Overview of a cooling concept with vacuum rf technology

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(on behalf of the VCC team)

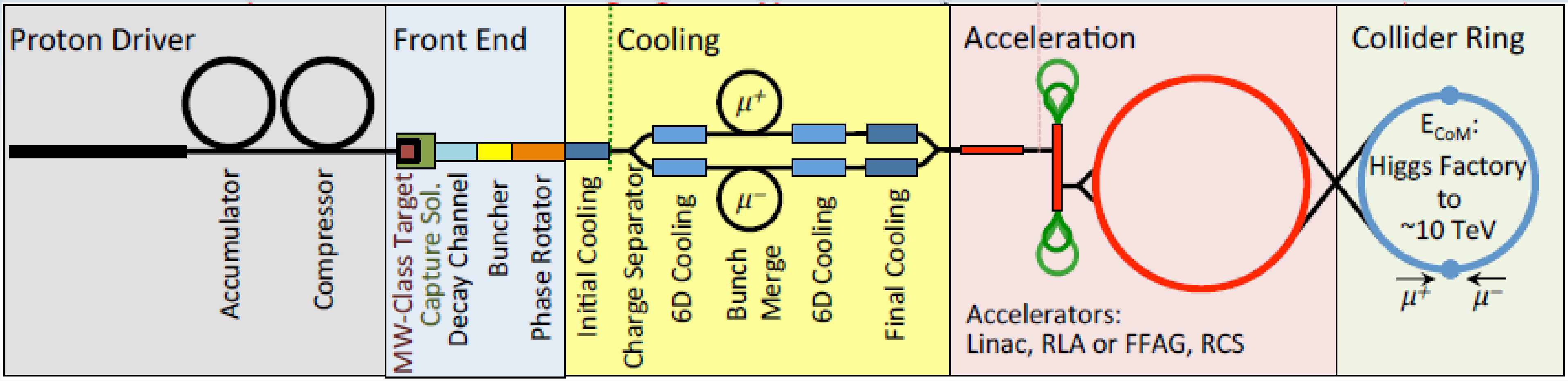
Brookhaven National Laboratory

MAP Spring Meeting, FNAL, Batavia IL

May 28, 2014

Motivation

Muon Collider (Muon Acceleration Staging Study)



- Goal: Design & simulate a complete cooling channel
- Effort will be based on a Vacuum Cooling Channel (VCC) concept

VCC design group

Concept Leaders
R. B. Palmer & D. Stratakis

6D Theory & Simulation

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V. Balbekov[2]
Y. Bao[4]
J. S. Berg[1]
D. Grote[3]
D. Neuffer[2]
R. B. Palmer[1]
T. Roberts[7]
D. Stratakis[1]
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Vacuum RF system

D. Bowring[2]
D. Li[5]
T. Luo[5]
A. Moretti[2]
Y. Torun[2]

Magnet system

I. Novitski[2]
S. Prestemon[5]
A. Zlobin[2]
F. Borgnolutti[5]
H. Witte[1]

Absorbers

A. Bross[2]
K. McDonald[6]
D. Summers[8]

[1]BNL
[2]FNAL
[3]LLNL
[4]UCR
[5]LBNL
[6]Princeton Univ.
[7]Muons,Inc
[8]Univ. Mississippi

Outline

- Review of Vacuum Cooling Channel (VCC) concept
- Review key parameters needed (magnets, rf, absorbers)
- Show a “End-To-End” simulation that satisfies MAP emittance goal
- Major accomplishments after Feb. 2014 DOE review
- What we learned from the VCC Workshop (May, 2014)
- Outlook
- Summary

Accomplishments after DOE Review

- Major accomplishments after Feb. review:
  - Optimization algorithms for fast tracking (Stratakis)
  - Design and simulation of matching sections (Palmer, Stratakis)
  - Further cooling: From 0.33 to 0.28 mm transversely (Stratakis)
  - Mechanical & thermal analysis of Be windows for VCC (Luo)
  - Magnet design feasibility study for VCC (Borgnolutti, Prestemon, Witte)
  - Design of a transverse bunch-merge for VCC delivered (Bao)
  - Theor. framework to predict VCC effectiveness (Neuffer, Stratakis)
  - First pass on final cooling with VCC (Palmer, Sayed)
- Hosted a VCC workshop at LBNL (May 2014)
  - Important lessons learned on rf and magnet design

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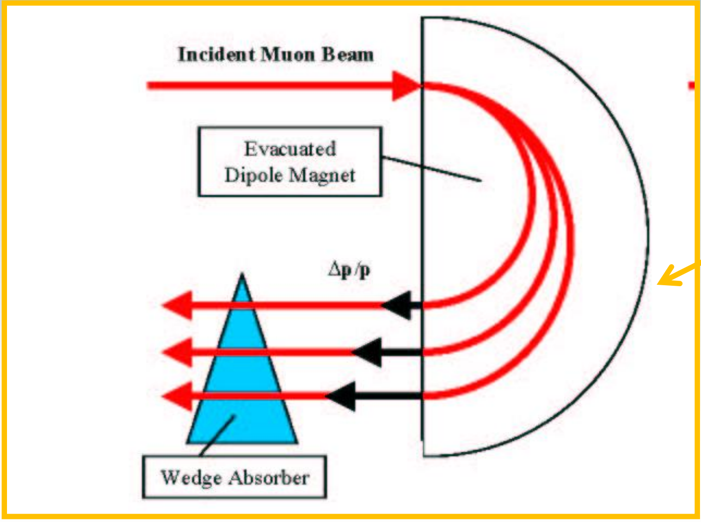
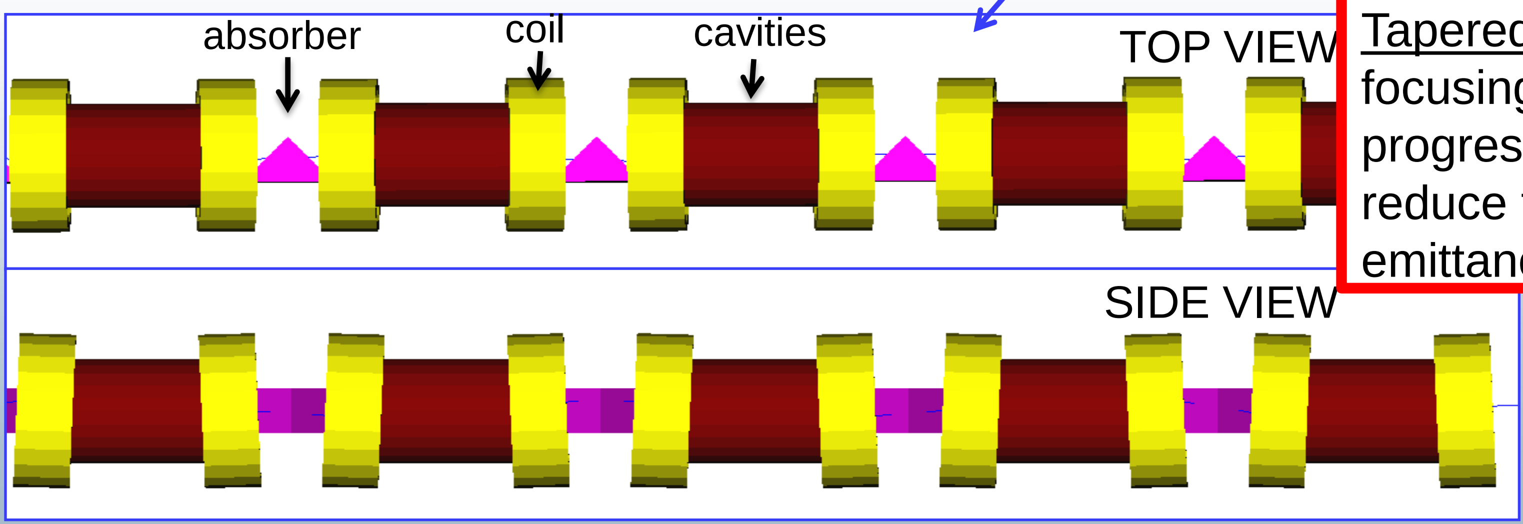
Vacuum RF Cooling Channel



Concept: Generate dispersion and cool via emittance exchange in a wedge absorber

Proposed solution: Rectilinear channel with tilted alternating solenoids and wedge absorbers

