Ring Coolers

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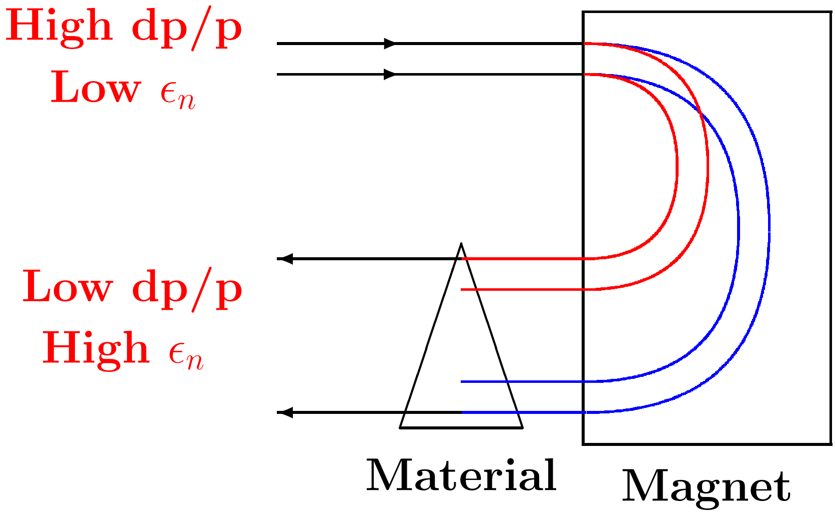
Longitudinal Cooling



- dp/p reduced
- But σ_y increased
- Long Emittance reduced
- Trans Emittance Increased
- "Emittance Exchange"
- **Needs Bending for Dispersion**
- **Suggests a Ring**

Emittance Exchange Studies

- Attempted **separate** cooling & exch.
  - Wedges in Bent Solenoids
  - Wedges in Helical Channels[1]
    Poor performance
- Rings with **alternate** cooling & exchange
  - Balbakov[2] with solenoid focus
    achieved Merit ≈**38-100**
- Rings with **combined** cooling & exchange
  - Garren et al[3] Quadrupole focused ring
    achieved Merit ≈**16**
  - Palmer et al Solenoid lattice[4]
    achieved Merit ≈**160-200**

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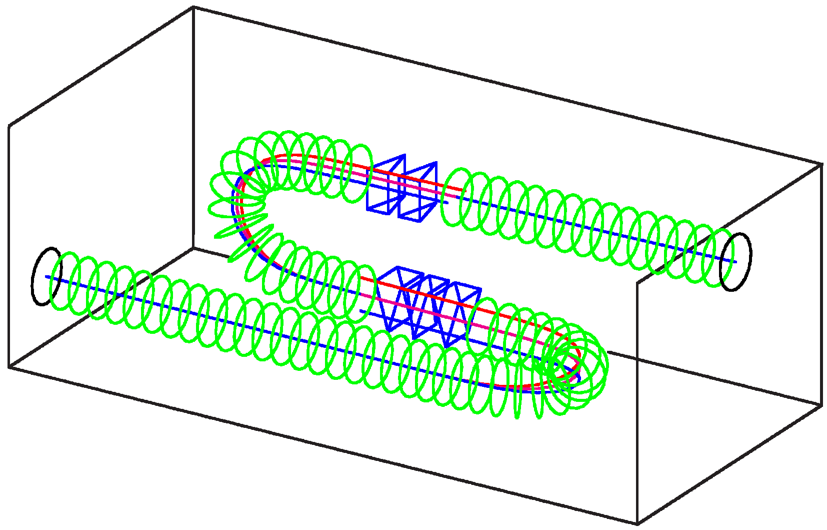
[1]MUC-146, 147, 187, & 193
[2]MUC-232 & 246
[3]Snowmass Proc.
[4]MUC-239

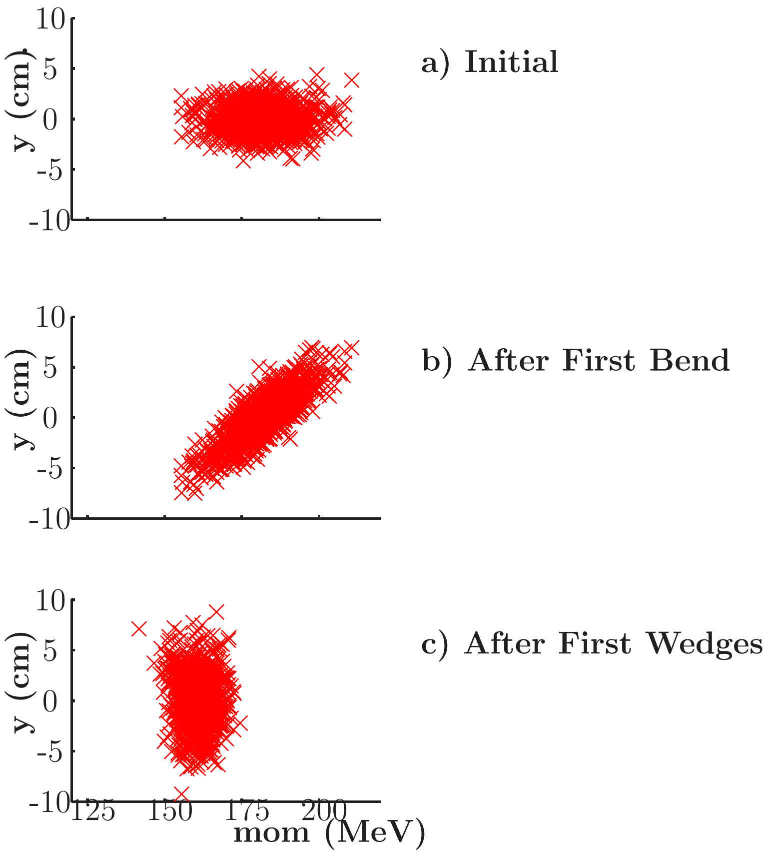
Early Concept of Bent Solenoids



Horizontal Bend $\longrightarrow$ Vert Dispersion
Wedge removes Disp. $\longrightarrow$ increases y
Vertical Bend Horizontal $\longrightarrow$ Dispersion
Wedge removes Disp. $\longrightarrow$ increases x

