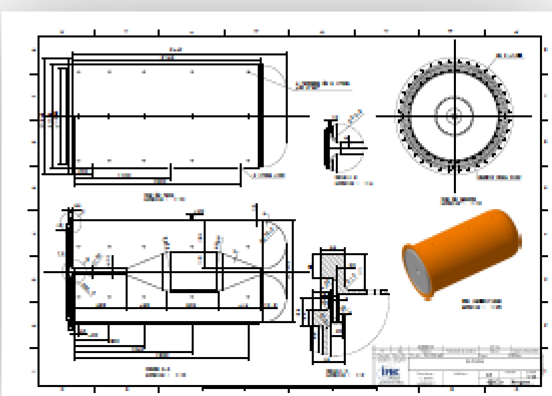
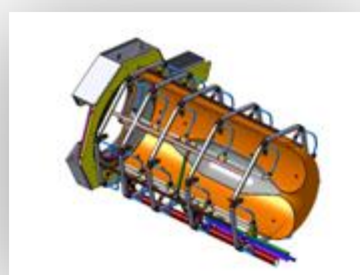
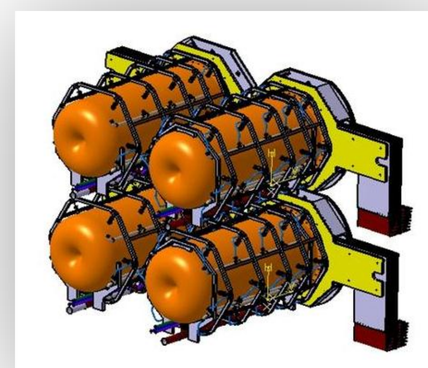
Horn studies for the CERN to Fréjus neutrino Super Beam

Nikolas Vassilopoulos on behalf of WP2,
IPHC, Strasbourg





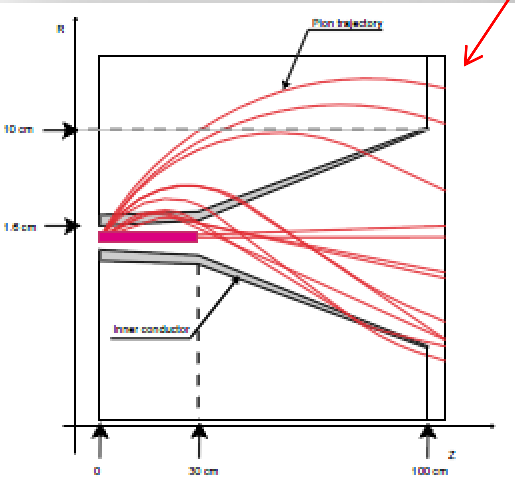


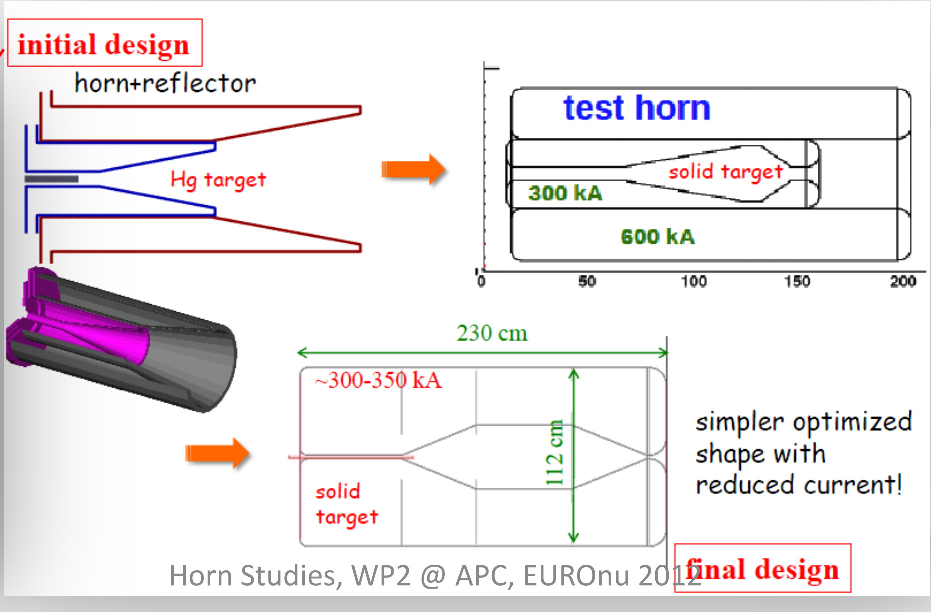
Horn evolution

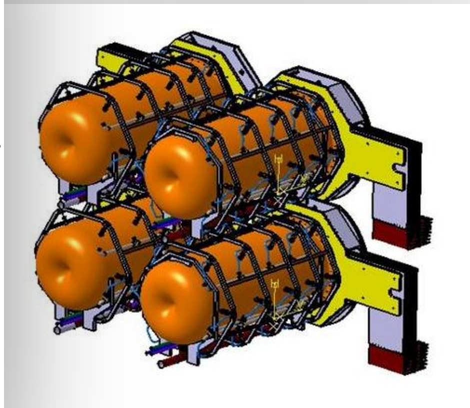
details in WP2 notes @ http://www.euronu.org/

evolution of the horn shape after many studies:

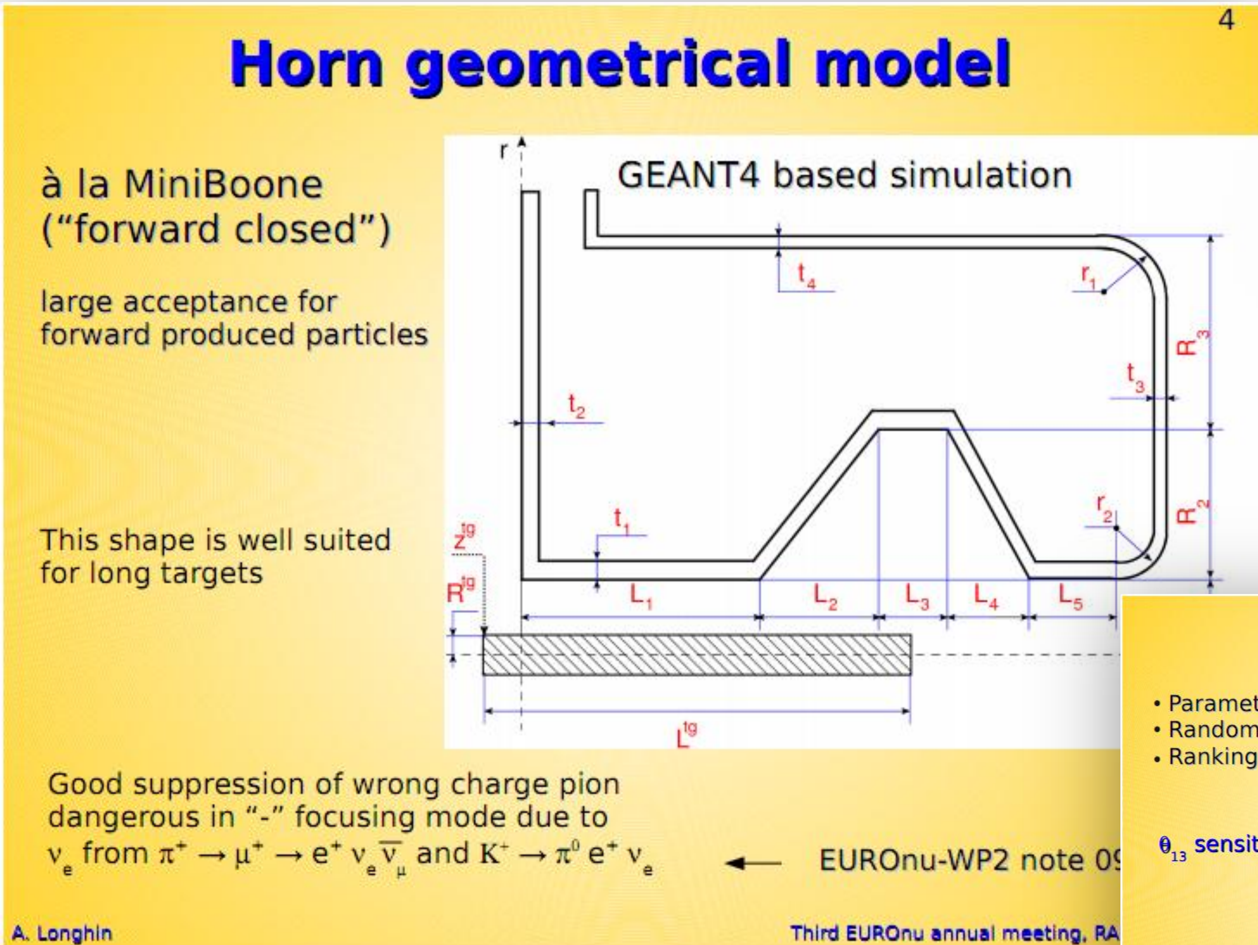
- triangle shape (van der Meer) with target inside the horn : in general best configuration for low energy beam
  ⇓
- triangle with target integrated to the inner conductor : very good physics results but high energy deposition and stresses on the conductors
  ⇓
- forward-closed shape with target integrated 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



