Study of non-linear magnetic fields in the ATF extraction region on the emittance growth

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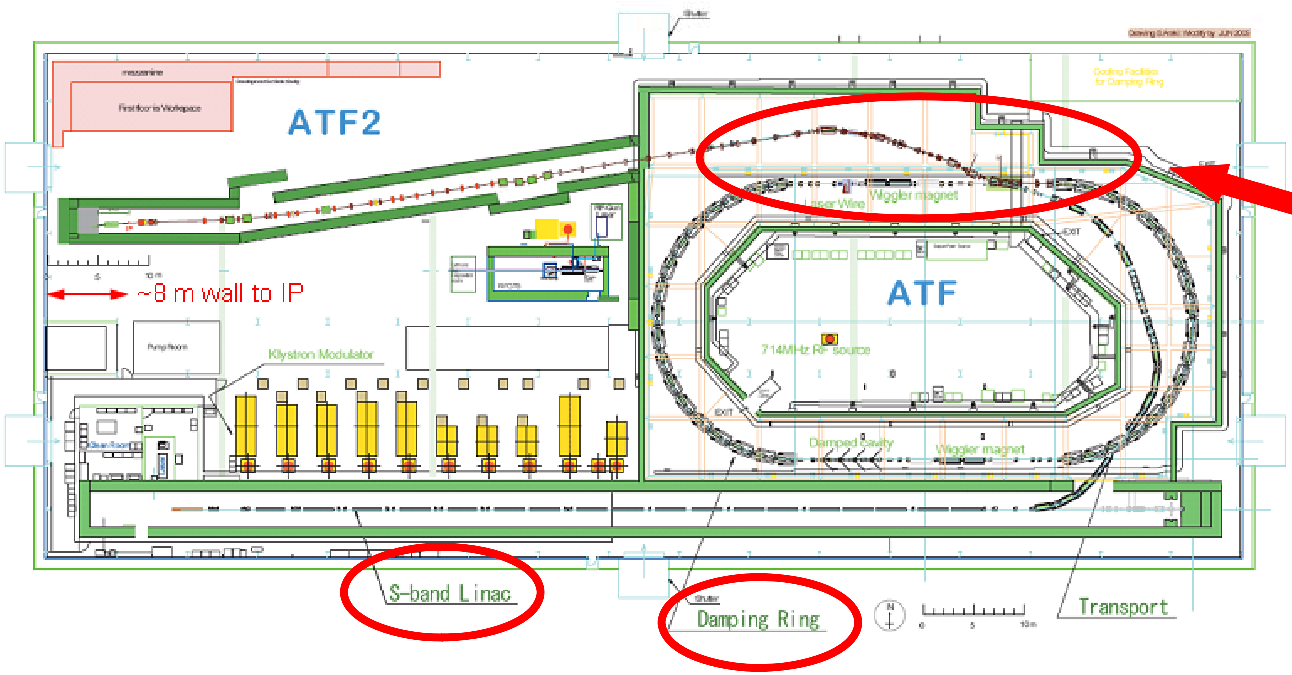
Accelerator Test Facility (ATF) and ATF2

ATF was built in KEK (Japan) to create small emittance beams.

The Damping Ring of ATF has a world record of the normalized emittance of 3×10^{-8} m rad.

ATF2 is being built to study the feasibility of focusing the beam into a nanometer spot in a future linear collider.



Extraction line drives the beam from ATF to ATF2

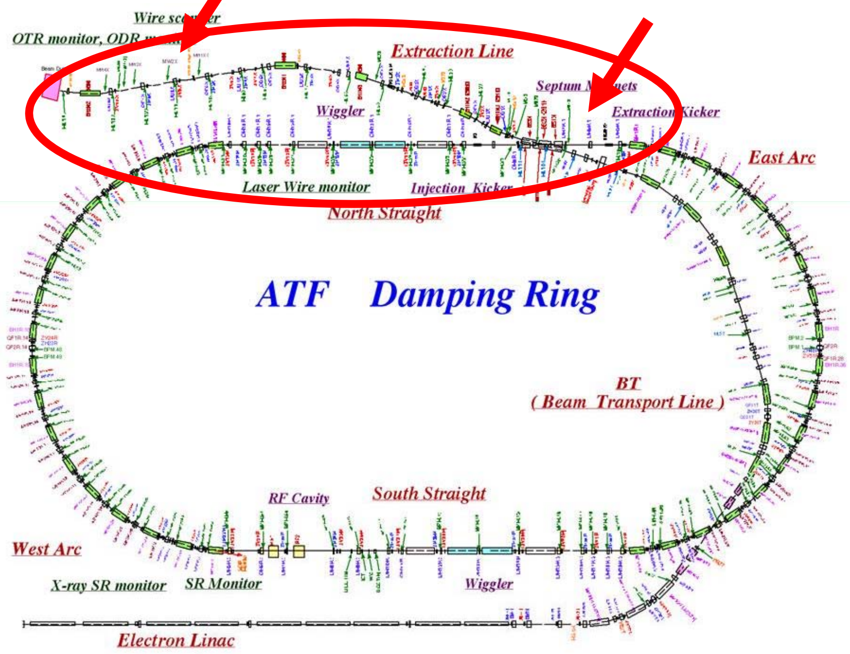
Accelerator Test Facility (ATF) and ATF2

Extraction Line

The Extraction Line (EXT) drives the beam from the ATF DR to the ATF2 Final Focus beam line

