The ESS neutrino Super Beam (ESSνSB)

George Fanourakis
INPP – NCSR «Demokritos»

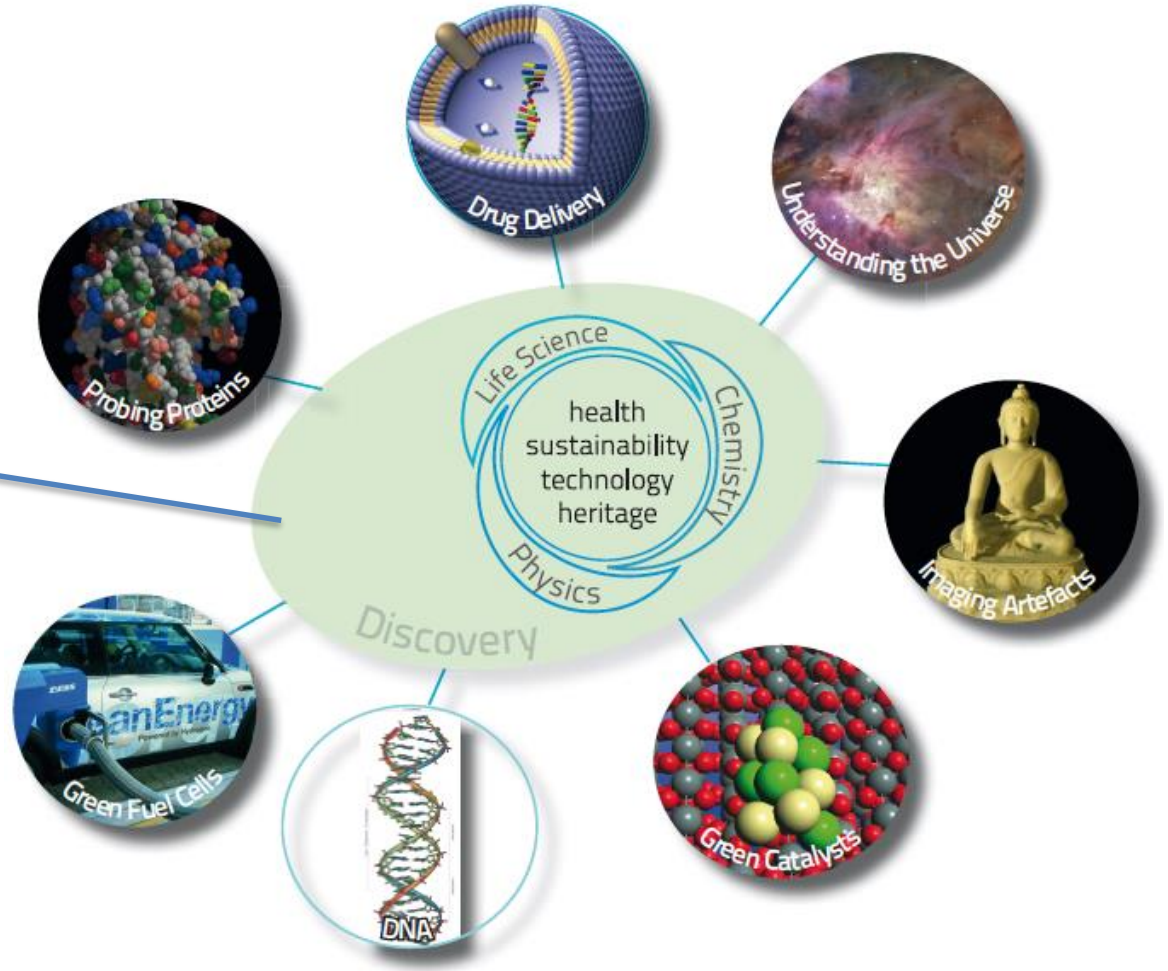
Work supported also by
cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Most slides provided by
Marcos Dracos
CNRS Strasburg

Overview

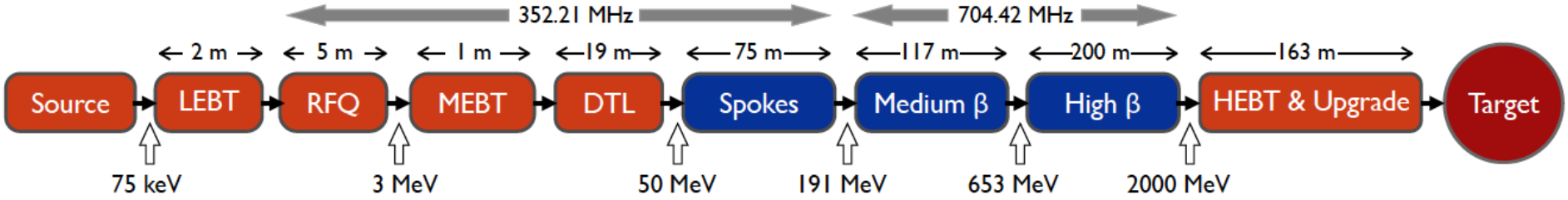
- The European Spallation Source
- The neutrino beam using the ESS facility
- The needed ESS linac modifications
- Physics performance
- EU support and the Conceptual Design Study
- INPP involvement

European Spallation Source

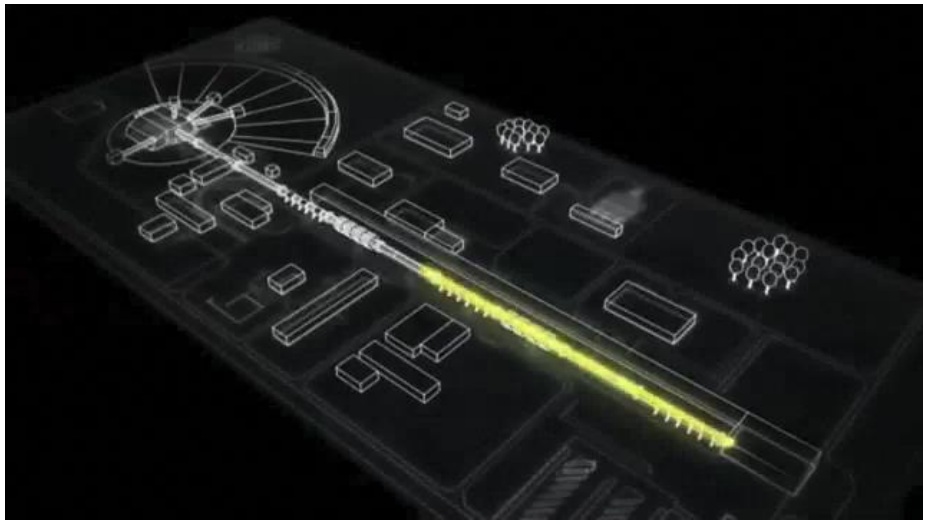


under construction since 2014
(~1.85 B€ facility)

