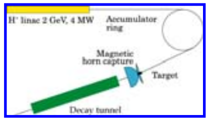
Safety issues for WP2

E. Baussan on behalf of WP2

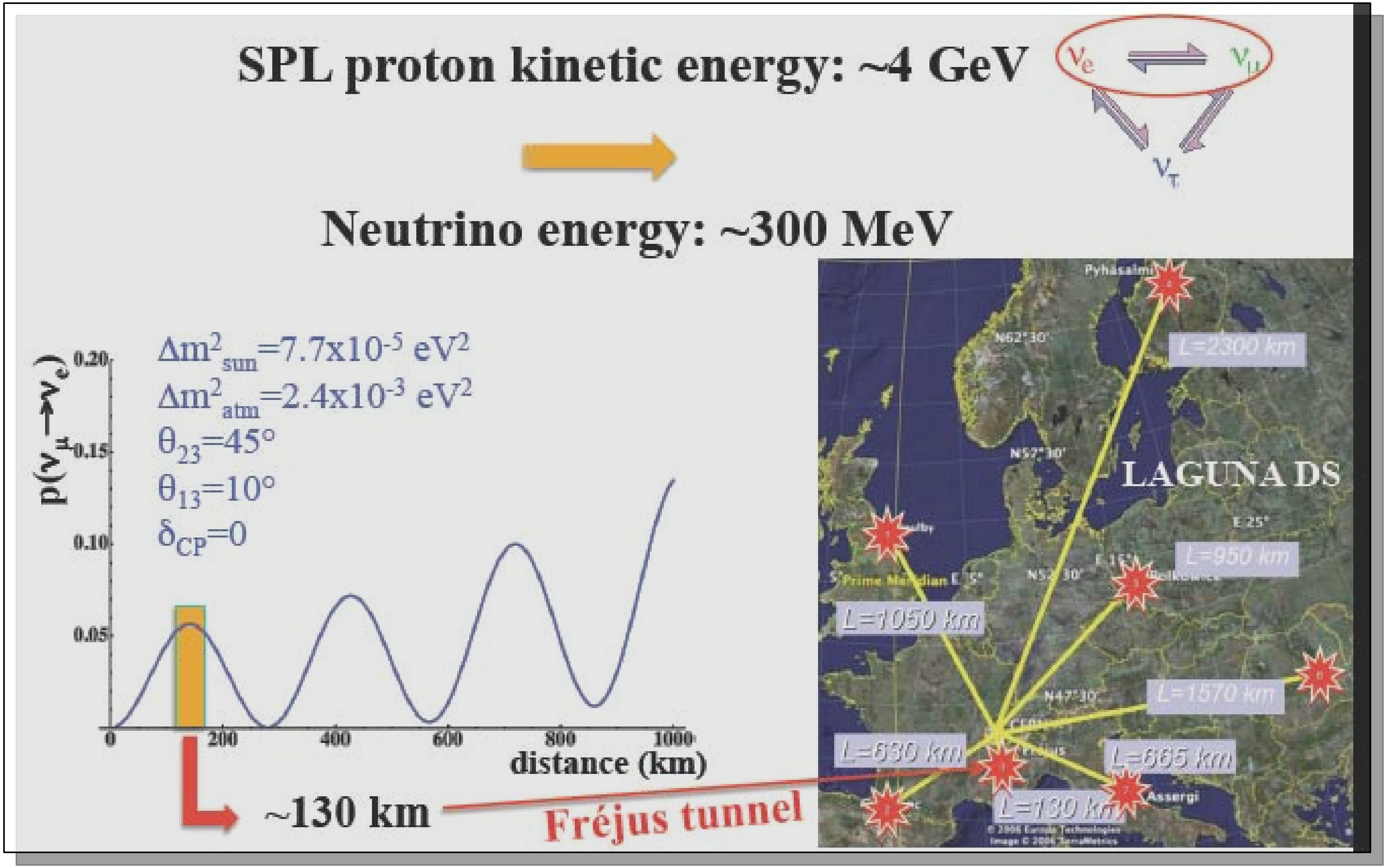
Safety Issues for WP2



Outlines:

- Physics with a neutrino superbeam
- Technological Challenge
- Status on WP2
- Safety
    - ALARA Approach
    - Simulation

Neutrino Beam Experiments



SPL proton kinetic energy: ~4 GeV

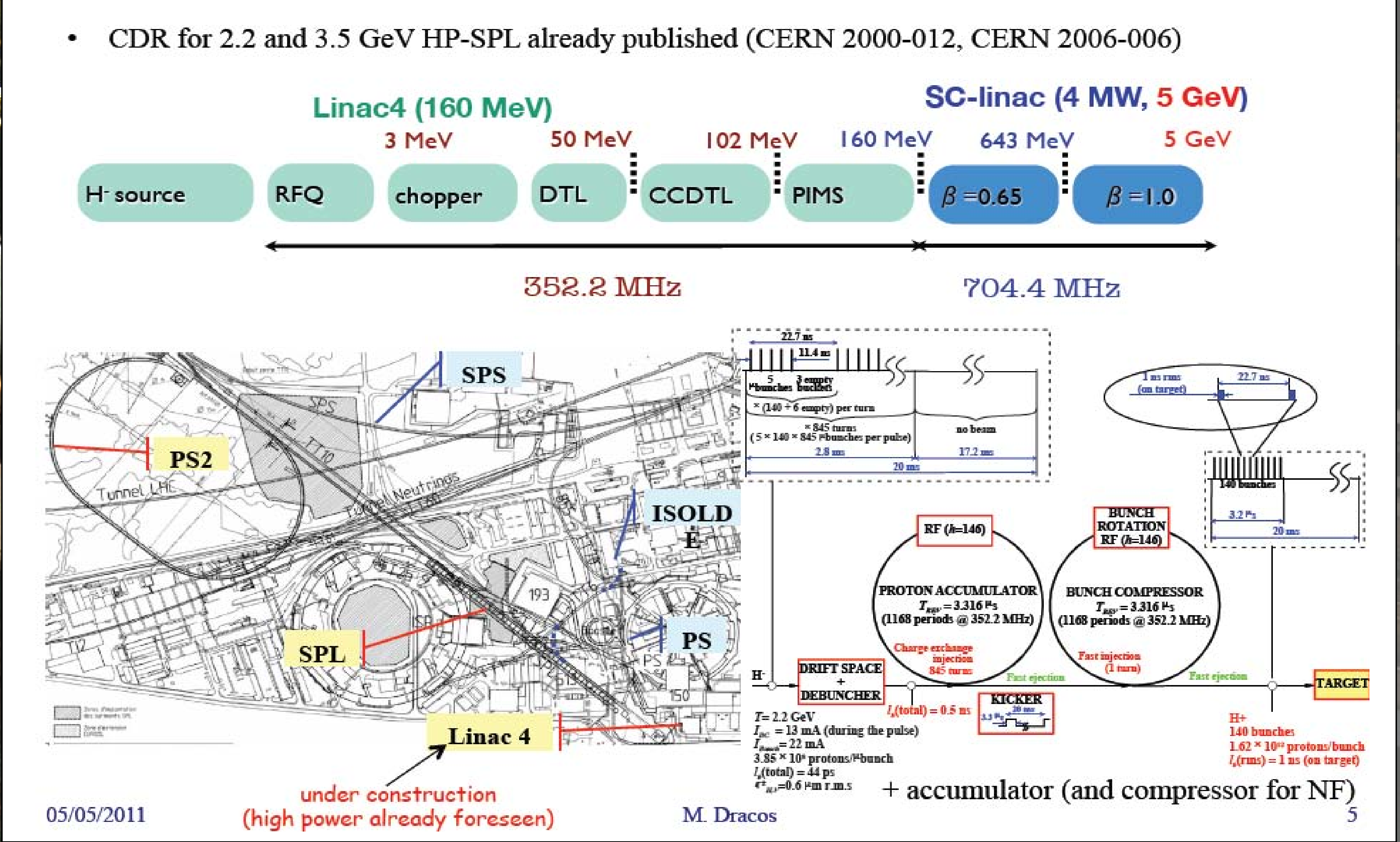
Neutrino energy: ~300 MeV

$\Delta m^2_{sun}=7.7\times10^{-5}\ eV^2$
$\Delta m^2_{atm}=2.4\times10^{-3}\ eV^2$
$\theta_{23}=45°$
$\theta_{13}=10°$
$\delta_{CP}=0$

~130 km

Fréjus tunnel

HP-SPL for neutrino beams



- CDR for 2.2 and 3.5 GeV HP-SPL already published (CERN 2000-012, CERN 2006-006)

Linac4 (160 MeV) **SC-linac (4 MW, 5 GeV)**

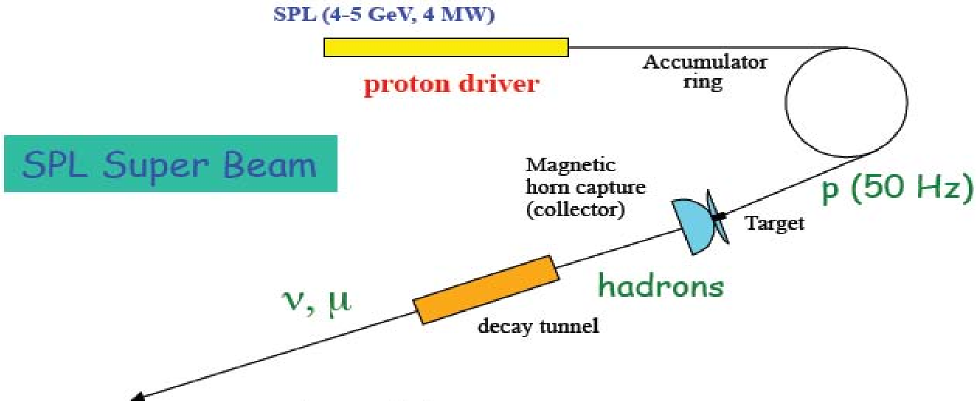
T = 2.2 GeV
I_{PLC} = 13 mA (during the pulse)
I_{bunch} = 22 mA
3.85×10^{8} protons/μbunch
l_b(total) = 44 ps
$\epsilon^*_{H,V}$ = 0.6 μm r.m.s

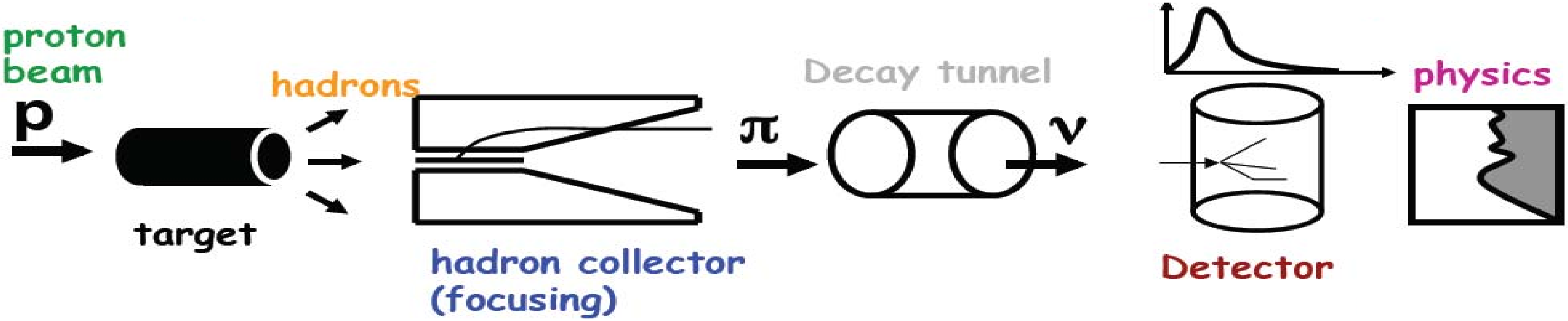
under construction
(high power already foreseen)

+ accumulator (and compressor for NF)

