Status of HEMC Scenario

Including Cooling Losses and "efficiency"

R. B. Palmer (BNL) JLAB December 08

- Introduction to complete cooling system
- Defining 'Efficiency' Q
- Estimated transmissions, using Q, for old lattices

- Breakdown problem in fields
- Use of bucking coils to remove field at rf
  – Use on final 805 MHz Guggenheim

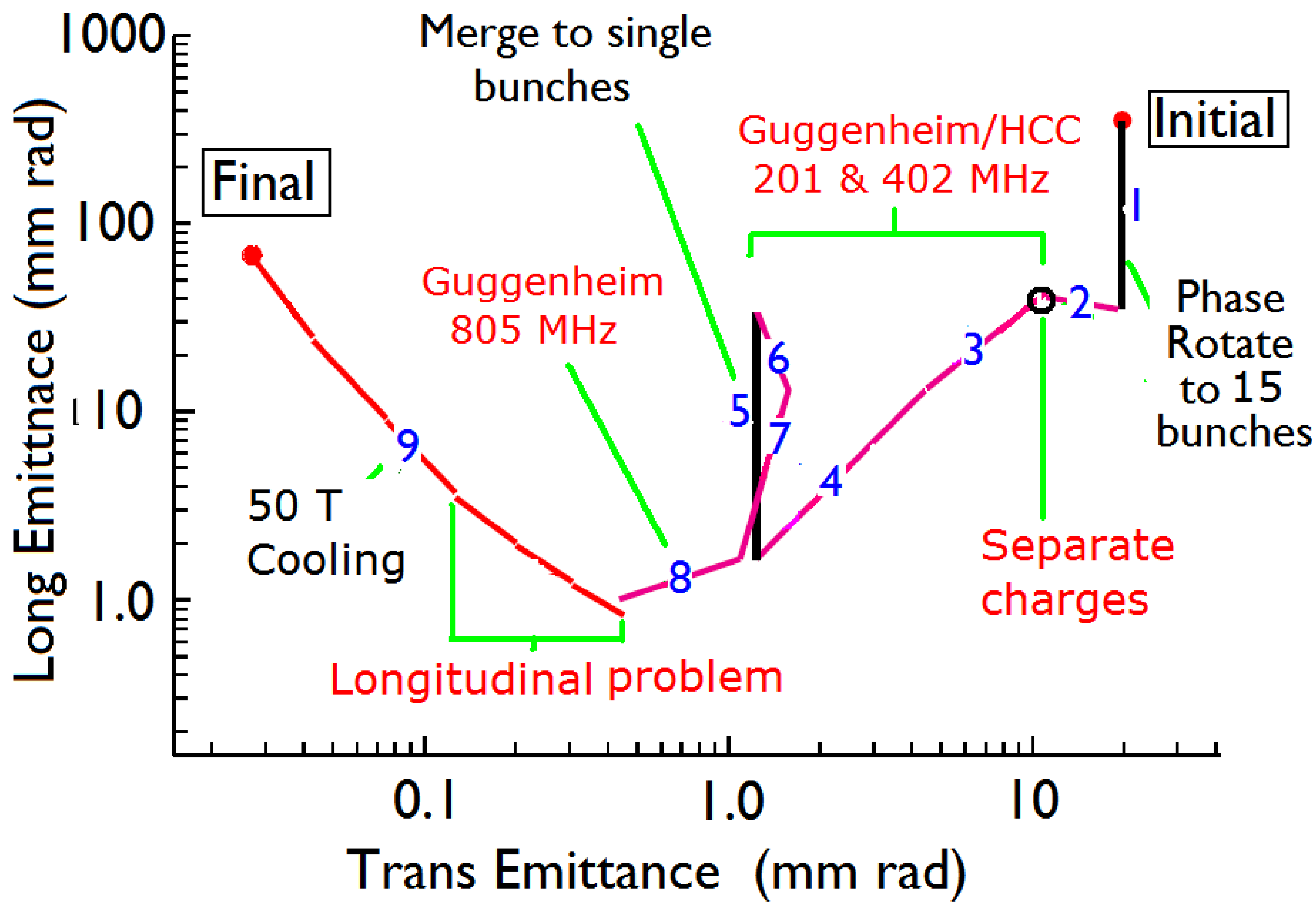
- Use of Magnetic Insulation
  – Pre-cooling
  – 201 & 402 MHz Guggenheims
  – Final 805 MHz Guggenheim
- Summary & Conclusion

Collider Parameters

Same as last year   included for reference

C of m Energy	1.5	4	TeV
Luminosity	1	4	10^{34} cm^{2}sec^{-1}
Muons/bunch	2	2	10^{12}
Ring circumference	3	8.1	km
Beta at IP $= \sigma_z$	10	3	mm
rms momentum spread	0.1	0.12	%
Required depth for ν rad	13	135	m
Repetition Rate	12	6	Hz
Proton Driver power	$\approx$4	$\approx$ 1.8	MW
Muon Trans Emittance	25	25	pi mm mrad
Muon Long Emittance	72,000	72,000	pi mm mrad

- Based on real Collider Ring designs, though both have problems
- Emittance and bunch intensity requirement same for all examples
- Luminosities are comparable to CLIC's
- Depth for ν radiation keeps off site dose < 1 mrem/year



Most Serious Questions

1. Transmission
2. Breakdown in Cooling rf and effect on #1 Discussed here
3. Separation of charges and effect on #1 Fernow
4. Early 50 T cooling and effect on #1 Next

Transmission and definition of 'Efficiency' Q

If one multiplies the transmissions of all simulations, the result is around 1% and quite unacceptable. But much of the losses come from poor initial matching and lack of tapering. To estimate transmission with good matching and tapering we define a cooling efficiency Q

$$Q_6(z) = \frac{d\epsilon_6/\epsilon_6}{dN/N} \tag{1}$$

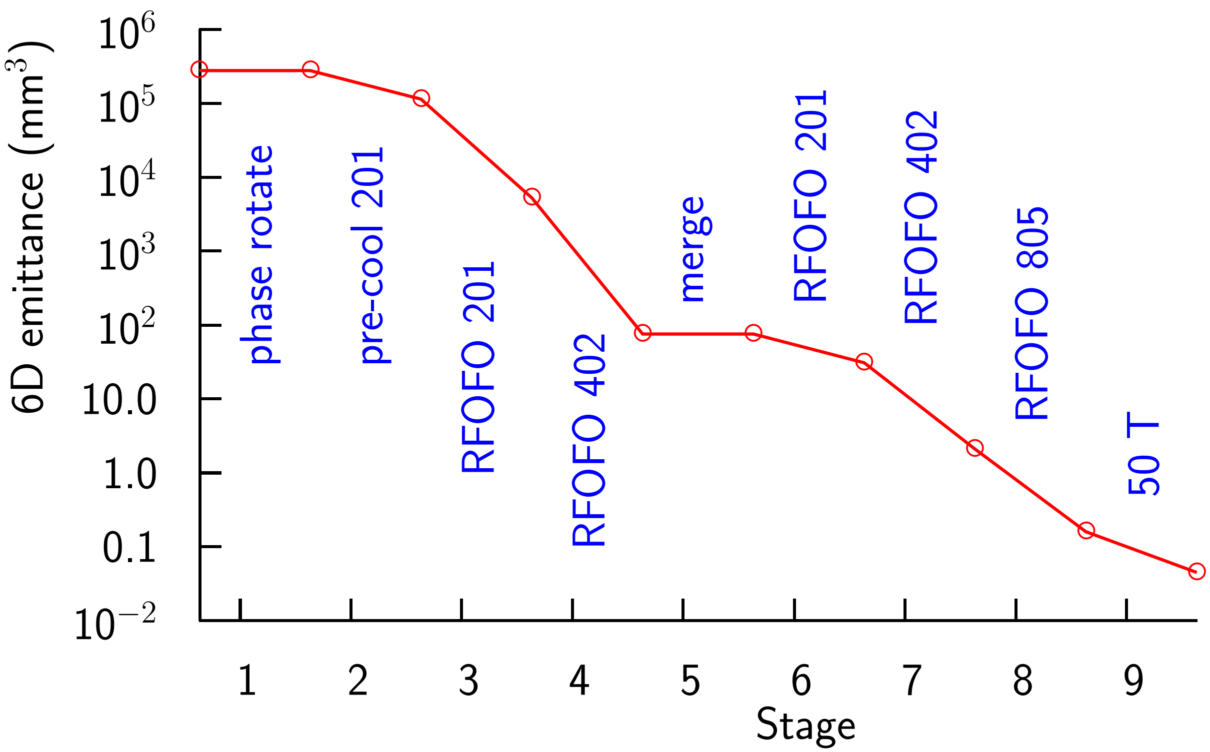
Note, if $Q_6(z)$=constant, then

$$\int_o^n \frac{d\epsilon_6}{\epsilon_6} = Q_6 \int_o^n \frac{dN}{N}$$

$$\mathrm{Ln}\left(\frac{\epsilon_6(n)}{\epsilon_6(o)}\right) = Q_6 \ \mathrm{Ln}\left(\frac{N(n)}{N(o)}\right)$$

$$\frac{N(n)}{N(o)} = \left(\frac{\epsilon_6(n)}{\epsilon_6(o)}\right)^{1/Q_6} \tag{2}$$

