Xtrack

a2b tracking = after gun to before undulator

implemented in Matlab

solvers = Qfield (3d, 2d-slice and periodic)
CSR (to be implemented)
wakes (as in Astra)

tracker = 2nd order transport for most element
not for cavities (= monopole standing waves) → 1st order
no fringe fields → hard edged
special treatment: cavities with coupler kicks and rf curvature

objects = particles: 3d, 2d-slice and periodic
moments (6D offset + correlations)

to be implemented (in near future)
element error in strength and alignment
CSR
special treatment: higher (>2) order longitudinal dispersion

Example 1: XFEL

a2b tracking = after gun to before undulator
3.2m before BC1

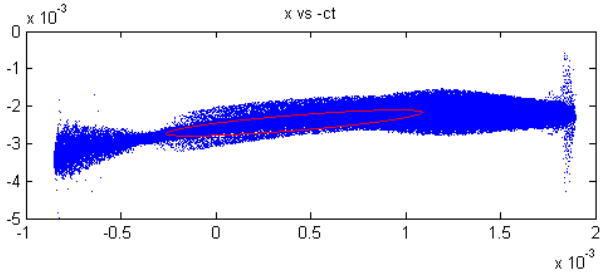
config = command structure
to specify **LongTable**
to specify start object
to overwrite defaults (f.i. rf settings, energy profile, bunch compressors, tracking parameters)
to specify output

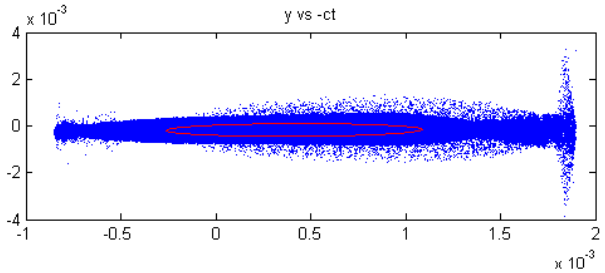
LongTable = beamline description
needs preprocessor; for specification of elements, and groups (as BCs, linacs); each generic path needs its own table; “work is done once for all time”
here: based on Winfried Decking’s long list (Excel)

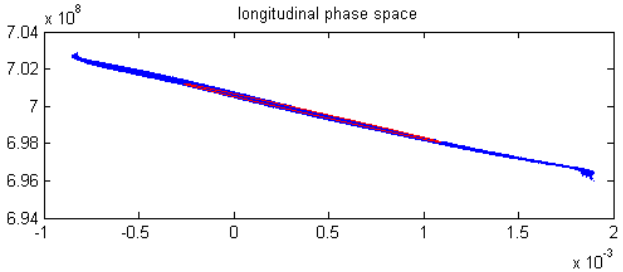
start object f.i. from Astra
needs preprocessor to create required structure
here: 200k particles or 10k particles (sampled from 200k)
or moments or slice or period sample

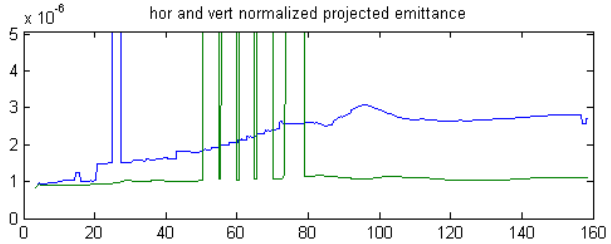
200k particles ~ 155 m , default output → overview plot on screen

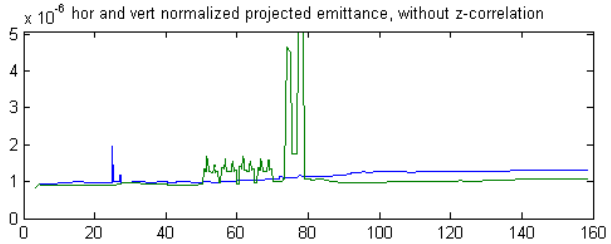
~ 360 seconds (for default numerical parameters)

