Exercising emittance measurements in the ATF EXT line

J. Brossard / C. Rimbault / P. Bambade (LAL) http://flc-mdi.lal.in2p3.fr/

The main goals of this study are :

- Explain why the **measured vertical emittance** is higher than the theoritical one.

- Quantify the **wire scanner error effect** on the emittance reconstruction method.

- Find a new emittance reconstrcuction method **less sensitive to wire scanner error**.
  (« Quadrupole Strengh Variation » method is under study).

In this presentation, only a 4d method is presented... a 6d analysis migth be a possible upgrade of this study...

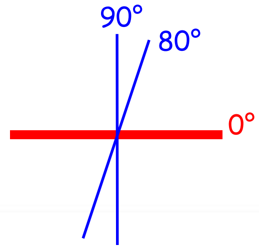
Assumption :

- *no jitter.*
- *no ground motion.*
- *perfect ATF-EXT line.*
- *no energy spread (E_0=1.3 GeV)*

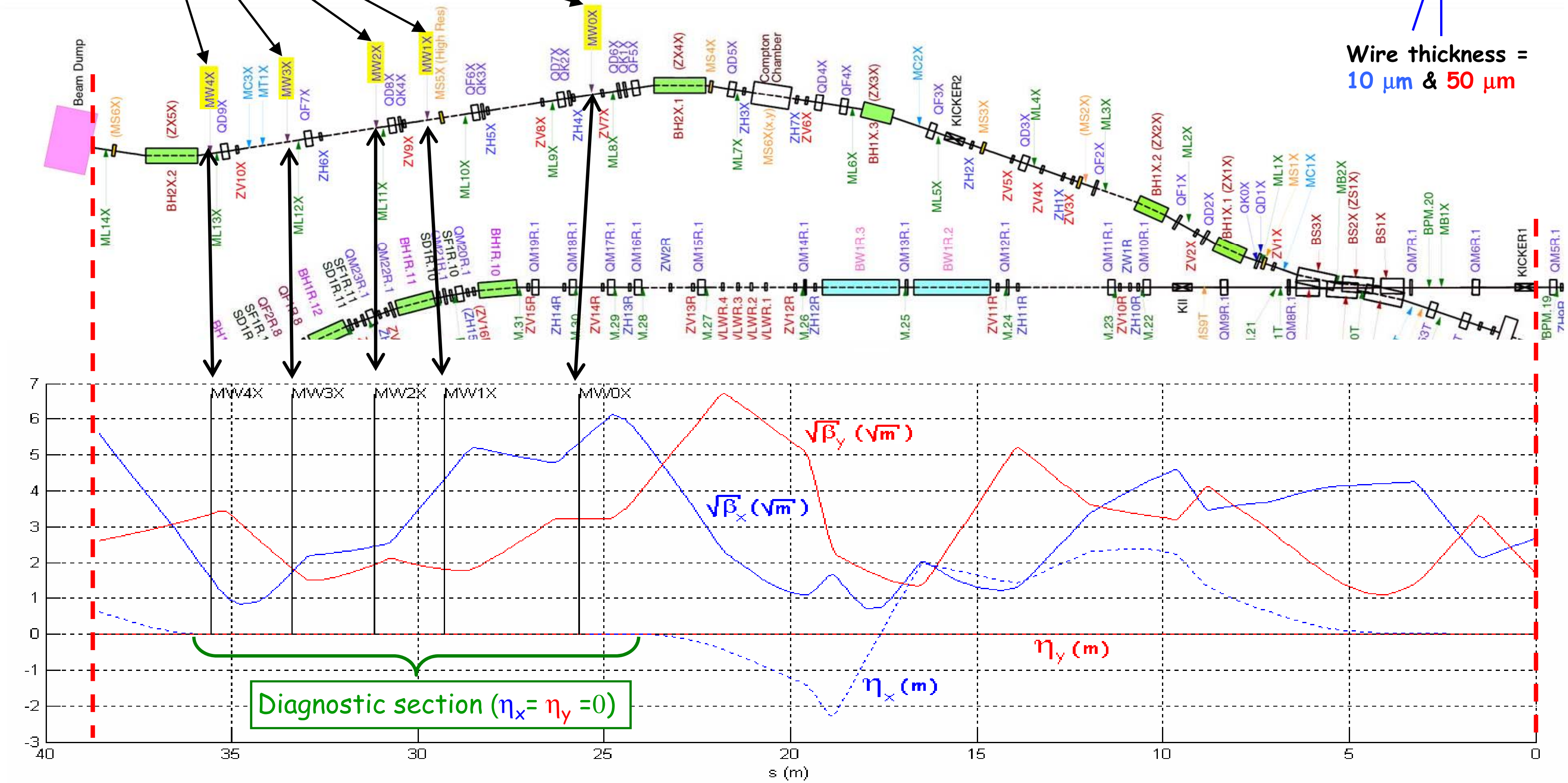
ATF EXT line description & wire scanner position

5 positions for wire scanners

Each position is equipped with 3 wire scanners oriented at 0, 90 and 80° for x,y and 80° beam-size measurement.



