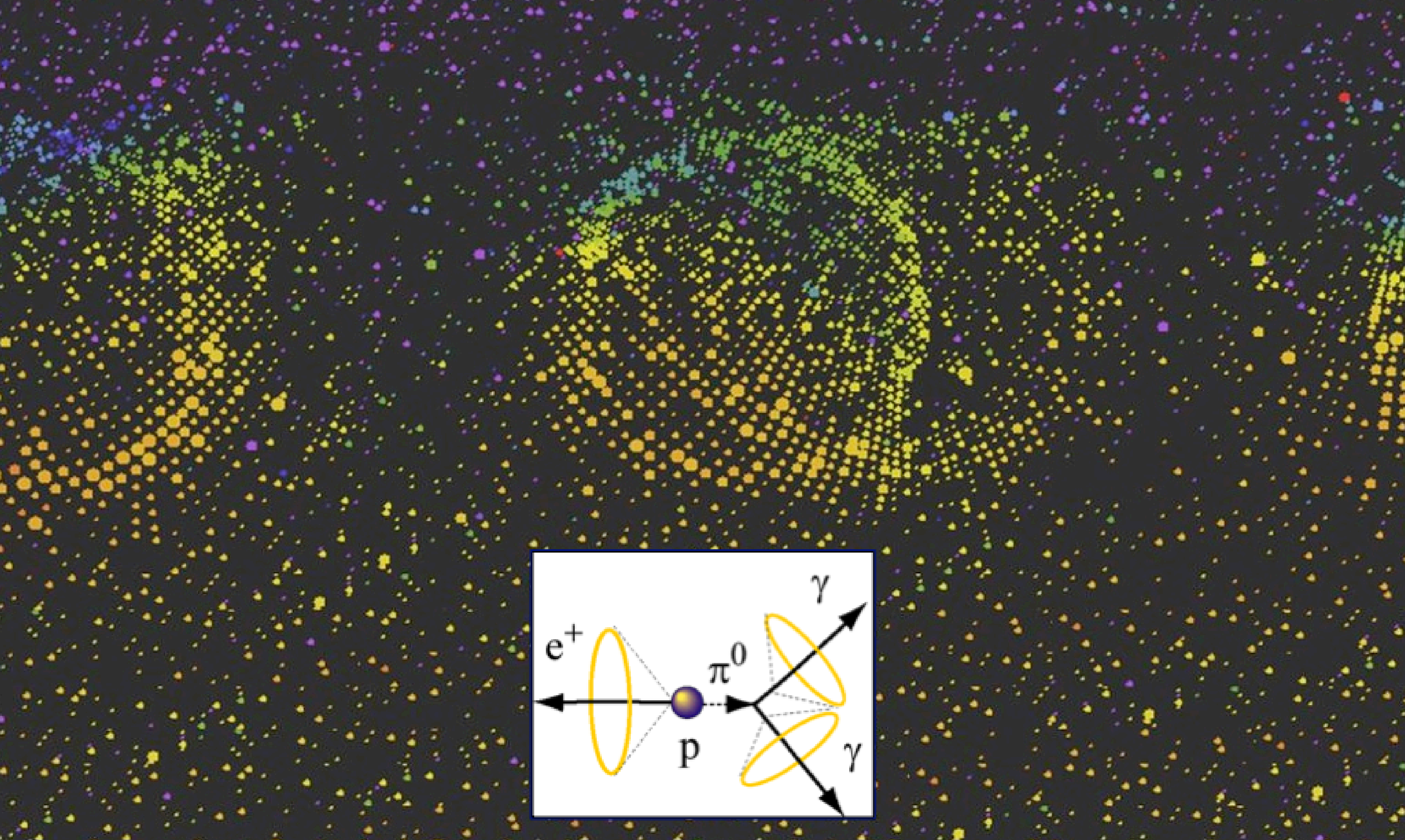
Depth 1232 m
Truck access tunnels
Two ore hoist shafts



