Beam Dynamics in FLASH with 3rd Harmonic Module

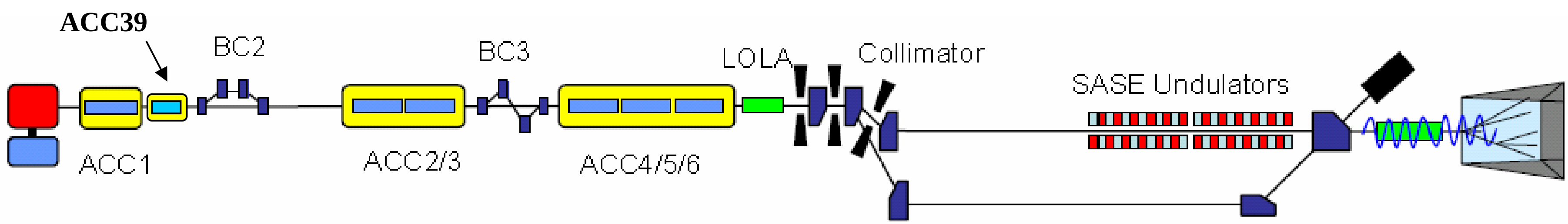
Igor Zagorodnov

19.01.2009

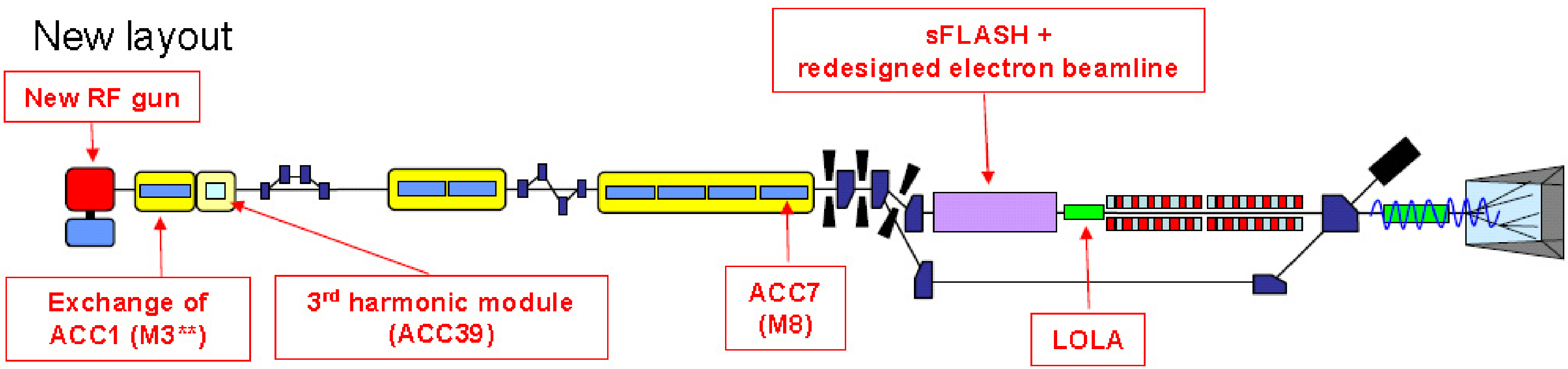
BD meeting, DESY

Layout

Present layout + ACC39 is considered in the talk

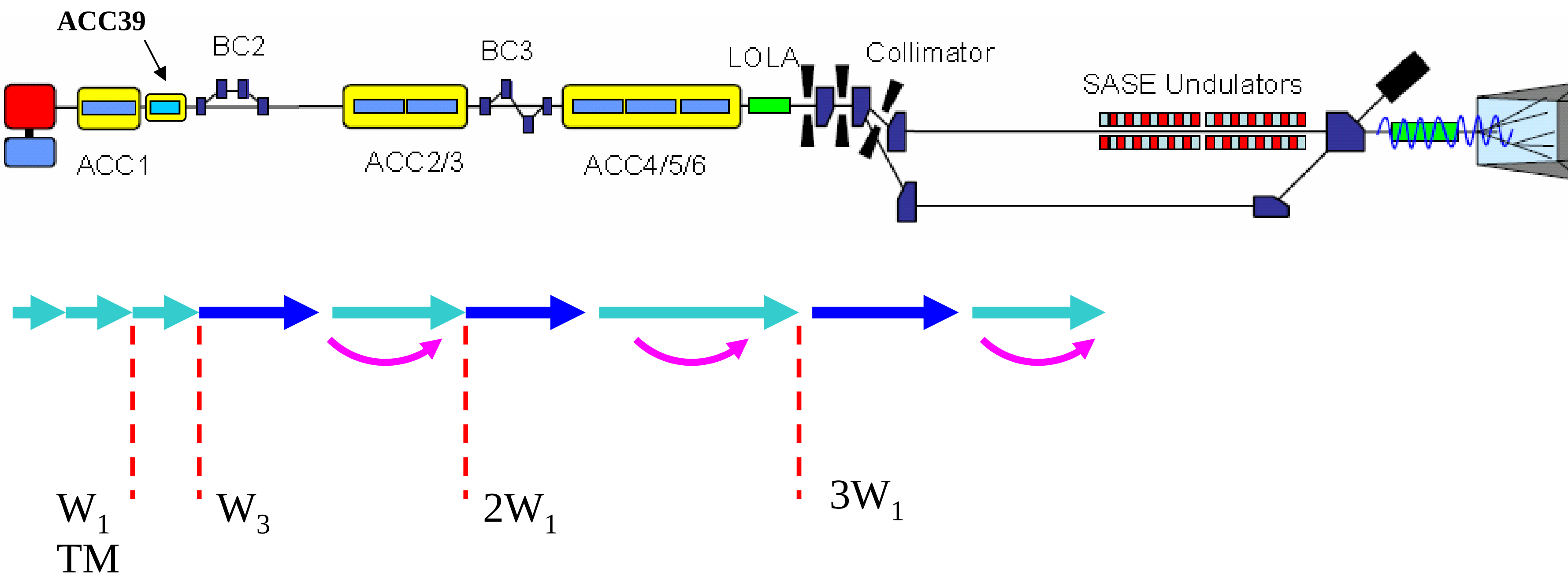


New layout



3D simulation setup

M. Krasilnikov - Input Desk for ASTRA gun simulations for 1nC, 0.5 nC, 0.25nC
N. Golubeva – MAD optics for 1 GeV



ASTRA (m=0 solver, on axis bunch)

CSRtrack (1D model)

Linear Transformation (slice centers)

W_1-TESLA cryomodule wake

W_3- ACC39 wake

TM- transverse matching to the design optics

3D simulation setup

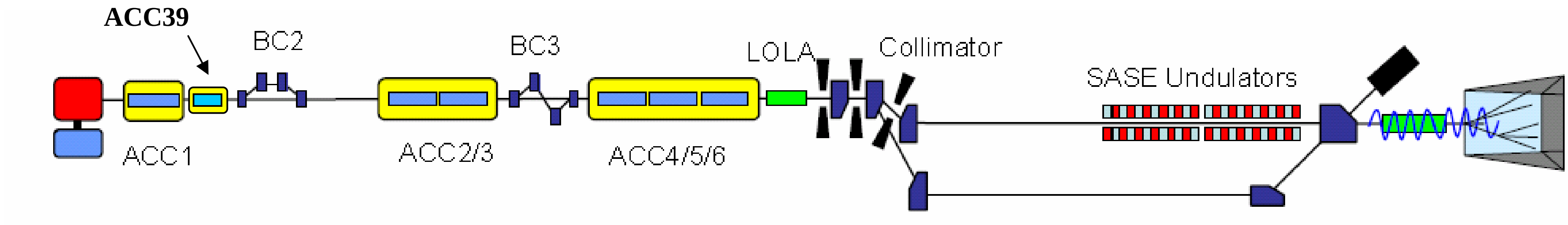
GlueTrackM – a control script in Matlab.
S2E simulation time on Ferrari for 200k particles is about 10 hours.

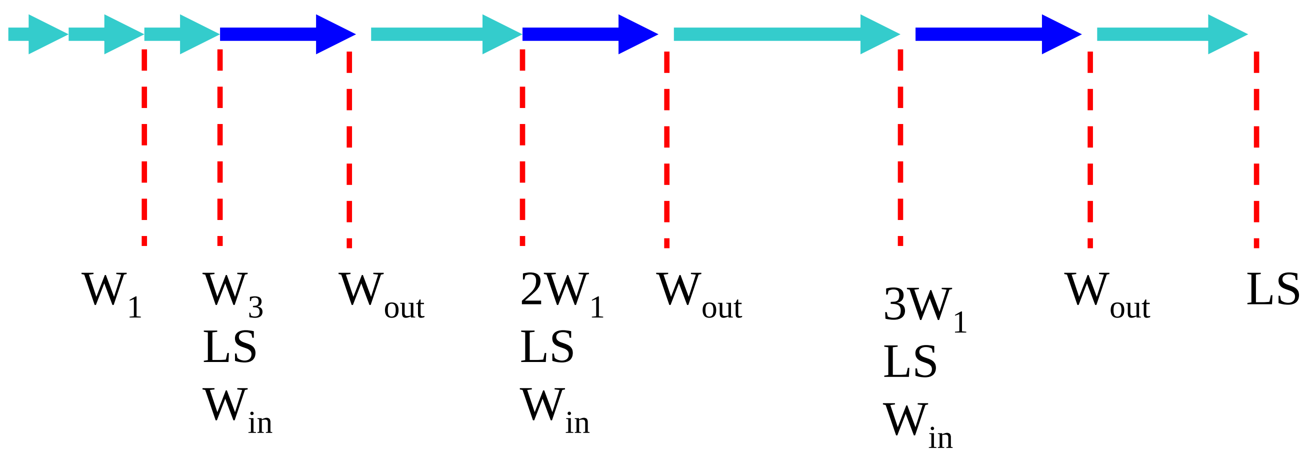
```
clear all; close all;
OS_LINUX=false;
M=5000; % particles in slice

PhysConsts;
home=cd;
if OS_LINUX,
  type_cmn='cat';    copy_cmn='cp';     mpi='mpistart ';
  generator=['.'  filesep 'generator.exe'];
  astra=[mpi home  filesep '_Codes' filesep 'ASTRA_L64' filesep 'astra'];
  csrtrack=[home  filesep '_Codes' filesep 'CSRtrack_L64' filesep 'CSRtrack_1.201.wic.exe'];
else
  type_cmn='type';    copy_cmn='copy';      mpi='';
  generator=['.'  filesep 'generator.exe'];
  astra=[mpi home  filesep '_Codes' filesep 'astra' filesep 'astra'];
  csrtrack=[home  filesep '_Codes' filesep 'CSRtrack' filesep 'CSRtrack_1.201_64_may2007.exe'];
end;

%sections
M0=1;    dirM0=[filesep 'M0_Particles'];                %generate particles
N0=1;    dirN0=[filesep 'N0_Injector_0_2m60'];          %start Astra from cathode
N1=1;    dirN1=[filesep 'N1_Injecror_2m60_13m88'] ;      %run Astra through ACC1
N2=0;    dirN2=[filesep 'N2_Injector_13m88_21m09'];      %run Astra through ACC13
N3=0;    dirN3=[filesep 'N3_BC2_21m09_26m15'];           %run CSRtrack through BC2
N4=0;    dirN4=[filesep 'N4_Linac0_25m15_67m53'];        %run Astra through Linac0
N5=0;    dirN5=[filesep 'N5_BC3_67m53_82m65'];           %run CSRtrack through BC3
N6=0;    dirN6=[filesep 'N6_Linac1_81m65_152m55'];       %run Astra through Linac1
N7=0;    dirN7=[filesep 'N7_Dogleg_52m55_160m64'];       %run CSRtrack through dogleg
N8=0;    dirN8=[filesep 'N8_Drift_159m64_203m71'];       %run Astra upto undulator
```

1D (longitudinal phase space) simulation setup





accelerator

$$E_1(s_1) = E_0(s_0) + V\cos(ks_0 + \varphi)$$
$$s_1 = s_0$$

compressor

$$E_1(s_1) = E_0(s_0(s_1))$$
$$s_1(s_0) = s_0 - \left(r_{56}\delta_0^{\;1} + t_{566}\delta_0^{\;2} + u_{5666}\delta_0^{\;3}\right)$$

W1 -TESLA cryomodule wake
W_3 - ACC39 wake
LS - space charge wake
W_{in}, W_{out} - wakes to simulate CS and edge radiation in BCs

1D (longitudinal phase space) simulation setup

```
function [P,C1,C12,C13,V11,V21,V31]=Flash(P0,q0,v,f,fi11,fi13, V13,fi21,V31,fi31,E1,r56_1,...
    t566_1,u5666_1,E2,r56_2,t566_2,u5666_2,...
    E3,r56_3,t566_3,u5666_3,see,wakes,lsc,M,savepart)
%global V11 V21 V31
if nargin<26, M=0.1; end;
if nargin<27, savepart=0; end;
 PhysConsts;
 sig0=std(P0(:,1));
 k = 2*pi*f/c;lambda=2*pi/k;
 P=P0;
 subplot(4,2,1); PlotParticles2D(P,see,q0,v) ;title('after gun');
 E0=P(1,2); dP11sc=0;dP13sc=0;
 E01=E1-V13*cos(fi13);
 if lsc==1,
     % L=11.3; beta=12.5; emit=1.9e-6;
     % [dP11sc, x, W] =AddLSC (P,q0,v,E0,E01,L,beta,emit);
      L=1.2; beta=15.33; emit=1.8e-6;
      [dP13sc, x, W] =AddLSC (P(:,1),q0,v,E01,E1,L,beta,emit);
      L=6; beta=15.33; emit=1.8e-6;
      [dP13_1sc, x, W] =AddLSC (P(:,1),q0,v,E1,E1,L,beta,emit);
      dP13sc=dP13sc+dP13_1sc;
 end;
 dP11w=0;dP13w=0; dPBC1_1w=0;
 if wakes==1,
      w0='Wakes/w0_11.txt';w1='0'; RLC='0';
      [dP11w, x, W] =AddWakeL (P(:,1),q0,v,w0,w1,RLC);
      w0='Wakes/w0_13.txt';w1='Wakes/w1_13.txt';
      RLC='Wakes/RLC_13.txt';
      [dP13w, x, W] =AddWakeL (P(:,1),q0,v,w0,w1,RLC);
      w0='0';w1='0';
      RLC='Wakes/RLC1_1.txt';
```

Matlab function for the S2E simulation of the FLASH.
Simulation time for 200k particles ~ seconds

1D (longitudinal phase space) simulation setup

Matlab script for the optimization

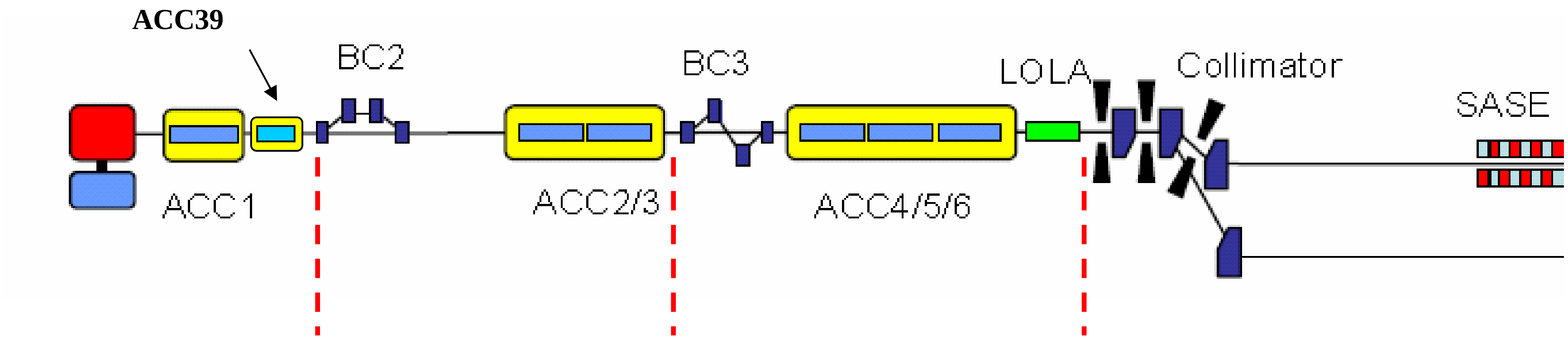
```
clear all; close all;
PhysConsts;
M=0.05; % smoothing parameter
global P0 q0 v f E10 r56_1 E20 r56_2 see wakes lsc
global I0 C10  C20 emitt0 t566_1 t566_2 u5666_1 u5666_2
global E30 r56_3 t566_3 u5666_3 V31 fi31
global V11 V21 V31
q0=1e-9; v=c;
see=1; %0-phase space; 1-current; 2-E_av and E_rms;
wakes=1; %0- no; 1-yes;
lsc=1; %0- no; 1-yes;
f = 1.3e9;
E10=127;   r56_1= -0.1808; t566_1= 0.295198; u5666_1= -0.437737;
E20=470;   r56_2= -0.048669; t566_2= 0.0733141; u5666_2= -0.0982712;
E30=1000;  r56_3=5.585e-4; t566_3=0.0588; u5666_3=-0.6417;
I0=1809;C10=7;C20=7;

infile='E:\S2E_3rdH\s2e\N1_Injecror_2m60_13m88\flash.0260.ast';
P0=LoadAstraParticles2D(infile); %n=length(P01);P0=P01(1:10:n,:);P01=[];
P0(:,1)= P0(:,1)-P0(1,1); n=length(P0(:,1));

[fi11,V11,fi13,V13,fi21,V21,fi31,V31]=FindFlashParameters(P0(1:4:n,1:2),E10,E20,..
            E30,r56_1,t566_1,u5666_1,r56_2,f,1/C10,1/C20);
options = optimset('TolFun',1e-1);
par=fminsearch(@Optim3,[fi11,fi13, V13,fi21],options);
fi11=par(1);fi13=par(2);V13=par(3);fi21=par(4);
[P,C1,C12,C13]=Flash(P0,q0,v,f,fi11,fi13, V13,fi21,V31,fi31,E10,...
    r56_1,t566_1,u5666_1,E20,r56_2,t566_2,u5666_2,...
    E30,r56_3,t566_3,u5666_3,0,wakes,lsc,M,1);
```

