

NBI 2019 : 11th International Workshop on Neutrino Beams and Instrumentation



Funded by the Horizon 2020
Framework Programme of the
European Union



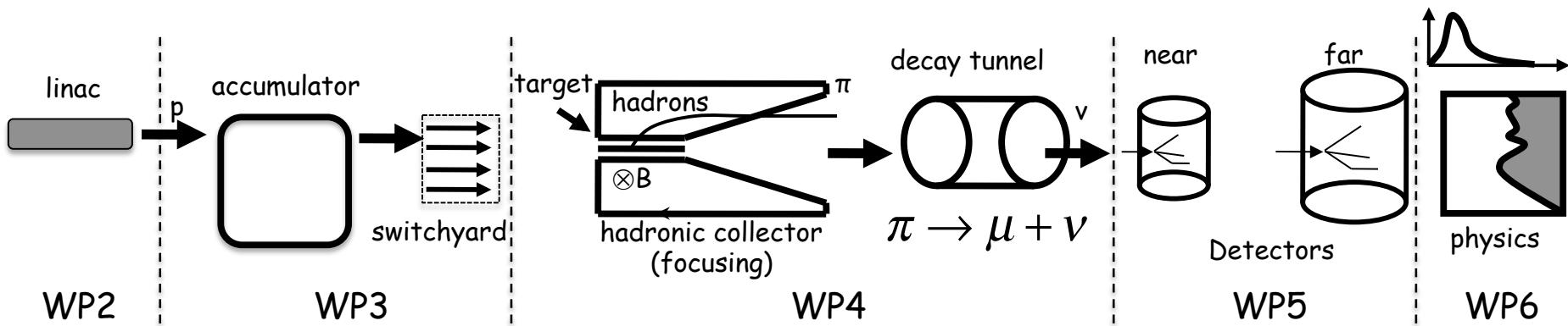
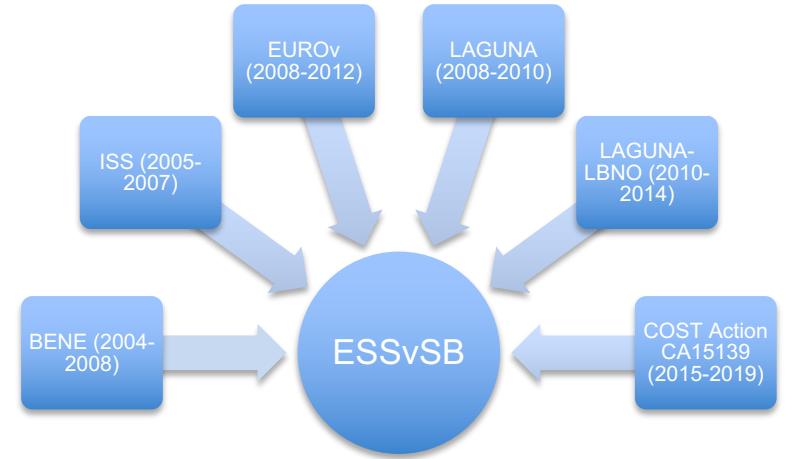
The ESSvSB Target Station



