Training of a neural network to model the MYRRHA LEBT for reliability improvements

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Outline

Introduction

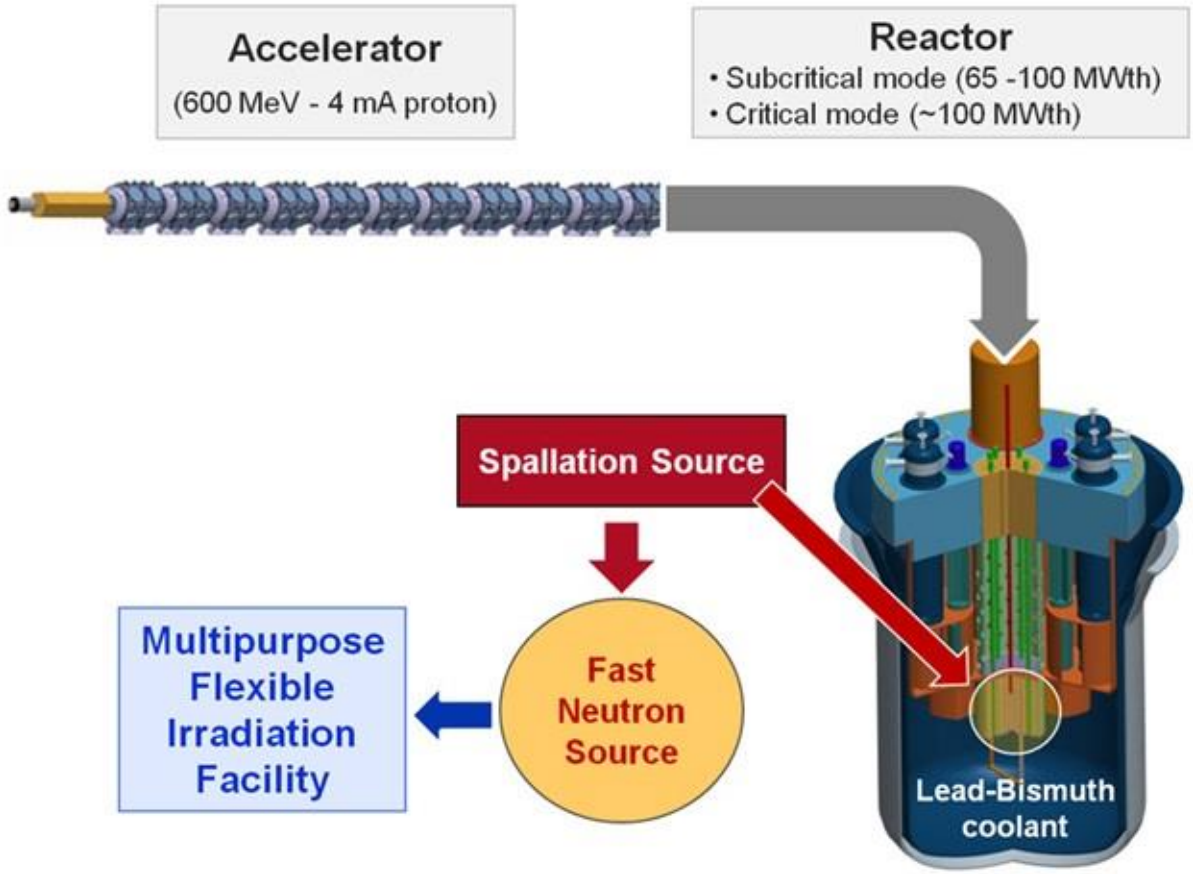
- The MYRRHA project
- Low energy beam transport line

Machine learning

- Training databases
- Network performances
- Transferability

Conclusion & Prospects

MYRRHA

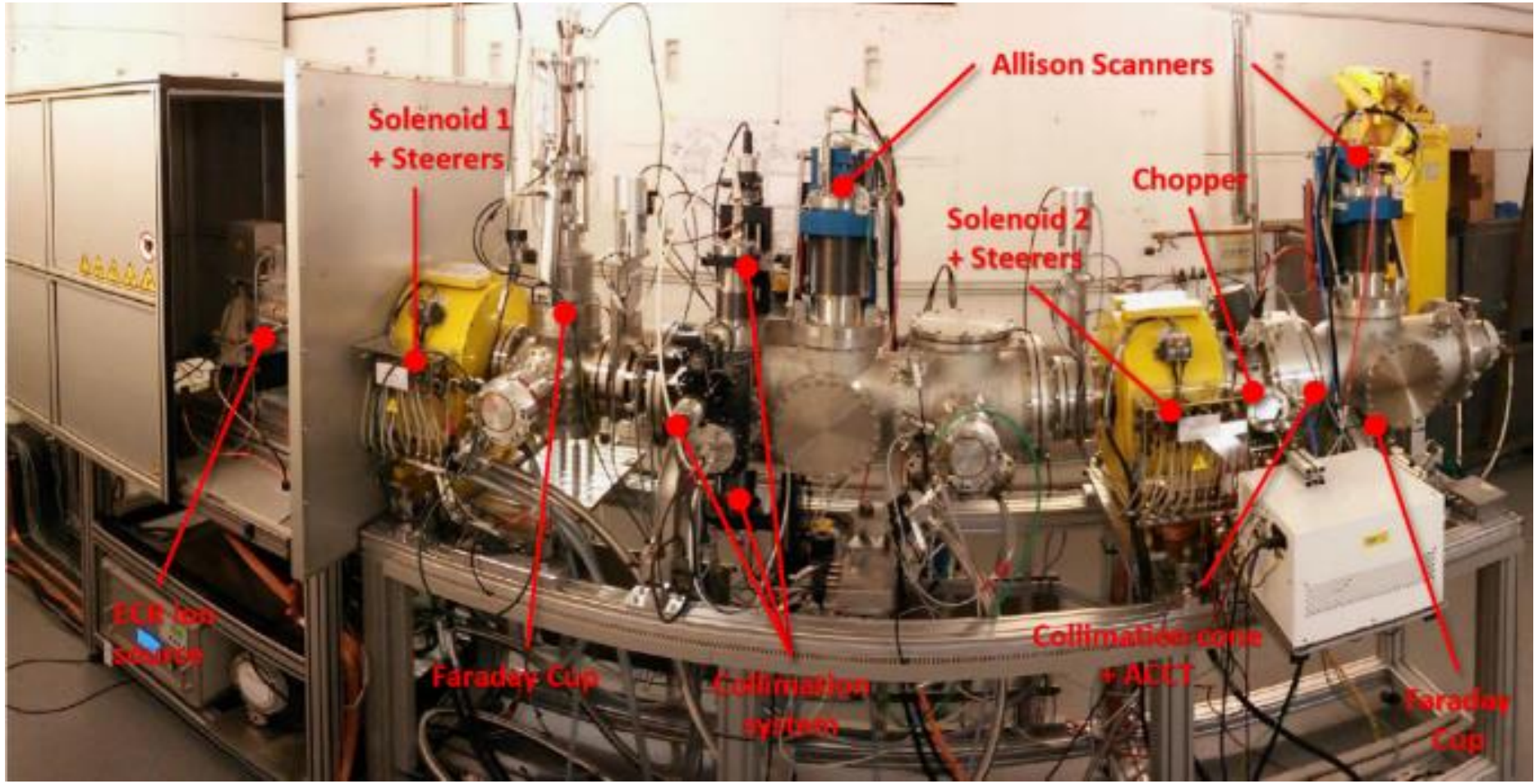


High power proton beam (up to 2.4 MW)