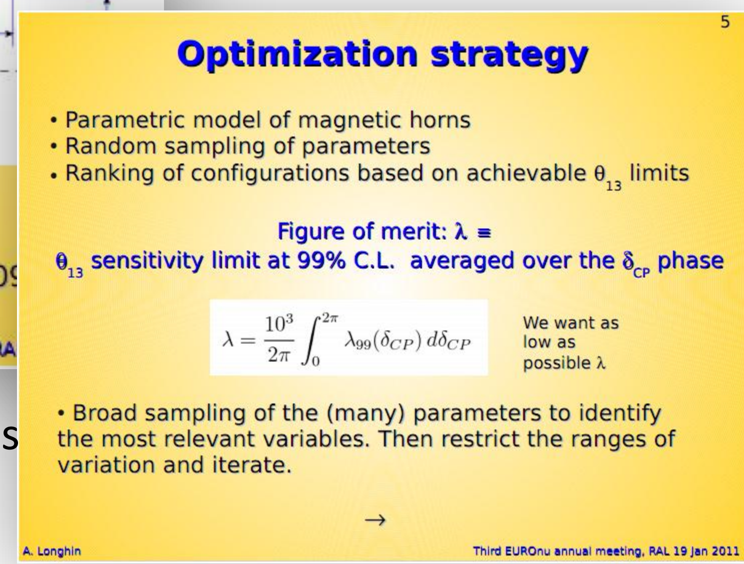




Horn shape and SuperBeam geometrical Optimization I

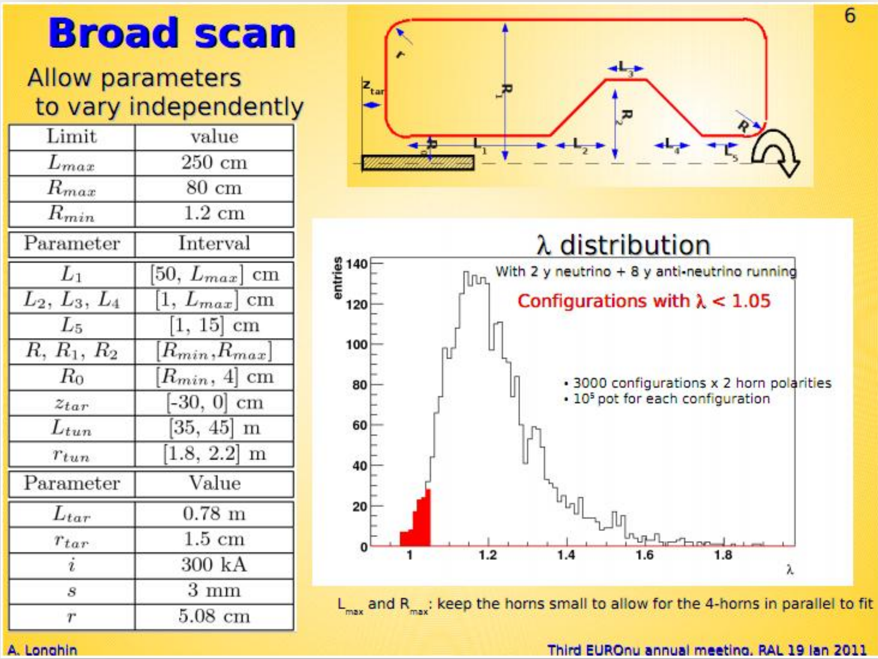


studies by A. Longhin, C. Bobeth

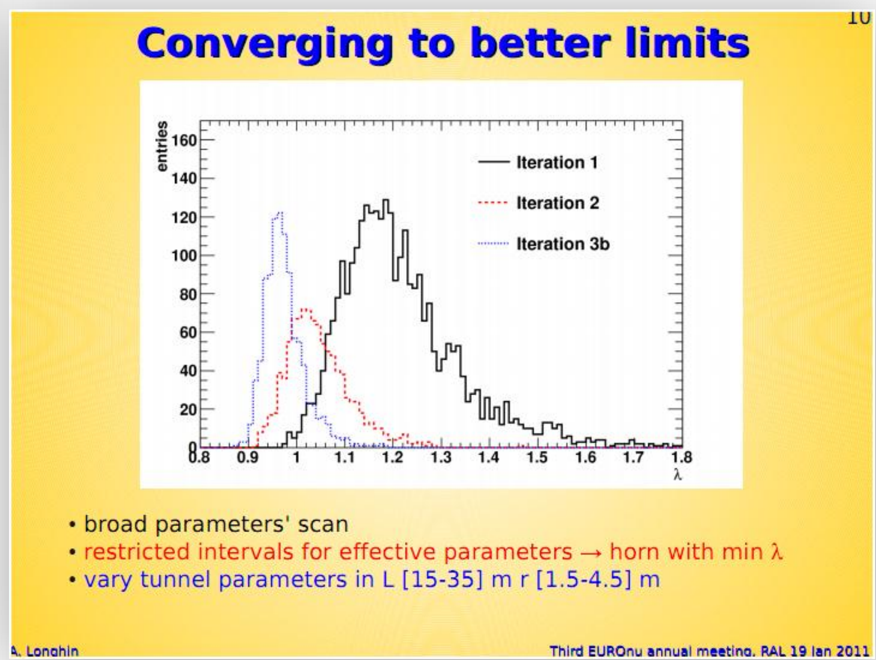


- ✓ parameterise the horn and the other beam elements as decay tunnel dimensions, etc...
- ✓ parameters allowed to vary independently
- ✓ minimize the δ_{cp}-averaged 99%CL sensitivity limit on $\sin^2 2\theta_{13}$

Horn Shape and SuperBeam geometrical Optimization II

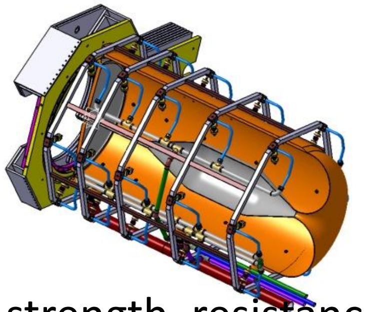


fix & restrict parameters then re-iterate for best horn parameters & SuperBeam geometry

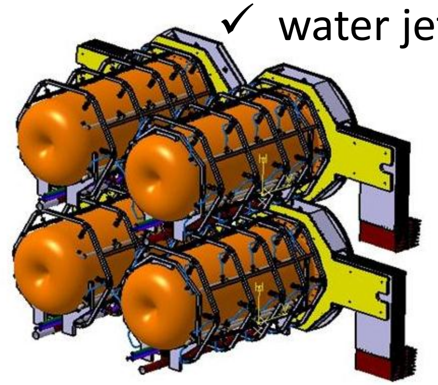


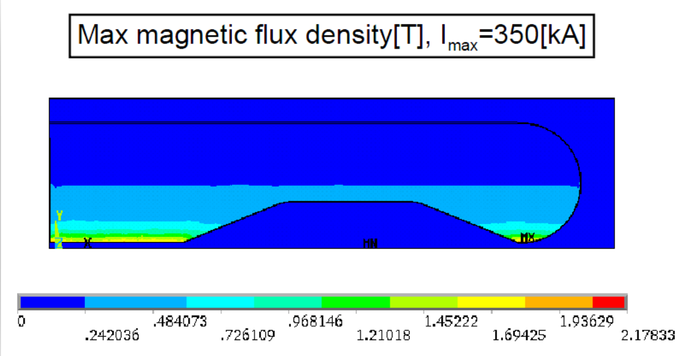
Parameters	value [mm]
L_1, L_2, L_3, L_4, L_5	589, 468, 603, 475, 10.8
t_1, t_2, t_3, t_4	3, 3, 3, 3
r_1, r_2	108
r_3	50.8
R^{tg}	12
L^{tg}	780
z^{tg}	68
R_2, R_3	191, 359
R_1 combined	12
R_1 separate	30