Analytical solution without self-fields as an initial guess

1D analytical solution without self fields



$E_1 = 127\text{MeV}$

$r_{56} = -0.1808[\text{m}]$

$t_{566} = 0.295198$

$u_{5666} = -0.437737$

$E_1 = 470\text{MeV}$

$r_{56} = -0.048669[\text{m}]$

$t_{566} = 0.0733141$

$u_{5666} = -0.0982712$

$E_3 = 1\text{GeV}$

$r_{56} = 5.585\text{e-}4[\text{m}]$

$t_{566} = 0.0588$

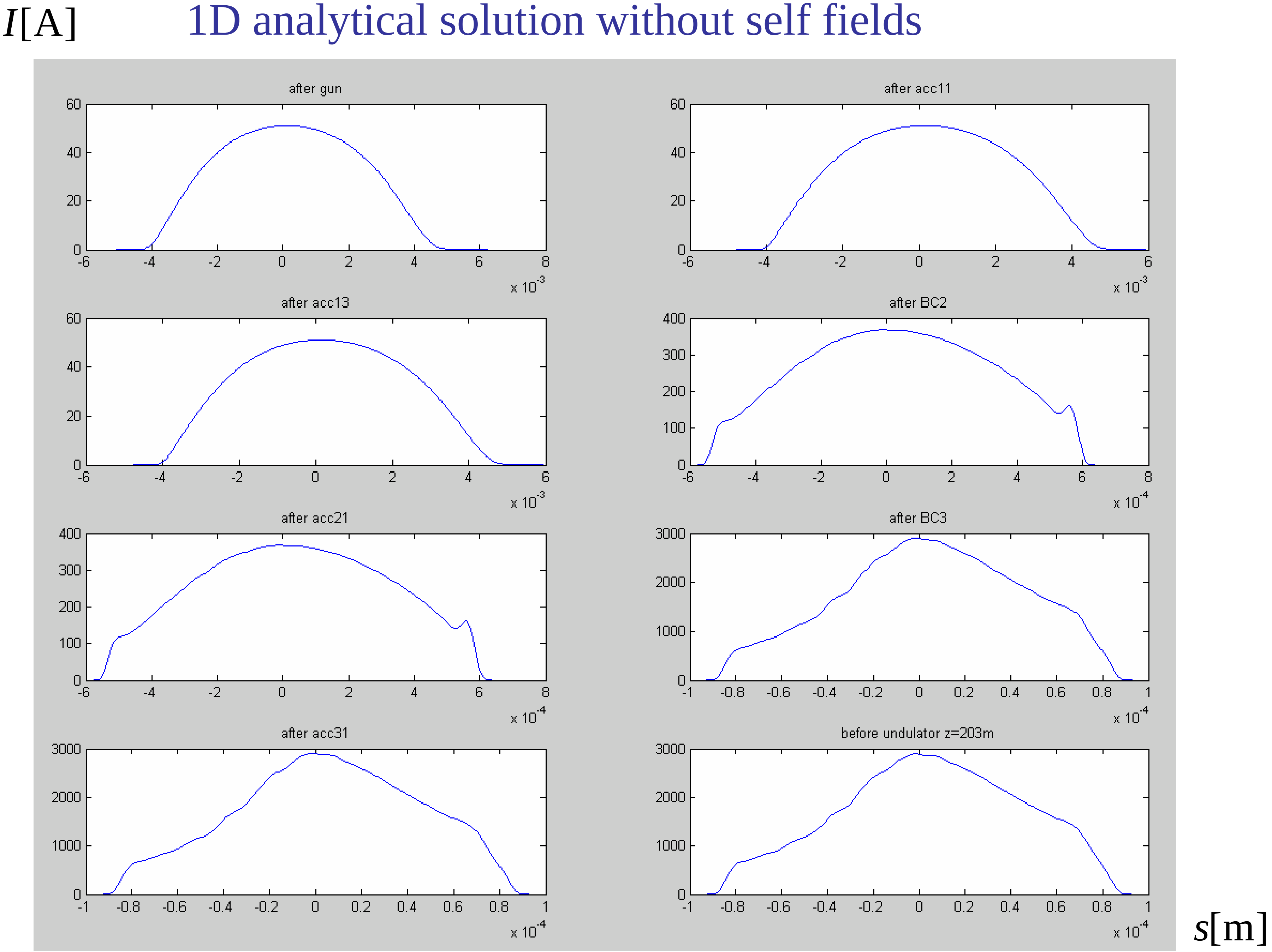
$u_{5666} = -0.6417$

$C_1 = 7$

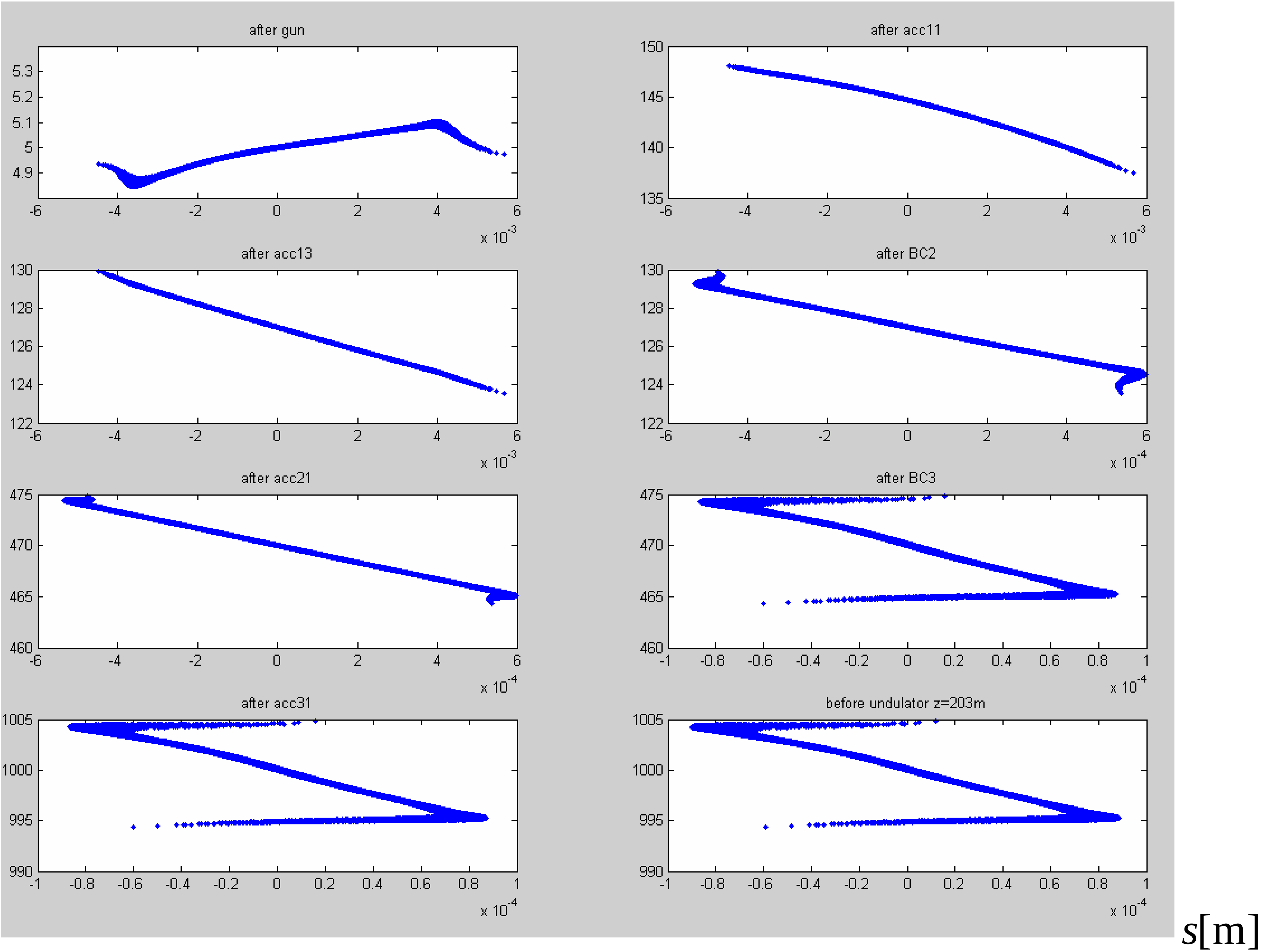
$C_2 = 7$

P0=LoadAstraParticles2D(infile);
[fi11,V11,fi13,V13,fi21,V21,fi31,V31]=
FindFlashParameters(P0(:,1:2),E10,E20,E30,r56_1,t566_1,u5666_1,r56_2,f,1/C10,1/C20);

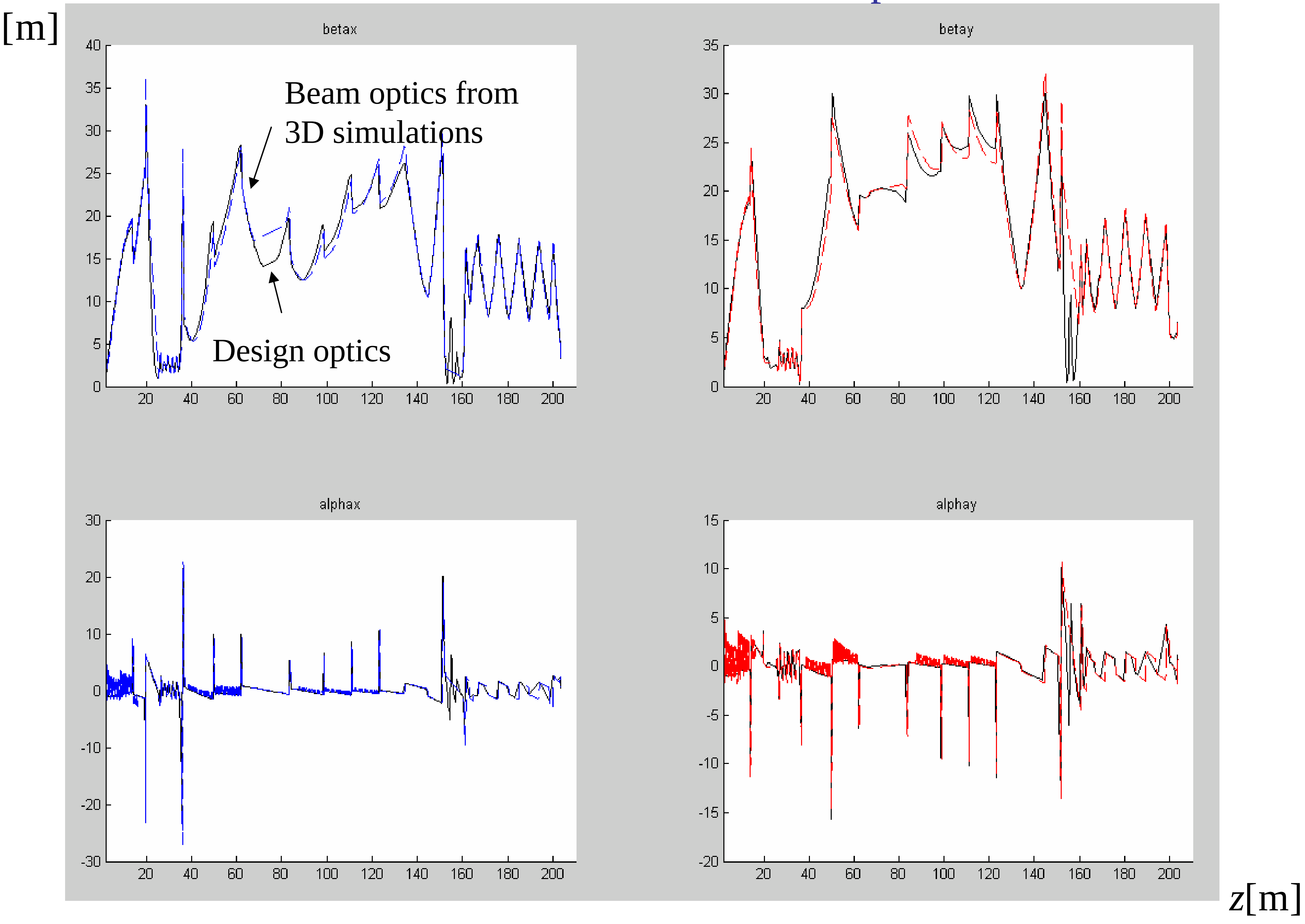
1D analytical solution without self fields



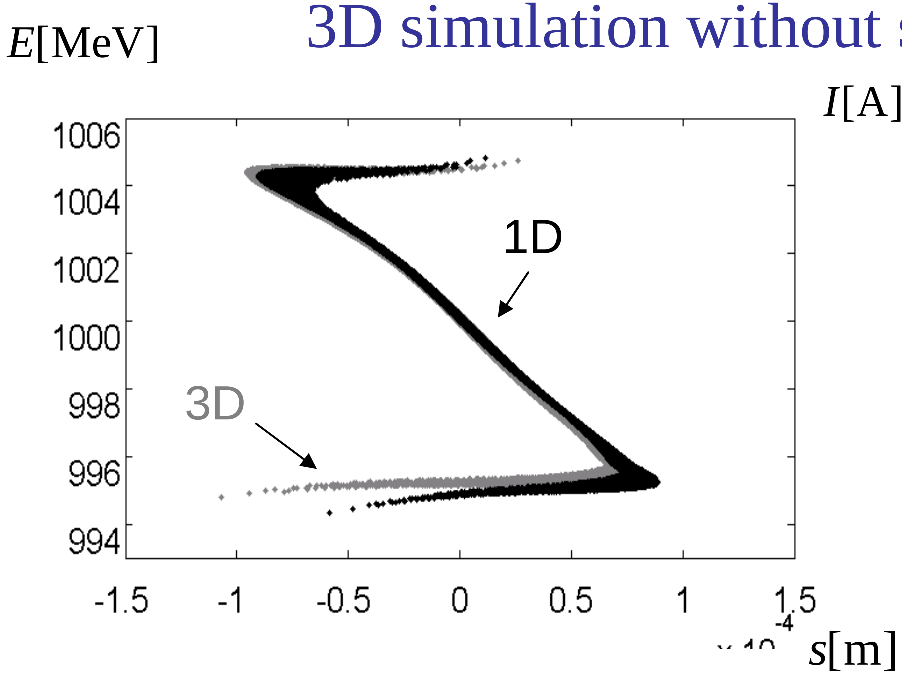
E[MeV] 1D analytical solution without self fields

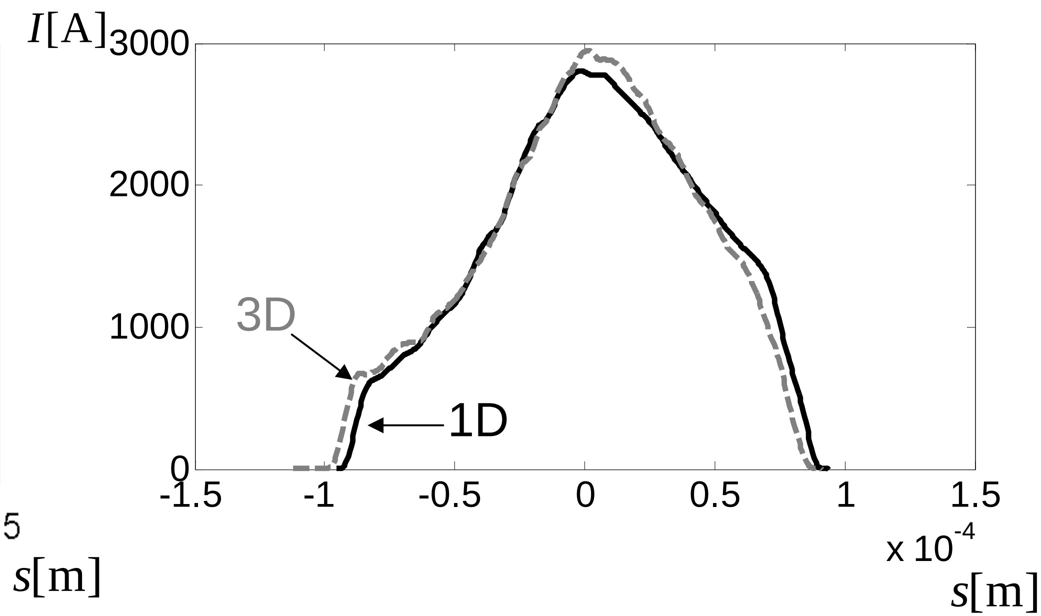


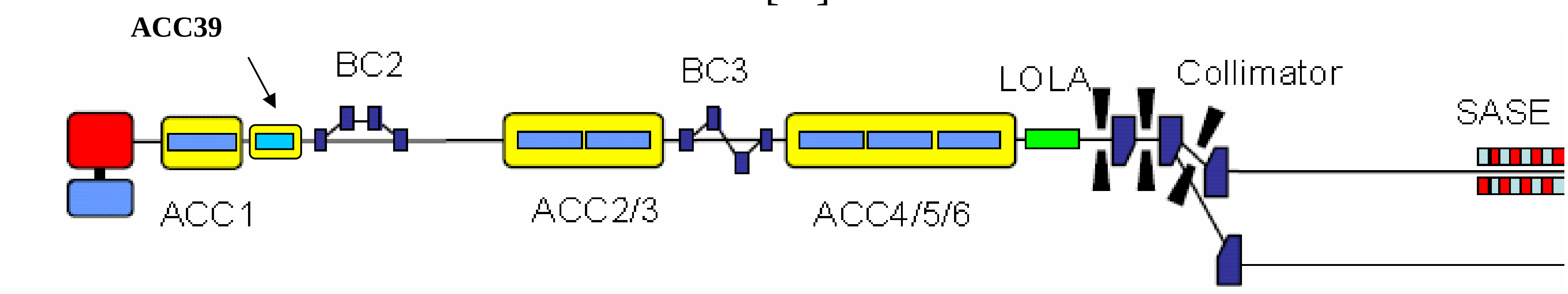
3D simulation without self fields. Optics.



3D simulation without self fields. Optics.



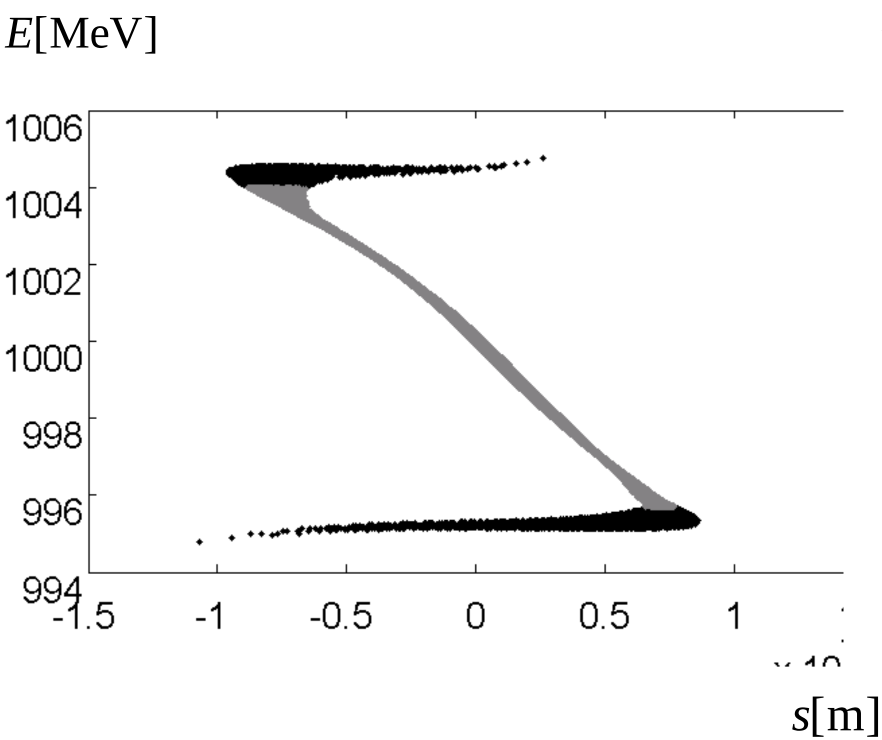


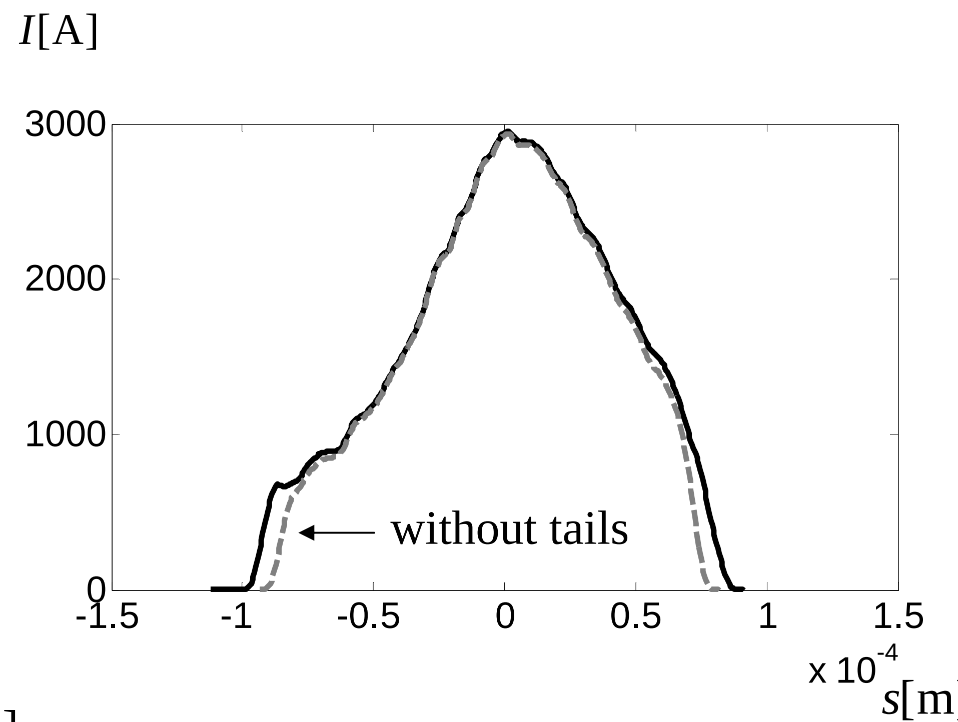


$\varphi_1 = 14.5485^o$ $\varphi_{39} = 193.8678^o$ $\varphi_2 = 23.4969^o$ $\varphi_3 = 0^o$

$V_1 = 144.3381[\text{MV}]$ $V_{39} = 18.2405[\text{MV}]$ $V_2 = 374.0126[\text{MV}]$ $V_3 = 530[\text{MV}]$

3D simulation without self fields. Tails charge?