Proton energy	600 MeV
Peak beam current	0.1 to 4.0 mA
Repetition rate	1 to 250 Hz
Beam duty cycle	10^{-4} to 1
Beam power stability	< ± 2% on a time scale of 100ms
Beam footprint on reactor window	Circular ∅85mm
Beam footprint stability	< ± 10% on a time scale of 1s
# of allowed beam trips on reactor longer than 3 sec	10 maximum per 3-month operation period
# of allowed beam trips on reactor longer than 0.1 sec	100 maximum per day
# of allowed beam trips on reactor shorter than 0.1 sec	unlimited

Extreme reliability

Low Energy Beam Transport Line



LEBT at LPSC, Grenoble (2017)

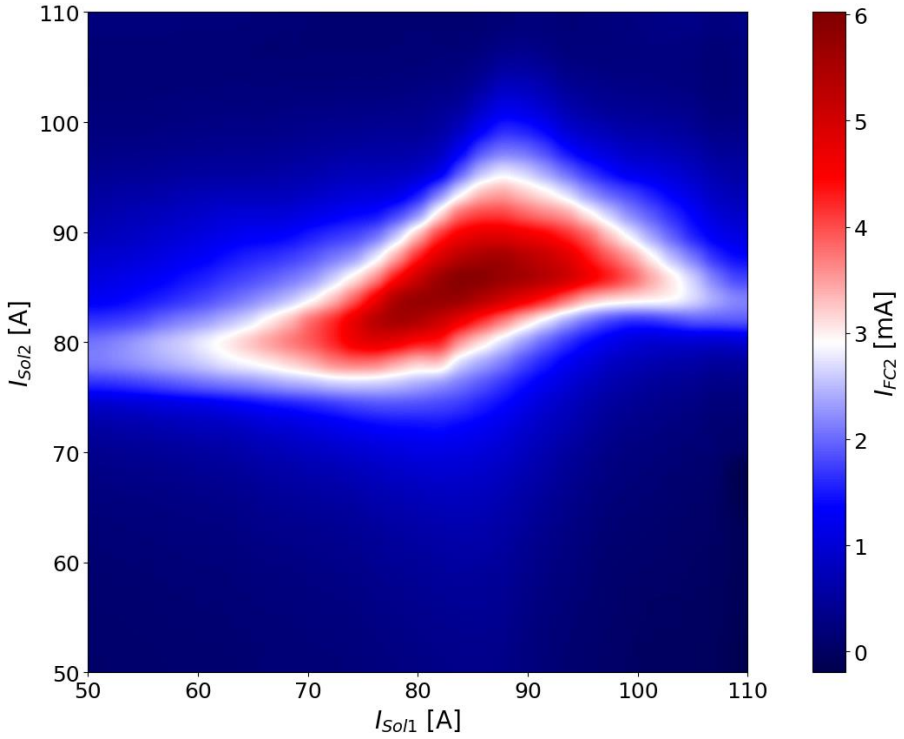
7 controls:

- Solenoids x2
- Steerers x4
- Collimator x1

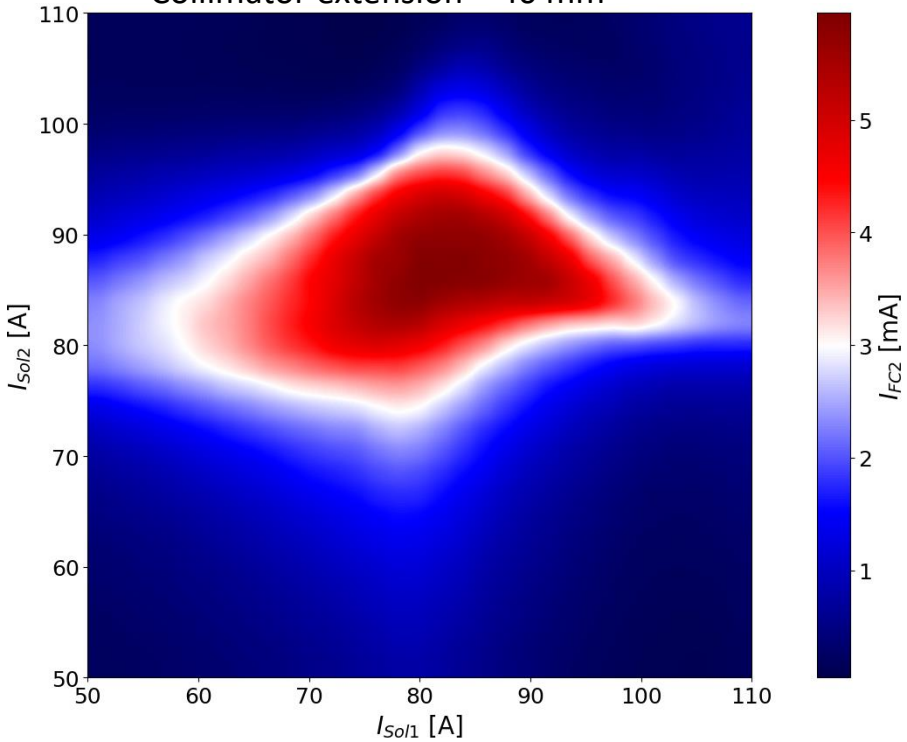
Transmission maps: solenoids

Beam current transmitted through the LEBT as a function of the solenoids focusing (current in the coils)

- $I_{Sol1}, I_{Sol2} \in [50, 110]$ A, $stepsize = 2$ A
- $I_{source} = 8$ mA
- $P = 1.2 \times 10^{-6}$ mbar
- $I_{Steerers} = 0$ A



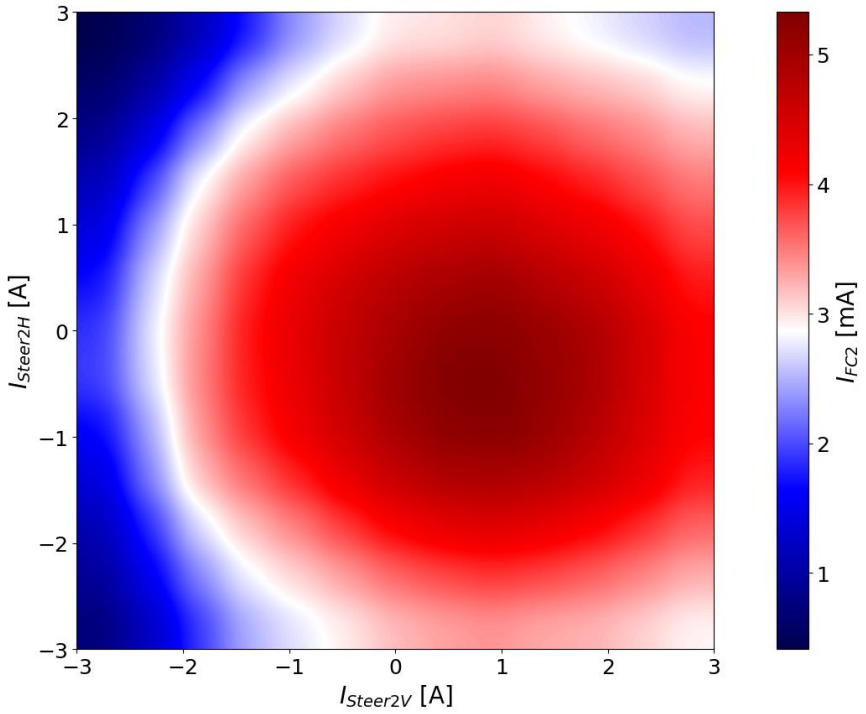
- $I_{Sol1}, I_{Sol2} \in [50, 110]$ A, $stepsize = 2$ A
- $I_{source} = 8$ mA
- $P = 1.9 \times 10^{-5}$ mbar (Ar injected for SC compensation)
- $I_{Steer2H} = -0.5$ A, $I_{Steer2V} = 0.75$ A
- Collimator extension = 40 mm



