ICHEP 2022 BOLOGNA

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The ESSνSB High Intensity neutrino SuperBeam

E. Baussan on behalf of ESSνSB Collaboration
IPHC-IN2P3/CNRS Strasbourg

ESS NEUTRINO SUPER BEAM

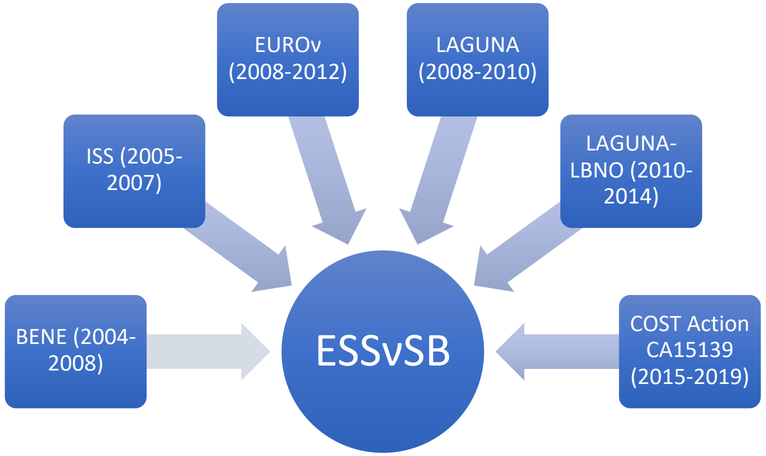
Funded by the Horizon 2020 Framework Programme of the European Union

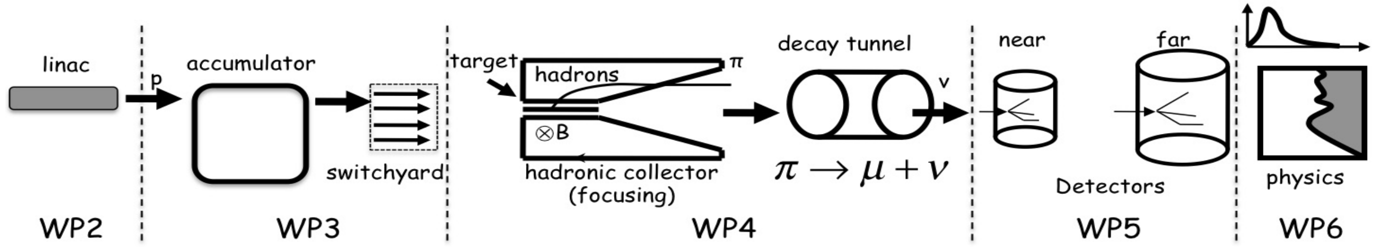
The ESSνSB High Intensity Neutrino Superbeam

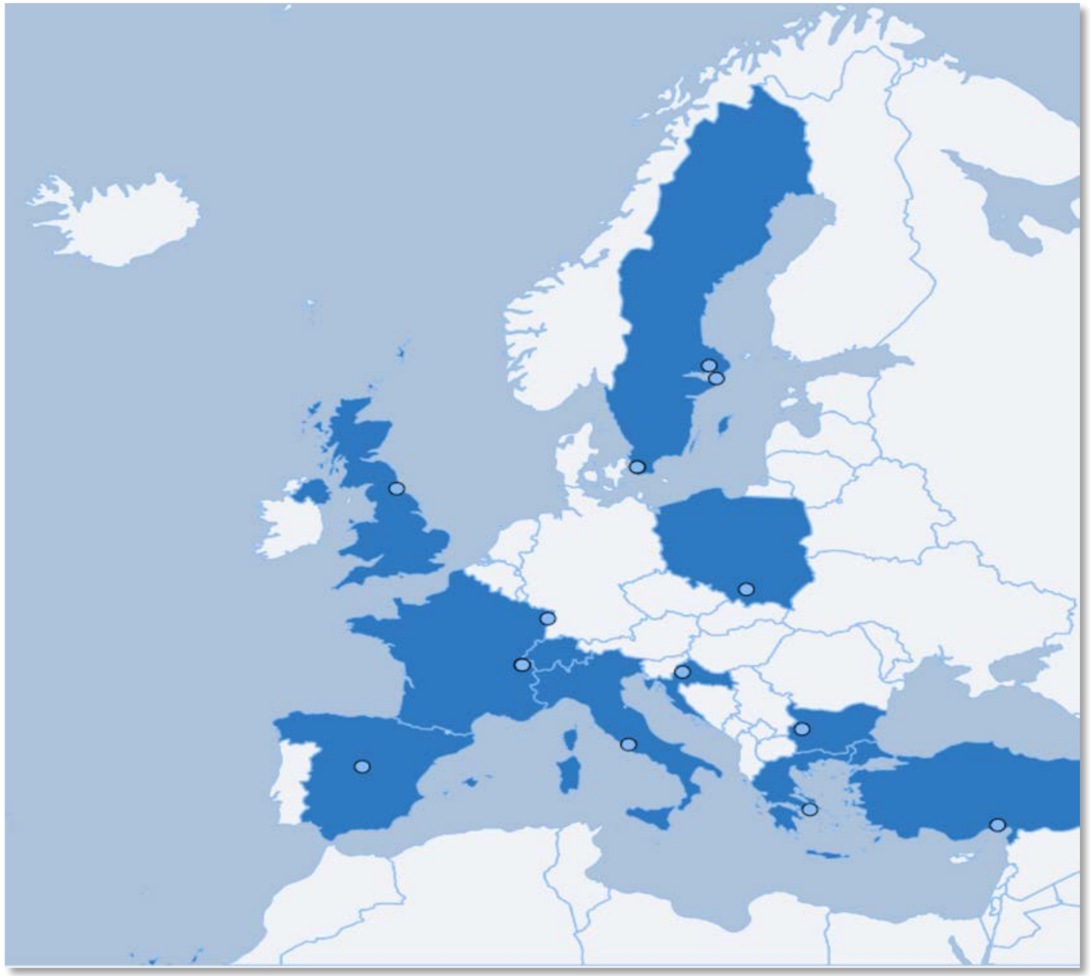
Overview of the project

A **H2020** EU **Design Study** (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
- **Approved end of August 2017**







Map of participants

ESSνSB has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 777419

Physics and Baseline

Oscillation probability $P(\nu_\mu \to \nu_e)$:

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

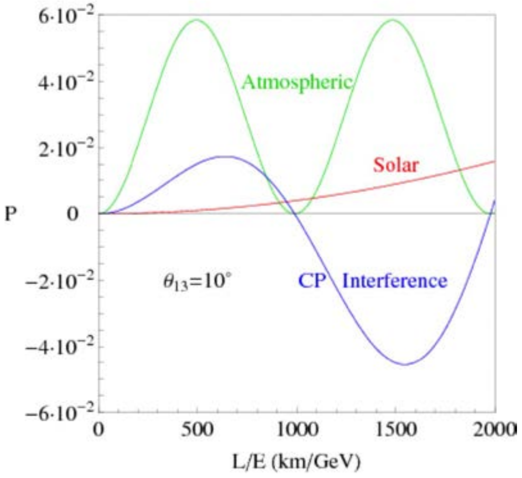
$$+ c_{23}^2 \sin^2 2\theta_{12} \left(\frac{\Delta_{12}}{A}\right)^2 \sin^2\left(\frac{AL}{2}\right) \quad \text{solar}$$

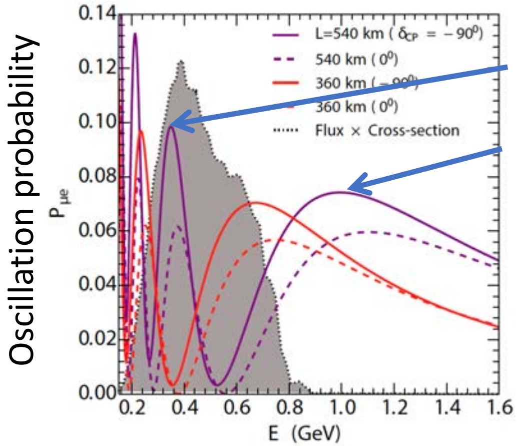
Non-CP terms

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

CP violating

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





The ESSνSB neutrino spectrum

2nd oscillation max. well covered

1st oscillation max.

Full coverage of the 2nd oscillation max.

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

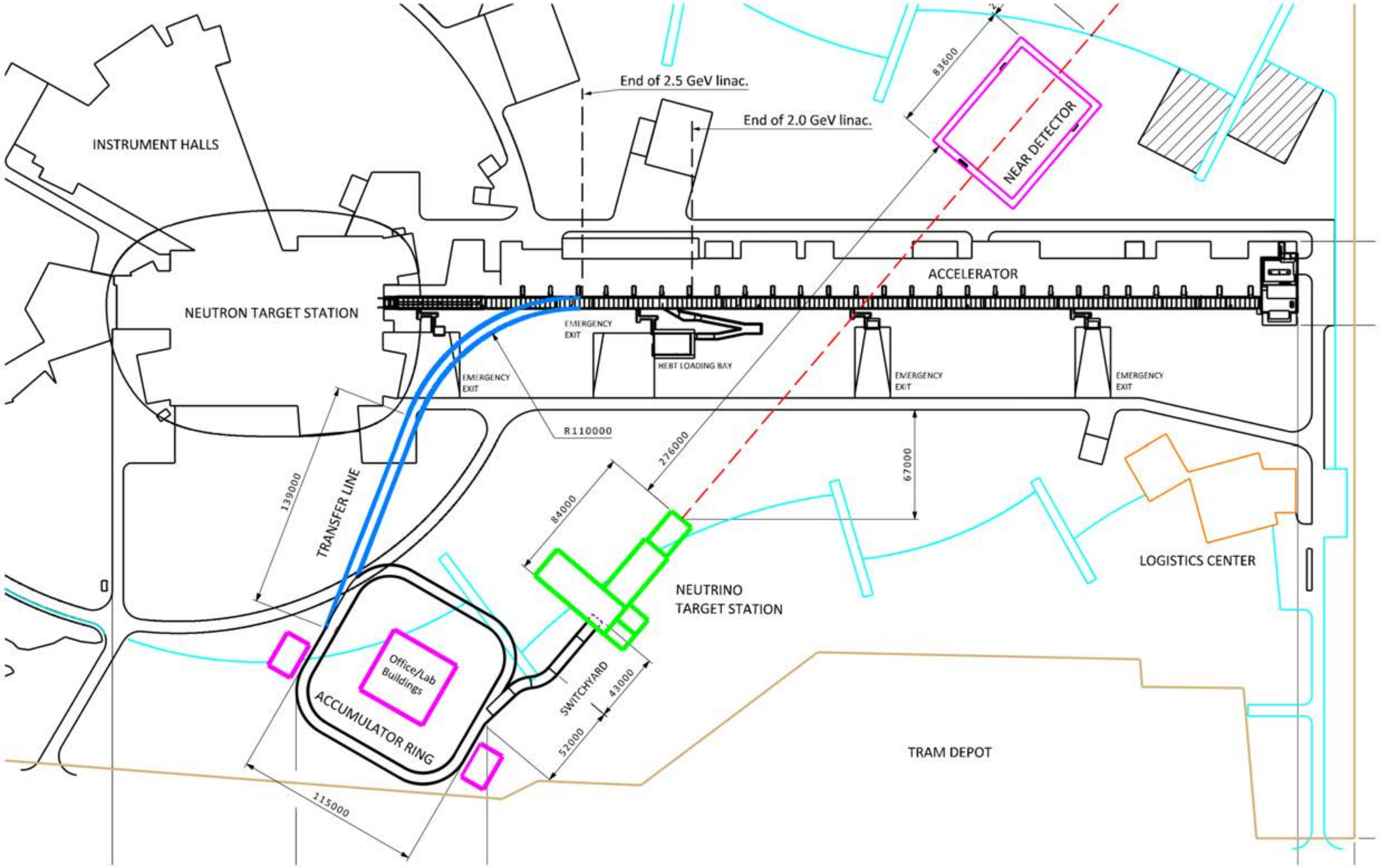
1st Oscillation Maximum : $A_{CP} \simeq 0.35 \sin(\delta_{CP})$
2nd Oscillation Maximum : $A_{CP} \simeq 0.70 \sin(\delta_{CP})$

The relative contribution of the interference term, in which the δ_{CP} phase appears, has a contribution enhanced in the second maximum compared to the first oscillation.

