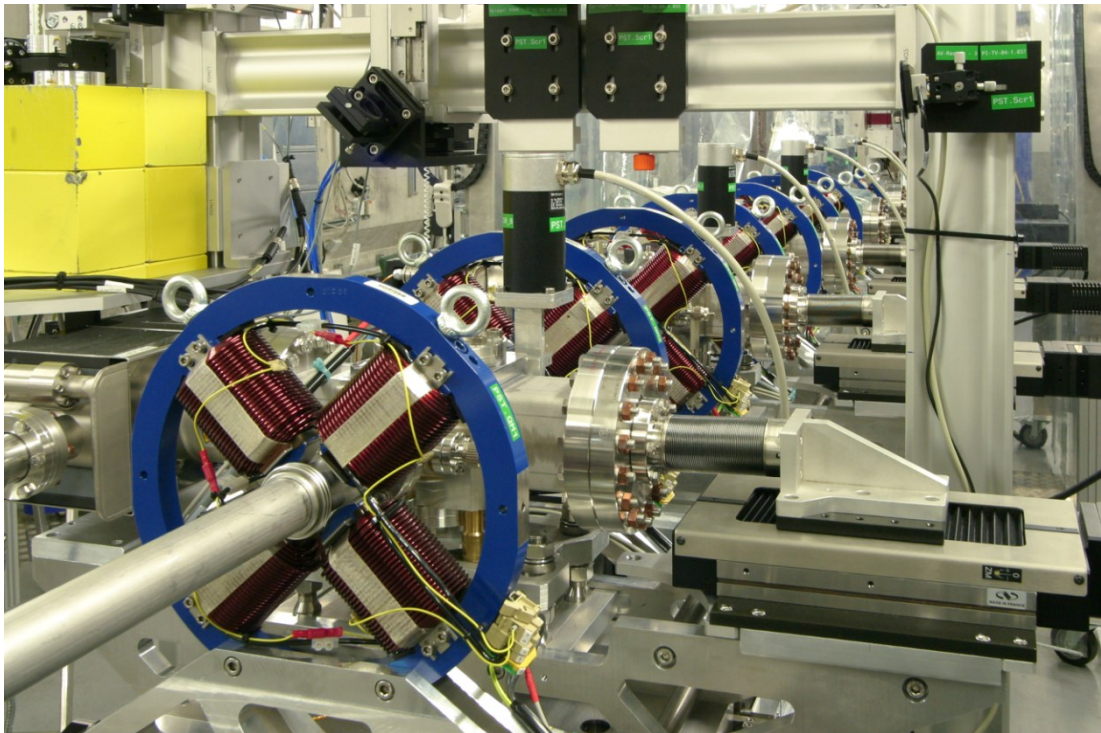
Space-charge matching of the transverse phase space at PITZ.

- Requirements of transverse beam matching at PITZ
- Transverse phase space tomography at PITZ
- Space-charge matching of periodic and dense lattices
- Space-charge matching of aperiodic and long lattices
- Summary and outlook