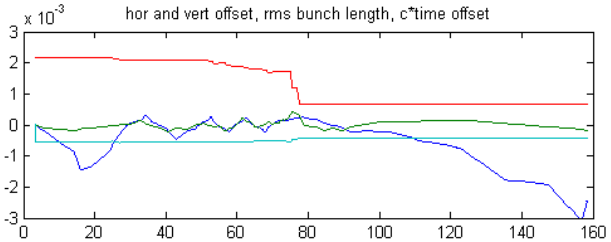


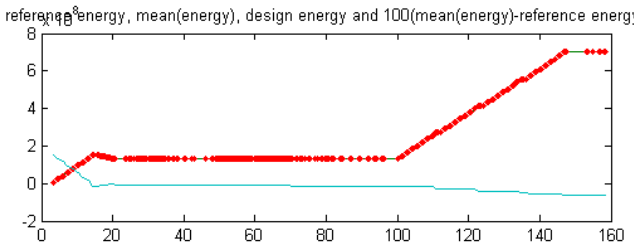


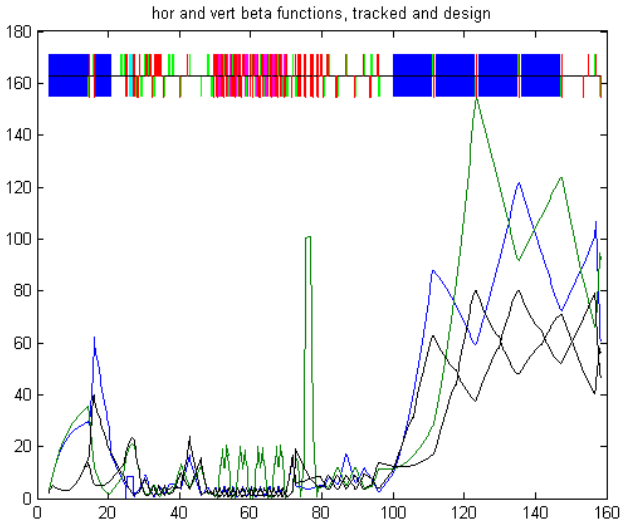


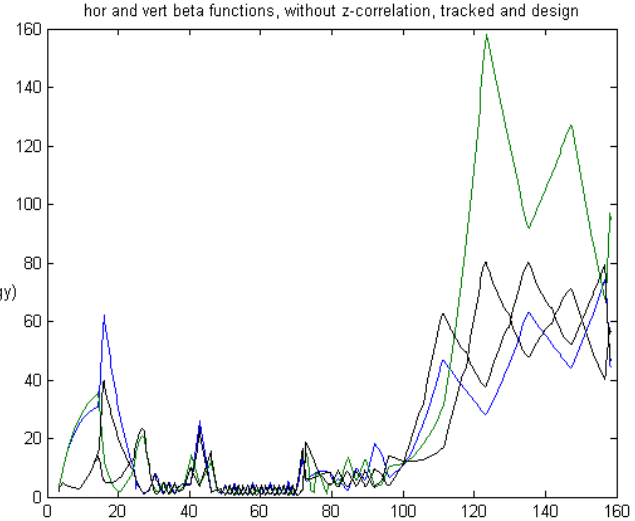


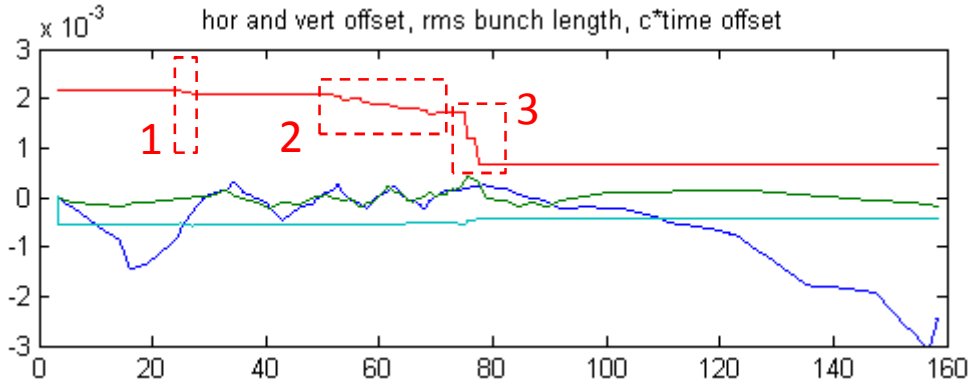






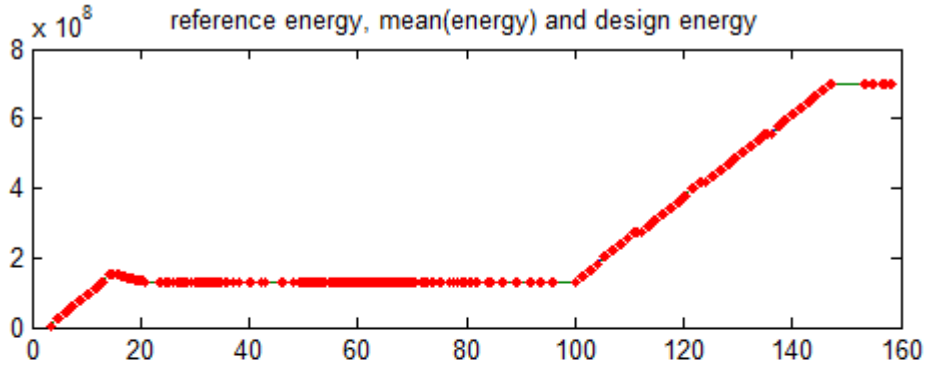


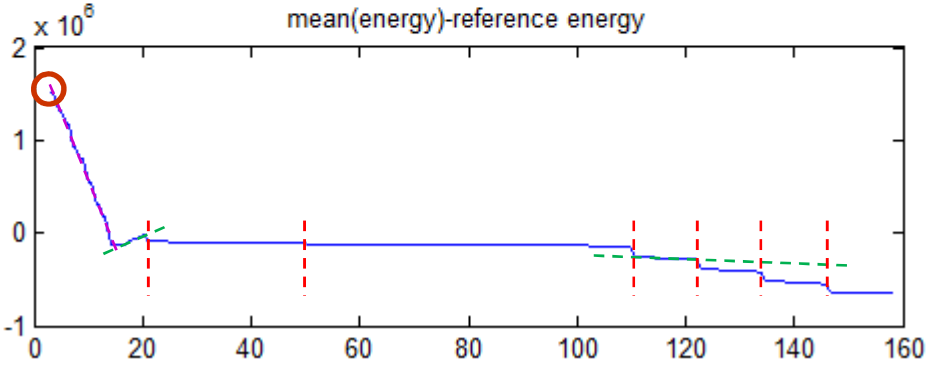


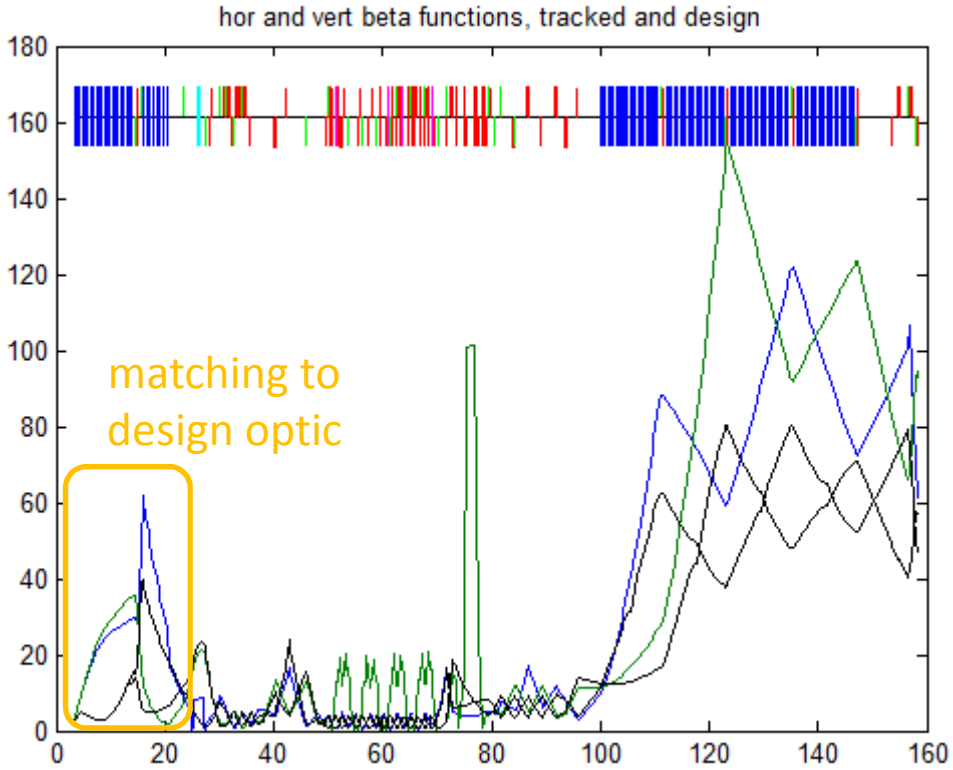


bunch length: 1) laser heater
2) dogleg
3) BC0

horizontal offset: coupler kicks of couplers in ACC1 and ACC39 + one hor. corrector
vertical offset: same coupler kicks
longitudinal offset: initial particle energy too high, bunch is “early”







- 1) (initial) reference energy is 5MeV, but mean particle energy (Astra) is 6.5MeV
- 2) ACC1 setting so that: mean particle energy ≈ reference energy
- 3) rf setting deviates (slightly) from required setting for reference energy
- 4) discrete wakes

config

config.run	.start_object	
	.stop	default
	.binsolv	default
	.effects	optional
config.machine	.LongTable	
	.project	optional
	.special	default
	.energy_profile	optional
	.chicanes	optional
	.wakes	optional
	.wakes_element	optional
	.CSR	optional
config.dynamic		optional
	.ACC	optional
	.Quad	optional
	.Hcor	optional
	.Vcor	optional
config.out		optional
	.return	optional
	.screen	optional
	.file	optional
	.monitor	optional

Example 2: PITZ

a2b tracking = 5.77m to ~13.05m

parameters and initial particles from Georgios Kourkafas

```
path('H:\My Documents\dohlus\MATLAB\XTrack',path);
path_machine=[];
path_in=[path_machine 'files\'];
path_out=path_in;
%
% config.machine ------------------------------------------------------
%
    % project and long table ..........................................
    config.machine.project='PITZ';
    config.machine.LongTable=[path_machine 'files\Pitz_LongTable'];
%
% config.run ----------------------------------------------------------
%
    stop=13.038;
    config.run.start_object =[path_in,'input_5p277_500k'];
    config.run.stop_object.absolut = stop;
%
% config.dynamic ------------------------------------------------------
%

%
% config.out ----------------------------------------------------------
%
    config.out.return={'X'};
    config.out.screen={'overview'};
    config.out.file={'dump',[path_out,'dump']};
%
%--- RUN IT ---------------------------------------------------------
%
out=XTrack(config);
```

machine description

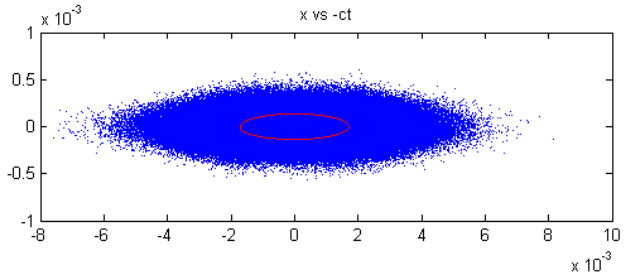
input object and
numerical parameters
here: 500 000 particles

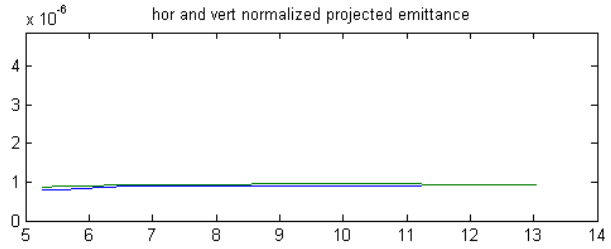
modification
f.i. rf, quads, steerers

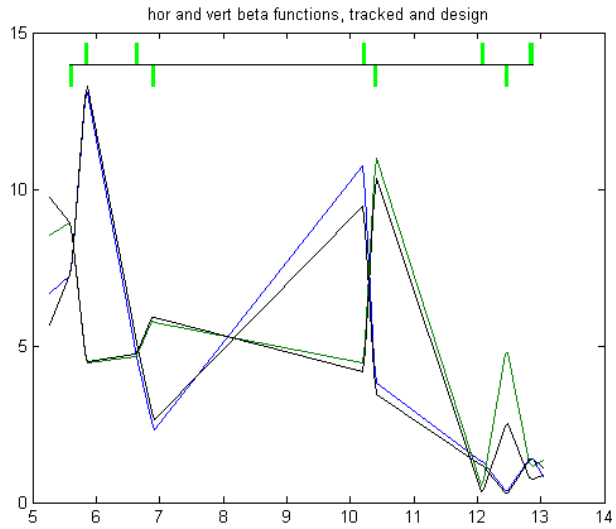
output requests

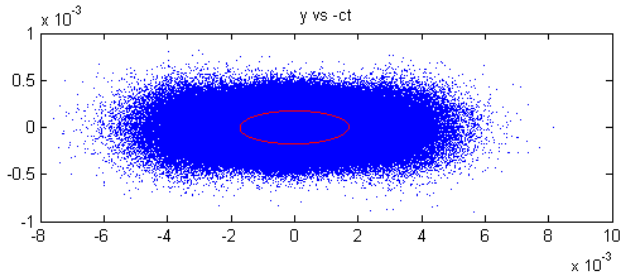
500k particles ~ 8 m

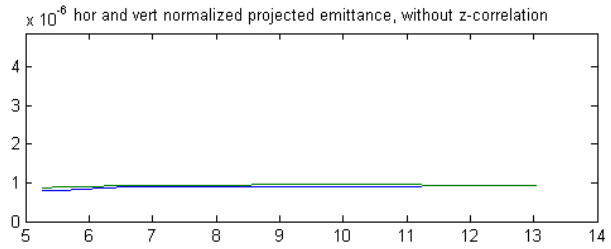
~ 40 seconds (for default numerical parameters)

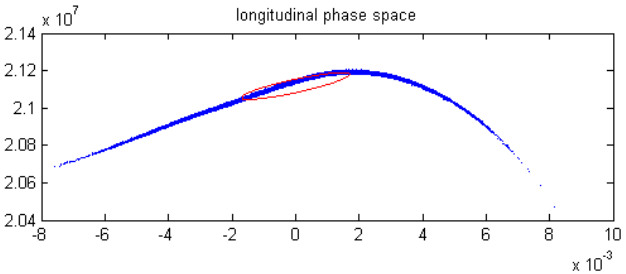


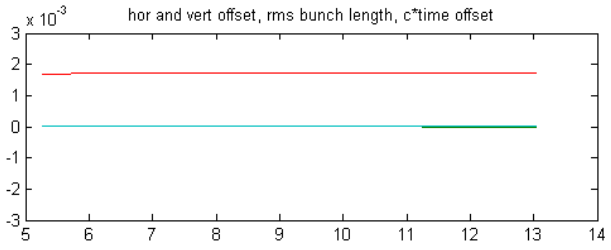


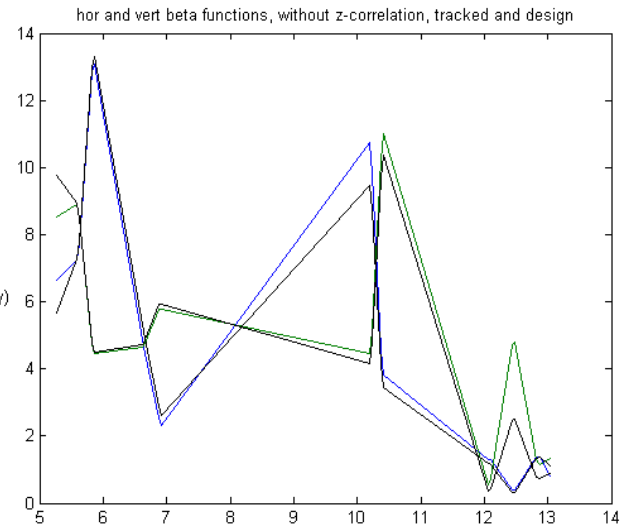


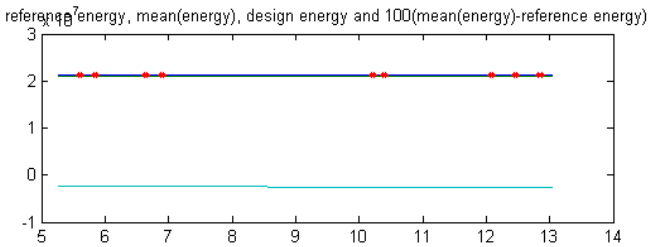








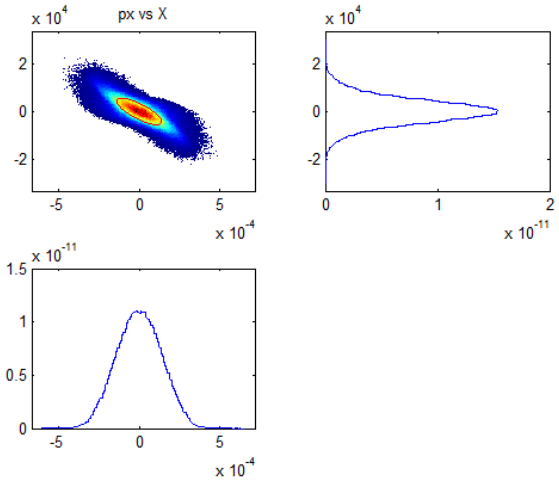




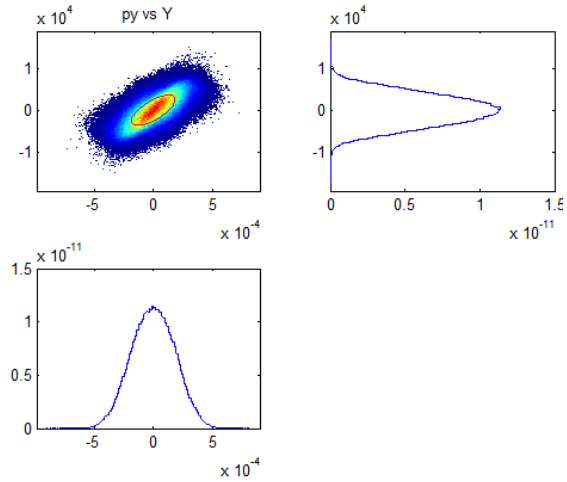
500k particles ~ 200 seconds (reduced tracking step width)

some post processing:

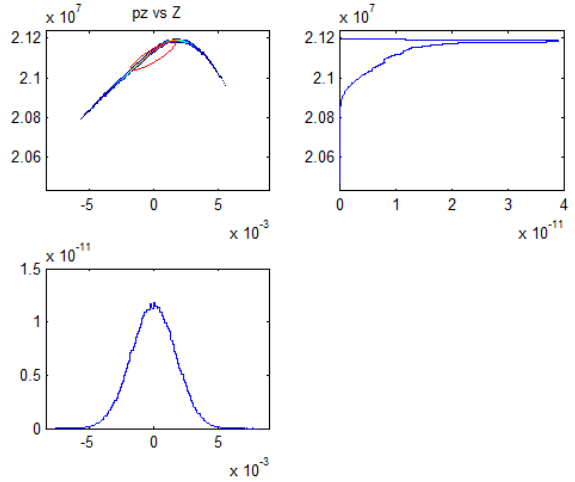
horizontal phase space



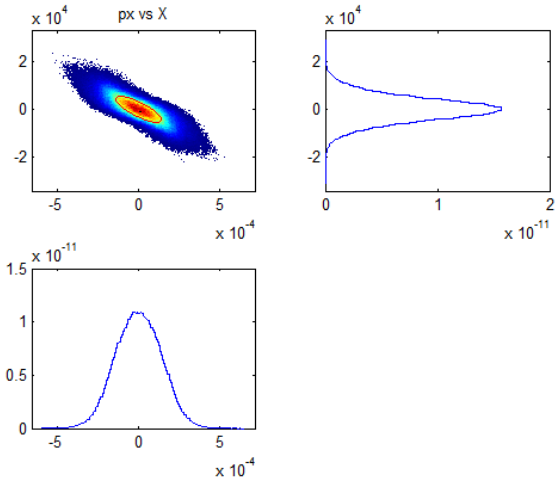
vertical phase space

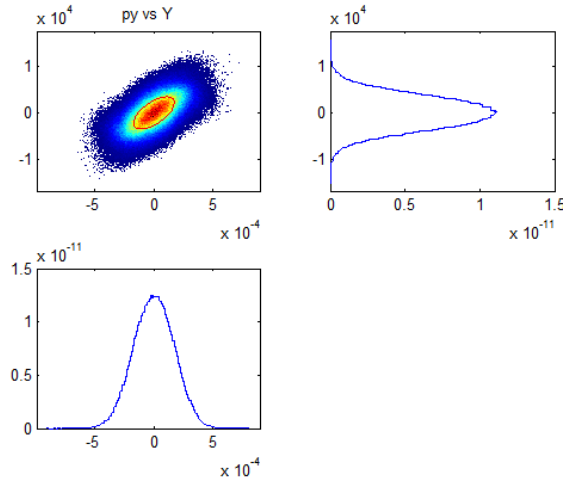


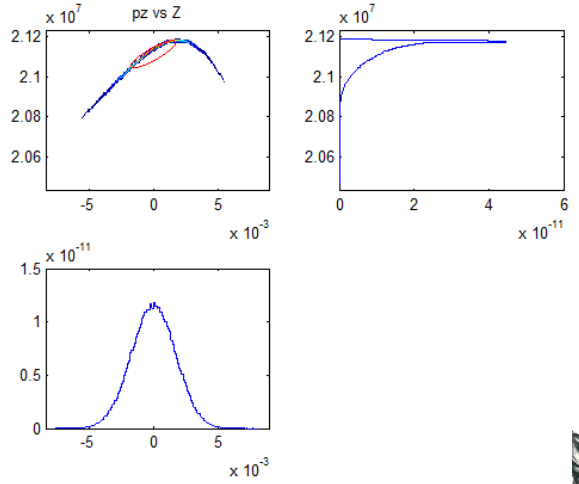
longitudinal phase space



with ASTRA after 3h 10 min:

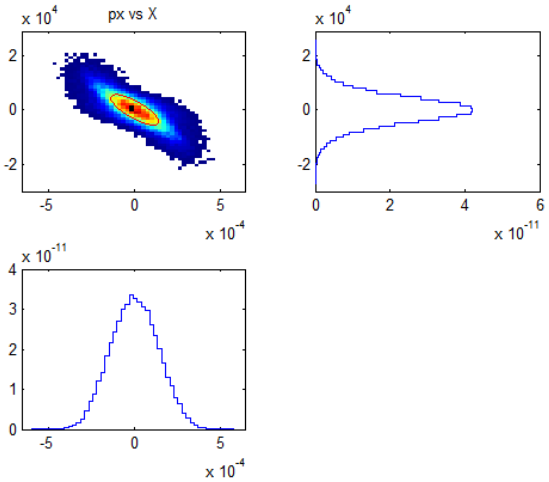




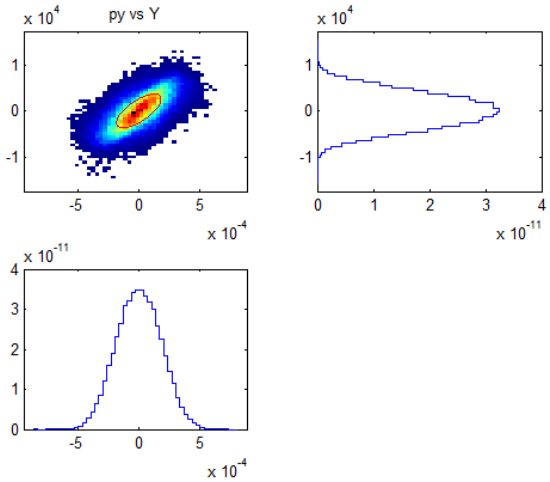


a bit faster: use less particles

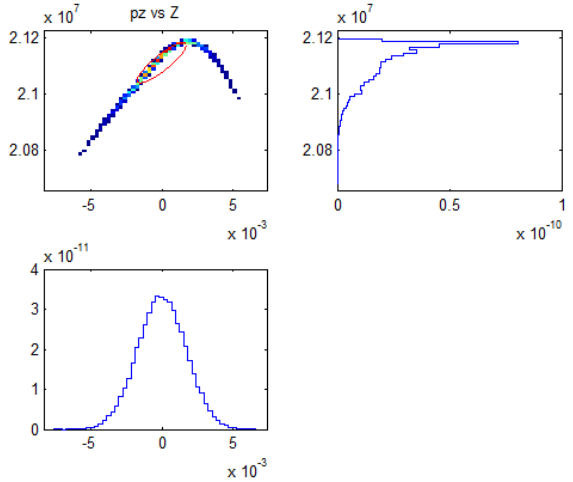
horizontal phase space



vertical phase space



longitudinal phase space



or moments tracking

just replace the input object:

```
%
% config.run ------------------------------------------------------------
%
    stop=13.038;
    config.run.start_object =[path_in,'input_5p277_500k'];
    config.run.stop_object.absolut = stop;
```

'input_5p277_50k'

'input_5p277_mom'

matlab files (*.mat)

Matching or Optimization

```
function [knew,mima]=aaa_match_Pitz()

    %
    % config.machine ------------------------------------------------------
    % config.run ----------------------------------------------------------
    % config.out ----------------------------------------------------------
    %
            machine, run and out settings as before
    %
    %--- PREPARE MINSERACH ---------------------------------------------------
    %
    function mima= FLASHmima(kq_ra)                                goal function
        %
        % config.dynamic ------------------------------------------------------
        %
        config.dynamic.Quad.ind=1:7;
        config.dynamic.Quad.K  =kq_ra;                    } modify quads
        %
        %--- RUN IT --------------------------------------------------------
        %
        out=XTrack(config);
        mima=out.mismatch(end,2)+out.mismatch(end,3);
    end
    %
    %--- DO MINSERACH --------------------------------------------------------
    %
    % initial: original table settings
    kq_ra=[-29.9605, 37.3535, 10.0201,-22.4622, 63.3285,-65.2458, 64.2956];
    options=optimset('MaxIter',25);

    [knew,mima]=fminsearch(@FLASHmima,kq_ra,options);   ← fminsearch

end
```

more about Example 1: XFEL

```
path('H:\My Documents\dohlus\MATLAB\XTrack',path);
path_machine=[]; path_out=[path_machine 'files_X\'];
%
% config.machine ------------------------------------------------------------
%   % project and long table ..........................................
    % define energy profile ..........................................
    % specify chicanes ...............................................
    % special settings  ..............................................
    % wakes (position table) .........................................
    % wakes_element (element table) ..................................
    % set CSR ........................................................
```

see next page

```
%
% config.run ----------------------------------------------------------------
%
    before_BC1=158.4259;
    config.run.start_object =[path_out,'X_XFEL_1nC_3p20_3_200k'];
    config.run.stop_object.absolut = before_BC1;
%
% config.dynamic ------------------------------------------------------------
%
    % cavities
    config.dynamic.ACC(1).ph = 12.0*pi/180;
    config.dynamic.ACC(1).V  = (145.61E6-1.2E6)/8/cos(config.dynamic.ACC(1).ph);
    config.dynamic.ACC(1).ind= 1:8;   % recheck indices generation
    config.dynamic.ACC(2).ph = pi;
    config.dynamic.ACC(2).V  = 20.2E6/8;
    config.dynamic.ACC(2).ind=(9:16);
    % quadrupoles
    config.dynamic.Quad.K    = [-1.176085127762258   1.135297849486740   0.359150257823380   0.089028171475876];
    config.dynamic.Quad.ind  = 1:4;
    % correctors
    config.dynamic.Hcor.kick =-0.000080;
    config.dynamic.Hcor.ind  = 6;
%
% config.out ----------------------------------------------------------------
%   % set monitor
    % set return
    % set file
    % set screen
```

