Funded by the Horizon 2020
Framework Programme of the
European Union

ESS
NEUTRINO
SUPER BEAM

# The Design Study of the Target Station for the ESS Neutrino Super Beam Project

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*On behalf of the ESSνSB Collaboration*

EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

**NUFACT2019, Daegu, Korea**

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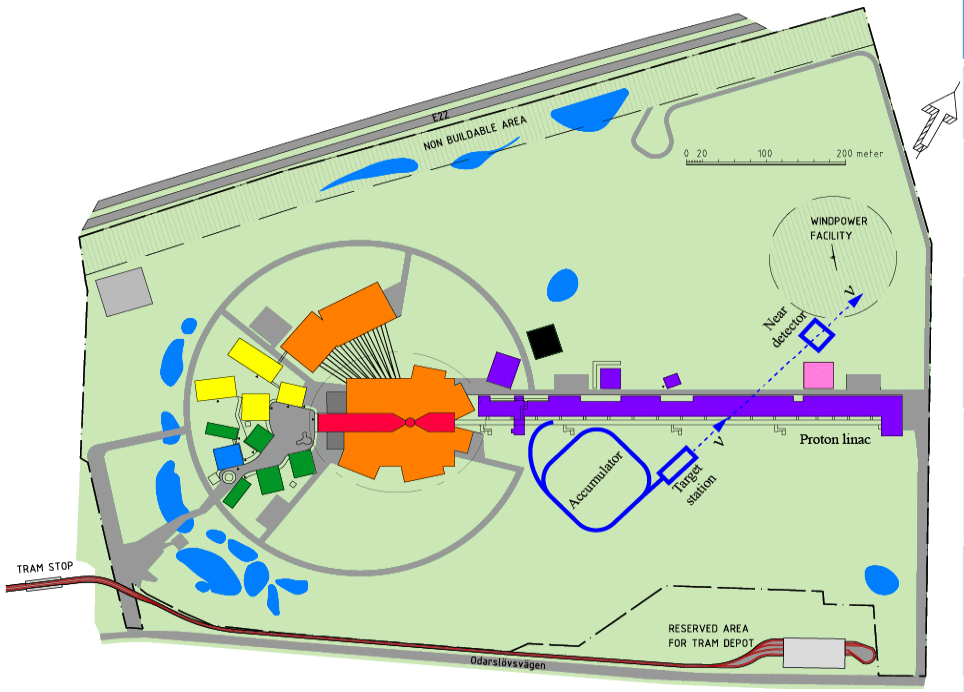
STRASBOURG

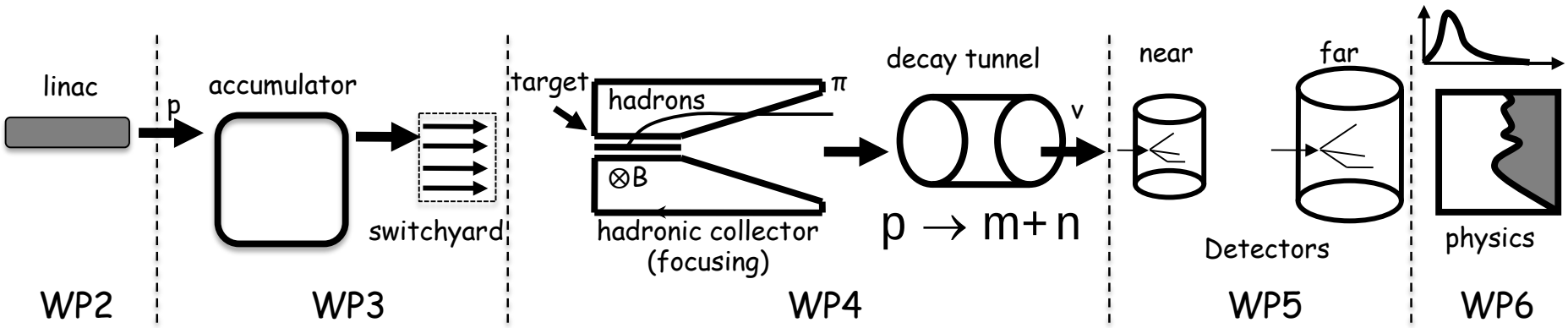
# The ESSνSB Project




| | ESS | ESS+ESSνSB |
|---|---|---|
| Ion | p | $p+H^-$ |
| Average Beam Power | 5 MW | 5+5 MW |
| Proton Kinetic Energy | 2 GeV | 2.5 GeV |
| Macro-pulse Current | 62.5 mA | 50mA |
| Pulse Repetition Rate | 14 Hz | 28 Hz |
| Annual Operating Period | 5000 h | 5000 h |

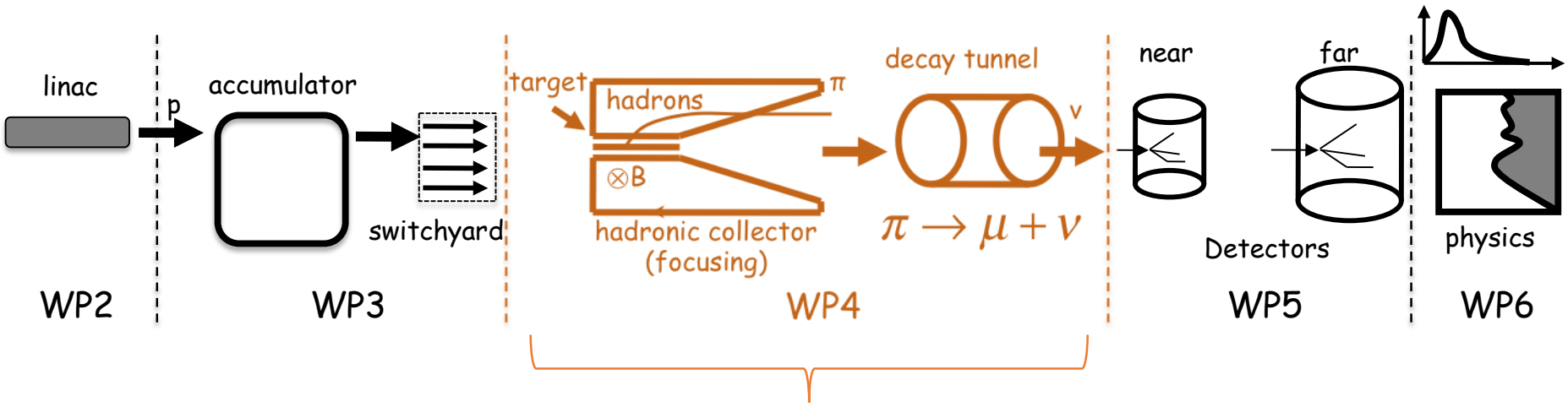
- The aim of the ESSνSB Project is to produce an intense neutrino superbeam by using the high power proton beam of the ESS LINAC to search for CP-violation in the leptonic sector
- In order to not affect the operations of the neutron spallation source program, some modifications are needed at the level of the LINAC

# The ESSνSB Project




- For the current phase of the project, different Work Packages are dedicated to the design of different parts of the experiment, which include the design of:
  - LINAC upgrade (Ben Folsom's Talk)
  - Accumulator ring (Ye Zou's Talk)
  - Target Station
  - Near and Far Detectors (Joochun Park's Talk)
  - Physics Reach (Monojit Gosh's Talk)

