Status of the SuperBeam WP

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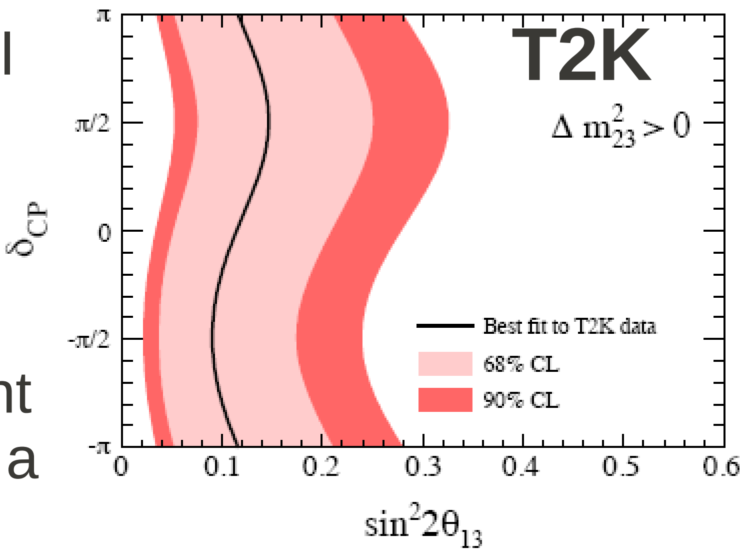
For the EUROnu WP2 team

EUROnu CB
CERN
October 10 2011

Motivation

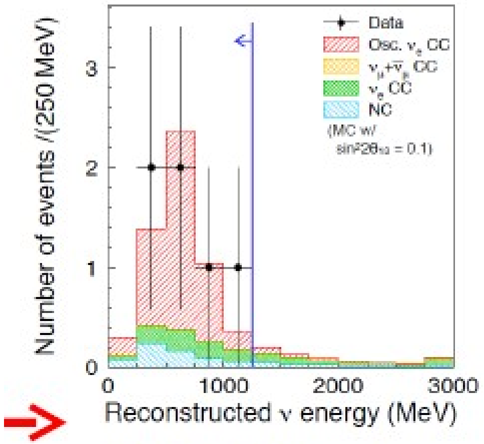
- Conventional neutrino beams are a powerful tool for the study of neutrino oscillations
- Currently several large scale HEP experiments using this technology: MINOS, OPERA, T2K
- The recent indications by T2K (and MINOS) point to the large θ_{13} region where a Super Beam has a good sensitivity



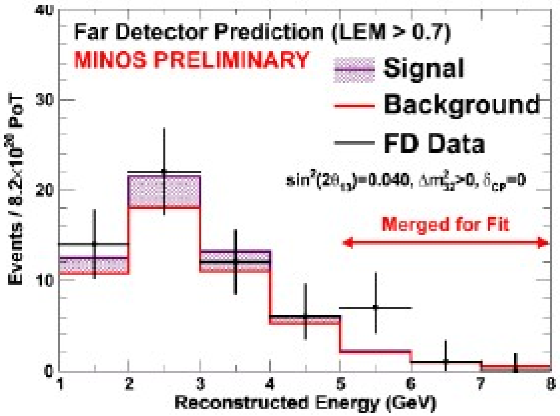
90% C.L. interval & Best fit point (assum

$0.03 < \sin^2 2\theta_{13} < 0.28$

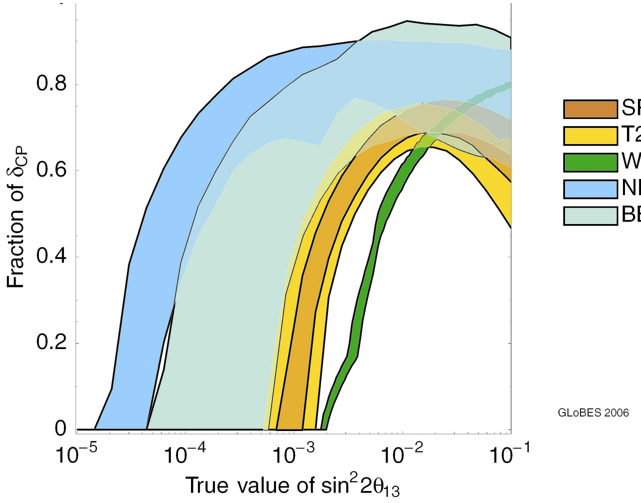
$\sin^2 2\theta_{13} = 0.11$

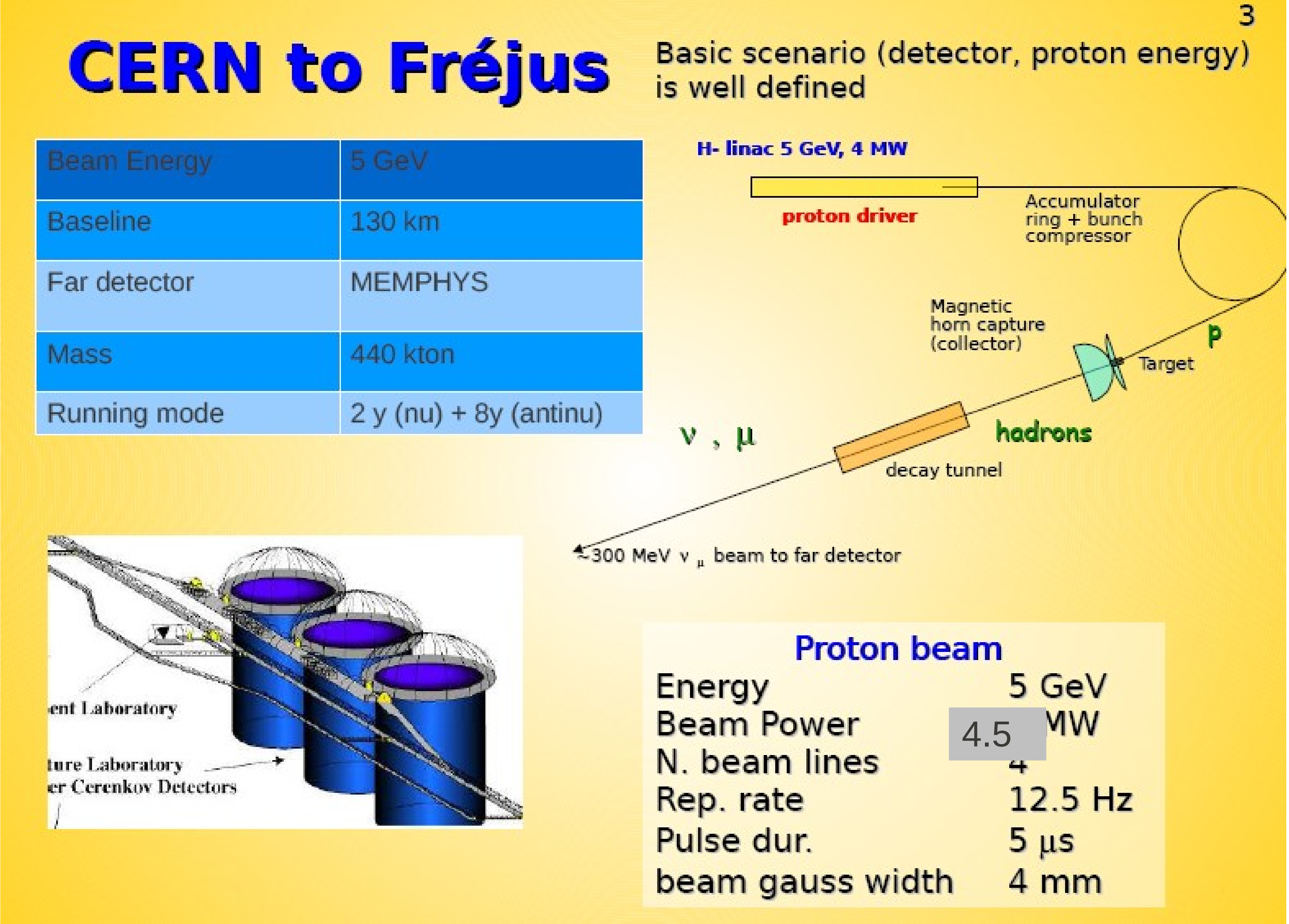


T2K (2.5σ)



MINOS (1.7σ)





CERN to Fréjus

Basic scenario (detector, proton energy) is well defined

Beam Energy	5 GeV
Baseline	130 km
Far detector	MEMPHYS
Mass	440 kton
Running mode	2 y (nu) + 8y (antinu)

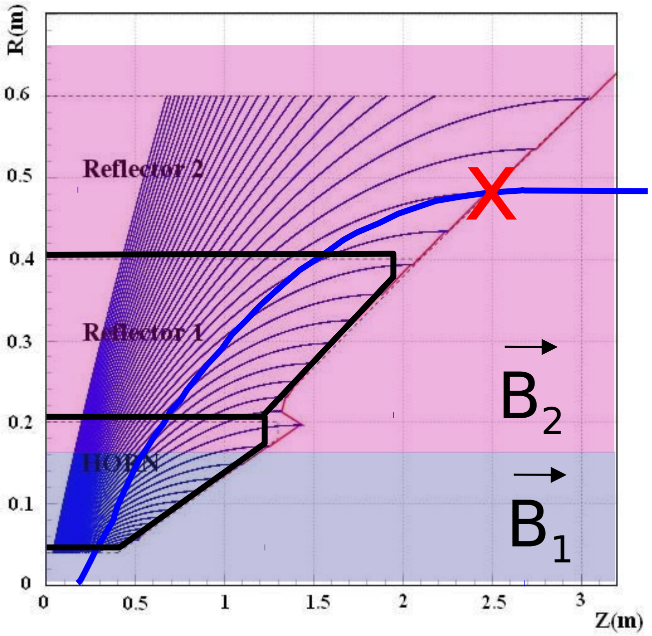
Proton beam

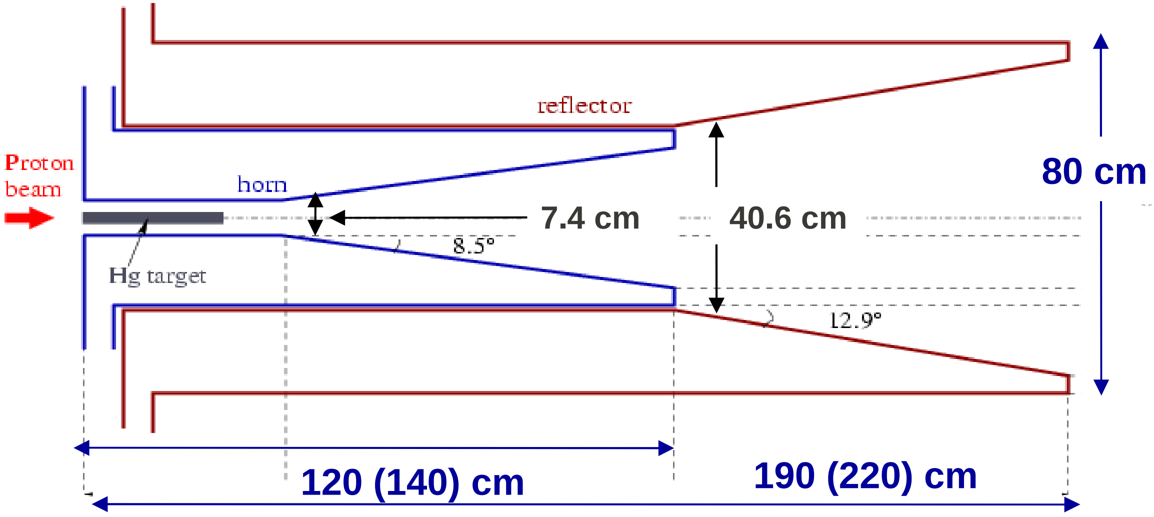
Energy	5 GeV
Beam Power	4.5 MW
N. beam lines	4
Rep. rate	12.5 Hz
Pulse dur.	5 μs
beam gauss width	4 mm

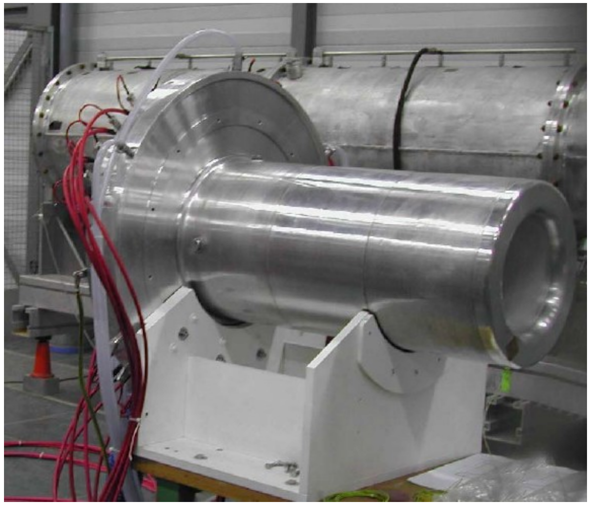
At the start of EUROnu no complete conceptual design of this facility

Why a new design ?

- The previous design for the CERN to Fréjus beam (**Campagne, Cazes : Eur Phys J C45:643-657,2006**) was based on a mercury target (30 cm length) and its quasi point like nature (optimization of the horn)
- Wecame to the conclusion that Mercury was not realistic for this Super Beam for several reasons
- This triggered a revision of the whole target and collector design







The WP2 team

- Cracow University of Technology
- STFC RAL
- IPHC Strasbourg
- Irfu-SPP, CEA Saclay

- E. Baussan, O. Besida, C. Bobeth , O. Caretta , P. Cupial , T. Davenne , C. Densham, M. Dracos ,M. Fitton , G. Gaudiot, M.Kozien ,B. Lepers, A. Longhin, P. Loveridge, F. Osswald , M. Rooney ,B. Skoczen , A. Wroblewski, G. Vasseur, N. Vassilopoulos, V. Zeter, M. Zito +...

Activities

- Beam simulation and optimization, physics sensitivities (Saclay)
- Beam/target interface (RAL)
- Target design (RAL, Strasbourg)
- Horn design (Strasbourg, Cracow)
- Target horn integration (Strasbourg, Cracow)
- Target station (RAL)
- Energy deposition, activation, safety (Strasbourg)

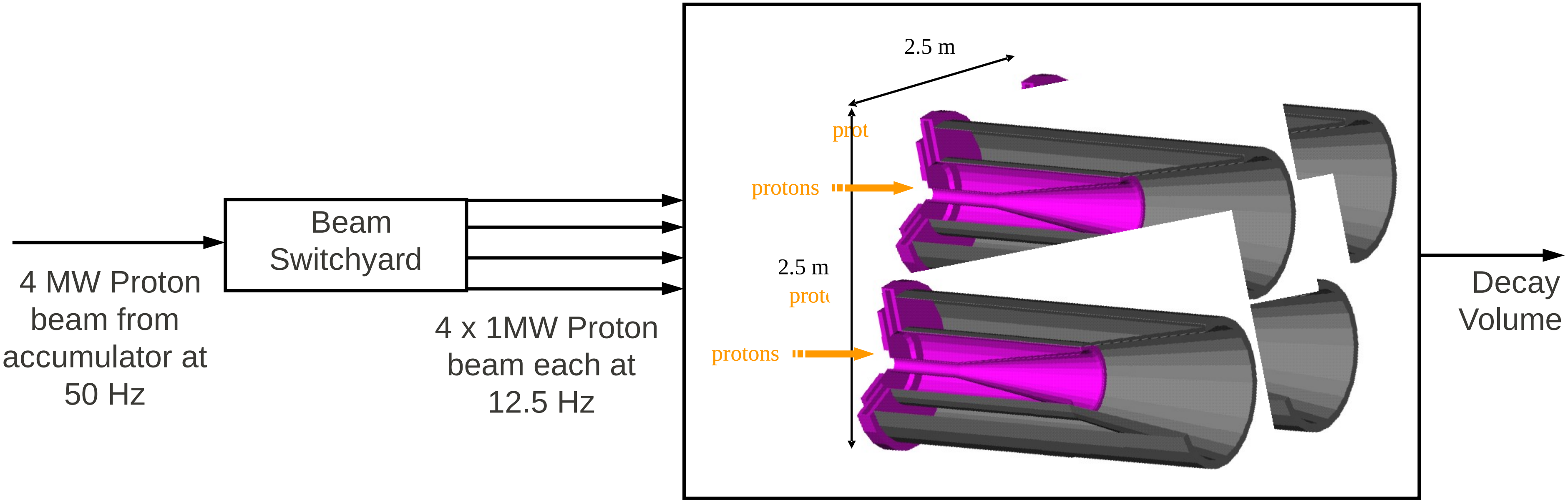
Important steps for the design

- Solid static target
- Use multiple (4) targets+collectors
- Each pulsed at 12.5 Hz
- Use single horn (no reflector)
- Optimization of horn shape → Miniboone shape
- A lot of progress towards a working solution, at constant (or improved) physics performance

Summary of main parameters

Parameter	Value
Beam Power	4 MW
Beam energy	4.5 GeV
Target length	78 cm
Target radius	1.2 cm
Decay tunnel radius	2m
Decay tunnel length	25m

Overall configuration



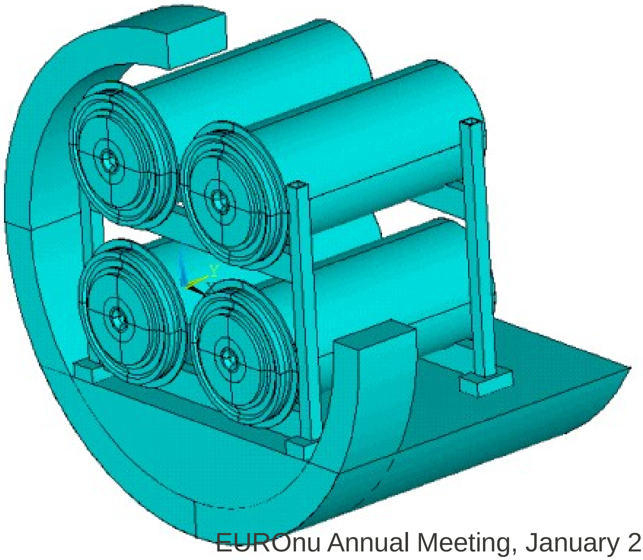
4 MW Proton beam from accumulator at 50 Hz

