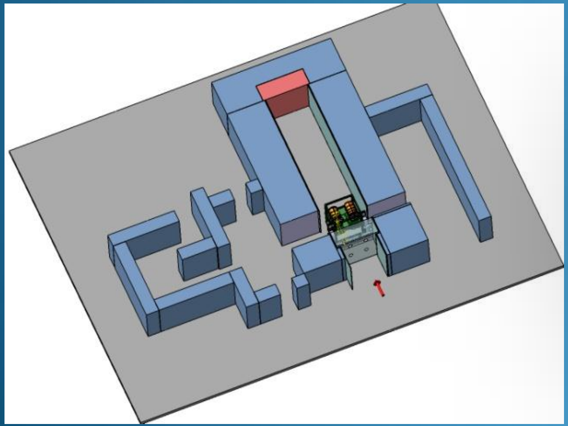
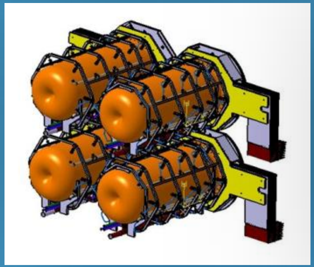
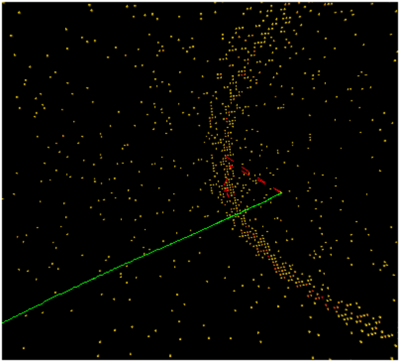
Optimization of the target and magnetic horn for the CERN to Fréjus neutrino beam

Nikolas Vassilopoulos, IPHC/CNRS, Strasbourg





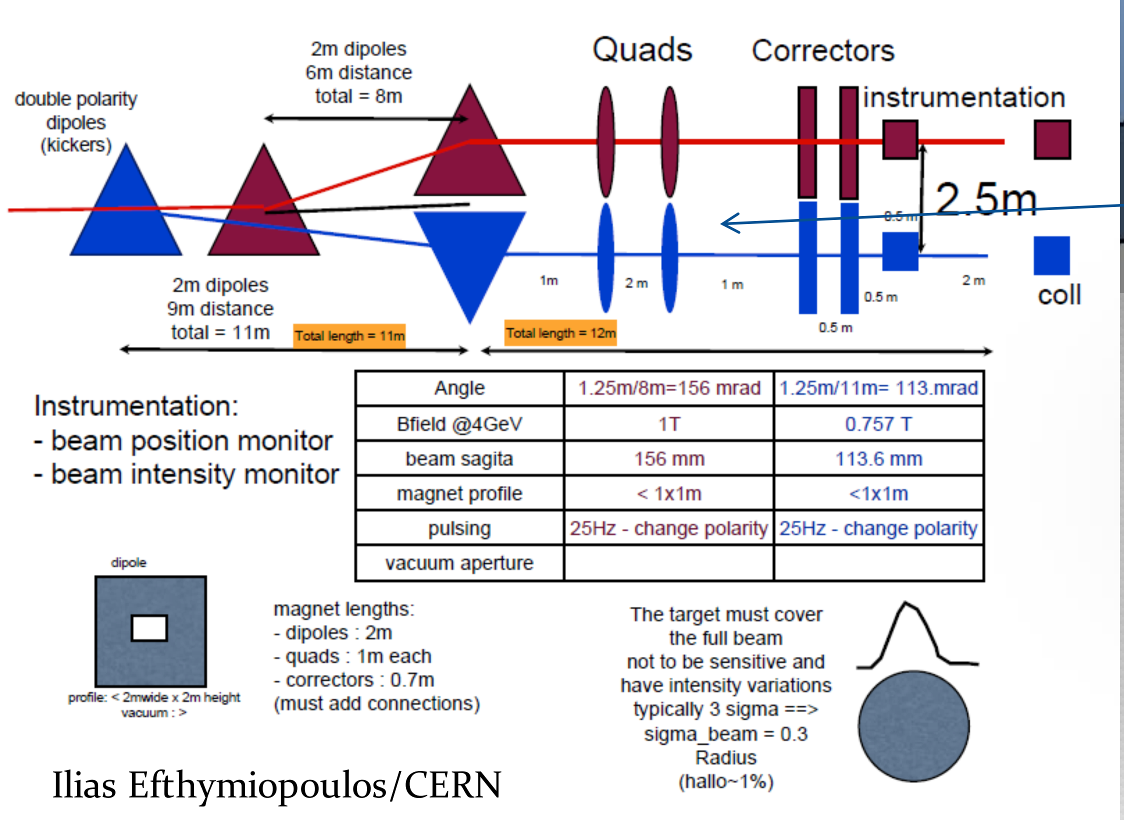


Talk layout

- Target Studies
- Horn shape & SuperBeam Geometrical Optimization
- Horn Thermo-mechanical Studies
- Energy Deposition, Irradiation and Safety Studies

Proton Beam and Target/Horn Station

- E_b = 4.5 GeV
- Beam Power = 4MW -> 4x1-1.3MW
- Repetition Rate = 50Hz -> 12.5Hz
- Protons per pulse = 1.1 x 10^{14}
- Beam pulse length = 0.6ms



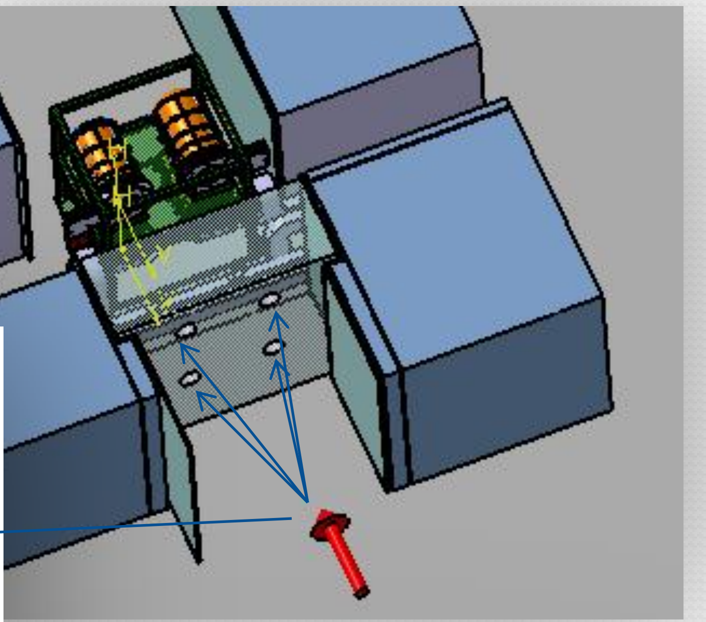
Instrumentation:
- beam position monitor
- beam intensity monitor

Angle	1.25m/8m=156 mrad	1.25m/11m= 113.mrad
Bfield @4GeV	1T	0.757 T
beam sagita	156 mm	113.6 mm
magnet profile	< 1x1m	<1x1m
pulsing	25Hz - change polarity	25Hz - change polarity
vacuum aperture		

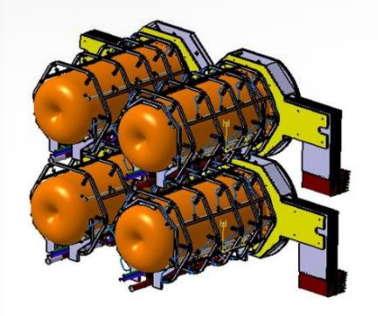
magnet lengths:
- dipoles : 2m
- quads : 1m each
- correctors : 0.7m
(must add connections)

The target must cover the full beam not to be sensitive and have intensity variations typically 3 sigma ==> sigma_beam = 0.3 Radius (hallo~1%)

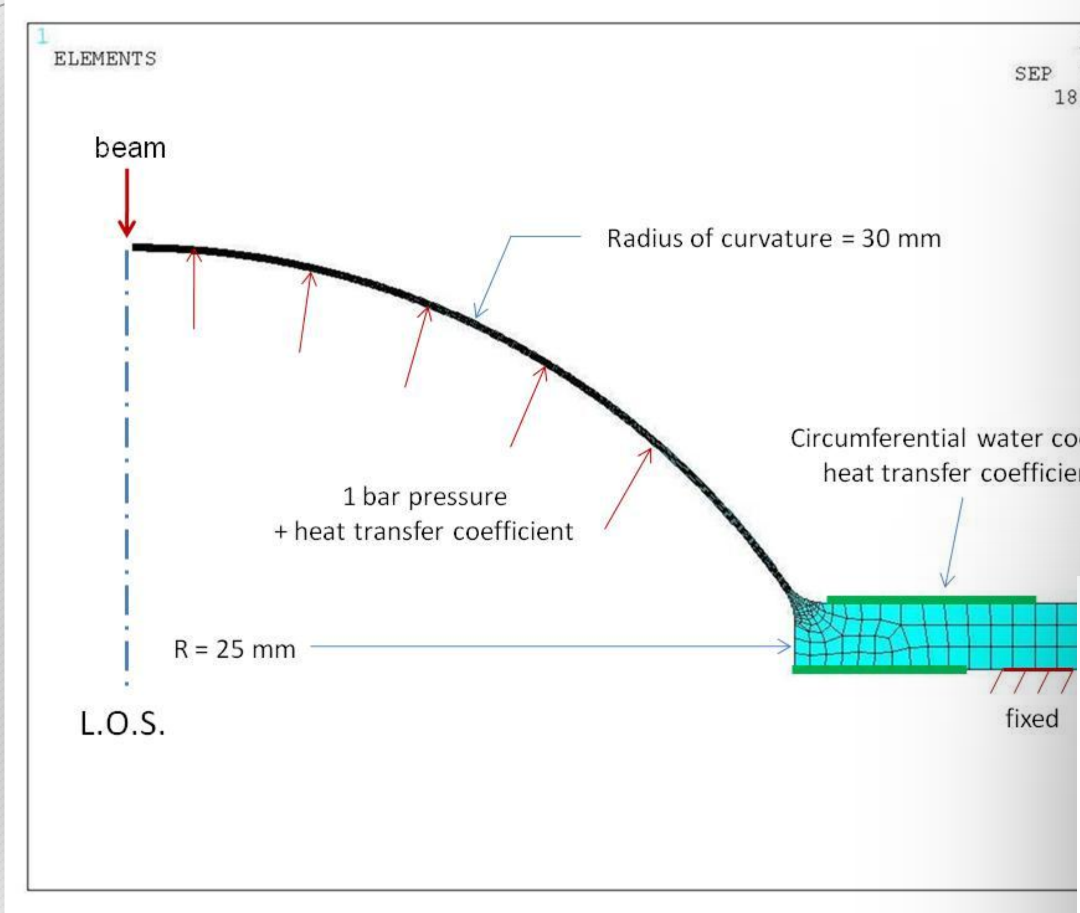
Ilias Efthymiopoulos/CERN

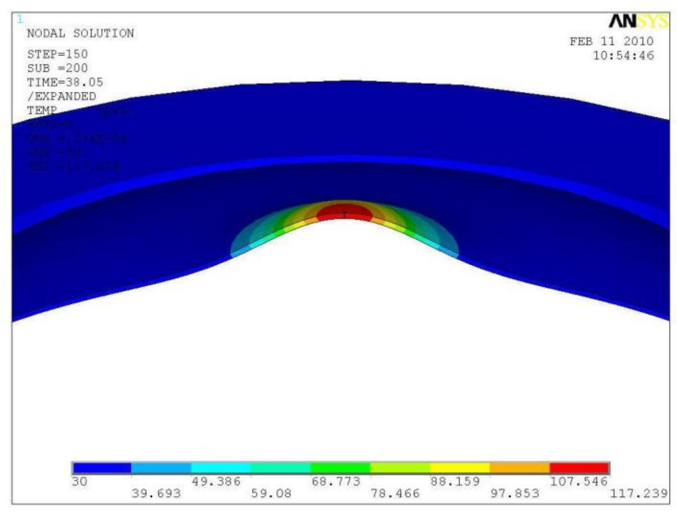


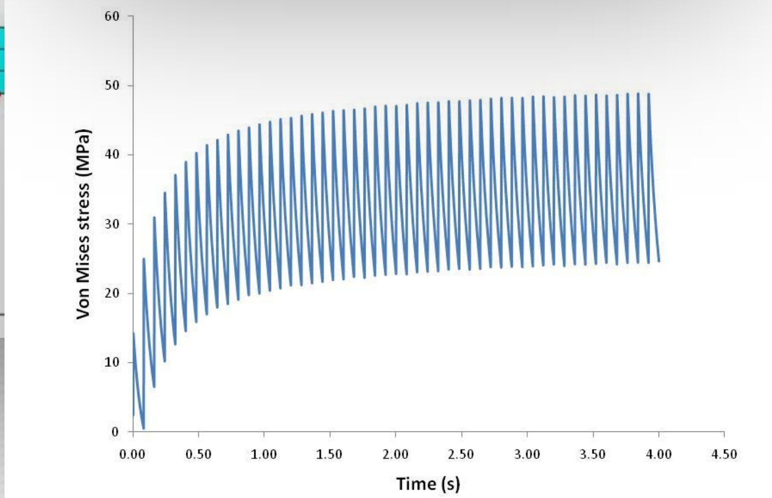
- 4-horn/target system in order to accommodate the 4MW
- power @ 1-1.3MW, repetition rate @ 12.5Hz for each target



beam window







0.25 mm thick beryllium window

Circumferentially water cooled (assumes 2000 W/m^{2}K)

Max temp ~ 180 °C Max stress ~ 50 MPa

(109°C and 39 MPa using He cooling)

feasible

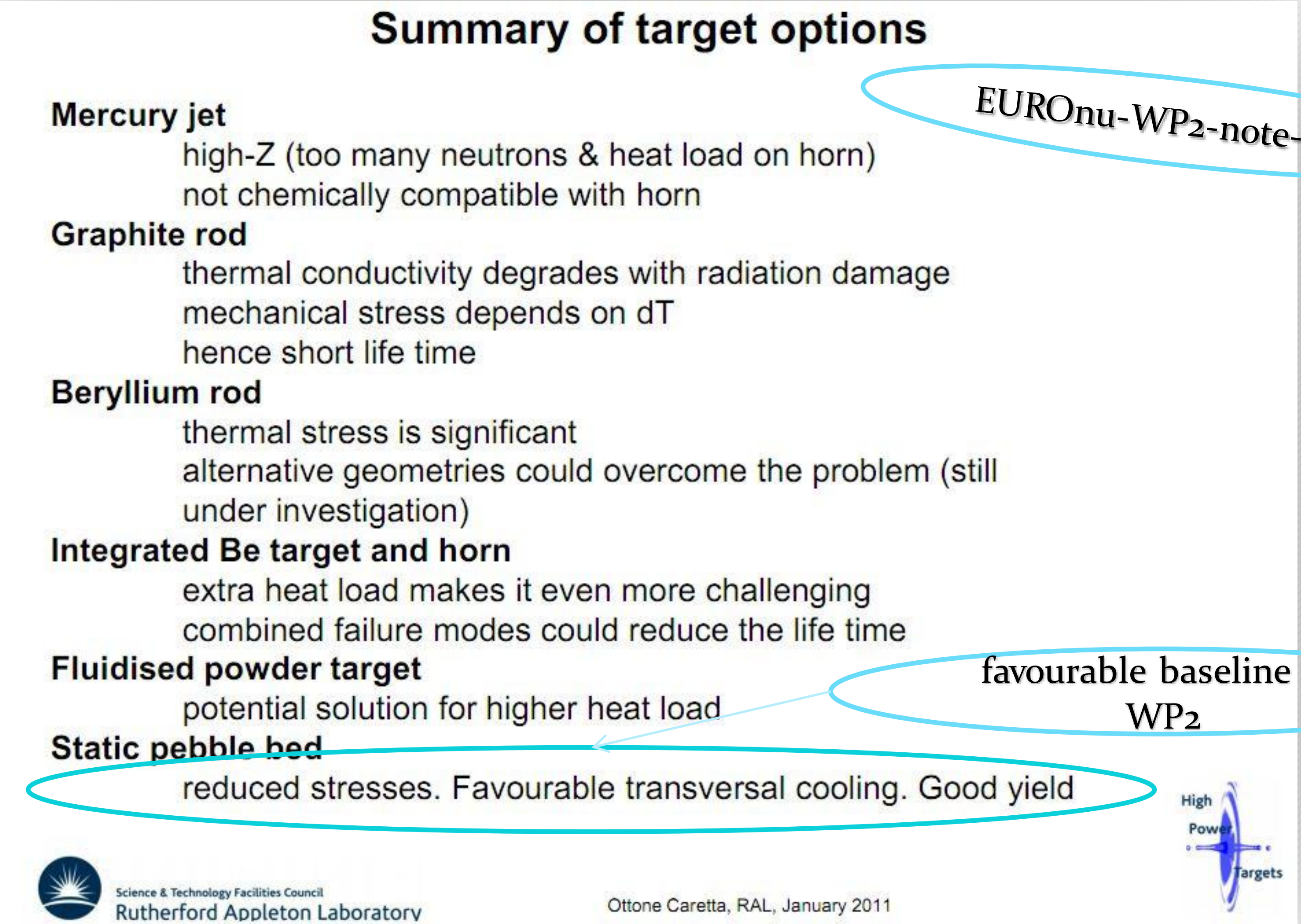
Matt Rooney

Important Issues for the engineering of the target

- Heat Removal
  - ✓ Beam ≈ 60 – 120kW depending on Target Material/configuration
- Thermal/mechanical stresses
  - ✓ long lived "quasi-static" stresses that generated by temperature variations within the target
  - ✓ inertial dynamic stress waves that are generated by the pulsed nature of the beam
- Cooling
  - ✓ water
  - ✓ helium
  - ✓ peripheral vs transversal cooling
- Neutron Production – heat load/damage of horn
- Safety
- Radiation resistance
- Reliability
- Pion yield

Chris Densham et al. @ RAL

from Liquid Targets to Static Packed one



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

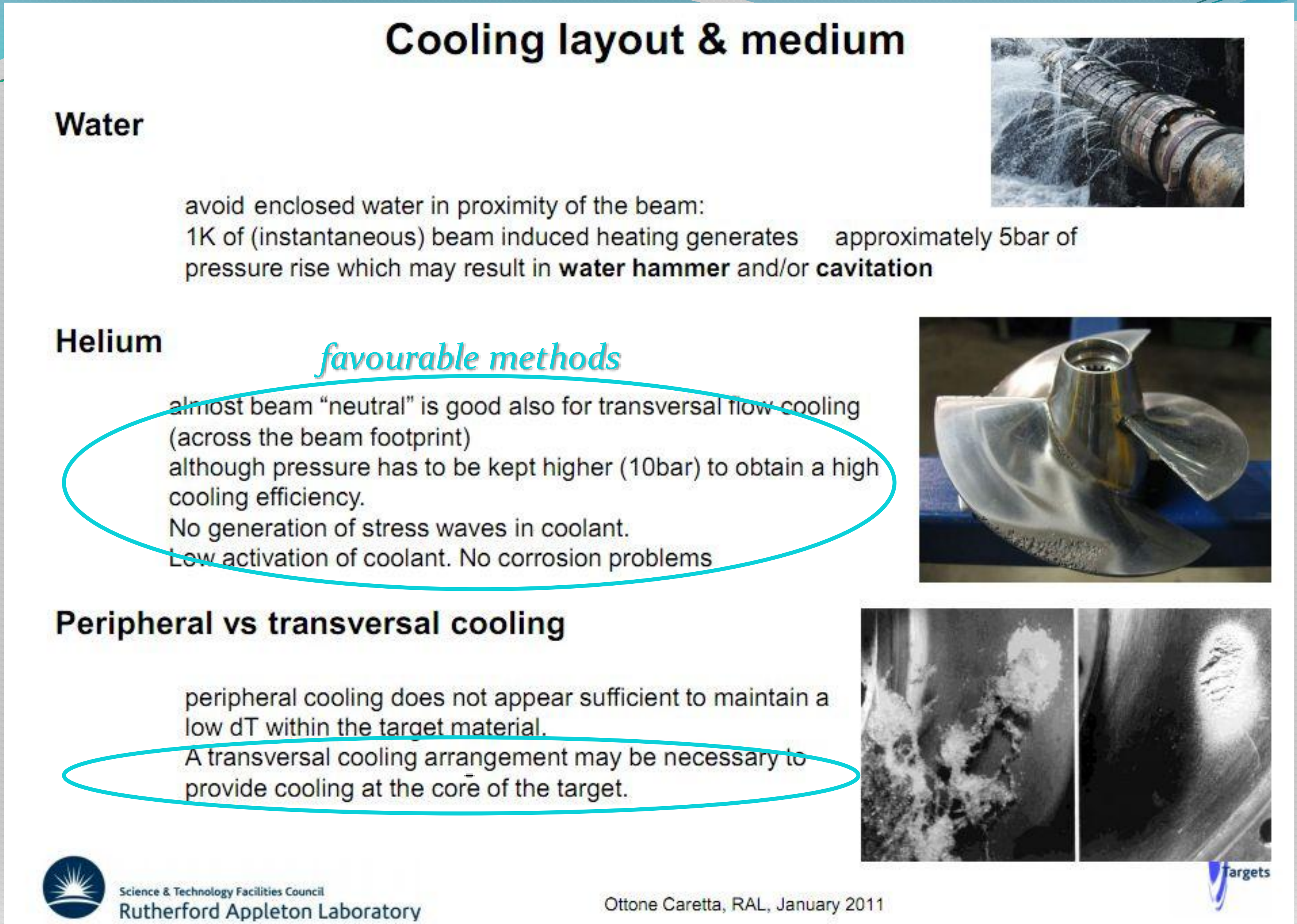
High Power Targets

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Ottone Caretta, RAL, January 2011

EUROnu-WP2-note-11-01

favourable baseline for WP2



Cooling layout & medium

Water

avoid enclosed water in proximity of the beam:
1K of (instantaneous) beam induced heating generates approximately 5bar of pressure rise which may result in **water hammer** and/or **cavitation**

Helium

favourable methods

almost beam "neutral" is good also for transversal flow cooling (across the beam footprint)
although pressure has to be kept higher (10bar) to obtain a high cooling efficiency.
No generation of stress waves in coolant.
Low activation of coolant. No corrosion problems

Peripheral vs transversal cooling

peripheral cooling does not appear sufficient to maintain a low dT within the target material.
A transversal cooling arrangement may be necessary to provide cooling at the core of the target.

