A new design for the CERN to Fréjus neutrino beam

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For the EUROnu WP2 team

NUFACT11

Geneva

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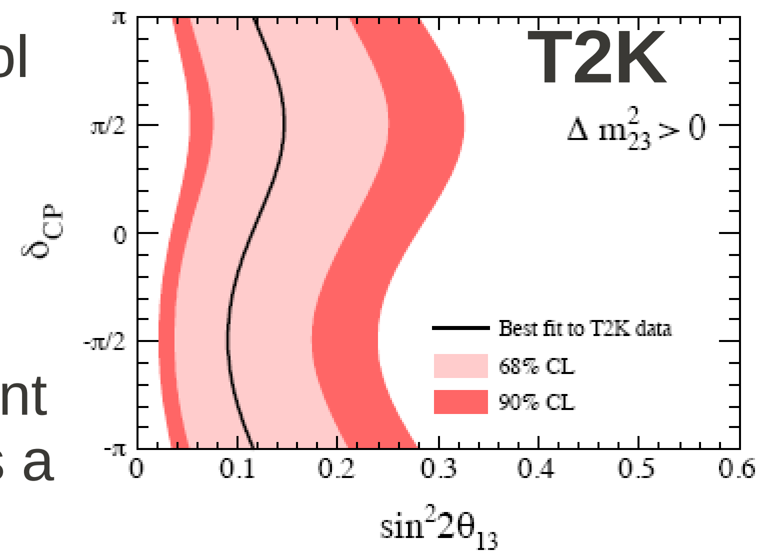
Irfu

cea

energie atomique • energies alternatives

Motivation

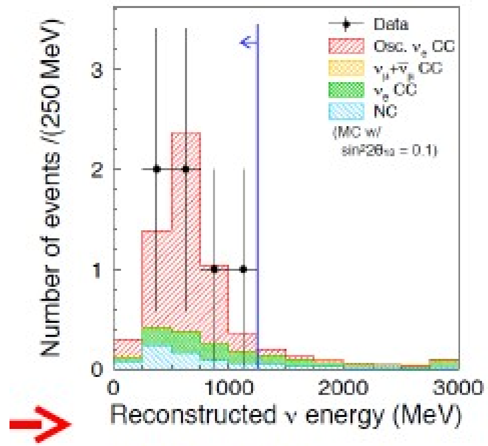
- Conventional neutrino beams are a powerful tool for the study of neutrino oscillations
- Currently several large scale HEP experiments using this technology: MINOS, OPERA, T2K
- The recent indications by T2K (and MINOS) point to the large θ_{13} region where a Super Beam has a good sensitivity



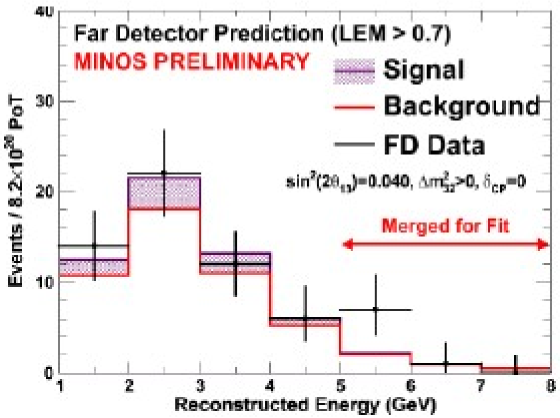
90% C.L. interval & Best fit point (assum

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

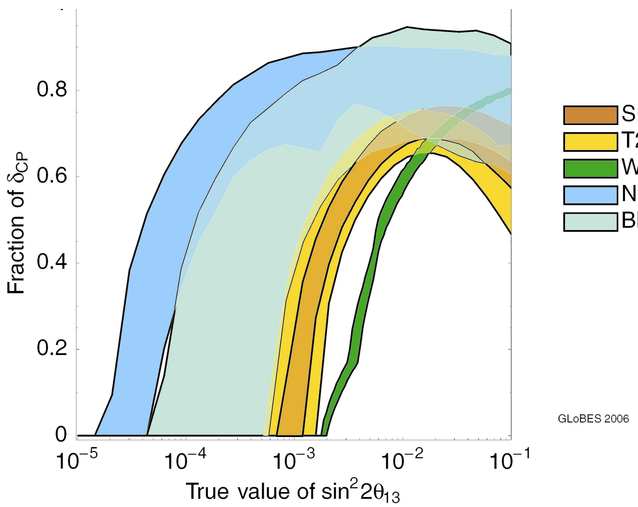
$\sin^2 2\theta_{13} = 0.11$



T2K (2.5σ)



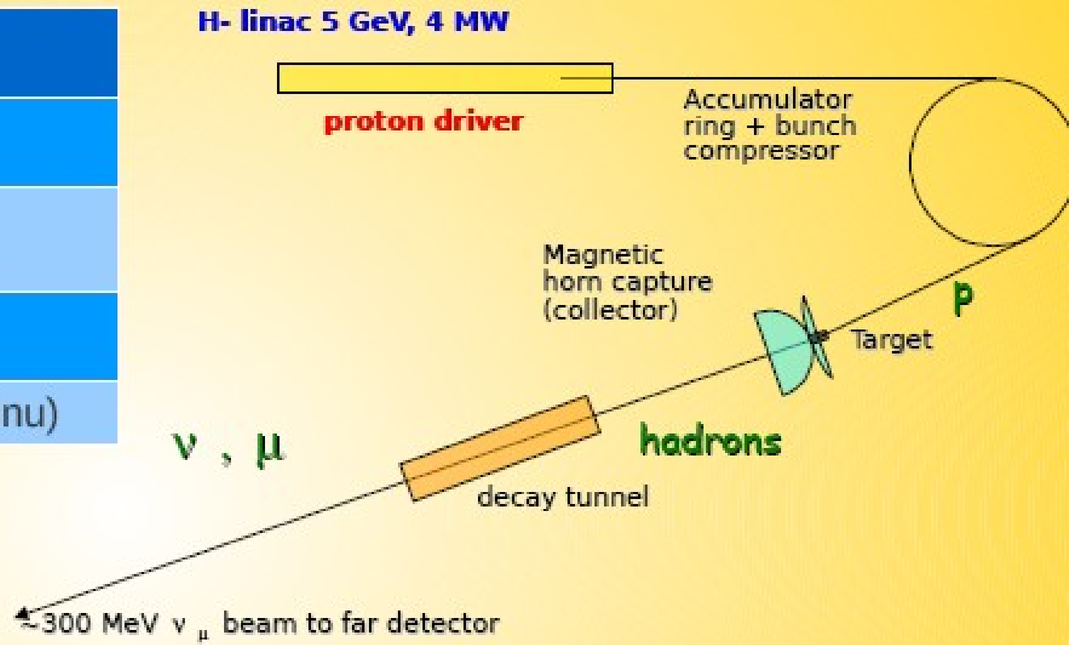
MINOS (1.7σ)

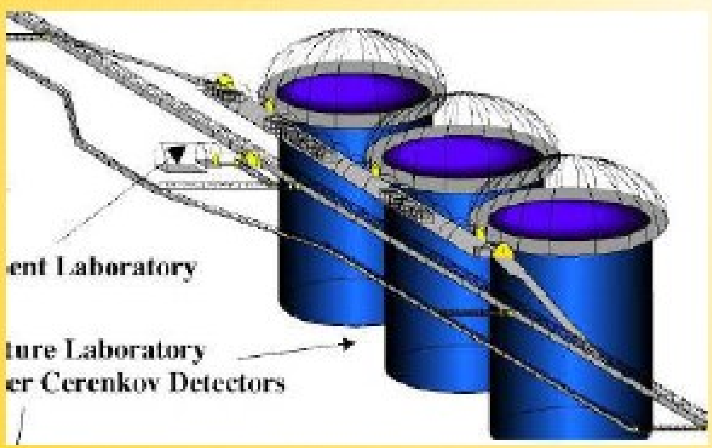


CERN to Fréjus

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)





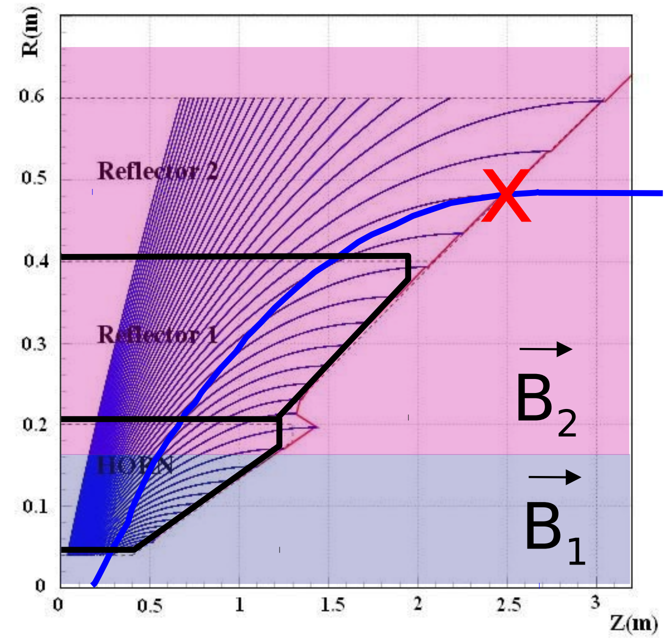
Proton beam

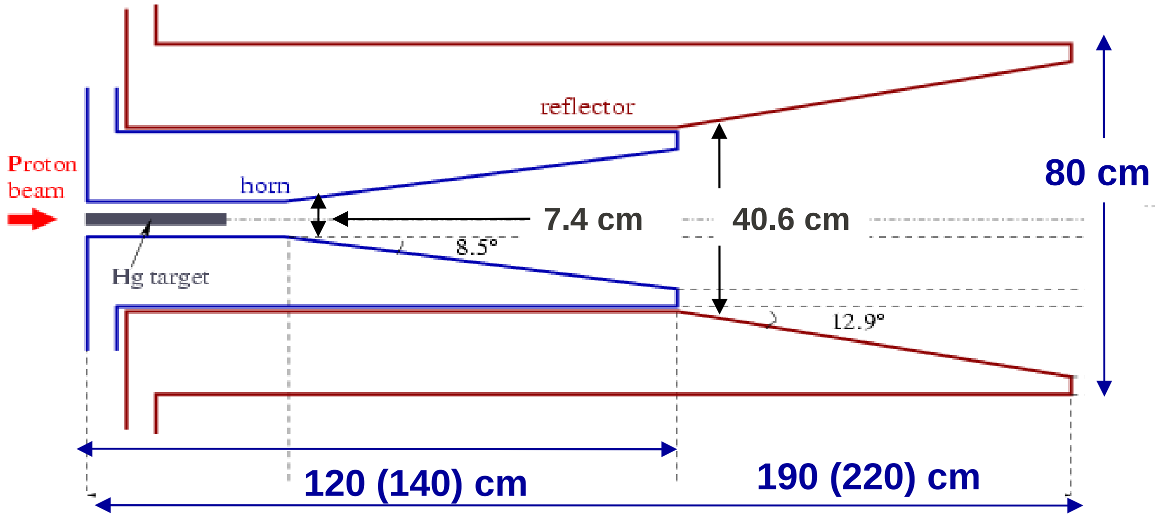
Energy	5 GeV
Beam Power	4.5 MW
N. beam lines	4
Rep. rate	12.5 Hz
Pulse dur.	5 µs
beam gauss width	4 mm

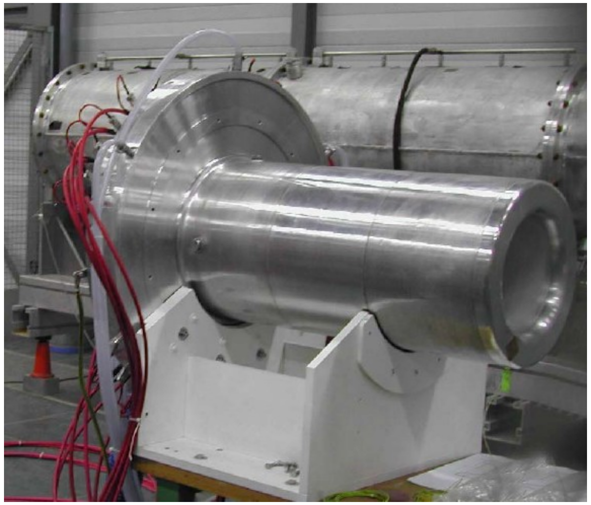
At the start of EUROnu no complete conceptual design of this facility

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)

Important steps for the design

- Solid static target (cf talk by C. Densham)
- Use multiple (4) targets+collectors
- Each pulsed at 12.5 Hz
- Use single horn (no reflector)
- Optimization of horn shape → Miniboone shape

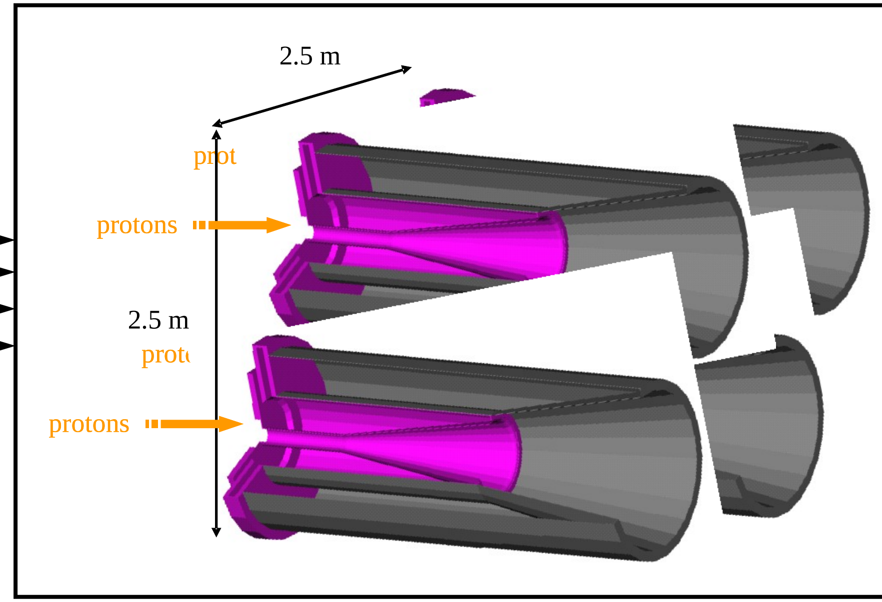
  → talk by N. Vasilopoulos
- A lot of progress towards a working solution, at constant (or improved) physics performance

