RFOFO Cooling Rings

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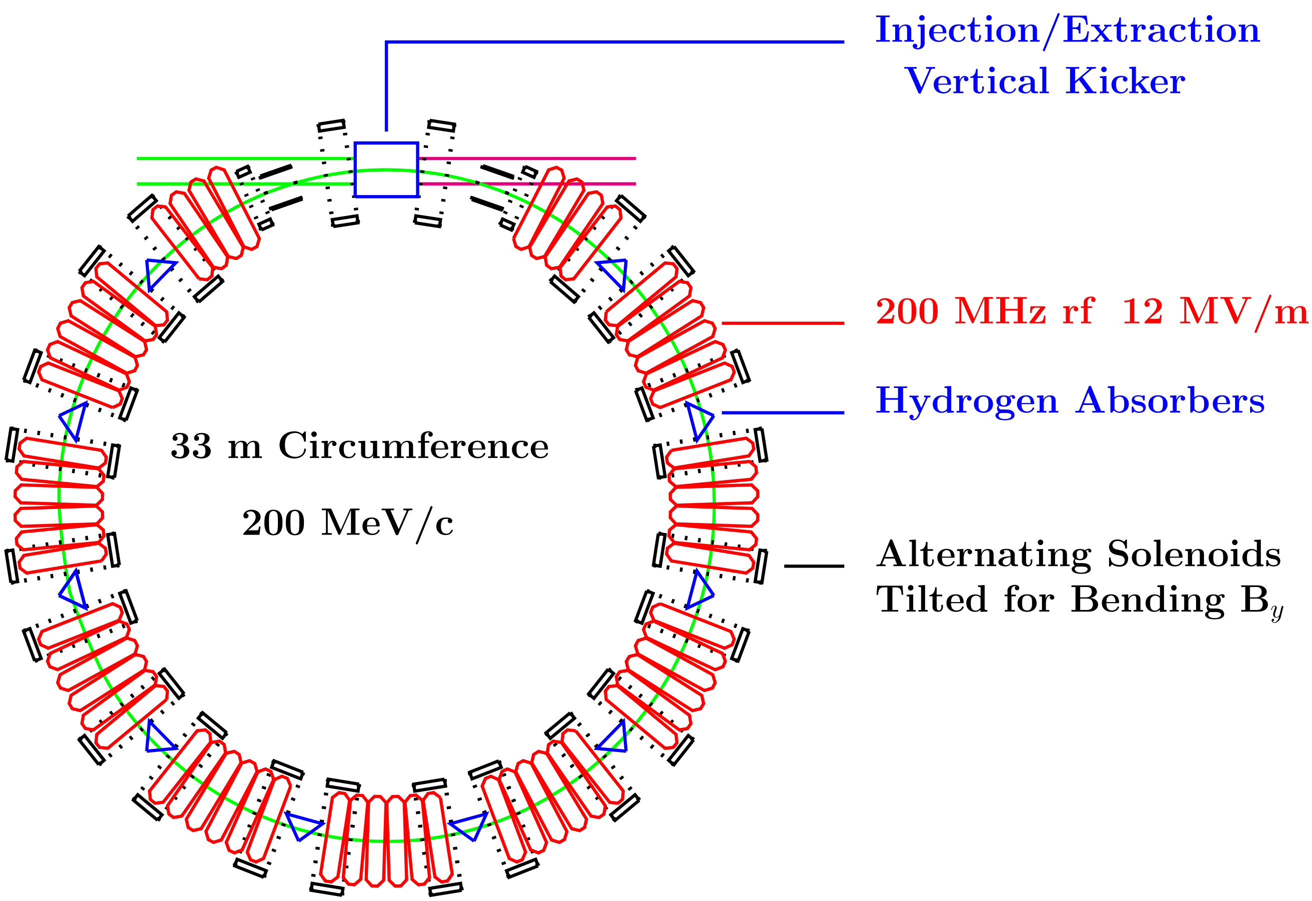
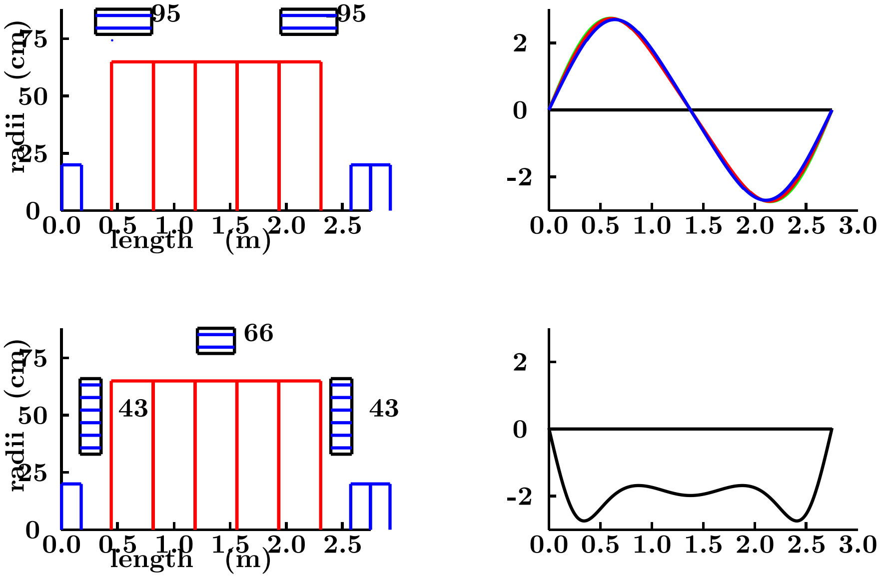
Shelter Island (May 2002)

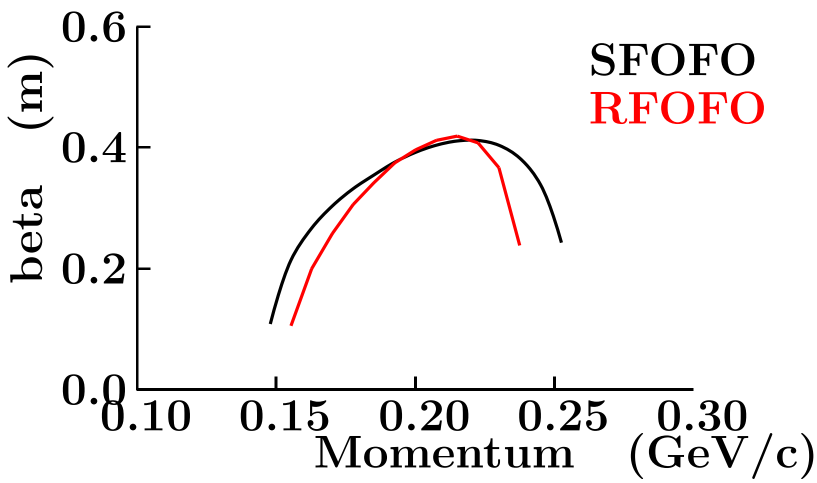


Simple but Sinful:

- **Rf in dispersive location**
- **Bending Field Index n=0**
  i.e. $\beta_x \neq \beta_y$

RFOFO vs SFOFO





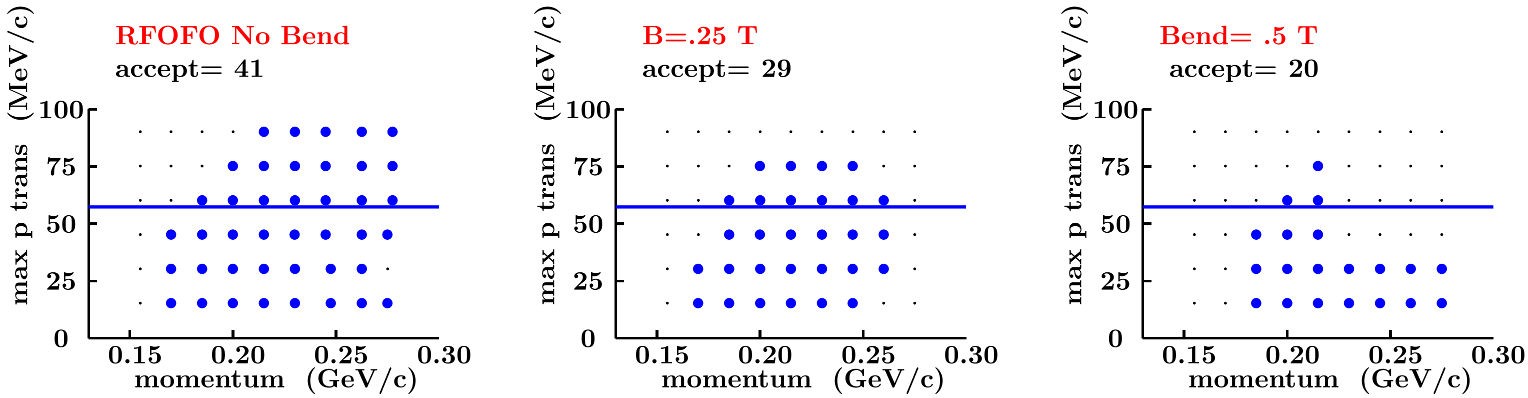
- RFOFO Mom acceptance worse

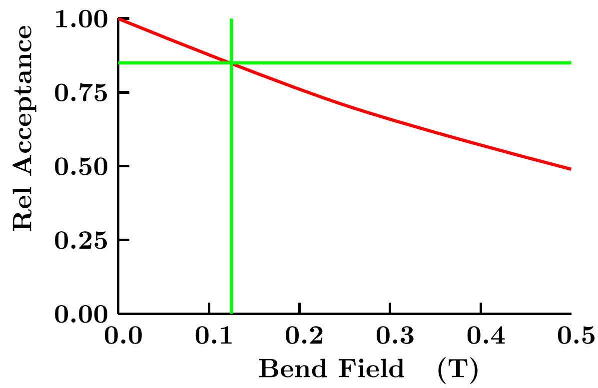
- But all cells the same

- **Fewer resonances**

Try adding By everywhere

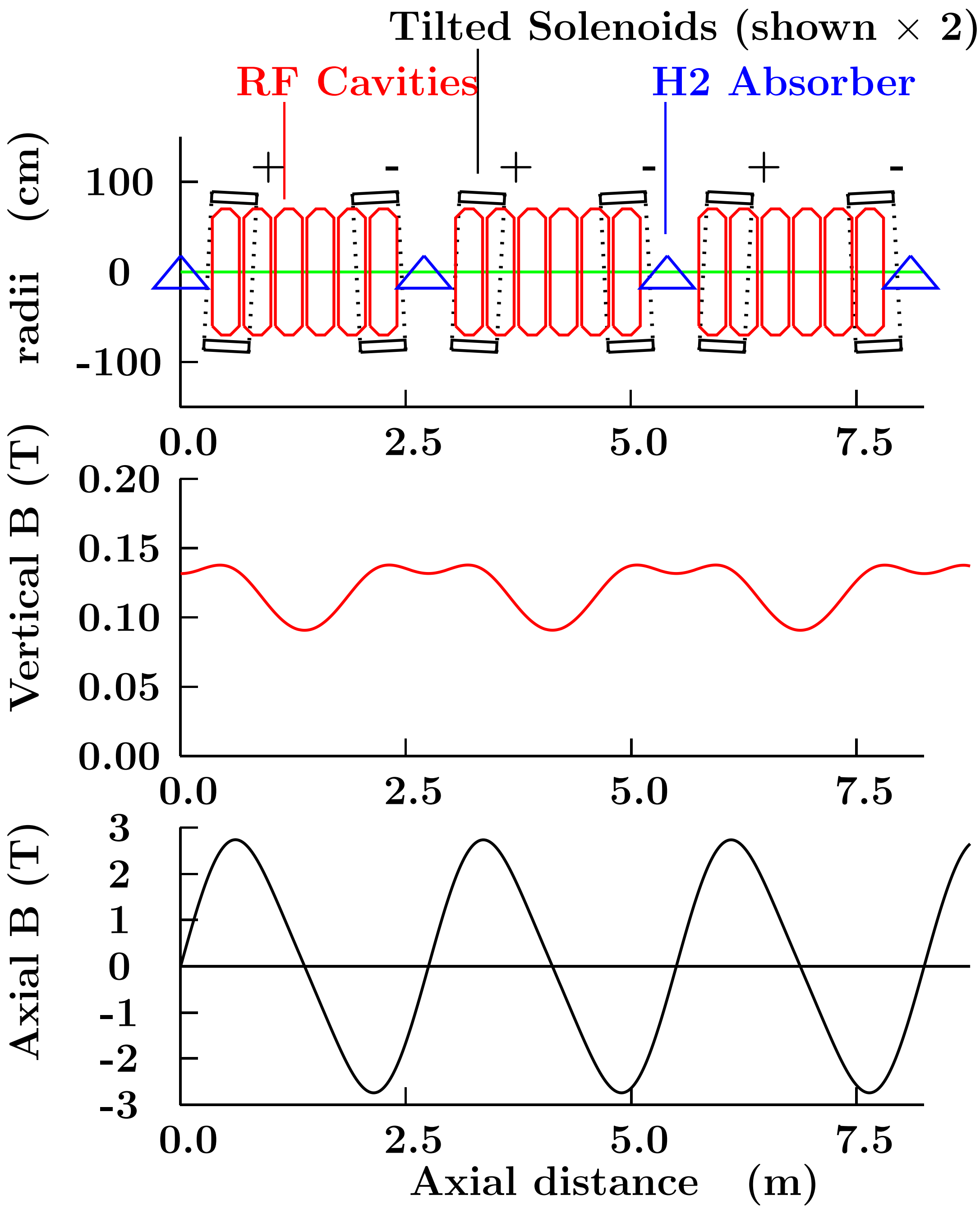
Acceptance vs. Bend Field



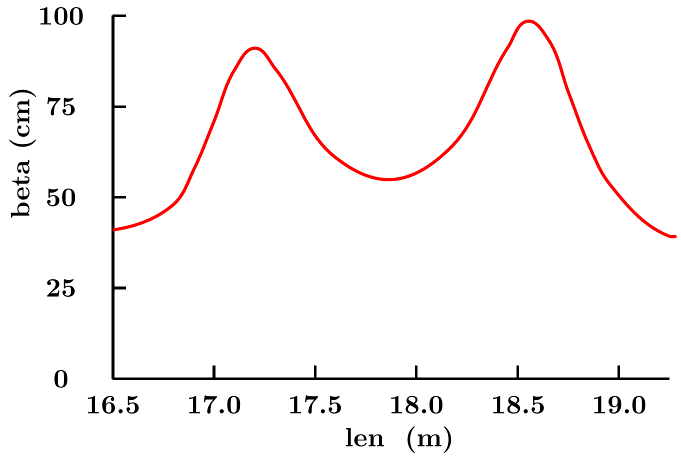


- **Use least possible bend:**