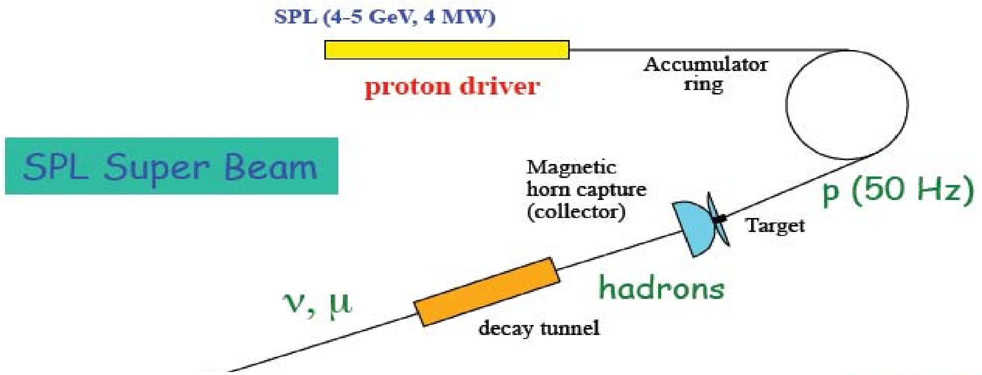
05/05/2011 M. Dracos 5

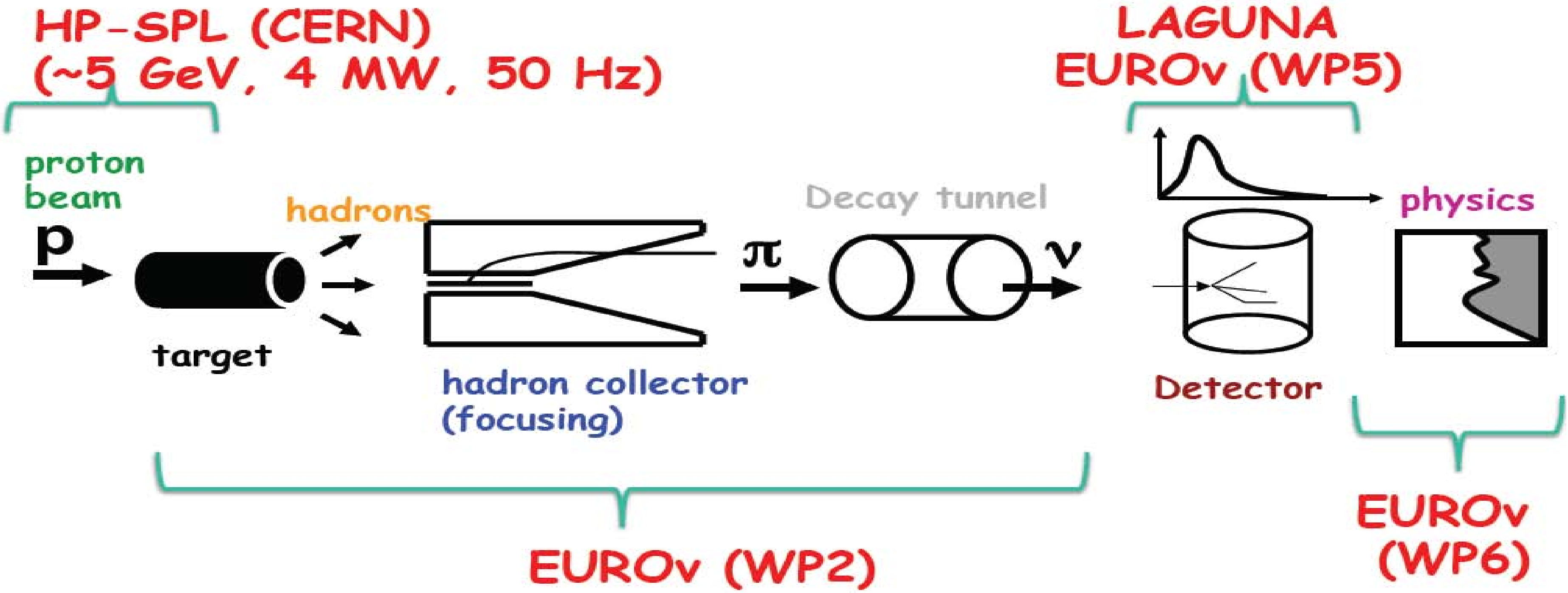
Super Beam Neutrino Experiment Layout



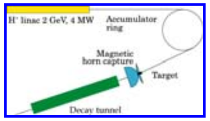


Super Beam Neutrino Experiment Layout

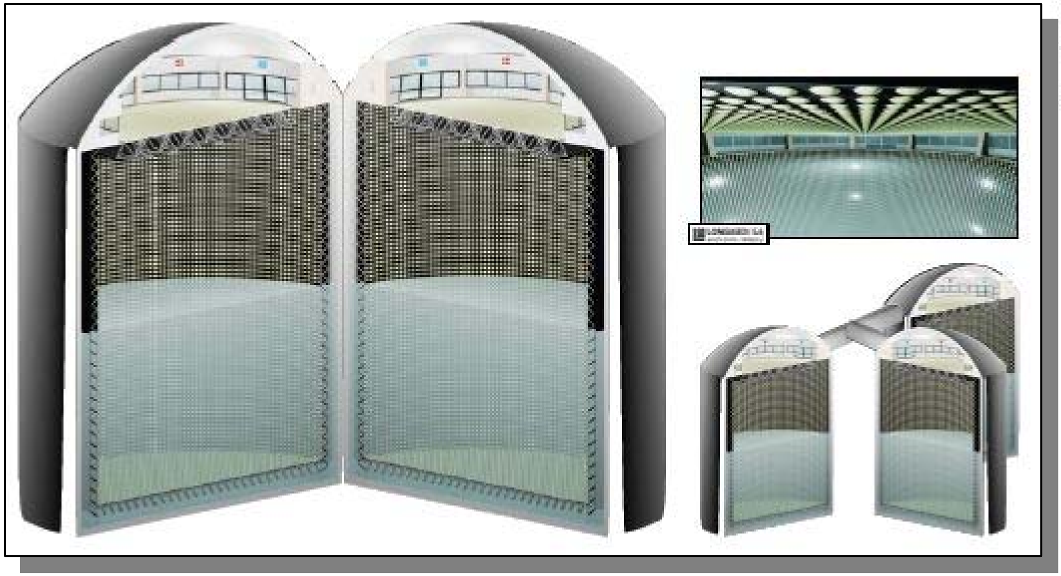


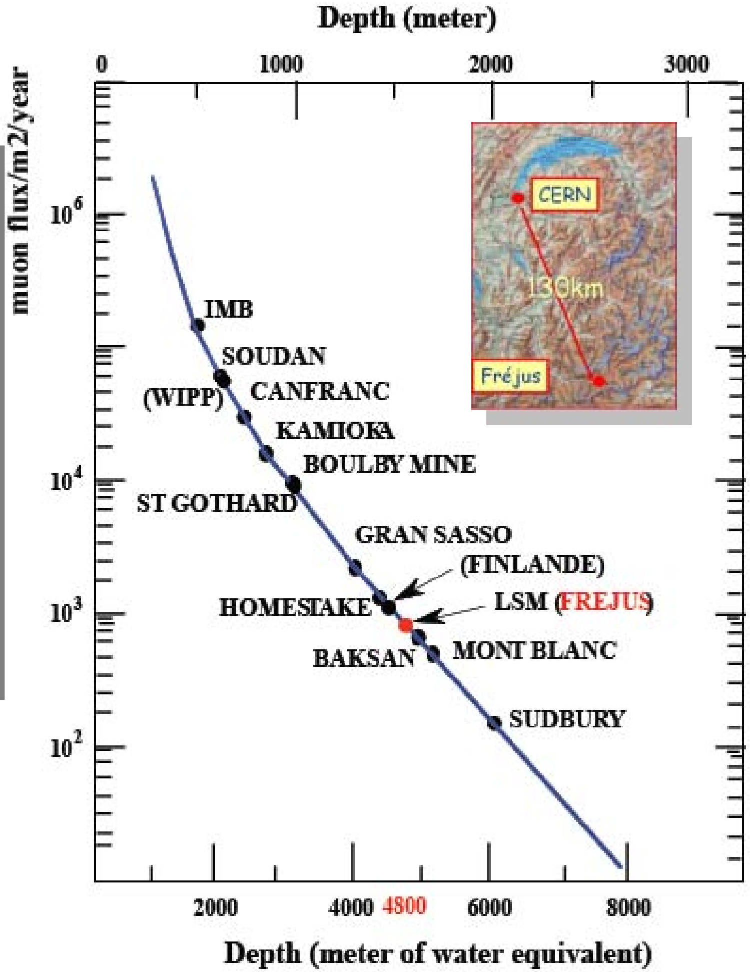


Super Beam Neutrino Experiment Layout



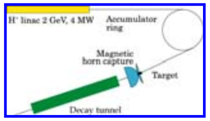
Memphys Detector:



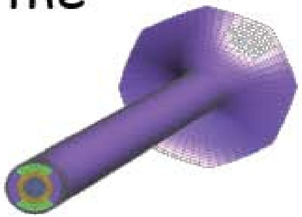


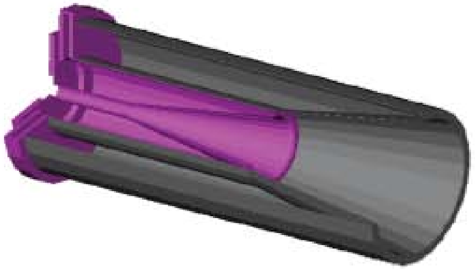
- **Underground water Cherenkov detector at *Laboratoire Souterrain de Modane* Fréjus at 4800 m.w.e.**
- **Total fiducial volume: up to 400 kton: 3 x 65mX60 modules could be designed up to 572kton: 3x 65mX80**
- **PMT R&D + detailed study on excavation existing & ongoing + prototype Cherenkov detector MEMPHYNO**

Technological challenge

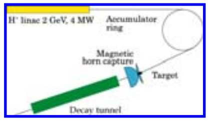


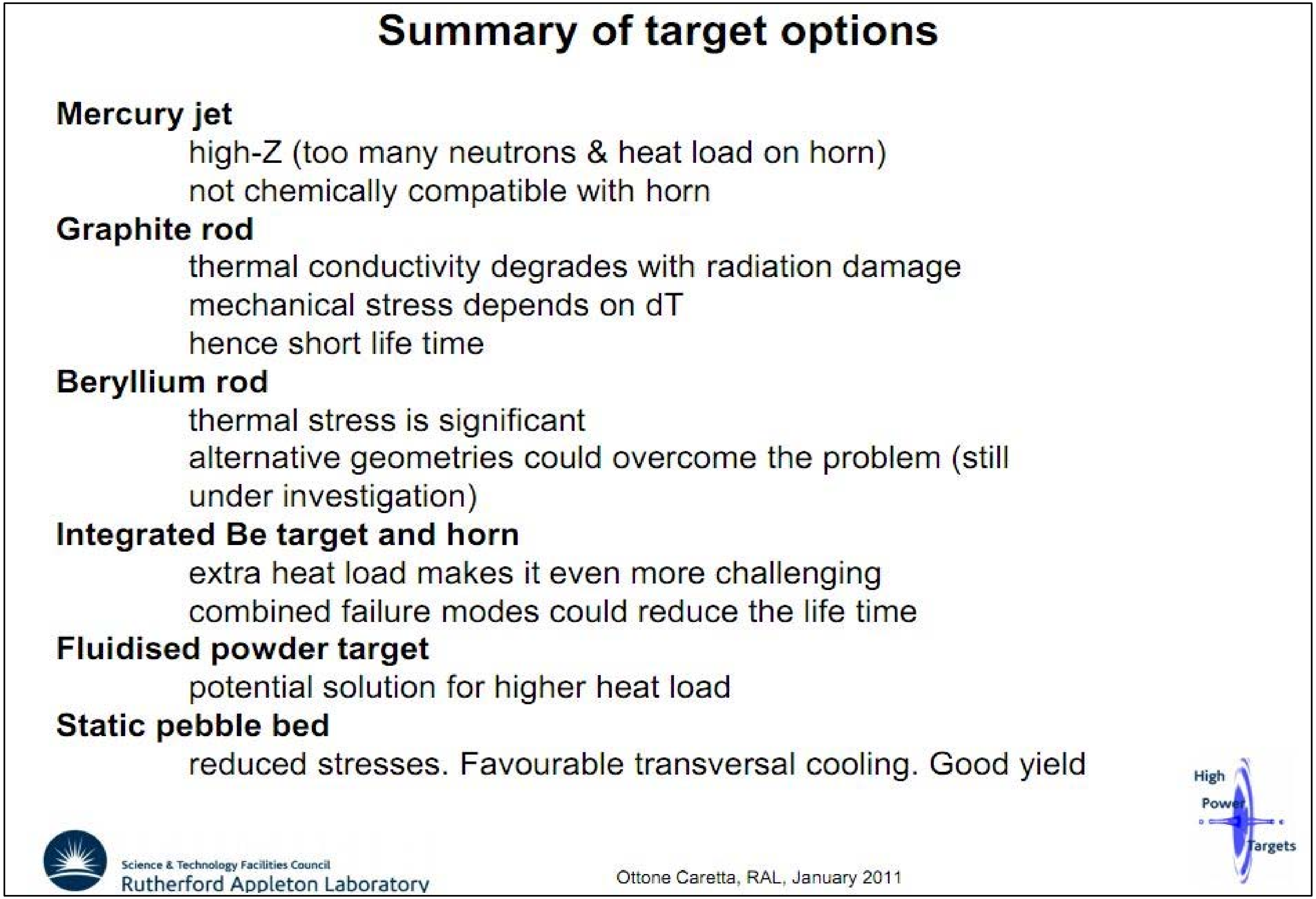
- Can we conceive a neutrino beam based on a multi-MW proton beam ?
- At the start of EUROν, no proven solution for the target and collector was proposed for this facility !
- Can we design a target for a multi-MW proton beam ?
- Can we do it with a reliable design without compromising the physics reach ?
- **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)





Target Technology





Summary of target options

Mercury jet
- high-Z (too many neutrons & heat load on horn)
- not chemically compatible with horn

Graphite rod
- thermal conductivity degrades with radiation damage
- mechanical stress depends on dT
- hence short life time

Beryllium rod
- thermal stress is significant
- alternative geometries could overcome the problem (still under investigation)

Integrated Be target and horn
- extra heat load makes it even more challenging
- combined failure modes could reduce the life time

Fluidised powder target
- potential solution for higher heat load

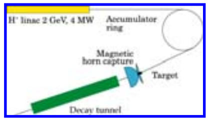
Static pebble bed
- reduced stresses. Favourable transversal cooling. Good yield

