Muon Colliders HTS Magnets

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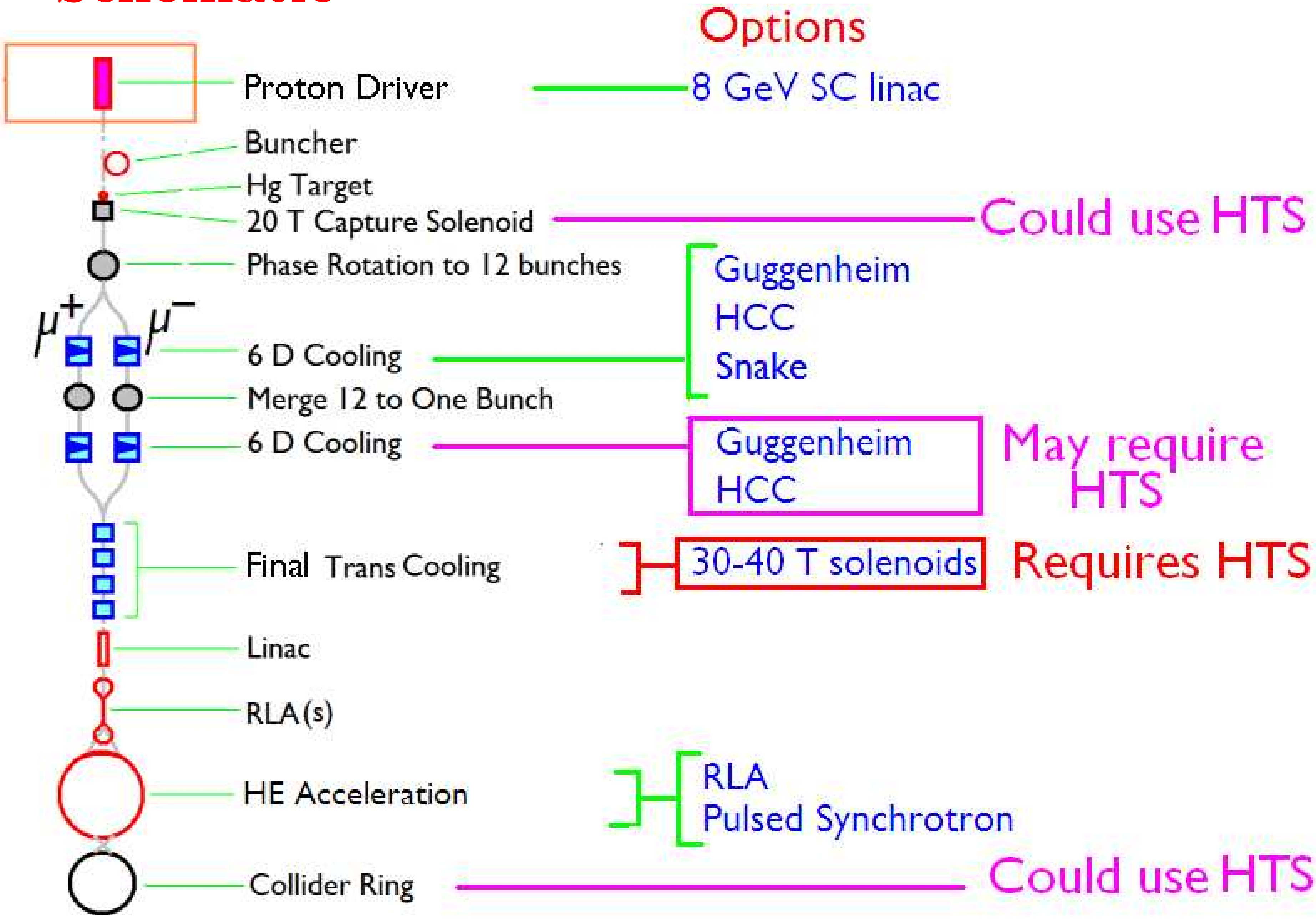
HTS Mini-Workshop
FNAL
5/30/12

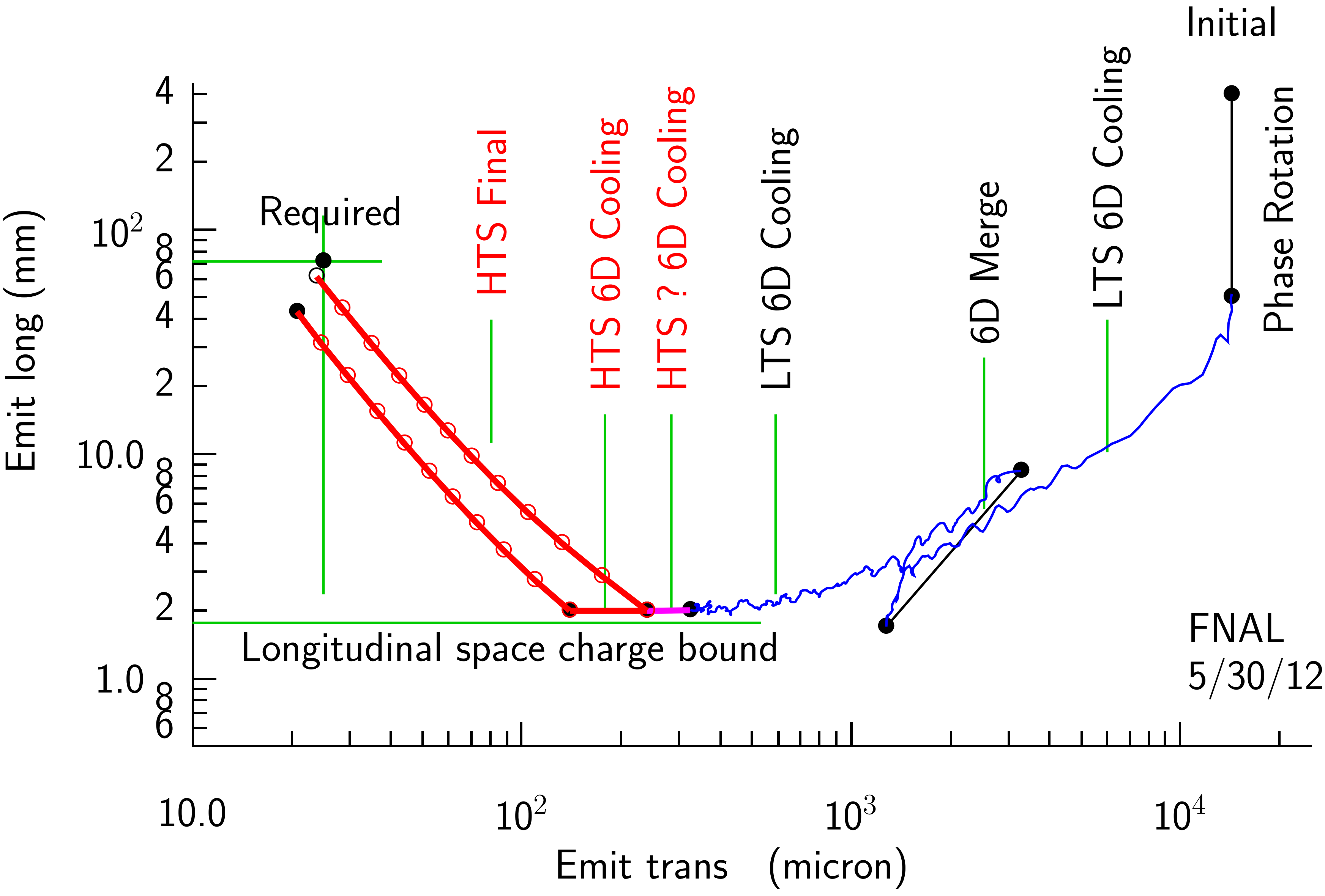
- Introduction
- Final Transverse Cooling
- Late 6D Cooling
- Conductor requirements
- Other possible HTS applications
  - Ring dipoles
  - Ring IR magnets
  - Pion capture magnet

