LOC meeting

Sorting for the Short Straight Section quadrupoles of Sectors 5-6

Y. Papaphilippou

Thanks to S. Fartoukh, M. Giovannozzi and A. Lombardi (AB-ABP)

P. Hagen, M. Modena, E. Todesco and T. Tortschanoff (AT-MAS)

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Sorting purpose and strategy

- Minimize the effect of quadrupole error (b_2) with respect to beta-beating
- Quality factor – integrated 2nd order resonance driving term
  - Four coefficients, one for each plane and aperture:

$$QF_{x,y} = \frac{|\sum_j \beta_{x,y_j} \bar{k}_j b_{2_j} e^{2i\mu_{x,y}}|}{\beta_{x,y_{max}} \bar{k}}$$

- Compare with random distribution of N=45 quads

$$(QF)_{rms} = \frac{\sqrt{N}}{2} b_{2_{rms}} \approx 3.4 b_{2_{rms}}$$

Local compensation and HP magnets

- Best match of b_2 between pairs of quads with phase advance of ~π/2 i.e., F (D) with consecutive F (D)
- Treat high-permeability (HP) magnets (**μ>1.008**) giving large b_2 individually
- Control evolution of 4+4 coefficients along the sector, giving more weight in the "realistic" scenario (when HP effect disappears, at cold)
- Monitor induced tune-shift, local beta and dispersion beating within the sector for each beam and b_2 scenario

$$\delta Q_{x,y} = \pm \frac{1}{4\pi} \sum_{j=1}^{45} \beta_{x,y_j} \bar{k}_j b_{2_j}$$

$$\frac{\delta\beta_{x,y}}{\beta_{x,y}}(s) = \pm \frac{\sum_{j=1}^{45} \beta_{x,y_j} \bar{k}_j b_{2_j} \cos\left[2(\pi Q_{x,y} - |\mu_{x,y}(s) - \mu_{x,y}(s_j)|)\right]}{2\sin(2\pi Q_{x,y})}$$

$$\frac{\delta D_x}{\sqrt{\beta_x}}(s) = -\frac{\sum_{j=1}^{45} \sqrt{\beta_{x_j}} D_{x_j} \bar{k}_j b_{2_j} \cos(\pi Q_x - |\mu_x(s) - \mu_x(s_j)|)}{2\sin(\pi Q_x)}$$

