Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

ELBE.

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

TECHNISCHE UNIVERSITÄT DRESDEN

November 3rd, 2017

— II. Physikalische Institut Göttingen —

Outline

My History

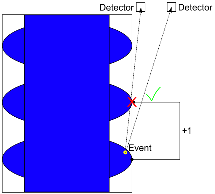
Motivation
- Emittance
- Compensation
- SRF Injector

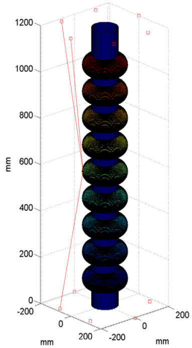
Compensation Schemes
- RF Focusing
- SC Solenoid
- TE Mode

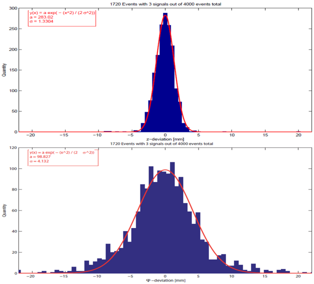
Conclusion
- Summary
- Outlook
- Acknowledgments

Bachelor's Thesis

- hundreds of TESLA cavities for XFEL
  ↪ feasibility study for 2nd sound test stand
- simulation with *Matlab*







- later '09 PhD studies of F. Schlander

My History

Motivation
Emittance
Compensation
SRF Injector

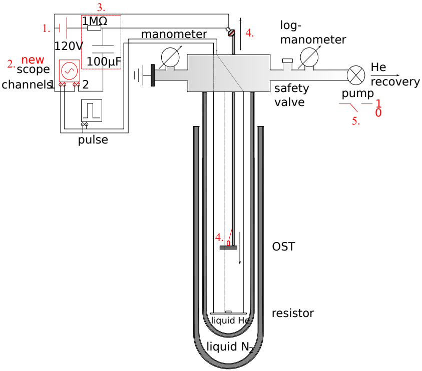
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Second Sound at Göttingen

- single OST setup with heater

  (borrowed from DESY)
- lots of noise suppression required



- bachelor's thesis of B. Schröder

My History

Motivation
Emittance
Compensation
SRF Injector

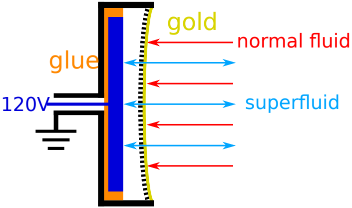
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Second Sound at CERN

- manufacture OSTs

capacitor design



My History

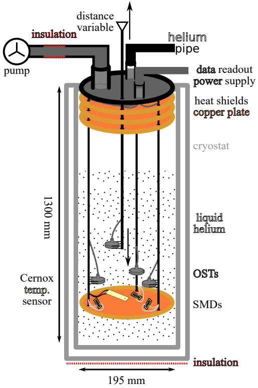
Motivation
Emittance
Compensation
SRF Injector

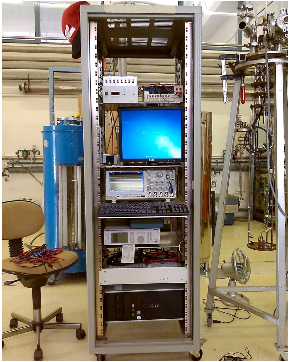
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Second Sound at CERN

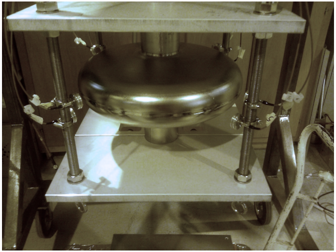
- manufacture OSTs
- test setup at cryolab *(multiple OSTs)*

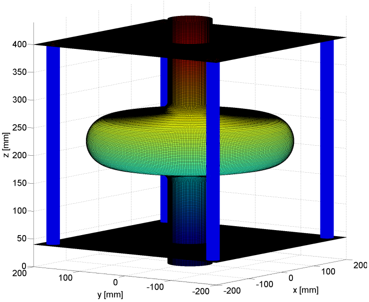




Second Sound at CERN

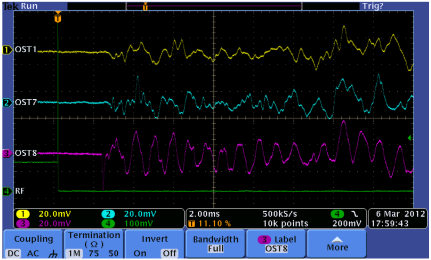
- manufacture OSTs
- test setup at cryolab *(multiple OSTs)*
- equip SPL test cavity

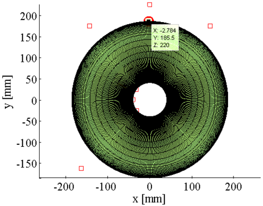




Second Sound at CERN

- manufacture OSTs
- test setup at cryolab *(multiple OSTs)*
- equip SPL test cavity





$\hookrightarrow$ cooperation with K. Liao, W. Weingarten

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Emittance Compensation for SRF Photoinjectors

$$\varepsilon = C \cdot \int_V \int_{V'} \mathrm{d}^3 x \, \mathrm{d}^3 p$$

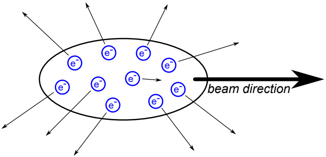
My History

Motivation
Emittance
Compensation
SRF Injector

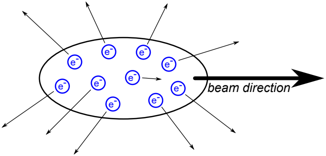
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors



Emittance Compensation for SRF Photoinjectors



- many sources of emittance → intrinsic and induced
  (thermal, RF, space charge, ...)

sources

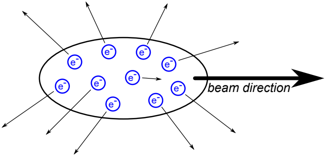
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors



- many sources of emittance → intrinsic and induced *(thermal, RF, space charge, ...)* sources
- accelerator physics → deliver beam for experiments

Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

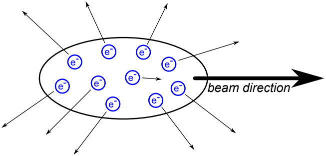
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors



- many sources of emittance → intrinsic and induced
  (thermal, RF, space charge, ...) sources
- accelerator physics → deliver beam for experiments
  ↪ looking at beam quality

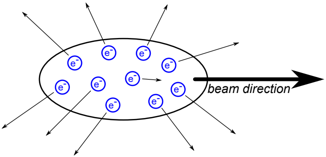
My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Emittance Compensation for SRF Photoinjectors



- many sources of emittance → intrinsic and induced
  (thermal, RF, space charge, ...) sources
- accelerator physics → deliver beam for experiments
  ↪ looking at beam quality
  ↪ brilliance/brightness

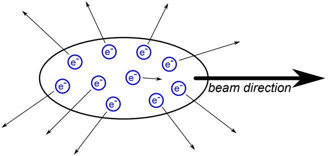
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors



- many sources of emittance → intrinsic and induced
  (thermal, RF, space charge, ...) sources
- accelerator physics → deliver beam for experiments
  ↪ looking at beam quality
    ↪ brilliance/brightness

$$B_{e^-} \propto \frac{1}{\varepsilon_x \, \varepsilon_y}$$

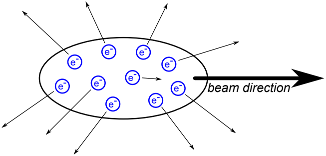
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors



- many sources of emittance → intrinsic and induced
  (thermal, RF, space charge, ...) sources
- accelerator physics → deliver beam for experiments
  ↪ looking at beam quality
  ↪ brilliance/brightness

$$B_{e^-} \propto \frac{1}{\varepsilon_x \varepsilon_y}$$

↪ transverse emittance

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$

My History

Motivation
Emittance
Compensation
SRF Injector

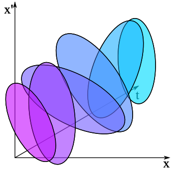
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$
- slice emittance

trace space & norm. RMS emittance



My History

Motivation
- Emittance
- Compensation
- SRF Injector

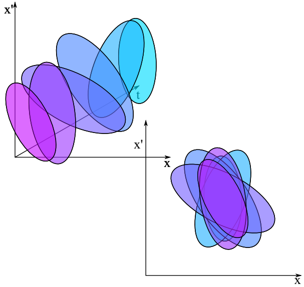
Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Emittance Compensation for SRF Photoinjectors

- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$
- slice emittance

trace space & norm. RMS emittance



My History

Motivation
Emittance
Compensation
SRF Injector

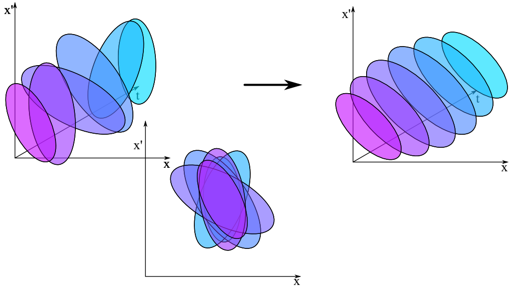
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$
- slice emittance

trace space & norm. RMS emittance



My History

Motivation
Emittance
Compensation
SRF Injector

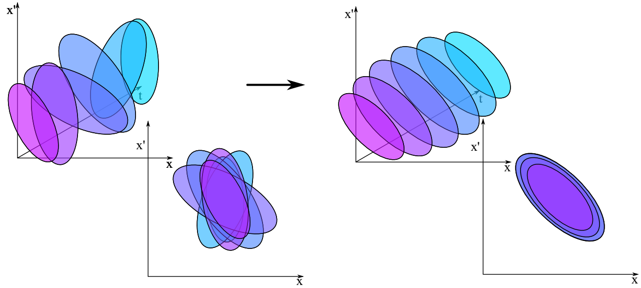
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$
- slice emittance

trace space & norm. RMS emittance

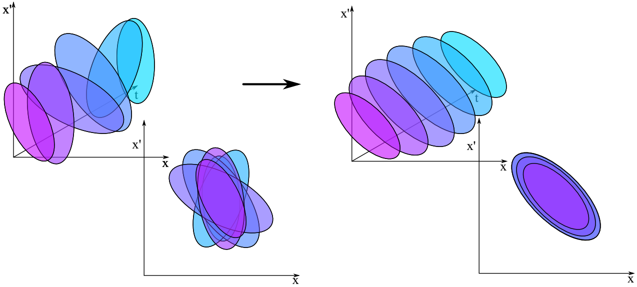


My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

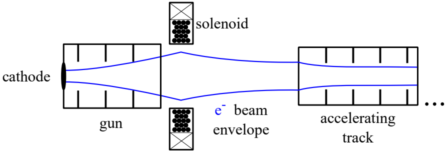
- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$
- slice emittance

trace space & norm. RMS emittance



- goal → generate minimum at acceleration

space charge



My History

Motivation
- Emittance
- Compensation
- SRF Injector

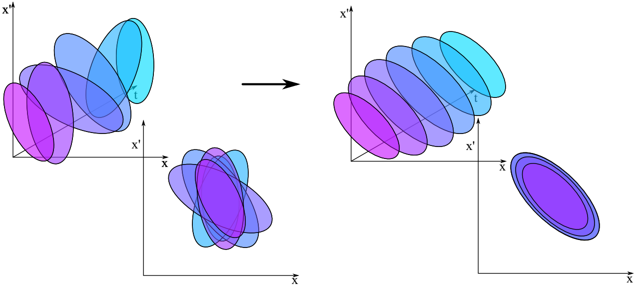
Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Emittance Compensation for SRF Photoinjectors