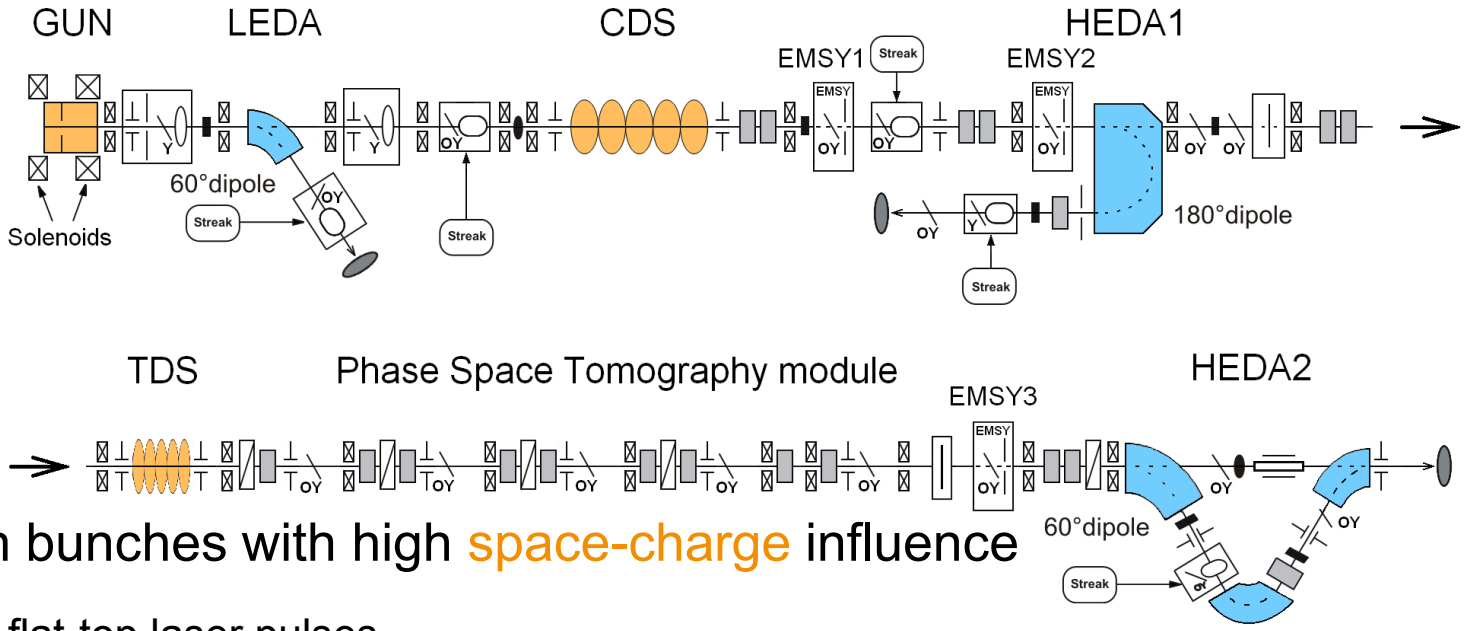


Georgios Kourkafas
DPG 2015, Wuppertal
10.03.2015

HELMHOLTZ ASSOCIATION

DESY

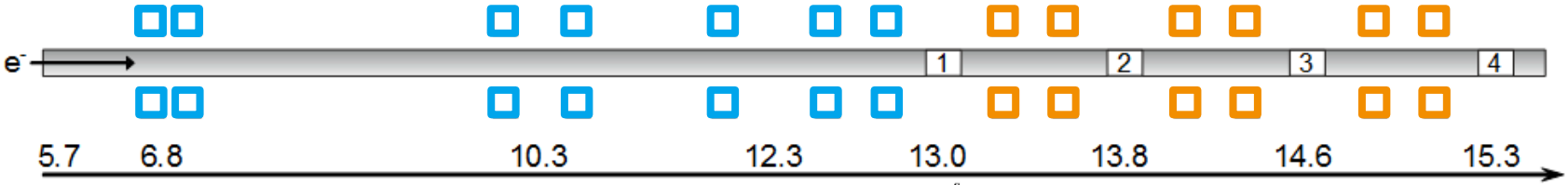
Requirements of transverse beam matching at PITZ



- Electron bunches with high space-charge influence
  - 20 ps flat-top laser pulses
  - 20 pC - 1 nC charge
  - up to 25 MeV/c momentum
- Various diagnostics and experiments require specific beam parameters at certain parts of the beamline → beam matching (e.g. PST)
- PITZ is a test facility with constantly changing machine parameters → fast matching results are needed

