Studies of Optical Functions for TTF Phase 2

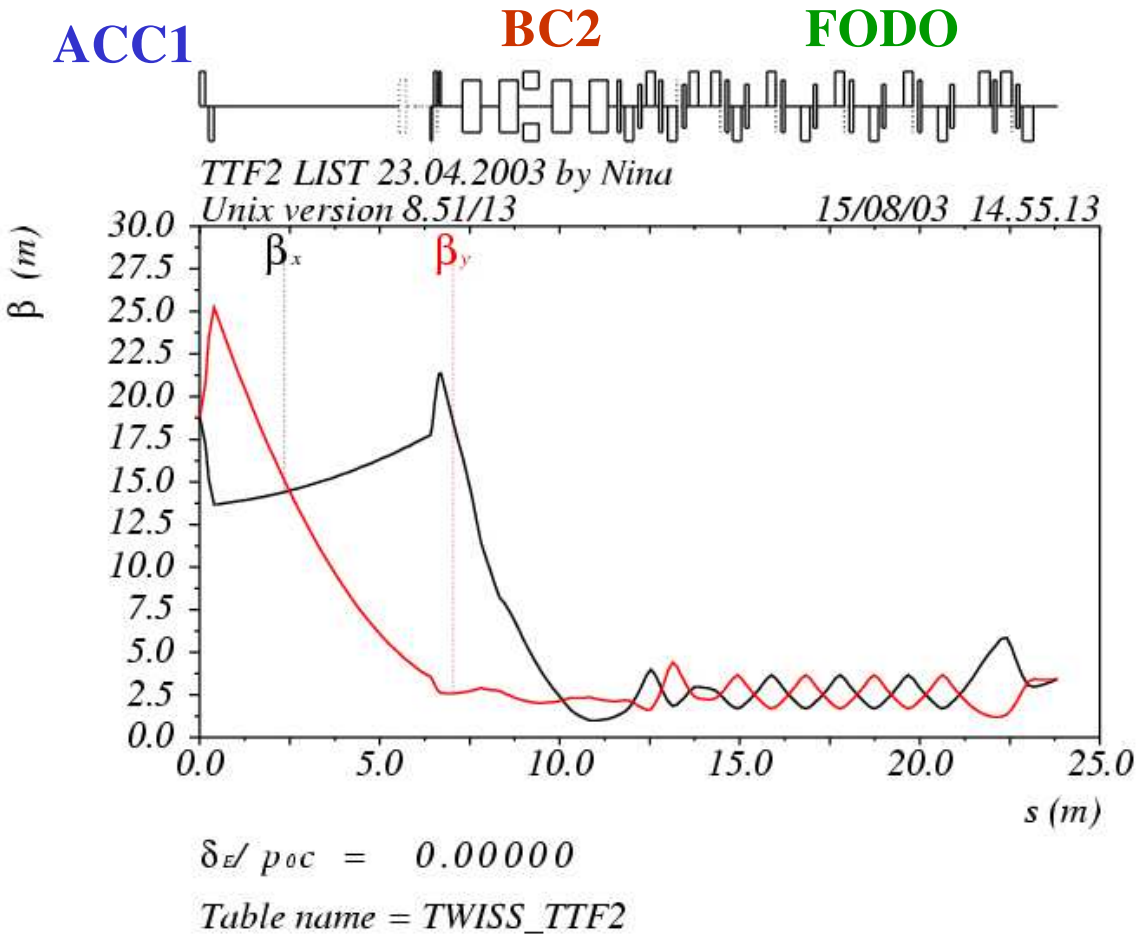
Nina Golubeva

MPY

Optical functions for the beam line starting from ACC1 module up to dump

- Beam line to undulator:
  - impact of different components
  - matching between sections
  - chromatic properties
  - effect of the transverse space charge (after final compression – BC3)
- Transverse focusing of undulator
- Bypass and beam line to dump

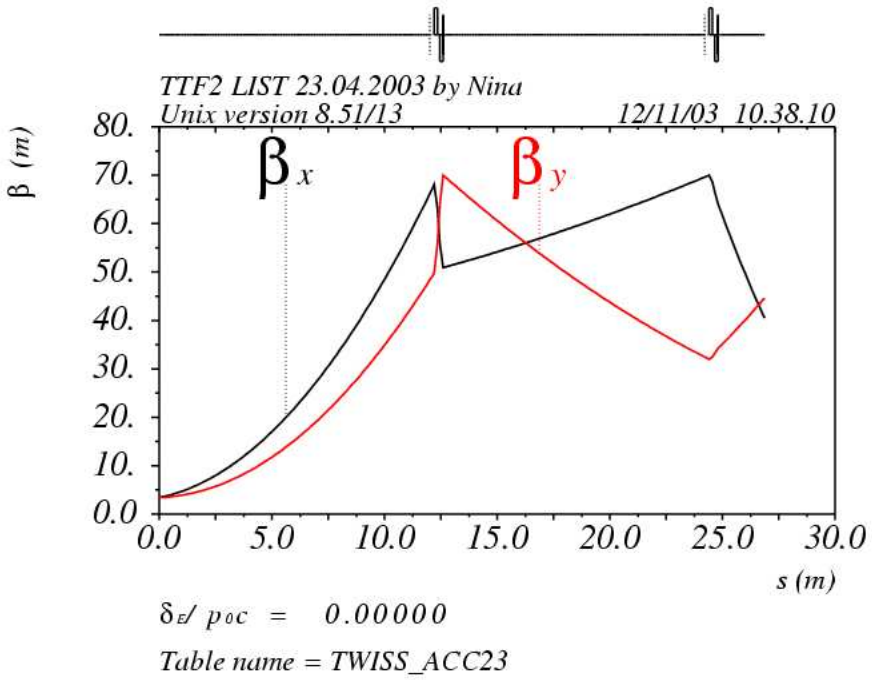
BC2 area with diagnostic section



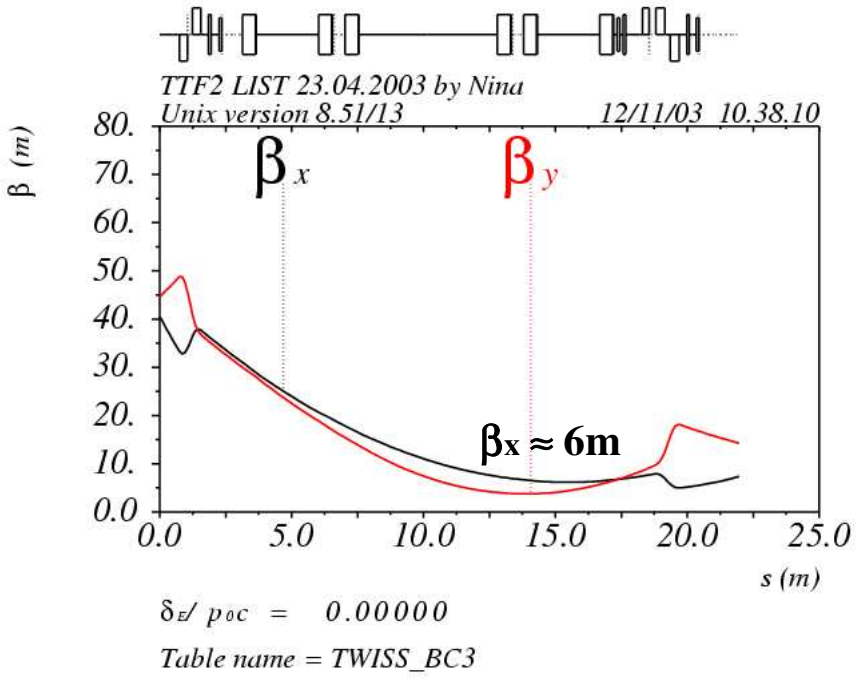
- **FODO lattice: L_{cell} = 1.9 m**
  $\mu_{x,y}$ = 45°
  $\beta_{x,y}$ ~ 2.5 m
- **BC2 area as a matching section to FODO lattice is flexible to beam parameters from injector**

