Simulated LOLA Measurements

LOLA setup

imaging: entrance-LOLA to OTR

about reconstruction method of filamentary phase space

simulated LOLA measurement*: no transverse beam dimensions

simulated LOLA measurement*: gaussian transverse shape

about coupler kick (=CK)

simulated LOLA measurement*: no emittance but CK

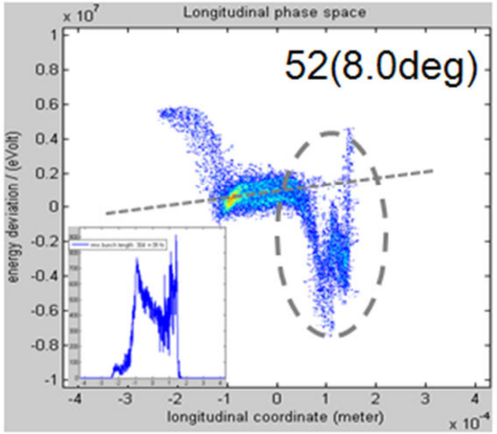
simulated LOLA measurement*: gaussian transv. + CK

simulated LOLA measurement*: CSR + CK

summary

* measurements 16th June 2010, see s2e-meeting in Oct.

middle compression is not understood



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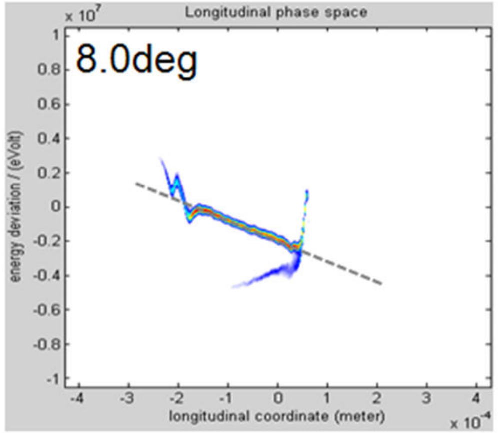


LOLA setup

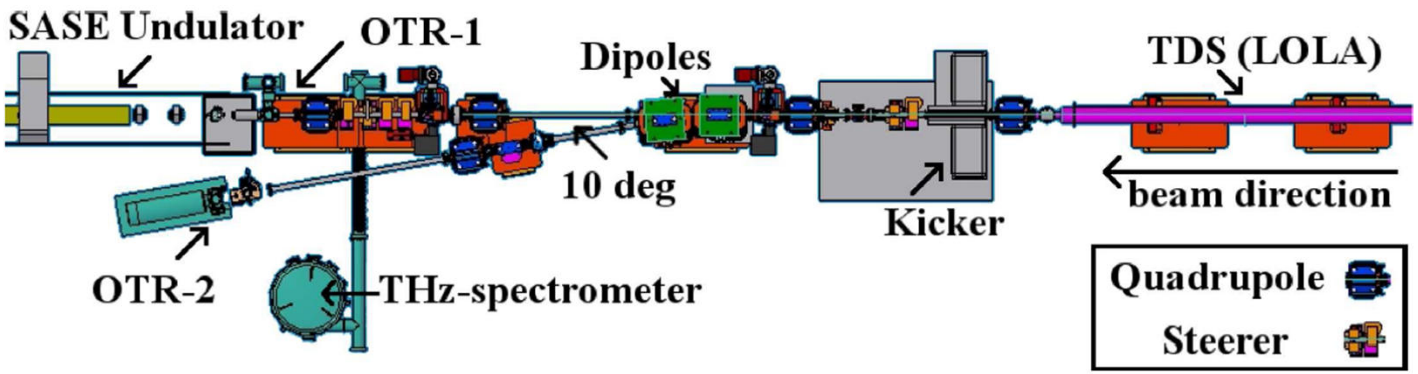


Figure: Aktuelles Design: Installiert im Februar 2010.

LOLA L = 3.826 m; 2.856 GHz
Drift L = 2.693 m
Bend L = 0.447 m; –5 deg
Drift L = 0.131 m
Bend L = 0.447 m; –5 deg
Drift L = 4.481 m
OTR 17.5 μm / pixel

LOLA setup

field expansion in LOLA close to axis
(for symmetry PEC in xz-plane and PMC in yz-plane)

$$\mathbf{E}(\mathbf{r},\mathbf{t}) = \mathrm{Re}\left\{ \begin{pmatrix} 0 \\ E_{y,0}(z) \\ E_{z,y}(z)y \end{pmatrix} \exp(j\omega t) \right\}$$

$$\mathbf{B}(\mathbf{r},\mathbf{t}) = \mathrm{Re}\left\{ \begin{pmatrix} B_{x,0}(z) \\ 0 \\ B_{z,x}(z)x \end{pmatrix} \exp(j\omega t) \right\}$$

with $E_{z,y} - E'_{y,0} = -j\omega B_{x,0}$

$$\mathbf{E} + \mathbf{v}\times\mathbf{B} \approx \mathrm{Re}\left\{ \begin{pmatrix} B_{z,x} x v_y \\ E_{y,0} + B_{x,0} v_z - B_{z,x} x v_y \\ E_{z,y} y - B_{x,0} v_y \end{pmatrix} e^{j\omega t} \right\} = \mathrm{Re}\left\{ \begin{pmatrix} 0 \\ E_{y,0} + B_{x,0} v_z \\ \left(-j\omega B_{x,0} + E'_{y,0}\right) y - B_{x,0} v_y \end{pmatrix} e^{j\omega t} \right\} + O^2$$

we need the transverse field on axis: $E_{y,0}(z), B_{x,0}(z)$

LOLA setup

approach $E_{y,0} + cB_{x,0} = \hat{E}(z)e^{-jk_0 z}$ with $k_0 = \dfrac{\omega}{c}$

$v_z = c$ and $\hat{E}(z)$ slowly compared to cell length

$v_y = 0$

$$V_y = \int \hat{E}(z-s)e^{-jk_0(z-s)}e^{j\frac{\omega}{c}z}dz = e^{jk_0 s}\int \hat{E}(z)dz$$

$$V_z = \cdots = -j\frac{\omega}{c}ye^{jk_0 s}\int \hat{E}(z)dz$$

(Panofsky-Wenzel theorem)

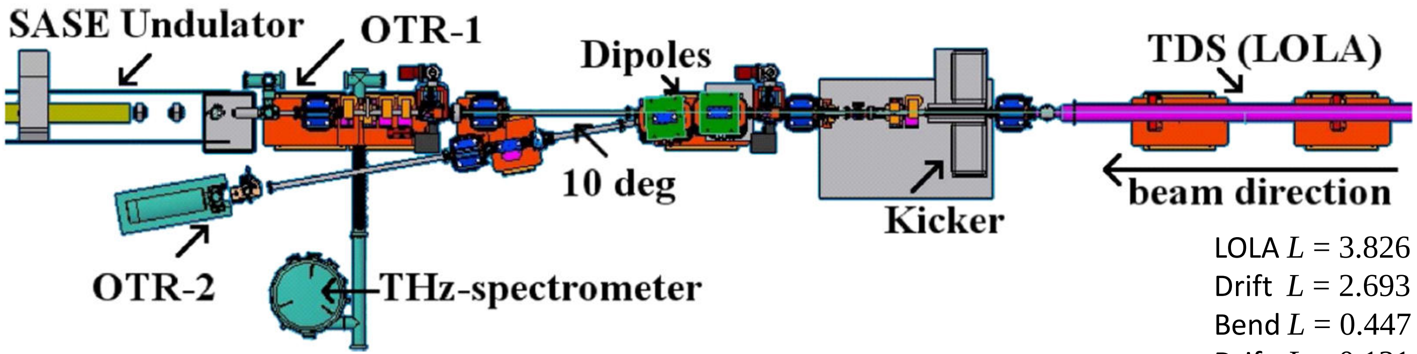
LOLA cavity, in reasonable approximation:

$$\begin{pmatrix} x_2 \\ x_2' \\ y_2 \\ y_2' \\ s_2 \\ \delta_2 \end{pmatrix} = \begin{pmatrix} 1 & L & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & L & KL/2 & 0 \\ 0 & 0 & 0 & 1 & K & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & K & KL/2 & K^2L/6 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_1' \\ y_1 \\ y_1' \\ s_1 \\ \delta_1 \end{pmatrix}$$

with $V_y \approx \pm 6.1\,\mathrm{MV}\sqrt{\dfrac{P}{\mathrm{MW}}}$

$$K = \frac{\omega}{c}\frac{eV_y}{\mathcal{E}}$$

imaging: entrance-LOLA to OTR



LOLA L = 3.826 m; 2.856 GHz
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Bend L = 0.447 m; –5 deg
Drift L = 0.131 m
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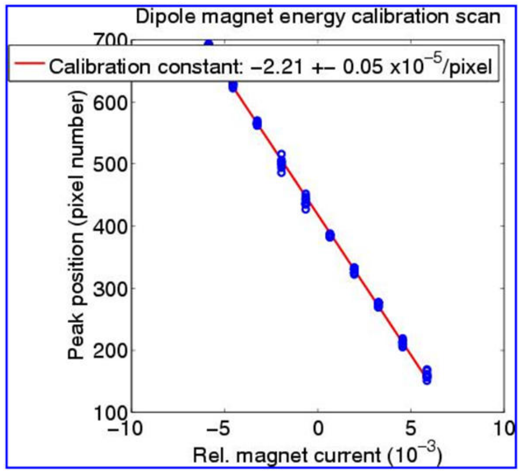
Drift L = 4.481 m
OTR 17.5 µm / pixel

full imaging function entrance-LOLA to OTR

energy calibration; theoretically:

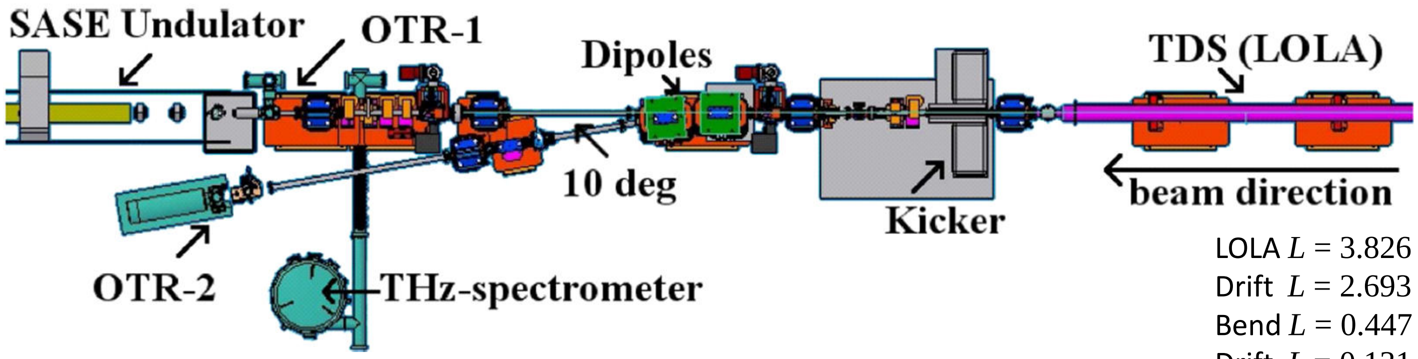
$$\frac{d\mathcal{E}/\mathcal{E}}{\text{pixel}} = 2.007 \cdot 10^{-5}$$



streak calibration; theoretically:

$$\frac{S}{\text{fsec/pixel}} = 17.23 \frac{\mathcal{E}/\text{GeV}}{\sqrt{P/\text{MW}}}$$

imaging: entrance-LOLA to OTR



LOLA L = 3.826 m; 2.856 GHz
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Drift L = 4.481 m
OTR 17.5 µm / pixel

example: $V_y \approx 30\,\mathrm{MV}$

$\mathcal{E} \approx 700\,\mathrm{MeV}$

"time" axis

"energy" axis

desired effect

streak (V_y) with positive sign:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix} \cdot \mathrm{T(Vy,Ene)} = \begin{pmatrix} 1 & 12.022 & 2.282 & 4.365 & 3.808 & 0.872 \\ 0 & 0 & 0.831 & 10.837 & 24.204 & 0 \end{pmatrix}$$

streak with negative sign, "time" axis flipped:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \end{pmatrix} \cdot \mathrm{T(-Vy,Ene)} = \begin{pmatrix} 1 & 12.022 & -2.282 & -4.365 & 3.808 & 0.872 \\ 0 & 0 & -0.831 & -10.837 & 24.204 & 0 \end{pmatrix}$$

imaging: entrance-LOLA to OTR

example: $V_y \approx 30\,\mathrm{MV}$

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"time" axis

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streak with negative sign, "time" axis flipped:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \end{pmatrix} \cdot \mathrm{T(-Vy,Ene)} = \begin{pmatrix} 1 & 12.022 & -2.282 & -4.365 & 3.808 & 0.872 \\ 0 & 0 & -0.831 & -10.837 & 24.204 & 0 \end{pmatrix}$$

imaging of long phase space to "time" & "energy" is not changed by sign of streak

significant "time" $\longrightarrow$ "energy" crosstalk for large streak

no crosstalk horizontal phase space to "time"

crosstalk horizontal to "energy" does not change with sigh of streak

crosstalk vertical to "time" & "energy" flips with sigh of streak

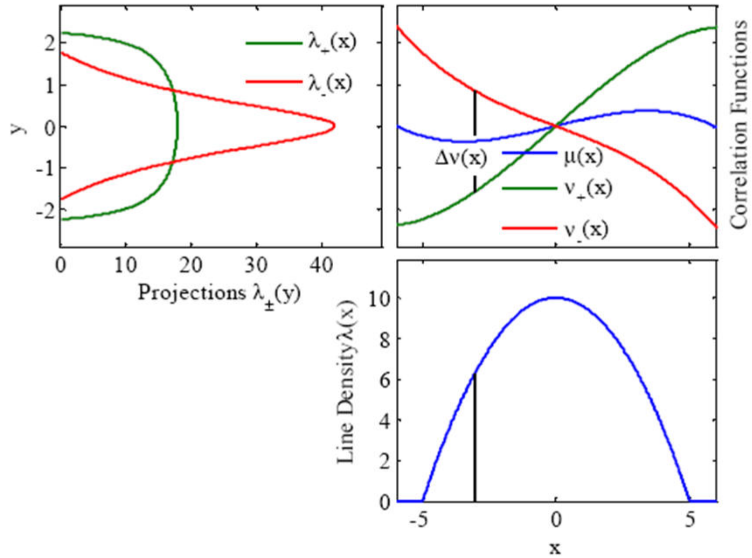
symmetric vertical phase space $\longrightarrow$ LOLA picture does not change with sign of streak

about reconstruction of filamentary phase space

based on the assumption of an filamentary phase space, a reconstruction method from two measurements with different sign of streak is proposed:

Reconstruction of a Filamentary Phase Space from two Projections

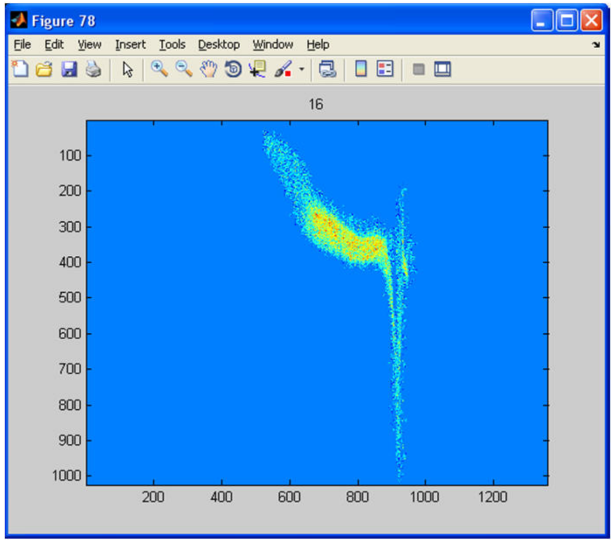
H. Loos†, SLAC, Menlo Park, CA 94025, USA

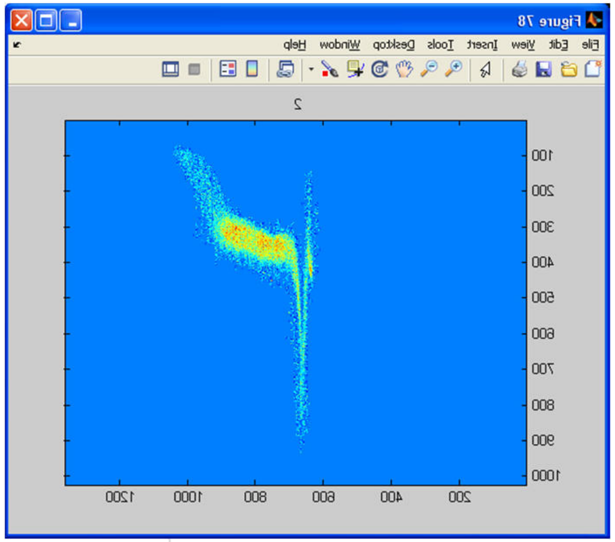


none of the errors, mentioned on the last transparency, is corrected by this method!

real LOLA measurement

streak with both signs:

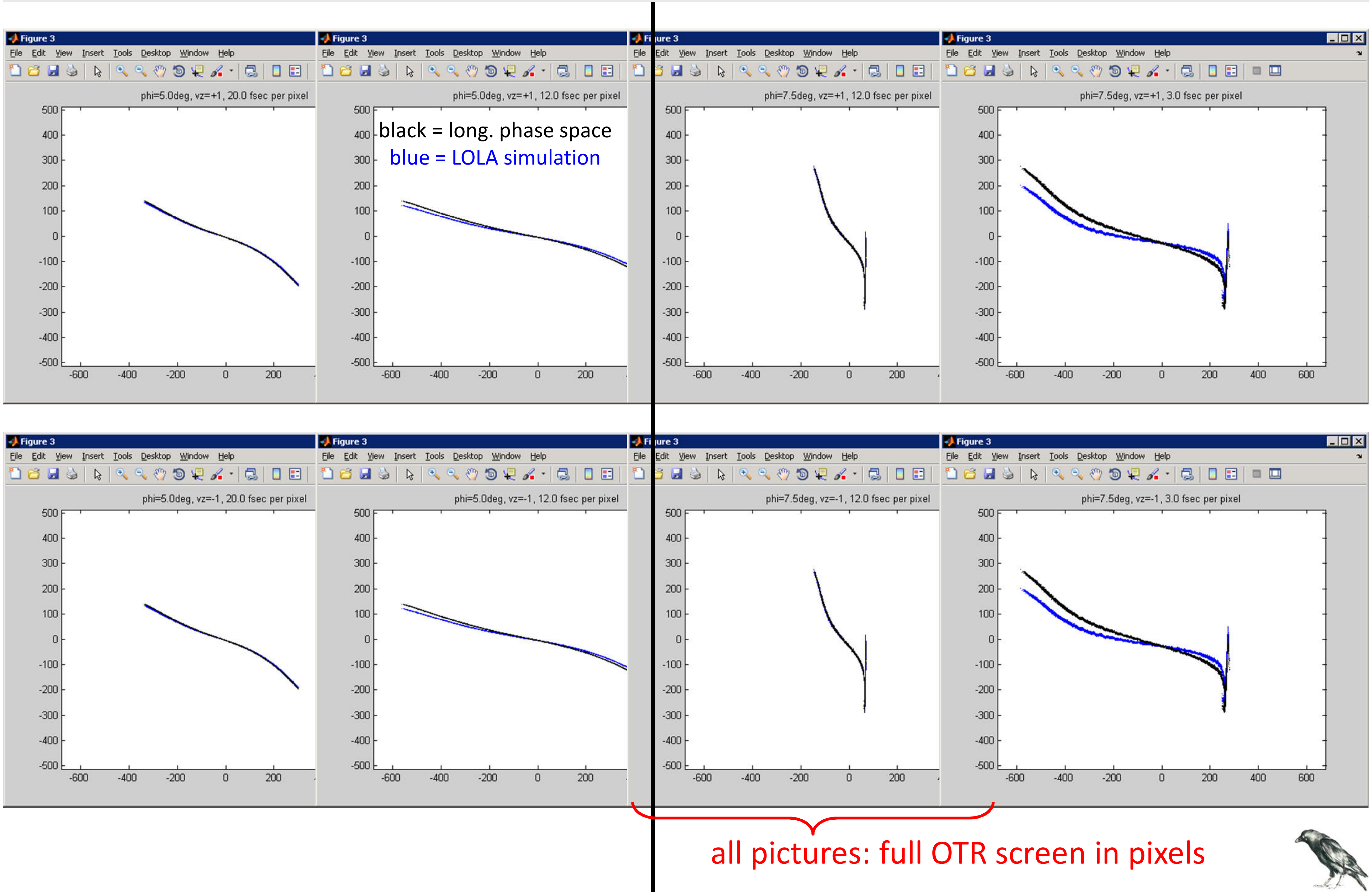




weak difference!
symmetric vertical phase space?

```
mess==40
 Tcalib='2011-06-16T204139-time_calibration-SDUMP.mat';
 Ecalib='2011-06-16T204338-energy_calibration-SDUMP.mat';
 RF_set='205900   165.10    7.60    18.2   -7.60   300.00    0.00   230.0
 Mnames    ={'2011-06-16T210918-6SDUMP.mat','2011-06-16T211139-6SDUMP.mat'}
 choices   ={[1:3 5:7 9:20]                ,[1:3 5:7 9:20]};
 directions={-1                            ,1};
```

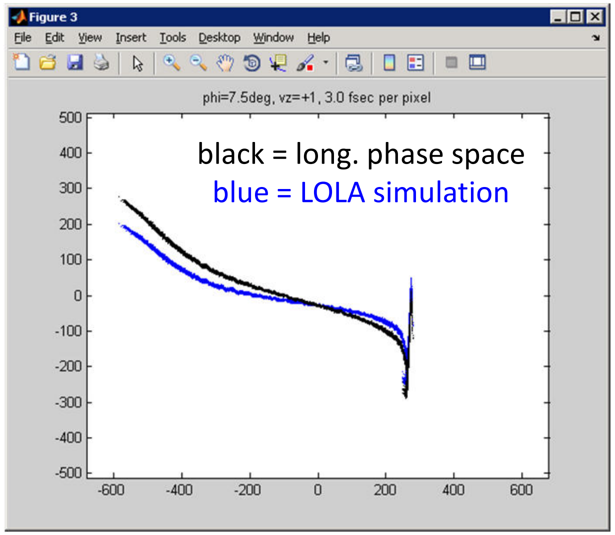
simulated LOLA measurement: no transverse beam dimensions