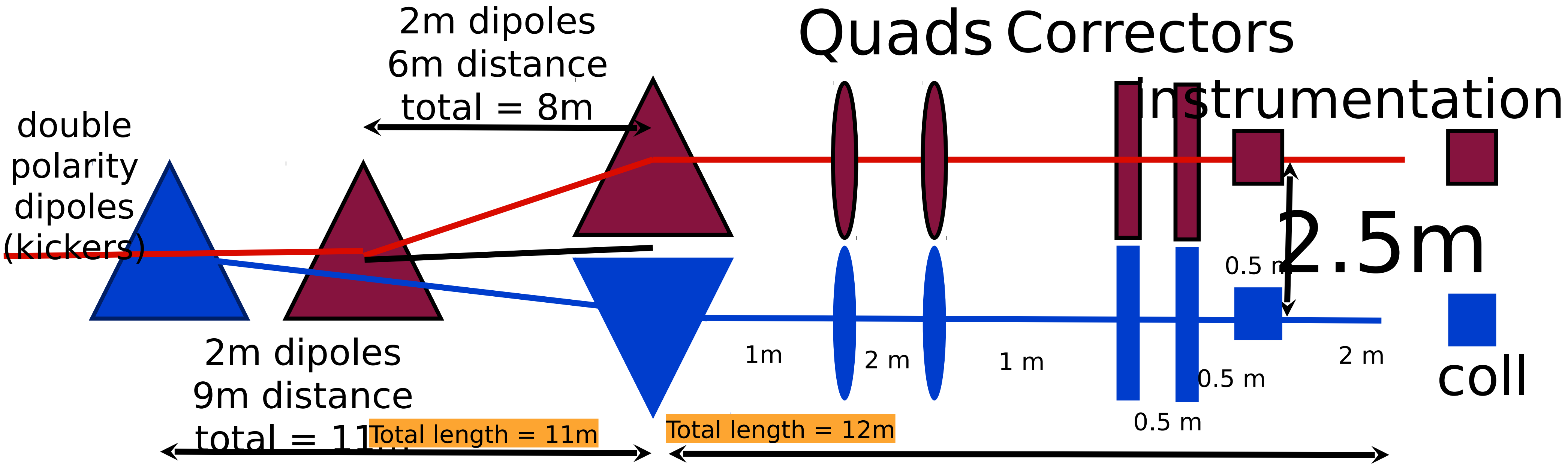
Beam Switchyard

4 x 1MW Proton beam each at 12.5 Hz

Decay Volume

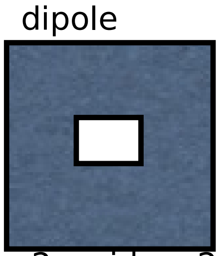
Target Station (4 targets, 4 horns)





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		



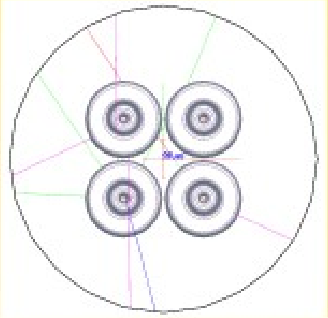
magnet lengths:
- dipoles : 2m
- quads : 1m each
- correctors : 0.7m
(must add connections)

The 4-horns scenario

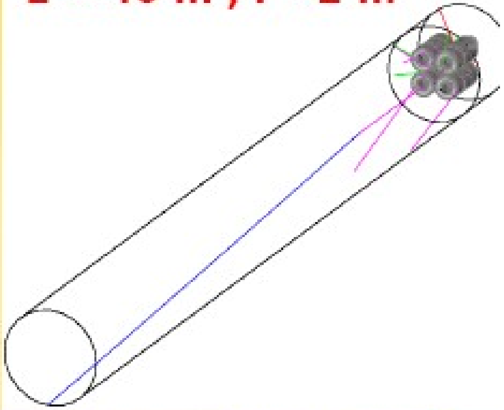
Reduced stress on target via
- **lower frequency (12.5 Hz) or**
- **lower p-flux (1 MW)**

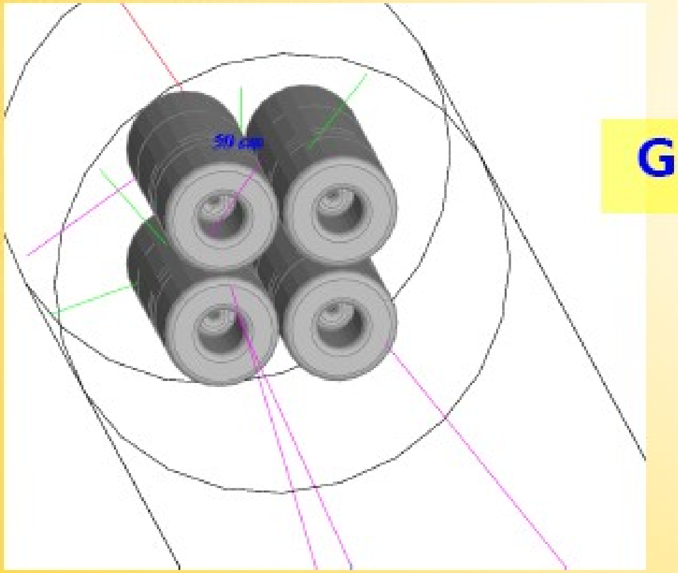
depending on injection strategy

Profits of horn compactness (r~0.5m)



L = 40 m , r =2 m

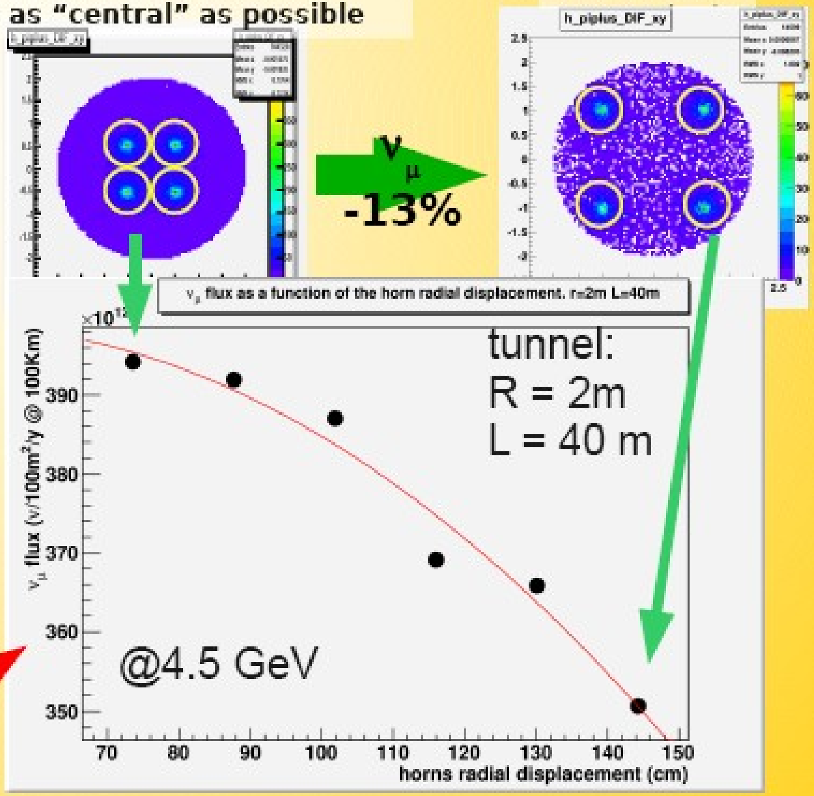




GEANT4

Baseline configuration with horns as “central” as possible

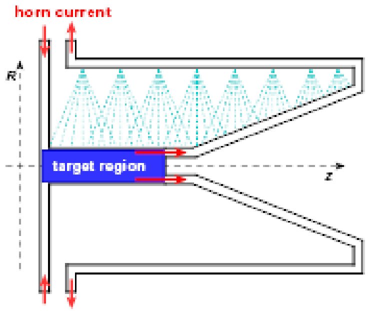
Worst case

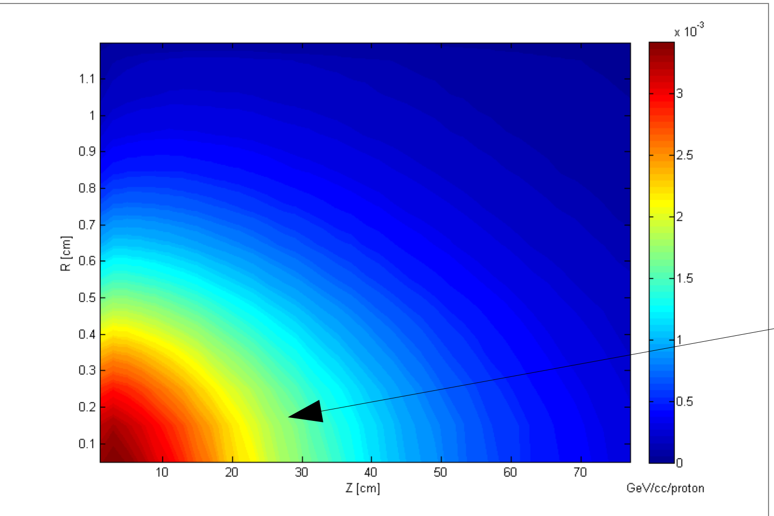


Small flux loss even up to big lateral displacements.

Target studies and baseline

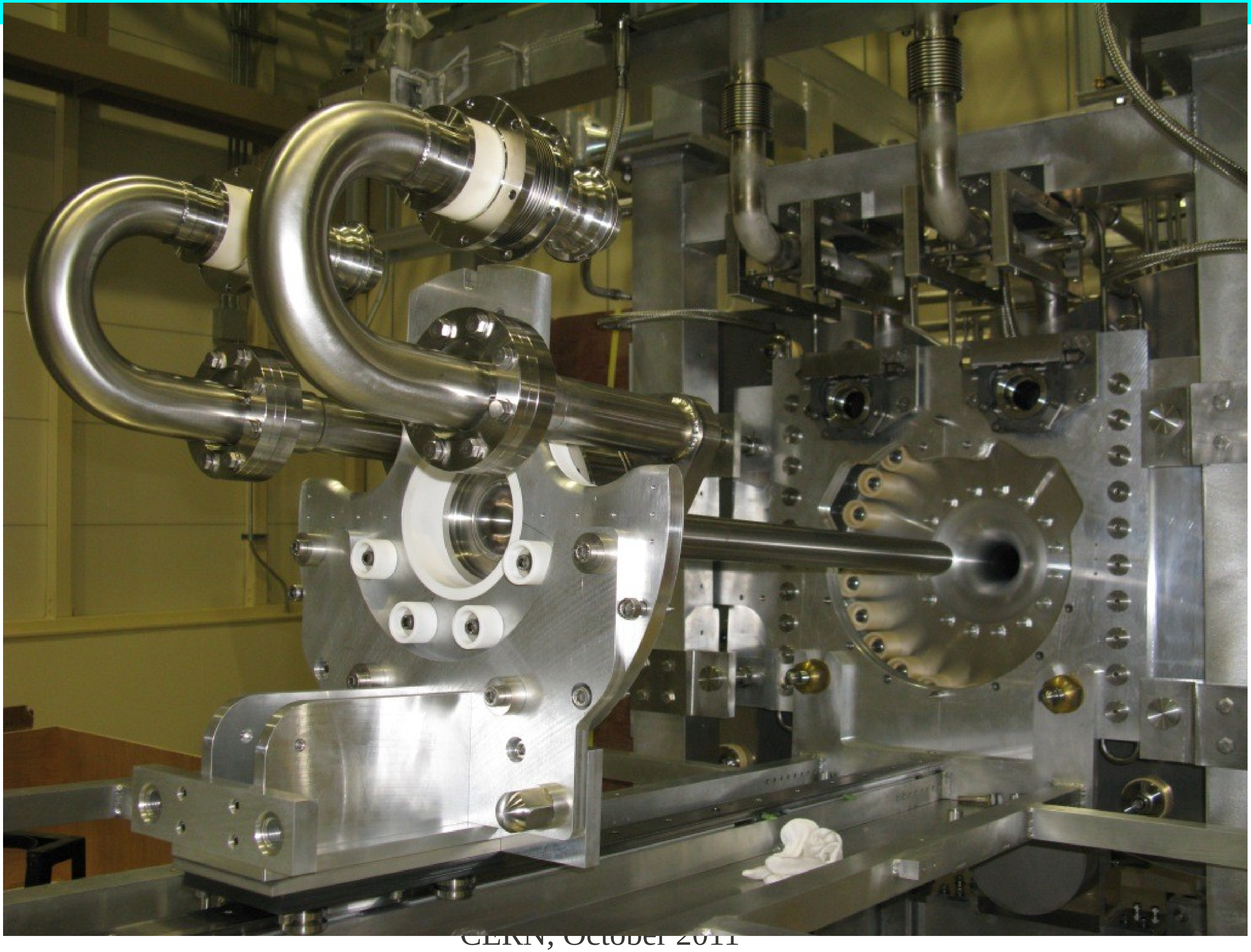
- In the past months we have focused on the target design
- We have considered:
  - A solid static low-Z target cleverly shaped
  - A one-piece (embedded) target+horn (conducting target)
  - A pebble bed target





A critical issue: very high power density in the upstream central volume

T2K graphite target



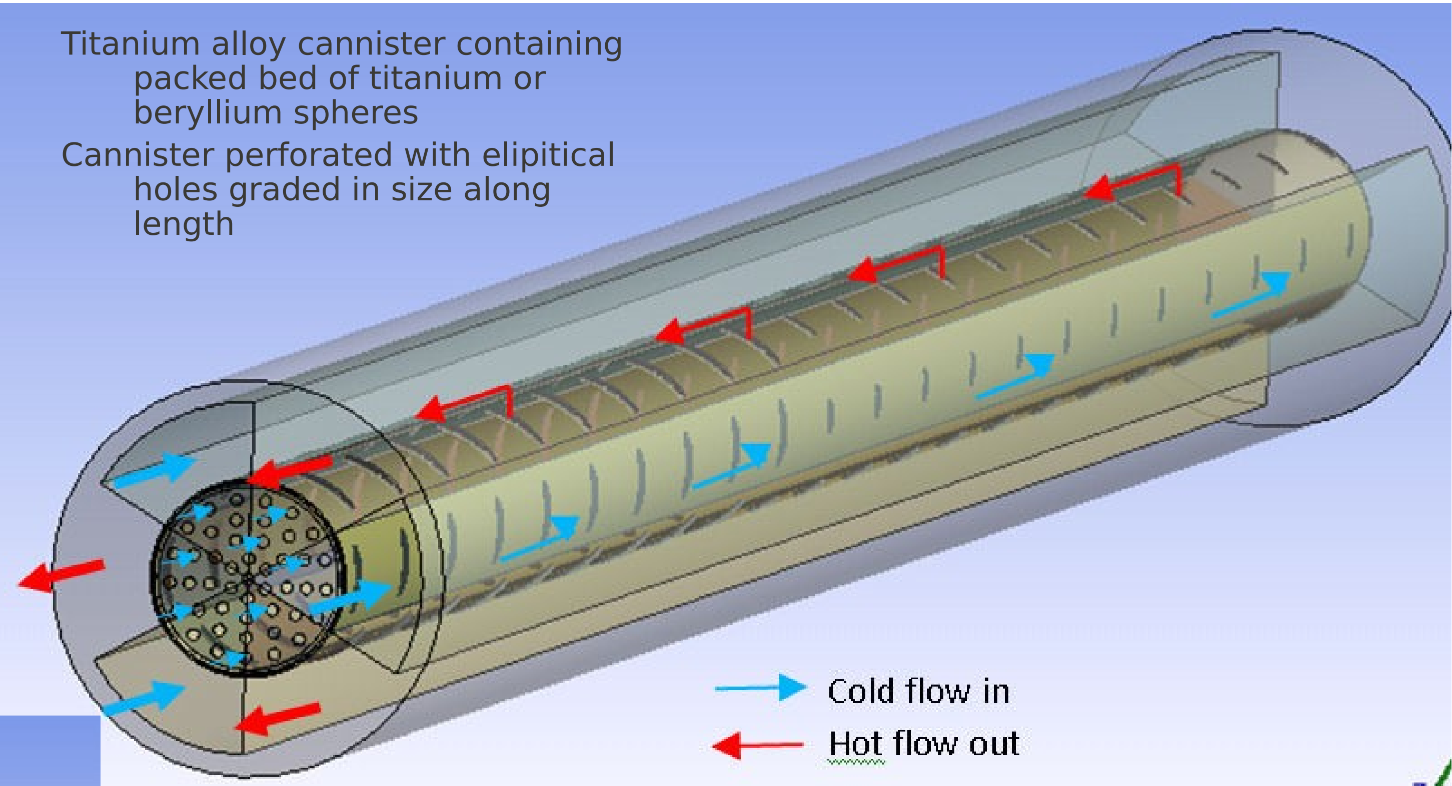
Proposed by Pugnat and Sievers

C. Densham, T. Davenne

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

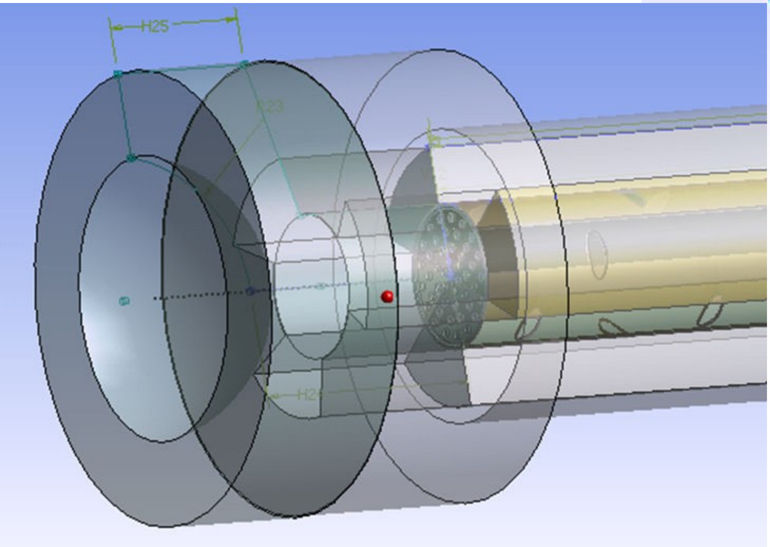
Packed bed cannister in parallel flow configuration

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



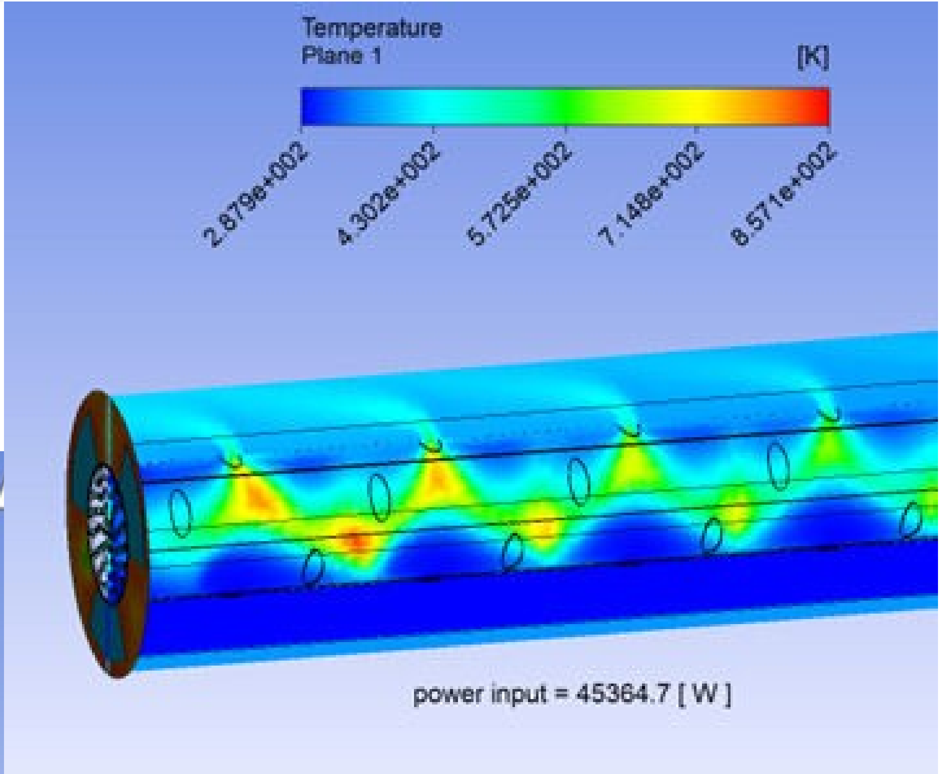
Model Parameters
Proton Beam Energy = 4.5GeV
Beam sigma = 4mm
Packed Bed radius = 12mm
Packed Bed Length = 780mm
Packed Bed sphere diameter = 3mm
Packed Bed sphere material : Beryllium or Titanium
Coolant = Helium at 10 bar pressure

