Analysis of ATF2 EXT & FFS Multipoles and Re-tuning Efforts

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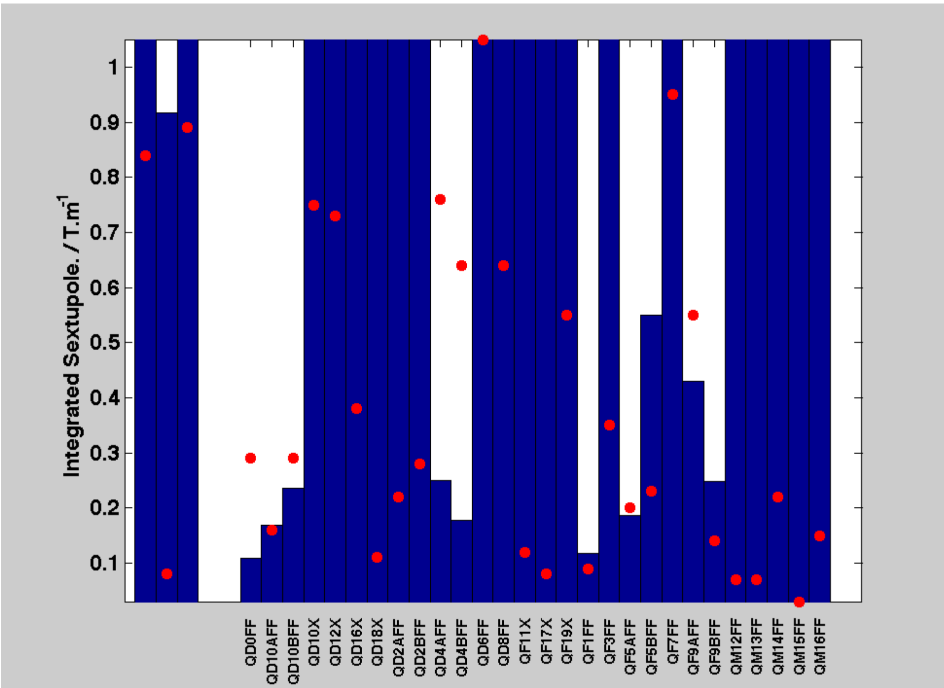
Overview

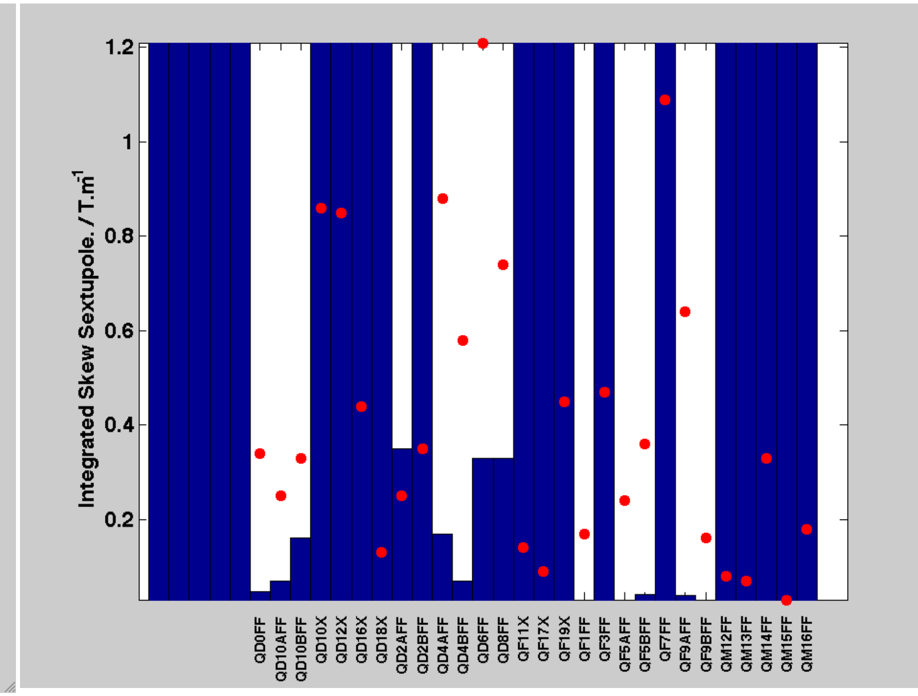
- Incorporate measured multipoles for all quads, bends and sextupoles in EXT and FFS into ATF2 simulation.
- With nominal 4mm / 0.1mm β_x / β_y optics, tracked vertical beam size at IP is 220nm (RMS) / 65nm (Gaussian Fit)
- Calculated multipole sensitivities for all magnets, show measured values which exceed stated sensitivities.
- Re-optimise non-linear matching of optics including measured multipoles.
- Run tuning simulation with re-tuned optics and observe and compare expected performance.

