RECONSTRUCTION OF CONTROLLED OCTUPOLAR ERRORS IN CERN-SPS

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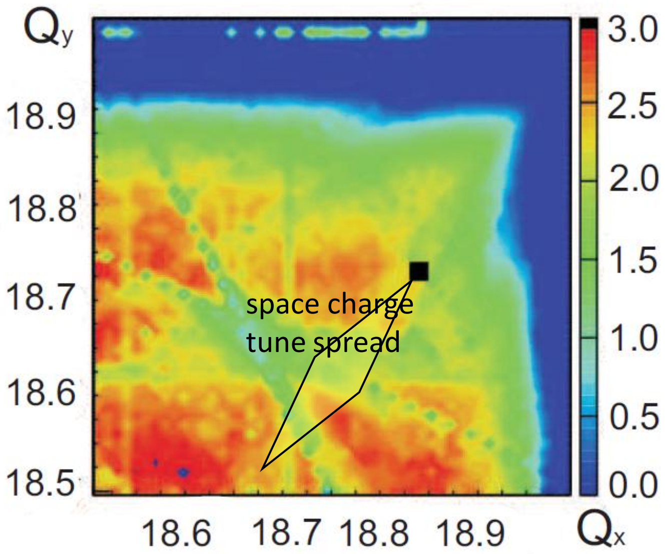
26 May 2010, IPAC, Kyoto, Japan

METHODS OF RECONSTRUCTION OF NONLINEAR COMPONENTS

O. Boine-Frankenheim, these proceedings

SIS100 tune diagram



KNOWLEDGE OF NONLINEAR ERRORS ALLOWS TO CONTROL AND COMPENSATE RESONANCE DRIVEN BEAM LOSS

NONLINEAR CHROMATICITY

G. Arduini et. al., PAC, Portland, USA, p. 2240 (2003)

RESONANCE DRIVING TERM

R. Bartolini et. al., ICAP, Chamonix, France, (2006)
R. Tomas et. al, Phys. Rev. ST 8, 024001 (2005)

ORBIT DEFORMATION via LOCAL BUMP

F. Pilat et al., PAC, Knoxville, USA, p. 601 (2005)

GLOBAL ORBIT DISTORTION

NONLINEAR TUNE RESPONSE MATRIX (NTRM) METHOD

G. Franchetti, A. Parfenova and I. Hofmann, Phys. Rev. ST 11, 094001 (2008)

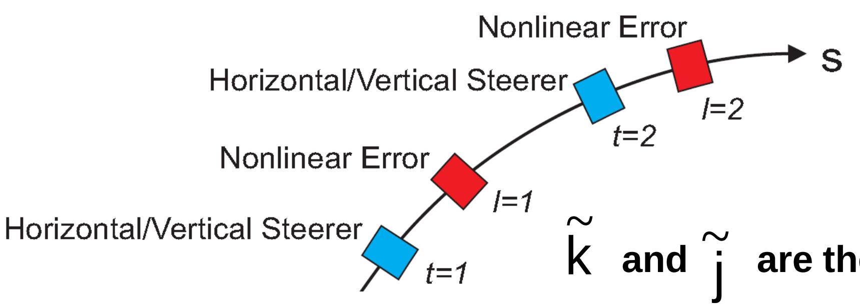
NTRM-MODELLING LINEARIZED THEORY

IF THE CLOSED ORBIT IS DEFORMED BY N_t OF STEERING ANGLES θ_X AND θ_Y

X-/Y- CLOSED ORBIT (CO) AT NONLINEAR ERROR

$$x,y_{COl} = \sum_{t=1}^{N_t} M_{lt}^{x,y}\theta_{x,yt}$$

EQUATIONS OF MOTION FOR A PARTICLE WITH A SMALL AMPLITUDE IN AN ACCELERATOR WITH A DEFORMED CO



$$\delta x'' + (k_x + \tilde{k})\delta x = \tilde{j}\,\delta y$$
$$\delta y'' + (k_y - \tilde{k})\delta y = \tilde{j}\,\delta x$$

$\tilde{k}$ **and** $\tilde{j}$ **are the feed down components due to the deformed CO**

CONTRIBUTION TO THE MACHINE TUNES WITH RESPECT TO THE DEFORMED CLOSED ORBIT

$$\Delta Q_{x,y} = \frac{1}{4\pi}\int_0^C \beta_{x,y}(s)\tilde{k}(s)ds$$

$$\tilde{k}_1 = K_1 \qquad \tilde{k}_2 = K_2 x_{CO} - J_2 y_{CO}$$

$$\tilde{k}_3 = K_3(x_{CO}^2 - y_{CO}^2)/2 - J_3 x_{CO} y_{CO}$$

RECONSTRUCTION OF CONTROLLED SEXTUPOLAR ERRORS IN GSI-SIS18

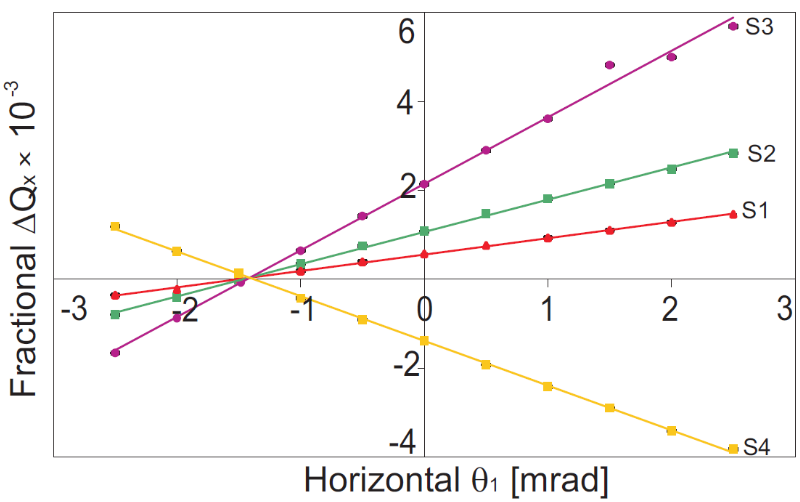
THE FIRST ORDER CONTRIBUTION ON THE MACHINE TUNES

$$\begin{cases} {}_xQ^x_t = \dfrac{1}{4\pi}\displaystyle\sum_{l=1}^{N_l} \beta_{xl} K_{2l} M^x_{lt} \\ \Delta Q_x = \displaystyle\sum_{t=1}^{N_t} {}_xQ^x_t \theta_{xt} \end{cases}$$

LINEAR SYSTEM (2 X 2) FOR 2 ERRORS

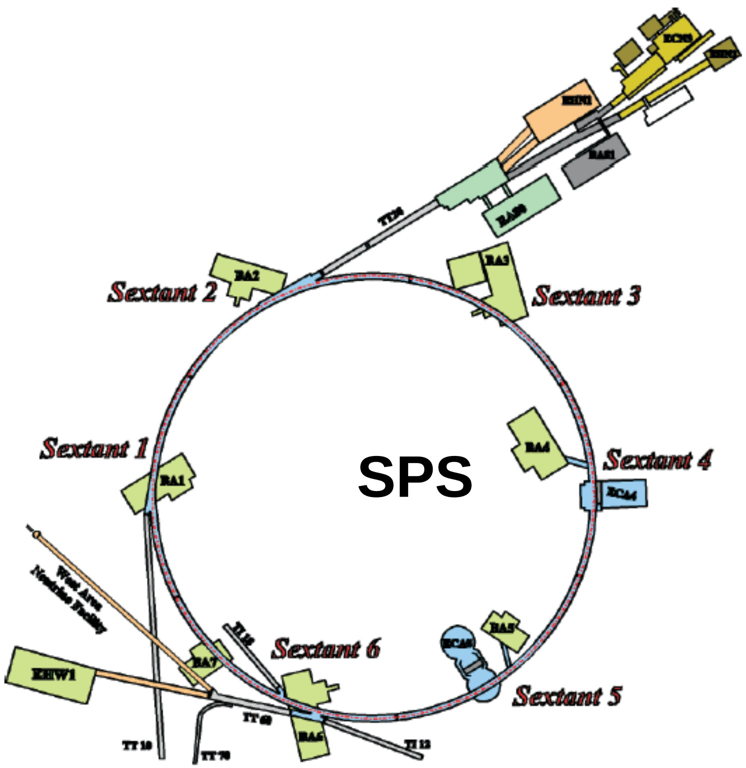
$$\boxed{{}_xQ^x_1} = \{\beta_{x1} K_{21} M^x_{11} + \beta_{x2} K_{22} M^x_{21}\}/4\pi$$

$$\boxed{{}_xQ^x_2} = \{\beta_{x1} K_{21} M^x_{12} + \beta_{x2} K_{22} M^x_{22}\}/4\pi$$



