Prospective of Neutrino Beams in Europe

IRN Neutrino

9-10 October 2024

Contribution to ESPPU2025 IRN document

Prospective of Neutrino Beams in Europe

New methods to control systematic uncertainties due to flux and neutrino cross section

- Precision on oscillation parameters, δ_{CP} precision, mass hierarchy, …
- Testing sterile neutrino, NSI,…

Neutrino superbeams proved their efficiency to perform precise measurements and the coming experiments such DUNE, T2K and HK will improve our knowledge of the neutrino sector.

Europe efficiently contributes to these collaborations, in particular CERN offers an ideal platform for R&D activities and successfully lead to the development of new technologies !

Europe will be play a major role in future by offering a rich complementary neutrino accelerator based program:

- developing **new neutrino beam experiments,**
- perform R&D on **innovative technology** (new materials, detectors,…)
- **synergies between other facilities**,…

A high-precision short-baseline neutrino beam at CERN

As suggested by the previous European Strategy, R&D have been carried out to support a new generation of neutrino cross sections experiments at the GeV scale that addresses **all challenges that cannot be solved by either current generation experiments or the DUNE and HyperKamiokande Near Detectors**.

NP06/ENUBET: is a Neutrino Platform experiment at CERN aimed at designing a beam with sub-percent precision in the ν_e and ν_μ flux and O(10%) precision on the neutrino energy using the technique of Monitored Neutrino Beams. Here, systematic uncertainties on the flux are removed by monitoring the rate of charged leptons in the decay tunnel. The ν_μ neutrino energy is measured a priori using the strong correlation between the neutrino energy and the production angle (i.e. the interaction vertex at the neutrino detector). **This is equivalent to have a monochromatic ν_μ beam with a 10% width, whose flux is known with <1% precision!**

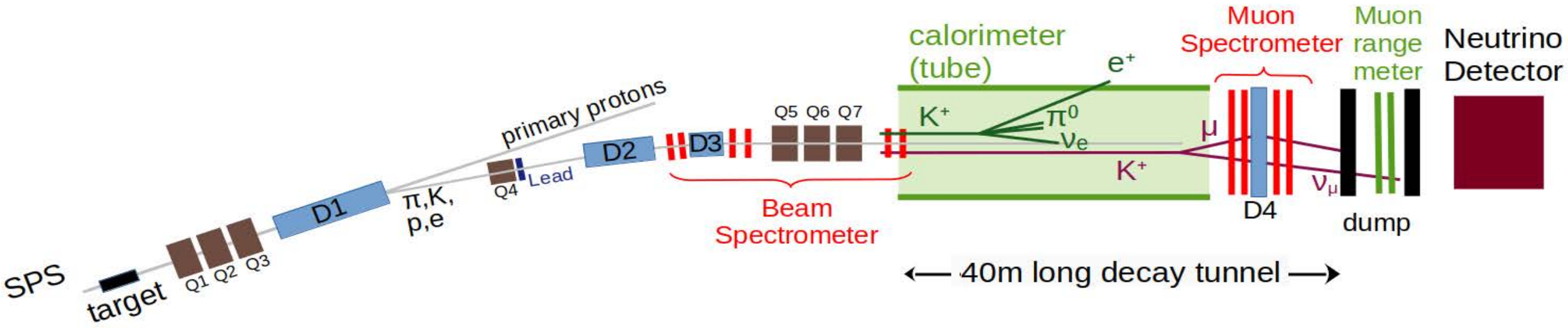
NuTAG: is a CERN-France-Italy proposal to instrument the ENUBET beamline with fast silicon trackers. They track the parent pion/kaons and the muons and reconstruct the neutrino energy by kinematics. **This is equivalent to have a monochromatic ν_μ beam with a 1% width and the first tagged neutrino beam ever build!**

CERN – in the framework of Physics Beyond Collider - is now evaluating the implementation of this beam at the CERN SPS accelerator, possibly using the ProtoDUNEs and WCTE (or its ≈100-ton extension) as neutrino detectors to perform cross-section measurements using the same target as DUNE (liquid argon) and HyperKamiokande (water).

