Computational Lecture: Photo-injectors

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PHY 542

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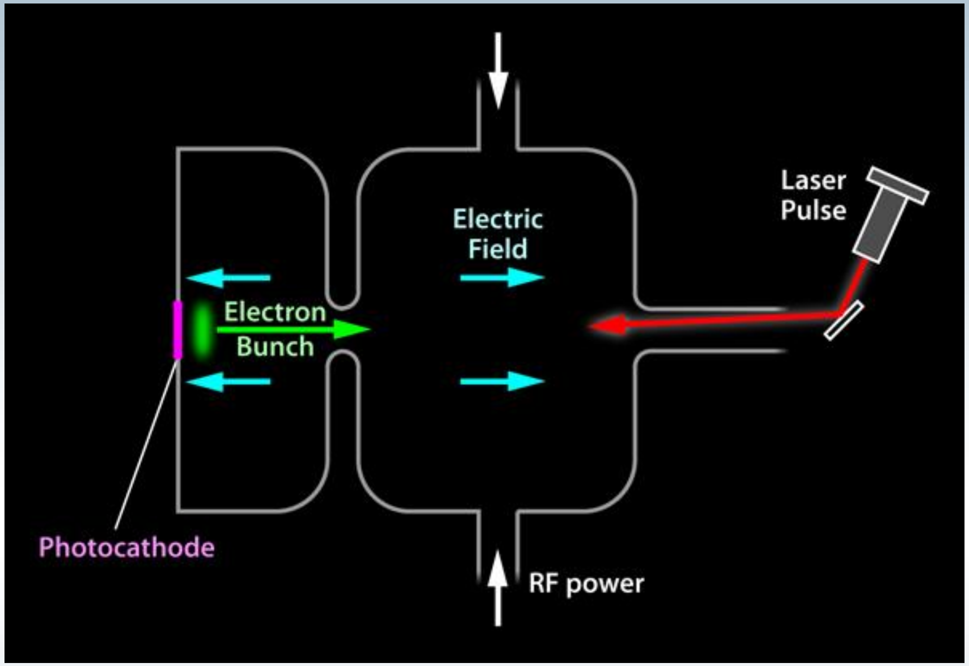
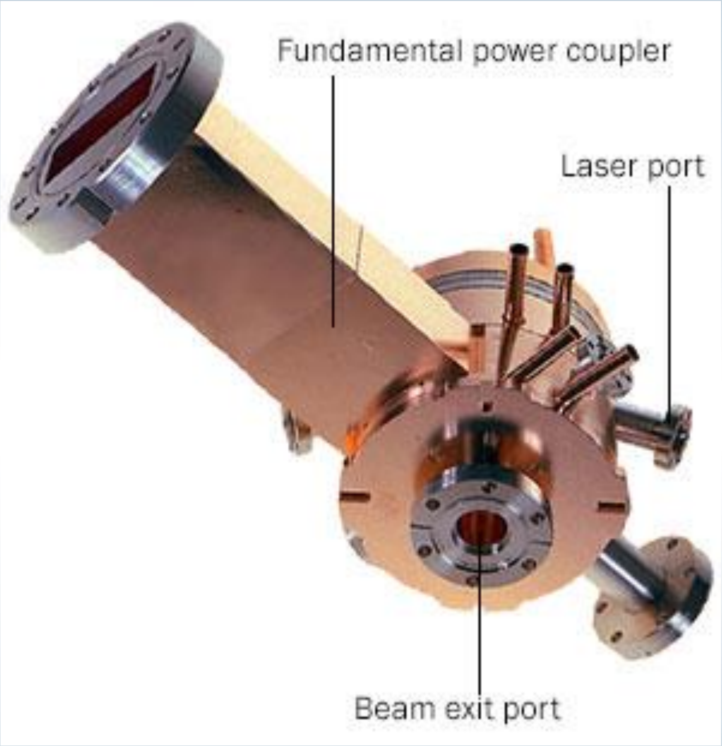
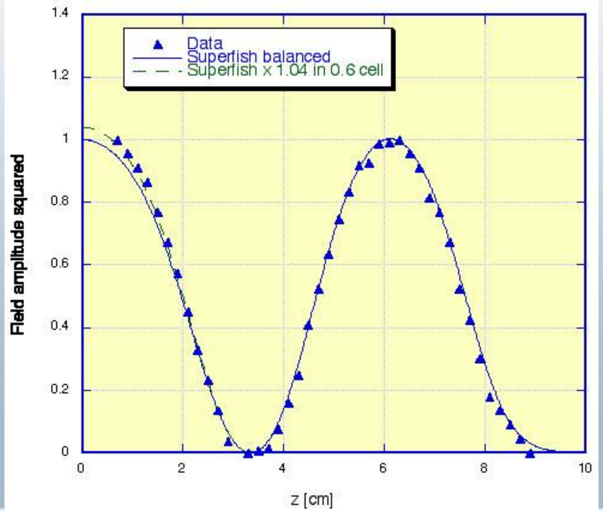
Photo-cathodes: Revisit



