Hybrid FFA Synchrotron

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Scaling FFA field

- Scaling FFA field goes as

$$B_z(r,\theta) = B_{z0}\left(\frac{r}{r_0}\right)^k F(\varphi)$$

k controls the focusing strength

Azimuthal dependence

Radial dependence

- k is fixed by the lattice requirements
- Strong focusing achieved by flipping the field
  - Require $B_z \rightarrow -B_z$

Introduction (2)

- Horizontal scaling FFA is uniquely defined by 3 parameters and one function
  - Field index k
  - Radius r_0
  - Spiral Angle
  - $B_0(\phi)$

} Fixed by construction (Field index k, Radius r_0, Spiral Angle)

} Can vary DF ratio (but that's all) ($B_0(\phi)$)

- To make an FFA
  - Build a magnet
  - Shim
  - Pray
- This is a problem at high intensity
  - Would like to choose working point
  - E.g. would like to explore tune working point
  - → Invent a magnet having variable *k*

Introduction (3)

- Horizontal FFAs are over-constrained
  - i.e. not enough free parameters
- E.g. magnet aperture **AND** tune are determined by *k*
  - If we want a small horizontal aperture we have to vary *k* → messes up the tune
- Consequences:
  - We end up with magnets needing huge horizontal aperture
  - We end up with an orbit that moves across the aperture
    - Equipment needs massive aperture – sometimes not possible
  - We end up with half of our magnets bending the beam *in the wrong direction!!*
    - 1 for the price of 3

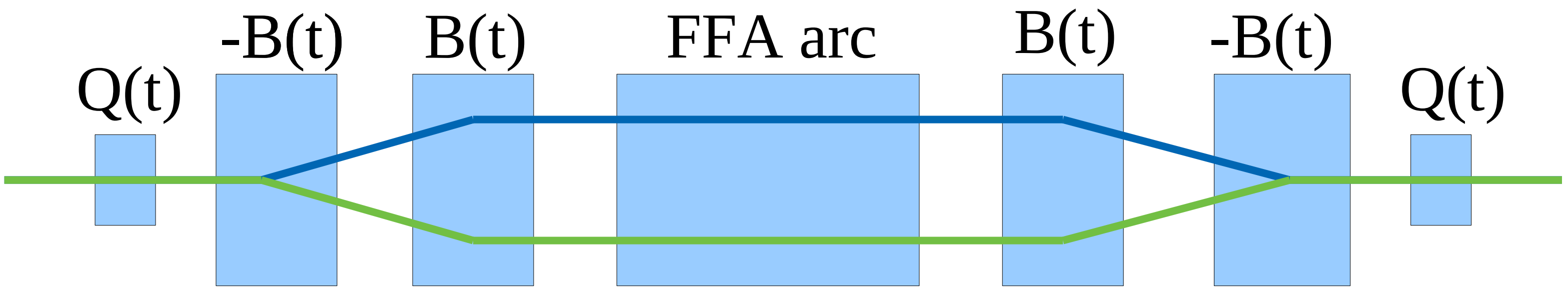
Example: injection

- Example
  - For high intensity protons, we would like to choose the working point
  - Need 2 parameters to choose horizontal and vertical tune
    - *k*
    - *DF ratio*
  - *If* we can vary k, then we move the injection point
    - Need to have extremely wide aperture kickers

Why FFAs?

- Advantage of FFAs
  - No ramping magnets → power hungry, expensive
  - Transverse hardware is largely independent of RF
    - No need to set RF according to magnet cycle
    - Longitudinal gymnastics is possible e.g. adiabatic capture, stacking
- Can we borrow from synchrotrons?
- Time-dependent insertion
  - Pulsed dipoles to suppress dispersion
  - Pulsed quadrupoles to adjust tune
  - Injection, RF and other hardware
- Bending done in time-independent fixed field magnets
  - Scale correctly with momentum
- Hybrid FFA-synchrotron = **Ffynchrotron**