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.**

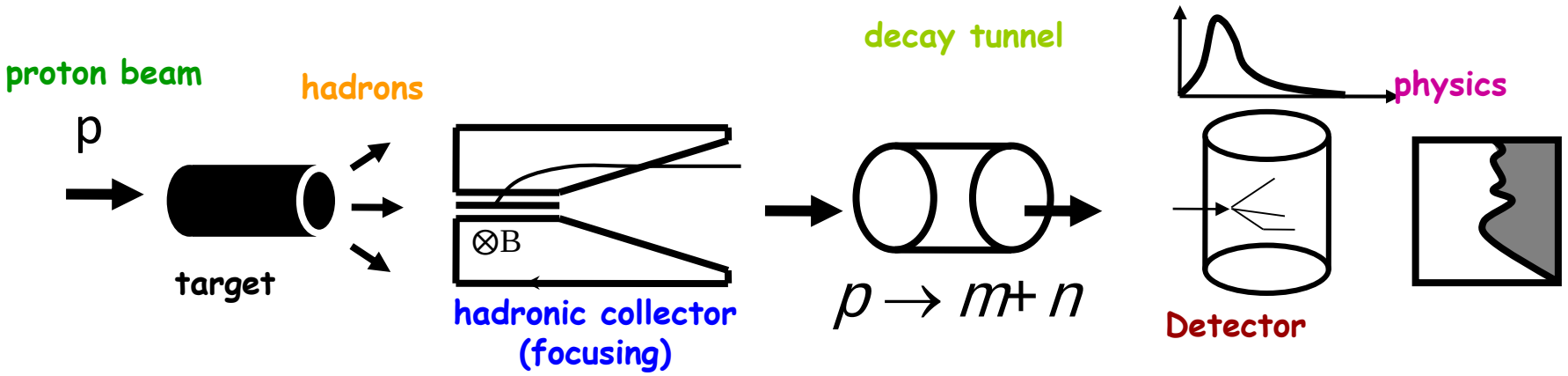


Linac ready by 2023 (full power)

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

by doubling the linac pulsing rate…

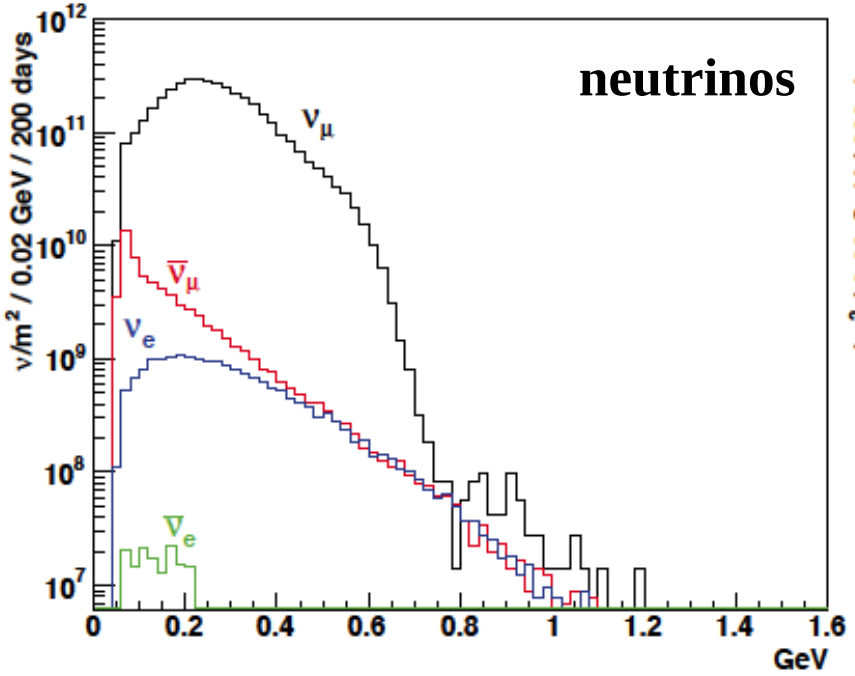
conventional neutrino (super) beam

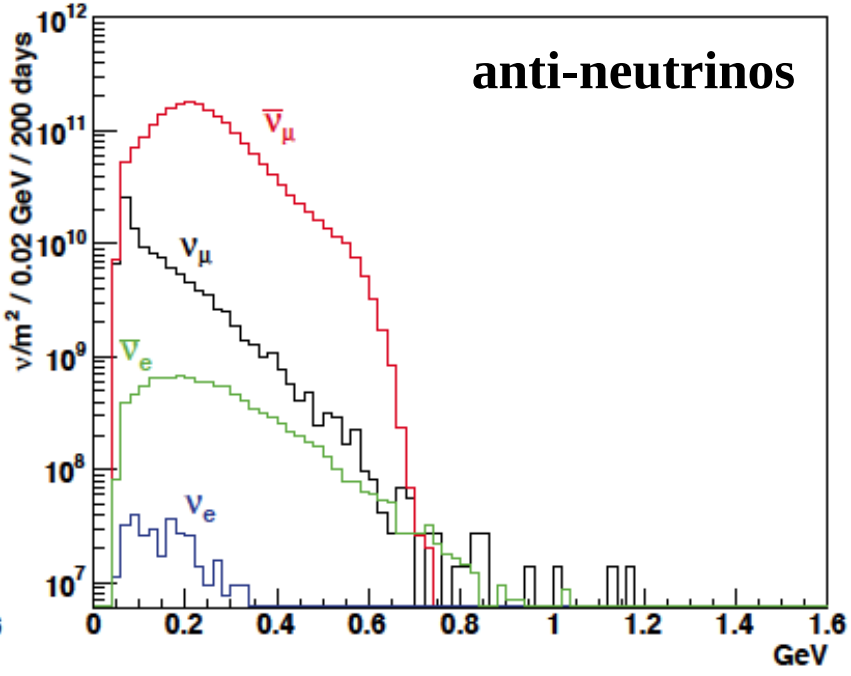


production of a powerful neutrino beam

Modifications of the ESS linac required, without affecting the neutron program of ESS: Cost ~ 250 MEuros

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 (200 days) in absence of oscillations.

Use the $\nu_\mu \rightarrow \nu_e$ oscillation for CP violation (primary ν_e contamination small enough ≈ 0.5%)

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

The primary aim of the ESSνSB initiative is to measure the parameters of the neutrino oscillation, in particular the leptonic CP-violating phase angle δ_{CP}.