This project is called ShortBaselineNeutrinos@PBC (SBN@PBC) and it is the most advanced proposal for a neutrino beam running at CERN in the next decade

Implementation of SBN@PBC

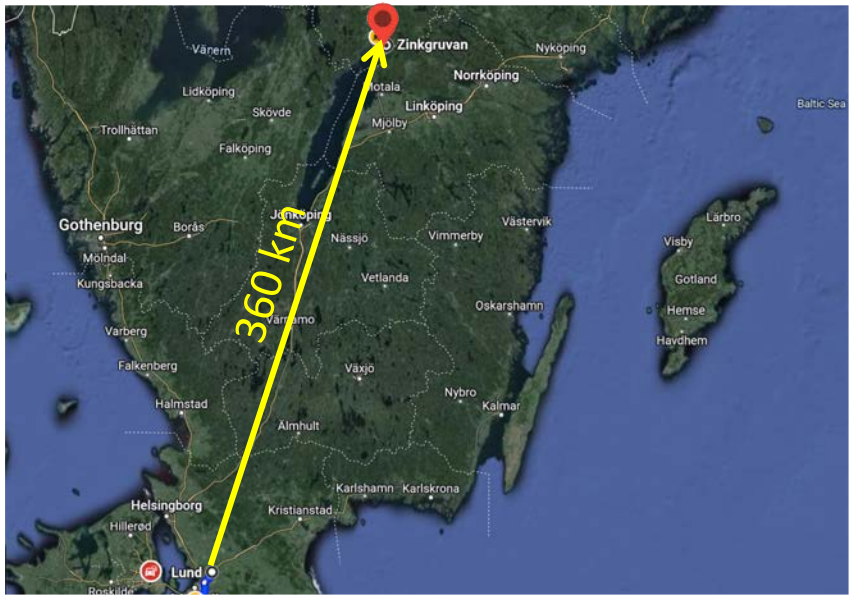
SBN@PBC is a horn-less narrow-band beam originating from 400 GeV/c protons slowly extracted from the CERN SPS. Slow extraction ensures tolerable particle rates in the tunnel for monitoring and tagging.