Accelerating section ACC2 / 3 and BC3 area

ACC2 / 3 section

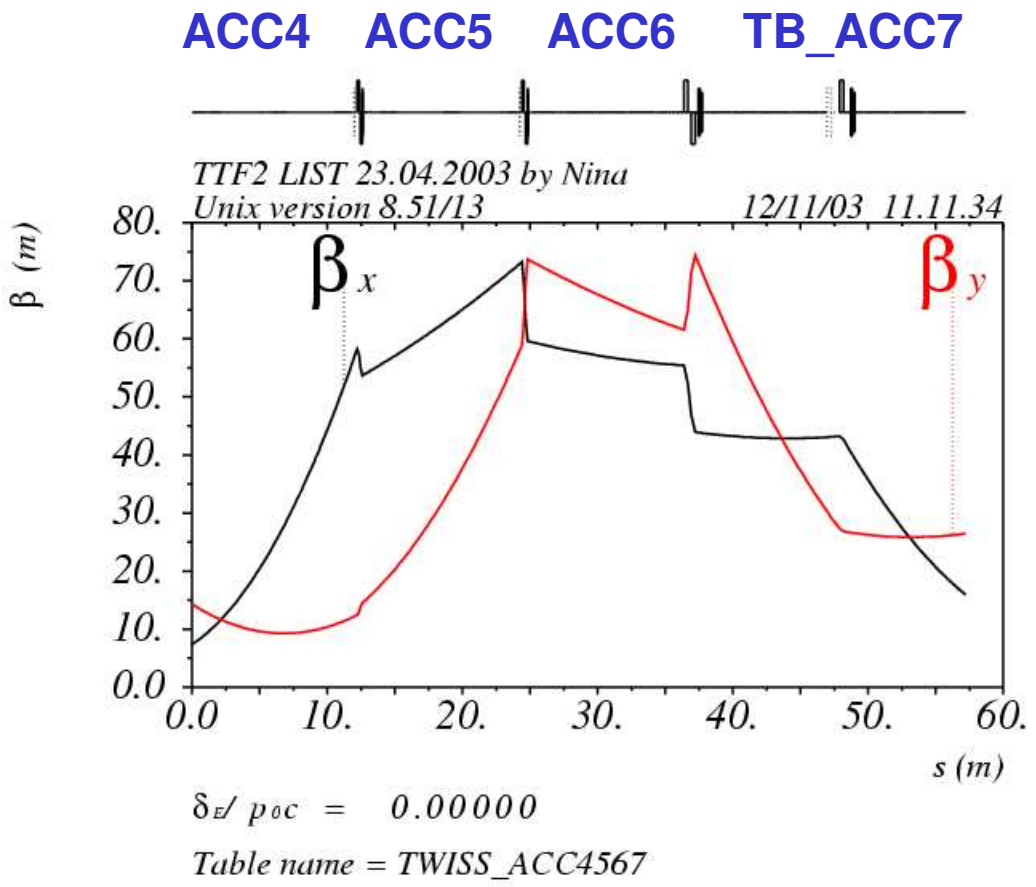


BC3 area



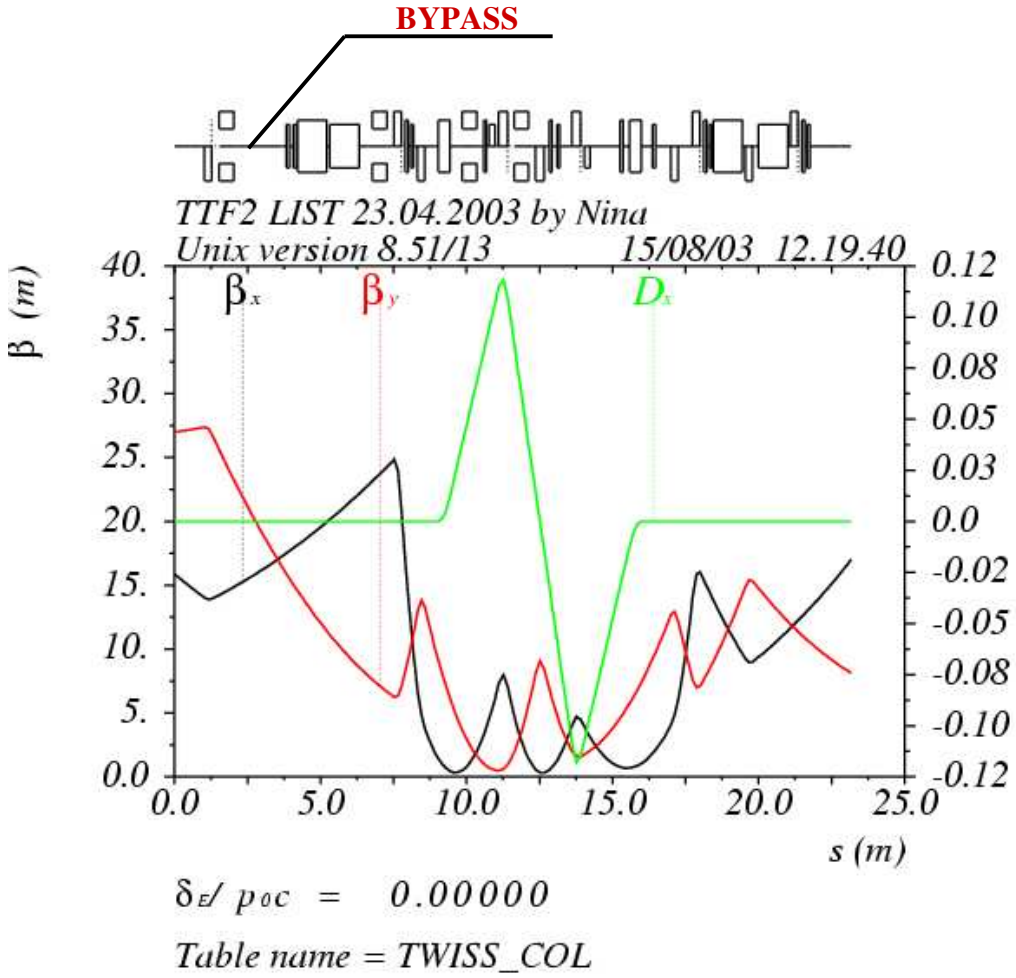
- **CSR effect: beam waist and small β-functions between two last dipoles**
- **Matching between BC2 and BC3 = f (E_0, E_{acc}, …)**

Section between BC3 & Collimator:
ACC4 / 5 and TB_ACC6 / 7



This section: matching section between BC3 and Collimator.

Collimator section with dogleg



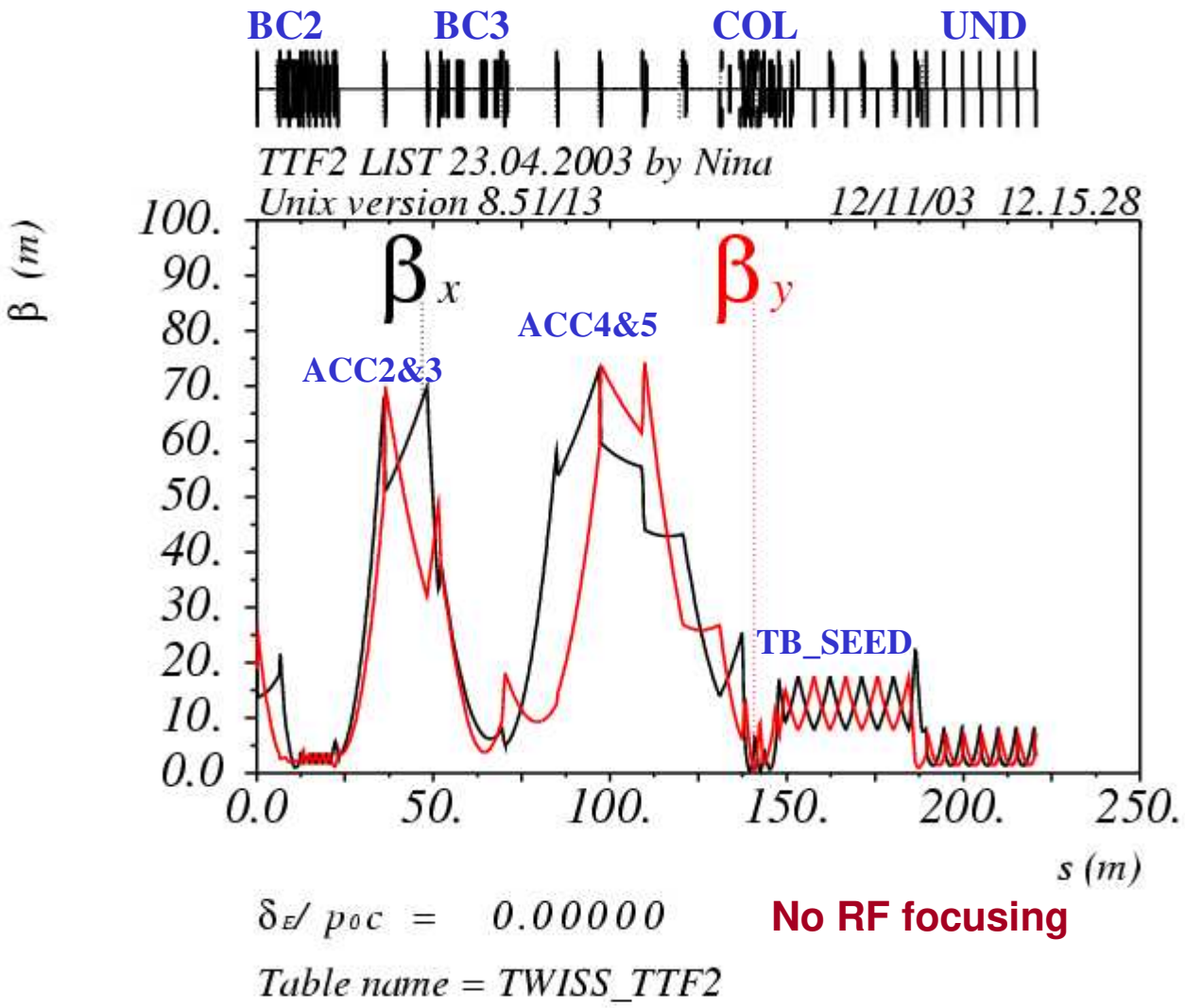
- Bending magnet to BYPASS
- Dogleg: L ≈ 7 m, Δx = 40 cm:
  - maximal Dx ≈ 11.5 cm
  - triplet between dipoles cancels the linear dispersion
  - 2 sextupoles for suppression of second order dispersion
  - β-functions ~ 5 m
- Collimation system:
  - 4 collimators
- Matching to undulator:
  - *f* (optical functions of und.)

Properties of different components

- BC2 bunch compressor
- FODO cells ($\mu_{x,y}=45°$)
- ACC2, ACC3
- BC3 bunch compressor
- ACC4, ACC5, TB_ACC6, TB_ACC7
- COLLIMATOR (with the dogleg)
- FODO in TB_SEED
- UNDULATOR

· Beam waist and small β between two last dipoles (CSR effect)
· L = 1.9 m => β ~ 2.5 m
· Matching (BC2, BC3) is *f* (E, Eacc, …)
· Beam waist and small β between two last dipoles (CSR effect)
· Matching (BC3, COLL) is f (E, Eacc, …)
· β (dogleg) ~ 5 m, 2 sextupoles, 4 Collimators: β(CT1/2) > 20m
· $\mu_{x,y} = 45^o$ => βmax ~ 17 m
· β ~ 4 m

Optical functions for the beam line from ACC1 module to undulator

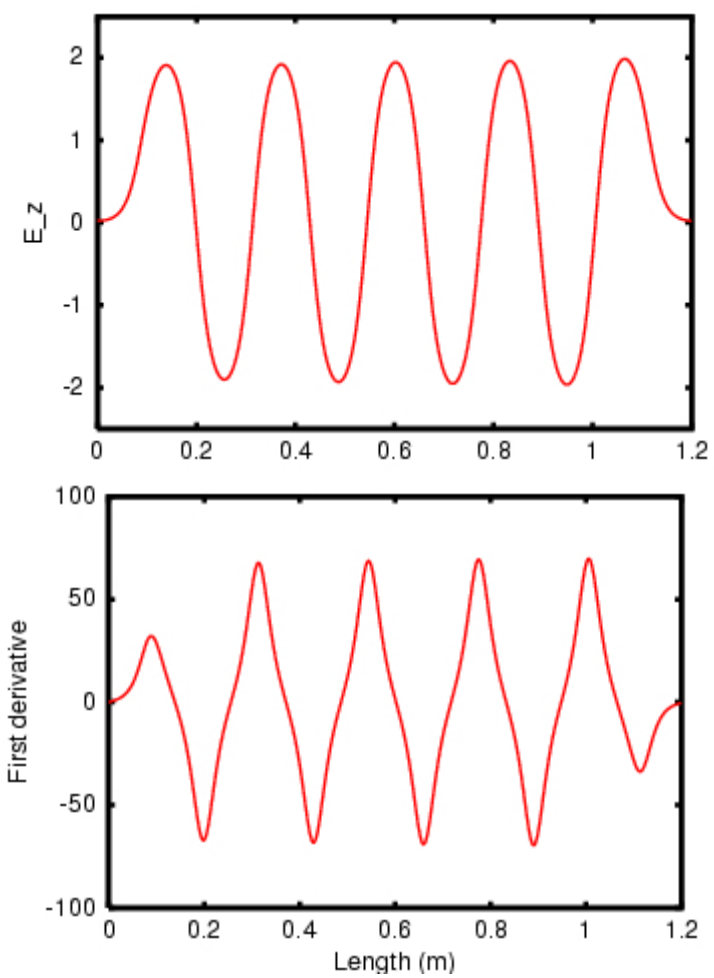


No RF focusing

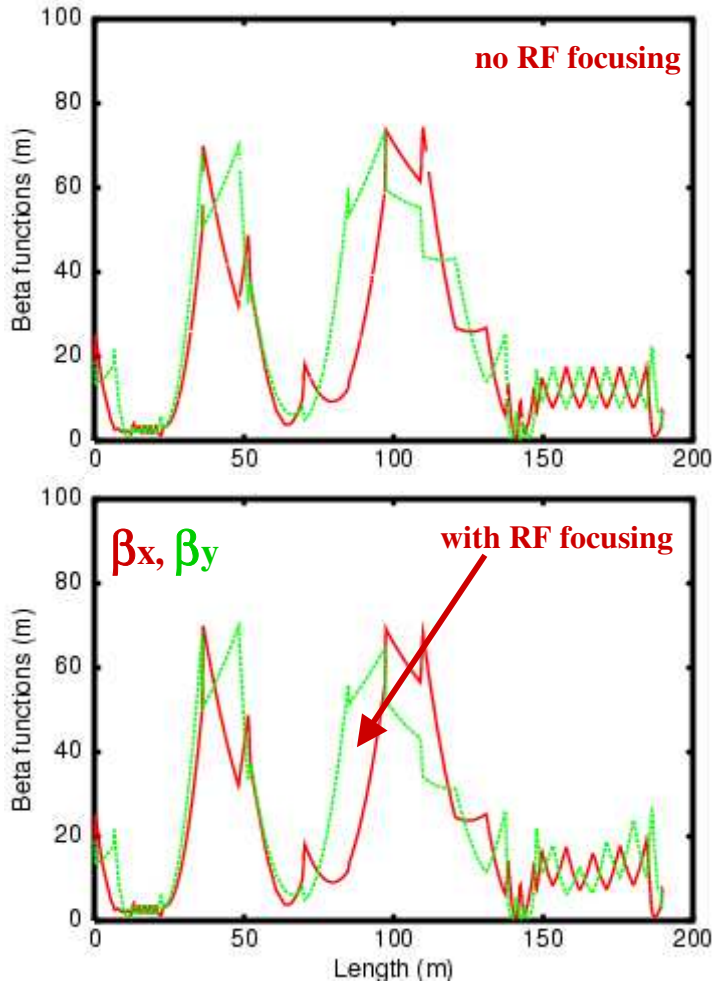
Transverse focusing of RF cavities

(not of principal importance in considered region, but ↷)

Accelerating field amplitude and its 1st derivative along the axis for the TESLA cavity (arbitrary units)



Changing of quadrupole strengths for recovering of original optical functions: up to 15%



