Emittance measurements with multiple wire-scanners and quadrupole scans in ATF EXT

C. Rimbault, Brossard, P. Bambade (LAL)

Main goal :

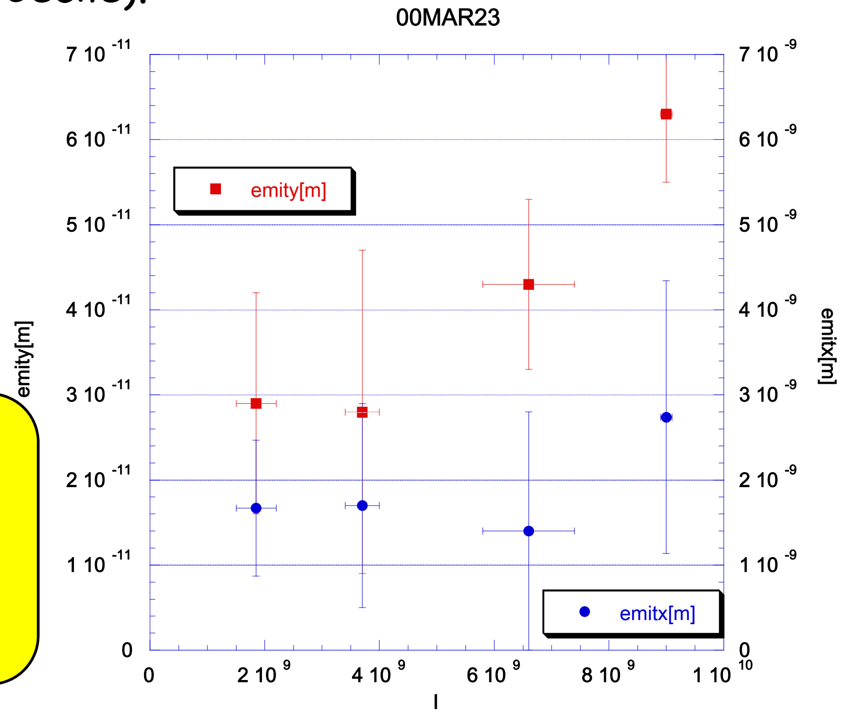
- Try to identify if the abnormal emittance growth (observed at high current) in the ATF extraction line could come from a systematic biais induced by the reconstruction method.

Two different methods have been performed on 6th of dec. 2007

- a « 4 wire scanner » method (presented by Julien).
- a « quadrupole scan » method (presented by Cécile).

The goal is to identify how the error measurement on beam size and dispersion values at wire scanner station could affect the emittance reconstruction method.

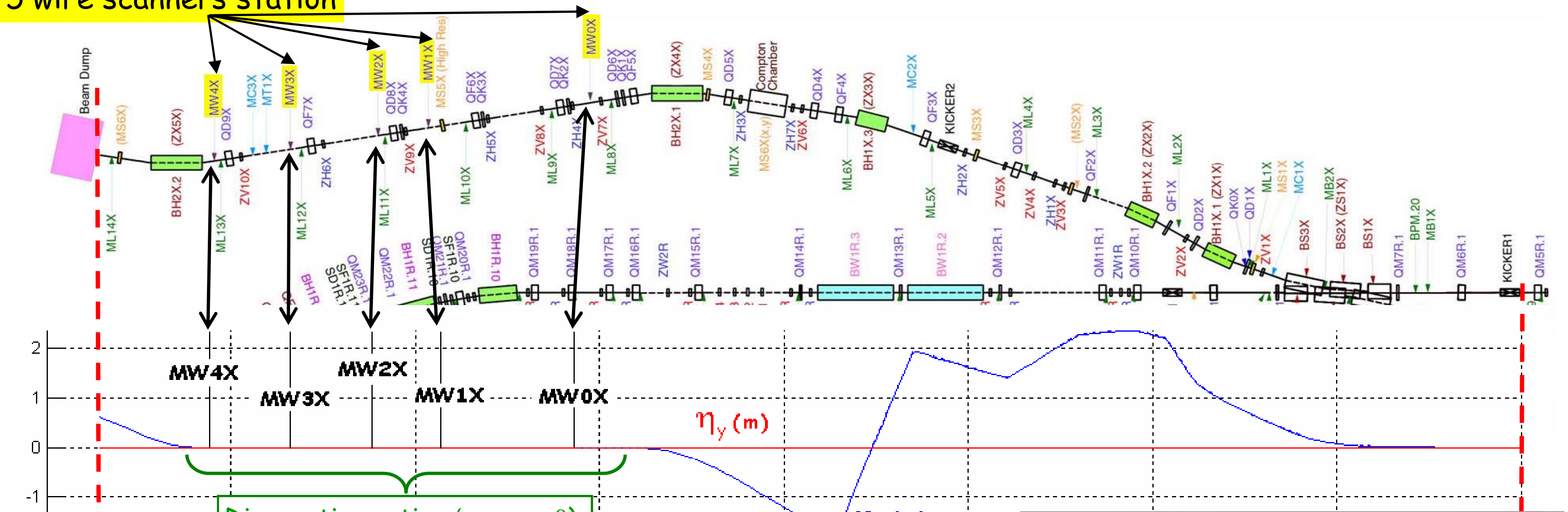
1 - Description of extraction line and wire scanner
2 - 4 wire scanner method.
3 - Damping ring emittance measurement
4 – 4 wire scanner emittance reconstruction
→ Quad scan method & emittance reconstruction



Shigeru Kuroda-San, LCWS’07, Hamburg

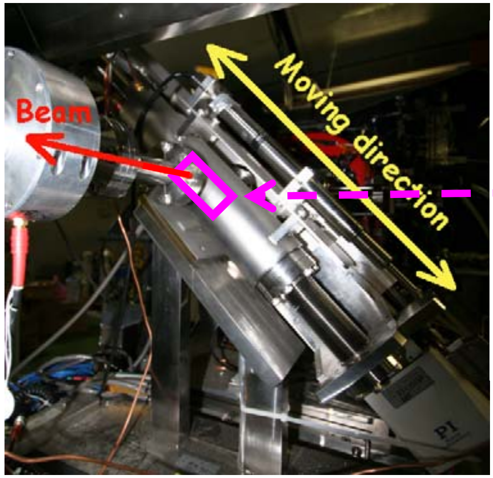
1 - ATF EXT line description & wire scanner position