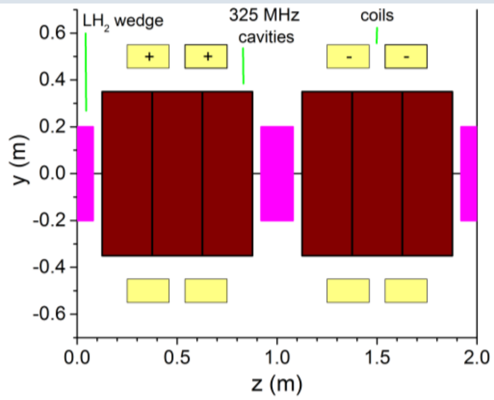


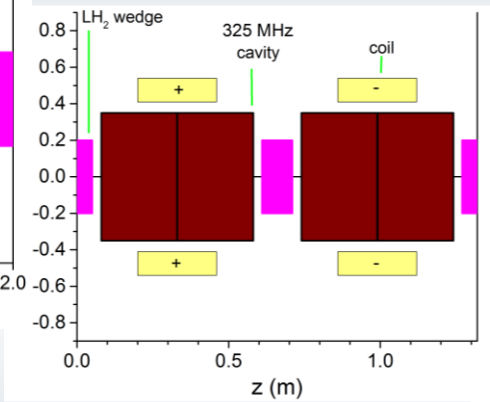
Tapered channel: The focusing field becomes progressively stronger to reduce the equilibrium emittance.

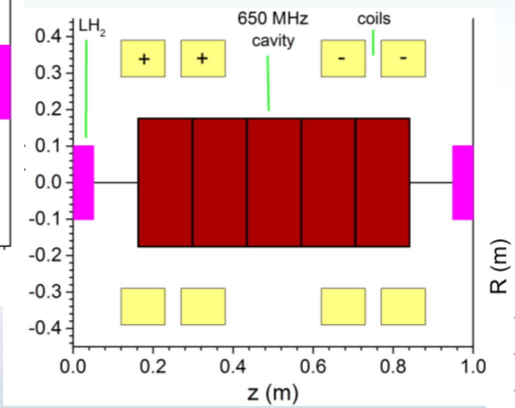
Lattice Proposed by Valeri Balbekov (FNAL)

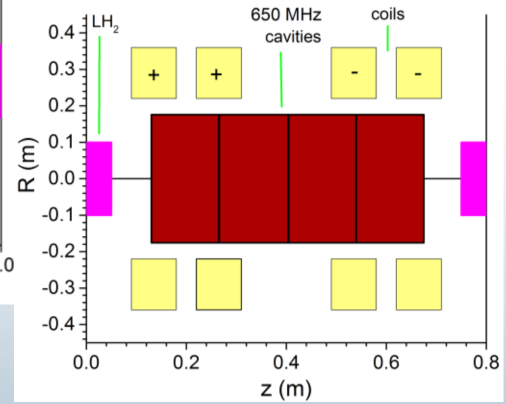
Cooling before merging (4 stages)

STAGE 1	STAGE 2	STAGE 3	STAGE 4
132 m (66 cells)	171.6 m (130 cells)	107 m (107 cells)	70.4 m (88 cells)









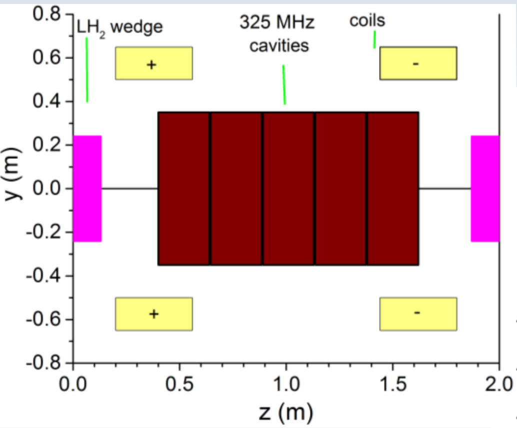
Absorber
TOP VIEW
LH only

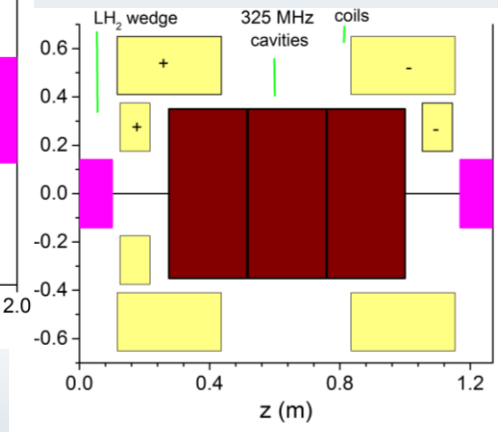
2.3 T (4.2 T)   3.5 T (8.4 T)   4.8 T (9.5 T)   6.0 T (11.8 T)

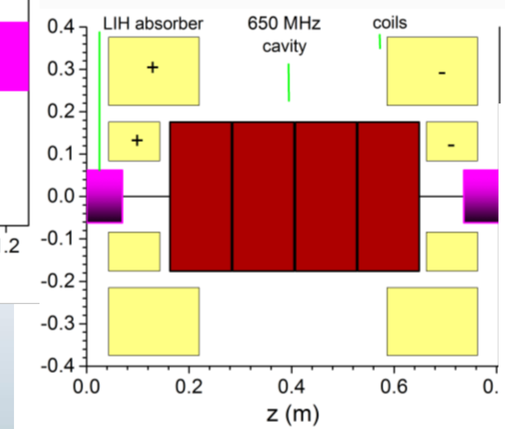
MAGNETIC FIELD   axis (coil)

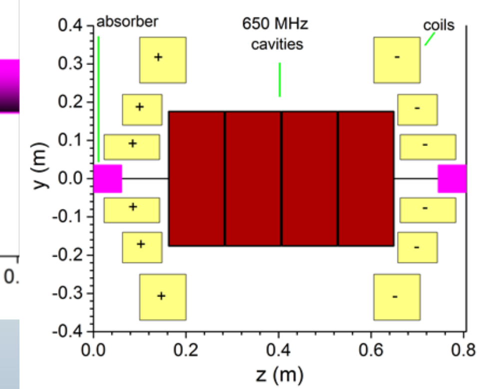
Cooling after merging (8 stages)

STAGE 2	STAGE 4	STAGE 6	STAGE 8
64 m (32 cells)	62.5 m (50 cells)	62 m (77 cells)	41.1 m (51 cells)







