Summary of SLAC simulation study of emittance growth in the ATF extraction line

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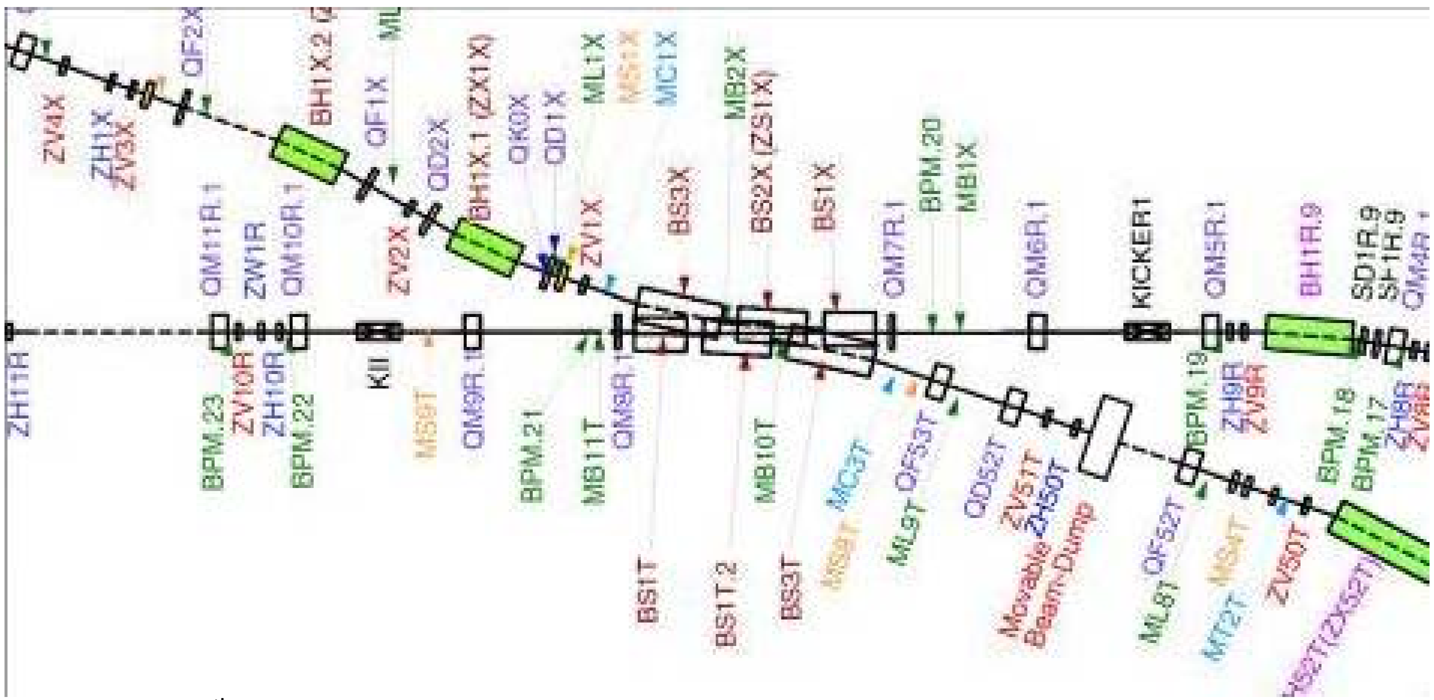
Current status

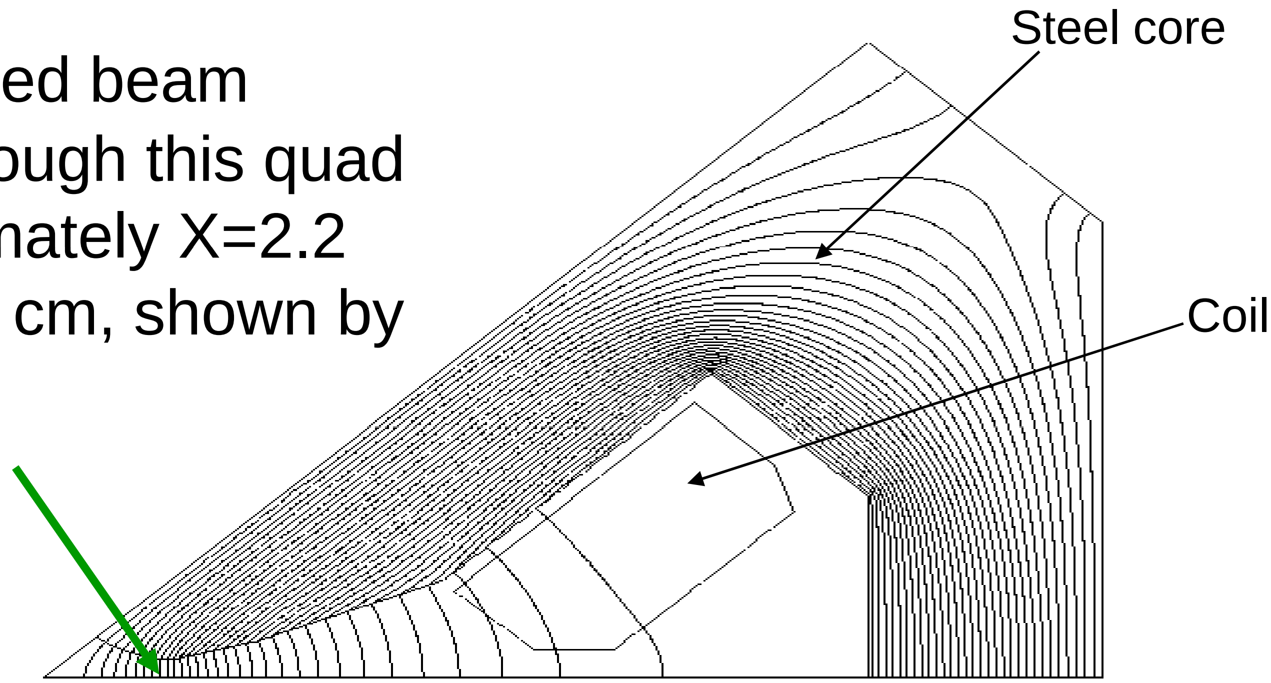
- 2D field calculations for QM7-like and septum A
- 3D field modeling for septum A
- Multipoles analysis for QM7-like magnet
- Tracking with QM7 multipoles
- Vertical emittance growth dependent on energy spread



QM7: 2D field mapping

- Cherrill generated the map of magnetic field in POISSON for the quad similar to QM7 (at 131 Amps). The aperture is just the same as QM7,and so the field is believed to be within 10% of Q7's field. Figure below shows 1/8th of the quad.

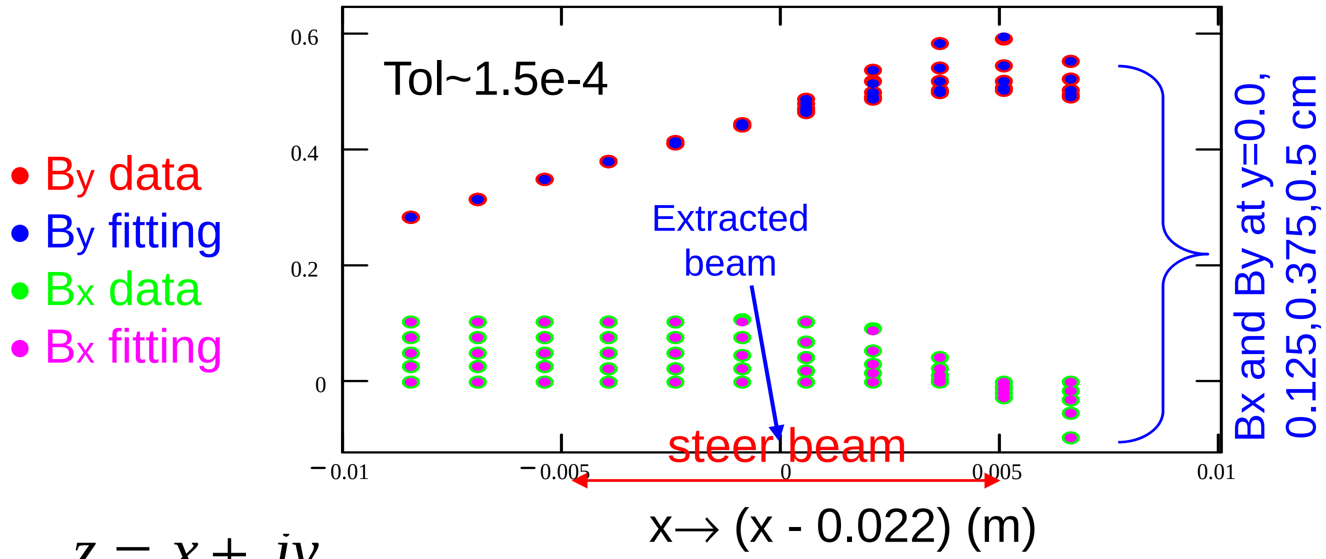
The extracted beam passes through this quad at approximately X=2.2 cm, Y =0.0 cm, shown by the arrow.



