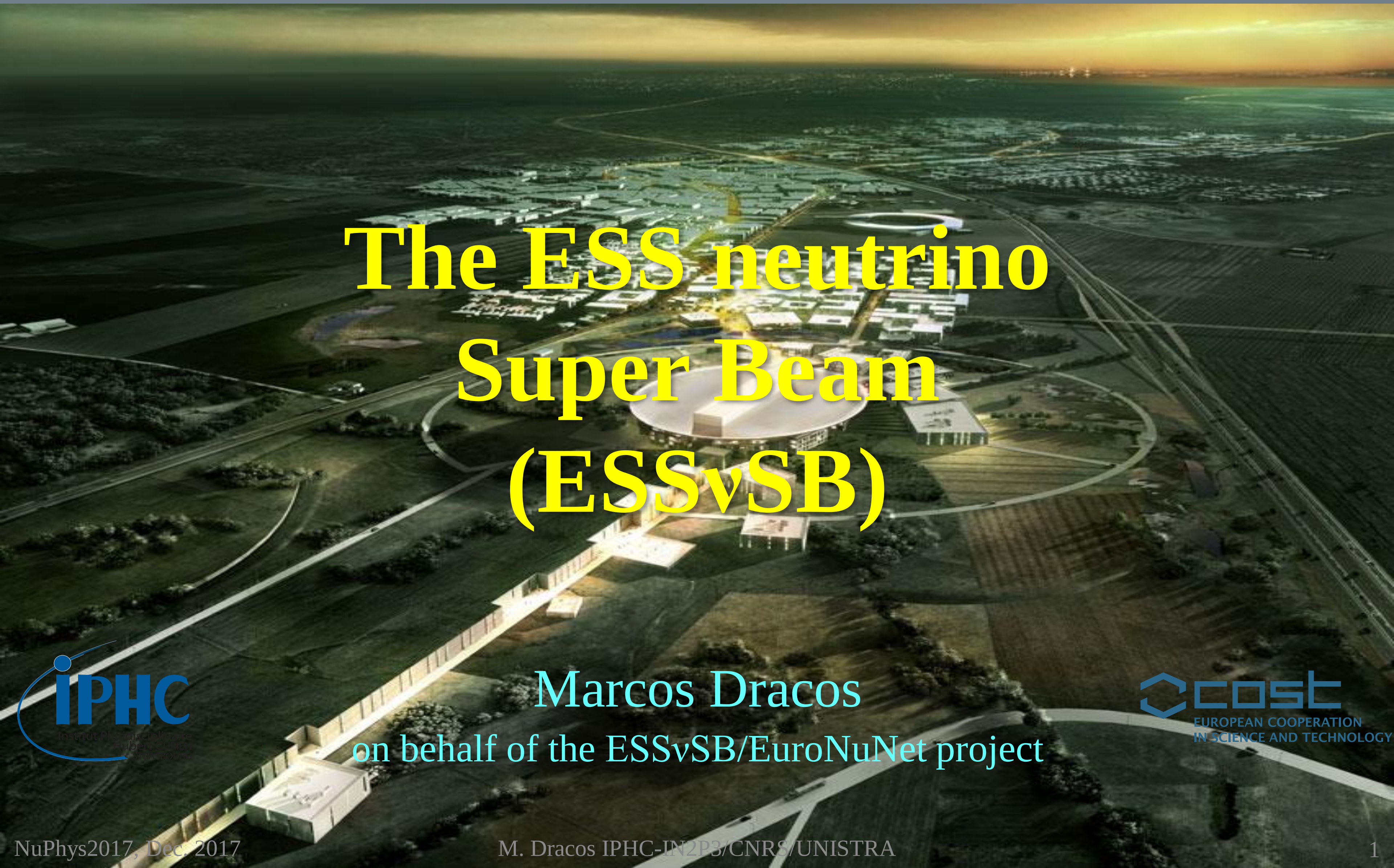


The ESS neutrino Super Beam (ESSνSB)

Marcos Dracos
on behalf of the ESSνSB/EuroNuNet project

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

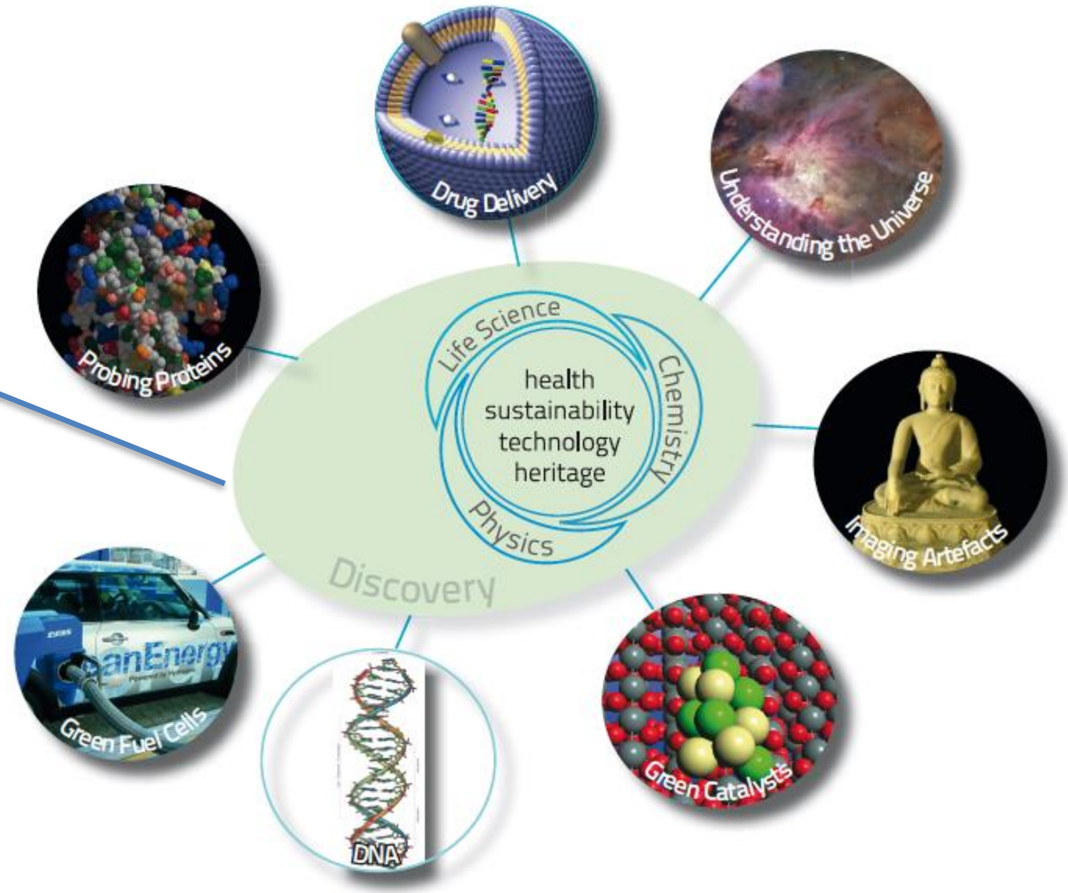
Overview

- The European Spallation Source
- The neutrino beam using the ESS facility
- The needed ESS linac modifications
- Ongoing activities
- Physics performance
- EU support

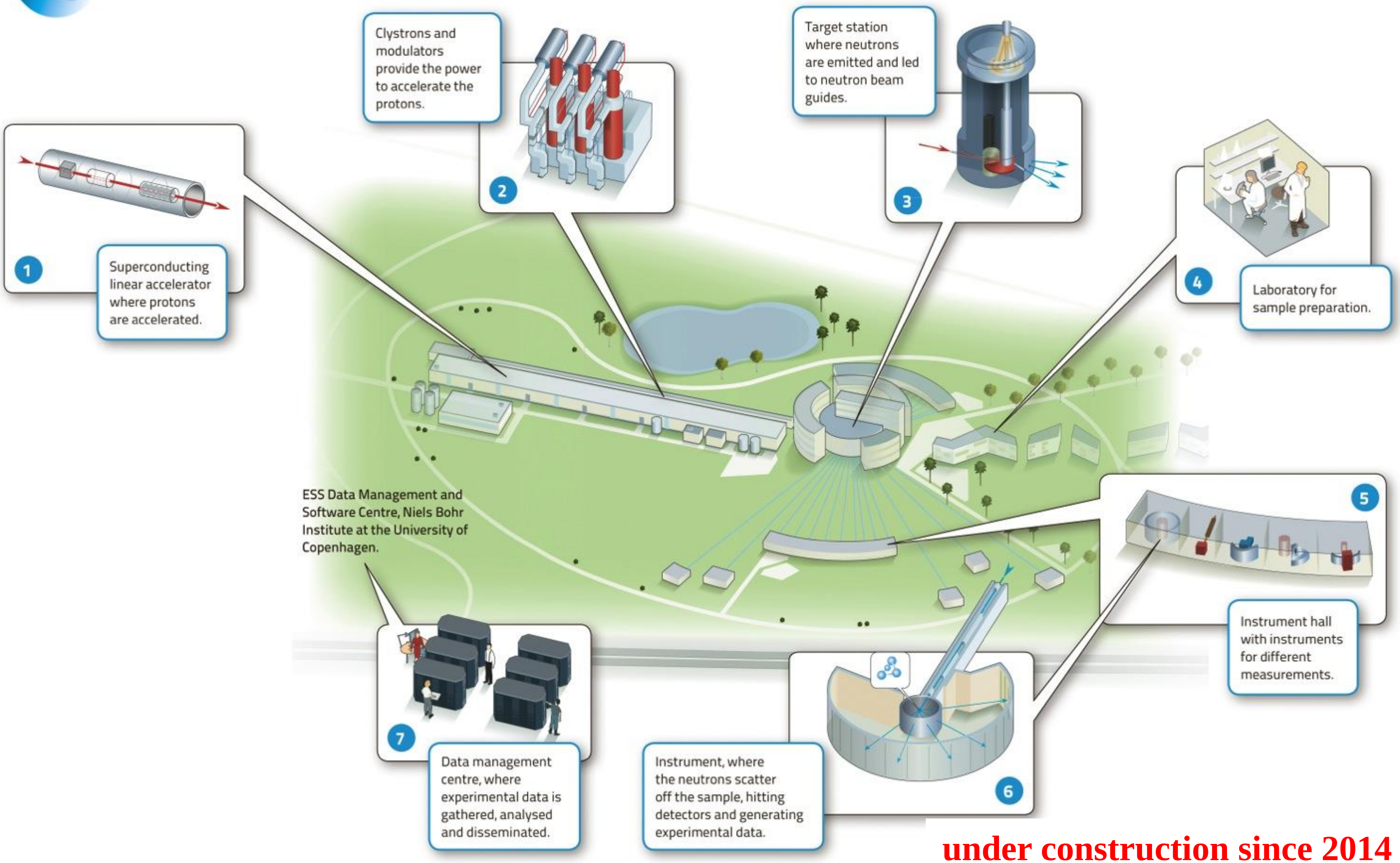
EUROPEAN SPALLATION SOURCE

European Spallation Source

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

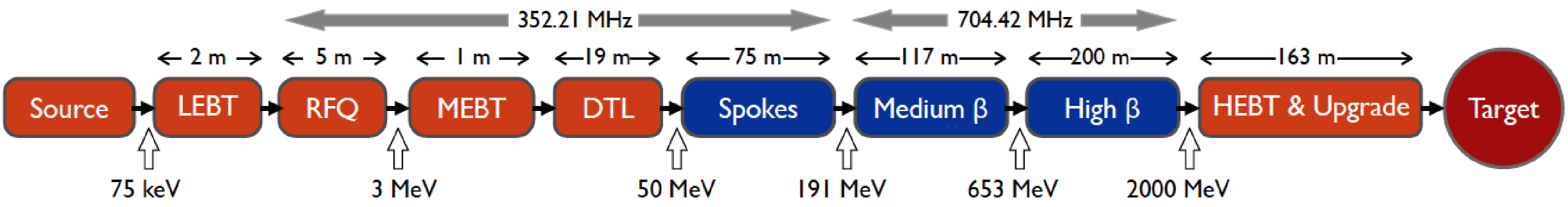


European Spallation Source

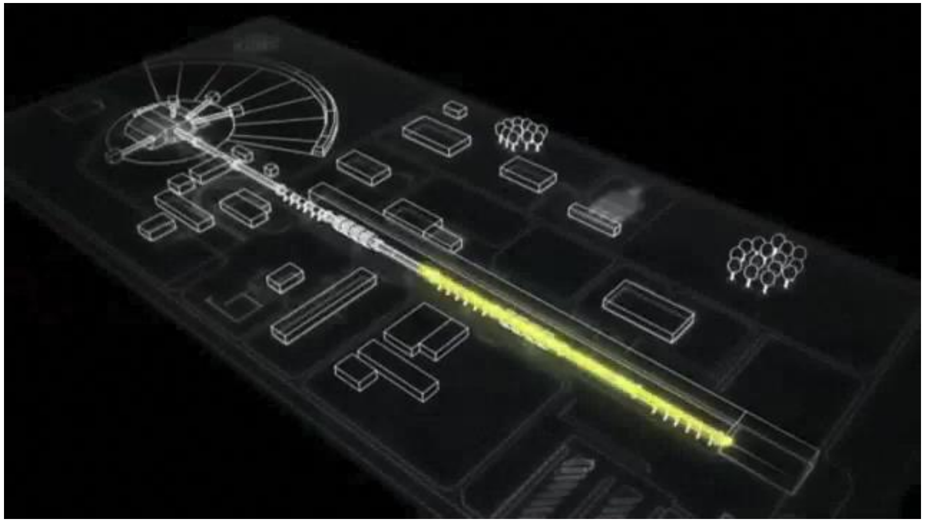


under construction since 2014
(~1.85 B€ facility)

