Optics studies at FLASH in 2016-2017.

FEL-Seminar

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Matching of the actual optics to design optics.

Task: Change quadrupoles upstream of the reference point in a way that Twiss parameters of measurement are equal to design Twiss parameters.

Need:
1. Optics engine ⇒ MAD8 + linac extension = LMAD
2. Actual optics of FLASH ⇒ read out magnet currents and feed into LMAD ⇒ script do this.
3. Matching engine ⇒ LMAD (SIMPLEX, MIGRAD, LMDIF)

- Quality factors for comparison of actual and design optics:

mismatch parameter: $m_p = \frac{1}{2}(\beta\hat{\gamma} - 2\alpha\hat{\alpha} + \hat{\beta}\gamma)$

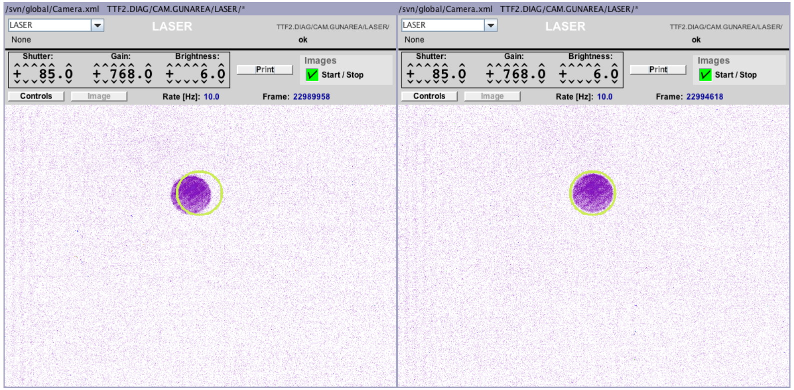
mismatch amplitude: $\lambda_p = m_p + \sqrt{m_p^2 - 1}$

⇒ The matching is done in a general way.
User can decide which point he wants to match in the beam line (FLASH1/2)

some measurements

some pre-setups before measuring beam sizes

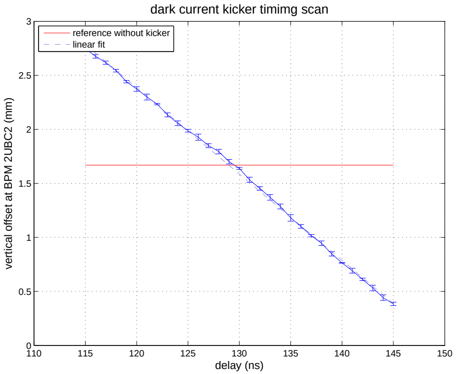
1. check laser position on virtual cathode



some measurements

some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
2. dark current kicker timing scan(?)



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some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
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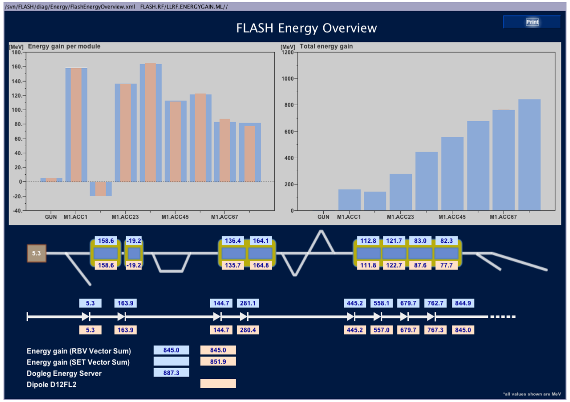
3. choose right energy profile



some measurements

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1. check laser position on virtual cathode
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3. choose right energy profile
4. check machine optics fit to energy profile

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5. measuring on-crest phases

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6. setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)

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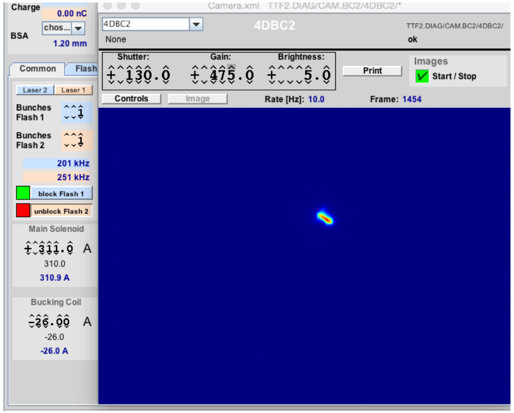
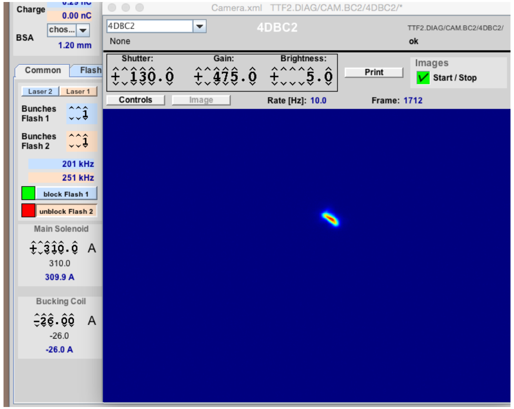
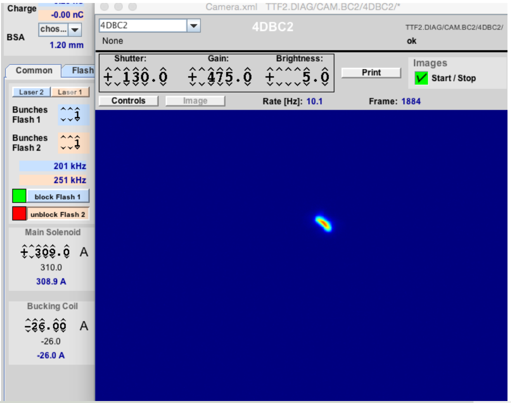
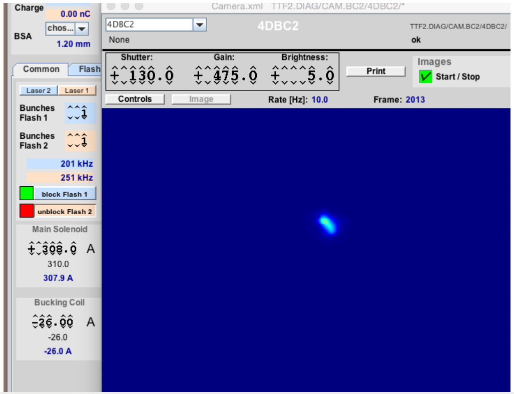
7. steering of the orbit in ACC1









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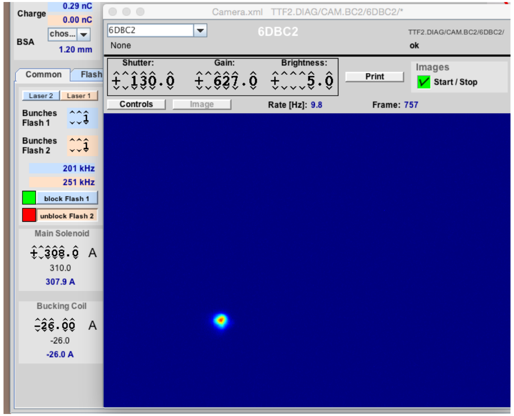

