

PAUL SCHERRER INSTITUT



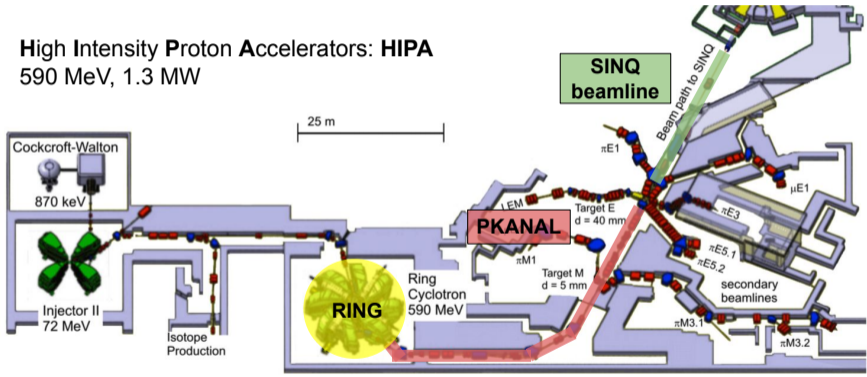
M. Zacharias :: Paul Scherrer Institut

Forecasting interlocks at HIPA

11/01/2021 :: GFA Seminar

- Introduction
- Problem Formulation
- Recurrence Plots and RPCNN Model
- Further training and evaluation of the 2019 model
- Training on 2020 data
- Automated workflow and retraining

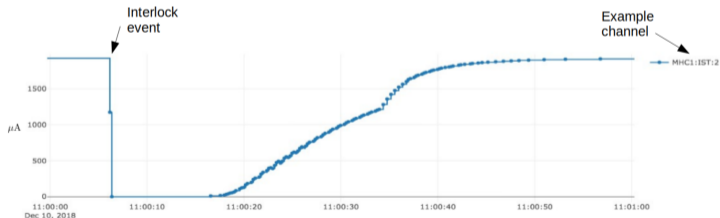
High Intensity Proton Accelerators: HIPA 590 MeV, 1.3 MW



Courtesy of Sichen Li

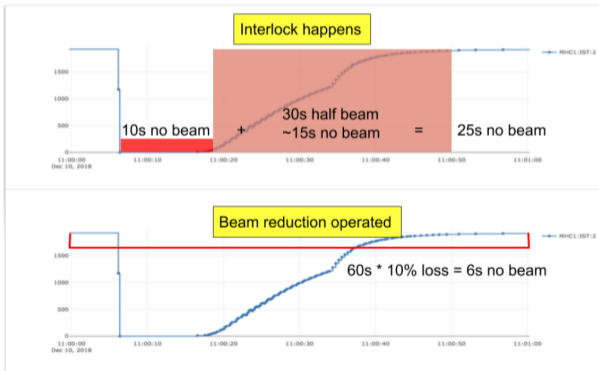
Channel	Section	Description (unit)
AHA:IST:2	PKANAL	Bending magnet (A)
CR1IN:IST:2	RING	Voltage of Ring RF Cavity 1 (kVp)
MHC1:IST:2	PKANAL	Beam current measurement at the ring exit (μA)

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Short beam interruptions make up $\sim 20\%$ of the total beam time loss

Assumption: If interlocks can be predicted, they can be prevented by a beam current reduction of 10%

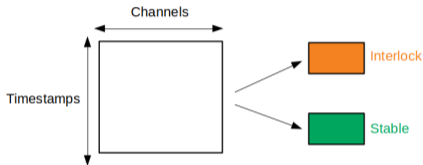


Courtesy of Sichen Li

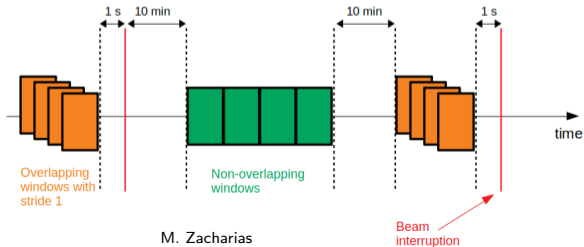
M. Zacharias

Classification approach: what gets classified?

"windows" of a multivariate timeseries

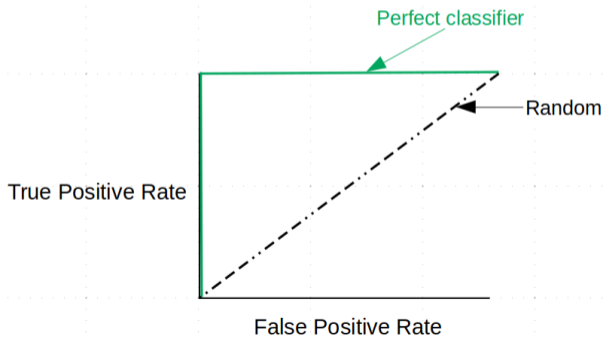


what are stable and interlock windows?



