Target station and optimization studies for ESS Super Beam

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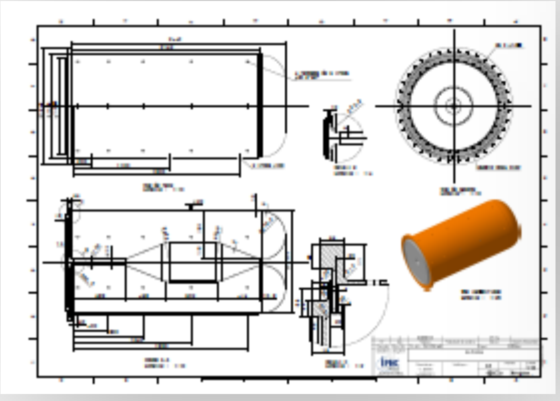
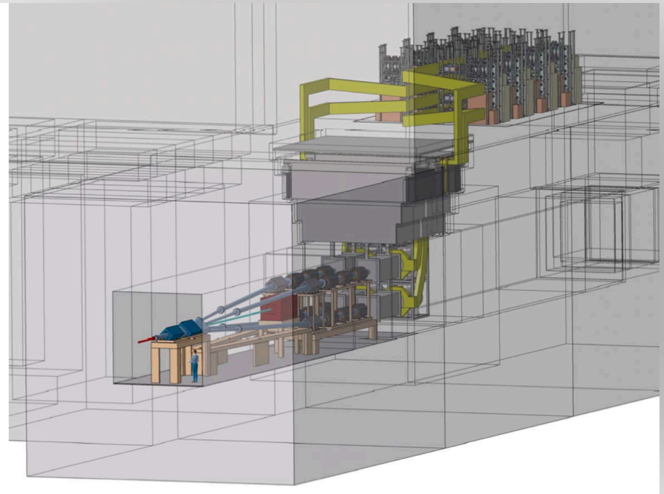
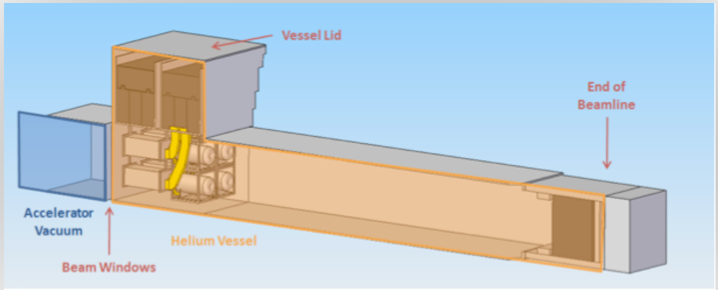
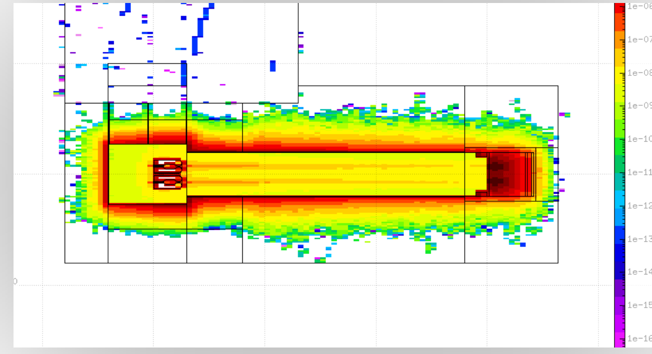






layout



- Target station description
- Target
- Horn

Studies on physics potential (sys. errors 5 % signal, 10% background, mass hierarchy assumed not known)

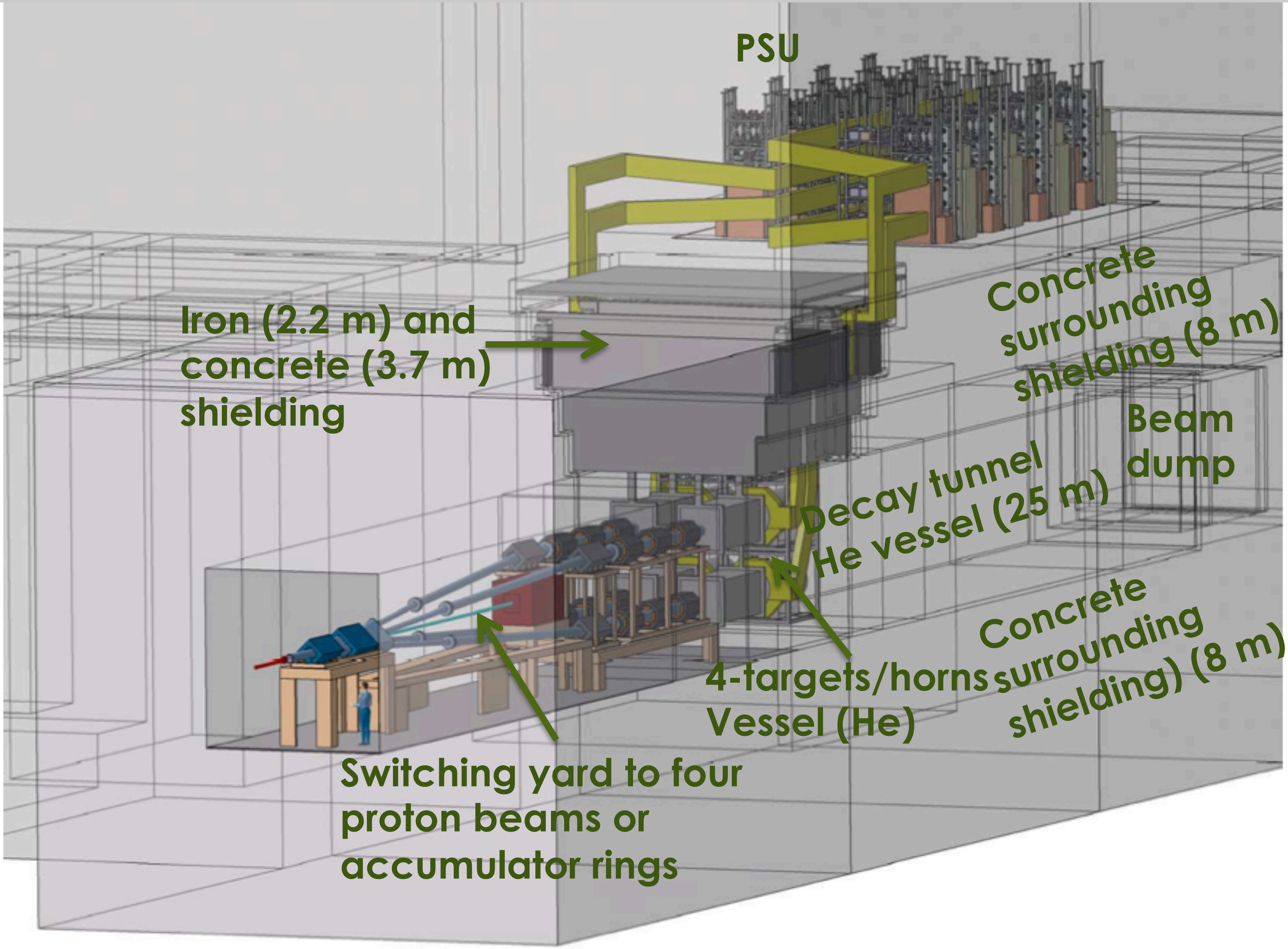
- Proton beam energy
- Horn’s current
- Target and decay tunnel length

also

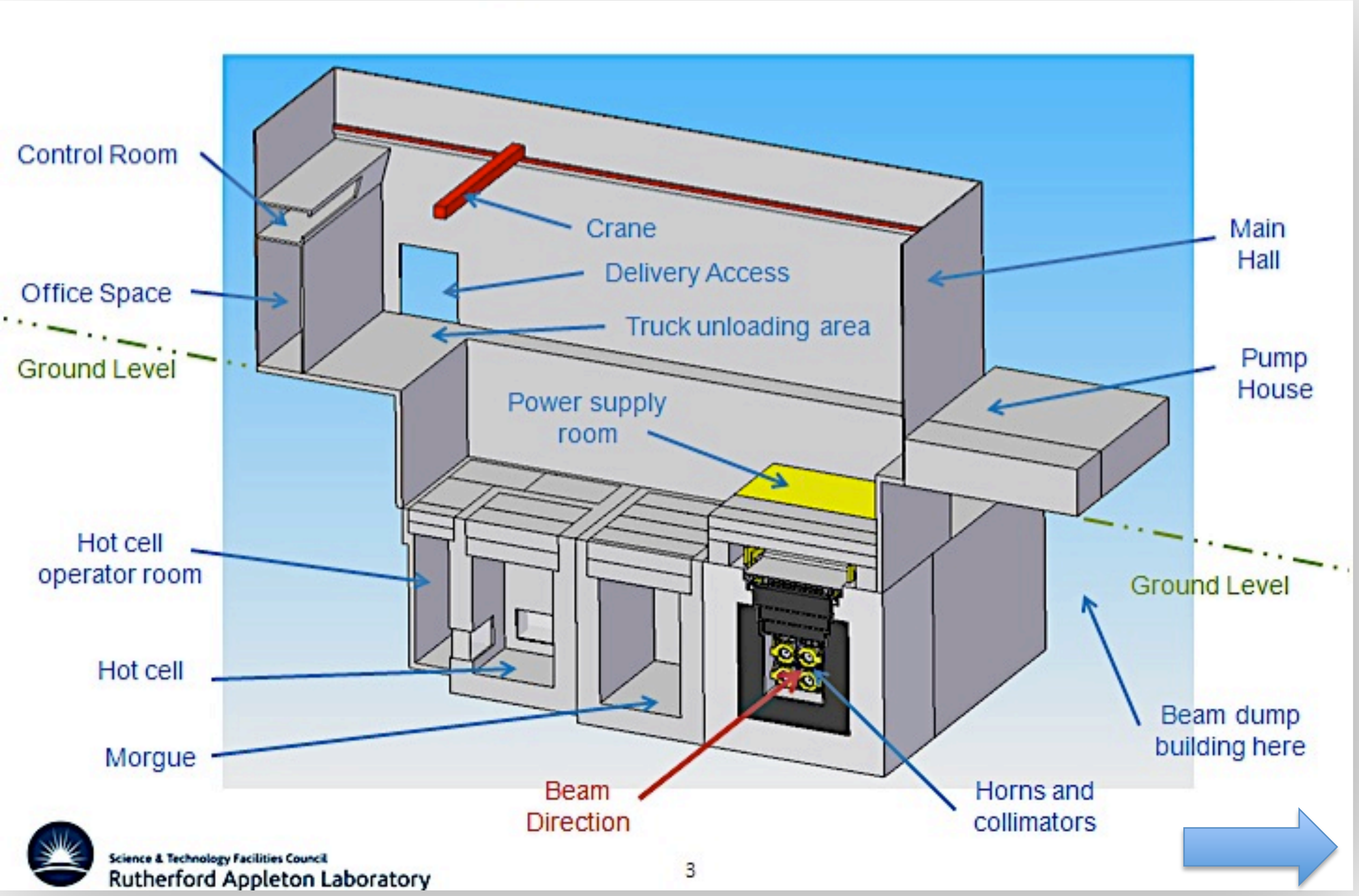
- Particle yield
- Perfect focusing vs horn’s focusing vs no focusing
- Energy deposition, radiation (neutrons), muons (near detector location)

Thanks to
Chris Densham and his team for the target studies et
Enrique Fernandez for the globes calculations and his input on results

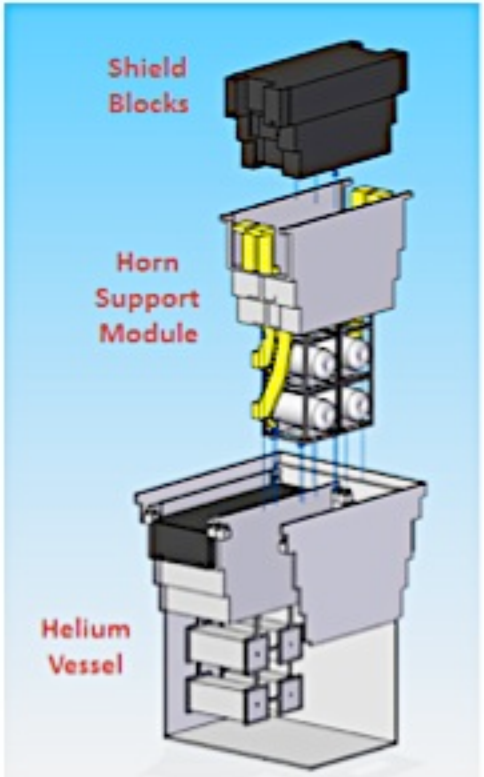
ESS Super beam layout
(adopted from SPL Super Beam - EUROnu)