E. Baussan on behalf of
ESSvSB Collaboration

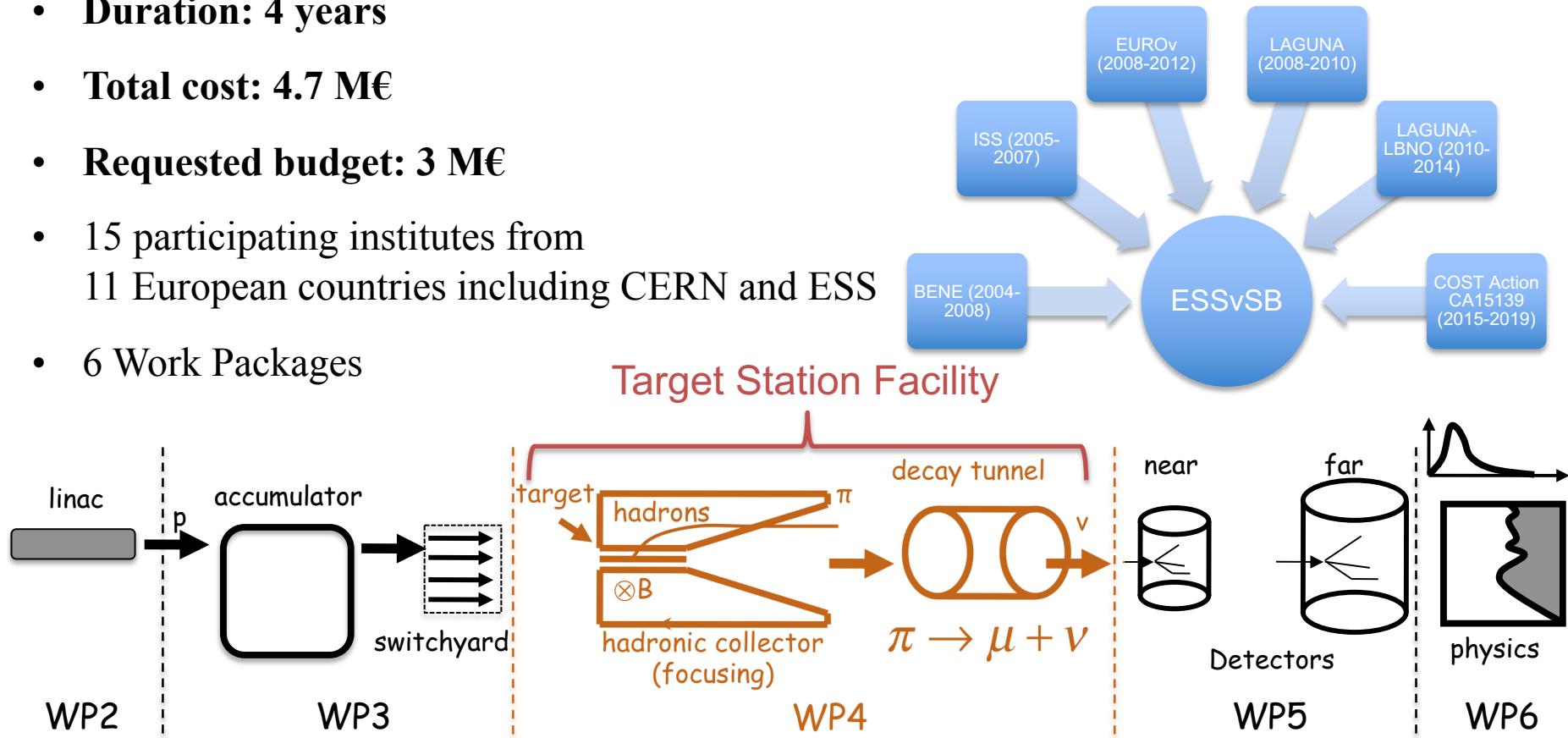
IPHC-IN2P3/CNRS Strasbourg

- **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



Web page: <http://essnusb.eu/site/>

- **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



Web page: <http://essnusb.eu/site/>

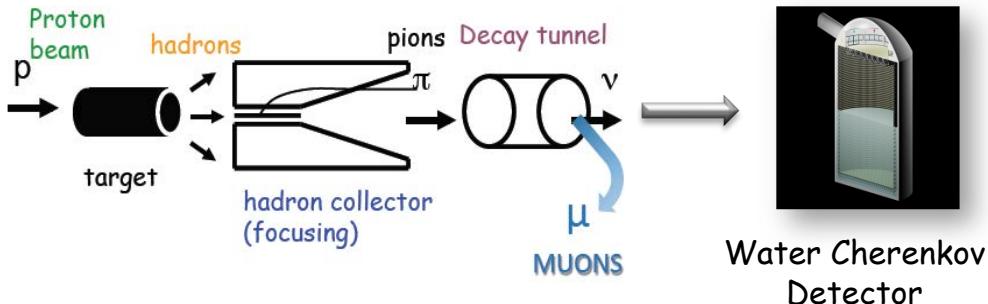
Baseline Layout



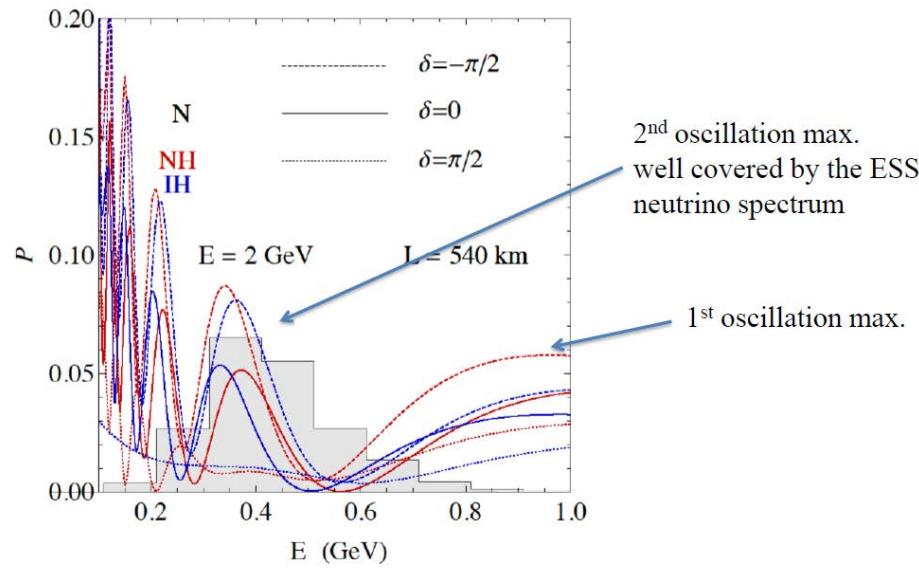
ESS
NEUTRINO
SUPER BEAM

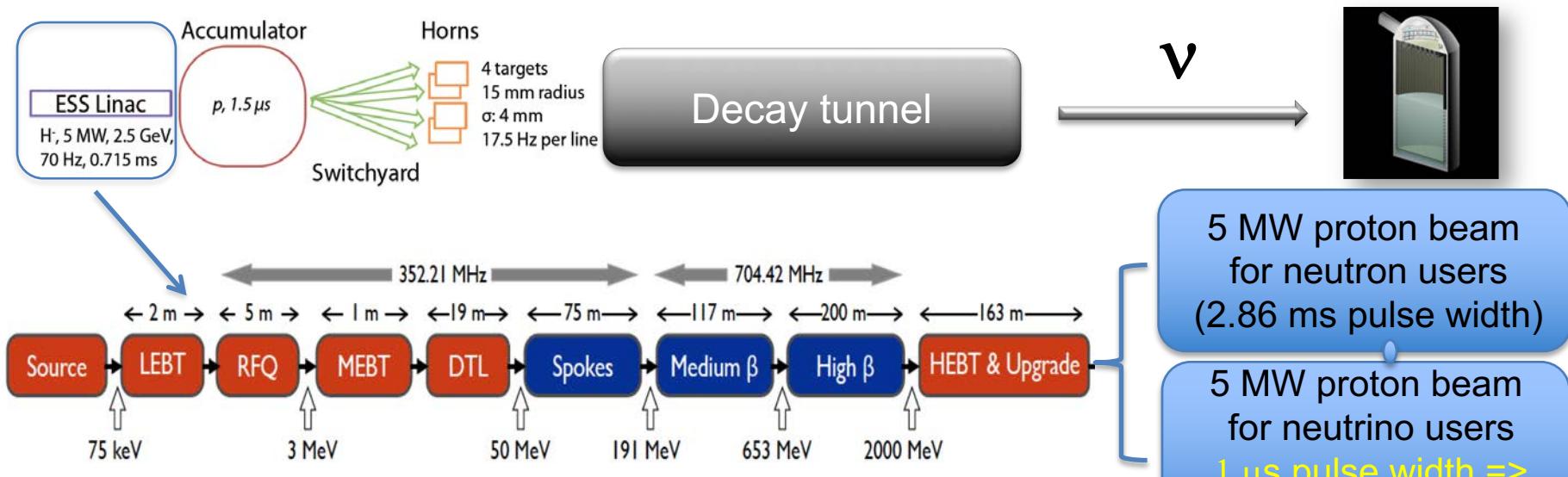


Funded by the Horizon 2020
Framework Programme of the
European Union



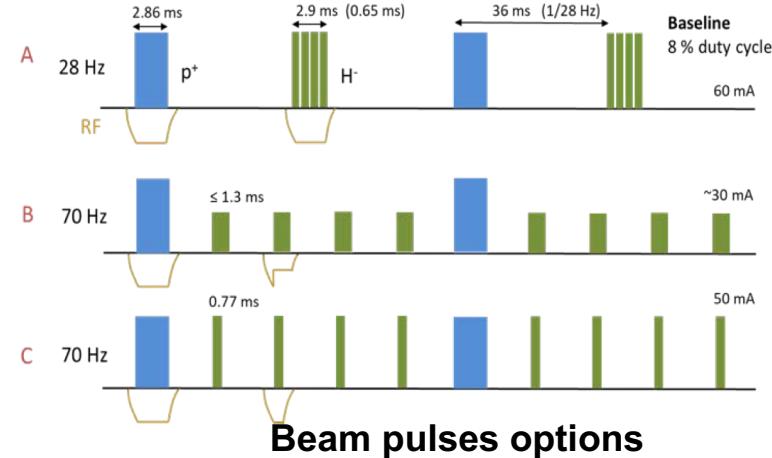
Given sufficient statistics, as obtainable with the ESS 5MW LINAC the sensitivity to CP violation is 3 times higher at the second oscillation maximum, as compared to the first



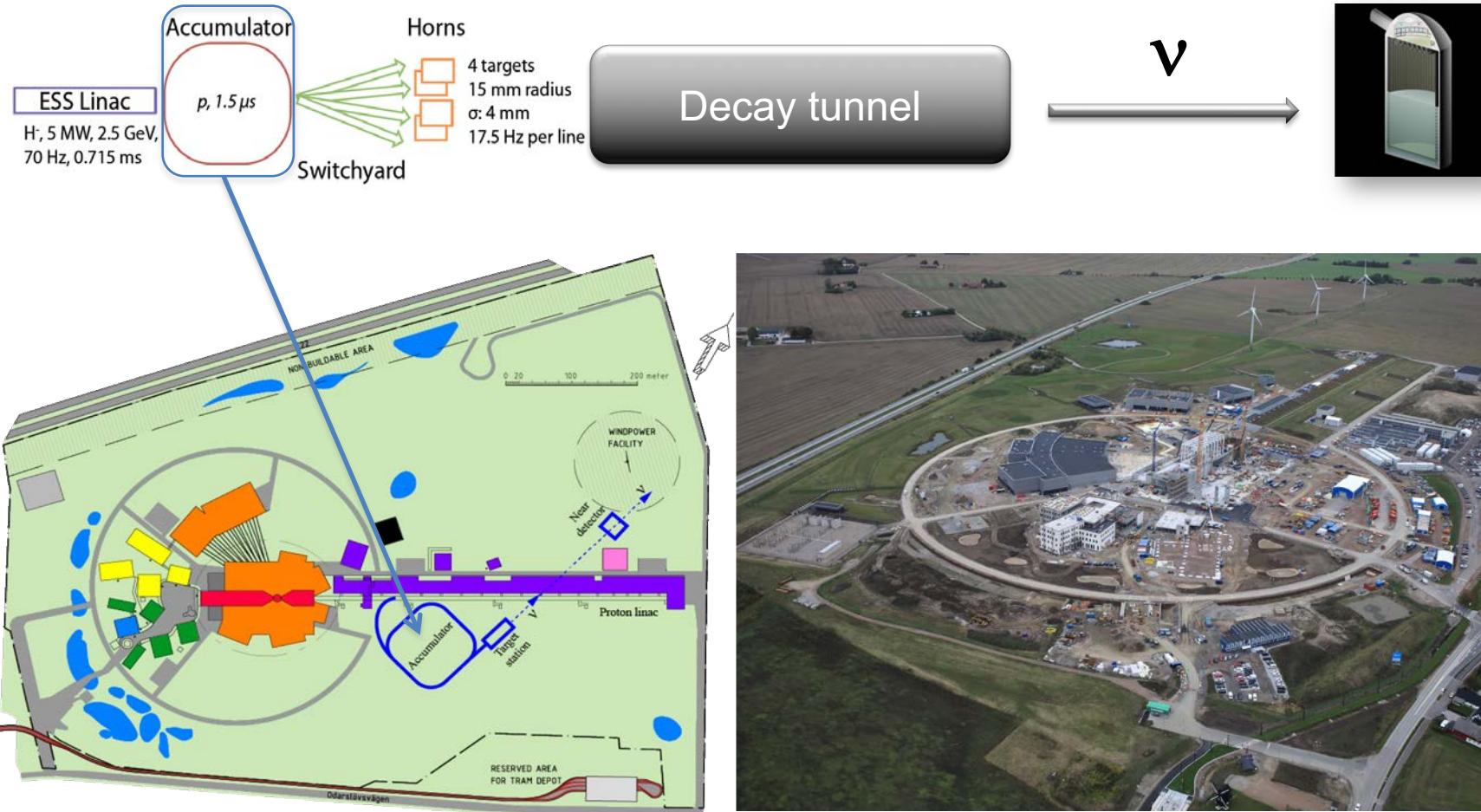


ESS LINAC requirements for a super beam

- 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

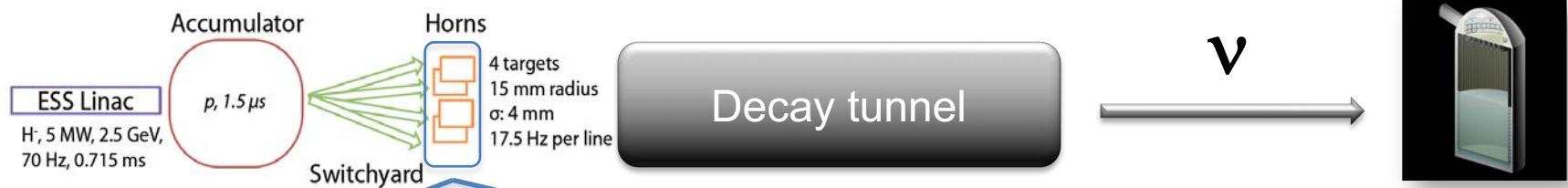


Geographical Implementation at ESS



ESS construction site (2019 Septembre 30)

Focusing system



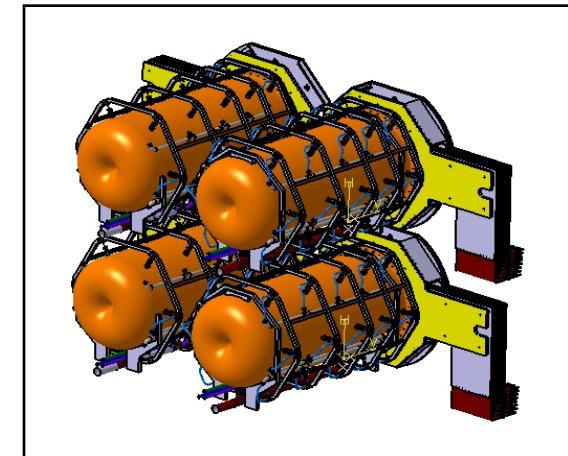
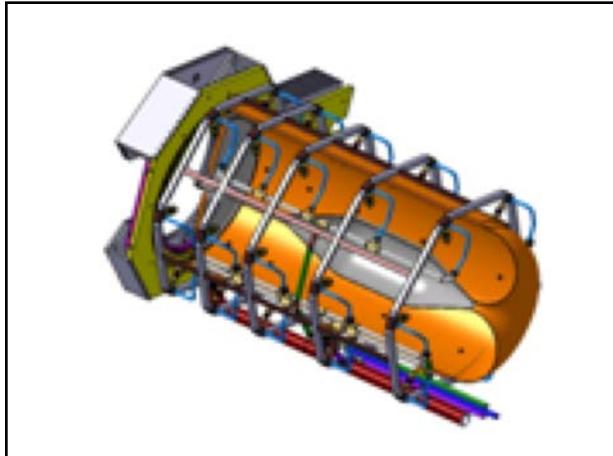
Target concept:

- Power 1.25 – 1.67 MW
- Potential heat removal rates at the hundreds of kW level
- Helium cooling
- Separated from the horn

Focusing system:

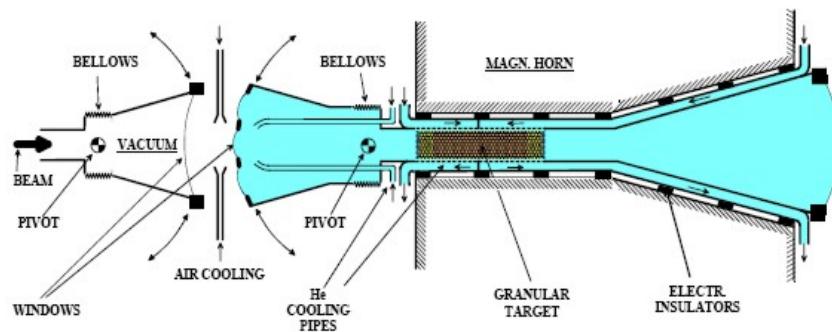
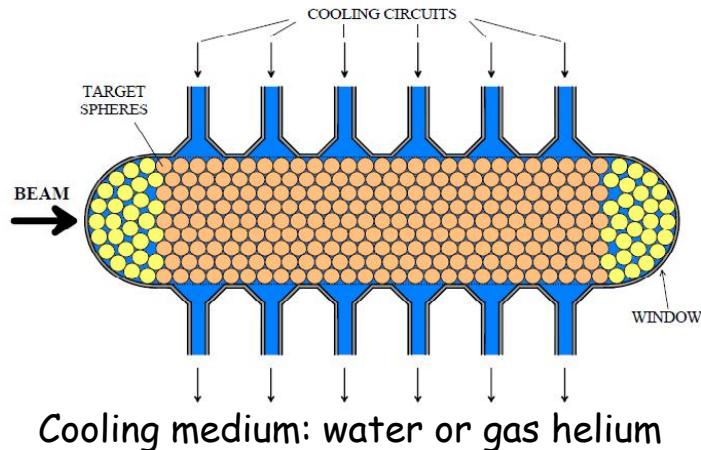
- 4-horn/target system to accommodate the MW power scale
- Solid target integrated into the inner conductor : very good physics results but high energy deposition and stresses on the conductors
- Best compromise between physics and reliability

Packed Bed/Segmented Target



Granular target concept

P. Sievers' proposal of a granular target at CERN (2001)



Concept of target integration inside a magnetic horn

Main conclusions (P. Sievers „A Stationary Target for the CERN-Neutrino-Factory“, CERN-NuFact-Note 065):

- Efficient heat removal and low dynamic stresses and pressures are achieved, mainly due to the small size in millimetre range of the target constituents in combination with relatively long proton bursts of several micro-second duration
- Further computational and experimental studies of the performance limits must be investigated
- These studies must include detailed considerations of the lifetime, due to the fatigue induced by the very high rate of the cycles per day, of the target spheres and, in particular, the entrance and exit windows
- Dedicated laboratory tests without the need of a proton beam should be devised to elucidate these problems

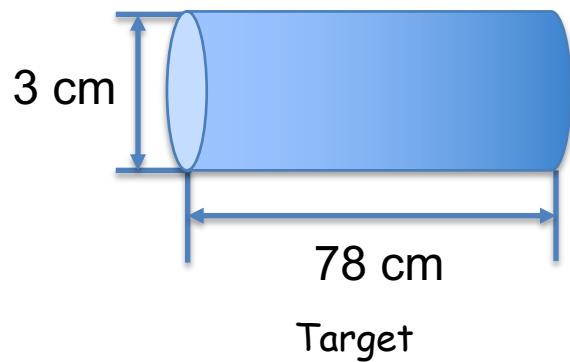
Granular target concept



Three operating horns (one horn suffers a failure), the higher values shown are for the ESSvSB conditions (1.66 MW/target)

The estimated energy density deposited in target spheres:

$$Q=9.4 \text{ kJ/kg/cycle} \quad (14 \text{ Hz})$$



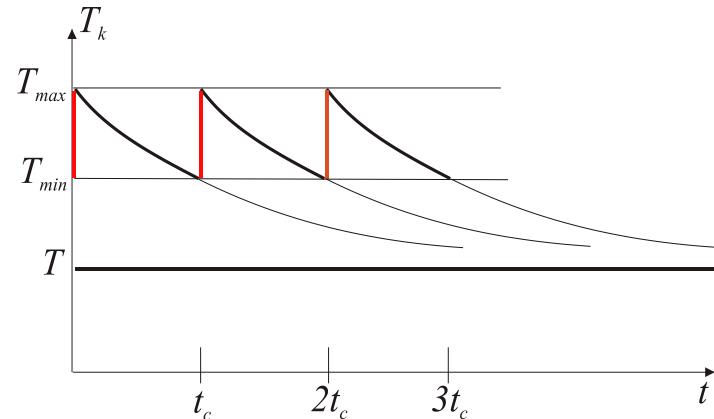
Spheres:
- Packing 66%
- Radius=1.5 mm

Heat transfer coefficient on the interface between the spheres and helium=1100 W/(K m²)

Parameters of helium entering the target:

$p_1=10$ bars, $T_1=273$ K, $v_1=200$ m/s (Mach number=0.2);
mass flow rate = 0.07 kg/s

Analytical Model:



T - steady-state temperature of the cooling medium (averaged over a cycle)

Results:

Helium outlet temperature $T_2=847$ K,
Helium outlet pressure 8.4 bar
Helium outlet velocity $v_2=689$ m/s (Mach number=0.4)

For helium inlet velocity $v_1=60$ m/s
(mass flow rate=0.02 kg/s),
the helium outlet temperature would be 2258 K

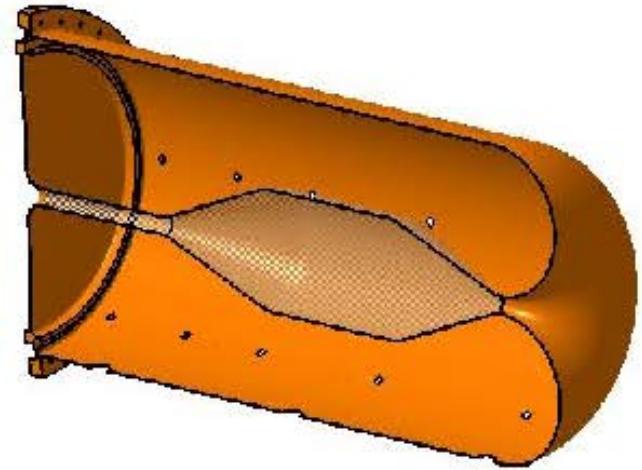
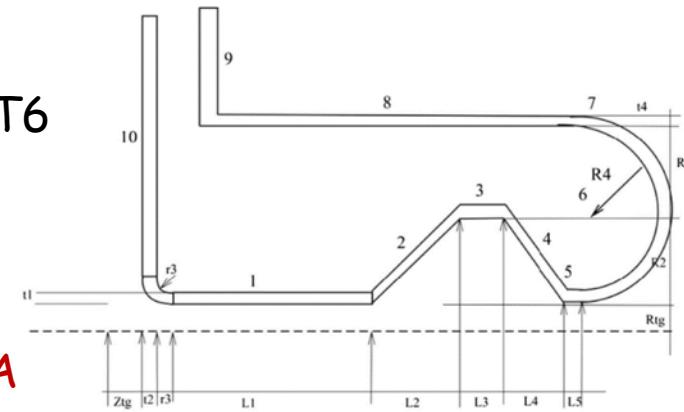
Horn Concept

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

=> Conductors geometry fixed by GEANT4/FLUKA
Simulation.

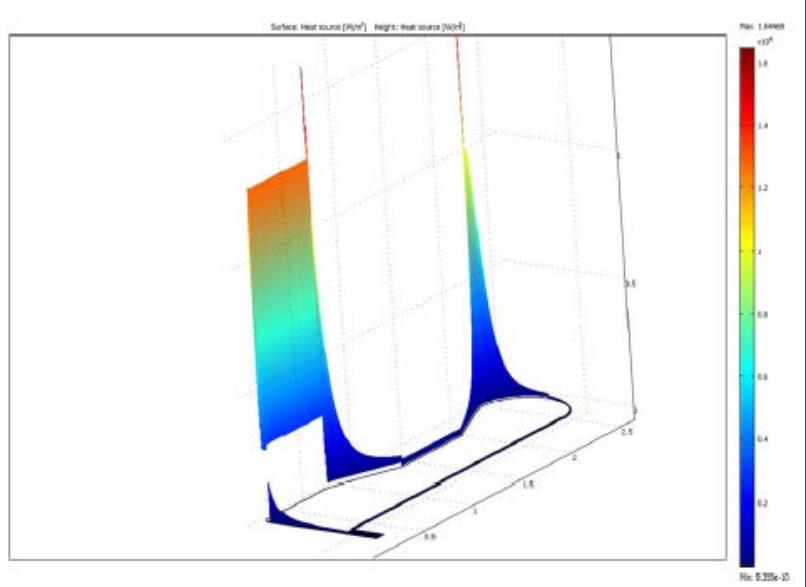
Horn major design issues:

- Steady-state temperature determined by the cooling system and the resulting static stress.
- Dynamic stress brought about by short-duration pulses.
- Assessment of the longevity (fatigue life) of the horn and its components.
- The performance of the cooling system.

