CERN

Machine-aided Beam Diagnostics

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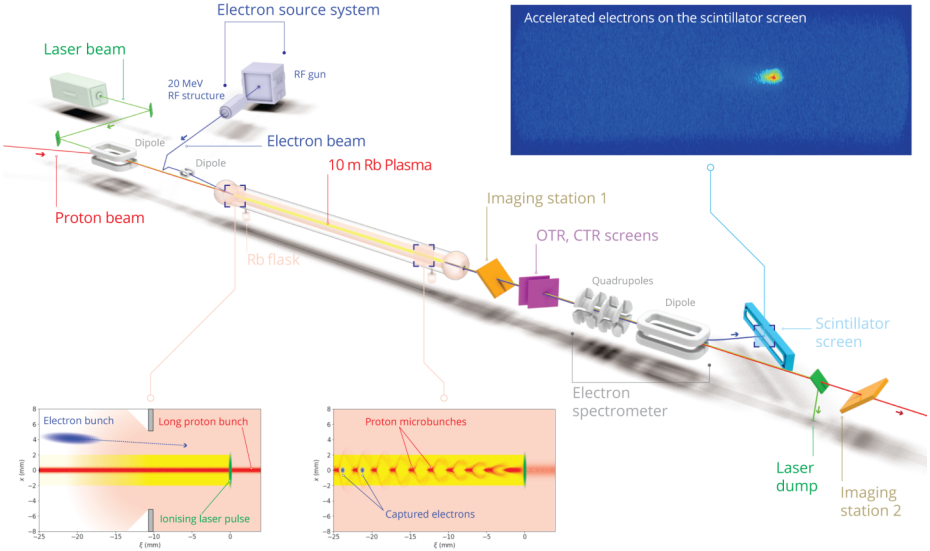
Outline


Electron source system
Laser beam
20 MeV
RF structure
RF gun
Dipole
Electron beam
Dipole
10 m Rb Plasma
Proton beam
Rb flask
Imaging station 1
OTR, CTR screens
Quadrupoles
Dipole
Scintillator
screen
Electron
spectrometer
Laser
dump
Imaging
station 2
Accelerated electrons on the scintillator screen
Electron bunch
Long proton bunch
Ionising laser pulse
Proton microbunches
Captured electrons
x (mm)
ξ (mm)

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

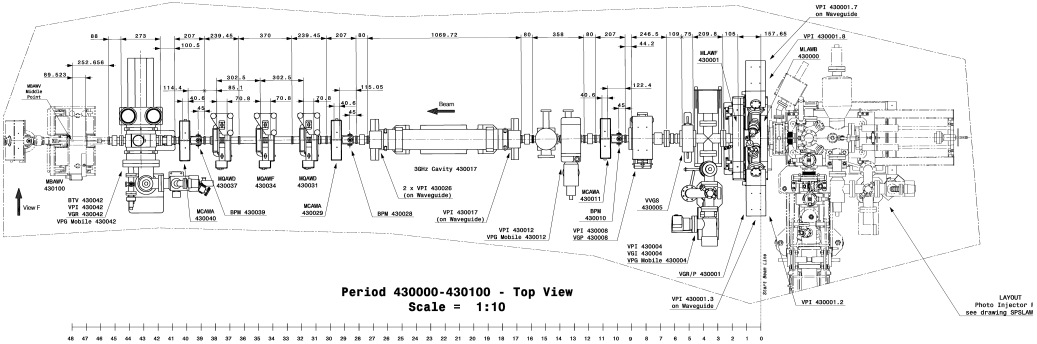
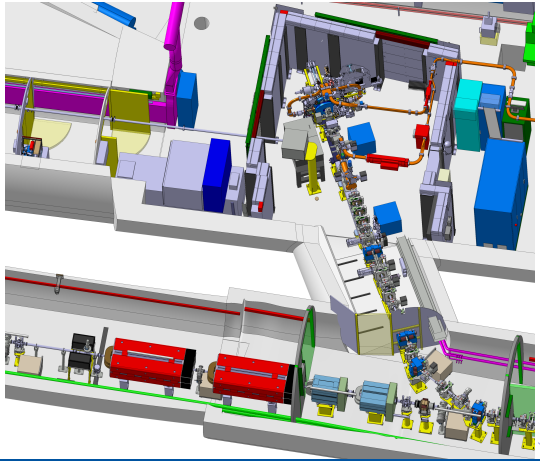