Normal errors	l	ΔK_2	Calc.	Exp.	Rel. Err., %
		$\times 10^{-2}$ [m^{-2}]			
S1	1 2	-2 1	-1.99 1.00	-1.79 1.02	10.5 1.8
S2	1 2	-4 2	-3.99 2.00	-4.13 1.55	3.3 22.7
S3	1 2	-8 4	-7.99 4.00	-7.61 3.90	4.9 2.5
S4	1 2	5 -3	5.00 -2.99	4.97 -2.74	0.6 8.7

EXPERIMENTAL BENCHMARKING IN CERN-SPS



SET 2 PROBING NORMAL OCTUPOLAR ERRORS AND USE 2 HORIZONTAL STEERERS

CHANGE THE CLOSED ORBIT AND MEASURE THE TUNE RESPONSE

RECONSTRUCT THE 2 OCTUPOLAR ERRORS

?

THE EFFECT OF THE OCTUPOLES

THE SECOND ORDER CONTRIBUTION TO THE MACHINE TUNES WITH RESPECT TO THE DISTORTED CO (CONSIDERING SEVERAL OCTUPOLAR ERRORS)

$$\begin{cases} {}_{x}Q_{tt}^{xx} = \dfrac{1}{2}\cdot\dfrac{1}{4\pi}\displaystyle\sum_{l=1}^{N_l}\beta_{xl}K_{3l}(M_{lt}^{x})^2 + O(2) \\ \Delta Q_x = \displaystyle\sum_{t=1}^{N_t} {}_{x}Q_{tt}^{xx}(\theta_{xt})^2 \end{cases}$$

l **IS INDEX FOR OCTUPOLES** (***N_l*=2**), *t* **IS INDEX FOR STEERERS** (***N_t*=2**)

A SECOND ORDER CONTRIBUTION FROM SEXTUPOLES O(2) EXISTS

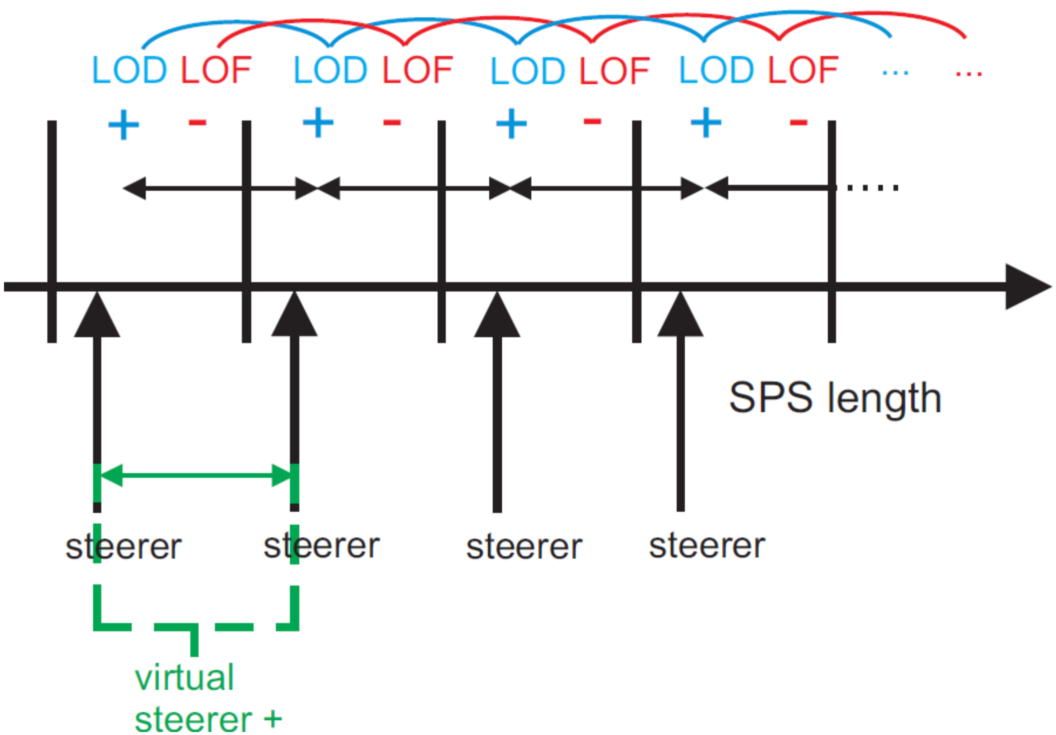
Ref. G. Franchetti et. al., Phys. Rev. ST 11, 094001 (2008)

WHEN THE NORMAL OCTUPOLAR ERRORS ARE EXCITED, ONLY HORIZONTAL ORBIT DEFORMATION CAN REVEAL THEM

DIFFICULTY DUE TO SYMMETRIC ARRANGMENT OF OCTUPOLES AND STEERERS IN CERN-SPS

TWO SERIES OF OCTUPOLES **LOF** AND **LOD** ARE ARRANGED WITH THE SAME PERIODICITY **(6)**

ALL THE STEERERS ARE SYMMETRICALLY PLACED IN THE RING



BREAKING THE SPS SYMMETRY

LINEAR SYSTEM (2 X 2) TO SOLVE

$$\boxed{\begin{array}{l} {}_xQ_{11}^{xx} \\[2em] {}_xQ_{22}^{xx} \end{array}}\begin{array}{l} =\{\beta_{x\,LOD}K_{3\,LOD}(M_{LOD\,1}^{x})^2+\beta_{x\,LOF}K_{3\,LOF}(M_{LOF\,1}^{x})^2\}/2/4\pi \\[2em] =\{\beta_{x\,LOD}K_{3\,LOD}(M_{LOD\,2}^{x})^2+\beta_{x\,LOF}K_{3\,LOF}(M_{LOF\,2}^{x})^2\}/2/4\pi \end{array}$$

FOR EACH STEERER S1, S2 OR S3, …ETC WITH θ_1 $\quad {}_xQ_{22}^{xx}={}_xQ_{11}^{xx}$

<u>COMBINING STEERERS GENERATES A NEW OPTICAL STRUCTURE!!!</u>

FOR A 'VIRTUAL' STEERER S+ WITH θ+ (COMBINATION OF S1 AND S2) $\theta_1=\theta_2=\theta_+$

$$S^+=(S1,S2)=(\theta_1,\theta_2)=\theta_+$$

$${}_xQ_+^{xx}=2({}_xQ_{11}^{xx}+\boxed{{}_xQ_{12}^{xx})}\neq{}_xQ_{11}^{xx}$$

THE EXPERIMENTAL CONDITIONS

1. ENERGY 26 GEV, INTENSITY ~ 10^{11}

2. HORIZONTAL STEERERS:

MDH10207 (AS S)
MDH10207 AND MDH20407 (AS S+)

