RFOFO Based Ring
6D Cooling Simulations

January 14, 2010

Pavel Snopok
Department of Physics and Astronomy
University of California, Riverside

OUTLINE

- RFOFO Ring and Guggenheim Lattice
- Open Cavity Lattice
- Comparison of Various Open Cavity Lattice Designs Aimed at Reducing RF Gradient
- Preliminary 805 MHz lattice simulations
- 201 MHz RFOFO acceptance studies
- Summary

INTRODUCTION

- Cooling Proposals:

  RFOFO ring/Guggenheim helix

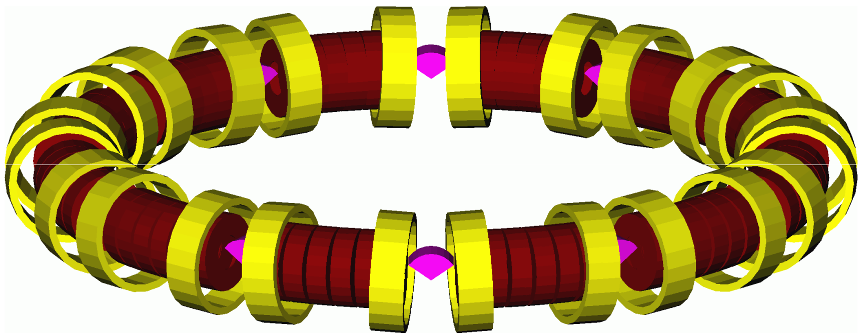
  Modification – Open cavity lattice

  Helical cooling channel (Muons, Inc.)

  FOFO snake (Y. Alexahin)

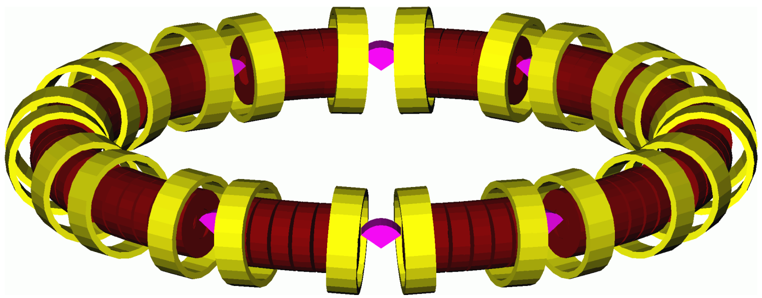
  Quadrupole & dipole rings

RFOFO RING



- Yellow – tilted magnetic coils generate bending & dispersion
- Purple – wedge absorbers for cooling & emittance exchange
- Red/brown – RF cavities restore energy lost in absorber in longitudinal direction

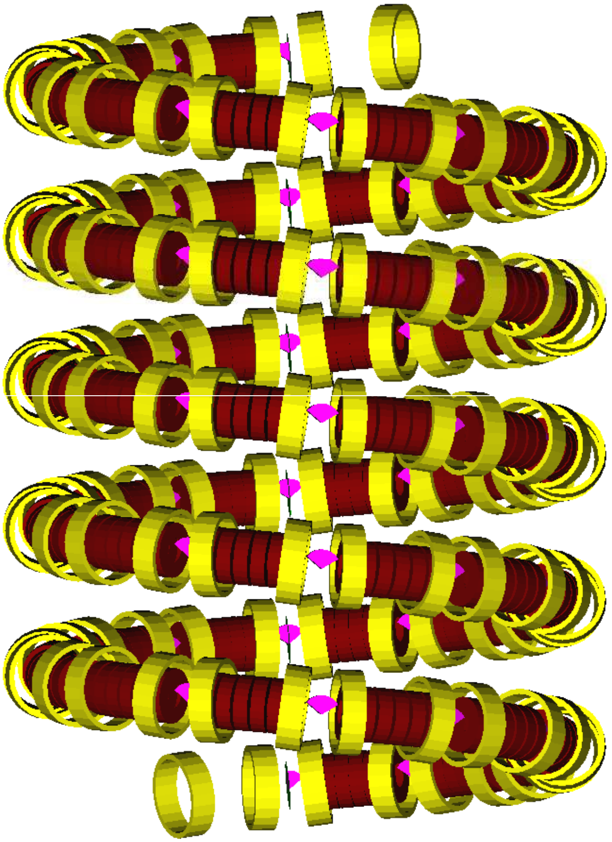
RFOFO RING AND GUGGENHEIM HELIX



RFOFO ring

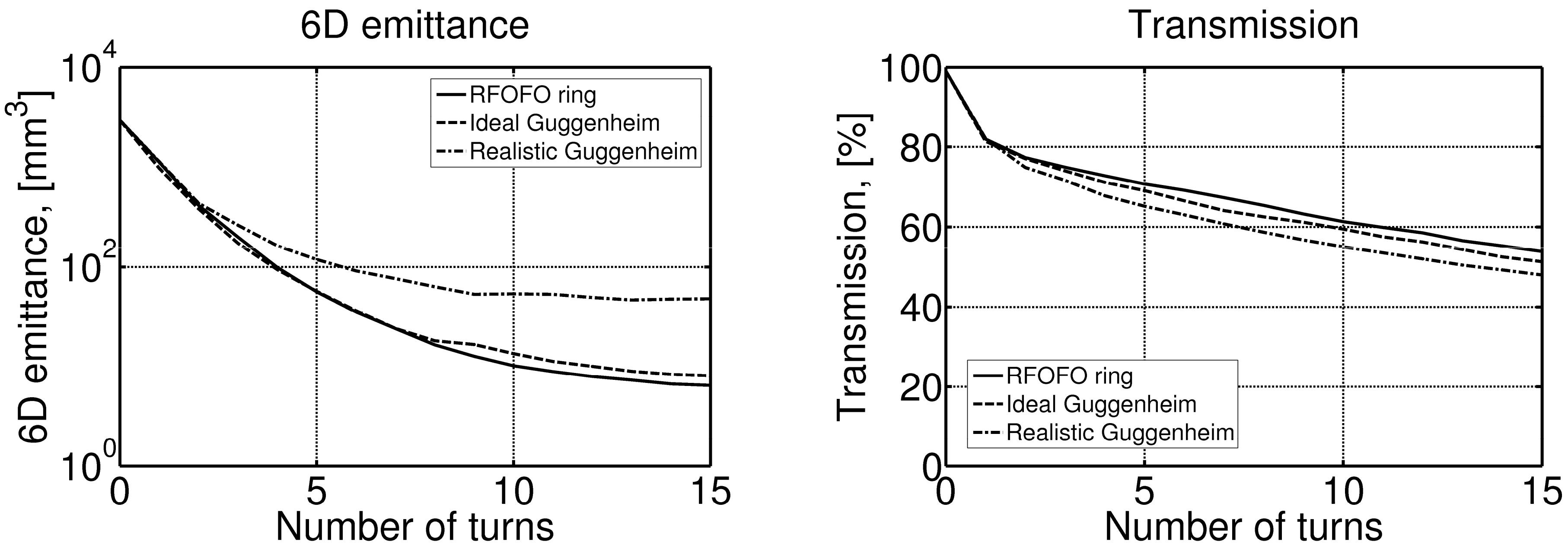
Advantages:
- Fast cooling
- Compact
- Reuse RF

