Profile and signal reconstruction with machine learning

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Abstract

The usage of machine learning for beam diagnostic application for GSI and FAIR will be presented. The reconstruction of space-charge distorted beam profiles from ionization profile monitors (IPMs) will be shown. Interaction of ionized electrons with the electromagnetic filed of the beam for high brightness or high energy beams leads to distorted profiles. Simple linear regression models showed very promising results for the beam width reconstruction. The complex artificial neural networks can reconstructed the whole beam profiles. The application of machine learning to time-domain signals like the longitudinal Schottky signals will be also presents. The fast analysis of very noise and space-charge distorted Schottky signals is of interest for the control of beam energy and momentum spread.

Beam profile reconstruction*

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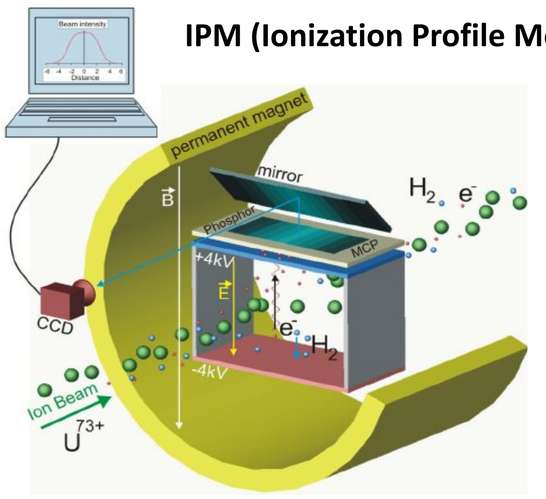
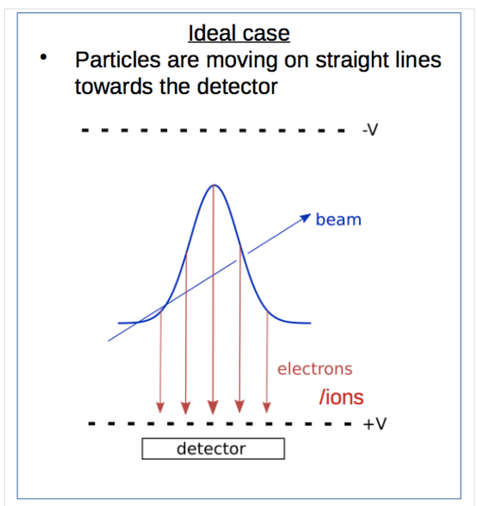
IPM (Ionization Profile Monitors)

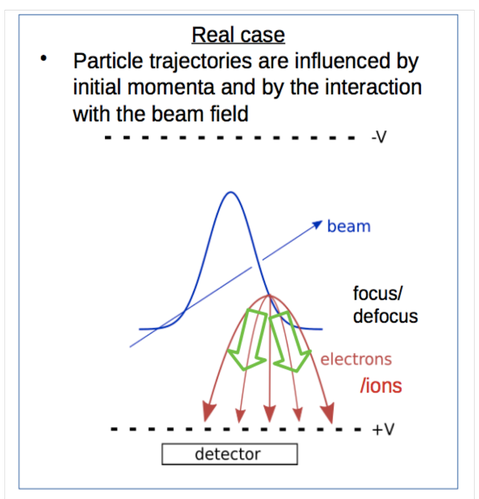


- Measures transverse profile of a particle beam.
- Rest gas (pressure 10^{-8} mbar) is ionized by the beam.
- Electric field is used to transport electrons/ions to a detector.
- Electromagnetic fields of primary beam can affect the particle movement towards the detector.