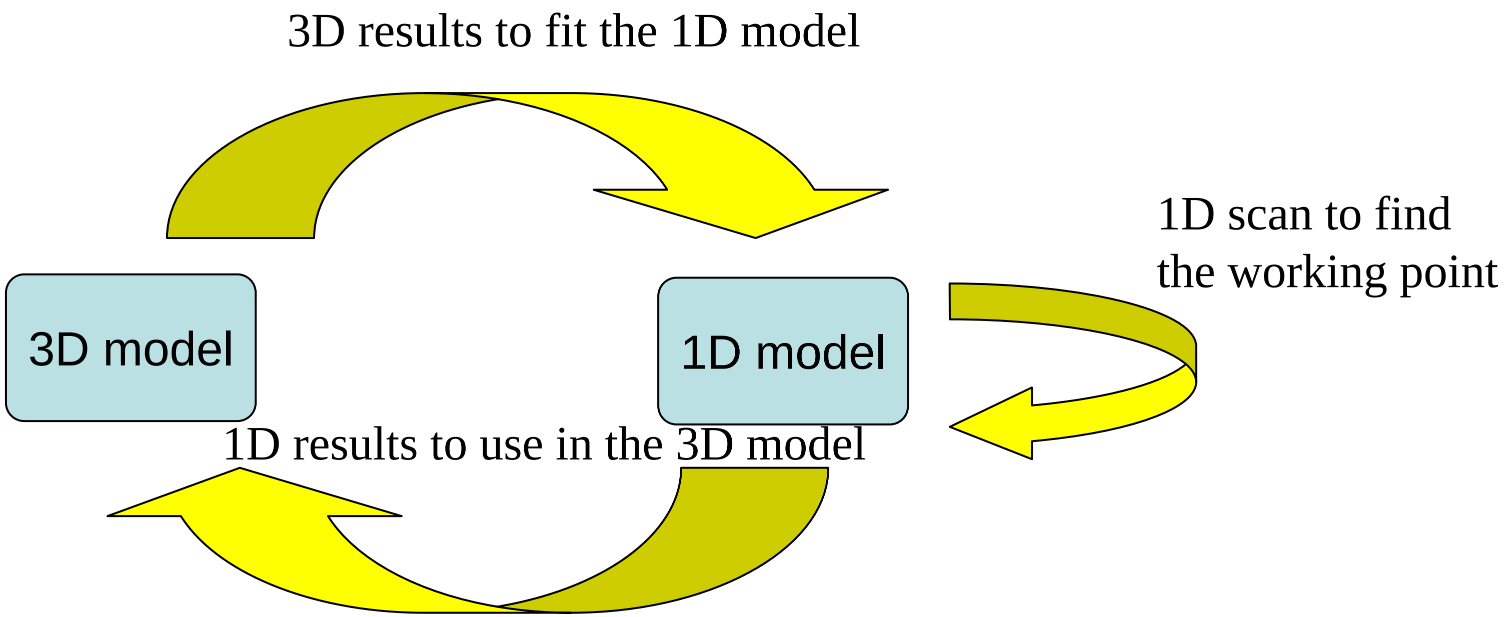




3D and 1D simulations with self fields.

1) space charge
2) space charge + cavity wakes
3) space charge +cavity wakes + self fields in BCs

1D model was checked through 3D.
Working points are found by minsearch() in 1D and then checked by 3D.
Finally, 1D model will be used to estimate RF tolerances.

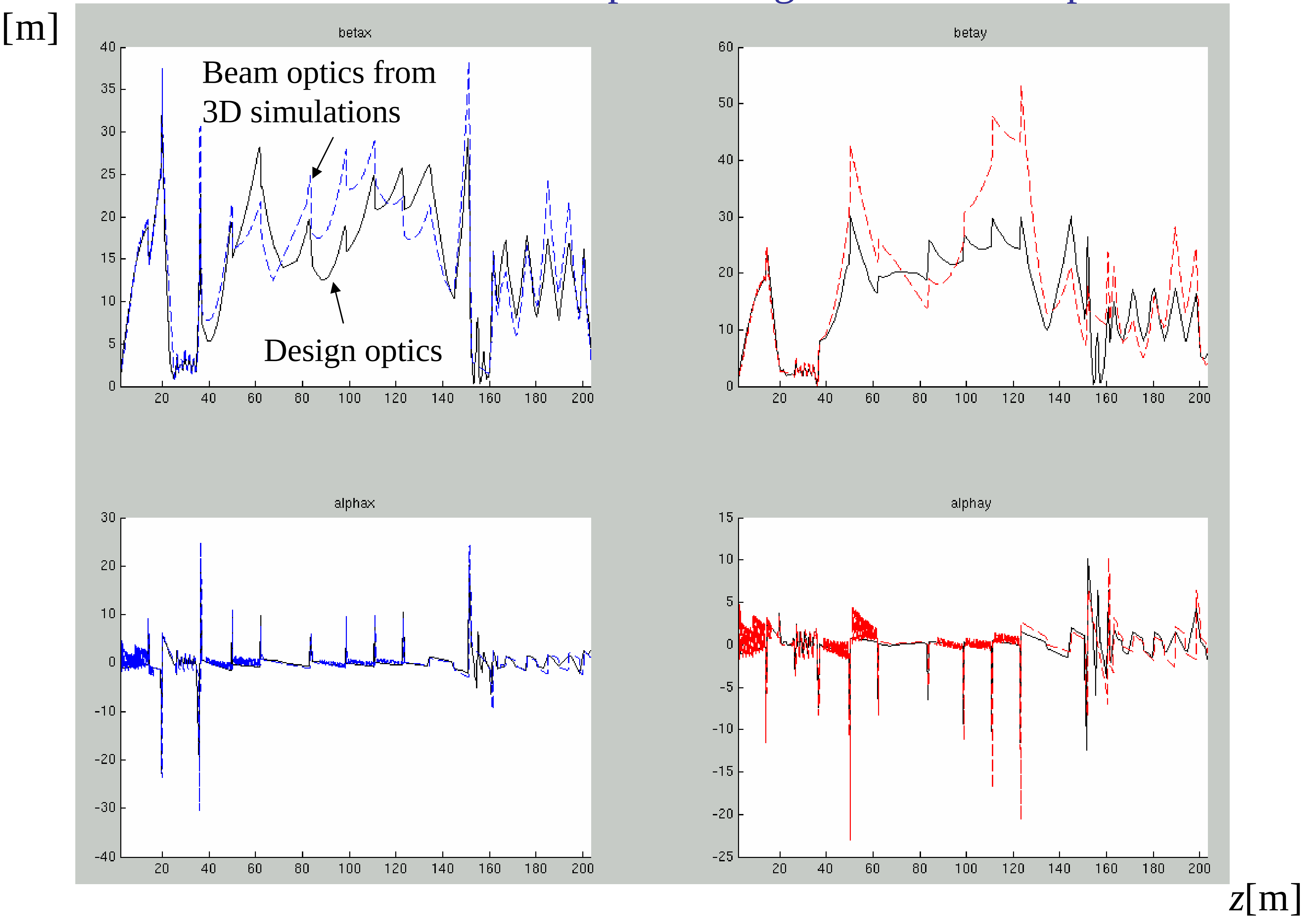


3D and 1D simulations with self fields.

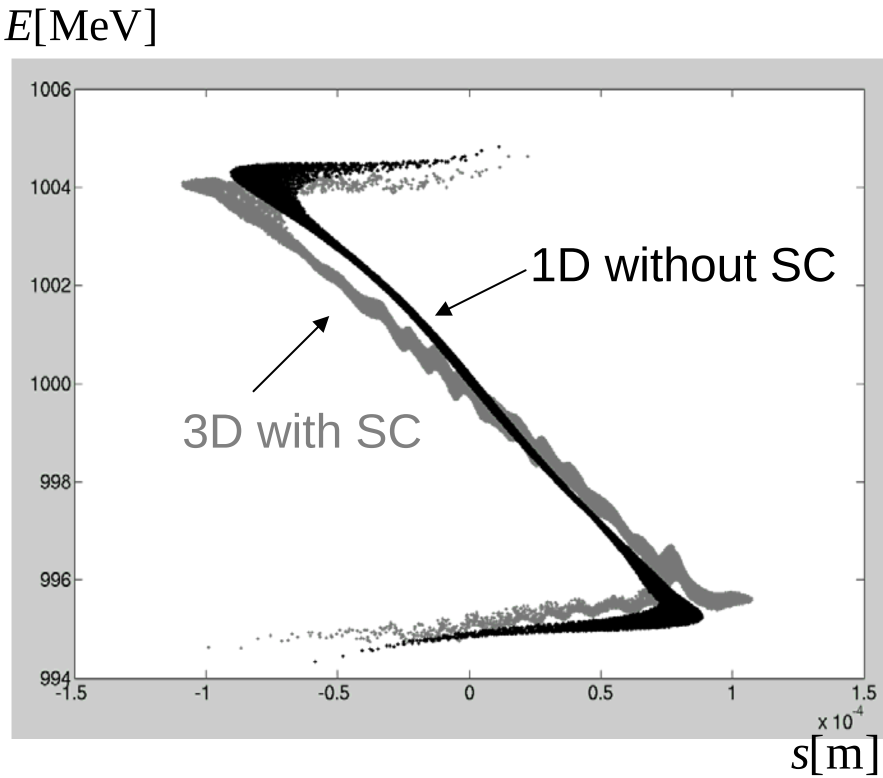
Work points from 1D optimization

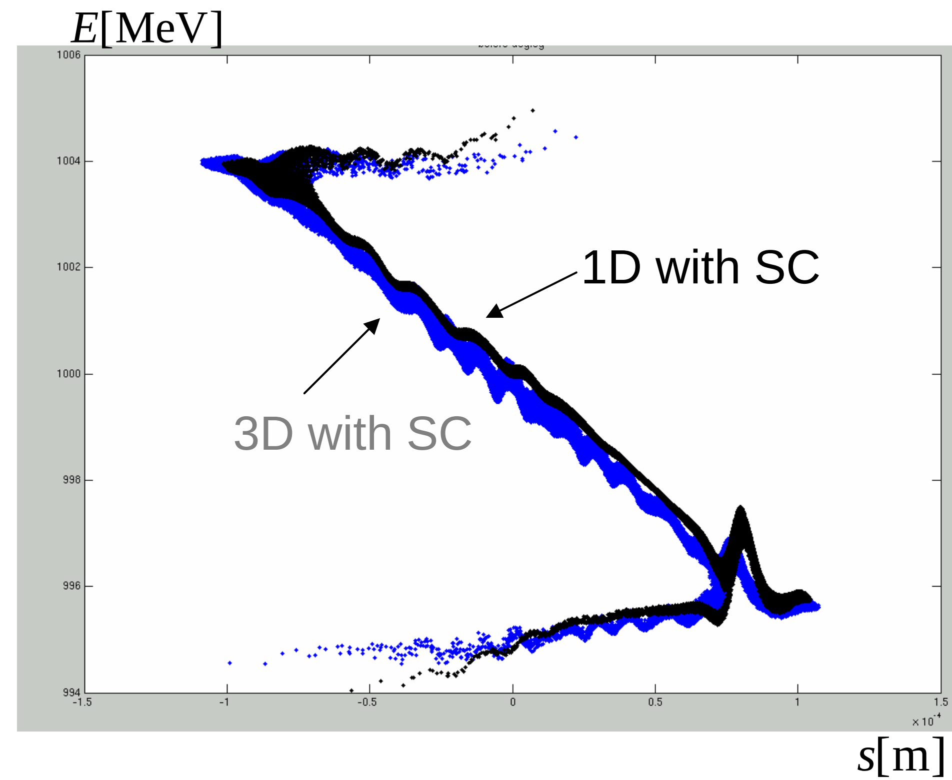
<table>
<tr><th></th><th>V_1, [MV]</th><th>φ_1, [deg]</th><th>V_{39}, [MV]</th><th>φ_{39}, [deg]</th><th>V_2, [MV]</th><th>φ_2, [deg]</th></tr>
<tr><td>without self fields, I=2500 A</td><td rowspan="2">144.34</td><td rowspan="2">14.549</td><td rowspan="2">18.24</td><td rowspan="2">193.87</td><td rowspan="2">374.01</td><td rowspan="2">23.497</td></tr>
<tr><td>+ space charge, I=2500</td></tr>
<tr><td>+ space charge +cavity wakes, I=2500</td><td>142.55</td><td>13.98</td><td>16.54</td><td>191.859</td><td>376.63</td><td>24.295</td></tr>
<tr><td>+ space charge +cavity wakes +BCself fields, I=2500</td><td>142.29</td><td>14.827</td><td>15.9</td><td>194.536</td><td>380.15</td><td>25.274</td></tr>
<tr><td>I=1809 with self fields</td><td>142.37</td><td>14.848</td><td>16</td><td>194.963</td><td>379.87</td><td>25.198</td></tr>
</table>

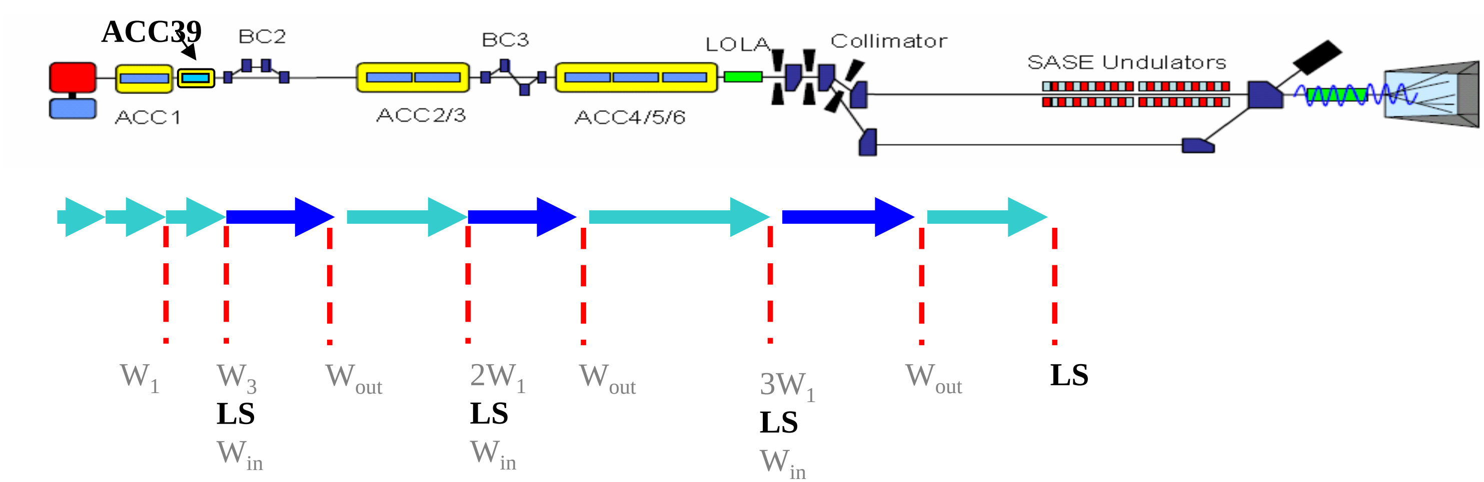
3D simulation with space charge in ASTRA. Optics.



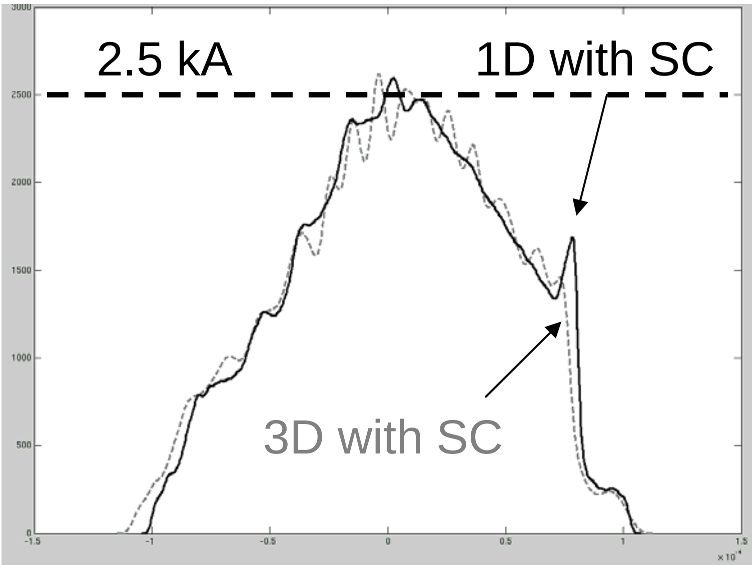
3D simulation with space charge in ASTRA.



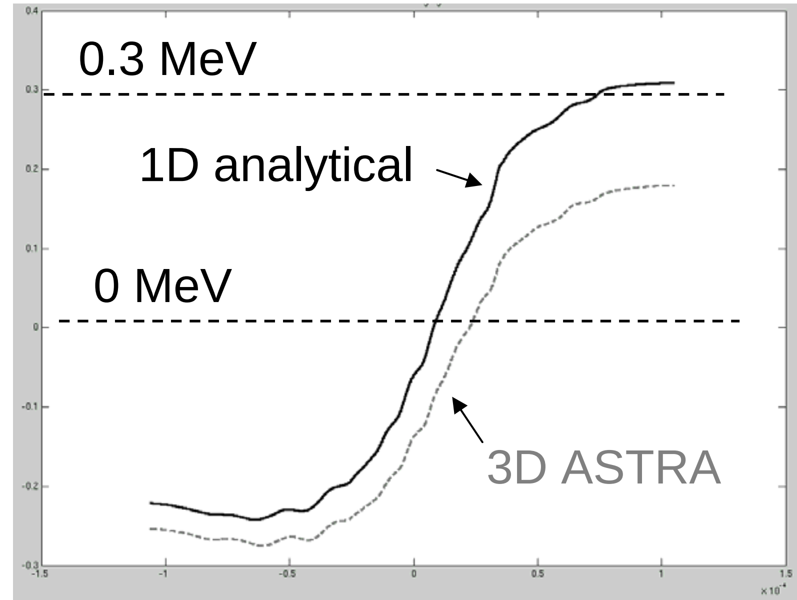




3D simulation with space charge in ASTRA.