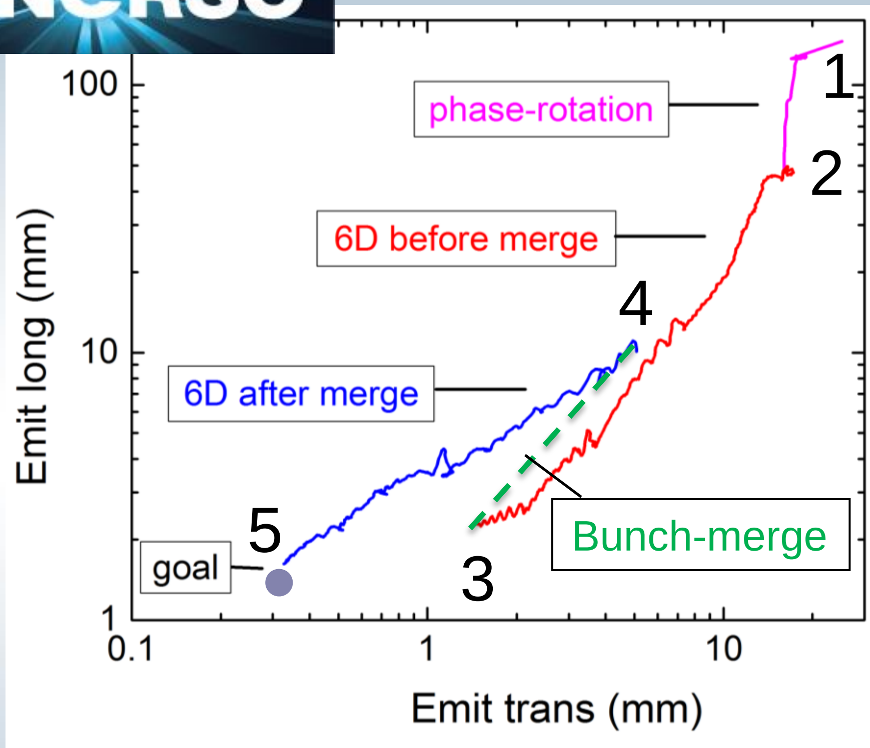


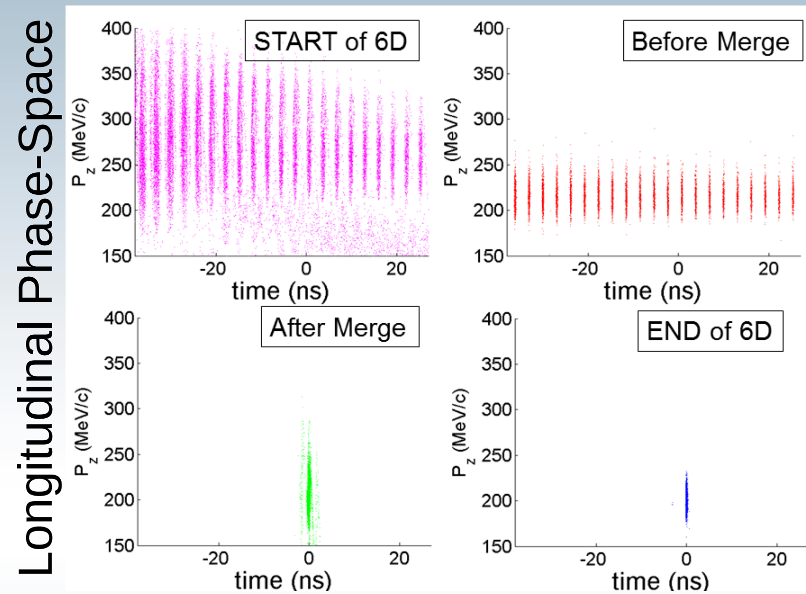
Absorber
TOP VIEW
LH & LIH

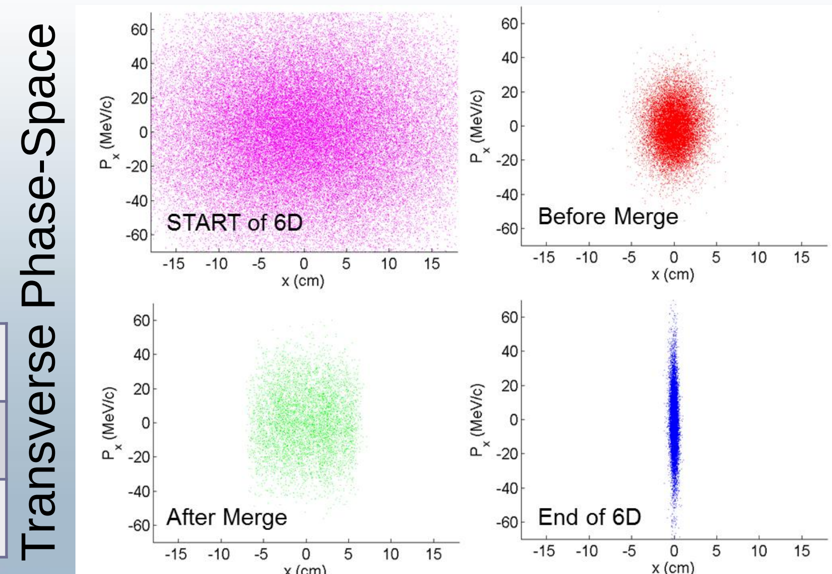
3.7 T (8.4 T) | 6.0 T (9.2 T) | 10.8 T (14.2 T) | 13.6 T (15.0 T)

MAGNETIC FIELD axis (coil)

Overall performance: End-to-End Simulation



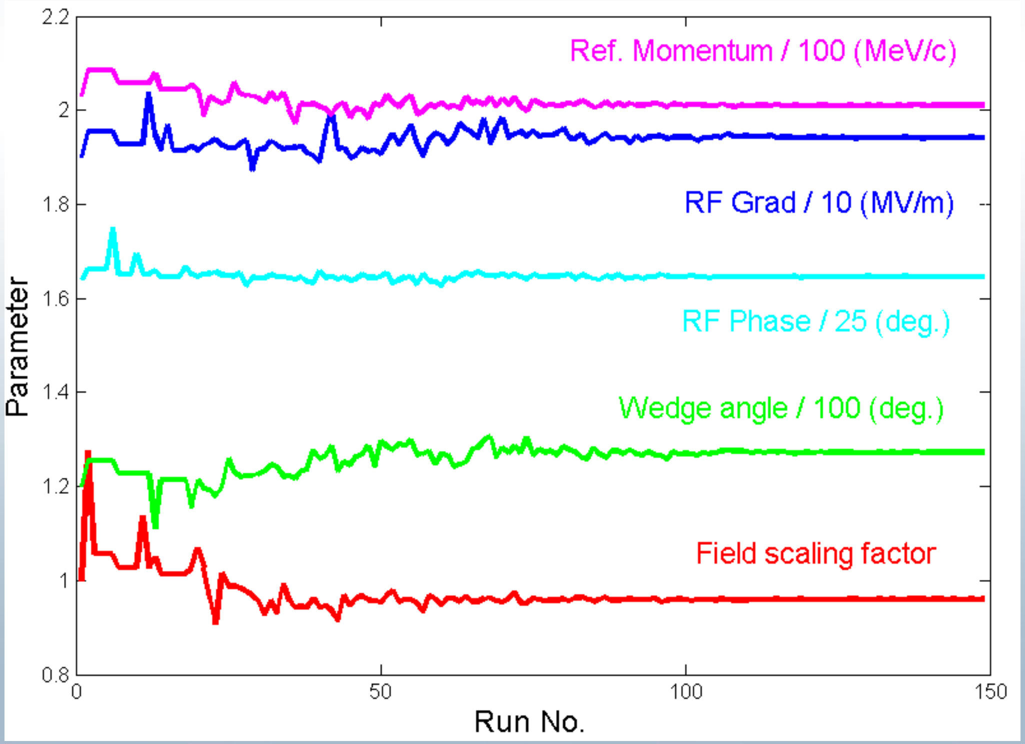


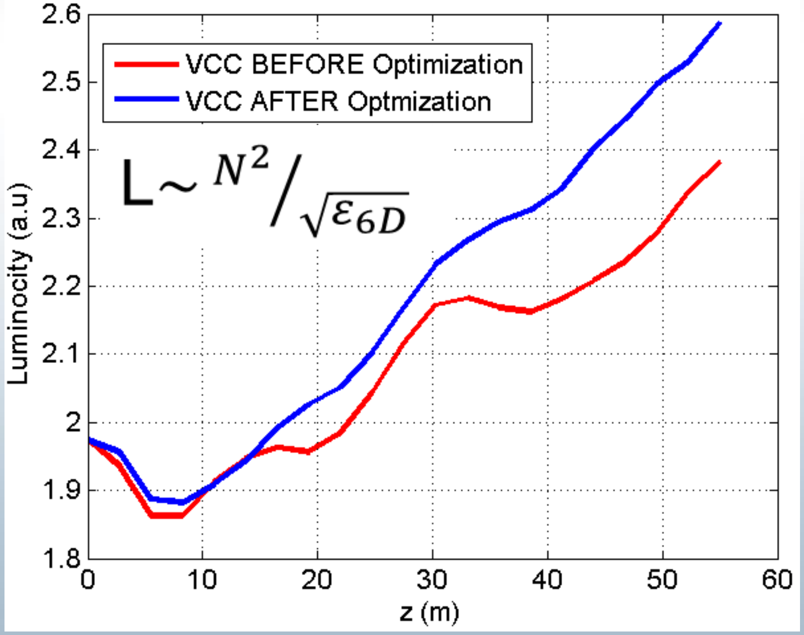


Parameters	MAP Goal	6D VCC
Emittance, Transv. (mm)	0.30	0.28
Emittance, Long. (mm)	1.50	1.57