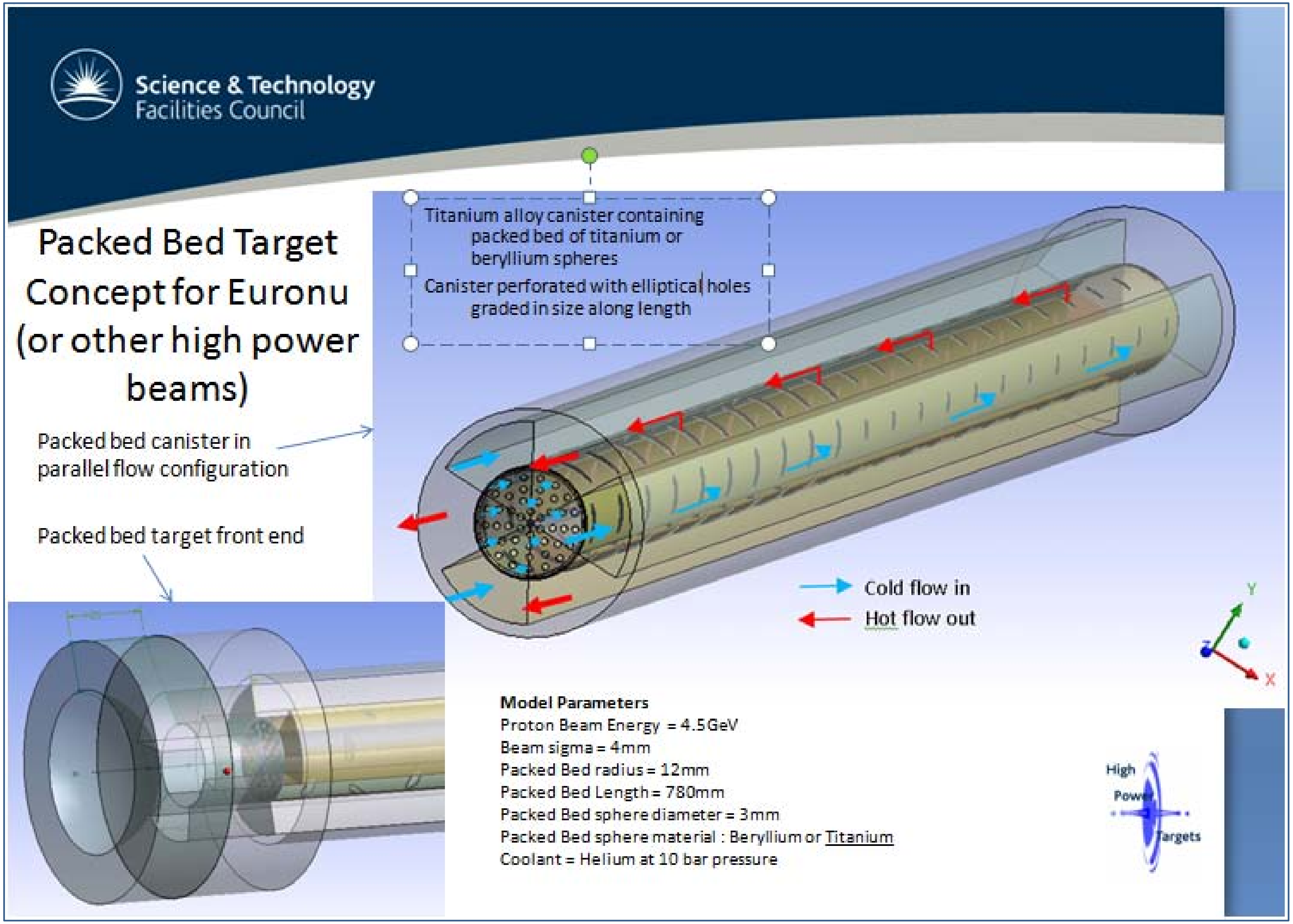
High Power Targets

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Ottone Caretta, RAL, January 2011

Target Technology





Science & Technology Facilities Council

Packed Bed Target Concept for Euronu (or other high power beams)

Packed bed canister in parallel flow configuration

Packed bed target front end

Titanium alloy canister containing packed bed of titanium or beryllium spheres

Canister perforated with elliptical holes graded in size along length

Model Parameters

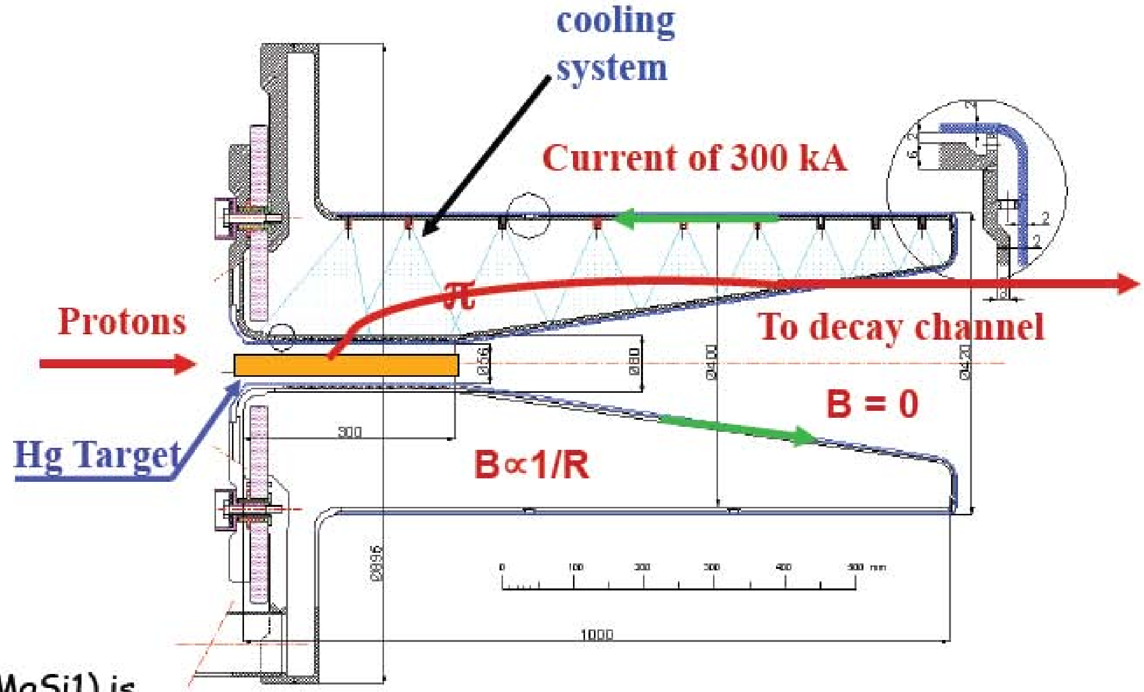
Proton Beam Energy = 4.5GeV
Beam sigma = 4mm
Packed Bed radius = 12mm
Packed Bed Length = 780mm
Packed Bed sphere diameter = 3mm
Packed Bed sphere material : Beryllium or Titanium
Coolant = Helium at 10 bar pressure

Horn : Previous Studies

- **First studies with old SPL characteristics:**
  - 2.2 GeV proton beam

For the horn skin AA 6082-T6 / (AlMgSi1) is an acceptable compromise between the 4 main characteristics:

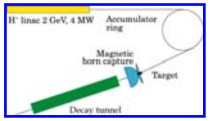
- Mechanical properties
- Welding abilities
- Electrical properties
- Resistance to corrosion
- Same for CNGS



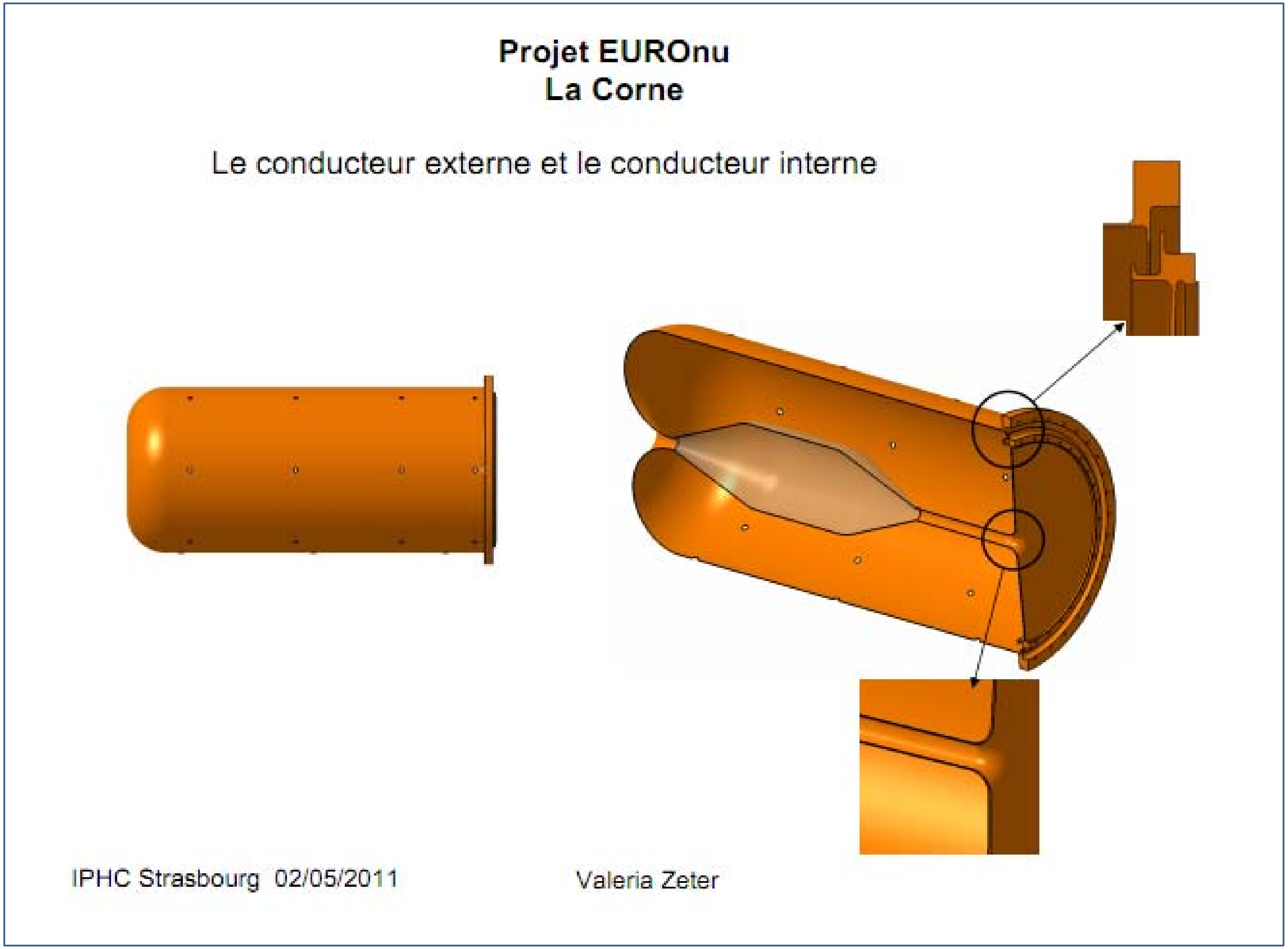
initial design satisfying both, Neutrino Factory and Super Beam

(see S. Gilardoni's thesis)

...but Al is not compatible with Mercury!



Horn: status for WP2

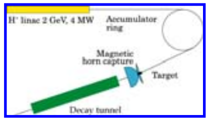


Projet EUROnu
La Corne

Le conducteur externe et le conducteur interne

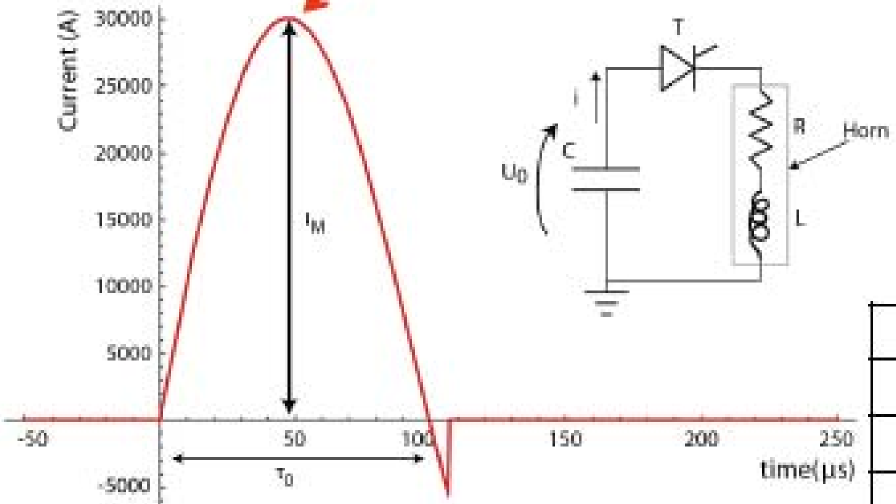
IPHC Strasbourg 02/05/2011

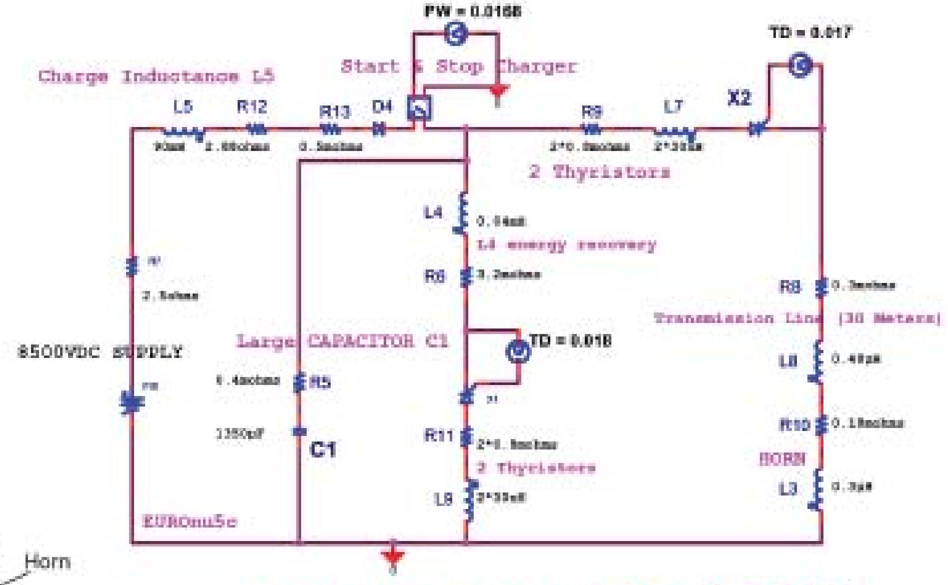
Valeria Zeter



Horn: status for WP2

focusing done during this "plateau"
proton pulse duration must be limited (<5 μs)





energy recuperation (>60%) and reinjection

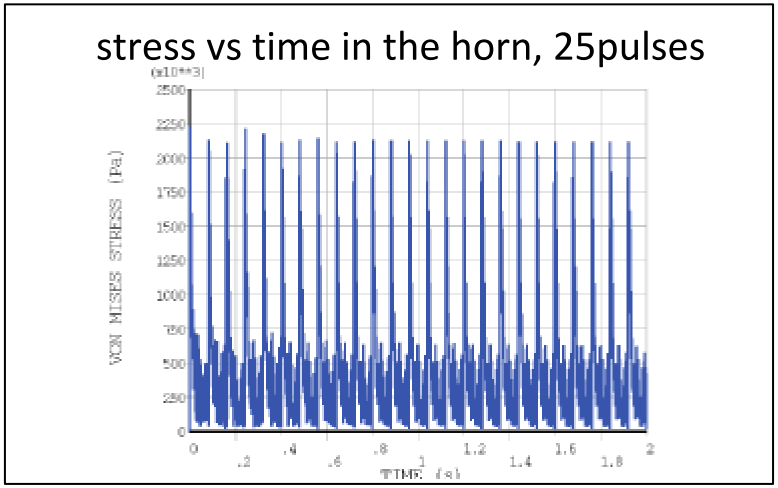
U_0	7 kV
I_M	300 kA (14.5 rms)
τ_0	100 μs
L	0.6 (0.4 Horn) μH
R	500 (180 Horn) μΩ
C	1500 μF

