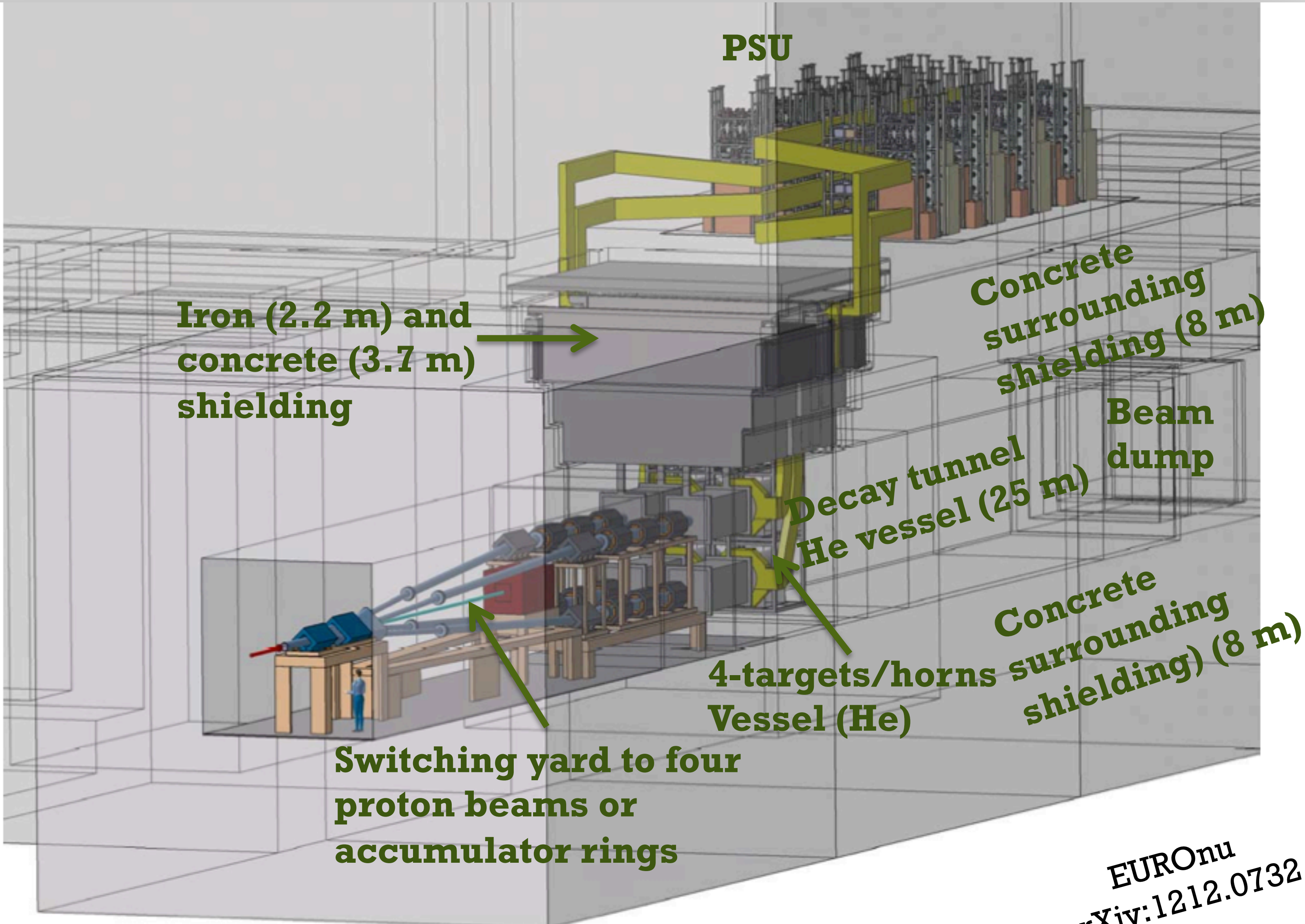
NUFACT14

ESSνSB: Update on secondary beam studies

Nikolaos Vassilopoulos
IPHC/CNRS

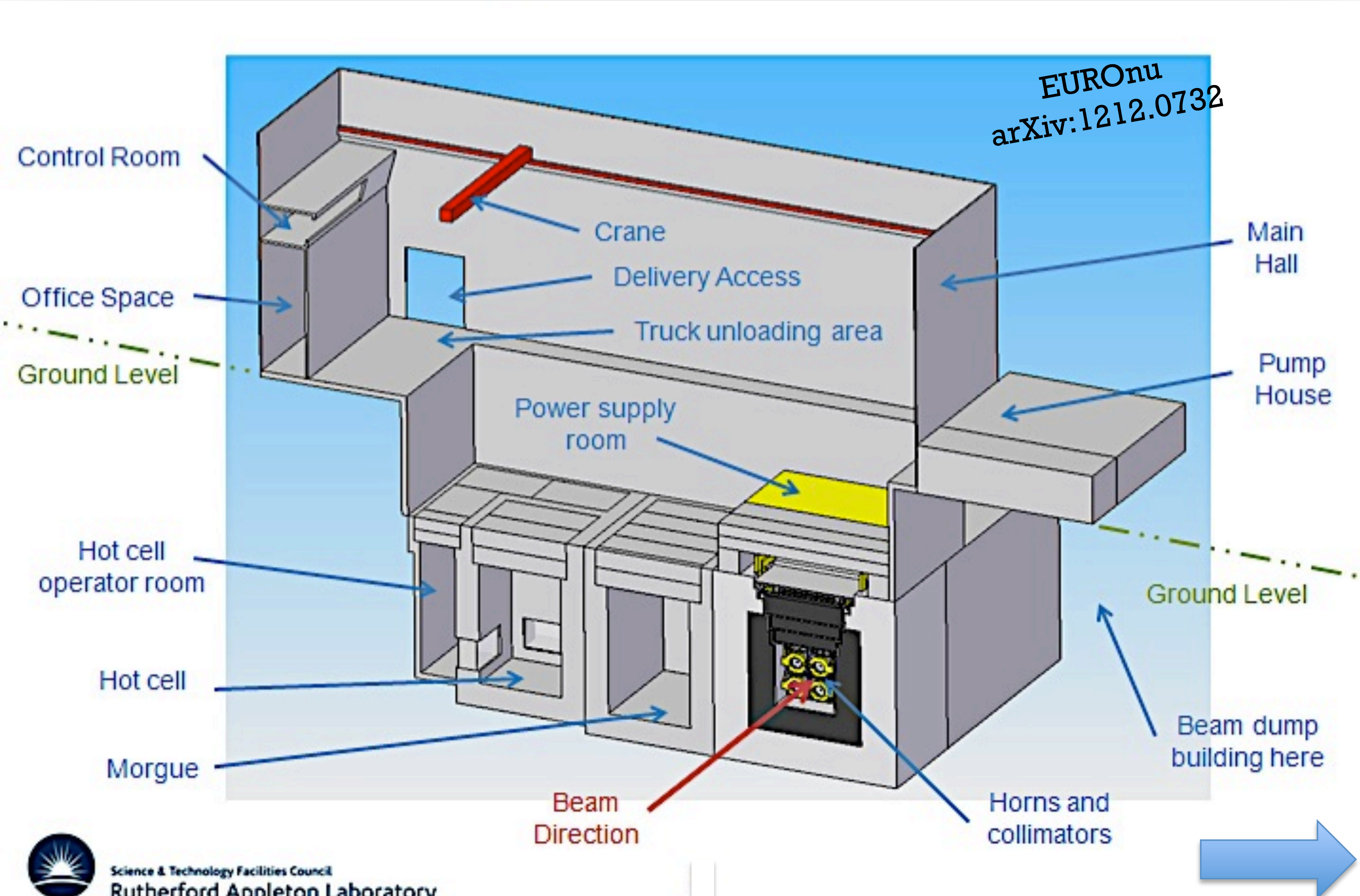
ESSνSB layout

(adopted from EUROnu Super Beam, inspired by J-PARC (T2K))

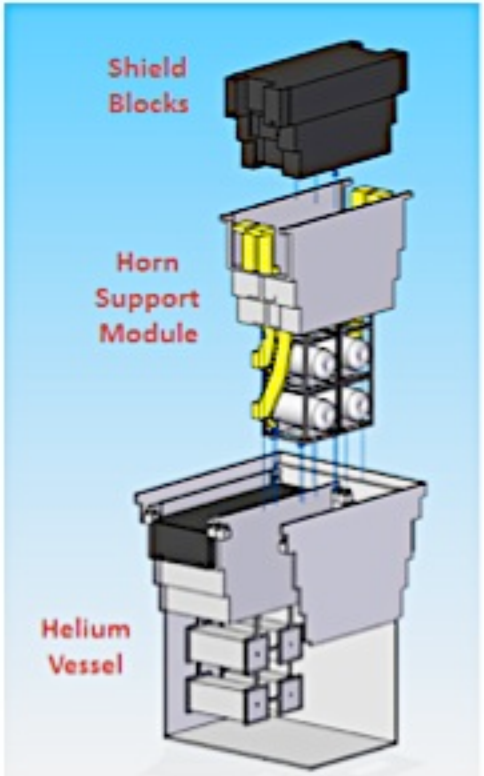


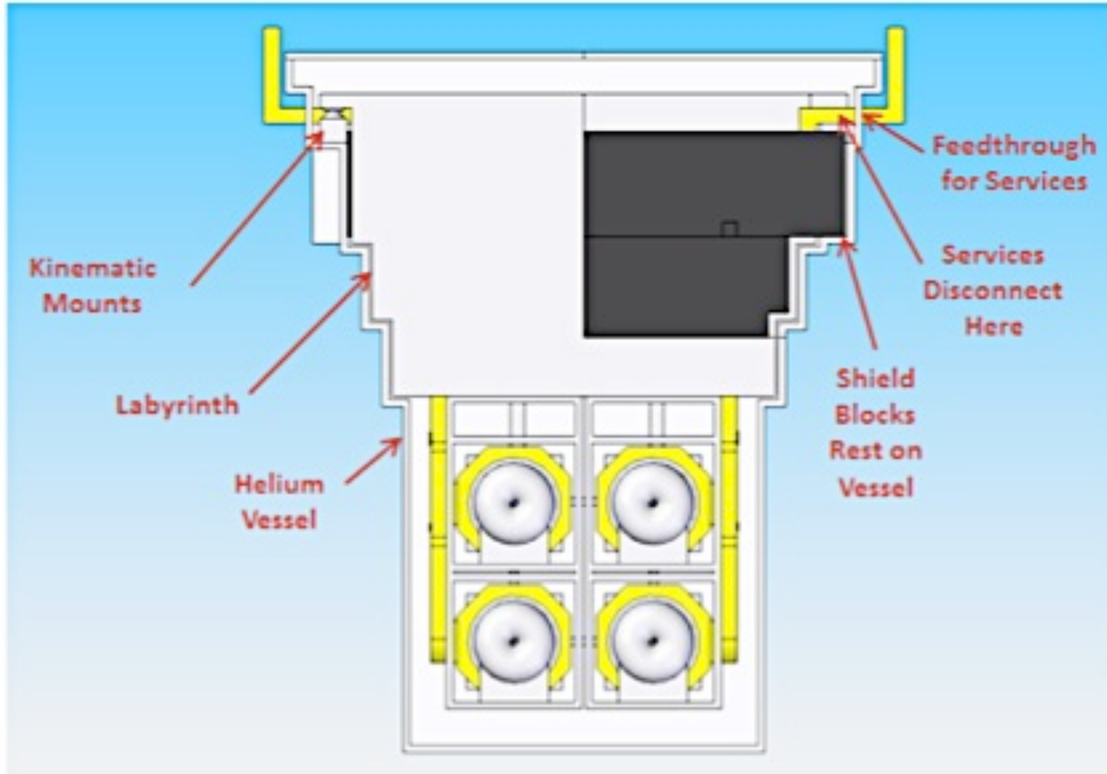
EUROnu arXiv:1212.0732

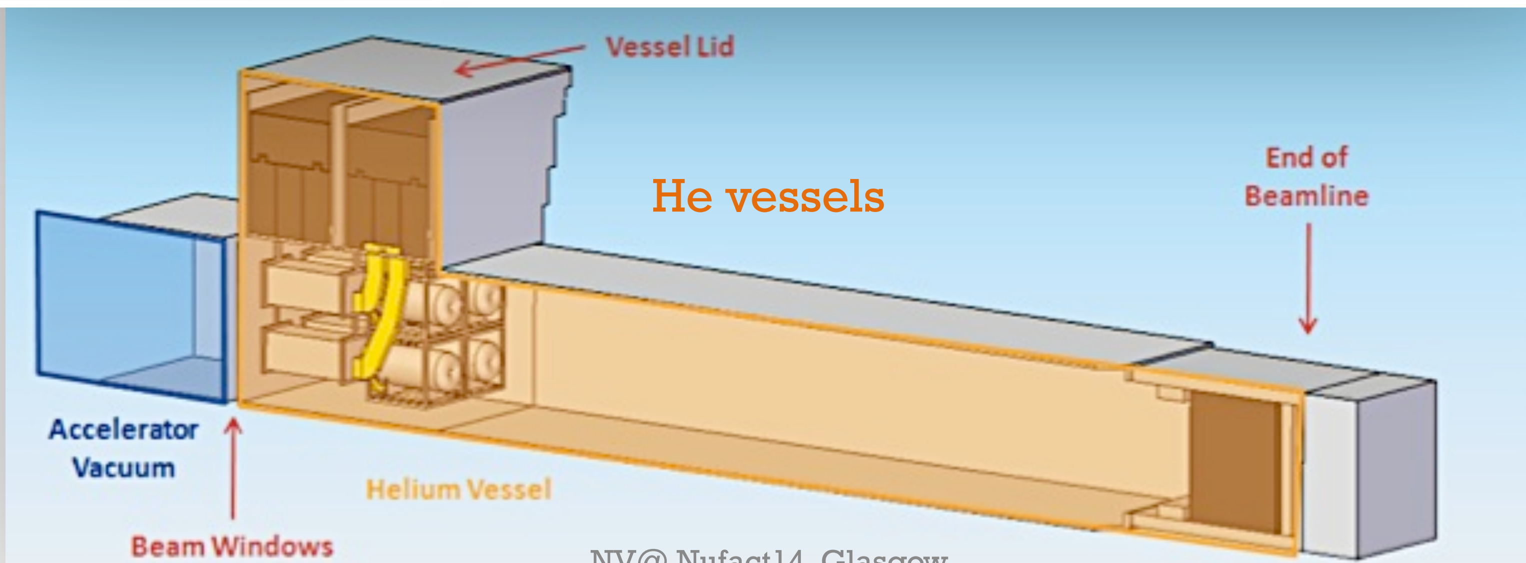
ESSνSB target station



He vessels

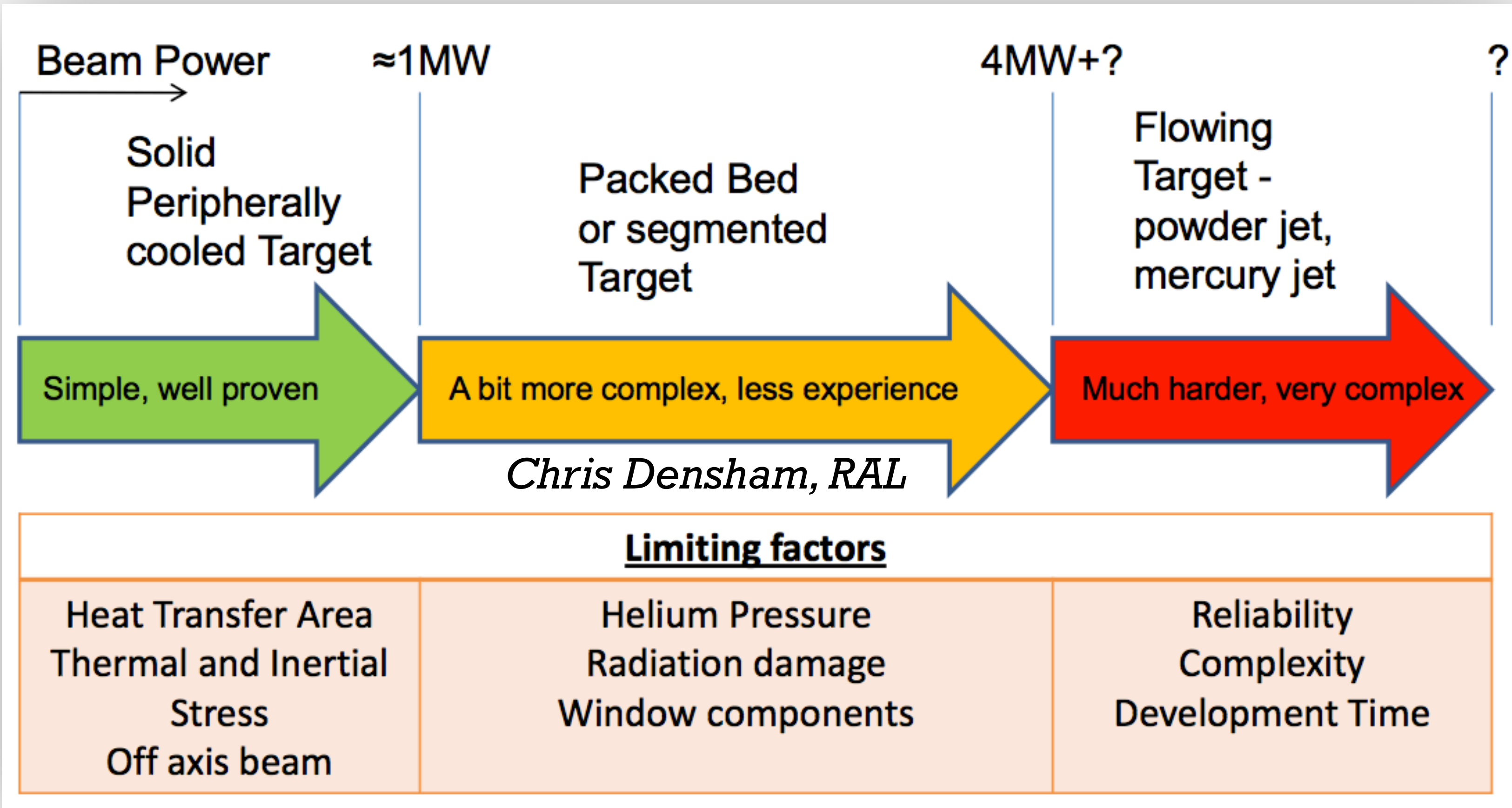

Shield Blocks
Horn Support Module
Helium Vessel


Kinematic Mounts
Labyrinth
Helium Vessel
Feedthrough for Services
Services Disconnect Here
Shield Blocks Rest on Vessel