QM7 multipole analysis

- We fitted the multipole coefficients of 2D magnetic field at extracted beam location (2.2cm, 0.0):

$$B_y + jB_x = \sum_{n=0} A_n (x + jy)^n$$



$$z = x + jy$$

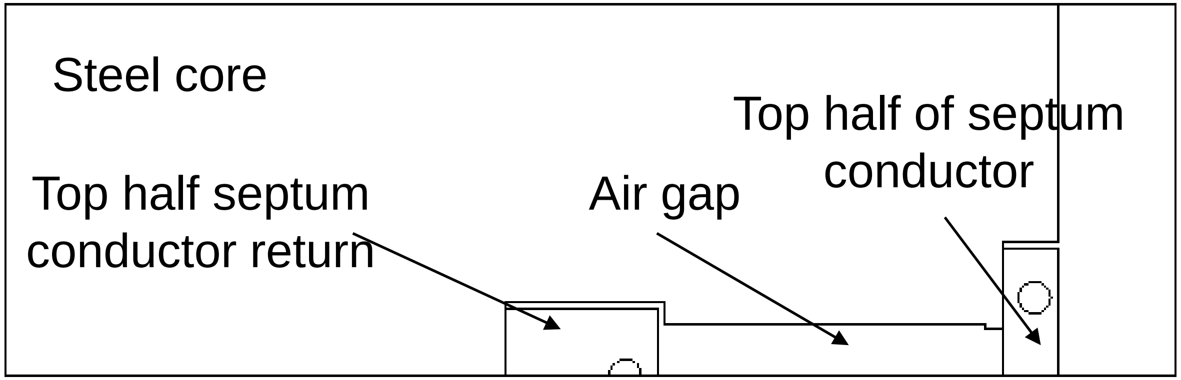
dipole: 0.4% low

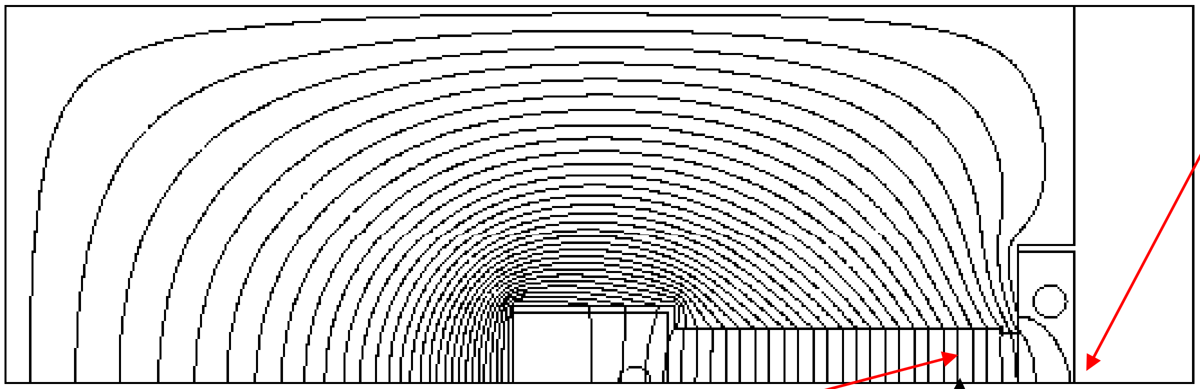
quadrupole: 20% low

$$B_y + jB_x = 0.461 + 17.557z - 959.345z^2 - 1.426 \cdot 10^5 z^3 - 9.898 \cdot 10^6 z^4$$
$$+ 4.93 \cdot 10^8 z^5 + 1.551 \cdot 10^{11} z^6 + 6.512 \cdot 10^{12} z^7 - 9.81 \cdot 10^{14} z^8$$
$$- 9.424 \cdot 10^{16} z^9 + 2.051 \cdot 10^{18} z^{10} + 4.082 \cdot 10^{20} z^{11} - 6.191 \cdot 10^{21} z^{12} - 1.281 \cdot 10^{24} z^{13}$$

Septum-A: 2D field mapping

Top half of Septum-A modelled in POISSON.

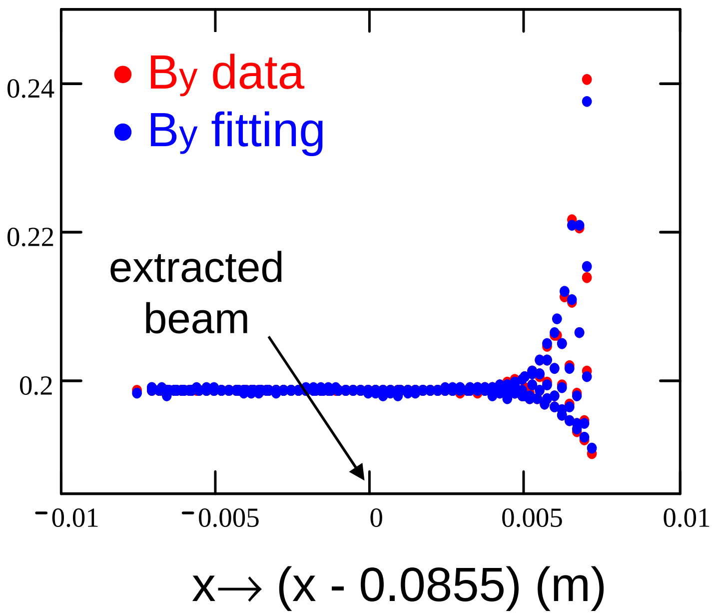


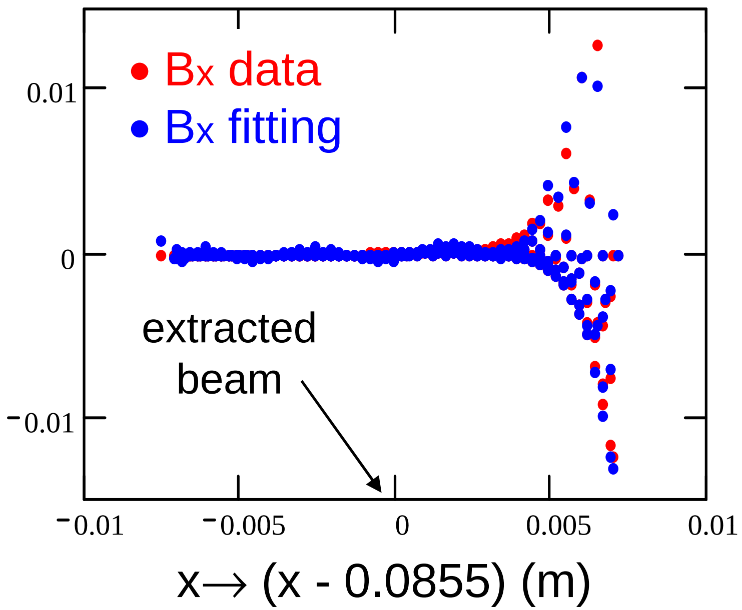


Septum-A multipoles analysis

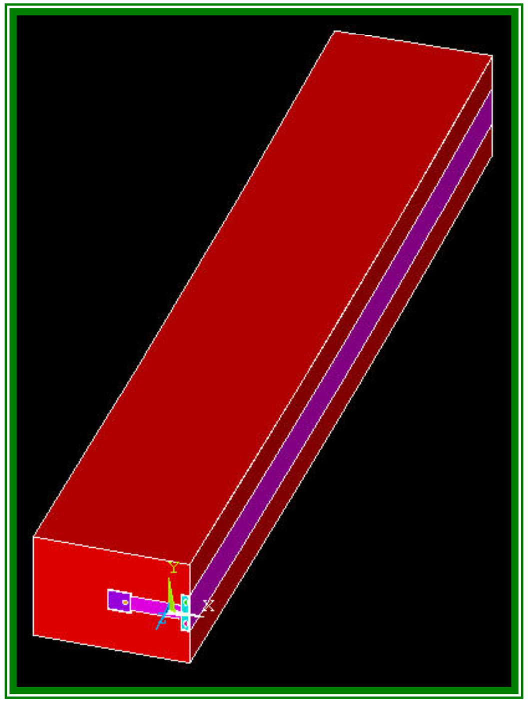
- Multipoles are initially analyzed based on 2D field data provided by Cherrill:

$$B_y + jB_x = \sum_{n=0} A_n (x + jy)^n$$



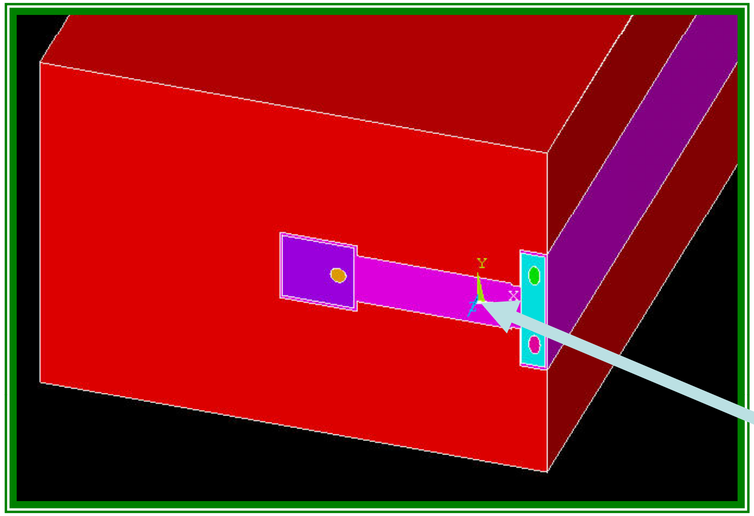


Septum A: 3D field mapping – J. Amann



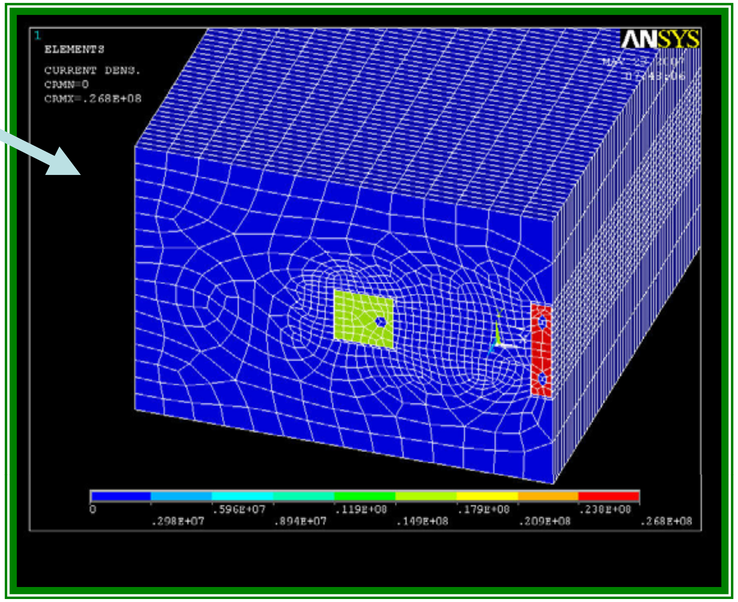
Progress so far...

- **Solid models created with SolidEdge – many thanks to KEK colleagues for details/drawings of extraction septa.**
- **Imported model as IGES to ANSYS for 3D magnetic analysis.**
- **Current distribution modeled for 1594A excitation current.**
- **Initially only model magnet, conductor and air gap within magnet yoke region. Exterior space not modeled to reduce problem size and complexity.**
- **Used ANSYS materials library for Cu conductor and A1010 carbon steel properties.**



Extracted Beam Location

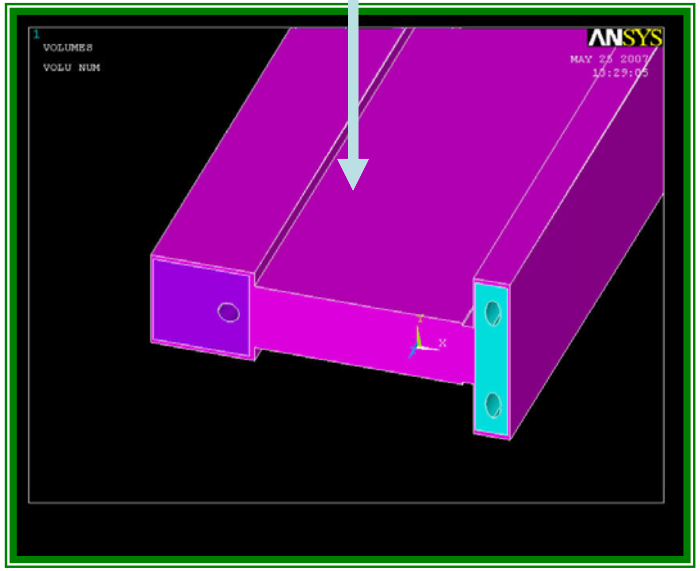
FEA Model



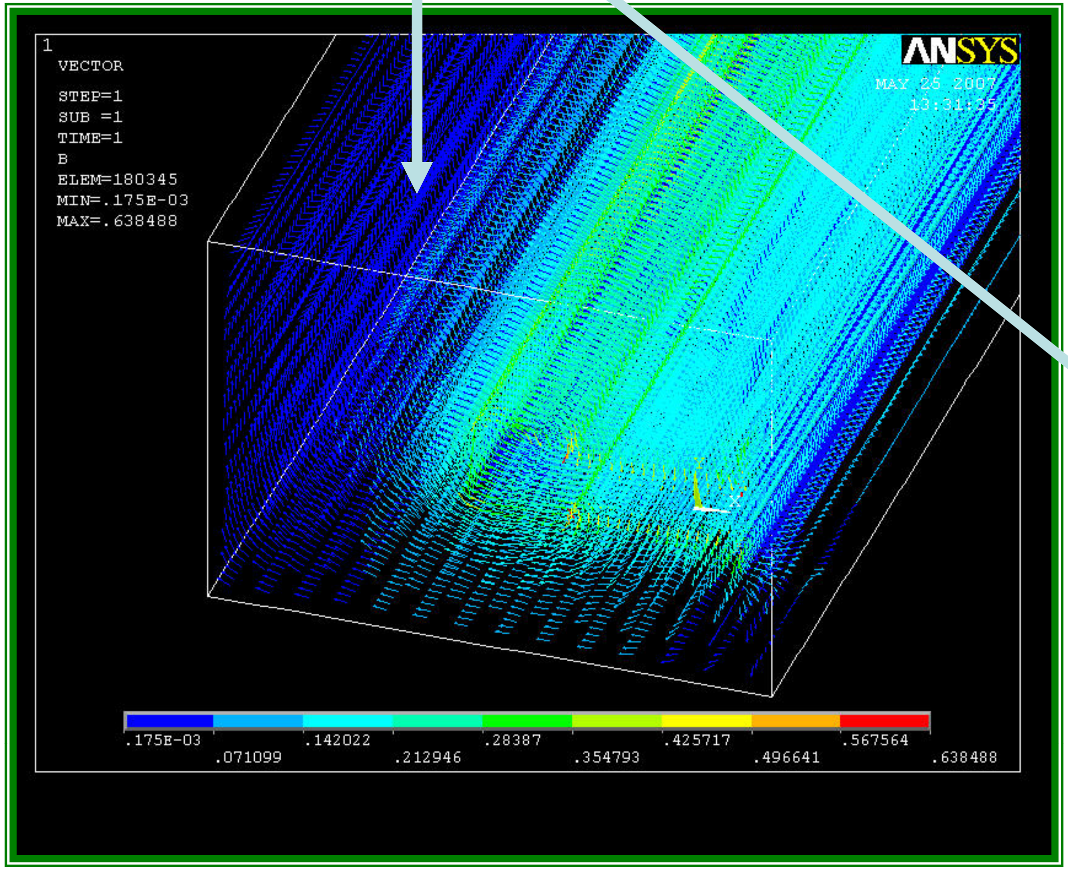
Septum A: 3D field mapping – J. Amann

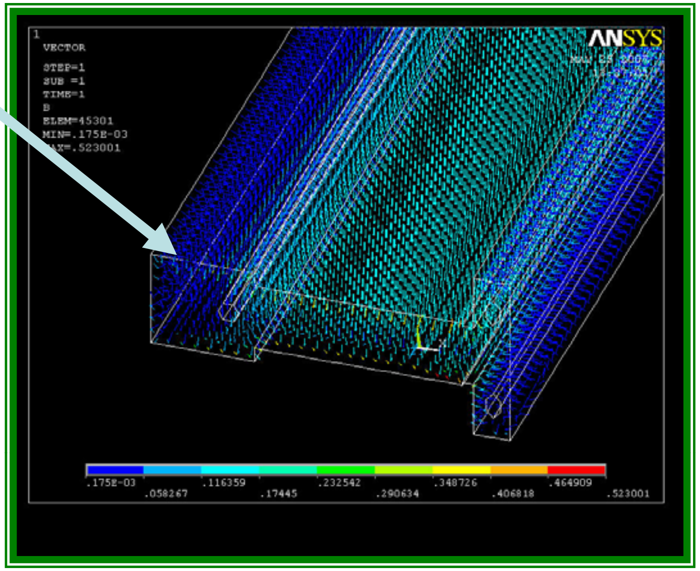
Results…
Gap field order of magnitude is correct.
However, gap field is about 15% lower than expected.
This is likely due to an error in the current density model, working to improve the accuracy of this result.
Output file is text file with Bx,By,Bz components.