Multipole Sensitivities

- Define sensitivity for multipole components as magnitude of component in question that causes RMS IP vertical beam size to grow by 1nm.
- Multipoles are quoted as integrated strengths in SI units with magnets powered according to nominal optics configuration.

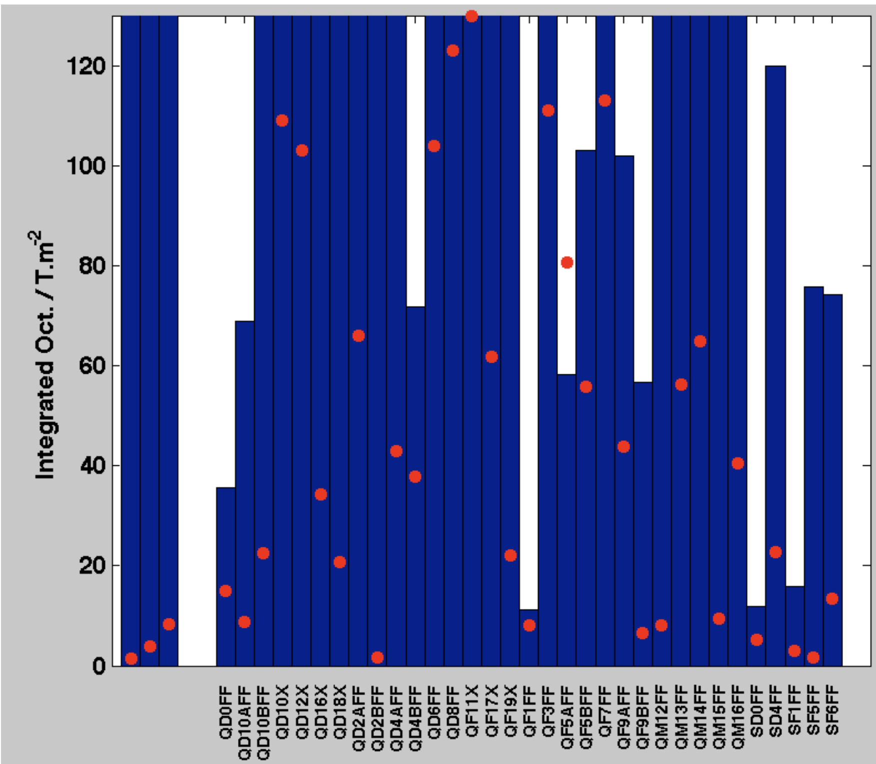
Sextupole Multipole Fields

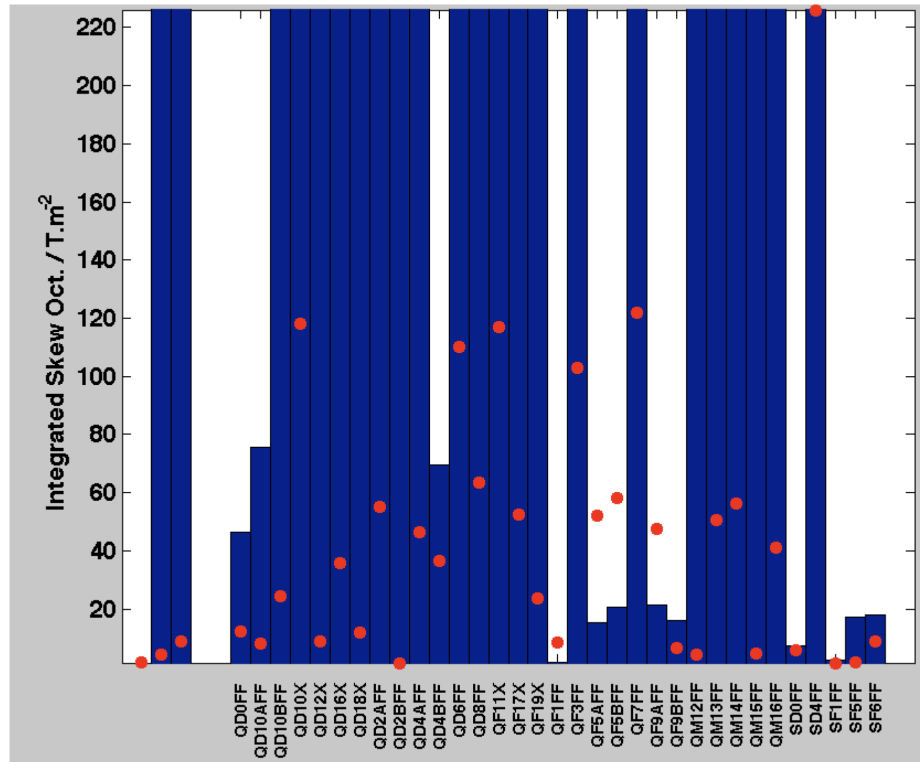




- **Sext & Skew-Sext multipole strength measurements and sensitivities**

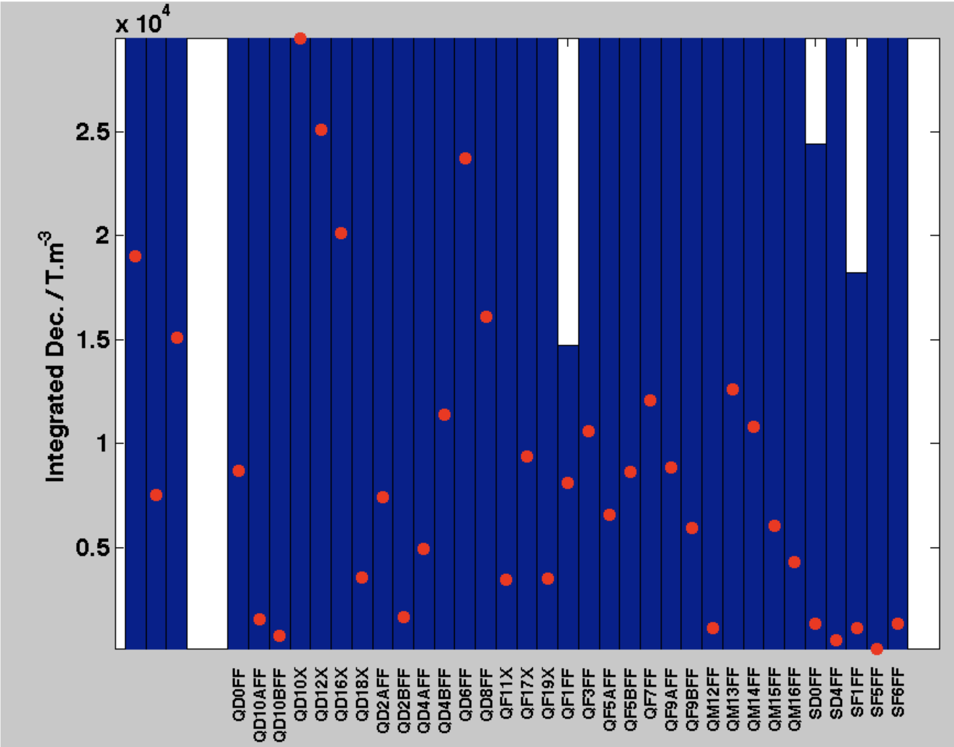
Octupole Multipole Fields

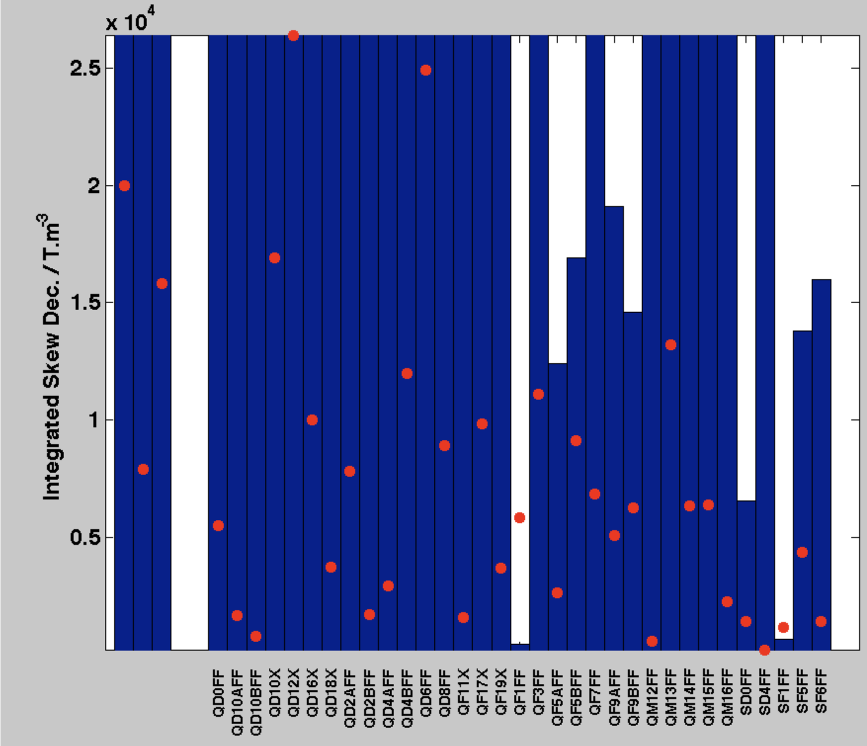




- **Oct & Skew-Oct multipole strength measurements and sensitivities**

Decupole Multipole Fields





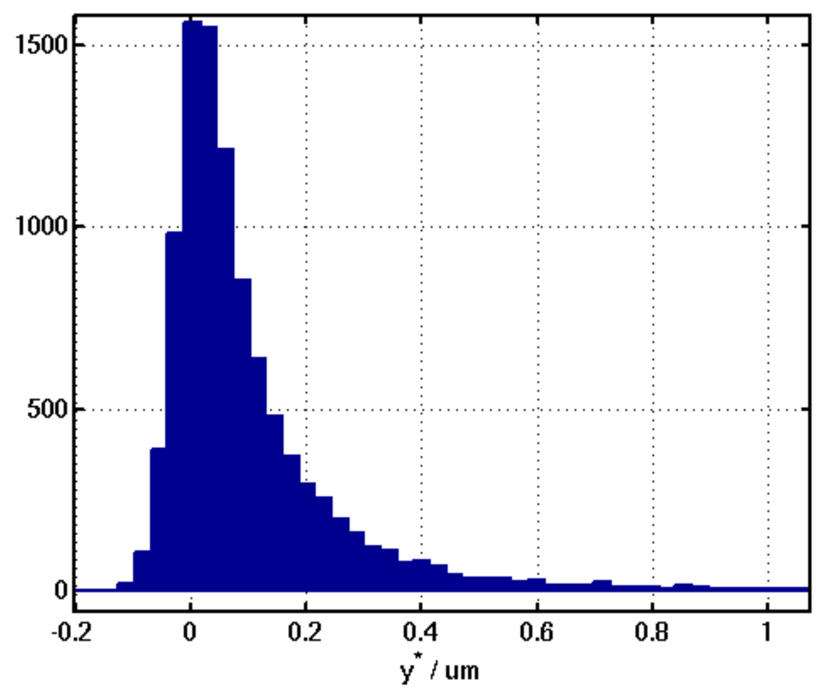