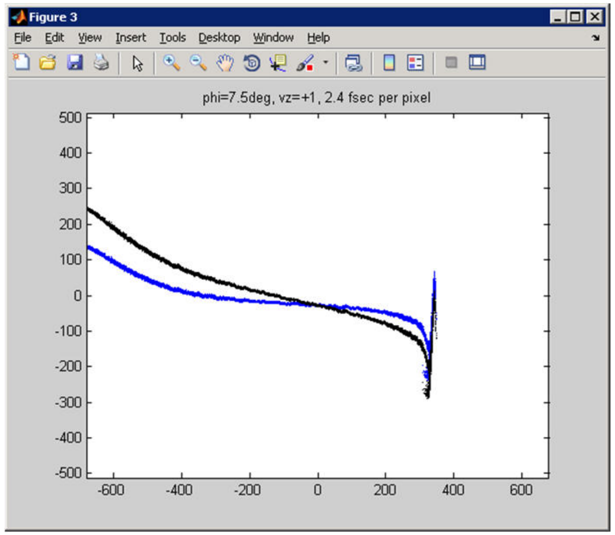


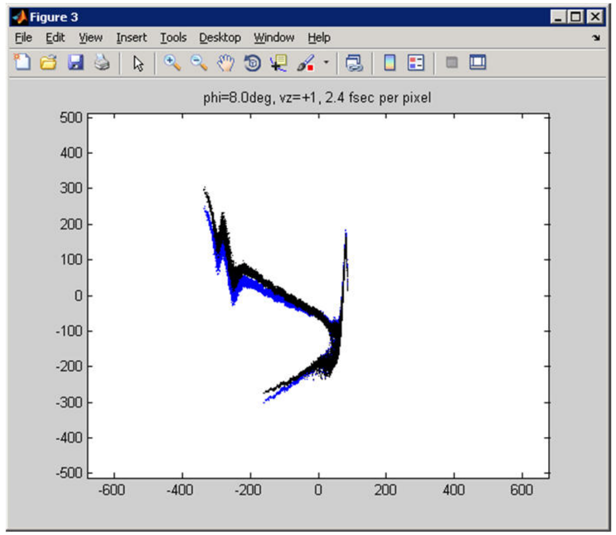
all pictures: full OTR screen in pixels

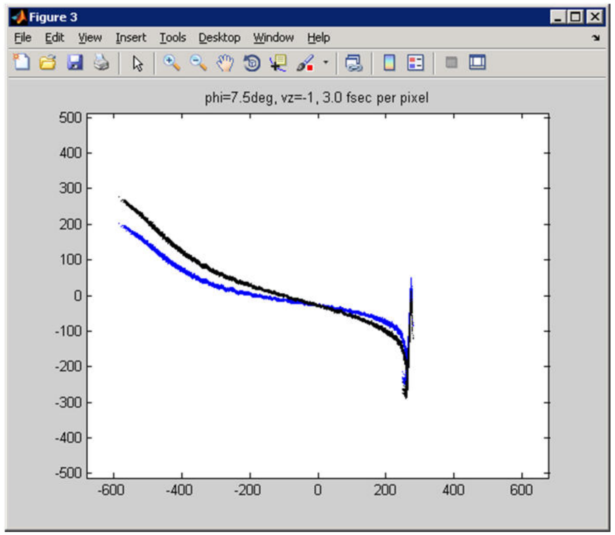
simulated LOLA measurement: no transverse beam dimensions

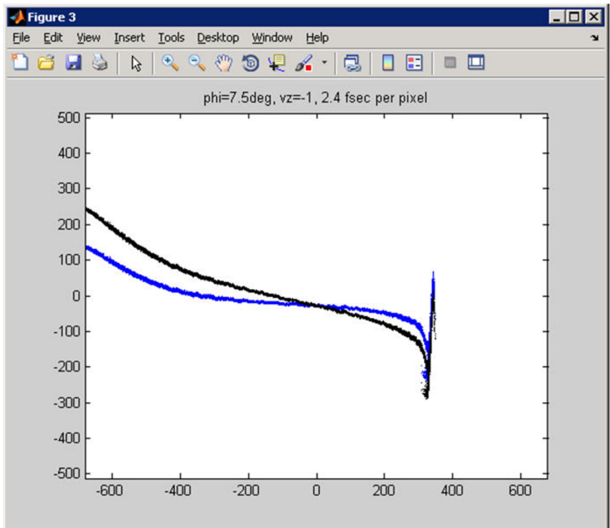
(P_{LOLA}=25MW)

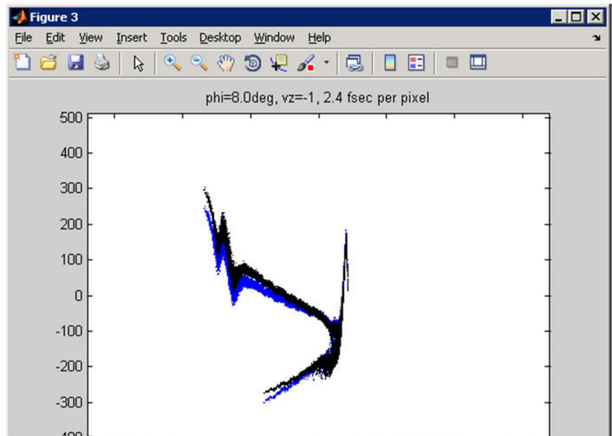


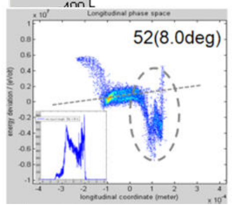




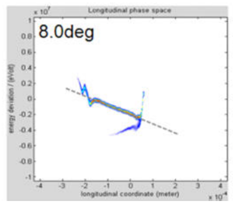


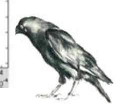






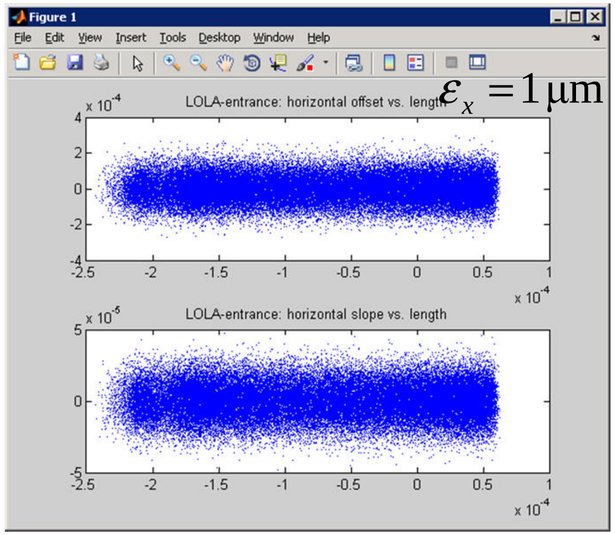
?

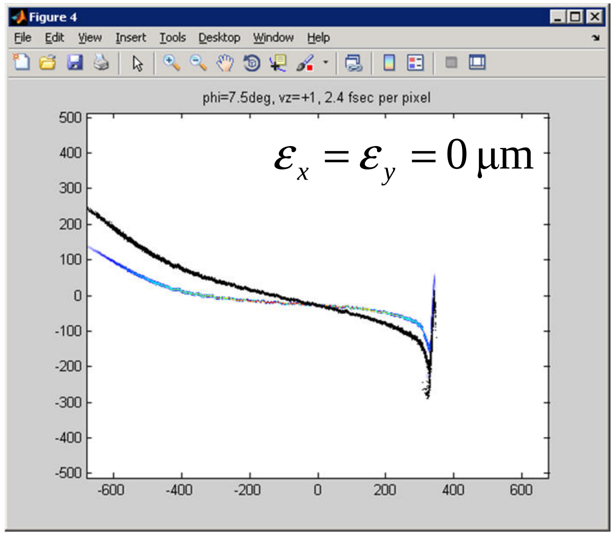


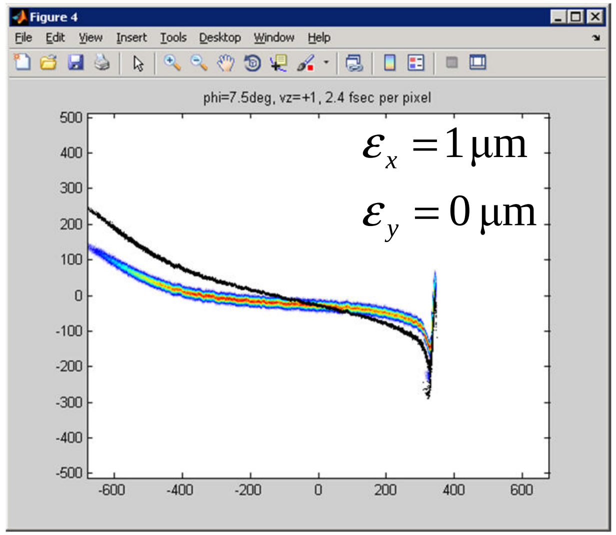


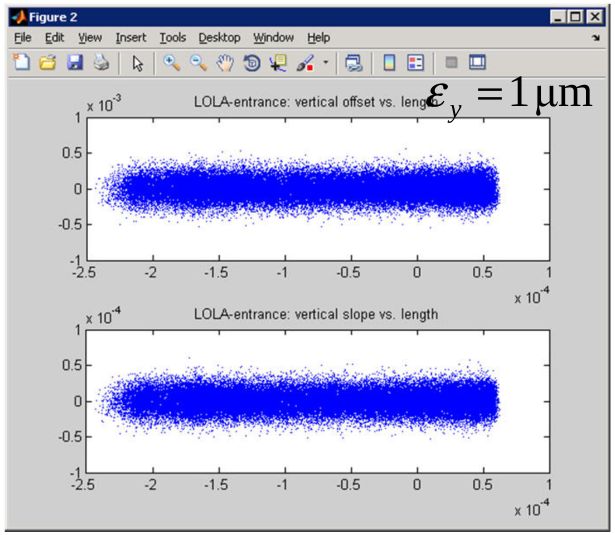
simulated LOLA measurement: gaussian transverse shape

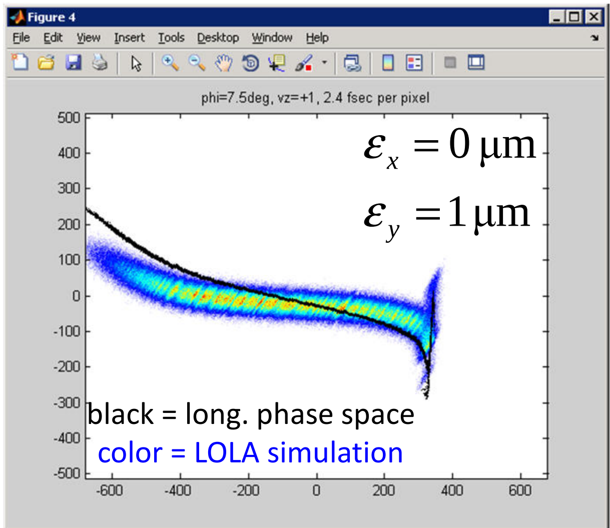
(design optics, emittance = 1um)