Challenges:
- Injection/extraction
- Absorber overheating
- Continuous operation



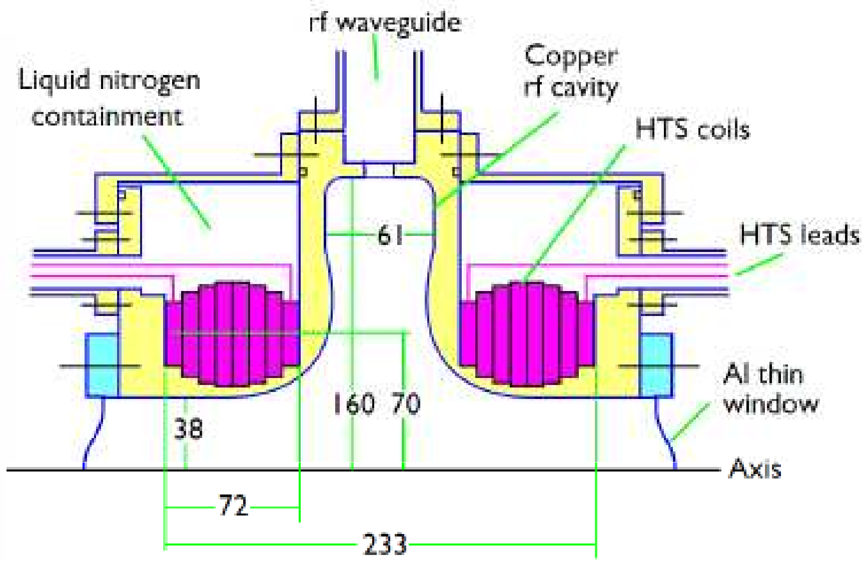
RFOFO-based Guggenheim helix

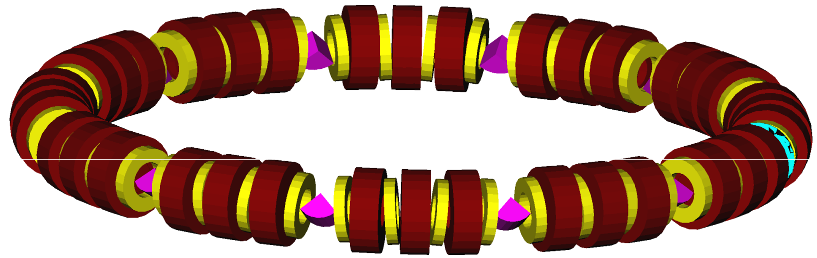
COMPARISON OF GUGGENHEIM AND RFOFO PERFORMANCE

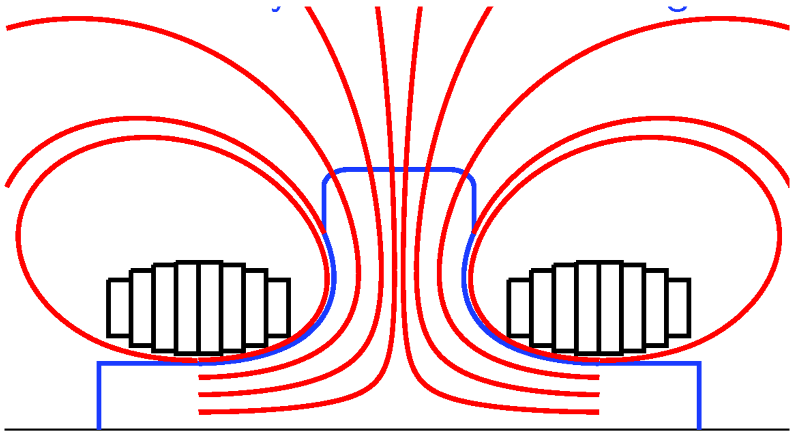


- 6D emittance reduced by factor of 448 in RFOFO ring or by factor of 360 in the Guggenheim helix (495m) with NO WINDOWS.
- Reduced by factor of 60 WITH WINDOWS in RF cavities and absorbers.

OPEN CAVITY LATTICE







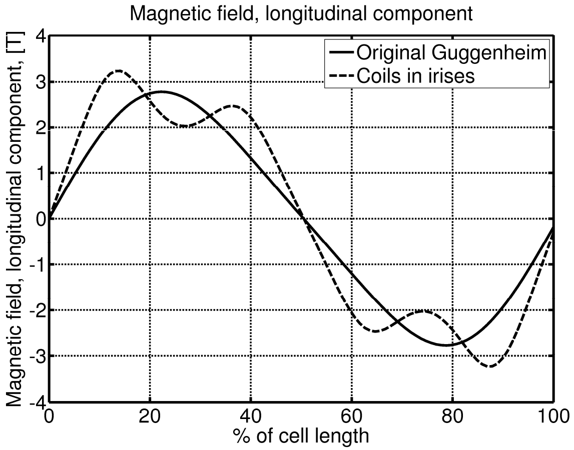
- Open cavity lattice
- Coils in the irises
- Coils tilted to generate bending field

COMPARISON OF OPEN CAVITY AND RFOFO PARAMETERS

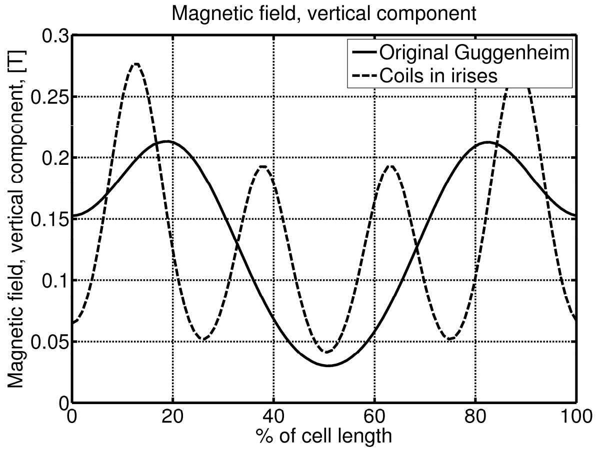
Parameter	Unit	Open cavity	RFOFO
Number of cells		12	12
Circumference	[m]	30.72	33.00
Radius	[m]	4.889	5.252
RF frequency	[MHz]	201.25	201.25
RF gradient	[MV/m]	16.075	12.835
Maximum axial field	[T]	3.23	2.80
Reference momentum	[MeV/c]	214	201
Coil tilt	[deg]	4.90	3.04
Number of coils per cell		4	2
Current densities	[A/mm^2]	[63,45,-45,-63]	[95,-95]
Number of RF cavities		3	6
Length of each RF cavity	[mm]	385	282.5
Absorber angle	[deg]	90	110
Absorber vertical offset	[cm]	12.0	9.5
Absorber axial length	[cm]	24.00	27.13
RF phase	[deg]	30.00	30.00