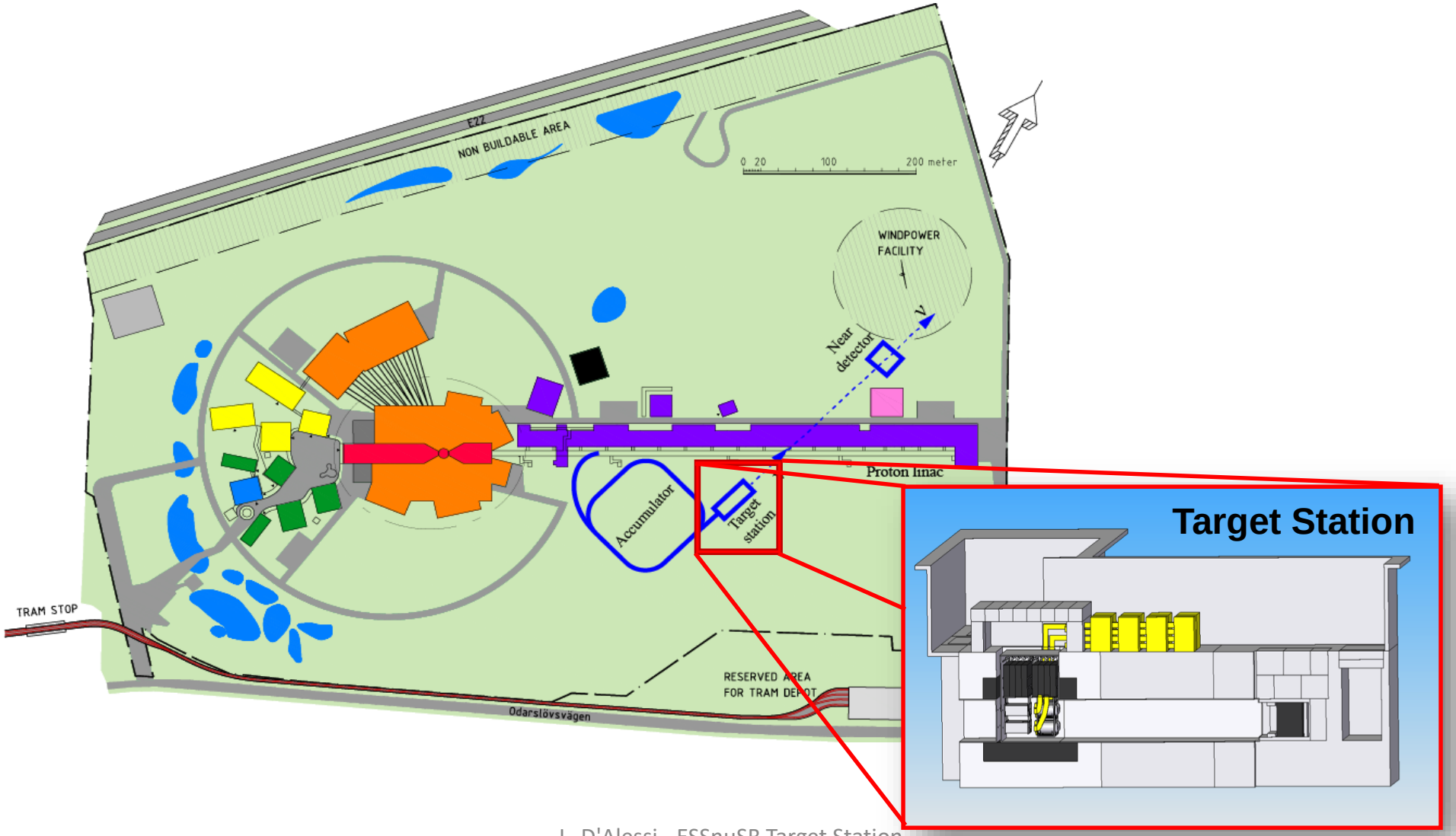
# The ESSνSB Project



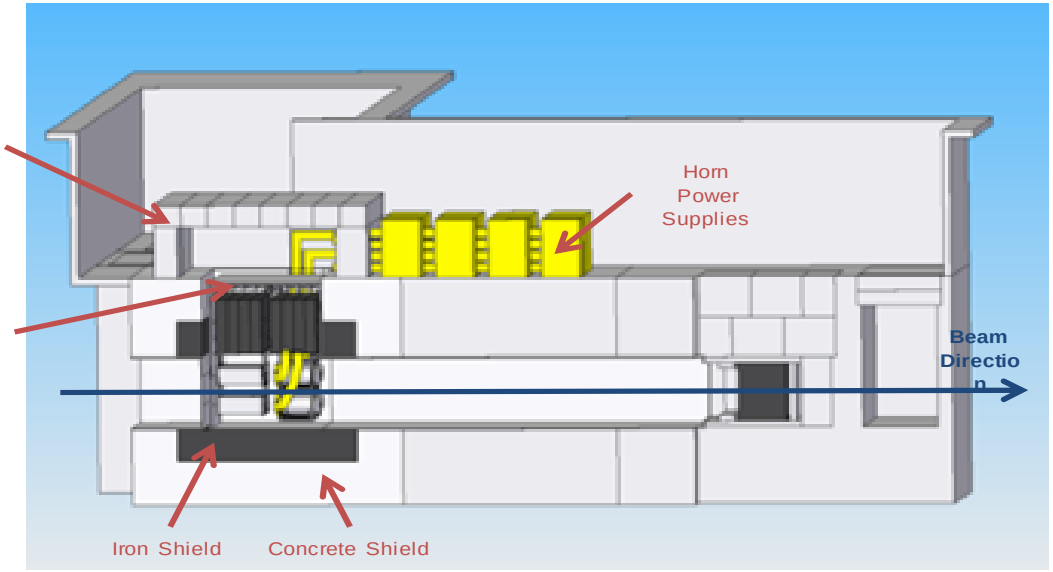

Target Station Facility

- Main components of the Target Station:
  - Target used for the hadron production (mainly pions)
  - Magnetic Horn for the focusing of the produced pions
  - Decay Tunnel
  - Beam Dump
- Design of the Target Station for the optimization of the neutrino beam intensity, reducing at the same time the electron neutrinos from the muon decay

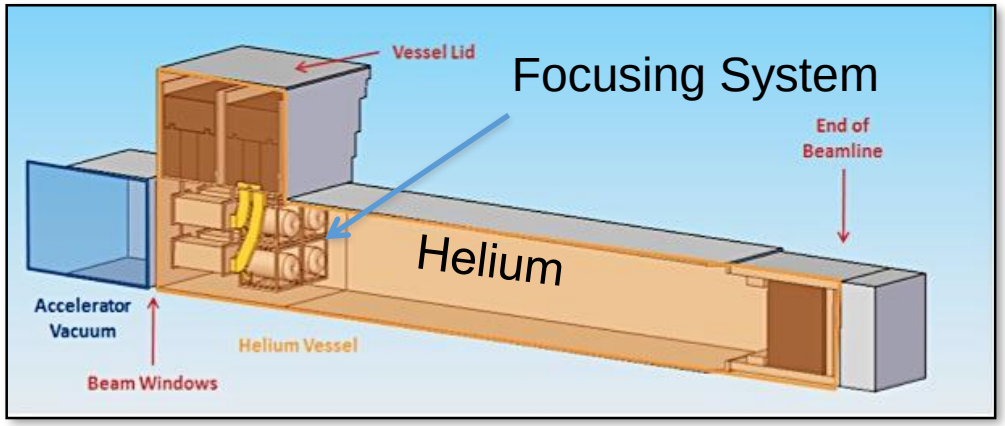
# The Target Station Facility at the ESS Site

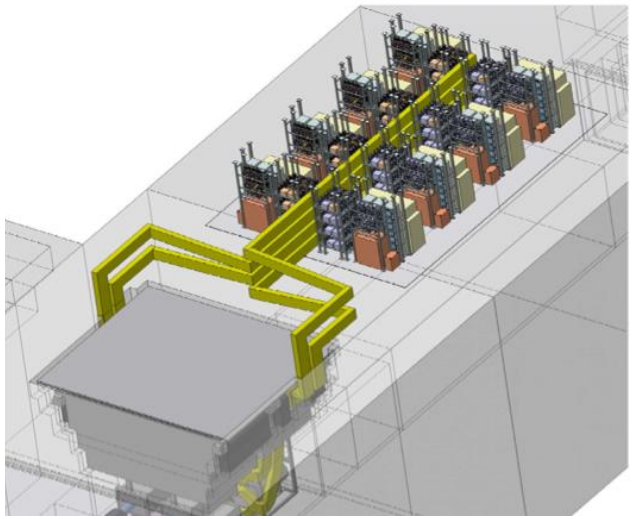


# Layout of the Target Station

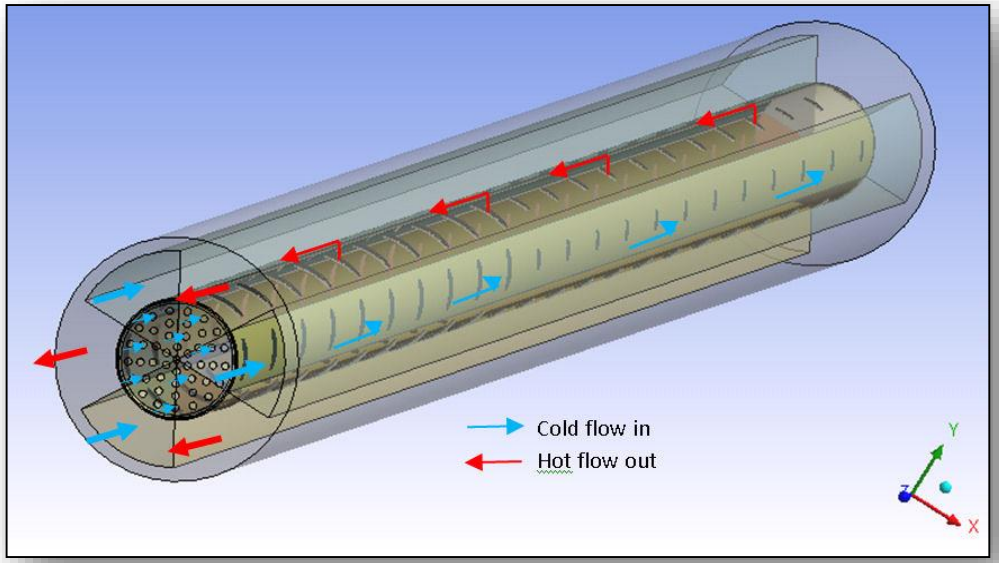


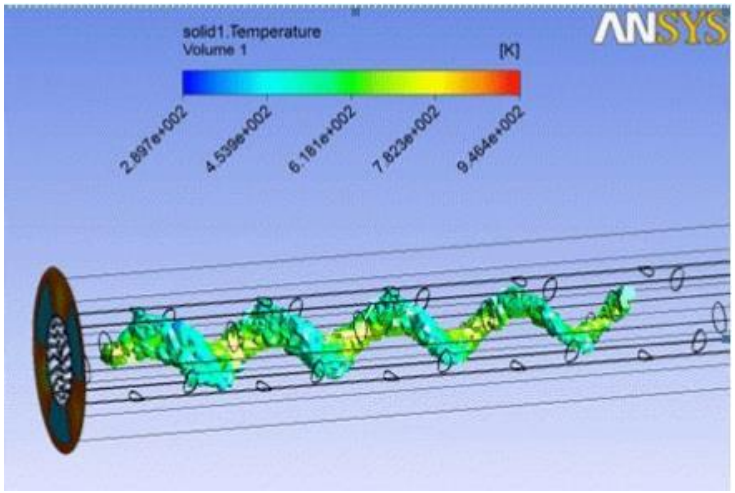

- Power Supply Unit to deliver 350 kA current per each Horn
- Each Module delivers a current of 44 kA max at 50 Hz