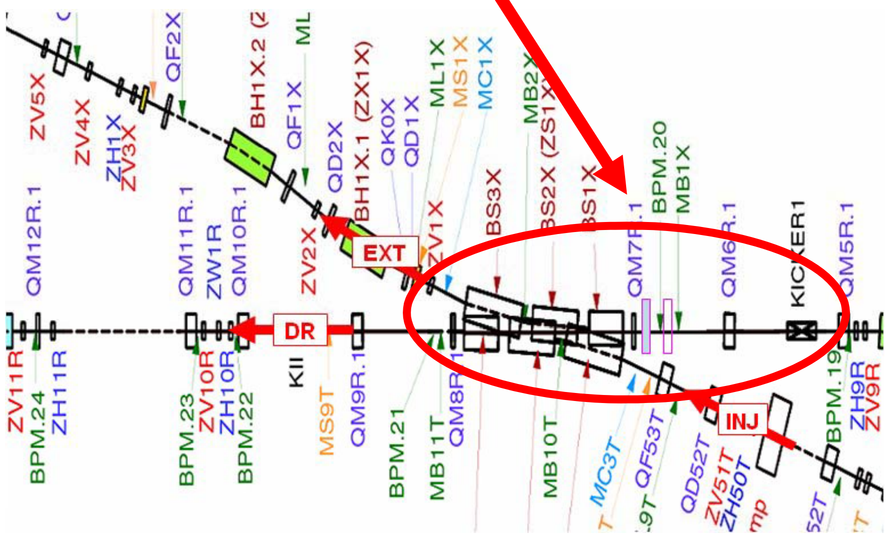
diagnostic section

extraction



Beam extraction process

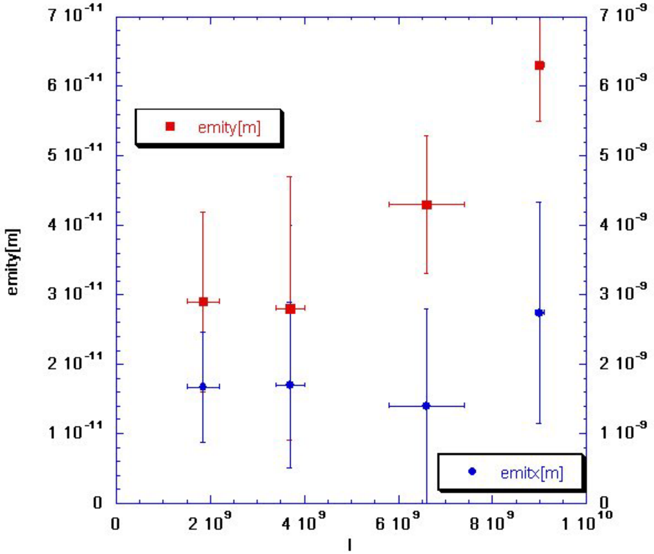
- **Shared magnets with the DR**
- **The beam passes off-axis**

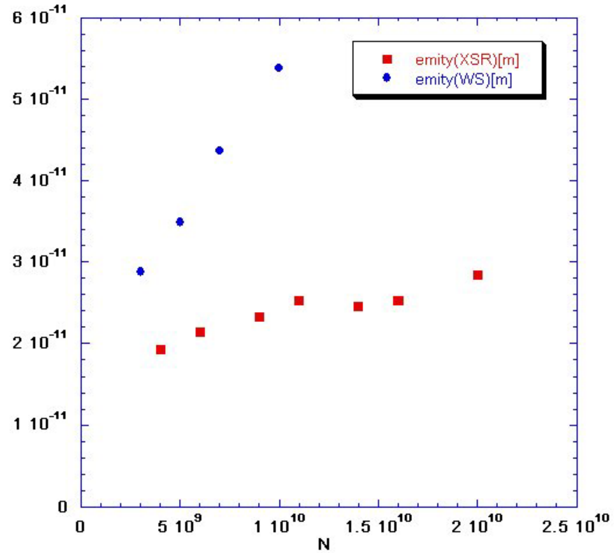


Accelerator Test Facility (ATF) and ATF2

Emittance growth in the EXT line

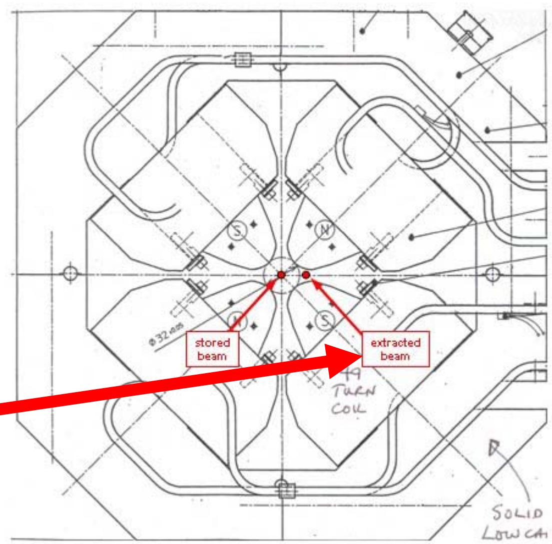
Since several years, the vertical emittane measured in the diagnostic section of the EXT line is significantly larger than the emittance measured in the DR.





Hypothesis

The beam experiences some non-linear magnetic fields while passing off-axis through the shared magnets.



Non-linear magnetic fields in the extraction region

Non-linearity of the magnetic field of the shared magnets:
QM6, QM7, BS1X, BS2X, BS3X

In order to quantify the effect of the non-linearity of the magnetic field on the extracted beam, the computation of the magnetic field on a finite mesh has been done with the code PRIAM.