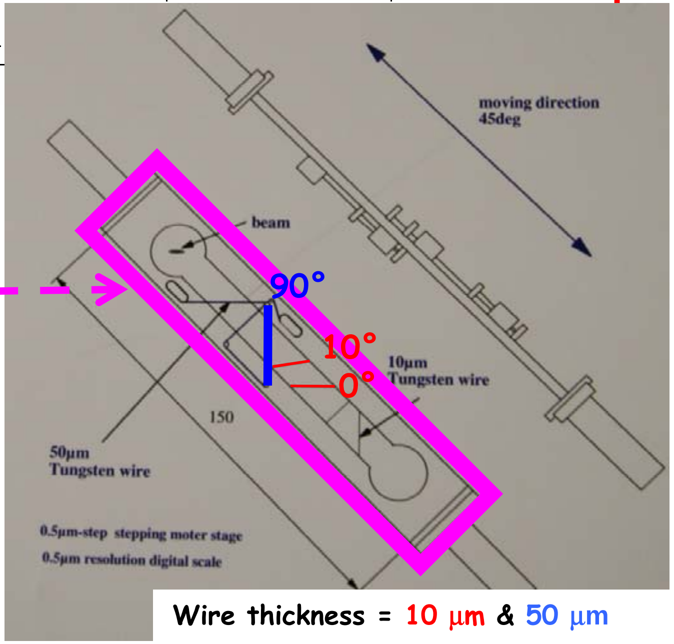
5 wire scanners station



Diagnostic section (η_x= η_y =0)

At each station, there are different wire scanner orientation for beam size and shape measurement.
For vertical (or horizontal) projected emittance measurement, only one wire scanner orientation is needed.
For x-y coupling measurement a tilt angle is also required.





Wire thickness = 10 µm & 50 µm

2 - Multi-wire scanner emittance reconstruction method

No coupling between reference point and wire scanner position → the following linear system is used to reconstruct the vertical projected emittance.

$$\begin{pmatrix} \sigma_{33}^{MW0X} \\ \sigma_{33}^{MW1X} \\ \cdots \\ \sigma_{33}^{MW4X} \end{pmatrix} = \begin{pmatrix} R_{33}^{(A->MW0X)2} & 2R_{33}^{(A->MW0X)}R_{34}^{(A->MW0X)} & R_{34}^{(A->MW0X)2} \\ R_{33}^{(A->MW1X)2} & 2R_{33}^{(A->MW1X)}R_{34}^{(A->MW1X)} & R_{34}^{(A->MW1X)2} \\ \cdots & \cdots & \cdots \\ R_{33}^{(A->MW4X)2} & 2R_{33}^{(A->MW4X)}R_{34}^{(A->MW4X)} & R_{34}^{(A->MW4X)2} \end{pmatrix} \begin{pmatrix} \sigma_6^A \\ \sigma_9^A \\ \sigma_{10}^A \end{pmatrix} = M_Y \begin{pmatrix} \sigma_6^A \\ \sigma_9^A \\ \sigma_{10}^A \end{pmatrix}$$

$$\sigma_{33}^{MWiX} = \left(\sigma_y^{measure@MWiX}\right)^2 - \left(\frac{d_{y\_wire}}{4}\right)^2 - \left(\frac{\Delta p}{p} * \eta_y^{MWiX}\right)^2$$

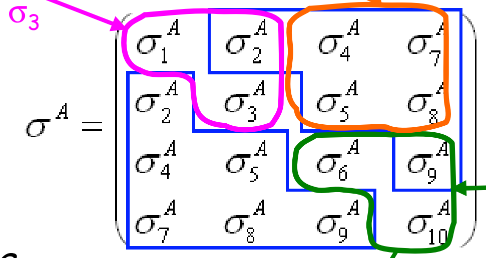
at the 5 wire scanners station

R_{ij} Linear transport coefficent

Beam matrix element at the reference point « A ».

σ_{10° measurements to defined σ_4 σ_5 σ_7 and σ_8

σ_x measurements to defined σ_1 σ_2 and σ_3



$$\sigma^A = \begin{pmatrix} \sigma_1^A & \sigma_2^A & \sigma_4^A & \sigma_7^A \\ \sigma_2^A & \sigma_3^A & \sigma_5^A & \sigma_8^A \\ \sigma_4^A & \sigma_5^A & \sigma_6^A & \sigma_9^A \\ \sigma_7^A & \sigma_8^A & \sigma_9^A & \sigma_{10}^A \end{pmatrix}$$

The y-beam size are corrected from wire scanner diameter d_{y_wire} and dispersion η_y (assuming $\Delta p/p = 8.10^{-4}$)

The reference point « A » is just in front MW0X wire scanner.

We will **focused on projected** ε_y **emittance** (*the other components will be analysed later*).

The Least Means Square Method (LMS) is used to find « the LMS solution ».

Then the projected emittance ε_y is computed using :

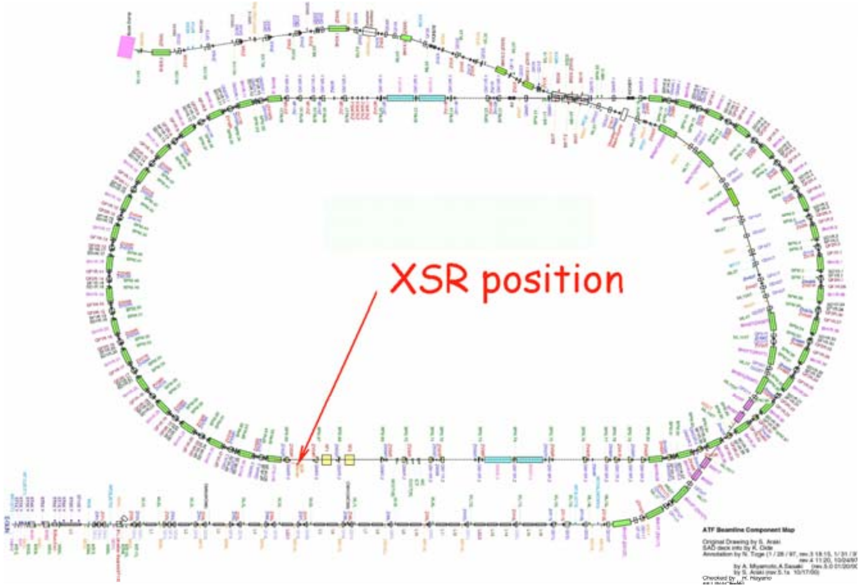
$$\boxed{\varepsilon_y = \sqrt{\sigma_6^A . \sigma_{10}^A - \left(\sigma_9^A\right)^2}}$$

