NUFACT BLACKSBURG, VIRGINIA ■ AUGUST 12-18, 2018

VIRGINIA TECH

The 20th International Workshop on Neutrinos from Accelerators

The ESSνSB Target and Horn Studies and Future developments

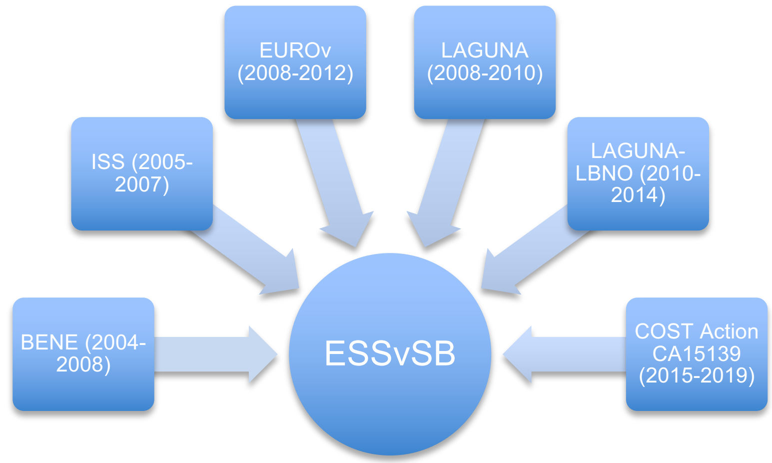
COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOL

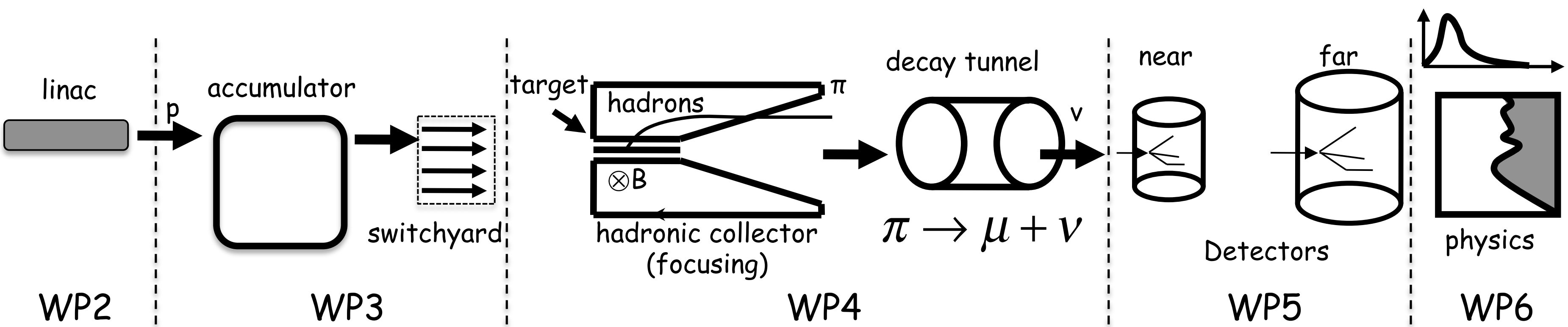
M. Dracos on behalf of ESSνSB Collaboration

IPHC-IN2P3/CNRS Strasbourg

ESSνSB at European Level

- **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





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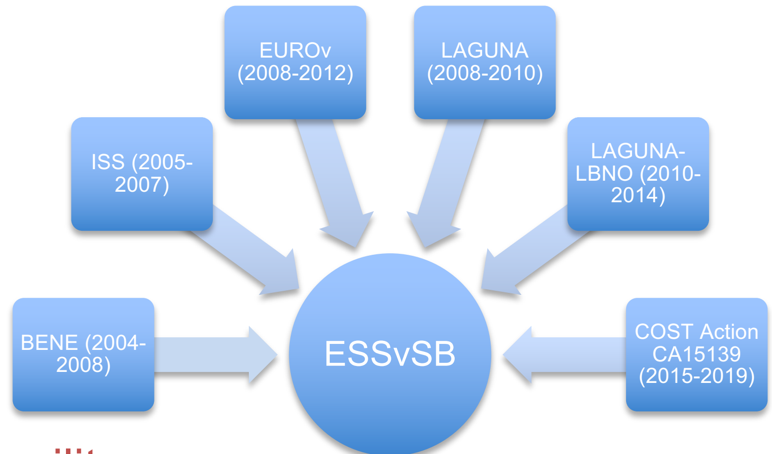
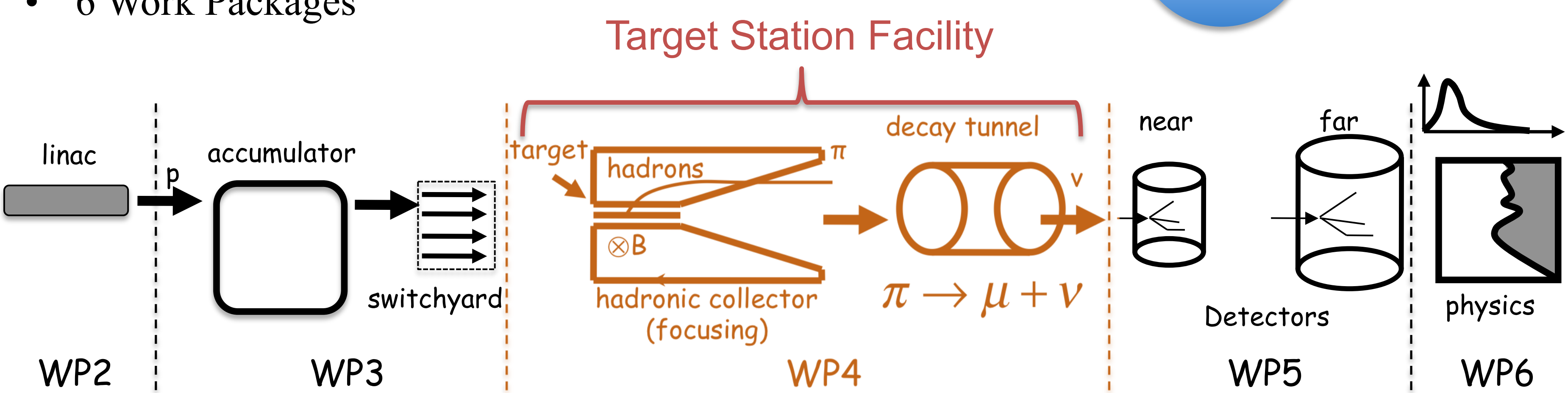


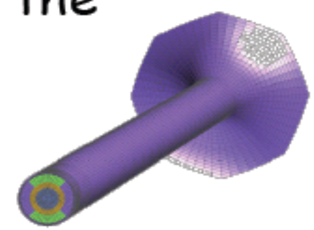


From Euroν to ESSνSB

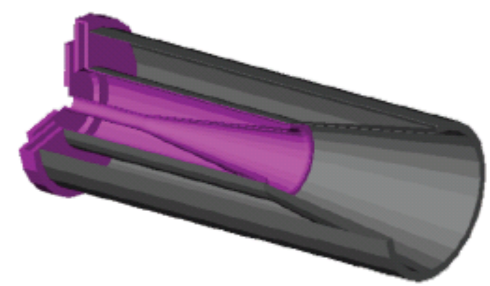
Parameter	SPL	ESS
Power (MW)	4	5
E_{p+} (GeV)	4.5	2, 2.5
Baseline (km)	130	365, 540
Target	Packed-bed	Packed-bed
Target length (cm)	78	53-78
Target radii (cm)	1.5	1.5
Horn	Forward closed	Forward closed
Horn current (kA)	350 @ 12.5 Hz	350 @ 14 Hz
# of horns/targets	4	4
Tunnel length (m)	25	15-25
Tunnel radii (m)	2	2
Exposure (years)	2 ν + 8 anti-ν	2 ν + 8 anti-ν

Neutrino beam based on Multi-Mega-Watt Proton Beam

- Can we conceive a neutrino beam based on a multi-MW proton beam ?
- At the start of EUROν, no proven solution for the target and collector was proposed for this facility !
- Can we design a target for a multi-MW proton beam ?
- Can we do it with a reliable design without compromising the physics reach ?
- **Target**
  - 300-1000 J/cm^3/pulse
  - Severe problems from: sudden heating, stress, activation
  - Solid versus liquid targets
  - cooling



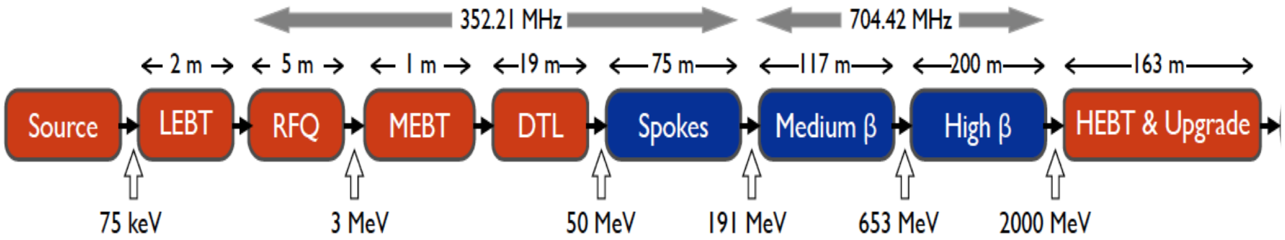
- **Horn**
  - horn+reflector integration
  - pulser (up to 600 kA)



- **Safety**
- **Lifetime** (supposed to run for 10 years)

ESSνSB Neutrino Beam Production

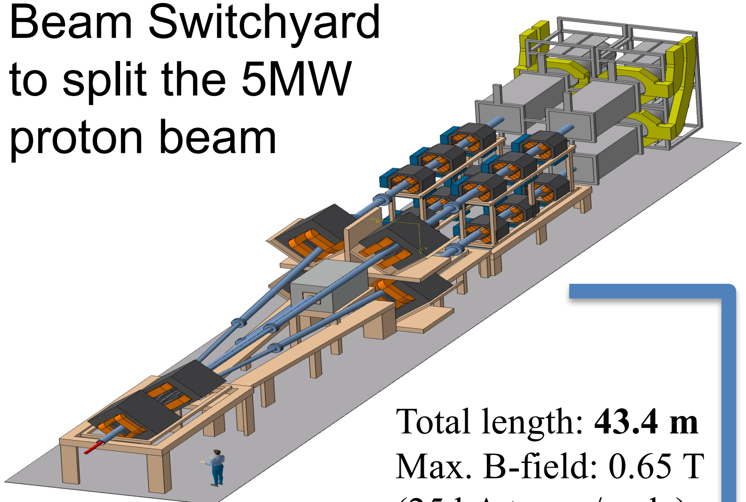
ESS Proton Beam LINAC



5 MW proton beam for neutron users (2.86 ms pulse width)

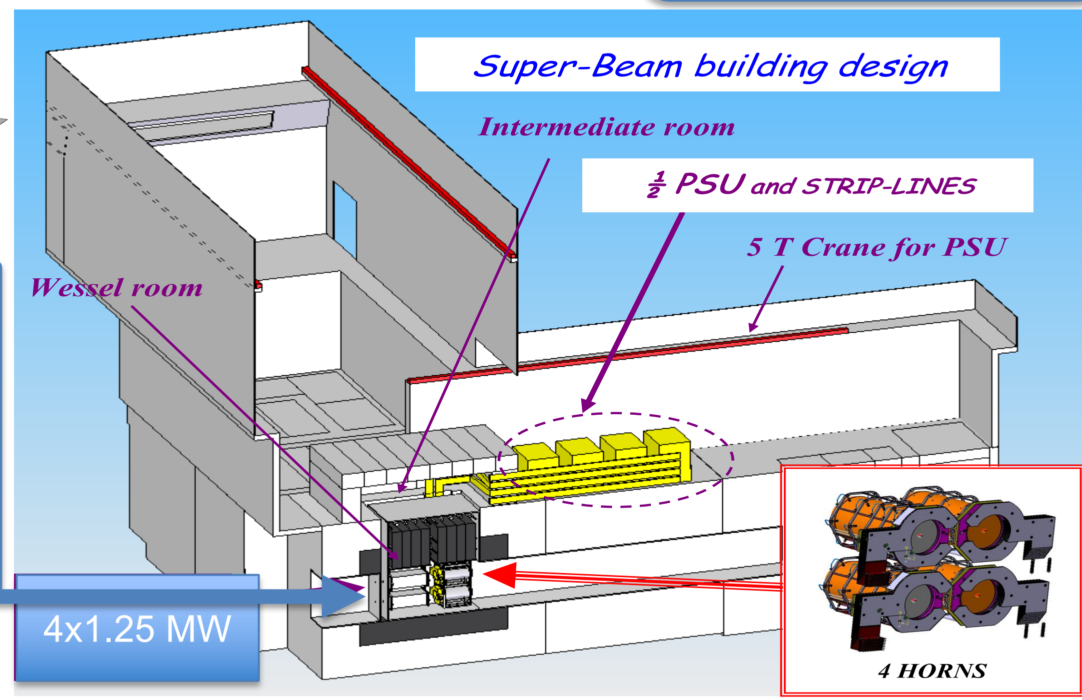
5 MW proton beam for neutrino users
1 μs pulse width =>
Accumulator requested