Polynomial fit with the code MINUIT in order to get a continuous representation of the magnetic field:

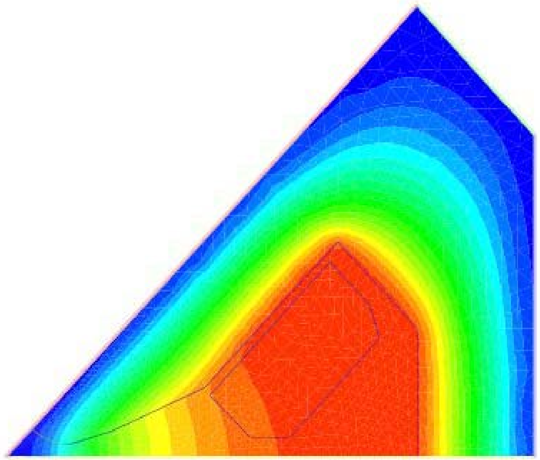
$$B_y + iB_x \sim \sum_{n=0}^{N} a_n (x+iy)^n$$

Multipole MAD coefficients:

$$KnL = \frac{L}{B_0 \rho_0} \frac{\partial^n B_y}{\partial x^n}$$

Non-linear magnetic fields in the extraction region

Non-linearity of the magnetic field of the QM6 quadrupole



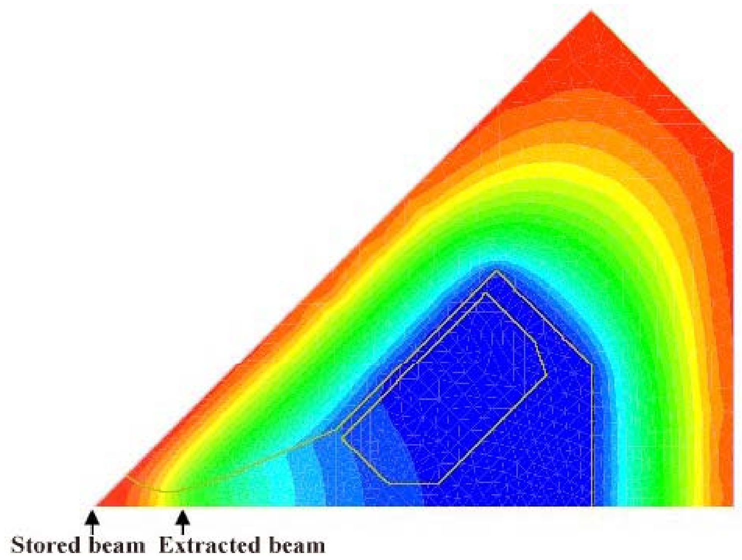
Dipole component 0.008%
Quadrupole component -0.03%

n	Kn (m^{-n})	MAD notation
0	-4.6262508E-3	K0L
1	-7.1158282E-1	K1L
2	-1.2577132E-1	K2L
3	3.6353697E+2	K3L
4	1.6886595E+6	K4L
5	3.8135083E+3	K5L
6	-3.5968711+E2	K6L
7	0.0	K7L
8	0.0	K8L

Zone of interest for tracking x=0.0065m y =0m

Non-linear magnetic fields in the extraction region

Non-linearity of the magnetic field of the QM7 quadrupole



	KN (m^{-n})	MAD notation
0	8.7560676E-3	K0L
1	3.0427593E-1	K1L
2	**-4.6587984E+1**	**K2L**
3	**-1.7011062E+6**	**K3L**
4	**-2.2447929E+6**	**K4L**
5	**-1.3556000E+06**	**K5L**
6	**1.9377000E+5**	**K6L**
7	**5.0501000E+4**	**K7L**
8	**2.7752000E+4**	**K8L**
9	**0.0**	**K9L**

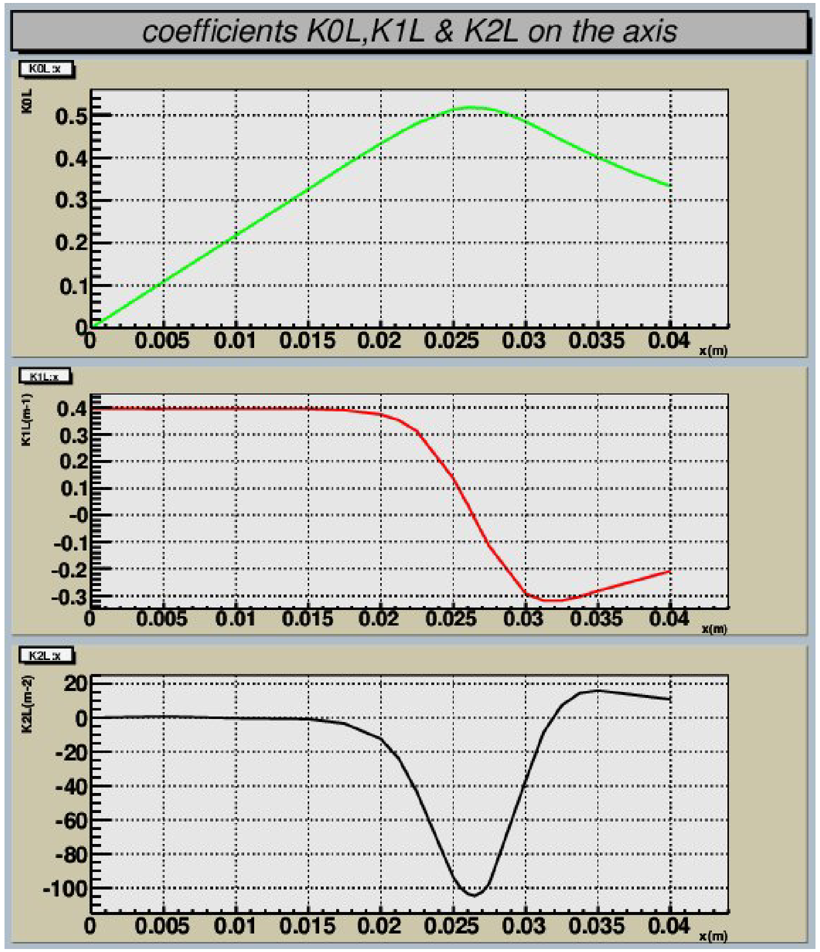
Dipole component -2%
Quadrupole component -24%

Zone of interest for tracking x=0.022 m y=0m

Non-linear magnetic fields in the extraction region

Non-linearity of the magnetic field of the QM7 quadrupole

At the extraction x=0.0225m, y=0m :