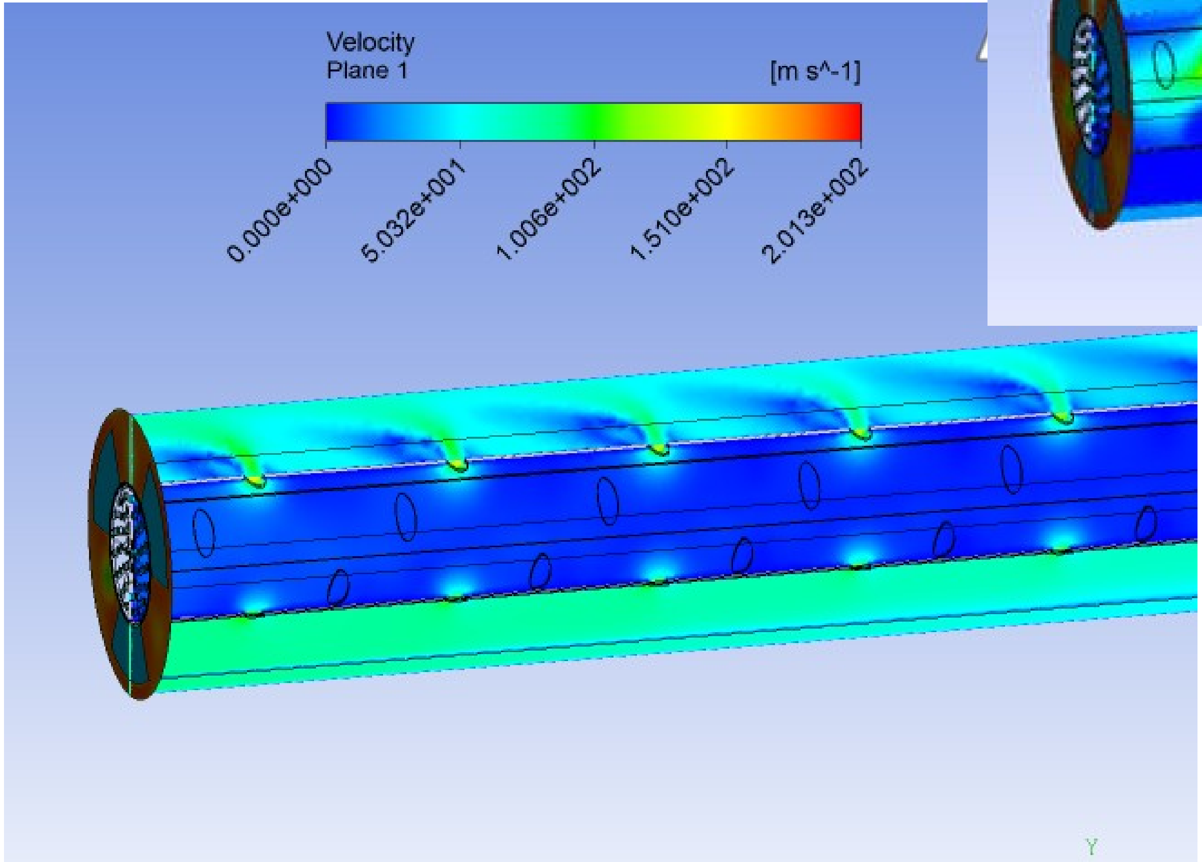
Helium Flow

<u>Helium Velocity</u>

Maximum flow velocity = 202m/s

Maximum Mach Number < 0.2





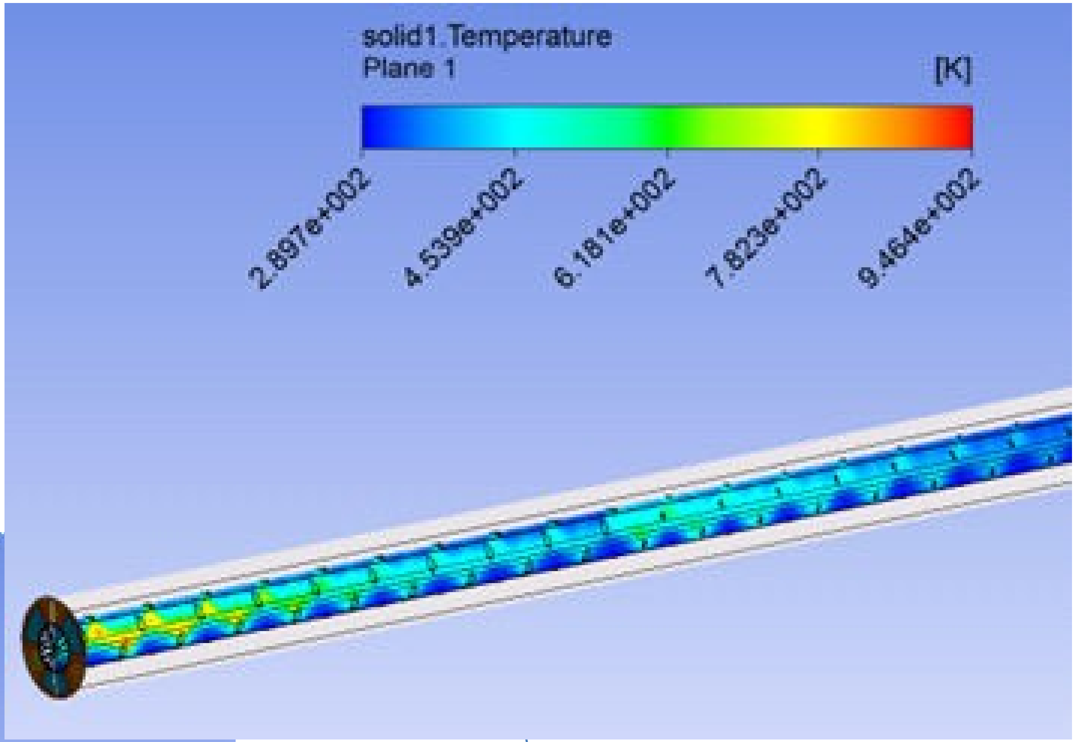
<u>Helium Gas Temperature</u>

Total helium mass flow = 93 grams/s

Maximum Helium temperature = 857K =584°C

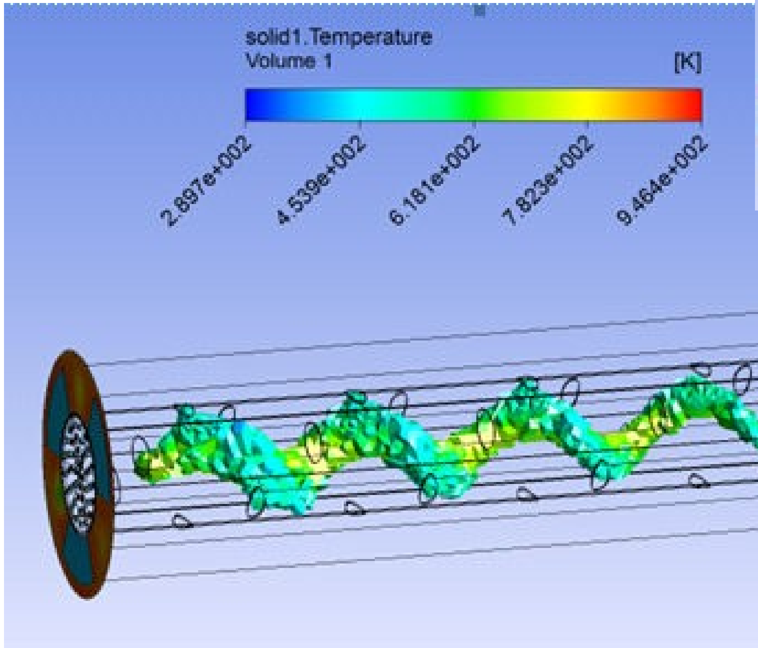
Helium average outlet Temperature = 109°C

Packed Bed



High Temperature region

Highest temperature Spheres occur near outlet holes due to the gas leaving the cannister being at its hottest



Titanium temperature contours

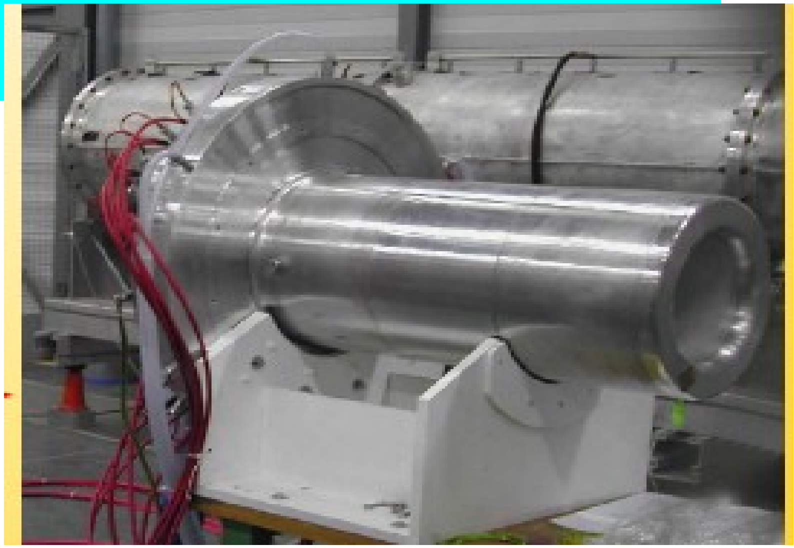
Maximum titanium temperature = 946K =673°C (N.B. Melting temp =1668°C)

Towards the target baseline

After these studies we have concluded that

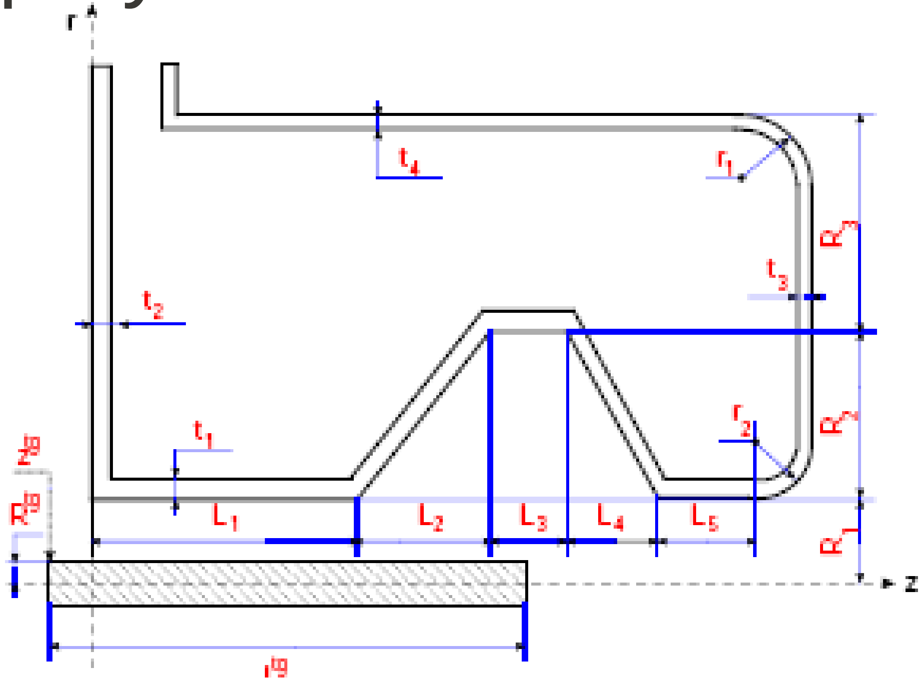
- The Titanium pebble bed target appears to be the best candidate (capable of multi-MW) → baseline choice
- The solid static target is feasible, pencil shape solution
- The embedded target is disfavored

Horn

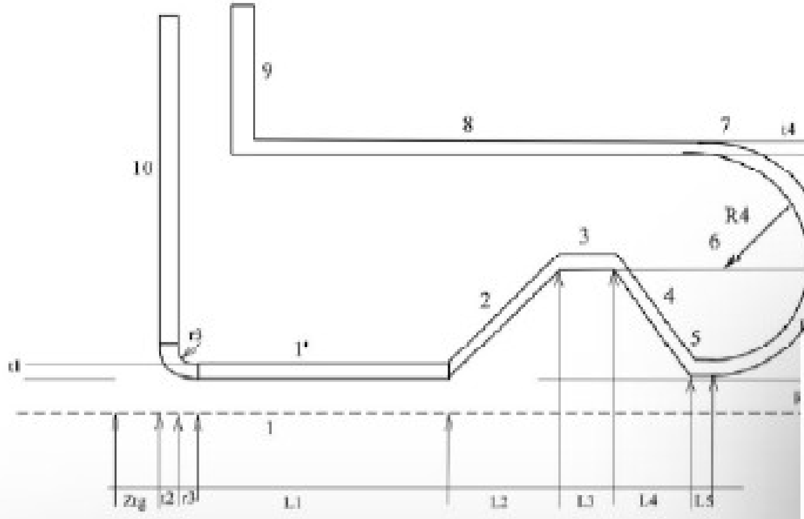


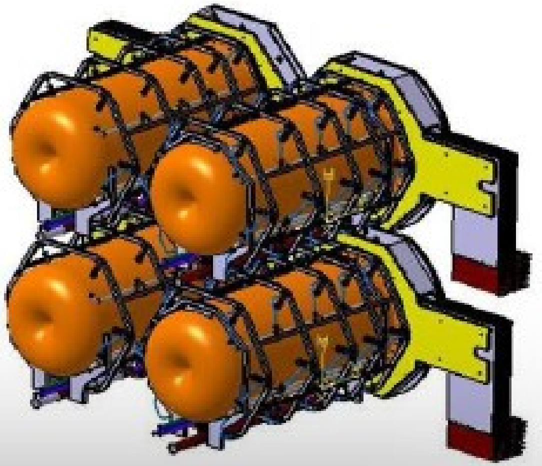
Baseline :

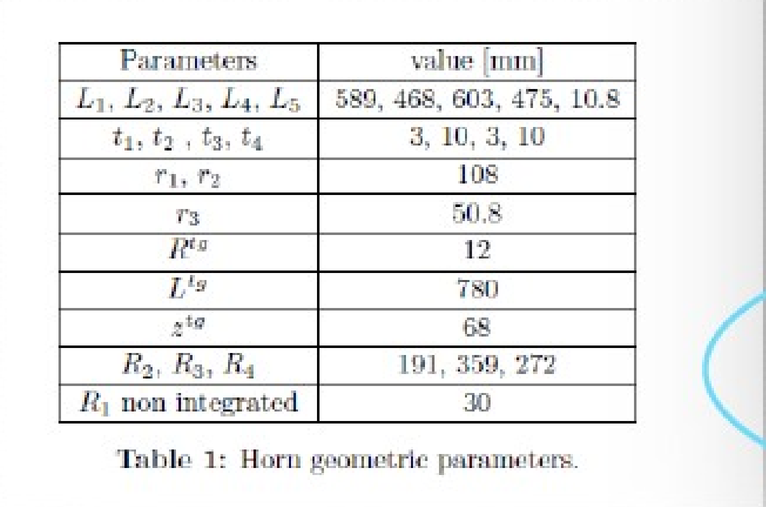
- Miniboone shape
- Aluminum
- Cooled with internal water sprays
- Pulsed with 300-350 kA



EUROnu scenario for 4-horn system

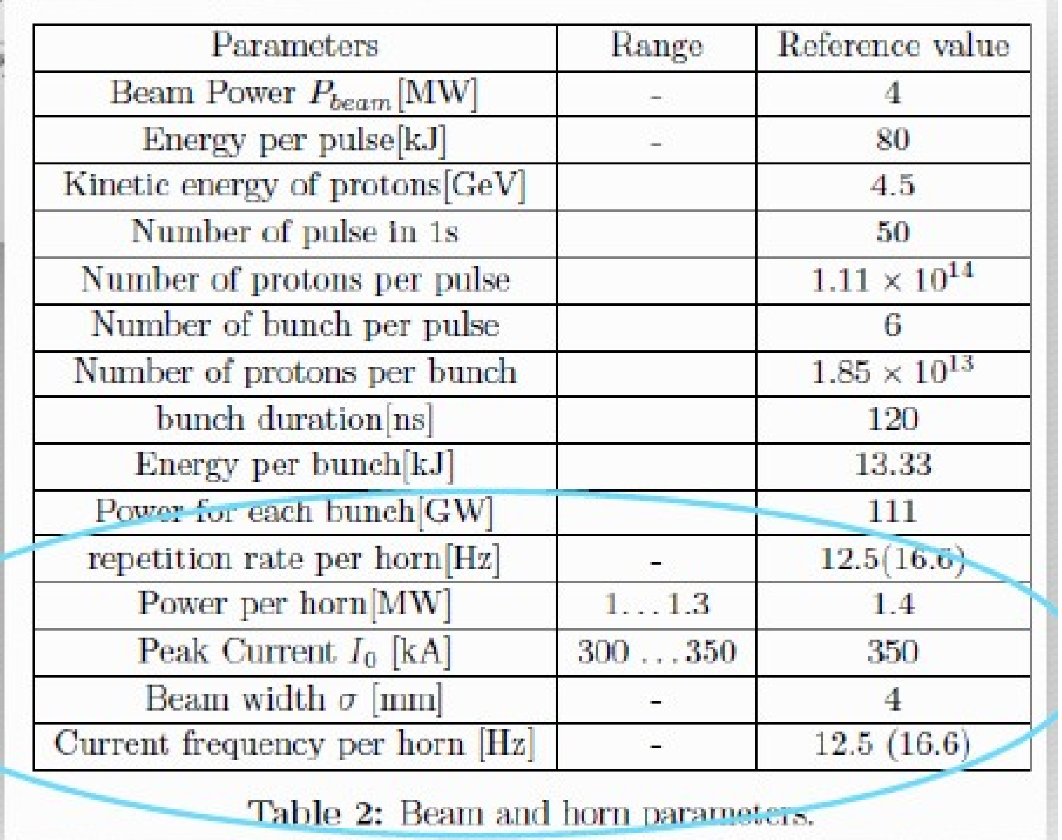






Parameters	value [mm]
L_1, L_2, L_3, L_4, L_5	589, 468, 603, 475, 10.8
t_1, t_2 , t_3, t_4	3, 10, 3, 10
r_1, r_2	108
r_3	50.8
R^{tg}	12
L^{tg}	780
z^{tg}	68
R_2, R_3, R_4	191, 359, 272
R_1 non integrated	30

Table 1: Horn geometric parameters.