Overall configuration

4 MW Proton beam from accumulator at 50 Hz

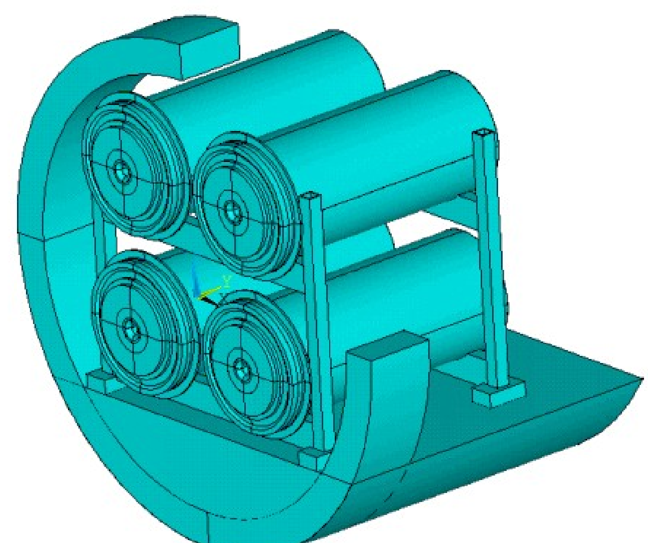
Beam Switchyard

4 x 1MW Proton beam each at 12.5 Hz



Target Station (4 targets, 4 horns)

Decay Volume

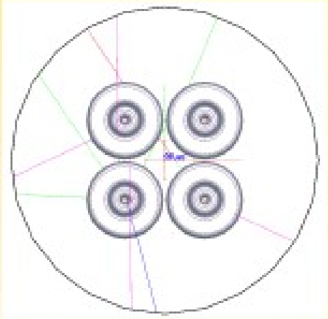


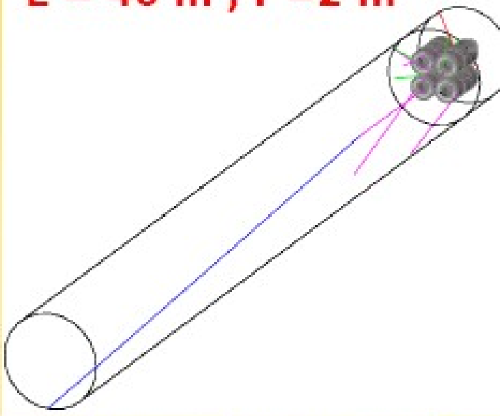
The 4-horns scenario

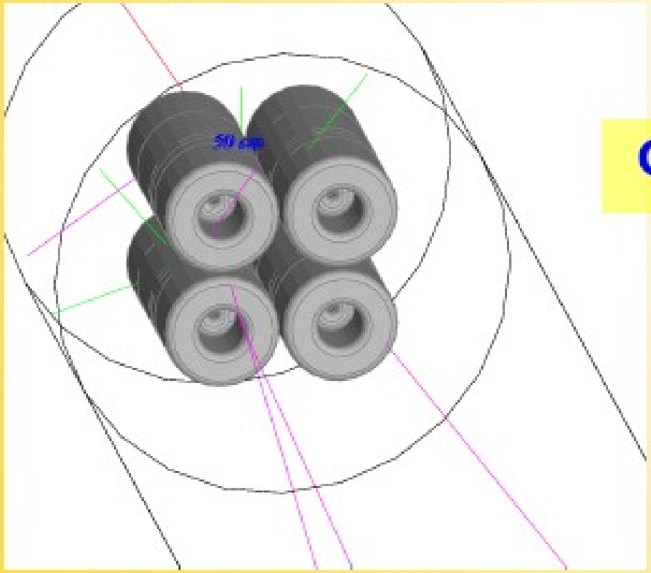
Reduced stress on target via
- **lower frequency (12.5 Hz) or**
- **lower p-flux (1 MW)**

depending on injection strategy

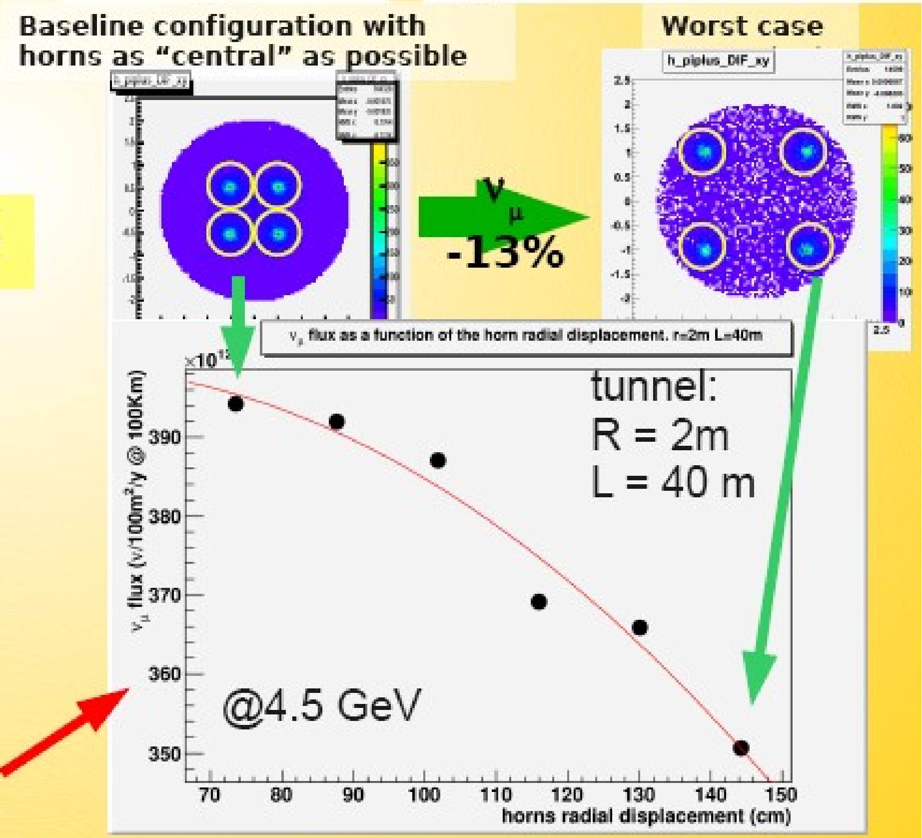
Profits of horn compactness (r~0.5m)







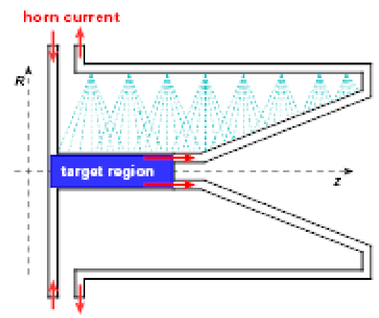
GEANT4

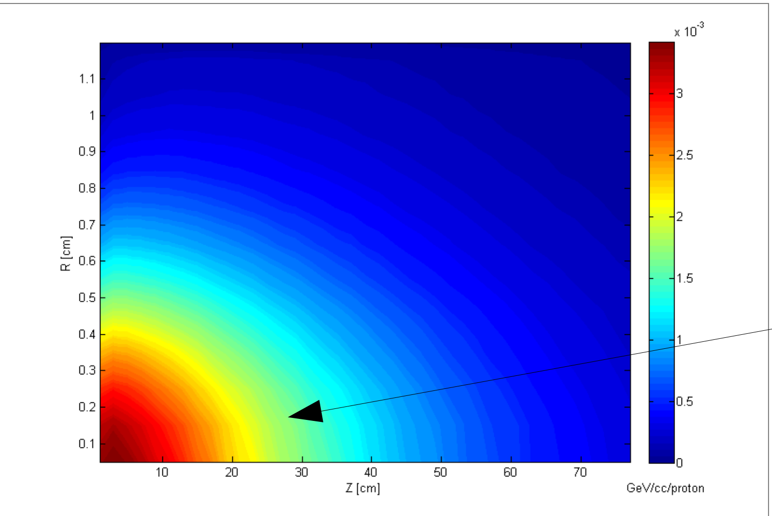


Small flux loss even up to big lateral displacements.

Target studies and baseline

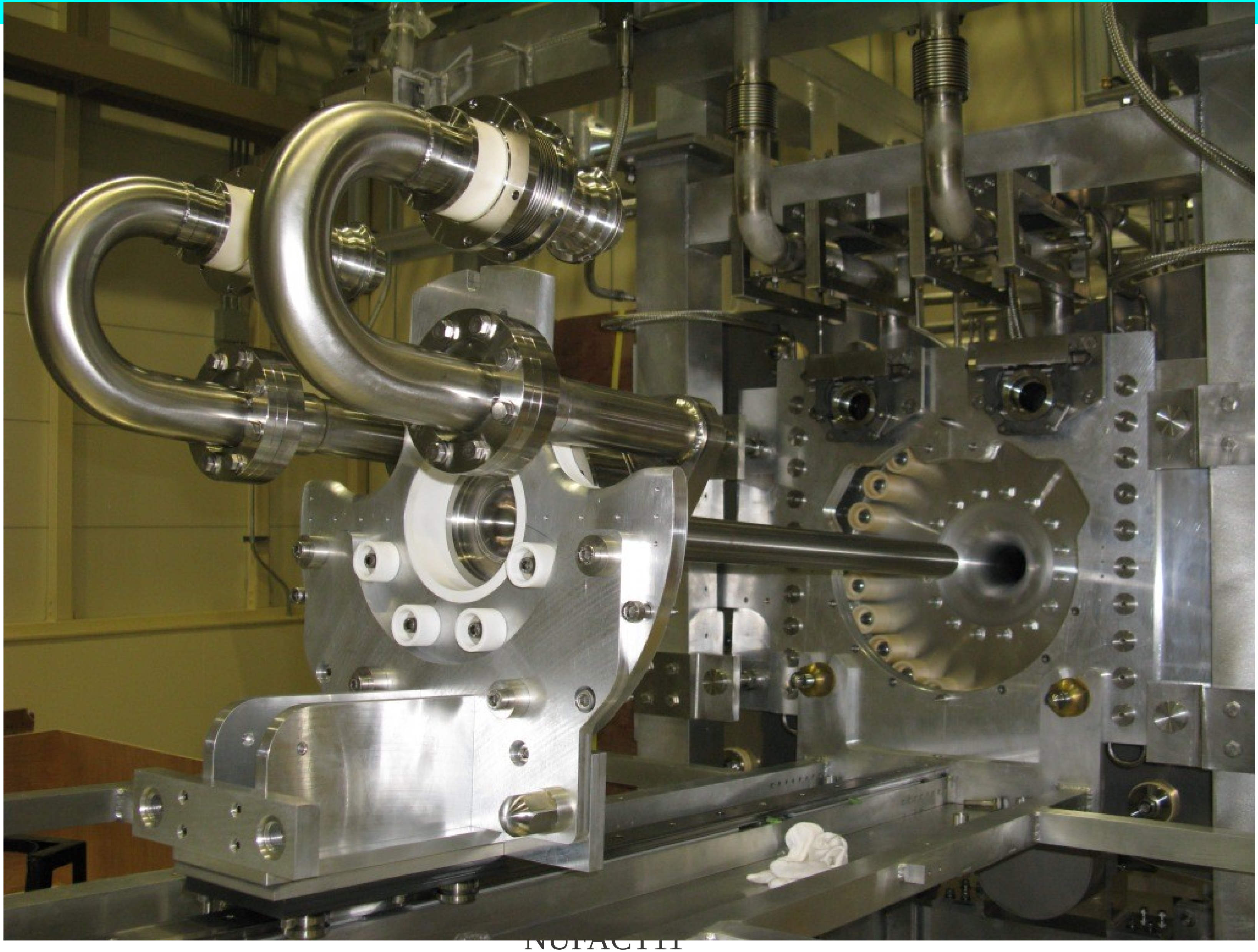
- In the past months we have focused on the target design
- We have considered:
  - A solid static low-Z target cleverly shaped
  - A one-piece (embedded) target+horn (conducting target)
  - A pebble bed target