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

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

Non-CP terms

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

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)

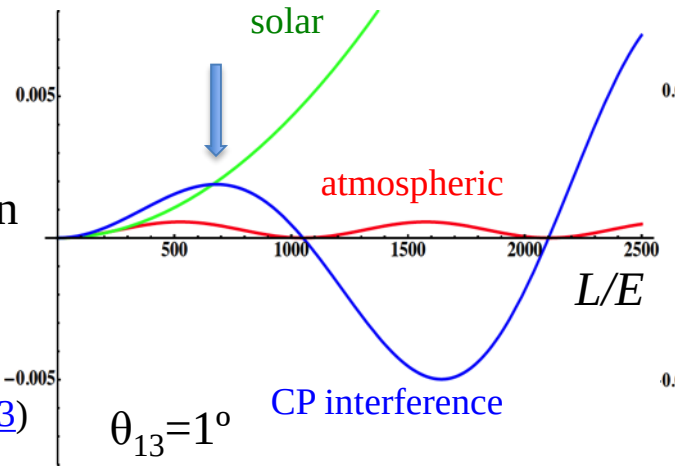
$$\mathcal{A} = \frac{P_{\nu_\mu \to \nu_e} - P_{\bar{\nu}_\mu \to \bar{\nu}_e}}{P_{\nu_\mu \to \nu_e} + P_{\bar{\nu}_\mu \to \bar{\nu}_e}}$$

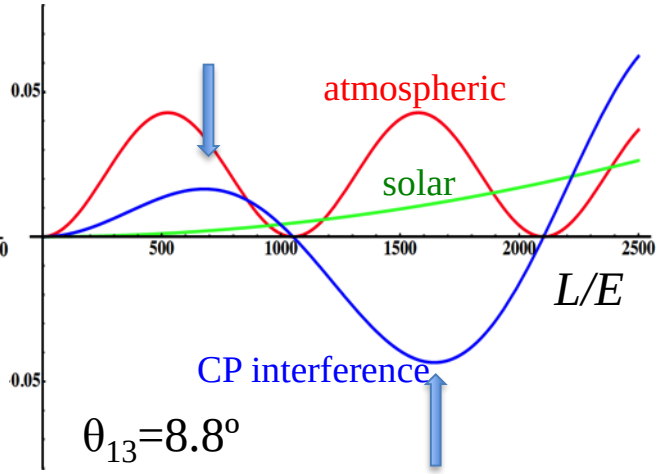
≠0 ⇒ CP Violation
be careful, matter effects also create asymmetry

Neutrino Oscillations with "large" θ_{13}

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

(arXiv:1110.4583)

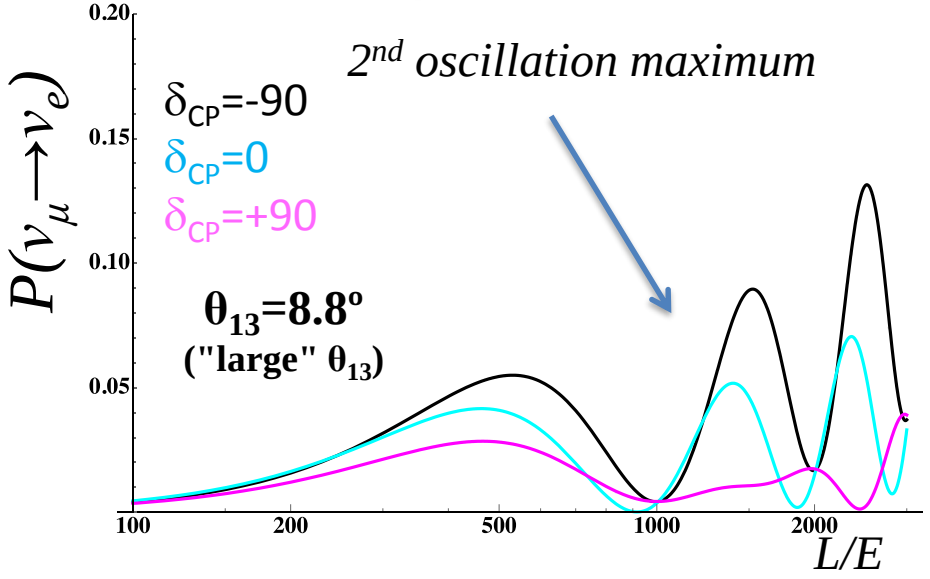




for "large" θ_{13} 1st oscillation maximum is dominated by atmospheric term

- 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.

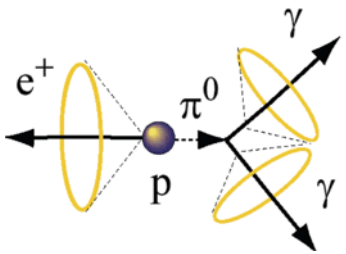
Can we go to the 2nd oscillation maximum using our proton beam?

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

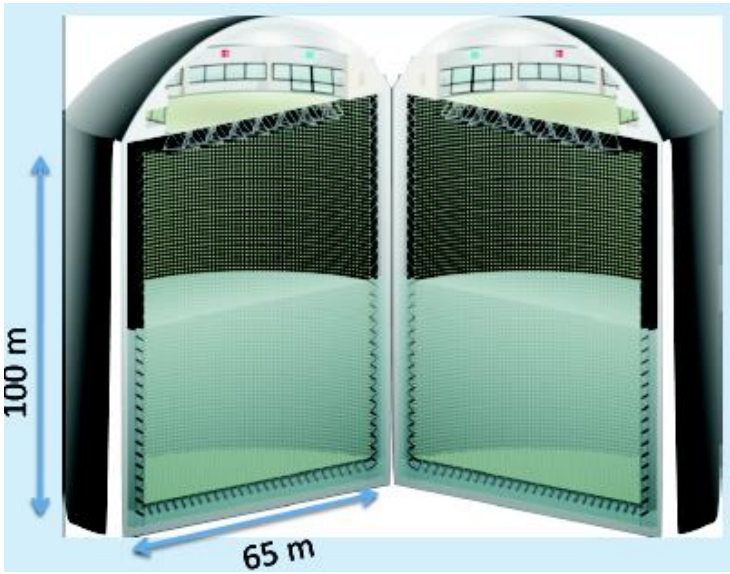
MEMPHYS like Cherenkov detector
(MEgaton Mass PHYSics studied by LAGUNA)

(arXiv: hep-ex/0607026)