3. A FAST TRANSVERSE KICK WAS GENERATED ON BOTH –X AND –Y PLANES

4. QX, QY WERE MEASURED FOR 1024 TURNS

5. THE STEERING RANGE [-150 μRAD; 150 μRAD]

6. CHROMATICITY SEXTUPOLES WERE SWITCHED ON

7. TWO OCTUPOLE FAMILIES WERE EXCITED WITH THE STRENGTHS LOF=2 M^{-3} AND LOD=4 M^{-3}

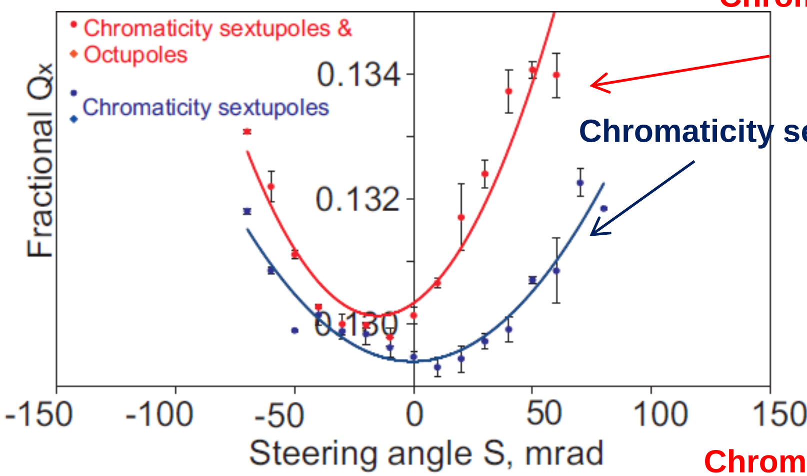
TUNE RESPONSE vs. CLOSED ORBIT DEFORMATION (COD)

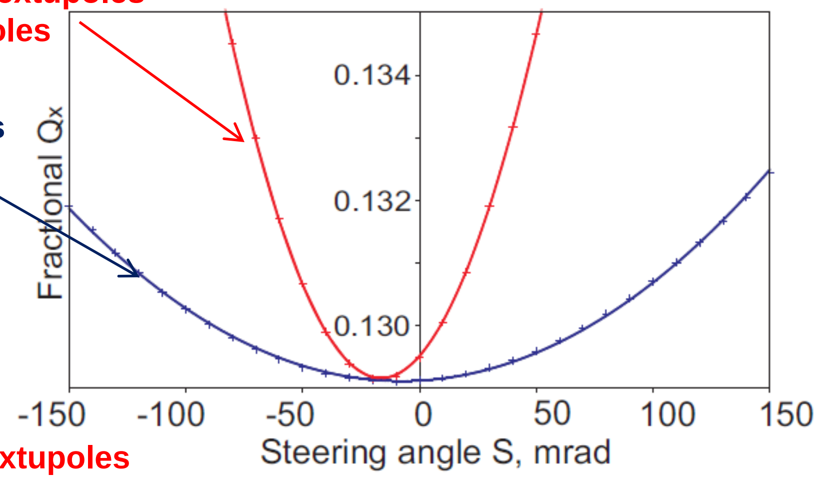
MEASUREMENT

SIMULATION

Chromaticity sextupoles & octupoles

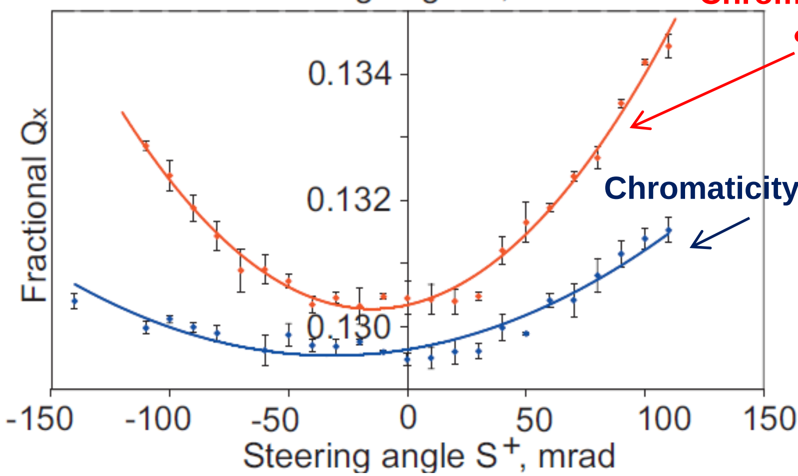
Chromaticity sextupoles

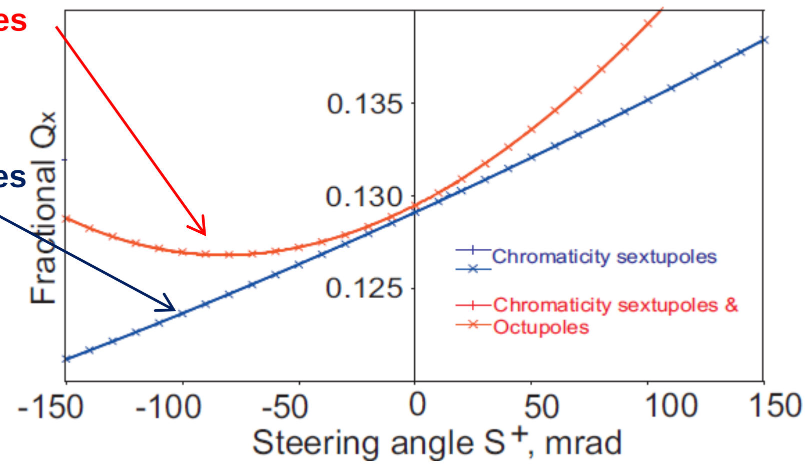




Chromaticity sextupoles & octupoles

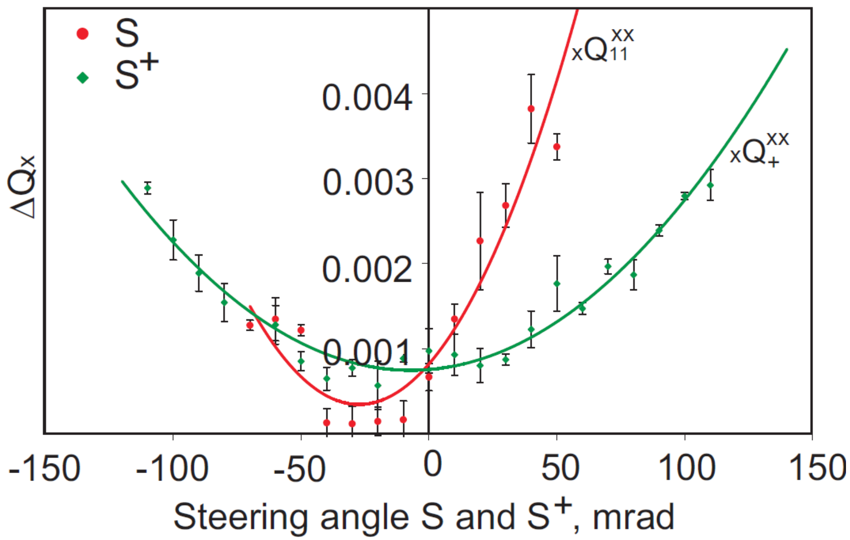
Chromaticity sextupoles



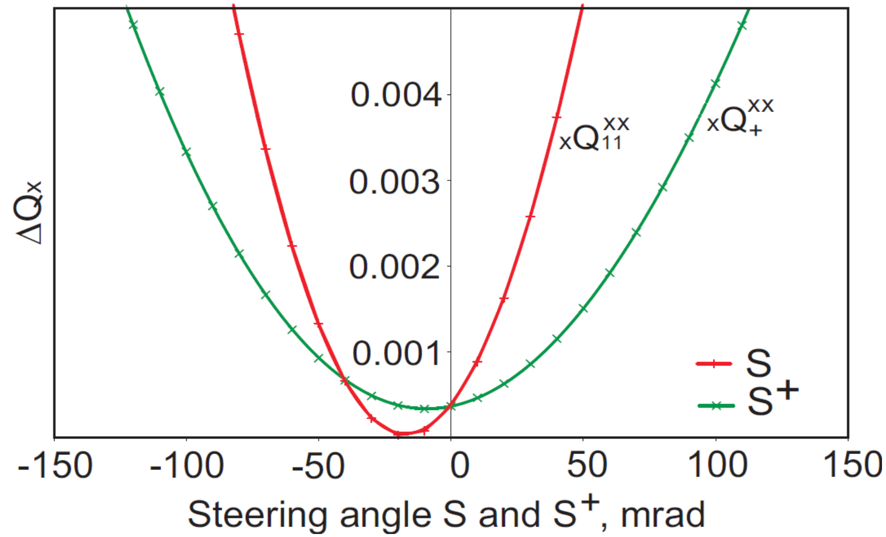


DIFFERENTIAL TUNE RESPONSE: CONTRIBUTION OF OCTUPOLES

MEASUREMENT



SIMULATION



$$ {}_{x}Q^{xx}_{tt} = \frac{1}{2}\cdot\frac{1}{4\pi}\sum_{l=1}^{N_l}\beta_{xl}K_{3l}(M^{x}_{lt})^2 + \cancel{O(2)} $$