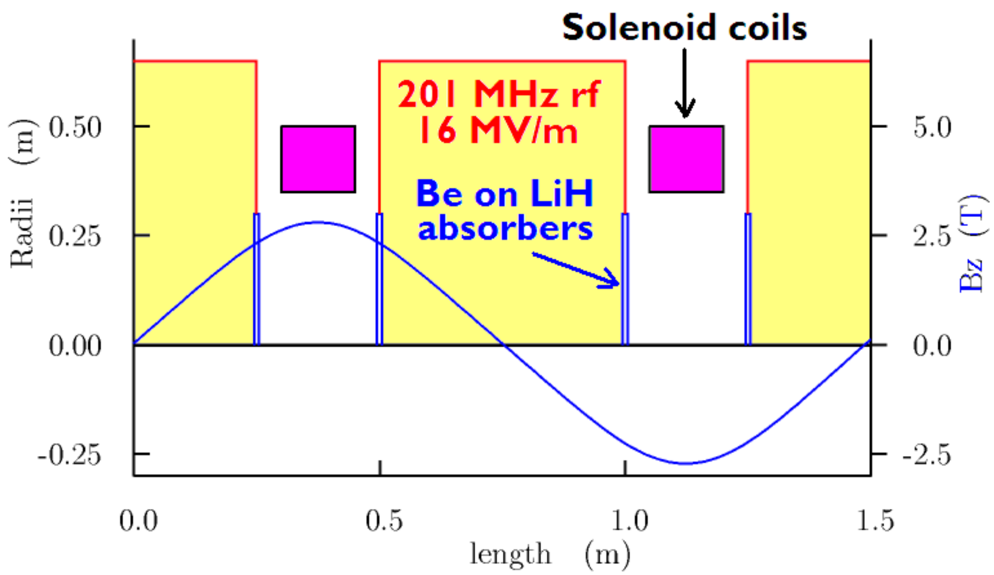
6D emittances vs. stage

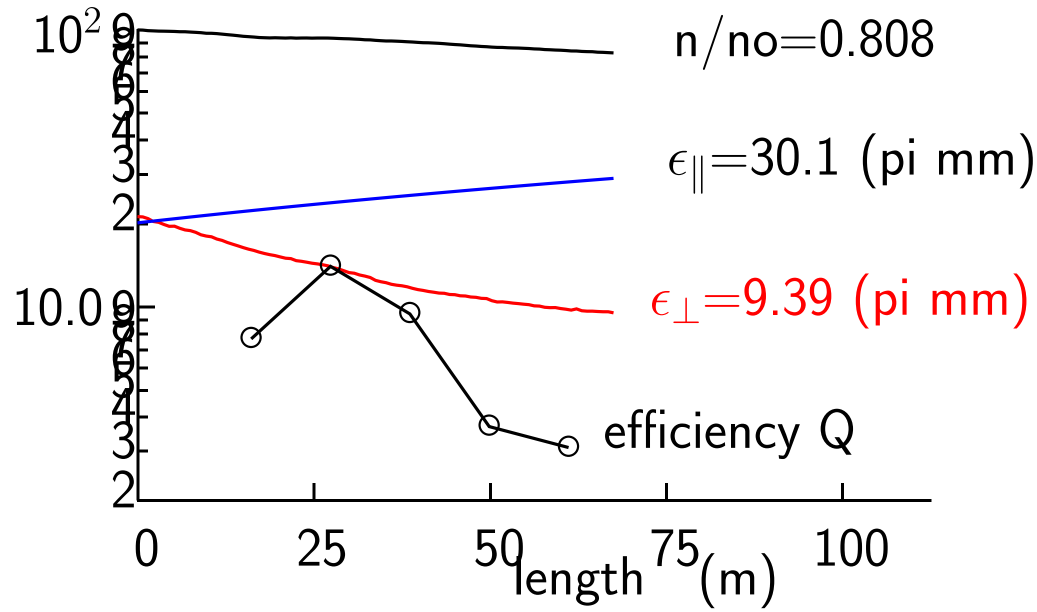


Stages	$\epsilon_6(1)$	$\epsilon_6(2)$	Ratio
Pre-Cool	280,000	115,000	2.4
201 &402 MHz RFOFOs	115,000	2.1	55,000
805 MHz RFOFO	2.1	0.15	13
50 T	0.15	0.045	3.6
All	280,000	0.045	6 10^6

We now need the Q's for each system to get predicted losses

Efficiency vs. length for Pre-cooling



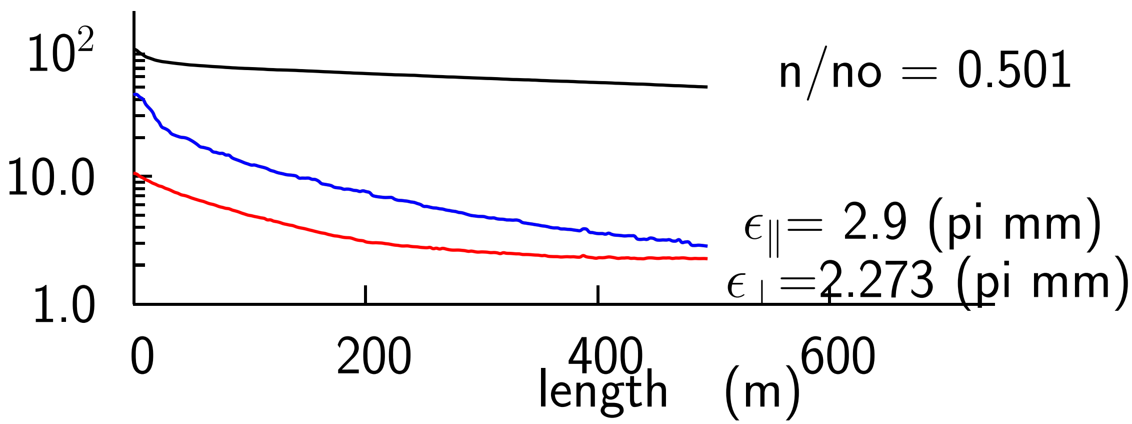


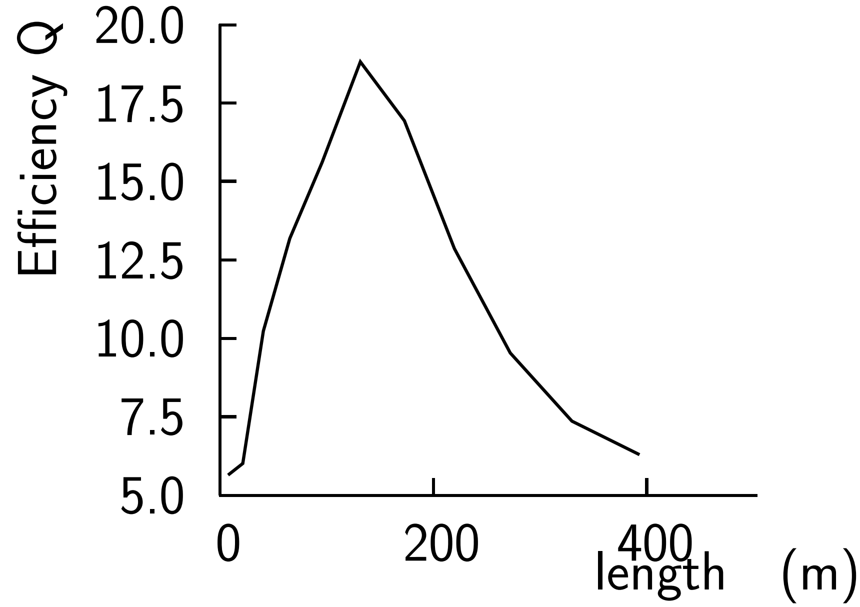
- Mismatch and Scraping losses at start
- Decay losses as emittances approach equilibrium at end
- Sweet region in between (Q$\approx$ 10)
- If tapered then the entire channel is operated in the sweet region
- 4D cooling in RFOFO lattices from 280,000 to 115,000 (mm^3) So expected

$$\frac{n_{final}}{n_{initial}} = \left(\frac{115,000}{280,000}\right)^{1/10} = 0.91$$

Efficiency vs. length for old RFOFO

- Mismatch and Scraping losses at start
- Decay losses as emittances approach eqilibrium at end
- Sweet region in between (Q$\approx$ 15)
- If tapered then the entire channel is operated in the sweet region

