ESS neutrino Super Beam plus

Co-funded by the European Union

WP3 : Target Station and Pion Extraction

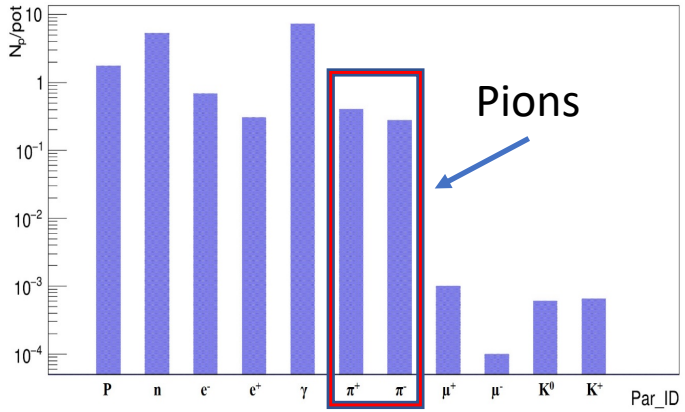
"Target Station Progress"

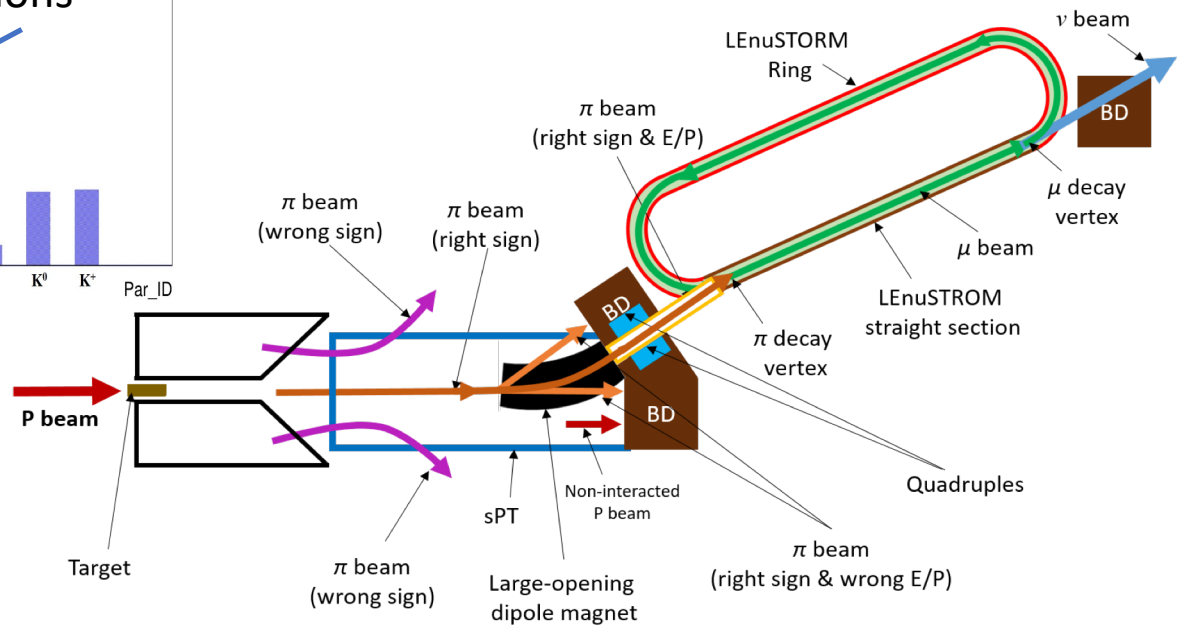
Eric Baussan on behalf WP3+ Members

ESSnuSB+
2nd Annual Meeting
Hamburg (23-27/09/2024)

Conceptual Design of the Target Station gor the ESSnuSB+ project

Co-funded by the European Union





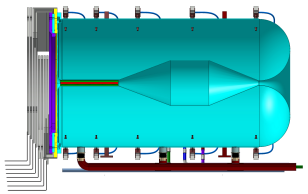
Goals:

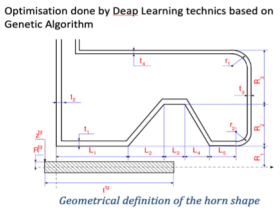
- Produce π^+/π^- high intensity beam
- Feed the LEnuSTORM ring
- Withstand the energy deposition from the 1.25 MW proton beam on the one horn/target system

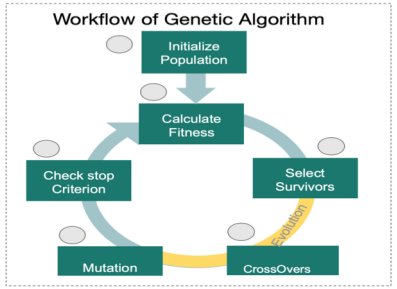
Requirements:

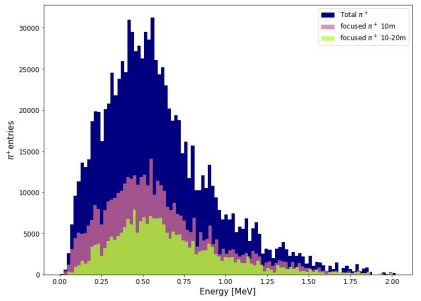
- Optimisation of the hadronic collector for pion production
- Design the pion extraction and deviation system
- Design the Power Supply Unit
- Radio safety studies

Horn Optimisation using deep learning method



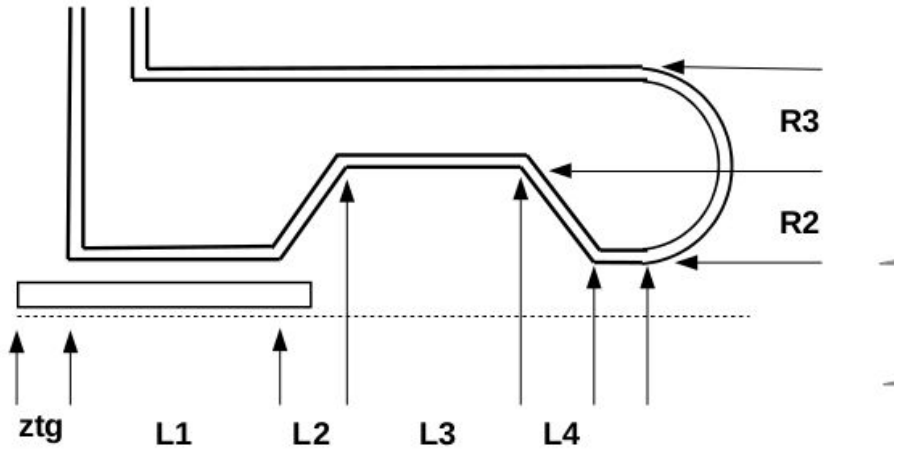






WP3 : Target Station

Horn Parameters:



For this work, the following parameters of the horn have been considered:

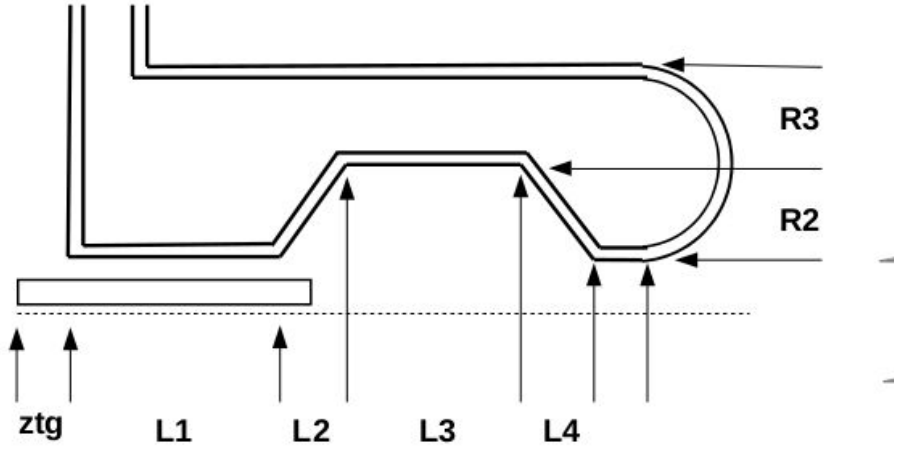
- L1, L2, L3, L4, R2, R3, ztg

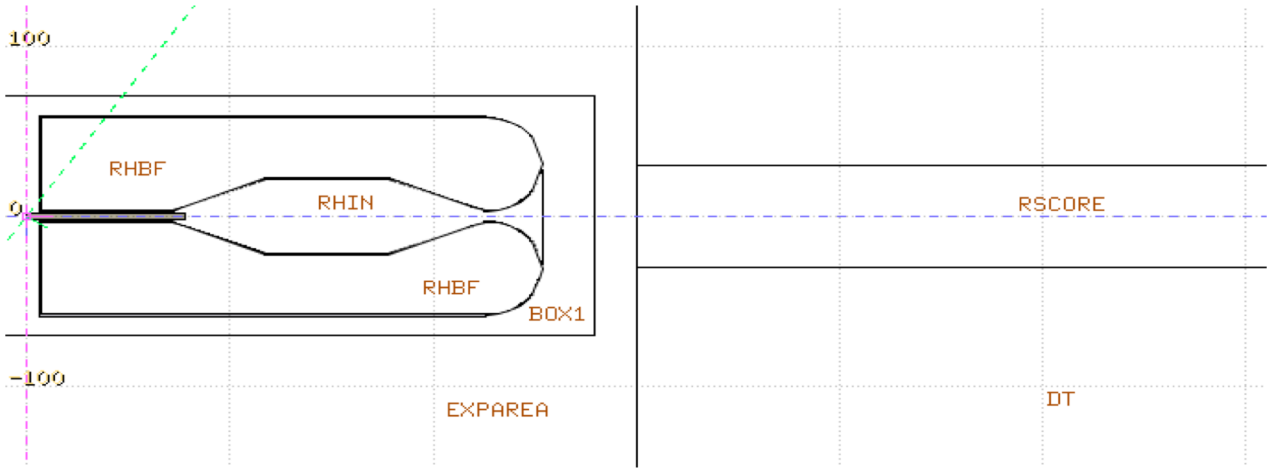
The value of the i-th parameter has been rescaled by a scale factor, which value is included in the range [0.5, 2.5], w.r.t. the corresponding baseline value.

Parameter	Baseline (cm)	Scale factor range
L1	83.08	[1.0, 2.5]
L2	46.80	[0.5, 2.5]
L3	60.30	[0.5, 2.5]
L4	47.50	[0.5, 2.5]
L5	1.08	—
R0	54.40	[0.5, 2.5]
h0	3.30	—
h1	22.10	—
ztg	8.10	[0.5, 2.5]

WP3 : Target Station

Horn Parameters:





For this work, the following parameters of the horn have been considered:

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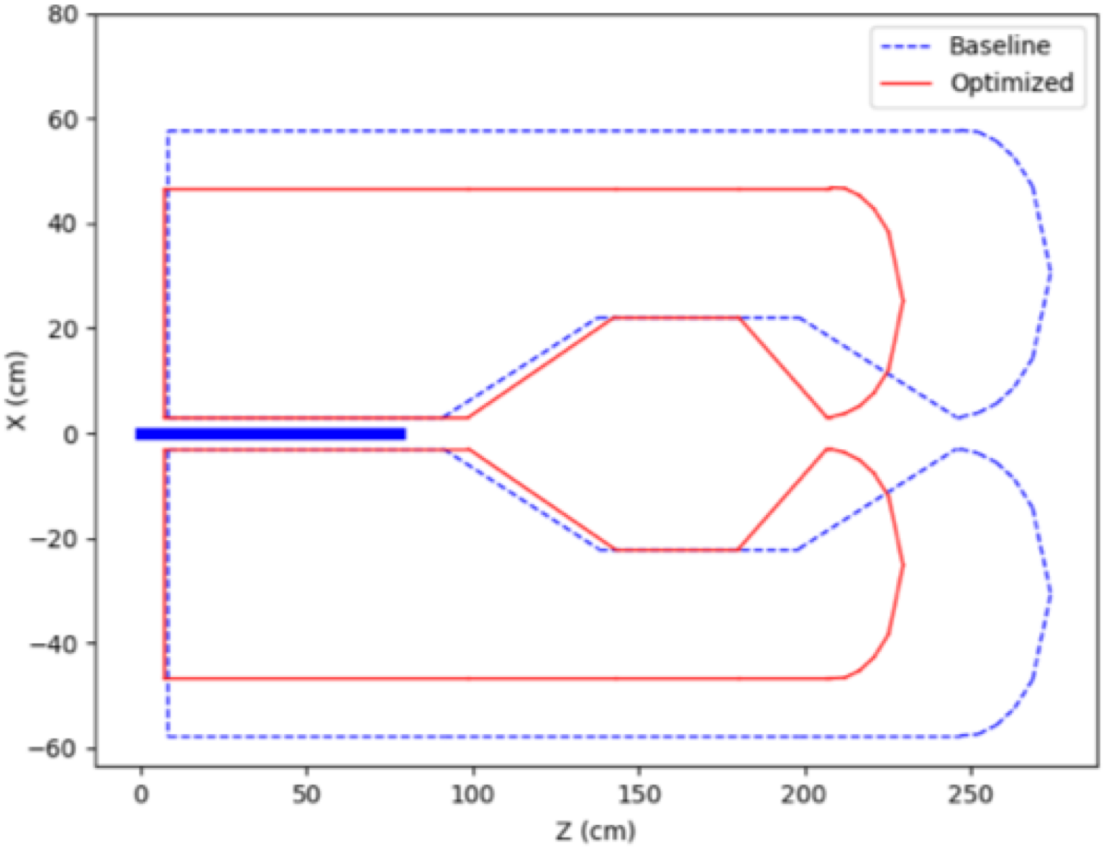
The value of the i-th parameter has been rescaled by a scale factor, which value is included in the range [0.5, 2.5], w.r.t. the corresponding baseline value.

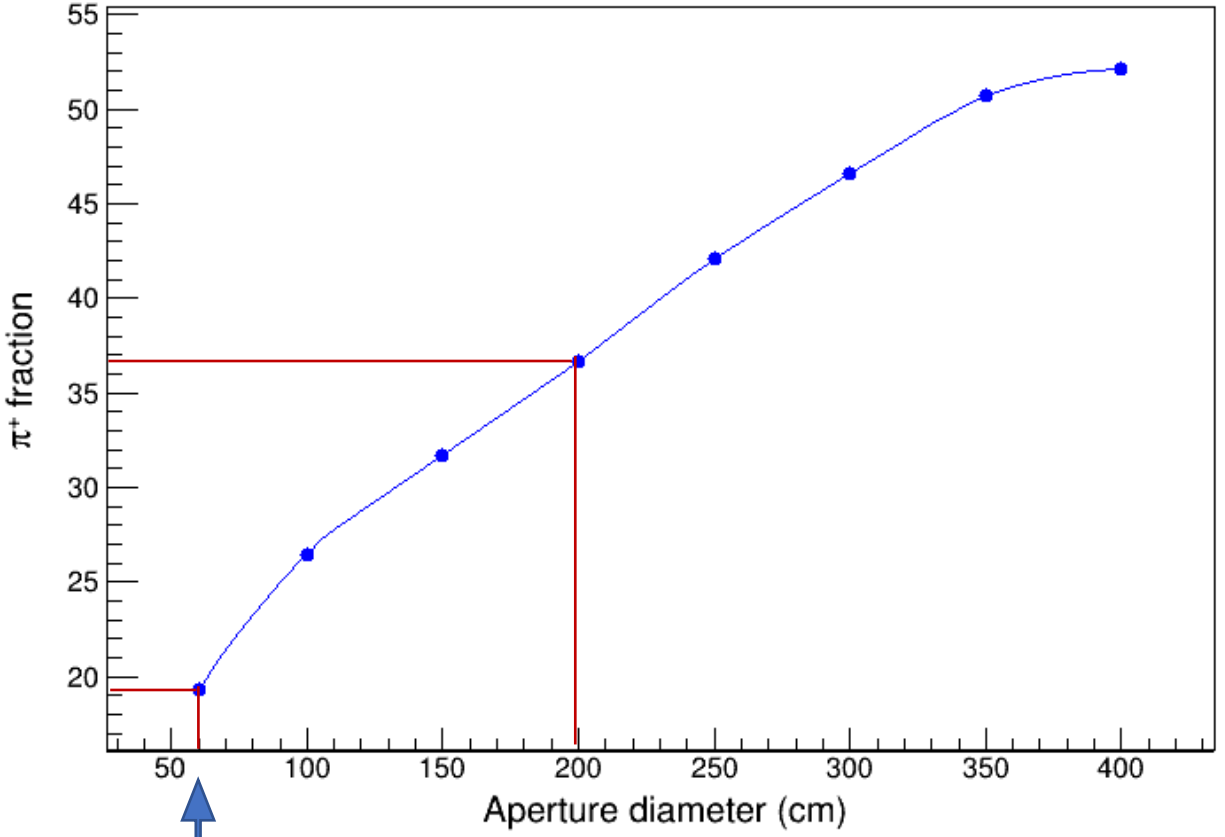
- Note: aperture at ~50 cm from horn
- Pions scored with all energies
- Figure of merit for optimization:

$$f_{\pi^{\pm}} = \frac{N_{\pi^{\pm}}^{Scored}}{N_{\pi^{\pm}}^{Target}}$$

Note: Current is fixed at 350 kA
Parameters h0, h1 and L5 are fixed

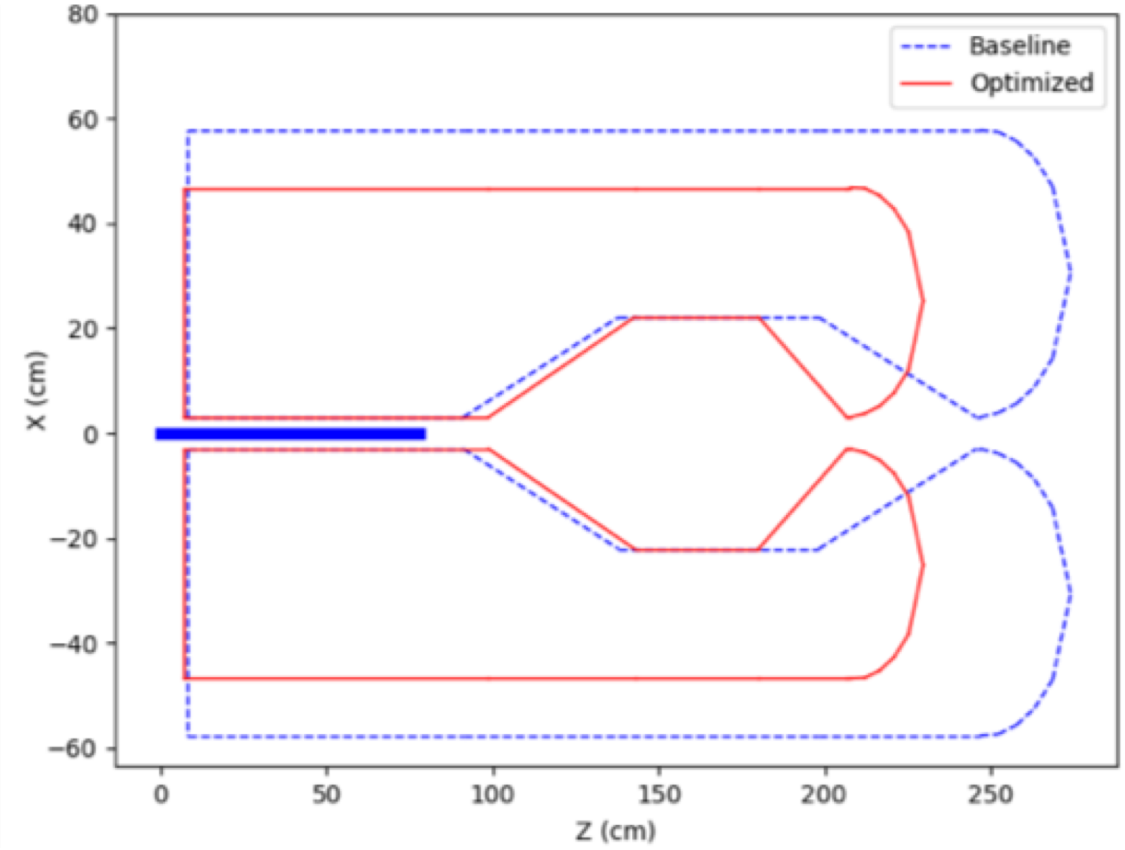
WP3 : Target Station





Optimized horn

WP3 : Target Station



Reshaped horn

Parameter	Baseline (cm)	Scale factor range	Best fit (cm)
L1	83.08	[1.0, 2.5]	91.66
L2	46.80	[0.5, 2.5]	43.99
L3	60.30	[0.5, 2.5]	37.38
L4	47.50	[0.5, 2.5]	26.60
L5	1.08	—	1.08
R0	54.40	[0.5, 2.5]	43.52
h0	3.30	—	3.30
h1	22.10	—	22.10
ztg	8.10	[0.5, 2.5]	7.14