- dp/p reduced
- Emittance x and y increased

Simulation of 1 Bend

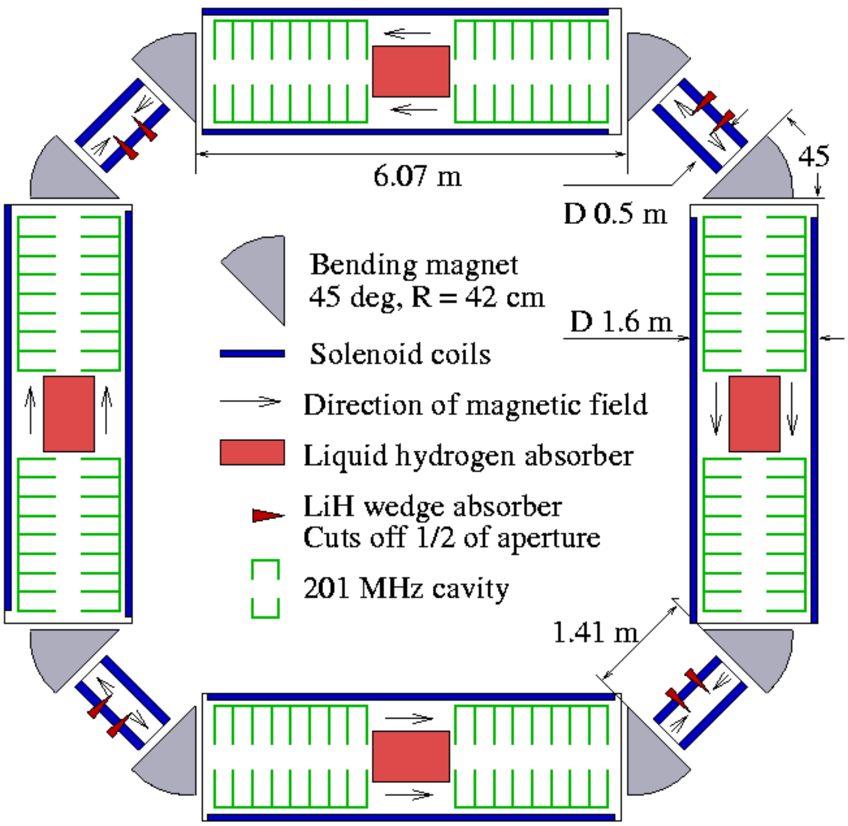


But Longitudinal Dynamics a Disaster:

- Too long without RF
- Works poorly with RF
- hard to match to transverse channel

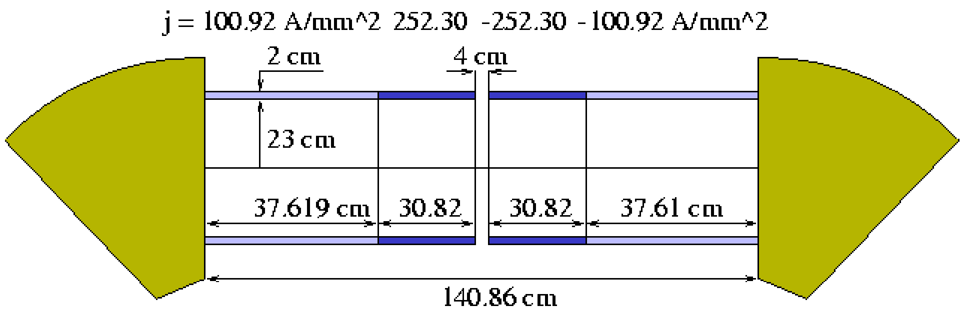
Balbekov 6D Cooling Ring

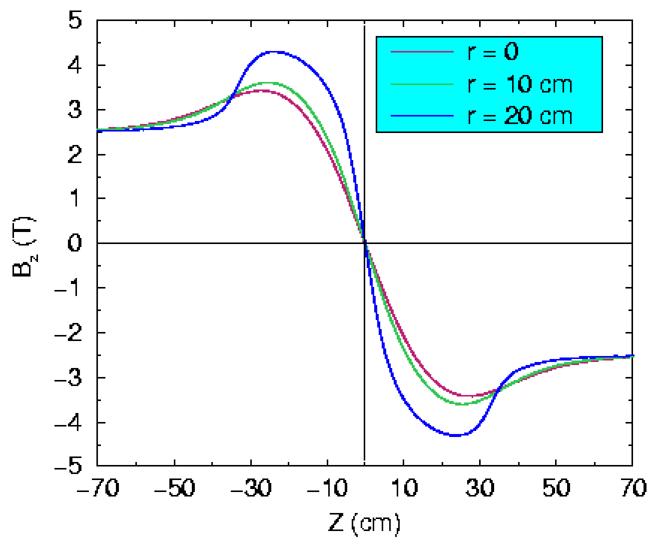
Alternate transverse cooling with H2 with emittance exchange in Li wedge



Circumference	36.963 m
Cell Length	2.27+6.97=9.25 m
Energy	250 MeV
Max B_z	5.155 T
RF Frequency	205.69 MHz
Gradient	15 MV/m