Transmission maps: Steerers

Beam current transmitted through the LEBT as a function of the current in the steerers

- $I_{Steer2V}, I_{Steer2H} \in [-3,\ \ 3]$ A, $stepsize = 0.5$ A
- $I_{source} = 8$ mA
- $P = 1.9 \times 10^{-5}$ mbar (Ar injected for SC compensation)
- $I_{Sol1} = 65.6$ A, $I_{Sol2} = 77.9$ A
- Collimator extension = 0 mm



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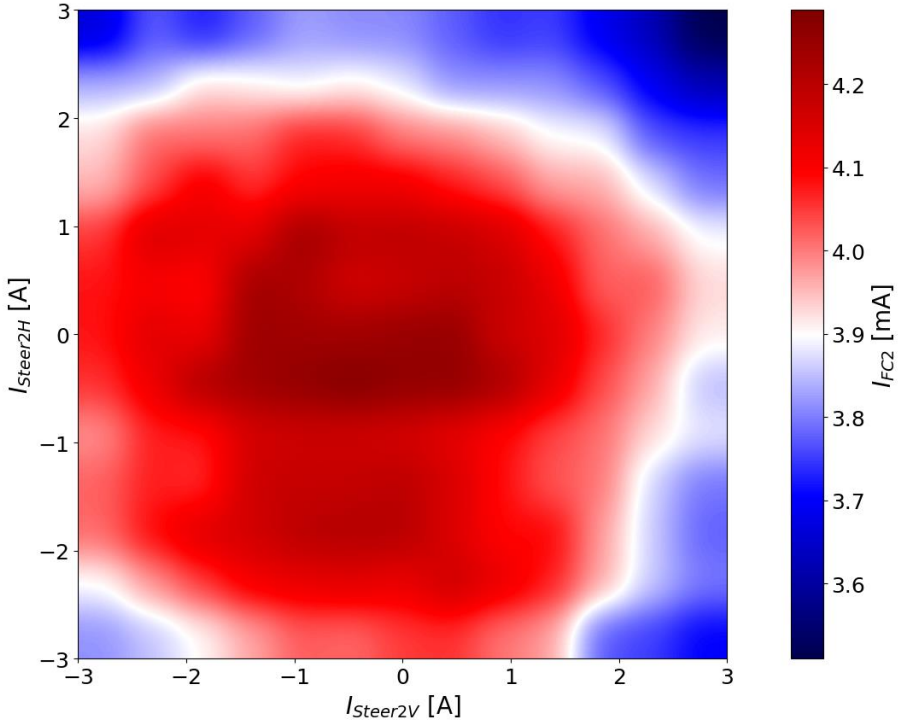


Machine Learning

- Objectives

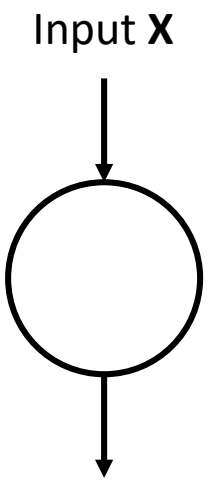
  Fast control and tuning for different linac beam modes (peak current, duty cycle)

- How ?

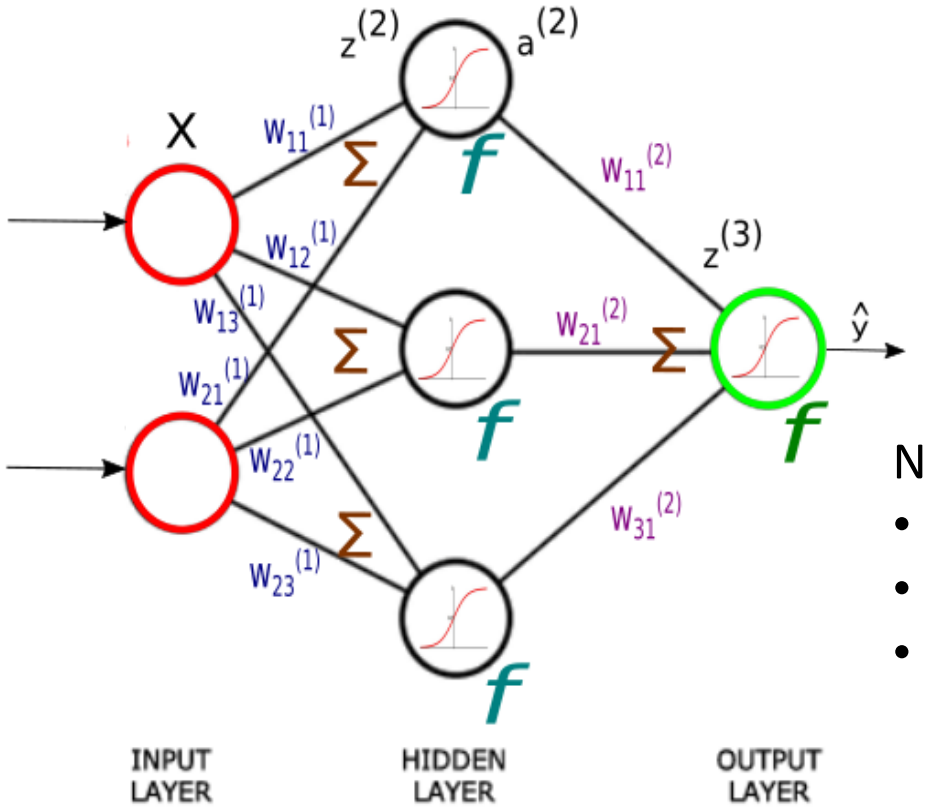
  Training of an experimental model using supervised learning