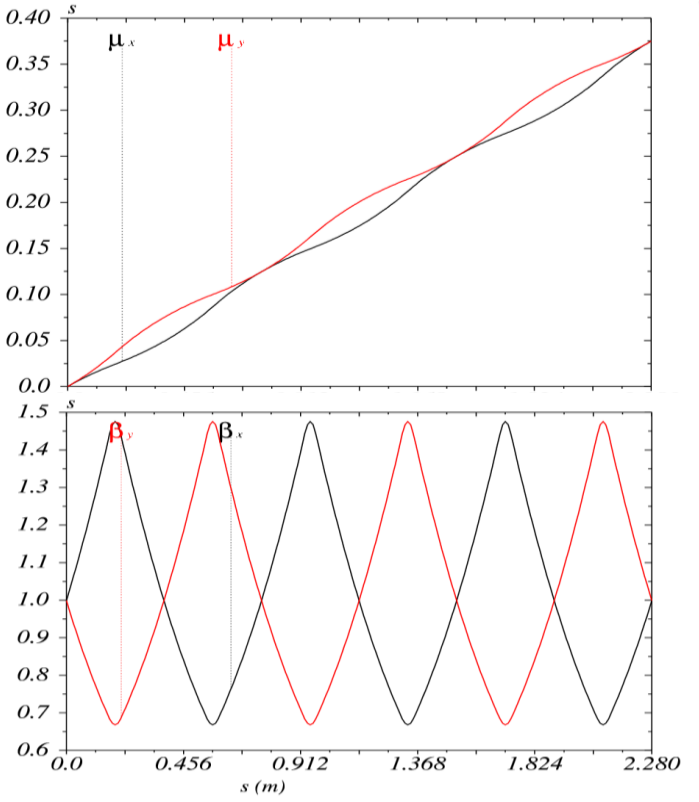
Transverse Phase Space Tomography (PST) at PITZ

- Tomographic reconstruction of the beam's phase space using 4 projections



- Components:

1. PST lattice (FODO) for the data acquisition
   → periodic and dense quadrupole focusing
2. Matching lattice for the necessary beam parameters in front of the PST lattice
   → aperiodic and sparse focusing



- Matching requirements:

1. equidistant phase advance values (45°) @ each PST screen
2. Twiss parameters @ 1st screen → $\beta_{x,y} = 1$ m, $\alpha_{x,y} = \pm 1$

Space-charge matching of periodic and dense lattices (I)

- Under the conditions of :
  - ✓ periodic focusing
  - ✓ (fairly) constant emittance

  the smooth-approximation theory* can be used to correlate the beam dynamics **without** and **with** space charge (linear component)
- Enables codes with no space-charge consideration (MAD) to perform space-charge matching by a proper scaling of the used beam parameters

1. Requirements: space-charge density (emittance and generalized perveance)
2. The desired matching constrains (45º) are scaled accordingly (e.g. 55º)
3. A traditional MAD matching is performed using the scaled parameters
4. Reverse-scaling of the MAD results to obtain the actual corresponding values

* Martin Reiser: Theory and Design of Charged Particle Beams, Wiley

Space-charge matching of periodic and dense lattices (II)

> Matching result of a beam with 1 nC, 22 ps, 25 MeV/c, 1 mm·mrad evaluated with ASTRA

	Phase-advance mismatch @ 1st screen	2nd screen	3rd screen
X plane			
Traditional MAD matching	-3.1°	-16.9°	-34.5°
MAD with space charge compensation	-0.9°	-0.9°	-1.2°
Y plane			
Traditional MAD matching	-4.7°	-20.2°	-37.8°
MAD with space charge compensation	-1.9°	-4.5°	-3.6°

> The phase-advance mismatch is reduced from 38° to 5° with the space-charge compensation (significant improvement for tomography)

> Method yields almost instant results

Space-charge matching of aperiodic and long lattices (I)

- The conditions of periodicity and constant emittance are no longer valid
- Except from its defocusing effect, space charge also induces correlated emittance growth
- Different slices of the beam obtain different transverse parameters, overlapping in the phase space