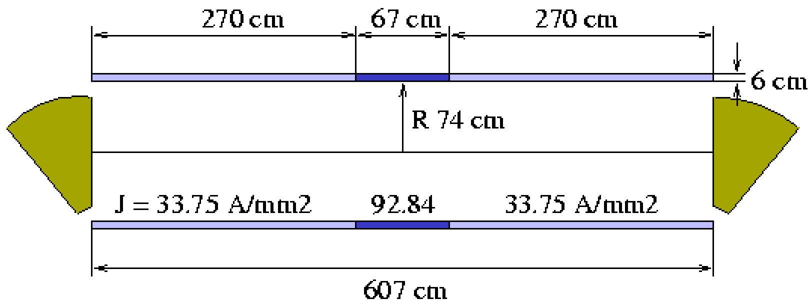
Short Straight

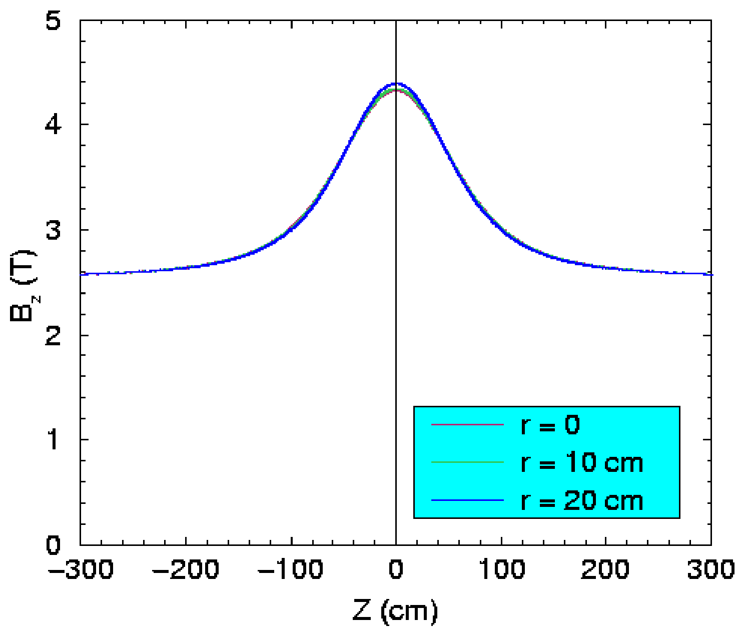




- Field flip in center
- Max Dispersion in center
- LiH Wedge in center

Long Straight

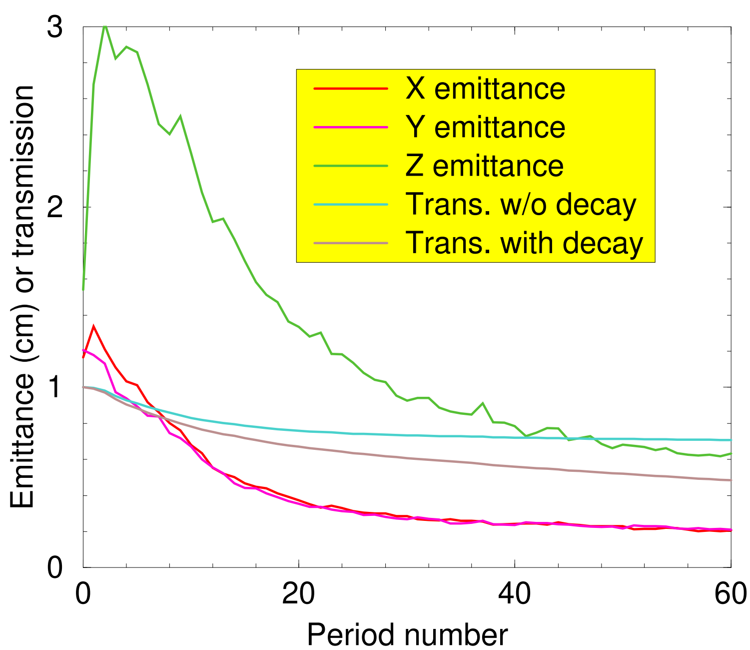




- No flip & No Dispersion
- Higher field & lower β at center
- Hydrogen Absorber at center
- RF on either side

Performance

	Before	After	Ratio
$\epsilon_\perp$ (cm)	1.2	0.21	5.7
$\epsilon_\parallel$ (cm)	1.5	0.63	2.4
ϵ_6 (cm^3)	2.2	0.028	79
N/N_0, no decay	1	0.71	0.71
N/N_0, inc. decay	1	0.48	0.48
Merit	1	38	**38**



Conclusion for Balbakov

- Good cooling in all dimensions **FIRST**
- Merit Factor 38
  Fernow with ICOOL got 94

BUT

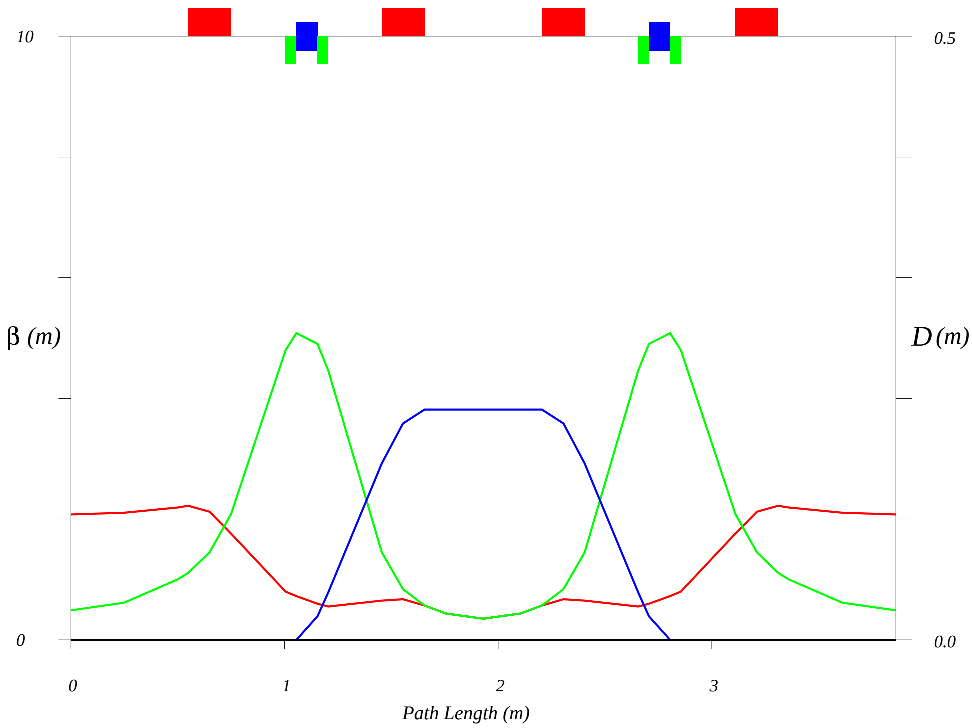
- Calculated without Maxwellian fields
- Design of bends proving hard
- Injection and extraction very hard
  Merit $\rightarrow$ 3.9 with missing rf

Quadrupole Ring

Garren, Kirk et al

- Motivation
  - Easier to design lattice (dispersion suppression, etc.)
  - More experience than with solenoids
- Thick wedge: both cooling and longitudinal/transverse coupling
- Long. and Transverse in same Cell
- Limit phase advance per cell
- Avoid crossing resonances

