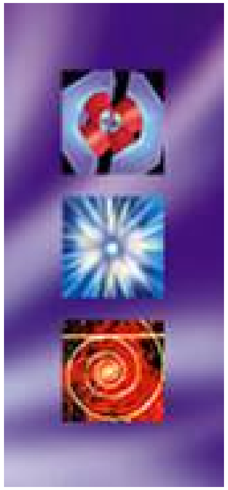
Crab cavity system design

Snowmass

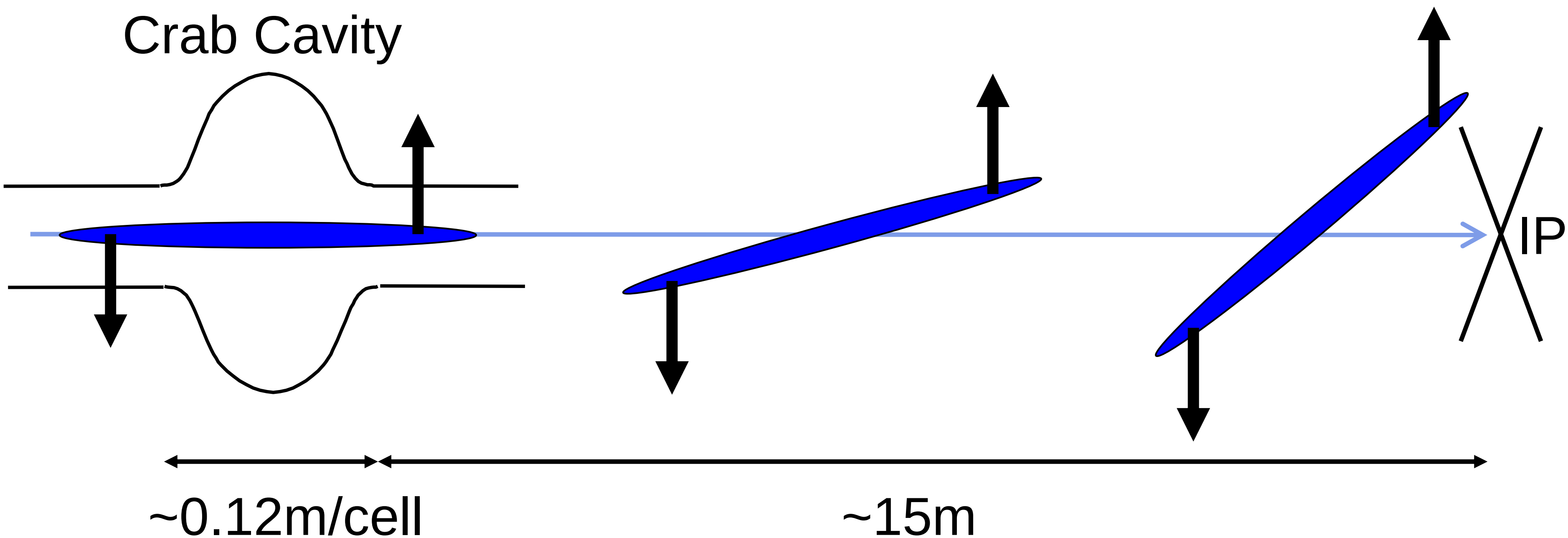
19/08/2005



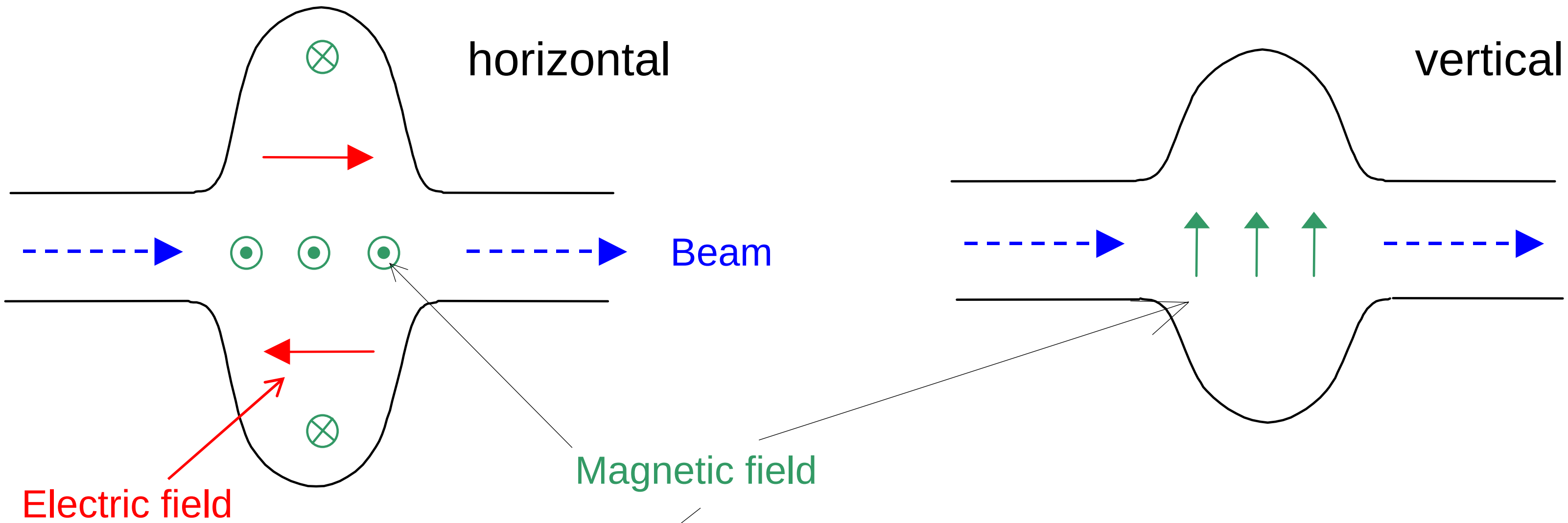
Graeme Burt – Lancaster University
Philippe Goudket – ASTeC