Figure: Transport ← Diag. ← Quadx3 ← Booster ← Diag. (pepper pot) ← Solenoid + RF Cathod

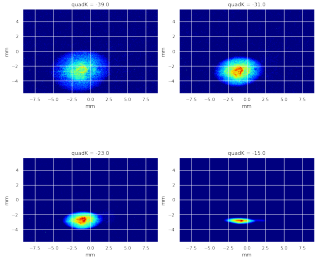
Emittance as Optimization Objective

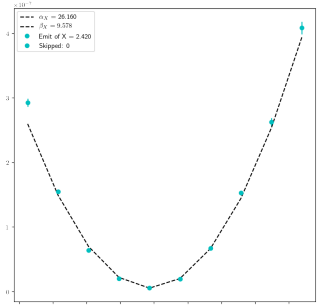
- High e^- density bunch at low p_z creates problem
- RF only produce 5.8 MeV, space charge effect is pronouced
- Transport line is long due to physical constrain
- Pure optics after the booster (18 MeV), thus **emittance** out of here is critical



Conventinal Emittance measurement

- Through quadruple scan, one can measure emittance indirectly via fittings
- Takes >1 minute for a complete scan
- Measurement will disrupte nominal conditional for the beam

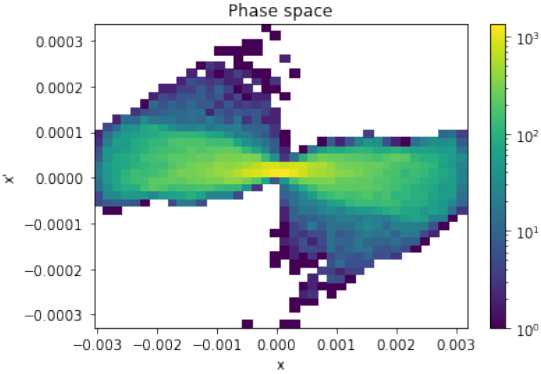




Study via simulation

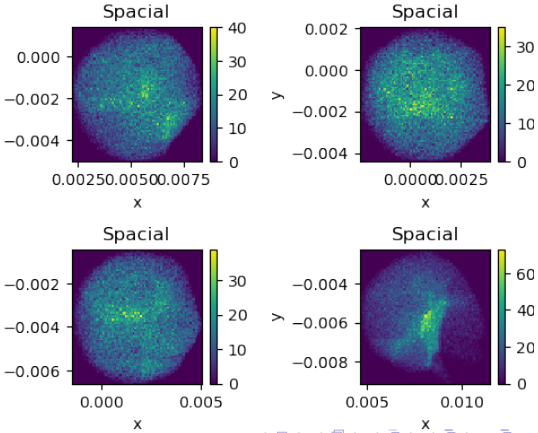
Given nominal values of machine parameters, space tracking simulation can produce convincing result using < 10k particles.

- Good for testing new approach (hint: macihne learinng), as online beam time is precious
- Reproduces a large range of physical parameters, robustness can be tested.



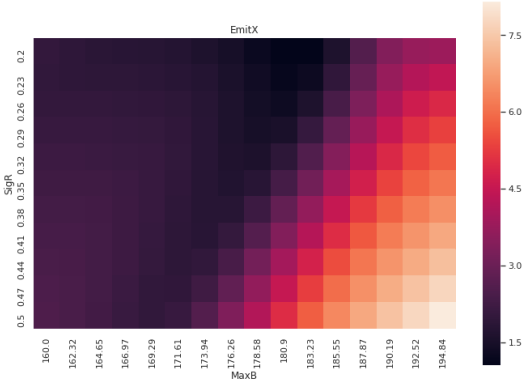
ASTRA — by Klaus Floettmann @ DESY

- 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.