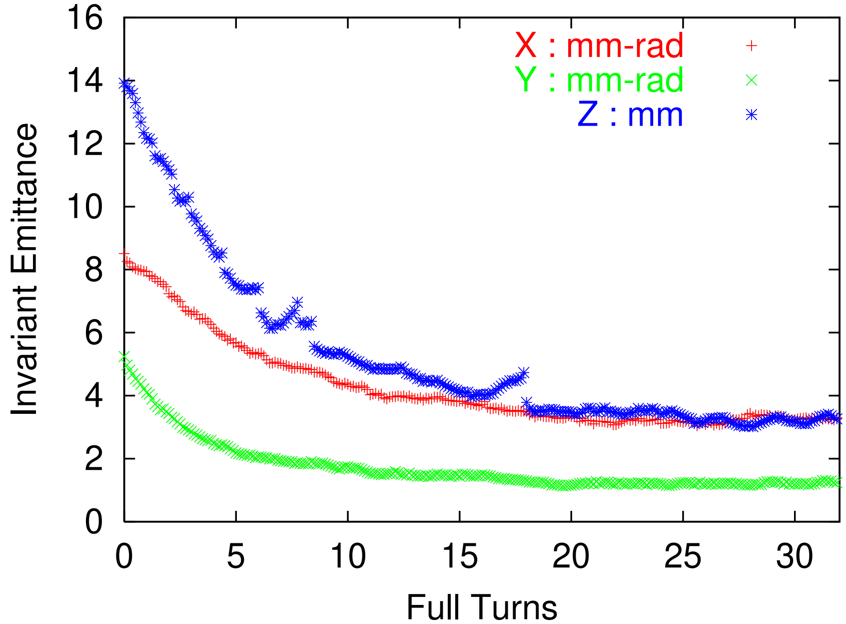
One of 8 Cells

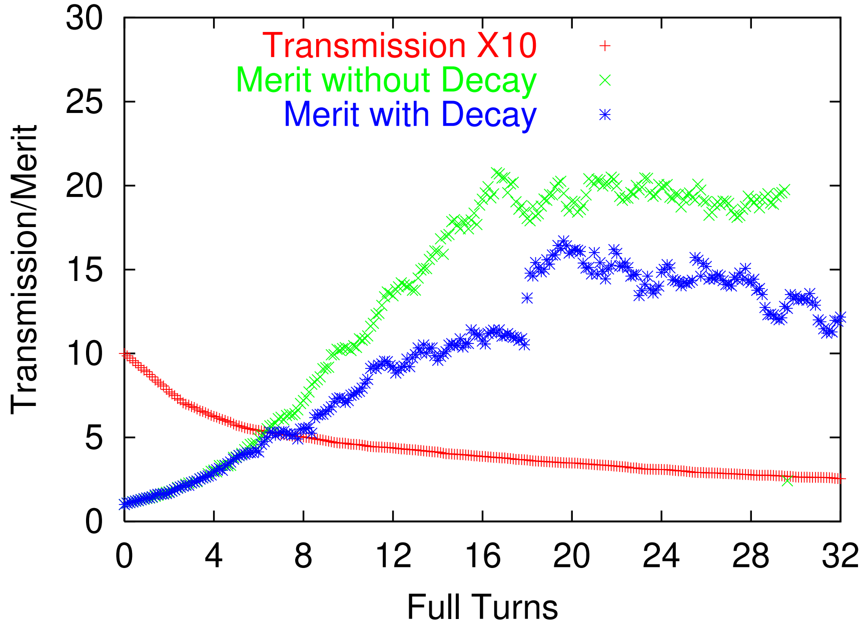


Parameters

Circumference	31 m
Cell Length	3.8 m
Momentum	250 MeV/c
Magnet aperture (full)	40 cm
Max pole tip field	2 T
RF Frequency	200 MHz
RF Gradient	16 MV/m

Performance





	Before	After	ratio
ϵ_x (mm)	8.5	3.4	2.5
ϵ_y (mm)	5.2	1.2	4.2
$\epsilon_\parallel$ (mm)	14	3.8	3.7
ϵ_6 (mm^3)	0.62	0.015	39
N/N_0, inc. decay	1	0.41	.41
Merit	1	16	**16**

Conclusion

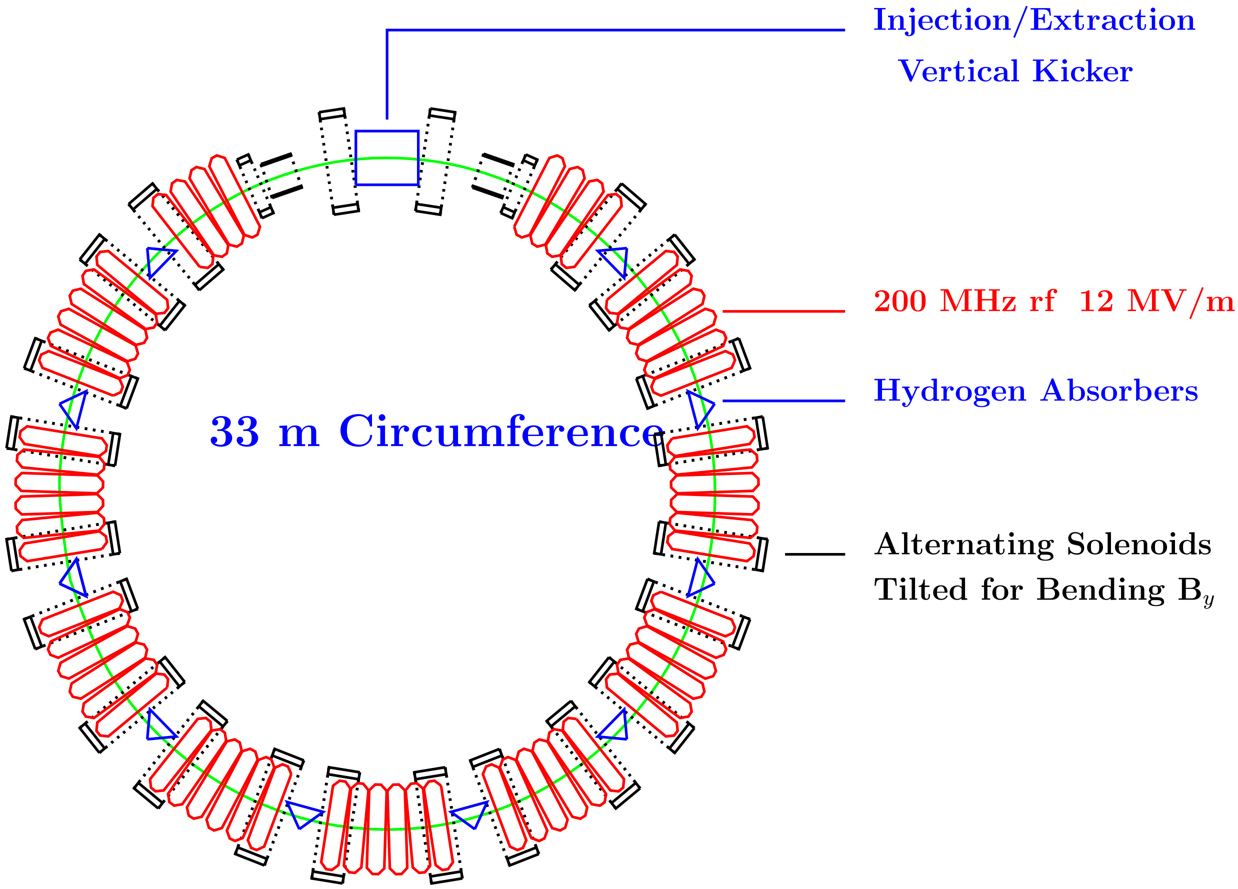
- Final trans. emittance similar to Balbakov
- Longitudinal emittance lower than Balbakov

