Quadrupole Tune Identification by Pattern Matching

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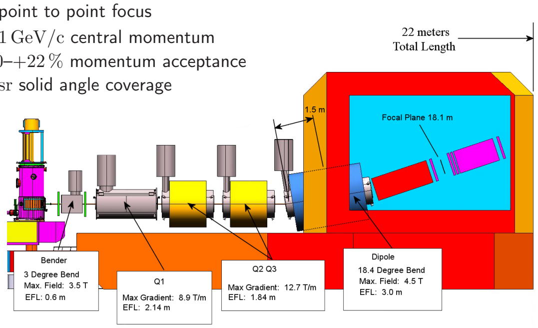
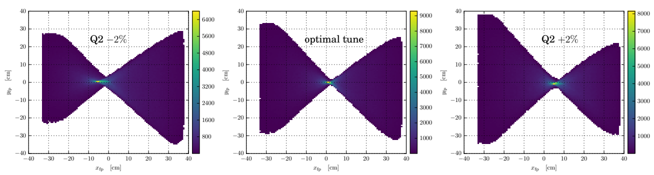
Super High Momentum Spectrometer

- new spectrometer for JLab's Hall C
- optics defined by five magnets:
  - $3°$ horizontal bender, three quadrupoles and $18.4°$ vertical bender
  - Q1 and Q3 have vertical focusing and Q2 horizontal
  - point to point focus
- 2–$11\,\mathrm{GeV/c}$ central momentum
- -10–$+22\,\%$ momentum acceptance
- $4\,\mathrm{msr}$ solid angle coverage

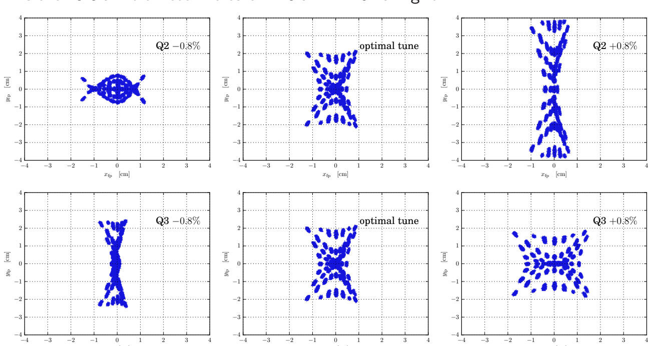


Establishing Optimal Tune

- need to establish optimal tune for quadrupoles during commissioning
- look at changes of patterns in focal plane when changing magnet's strength
- four focal plane variables
  - locations in dispersive and non-dispersive directions: x_{fp} and y_{fp}
  - corresponding angles: x'_{fp} and y'_{fp}
- coarse tuning done with $^{12}\mathrm{C}$ quasi-elastic scattering and "hourglass" patterns

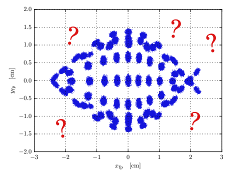


- fine tuning done with $^{12}\mathrm{C}$ elastic scattering and inner sieve
- sieve: $0.6\,\mathrm{cm}$ diameter holes on $2.5\,\mathrm{cm} \times 1.64\,\mathrm{cm}$ grid



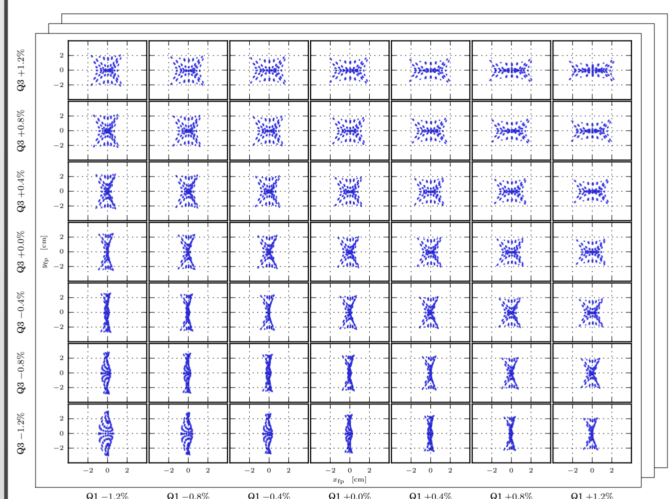
Problem?

- in reality each of three quadrupoles can be offset from optimal tune
- remember, have "inverse" problem
  - need to figure out which tune produced observed patterns
  - not how the pattern for a given tune would look like
- need to disetangle effect of each magnet
- quadrupoles have similar effects on patterns, especially Q1 and Q3

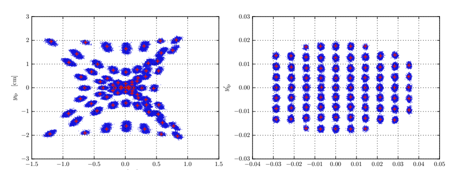


Database Generation

- ran simulation for different settings of quadrupoled
- created a 3D lookup table table of focal plane patterns



- selected ray of events corresponding to each sieve hole using y'_{fp} vs x'_{fp} plot
- determined a centroid for these rays in focal plane variables
- stored these points in a database for later comparison



Pattern Matching

- have an unknown tune
- fit the pattern as described in Database generation bubble
- calculate distance to each of the tunes in the grid by

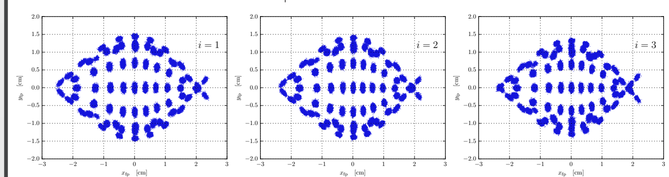
$$d = \sum_{\text{holes}} \left[\frac{(x_{\mathrm{fp}} - \tilde{x}_{\mathrm{fp}})^2}{l_x^2} + \frac{(y_{\mathrm{fp}} - \tilde{y}_{\mathrm{fp}})^2}{l_y^2} + \frac{(x'_{\mathrm{fp}} - \tilde{x}'_{\mathrm{fp}})^2}{l_{x'}^2} + \frac{(y'_{\mathrm{fp}} - \tilde{y}'_{\mathrm{fp}})^2}{l_{y'}^2} \right]$$

- l_i are typical sizes to normalize contribution of each coordinate
- compare patterns of tunes with smallest distances to unknown tune

Results

- ideally, the closest grid tune would have the smallest distance to unknown tune
- results for "unknown" tune: Q1 $+0.84\%$ Q2 -0.78% Q3 $+1.10\%$

i	d	Q1 [%]	Q2 [%]	Q3 [%]
1	0.01216	0.8	-0.8	1.2
2	0.01364	1.2	-0.8	0.8
3	0.01419	0.4	-0.8	1.2
4	0.06437	0.8	-0.8	0.8
5	0.10286	1.2	-0.8	1.2



- unfortunately, closest tune does not always have smallest distance
- usually the Q2 matching is very accurate
- can have difficulties matching Q1 and Q3
- however, a good match is achieved by "averaging"
- after averaging first three results: Q1 $+0.80\%$ Q2 -0.80% Q3 $+1.10\%$

Possible Improvements

- try interpolating grid?
- try fitting pattern dependence on quadrupole changes?
- use neural networks?

Conclusion

- characterizing unknown tunes by eye is tedious when all quadrupoles are offset
- the automatic pattern recognition works reasonably well
- produces good first guess of where to look
- sometimes has problems with characterizing Q1 and Q3
- averaging helps produce better results
- accuracy limited by grid spacing