Neural Network

An artificial neuron



Output $a = f(\boldsymbol{W}\boldsymbol{X} - b)$

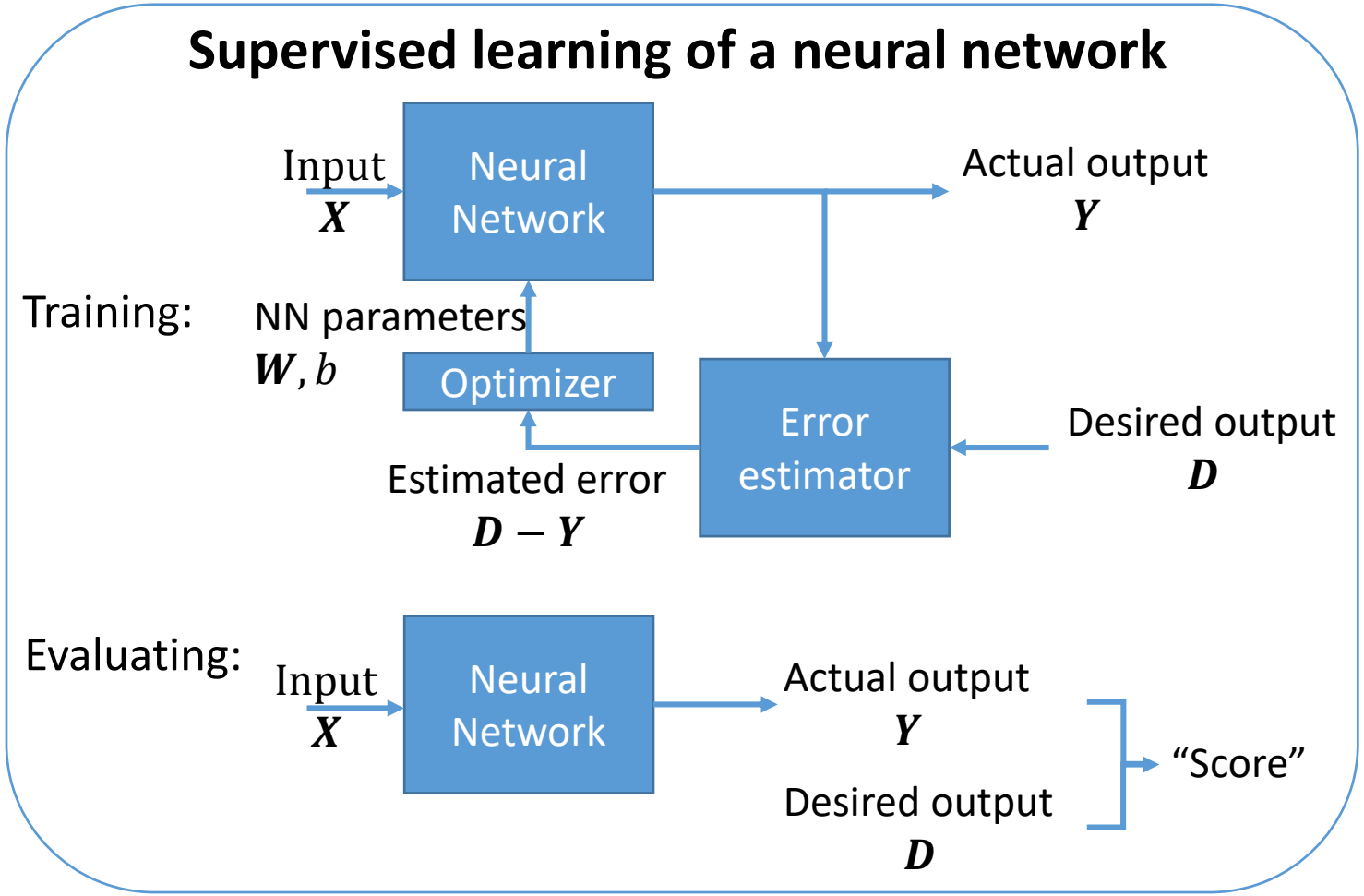


Network caracteristics:

- Dense
- ReLu (hidden layers)
- Sigmoid (output layer)

Can fit any continuous function

Supervised Learning



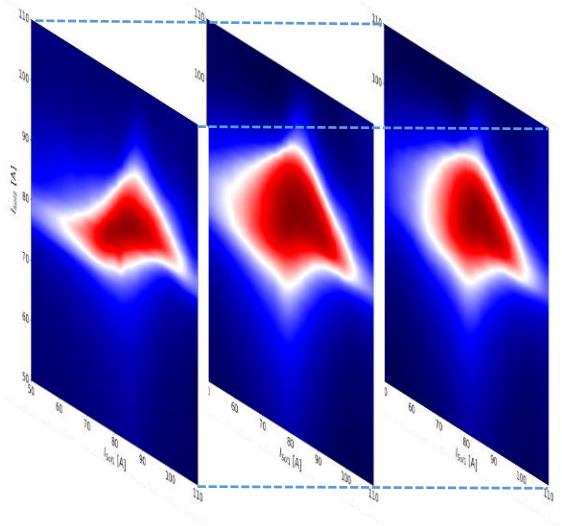
Parameters

- Learning rate: from 0.1 down to 0.001
- Error estimator: MSE
- Optimizer: SGD

Dataset

MYRRHA (SCK*CEN, Belgium)

- ~20000 measurements



Slices at different slits extensions

19 “slices” with solenoids
6 “slices” with steerers

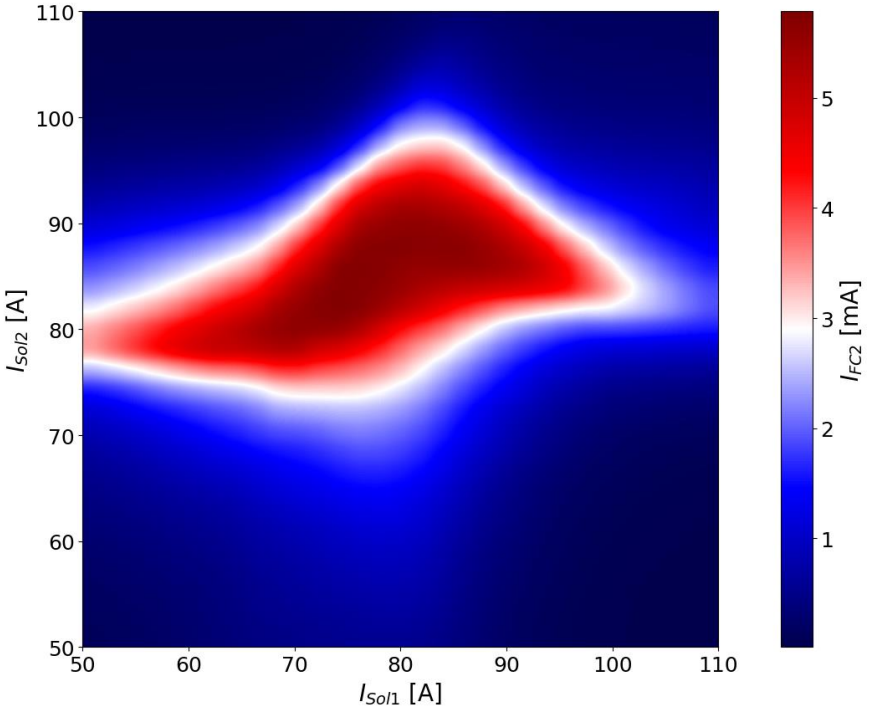
→ Dataset

- 60% → Training data
- 20% → Evaluation data
- 20% → Validation data

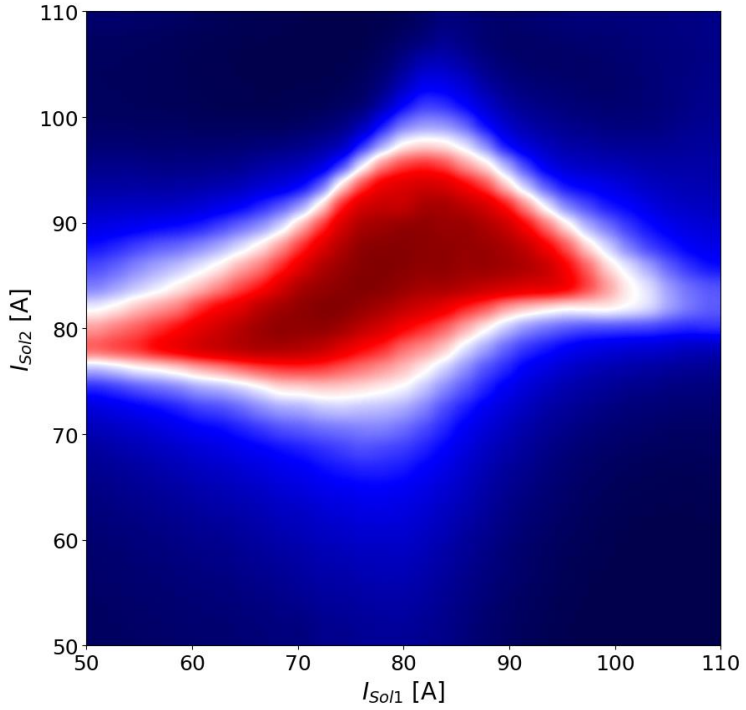
Input				Desired output
Current in steerers x4 [A]	Current in solenoids x2 [A]	Collimator opening x1 [m]	Pressure gauge x3 [bar]	Current in FC2 [A]