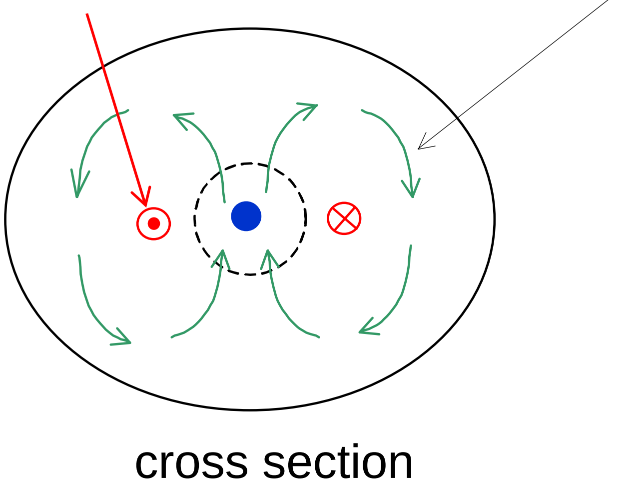
What is a crab cavity?

- A crab cavity imparts a transverse momentum to the bunch.
- The bunch continues to rotate outside the cavity.



Why is a crab cavity different from an accelerating cavity?

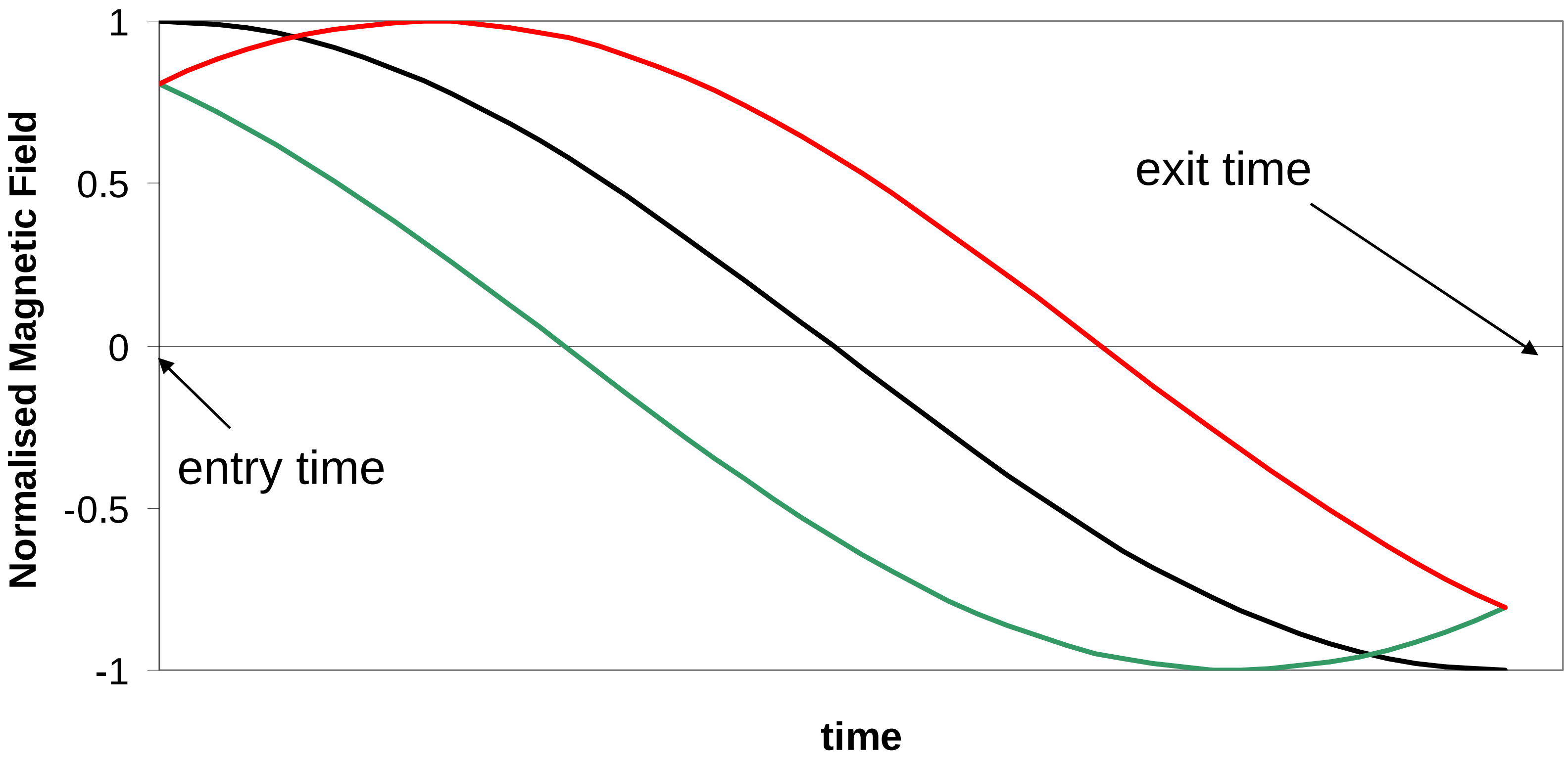




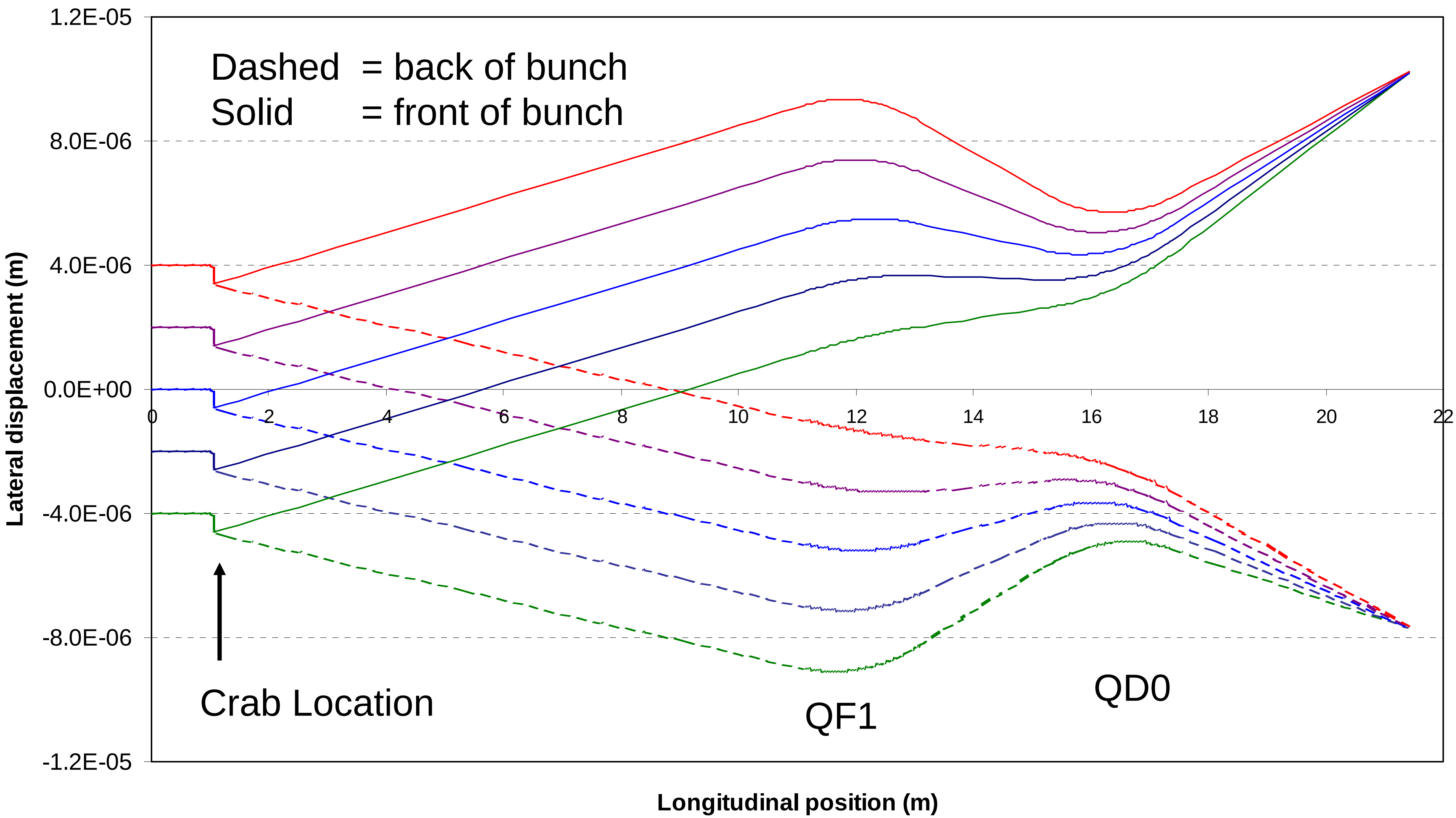
- Use of the magnetic field of a TM_{110} horizontal dipole mode