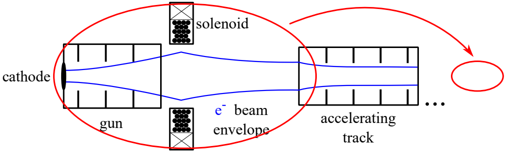
- projected emittance in trace space $x, x' = \frac{dx}{dz} = \frac{p_x}{p_z}$
- slice emittance

trace space & norm. RMS emittance



- goal → generate minimum at acceleration

space charge



- injector determines offset/evolution

Emittance Compensation for SRF Photoinjectors

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- benefits of superconductivity for accelerators

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- benefits of superconductivity for accelerators

power conversion

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- benefits of superconductivity for accelerators

power conversion CW operation

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- benefits of superconductivity for accelerators

  power conversion CW operation

- SRF injector combines advantages of
  1. high rep. rates (DC guns) and
  2. large bunch charges and low emittance (RF injectors)

Emittance Compensation for SRF Photoinjectors

- benefits of superconductivity for accelerators

  power conversion CW operation

- SRF injector combines advantages of
  1. high rep. rates (DC guns) and
  2. large bunch charges and low emittance (RF injectors)
- ELBE requires flexible CW source

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Compensation for SRF Photoinjectors

- benefits of superconductivity for accelerators

  power conversion CW operation

- SRF injector combines advantages of
  1. high rep. rates (DC guns) and
  2. large bunch charges and low emittance (RF injectors)
- ELBE requires flexible CW source → SRF Gun

ELBE history @ HZDR

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

ELBE SRF Gun II

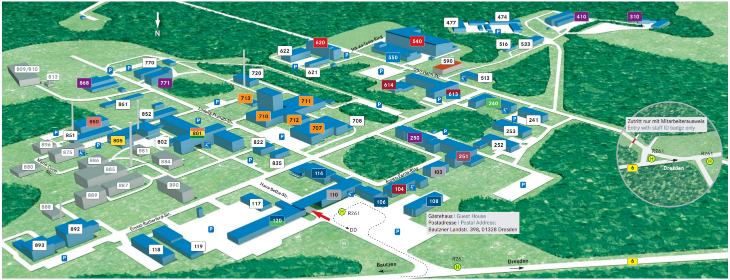
My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

ELBE SRF Gun II



ELBE SRF Gun II

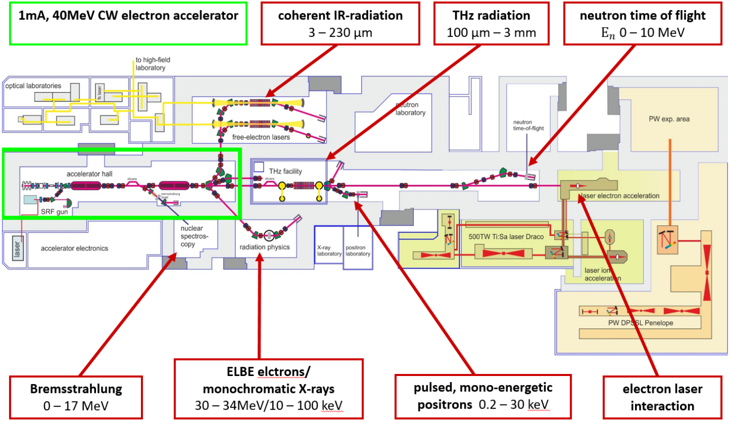
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

ELBE SRF Gun II



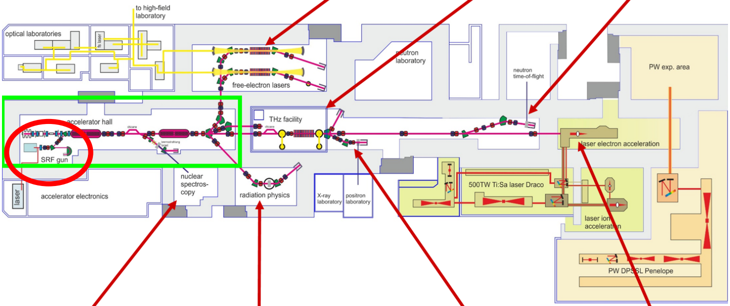
ELBE SRF Gun II

1mA, 40MeV CW electron accelerator

coherent IR-radiation 3 – 230 µm

THz radiation 100 µm – 3 mm

neutron time of flight E_n 0 – 10 MeV



Bremsstrahlung 0 – 17 MeV

ELBE elctrons/ monochromatic X-rays 30 – 34MeV/10 – 100 keV

pulsed, mono-energetic positrons 0.2 – 30 keV

electron laser interaction

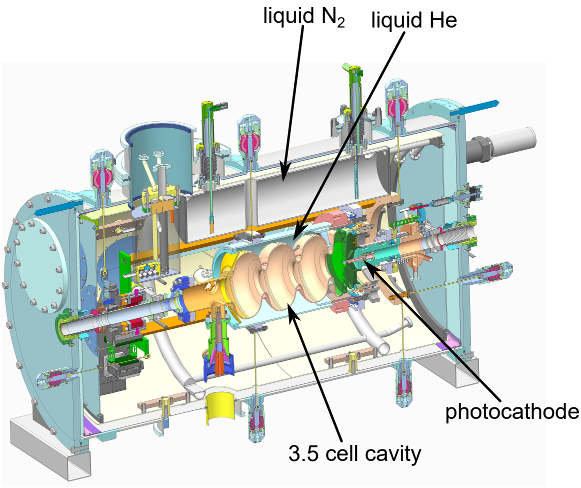
My History

Motivation
- Emittance
- Compensation
- SRF Injector

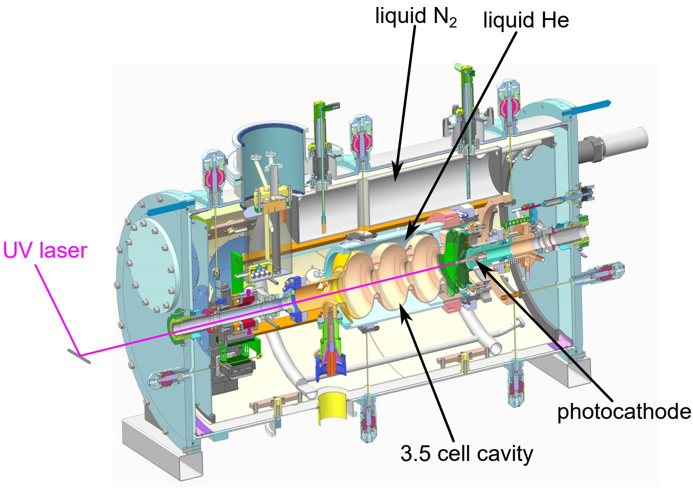
Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

ELBE SRF Gun II



ELBE SRF Gun II



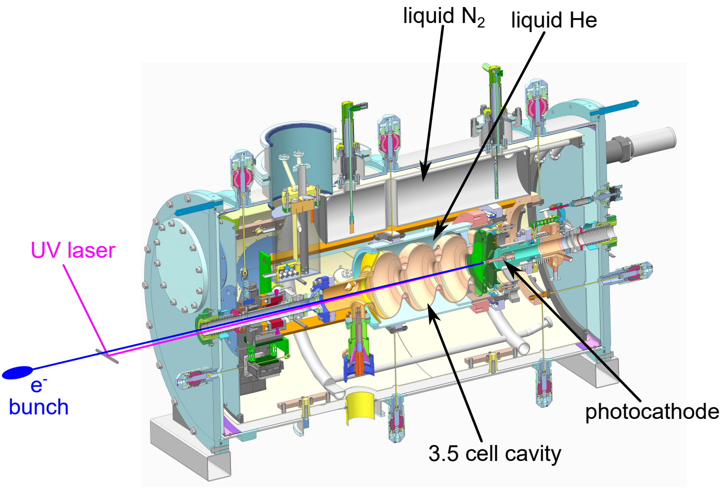
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

ELBE SRF Gun II



My History

Motivation
- Emittance Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Challenge

My History

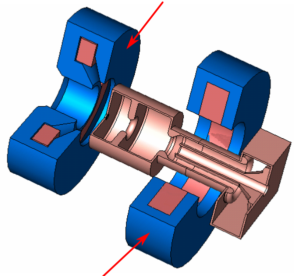
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Challenge

- compensation for normal conducting injectors



My History

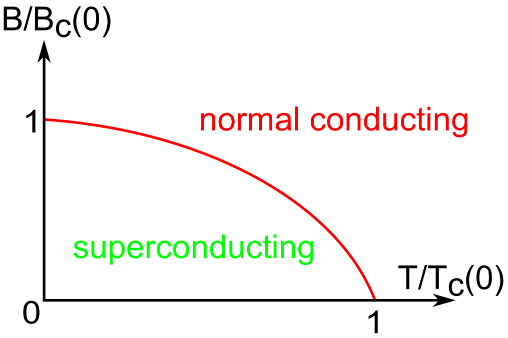
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Challenge

- compensation for normal conducting injectors



- SC limits use of magnetic fields

My History

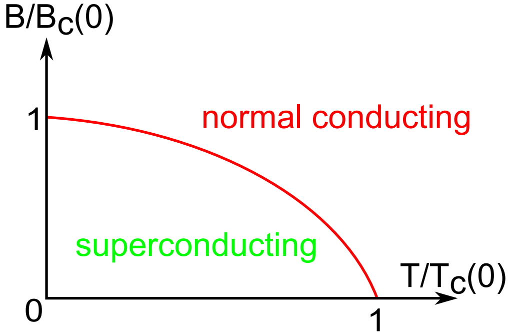
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Challenge

- compensation for normal conducting injectors



- SC limits use of magnetic fields
  ↪ find more elaborate solution(s)

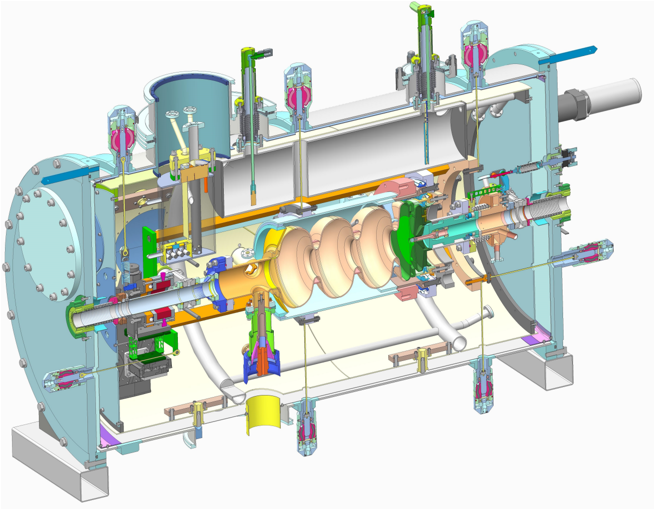
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

RF Focusing



My History

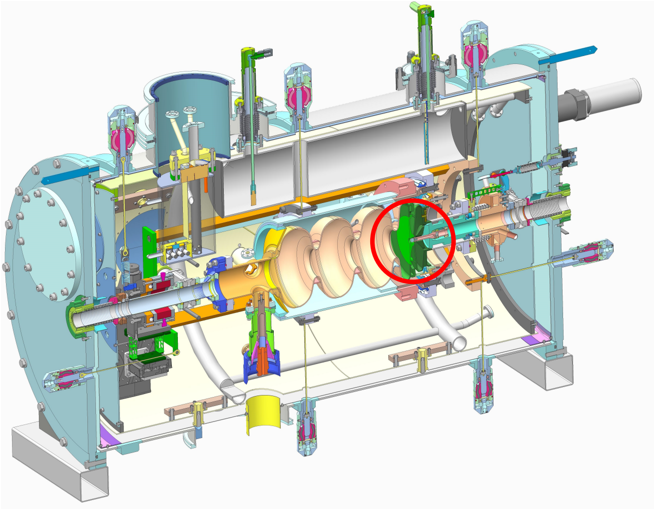
Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