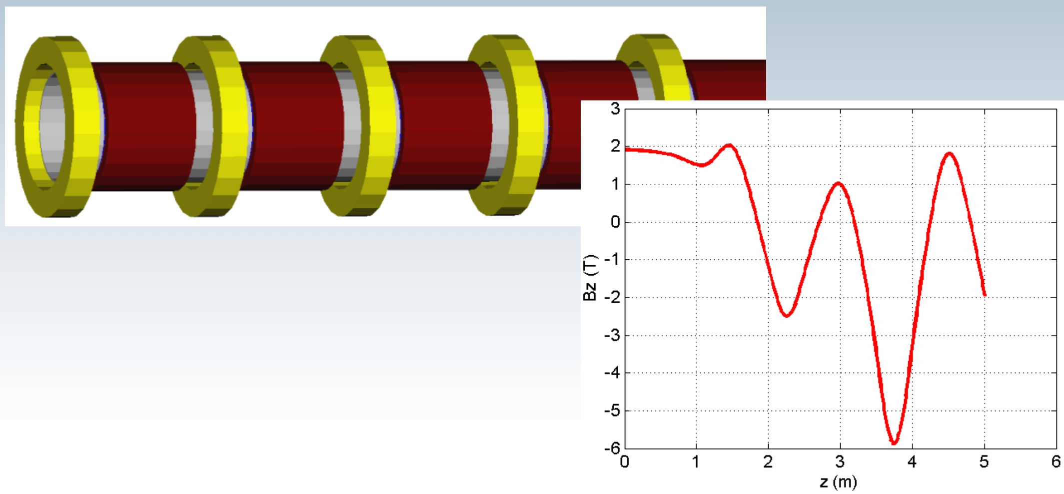
Multivariable Optimization for VCC

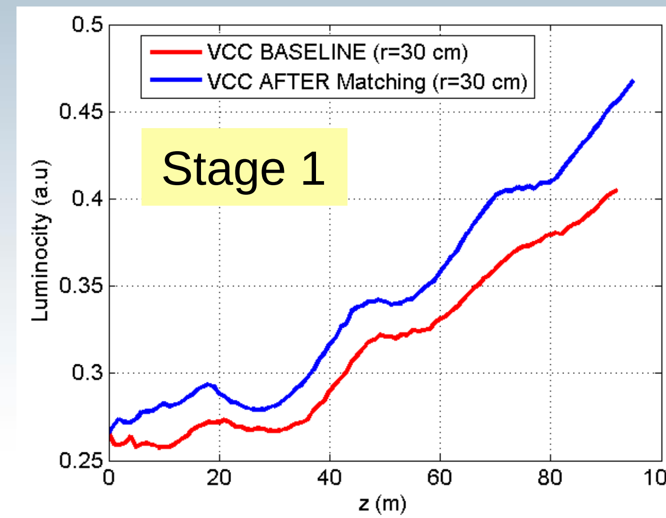
- Nelder-Mead algorithm: Objective is to maximize luminosity.
- Integrated in NERSC with ICOOL-MPI
- Applied for VCC optimization: 8 parameters each time





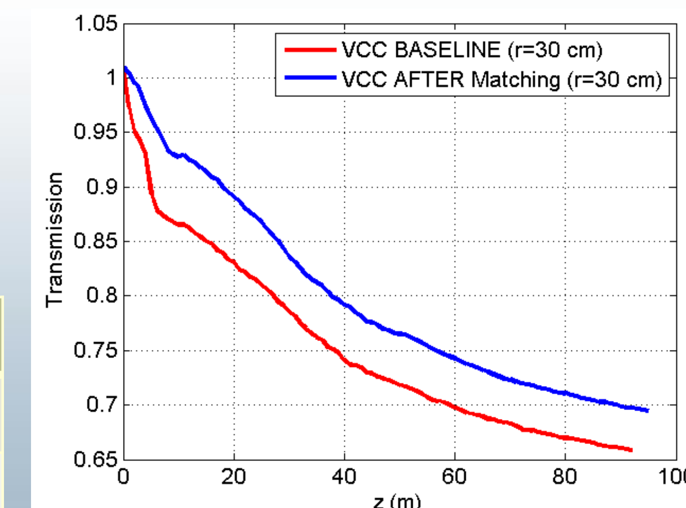
Matching to 6D VCC from Phase-Rotator



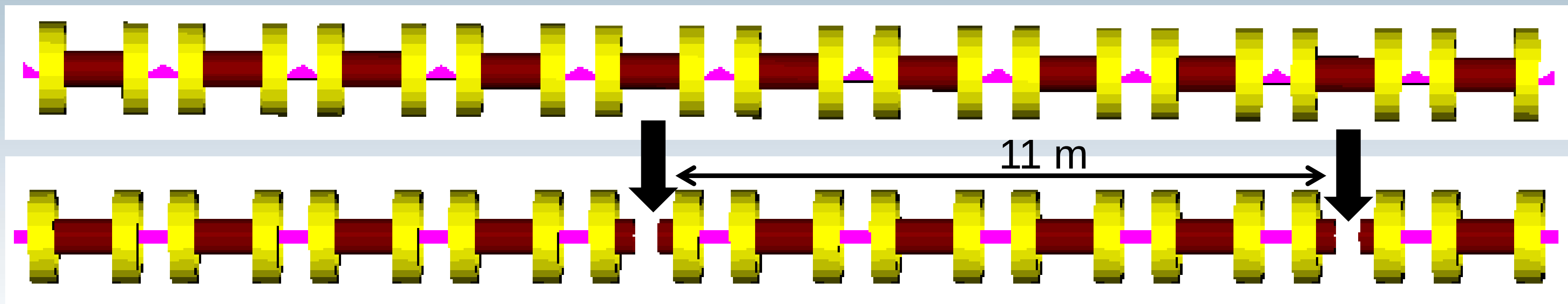


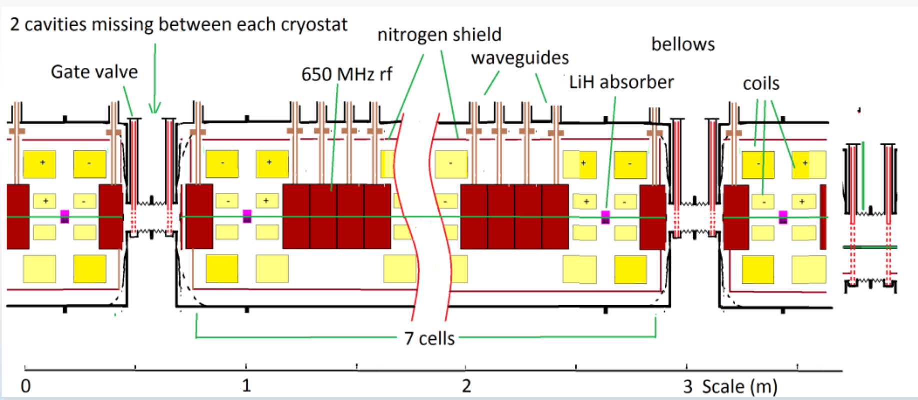
- Matching with 9 solenoidal coils
- ~4% gain in performance
- Allows reducing aperture 35 → 30 cm

Parameter	Baseline	With Matching
Cool rate (trans.)	2.13	2.19
Cool rate (long.)	2.76	2.81
Transmission	65.2% (132 m)	68.8% (132 m)