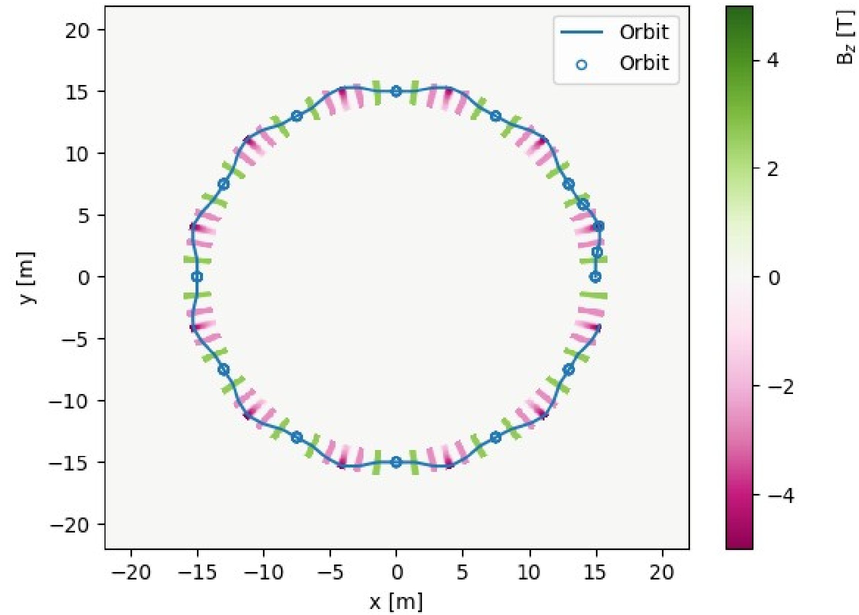
Schematic

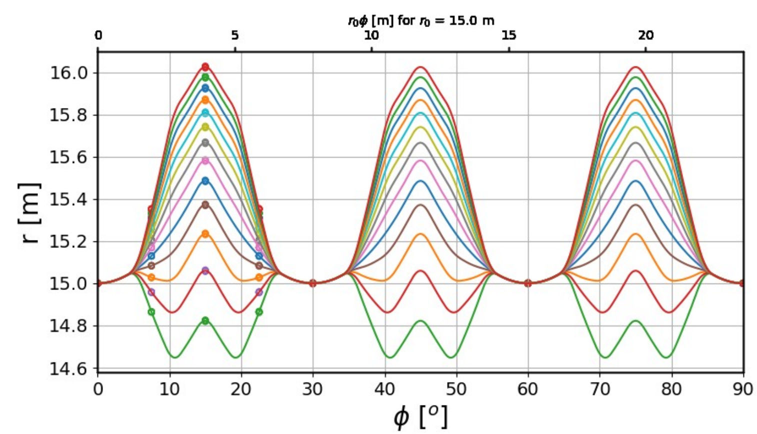


- Schematic
  - Q: pulsed quadrupoles (and other hardware)
    - Q(t) scaled with momentum to adjust working point
  - B: pulsed dipole
    - Choose B(t) to bring orbit into FFA arc
    - (Check: what happens to Dispersion?)
  - FFA arc: scaling FFA arc

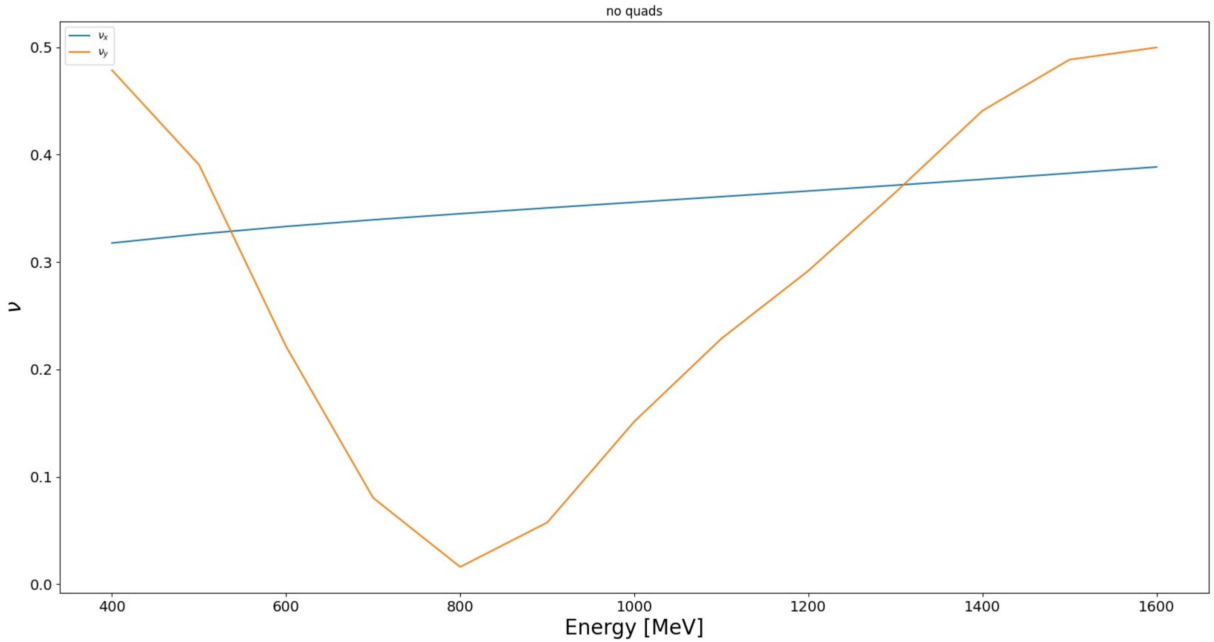
Layout

- First pass
  - Weak focusing
  - F magnet only
  - Pulsed dipoles cancel the momentum spread in straight sections