Solid Model Yoke Removed



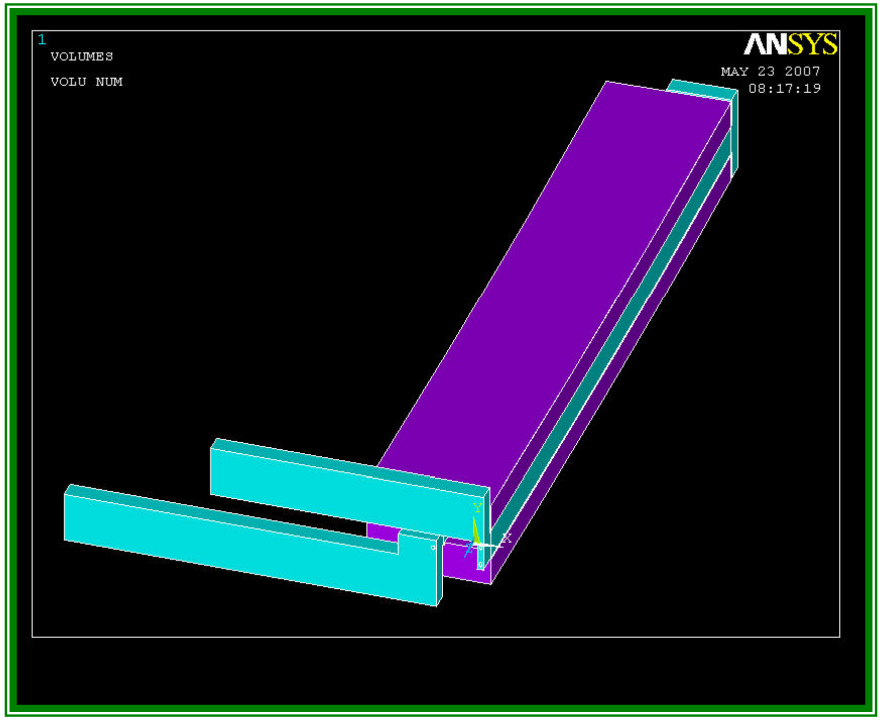
Magnetic Flux Density Vector Plot

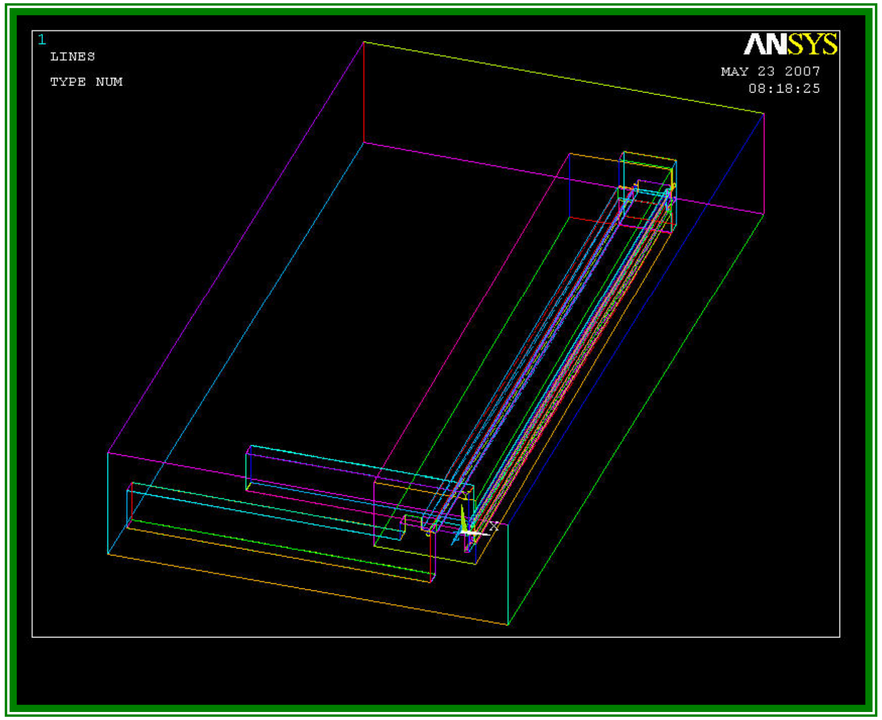




Septum A: 3D field mapping – J. Amann

Current Work In Progress….





Expanded model to include full conductor and exterior air space surrounding magnet.
This increases model size and number of mesh elements significantly.
Currently working on a mesh which will not exceed memory limitations of Windows 32bit OS, yet provide accurate modeling of magnet structure.
Investigating higher performance computing solutions (64bit) in order to model at a very fine mesh density (<2mm) and avoid memory limitations of Windows 32bit OS.
Create 3D models for QM7 and extraction septa B and C.

QM7 effects: 'ideal' beam position

- Magnet errors applied
  - Dipole: Δy=0.1mm (rms)
  - Quad: tilt=0.3 mrad, Δx=50μm, Δy=30μm (rms)
- QM7 magnet multipoles applied
- Elegant code is used to measure effects at each step:
  - W/o orbit correction
  - W/ orbit correction
  - W/ orbit correction and dispersion reduction
  - W/ orbit and coupling corrections, and ηy
- Initial parameters at the ATF2 entrance:
  - $\gamma\varepsilon x$/ $\gamma\varepsilon y$ = 5.09 μm/30 nm (rms), δp = 0.08% (rms) and σz = 8 mm (rms)
  - Dx/Dx' = -0.178E-2/3.76E-3, and other Twiss
- 10 seeds are applied for the magnet errors
- Emittance is measured at the diagnostics station; no obvious emittance growth observed after coupling correction.