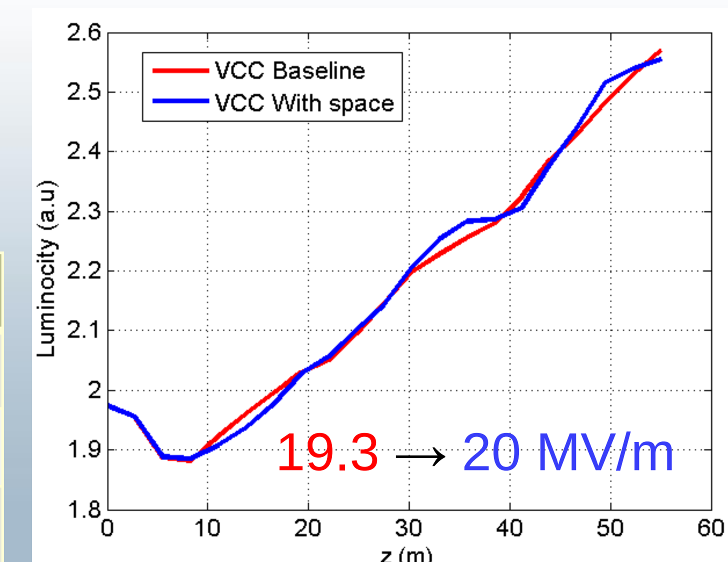
Lattice Space for Cryostats





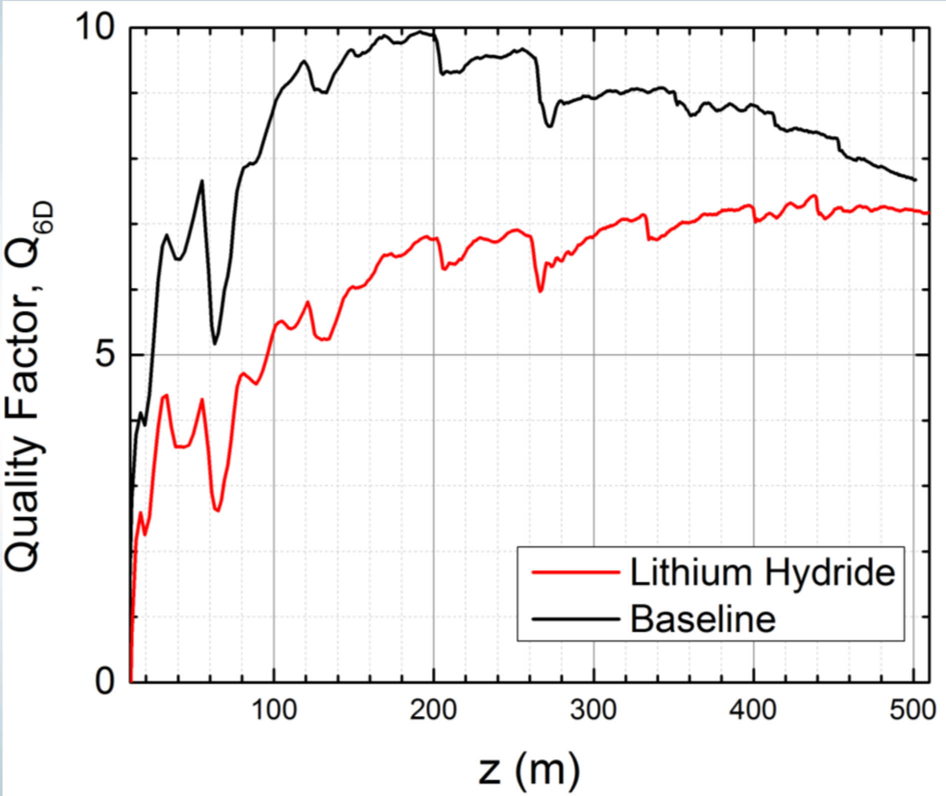
- Space generated for diagnostics, cryostats

Parameter	Baseline	With Space
Cool rate (trans.)	1.49	1.49
Cool rate (long.)	1.30	1.35
Transmission	87.2% (55 m)	86.4% (55 m)



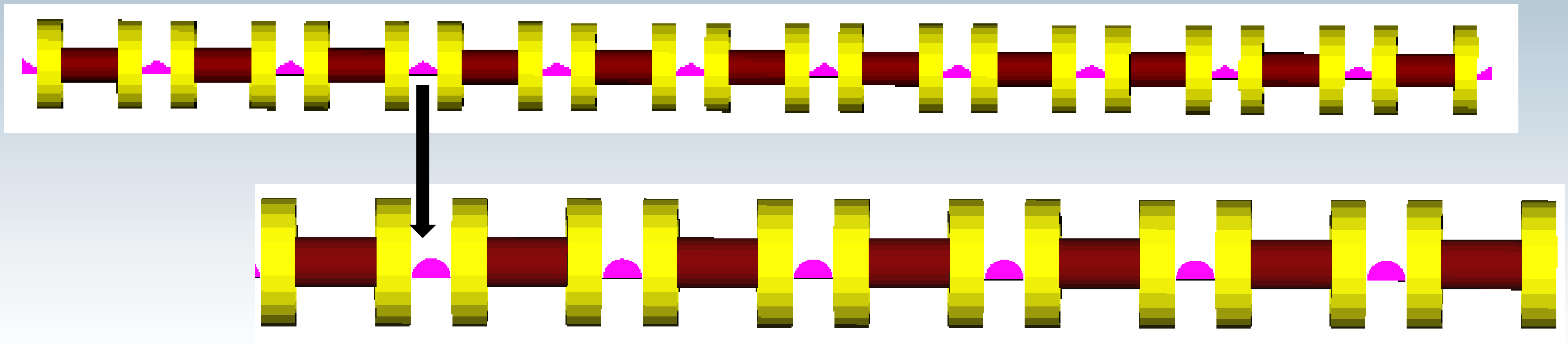
Cooling with LiH vs. LH

- Post-Merger has 8 stages
- Two alternative cases:
  - Baseline: First 4 stages with liquid hydrogen (LH) and last 4 with Lithium Hydride (LiH)
  - Alternative: All stages with LiH
- Quality factor, Q is used for lattice evaluation
- Both lattices reach the MAP goal for the emittances
- Baseline more promising

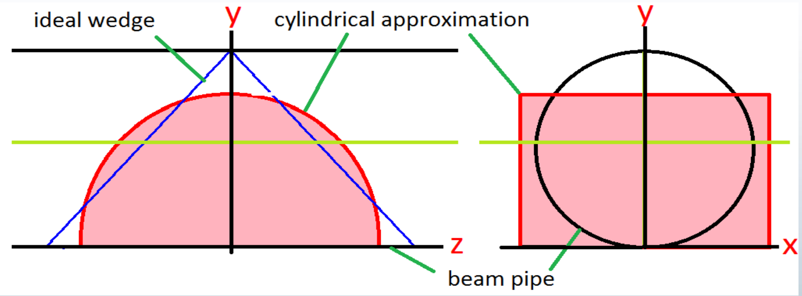


$$Q_6(z) = \frac{d\epsilon_6/\epsilon_6}{dN/N}$$

Wedges vs. Cylinders

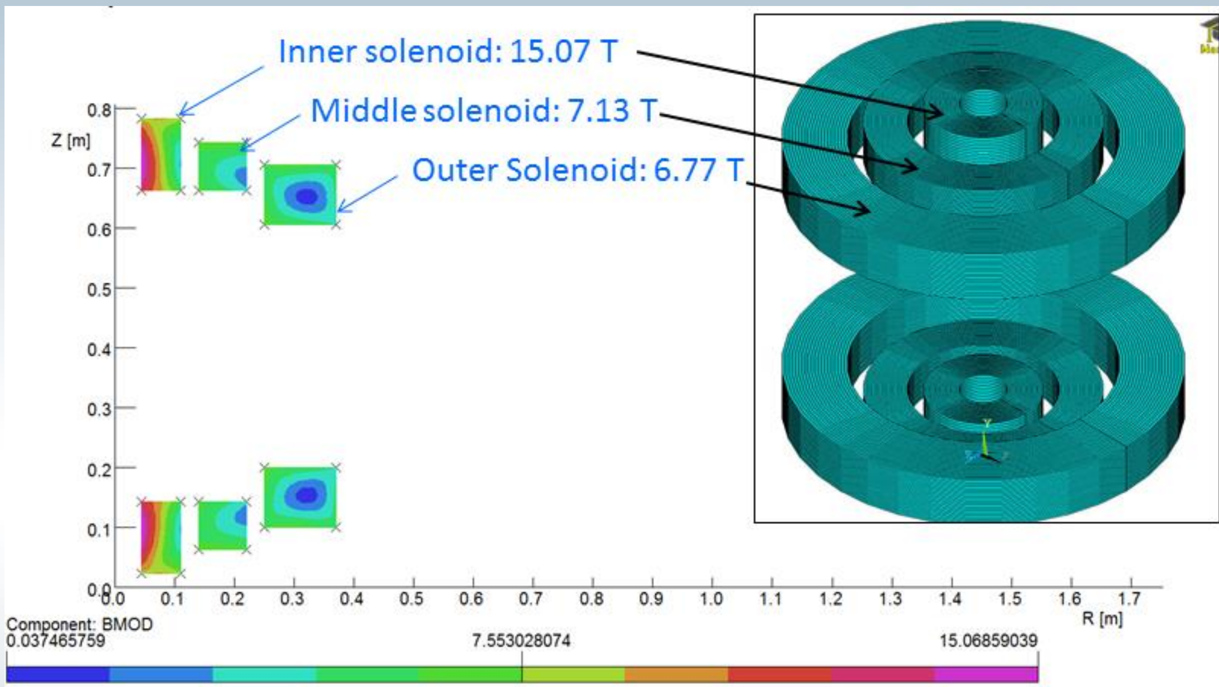


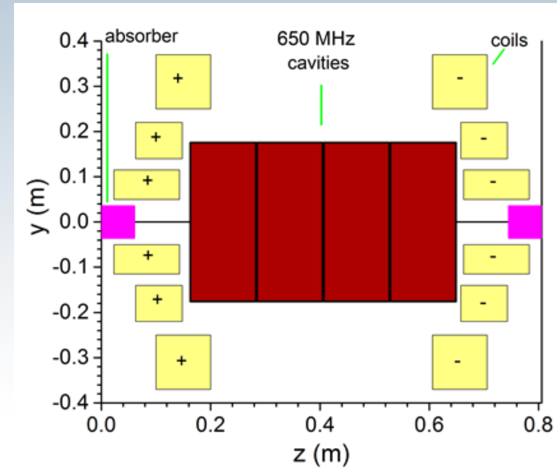
- For LH absorber it is easier to construct a cylindrical absorber
- Slightly degrades cooling