see page after next page

```
%-------------------------------------------------------------------------
%--- RUN IT ------------------------------------------------------------
%-------------------------------------------------------------------------
out=XTrack(config);
```

modify ACC1

modify quads
(result of matching)

horizontal corrector

```
%
% config.machine ------------------------------------------------------
%
    % project and long table ..............................................
        config.machine.project='XFEL';
        config.machine.LongTable=[path_machine 'files_LongTable\XFEL_LongTable'];
    % define energy profile ...............................................
    % specify chicanes ....................................................
        Radius0_liste= 3.778137848347333;
        config.machine.chicanes{1}=struct('name','BC0','invRadius',1.3/Radius0_liste);
    % special settings  ...................................................
        % tesla cavity:
        pen_depth=0.006; Reab=0.9977; Imab=0.0033;
        config.machine.special{1}=struct('type_id',10001300,...
                                         'parameters',[5 pen_depth;...
                                                       6 Reab;...
                                                       7 Imab]);
        % undulator:
        lambda_u=0.074; Ku=1.36;
        config.machine.special{3}=struct('element_name','UNDU.49.I1',...
                                         'parameters',[1 lambda_u;...
                                                       2 Ku]);
    % wakes (position table) ..............................................
        iw=0;
        % monopole wakes from impedance data base
        iw=iw+1; config.machine.wakes{iw}=struct('where',24.77,...
             'file_name',[path_machine 'files_wakes\wake_0002.700_0024.770_MONO.dat'],'type',0);
        iw=iw+1; config.machine.wakes{iw}=struct('where',50.08,...
             'file_name',[path_machine,'files_wakes\wake_0027.390_0050.080_MONO.dat'],'type',0);
                 . . .
        iw=iw+1; config.machine.wakes{iw}=struct('where',2213.00,...
             'file_name',[path_machine,'files_wakes\wake_2035.190_2213.000_MONO.dat'],'type',0);
    % wakes_element (element table) ......................................
        % {2}=module with tesla cavities, {4}=module with third harmonic cavities
        config.machine.wakes_element{2}=struct(...
            'file_name',[path_machine,'files_wakes\TESLA_MODULE_WAKE_TAYLOR.dat'],'type',2,'weight',1,'keep',1);
        config.machine.wakes_element{4}=struct(...
            'file_name',[path_machine,'files_wakes\THIRD_HARMONIC_SECTION_WAKE_TAYLOR.dat'],'type',2,'weight',2,'keep',0);
    % set CSR ............................................................
        % define CSR ranges: {1}=LH, {2}=DOGLEG, {3}=BC0, {4}=BC1, {5}=BC2
        config.machine.CSR{1}={struct('element_idx',[2, 1,0])    ,struct('element_idx',[2, 4,0])   ,struct('active',false,'SC',true)};
        config.machine.CSR{2}={struct('element_idx',[2, 5,0])    ,struct('element_idx',[2,20,0])   ,struct('active',false)};
        config.machine.CSR{3}={struct('element_idx',[2,21,-0.01]),struct('element_idx',[1,39,1.5]),struct('active',true)};
        config.machine.CSR{4}={struct('element_idx',[2,21,0])    ,struct('element_idx',[2,24,0])   ,struct('active',false)};
        config.machine.CSR{5}={struct('element_idx',[2,21,0])    ,struct('element_idx',[2,24,0])   ,struct('active',false)};
%
% config.run ----------------------------------------------------------
%
```

```
%
% config.out ------------------------------------------------------------
%
    im=0;
    im=im+1; config.out.monitor{im}=struct('stop',[],...
                                           'text','end of tracking',...
                                           'selector','X',...
                                           'file_name',[path,'XFEL_X_1nC_end']);
    im=im+1; config.out.monitor{im}=struct('element_idx',[2, 1,-0.5],...
                                           'text','0.0755 before LH',...
                                           'selector','X');
    im=im+1; config.out.monitor{im}=struct('element_idx',[2, 4, 1.5],...
                                           'text','0.0755 after LH',...
                                           'selector','X');
    im=im+1; config.out.monitor{im}=struct('element_idx',[2, 5,-0.5],...
                                           'text','0.1006 before I1 dogleg',...
                                           'selector','X');
    im=im+1; config.out.monitor{im}=struct('element_idx',[2,20, 1.5],...
                                           'text','0.1006 after I1 dogleg',...
                                           'selector','X');
             . . .

    im=im+1; config.out.monitor{im}=struct('where',391.353702000000+0.1,...
                                           'text','0.1 after BC2',...
                                           'selector','X');
    im=im+1; config.out.monitor{im}=struct('where',1654.45020200000-0.1,...
                                           'text','0.1 before CL dogleg',...
                                           'selector','X');
    im=im+1; config.out.monitor{im}=struct('where',1827.45023300000+0.1,...
                                           'text','0.1 after CL dogleg',...
                                           'selector','X');

    config.out.return={'X','momenta','Table','monitor'};
    config.out.file={'X'       ,[path_out,'XFEL_X_1nC_158p4_10k_3'];...
                     'momenta',[path_out,'XFEL_momenta_1nC_158p4'];...
                     'Table'   ,[path_out,'XFEL_table'];...
                     'dump'    ,[path_out,'XFEL_dump_158p4']};
    config.out.screen={'overview','beta','beta_without_z','energy_profile'};
%-------------------------------------------------------------------------
%--- RUN IT ------------------------------------------------------------
%-------------------------------------------------------------------------
out=XTrack(config);
```

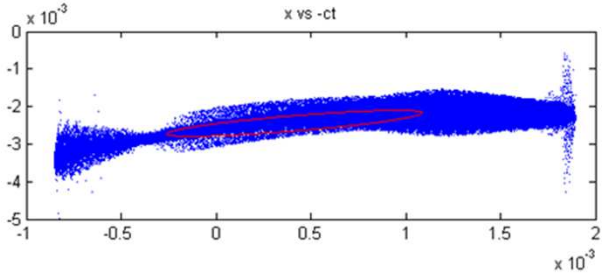
"online monitor"

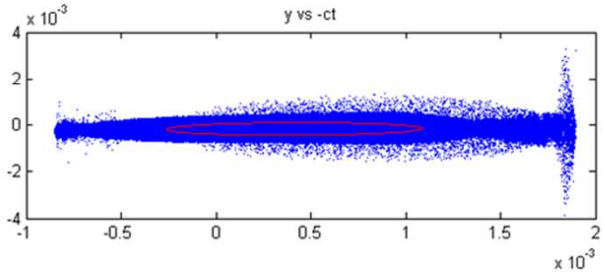
after tracking

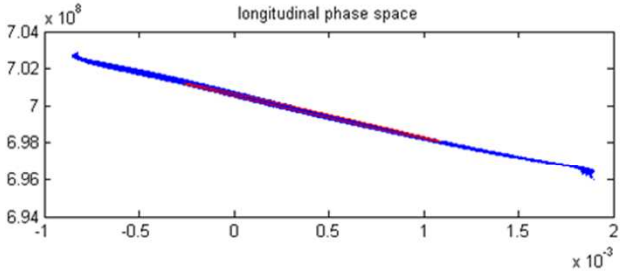
200k particles

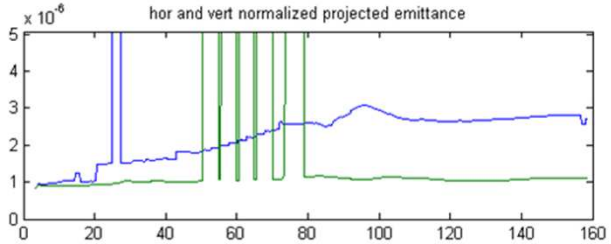
~ 155 m , default output → overview plot on screen

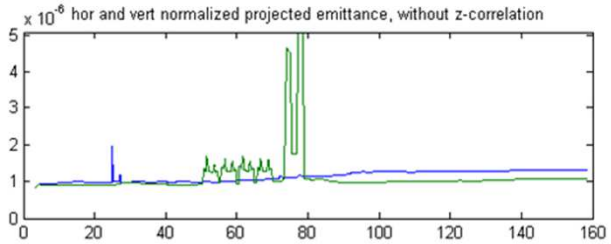
~ 360 seconds (for default numerical parameters)