- The field gives a phase-dependant transverse momentum kick to the beam

Why is a crab cavity different from an accelerating cavity?

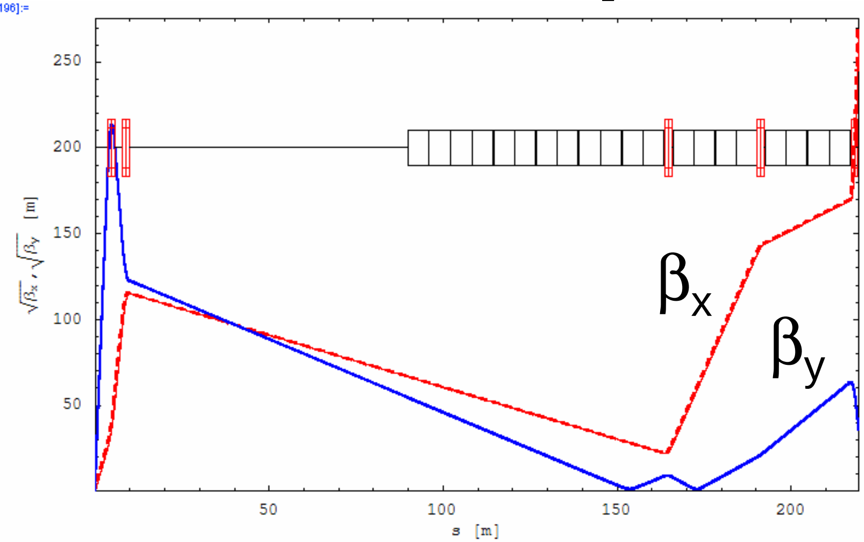
- Magnetic Field as seen by front, middle, and back of the bunch as a function of position across the cavity.
- *(At any instant the magnetic field is uniform across the cavity)*