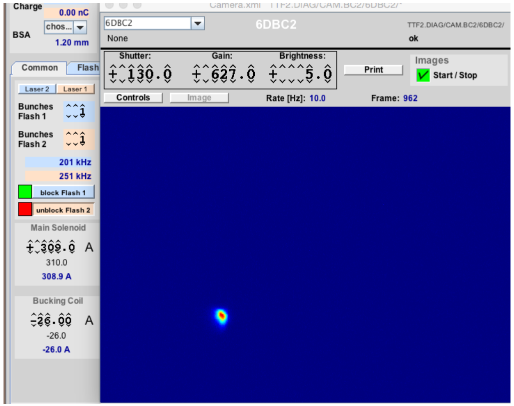

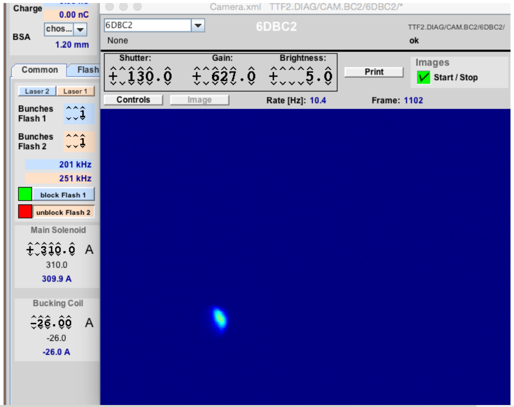

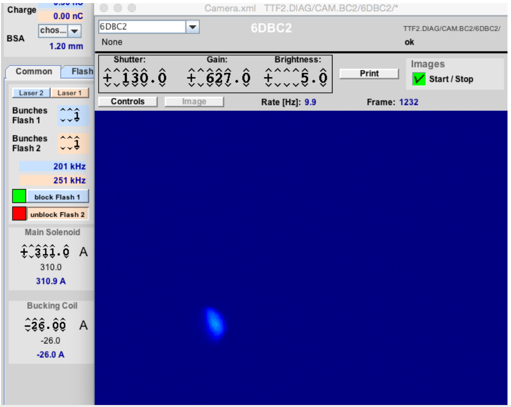

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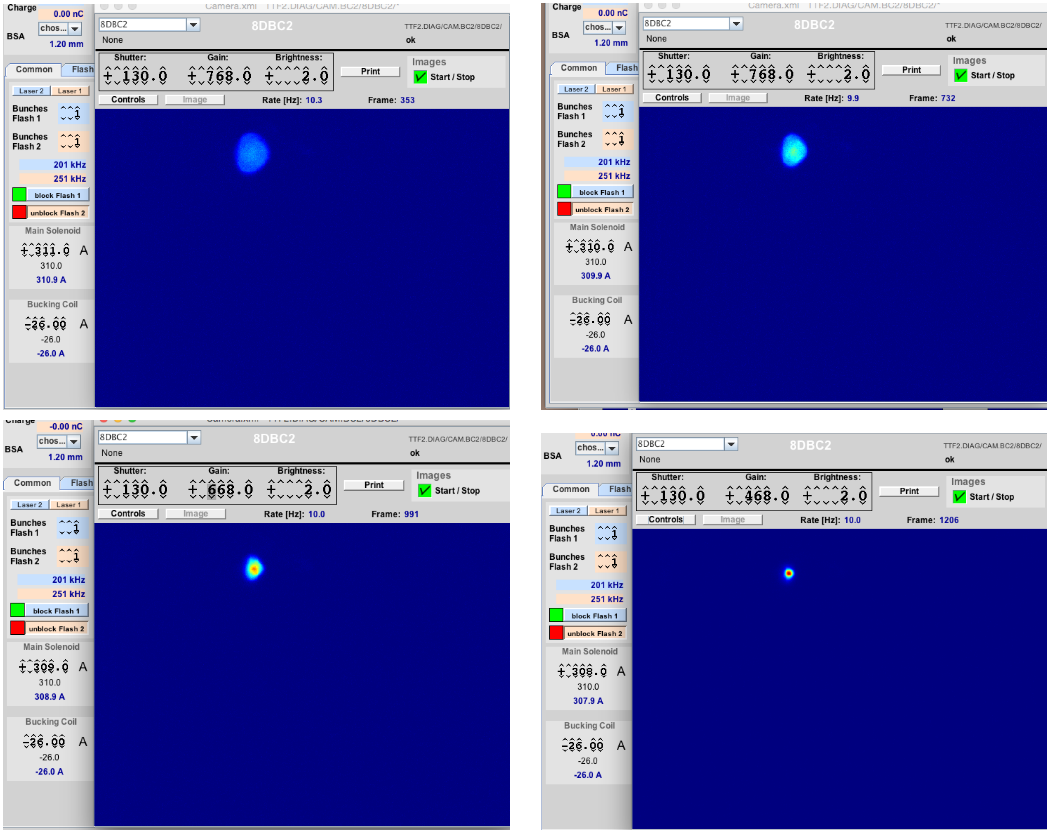

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1. check laser position on virtual cathode
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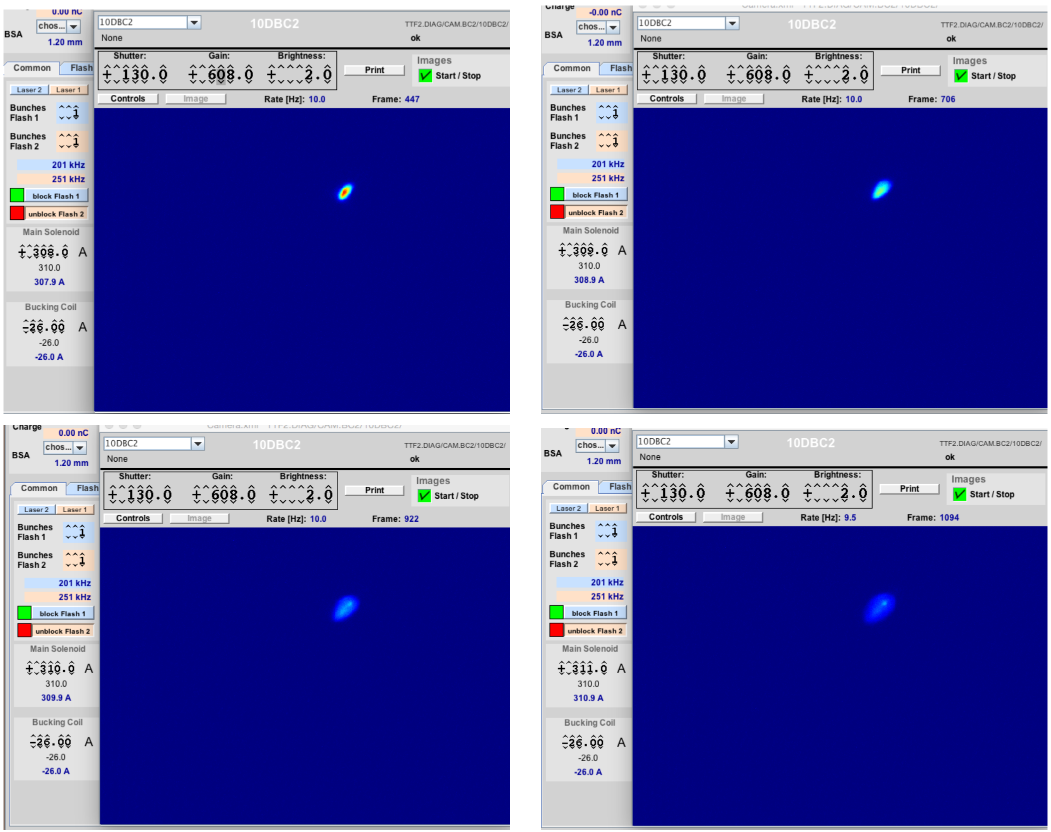
3. choose right energy profile
4. check machine optics fit to energy profile
5. measuring on-crest phases
6. setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
7. steering of the orbit in ACC1
8. setup minimum E-spread



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some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
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3. choose right energy profile
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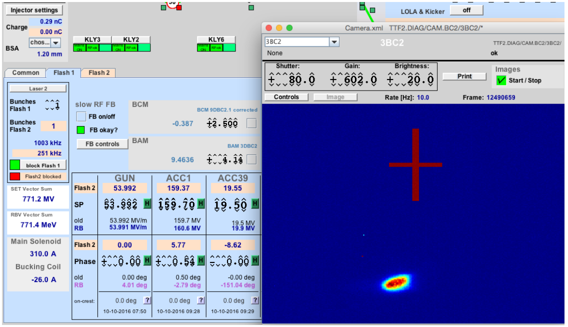
5. measuring on-crest phases
6. setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
7. steering of the orbit in ACC1
8. setup minimum E-spread
9. optimizing beam spots on DBC2 screens using solenoid current



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1. check laser position on virtual cathode
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3. choose right energy profile
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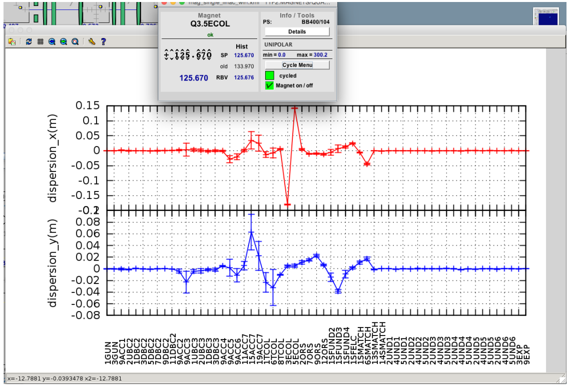
5. measuring on-crest phases
6. setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
7. steering of the orbit in ACC1
8. setup minimum E-spread
9. optimizing beam spots on DBC2 screens using solenoid current
10. close dispersion in dogleg and FL2EXTR



some measurements

injector matching for different charges

charge: 0.29 nC, BSA: 1.2 mm

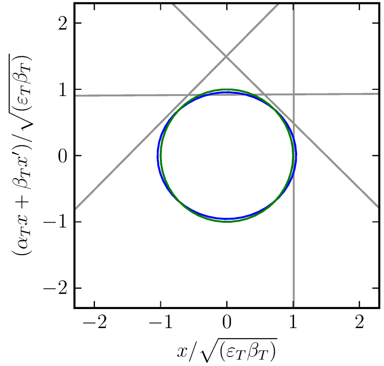
4DBC2 6DBC2 8DBC2 10DBC2

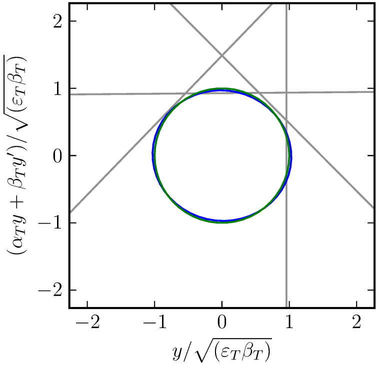
β_T = 2.45 m β_M = 2.68 +- 0.07 m
α_T = -1.18 α_M = -1.30 +- 0.04
ε_T = 0.49 um ε_M = 0.49 +- 0.01 um

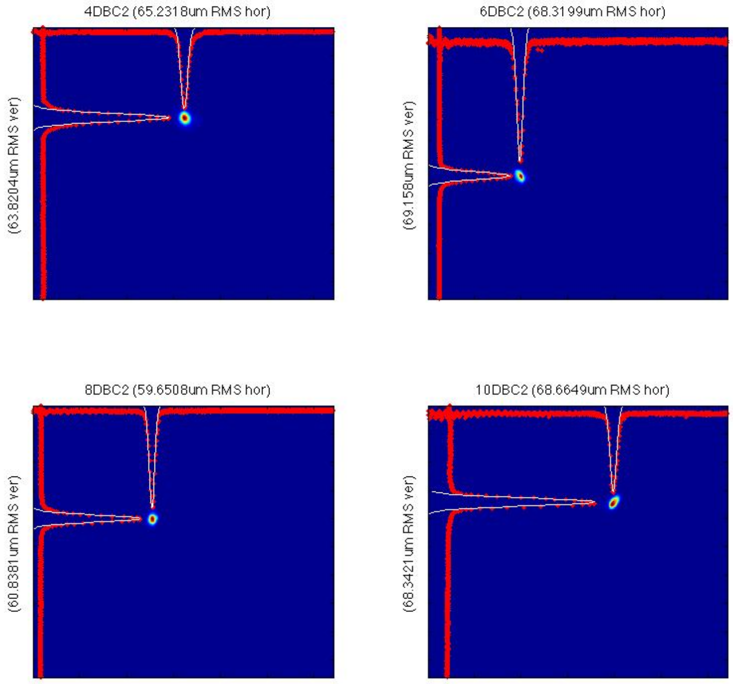
m_P = 1.00 λ_P = 1.09

β_T = 2.58 m β_M = 2.73 +- 0.06 m
α_T = 1.24 α_M = 1.34 +- 0.05
ε_T = 0.49 um ε_M = 0.49 +- 0.01 um

m_P = 1.00 λ_P = 1.06







charge: 0.41 nC, BSA: 1.2 mm

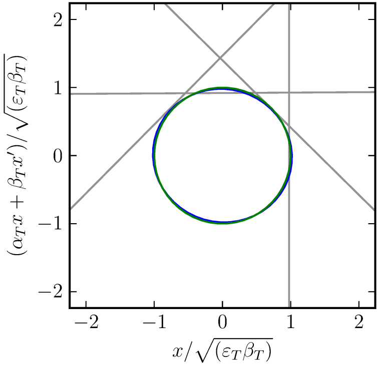
4DBC2 6DBC2 8DBC2 10DBC2

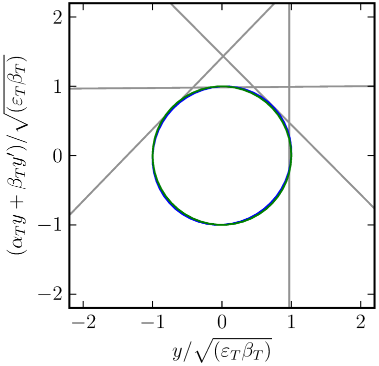
β_T = 2.45 m $\quad$ β_M = 2.55 +- 0.06 m
α_T = -1.18 $\quad$ α_M = -1.20 +- 0.03
ε_T = 0.54 um $\quad$ ε_M = 0.54 +- 0.01 um