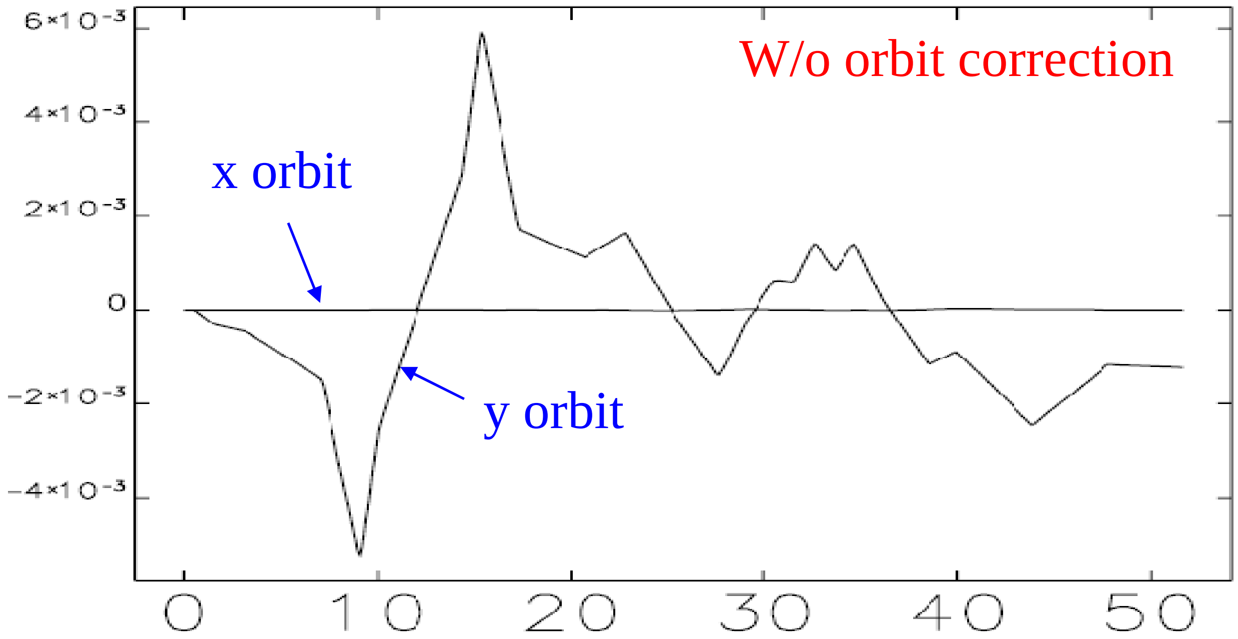
QM7 effects: scan beam position

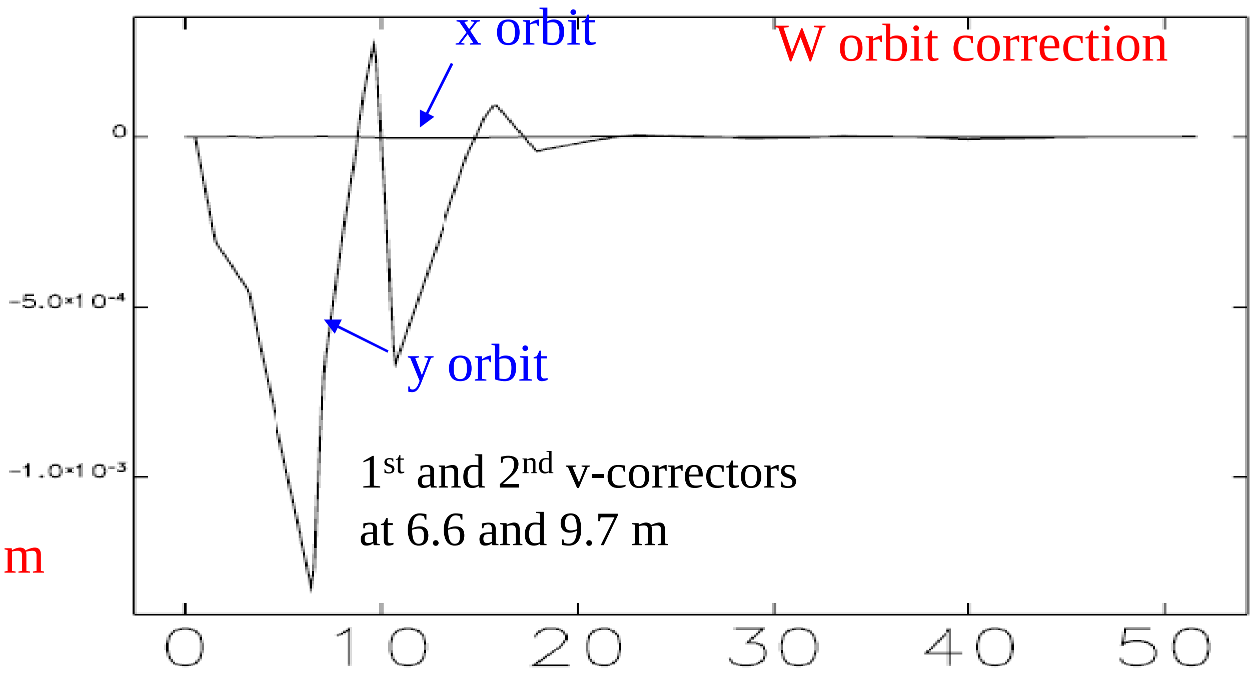
(No magnet has errors except QM7)

- Horizontal scan (changed by kicker angle) ±5mm: w/ coupling and η_y corrections; no obvious effects again.
- Vertical scan (vertical kick) 0.8 mm offset at QM7
  - W/o orbit corr. (emittance growth 45% w/o dispersion term) and w/ orbit correction (37% and 78% w/o and w/ dispersion term)
  - W/ η_y correction (33% for w/o and w/ dispersion term)
  - W/ coupling corr. for QM7 harmonics represented as multipoles:

    Emittance growth 32% for 0.8mm vertical offset at QM7;
    Multipoles matrix are not included in matrix calculation in elegant code;
    Have residual effects even after coupling correction;
    Sextupoles dominated to generate the emittance growth
  - W/ coupling corr. for QM7 field (up to sextupole)

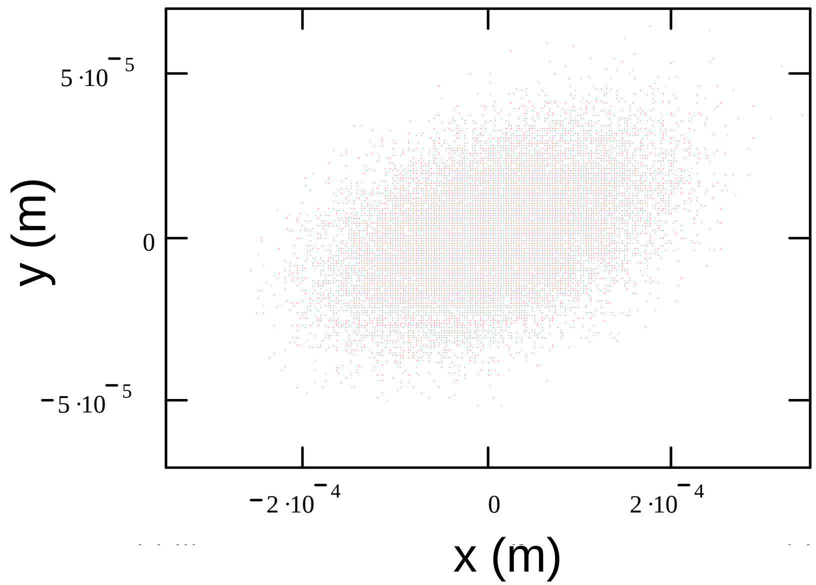
    Dipole and quadrupoles field are built into the QM7 magnet in the deck;
    Replace sextupole multipole with a thin sextupole (it uses kick method based on symplectic integration) so that the sextupole matrix is included;
    Emittance growth only 1% with the perfect coupling correction





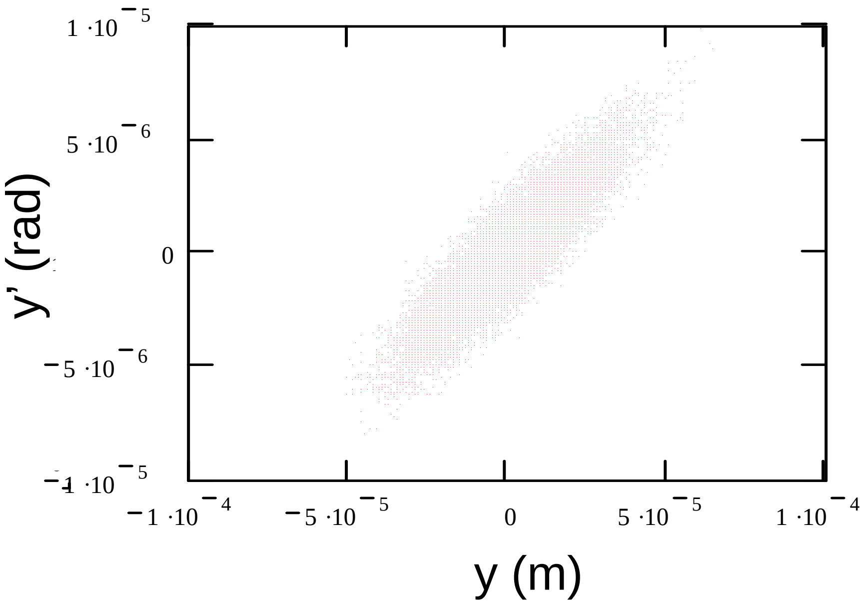
All units in m

Phase space at the EXT end

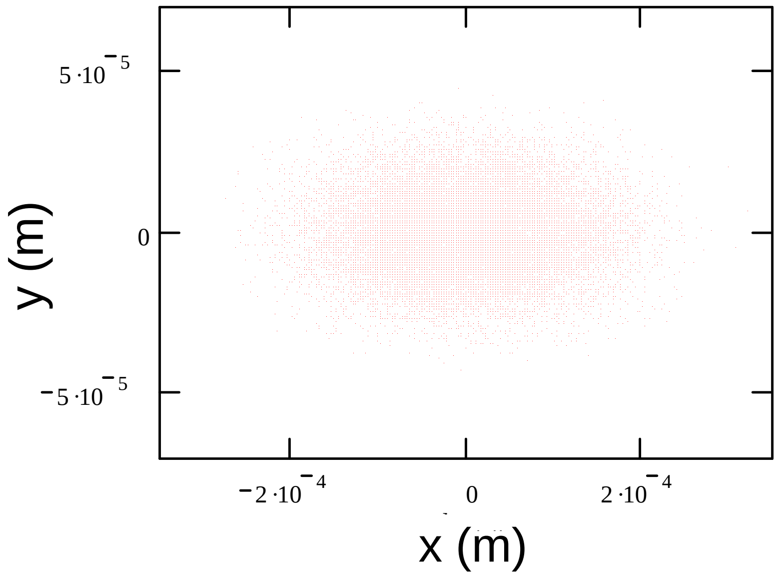


- W/ orbit correction, and
- W/ dispersion reduction, and
- W/coupling correction, and