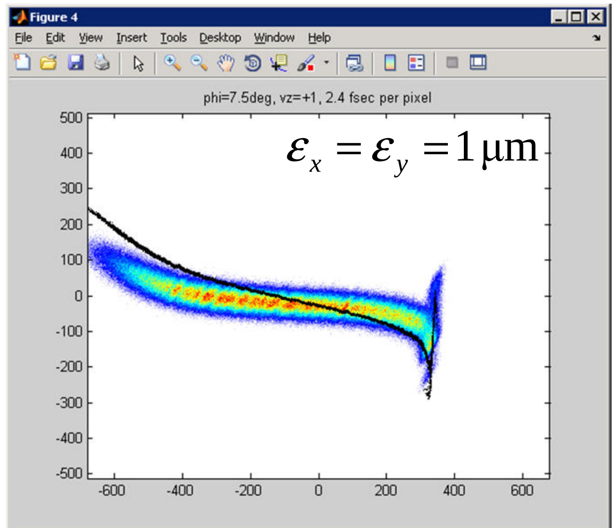




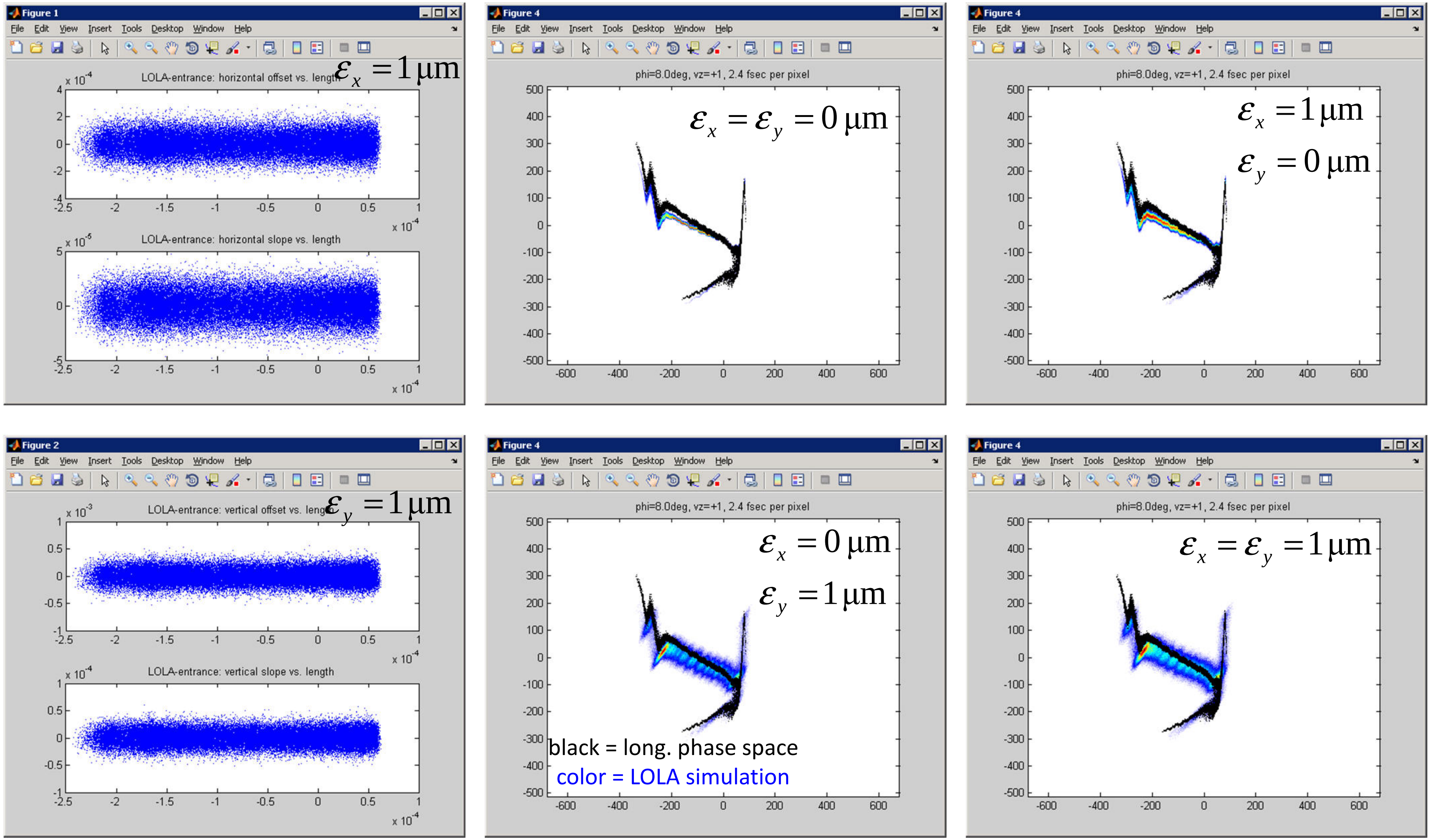








simulated LOLA measurement: gaussian transverse shape

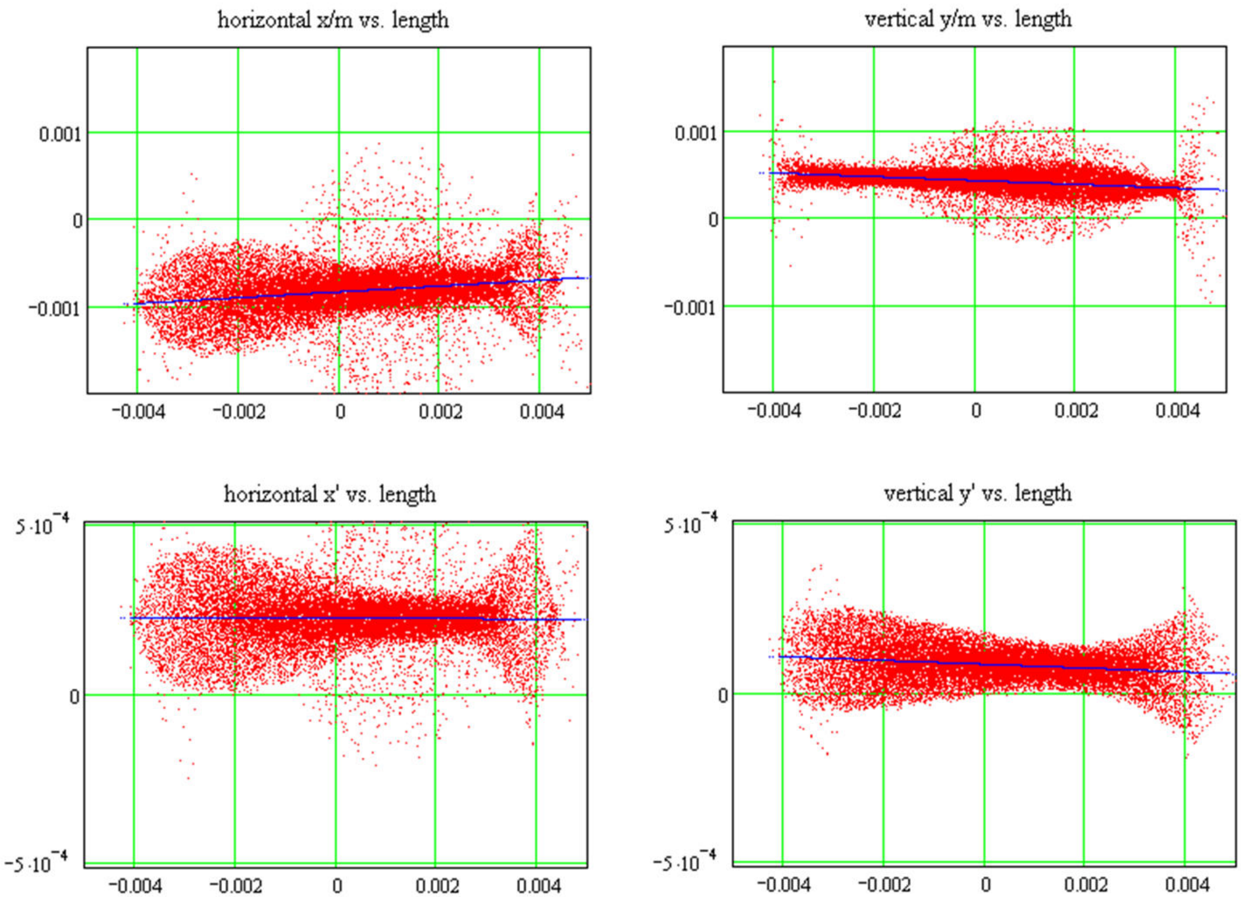


so far no difference for vz=+-1

about coupler kick

horizontal & vertical parameters vs. length at BC2 entrance

(TW mode, ACC1 145 MV, 4.7 deg, ACC39 20MV, -144.7 deg)



coupler kicks with numbers as on the next page

about coupler kick

numbers:

```
Matrix = [ (vx)    (dvx/dx)    (dvy/dy)
           (vy)    (dvy/dx)    (dvy/dy) ]
-------------------------------------------------------------------
```

TESLA Cavity

upstream = $(-54.8+13.0i)\cdot 10^{-6}$
$(-22.4+14.1i)\cdot 10^{-6}$]

downstream = $(-26.8+19.0i)\cdot 10^{-6}$
$(41.1+6.0i)\cdot 10^{-6}$]

```
-------------------------------------------------------------------
Third harmonic cavity orientation 1

upstream=
[ -0.0001418+ 0.0002761i   0.006803-0.014275i   0.011683-0.027045i
  -0.0000599+ 0.0001751i   0.011683-0.027045i  -0.006803+0.014275i ]


downstream=
[ -0.0003923- 0.0001021i   0.014767-0.024901i   0.011434+0.030693i
   0.0000677+ 0.0002085i   0.011434+0.030693i  -0.014767+0.024901i ]

-------------------------------------------------------------------
3rd harmonic cavity, orientation 2

upstream=
[ -0.0003923+ 0.0001021i  -0.014767-0.024901i   0.011434-0.030693i
  -0.0000677+ 0.0002085i   0.011434-0.030693i   0.014767+0.024901i ]


downstream=
[ -0.0001418-0.0002761i  -0.006803-0.014275i   0.011683+0.027045i
   0.0000599+0.0001751i   0.011683+0.027045i   0.006803+0.014275i ]
```

TESLA cavity in pure traveling wave operation (my old MAFIA calculation before 2005, Qe=2.5E6)
3^{rd} harmonic cavity in pure SW operation (fields from E. Gjonaj)