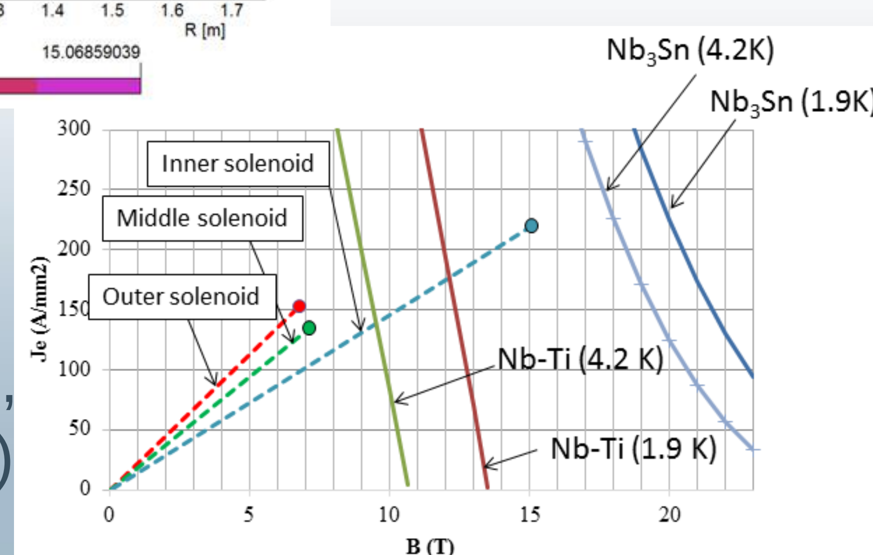
Parameter	Wedge (Base)	Cylinders
Cool rate (trans.)	1.48	1.46
Cool rate (long.)	1.23	1.18
Transmission	90% (55 m)	90% (55 m)

Magnet Design (last stage)

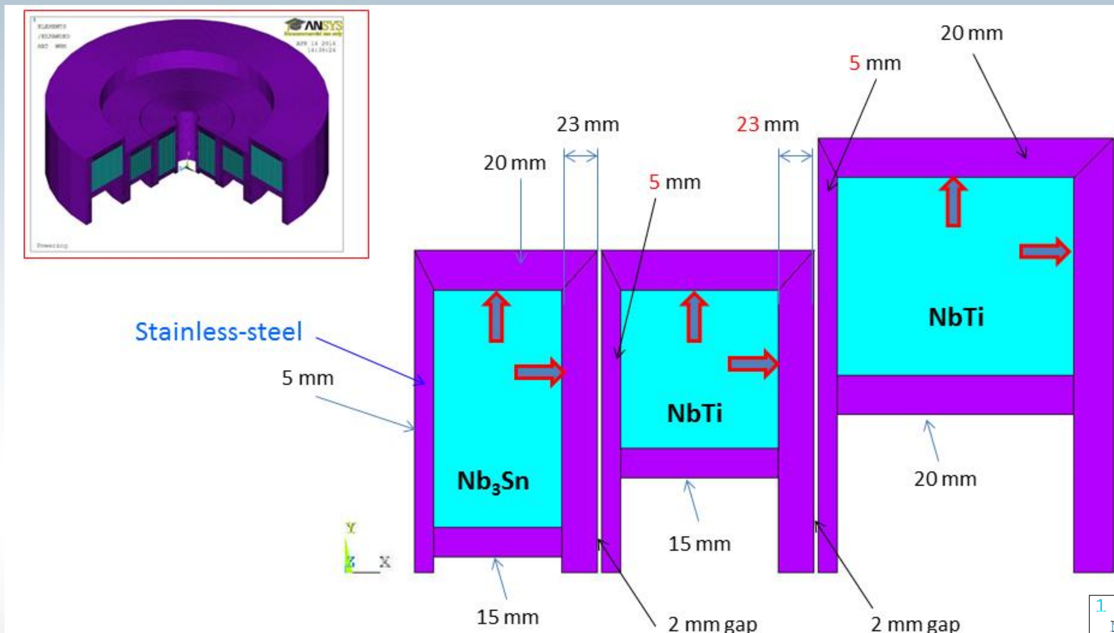


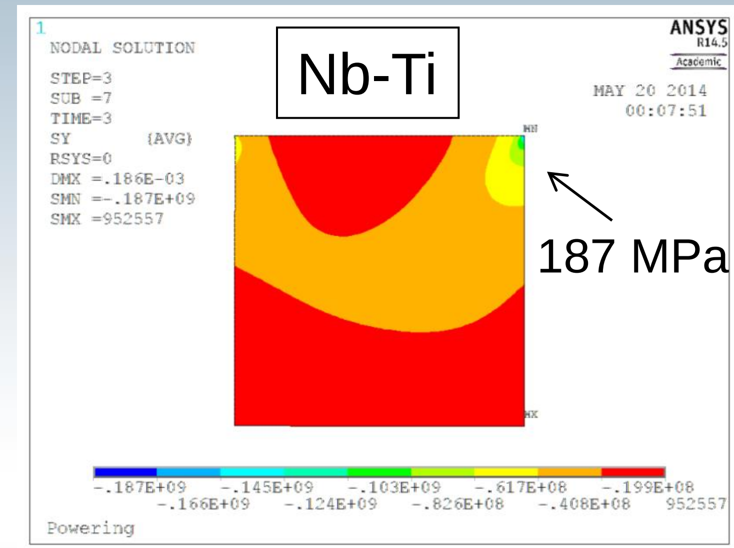


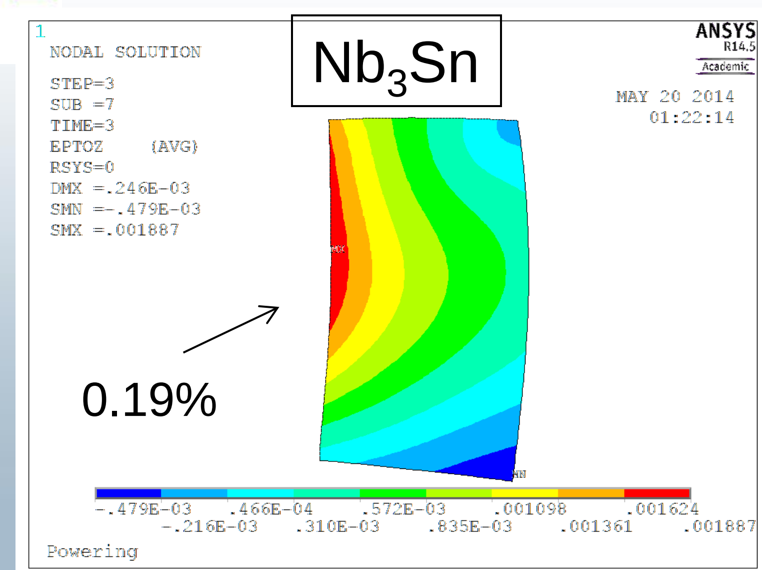
- Inner coil: Nb_3Sn
- Middle, outer: Nb-Ti
- Collaborating effort: Borgnolutti, Prestemon, (LBNL) Witte (BNL)