Receiver operating characteristic (ROC) plots

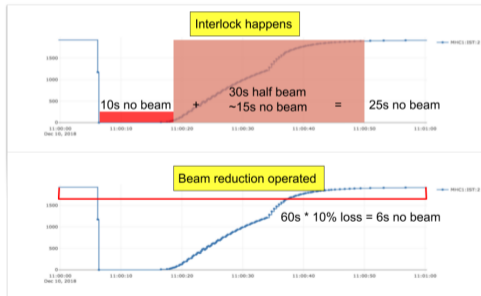
True positive rate (TPR) against the false positive rate (FPR) of the model predictions as a function of the discrimination threshold



How many false positives can we tolerate?

Beam time saved in seconds per interlock:

$$T_s = -25 * TPR + 6 * TPR + 45 * 6 * FPR$$

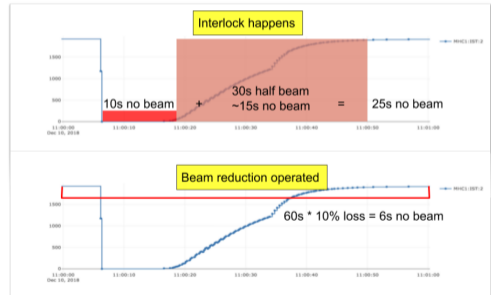


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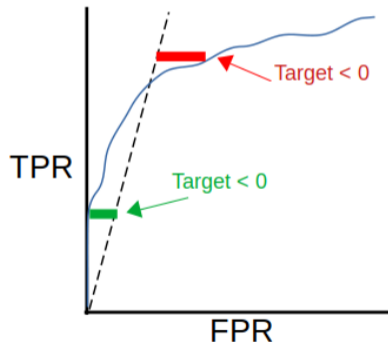
stable state is 45 times more likely
to occur than interlock state



How many false positives can we tolerate?

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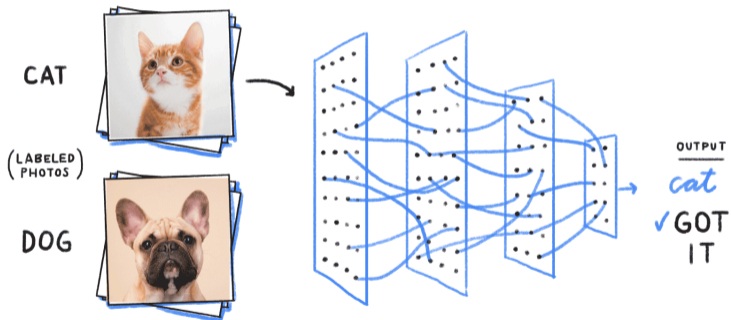
	2019	2020
number of days recorded	88	130
number of channels	376	450
number of interlocks	2027	3161
number of considered interlocks	894	1281

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Only considered Interlocks that

- are connected to "Losses"
- are at least 5 min apart

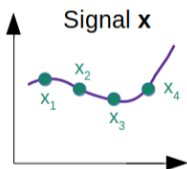
Successful in image classification method



source: <https://medium.com/@harsathAI/cats-and-dogs-classifier-convolutional-neural-network-with-python-and-tensorflow-9-steps-of-6259c92802f3>

Global Recurrence Plots

$$D_{i,j} = \begin{cases} \|x_i - x_j\|, & \|x_i - x_j\| \leq \epsilon \\ \epsilon, & \|x_i - x_j\| > \epsilon \end{cases}$$