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



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

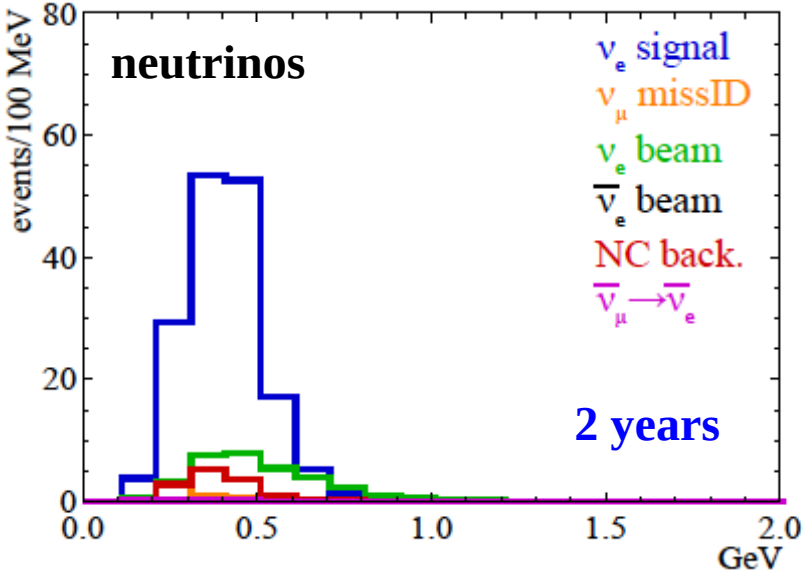


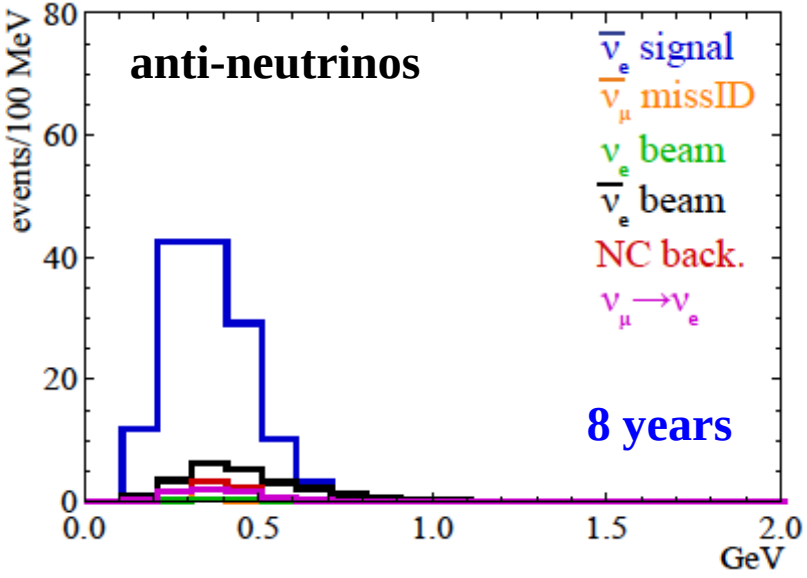
Neutrino spectra

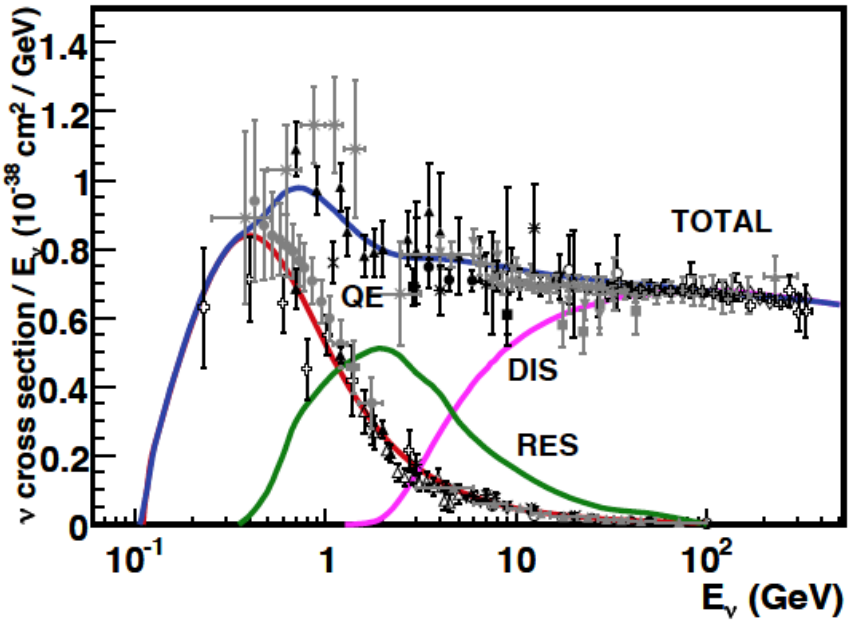
540 km (2 GeV), 10 years, ~300 events

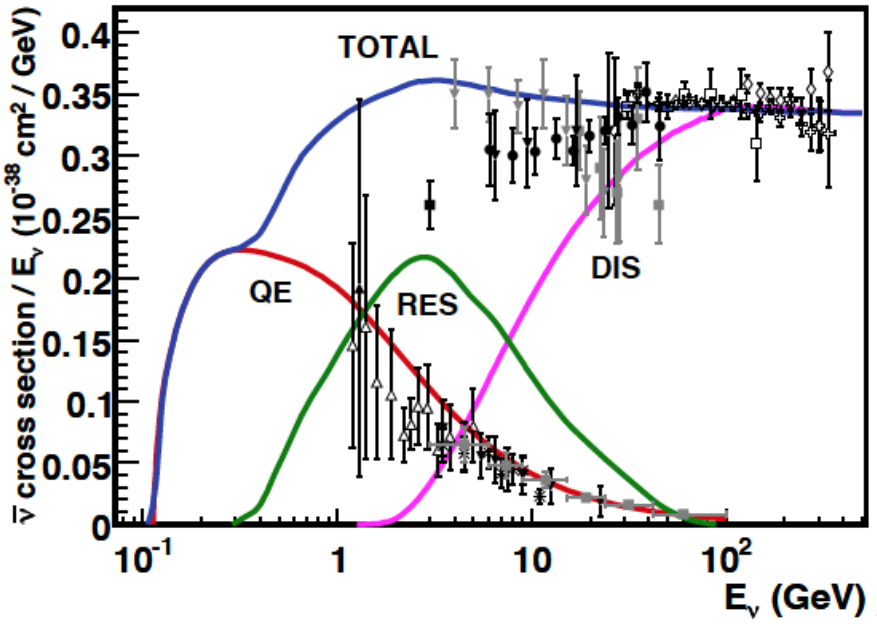
below ν_τ production, almost only QE events