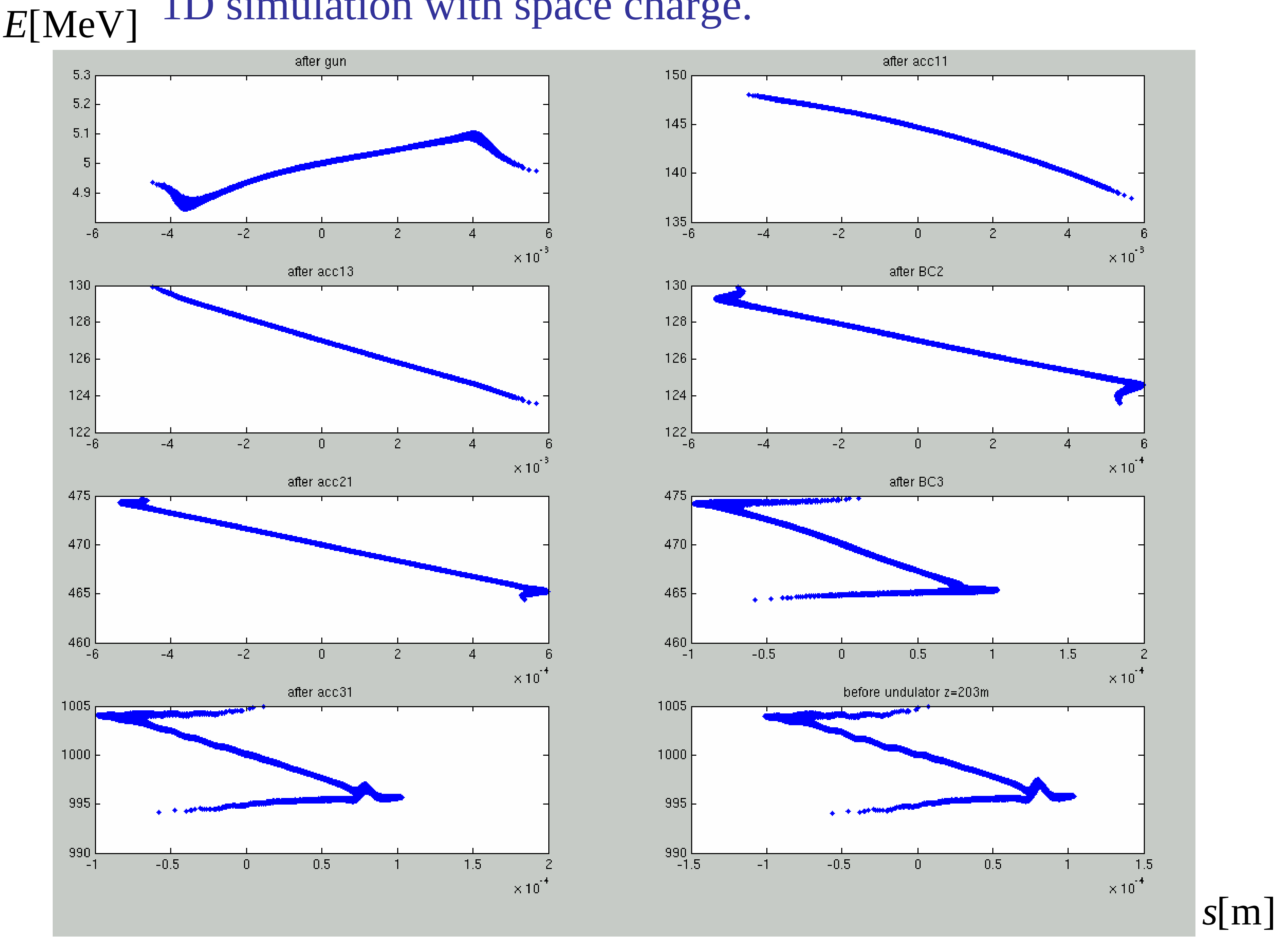


Current at z=203 m

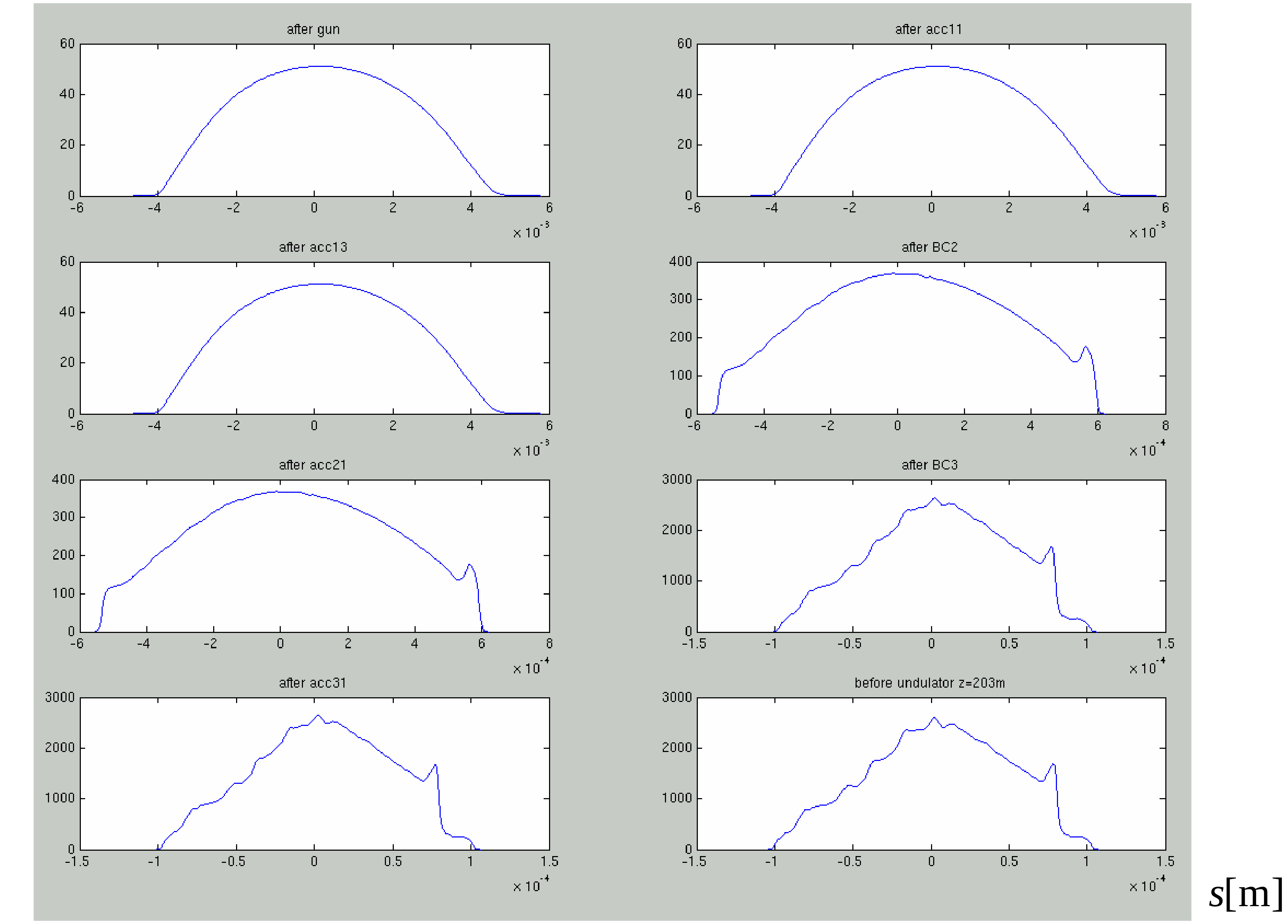


SC wake between BCs

1D simulation with space charge.

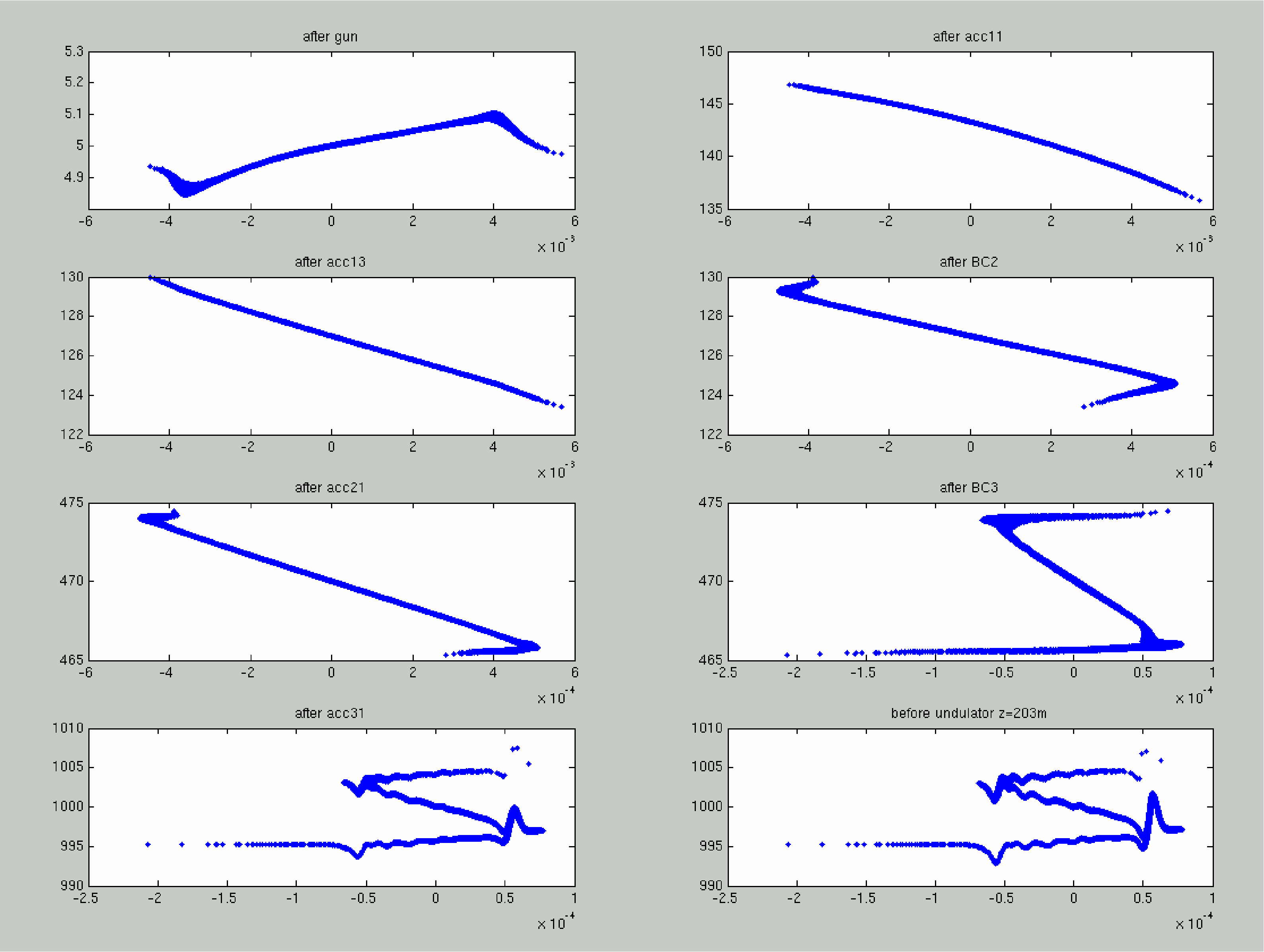


1D simulation with space charge.



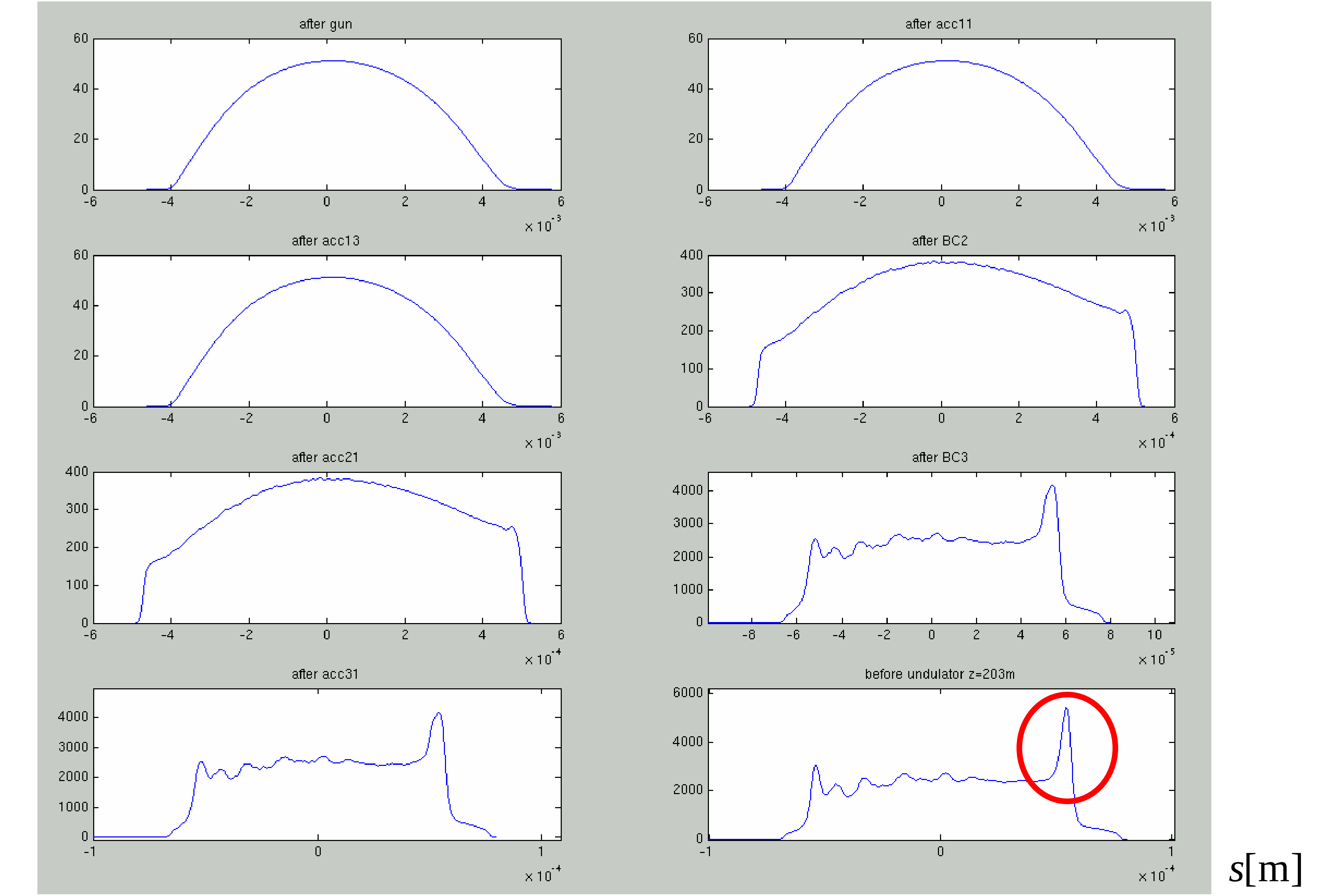
1D simulation with space charge + cavity wakes.

E[MeV]

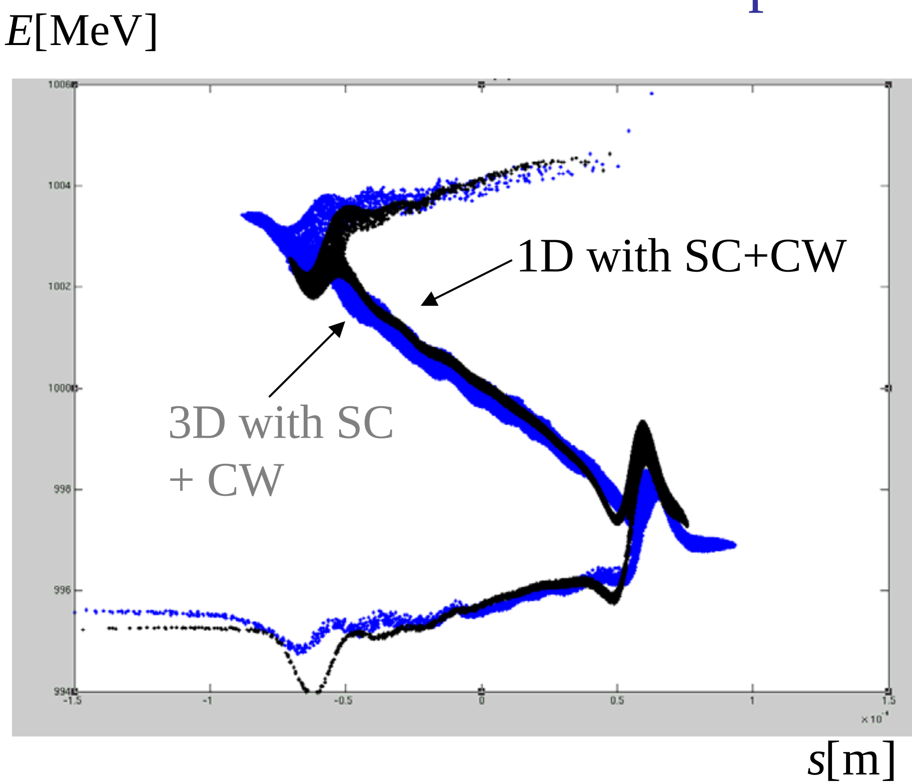


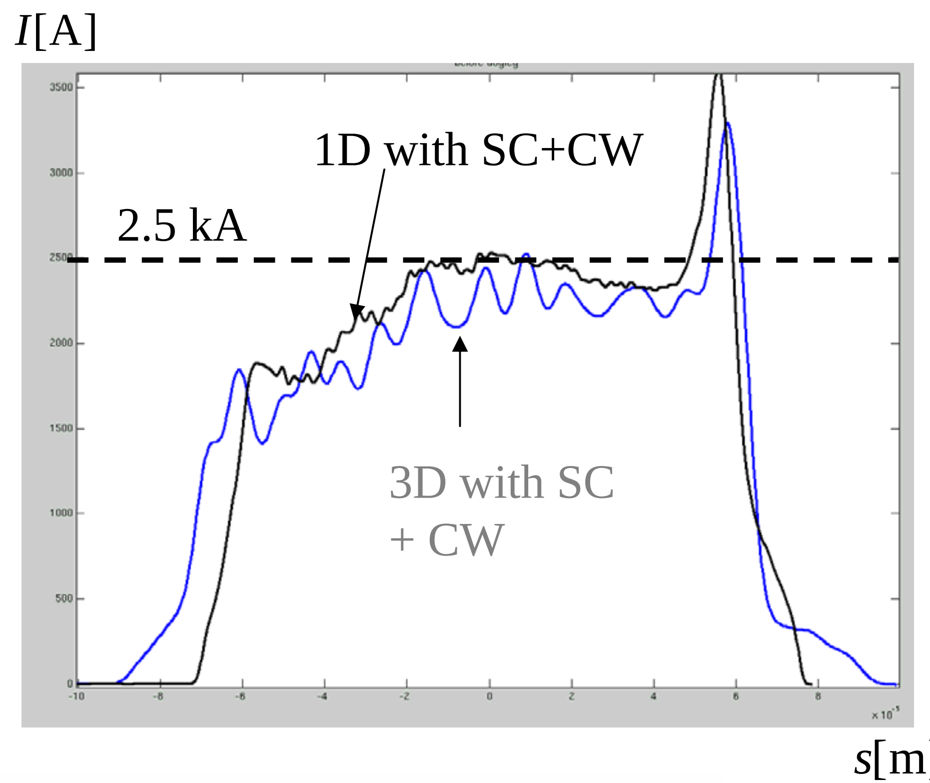
s[m]

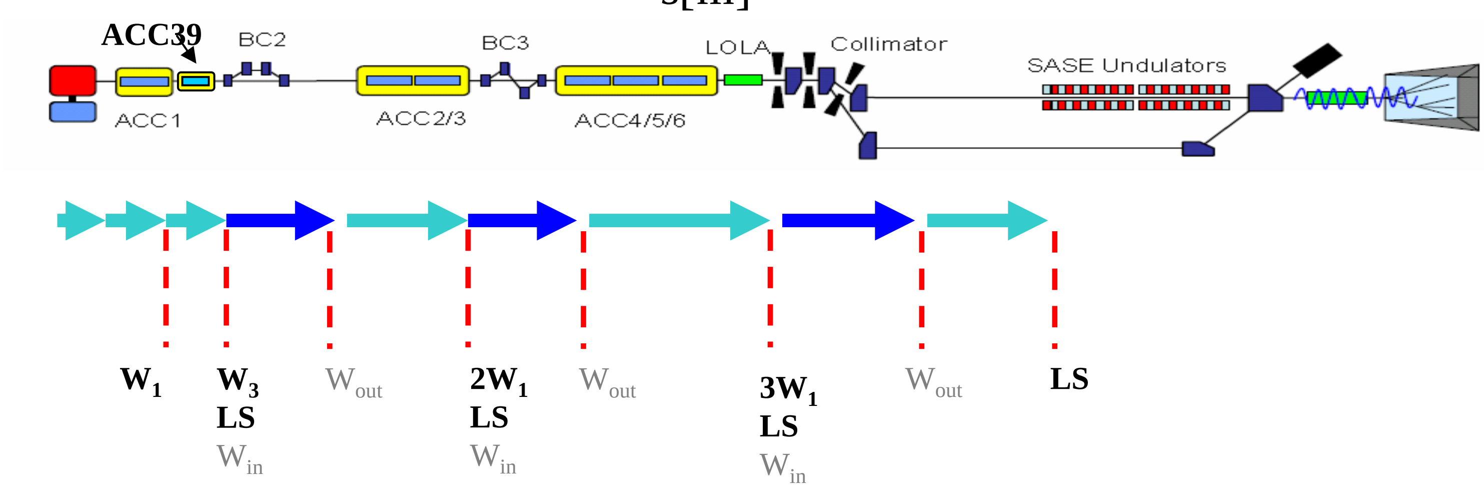
1D simulation with space charge + cavity wakes.



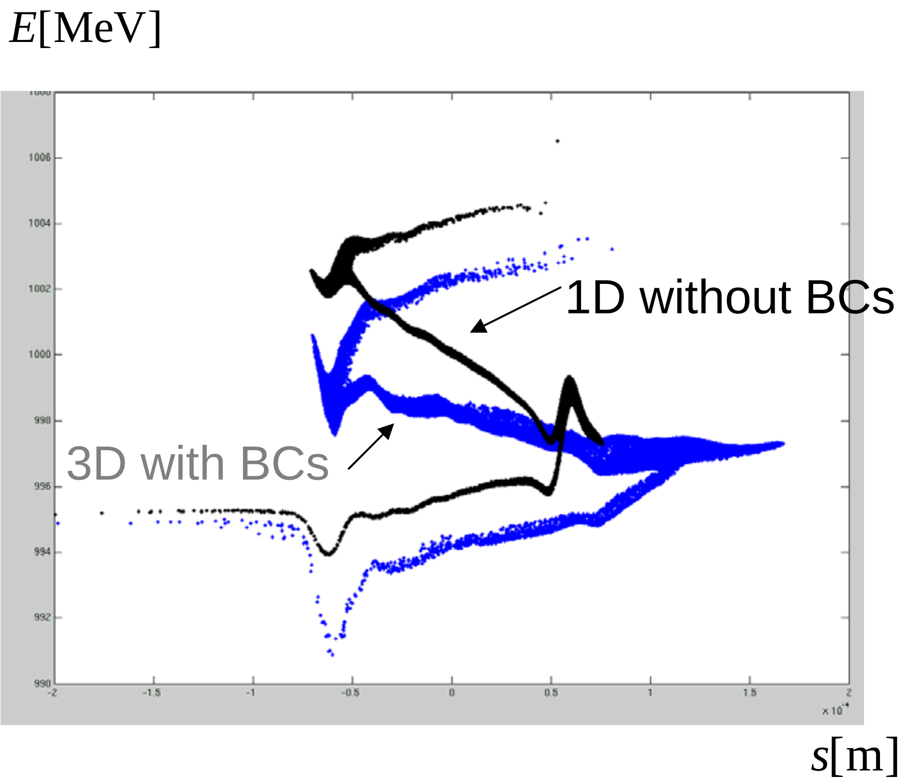
3D simulation with space charge + cavity wakes.