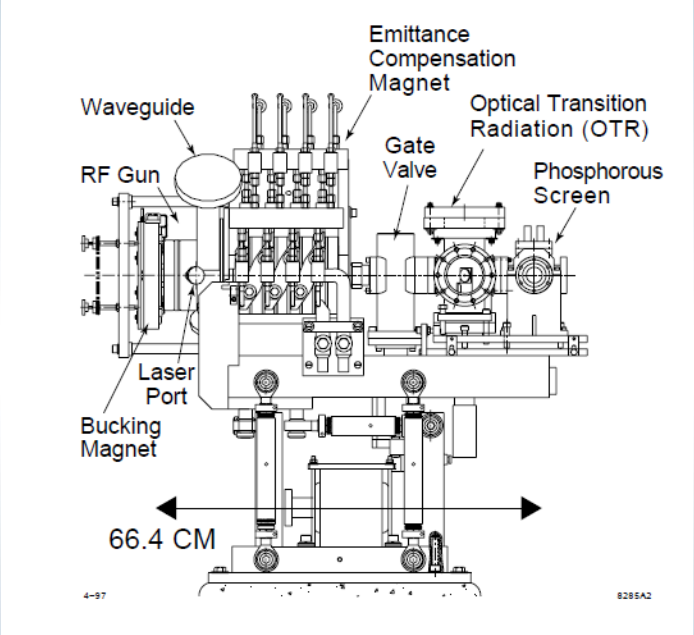




- Time structure of the electron beam is controlled by the laser

ATF Parameters

- 1.6 cell copper cavity
- 2856 MHz (S-Band)
- Cu cathode with QE=4.5×10^{-5}
- Max rf gradient 110-130 MV/m
- Nd:YAG laser energy 30 microJ at 266 nm
- Laser spot size on cathode: 1 mm
- Charge: 0.001 -3 Nc
- Energy: ~ 5 MeV



Check that those parameters are correct!

How do we model the beam?

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_o} \qquad \nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \nabla \times \vec{B} = \mu_o \left(\vec{J} + \varepsilon_o \frac{\partial \vec{E}}{\partial t} \right)$$

$$\frac{\partial \vec{p}}{\partial t} = q\left(\vec{E} + \vec{v} \times \vec{B} \right)$$

$$\frac{\partial \vec{r}}{\partial t} = \frac{c\vec{p}}{\sqrt{m^2 c^2 + \left| \vec{p} \right|^2}}$$

And … we're done, right?

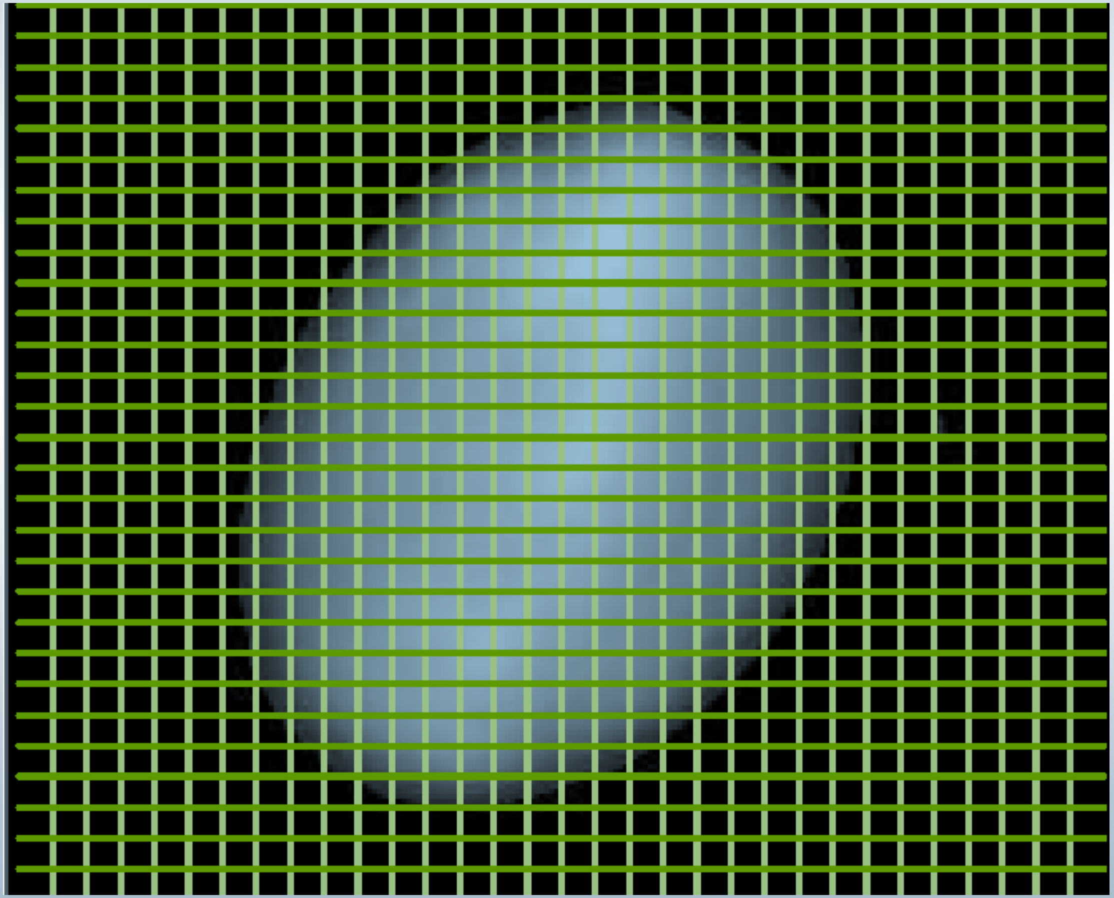
Where do the fields come from?