$\delta_{CP}=0$

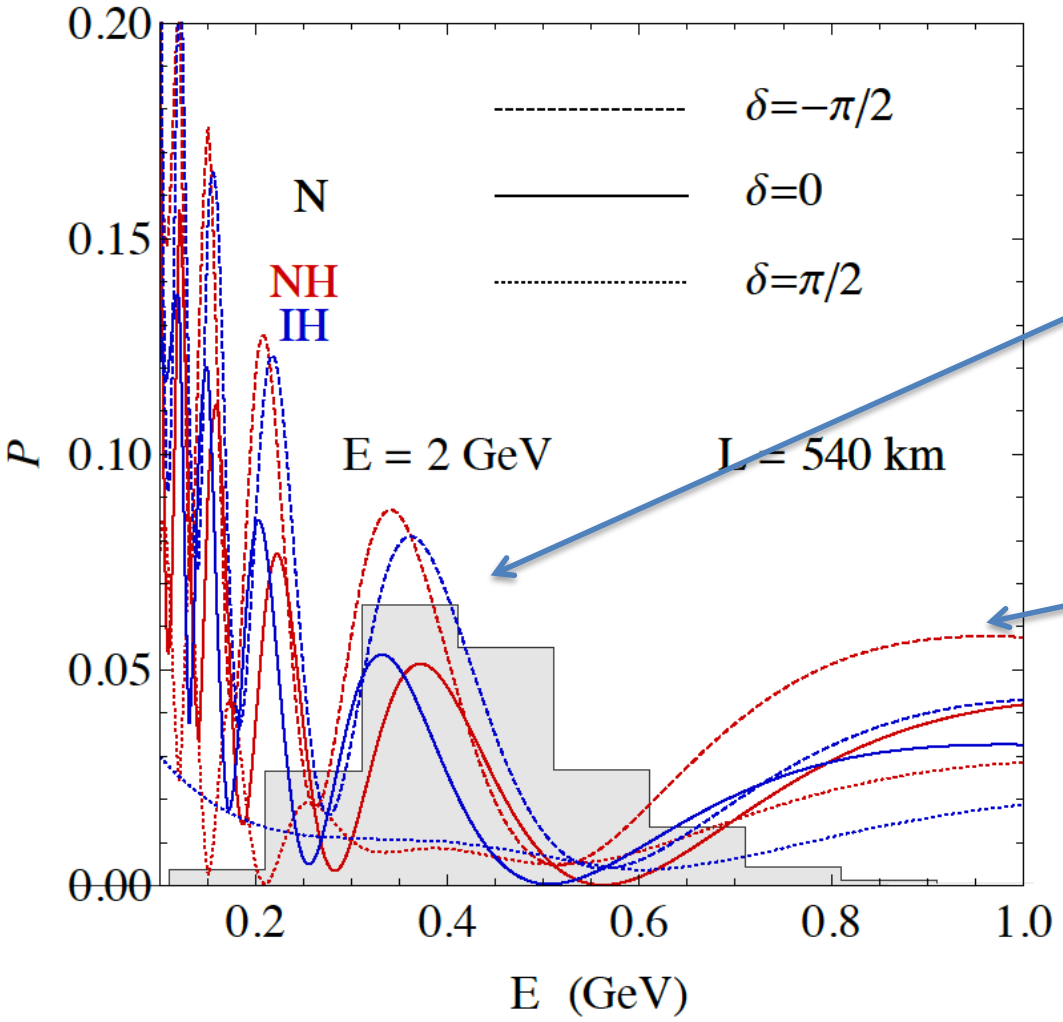








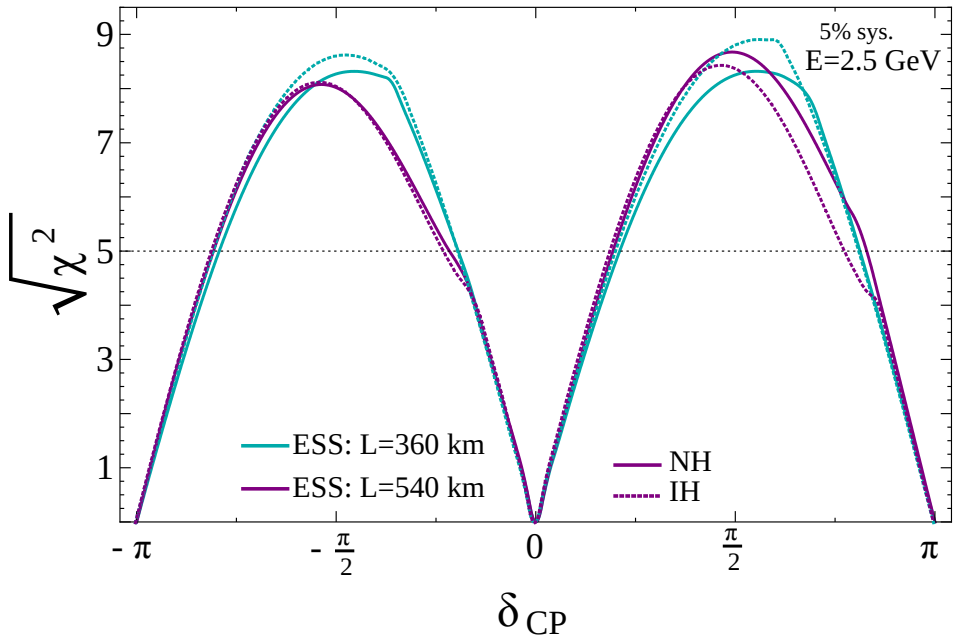
2nd Oscillation max. coverage

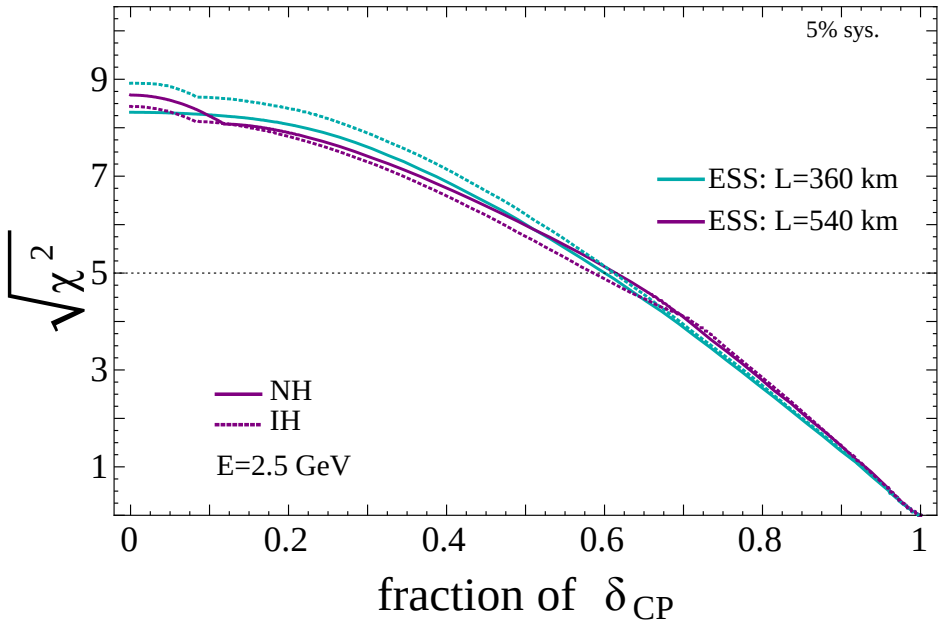


2nd oscillation max. well covered by the ESS neutrino spectrum

1st oscillation max.

Physics Performance



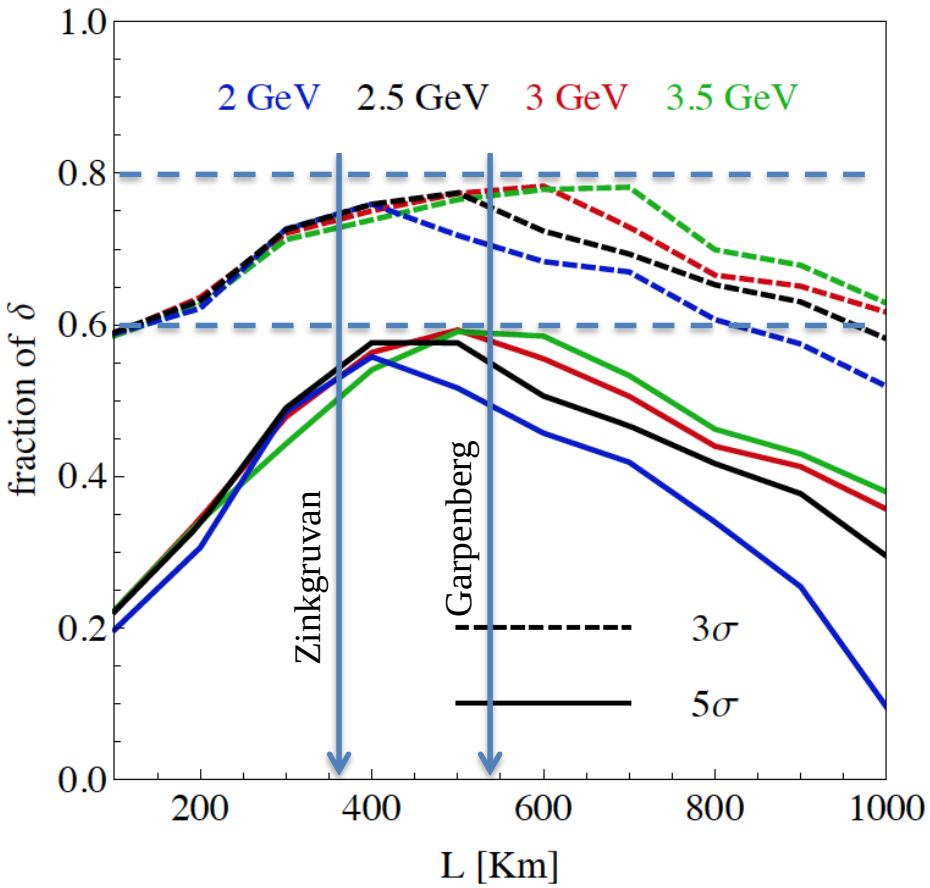


- little dependence on mass hierarchy (not so long baseline),