Horn Stress Studies

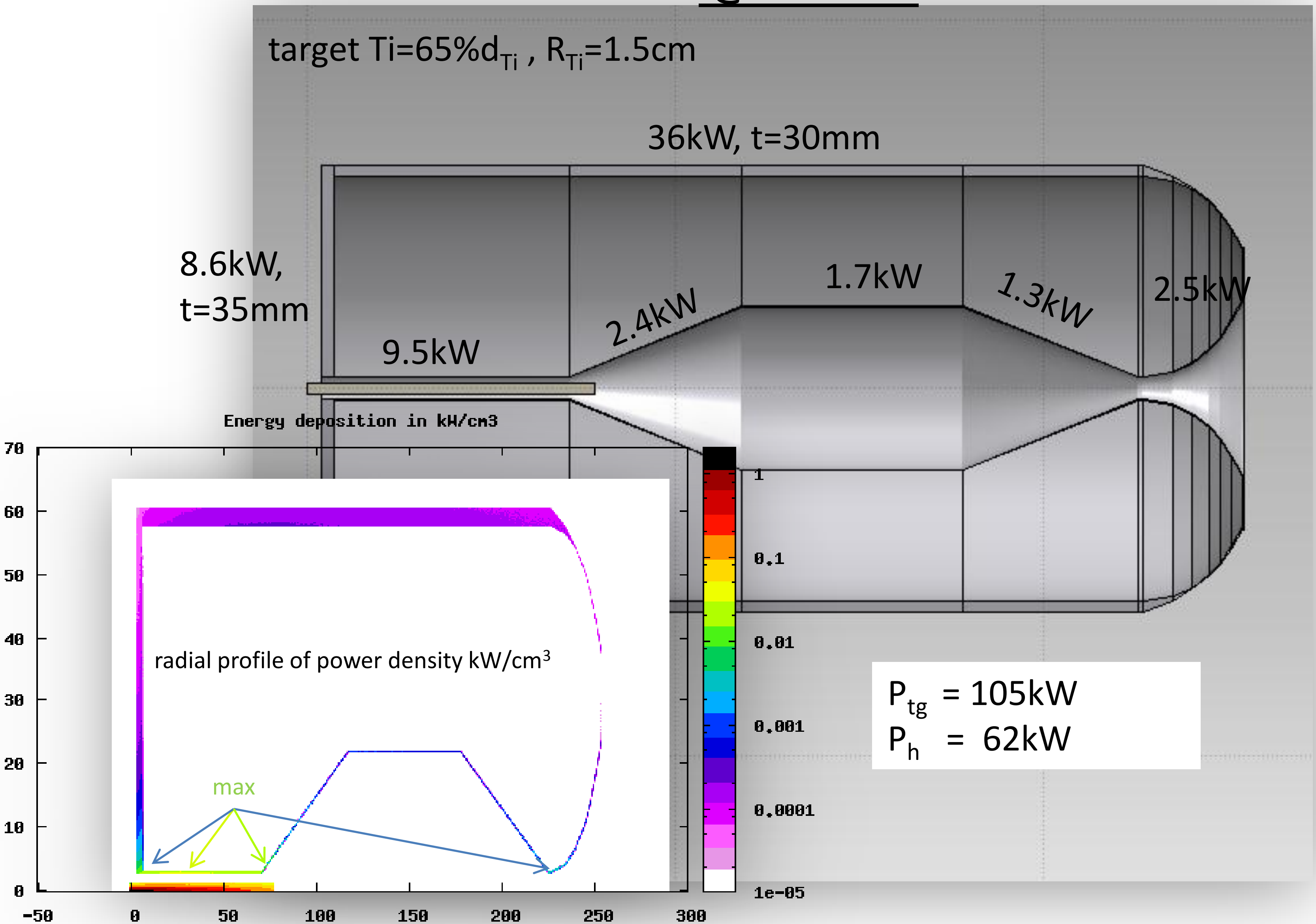


- horn structure
  - ✓ Al 6061 T6 alloy good trade off between mechanical strength, resistance to corrosion, electrical conductivity and cost
  - ✓ horn thickness as small as possible: best physics, limit energy deposition from secondary particles but thick enough to sustain dynamic stress
- horn stress and deformation
  - ✓ static mechanical model, thermal dilatation
  - ✓ magnetic pressure pulse, dynamic displacement
  - ✓ COMSOL, ANSYS software
- cooling
  - ✓ water jets