  0.125 T gives 12 cell, 33 m Circ.
- **Ang acceptance 75/200=0.37 rad.**
  $\gg$ any Quad Channel

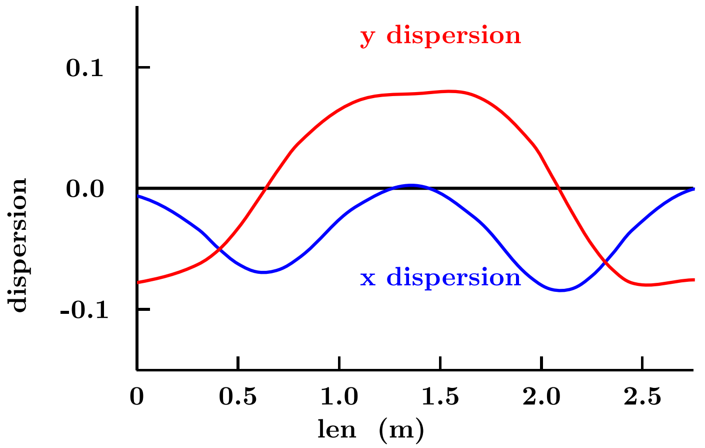
How to generate By



Beta and Dispersion



beta is $\approx$ straight case



Dispersion is rotating back and forth

Params for 1st Simulation

Coils

len1	dl	rad	dr	tilt	I/A
m	m	m	m	deg	A/mm^2
0.300	0.500	0.770	0.110	1.5	95.27
1.950	0.500	0.770	0.110	-1.5	-95.27

amp turns 10.48 (MA)
amp turns length 54.3 (MA m)
cell length 2.75 (m)