ESS proton linac



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

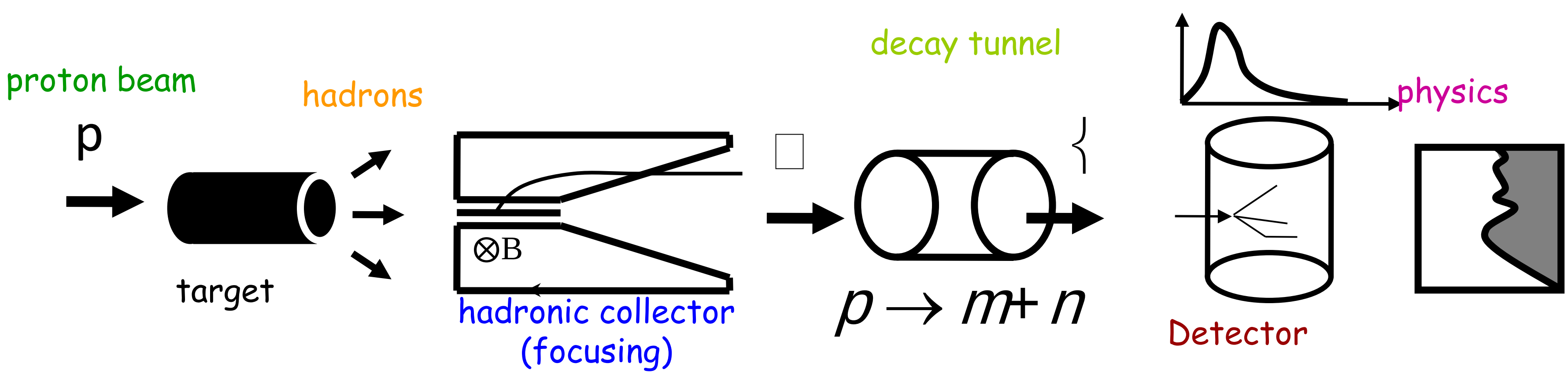


Linac ready by 2023 (full power)

What kind of neutrino beam can we extract using this linac?

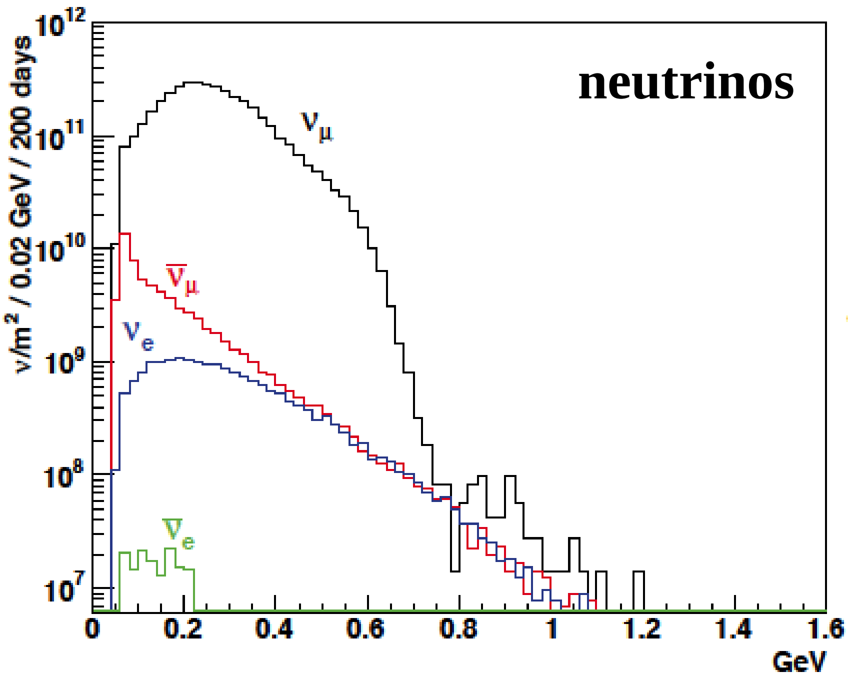
by doubling the linac pulsing rate…

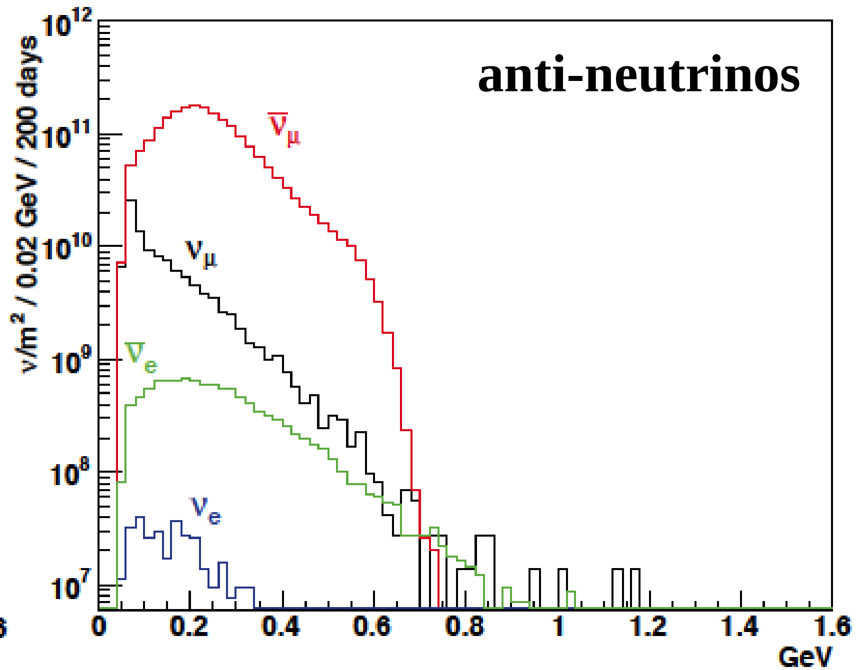
conventional neutrino (super) beam



production of a powerful neutrino beam

ESSνSB ν energy distribution (without optimisation)





- almost pure ν_μ beam
- small ν_e contamination which could be used to measure ν_e cross-sections in a near detector

	positive		negative	
	N_ν $(\times 10^{10})/\mathrm{m}^2$	%	N_ν $(\times 10^{10})/\mathrm{m}^2$	%
ν_μ	396	97.9	11	1.6
$\bar{\nu}_\mu$	6.6	1.6	206	94.5
ν_e	1.9	0.5	0.04	0.01
$\bar{\nu}_e$	0.02	0.005	1.1	0.5

at 100 km from the target and per year (in absence of oscillations)

CP Violating Observables ($\nu_\mu \rightarrow \nu_e$)

$$P_{\nu_\mu\rightarrow\nu_e(\bar{\nu}_\mu\rightarrow\bar{\nu}_e)} = s_{23}^2 \sin^2 2\theta_{13}\left(\frac{\Delta_{13}}{\tilde{B}_\mp}\right)^2 \sin^2\left(\frac{\tilde{B}_\mp L}{2}\right)$$

atmospheric

$$+c_{23}^2 \sin^2 2\theta_{12}\left(\frac{\Delta_{12}}{A}\right)^2 \sin^2\left(\frac{AL}{2}\right)$$

solar

Non-CP terms

$$+\tilde{J}\frac{\Delta_{12}}{A}\frac{\Delta_{13}}{\tilde{B}_\mp}\sin\left(\frac{AL}{2}\right)\sin\left(\frac{\tilde{B}_\mp L}{2}\right)\cos\left(\pm\delta_{CP}-\frac{\Delta_{13}L}{2}\right)$$

interference

CP violating

$$\tilde{J} \equiv c_{13}\sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13},\ \Delta_{ij} \equiv \frac{\Delta m_{ij}^2}{2E_\nu},\ \tilde{B}_\mp \equiv \left|A \mp \Delta_{13}\right|,\ \ A = \sqrt{2}G_F N_e$$

matter effect
⇒ accessibility to mass hierarchy
⇒ very long baseline
(small in our case)

$$\mathcal{A} = \frac{P_{\nu_\mu\rightarrow\nu_e} - P_{\bar{\nu}_\mu\rightarrow\bar{\nu}_e}}{P_{\nu_\mu\rightarrow\nu_e} + P_{\bar{\nu}_\mu\rightarrow\bar{\nu}_e}}$$

≠0 ⇒ CP Violation
be careful, matter effects also create asymmetry

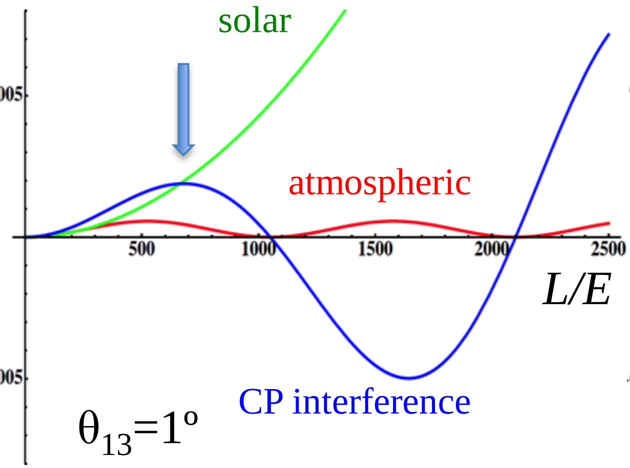
Neutrino Oscillations with "large" θ_{13}

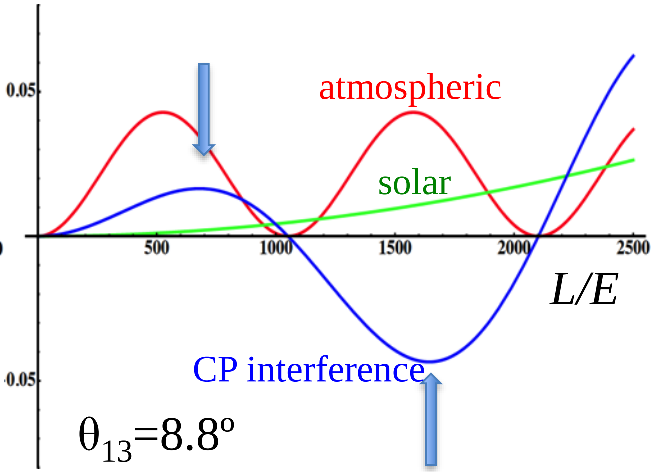
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

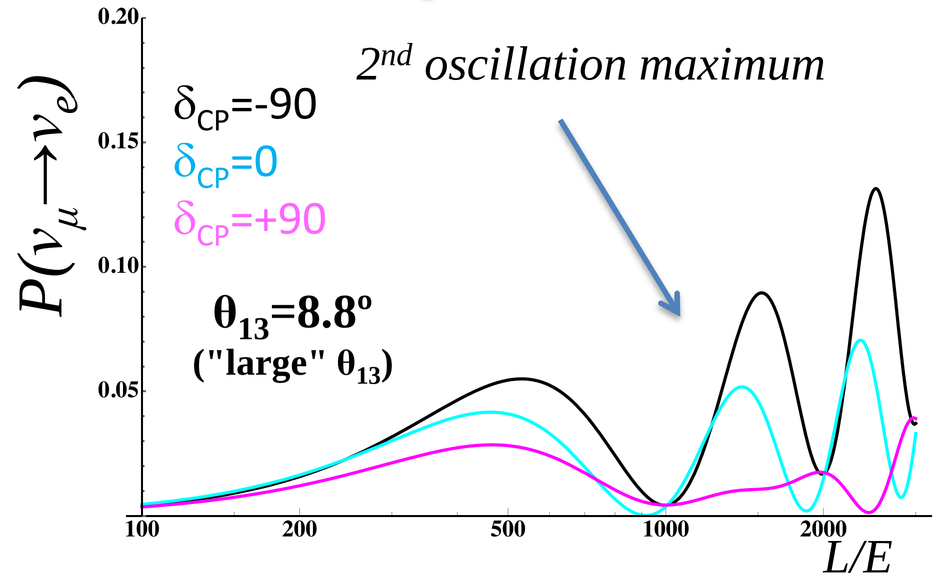
for small θ_{13} 1st oscillation maximum is better

(arXiv:1110.4583)





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



- 1st oscillation max.: $A=0.3\sin\delta_{CP}$
- 2nd oscillation max.: $A=0.75\sin\delta_{CP}$

(see arXiv:1310.5992 and arXiv:0710.0554)

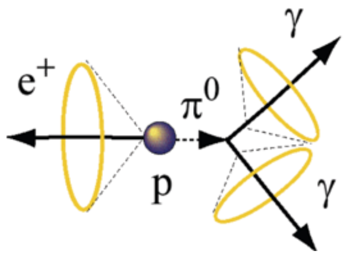
more sensitivity at 2nd oscillation max.

Can we go to the 2nd oscillation maximum using our proton beam?