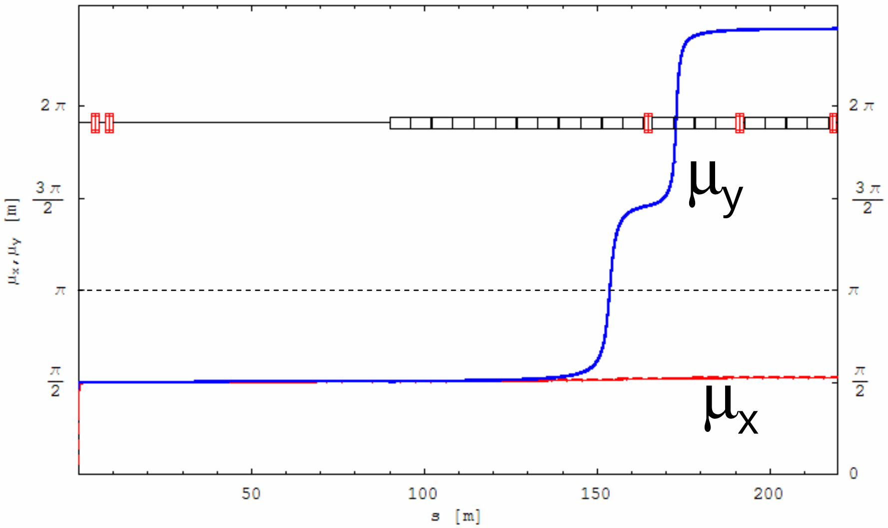


Beam dynamics - Action of Quadrupoles



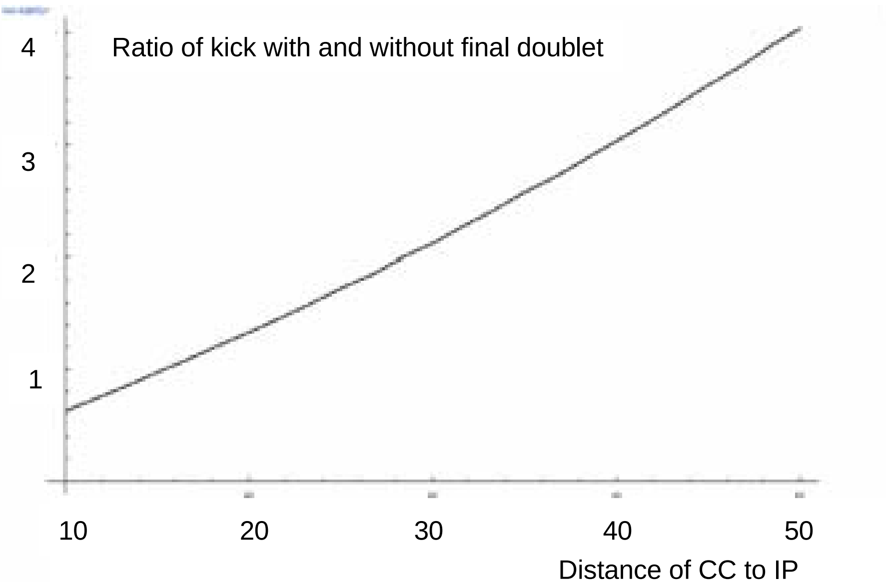
Location of the crab cavity





The displacement of particles at the IP due to the influence of the crab cavity is a function of β_x at the crab cavity location.

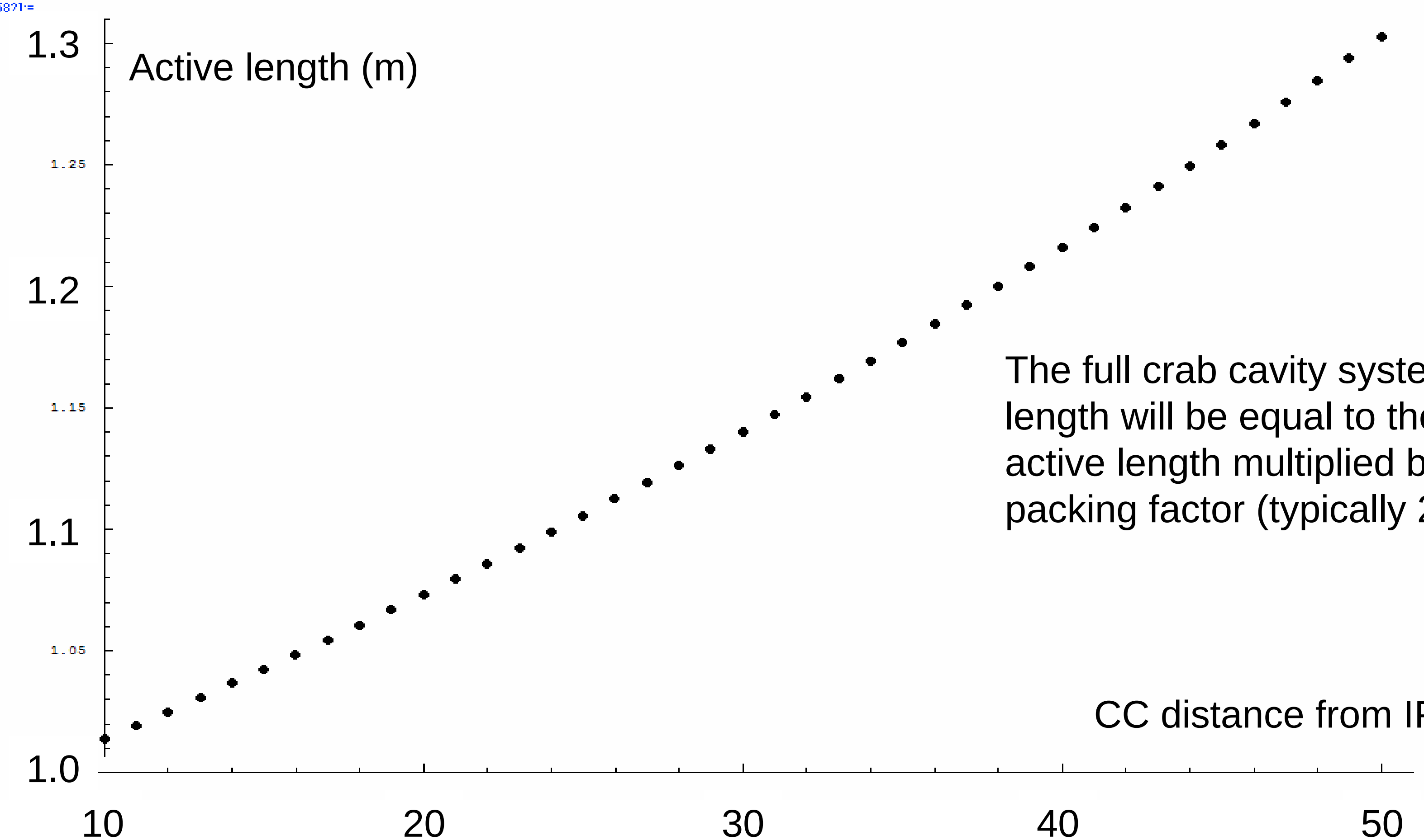
$$x_{IP} = 0.021x' \frac{\sqrt{\beta_x(CC)}}{\sqrt{\beta_x(IP)}}$$