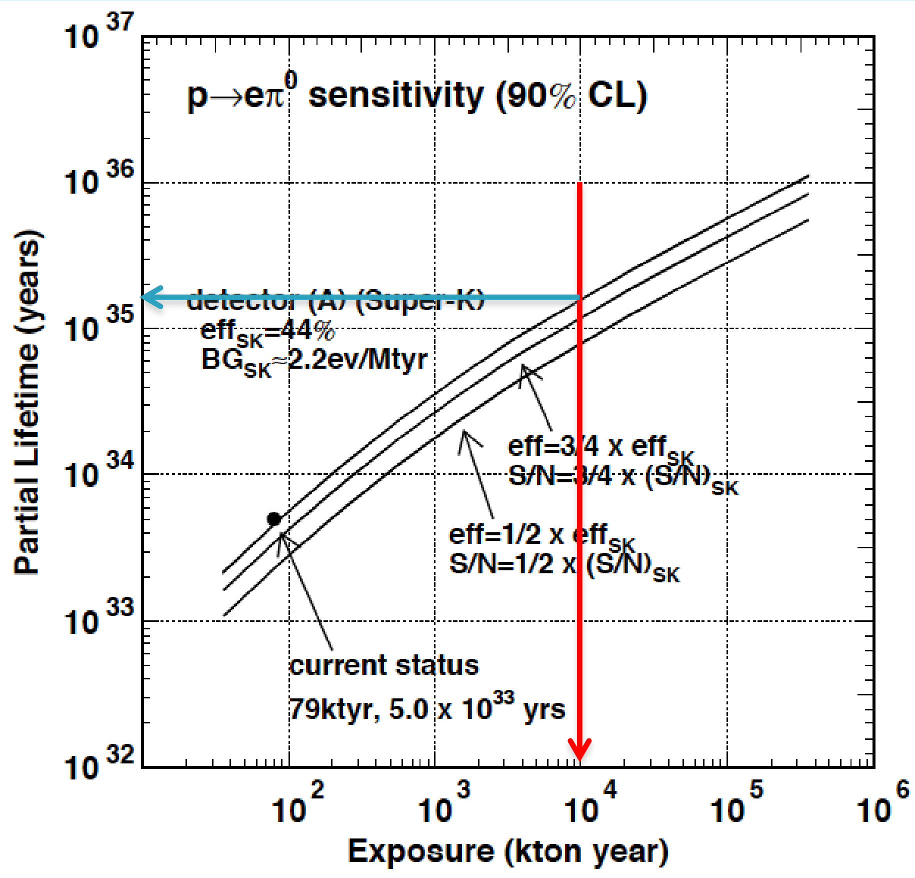
A new ore hoist schaft is planned to be ready i 1 year, **leaving the two existing shafts free for other uses**