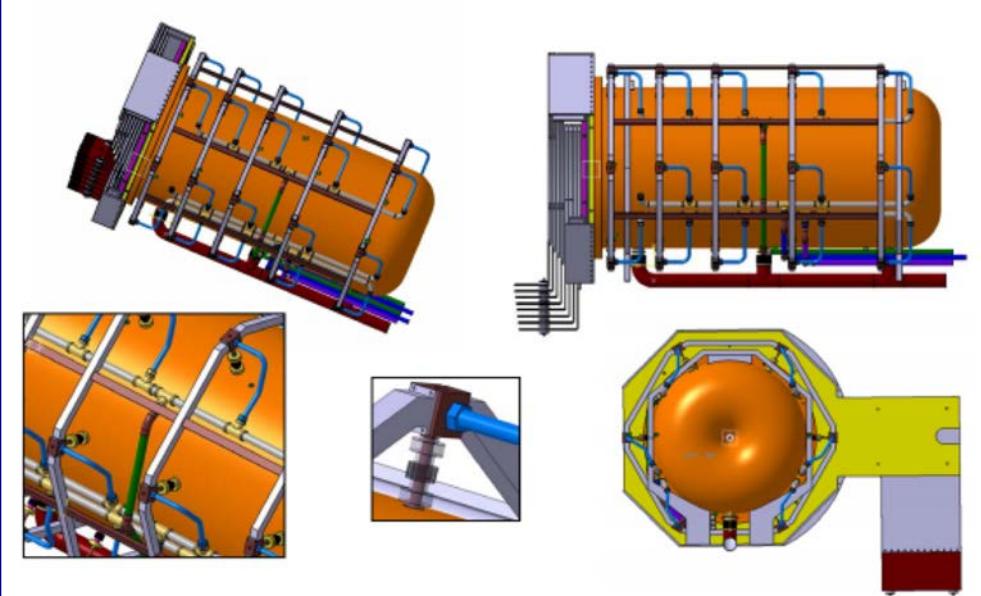


Horn Cross Section

Horn Concept



Temperature distribution



Water pipe distribution

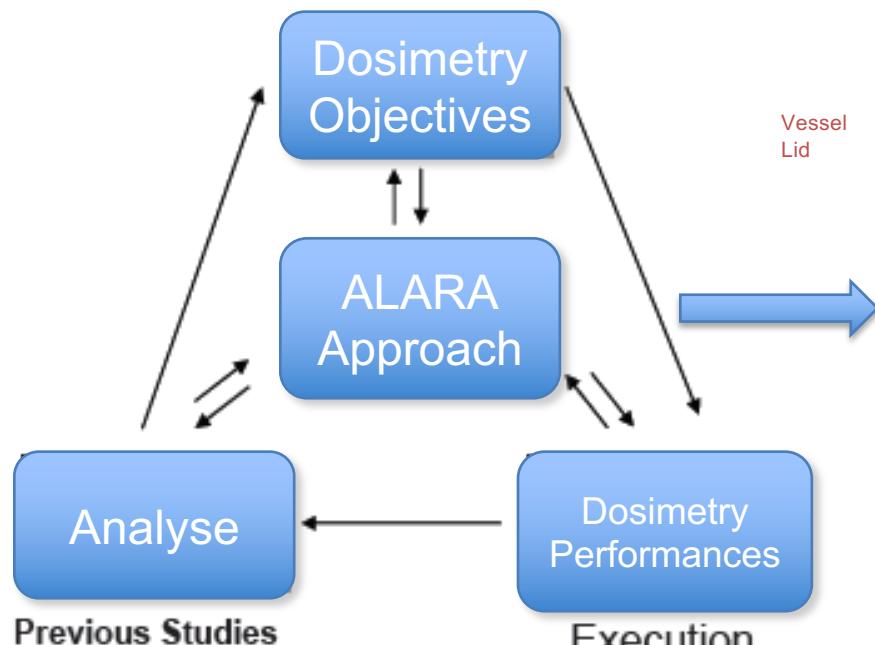
Cooling system:

- 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
- $\{h_{\text{corner}}, h_{\text{horn}}, h_{\text{inner}}, h_{\text{convex}}\} = \{3.8, 1, 6.5, 0.1\}$ kW/(m²K) for $T_{\text{Al-max}} = 60$ °C (assuming 1 MW per horn)

Target Station Facility

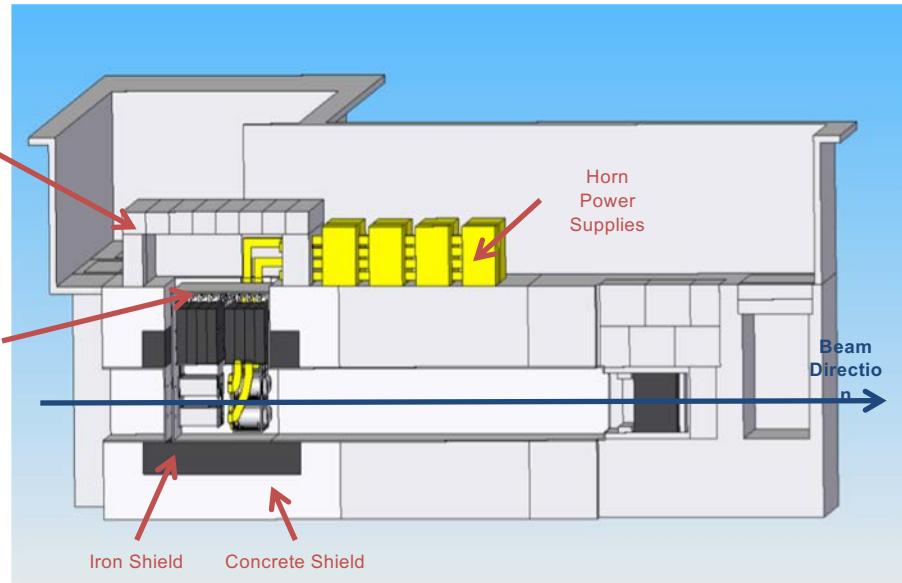
ALARA Approach:

Anticipate and reduce individual and collective exposition to radiations.



As Low As Reasonably Achievable

Feedback from previous experiments is crucial

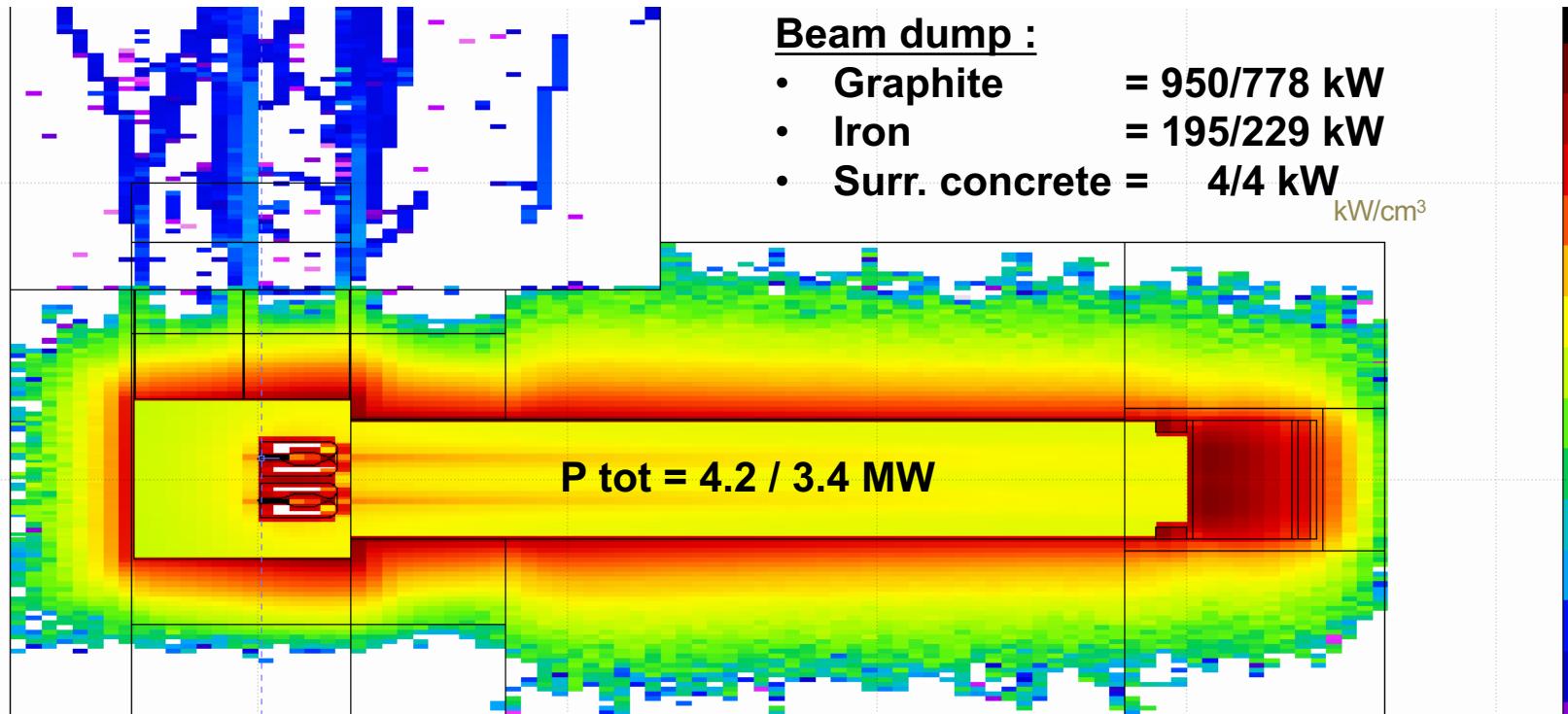


Building “rooms”

- Open Top geometry for the Target Station Room, Decay Tunnel, Beam Dump
 - Hot Cell (Repair Target Station elements)
 - Morgue (Store radioactive wastes)
 - Horn Power Supply Room , Power supply outside of the main building ?
- => Energy Deposition and Dose Rate Estimation with FLUKA Simulation

Target Station Facility

Power deposition comparison : 5 MW / 4 MW for the whole target station



Horns/Target gallery

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

Decay tunnel

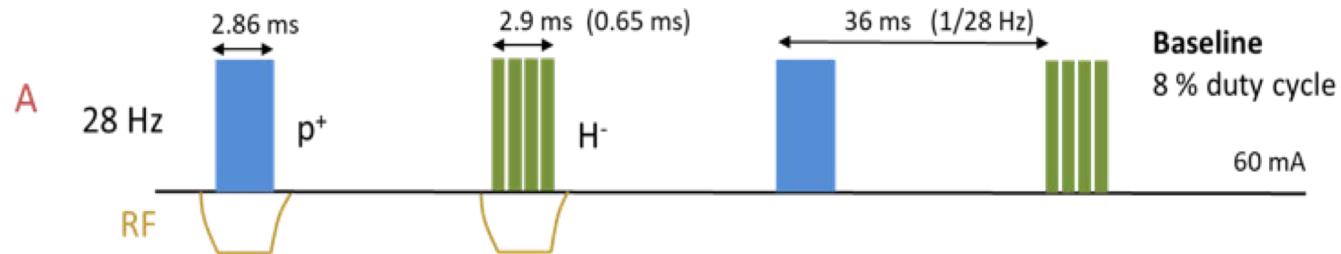
- Iron vessel = 424/390 kW
- Upstream iron = 670/610 kW
- Surr. concrete = 467/485 kW