300 kA/50Hz it's a real challenge

Horn: Dynamic Stress Analyses due to Thermal and Magnetic pulses

Dynamic stresses are due to

- Transient Joule heating due to the current passing through the horn's skin
- Secondary Particles
- Magnetic Pulses/forces


stress vs time in the horn, 25pulses

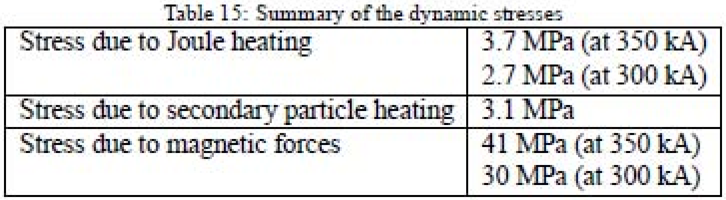
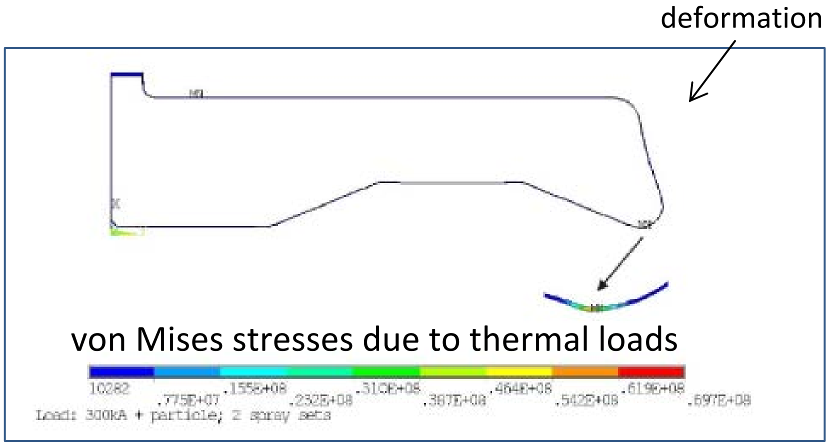
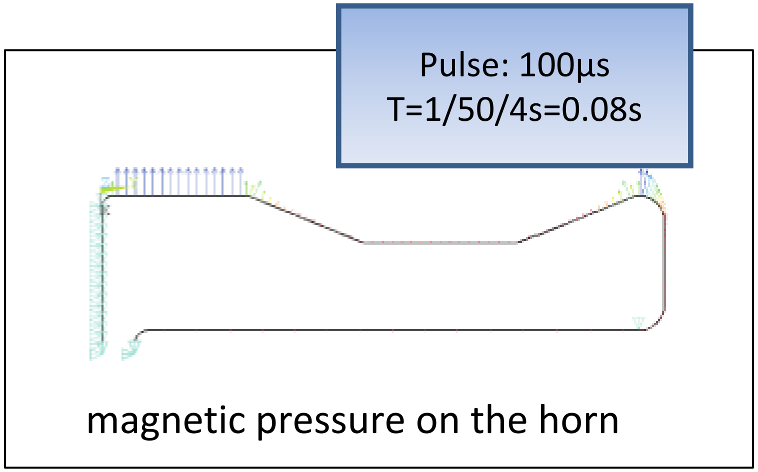


Table 15: Summary of the dynamic stresses

Stress due to Joule heating	3.7 MPa (at 350 kA) 2.7 MPa (at 300 kA)
Stress due to secondary particle heating	3.1 MPa
Stress due to magnetic forces	41 MPa (at 350 kA) 30 MPa (at 300 kA)



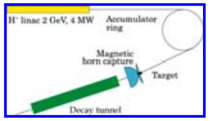
von Mises stresses due to thermal loads


Pulse: 100µs
T=1/50/4s=0.08s

magnetic pressure on the horn

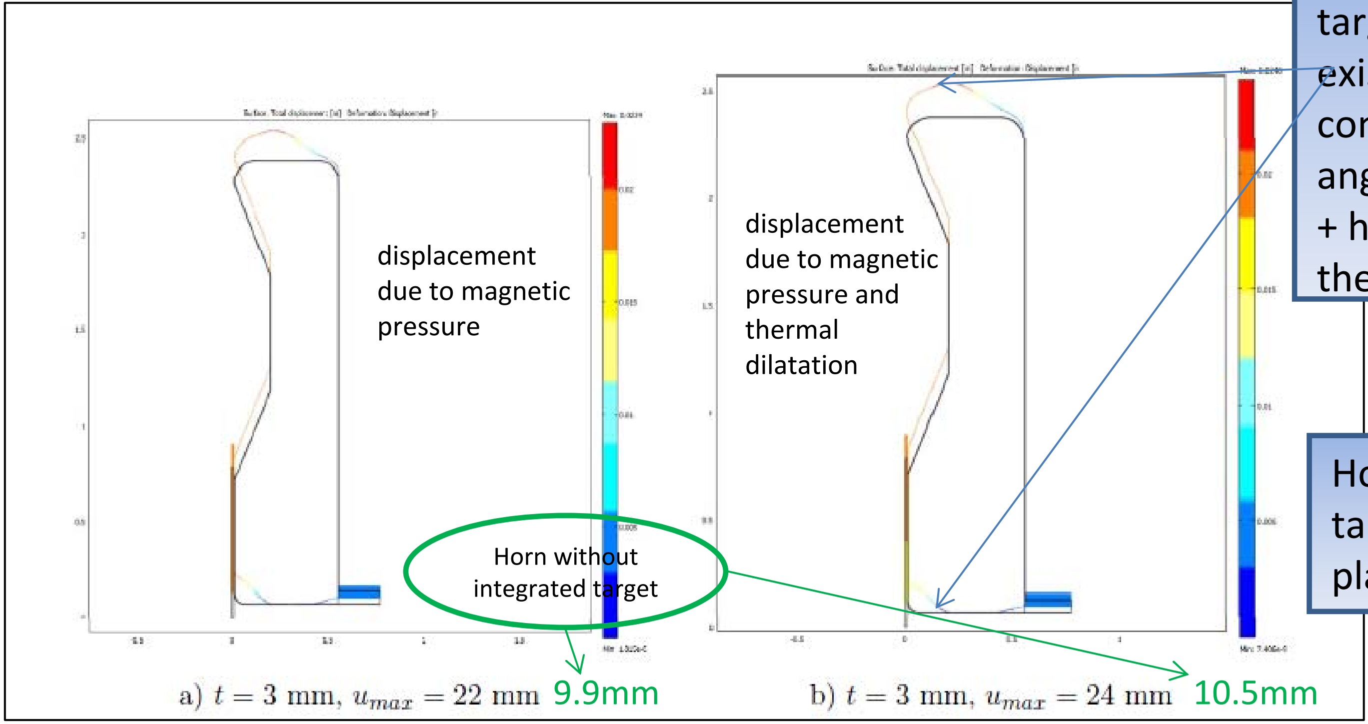
static stress ⇨

Horn: Static stress, deformation



- in order to assess the horn deformation and horn life time, the calculation of the stress inside the horn is necessary. The stress level in the structure should be low enough in comparison with the fatigue limit of the materials. Loads coming from the magnetic pressure and the thermal dilatation of the material

- dynamic stress superimposed on the quasi-static stress are the basis of the fatigue life time estimate of the horn – work ongoing


displacement due to magnetic pressure

displacement due to magnetic pressure and thermal dilatation

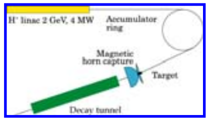
Horn without integrated target

a) $t = 3$ mm, $u_{max} = 22$ mm 9.9mm

b) $t = 3$ mm, $u_{max} = 24$ mm 10.5mm

horn with integrated target: highly stress domain exists on the inner conductor and in the right angles connection domains + high energy deposition on the inner conductor

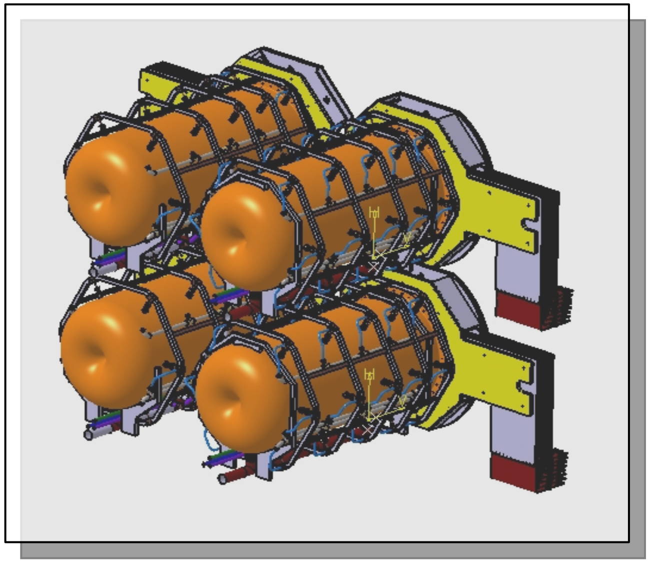
Horn with separated target and rounded back-plate, corners

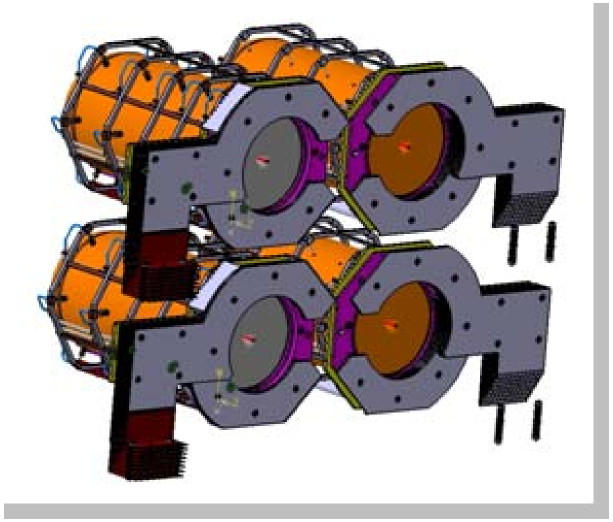


Horn: status for WP2

Target Station Baseline :

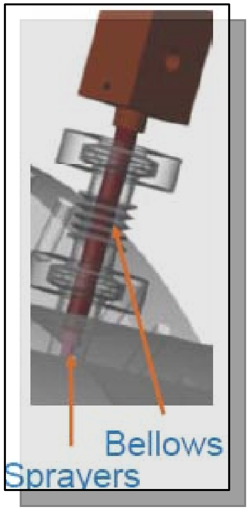
- Solid Static target
- Use multiple 4 targets+ horns
- Beam frequency 12.5 Hz
- Cooling (EUROnu WP2 Note 10-06)
- Power distribution due to Joule losses & secondary particles
- Energy balance, to maintain working temperature
- Flow rate
- Jet distribution along the outer conductor
- h correlation for jets’ geometry





Feed back from other neutrino beam experiments

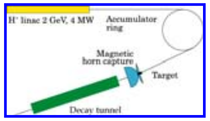
- **Recommandations from others facilities:**
  - Cracks in welds
  - Use flexible pipes to reduce stress and fatigue
  - Water leaks due to galvanic corrosion => avoid trapped water and choose material carefully
  - Use semi flexible conductor because of important magnetic force between stripline => can break cable
  - Heat dissipation of the stripline
  - Remote design for repairing/exchange
  - Need Spares
  - …