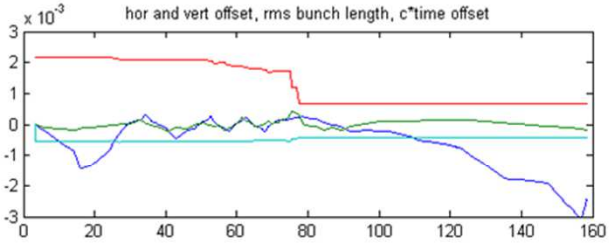


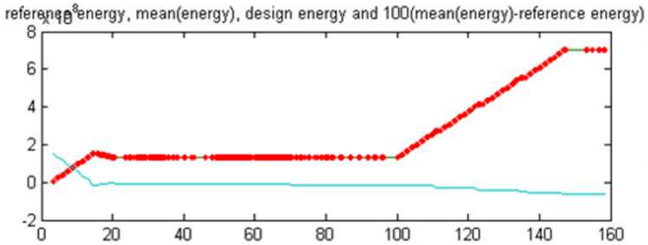


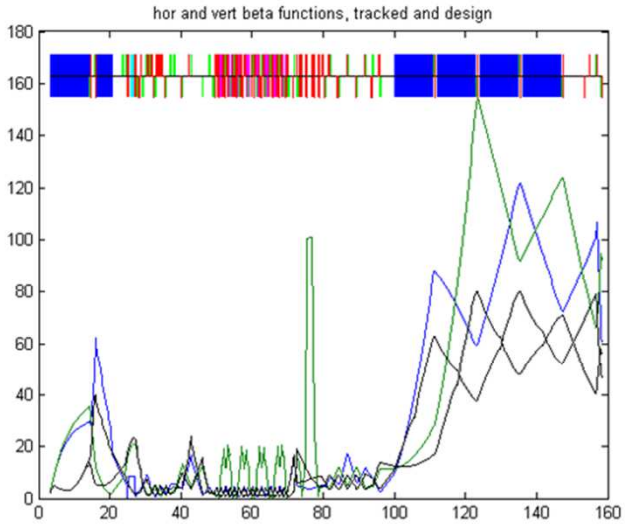


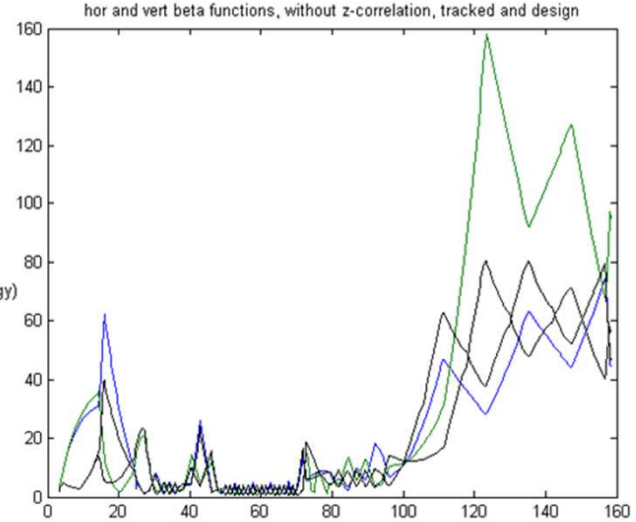








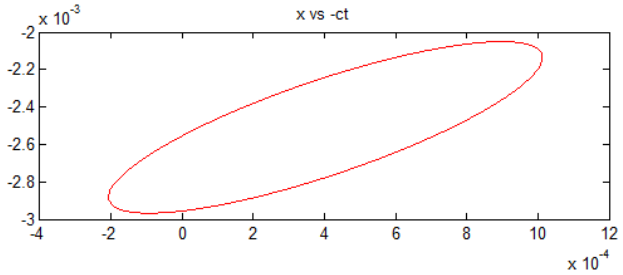


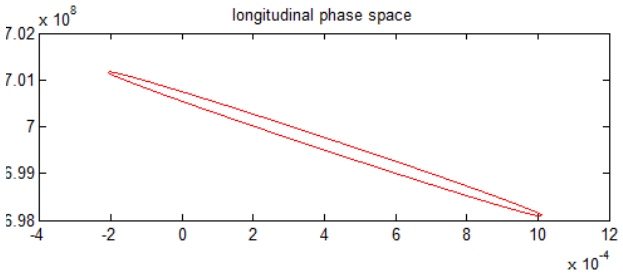


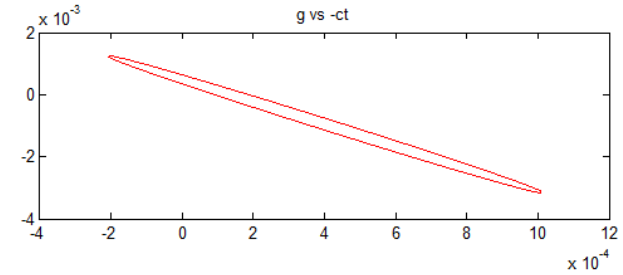
moments

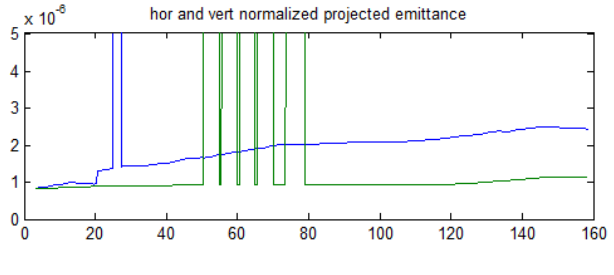
~ 155 m

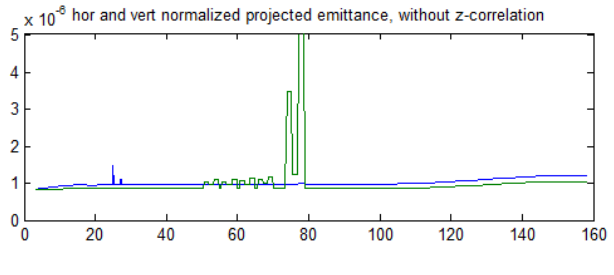
~ 2 seconds (for default numerical parameters)

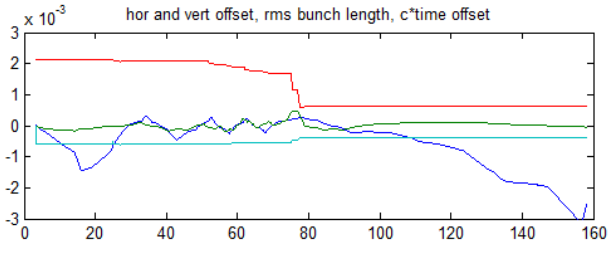


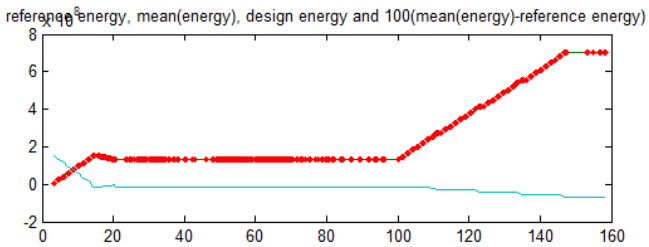


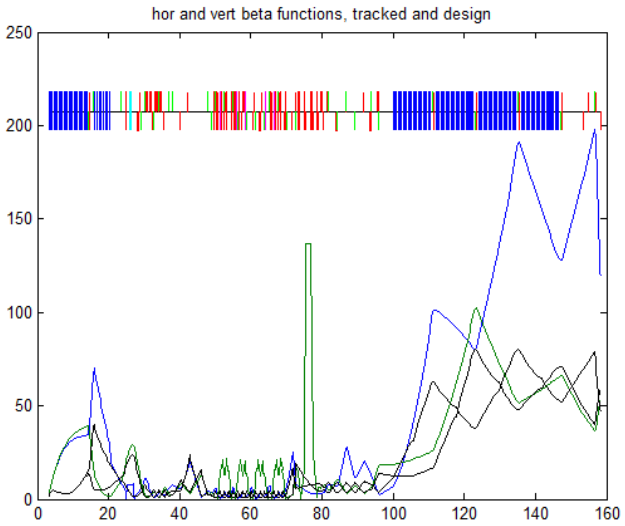


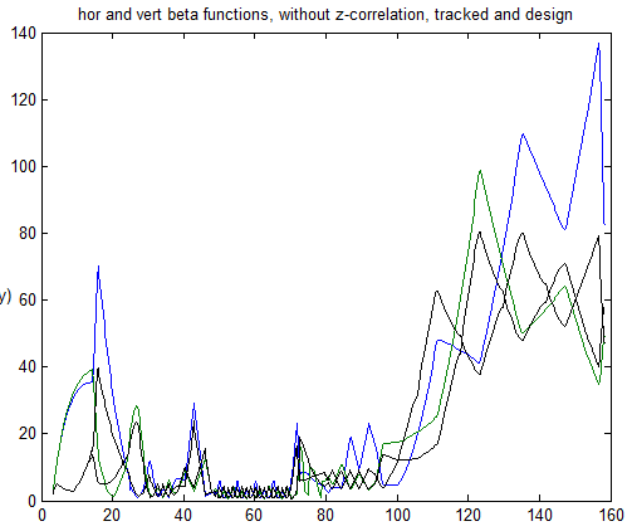






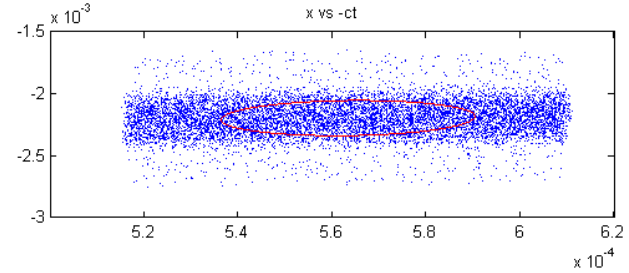


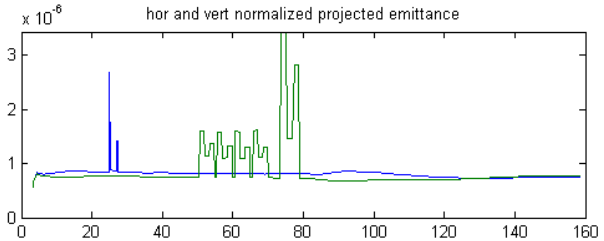


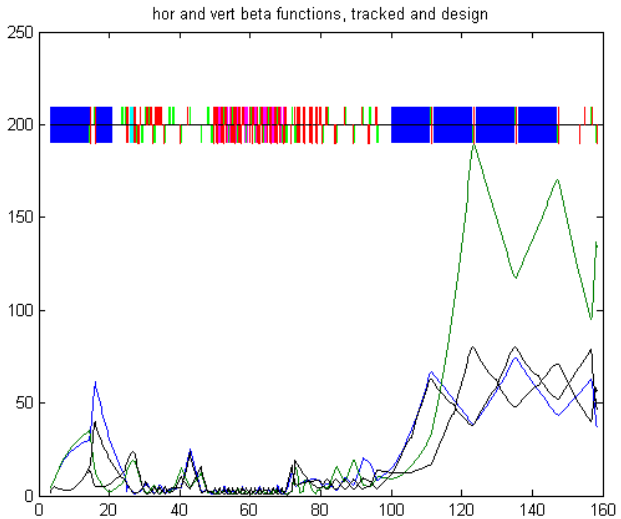


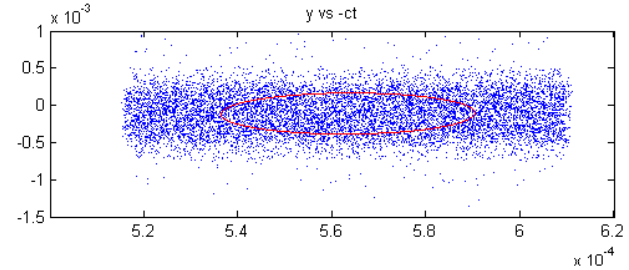
middle slice ~ 155 m

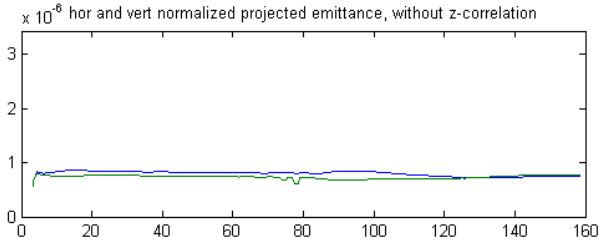
(10 k particles) ~ 11 seconds (for default numerical parameters)