Beam Switchyard to split the 5MW proton beam



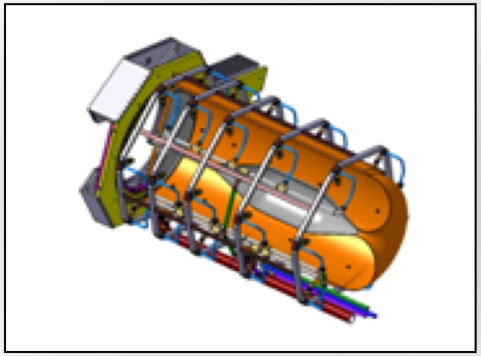
Total length: **43.4 m**
Max. B-field: 0.65 T
(25 kA turns / pole)
Dipole length: 2 m

IPAC'15 Proceedings: E. Bouquerel, "*Design Status of the ESSnuSB Switchyard*", MOPWA017

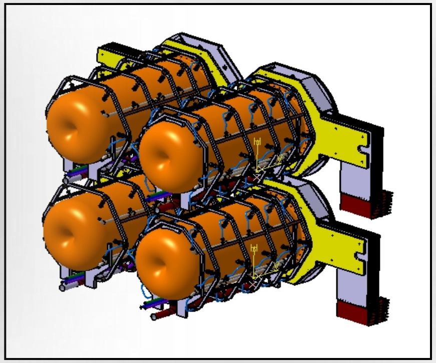


WP4 Investigations:

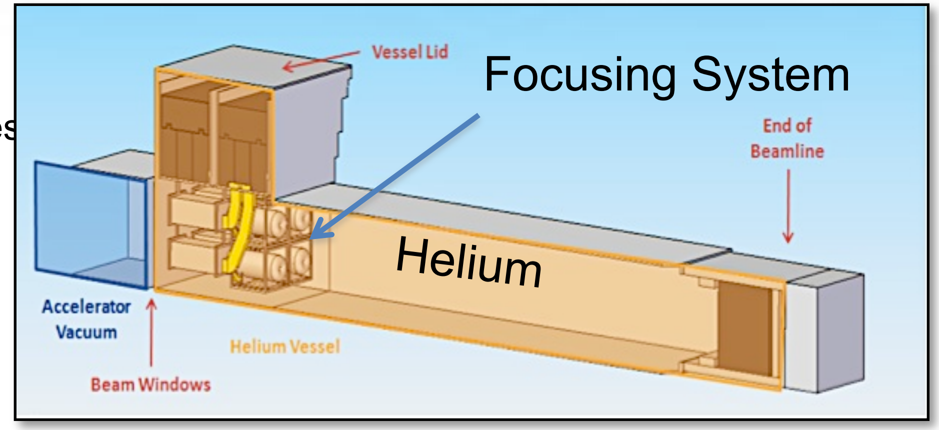
- Optimize the Hadron Collector
  - Target Technology
    - Power 1.25 – 1.6 MW
    - Potential heat removal rates at the hundreds of kW level
    - Helium cooling
    - Separated from the Horn
  - Focusing System
    - Accommodate the 5 MW power scale
    - Solid target integrated into the inner conductor : very good physics results but high energy deposition and stresses on the conductors
    - Best compromise between physics and reliability
- Target Station Facility
  - Supporting structure for focusing system
  - Shielding, Beam Dump
  - Power Supply Station, Cooling,…
  - Safety Aspect



Horn



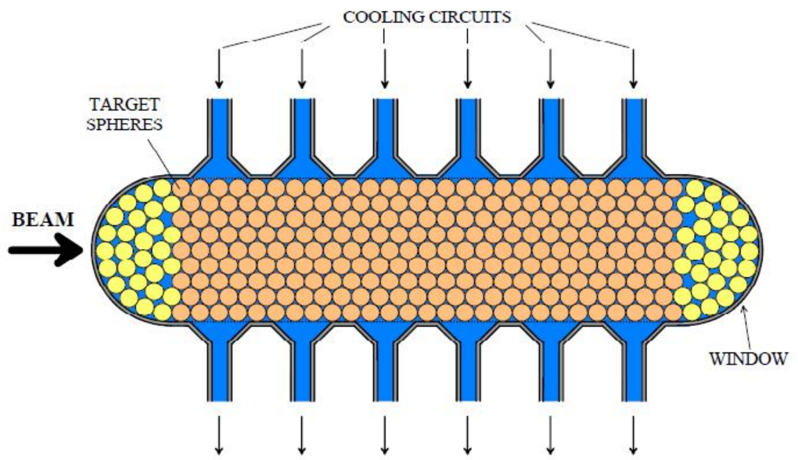
Four Horn System



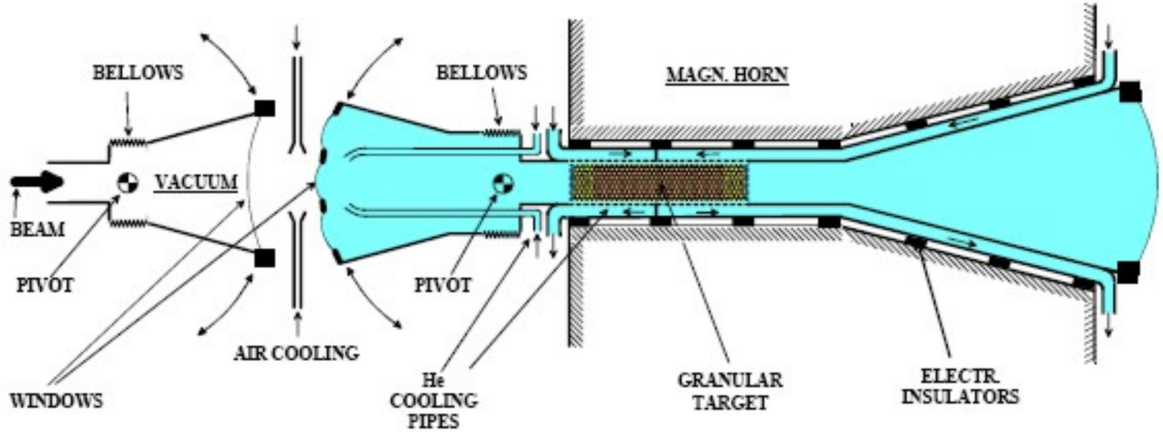
ESSνSB Target Station Concept

Target Concept

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

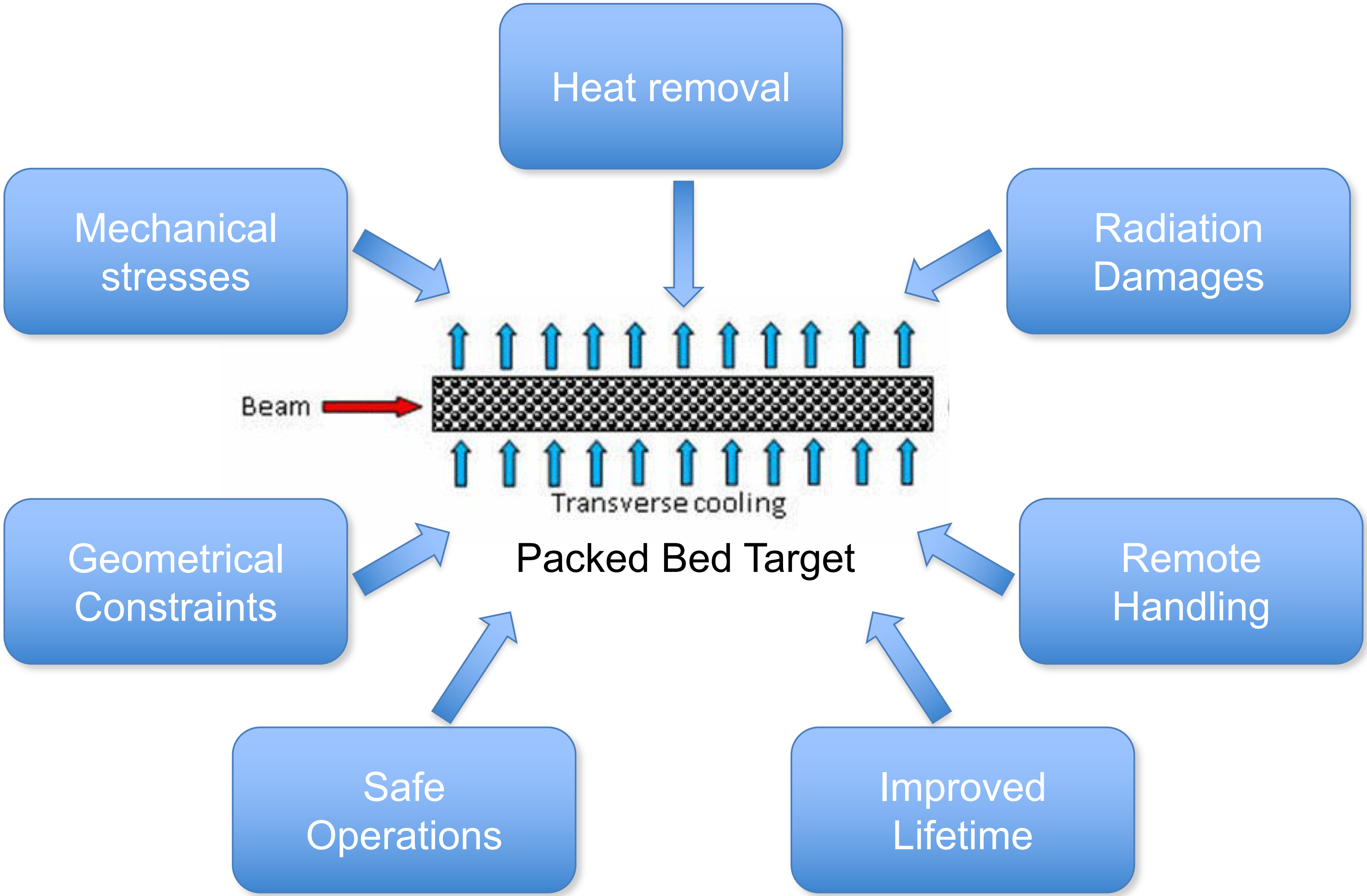


COOLING MEDIUM:
water or gas helium



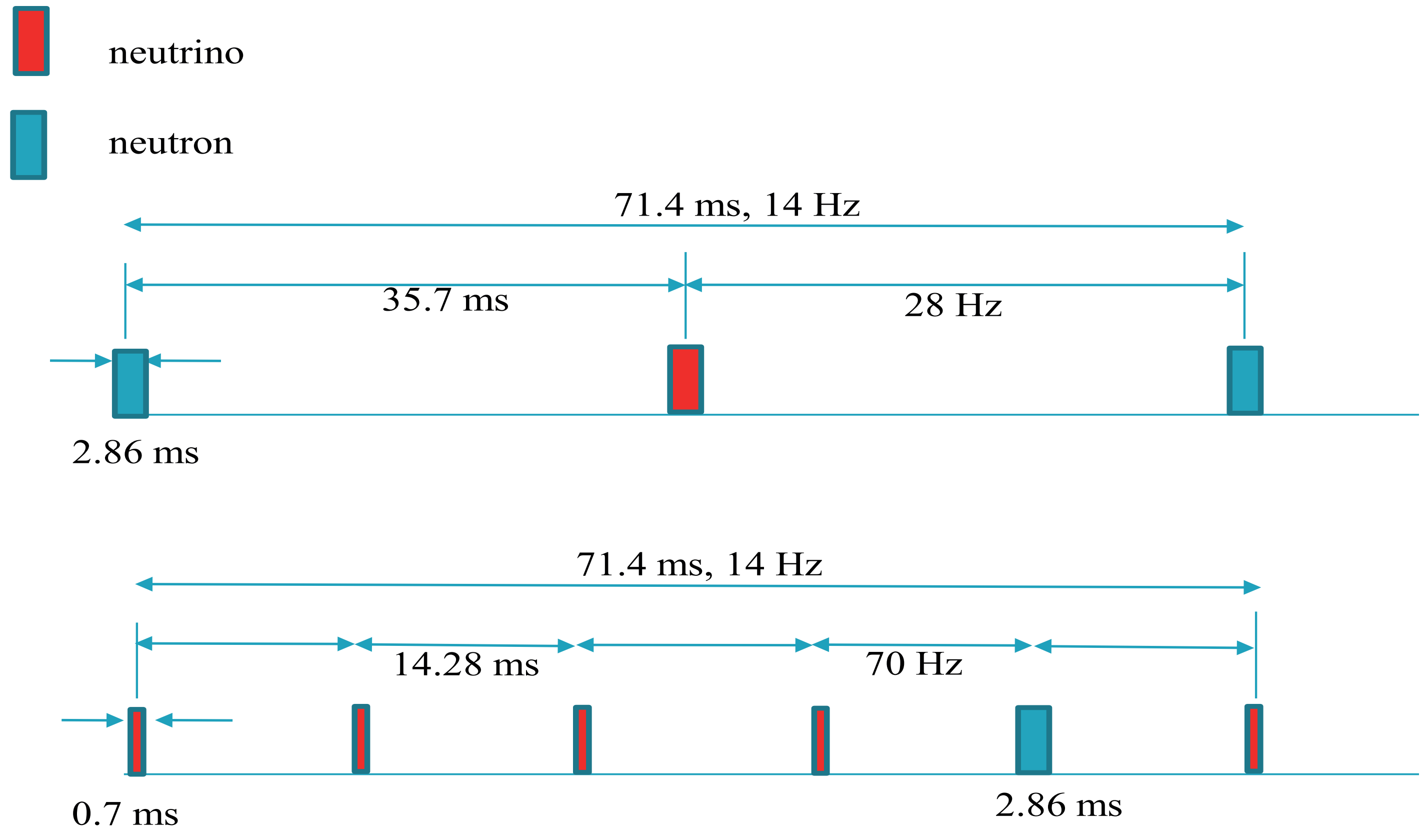
Concept of target integration inside a magnetic horn