Vessel Lid
End of Beamline
Accelerator Vacuum
Helium Vessel
Beam Windows

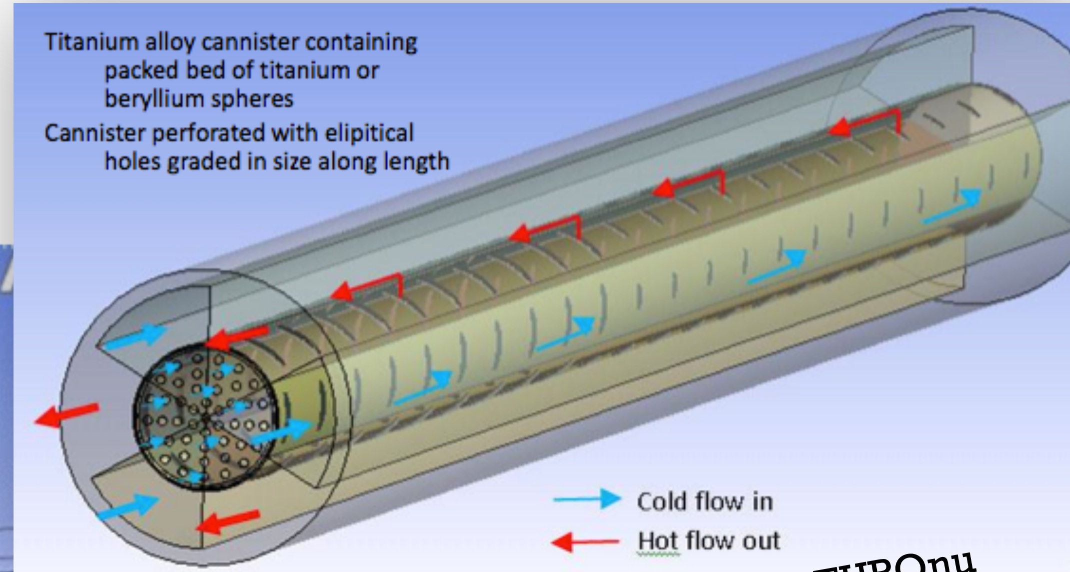
Why MW proton Beam power and which target ?

- Need multi-MW power in order to explore new physics in neutrino oscillations
- Past or current experiments function with less than 0.5 MW proton power on targets
- Main problem target lifetime and irradiation of beam materiel

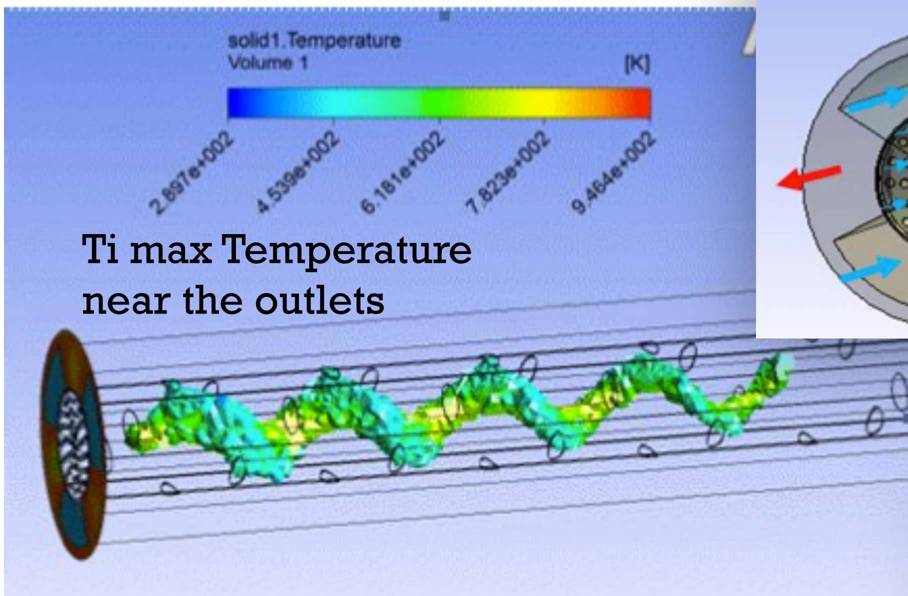


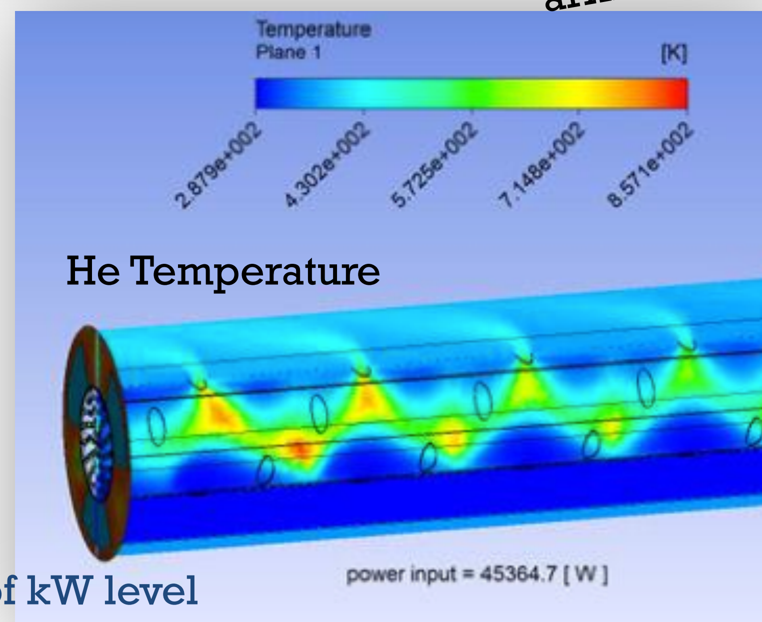
EUROnu (past) and currently HiRadMat at CERN look for solutions

Packed-bed target for ESSνSB



EUROnu
arXiv:1212.0732





- Packed Ti spheres (3-4 mm diameter)
- 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

Davenne Tristan/RAL

ESSνSB horn studies

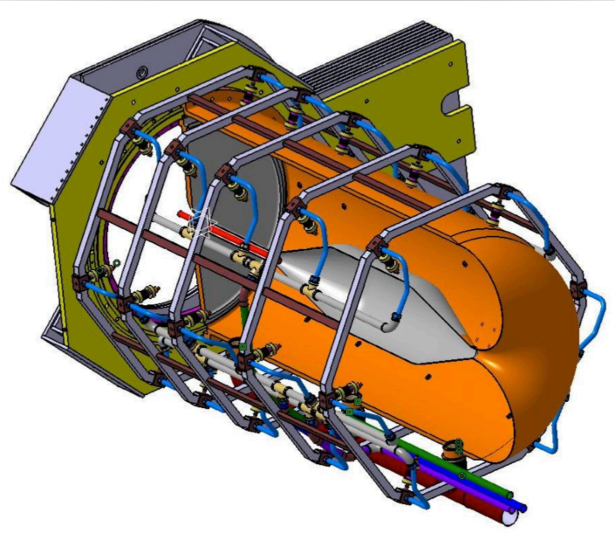
Horn structure

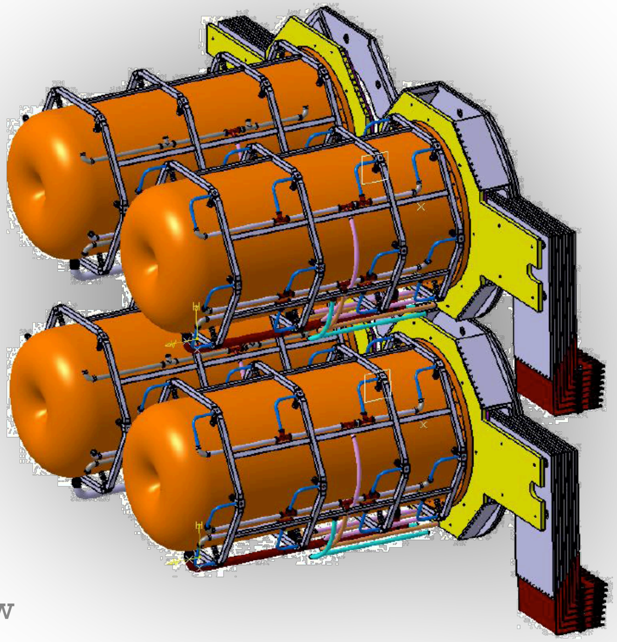
- Al 6061 T6 alloy good trade off between mechanical strength, resistance to corrosion, electrical conductivity and cost
- Four-horns assembly

Horn stress and deformation

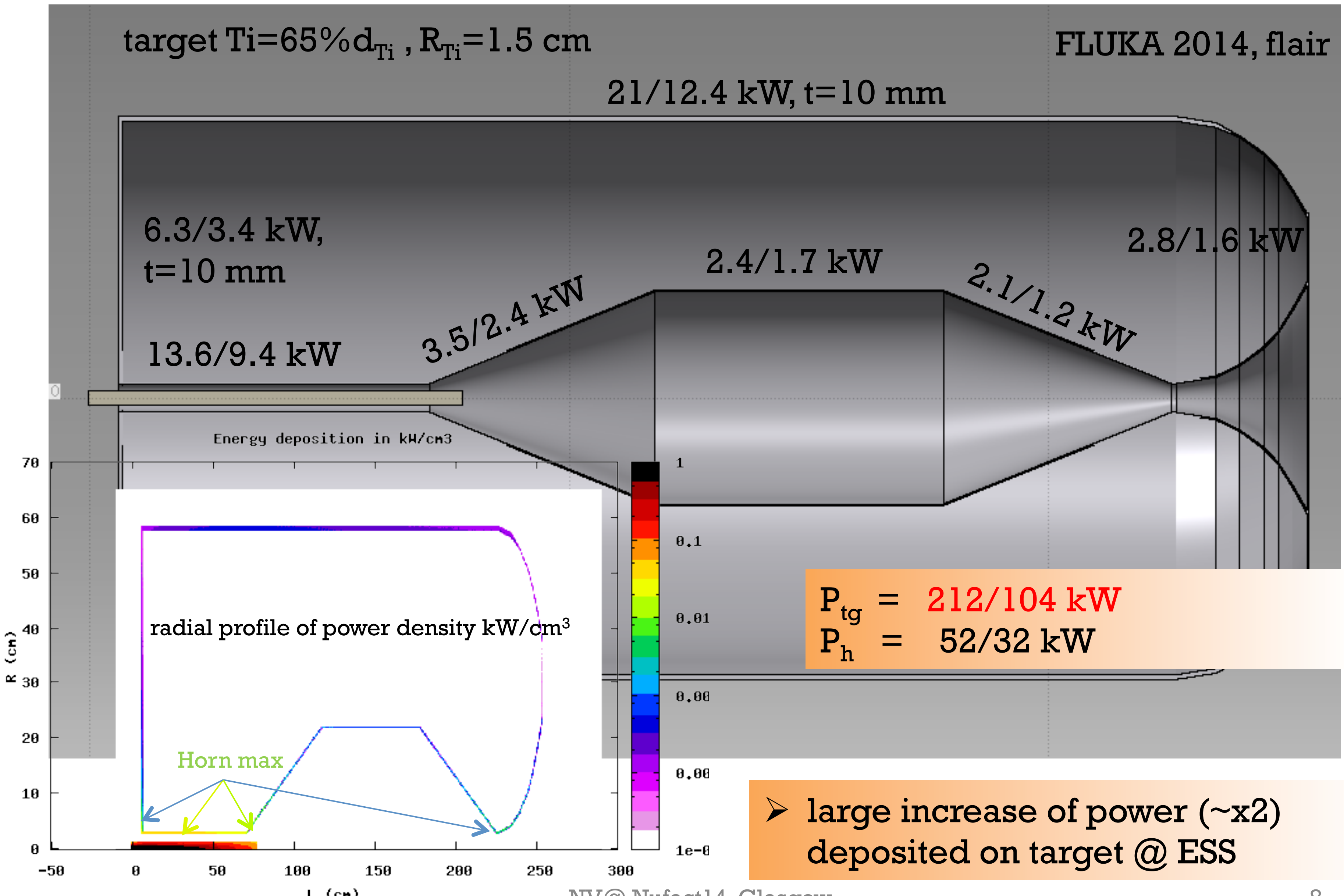
- Static mechanical model: thermal dilatation
- Magnetic pressure pulse: dynamic displacement
- 60 planar or elliptical water jets for cooling, flow rate between 60-120l/min, heat cooling coefficient 1-7 kW/(m^2K)
- Horn lifetime at least 1 year from fatigue analysis (30 – 60 MPa max stress - depending on cooling)

EUROnu
arXiv:1212.0732





Energy Deposition from secondary particles, 3 horns, ESSνSB -1.6 MW/EUROnu -1.3 MW



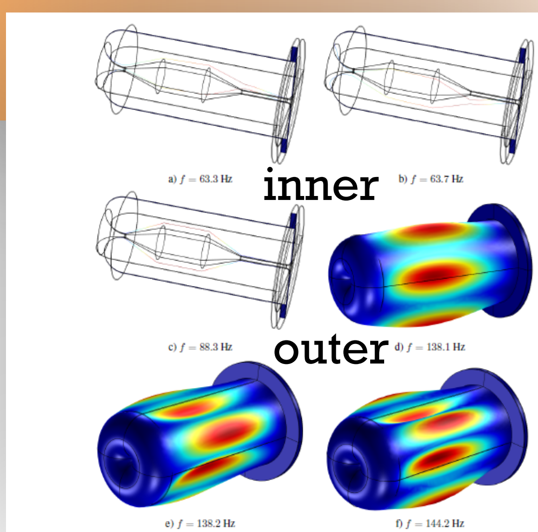
- large increase of power (~x2) deposited on target @ ESS

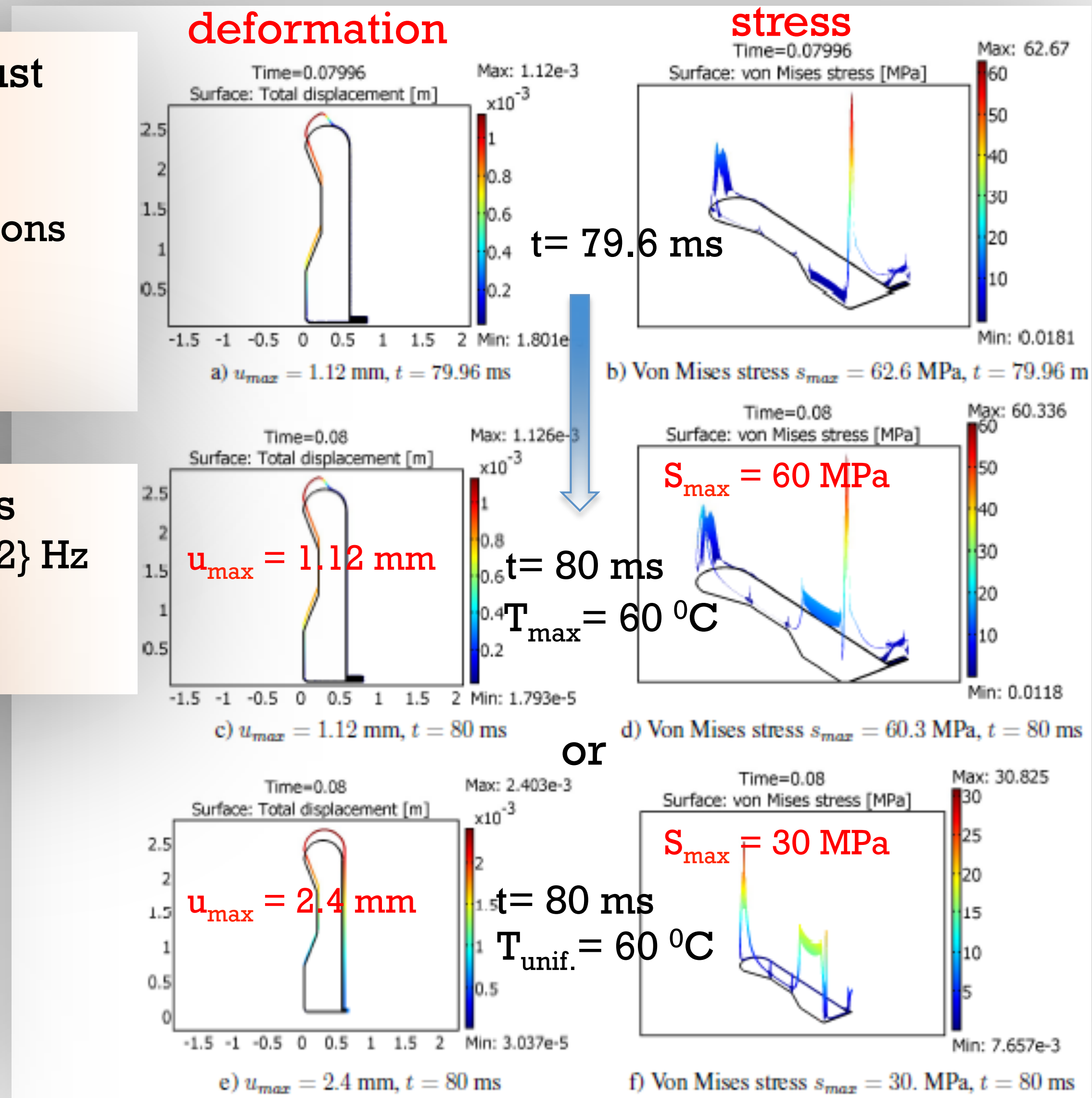
Horn's stresses due to thermal dilatation and magnetic pressure for 350 kA @ 12.5 Hz, EUROnu

displacements and stress plots just before and on the peak

- maximum stress on the corner, upstream inner and convex regions
- uniform temperature minimizes stress, max = 30 MPa