Two considered baselines (Zinkgruvan 360 km & Garpenberg 540 km)

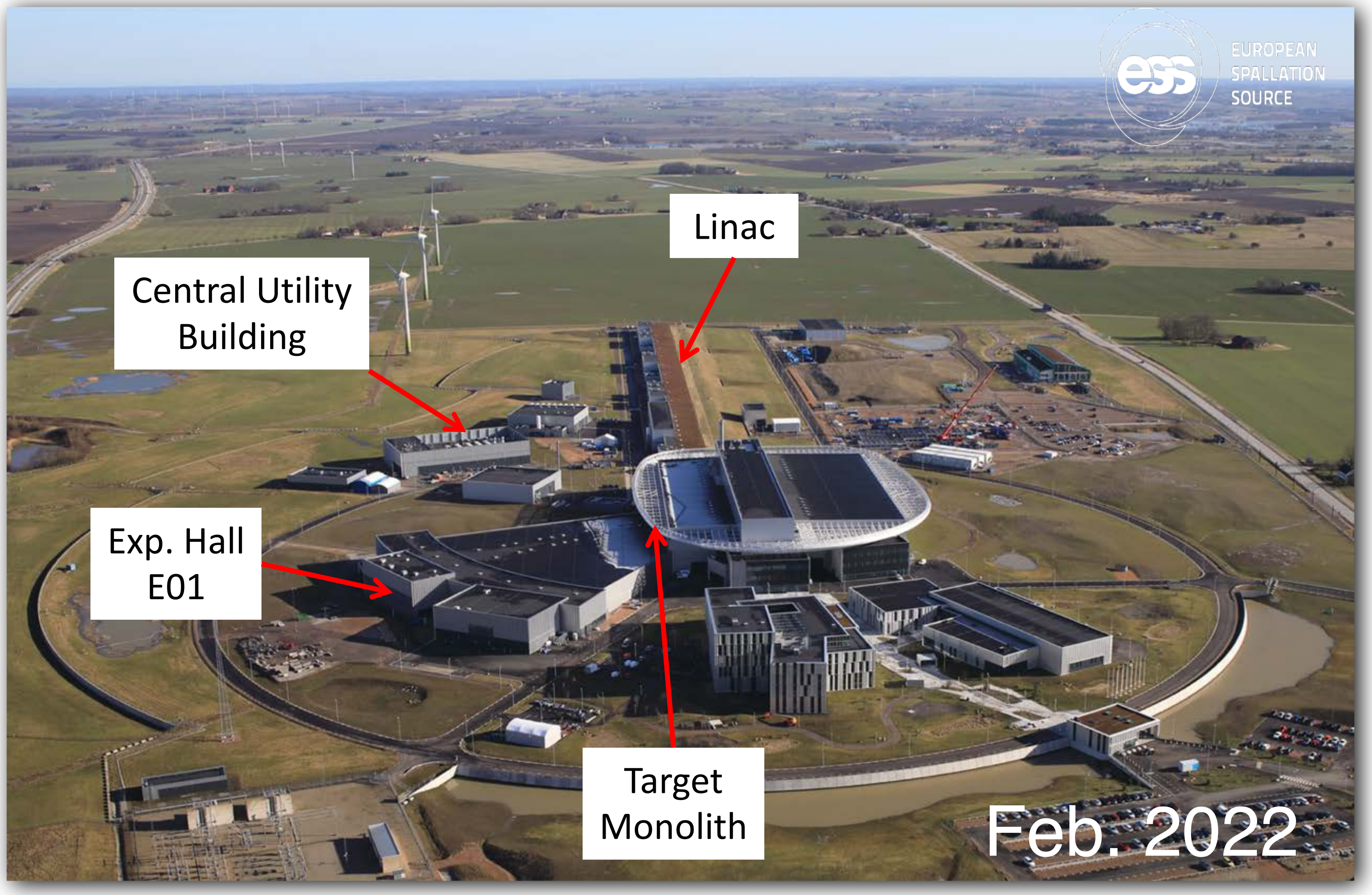
The ESSνSB High Intensity Neutrino Superbeam

Implementation on ESS Site



The ESSνSB High Intensity Neutrino Superbeam

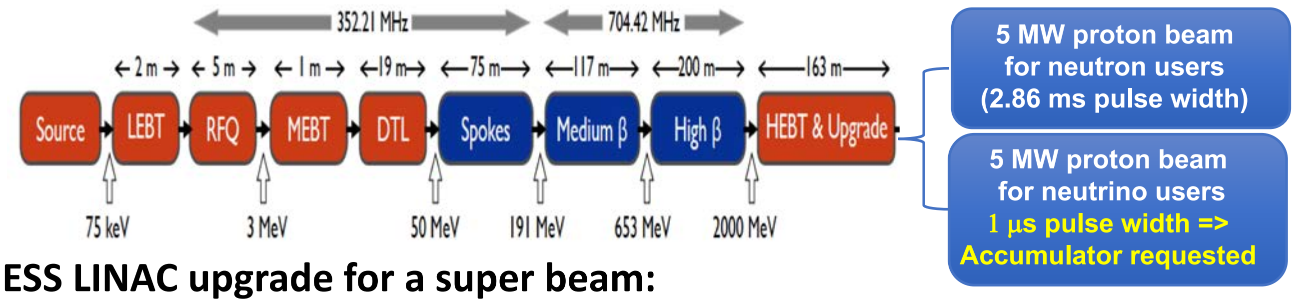
European Spallation Source



View of the ESS site at Lund

The ESSνSB High Intensity Neutrino Superbeam

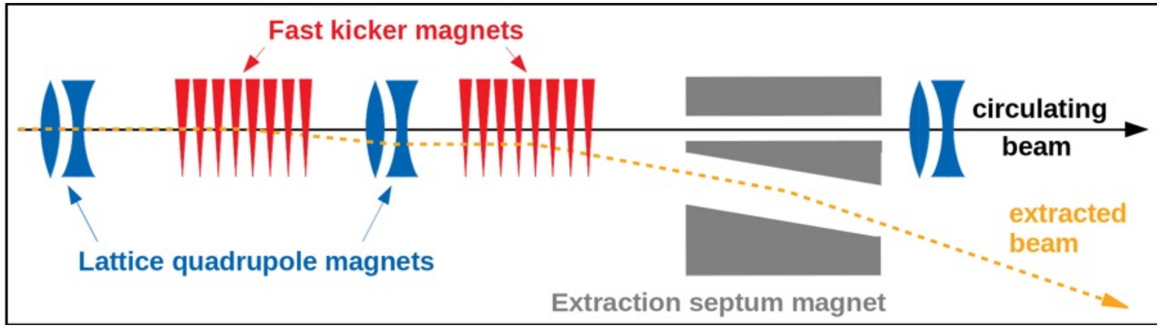
The upgrade of the ESS facility



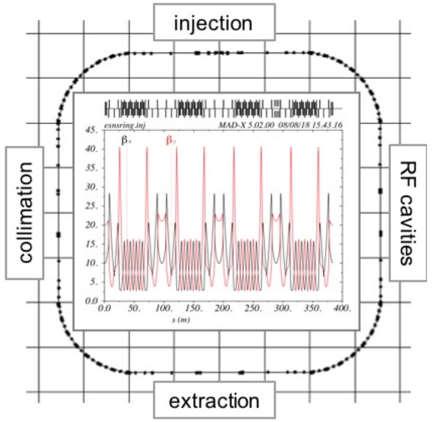
ESS LINAC upgrade for a super beam:

- Increase beam power : 5 MW to 10 MW
- Extra RF power capacity
- Accumulator ring to shorten the pulses to micro second order for the horn
- Extra H^- source for additional pulses

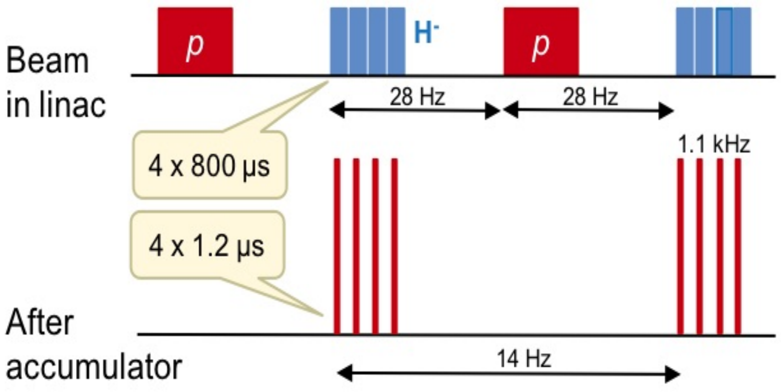
Ring-to-switchyard transfer line and beam switchyard bring the proton pulses from the ring extraction to the beam switchyard and distribute the resulting four beam batches over four targets.