Parameters of the reshaped horn

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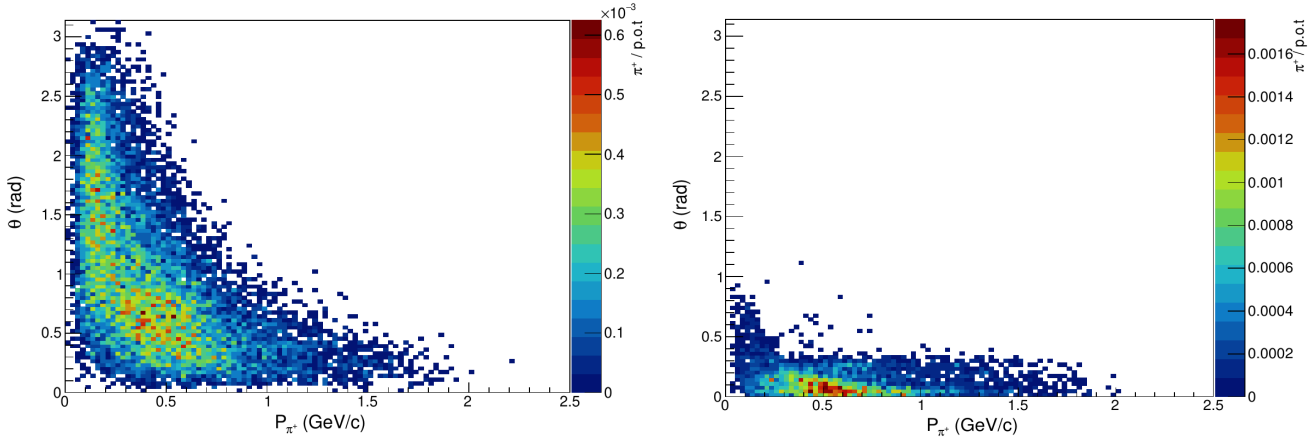
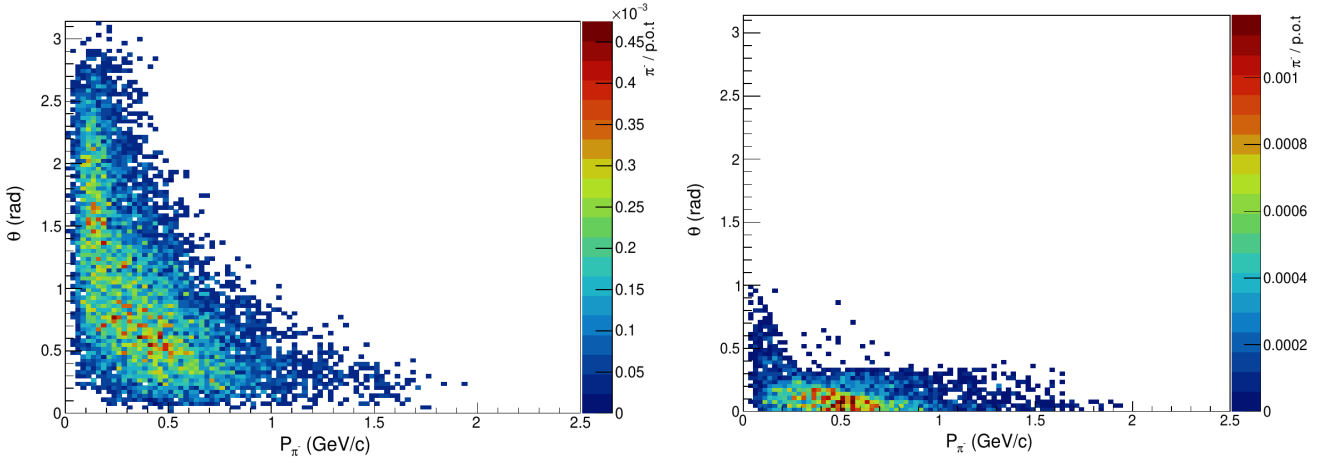
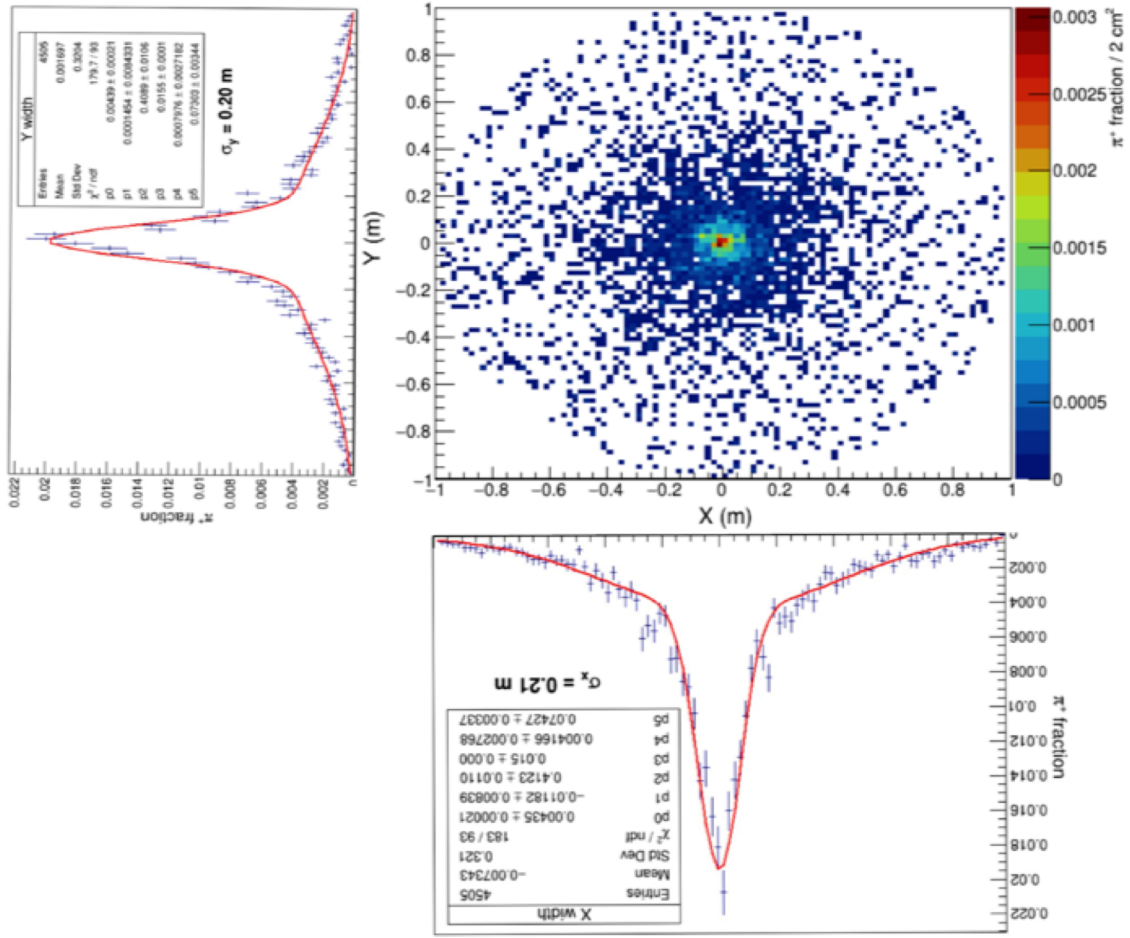


(Left) Momentum vs. angle distribution of positive pions exiting the target and (right) entering the aperture of 2m diameter 50 cm from the horn.



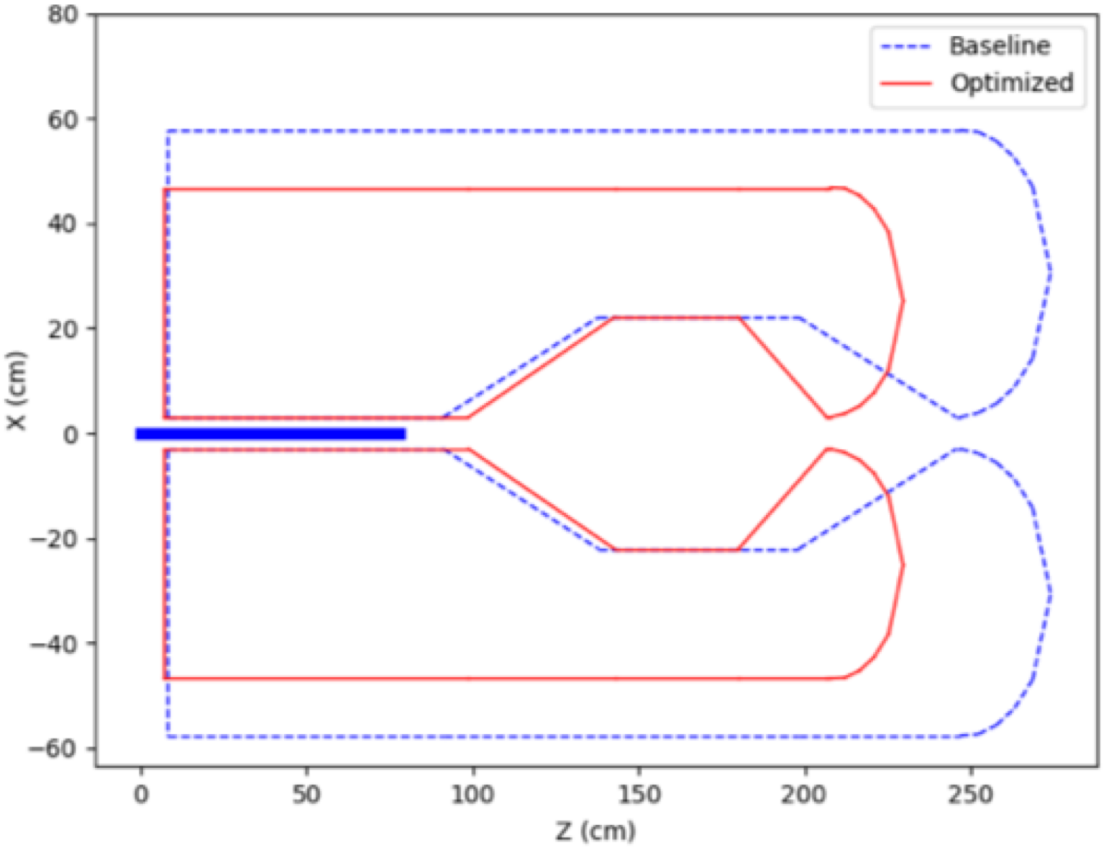
(Left) Momentum vs. angle distribution of negative pions exiting the target and (right) entering the aperture of 2m diameter 50 cm from the horn.