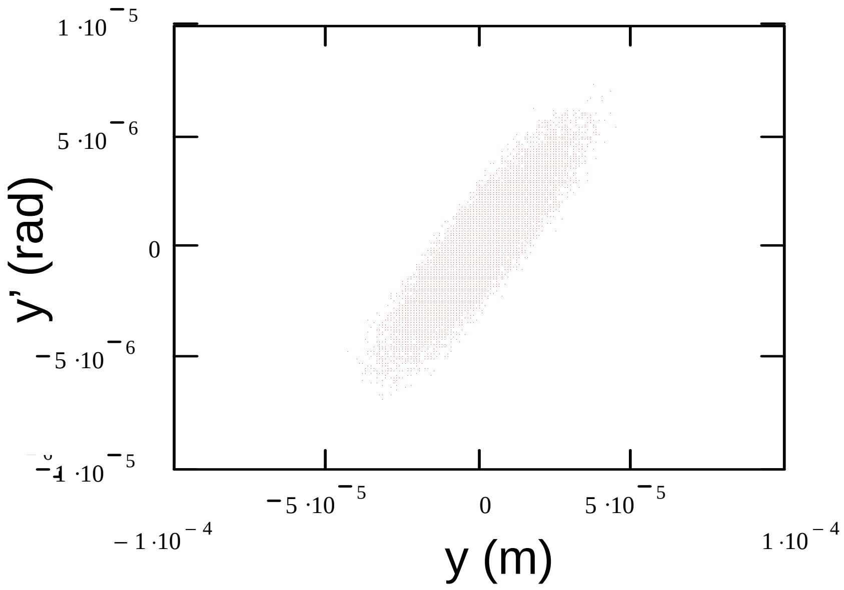
(harmonics represented as multipoles)



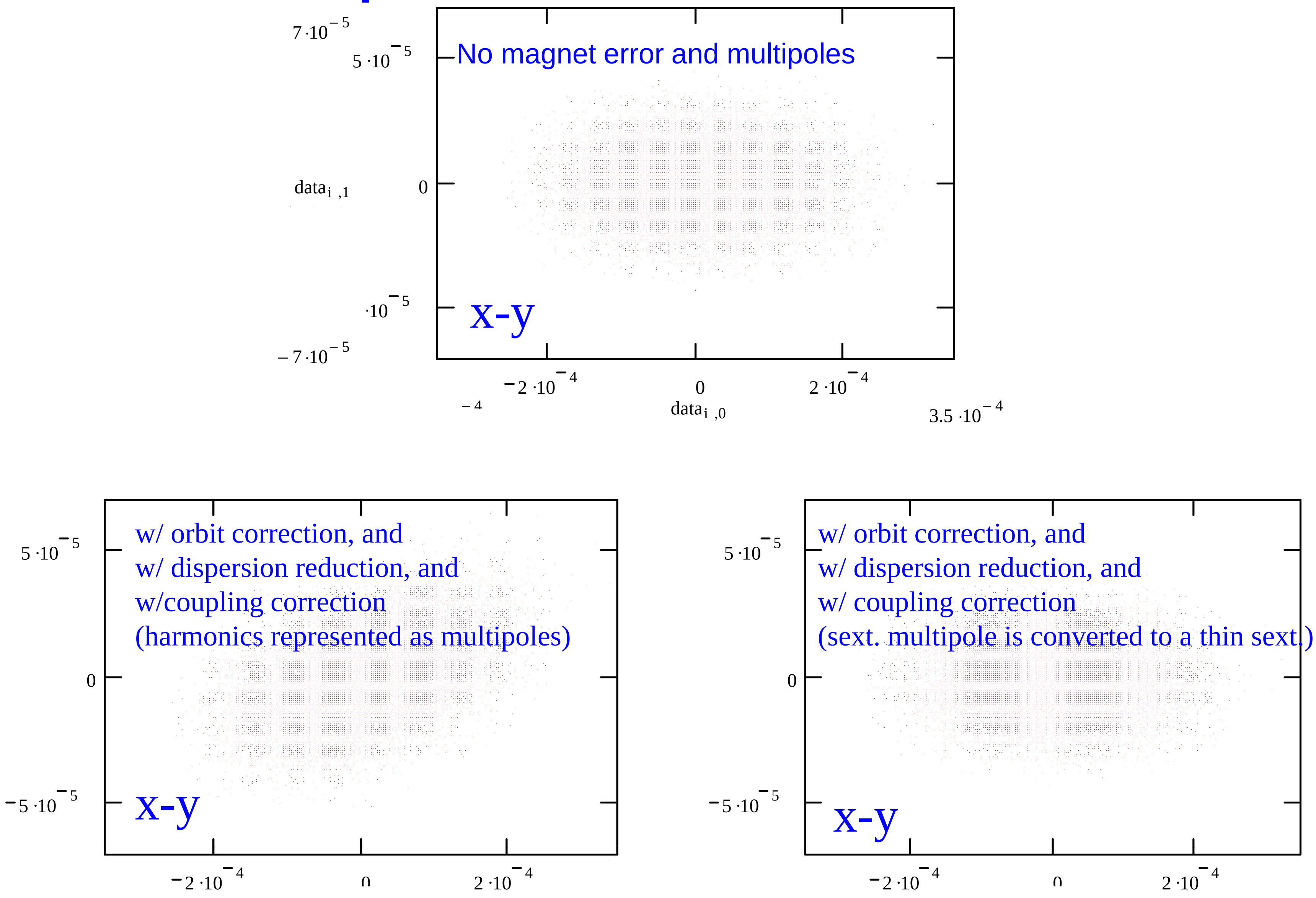
Phase space at the EXT end



W/ orbit correction, and
W/ dispersion reduction, and
W/ coupling correction
(sext. multipole is converted to a thin sext.)