RF Focusing

- focusing via RF field in half-cell



My History

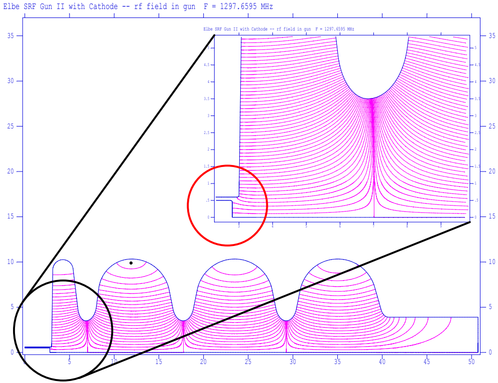
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

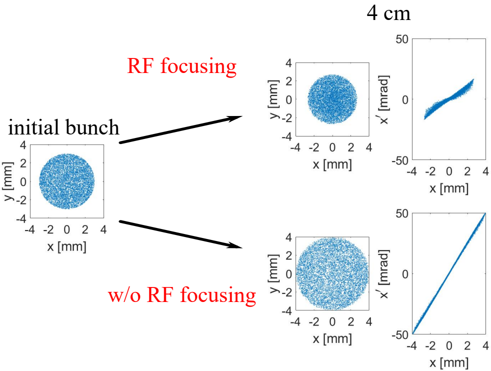
RF Focusing

- focusing via RF field in half-cell



RF Focusing

- focusing via RF field in half-cell

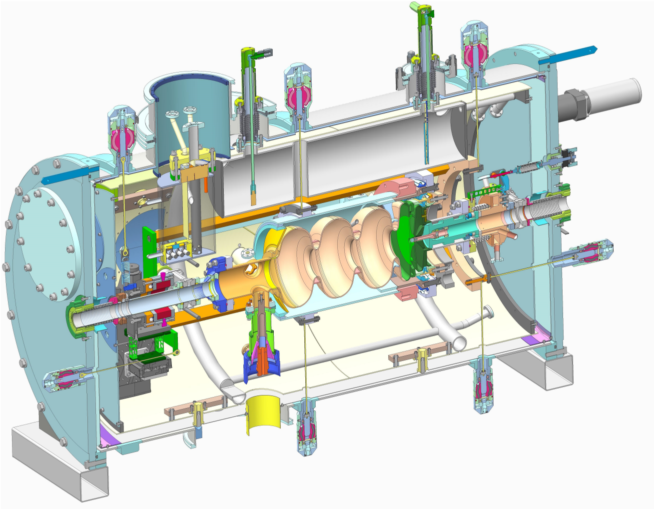


- counteract repulsion forces at cathode

displacement

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments

Superconducting Solenoid



My History

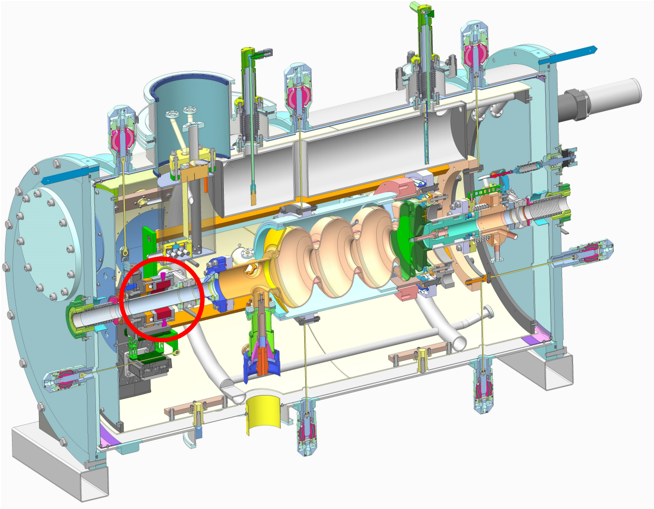
Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Superconducting Solenoid

- get as close as possible w/o affecting cavity



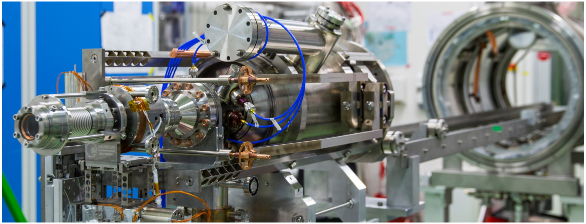
My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
- -

Installation and Commissioning



- installation inside cryostat ≈ 70 cm from cathode

Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

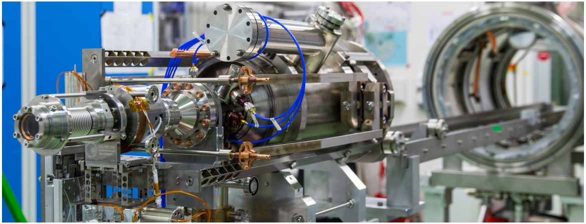
My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Installation and Commissioning



- installation inside cryostat $\approx$ 70 cm from cathode
- commissioning during installation:

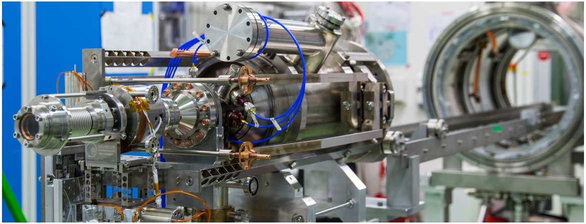
My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

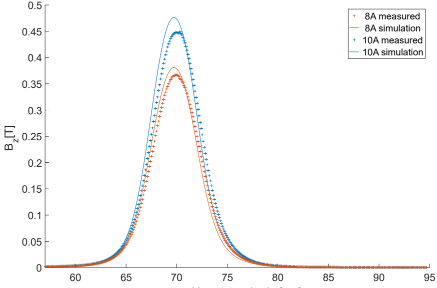
Conclusion
Summary
Outlook
Acknowledgments
-

Installation and Commissioning



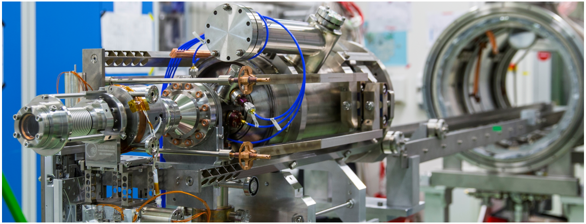
- installation inside cryostat ≈ 70 cm from cathode
- commissioning during installation:

a field profile



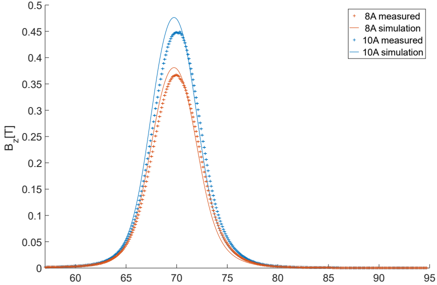
My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Installation and Commissioning



- installation inside cryostat ≈ 70 cm from cathode
- commissioning during installation:

a field profile
b shielding
c degaussing
d thermal stability
e protective circuit
...



Simulation Studies

My History

Motivation
Emittance
Compensation
SRF Injector

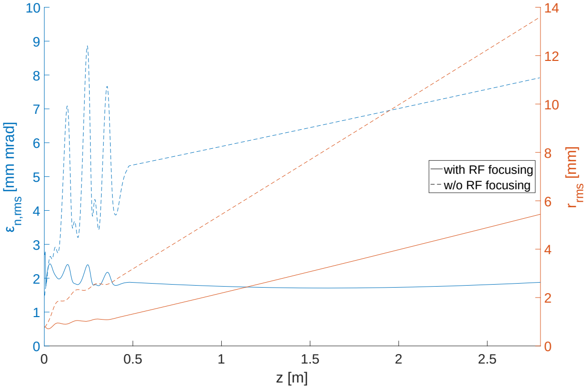
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Simulation Studies

- optimize RF focusing alone (250 pC)

input param.



My History

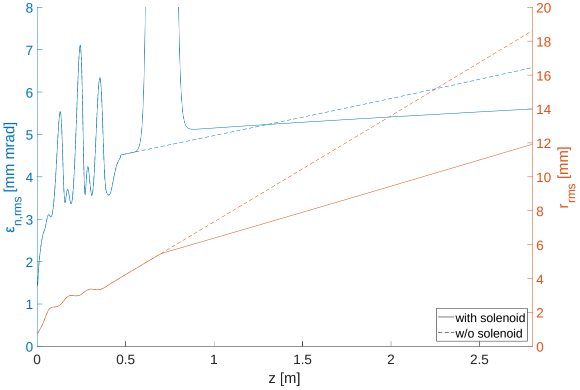
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Simulation Studies

- optimize RF focusing alone (250 pC) input param.
- optimize solenoid alone



My History

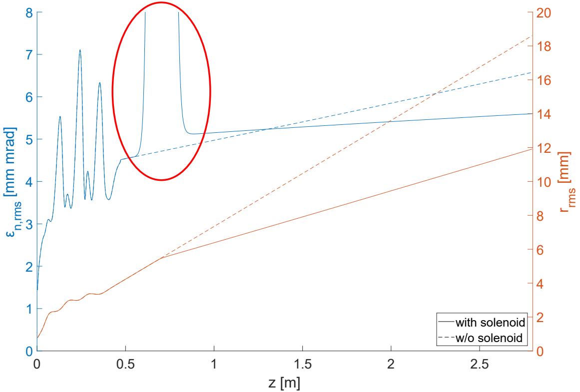
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Simulation Studies

- optimize RF focusing alone (250 pC) input param.
- optimize solenoid alone solenoid



My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

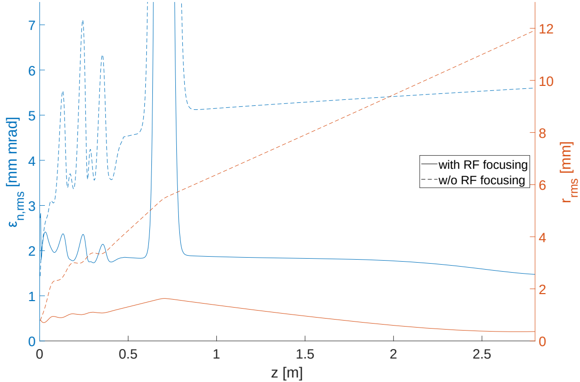
Conclusion
- Summary
- Outlook
- Acknowledgments
- -

Simulation Studies

- optimize RF focusing alone (250 pC)
- optimize solenoid alone

input param.

solenoid



- ... combine the two!

trace space

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Measurements

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Measurements

- 160 pC:

My History

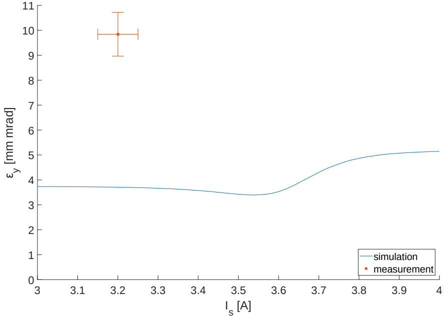
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Measurements

- 160 pC:



My History

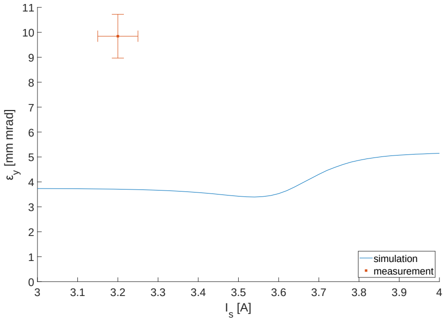
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

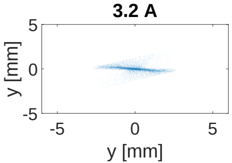
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Measurements