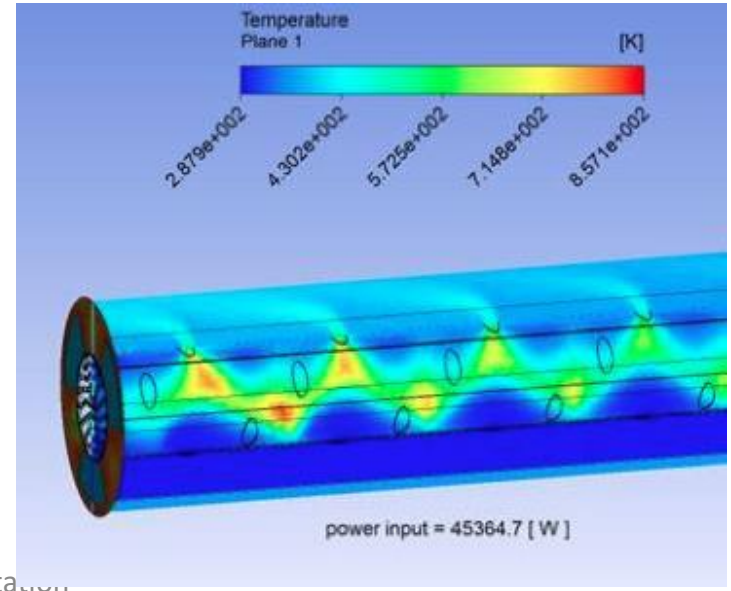


# Target Conceptual Design

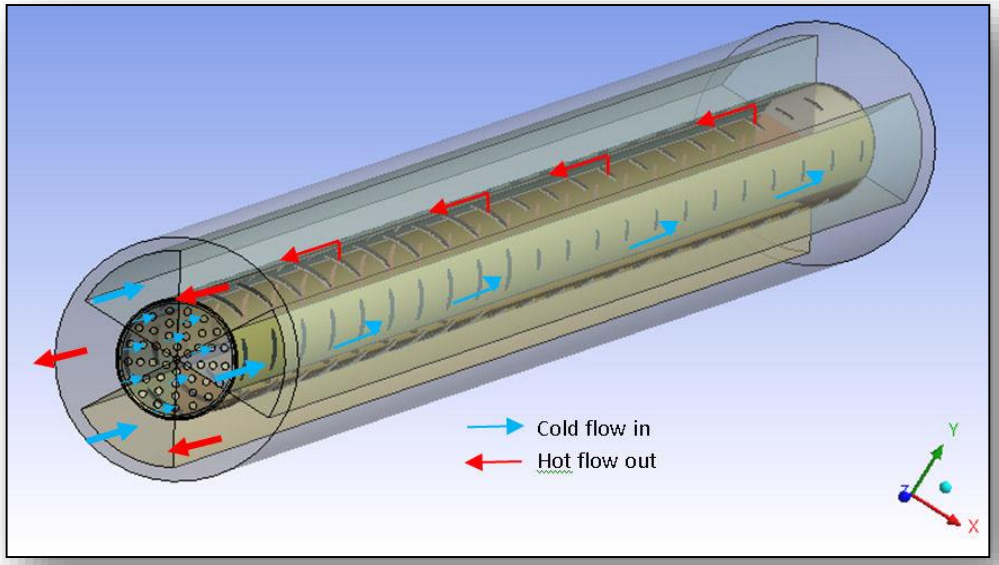


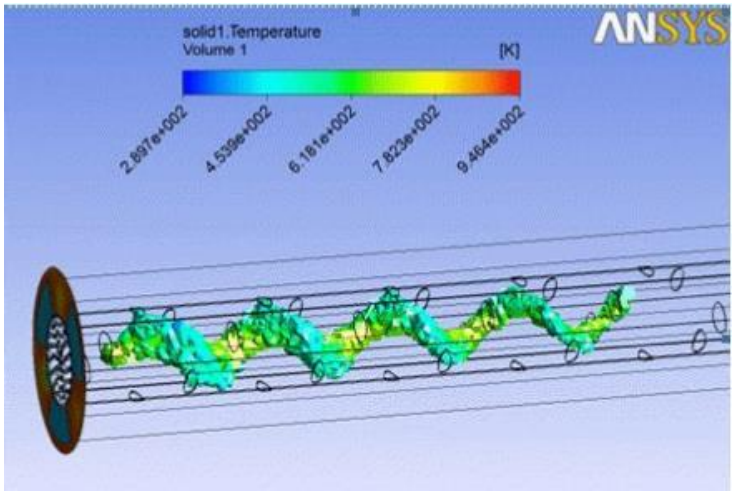



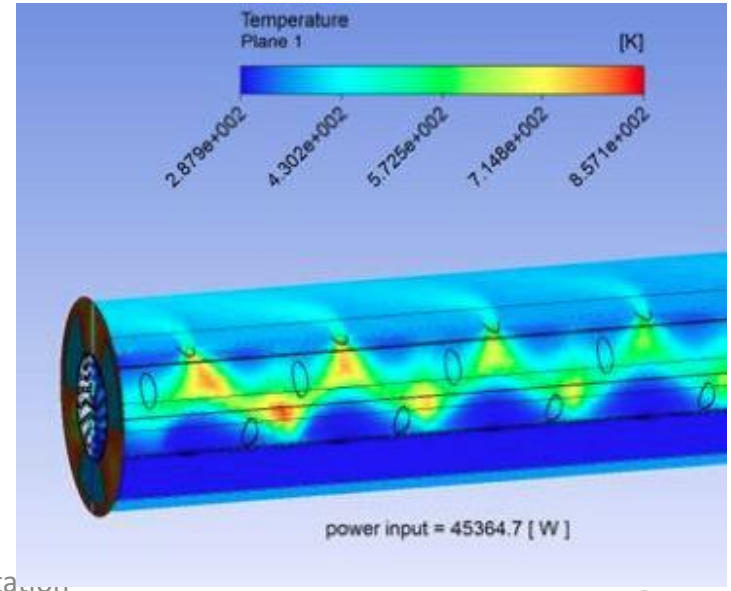




- Packed-bed target studied at RAL within the EuroNu project ( arXiv:1212.0732 )
- Titanium alloy canister containing packed bed of titanium spheres (Gas Helium as cooling medium)
- Single sphere diameter: 3 mm
- Canister radius/length: 12 mm / 780 mm

# Target Conceptual Design



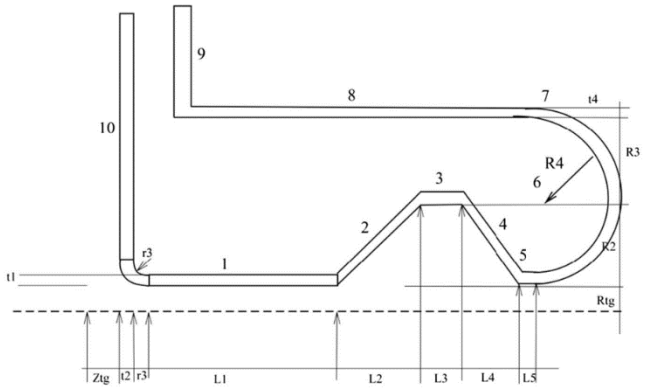



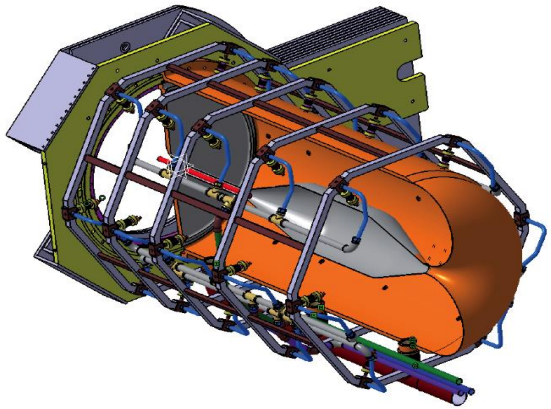



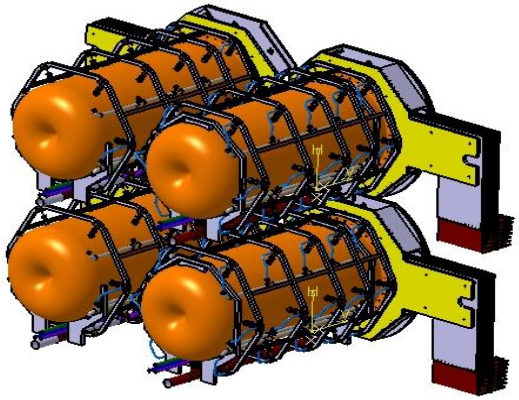

Work under investigation:

- Detailed analysis of the vibrations of the spheres
- Thermal stress calculations in the spheres
- Fatigue life estimate of the spheres
- Numerical study of the dynamic and thermal phenomena in the pebble bed target
- Target cooling issues
- Environmental effects (radiation damage, cavitation issues, etc.)