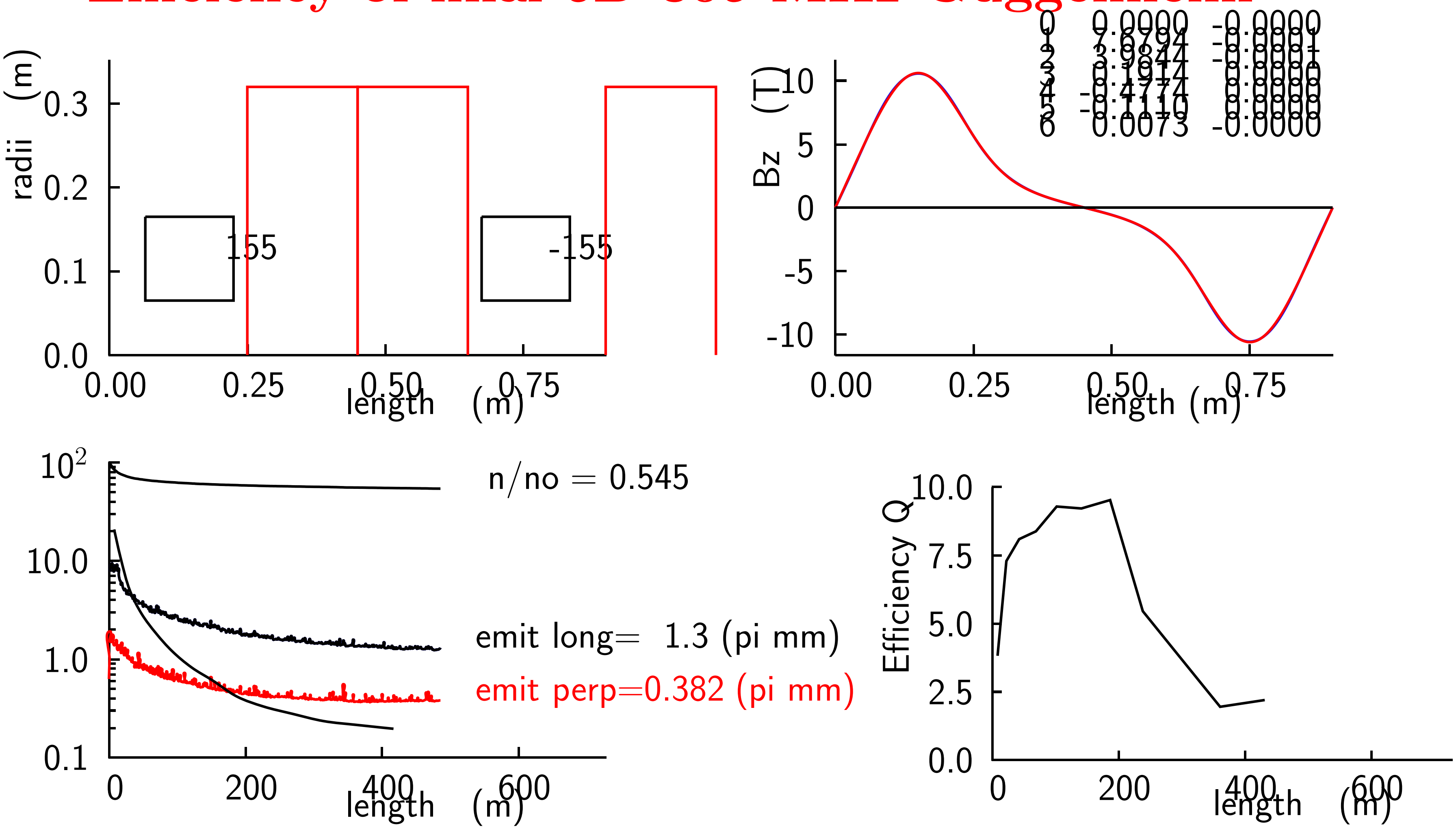




Required 6D cooling in RFOFO lattices from 280,000 to 2.1 (mm^3) So expected

$$\frac{n_{final}}{n_{initial}} = \left(\frac{2.1}{115,000}\right)^{1/15} = 0.48$$

Efficiency of final 6D 805 MHz Guggenheim



- Sweet region in between (Q$\approx$ 8)
- Required 6D cooling from 2.1 to 0.16 (mm^3) So expected

$$\frac{n_{final}}{n_{initial}} = \left(\frac{0.16}{2.1}\right)^{1/8} = 0.72$$

Transmission for whole scheme

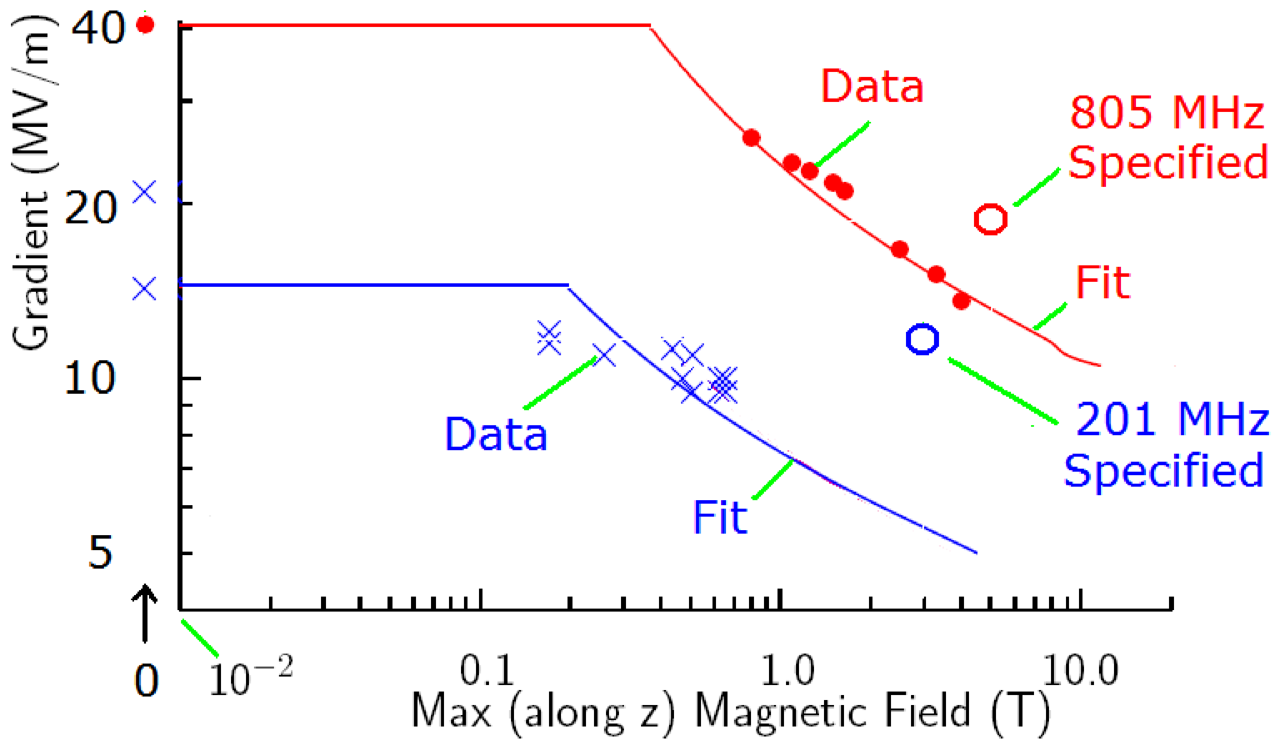
For use of only 15 bunches	0.7
Charge separation	0.9 ???
Losses in 4D Pre-cooling at 201 MHz	0.9 from above
Losses in 6D Guggenheims at 201 & 402 MHz	0.48 from above
Losses in merging	0.7
Losses in 805 MHz 6D	0.72 from above
Losses in 50 T cooling	0.7
Losses in Acceleration	0.7

$$Trans = (0.7 \times \ 0.9 \times 0.9 \times 0.48 \times \ 0.7 \times 0.72 \times 0.7 \times 0.7 \times) = 0.075$$

which what we have been estimating before

rf Breakdown problem

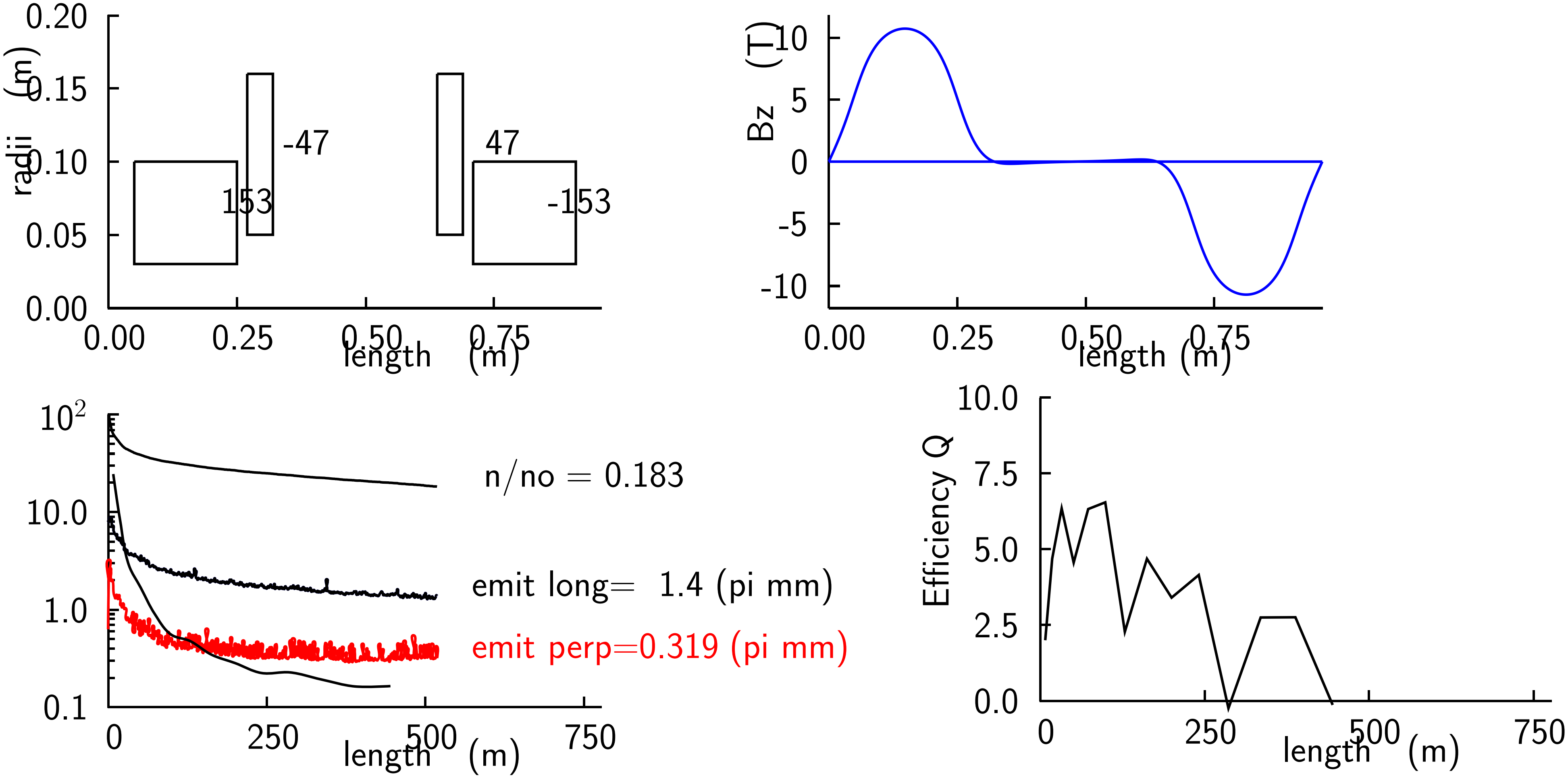
- Current design will not work
- High pressure gas HCC may work
  - Effect of beam unknown
  - Integration of rf still a problem