IPAC'17 Proceedings: E. Bouquerel et al, "Energy deposition and activation studies of the ESSnuSB Horn Station", MOPIK029

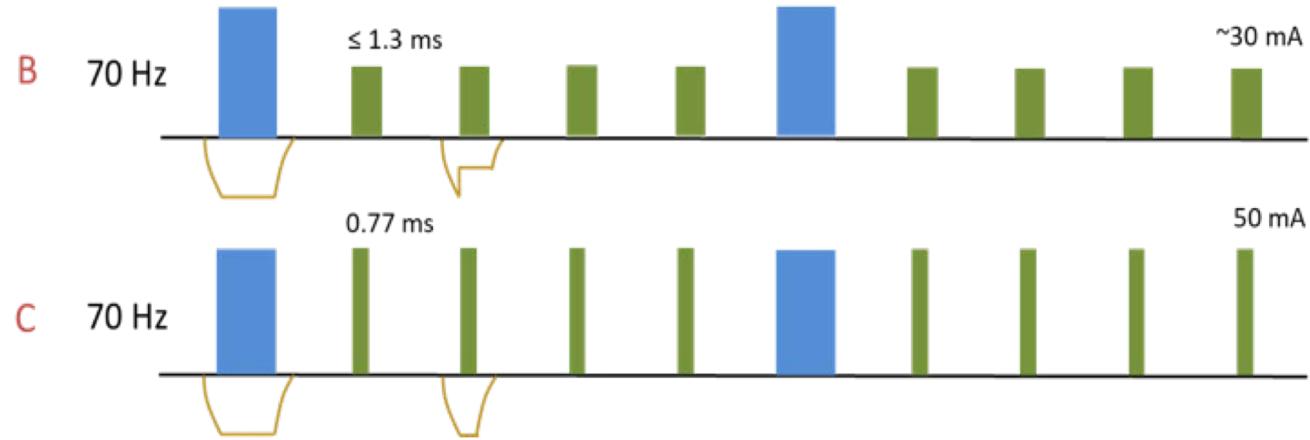
POWER SUPPLY STATION

Pulses baselines under investigations

A:
750 μ s between each pulse



B,C:
14ms between each pulse



The pulses will then be compressed to about 1.2 μ s

Horn Power Supply : Modular Approach



ESS
NEUTRINO
SUPER BEAM



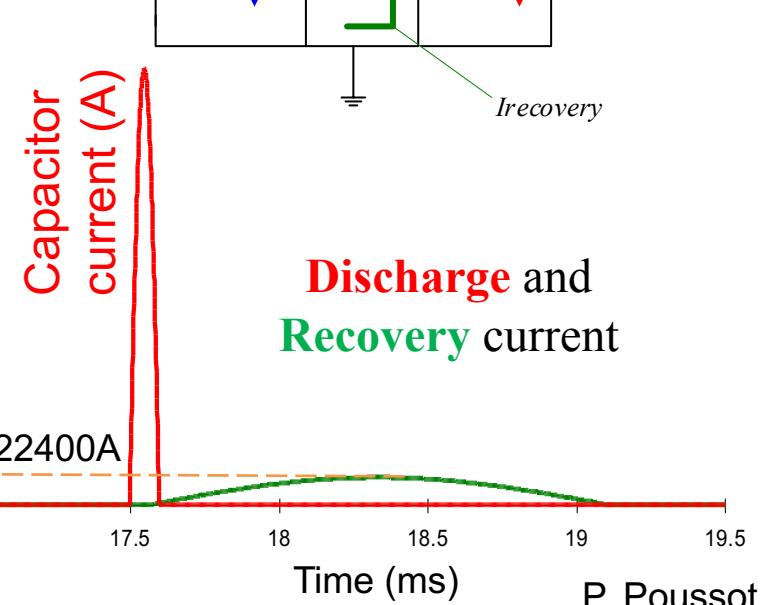
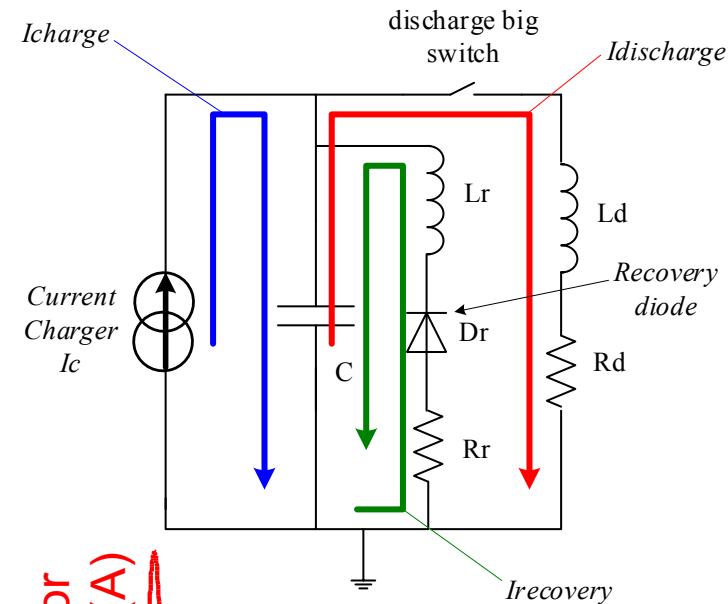
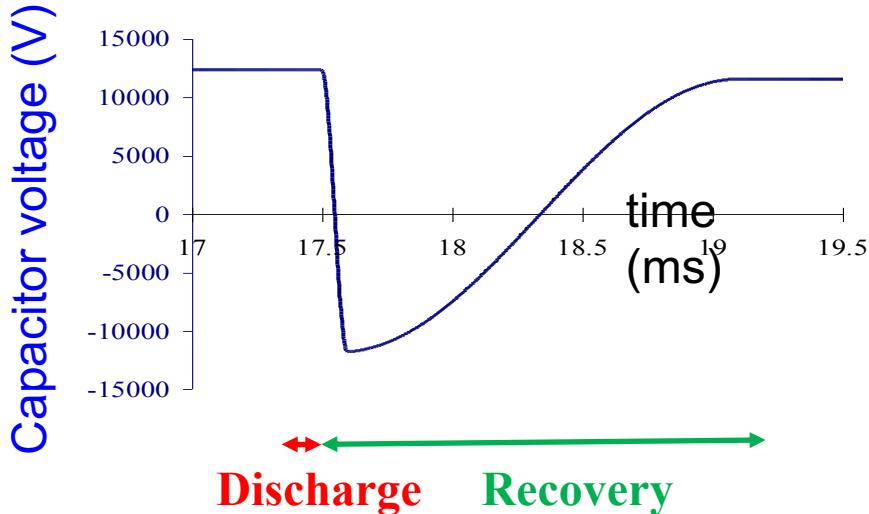
Funded by the Horizon 2020
Framework Programme of the
European Union

⇒ Voltage of capacitor in discharged and recovery stages is governed by the general equation:

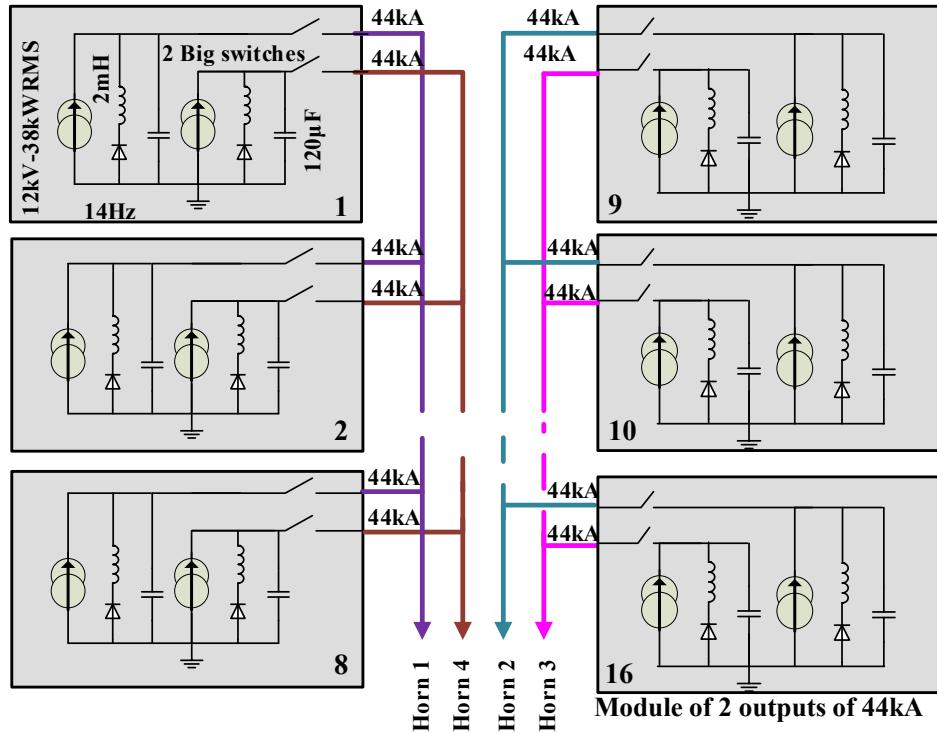
$$\frac{d^2V}{dt^2} + 2m\omega \frac{dV}{dt} + \omega^2 V = 0 \text{ with } \omega = \frac{1}{\sqrt{LC}} \text{ and } m = \frac{R}{2} \sqrt{\frac{C}{L}}$$