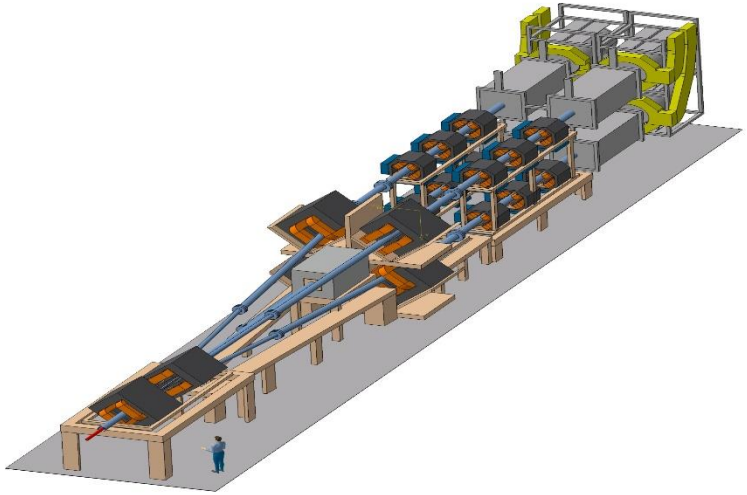
# Magnetic Horn Conceptual Design



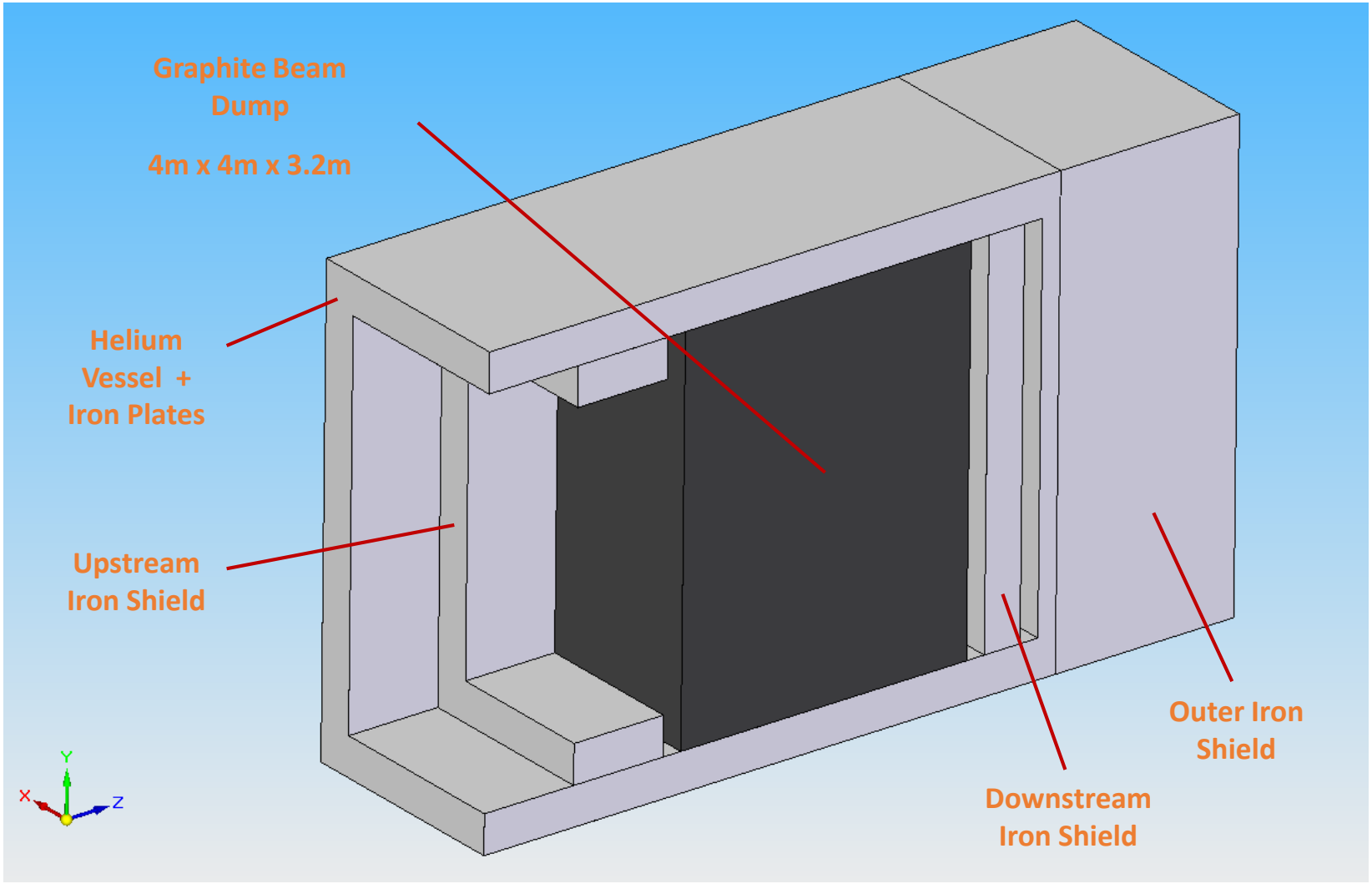





- MiniBooNe-Like Horn made of Al T 6061-T6
- Following the Design for the EUROnu Project
- Horn Diameter/Length: 1.2 m / 2.4 m
- Inner/Outer Conductor Thickness: 3 mm/ 10 mm
- Peak Current: 350 kA
- 4-horn system ( each horn receiving proton beam of 1.25 MW power from switchyard)
- An update of the magnetic horn design is on going to improve the focusing properties and to assess the longevity of the horn and the efficiency of the cooling system



# Beam Dump

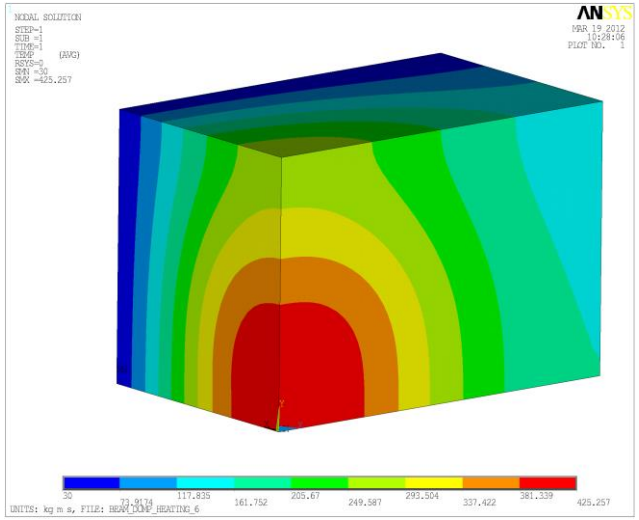



*From EUROnu Design*

# Beam Dump

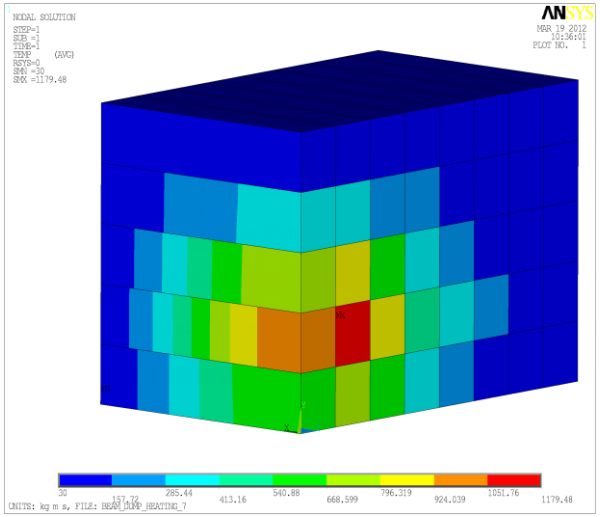
Several configurations have been tested to optimize heat exchange:

**Case 1 Solid Graphite**



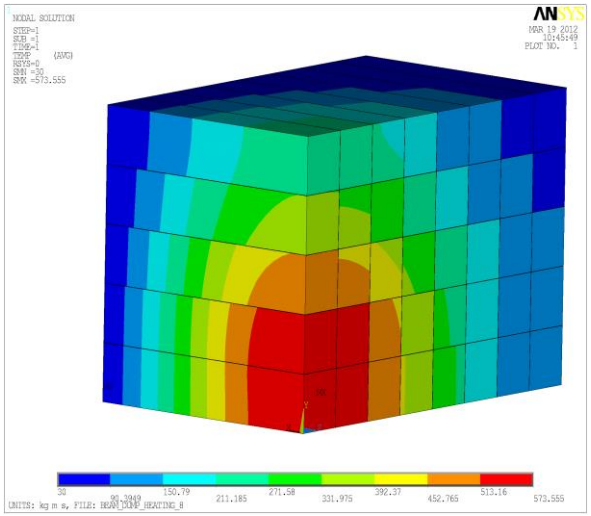
- Best case scenario, but impossible in practice
- Results agree with hand calculation

**Case 2: Graphite blocks, no heat transfer across gaps**



- Worst case scenario for heat transfer
- 0.4m x 0.4m extruded sections – similar to T2K