BUT

- Currently Less acceptance and thus less Merit
- Probably due to use of Quads vs Solenoids

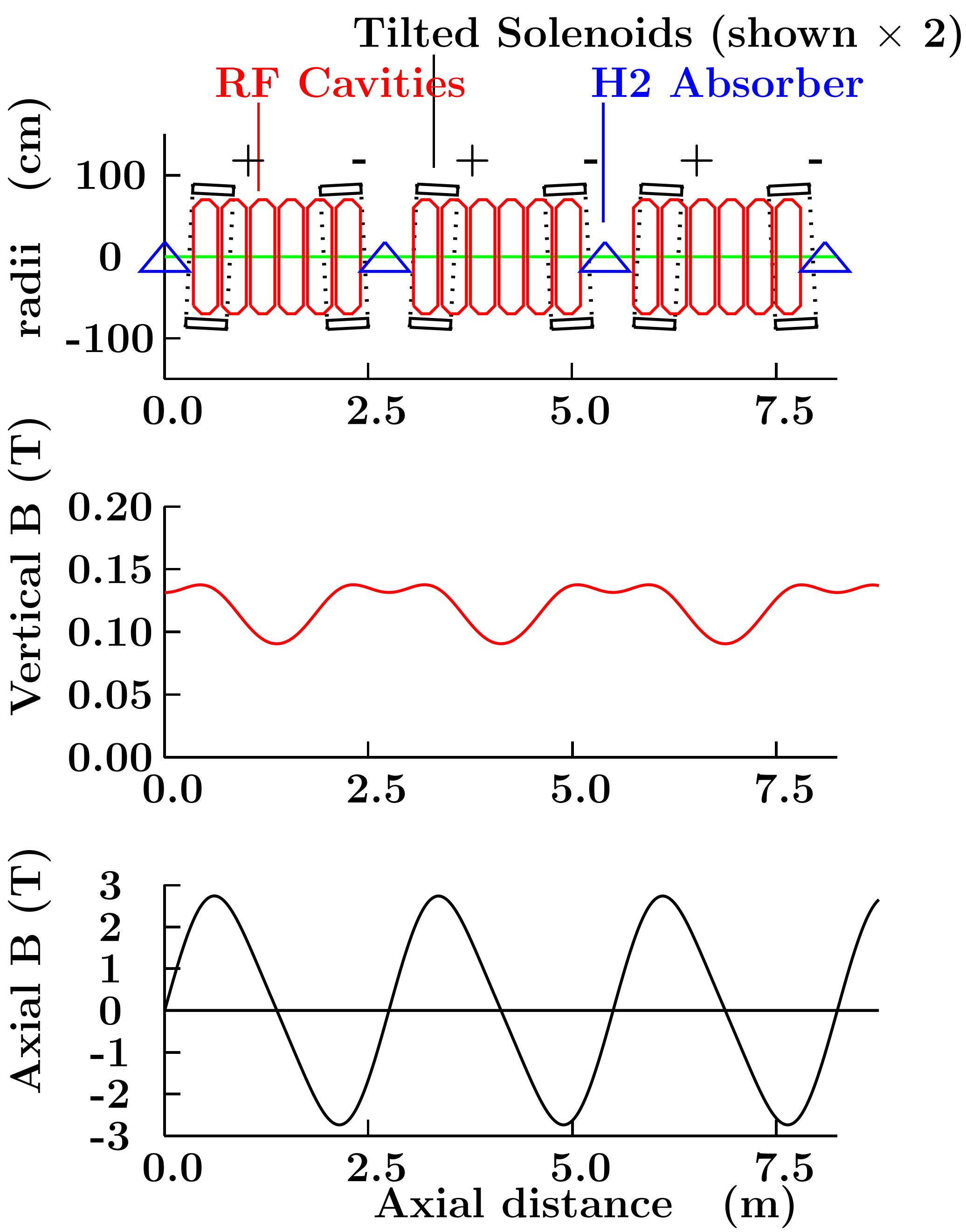
RFOFO Ring Cooler

J.S. Berg, R. Fernow, J. Gallardo,
W. Lau, R.B. Palmer, L. Reginato,
D. Summers Y. Zhao



- Long. and Transverse in same Cell
- Limit phase advance per cell
- Avoid crossing resonances
- Use Solenoid Lattice

Tilt Focus Coils for Bend .



Parameters for Simulation

Lattice

Circumference	m	33
Cells		12
Max Bz	T	2.7
Coil Tilts	deg.	2.8
Ave Momentum	MeV/c	220
Min Trans. Beta	cm	40
Dispersion	cm	8