For Vacuum rf

- Bucking the field at rf should work
  - Are losses a problem ? see below
- Magnetic insulation should work
  - Are losses a problem ? see below

Bucking the fields at the rf e.g. 805 MHz lattice



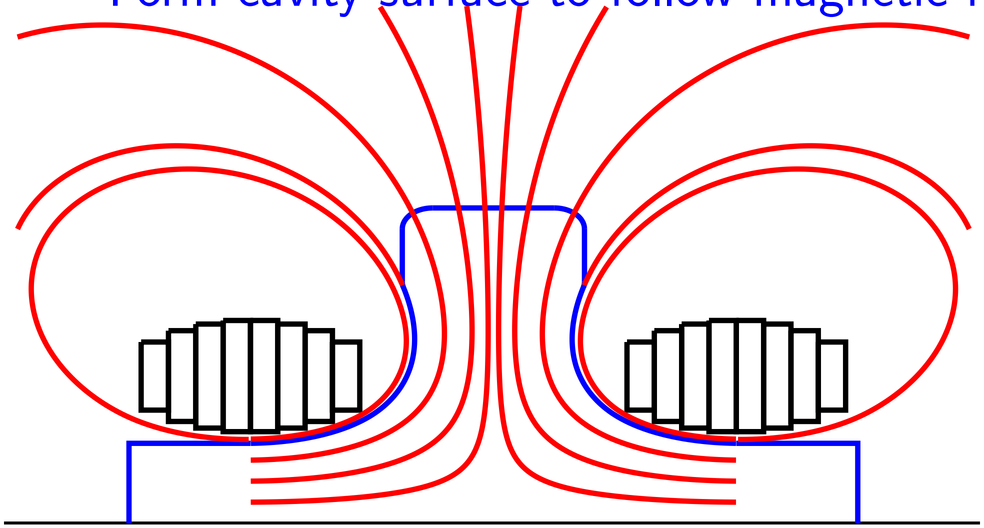
Sweet region in between only (Q≈ 4) and:

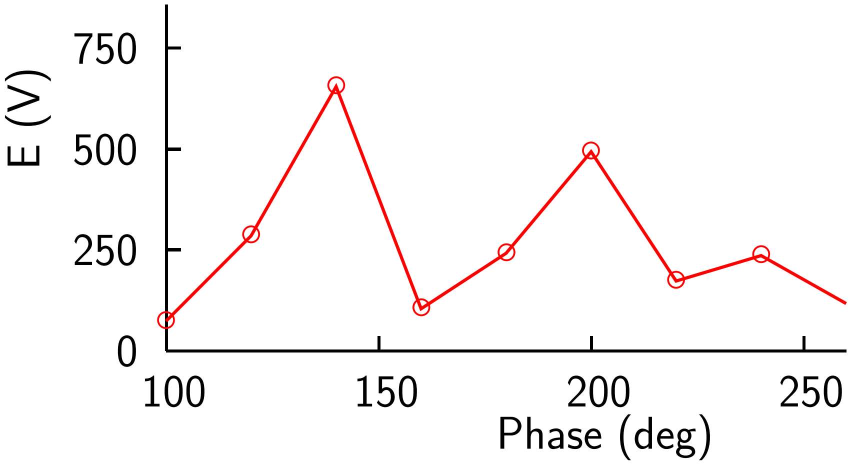
$$\frac{n_{final}}{n_{initial}} = \left(\frac{0.16}{2.1}\right)^{1/4} = 0.52$$

52% c.f.72% Which is not so good

Magnetic Insulation

Form cavity surface to follow magnetic field lines

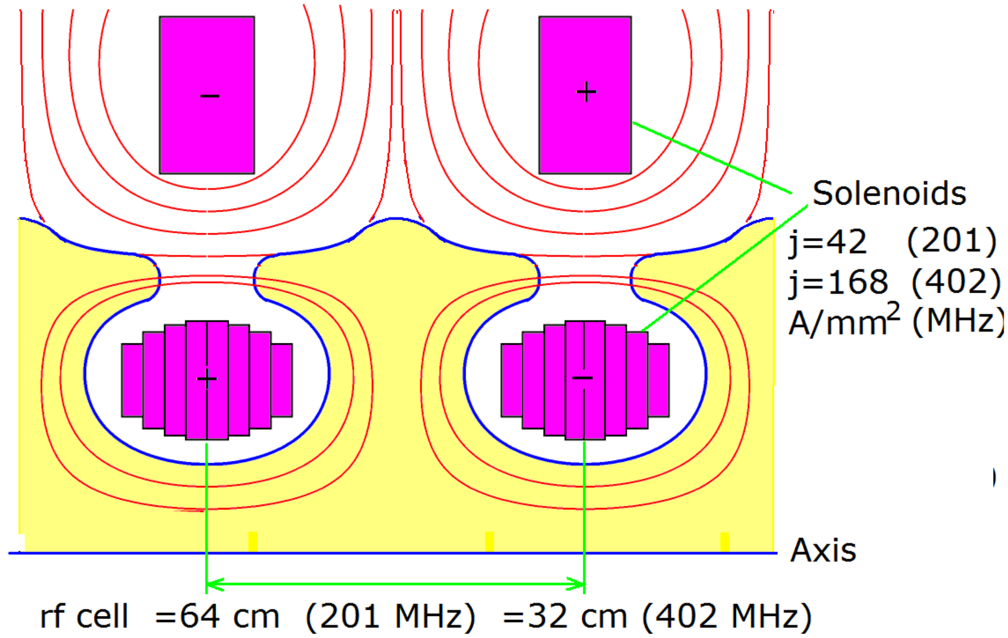




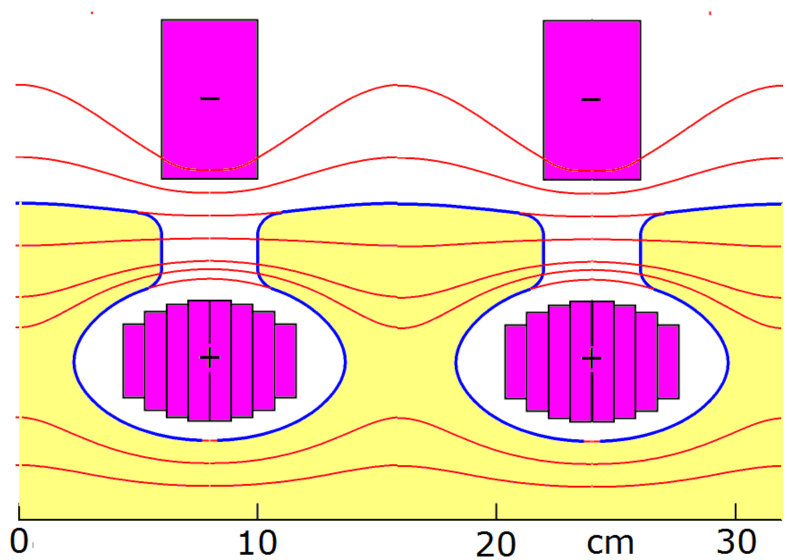
- All tracks return to the surface
- Energies are very low
- No dark current, No X-Rays !
- No danger of melting surfaces
- But secondary emission $\longrightarrow$ problems ?
- Grateful to SLAC for help
- This cavity is inefficient $\mathcal{E}_{\rm surface} \approx 4 \times \mathcal{E}_{\rm acc}$
  Not acceptable