Mechanical Model

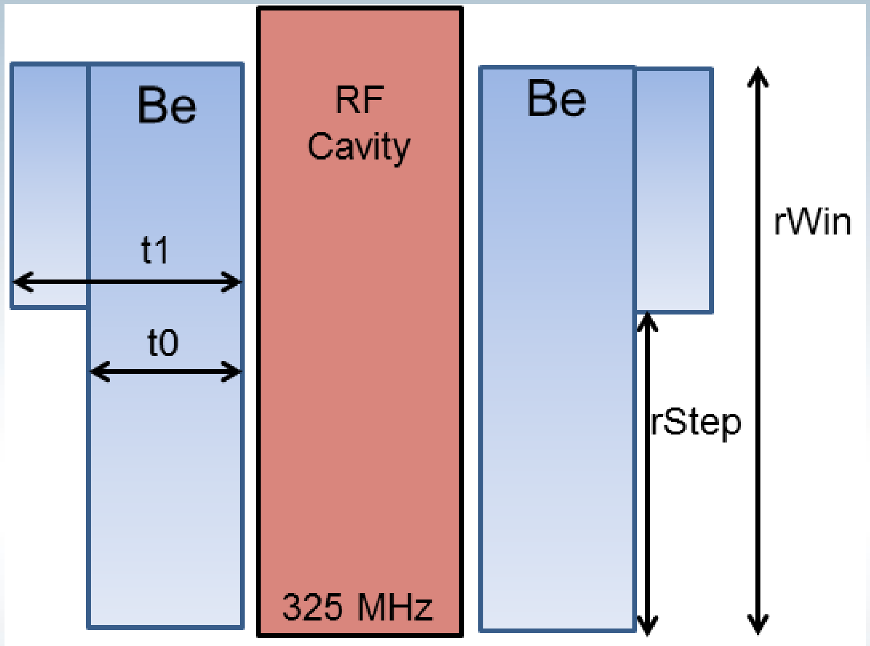






- Azimuthal strain in the inner solenoid (19%) is within Nb_3Sn irreversible limit (25%)
- Stress for Nb-Ti is less than its yield strength (300 Mpa)

Be Windows Simulation Model



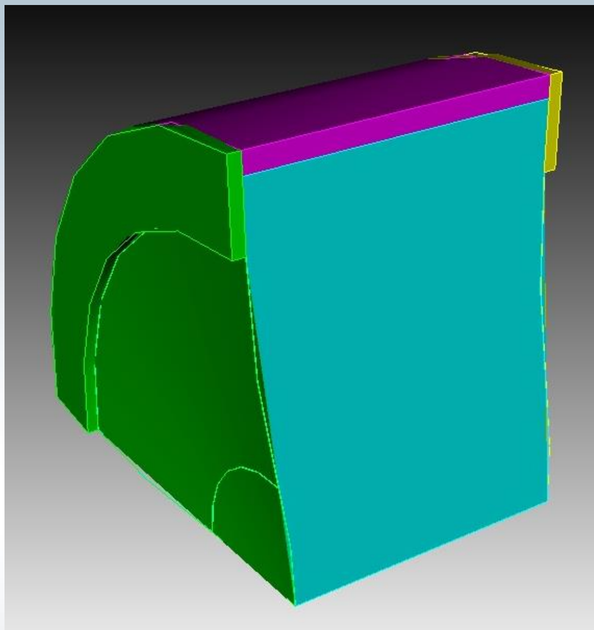
Stage	f (MHz)	rWin (cm)	rStep (cm)	t0 (mm)	t1 (mm)
1	325	30	16	0.3	1.4
2	325	25	15	0.2	0.8
3	650	19	10	0.2	0.6
4	650	13.2	11.4	0.125	0.38

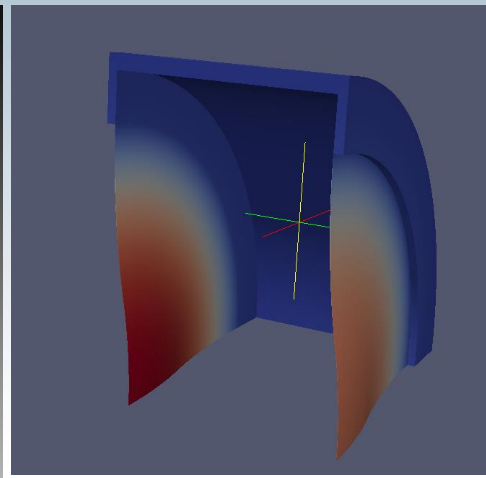
- Stepped Be window: All stages have two steps.

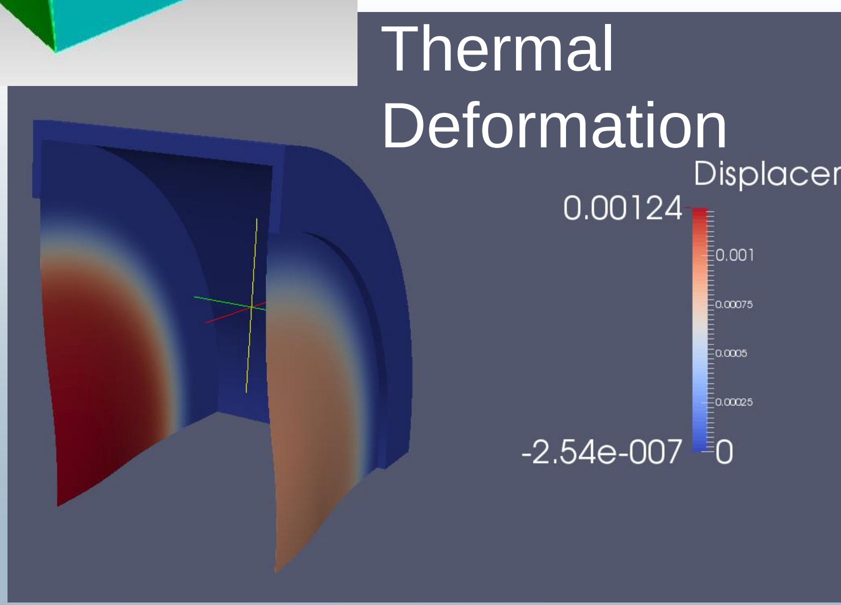
Channel before merge, ONLY!

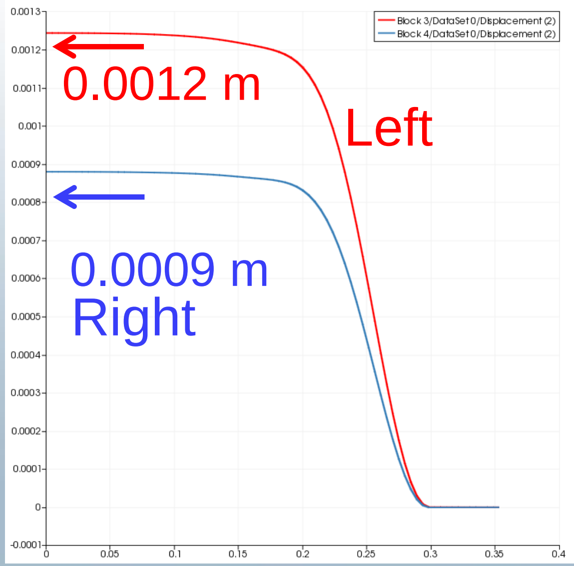
Parameter	Baseline	With Be
Cool rate (trans.)	11.8	10.7
Cool rate (long.)	20.7	18.0
Transmission	49.1%	46.0%

Be Windows TEM3p Simulation (Luo)