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

T2K graphite target



Proposed by Pugnat and Sievers

Science & Technology Facilities Council

C. Densham, T. Davenne

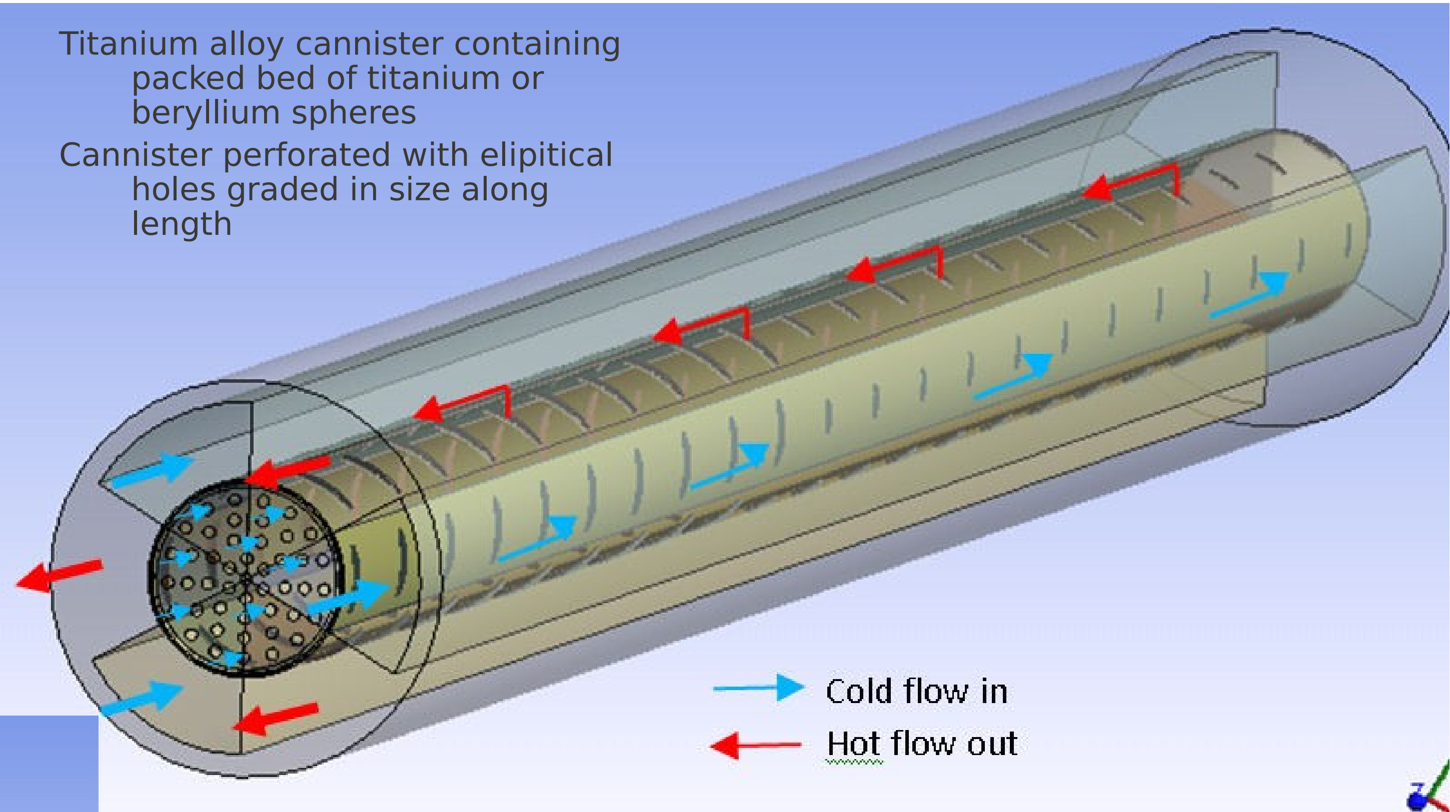
Packed Bed Target Concept for Euronu (or other high power beams)

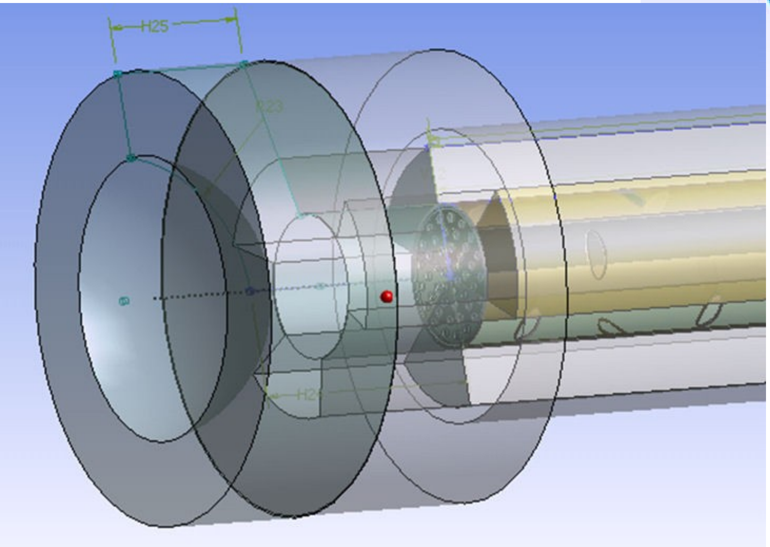
Packed bed cannister in parallel flow configuration

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

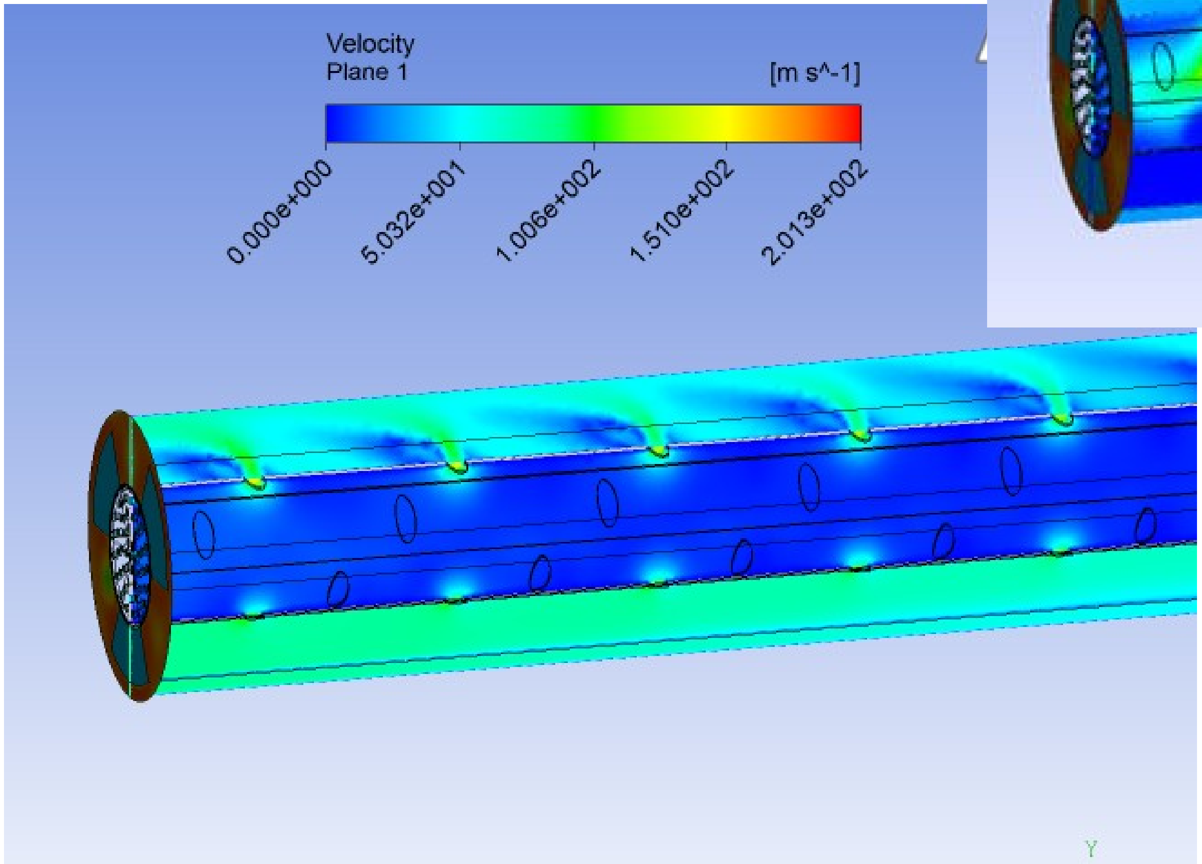
High Power Targets

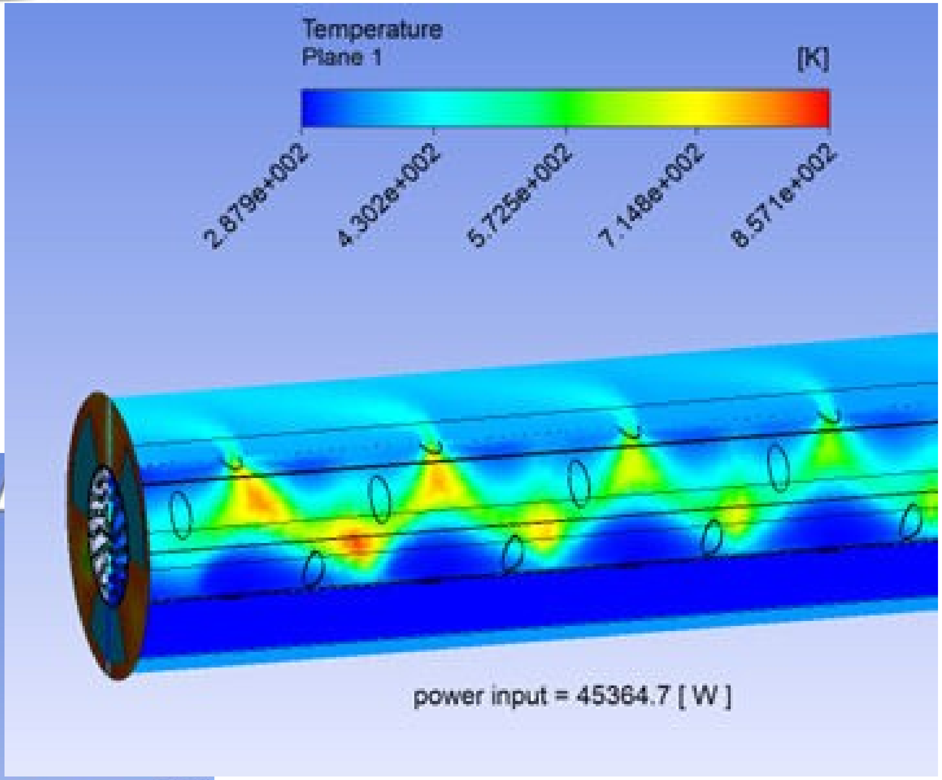
Helium Flow

Helium Velocity

Maximum flow velocity = 202m/s

Maximum Mach Number < 0.2





Helium Gas Temperature

Total helium mass flow = 93 grams/s

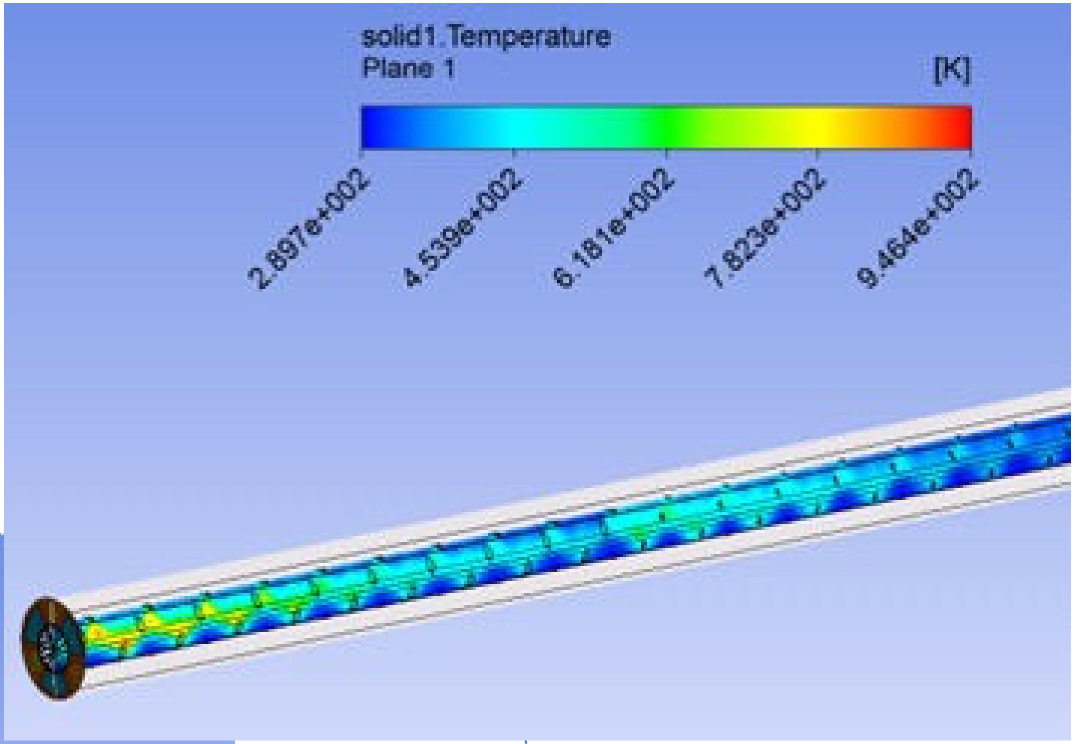
Maximum Helium temperature = 857K =584°C