3 - Damping ring emittance measurement

Results obtained from the shift 6 dec 2007. (SET file : SET07DEC6_1732.dat)

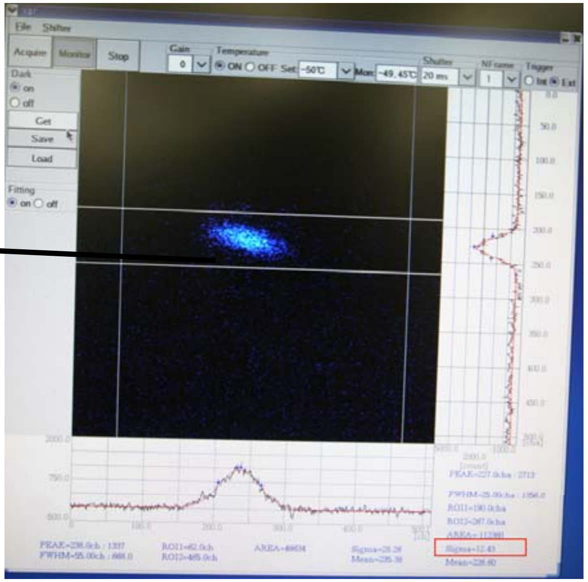
Beam tuning in DR : Orbit, dispersion and coupling correction

Emittance measurement in DR using XSR



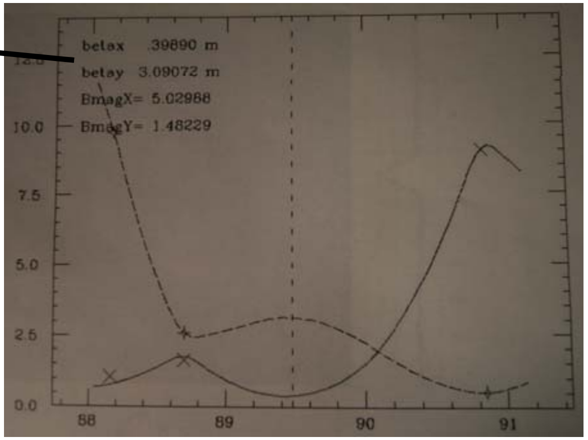
x-beam size = 15 µm

y-beam size = 34 µm



βx =0.399 m

βy =3.091 m



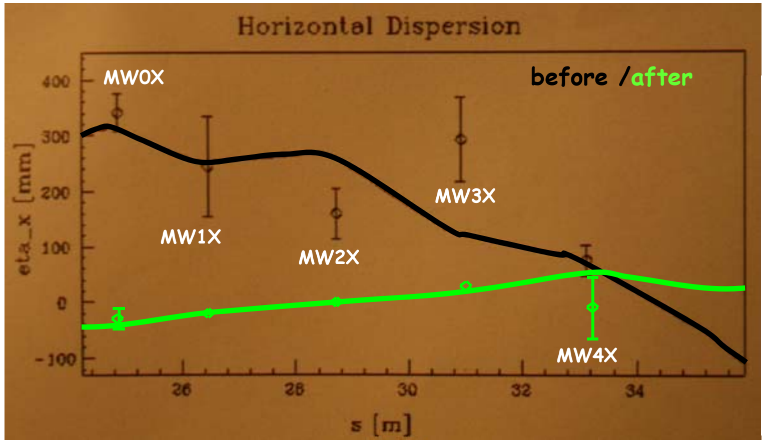
In the damping ring :

->ε_x ~ **2.9 nm.rad** ~ 1.5* nom. value (2 nm.rad)

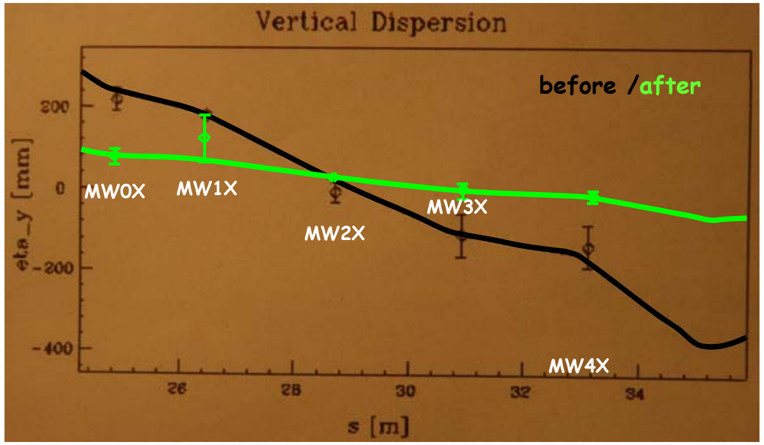
->ε_y ~ **72 pm.rad** ~ 3.6* nom value (20 pm.rad)

4 - wire scanner emittance reconstruction

Dispersion correction in the extraction line



	x-dispersion	error	y-dispersion	error
MW0X	278.144	36.697	211.129	13.717
MW1X	220.933	22.461	-16.085	10.172
MW2X	115.331	17.724	-116.444	15.074
MW3X	53.779	32.165	-201.389	15.711



	x-dispersion	error	y-dispersion	error
MW0X	-31.878	1.336	58.759	7.207
MW1X	10.538	0.522	-0.719	5.354
MW2X	33.505	0.826	-26.579	8.942
MW3X	63.101	1.653	-50.613	9.959

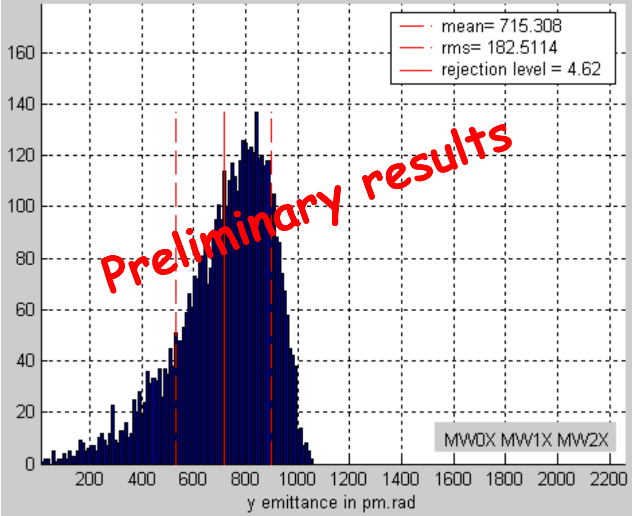
If η_y @ WS ~ 10 mm then $(\delta\eta_y)^2$ ~ 8 μm ~ nominal beam size at WS without dispersion.