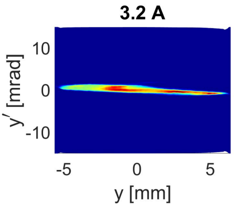
- 160 pC:



simulation



measurement



My History

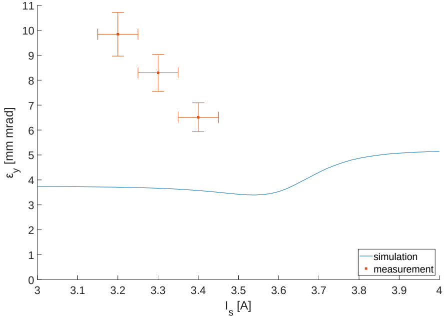
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

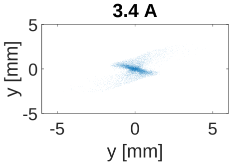
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Measurements

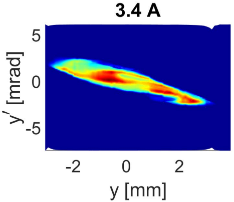
- 160 pC:



simulation



measurement



My History

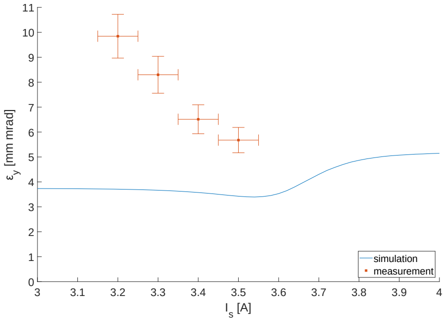
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

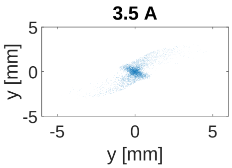
Conclusion
Summary
Outlook
Acknowledgments
-

Emittance Measurements

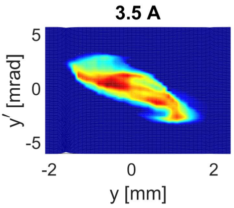
- 160 pC:



simulation



measurement



My History

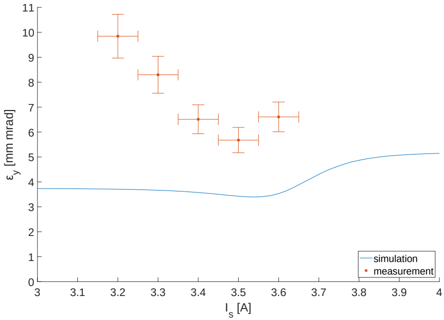
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

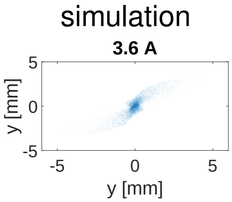
Conclusion
Summary
Outlook
Acknowledgments
-

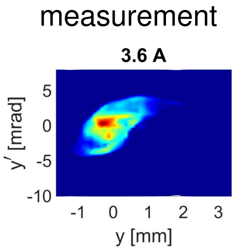
Emittance Measurements

- 160 pC:



laser profile





Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

My History

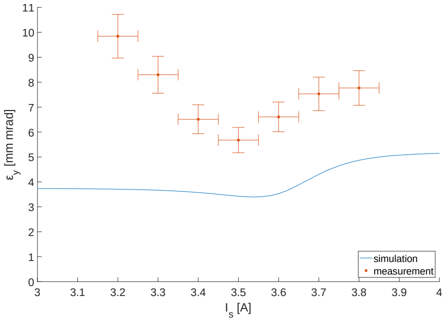
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

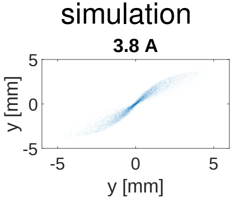
Conclusion
Summary
Outlook
Acknowledgments
-

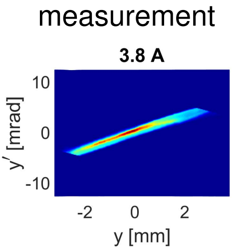
Emittance Measurements

- 160 pC:



laser profile





My History

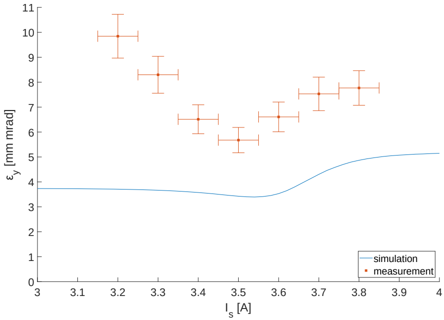
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

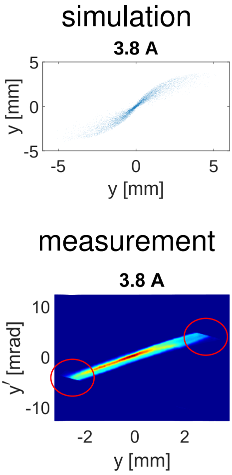
Emittance Measurements

- 160 pC:

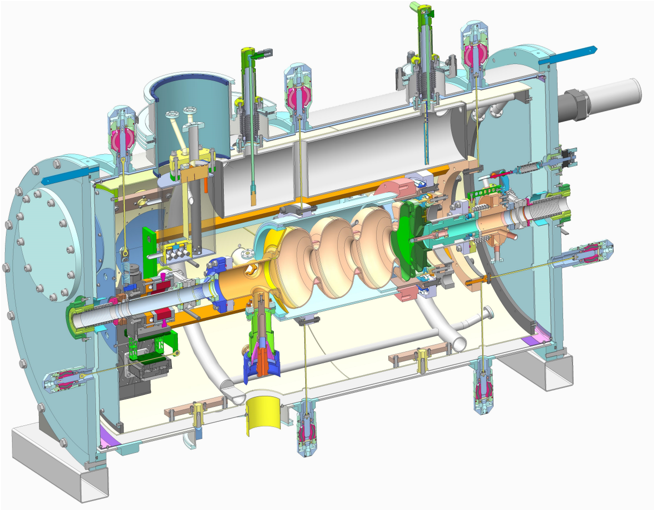


laser profile

measurement setup



Transverse Electric Mode



My History

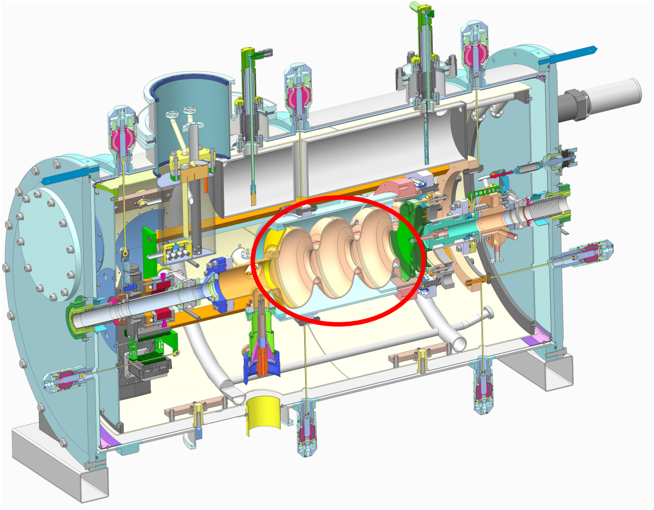
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

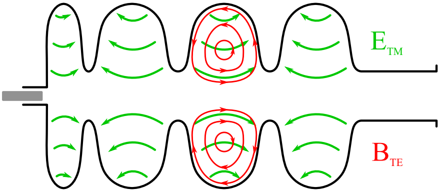
Transverse Electric Mode

- solenoid field inside the cavity by RF means



Transverse Electric Mode

- solenoid field inside the cavity by RF means



- trans. magnetic and electric mode in one cavity

My History

Motivation
Emittance Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

RF Measurements

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

RF Measurements

- second 3-1/2 cell cavity at JLab

RF setup

My History

Motivation
Emittance
Compensation
SRF Injector

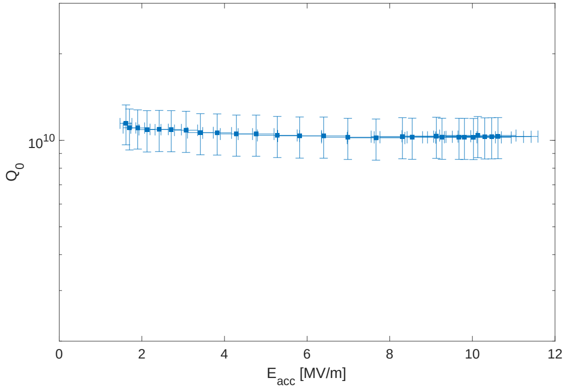
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

RF Measurements

- second 3-1/2 cell cavity at JLab
- Q_0 vs E_{acc} measurement for the TM mode

RF setup



My History

Motivation
Emittance
Compensation
SRF Injector

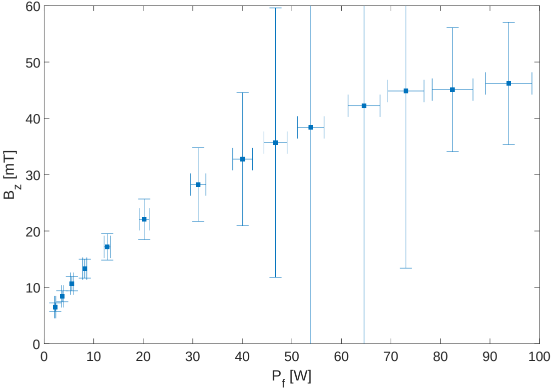
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

RF Measurements

- second 3-1/2 cell cavity at JLab
- Q_0 vs E_{acc} measurement for the TM mode
- TE mode excited in parallel

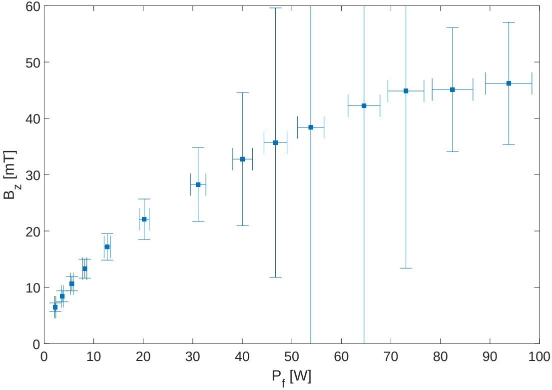
RF setup



RF Measurements

- second 3-1/2 cell cavity at JLab
- Q_0 vs E_{acc} measurement for the TM mode
- TE mode excited in parallel

RF setup



↪ reached about 47 mT on axis w/o effect on TM

My History

Motivation
Emittance
Compensation
SRF Injector

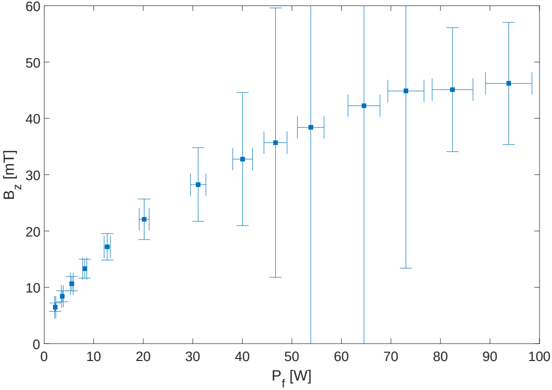
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

RF Measurements

- second 3-1/2 cell cavity at JLab
- Q_0 vs E_{acc} measurement for the TM mode
- TE mode excited in parallel

RF setup



↪ reached about 47 mT on axis w/o effect on TM

- additional surface field contribution

surface field

Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Simulation of TE Mode

My History

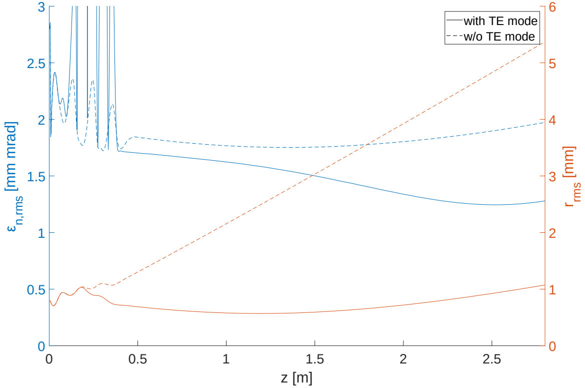
Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Simulation of TE Mode