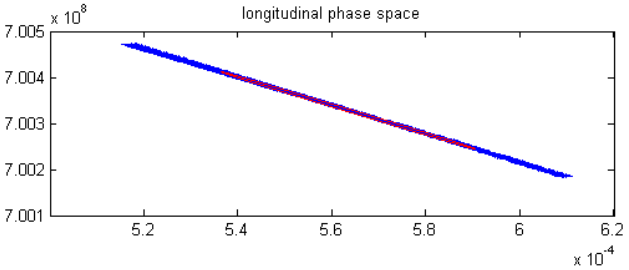


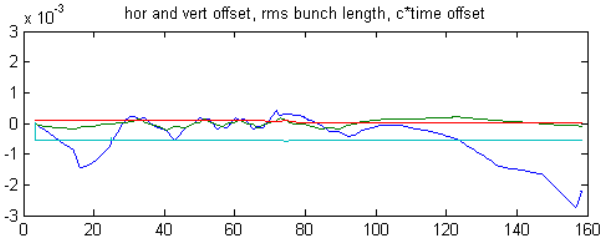


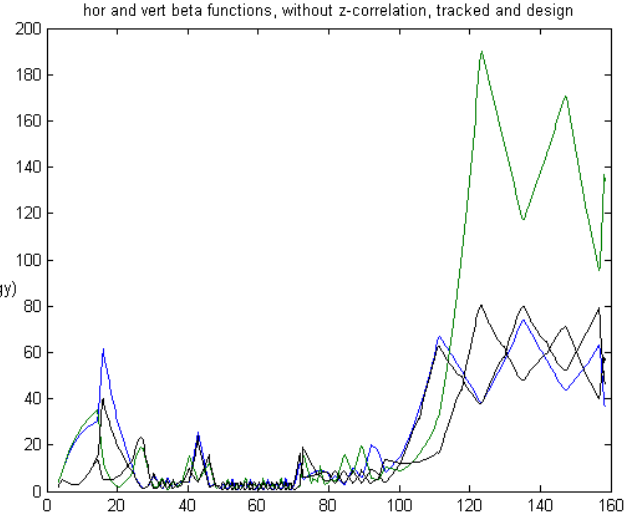


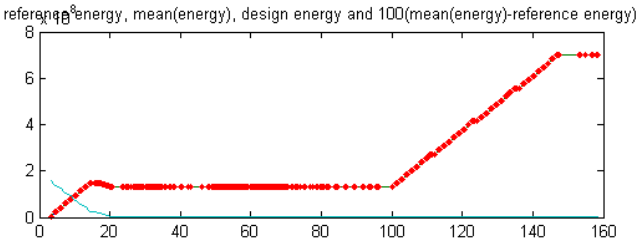












Example 3: FLASH

a2b tracking = after gun to before undulator
2.6m before LOLA … after LOLA … undulator

200k particles ~ 190 m to LOLA
~ 330 seconds (for default numerical parameters)

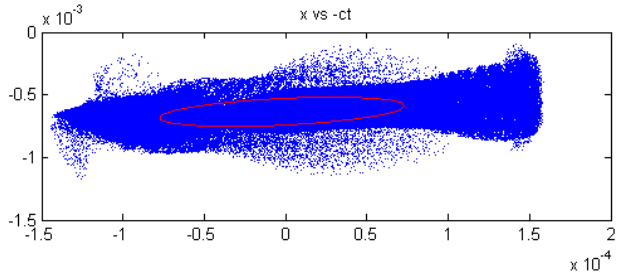
config = beamline description
similar to XFEL, less compressors
modified energy profile

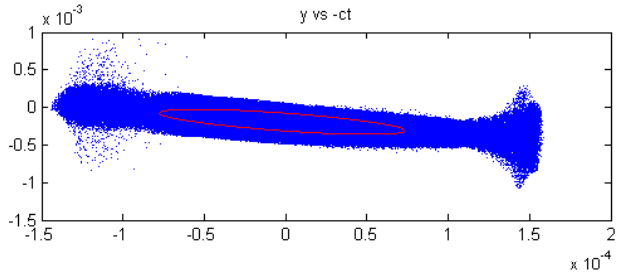
LongTable = beamline description
based on Eduard Prat's list (Elegant), two versions:
FLASH_LongTable to SASE undulator
FLASH_LOLA_LongTable to OTR6 (spectrometer on)

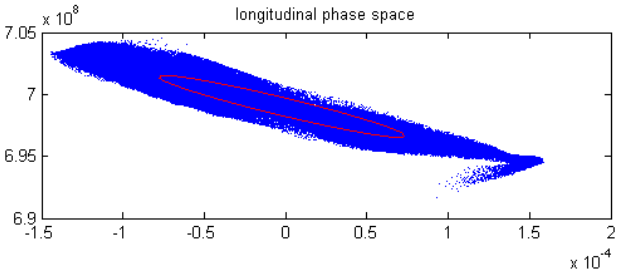
start object 200k particles from Astra

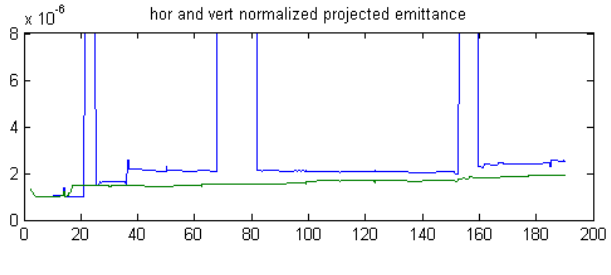
200k particles ~ 190 m , default output → overview plot on screen

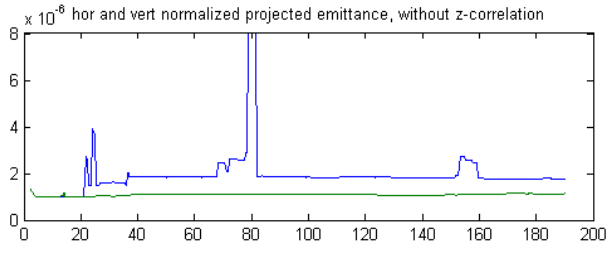
~ 320 seconds (for default numerical parameters)