- **Dec & Skew-Dec multipole strength measurements and sensitivities**

Magnet Multipole Measurements which Exceed Sensitivity Requirements

- Sext ($T.m^{-1}$)
  - QD0FF: meas=0.29; sens=0.11
  - QD10BFF: meas=0.29; sens=0.24
  - QD4AFF: meas=0.76; sens=0.25
  - QD4BFF: meas=0.64; sens=0.18
  - QF5AFF: meas=0.20; sens=0.19
  - QF9AFF: meas=0.55; sens=0.43
- Skew Sext ($T.m^{-1}$)
  - QD0FF: meas=0.34; sens=0.048
  - QD10AFF: meas=0.25; sens=0.069
  - QD10BFF: meas=0.33; sens=0.16
  - QD4AFF: meas=0.88; sens=0.17
  - QD4BFF: meas=0.58; sens=0.069
  - QD6FF: meas=1.21; sens=0.33
  - QD8FF: meas=0.74; sens=0.33
  - QF1FF: meas=0.17; sens=0.0024
  - QF5AFF: meas=0.24; sens=0.025
  - QF5BFF: meas=0.36; sens=0.041
  - QF9AFF: meas=0.64; sens=0.04
  - QF9BFF: meas=0.16; sens=0.025
- Oct ($T.m^{-2}$)
  - QF5AFF: meas=80.6; sens=58.2
- Skew Oct ($T.m^{-2}$)
  - QF1FF: meas=8.33; sens=1.64
  - QF5AFF: meas=52.3; sens=15.5
  - QF5BFF: meas=58.0; sens=20.8
  - QF9AFF; meas=47.4; sens=21.4
- Skew Dec ($T.m^{-3}$)
  - QF1FF: meas=5830; sens=454
  - SF1FF: meas=1170; sens=685
- 12-pole ($T.m^{-4}$)
  - QF1FF: meas=1.21E7; sens=2.05E6
- Skew 12-pole ($T.m^{-4}$)
  - QF1FF: meas=6.66E6; sens=1.29E5
  - QF5AFF: meas=1.41E7; sens=8.87E6

Tracking Results

- With no other errors, track beam through model lattice with measured multipole magnitude and angles added (Lucretia).
- σ_y = 220nm (RMS) / 65nm (Fit)
- σ_x = 4.1um (RMS) / 3.1um (Fit)
- Both x and y beam distributions at IP highly non-gaussian.