Phase space X-Y at the EXT end

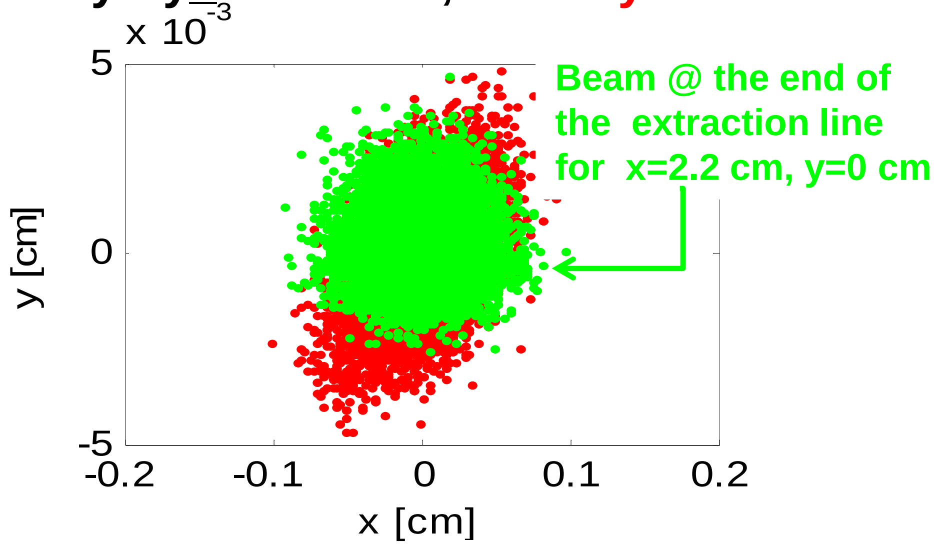


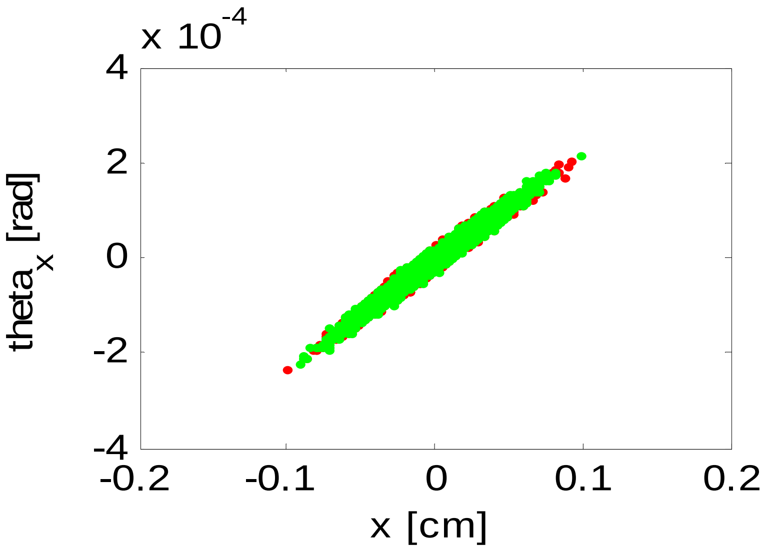
Alternative beam tracking code

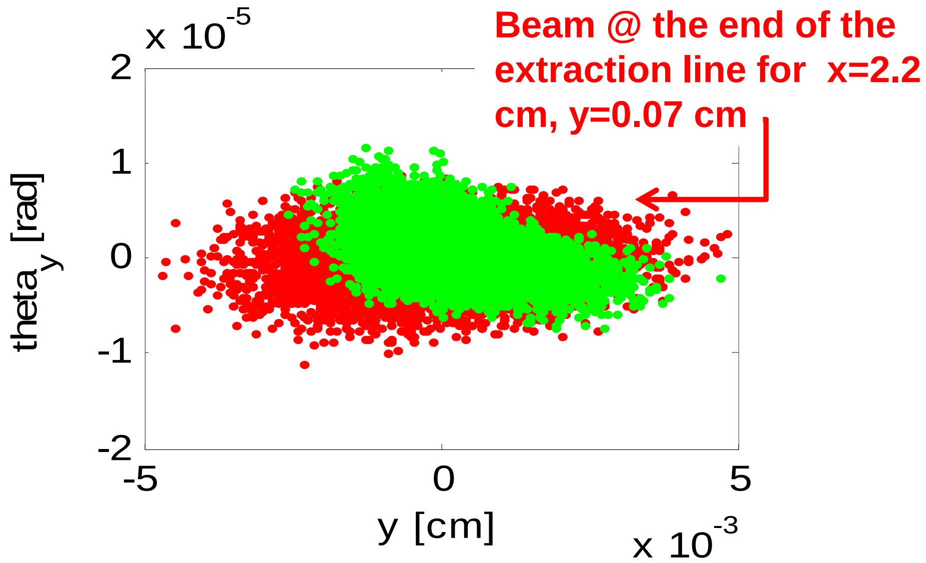
- We developed a code that allows one to do the tracking in any given field, rather than first fitting the field with multipoles and then using these multipoles in conventional tracking codes.
- This approach might be useful for 3D field tracking
- The results of our code are consistent with ELEGANT results

X=2.2 cm, y=0.07 cm

Ey/Ey_nom=1.42; w/o any correction

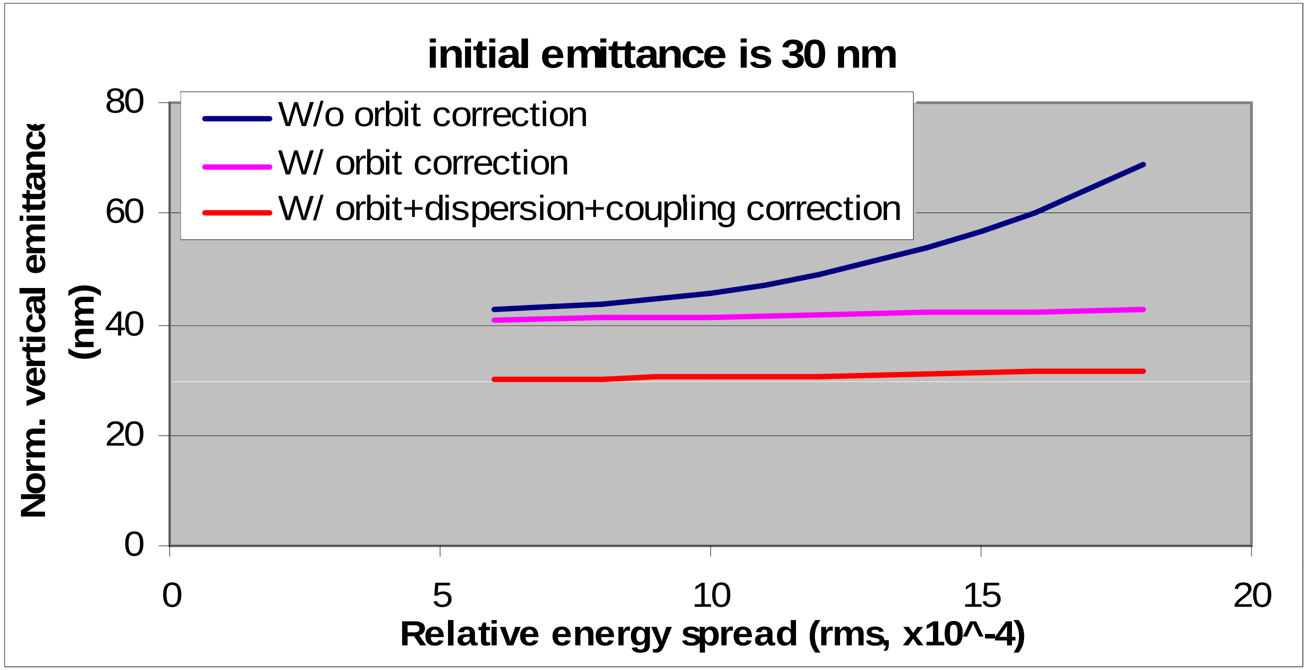






Vertical emittance vs energy spread

- Energy spread varies as bunch population changes.
- We scan the vertical emittance with the energy spread; the emittance is measured at different correction steps.
- All magnets have no errors except QM7; the extracted beam has a vertical offset of 0.8 mm, i.e., extracted beam is at (2.2cm, 0.8mm) at QM7.



Very Recent Status of ATF(Mar.2007)

1. Injection

   Strategic study by RF Gun experts

   $\rightarrow 2\times 10^{10}$/bunch in single bunch operation down to EXT

   Gun laser sometimes unstable.

   Need #10 Mod repair for multi-bunch operation

2. DR

   Routine tuning(η and coupling correction)

   $\rightarrow$emity$\approx$1e-11m(zero-current limit)

3. EXT

   Still observed emittance growth

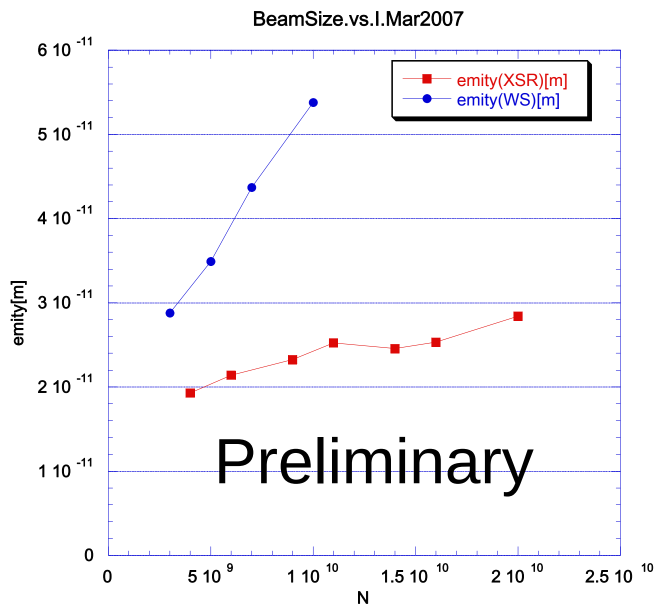
   $\rightarrow$Issue for study (So long no study since 2000)

   ε measurement usually suffers from limited strength of skew Q for η correction. No coupling correction.

Many R&Ds are on-going well.

e.g. LW, Cav.BPM, New DR BPM, FONT4, …..