- tracking of 250 pC
  (second cell (≈ 2.5 GHz), incl. RF focusing)



My History

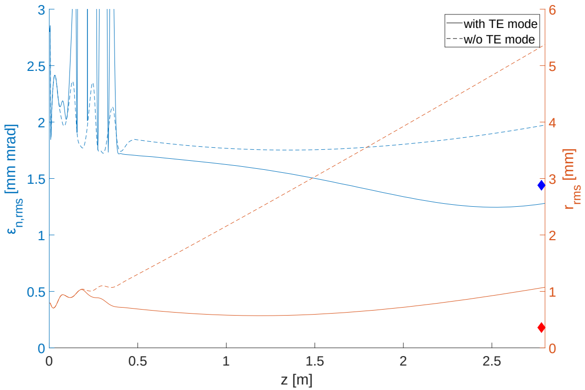
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

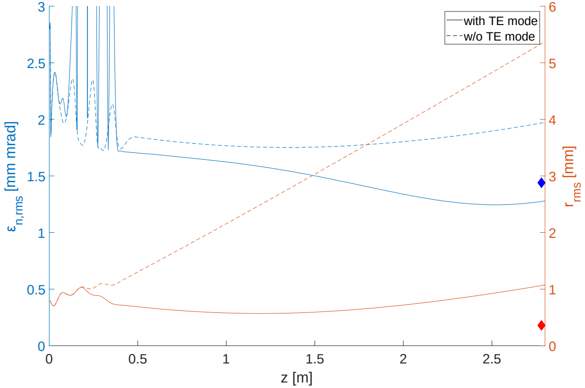
Simulation of TE Mode

- tracking of 250 pC
  (second cell (≈ 2.5 GHz), incl. RF focusing)
- similar to solenoid



Simulation of TE Mode

- tracking of 250 pC
  (second cell (≈ 2.5 GHz), incl. RF focusing)
- similar to solenoid



- disadvantage of phase dependency

My History

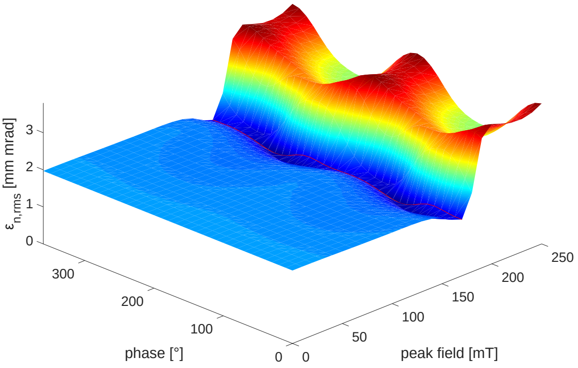
Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Simulation of TE Mode

- tracking of 250 pC
  (second cell ($\approx$ 2.5 GHz), incl. RF focusing)
- similar to solenoid



- disadvantage of phase dependency
  $\hookrightarrow$ $\sigma_\varepsilon \approx 6\,\%$ and $\sigma_r \approx 5\,\%$

more results

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  ↪ but there are solutions

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  $\hookrightarrow$ but there are solutions
  - RF focusing $\leftrightarrow$ SC solenoid

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  $\hookrightarrow$ but there are solutions
  - RF focusing $\leftrightarrow$ SC solenoid
    $\hookrightarrow$ installed, commissioned, studied with Gun II

My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
  - -

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  ↪ but there are solutions
  - RF focusing ↔ SC solenoid
    ↪ installed, commissioned, studied with Gun II

      250 pC gain by 4.8 ← sim.
      160 pC $\varepsilon \approx$ 5.7 mm mrad ← meas.

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  $\hookrightarrow$ but there are solutions
  - RF focusing $\leftrightarrow$ SC solenoid
    $\hookrightarrow$ installed, commissioned, studied with Gun II

      250 pC gain by 4.8 $\leftarrow$ sim.
      160 pC $\varepsilon \approx$ 5.7 mm mrad $\leftarrow$ meas.

  - TE Mode

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  $\hookrightarrow$ but there are solutions
  - RF focusing $\leftrightarrow$ SC solenoid
    $\hookrightarrow$ installed, commissioned, studied with Gun II

    250 pC gain by 4.8 $\leftarrow$ sim.
    160 pC $\varepsilon \approx$ 5.7 mm mrad $\leftarrow$ meas.

  - TE Mode
    $\hookrightarrow$ first RF measurements at JLab

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  $\hookrightarrow$ but there are solutions
  - RF focusing $\leftrightarrow$ SC solenoid
    $\hookrightarrow$ installed, commissioned, studied with Gun II

    250 pC gain by 4.8 $\leftarrow$ sim.
    160 pC $\varepsilon \approx$ 5.7 mm mrad $\leftarrow$ meas.

  - TE Mode
    $\hookrightarrow$ first RF measurements at JLab

    250 pC average gain by 4.7 $\pm$ 5 % $\leftarrow$ sim.
    $\hookrightarrow$ surface contribution, phase dependency

My History

Motivation
Emittance Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  $\hookrightarrow$ but there are solutions
  - RF focusing $\leftrightarrow$ SC solenoid
    $\hookrightarrow$ installed, commissioned, studied with Gun II

    250 pC gain by 4.8 $\leftarrow$ sim.
    160 pC $\varepsilon \approx 5.7$ mm mrad $\leftarrow$ meas.

  - TE Mode
    $\hookrightarrow$ first RF measurements at JLab

    250 pC average gain by $4.7 \pm 5\,\%$ $\leftarrow$ sim.
    $\hookrightarrow$ surface contribution, phase dependency
    solenoid vs TE mode $\rightarrow$ simpler approach?

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  ↪ but there are solutions
  - RF focusing ↔ SC solenoid
    ↪ installed, commissioned, studied with Gun II

      250 pC gain by 4.8 ← sim.
      160 pC $\varepsilon \approx 5.7$ mm mrad ← meas.

  - TE Mode
    ↪ first RF measurements at JLab

      250 pC average gain by $4.7 \pm 5\,\%$ ← sim.
      ↪ surface contribution, phase dependency
      solenoid vs TE mode → simpler approach?

- concepts independent of particular injector design

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Summary

- SRF injector concept offers great potential
- emittance compensation challenging
  ↪ but there are solutions
  - RF focusing ↔ SC solenoid
    ↪ installed, commissioned, studied with Gun II

    250 pC gain by 4.8 ← sim.
    160 pC $\varepsilon \approx 5.7$ mm mrad ← meas.
  - TE Mode
    ↪ first RF measurements at JLab

    250 pC average gain by $4.7 \pm 5\,\%$ ← sim.
    ↪ surface contribution, phase dependency
    solenoid vs TE mode → simpler approach?
- concepts independent of particular injector design
  ↪ benefit to SRF injector community
  (bERLinPro, ...)

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

RF focusing further experiments measurements

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments	measurements
SC solenoid	new solenoid being commissioned for Gun III	

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments	measurements
SC solenoid	new solenoid being commissioned for Gun III	
TE mode	further RF studies at JLab ↪ beam dynamics in real injector	

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments	measurements
SC solenoid	new solenoid being commissioned for Gun III	
TE mode	further RF studies at JLab $\hookrightarrow$ beam dynamics in real injector	
cathodes/laser	issues with stability & reproducibility	

My History

Motivation

Emittance Compensation

SRF Injector

Compensation Schemes

RF Focusing

Concept

SC Solenoid

Concept

Simulation

Measurement

TE Mode

Concept

Measurement

Simulation

Conclusion

Summary

Outlook

Acknowledgments

-

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments (measurements)
SC solenoid	new solenoid being commissioned for Gun III
TE mode	further RF studies at JLab $\hookrightarrow$ beam dynamics in real injector
cathodes/laser	issues with stability & reproducibility new types, improved prep., ...

My History

Motivation
Emittance Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments (measurements)
SC solenoid	new solenoid being commissioned for Gun III
TE mode	further RF studies at JLab $\hookrightarrow$ beam dynamics in real injector
cathodes/laser	issues with stability & reproducibility new types, improved prep., ... SLM, sys. upgrade $\rightarrow$ cooperation

codes | laser profile | x-corr.

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments (measurements)
SC solenoid	new solenoid being commissioned for Gun III
TE mode	further RF studies at JLab $\hookrightarrow$ beam dynamics in real injector
cathodes/laser	issues with stability & reproducibility new types, improved prep., ... SLM, sys. upgrade $\rightarrow$ cooperation

codes | laser profile | x-corr.

- dedicated gun lab at HZDR

My History

Motivation
- Emittance
- Compensation
- SRF Injector

Compensation Schemes
- RF Focusing
  - Concept
- SC Solenoid
  - Concept
  - Simulation
  - Measurement
- TE Mode
  - Concept
  - Measurement
  - Simulation

Conclusion
- Summary
- Outlook
- Acknowledgments
- -

Outlook

- emittance compensation at HZDR and beyond

RF focusing	further experiments *measurements*
SC solenoid	new solenoid being commissioned for Gun III
TE mode	further RF studies at JLab $\hookrightarrow$ beam dynamics in real injector
cathodes/laser	issues with stability & reproducibility new types, improved prep., ... SLM, sys. upgrade $\rightarrow$ cooperation *codes* *laser profile* *x-corr.*

- dedicated gun lab at HZDR
  $\hookrightarrow$ dedicated resources $\leftrightarrow$ dedicated people (laser)

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Resume

If you ...

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Resume

If you ...
use all your strength,

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Resume

If you ...
use all your strength, push sometimes,

Resume

If you ...
use all your strength, push sometimes, climb high when needed,

My History
Motivation
Emittance
Compensation
SRF Injector
Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation
Conclusion
Summary
Outlook
Acknowledgments
-

Resume

If you ...
use all your strength, push sometimes, climb high when needed, hang in there when things get stuck,

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Resume

If you ...
use all your strength, push sometimes, climb high when needed, hang in there when things get stuck, your dreams might just learn to fly!

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Resume

If you ...
use all your strength, push sometimes, climb high when needed, hang in there when things get stuck, your dreams might just learn to fly!
Plus, there is also some fun on the way!

My History

Motivation
Emittance
Compensation
SRF Injector

Compensation Schemes
RF Focusing
Concept
SC Solenoid
Concept
Simulation
Measurement
TE Mode
Concept
Measurement
Simulation

Conclusion
Summary
Outlook
Acknowledgments
-

Backup

"All is fair in Love and War ...
and in the backup slides"

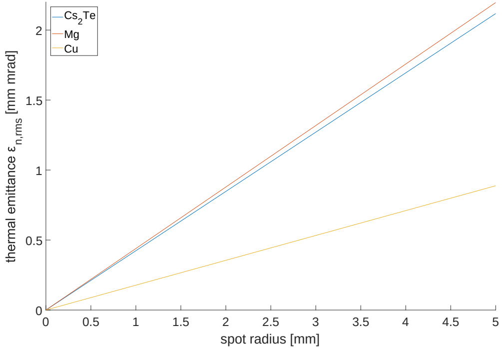
P.C.