⇒ peak current I is given by : $I_{peak} = V_o \sqrt{\frac{C}{L}}$

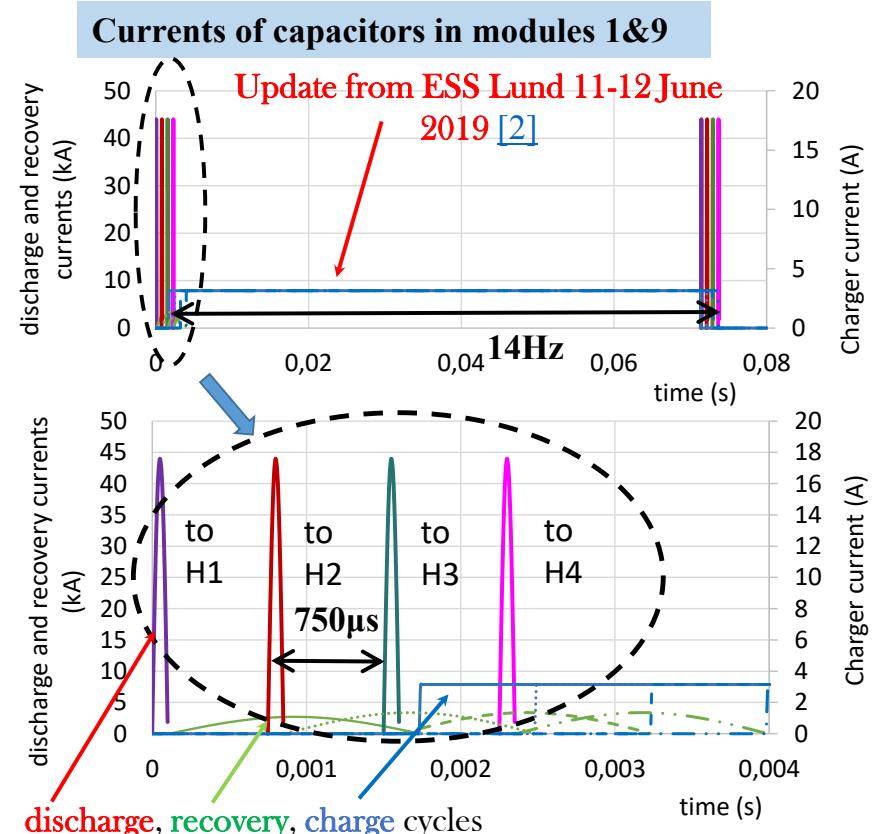
⇒ final capacitor voltage : $V_{end}(T_{end}) = -V_o e^{-m\pi}$



Baseline A : 750 μ s



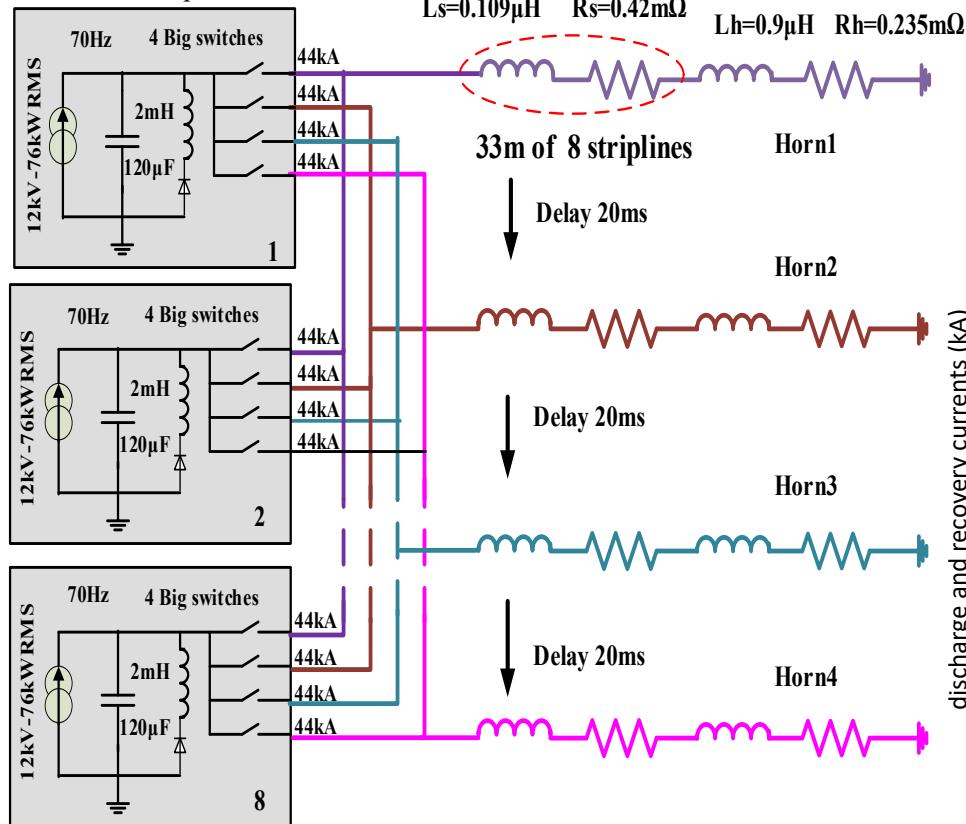
- 8 modules of 44kA connected in parallel to provide 350kA to 1 horn.
- 16 modules needed for 4 horns



P. Poussot

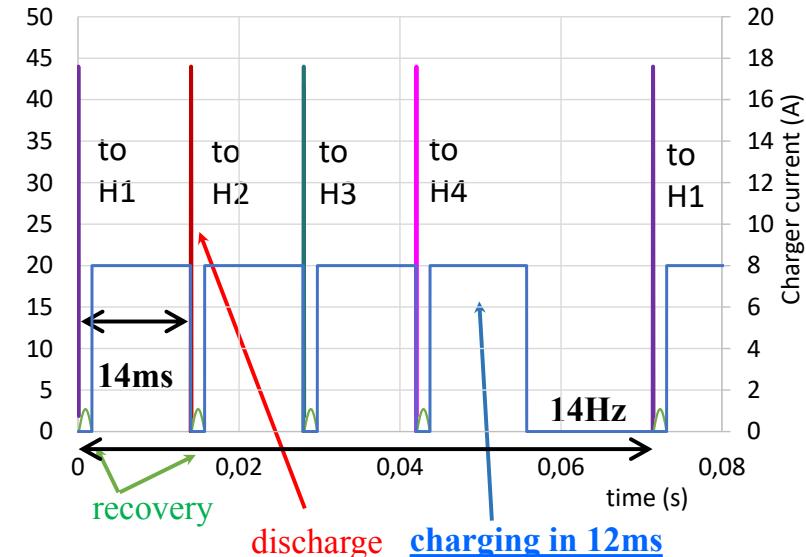
Baseline A : 14 ms

Module of 4 outputs of 44kA



- ☞ 8 modules of 44kA connected in parallel to provide 350kA to 1 horn
- ☞ 8 modules needed for 4 horns

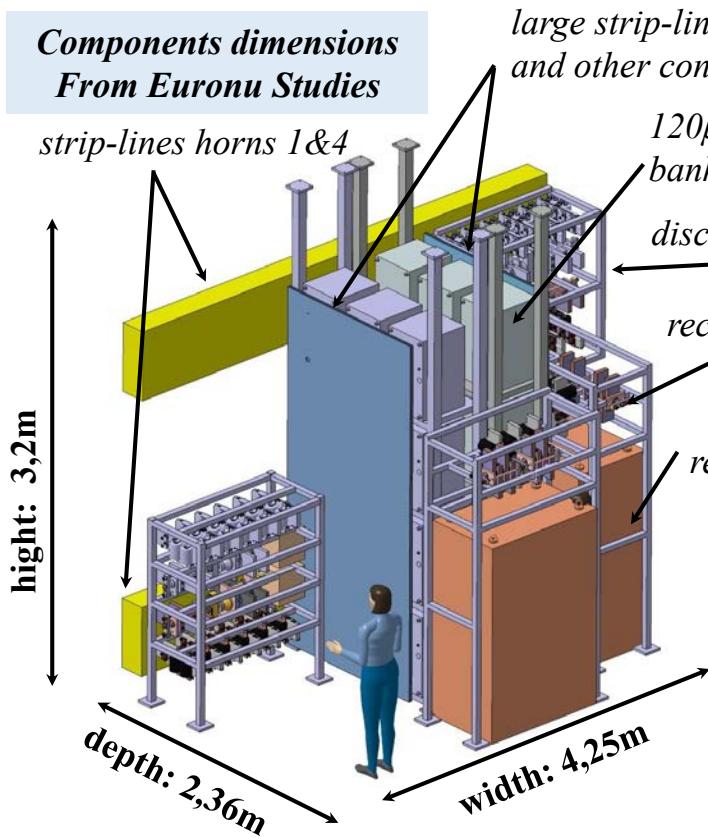
Currents of the 120 μ F capacitor module



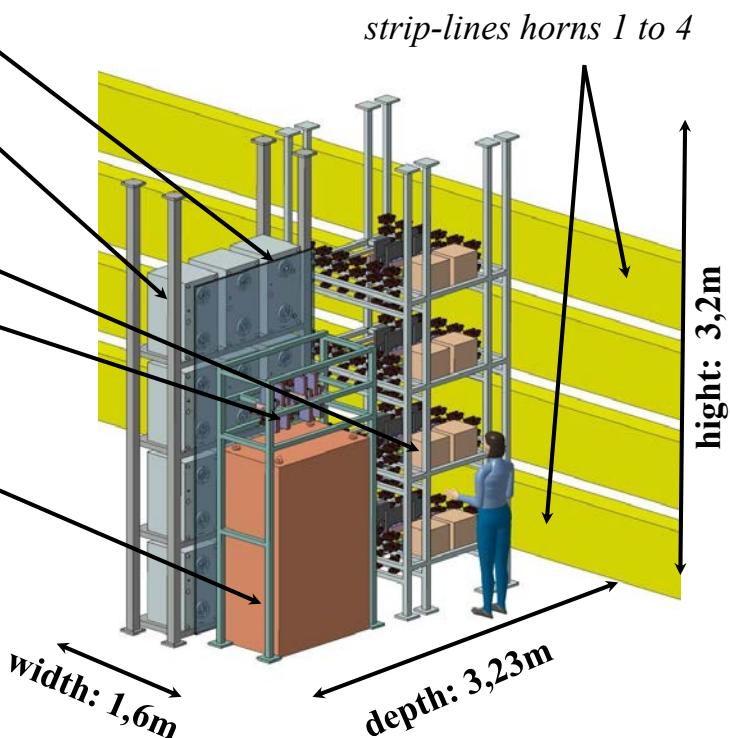
P. Poussot

Baseline A (16 modules needed)