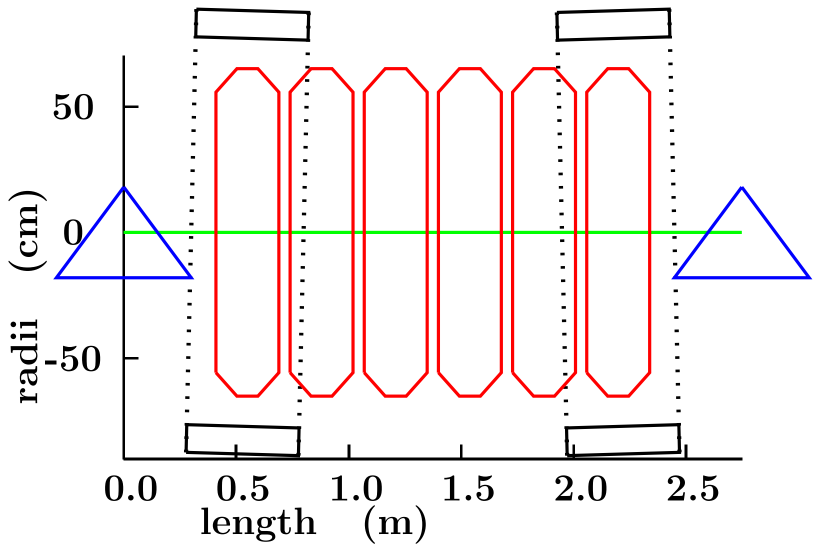
Wedge

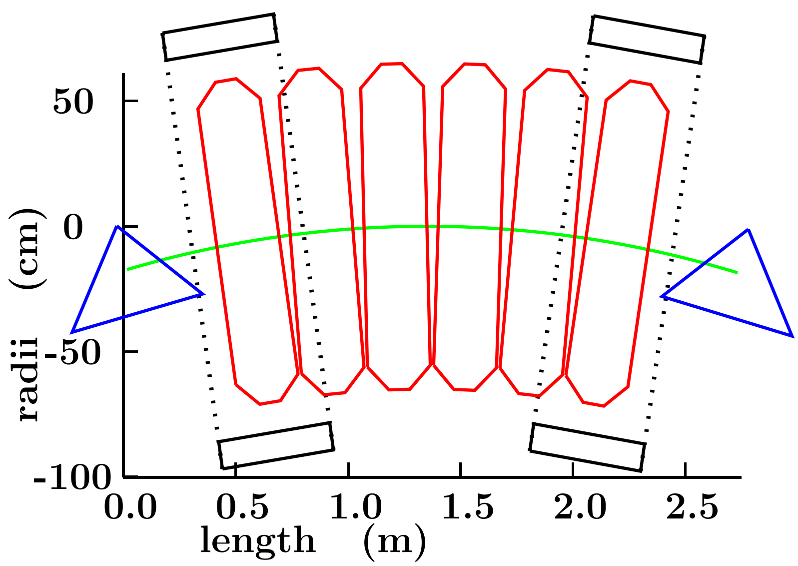
Material		H2
Windows		none
Radius	cm	18
central thickness	cm	28.6
min thickness	cm	0
wedge angle	deg	76.93
wedge azymuth from vertical	deg	30

RF

Cavities		6
Lengths	cm	28
Central gaps	cm	5
Radial aperture	cm	25
Frequency	MHz	201.25
Gradient	MV/m	12
Phase rel to fixed ref	deg	25
Windows		none

RF & Absorber Layout



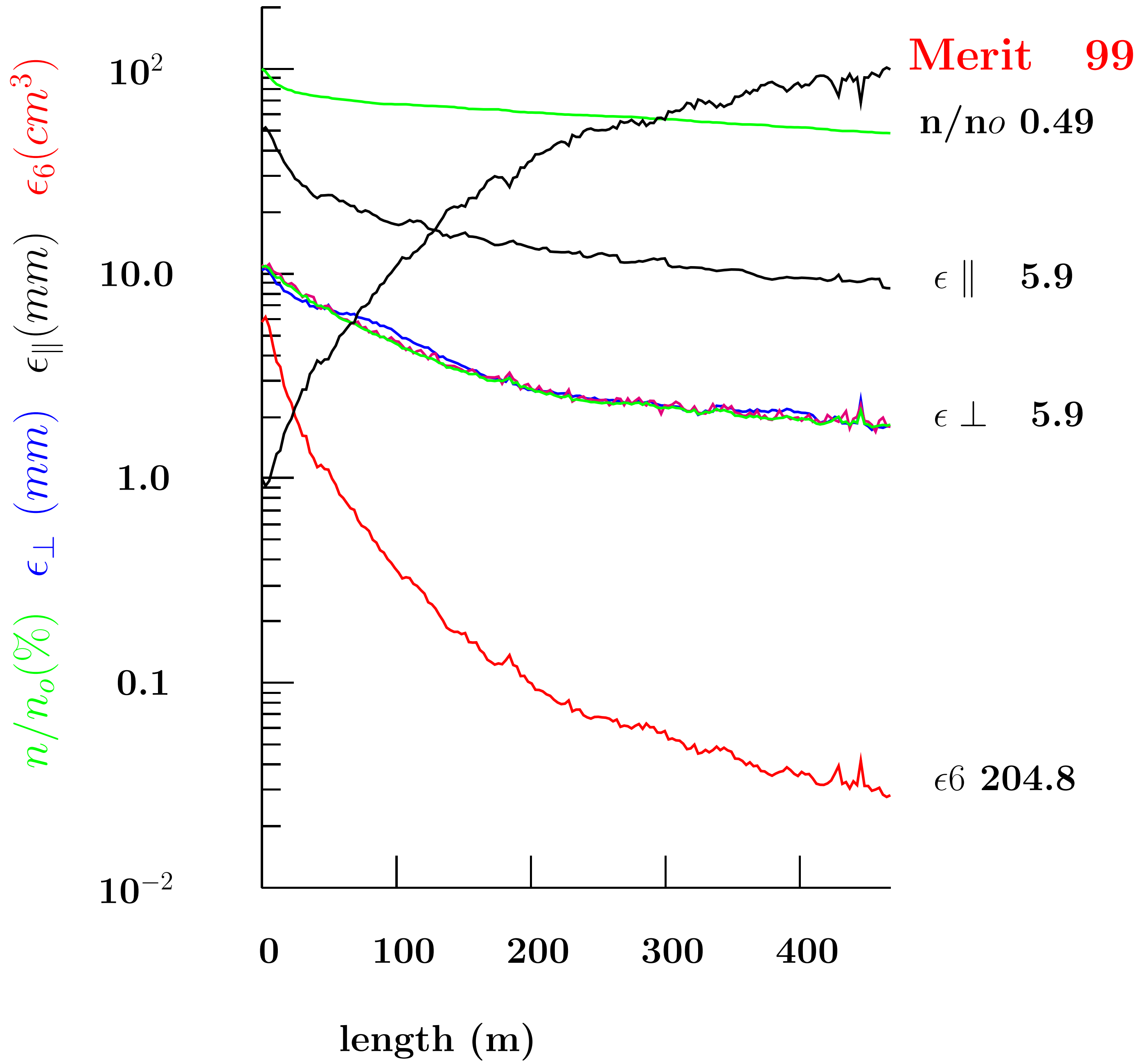


- New ICOOL (2.38) for wedge rf
- Wedges shown 0 and 90 deg.
  true angle 30 deg

ICOOL Simulation

Input From Study 2

n/n = 485 / 1000



Cooling Efficiency

"Merit" is maximized by cooling for as long as possible in a given ring, even if the gains are slow. This will not give the best final performance for multiple rings. We define a local criterion: "Cooling Efficiency" (Q).