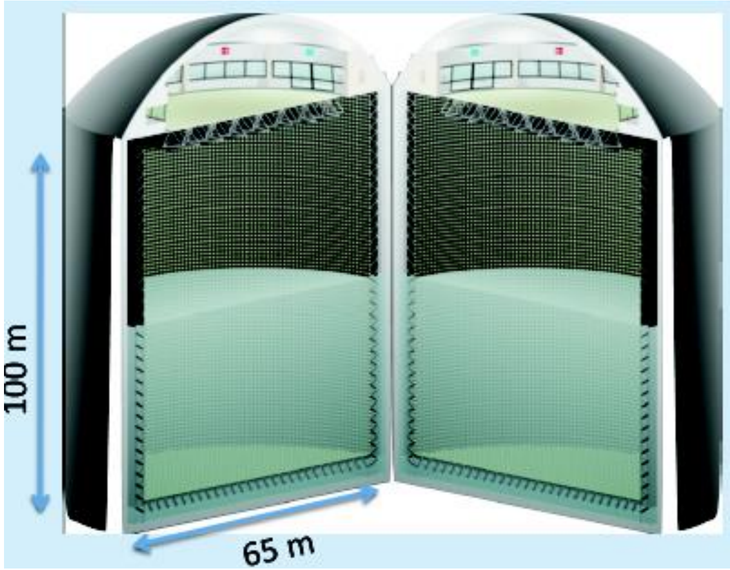
Yes, if we place our far detector at around 500 km from the neutrino source.

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

(arXiv: hep-ex/0607026)



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



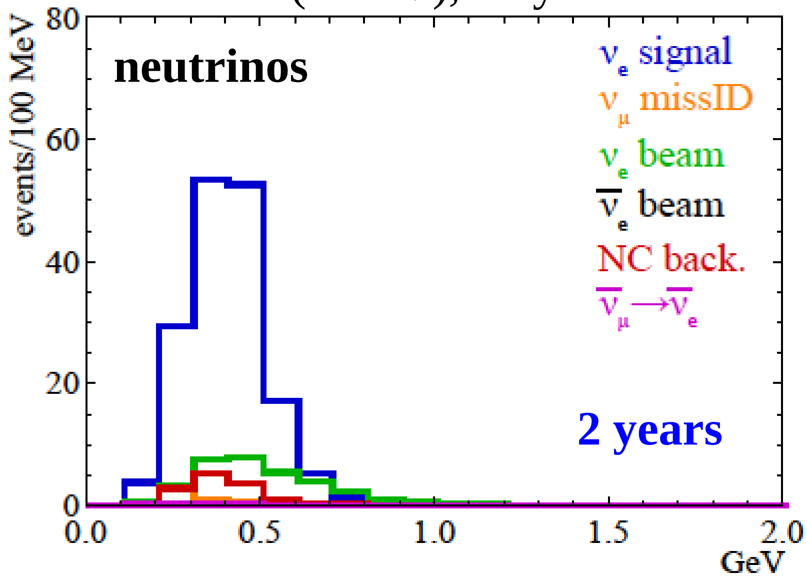
- 500 kt fiducial volume (~20xSuperK)
- Readout: ~240k 8” PMTs
- 30% optical coverage

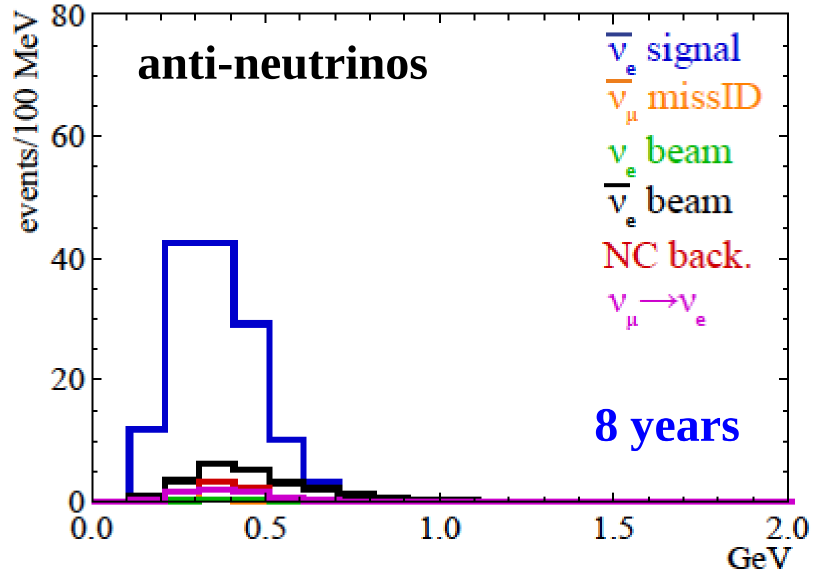
Neutrino spectra

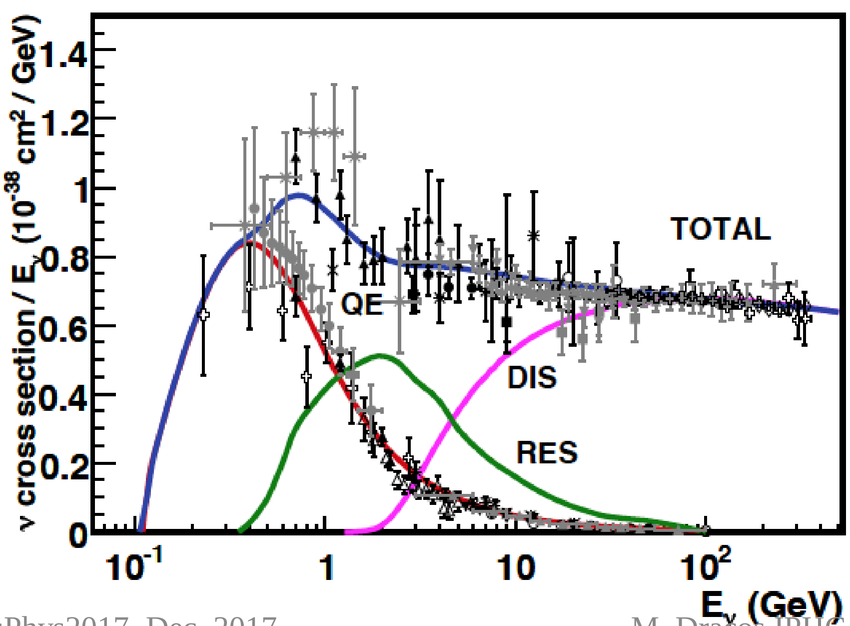
540 km (2 GeV), 10 years

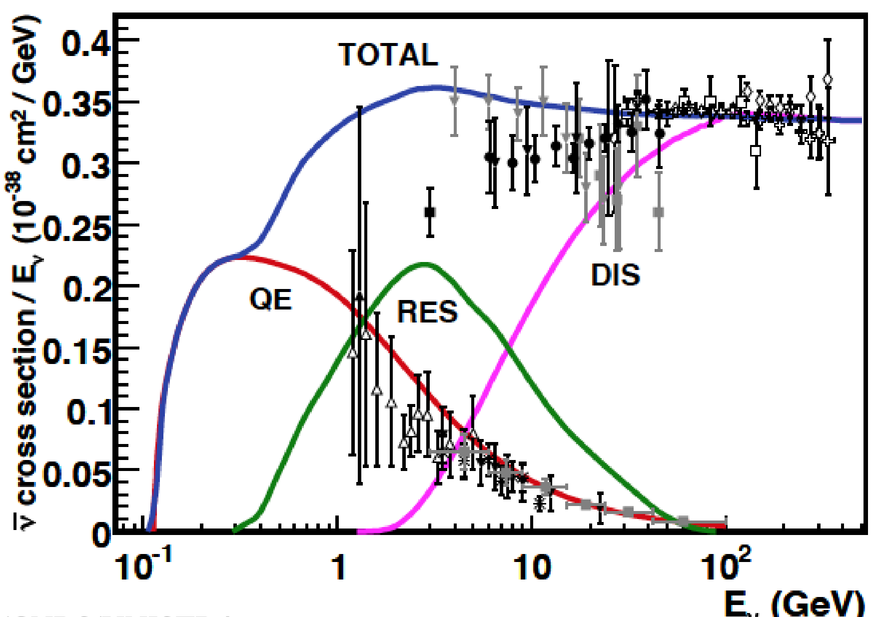
below ν_τ production, almost only QE events

$\delta_{CP}=0$

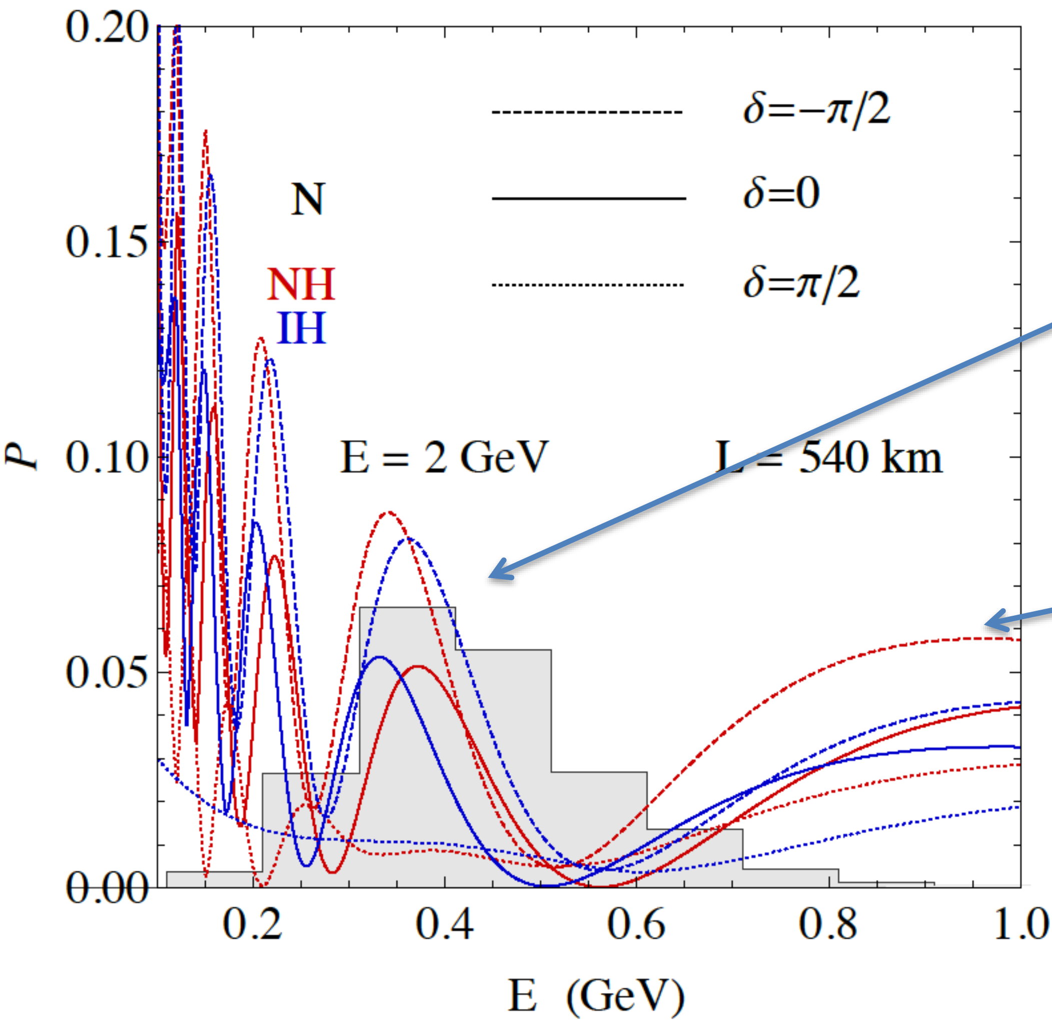








2nd Oscillation max. coverage



2^{nd} oscillation max. well covered by the ESS neutrino spectrum

1^{st} oscillation max.

ESS Linac modifications to produce a neutrino Super Beam

How to add a neutrino facility?

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

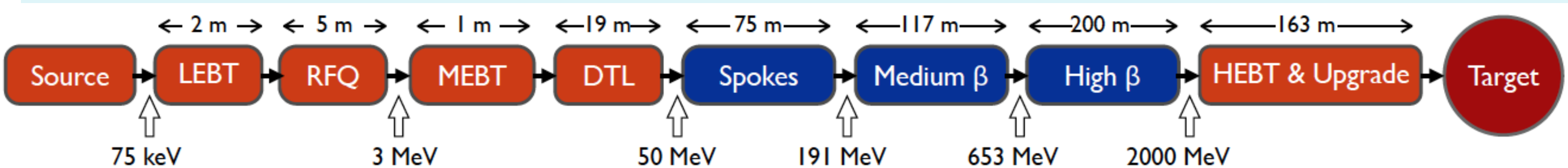
Required modifications of the ESS accelerator architecture for ESSνSB

F. Gerigk and E. Montesinos
CERN, Geneva, Switzerland

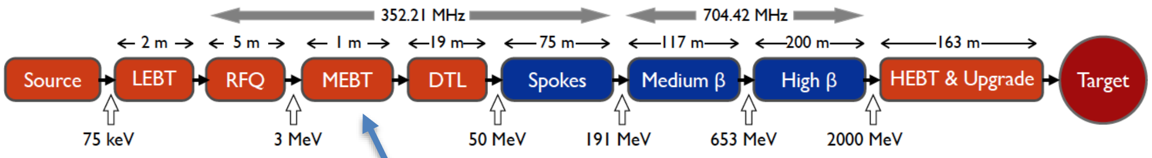
CERN-ACC-NOTE-2016-0050 8 July 2016

Contents

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



Preparing the ESS linac for operation at 10 MW with a 8% duty cycle and 28 Hz pulsing

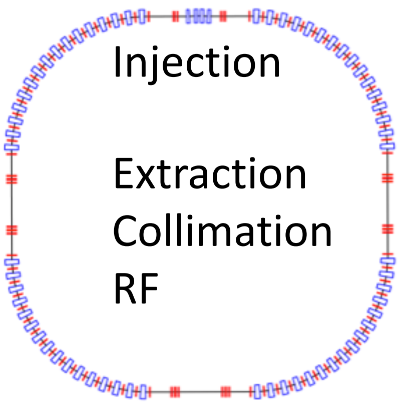


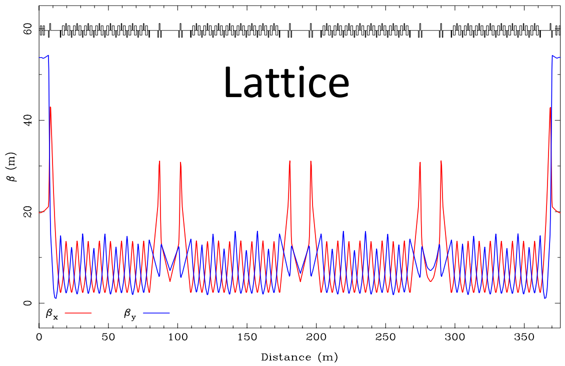
For the medium-beta elliptical-cavity part ESS is planning to use tetrodes. Thales has developed a new screen grid with graded wire thickness making operation at **10 % duty cycle** possible.