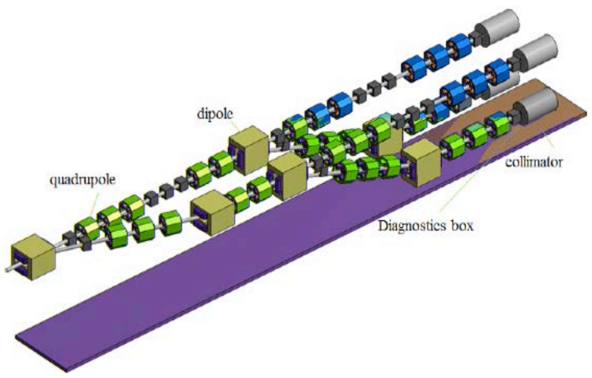
The switchyard splits the 5MW proton beams in four parts



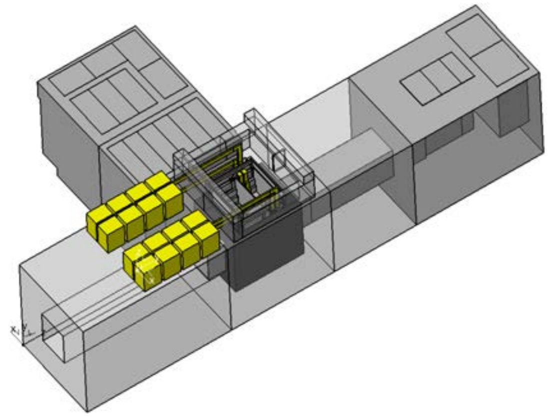
Accumulator (384m)



Proton beam pulses



Beam Switchyard



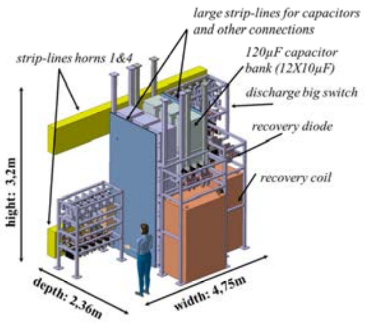
Target Station Facility

The ESSνSB High Intensity Neutrino Superbeam

The MW Target Station

Power Supply Unit

- 16 modules (350 kA, 1.3 µs)
- Located above the switchyard
- Outside of radioactive part of Facility



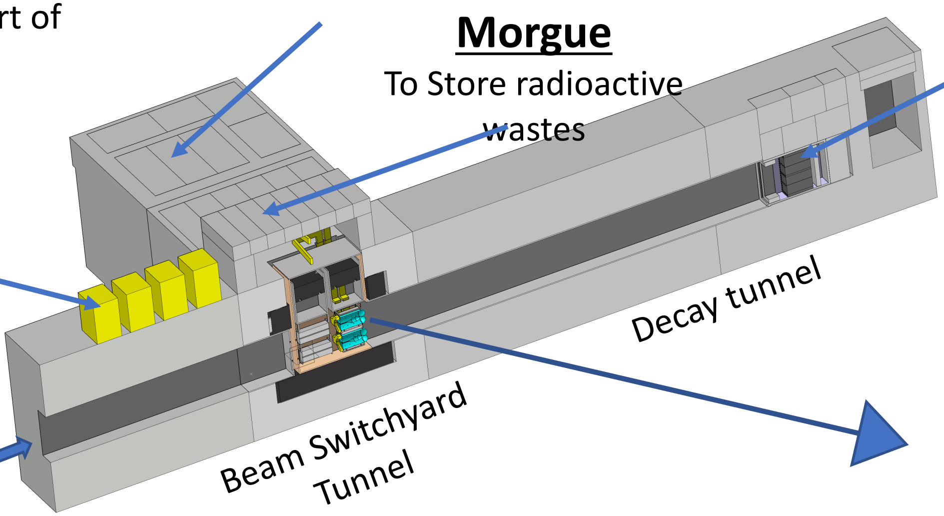
Hot Cell

- Able to manipulate/repair hadronic collector
- Work under Radioactive Environment

Morgue

To Store radioactive wastes

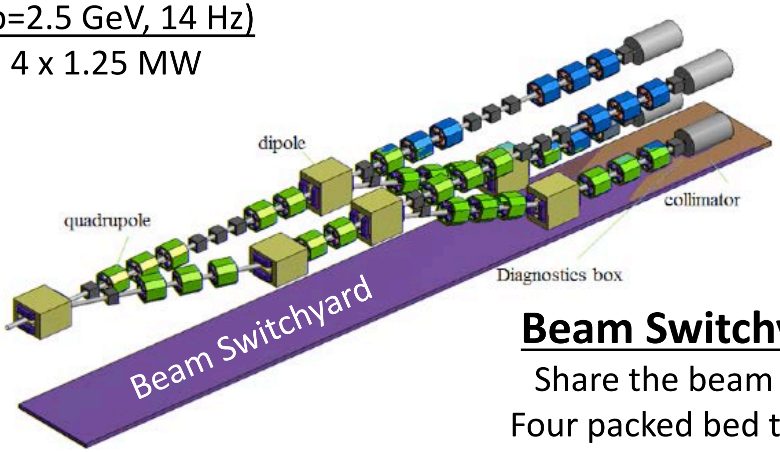
Beam dump



Proton Beam

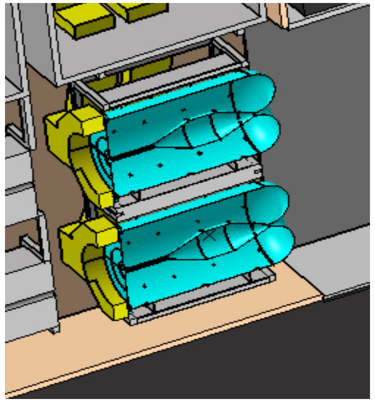
(Ep=2.5 GeV, 14 Hz)

4 x 1.25 MW

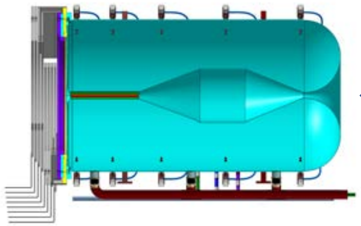


Beam Switchyard

Share the beam over Four packed bed targets



Hadronic Collector

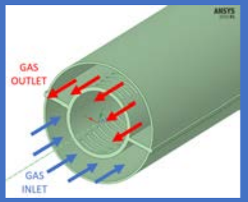


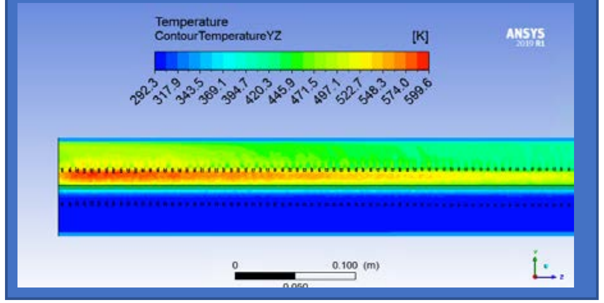
Horn

Shape optimized with genetic algorithm

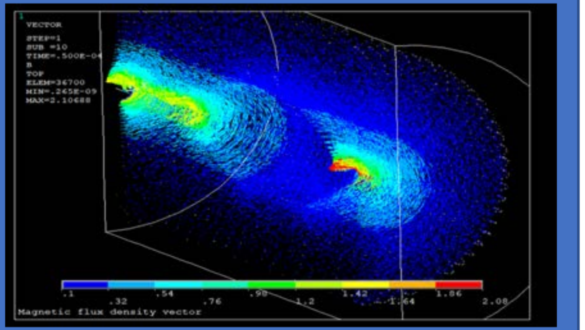
Granular Target Concept

- Target made of 3 mm titanium spheres cooled by transverse helium gas cooling



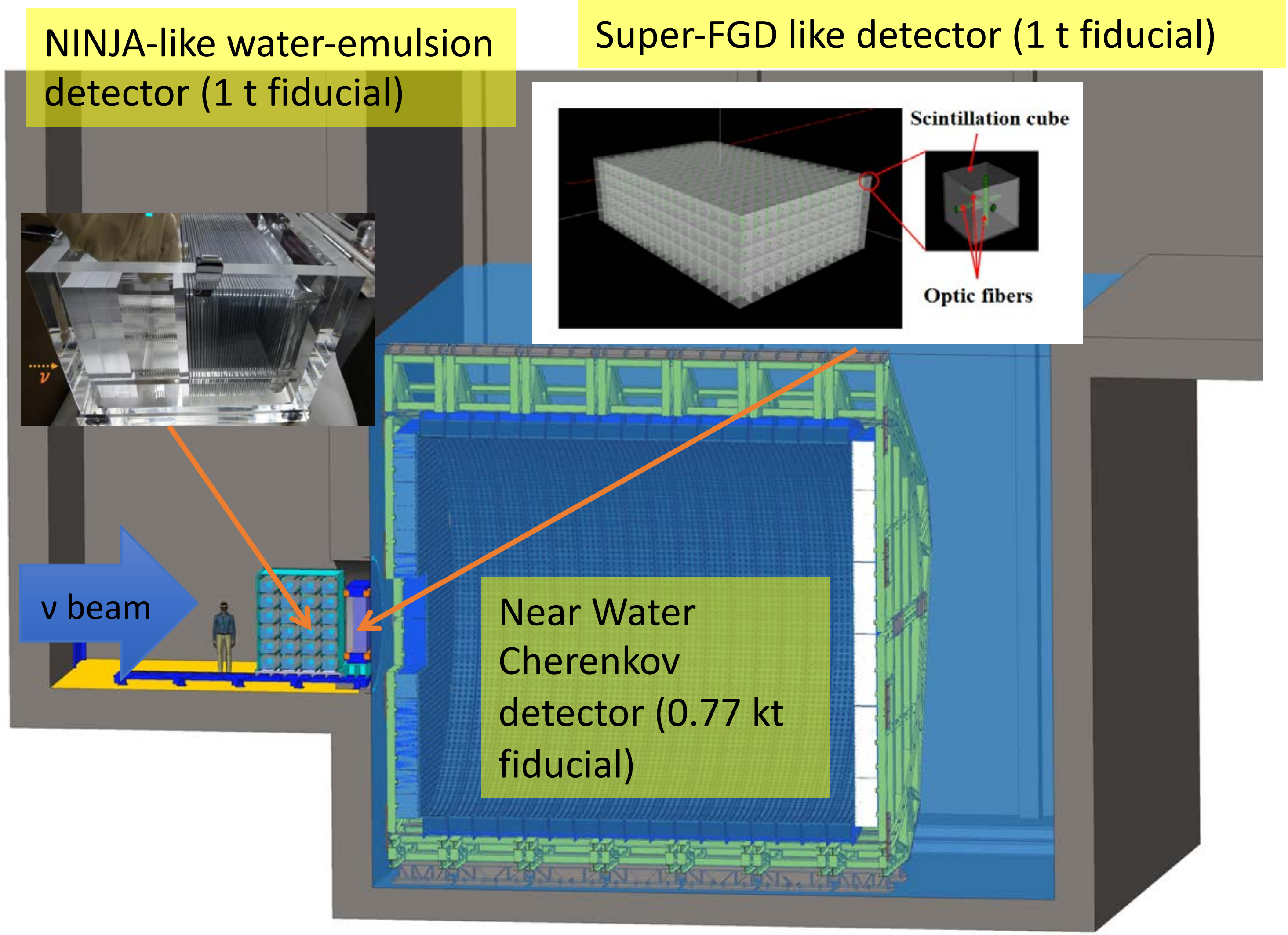


Magnetic field (350 kA; 1.3 µs pulse)