More rf efficient insulated multi-cell lattices

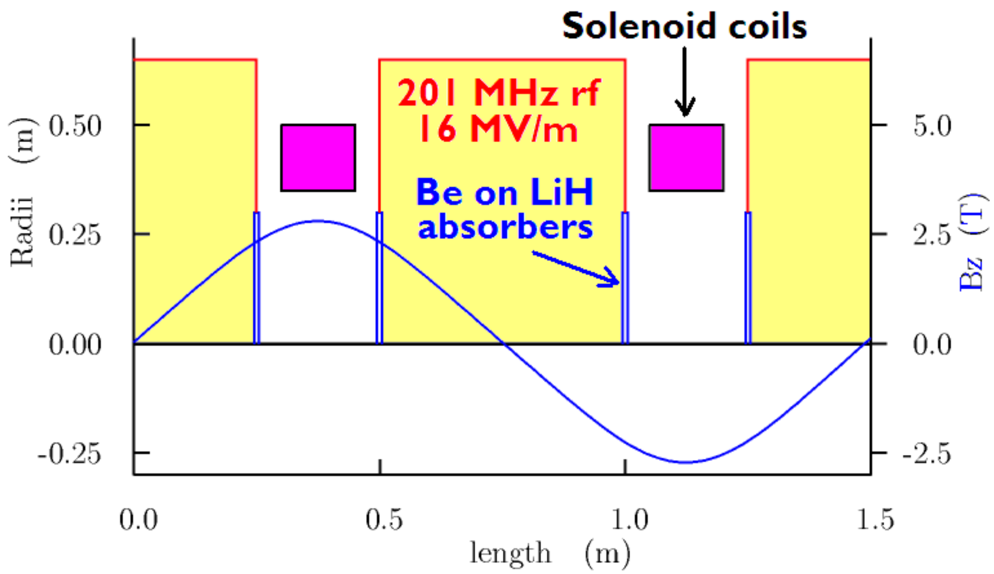
With alternating axial fields
e.g. for Pre-cooling FOFO
or as part of RFOFO

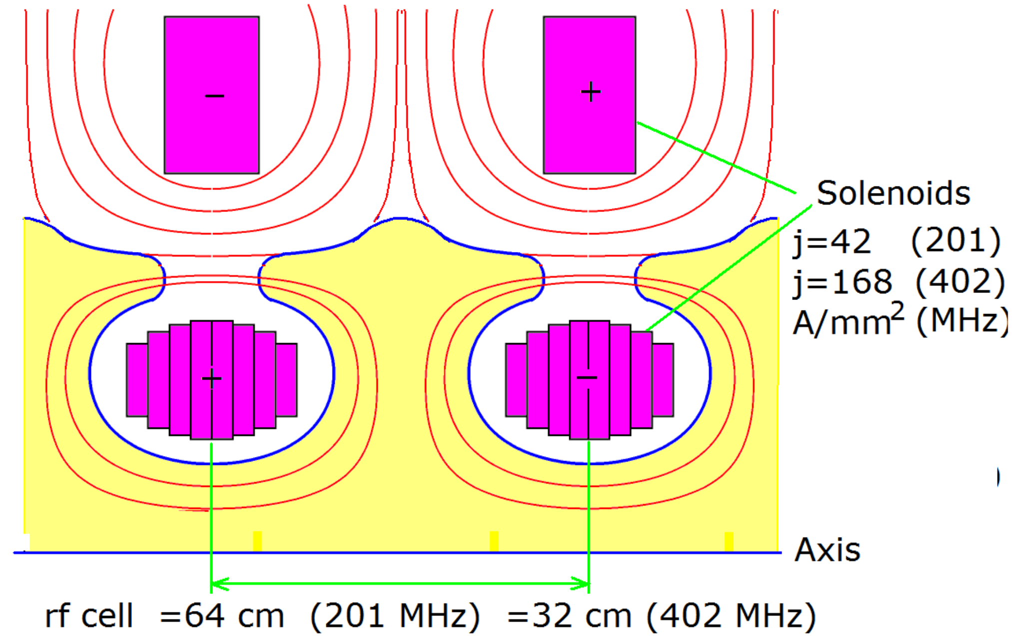


With axial fields in same
direction as
part of FOFO



Magnetically insulated Pre-cooling lattice



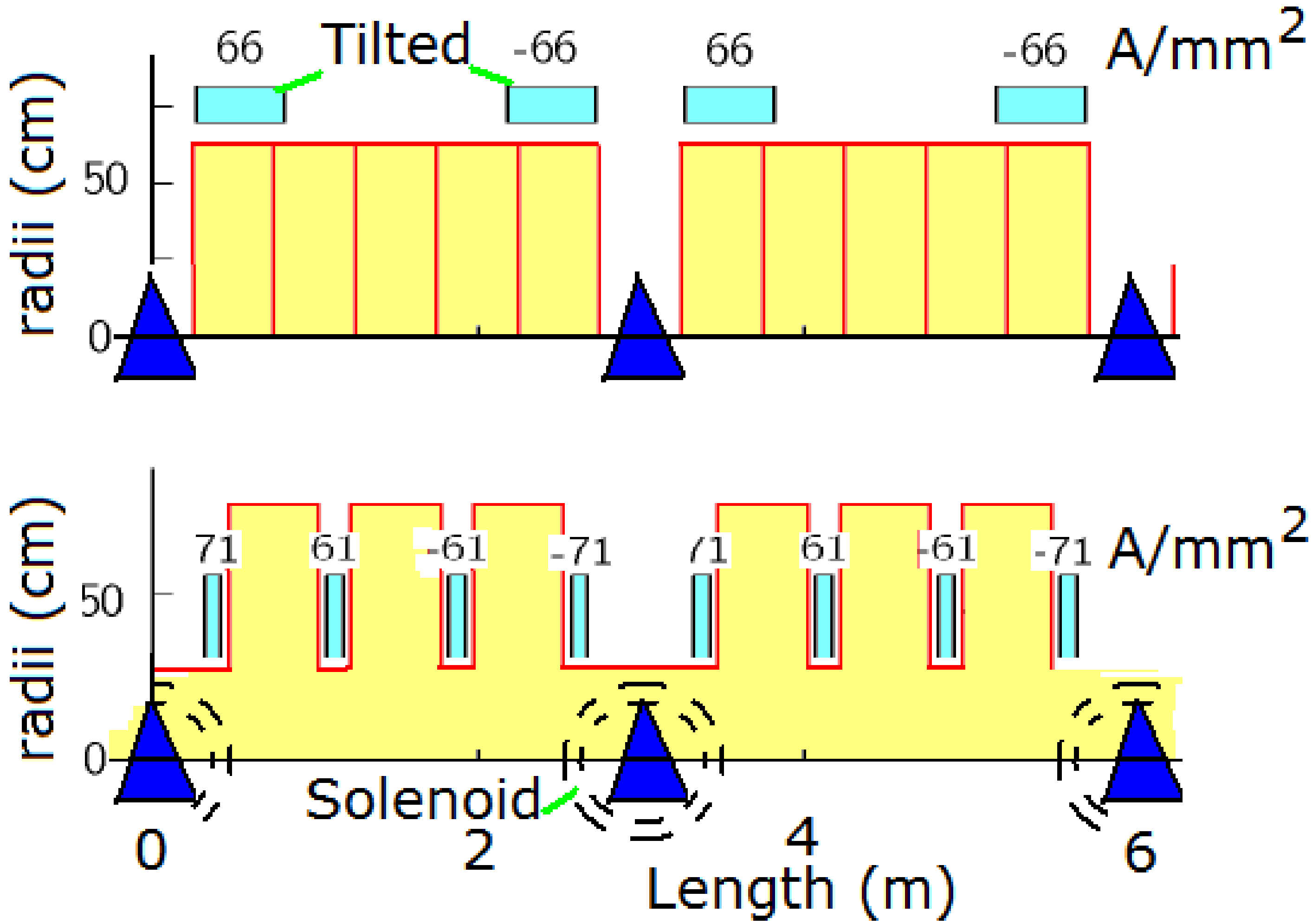


- Fields on axis are almost identical
- So losses expected to be the same

Magnetically insulated RFOFO lattices

Old RFOFO
with coils outside

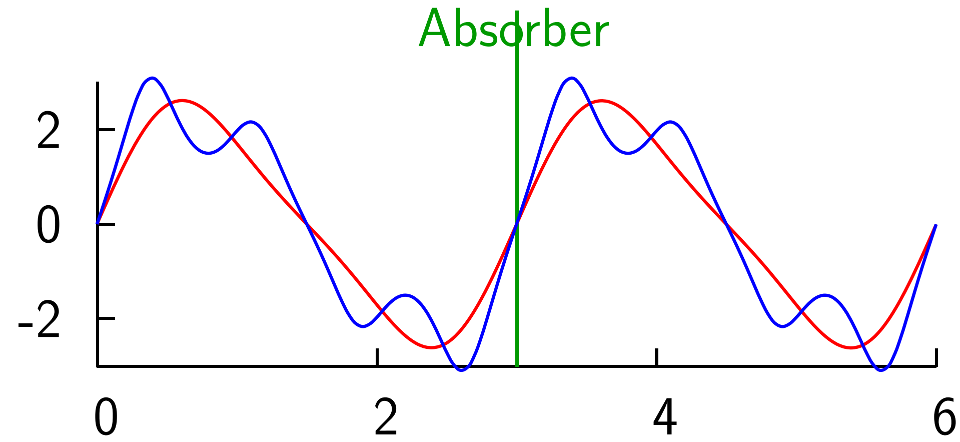
Approximated
lattice using
coils in open irises



This is not quite the magnetically insulated lattice, since it does not have the outer reverse coils, but the fields on axis will be very similar