$$\frac{\partial \vec{p}}{\partial t} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

- Generally, E and B are or can be
  - Functions of both position and time
  - Generated by sources:
    - Outside the beam (magnets)
    - Generated by the beam itself (space-charge)
    - Arise as a result of the structures and elements the beam transverses (wakefields synchrotron radiation?

Approaches to modeling

Particle—in-cell codes (PIC codes)



PIC codes

Particle-in-Cell

- Place a grid over the simulation space
- Find E, B on the grid points
  - external elements
  - fields from the beam
- Extrapolate and apply to the beam
- Integrate to advance the particle positions and momenta, fields

- Pros
  - somewhat intuitive
  - in principle, accurate to any desired order
  - does not rely on analytic description of the beam or elements of the accelerator
- Cons
  - tends to be rather slow
    - large number of grid points
    - small timesteps
  - hard to model an entire machine
  - practically, still needs analytic models for “external” fields
  - getting the physics right can be challenging

ASTRA Code

ASTRA

A Space Charge Tracking Algorithm

The ASTRA program package can be downloaded free of charge for non-commercial and non-military use. Dissemination to third parties is illegal. DESY reserves copyrights and all rights for commercial use for the program package ASTRA, parts of the program package and of procedures developed for the program package.

DESY undertakes no obligation for the maintenance of the program, nor responsibility for its correctness, and accepts no liability whatsoever resulting from its use.

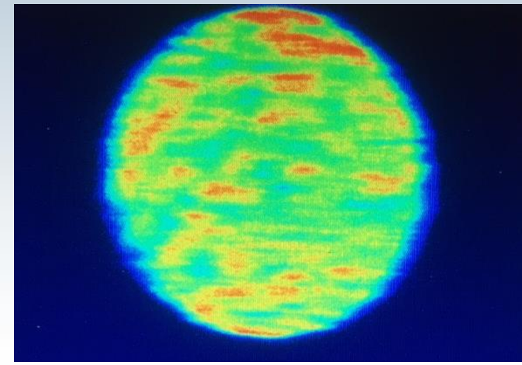
- Source: http://www.desy.de/~mpyflo/
- Very simple code! Commonly used for photo-injectors!

ASTRA : Beam generation

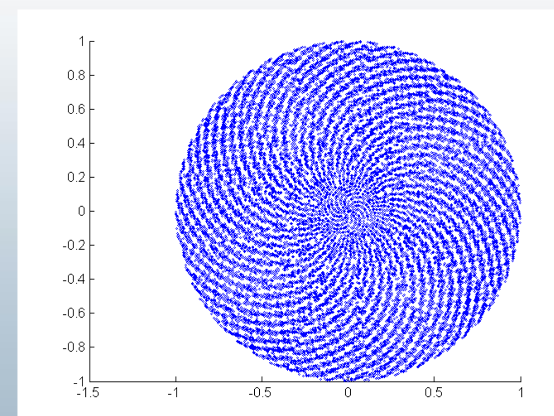
- Create the laser beam
- Sent the laser to cathode
- Produce electron beam

```
&INPUT
 Add=.F,
 ! FILE NAME TO CREATED (ELECTRON DISTRIBUTION)
 FNAME = 'astra1in.part'
 IPart=2000
 Species='electrons'
 Probe=.True.
 Noise_reduc=.T.
 Cathode=.T.
 ! BUNCH CHARGE
 Q_total=0.050
 Ref_zpos=0.
 Ref_clock=0E-3
 Ref_Ekin=0.
 ! LASER LONGITUDINAL PROFILE
 Dist_z='gauss', sig_clock=2.0E-3, Lt=0., rt=0.
 Dist_pz='i', LE=0.750E-03
 ! LASER TRANSVERSE PROFILE
 Dist_x= 'radial', Lx=1.095
 Dist_px='radial', Nemit_x=0.,   cor_px=0.0E0
 Dist_y= 'radial', Ly=1.095
 Dist_py='radial', Nemit_y=0.,   cor_py=0.0E0
```