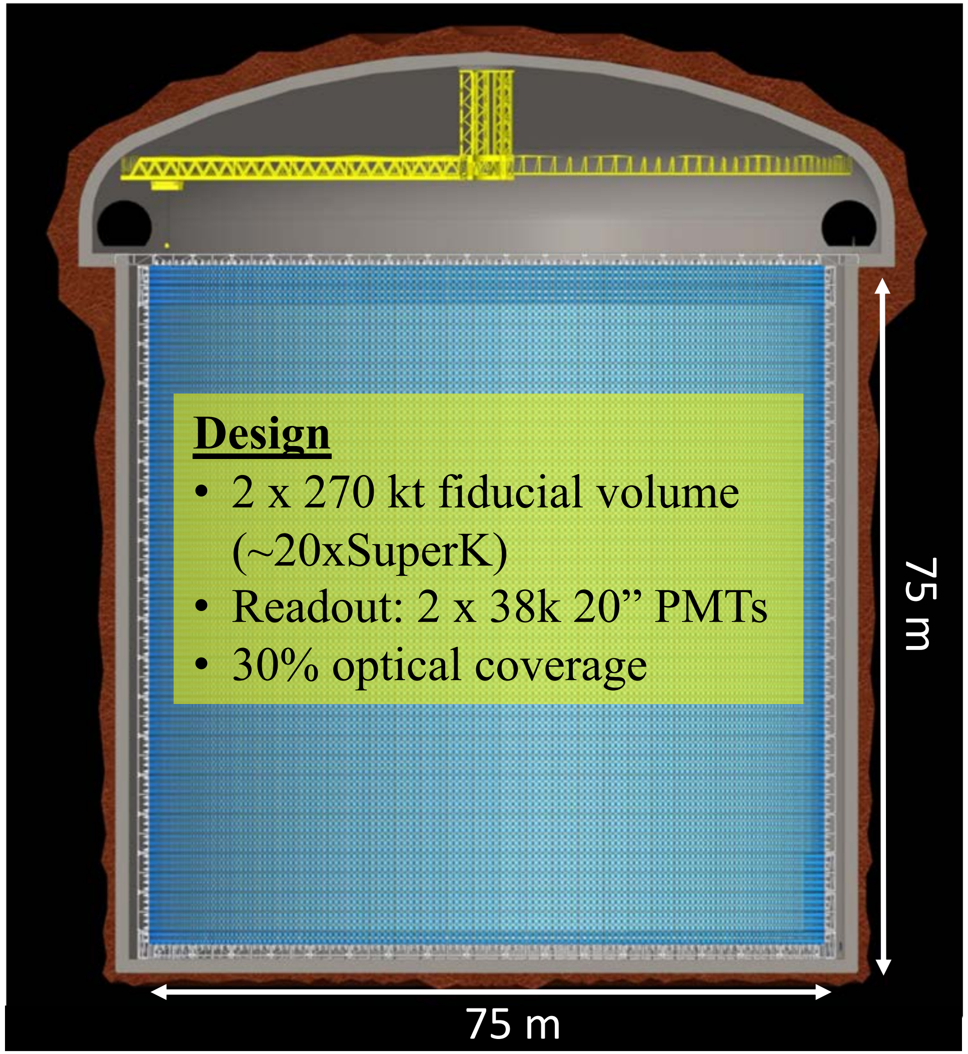


The ESSνSB High Intensity Neutrino Superbeam

Near and Far Detector Design

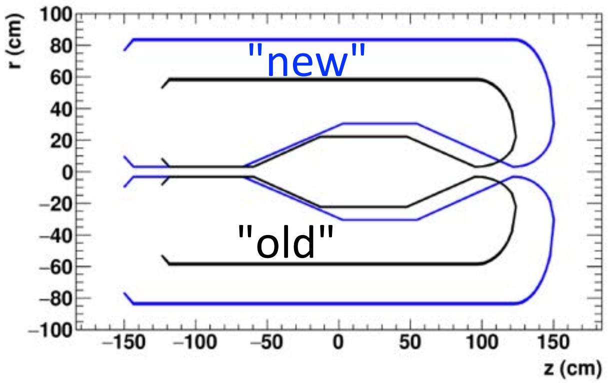


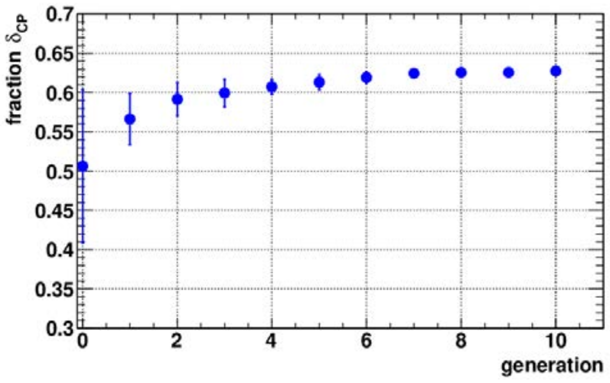
Near Detector



Far Detector

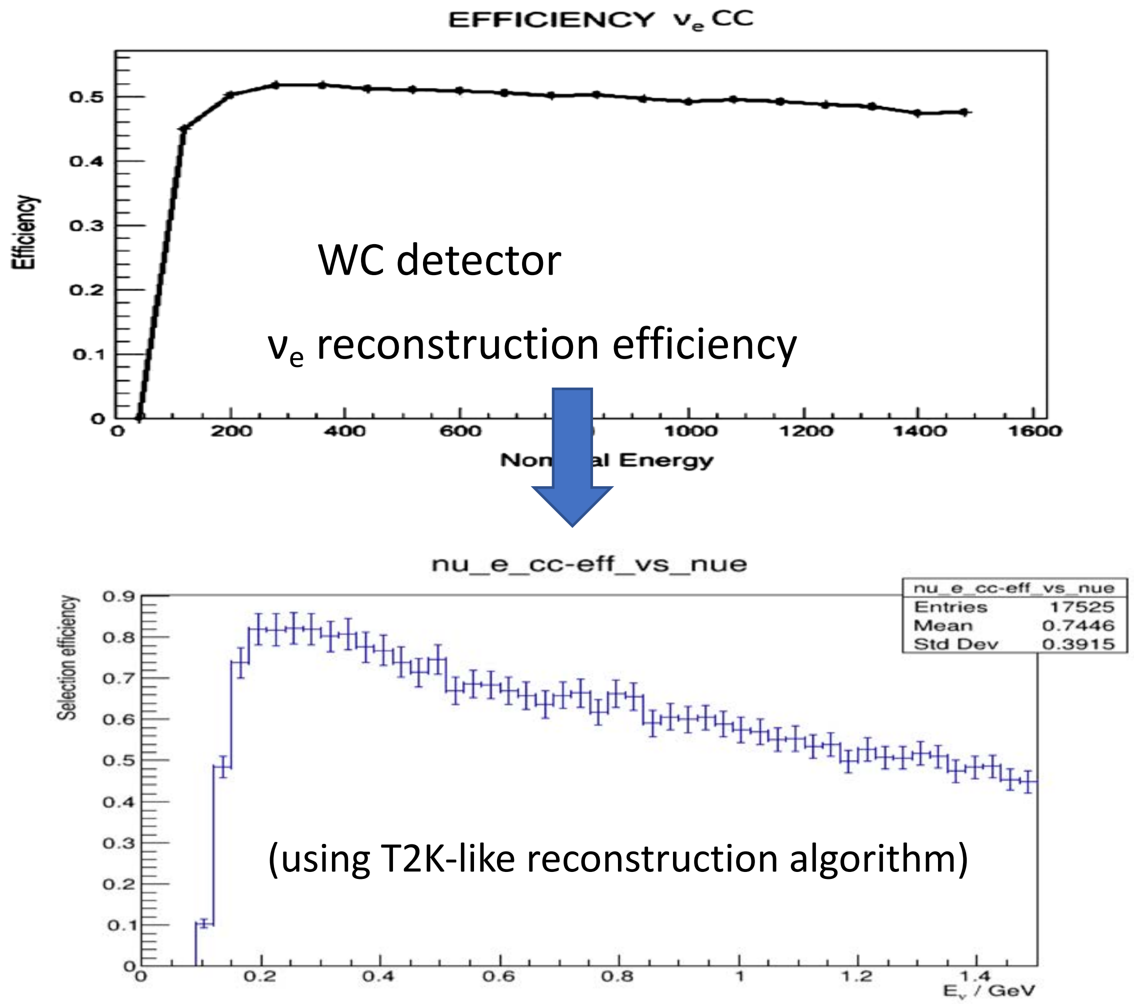
- New deep learning methods based on Genetic Algorithm (GA) has been considered to improve the sensitivity of the experiment.





This new method has been applied to optimize the size and the inner conductor of the hadronic collector with the geometrical parameter (length and width of the decay tunnel of the Target Station).

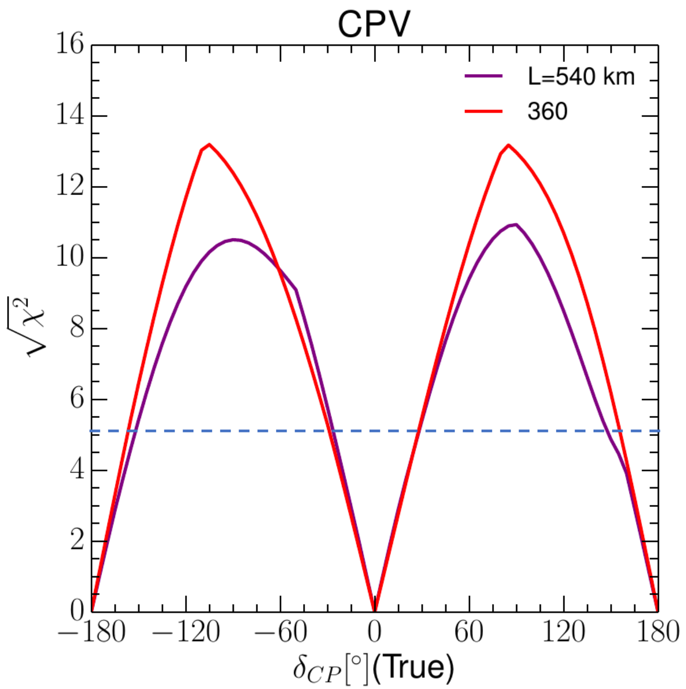
- New migration matrices for the far detector



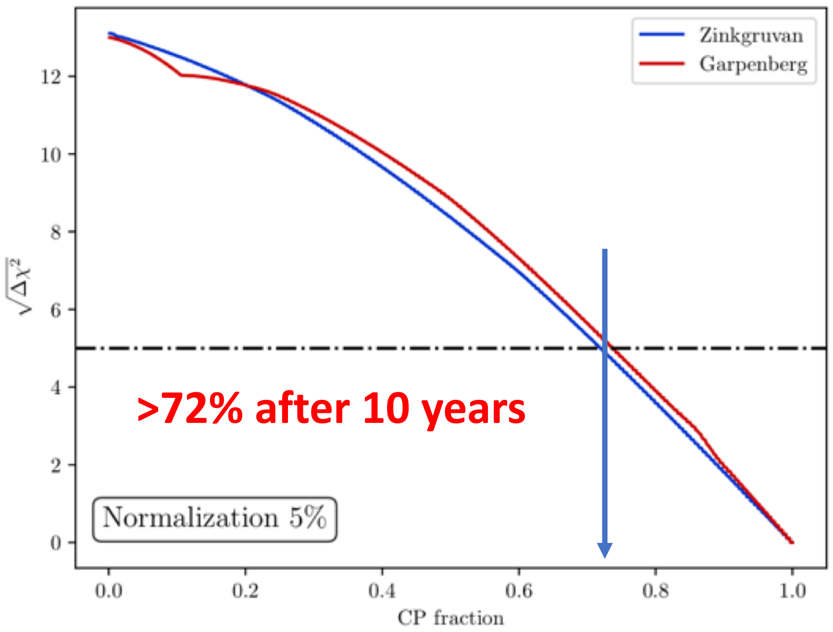
Updated physics performance of the ESSnuSB experiment,