Model output

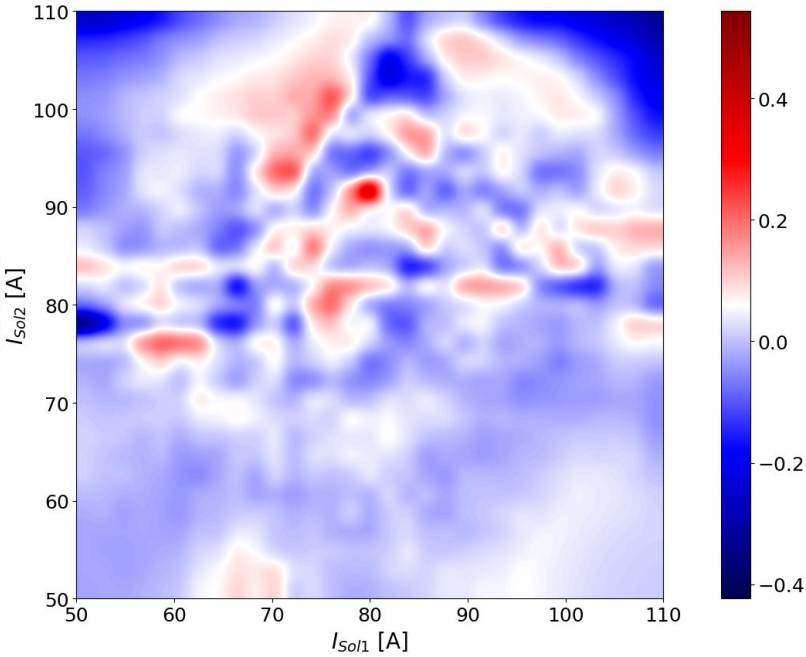
Experimental



Model



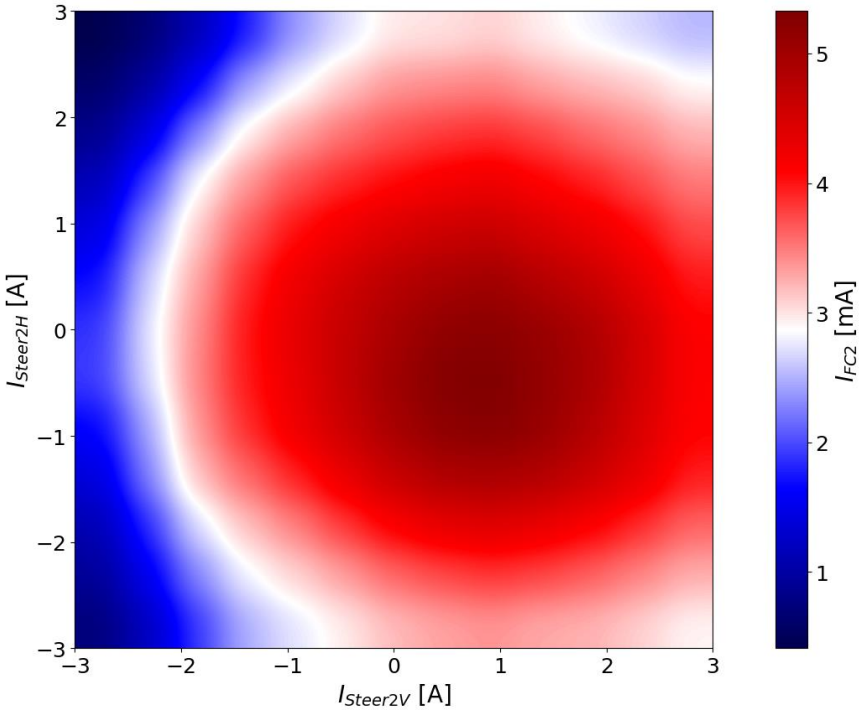
Error



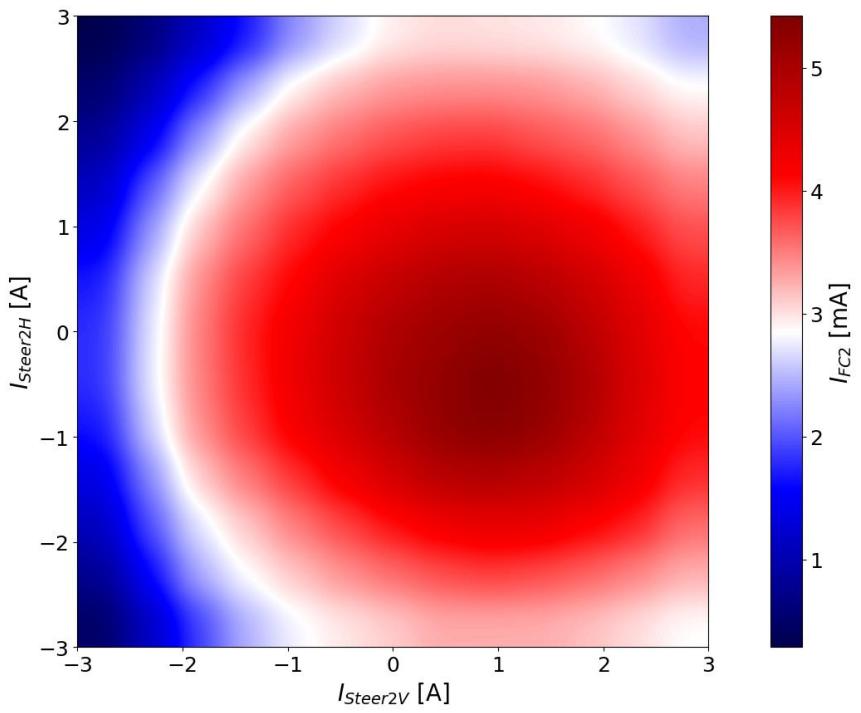
Execution time ≈ 1 ms

Model output

Experimental



Model



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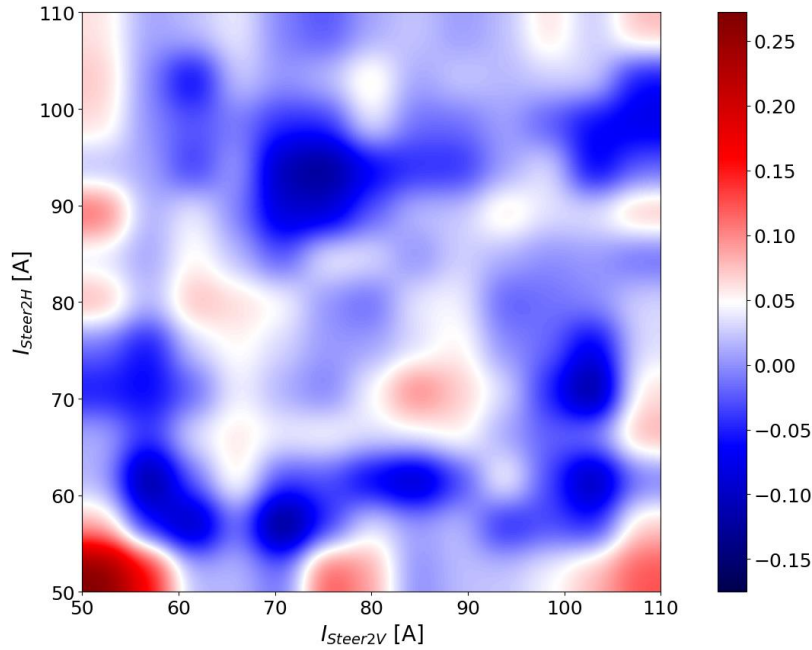