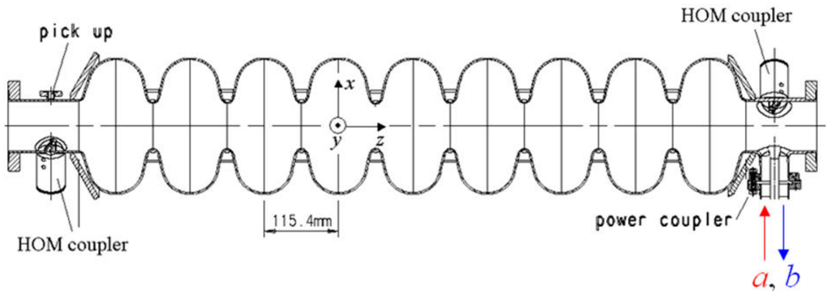
about coupler kick

numbers:

TESLA Cavity

upstream = $(-54.8+13.0i)\cdot 10^{-6}$
$(-22.4+14.1i)\cdot 10^{-6}$

downstream = $(-26.8+19.0i)\cdot 10^{-6}$
$(\ 41.1+\ 6.0i)\cdot 10^{-6}$



other numbers: (s2e-meeting Mai 2007)

upstream = $(-57.1+6.6i)\cdot 10^{-6}$
$(-41.4-3.5i)\cdot 10^{-6}$

	forward	backward
z_pen = 6 mm, forward		backward
downstream =	$(-25.0+51.5i)\cdot 10^{-6}$	$(-52.3-\ 8.1i)\cdot 10^{-6}$
	$(\ 32.2+\ 5.2i)\cdot 10^{-6}$	$(\ 32.4+\ 5.8i)\cdot 10^{-6}$
z_pen = 8 mm, forward		
downstream =	$(\ 0.5+53.7i)\cdot 10^{-6}$	$(-39.2-33.6i)\cdot 10^{-6}$
	$(\ 32.4+\ 5.1i)\cdot 10^{-6}$	$(\ 33.0+\ 5.6i)\cdot 10^{-6}$

about coupler kick

numbers:

TESLA Cavity
upstream = $(-54.8+13.0i)\cdot 10^{-6}$
$(-22.4+14.1i)\cdot 10^{-6}$

downstream = $(-26.8+19.0i)\cdot 10^{-6}$
$(41.1+6.0i)\cdot 10^{-6}$

more other numbers:

ofessional - [tupp019_Bane_Wakefield_and_RF_kicks.pdf]

a loaded gradient of 31.5 MV/m, on crest acceleration, and critical coupling for the FM coupler (which implies $Q_{ext} \approx 3.5 \times 10^6$). To reach this coupling the center conductor of the FM coupler needs to intrude into the beam pipe by $\sim$ 6 mm. Our calculated RF kicks using OMEGA3P are given in Table 2. The results of the other two programs are in essential agreement.

Table 2: RF kick on-axis due to coupler asymmetry in [kV]. Re(V) is the in-phase, Im(V) the out-of-phase kick.

Region	V_x	V_y
Upstream	$-1.82+0.22i$	$-1.29-0.11i$
Downstream	$-0.79-1.62i$	$+1.15+0.28i$
Total	$-2.61-1.40i$	$-0.13+0.17i$

05 Beam Dynamics and Electromagnetic Fields

upstream
$(-57.8+7.0i)\cdot 10^{-6}$
$(-25.1-51.4i)\cdot 10^{-6}$
downstream
$(-41.0-3.5i)\cdot 10^{-6}$
$(36.5+5.4i)\cdot 10^{-6}$

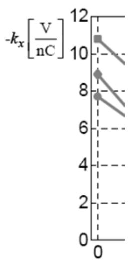
Proceedings of EPAC08, Genoa, Italy

$\mathbf{V}(x,y)=\int(\mathbf{E}(\mathbf{r})+c\mathbf{e}_z\times\mathbf{B}(\mathbf{r}))\exp(i\omega z/c)dz$ and com-
:oefficients v_{x0}, v_{y0}, v_{xx}, v_{xy}, v_{yx}, v_{yy}. The coefficients ie up- and down-stream couplers (TDR TESLA ' adjusted to Q_{ext}=2.5·10[6] and operated without re- ons) have been calculated from a decaying eigenso- [http://adweb.desy.de/~mpymax/mafia/HOM_Coup lex.html]. They are listed in Tab. 1.

Table 1: RF kick coefficients

	upstream	downstream
$v_{x0}\cdot 10^6$	-57+7i	-23+52i
$v_{xx}\cdot 10^6$/mm	1.0-0.7i	-3.7-2i
$v_{xy}\cdot 10^6$/mm	3.4+0.2i	3.0+0.4i
$v_{y0}\cdot 10^6$	-42-3i	30+5i
$v_{yx}\cdot 10^6$/mm	3.4+0.2i	3.0+0.4i
$v_{yy}\cdot 10^6$/mm	-1.1+0.6i	3.8+1.9i

250·10[6] mesh poi
408 processor cor
curves obtained
obtained by coars



upstream
$(-57+7i)\cdot 10^{-6}$
$(-23+52i)\cdot 10^{-6}$
downstream
$(-42-3i)\cdot 10^{-6}$
$(30+5i)\cdot 10^{-6}$

http://lss.fnal.gov/archive/2008/conf/fermilab-conf-08-193-td.pdf

Table I. The RF kick for upstream and downstream couplers.

		Direct integration	P-W theorem
Upstream HOM coupler	$10^6 V_{0x}/V_a$	-68.8+3.7i	-65.6+7.6i
	$10^6 V_{0y}/V_a$	-48.3-3.4i	-53.1-2.1i
Downstream HOM&main couplers	$10^6 V_{0x}/V_a$	-36.5+66.1i	-27.3+67.2i
	$10^6 V_{0y}/V_a$	41.0+14.5i	40.9+12.8i

The results are in agreement with calculations presented

upstream
$(-68.8+3.7i)\cdot 10^{-6}$
$(-48.3-3.4i)\cdot 10^{-6}$
downstream
$(-36.5+66.1i)\cdot 10^{-6}$
$(41.0+14.5i)\cdot 10^{-6}$

but the geometry is probably different

about coupler kick

used for the following: (TW mode, ACC1 145 MV, 4.7 deg, ACC39 20MV, -144.7 deg)

$$U13x := (-54.8 + 13.0i)\cdot 10^{-6} \qquad U39x1 := (-142 + 276i)\cdot 10^{-6} \qquad U39x2 := (-392 + 102i)\cdot 10^{-6}$$

$$U13y := (-22.4 + 14.1i)\cdot 10^{-6} \qquad U39y1 := (-60 + 175i)\cdot 10^{-6} \qquad U39y2 := (-68 + 209i)\cdot 10^{-6}$$

$$D13x := (-26.8 + 19.0i)\cdot 10^{-6} \qquad D39x1 := (-392 + 102i)\cdot 10^{-6} \qquad D39x2 := (-142 - 276i)\cdot 10^{-6}$$

$$D13y := (41.1 + 6.0i)\cdot 10^{-6} \qquad D39y1 := (68 + 209i)\cdot 10^{-6} \qquad D39y2 := (60 + 175i)\cdot 10^{-6}$$

time dependent part: same order of magnitude!

ACC13

$$8\cdot V\_ACC13\cdot(U13x + D13x) = -9.738\times 10^{4} + 2.924i\times 10^{4}$$

$$8\cdot V\_ACC13\cdot(U13y + D13y) = 2.244\times 10^{4} + 2.412i\times 10^{4}$$

$$\left|8\cdot V\_ACC13\cdot(U13x + D13x)\right| = 1.017\times 10^{5}$$

$$\left|8\cdot V\_ACC13\cdot(U13y + D13y)\right| = 3.185\times 10^{4}$$

ACC39

$$2\cdot V\_ACC39\cdot(U39x1 + U39x2 + D39x1 + D39x2) = 3.958\times 10^{4} + 1.803i\times 10^{4}$$

$$2\cdot V\_ACC39\cdot(U39y1 + U39y2 + D39y1 + D39y2) = 1.775\times 10^{4} - 2.507i\times 10^{4}$$

$$\left|2\cdot V\_ACC39\cdot(U39x1 + U39x2 + D39x1 + D39x2)\right| = 4.349\times 10^{4}$$

$$\left|2\cdot V\_ACC39\cdot(U39y1 + U39y2 + D39y1 + D39y2)\right| = 3.072\times 10^{4}$$

simulated LOLA measurement: no emittance but coupler kick

design optics

with self effects: perturbation approach

only CK before BC2 is considered here

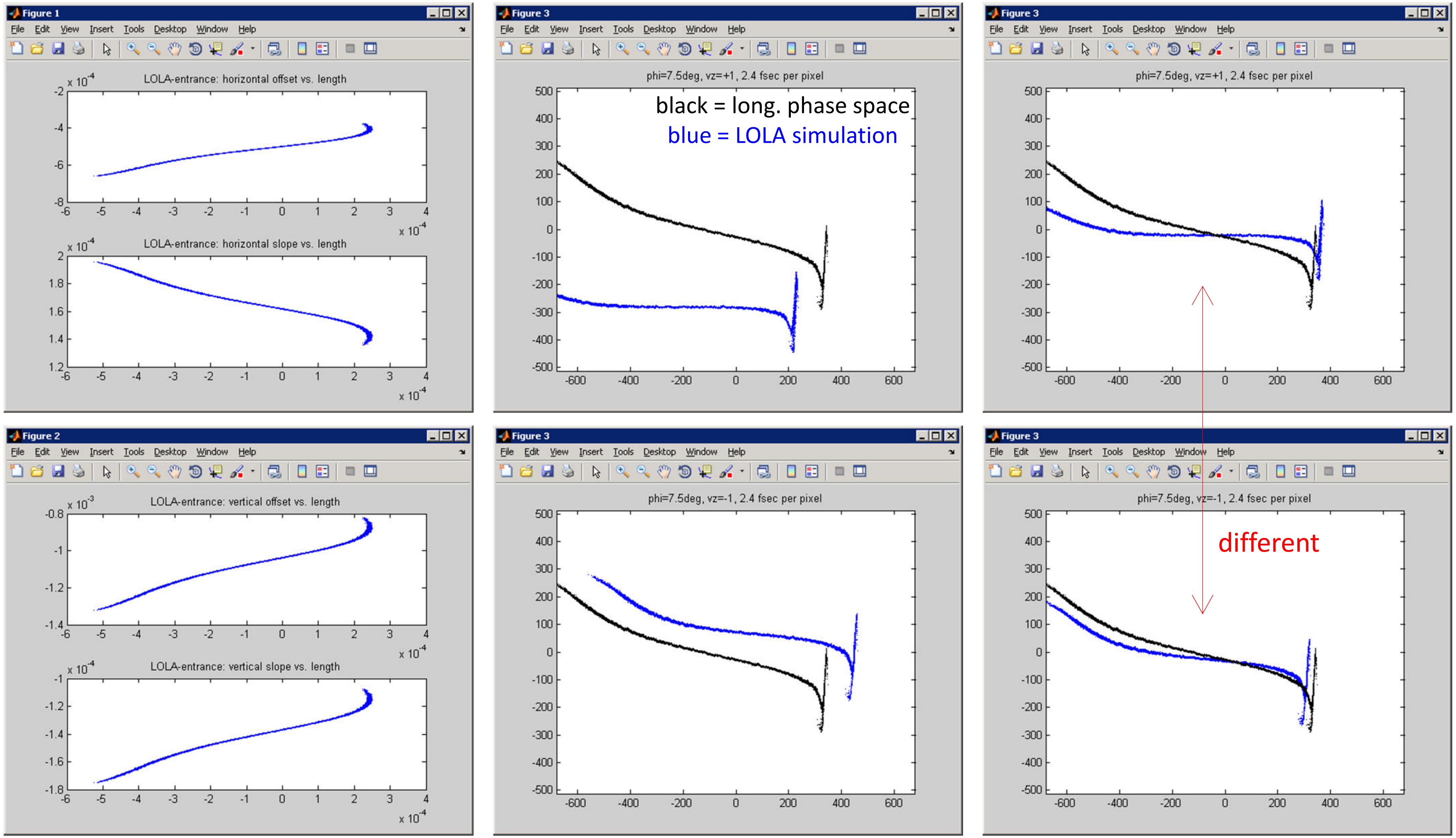
it depends on cavity phases & amplitudes and on TW/SW modus