Wedge

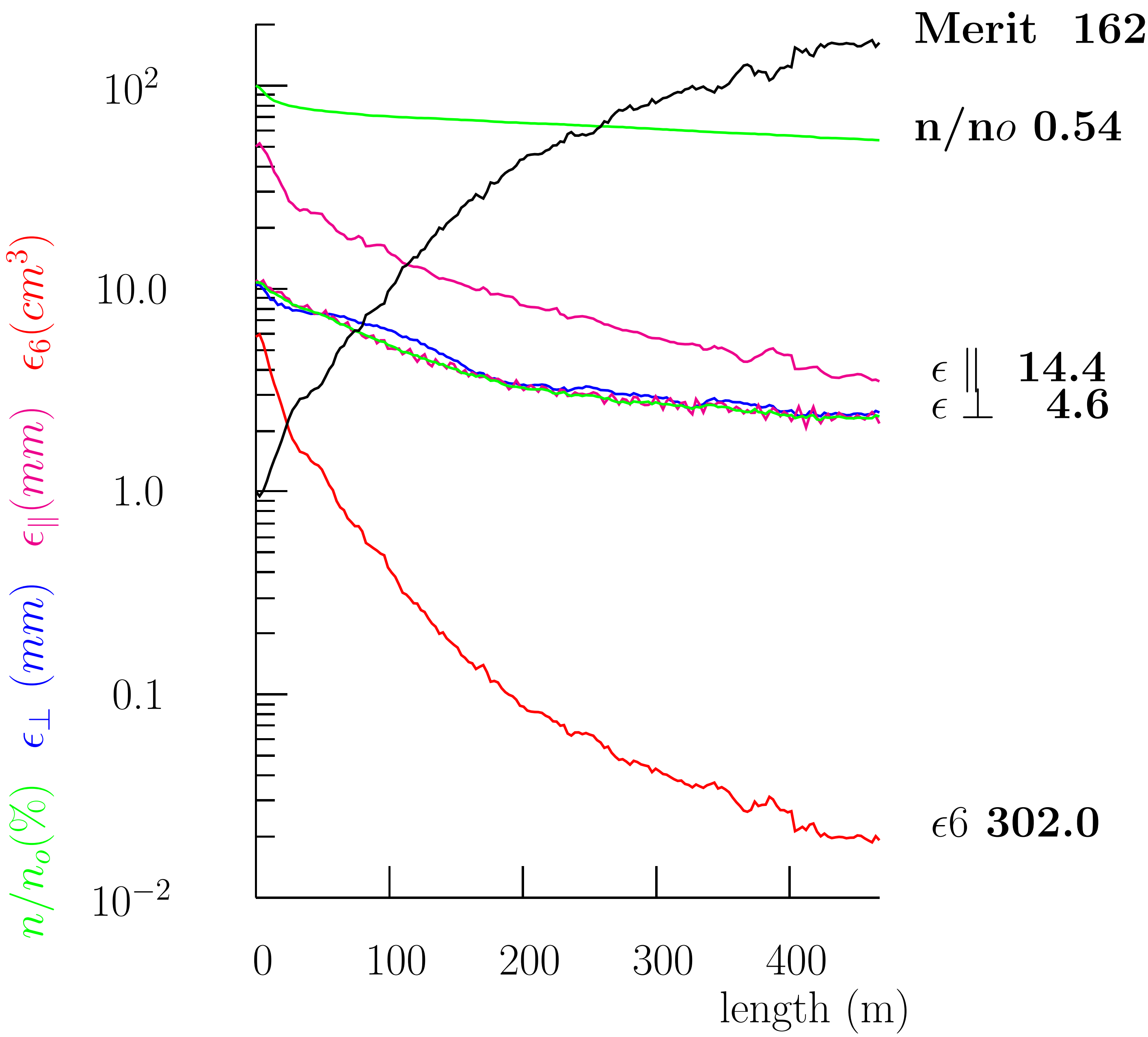
Material		H2
Windows		none
central thickness	cm	28.6
wedge angle	deg	100

RF

Cavities/cell		4
Frequency	MHz	201.25
Gradient	MV/m	16
Windows		none

Performance

Simulation done with Maxwellian Fields

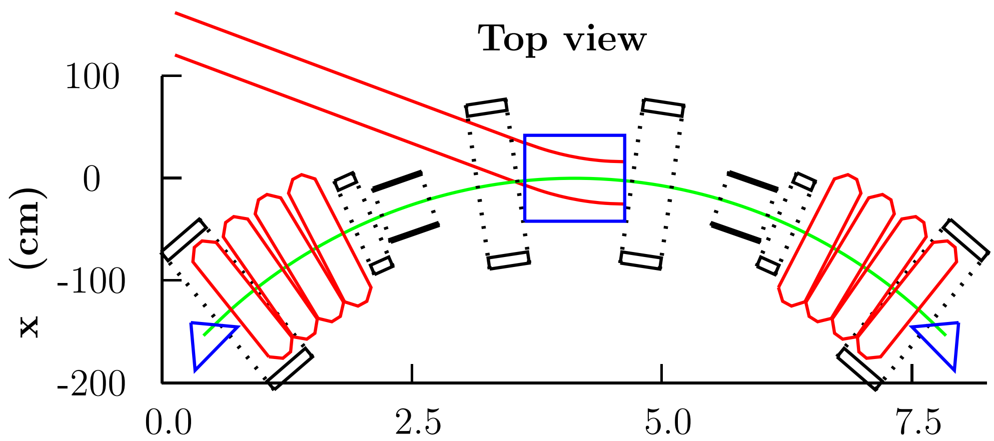


Performances

	len m	trans %	$\epsilon_\perp$ π mm	$\epsilon_\parallel$ π mm	ϵ_6 $\pi^3\mathrm{cm}^3$	merit	End Fields
Study 2							
initial	108		10.7	50.1	5.787		
final		**50**	**2.3**	**38**	0.2	**15**	**yes**
ratio			4.7	1.4	30		
Balbekov							
initial			12	15	2.16		
final	555	**48**	**2.1**	**6.3**	.028	**38**	**no**
ratio			5.7	2.38	79		
Quadrupole							
initial			8.5×5.2	14	0.62		
final	495	**41**	**3.4×1.2**	**3.8**	.016	**16**	**no**
ratio			2.5×4.2	3.7	39		
RFOFO							
initial			10.7	50.1	5.787		
final	468	**54**	**2.3**	**3.5**	0.019	**162**	**yes**
ratio			4.6	14.4	302.0		

- Similar final transverse emittance
- Similar transmission
- RFOFO Ring has
  greatest ratios if acceptance/equilibrium