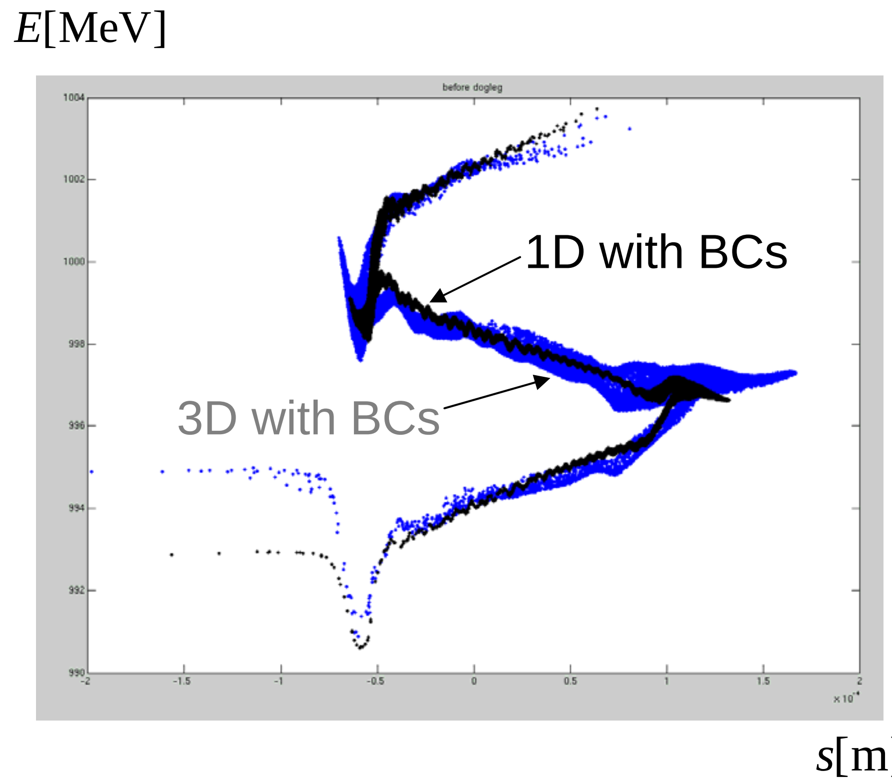


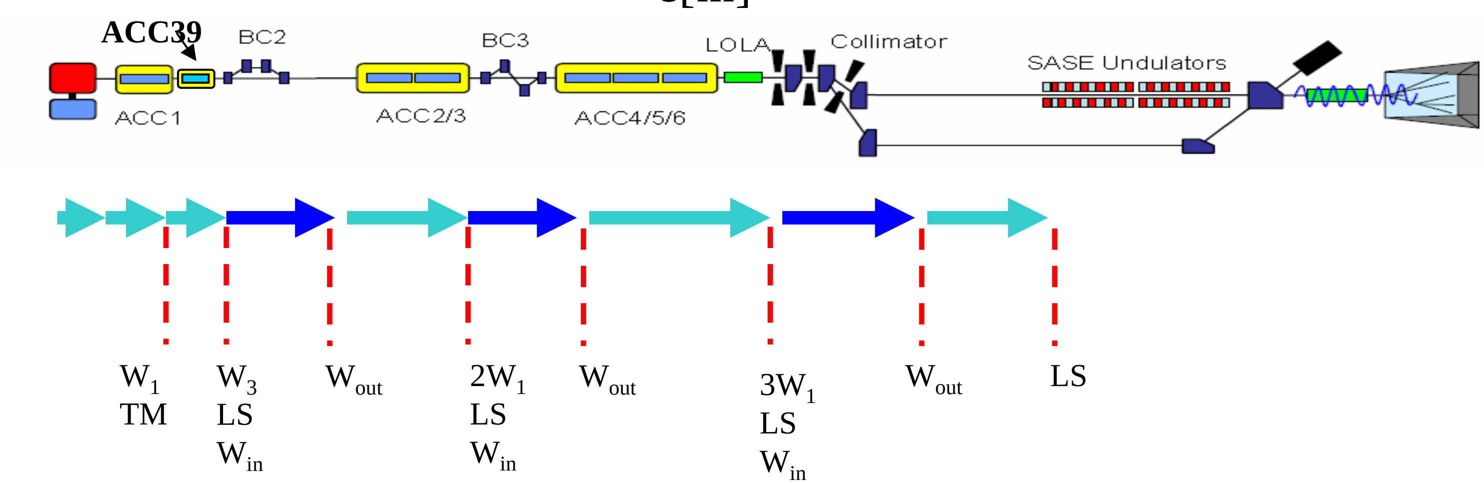




3D simulation with space charge + cavity wakes+self fields in BCs.

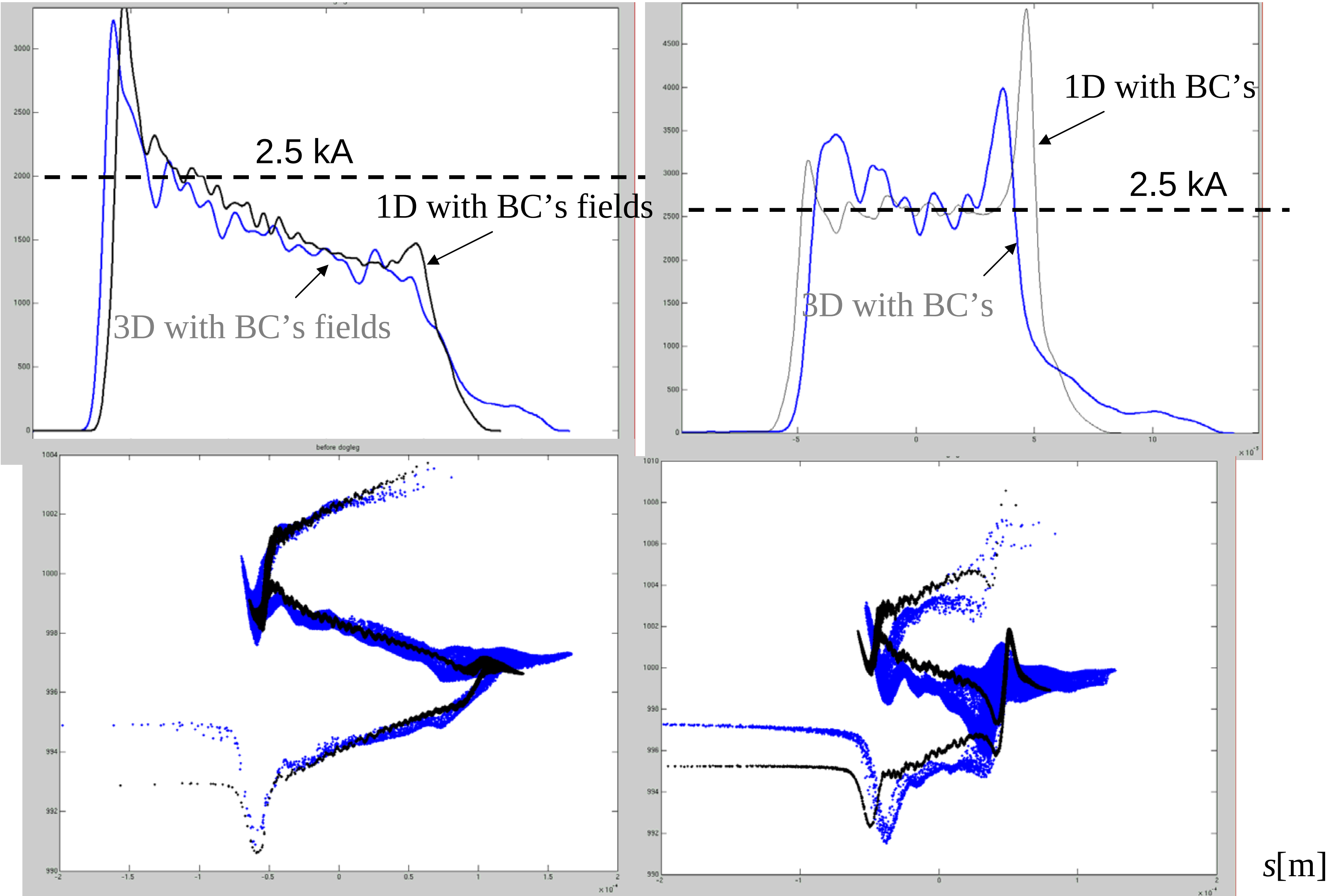




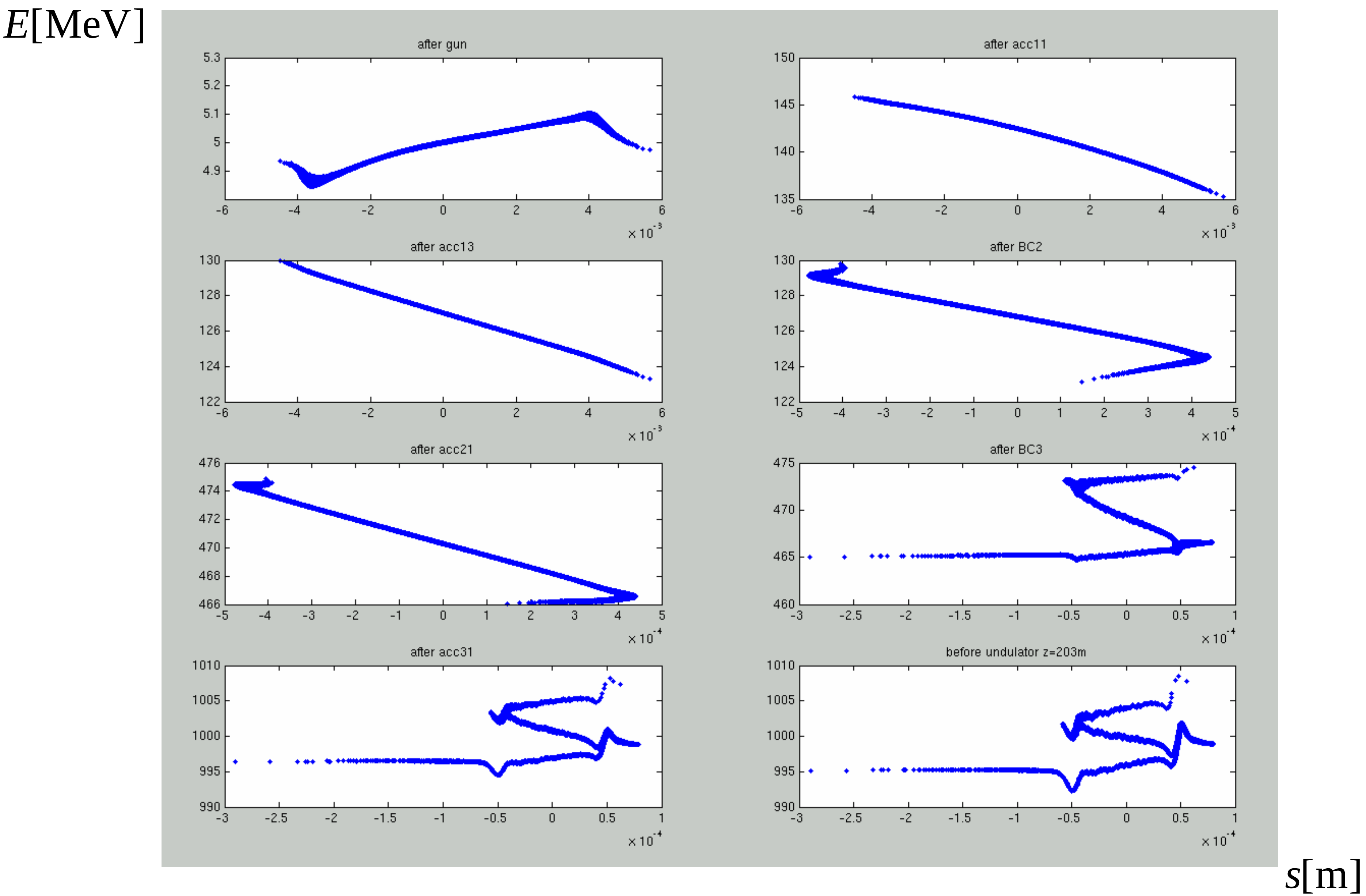


3D simulation with space charge + cavity wakes+self fields in BCs.

Optimized for I=2500A without BCs fields | Optimized for I=2500A with BCs fields

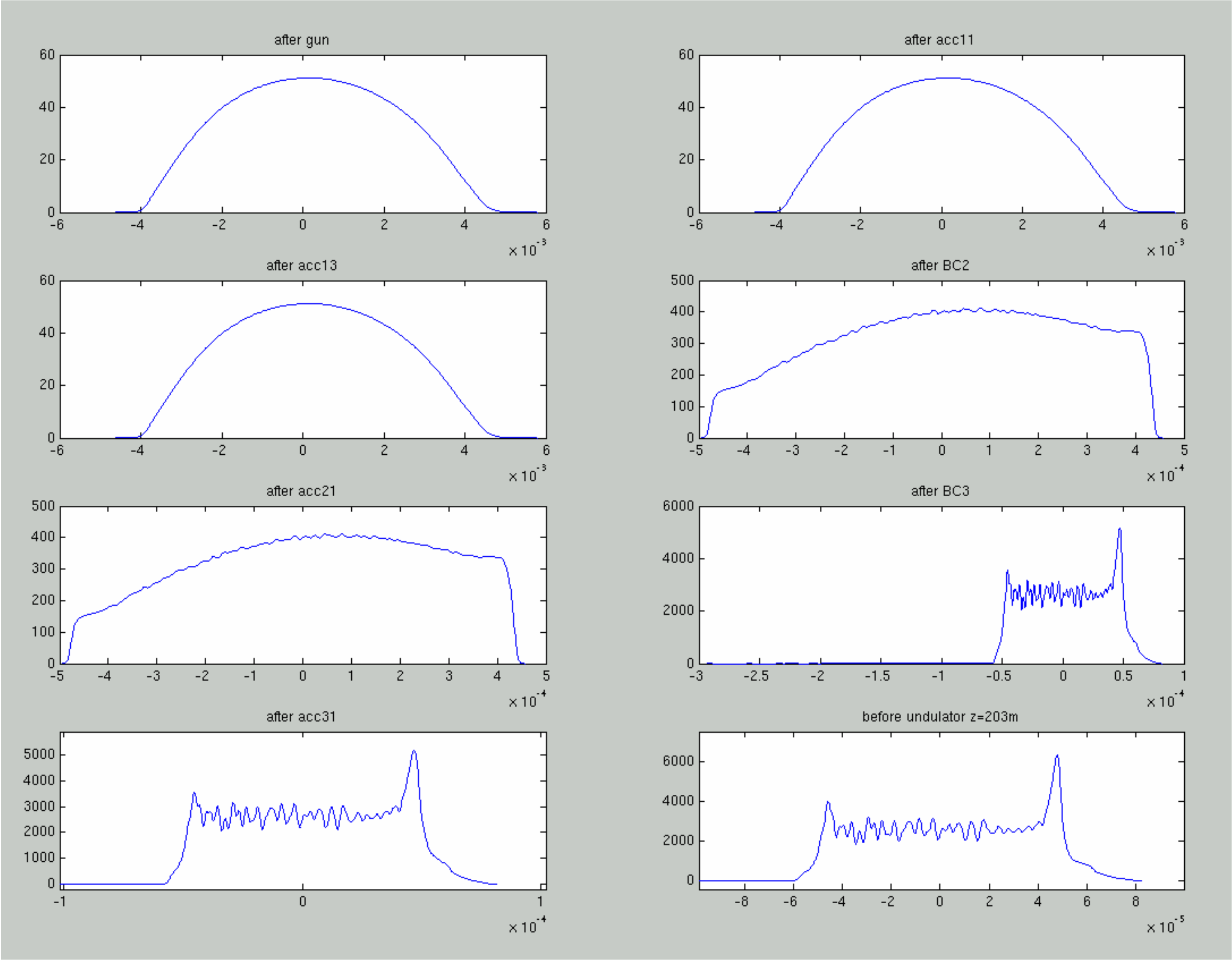


3D simulation with space charge + cavity wakes+self fields in BCs.



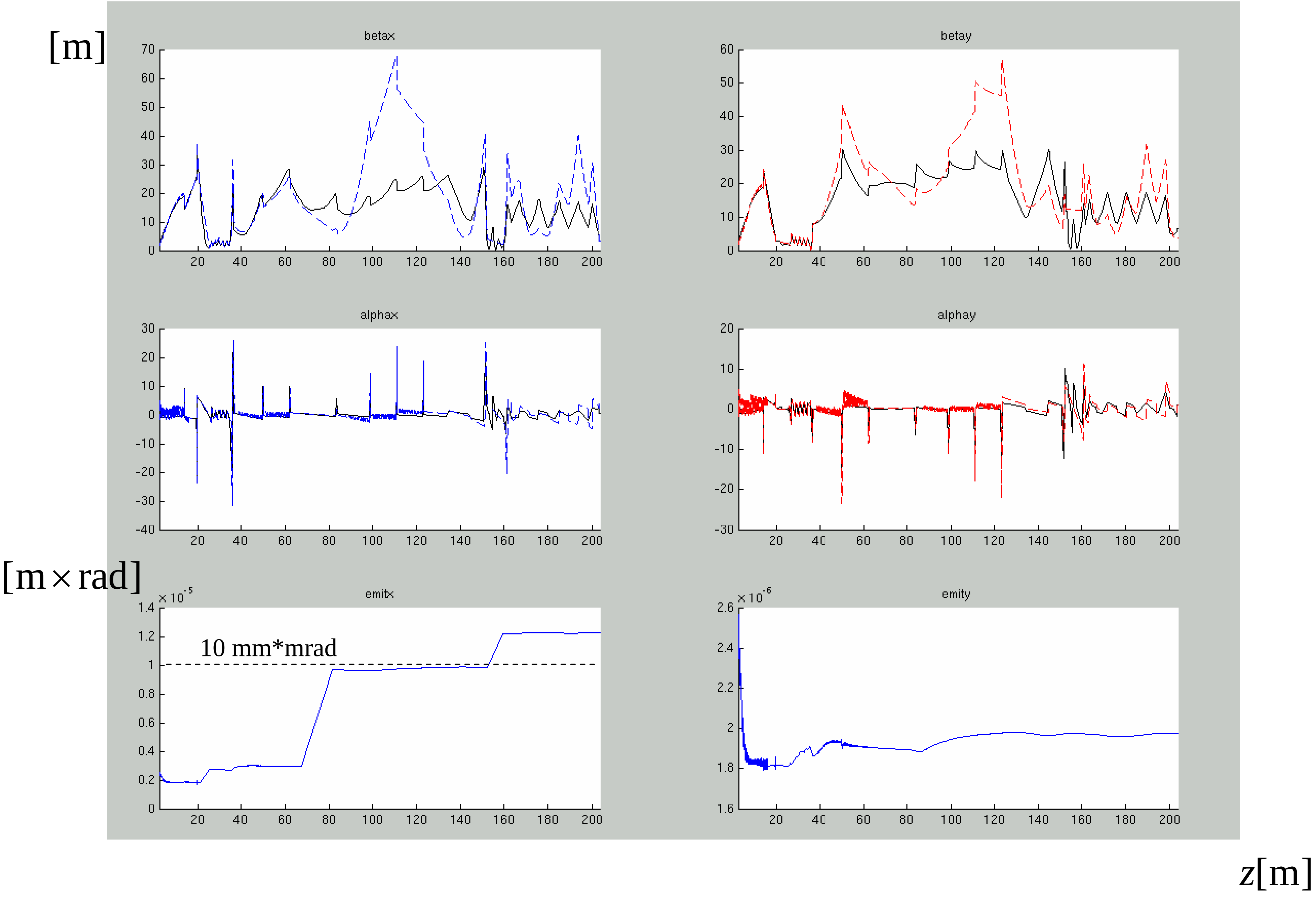
3D simulation with space charge + cavity wakes+self fields in BCs.