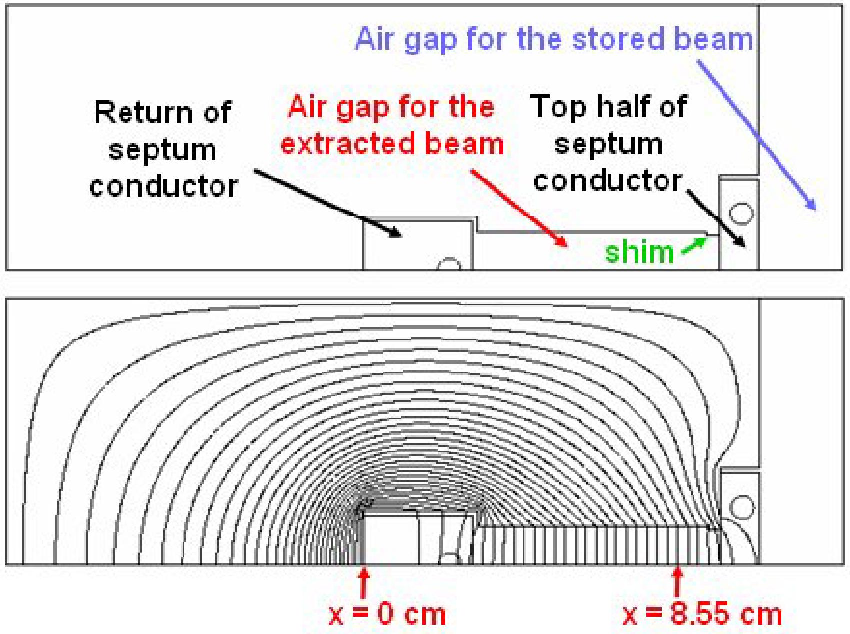
Dipole component appears

Quadrupole component reduced ~ 24% with respect to the DR

Non negligible sextupole component (coupling)

Non-linear magnetic fields in the extraction region

Non-linearity of the magnetic field of the BS1X septum magnet



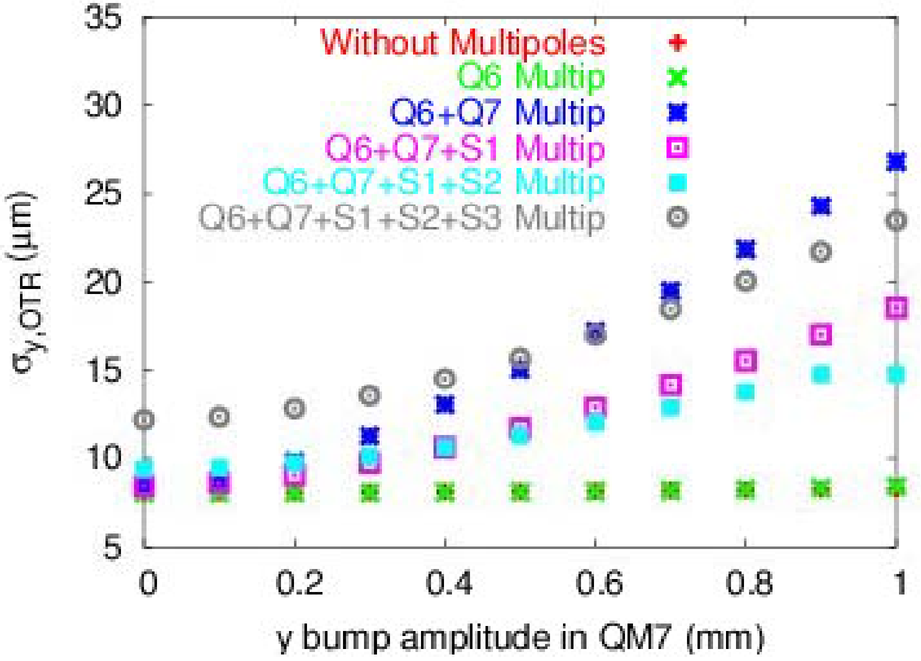
N	KN (m^{-1})	MAD notation
0	2.7585491E-2	K0L
1	5.2786983E-2	K1L
2	2.1460701E+1	K2L
3	-1.5781718E+4	K3L
4	-1.0460598E+7	K4L
5	-2.1616222E+8	K5L
6	2.9440168E+7	K6L
7	-5.5875949E+7	K7L
8	4.4411777E+8	K8L
9	0.0	K9L

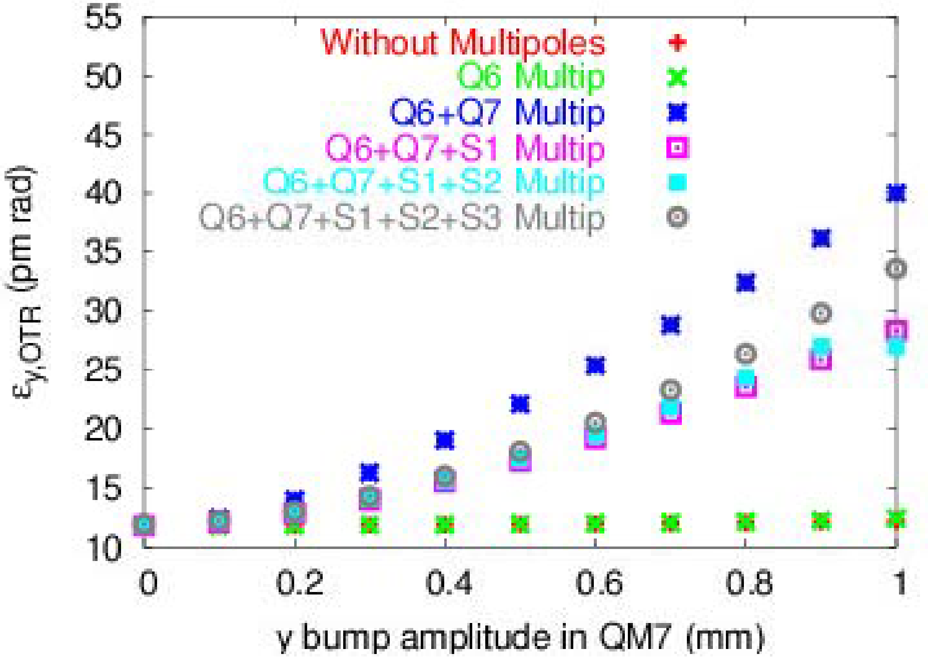
Dipole component -1.7%
Quadrupole component small
Sextupolar component non negligible