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Ottone Caretta, RAL, January 2011

Targets

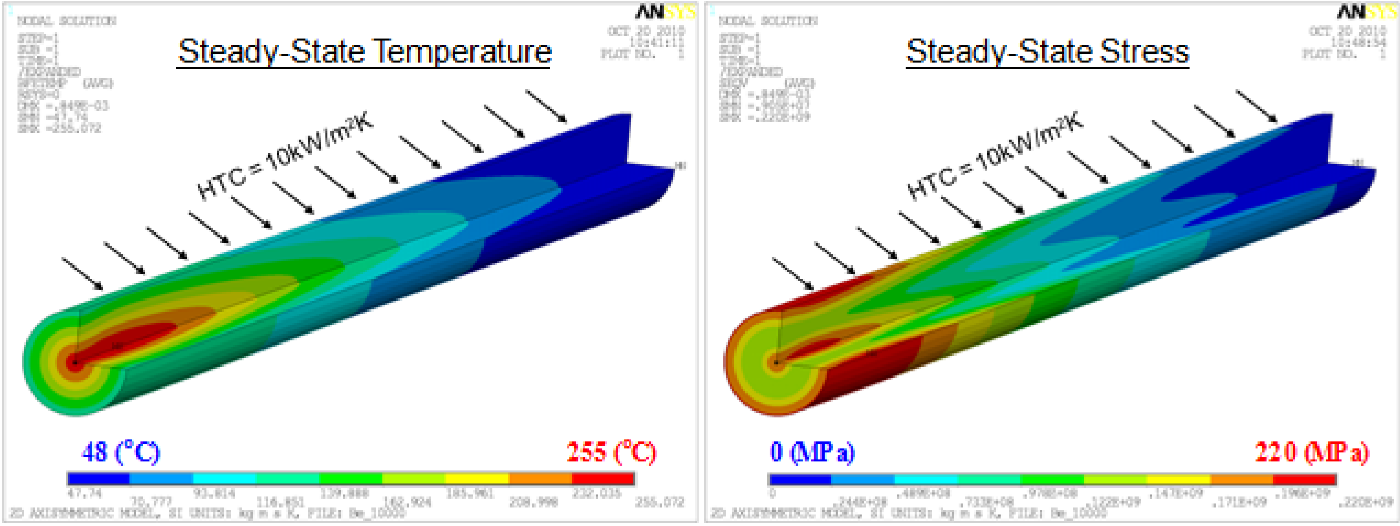
Ottone Caretta/RAL

Cylindrical Solid Target

with peripheral cooling

- Initial baseline was a solid cylindrical beryllium target. This has since been ruled out
  - At thermal equilibrium (after a few hundred beam pulses) large temperature variations develop within the target
  - The large ΔT between the target surface and core leads to an excessive steady-state thermal stress
  - This ΔT depends on the material thermal conductivity and cannot be overcome by more aggressive surface cooling

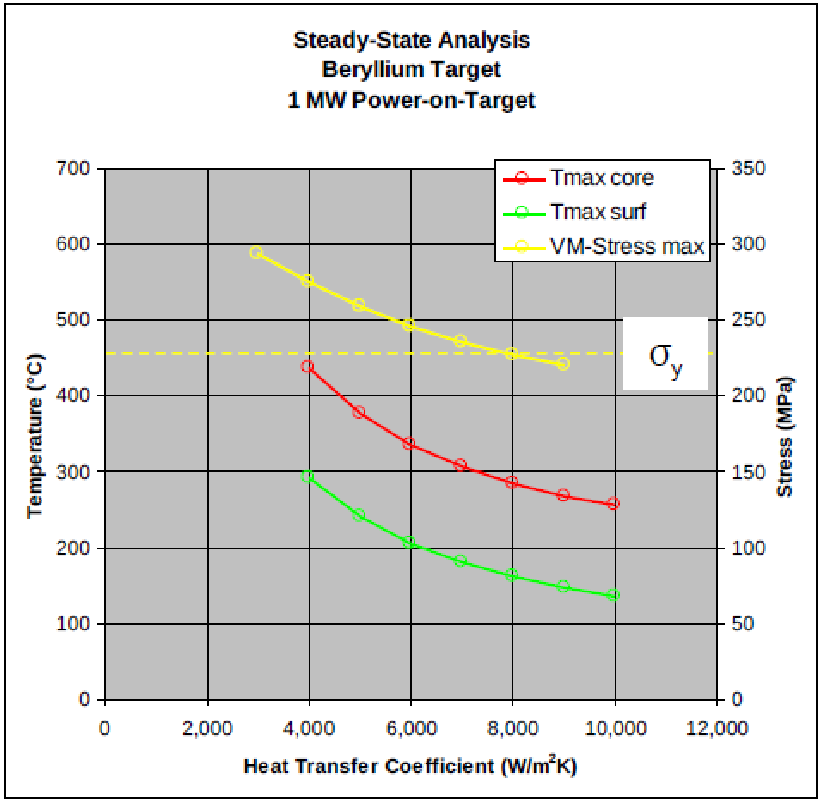
ruled out

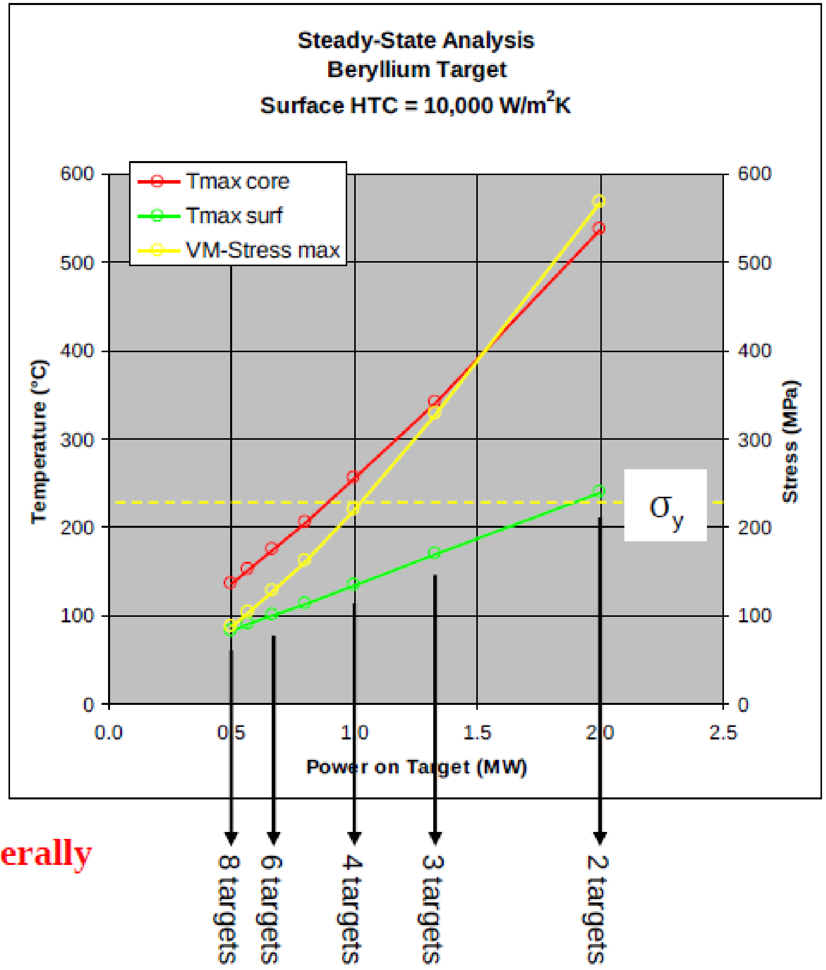


Temperature (left) and and Von-Mises thermal stress (right) corresponding to steady state operation of a peripherally cooled cylindrical beryllium target

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Stress in a EURONu solid peripherally cooled beryllium target


Steady-State Analysis
Beryllium Target
1 MW Power-on-Target


Steady-State Analysis
Beryllium Target
Surface HTC = 10,000 W/m²K

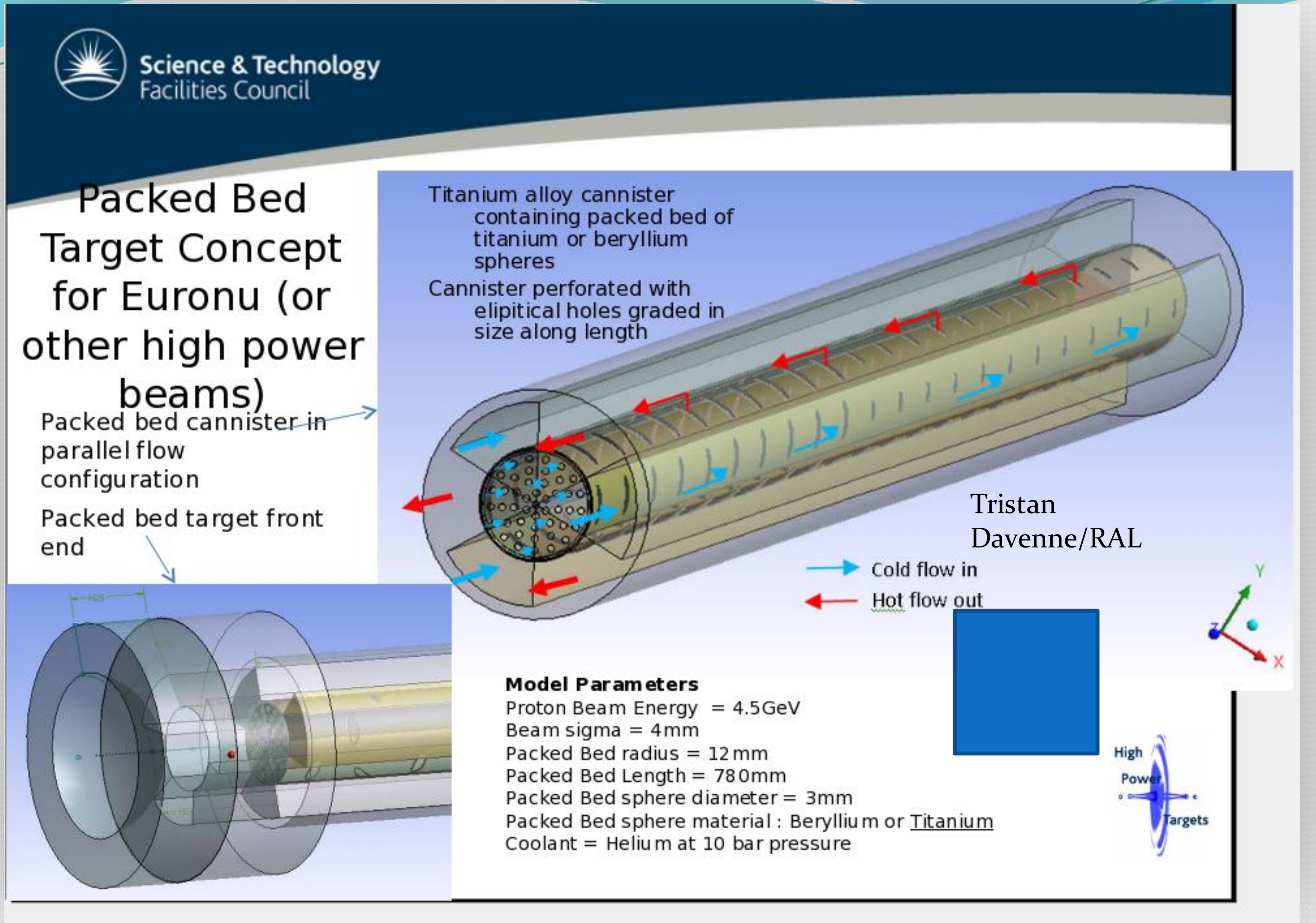
Reached limit for a solid peripherally cooled target

What is heat dissipation capability of a packed bed target?

Peter Loveridge, January 2011

Packed bed Target

- Why packed bed target with transversal cooling is the baseline option ?
  - ✓ Large surface area for heat transfer
  - ✓ Coolant able to access areas with highest energy deposition
  - ✓ Minimal stresses
  - ✓ Potential heat removal rates at the hundreds of kW level
  - ✓ Pressurised cooling gas required at high power levels
  - ✓ Bulk density lower than solid density
  - ✓ From a thermal and engineering point of view seems a reasonable concept where stress levels in a traditional solid target design look concerningly high



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

Packed bed cannister in parallel flow configuration

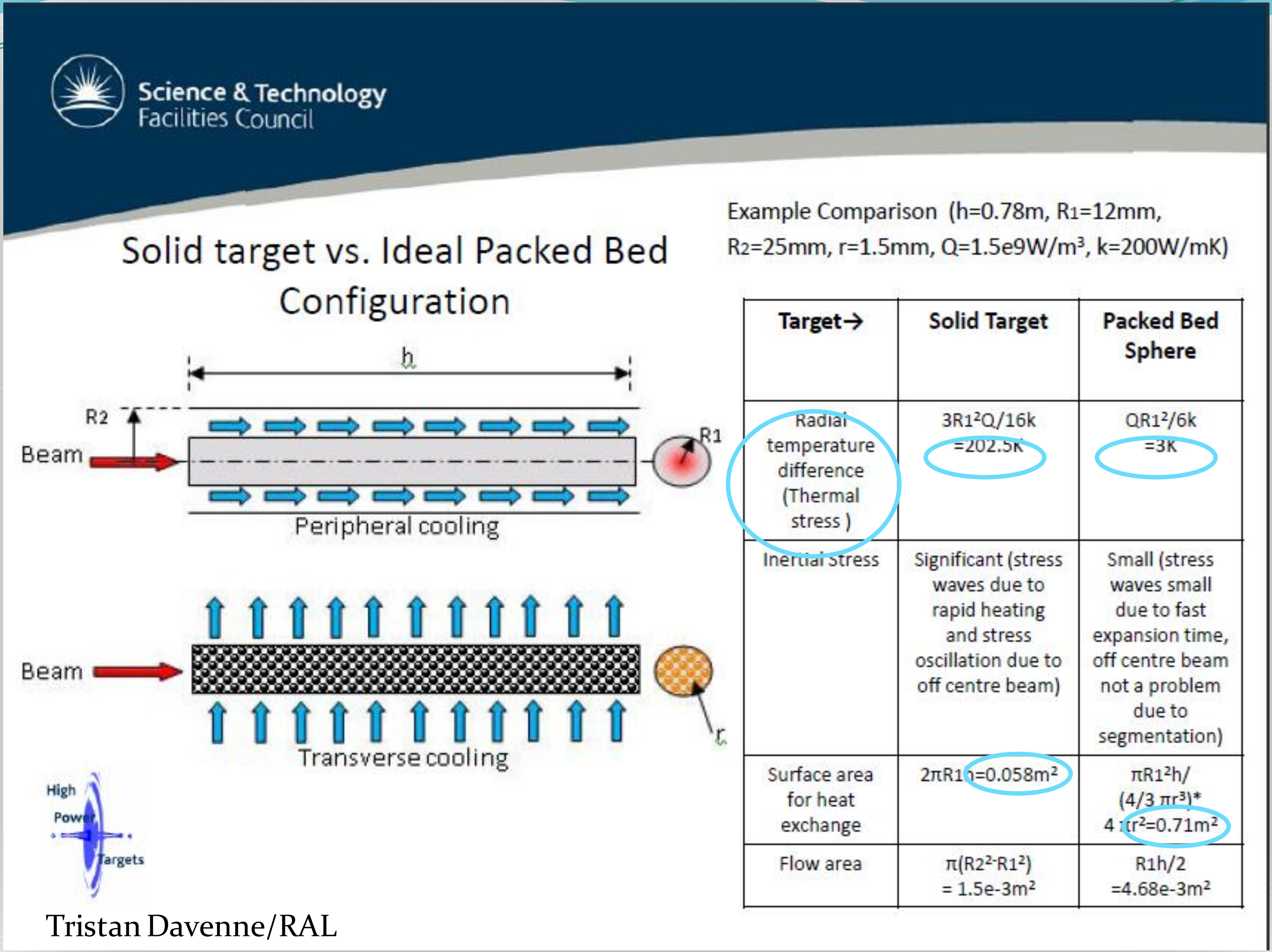
Packed bed target front end

Titanium alloy cannister containing packed bed of titanium or beryllium spheres

Cannister perforated with elipitical 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

Tristan Davenne/RAL



Science & Technology Facilities Council

Solid target vs. Ideal Packed Bed Configuration

Example Comparison (h=0.78m, R_1=12mm, R_2=25mm, r=1.5mm, Q=1.5e9W/m³, k=200W/mK)

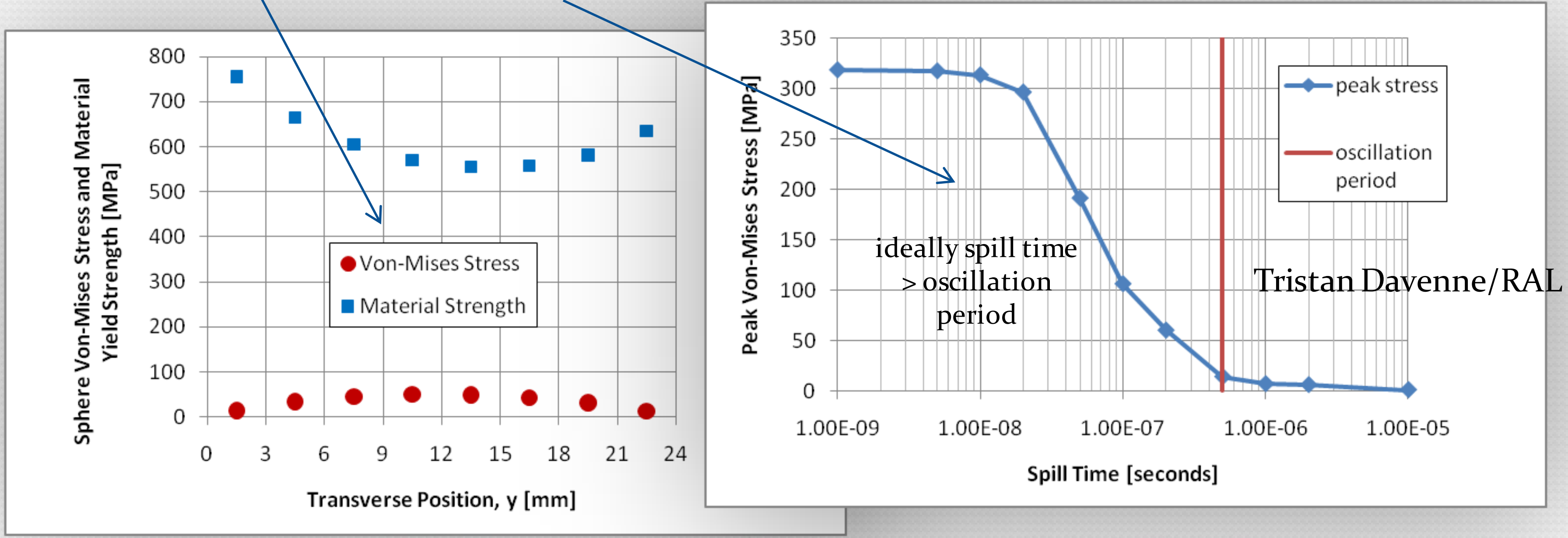
Target→	Solid Target	Packed Bed Sphere
Radial temperature difference (Thermal stress)	$3R_1^2Q/16k$ =202.5K	$QR_1^2/6k$ =3K
Inertial Stress	Significant (stress waves due to rapid heating and stress oscillation due to off centre beam)	Small (stress waves small due to fast expansion time, off centre beam not a problem due to segmentation)
Surface area for heat exchange	$2\pi R_1h$=0.058m²	$\pi R_1^2h/(4/3\,\pi r^3)*4\pi r^2$=0.71m²
Flow area	$\pi(R_2^2-R_1^2)$ = 1.5e-3m²	$R_1h/2$ =4.68e-3m²