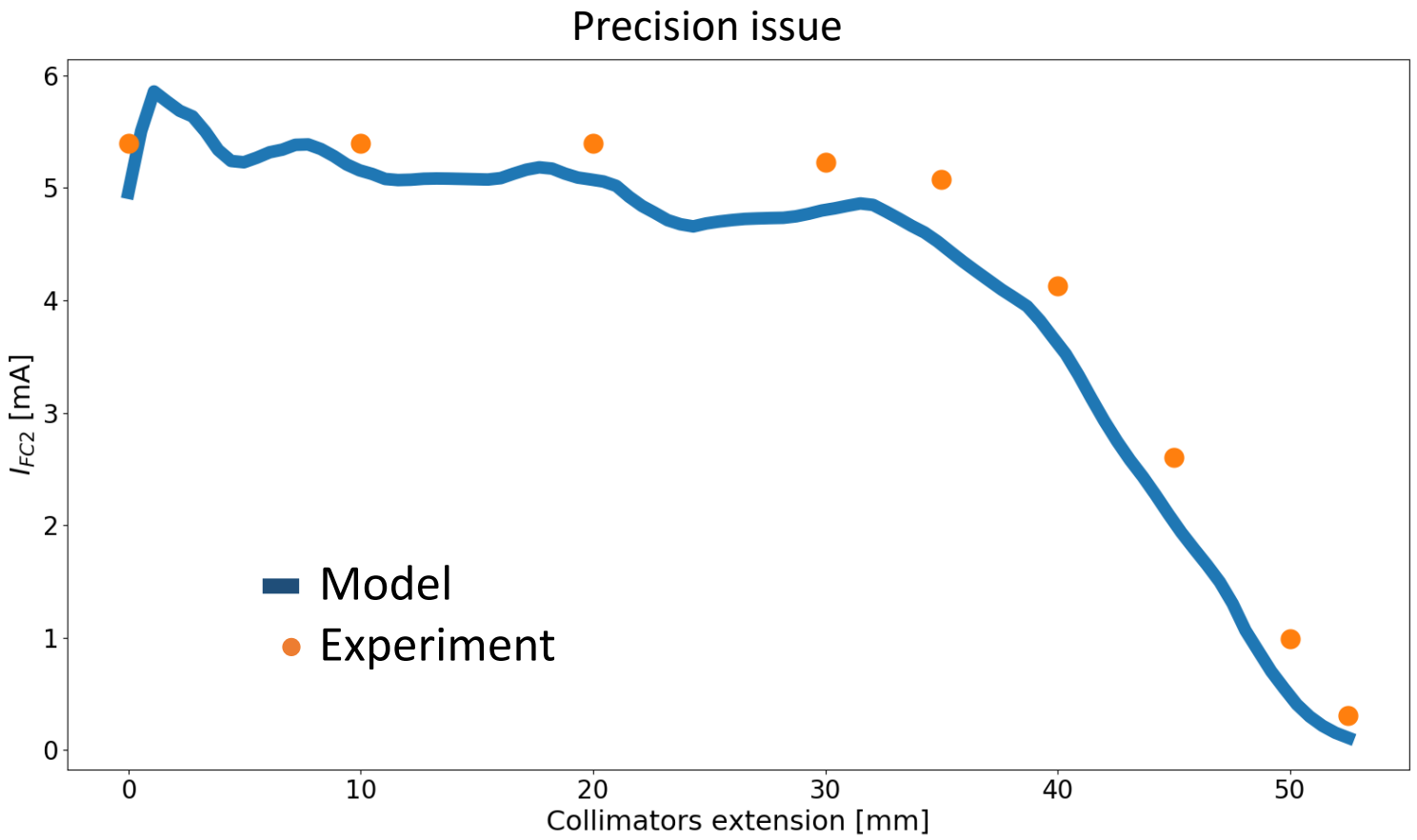


Model output : Identified issues & improvements



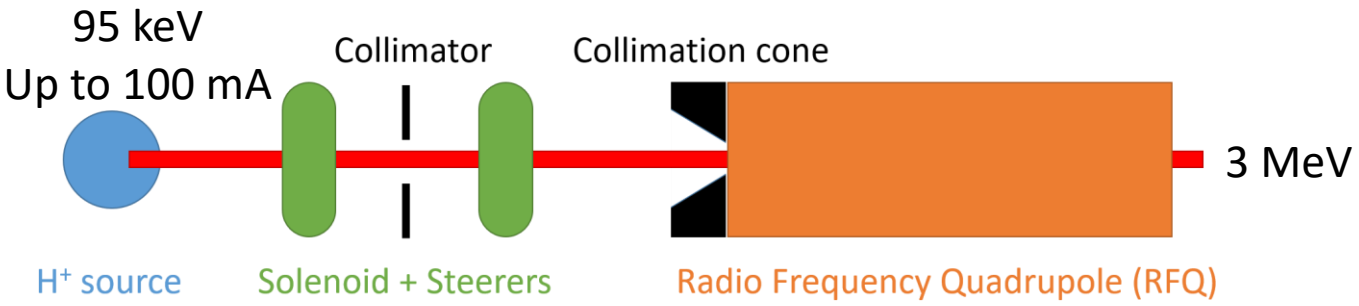
How to improve ?

More training data !

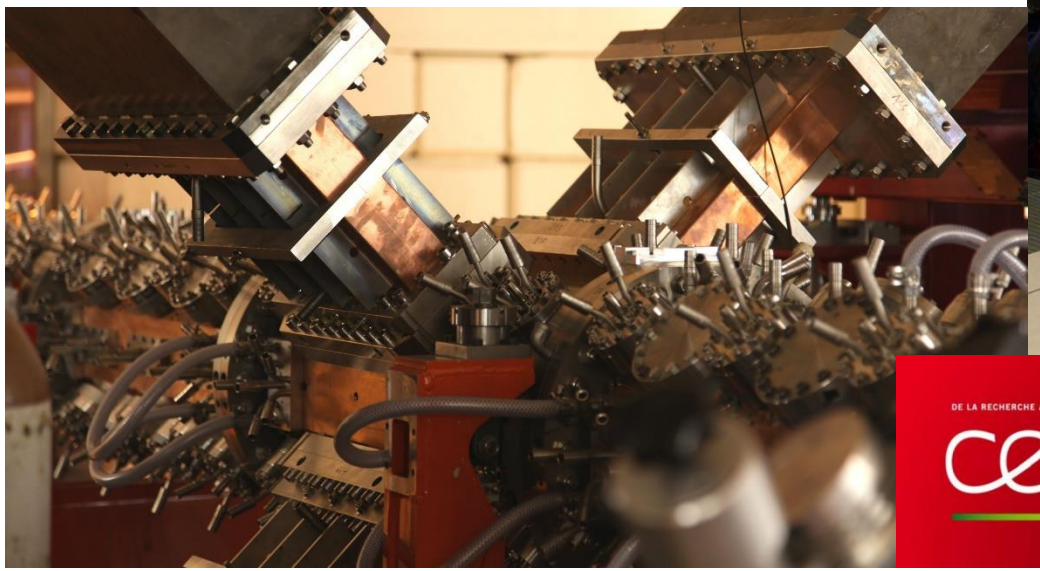
Simulation or Measurements

RFQ prospect: IPHI collaboration

Same configuration as MYRRHA (LEBT + RFQ)