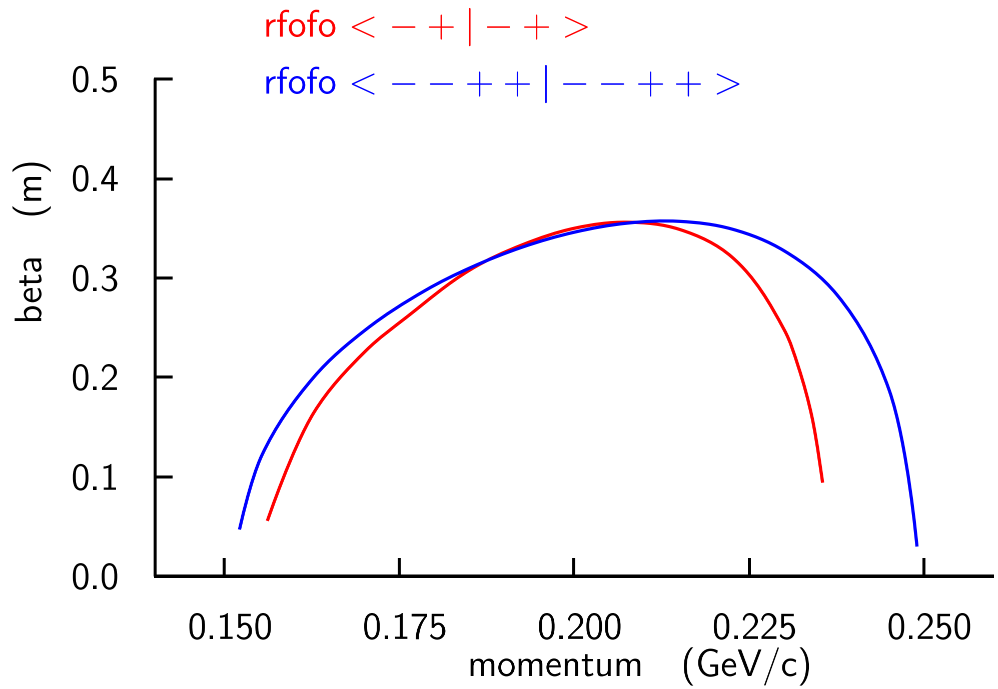
Fields vs. z

Red is for coils outside
Blue is for coils in irises



Betas vs. Momentum

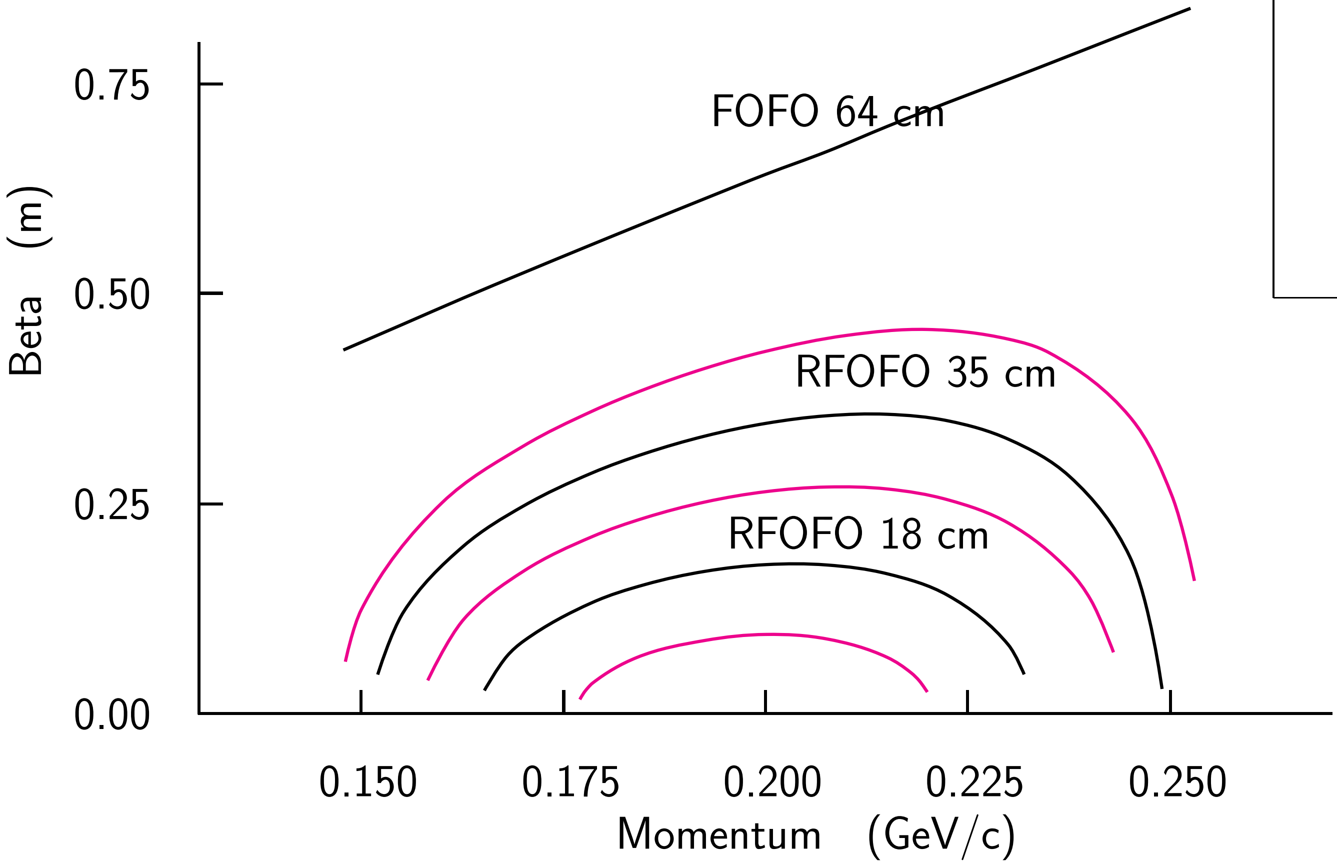
Red is for coils outside
Blue is for coils in irises



- Open cell RFOFO has significantly more momentum acceptance than old version
- But richer harmonic content that could lead to losses

Tunability

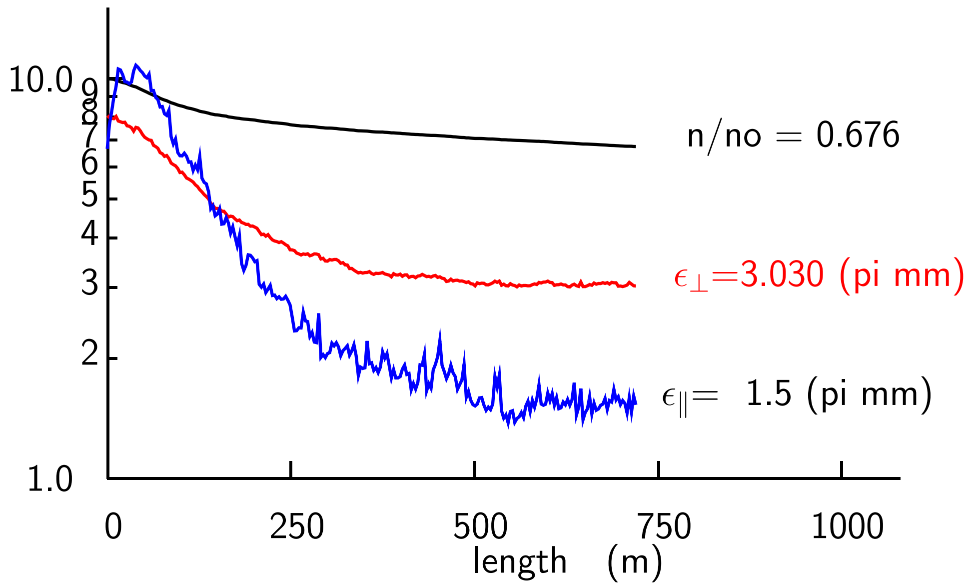
Beta Max cm	j1 A/mm^2	j2 a/mm^2
45.7	54	42
35.7	59	39
27.0	64	34
12.3	78	24
9.5	83	0

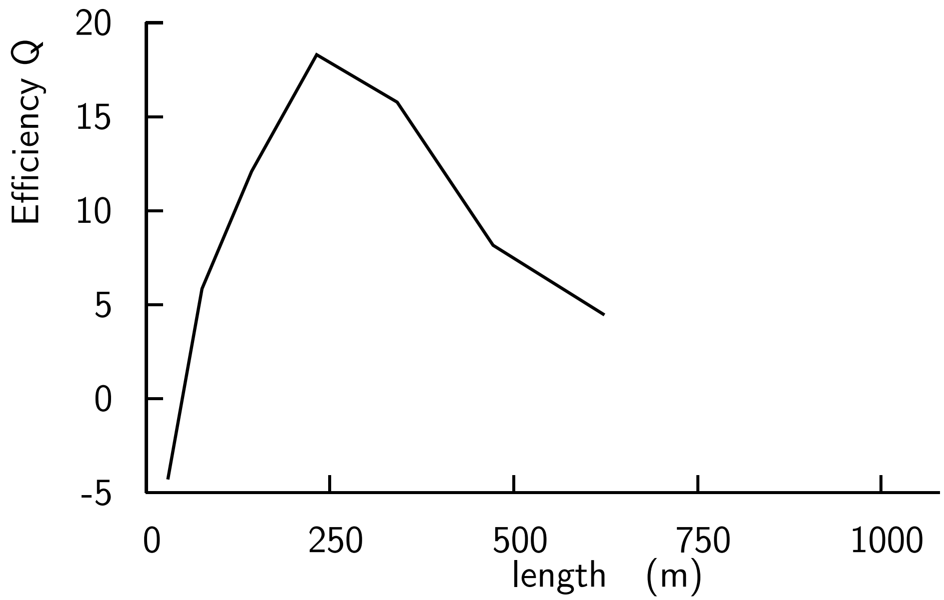


- Beta adjustable from 10 to 42 cm with RFOFO
- And to 64 cm or more with FOFO
- All by adjusting currents alone