Striplines plate with soft transition

Safety in the SB Framework

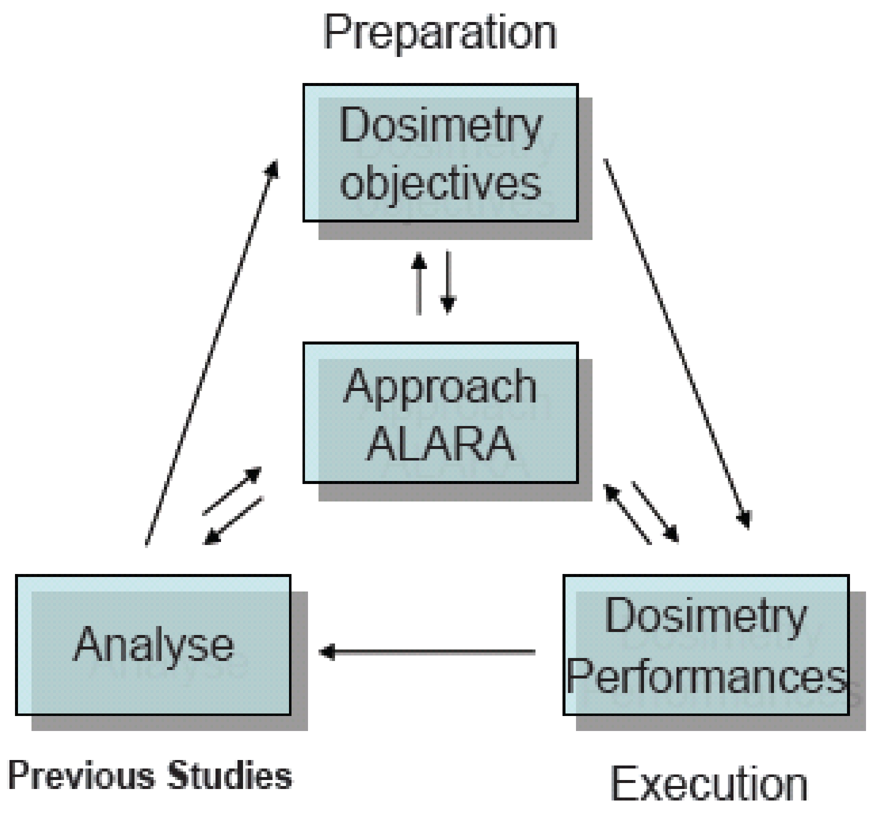
Toward a safety WP2 roadmap



- **ALARA approach :**

⇒ **Anticipate and reduce individual and collective exposition to radiation**

- **Iterative processes :**
  - Préparation
    - Building Structure lists of materials
    - Dose Equivalent Rate Estimation
    - Optimize procedure during operation and maintenance phases
    - Evaluate residual activity of wastes ….
  - Execution
  - Safety Analyse from previous facilities (WANF, CNGS, NuMi, J-PARC…)



Preparation

Dosimetry objectives

Approach ALARA

Analyse

Dosimetry Performances

Previous Studies

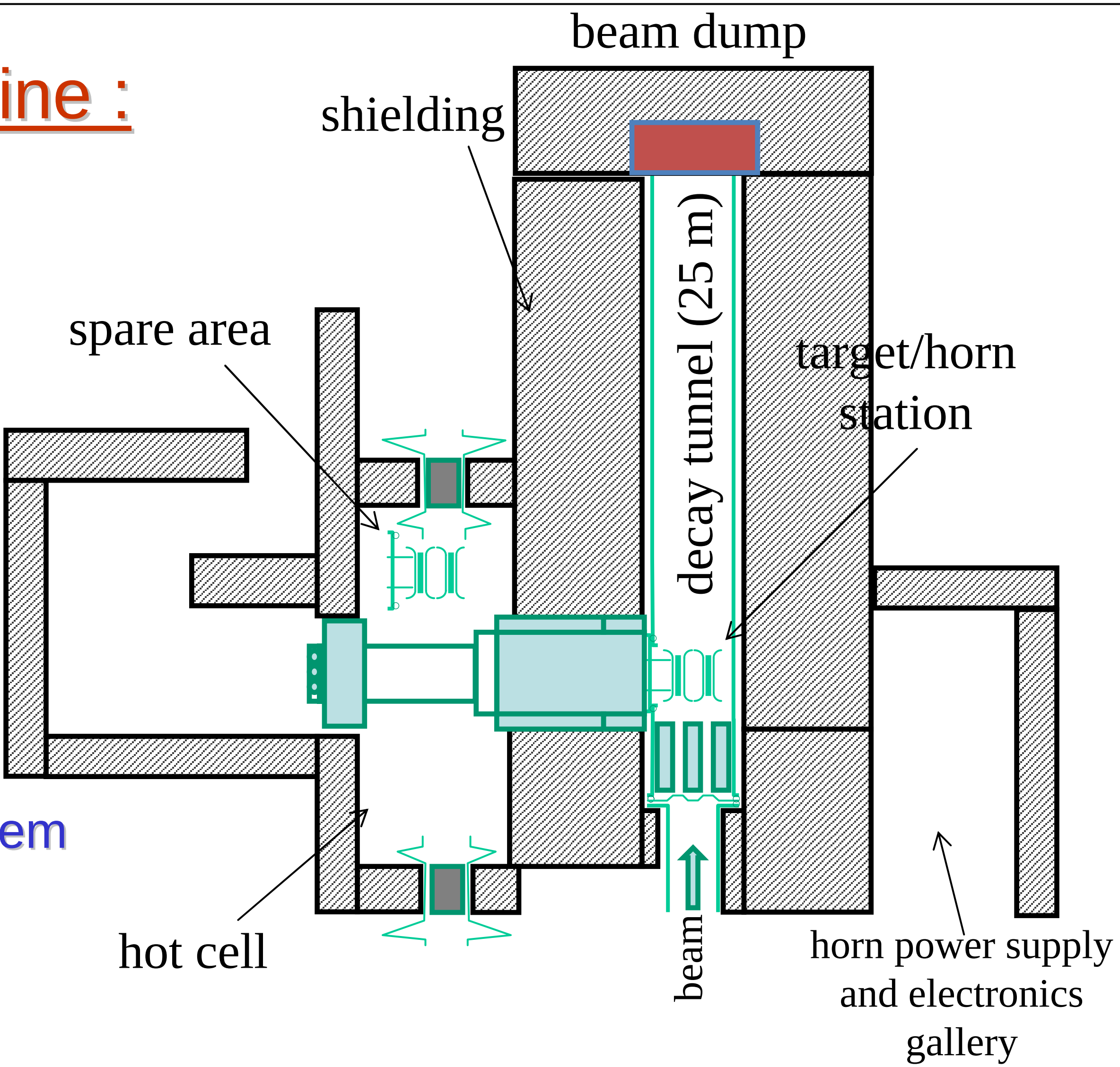
Execution

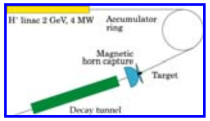
As Low As Reasonably Achievable

Design

Design of the SB line :

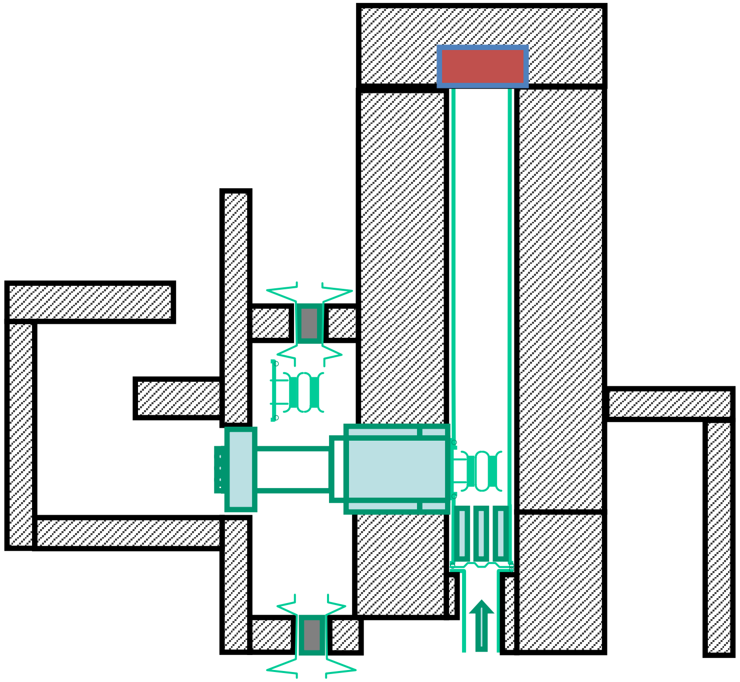
- **Proton Driver line**
- **Experimental Hall**
  - MW Target Station
  - Decay Tunnel
  - Beam Dump
- **Maintenance Room**
- **Service Gallery**
  - Power supply
  - Cooling system
  - Air-Ventilation system
- **Waste Area**





Safety : Elements

MW Target Station :

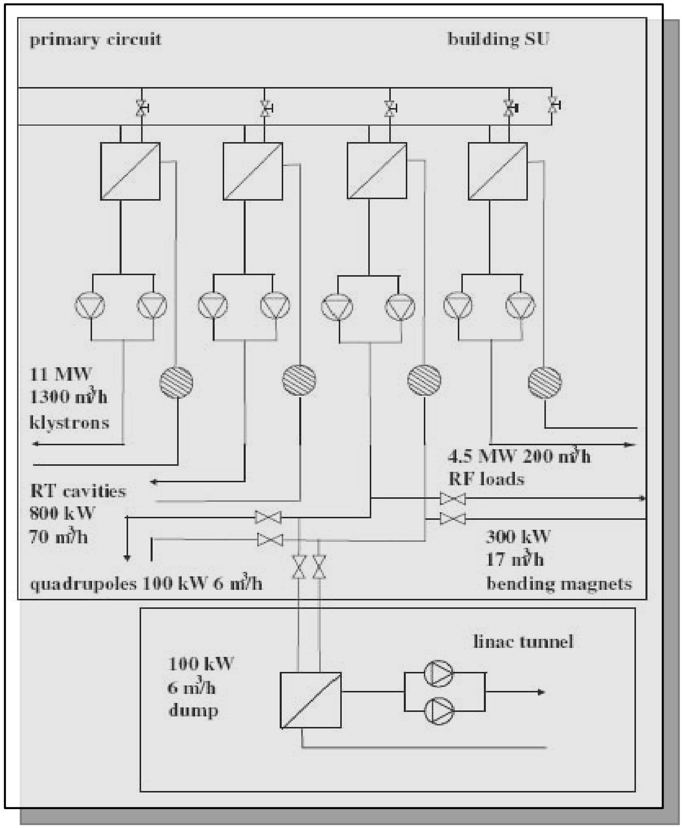


- Focusing System
- Crane System
- Automated robot
- Mechanical structure for the for horn
- Dose Rate Monitoring System
- Residual Dose Rate Plateform
- Operation under helium Atmosphere
  - flushing with air
  - filter to measure radioactive pollution (dust, tritium …)
- Investigation of other radionucleides transport (environmental constraint)
- …

Complementary infrastructures

SPL Cooling system :

Conceptual design of the SPL II, A high-power superconducting H- linac at CERN – CERN-2006-006 - 12 July 2006



*Schematic diagram of the main cooling plant

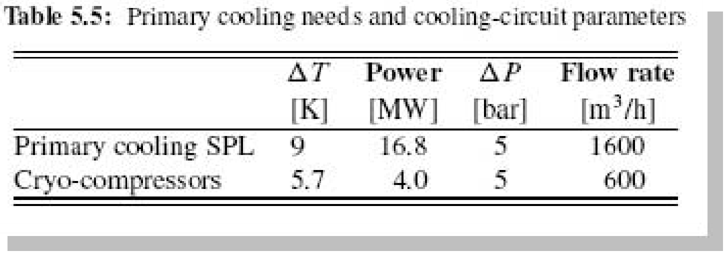


Table 5.5: Primary cooling needs and cooling-circuit parameters

	ΔT [K]	Power [MW]	ΔP [bar]	Flow rate [m^3/h]
Primary cooling SPL	9	16.8	5	1600
Cryo-compressors	5.7	4.0	5	600

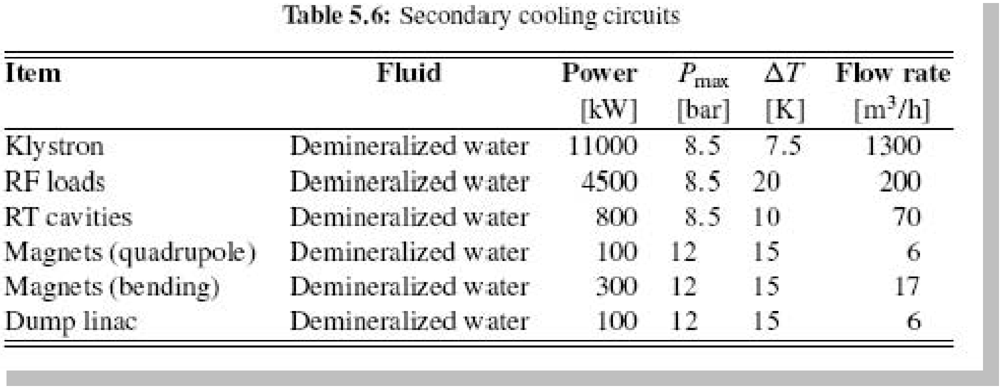


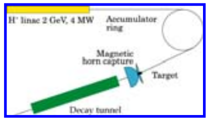
Table 5.6: Secondary cooling circuits

Item	Fluid	Power [kW]	$P_{\max}$ [bar]	ΔT [K]	Flow rate [m^3/h]
Klystron	Demineralized water	11000	8.5	7.5	1300
RF loads	Demineralized water	4500	8.5	20	200
RT cavities	Demineralized water	800	8.5	10	70
Magnets (quadrupole)	Demineralized water	100	12	15	6
Magnets (bending)	Demineralized water	300	12	15	17
Dump linac	Demineralized water	100	12	15	6

Complementary plants needed for

- cooling the 4 horns, decay tunnel and beam dump
- cooling and recirculating helium inside the vessel

Complementary infrastructures



Electrical infrastructure :

Conceptual design of the SPL II, A high-power superconducting H- linac at CERN – CERN-2006-006 - 12 July 2006