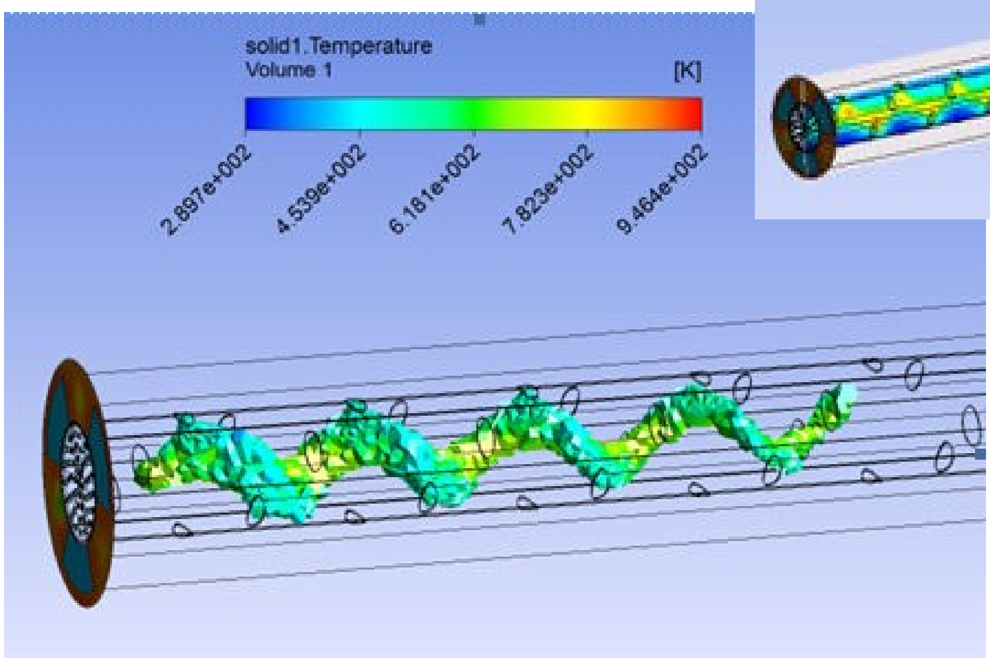
Helium average outlet Temperature = 109°C

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

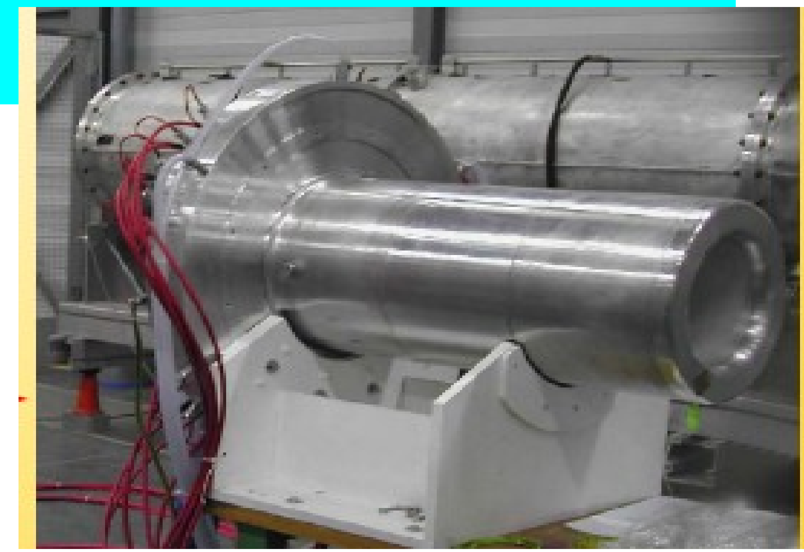
Maximum titanium temperature = 946K =673°C (N.B. Melting temp =1668°C)

Towards the target baseline

After these studies we have concluded that

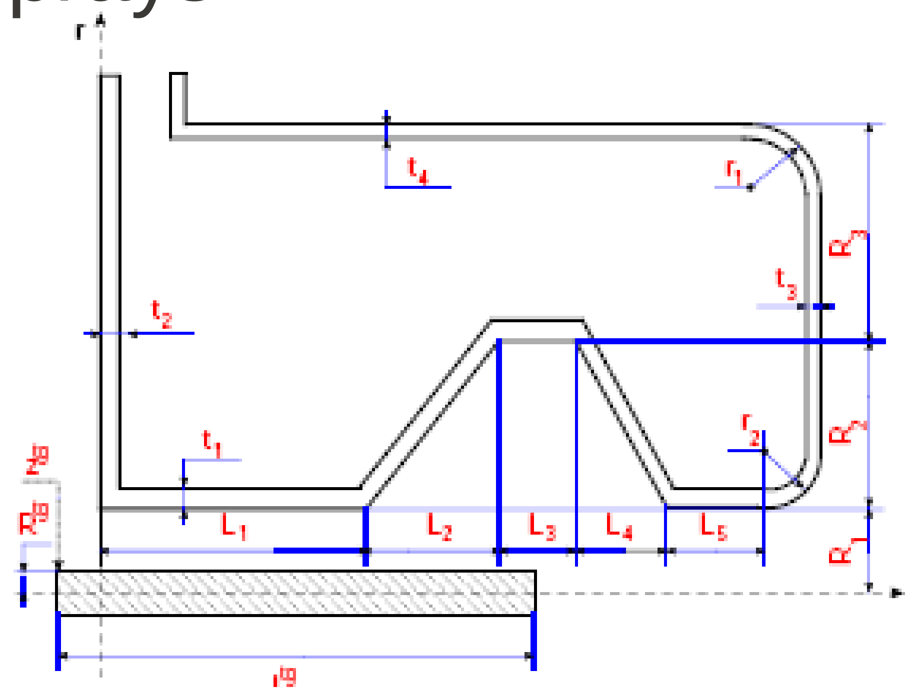
- The Titanium pebble bed target appears to be the best candidate (capable of multi-MW) → baseline choice
- The solid static target is feasible, pencil shape solution
- The embedded target is disfavored

Horn



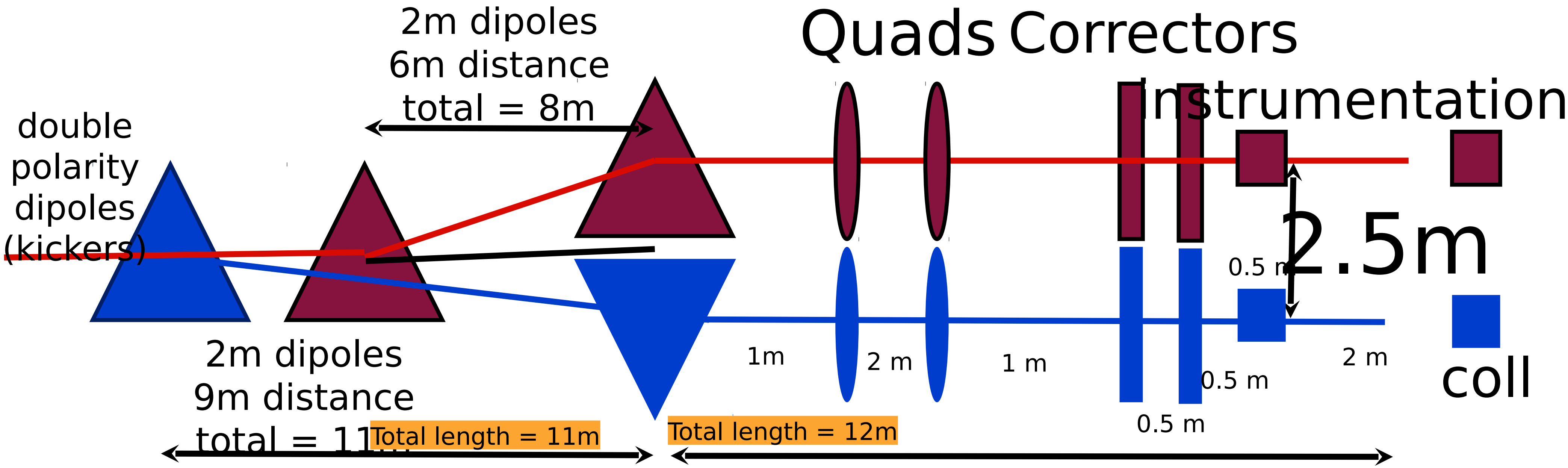
Baseline :

- Miniboone shape
- Aluminum
- Cooled with internal water sprays
- Pulsed with 300-350 kA
- Talk by N. Vassilopoulos



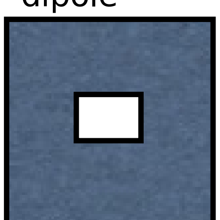
Summary of main parameters

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



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		

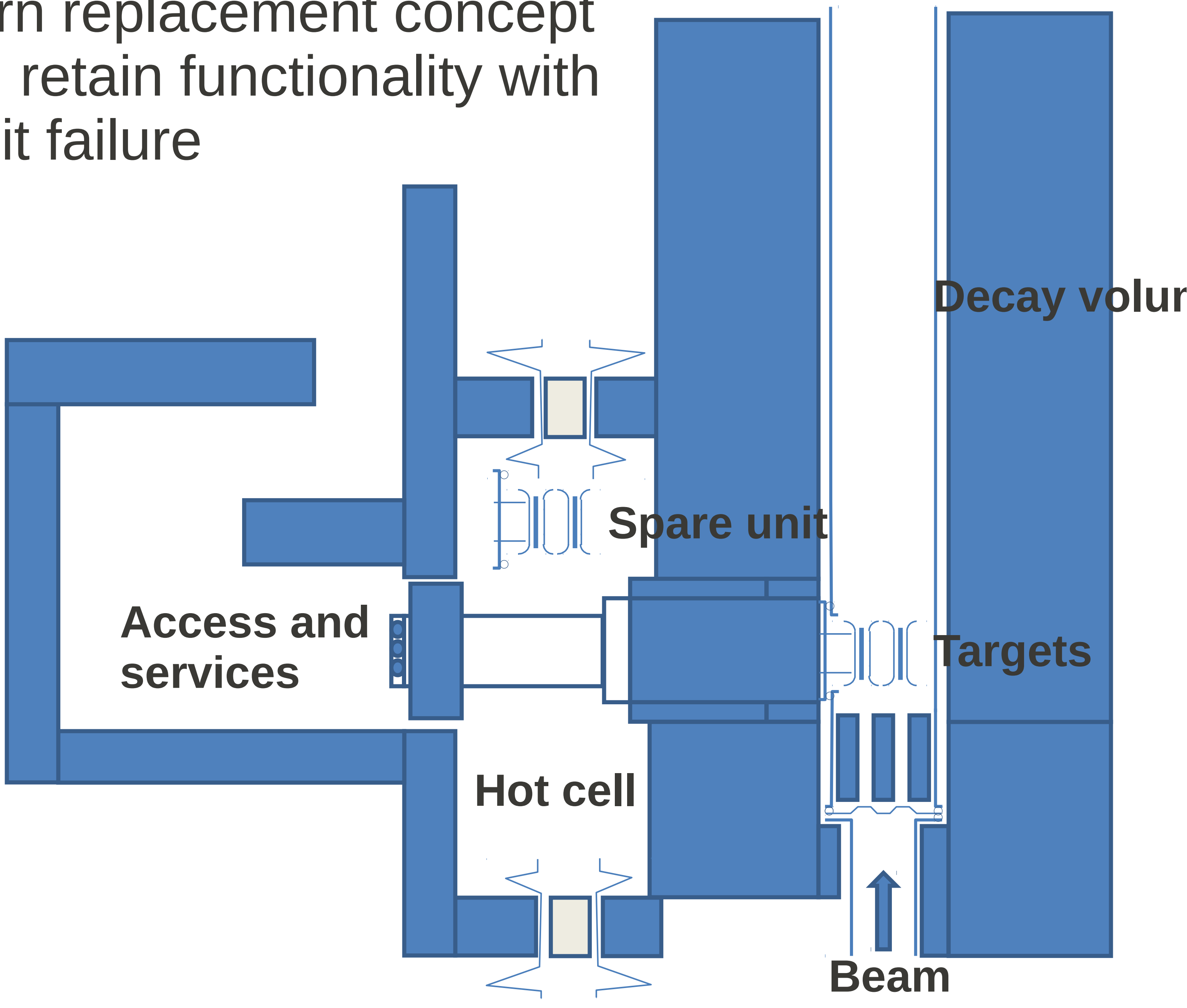


magnet lengths:
- dipoles : 2m
- quads : 1m each
- correctors : 0.7m
(must add connections)

TARGET STATION CONCEPT

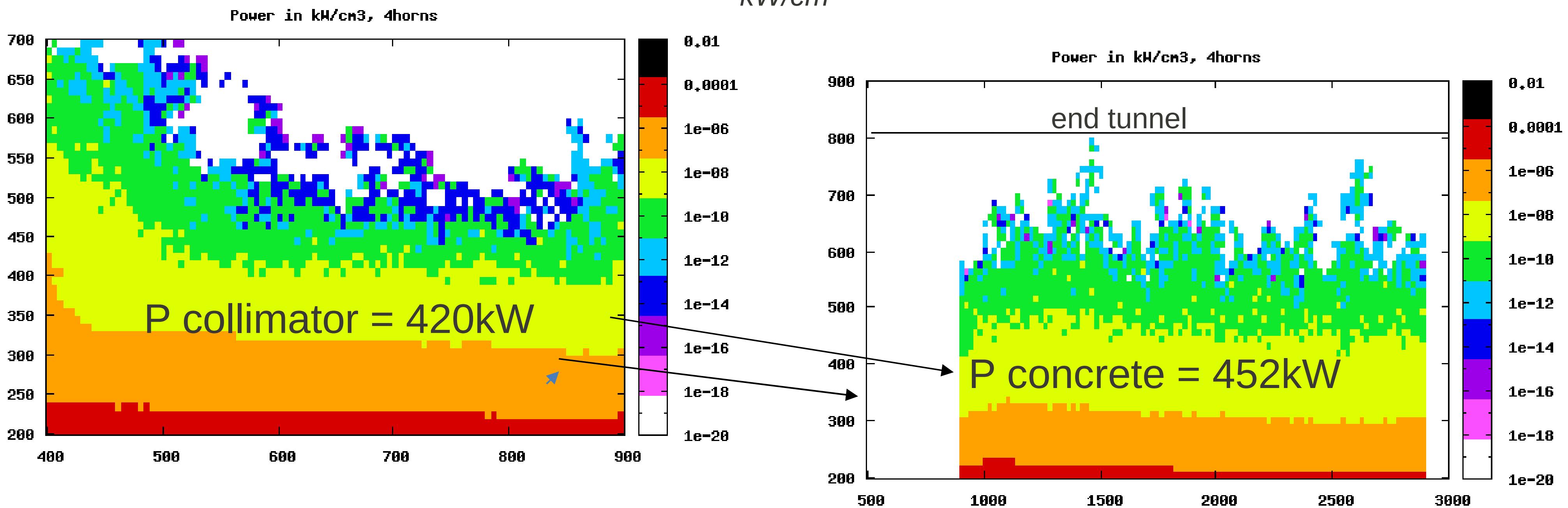
C. Densham

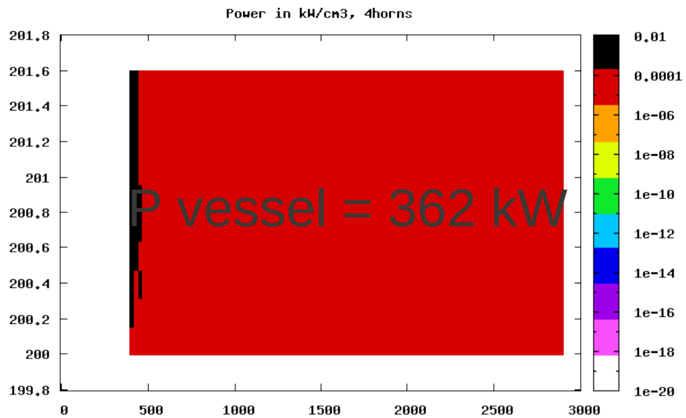
Target and horn replacement concept
Requirement : retain functionality with
1 (out of 4) unit failure
1.3 MW each