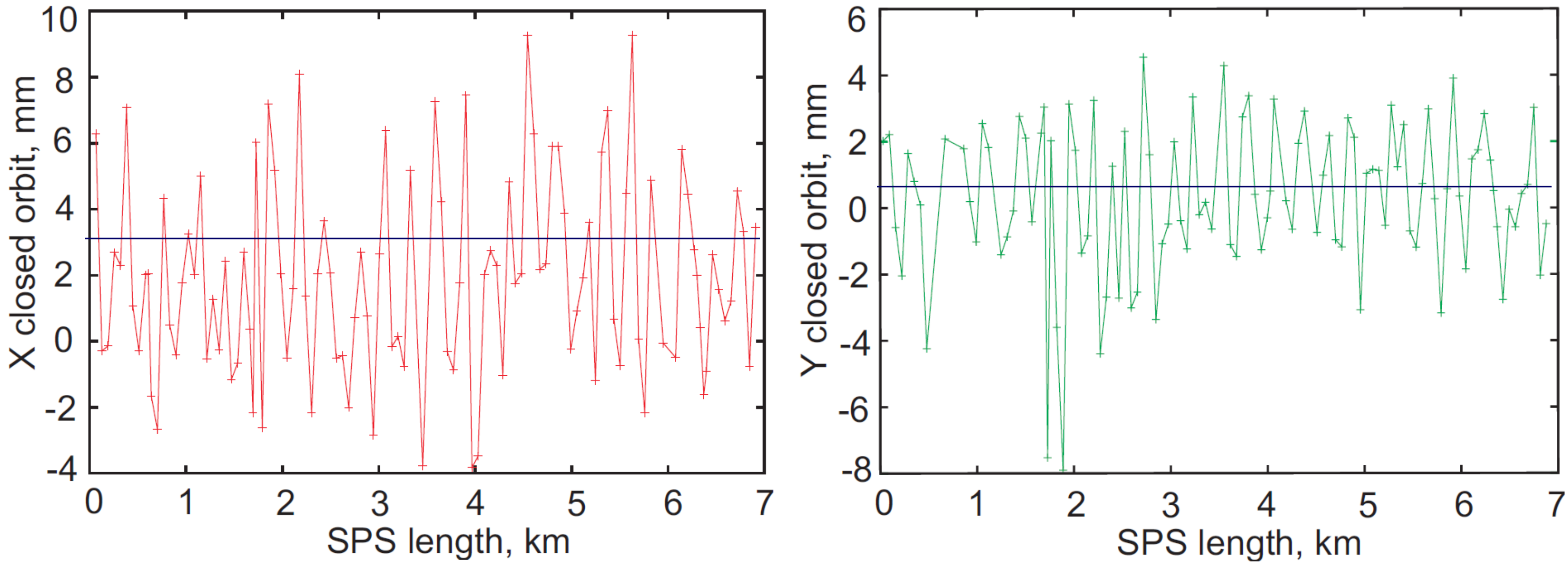
NOTE THAT:

1. LARGE TUNE FLUCTUATIONS WERE OBSERVED IN THE MEASUREMENT
2. STEERERS **S** AND **S+** WERE VARIED ALMOST TO THE MAXIMUM STEERING RANGE **[-150 μRAD; 150 μRAD]**
3. OCTUPOLES WERE EXCITED STRONG **LOF=2 M^{-3}** AND **LOD=4 M^{-3}**

MEASUREMENT OF INITIAL CLOSED ORBIT (CO)

PRECONDITION FOR NTRM IS INITIALLY CORRECTED CO

THE METHOD HAD TO BE APPLIED WITH A CERTAIN INITIAL CO DISTORTION

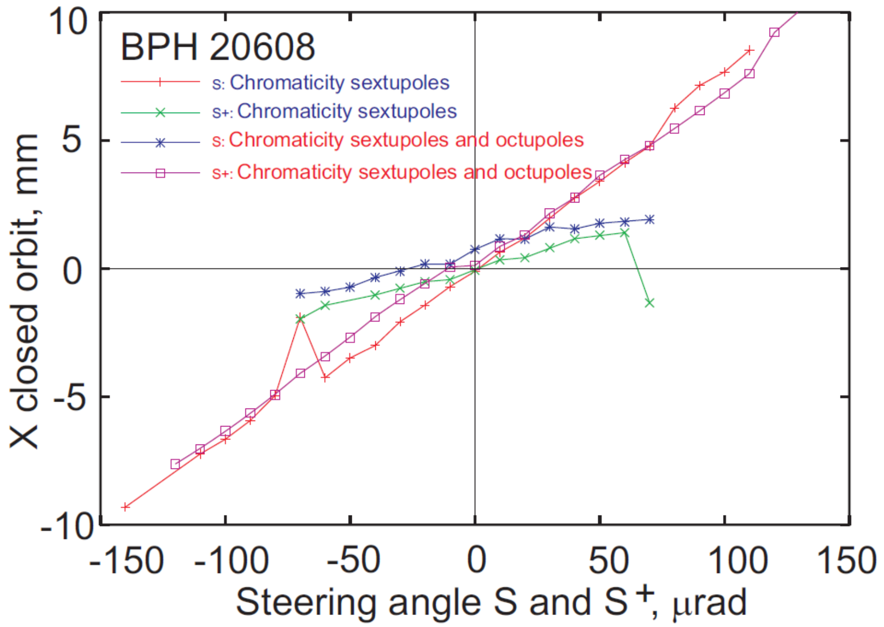


MEASURED AND SIMULATED CLOSED ORBIT DEFORMATION (COD)

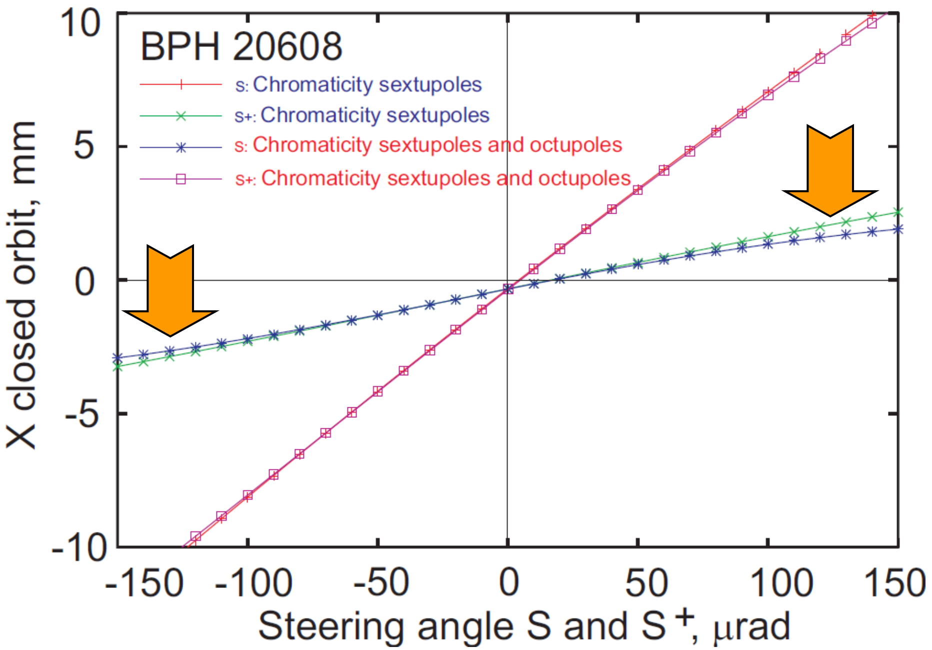
ARE WE IN THE REGIME OF LINEAR COD?