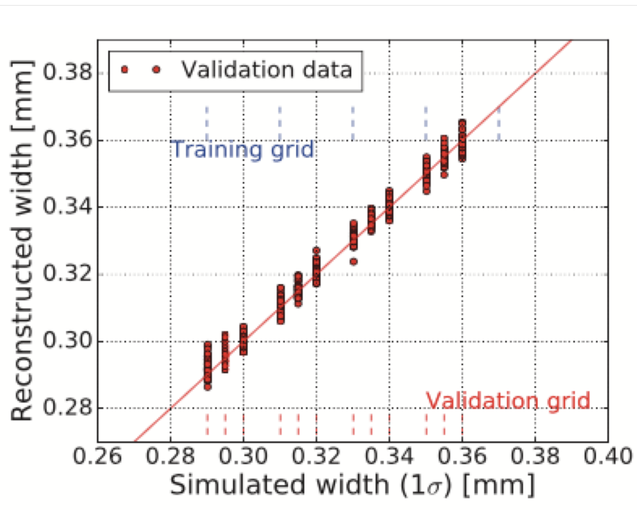
- First investigations with machine learning, using simulated data, yield promising results.
- Even linear regression showed promising results for the beam width reconstruction.
- Method has a potential to extend usability and reduce cost of IPMs for high brightness beams.

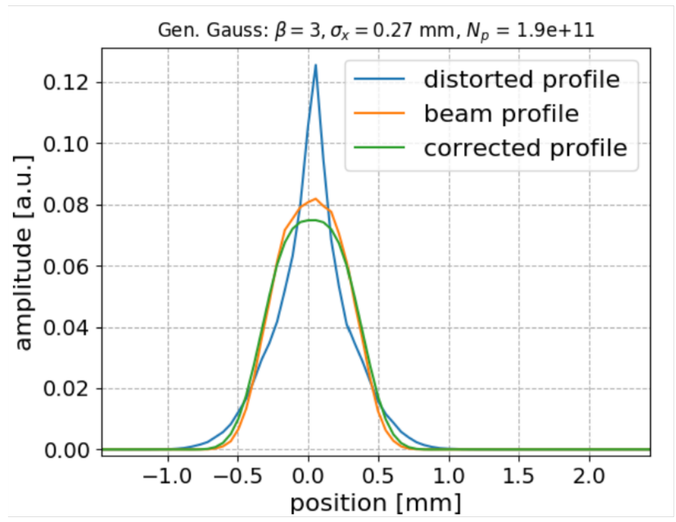
Profile distortion in IPM





Profile correction using ANN





- Value of beam size restored with 1% accuracy!
- Results for Gaussian profiles: Very good profile shape reconstruction.

References:
D. Vilsmeier et al. in Proc. IPAC 2018, pp. 6--9.;
M. Sapinski et al. in Proc. HB'18, Daejeon, Korea, 2018

Schottky signals reconstruction**

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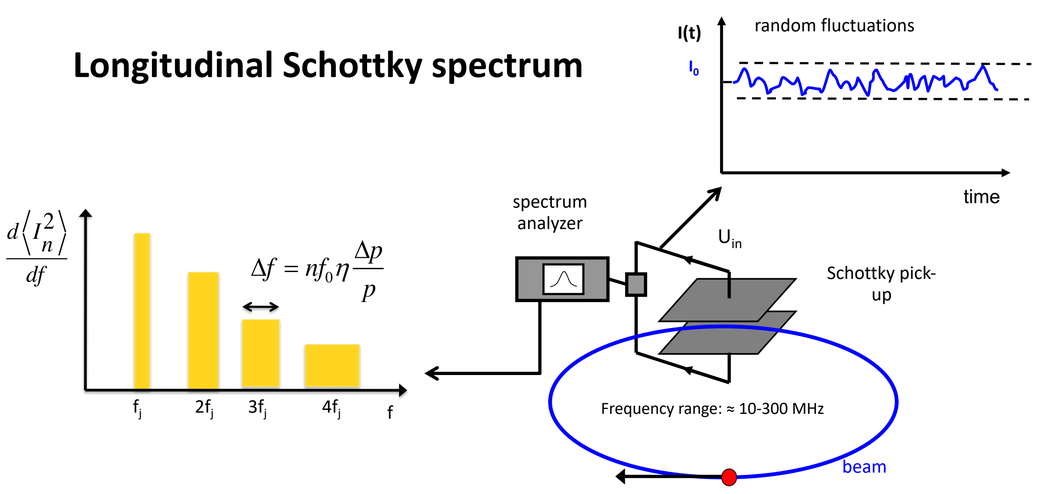
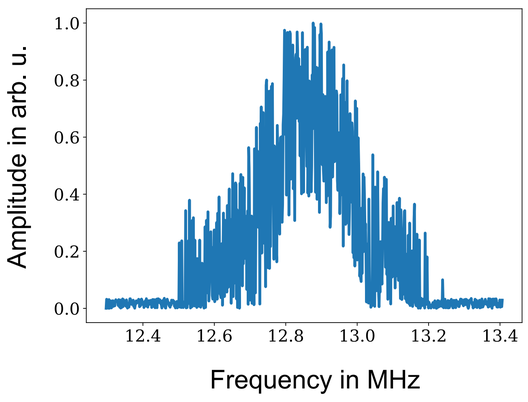
Longitudinal Schottky spectrum