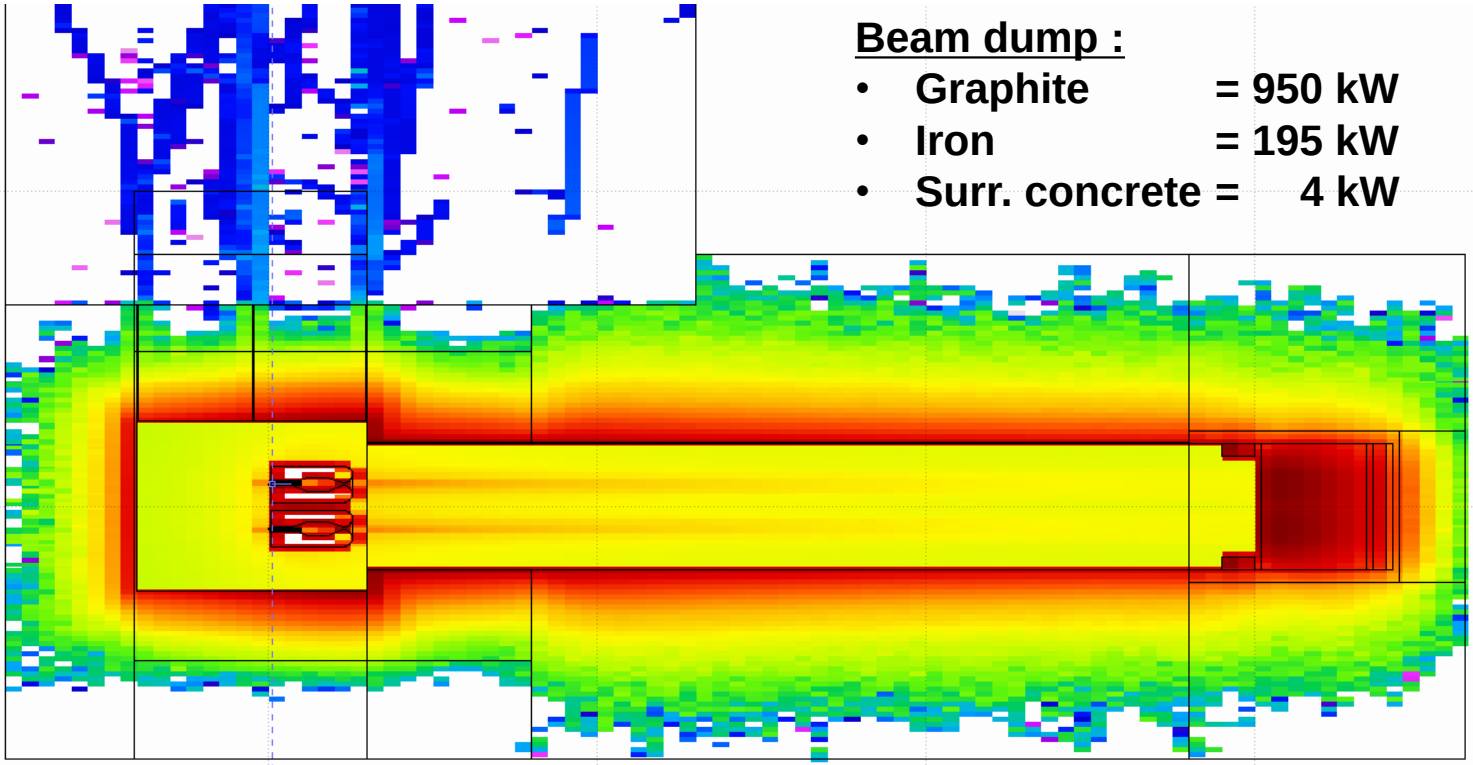
**Case 3: Graphite blocks, helium conduction across gaps**



- Assumed 2mm helium gaps – conservative
- Assumed no convection – conservative

***From EUROnu Design***

# Target Station Energy Deposition



**Beam dump :**
- Graphite = 950 kW
- Iron = 195 kW
- Surr. concrete = 4 kW

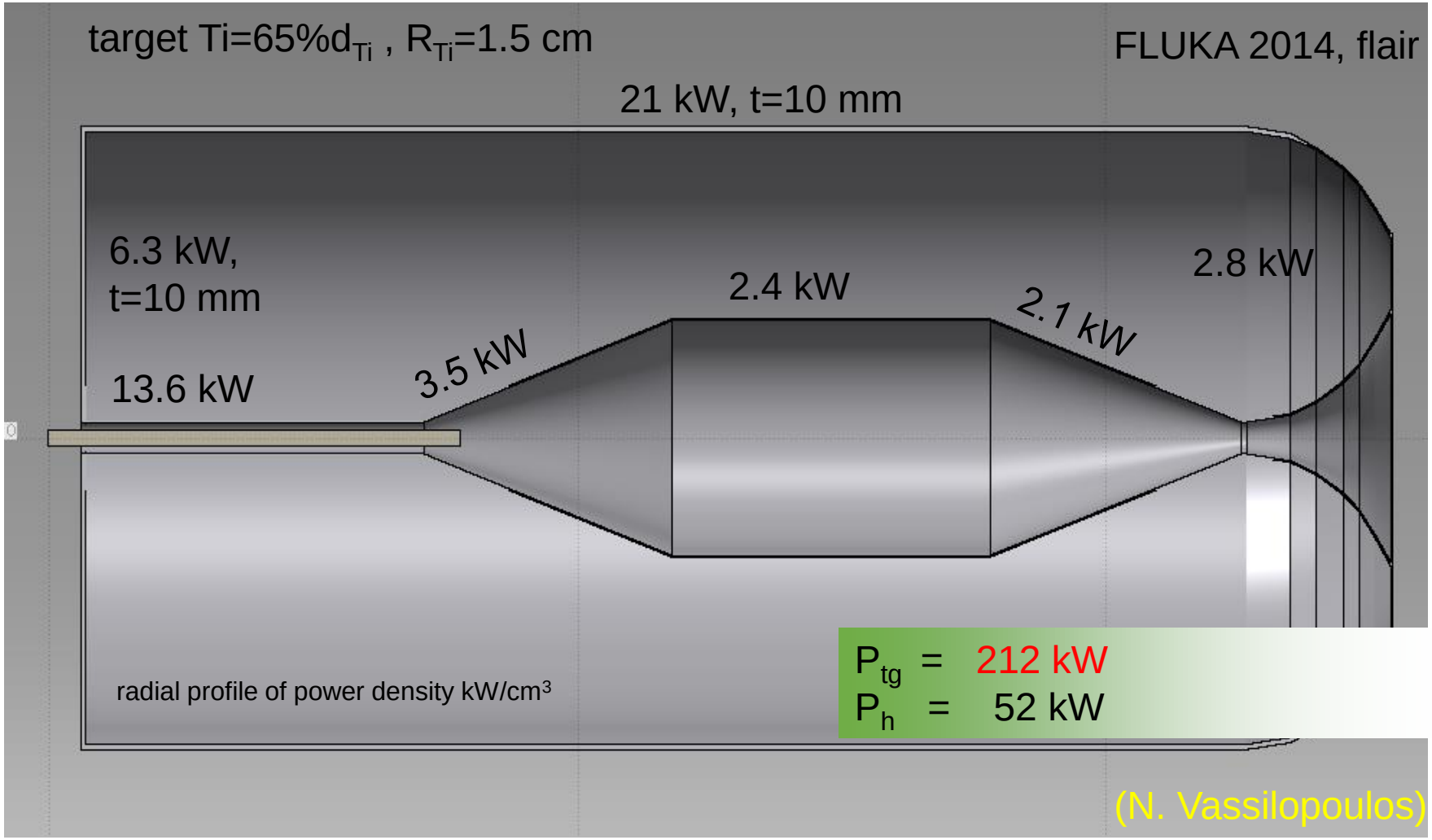
**Horns/Target gallery**
- Iron = 613 kW
- Horn = 50 kW
- Target = 168 kW

**Decay tunnel**
- Iron vessel = 424 kW
- Upstream iron = 670 kW
- Surr. concrete = 467 kW

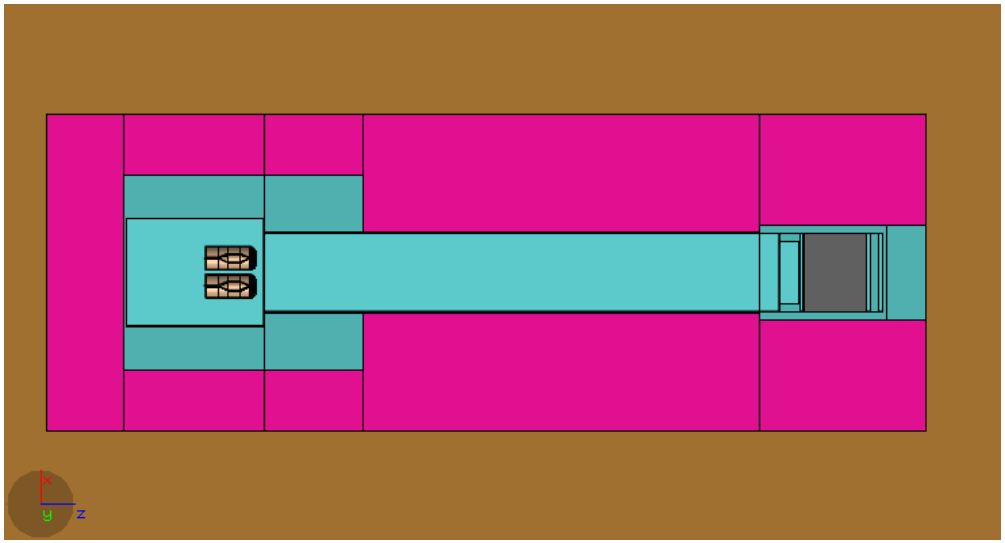
(N. Vassilopoulos)