A CO EXAMPLE FROM A SINGLE BPM (#20608)

MEASUREMENT



SIMULATION



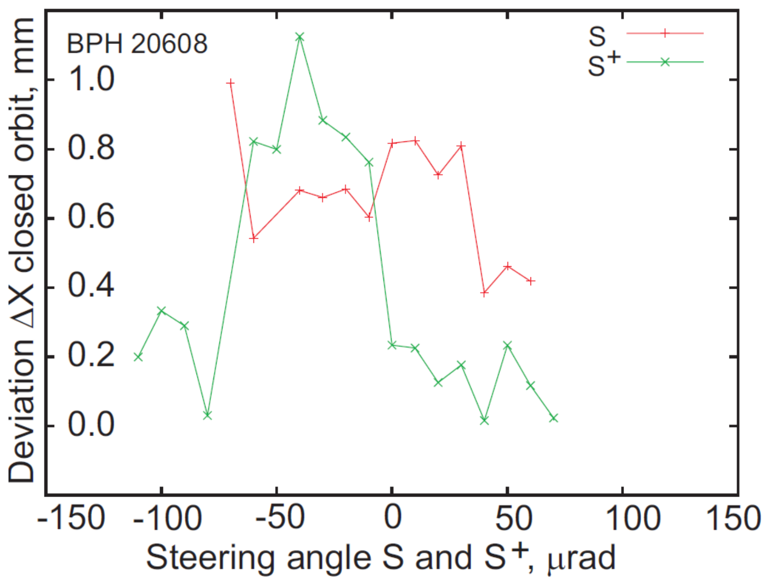
steerer S is steerer MDH10207

steerer S+ is a combination of steerers MDH10207 and MDH20407

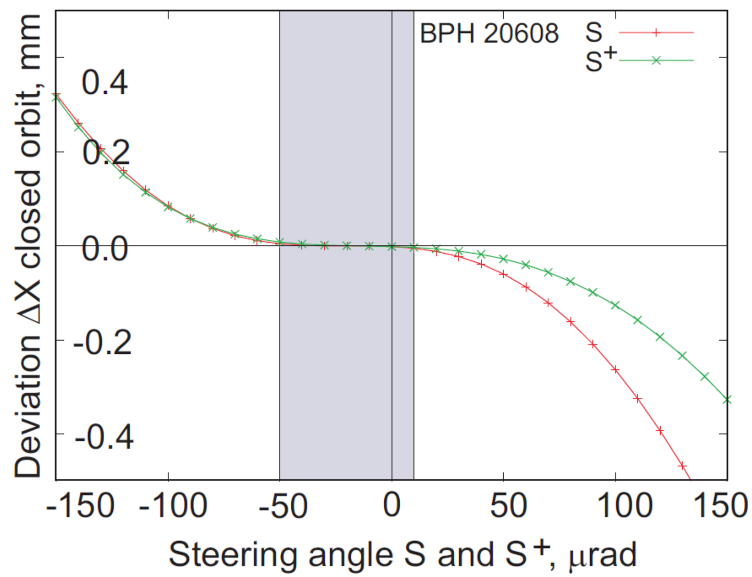
MEASUREMENT AND SIMULATION: DIFFERENTIAL CO RESPONSE

SUBTRACTING CO MODULATION WITH- (LOF=2 M^{-3} AND LOD=4 M^{-3}) AND WITHOUT OCTUPOLES FOR EACH STEERER S AND S+ RESPECTIVELY

MEASUREMENT



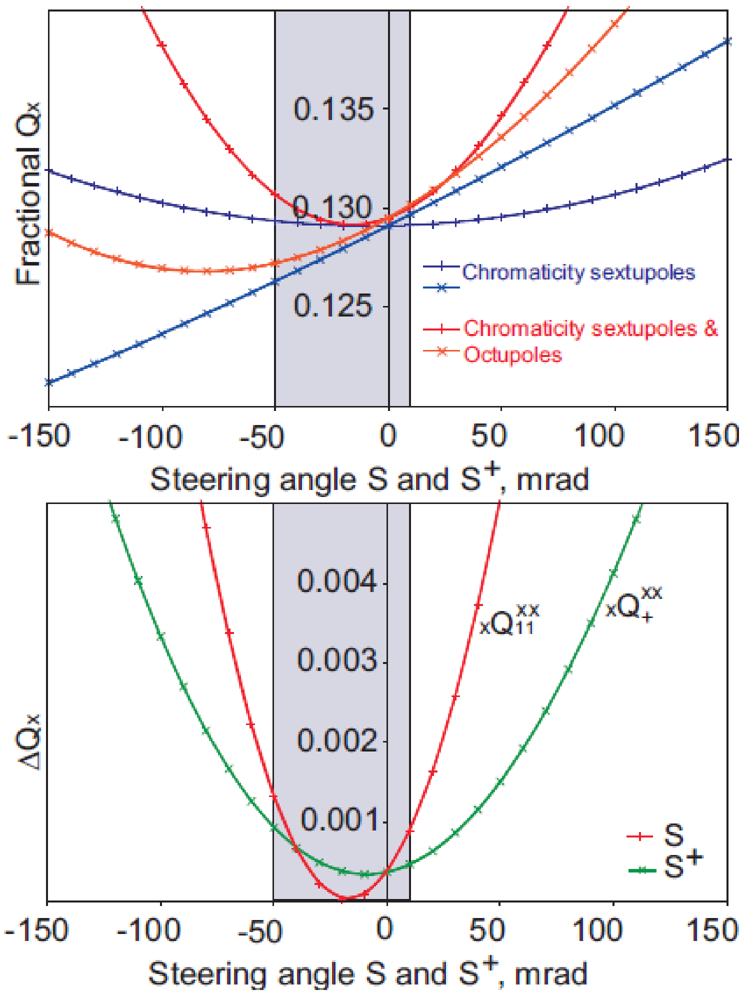
SIMULATION



THE MEASURED CO DATA DO NOT ALLOW TO DETERMINE THE RANGE OF THE LINEAR CO REGIME!