Eur.Phys.J.C 81 (2021) 12, 1130

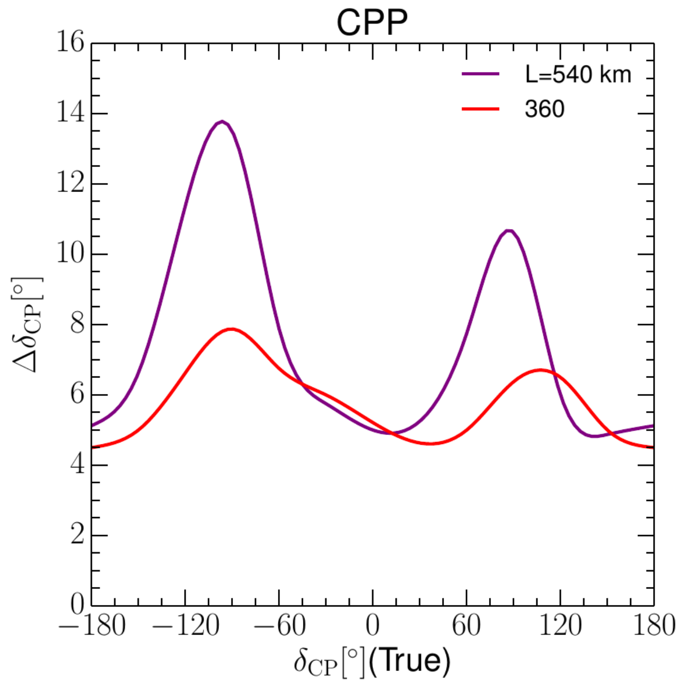
DOI:10.1140/epjc/s10052-021-09845-8, arXiv:2107.07585



δ_{CP} coverage measurement



δ_{CP} fraction coverage



Precision measurement

The ESSνSB High Intensity Neutrino Superbeam

Possible Schedule (2ème génération)

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

2012: inception of the project

Nucl. Phys. B 885 (2014) 127

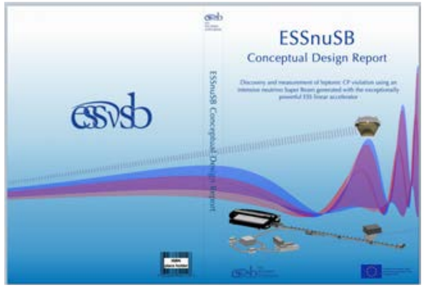
2016-2019: beginning of COST Action EuroNuNet

ESS NEUTRINO SUPER BEAM

2018: beginning of ESSvSB Design Study (EU-H2020)

2022: End of ESSvSB Design Study, CDR and preliminary costing

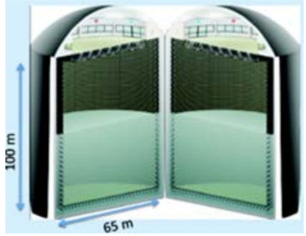
arxiv.org/abs/2206.01208



ESFRI

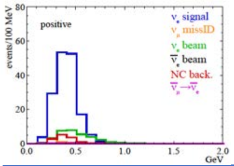
2022-2026: Preparatory Phase, TDR

2026-2028: Preconstruction Phase, International Agreement

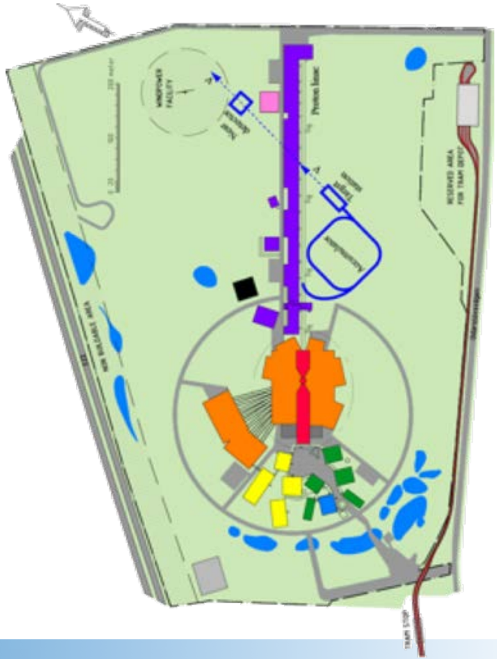


EUROPEAN SPALLATION SOURCE

2028-2036: Construction of the facility and detectors, including commissioning

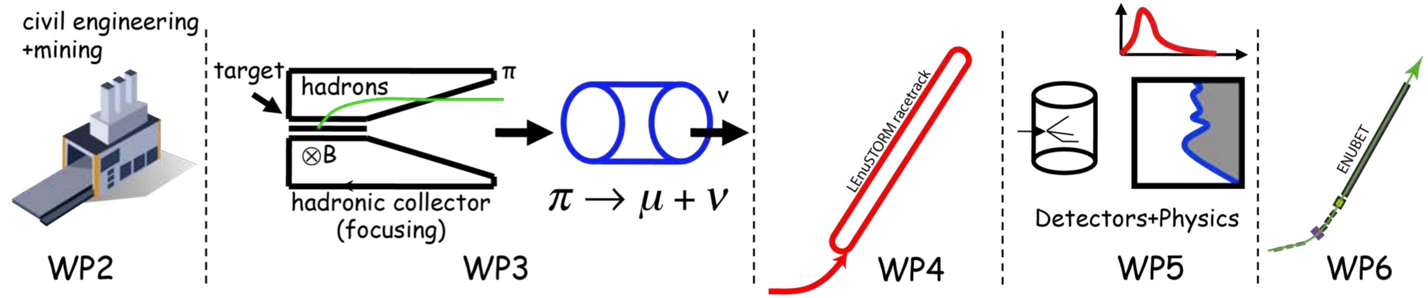


2037-: Data taking

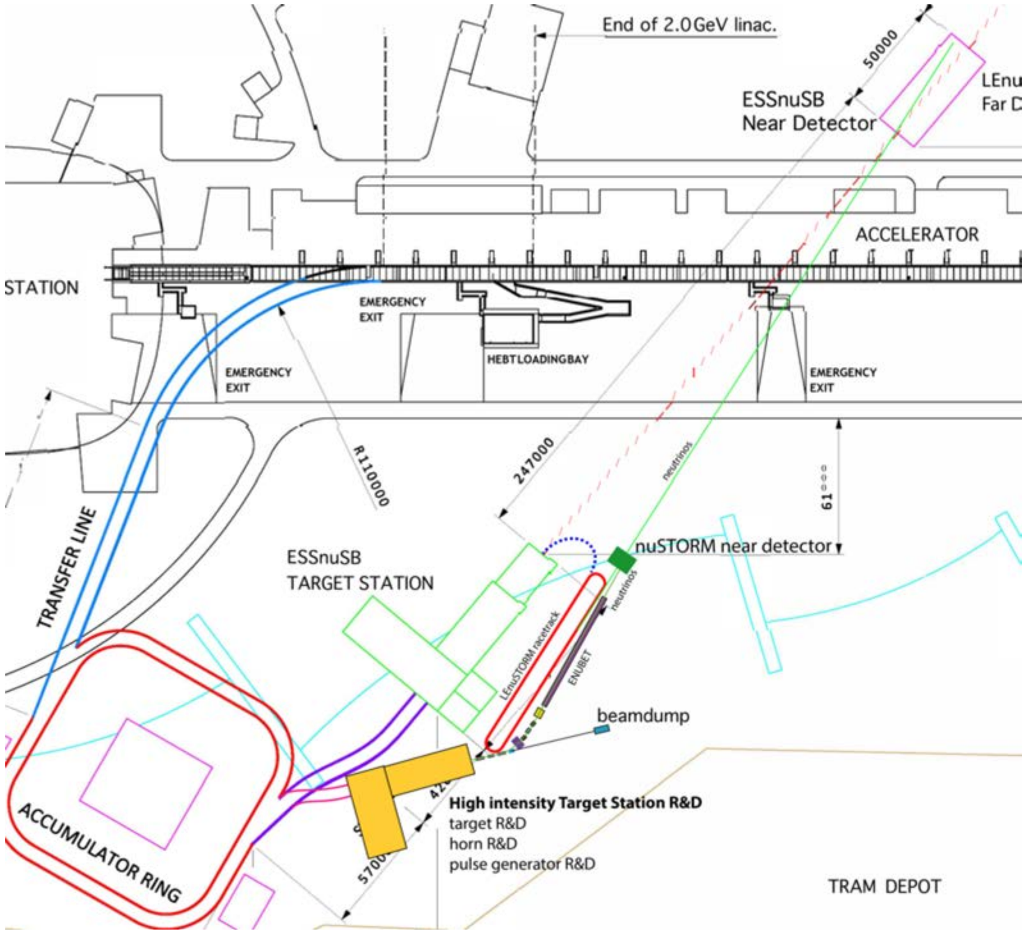


The continuation : ESSνSB+

1. **Design of a racetrack storage** ring for low energy muons produced with a beam from the ESS linac.
2. Design a transfer system from the initial **collection and extraction of pions** behind the target station, up to the injection point.
3. Design a **transfer line** from the ESSνSB ring-to-switchyard transfer line to the Low Energy **nuSTORM target** (cross section measurement, sterile neutrino searches).
4. Design an **injection scheme** for the racetrack storage ring
5. Design a **Monitored Neutrino Beam** (low energy ENUBET for cross-section measurement)
6. **Optimize the performance** of the ESSνSB accelerator complex



Excellent supporting letter from the ESS director



Cross-section measurements with:

- Low Energy nuSTORM: $\pi \longrightarrow \mu \longrightarrow e+\nu_\mu+\nu_e$
- Low Energy ENUBET: $\pi \longrightarrow \mu+\nu_\mu$

Outlines:

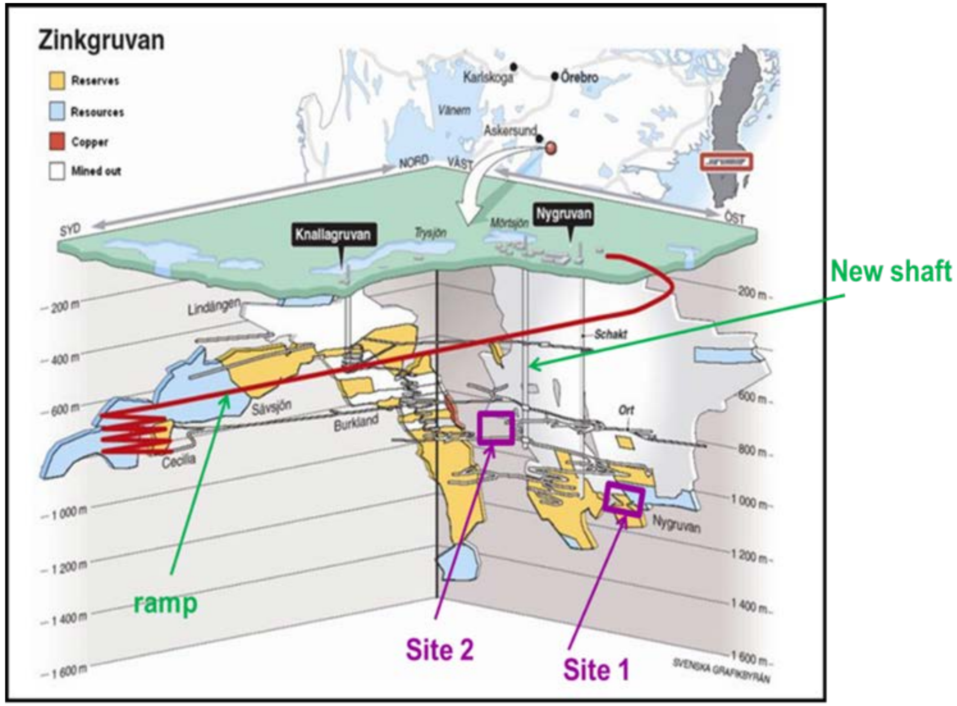
- The ESSνSB project proposes to the community a very intense neutrino superbeam based on the 5 MW LINAC which will be able to measure precisely δ_{CP} .
- Thanks to its specific baseline and the recent progresses in term of optimization, the ESSνSB facility will allow to cover more than 70% of δ_{CP} range and 8° precision after 10 years of data taking.
- The ESSnuSB+ acts as an intermediate stage and offers lots of opportunities for a synergetic approaches for many facilities especially using muons.
- In addition, the ESS facility has a broad range of fundamental physics complementary to neutrino physics (proton lifetime, astroparticules,…).