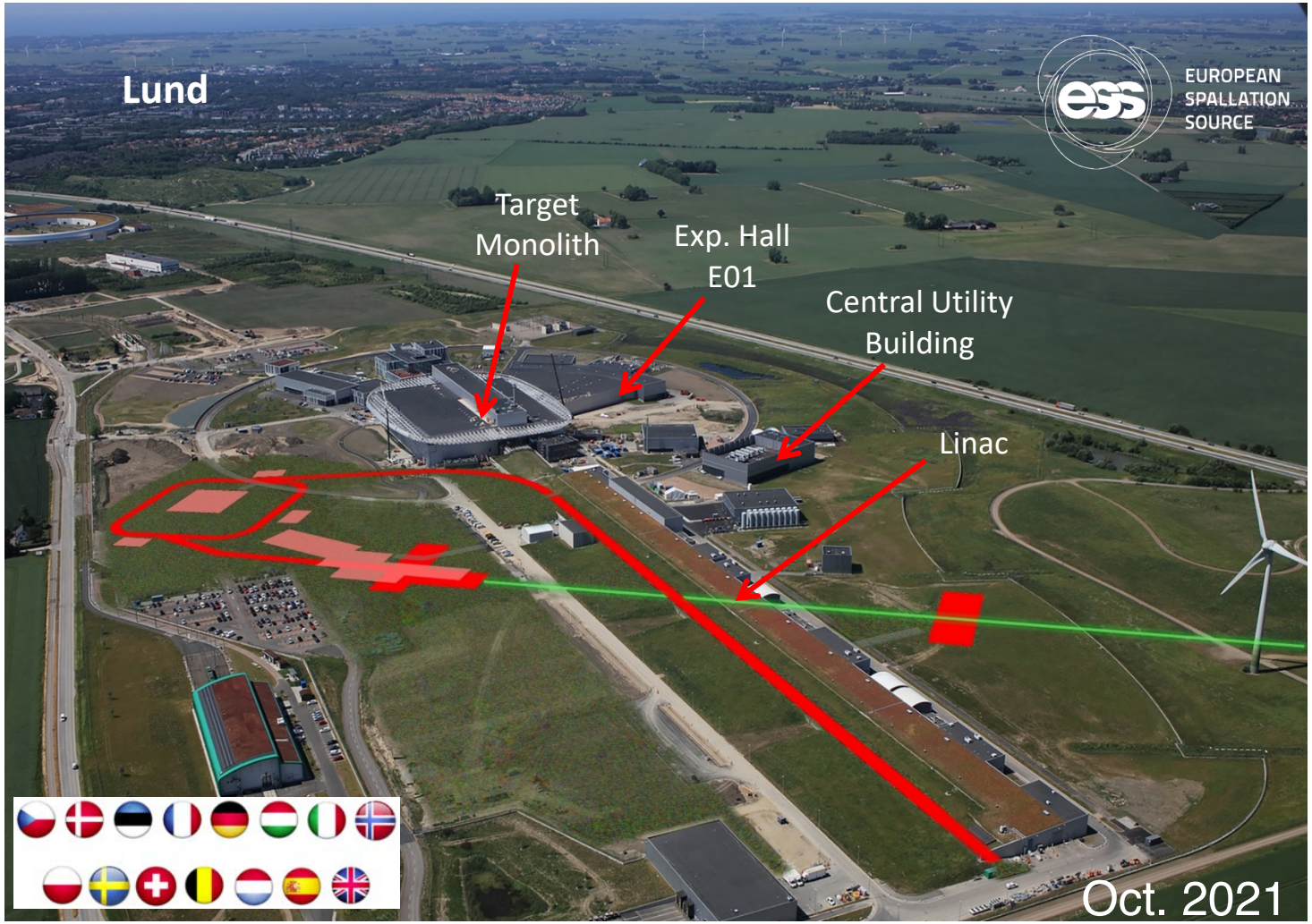


Current implementation options at CERN include the CERN North Area—where ProtoDUNEs are located—and other areas capable of accommodating detectors of similar size. The optimization conducted so far ensures that the cross-section measurements of SBN@PBC can be completed within a few years of data taking, without interfering with the rest of CERN's fixed-target program (e.g., SHIP).

Prospective of Neutrino Beams in Europe

- The ESS facility is under construction in Lund, Sweden ➔ **First beam on target in 2025**
- The most powerful proton linear accelerator
- The world's most powerful neutron source
- Designed for $E_{kinetic}$ = 2 GeV and power of 5 MW ➔ **Makes longer baseline possible**