Define

$$Q(x) = \frac{d\epsilon_6/\epsilon_6}{dN/N}$$

Note, if Q(x)=constant, then

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

$$Ln\left(\frac{\epsilon_6(n)}{\epsilon_6(o)}\right) = Q \; Ln\left(\frac{N(n)}{N(o)}\right)$$

$$\left(\frac{\epsilon_6(n)}{\epsilon_6(o)}\right) = \left(\frac{N(n)}{N(o)}\right)^Q$$

or

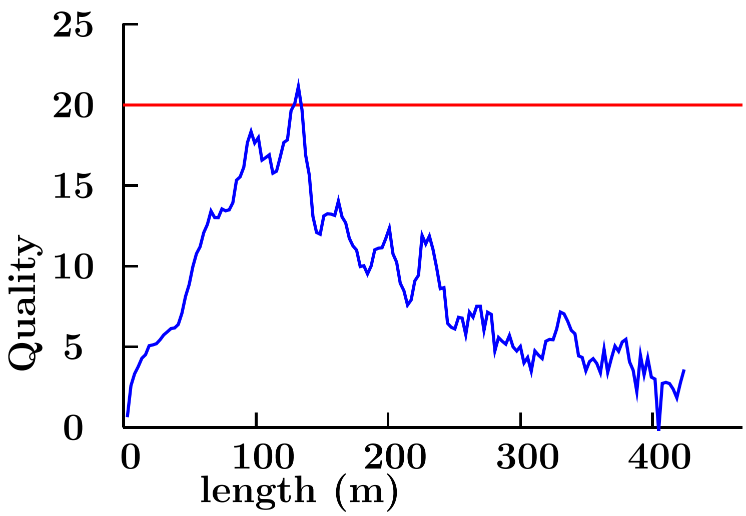
$$\frac{N(n)}{N(o)} = \left(\frac{\epsilon_6(n)}{\epsilon_6(o)}\right)^{1/Q}$$

e.g. for a collider

$$\frac{\epsilon_6(n)}{\epsilon_6(o)} = 10^{-6}, \quad \frac{N(n)}{N(o)} \;=\; \;=\; 0.5$$

$$\text{Required } Q \;=\; ln\left(\frac{10^{-6}}{0.5}\right) \;=\; 20$$

For Hydrogen without windows or Injection/extraction

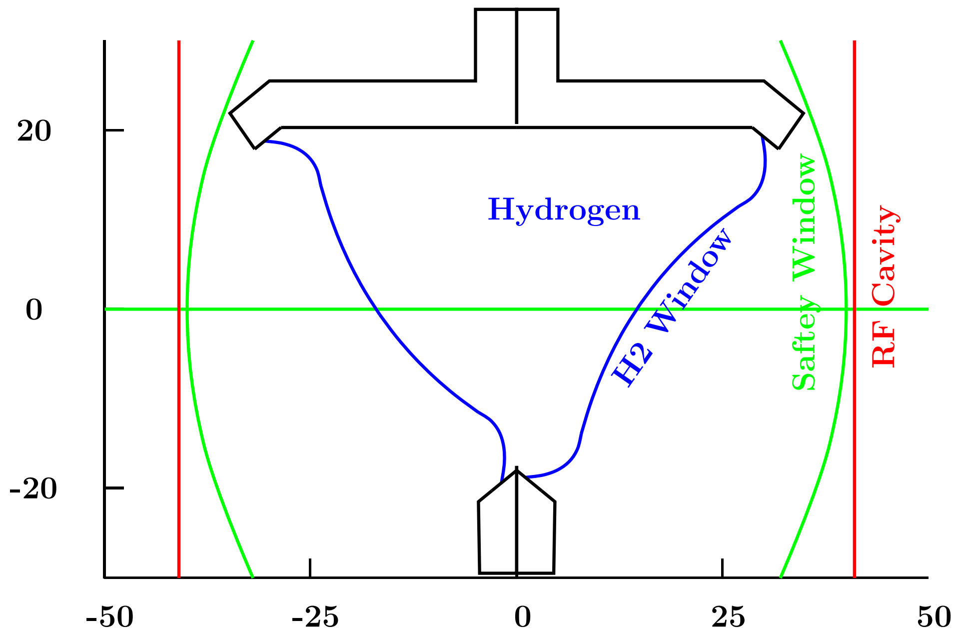


Almost ok even for collider.

But

for only short length
no windows,
no injection/extraction

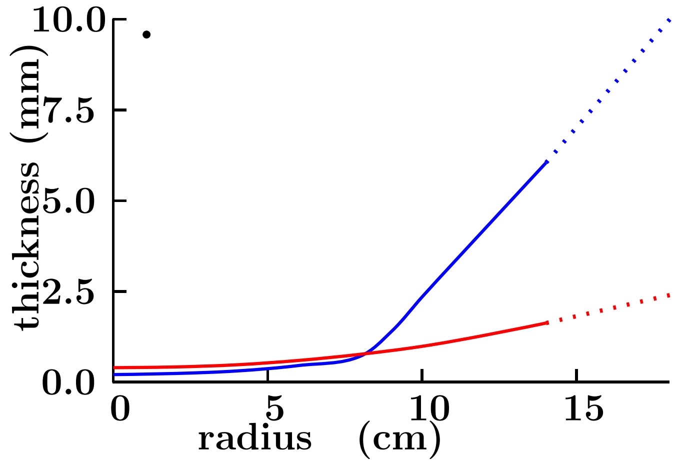
Hydrogen Absorber



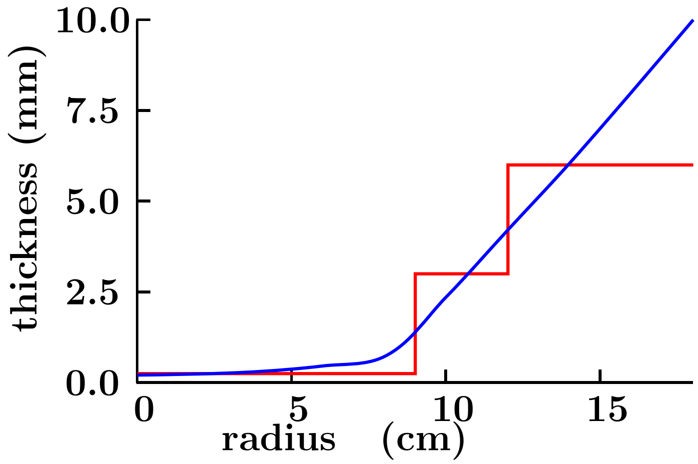
- "Bellows" type Windows
- One Convex, One Concave ?