Website : https://essnusb.eu/

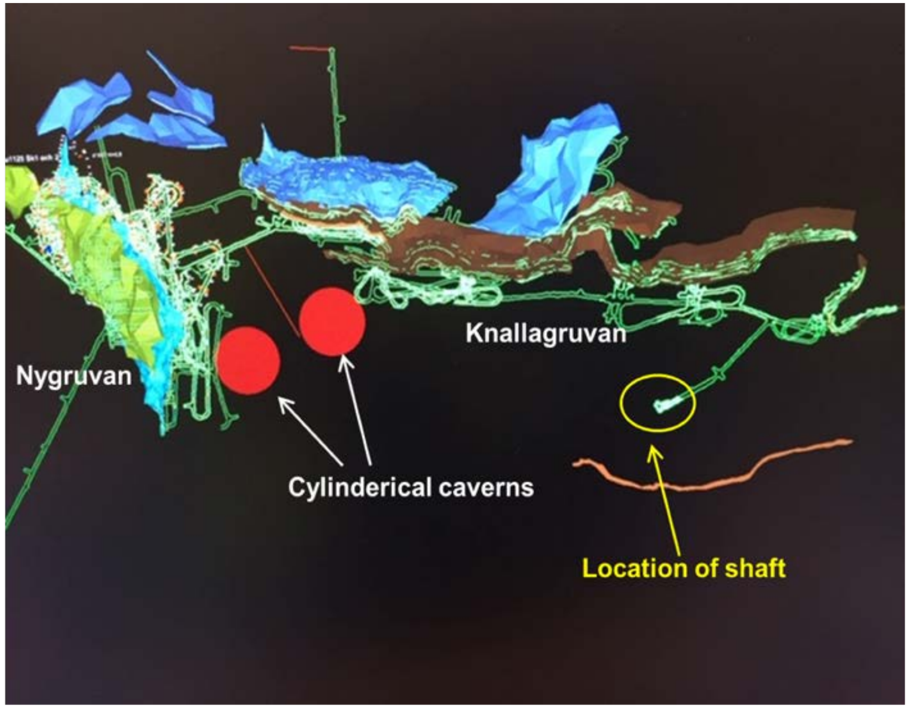
Conceptual Design Report
available on arxiv : arxiv.org/abs/2206.01208

BACKUP

Zinkgruvan mine



Potential location in Site 2



Site 2 is considered as best considering access to main transport infrastructure and located in an area less disturbed by mining activities

The ESSνSB High Intensity Neutrino Superbeam

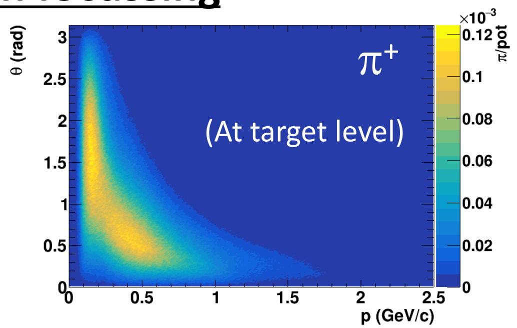
Optimization Procedure

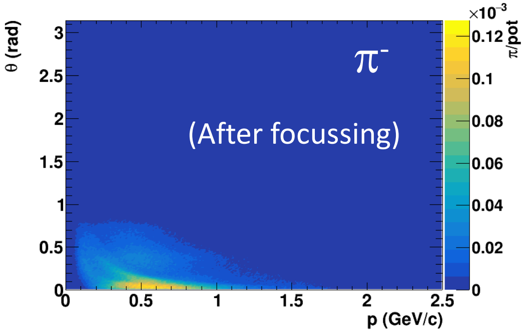
Neutrino beam production

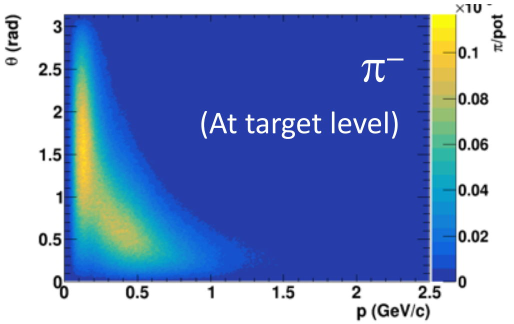
$\pi^+ \rightarrow \mu^+ + \nu_\mu$ (Positive polarity)

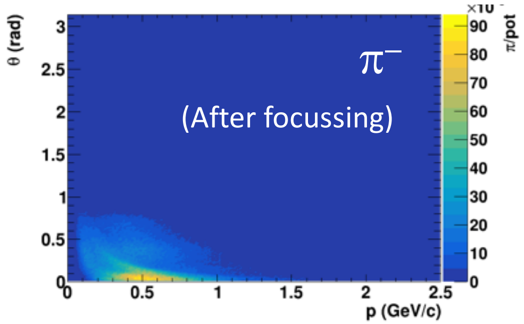
$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ (Negative polarity)

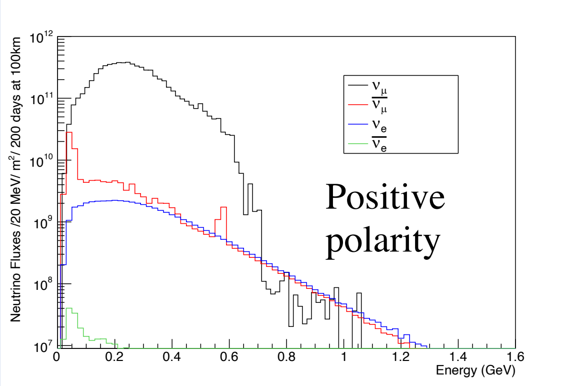
Horn focussing

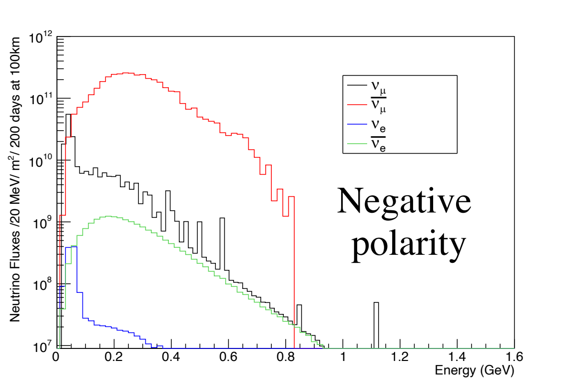








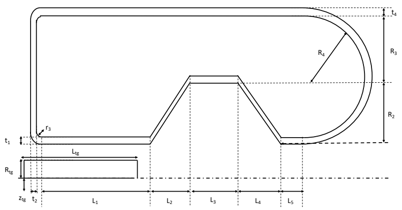




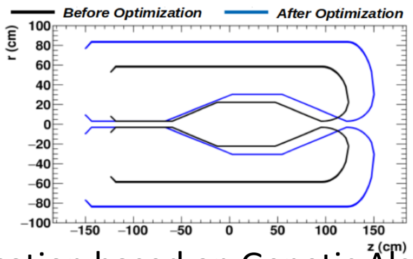
Neutrino flux composition.

	ϕ_ν $10^{10}.m^{-2}$	%	ϕ_ν $10^{10}.m^{-2}$	%
ν_μ	674	97.6	20	4.7
$\bar{\nu}_\mu$	11.8	1.7	396	94.8
ν_e	4.76	0.67	0.13	0.03
$\bar{\nu}_e$	0.03	0.03	1.85	0.43

Optimisation procedure



Horn parametrisation



Optimisation based on Genetic Algorithm

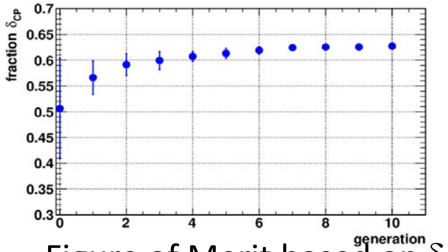
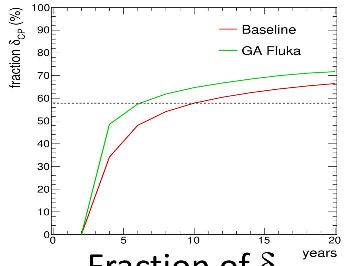