G. Burt, P. Goudket

Location of the crab cavity (effect on space required)

Active length required to achieve 10mrad bunch rotation for 1TeV CM assuming 6MV/m transverse deflecting voltage at 3.9GHz



The full crab cavity system length will be equal to the active length multiplied by a packing factor (typically 2-4)

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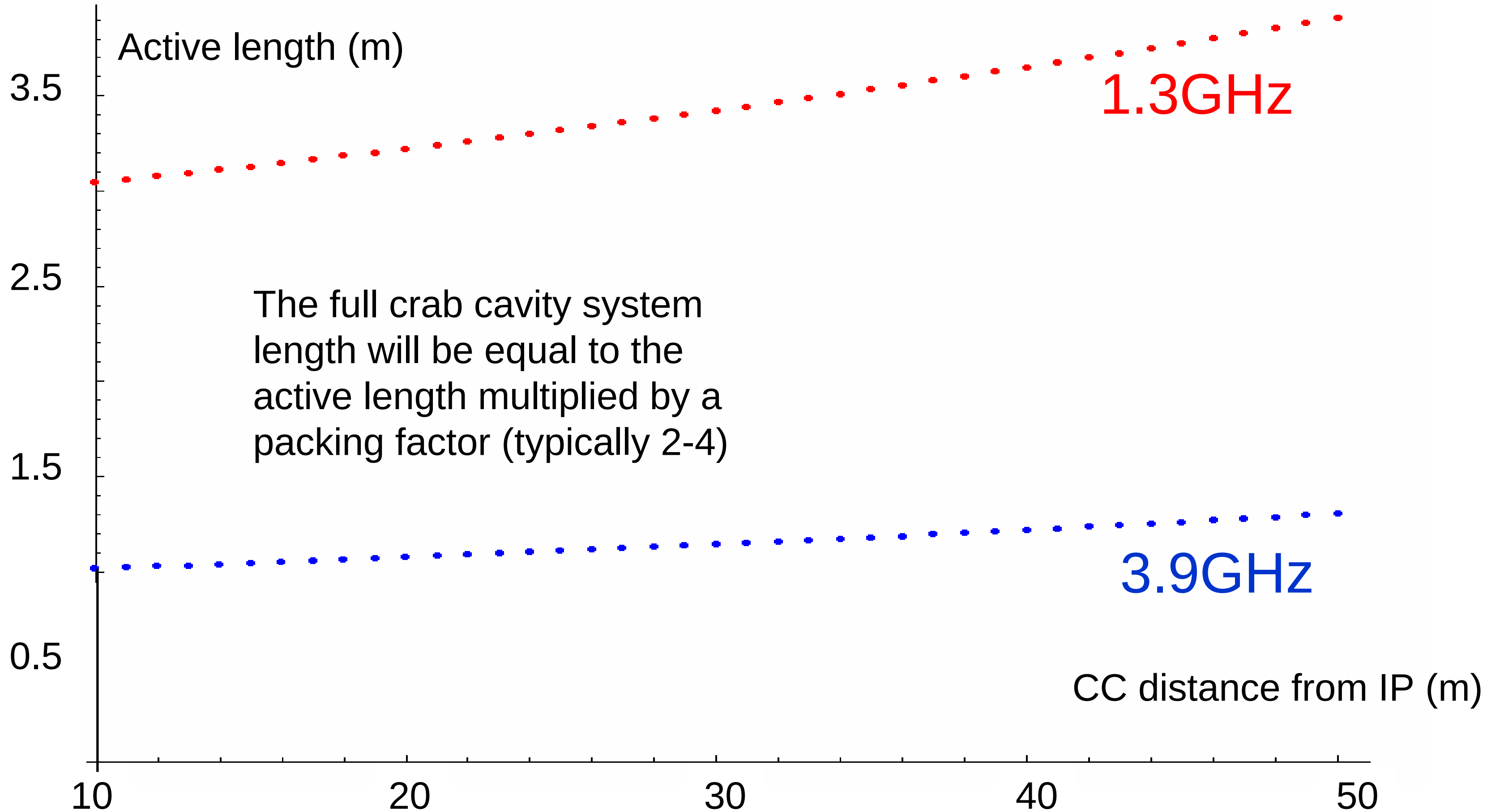
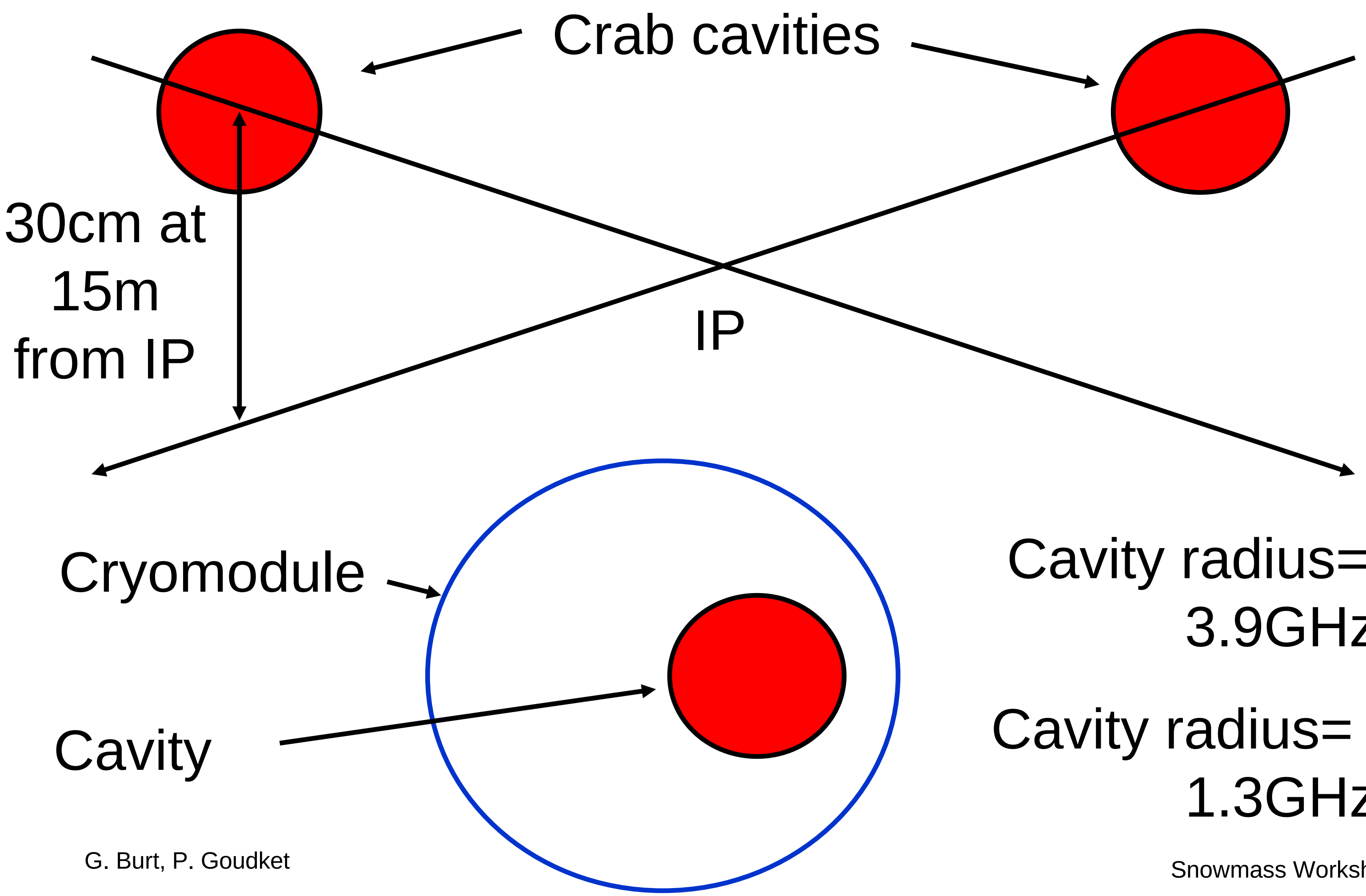
Location of the crab cavity (effect on space required)