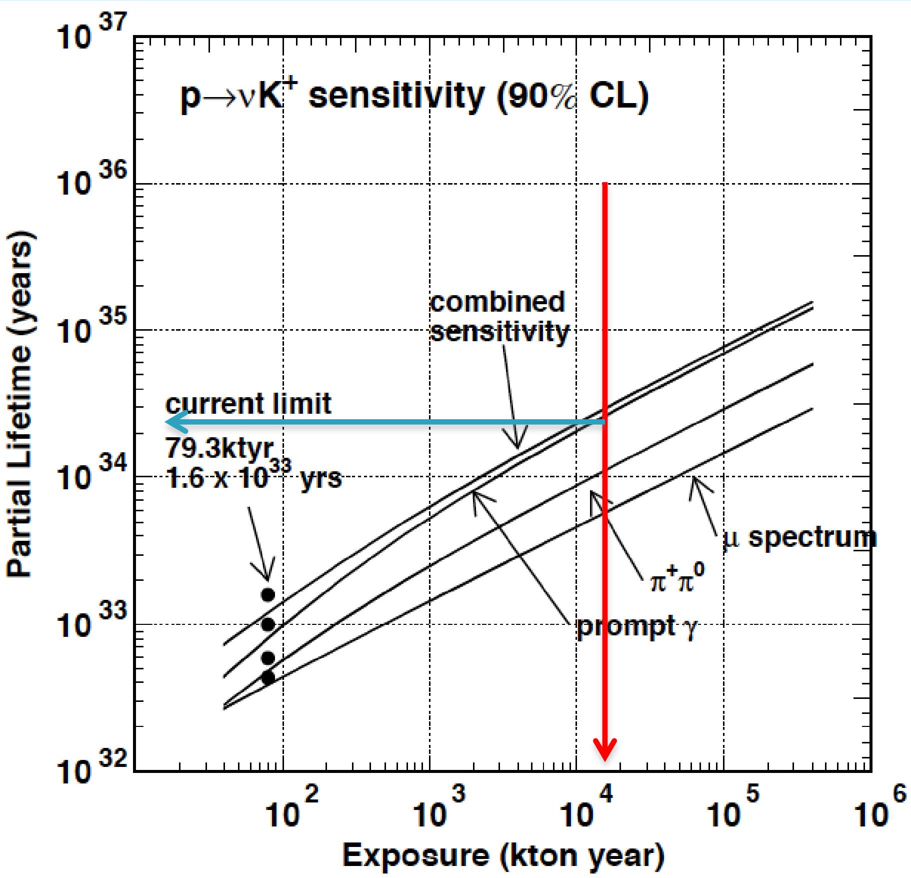
Granite drill cores

Proton Decay



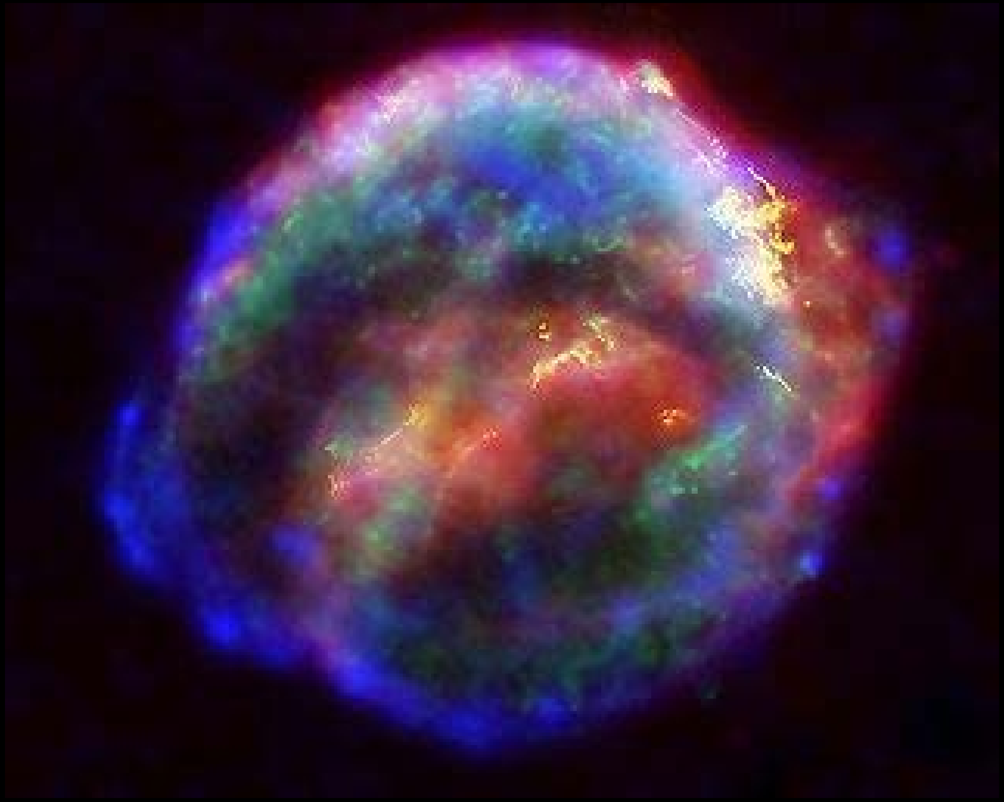
ESSnuSB-MEMPHYS sensitivities
proton decay





(arXiv: hep-ex/0607026)