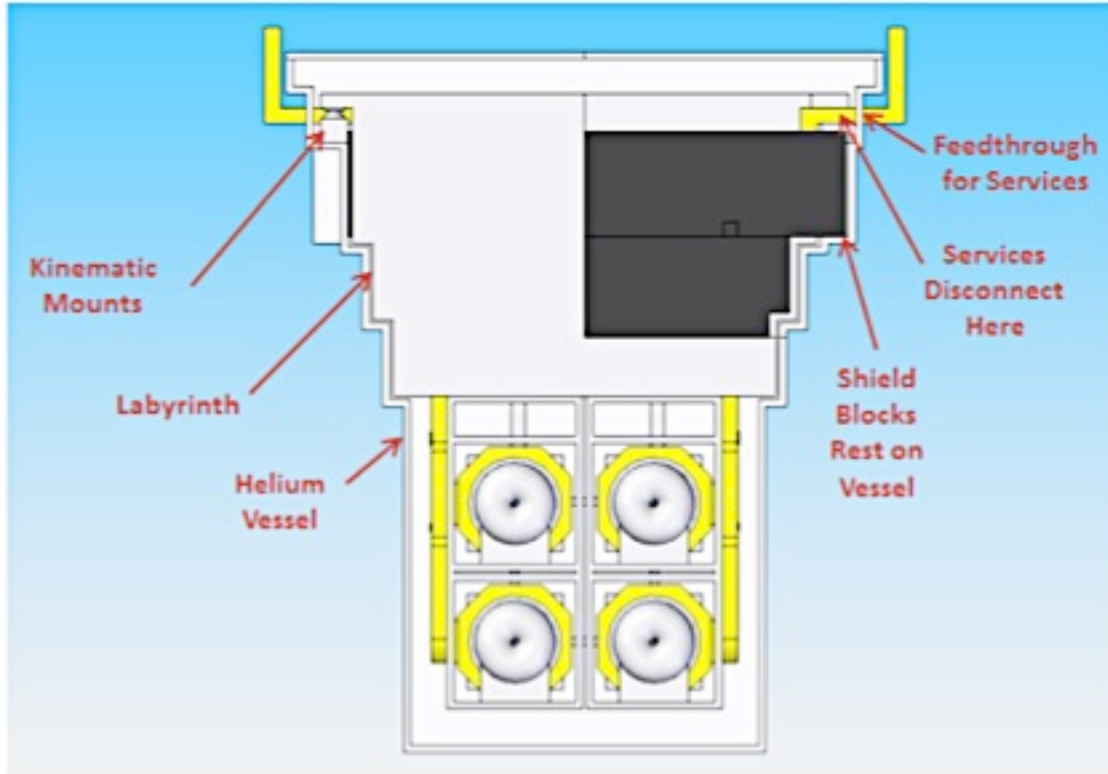
Super beam Four-horn/target station



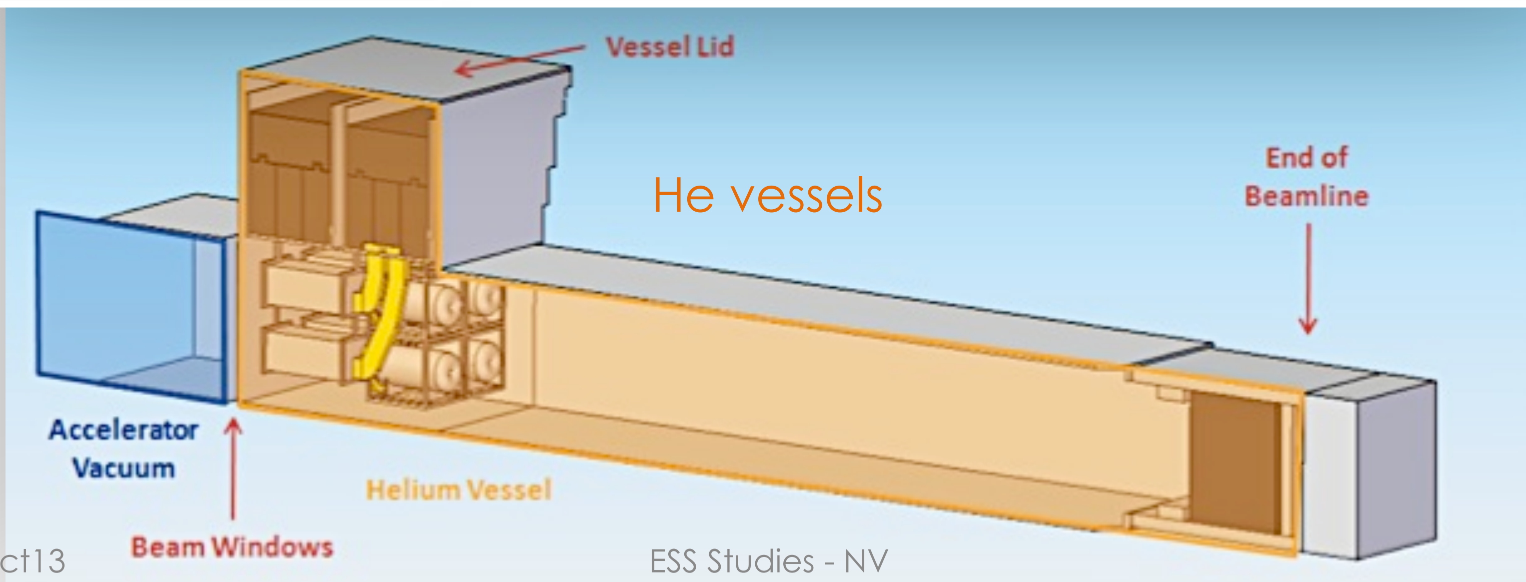
He vessels



Shield Blocks
Horn Support Module
Helium Vessel



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

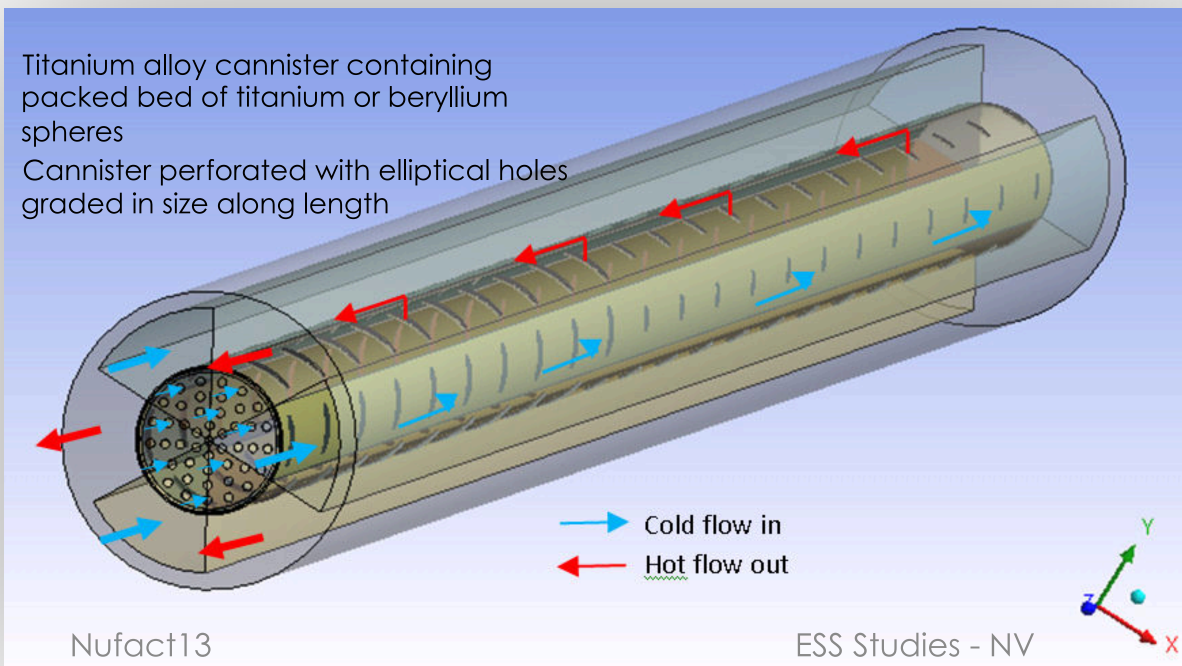


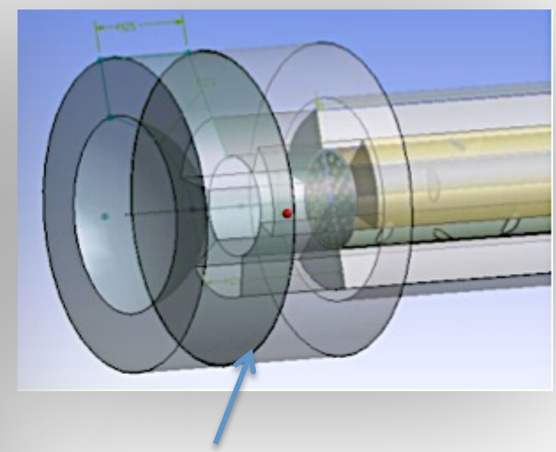
Vessel Lid
End of Beamline
Accelerator Vacuum
Helium Vessel
Beam Windows

Target: packed bed

- Large surface area for heat transfer
- Coolant able to access areas with highest energy deposition
- Potential heat removal rates at the hundreds of kW level
- Pressurised cooling gas required at high power levels
- Minimal stresses
- Tests of such a target are planned using the HiRadMat high intensity proton irradiation facility at CERN
- Full study in EUROnu.org, arXiv:1212.0732 (SPL super beam)

- Titanium alloy cannister containing packed bed of titanium or beryllium spheres
- Cannister perforated with elliptical holes graded in size along length



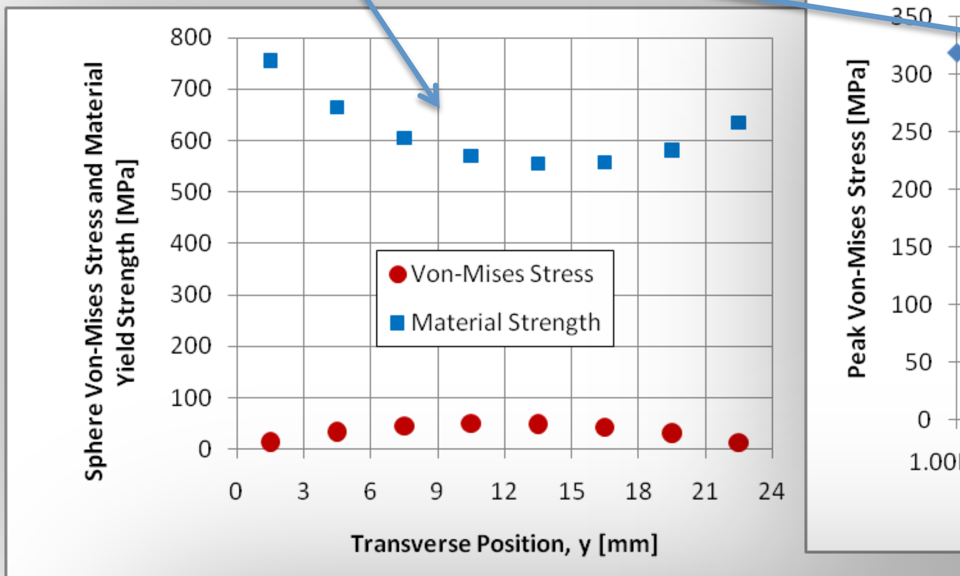


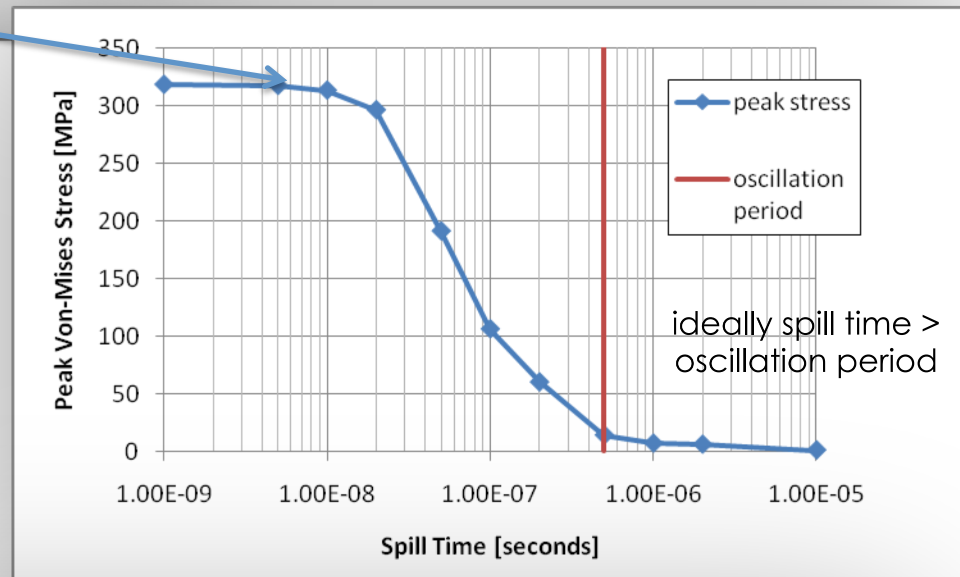
- Beam window, Be is a candidate
- Pressure stresses can be dealt by having a hemispherical window design
- Separation from target station coolant

Stresses for the Packed bed target

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

- Quasi thermal and Inertial dynamic stress components





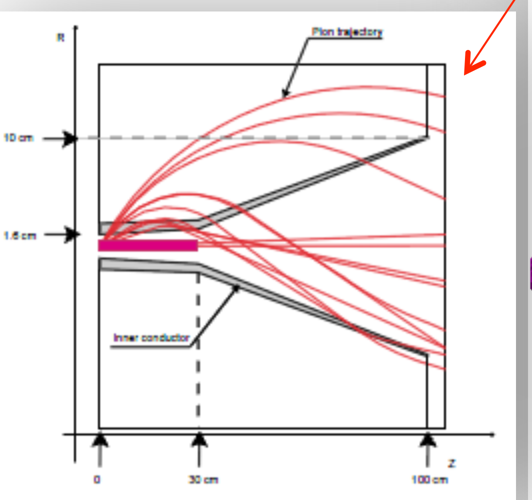
INPUTS					LIMITING FACTORS				
Beam Power	heat deposited	Sphere diameter	Helium pressure	Maximum Power Deposition	Maximum Helium Temperature	Sphere Core Temperature	Max Sphere VMStress	Minimum Yield Stress / VMStress	Pressure Drop
1MW	50kW	3mm	10bar	2.2e9W/m3	133°C	296°C	49MPa	11.7	0.45bar
1.3MW	65kW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

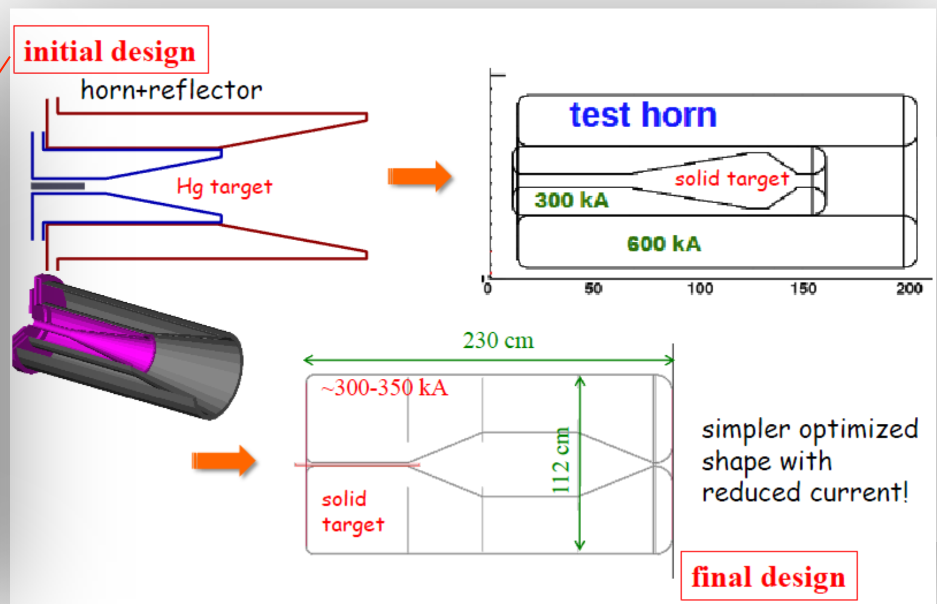
Horn evolution

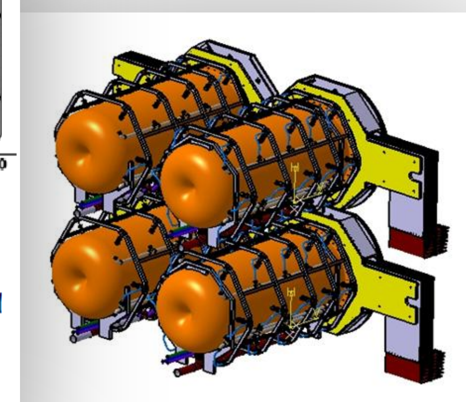
details in WP2 notes @ http://www.euronu.org/

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



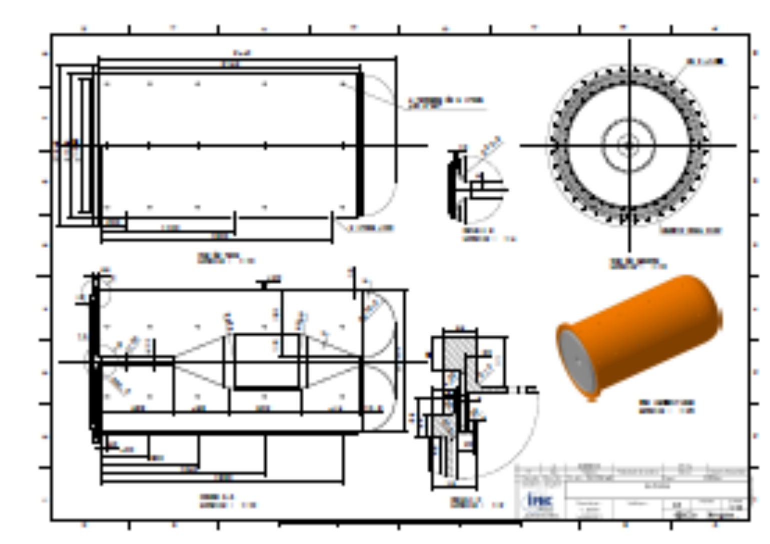


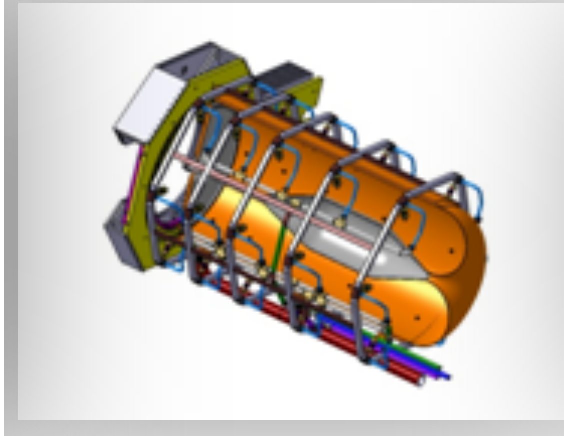


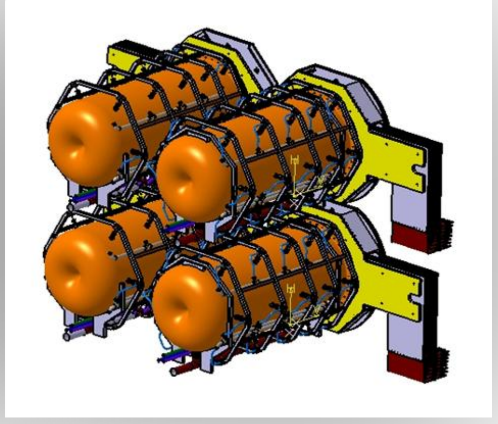
Horn studies

- 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
  - Horn lifetime at least 1 year from fatigue analysis (30 – 60 MPa max stress depending on HTCs)
  - 60 water jets for cooling

Full study in EUROnu, arXiv:1212.0732







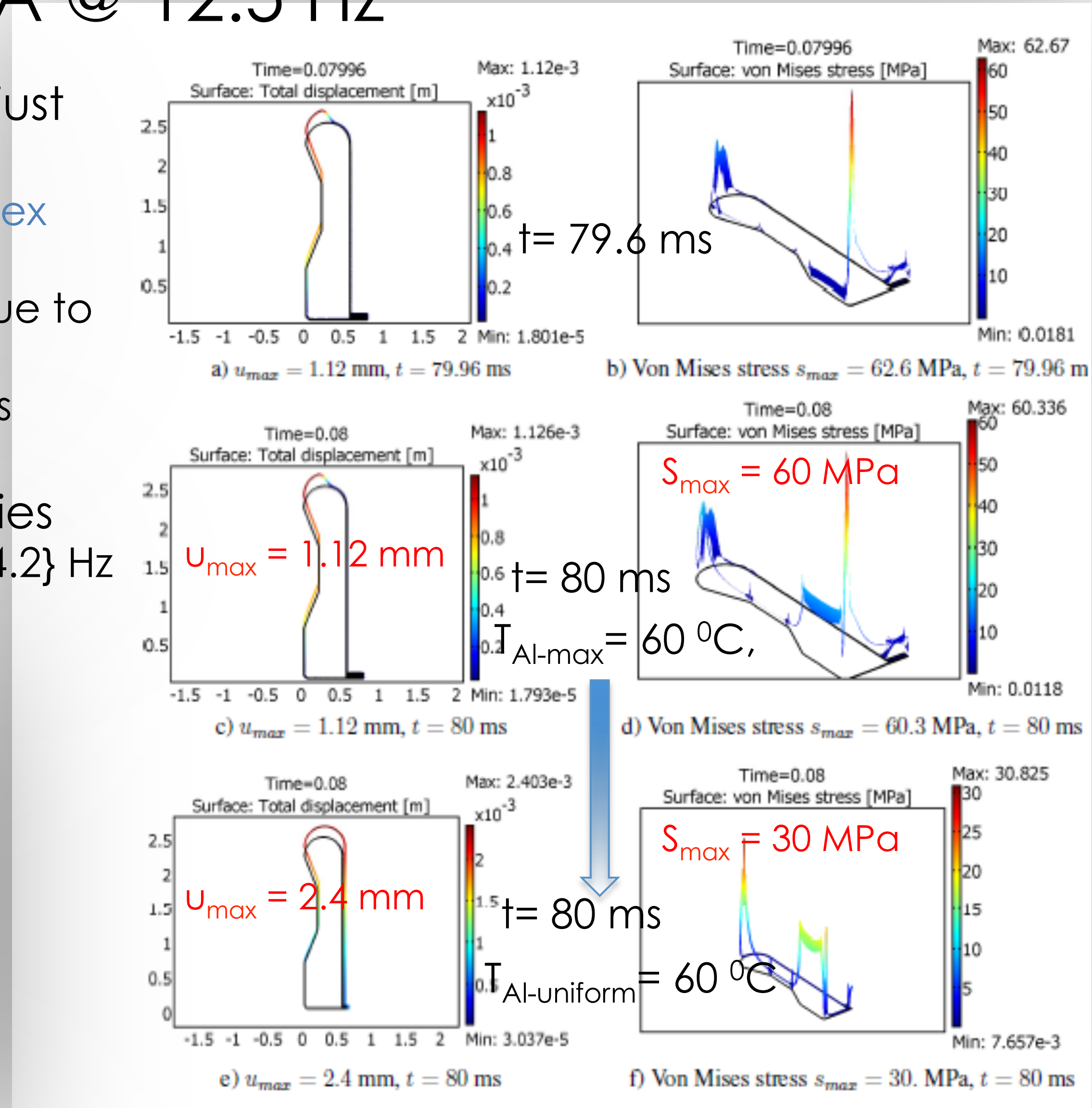
Stress due to thermal dilatation and magnetic pressure for 350 kA @ 12.5 Hz