APPLICABILITY OF THE NTRM THEORY

SIMULATION



NUMERICALLY RECONSTRUCTED STRENGTHS FOR THE TWO OCTUPOLAR SERIES:

1. **CO IN LINEAR REGIME**

LOF=1.99 M^{-3} AND LOD=4.01 M^{-3}

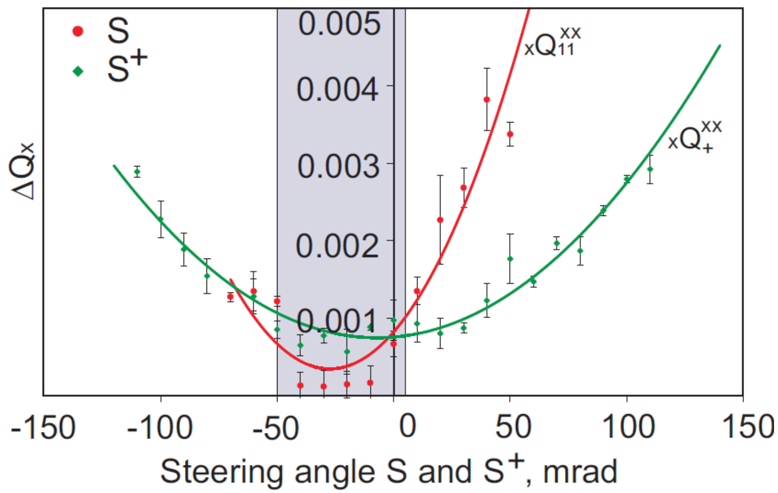
2. **CO TAKEN OVER THE FULL RANGE [-150 μRAD; 150 μRAD]**

LOF=0.86 M^{-3} AND LOD=18.24 M^{-3}

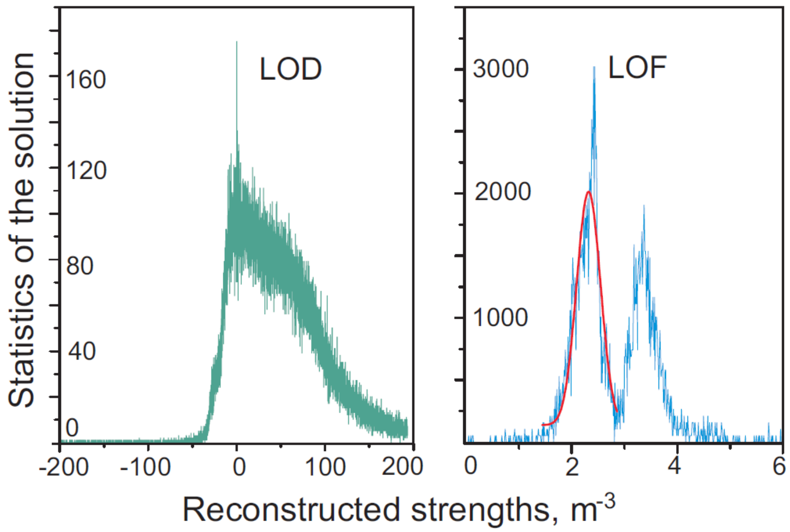
FOR A WEAKER OCTUPOLAR EXCITATION THE LINEAR REGIME OF THE CLOSED ORBIT IS LARGER

RESULTS AND DISCUSSION

SMALLER RANGE



THE RECONSTRUCTION DEPENDS ON THE STEERER VARIATION RANGE!!!



RESULTS FOR ALL RANGES ARE SHOWN

LOD IS NOT RECONSTRUCTED TO THE SET VALUE

LOF=2.35 +/- 0.32 M^{-3}

CONCLUSION

RECONSTRUCTION OF SEXTUPOLES IN GSI-SIS18:

THE NEW NTRM METHOD WAS SUCCESSFULLY VALIDATED WITH TWO CONTROLLED SEXTUPOLAR ERRORS IN GSI-SIS18. THE BENCHMARKING OF NTRM CONTINUES WITH EXPERIMENTS FOR SIX TO TWELVE CONTROLLED SEXTUPOLAR ERRORS

RECONSTRUCTION OF OCTUPOLES IN CERN-SPS:

A FIRST ATTEMPT TO RECONSTRUCT EXPERIMENTALLY TWO CONTROLLED OCTUPOLAR ERRORS USING THE NTRM WAS CARRIED OUT IN CERN-SPS,

LARGE TUNE FLUCTUATIONS HAVE REQUIRED:

1. STRONG SET VALUES FOR OCTUPOLES &
2. A LARGE RANGE OF COD, WHICH ARE NOT OPTIMAL FOR THE NTRM METHOD.
3. THE SYMMETRIC ARRANGEMENT OF STEERERS & OCTUPOLES HAS CREATED ADDITIONAL DIFFICULTIES.
4. THE NTRM HAD TO BE APPLIED WITH A CERTAIN INITIAL CO DISTORTION.

AS A RESULT ONLY ONE OF THE TWO SET OCTUPOLES COULD BE RECONSTRUCTED

LOF=2.35 +/- 0.32 m^{-3}

CONTENT

1. INTRODUCTION

2. NTRM and EXPERIMENT in CERN-SPS

a. CONSEQUENCES OF THE SPS SYMMETRY
b. THE EXPERIMENTAL PROCEDURE
c. NUMERICAL EXAMPLES

3. EXPERIMENTAL RESULTS

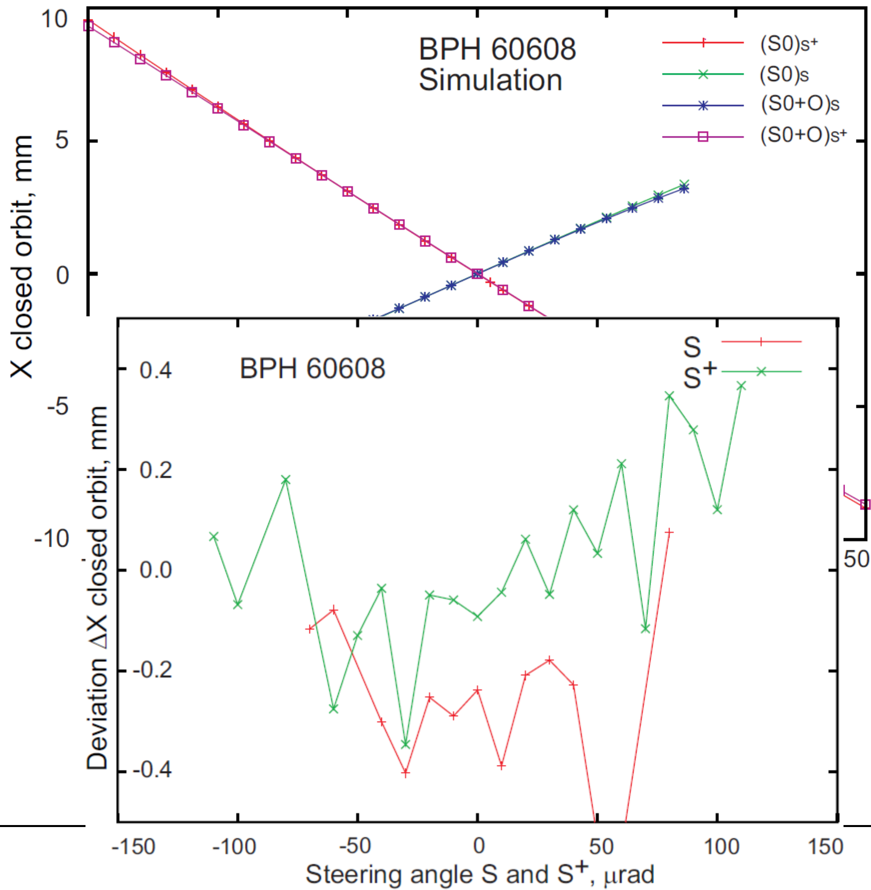
a. MEASUREMENT PARAMETERS
b. LIMITS OF NTRM APPLICATION