COMPARISON OF OPEN CAVITY LATTICE AND RFOFO MAGNETIC FIELDS

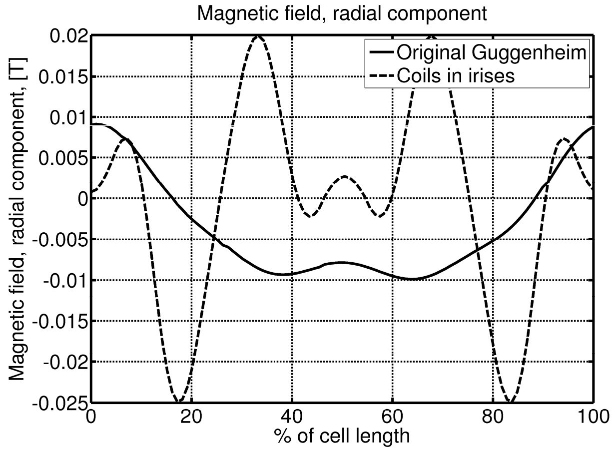
Longitudinal



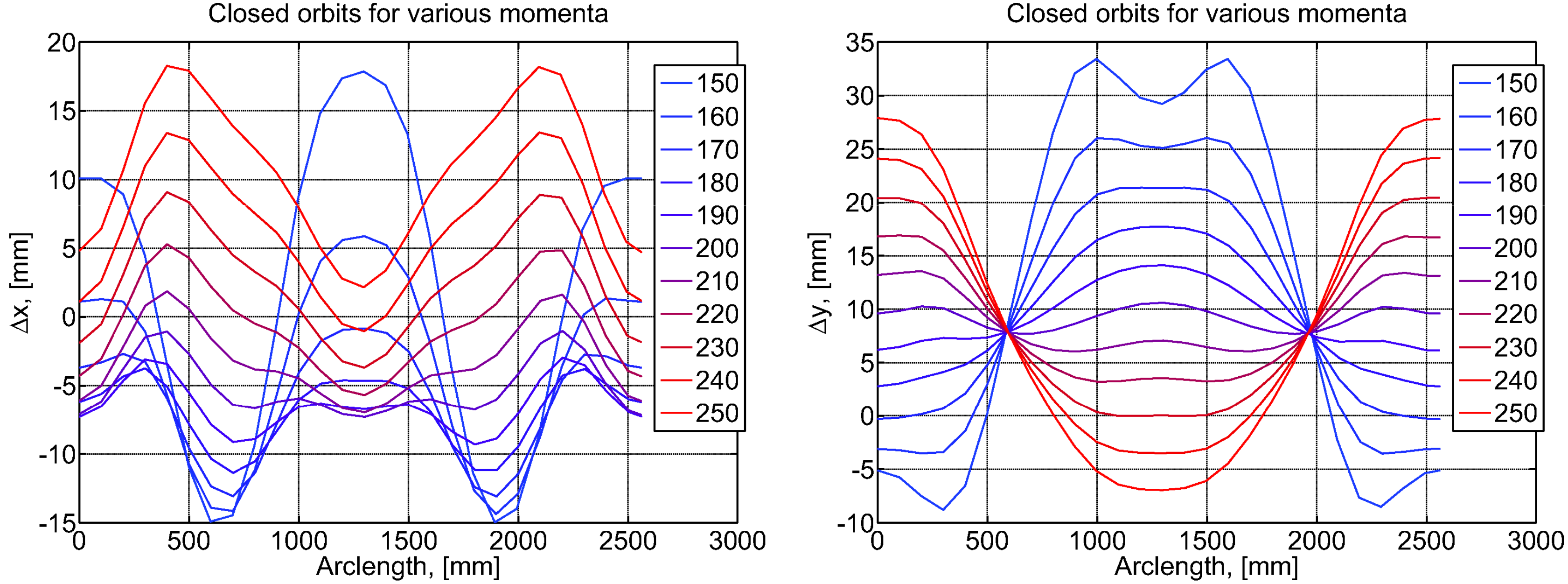
Vertical



Radial

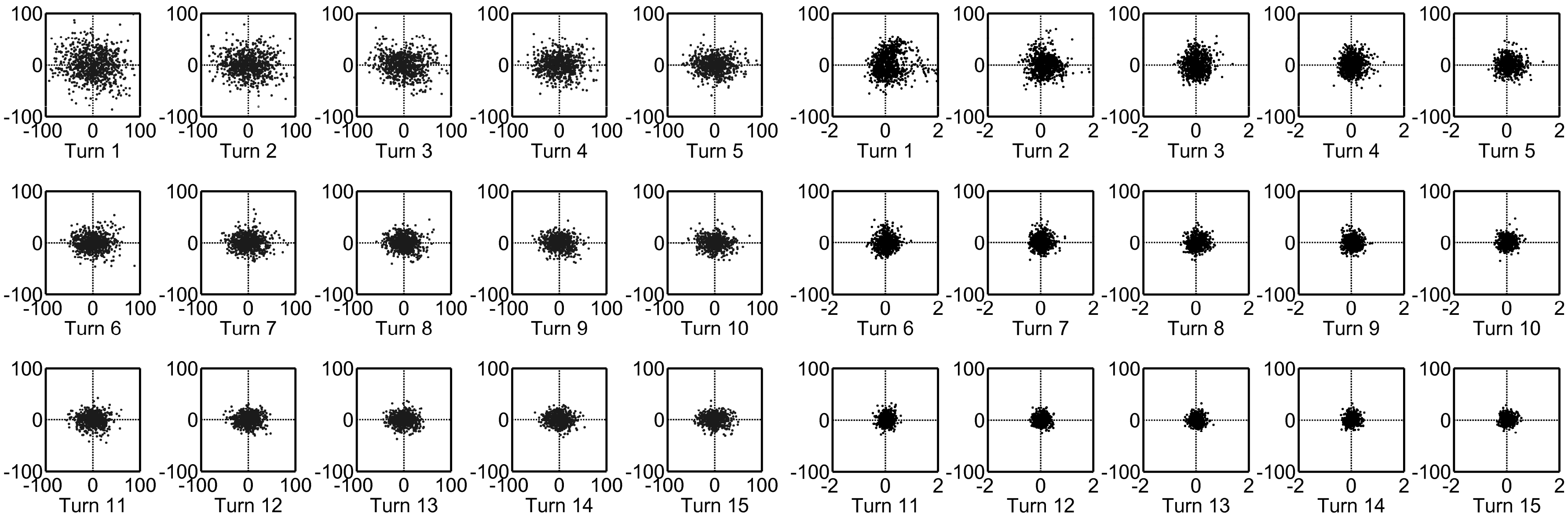


OPEN CAVITY LATTICE – OFFSETS FOR CLOSED ORBITS



OPEN CAVITY LATTICE – PHASE PORTRAITS

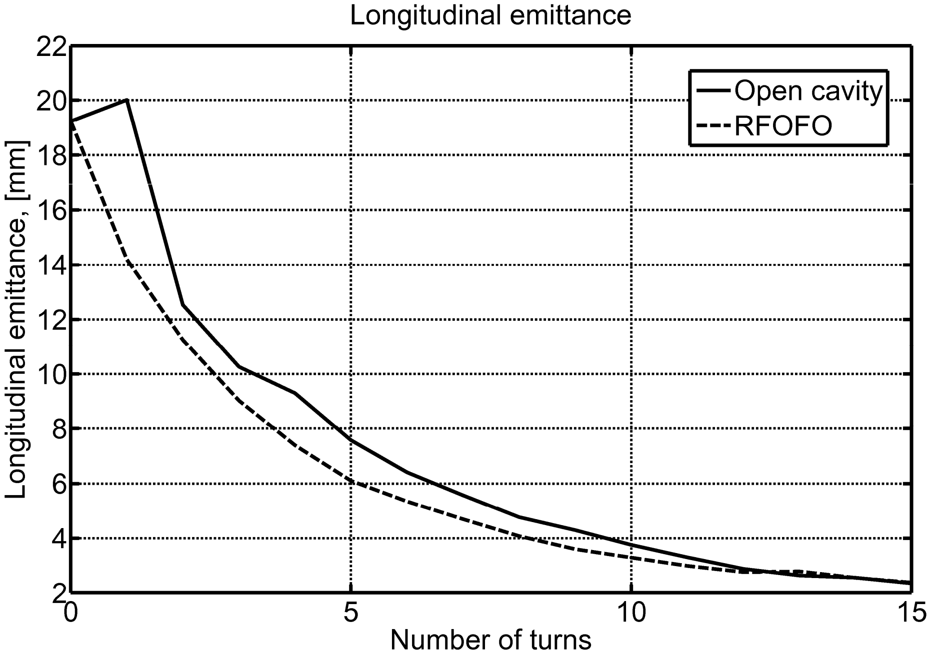
Emittance reduced until equilibrium emittance reached