Schematic

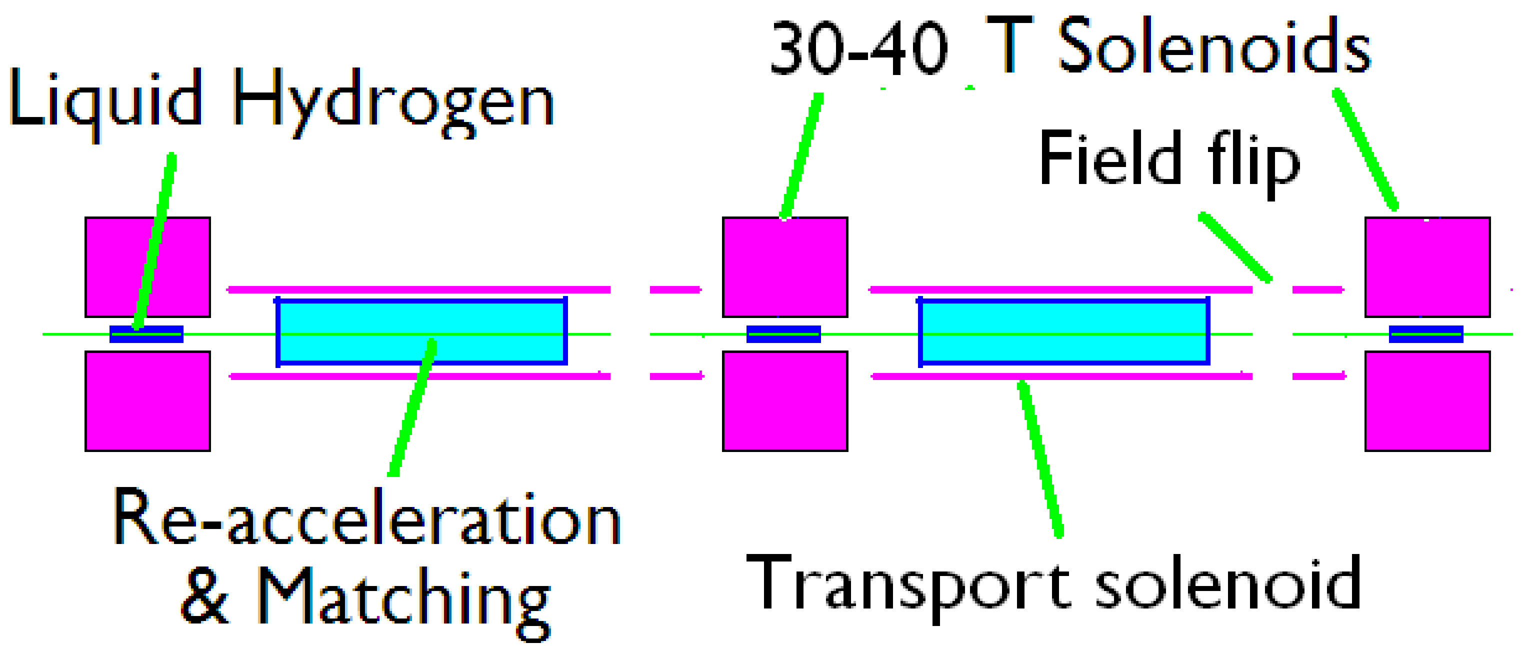

Options
Proton Driver
8 GeV SC linac
Buncher
Hg Target
20 T Capture Solenoid
Could use HTS
Phase Rotation to 12 bunches
μ^+
μ^-
6 D Cooling
Guggenheim
HCC
Snake
Merge 12 to One Bunch
6 D Cooling
Guggenheim
HCC
May require HTS
Final Trans Cooling
30-40 T solenoids
Requires HTS
Linac
RLA(s)
HE Acceleration
RLA
Pulsed Synchrotron
Collider Ring
Could use HTS

Cooling Sequence

ICOOL Simulations of 6D cooling are for Guggenheim lattices



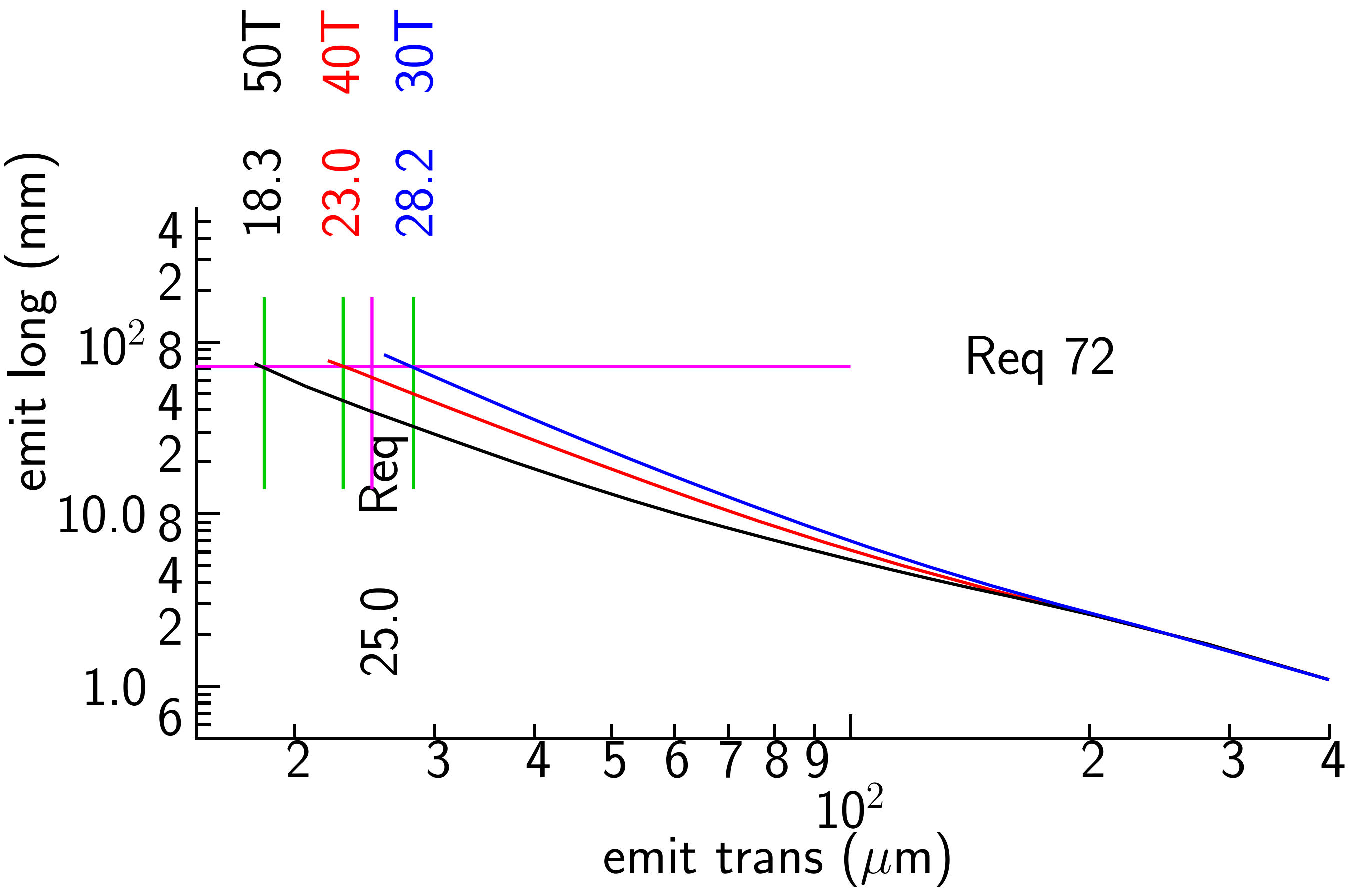
Final Cooling to $\epsilon_\perp$=20 μm $\epsilon_\parallel$=43 mm