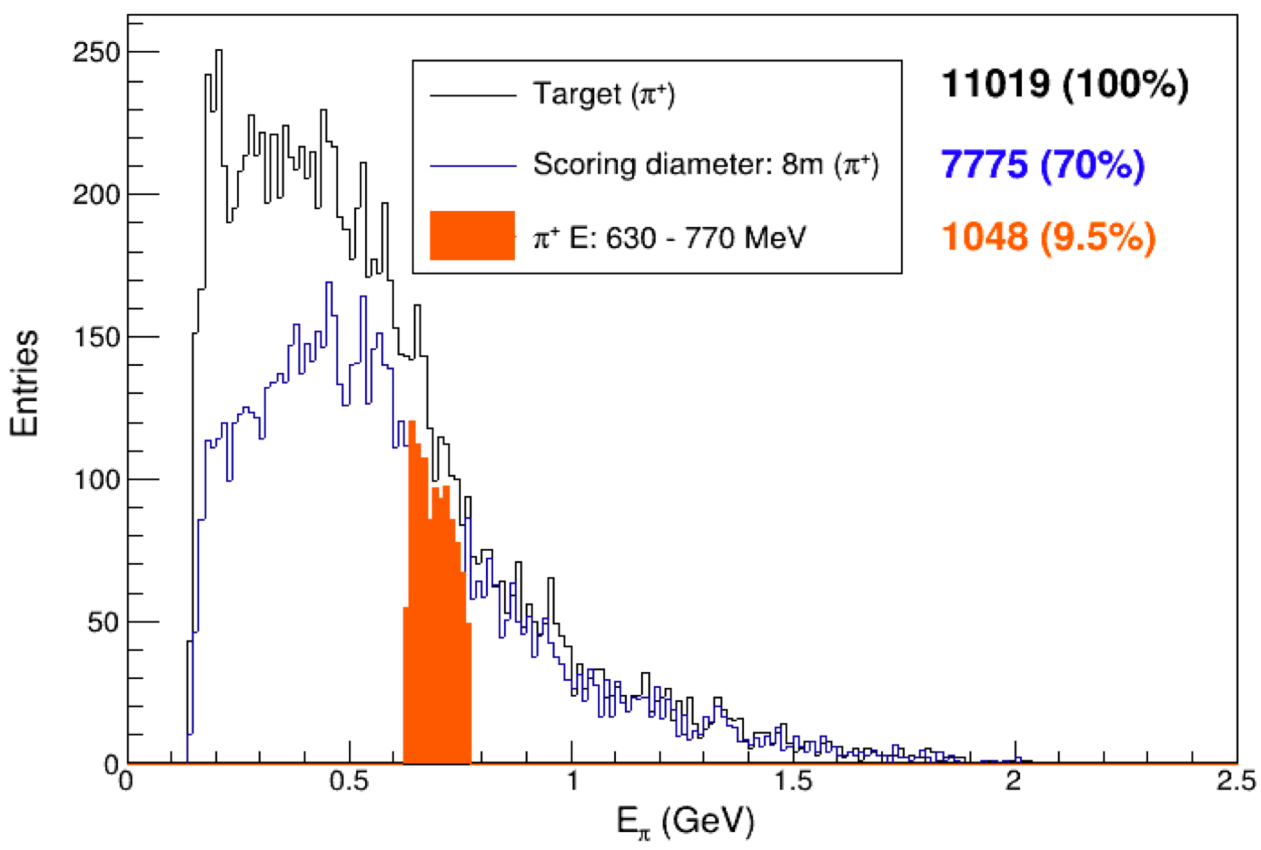


Pion beam spatial distribution at the entrance of the magnetic dipole. Upper and left plots show the projections on the X- and Y-axis of the pion beam distribution with Gaussian fit.

WP3 : Target Station

p.o.t: 4*e4

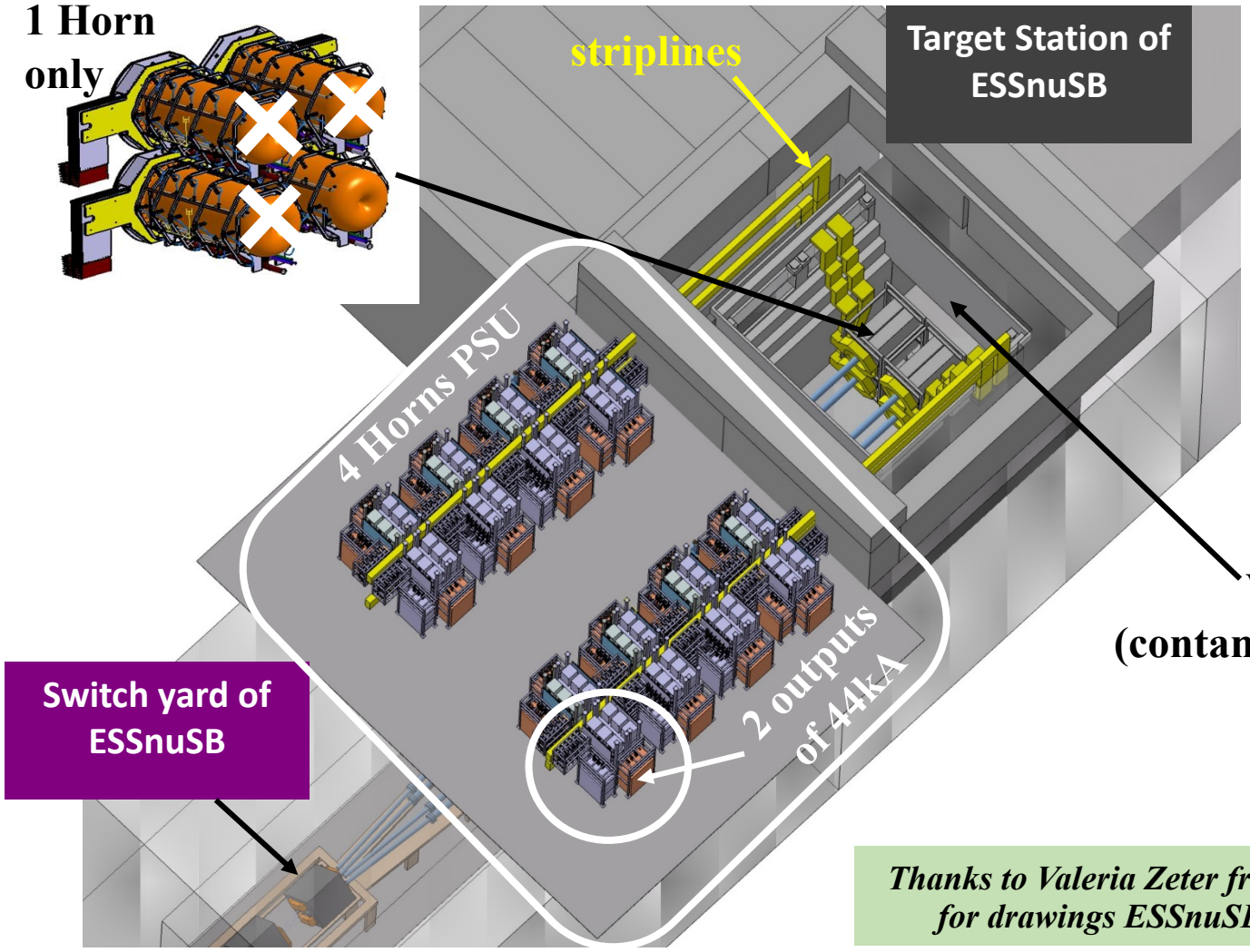




Region of Interest : 700 ± 70 MeV => ~2.7% pions in 60 cm aperture

Power Supply Unit

WP3 : Target Station

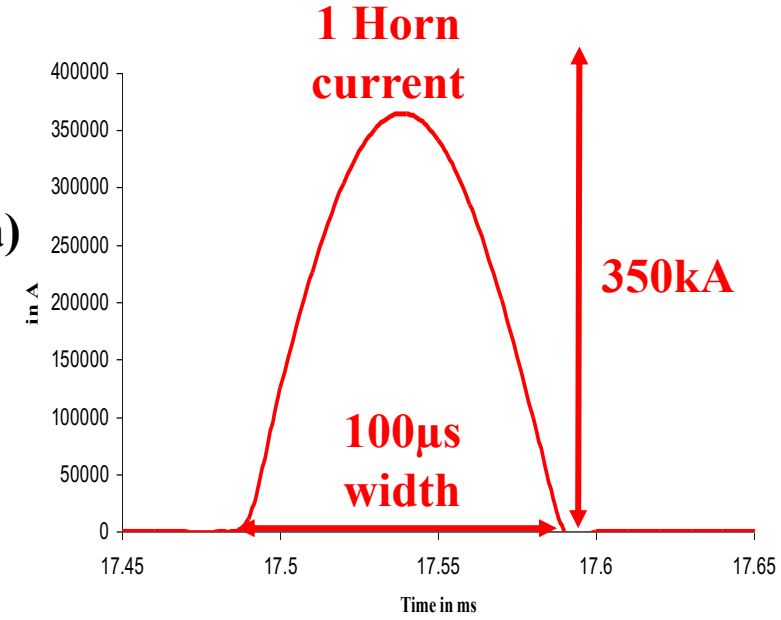


(P.Poussot)

Thanks to Valeria Zeter from IPHC for drawings ESSnuSB PSU

⇨ **ESSnuSB+ PSU specifications**

- **1 horn pulsed @ 14Hz**
- **supply 1/2 sinusoid 350kA peak current, 100µs width**
- **high RMS current to the horn: 9,3kA**
- **long lifetime of 3,6 billions cycles (300daysX10years @ 14Hz)**