- δ_{CP} coverage at 5 σ C.L. up to 60%,
- δ_{CP} accuracy down to 6° at 0° and 180° (absence of CPV for these two values),
- not yet optimized facility.

Even in this non-optimised case (E=2.5 GeV), **ESSvSB would discover CP violation for at the level of 60% of the possible δ_{CP} values**

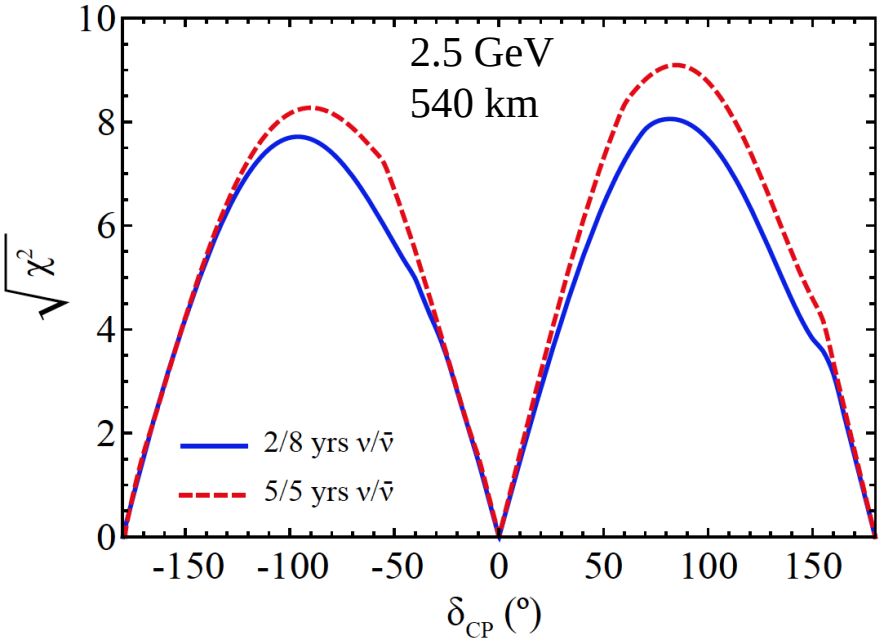
Which baseline?