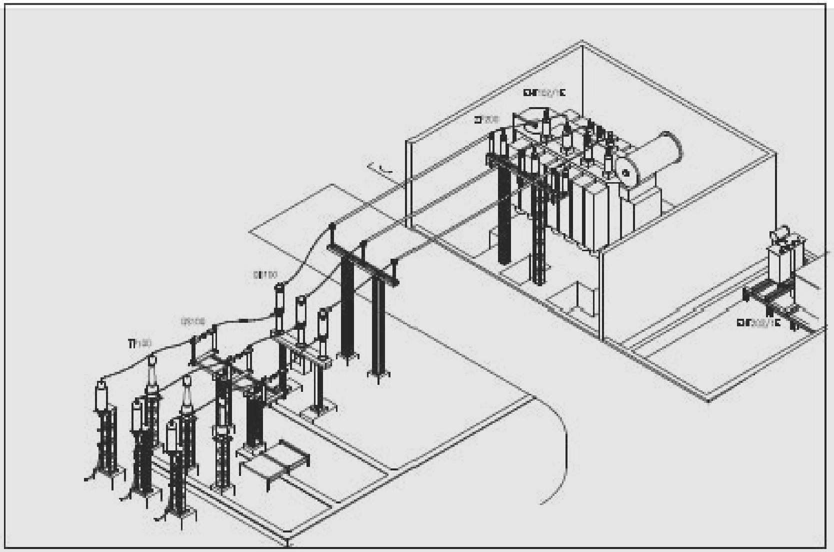


Fig. 5.9: Layout of CERN's standard 66/18 kV substation

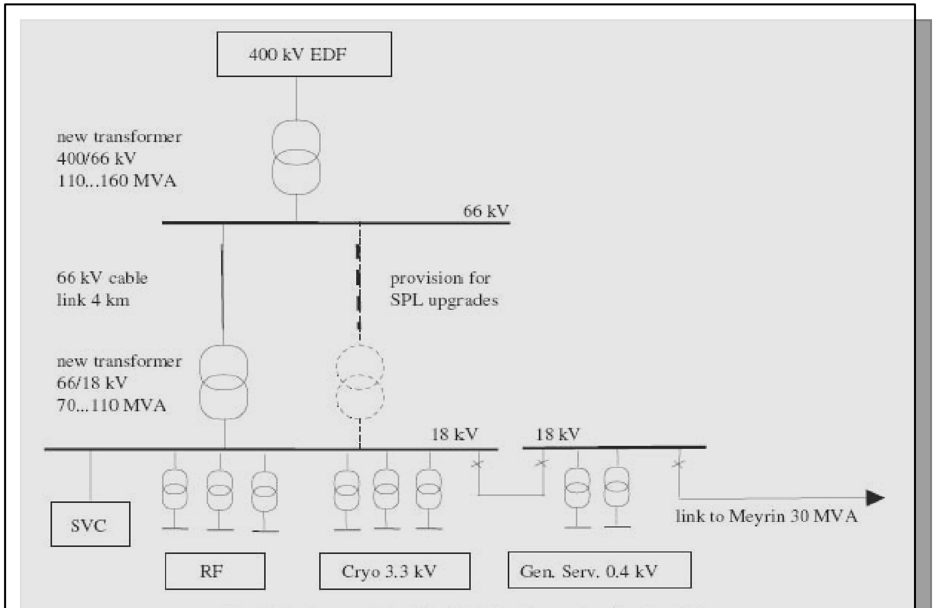
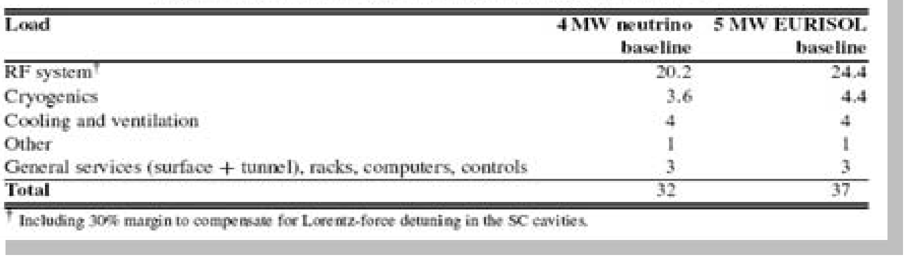


Fig. 5.10: Proposed electrical distribution system for the SPL

Table 5.9: Electrical power requirements (MW) of the SPL (r.m.s. values)

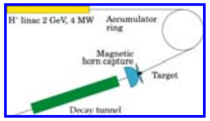


Load	4 MW neutrino baseline	5 MW EURISOL baseline
RF system†	20.2	24.4
Cryogenics	3.6	4.4
Cooling and ventilation	4	4
Other	1	1
General services (surface + tunnel), racks, computers, controls	3	3
Total	32	37

† Including 30% margin to compensate for Lorentz-force detuning in the SC cavities.

Complementary plants needed for the super beam infrastruture
- **alimentation station for the horns**
- **air conditioning installation**

Radiation simulation : shielding investigation



Beam Features (CNGS like):

- Proton Energy : 400 GeV/c
- Intensity : 8.0 10^{12} pps
- Irradiation time : 200 days

Target:

- Material : Graphite
- Cylinder : 130 cm x 4mm (Diameter)

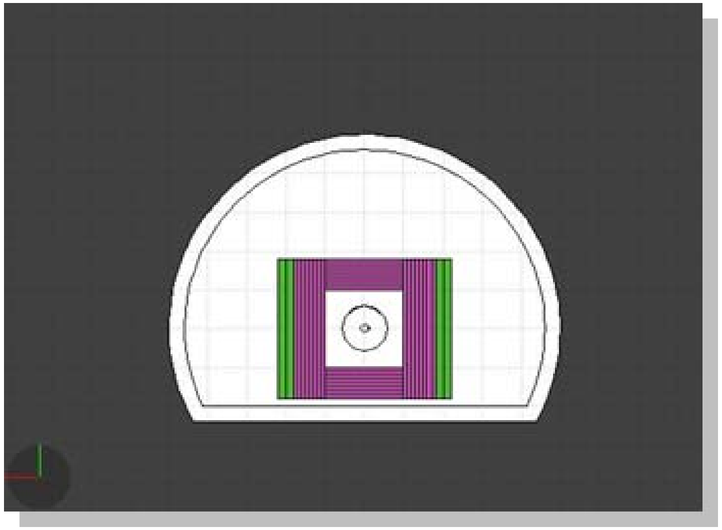
Horn:

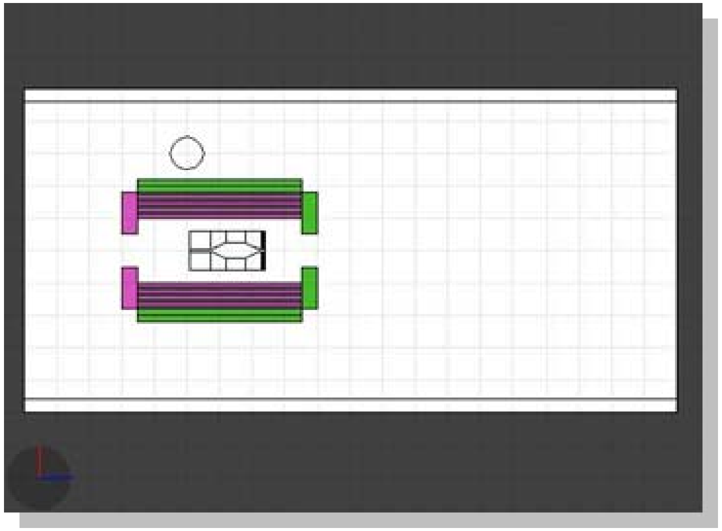
- Material : Anticorodal 110

Shielding for the Target Station :

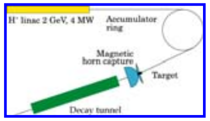
- Walls and roof : 80 cm of Iron,
  8 Slabs (2.5m x 2m x10cm)
- Lateral and Front Marble Slabs
- Front Iron Slab

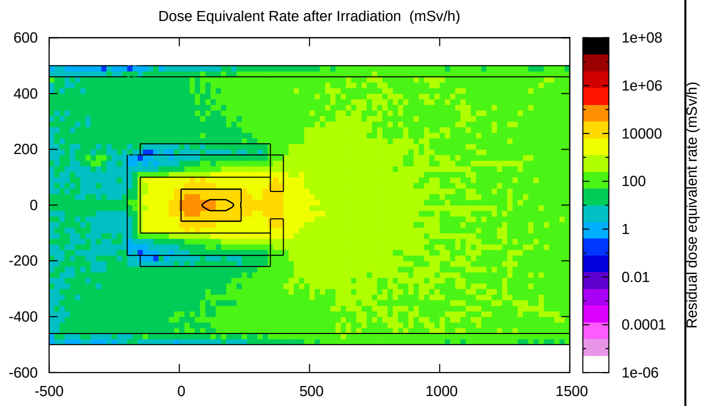
⇒ Evolution of the DER with time performed with FLUKA 2011.2.3



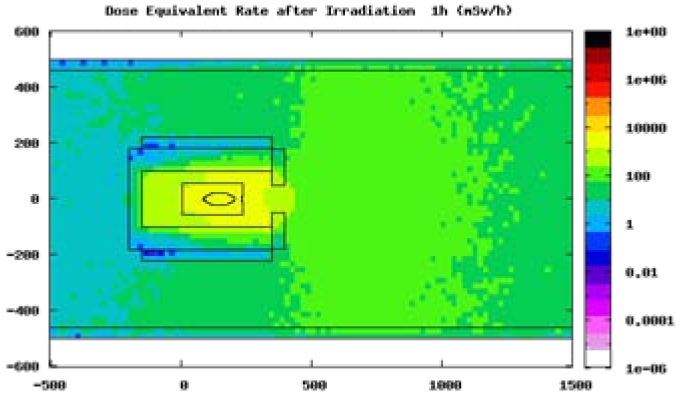


Radiation simulation : shielding investigation

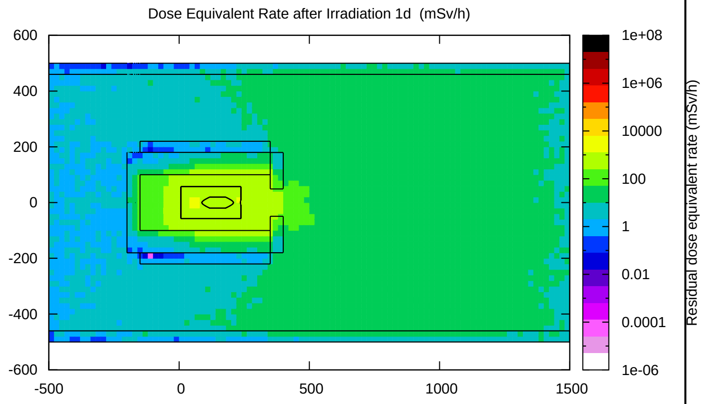




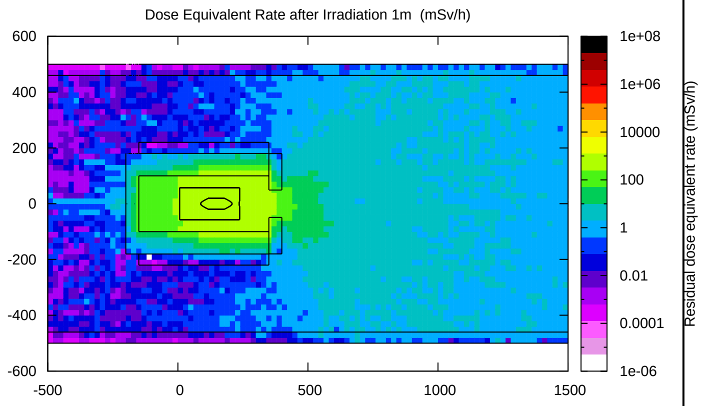
DER (mSv/h) after stopping irradiation



DER (mSv/h) after 1hour of cooling time



DER (mSv/h) after 1day of cooling time



DER (mSv/h) after 1month of cooling time

Radiation simulation : shielding investigation

Beam Features:

- Proton Energy : 4,5 GeV/c
- Intensity : 18. 10^{14} pps
- Irradiation time : 200 days

Target:

- Material : Titanium
- Cylinder : 78 cm x 1.5mm (Diameter)

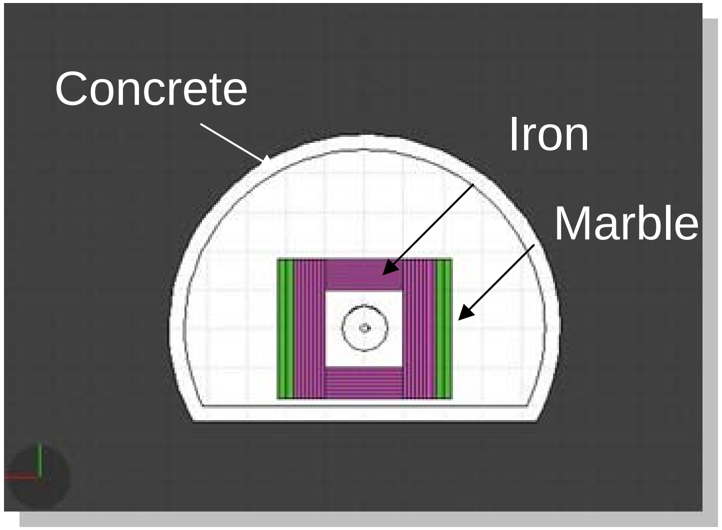
Horn:

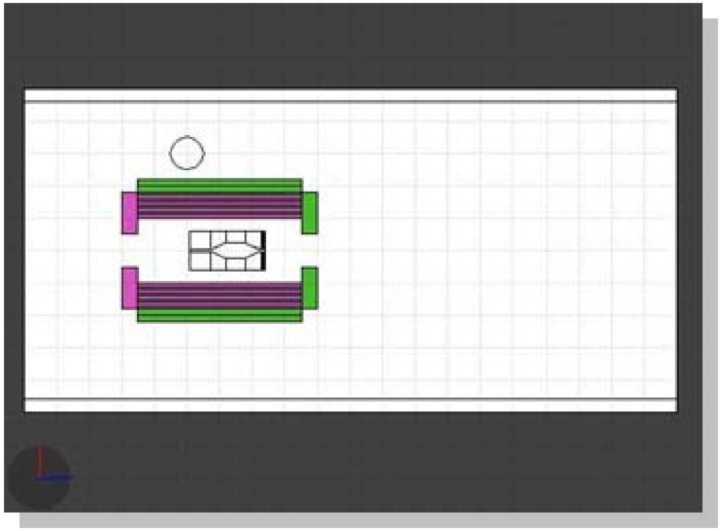
- Material : Anticorodal 110

Shielding for the Target Station :