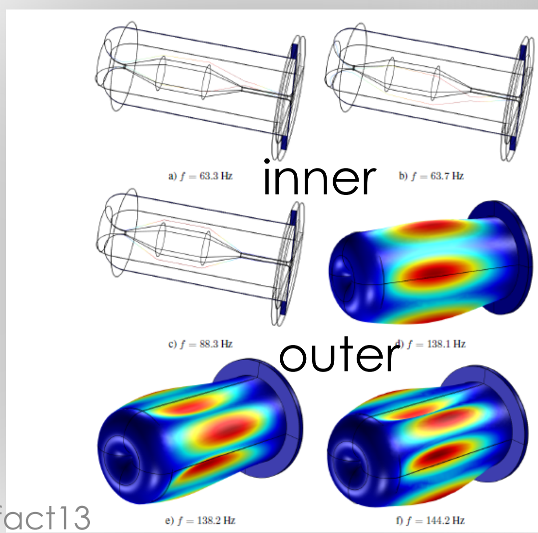
displacements and stress plots just before and on the peak

- stress on the corner and convex region
- stress on the upstream inner due to pulse
- uniform temperature minimizes stress, max = 30 MPa

modal analysis, eigenfrequencies

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





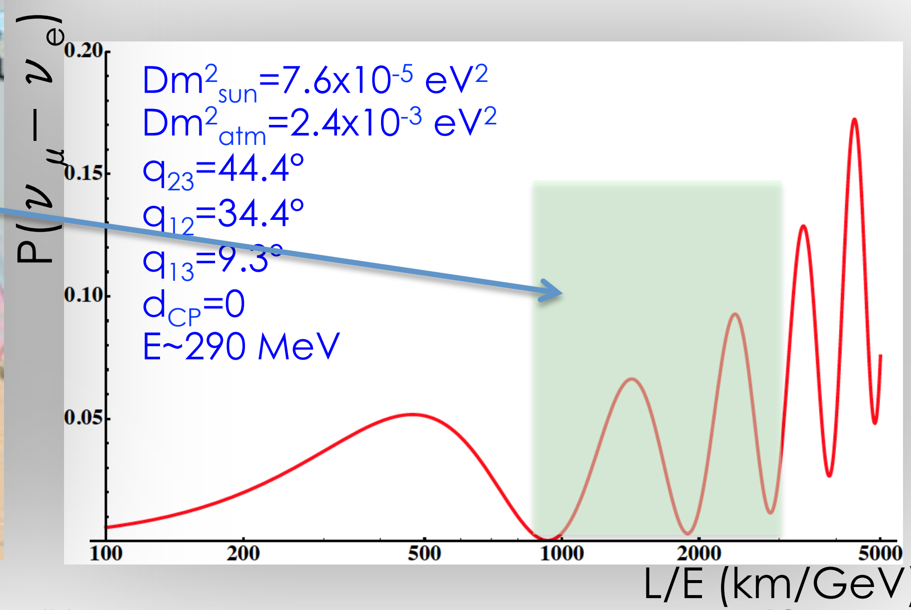
peak magnetic field each T=80ms (4-horns operation)

Are the adopted SPL Super Beam parameters fit well the ESS case ?

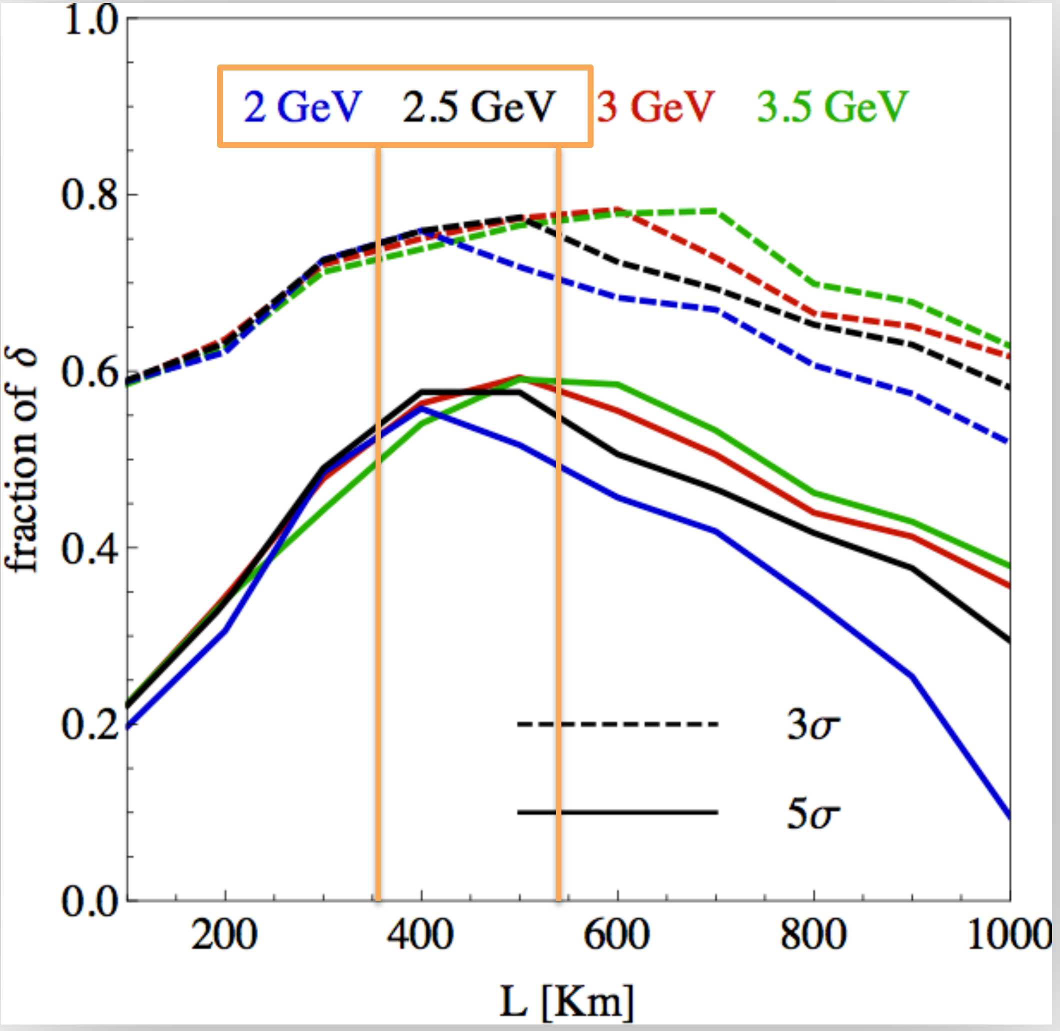
Parameter	SPL	ESS
Power (MW)	4	5
E_{p+} (GeV)	4.5	2, 2.5
Baseline (km)	130	365, 540
Target	Packed-bed	Packed-bed
Target length (cm)	78	53-78
Target radii (cm)	1.5	1.5
Horn	Forward closed	Forward closed
Horn current (kA)	350 @ 12.5 Hz	350 @ 14 Hz
# of horns/targets	4	4
Tunnel length (m)	25	15-25
Tunnel radii (m)	2	2
Exposure (years)	2 ν + 8 anti-ν	2 ν + 8 anti-ν

Reminder: collection of possible detector locations in Sweden

- Many mines (active or not) are available
- What is the optimal position for CPV?
- MH might be discovered at 5σ with including atmospheric ν



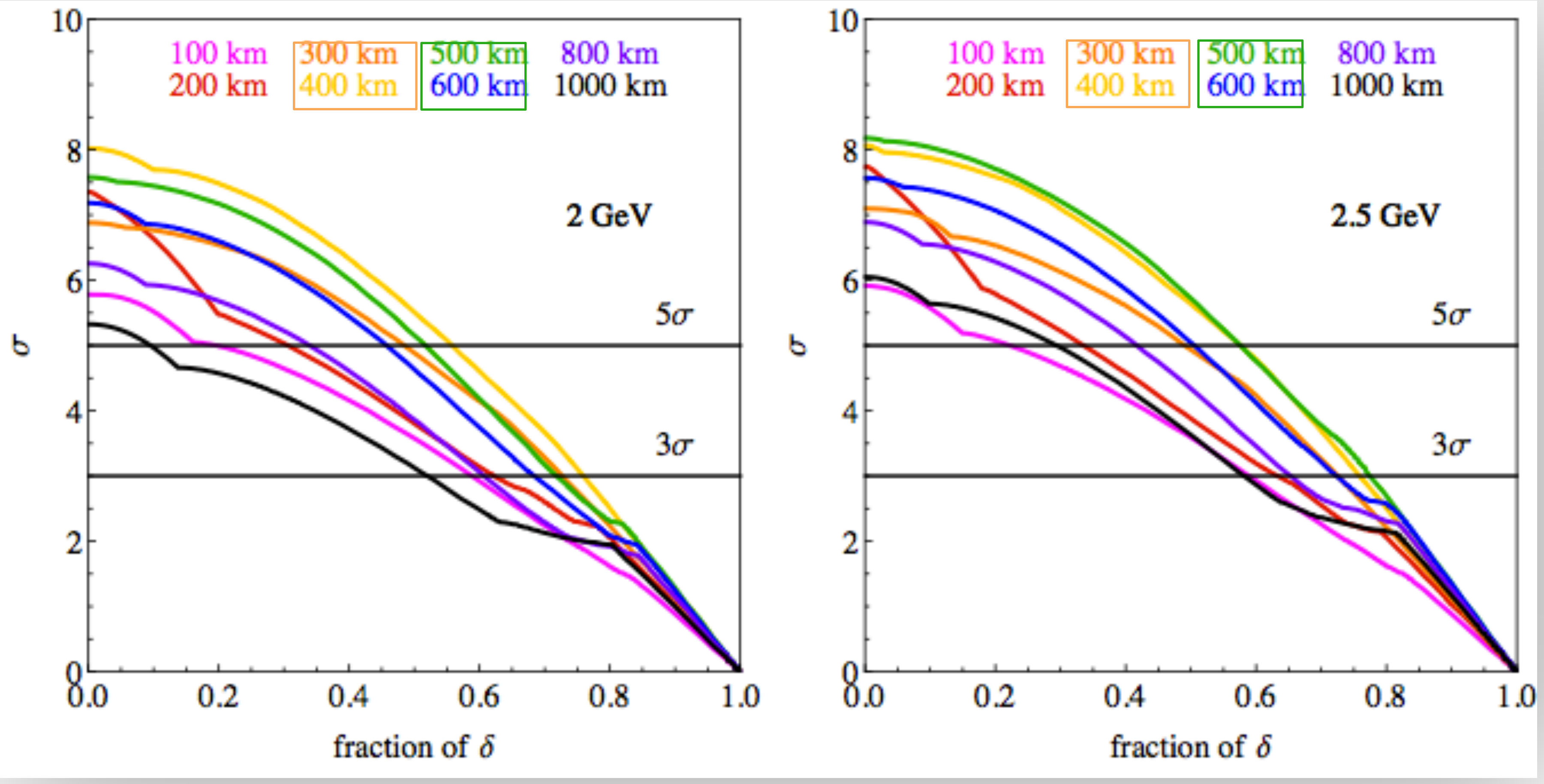
are our candidate baselines good enough?



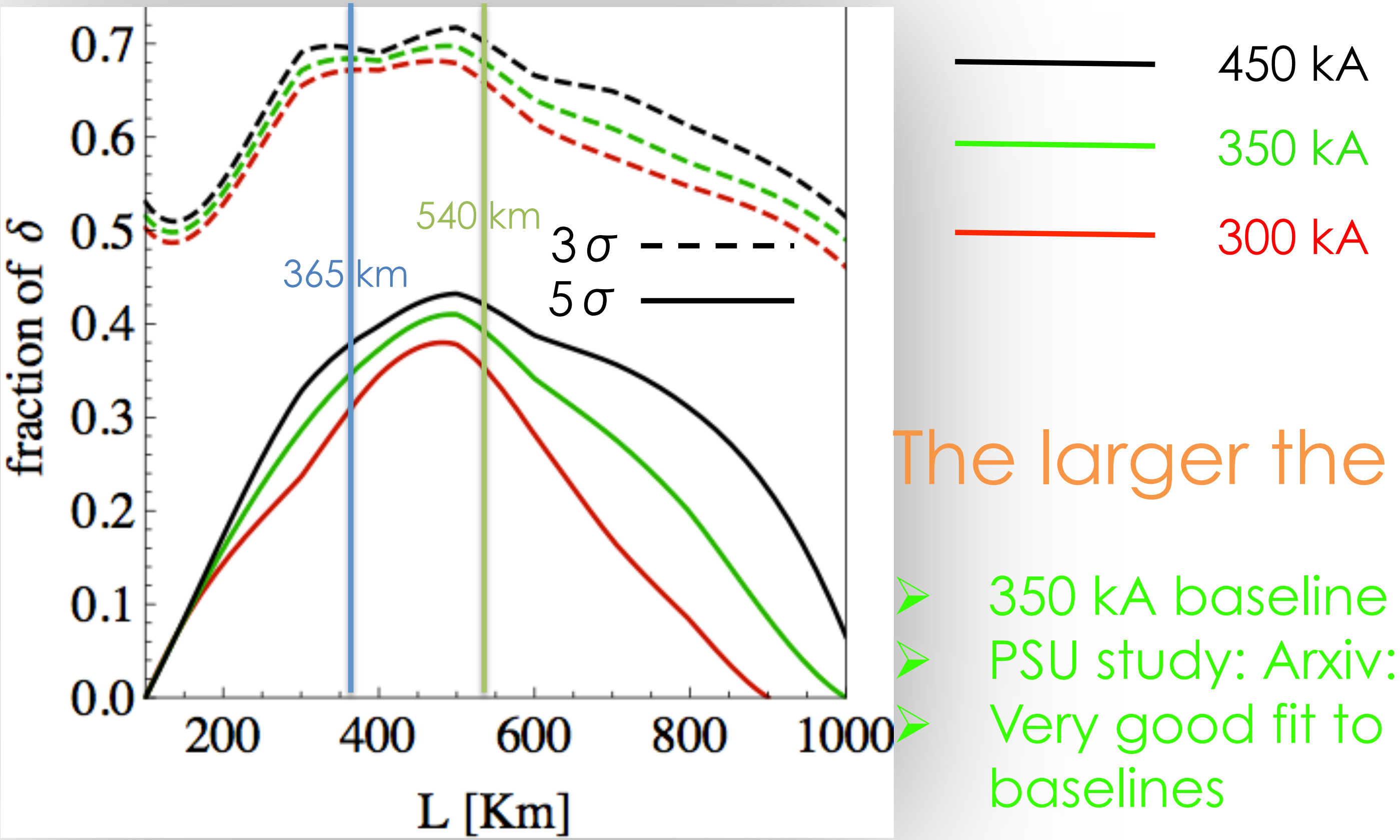
Yes

Very good baselines for the following mines :

- Zinkgruvan at 365 km
- Garpenberg at 540 km
- Site studies under way



Horn Current ?