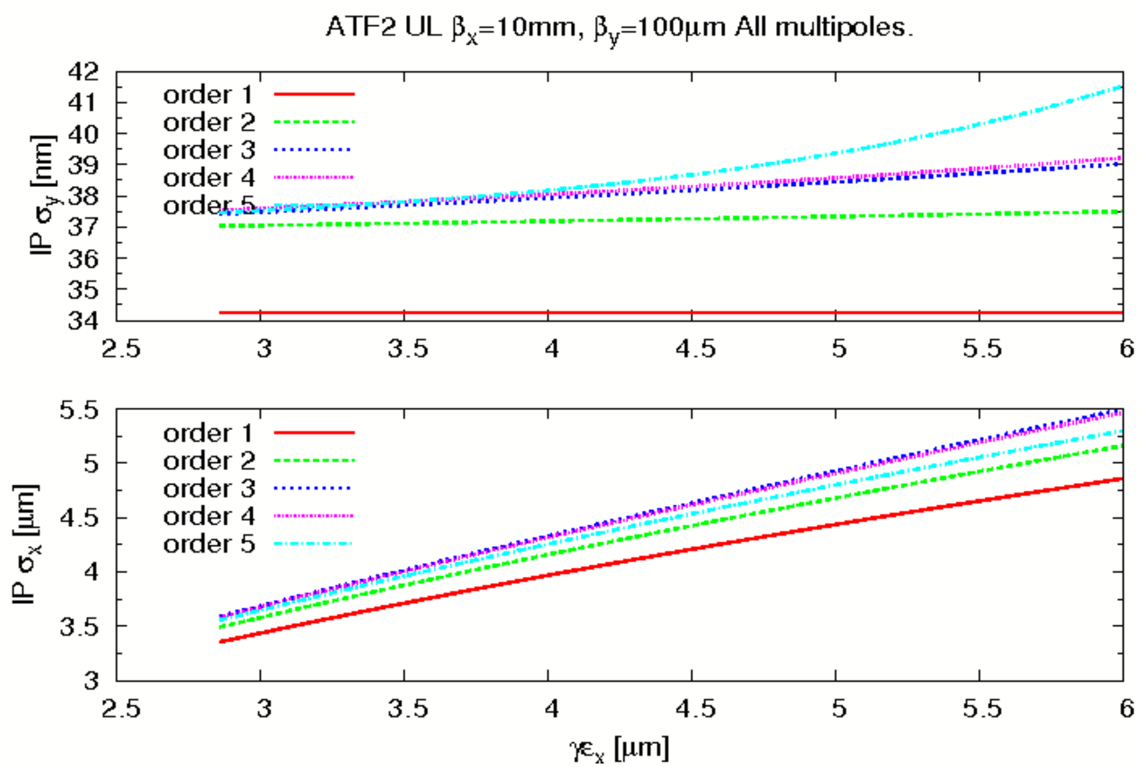


Optimisation of Optics Including Multipole Data

- **MAPCLASS used to rematch and optimise lattice including multipole fields to try and recover nominal IP vertical beam size.**
- **Quantities on the right are re-matched values different from initial nominal lattice. *Note the inclusion of design sextupole rolls.***
- **The vertical beta function was left unchanged at 0.1mm, but horizontal had to be increased by a factor of 2.5 to 1cm.**

```
ksf6ff =      45.02265407 ;
ksf5ff =      -26.9434435 ;
ksd4ff =      152.5391892 ;
ksf1ff =     -22.38137452 ;
ksd0ff =      41.20558391 ;
sf6tilt =  -0.01246444319 ;
sf5tilt =  0.009102481889 ;
sd4tilt =  -0.01427832723 ;
sf1tilt =  -0.04258038011 ;
sd0tilt =  -0.03147326184 ;
kqm16ff =     2.924170943 ;
kqm15ff =   -0.2795777162 ;
kqm14ff =    -4.768046545 ;
kqm13ff =     4.508634198 ;
kqm12ff =     1.469984966 ;
kqm11ff =    0.4389927394 ;
kqd10ff =    -1.465121307 ;
kqf9ff =      1.853857007 ;
kqd8ff =     -3.074271679 ;
kqf7ff =      2.717880616 ;
kqd6ff =     -3.050190084 ;
kqf5ff =      1.949024326 ;
kqd4ff =     -1.555892097 ;
kqf3ff =      2.830240649 ;
kqd2aff =    -1.361293174 ;
kqd2bff =    -1.369873894 ;
kqf1ff =      1.566624722 ;
kqd0ff =      -2.87401948 ;
```