Get distance matrix

	x_1	x_2	x_3	x_4
x_1	0		1	
x_2		0		5
x_3	1		0	
x_4				0

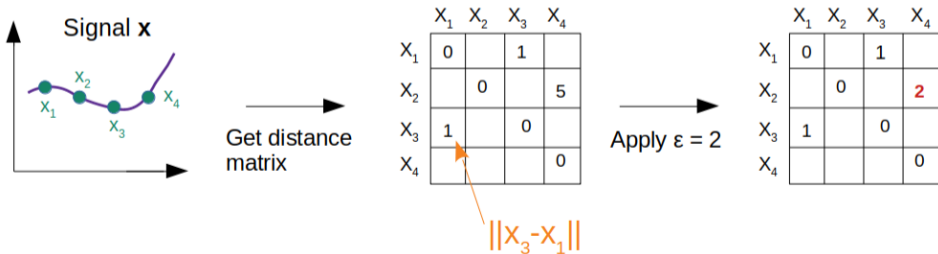
Apply $\epsilon = 2$

	x_1	x_2	x_3	x_4
x_1	0		1	
x_2		0		2
x_3	1		0	
x_4				0

$\|x_3 - x_1\|$

Global Recurrence Plots

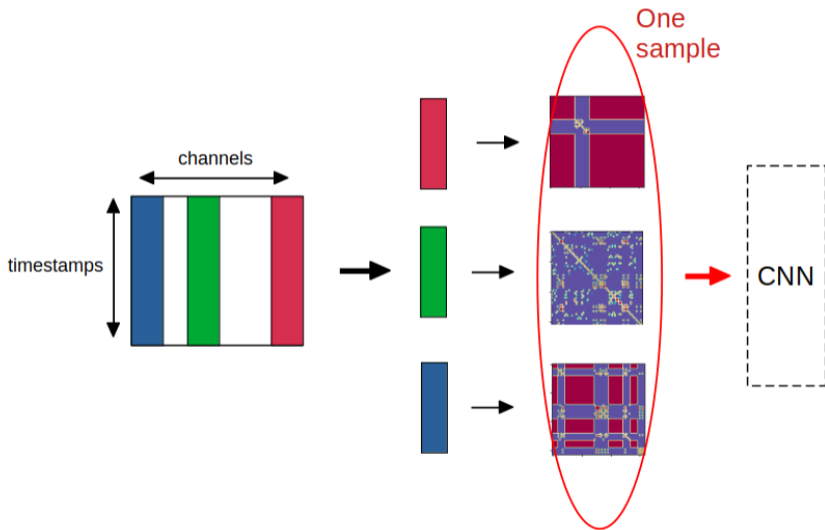
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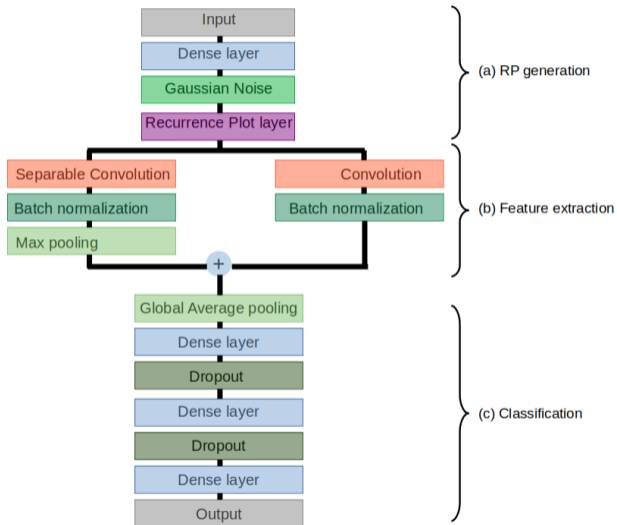
signal length : 12 s, time step : 0.2 s

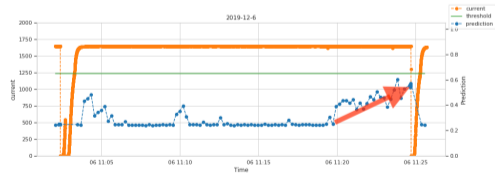
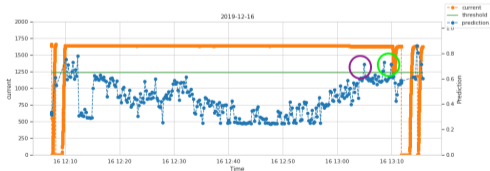
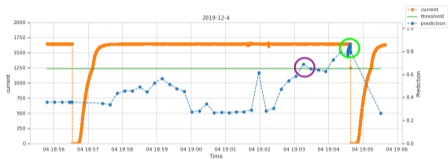