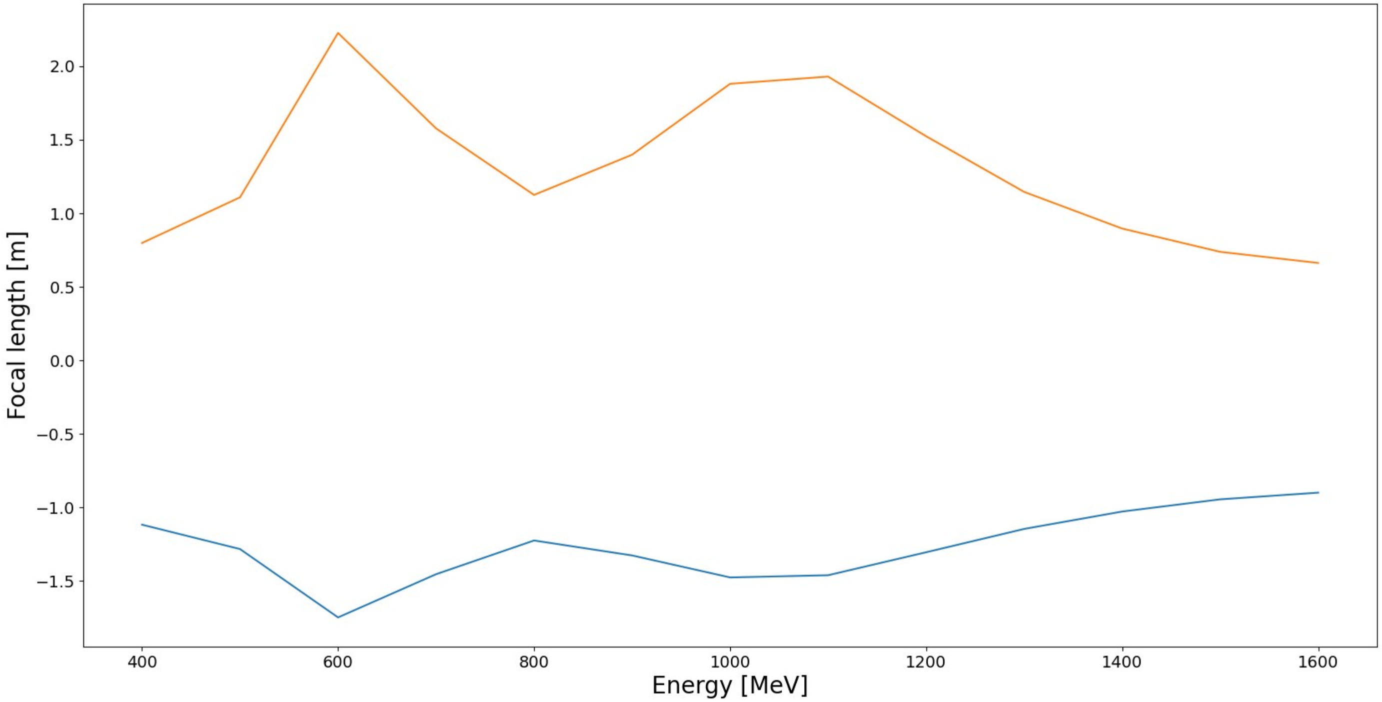


Tune



- Horizontal tune excursion is quite limited
- Vertical tune excursion is rather large