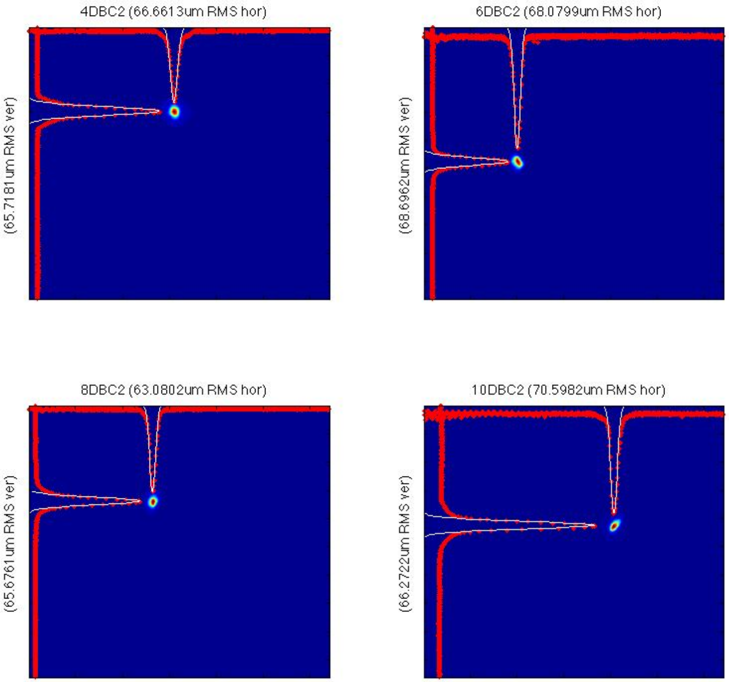
m_P = 1.00 $\quad$ λ_P = 1.05

β_T = 2.58 m $\quad$ β_M = 2.58 +- 0.07 m
α_T = 1.24 $\quad$ α_M = 1.20 +- 0.05
ε_T = 0.51 um $\quad$ ε_M = 0.51 +- 0.02 um

m_P = 1.00 $\quad$ λ_P = 1.04







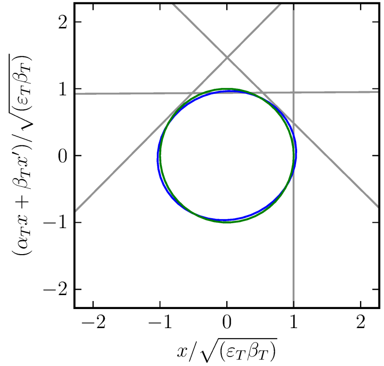
some measurements

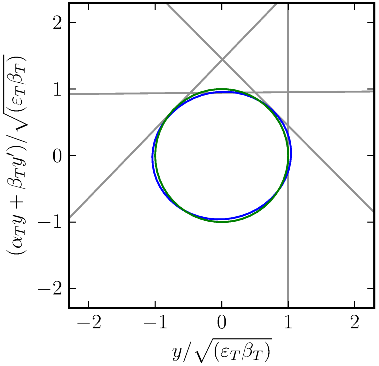
injector matching for different charges

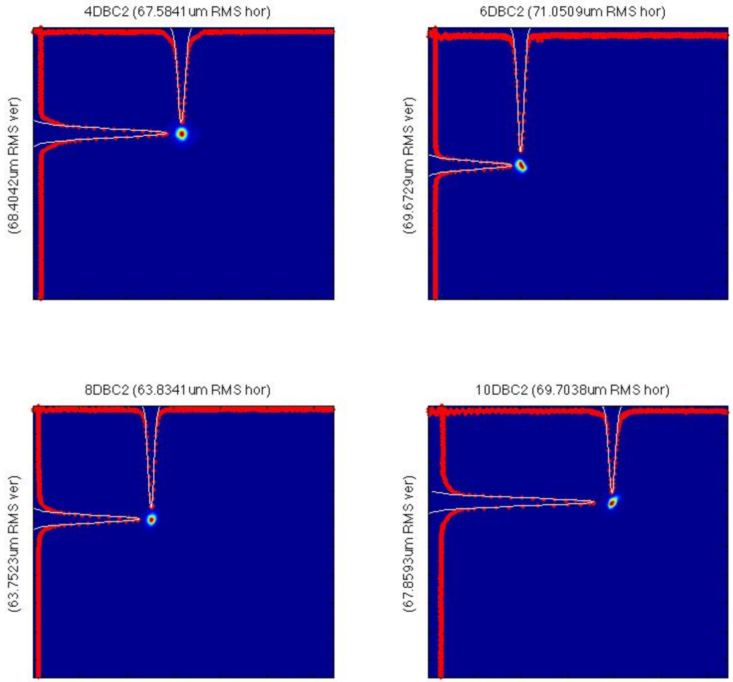
charge: 0.47 nC, BSA: 1.3 mm

4DBC2 6DBC2 8DBC2 10DBC2

β_T = 2.45 m	β_M = 2.63 +- 0.08 m	β_T = 2.58 m	β_M = 2.80 +- 0.08 m
α_T = -1.18	α_M = -1.32 +- 0.04	α_T = 1.24	α_M = 1.31 +- 0.06
ε_T = 0.53 um	ε_M = 0.53 +- 0.01 um	ε_T = 0.52 um	ε_M = 0.52 +- 0.02 um
m_P = 1.00	λ_P = 1.09	m_P = 1.00	λ_P = 1.10







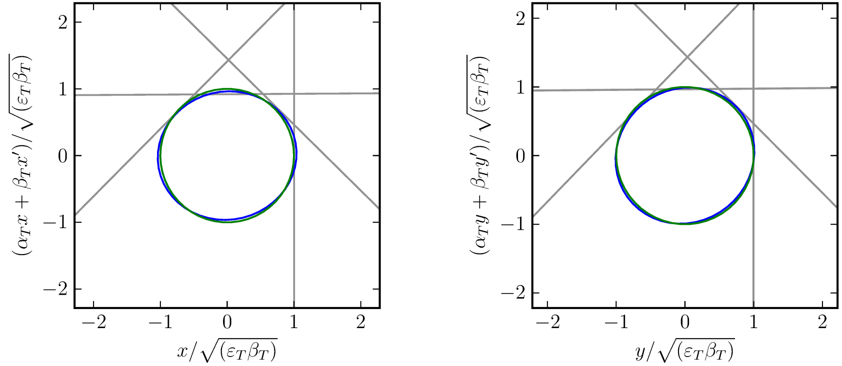
some measurements

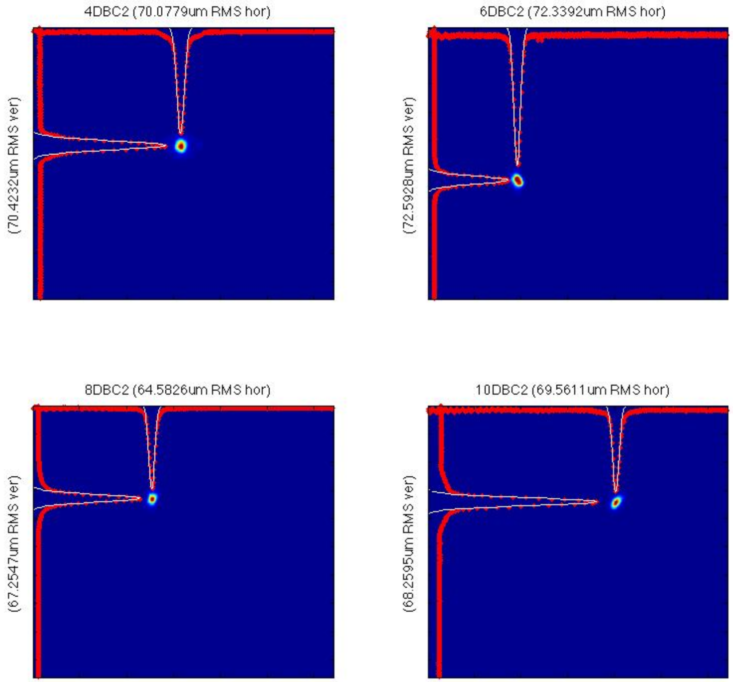
injector matching for different charges

charge: 0.57 nC, BSA: 1.5 mm

4DBC2 6DBC2 8DBC2 10DBC2

β_T = 2.45 m	β_M = 2.64 +- 0.09 m	β_T = 2.58 m	β_M = 2.63 +- 0.07 m
α_T = -1.18	α_M = -1.31 +- 0.05	α_T = 1.24	α_M = 1.20 +- 0.05
ε_T = 0.57 um	ε_M = 0.57 +- 0.01 um	ε_T = 0.55 um	ε_M = 0.55 +- 0.01 um
m_P = 1.00	λ_P = 1.09	m_P = 1.00	λ_P = 1.07