Semi-automatic algorithm

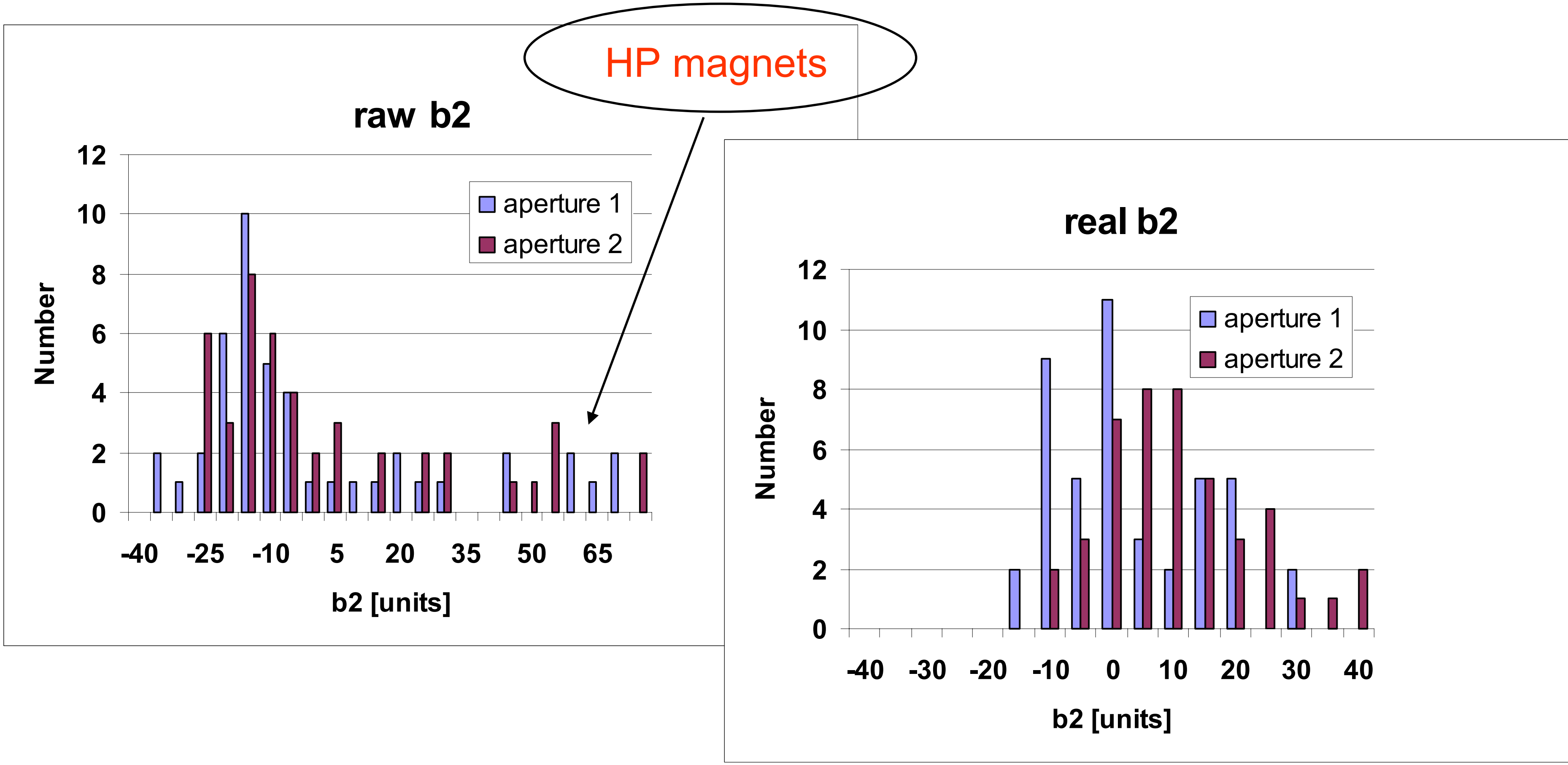
- Pair neighboring (de)focusing magnets within a type having similar b_2 (raw and "realistic") and permeability
- Match pairs across neighboring SSS types and use individual MQ's for missing SSS to best match the pairs
- Reiterate (doing permutations) until converging to minimum
- Try to balance the 4 + 4 coefficients to a minimum (least square sense) with weight to the realistic case (when HP effect disappears)
- **Check with magnet experts for magnet availability** (if yes ☺ if not ☹☹☹ and reiterate)

Sector 5-6 features

- 45 SSS quads, following the pattern 1+2*2+3+3*4+6+9+10=45 (as in all sectors)
  - 20 with trim quads (MT), 21 with octupoles (MO), 4 with skew quads (MS)
- All 10 types of SSS appear also in sectors 7-8 and 1-2
- **12 SSS** with high permeability (2 marginal cases in only one and opposite aperture)
- Slots already allocated (**10 paired**) but not frozen (move them around within a type).
- **10 SSS** of **3 different types** are not yet assembled, giving flexibility to choose from a large pool of individual MQs (around 30) not yet assigned in a cold mass (ACCEL fabrication table by T. Tortschanoff)

Cold Mass Equipment Code	Total in arc of Sector 5-6
LQMSD	4
LQMTE	10
LQMTH	6
LQMTJ	4
LQMOE	9
LQMOK	4
LQMON	2
LQMOP	2
LQMOU	3
LQMOV	1