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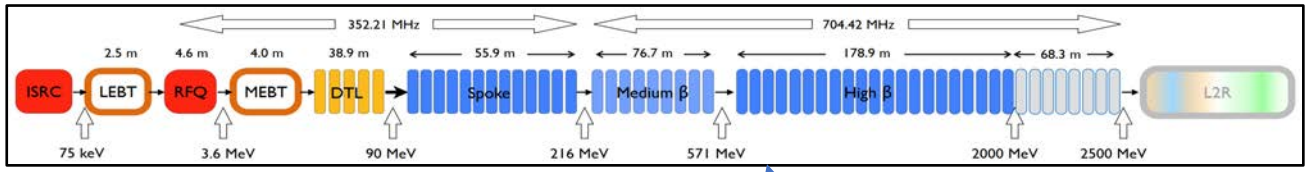
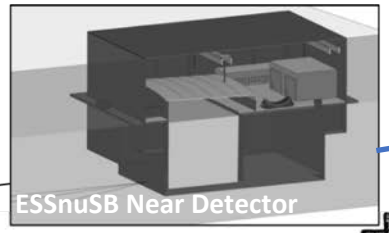
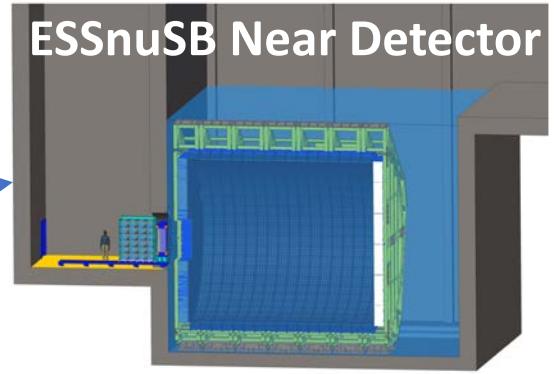
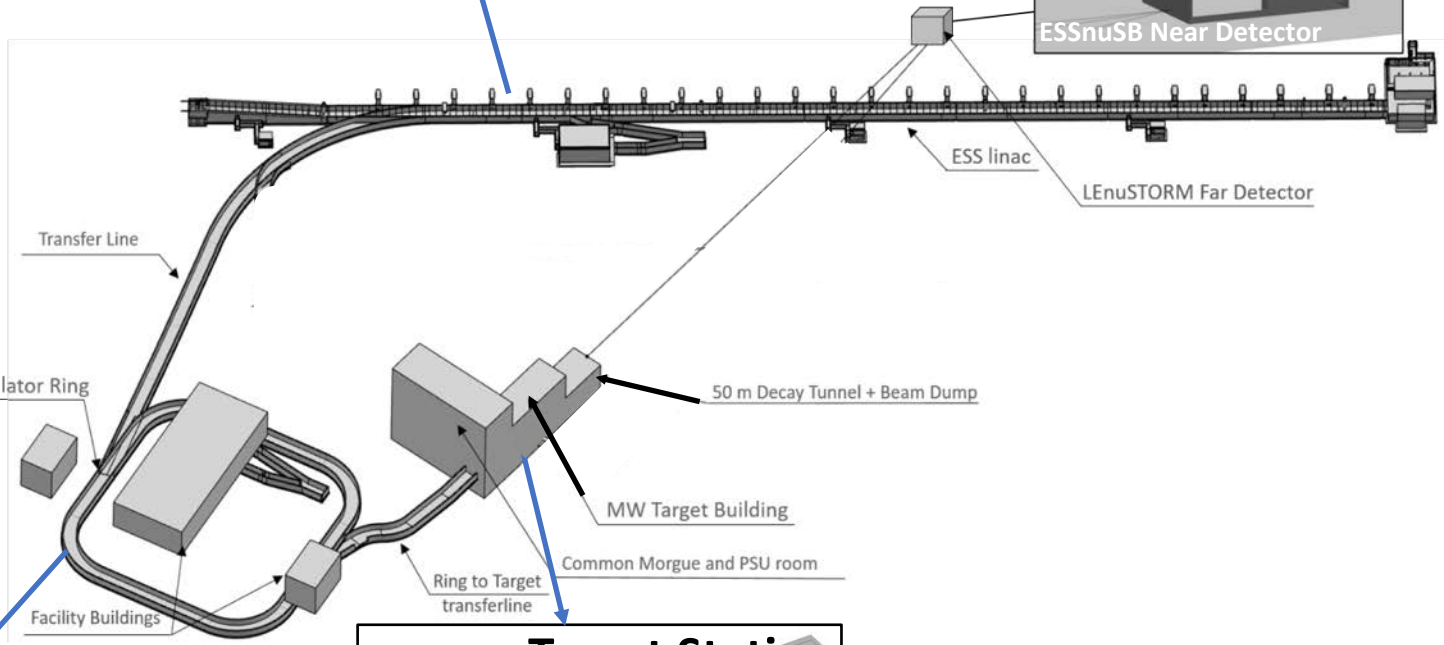
ESSnuSB (5 MW)