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 at 14 Hz and later on will be tested at 28 Hz.

Accumulation Ring

The accumulator is needed to compress to less than few µs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA, power consumption, Joule effect), but also keeping a reasonable size of the ring.



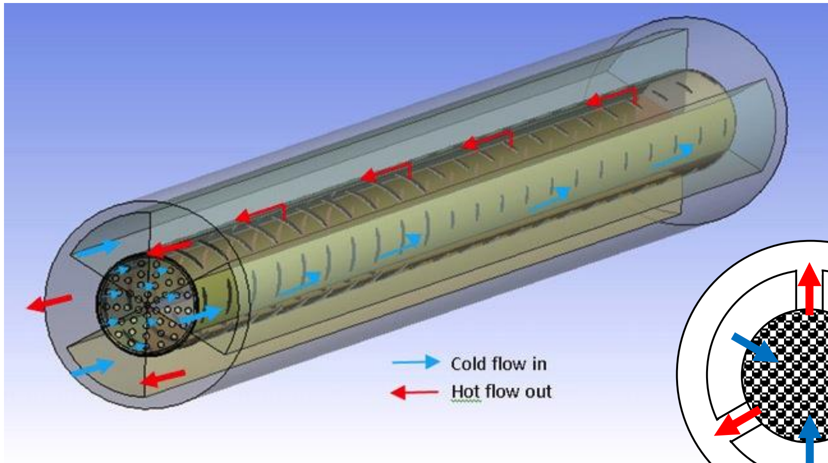


- **Baseline**: **single-ring accumulator**
  - Current studies give a 376 m circumference accumulator ring 1.32µs.
  - 1 ring leads to a very large space–charge **tune–shift** of about **0.75**.
- **Option: 4 superposed rings** located in the same tunnel,
  - Each ring receives 1/4 of the bunches during the multi–turn injection,
  - This will lead to a reduction of the **tune shift** to the level of around **0.2** (acceptable for the 2.86 ms storage time),
  - There has to be enough space between the bunches in the bunch train from the linac to permit the beam distribution system to inject from one ring to the next one,
  - Experience already exists from the CERN PS Booster of using 4 superimposed rings with the aim to avoid high space charge effects.

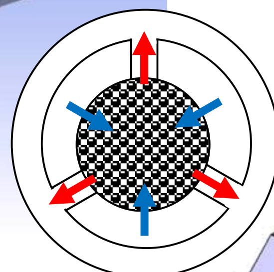
Mitigation of high power effects

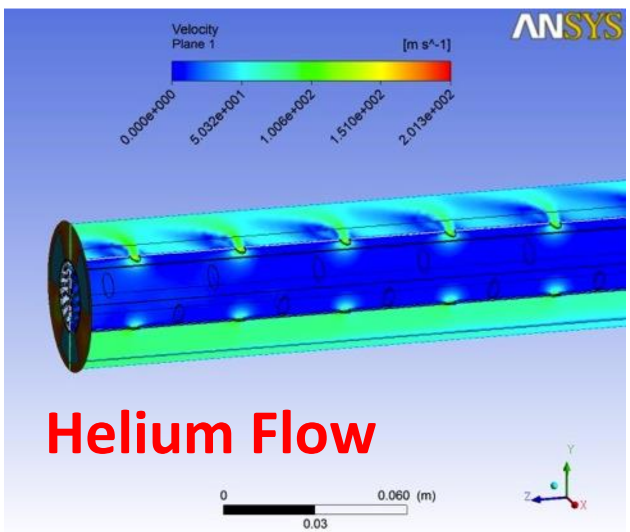
(4-Target/Horn system for EUROν Super Beam)

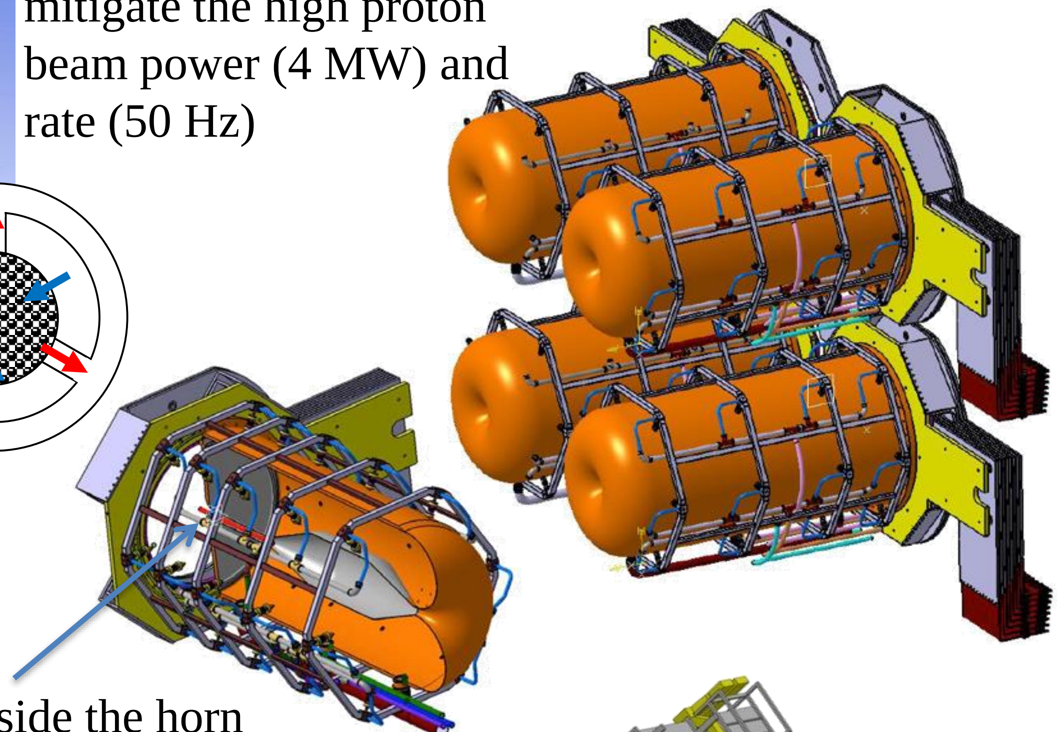
Packed bed canister in symmetrical transverse flow configuration (titanium alloy spheres)



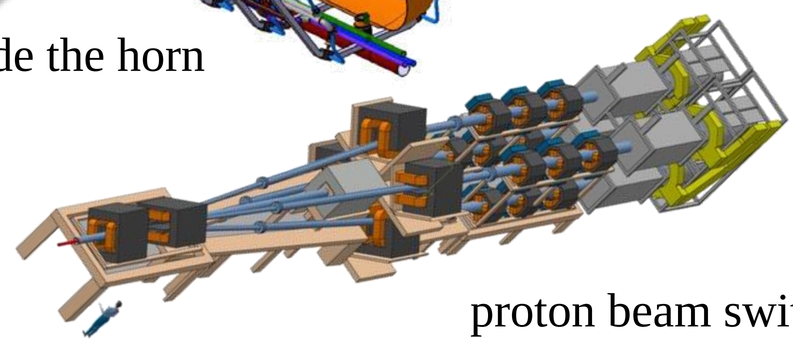
4-target/horn system to mitigate the high proton beam power (4 MW) and rate (50 Hz)







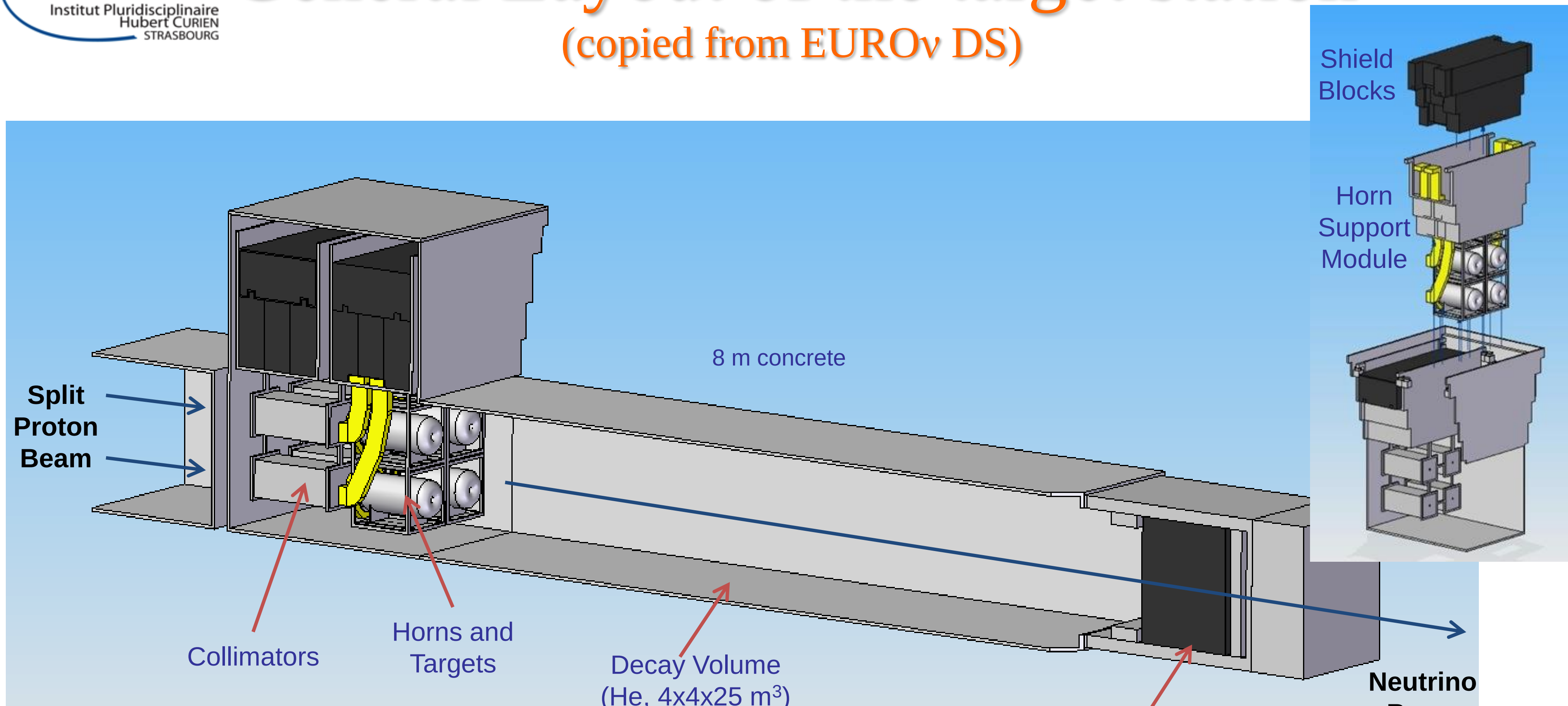
target inside the horn

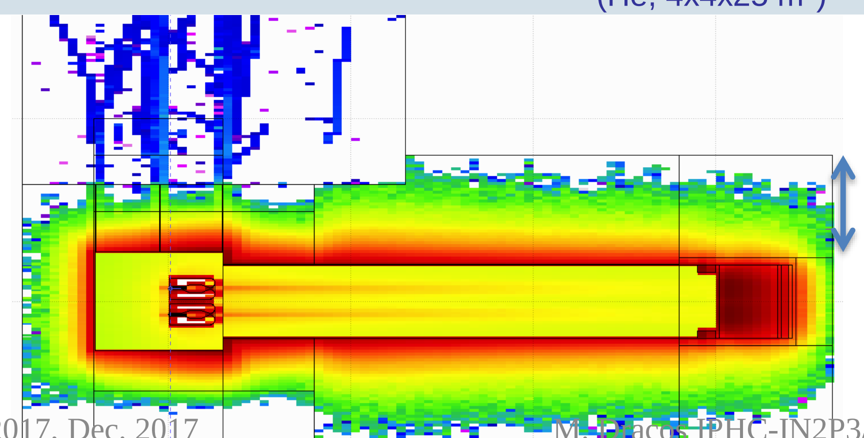


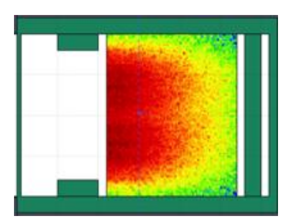
proton beam switchyard

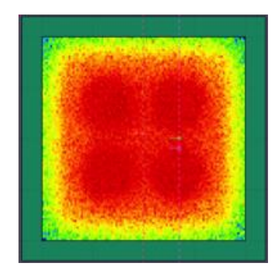
General Layout of the target station

(copied from EUROν DS)