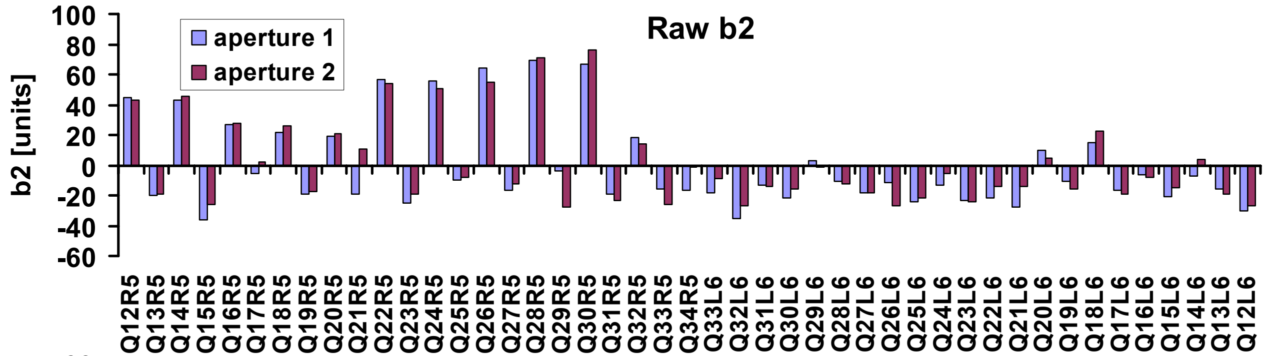
Sector 5-6, b_2 distribution

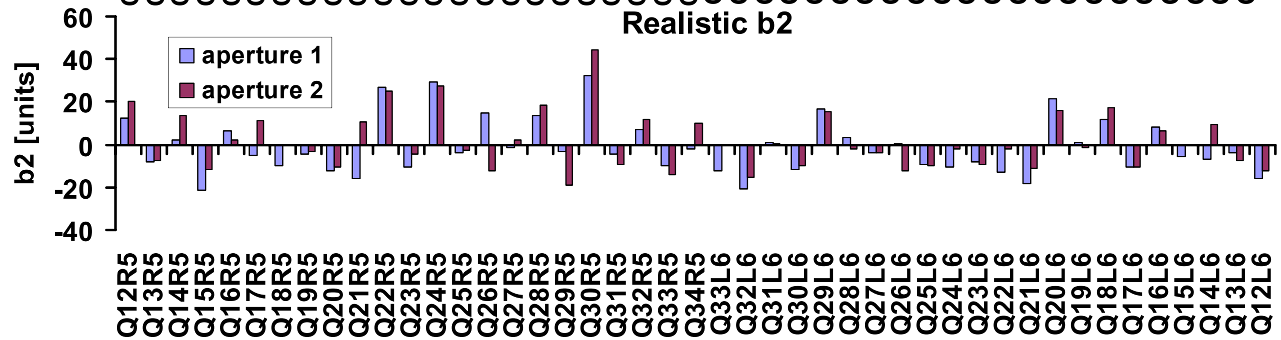


- The rms values of the "raw" b_2 for both apertures is **29**
- The rms values of the "realistic" b_2 (if the HP effect disappears at cold) for both apertures is **13**