Insertion for Inject/Extract

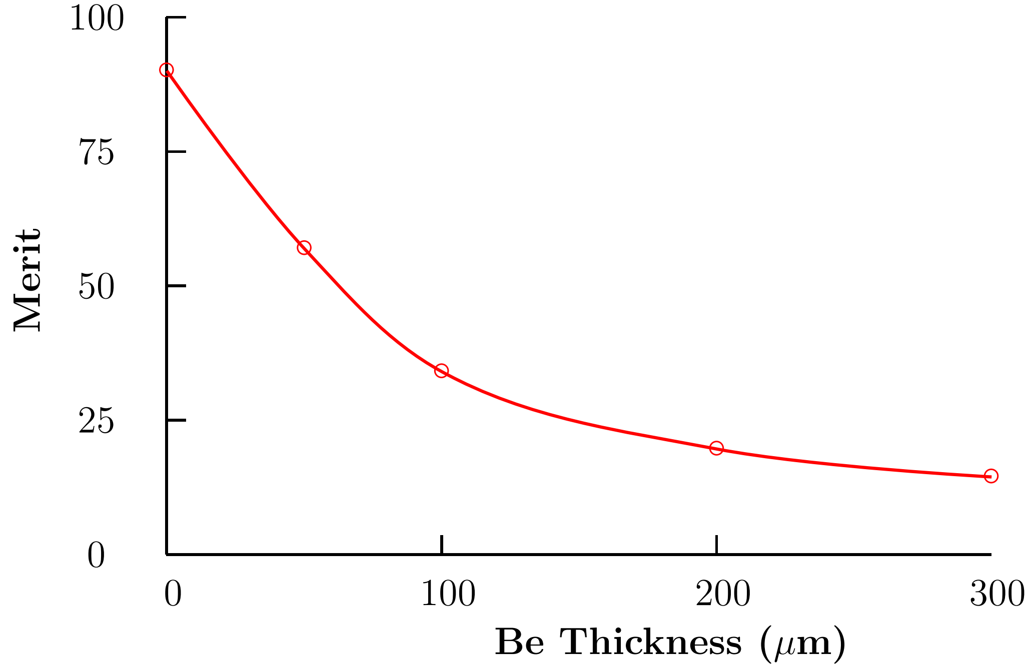


- First Simulation gave Merit = 10
  Synchrotron tune = 2.0: Integer
- Increase energy, wedge angle, and add matching.
- Merit **160 → 110**
- Can probably be improved

Common Problems

Difficult Question 1

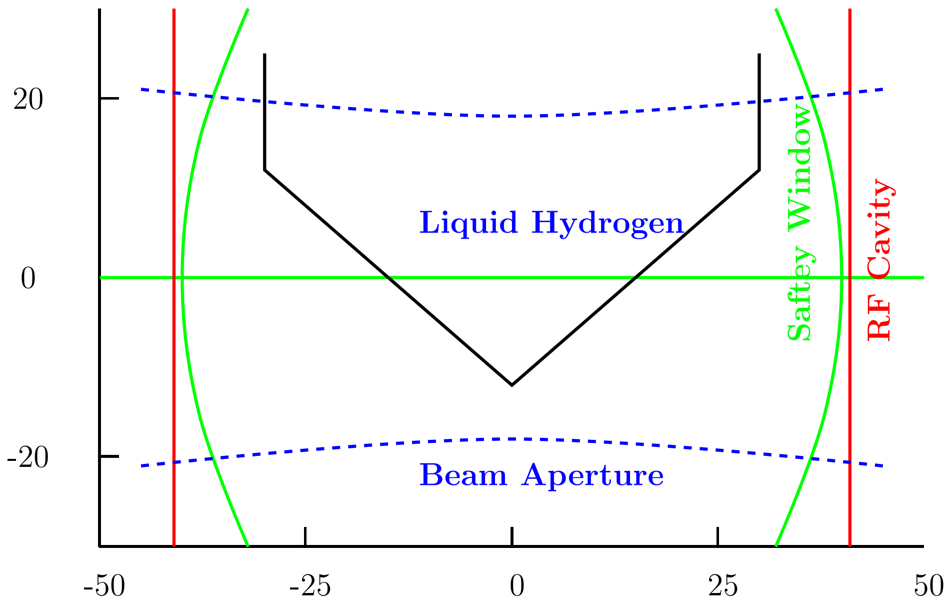
RF windows must be very thin



- Study 2: 200-300 microns
- Need ≈25 microns
- RF at 70 deg will help

Difficult Question 2

Design of wedge absorber



- Does not cross aperture
- Several kW Disipation
- Windows very thin

Difficult Question 3

Injection Kicker

Minimum Required kick

$$\text{for :} \qquad f_\sigma = \frac{\mathrm{Ap}}{\sigma} \qquad \mu = \mathrm{inf}$$

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

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

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

Compare with others

For $\epsilon_\perp = 10\ \pi$mm, $\beta_\perp = 1$m, & τ=50 nsec:

After correction for finite μ and leakage flux:

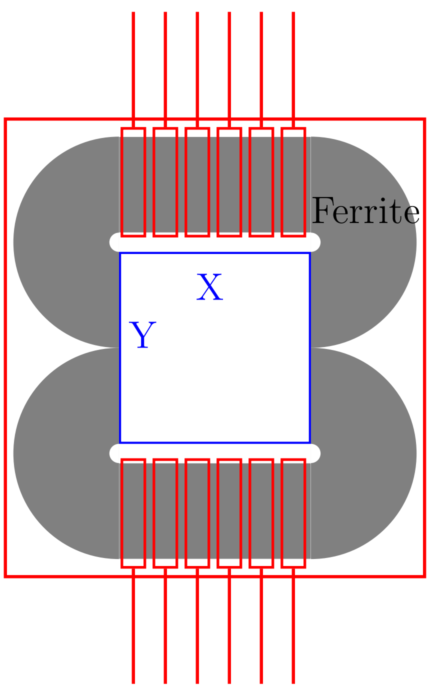
		μ Cooling	CERN $\bar{p}$	Ind Linac
$\int Bd\ell$	Tm	.30	.088	
L	m	1.0	$\approx$5	6.0
$t_{\rm rise}$	ns	**50**	**90**	**40**
B	T	**.30**	**$\approx$0.018**	**0.6**
X	m	.42	.08	
Y	m	.63	.25	
$V_{\rm 1turn}$	kV	**3,970**	**800**	**6,000**
$U_{\rm magnetic}$	J	**10,450**	**$\approx$13**	**10,000**

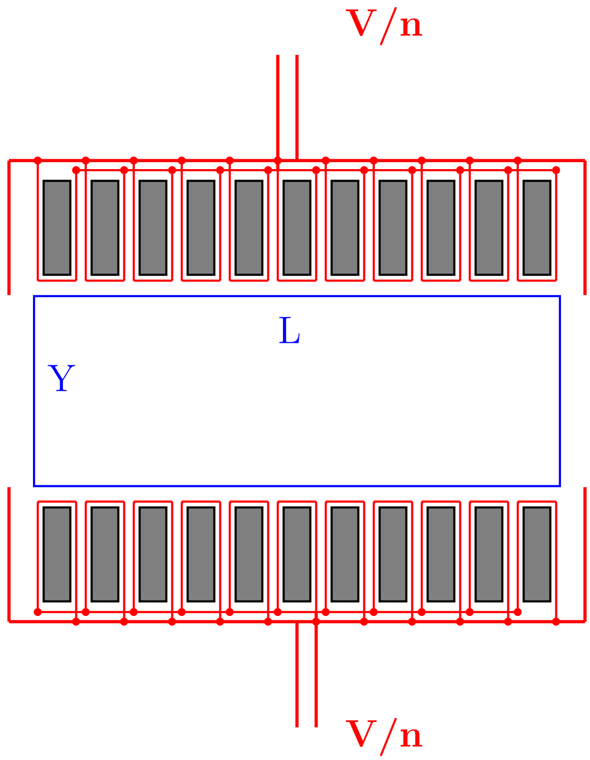
Note

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

Induction Kicker

- As in an Induction Linac:
  Divide Yoke into slices
- Feed loops in parallel
  Solves Voltage Problem
- Conducting Box Removes
  Stray Field Return