- 13 stages: lengths from 3.5 to 76 cm, bore diameters3-4 cm
- Liquid hydrogen pipes inside high field magnets
- rf in low fields

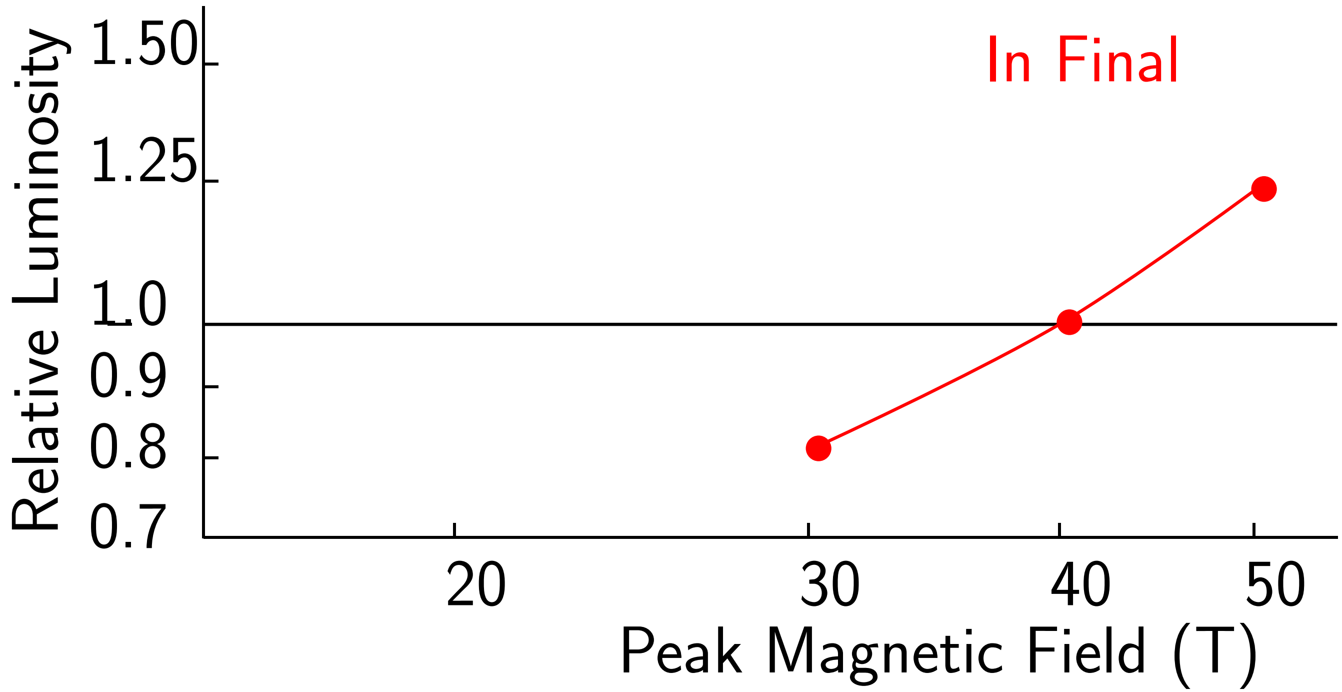
Emittances vs. Maximum Field

- ICOOL simulations of cooling in liquid hydrogen
- Matching and re-acceleration still only simulated last stages



Effect on collider performance

- Assuming fixed numbers of muons per bunch
- Then luminosity inversely proportional to emittance