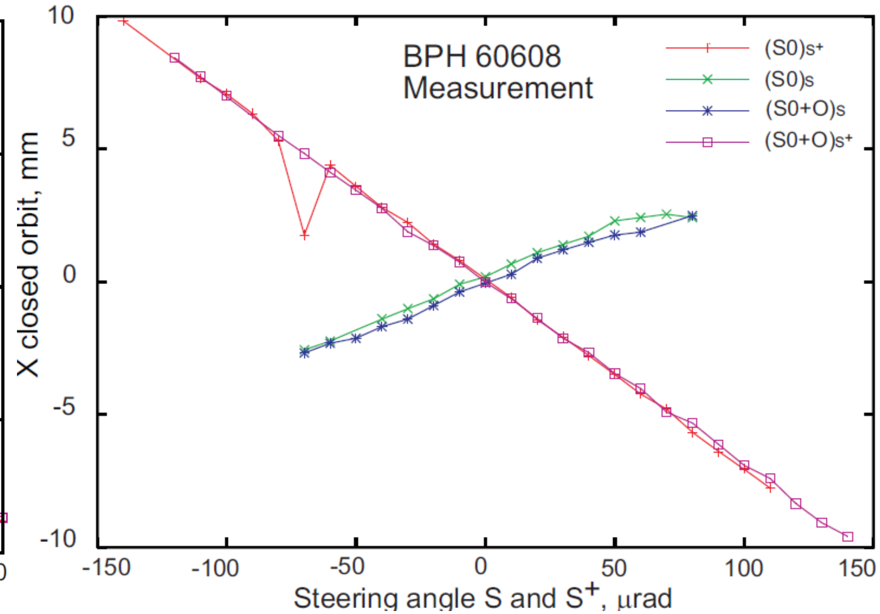
4. CONCLUSION

MEASURED AND SIMULATED CO

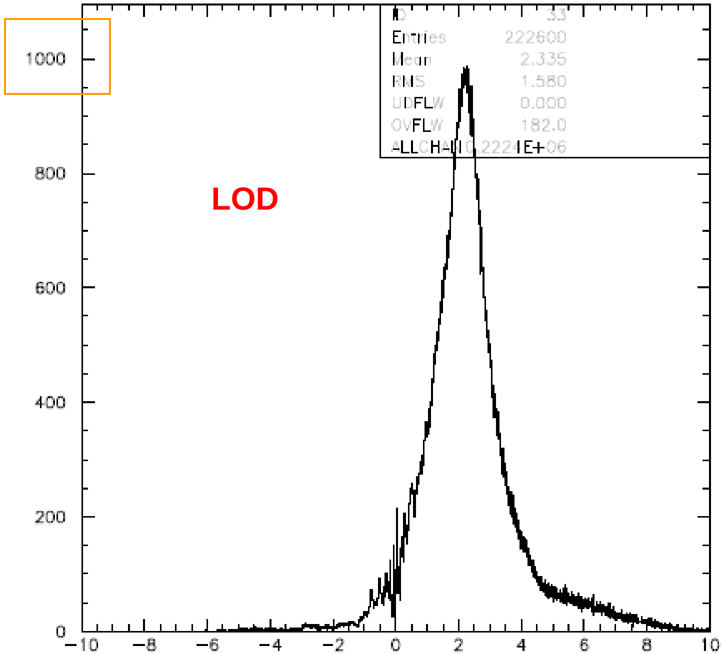
Another BPM

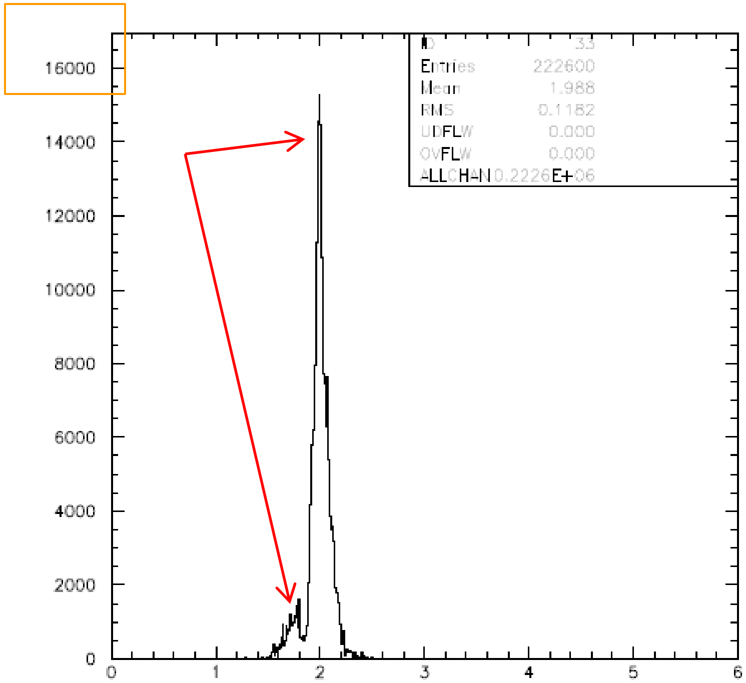
A CO example from a single BPM (#60608) measured and simulated.



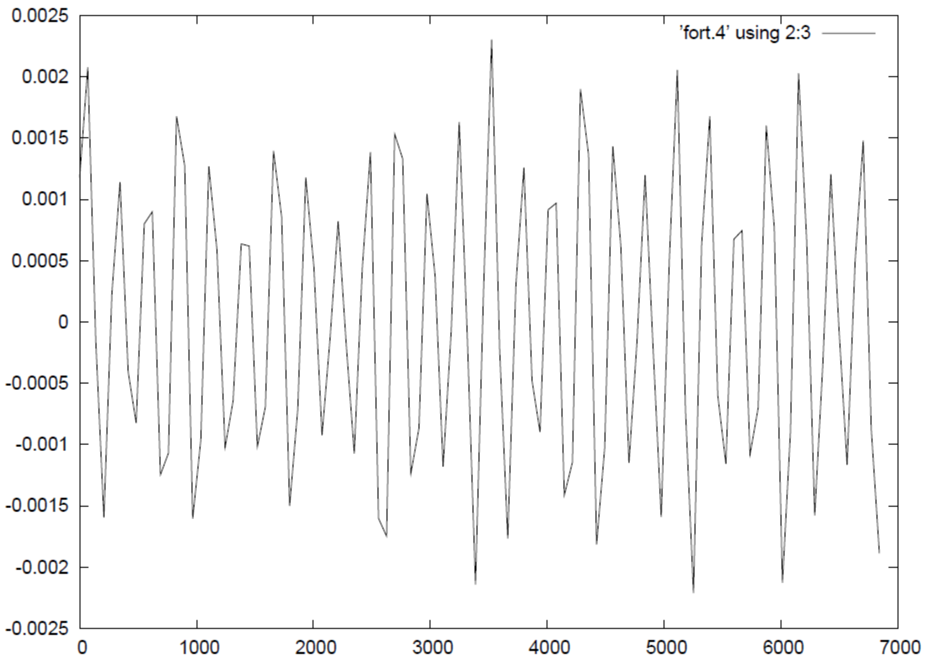


STATISTICAL APPROACH FOR SIMULATION DATA





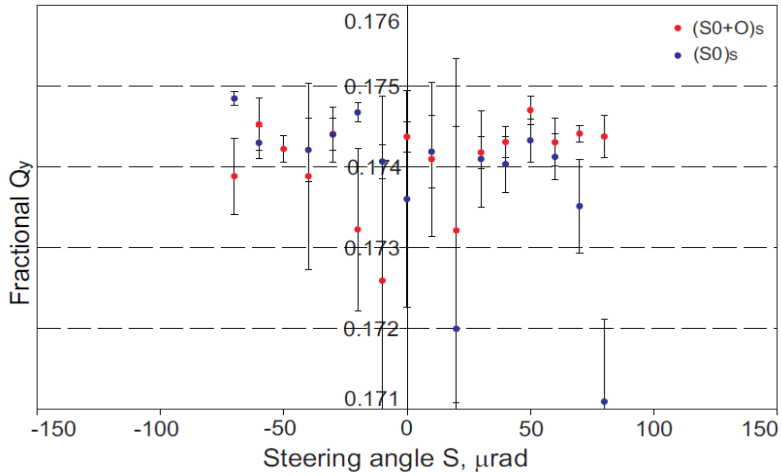
INITIAL CO DEFORMATION FOR THE SIMULATION