Active length required to achieve 10mrad bunch rotation for 1TeV CM assuming 6MV/m transverse deflecting voltage



Transverse size



Cavity radius= 5cm at 3.9GHz

Cavity radius= 15cm at 1.3GHz

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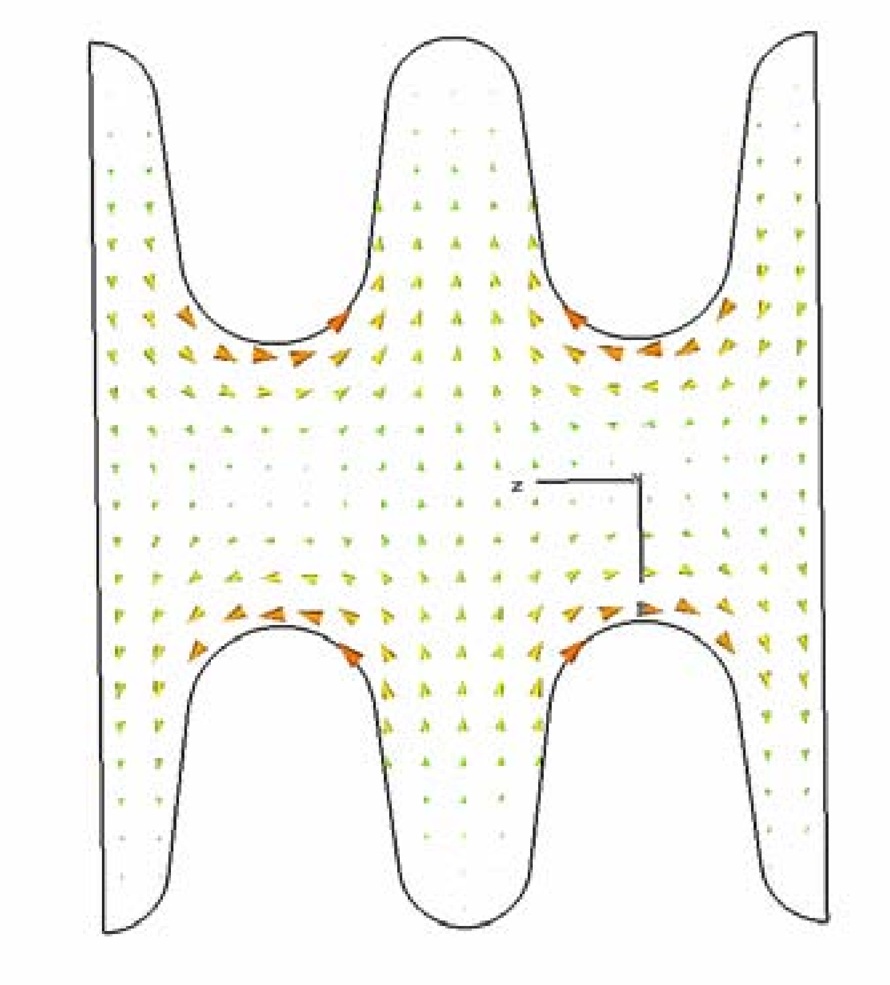
Fermilab cavity, improvements and 1.3GHz cavity