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





horn lifetime

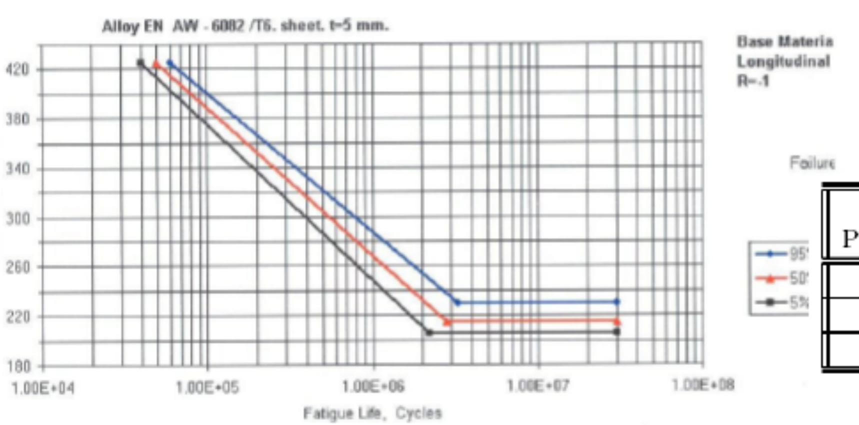
lower than 60 MPa expected

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 %	$6.6 \cdot 10^6$	$8.25 \cdot 10^7$

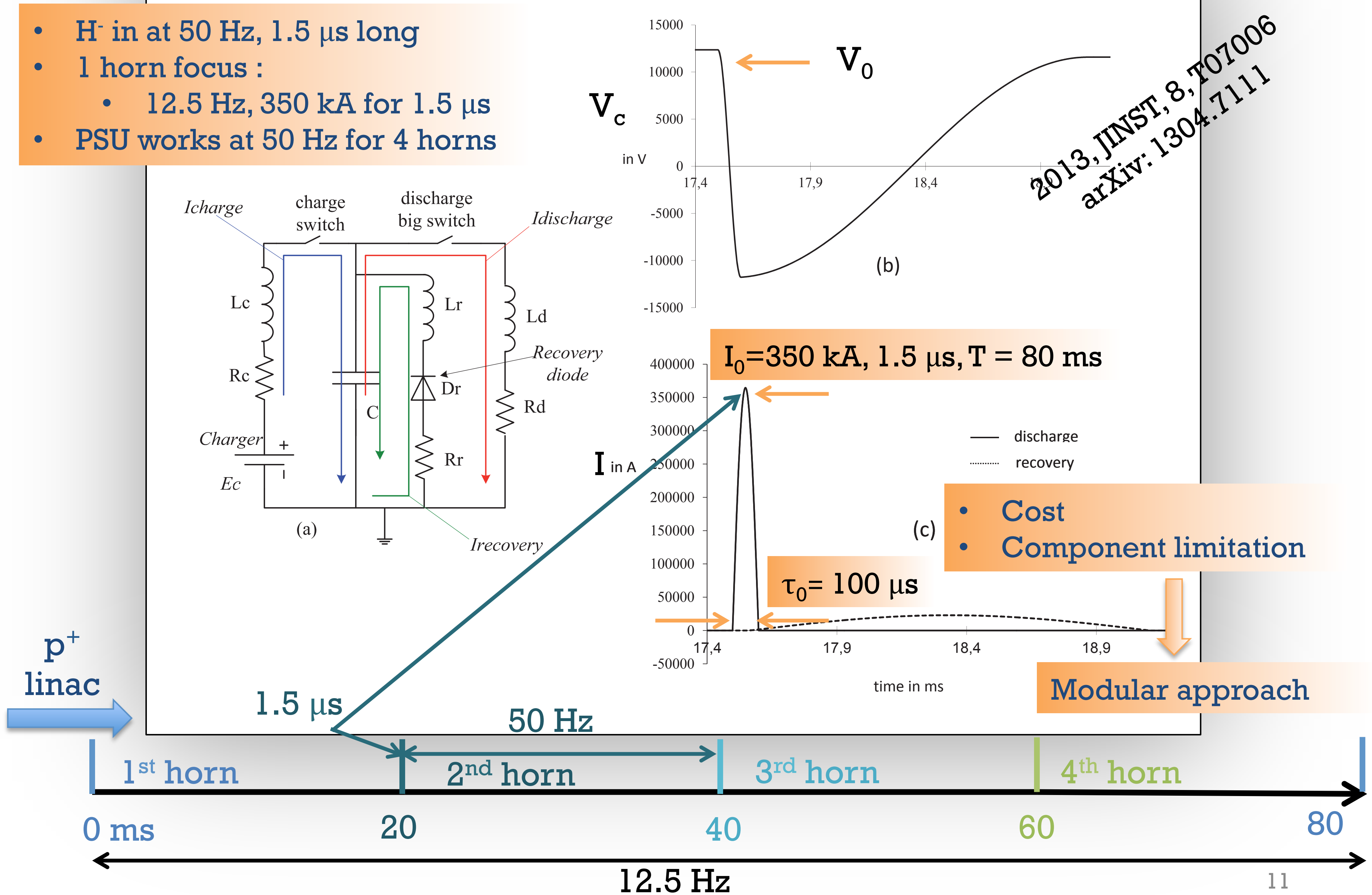
A.Niesłony

$1.25\ 10^8$ pulses = 200 days = 1 year

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

PSU EUROnu : Direct discharged and capacitive energy recovery through recovery circuit

- H^- in at 50 Hz, 1.5 μs long
- 1 horn focus :
  - 12.5 Hz, 350 kA for 1.5 μs
- PSU works at 50 Hz for 4 horns

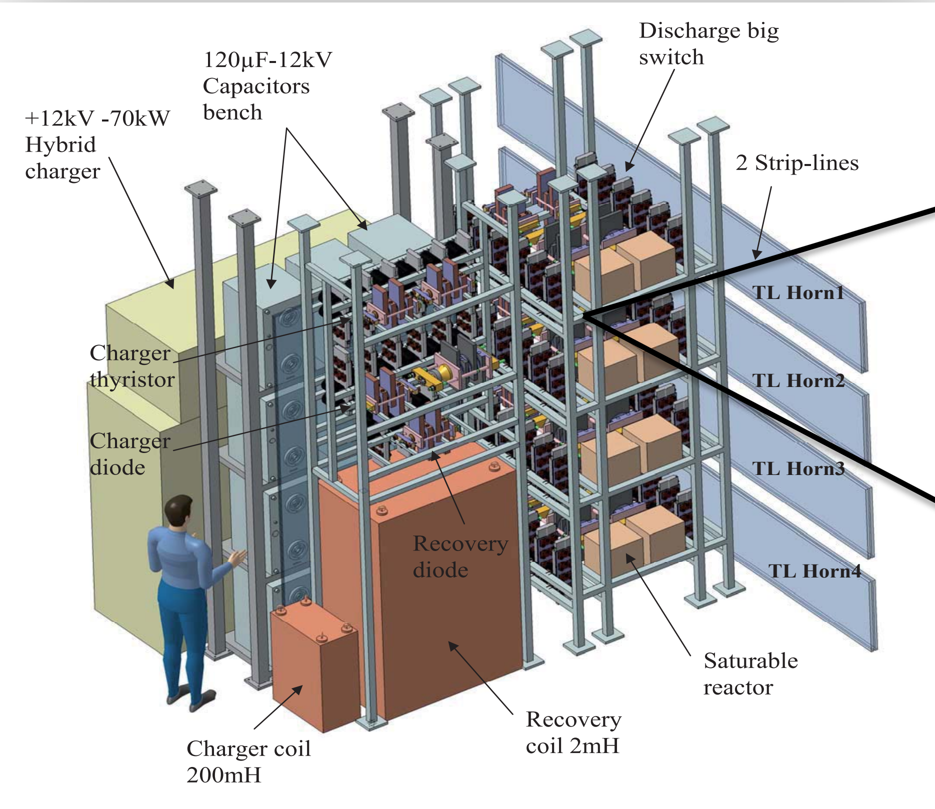


- Cost
- Component limitation

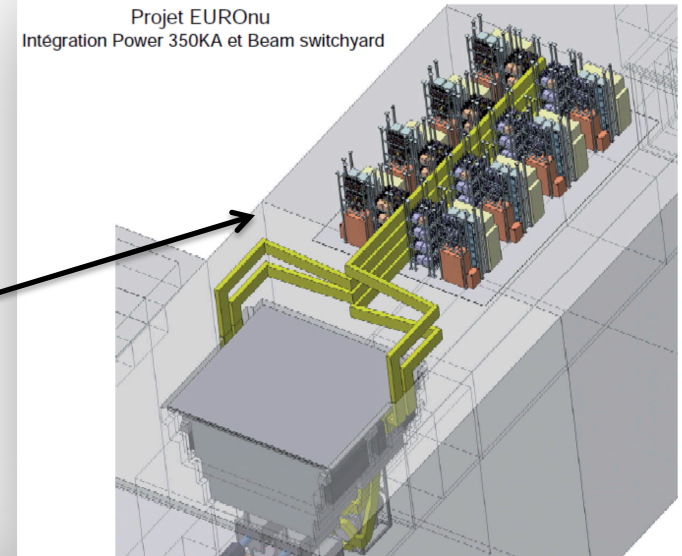
Modular approach

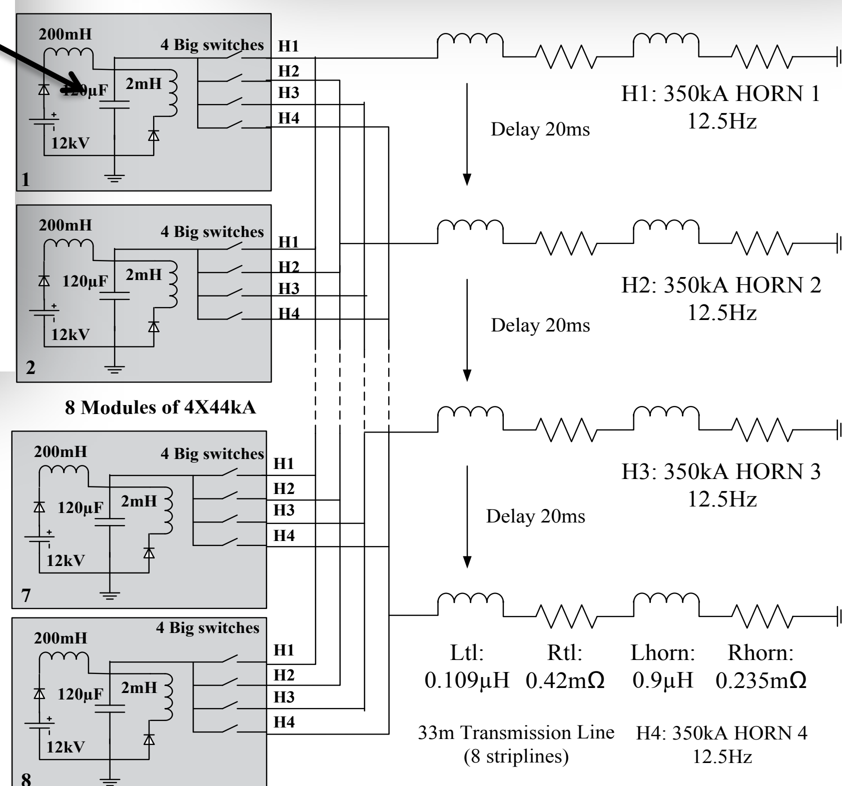
PSU EUROnu

a 4x44 kA module



x 8



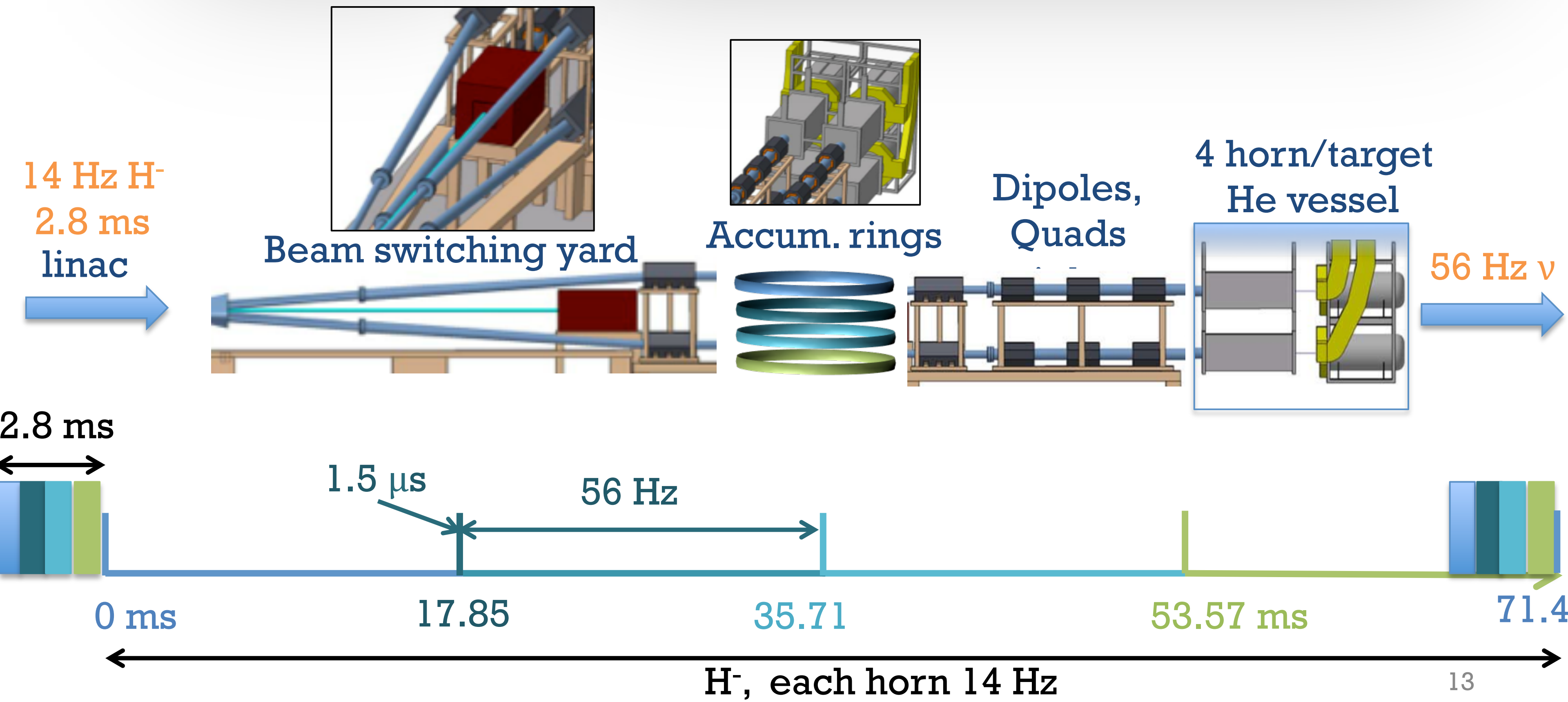


- PSU: 8 times 4x44 kA modules
- 1-charger/capacitor/coil, 4-switches per 4x44 kA module
- 8 strip lines merged into 4 transmission lines in-out/horn
- 97 % Energy recuperation

ESSνSB: 4-rings, ν at 56 Hz

In : H^- (Hz)	Out : ν (Hz)
14	56

Area PSU (m^2)	Power Consumption (kW)	Cost MEuro
194	560 kW	~4



How flat is the current pulse at peak ?
How it correlates with protons on target width τ_{H-}?