Sequence and driving term evolution

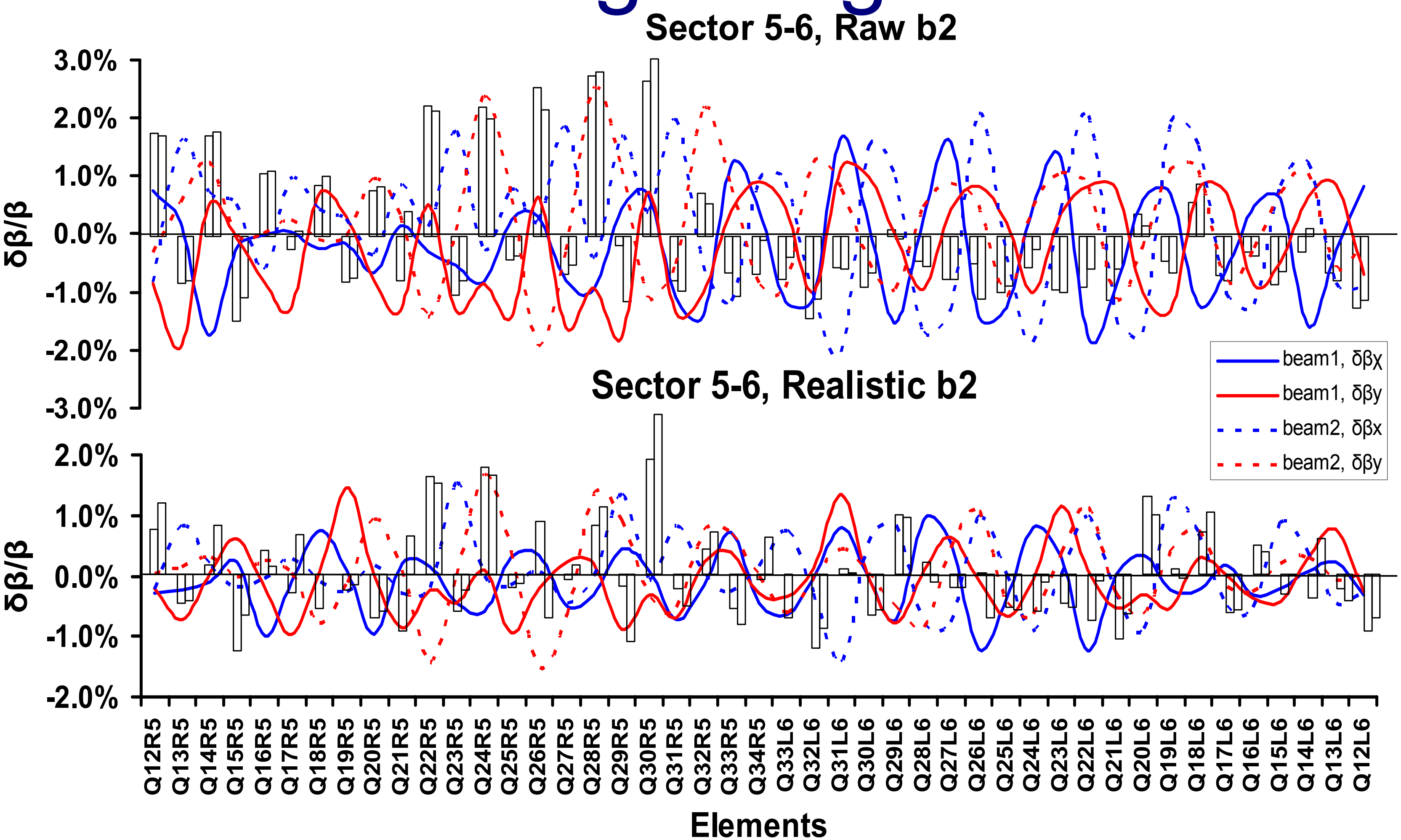
Name	SSS #	b2 [units]		ected b2 [u		μr	
		v1	v2	v1	v2	v1	v2
LQATH.12R5	SSS250	46	43	8	14	1.018	1.015
LQATM.13R5	SSS259	-20	-17	-15	-12	1.003	1.003
LQATH.14R5	SSS251	45	45	-2	7	1.021	1.018
LQATQ.15R5	MQ351	-32	-20	-25	-13	1.002	1.002
LQATH.16R5	SSS252	29	28	2	-4	1.014	1.016
LQATM.17R5	SSS342	-5	4	-12	7	1.007	1.004
LQATH.18R5	SSS318	27	29	-12	-4	1.018	1.016
LQATQ.19R5	MQ353	-15	-12	-8	-5	1.002	1.002
LQATH.20R5	SSS319	22	23	-16	-16	1.018	1.018
LQATM.21R5	SSS348	-19	13	-22	6	1.006	1.007
LQOAG.22R5	SSS324	58	54	23	19	1.017	1.017
LQASE.23R5	MQ342	-21	-13	-14	-6	1.002	1.002
LQOAG.24R5	SSS323	58	51	25	21	1.016	1.015
LQOAR.25R5	SSS343	-10	-6	-10	-7	1.005	1.005
LQOAG.26R5	SSS325	66	55	10	-19	1.024	1.030
LQASE.27R5	MQ344	-12	-6	-5	1	1.002	1.002
LQOAG.28R5	SSS327	71	71	9	12	1.026	1.025
LQOBF.29R5	SSS253	-3	-26	-10	-23	1.007	1.004
LQOAM.30R5	SSS237	69	77	28	38	1.019	1.018
LQOAV.31R5	MQ339	-15	-18	-8	-11	1.002	1.002
LQOAG.32R5	SSS322	20	15	2	5	1.011	1.008
LQOBJ.33R5	SSS351	-16	-24	-16	-19	1.005	1.003
LQOAM.34R5	SSS239	-14	-1	-6	4	1.002	1.003
LQOBF.33L6	SSS345	-18	-7	-19	-5	1.005	1.004
LQOAM.32L6	SSS326	-33	-27	-25	-22	1.002	1.003
LQOAV.31L6	MQ348	-9	-8	-3	-1	1.002	1.002
LQOAG.30L6	SSS033	-20	-16	-16	-17	1.004	1.005
LQOBF.29L6	SSS022	3	1	10	11	1.003	1.001
LQOAM.28L6	SSS027	-8	-12	-1	-9	1.002	1.004
LQASE.27L6	MQ346	-15	-13	-8	-6	1.002	1.002
LQOAG.26L6	SSS240	-9	-27	-4	-19	1.003	1.002
LQOAR.25L6	SSS254	-24	-20	-16	-14	1.002	1.003
LQOAG.24L6	SSS241	-11	-5	-15	-9	1.006	1.006
LQASE.23L6	MQ343	-19	-18	-12	-11	1.002	1.002
LQOAG.22L6	SSS236	-20	-14	-17	-8	1.004	1.003
LQATM.21L6	SSS260	-27	-12	-25	-16	1.004	1.006
LQATH.20L6	SSS248	12	5	17	10	1.003	1.003
LQATQ.19L6	MQ210	-7	-10	-3	-3	1.003	1.002
LQATH.18L6	SSS246	17	23	7	11	1.008	1.009
LQATM.17L6	SSS257	-16	-17	-17	-15	1.005	1.004
LQATH.16L6	SSS321	-5	-8	4	0	1.002	1.002
LQATQ.15L6	MQ345	-17	-9	-10	-2	1.002	1.002
LQATH.14L6	SSS247	-5	4	-11	3	1.007	1.005
LQATM.13L6	SSS258	-16	-17	-10	-12	1.003	1.003
LQATH.12L6	SSS335	-29	-27	-21	-19	1.002	1.002