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⇨ Voltage of capacitor in an oscillation circuit is governed by the general equation:

$$\frac{d^2V}{dt^2} + 2m\omega\frac{dV}{dt} + \omega^2 V = 0 \quad \text{with} \quad \omega = \frac{1}{\sqrt{LC}} \quad \text{and} \quad m = \frac{R}{2}\sqrt{\frac{C}{L}}$$

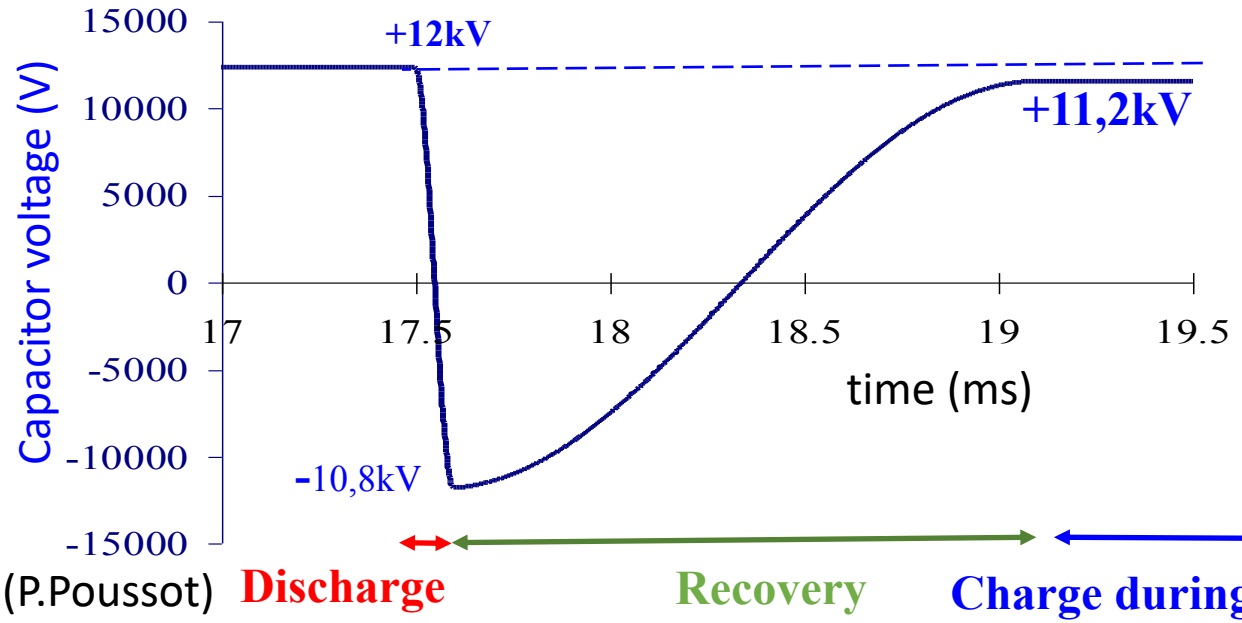
$$i(t) = V_o.C.\omega.e^{-m\omega t}\sin\omega t$$

$$\frac{di(t)}{dt} = V_o.C.\omega^2.e^{-m\omega t}(\cos\omega t - m\sin\omega t)$$

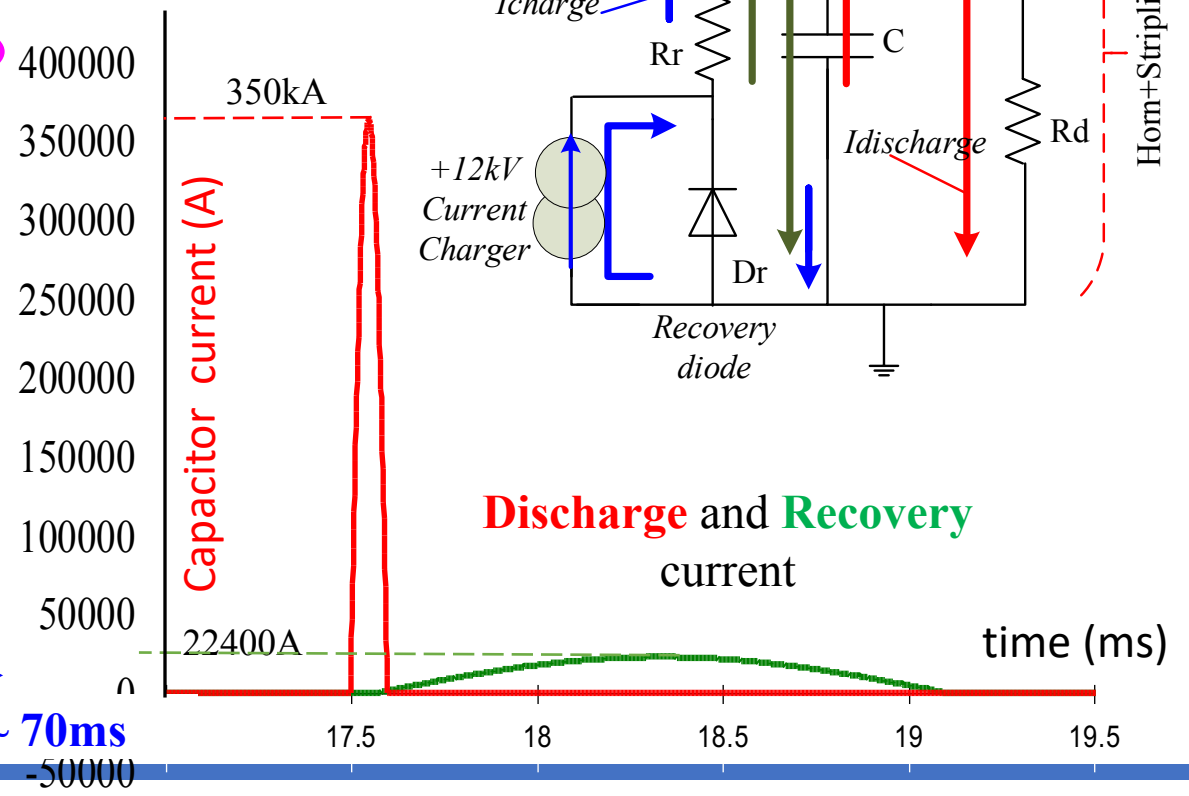
☞ peak current: $I_{peak} = V_o\sqrt{\frac{C}{L}}$

☞ final voltage: $V_{end}(T_{end}) = -V_o.e^{-m\pi}$

☞ dI/dt(t=0): $\frac{di(t=0)}{dt} = \frac{V_o}{L}$



(P.Poussot)