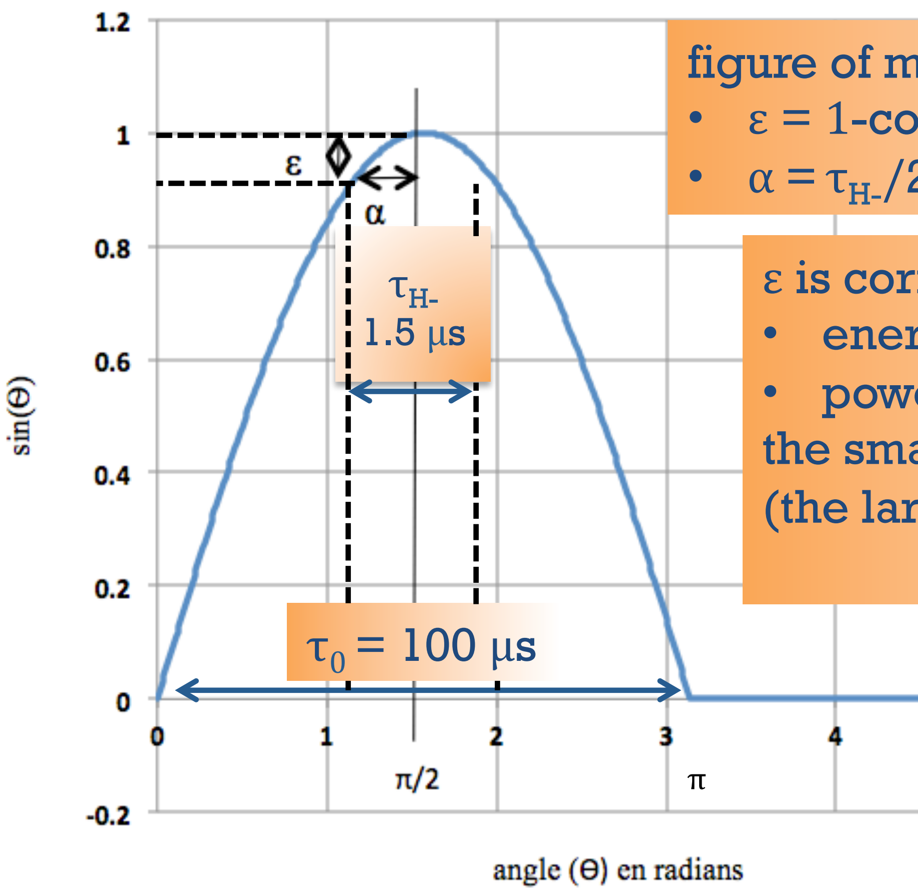


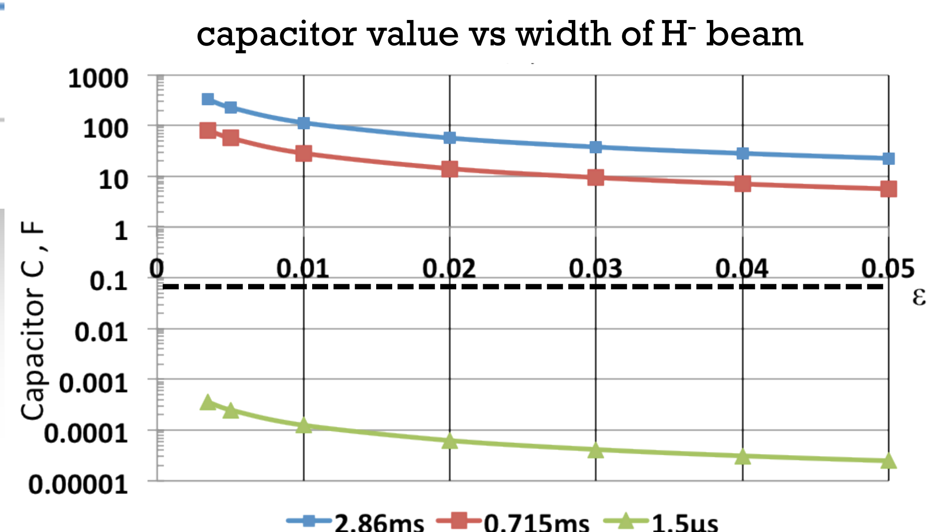
figure of merit, parameter ε "variance"

- $\varepsilon = 1 - \cos\alpha$
- $\alpha = \tau_{H-}/2 \cdot \pi/\tau_0$ in radians

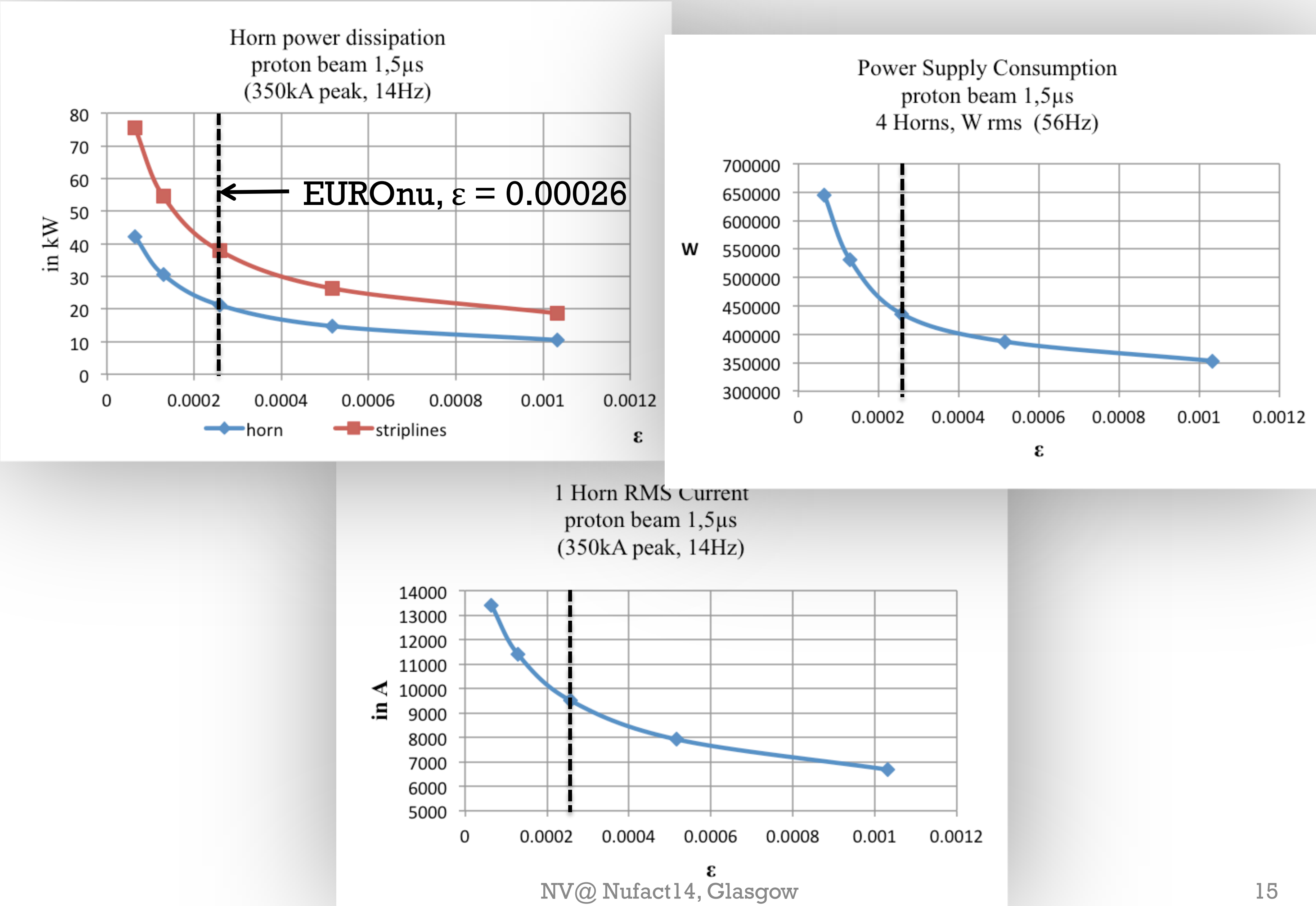
ε is correlated to

- energy storage
- power consumption

the smaller ε the costlier or not feasible
(the larger the integral I x Time)



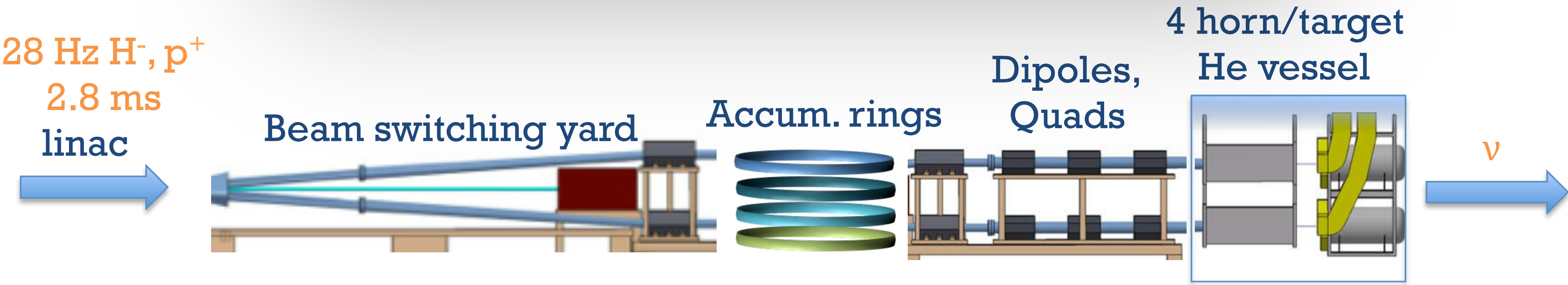
4-rings, ν at 56 Hz, ε analyses

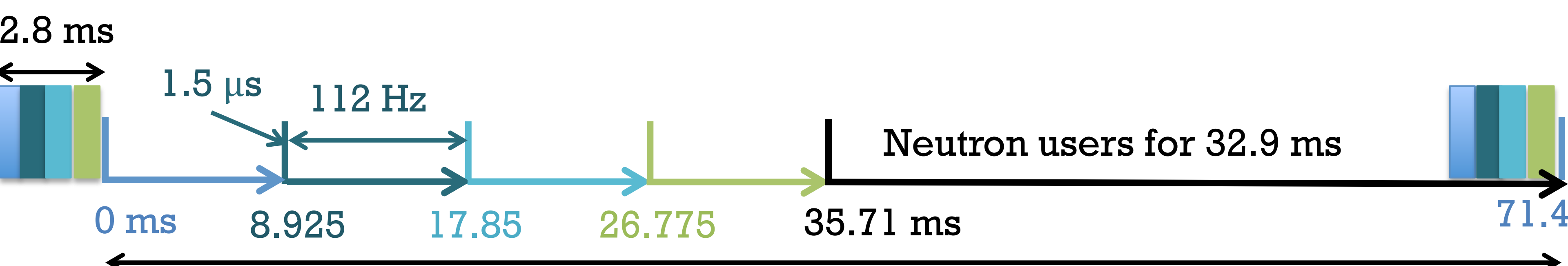


ESSνSB: 4-rings, ν at 112 Hz + 35.71 ms neutron gap

	Capacitor charger	Area PSU	Power consumption	Cost
1.b.i)	2 x 56 Hz	x 1.3	x 1	x 1.5
1.b.ii)	1 x 112 Hz	x 1.2	x 1.5	x 1.1

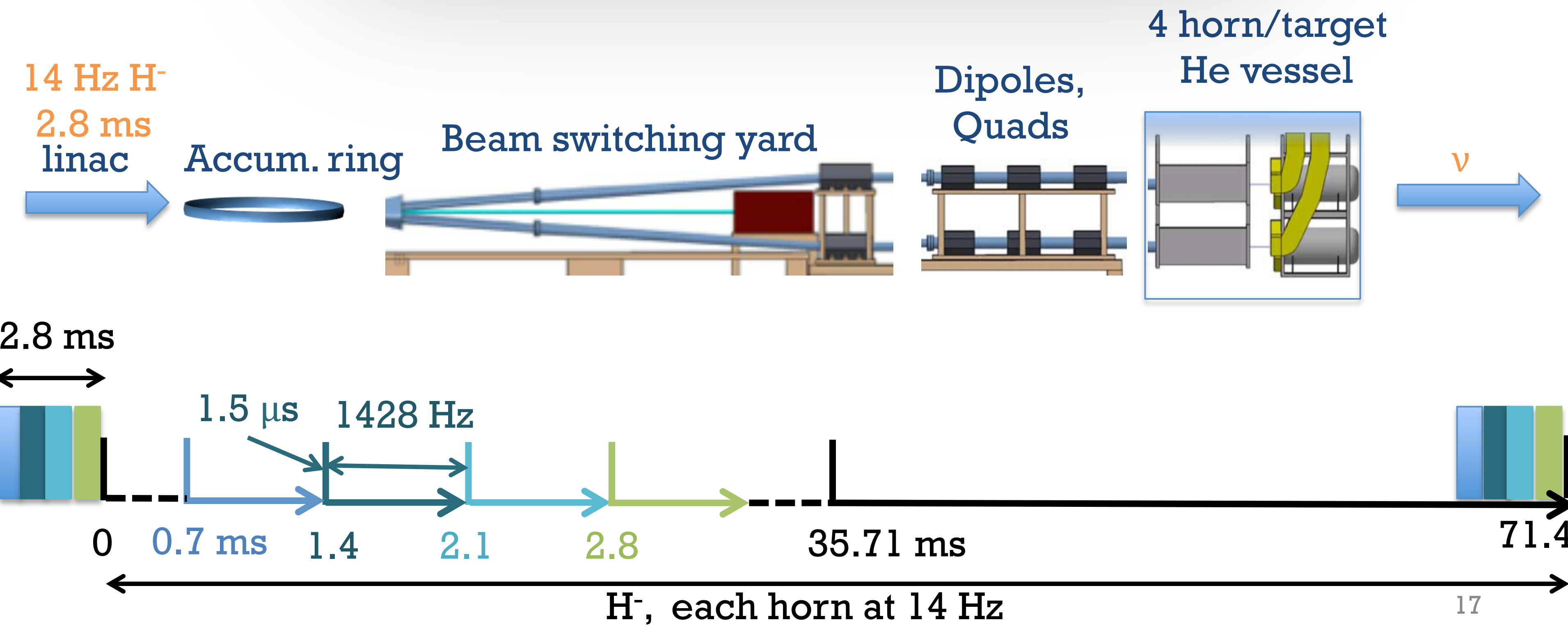
baseline





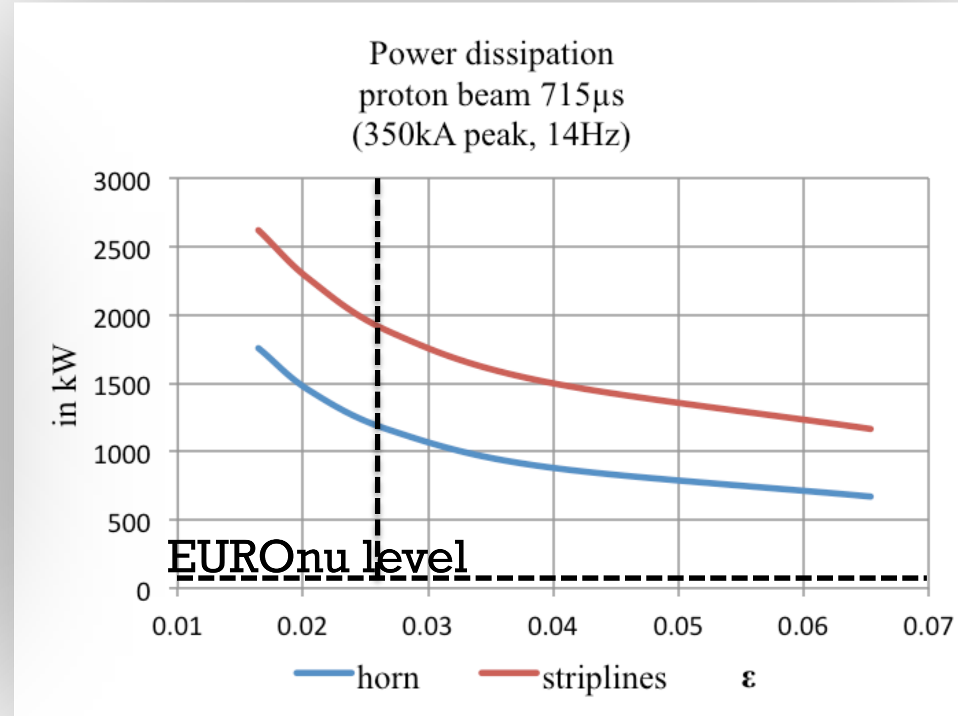
ESSνSB: 1 ring, ν 1428 Hz (4 times every 0.7 ms) + 68.6 ms gap

Capacitor charger	Area PSU	Power consumption	Cost
4 at 14 Hz	x 1.7	x 1	x 2.5



also…no ring,ν during 2.8 ms (4 horns x 0.7 ms) + 68.6 ms gap, transformer

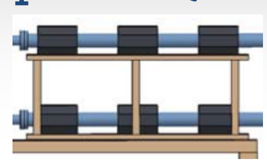
Area PSU	Power consumption	Cost
not feasible high power dissipation on horn and striplines and consumption		