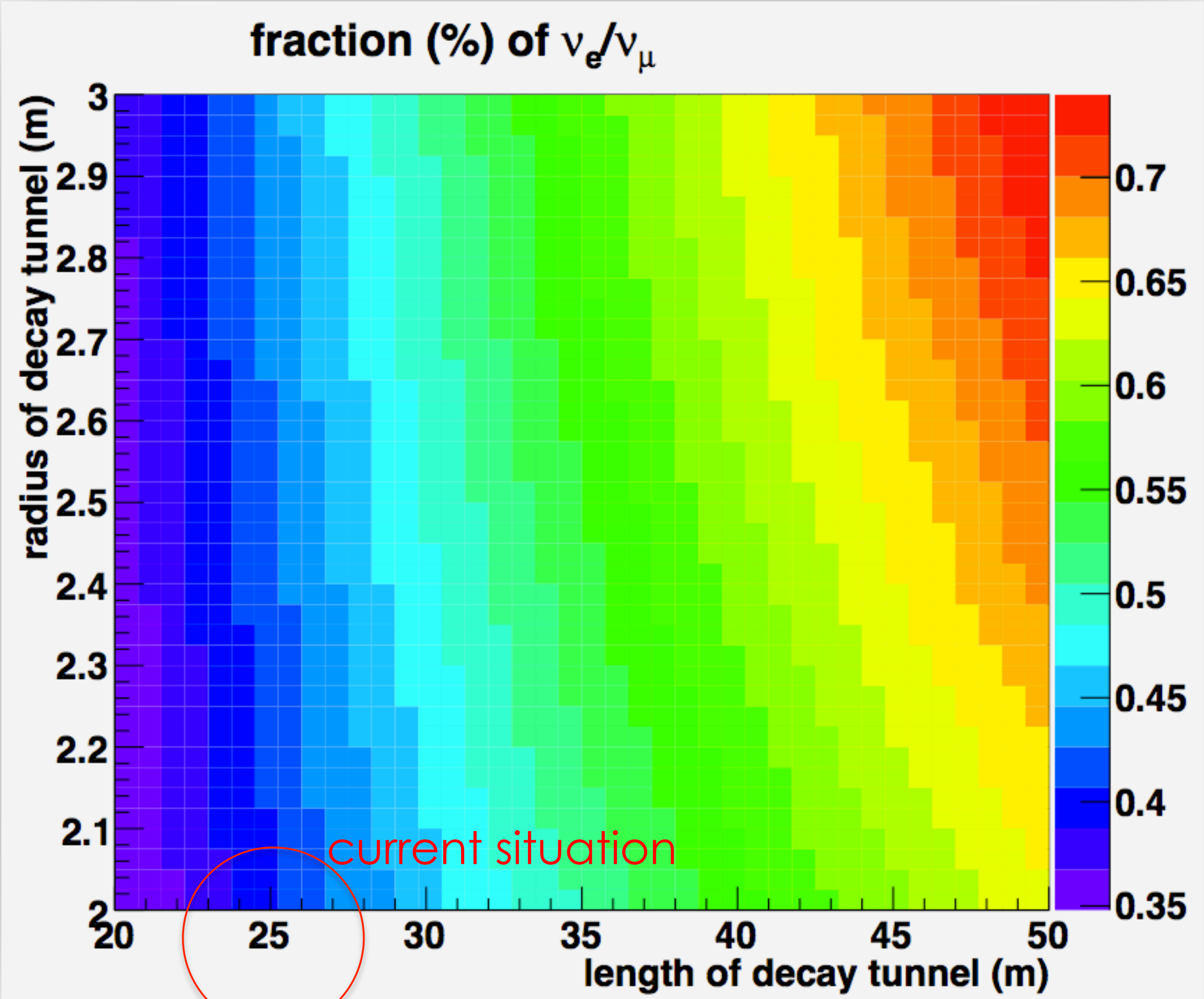


lower p.o.t. per year for this study – not to compare with main results

The larger the better (B~I/r)

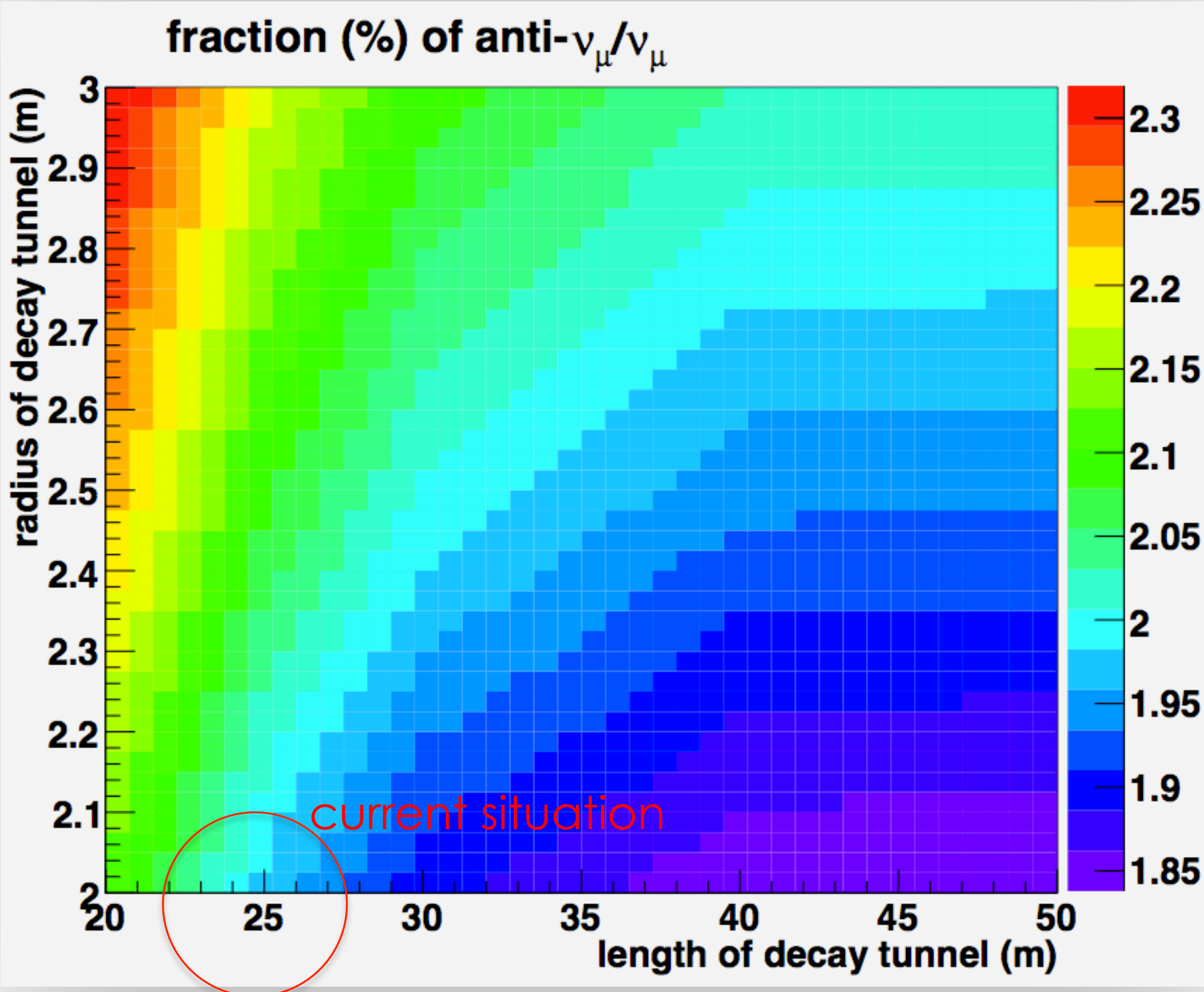
- 350 kA baseline
- PSU study: Arxiv:1304.7111
- Very good fit to 365 and 540 km baselines

ν_e contamination, for detected neutrinos



- ν_e contamination increases with respect to DT length, radii
- Lower than 1 %
- @ L = 25 m, 50 % of π^+ s decay

anti-ν_μ contamination for detected neutrinos

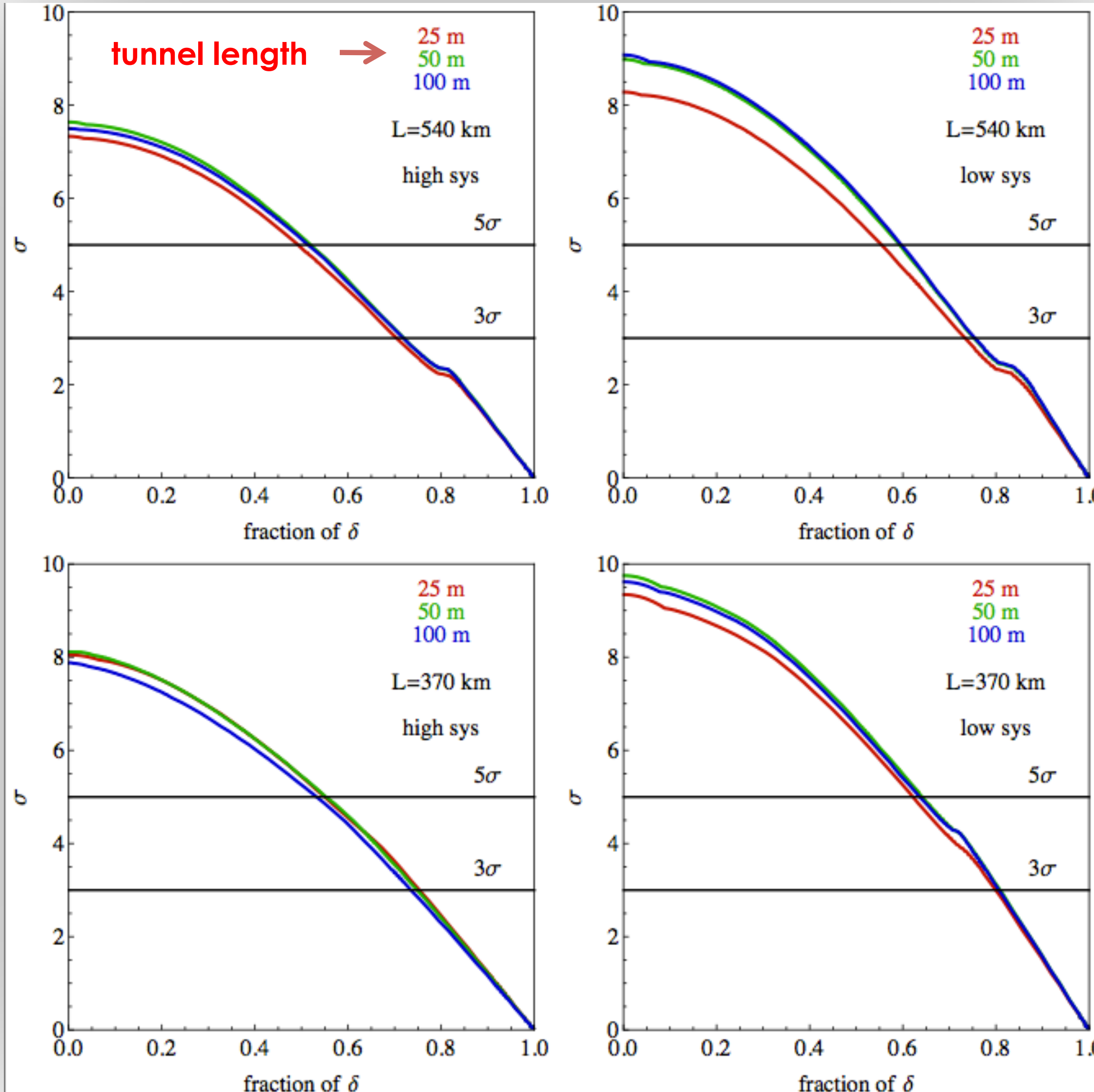


- anti-ν_μ contamination decreases with respect to DT length

is the increased ν_e contamination more significant than the increased flux ?

try the following tunnel parameters:

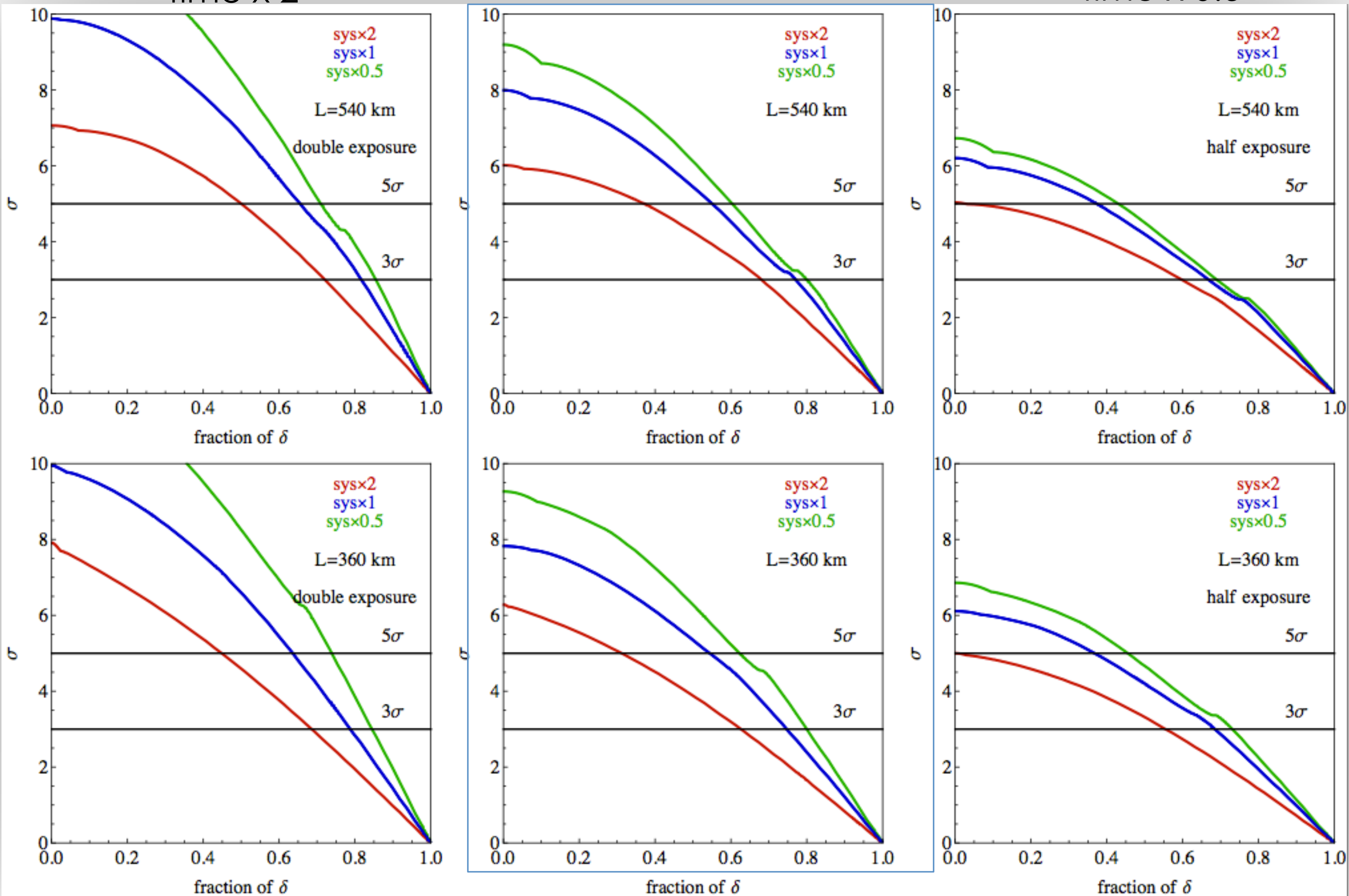
Length (m)	Radius (m)	% of decayed π^+
25 (baseline)	2 (low-limit for 4-horns)	50
50	2	72
100	2	92



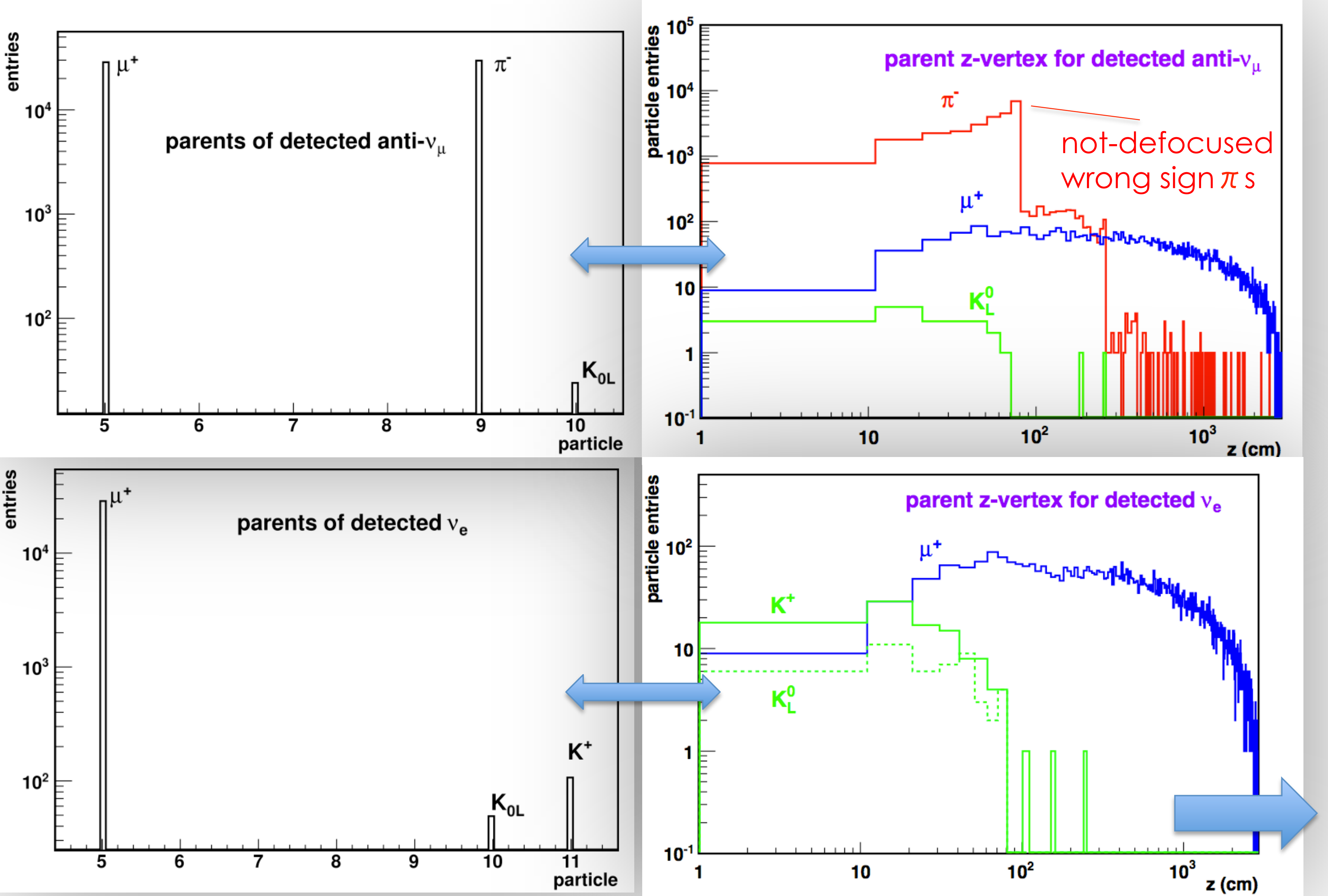
No significant increase in physics performance by using lengthier decay tunnel

Systematics, time vs physics

time x 2 | Baseline | time x 0.5



Can we use a smaller target and decay tunnel ?



