The ESSνSB Switchyard, Target Station and Facility Performances

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Next generation of neutrino accelerator based experiments will address the fundamental questions on CP violation and Mass Hierarchy.

Common efforts are needed to realize the future facilities:

- Accelerator challenges to develop a proton driver at MW scale.
- R&D program for Mt scale detectors with conventional or novel technology with improved sensitivity.
- An international program based on an incremental approach has been established (LBNF/DUNE, T2K,...) taking benefits from previous studies...
Design:

- Producing a high intensity neutrino beam from MW proton beam is a technical challenge and requires R&D:
  - Target able to support Multi Mega Watt proton beam
  - Focusing system with minimum failures during run time
  - Remote handling system for maintenance
- Minimize risk of failures during beam operations
- Safety for workers
- Respect environmental conditions
- Reduce production and running costs
- …
ESS LINAC requirements 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
- Several beam pulse profiles are under investigations
Accumulator implementation on ESS site

ESS construction site

IPAC’15 Proceedings: E. Wildner et al., “The Accumulator of the ESSnuSB for Neutrino Production”, THPF100
Update of the switchyard preliminarily designed for EUROv with ESS beam parameters (Config.1)

- Other possible layouts currently being studied (Config.2)
- Selection criteria: number of magnetic elements needed + type of operation (i.e. simple or bi-polar) + prospective of beam dump requirements.

**Configuration 1**
- Total length: 43.4 m
- Max. B-field: 0.65 T
- (25 kA turns / pole)
- Dipole length: 2 m

**Configuration 2**
- Total length: 72.2 m
- Max. B-field: 0.73 T
- (29 kA turns / pole)
- Dipole length: 2 m

IPAC’15 Proceedings: E. Bouquerel, “Design Status of the ESSnuSB Switchyard”, MOPWA017

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**Target concept:**
- Power 1.25 – 1.6 MW
- Potential heat removal rates at the hundreds of kW level
- Helium cooling
- Separated from the horn

**Focusing system:**
- 4-horn/target system to accommodate the MW power scale
- Solid target integrated into the inner conductor: very good physics results but high energy deposition and stresses on the conductors
- Best compromise between physics and reliability

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ESS Linac
H, 5 MW, 2.5 GeV, 70 Hz, 0.715 ms

Accumulator

Horns
4 targets
15 mm radius
Ø 4 mm
17.5 Hz per line

Switchyard

Decay tunnel

Accumulator

Horns
4 targets
15 mm radius
Ø 4 mm
17.5 Hz per line

Switchyard
Target Concept

Mechanical stresses

Geometrical Constraints

Heat removal

Radiation Damages

Remote Handling

Safe Operations

Improved Lifetime

Transverse cooling

Beam

Packed Bed Target
Packed Bed Target

Target: 3 mm diameter titanium spheres
Proton Beam: 4.5 GeV, 1MW (SPL - Parameters)
Beam width: 4 mm
Target geometry radius/Length: 12 mm / 780 mm
Coolant: Helium at 10 bar pressure

Titanium temperature contours:
Temperature < 673°C (Melting temp = 1668°C)

=> Concept will be upgraded for ESSvSB
5.6. Transient mechanical model

The transient stress from the magnetic pressure pulse is significant mainly for the inner conductors of the horn with small radius such as the inner conductor parallel to the target and inner waist in the downstream region.

\[ u_{\text{max}} = 2.4 \text{ mm}, \quad t = 80 \text{ ms} \]

\[ s_{\text{max}} = 30 \text{ MPa}, \quad t = 80 \text{ ms} \]

Figure 16: Displacement field a) and von Mises stress b) due to thermal dilatation with uniform temperature \( T_{\text{horn}} = 60^\circ C \)

5.7. Cooling system

The heat sources are: electrical resistive losses from pulsed currents and secondary particles generated from the proton beam/target interaction. The heat transfer coefficient depends on the two water phases, the flow rate, the geometry, and the disposition of the nozzles. Assuming an initial inlet temperature and outlet temperature \( \{ T_{\text{i}}, T_{\text{outlet}} \} = \{ 20, 60 \text{ }^\circ \text{C} \} \) and a total power to removed of \( 31 \text{ kW} \).