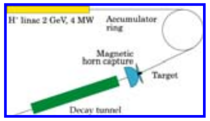
- Walls and roof: 80 cm of Iron,
  8 Slabs (2.5m x 2m x10cm)
- Lateral and Front Marble Slabs
- Front Iron Slab

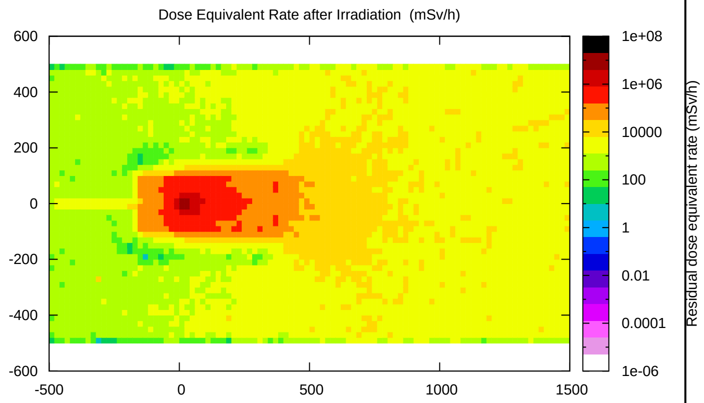
⇒ Evolution of the DER with time performed with FLUKA 2011.2.3



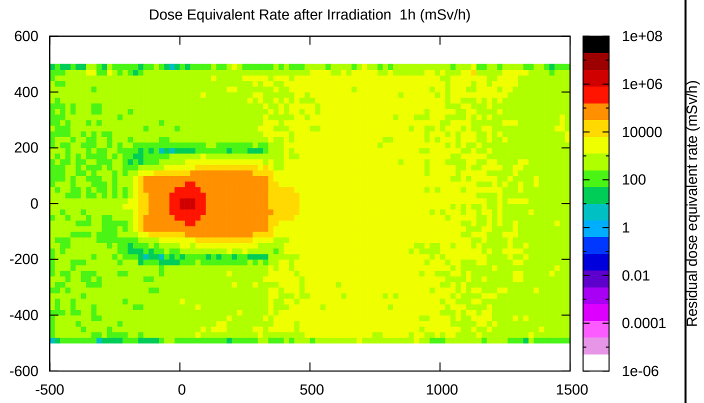


Radiation simulation : shielding investigation

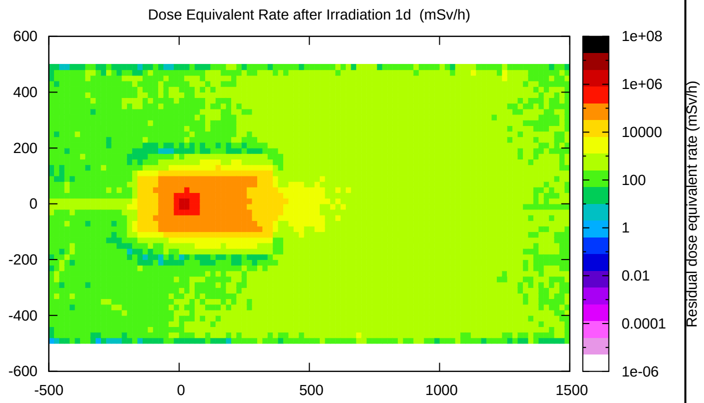




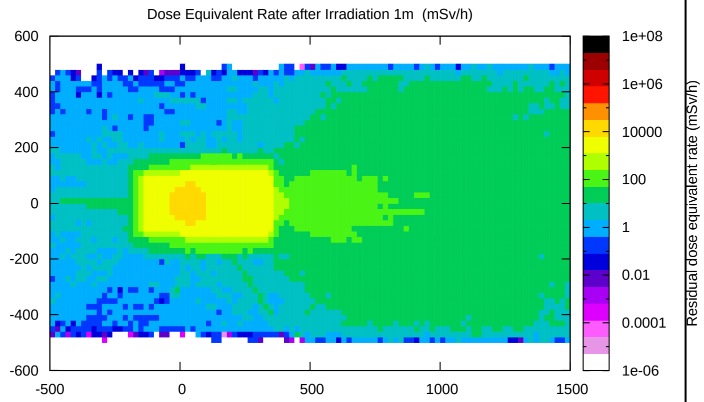
DER (mSv/h) after stopping irradiation



DER (mSv/h) after 1 hour of cooling time



DER (mSv/h) after 1 day of cooling time



DER (mSv/h) after 1month of cooling time

Radiation simulations : Four Horn Station

Chemical composition of Material:

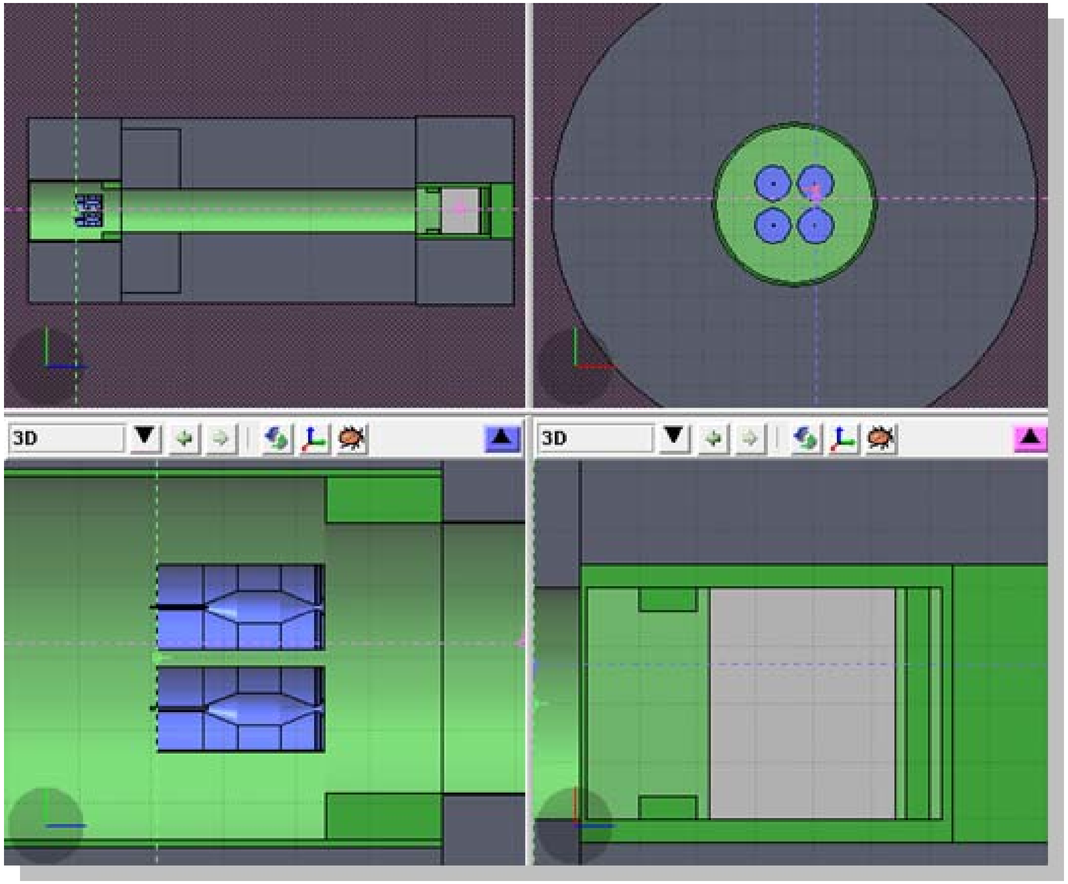
Target => Ti(100%)

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%)

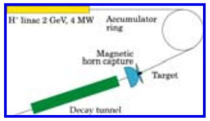
Tunnel => Concrete
O(52.9%), Si(33.7%), Ca(4.4%), Al(3,49%), Na(1,6%), Fe(1.4%), K(1,3%), H(1%), Mn(0.2%), C(0.01%)

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%)

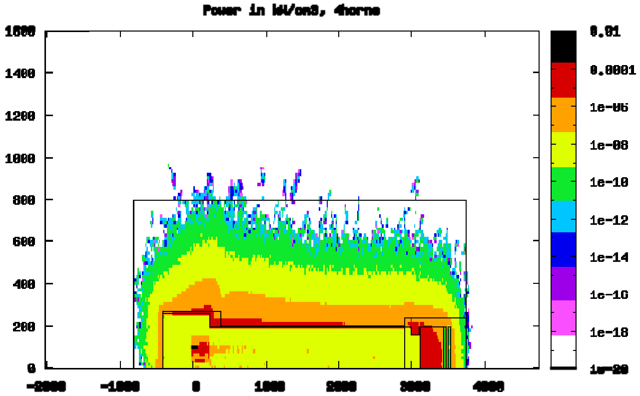


Four horn station layout

Simulations : Energy deposition for the Four Horn Station

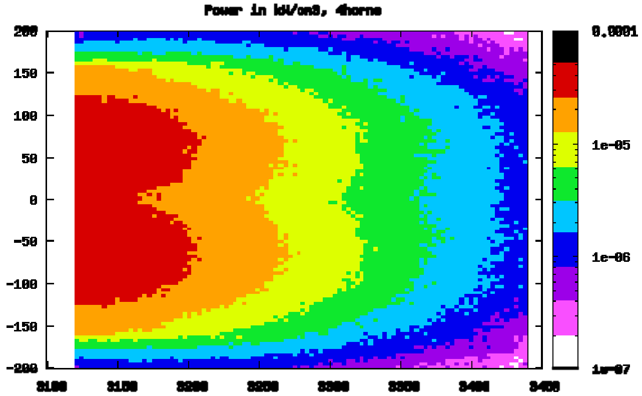


Transverse view



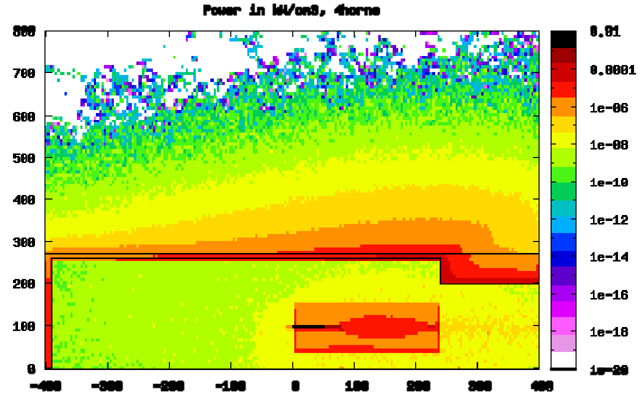
Energy deposition (kW/cm^3) in the all layout

Transverse view



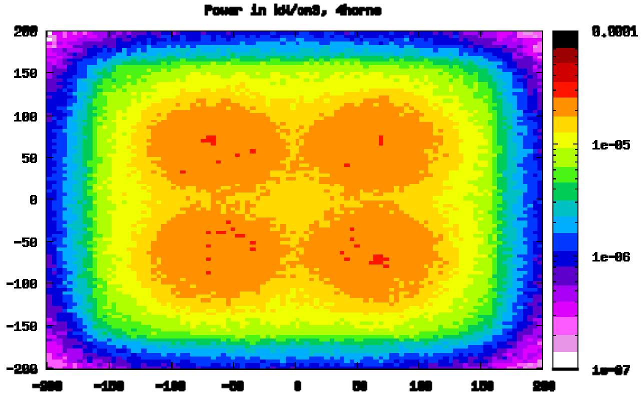
Beam dump energy deposition (kW/cm3)

Transverse view



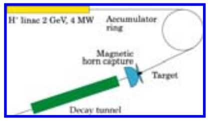
Target station energy deposition (kW/cm3)

Front view

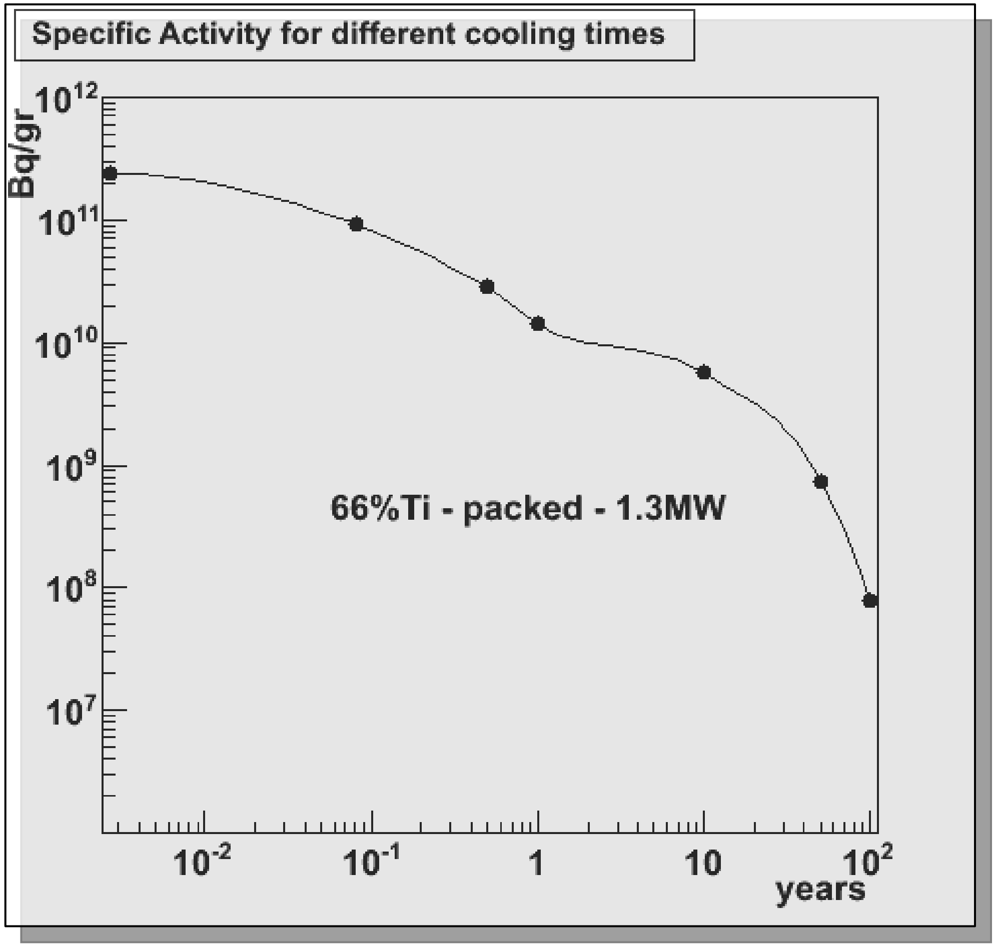


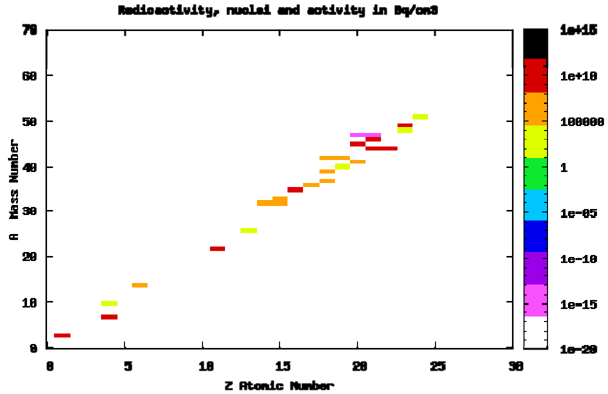
Beam dump energy deposition (kW/cm3)