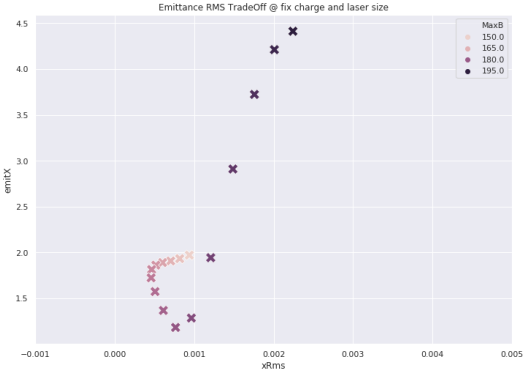


Correlations and Features

- 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 confirmes the effect of slice emittance alignment (on overall emittance)



Information Extraction

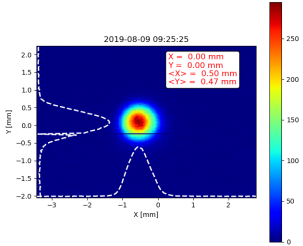
- Extract observables from simulated distribution near the end of beam line
- Record machine parameters as training input as well.

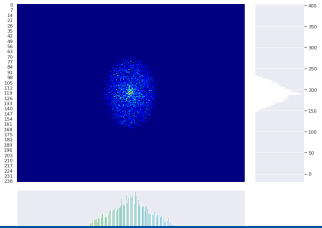
Runs	Current(A)	Laser(mm)	Charge(nC)
1	192.516	0.29	0.33
2	176.258	0.44	0.29
3	173.935	0.20	0.15
4	176.258	0.26	0.15
5	192.516	0.35	0.15
...	...	...	...
...	...	...	...
...	...	...	...

Beam Size Fitting

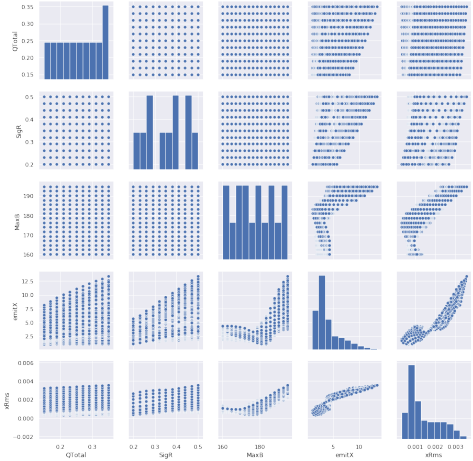
- Laser & Beam profile can usually be fitted by a Gaussian dist.
- In extreme case may use rms of raw pixels
- Emittance can be obtained also (with + of phase space info)

Runs	...	RMS(mm)
1	...	0.181
2	...	0.173
3	...	...



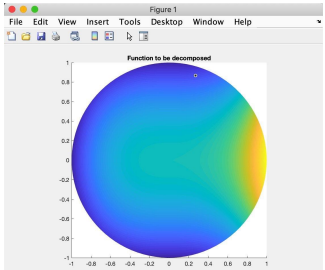


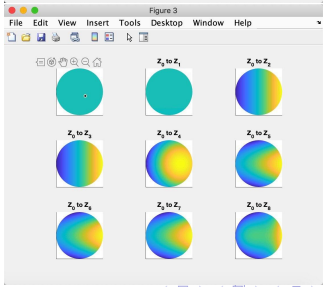
Pairplot of Inputs and Argumented Variables



Idea: Zernike Poly. Decompositon

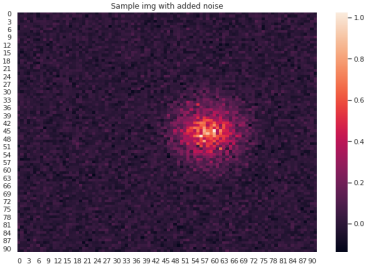
- Widly used in Optical physics. At lens approximation, beamline is optics
- Use the coefficients of the first n terms as input parameters
- However, discrete decomposition requires interpolation onto unit disk and the double integral takes a lot of time.