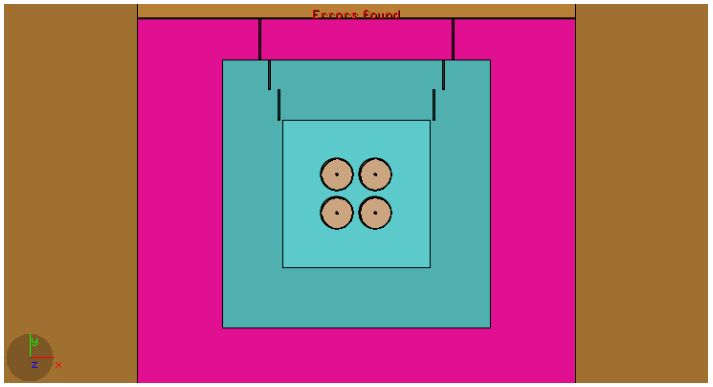
IPAC'17 Proceedings: E. Bouquerel et al, "*Energy deposition and activation studies of the ESSnuSB Horn Station*", MOPIK029

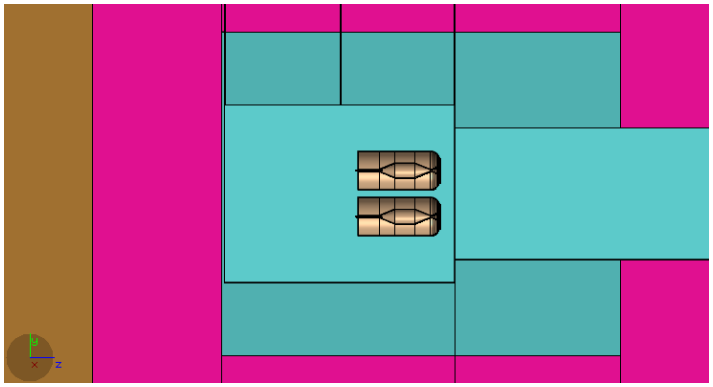
# Energy Deposition (Target+Horn)

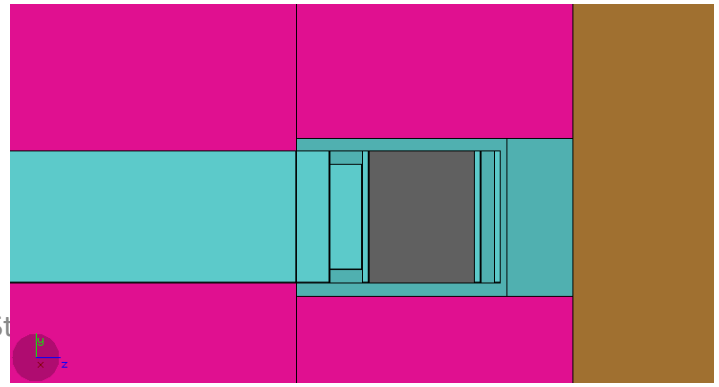


# Simulation of Particle Production in the Target Station









- Target Station geometry implemented in a FLUKA code (N. Vassilopoulos)
- Titanium target: continous medium with reduced density ( 66% $\rho_{Ti}$ )
- Protons with 2.5 GeV kinetic energy, gaussian profile with 1 $\sigma$ = 4 mm
- The same code is used also for calculation of Energy Deposition
- Results shown for I = 350 kA

# Pion Distribution

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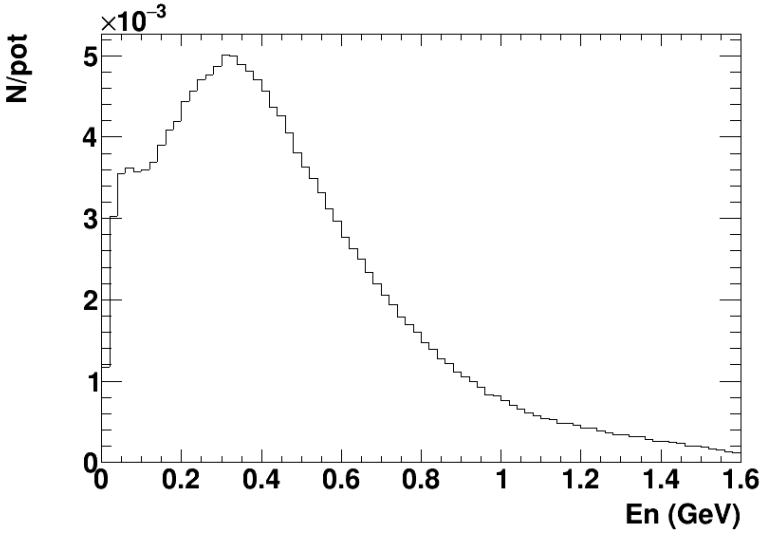
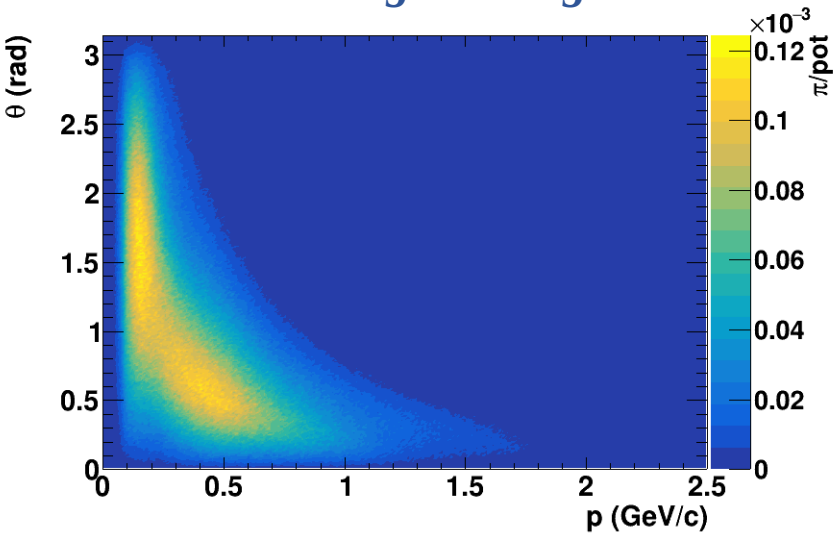
### *Positive Horn Polarity*

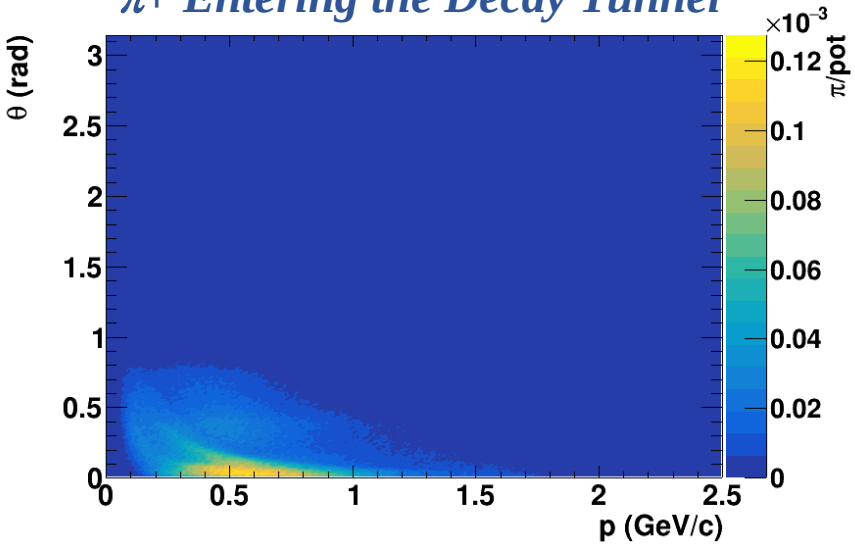
- Total Number of pions produced per P.O.T.:
  - π+ = 0.32/pot
  - π- = 0.22/pot
  - π+ entering the Decay Tunnel = 0.16/pot
  - π- entering the Decay Tunnel = 0.04/pot