Emittance Sources

intrinsic/thermal emittance photoelectric effect

spot size & type of material

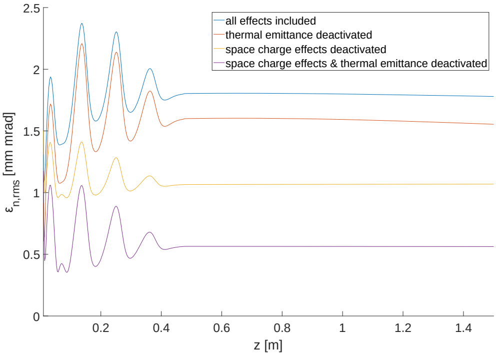
@SRF Gun: Cs_2Te & Cu/Mg



back

Emittance Sources

intrinsic/thermal emittance photoelectric effect
spot size & type of material
@SRF Gun: Cs_2Te & Cu/Mg

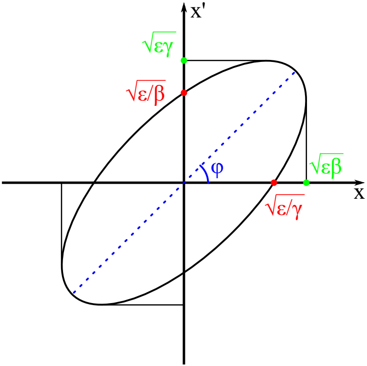


induced emittance space charge, RF field,
chromatic/geometric aberrations, ...

back

Trace Space

- trace space $x' = \frac{dx}{dz} = \frac{p_x}{p_z}, y' = \frac{p_y}{p_z}, z' = \frac{\Delta p_z}{\gamma^2 p_z}$



$$\hookrightarrow \varepsilon = \gamma x^2 + 2\alpha x x' + \beta x'^2$$

- RMS & normalization

$$\varepsilon_{\text{n,rms}} = \beta\gamma \cdot \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle x x' \rangle^2}$$

back

History at HZDR

1988 first proposal *H. Piel et al., 10th FEL Conf.*

1991 first experiments *A. Michalke, PhD Thesis, Wuppertal, 1992*

1997 start of development at HZDR (FZR → FZD)

2002 first operating half cell

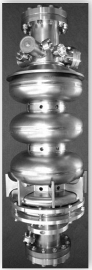
2004 design of the 3-1/2-cell cavity

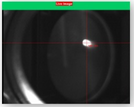
2007 first beam with the new gun

2008 transfer system for photo cathodes

2010 first beam in the ELBE

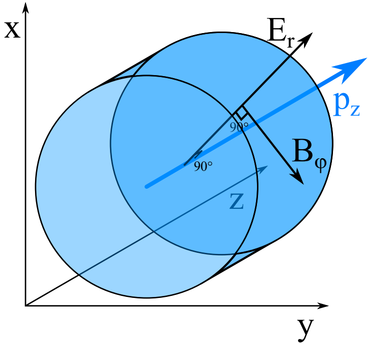
2014 installation of ELBE SRF Gun II





back

Space Charge



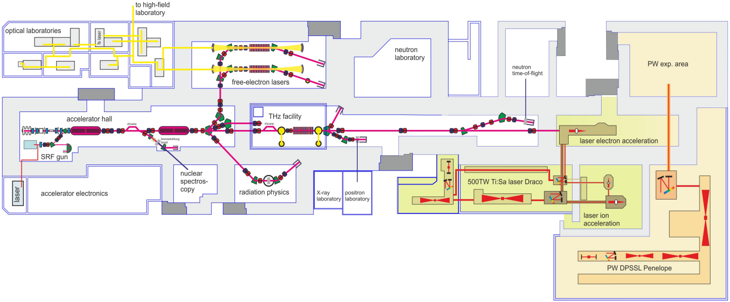
$$F_r = q \cdot \left(\vec{E} + \vec{v} \times \vec{B}\right)_r$$

$$= \frac{q^2 \rho}{2\,\varepsilon_0}\, r \left(1 - \beta^2\right)$$

$$\Rightarrow \qquad \lim_{\beta \to 1} F_r = 0$$

back

The ELBE Facility



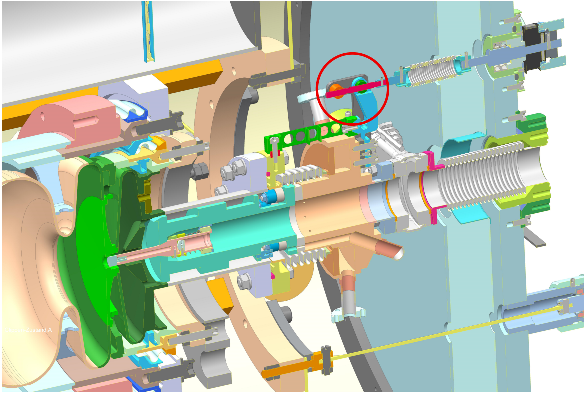
- The ELBE – a multipurpose CW machine
- Electron Linear accelerator with high Brilliance and low Emittance

back

Cathode Displacement

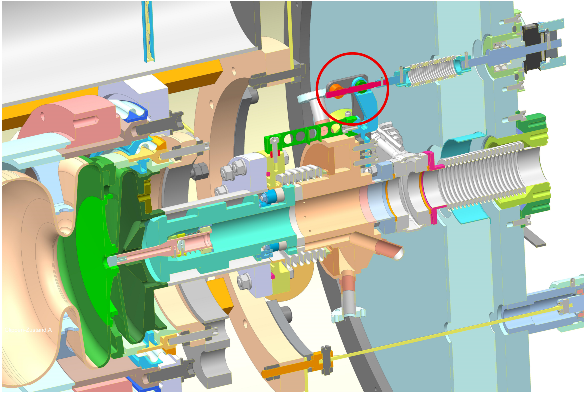
Cathode Displacement

- cathode tuner in cryostat



Cathode Displacement

- cathode tuner in cryostat

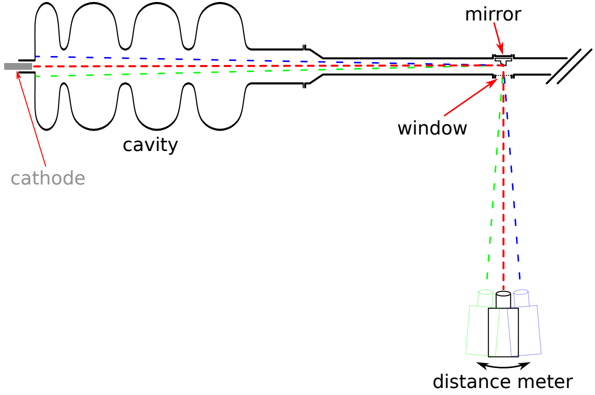


- design $\Delta z \approx 2\,\text{mm} \pm 600\,\mu\text{m}$

back

Cathode Position

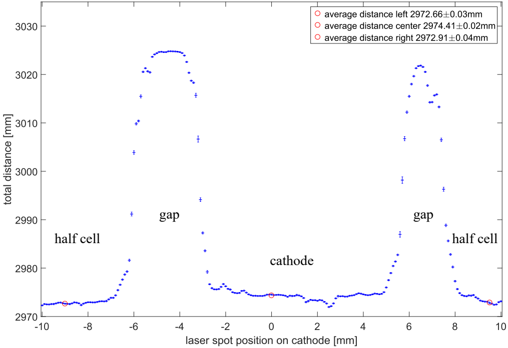
- determine exact cathode position *(F. Roscher)*



back

Cathode Position

- determine exact cathode position *(F. Roscher)*
- copper cathode during commissioning

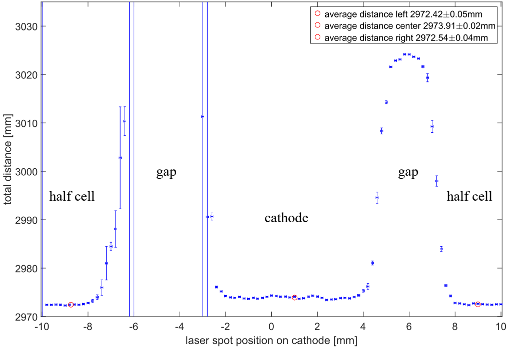


- $c_p = 1.56 \pm 0.02\,\mathrm{mm}$

back

Cathode Position

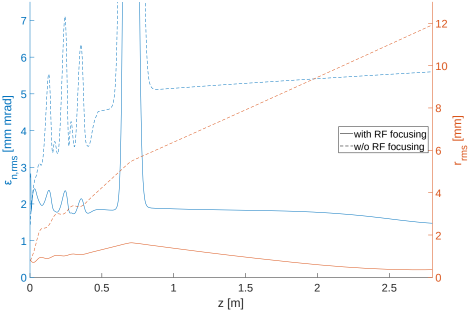
- determine exact cathode position *(F. Roscher)*
- magnesium cathode