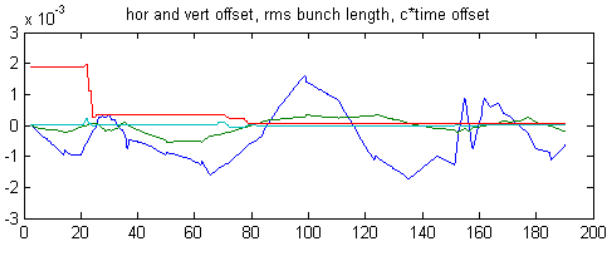


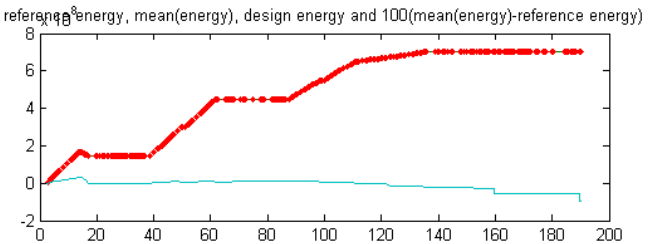


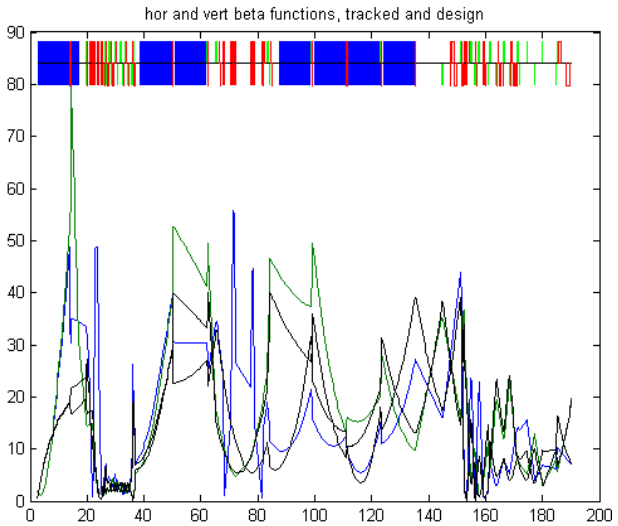


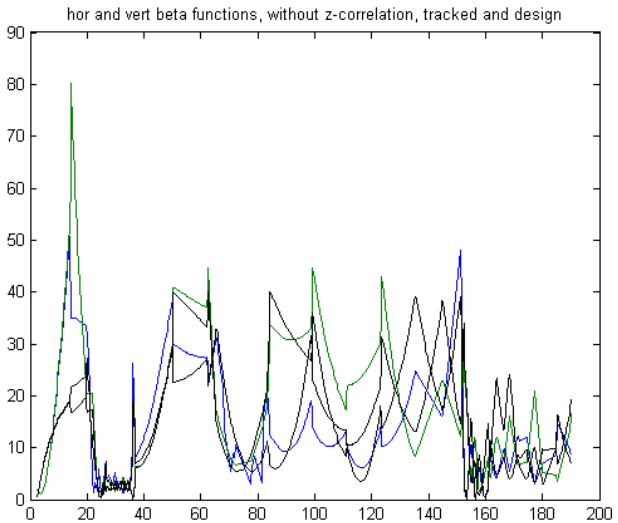




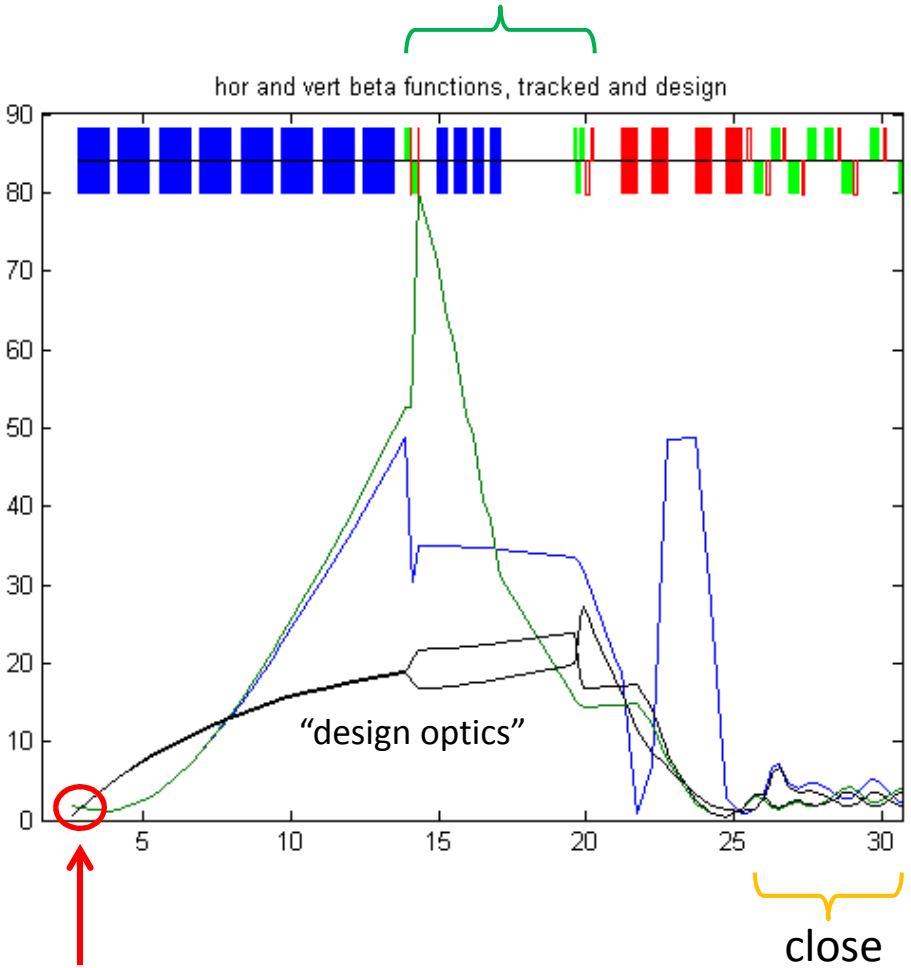






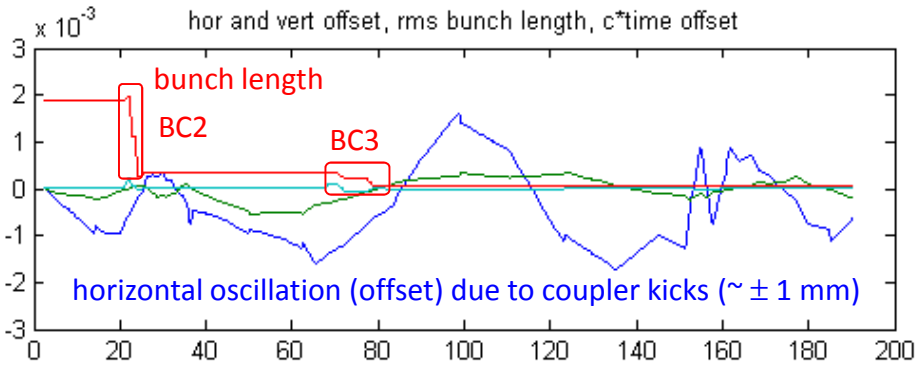


SC matching with 5 quadrupoles



distribution from Astra

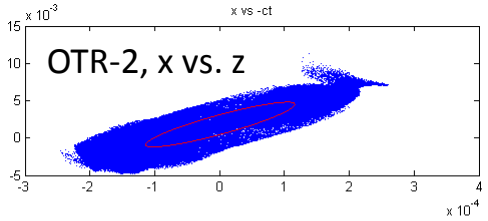
close to design



FLASH-LOLA

(spectrometer on)

"streak" = 0



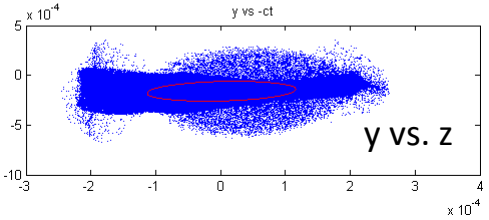
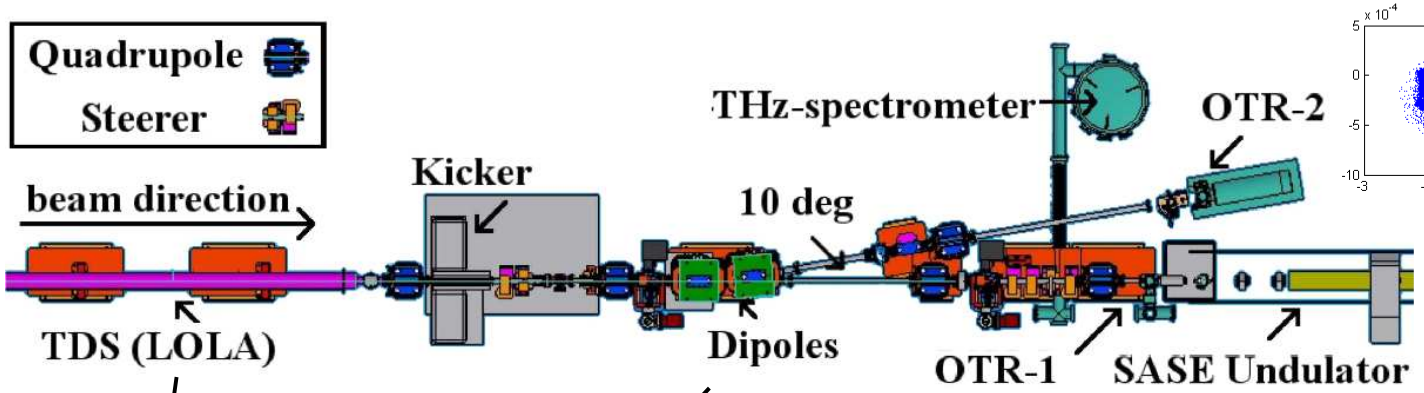
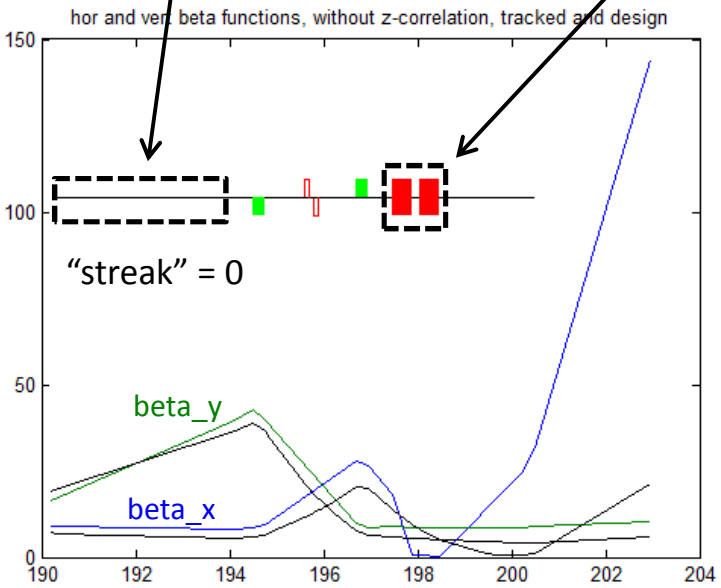
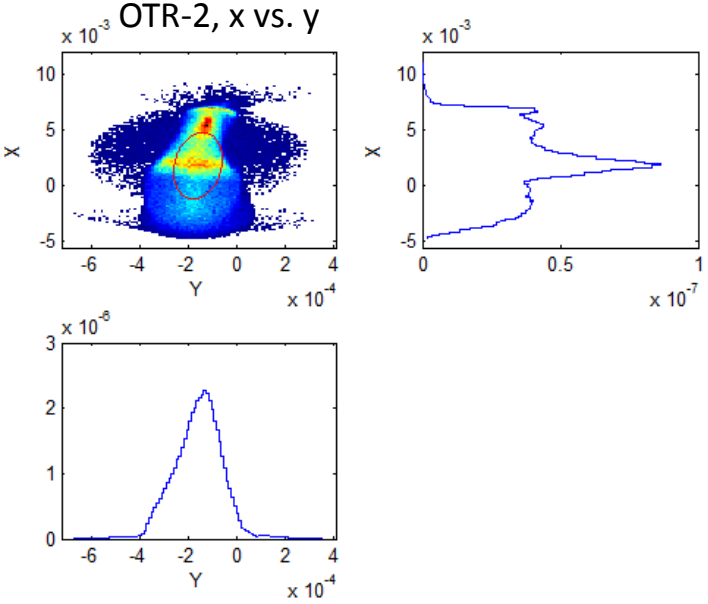


Figure: Design Installiert im Februar 2010





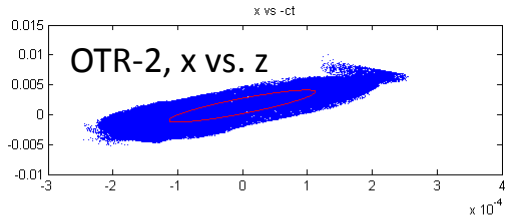
OTR-2, x vs. y



FLASH-LOLA

(spectrometer on)