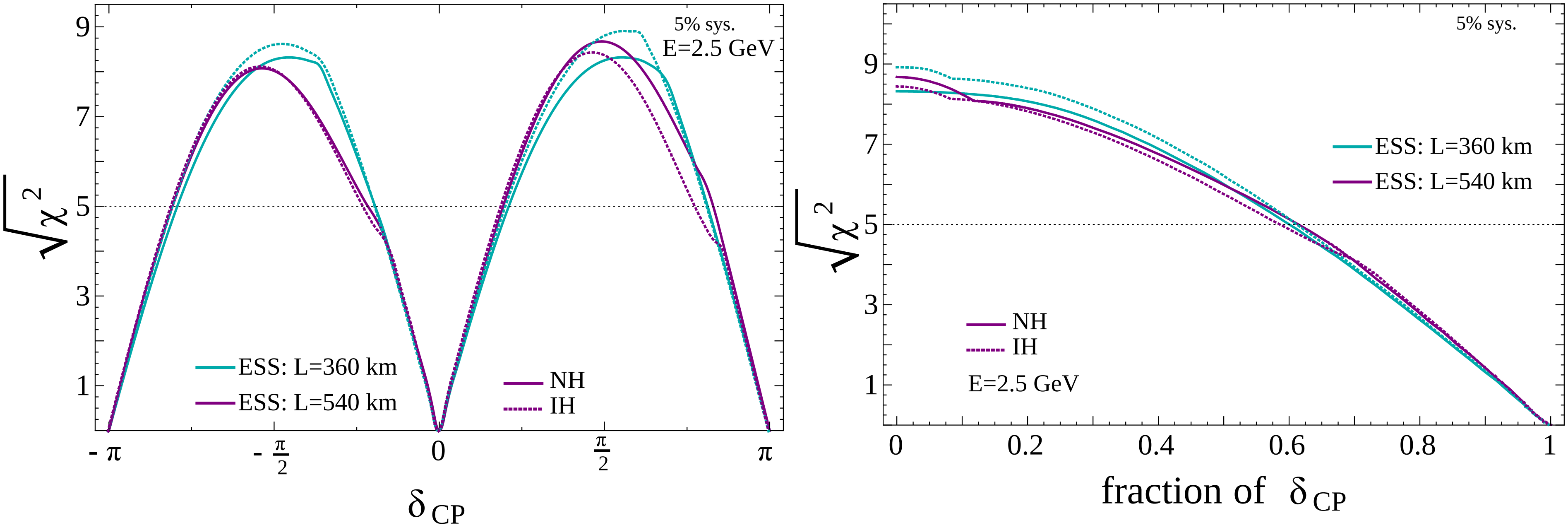








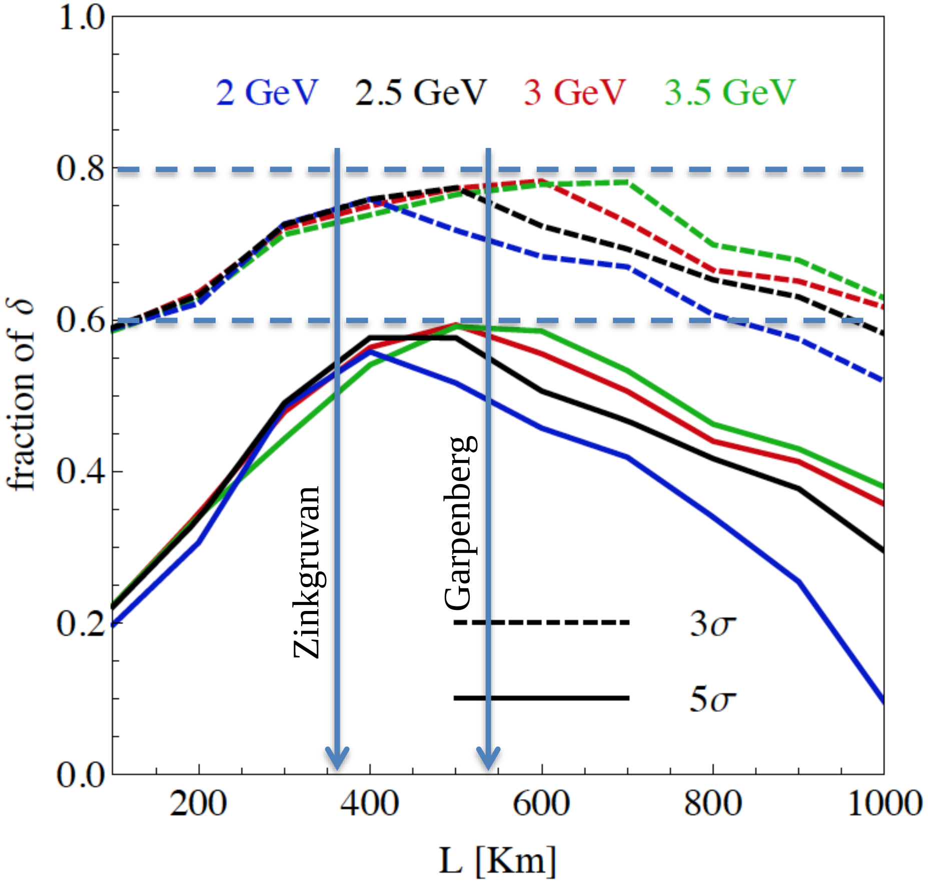
Physics Performance



- little dependence on mass hierarchy (not so long baseline),
- δ_{CP} coverage at 5 σ C.L. up to 60%,
- δ_{CP} accuracy down to 6° at 0° and 180° (absence of CPV for these two values),
- not yet optimized facility.

Which baseline?

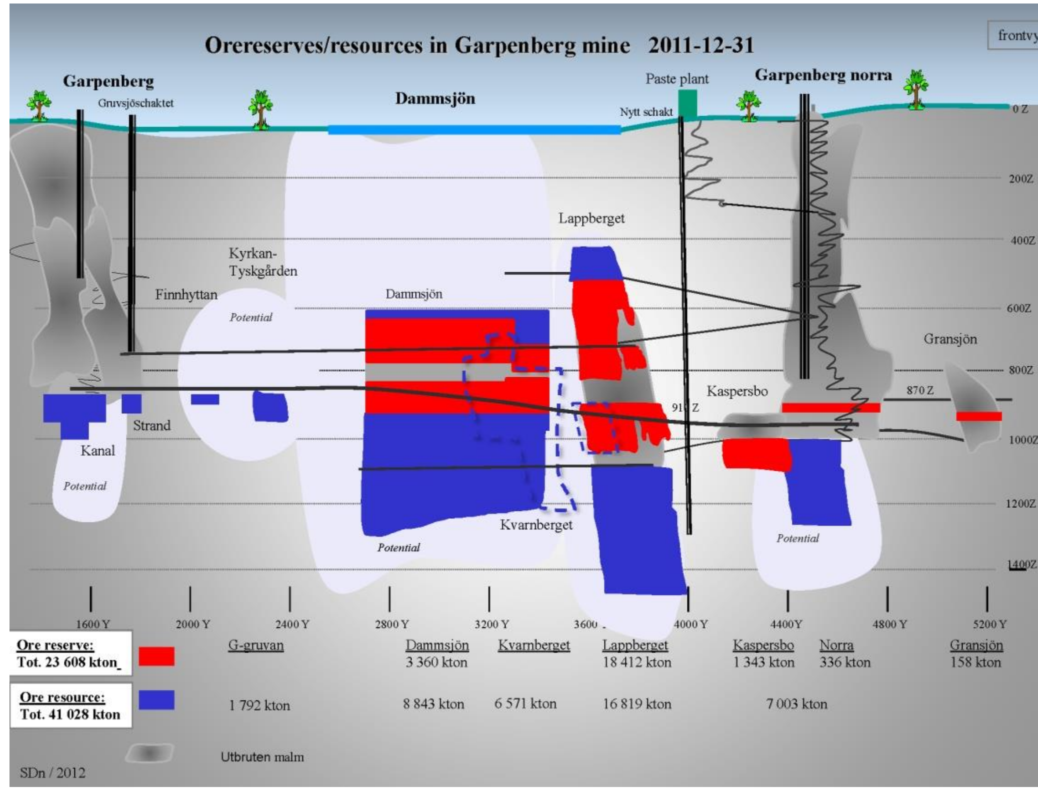
CPV (*Nucl. Phys. B 885 (2014) 127*)



- ~60% δ_{CP} coverage at 5 σ C.L.
- >75% δ_{CP} coverage at 3 σ C.L.
- **systematic errors: 5%/10% (signal/backg.)**

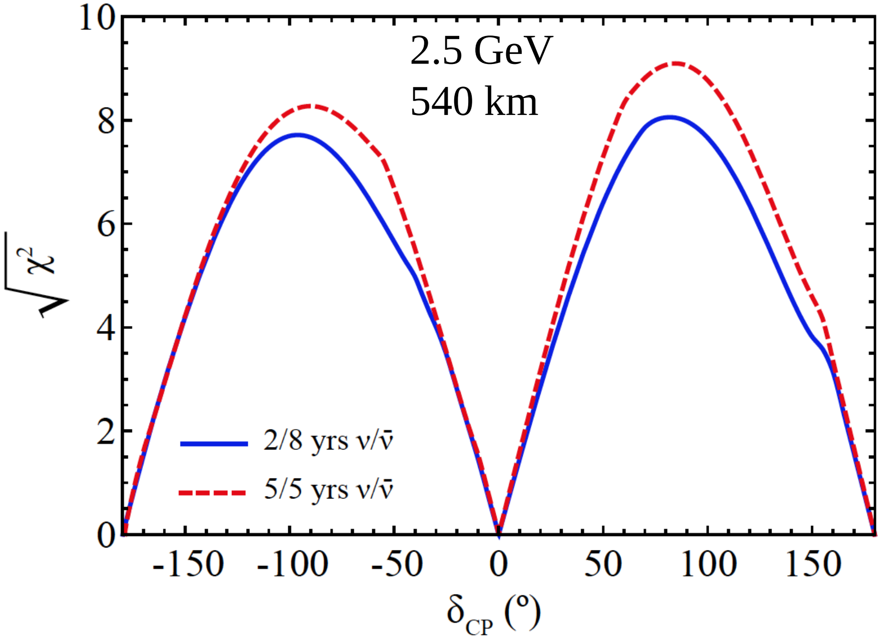
The Garpenberg mine

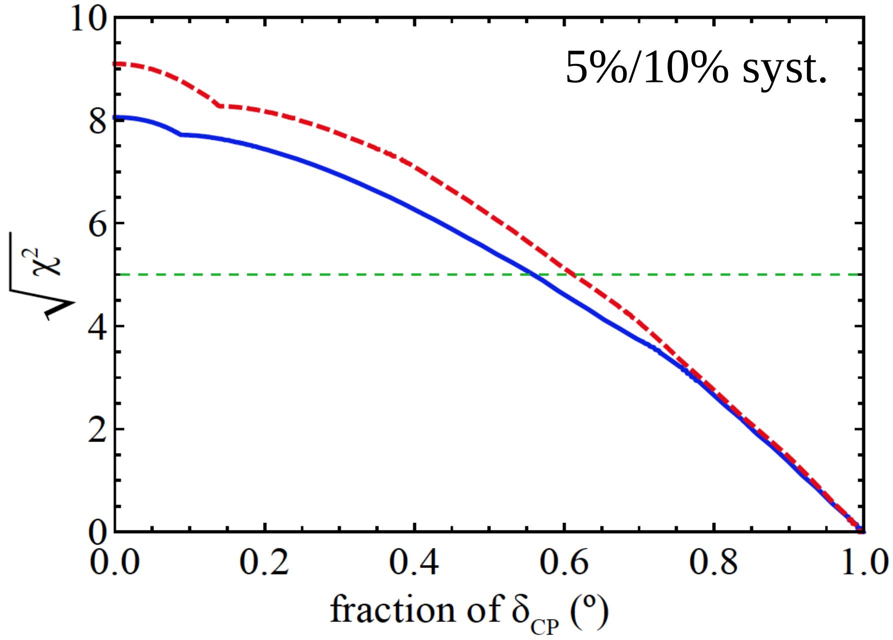
- Distance from ESS Lund **540 km**
- Depth **1232 m**
- Truck **access tunnel**
- **Hoist shaft** free to use by ESSnuSB
- Rock-engineering prospection and studies in the Garpenberg-mine granite-zones



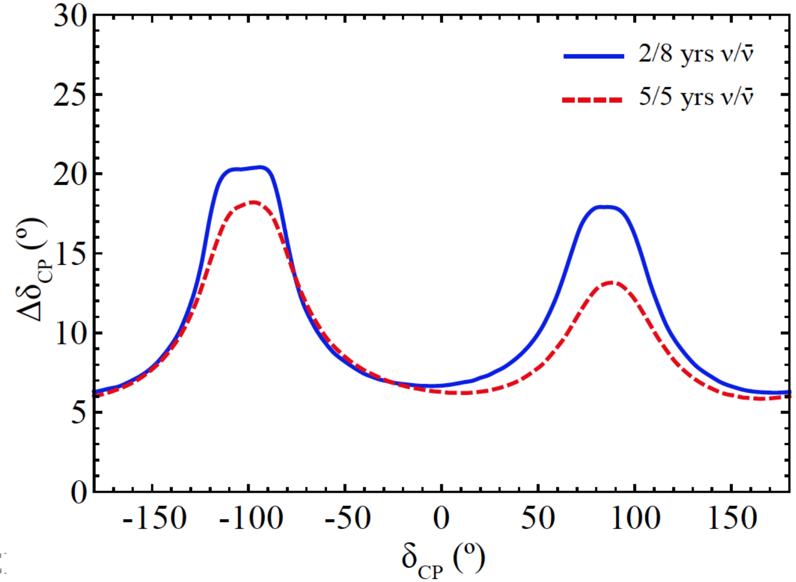
The owner of the Garpenberg mine, Boliden AB, has signed an MoU with Uppsala University, permitting agents of the University to access and make investigation in the Garpenberg mine.