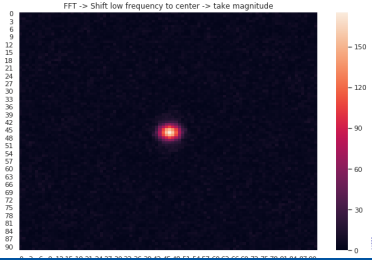




Instead, 2D Fast-Fourier as Feature Extraction

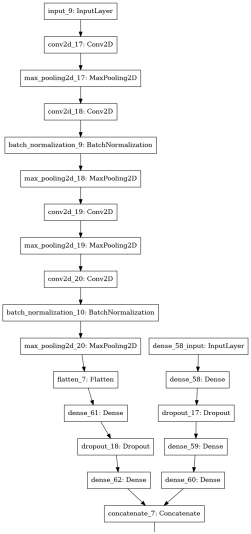
- Widly used in more places.
- Take magnitude, and flatten out before feeding into the model.
- One step closer to just use a full CNN, as we will see, have better performance.





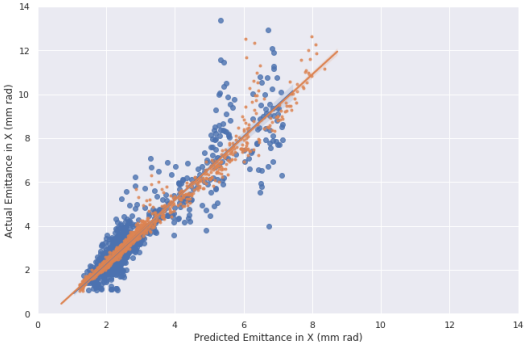
Overview of the model

- 2 options explored: conventional feature extracton vs. CNN on image side.
- In case of CNN, we have two types of input – image and scalars (machine parameters)
- Adpot Dropout layers to supress over fitting.
- Trains on a GTX 1070 under 5 minutes.



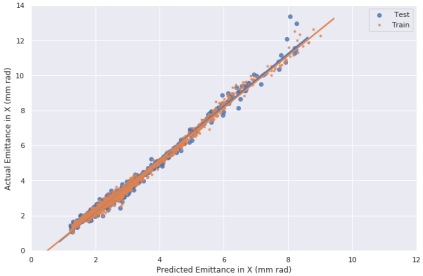
FFT -> DNN

- It 'fits', but the slope is off
- Also trend between test and train is not ideal.

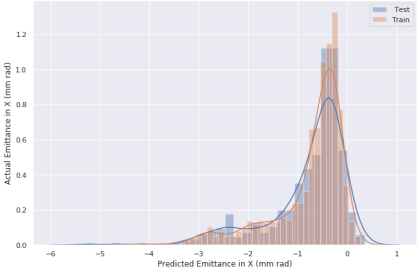


CNN -> DNN

- Much better fit on both test and train set

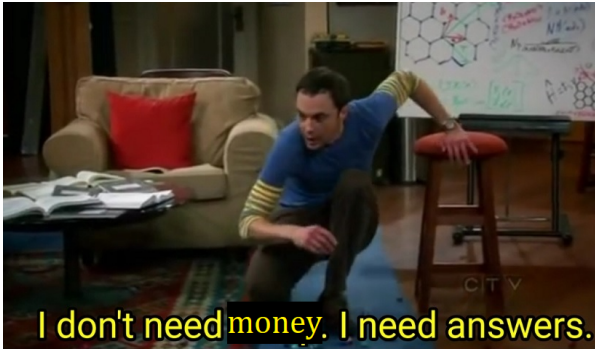


- Slope is close to one



Future Perspective

- AWAKE is starting its run 2 soon
- Conduct similar study using experimental data
- Exploit simulation data to do Bayesian inference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