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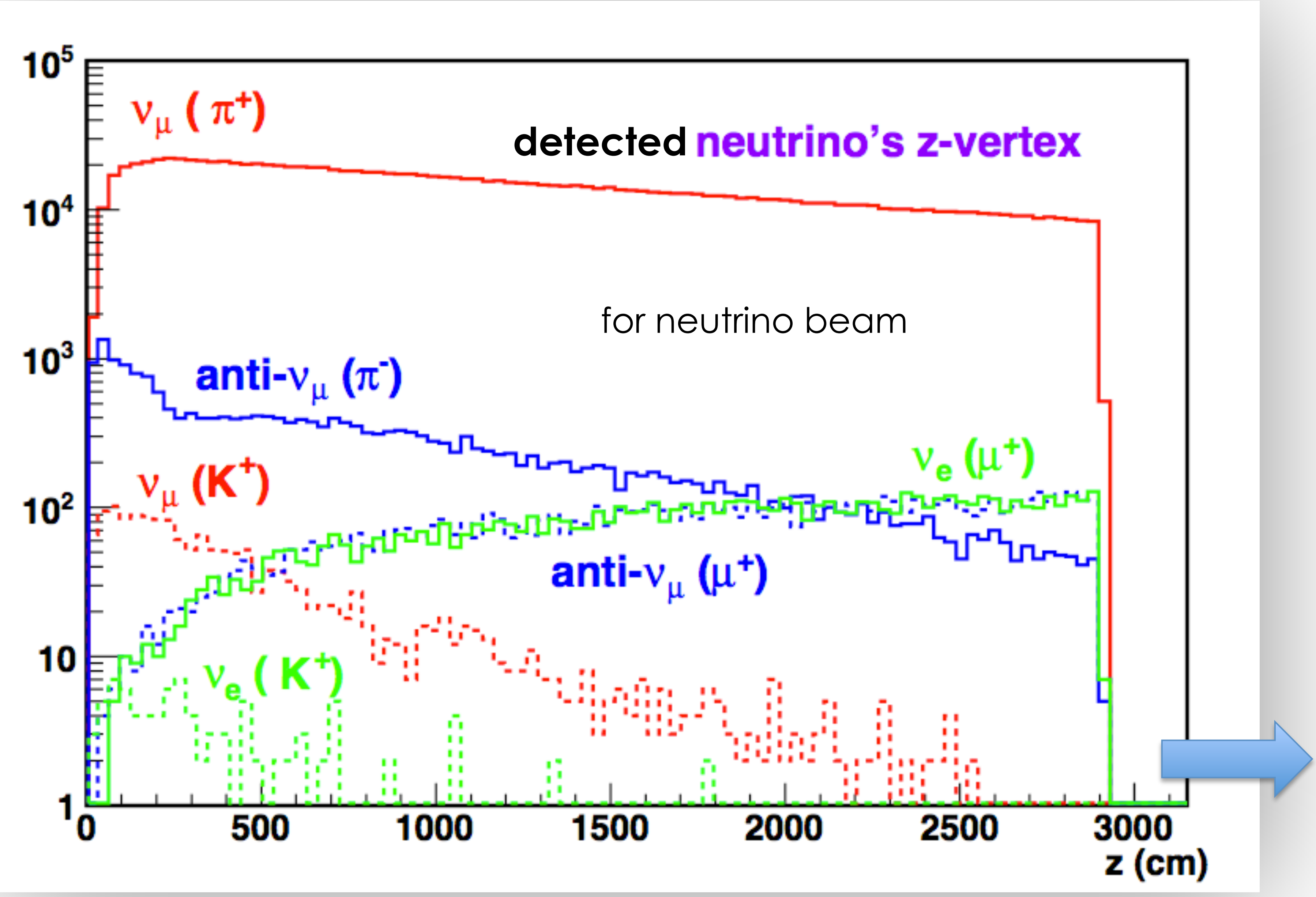
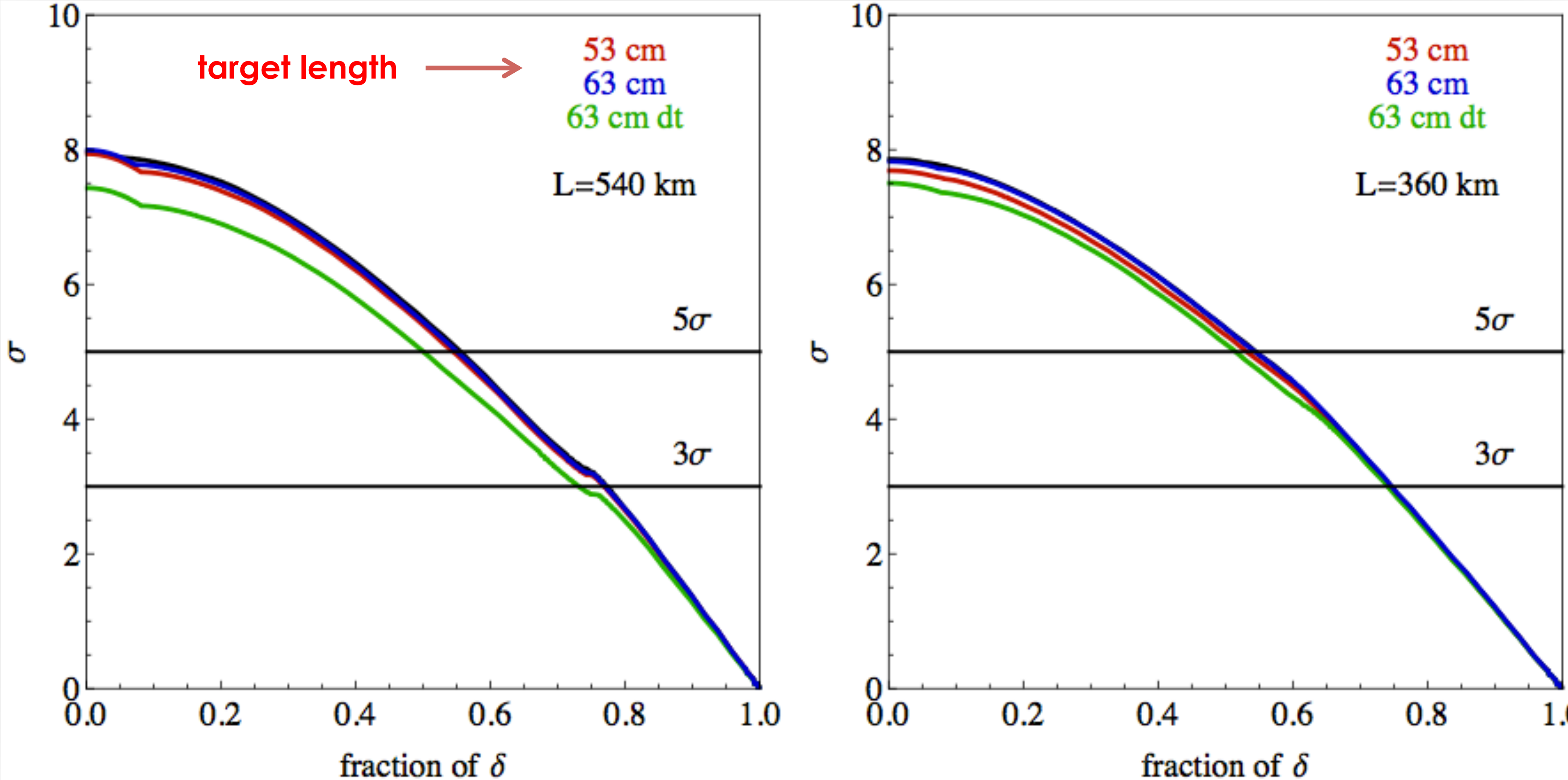


Particle production at target

Particles per p^+ for baseline ESS target parameters and also for different radii, lengths SPL is shown for comparison (fluka 2013)

ESS Ti packed-bed			
particles/p^+	π^+	π^-	n
$r_{1.25}$	0.27	0.17	4.4
$r_{1.50}$, L_{78} (baseline)	0.29	0.17	4.8
$r_{1.50}$, L_{63}	0.28	0.17	4.5
$r_{1.50}$, L_{53}	0.26	0.16	4.3
$r_{2.00}$	0.30	0.18	5.3
SPL	0.67	0.52	6.6

- For a year there are 2.8 more protons in ESS than SPL



the target size and decay tunnel length could be reduced at no-cost

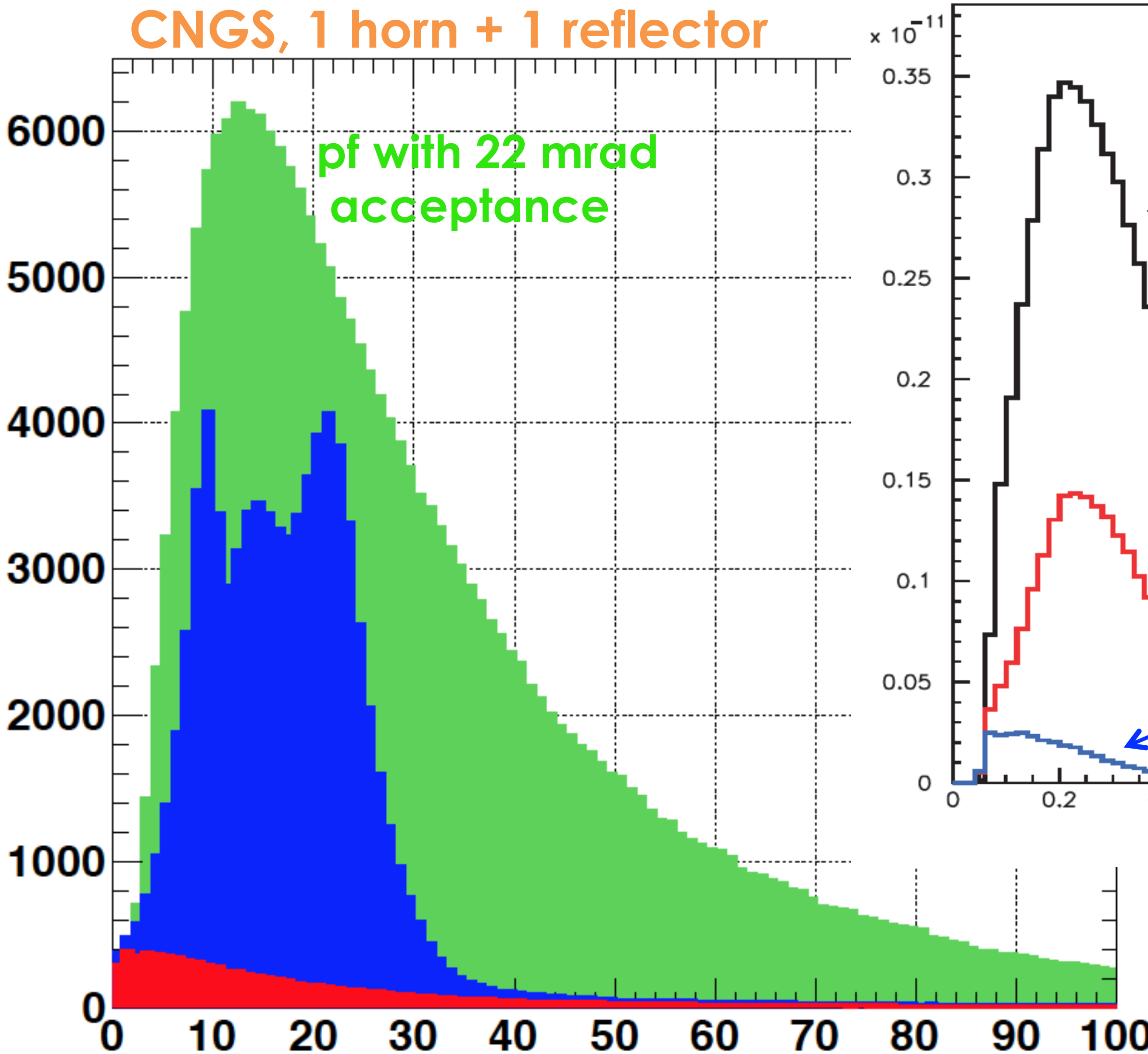
- Less irradiation
- Smaller civil-engineering cost

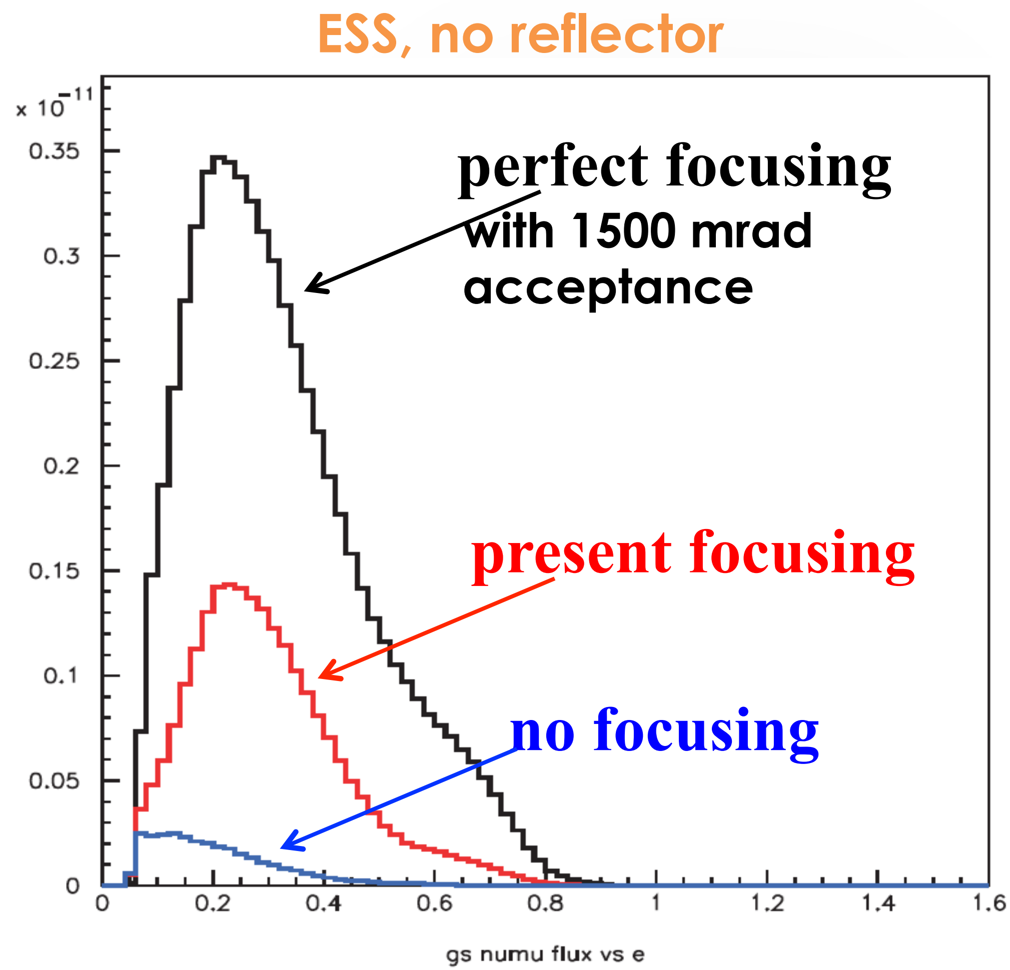
Perfect focusing studies
is the horn focusing well ?