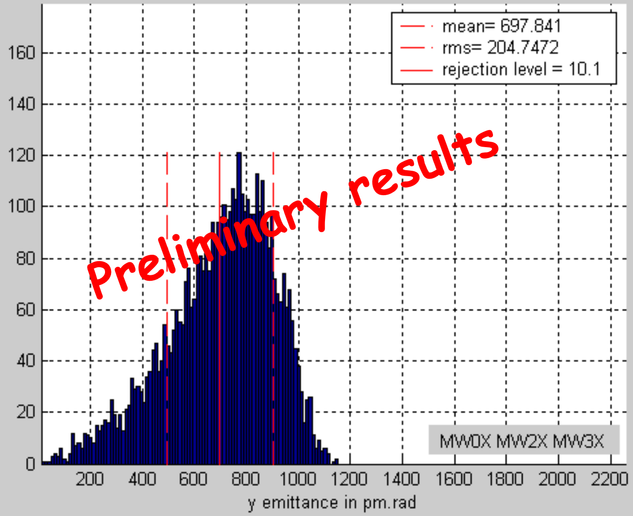
Beam size measurement at wire scanner position

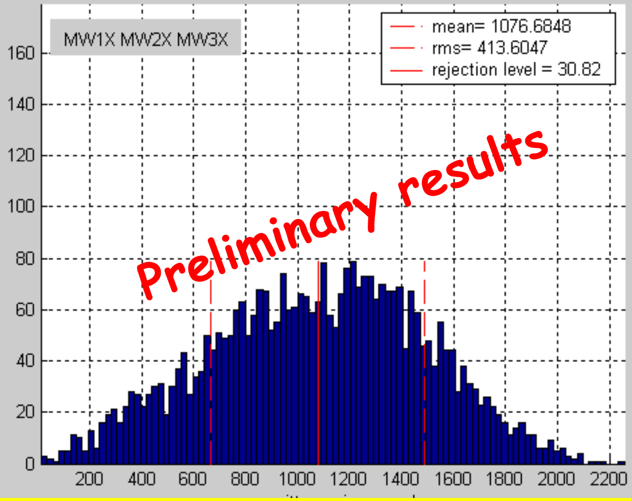
	MW0X	MW1X	MW2X	MW3X
Sigy (micrometer)	57.8±1.6	58.6±3	106.6±3	118.8±3

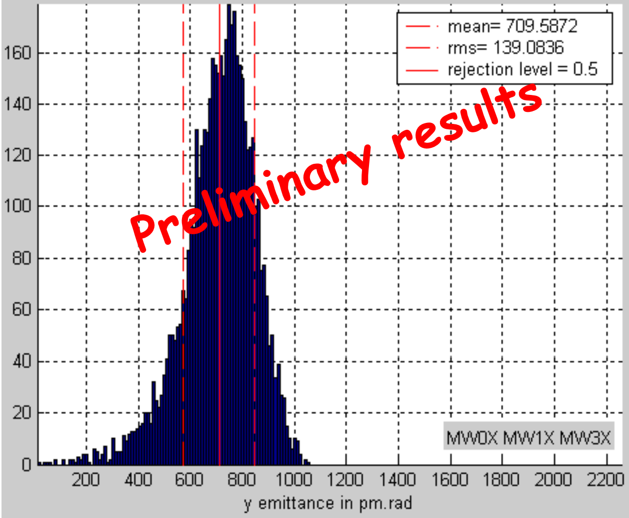
4 - Extraction line vertical emittance reconstruction

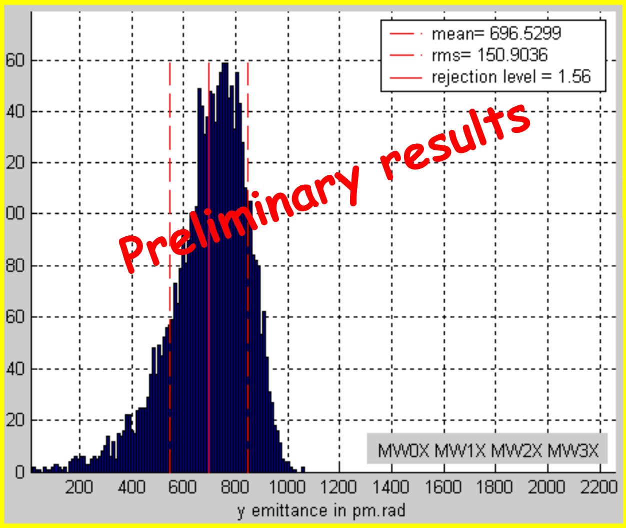
With such dispersion and beam size measurements at wire scanner station, the vertical emittance can be estimated in the extraction line (using the linear optics matrix computed by **M. Woodley** based on the real machine status : SET file : SET07DEC6_1732.dat)











4 wire scanner

ε_y ~ **(670 +/- 150)* pm.rad**

SAD gave emittance between
0 and 10 pm.rad

Preliminary results

The phase advanced between wire scanner has to be checked

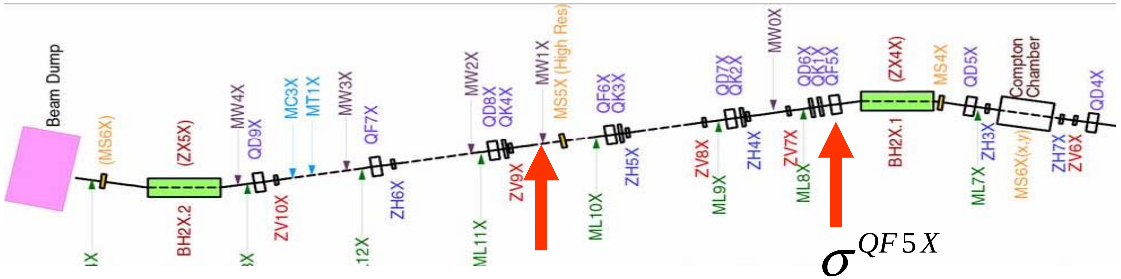
*Based on 5 000 run

Emittance measurements using quadrupole and skew quadrupole scans

Method
Reconstructed Emittance from the 6th December measurements
Estimation of the coupling
Conclusions

C. Rimbault, P. Bambade, J. Brossard, LAL-Orsay
Fifth ATF2 Project Meeting, KEK, 19-21 December 2007

Emittance measurements using quadrupole and skew quadrupole scans



$$\sigma^{QF5X}$$

$$\sigma^{MW1X} = R\sigma^{QF5X}R^T$$

Transfer Matrix $R = SQ$ with

$$S = \begin{pmatrix} S_{11} & S_{12} & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 \\ 0 & 0 & S_{33} & S_{34} \\ 0 & 0 & S_{43} & S_{44} \end{pmatrix} \qquad Q = \begin{pmatrix} 1 & 0 & 0 & 0 \\ k & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -k & 1 \end{pmatrix}$$

The measured beam sizes, σ^M, at MW1X are expressed as a parabolic function of the strength of QF5X, described by 3 fit parameters. Reconstructing those parameters make enable the twiss parameter determination at QF5X position, via the reconstruction of σ_{11}, σ_{12}, σ_{22}, σ_{33}, σ_{34}, σ_{44}.