Radiation simulations : Four Horn Station

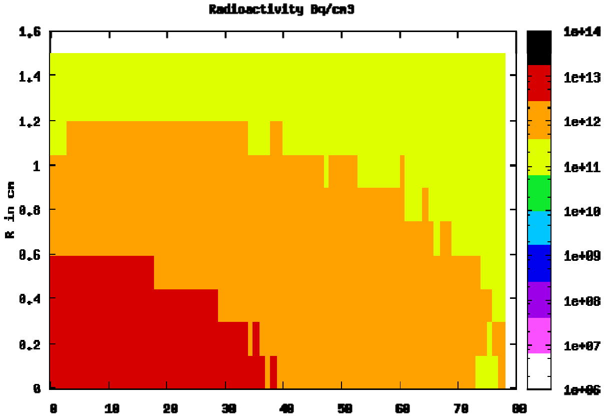


Evolution of the target activity with cooling time:



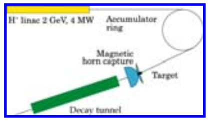


Radionucleides after 1 day (Z,A)

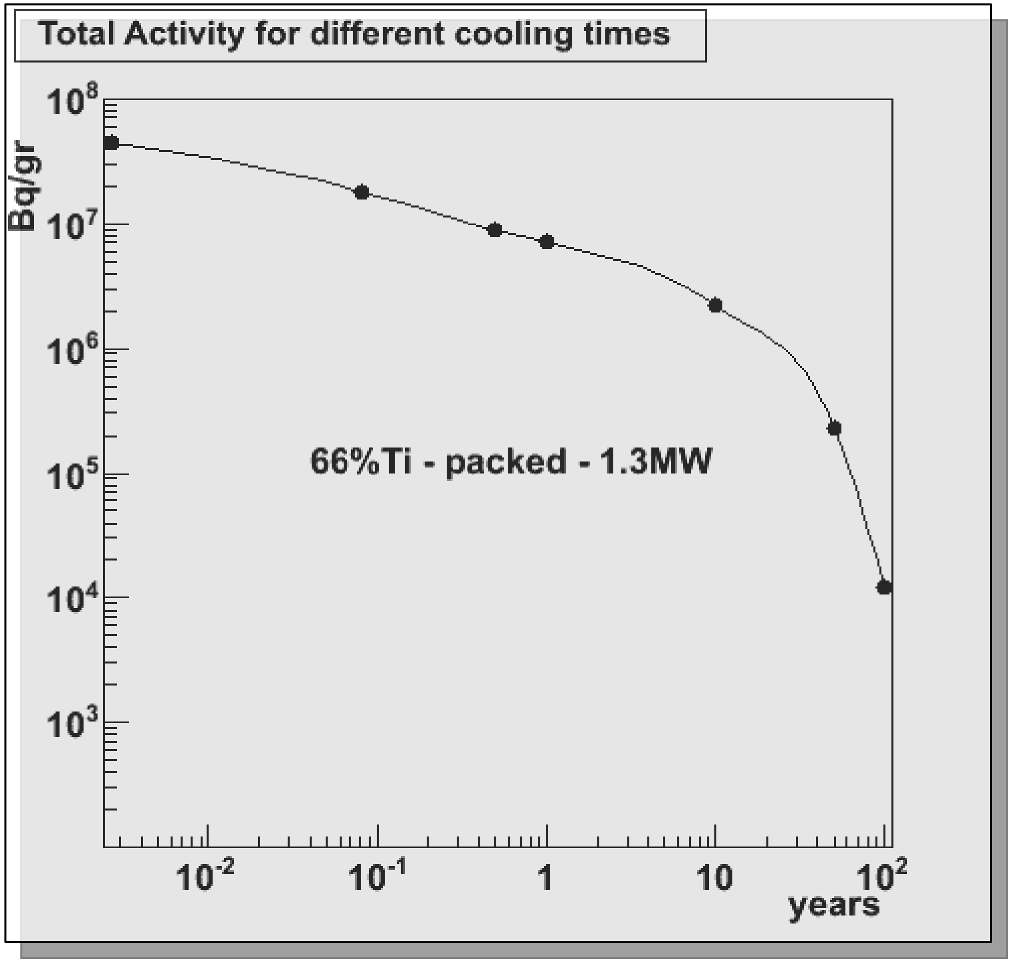


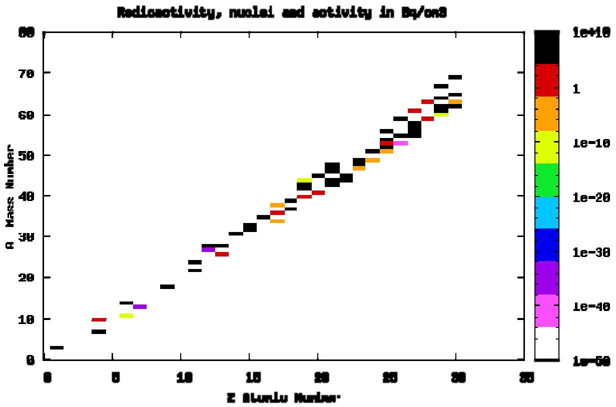
Radioactivity after 1 day ($Bq.cm^{-3}$)

Radiation simulations : Four Horn Station

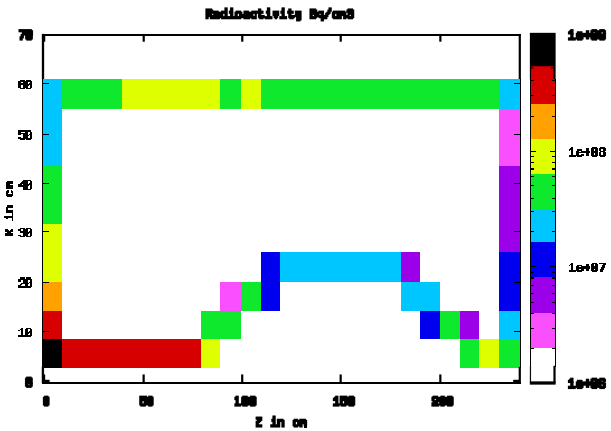


Evolution of the horn activity with cooling time:



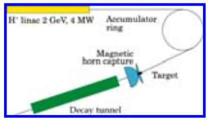


Radionucleides after 1 day (Z,A)

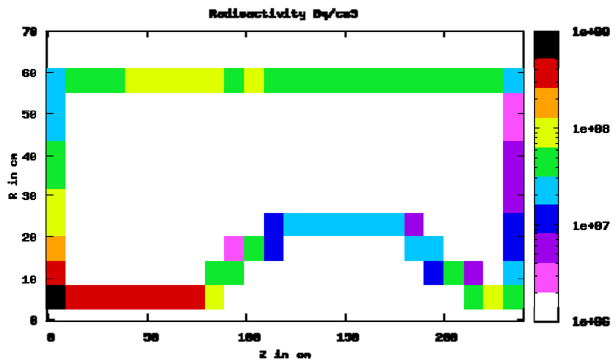


Radioactivity after 1 day (Bq.cm^{-3})

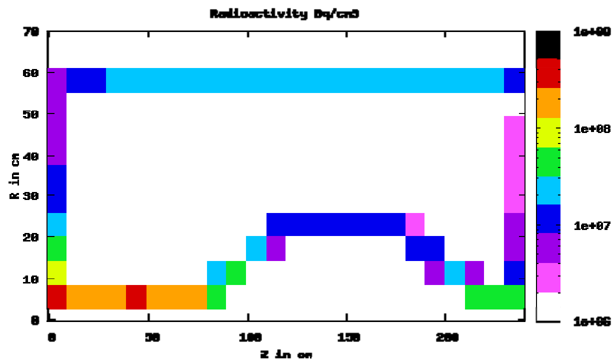
Radiations simulations : Four Horn Station



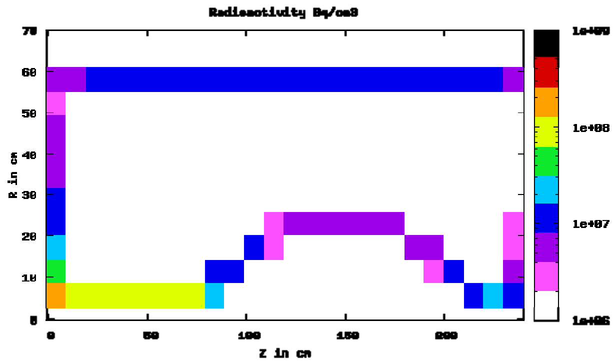
Evolution of the horn activity with cooling time:



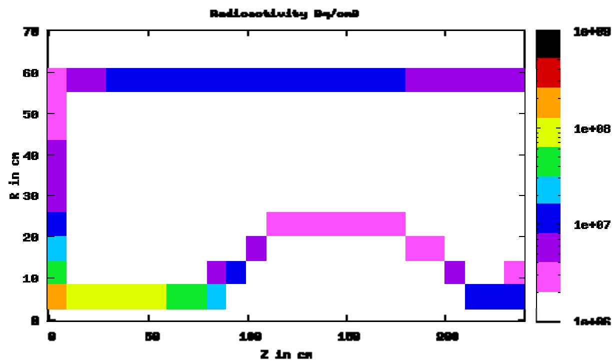
DER (mSv/h) after 1d of cooling time



DER (mSv/h) after 1m of cooling time

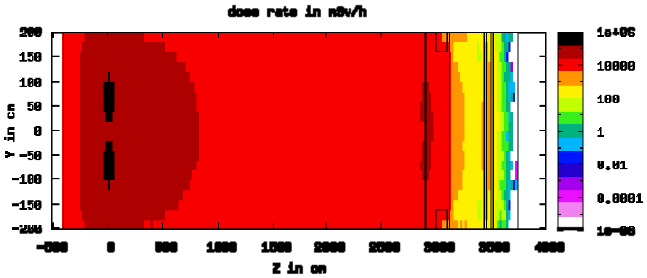


DER (mSv/h) after 6m of cooling time

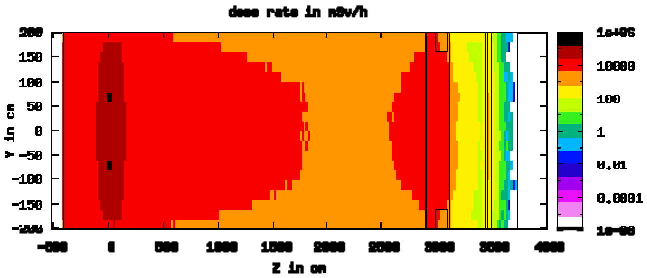


DER (mSv/h) after 1y of cooling time

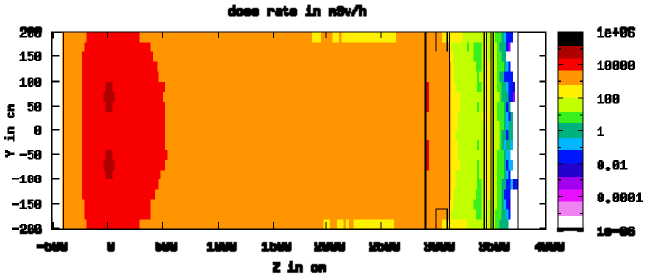
Radiation simulations : All Layout



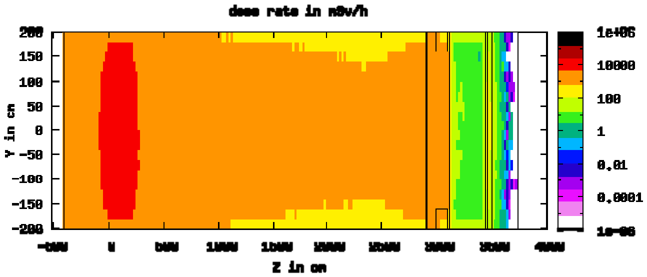
DER (mSv/h) after 1d of cooling time



DER (mSv/h) after 1m of cooling time

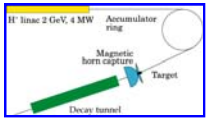


DER (mSv/h) after 6m of cooling time



DER (mSv/h) after 1y of cooling time

Radiation simulations : Four Horn Station



Next Steps :

- Full Design simulation of the installation
- Contribution of each element to the dose rate
- Individual and collective dose rate calculation with cooling times
- Intervention Scenarios (normal operation, maintenance, emergency….)
- Costing