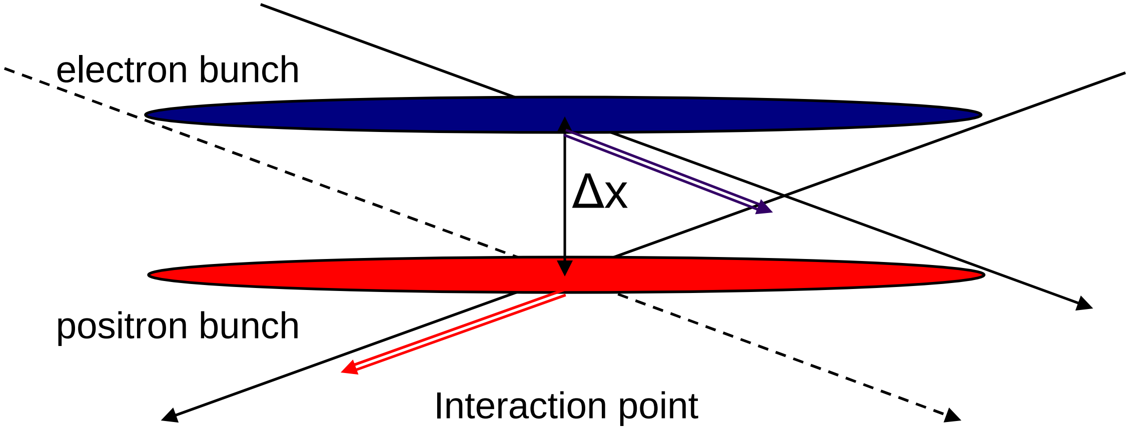
- Current deflecting cavity exists at Fermilab, 13 cells per cavity, 6MV/m at 3.9GHz
- We are working on a cavity which can reach 8MV/m for the same surface magnetic field, with fewer cells per cavity.
- Higher gradients can be achieved at 1.3GHz, however cavity size is an issue.



Phase Jitter

Crabbed crossing angle with phase jitter

Effective head-on collision



$$\Delta x \propto \frac{\theta_r \sin(\Delta\varphi)}{\omega}$$

	Phase error (degrees)	
Crossing angle	*1.3GHz*	*3.9GHz*
2mrad	0.222	0.665
10mrad	0.044	0.133
20mrad	0.022	0.066

Phase control

- Tolerance for a 20mrad crossing angle with 1.3GHz cavities
  - 3% voltage stability ✓
  - ~2 degrees absolute phase error ✓
  - 0.022 degrees phase jitter !

Possible solution:

Fast FPGA-based control systems with sufficient phase stability for the crab cavity system are being developed.

