HCC-based LEMC Scenario Progress

Rolland Johnson
Muons, Inc.

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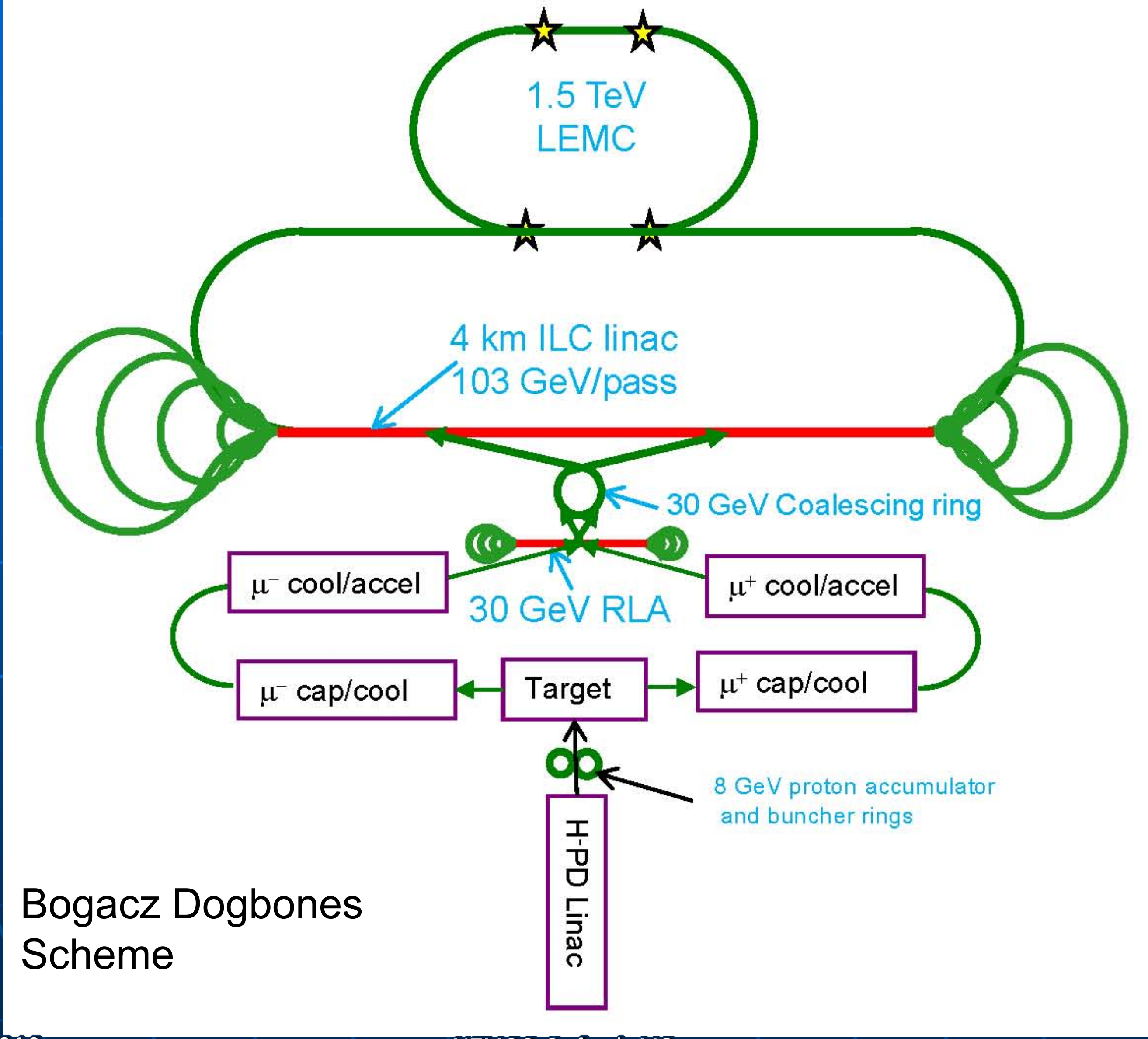
LEMC Scenario (2008)



HCC-based LEMC Scenario Progress (as discussed at the MCDW @ BNL 6 weeks ago)