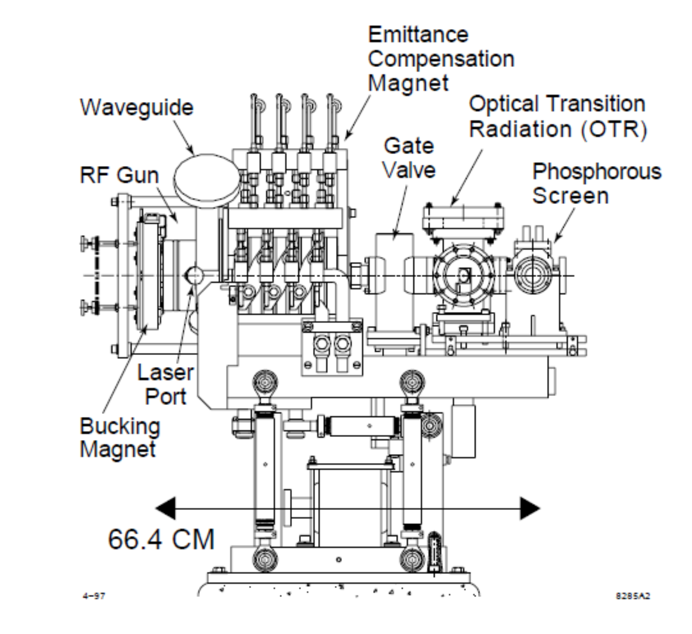
Beam in experiment

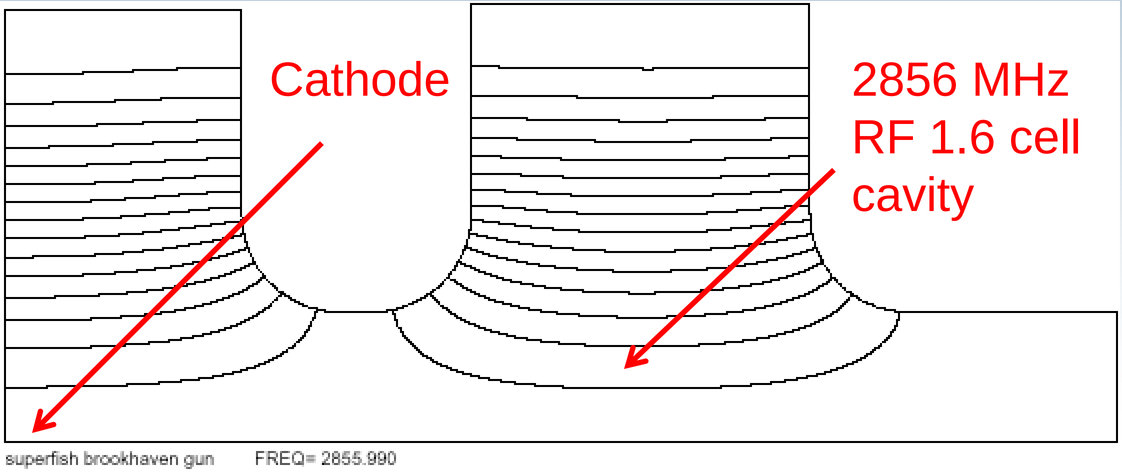


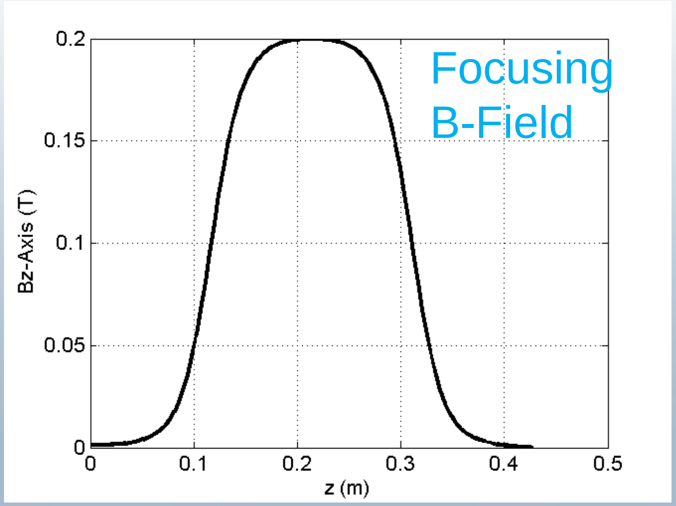
Beam in simulation

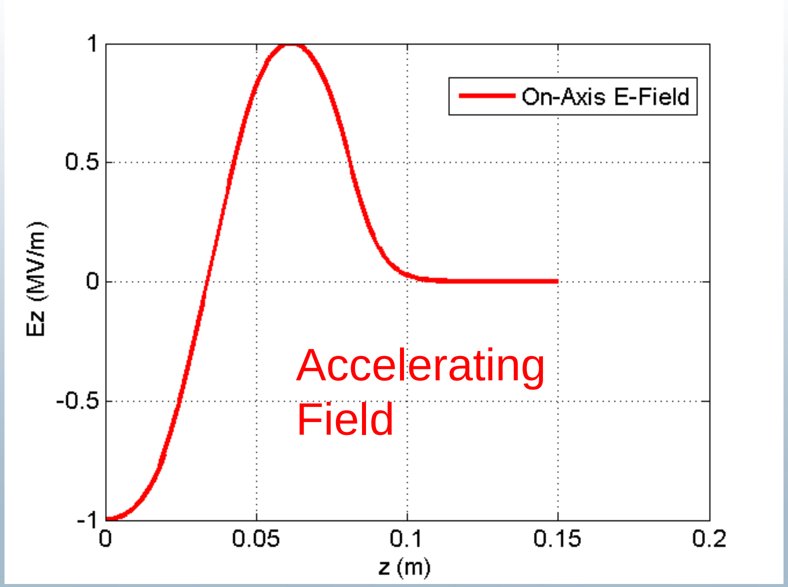


ASTRA: Track inside photocathode





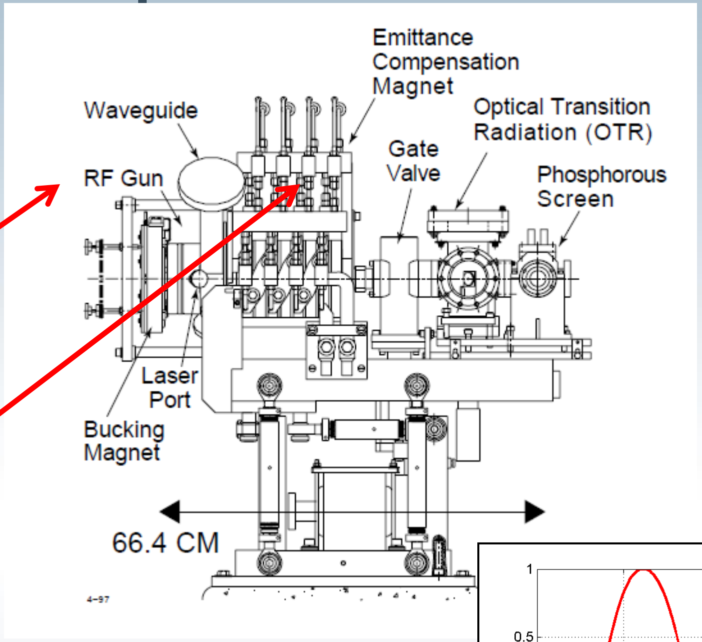


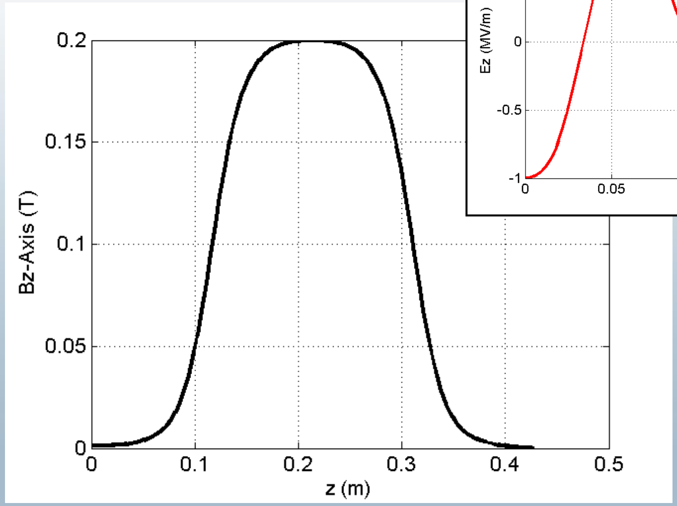


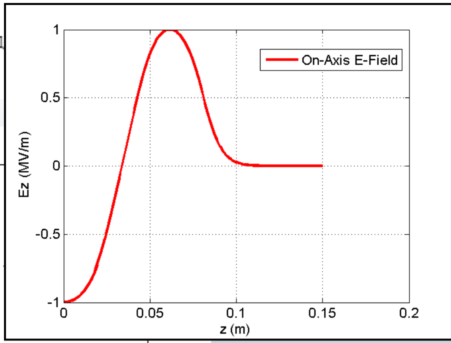
ASTRA: Track inside photocathode

```
&NEWRUN
Head='ATF 2 Gun'
RUN=1,
Loop=F, Nloop=0
Distribution= 'astra1in.part',
check_ref_part=.F,
ZSTART=0.0,     ZSTOP=0.50
/

&CHARGE
! SPACE-CHARGE ON OR OFF
Loop=F
LSPCH=T
! use the following mesh for appropriate number of macroparticles
Nrad=10,
Nlong_in=12,
Cell_var=2.0
min_grid=0.4e-6
Max_scale=0.05
Max_count=10
Lmirror=.T
/
&Aperture
Loop=F
Lapert=F
File_Aperture='Aperture.dat'
/
&CAVITY
! RF GUN CAVITY
Loop=.F,
LEFieLD=.T
FILE_EFieLD(1) = 'rfgunFIELD.dat', C_smooth(1)=10,
Nue(1)=2.856,   MaxE(1)=110.00, Phi(1)=-12.0,   C_pos(1)=0.0,
C_higher_order(1)=T

/
&SOLENOID
! COMPENSATION SOLENOID
Loop=.F,
LBFieLD=.T,
FILE_BFieLD(1)='compenSOL_axial.dat',
S_noscale=.F,
MaxB(1)=0.20, S_smooth(1)=10,
S_pos(1)=0.00, S_xoff(1)=0.0, S_yoff(1)=0.0, S_higher_order(1)=T
/
```