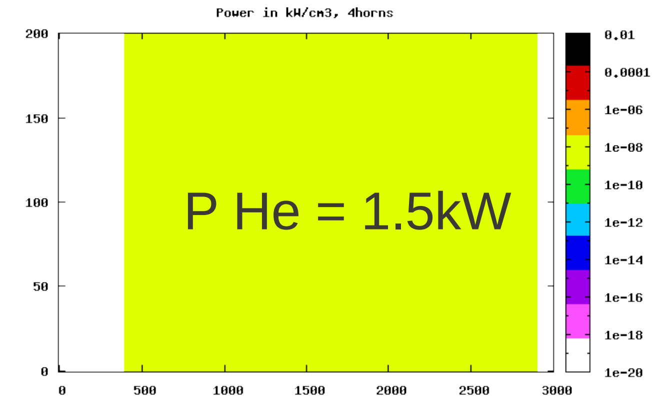


Power in Decay Tunnel Elements

R-Z
Power density distribution in
kW/cm³







Fluxes and sensitivity

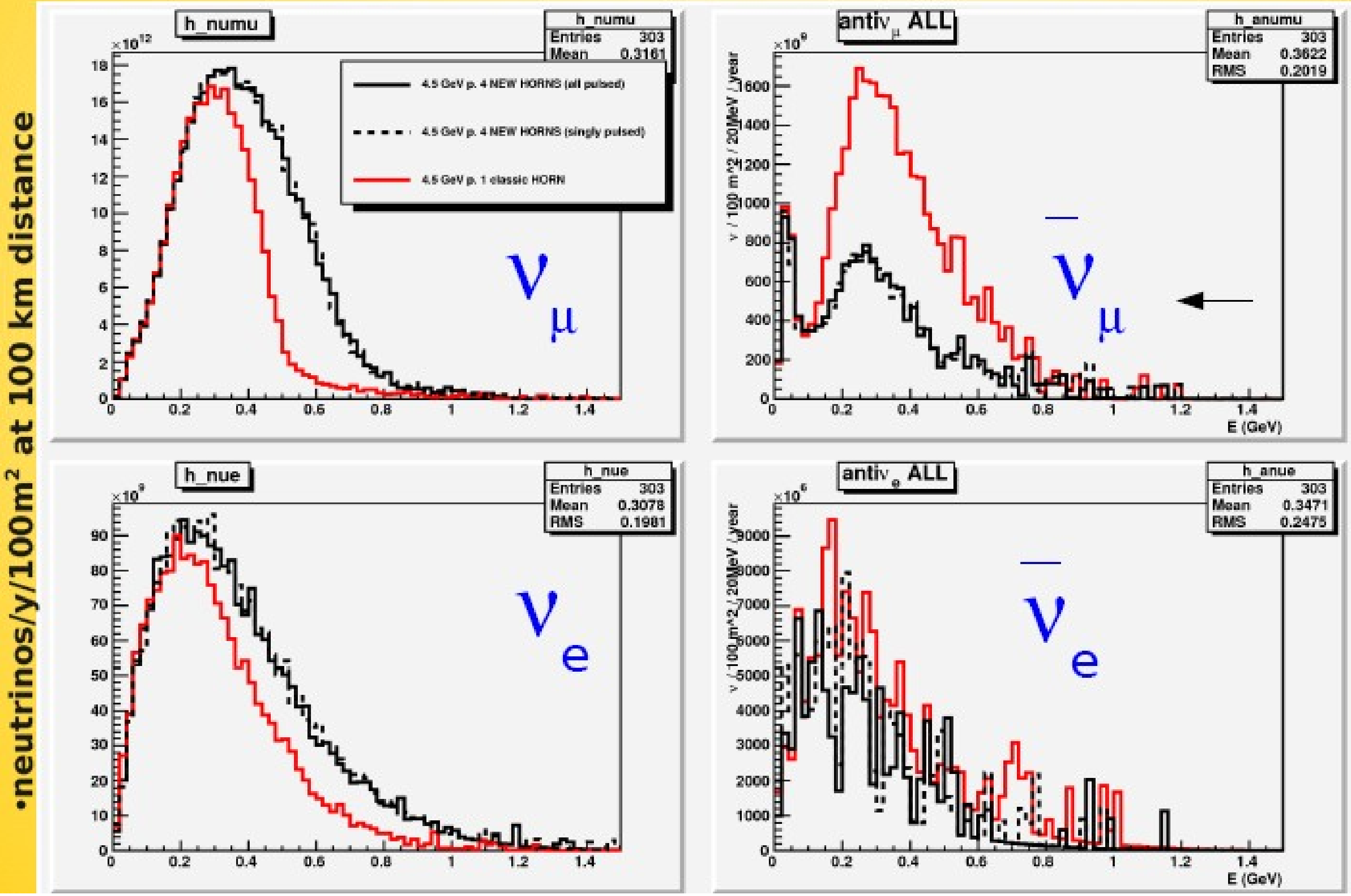
All the following results are summarized in

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.)