ESS linac

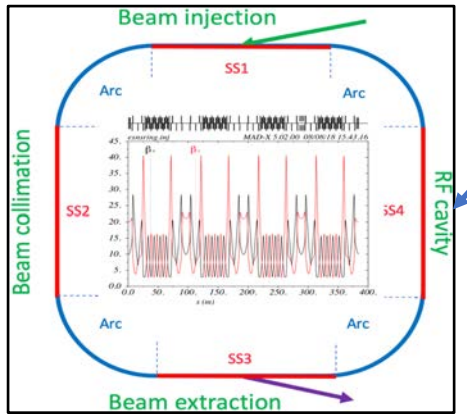




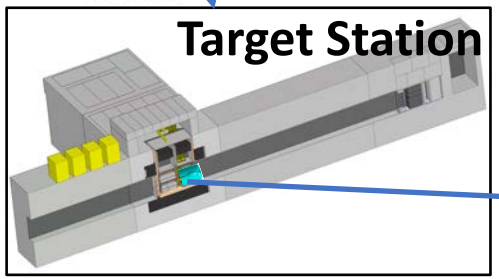




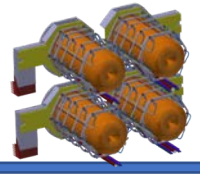
Accumulator Ring



Target Station



Four horn-target system



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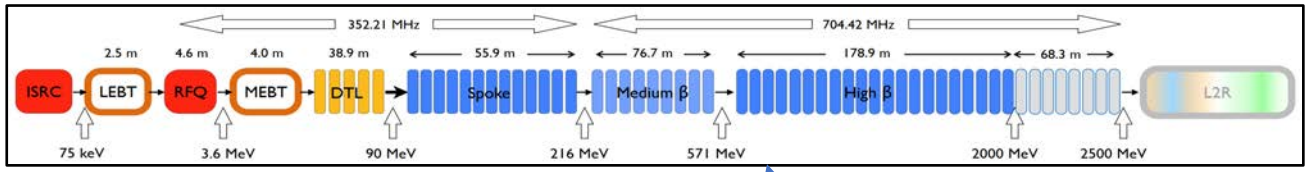
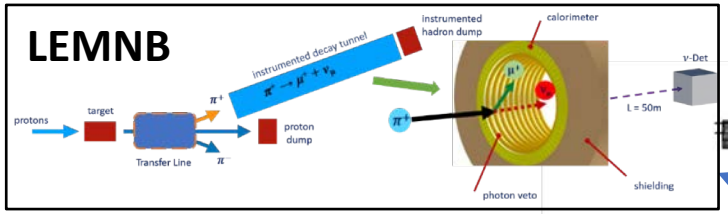
ESSnuSB+ (1.25 MW)