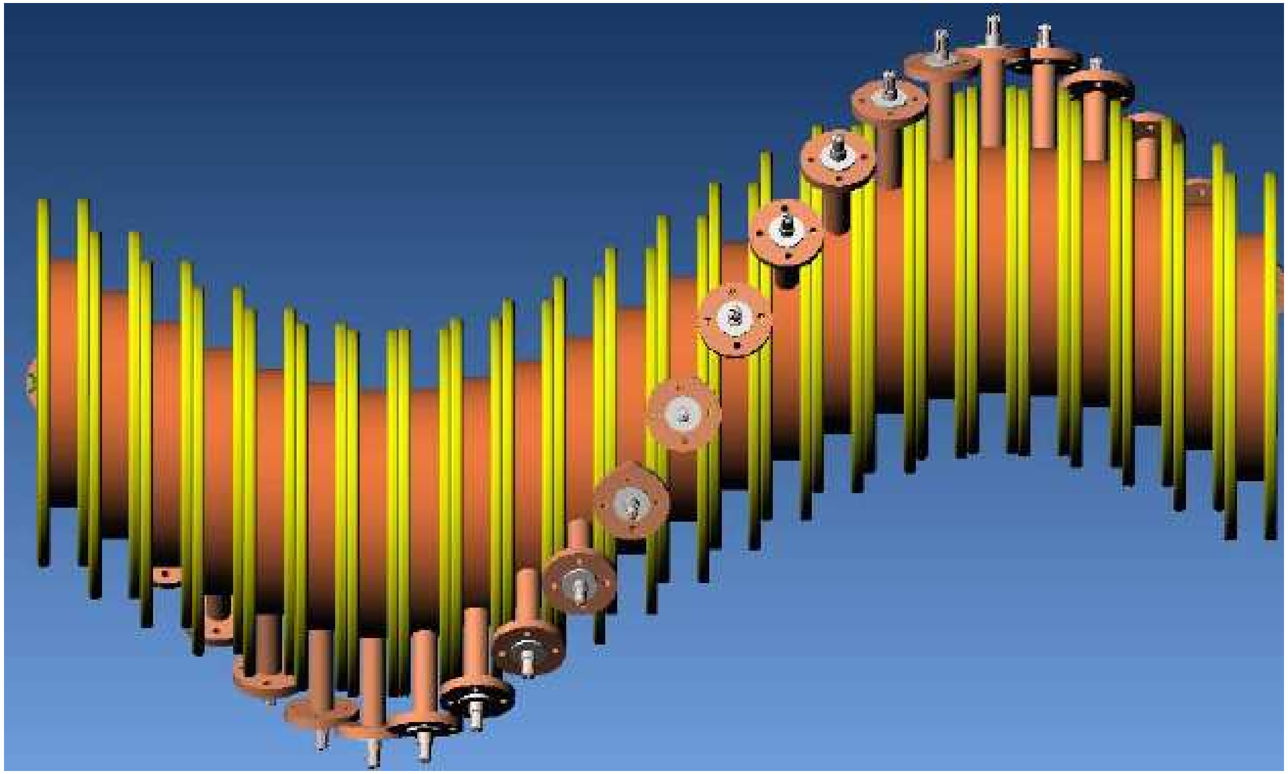


Approximate dependence $$\mathcal{L} \propto \sqrt{\frac{1}{\mathrm{B}}}$$

6D Cooling

- 3 Methods:
  - FOFO snake cools both charges
    but not suitable for late stages
    does not need HTS
  - Helical Cooling Channel
    Uses high pressure hydrogen gas
    as absorber and stops breakdown in magnetic fields
  - Guggenheim helical lattice
    uses liquid hydrogen absorbers
    requires vacuum rf in magnetic fields

Helical Cooling Channel (HCC)



- Figure does not show an outer straight solenoid
- Ceramic loaded rf cavities inside the helical magnets filled with hydrogen gas at 50-70 Kelvin

HCC coil parameters for stages 2, 6, & 7

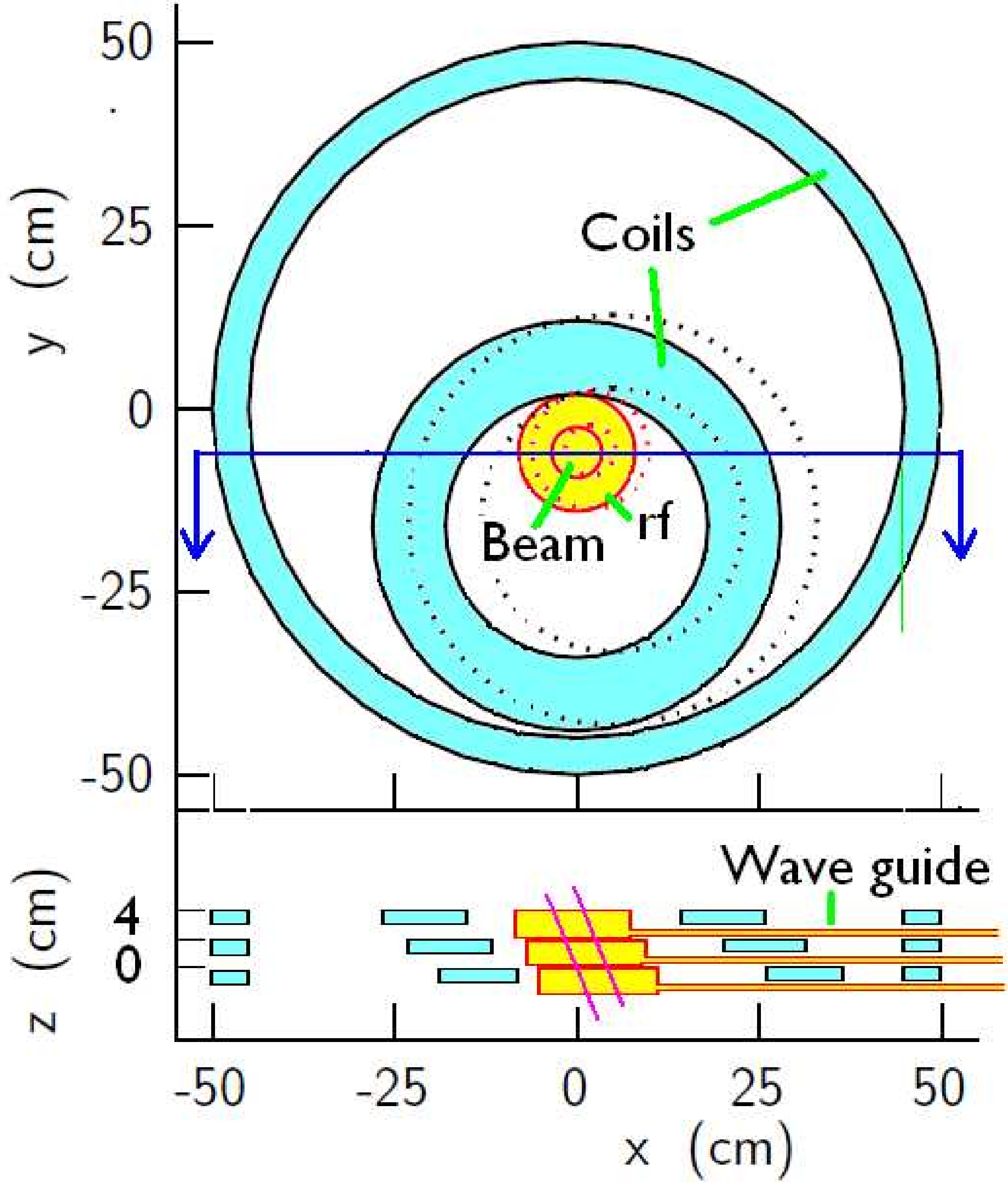
stage	R_c	λ	B_z	R1	R2	n	L_K	j	$\epsilon_\perp$	
	m	m	T	m	m		m	A/mm^2	mm	
2	.28	1	.55	.35	.4	20	.025	194	10	Kashikin
6	.16	.4	6.73	.18	.28	20	.01	332.9	0.4	Kashikin
7	.12	.3	8.97	.135	.21	20	.0075	592	0.3	Extrapolated

R_c is the radius of the helix on which the coil centers lie, λ is the period of that helix, B_z is the axial field of a solenoid outside the Kashikin coils. n is the number of coils per period, R1 and R2 are the inside and outside radii and L_K is the length of the coils, j is the current density.