Optimisations to be done





- **optimizations are coming**:
  - with the present configuration: 5/5 yrs seems better than 2/8 yrs,
  - horn shape,
  - detector efficiency (cheaper PMTs with higher QE),
  - near detector.



Garpenberg Research Infrastructure Project for Neutrinos (GRIPnu)

A Socio-economic and Industrial Study of the Consequences of constructing a World-leading Neutrino Detector in Garpenberg in Region Dalarna commissioned by Garpenberg Council

Translated from Swedish by Colin Carlile, Uppsala University March 2017

Summary Description of the GRIPnu project

Project Leader: Hedemora Enterprise AB

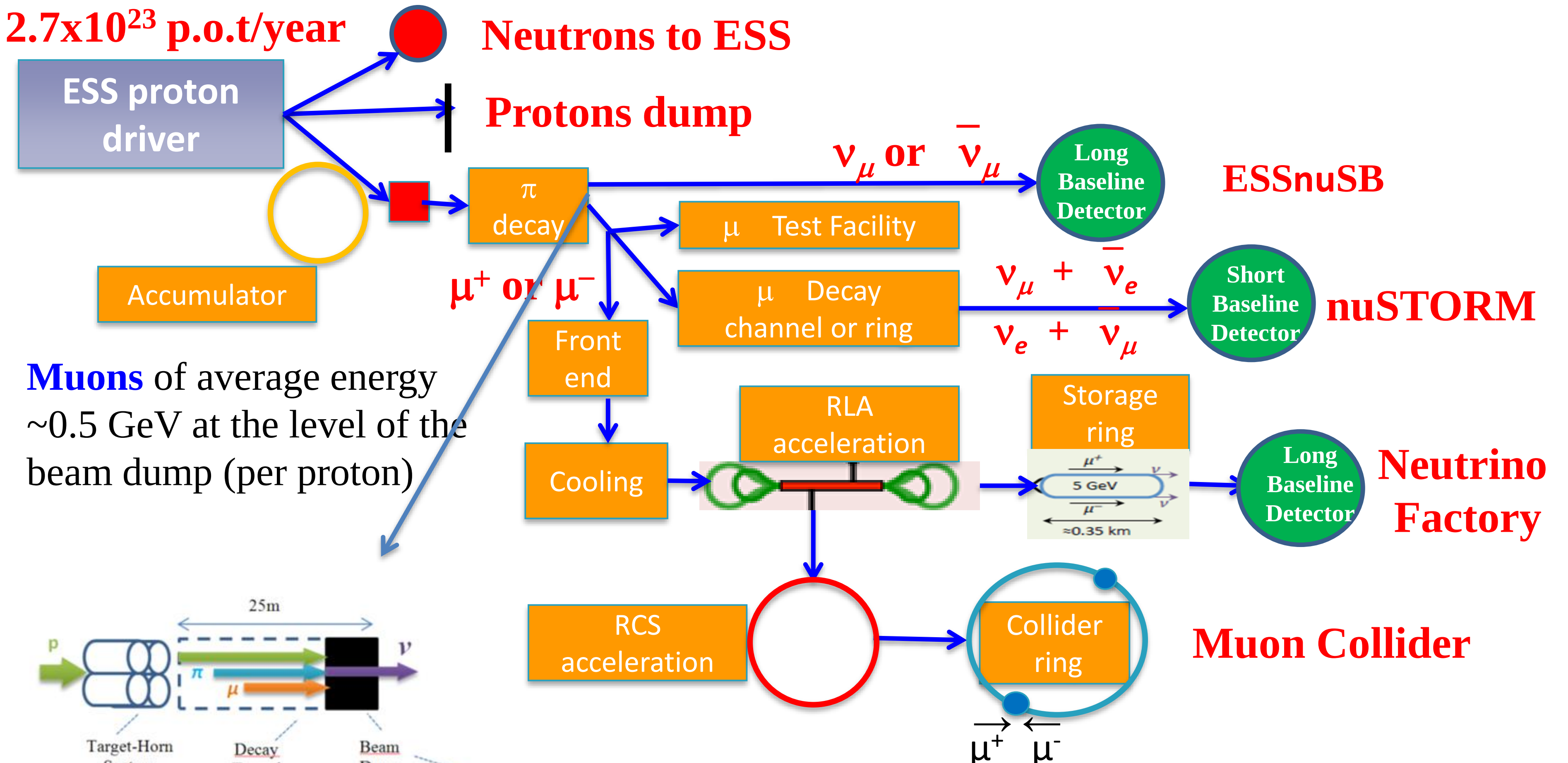
Geography: North Central Sweden, Skåne-Blekinge and East Central Sweden

Type of project: National Regional funds programme, Investment Priority 1b

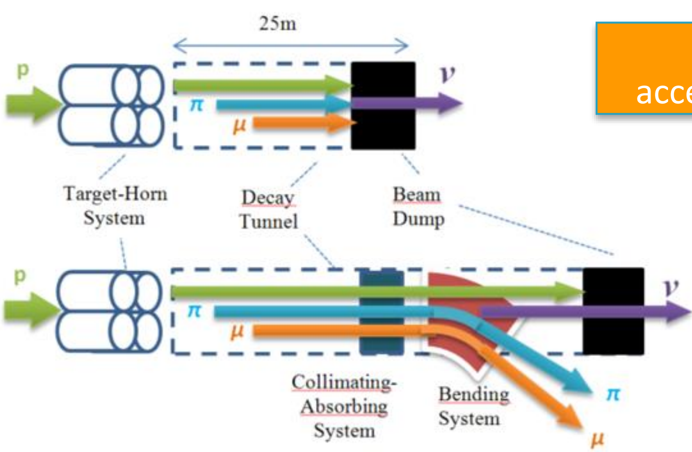
The national strategy for ESS, the European Spallation Source, indicates that the very significant investment in international research infrastructures that is taking place in southern Sweden will also be reflected more widely within Sweden. The GRIPnu project enables the ESS venture to add a second node which would have significant positive effects in central Sweden, and enable contacts to be established between both academia and industry. The ESS accelerator will be the world's most powerful accelerator with a beam power of 5 MW. A European research consortium ESSnuSB, within the framework of the EU COST Action, has been active since 2012, planning an ambitious world-leading research project on neutrinos, which is based upon the use of the ESS accelerator in Lund, and within which the FREIA Laboratory in Uppsala, currently is strongly committed.

Table of Contents

ESS neutrino and muon facility

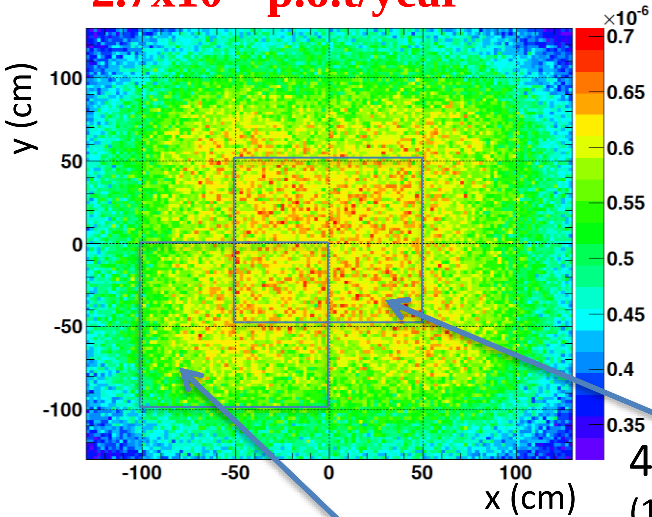


Muons of average energy ~0.5 GeV at the level of the beam dump (per proton)



Muons at the level of the beam dump

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



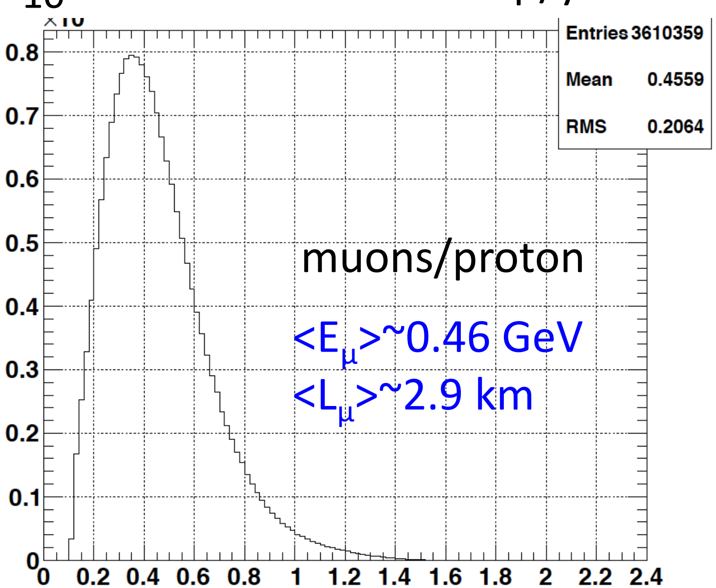
muons at the level of the beam dump (per proton)

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

4.1x10^{20} μ/year

more than 4x10^{20} μ/year from ESSS compared to 10^{14} μ used by all experiments up to now (10^{18} μ for COMET in the future).

10^{-3}



muons/proton

$<E_\mu>\sim 0.46$ GeV

$<L_\mu>\sim 2.9$ km

x (cm)

- 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 using a near detector,
- low energy nuSTORM,
- Neutrino Factory,
- **Muon Collider**.