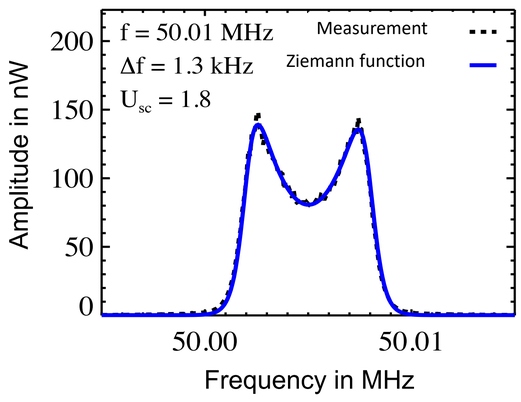
- Beam energy and momentum spread should be routinely measure from Schottky spectrum:
  - Difficult: Space charge effects, multi-stream instability, 'turbulence', etc.
- Time-averaging of the spectrum can smooth out this noise.
- For FAIR faster evaluate of Schottky signal is highly desirable.
- Is ML maybe a solution?:
  - Good accuracy (< 1%) for determination of beam energy (revolution frequency).
  - Worse accuracy (< 10%) for momentum spread determination.

- Usually shape of single Schottky band present beam profiles, i.e Gaussian profile
- Space charge effects or instability can deform the signal shape

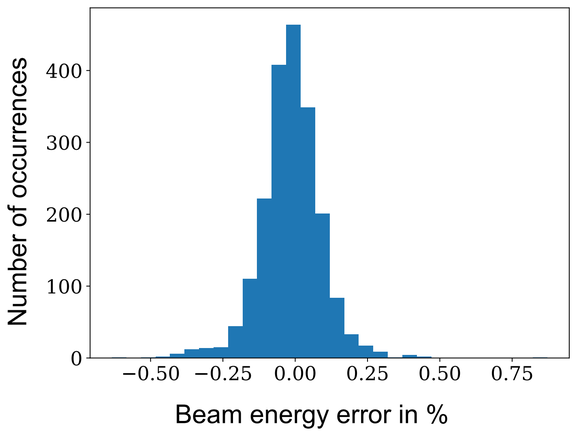
Noisy Schottky spectrum

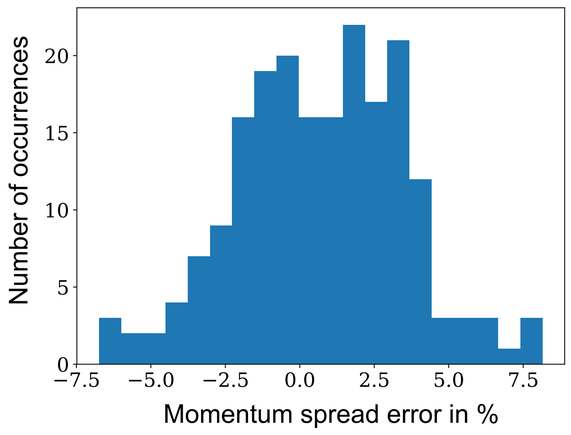


Space charge deformation



Determination of Schottky signal with RBF-Kernel SVR





References:
S. Appel, PhD Thesis TU Darmstadt 2011;
S. Appel et al. Phys. Rev. ST Accel. Beams 15, 054201 (2012);
L. F. Formigari, Master Thesis, TU Darmstadt 2018