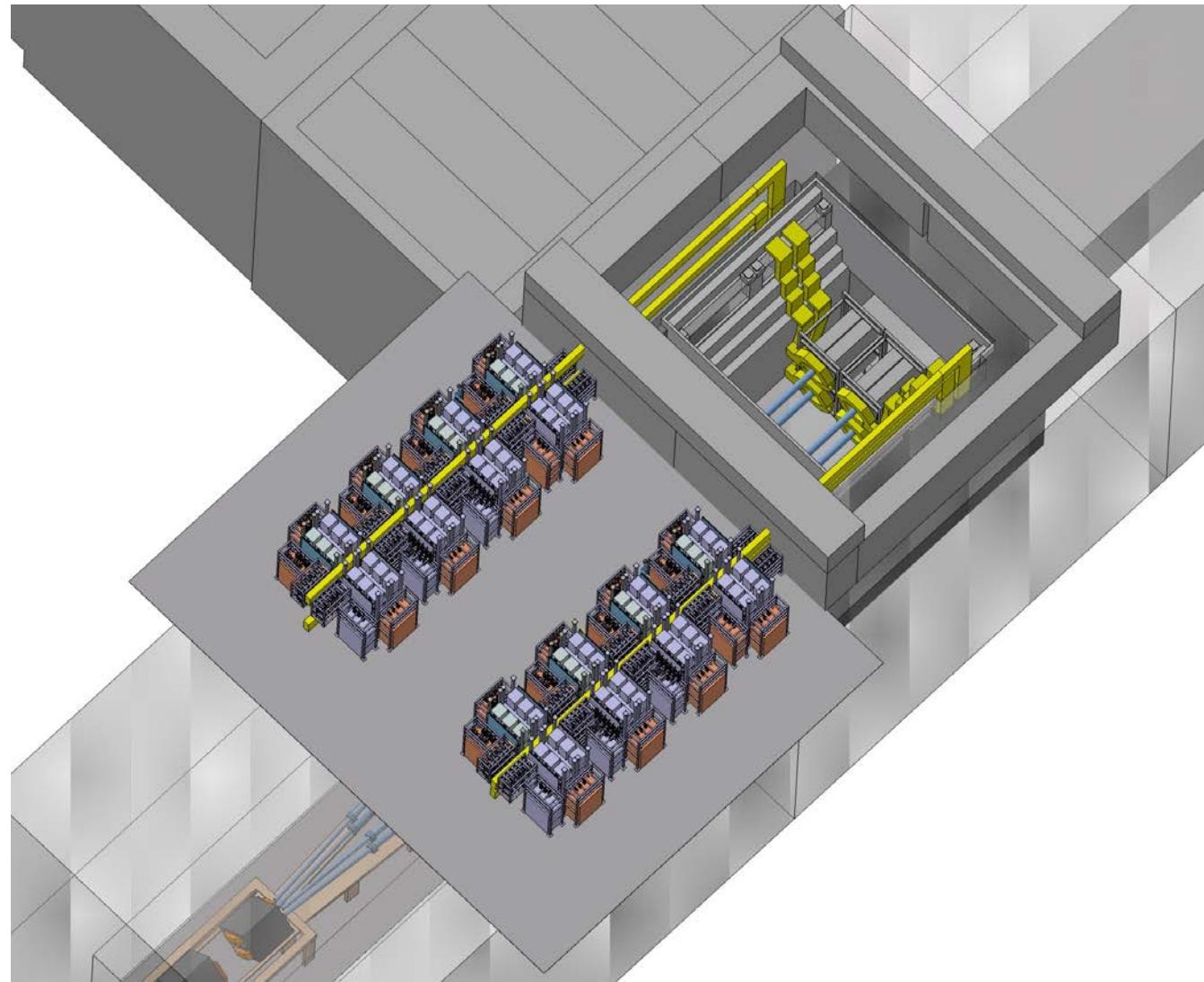
Components dimensions
From Euronu Studies



Baseline B,C (8 modules needed)



Horn Power Supply



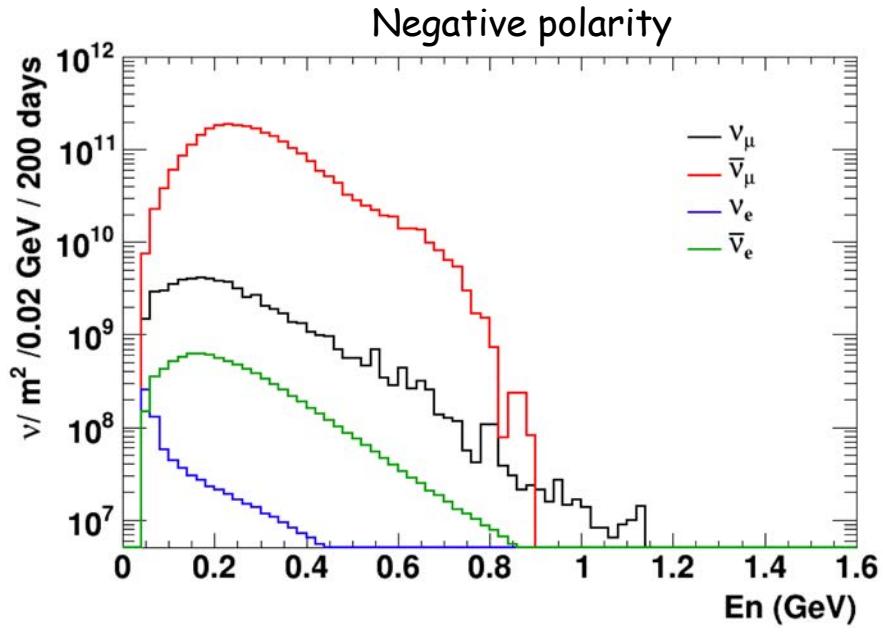
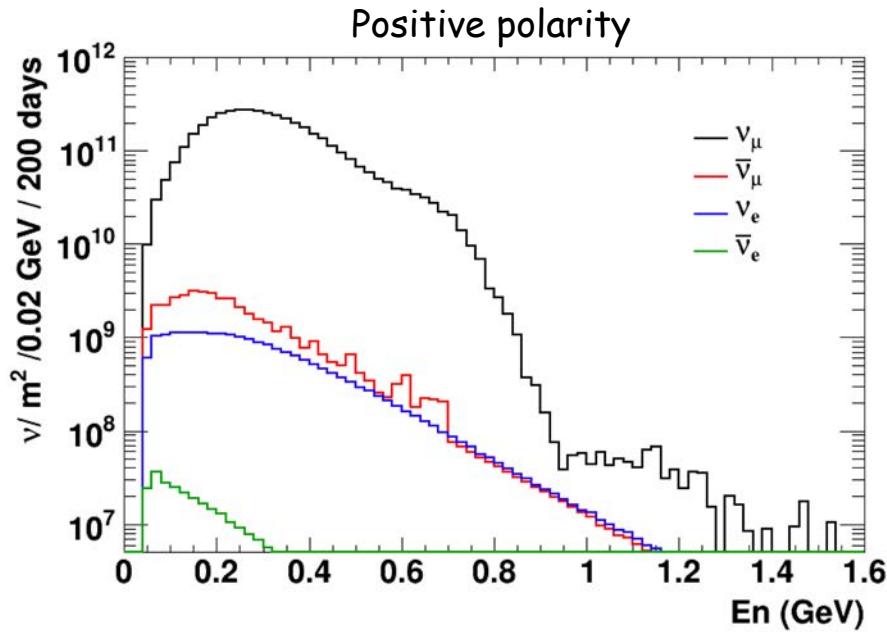
Physics performances