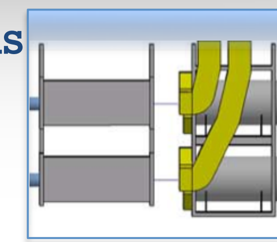


14 Hz H⁻
2.8 ms
linac

Beam switching yard

Dipoles+Quads





4 horn/target
He vessel

14 Hz ν

2.8 ms

1^{st} 2^{nd} 3^{rd} 4^{th} horn

2.8 ms

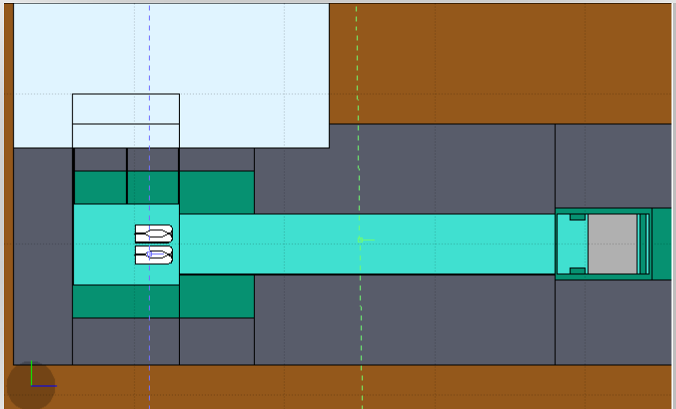
0 ms

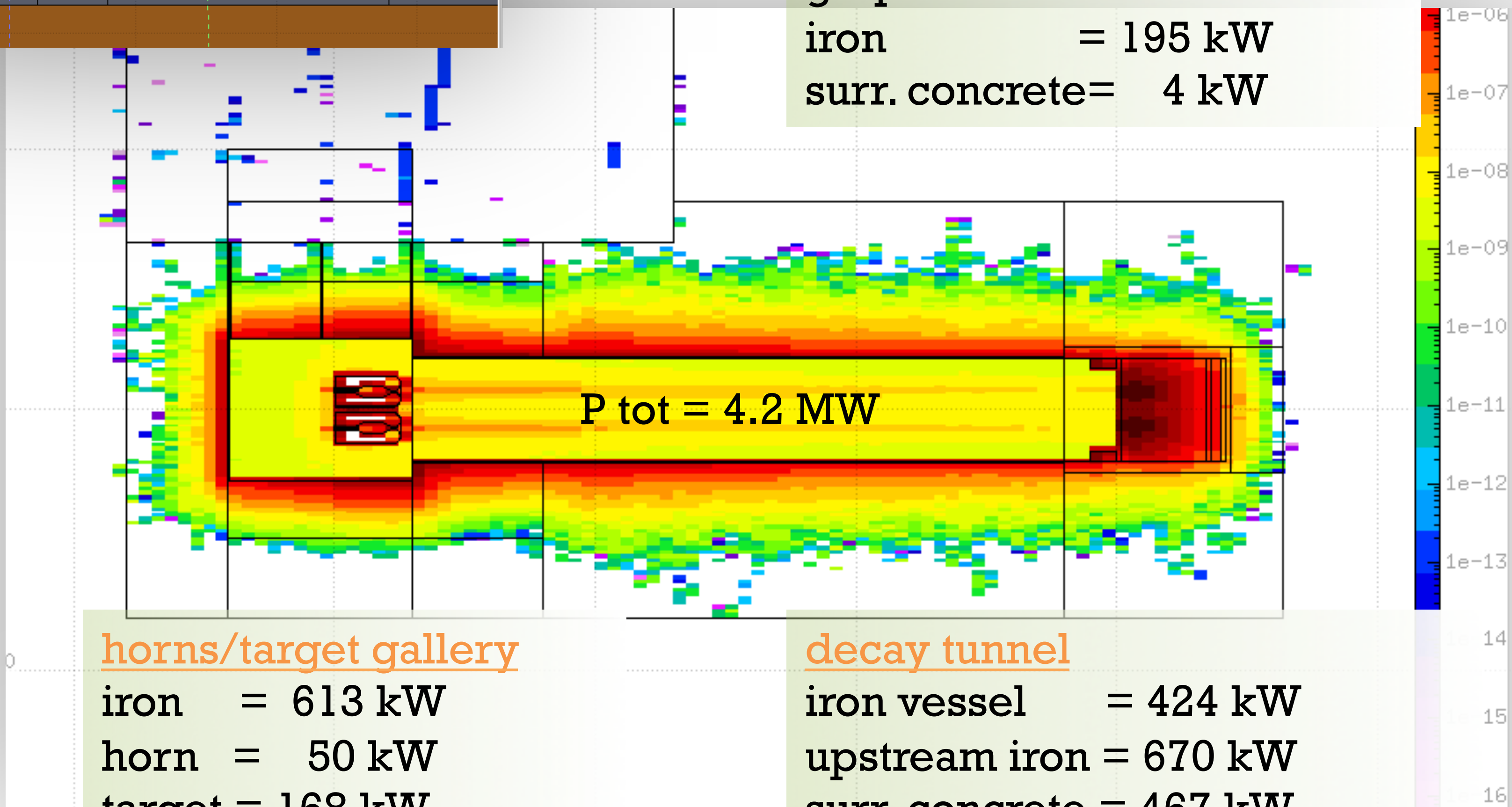
71.54 ms

H⁻, 1-horn at14 Hz

ESSνSB(5 MW) power distribution

iron, concrete, molasse, He





beam dump

graphite = 950 kW
iron = 195 kW
surr. concrete= 4 kW

horns/target gallery

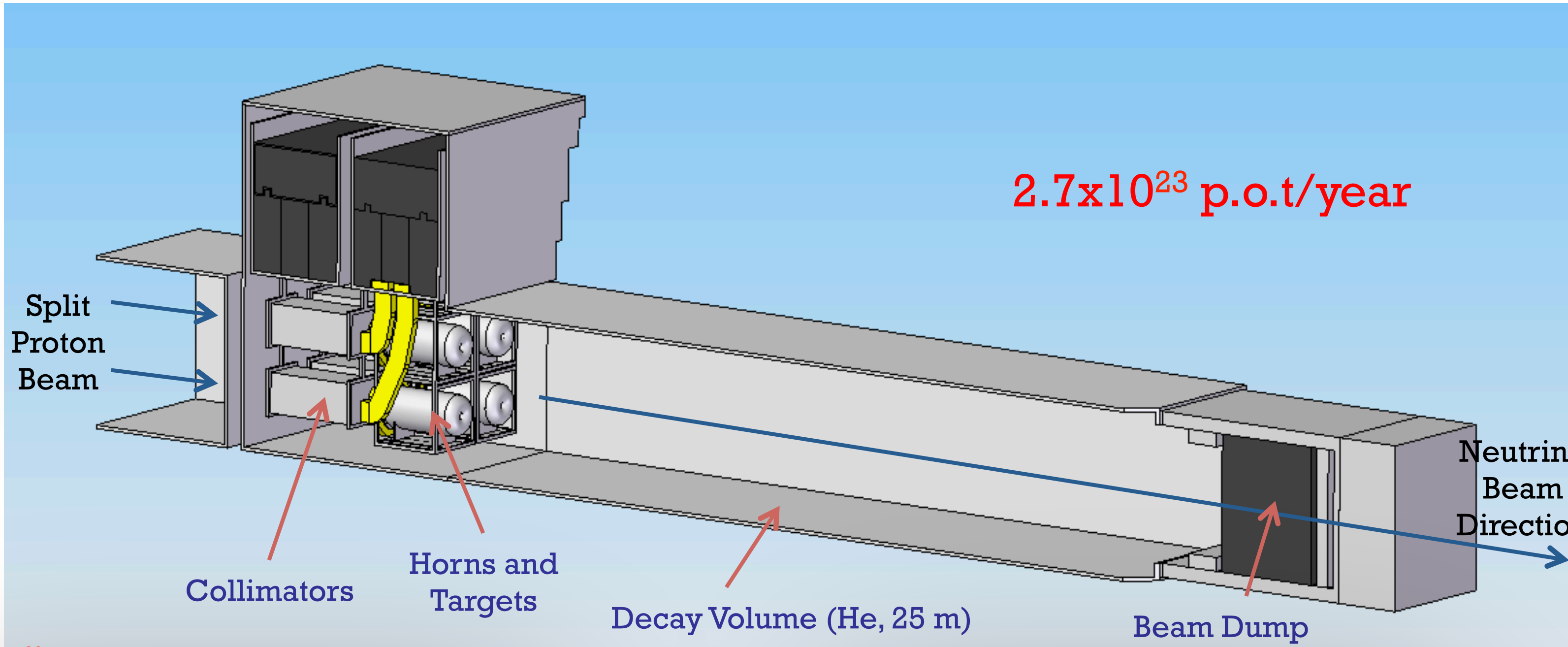
iron = 613 kW
horn = 50 kW
target = 168 kW

decay tunnel

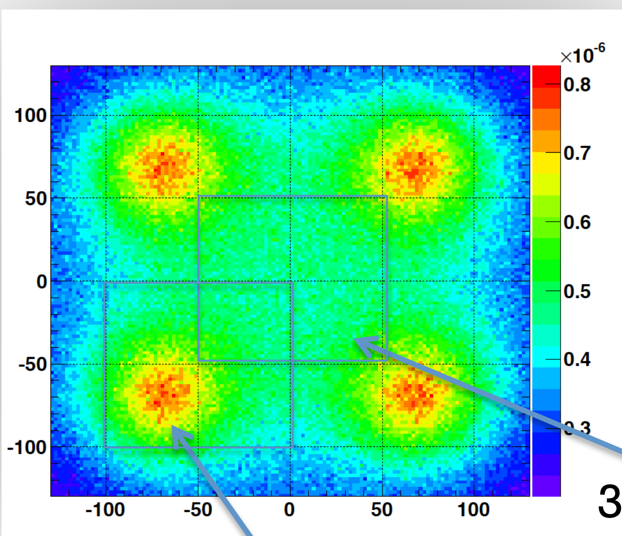
iron vessel = 424 kW
upstream iron = 670 kW
surr. concrete = 467 kW

FLUKA 2013, flair

Target Station and muons (2 GeV protons)



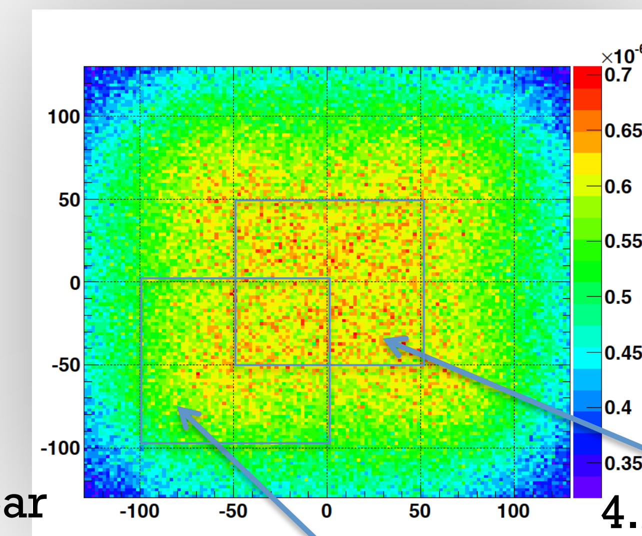
Distributions at the level of the beam dump



pions at the level of the beam dump (per year)

$3.5x10^{20}$ π/year

$3.7x10^{20}$ π/year

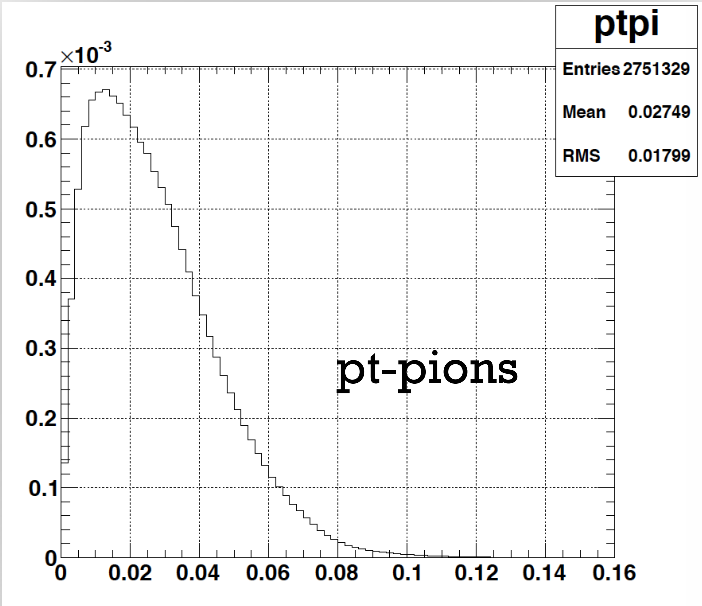


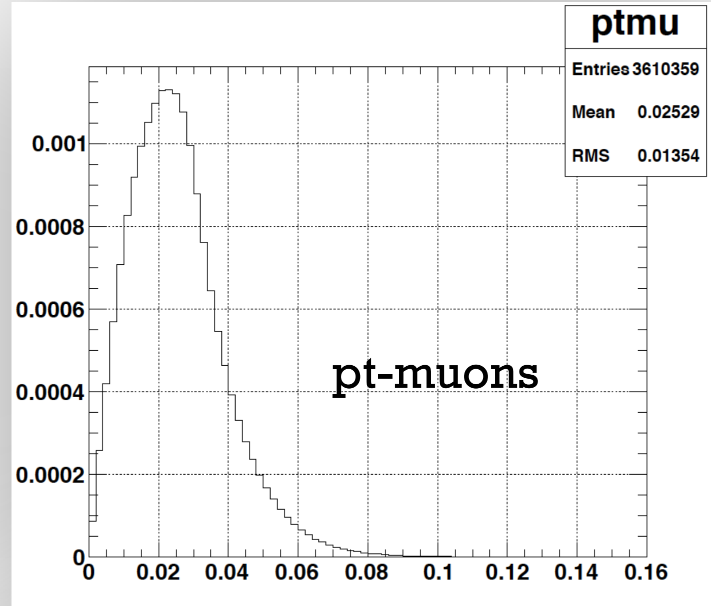
muons at the level of the beam dump (per proton)

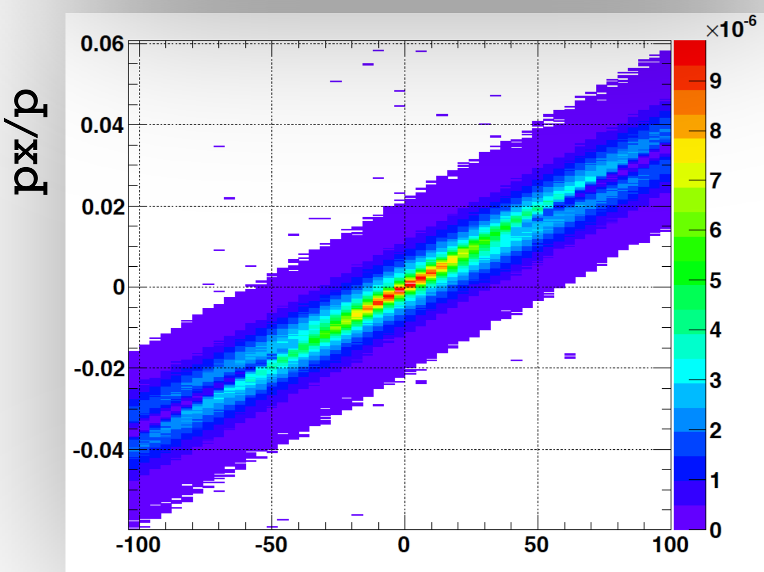
$4.2x10^{20}$ μ/year

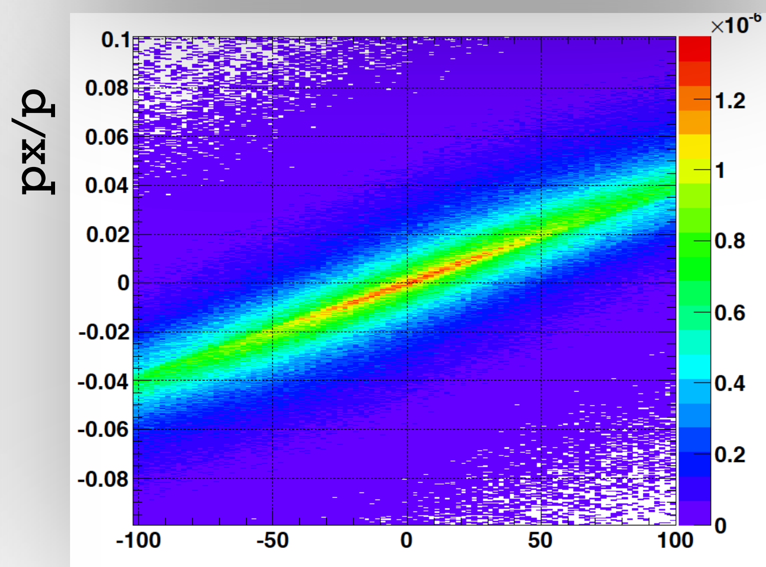
$4.1x10^{20}$ μ/year

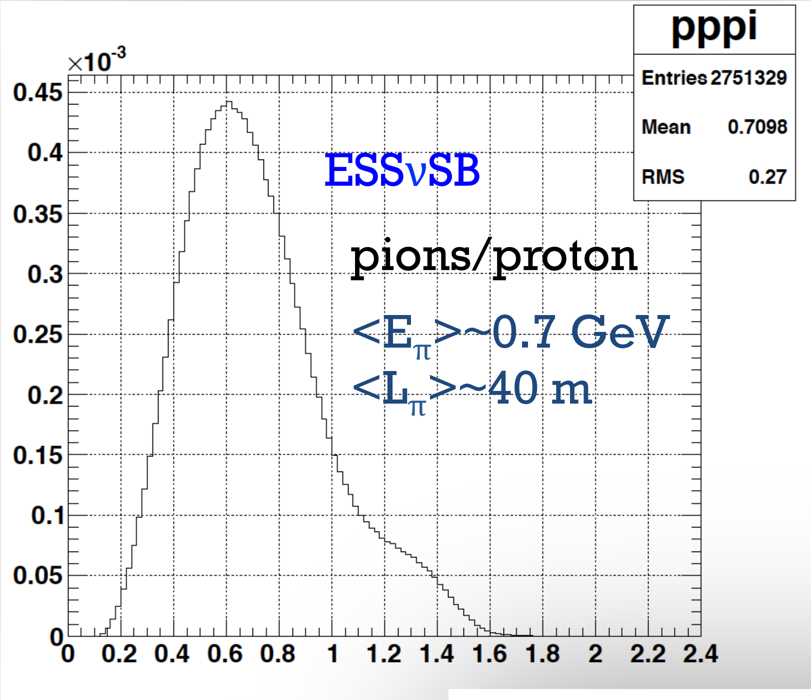
Distributions at the level of the beam dump