Horn Design:

- MiniBooNe-Like Horn
- Material: Aluminum Al T 6061 – T6
- Geometry: Length 2.4 m – Diameter 1.2 m
- Inner/Outer conductor thickness: 3 mm /10 mm
- Peak Current: 350 kA

=> Concept will be upgraded for ESSνSB
Cooling system

- Planar and/or elliptical water jets
- 30 jets/horn, 5 systems of 6-jets longitudinally distributed every 60°
- Flow rate between 60-120l/min, h cooling coefficient 1-7 kW/(m²K)
- Longitudinal repartition of the jets follows the energy density deposition

\[ \{h_{\text{corner}}, h_{\text{horn}}, h_{\text{inner}}, h_{\text{convex}}\} = \{3.8, 1, 6.5, 0.1\} \text{ kW/(m}^2\text{K)} \text{ for } T_{Al-\text{max}} = 60 ^\circ\text{C} \]
Horn Energy Deposition

ESSvSB 1.6 MW / EUROnu -1.3 MW

target Ti = 65% d_{Ti}, R_{Ti} = 1.5 cm

21/12.4 kW, t = 10 mm

6.3/3.4 kW, t = 10 mm

13.6/9.4 kW

2.4/1.7 kW

3.5/2.4 kW

2.1/1.2 kW

2.8/1.6 kW

P_{tg} = 212/104 kW

P_{h} = 52/32 kW

radial profile of power density kW/cm^3

Horn max

(E. Baussan - IPHC/CNRS-IN2P3/UNISTRA)
Target Station Requirements

- Focusing System
- Crane System
- Automated robot
- Supporting structure for focusing system
- Dose Rate Monitoring System
- Residual Dose Rate platform
- Operation under helium atmosphere
  - flushing with air
  - filter to measure radioactive pollution (dust, tritium …)
- Investigation of other radionuclides transport (environmental constraint)
Target Station concept studied by EUROnu
Target Station Concept
Horn Power Supply and Strip lines

- each MODULE delivers a current of 44kA max at F=50HZ
- For each HORN: current of 350kA max at 12.5HZ
- energy recuperation (>90%) and reinjection
- lifetime > 13 Bcycles (10 years, 200 days/year)
Horn Power Supply and Strip lines

Projet EUROnu
Intégration Power 350KA et Beam switchyard
**ALARA Approach:**

- Anticipate and reduce individual and collective exposition to radiation

**Iterative processes**

- Preparation
  - Building structure list of materials
  - Dose Equivalent Rate Estimation
  - Optimize operation during maintenance and running phases
  - Evaluation residual activity of wastes
- Execution
- Feedback from previous facilities (WANF, CNGS, NuMI, j-PARC, …)
Beam dump:
- Graphite = 950/778 kW
- Iron = 195/229 kW
- Surr. concrete = 4/4 kW

Decay tunnel:
- Iron vessel = 424/390 kW
- Upstream iron = 670/610 kW
- Surr. concrete = 467/485 kW

Horns/Target gallery:
- Iron = 613/437 kW
- Horn = 50/32 kW
- Target = 168/85 kW

Target Station Energy Deposition
ESSvSB 1.6 MW / EUROnu -1.3 MW

(N. Vassilopoulos)
Safety: Material Activation

(Titanium density 66%)
All the radionuclide's created, especially $^{22}$Na and tritium, could represent a hazard by contaminating the ground water.
Other possible physics
Muons at the level of the beam dump

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

\[ \text{muons at the level of the beam dump (per proton)} \]

\[ 4.1 \times 10^{20} \mu/\text{year} \]

\[ 4.2 \times 10^{20} \mu/\text{year} \]

- input beam for future 6D \( \mu \) cooling experiments (for muon collider),
- good to measure neutrino x-sections (\( \nu_\mu, \nu_e \)) around 200-300 MeV using a near detector,
- low energy nuSTORM,
- Neutrino Factory,
- Muon Collider.
Muons of average energy ca. 0.5 GeV at the level of the beam dump (per proton)
Summary:

- European Spallation Source is under construction and will provide a 5 MW beam power by 2023.
- ESSνSB Project offers a good opportunity to study CP violation in leptonic sector with an improved sensitivity thanks to the 2nd Oscillation maximum.
- Technical constraints of a Super Beam with a Multi Mega Watt proton driver have been studied in the EUROnu WP2 framework and will be upgraded for ESSνSB.
- ESSνSB can also be used as a platform to develop future muon beam experiments.