Stage 7 is needed to reach assumed base line performance

Stage 6 HCC Section

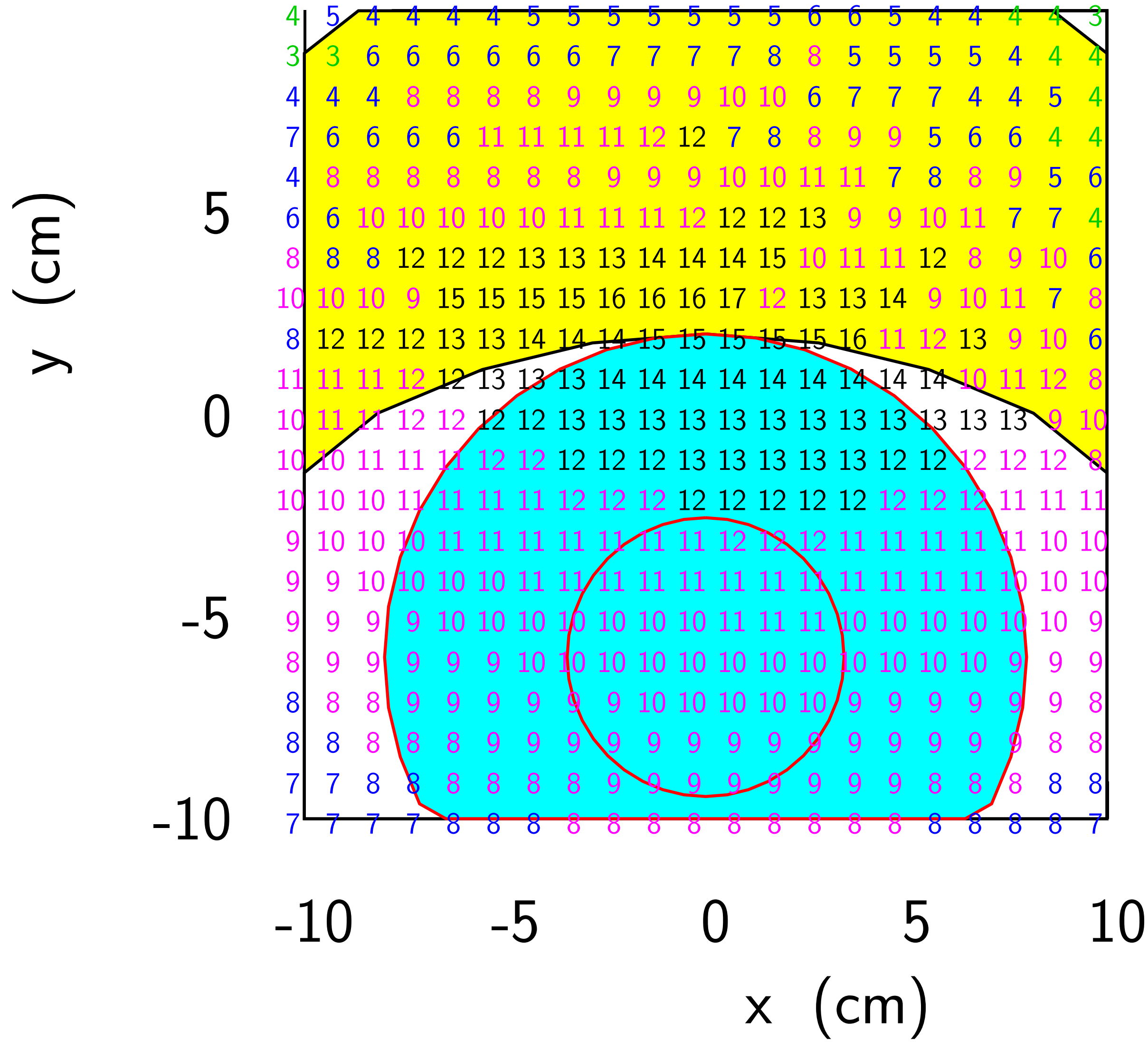
Scaled stage 7, for assumed baseline, is smaller in all dimensions by 3/4



Stage 6
HCC
Local fields

Maximum field 17.2 T

Scaled stage 7, for assumed baseline, field higher by $(4/3)^2 =$ 30.6 T

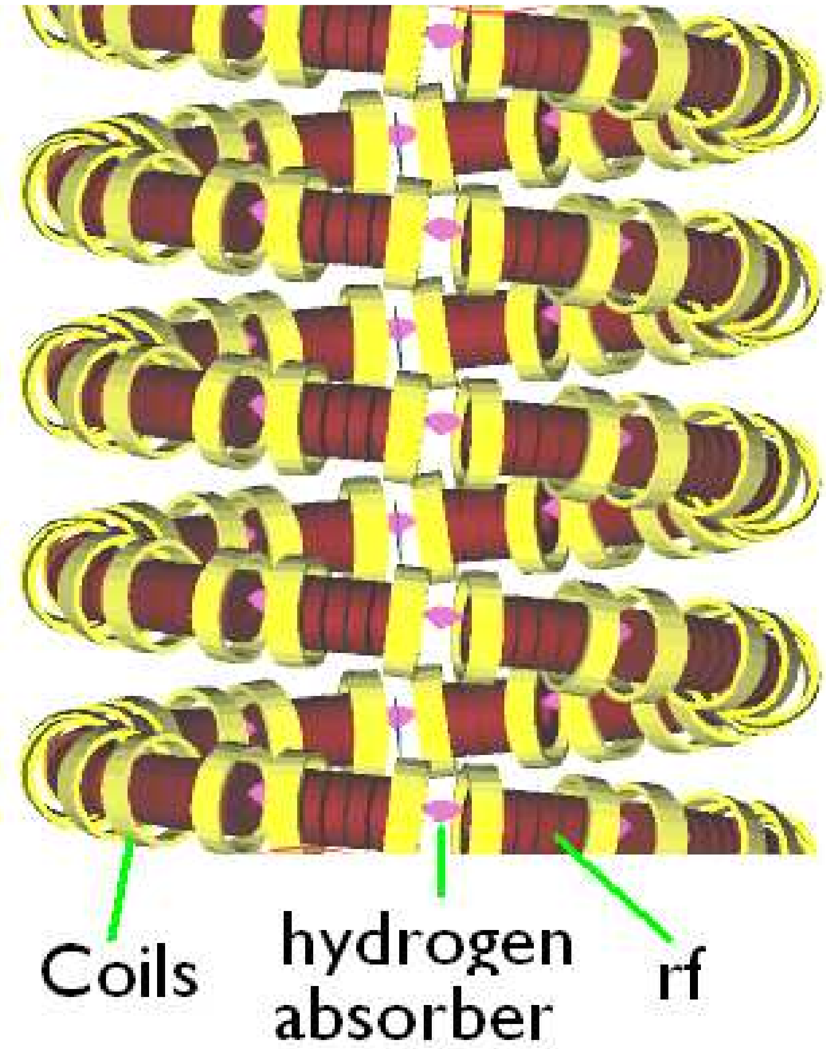


Guggenheim

Two versions:

1. "RFOFO" solenoids polarities alternate
   Lower fields on rf
   but higher current densities

2. "Non-flip" solenoids all have same polarity
   Higher fields on rf
   but lower current densities



Parameters of RFOFO 2 lattices

file			rf		rf	coil					
in	β	cell	f	$\mathcal{E}$	frac	z1-z2	r1-r2	j	$\hat{B}$	B_o	$\epsilon_\perp$
tapr	cm	cm	MHz	MV/m		cm	cm	A/mm^2	T	T	mm
036	3.4	68.75	805	20.05	0.5	3.00-13.00	6.50-21.75	291.9	20.8	14.8	0.3
037	2.8	68.75	805	20.05	0.5	2.50-13.00	4.88-19.63	257.5	19.2	15.8	0.24