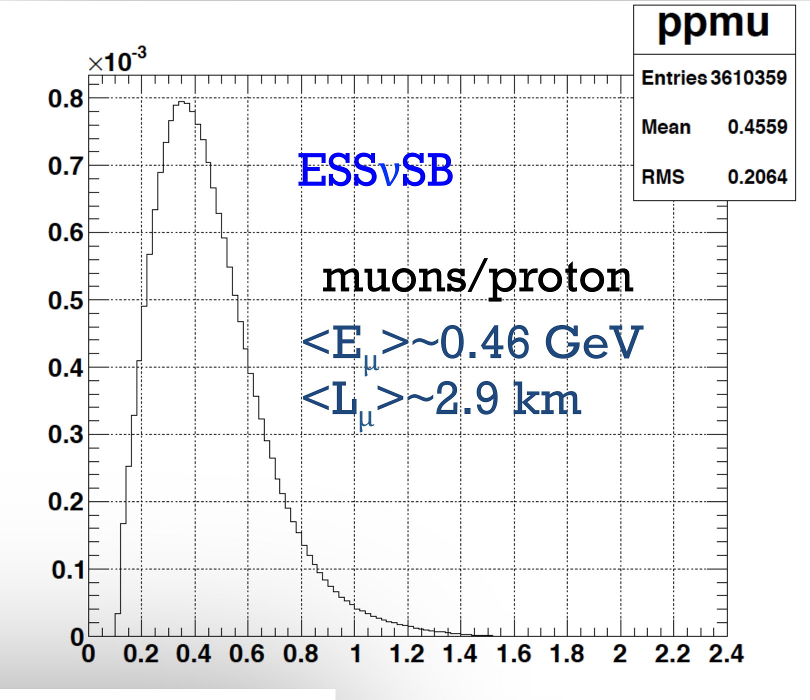


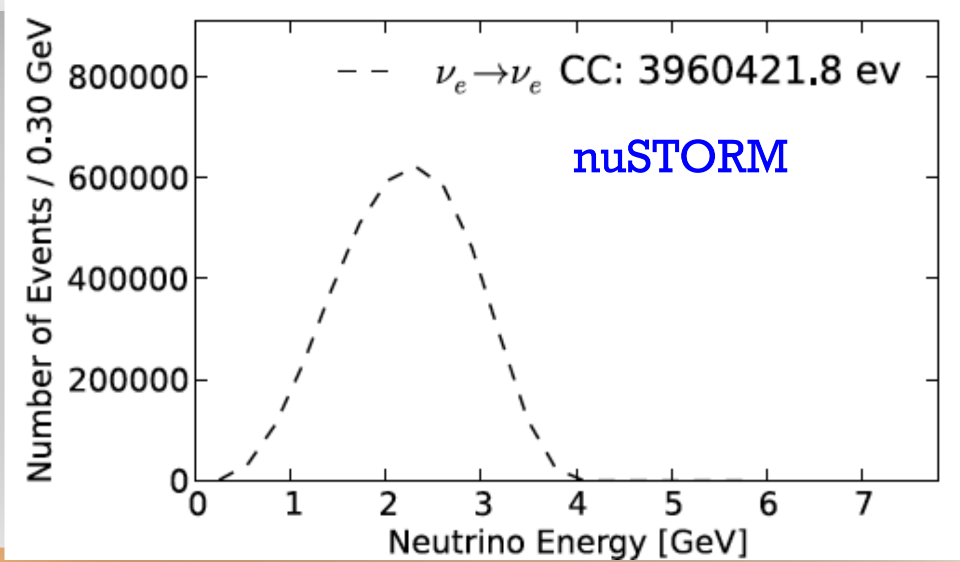






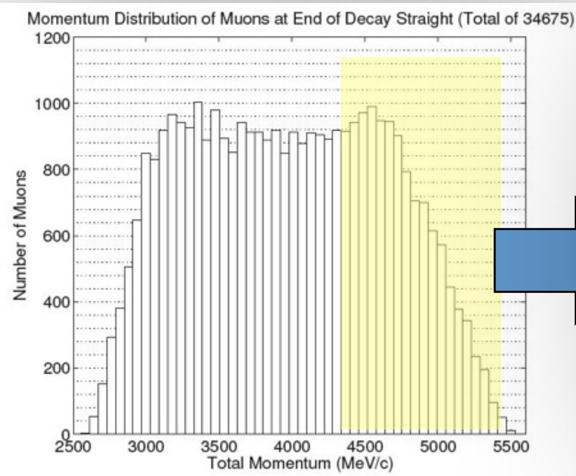


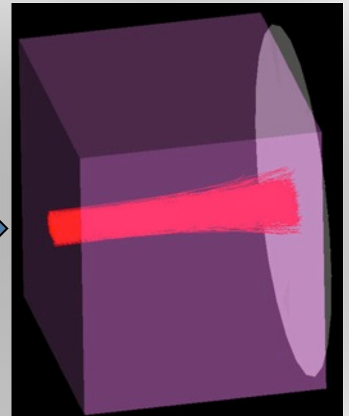


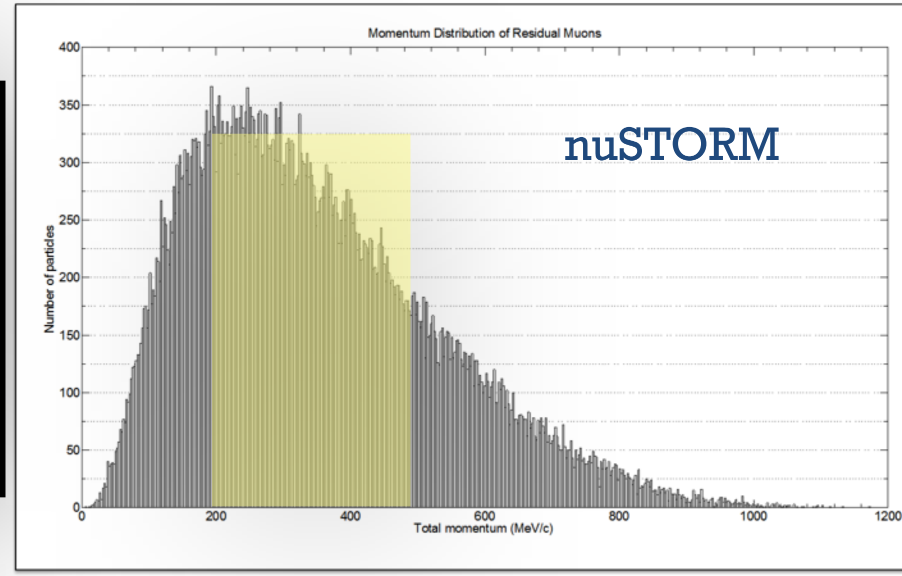


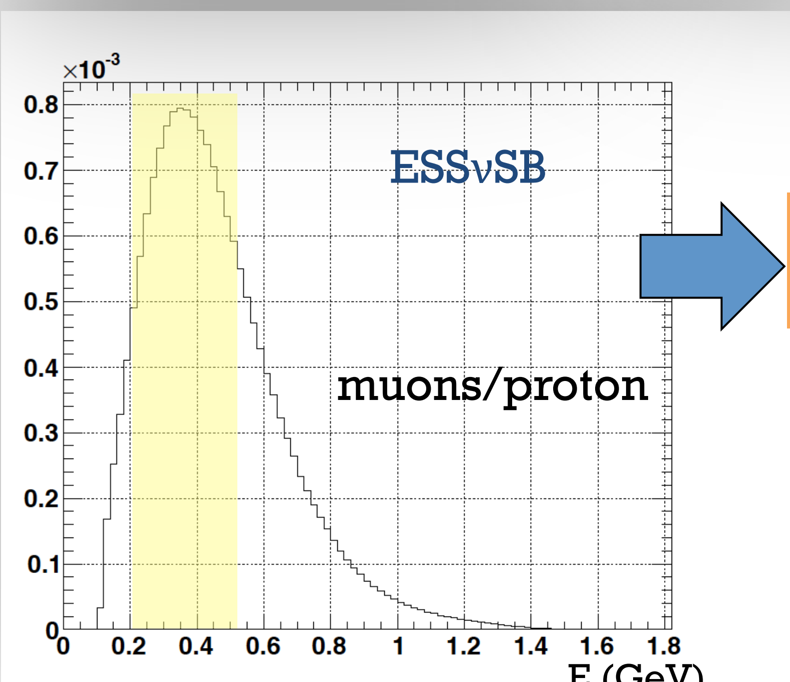
significantly lower energy than nuSTORM muons
good to measure neutrino x-sections around 200-300 MeV

Low energy muon beam









~10^{12} m/pulse in 200 < P(MeV/c) < 500 (for 1 m^2)
(2.6x10^{20} μ/year, at the level of the beam dump)

Input beam for future 6D m cooling experiments

Comments, future work

Packed-bed target:

- A CFD model of a packed bed target concept for 1MW beam power indicates the feasibility of such a target (EUROnu)
- Vibration levels and relative motion and wear between spheres is as yet an unknown: an in-beam test needed (HiRadMat at CERN ?)
- Induction heating offers potential for an offline test of the heat transfer and pressure drop characteristics of a packed bed design

C. Densham et al., RAL

Horn:

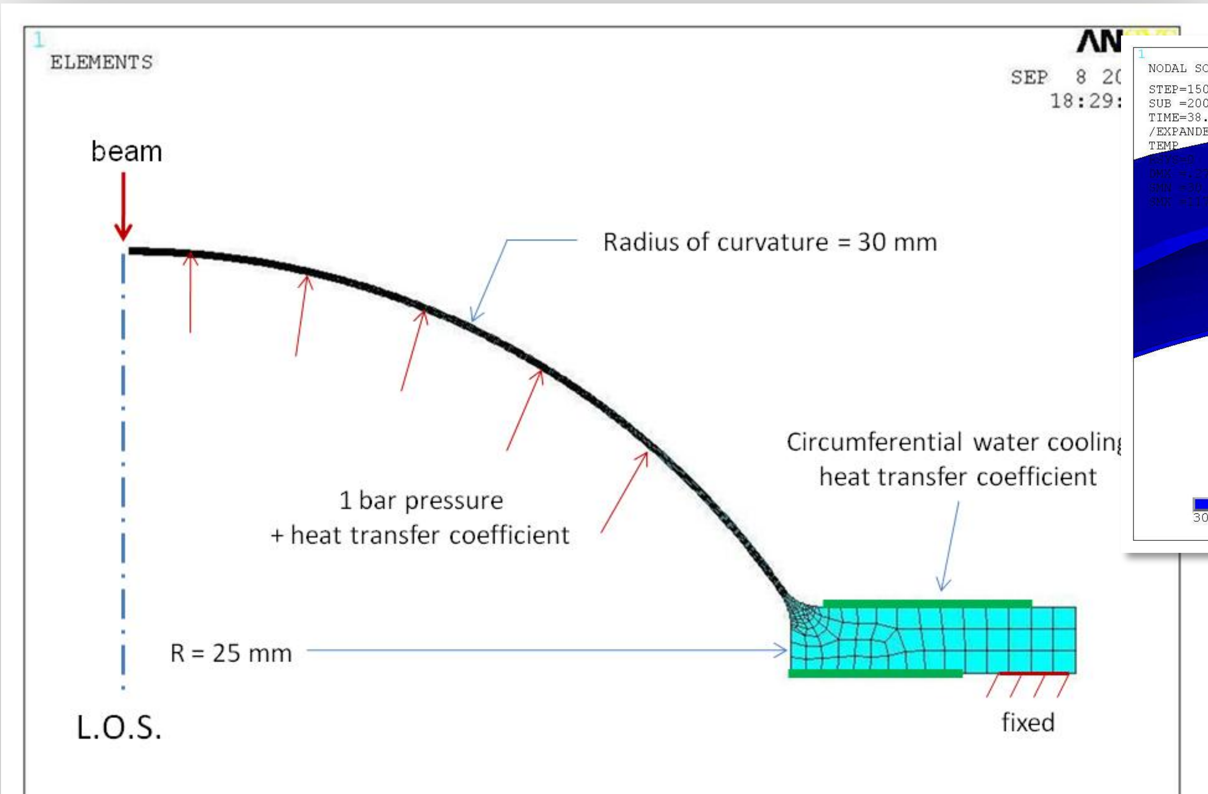
- "Too hard to die" in neutrino experiments. Preliminary fatigue studies (EUROnu) show horn's lifetime > 1 year (10^8) cycles. Further studies needed
- Achieving proper cooling is crucial for the horn's lifetime: tests needed for the existing design

PSU:

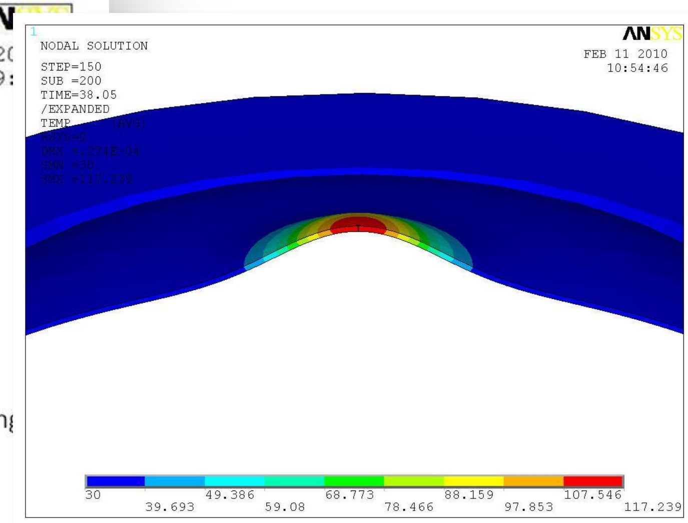
- Build and test a 4x44 kA module

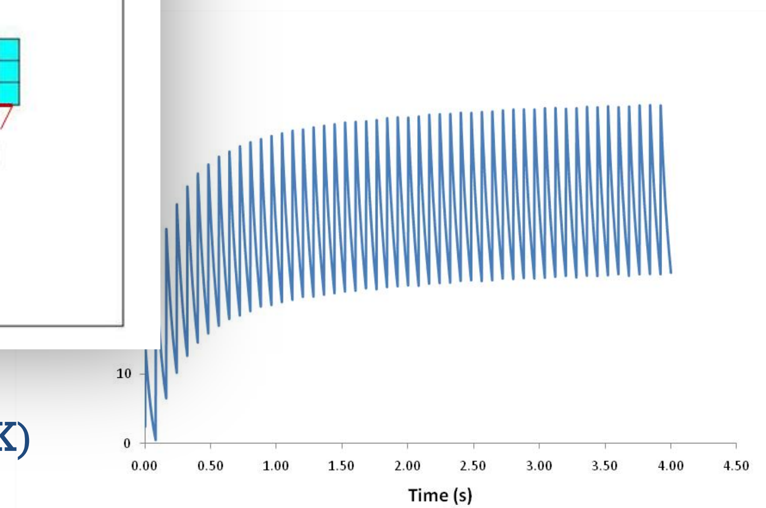
Muons could be used by a nuSTORM facility for low energy (< 500 MeV) neutrino cross-section measurements

Beam window



For SPL Super Beam MW





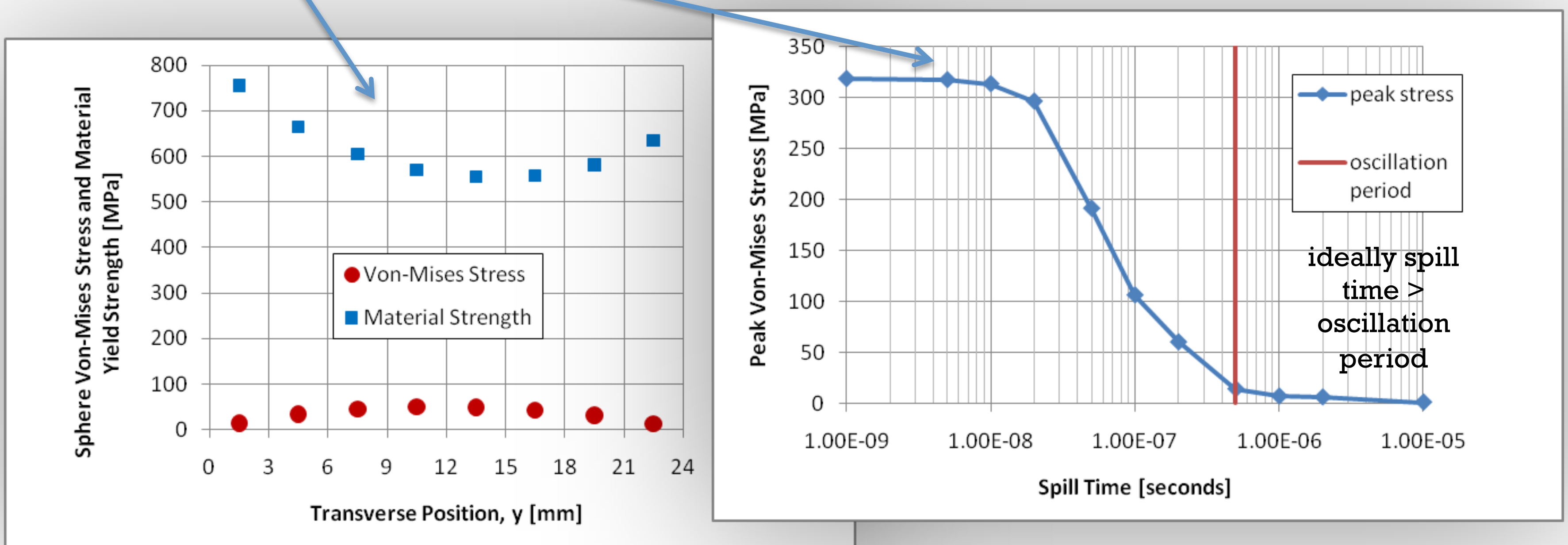
0.25 mm thick beryllium window
Circumferentially water cooled (assumes 2000 W/m^{2}K)
Max temp ~ 180 °C Max stress ~ 50 MPa
(109°C and 39 MPa using He cooling)