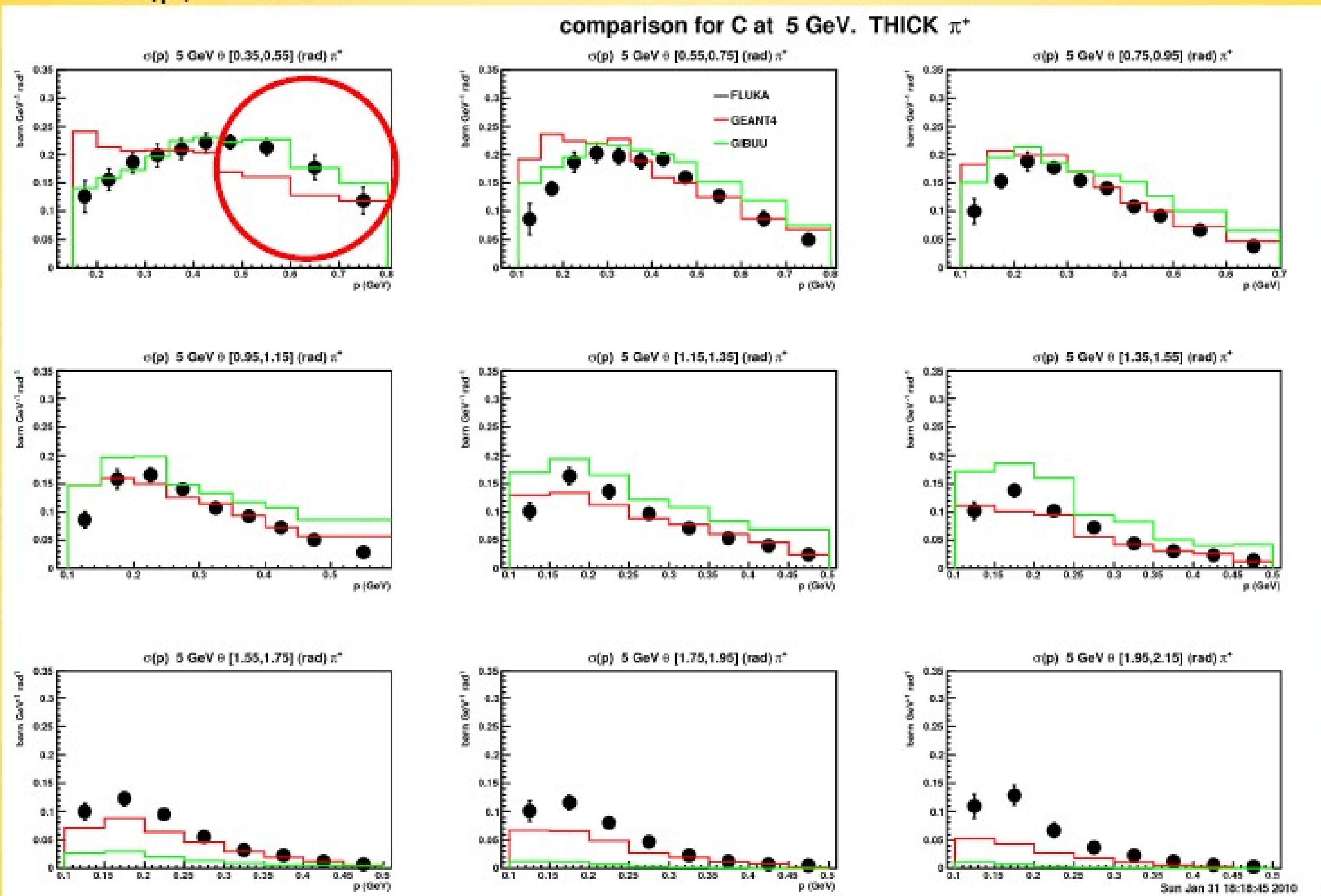
GEANT4

@ 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

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

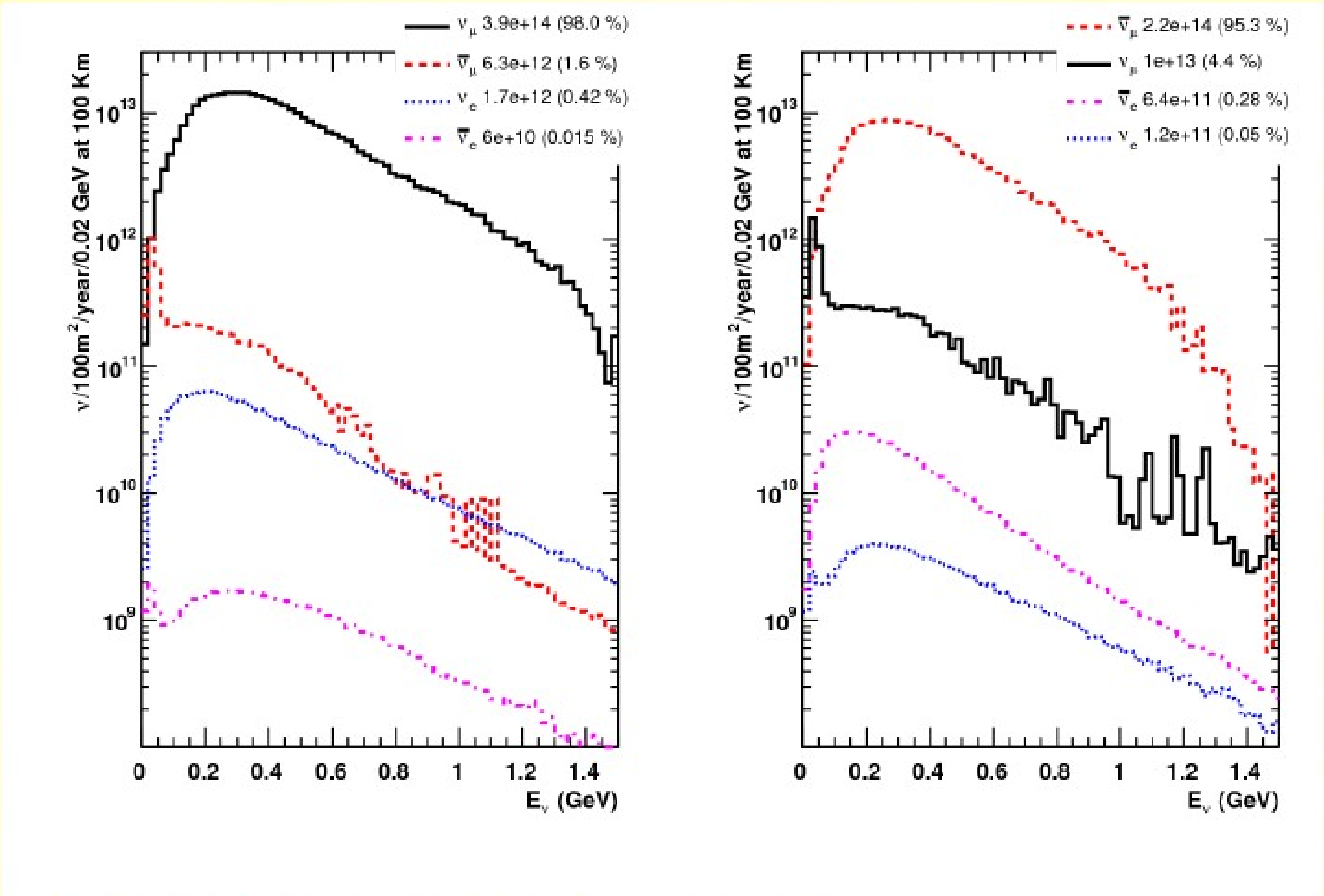
σ(p) in θ bins



tends to underestimate production at large angles

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

Optimised horn: fluxes

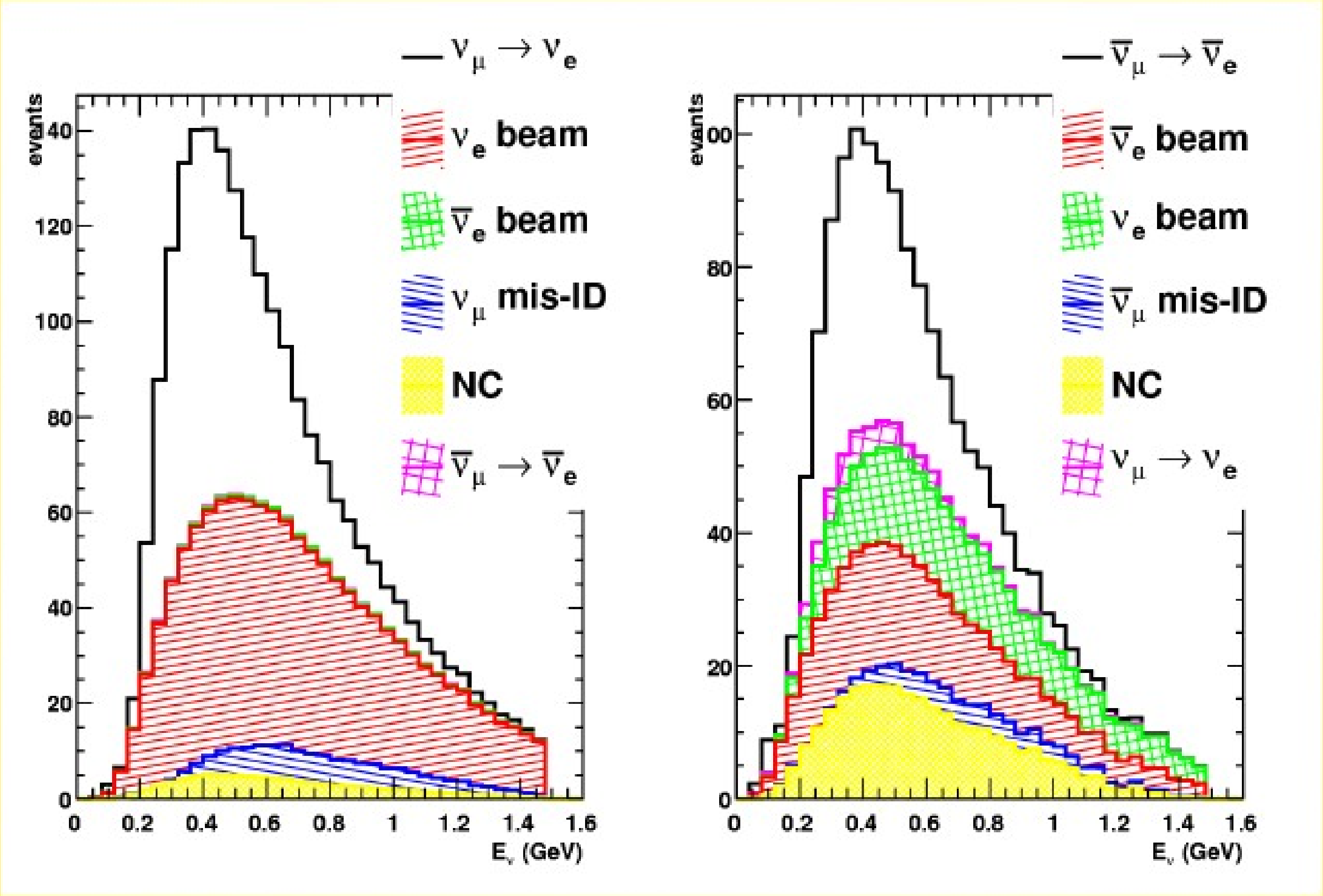


Fluxes in GloBES format are available online here:

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

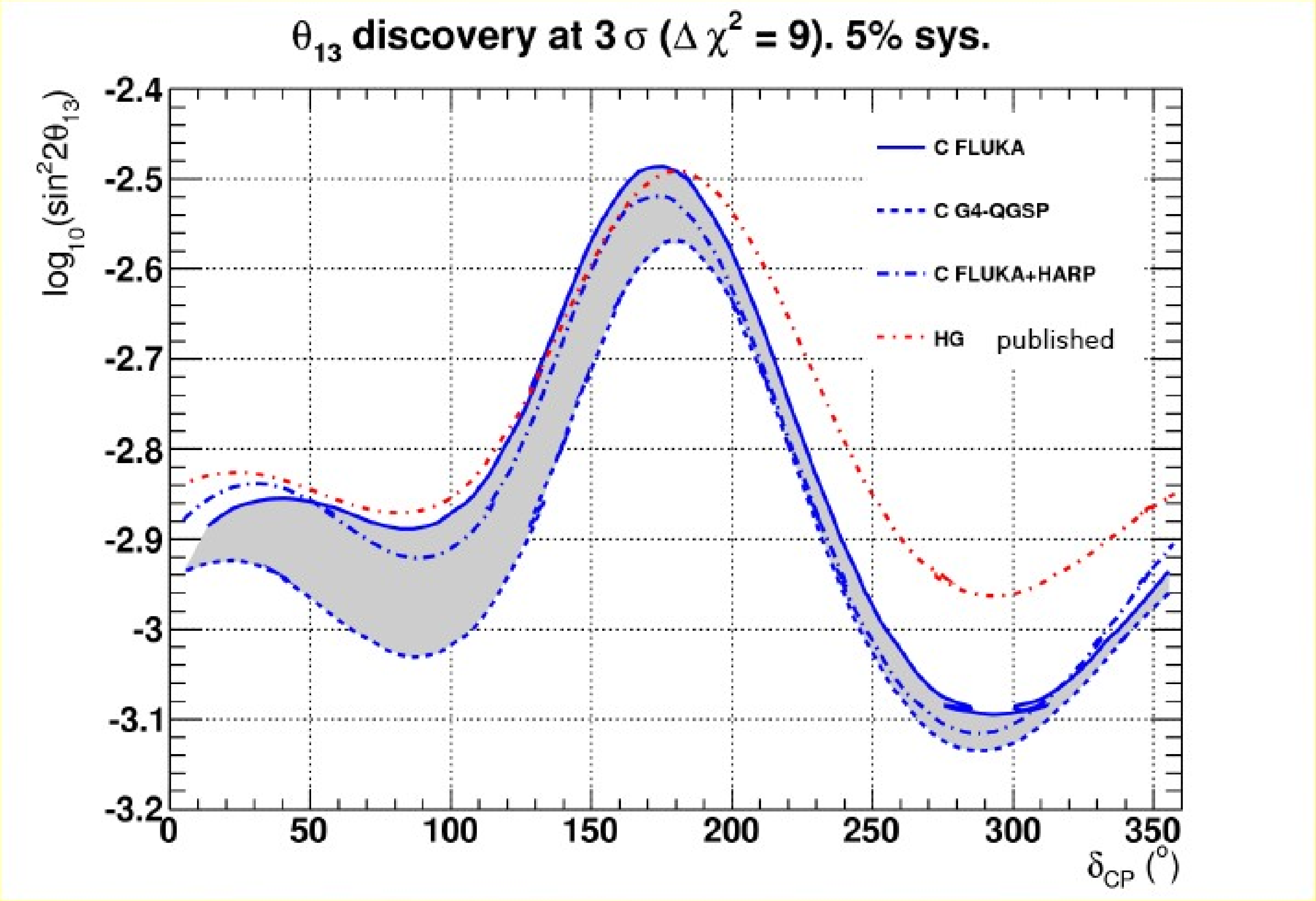
Event rates in MEMPHYS

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



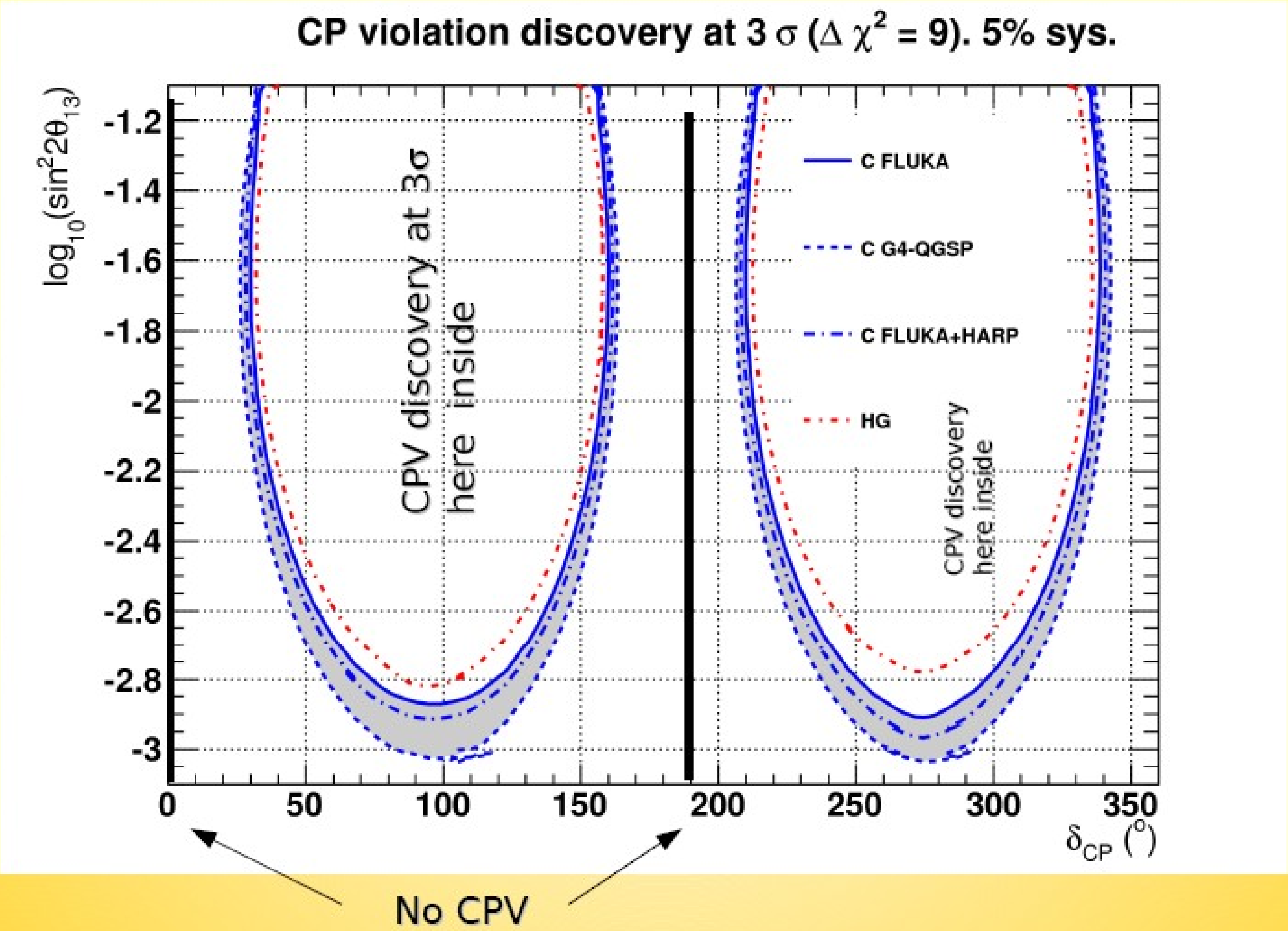
Based on the public MEMPHYS parametrization (AEDL) distributed with GLoBES
Bulk of the background from intrinsic beam electron component

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



Next steps

- Beam switch-yard design (1-> 4): in progress
- Activation and shielding studies (cost driver !)
- Target station layout and overall costing
- Explore the synergy with the Beta Beam : layout, costing and physics sensitivity (CP and CPT studies)