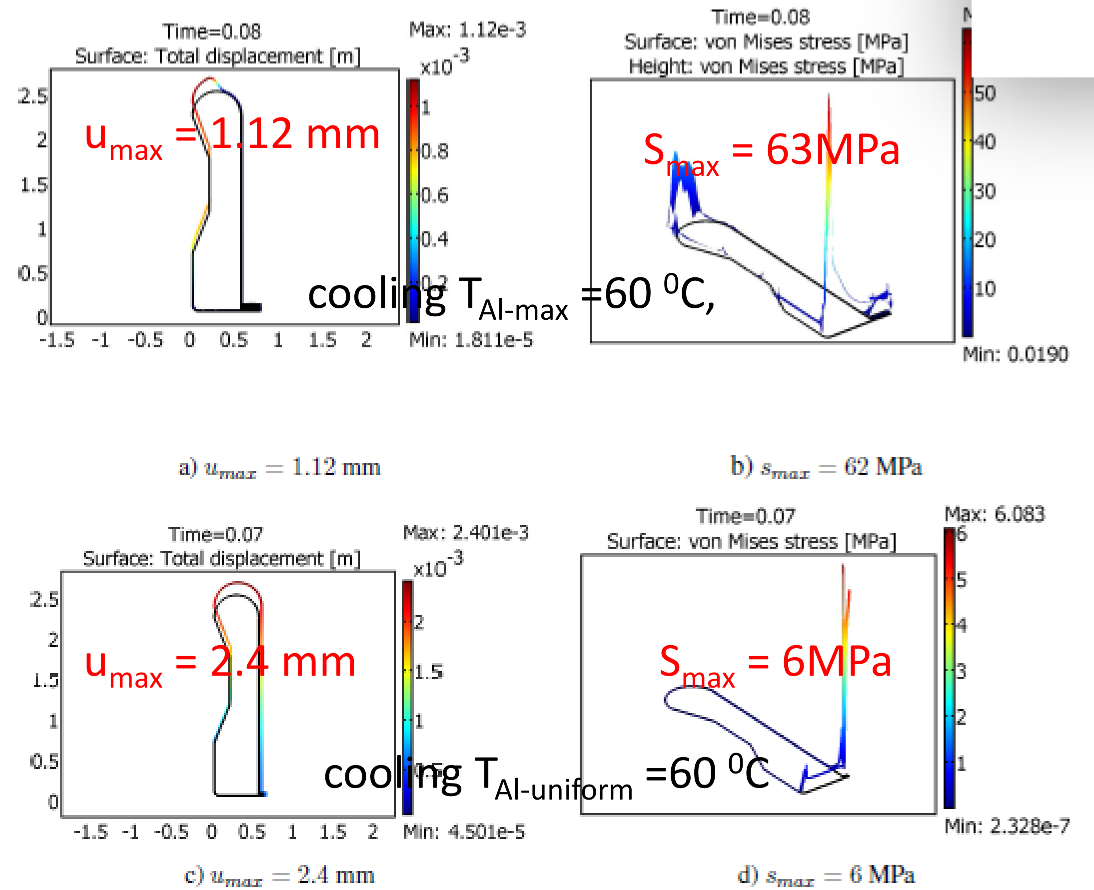


Energy Deposition from secondary particles @1.3 MW

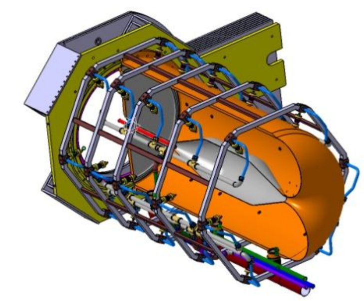


Stress Analysis

- Thermo-mechanical stresses:
  - ✓ secondary particles energy deposition and joule losses
  - ✓ T=60ms, (worst scenario, 1horn failed) ,τ_{0l}=100µs, electrical model: I_0 = 350kA, f=5kHz, I_{rms}=10.1kA,



a) $u_{max} = 1.12$ mm b) $s_{max} = 62$ MPa
c) $u_{max} = 2.4$ mm d) $s_{max} = 6$ MPa



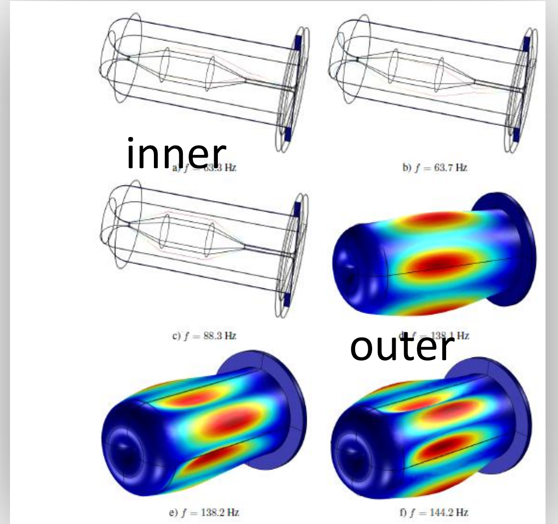
stress minimized when horn has uniform temperature