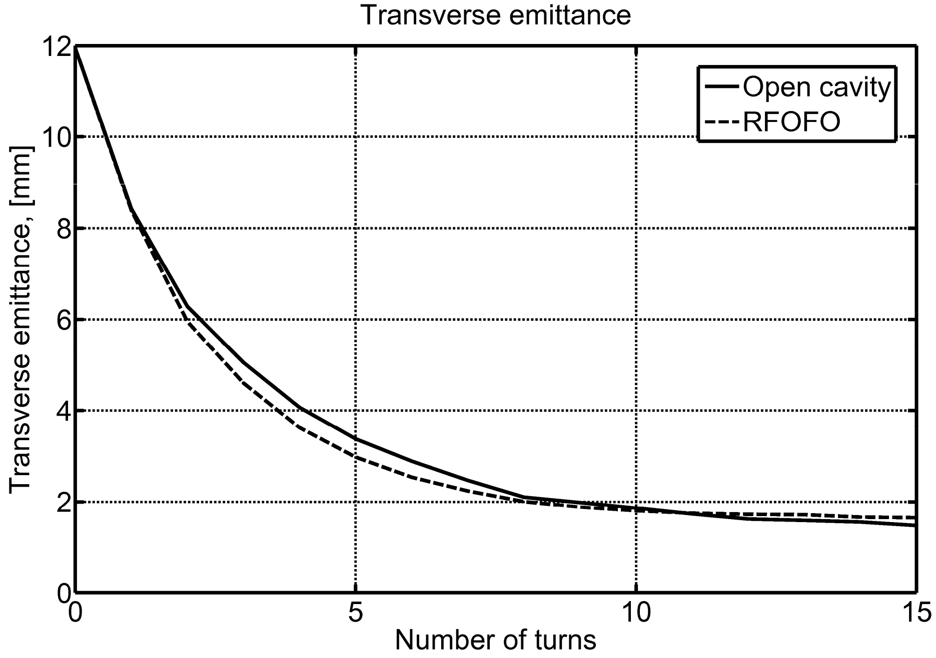
x - p_x $\qquad$ t - p_z

COMPARISON OF OPEN CAVITY AND RFOFO PERFORMANCE

Longitudinal emittance



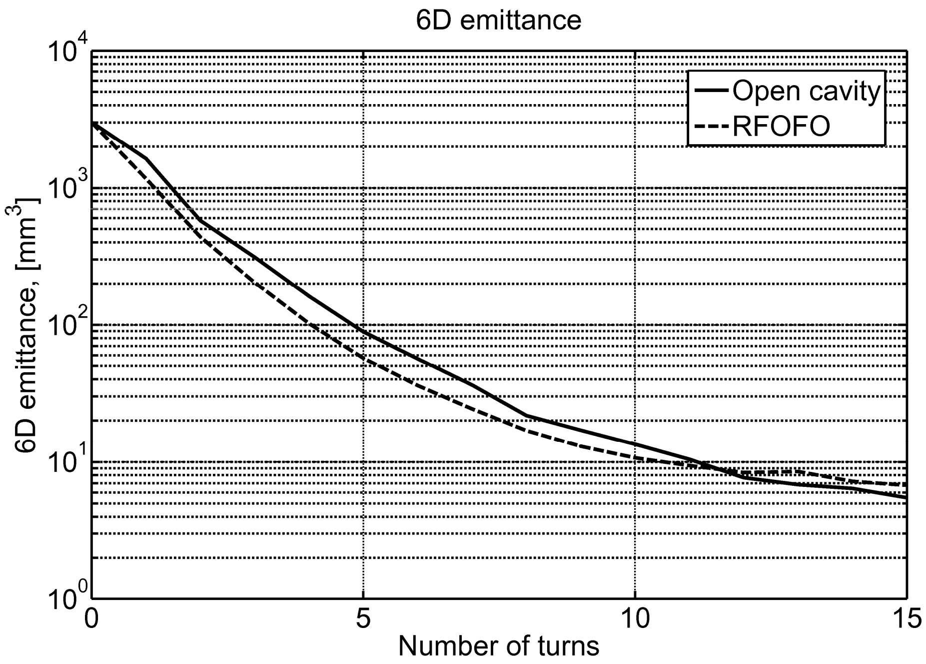
Transverse emittance



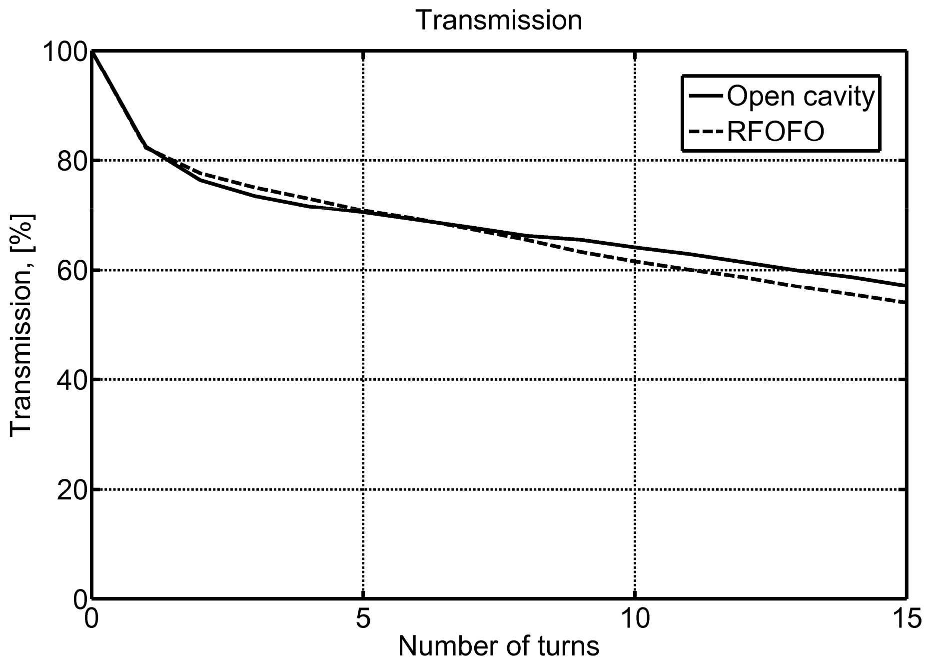
WITH decay and stochastic processes

COMPARISON OF OPEN CAVITY AND RFOFO PERFORMANCE

6D emittance



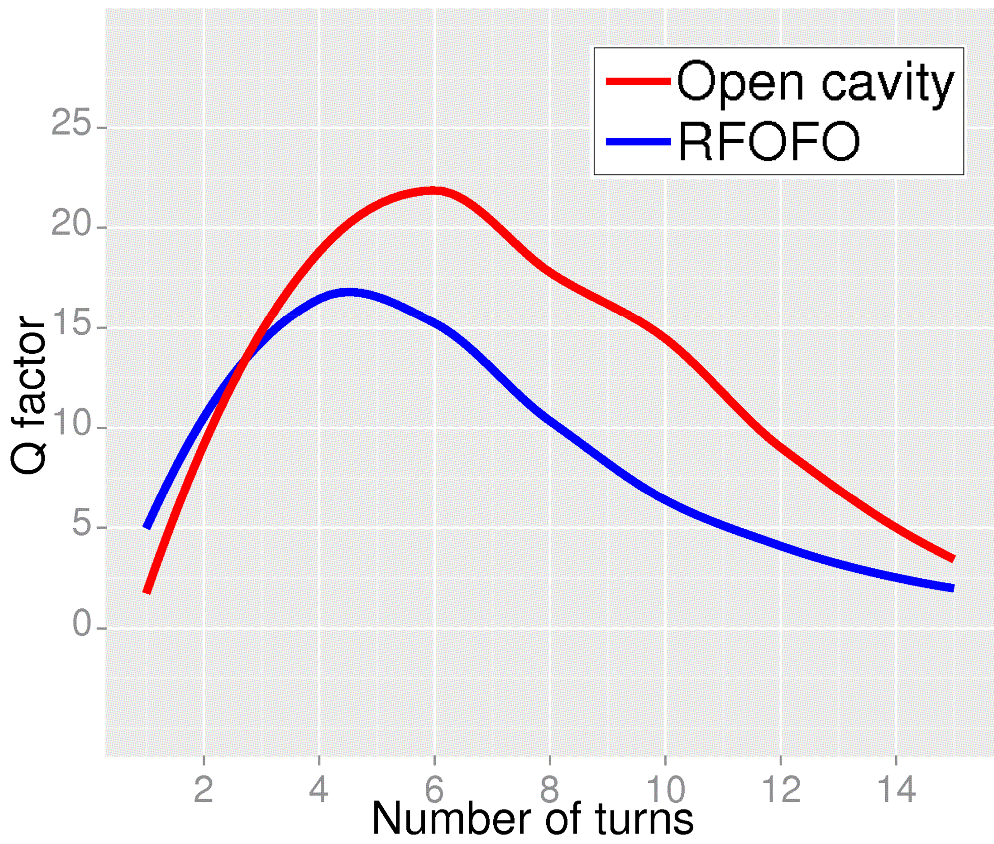
Transmission



WITH decay and stochastic processes

COMPARISON OF OPEN CAVITY AND RFOFO PERFORMANCE – Q-FACTOR

$$Q = \frac{d\varepsilon_{6D}^{N}/ds}{dN/ds}\,\frac{N(s)}{\varepsilon_{6D}^{N}(s)}$$

