THPV040

NEW MACHINE LEARNING MODEL APPLICATION FOR THE AUTOMATIC LHC COLLIMATOR BEAM-BASED ALIGNMENT

G. Azzopardi*, CERN, Geneva, Switzerland, G. Ricci, Sapienza Università di Roma

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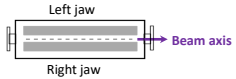
Introduction



- A collimation system protects the LHC.
- All collimators aligned before each year of operation, using beam-based alignment (BBA).
- Beam Loss Monitors (BLMs) record beam losses generated by collimators as they touch the beam.
- The alignment relies on classifying between spurious and alignment spikes.
- An alignment campaign can produce more than 1000 observation spikes.

Semi-automatic BBA

- Since 2011, semi-automatic alignment.

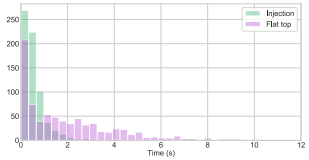
User	Select collimator
User	Select BLM threshold to stop jaw moving
AUTO	Collimator moves towards beam Movement stops when threshold exceeded
User	Collimator aligned? No - repeat, Yes - save

Aligning 40+ collimators requires 4-5 experts.

Fully-automatic BBA

- Since 2018, fully-automated using supervised ML to classify spikes.
- Fixed waiting time after the collimator stops moving:
  - 4 s @ Inj, 6 s @ FT
- Average of 95 % precision
- Speeds-up alignments by 70 %, from 3 hours to 50 minutes.

	Semi-auto	Fully-auto
Collimators	75	77
Total time	2h 31m 59s	49m 17s
Moving time	58m 13s	18m 14s
Total alignments	1903	637
Moving time	38.3 %	38.0 %
Alignments /Coll	25.37	8.27

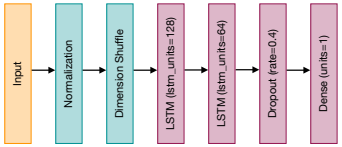


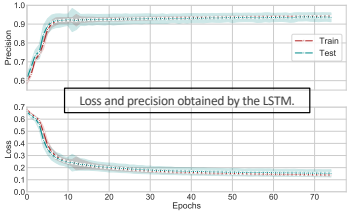
BLM signal decay time distributions.

LSTM-RNN for Spike Classification

- **Proposed Solution:** LSTM-RNN to continuously classify spikes in real-time and automatically adjust to spike decay length.
- 2973 samples collected from alignments during 2016-2018.
- **Input:** BLM signal scaled with the collimator position in sigma.
- **Results:** 10-fold cross-validation randomly stratified 30 times.
  - Average of 94% precision on testing sets.
- Precision is used to avoid false positives
  - False detection is more grievous than not detecting a spike.
- Precision calculated using the classification at end of each sample:
  - A classification score > 50 % classified as alignment spike.

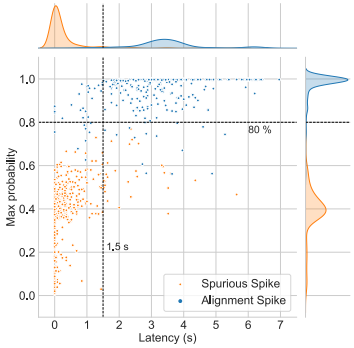
LSTM network architecture.





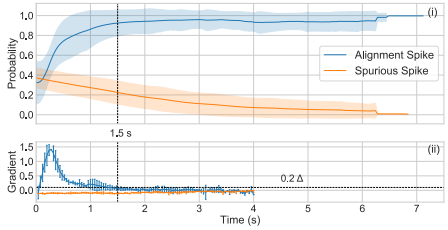
Loss and precision obtained by the LSTM.

Spike Classification Analysis



Distribution of max. probabilities achieved by the two spike classes and the required latency.

Continuous spike classification results at each time step.