"streak" = 20 MeV



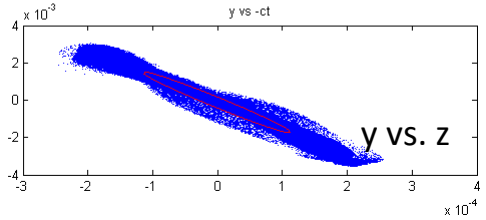
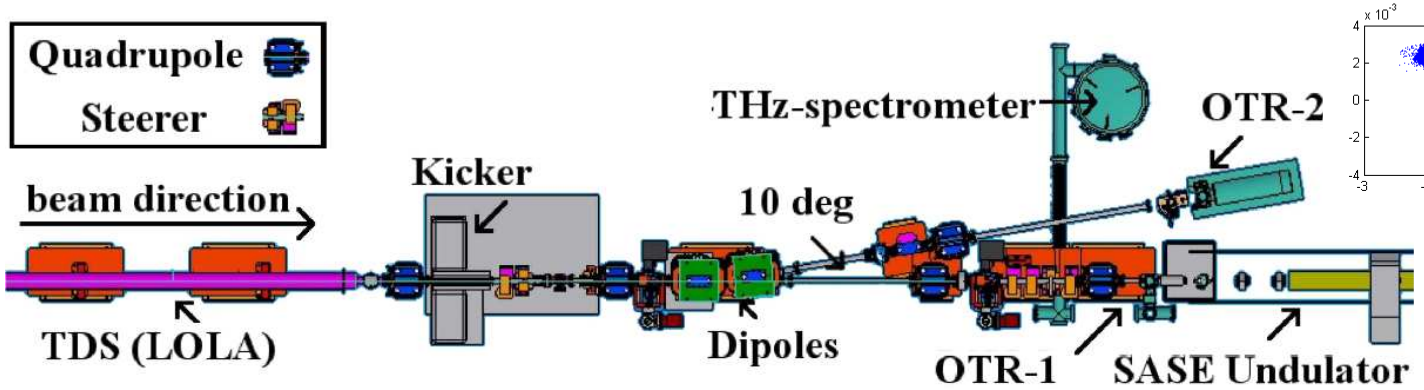
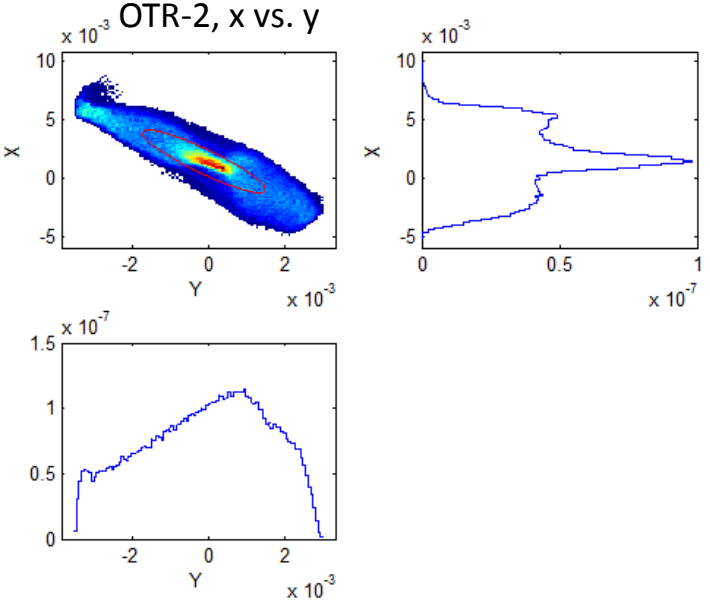
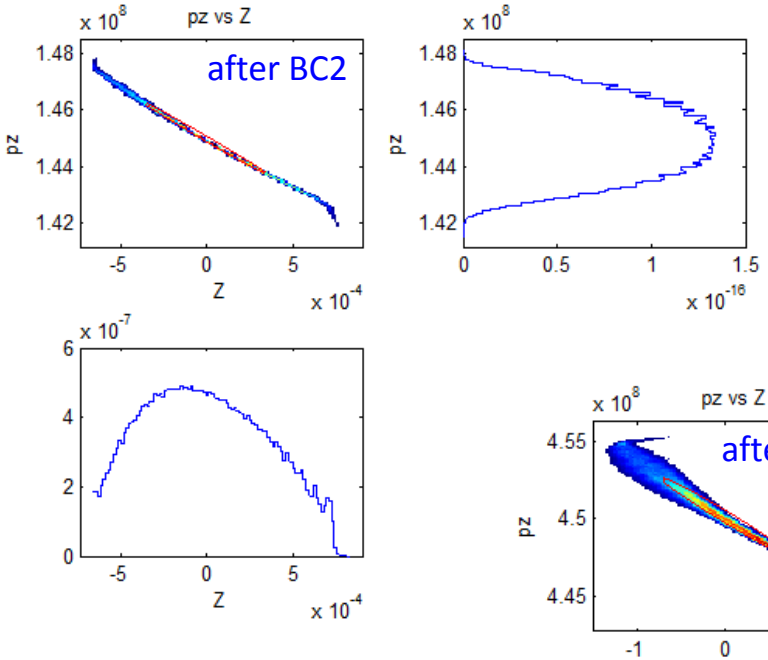


Figure: Design Installiert im Februar 2010

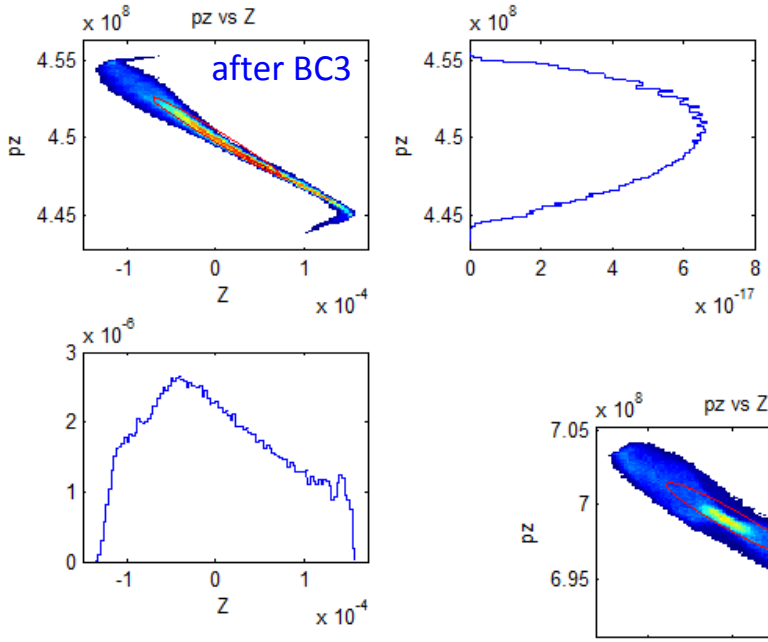


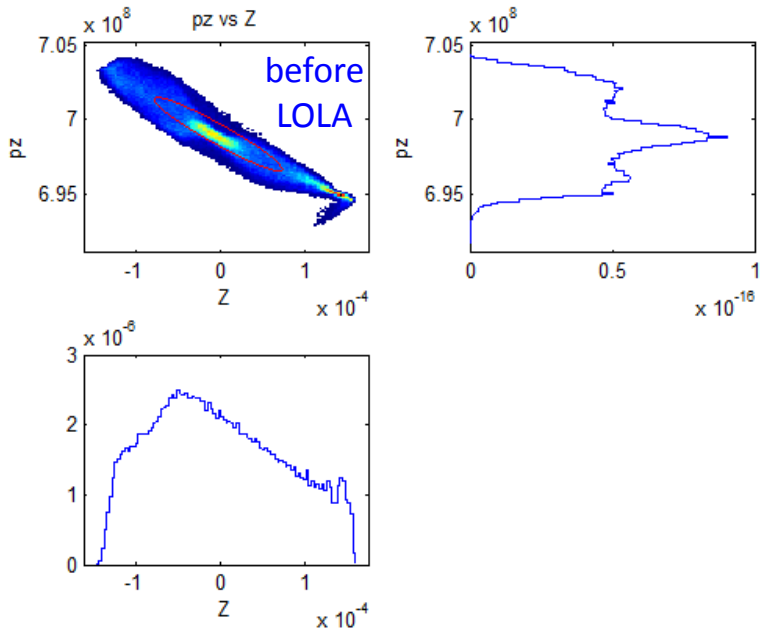
OTR-2, x vs. y



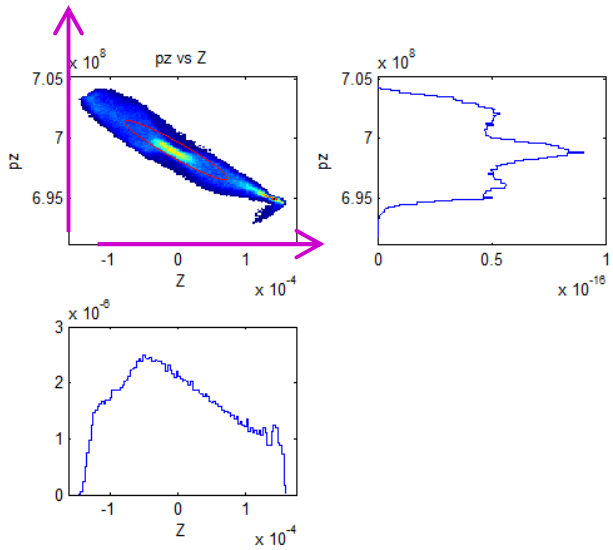


longitudinal phase space, in Flash, before LOLA



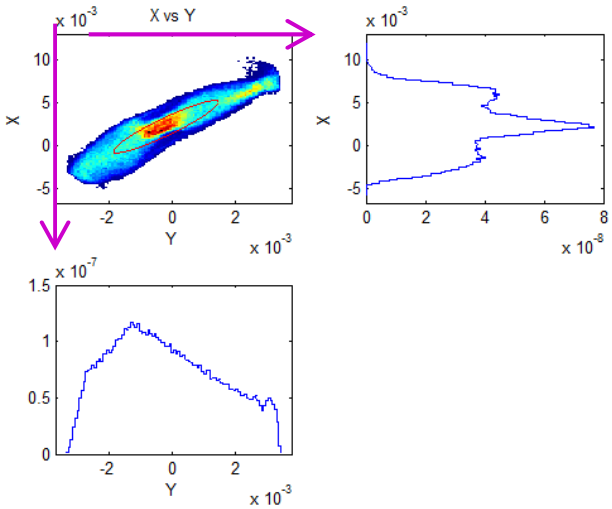


longitudinal phase space before LOLA



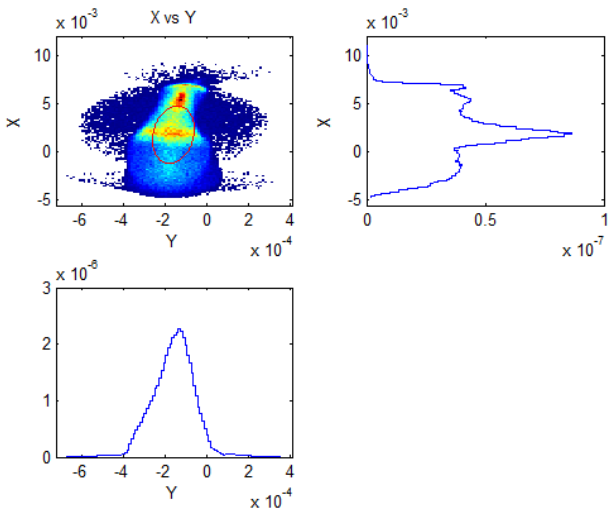
OTR-2

"streak" = 20 MeV, φ=0



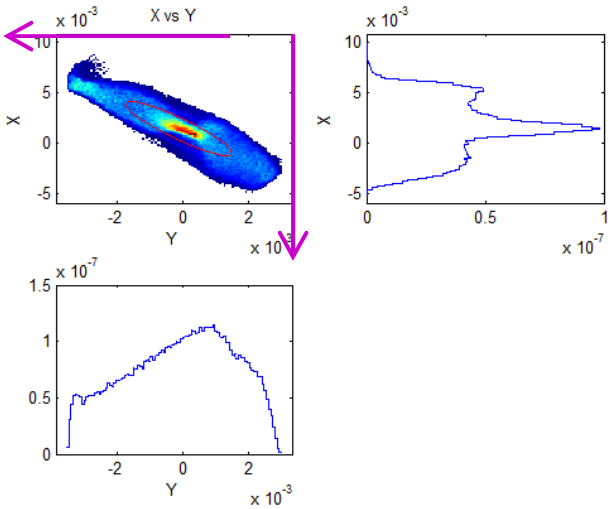
OTR-2

"streak" = 0



OTR-2

"streak" = 20 MeV, φ=180 deg



Summary / Conclusion / Missing

summary/conclusion

efficient space charge tracking in **one program**
hard edged magnets
there may be bugs
structure of input and data/tables not completely defined
promising start

missing

user guide and users
CSR: projected method, no shielding, 3d trajectory,
not by tables (different from rftweak)
misalignment
higher order (>2) longitudinal dispersion correction
s-type compressor
utilities to prepare long tables, start object and wakes
library of long tables
library of start objects (similar to rftweak)