Discharge and **Recovery** current

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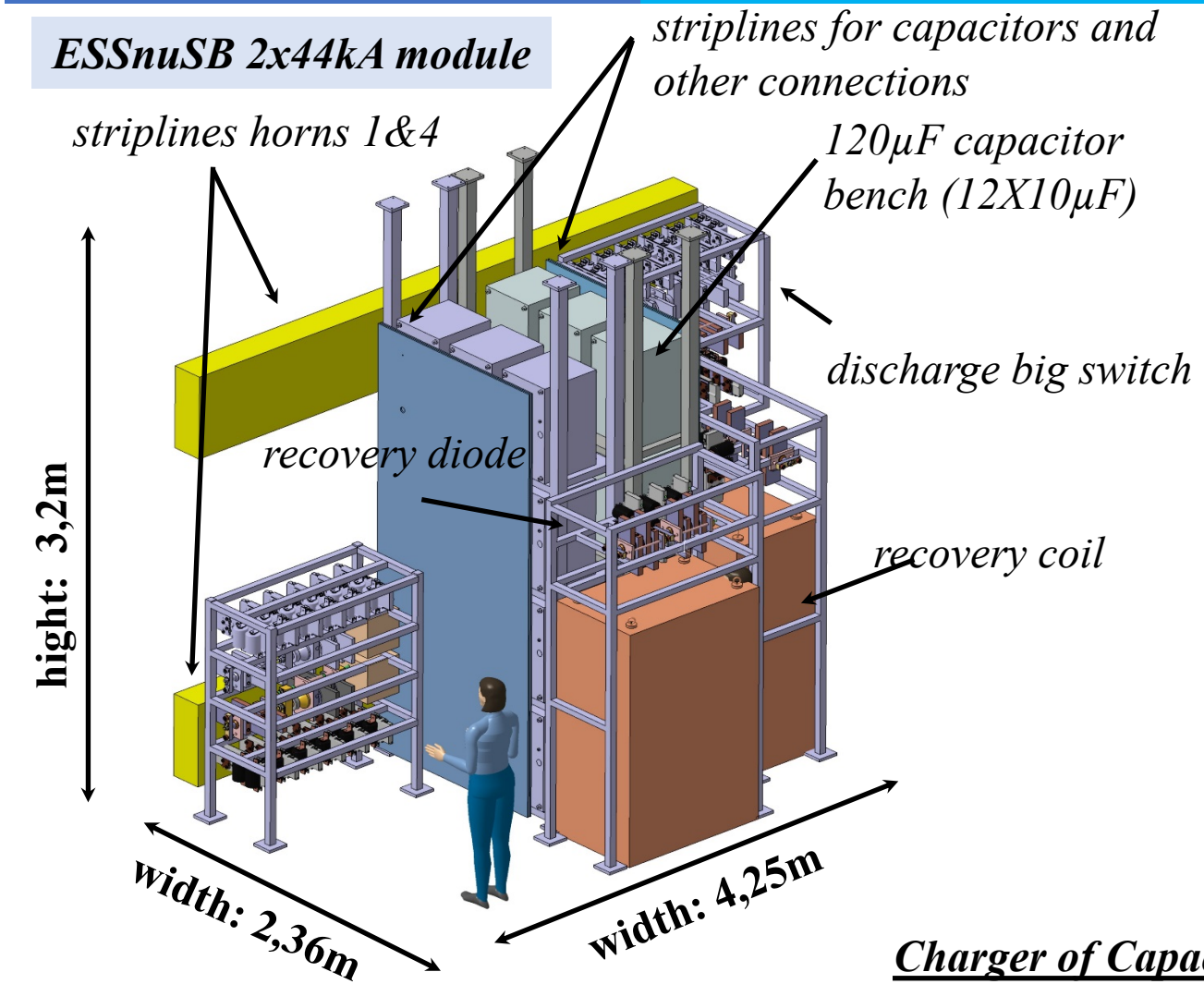
ESSnuSB 2x44kA module



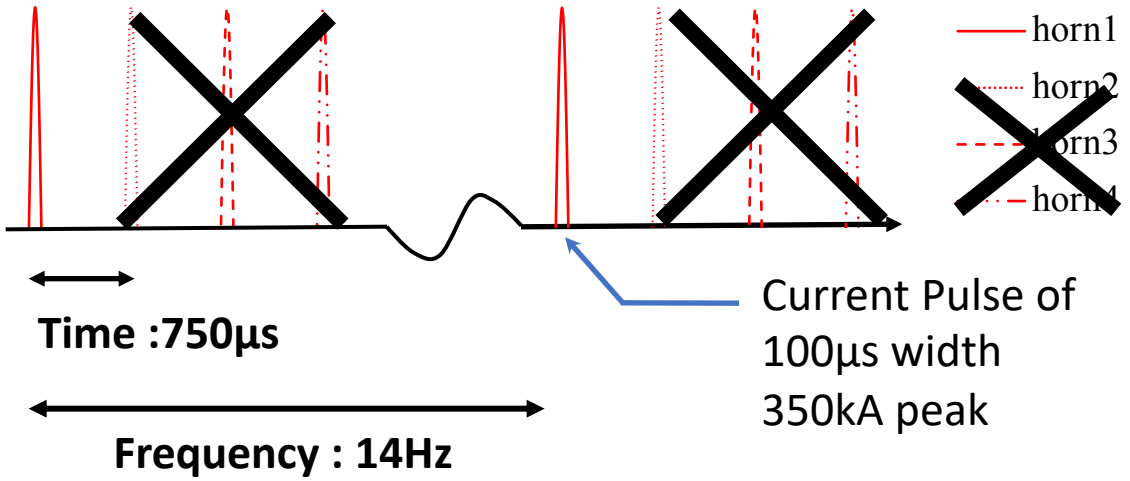
(P.Poussot)

For ESSnuSB+

- *module reduced to 1 output of 44kA*
- *update dimensions of PSU room: 8 Modules branched in parallel to deliver 350kA*
- *update solution of bigswitch for increasing electrical safety margin*
- *update definitions and performances (stability of regulation) of the capacitor bench current charger*

Charger of Capacitor not drawned (dimensions width*depth*high ∽ 0,5*0,75*0,5m)

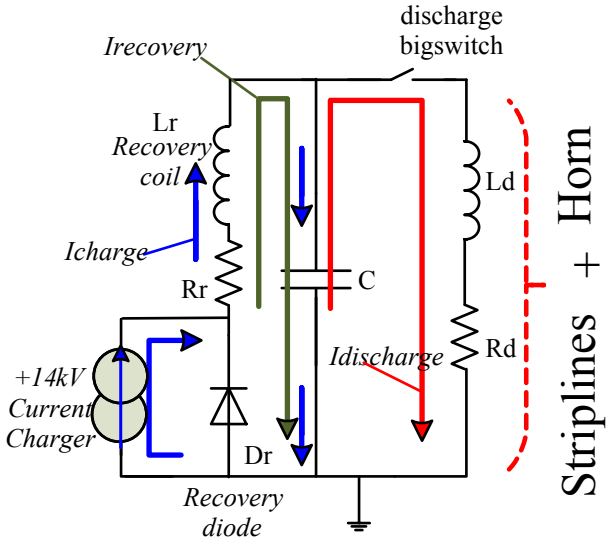
WP3 : Target Station



Ipeak: 350kA C=1000µF	Baseline (Euronu)	Update (EssnuSB)	ESSnuSB+
Ld, µH	1,041	1,47	<< 1,5
Rd, mΩ	0,89	1	<< 1
Vc/-Vc, kV	+12/-11,5	**13,7/-13,2**	<< 14kV
$I_{discharge}$ dI/dt (kA/µs)	11,5	**9,3**	<< 11,5
$I_{recovery}$ peak (kA)	22,4	**25,6**	<< 26

Electrical characteristics 1 Horn (ESSnuSB)	
Lhorn	1,35µH
Rhorn	0.352mΩ
I rms at 14Hz	9.3kA

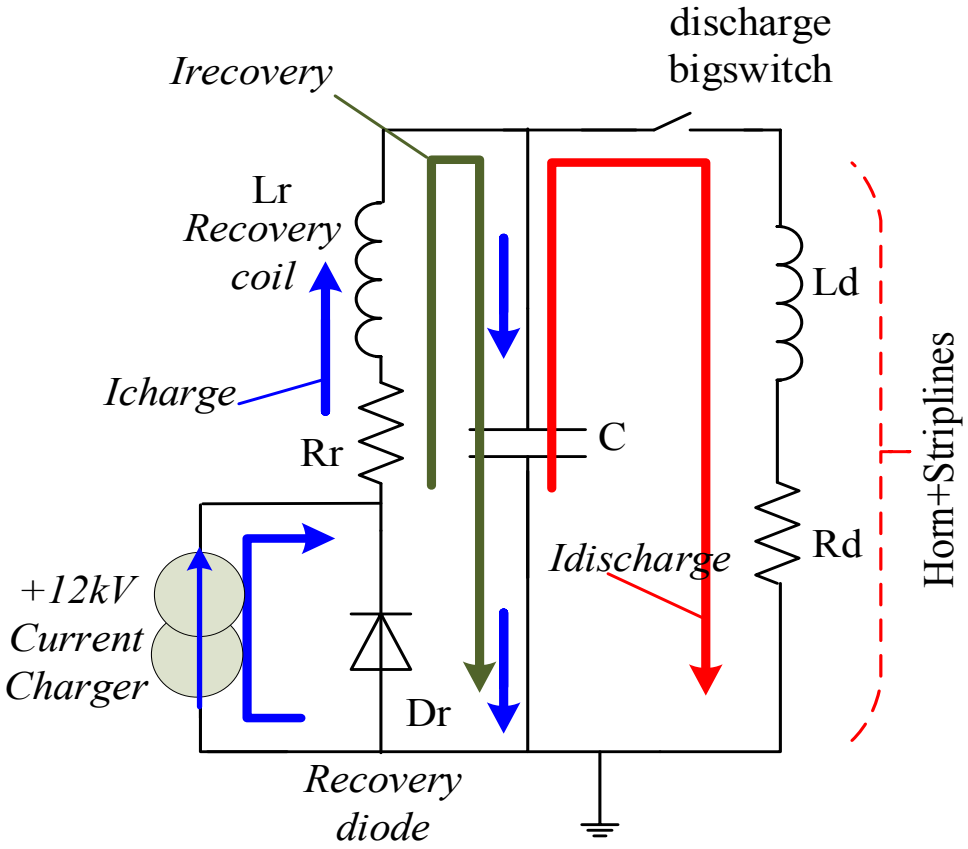
(P.Poussot)