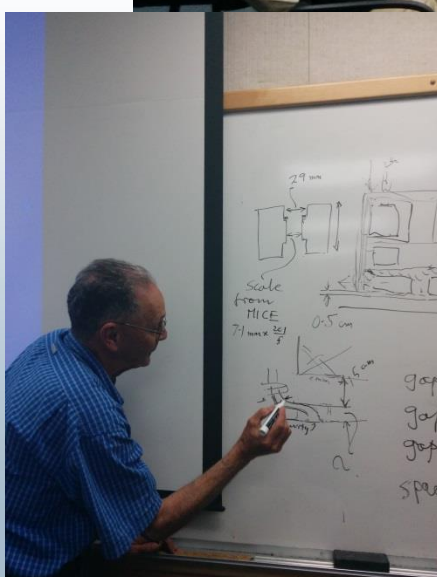


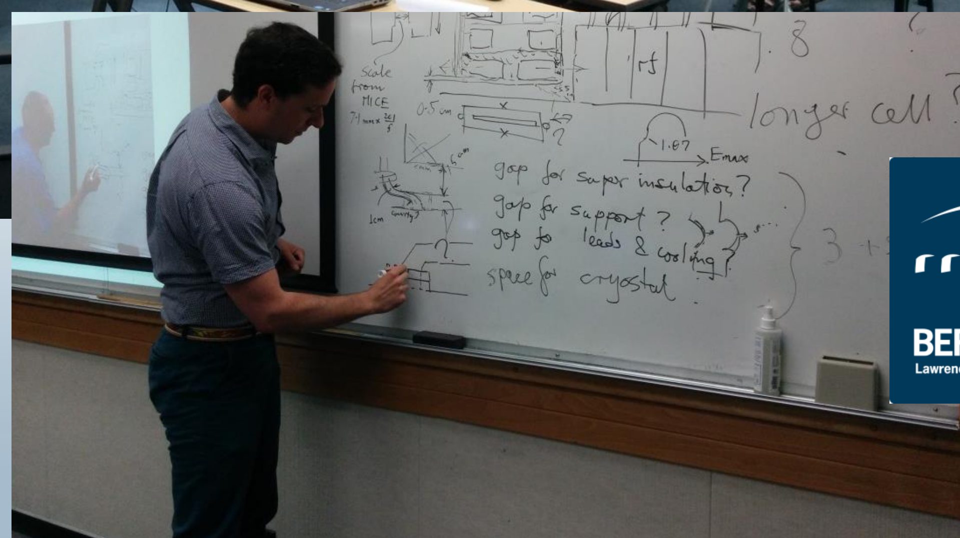




Recommendations from VCC workshop

Hosted at LBNL, May 13-14, 2014





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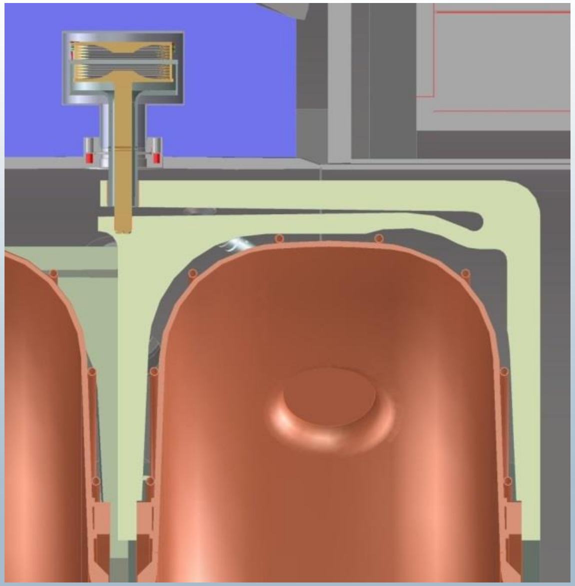
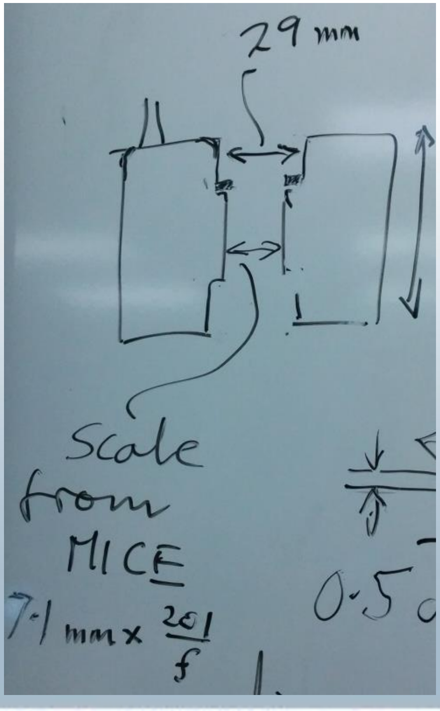
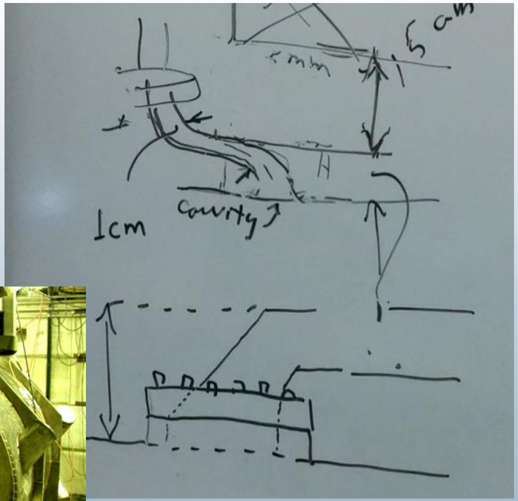
What we learned from workshop 1

- RF Cavity Design:
  - A separation of 5.0 cm (2.5 cm each) needs to be added between cavities for tuners and flanges
  - Cavities can be powered by a curved waveguide-> simplifies the focusing magnet (no need to split the coils).

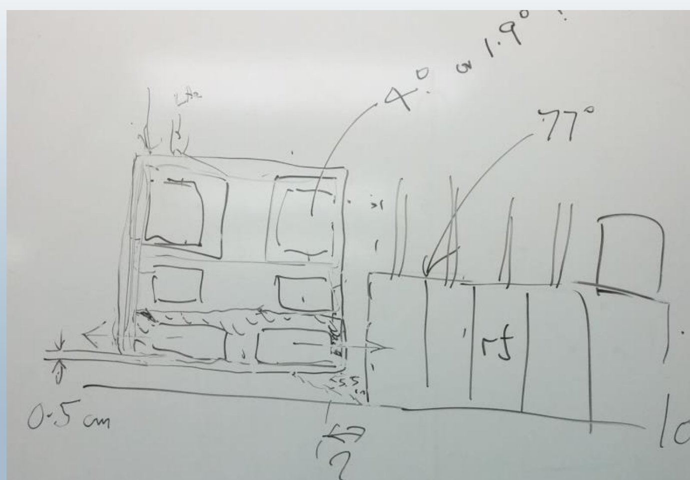


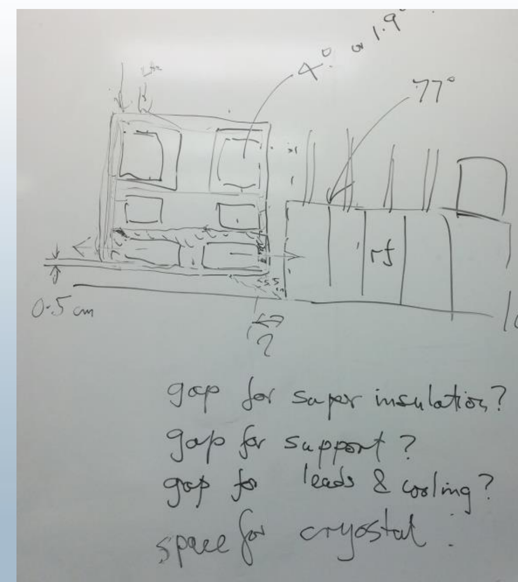




What we learned from workshop 2

- Magnets:
  - Stage 8 (last stage) looks feasible.
  - Some stages need to be modified. Coils require at least 5 cm extra space in the longitudinal direction to place He bath and coil feeds in/out.
  - Calculation of forces & stresses for earlier stages required
  - Evaluate quench protection





Future work towards IBS

- Absorbers:
  - We will evaluate a channel with LiH absorbers only
- Lattice Design work
  - Redesign stages to allow more space for coils and rf
  - Add extra space for diagnostics to all stages
  - Matching to a 3T solenoid
- RF windows
  - Calculate deformation, stresses, freq. detuning for Stage 1
- Report write-up by end of FY 14.

Other VCC talks in this MAP Meeting

- Vacuum RF/ Be window Update
  - May 28 at 11:45 am: Bowring, Luo
- Magnet requirements
  - May 28 at 1:30 pm: Prestemon
- Initial Cooling
  - May 28 at 5:15 pm: Alexahin
- Final Cooling
  - May 29 at 8:15 am: Sayed
- Bunch Merge
  - May 29 at 9:30 am: Bao

Five VCC Contributions to IPAC

- Cooling with vacuum technology overview
  - Poster TUPME020
- Theoretical framework for predicting efficiency of VCC
  - Poster TUPME021
- Magnet design feasibility for VCC
  - Poster WEPRI103
- Cooling with a hybrid channel with gas filled rf
  - Poster TUPME024
- Final cooling
  - Poster TUPME019

Summary

- We defined a concept for 6D cooling based on a rectilinear channel
- We specified the required magnets, cavities and absorbers for the cooling channel before & after the merger.
- "End-to-end" simulation: Final emittances are: 0.28 mm (T) [0.30 mm] and 1.57 mm (L) [1.50 mm].
- Magnet feasibility study for the last VCC stage with encouraging results.
- Mechanical and thermal analysis of rf windows initiated.
- Some stages need modifications.