I[A]

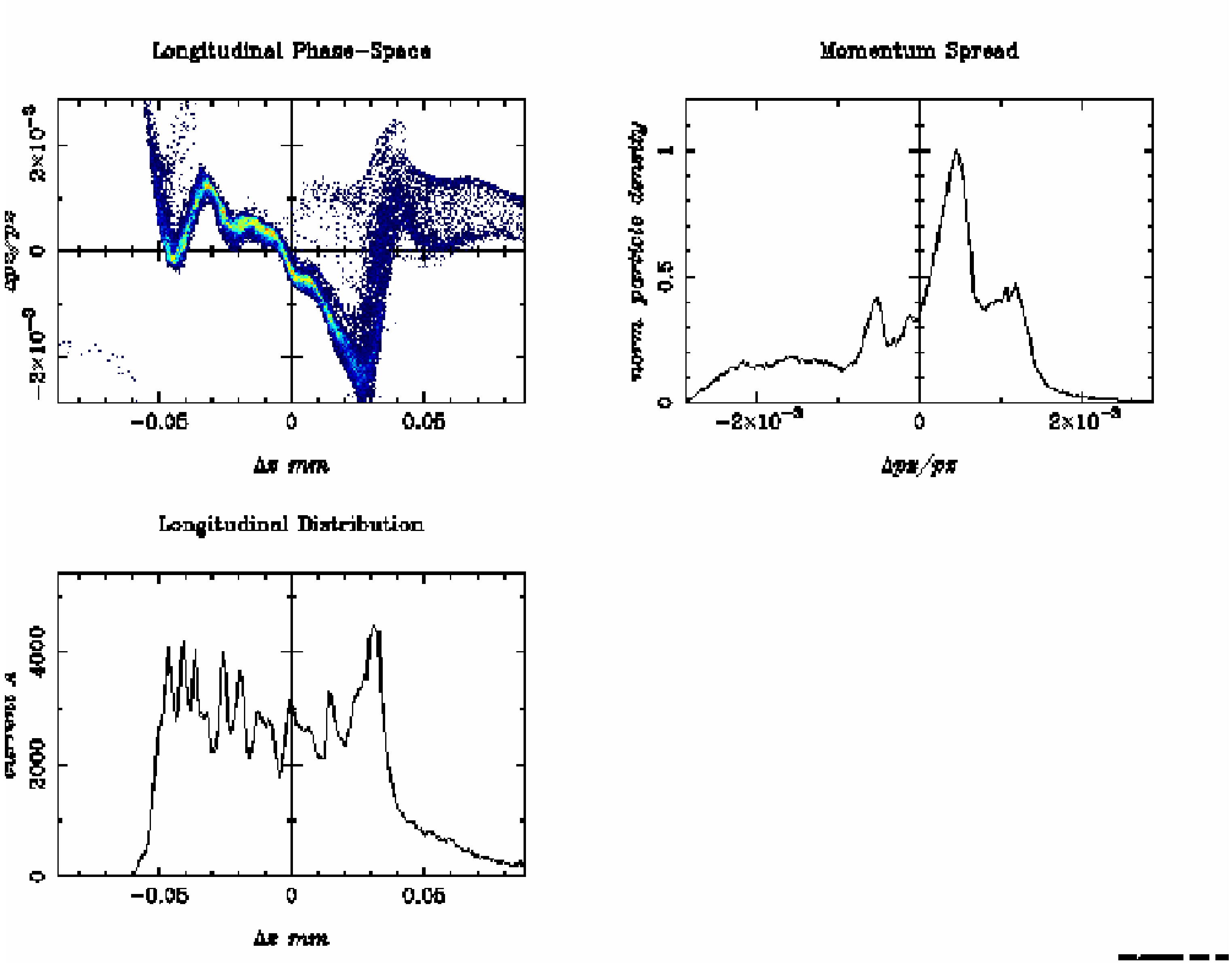


s[m]

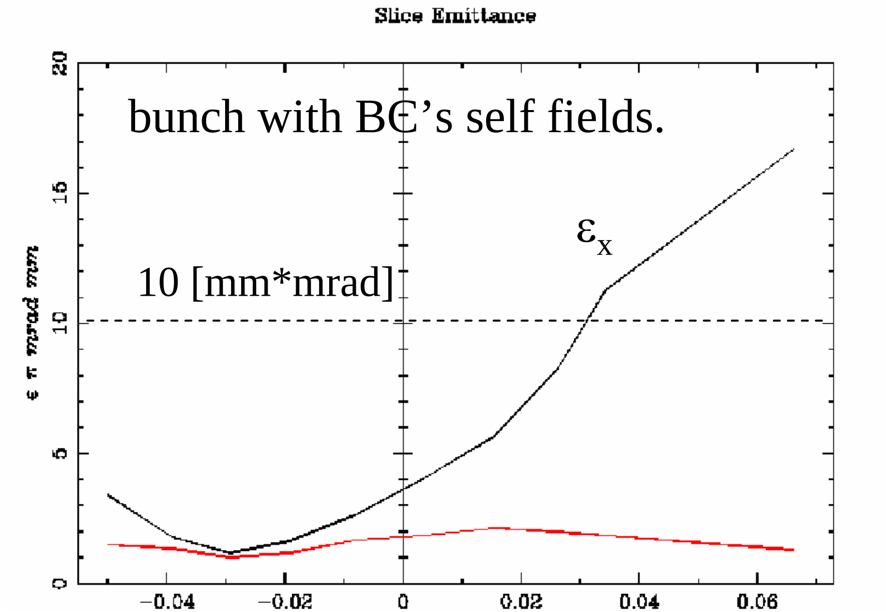
3D simulation with space charge + cavity wakes+self fields in BCs.

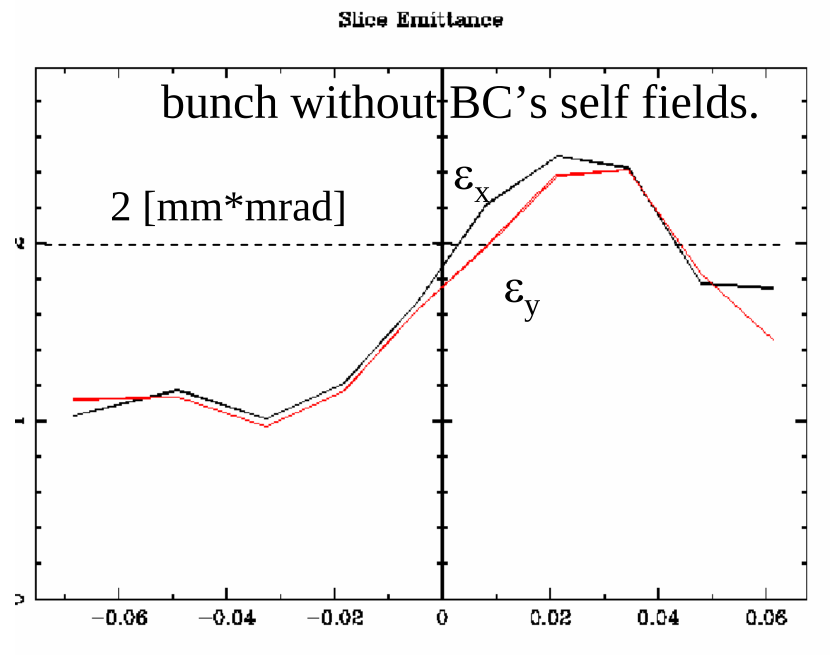


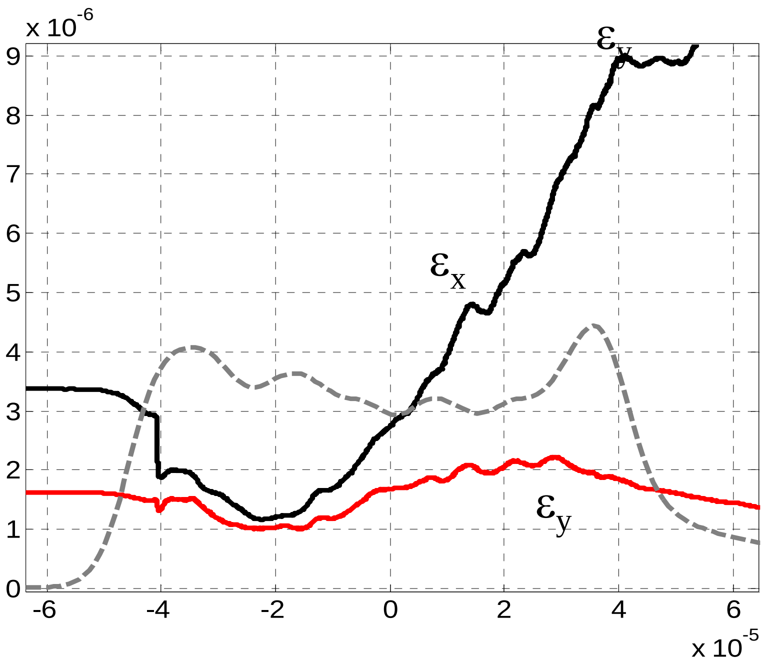
3D simulation with self fields for I=2500A.



3D simulation with self fields for I=2500A.

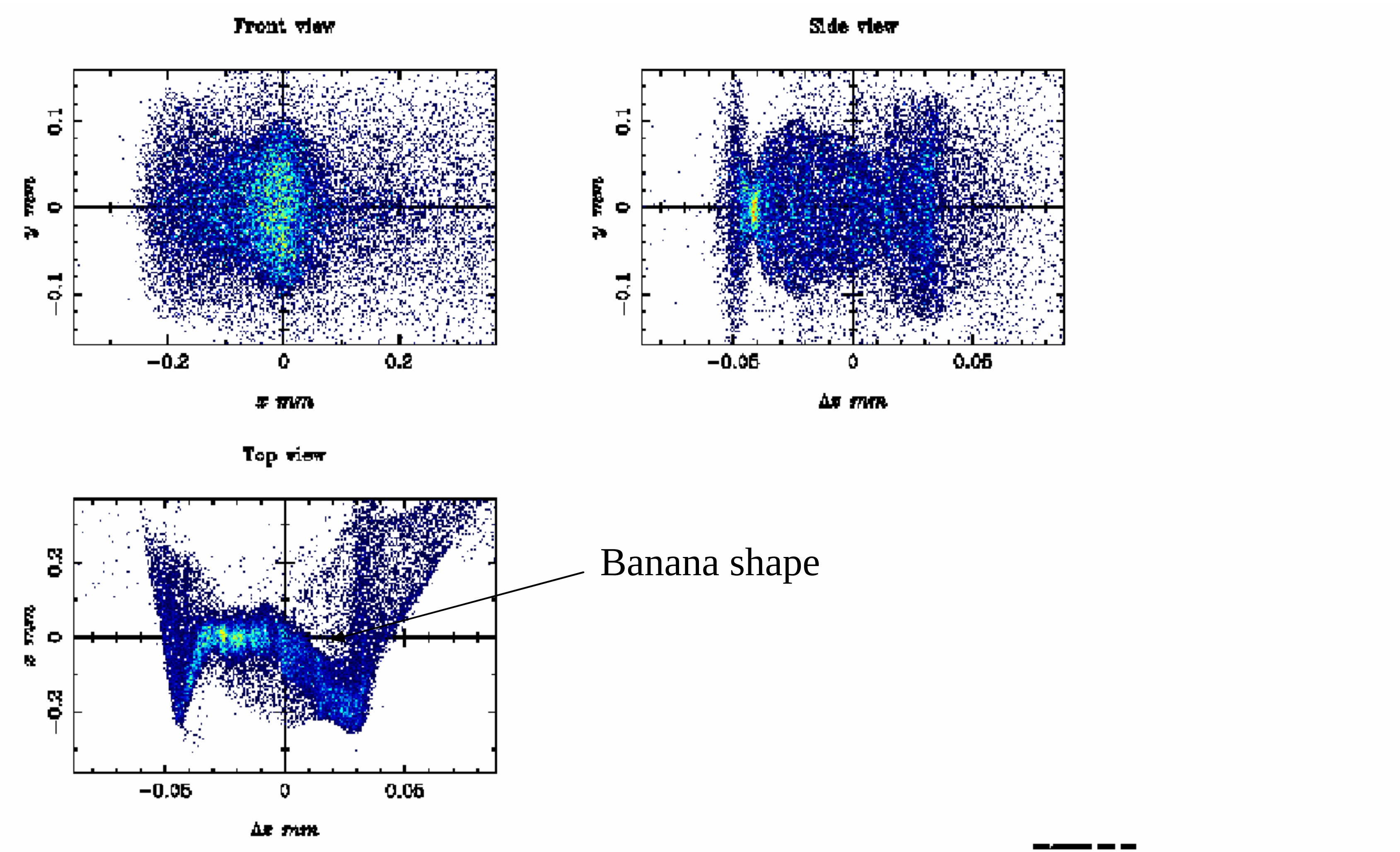






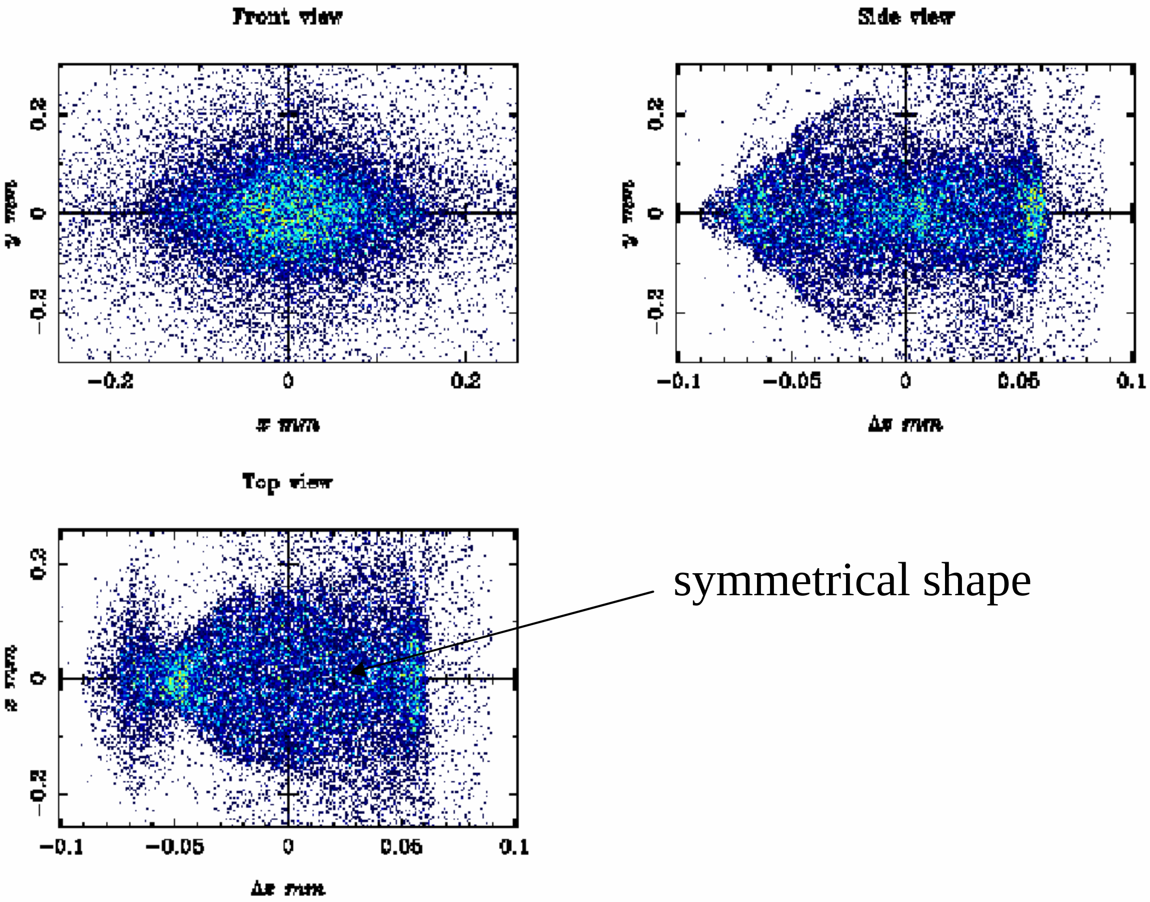
3D simulation with self fields for I=2500A.

front, side and top view of the bunch with BC’s self fields.

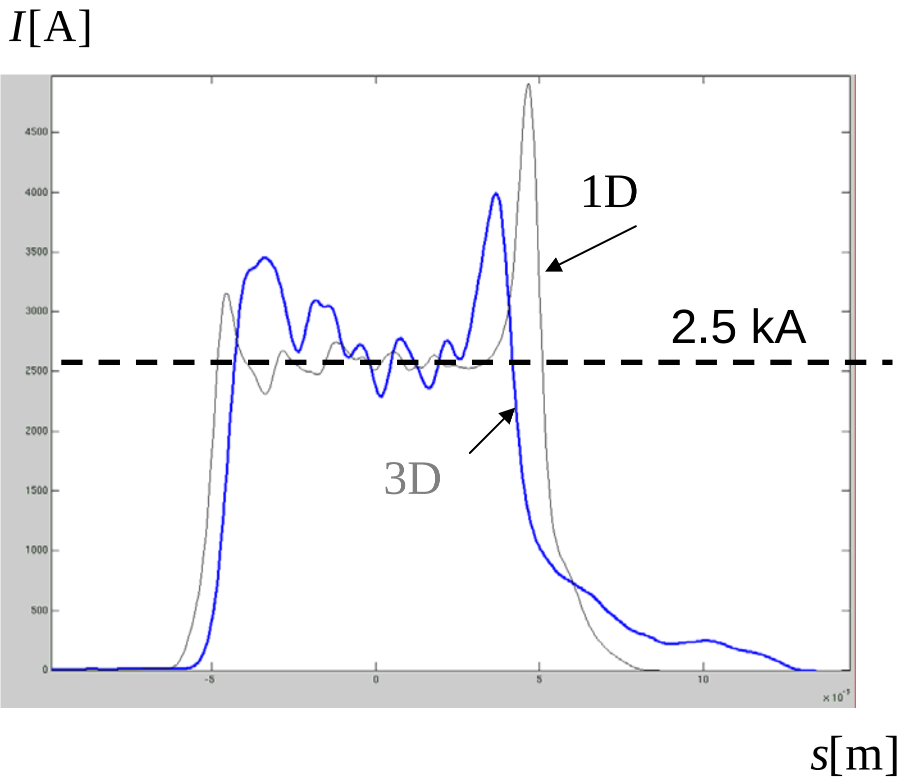


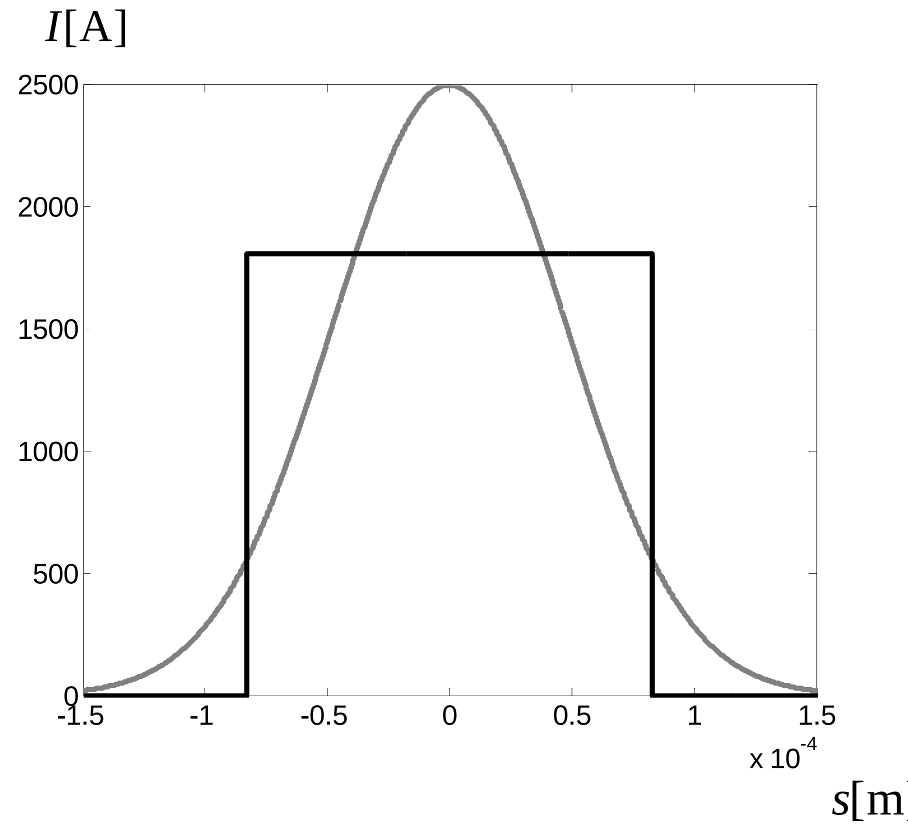
3D simulation with self fields for I=2500A.

front, side and top view of the bunch without BC’s self fields.