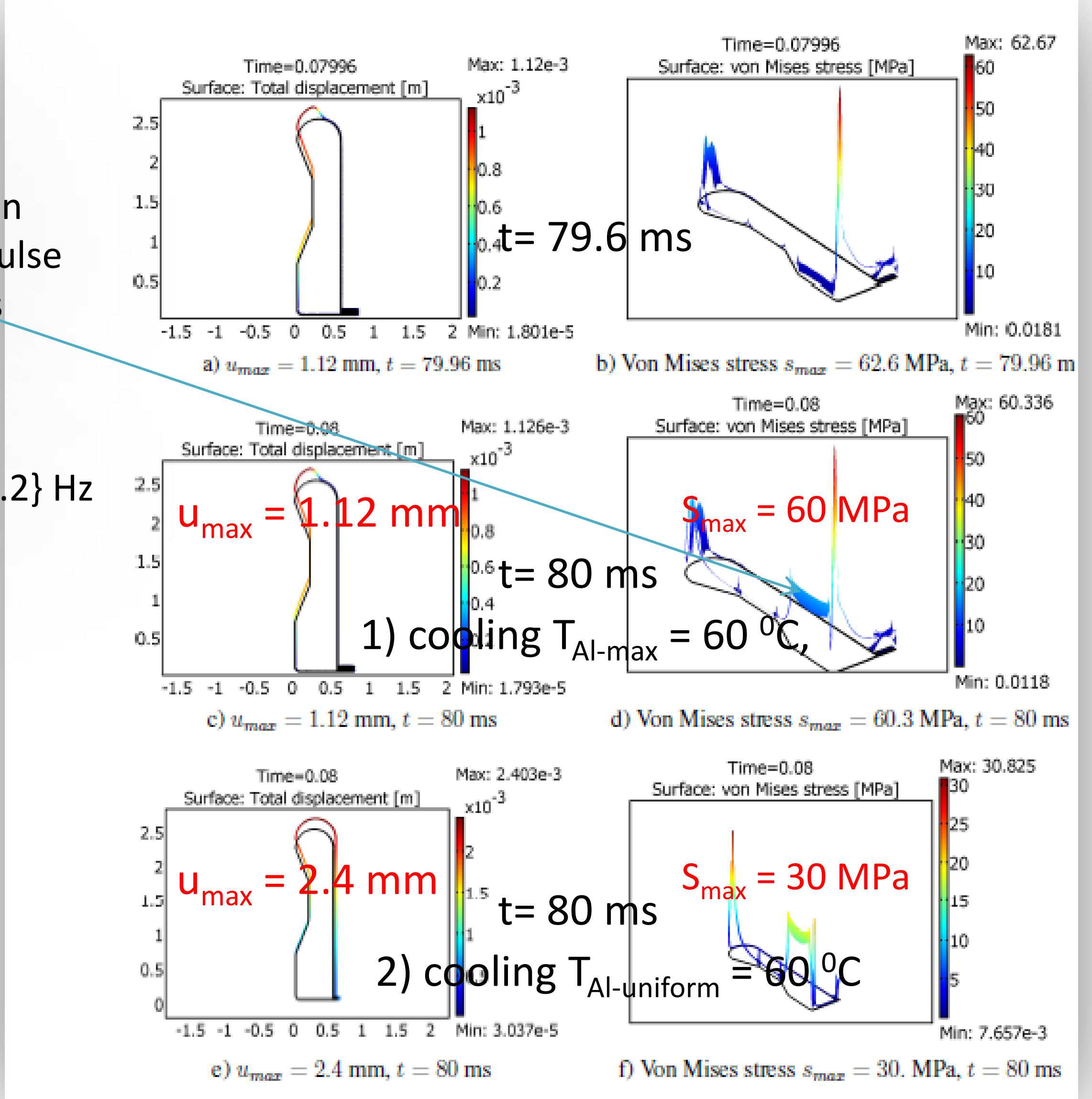
G. Gaudiot, B. Lepers,
F. Osswald, V. Zeter/IPHC,
P. Cupial , M. Kozien, L. Lacny,
B. Skoczen *et al.* /Cracow Univ. of Tech.

Stress due to thermal dilatation and magnetic pressure

- displacements and stress plots just before and on the peak
  - ✓ stress on the corner and convex region
  - ✓ stress on the upstream inner due to pulse
  - ✓ uniform temperature minimizes stress

- modal analysis, eigenfrequencies
  - ✓ f = {63.3, 63.7, 88.3, 138.1, 138.2, 144.2} Hz