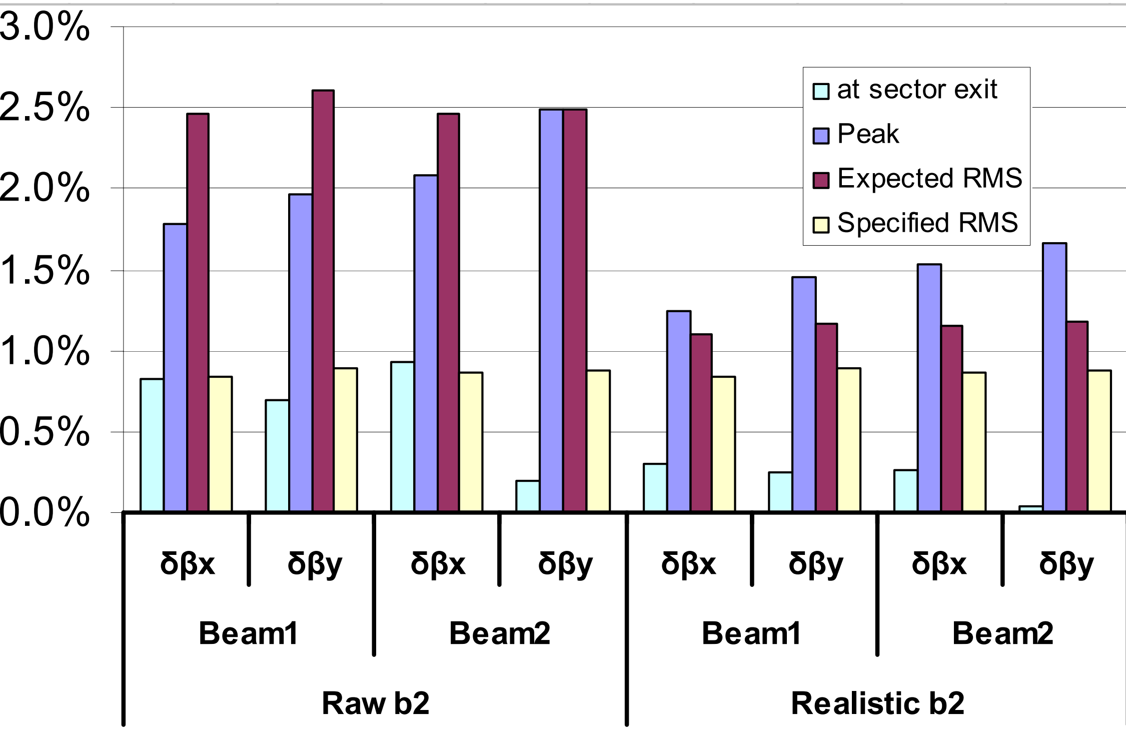
- Final result:
  - Coefficients for raw b_2 : **36, 32** (aperture/beam 1) and **42, 14** (aperture/beam 2) as compared to rms QF of **102** and **100**
  - Coefficients for "realistic" b_2 : **12, 9** and **12, 2** as compared to rms QF of **46** and **47**