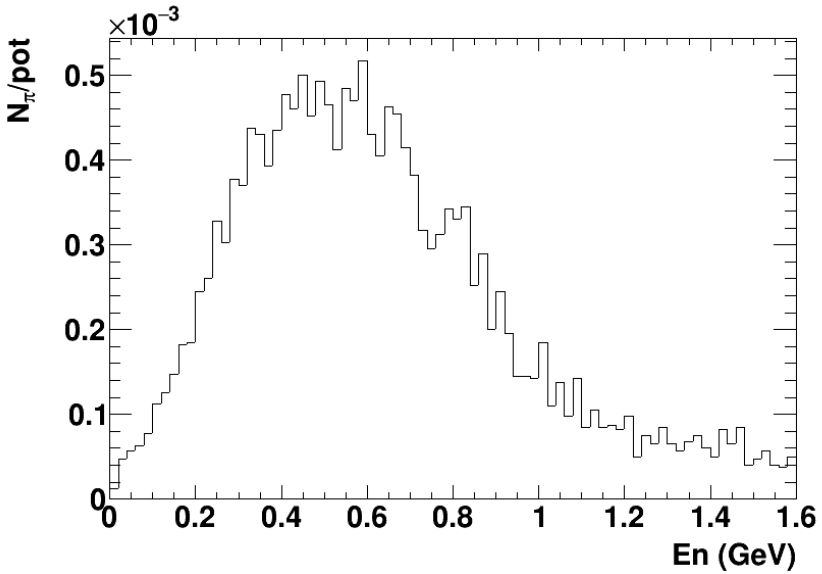

### *π+ Exiting the Target*



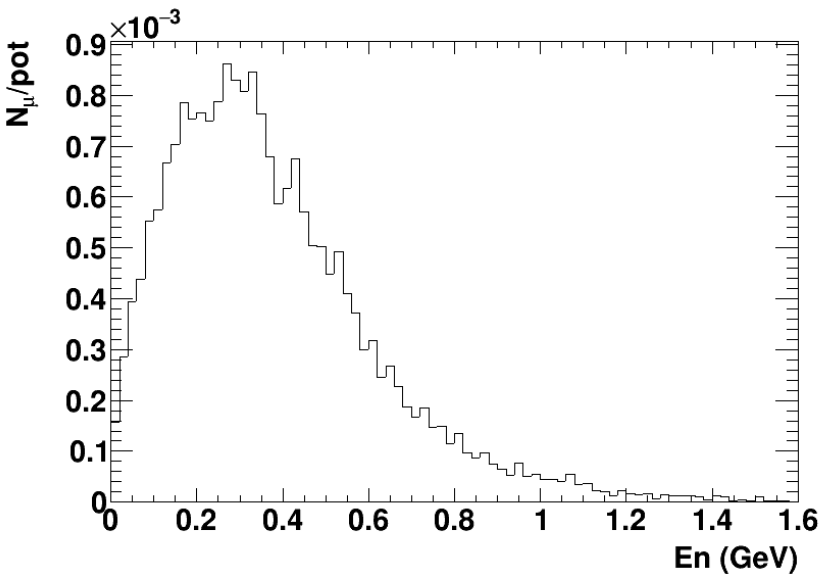

### *π+ Entering the Decay Tunnel*



# Distribution of Pions and Muons at the Beam Dump




*Pions entering the Beam Dump*

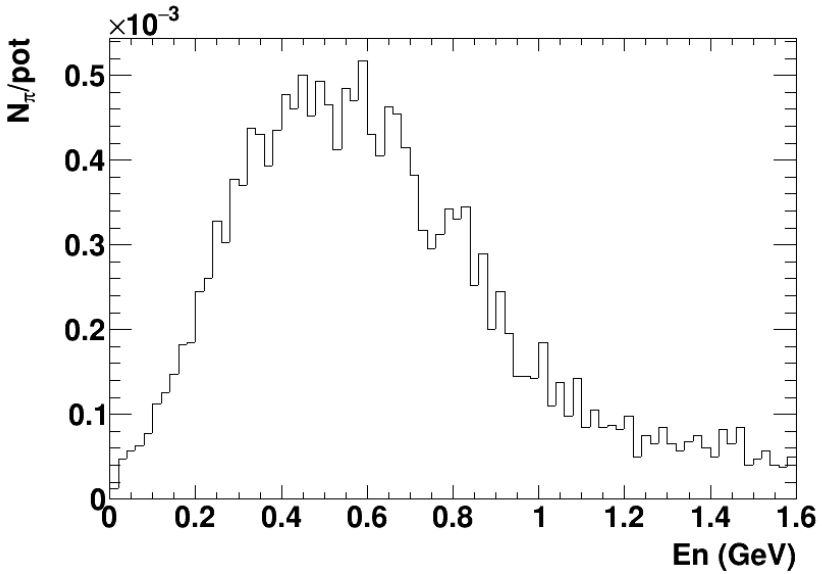



*Muons entering the Beam Dump*

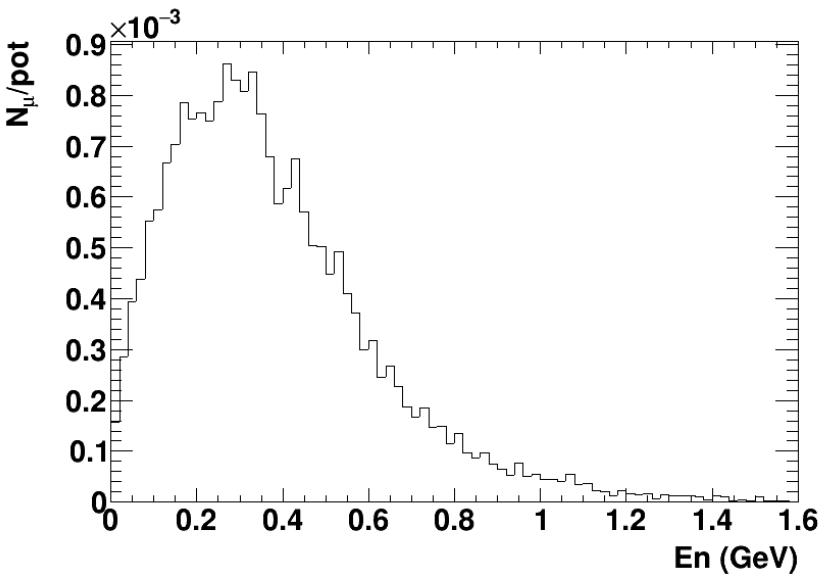
- Total Number (per P.O.T.): $1.7 \times 10^{-2}$
- Mean Kinetic Energy: 0.63 GeV

- Total Number (per P.O.T.): $2 \times 10^{-2}$
- Mean Kinetic Energy: 0.38 GeV

# Distribution of Pions and Muons at the Beam Dump

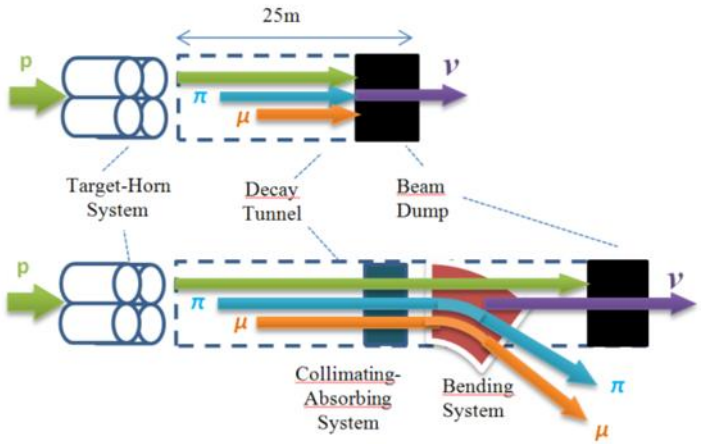



*Pions entering the Beam Dump*




*Muons entering the Beam Dump*

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



# Neutrino Spectra

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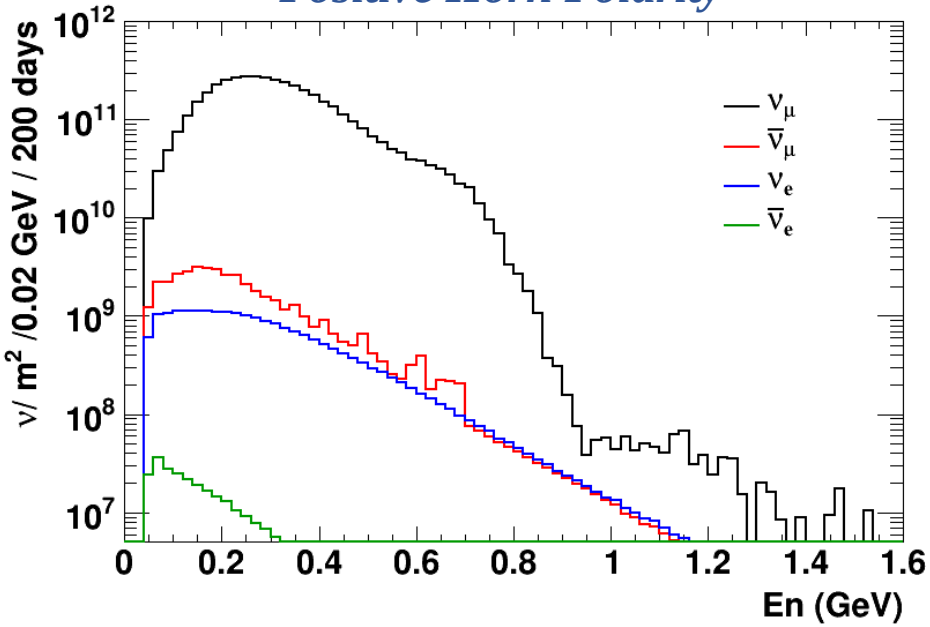
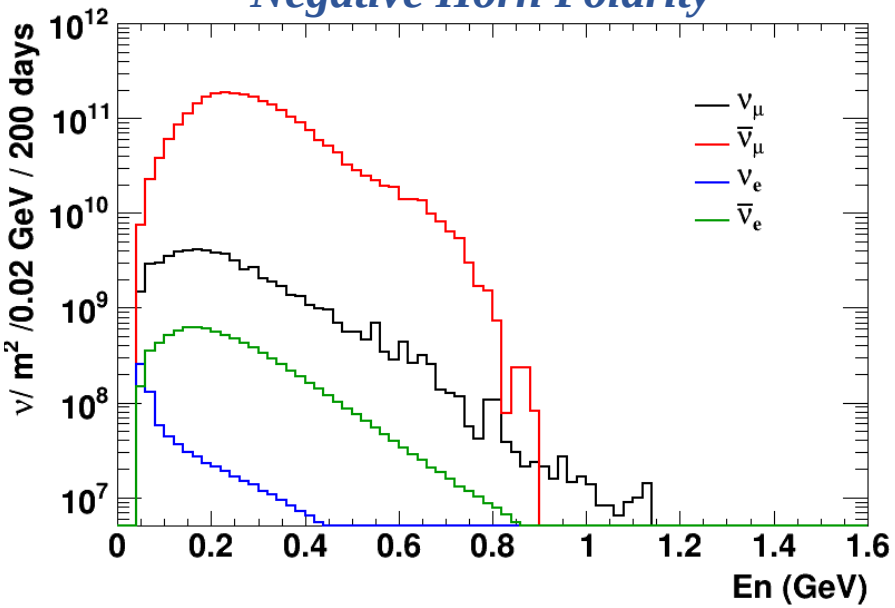
*Positive Horn Polarity*