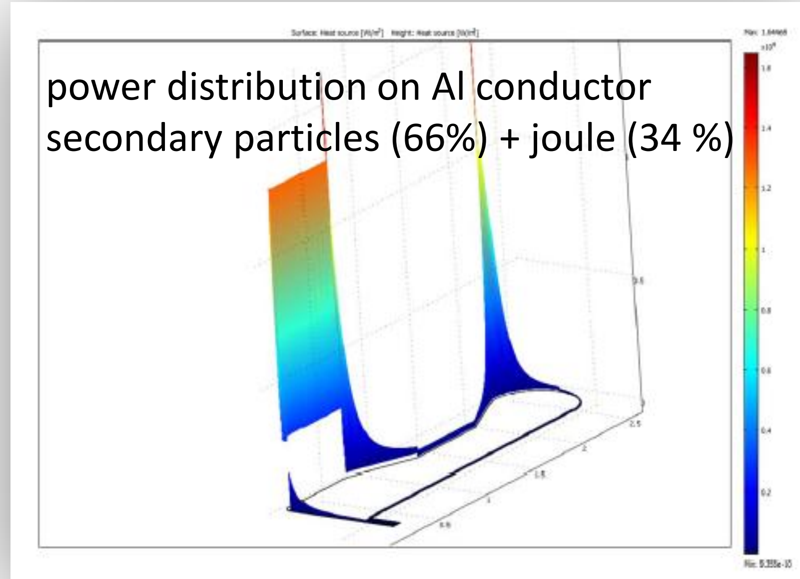


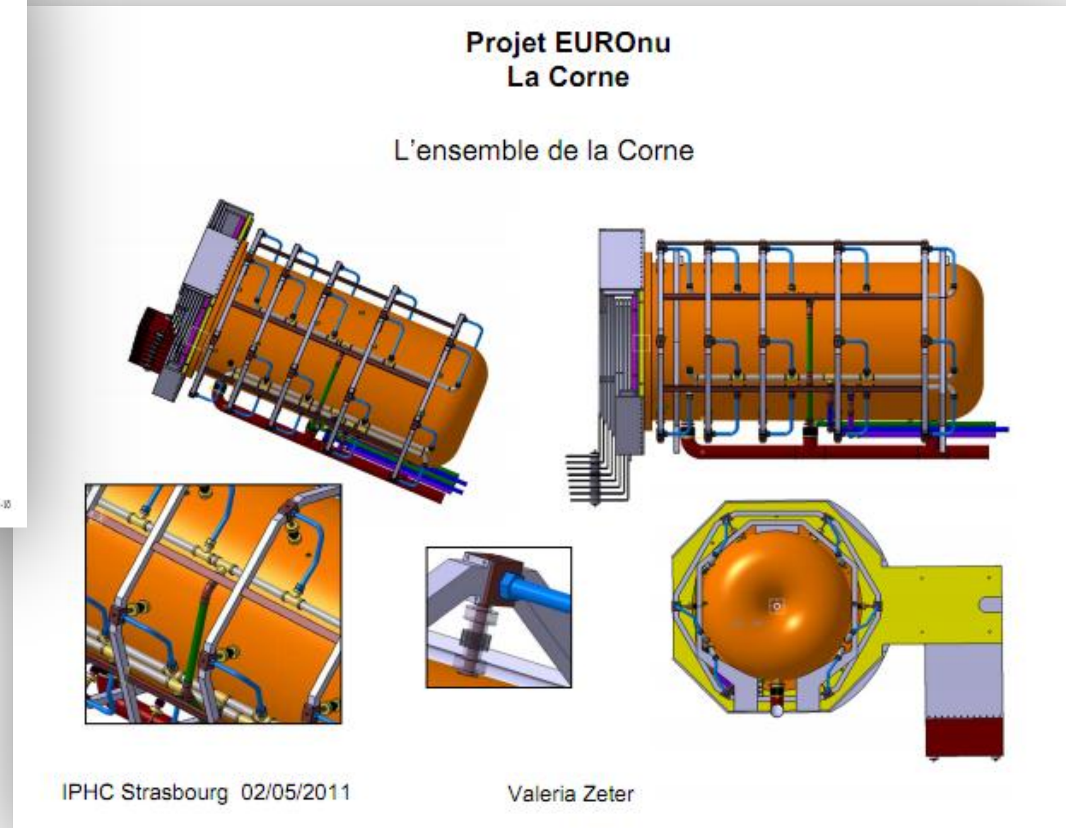


peak magnetic field each T=80ms (4-horns operation)

Horn cooling

power distribution on Al conductor
secondary particles (66%) + joule (34 %)





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-max} = 60 ^{0}C

horn lifetime

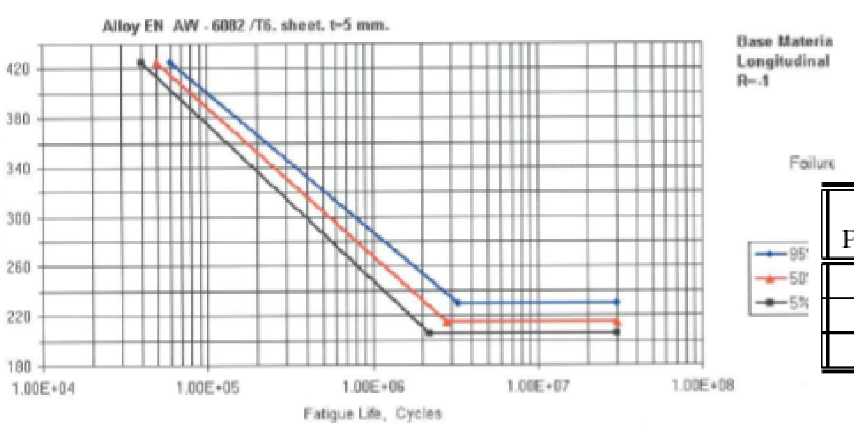
6 – 60 MPa expected

Horn response under pulse magnetic forces

SINGLE PULSE with static thermal stress SVM=102.5 MPa
and maximal magnetic stress SMAX=41 MPa – estimated life time

S-N curve - probability	Life time [s]		
	Rayleigh	Dirlik	Benasciutti-Tovo
95%	2.7076e+007	8.6147e+007	7.9627e+007
50%	6.0195e+006	1.8589e+007	1.7026e+007
5%	2.1816e+006	6.5918e+006	6.0132e+006

highly conservative



NUMBER OF PULSES
Dirlik model
f = 12.5 Hz

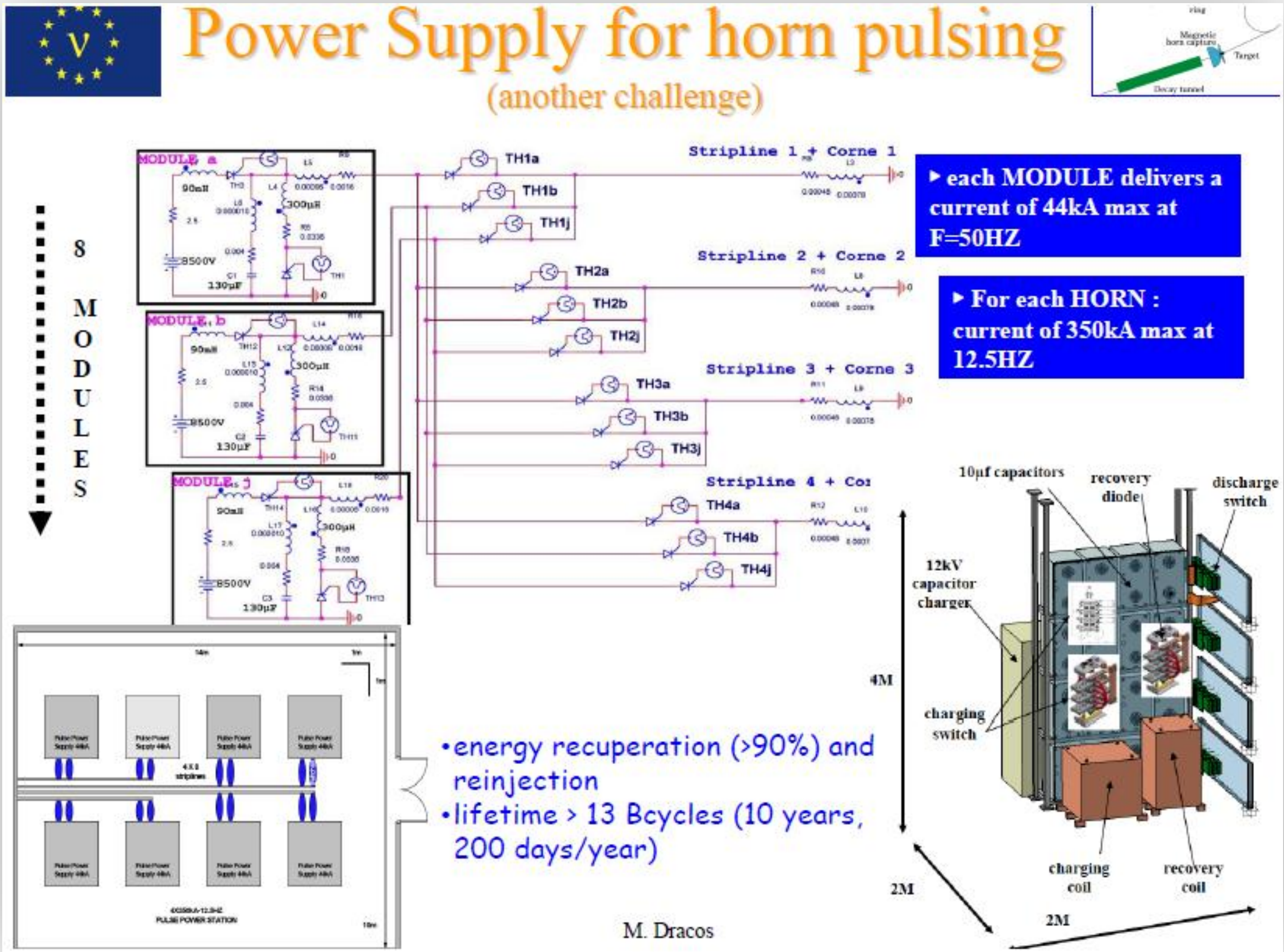
S-N CURVE PROBABILITY	LIFE TIME [s]	NUMBER OF PULSES
95 %	$8.6 \cdot 10^7$	$1.08 \cdot 10^9$
50 %	$1.9 \cdot 10^7$	$2.38 \cdot 10^8$
5 %	$6.6 \cdot 10^6$	$8.25 \cdot 10^7$