Beta-beating along the sector



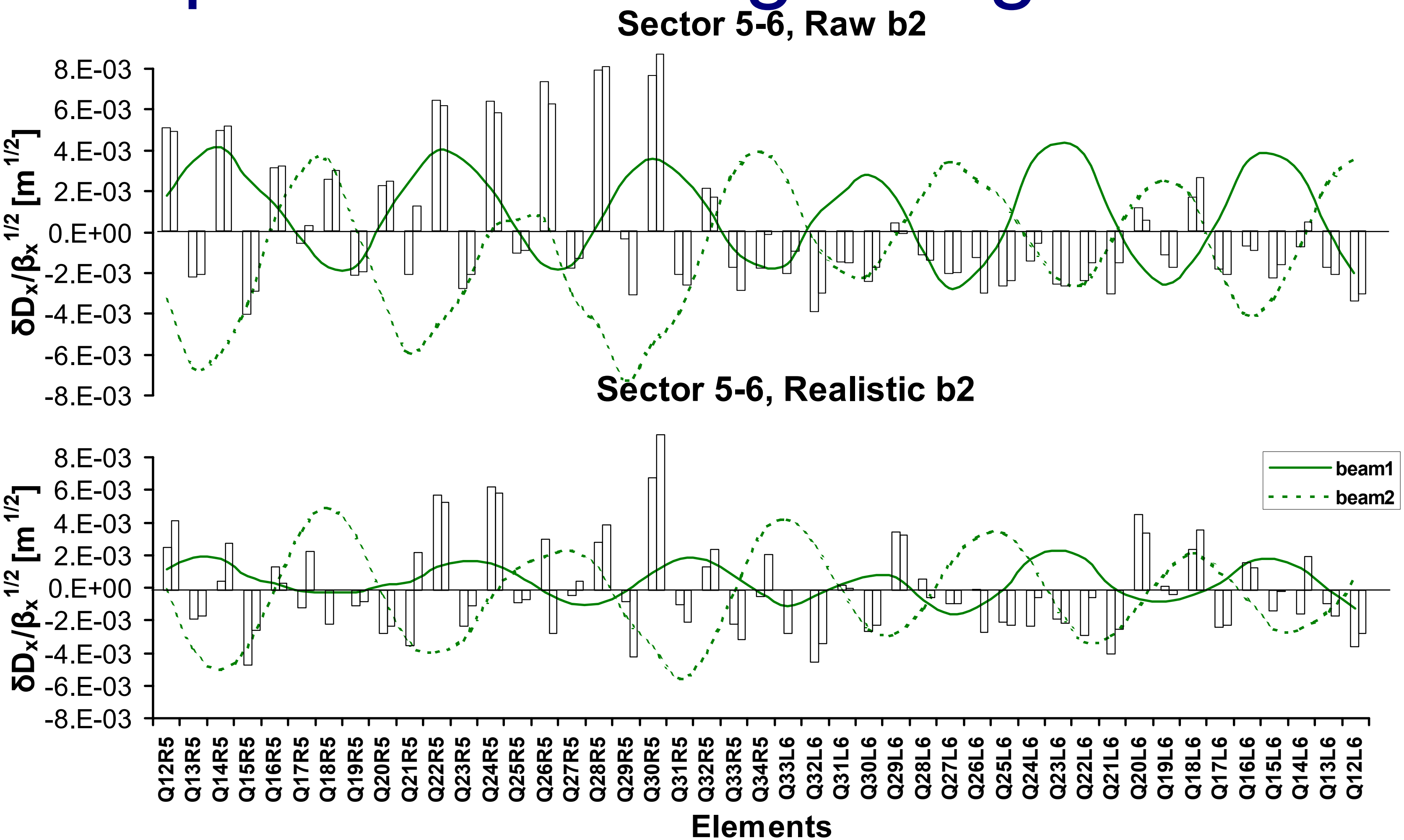
- Peak β-beating for raw of b_2 of **2.5%** on HP magnets (0.9% at sector exit)
- Peak β-beating for realistic b_2 of **1.7%** (0.3% at sector exit)