ICOOL simulation of Open Cavity Solution

e.g. 35 cm beta example

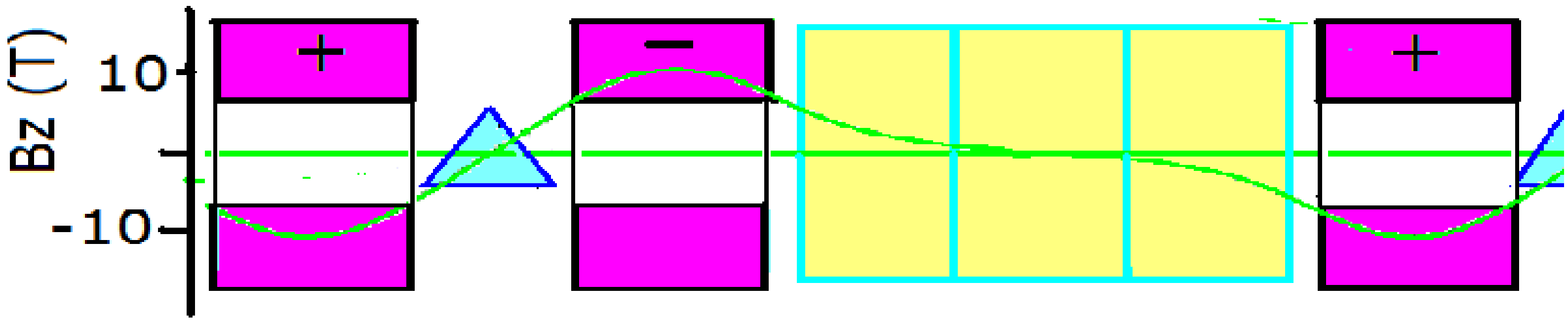




- Sweet region in between (Q$\approx$ 15)
- Same as for coils outside rf
- larger acceptance must cancel effects of richer fourier components

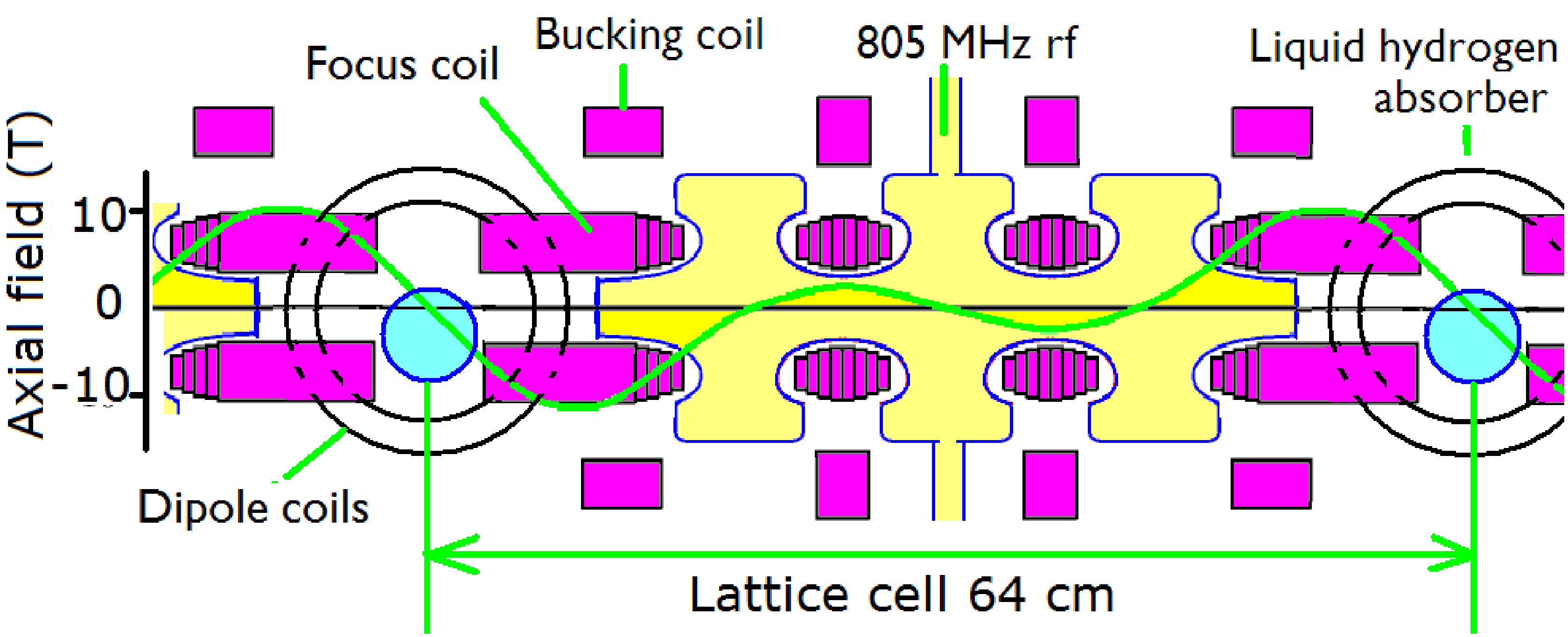
Mag-Insulated version of 805 MHz lattice

Old simulated lattice



Mag Ins version

Not yet simulated



Summary of Qs

Pre-cooler FOFO	10
Coils outside RFOFO	15
Open Iris RFOFO	15
805 MHz RFOFO	8
805 MHz with bucked field	4

Gradients

	Old				Mag Ins			
Stage	cell	grad	z frac	Q	cell	grad	z frac	Q
201 Precooler	0.75	16	0.66	10	0.64	11	0.75	$\approx$10
201 RFOFO	2.75	10.3	0.8	15	2.56	11	0.75	$\approx$15
402 RFOFO	1.375	16	0.8	15	1.28	16	0.75	$\approx$15
805 RFOFO	0.9	16	0.73	8	0.64	15.6	0.75	$\approx$8

With open iris cavities, acceleration will be about half surface fields
25/2=12 for 201 MHz 35/2=17 for 402 MHz 50/2=25 for 805 MHz
So the above accelerating gradients look ok

Estimated total transmission $\approx$ 7.5
The same as previous estiamtes, but still very uncertain

Conclusion

- Overall transmission is a critical question
- Without tapering, and with imperfect matching, losses in ICOOL simulations are unacceptable
- It is useful to determine efficiencies (Q) vs z in cooling simulations
- Good matching and tapering should maintain the efficiencies at their 'sweet' values
- With this assumption, transmission is around 7% as assumed in HEMC parameters

- In old Guggenheim lattices, the fields on the rf cavities will cause breakdown
- Adding bucking coils to remove fields at rf increase losses
- Use of magnetic insulation apears not to increase losses