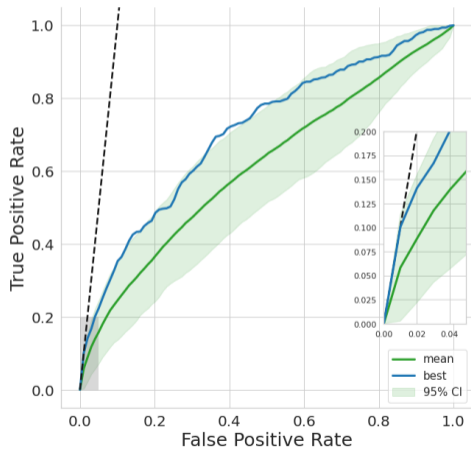
From time series to images



RPCNN model

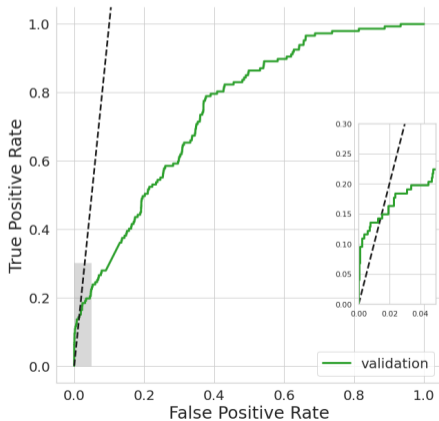






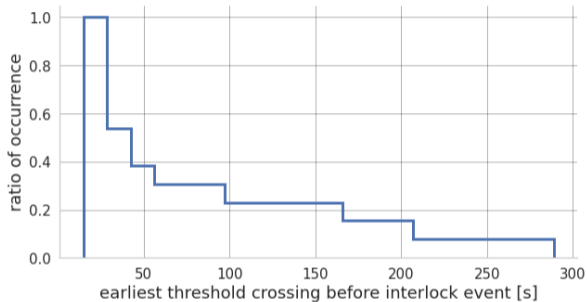
Model	Beam time saved [s/interlock]	AUC
Best	0.5 ± 0.2	0.71 ± 0.01
Mean over initializations	0.1 ± 0.1	0.61 ± 0.04

- after a FP samples in the next 2 min are ignored
- a positive in a range of 1 min before an interlock qualifies the event as a TP

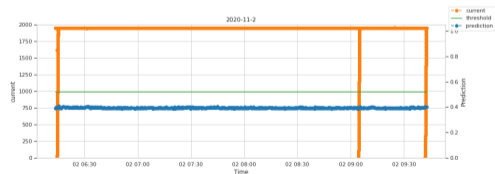
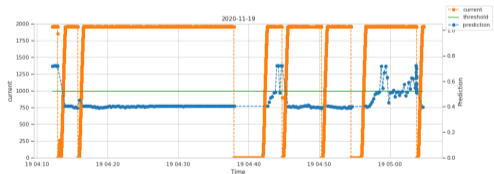
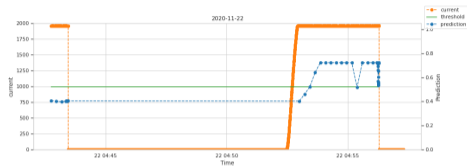
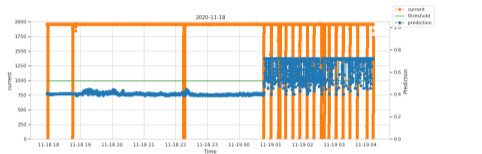


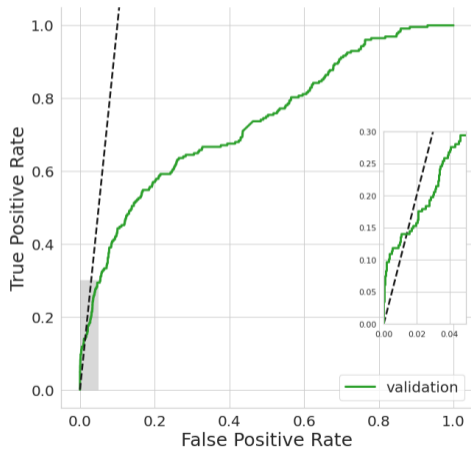
Beam time saved [s/interlock]	AUC
1.5	0.76

2019 data interlock detection range



- various detection ranges
- Some interlocks are predicted up to 5 min in advance



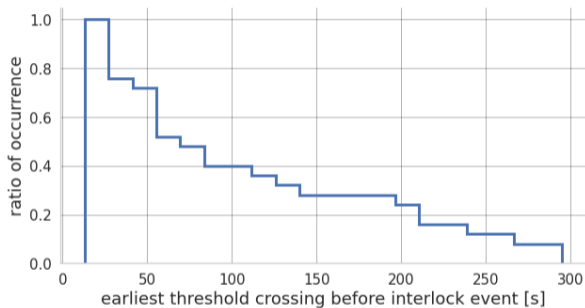


Beam time saved [s/interlock]	AUC
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1.4