Supernova

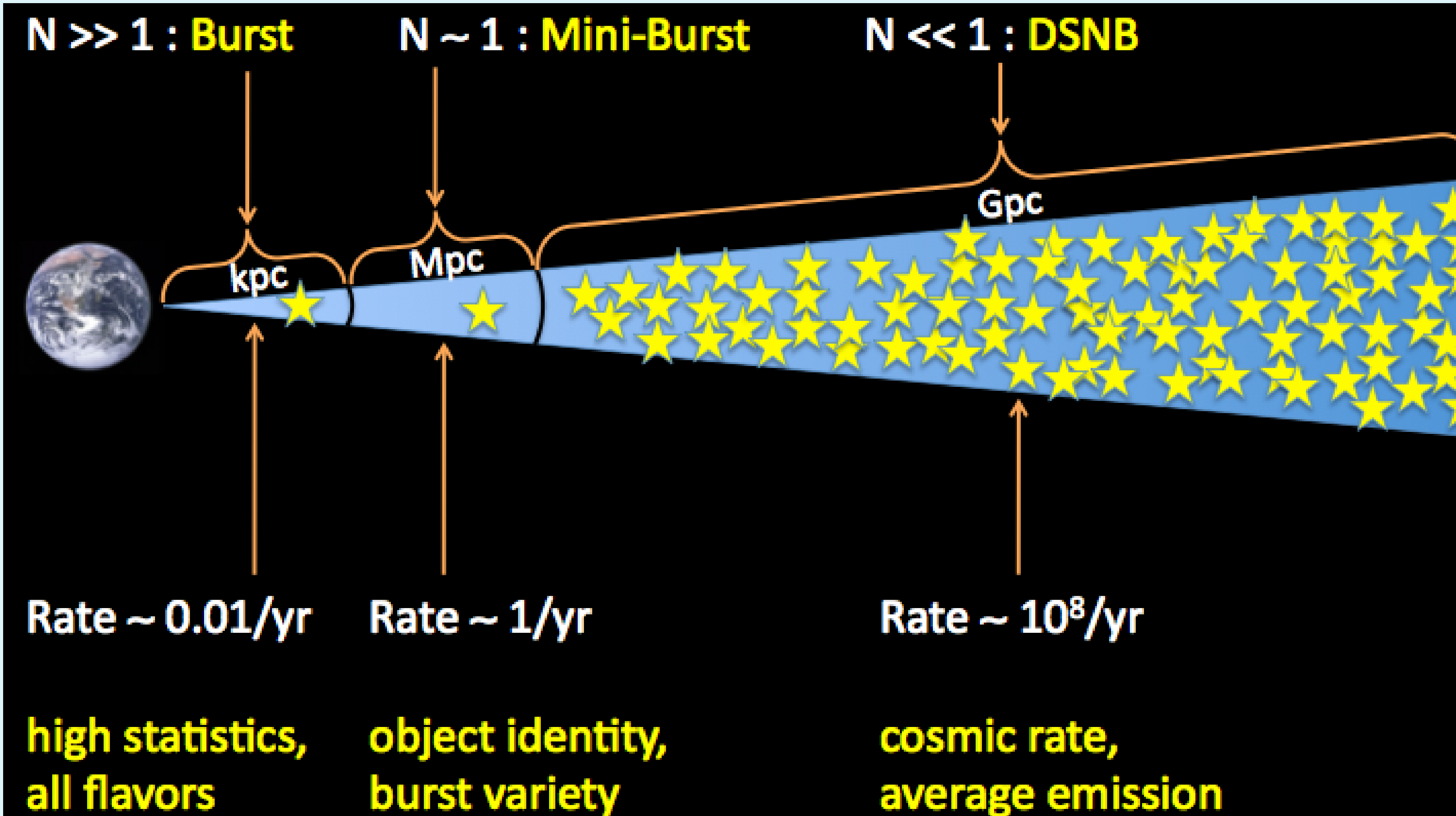


Distance scale and exp'd rate

Milky way

Nearby galaxies

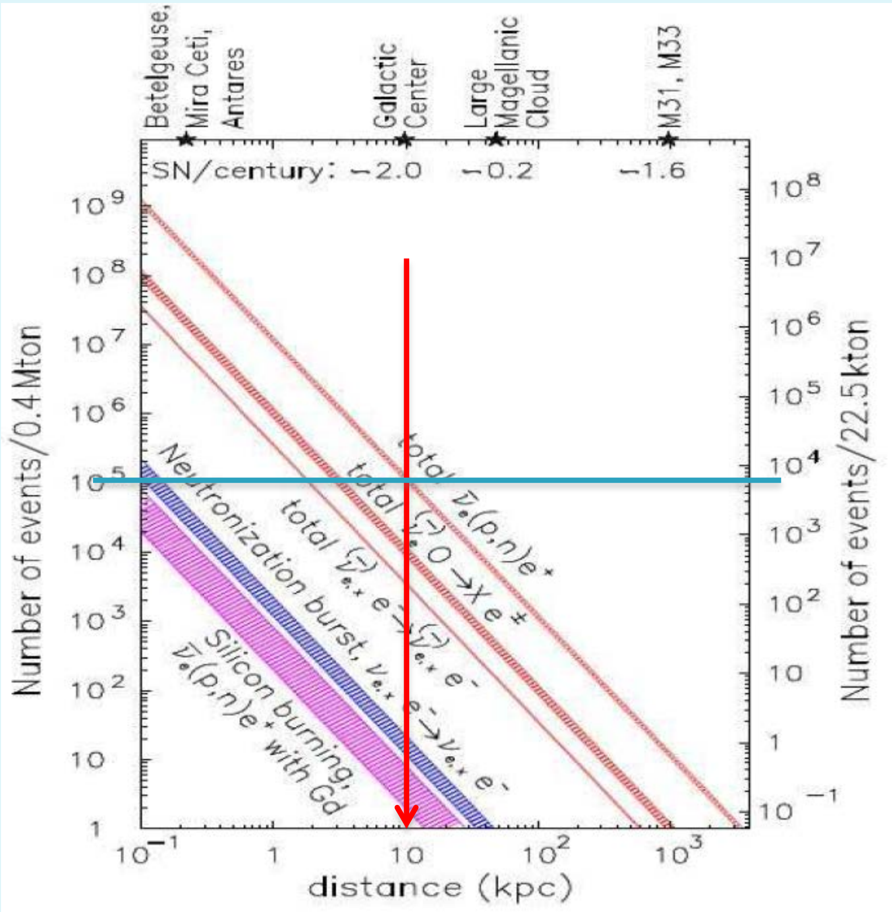
distant galaxies