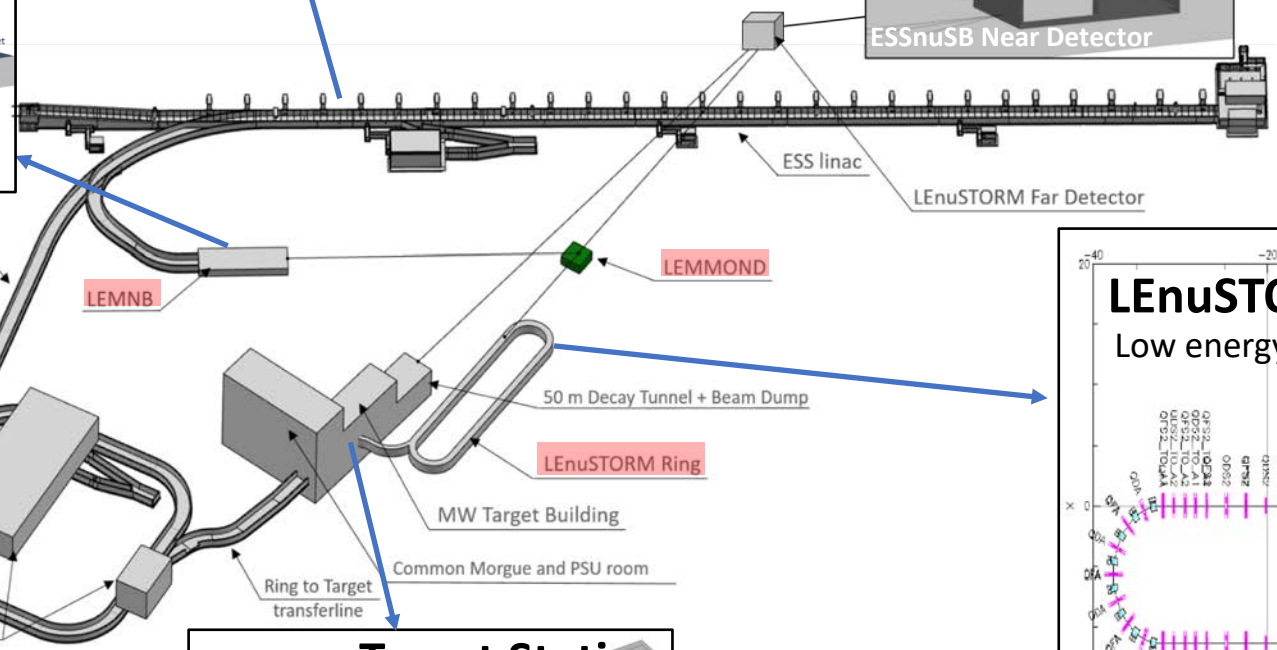
ESS linac

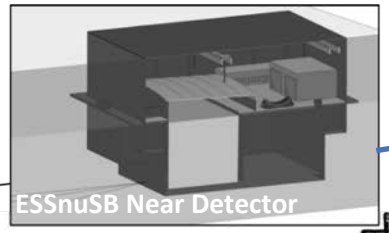


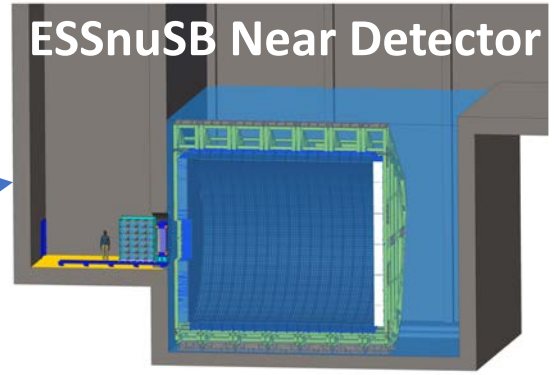
LEMNB



Low Energy Monitored neutrino Beam







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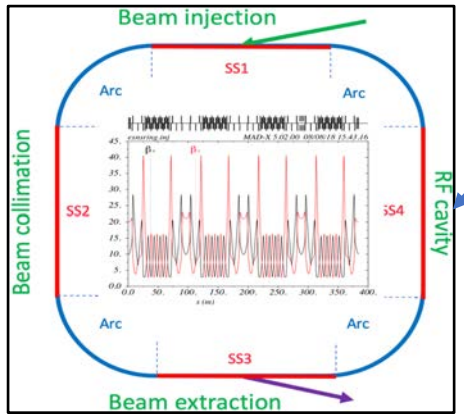

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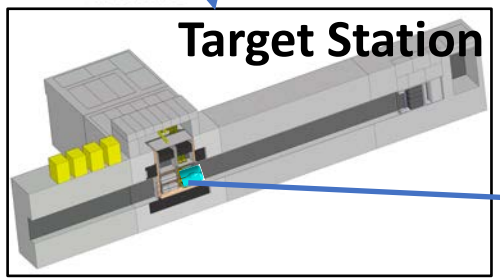
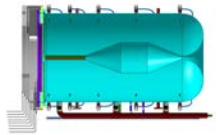
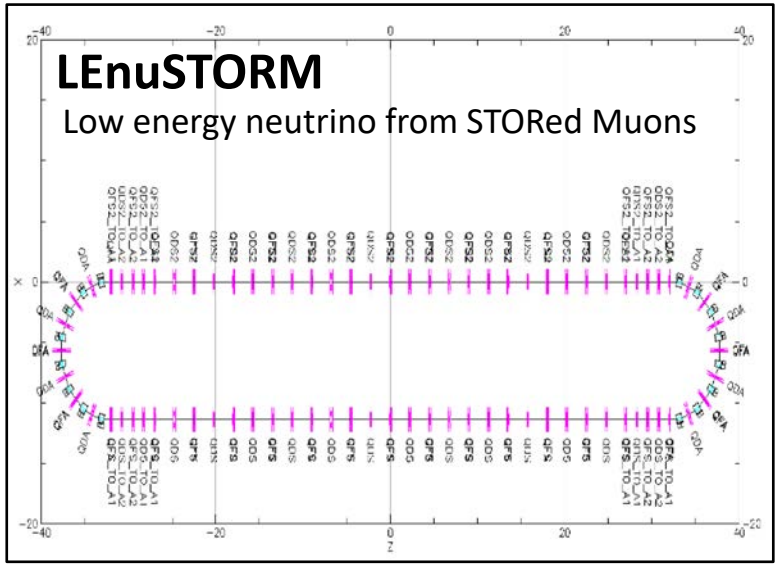