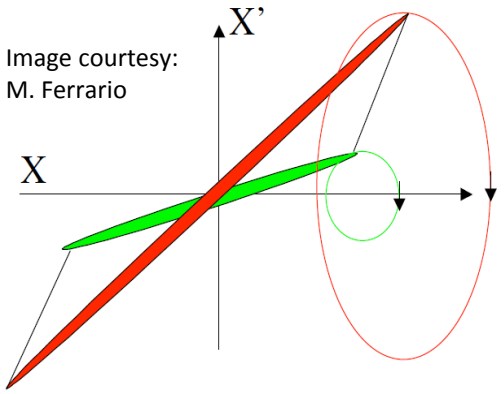
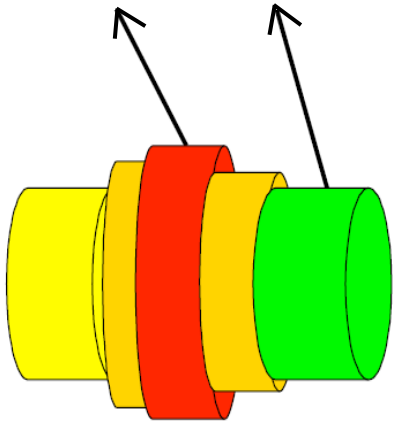


Image courtesy:
M. Ferrario

- In order to achieve the target values all along the bunch, the matching procedure has to suppress the emittance oscillations
- Solution comes from the SC software (HZB): linear space-charge fields (quick implementation) for each longitudinal slice of the bunch

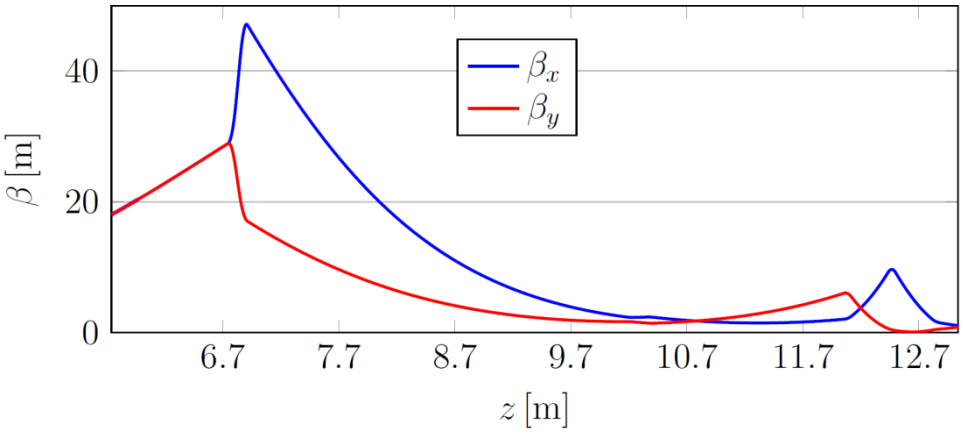


…more details on SC: Thursday, Andreas Ginter, AKBP 15.8

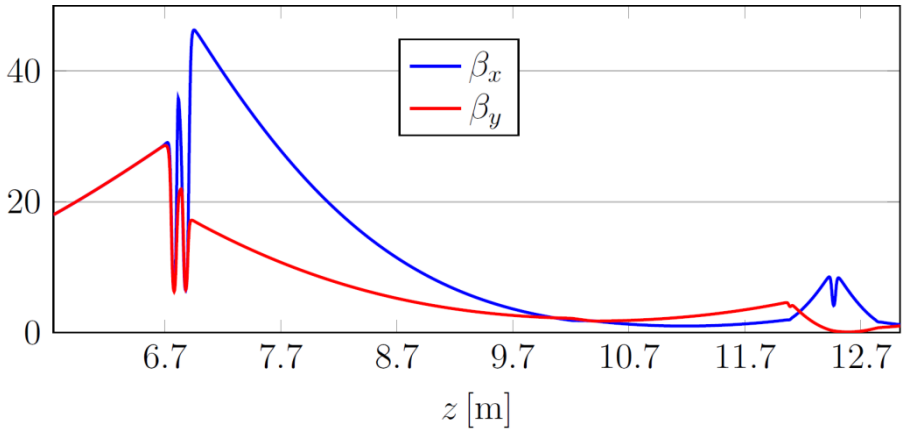
Space-charge matching of aperiodic and long lattices (II)