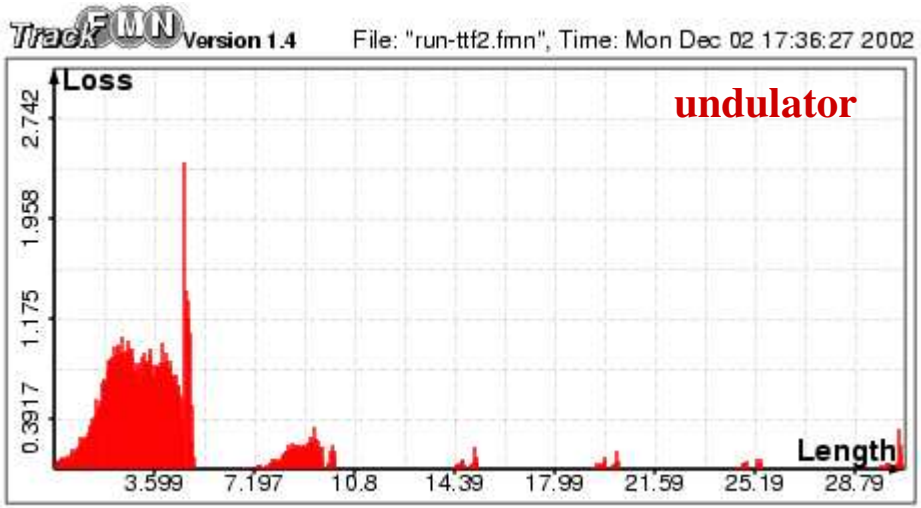
Collimation system

TESLA Report 2003-17

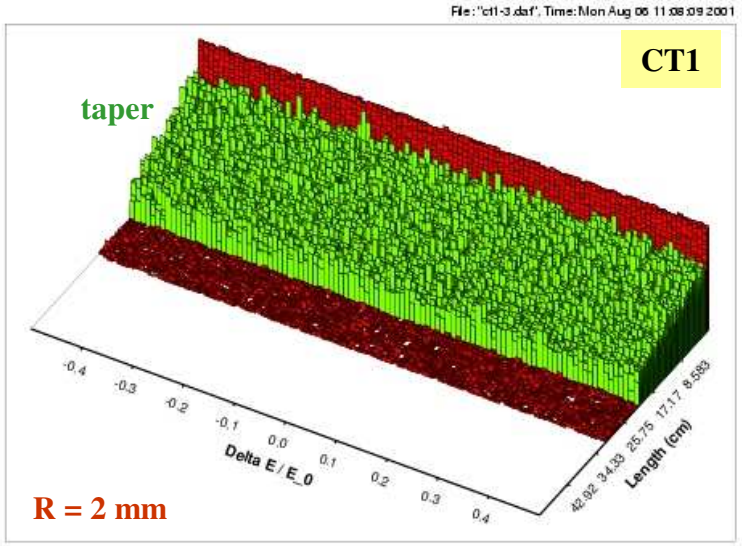
- Protection of undulator: transverse & energy collimation
- Protection against off-energy and mis-steered beams

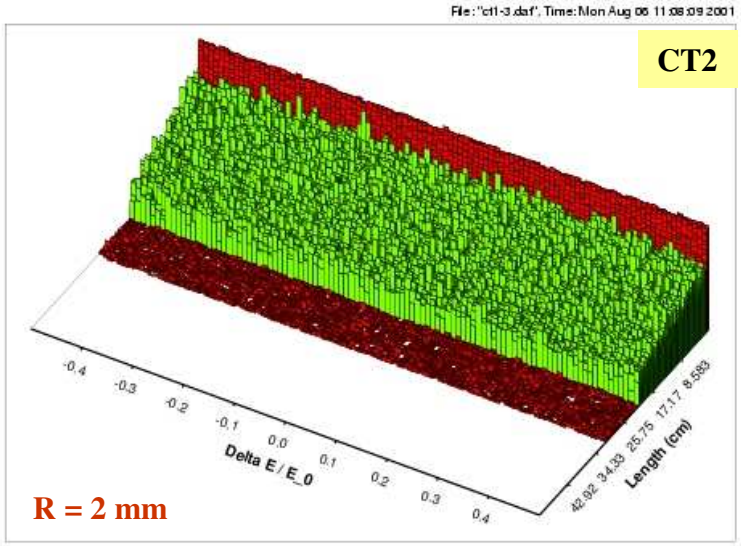
- **4 primary collimators: two in 1st straight section + two in dogleg**
- **Last collimator (CE2) is located in the dogleg, upstream of second dipole magnet: only secondary e^- can reach undulator**
- **Energy collimator CE2 defines the energy bandwidth of beam line: $|\Delta E| > 3\%$ will be stopped at aperture diameter of 4 mm.**

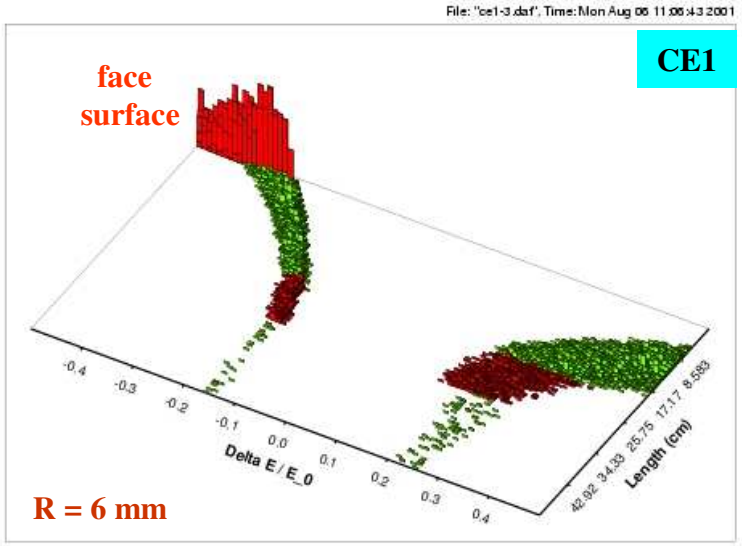
Example of loss distribution: collimators are opened $\Rightarrow$

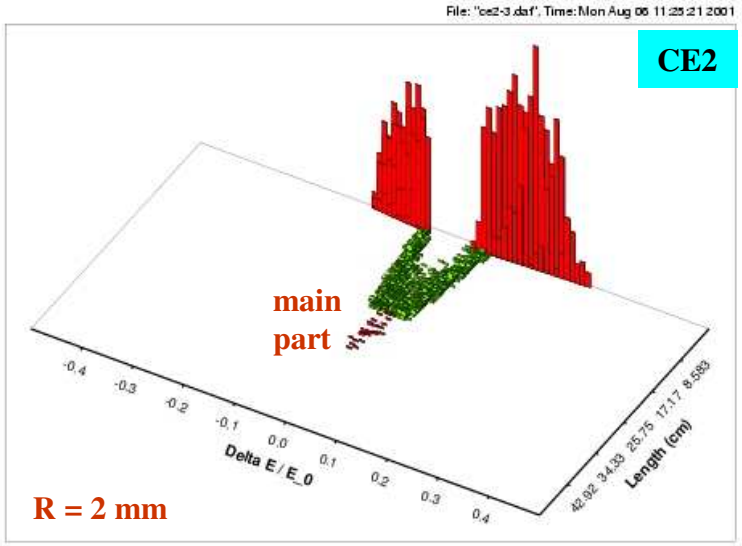


Loss distribution of primary particles along collimator length: Scheme 2







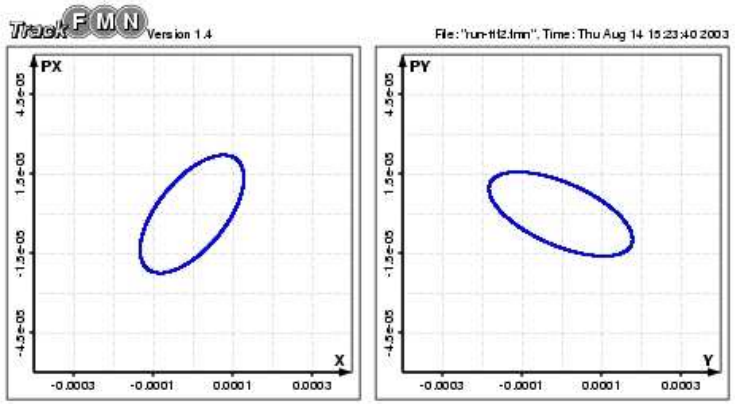


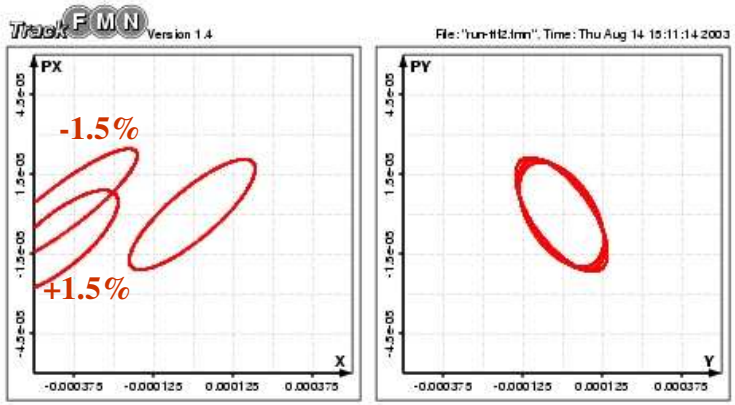
Chromatic properties

Section between BC3 and COLL

Collimator section (final)

Initial



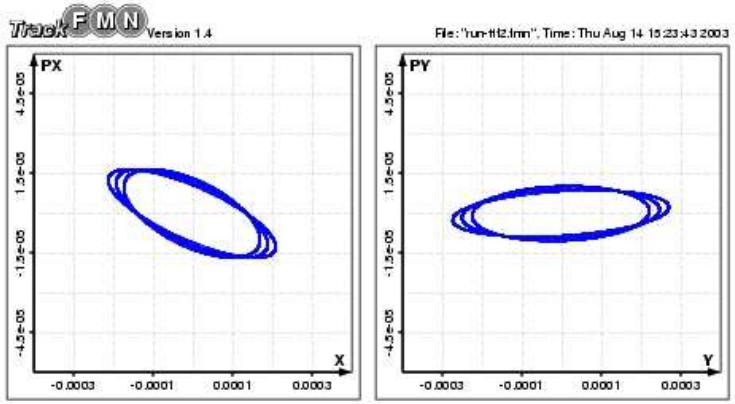


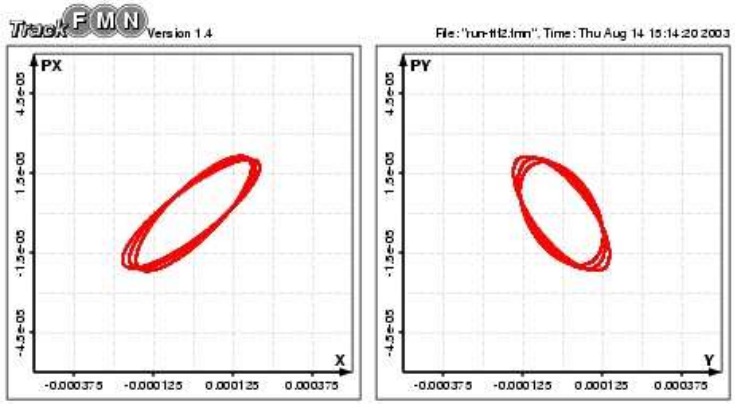
Sext. off

3 ellipses: -3%, 0%, +3%

3 ellipses: -1.5%, 0%, +1.5%

Final





Sext. on

E = 380 MeV

E = 445 MeV

Chromatic properties

1. **Collimator section with the dogleg:**
   - **second order dispersion is suppressed by 2 sextupoles**
   - **particles with the energy offset less ±1.5% pass through with small distortion of beam parameters**
2. **Matching sections:**
   - **tuned to let the particles with the energy offset less ±3% pass through with small distortion of beam parameters**
3. **Beam line from ACC1 module to undulator:**
   - **has an energy acceptance of about ±1.5%**
   - **particles with $|\Delta E| > 3\%$ will be picked up by collimators (with design apertures)**