Optimisation Results



Lucretia Tracking IP sizes

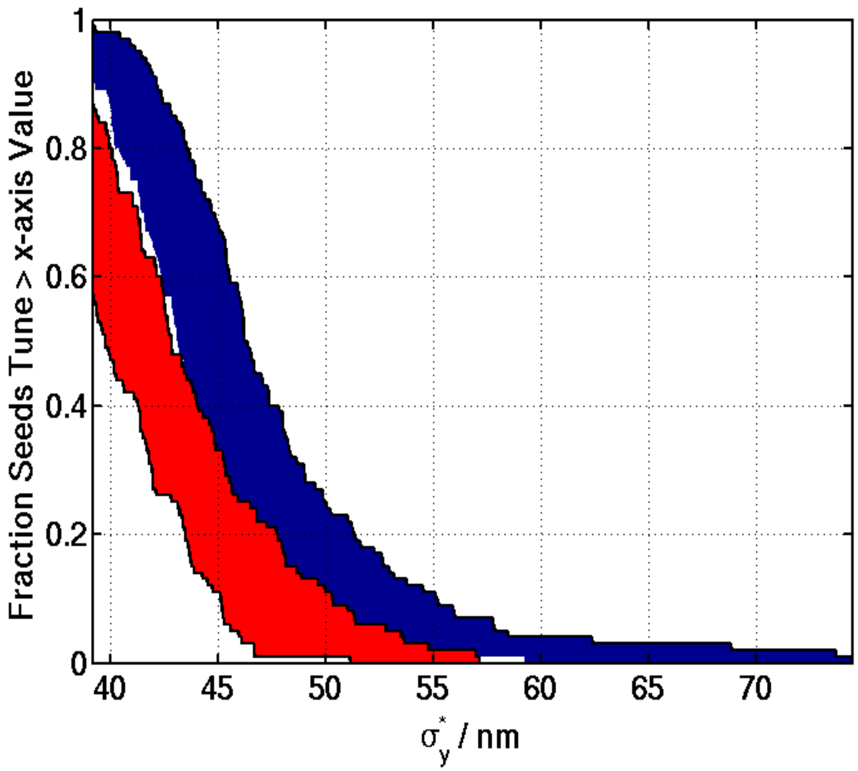
σ_x = 4.5um (RMS) 4.4um (Fit)
σ_y = 44nm (RMS) 42nm (Fit)

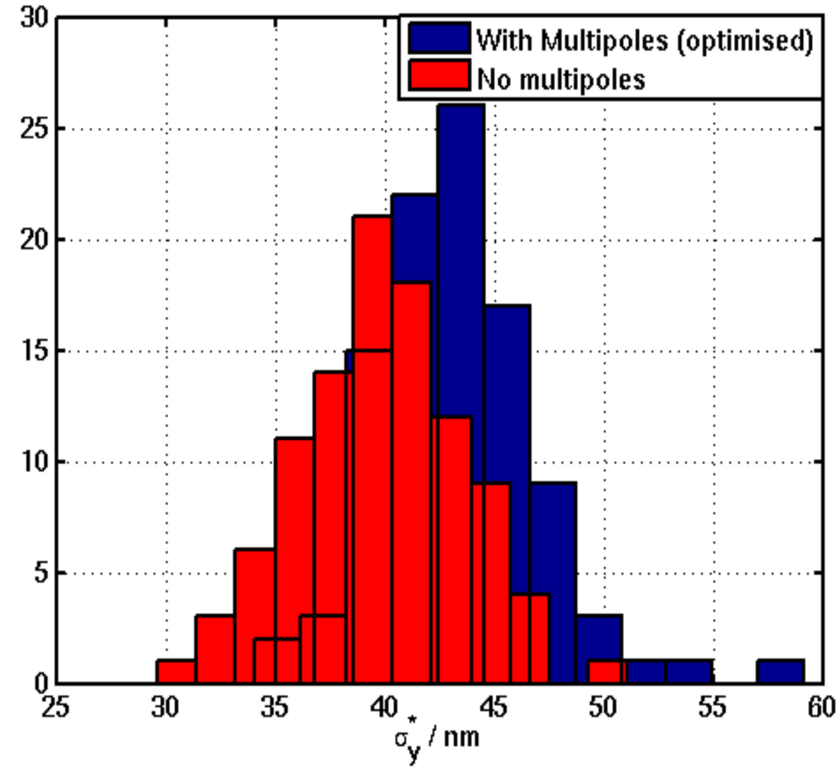
- **Graph shows MADX/PTC beam size calculation with re-matched optics and variable horizontal emittance.**
- **Box shows tracking results with Lucretia (emittance = 5um / 30nm Normalised x / y)**

Multi-seed ATF2 Tuning Simulation with Multipoles and Optimised Lattice

- Use Lucretia Monte Carlo model with standard set of machine error parameters
- Apply standard tuning process with re-optimised lattice and compare performance with multipole-free lattice configuration.
- Look to see if presence of multipoles and increased aspect ratio at IP has deleterious effect on tuning performance.