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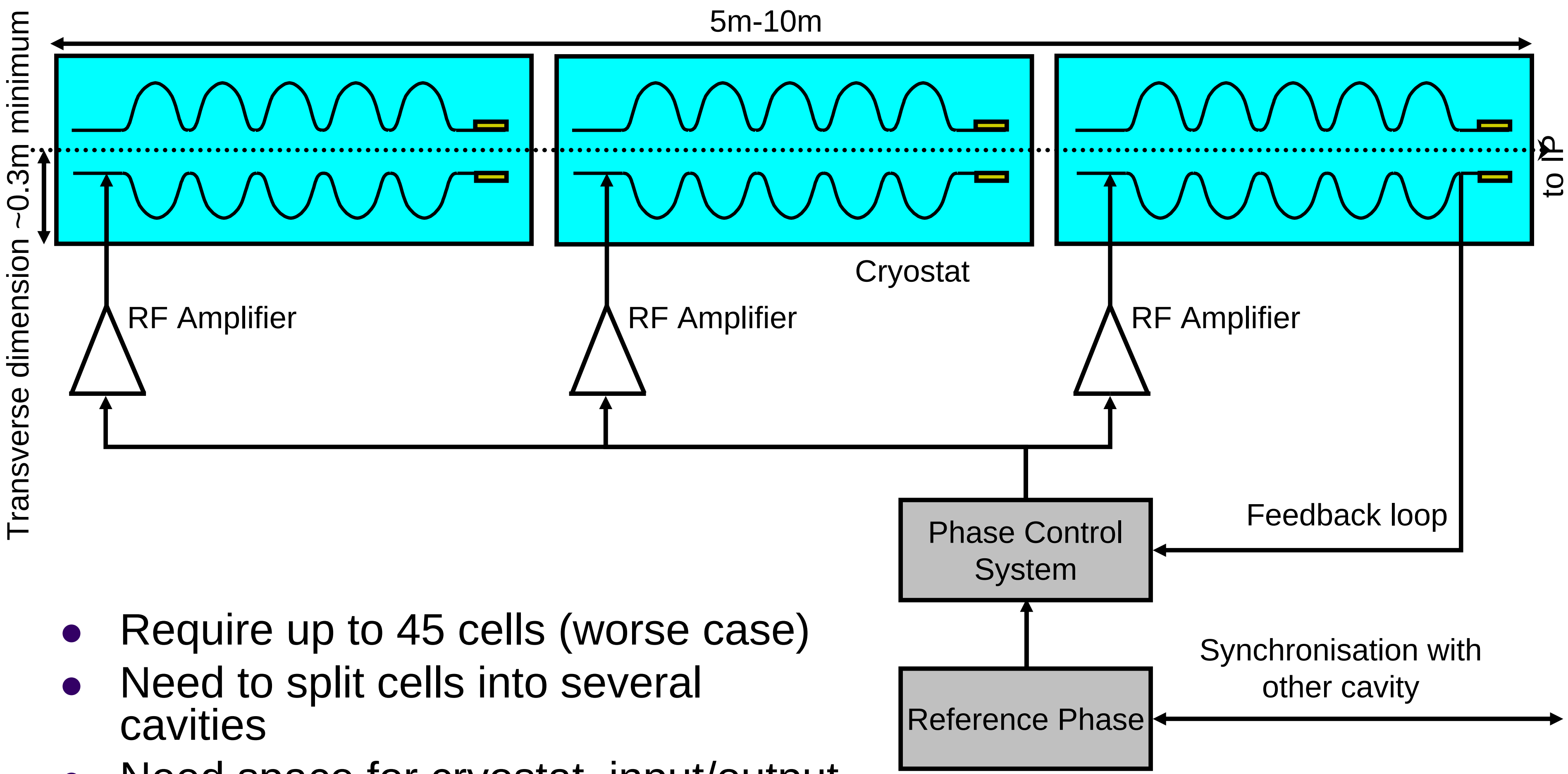
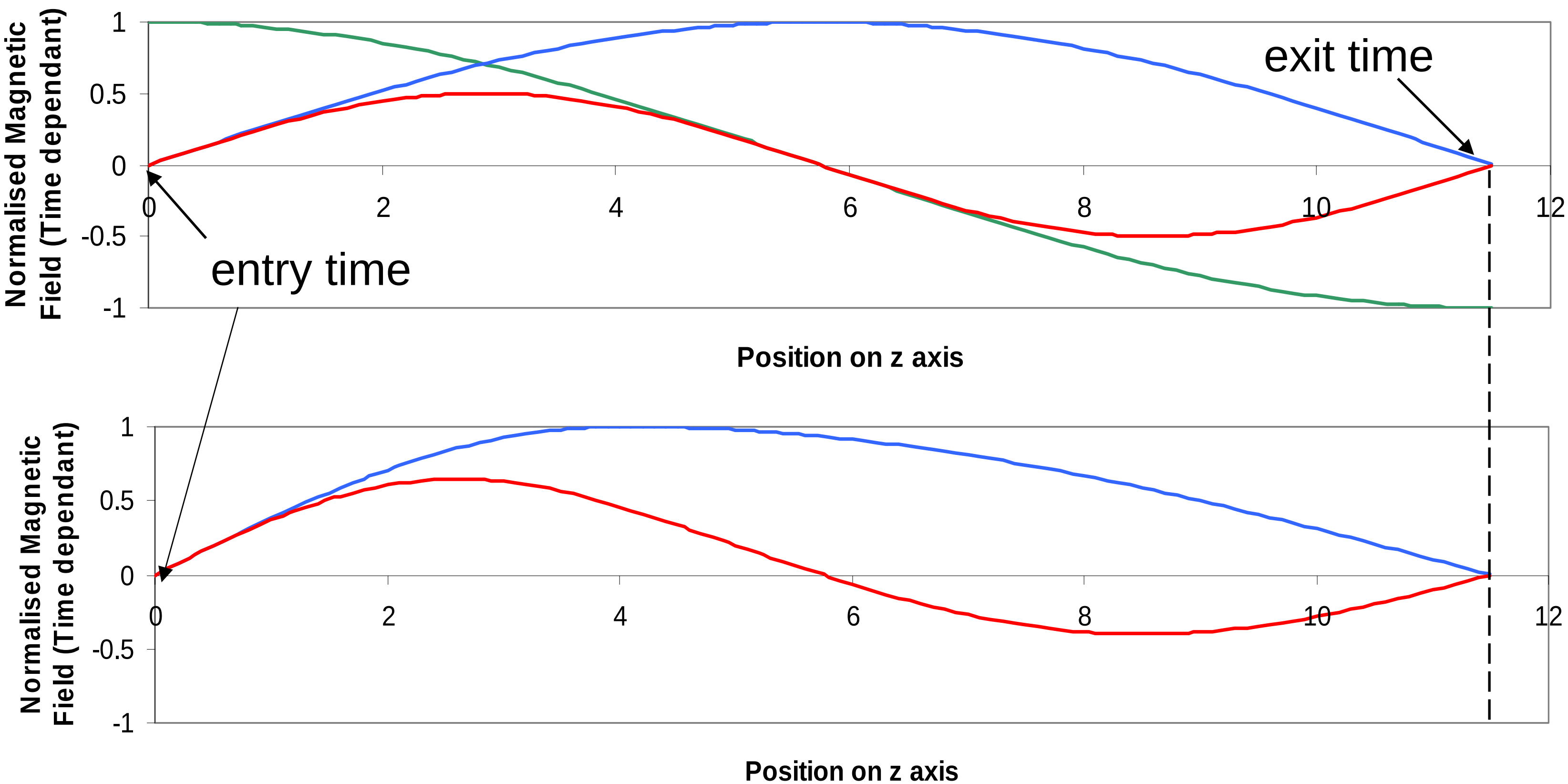
What might a Superconducting crab cavity system look like?



- Require up to 45 cells (worse case)
- Need to split cells into several cavities
- Need space for cryostat, input/output couplers, tuning mechanisms…

Cavity asymmetry / microphonics

- Magnetic field as seen by the middle of the bunch as a function of position across a cavity cell.



Order of modes in an elliptical cavity

TM010
accelerating mode

Need to extract the fundamental mode

Higher order modes

TM110v/TE111v

TM011

frequency

TE111h

TM110h
crabbing mode

Extraction of the lower order mode and the higher order modes is essential to minimise disruption of the beam.

v-vertical
h-horizontal

Frequency Choice, 3.9GHz

Pros

- Size of cavity is inversely proportional to frequency.
- The phase tolerance is relaxed for higher frequencies.

Cons

- At 1.3GHz an IOT could be used which is ~10 times more phase stable than a klystron.
- Wakefield voltages are proportional to frequency.
- Higher gradients can be achieved at 1.3GHz.

More research is needed

Conclusions

- The cavity should be placed as close as possible to the final doublet in order to minimise the required kick.
- Cavity space required will be between 2 metres and 13 metres (not necessarily contiguous).
- 3.9GHz is the most likely frequency choice for the cavities, however 1.3GHz may be the only workable solution depending on wakefields and the phase stability of the rf system.