Wire thickness = 10 μm & 50 μm



4d - reconstruction method based on 5 wire scanner measurements

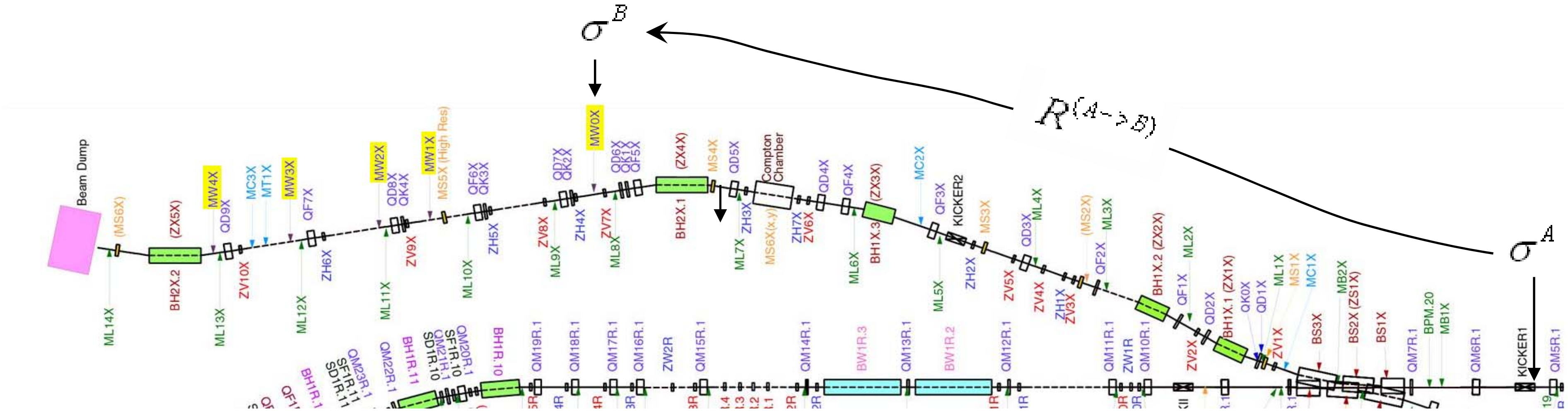
4d-beam matrix at point A :

$$\sigma^A = \begin{pmatrix} <x^A x^A> & <x^A x^{A\prime}> & <x^A y^A> & <x^A y^{A\prime}> \\ <x^{A\prime} x^A> & <x^{A\prime} x^{A\prime}> & <x^{A\prime} y^A> & <x^{A\prime} y^{A\prime}> \\ <y^A x^A> & <y^A x^{A\prime}> & <y^A y^A> & <y^A y^{A\prime}> \\ <y^{A\prime} x^A> & <y^{A\prime} x^{A\prime}> & <y^{A\prime} y^A> & <y^{A\prime} y^{A\prime}> \end{pmatrix} = \begin{pmatrix} \sigma^A_{11} & \sigma^A_{21} & \sigma^A_{31} & \sigma^A_{41} \\ \sigma^A_{21} & \sigma^A_{22} & \sigma^A_{32} & \sigma^A_{42} \\ \sigma^A_{31} & \sigma^A_{32} & \sigma^A_{33} & \sigma^A_{43} \\ \sigma^A_{41} & \sigma^A_{42} & \sigma^A_{43} & \sigma^A_{44} \end{pmatrix} = \begin{pmatrix} \sigma^A_{1} & \sigma^A_{2} & \sigma^A_{4} & \sigma^A_{7} \\ \sigma^A_{2} & \sigma^A_{3} & \sigma^A_{5} & \sigma^A_{8} \\ \sigma^A_{4} & \sigma^A_{5} & \sigma^A_{6} & \sigma^A_{9} \\ \sigma^A_{7} & \sigma^A_{8} & \sigma^A_{9} & \sigma^A_{10} \end{pmatrix}$$

4d-beam matrix at point B :

$$\sigma^B = R^{(A->B)} \sigma^A \left(R^{(A->B)}\right)^T = \begin{pmatrix} R_{1j}R_{1k}\sigma^A_{jk} & R_{1j}R_{2k}\sigma^A_{jk} & R_{1j}R_{3k}\sigma^A_{jk} & R_{1j}R_{4k}\sigma^A_{jk} \\ R_{2j}R_{1k}\sigma^A_{jk} & R_{2j}R_{2k}\sigma^A_{jk} & R_{2j}R_{3k}\sigma^A_{jk} & R_{2j}R_{4k}\sigma^A_{jk} \\ R_{3j}R_{1k}\sigma^A_{jk} & R_{3j}R_{2k}\sigma^A_{jk} & R_{3j}R_{3k}\sigma^A_{jk} & R_{3j}R_{4k}\sigma^A_{jk} \\ R_{4j}R_{1k}\sigma^A_{jk} & R_{4j}R_{2k}\sigma^A_{jk} & R_{4j}R_{3k}\sigma^A_{jk} & R_{4j}R_{4k}\sigma^A_{jk} \end{pmatrix}$$

Where $R^{(A->B)}$ is the 4D-linear optic matrix from point A to point B.