Tuning Simulation Results



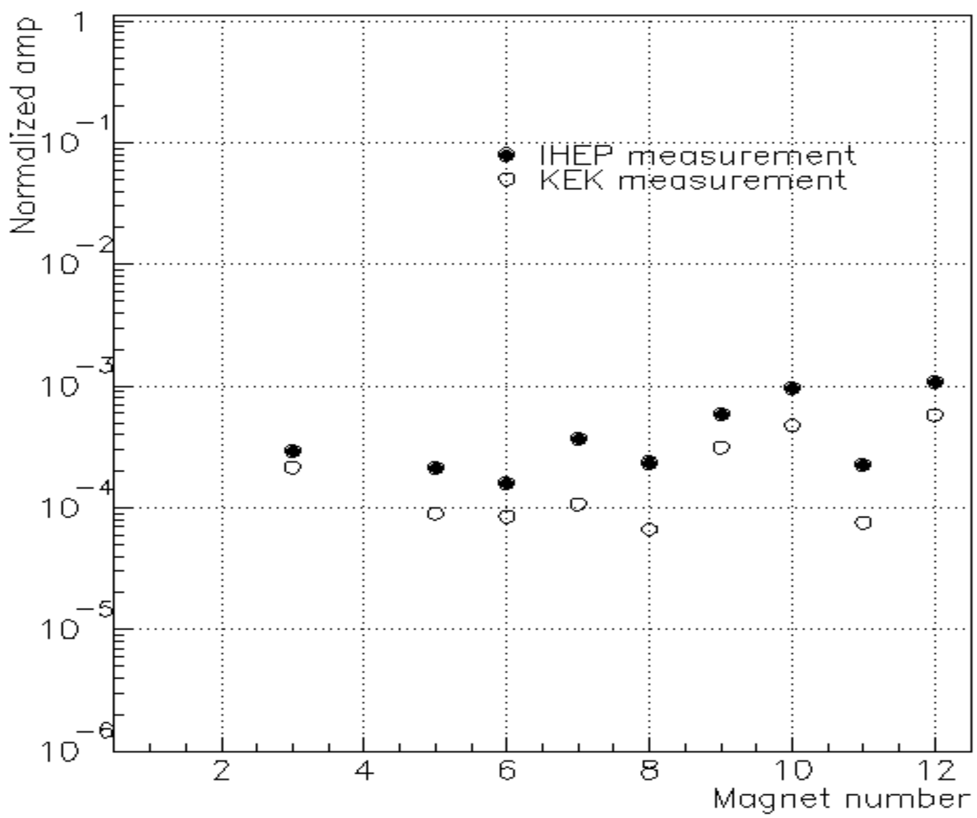


- 100 seed tuning simulation for nominal lattice, with and without multipoles
- Histogram on right for fitted IP size
- Left plot shows range between RMS and fitted sizes.

Tuning Simulation Results

- Nominal lattice (no multipoles)
  - No errors, 37.0 nm (Fit) 38.0 nm (RMS)
  - With errors and tuning
    - 50% seeds < 39.6 nm (Fit) 42.7 nm (RMS)
    - 90% seeds < 44.7 nm (Fit) 50.0 nm (RMS)
- Optimised lattice with multipoles
  - No errors, 42 nm (Fit) 44 nm (RMS)
  - With errors and tuning
    - 50% seeds < 43.0 nm (Fit) 46.1 nm (RMS)
    - 90% seeds < 47.2 nm (Fit) 54.5 nm (RMS)