Effects of transverse space charge forces

- **Beam line after final compression (BC3):**
  after ACC4 module to undulator

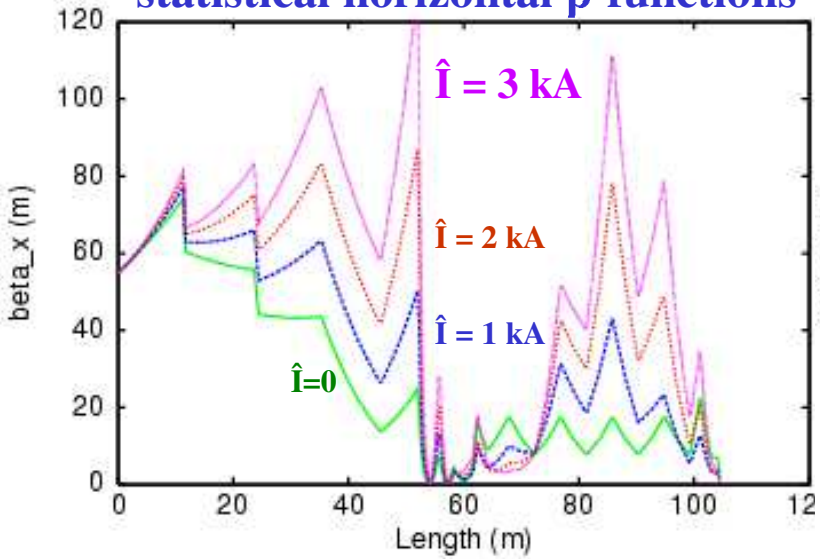
- **Beam parameters (Gaussian distribution):**

$$E_0 = 450 \text{ MeV}$$
$$\hat{I} = (0 - 3) \text{ kA}$$
$$\varepsilon_n = 2\ \mu\text{m}$$

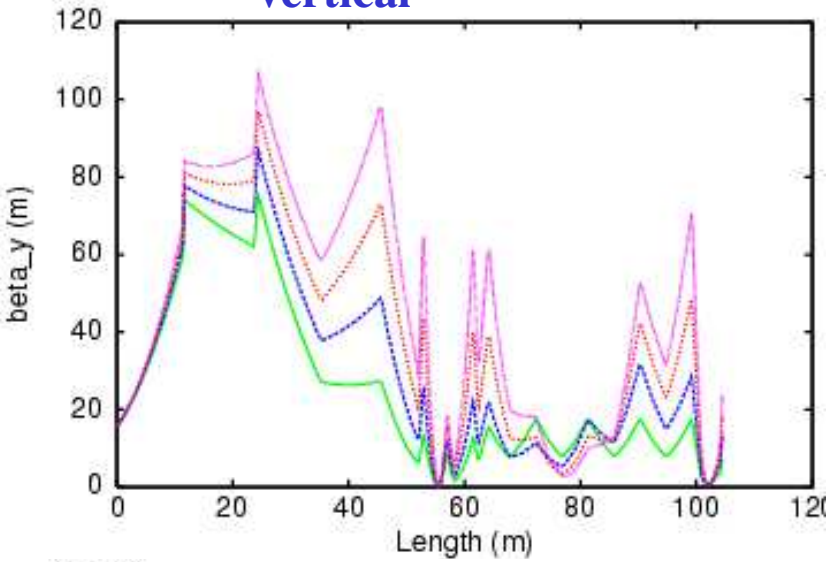
Beta-functions taking into account space charge forces

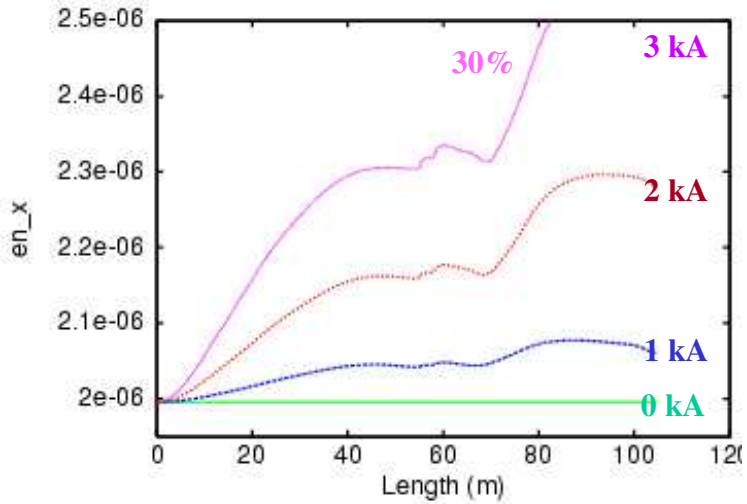
Simulations:
Np = 10^5 - 10^6
Grid: 128 – 512
Nsp-kick / elem = 2 – 20

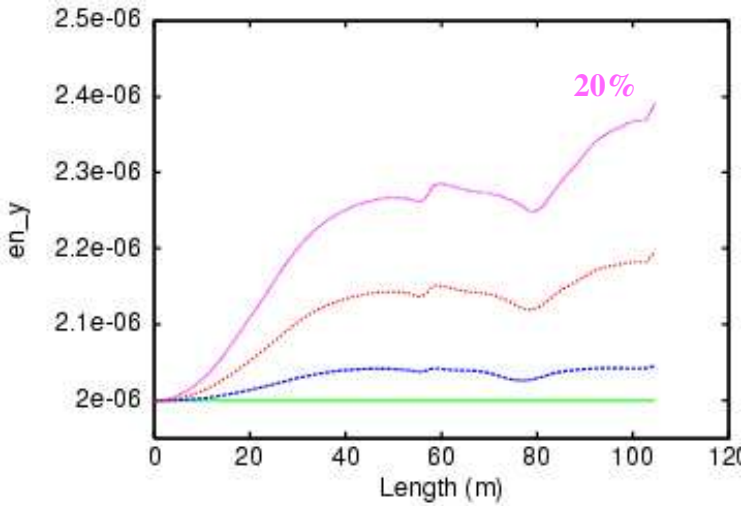
statistical horizontal β-functions



vertical

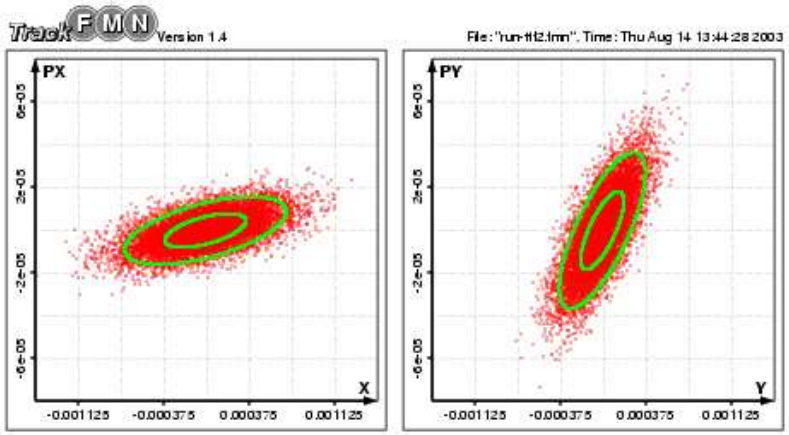


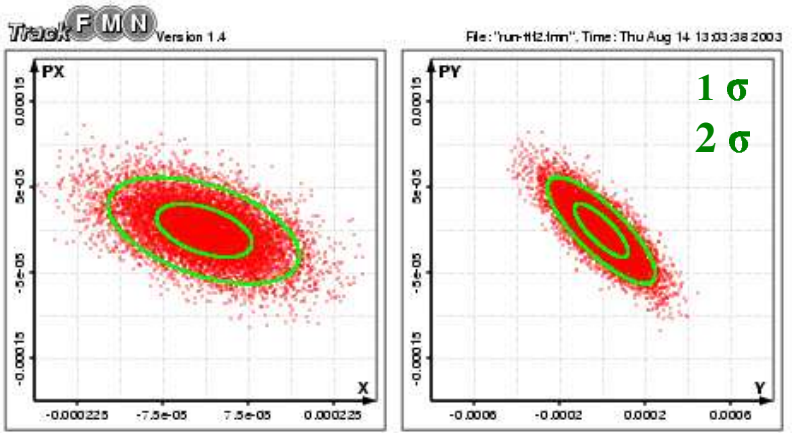




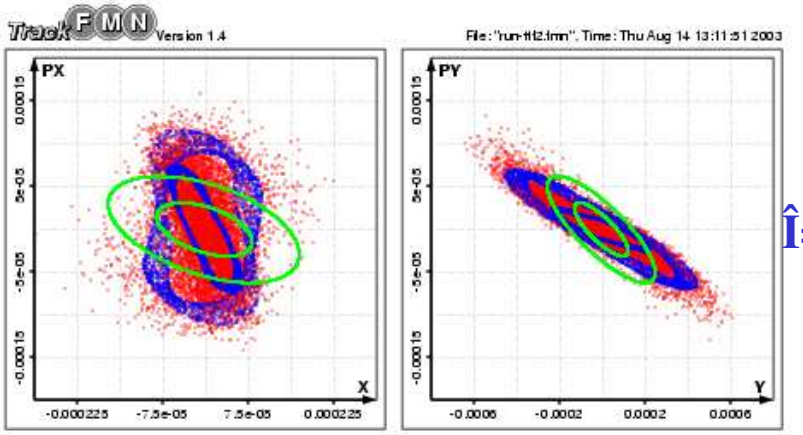
Phase space plots at undulator entrance with space charge effects

initial: ACC4 exit | **final: undulator entrance**





Î=0

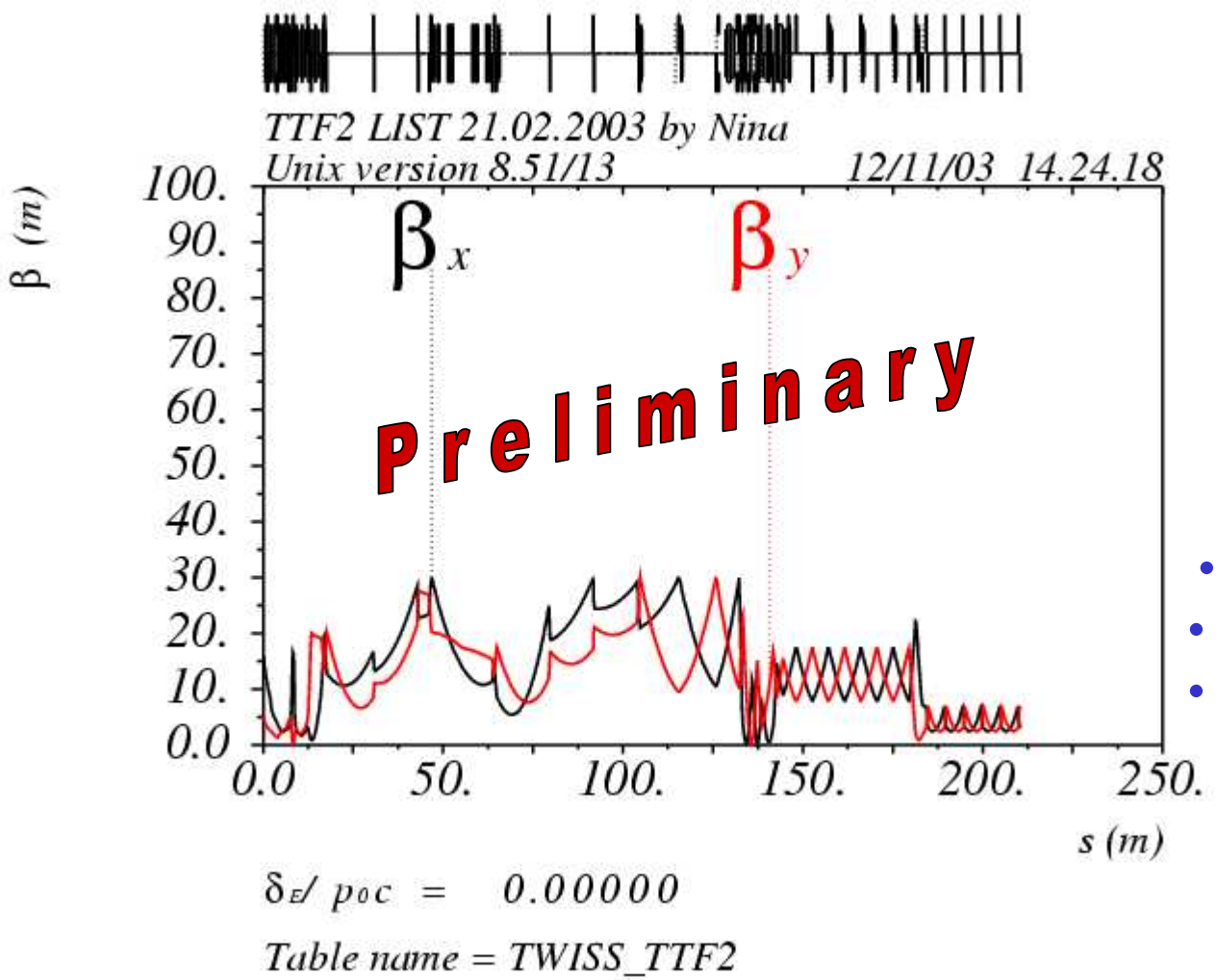


Î=2kA

Red: 10 000 particles, Gaussian distr.
Green (I=0) & Blue (I=2kA): test particles:
– do not contribute in space charge forces
– are tracked in space charge field of the main beam