Matt Rooney/RAL

Stresses for the Packed bed target

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

- Quasi thermal and Inertial dynamic stress components

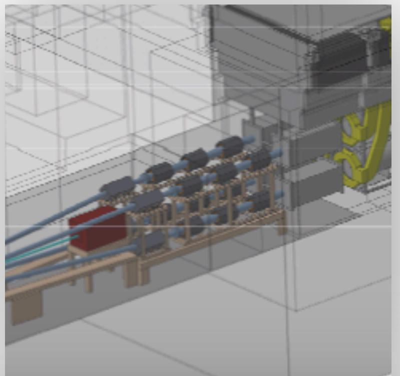


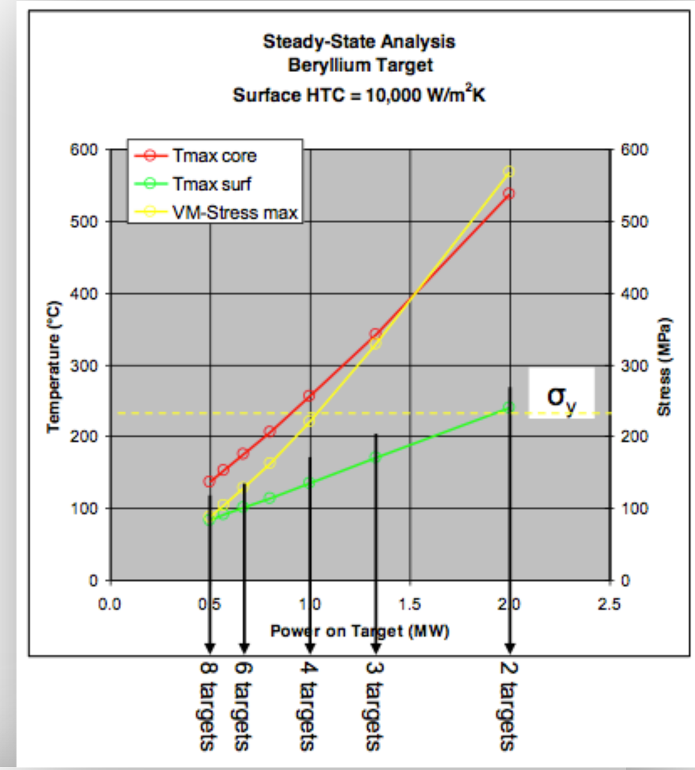
INPUTS					LIMITING FACTORS				
Beam Power	heat deposited	Sphere diameter	Helium pressure	Maximum Power Deposition	Maximum Helium Temperature	Sphere Core Temperature	Max Sphere VMStress	Minimum Yield Stress / VMStress	Pressure Drop
1MW	50kW	3mm	10bar	2.2e9W/m3	133°C	296°C	49MPa	11.7	0.45bar
1.3MW	65kW	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

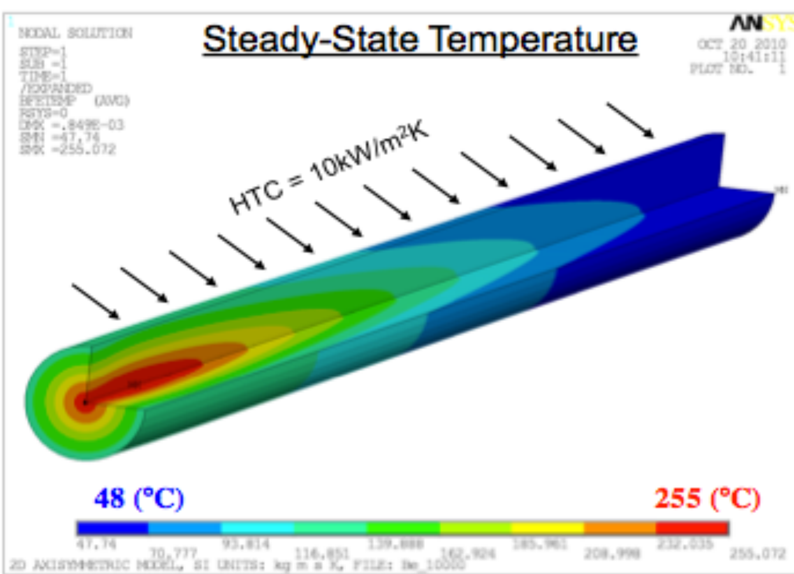
Davenne Tristan/RAL

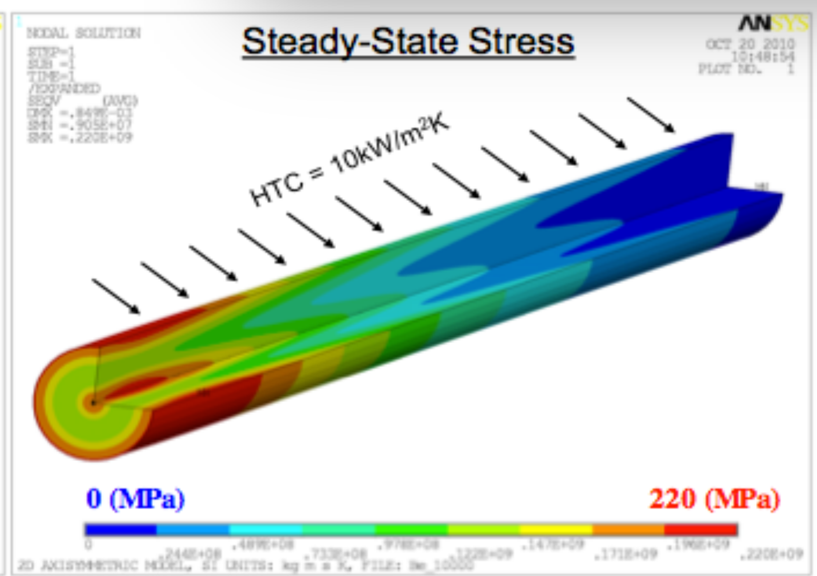
Be @ 4 MW

- Thermal stress depends on ΔT
  - Can not be overcome with more aggressive surface cooling
- Break the 4 MW to 4 x 1 MW targets

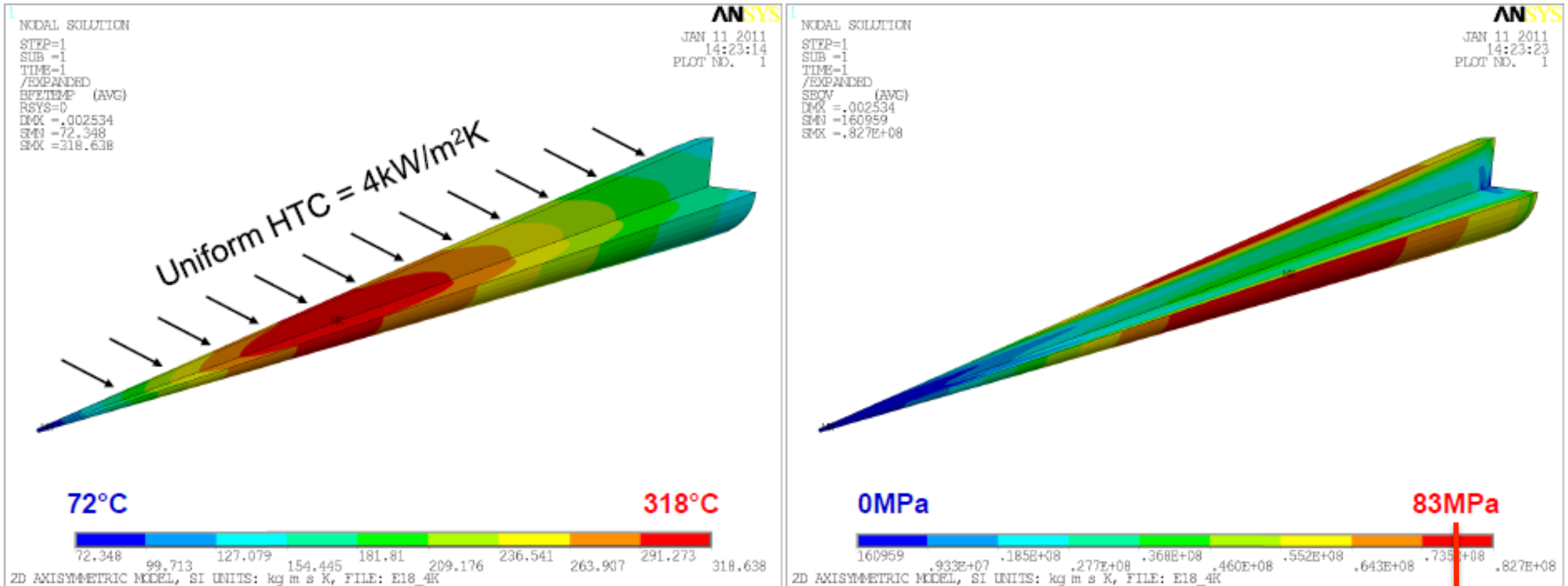






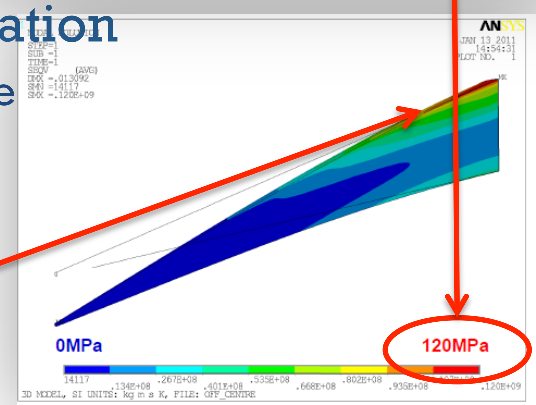


Alternative solution: pencil "closed" Be Solid target

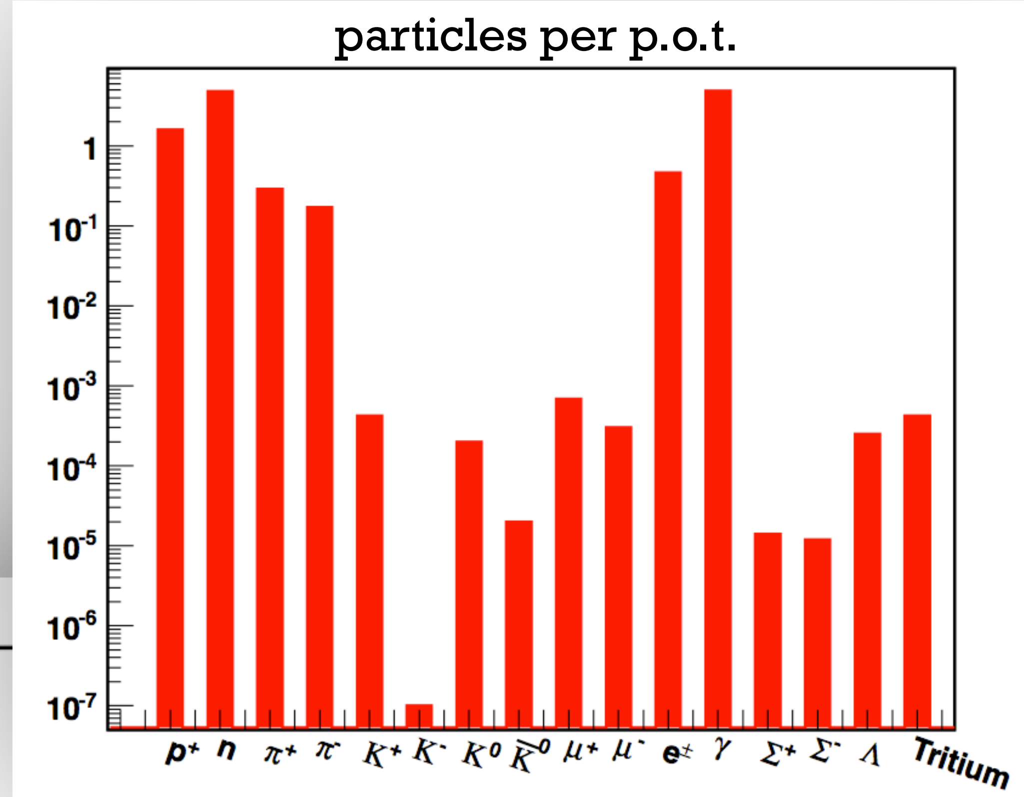


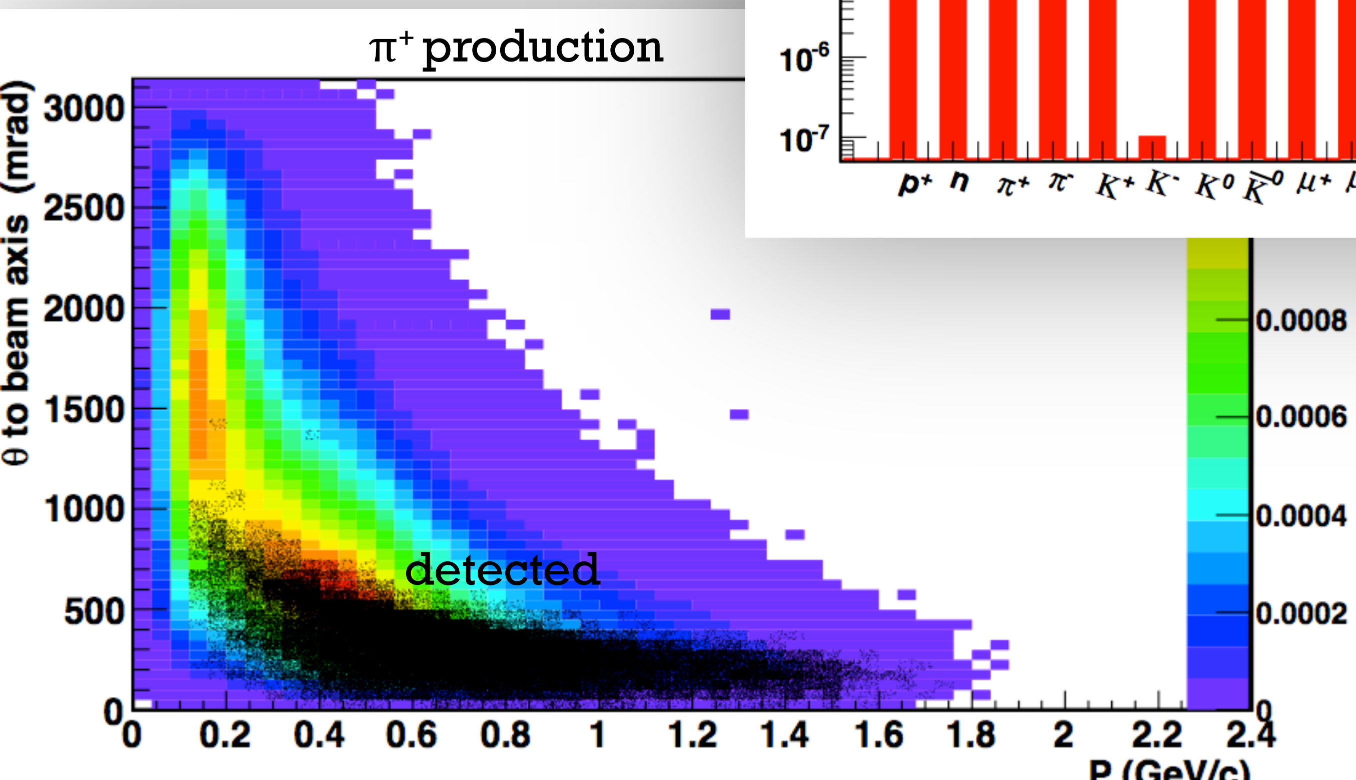
Temperature (left) and Von-Mises thermal stress (right) corresponding to a steady state operation with a surface HTC = 4kW/m²K, bulk fluid temp = 30°C