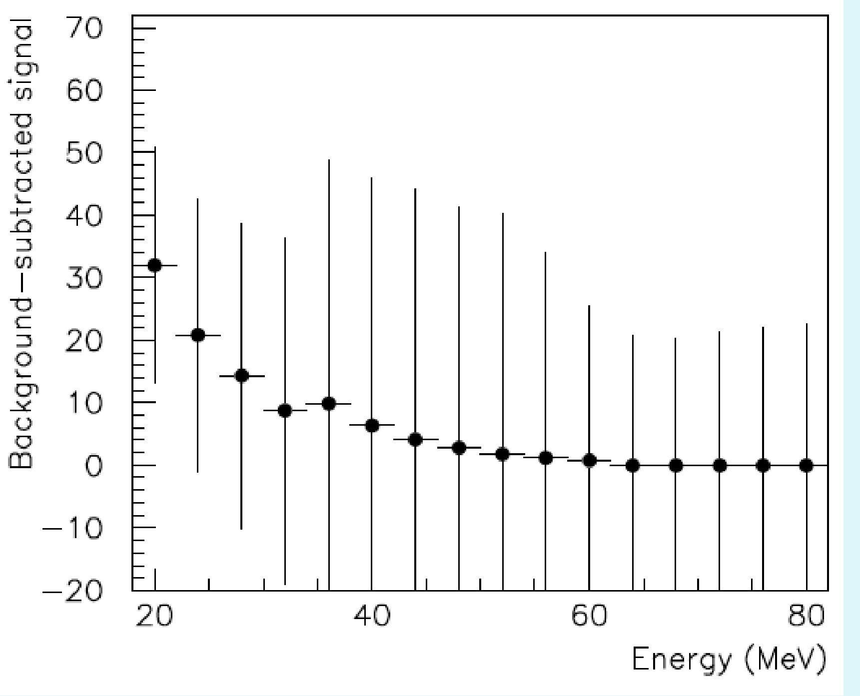
Beacom@NU2012

ESSnuSB-MEMPHYS sensitivities
Supernova explosion and relics

MEMPHYS



SUPERK



Diffuse Supernova Neutrinos
(10 years, 440 kt)