BS2X and BS3X scaled from BS1X

Zone of interest for tracking x=0.0855m, y=0m

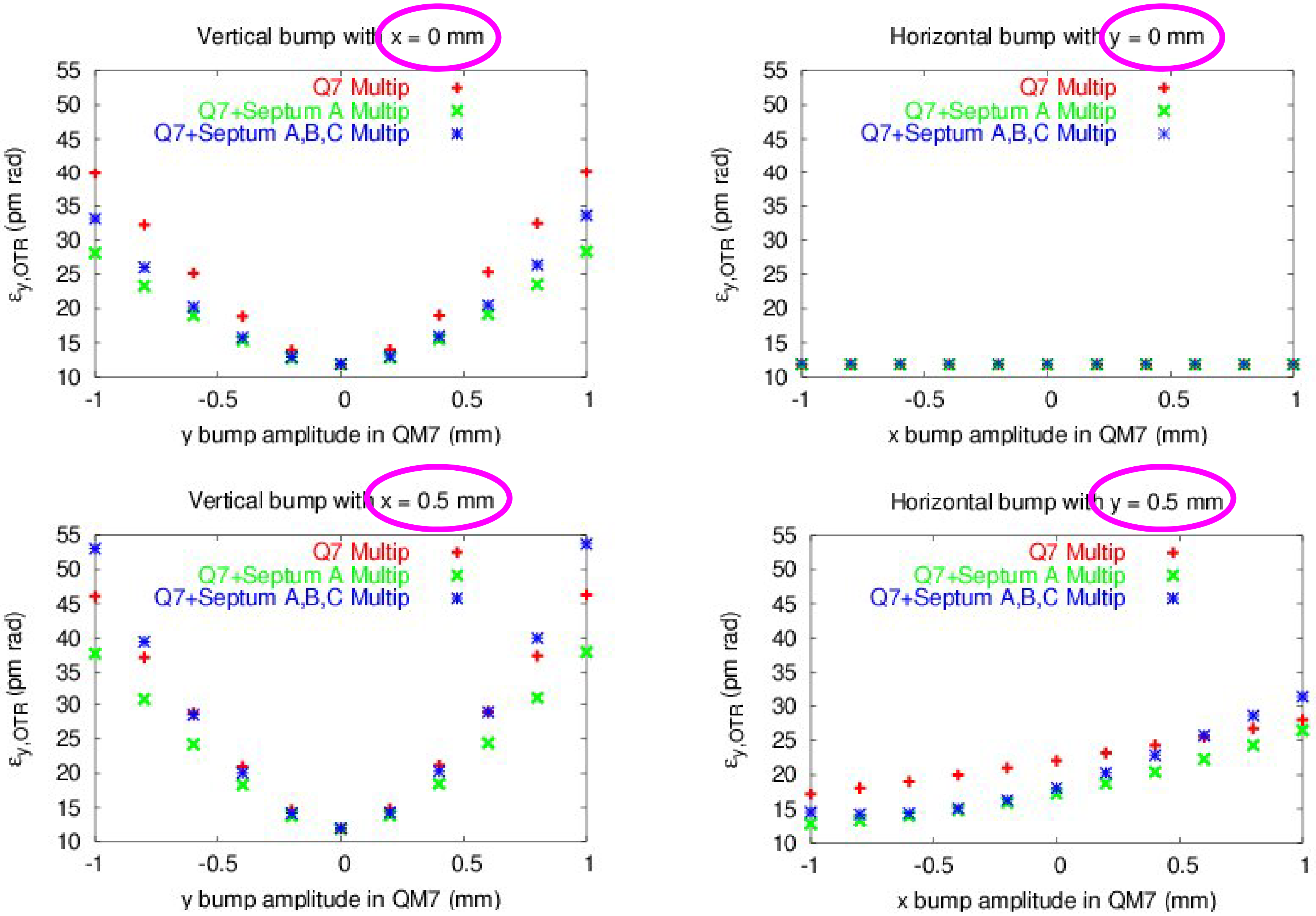
Tracking simulations including non-linear fields in different magnets