One horn-target system



LEnuSTORM

Low energy neutrino from STORed Muons



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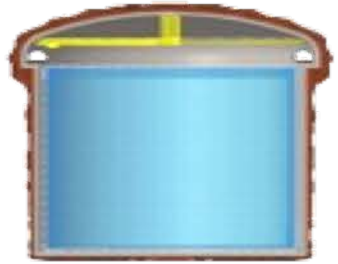
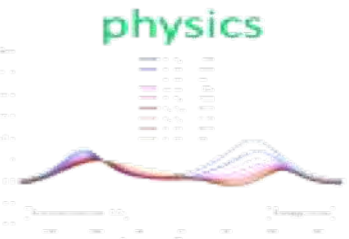




ϑ_{13} measurement

Nobel prize:
T. Kajita &
A. McDonald

ESFRI

EUROPEAN SPALLATION SOURCE

ESS neutrino Super Beam plus

ESS NEUTRINO SUPER BEAM

2018-2022: ESSvSB Design Study, CDR (EU-H2020)

2023-2026: ESSvSB+ Design Study, CDR (EU-HE) and preparatory phase

2026-2028: TDR Phase, International Agreement

taking

2028-2038: Construction of the facility and detectors, including commissioning

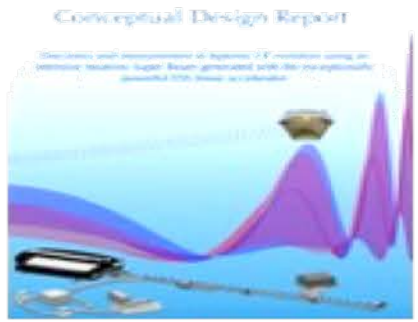
2015

2016-2020: COST Action EuroNuNet

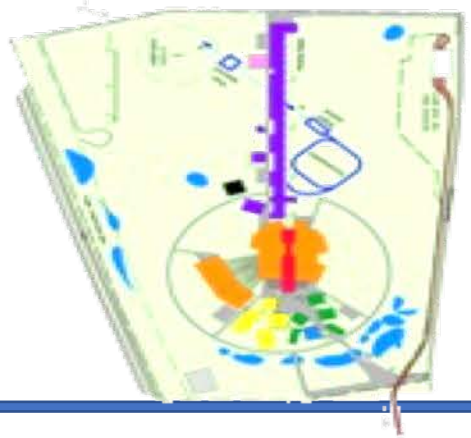
2012: inception of the ESSnuSB project

Nucl. Phys. B 885 (2014) 127

2008-2012: EUROv Design Study (FP7)