Results: The LSTM can be used to classify:

- When the probability gradient < 0.2 (requires ~1-1.5 s @ Inj).
- Spurious spike < 80 %, then begin next alignment.
- Alignment spike >= 80 %, then fit exp. func. for ~98.5 % decay.
  - On average already decayed (mean 0.61 s).

Results & Conclusions

- This analysis increased the precision to **98 %.**
- Factor 4 speed-up compared to the present implementation with supervised ML.
- Aligning the two beams in **parallel**, resulted in 79 collimators aligned in 50 minutes at injection.
  - LSTM could theoretically require ~24.56 minutes.
- The LSTM is readily available to be incorporated into the alignment software for testing during the LHC Run 3.

	Injection	Flat top
Start time	1 s	1.5 s
Mean	1.07 s	1.54 s
Stand. dev.	0.1 s	0.06 s
Maximum	1.72 s	2.04 s

LSTM classification latency using the analysis presented.

Case	Supervised ML	~50% speed-up LSTM-RNN
1 coll @ Inj	53.8 s	27.43 s
+ 1 spurious spike	69.1 s	33.94 s
79 colls @ Inj	70.84 mins	36.12 mins
+1 spurious spike	90.98 mins	44.69 mins
1 coll @ FT	71.8 s	35.8 s
+1 spurious spike	93.1 s	43.72 s
79 colls @ FT	94.53 mins	47.14 mins
+1 spurious spike	122.58 mins	57.56 mins

The average theoretical minimum time for **sequential** alignments.

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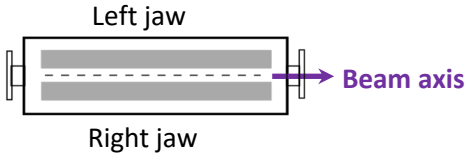

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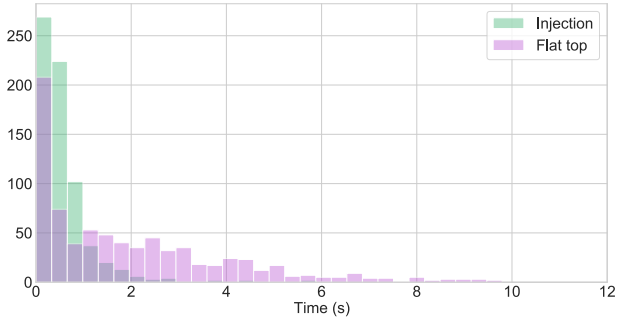

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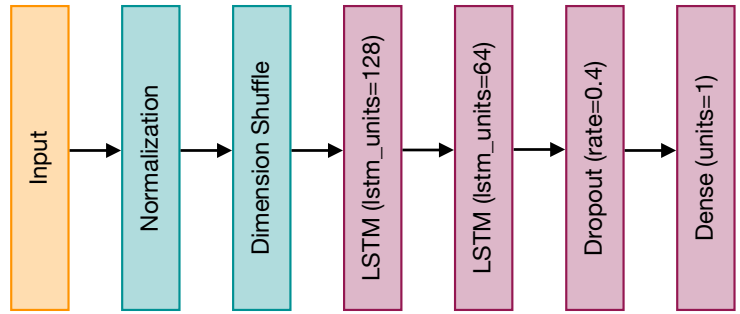