- 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



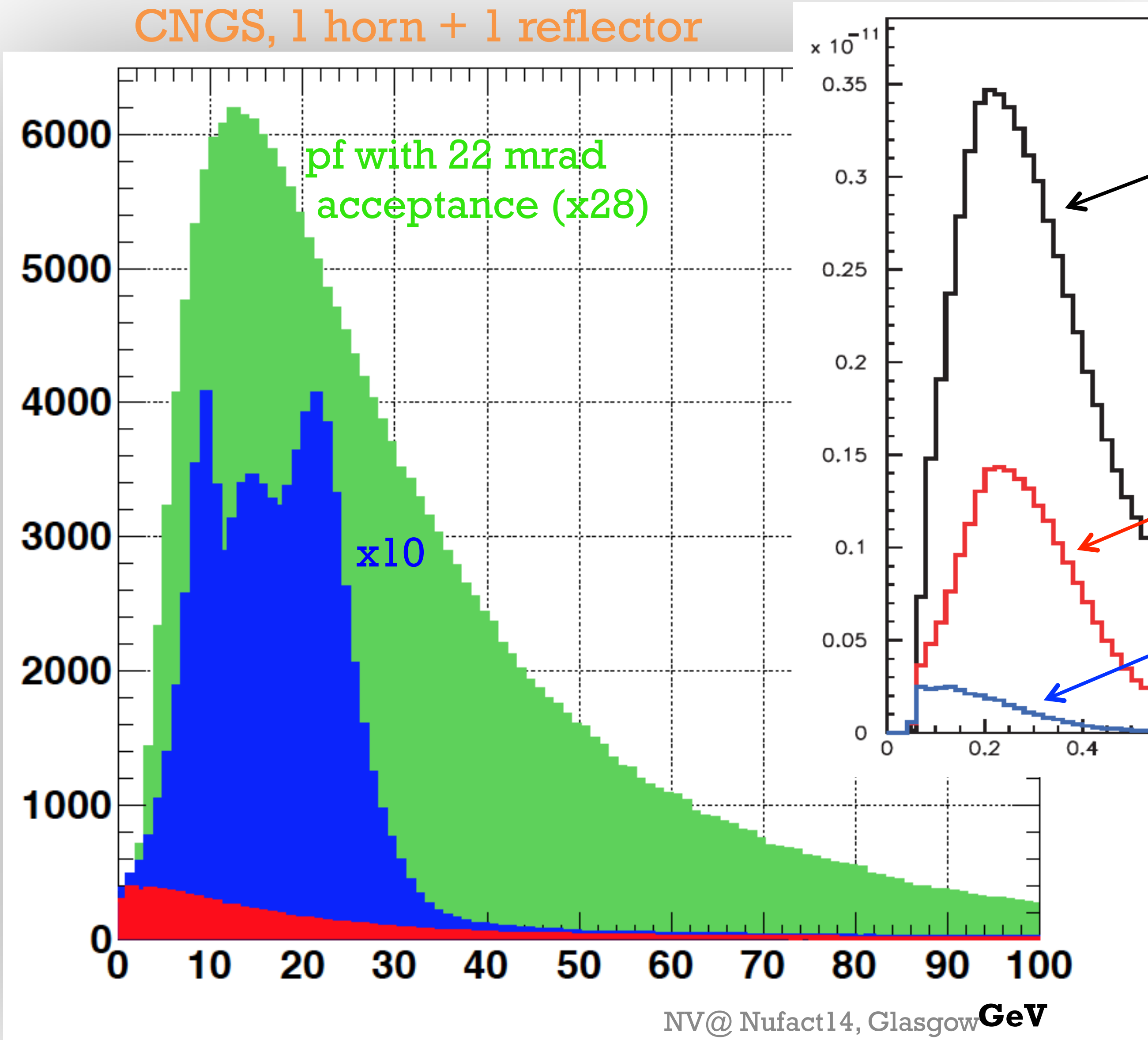
ESSνSB target: particle production

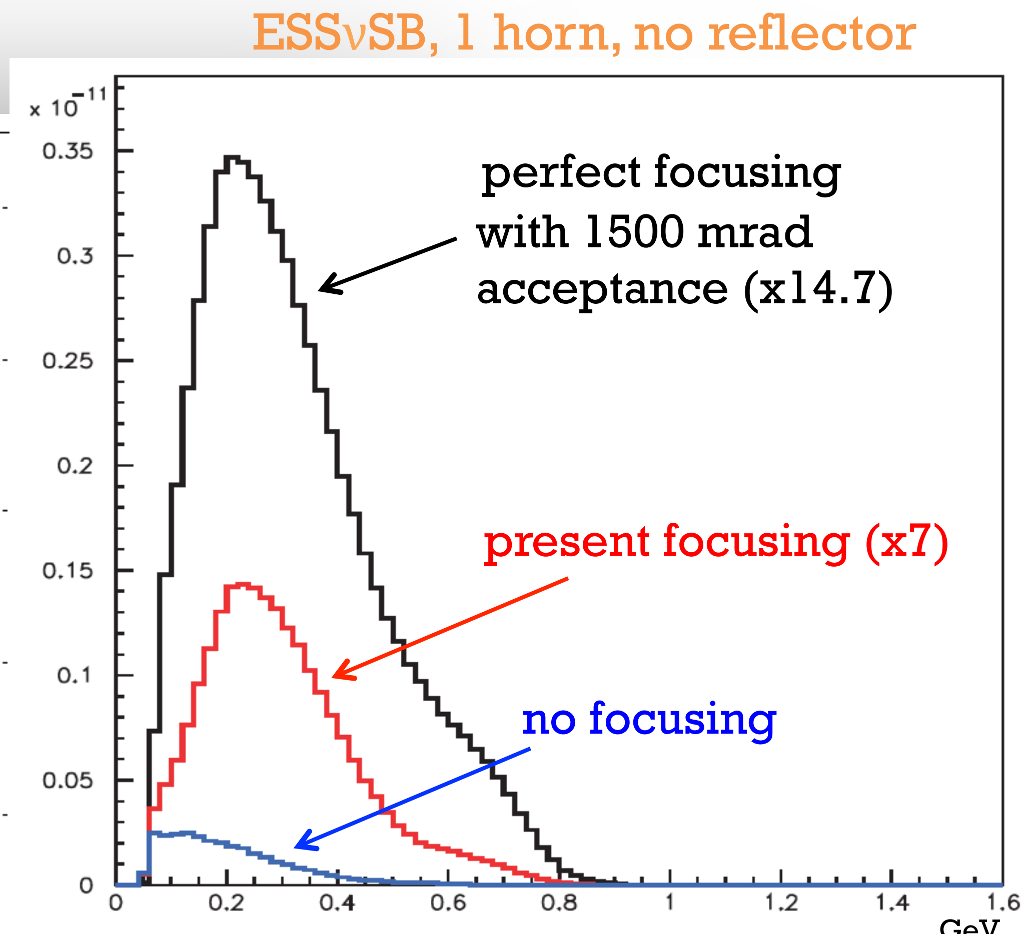




FLUKA 2014

Perfect focusing vs nf vs focus



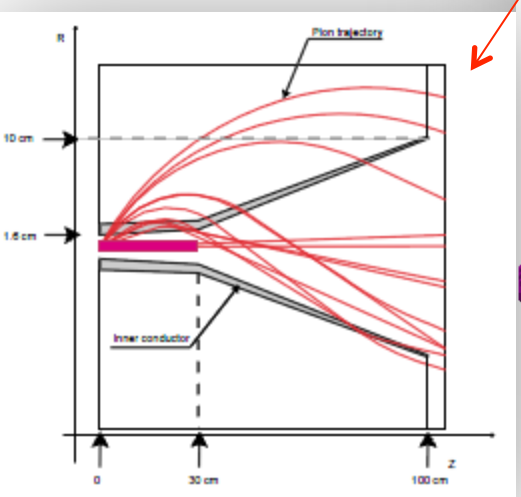


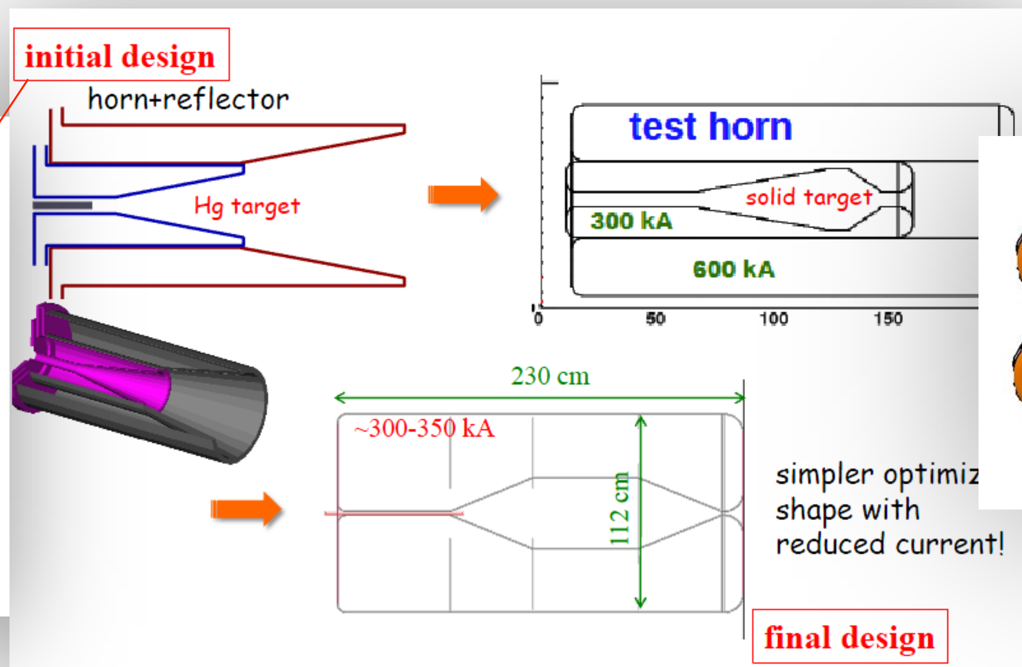
Horn evolution

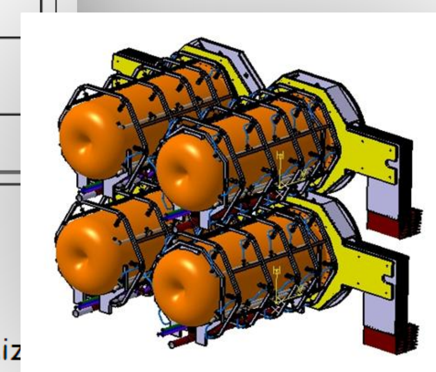
details in WP2 notes @ http://www.euronu.org/

Evolution of the horn shape after many studies:

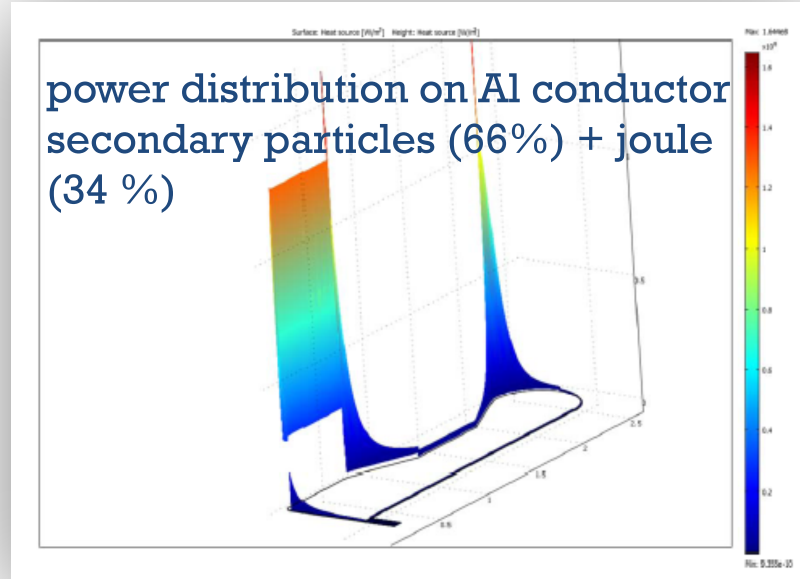
- Triangle shape (van der Meer) with target inside the horn: in general best configuration for low energy beams
- Triangle with integrated target to the upstream inner conductor part: very good physics results but high energy deposition and stresses on the conductors
- Forward-closed with integrated target: best physics results, best rejection of wrong sign mesons but high energy deposition and stresses
- Forward-closed with target inside the horn: best compromise between physics and reliability
- 4-horn/target system to accommodate the MW power scale

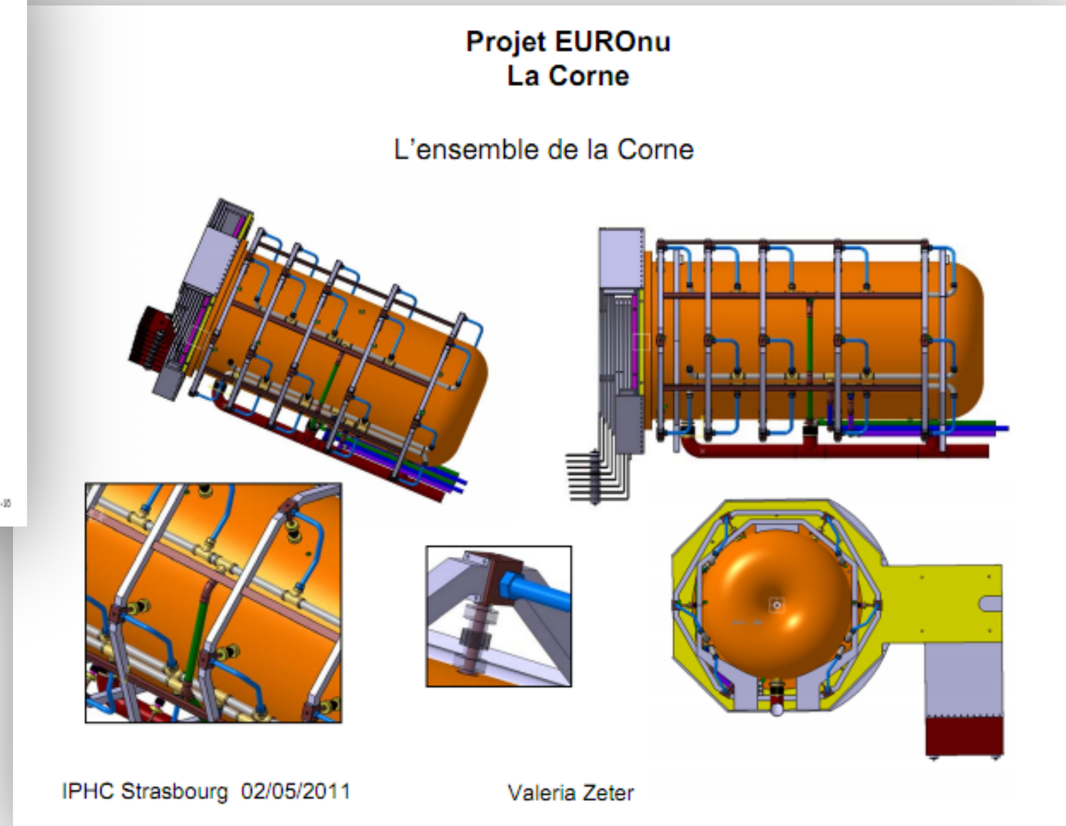






Horn cooling, EUROnu





cooling system

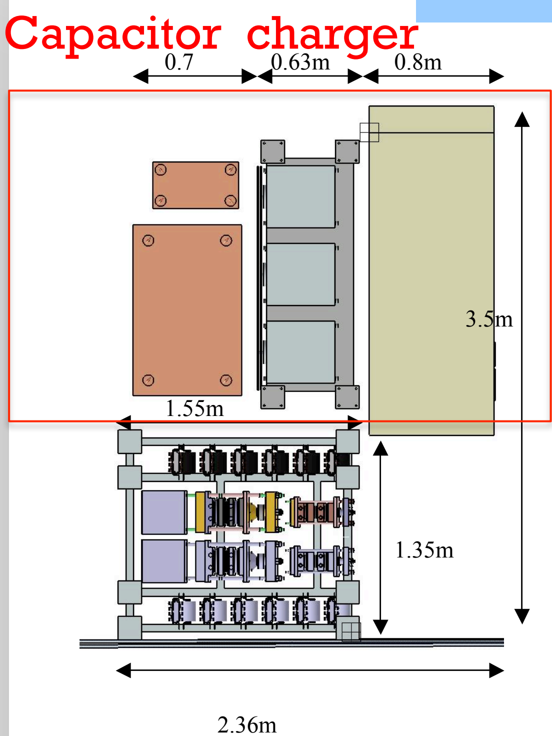
- Planar and/or elliptical water jets
- 30 jets/horn, 5 systems of 6-jets longitudinally distributed every 60^0
- Flow rate between 60-120l/min, heat cooling coefficient 1-7 $kW/(m^2K)$
- Longitudinal repartition of the jets follows the energy density deposition
- $\{h_{corner}, h_{horn}, h_{inner}, h_{convex}\} = \{3.8, 1, 6.5, 0.1\}$ $kW/(m^2K)$ for $T_{Al\text{-}max} = 60\ {}^0C$

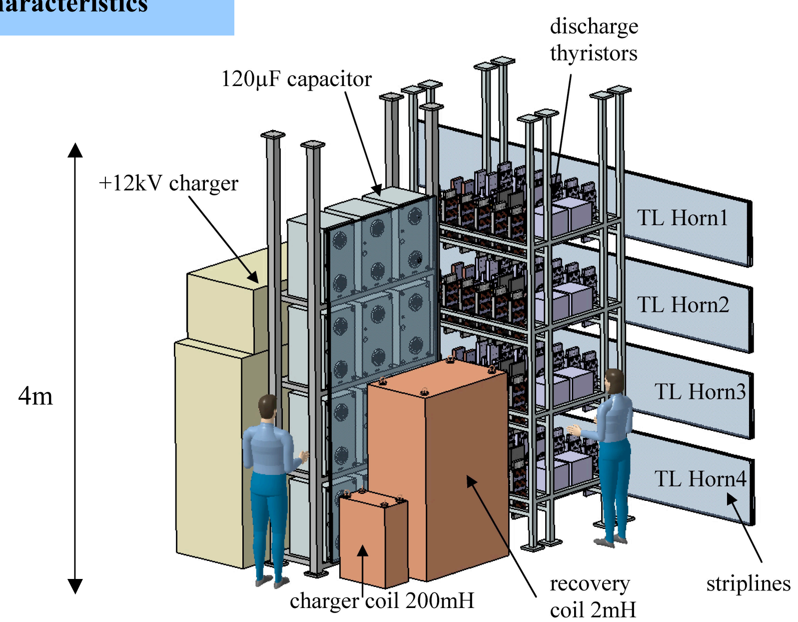
4x44 kA module

APC-Paris-12-15 June 2012

4X44kA PSU Module:
Mechanicals characteristics

PSU Design for 4 Horns/EUROv-WP2





Pulse power Supply 44kA	Dimensions, m widthX heightX depth	Weight ,KG
discharge switches	1.55X4X1.35	1600
recovery coil	0.7X1.7X1.1	2200
charge coil	0.55X0.3X0.75	190
capacitors	0.63X4X1.73	1700
charger	0.8X2.53X2.1	2400
supports		300
TOTAL	2.5X4X3.5	8400

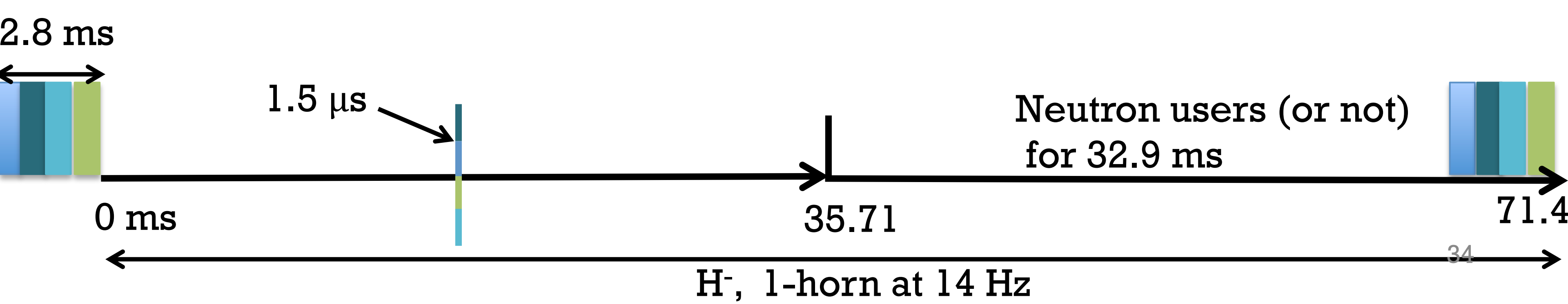
CNRS-IPHC Pascal POUSSOT

8

2.a) 4-rings, ν at 14 Hz-simultaneously

<u>EUROnu modifications</u>

Capacitor charger	Area PSU	Power consumption	Cost
4 x 14 Hz	x 1.7	x 1	x 2.5



2.b) 4-rings, ν at 14 Hz-simultaneously, 4-horns chained in series, transformer

EUROnu modifications

Capacitor charger	Area PSU	Power consumption	Cost	Remarks
1 x 14 Hz	x 1.2	x 8	x 2.6	transformer to reduce C
				lower recovery eff.
				1 horn fails-all stop