4d - reconstruction method based on 5 wire scanner measurements

If the 4d-linear transport matrix from point A to B is uncoupled

$$R=\begin{pmatrix} R_{11} & R_{12} & 0 & 0 \\ R_{21} & R_{22} & 0 & 0 \\ 0 & 0 & R_{33} & R_{34} \\ 0 & 0 & R_{43} & R_{44} \end{pmatrix}$$

Then

$$\sigma_{11}^{B} = (R_{11}^{2})\,\sigma_{1}^{A} + (2R_{11}R_{12})\,\sigma_{2}^{A} + (R_{12}^{2})\,\sigma_{3}^{A} = \left(\sigma_{x}^{B}\right)^{2} \text{ =(x-beam size @ B)}^2$$

$$\sigma_{33}^{B} = (R_{33}^{2})\,\sigma_{6}^{A} + (2R_{33}R_{34})\,\sigma_{9}^{A} + (R_{34}^{2})\,\sigma_{10}^{A} = \left(\sigma_{y}^{B}\right)^{2} \text{ =(y-beam size @ B)}^2$$

$$\sigma_{13}^{B} = (R_{11}R_{33})\,\sigma_{4}^{A} + (R_{12}R_{33})\,\sigma_{5}^{A} + (R_{11}R_{34})\,\sigma_{7}^{A} + (R_{12}R_{34})\,\sigma_{8}^{A}$$

-> For « n » points (B,C,…Z), where the x beam size is measure, we have :

$$\begin{pmatrix} \sigma_{11}^{B} \\ \sigma_{11}^{C} \\ \cdots \\ \sigma_{11}^{Z} \end{pmatrix} = \begin{pmatrix} R_{11}^{(A->B)2} & 2R_{11}^{(A->B)}R_{12}^{(A->B)} & R_{12}^{(A->B)2} \\ R_{11}^{(A->C)2} & 2R_{11}^{(A->C)}R_{12}^{(A->C)} & R_{12}^{(A->C)2} \\ \cdots & \cdots & \cdots \\ R_{11}^{(A->Z)2} & 2R_{11}^{(A->Z)}R_{12}^{(A->Z)} & R_{12}^{(A->Z)2} \end{pmatrix} \begin{pmatrix} \sigma_{1}^{A} \\ \sigma_{2}^{A} \\ \sigma_{3}^{A} \end{pmatrix} = M_{X} \begin{pmatrix} \sigma_{1}^{A} \\ \sigma_{2}^{A} \\ \sigma_{3}^{A} \end{pmatrix}$$

If we know how to solve this linear system then, we can compute the horizontal emittance :

$$\varepsilon_{x}^{A} = \sqrt{\sigma_{1}^{A}.\sigma_{3}^{A} - \left(\sigma_{2}^{A}\right)^{2}}$$

Similar analysis can be performed to estimate : σ_4, to σ_{10} … and ε_y can be estimated.

4d - reconstruction method based on 5 wire scanner measurements

If n<3 No solution.

If n==3 and M_x^{-1} exist then the solution is known and unique.

If n>3 the sytem is « overestimated » and the Least Mean Square (LMS) method can be used to find the « LMS » solution. (in ATF n==5)

First question : How sensitive to wire scanner errors this method is ?

Second question : What happen if the QM6 quadrupole strength is reduce by 20% ?

First question : How sensitive to wire scanner errors this method is ?

Assumption : the relative error level on « measurements » at position MW0X, MW1X, MW2X, MW3X and MW4X is identical, and tested for values ranging between 0 and 30%

WS	Sigma_x nominal (micron)	10% error (micron)	20% error (micron)	30% error (micron)	Wire scanner thickness (micron)
MW0X	238.67	24	48	72	10
MW1X	192.77	19	39	58	10
MW2X	109.4	11	22	33	10
MW3X	77.04	8	15	23	10
MW4X	70.14	7	14	21	10

WS	Sigma_y nominal (microns)	10% error (micron)	20% error (micron)	30% error (micron)	Wire scanner thickness (micron)
MW0X	14.46	1	3	4	5
MW1X	8.11	1	2	2	5
MW2X	8.67	1	2	3	5
MW3X	8.21	1	2	2	5
MW4X	14.98	1	3	4	5

$$\sigma_{sim}^{X\,\%} = (1+r)\sigma_{ideal}$$

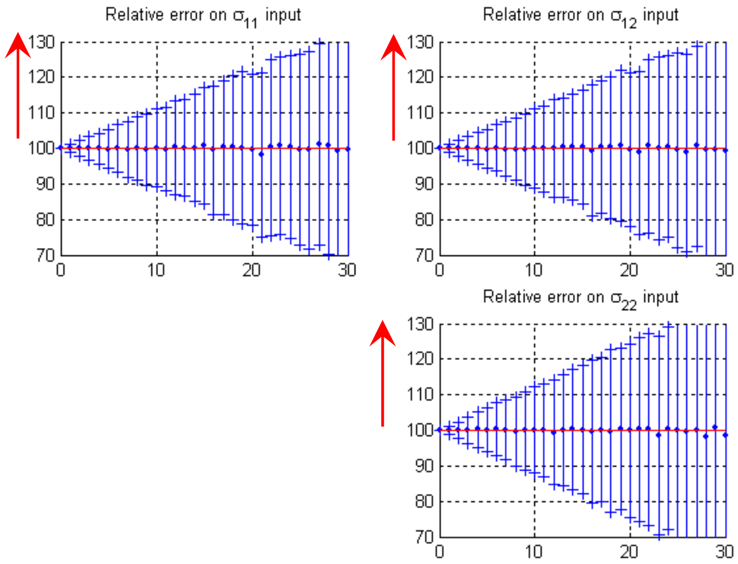
Where « r » comes from a gaussian distribution having zero mean and X/100 rms