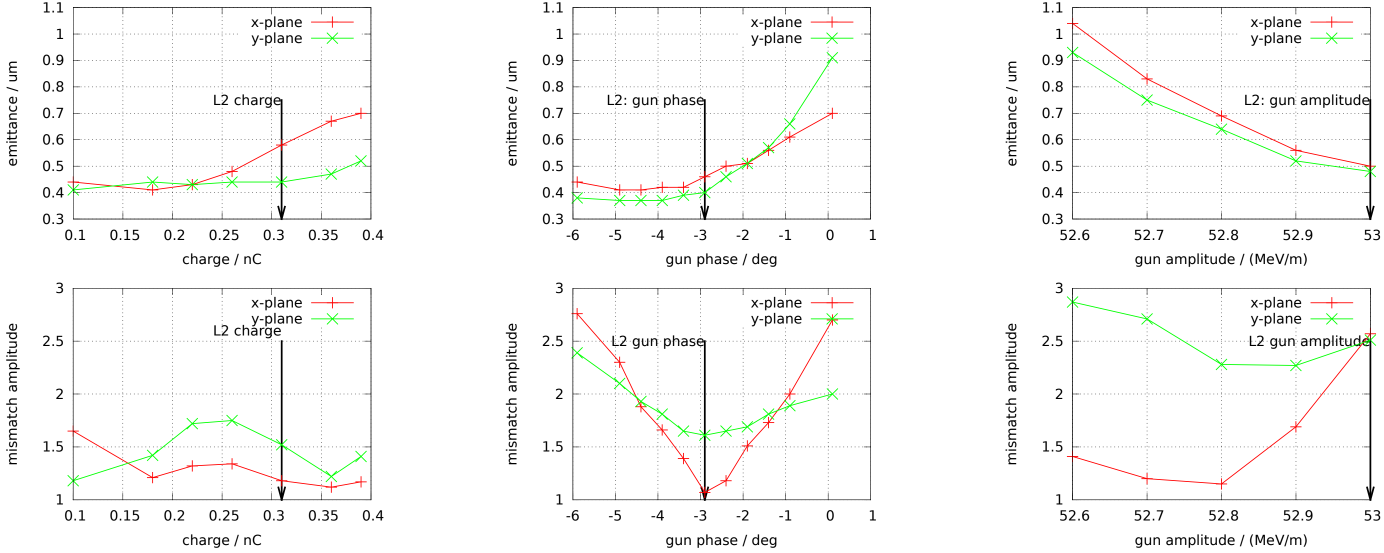
some measurements

Injector match of LASER 1 while LASER 2 is matched using free parameters

LASER 1 pulse energy $\Rightarrow$ bunch charge

GUN phase

GUN gradient



some measurements

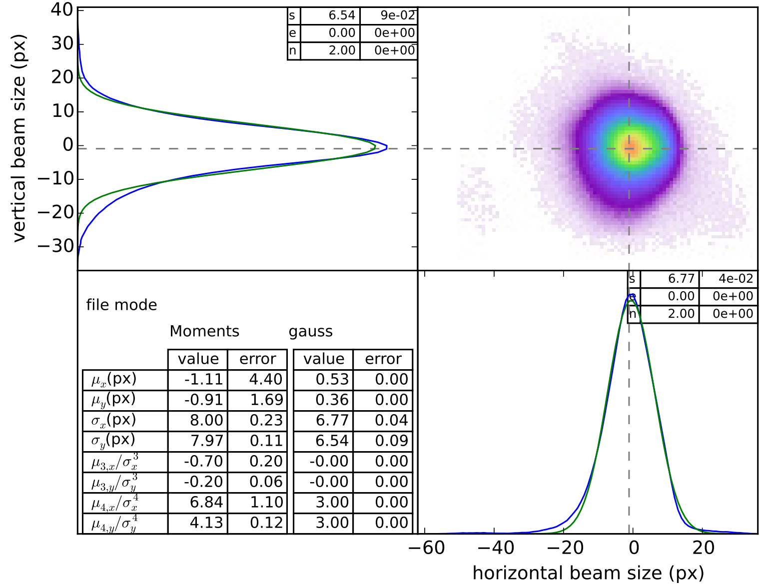
comparing different beam size estimations methods

OTR8DBC2

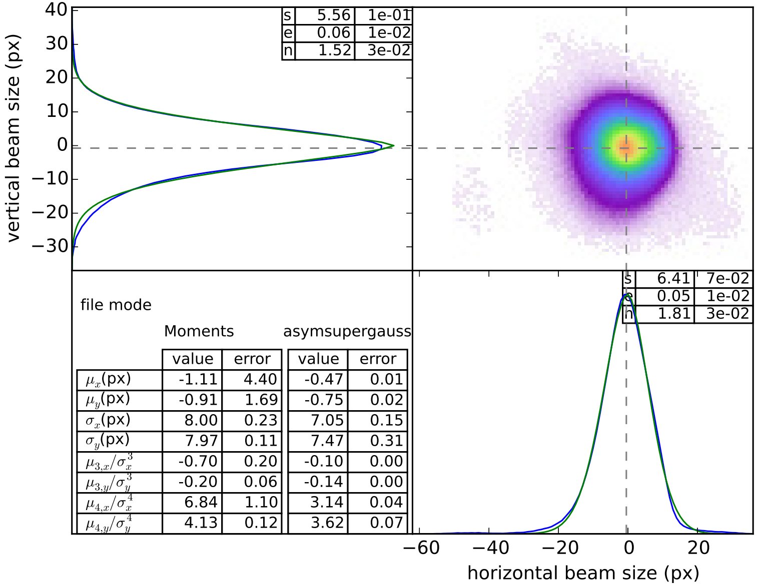
gauss: $f(x) = A\exp^{-\frac{(x-x_0)^2}{2s^2}}$

asymsupergauss: $g(x) = A\exp^{-\frac{|x-x_0|^n}{2|s(1+sign(x-x_0)e)|^n}}$

ver/beamprofile_server/MeasurementData/2016-10-11T140035-OTR.DBC2/Image-OTR.8DBC2-2(



ver/beamprofile_server/MeasurementData/2016-10-11T140035-OTR.DBC2/Image-OTR.8DBC2-



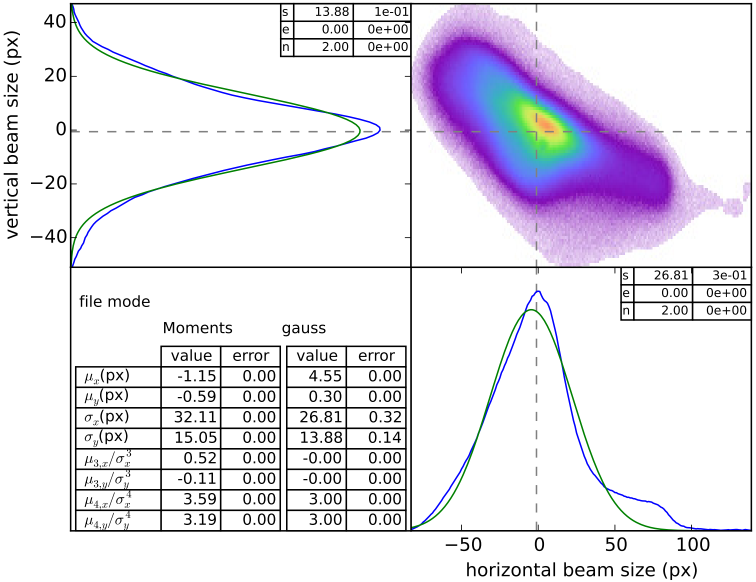
some measurements

comparing different beam size estimations methods

OTR5DBC3

gauss: $f(x) = A \exp^{-\frac{(x-x_0)^2}{2s^2}}$

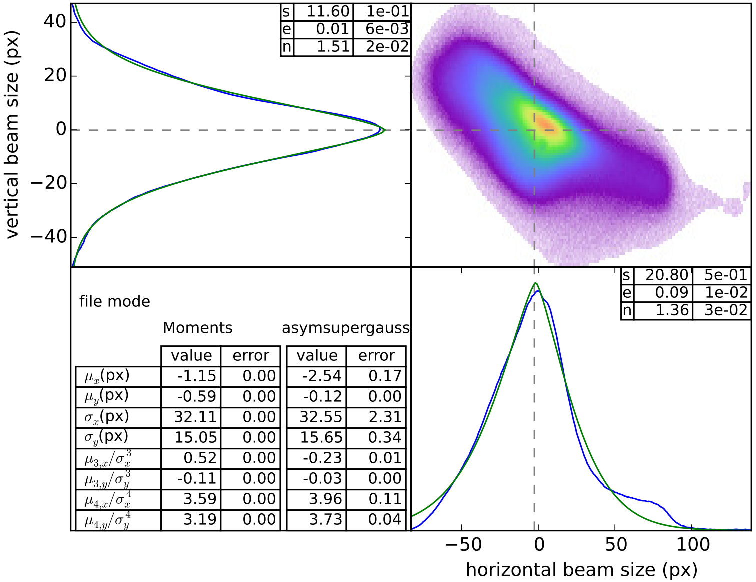
BeamSize_ROI_0010.dat



	Moments value	Moments error	gauss value	gauss error
μ_x(px)	-1.15	0.00	4.55	0.00
μ_y(px)	-0.59	0.00	0.30	0.00
σ_x(px)	32.11	0.00	26.81	0.32
σ_y(px)	15.05	0.00	13.88	0.14
$\mu_{3,x}/\sigma_x^3$	0.52	0.00	-0.00	0.00
$\mu_{3,y}/\sigma_y^3$	-0.11	0.00	-0.00	0.00
$\mu_{4,x}/\sigma_x^4$	3.59	0.00	3.00	0.00
$\mu_{4,y}/\sigma_y^4$	3.19	0.00	3.00	0.00

asymsupergauss: $g(x) = A \exp^{-\frac{|x-x_0|^n}{2|s(1+sign(x-x_0)e)|^n}}$

BeamSize_ROI_0010.dat



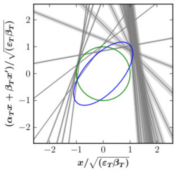
	Moments value	Moments error	asymsupergauss value	asymsupergauss error
μ_x(px)	-1.15	0.00	-2.54	0.17
μ_y(px)	-0.59	0.00	-0.12	0.00
σ_x(px)	32.11	0.00	32.55	2.31
σ_y(px)	15.05	0.00	15.65	0.34
$\mu_{3,x}/\sigma_x^3$	0.52	0.00	-0.23	0.01
$\mu_{3,y}/\sigma_y^3$	-0.11	0.00	-0.03	0.00
$\mu_{4,x}/\sigma_x^4$	3.59	0.00	3.96	0.11
$\mu_{4,y}/\sigma_y^4$	3.19	0.00	3.73	0.04

some measurements

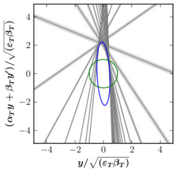
BC3 matching

theory optics	theory optics	theory optics	symmetrized QS
Q1DBC3 $\rightarrow$ OTR5DBC3	Q2DBC3 $\rightarrow$ OTR5DBC3	Q3DBC3 $\rightarrow$ OTR5DBC3	Q3DBC3 $\rightarrow$ OTR5DBC3