IPHI @ CEA Saclay

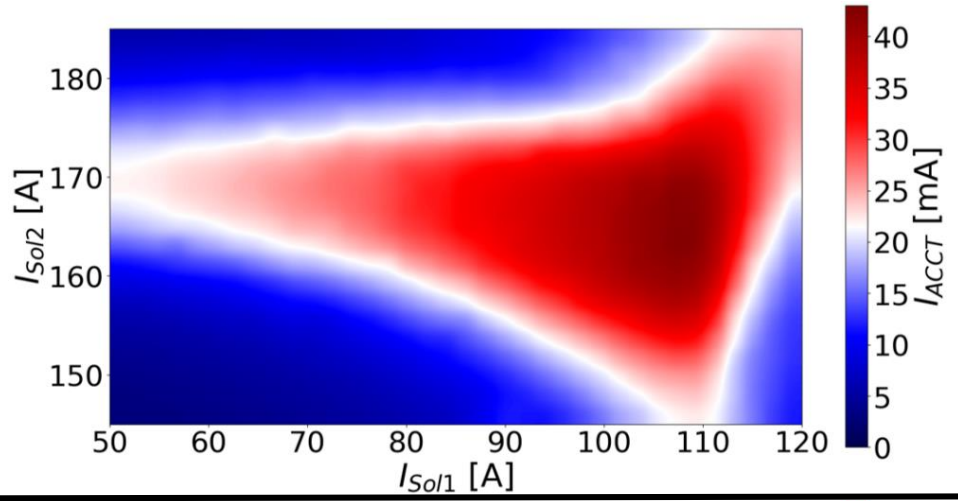


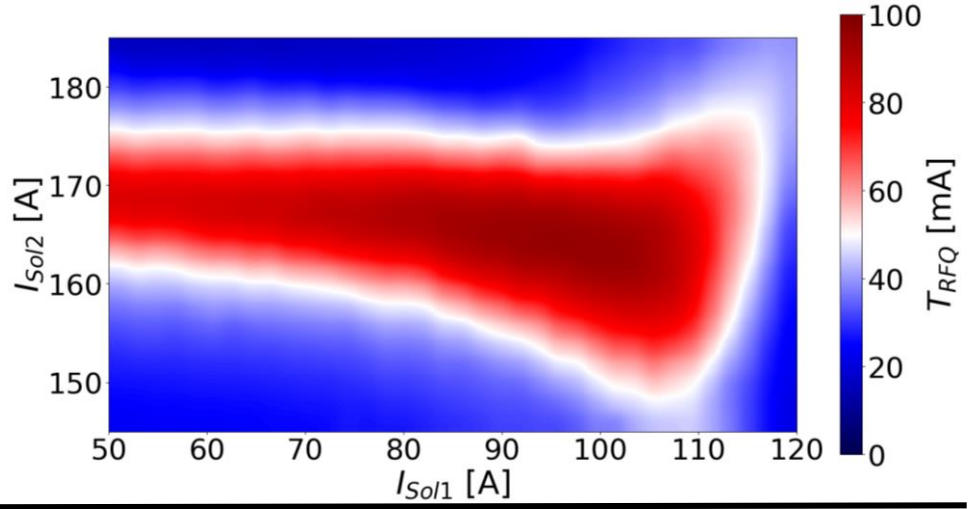
RFQ prospect: IPHI collaboration

RFQ output current

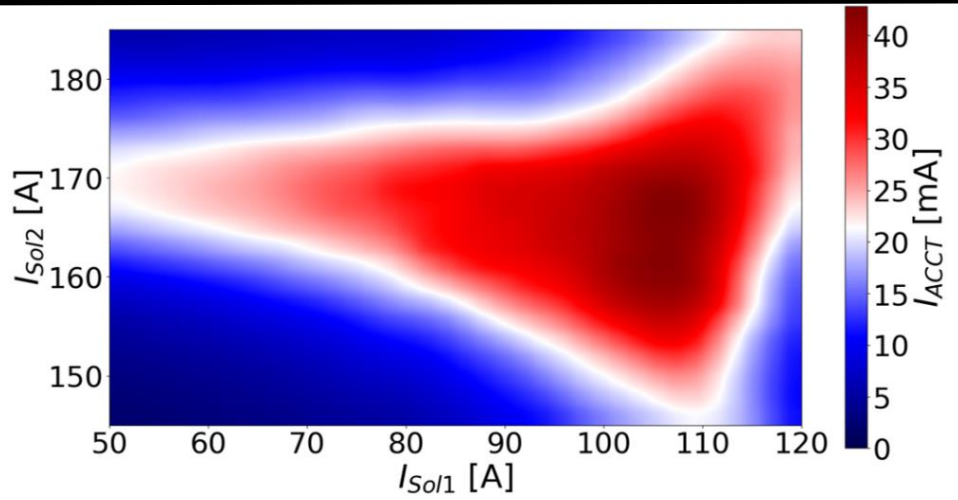
RFQ transmission

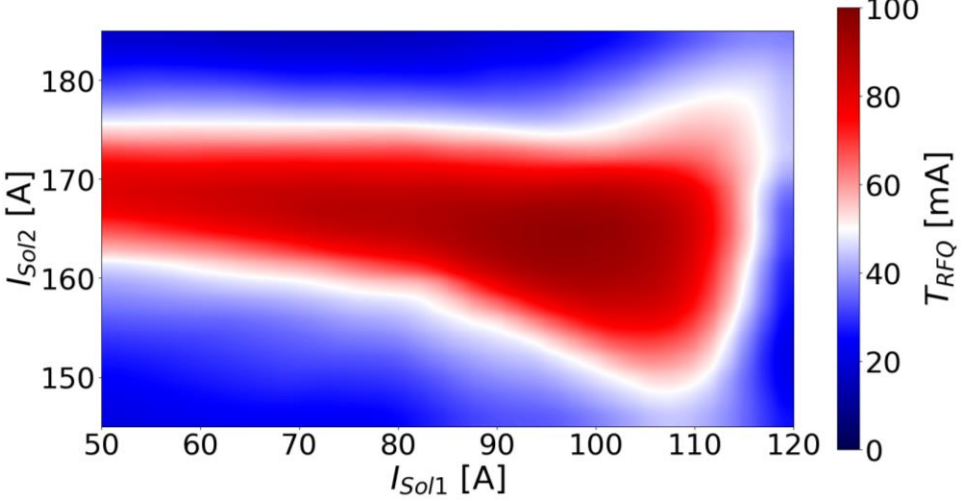
Experimental





Model





Conclusion & prospects

- Machine Learning model
  - Training of an experimental model is possible
  - Improvement to be made
    - Optimize training: solve overfit issues
    - Optimize neural network (minimize training/execution time): #neurons, #layers, …
- Prospects
  - Training of a neural network controller
  - From desired current and RFQ transmission ➔ solenoid settings
  - Applications to SC cavities fast fault-recovery


thank you
danke
рахмат
謝謝
ngiyabonga
teşekkür ederim
Баярлалаа
спасибо
taafetai lava
mersi
barka
welalin
tack
spas
dank je
misaotra
matondo
paldies
gracias
tapadh leat
mahalo
хвала
asante
manana
kiitos
dankie
vinaka
blagodaram
bedankt
hvala
mauruuru
köszönöm
enkosi
bayarlalaa
gracie
dziękuję
dankon
akun
djiere dieuf
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mamnun
go raibh maith agat
murakoze
tenki
chnorakaloutioun
gracies
sulpay
taiku
sobodi
dekuji
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mesi
sagolun
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kop khun krap
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grazie
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terima kasih
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dhanyavadagalu
shukriya
мерси
kam sah hamnida
rahmat
감사합니다
xiexie
ευχαριστώ
merci