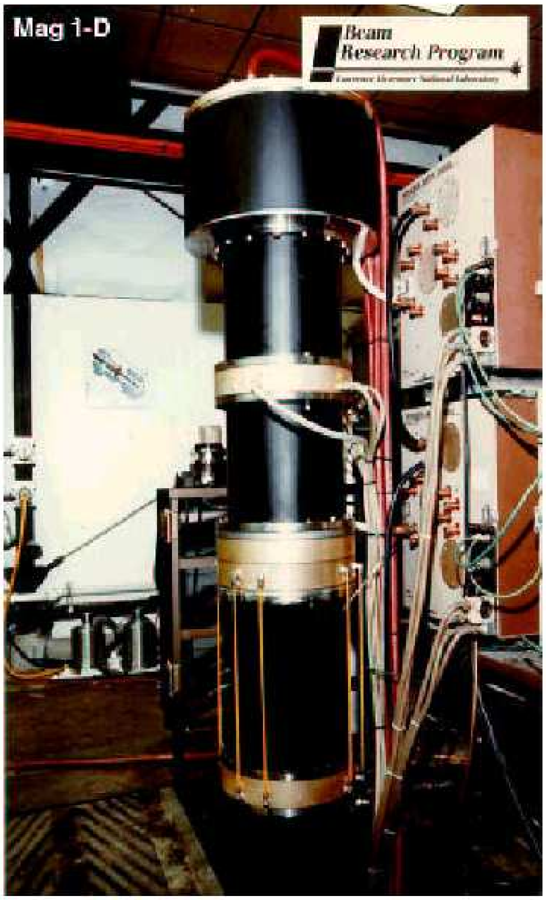


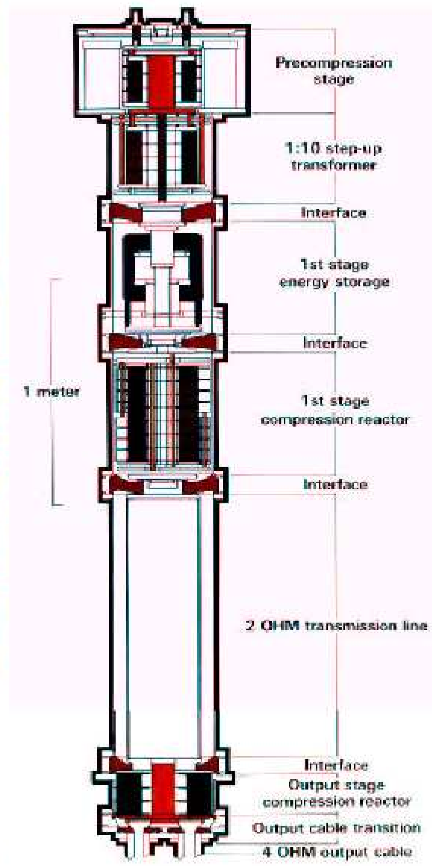
End View

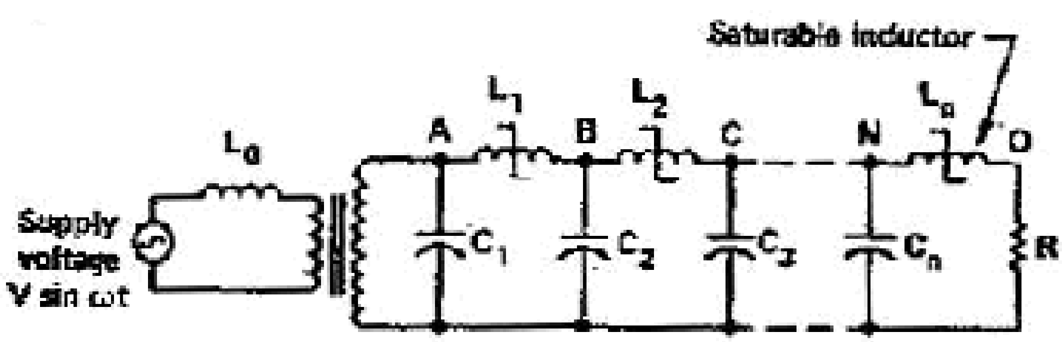
Side View

Magnetic Amplifiers

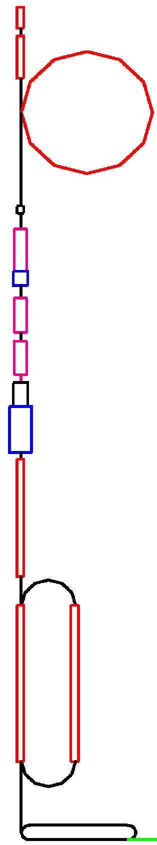
- Used to drive Induction Linacs
- similar to ATA or DARHT
- switch low Amp long pulse
- Mag-Amp compresses pulse







Can Rings Save Costs?



	% of Cost
(p Driver)	
Hg Target	(6 %)
Phase Rotation	(27 %)
Cooling	(22 %)
Acceleration	(37 %)
Storage Ring	(7 %)

- We know of savings for Phase Rotation
- ≈30 m Cooling Rings should be cheaper than 108 m linear cooling
- Lower Emittance will reduce acceleration and storage costs

Can Rings make Colliders?

- We need Merit $\approx$5 10^5 for Collider
- 3 rings might achieve this

BUT

- New Front end design needed
- New Final emittance ring needed
- A problem with transmission

$$0.5 \times 0.5 \times 0.5 = 0.125$$

is not good enough

Ring Cooler Conclusion

- **Need very thin windows**
- **Work needed on H2 wedge**
- **Work needed on Insertion**
- **The Kicker is the least certain**
- **Need pre-cooler or other ideas to match phase space into short bunch train**

BUT

- **Much better than linear coolers**
- **Should be Cheaper**
- **Might lower acceleration cost**
- **Some Real hope that Collider requirements can be met**