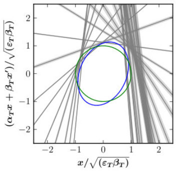
$\beta_T = 10.33$ m $\beta_M = 12.54$ +- 1.69 m
$\alpha_T = -0.91$ $\alpha_M = -1.93$ +- 0.21
$\varepsilon_T = 4.27$ um $\varepsilon_M = 4.27$ +- 0.40 um
$m_P = 1.30$ $\lambda_P = 2.13$



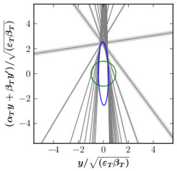
$\beta_T = 19.60$ m $\beta_M = 4.15$ +- 0.10 m
$\alpha_T = -1.26$ $\alpha_M = -0.04$ +- 0.02
$\varepsilon_T = 3.72$ um $\varepsilon_M = 3.72$ +- 0.09 um
$m_P = 2.59$ $\lambda_P = 4.97$



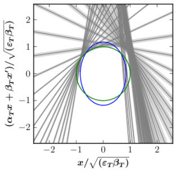
$\beta_T = 9.34$ m $\beta_M = 7.74$ +- 0.30 m
$\alpha_T = 1.43$ $\alpha_M = 0.91$ +- 0.04
$\varepsilon_T = 5.11$ um $\varepsilon_M = 5.11$ +- 0.14 um
$m_P = 1.06$ $\lambda_P = 1.42$



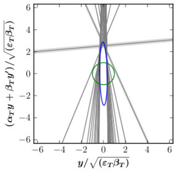
$\beta_T = 25.30$ m $\beta_M = 3.98$ +- 0.12 m
$\alpha_T = -6.86$ $\alpha_M = -0.97$ +- 0.03
$\varepsilon_T = 4.74$ um $\varepsilon_M = 4.74$ +- 0.12 um
$m_P = 3.29$ $\lambda_P = 6.43$



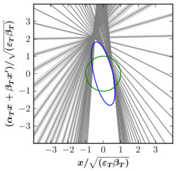
$\beta_T = 6.33$ m $\beta_M = 4.59$ +- 0.61 m
$\alpha_T = 2.86$ $\alpha_M = 2.08$ +- 0.22
$\varepsilon_T = 5.38$ um $\varepsilon_M = 5.38$ +- 0.49 um
$m_P = 1.05$ $\lambda_P = 1.38$



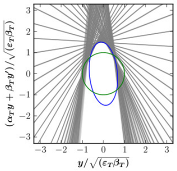
$\beta_T = 39.59$ m $\beta_M = 4.90$ +- 0.25 m
$\alpha_T = -16.40$ $\alpha_M = -1.88$ +- 0.09
$\varepsilon_T = 6.03$ um $\varepsilon_M = 6.03$ +- 0.24 um
$m_P = 4.20$ $\lambda_P = 8.27$



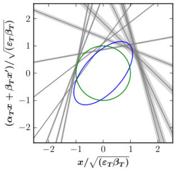
$\beta_T = 5.38$ m $\beta_M = 2.46$ +- 0.20 m
$\alpha_T = 2.60$ $\alpha_M = 1.89$ +- 0.13
$\varepsilon_T = 3.39$ um $\varepsilon_M = 3.39$ +- 0.20 um
$m_P = 1.86$ $\lambda_P = 3.44$



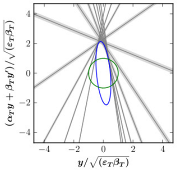
$\beta_T = 4.35$ m $\beta_M = 1.99$ +- 0.07 m
$\alpha_T = 2.11$ $\alpha_M = 1.12$ +- 0.05
$\varepsilon_T = 3.01$ um $\varepsilon_M = 3.01$ +- 0.10 um
$m_P = 1.35$ $\lambda_P = 2.26$



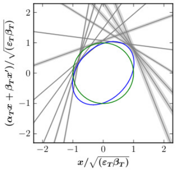
$\beta_T = 10.33$ m $\beta_M = 12.09$ +- 2.49 m
$\alpha_T = -0.91$ $\alpha_M = -1.82$ +- 0.33
$\varepsilon_T = 4.14$ um $\varepsilon_M = 4.14$ +- 0.62 um
$m_P = 1.26$ $\lambda_P = 2.02$



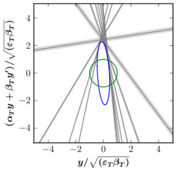
$\beta_T = 19.60$ m $\beta_M = 5.01$ +- 0.23 m
$\alpha_T = -1.26$ $\alpha_M = 0.09$ +- 0.03
$\varepsilon_T = 3.74$ um $\varepsilon_M = 3.74$ +- 0.18 um
$m_P = 2.41$ $\lambda_P = 4.60$



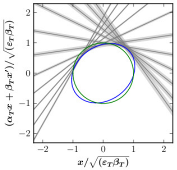
$\beta_T = 9.34$ m $\beta_M = 9.62$ +- 0.53 m
$\alpha_T = 1.43$ $\alpha_M = 1.12$ +- 0.08
$\varepsilon_T = 5.63$ um $\varepsilon_M = 5.63$ +- 0.26 um
$m_P = 1.06$ $\lambda_P = 1.41$



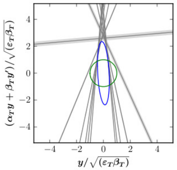
$\beta_T = 25.30$ m $\beta_M = 5.14$ +- 0.47 m
$\alpha_T = -6.86$ $\alpha_M = -1.12$ +- 0.15
$\varepsilon_T = 4.77$ um $\varepsilon_M = 4.77$ +- 0.42 um
$m_P = 2.74$ $\lambda_P = 5.30$



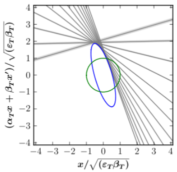
$\beta_T = 6.33$ m $\beta_M = 6.92$ +- 4.10 m
$\alpha_T = 2.86$ $\alpha_M = 2.90$ +- 1.50
$\varepsilon_T = 6.64$ um $\varepsilon_M = 6.64$ +- 3.18 um
$m_P = 1.03$ $\lambda_P = 1.27$



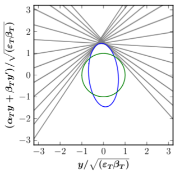
$\beta_T = 39.59$ m $\beta_M = 7.67$ +- 2.82 m
$\alpha_T = -16.40$ $\alpha_M = -2.91$ +- 0.91
$\varepsilon_T = 5.72$ um $\varepsilon_M = 5.72$ +- 1.65 um
$m_P = 2.87$ $\lambda_P = 5.55$



$\beta_T = 5.38$ m $\beta_M = 2.87$ +- 1.26 m
$\alpha_T = 2.60$ $\alpha_M = 2.33$ +- 0.92
$\varepsilon_T = 3.87$ um $\varepsilon_M = 3.87$ +- 1.36 um
$m_P = 2.03$ $\lambda_P = 3.79$



$\beta_T = 4.35$ m $\beta_M = 2.07$ +- 0.24 m
$\alpha_T = 2.11$ $\alpha_M = 1.14$ +- 0.18
$\varepsilon_T = 3.15$ um $\varepsilon_M = 3.15$ +- 0.36 um
$m_P = 1.31$ $\lambda_P = 2.15$



some measurements

BC3 matching, back-tracking measurements to STARTACC2 to compare recontruction results

full data set:

		Q1DBC2→OTR5DBC3		Q2DBC2→OTR5DBC3		Q3DBC2→OTR5DBC3		symm. QS: Q3DBC2→OTR5DBC3	
	Design	Reconstructed	Measured	Reconstructed	Measured	Reconstructed	Measured	Reconstructed	Measured
Location	STARTACC2	STARTACC2	MQ1DBC3.U	STARTACC2	MQ2DBC3.U	STARTACC2	MQ3DBC3.U	STARTACC2	MQ3DBC3.U
Beta x (m)	+7.237	+8.394	+12.537	+6.731	+7.742	+7.280	+4.593	+16.233	+2.456
Alpha x	-0.178	-0.925	-1.927	-0.281	+0.915	+0.025	+2.076	-1.965	+1.891
Beta y (m)	+6.046	+7.907	+4.149	+9.379	+3.983	+12.441	+4.902	+3.042	+1.985
Alpha y	-0.093	+1.576	-0.041	+2.082	-0.967	+2.798	-1.875	-0.690	+1.124

limited data set: 11 points around the waist

	Design	Reconstructed	Measured	Reconstructed	Measured	Reconstructed	Measured	Reconstructed	Measured
Location	STARTACC2	STARTACC2	MQ1DBC3.U	STARTACC2	MQ2DBC3.U	STARTACC2	MQ3DBC3.U	STARTACC2	MQ3DBC3.U
Beta x (m)	+7.237	+8.222	+12.088	+8.019	+9.625	+8.700	+6.917	+16.450	+2.872
Alpha x	-0.178	-0.860	-1.822	-0.477	+1.123	-0.426	+2.897	-2.182	+2.326
Beta y (m)	+6.046	+8.786	+5.013	+9.223	+5.138	+10.068	+7.669	+3.164	+2.072
Alpha y	-0.093	+1.540	+0.087	+1.772	-1.124	+1.905	-2.906	-0.681	+1.141

some measurements

SFUND matching

charge: 0.41 nC, BSA: 1.2 mm

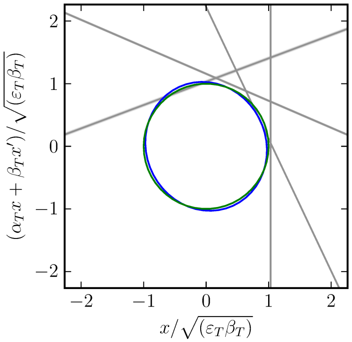
1SFUND1 1SFUND2 1SFUND3 1SFUND4

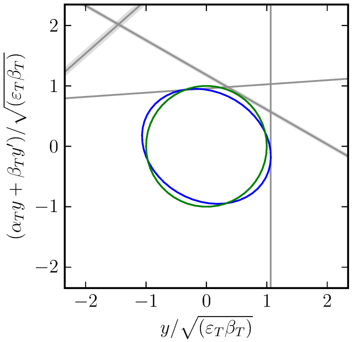
β_T = 4.20 m　　β_M = 3.98 +- 0.05 m　　β_T = 6.74 m　　β_M = 7.67 +- 0.62 m

