Longitudinal Phase Space Tomography with CDS Booster

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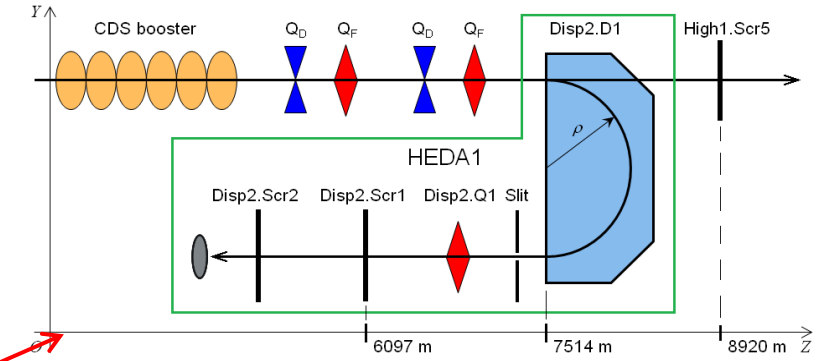
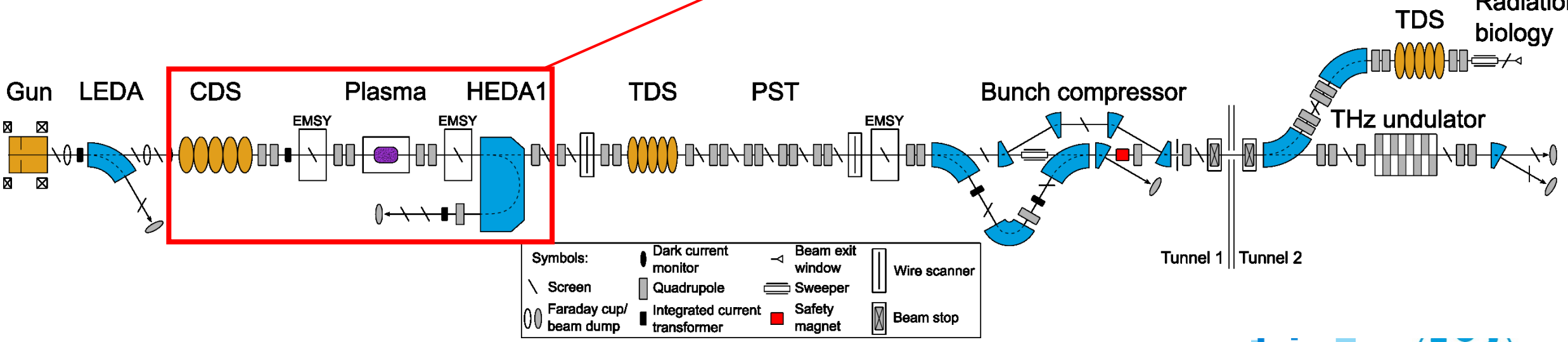
PITZ Physics Seminar, DESY





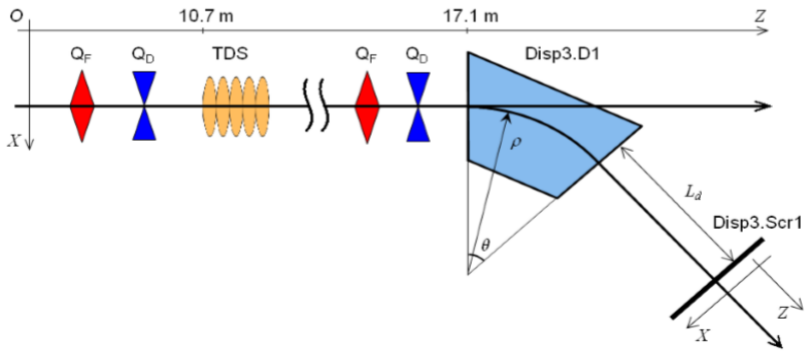
LPS characterization of high brightness electron beams