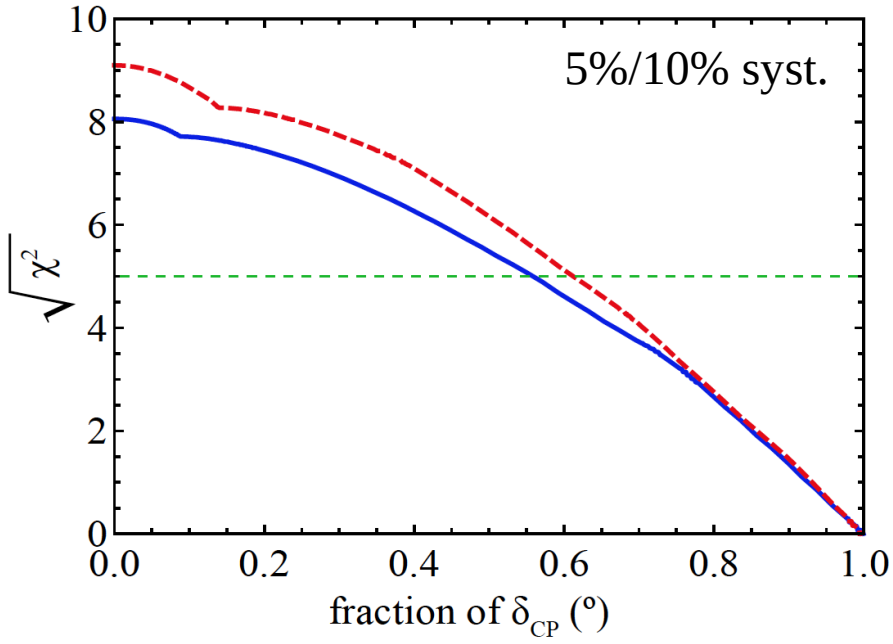
CPV (*Nucl. Phys. B 885 (2014) 127*)



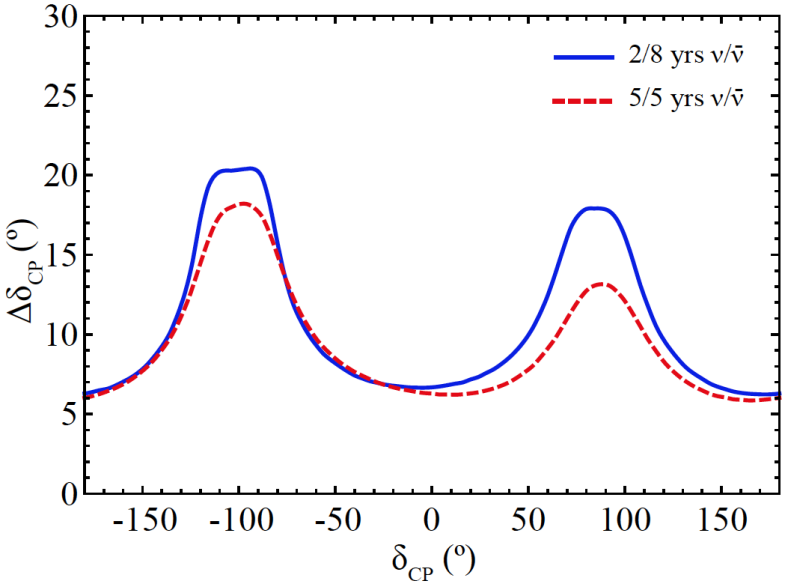
- ~60% δ_{CP} coverage at 5 σ C.L.
- >75% δ_{CP} coverage at 3 σ C.L.
- **systematic errors: 5%/10% (signal/backg.)**

Optimisations to be done

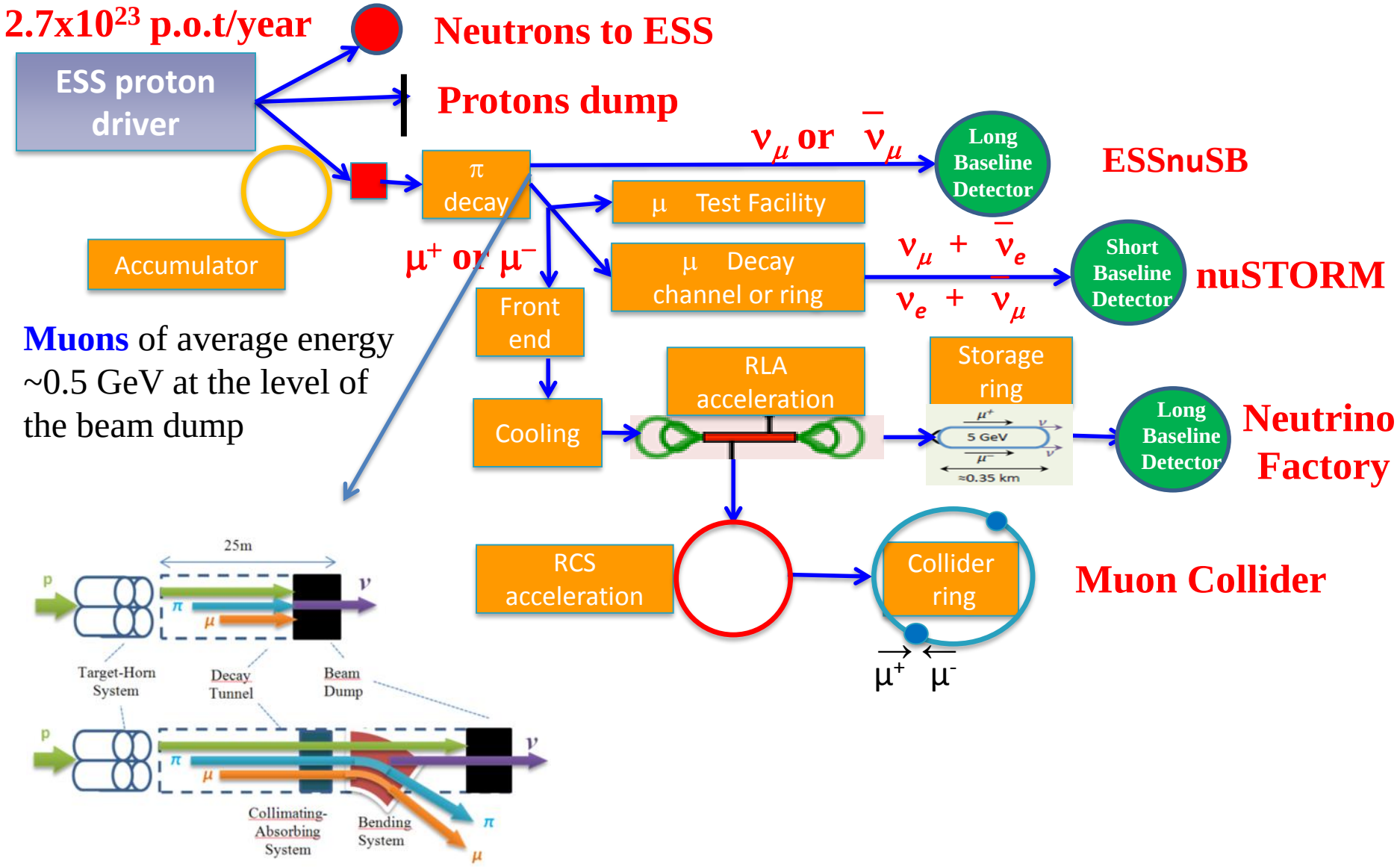




- **optimizations are coming**:
  - with the present configuration: 5/5 yrs seems better than 2/8 yrs,
  - horn shape,
  - detector efficiency (cheaper PMTs with higher QE),
  - near detector.