- Test beam : 1 nC, 25 MeV/c, 20 ps, 0.8 mm·mrad
- Matching goal (7.3 m downstream, 7 quads): **$\beta_{x,y}$ = 1.0 m, $\alpha_{x,y}$ = ±1.1**

SC



ASTRA

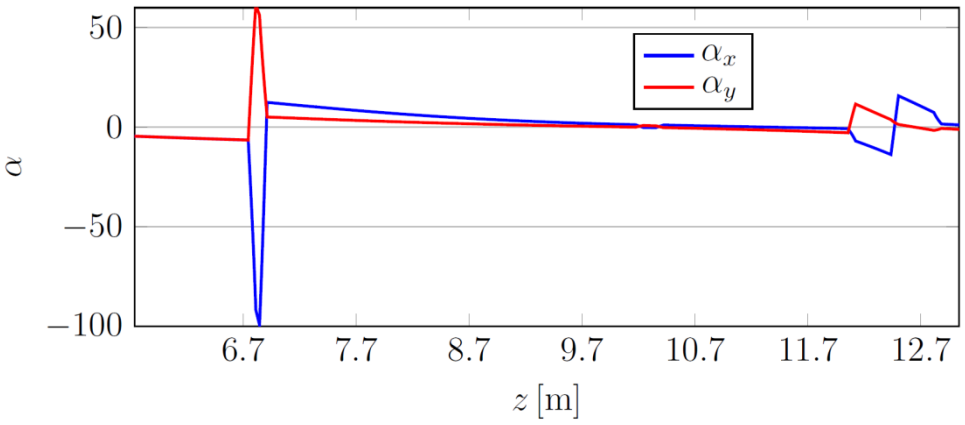


- Matching result: SC (~20 min) → β_x = 1.1 m, β_y = 0.8 m, α_x = 1.1, α_y = -1.1
  ASTRA (~3.5 h / single run) → β_x = 1.2 m, β_y = 1.0 m

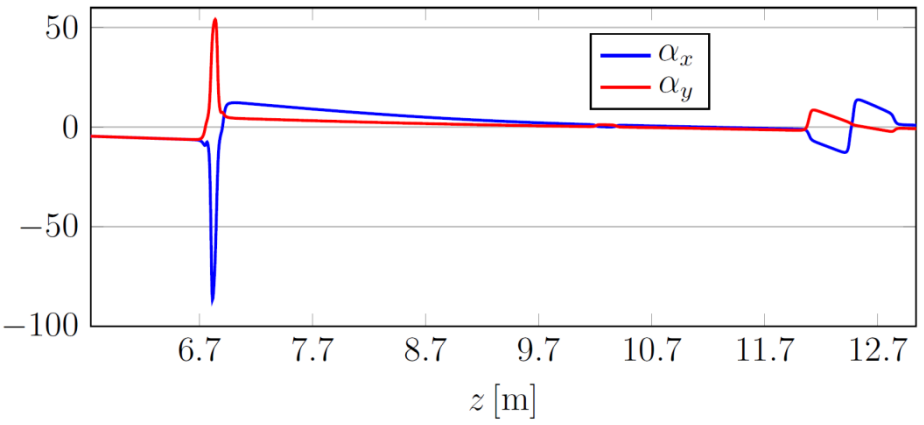
Space-charge matching of aperiodic and long lattices (II)

- Test beam : 1 nC, 25 MeV/c, 20 ps, 0.8 mm·mrad
- Matching goal (7.3 m downstream, 7 quads): $\beta_{x,y}$ = 1.0 m, $\alpha_{x,y}$ = ±1.1