for short bunches CK of cavities after BC2 negligible, but probably not for on-crest measurement (needed to determine the uncompressed bunch length)

simulated LOLA measurement: no emittance but coupler kick

phi = 7.5 deg

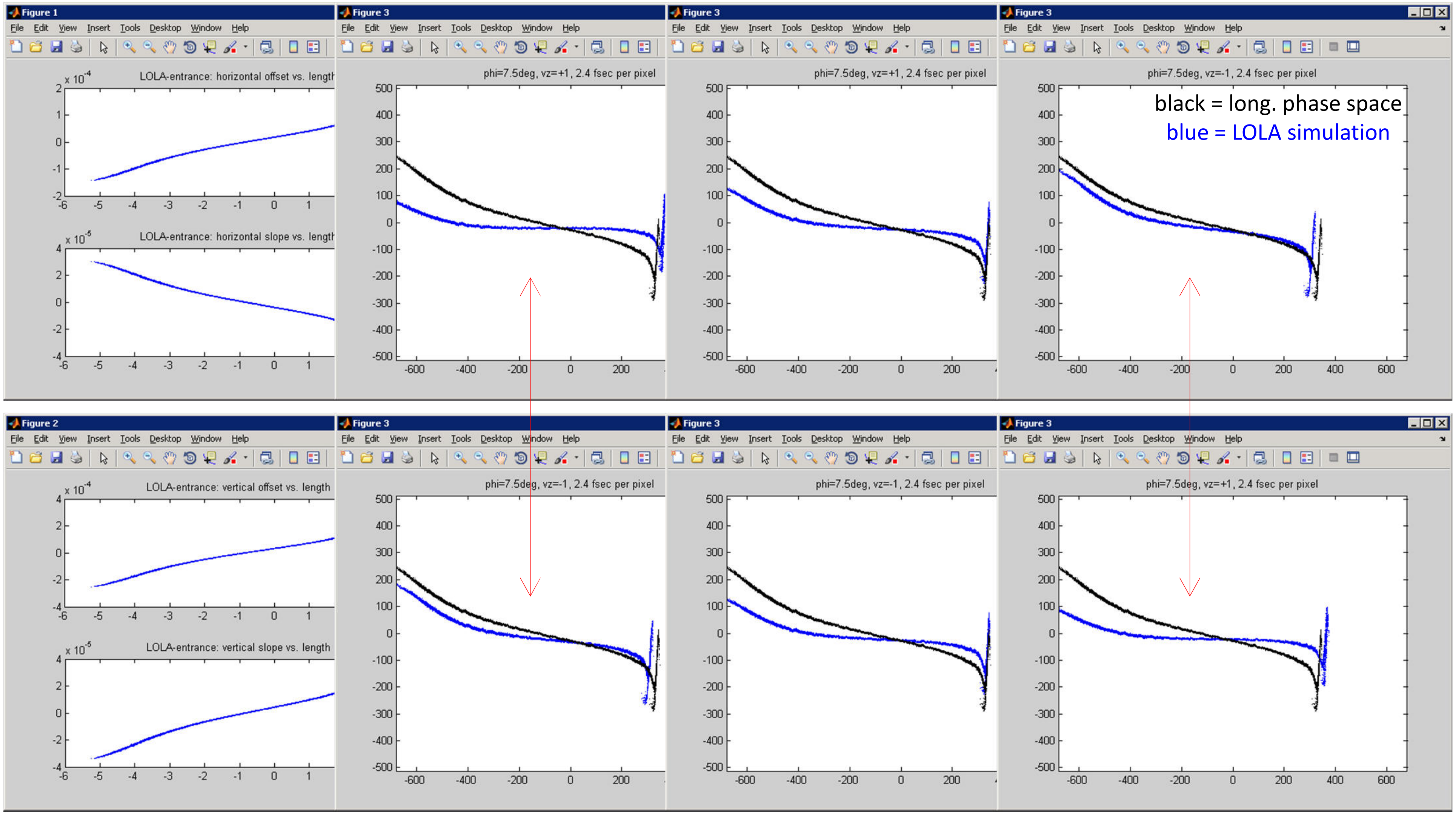
transverse due to CK | absolut | only time dependent part of CK



simulated LOLA measurement, no emittance but coupler kick

phi = 7.5 deg — only time dependent part of CK

transverse due to CK — hor.+vert. CK — hor. CK — vert. CK

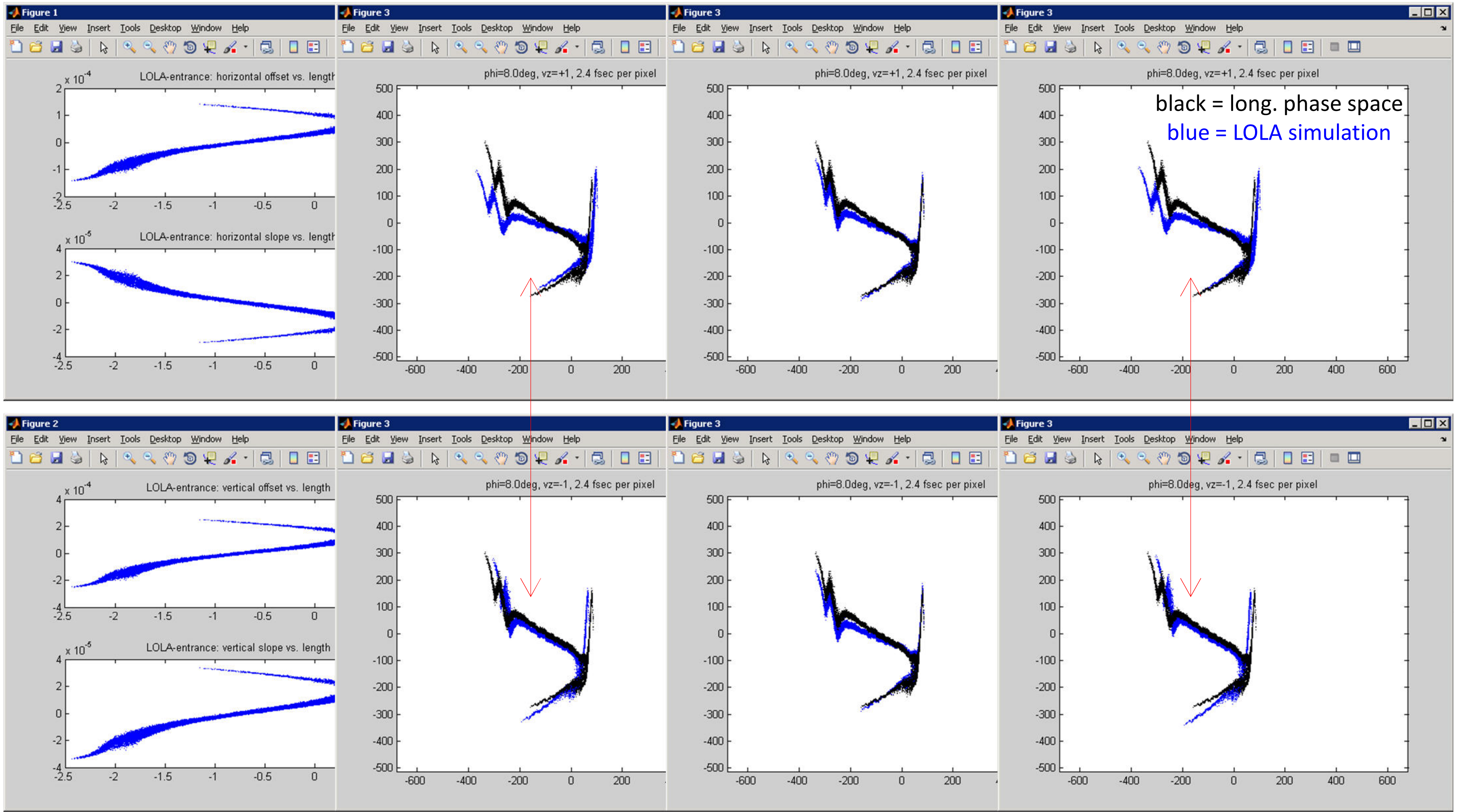


simulated LOLA measurement, no emittance but coupler kick

phi = 8.0 deg

only time dependent part of CK

transverse due to CK | hor.+vert. CK | hor. CK | vert. CK



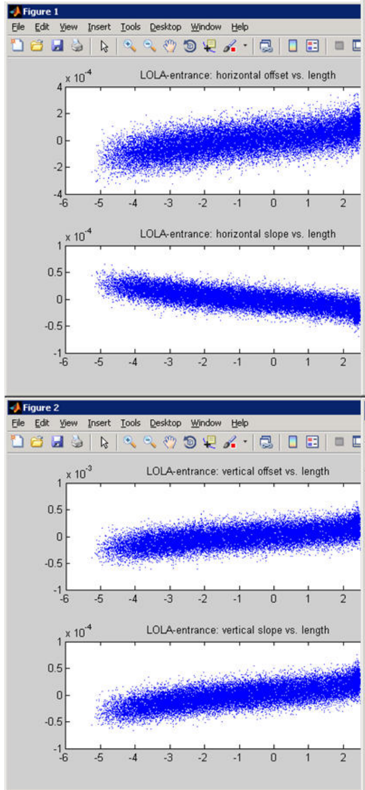
simulated LOLA measurement, gaussian transverse + CK