Target Concept



Target Concept

Several proton beam pulse structure are under investigation:

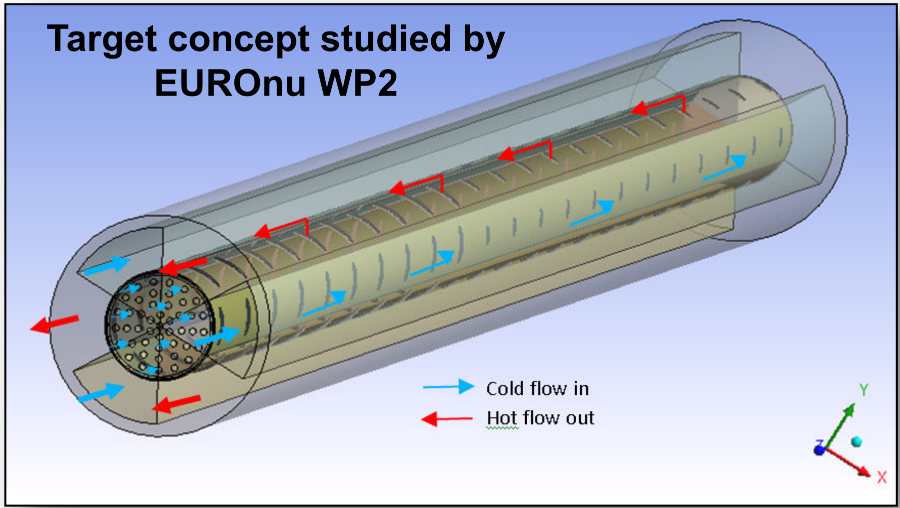


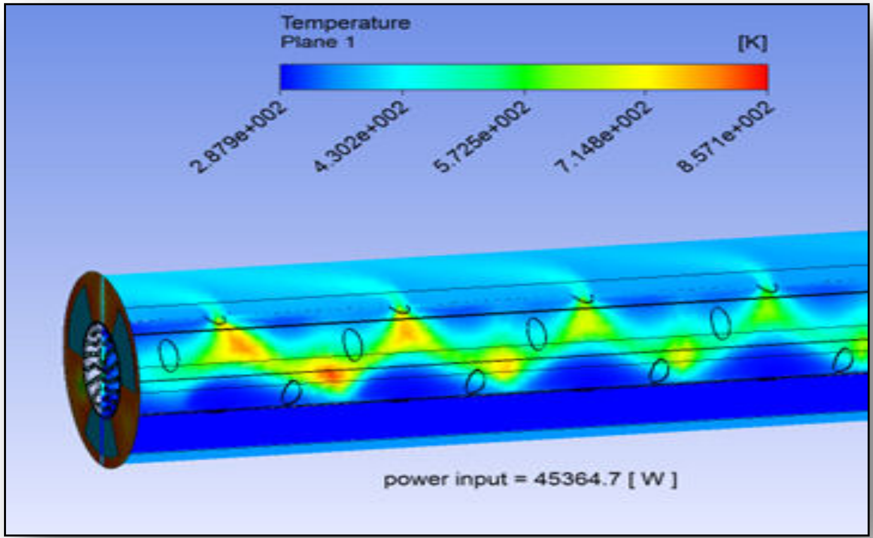
Packed Bed Target

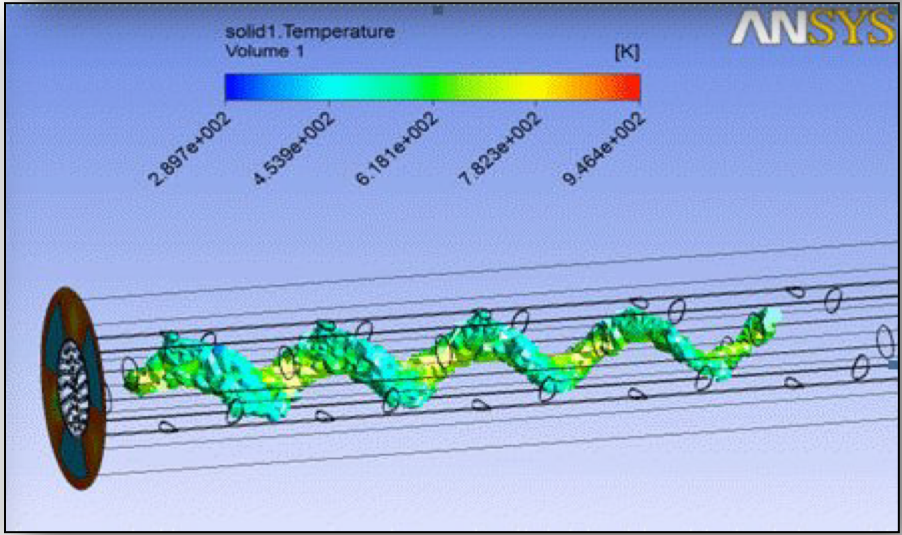
Target : 3 mm diameter titanium spheres
Proton Beam : 4.5 GeV, 1MW (SPL - Parameters)
Beam width : 4 mm
Target geometry radius/Length : 12 mm / 780 mm
Coolant : Helium at 10 bar pressure

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

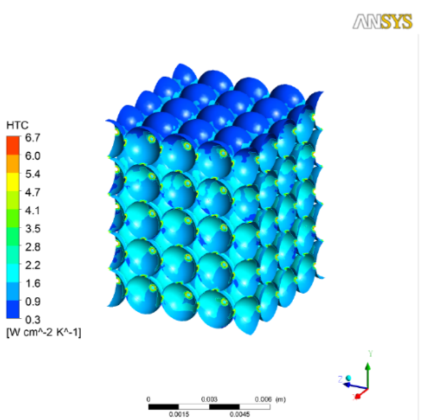
=> Concept will be upgraded for ESSνSB

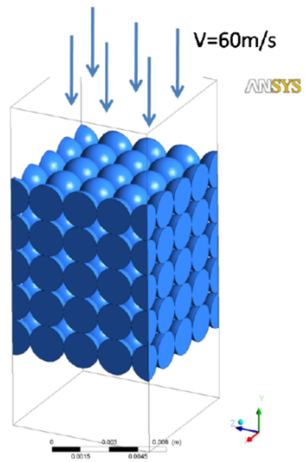


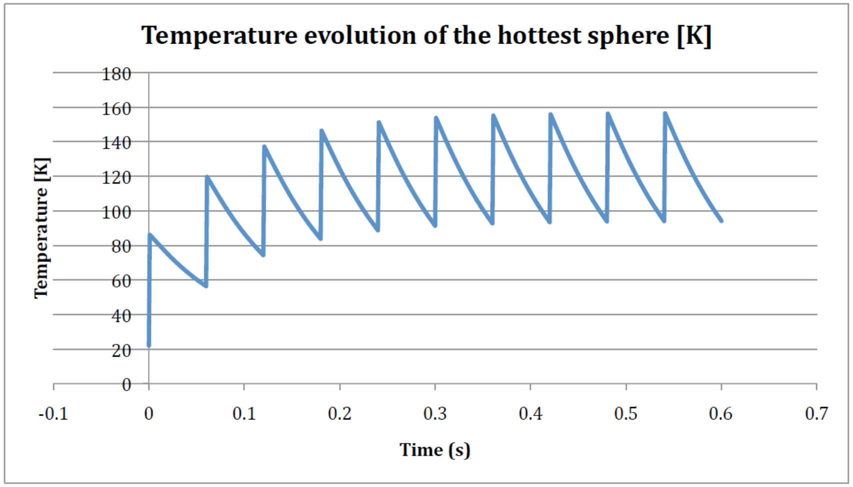




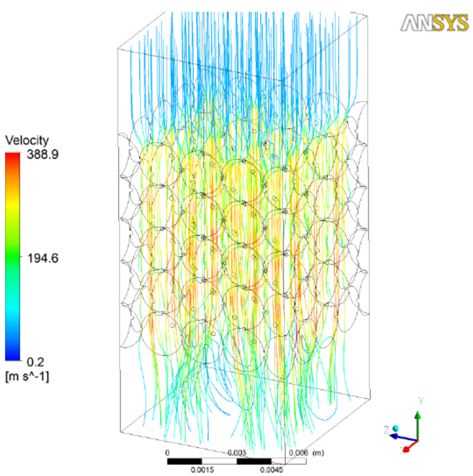
Packed-bed target, studied at RAL within the EUROnu project (arXiv: 1212.0732)

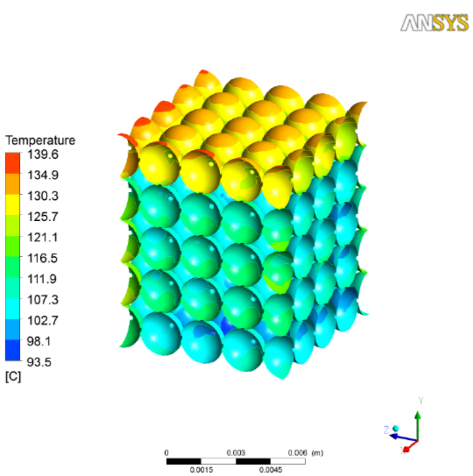






Some of the results obtained by C.Khoroua and E.Noah at ESS





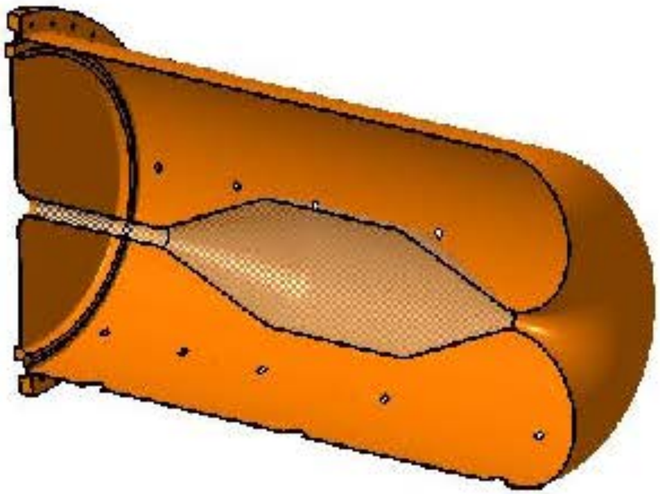
Work under investigation :

- 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.)