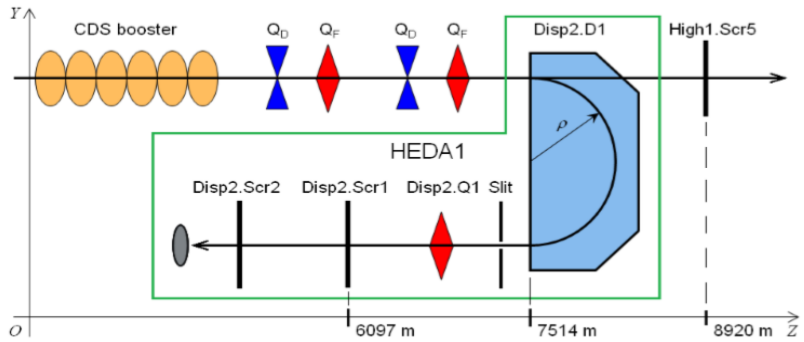
Introduction

- FELs require a high brightness electron beam with the following parameters:
  - small transverse and longitudinal sizes
  - small divergence and energy spread
  - high peak current

All figures and equations are taken from Dimitri's thesis

- Longitudinal Phase Space Characterization at PITZ
  - TDS + HEDA2
  - Booster Phase Scan + HEDA 1

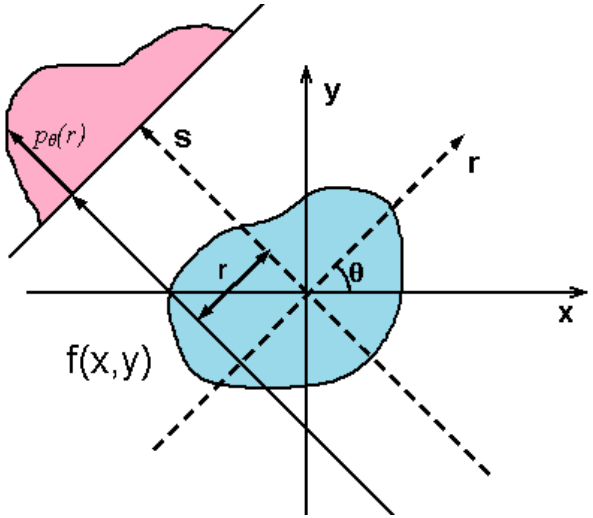




LPS characterization via Tomography

What is Tomography?

- Obtain 2D distribution from 1D projection



How is Tomography applied at PITZ?

- measurements of the momentum spectra while varying the electron bunch energy chirp
- energy chirp can be introduced by varying the RF phase of the CDS booster
- resulting momentum distribution can be measured with a dipole spectrometer downstream HEDA1

LPS characterization via Tomography

Reconstruction Algorithm

- Algebraic Reconstruction Technique (ART)
- Maximum Entropy (MENT)
- Filtered Back Projection Technique (FBP)

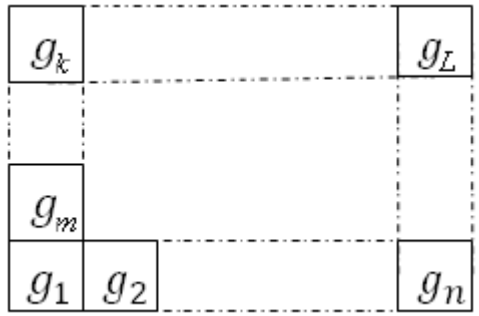
Algebraic Reconstruction Technique (ART)

- Relation between projection and image pixel

$$p_{ij} = \sum_{l=1}^{L} a_{ijl} \cdot g_l.$$

- p_{ij} is projection
- g_l is reconstructed image pixel
- a_{ijl} is built from beam transport function of accelerating structure

$$p_{z_1} = p_{z_0} + V \cdot cos\left(\omega(t - \frac{z_0}{c}) - \varphi_0\right)$$



- Iterative Procedure

$$g_q^{(k+1)} = g_q^{(k)} + \sum_{ij} \frac{a_{ijq}(p_{ij} - \sum_l a_{ijl} \cdot g_l^{(k)})}{\sum_{nm} a^2{}_{inm}}$$