Tristan Davenne/RAL

Stresses for the Packed bed target

EUROnu example, 24mm diameter cannister packed with 3mm Ti6Al4V spheres

- Quasi thermal and Inertial dynamic components

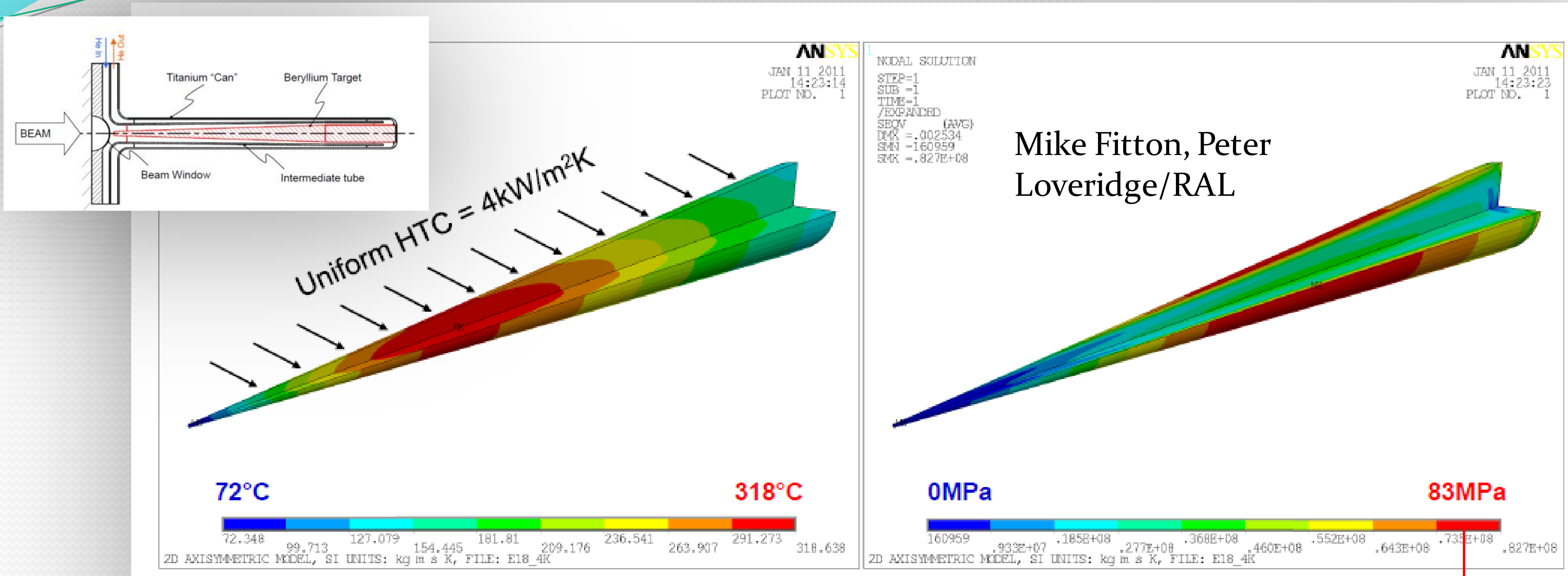


ideally spill time > oscillation period

Tristan Davenne/RAL

INPUTS					LIMITING FACTORS				
Beam Power	heat deposited	Sphere diameter	Helium pressure	Maximum Power Deposition	Maximum Helium Temperature	Sphere Core Temperature	Max Sphere VMStress	Minimum Yield Stress / VMStress	Pressure Drop
1MW	50kW	3mm	10bar	2.2e9W/m3	133°C	296°C	49MPa	11.7	0.45bar
1.3MW	65kW	3mm	10bar	2.9e9W/m3	133°C	331°C	65MPa	8.7	0.73bar
4MW	200kW	3mm	10bar	8.8e9W/m3	200°C	650°C	116MPa	3.8	2.8bar
4MW	200kW	3mm	20bar	8.8e9W/m3	133°C	557°C	140MPa	3.2	3.4bar
4MW	200kW	3mm	20bar	8.8e9W/m3	200°C	650°C	116MPa	3.8	1.4bar

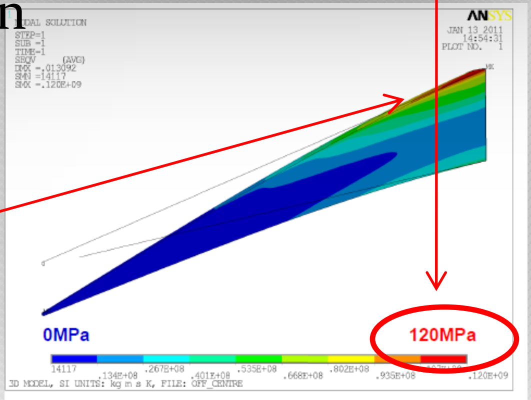
Alternative solution: pencil “closed” Be Solid target



Mike Fitton, Peter Loveridge/RAL

Temperature (left) and Von-Mises thermal stress (right) corresponding to a steady state operation with a surface HTC = 4kW/m²K, bulk fluid temp = 30°C

- Pencil like Geometry merits further investigation
  - ✓ Steady-state thermal stress within acceptable range
  - ✓ Shorter conduction path to coolant
  - ✓ Pressurized helium cooling appears feasible
  - ✓ Off centre beam effects could be problematic?
  - ✓ Needs further thermo-mechanical studies



Horn Studies

evolution of the horn shape after many studies:

details in WP2 notes @
http://www.euronu.org/

- triangle shape (van der Meer) with target inside the horn : in general best configuration for low energy beam

⇩

- triangle with target integrated to the inner conductor : very good physics results but high energy deposition and stresses on the conductors

⇩

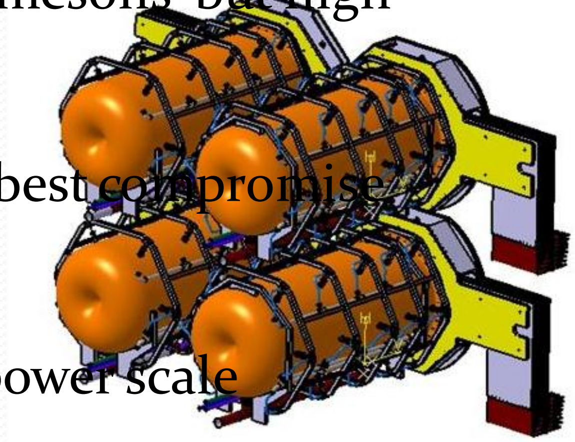
- forward-closed shape with target integrated to the inner conductor : best physics results, best rejection of wrong sign mesons but high energy deposition and stresses

⇩

- forward-closed shape with no-integrated target: best compromise between physics and reliability

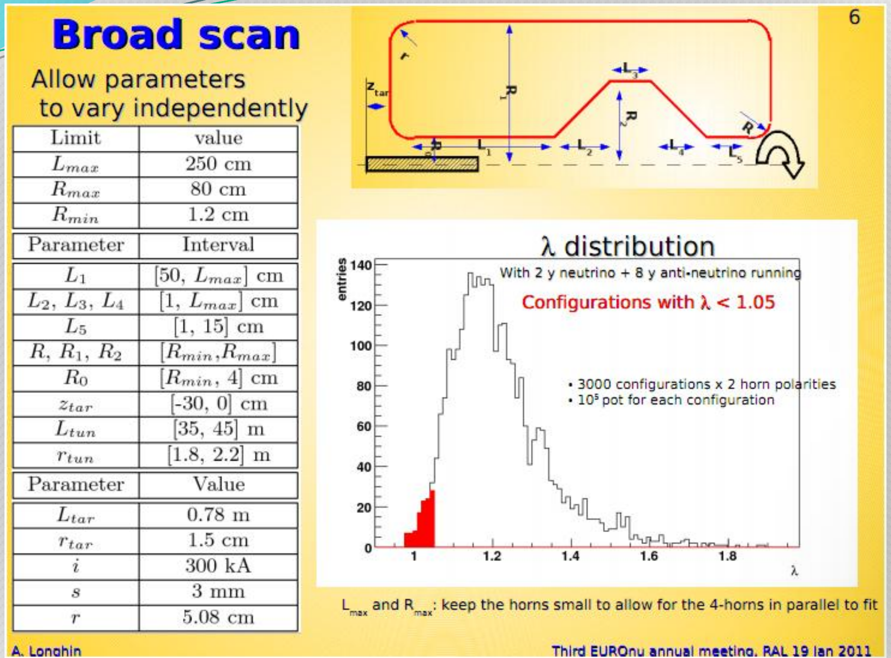
⇩

- 4-horn/target system to accommodate the MW power scale



Horn Shape and SuperBeam geometrical Optimization

- minimize λ, the δ_{cp}-averaged 99%CL sensitivity limit on $\sin^2 2\theta_{13}$
- broad scan, then fix & restrict parameters then re-iterate for best horn parameters & SuperBeam geometry



Broad scan

Allow parameters to vary independently

Limit	value
L_{max}	250 cm
R_{max}	80 cm
R_{min}	1.2 cm

Parameter	Interval
L_1	$[50, L_{max}]$ cm
L_2, L_3, L_4	$[1, L_{max}]$ cm
L_5	[1, 15] cm
R, R_1, R_2	$[R_{min}, R_{max}]$
R_0	$[R_{min}, 4]$ cm
z_{tar}	[-30, 0] cm
L_{tun}	[35, 45] m
r_{tun}	[1.8, 2.2] m

Parameter	Value
L_{tar}	0.78 m
r_{tar}	1.5 cm
i	300 kA
s	3 mm
r	5.08 cm

λ distribution

With 2 y neutrino + 8 y anti-neutrino running

Configurations with λ < 1.05

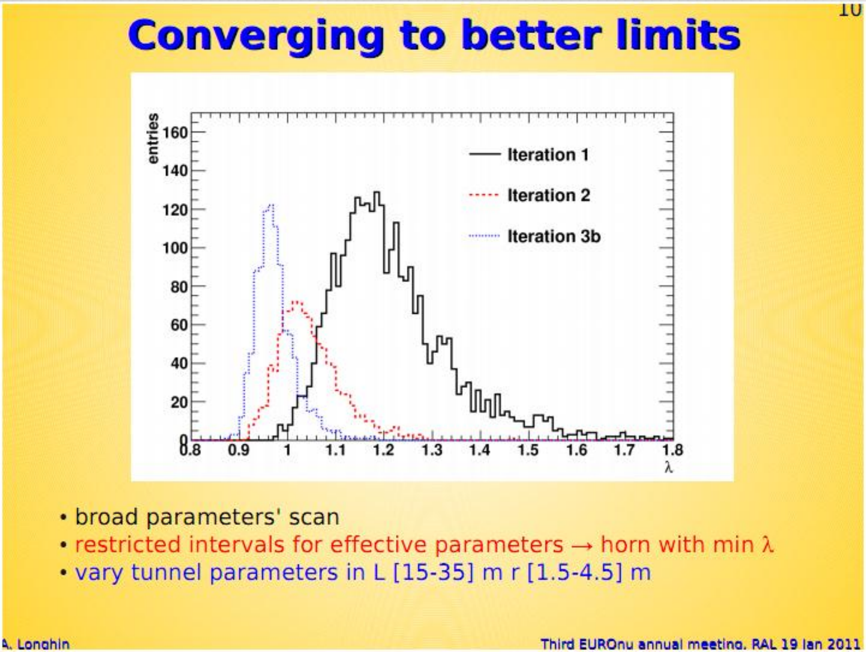
- 3000 configurations x 2 horn polarities
- 10^5 pot for each configuration

L_{max} and R_{max}: keep the horns small to allow for the 4-horns in parallel to fit

A. Longhin

Third EUROnu annual meeting, RAL 19 Jan 2011

A. Longhin/CEA

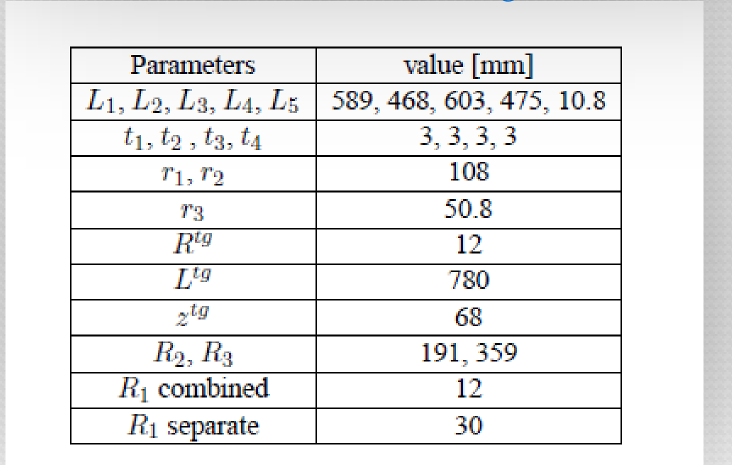


Converging to better limits

- broad parameters' scan
- restricted intervals for effective parameters → horn with min λ
- vary tunnel parameters in L [15-35] m r [1.5-4.5] m

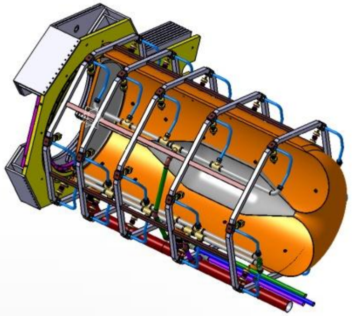
A. Longhin

Third EUROnu annual meeting, RAL 19 Jan 2011



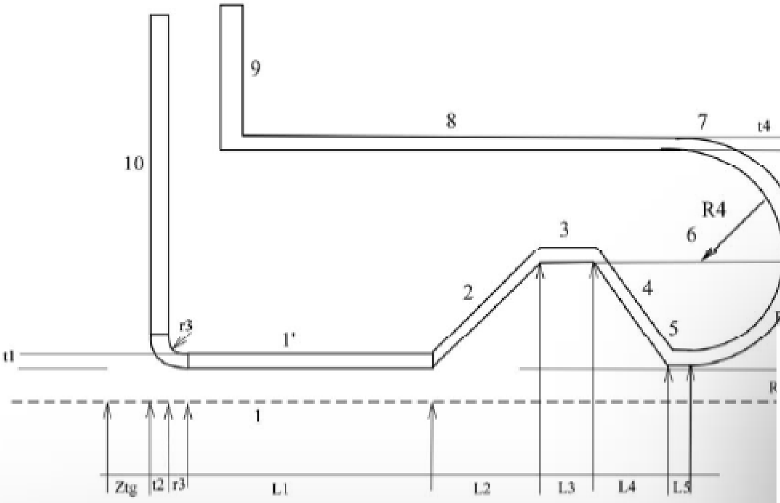
Parameters	value [mm]
L_1, L_2, L_3, L_4, L_5	589, 468, 603, 475, 10.8
t_1, t_2, t_3, t_4	3, 3, 3, 3
r_1, r_2	108
r_3	50.8
R^{tg}	12
L^{tg}	780
z^{tg}	68
R_2, R_3	191, 359
R_1 combined	12
R_1 separate	30

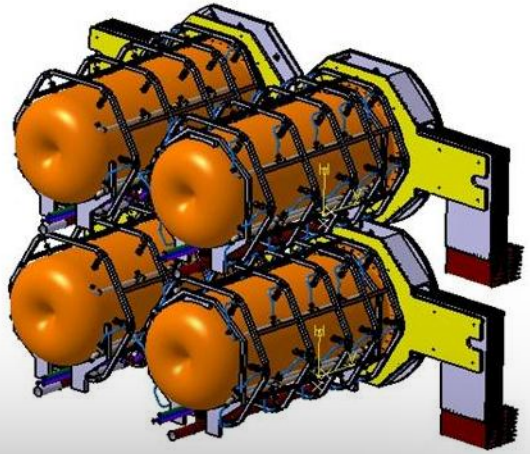
Horn Stress Studies

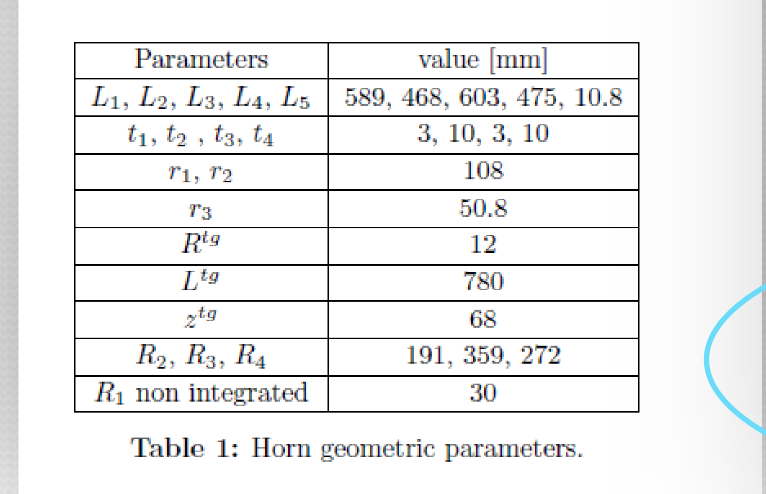


- horn structure
  - Al 6061 T6 alloy; good trade off between mechanical strength, resistance to corrosion and electrical conductivity and cost
  - horn thickness has to be as small as possible for the best physics performance and to limit energy deposition from secondary particles but thick enough to sustain dynamic stress from the pulsed currents.
- horn stress and deformation
  - magnetic pressure and thermal dilatation
  - COMSOL, ANSYS software
- cooling
  - water

EUROnu scenario for 4-horn system

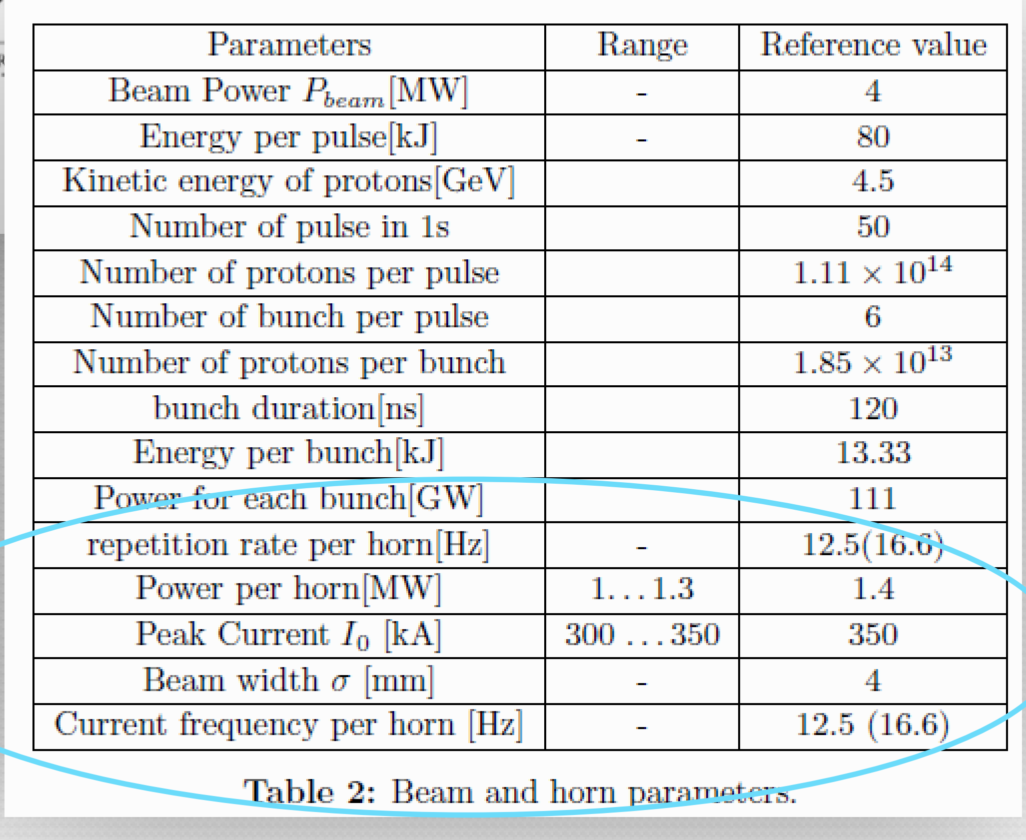






Parameters	value [mm]
L_1, L_2, L_3, L_4, L_5	589, 468, 603, 475, 10.8
t_1, t_2, t_3, t_4	3, 10, 3, 10
r_1, r_2	108
r_3	50.8
R^{tg}	12
L^{tg}	780
z^{tg}	68
R_2, R_3, R_4	191, 359, 272
R_1 non integrated	30

Table 1: Horn geometric parameters.