SC



ASTRA



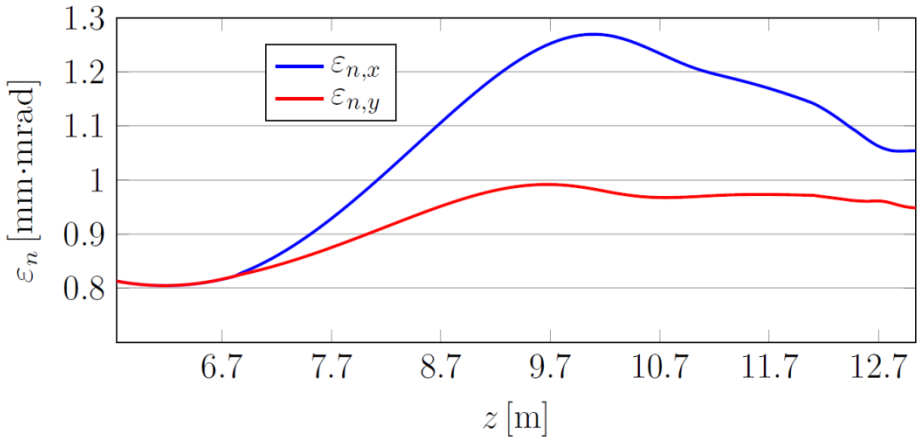
- Matching result: SC (~20 min) → β_x = 1.1 m, β_y = 0.8 m, α_x = 1.1, α_y = -1.1
  ASTRA (~3.5 h / single run) → β_x = 1.2 m, β_y = 1.0 m, α_x = 1.0, α_y = -0.8

1. the delivered mismatch is well acceptable

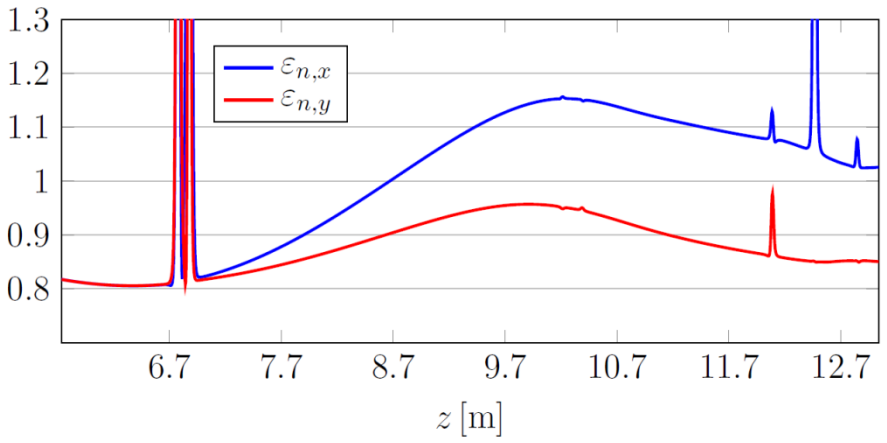
Space-charge matching of aperiodic and long lattices (II)

- Test beam : 1 nC, 25 MeV/c, 20 ps, 0.8 mm·mrad
- Matching goal (7.3 m downstream, 7 quads): $\beta_{x,y}$ = 1.0 m, $\alpha_{x,y}$ = ±1.1

SC



ASTRA



- Matching result: SC (~20 min) → ε_x = 1.1 mm·mrad, ε_y = 1.0 mm·mrad
  ASTRA (~3.5 h / single run) → ε_x = 1.0 mm·mrad, ε_y = 0.9 mm·mrad

1. the delivered mismatch is well acceptable
2. the non-linear space charge has a minor effect in the beam dynamics

Summary and outlook

- The incorporation of space charge in the transverse matching at PITZ is possible by:
  - combining the smooth-approximation theory with MAD → instant solution for periodic lattices of dense focusing
  - using the linear space-charge fields for a sliced bunch in SC → quick solution for irregular lattices
- Both solutions yield very good results in the most time-efficient way
- Useful also for compressed beams of high energy and peak current (e.g. bunch compressor exits of FELs)
- The performance of these methods has to be validated experimentally

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THANK YOU.