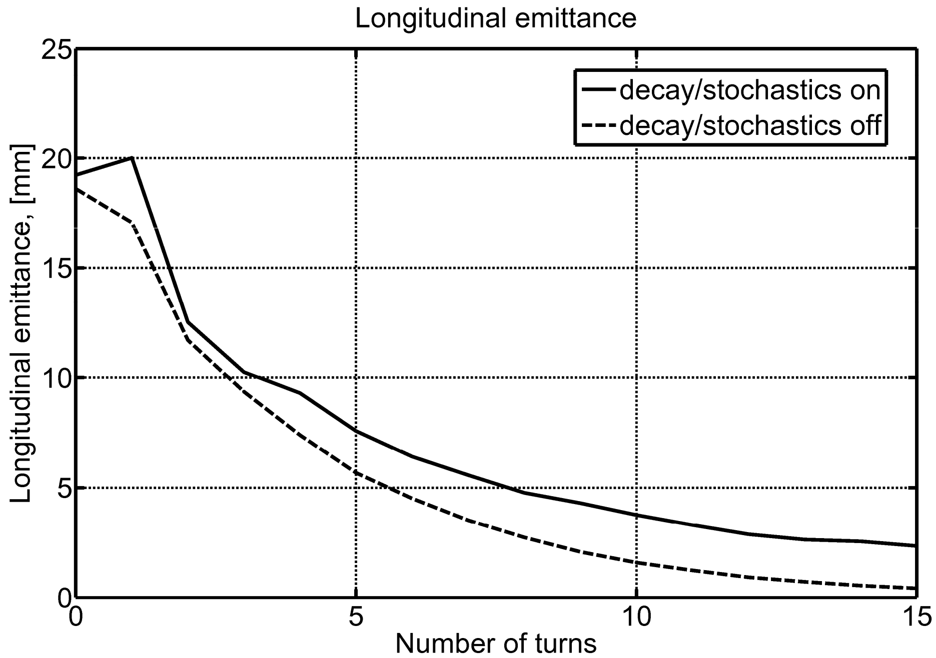


COMPARISON OF OPEN CAVITY AND RFOFO PERFORMANCE – QUANTITATIVE

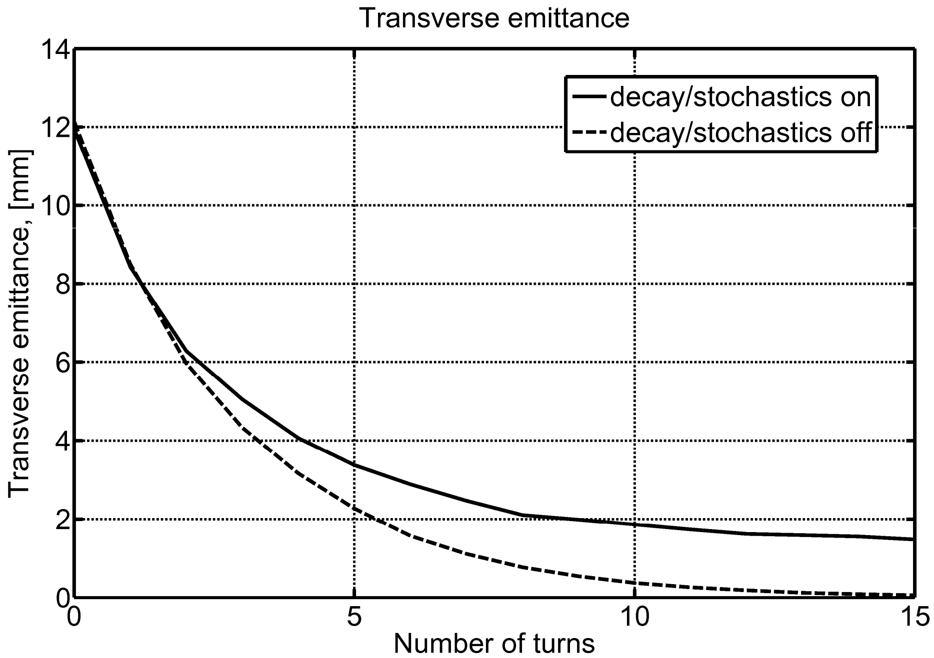
Structure	$\varepsilon_{\perp}$ [mm]	$\varepsilon_{\parallel}$ [mm]	ε_{6D} [mm^3]	Transmission [%]
Initial	12	19	3000	100
Open cavity (15 turns)	1.5	2.3	5.5	57
RFOFO (14 turns)	1.7	2.5	7.2	56
RFOFO (15 turns)	1.6	2.4	6.7	54

PERFORMANCE OF OPEN CAVITY LATTICE – DECAY/STOCHASTICS ON AND OFF

Longitudinal emittance



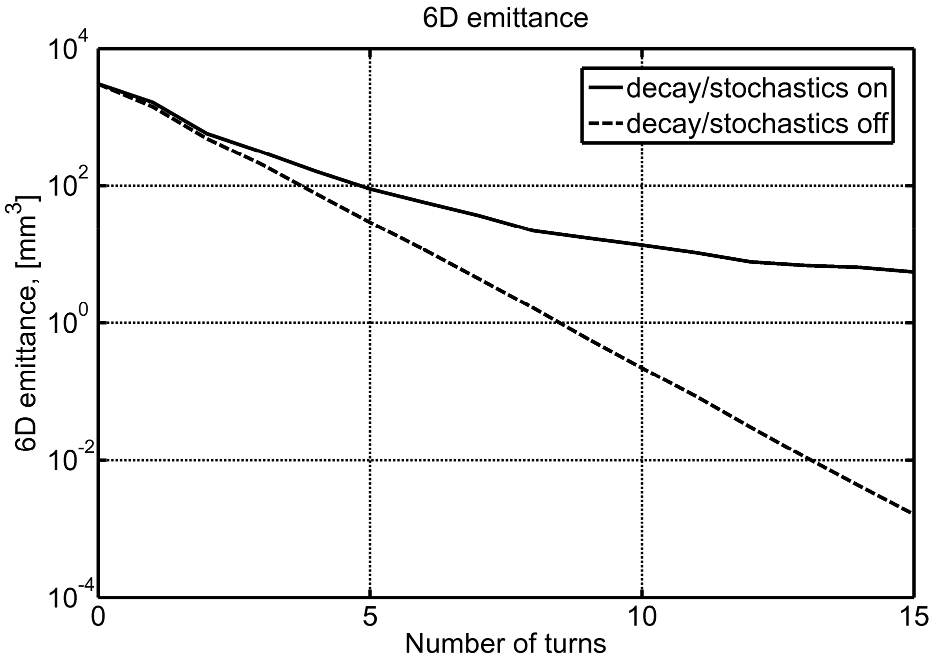
Transverse emittance



No decay/stochastics – no equilibrium emittance – both longitudinal and transverse emittances shrink to zero