From I=2500A to I=1809A.

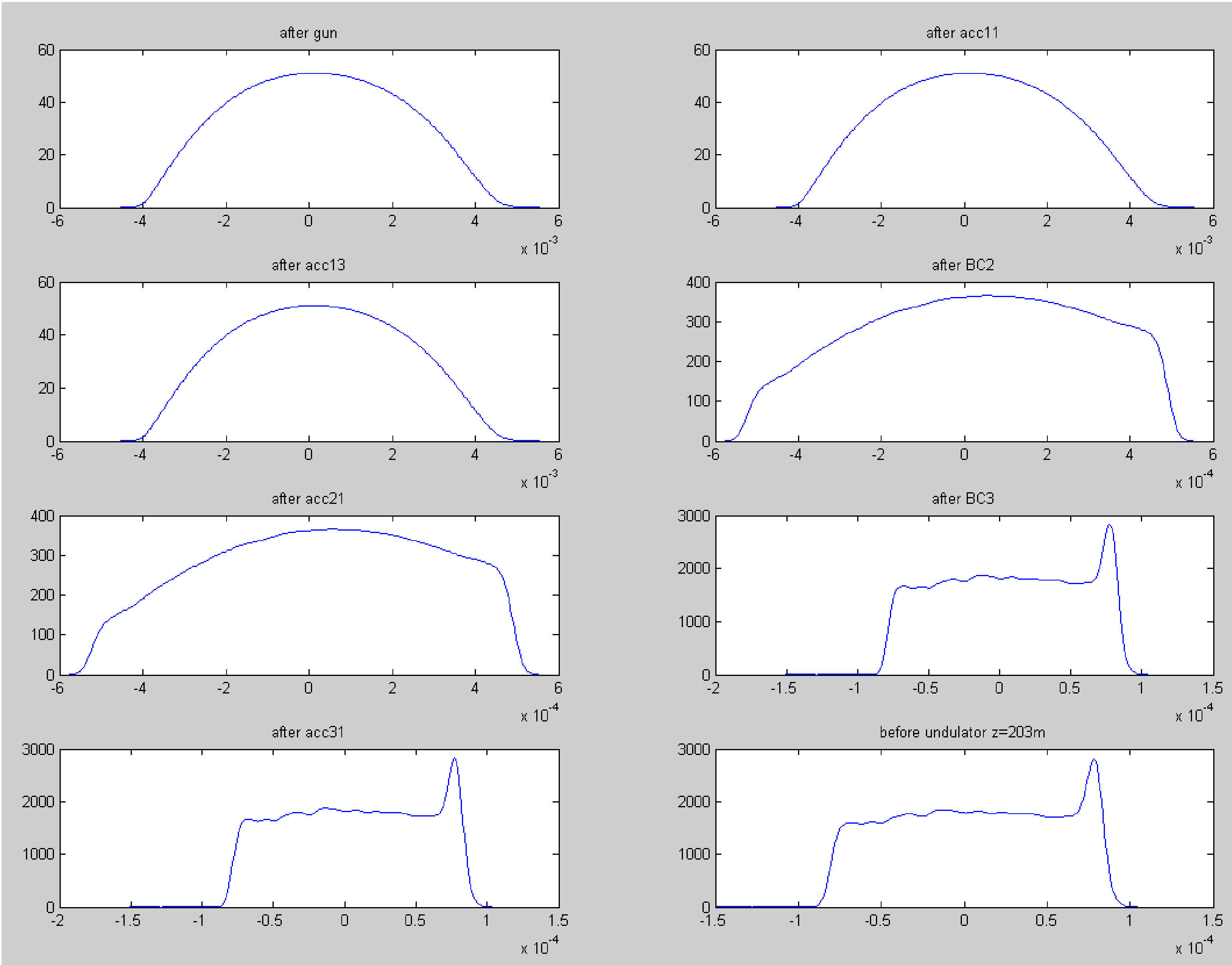




Rectangular and Gaussian bunches with the same rms length

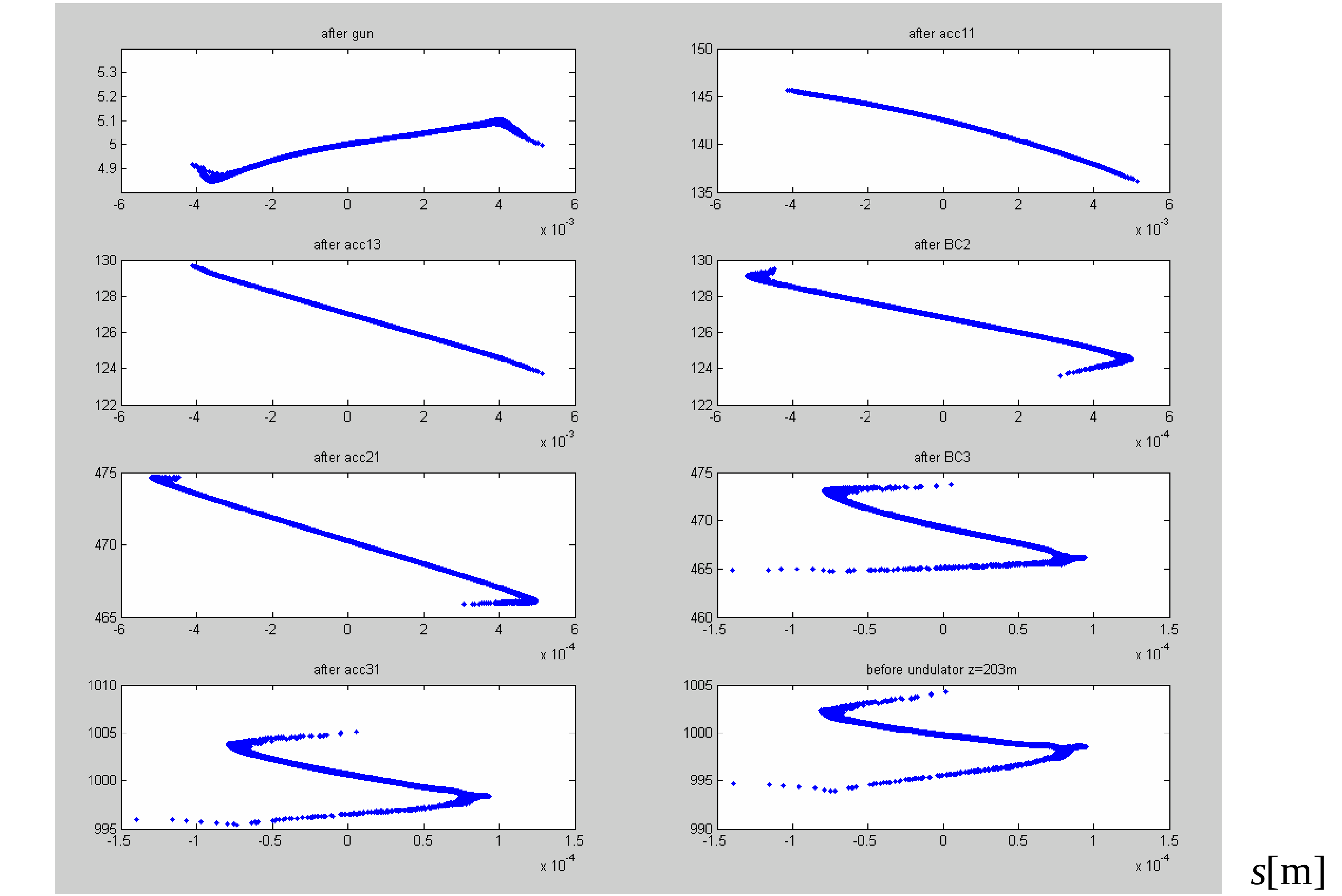
I[A]

3D simulation with self fields for I=1809A.

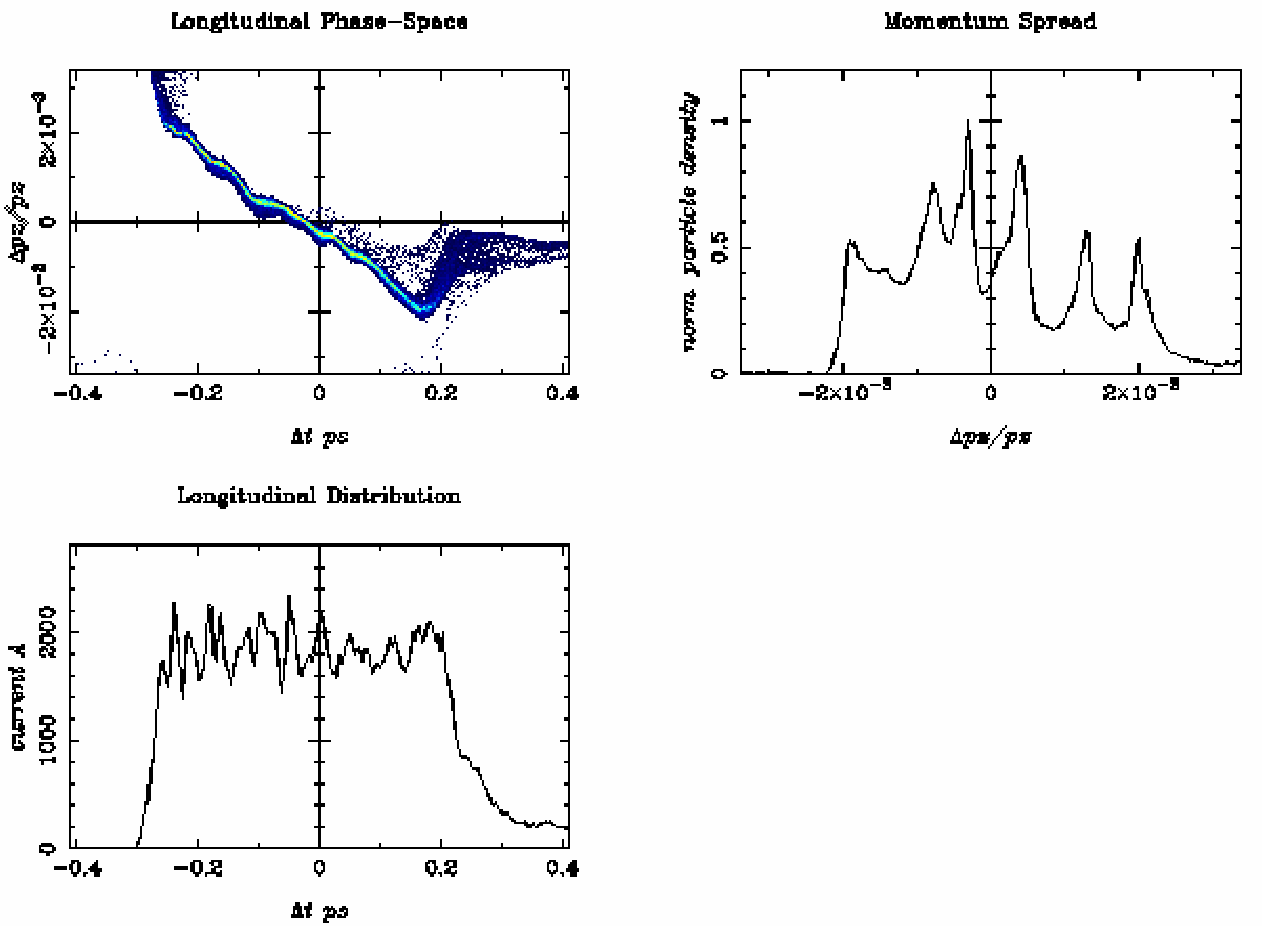


s[m]

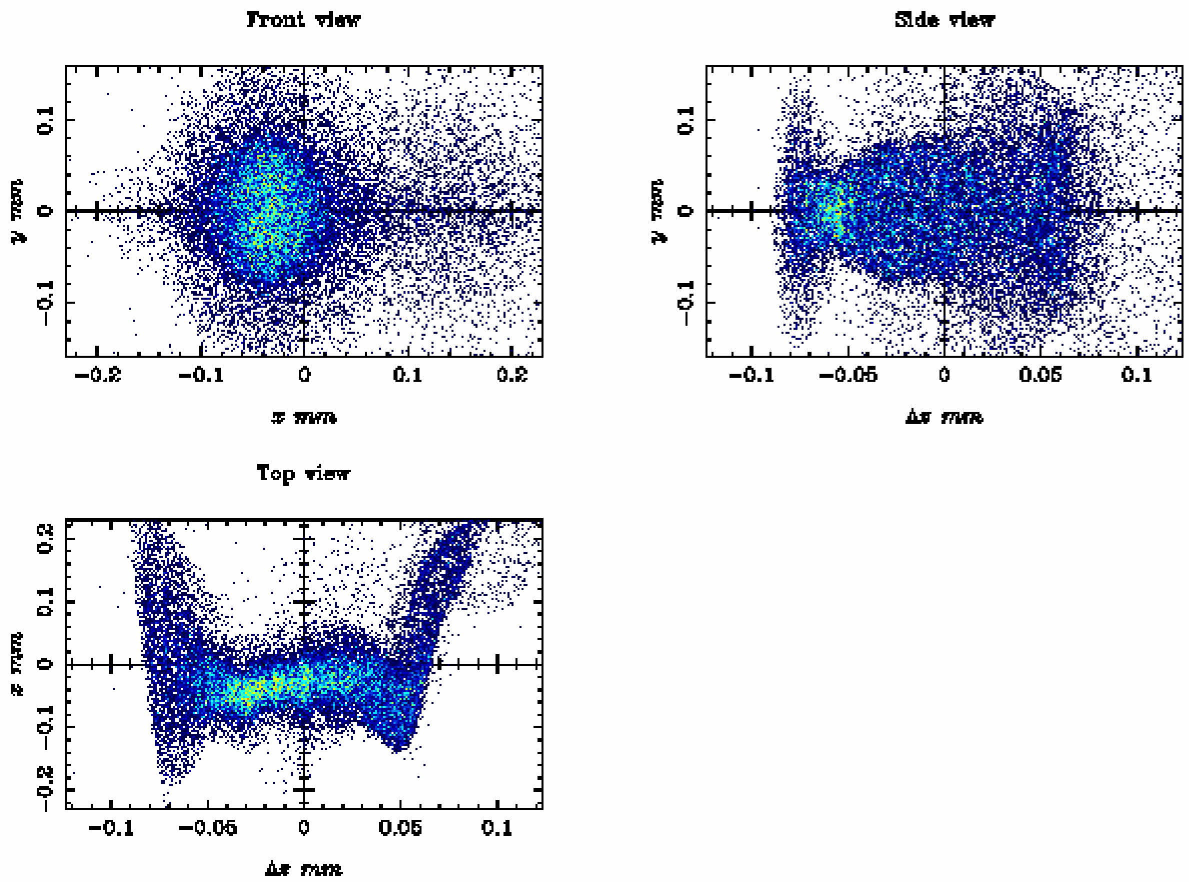
3D simulation with self fields for I=1809A.



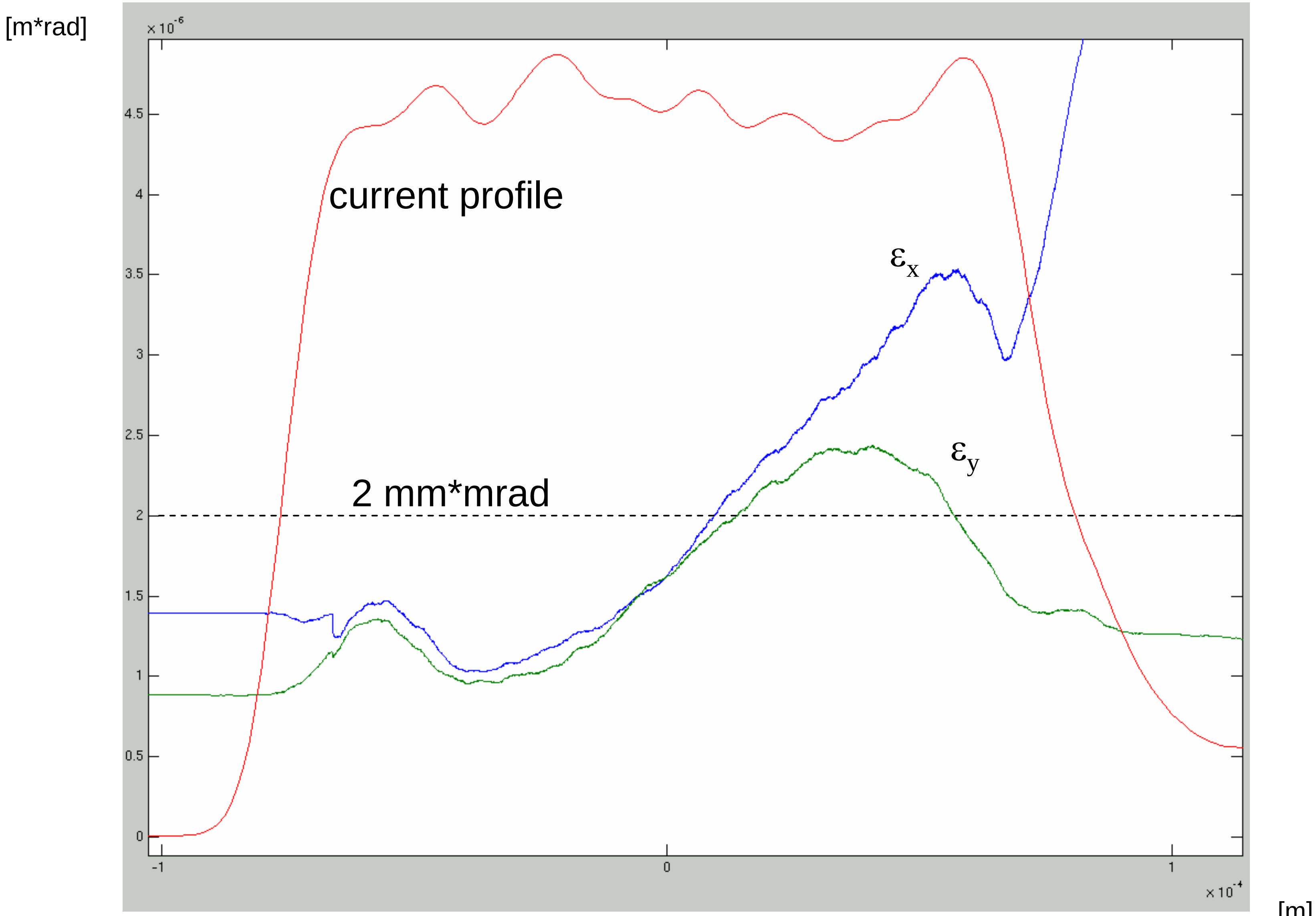
3D simulation with self fields for I=1809A.