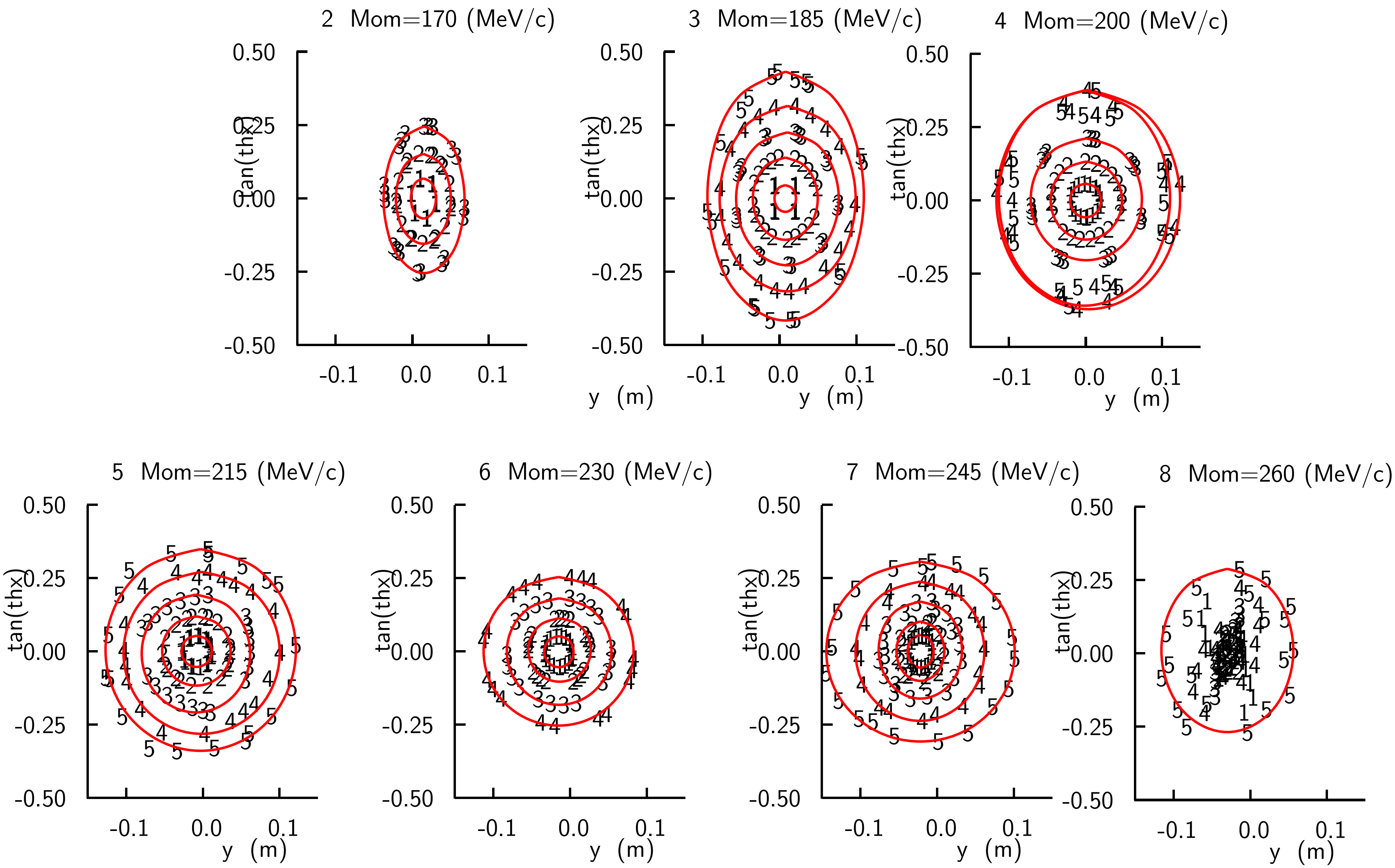
To be done

- Run Cavel on these lattices
- Simulate magnetically insulated lattices
- Study forces, current densities etc of coils
- Determaine tolerances: must every cavity shape be different
- Go back to early 50 T cooling
  - Currently bunches are not preserved in early stages causing longitudinal emitance growth
  - Using lower B and energy will help
  - But probably needs new lattice cooling at lower momenta
  - Also try reverse emittance exchange

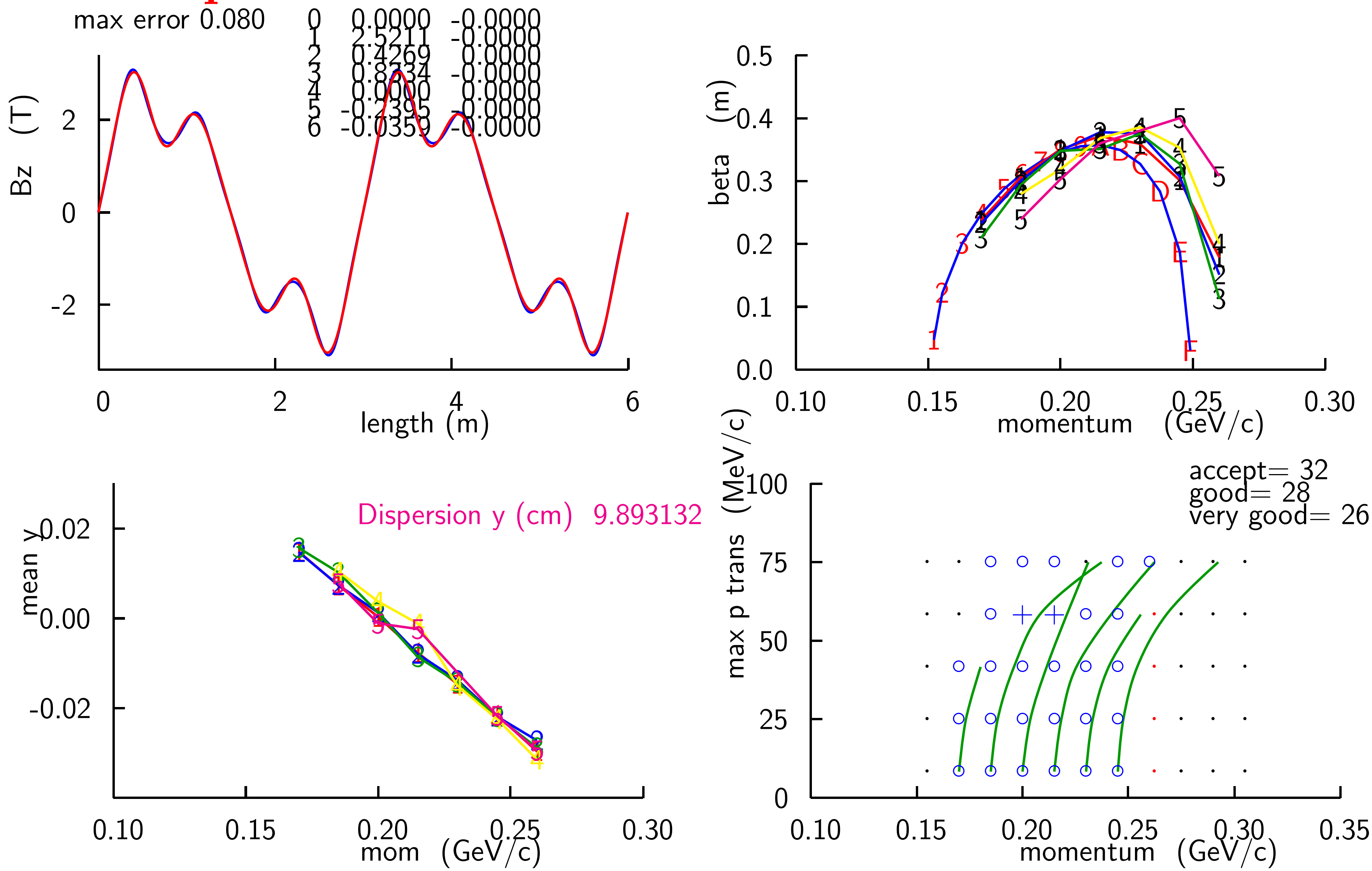
Appendices

- Phase plots for coil in iris RFOFO lattice
- other plots of coil in iris RFOFO lattice
- 805 MHz lattice field lines
- Pre-Cooling FOFO lattice with zero moment coils

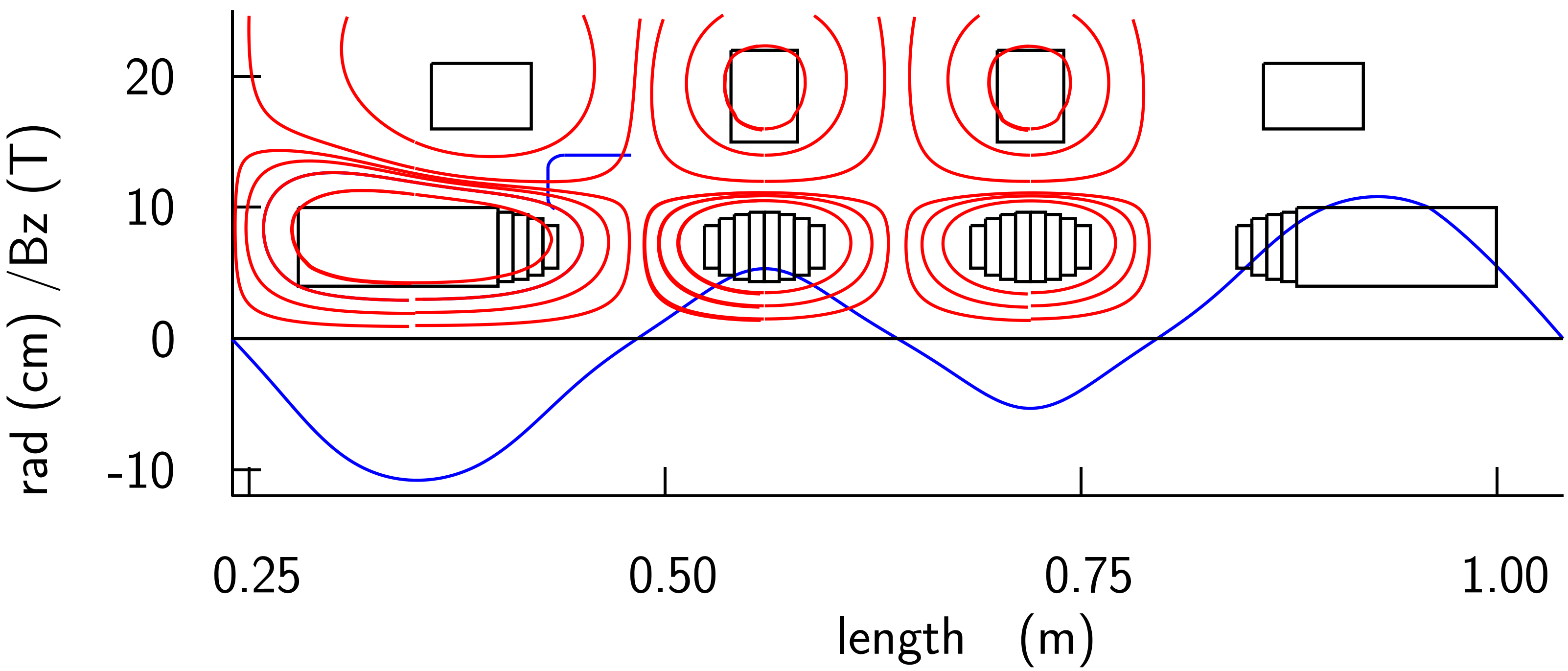
Phase plots for Open cavity solution



Cell parameters



805 field lines



201 neutral moment FOFO