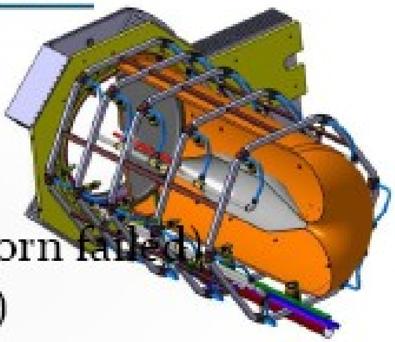


Parameters	Range	Reference value
Beam Power P_{beam}[MW]	-	4
Energy per pulse[kJ]	-	80
Kinetic energy of protons[GeV]		4.5
Number of pulse in 1s		50
Number of protons per pulse		1.11×10^{14}
Number of bunch per pulse		6
Number of protons per bunch		1.85×10^{13}
bunch duration[ns]		120
Energy per bunch[kJ]		13.33
Power for each bunch[GW]		111
repetition rate per horn[Hz]	-	12.5(16.6)
Power per horn[MW]	$1 \ldots 1.3$	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)

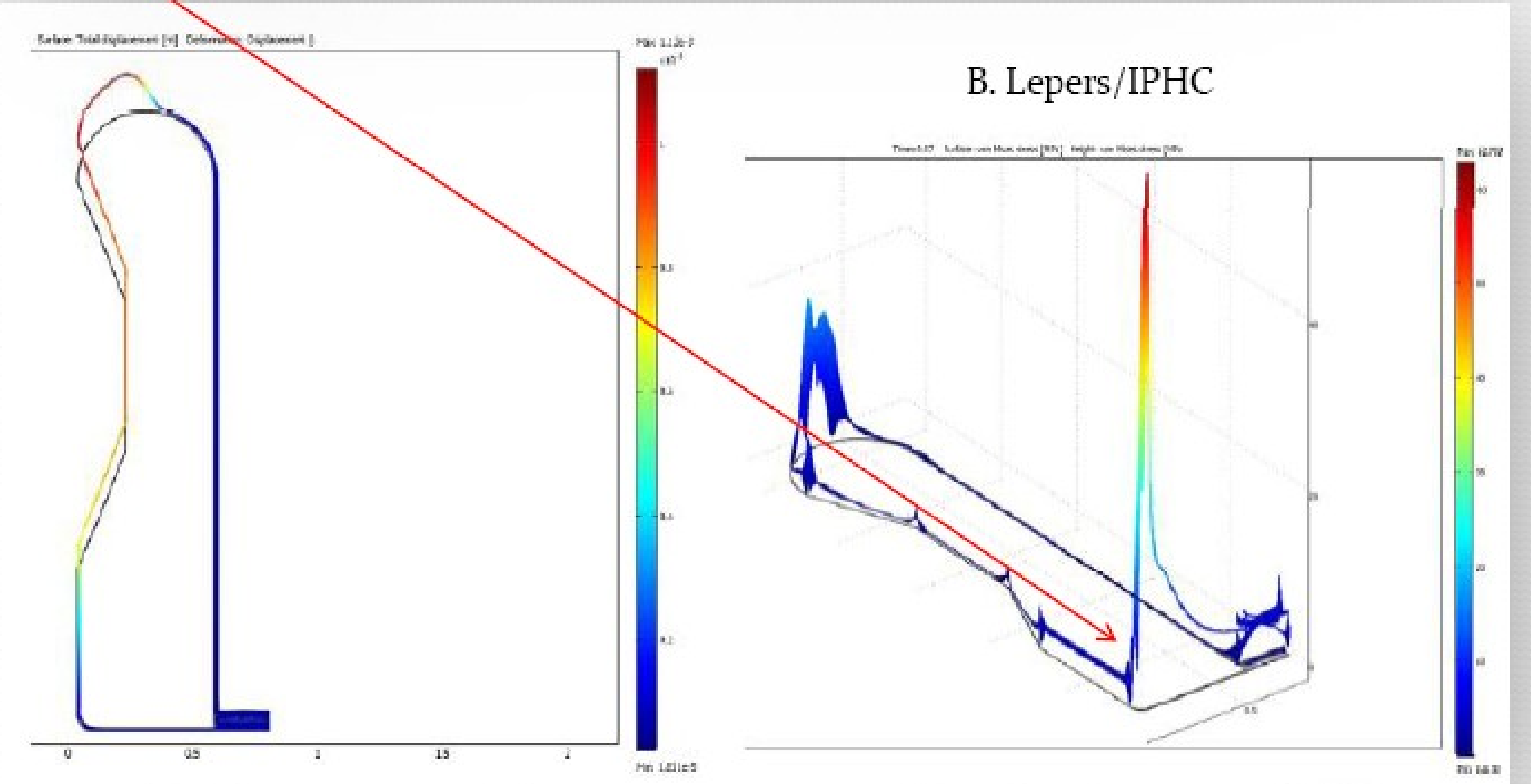
Table 2: Beam and horn parameters.

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)
  - ✓ $T_{Al}=60°C$, $\{h_{corner}, h_{inner}, h_{horn/out}\} = \{6.5, 3.8, 0.1\}$ kW/(m²K)
  - ✓ $S_{max} = 62MPa$



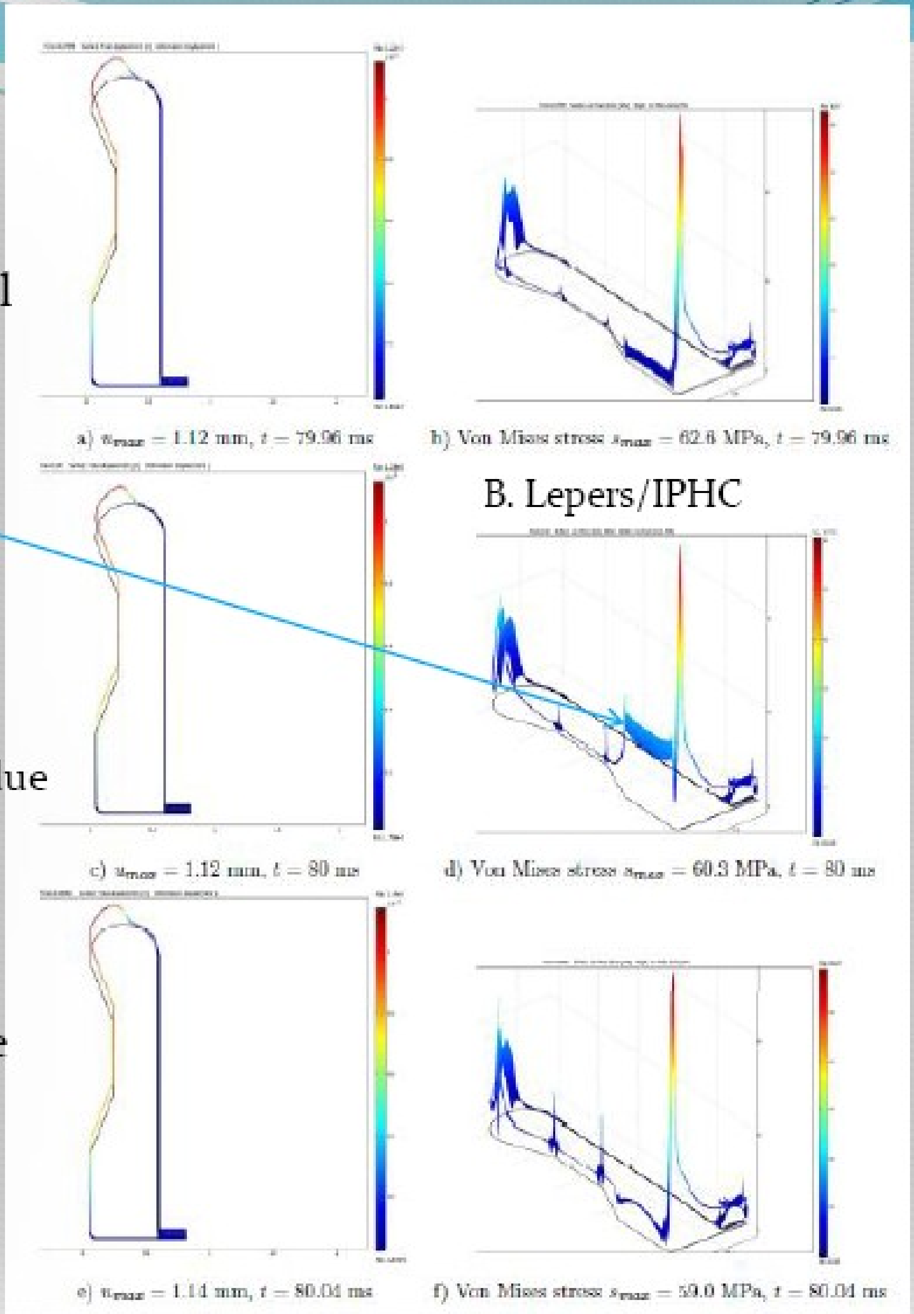
B. Lepers/IPHC

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

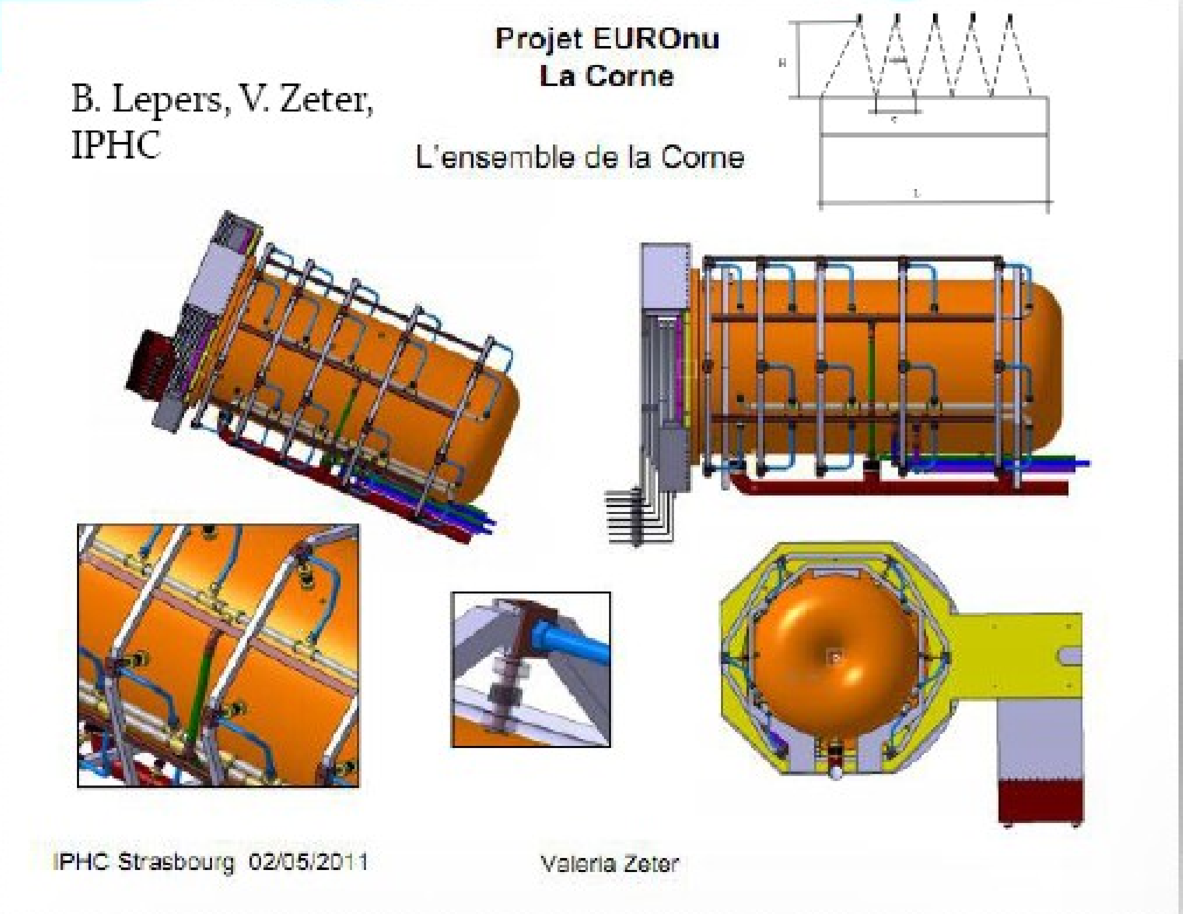
B. Lepers/IPHC

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



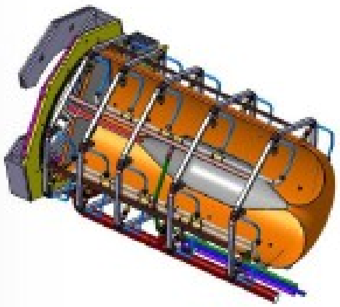
B. Lepers, V. Zeter, IPHC

Projet EUROnu
La Corne

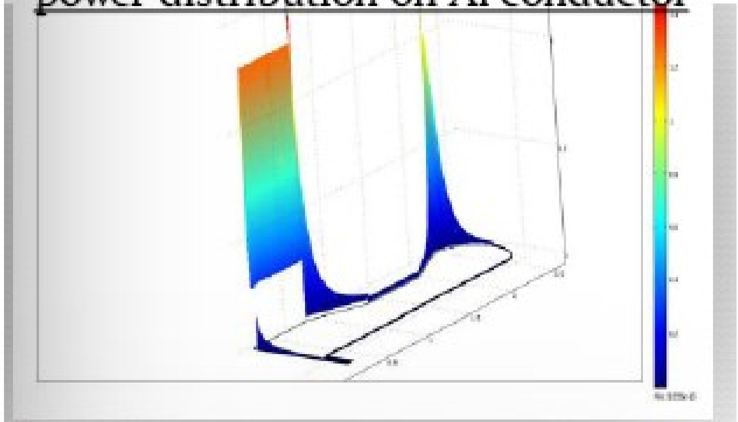
L'ensemble de la Corne

IPHC Strasbourg 02/05/2011

Valeria Zeter



power distribution on Al conductor

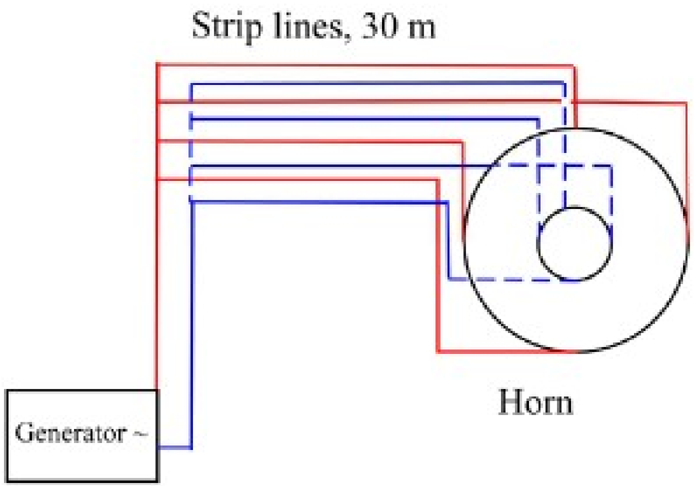


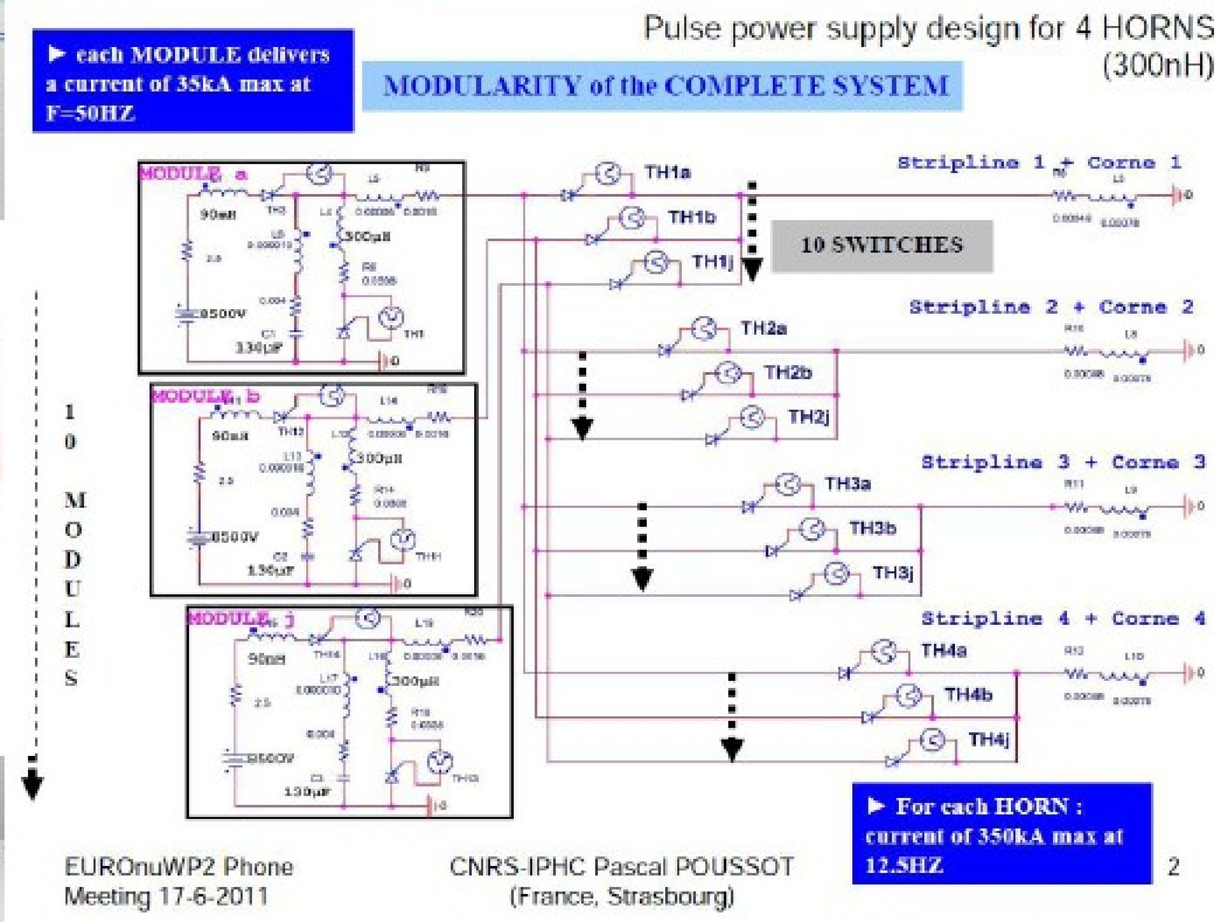
- ✓ planar and/or elliptical water jets
- ✓ flow rate between 60-120l/min
- ✓ h cooling coefficient 1-7 kW/(m^2K)
- ✓ EUROnu-Note-10-06