The minimum relative error level for y-beam size measurement is at least equal to 13% (D/4~1.25 microns)

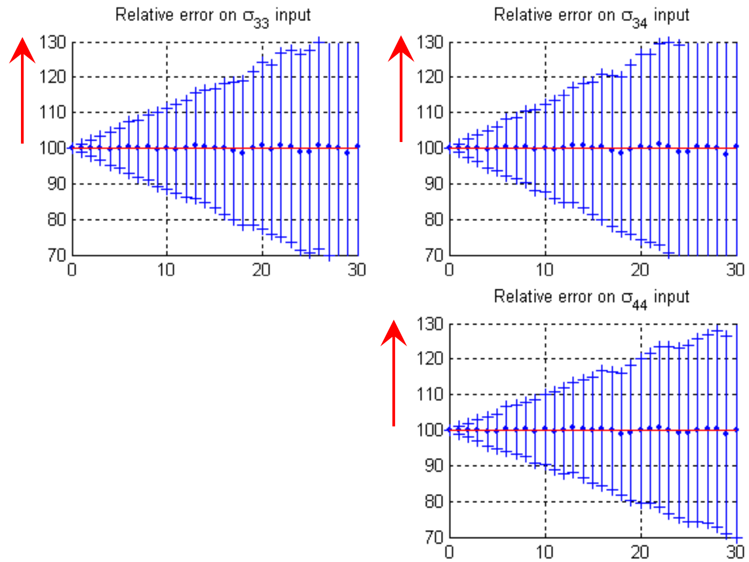
First question : How sensitive to wire scanner errors this method is ?

For each error level, 1000 « measure » have been tested.