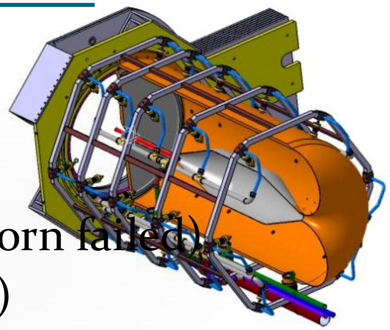


Parameters	Range	Reference value
Beam Power P_{beam}[MW]	-	4
Energy per pulse[kJ]	-	80
Kinetic energy of protons[GeV]		4.5
Number of pulse in 1s		50
Number of protons per pulse		1.11×10^{14}
Number of bunch per pulse		6
Number of protons per bunch		1.85×10^{13}
bunch duration[ns]		120
Energy per bunch[kJ]		13.33
Power for each bunch[GW]		111
repetition rate per horn[Hz]	-	12.5(16.6)
Power per horn[MW]	1...1.3	1.4
Peak Current I_0 [kA]	300 ...350	350
Beam width σ [mm]	-	4
Current frequency per horn [Hz]	-	12.5 (16.6)

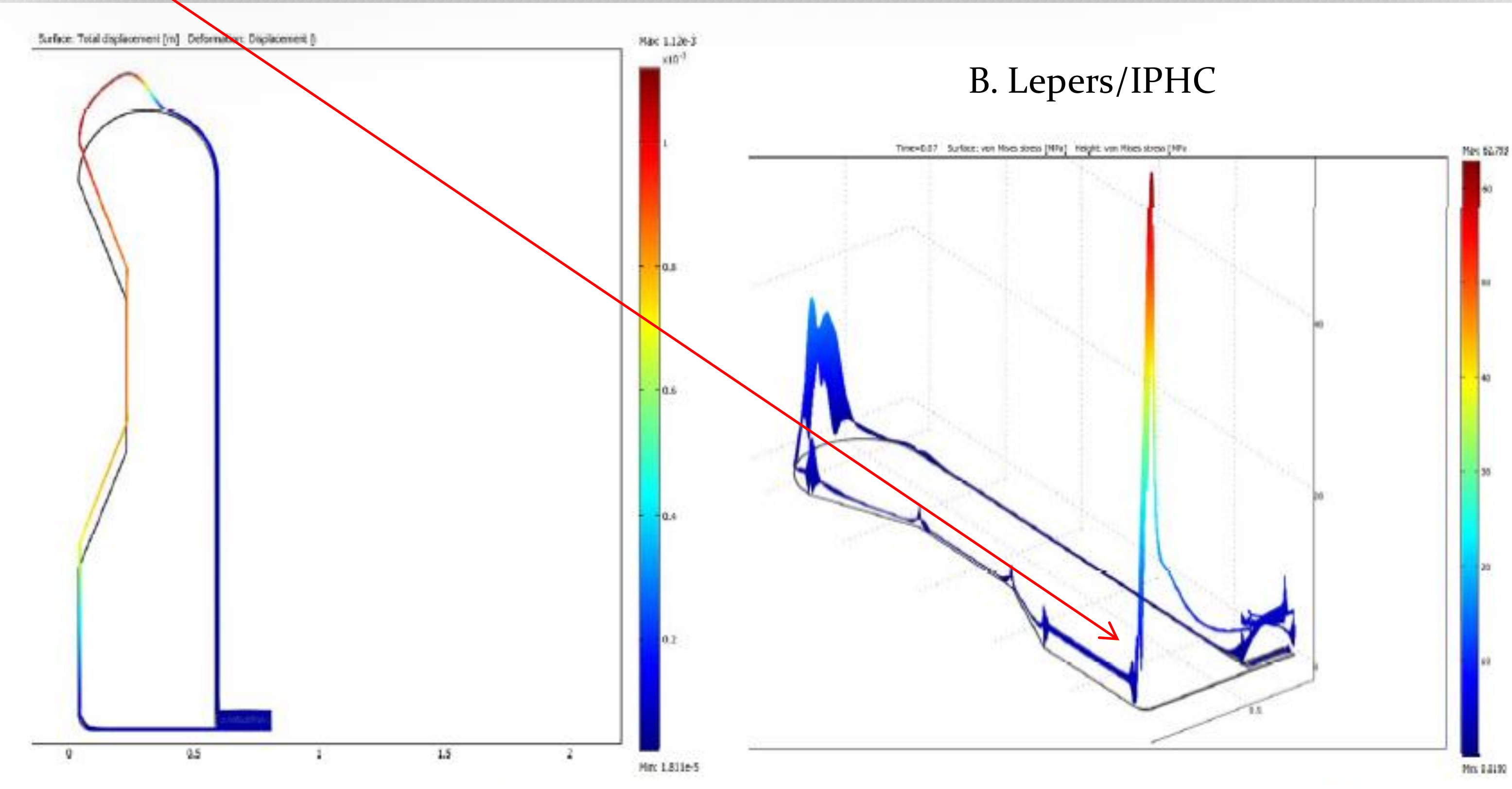
Table 2: Beam and horn parameters.

Stress Analysis for the SPL SuperBeam Horn I

B. Lepers/IPHC, P. Cupial , L. Lacny/Cracow Univ. of Tech.



- Thermo-mechanical stresses:
  - ✓ secondary particles energy deposition and joule losses
  - ✓ $T=60ms$, $\tau_0=100\mu s$, $I_{rms}=10.1kA$, $f=5kHz$ (worst scenario, 1horn failed)
  - ✓ $T_{Al}=60^oC$, $\{h_{corner}, h_{inner}, h_{horn/out}\}=\{6.5, 3.8, 0.1\}$ kW/(m²K)
  - ✓ $S_{max} = 62MPa$



B. Lepers/IPHC

a) displacement $u_{max} = 1.12$ mm

b) Von Mises stress $s_{max} = 62$ MPa

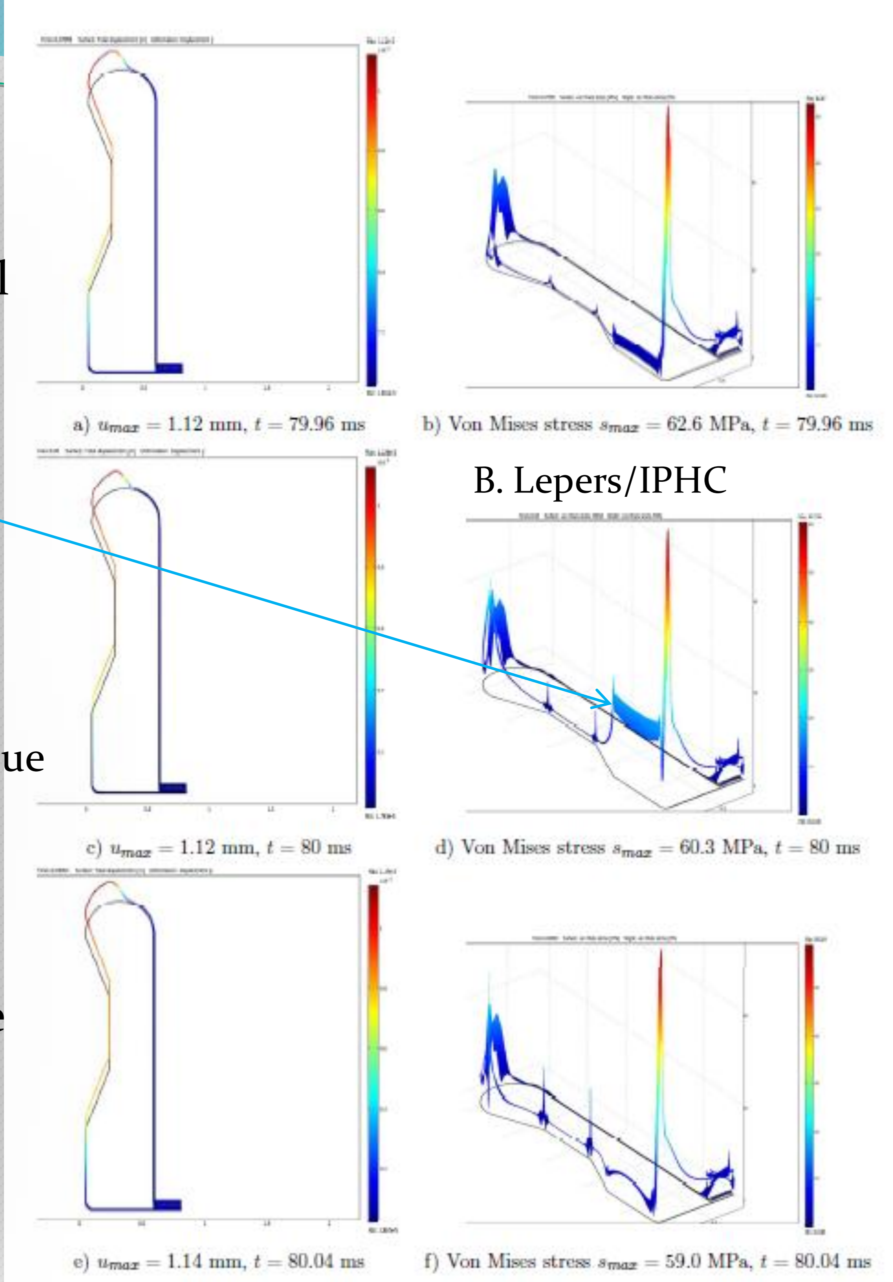
Stress Analysis II

➢ Combined analysis of Thermo-mechanical and magnetic pressure induced stresses:

- ✓ significant stress or the inner conductor especially, for the upstream corner and downstream plate inner part
- ✓ high stress at inner conductor welded junctions
- ✓ thermal dilatation contributes to longitudinal stress; displacement is low due to the magnetic pulse
- ✓ maximum displacement at downstream plate

➢ horn lifetime estimation: results have to be compared with fatigue strength data

➢ more water-jet cooling might be applied



a) $u_{max} = 1.12$ mm, $t = 79.96$ ms

b) Von Mises stress $s_{max} = 62.6$ MPa, $t = 79.96$ ms

B. Lepers/IPHC

c) $u_{max} = 1.12$ mm, $t = 80$ ms

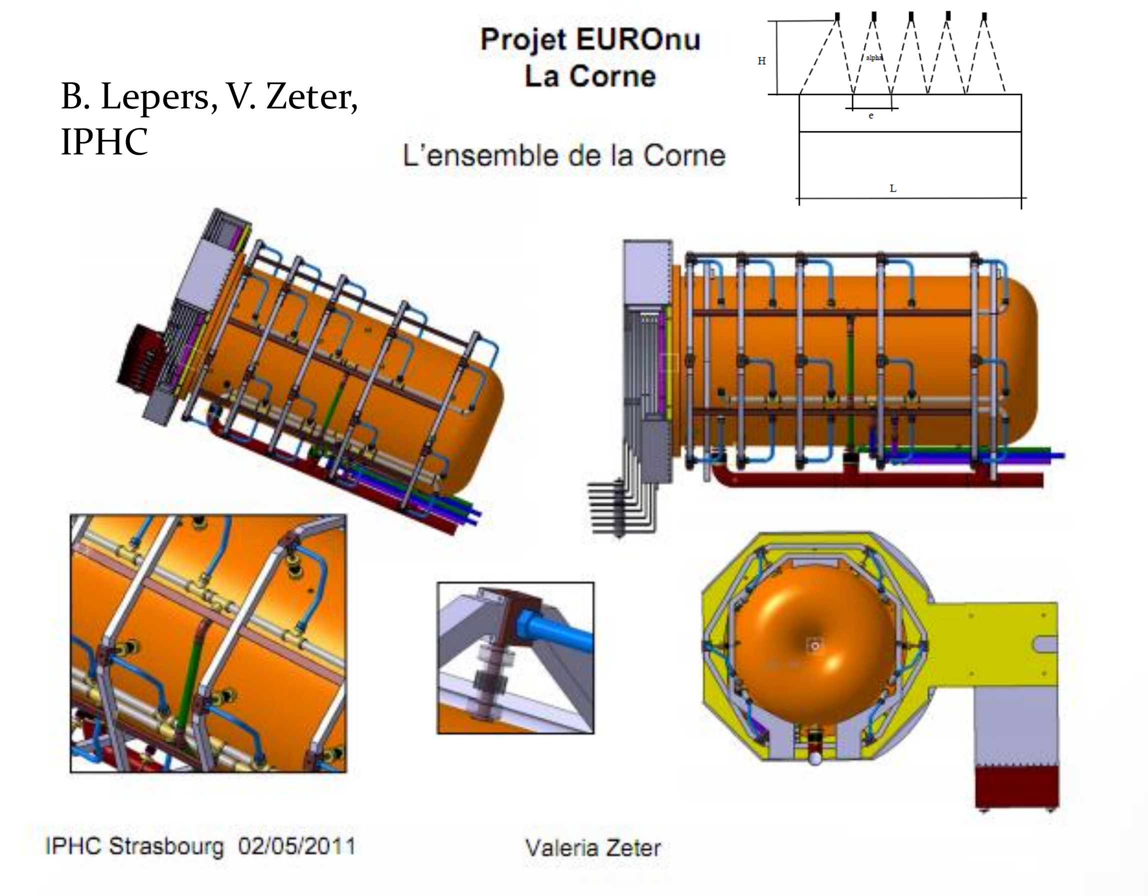
d) Von Mises stress $s_{max} = 60.3$ MPa, $t = 80$ ms

e) $u_{max} = 1.14$ mm, $t = 80.04$ ms

f) Von Mises stress $s_{max} = 59.0$ MPa, $t = 80.04$ ms

displacement and stress time evolution, peak magnetic field each T=80ms (4-horns)

Cooling Studies



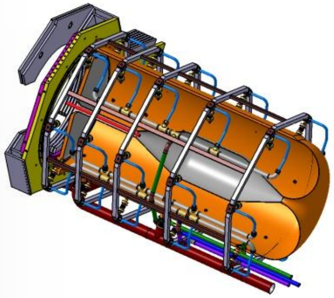
B. Lepers, V. Zeter, IPHC

Projet EUROnu
La Corne

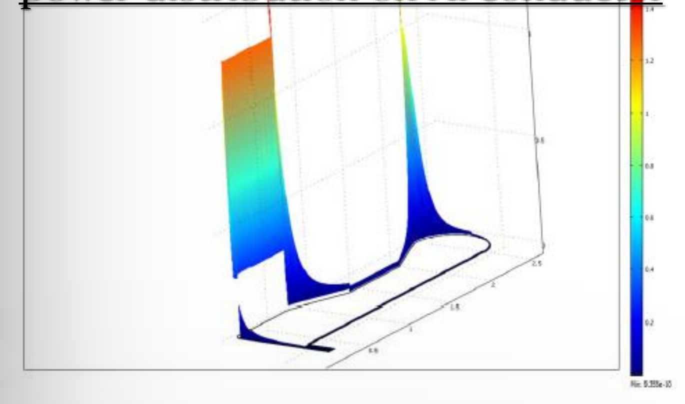
L'ensemble de la Corne

IPHC Strasbourg 02/05/2011

Valeria Zeter



power distribution on Al conductor



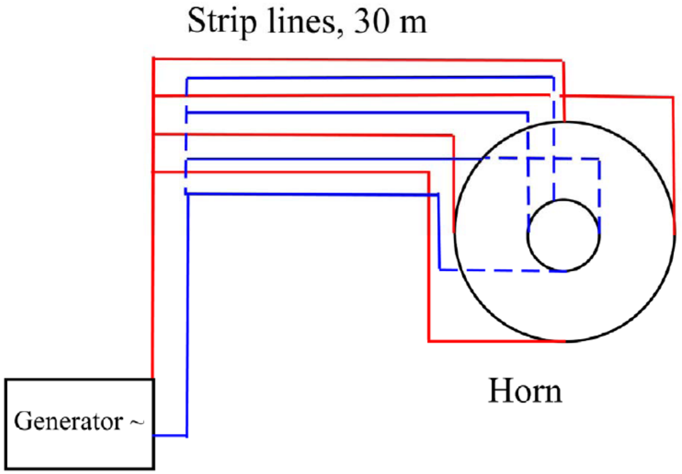
- ✓ planar and/or elliptical water jets
- ✓ flow rate between 60-120l/min
- ✓ h cooling coefficient 1-7 kW/(m²K)
- ✓ EUROnu-Note-10-06

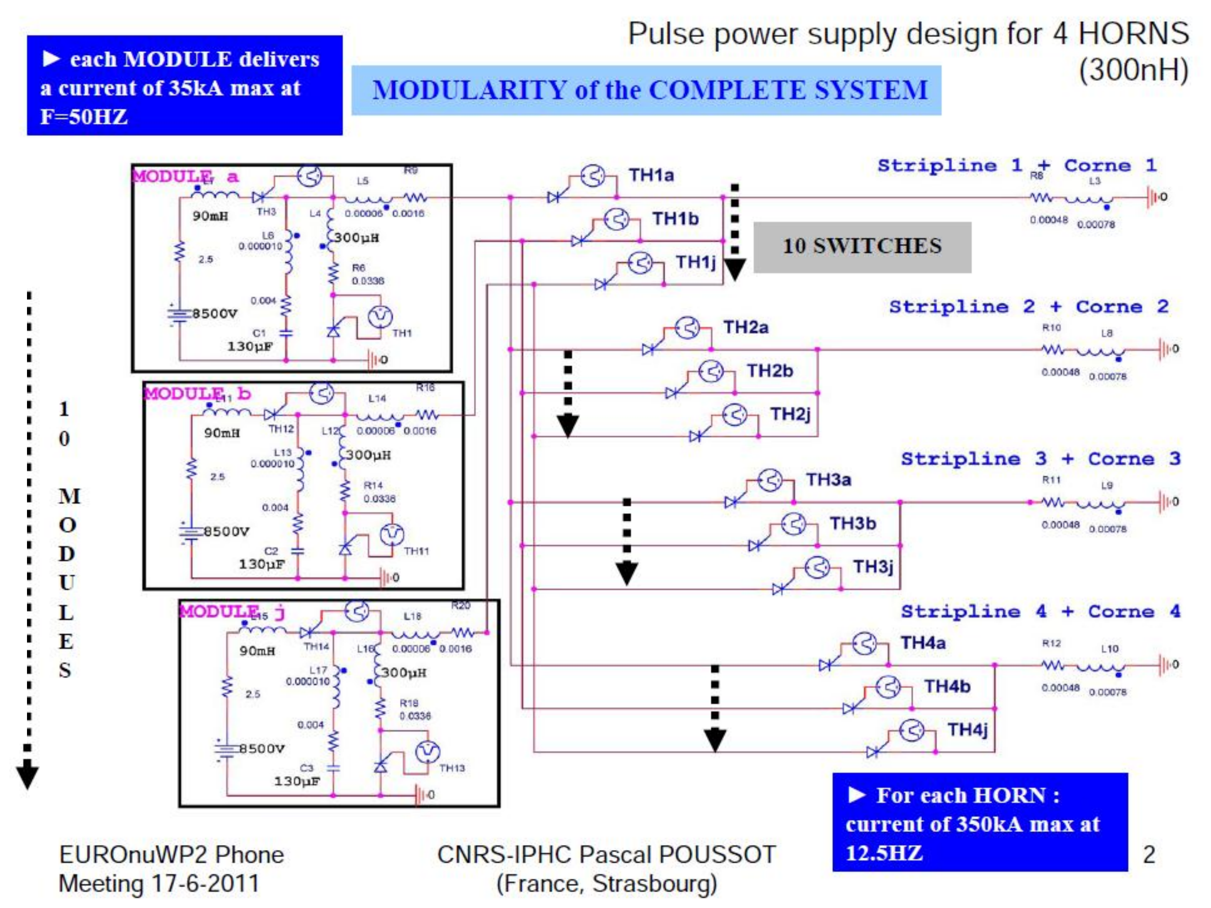
➢ design for 60°C uniform horn temperature:

- ✓ $\{h_{corner}, h_{inner}, h_{outer/horn}\} = \{6.5, 3.8, 1\}$ kW/(m²K)/longitudinal repartition of the jets follows the energy density deposition
- ✓ 30 jets/horn, 5 systems of 6-jets longitudinally distributed every 60°

Power Supply Studies

P. Poussot, J. Wurtz/IPHC





Pulse power supply design for 4 HORNS (300nH)

► each MODULE delivers a current of 35kA max at F=50HZ

MODULARITY of the COMPLETE SYSTEM

10 SWITCHES

10 MODULES

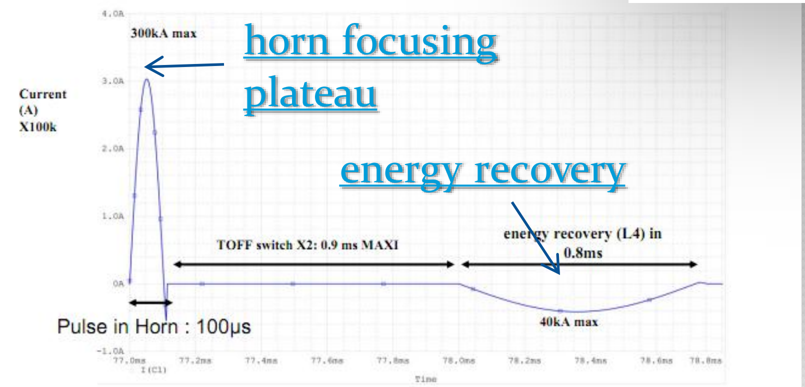
► For each HORN : current of 350kA max at 12.5HZ

EUROnuWP2 Phone Meeting 17-6-2011

CNRS-IPHC Pascal POUSSOT (France, Strasbourg)