- $c_p = 1.41 \pm 0.03\,\mathrm{mm}$

back

Trace Space

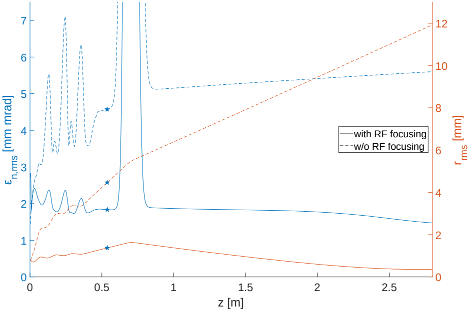


back

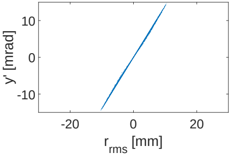
Trace Space

Emittance Compensation for SRF Photoinjectors

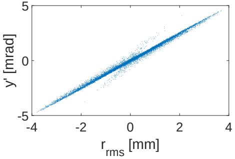
Hannes Vennekate



w/o RF focus

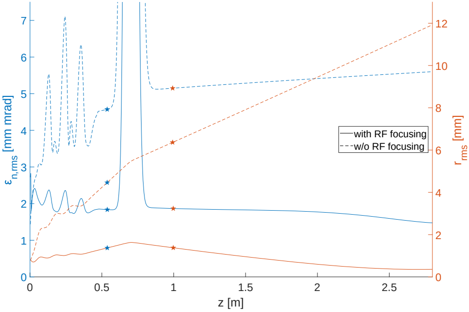


with RF focus

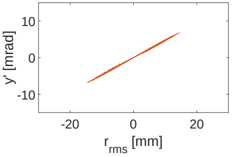


back

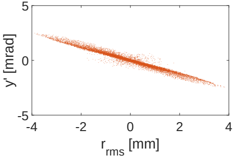
Trace Space



w/o RF focus

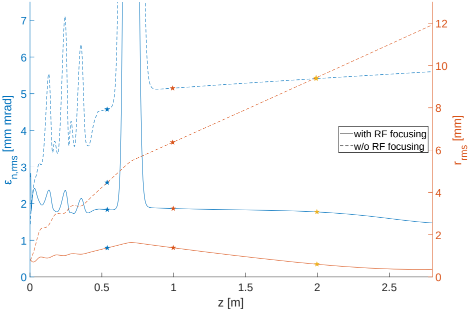


with RF focus

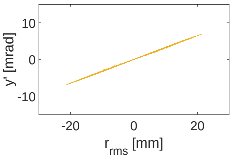


back

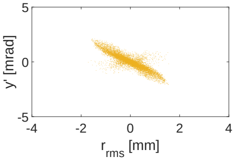
Trace Space



w/o RF focus

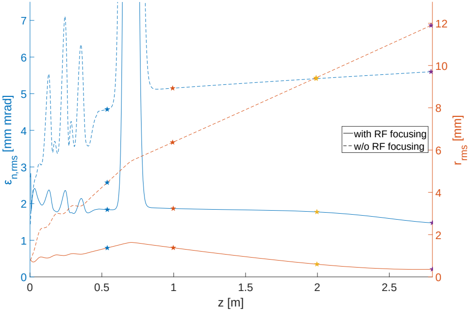


with RF focus

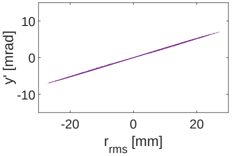


back

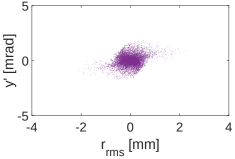
Trace Space



w/o RF focus

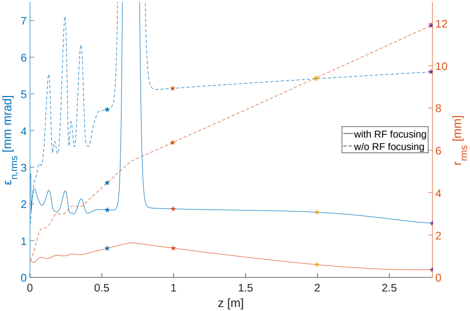


with RF focus



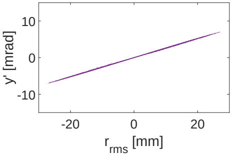
back

Trace Space

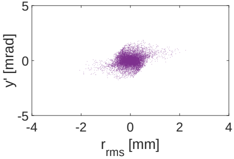


- RF focusing → emittance
  solenoid → beam extent

w/o RF focus



with RF focus

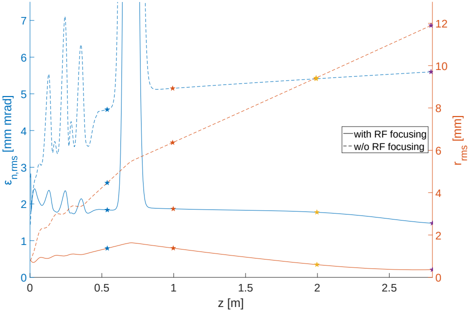


back

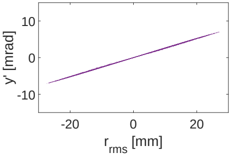
Trace Space

Emittance Compensation for SRF Photoinjectors

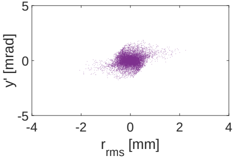
Hannes Vennekate



w/o RF focus



with RF focus

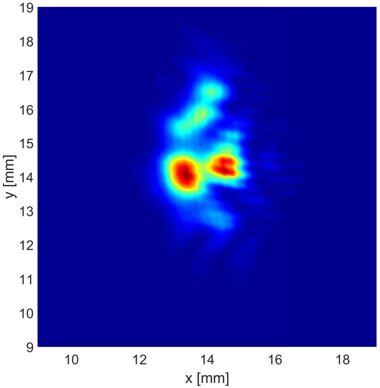


- RF focusing → emittance
  solenoid → beam extent
  ↪ combination is key

◂ back

Transverse Laser Profile

- full beam profile



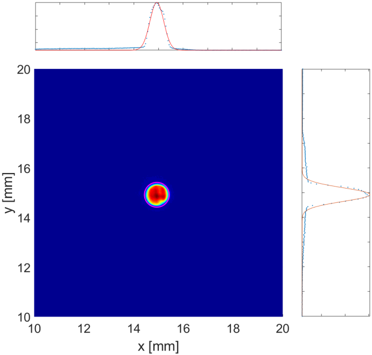
back

Transverse Laser Profile

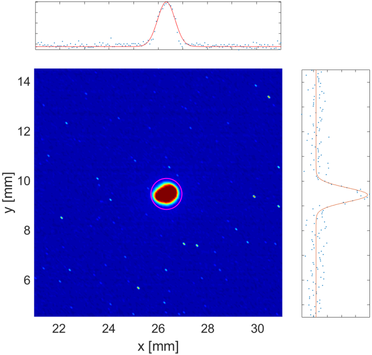
Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

- full beam profile
- 0.5 mm aperture



laser table

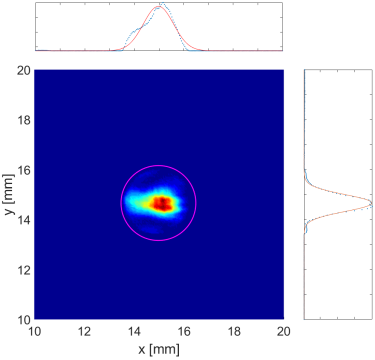


virtual cathode

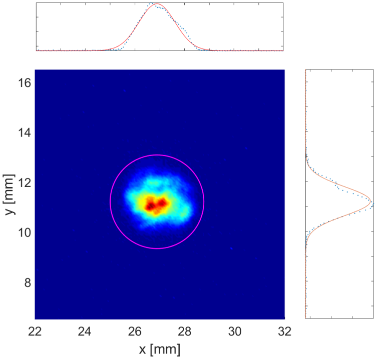
back

Transverse Laser Profile

- full beam profile
- 0.5 mm aperture
- 1.5 mm aperture



laser table



virtual cathode

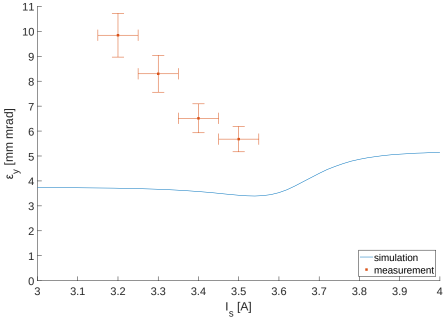
back

Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

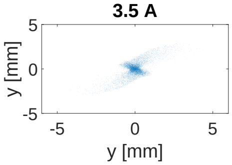
Emittance Measurements

- 160 pC, cathode ≈ 1.8 mm

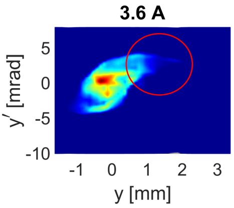


back

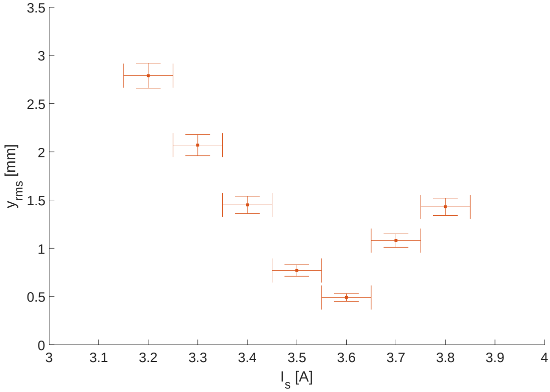
simulation



measurement

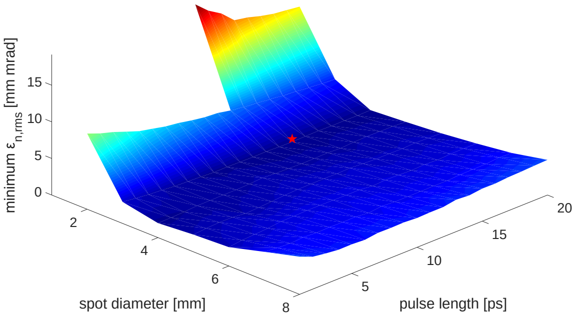


Beam Extent Measurement



back

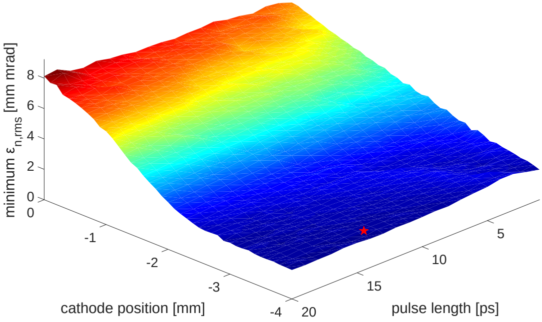
Initial Parameters



bunch charge [pC]	E_{acc} $\left[\frac{MV}{m}\right]$	cath. position [mm]	pulse length [ps]	spot diameter [mm]	$\varepsilon_{n,rms}$ [mm mrad]	r_{rms} [mm]
250	8	−3.9	14	3	1.86	5.43
500	8	−3.9	17	4	2.91	5.89

back

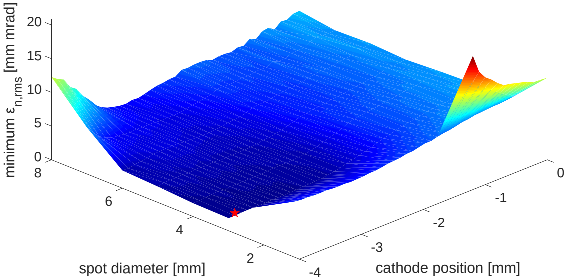
Initial Parameters



bunch charge [pC]	E_{acc} $\left[\frac{\text{MV}}{\text{m}}\right]$	cath. position [mm]	pulse length [ps]	spot diameter [mm]	$\varepsilon_{n,rms}$ [mm mrad]	r_{rms} [mm]
250	8	−3.9	14	3	1.86	5.43
500	8	−3.9	17	4	2.91	5.89

back

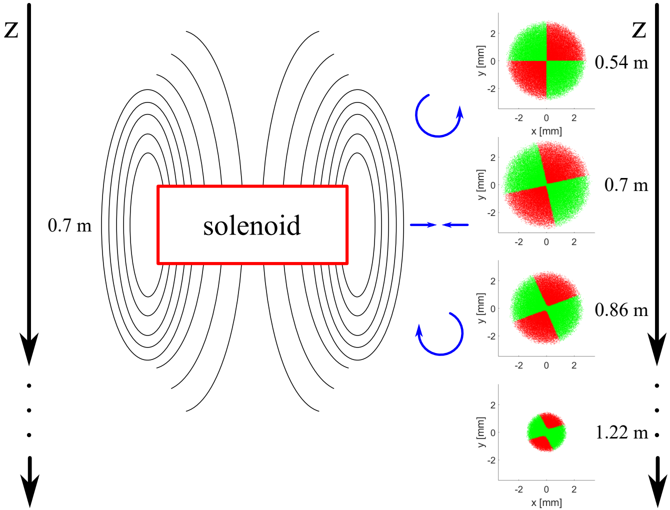
Initial Parameters



bunch charge [pC]	E_{acc} $\left[\frac{MV}{m}\right]$	cath. position [mm]	pulse length [ps]	spot diameter [mm]	$\varepsilon_{n,rms}$ [mm mrad]	r_{rms} [mm]
250	8	−3.9	14	3	1.86	5.43
500	8	−3.9	17	4	2.91	5.89

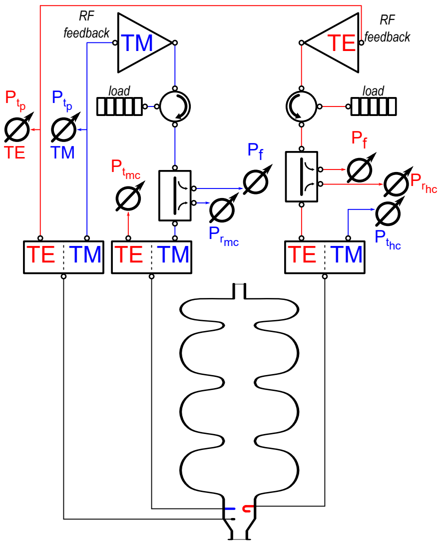
back

Solenoid Working Principle



back

RF Setup at JLab



Emittance Compensation for SRF Photoinjectors

Hannes Vennekate

back

RF Setup at JLab

back

RF Setup at JLab

back

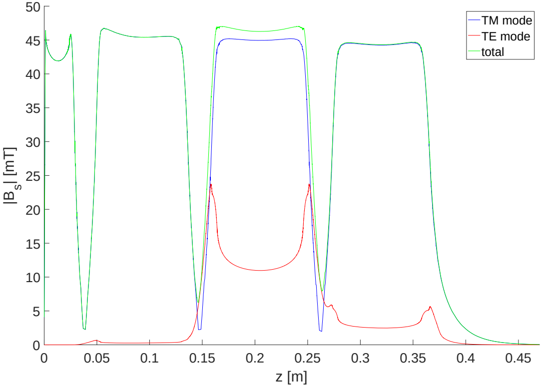
Surface Field TE Mode

- additional contribution to surface field by TE mode

back

Surface Field TE Mode

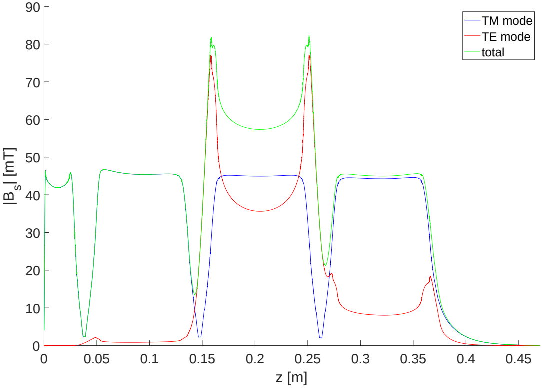
- additional contribution to surface field by TE mode
- Measurement at JLab:
  surface field contribution low