The plot shows the mean and +/- 1 rms

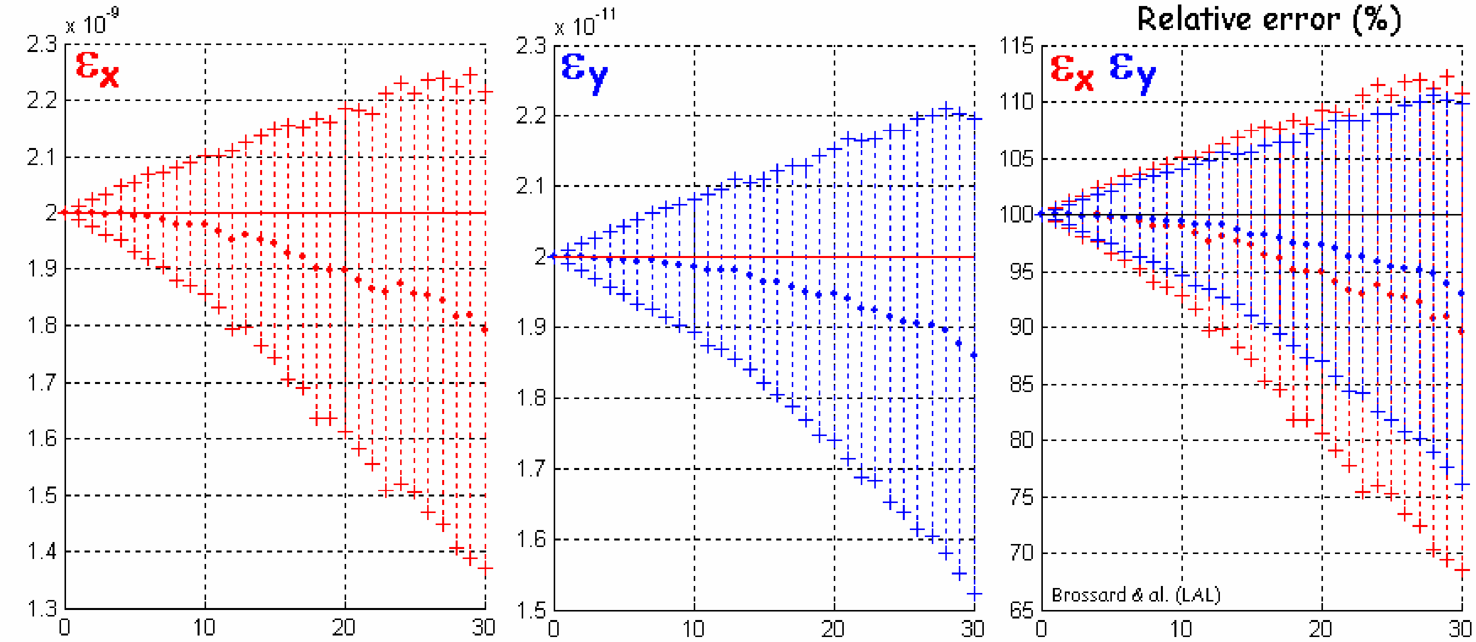


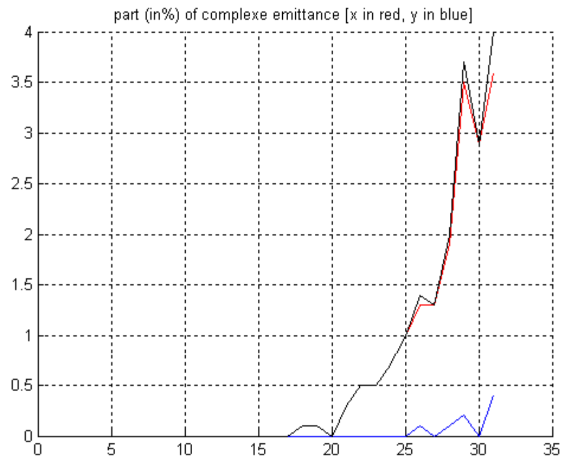
The maximum relative errors (define by the rms value) on σ_{11}, σ_{12}, σ_{22}, σ_{33}, σ_{34} and σ_{44} values are approximatively between -30% and +30%



First question : How sensitive to wire scanner errors this method is ?

Impact on horizontal and vertical emittance reconstruction …





→ This method leads to underestimate vertical <u>and</u> horizontal emittance.

A part of the 1000 tested « measurements » lead to a unphysical results.

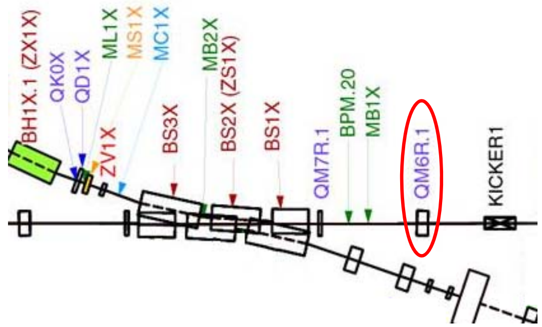
In the current analysis, this rejection level is always lower than 4%.

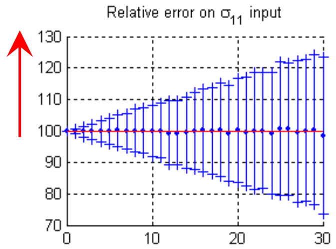
The underestimation of horizontal emittance is higher than the vertical one.

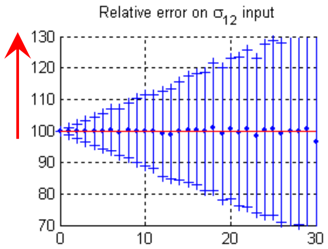
Second question : What happen if the QM6 quadrupole strength is reduce by 20% ?

QM6 is the first bending magnet (with quadrupole part) after the kicker.

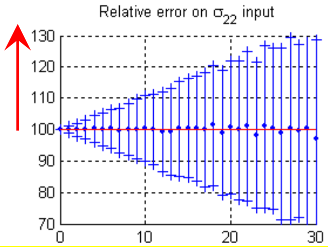
The quad. strength of this element might have been over-estimated…(TBC)



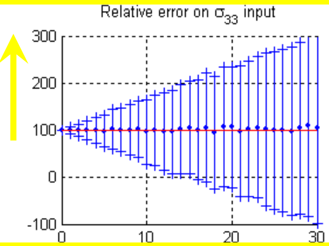


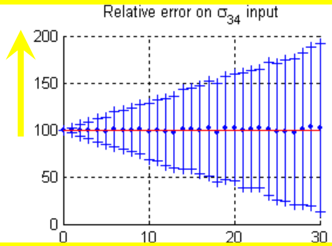


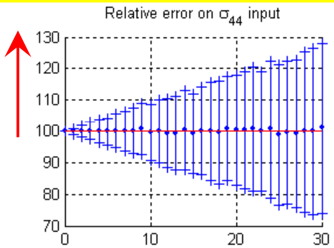
The maximum error level on σ_{11}, σ_{12}, σ_{22} and σ_{44} is similar to the previous analysis (i.e : +/- 30%)



The maximum error level on σ_{33} and σ_{34} reach +100 or +200% !!!