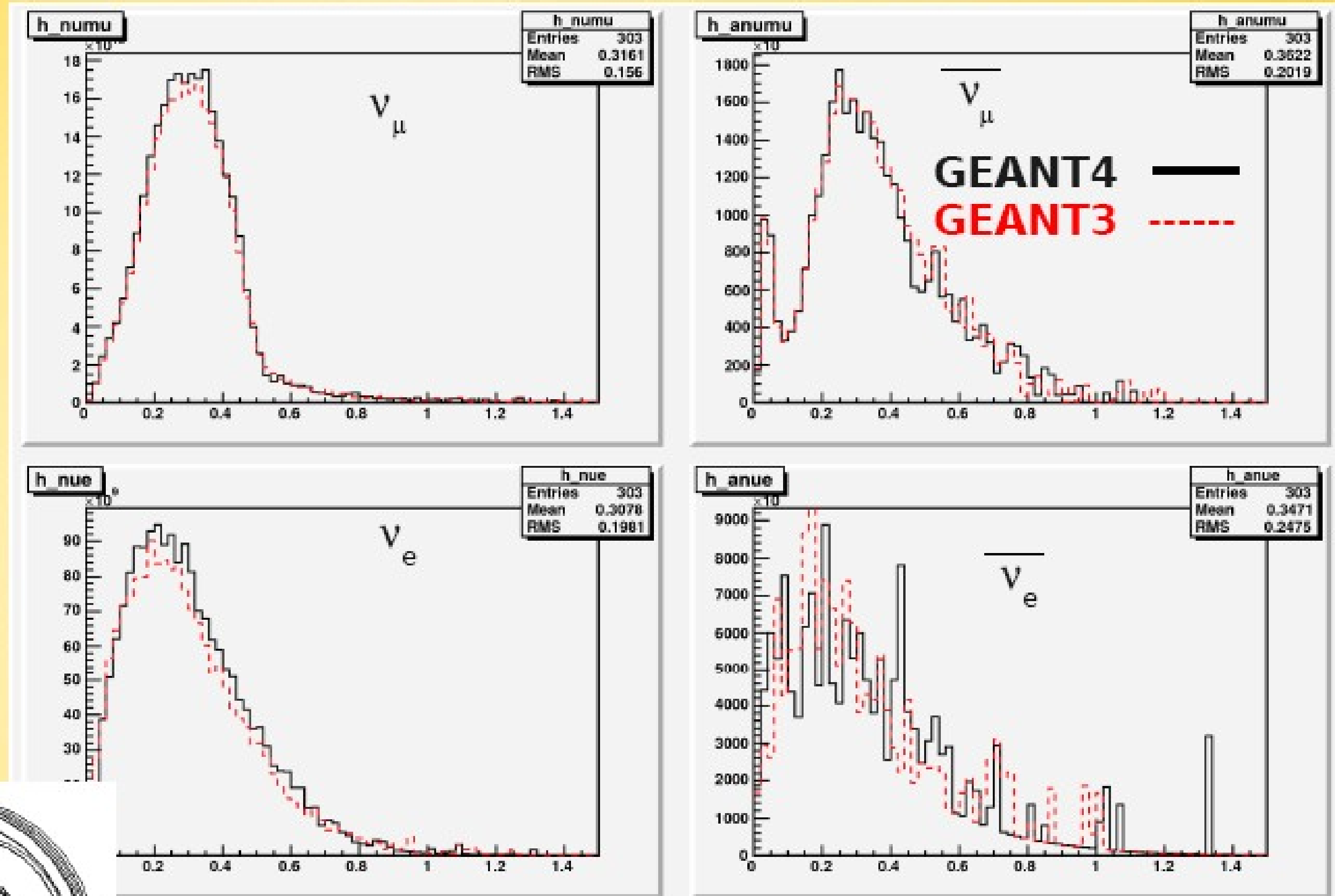
Conclusions

- 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
- The SuperBeam is a well proven technological option for the next round of experiment towards CP violation!

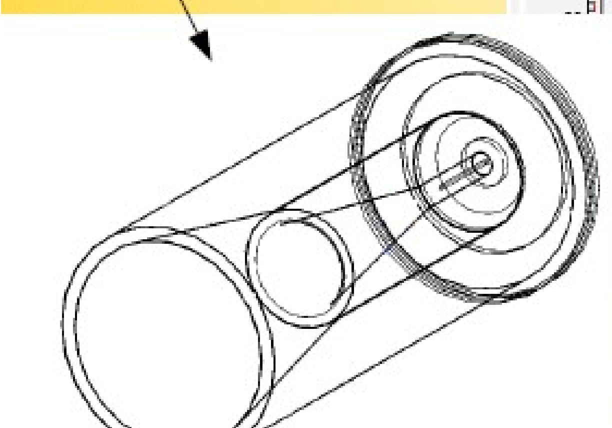
GEANT3-4 comparison with SPL standard horn

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

Fluxes comparison with the original horn geometry



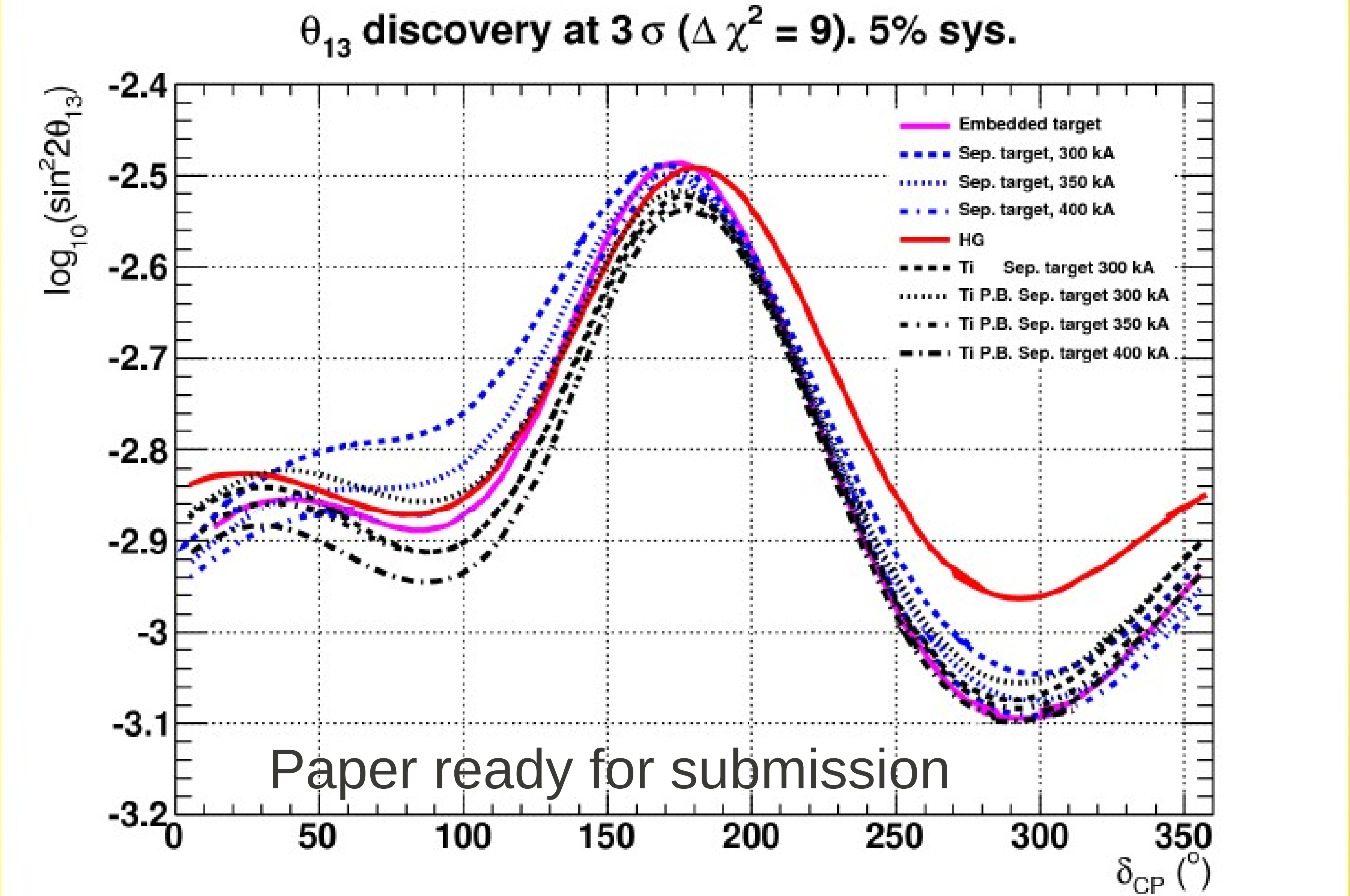
standard horn geometry (GEANT4)



Good agreement found between the two simulation programs

Θ_{13} discovery potential

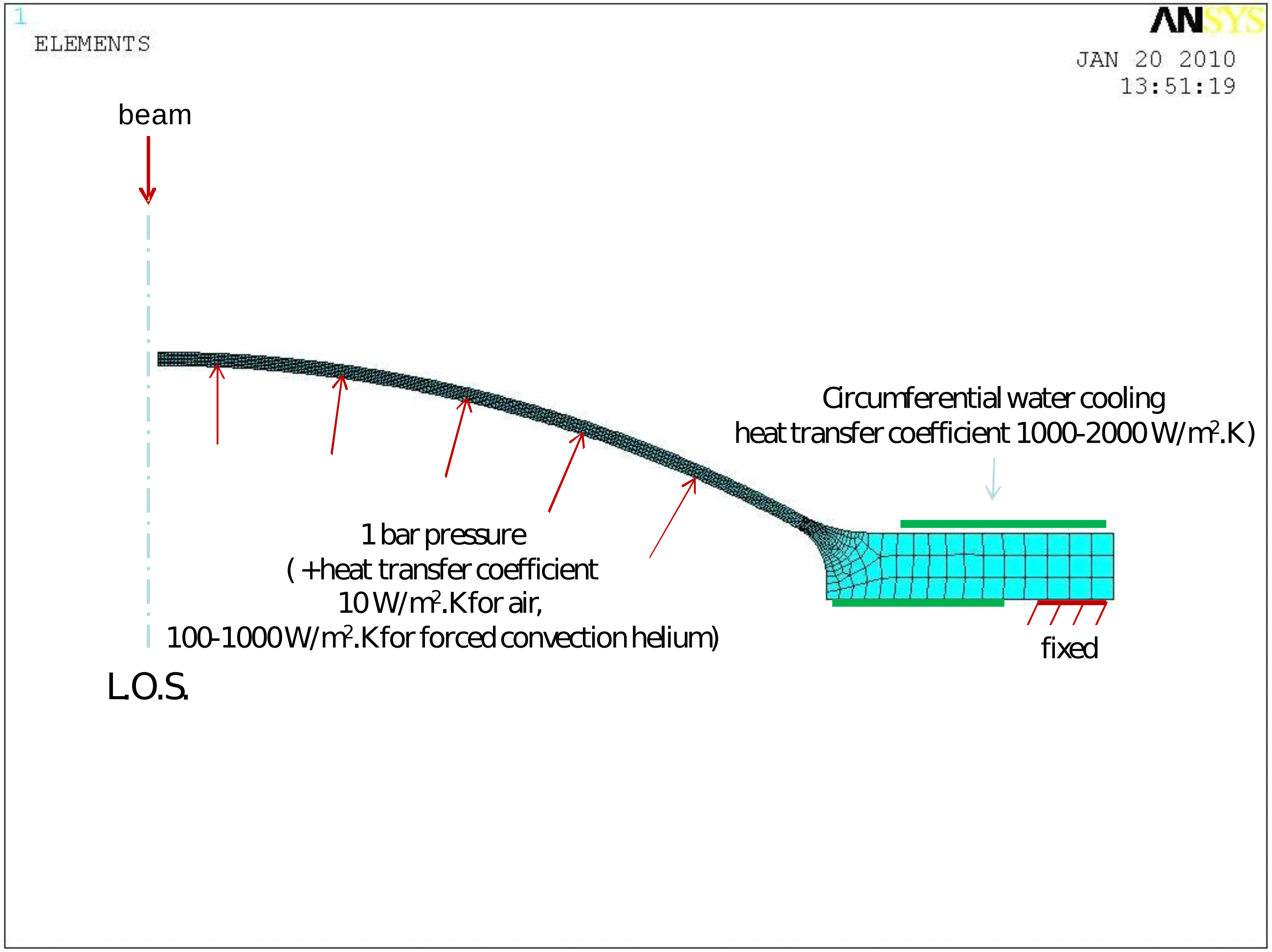
A. Longhin



Paper ready for submission

Beam window study

- Beryllium with water or helium cooling feasible

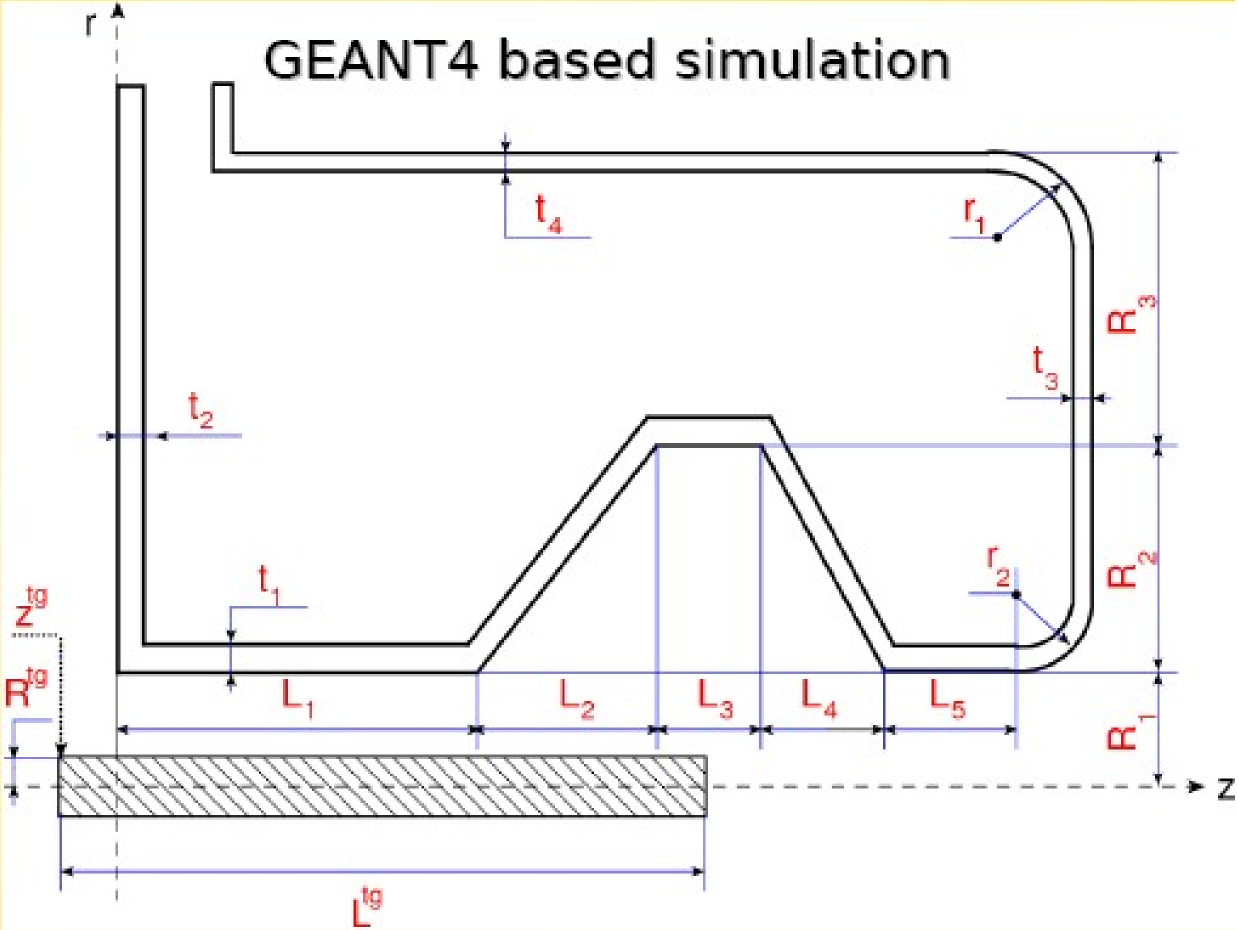


Horn geometrical model

à la MiniBoone
("forward closed")