CPU time = 90 sec (grid: 256x256, Nsp/elem=5)

Another optical functions for the beam line from BC2 entrance to undulator

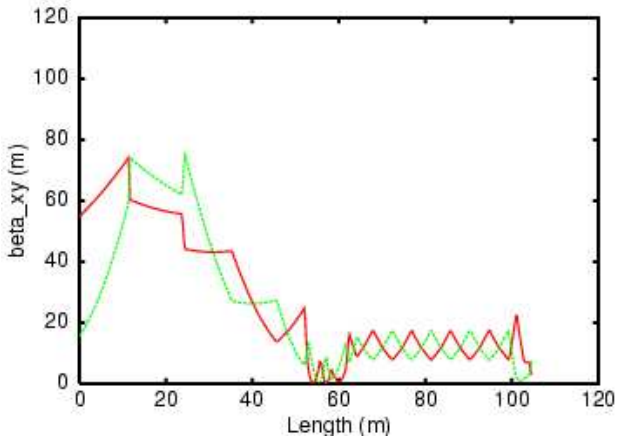


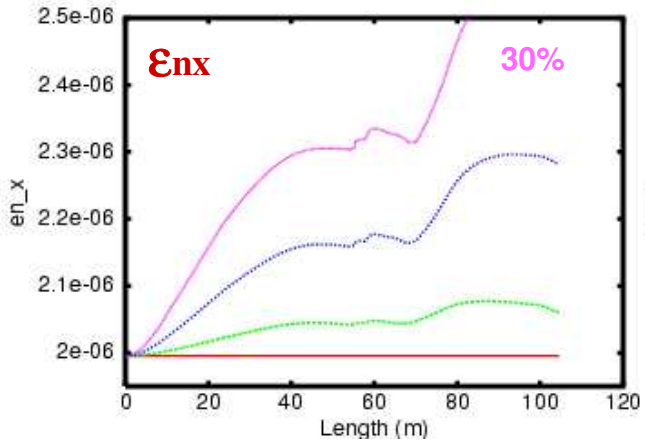
FODO lattice in BC2 area is not used.

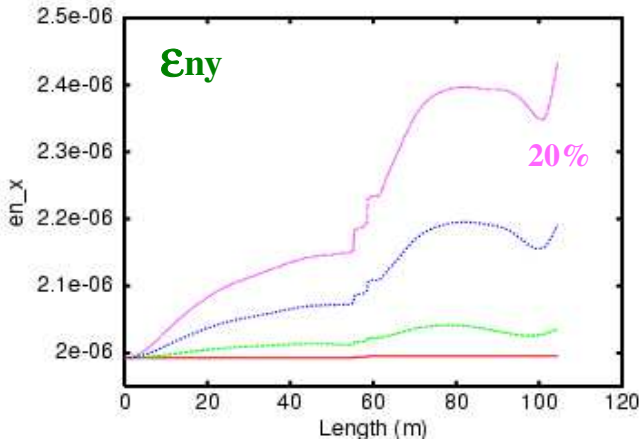
MBC3 :

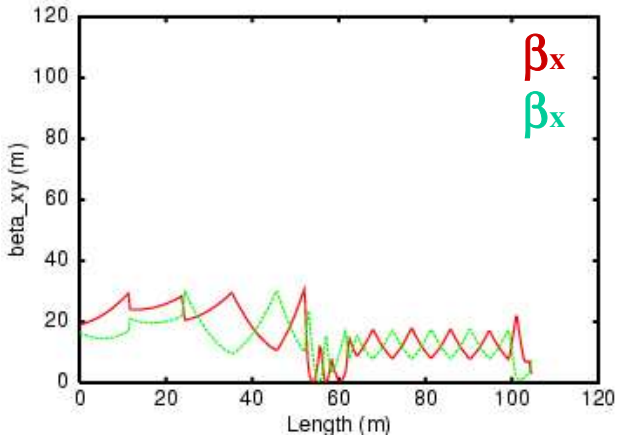
- **βx ~ (30-11) m**
- **αx ~ 0 in BC3**
- **βy ~ (20-16) m**

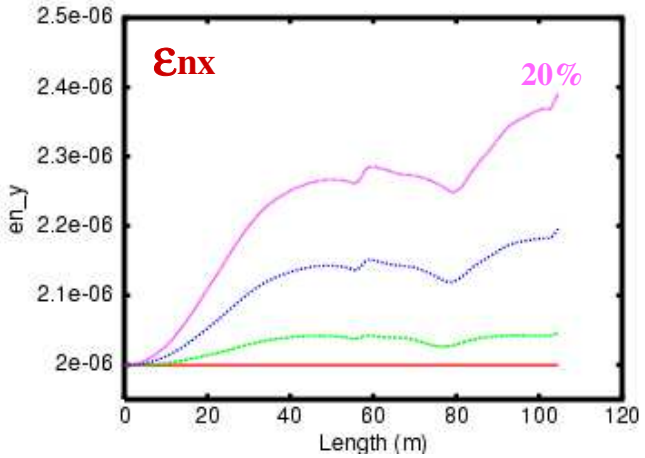
Comparison of two optics: beta functions and emittances with space charge effects in section: ACC5 + TB_ACC6 + TB_ACC7 + Coll + TB_Seed

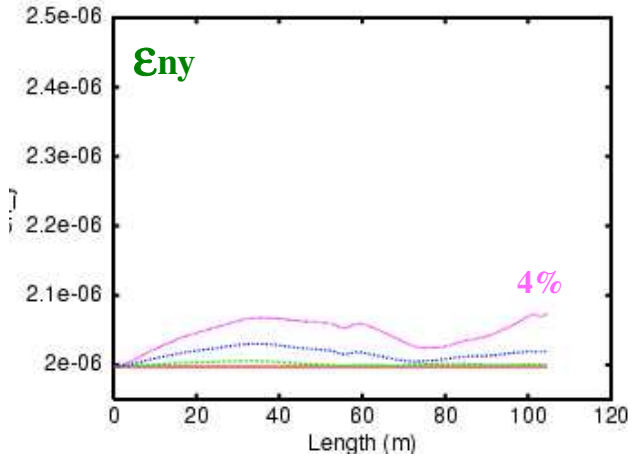








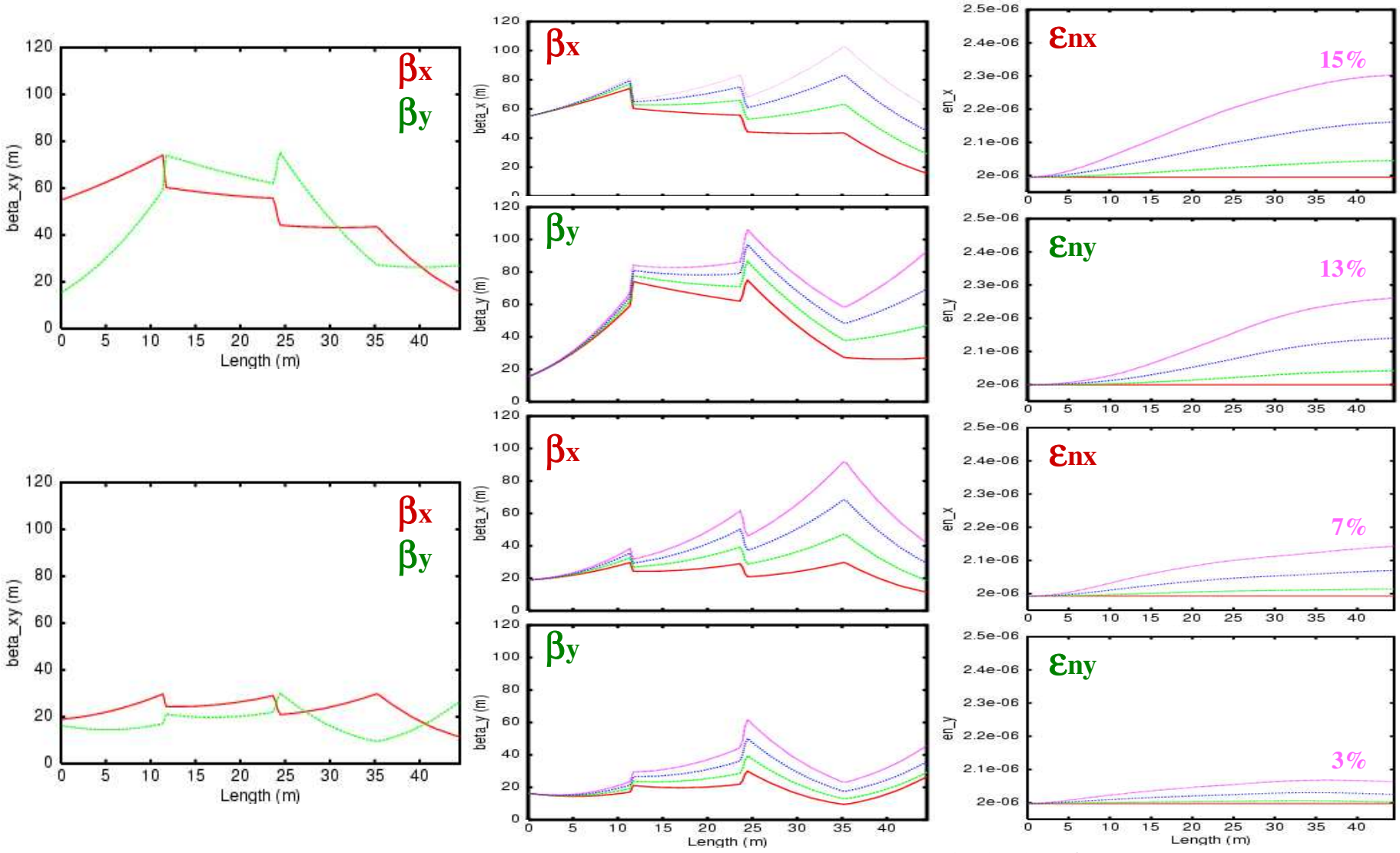




I = 0

I = 0, 1, 2, 3 kA

Comparison of two optics: optical functions and emittances with space charge effects in section: ACC5 + TB_ACC6 + TB_ACC7



I = 0, 1, 2, 3 kA

Transverse focusing of Undulator

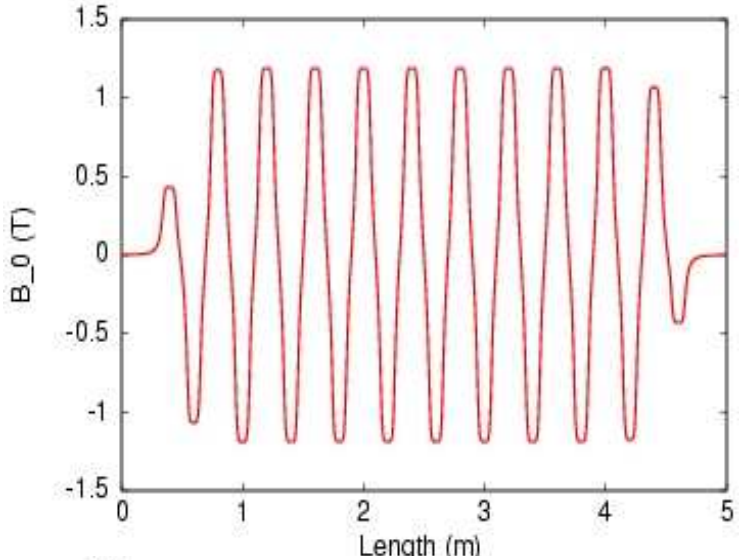
1. Undulator: 6 cells, L_{cell} = 5.098 m, $L_{segment}$ = 4.4922 m.
2. Undulator field: at present, a sine magnetic field.
   (Next step: measured fields of undulator segment and quadrupoles.
   All needed tools are already allowed.)