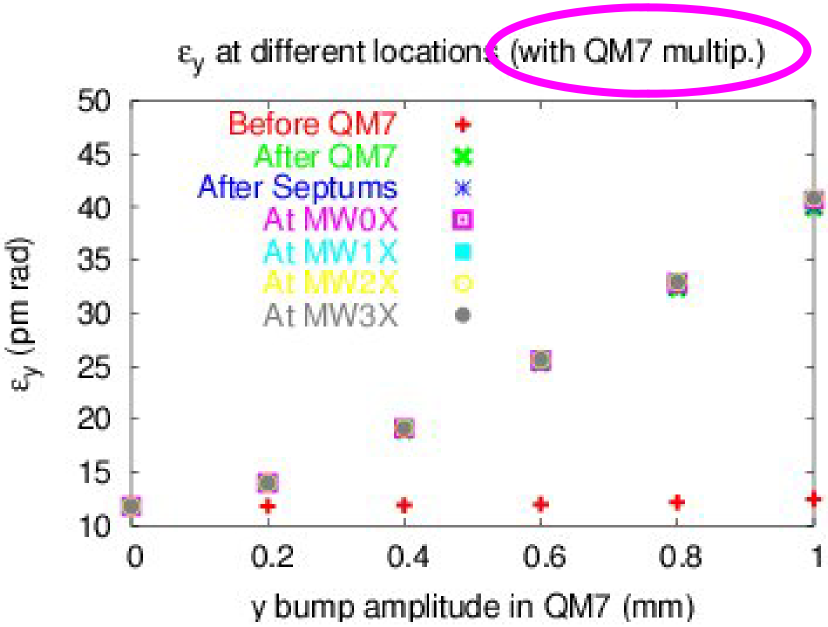


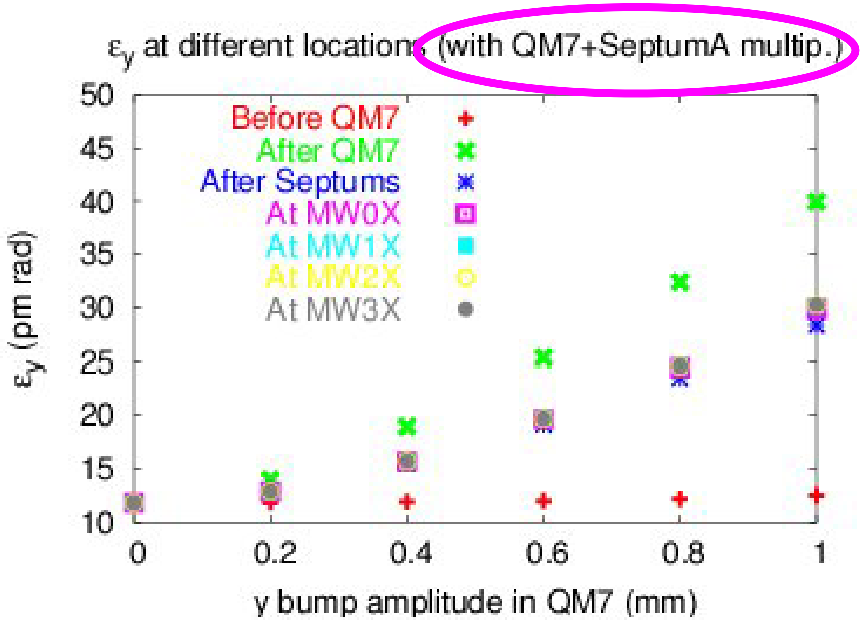
Tracking performed with MAD and PLACET without horizontal bumps

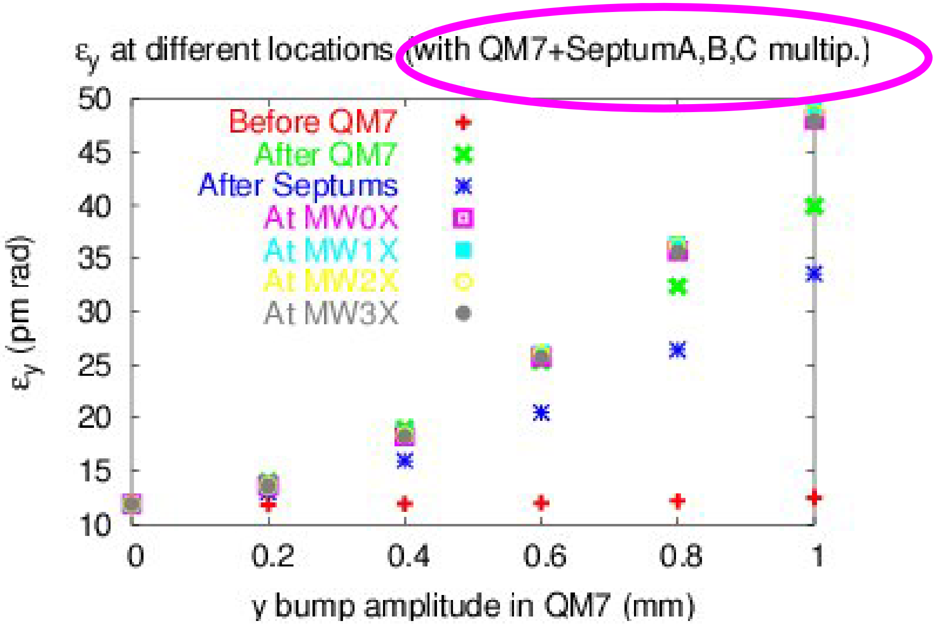
Tracking simulations for different x/y bump amplitudes



Tracking simulations for different y bump amplitudes for calculting emittances at different locations of the EXT line