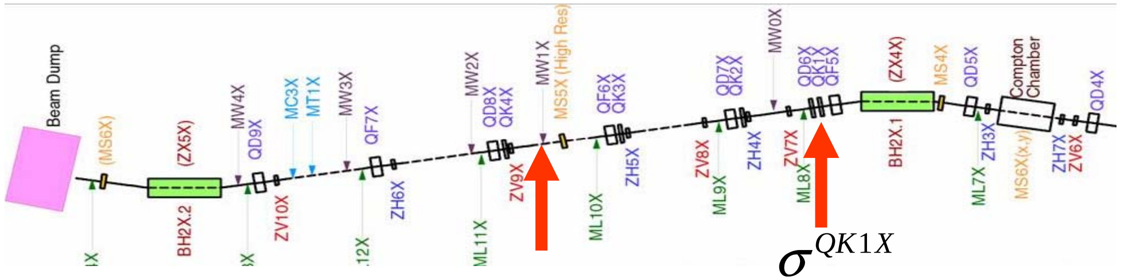
$$\sigma_{11}^M = S_{11}^2\sigma_{11}^{QF} + 2S_{11}S_{12}\sigma_{12}^{QF} + S_{12}^2\sigma_{22}^{QF} + k(S_{11}\sigma_{11}^{QF} + S_{12}\sigma_{12}^{QF})2S_{12} + k^2\sigma_{11}^{QF}S_{12}^2 \Leftrightarrow A_x(k-B_x)^2 + C_x$$

$$\sigma_{33}^M = S_{33}^2\sigma_{33}^{QF} + 2S_{33}S_{34}\sigma_{34}^{QF} + S_{34}^2\sigma_{44}^{QF} + k(S_{33}\sigma_{33}^{QF} + S_{34}\sigma_{34}^{QF})2S_{34} + k^2\sigma_{33}^{QF}S_{34}^2 \Leftrightarrow A_y(k-B_y)^2 + C_y$$

$$\left.\boxed{\begin{aligned} \sigma_{11}^Q &= \frac{A_x}{S_{12}^2} \\ \sigma_{22}^Q &= \frac{1}{S_{12}^2}\left(A_x B_x^{\ 2} + 2\frac{S_{11}}{S_{12}}A_x B_x + \frac{S_{11}^2}{S_{12}^2}A_x + C_x\right) \\ \sigma_{12}^Q &= -\frac{A_x}{S_{12}^2}\left(B_x + \frac{S_{11}}{S_{12}}\right) \end{aligned}}\right\} \Rightarrow \varepsilon_x = \sqrt{\sigma_{11}^Q\sigma_{22}^Q - \sigma_{12}^Q} = \sqrt{\frac{A_x C_x}{S_{12}^4}}$$

And the same for $\sigma_{33}\,\sigma_{34}\,\sigma_{44} \rightarrow \varepsilon_y$

Emittance measurements using quadrupole and skew quadrupole scans



$$\sigma^{QK1X}$$

$$\sigma^{MW1X} = R\sigma^{QK1X}R^T$$

Transfer Matrix $R = SQ$ with

$$S = \begin{pmatrix} S_{11} & S_{12} & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 \\ 0 & 0 & S_{33} & S_{34} \\ 0 & 0 & S_{43} & S_{44} \end{pmatrix} \qquad Q = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & k & 0 \\ 0 & 0 & 1 & 0 \\ k & 0 & 0 & 1 \end{pmatrix}$$

The measured beam sizes, σ^M, at MW1X are expressed as a parabolic function of the strength of QK1X, described by 3 fit parameters. If no coupling, the parabola is centered at zero.

$$\sigma_{11}^M = S_{11}^2\sigma_{11}^{QK} + 2S_{11}S_{12}\sigma_{12}^{QK} + S_{12}^2\sigma_{22}^{QK} + k(S_{11}\sigma_{13}^{QK} + S_{12}\sigma_{23}^{QK})2S_{12} + k^2\sigma_{33}^{QK}S_{12}^2 \Leftrightarrow D_x(k-E_x)^2 + F_x$$

$$\sigma_{33}^M = S_{33}^2\sigma_{33}^{QK} + 2S_{33}S_{34}\sigma_{34}^{QK} + S_{34}^2\sigma_{44}^{QK} + k(S_{33}\sigma_{13}^{QK} + S_{34}\sigma_{14}^{QK})2S_{34} + k^2\sigma_{11}^{QK}S_{34}^2 \Leftrightarrow D_y(k-E_y)^2 + F_y$$

$$D_x = S_{12}^2\sigma_{33}^{QK} \qquad D_y = S_{34}^2\sigma_{11}^{QK}$$

$$\boxed{-D_xE_x = S_{12}(S_{11}\sigma_{13}^{QK} + S_{12}\sigma_{23}^{QK}) \qquad -D_yE_y = S_{34}(S_{33}\sigma_{13}^{QK} + S_{34}\sigma_{14}^{QK})}$$

$$D_xE_x^2 + F = S_{11}^2\sigma_{11}^{QK} + 2S_{11}S_{12}\sigma_{12}^{QK} + S_{12}^2\sigma_{22}^{QK} \qquad D_yE_y^2 + F = S_{33}^2\sigma_{33}^{QK} + 2S_{34}S_{33}\sigma_{34}^{QK} + S_{34}^2\sigma_{44}^{QK}$$