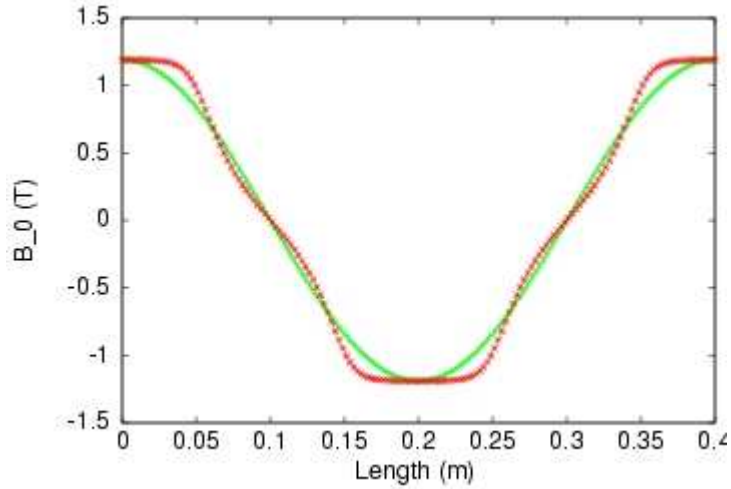
A. Stability region for undulator cell as a function of energy.
B. Choosing of working point for quadrupoles.
   Criterion was used:

$$ABS = \frac{1}{L_{segment}} \int \sqrt{(\beta_x \ \beta_y)} \ \rightarrow \ \min$$

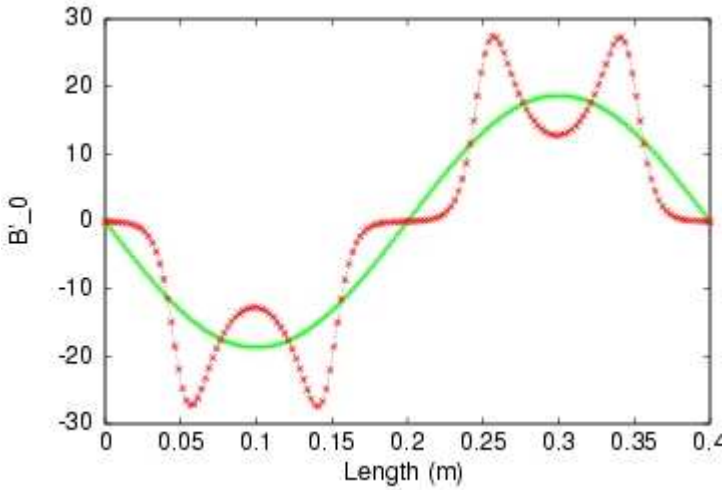
Model of undulator field

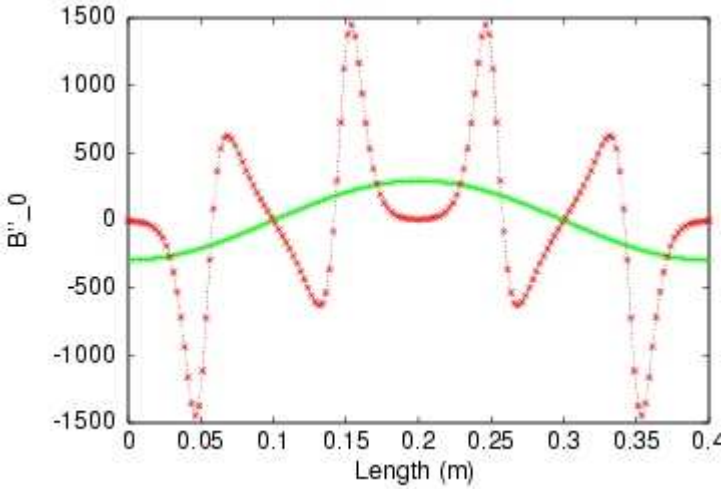
Field profile on the axis for FIR undulator (O. Kozlov)



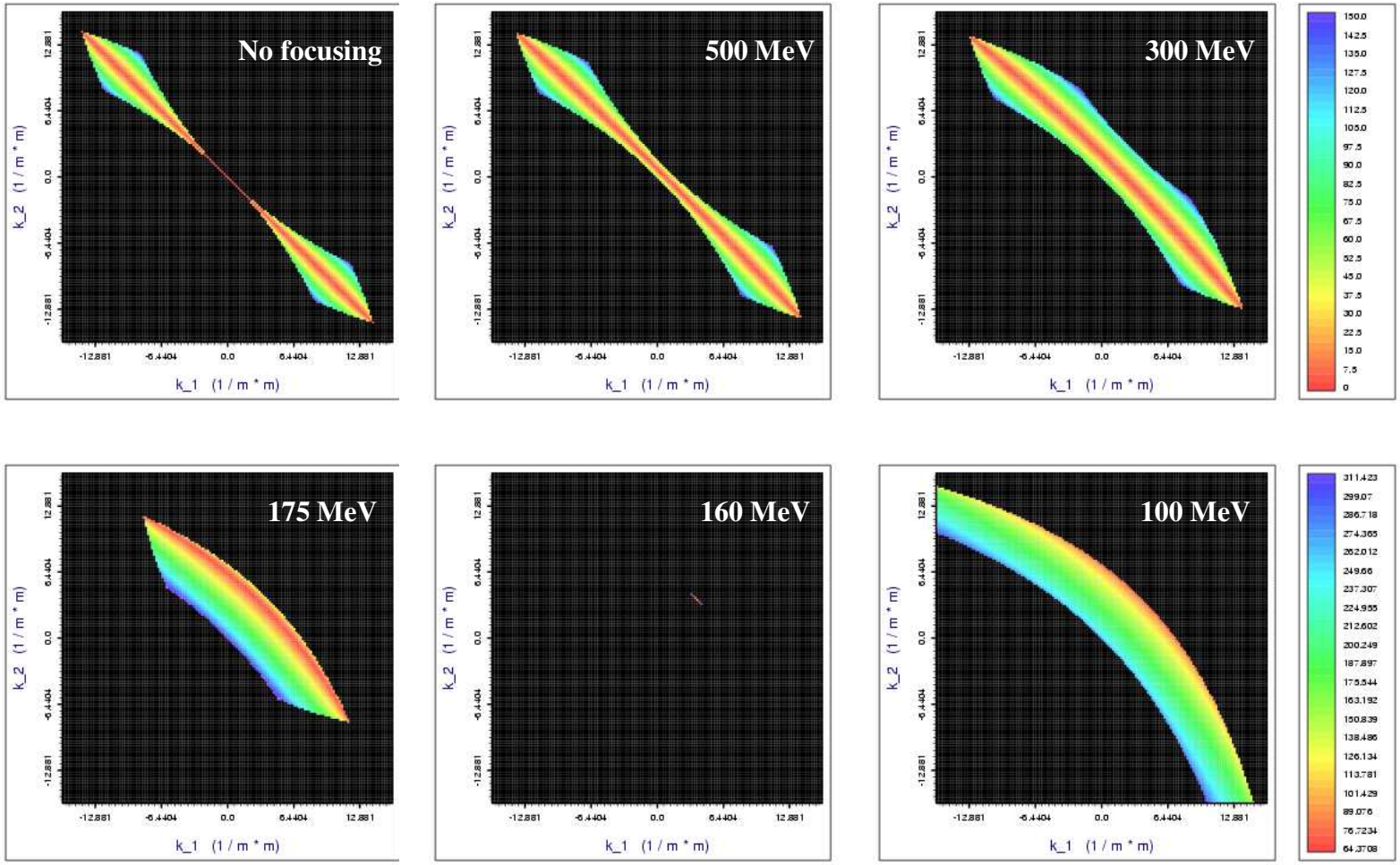


First and second derivatives for one period (green: sine field)