Electrical margin safety		Baseline (Euronu)	Update (EssnuSB)
Discharge Bigswitch	Vdrm	47%	39%
	|Vrrm|	25%	**16%**
Recovery diode	|Vrrm|	50%	42%

⤻ +-14kVmax applied on horn

WP3 : Target Station

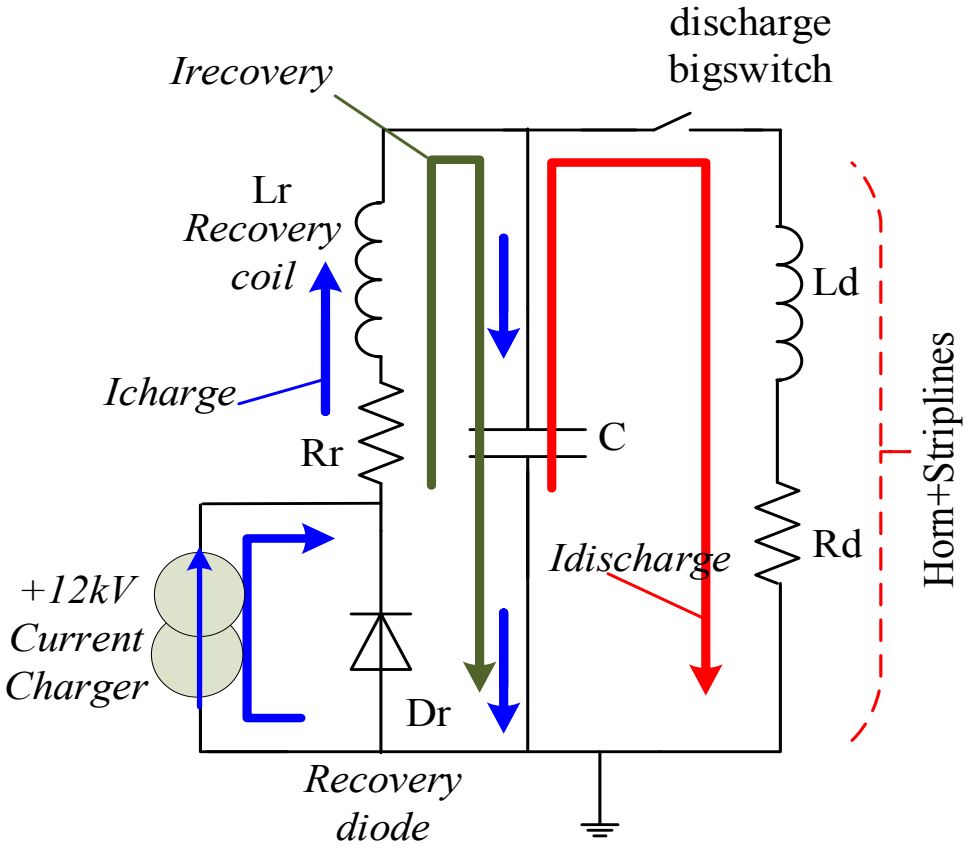


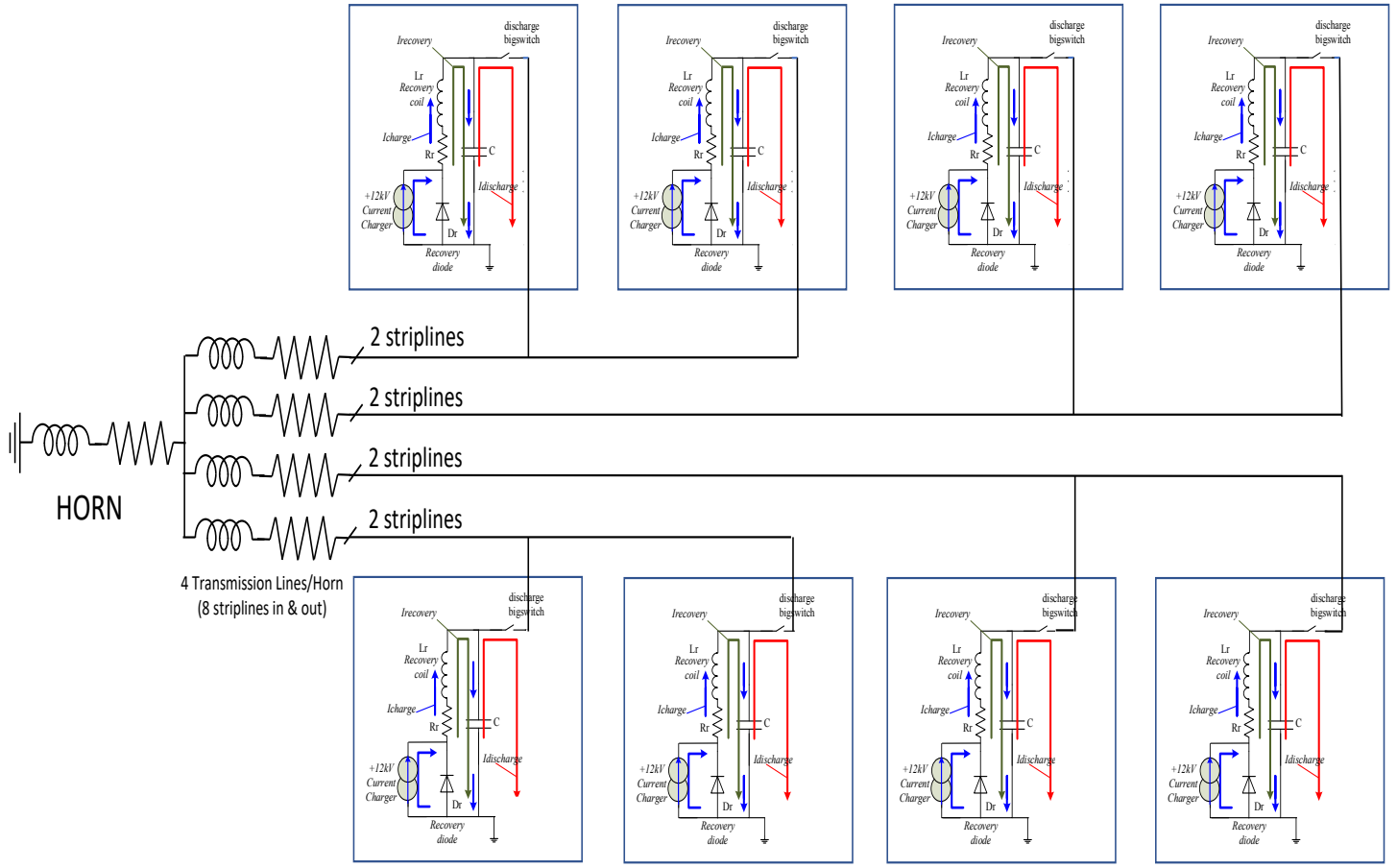
New values for the electrical components

C = 1120 µF	Charging	Discharging	Recovery
Ec = 10kV	Lc = 25 mH	Ld = 0.911 µH	Lr = 0.25 mH
Ipeak = 350 kA	Rc = 0.475 Ω	Rd = 0.866 mΩ	Rr = 5.94 mΩ
m	0.050	0.0152	0.0063
ω (rd/s)	189	31300	1890
dI(t=0)/dt (A/µs)	0.014	10955	38
V_0 (V)	9332	10000	-9518
V_{end} (V)	10000	-9518	9332
I_{peak} (A)	69	350 k	20.14 k
IRMS (A)	23.46	9276	2173

=> No impact on the PSU concept due to the change of the horn shape

WP3 : Target Station





Layout of the transmission and strip lines for one horn providing 350 kA at 14 Hz.

WP3 : Target Station

Summary:

- Horn has been reshaped to optimize the pion fraction and lead to an overall reduction in the size of the horn.
- Small fraction of pions in the region of interest 700 ± 70 MeV at few percent level.
- Power Supply Unit has been update with respect to the new shape of the horn and no change of the concept.