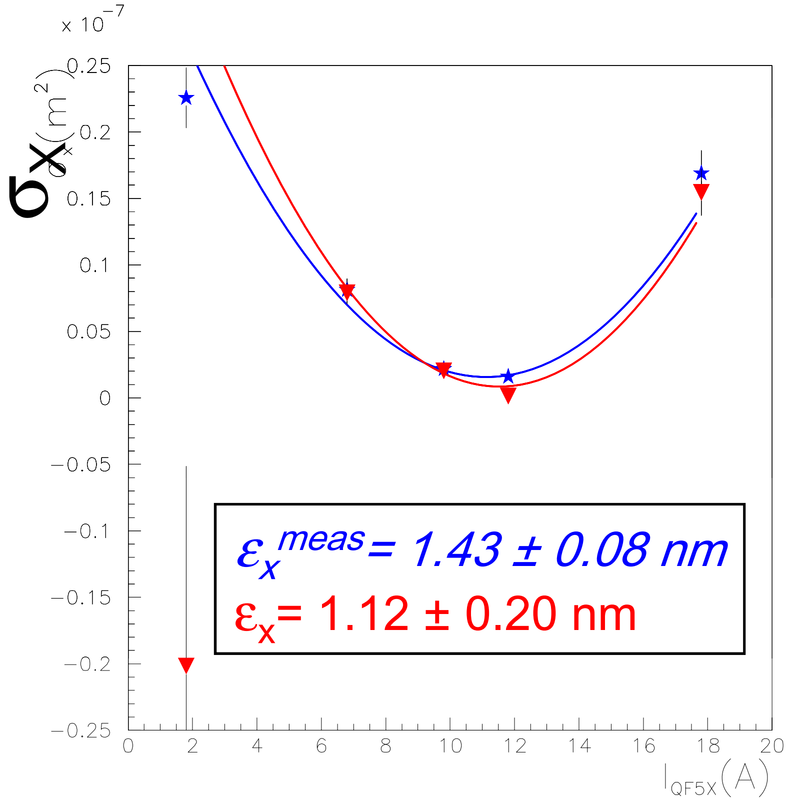
σ_{11}, σ_{12}, σ_{22}, σ_{33}, σ_{34}, σ_{44}.at QK1X can be deduced from previous step, knowing the R matrix (QF5X + drift). To determine coupling elements σ_{13}, σ_{23}, σ_{14} one needs measurements at 2 wires scanners.

Emittance reconstruction from beam size measurements on 6th December 2007

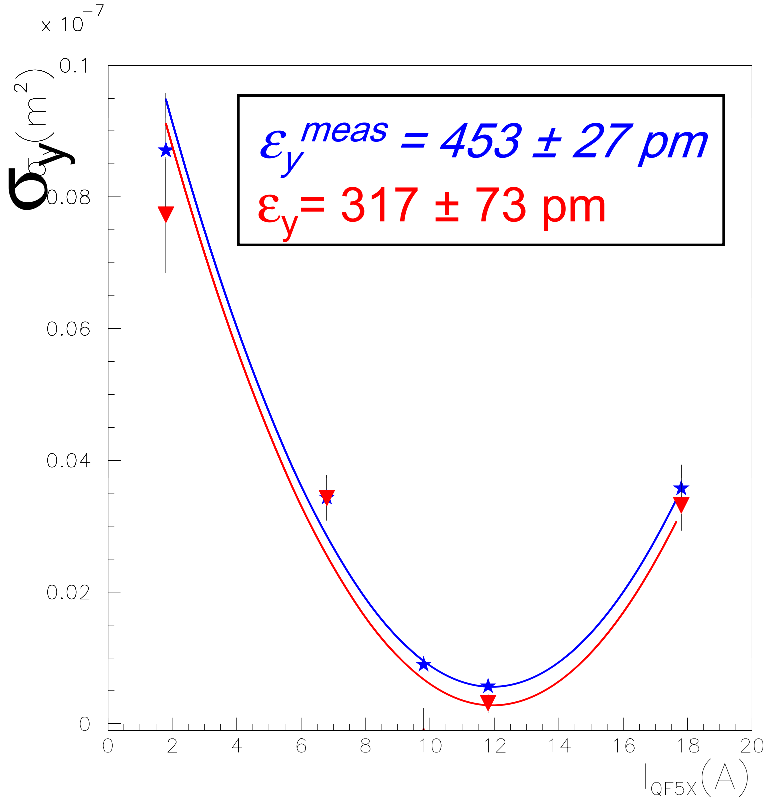
- Measured emittance in the damping ring: ε_x=3nm ; ε_y=70pm
- 1 normal quad QF5X scan + 1 skew quad QK1X scan at MW1X wire scanner.
- Dispersion was measured for each intensity of QF5X and QK1X

$$\sigma^2_{meas} = (\varepsilon\beta)^2 + \left(\eta\frac{\Delta p}{p}\right)^2 + \left(\frac{d_{wire}}{4}\right)^2$$

with: d_{wire}= 50µm for x and 10µm for y
$\Delta p/p$ = 8e-4
$\Delta\sigma/\sigma$ = 0.05