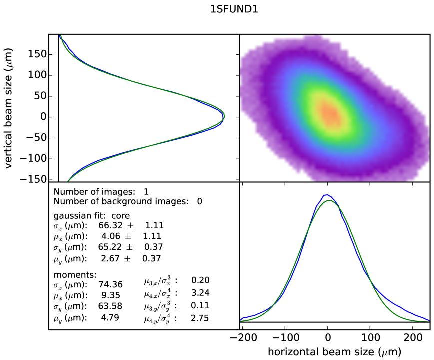
α_T = -0.36　　α_M = -0.28 +- 0.03　　α_T = 1.04　　α_M = 1.37 +- 0.17

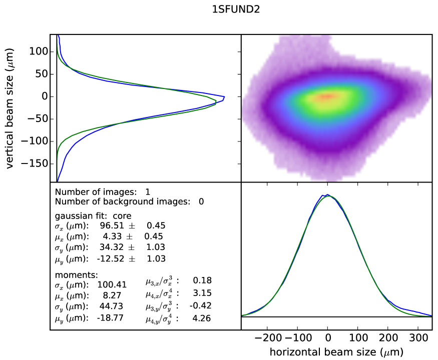
ε_T = 1.49 um　　ε_M = 1.49 +- 0.04 um　　ε_T = 0.85 um　　ε_M = 0.85 +- 0.07 um

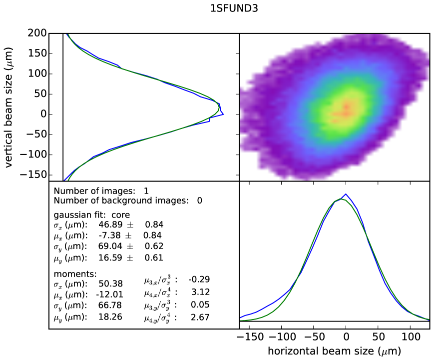
m_P = 1.00　　λ_P = 1.09　　m_P = 1.02　　λ_P = 1.24

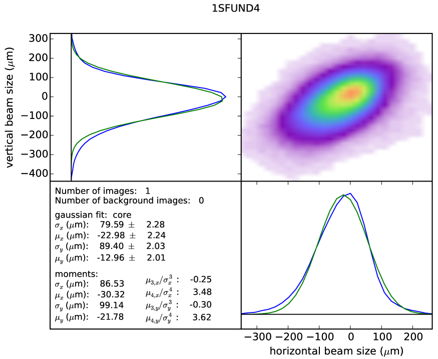












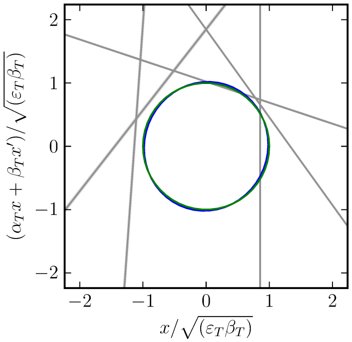
some measurements

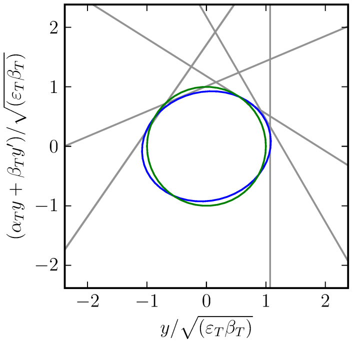
undulator match

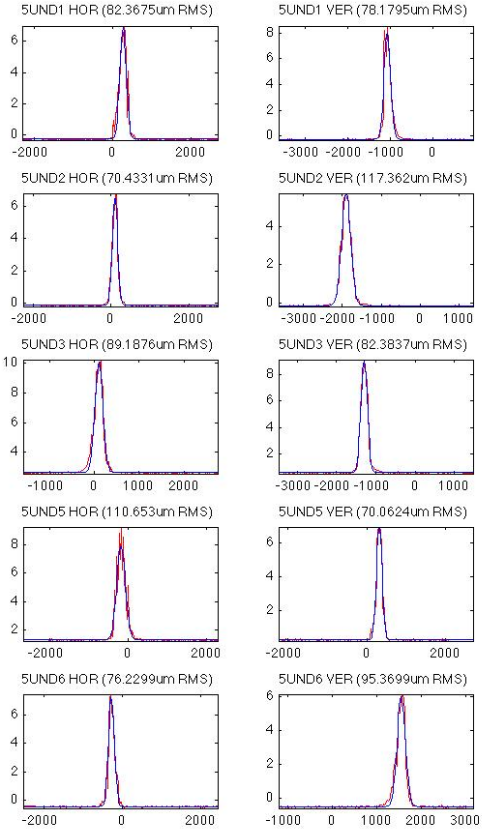
charge: 0.41 nC, BSA: 1.2 mm

WIRE5UND1 WIRE5UND2 WIRE5UND3 WIRE5UND5 WIRE5UND6

β_T = 13.06 m	β_M = 12.60 +- 0.57 m	β_T = 6.30 m	β_M = 7.40 +- 0.12 m
α_T = 1.18	α_M = 1.11 +- 0.09	α_T = -0.66	α_M = -0.85 +- 0.03
ε_T = 1.08 um	ε_M = 1.08 +- 0.06 um	ε_T = 1.28 um	ε_M = 1.28 +- 0.03 um
m_P = 1.00	λ_P = 1.05	m_P = 1.02	λ_P = 1.19





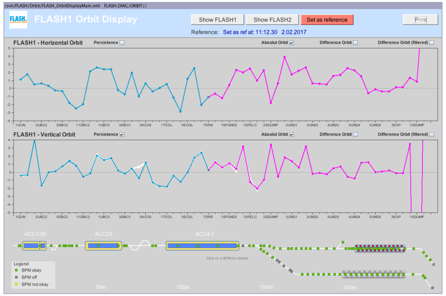


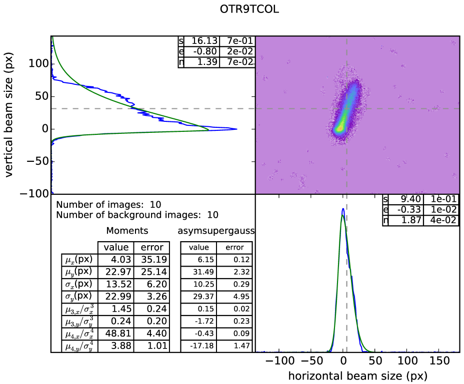
Bunch shape dependence on orbit in BC3.

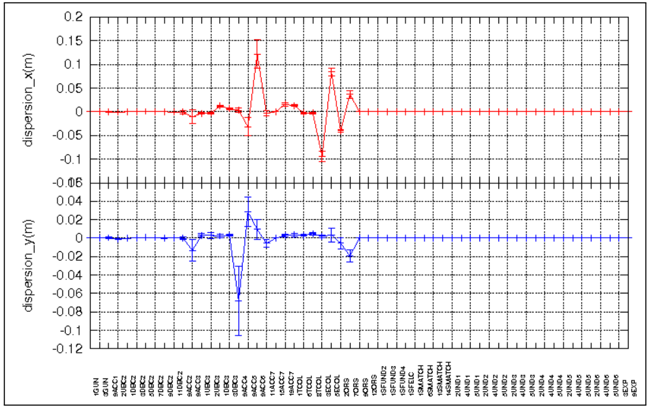
Dispersion is not an explanation:

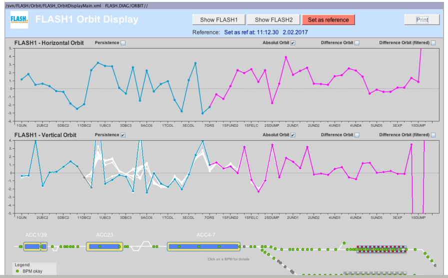
$$\frac{\Delta E}{E} = \frac{200\,\mathrm{keV}}{700\,\mathrm{MeV}} \rightarrow D \sim 1\,\mathrm{m} \text{ or}$$

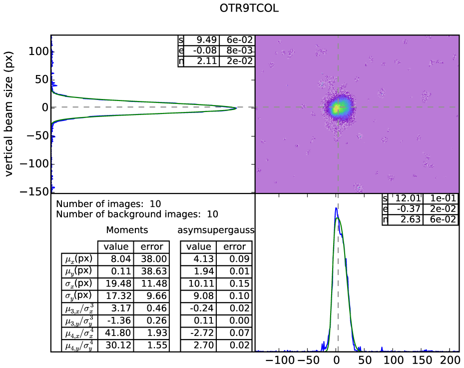
$$\frac{\Delta E}{E} = \frac{8.5\,\mathrm{MeV}}{700\,\mathrm{MeV}} \rightarrow D \sim 2.3\,\mathrm{cm}$$

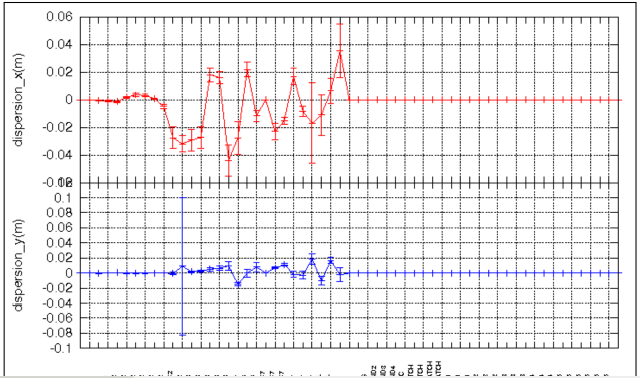










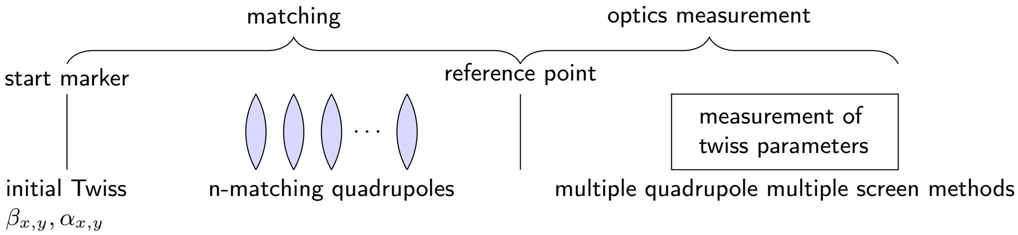


Appendix.