ESSvSB CDR



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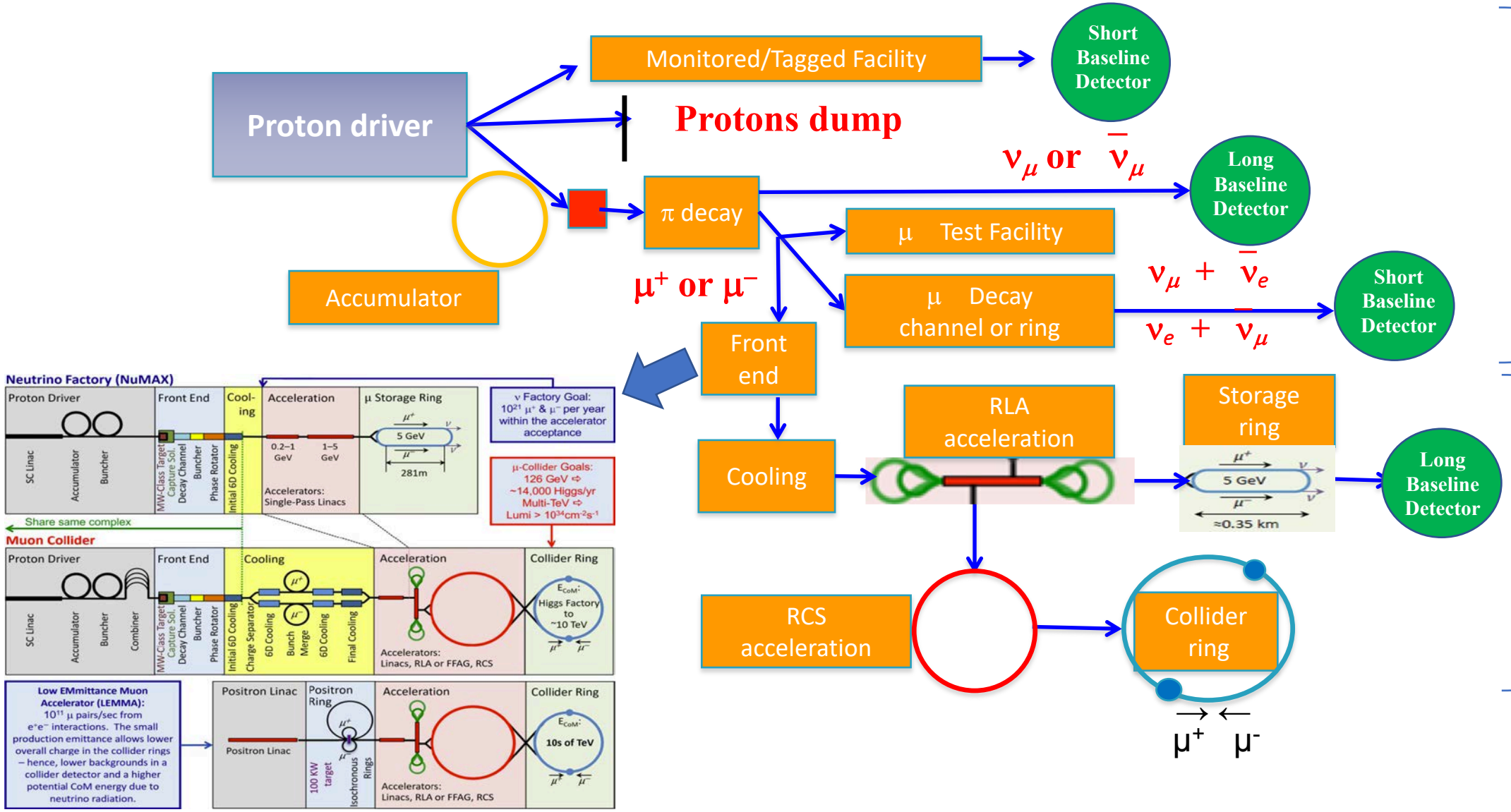
Synergy aspects



Prospective of Neutrino Beams in Europe

- Numerous programs has been funded (Euronu, Laguna, laguna-LBNO, EnuBET, ESSnuSB, ESSnuSB+) to investigate the possibility to host neutrino beam facilities in Europe.
- Several options based on different innovative techniques are proposed at low and high beam power.
- The development of such facilities will be the opportunity to develop a rich physics and R&D program which is complementary to current experiments.
- Challenges in term of R&D for materials (e.g. HiRadMat at CERN).
- Synergy with other projects can generate also common interests such muon collider.