Machine-aided Beam Diagnostics

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Outline

Overview
  Design of AWAKE
  Beamline Goal

Beamline Studies
  Simulation and its Studies
  Mixed Data Model

Learning and Results
  Layers and Inputs Importance
  Results and Future Perspective
Basic Parameters of electron line

- $e^-$ bunches
  - Delivered by Photoinjector, 5 ps bunch length, ~0.2mm rms size
  - RF + Booster $\Rightarrow$ 18 MeV
  - Quality will affect quality of acceleration in plasma cell
**Figure:** Transport ← Diag. ← Quadx3 ← Booster ← Diag. (pepper pot) ← Solenoid + RF Cathod
Emittance as Optimization Objective

- High $e^-$ density bunch at low $p_z$ creates problem
- RF only produce 5.8 MeV, space charge effect is pronounced
- Transport line is long due to physical constrain
- Pure optics after the booster (18 MeV), thus **emittance** out of here is critical
Conventional Emittance measurement

- Through quadrupole scan, one can measure emittance indirectly via fittings

- Takes >1 minute for a complete scan

- Measurement will disrupt nominal conditional for the beam
Study via simulation

Given nominal values of machine parameters, space tracking simulation can produce convincing result using < 10k particles.

▶ Good for testing new approach (hint: machine learning), as online beam time is precious

▶ Reproduces a large range of physical parameters, robustness can be tested.
ASTRA — by Klaus Floettmann @ DESY

- Splits macro particles distribution @ cathod

- Structures simulated: RF gun, Solenoid, (3D)TWS Booster (no quadruple)

- Runs tracking & space charge simulation (important at low p)
Parameter Selection

- With the hope of moving this to become a experiment driven studies, we select parameters we can scan easily

- Calculate emittance from truth information for regression

- Record machine parameters as training input as well.
Correlations and Features

- Correlation between Emittance and Current in solenoid

- Clearly correlated given a small dimension of (3) parameters, yet still messy

- Spans a large range, most of which means 'bad' physics in experiment
Correlations and Features

- Scan only the current, we can see beam size and emittance varies together

- The tradeoff curve confirms the effect of slice emittance alignment (on overall emittance)
Information Extraction

- Extract observables from simulated distribution near the end of beam line
- Record machine parameters as training input as well.

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<th>Current(A)</th>
<th>Laser(mm)</th>
<th>Charge(nC)</th>
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Beam Size Fitting

- Laser & Beam profile can usually be fitted by a Gaussian dist.
- In extreme case may use rms of raw pixels
- Emittance can be obtained also (with + of phase space info)

<table>
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<tr>
<th>Runs</th>
<th>RMS(mm)</th>
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<tbody>
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<tr>
<td>3</td>
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Pairplot of Inputs and Argumented Variables
Idea: Zernike Poly. Decomposition

- Widely used in Optical physics. At lens approximation, beamline is optics

- Use the coefficients of the first \( n \) terms as input parameters

- However, discrete decomposition requires interpolation onto unit disk and the double integral takes a lot of time.
Instead, 2D Fast-Fourier as Feature Extraction

- Widely used in more places.

- Take magnitude, and flatten out before feeding into the model.

- One step closer to just use a full CNN, as we will see, have better performance.
Overview of the model

- 2 options explored: conventional feature extraction vs. CNN on image side.
- In case of CNN, we have two types of input – image and scalars (machine parameters)
- Adopt Dropout layers to suppress overfitting.
- Trains on a GTX 1070 under 5 minutes.
FFT -> DNN

- It ‘fits’, but the slope is off
- Also trend between test and train is not ideal.
CNN -> DNN

- Much better fit on both test and train set
- Slope is close to one
Future Perspective

- AWAKE is starting its run 2 soon
- Conduct similar study using experimental data
- Exploit simulation data to do Bayesian inference
I don't need money. I need answers.