- ➤ design for 60°C uniform horn temperature:
  - ✓ $\{h_{corner}, h_{inner}, h_{outer/horn}\} = \{6.5, 3.8, 1\}$ kW/(m^2K)/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

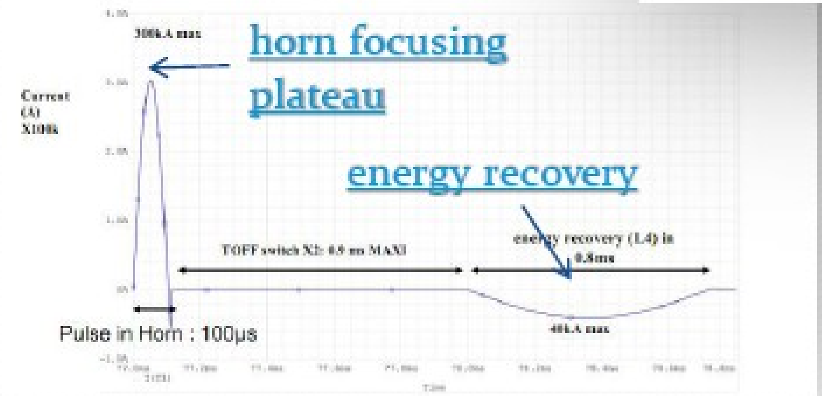
► For each HORN : current of 350kA max at 12.5HZ

EURОnuWP2 Phone Meeting 17-6-2011

CNRS-IPHC Pascal POUSSOT (France, Strasbourg)

2

energy recovery with self : current in capacitor C



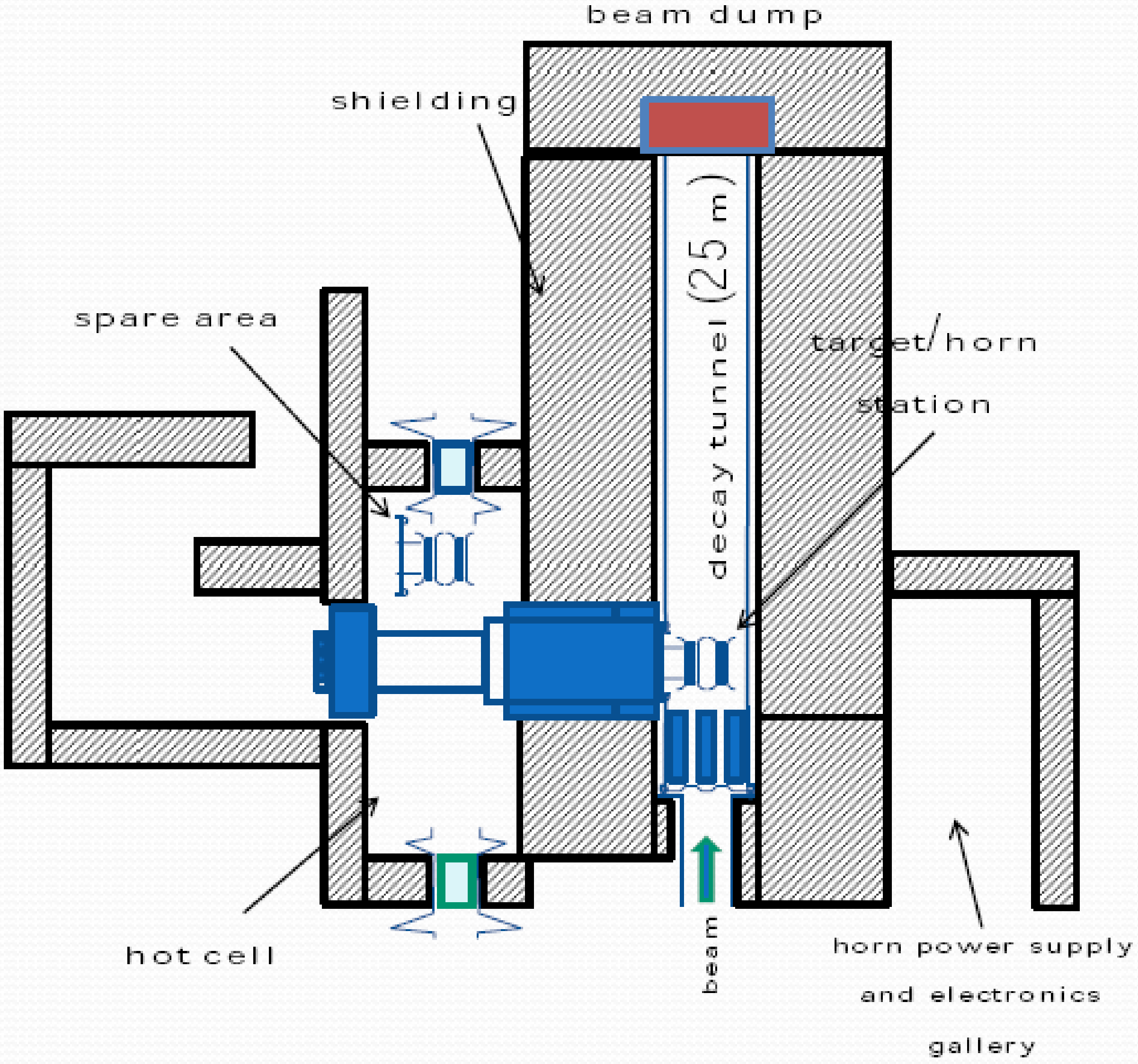
Energy recovery with an inductance L, switch and capacitor:

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

Safety II

Design includes:

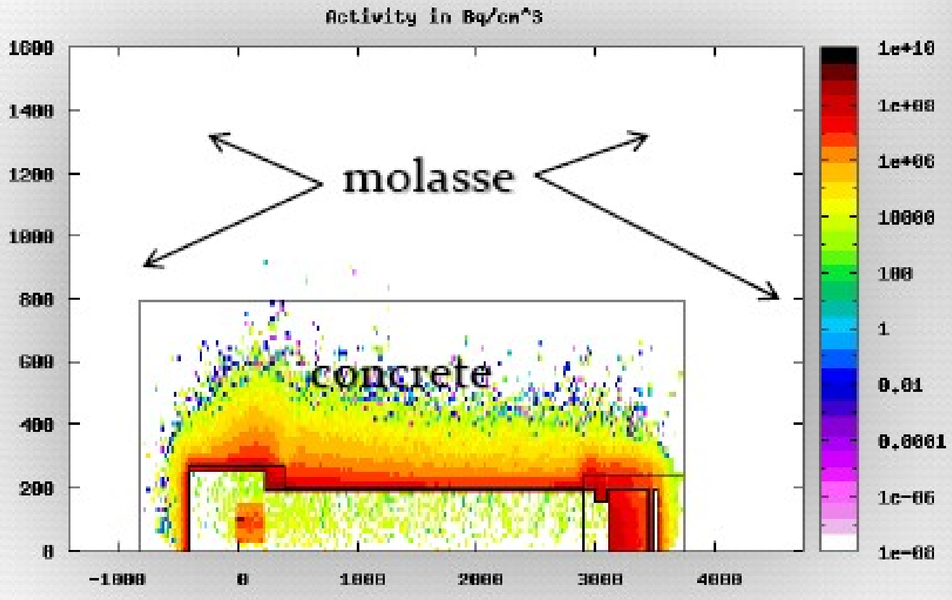
- Proton Driver line
- Experimental Hall
  - ✓ MW Target Station
  - ✓ Decay Tunnel
  - ✓ Beam Dump
- Maintenance Room
- Service Gallery
  - ✓ Power supply
  - ✓ Cooling system
  - ✓ Air-Ventilation system
- Waste Area

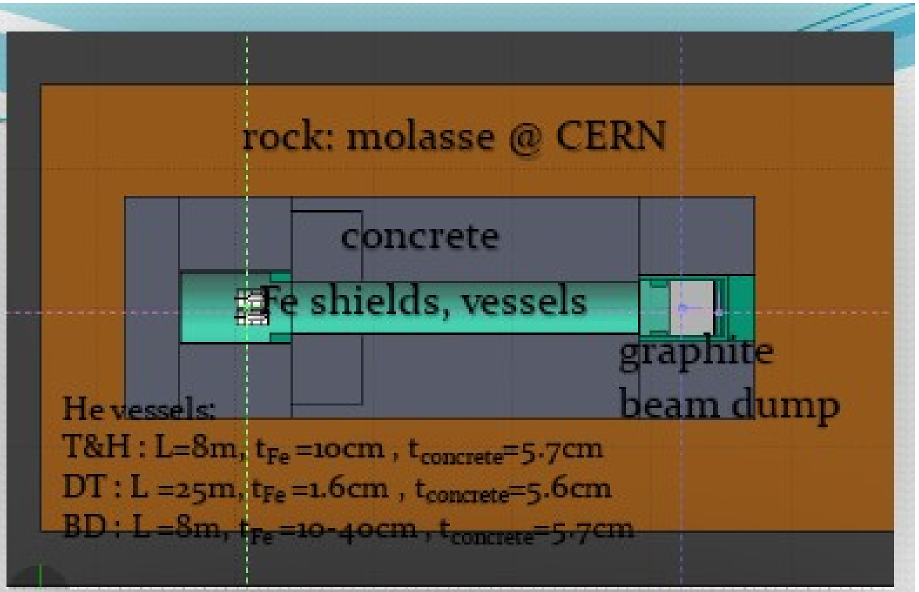


Energy deposition and Activation Studies

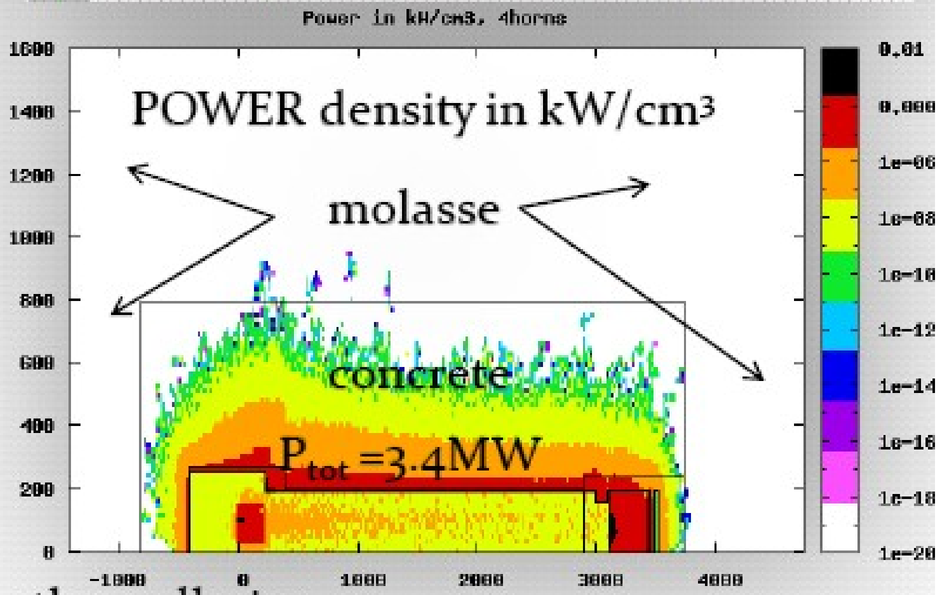
FLUKA MC + FLAIR

ACTIVITY density in Bq/cm^3





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

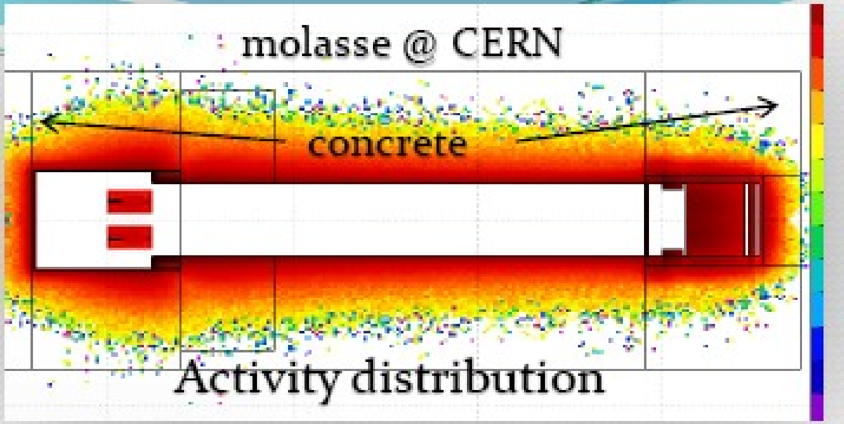


- energy is confined from concrete thickness
- minimum activation of molasse rock
- minimum/none effective dose to humans in other galleries
- detailed tables of the radionuclides
- water contamination from tritium is well kept under safety levels

Eric Baussan,
N. Vassilopoulos/IPHC

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:

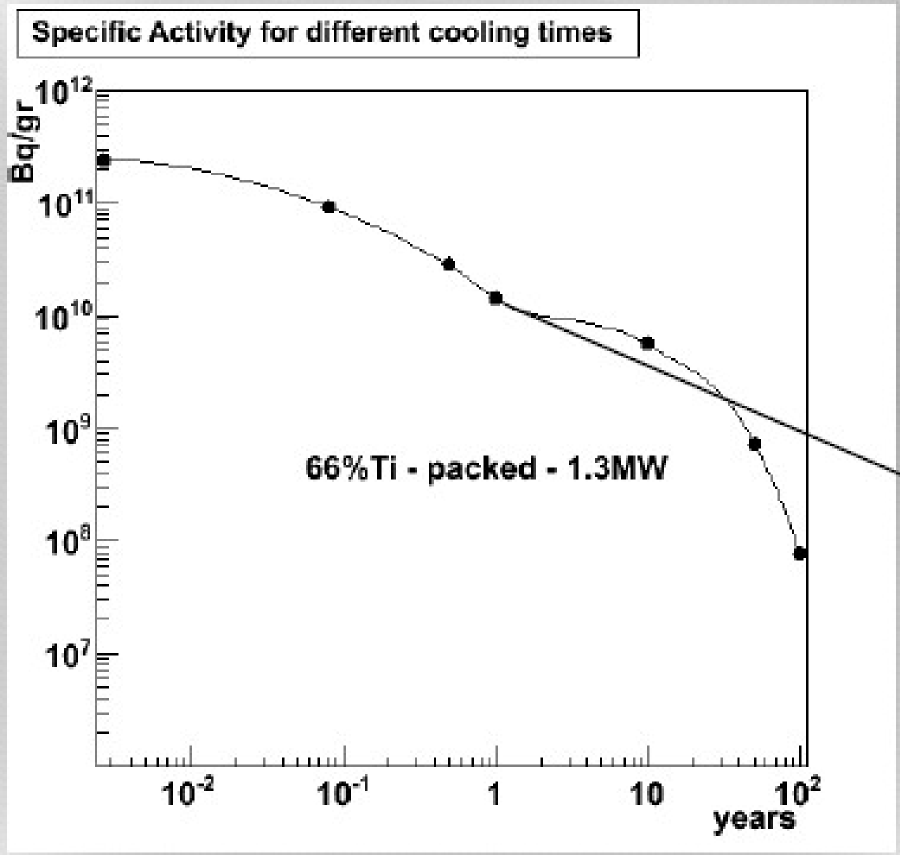
- ➢ of all the radionuclide's created ^{22}Na and tritium could represent a hazard by contaminating the ground water. Limits in activity after 1y=200days of beam:

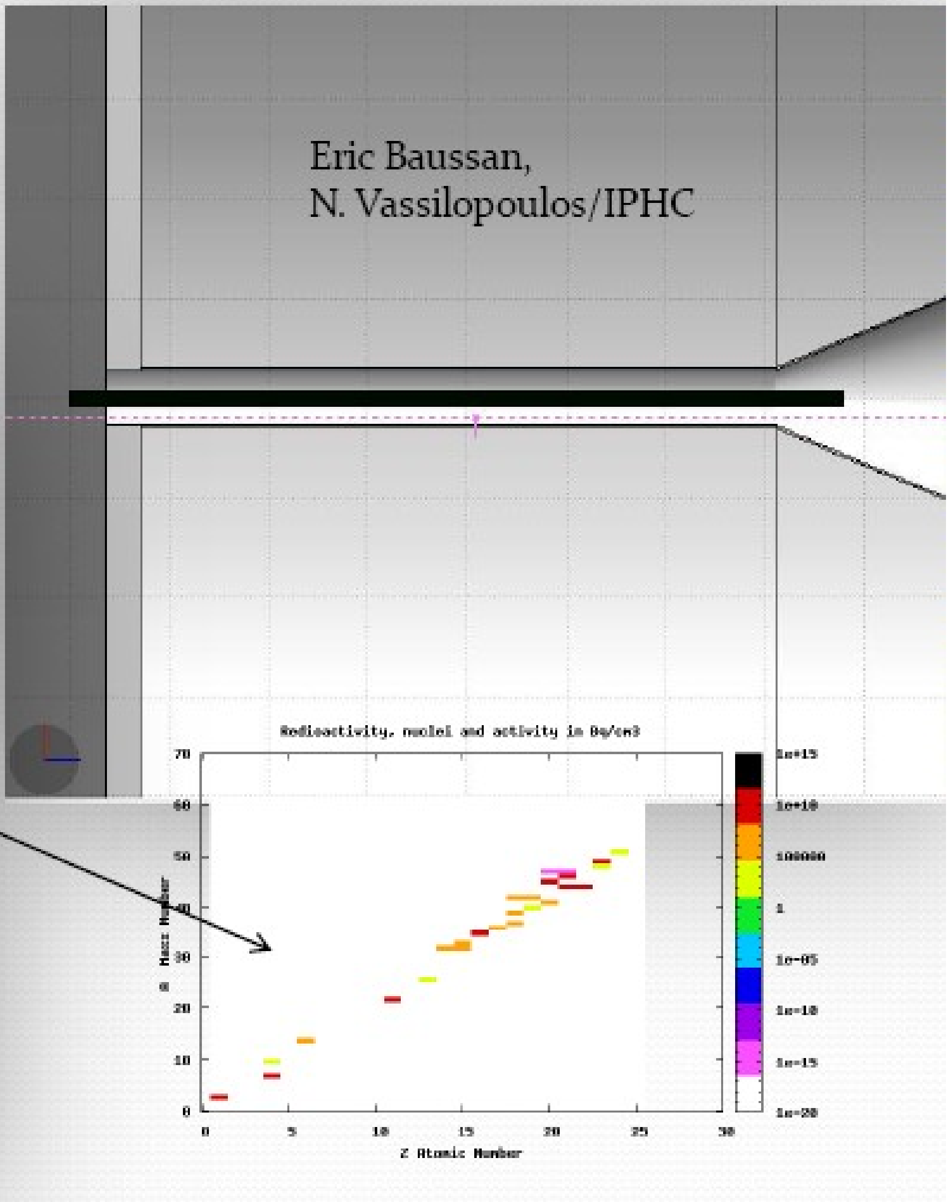
CERN annual activity constraints in molasse (for achieving 0.3mSv for the public through water)		**SuperBeam, (preliminary)**
^{22} Na	4.2 x 10^{11} Bq	- (to be investigated)
tritium	3.1 x 10^{15} Bq	6x10^8 Bq