2

energy recovery with self : current in capacitor C1

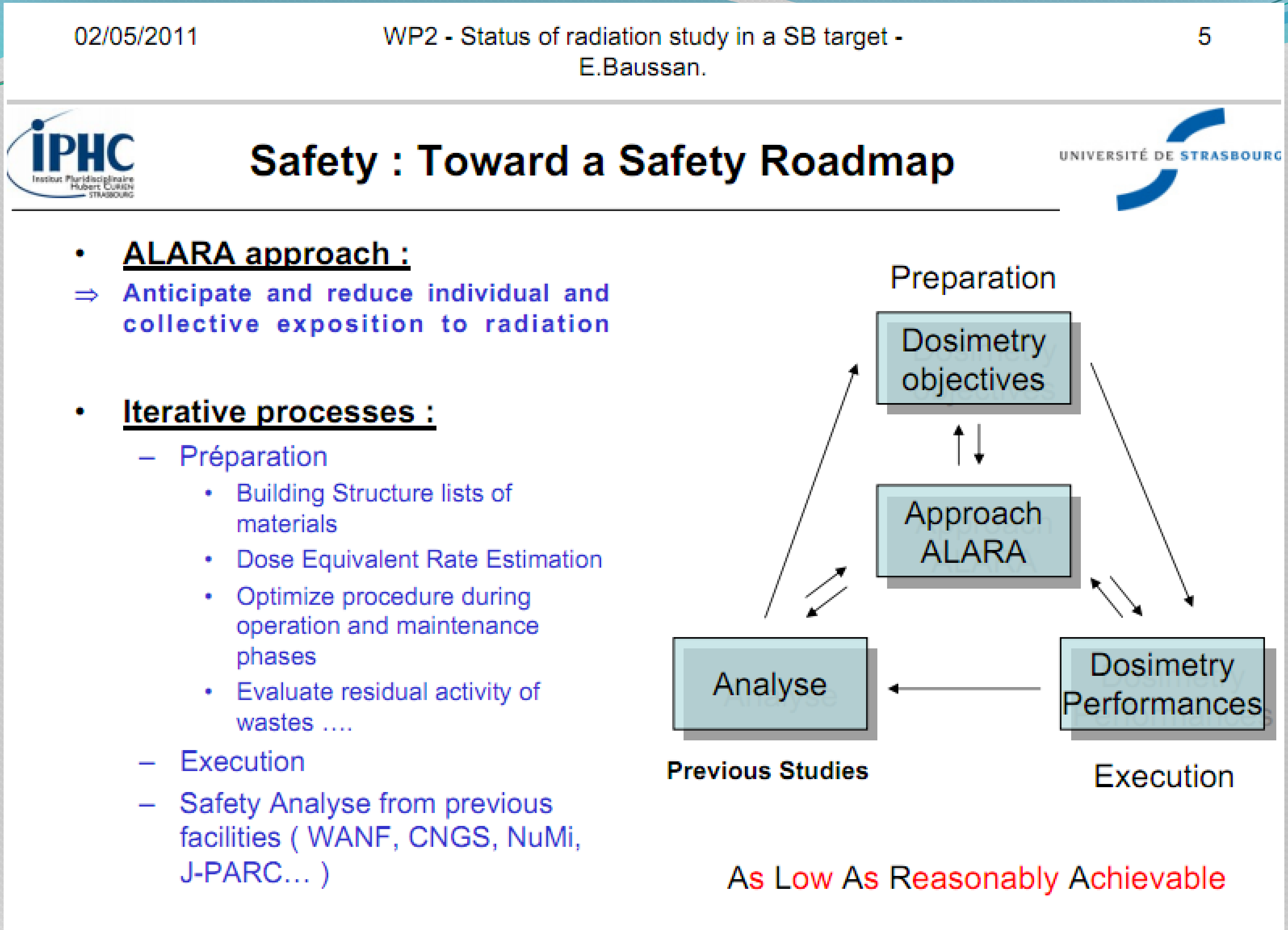


horn focusing plateau

energy recovery

Energy recovery with an inductance L, switch and capacitor:

- good energy recuperation 60%
- best solution in terms of feasibility and cost



02/05/2011 WP2 - Status of radiation study in a SB target - E.Baussan. 5

Safety : Toward a Safety 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

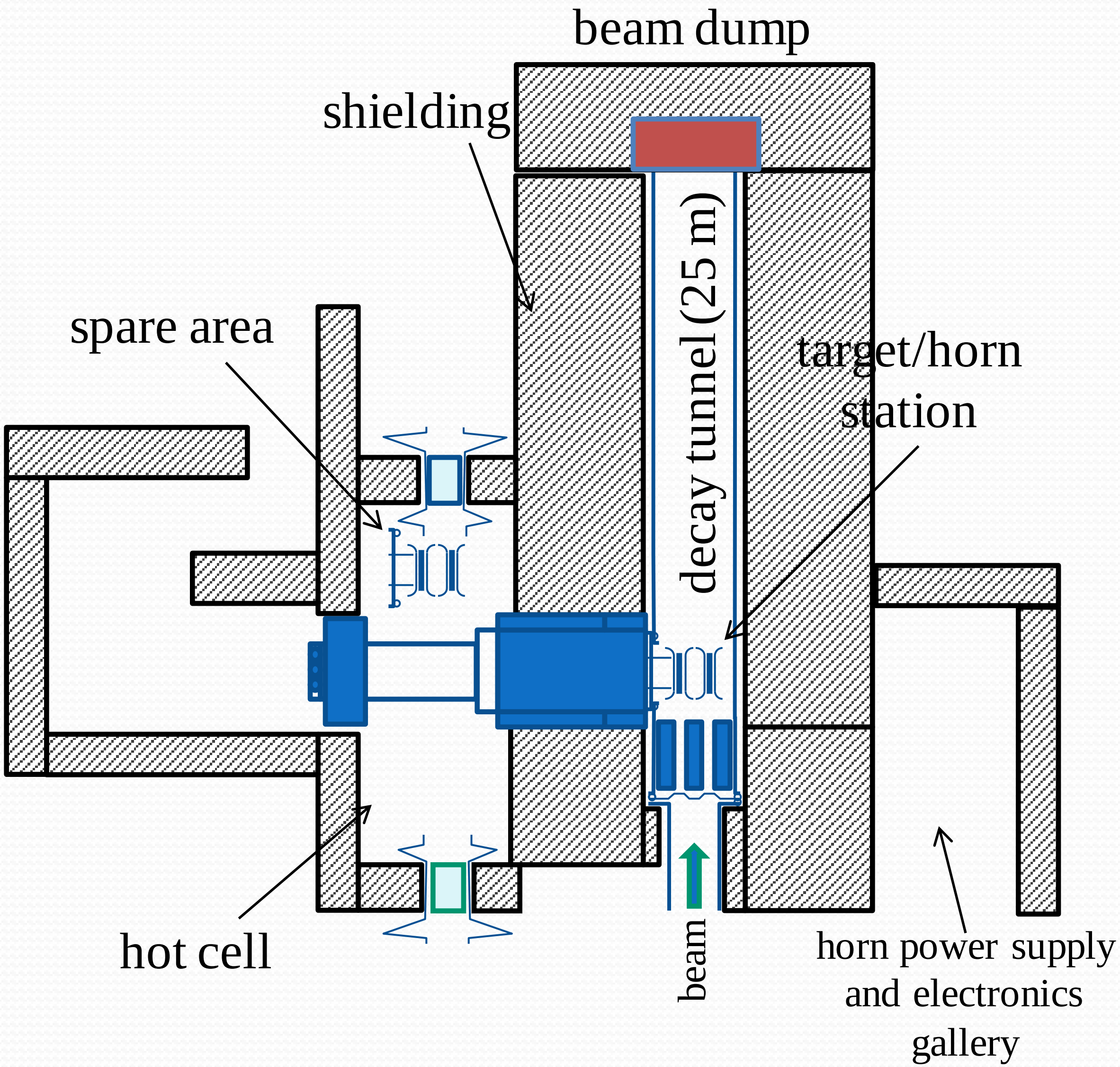
As Low As Reasonably Achievable

for Experimental Hall (Target/Horns, DT, Beam Dump), Safety Gallery, Maintenance Room, Waste Area

Safety II

Design includes:

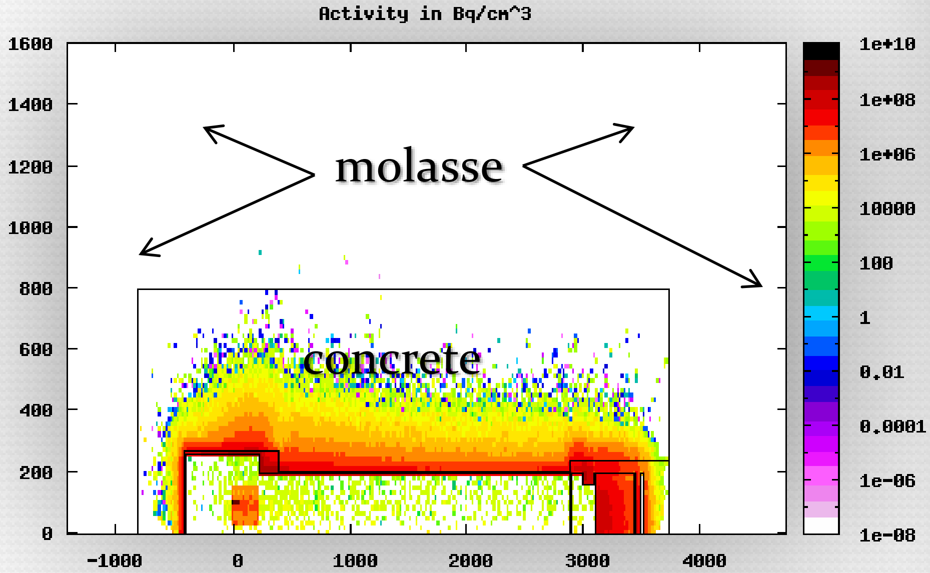
- Proton Driver line
- Experimental Hall
  - ✓ MW Target Station
  - ✓ Decay Tunnel
  - ✓ Beam Dump
- Maintenance Room
- Service Gallery
  - ✓ Power supply
  - ✓ Cooling system
  - ✓ Air-Ventilation system
- Waste Area

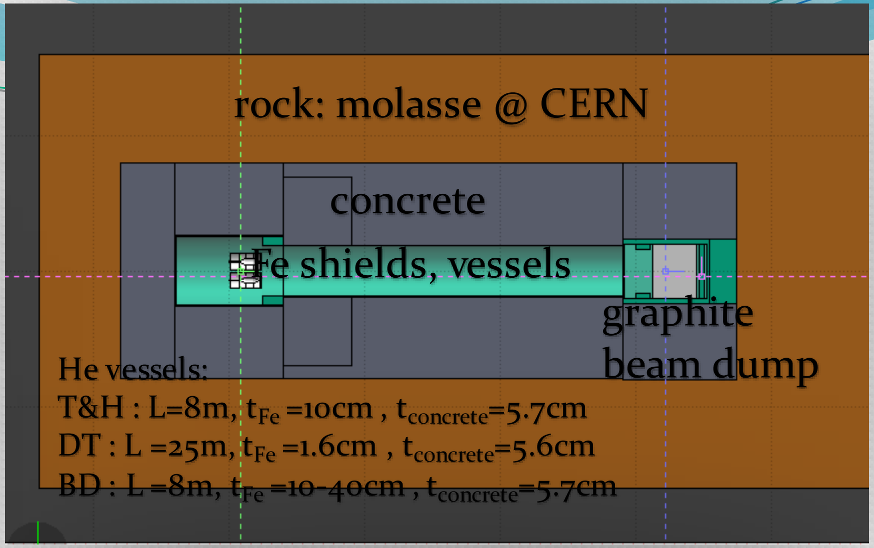


Energy deposition and Activation Studies

FLUKA MC + FLAIR

ACTIVITY density in Bq/cm³



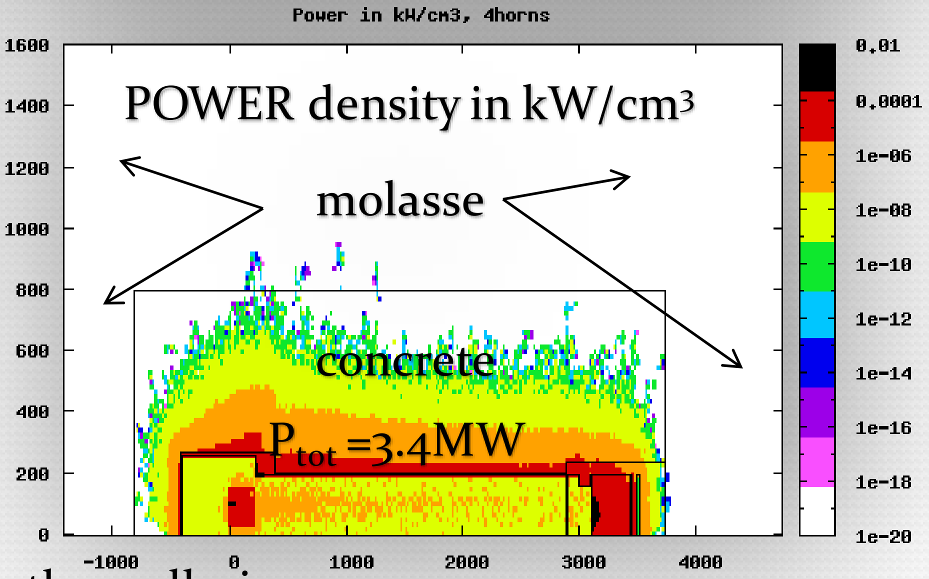


He vessels:

T&H : L=8m, t_{Fe} =10cm , $t_{concrete}$=5.7cm

DT : L =25m, t_{Fe} =1.6cm , $t_{concrete}$=5.6cm

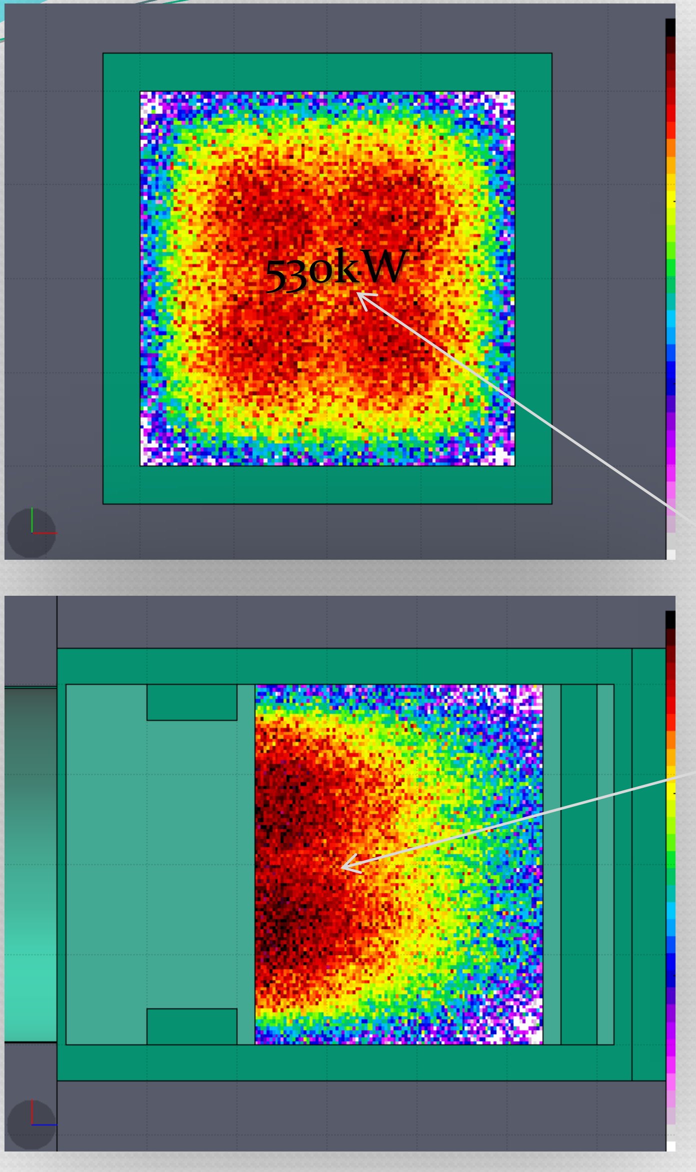
BD : L =8m, t_{Fe} =10-40cm , $t_{concrete}$=5.7cm



- energy is confined from concrete thickness
- minimum activation of molasse rock
- minimum/none effective dose to humans in other galleries
- detailed tables of the radionuclides
- water contamination from tritium is well kept under safety levels

Eric Baussan,
N. Vassilopoulos/IPHC

Energy Deposition in Beam Dump vessel



- concrete:
- t = 5.6m
- L = 8.4m

- He vessel + iron plates, water cooled
  - t_{Fe} = 10-40cm
  - L_{Fe} = 4m

- upstream shield (iron plates), water cooled
- t_{Fe} = 40cm
- L_{Fe} = 1m

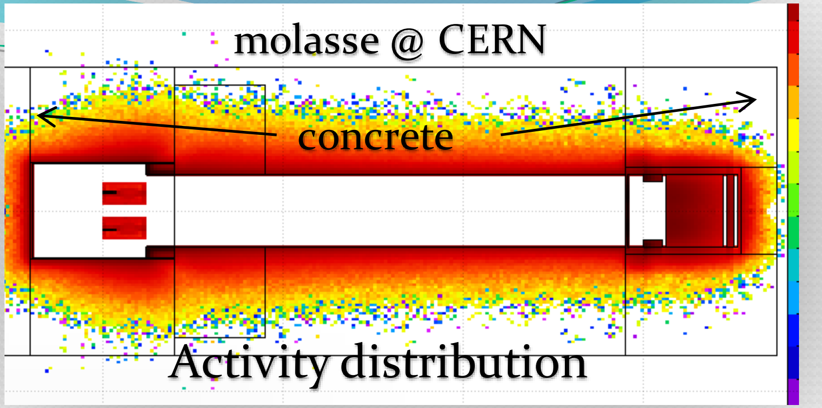
- Graphite beam dump:
- L = 3.2m, W = 4m, H = 4m
- P = 530kW

- downstream iron shield (iron plates), water cooled:
- L_{Fe} = 40cm, W_{Fe} = 4m, H_{Fe} = 4m
- P_{Fe} = 10.3kW

- outer iron shields (iron plates), water cooled
- L_{Fe}= 2m, W_{Fe} = 4.8m, H_{Fe} = 4.8m
- P_{Fe} = 1.1kW

Activation in molasse

(full 4horn simulation, medium stats: 10^6 protons, 20% error)



study set up:

- ✓ packed Ti target, 65%d_{Ti}
- ✓ 4MW beam, 4horns, 200days of irradiation

- ➢ minimum activation leads to minimum water contamination
- ➢ concrete thickness determines the activation of the molasse

results:

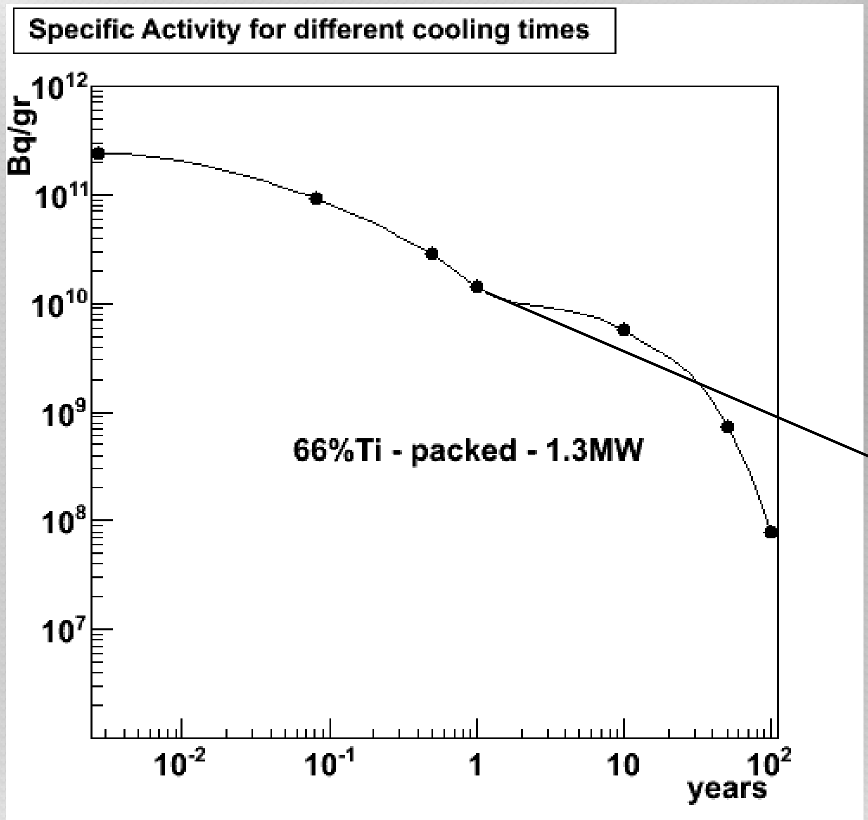
➢ of all the radionuclide's created ^{22}Na and tritium could represent a hazard by contaminating the ground water. Limits in activity after 1y=200days of beam:

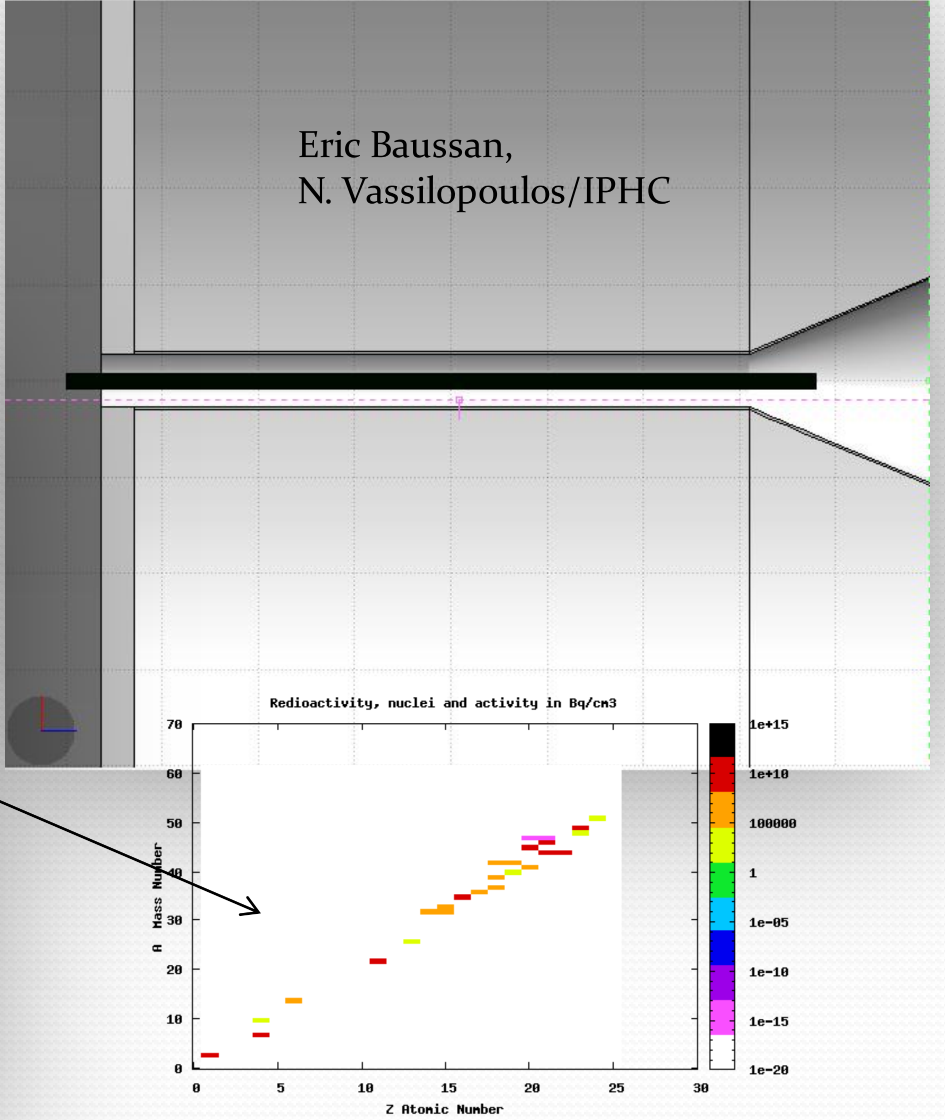
CERN annual activity constraints in molasse (for achieving 0.3mSv for the public through water)		**SuperBeam, (preliminary)**
^{22}Na	4.2×10^{11} Bq	- (to be investigated)
tritium	3.1×10^{15} Bq	6×10^8 Bq

Target Activity at Storage Area

study set up:

- packed Ti target, 65%d_{Ti}
- 1.3MW beam, 200days of irradiation
- no other activation at storage area




Eric Baussan,
N. Vassilopoulos/IPHC

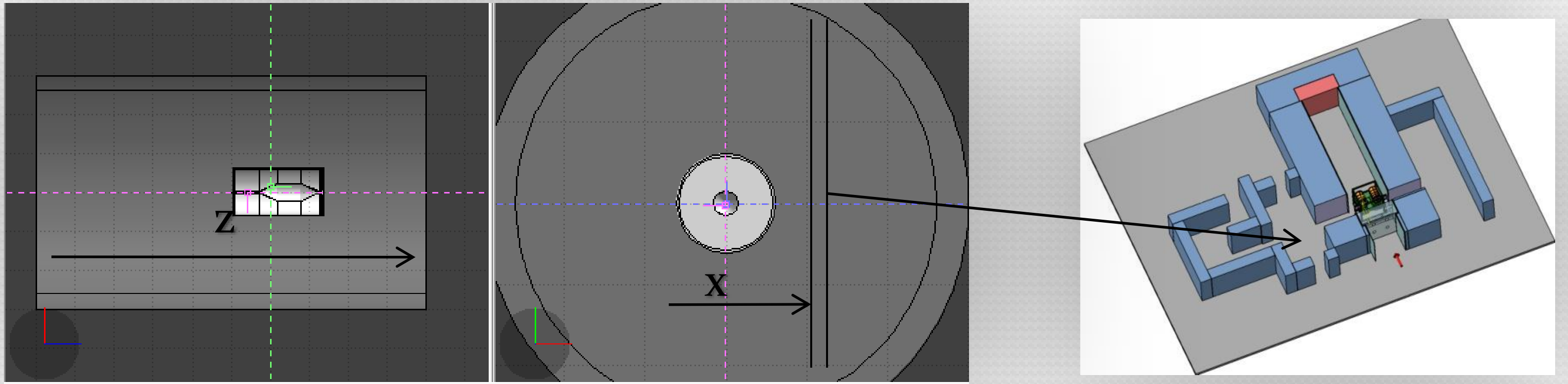
Dose Rates for target/horn at Storage/Service Area, I

radiation limits as in CNGS notes:

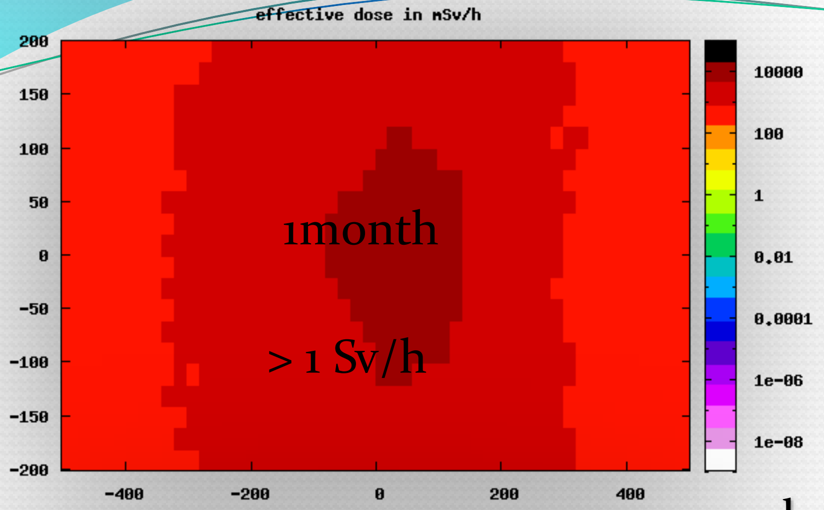
	Limits per 12-months period (mSv)	
	Public	Workers
France	< 1	< 20
Switzerland	< 1	< 20
CERN	**< 0.3**	**< 20, if .gt. 2mSv/month report to Swiss authorities**

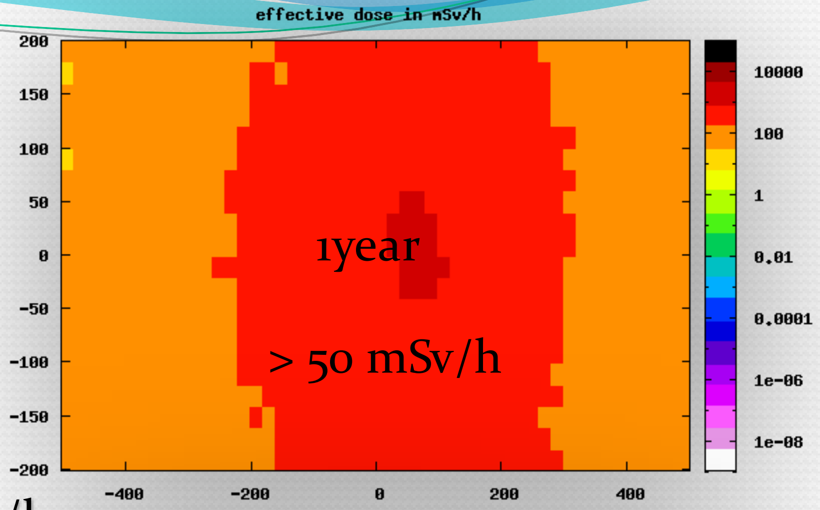
rates (e.g.):

- at 60cm distance from the outer conductor (calculation of the rates using 20cmx20cmx20cm mesh binning through out the layout -> choose a slice of x-axis with 20cm thickness and 60cm away)

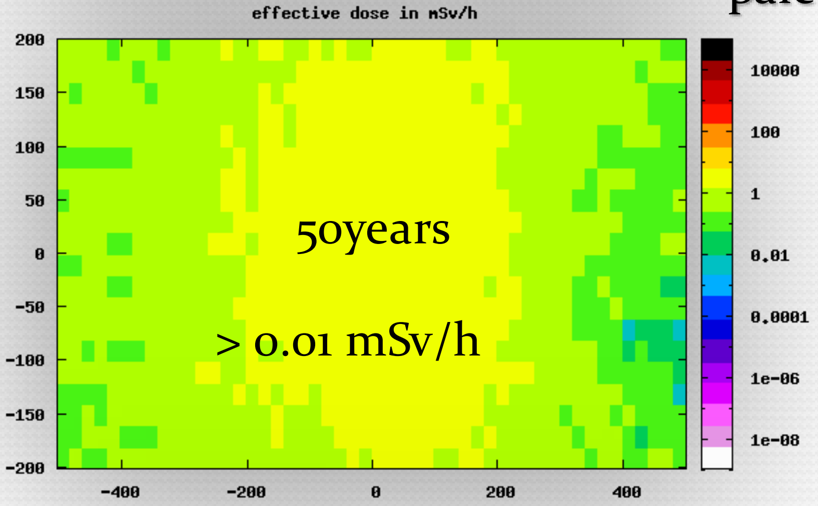


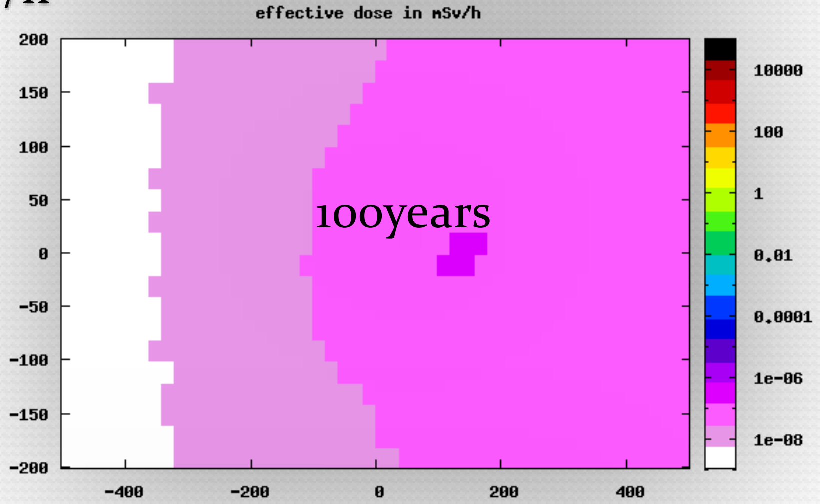
Dose Rates target/horn at Storage Area, II





palette in mSv/h





- high effective dose rates for the target/horn system makes them inaccessible

-> remote handling mandatory

Eric Baussan,
N. Vassilopoulos/IPHC

Conclusions

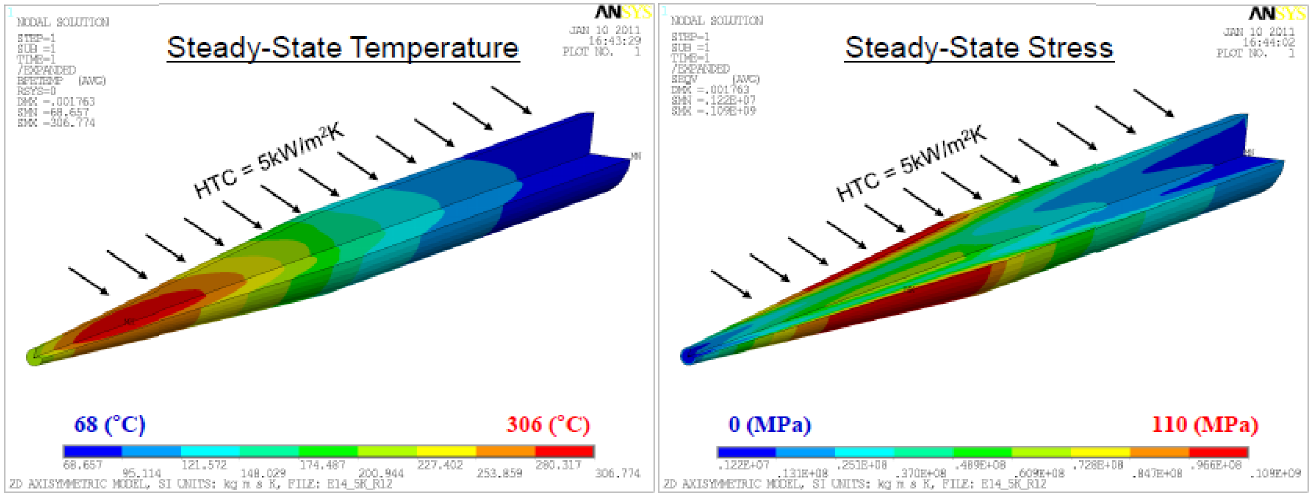
- Horn with separated target baseline as result of dynamic and static stress analyses
- 4-horn system to reduce the 4MW power effects
- Horn shape defined as forward-closed due to best physics results and reliability issues
- Packed-bed Target is preferable in multi-Watt beam environment due to minimum stresses and high heat rate removal due to transverse cooling among others
- Stress analysis support the feasibility of the target/horn design. Furthermore the power supply design looks feasible as well
- Minimum activation in molasse rock for current secondary beam layout
- High dose rates in Storage Gallery -> remote handling for repairs mandatory

to be continued …

Thanks

"Pencil Shaped" Solid Target

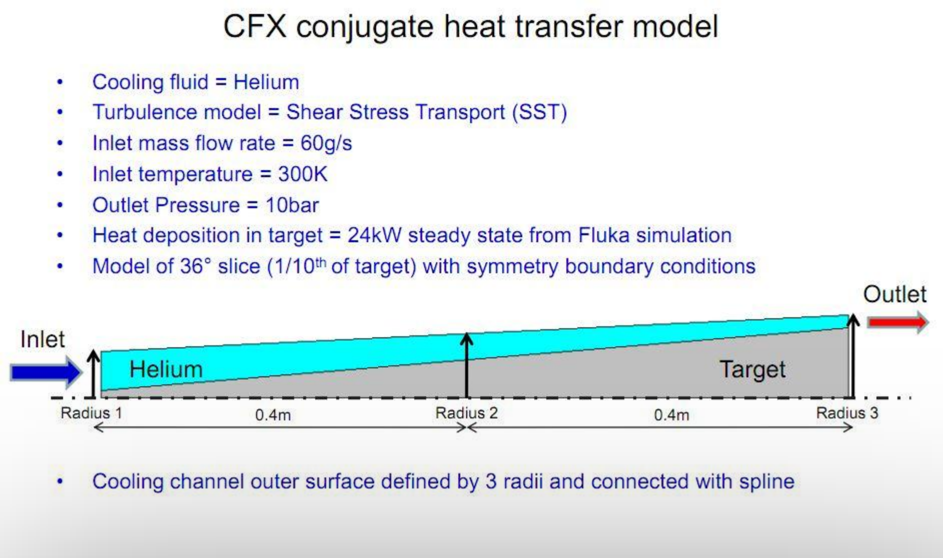
- A potential solution may be found by shaping the upstream end of the target such that the cooling fluid is in close proximity to the region of peak energy deposition
  - Shorter conduction path to coolant
  - Reduced ΔT between surface and location of Tmax
  - Thermal stress is reduced to an acceptable level
  - Able to operate with a factor 2 x less aggressive surface cooling
  - Pressurised helium gas cooling appears feasible



Temperature (left) and Von-Mises thermal stress (right) corresponding to steady state operation of a peripherally cooled "pencil shaped" beryllium target

Science & Technology Facilities Council
Rutherford Appleton Laboratory

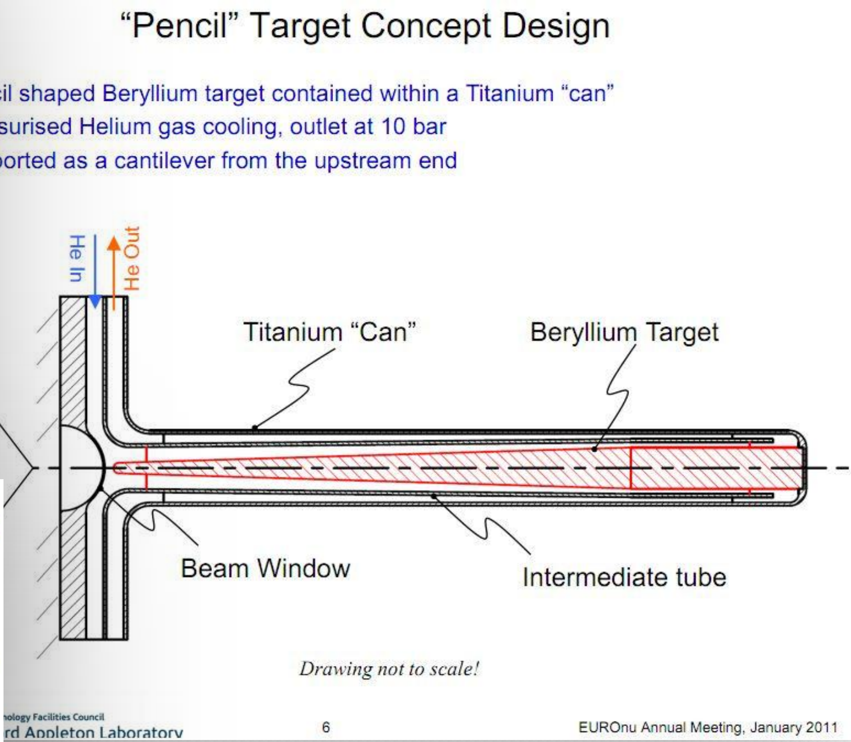
pen like target: cooling



CFX conjugate heat transfer model

- Cooling fluid = Helium
- Turbulence model = Shear Stress Transport (SST)
- Inlet mass flow rate = 60g/s
- Inlet temperature = 300K
- Outlet Pressure = 10bar
- Heat deposition in target = 24kW steady state from Fluka simulation
- Model of 36° slice (1/10th of target) with symmetry boundary conditions

- Cooling channel outer surface defined by 3 radii and connected with spline

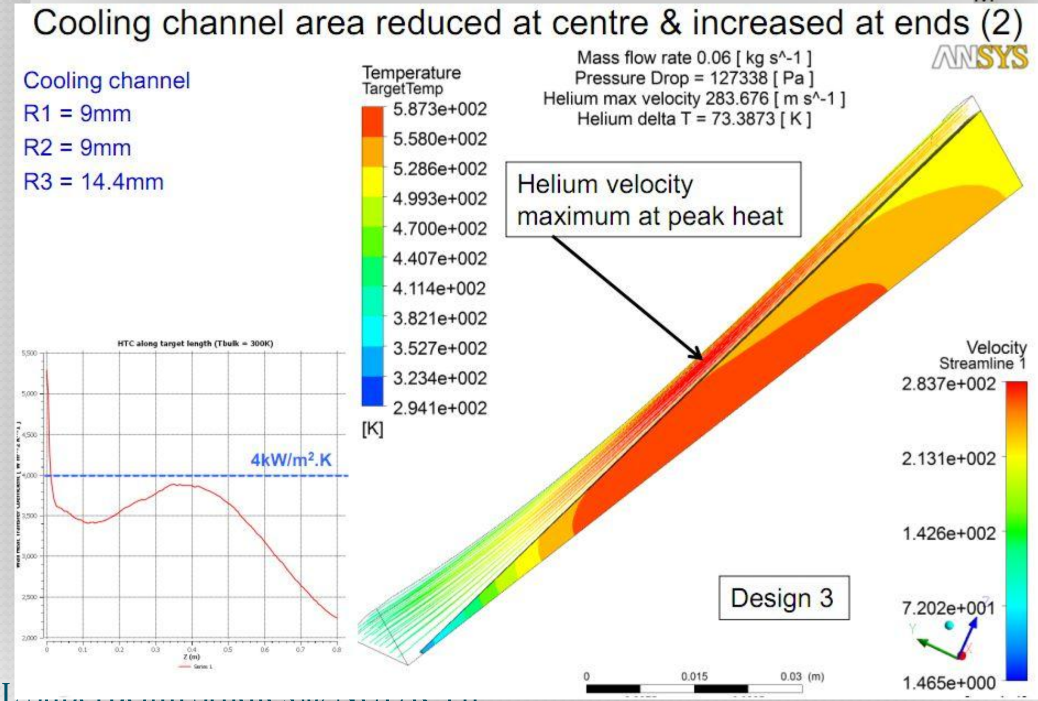


“Pencil” Target Concept Design

Pencil shaped Beryllium target contained within a Titanium “can”
Pressurised Helium gas cooling, outlet at 10 bar
Supported as a cantilever from the upstream end

Drawing not to scale!

nology Facilities Council
rd Appleton Laboratory
6
EUROnu Annual Meeting, January 2011



Cooling channel area reduced at centre & increased at ends (2)