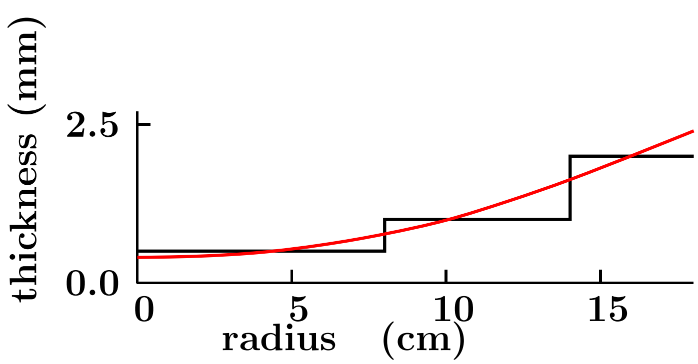
Hydrogen Windows

Compare Conventional & Bellows types



Approximate by steps for ICOOL





ICOOL Results

No RF or Saftey Windows

Absorber	window	center thickness mm	Merit	Maximum Q
Hydrogen	none		92	20
”	Conventional	0.5	31	7
”	Bellows	0.25	41	10
”	Bellows	0.125	61	18
LiH	none		19	7

- Rings are more sensitive to windows than linear cooling
- Maximum Efficiency is less damaged than Merit
- Implies use of more rings: Expensive
- Even 125 micron Al degrades Merit 92 $\rightarrow$ 61
- Must Condider AlBemet, Li, LiH as window materials

RF Windows

- **Current Be Foils too thick**
  although not yet simulated
- **Propose Nitrogen temp RF**
  - **expansion coeff = 1/10**
    →Thinner windows
  - **RF Power = 1/2.5**
  - **Cryo Cost < RF Savings ?**
  - **radiation heating to H2 down**
  - **Same vacuum for RF and Coils**

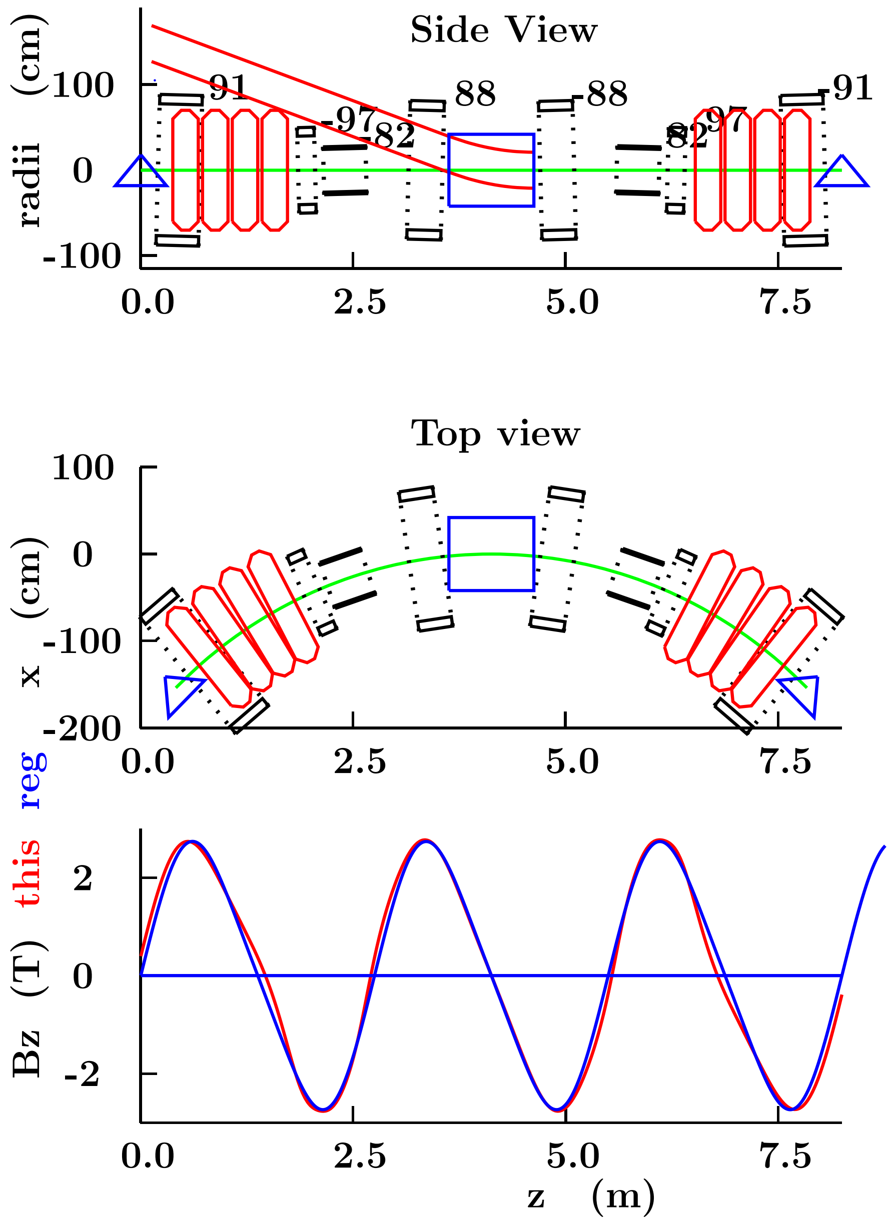
Wall Power if 77 deg RF

If η_{RF} (wall to RF) = 25 %
and η_{Cryo} = 50% of Carnot = 15 %
and rf power = P_{RF}
then

$$\frac{P_{\rm wall}(\rm cold)}{\rm P_{wall}(warm)} = \frac{[P_{RF}/\eta_{RF} \ + \ P_{RF}/\eta_{Cryo}] \ \ /2.5}{P_{RF}/\eta_{RF}} \approx 1.0$$

Not obviously a greater

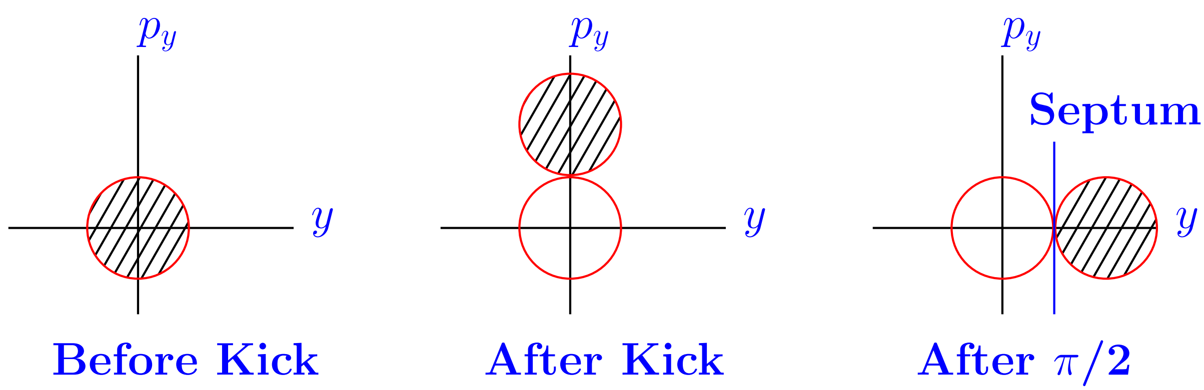
Injection/Extraction



- First Simulation gave Merit = 10
  Synchrotron tune = 2.0: Integer
- Change Circ. to 41 m: Merit = 55
- Improvements probable by matching