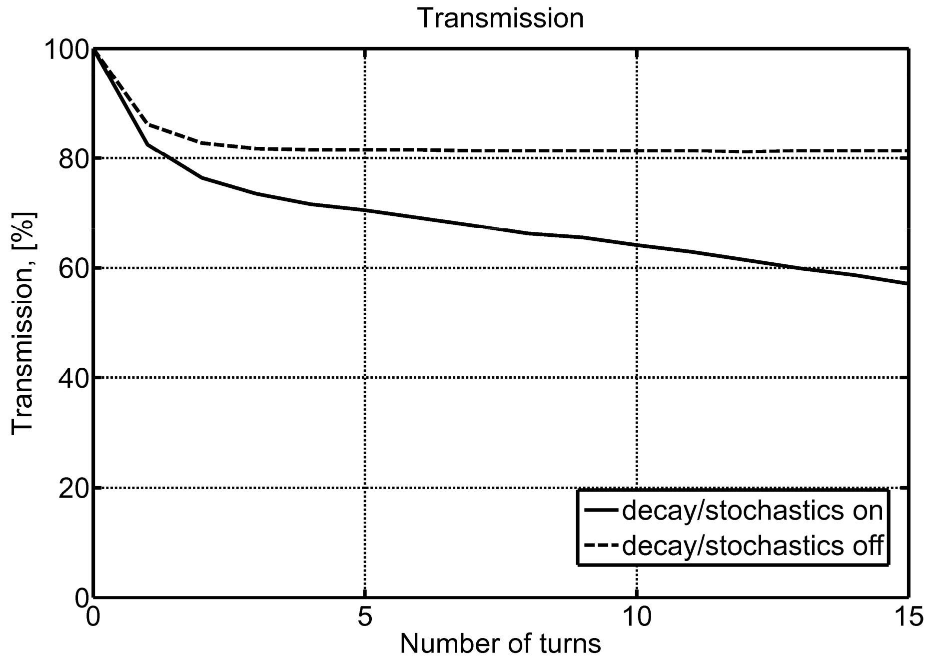
PERFORMANCE OF OPEN CAVITY LATTICE – DECAY/STOCHASTICS ON AND OFF

6D emittance



No decay/stochastics – 6D emittance shrinks exponentially

Transmission



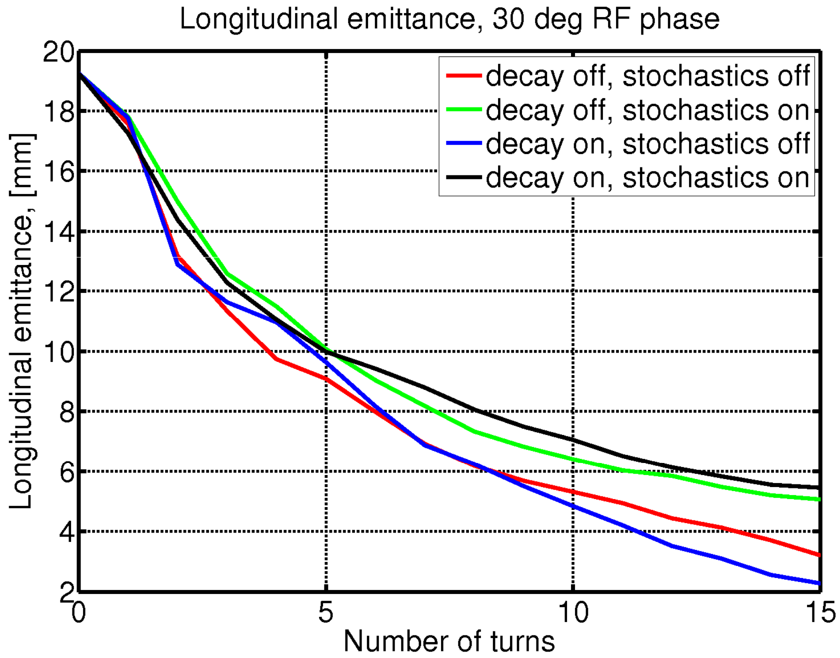
No decay/stochastics – transmission stabilizes after 3 turns to 81%

COMPARISON OF VARIOUS OPEN CAVITY RING DESIGNS AIMED AT REDUCING RF GRADIENT

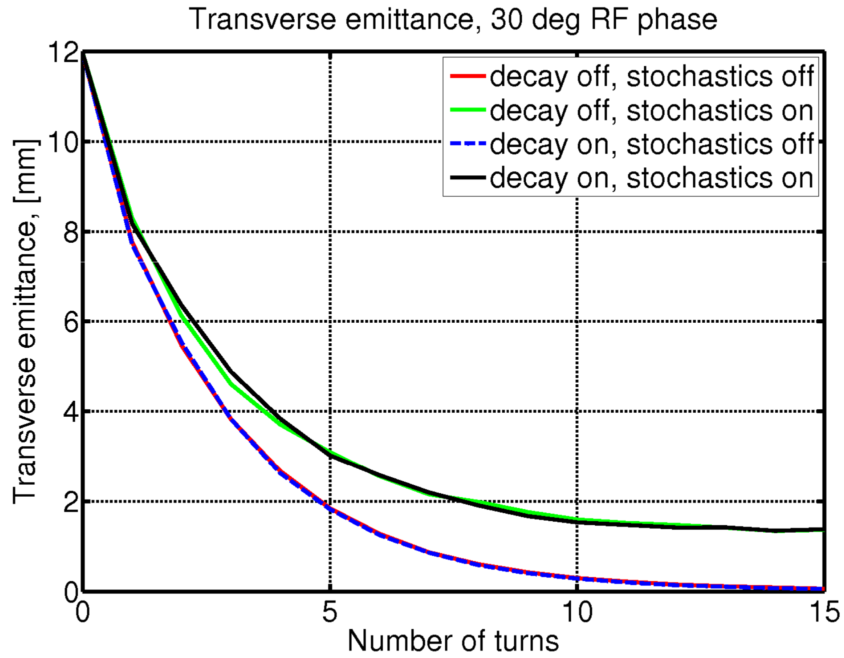
	Open cavity, 30°	Open cavity, 35°	Scaled open cavity, 30°	Scaled open cavity, 35°
R, [m]	4.89	4.89	5.25	5.25
Circumference, [m]	30.72	30.72	33.00	33.00
RF phase, [deg]	30	35	30	35
RF gradient, [MV/m]	16.0	14.0	14.8	12.9
ε_{6D} initial/final, [mm^3]	3000/5.5	3000/5.6	3000/10	3000/9.1
Transmission, 15 turns [%]	57	47	52	50