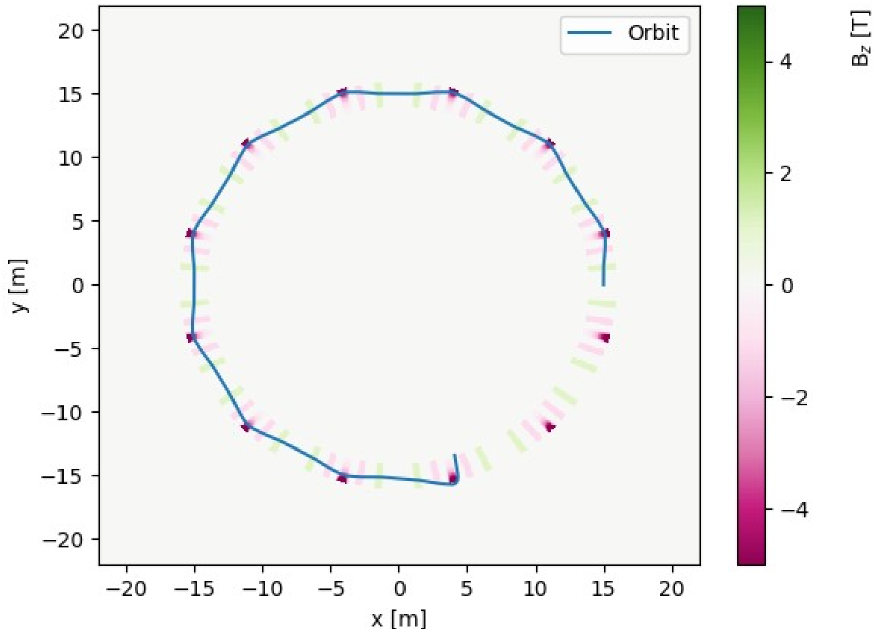
Constant Tunes

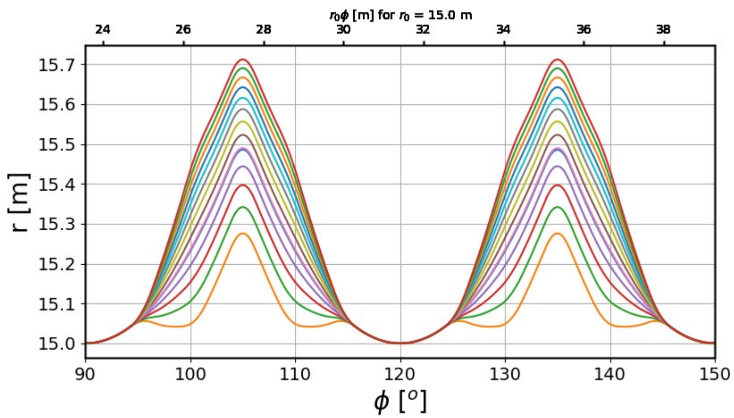


- We can solve for Q analytically to give constant tunes
  - Assume thin lens approximation
  - Plot focal length of the lens.

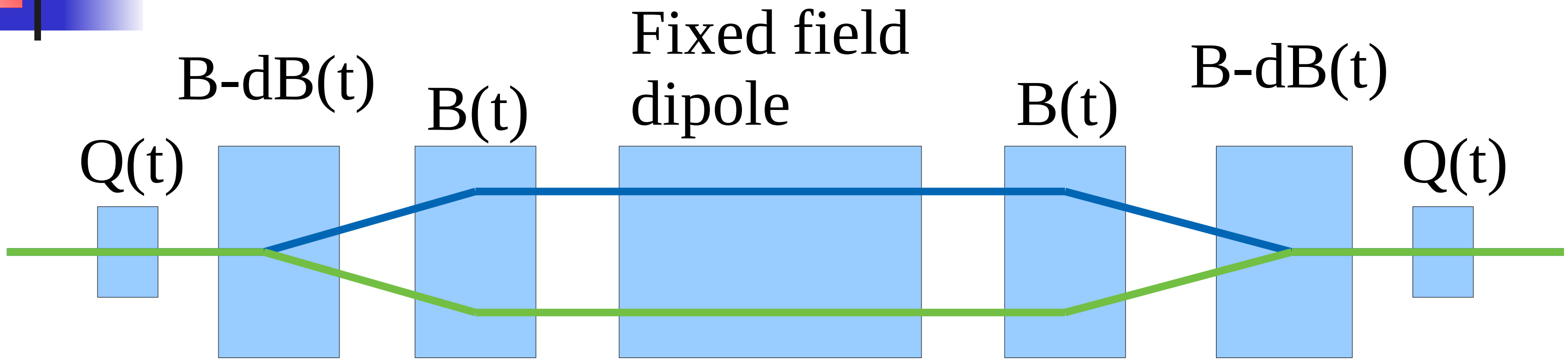
Higher k

- Can use a higher k-value
  - We can correct tune in the quads
  - Tune independent of e.g. closed orbit





Application to muon collider



- Muon collider acceleration is similar to this concept
  - But use dipoles (FFA with k = 0!)
- Pulsed dipoles are big challenge
  - Pulse length needs to be very short to fight muon decay
  - Powering is tricky
    - Stored energy, eddy currents etc
    - Synchronisation with RF
- FFAs are disfavoured due to
  - reverse bends
  - Beam moving across RF/etc
- Plan: apply the concept to MuC lattice

Conclusions

- FFAs are overconstrained
  - Many efforts in recent years dedicated to breaking the scaling law, while maintaining constant tune
- Can use pulsed magnets to unconstrain the lattice
  - Hopefully pulsed dipoles become not so demanding
  - Pulsed quadrupoles can be used for tuning/optimisation
- Hybrid FFA-synchrotron
  - **Ffynchrotron**
- Can make
  - e.g. injection easier in proton Ffynchrotron
  - e.g. relax constraints on dipoles in muon Ffynchrotron