For 10 kpc: ~10^5 events

The ESSnuSB Collaboration

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
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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[i] *Laboratoire Souterrain de Modane, F-73500 Modane, France*
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[l] *Department of Theoretical Physics, School of Engineering Sciences, KTH Royal Institute of Technology, AlbaNova University Center, SE-106 91 Stockholm, Sweden*
[m] *IPHC, Université de Strasbourg, CNRS/IN2P3, F-67037 Strasbourg, France*
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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

Supported by ESS, by the owner of the mine and by the local authorities

- In a letter to the EC H2020 Research Infrastructure Office the **ESS CEO Jim Yeck** writes: "Given the high scientific interest in exploring the possibility of using the future ESS linear accelerator for neutrino physics…ESS management agrees to provide information and general support for the ESSnuSB collaboration's ongoing studies."

- 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.

- 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.

Dalahäst
Mascot 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.**

ESSnuSB Design Study funding

Recently (last Friday) a EU COST network application for ESSuSB was accepted with 57 out of 65 marks. Quotation from the evaluation report:

"The main strengths are that the present project is unique in Europe, and at this moment there are no other similar plans in the continent and it is building on a number of previous European projects. Only two other, similar projects exist in the USA and Japan.

In addition, the project is not only complementary to the projects in the USA and Japan but clearly competitive with them, because the infrastructure proposed, which plans to locate the detector at the second neutrino oscillation maximum, will provide a much better and larger accuracy than the other two projects."

Currently we are waiting for the outcome of ESSnuSB applications submitted to the Swedish SRC and to the European Economic Growth Foundation. Submission of a EU Design Study application is planned for autumn 2016. Funding of the Design Study remains a critical item.

Conclusions and summary

We conclude that the ESSnuSB project:

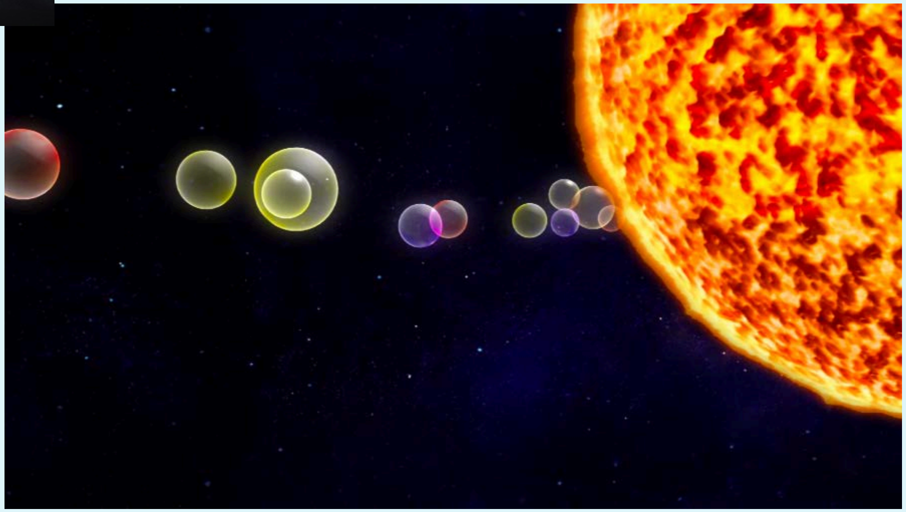
has the best physics potential for CP violation studies, compared to the other proposed Super Beam projects in the world,

has a cost smaller than the other proposed projects as thee baseline accelerator is already financed and under construction,

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 sufficiently advanced in its concept, benefitting from the European EUROnu and Laguna-LBNO design studies and from the ESS studies, to be ready to start data taking in about 10 years from now 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, and its high performance for proton decay and neutrino astroparticle research the potential to attract new collaborators