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





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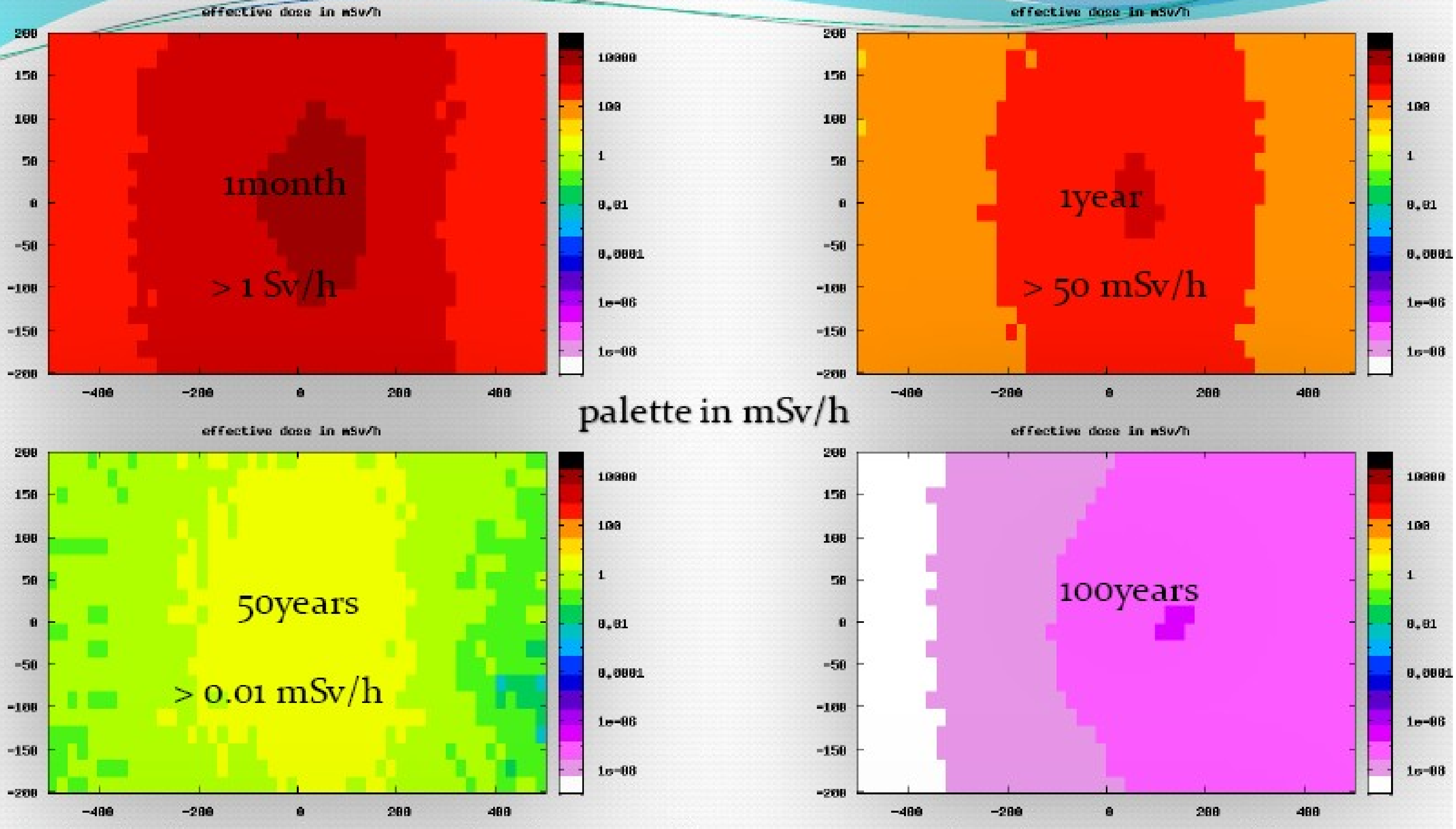
N. Vassilopoulos/IPHC

Dose Rates target/horn at Storage Area, II



palette in mSv/h

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

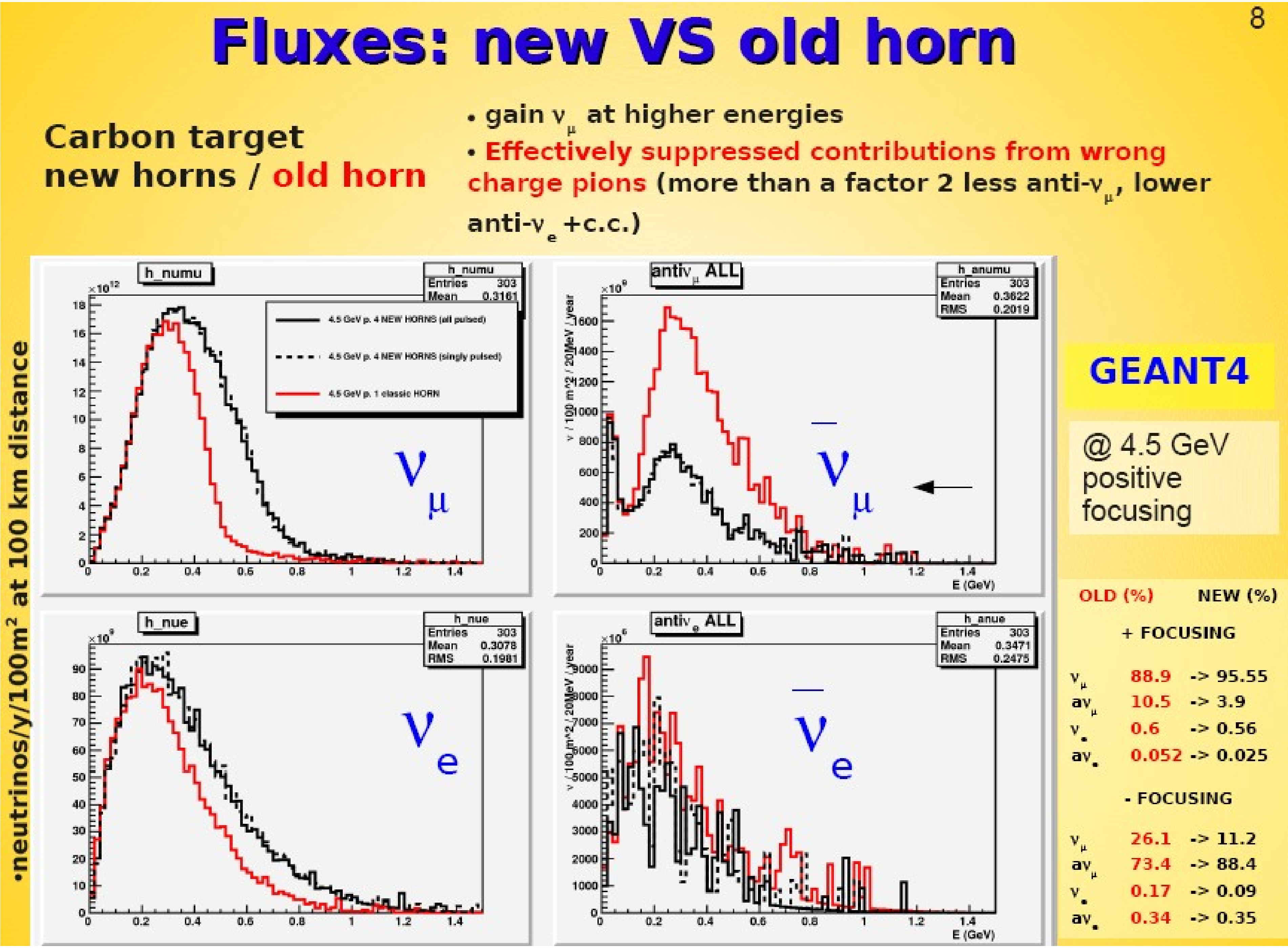
<u>-> remote handling mandatory</u>

Eric Baussan,
N. Vassilopoulos/IPHC

Fluxes and sensitivity

All the following results are summarized in

http://arxiv.org/abs/1106.1096



Fluxes: new VS old horn

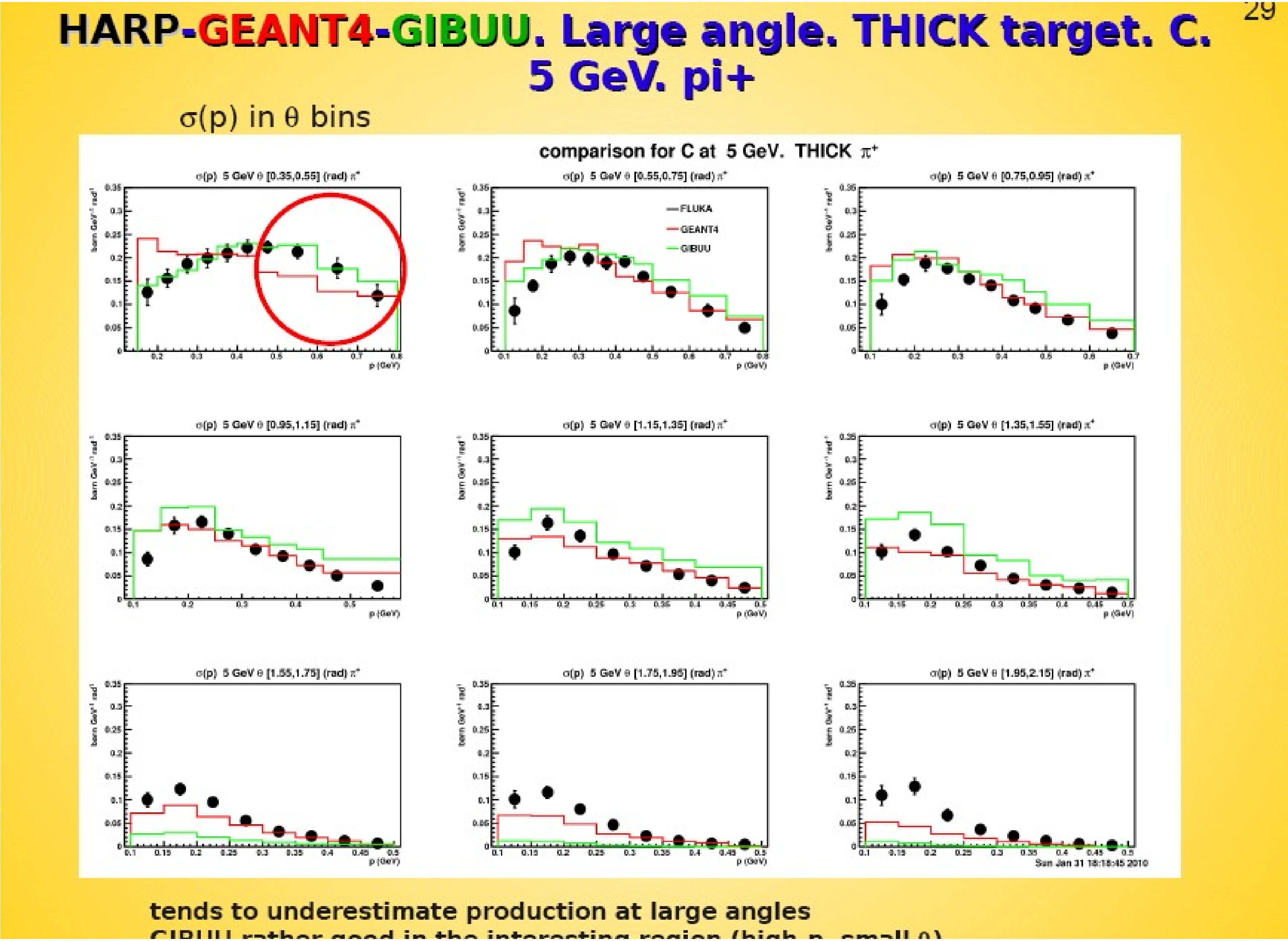
Carbon target
new horns / old horn

- gain ν_μ at higher energies
- Effectively suppressed contributions from wrong charge pions (more than a factor 2 less anti-ν_μ, lower anti-ν_e +c.c.)

GEANT4

@ 4.5 GeV
positive
focusing

	OLD (%)	NEW (%)
+ FOCUSING		
ν_μ	88.9	-> 95.55
aν_μ	10.5	-> 3.9
ν_e	0.6	-> 0.56
aν_e	0.052	-> 0.025
- FOCUSING		
ν_μ	26.1	-> 11.2
aν_μ	73.4	-> 88.4
ν_e	0.17	-> 0.09
aν_e	0.34	-> 0.35



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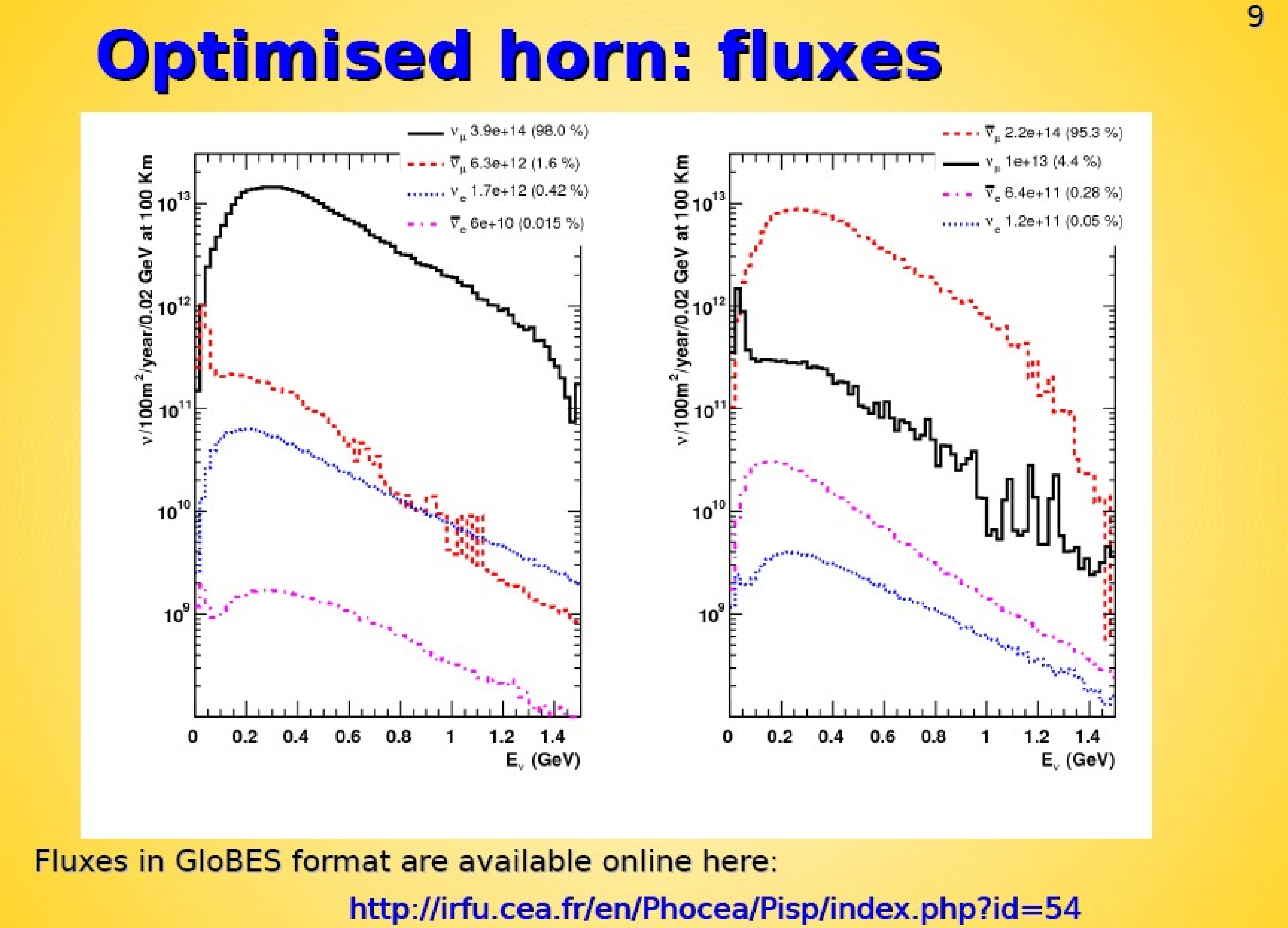
HARP-GEANT4-GIBUU. Large angle. THICK target. C. 5 GeV. pi+

σ(p) in θ bins

tends to underestimate production at large angles

GIBUU rather good in the interesting region (high p, small θ)