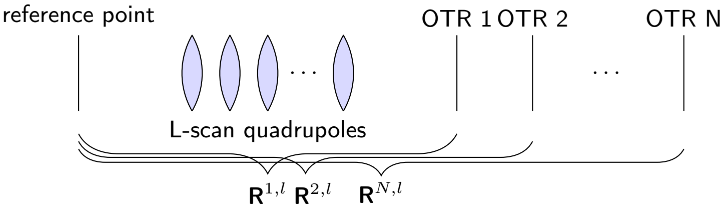
Matching of the actual optics to design optics.

Procedure:

1. Measurement of the current Twiss parameters at a reference point.
2. Reconstruct Twiss parameters at a start marker upstream of the matching quadrupoles.
   ↳ This is done by 'matching' the initial Twiss parameter using LMAD.
3. Match the actual optics to design optics at reference point by user defined quadrupoles.
   ↳ This is done by LMAD.
4. Generate a current list of the new quadrupole strengths.



Emittance and optics measurement.



Special cases:

1. Single quad scan: L=1, N=1
2. 4-screen method: L=0, N=4

Set of equations has to be solved: (with (n,l)-th measured beam size $\sigma_{n,l}$)

$$\mathsf{M}_{(n,l),1\cdots 3} = \left(\left(\mathsf{R}^{(n)}_{l\leftarrow 0}\right)^2_{q,q},\ 2\left(\mathsf{R}^{(n)}_{l\leftarrow 0}\right)_{q,q}\left(\mathsf{R}^{(n)}_{l\leftarrow 0}\right)_{q,p},\ \left(\mathsf{R}^{(n)}_{l\leftarrow 0}\right)^2_{q,p}\right)$$

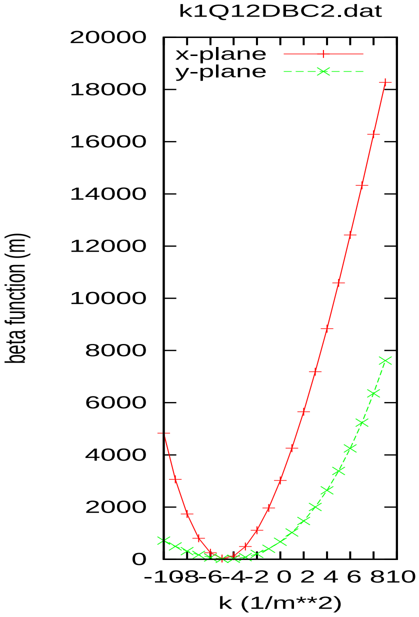
$$\mathsf{M}\begin{pmatrix}\sigma_0^2\\ \mathrm{Cov}(q,p)_0\\ \sigma_{p,0}^2\end{pmatrix} = \begin{pmatrix}\sigma^2_{n=1,l=1}\\ \cdots\\ \sigma^2_{n,l}\\ \cdots\\ \sigma^2_{n=N,l=L}\end{pmatrix}$$

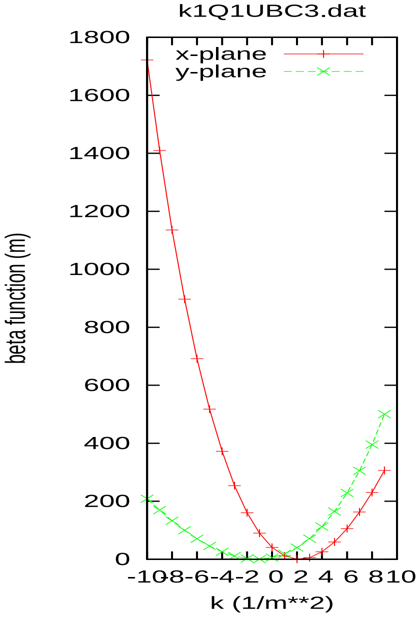
$$\boxed{\begin{aligned}\sigma_0^2 &= \beta_0\varepsilon\\ \mathrm{Cov}(q,p)_0 &= -\alpha\varepsilon\\ \sigma_{p,0}^2 &= \gamma_0\varepsilon\\ \varepsilon^2 &= \sigma_0^2\sigma_{p,0}^2 - \mathrm{Cov}(q,p)_0^2\end{aligned}}$$

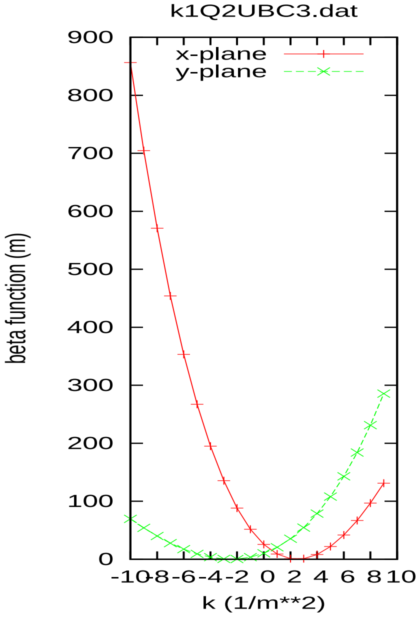
- Transfer matrix **R**
- x-plane: (q,p) = (1,2)
- y-plane: (q,p) = (3,4)