PERFORMANCE OF OPEN CAVITY LATTICE SCALED WITH 30° RF PHASE

Longitudinal emittance

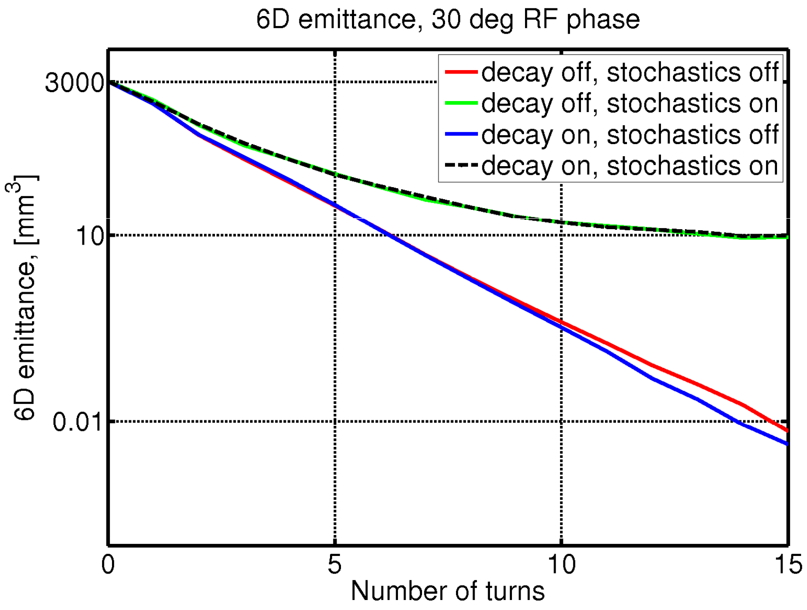


Transverse emittance

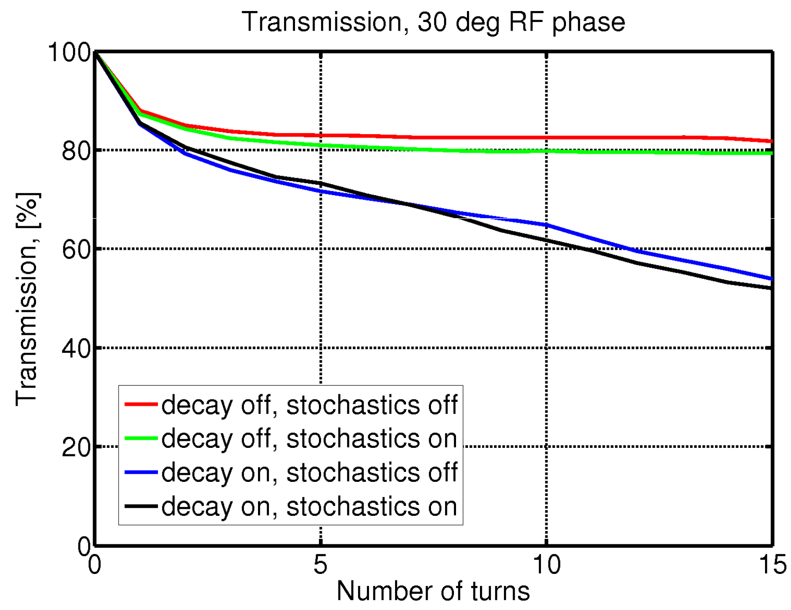


PERFORMANCE OF OPEN CAVITY LATTICE SCALED WITH 30° RF PHASE

6D emittance



Transmission

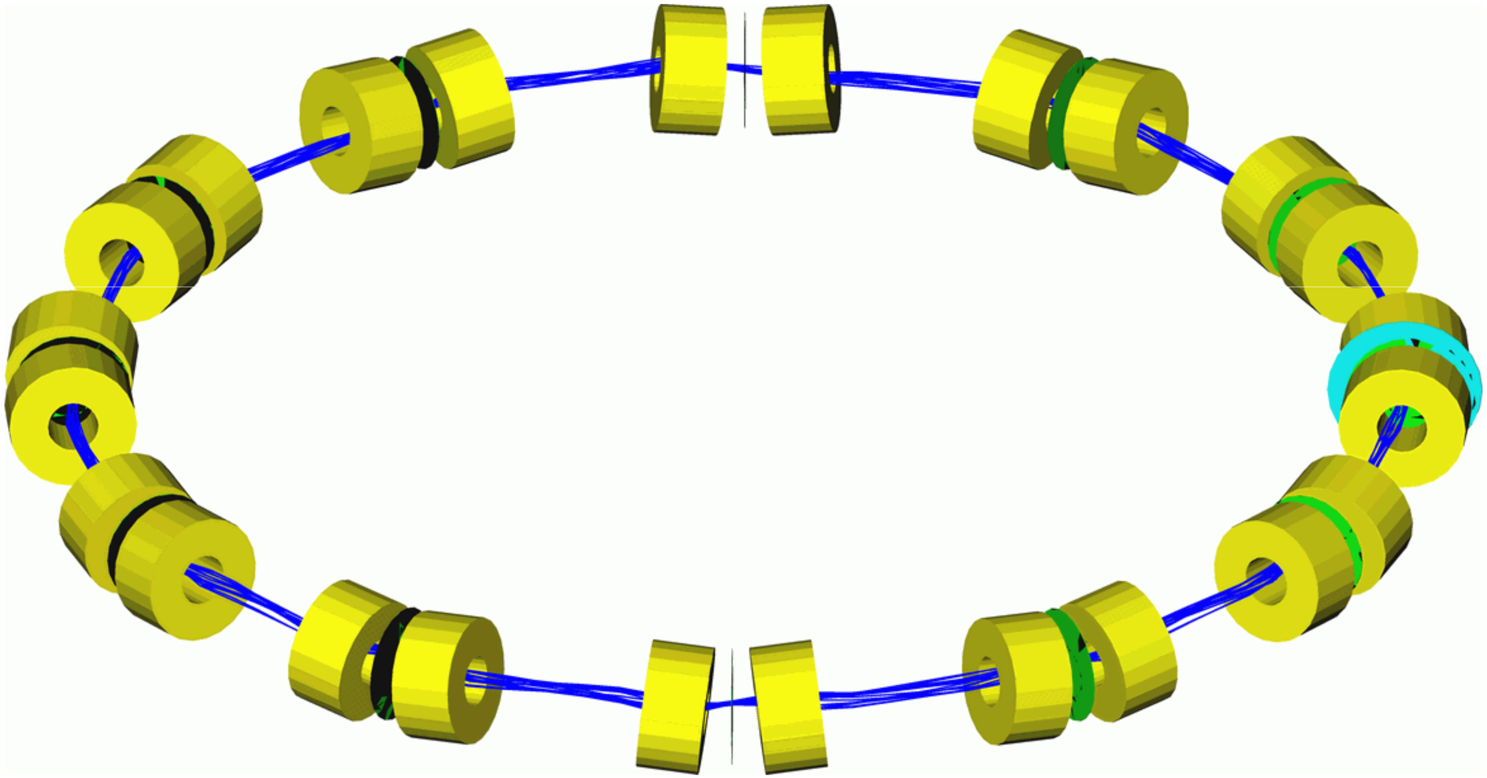


PLANS

- Working on 805 MHz channel simulation in G4Beamline
  - Tipped solenoids vs. constant dipole field (with Rick Fernow)
- Categorize reasons for present transmission losses
- Plus longer term items

805 MHz LATTICE

3D side view



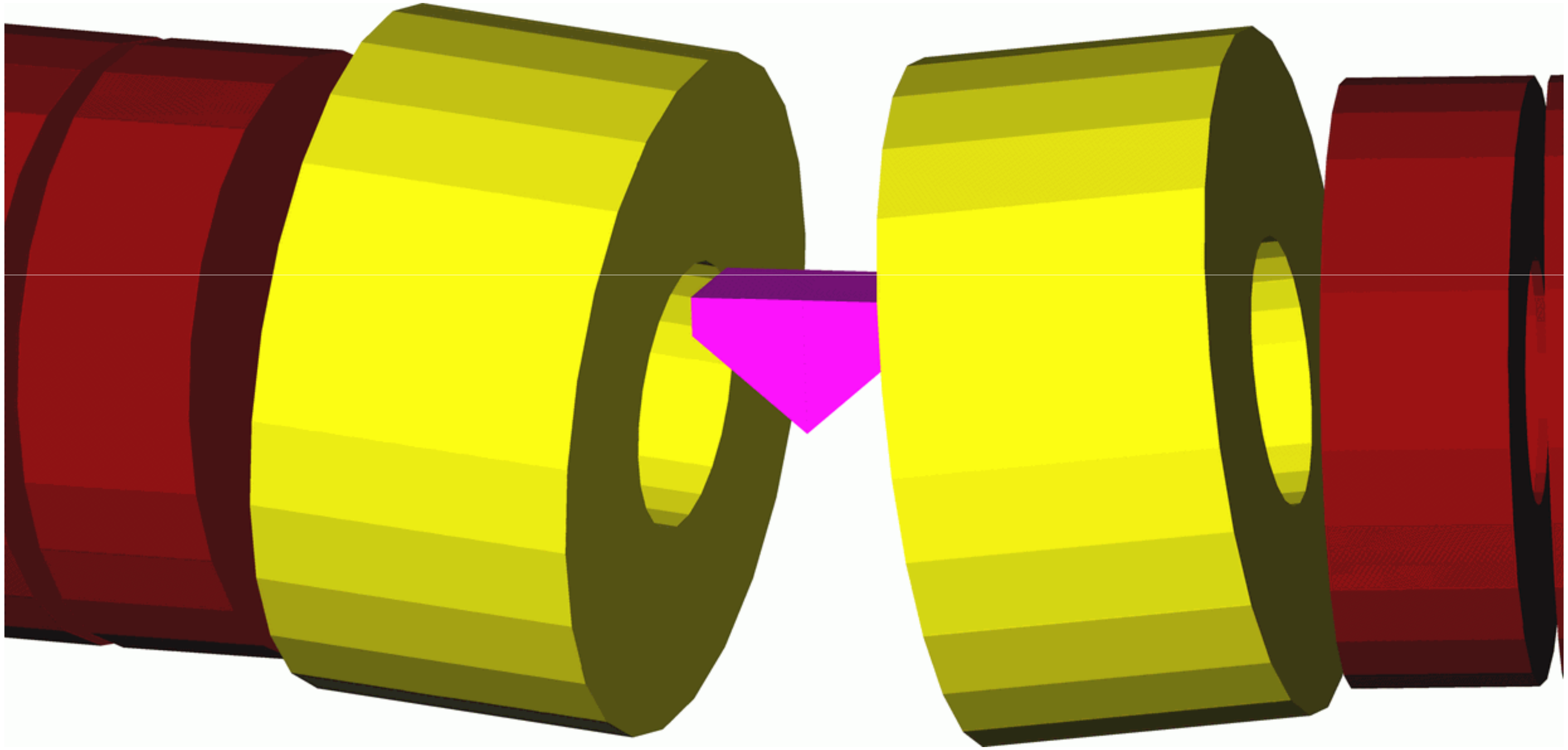
Coil tilt is 5.96 degrees; the lattice is not uniform: coils around absorbers + long straight sections

805 MHz LATTICE PARAMETERS

Radius, [m]	1.719
Circumference, [m]	10.8
Coil tilt, [deg]	5.96
Coil radial offset, [mm]	8
Current density, [A/mm^2]	155.2
Cell length, [m]	0.9
RF length, [cm]	10x4
RF gradient, [MV/m]	16
RF frequency, [MHz]	805
Absorber angle, [deg]	100