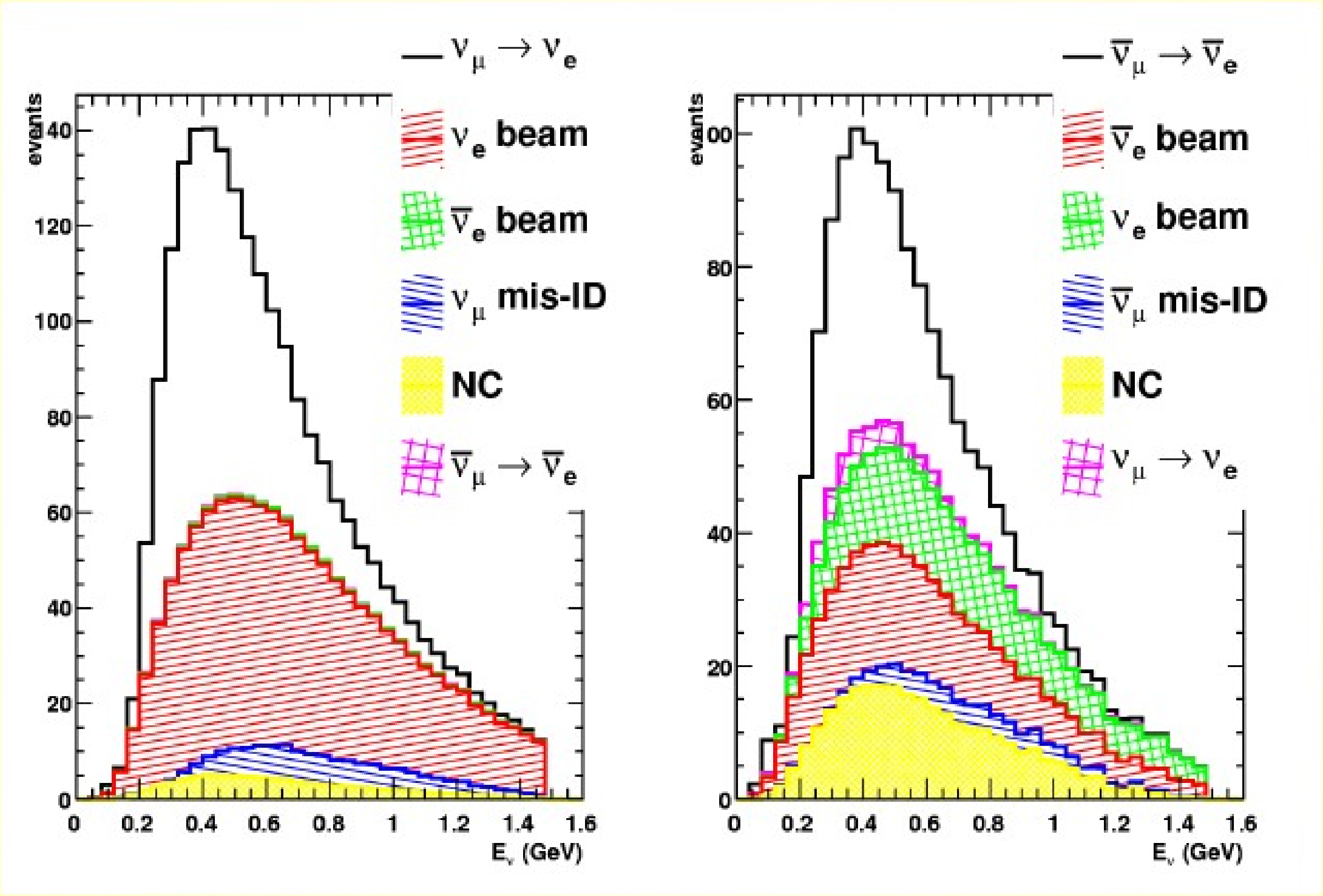
Optimised horn: fluxes

Fluxes in GloBES format are available online here:

http://irfu.cea.fr/en/Phocea/Pisp/index.php?id=54

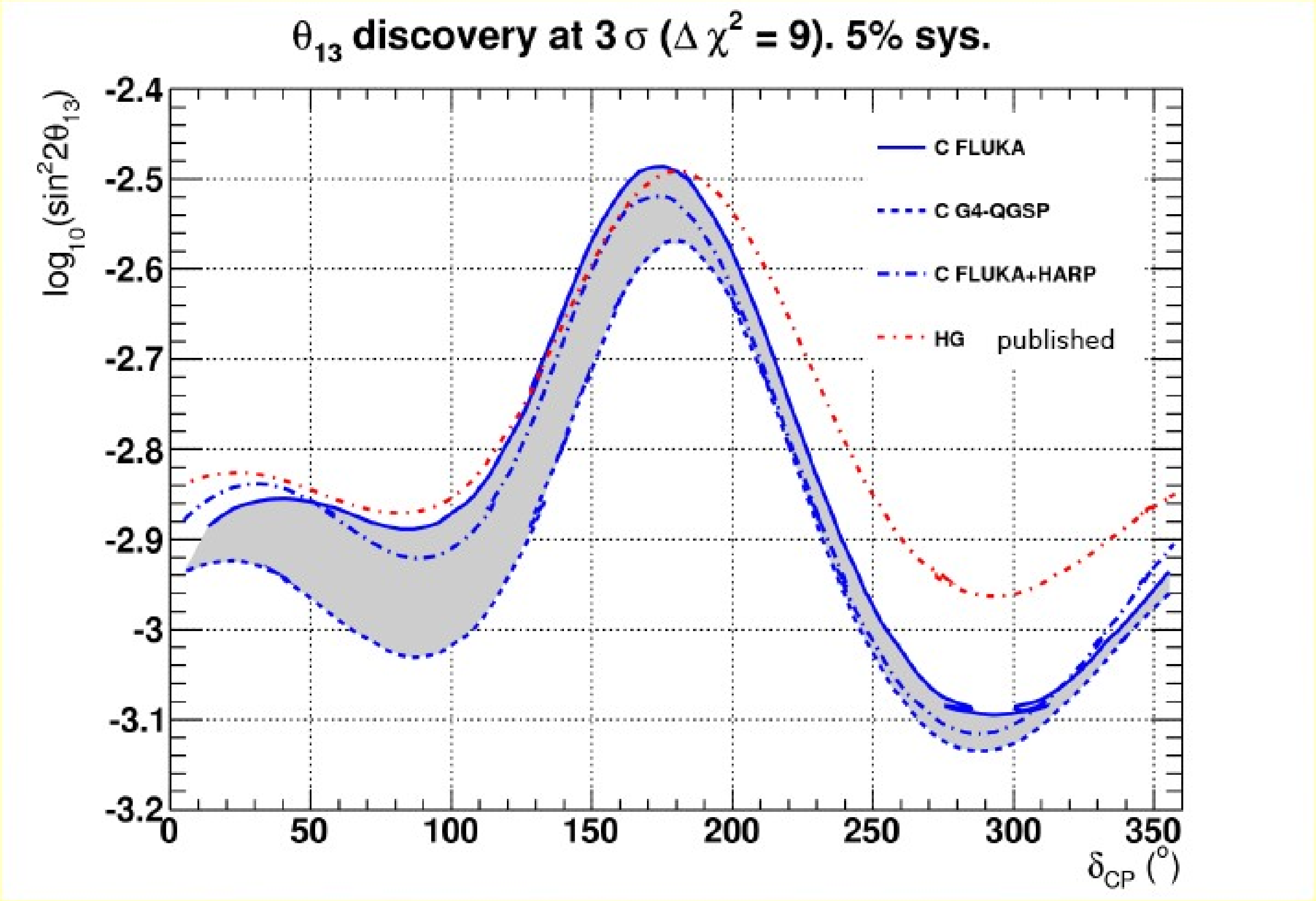
Event rates in MEMPHYS

$\sin^2 2\theta_{13} = 0.01,\ \delta_{CP} = 0$



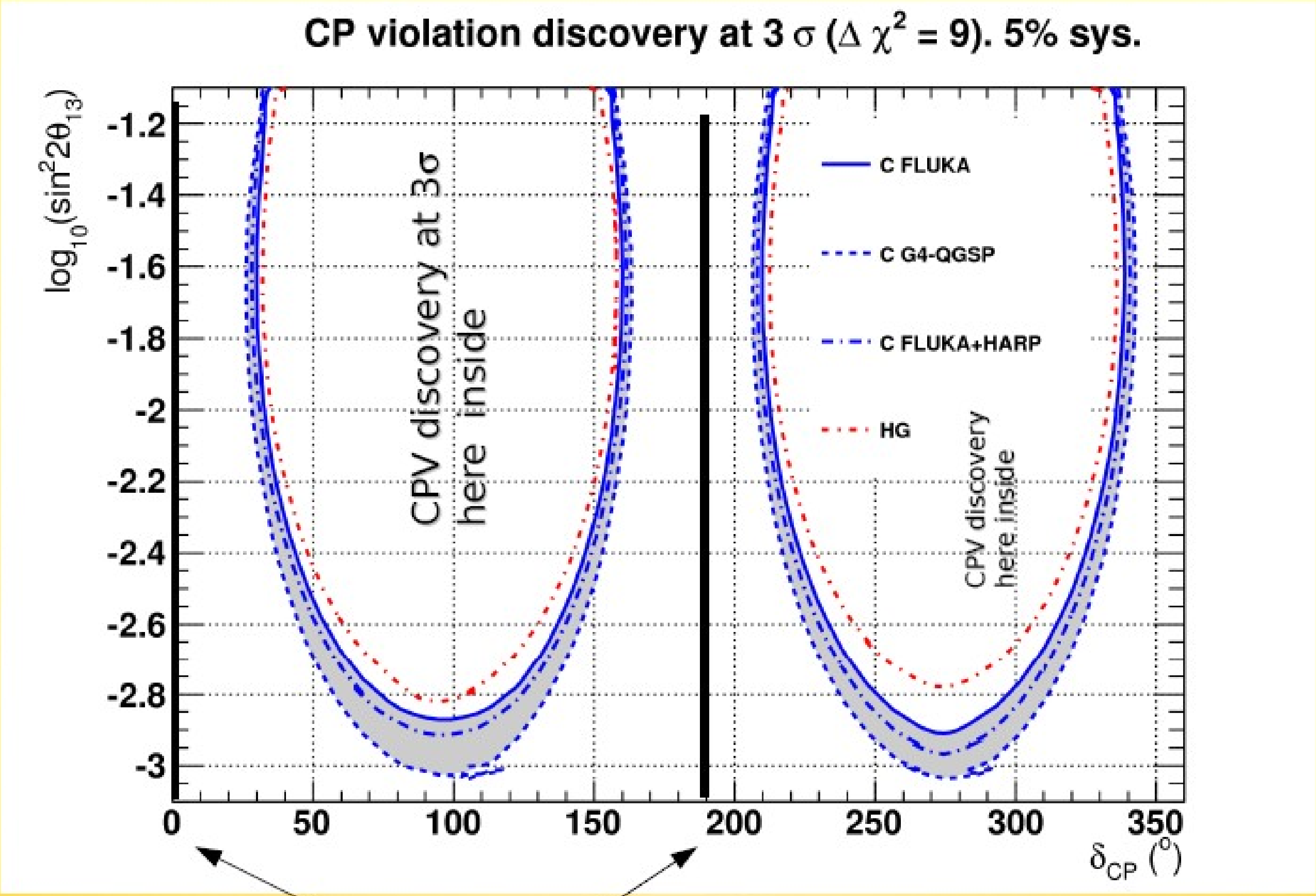
Based on the public MEMPHYS parametrization (AEDL) distributed with GLoBES
Bulk of the background from intrinsic beam electron component

Discovery of $\theta_{13} \neq 0$



Using GEANT4 for p-target interactions or reweighting FLUKA to HARP data yields better limits

Discovery of CP violation


CP violation discovery at 3 σ ($\Delta \chi^2 = 9$). 5% sys.

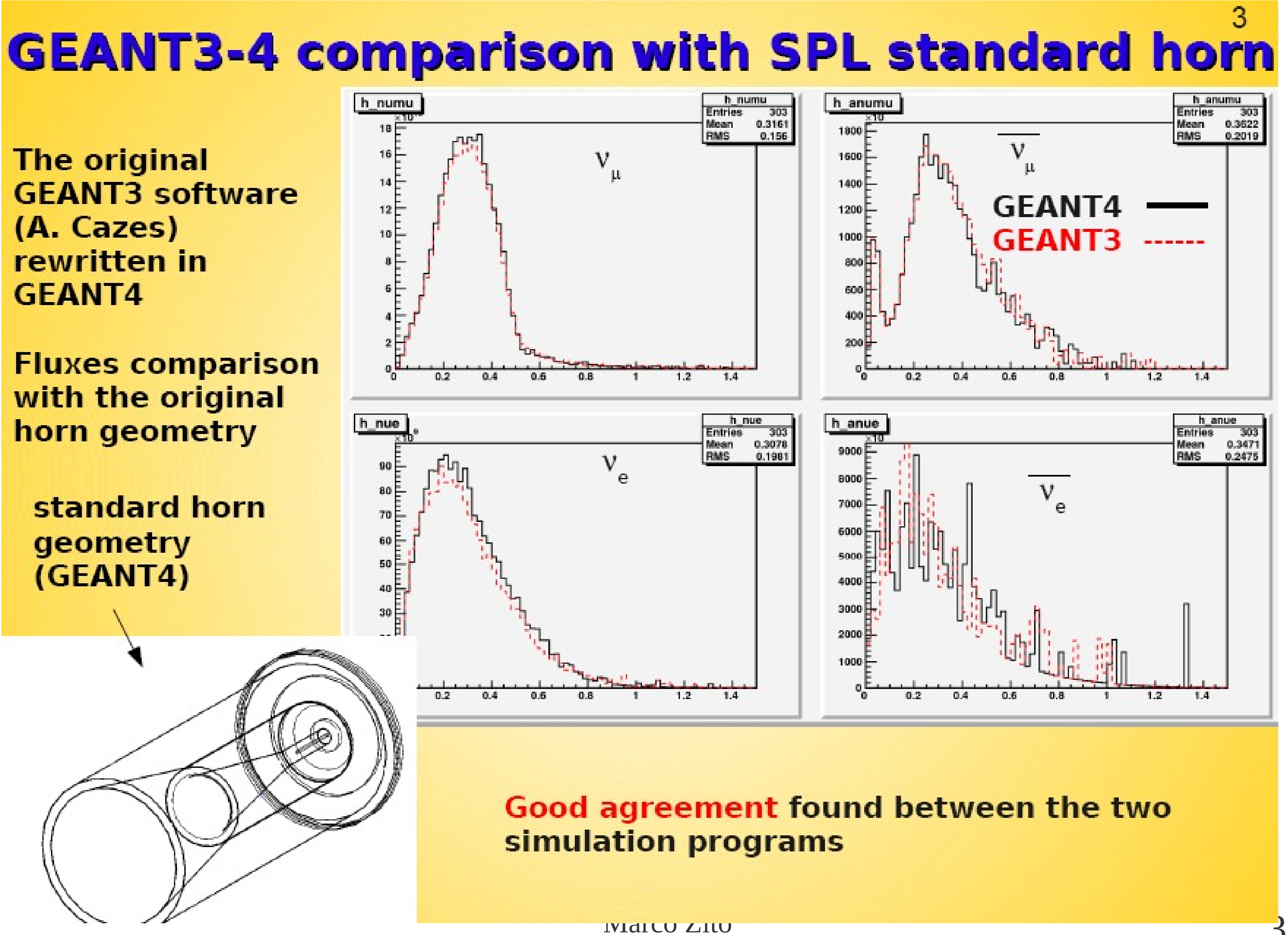
No CPV

Next steps

- Beam switch-yard design (1-> 4): in progress
- Activation and shielding studies (cost driver !) in progress
- Target station layout and overall costing

Conclusions

- We have produced a baseline design for a 4-MW neutrino beam based on SPL (recently completed note EUROnu-WP2-11-01)
- It is composed of four identical systems, with a pebble-bed target and a magnetic horn
- We have produced a detailed simulation of the neutrino intensity and composition, event rates and sensitivity
- Aim: finalize current studies (end of the year) and document our conceptual design in a final report.



GEANT3-4 comparison with SPL standard horn

The original GEANT3 software (A. Cazes) rewritten in GEANT4

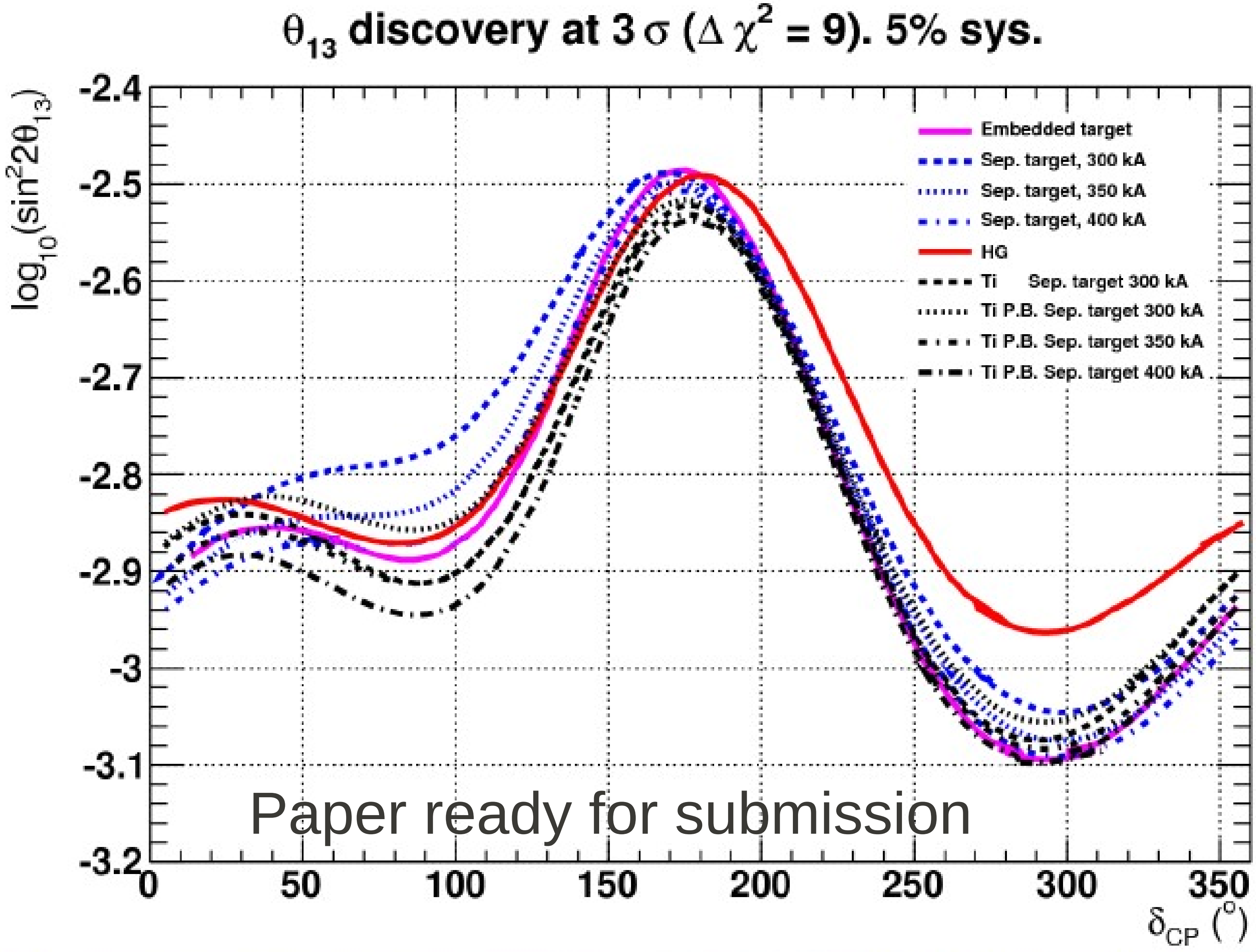
Fluxes comparison with the original horn geometry

standard horn geometry (GEANT4)