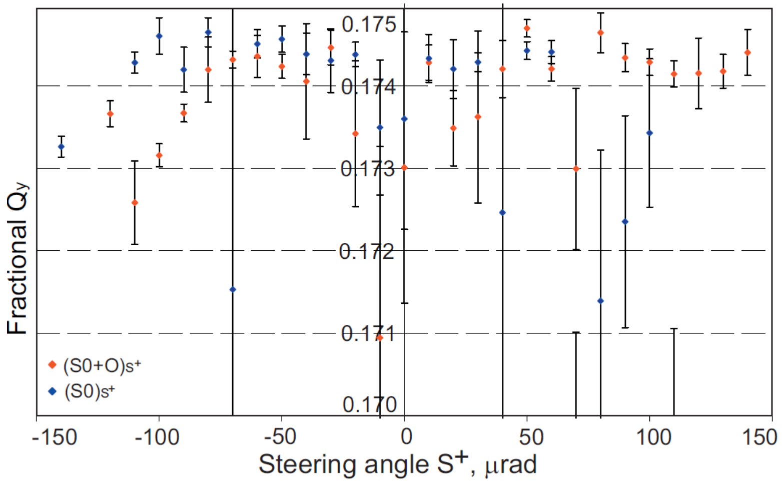


WITH AN INITIAL COD OF ~ 2MM

MEASURED VERTICAL TUNE RESPONSE vs. COD

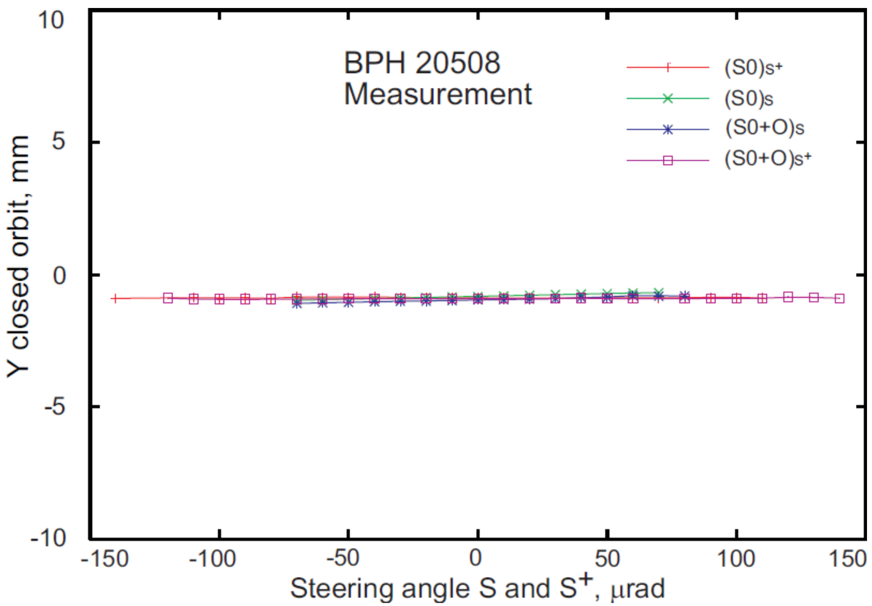
Measurement is not conclusive because of the large errorbars

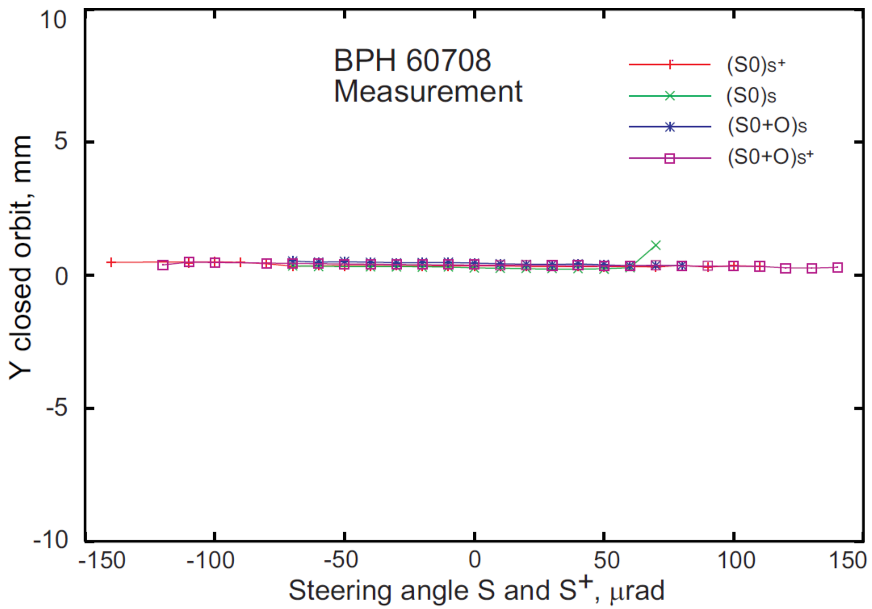




GSI

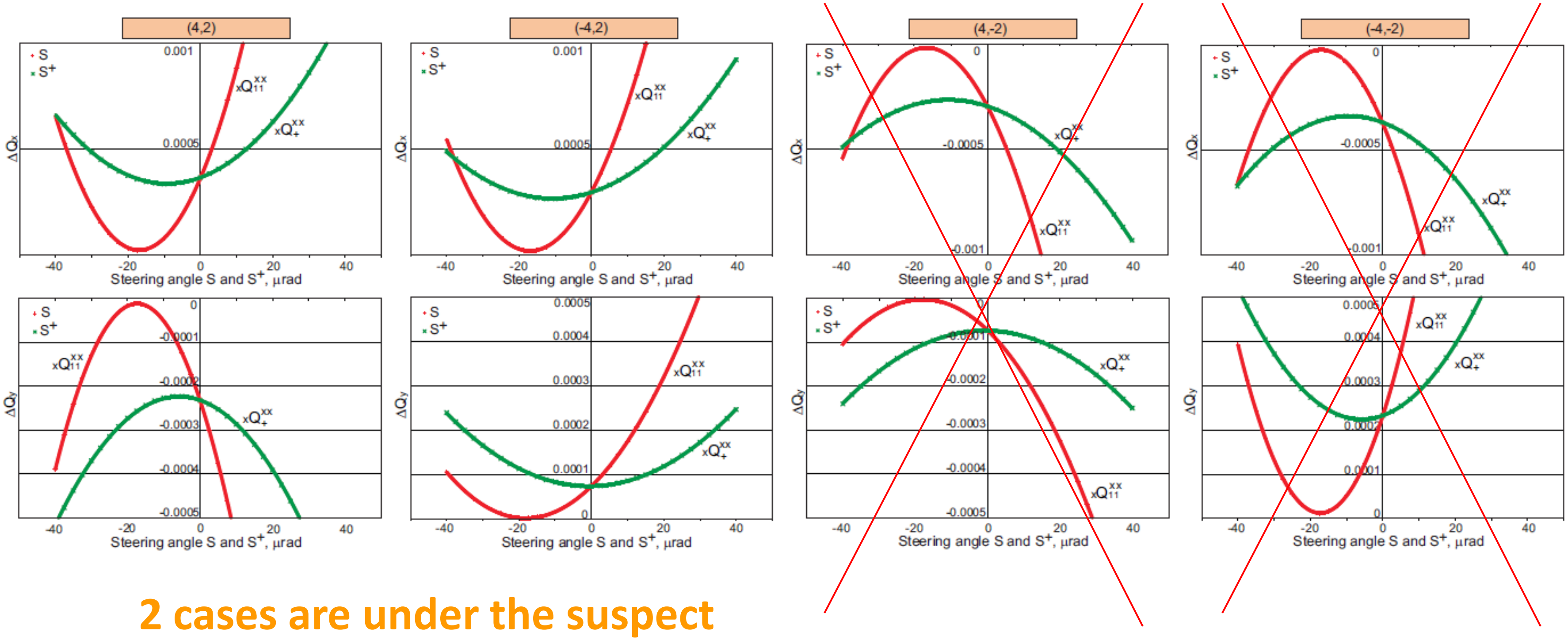
MEASURED VERTICAL CO





DIFFERENTIAL TUNE RESPONSE: PHYSICS OF OCTUPOLES

Measuring both tunes allows to identify the polarity right away



2 cases are under the suspect