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

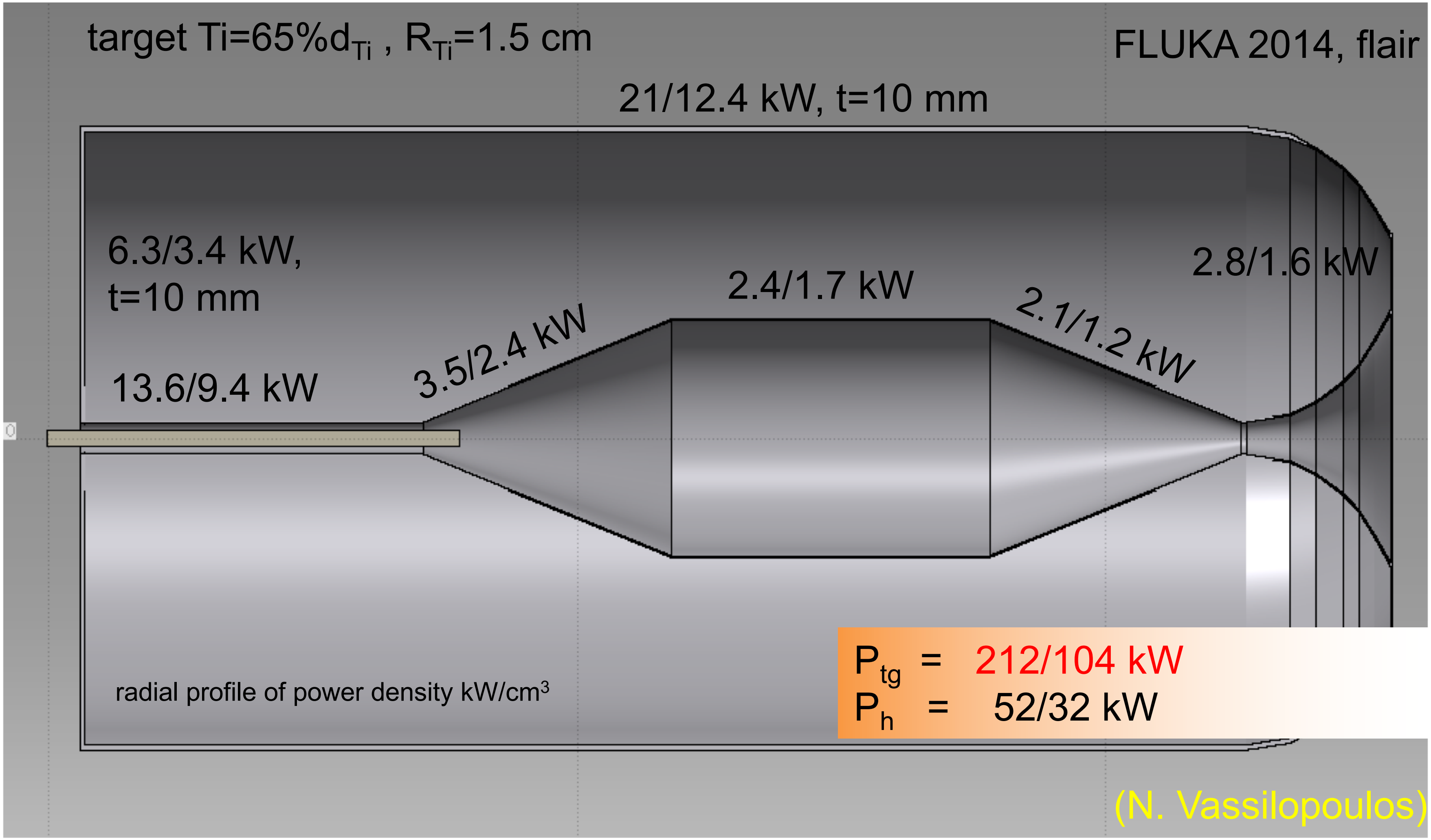
=> Concept will be upgraded for ESSνSB



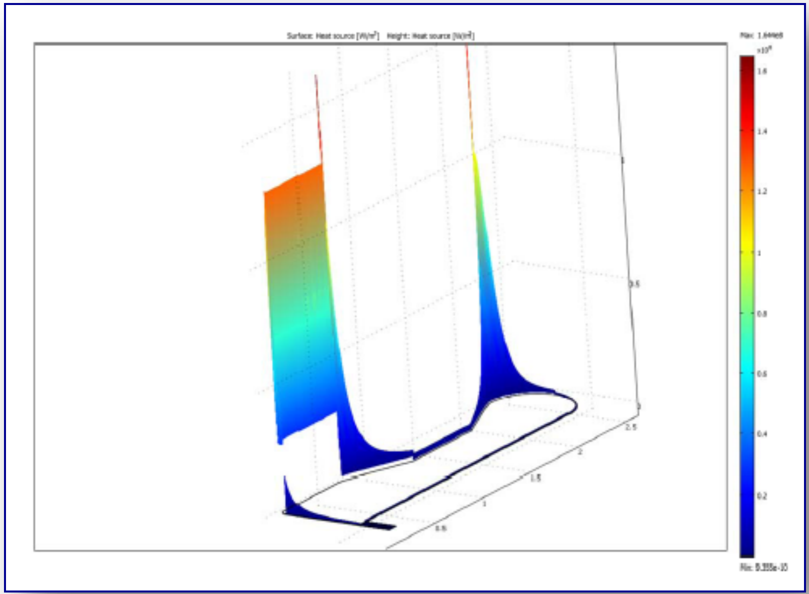
Horn major design issues

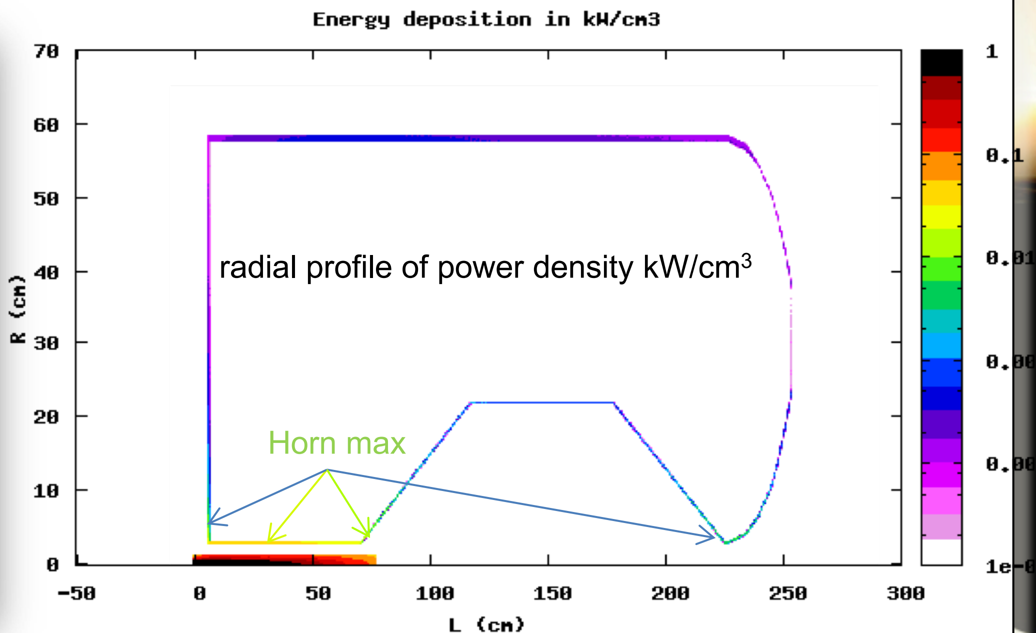
- Steady-state temperature determined by the cooling system and the resulting static stress.
- Dynamic stress brought about by short-duration pulses.
- Assessment of the longevity (fatigue life) of the horn and its components.
- The performance of the cooling system.

Horn Energy Deposition
ESSvSB 1.6 MW / EUROnu -1.3 MW



P_{tg} = 212/104 kW
P_h = 52/32 kW





Cooling system

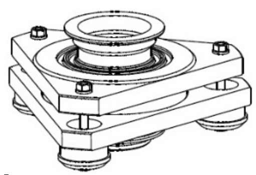
- Planar and/or elliptical water jets
- 30 jets/horn, 5 systems of 6-jets longitudinally distributed every 60^0
- Flow rate between 60-120l/min, h cooling coefficient 1-7 kW/(m^2K)
- Longitudinal repartition of the jets follows the energy density deposition
- $\{h_{corner}, h_{horn}, h_{inner}, h_{convex}\} = \{3.8, 1, 6.5, 0.1\}$ kW/(m^2K) for $T_{Al\text{-}max} = 60\ ^0C$

Feedback from previous experiments

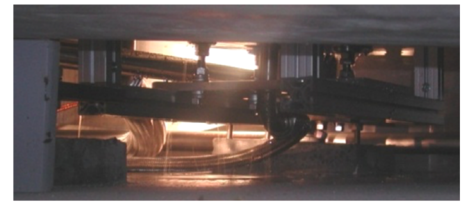
Some practical issues regarding horn design, CNGS horn

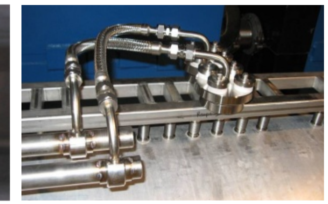
(courtesy Ans Pardons, CERN)

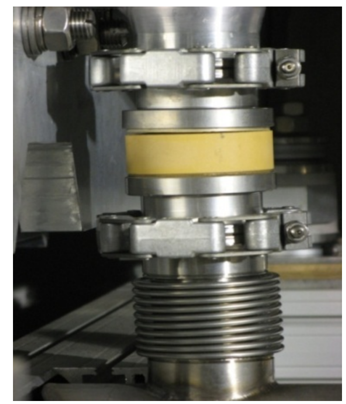
- 2006: Water Outlet Leak
  - Badly designed brazed & machined ceramic assembly
  - All brazed ceramics in horns replaced

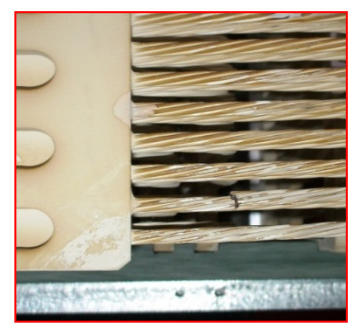


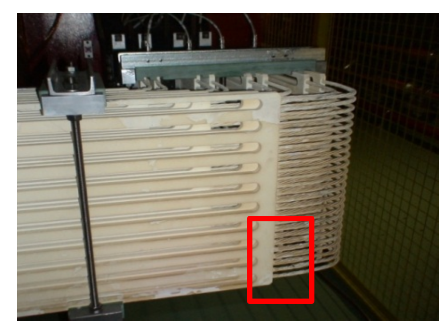
- 2007: broken Stripline cable
  - Insufficiently restrained & brazing-weakened cables
  - Replaced with restrained & (more) rigid solution of Ag-plated copper plates











Horn

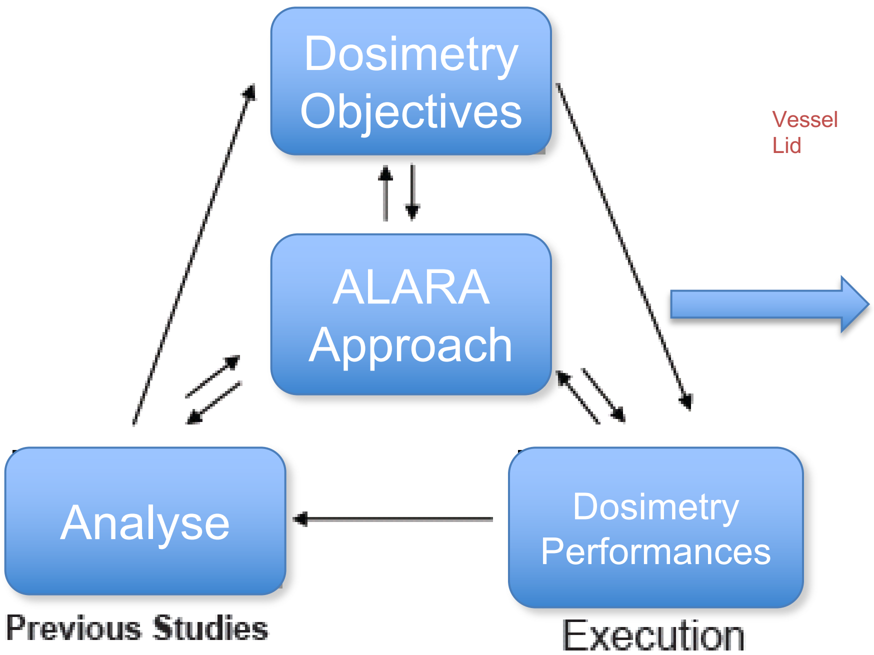
Work under investigation :

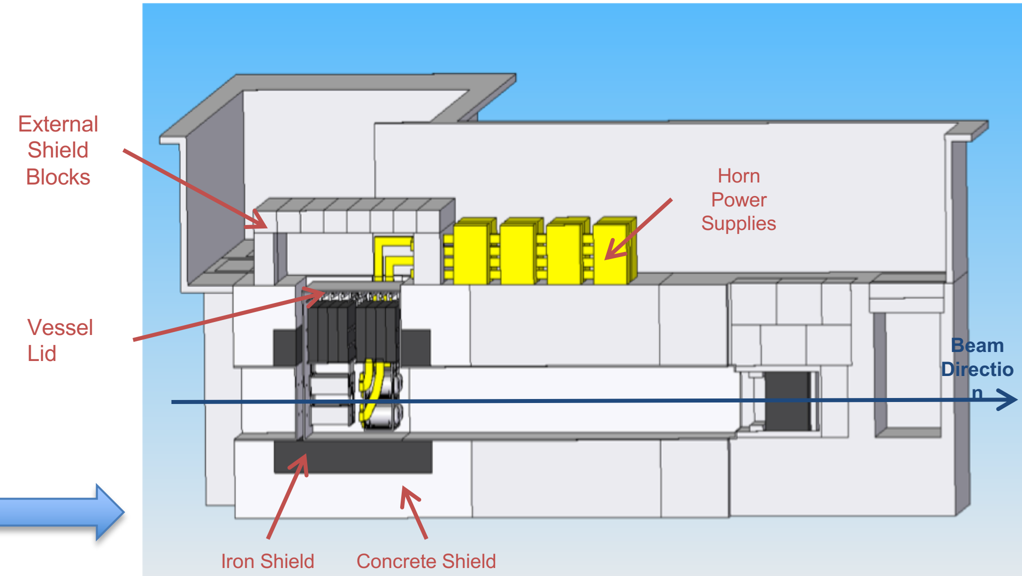
- Optimization of the horn geometry for the ESSνSB conditions.
- Dynamic analysis of the horn with auxiliary equipment (e.g. vibration transmission from the horn to cooling system and ways of mitigating the problem).
- The analysis of the horn cooling system (possibilities of using heat exchange results for assessing the performance of the cooling system; tuning the model to the existing experimental results).
- Fatigue life analysis of the horn with auxiliary equipment.

Target Station Concept

ALARA Approach:

Anticipate and reduce individual and collective exposition to radiations.