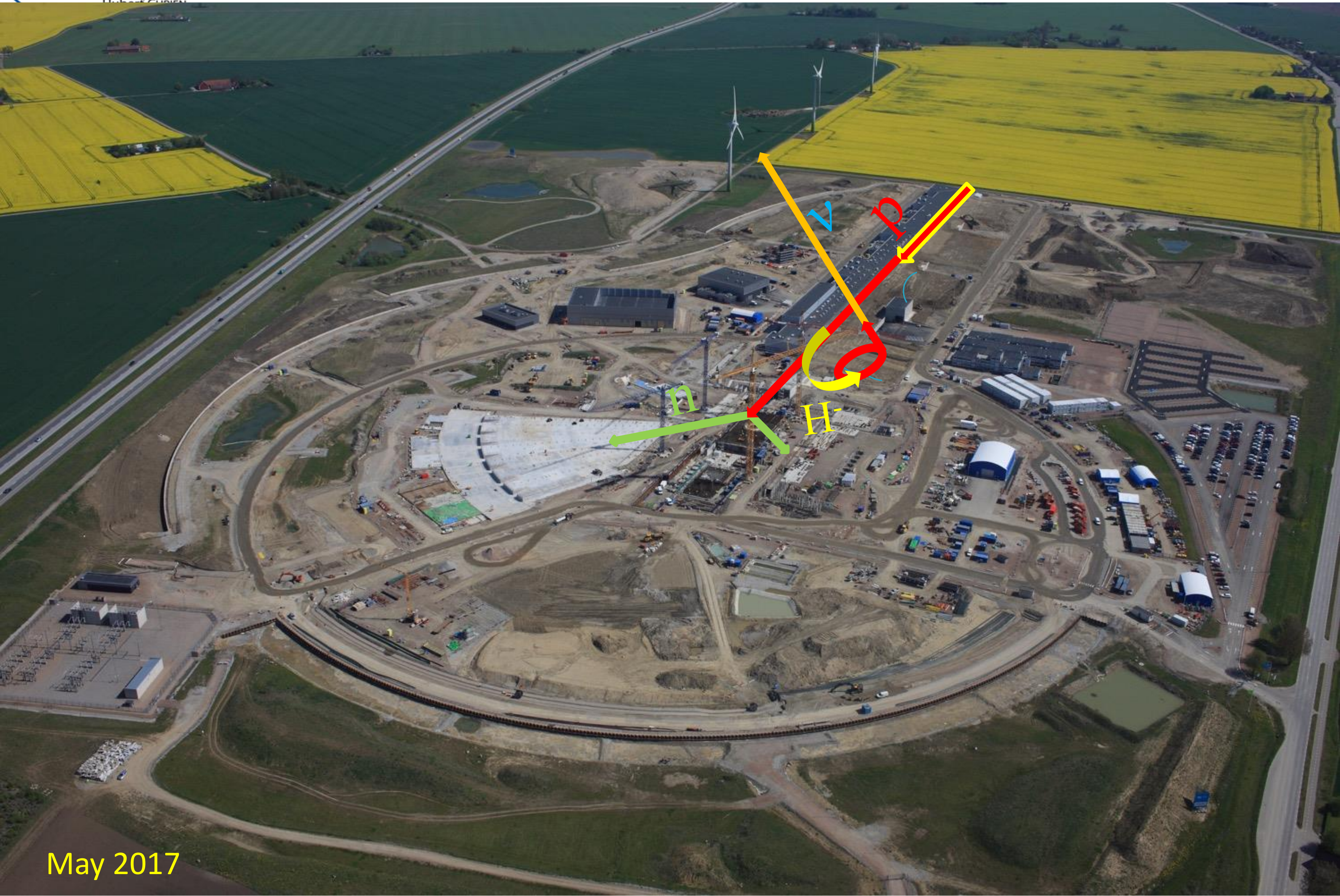
ESS under construction

Linac

Beam Line Gallery

target monolith

ESS construction site

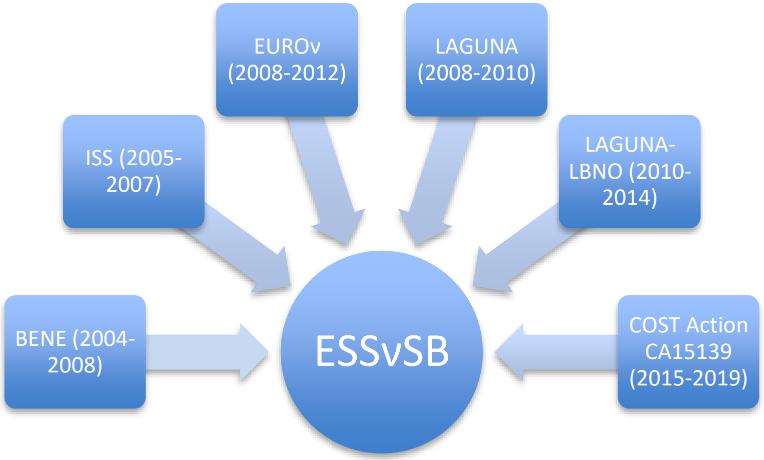


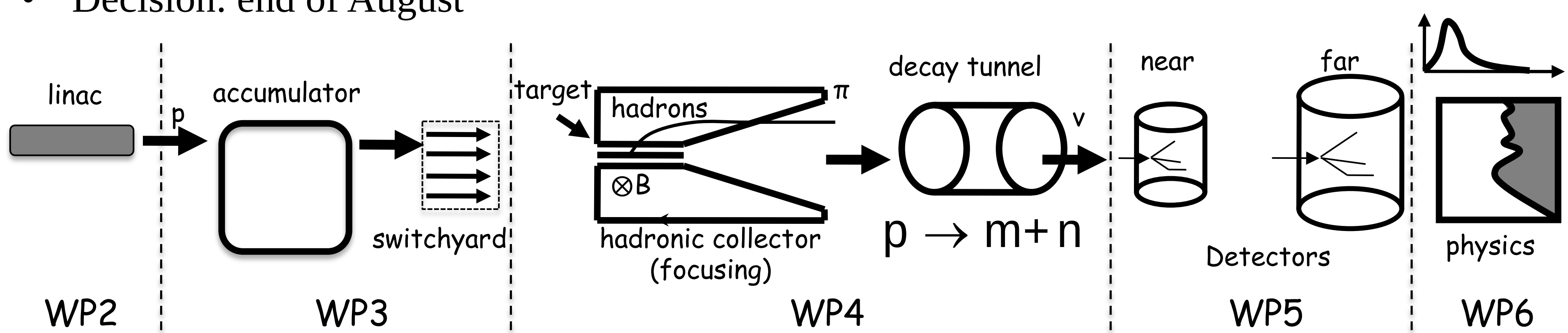
ESSνSB at the European level

- **COST application for networking has been succeeded: CA15139 (2016-2019)**
  - **EuroNuNet** : *Combining forces for a novel European facility for neutrino-antineutrino symmetry violation discovery* (**http://www.cost.eu/COST_Actions/ca/CA15139**)
  - **Major goals of EuroNuNet**:
    - to aggregate the community of neutrino physics in Europe to study the ESSνSB concept in a spirit of inclusiveness,
    - to impact the priority list of High Energy Physics policy makers and of funding agencies to this new approach to the experimental discovery of leptonic CP violation.
    - 13 participating countries (network still growing).

ESSvSB at the European level

- A **H2020** EU **Design Study** has been submitted end of March (Call INFRADEV-01-2017)
  - **Title of Proposal**: Discovery and measurement of leptonic CP violation using an intensive neutrino Super Beam generated with the exceptionally powerful ESS linear accelerator
  - **Duration: 4 years**
  - **Total cost: 4.7 M€**
  - **Requested budget: 3 M€**
  - 15 participating institutes from 11 European countries including CERN and ESS
  - 6 Work Packages
  - Decision: end of August





Design Study ESSvSB

EUROPEAN COMMISSION
DIRECTORATE-GENERAL RESEARCH & INNOVATION

Directorate B - Open Innovation and Open Science
RTD.B.4

approved!

Brussels,

Marine MOGUEN-TOURSEL
CENTRE NATIONAL DE LA
RECHERCHE SCIENTIFIQUE CNRS
RUE MICHEL ANGE 3
75794 PARIS
FRANCE

Subject: Horizon 2020 Framework Programme
Call for proposals: H2020-INFRADEV-2016-2017 (H2020-INFRADEV-2017-1)
Proposal: 777419 — ESSnuSB
Evaluation result letter — GAP invitation letter

Dear Madam/Sir,

I am writing in connection with your proposal for the above-mentioned call.

Having completed the **evaluation**, we are pleased to inform you that your proposal has **passed this phase** and that the Commission would now like to **start grant preparation**.

Please find enclosed the evaluation summary report (ESR), based on the comments and opinion of the experts that evaluated the proposal for the Commission.

Design Study ESSνSB (2018-2021)

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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

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

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

very supportive letter from ESS director

- Grant Agreement already signed,
- Official start date 1st of January 2018.

ESSνSB has already started engaging postdocs.

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

ESSvSB kick-off meeting in Lund

ESSnuSB kick-off meeting

15-16 January 2018
European Spallation Source ERIC
Europe/Stockholm timezone

- Overview
- Scientific Programme
- Timetable
- Contribution List
- Author List
- My Conference
- Registration
  - Modify my Registration
- Participant List
- Accommodation
- How to get to Lund and ESS

Support

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The kick-off meeting of the EU project ESSnuSB will take place at ESS in Lund (Sweden) the 15th and 16th of January 2018.

The first day (14:00-18:00) will be devoted to the Governing Board meeting where decisions have to be taken mainly concerning the project organisation. The presence of one representative per institute is essential.

During the second day (09:00:13:00), the Work Packages will have the occasion to present their organisation and objectives.

Please, feel free to spread this information to all interested people in your institute or institution.

Please register to the meeting at your earliest convenience, but latest on December 19. As there is Christmas and New Year in between it would be good to know number of participants before this.

NB that Accommodation needs to be confirmed by you, latest on January 1st. After this date they will release the room booking. If you are late, you can still book the rooms for the ESS price, if they still have availability. If so, please refer to Caroline Prabert to get the ESS price.

There is a possibility that a visit to the Accelerator tunnel can be arranged the second day when the meeting will be held at the construction site office. Do sign up for this if you are interested, but nothing can be guaranteed today, due to what work will be ongoing that date.

Wishing you all welcome.
Marcos Dracos

You are welcome

https://indico.esss.lu.se/event/965/overview

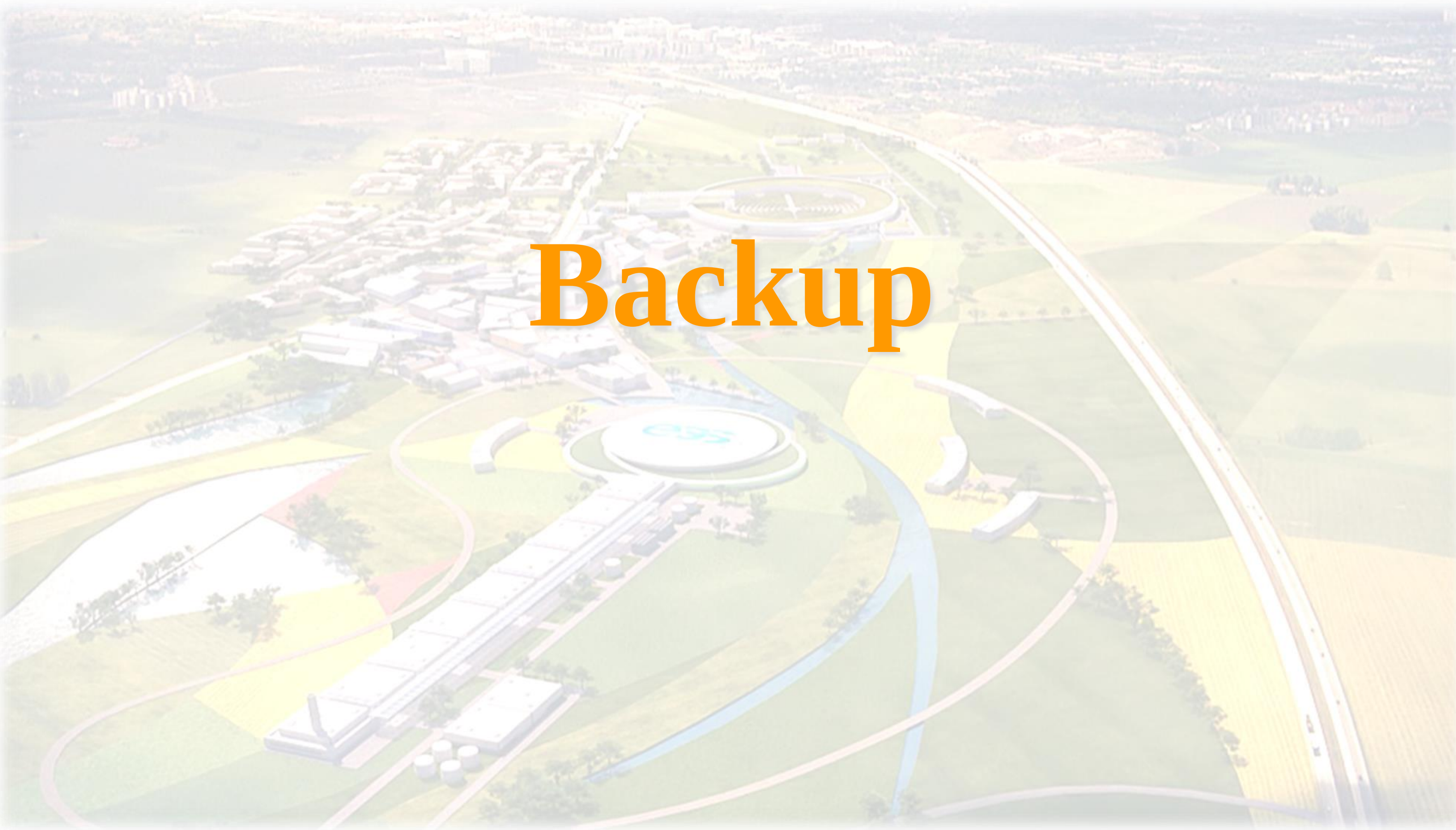
Starts 15 Jan 2018 14:00

European Spallation Source ERIC

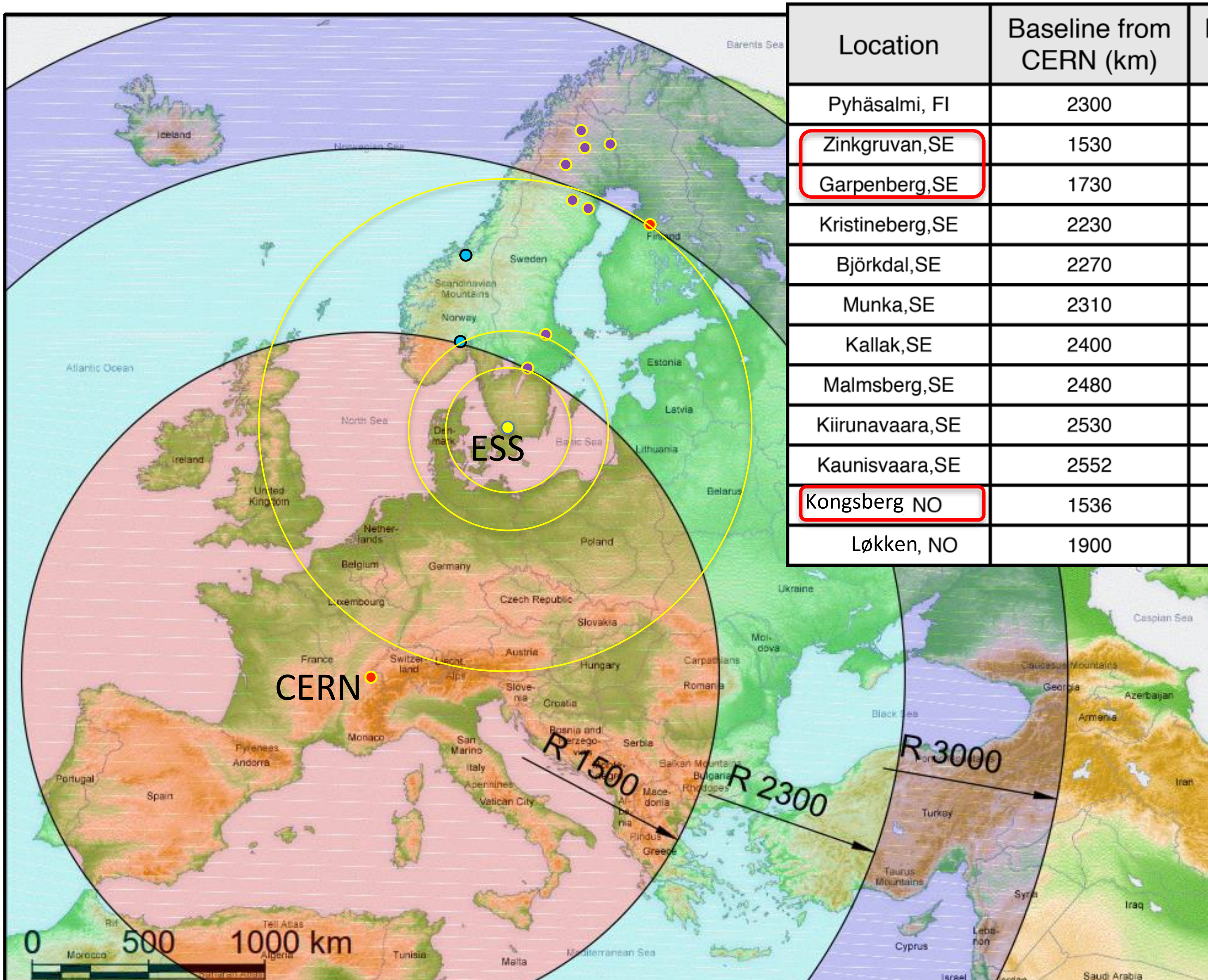
Conclusion

- Significantly better CPV sensitivity at the 2nd oscillation maximum.
- ESS will have enough protons to go to the 2nd oscillation maximum and increase its CPV sensitivity.
- CPV: 5 σ could be reached over 60% of δ_{CP} range (ESSνSB) with large potentiality.
- Large associated detectors have a rich astroparticle physics program.
- The European Spallation Source Linac will be ready in less than 8 years (5 MW, 2 GeV proton beam by 2023), upgrade decisions by this moment.
- Rich muon program.
- COST network project CA15139 supports this project.
- The EU-H2020 Design Study ESSνSB is approved and will start soon.