Models performances in numbers

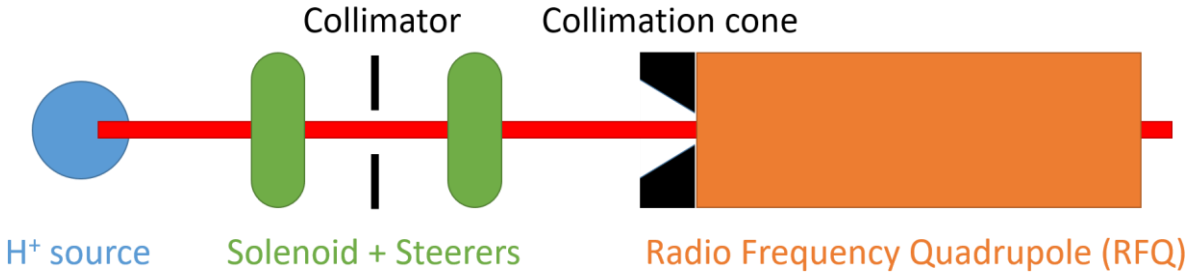
- Execution time $\sim 10\ \mu s$

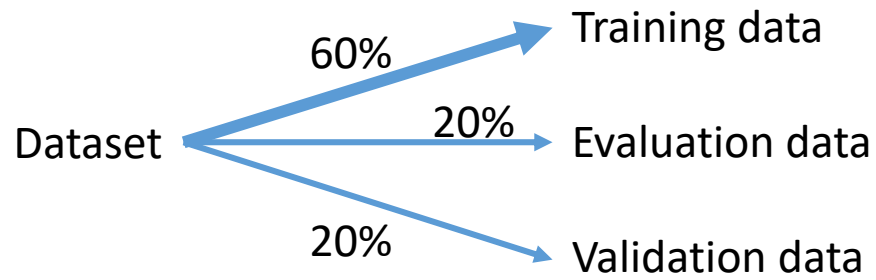
$$RMSE = \sqrt{\frac{\sum_{y_i}\left(y_i^{true} - y_i^{model}\right)^2}{N_{y_i}}}$$

- Quality evaluation: RMS error

	MYRRHA	IPHI	
Outputs	Beam current [mA]	Beam current [mA]	RFQ transmission [%]
RMSE on training dataset	0.09	0.66	1.25
RMSE on validation dataset	0.10	0.79	1.62
RMSE on test dataset	0.10	0.81	1.65
RMSE on whole dataset	0.09	0.72	1.42

RFQ prospect: IPHI collaboration



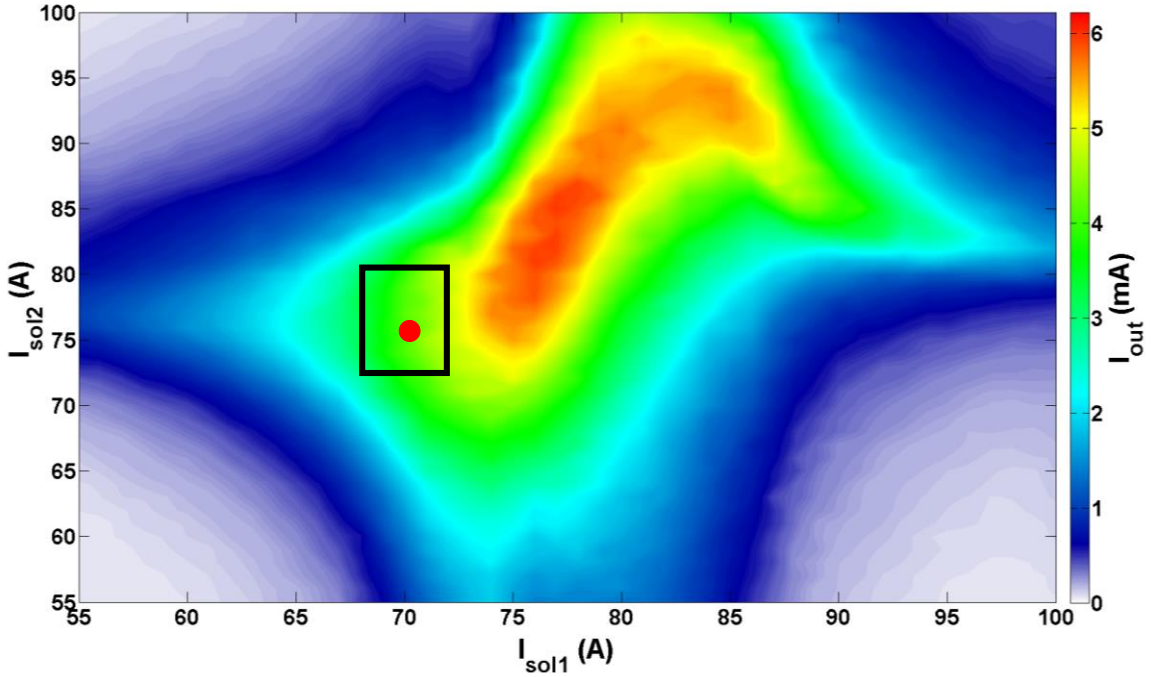


IPHI (CEA Saclay, France)

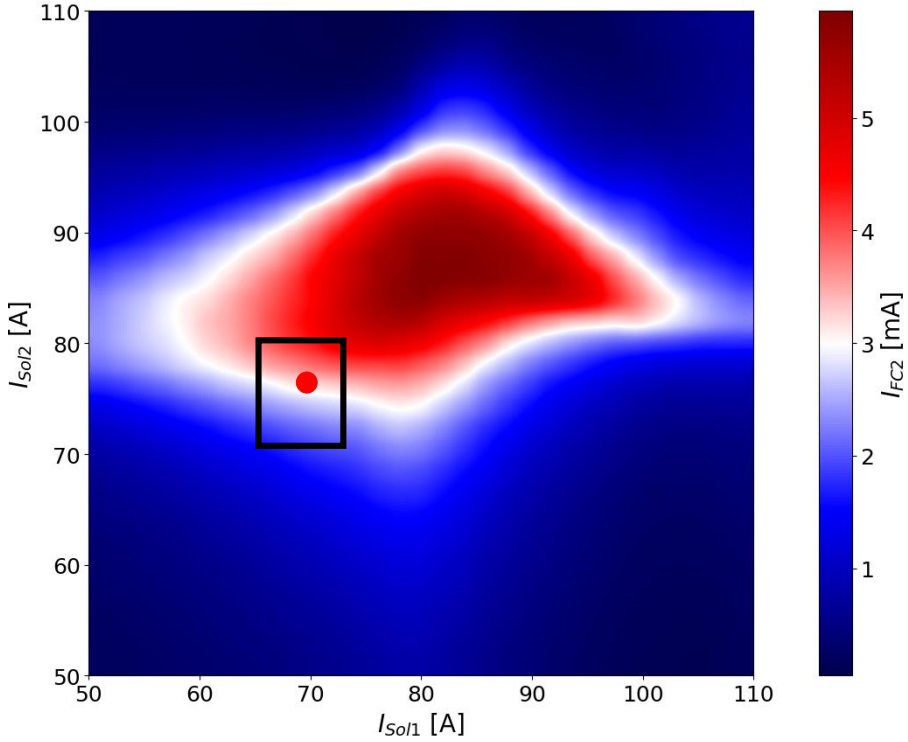
- ~8000 measurements

Input			Desired output	
Current in solenoids [A]		Collimator opening [m]	Beam current output [mA]	Transmission [/]
I_{sol1}	I_{sol2}	r_{coll}	$I_{Beam,out}$	T_{RFQ}

Comparison Grenoble-LLN



- I_{source} = 9 mA
- P = 2.4 10^{-5} mbar
- Collimator aperture : 37 mm
- Steerers settings inside solenoid 2 :
  - $I_{steererH}$ = 0.5 A
  - $I_{steererV}$ = -2 A



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