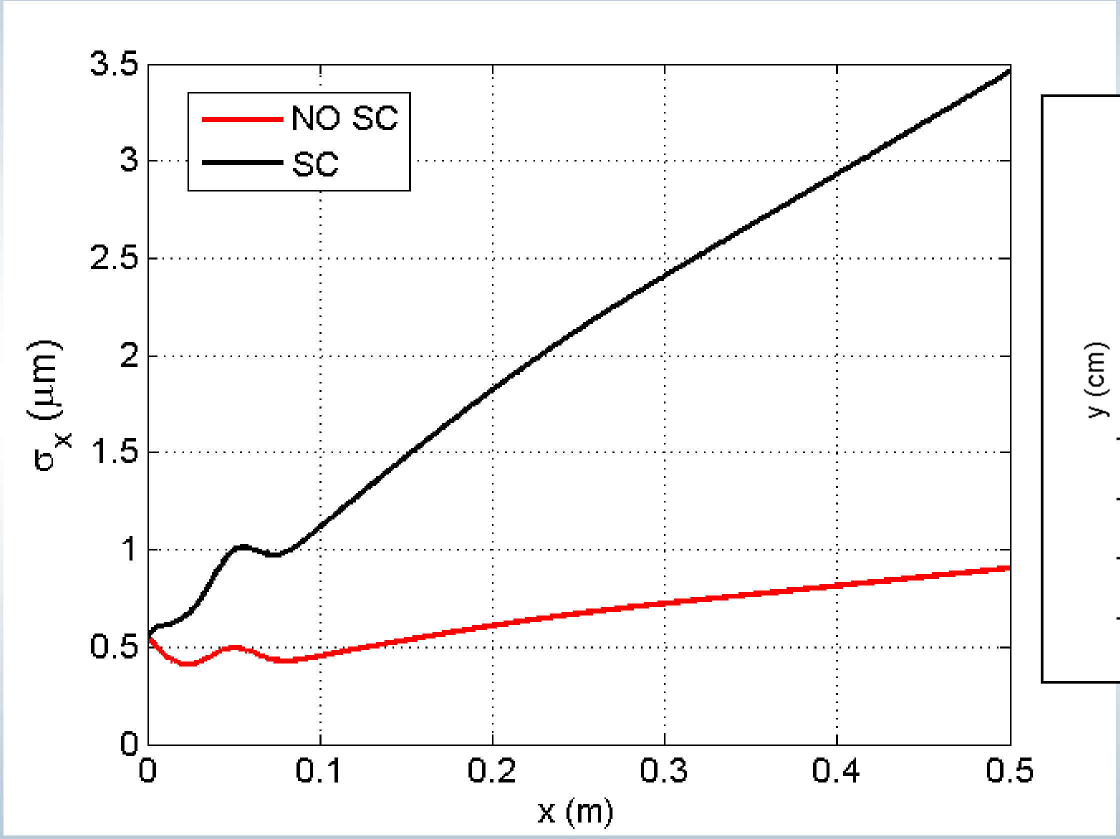
Space-Charge

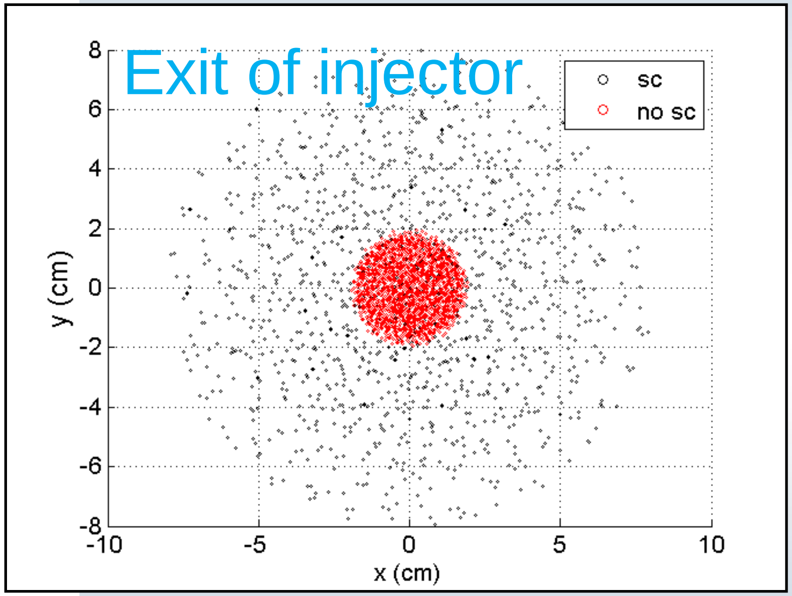




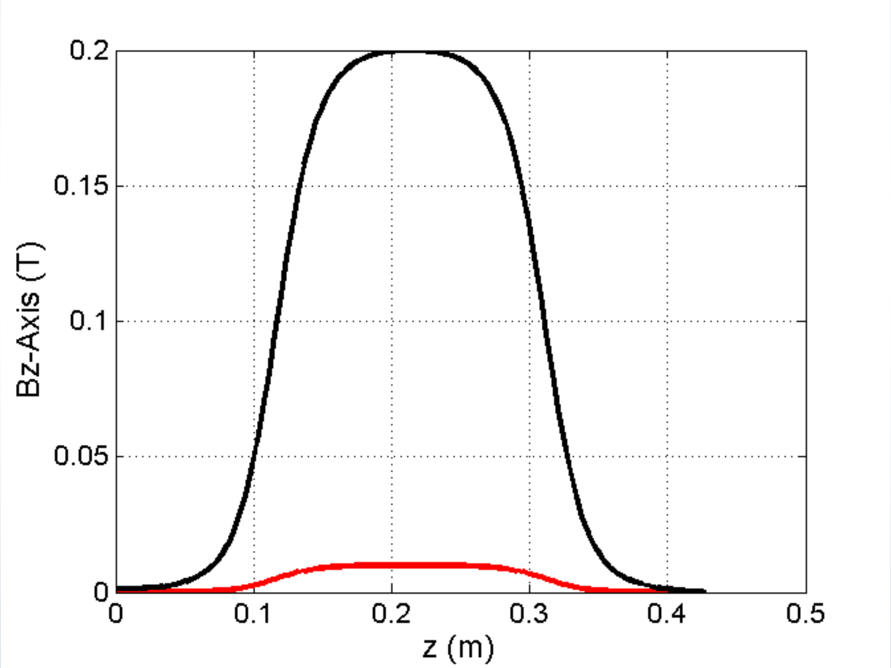