- Fields on rf up to 6 T

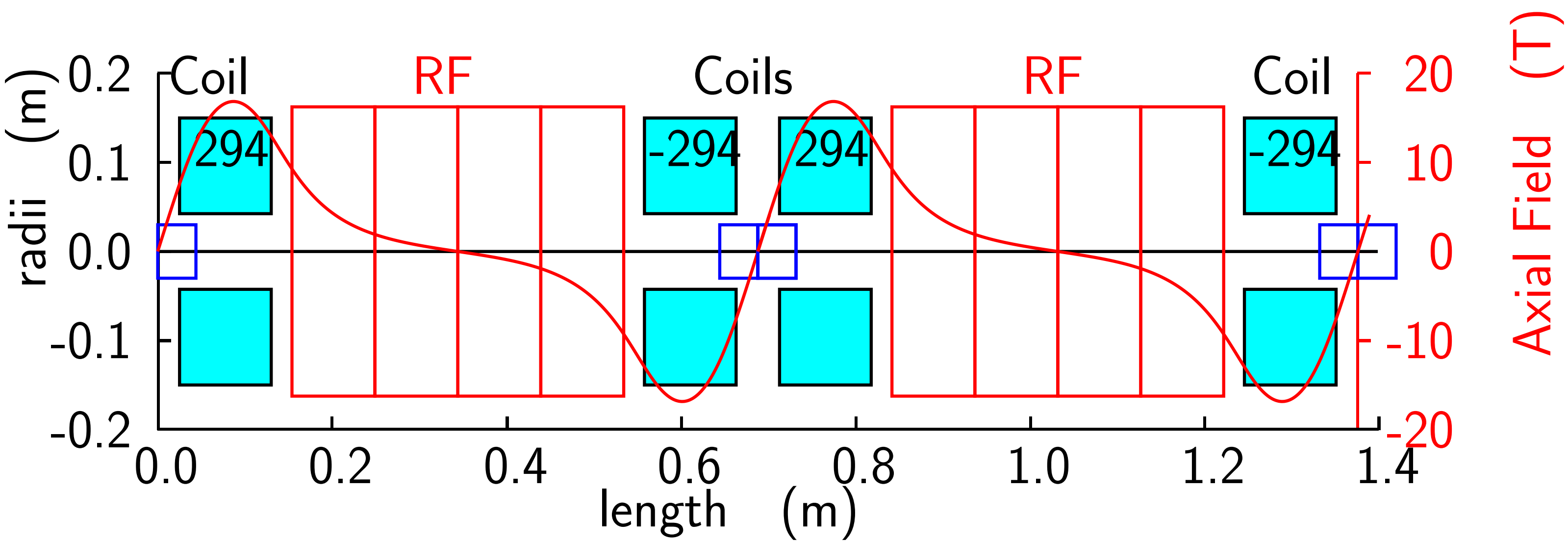
Parameters of Non-flip lattices with HTS

	cell	Mom	beta	emit	L	r1	r2	j	Bo	Bmax	$\epsilon_\perp$
	cm	MeV/c	cm	mm	cm	cm	cm	A/mm^2	T	T	mm
37h	41.0	200	2.8	0.24	16.8	4.2	21.6	174	23.6	24.7	0.24
38h	41.0	200	2.3	0.20	16.8	3.8	18.8	197	24.4	25.3	0.20
39h	41.0	200	1.9	0.17	16.8	2.6	17.6	199	26.0	26.2	0.17
40h	33.6	160	1.5	0.14	13.4	2.1	14.1	253	26.3	26.6	0.14