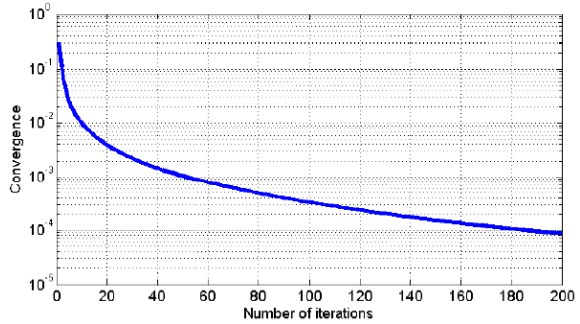
- Initial guess is array with 0 elements

LPS characterization via Tomography

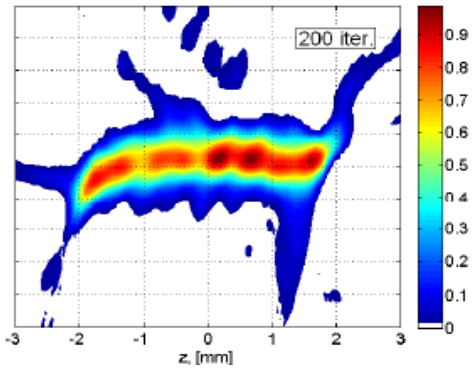
Algebraic Reconstruction Technique (ART)

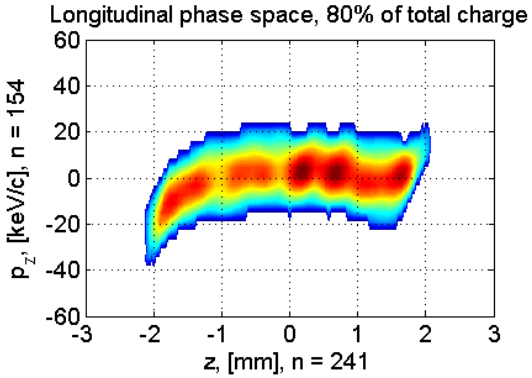
- Convergence criterion

$$C(k) = \sqrt{\frac{\sum_q \left(g_q^{(k)} - g_q^{(k-1)}\right)^2}{q_{max}}} \Big/ max(g^{(k)})$$



- Reconstructed LPS
  - Reconstruction artifacts because of noise and inconsistency in the measured projection
  - Overestimation of rms longitudinal emittance
  - Charge cut applied to eliminate artifacts

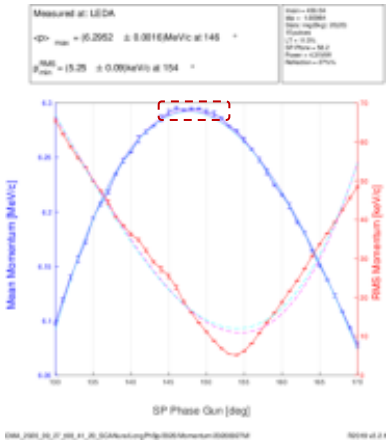




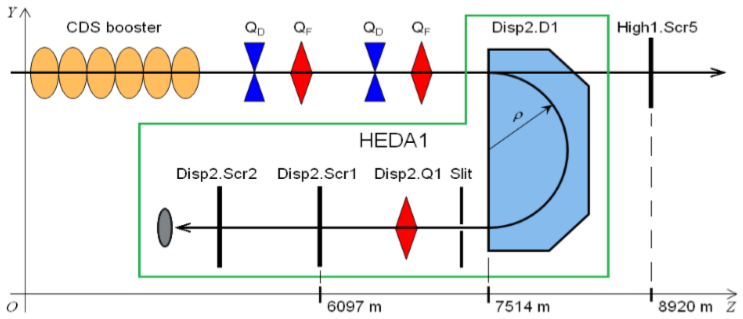
LPS characterization via Tomography

Possible Improvements

- ✓ Initial matrix definition g(0) from momentum scan of LEDA



- ✓ Beam focused using Q6 on H1.Scr5 for every phase for momentum measurement at HEDA1