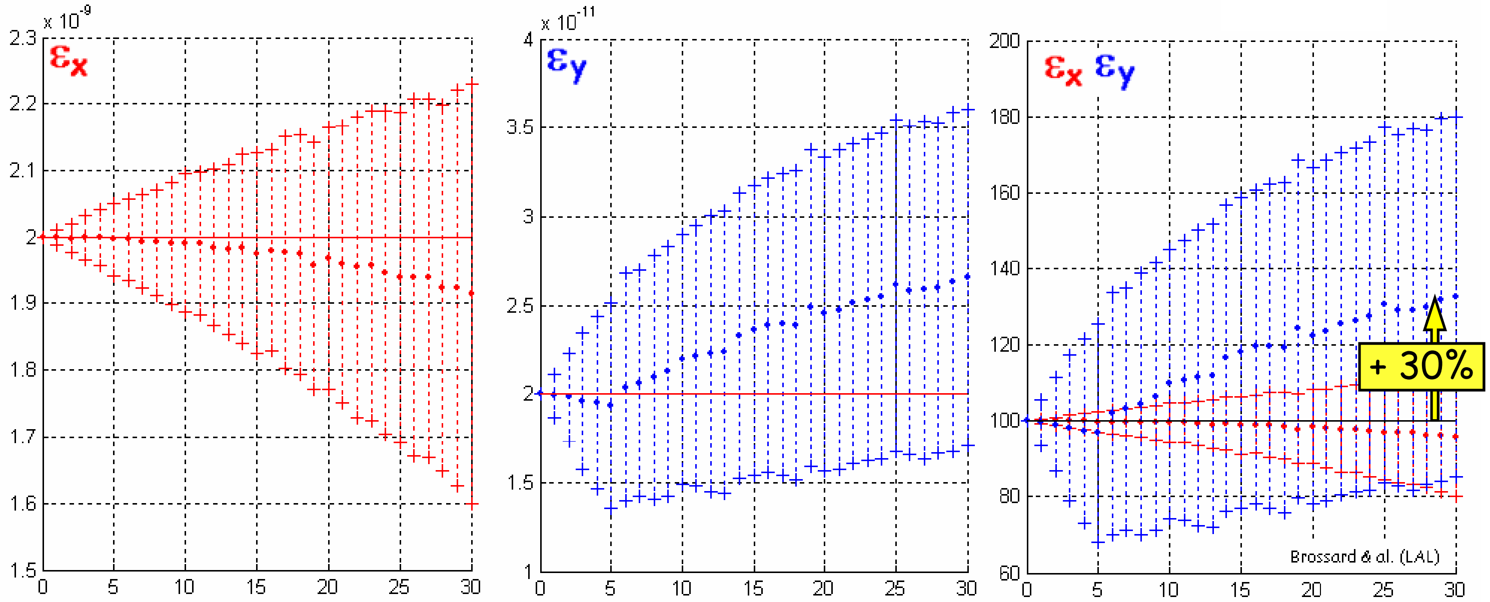


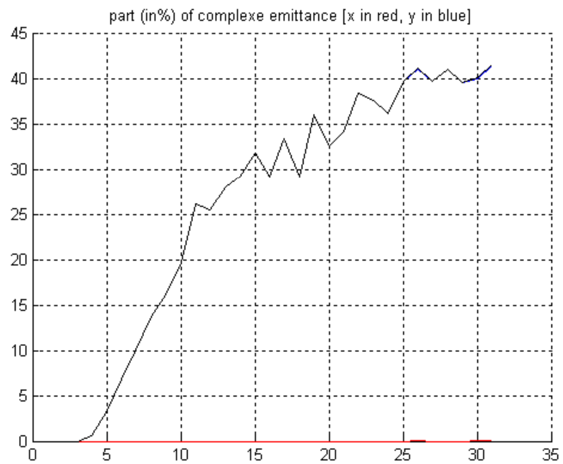


Second question : What happen if the QM6 quadrupole strength is reduce by 20% ?

Impact on horizontal and vertical emittance reconstruction …

Absolute values (m.rad) | Absolute values (m.rad) | relative values (%)





In presence of WS error, the

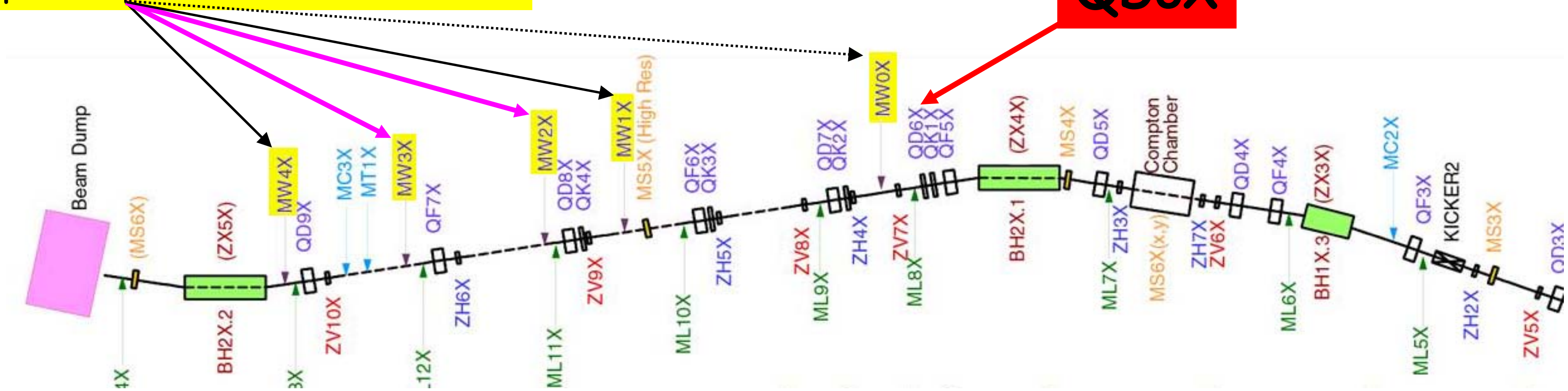
- horizontal emittance is sligthly underestimated
- vertical emittance is greatly over-estimated.