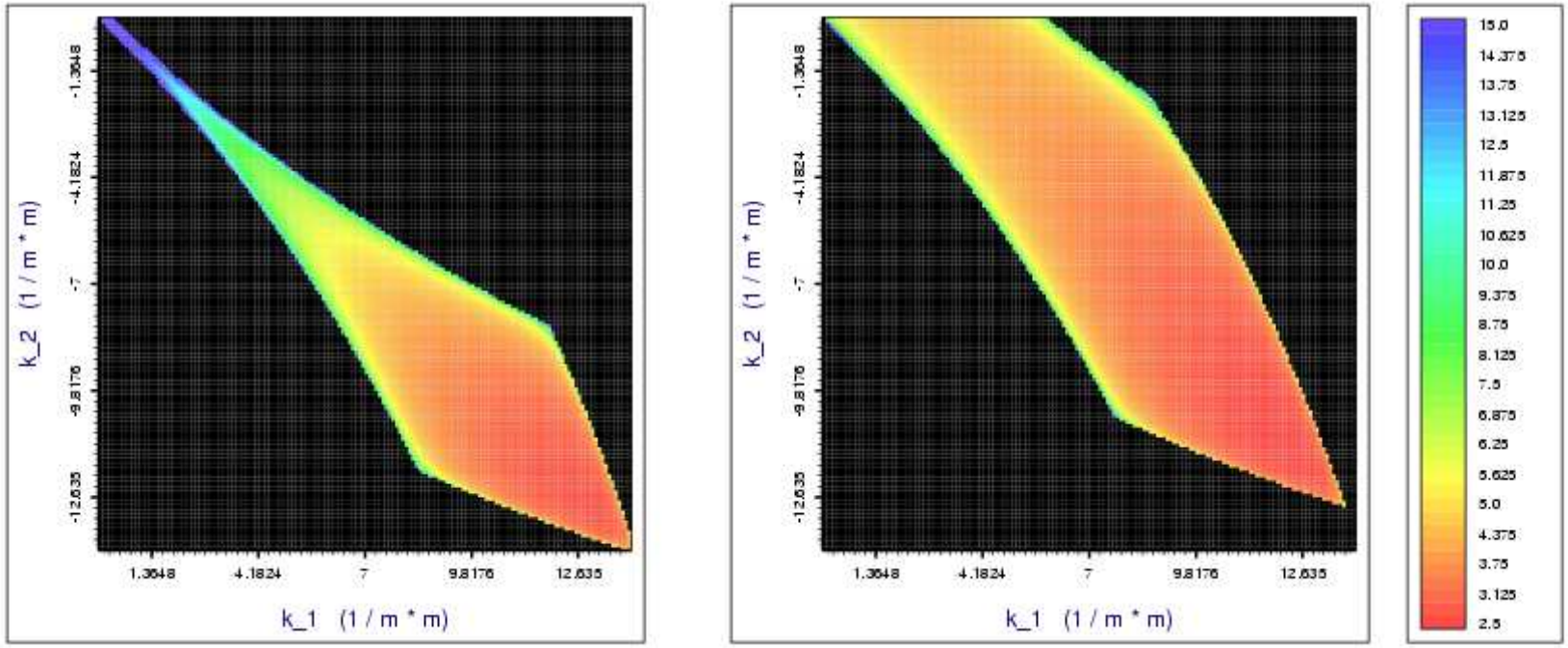




Stability region for TTF2 undulator: $|\mu_x - \mu_y|$



Average beam area

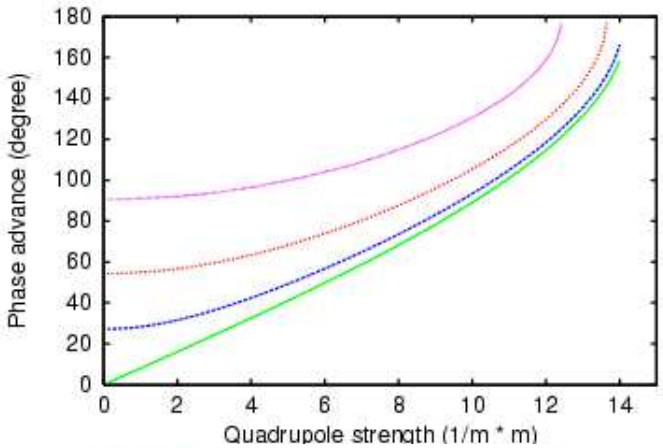


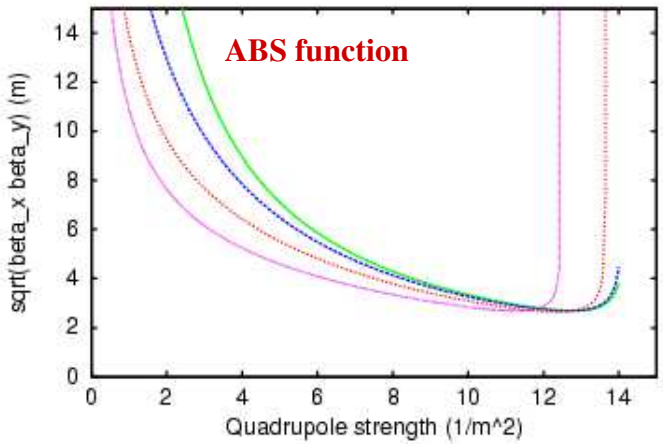
E = 1 GeV **E = 300 MeV**

ABS function (within stability region) with undulator focusing.

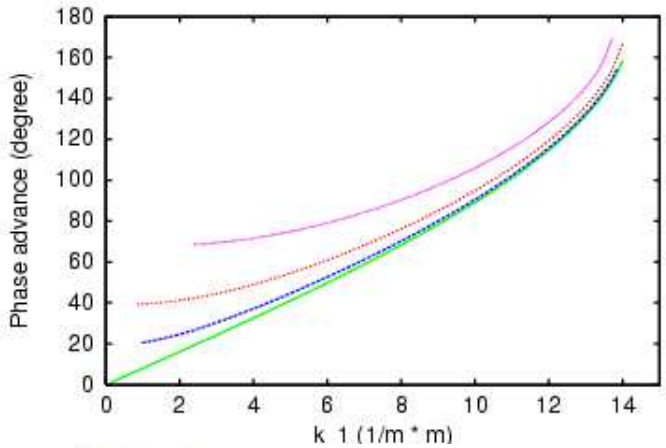
Phase advance and Average beam area

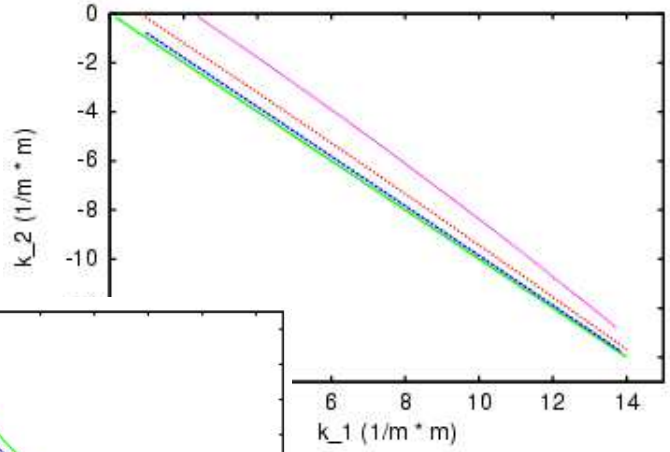
k_1 = -k_2 > 0

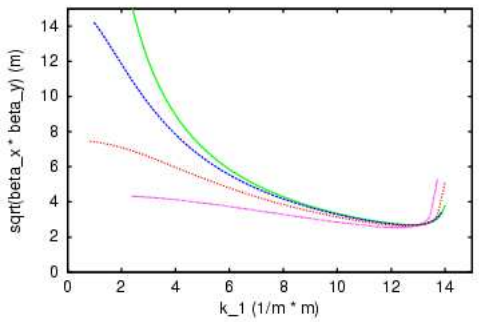




μ_x = μ_y







Curves: no focusing, 1 GeV,
500 MeV, 300 MeV

Beam line to dump and Bypass

Undulator beam line

1. High intensity mode:
   - $\sigma x \cdot \sigma y \geq 4$ mm² at window
2. OTR $\Delta E/E$ measurement:
   - $\sigma x \cdot \sigma y \geq 0.1$ mm² at wind.
   - $\beta \approx 0.1$ m at OTR
3. e^- beam diagnostics in EXP (FIR undulator):
   - $\beta x,y < 50$ m
4. Commissioning:
   - Nbunches < 100

Bypass beam line

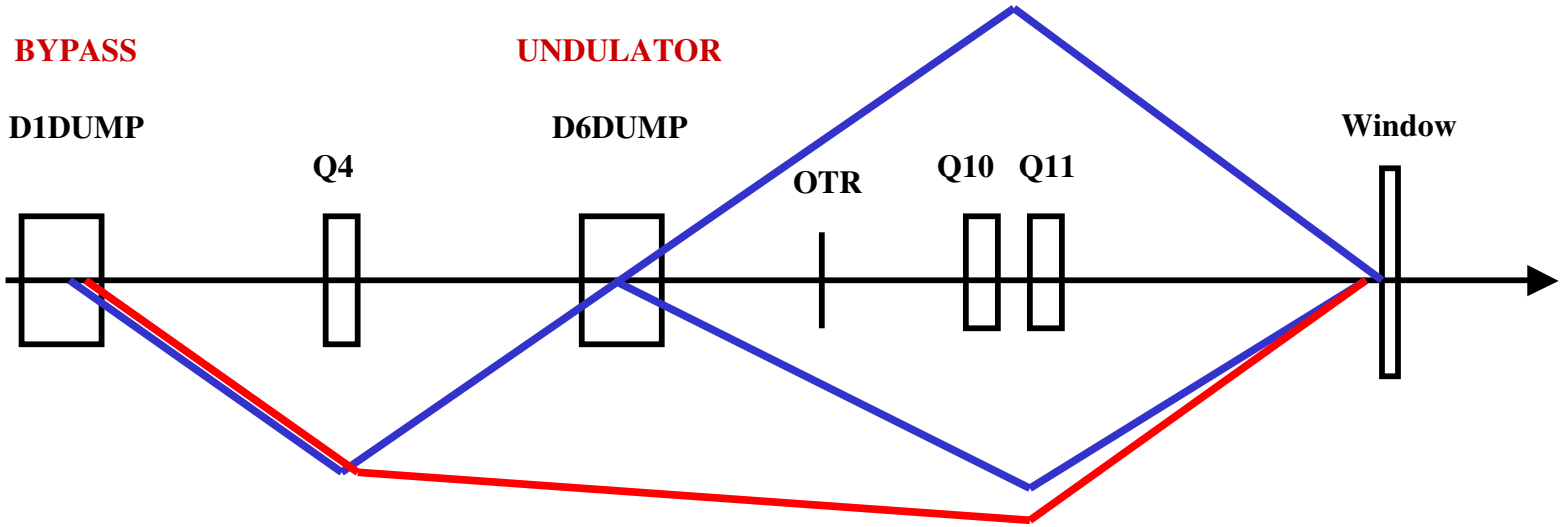
1. High intensity mode:
   - $\sigma x \cdot \sigma y \geq 4$ mm² at window
2. OTR $\Delta E/E$ measurement:
   - $\sigma x \cdot \sigma y \geq 0.1$ mm² at wind.
   - $\beta \approx 0.1$ m at OTR
3. Material test facility:
   - $\sigma x \cdot \sigma y \leq 150 \times 150$ μm² at target
4. Commissioning:
   - Nbunches < 100

Beam line to dump: Dispersion

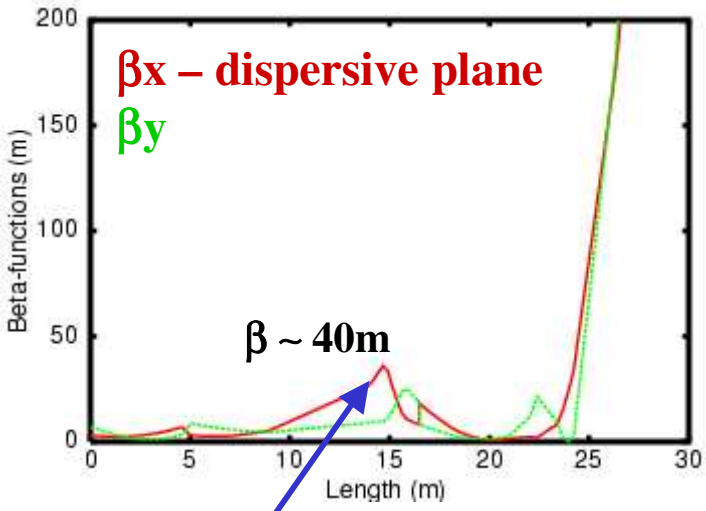
At exit window (M. Schmitz): dispersion D ≈ 0 (D < 0.5 m)

Solution 1 : Q10/Q11DUMP have fixed strengths (M. Schmitz)

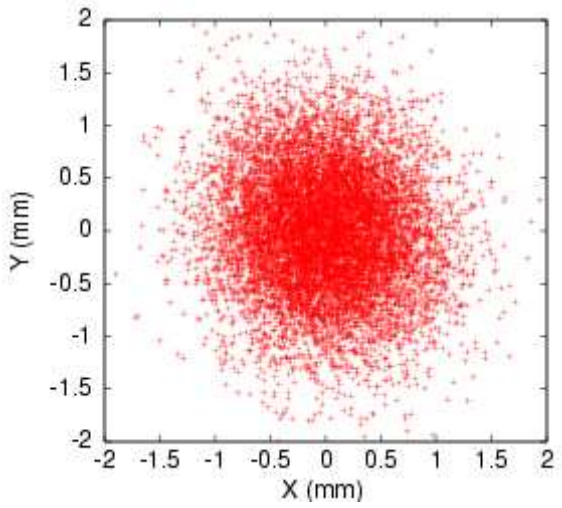
Solution 2 : Q10/11DUMP are different for beams from undulator and bypass, Q4 is weaker