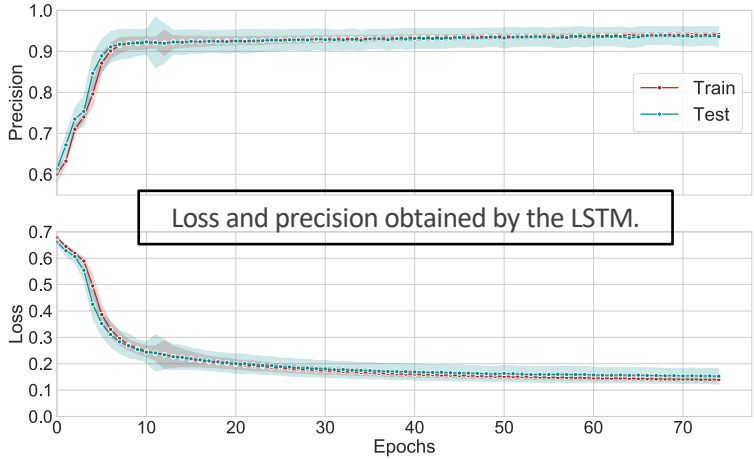

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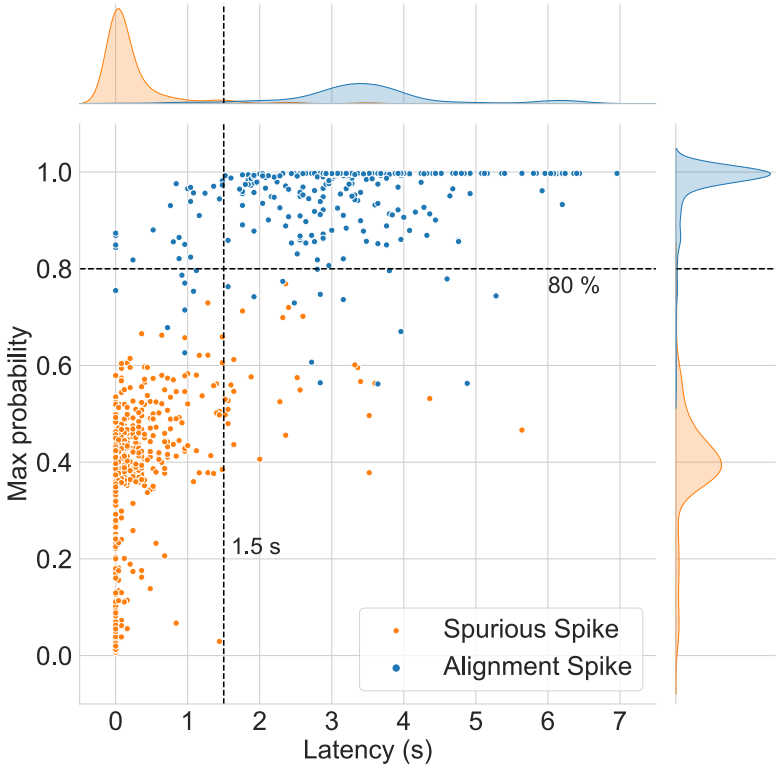

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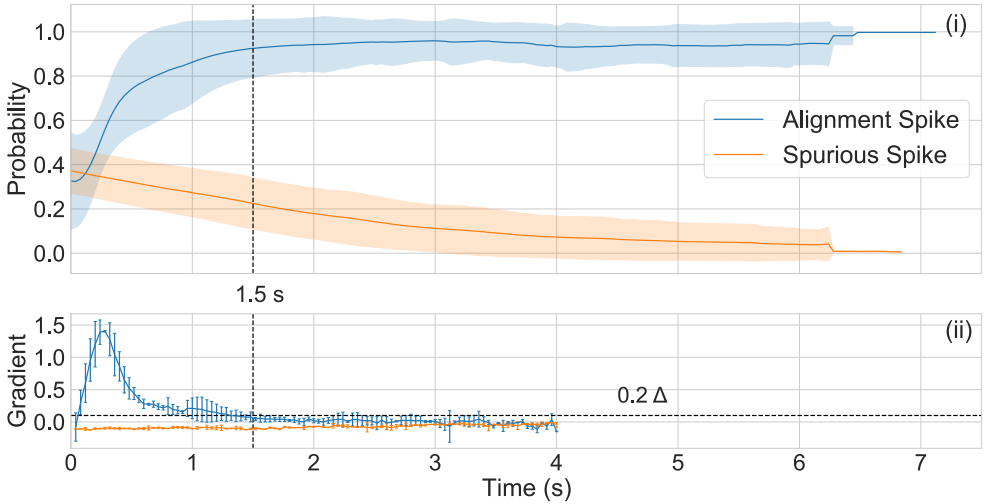

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