- Examine the quality of focusing
- Compare neutrino fluxes or events of perfect focus and no focus with the specified optics
- Application depends on the focusing optics and particle production for low, medium and high energy beams
- Method: focus parallel ($P_T=0$, $P_Z=P$) in respect to the beam axis all charged particles at the exit of target with a given acceptance limit

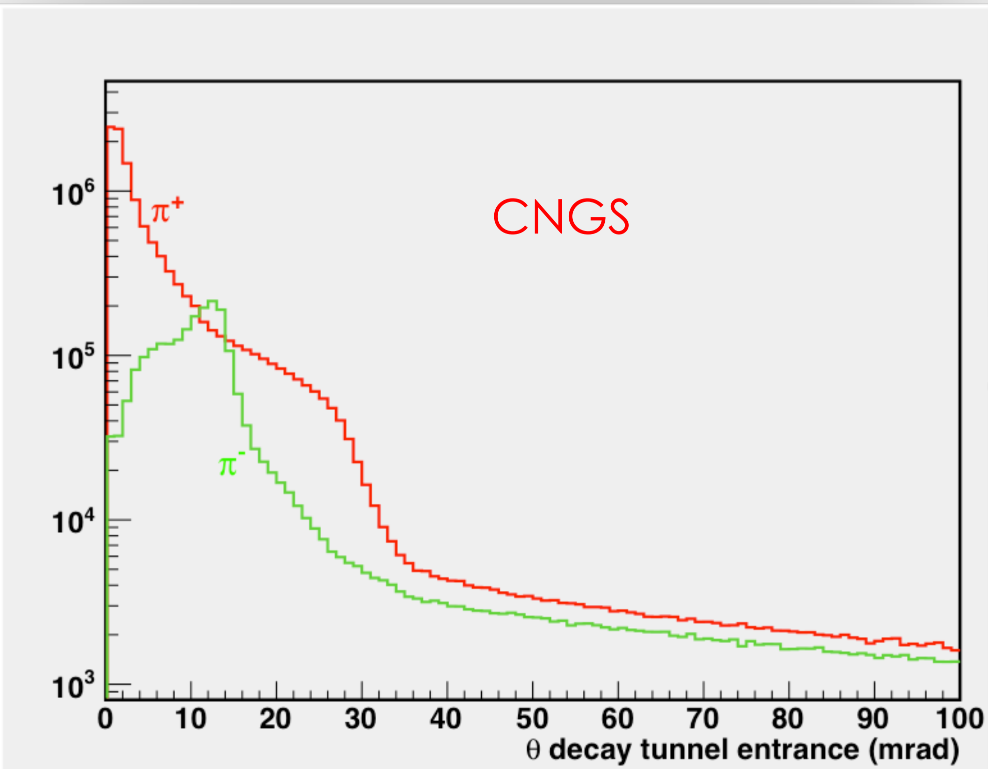
Comparison between ESS and CNGS beams

pf vs nf vs focus

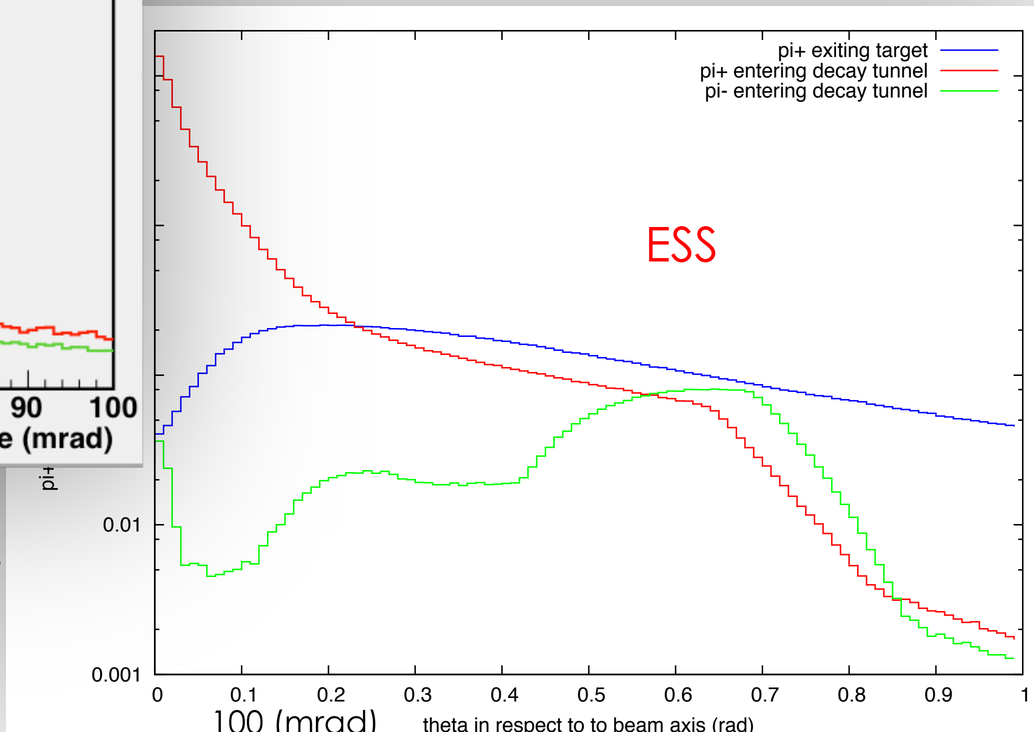




focusing-defocusing effect of the optics π^+, π^- at the entrance of decay tunnel

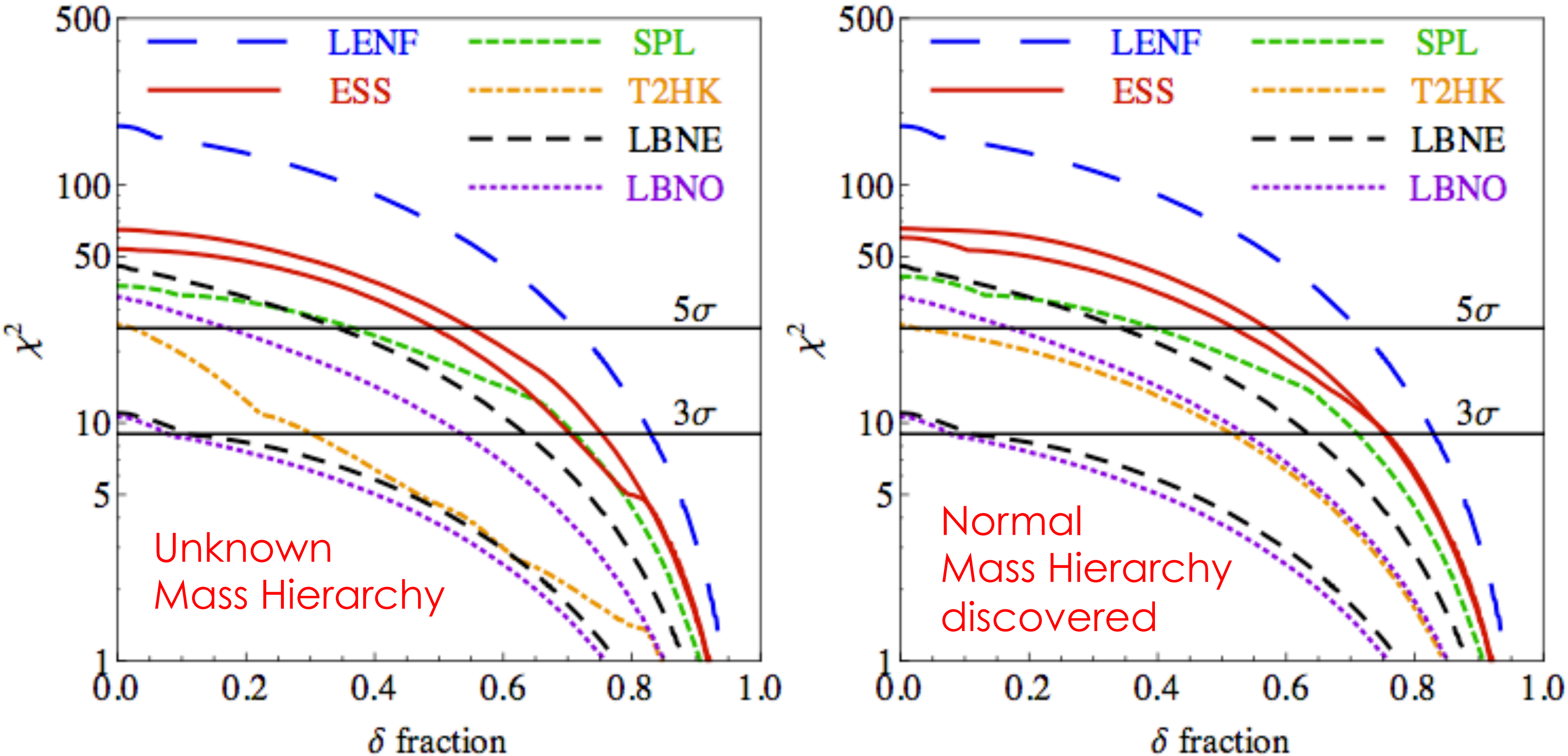


ESS: good focusing effect, large θs and wider acceptance range @ production



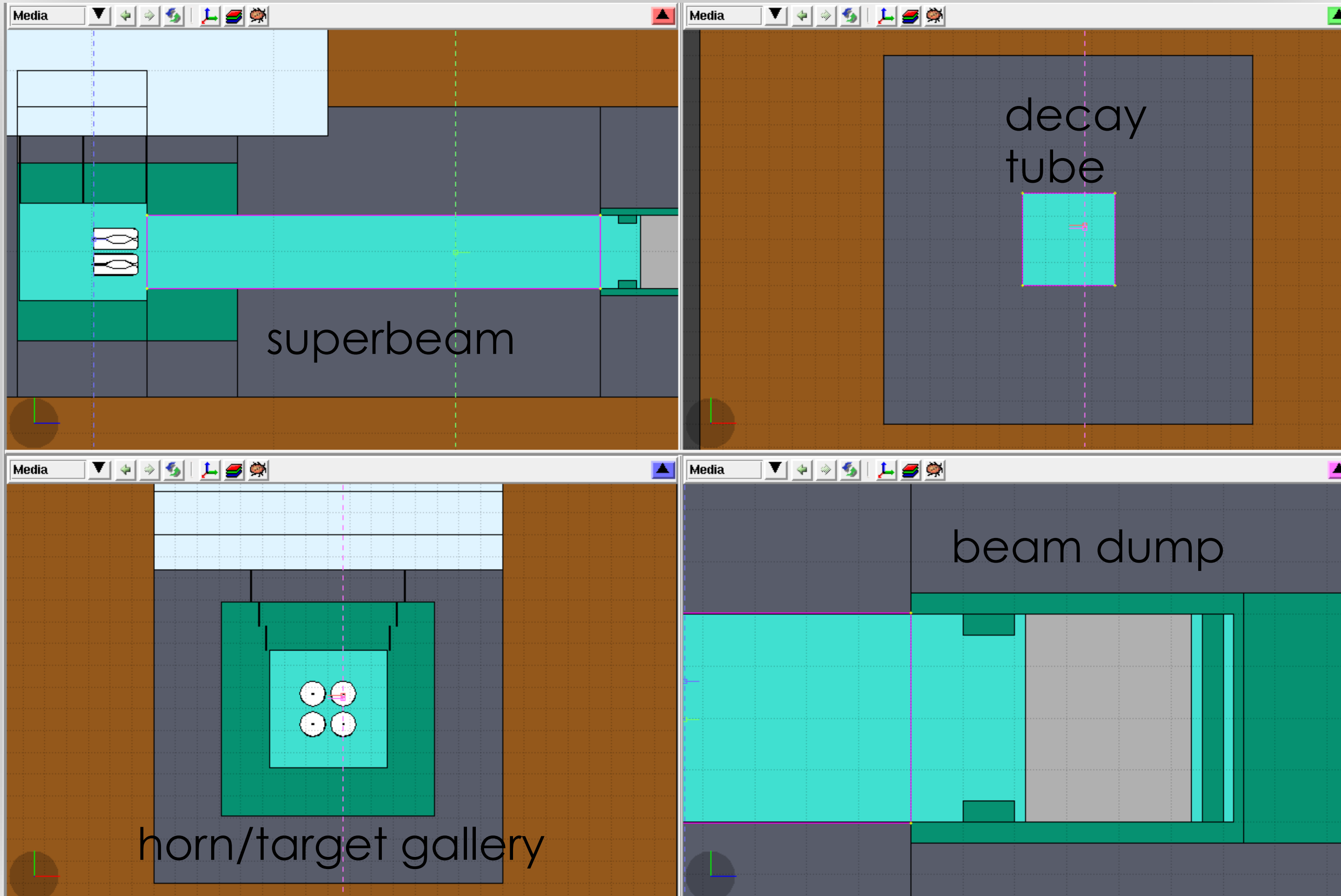
CNGS: Stronger focusing effect due to higher beam energy, lower θs and acceptance @ production

ESS with adopted parameters offers the best physics after LENF



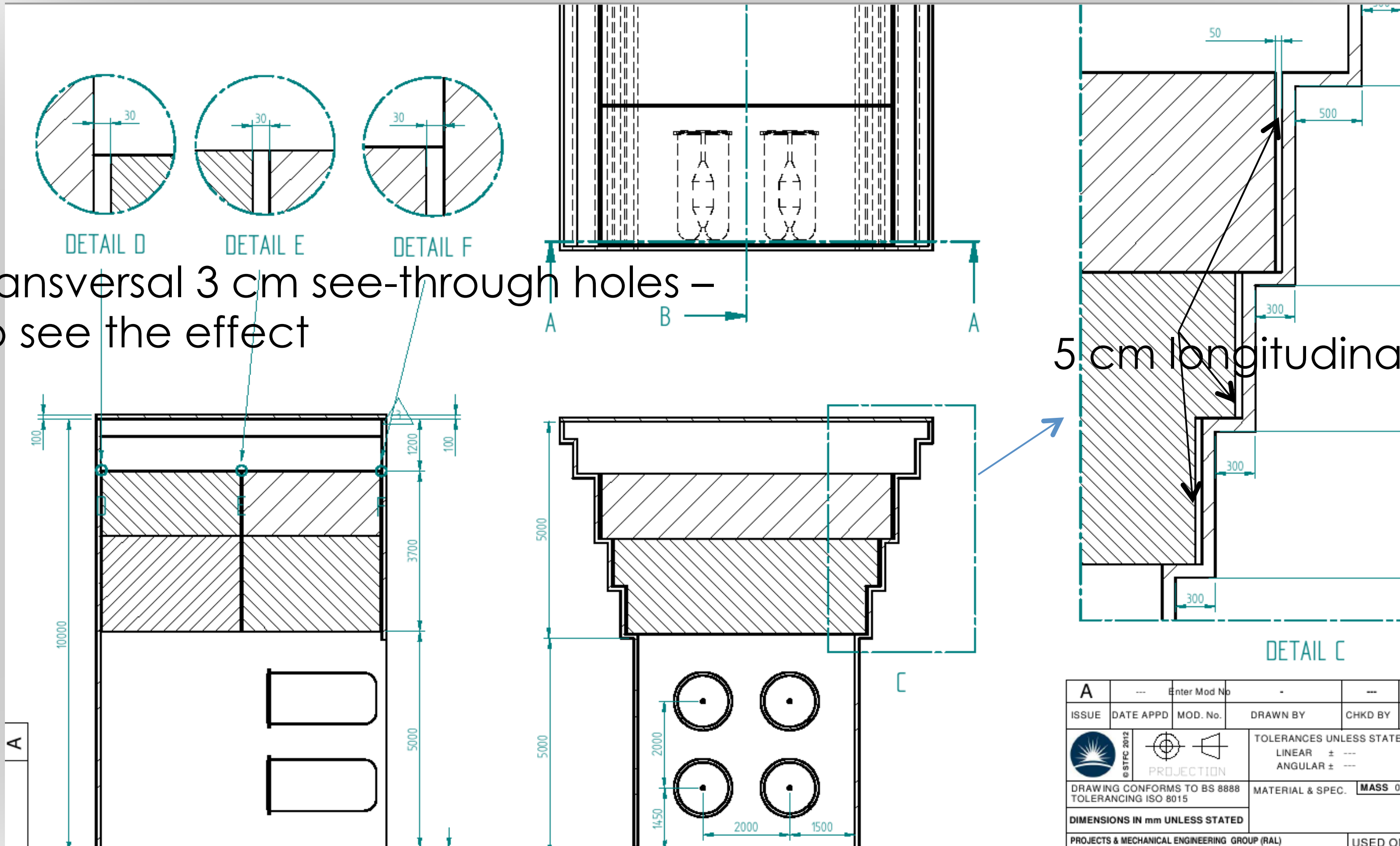
- LENF, Low Energy Neutrino factory (2000 m, 100 kt MIND, 4 MW)
- SPL Super Beam, CERN to Frejus (120 km, 500 kt WC, 4 MW)
- ESS Super Beam (540 km, 365 km 500 kt WC, 5 MW)
- LBNO, CERN to Pyhasalmi (SPS, 2300km, 20 kt, 100 kt LAr, 0.8 MW)
- T2HK Japan Super Beam Project(300 km, 560 kt WC, 1.6 MW)
- LBNE USA long Baseline (1300 km, 10 kt, 33 kt LAr, 0.8 MW, 2.3 MW)

simulation layout for radiation
fluka, flair gui/analysis
iron-shields, concrete, molasse, He



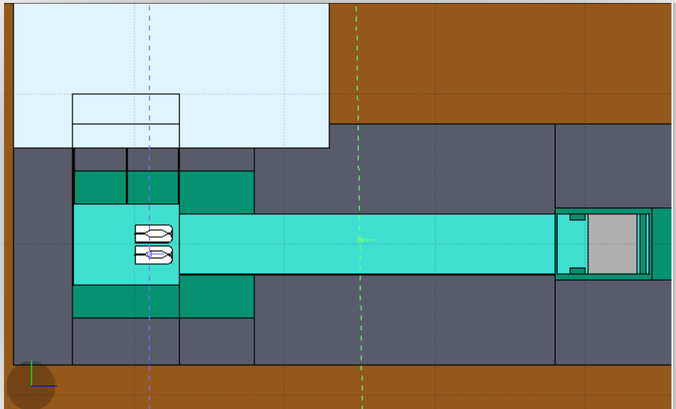
horn/target gallery

geometry for horn/target gallery – including holes:



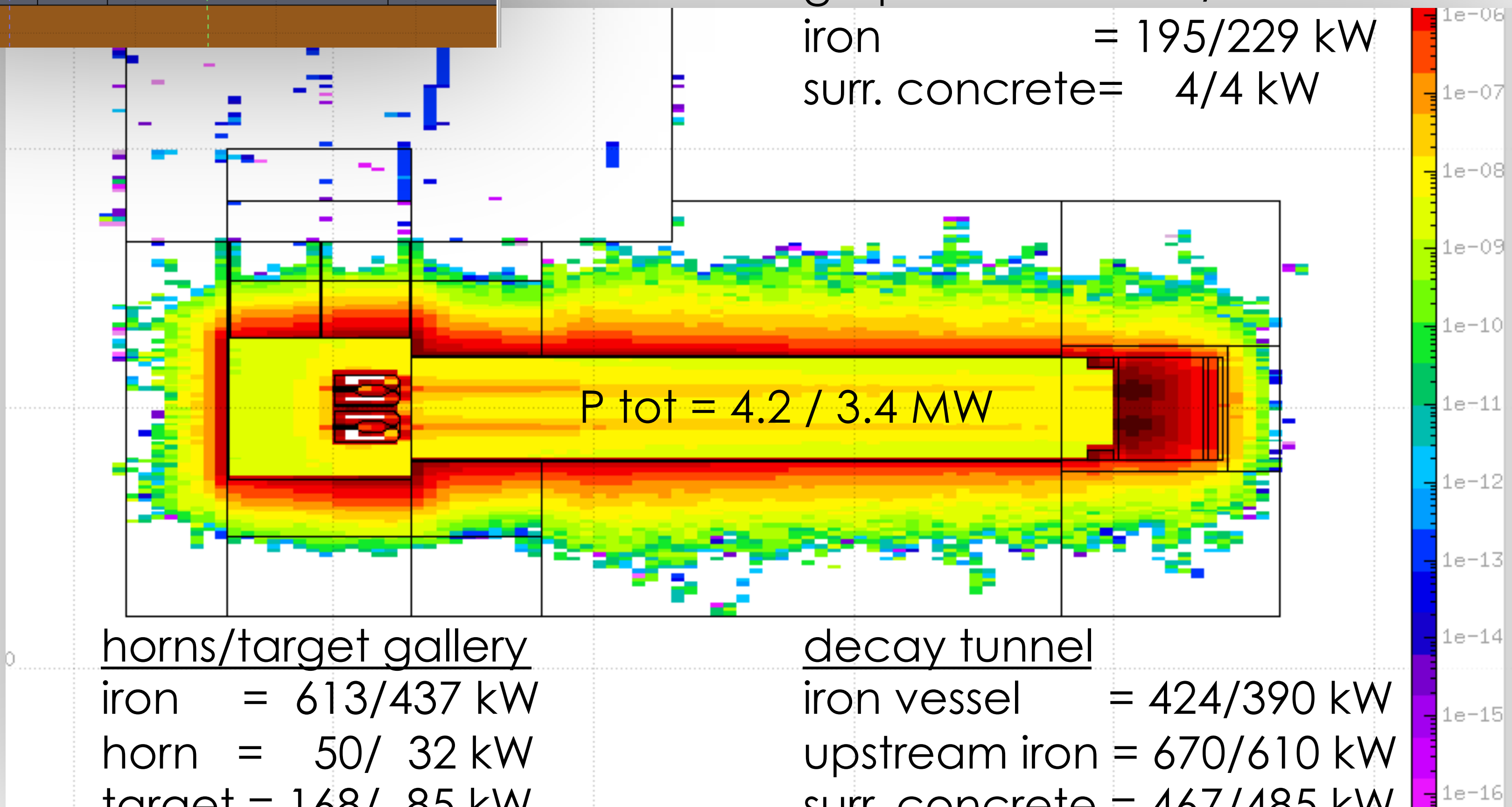
transversal 3 cm see-through holes – to see the effect

5 cm longitudinal holes



ESS/SPL power distribution

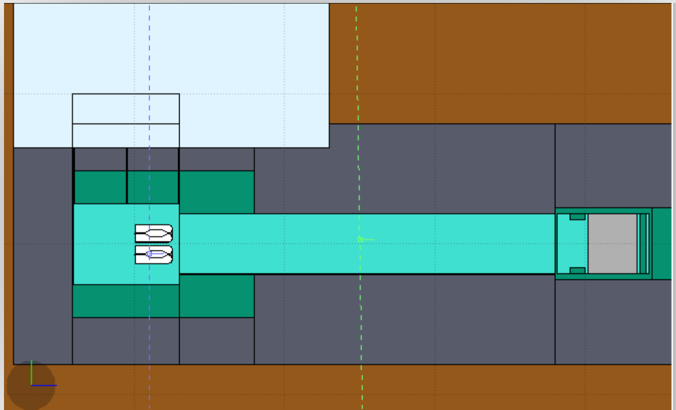
iron, concrete, molasse, He



<u>beam dump</u>
graphite = 950/778 kW
iron = 195/229 kW
surr. concrete = 4/4 kW

<u>horns/target gallery</u>
iron = 613/437 kW
horn = 50/ 32 kW
target = 168/ 85 kW

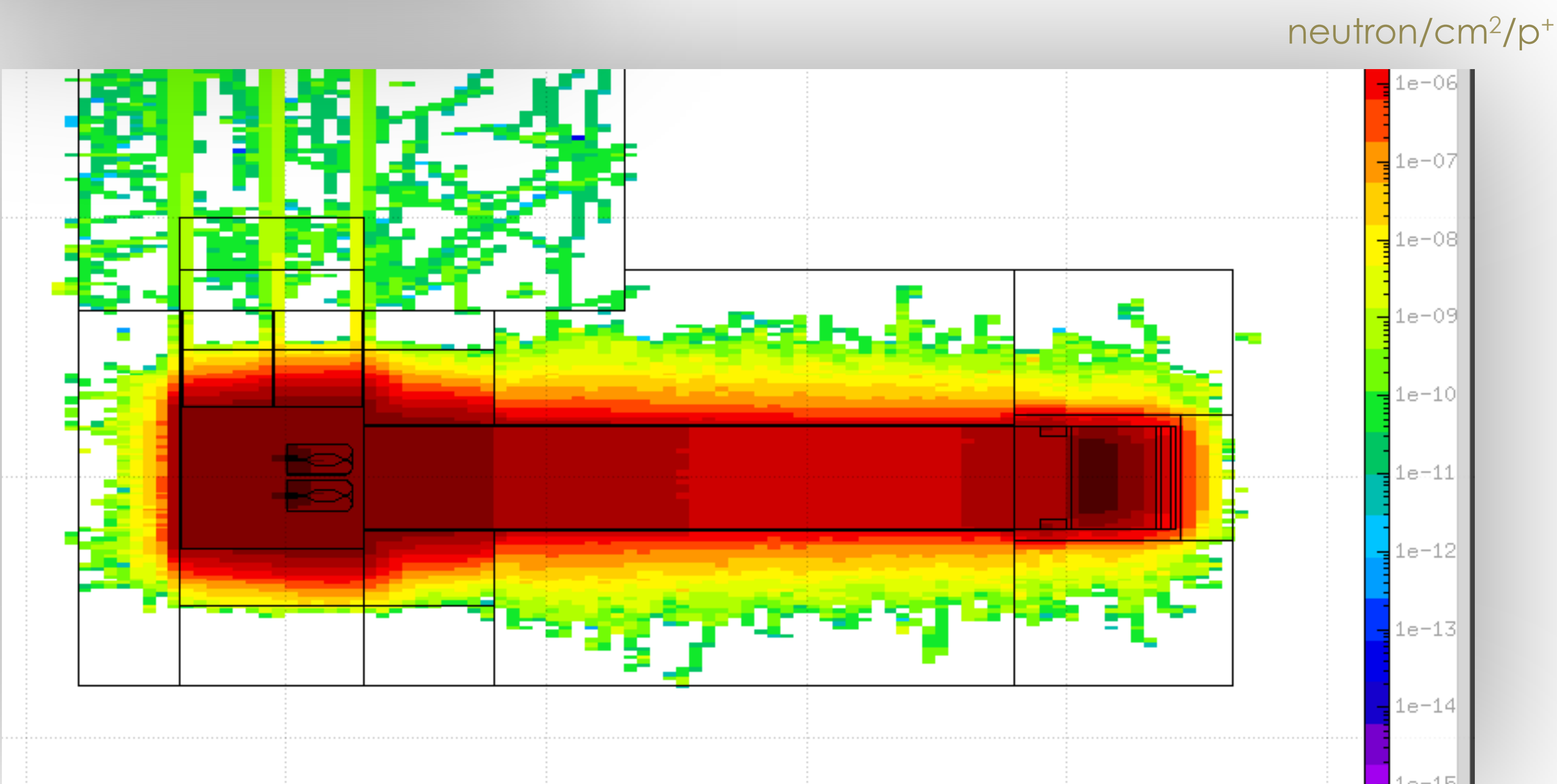
<u>decay tunnel</u>
iron vessel = 424/390 kW
upstream iron = 670/610 kW
surr. concrete = 467/485 kW

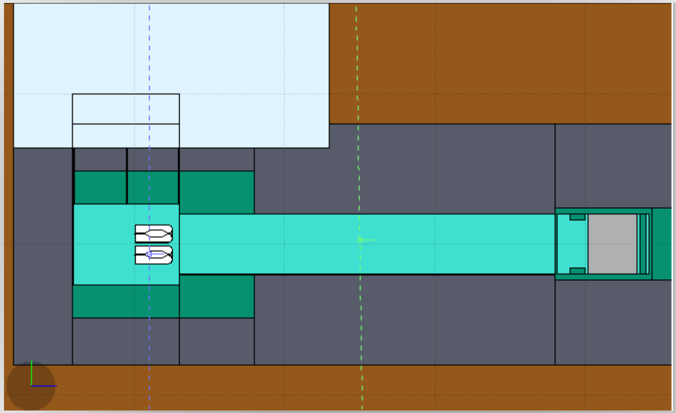


ESS neutron flux

iron, concrete, molasse, He

- SPL shielding achieves 10 μSv/h above target and horn, for ESS might be sufficient
- On-going studies

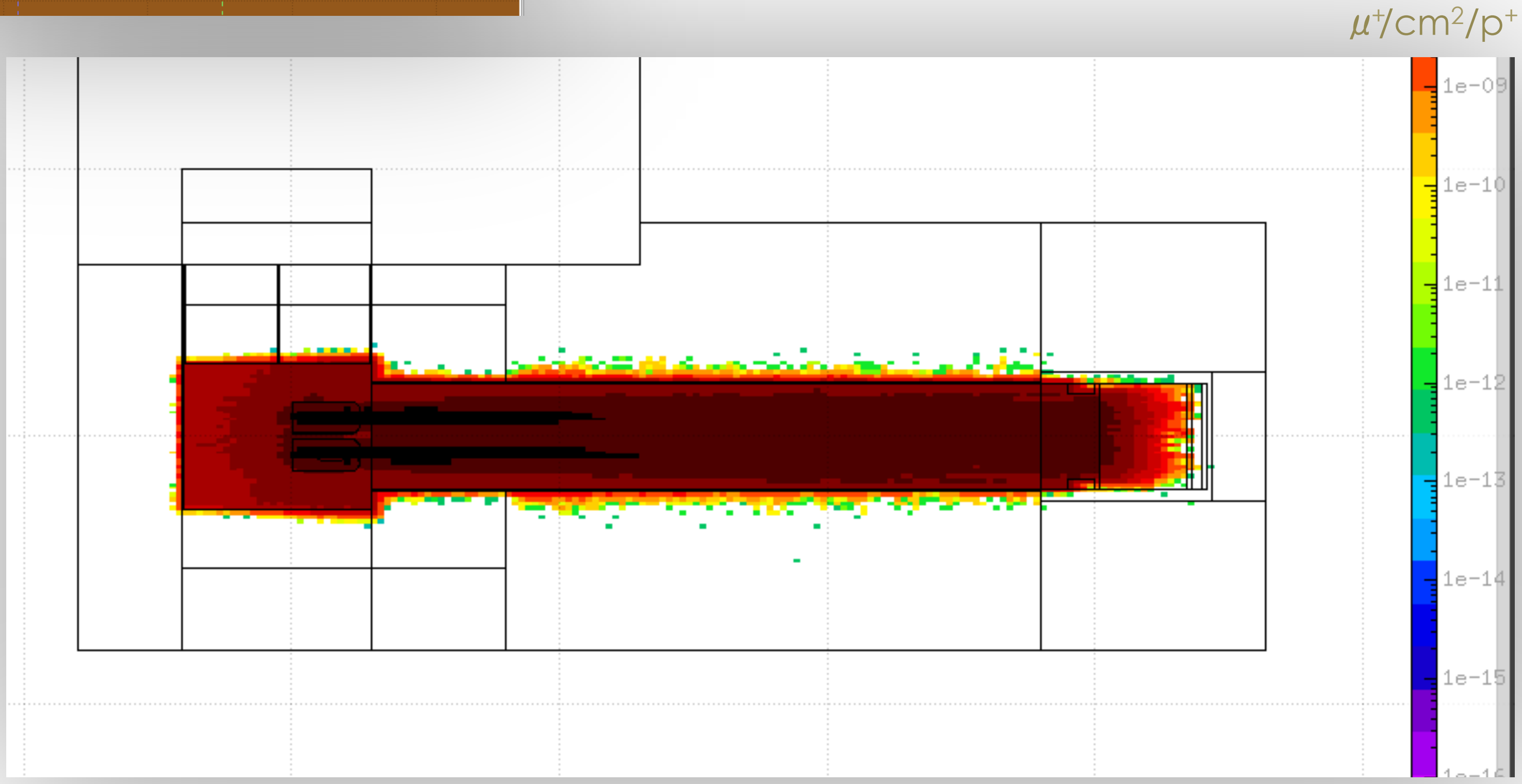




ESS muon flux

iron, concrete, molasse, He

- Preliminary, needs more stats
- Near detector could be placed few 10ths of meters after the bump dump gallery



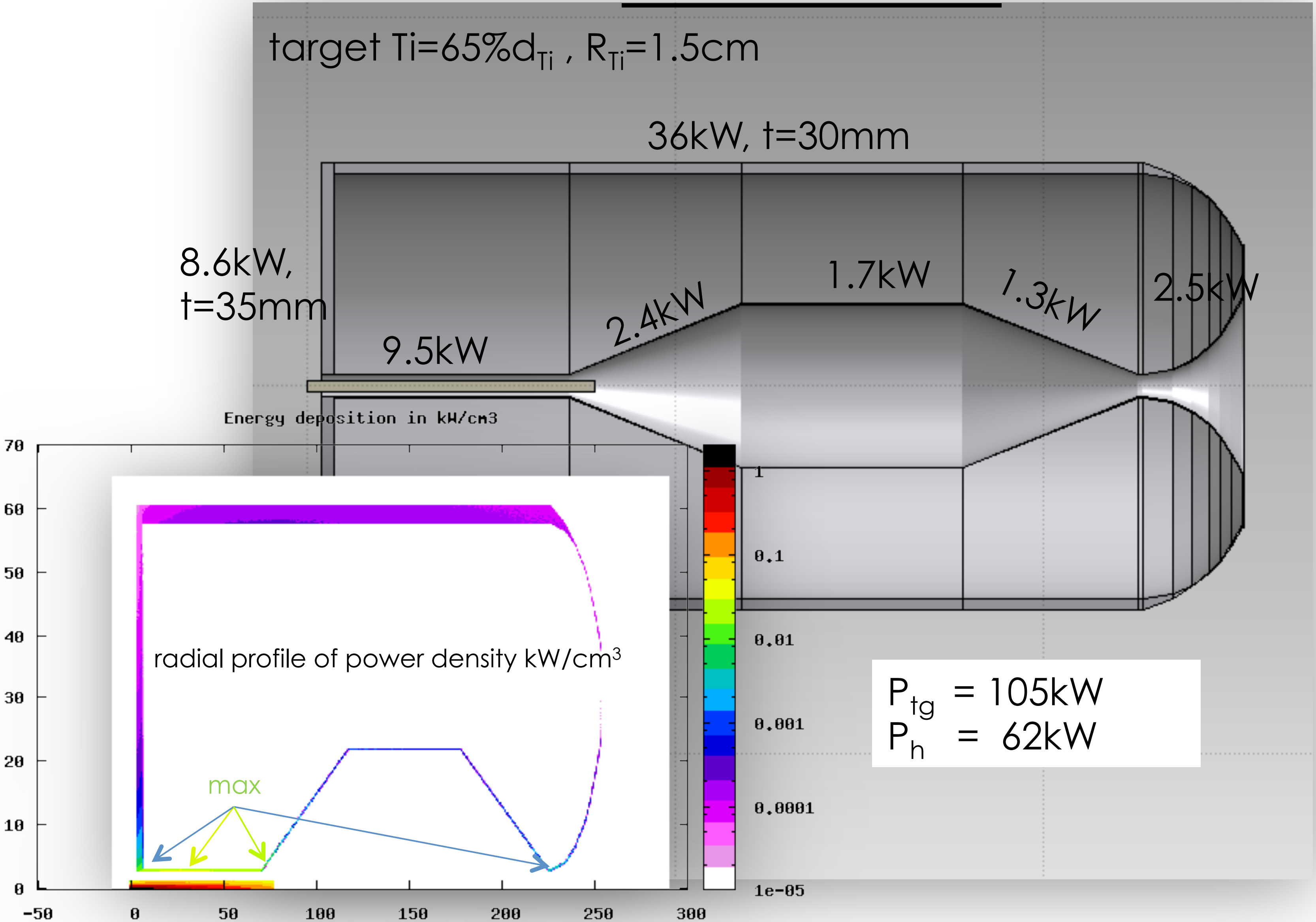
summary

- ESS has the best physics performance after LENF with adopted SPL’s secondary beam parameters
- Additional irradiation due to higher power and less proton energy for ESS looks manageable