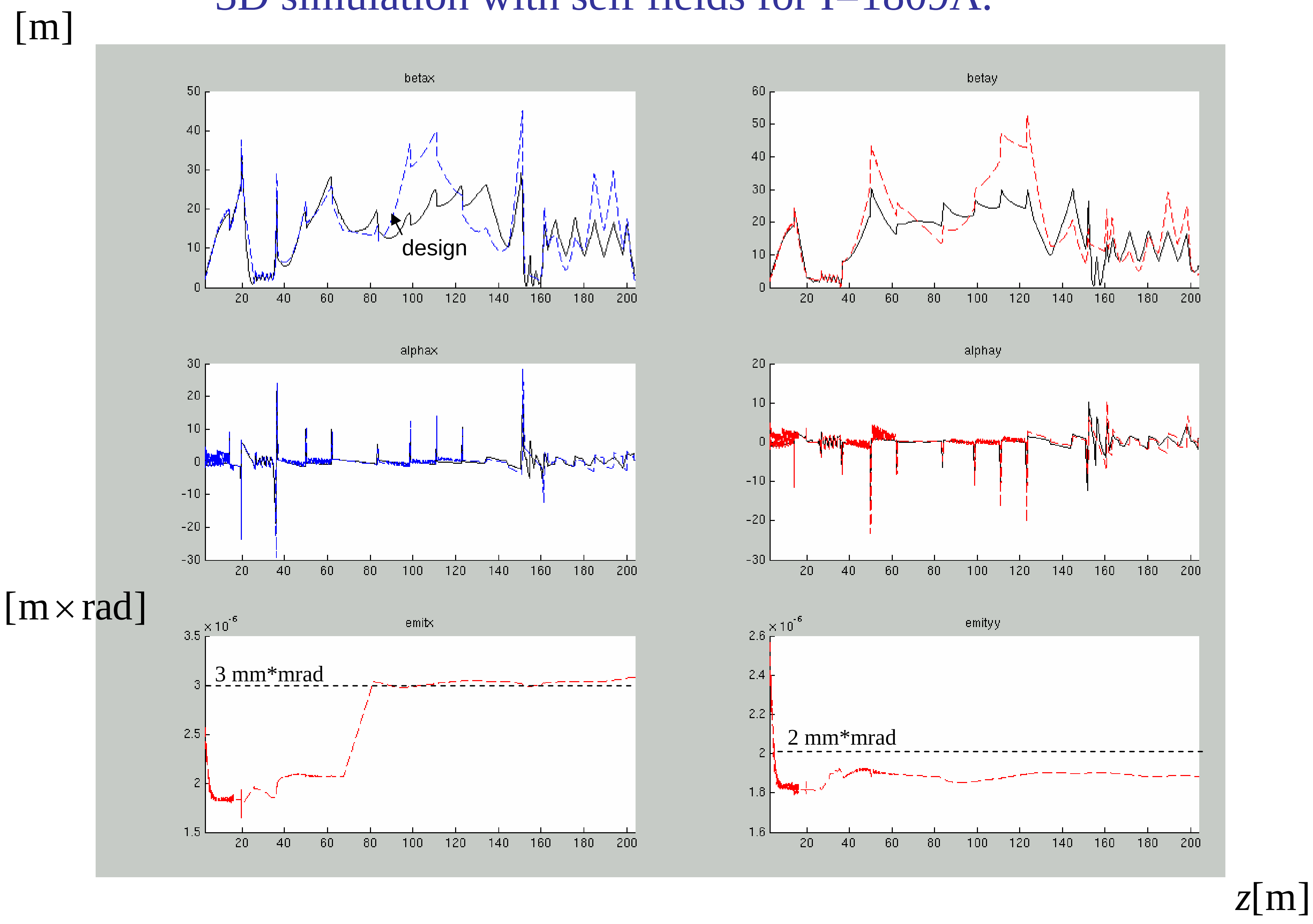
3D simulation with self fields for I=1809A.



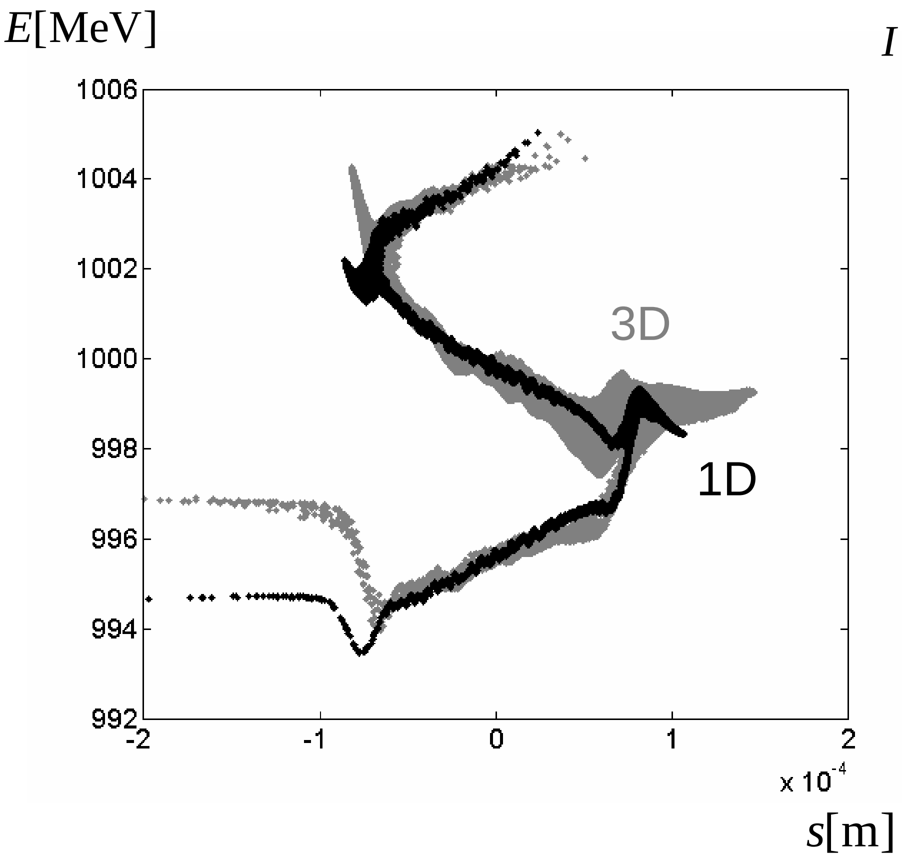
3D simulation with self fields for I=1809A.

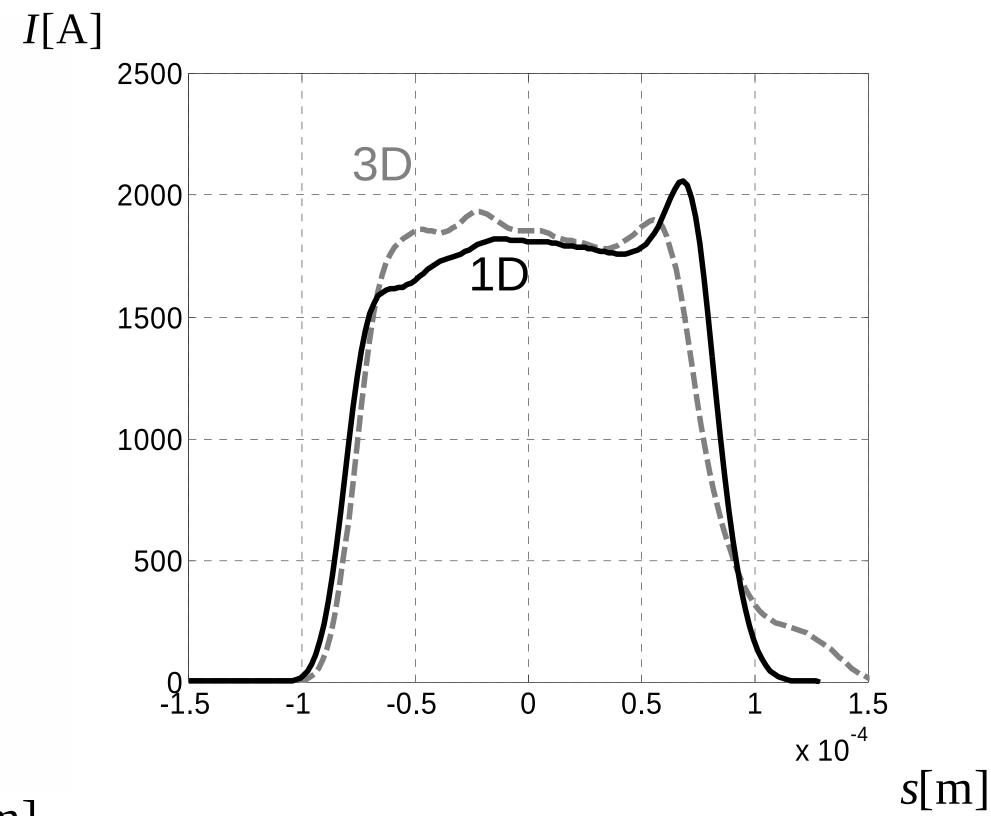


3D simulation with self fields for I=1809A.



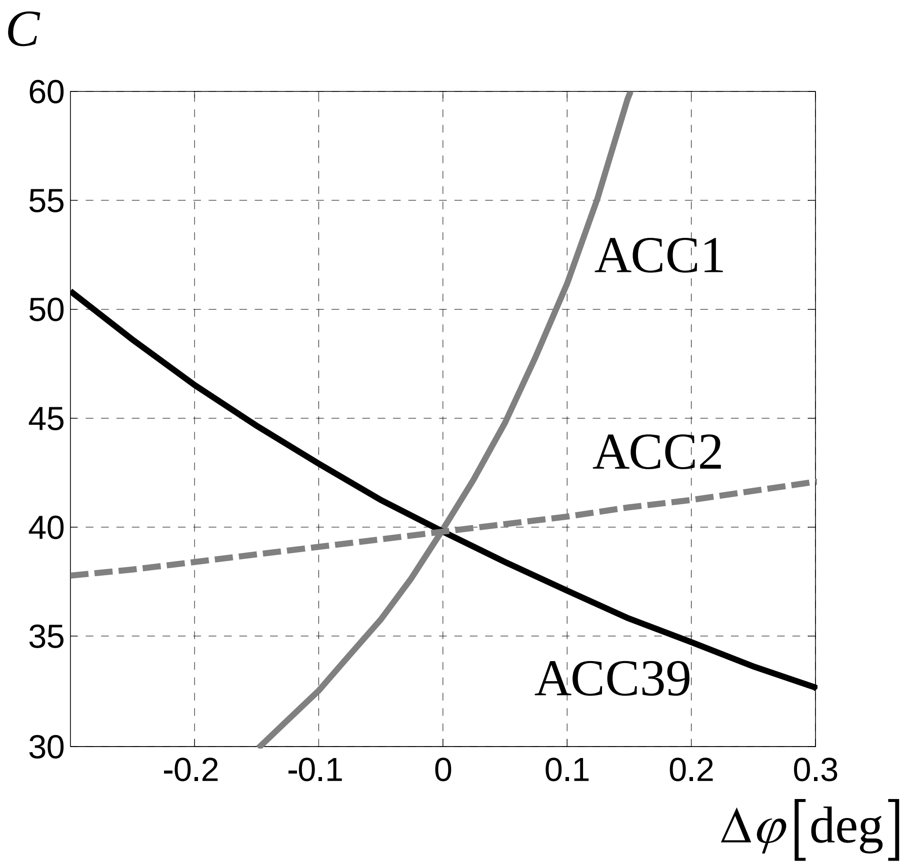
1D model vs 3D model.

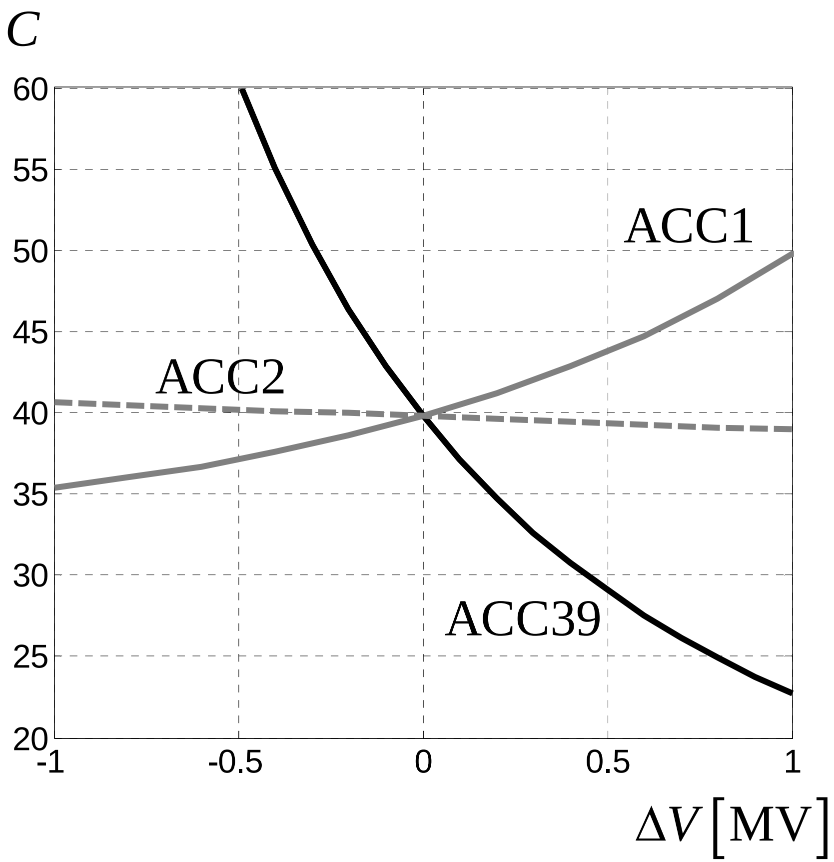




1D model agrees with 3D model.
We use the 1D model to estimate the RF tolerances.

Compression vs. RF parameters





$$C = \frac{\sigma_{13m}}{\sigma_{203m}} - \text{compression}$$

RF tolerances

Tolerances (relative derivatives)

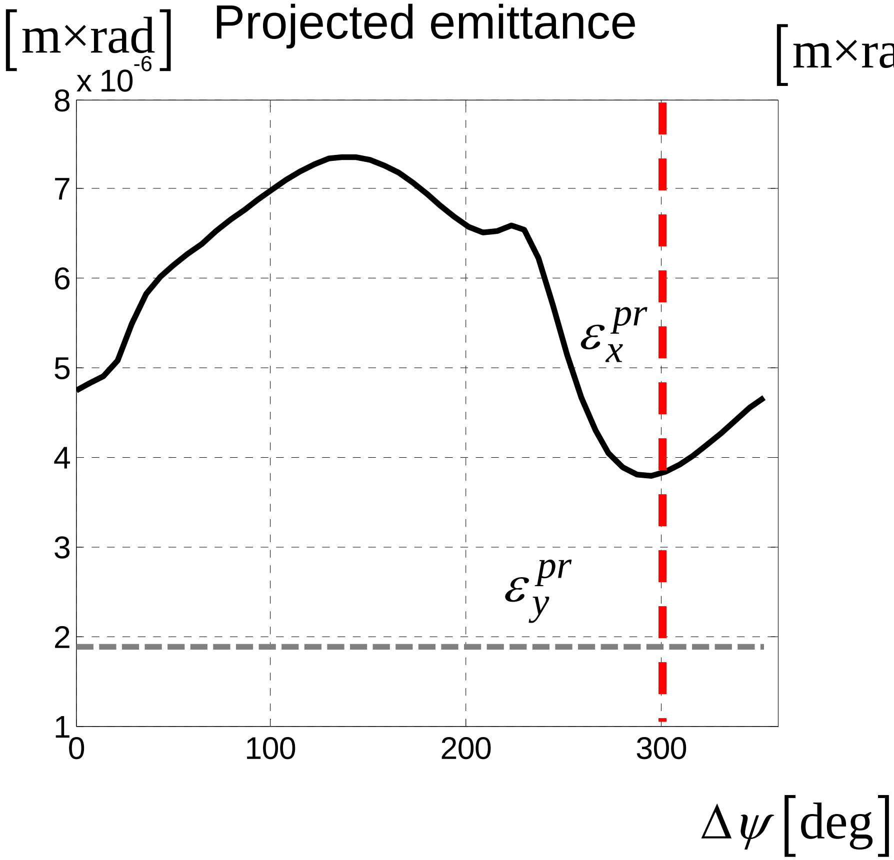
	$\frac{1}{C}\frac{\partial C}{\partial \varphi},[\text{deg}^{-1}]$	$\frac{1}{C}\frac{\partial C}{\partial V},[\text{MV}^{-1}]$
ACC1	2.23	0.16
ACC39	-0.73	-0.72
ACC2	0.18	-0.02

Tolerances (10 % change of compression)

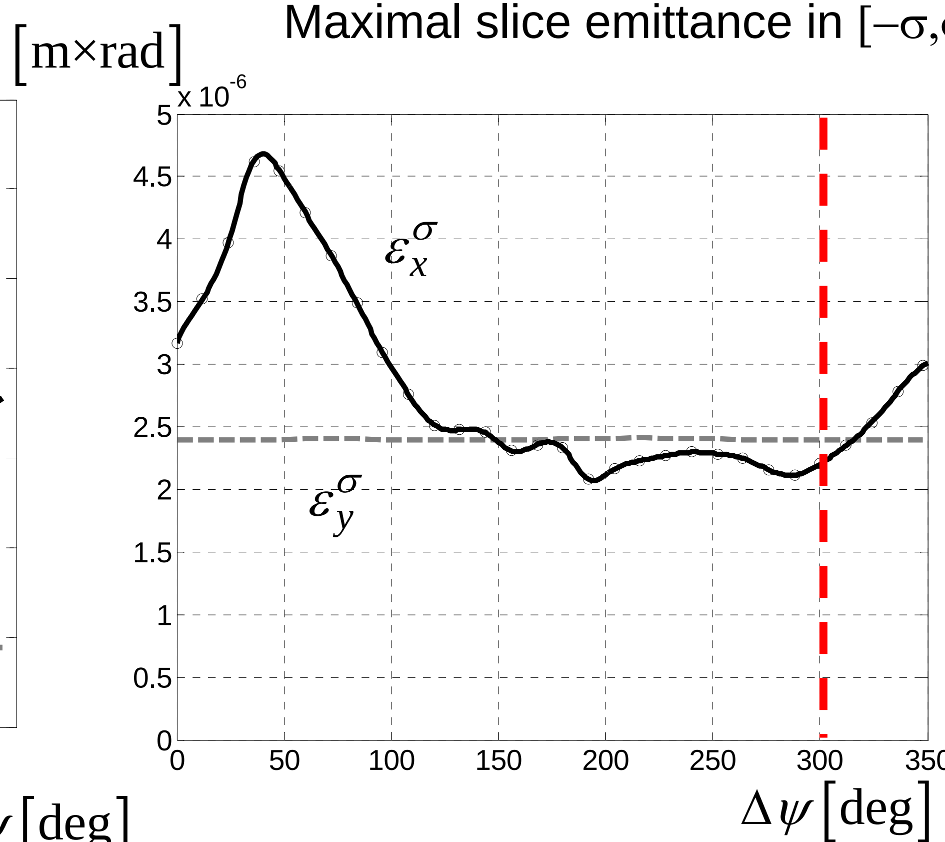
	$\lvert\Delta\varphi\rvert,[\text{deg}]$	$\lvert\Delta V\rvert,[\text{MV}]$
ACC1	**0.045**	0.62
ACC39	0.14	**0.14**
ACC2	0.56	4.6

How to improve? A phase shift between BCs.

Projected emittance



Maximal slice emittance in [−σ,σ]



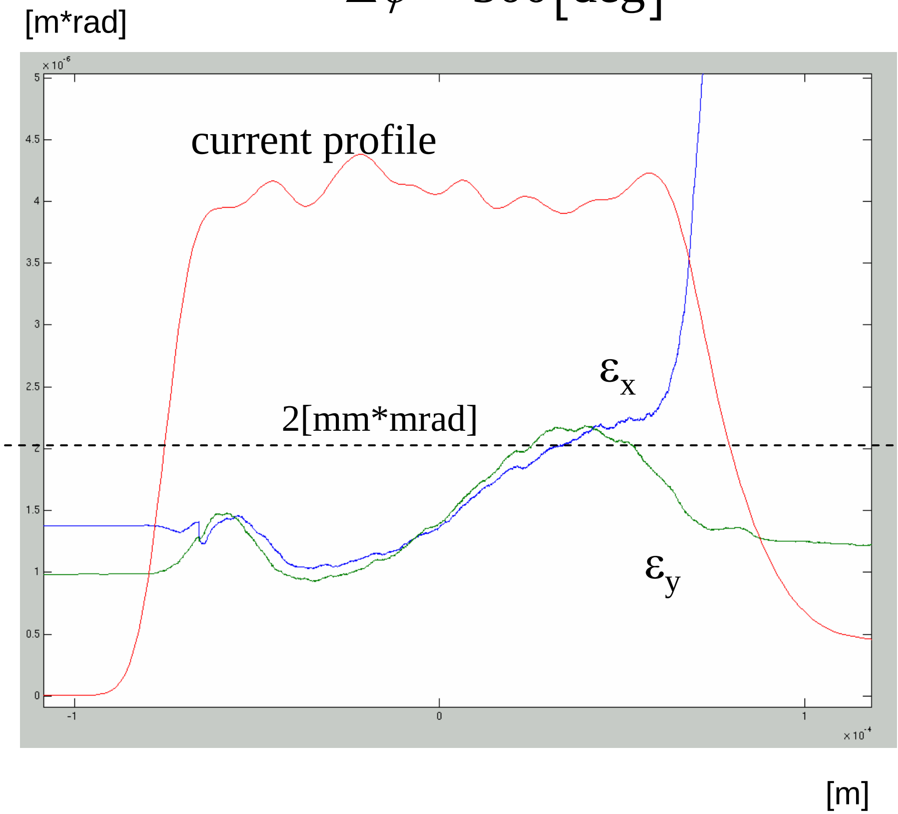
$$\varepsilon^{\sigma} = \max_{s\in[-\sigma,\sigma]} \varepsilon^{sl}(s)$$

$$\Delta\psi = 300\,[\mathrm{deg}] - ?$$

How to improve? A phase shift between BCs.

Slice emittance

$\Delta\psi = 300[\deg]$



Slice emittance

$\Delta\psi = 0[\deg]$