Figure of Merit based on δ_{cp}

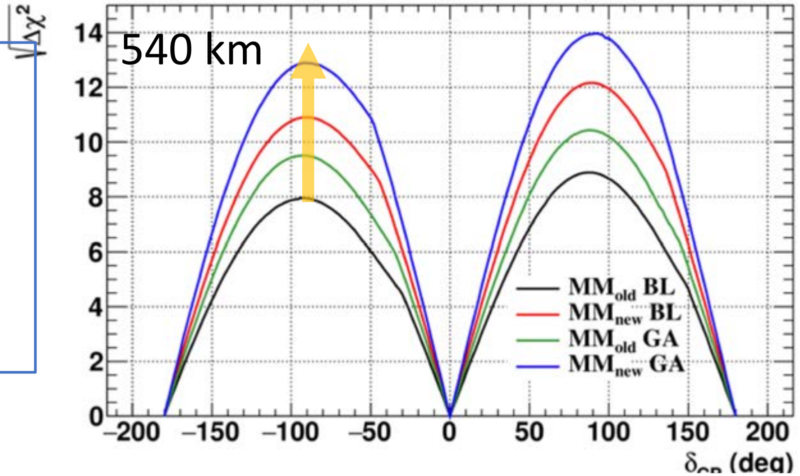


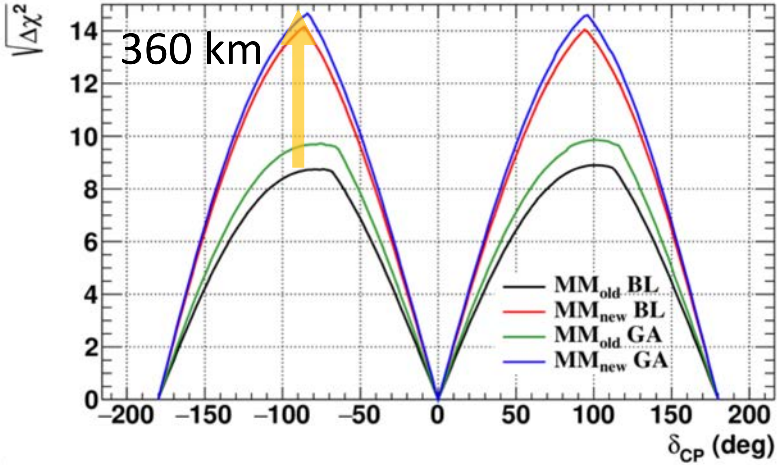
Fraction of δ_{cp}

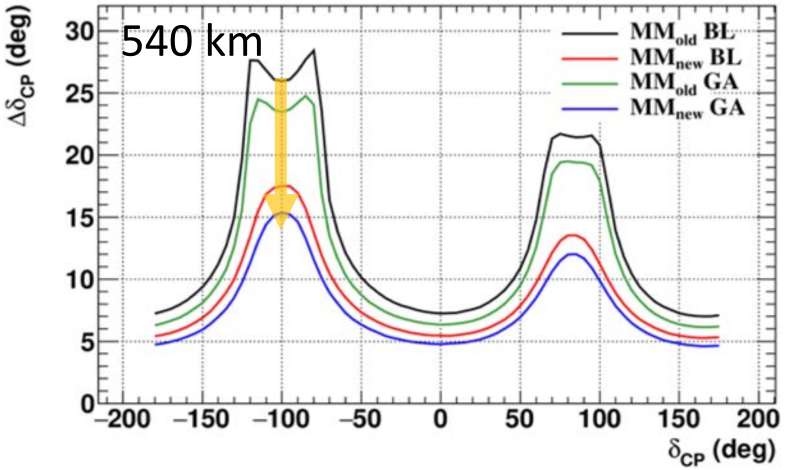
Improvement and Optimization for precision

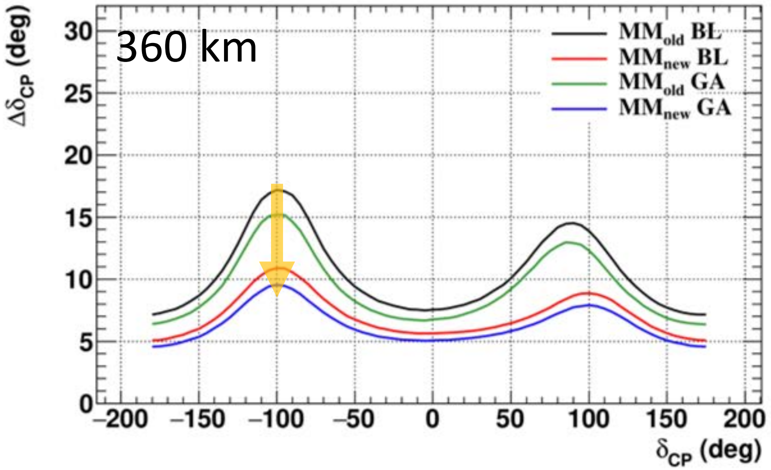
ESSnuSB

- $\theta_{12} = 33.44°$
- $\theta_{13} = 8.57°$
- $\theta_{23} = 49.2°$
- $\Delta m^2_{21} = 7.42e\text{-}5$
- $\Delta m^2_{31} = +2.52e\text{-}3$
- 2nd osc. max.
- 507 ktons far detector







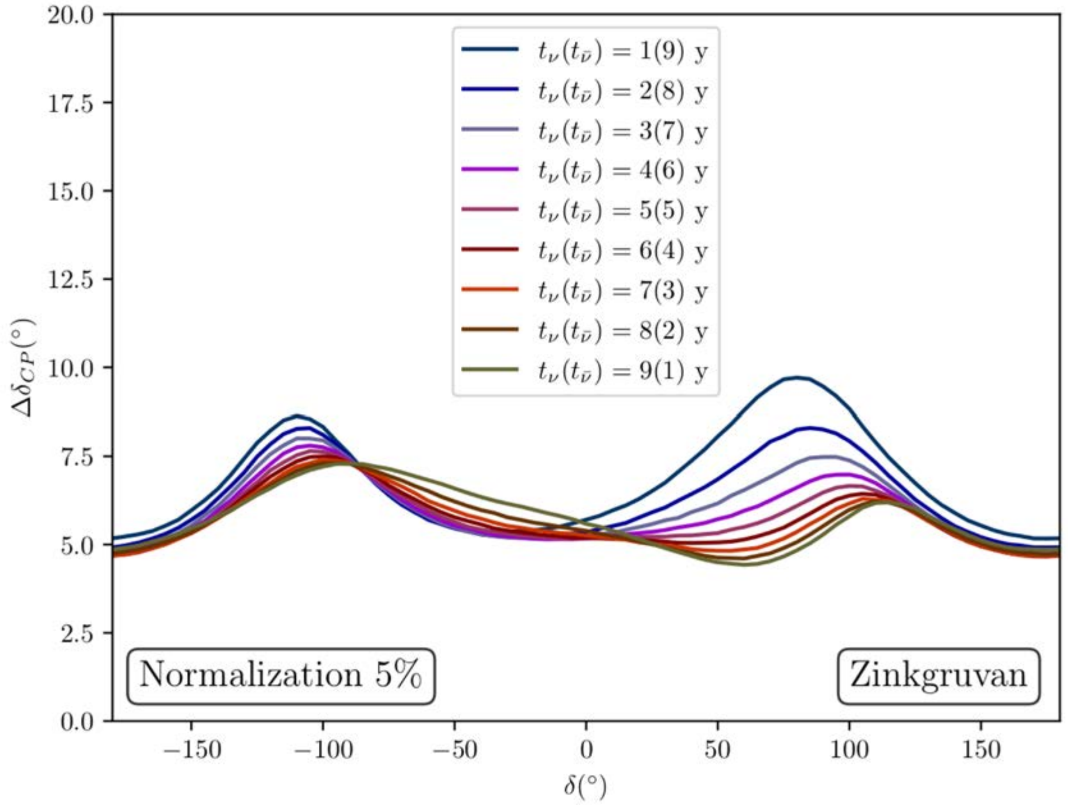


https://arxiv.org/abs/2107.07585

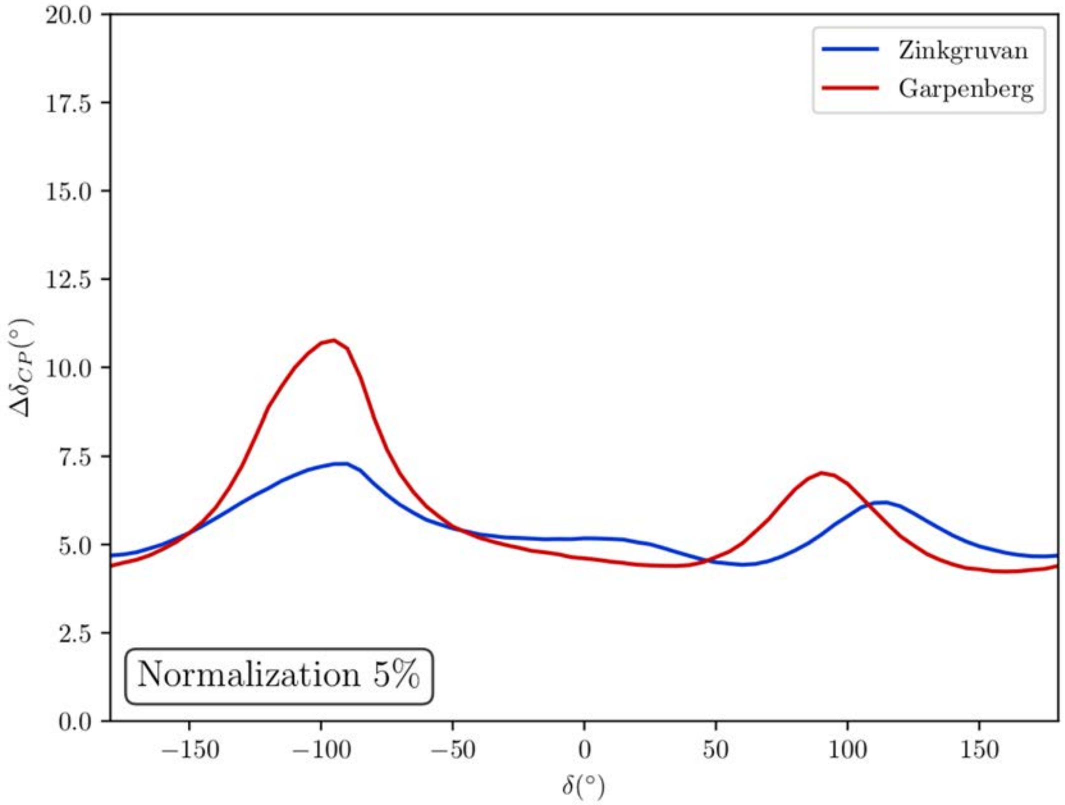
Optimization for precision

Supposing that value of δ_{CP} is roughly known at ESSνSB time

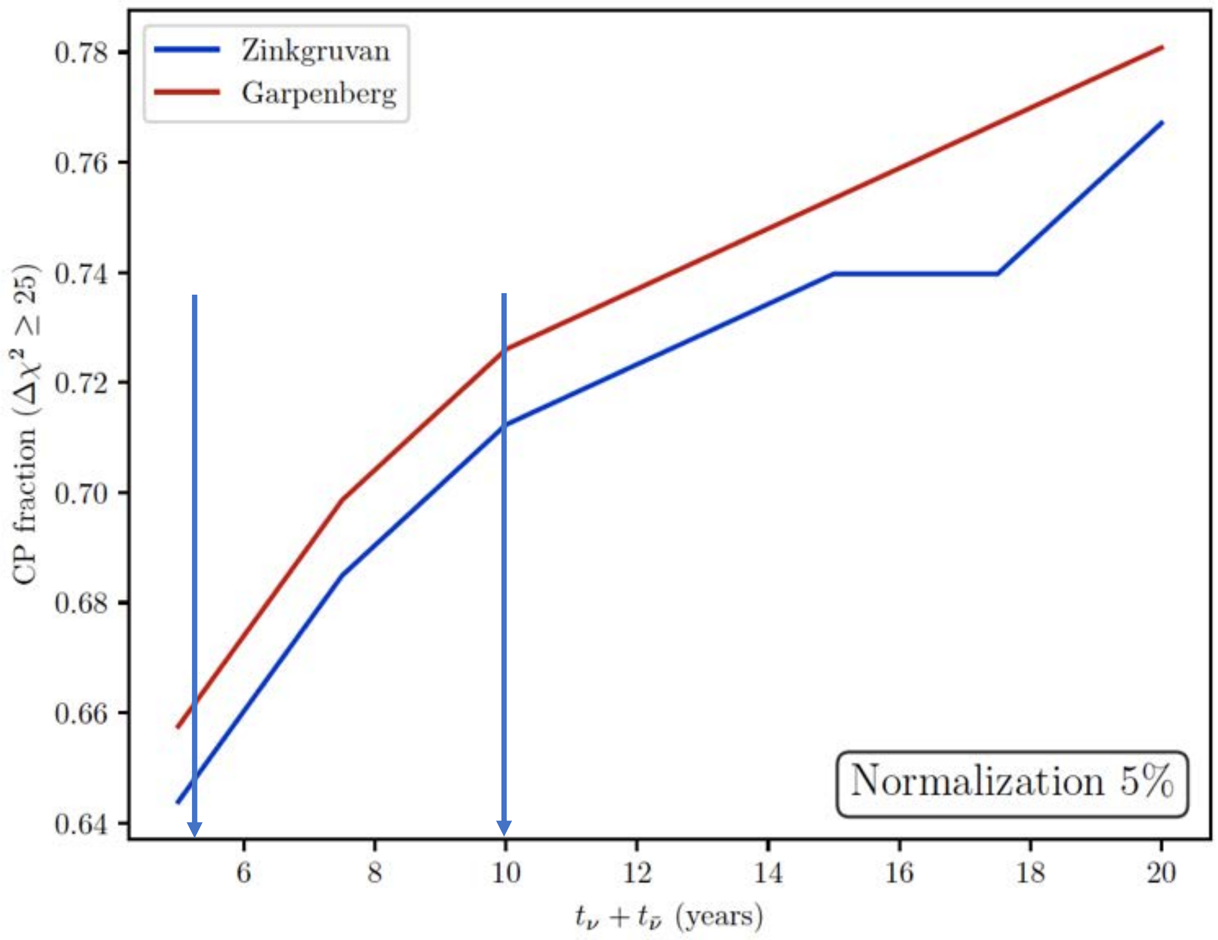
Precision for different neutrino (antineutrino) run times