some more quad scans

in theory

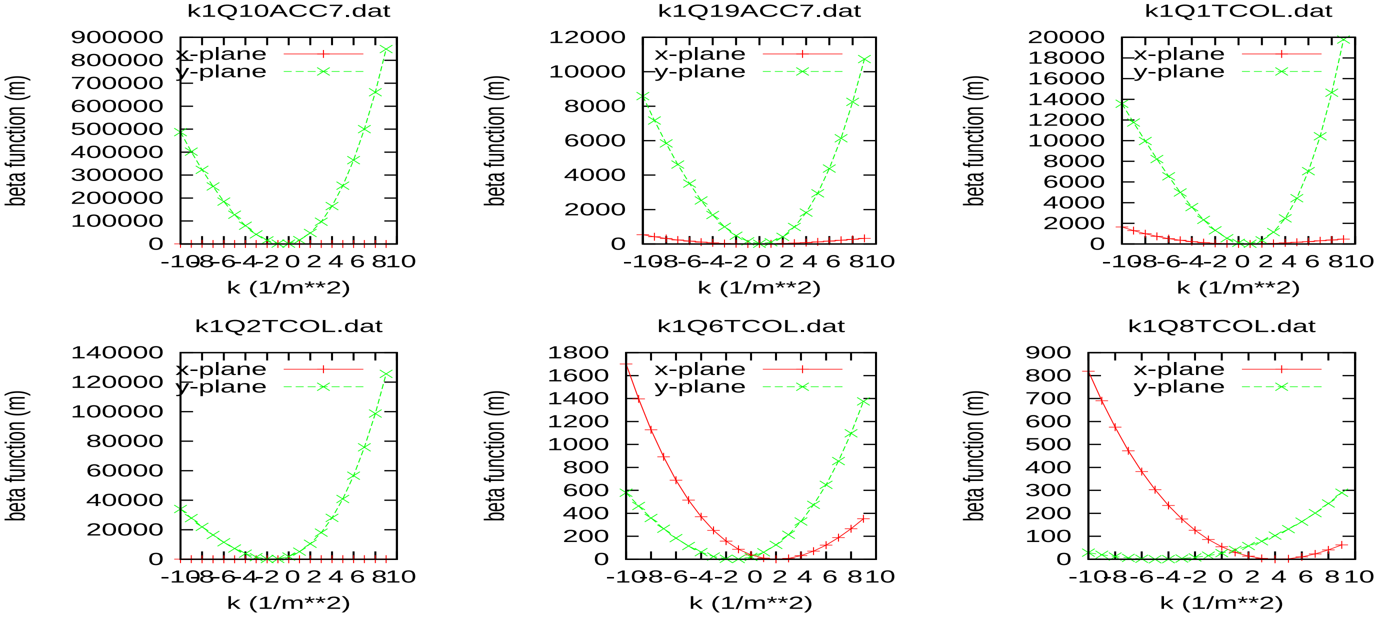






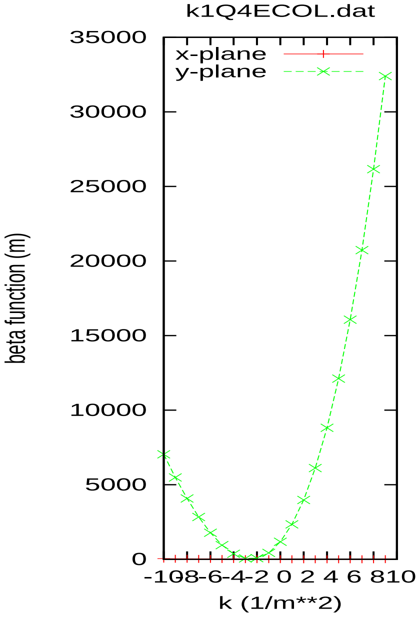
some more quad scans

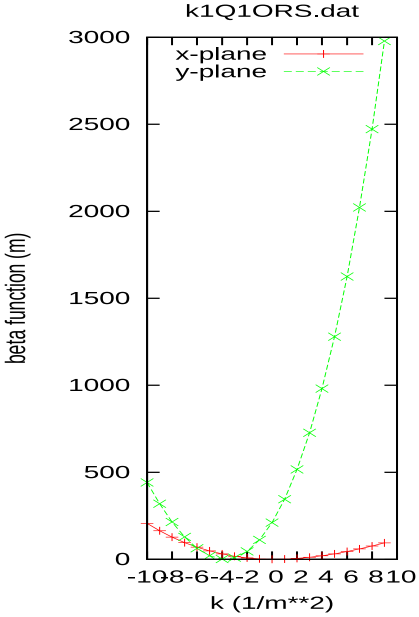
in theory

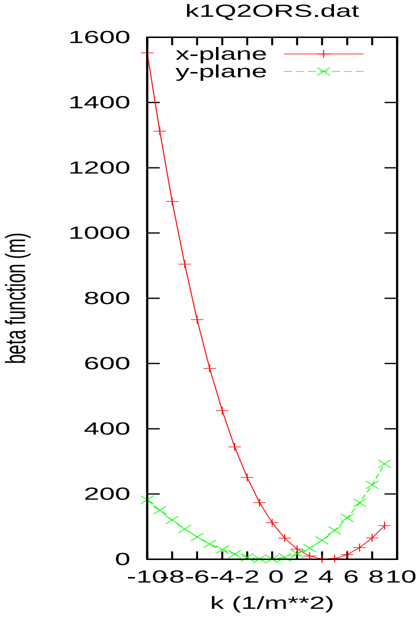


some more quad scans

in theory

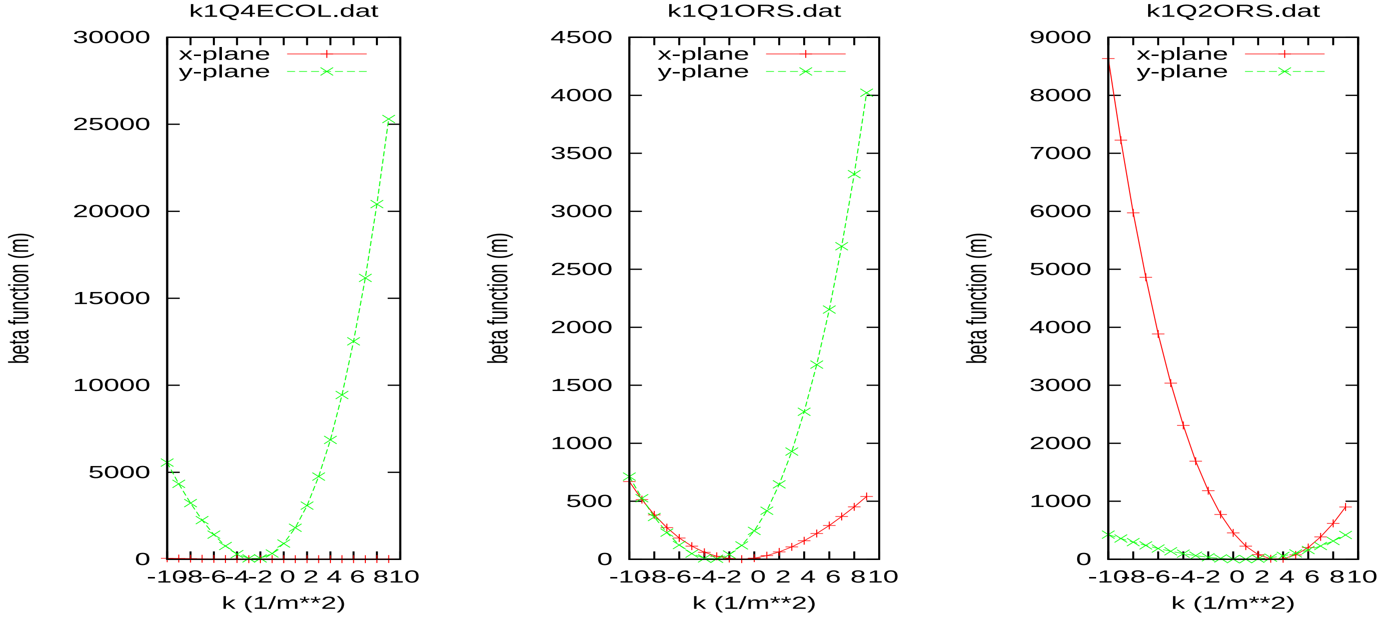






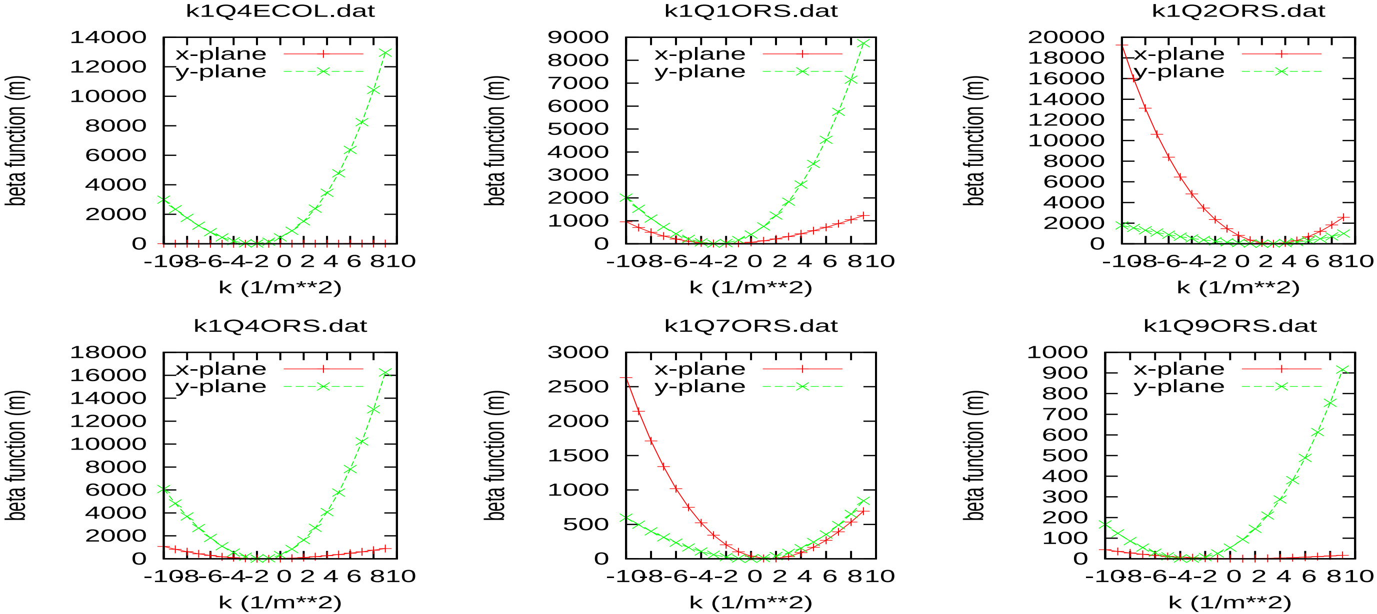
some more quad scans

in theory



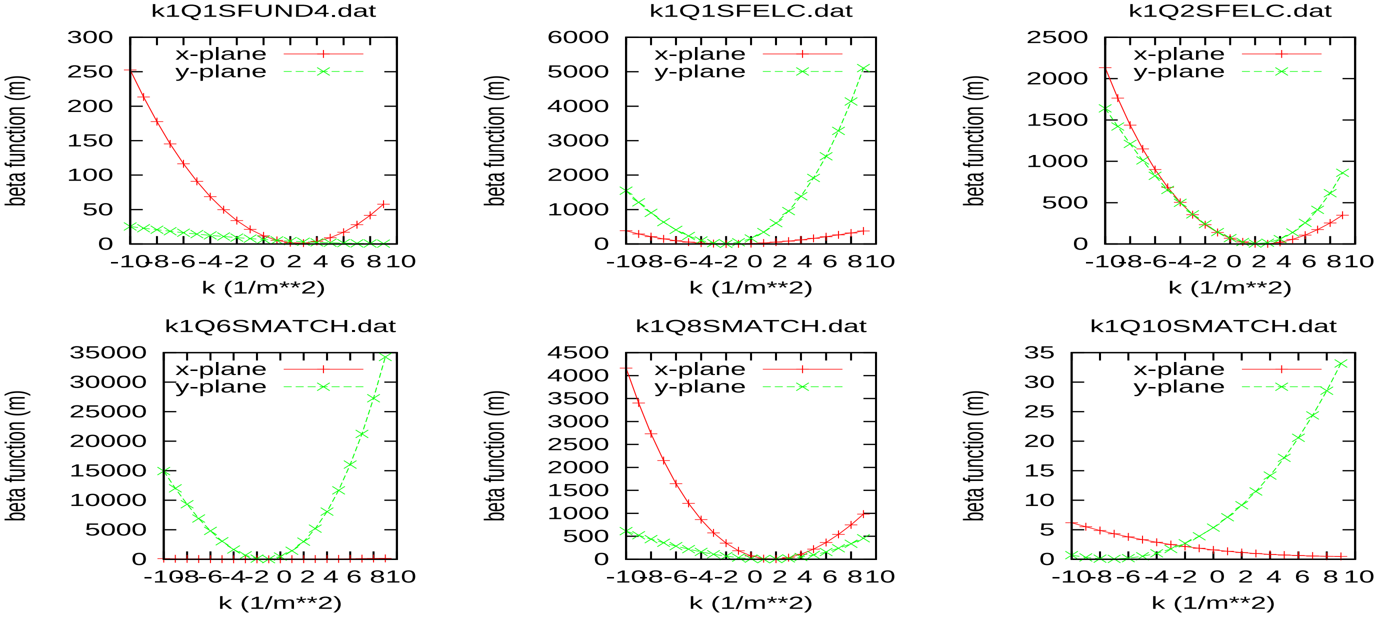
some more quad scans

in theory



some more quad scans

in theory



some more quad scans

in theory