Studies on going

Thanks

Energy Deposition from secondary particles @1.3 MW @SPL



P_{tg} = 105kW
P_h = 62kW

horn lifetime

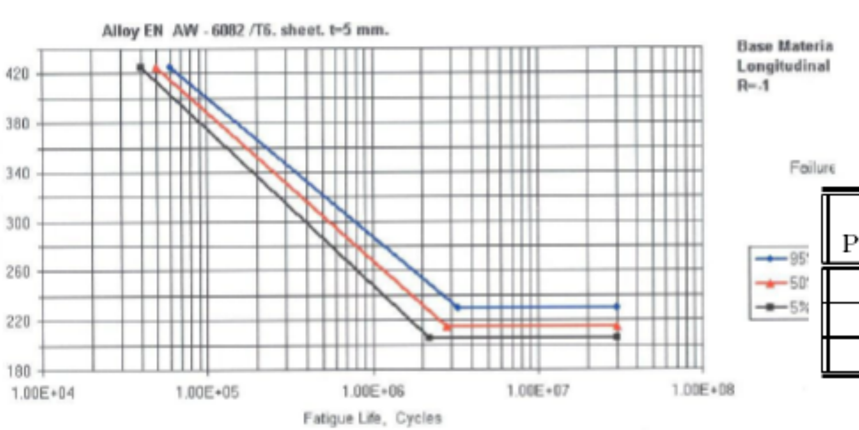
lower than 60 MPa expected

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

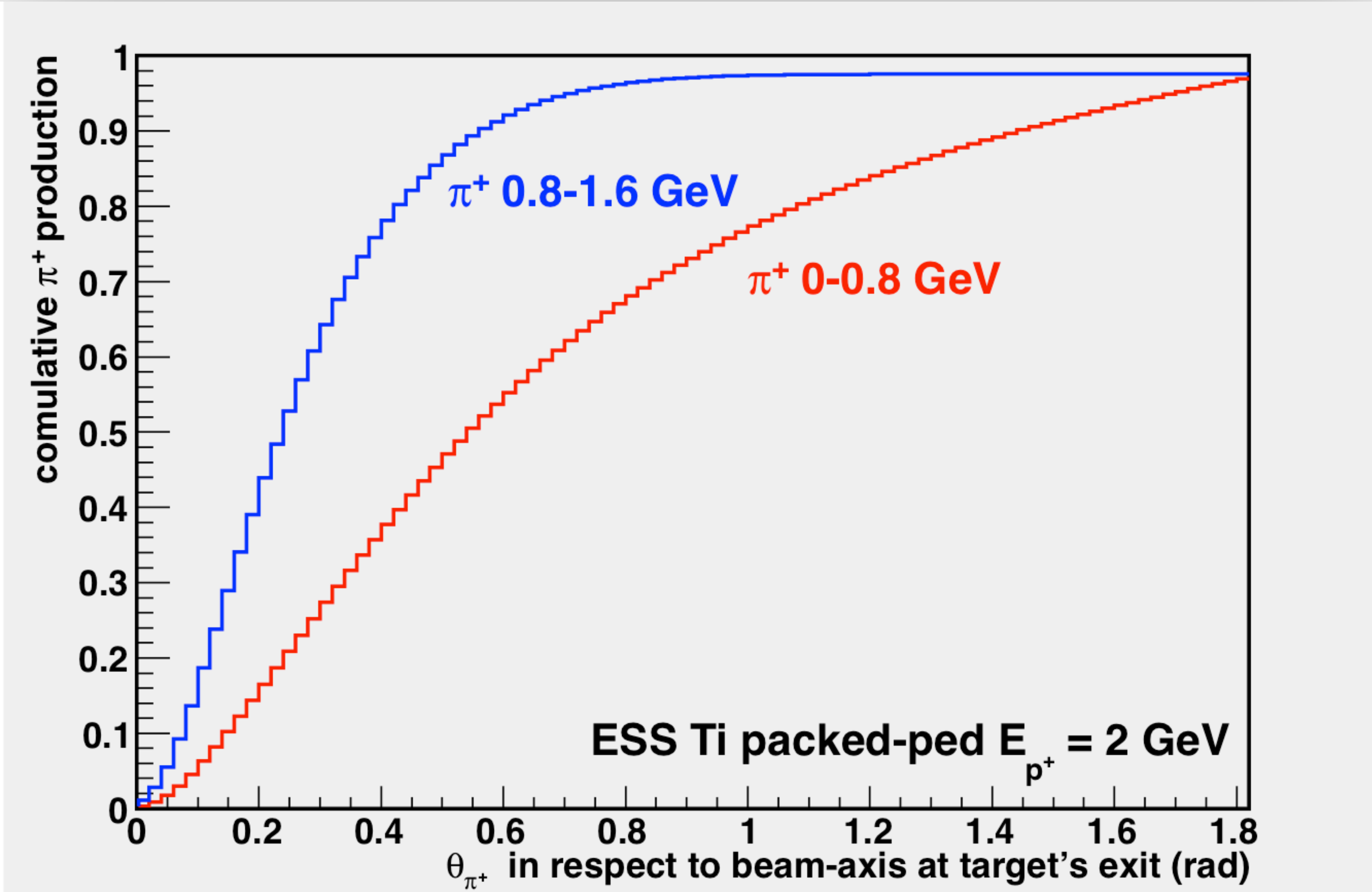
S-N CURVE PROBABILITY	LIFE TIME [s]	NUMBER OF PULSES
95 %	$8.6 \cdot 10^7$	$1.08 \cdot 10^9$
50 %	$1.9 \cdot 10^7$	$2.38 \cdot 10^8$
5 %	$6.6 \cdot 10^6$	$8.25 \cdot 10^7$

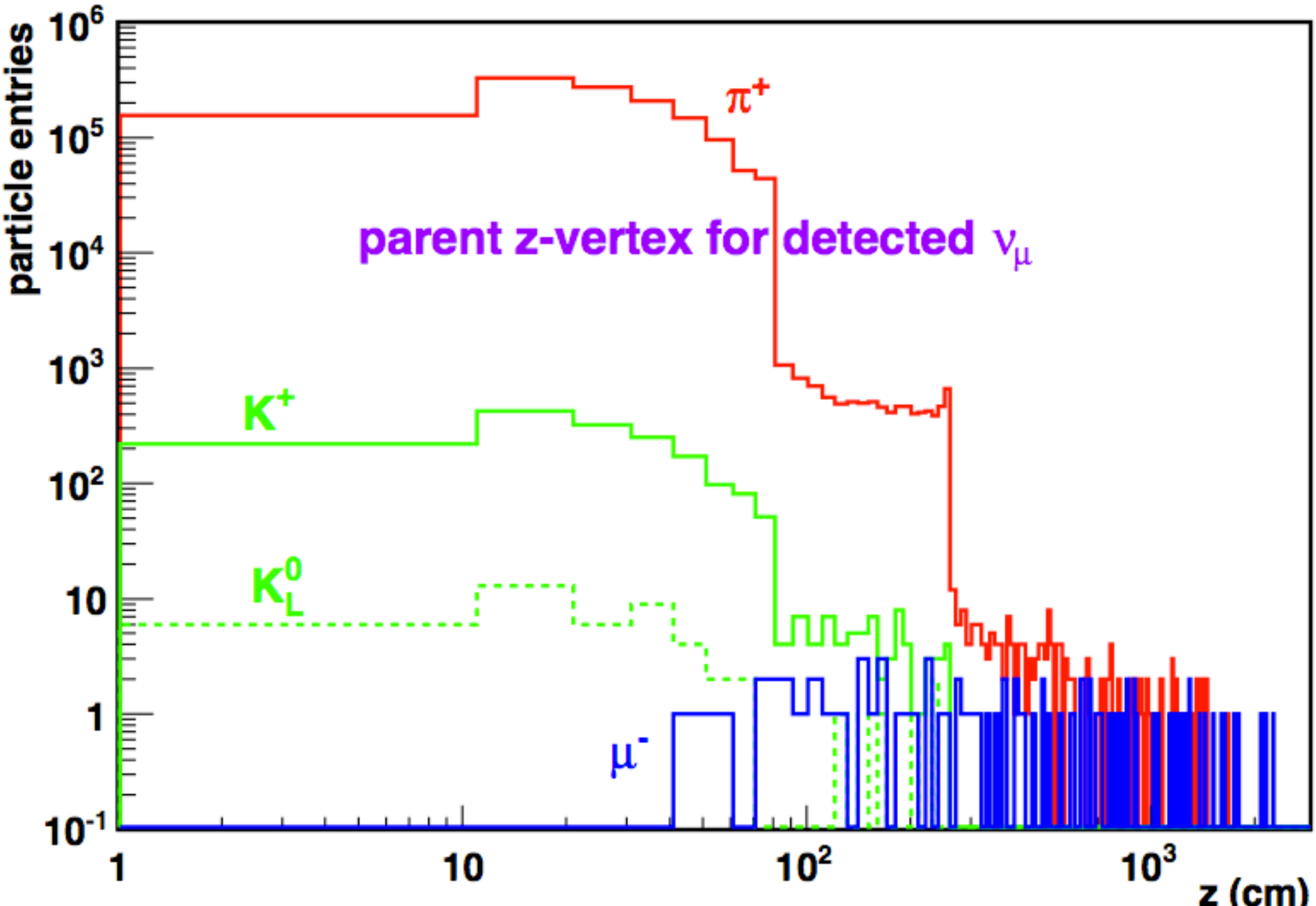
$1.25\ 10^8$ pulses = 200 days = 1 year

A.Niesłony

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

Cumulative pion production at target



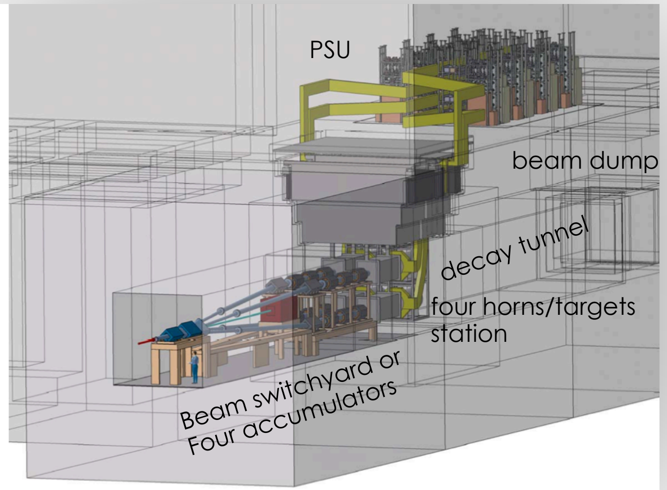


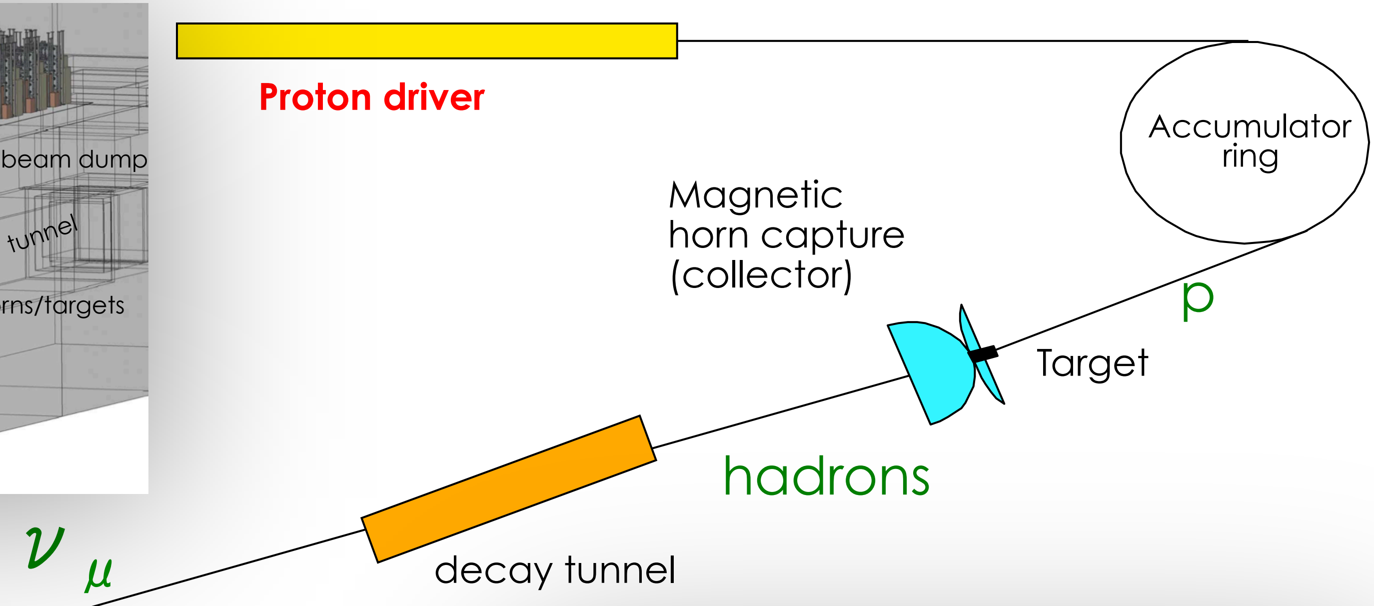
particle entries
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
1
10
10^2
10^3
z (cm)
π^+
parent z-vertex for detected ν_μ
K^+
K_L^0
μ^-

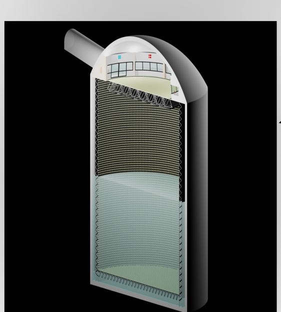
Reminder: ESS neutrino super beam

- Based on ESS arXiv:1212.5058, EUROnu WP2 for SPL super beam, WP5 for MEMPHYS studies, Phys. Rev. ST Accel. Beams 16, 061001 (2013)

ESS Linac, (2.5 (2) GeV, 5 MW, modified for 50 Hz super beam)

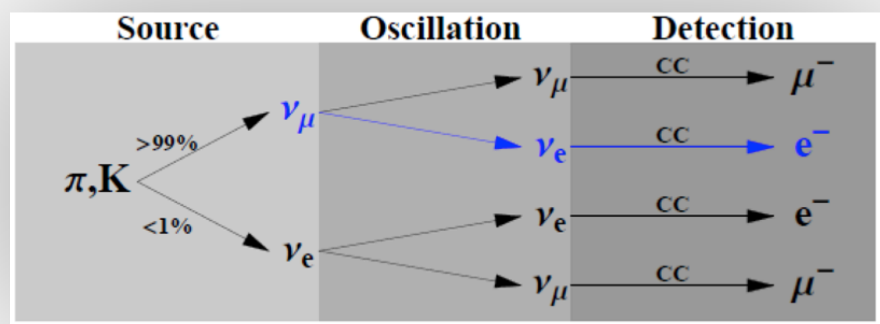






~ 290 MeV ν_μ beam to far MEMPHYS water Cherenkov detector

~400 – 500 km



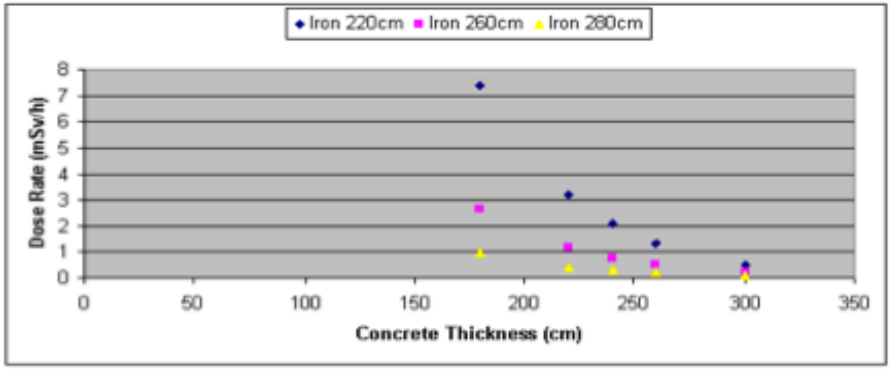


Figure 161: Evolution of the dose equivalent rate for several configuration of iron and concrete.

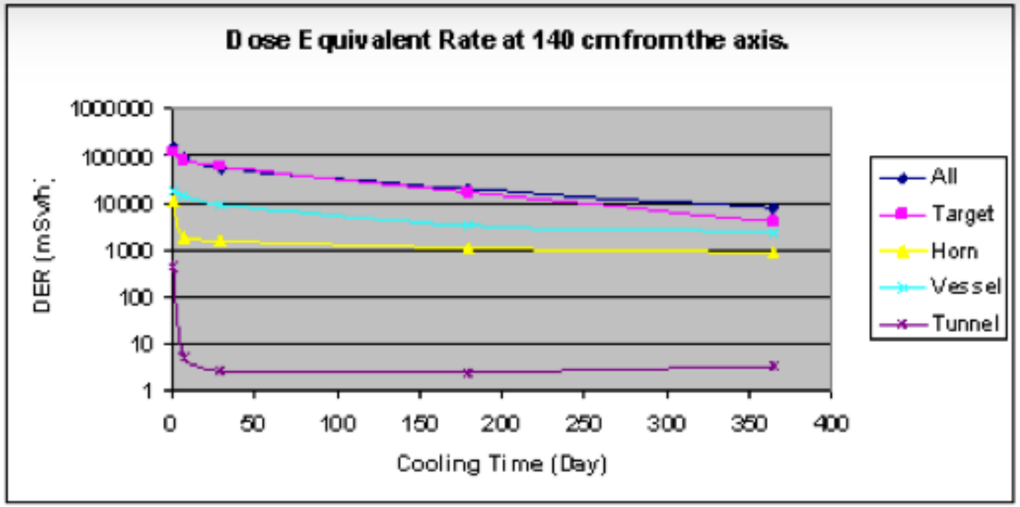
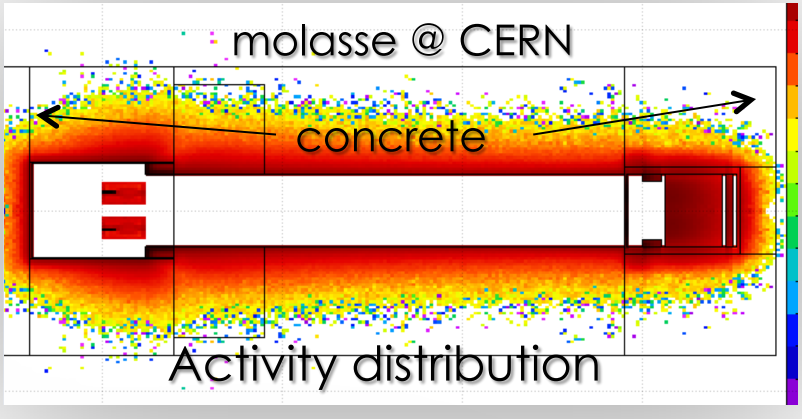


Figure 151: Dose equivalent rate contributions in mSv/h.

SPL: Activation in molasse



preliminary

study set up:
✓ packed Ti target, 65%d_{Ti}
✓4MW beam, 4horns, 200days of irradiation

- minimum activation leads to minimum water contamination
- ^{22} Na and tritium could represent a hazard by contaminating the ground water

CERN annual activity constraints in molasse (0.3mSv/year for the public through water)		**Super Beam**
^{22} Na	4.2×10^{11} Bq	$\sim 10^{8}$ Bq
tritium	3.1×10^{15} Bq	$\sim 10^{8}$ Bq

- Activation lower than CERN's limits

Radiation Studies for horn/target gallery