Kicker

Minimum Required kick



$$I = \left(\frac{f_\mu \; 4 \; f_\sigma^2 \; m_\mu}{\mu_o \; c}\right) \quad \frac{\epsilon_n}{L}$$

$$V = \left(\frac{f_\Phi \; 4 \; f_\sigma^2 \; m_\mu \; R}{c}\right) \quad \frac{\epsilon_n}{\tau}$$

$$U = \left(f_\mu \; f_\Phi \quad \frac{m_\mu^2 \; 8 \; f_\sigma^4 \; R}{\mu_o \; c^2}\right) \quad \frac{\epsilon_n^2}{L}$$

- **muon** ϵ_n $\gg$ **other** ϵ_n**'s**
- **So muon kicker Joules** $\gg$ **other kickers**
- **Nearest are** $\bar{p}$ **kickers**

Compare with others

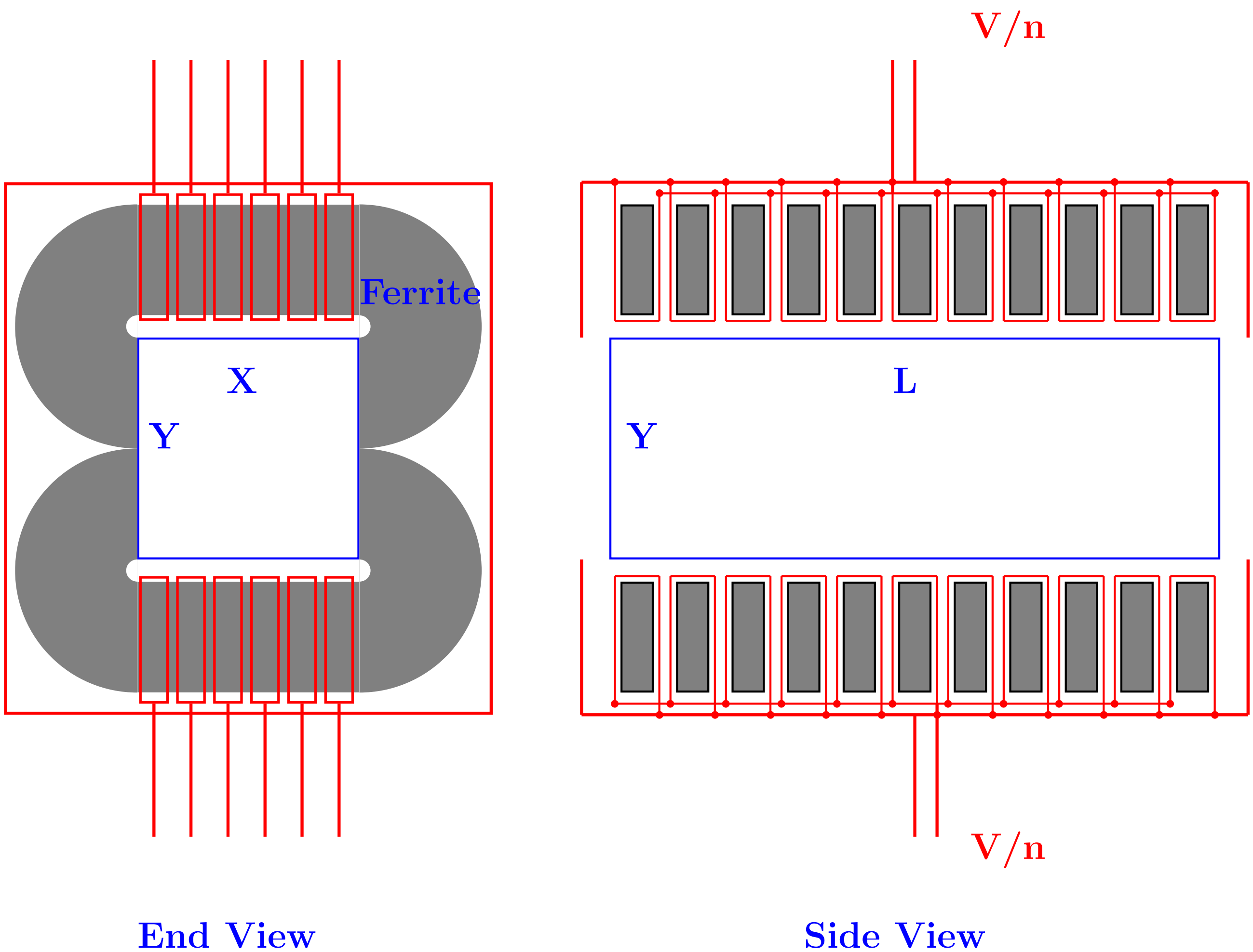
		μ Cooling	CERN $\bar{p}$	Ind Linac
$\int Bd\ell$	Tm	.30	.088	
L	m	1.0	≈5	5.0
$t_{\rm rise}$	ns	50	90	40
B	T	.30	≈0.018	0.6
X	m	.42	.08	
Y	m	.63	.25	
$V_{\rm 1turn}$	kV	3,970	800	5,000
$U_{\rm magnetic}$	J	10,450	≈13	8000

Note

- J is 3 orders above $\bar{p}$
- Same order as Induction
- And t same order
- But V is too High