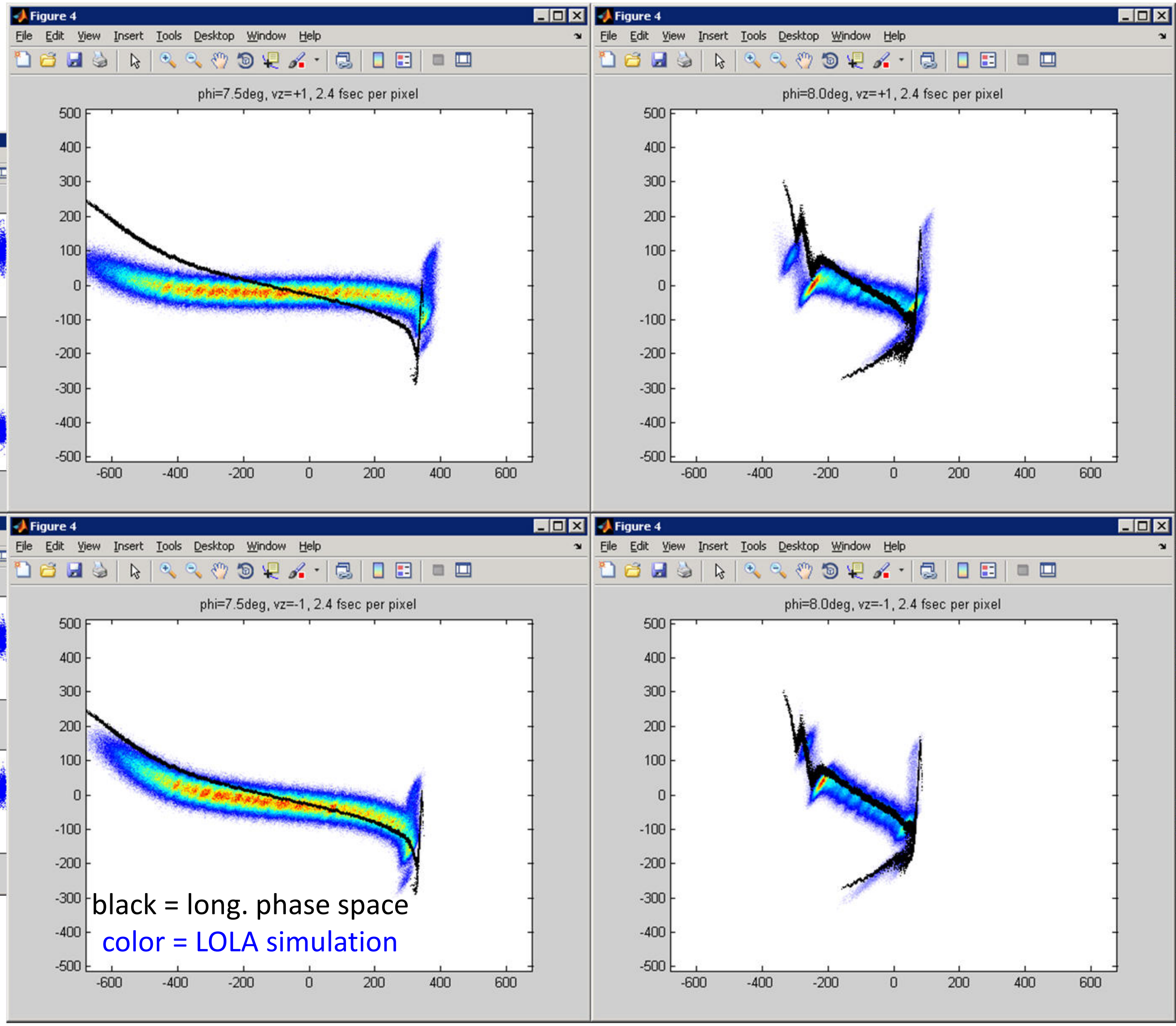
starts from design optics (emittance=1um)

phi = 7.5 deg

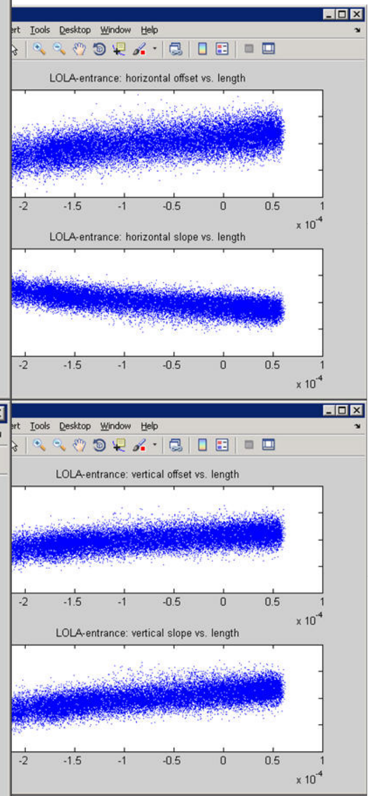
phi = 8.0 deg

transverse





transverse



simulated LOLA measurement, CSR-transverse + CK

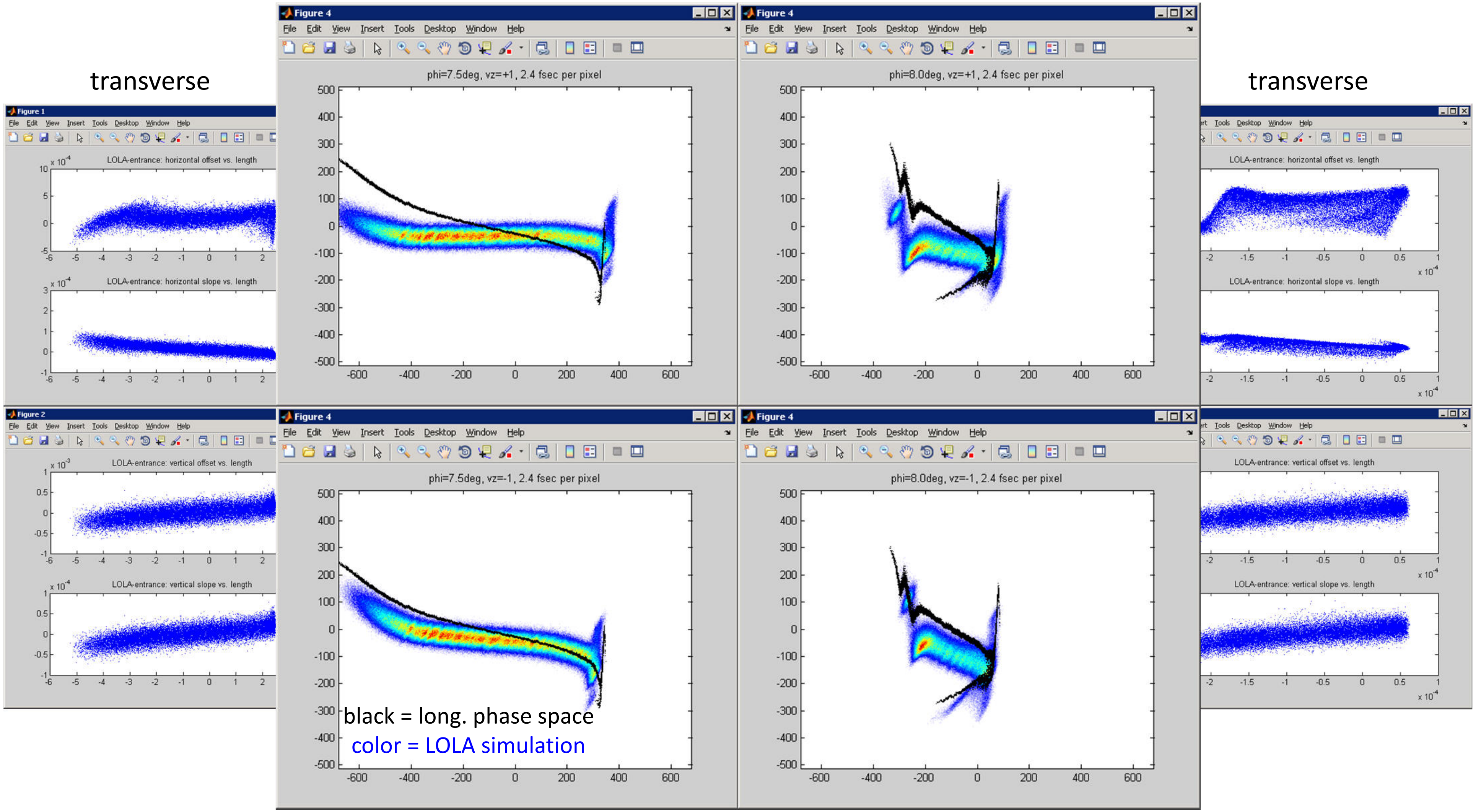
horizontal CSR; starts from design optics (emittance=1um)

phi = 7.5 deg

phi = 8.0 deg

transverse

transverse



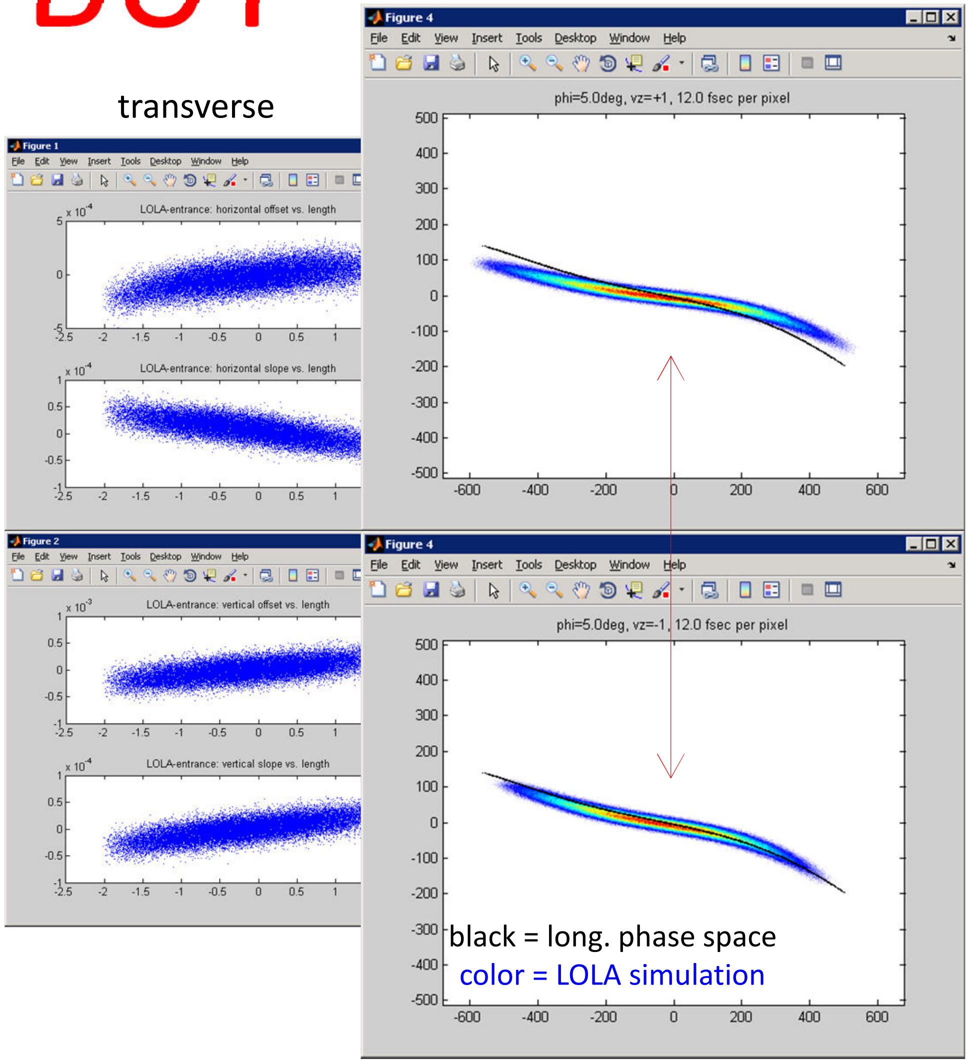
simulated LOLA measurement, CSR-transverse + CK