Thanks for your attention



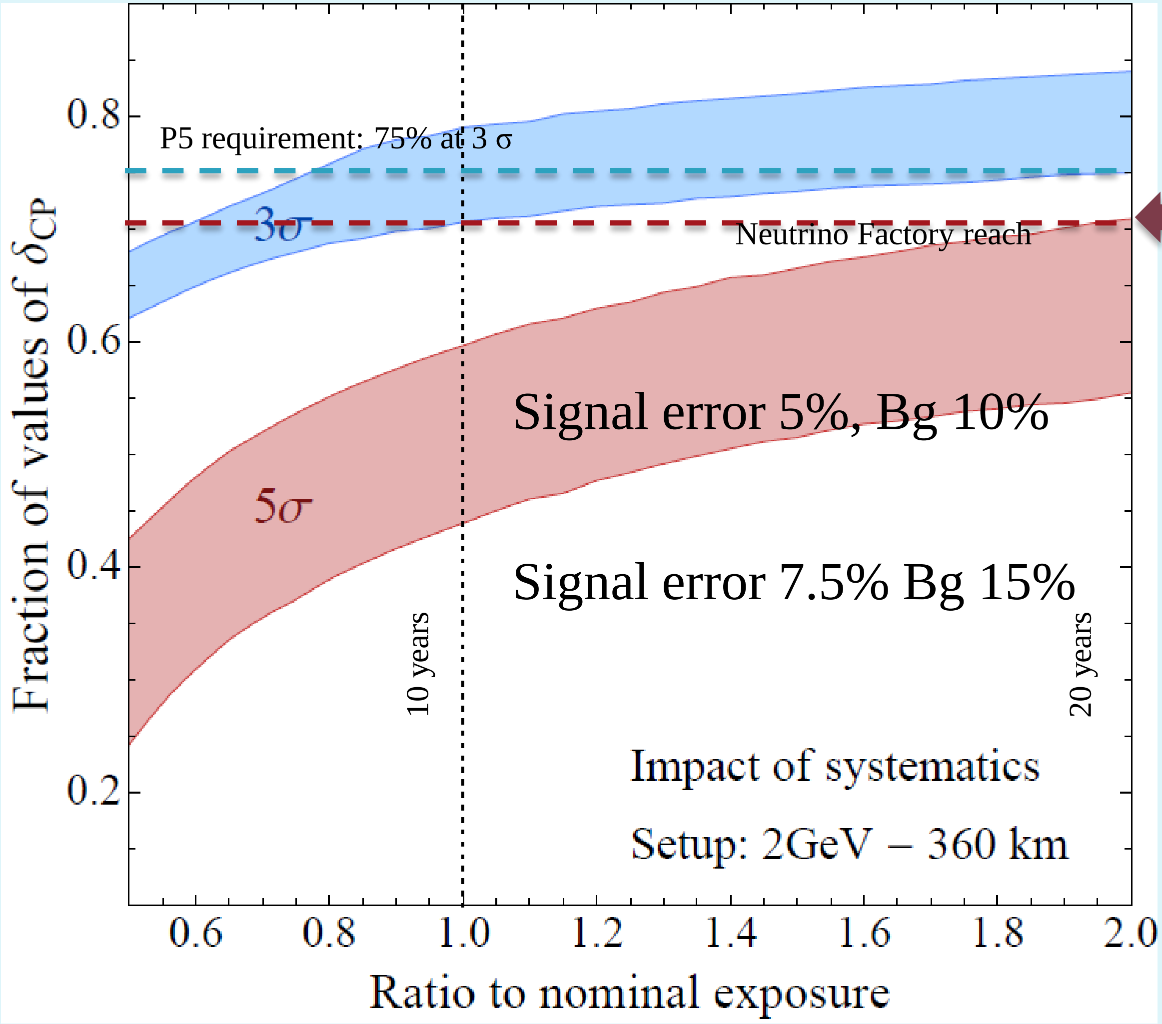
Systematic errors

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)



(courtesy P. Coloma)

Improvement of δ_{CP} coverage with statistics

"Opt." case for systematics