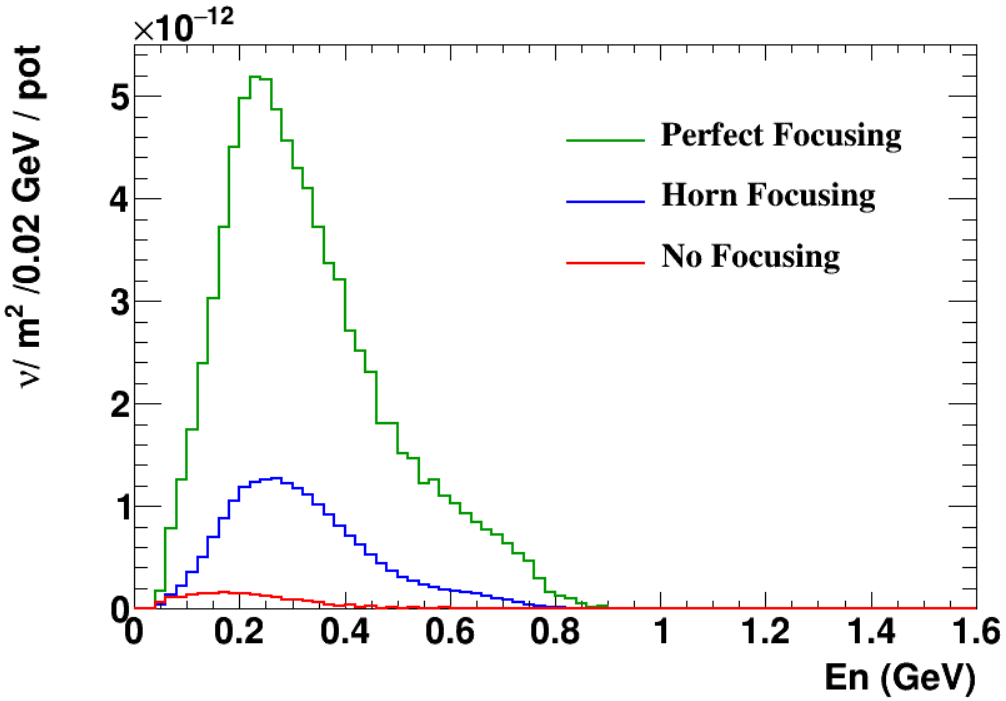

*Negative Horn Polarity*




| | Positive | | Negative | |
|---|---|---|---|---|
| | $N_\nu\,(10^{10}/m^2)$ | % | $N_\nu\,(10^{10}/m^2)$ | % |
| $\nu_\mu$ | 431 | 98.5 | 6.0 | 2.25 |
| $\bar{\nu}_\mu$ | 4.34 | 0.99 | 260 | 97.4 |
| $\nu_e$ | 2.15 | 0.49 | 0.08 | 0.03 |
| $\bar{\nu}_e$ | 0.03 | 0.01 | 0.87 | 0.32 |

*Flux Calculated at 100 km distance from TS*

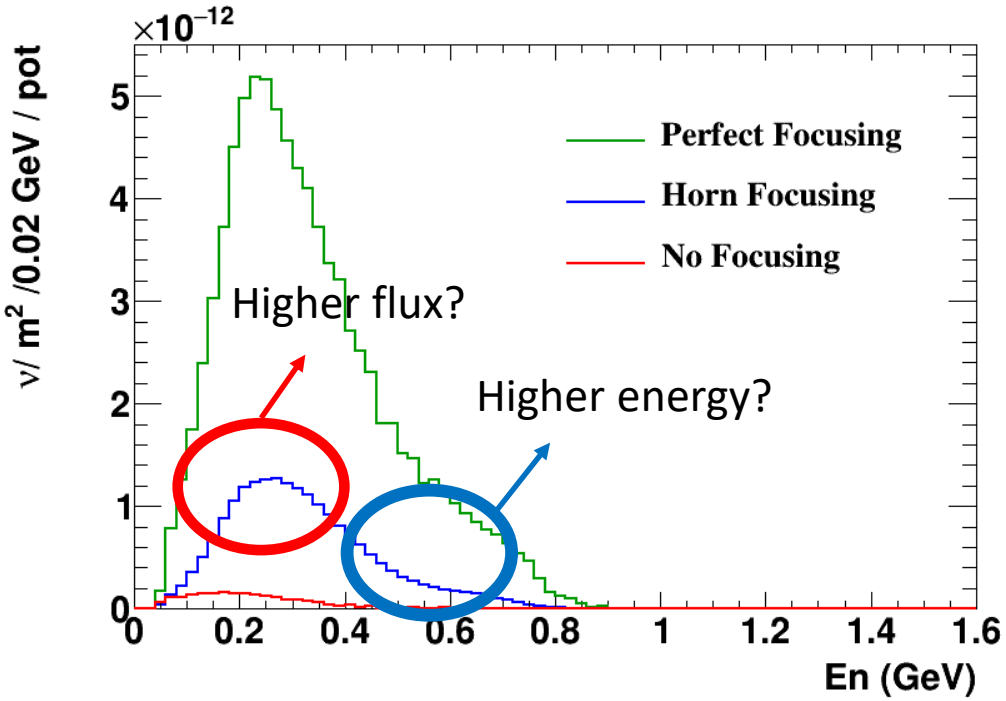
# Efficiency Study of the Target Station




- 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 investigation on the Decay Tunnel, to assess the contribution of the electron neutrino contamination compared with the muon neutrino flux.

# Efficiency Study of the Target Station

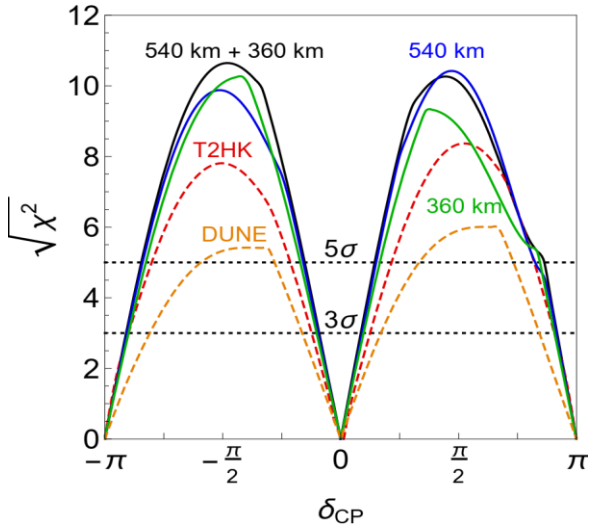


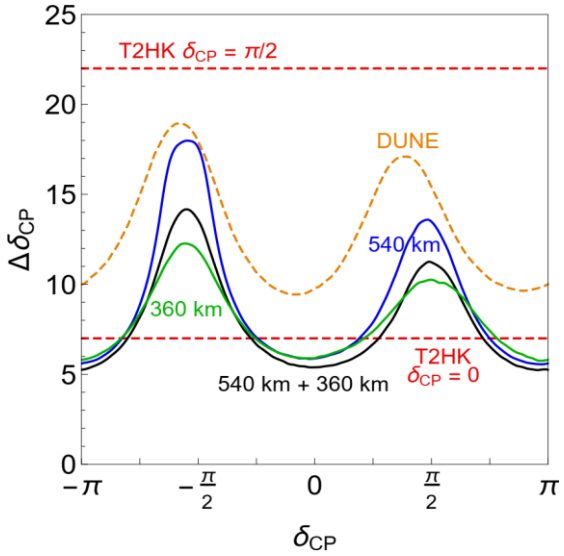

- Optimization of the Target Station through parametric study based on the geometry of the horn and of the Decay Tunnel (in order to shift the mean neutrino energy to higher values)

- Further investigation on the Decay Tunnel, to assess the contribution of the electron neutrino contamination compared with the muon neutrino flux.

# Sensitivity to $\delta_{CP}$ Discovery

- Previous studies showed the potentiality to measure the $\delta_{CP}$ phase with the neutrino super beam produced at the ESS site ( up to 60% coverage at 5 $\sigma$ CL )
- Sensitivity to measurement of $\delta_{CP}$ phase depends on location of far detector.
- Another important criterion for optimization is the precision of the measurement ( $\Delta\ \delta_{CP}$ ).
- This criterion will be used for the design of the magnetic horn and decay tunnel.




*360 km -> Zinkgruvan Mine (Sweden)*
*540 km -> Garpenberg Mine (Sweden)*

# Conclusions and Perspectives

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- The ESSνSB project proposes to build a European facility for production of high intensity neutrino superbeam for precise determination of CP violation in the leptonic sector.
- The aim of the design study of the ESSνSB Target Station is to improve the efficiency of the current baseline of the Magnetic Horn and Decay Tunnel.
- Thermo-mechanical studies done during the EUROnu phase will be updated taking into account of the required sensitivity of the experiment to the $\delta_{CP}$ measurement.
- Further characterization and study of muons from Beam Dump to investigate potential application to future projects.