BUT

phi = 5.0 deg

long bunch, low compression

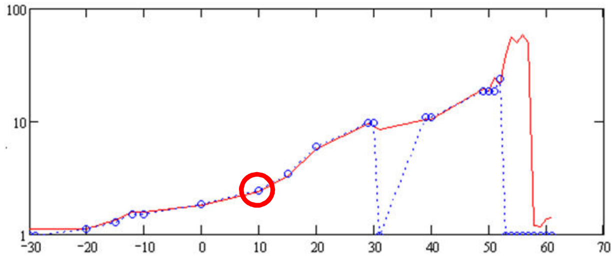
transverse



this difference has not been observed

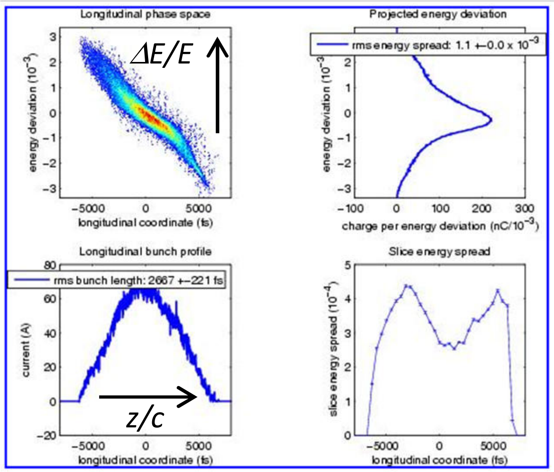
real LOLA measurement   phi = 5.0 deg

index = 10



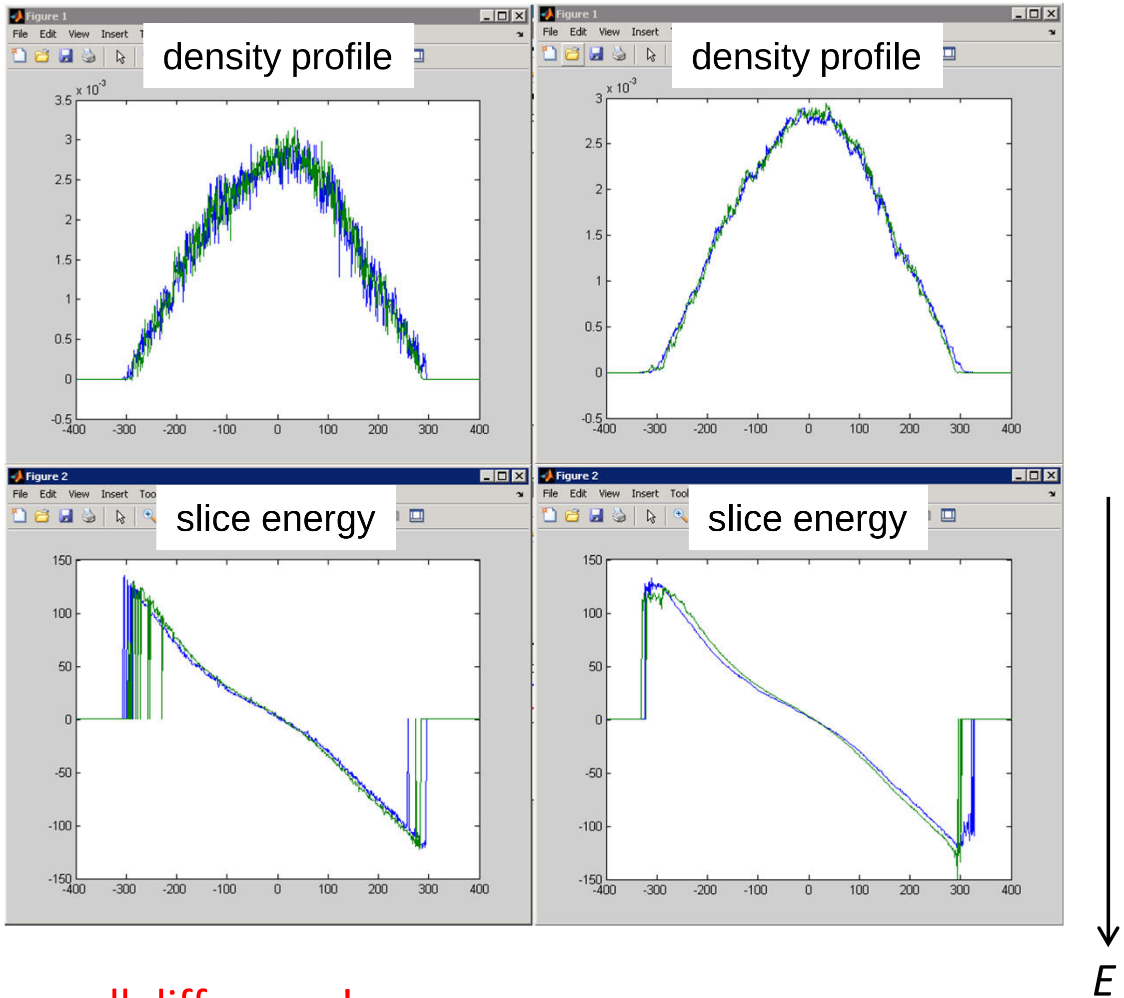
log-book:

16.06.2011 19:55	ttflinac	tp2c99b905_d98f_4011_926a_1308318b535d.ps



slope 1   slope 2 (z-flipped)

single measurement   20 measurements averaged   z

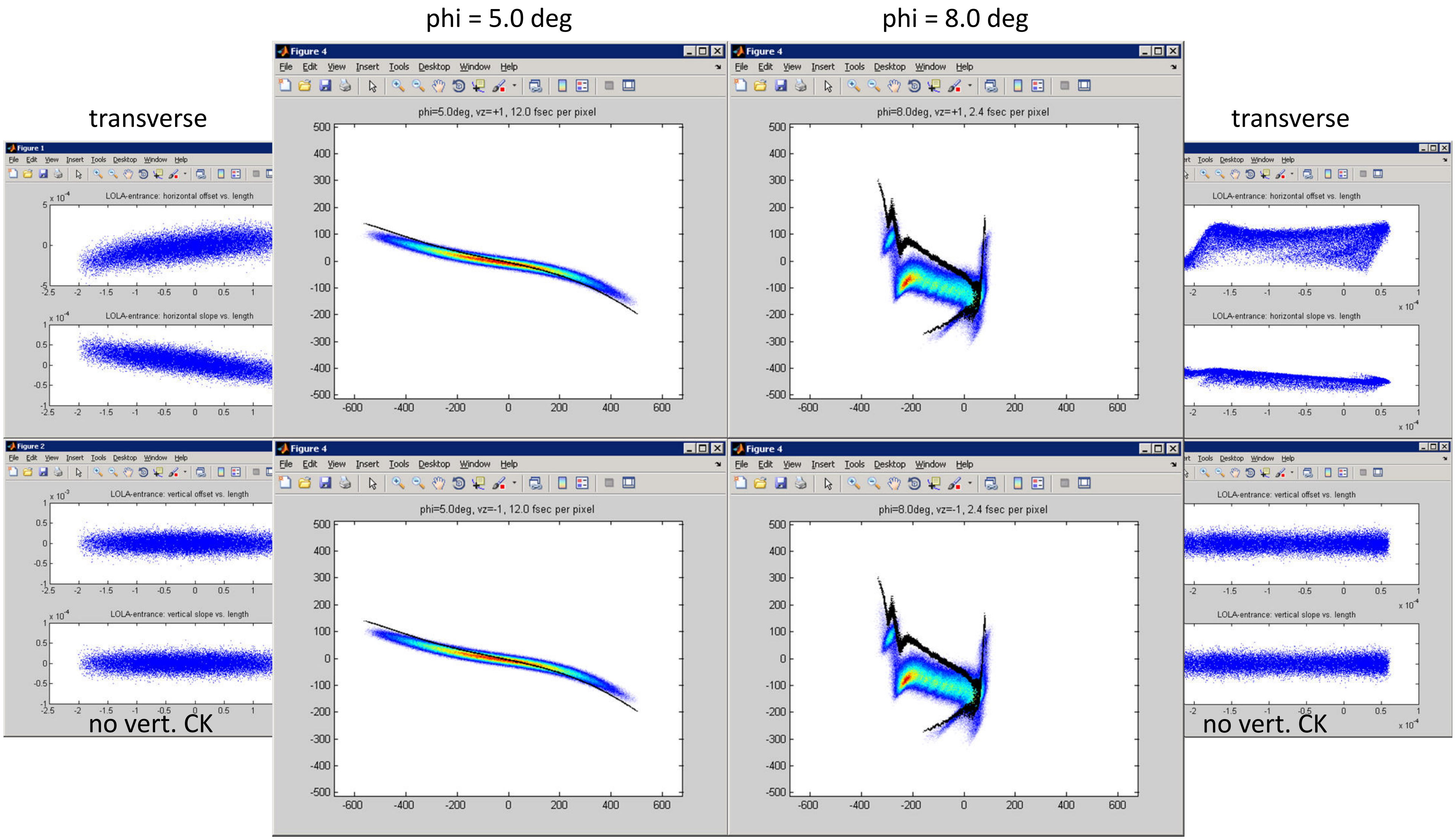


small difference!

???: vertical distribution nearly symmetric

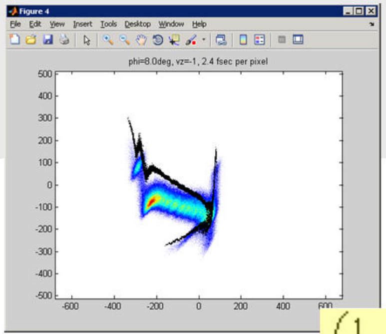
simulated LOLA measurement, CSR-transverse + horizontal CK

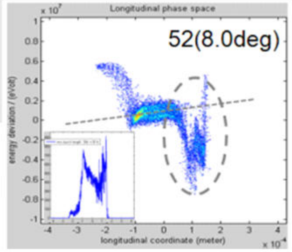
horizontal CSR; starts from design optics (emittance=1um)



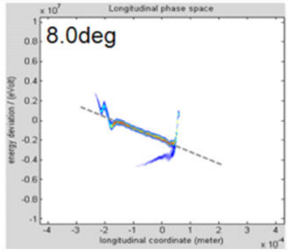
same picture for both streaks, no error in time measurement

summary





?



$$\begin{pmatrix} 1 & 12.022 & 2.282 & 4.365 & 3.808 & 0.872 \\ 0 & 0 & 0.831 & 10.837 & 24.204 & 0 \end{pmatrix}$$

"energy" axis

"time" axis

right direction, but not enough

"energy" measurement:

- significant crosstalk from "time" meas. for strong streak
- crosstalk from hor. & vert. phase-space
- vert. phase space: sign flips with streak

"time" measurement:

- only crosstalk from vertical phase space

CK still unknown; horizontal part depends on cavity operation

CK affects LOLA measurement

- horizontal $\rightarrow$ "energy" measurement
- vertical $\rightarrow$ "energy" and "time"

vertical CK perhaps overestimated