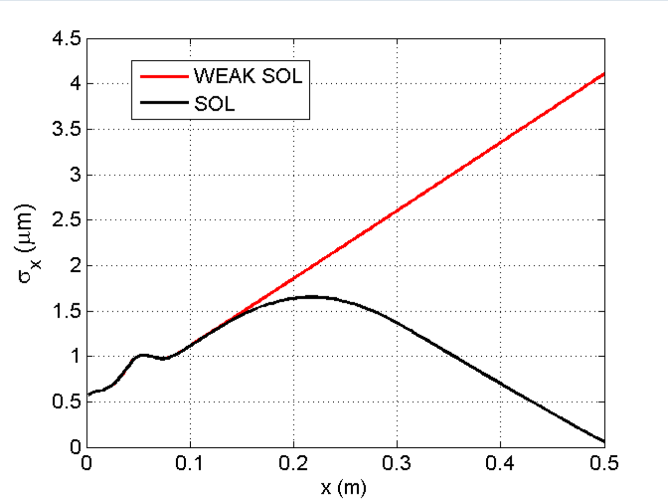
You will check space-charge effect

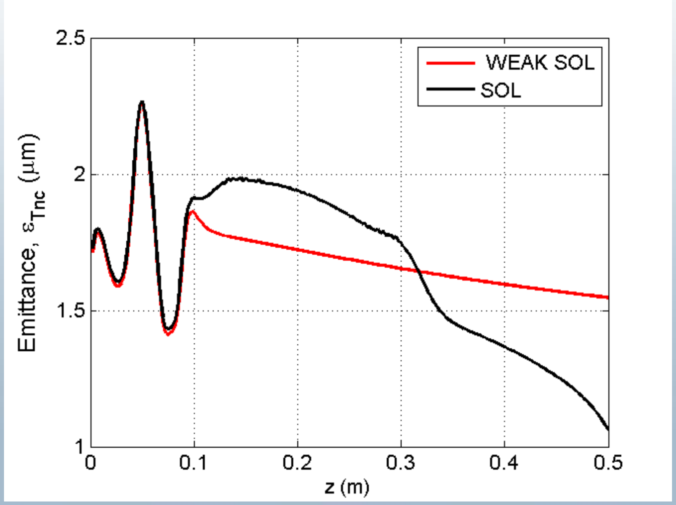