Beta-beating summary for sector 5-6



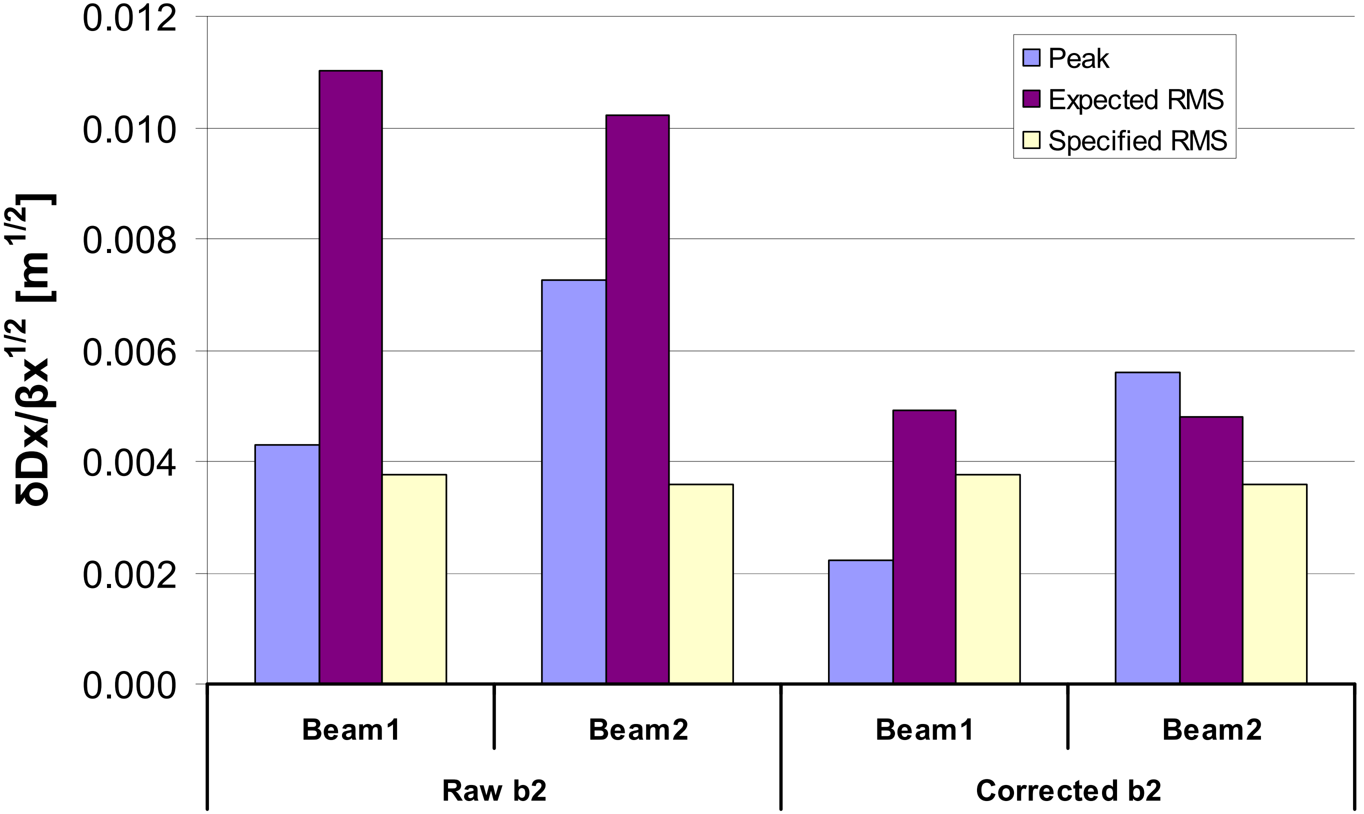
- Raw b_2
  - β-beating at the exit of sector ~ 3 times smaller than expected rms value
  - Smaller or equal to the specified rms value (for rms b_2 of 10 units)
- Realistic b_2
  - β-beating at the exit of sector ~ 2 times smaller than expected rms value
  - Smaller than the specified rms value
- For both cases, β-beating at the exit of the sector of less than 1% (0.3% for the realistic case)
- Comparing to the worse case scenario of a random distribution (3σ), reduction of the peak beta beating due to sorting is dramatic (factor of 4 smaller)