Beam line from undulator to dump: $D_{window} \sim 0$



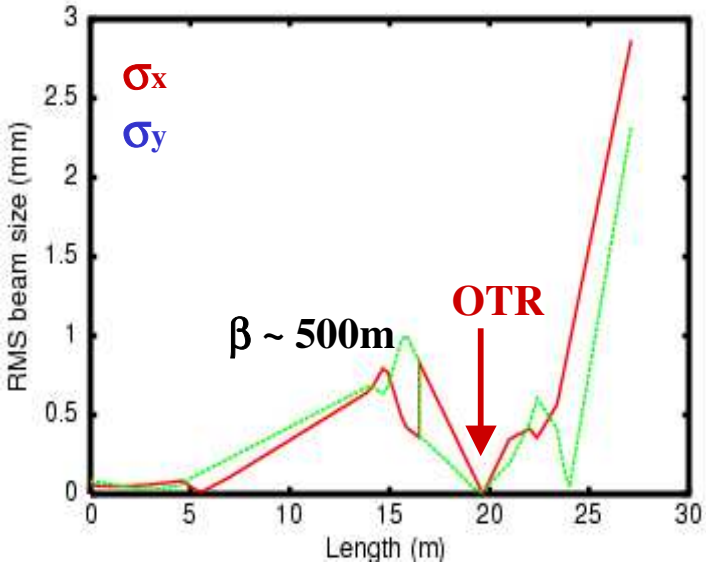
e^- beam diagnostics in EXP



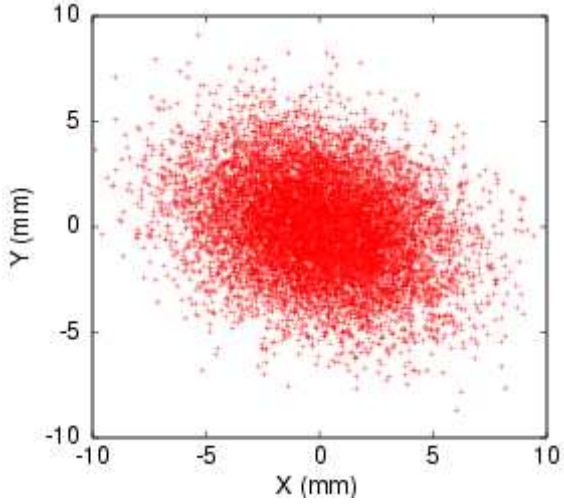
Beam spot size at window

$E_0 = 1$ GeV

$\varepsilon_{nx,ny} = 2$ μm



RMS beam sizes along the line for full operation and OTR measurement

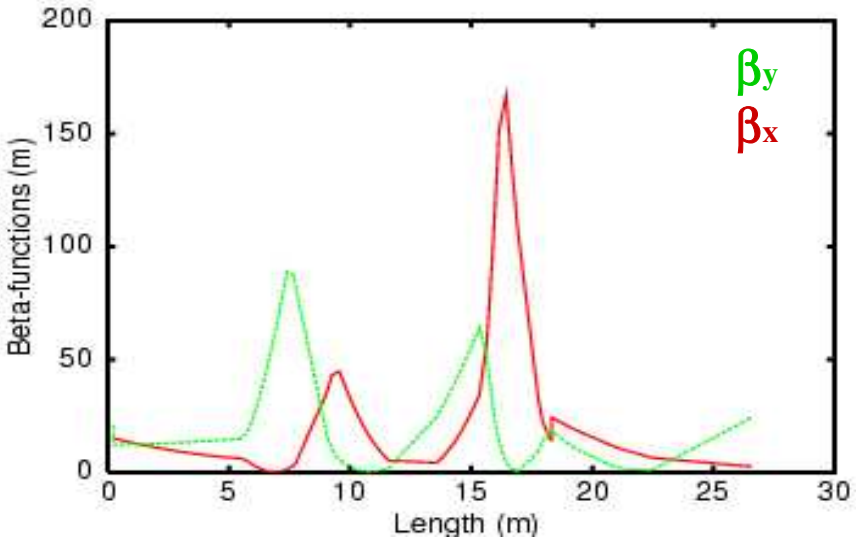


Beam spot size at window

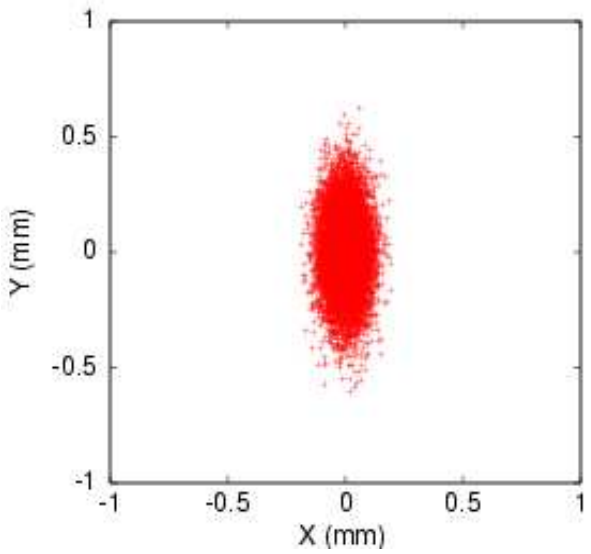
Bypass beam line

1. Input beam parameters: fixed point in Collimator section.
2. Tilted section — tilted dogleg + compensation of coupling (3 quads) — is frozen.
3. Straight section (L ≈ 77 m):
   - 2 doublets for material tests
   - 3 quads for beam transport separated by 17 m drifts.
4. Solution 2 for dispersion (different setting of Q10/11DUMP quadrupoles for two beam lines) simplifies the matching from the bypass to the dump line.

Bypass tilted section



Statistical beta functions
along the tilted section



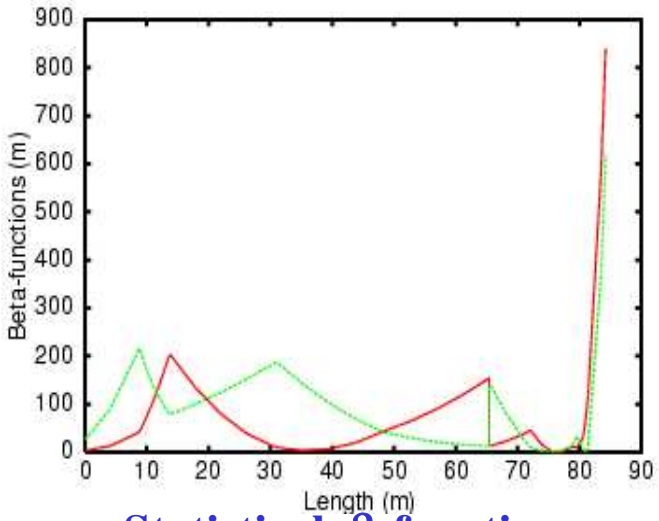
Tracking results: X-Y plane
at the exit of tilted section

Matrix of tilted section:

-0.374521	6.429117	0.000004	0.000011
-0.184375	0.494940	0.000000	0.000002
0.000004	0.000011	-0.374513	6.429141
0.000000	0.000002	-0.184373	0.494944

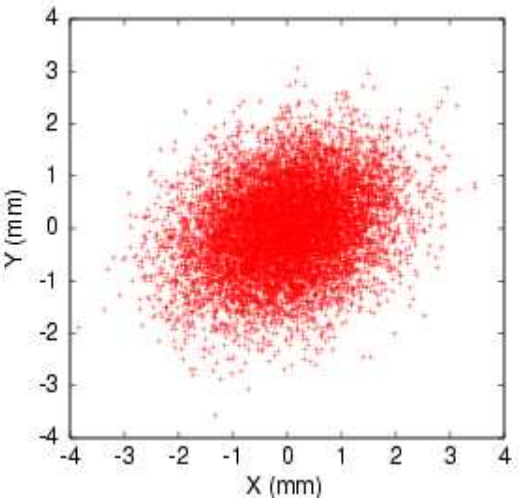
Gaussian beam:
E_0 = 1 GeV
$\varepsilon_{nx,ny}$ = 2 μm

Straight section of Bypass and Beam line to dump: Solution 2 for dispersion



Statistical β-functions

(x refers to dispersive plane)



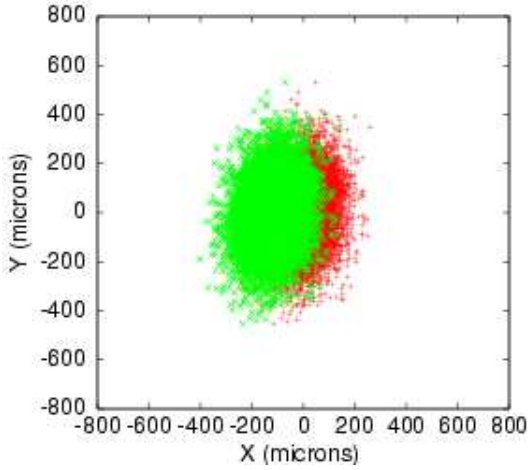
Tracking results:

X-Y plane at window

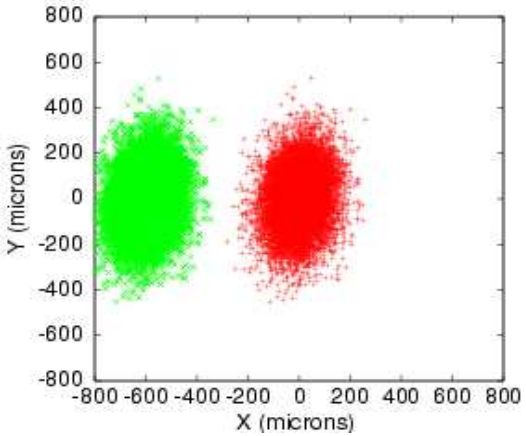
Gaussian beam:

E_0 = 1 GeV

$\varepsilon_{nx,\,ny}$ = 2 μm



ΔE / E = 10^{-4}



ΔE / E = 5 ·10^{-4}

Tracking results:

X-Y plane at OTR9

D ≈ -1.2 m

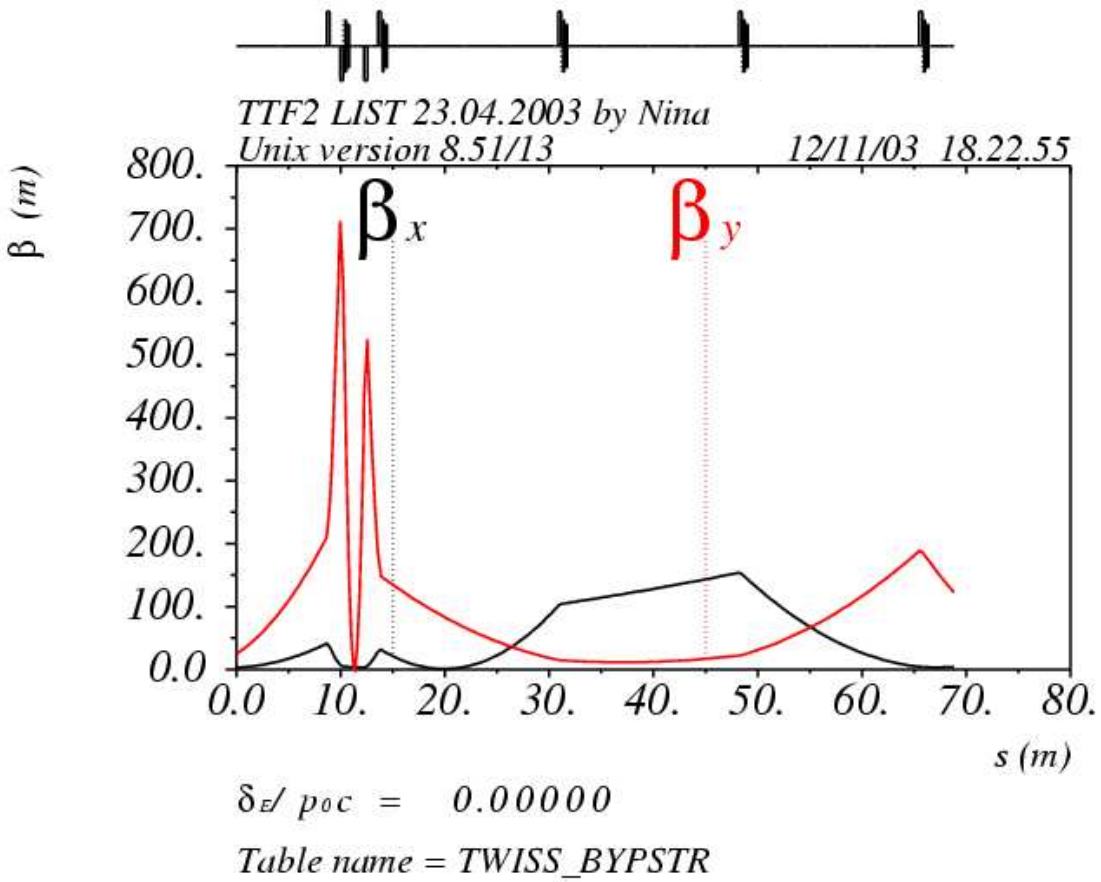
Gaussian beam:

E_0 = 1 GeV

$\varepsilon_{nx,ny}$ = 10 μm

ΔE / E = 0

Material tests in Bypass



At target:
β_x , $\beta_y \approx 4$ m

$E_0 = 750$ MeV
$\varepsilon_n = 10$ μm
$\sigma_{x,y} \sim 165$ μm