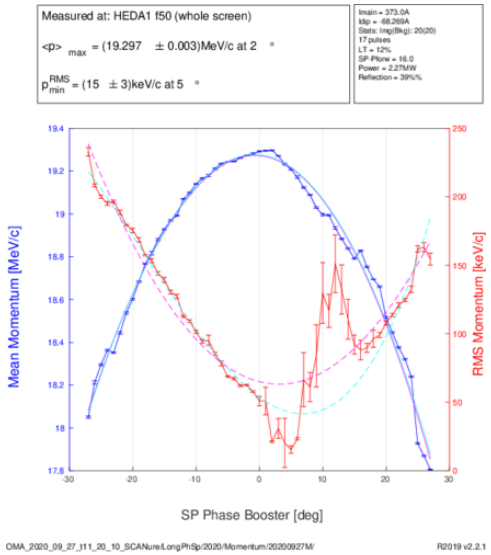
- ✓ NoP adjusted for every phase for best resolution
- ✓ Varying booster power levels and then fitting projections for phase scan simultaneously for reconstruction of LPS before the booster
- ✓ Varying booster power levels for estimation of space charge scaling effect from longitudinal phase space (how bunch length and bunch energy spread scales)
- ✓ Introduction of Machine Learning for improved reconstruction

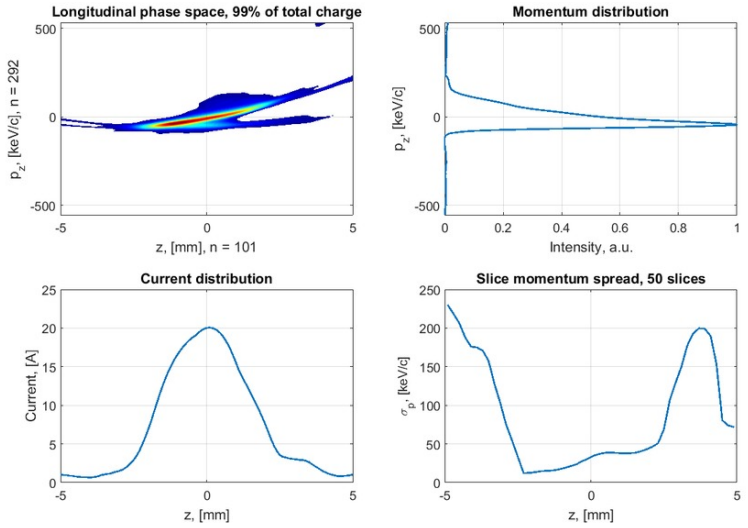
(*Proceedings of the 2018 CERN–Accelerator–School course on Numerical Methods for Analysis, Design and Modelling of Particle Accelerators, Thessaloniki, (Greece)*)

LPS characterization via Tomography

Methodical studies for LPS tomographic reconstruction (run week 41)

- HIGH1.Scr5 (reference screen for HEDA1 measurements) was not available, HIGH1.Scr4 was used instead (centered, underfocused beam)
- OMA has been modified – phase scan is waiting for each phase for magnets/NoP tuning





Gun:6.3MeV/c; MMMG, 250pC; BSA=1.0mm

Longitudinal Emittance (100%) = 116.83 [mm*keV/c]

Data saved in

//afs/ifh.de/group/pitz/doocs/measure/LongPhSp/2020/PhaseSpace/20200927M_11_20_10_1_v4

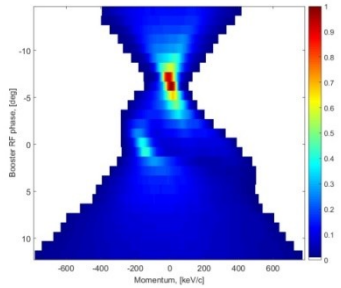
dpz = 3.734 [keV/c]

dz = 0.100 [mm]

RMS bunch length = 1.59 [mm]

RMS momentum spread = 88.46 [keV/c]

Longitudinal Emittance (99%) = 97.95 [mm*keV/c]



Problems:

1. Projections are taken from OMA (not proper bkg/signal processing)
2. HEDA1, zoom option
   → off-center momentum is not consistent with whole screen → calibration error for the zoom option?
   → bug in the reconstruction script for zoom option? (cosine modeling curve)

THANK YOU