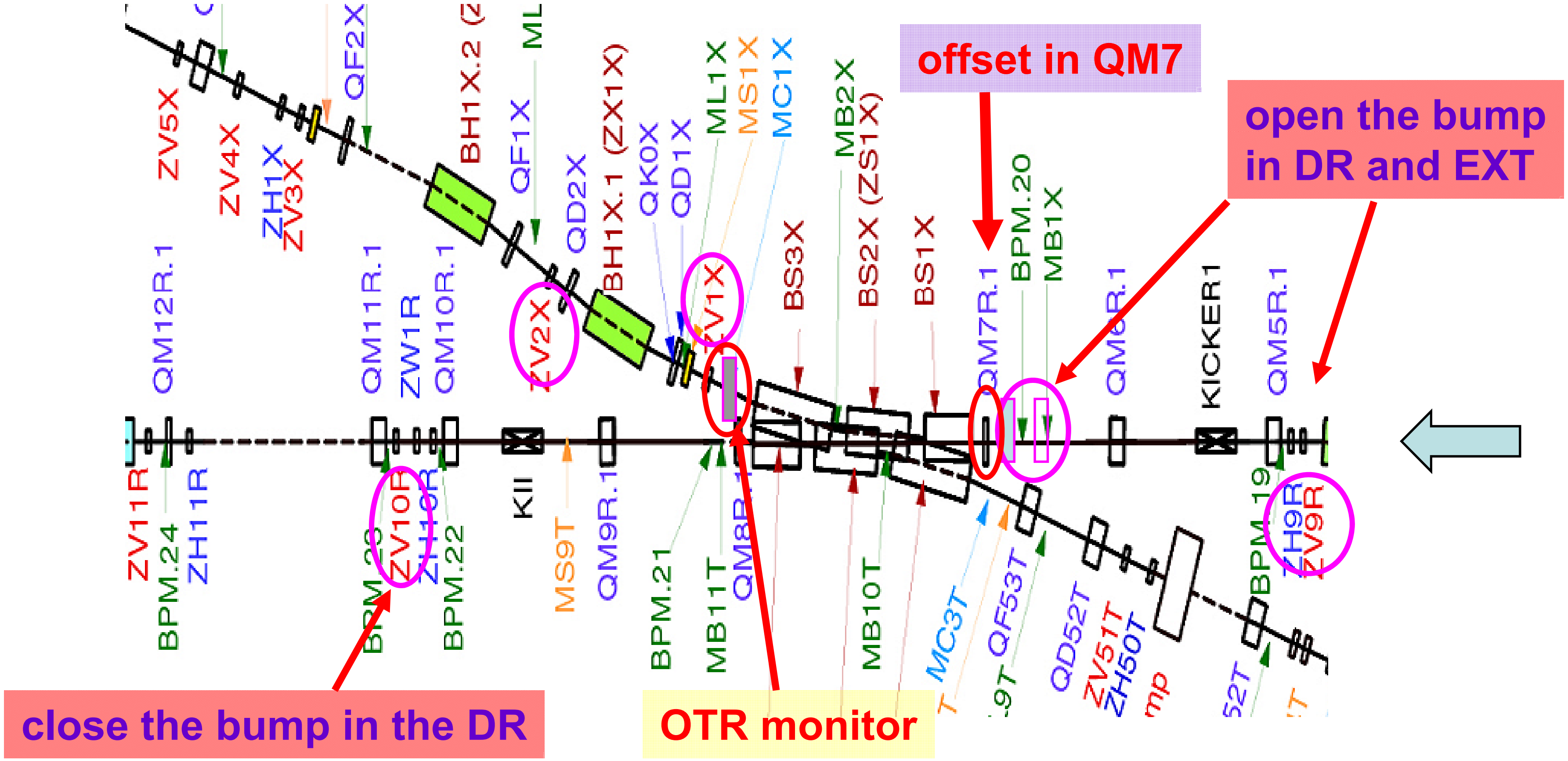
ATF: Experimental Proposal

Beam size after the shared magnets is correlated with the emittance:

- OTR monitor recently installed images the beam angular spread out of QM7

- Creating bumps in QM7 to probe effects on the vertical emittance

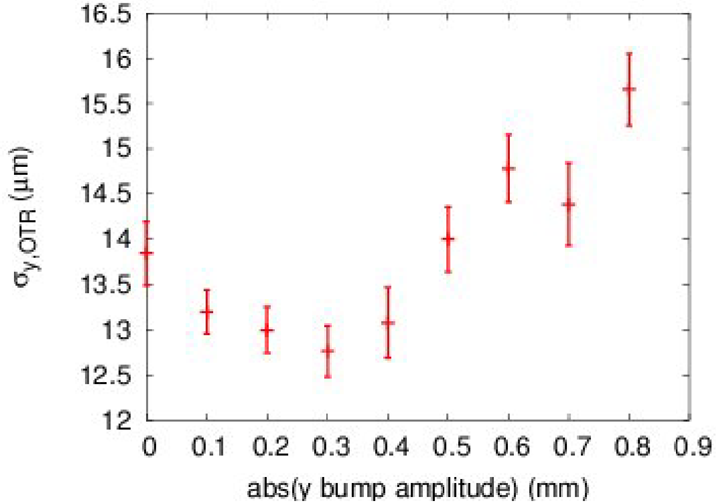
- Measure beam sizes at the DR (XSR monitor) and the EXT line (OTR monitor) as a function of the bump amplitude



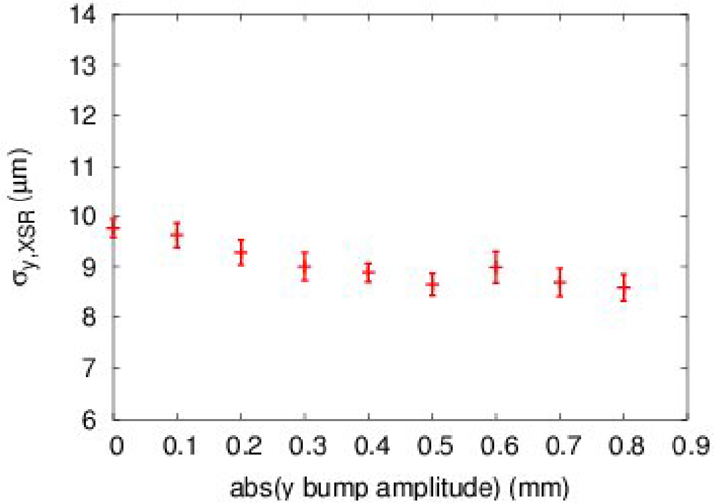
ATF: Experimental Work (Dec'07-May'08)

Vertical beam size *vs* vertical bump amplitude at QM7

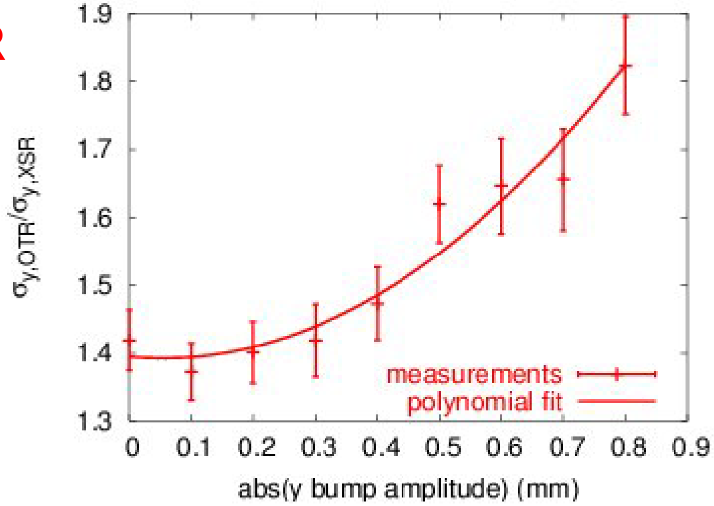
Extraction Line (OTR monitor)