S.Kuroda(KEK)



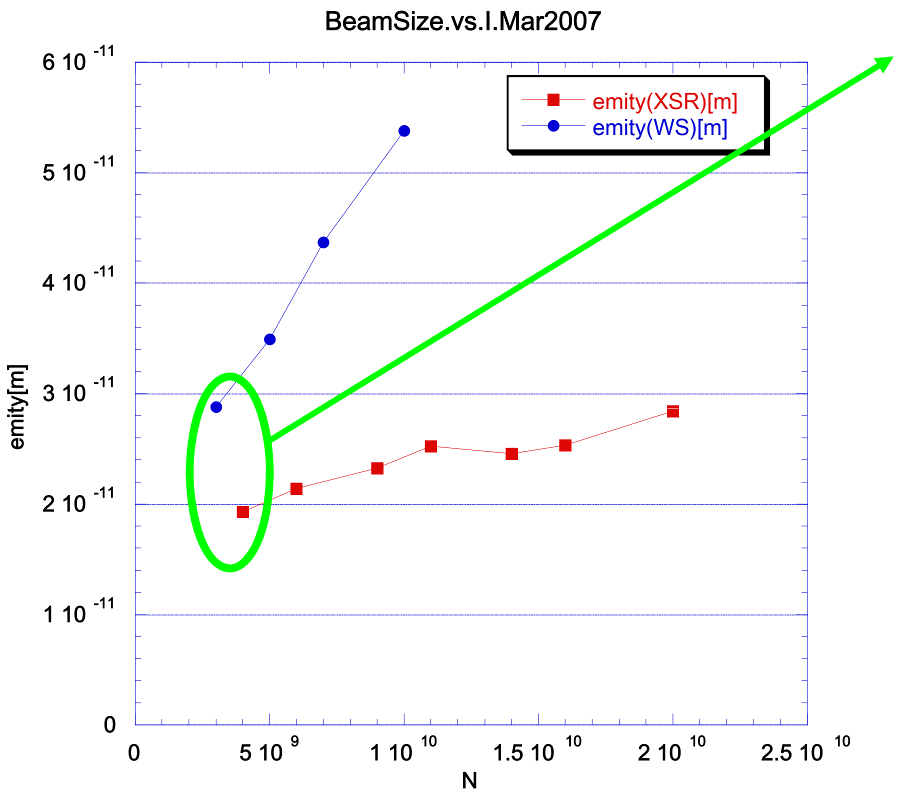
XSR meas. βx=1.69m 13Mar2007

WS meas. Δp/p=9e-4 15Mar2007

Comment on Kuroda-san's data: NOT surprise to have significant vertical emittance growth w/o coupling correction; plus, did you have good orbit corrections? If not, we really predict that the emittance significantly increases with the energy spread (or beam intensity)

Vertical emittance growth vs beam position in QM7

- Can the growth of emittance with beam current be explained by the wakefields?

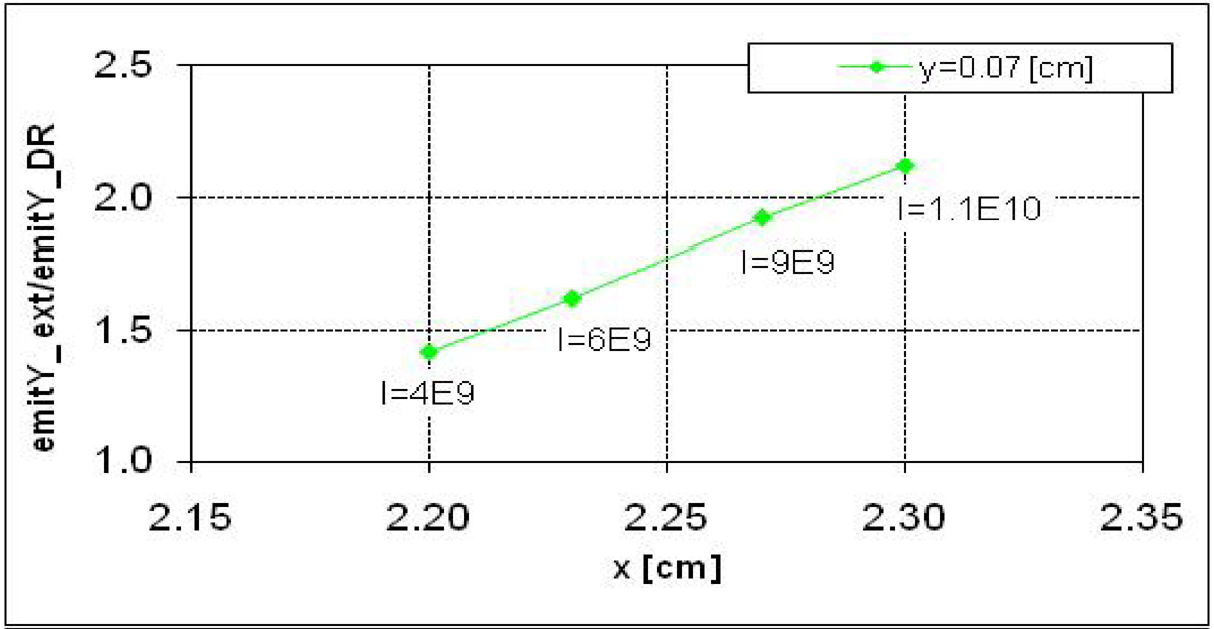


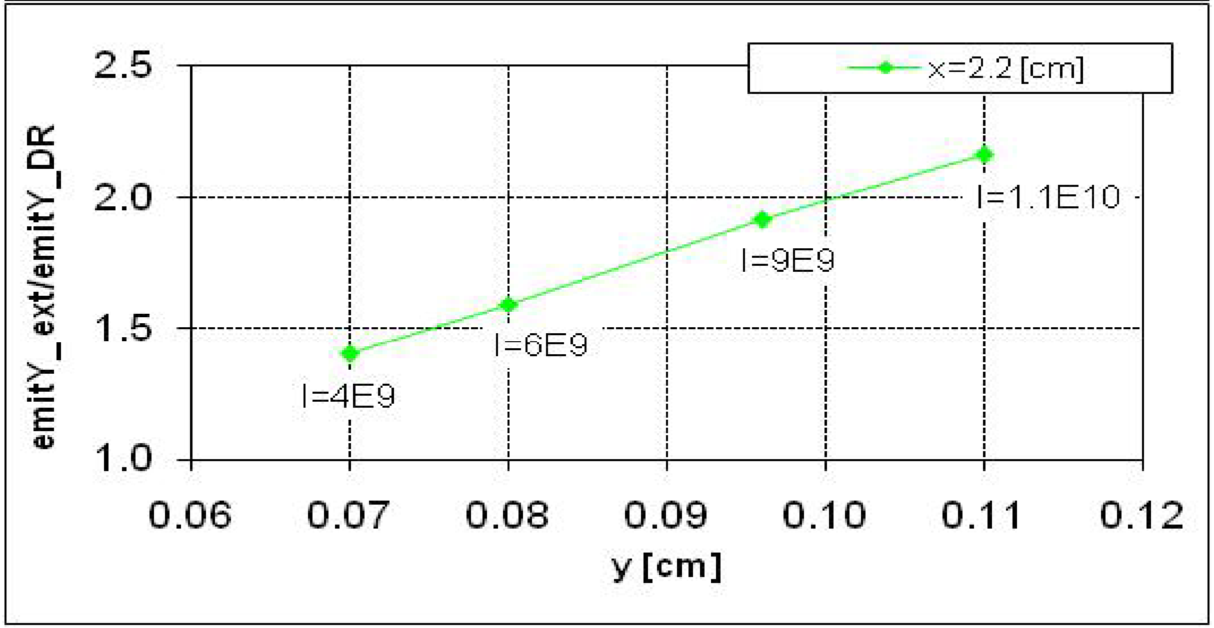
- For I=4E9 the ratio of emittances is approximately $emity_{ext}/emity_{DR} \sim 1.4$. Such ratio corresponds to beam position in QM7 x=2.2cm, y=0.07cm.
- As beam current changes wakefields move beam in x and/or y directions.
- What beam motion in QM7 can explain the emittances' ratios observed in the experiment?

next slide

Vertical emittance growth vs beam position in QM7

- Using the "alternative" beam tracking code we scanned QM7 vertically and horizontally.
- In case the beam trajectory in QM7 is (2.2, 0.07) cm for I=4E9 the growth in emittance with beam current can be explained by respective x or y beam shifts. w/o any corrections.
- Can wakefields provide 300um y shift or 1mm x shift for current change from 4E9 to 1.1E10?
- It would be extremely interesting to install trajectory correctors in front of QM7 and conduct beam scanning experiment.





Summary

- Magnets' fields modeled for the EXT beamline:
  - 2D of QM7-like
  - 2D of Septum A
  - 3D of Septum A
- No obvious emittance growth is observed from the preliminary tracking with the applied QM7 multipoles after *perfect coupling correction*.
- W/o orbit correction vertical emittance significantly increases with energy spread (or beam current).
- Not surprise to observe significant vertical emittance growth w/o coupling correction.