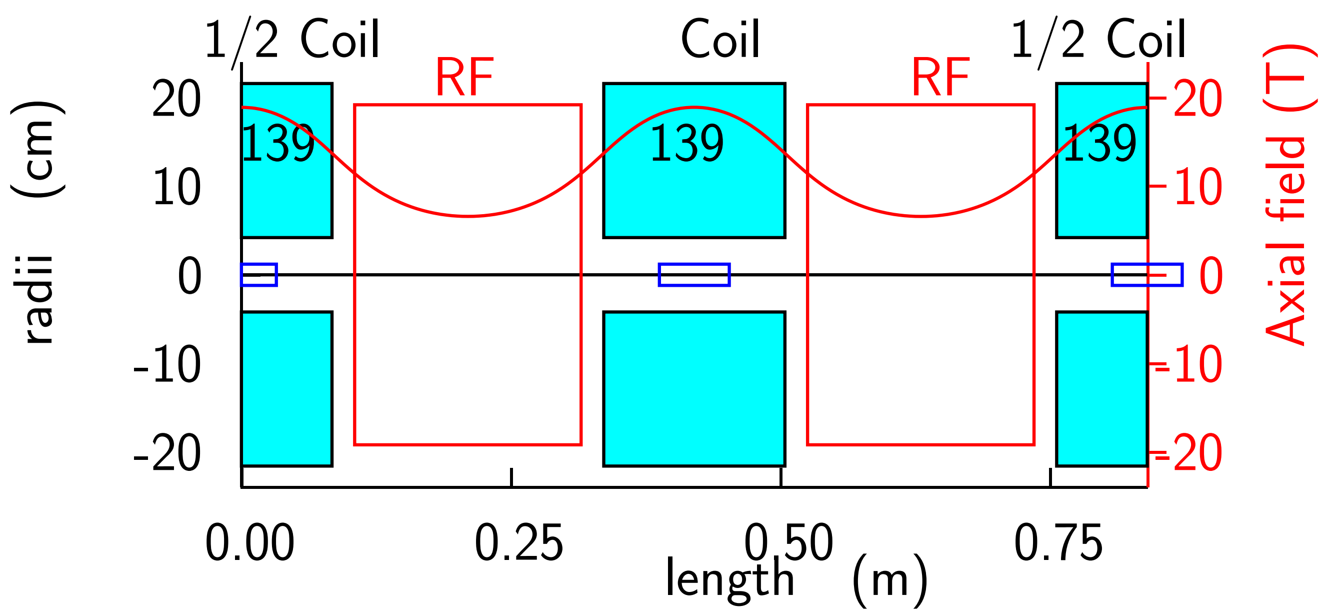
- Fields on rf up to 12 T

Non-flip vs. RFOFO Guggenheims

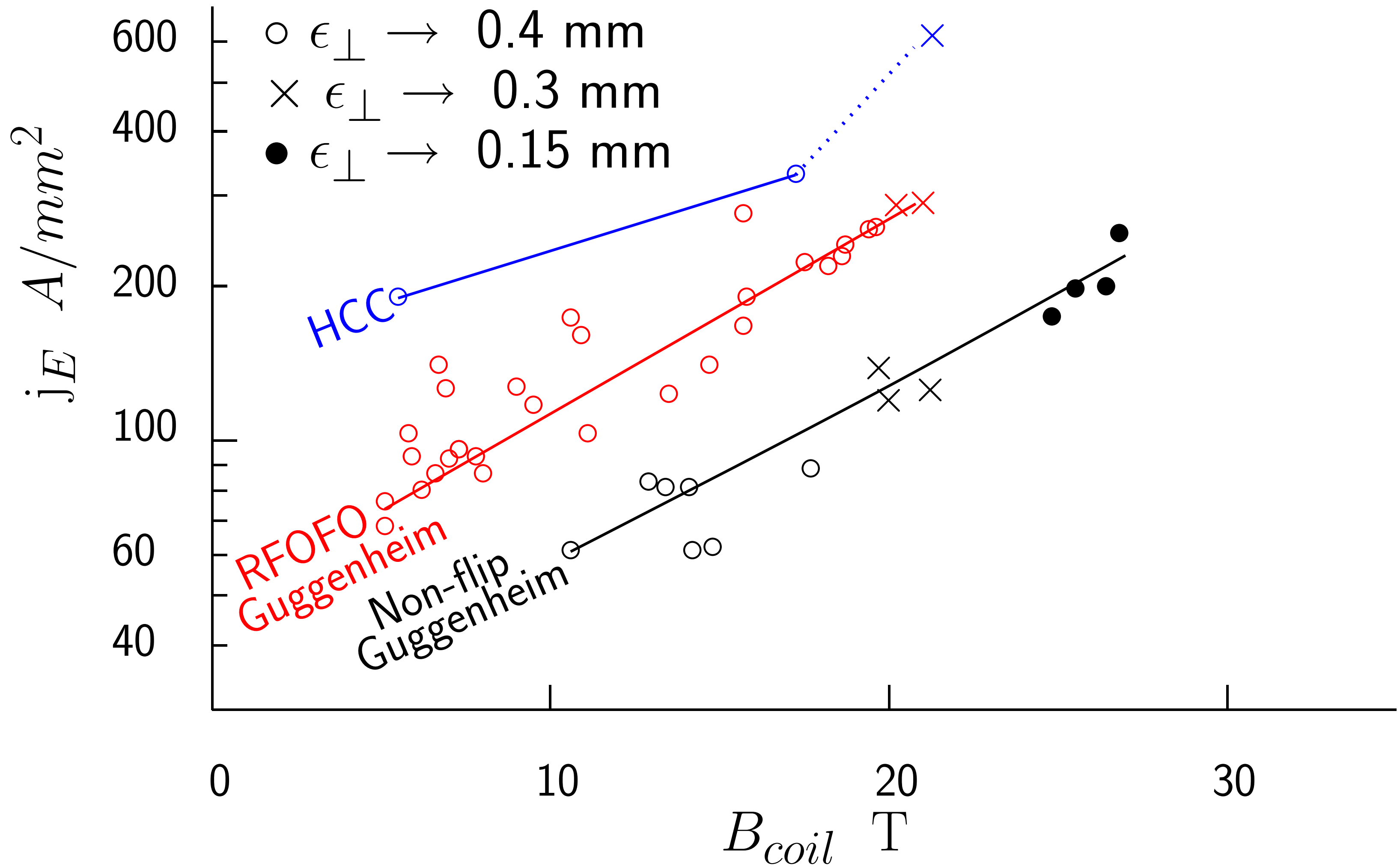
RFOFO
Guggenheim
B(rf)=6 T



Non-Flip
Guggenheim
B(rf)=12 T

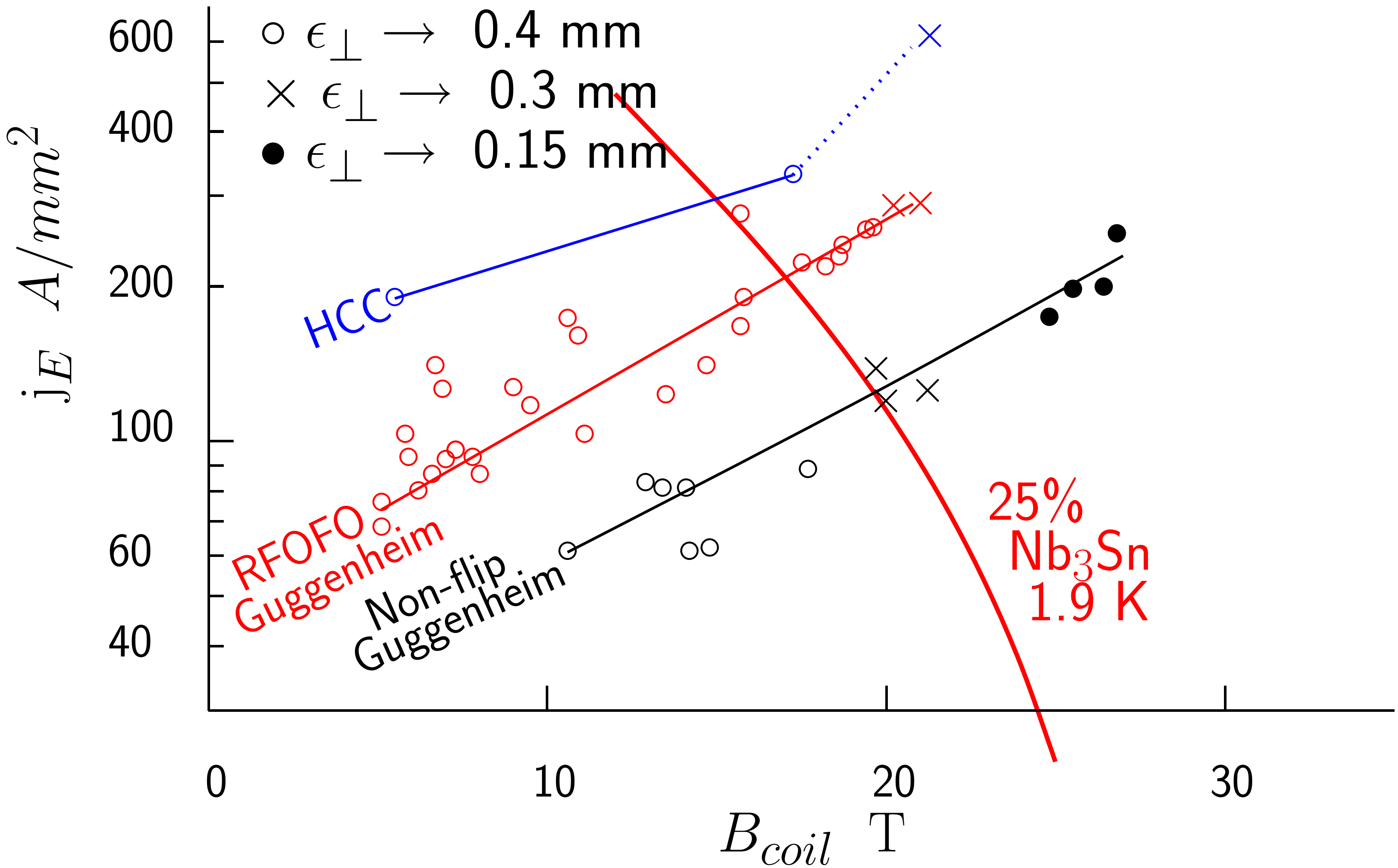


6D cooling Conductor Requirements



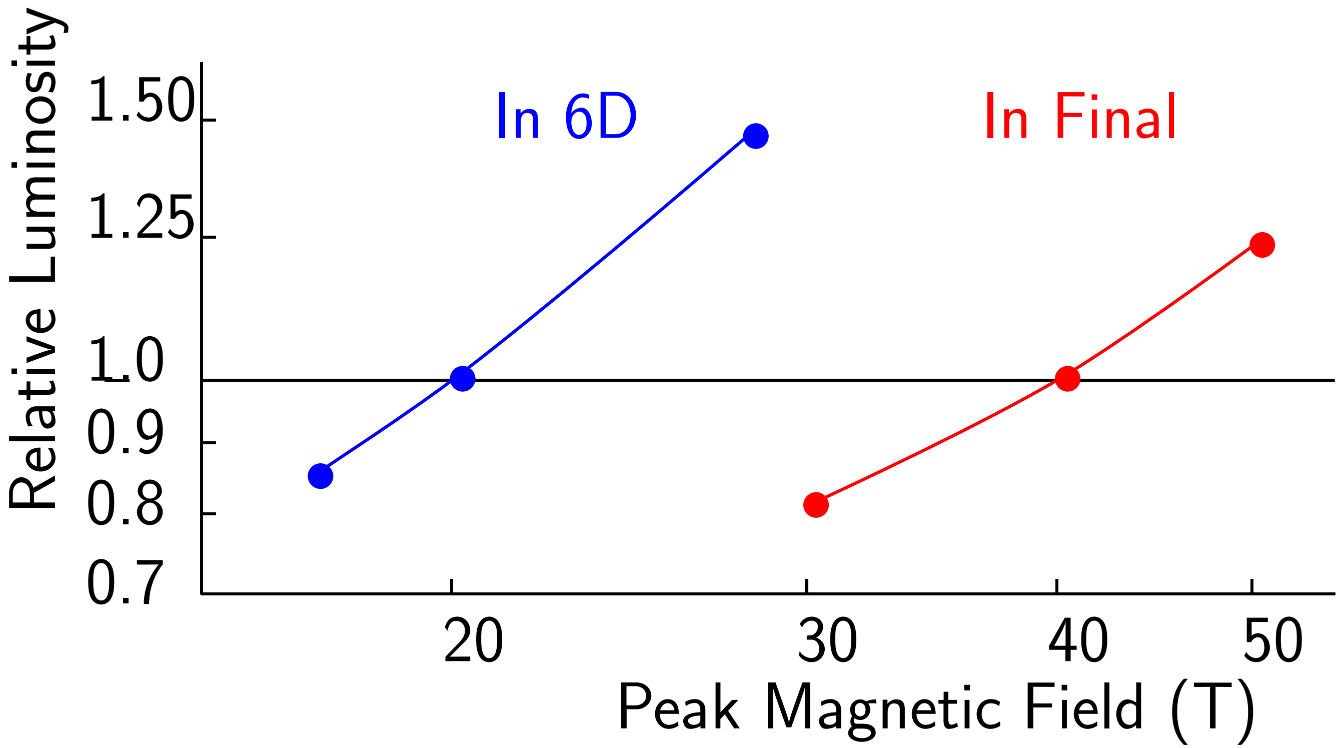
- Local magnetic fields, for given emittances, almost independent of method
- But current densities differ a lot

Compare with best likely LTS Capabilities



- Non-flip Guggenheim might meet baseline without HTS
- HCC and RFOFO Guggenheims need HTS for baseline
- Non-flip Guggenheim with HTS allows enhanced performance

Relative Luminosity Gains



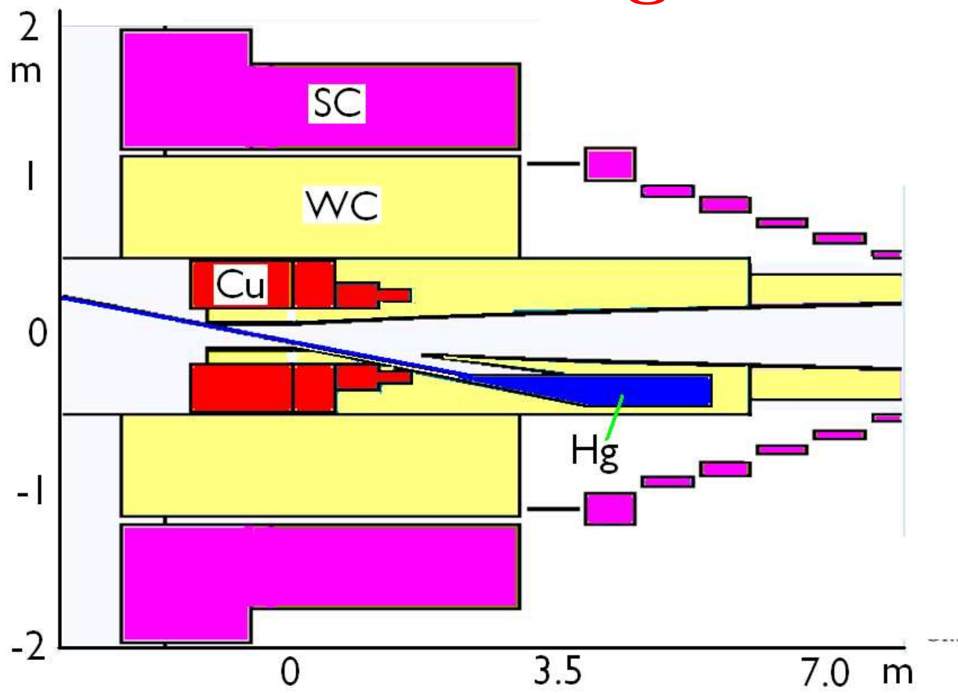
Ring Dipole Magnets

- In the current baseline, are assumed to use Nb_3Sn.
- But Luminosiy/beam power in a muon collider is proportional to average bending field,
- So the use of HTS to raise this field increases luminosity for same radiation.
- It remains attractive for the future.
- Only a BSCCO cable could meet the field quality requirements.

Ring IR Magnets

- In the current baseline, are assumed to use Nb_3Sn.
- But heating from decay electrons is challenging
- HTS at a somewhat higher temperature could be, but has not yet been, considered.
- Magnetization in YBCO makes it unable to meet the required field quality,
- So only BSCCO would be the only option.

Possible HTS for Target & Capture



- 20 T used to capture pions:
  - Copper coil gives 6 T,but uses 15 MW of wall power
  - Super-conducting solenoid give 14 T, tapering to 3 T, but has huge stored energy

- HTS might save wall power
- But just lowering the field to 15 T looks more attractive

Summary

Application	Axial Field (T)	Current density	Field quality	Stored Energy	Preferred conductor	Need
MUON COLLIDER						
1) Final Cooling	30-40	moderate	low	high	YBCO	very high
2) Earlier 6D Cooling	$\leq$18	high	low	moderate	YBCO	high
3) Late 6D Cooling	$\leq$25	high	low	moderate	YBCO	high
4) Ring IR magnets	12-20	moderate	high	high	BSCCO	low
5) Ring dipoles	10-20	moderate	high	high	BSCCO	low
6) Pion Capture	15-20	low	low	high	BSCCO	very low