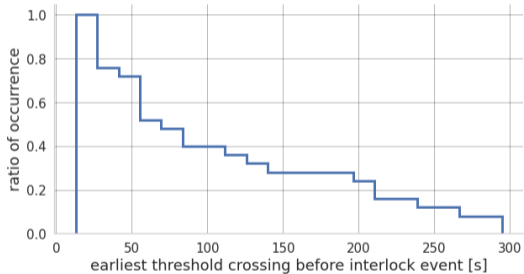
0.73

2020 data interlock detection range

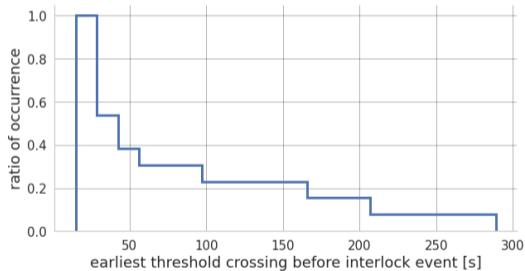


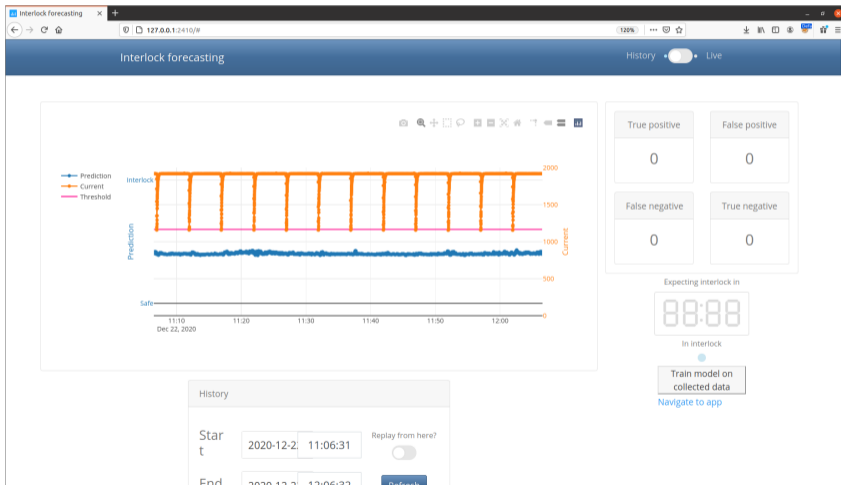
2020 data interlock detection range

2020

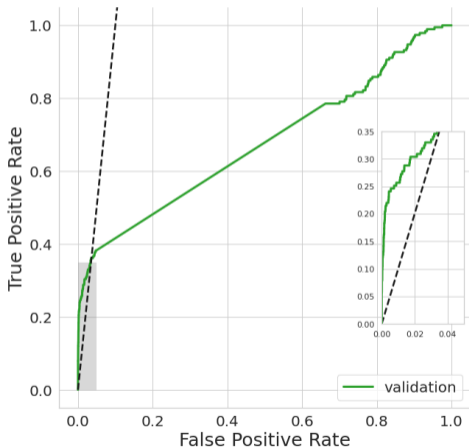


2019





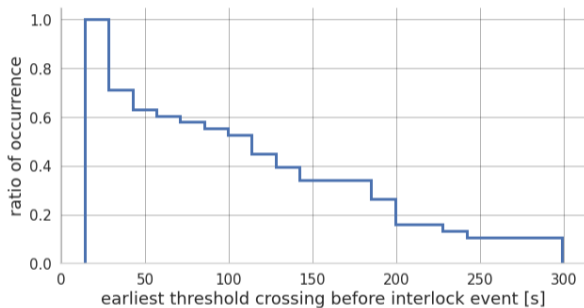
Preliminary results retraining



- retrained on previous training data with only 1 sample per interlock and 1 additional week of data
- validated on remaining november and december data
- training and validation data proportion remained identical

Beam time saved [s/interlock]	AUC
3.4	0.67

Preliminary results retraining



- RPCNN can save beam time on both 2019 and 2020 data
overall: 22.6 min (2019) and 21.2 min (2020)
with retraining: 72.5 min (2020)
- Some interlocks are detected up to 5 min in advance
- Retraining an existing model seems to improve its performance
- Workflow has been established to obtain models for the next machine run

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Next steps:

- Put forward model and workflow in beam development
- Transfer learning to make more data available
- improve continuous training

Thanks to

A. Adelmann
(NES/LSM)

D. Reggiani

F. Perez Cruz
(SDSC)

J. Coello

J. Snuverink

M. Schippers

S. Li (NES/LSM)