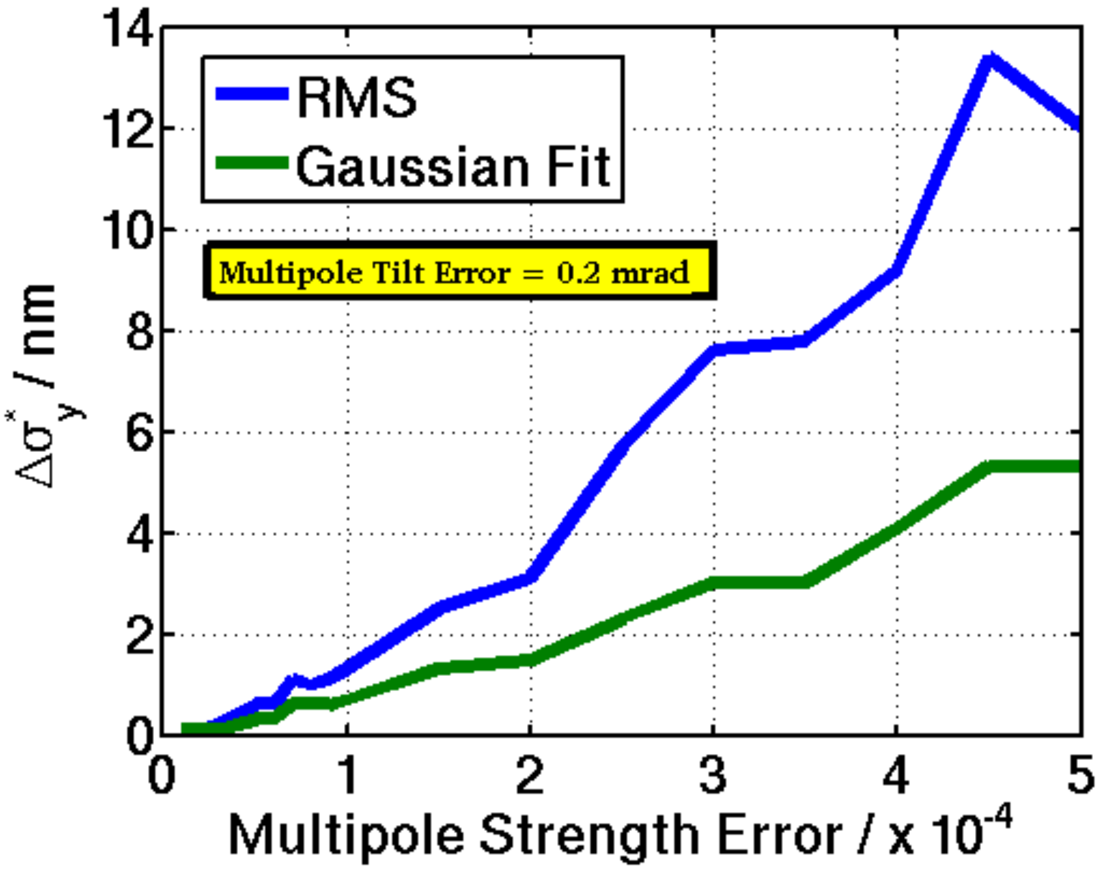
Multiupole Measurement Errors



- **From talk given by Masuzawa-san et al (Aug 2006)**
- **Reproducibility of multipole amplitudes at ~few 10^-4 level seems reasonable.**
- **Error on multipole tilt angle measurement assumed to be ~0.2mrad.**

Multipole Measurement Tolerances

- Use RMS error of between 0.1-5 x 10^-4 (error on measurement of Bn/B2) and 0.2 mrad.
  - O(few mrad) still OK
- Apply RMS distribution of errors to all multipole components for all measured magnets.
- Plot RMS spread of tracked beam sizes for 100 seeds of error configurations.
- These are “bare” beam size measurements. The tuning process will ameliorate some of this effect.



Swap Around QEA Magnets?

- Swapping around magnets as specified on the right gives an optimal configuration of multipole components amongst QEA quads.
- IP vertical beam size in this configuration 90nm (RMS) / 50nm (Fit).
- With this configuration 4 QEA's have multipole components that exceed sensitivity specifications, but less so than before. Most of remaining beam size growth from final doublet system as before.
  - QD10AFF
  - QF5AFF
  - QF9AFF
  - QF9BFF
- Re-optimisation studies with this deck continuing. Can this deck be optimised with nominal sigma_y and smaller sigma_x?
- Full list of multipole components in this configuration in accompanying excel sheet.

QM13FF <--> QF9AFF

QF17X <--> QF5AFF

QM15FF <--> QF5BFF

QF11X <--> QD4BFF

QD18X <--> QF9BFF

QM12FF <--> QD4AFF

QM14FF <--> QD6FF

QM16FF <--> QD10AFF

QD8FF <--> QD16X

QD10BFF <--> QM14R2

Summary

- The measured multipole fields of the ATF2 EXT and FFS magnets were included into our models, optimised and the expected tuning performance analysed and presented.
- The deleterious effects of the multipoles can be mostly mitigated by rematching the optics at the expense of increasing the IP horizontal beam size and increasing the x:y beam size ratio.
- The tuning performance of the machine in the presence of errors is unchanged by the existence of the multipole fields with the re-optimised lattice.
- Matters may well improve if we swap around some QEA magnets and/or perform a program of re-measurement and shimming of magnets.