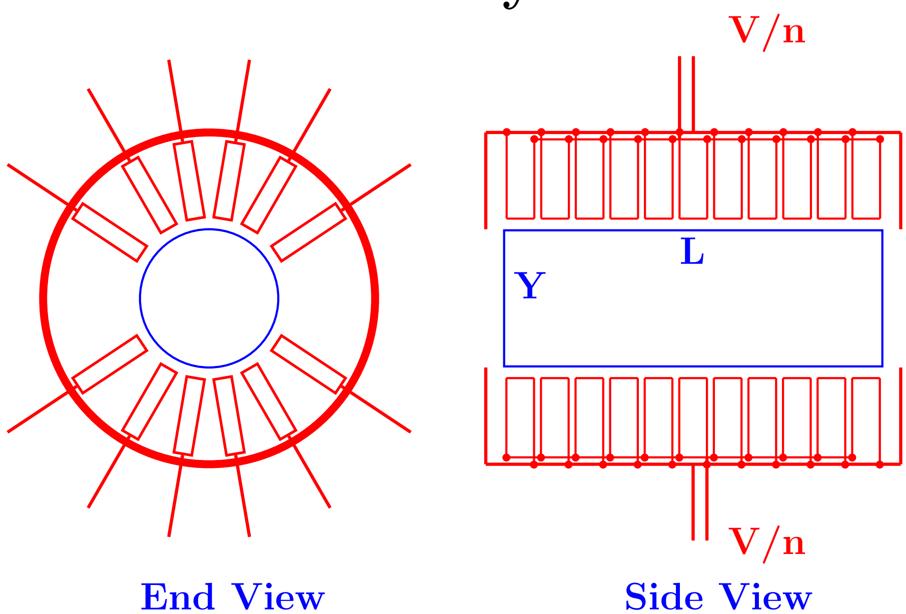
New Idea

- **Drive Flux Return**
- **Subdivide Flux Return**
- **Conducting Box Removes Stray Field Return**



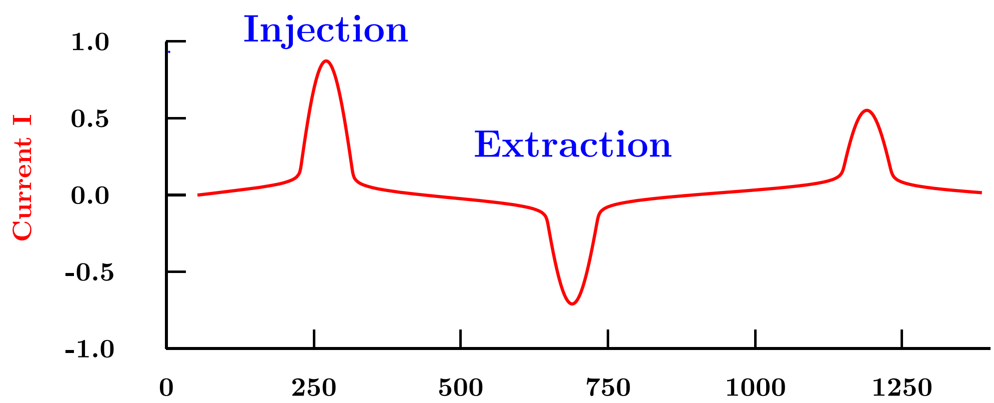
Works with no Ferrite

- **V = the same**
- **U**$\approx$ $2\times$
- **I**$\approx$ $2\times$
- **No rise time limit**
- **Not effected by solenoid fields**

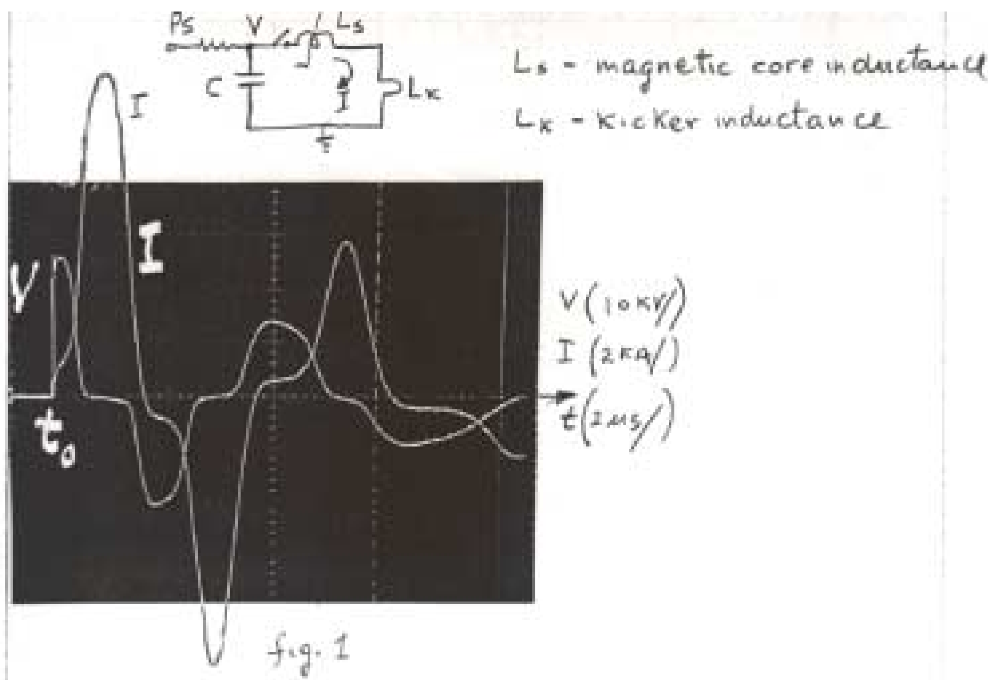


- **If non Resonant: 2 Drivers for inj. & extract.**
  Need 24 $\times$2 Magamps ($\approx$ 20 M\$)
- **If Resonant: 1 Driver, 2$\times$efficient**
  Need 12 Magamps ($\approx$ 5 M\$)

Resonant Circuit



Circuit Model



- May be hard for many turns
- Not simulated with initial stages

Conclusion

- **Much better than Quad Rings**
- **Similar to Balbakov's**
- **But Maxwellian & Realistic Fields**

Need to Study

- **Integration in a system**
  Front end, E, freq etc
- **Wedge absorber design**
- **Thin H2 windows,**
  e.g. AlBemet
- **Thin Be Windows,**
  e.g. Nitrogen Temp RF
- **Injection Extraction Tracking**
- **Kicker**
- **Cost Reduction (Don's idea)**
- **SFOFO More Sin:**
  Pi Resonance in Acceptance.
  Valeri gets away with it.