Good agreement found between the two simulation programs

Θ_{13} discovery potential

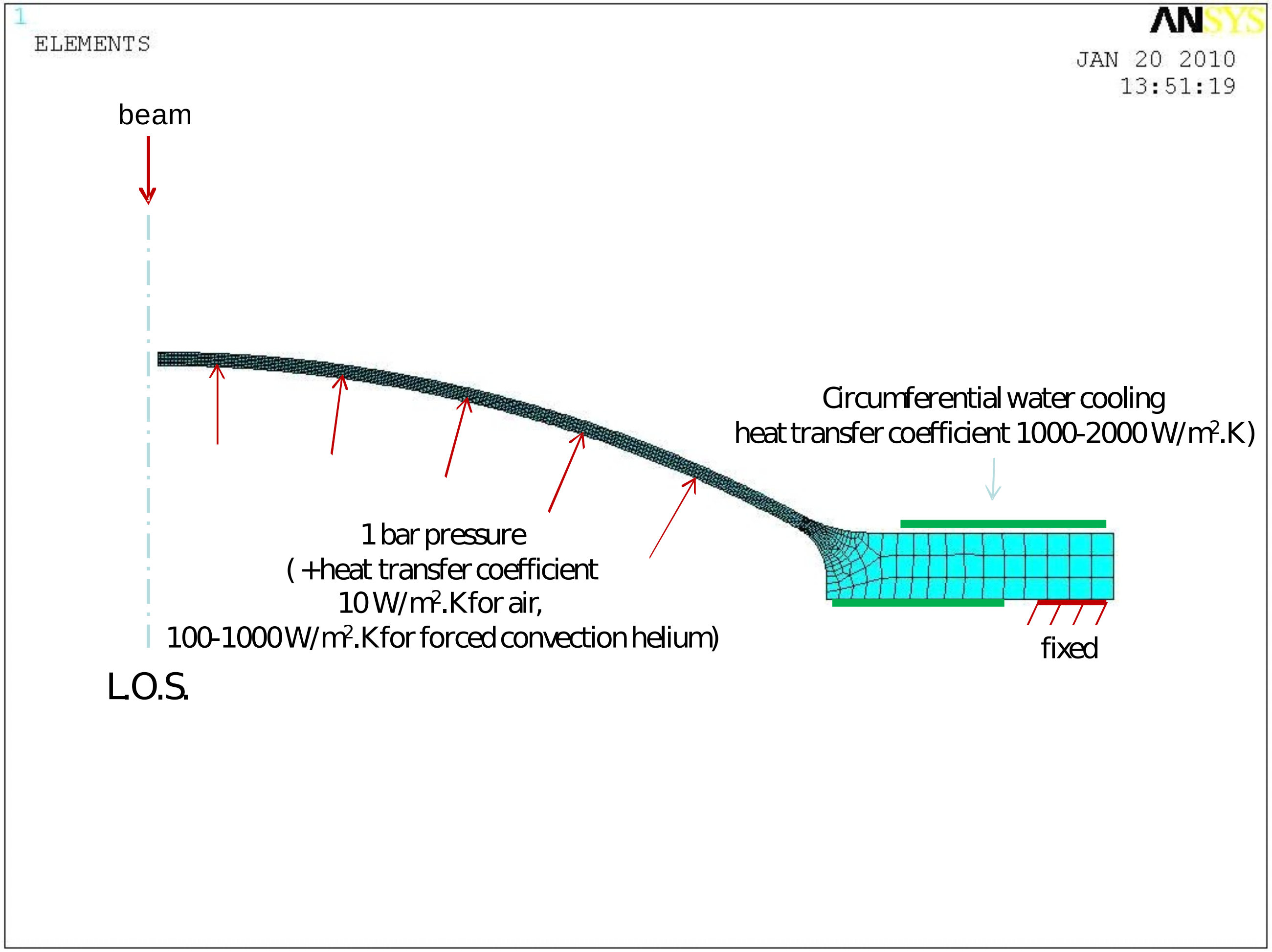
A. Longhin

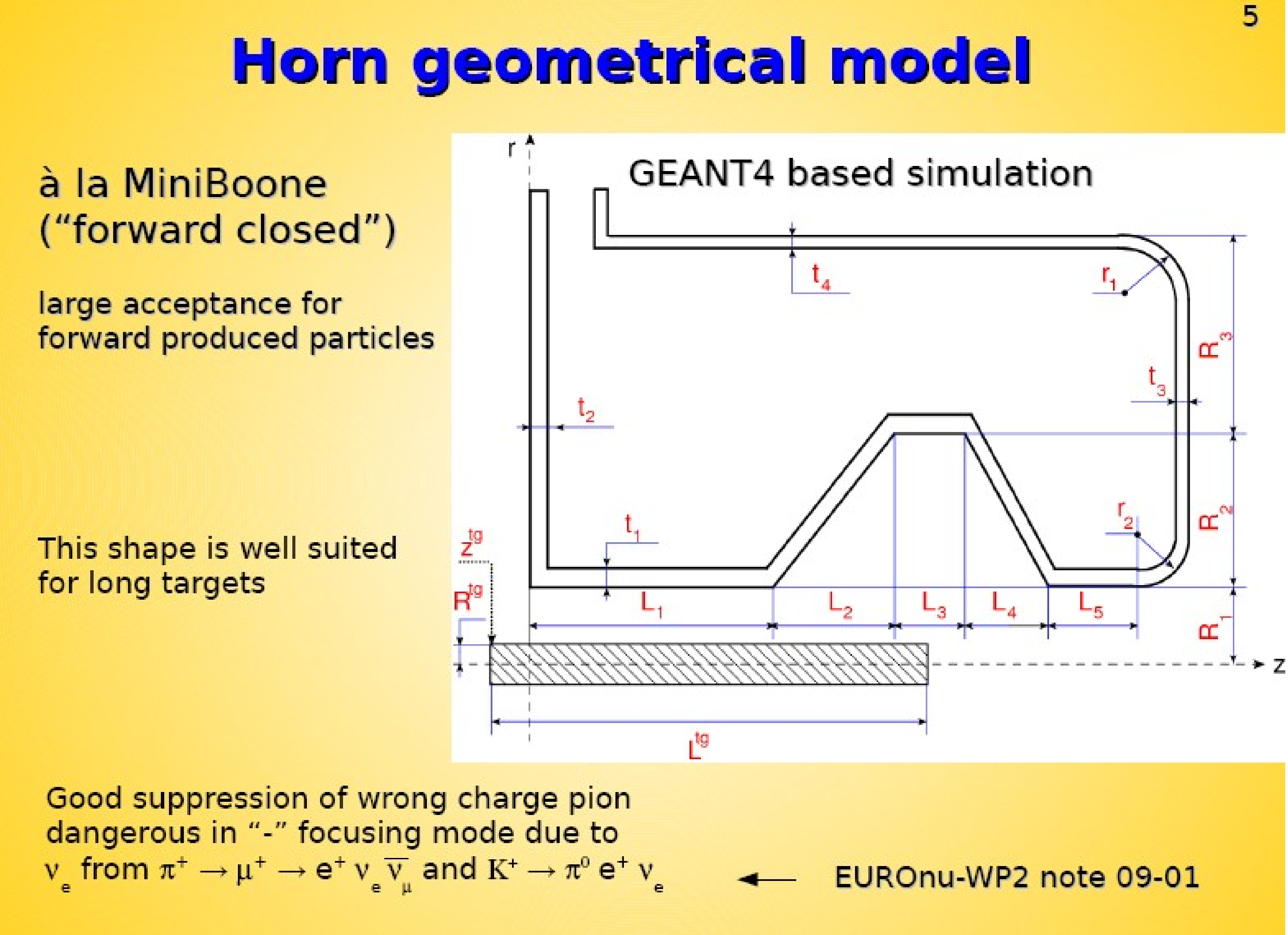


Paper ready for submission

Beam window study

- Beryllium with water or helium cooling feasible





Horn geometrical model

à la MiniBoone
(“forward closed”)

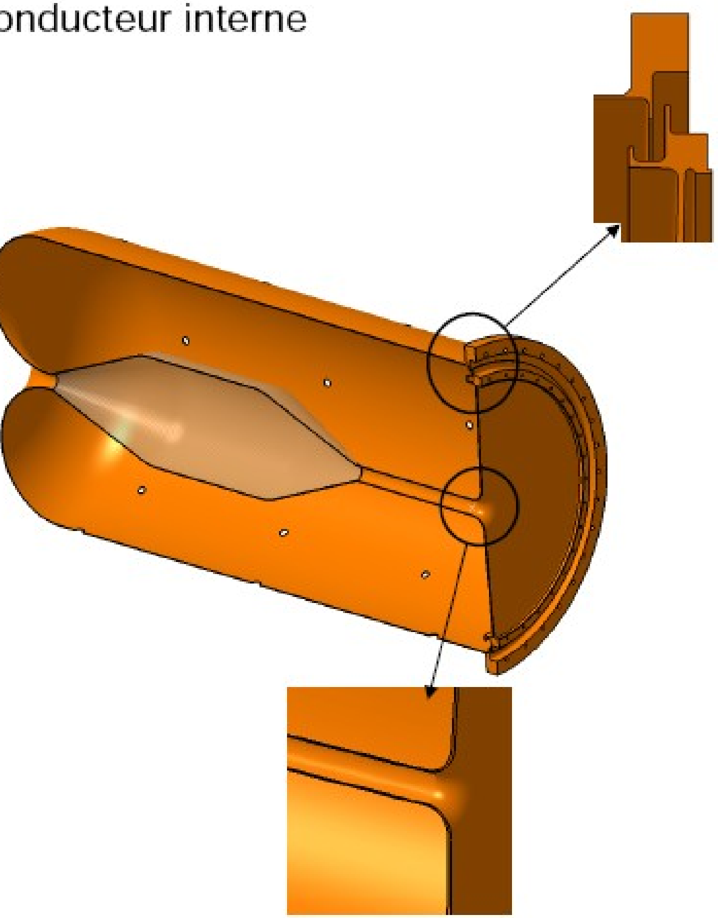
large acceptance for forward produced particles

This shape is well suited for long targets

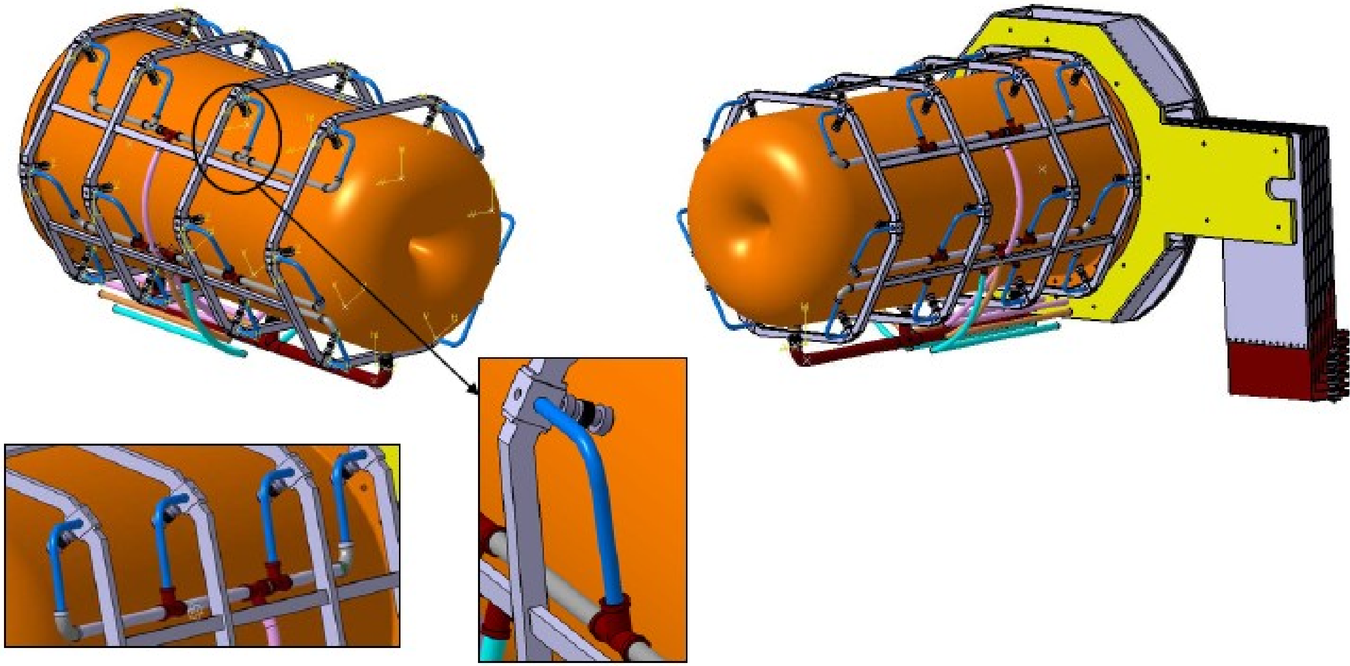
Good suppression of wrong charge pion dangerous in “-” focusing mode due to ν_e from $\pi^+ \to \mu^+ \to e^+ \nu_e \overline{\nu}_\mu$ and $K^+ \to \pi^0 e^+ \nu_e$ ← EUROnu-WP2 note 09-01

Horn drawings with cooling system

onducteur interne

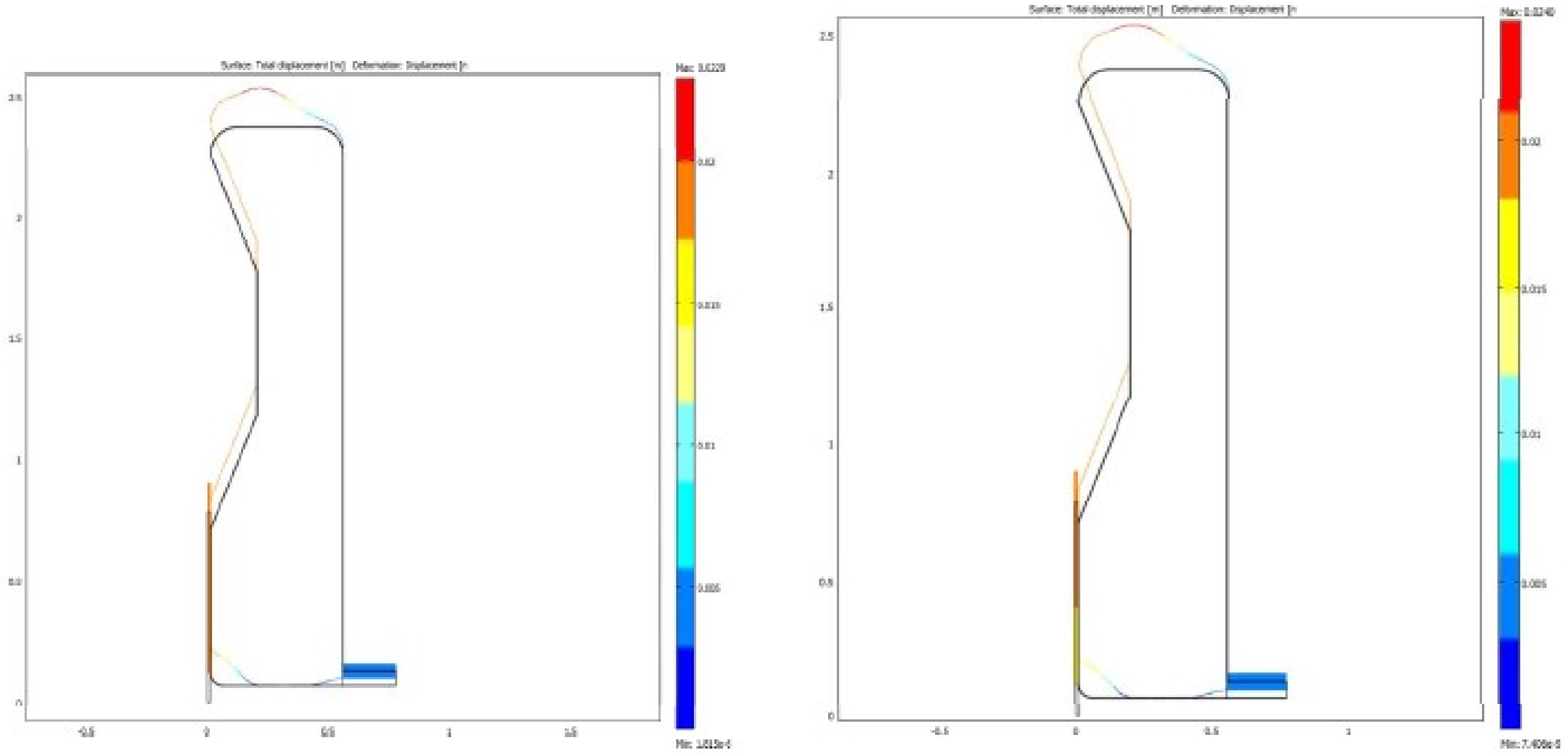


L'ensemble de la Corne



DISPLACEMENT FIELD, $t = 3$ MM

B. Lepers



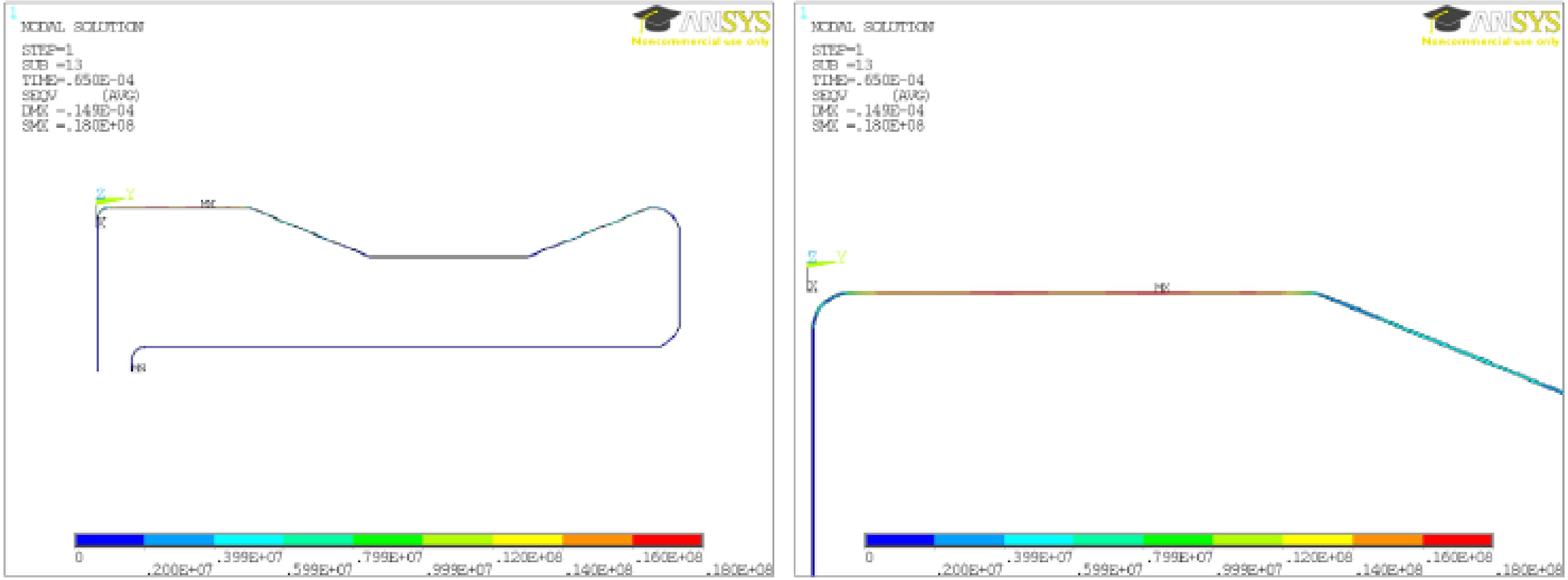
a)

b)

FIGURE: Displacement field for the horn with thickness $t = 3$ mm, magnetic pressure $u_{max} = 23$ mm a) and magnetic pressure + thermal dilatation $u_{max} = 24$ mm b) for cooling scenario 2

Response to magnetic pulses

P. Cupial



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