Dispersion beating along the sector



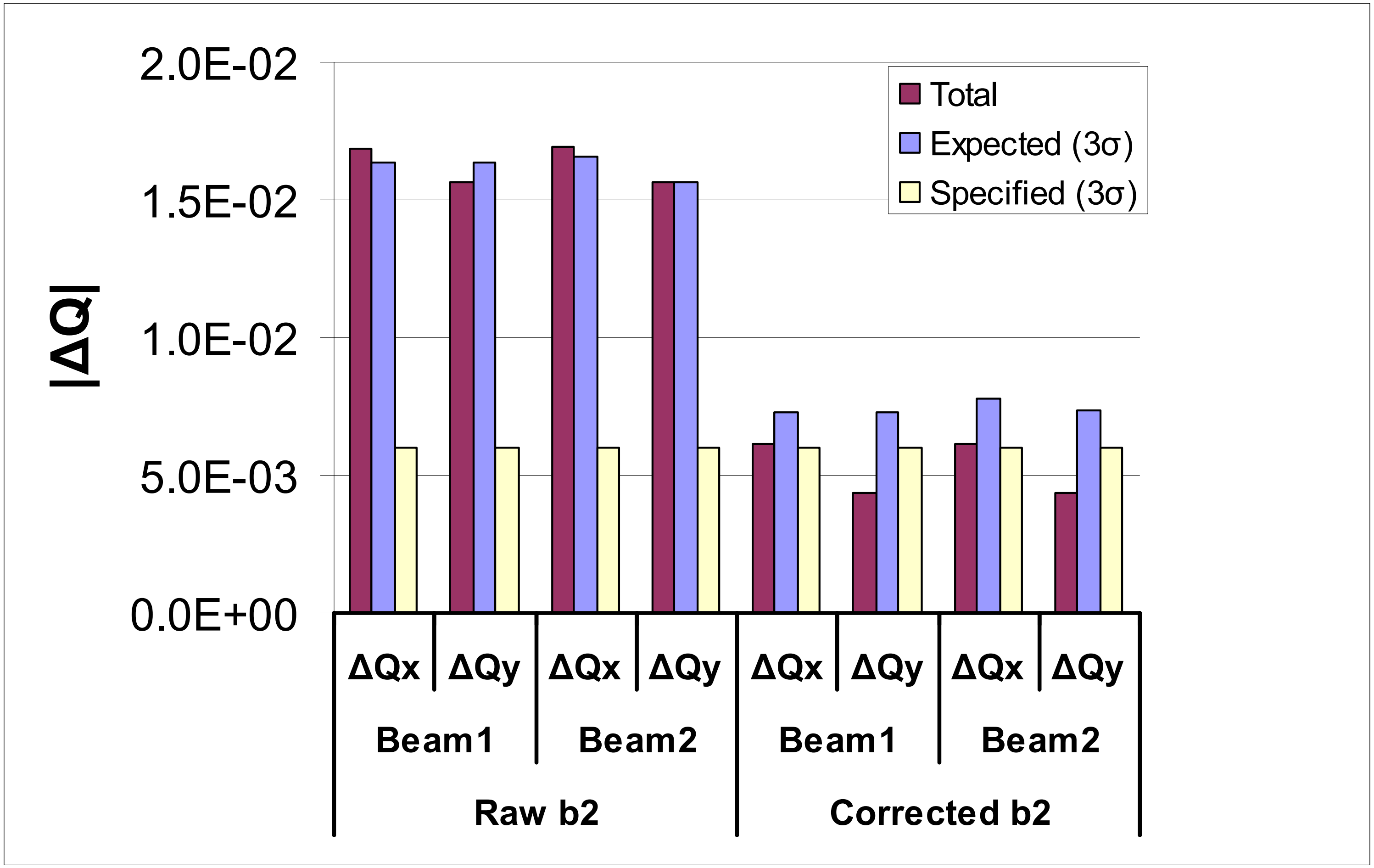
- Peak dispersion beating for raw of b_2 of **4e-3** and **7e-3 $m^{1/2}$**
- Peak dispersion beating for realistic of b_2 of **2e-3** and **6e-3 $m^{1/2}$**

Dispersion beating summary for sector 5-6



- Dispersion beating smaller or equivalent to the expected rms value but larger than the specified rms
- Comparing to a worse case scenario of a random distribution (3σ) the dispersion beating due to sorting is comfortable (although not targeted during the procedure)

Induced tune-shift for sector 5-6



- Induced tune-shift for raw b_2 is equivalent to the expected value (3σ), but largely higher than the specified (effect of large number of HP magnets)
- Situation is much better for realistic b_2 (factor of 3 less and within specs)

Conclusion for 4 Sectors

- Extremely efficient sorting due to production anticipation (MQs)
- β-beating at exit of the sector less than **1.1%** for raw b_2 or **0.3%** for the realistic case.
- Its peak value is less than **3.6%** for raw or **1.8%** for realistic b_2
- Other sector linear optics properties (dispersion, tune-shift) well behaved and within specs (although not controlled)

To be continued

- Comparison with worst case random distributions within the same SSS types
- Global comparison for all sectors (including dipoles – S. Fartoukh)
- Check influence of measurement uncertainty (5-10 units)
- Built the machine models for quads
- Compare analytical estimates with simulations (MAD)