Cooling channel
R1 = 9mm
R2 = 9mm
R3 = 14.4mm

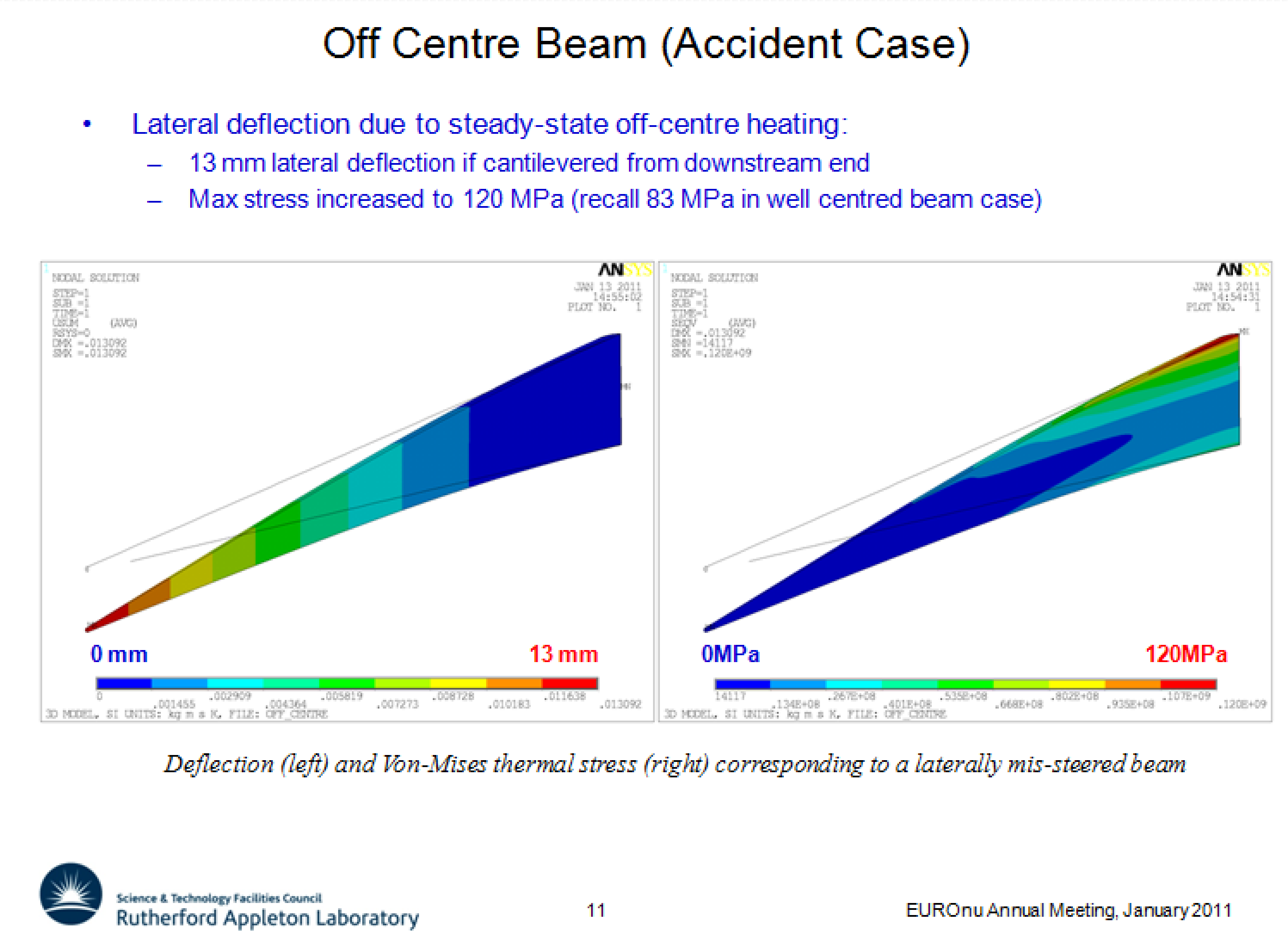
Mass flow rate 0.06 [kg s^-1]
Pressure Drop = 127338 [Pa]
Helium max velocity 283.676 [m s^-1]
Helium delta T = 73.3873 [K]

Helium velocity maximum at peak heat

Design 3

looks feasible

considerations:



Off Centre Beam (Accident Case)

- Lateral deflection due to steady-state off-centre heating:
  - 13 mm lateral deflection if cantilevered from downstream end
  - Max stress increased to 120 MPa (recall 83 MPa in well centred beam case)

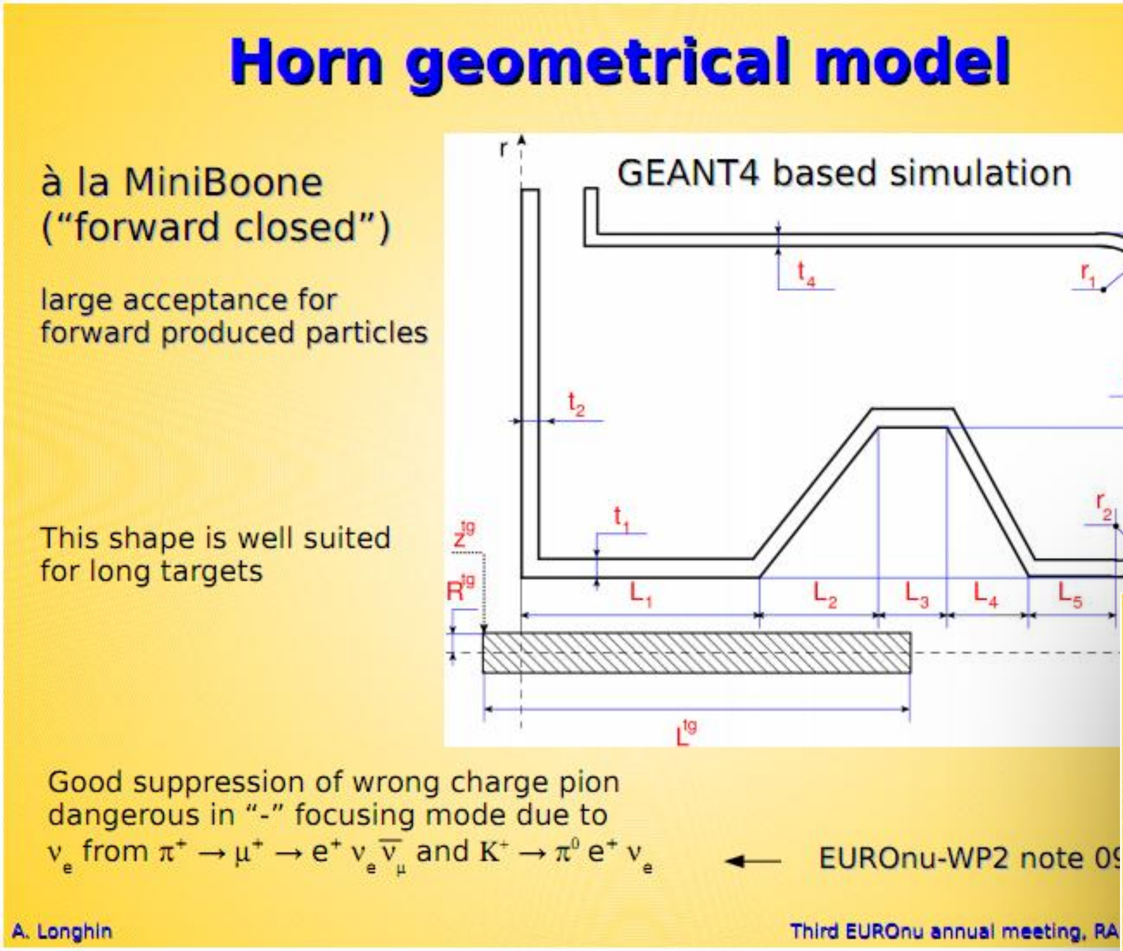
Deflection (left) and Von-Mises thermal stress (right) corresponding to a laterally mis-steered beam

Science & Technology Facilities Council
Rutherford Appleton Laboratory

11

EUROnu Annual Meeting, January 2011

Horn shape and SuperBeam geometrical Optimization I



4

Horn geometrical model

à la MiniBoone
(“forward closed”)

large acceptance for
forward produced particles

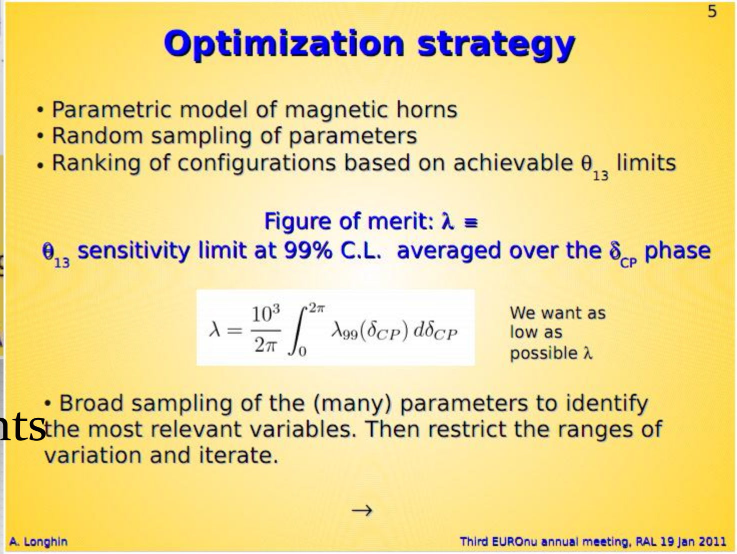
This shape is well suited
for long targets

Good suppression of wrong charge pion
dangerous in “-” focusing mode due to
ν_e from $\pi^+ \rightarrow \mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$ and $K^+ \rightarrow \pi^0 e^+ \nu_e$ ← EUROnu-WP2 note 09

A. Longhin

Third EUROnu annual meeting, RA

studies by A. Longhin,
EUROnu-WP2-10-04



5

Optimization strategy

- Parametric model of magnetic horns
- Random sampling of parameters
- Ranking of configurations based on achievable θ_{13} limits

Figure of merit: $\lambda \equiv$
θ_{13} sensitivity limit at 99% C.L. averaged over the δ_{CP} phase

$$\lambda = \frac{10^3}{2\pi}\int_0^{2\pi} \lambda_{99}(\delta_{CP})\, d\delta_{CP}$$

We want as
low as
possible λ

- Broad sampling of the (many) parameters to identify the most relevant variables. Then restrict the ranges of variation and iterate.

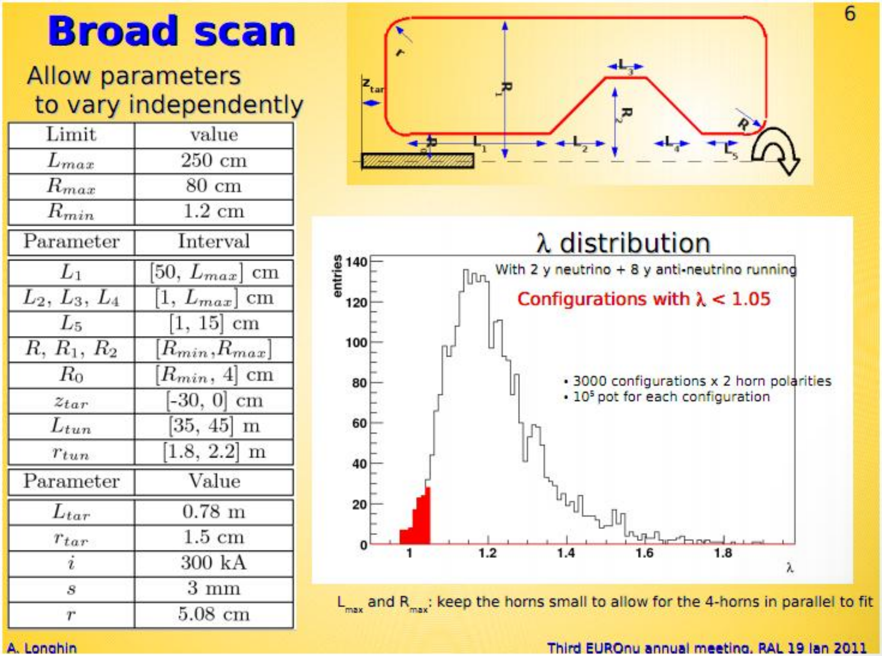
→

A. Longhin

Third EUROnu annual meeting, RAL 19 Jan 2011

- ✓ parameterise the horn and the other beam elements
- ✓ as decay tunnel dimensions, etc…
- ✓ parameters allowed to vary independently
- ✓ minimize the δ_{cp}-averaged 99%CL sensitivity limit on $\sin^2 2\theta_{13}$

Horn Shape and SuperBeam geometrical Optimization II



6

Broad scan

Allow parameters to vary independently

Limit	value
L_{max}	250 cm
R_{max}	80 cm
R_{min}	1.2 cm

Parameter	Interval
L_1	$[50, L_{max}]$ cm
L_2, L_3, L_4	$[1, L_{max}]$ cm
L_5	[1, 15] cm
R, R_1, R_2	$[R_{min}, R_{max}]$
R_0	$[R_{min}, 4]$ cm
z_{tar}	[-30, 0] cm
L_{tun}	[35, 45] m
r_{tun}	[1.8, 2.2] m

Parameter	Value
L_{tar}	0.78 m
r_{tar}	1.5 cm
i	300 kA
s	3 mm
r	5.08 cm

λ distribution

With 2 y neutrino + 8 y anti-neutrino running

Configurations with λ < 1.05

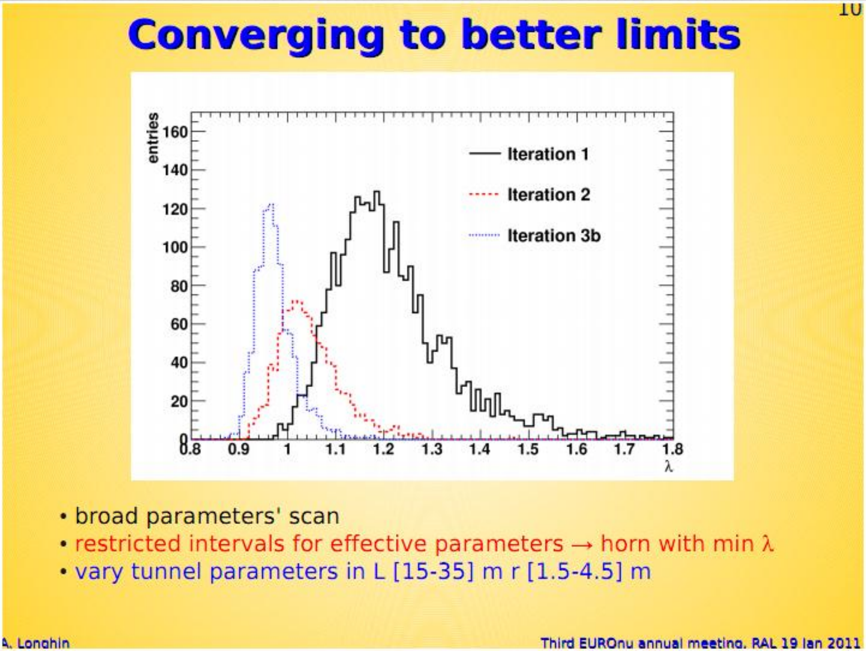
- 3000 configurations x 2 horn polarities
- 10^5 pot for each configuration

L_{max} and R_{max}: keep the horns small to allow for the 4-horns in parallel to fit

A. Longhin

Third EUROnu annual meeting, RAL 19 Jan 2011

fix & restrict parameters then re-iterate for best horn parameters & SuperBeam geometry



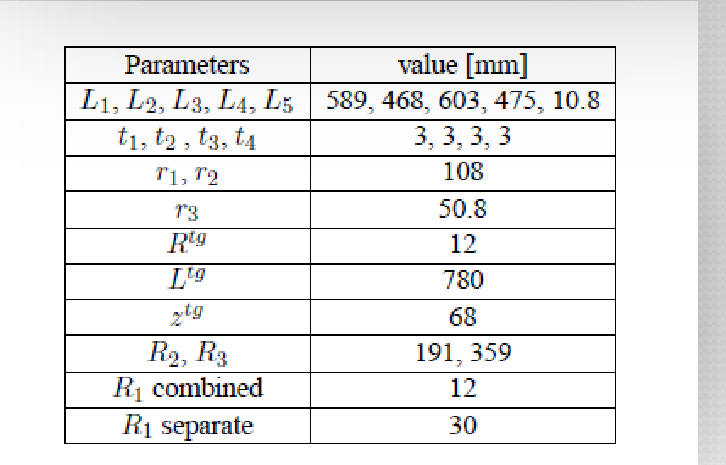
10

Converging to better limits

- broad parameters' scan
- restricted intervals for effective parameters → horn with min λ
- vary tunnel parameters in L [15-35] m r [1.5-4.5] m

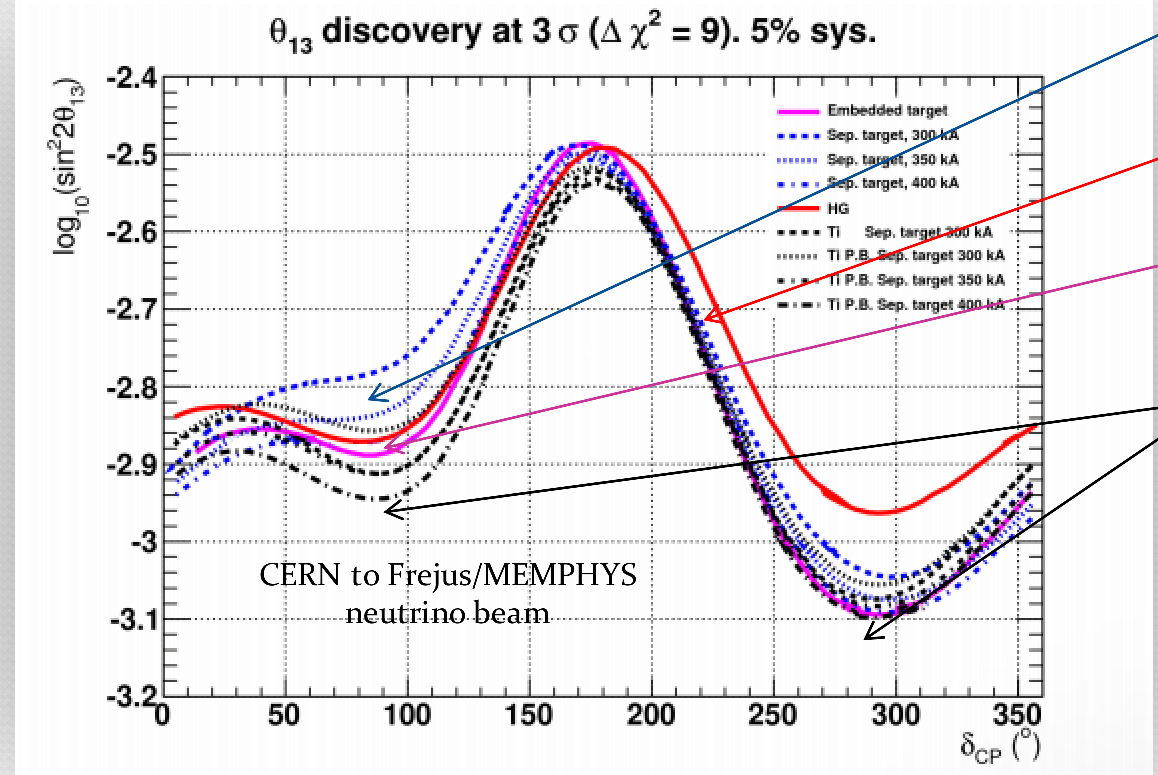
A. Longhin

Third EUROnu annual meeting, RAL 19 Jan 2011



Parameters	value [mm]
L_1, L_2, L_3, L_4, L_5	589, 468, 603, 475, 10.8
t_1, t_2, t_3, t_4	3, 3, 3, 3
r_1, r_2	108
r_3	50.8
R^{tg}	12
L^{tg}	780
z^{tg}	68
R_2, R_3	191, 359
R_1 combined	12
R_1 separate	30