As Low As Reasonably Achievable

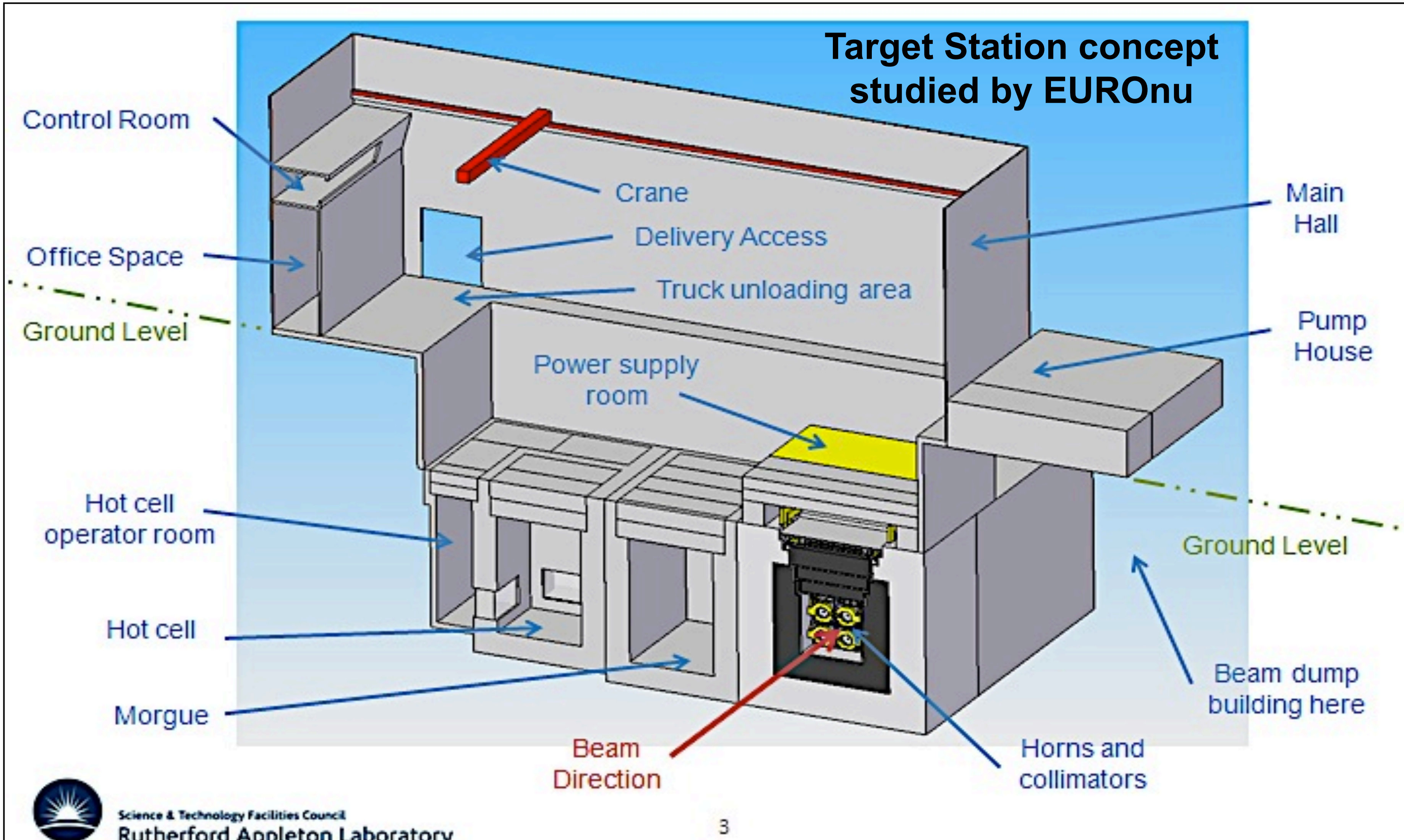
Feedback from previous experiments is crucial

Building "rooms"

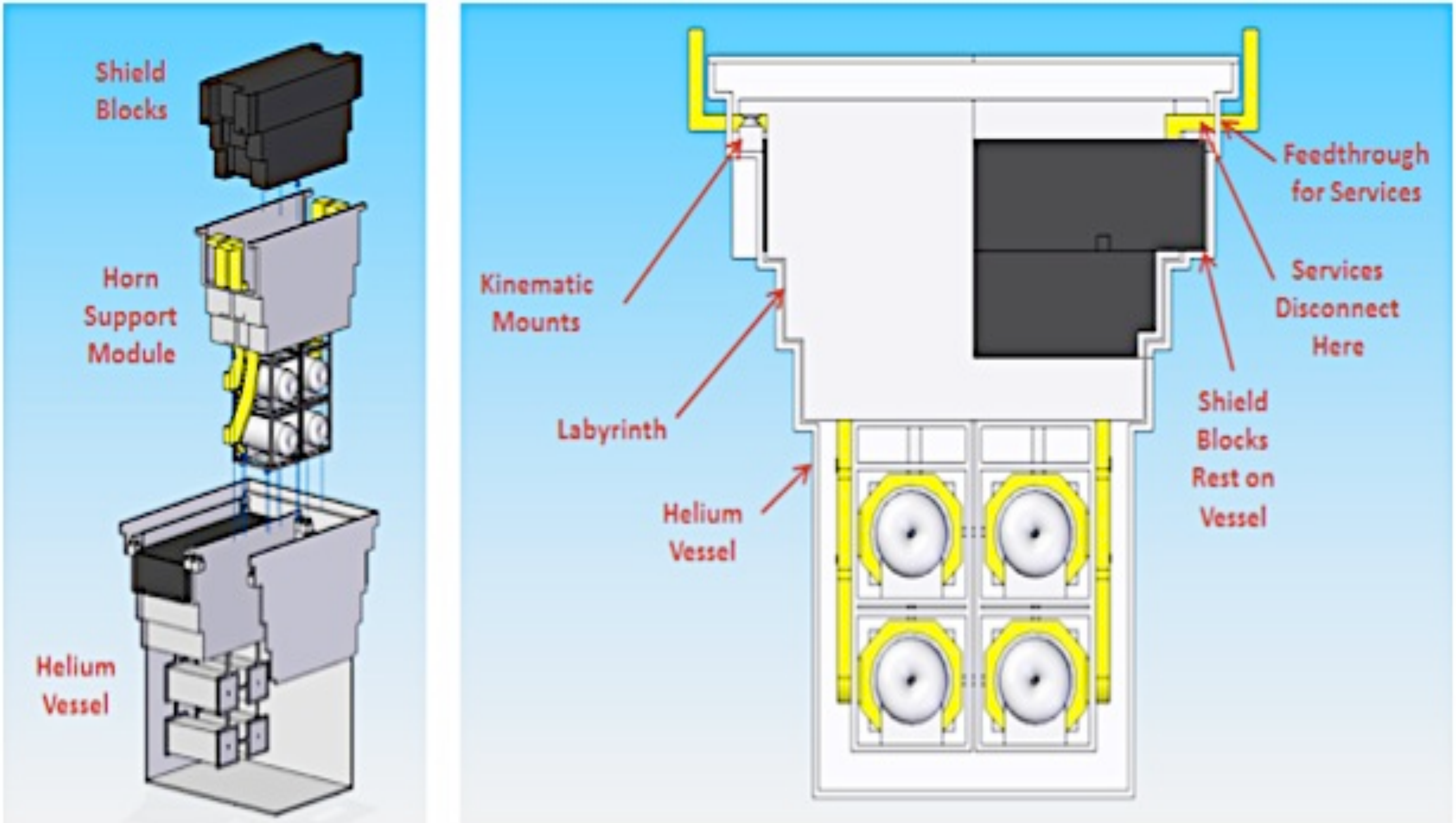
- Open Top geometry for the Target Station Room, Decay Tunnel, Beam Dump
- Hot Cell (Repair Target Station elements)
- Morgue (Store radioactive wastes)
- Horn Power Supply Room , Power supply outside of the main building ?

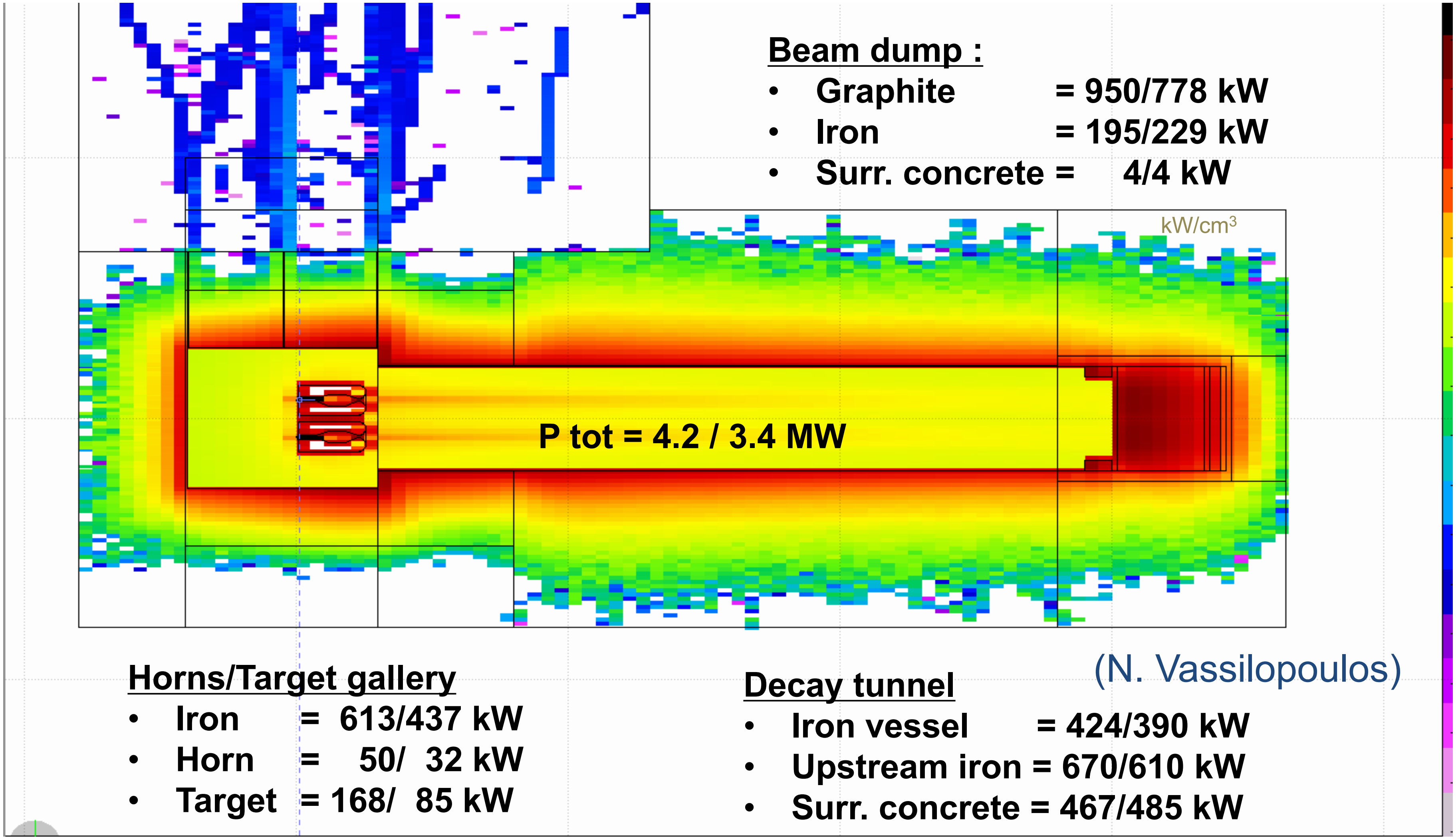
=> Energy Deposition and Dose Rate Estimation with FLUKA Simulation

Target Station Concept



Target Station Concept





Beam dump :

- Graphite = 950/778 kW
- Iron = 195/229 kW
- Surr. concrete = 4/4 kW

Horns/Target gallery

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

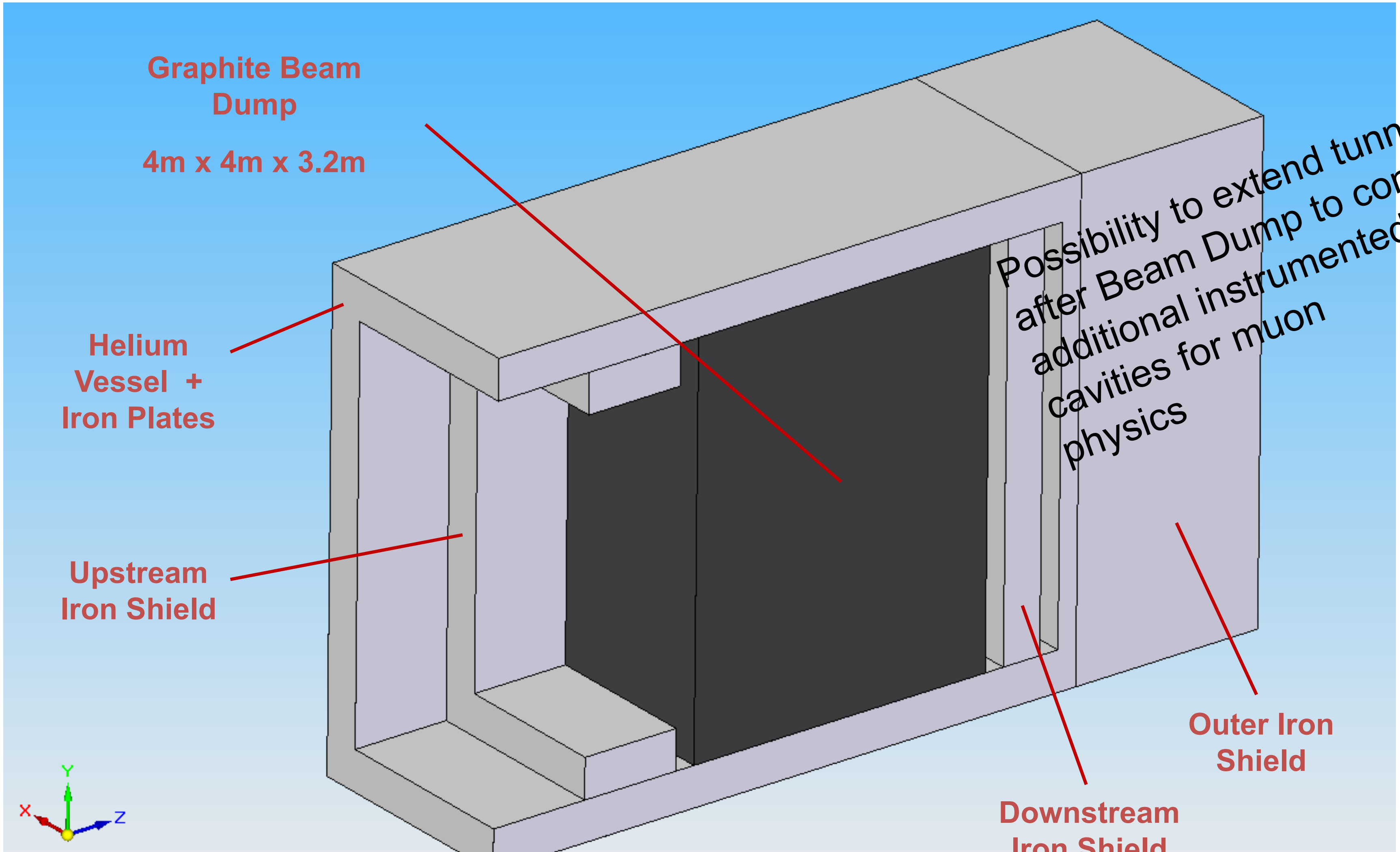
Decay tunnel

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

(N. Vassilopoulos)