ESS
NEUTRINO
SUPER BEAM

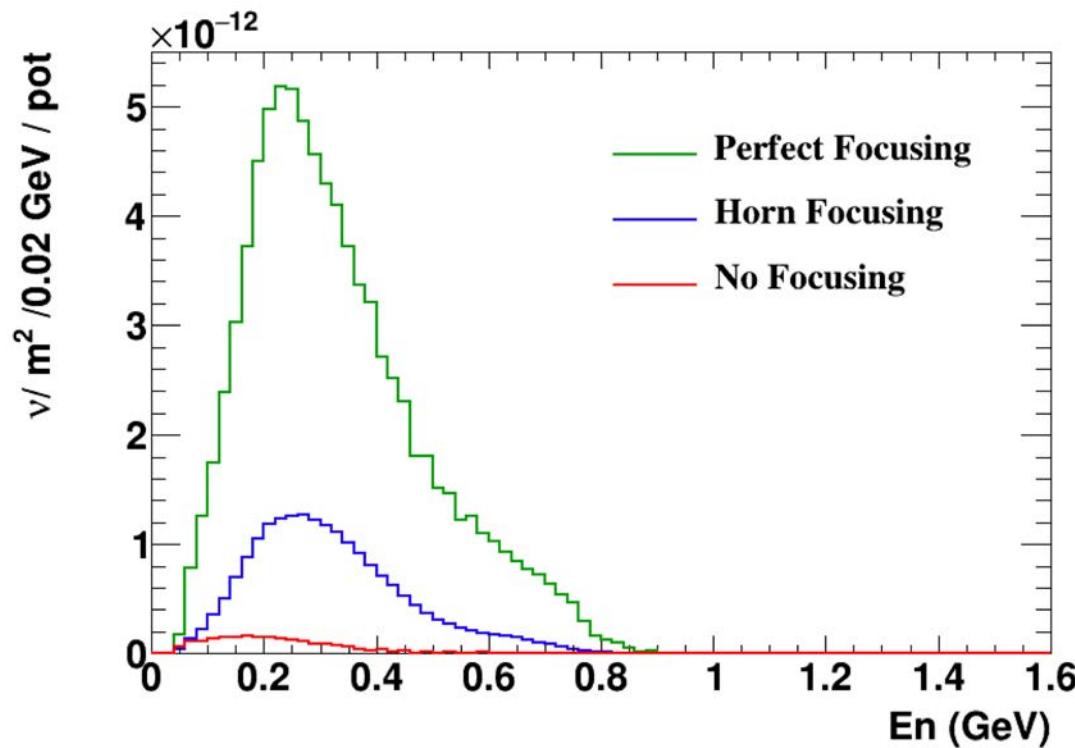


Funded by the Horizon 2020
Framework Programme of the
European Union



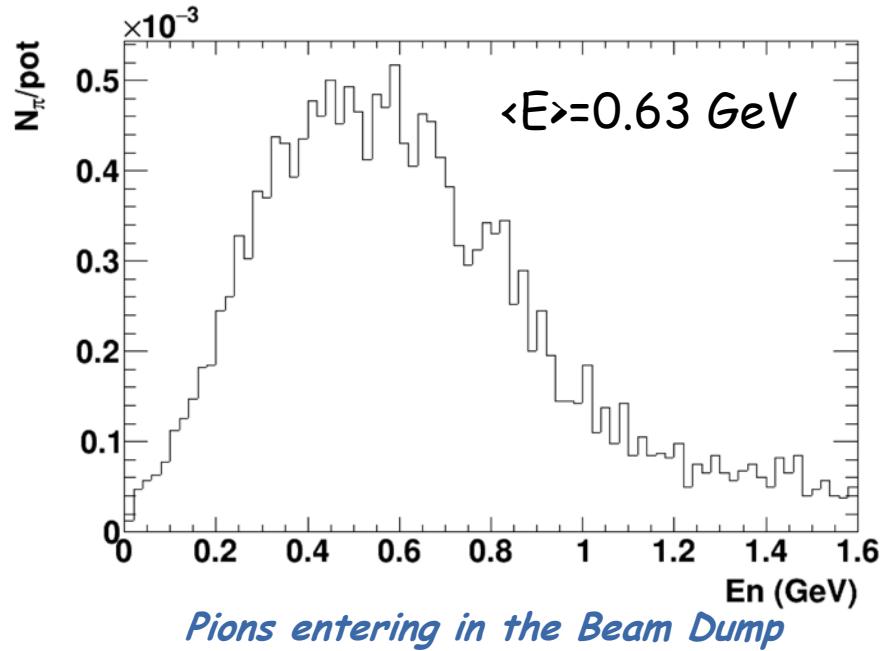
	Positive		Negative	
	$N_\nu (10^{10}/m^2)$	%	$N_\nu (10^{10}/m^2)$	%
ν_μ	431	98.5	6.0	2.25
$\bar{\nu}_\mu$	4.34	0.99	260	97.5
ν_e	2.15	0.49	0.08	0.03
$\bar{\nu}_e$	0.03	0.01	0.87	0.32

Focusing efficiency

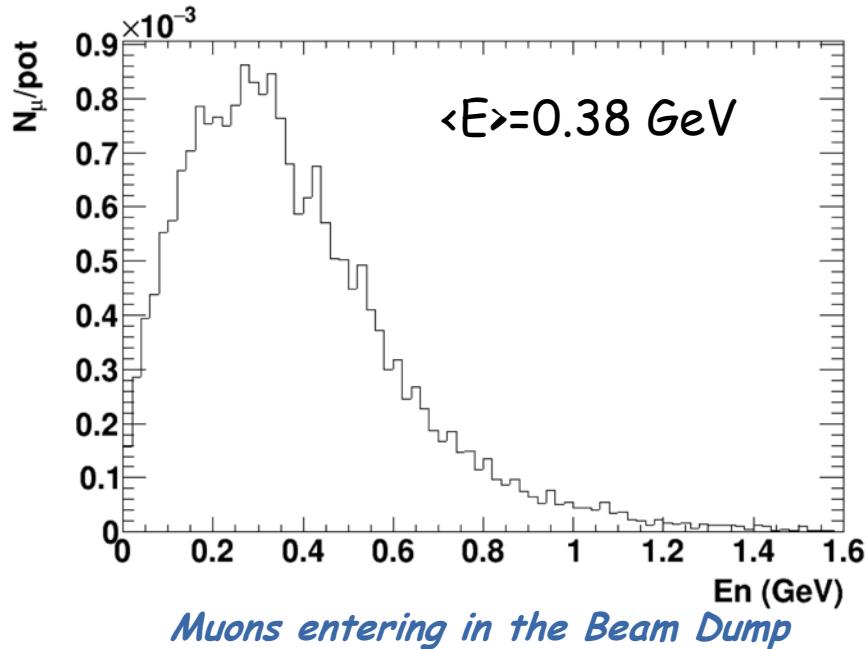


- Optimization of the Target Station through parametric study based on the geometry of the horn and of the decay tunnel (in order to shift the mean neutrino energy to higher values).
- Further investigations on the decay tunnel, to assess the contribution of the electron neutrino contamination compared with the muon neutrino flux.

Possible extensions

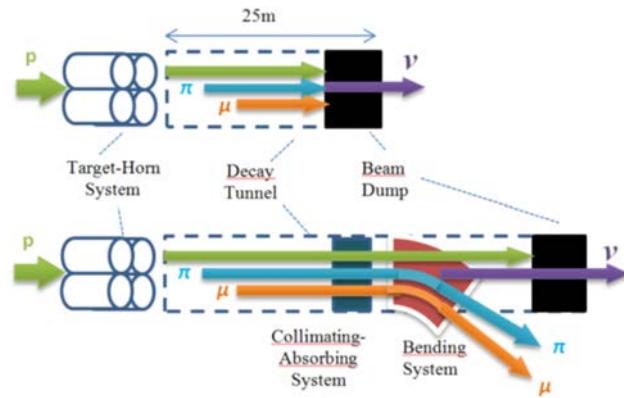


Pions entering in the Beam Dump

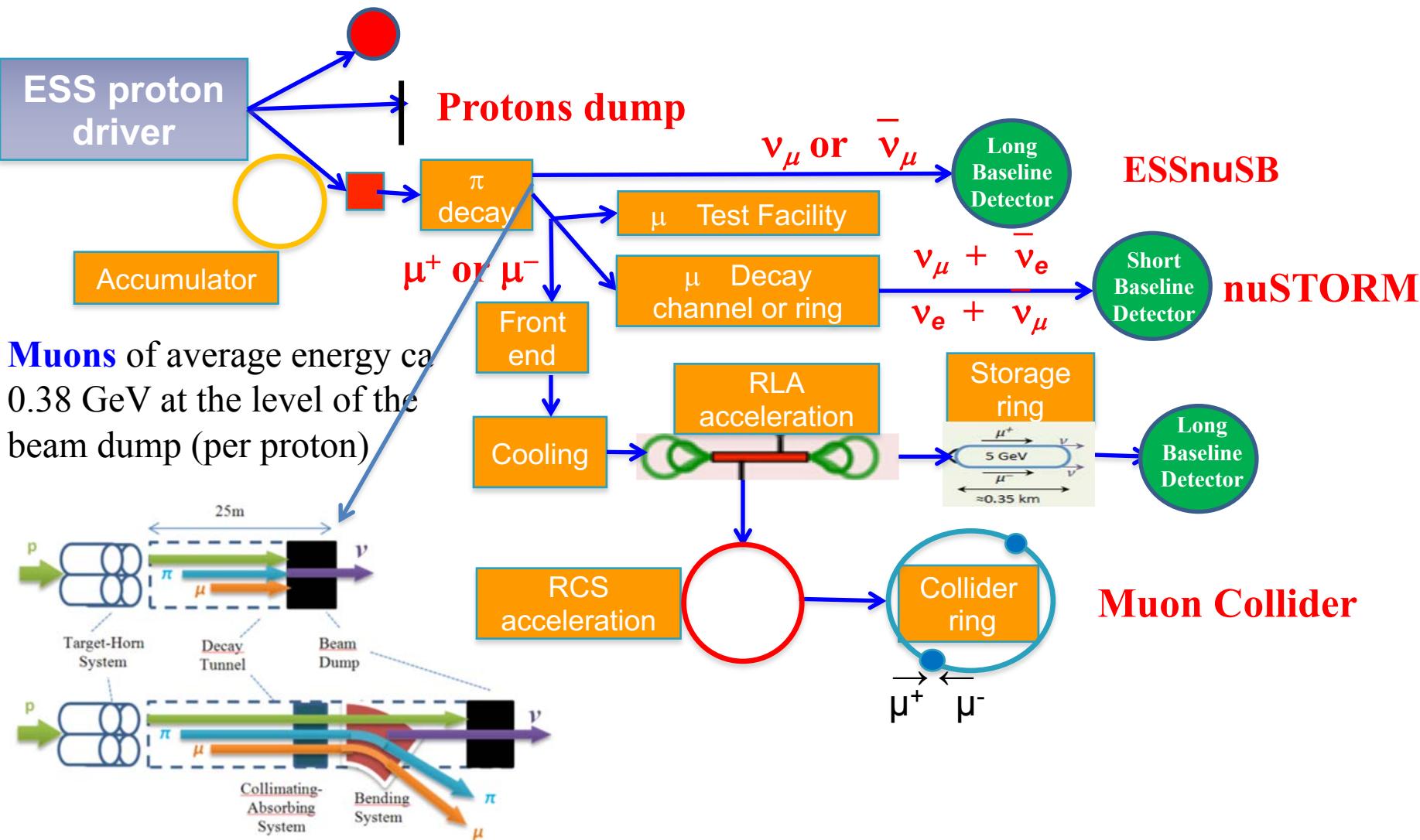


Muons entering in the Beam Dump

Muons from Beam Dump can be extracted for possible future experiments (neutrino factory, muon collider, ...)



Possible extensions



Summary:

- European Spallation Source is under construction and will provide a 5 MW beam power by 2023.
- ESSnuSB Project offers a good opportunity to study CP violation in leptonic sector with an improved sensitivity thanks to the 2nd Oscillation maximum in Europe with a Water Cherenkov Detector.
- Several technical constraints appear in the feasibility of the target station due to the high energy deposition. Mechanical design for the target and horn are on going to reduce the stress level and optimize life time.
- ESSnuSB can also be used as a platform to develop future experiments like muon beam experiments...