1.25 10^8 pulses = 200 days = 1 year

A.Niesłony

M.S.Kozień Fourth EUROnu Annual Meeting , June 12-15, 2012, APC, Paris 12/13

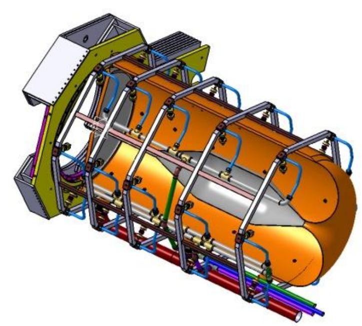
Power Supply



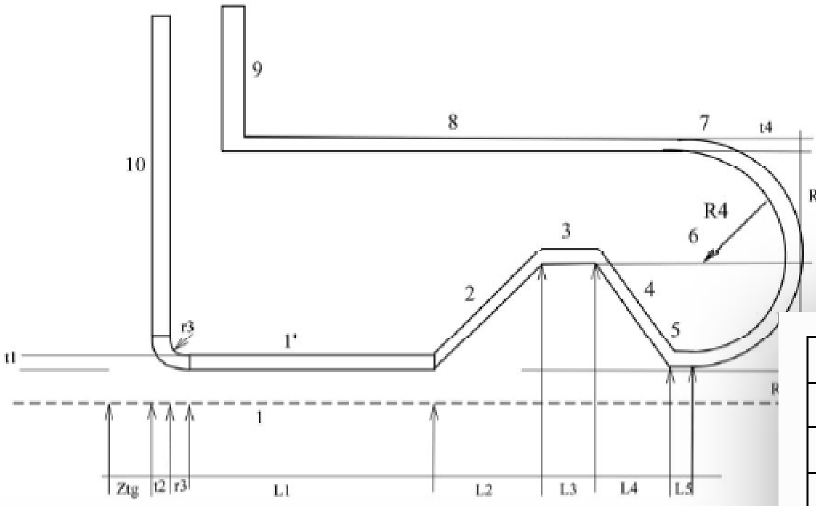
P. Poussot, J. Wurtz/IPHC

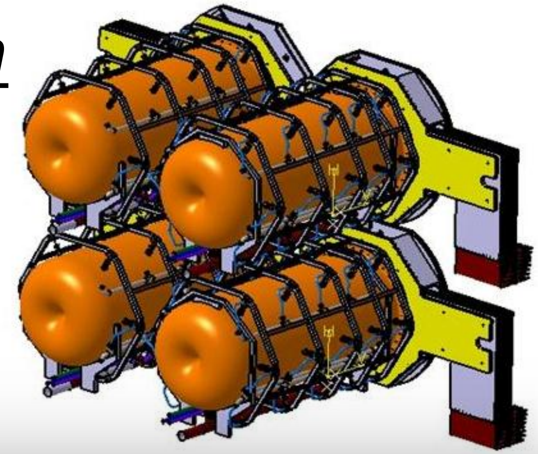
conclusions

- Al 6061 T6 alloy for radiation, reliability and cost
- convex shape defined for optimum physics
- low stress on inner conductor when uniform cooling is applied < 30 MPa
- horn lifetime > 10^8 cycles (1 year) highly conservative
- power supply & cooling R&D needed



4-horn system for power accommodation





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t_1, t_2 , t_3, t_4	3, 10, 3, 10
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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]	$1 \ldots 1.3$	1.4
Peak Current I_0 [kA]	$300 \ldots 350$	350
Beam width σ [mm]	-	4
Current frequency per horn [Hz]	-	12.5 (16.6)

Table 2: Beam and horn parameters.