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

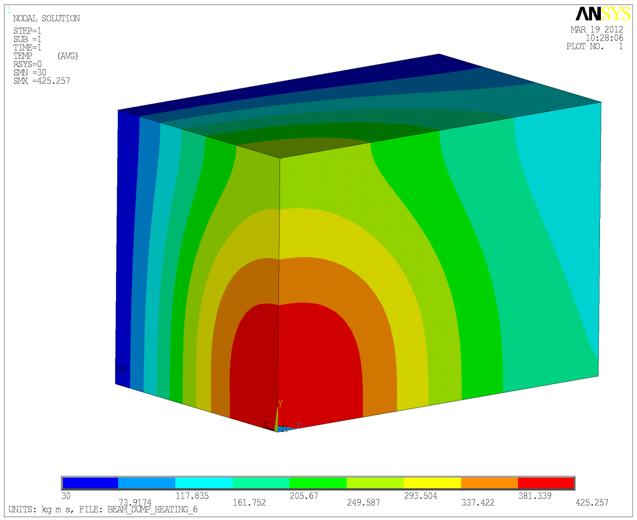
Beam Dump



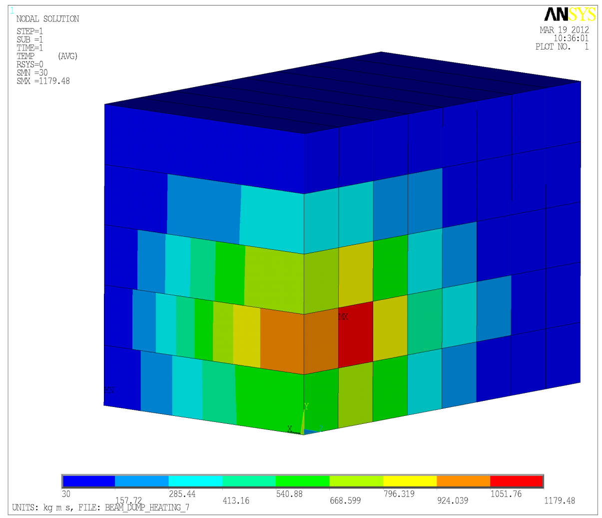
From Euronu

Several configurations have been tested to optimize heat exchange:

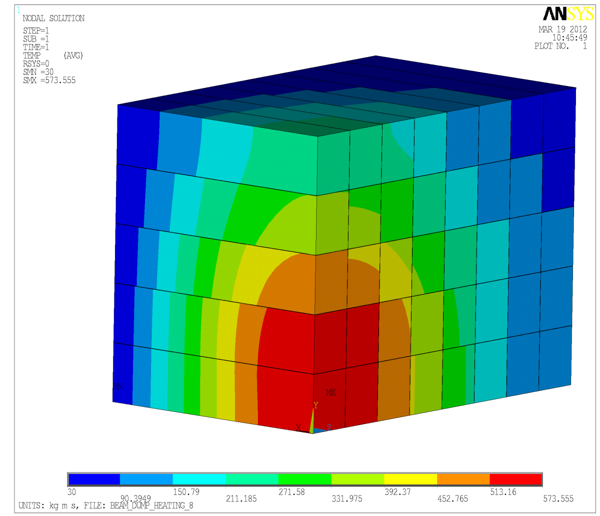
Case 1 Solid Graphite



Case 2: Graphite blocks, no heat transfer across gaps



Case 3: Graphite blocks, helium conduction across gaps



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

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

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

From Euronu

Material Composition

Chemical composition of Material:

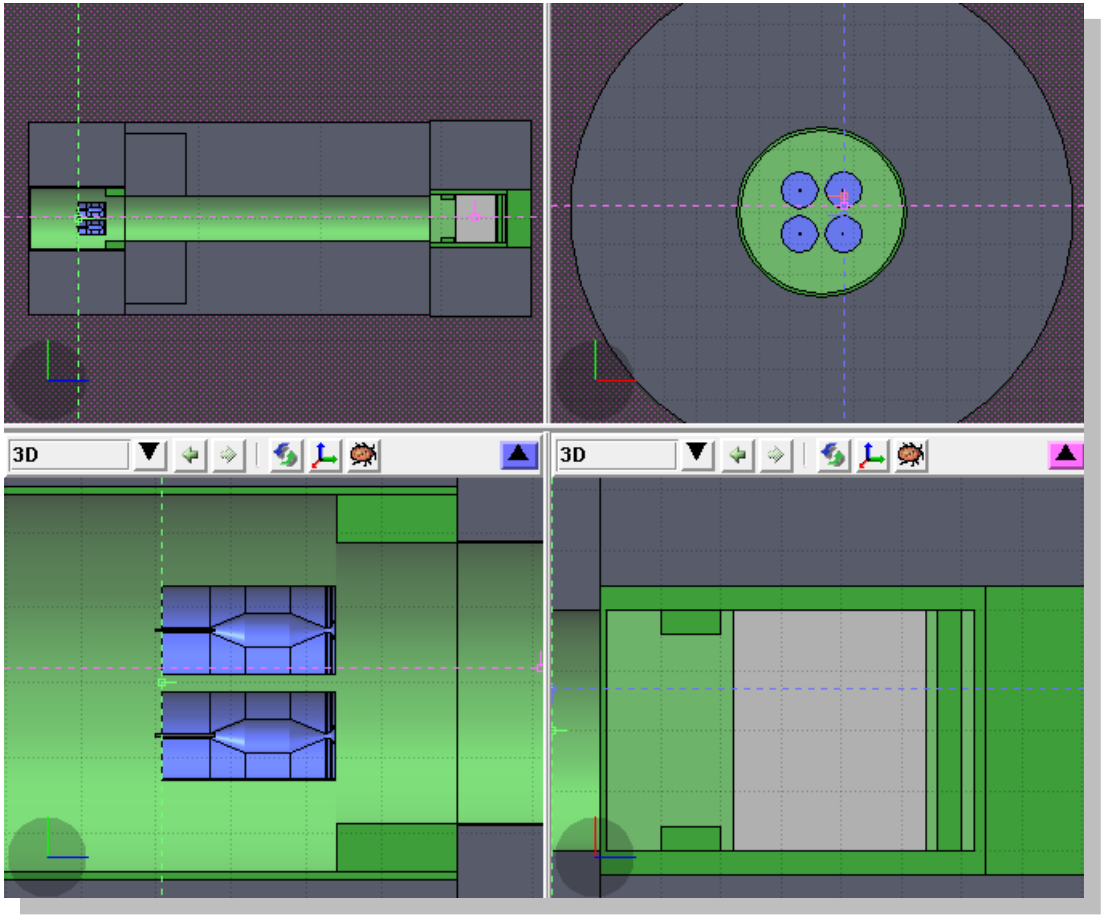
Target => Ti(100%)

Horn => Anticorodal 110 alloy
Al (95.5%), Si(1,3%), Mg(1,2%), Cr(0.2%), Mn(1%), Fe (0.5%), Zn(0.2%), Cu(0.1%)

Decay Pipe => Steel P355NH
Fe(96.8%), Mn(1.65%), Si(0.5%), Cr(0.3%), Ni(0.3%), C(0.2%)

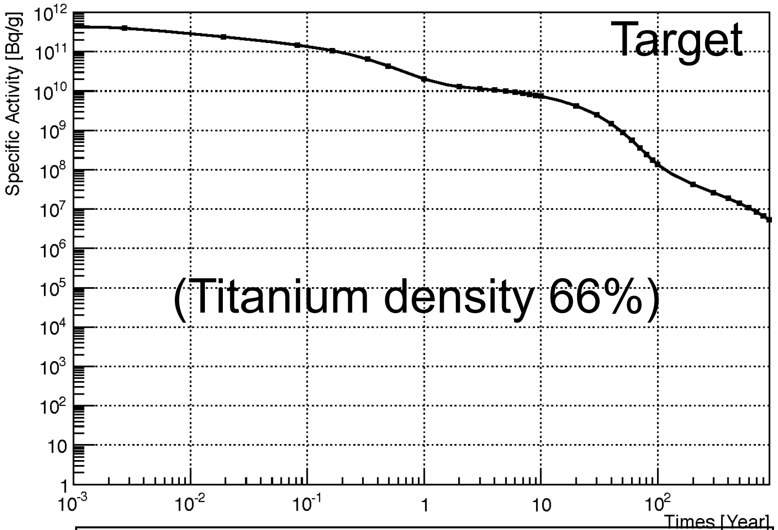
Tunnel => Concrete
O(52.9%), Si(33.7%), Ca(4.4%), Al(3,49%), Na(1,6%), Fe(1.4%), K(1,3%), H(1%), Mn(0.2%), C(0.01%)

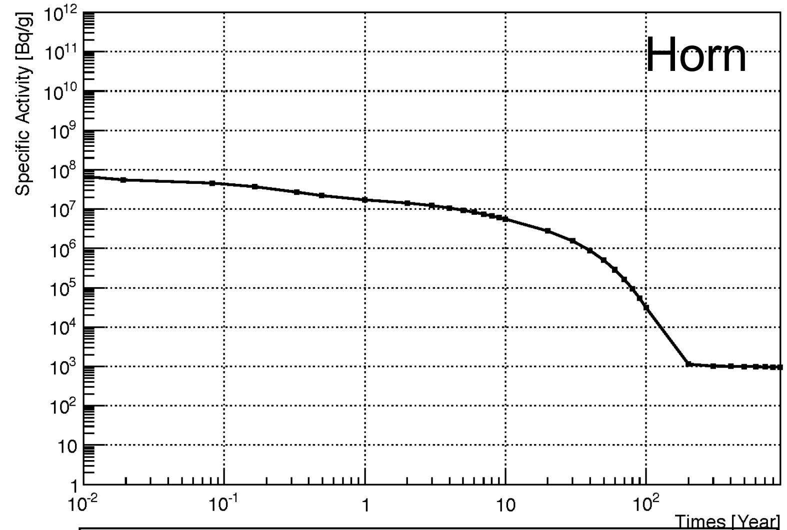
Surrounding Environment => Molasse
O(49%), Si(20%), Ca,(9.7%), Al(6.4%), C(5%), Fe(3.9%), Mg(3.2%), K(1%), Na(0.5%), Mn(0.1%)