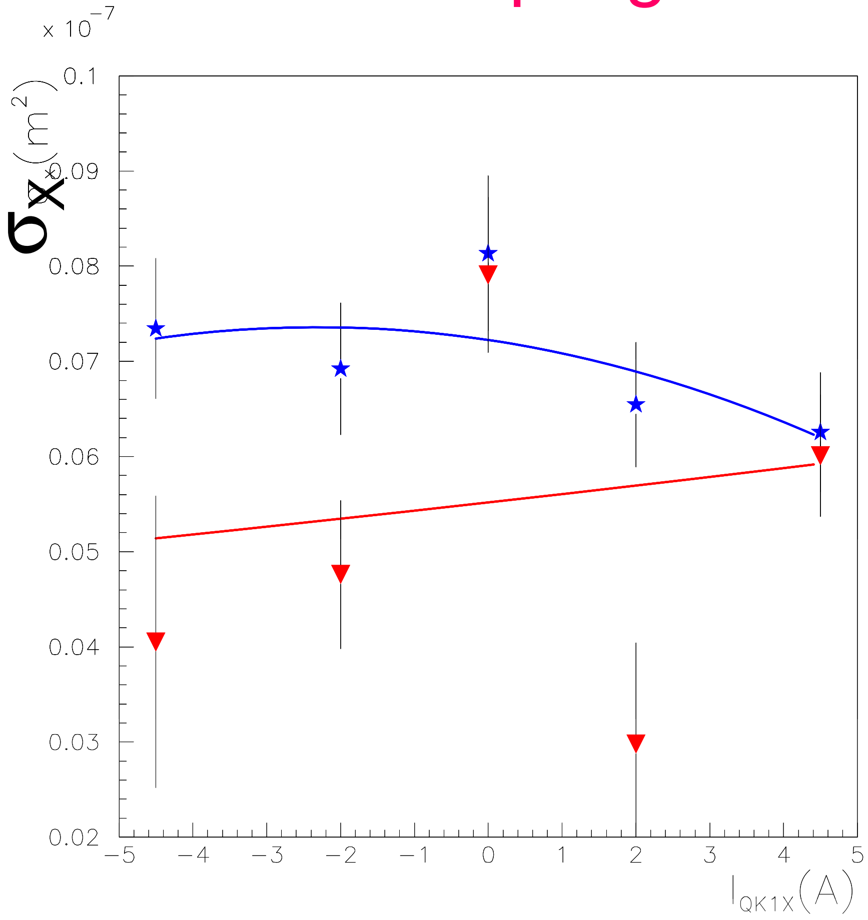


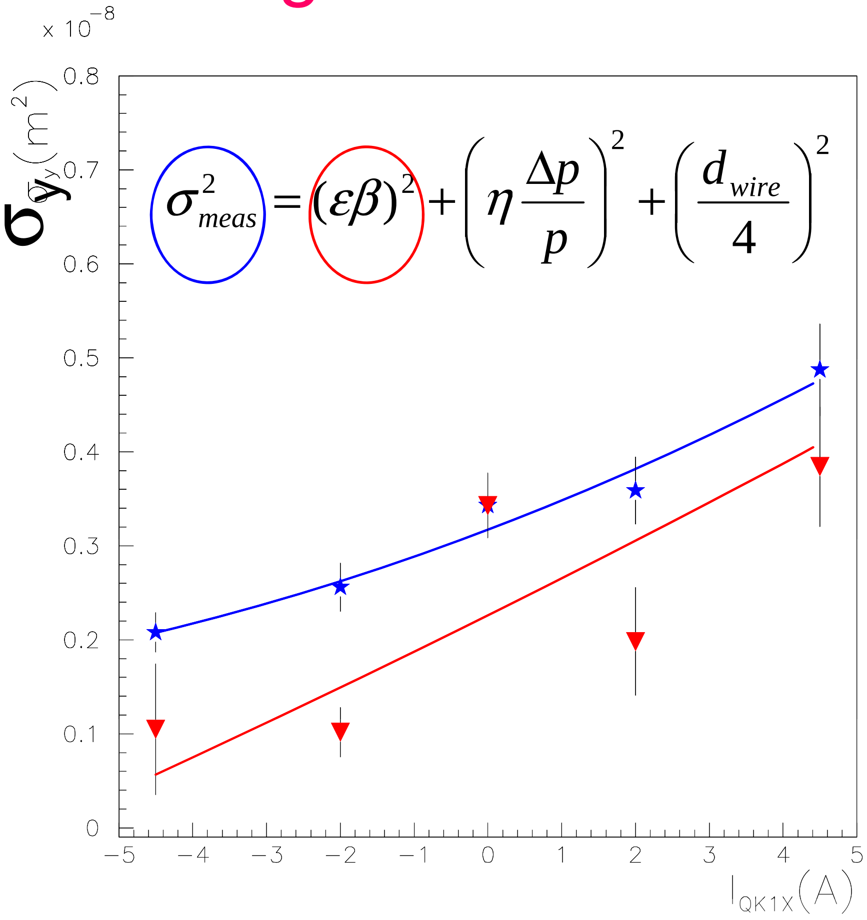
ε_x^{meas} = 1.43 ± 0.08 nm
ε_x = 1.12 ± 0.20 nm



ε_y^{meas} = 453 ± 27 pm
ε_y = 317 ± 73 pm

QK1X scan at MW1X wire scanner: coupling estimation using MAD8

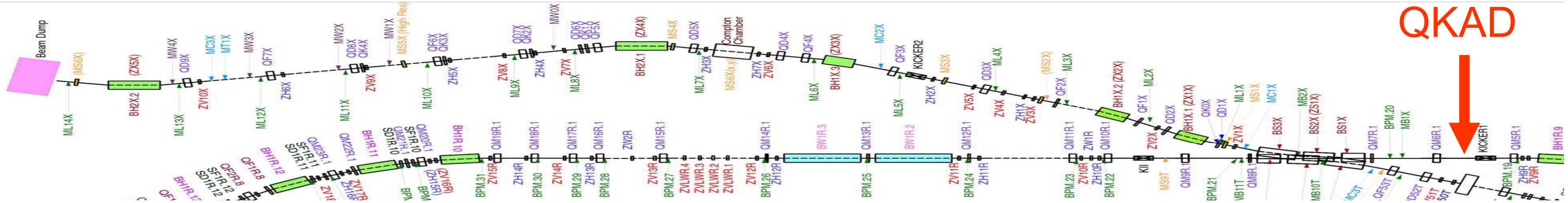




$$\sigma_{meas}^2 = (\varepsilon\beta)^2 + \left(\eta\frac{\Delta p}{p}\right)^2 + \left(\frac{d_{wire}}{4}\right)^2$$

The scan of QK1X is limited from -5A to +5A, no parabola reconstruction,
The coupling will be estimated using MAD8 with a “perfect” beam (ε_x=2 nm.rad ; ε_y=20 pm.rad) and the adapted extraction line.

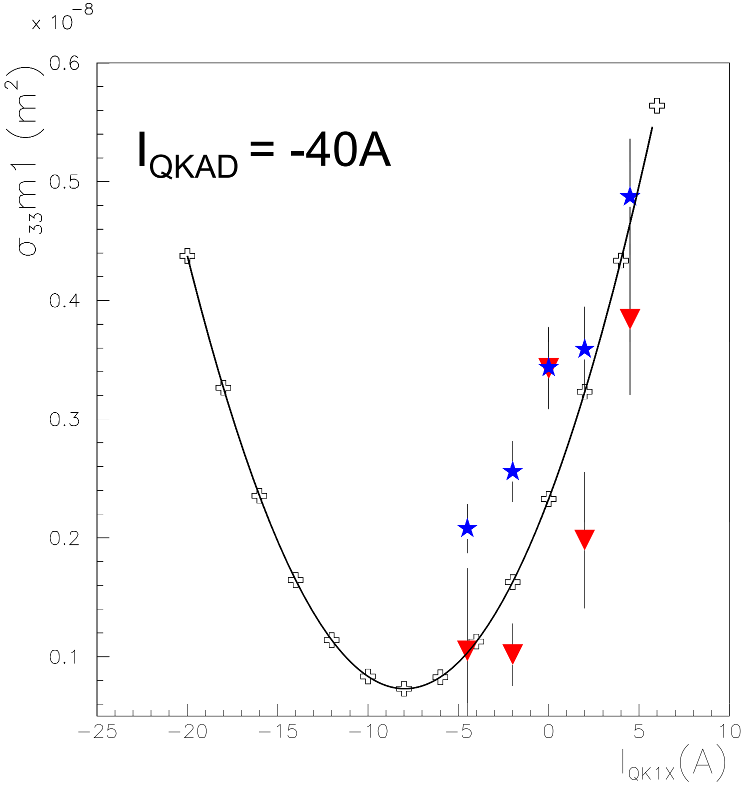
QK1X scan at MW1X wire scanner: coupling estimation using MAD8