Physics Performance for different Targets I

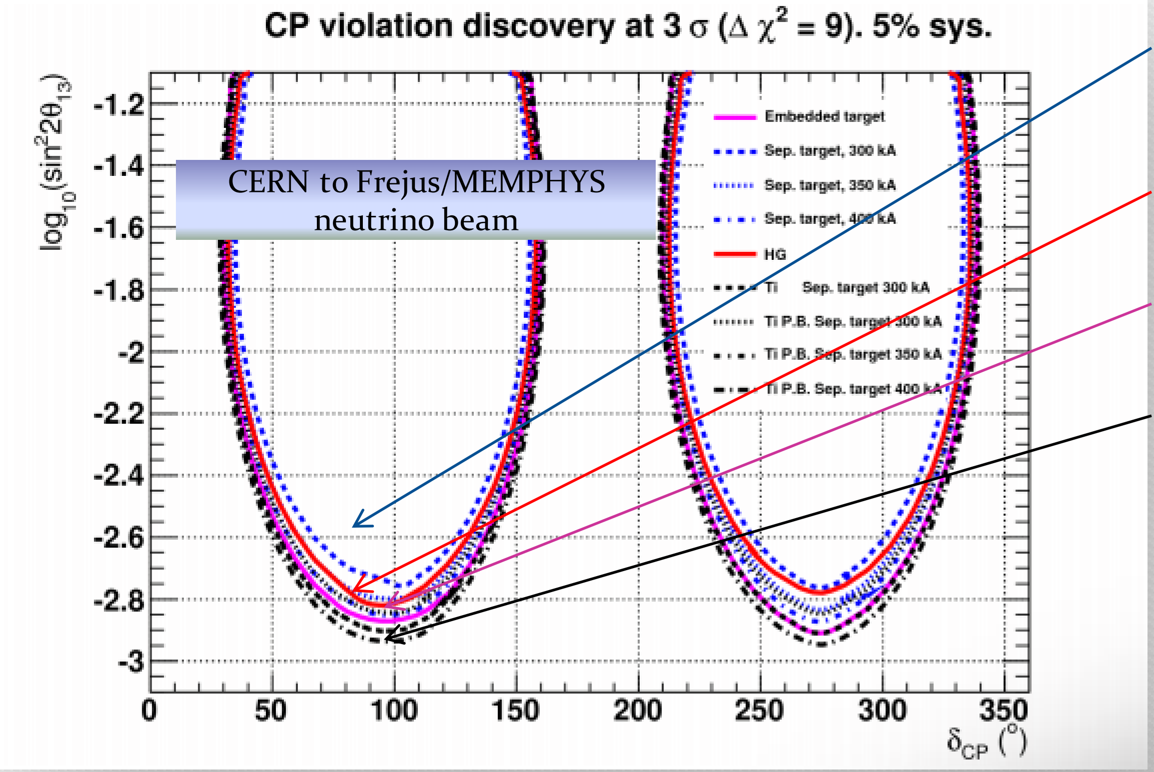


CERN to Frejus/MEMPHYS neutrino beam

- Graphite Solid target, $2\lambda_I$
- Hg, $2\lambda_I$
- Integrated target, $2\lambda_I$
- excellent performance of packed bed Ti, d= $74\%d_{Ti}$

any density reduction of packed could be recuperated increasing the horn current by 50, 100 kA

Physics Performance for different Targets II



CERN to Frejus/MEMPHYS neutrino beam

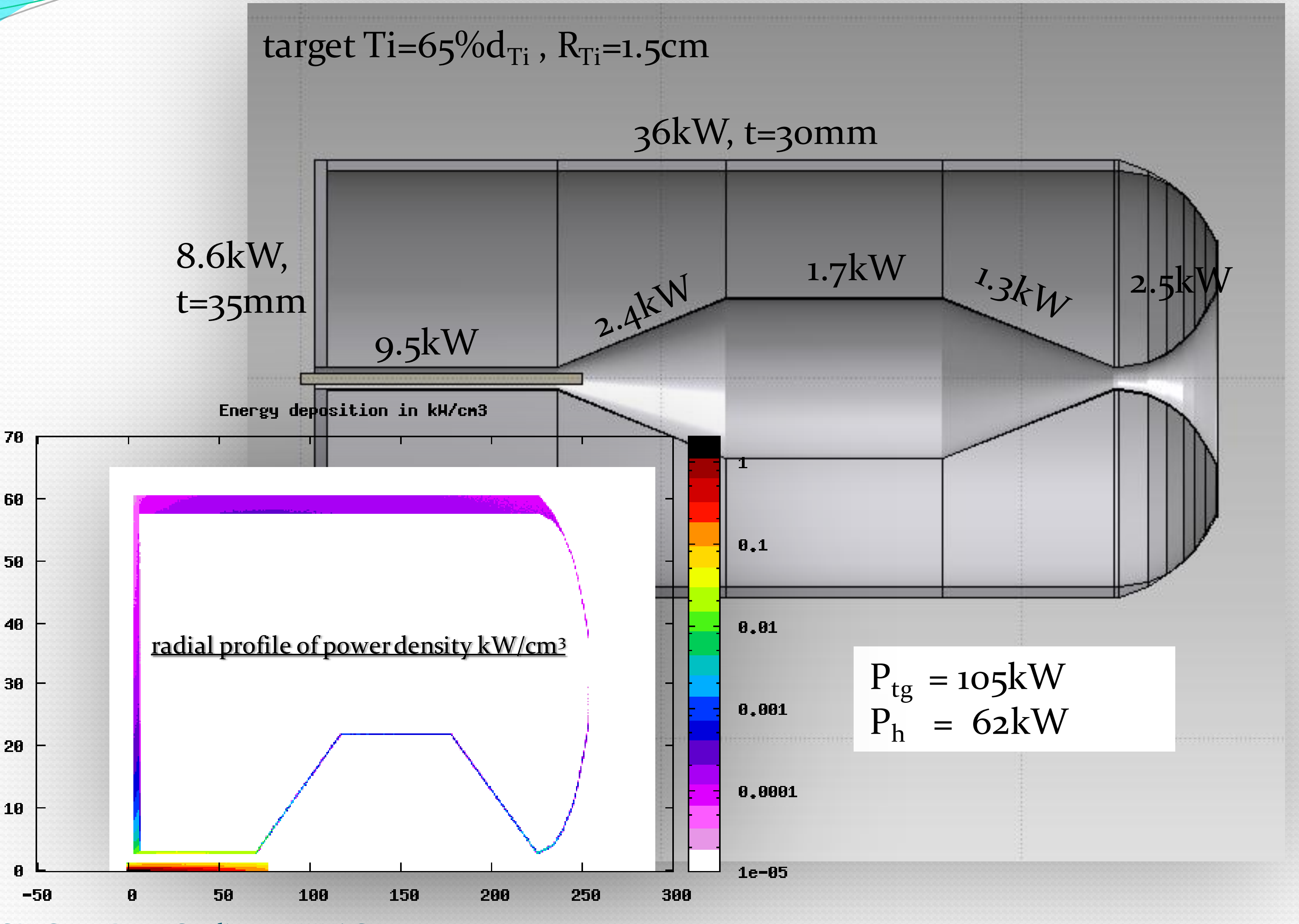
- Graphite Solid target, $2\lambda_I$
- Hg, $2\lambda_I$
- Integrated target, $2\lambda_I$
- excellent performance of packed bed Ti, d= 77%d_{Ti}

any density reduction of packed could be recuperated increasing the horn current by 50, 100 kA

Energy Deposition from secondary particles on Horn, 1.3MW, Ti packed bed target

FLUKA MC+FLAIR

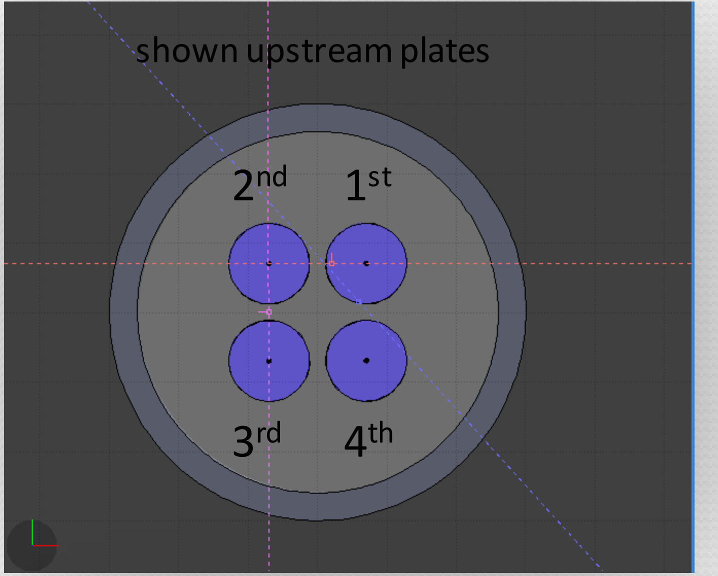
target Ti=65%d_{Ti} , R_{Ti}=1.5cm

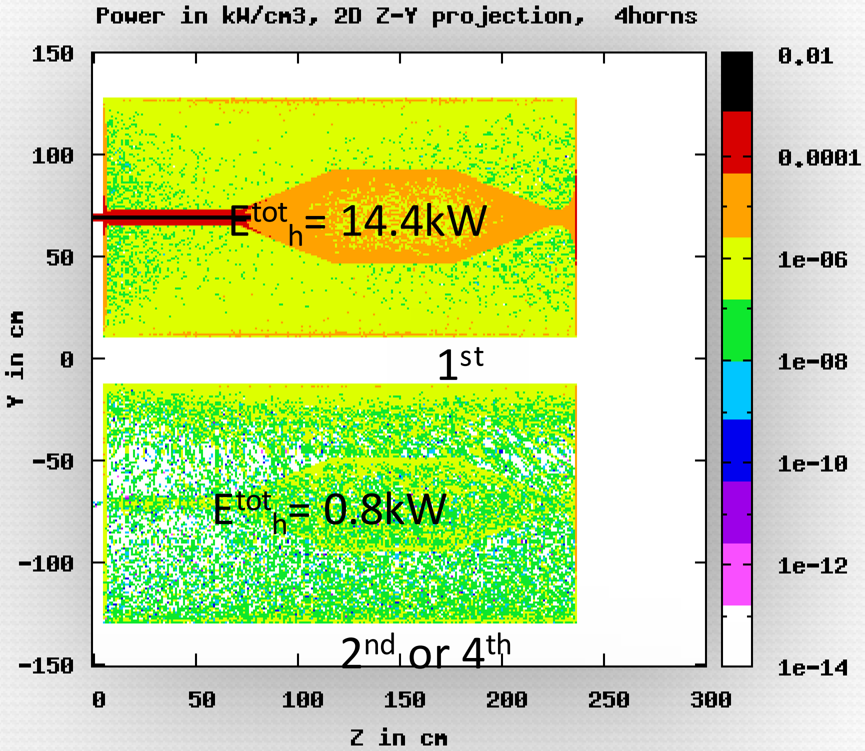


P_{tg} = 105kW
P_h = 62kW

Energy Deposition on horns # 2,4, active horn is #1

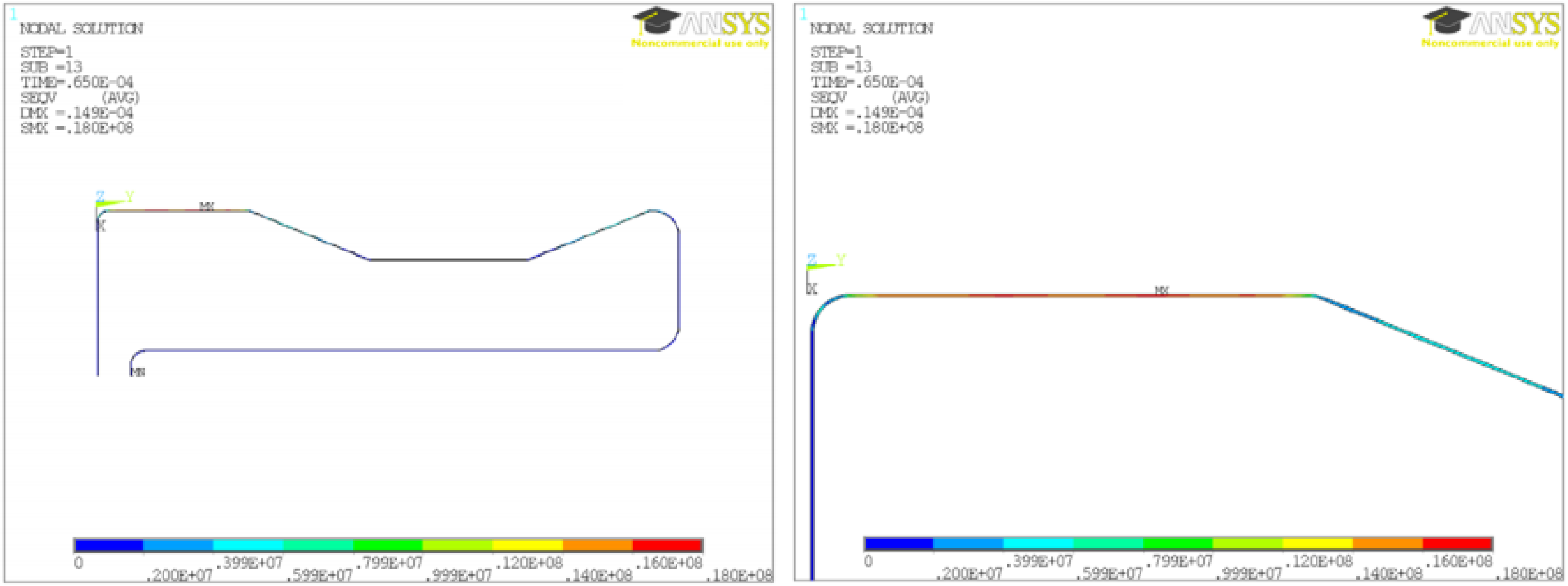
1.3MW beam, 350kA, graphite target





Power in kW for the horns next to the active one			
total	inner	outer	plates
0.8 (5.5% of active horn)	0.1	0.6 (50% of outer next to 1st)	0.1

Response to magnetic pulses

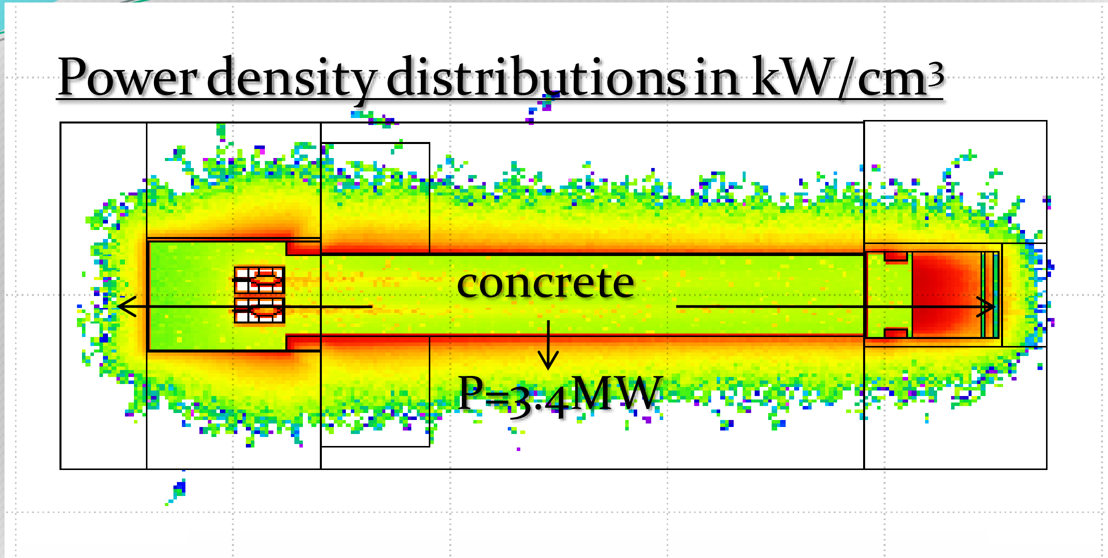


Maximum von Mises stress due to magnetic pulses = 18 MPa (at 300 kA)

= 24.5 MPa (at 350 kA)

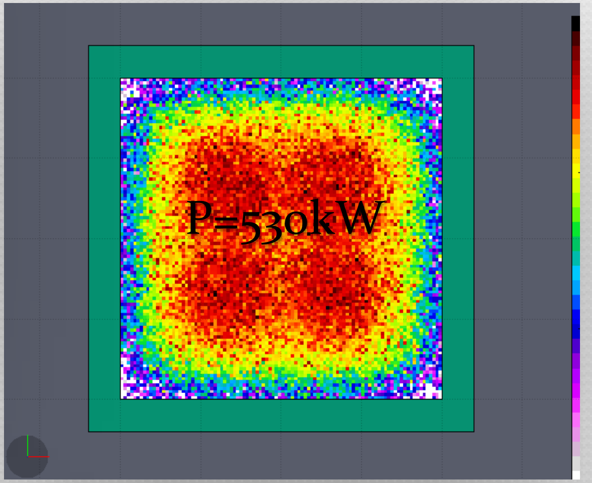
Piotr Cupial, EUROν Annual Meeting, Rutherford Appleton Laboratory, 18-21 January 2011

Energy deposition on SuperBeam Elements

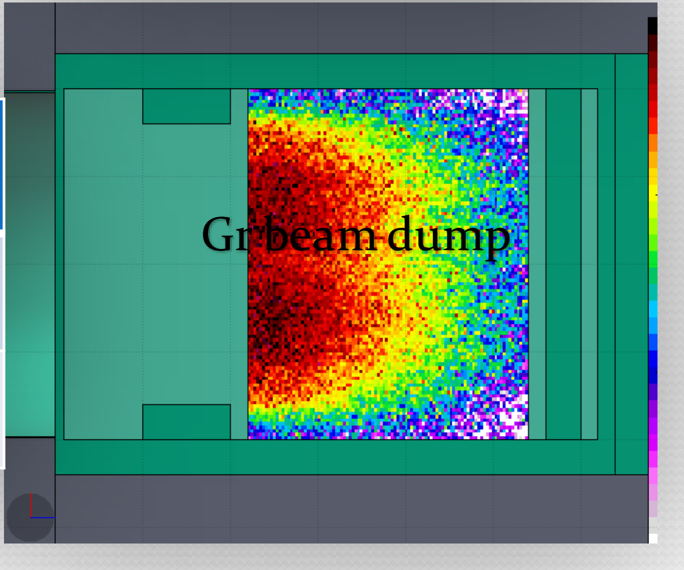

Power density distributions in kW/cm³

concrete

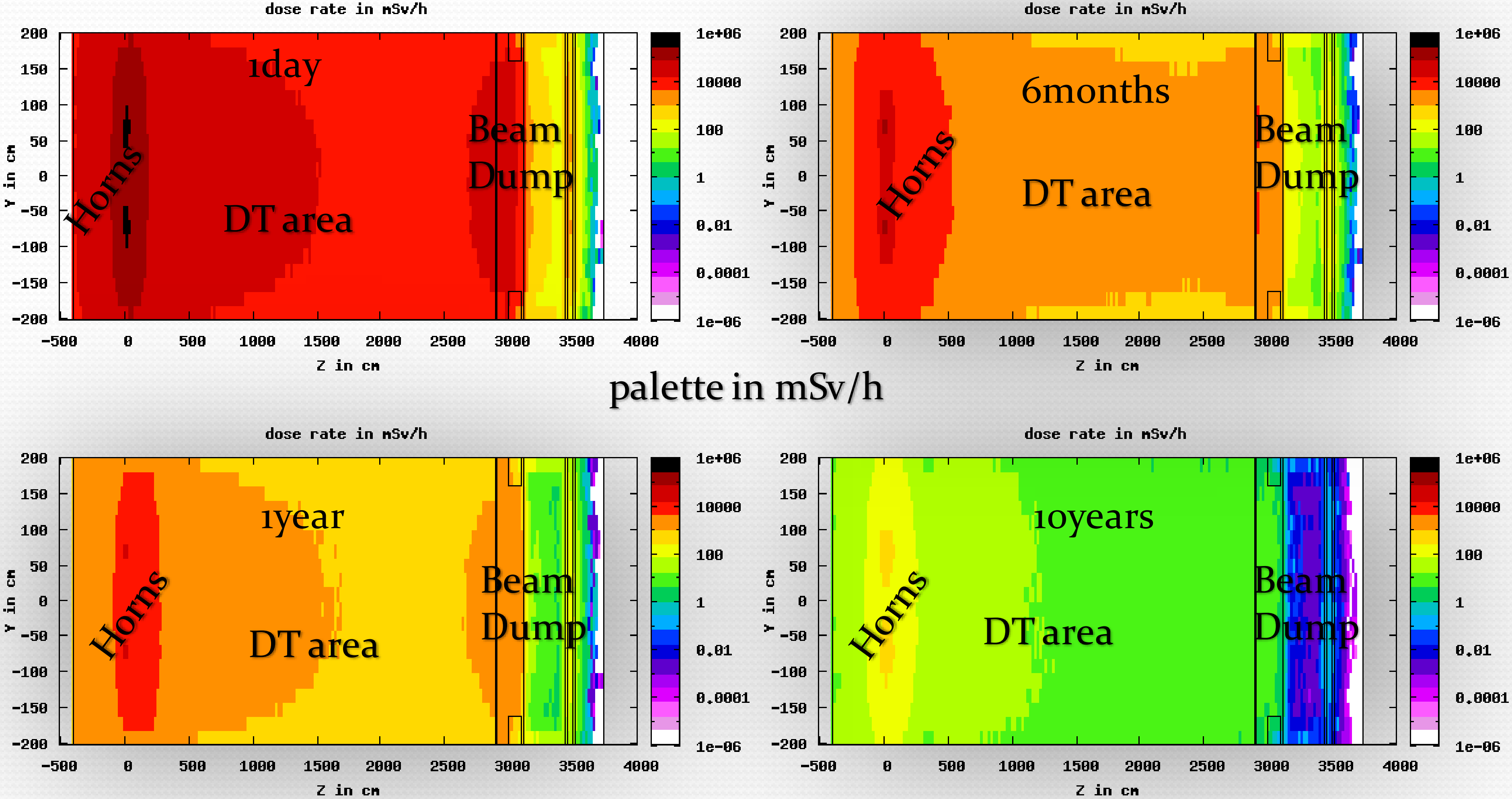
P=3.4MW


P=530kW

DT Fe vessel	DT concrete	Gr Beam Dump
320kW	720kW	530kW
water		water


Gr beam dump

<doses> in longitudinal plane along beam axis after 200d of irradiation



palette in mSv/h

- high dose rates along SuperBeam layout->remote handling mandatory for any part of the 4-horn system in target/horn station