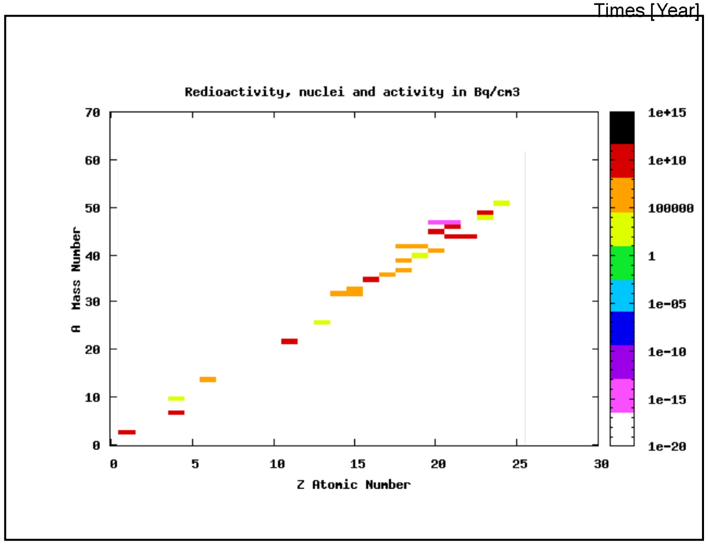


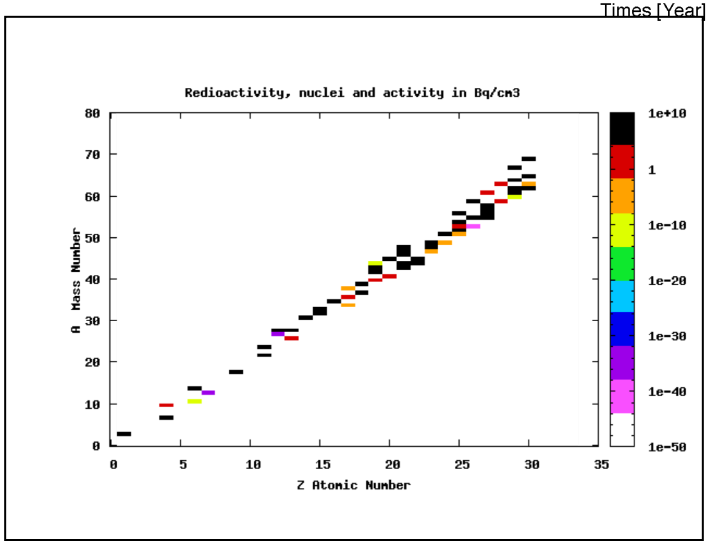
Four horn station layout

Material Activation

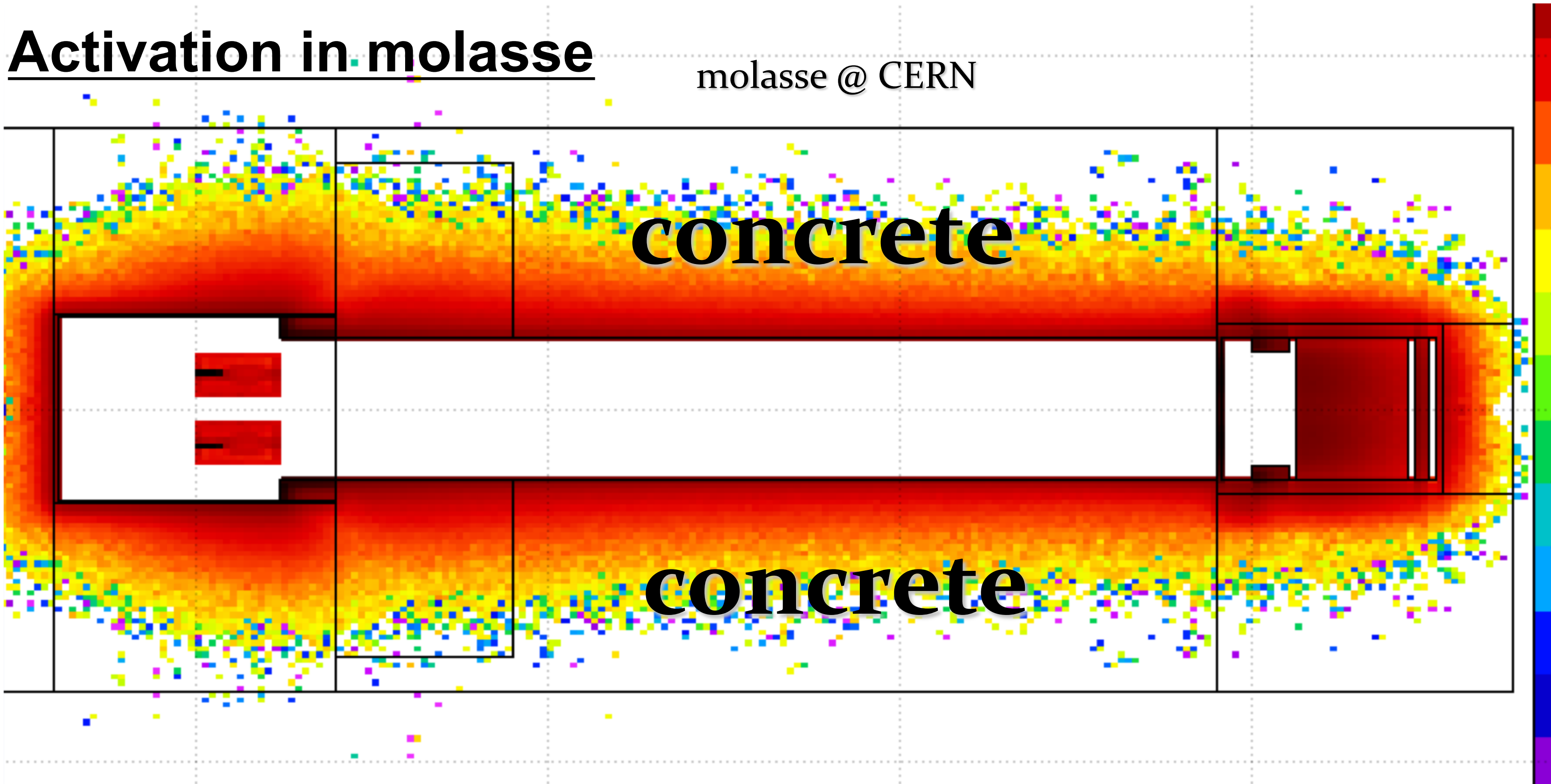








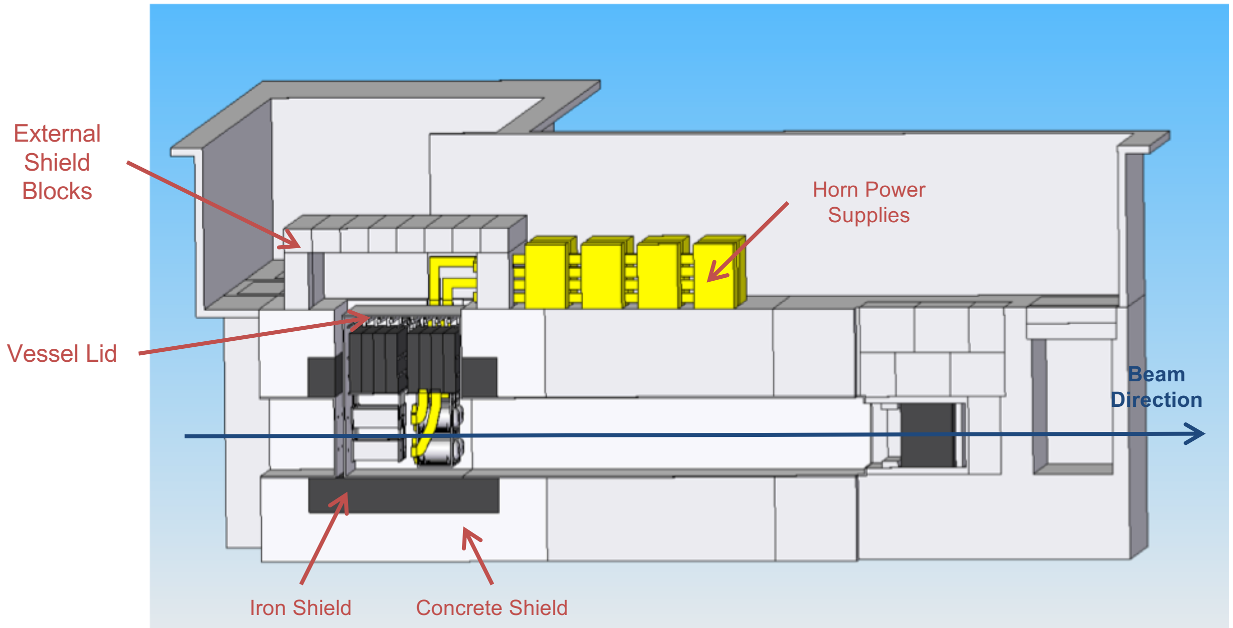
Activation in molasse

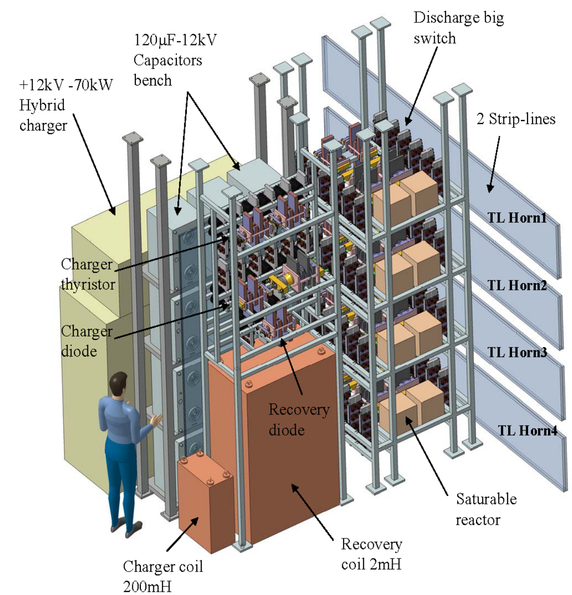


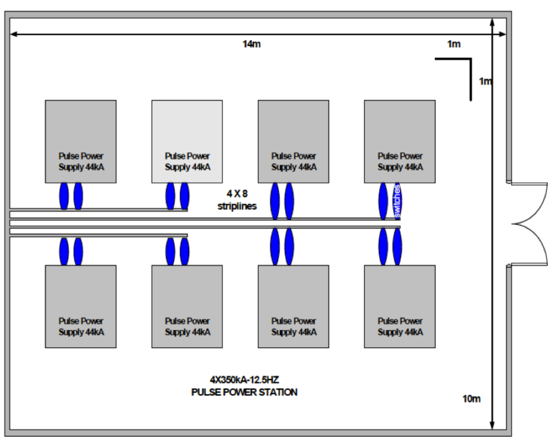
All the radionuclide's created, especially ^{22}Na and tritium, could represent a hazard by contaminating the ground water.

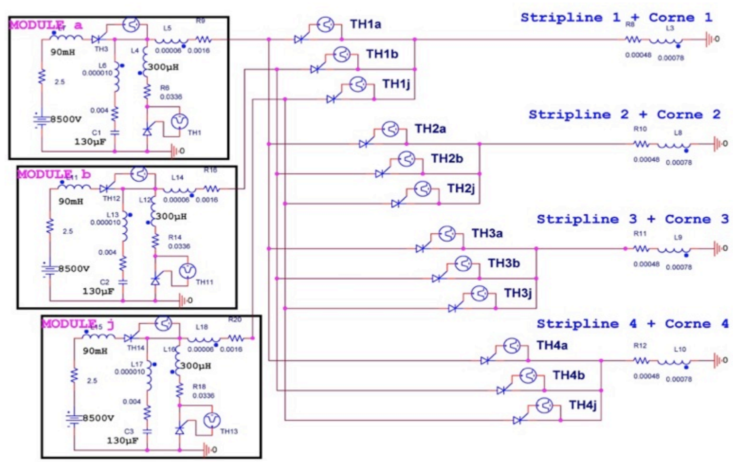
Power Supply Station

Horn Power Supply and Strip lines





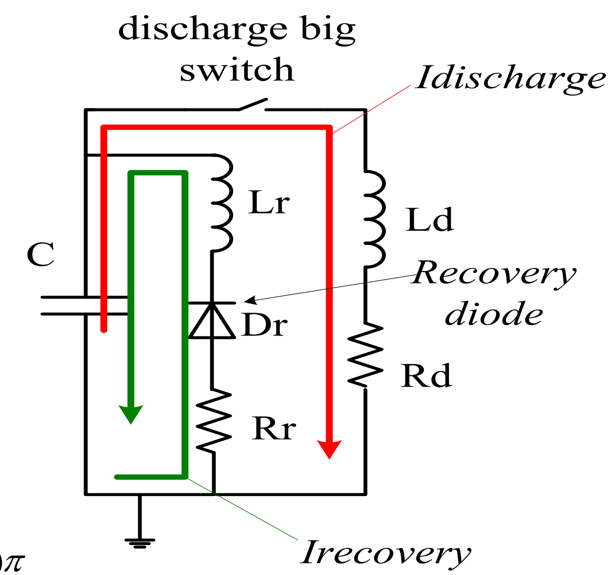




- each MODULE delivers a current of 44kA max at F=50HZ
- For each HORN : current of 350kA max at 12.5HZ
- energy recuperation (>90%) and reinjection
- lifetime > 13 Bcycles (10 years, 200 days/year)

Horn Power Supply and Strip lines

⇨ method of discharged capacitor in a damped oscillating Ld, Rd, C circuit

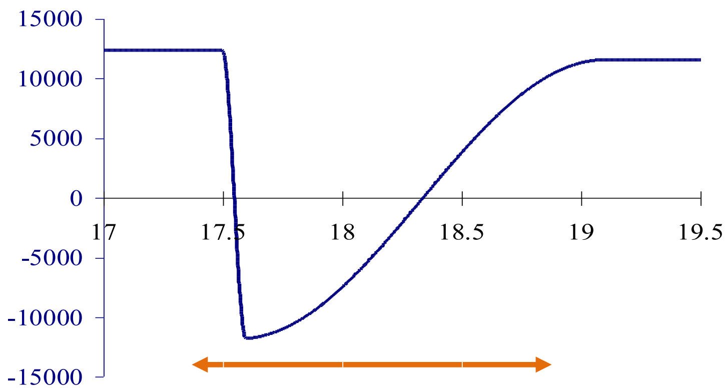


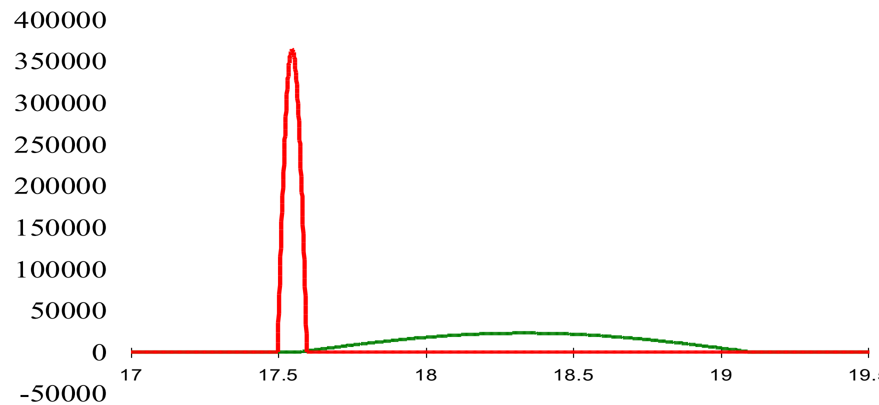
⇨ Voltage of capacitors governed by the equation:

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

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

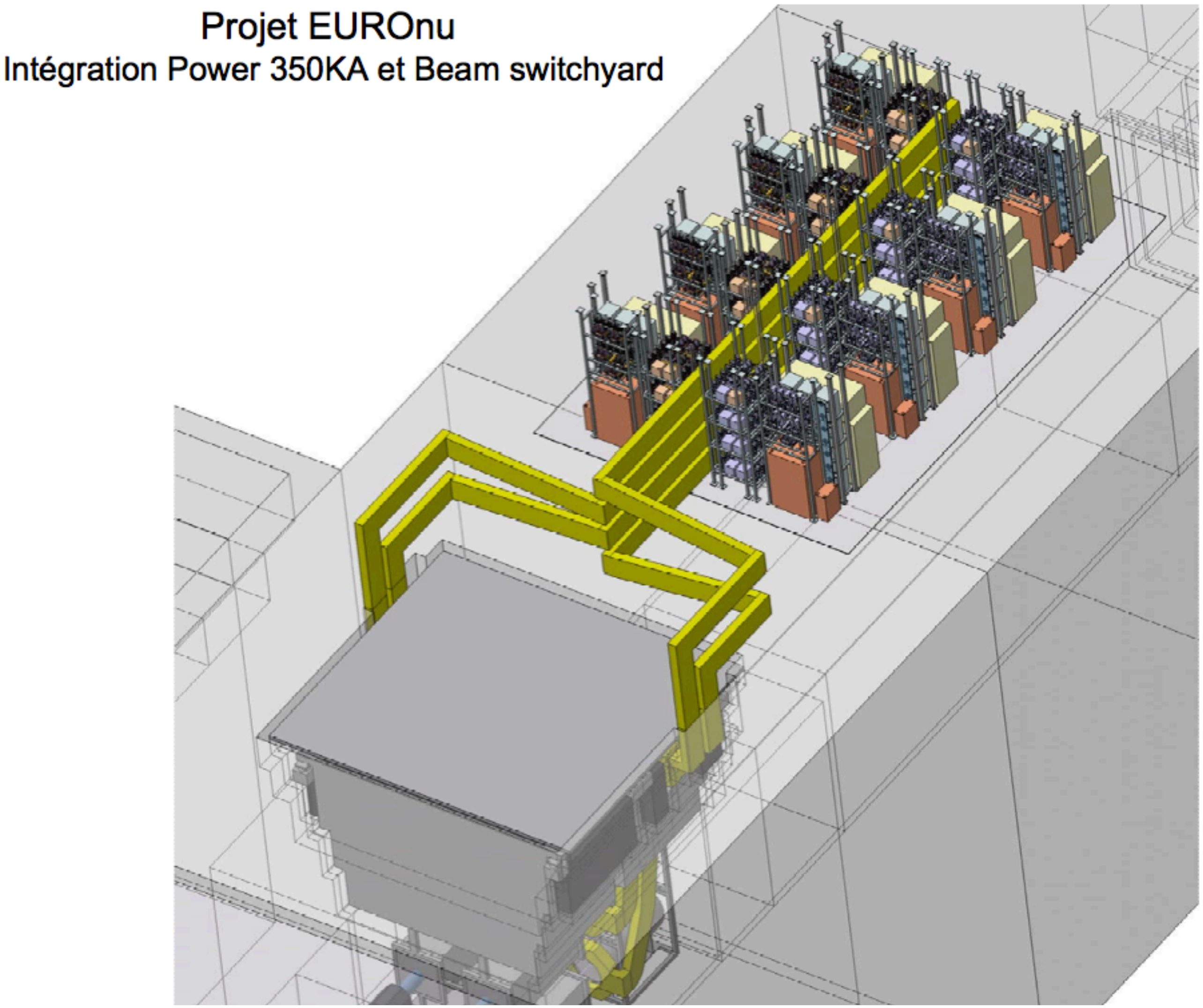
☞ final capacitor voltage : $V_{end}(I=0) = V_o . e^{-(m_d+m_r)\pi}$





P. Poussot et al, "Study of the pulse power supply unit for the four-horn system of the CERN to Fréjus neutrino super beam", JINST 8 (2013) T07006

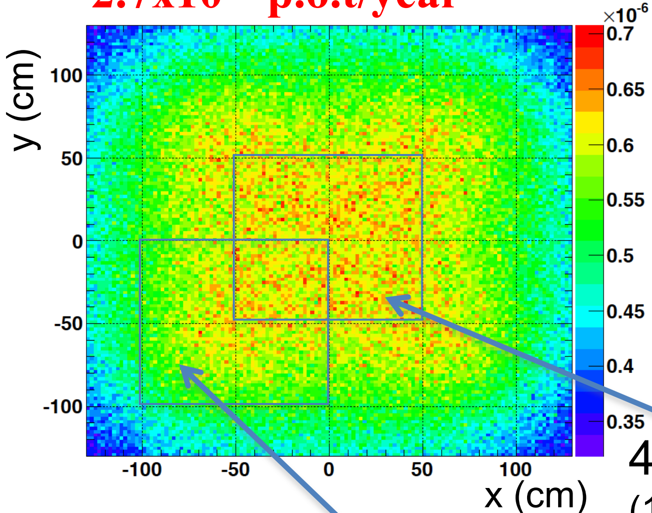
Horn Power Supply and Strip lines



Other possible physics

Muons at the level of the beam dump

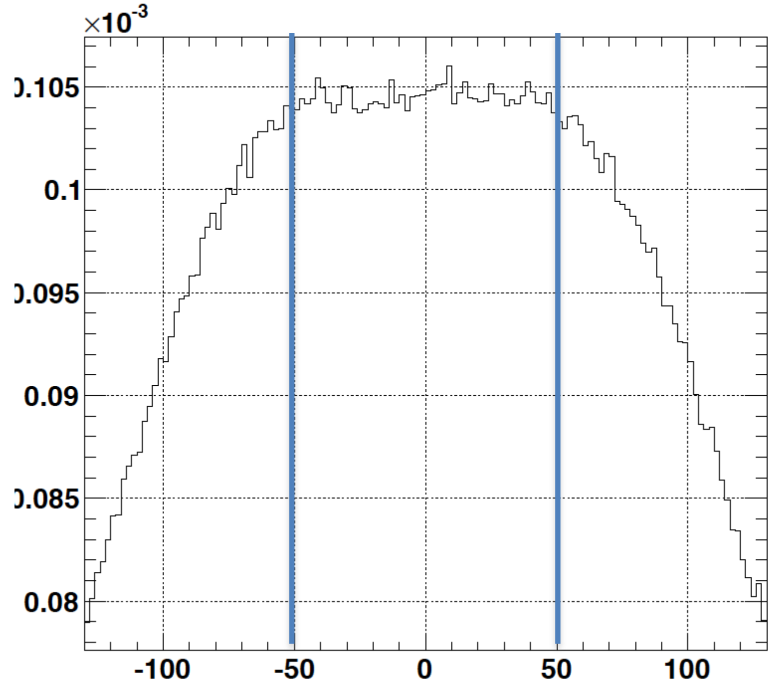
2.7x10^{23} p.o.t/year



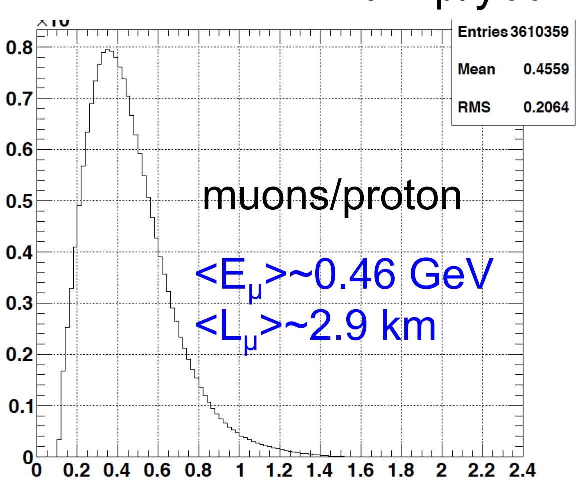
muons at the level of the beam dump (per proton)

4.2x10^{20} μ/year
(16.3x10^{20} for 4 m^2)

4.1x10^{20} μ/year

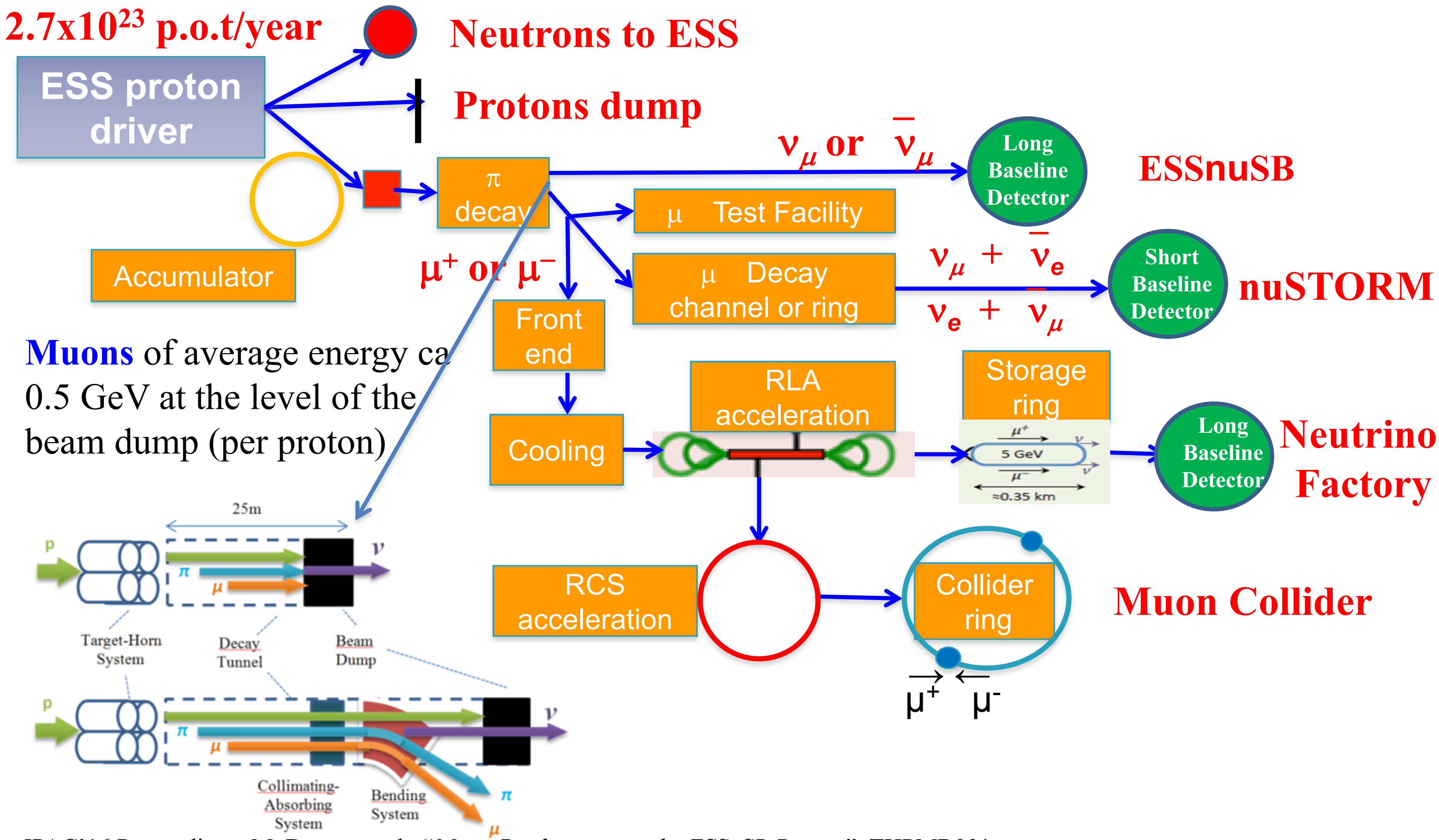


10^{-3}



- input beam for future 6D μ 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**.

Muons at the level of the beam dump



Muons of average energy ca 0.5 GeV at the level of the beam dump (per proton)

IPAC'16 Proceedings: M. Dracos et al, "*Muon Production via the ESSνSB Project*", THPMB001

Summary

- ESSνSB project has received funding from the European Union Horizon 2020 research and innovation program under grant agreement No 777419 (http://essnusb.eu/site/).
- European Spallation Source is under construction and will provide a 5 MW proton 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.