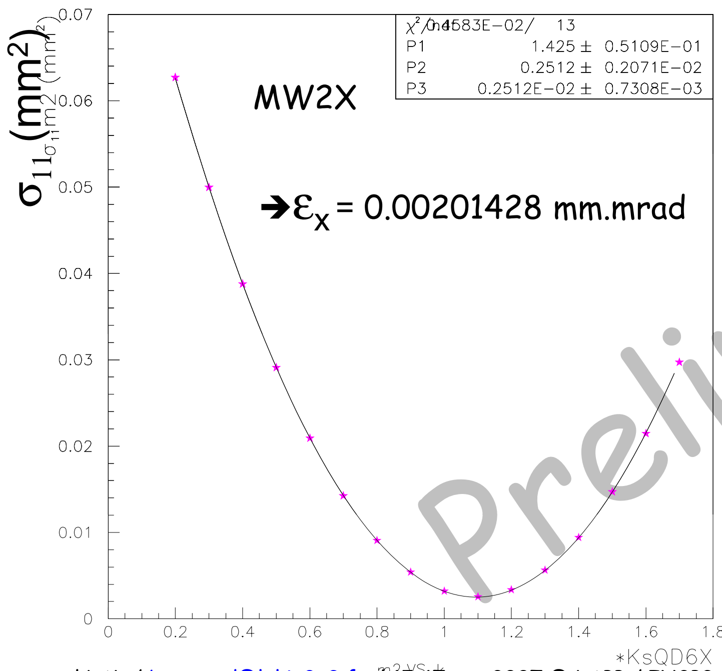
The rejection part increase… to reach 40% for error measurement of 30 %

Quadrupole Strengh Variation method - 1

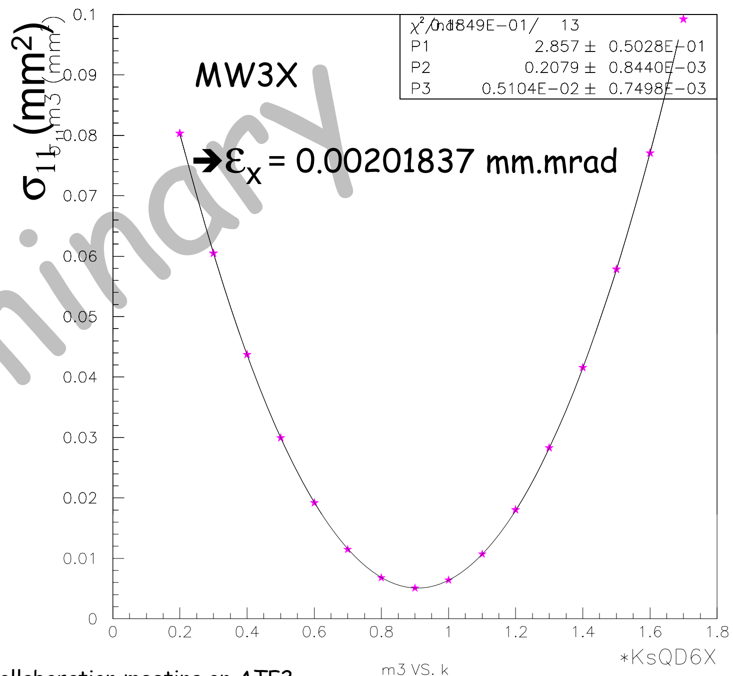
5 positions for wire scanners

QD6X





$\rightarrow \varepsilon_x = 0.00201428$ mm.mrad



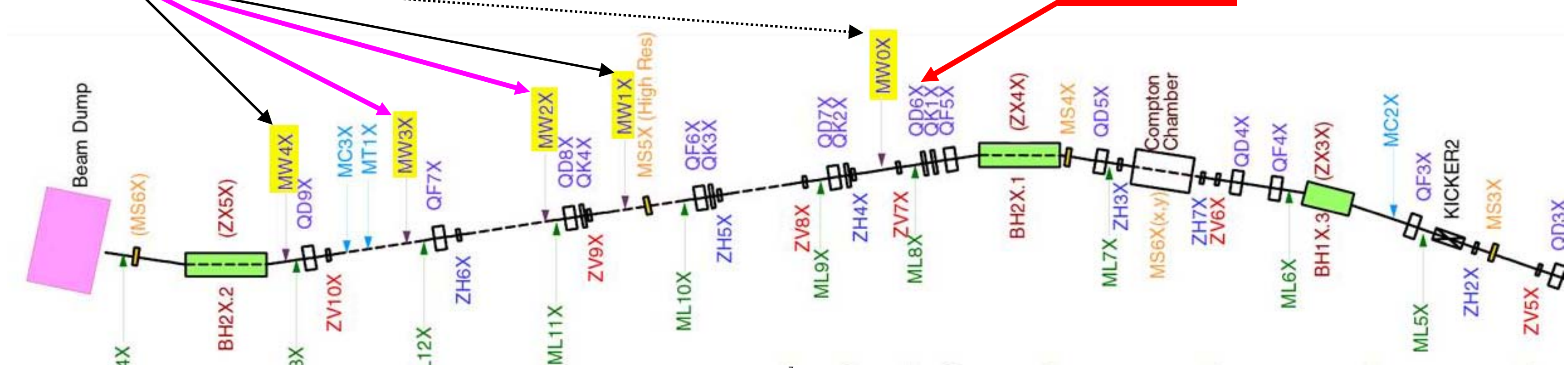
$\rightarrow \varepsilon_x = 0.00201837$ mm.mrad