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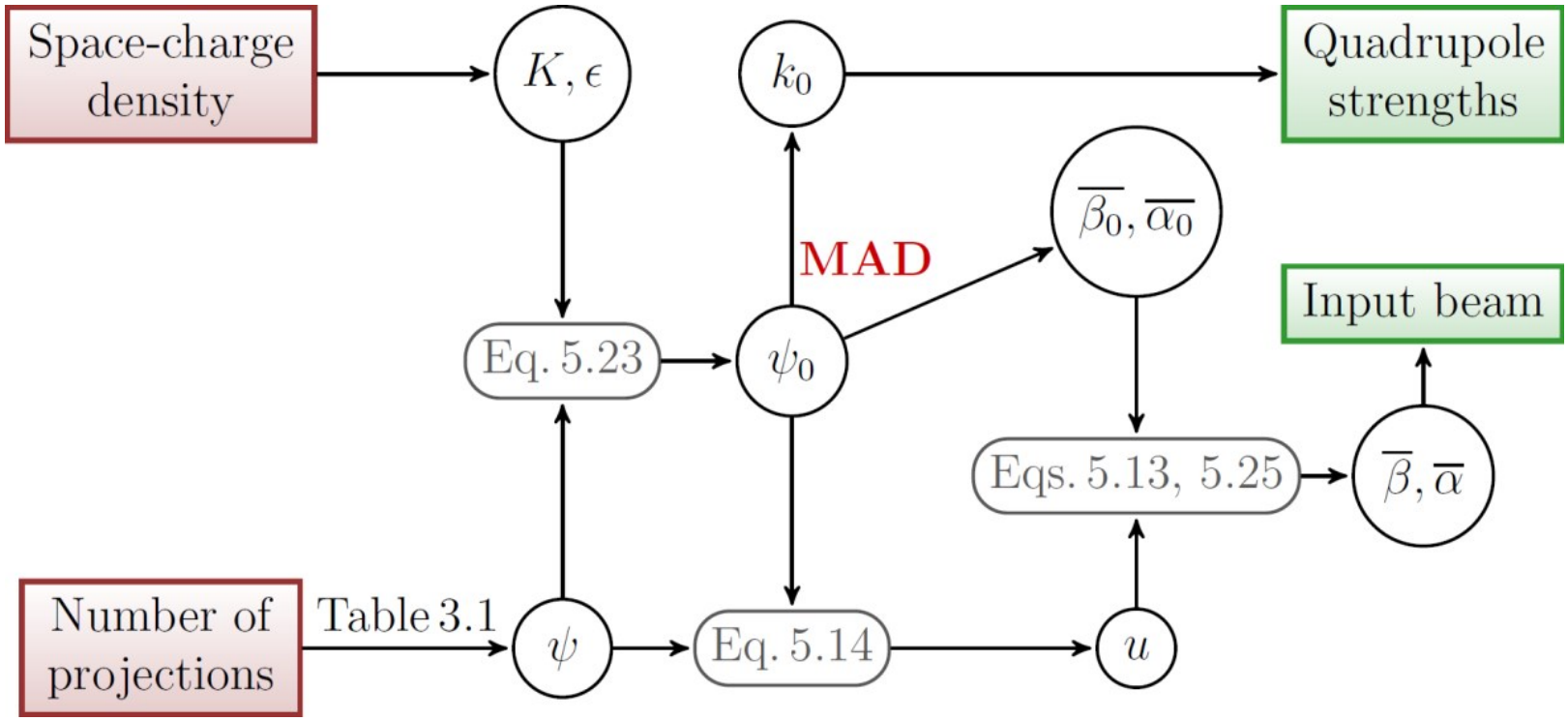
DESY

Backup Slides


Space-charge density
K, ϵ
k_0
Quadrupole strengths
$\overline{\beta_0}, \overline{\alpha_0}$
MAD
Input beam
Eq. 5.23
ψ_0
Eqs. 5.13, 5.25
$\overline{\beta}, \overline{\alpha}$
Number of projections
Table 3.1
ψ
Eq. 5.14
u