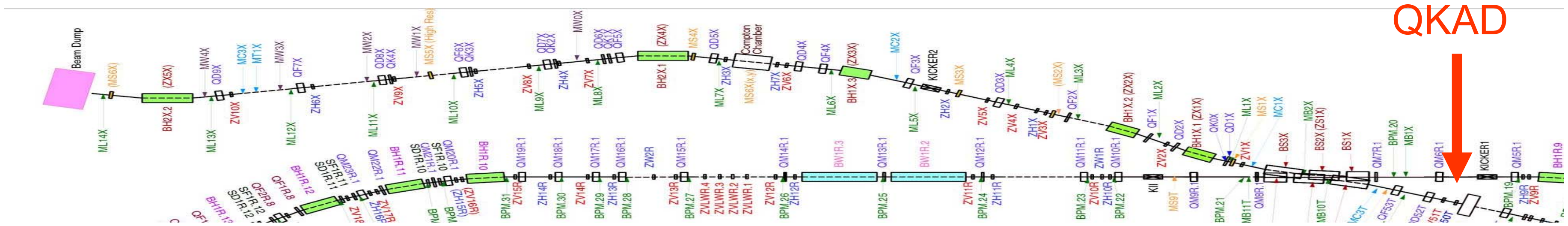
- A “virtual” skew, QKAD, quad. of type QK1X is introduced at the beginning of the Ext line.
- Its strength varies until fitting with the measured points at MW1X with QK1X scan.

  ➔the coupling is reproduced for

  I_{QKAD} : [-50; -35]A ≡ Ks[-0.258 ; -0.180]m^{-1}

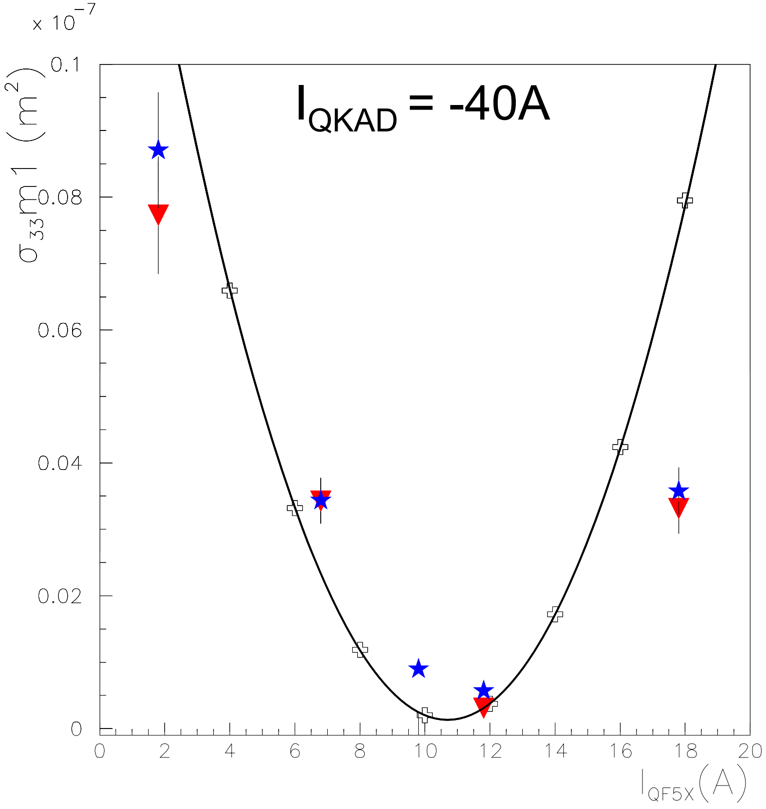


QK1X scan at MW1X wire scanner: coupling estimation using MAD8



- A scan of QF5X is simulated with different value of Ks_{QKAD}, and emittances are recontructed.

I_{QKAD} (A)	$Ks_{QKAD}(m^{-1})$	ε_x (nm.rad)	ε_y(pm.rad)
0	0	1.12 ± 0.20	317 ± 73
-35	-0.1804	2.02 ± 0.09	248 ± 17
-40	-0.2062	2.02 ± 0.09	284 ± 21
-45	-0.2320	2.03 ± 0.09	319 ± 27
-50	-0.2578	2.02 ± 0.09	354 ± 33



Conclusions on quad scan method

- Quadrupole scan method needs very precise correction of the orbit, else strength quad variation induce large beam deflections which may generate saturation at the wire scanner readout.

- This method does not require optimize phase advance between wire scanners.

- Dispersion has to be well measured for each quad. strength.

- The parabola are very sensitive to the optics, thus a rapid cross check is required with simulation before starting measurements, in order to “know what to do”.

- Skew quad scan is a simple way to verify if there is coupling, as the parabola should be zero centered without coupling.

- It was reconstructed a vertical emittance in the extraction line 15 times larger than the nominal one. This may be due to large coupling, estimated with mad using a like-QK1X skew quad at the entrance of the Ext line with a strength of [-0.258 ; -0.180]m^{-1}, i.e. 8 times larger than the standard ones.

Conclusions and Perspectives

- The dec 2007 shift dedicated to emittance measurement were very interesting. We learn a lot in ATF control room, with Kuroda-san and others colleagues.
- Others datas (not presented here) have been taken, and they still need to be accurately analysed (coupling estimation using the 10° wire scanner orientation have to be performed).
- We will try to estimate the intrinsic emittance, using some constrain fit method.
- For next emittance shift period, longer shift (~12 h seems to be the minimum) are mandatory for accurate measurements.

So, few results are still under analysed (for 4 wire scanner measurement). We have to work on datas obtained during Dec. shifts, and prepare an analysis interface between ATF computer and MAD, to computed the phase advance between wire scanner in « real time ».