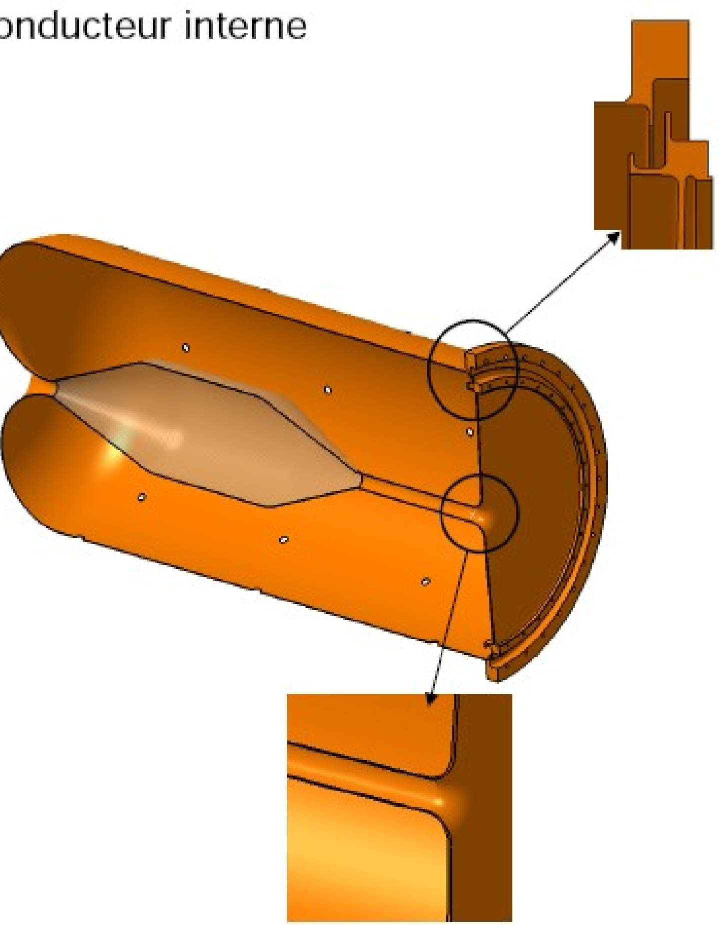
large acceptance for forward produced particles

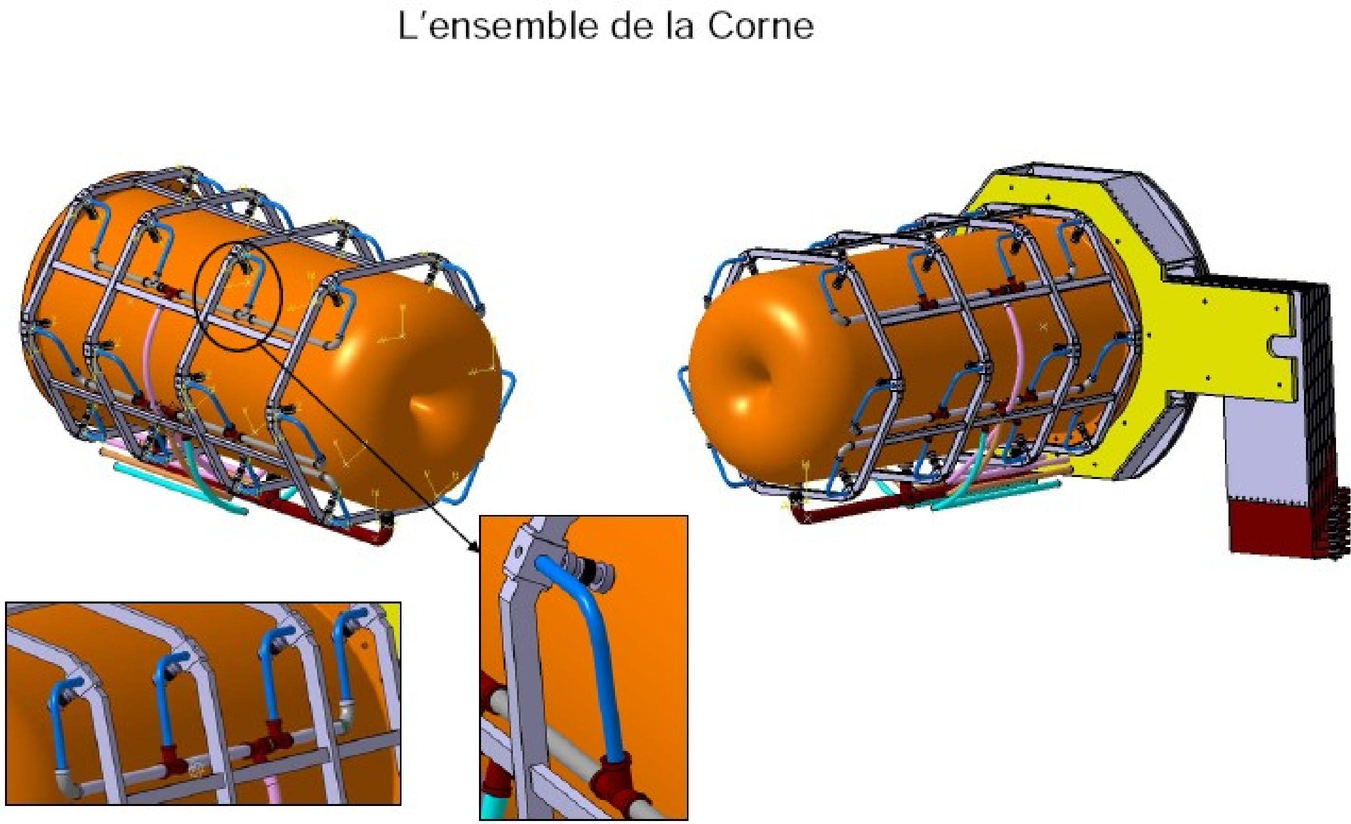
This shape is well suited for long targets



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

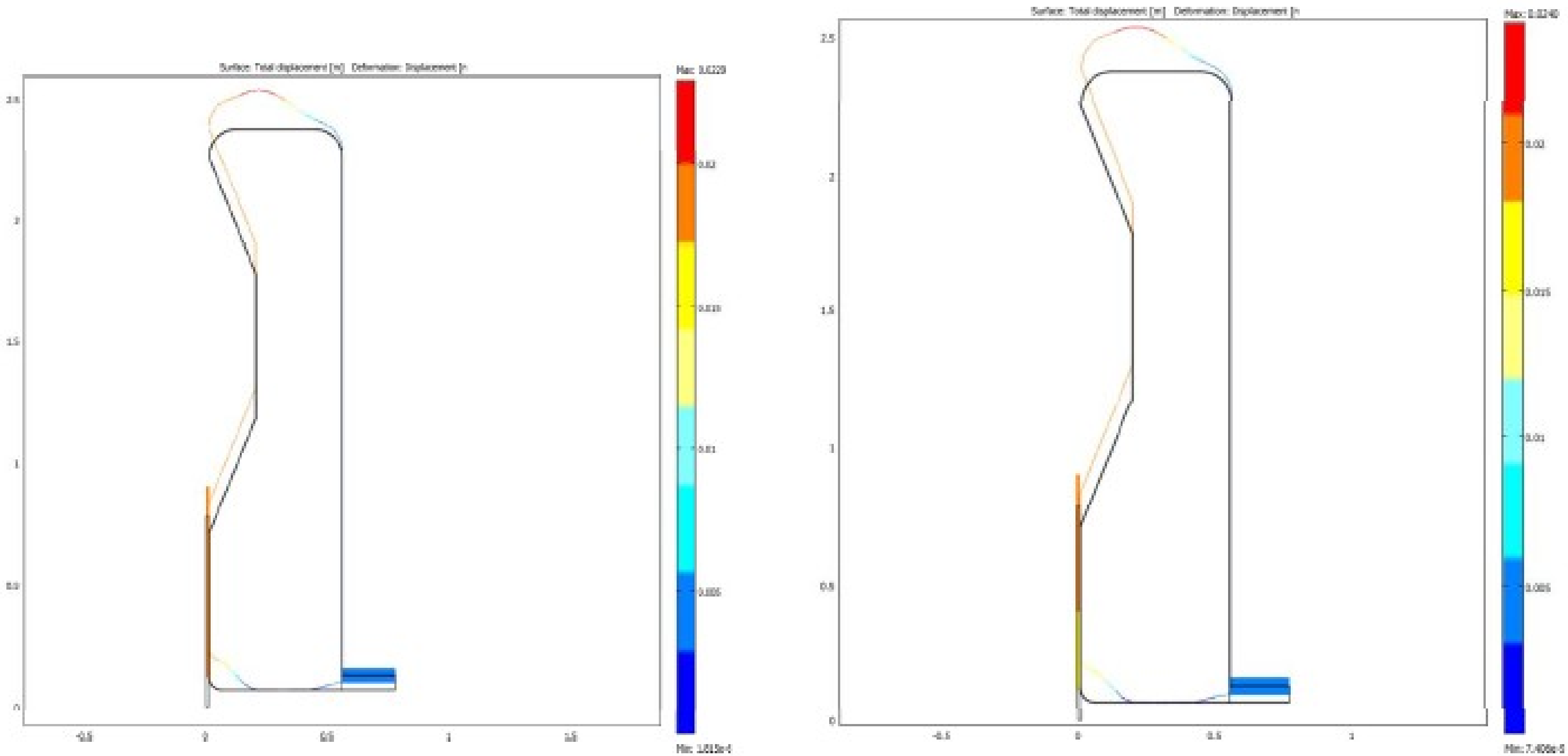
Horn drawings with cooling system





DISPLACEMENT FIELD, $t = 3$ MM

B. Lepers

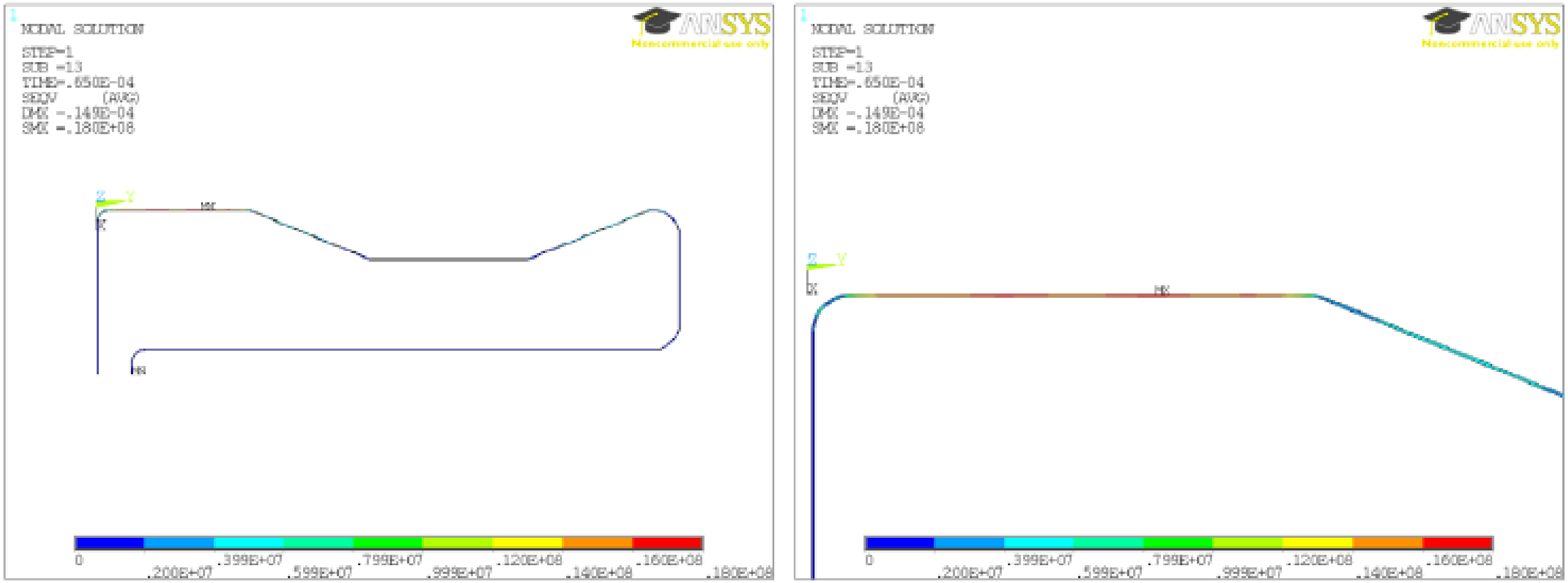


a) b)

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, EUROv Annual Meeting, Rutherford Appleton Laboratory, 18-21 January 2011

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