Backup



Possible locations for far detector



Location	Baseline from CERN (km)	Baseline from Protvino (km)	Baseline from ESS (km)
Pyhäsalmi, FI	2300	1160	1140
Zinkgruvan,SE	1530	1420	360
Garpenberg,SE	1730	1300	540
Kristineberg,SE	2230	1530	1080
Björkdal,SE	2270	1450	1100
Munka,SE	2310	1620	1160
Kallak,SE	2400	1700	1260
Malmsberg,SE	2480	1620	1320
Kiirunavaara,SE	2530	1700	1380
Kaunisvaara,SE	2552	1580	1390
Kongsberg NO	1536	1740	500
Løkken, NO	1900	1800	840

LAGUNA sites

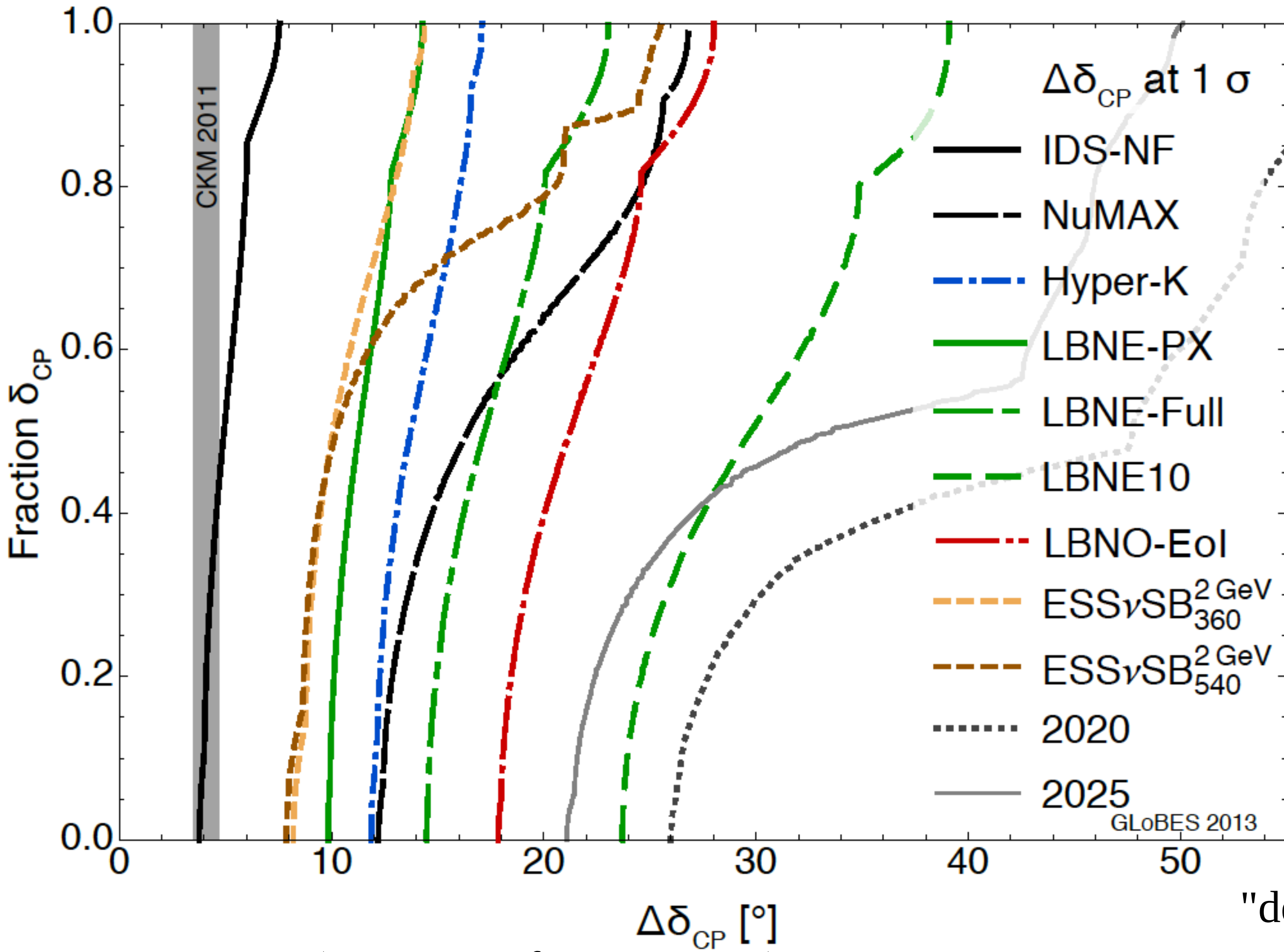
Systematic errors

Systematics	SB			BB			NF		
	Opt.	Def.	Cons.	Opt.	Def.	Cons.	Opt.	Def.	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 $\times$ 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%

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

δ_{CP} accuracy performance

(USA snowmass process, P. Coloma)

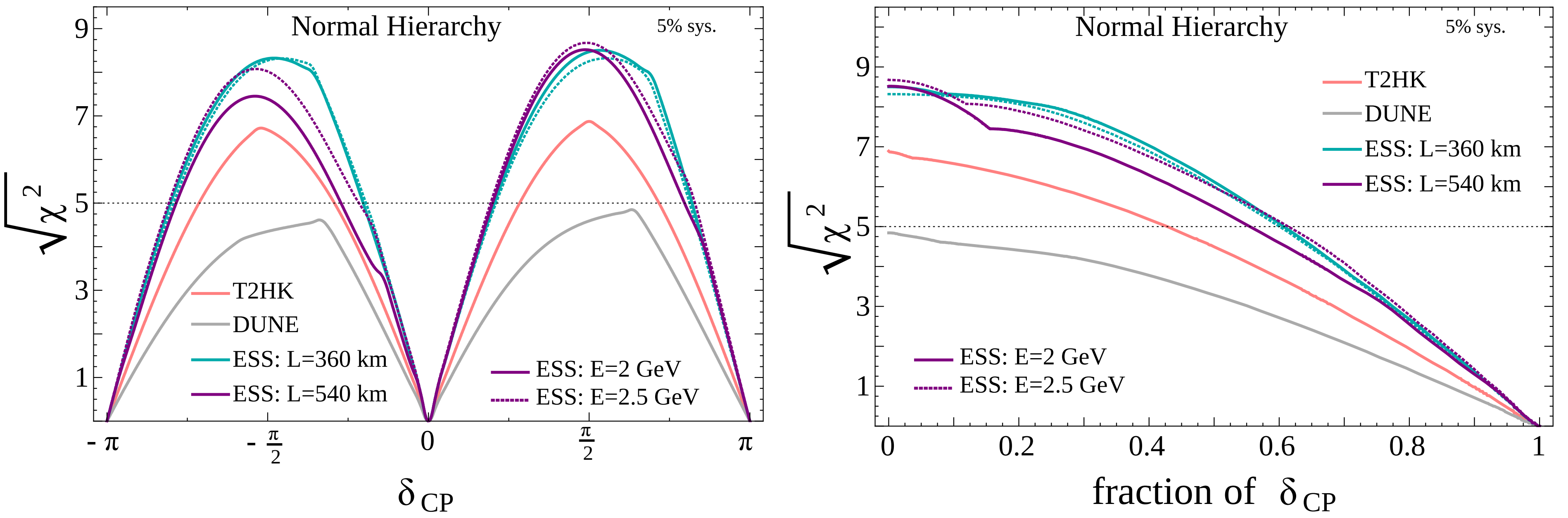


"default" column

for systematic errors see (7.5%/15% for ESSnuSB):

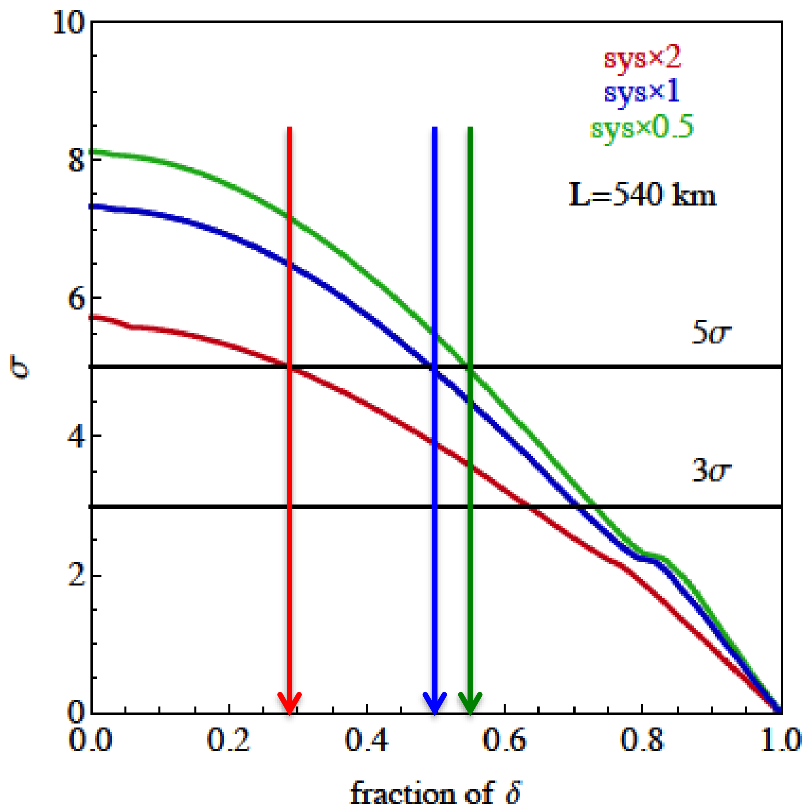
- Phys. Rev. D 87 (2013) 3, 033004 [arXiv:1209.5973 [hep-ph]]
- **arXiv:1310.4340 [hep-ex] Neutrino "snowmass" group conclusions**

Comparisons

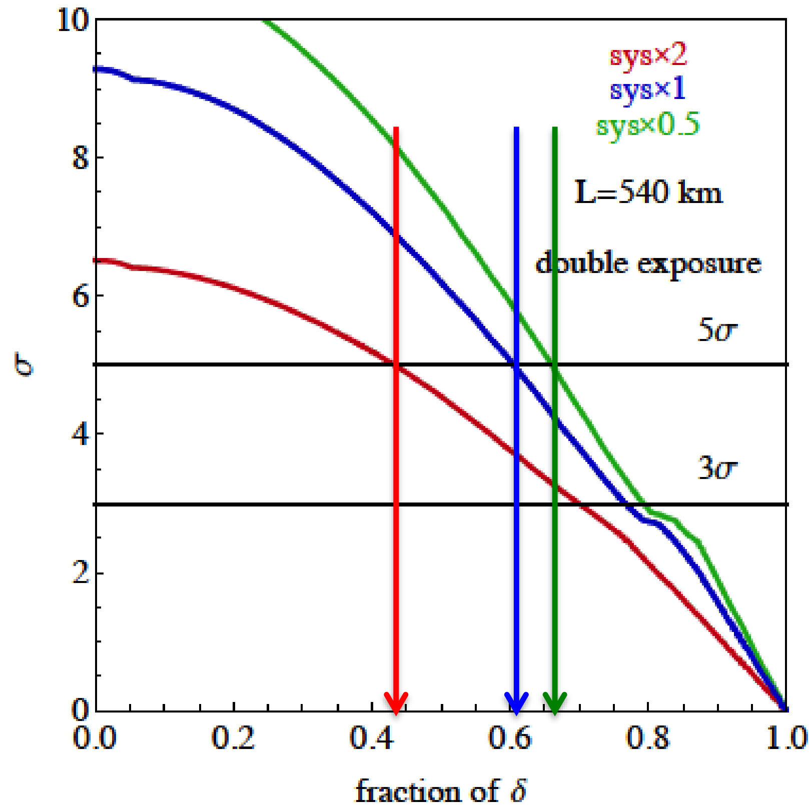


δ_{CP} coverage

CPV (2 GeV protons)



after 10 years



with 2 times more statistics

systematic errors (nominal values): 5%/10% for signal/background

more than 50% δ_{CP} coverage using reasonable assumptions on systematic errors