Damping Ring (XSR monitor)



OTR/XSR



(Measurements 19th Dec'07)

ATF: Experimental Work (Dec'07-May'08)

Simulations:

- **including non-linear fields in different magnets**
- **for different horizontal bump amplitudes in QM7 (nominal extraction 22.5 mm)**
- **with the input emittances the corresponding to the measured during the shift**

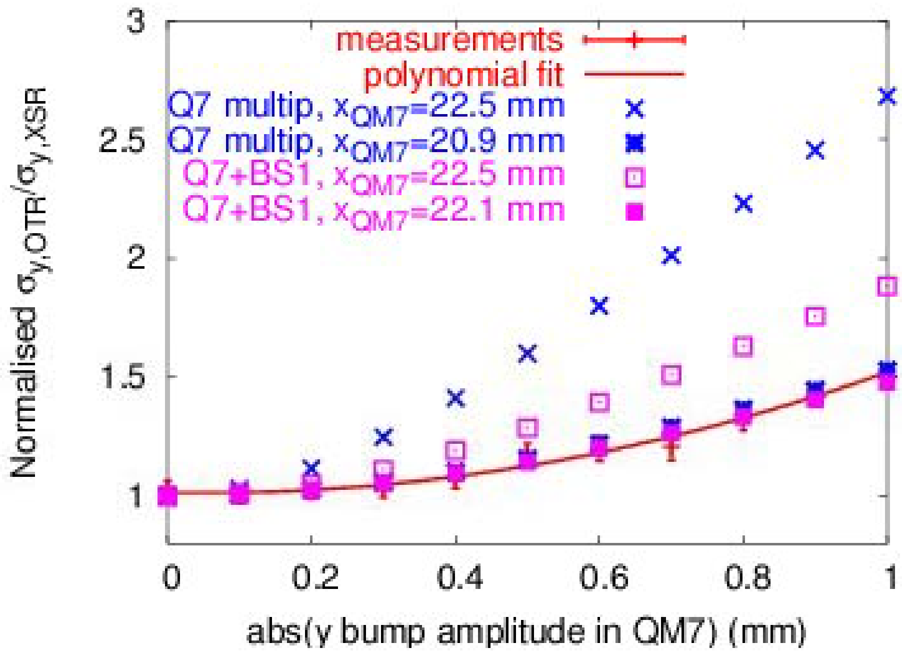
Measurements 19th Dec 2007

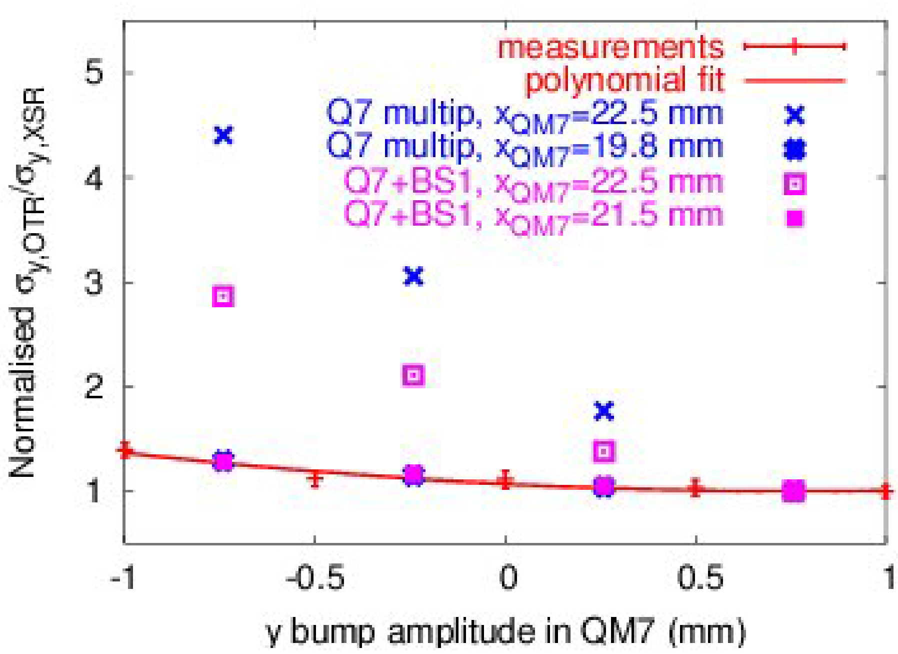
ε_y=36 pm ~ 3*$\varepsilon_{y,nom}$
ε_x=2.4 nm ~ 2*$\varepsilon_{x,nom}$

Measurements 28th May 2008

ε_y=24.0 pm ~ 2*$\varepsilon_{y,nom}$
ε_x=2.28 nm ~ 1.9*$\varepsilon_{x,nom}$

σ_y increase at the OTR as a function of the y bump amplitude





Conclusions

The non-linear content of: QM6, QM7, BS1X has been calculated with PRIAM. BS2X and BS3X scaled from BS1X, useful to perform the calculation for these two magnets.

Tracking simulations including non-linear field errors in: QM6, QM7, BS1X, BS2X and BS3X, shared by both the ATF EXT line and its DR, and orbit displacements from the reference orbit in the extraction region predict a vertical emittance growth of the extracted beam.

Simulations show that the non-linear fields are very sensitive to the horizontal extraction position.

Recently, measurements using closed orbit bumps in the DR to probe the relation between the extraction trajectory and the emittance growth in the EXT line have been carried out. The results show an emittance growth with a strong dependence with the extraction position.

Both horizontal and vertical positions of the beam in the extraction region have to be controled to avoid this emittance growth.