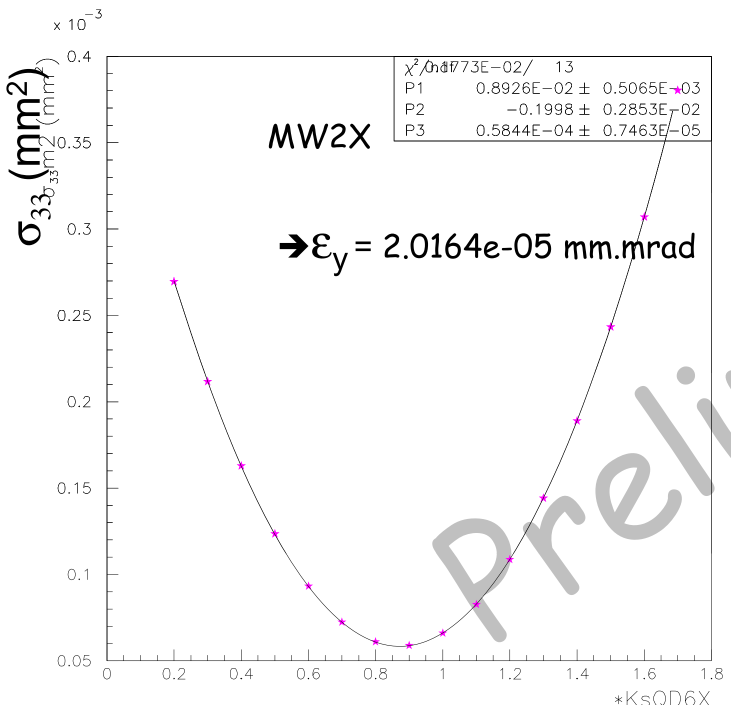
Preliminary

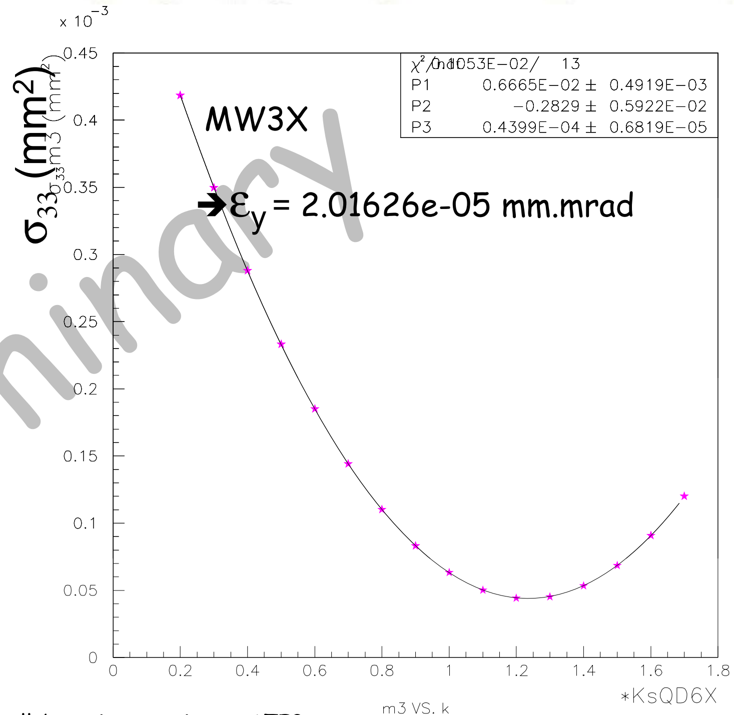
Quadrupole Strengh Variation method - 2

5 positions for wire scanners

QD6X







Conclusions and perspectives

Conclusions and persepctives

- For the nominal ATF-EXT line, the LMS* method based on the 5 existing wire scanners induced an underestimation of the vertical and horizontal emittance (function of WS error level).
- If the QM6 quadrupole strength is underestimated (by 20%) then the LMS method based on the 5 existing wire scanner induced a « small » horizontal emittance reduction and a « large » vertical emittance estimation (function of WS error level). *For QM7 quadrupole strength underestimation an symetric (x-y) effect is observed* (see extra slide).
- Compare the error sensitivity of the LMS reconstruction method with a « quadrupole strength variation » method.

Questions

- What are the real « quadrupole strength » of QM6 and QM7 (seen by the extracted bunch) ?
- Is it possible to determine WS positions leading to less error sensitive reconstruction method ?
- What is the sensitivity of « quadrupole strength variation » method ? (which quad ? which WS ?, new quad position ?, new WS position ? ….).
- Is it possible to realize more than 3 measurement per WS to reduce the error level ?
- others ideas ? …

* LMS : Least Mean Square

References

Many thanks to Mark Woodley for the input MAD file

(see : http://www.slac.stanford.edu/~mdw/ATF/EXT.mad)

References :

ATF Internal reports : ATF-99-01, ATF-00-06, ATF-99-17, ATF-99-08, ATF-00-01…

Extra-slide

QM6 quadrupole strength is reduce by 20% →

QM7 quadrupole strength is reduce by 20% →
(see M. Alabau Pons & al. Talk)