back

Surface Field TE Mode

- additional contribution to surface field by TE mode
- Measurement at JLab:
  surface field contribution low compared to 150 mT
  (*theoretical limit* 200 mT)



back

Simulation Results

emittance optimization results

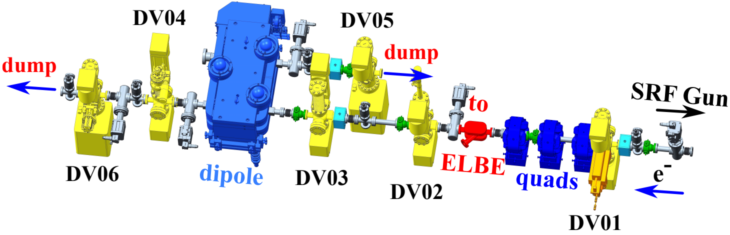
TE freq. [GHz]	peak cell #	bunch charge [pC]	$\varepsilon_{n,rms}$ [mm mrad]	r_{rms} [mm]	min. TE field [mT]
—	—	250	1.86	5.43	—
2.564	1	250	1.73	1.76	110
2.505	2	250	1.46	1.11	170
2.512	3	250	1.35	0.86	220
—	—	500	2.91	5.89	—
2.564	1	500	2.72	2.55	100
2.505	2	500	2.34	1.71	160
2.512	3	500	2.12	1.37	210

phase dependency

TE freq. [GHz]	peak cell #	bunch charge [pC]	$\varepsilon_{n,rms}$ deviation [mm mrad]	[%]	r_{rms} deviation [mm]	[%]
2.564	1	250	0.05	3.1	0.08	4.7
2.505	2	250	0.09	6.1	0.06	5.1
2.512	3	250	0.09	6.9	0.07	7.5
2.564	1	500	0.08	2.8	0.10	3.8
2.505	2	500	0.15	6.2	0.10	6.0
2.512	3	500	0.18	8.7	0.11	7.9

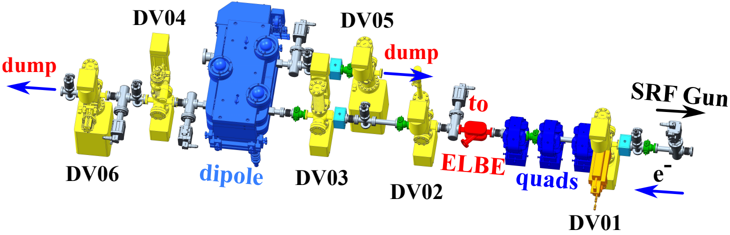
back

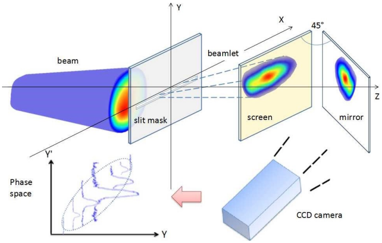
Emittance Measurement Setup



back

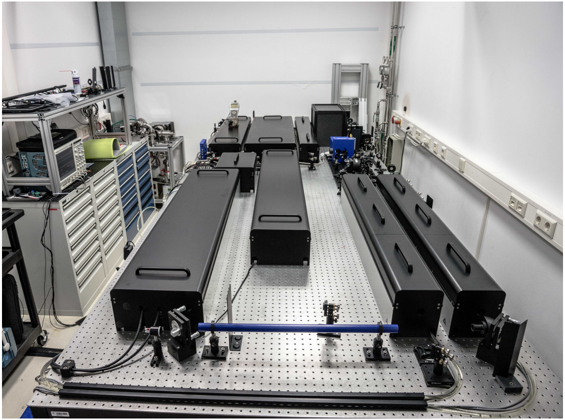
Emittance Measurement Setup





back

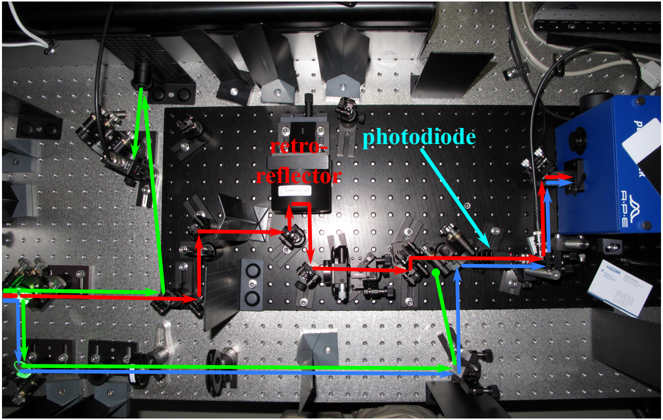
Auto- and Cross Correlation



laser table

back

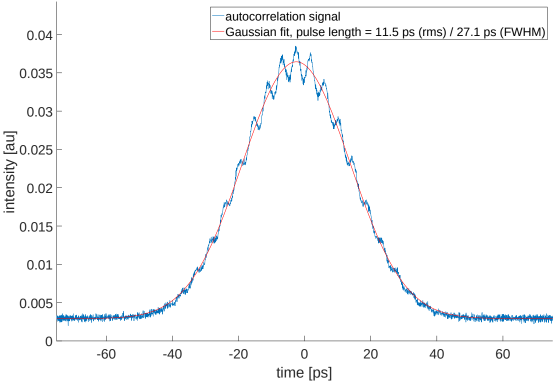
Auto- and Cross Correlation



correlation setup

back

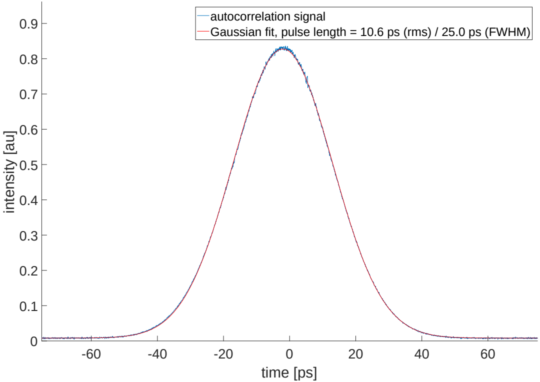
Auto- and Cross Correlation



autocorrelation before

back

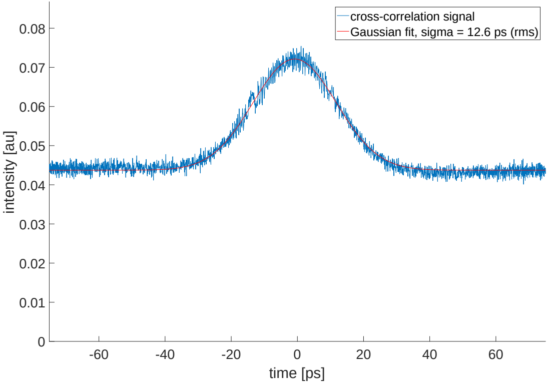
Auto- and Cross Correlation



autocorrelation after

back

Auto- and Cross Correlation



cross-correlation

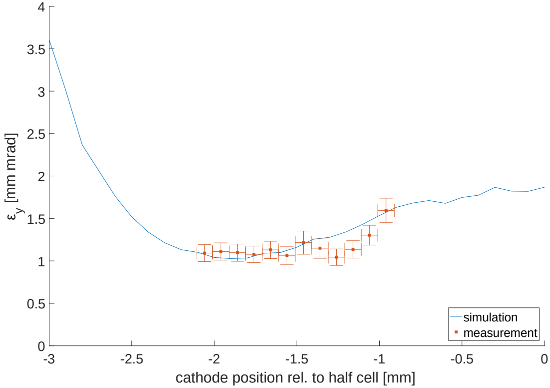
back

Emittance Measurements

back

Emittance Measurements

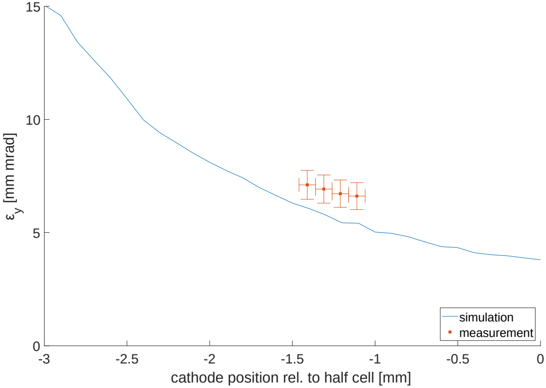
- low bunch charge 1.7 pC *(Cu cathode)*



back

Emittance Measurements

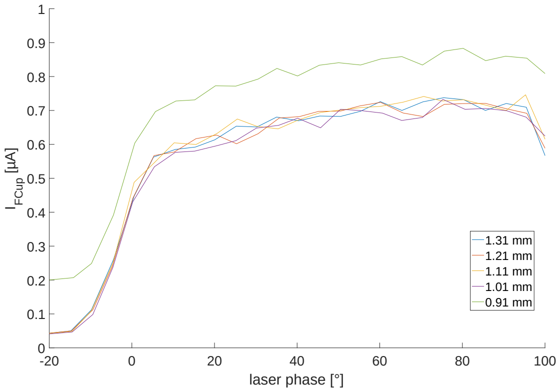
- high bunch charge 120 pC *(Mg cathode)*



back

Emittance Measurements

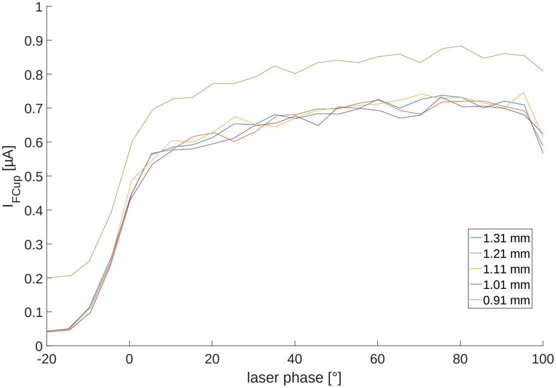
- high bunch charge 120 pC *(Mg cathode)*



back

Emittance Measurements

- high bunch charge 120 pC *(Mg cathode)*



↪ activated field emitter in gun @ 0.9 mm

back

Simulation Codes

ASTRA A Space charge TRacking Algorithm
maintained by DESY, Hamburg
↪ particle tracking

Poisson Superfish collection of code packages to compute static and RF magnetic fields as well as RF electric fields
maintained by Los Alamos Accelerator Code Group
d ↪ field generation

CST Computer Simulation Technology - Microwave Studio
↪ generation of TE field (A. Arnold)

back

Resume

If you ...

back

Resume

If you ...
use all your strength,

back

Resume

If you ...
use all your strength, push sometimes,

back

Resume

If you ...
use all your strength, push sometimes, climb high when needed,

back

Resume

If you ...
use all your strength, push sometimes, climb high when needed, hang in there when things get stuck,

back

Resume

If you ...
use all your strength, push sometimes, climb high when needed, hang in there when things get stuck, your dreams might just learn to fly!

back

Resume

If you ...
use all your strength, push sometimes, climb high when needed, hang in there when things get stuck, your dreams might just learn to fly!
Plus, there is also some fun on the way!

back