ESS neutrino and muon facility

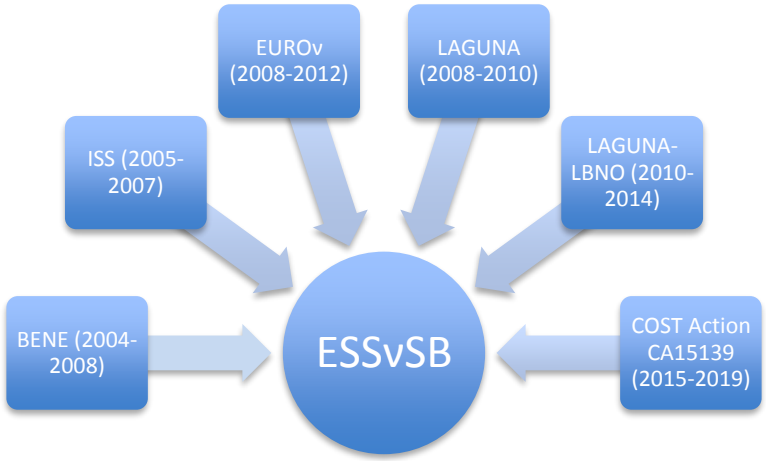


ESSνSB at the European level

- **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 2017



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 ESSvSB (2018-2021)

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.

ESSvSB 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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+46-721-792024

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

Starts 15 Jan 2018 14:00

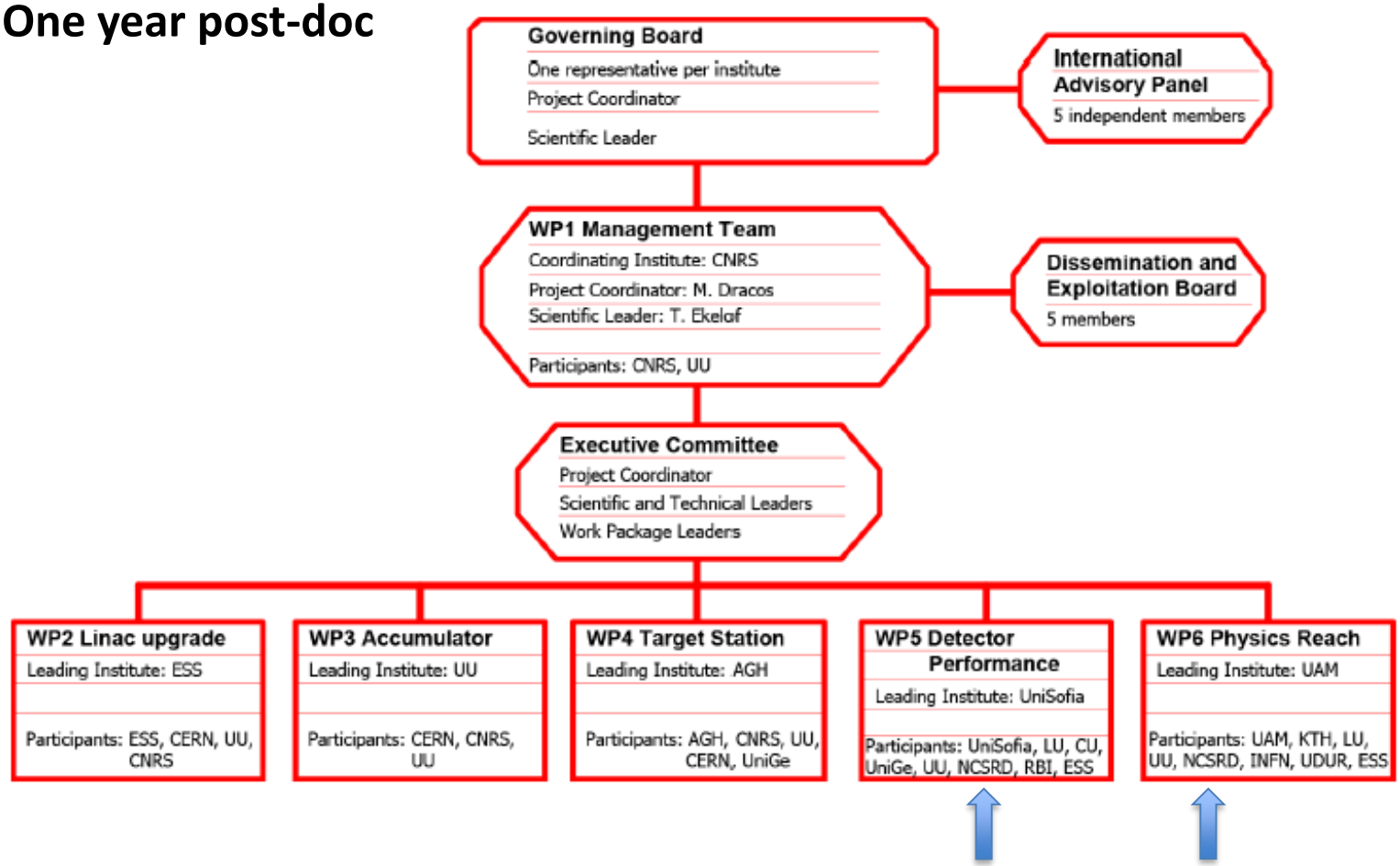
European Spallation Source ERIC

INPP involvement

Participants

- **George Fanourakis**
- **Theodoros Geralis**
- **George Stavropoulos**
- **One year post-doc**

INPP Budget: 64953



Conclusion

- Significantly better CPV sensitivity at the 2nd oscillation maximum.
- 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.
- COST network project CA15139 supports this project.
- The EU-H2020 Design Study ESSνSB is approved and has started.
- INPP plans to contribute to the ν Detectors optimization with respect to their physics potential and the Physics studies,