805 MHz LATTICE

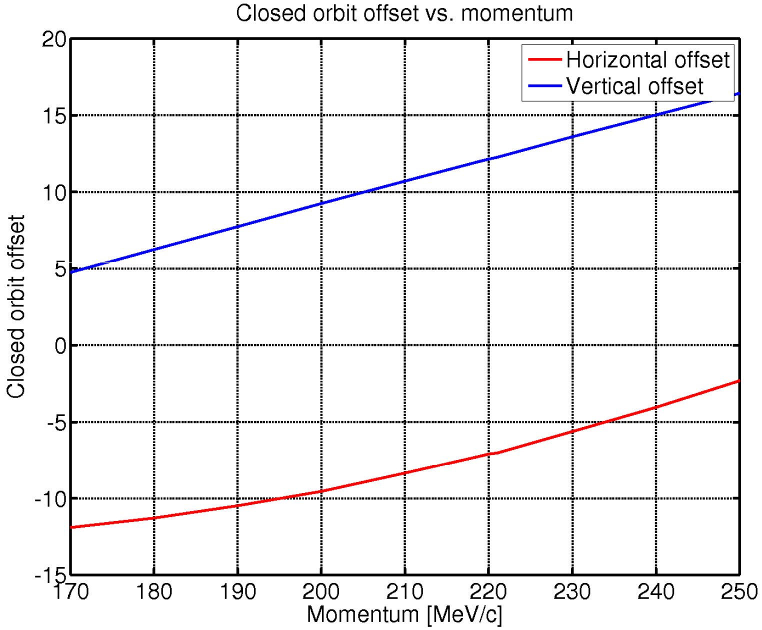
Absorber side view



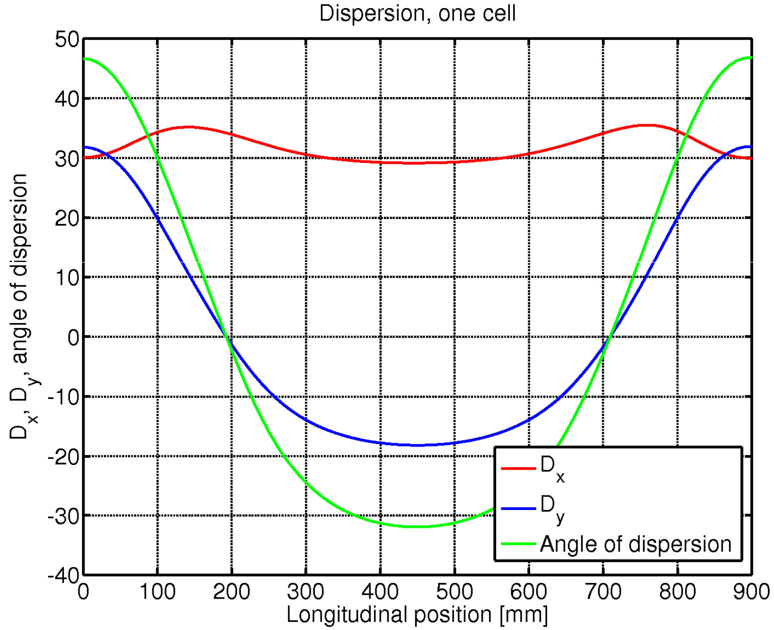
Very little room for the absorber if the coils are tilted; the absorber is narrow with edges cut

805 MHz LATTICE

Closed orbit offset vs momentum

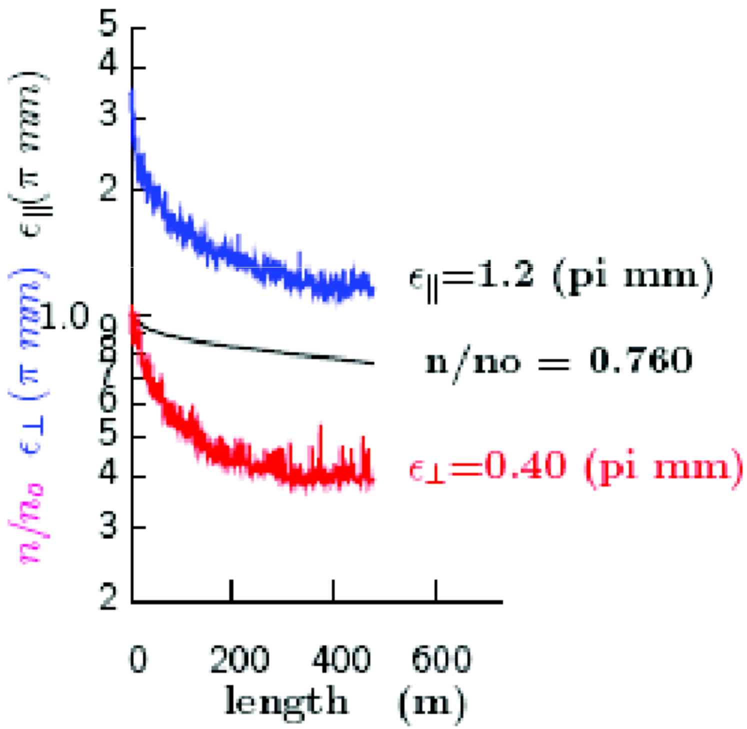


Dispersion



Vertical offset is linear with momentum; horizontal offset is quadratic.
Dispersion at the absorber symmetry plane: Dx=30 mm, Dy=32 mm;
hence, the absorbers should be rotated about 45 deg wrt horizonal,
=> more “real estate” issue

PRELIMINARY TRACKING RESULTS

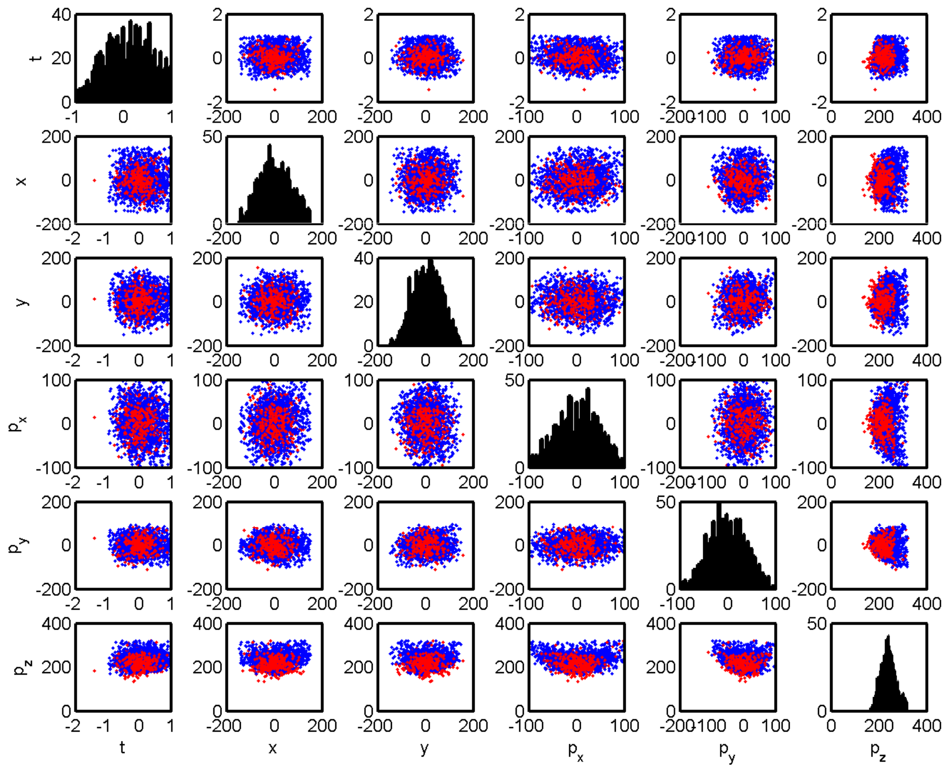


(R. Palmer)

My results so far:

- Transmission is at 50% after 15 turns (162 m)
- No element overlap
- Shortened absorbers ("house shaped")
- Shorter RF cavities, higher gradient (18 MV/m)

TRANSMISSION LOSSES IN A 201 MHz LATTICE



- Looking for a distribution that gets through with no losses
- There is potential (acceptance, blue dots)
- Acceptance is very sensitive to stochastic processes
- Red is the distribution we usually use (Tr=81%)
- More runs should reveal the part of the phase space which is not sensitive to stochastics

SUMMARY

- Open cavity lattice simulation results summarized and compared with RFOFO
- Open cavity lattice scaled and RF phase changed in effort to reduce RF gradient
- 805 MHz lattice preliminary studies presented

EXTRA SLIDES

COMPARISON OF OPEN CAVITY AND RFOFO PERFORMANCE – Q-FACTOR

$$Q = \frac{d\varepsilon_{6D}^{N}/ds}{dN/ds}\,\frac{N(s)}{\varepsilon_{6D}^{N}(s)}$$