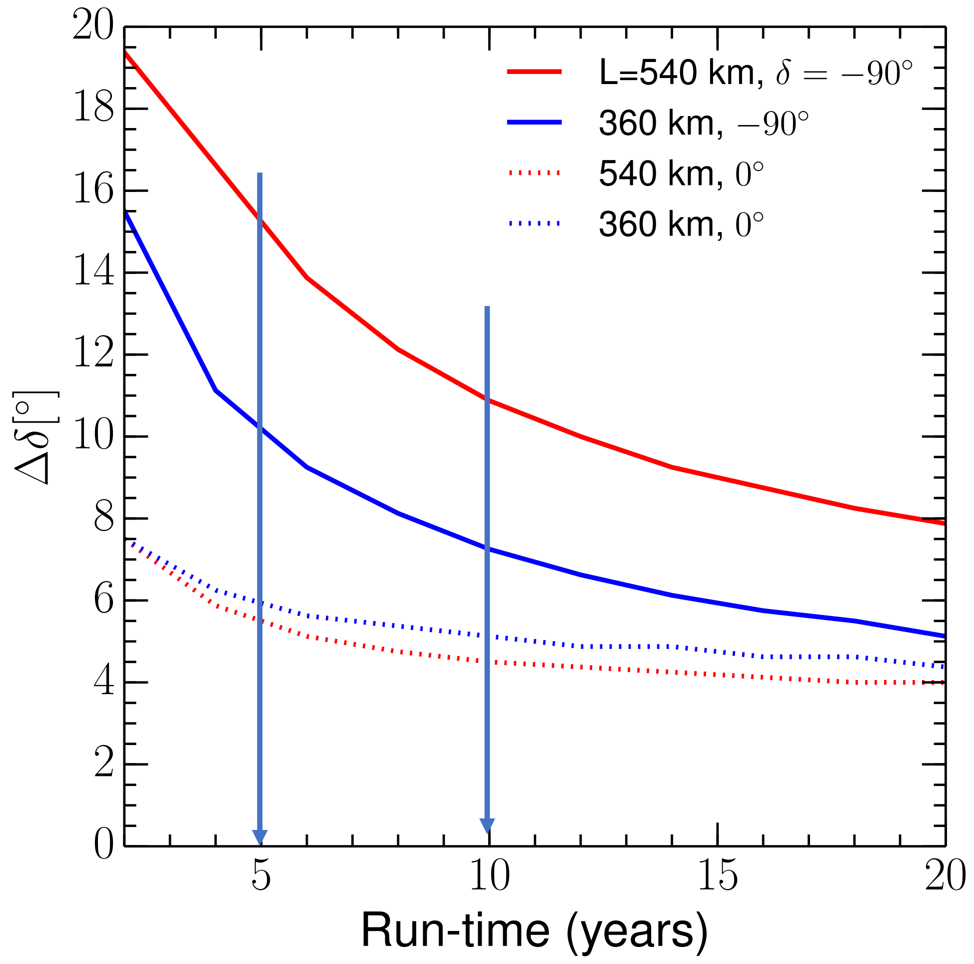
Optimal precision for known δ_{CP}



Physics Performances

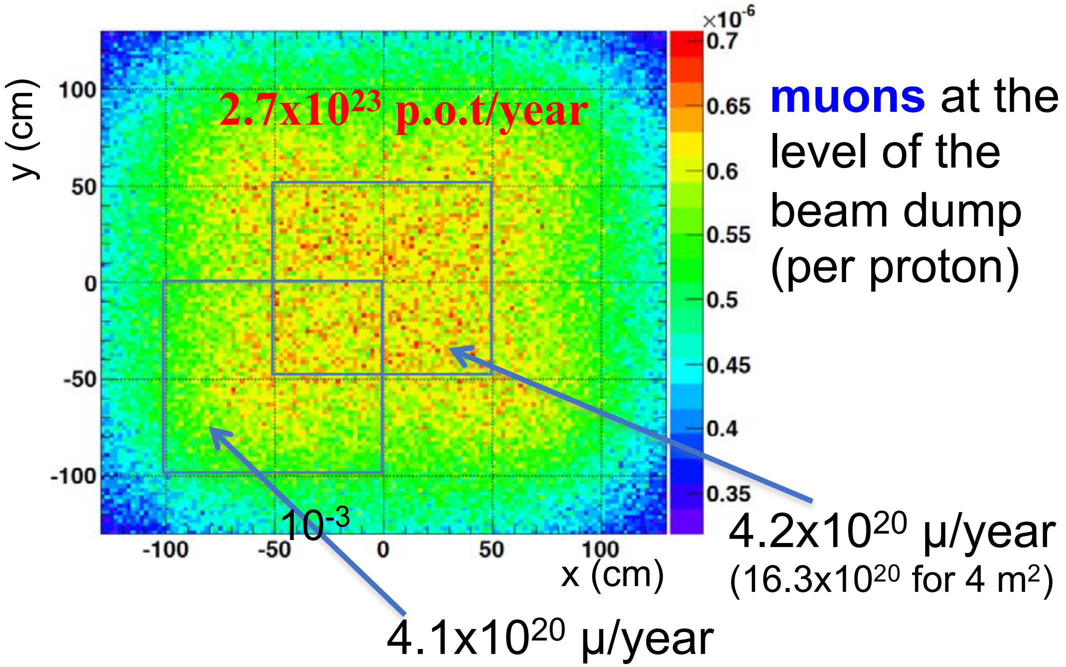


CPV discovery at 5 σ versus time

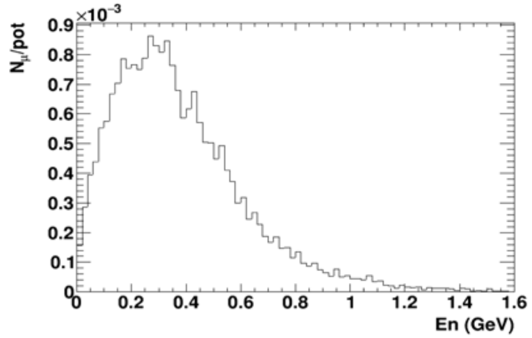


Precision versus time for δ_{CP}=0°, -90°.

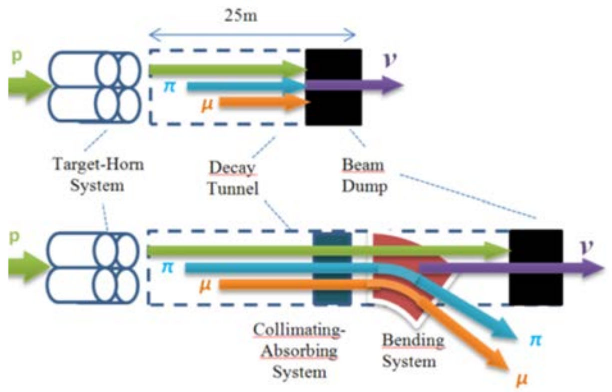
Future Research Activity

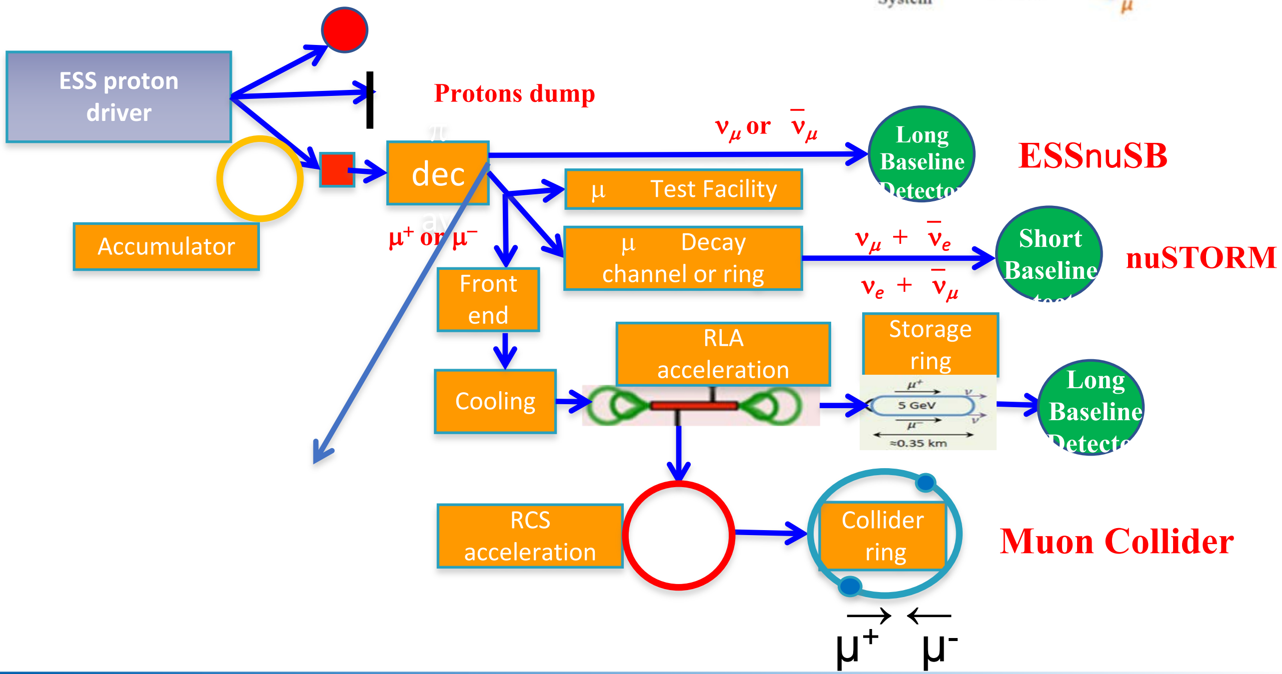


Future possible developments based on muons physics



Muons entering in the Beam Dump





- Input beam for future 6D m 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**.