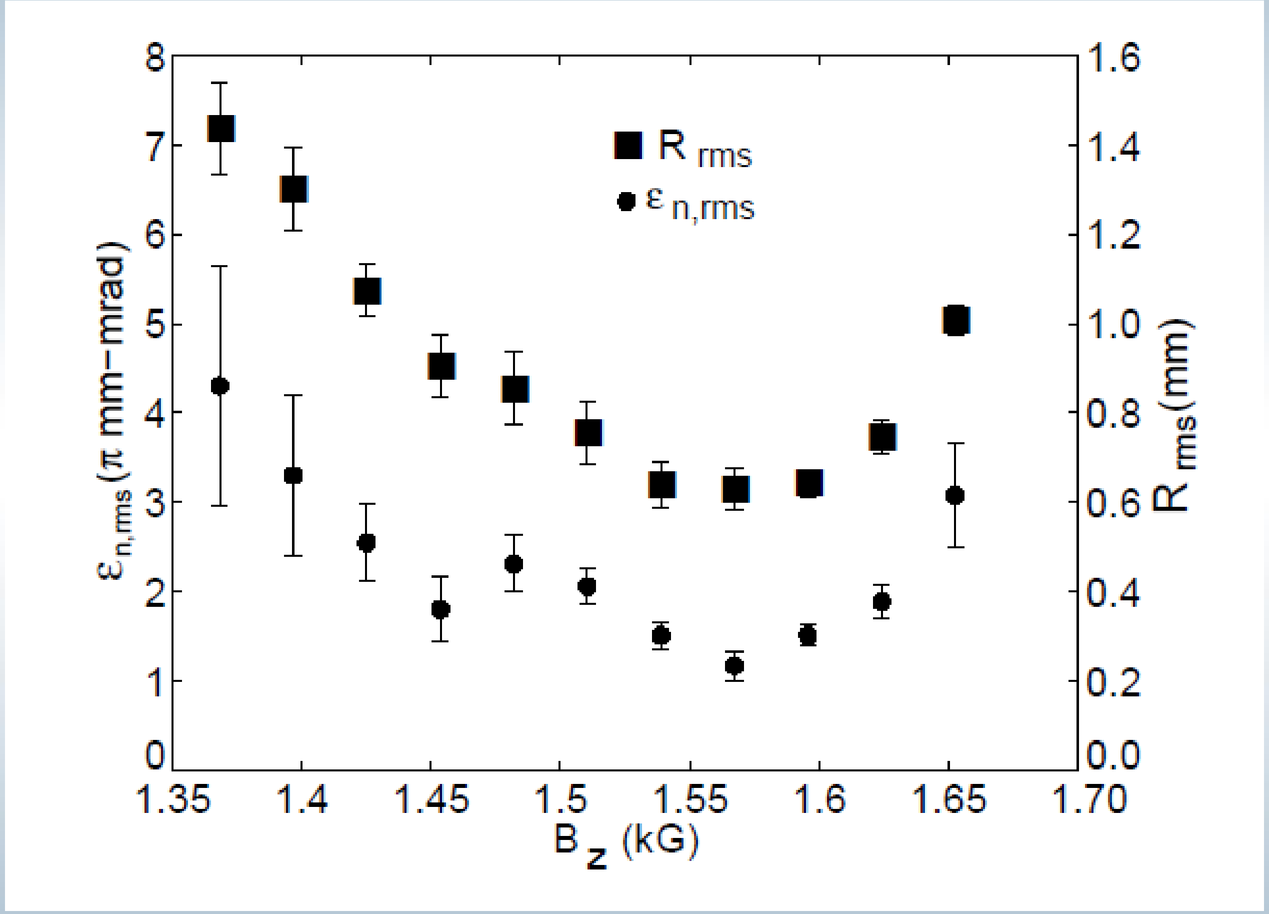
You will optimize focusing







You will tune the emittance



- Can you reproduce this result for the ATF injector?