•Proton Driver	- Chuck Ankenbrandt
•CW Linac PD	- Milorad Popovic
•Target	
•Pion Capture	- Dave Neuffer
•HCC Decay	- Cary Yoshikawa
•HCC Magnets	- Vladimir Kashikhin, Sasha Zlobin
•HCC RF	- Mike Neubauer, Alvin Tollestrup
•HCC Design, sims	- Katsuya Yonehara (can we build it?)
•HCC EPIC - REMEX	- Vasiliy Morozov
•LE RLA	
•Coalescing ring	
•HE RLA	- Alex Bogacz, Dejan Trbojevic
•Collider ring & low β	- Vadim Kashikhin
•Experiment Detector	- Mary Anne Cummings

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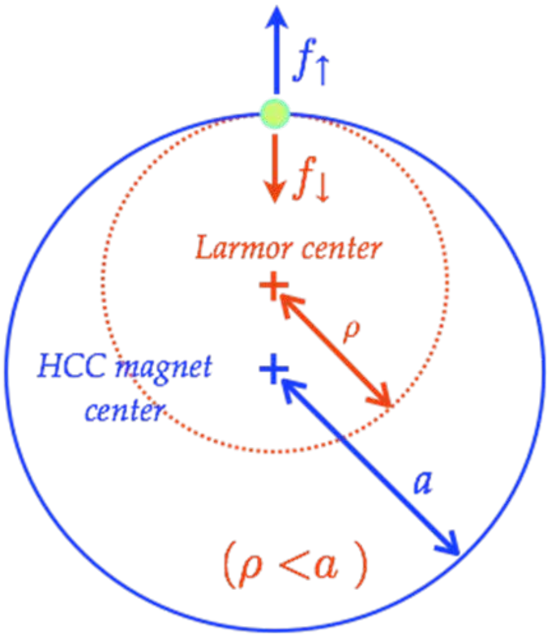
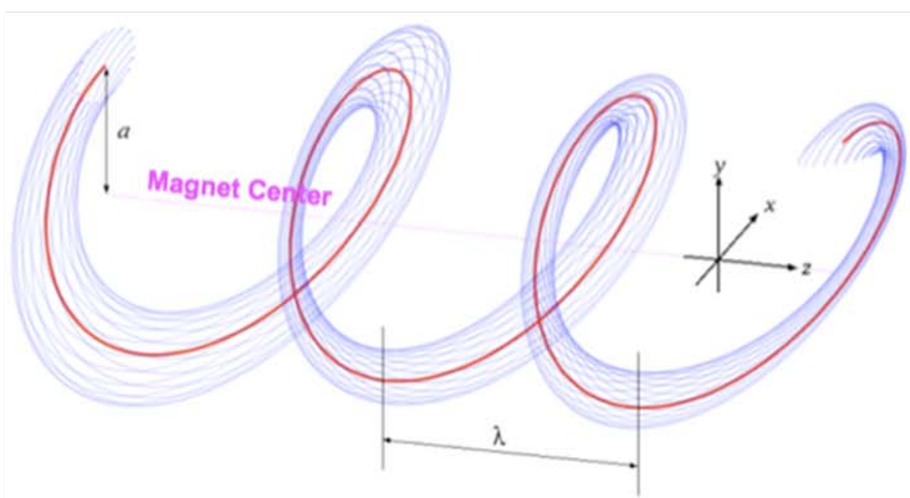
Helical Cooling Channel (HCC)



Projectile in transverse (x-y) plane



Particle motion in helical magnet

Larmor motion in pure solenoid

$$f_\downarrow = -\frac{e}{m_\mu} p_\varphi \cdot b_z$$

$$\rho = \frac{p_\varphi}{b_z}$$

Radial equation of motion with helical dipole

$$f = f_\uparrow + f_\downarrow = \frac{e}{m_\mu}(p_z b_\varphi - p_\varphi b_z)$$

$k = \frac{2\pi}{\lambda}$ HCC wavenumber

$\kappa = ka = \frac{p_\perp}{p_z}$ HCC pitch

Equation of motion for reference particle

$$p(a) = \frac{\sqrt{1+\kappa^2}}{k}\left(b_z - \frac{1+\kappa^2}{\kappa} b_\varphi\right)$$

Introduction of field gradient in bϕ generates dispersion function

Stability condition in transverse phase space

$$Q^4 - 2Q^2R + G = 0,$$

with

$$G = (q - g)\hat{D}^{-1} = \left(\frac{2q+\kappa^2}{1+\kappa^2} - \hat{D}^{-1}\right)\hat{D}^{-1}$$

and

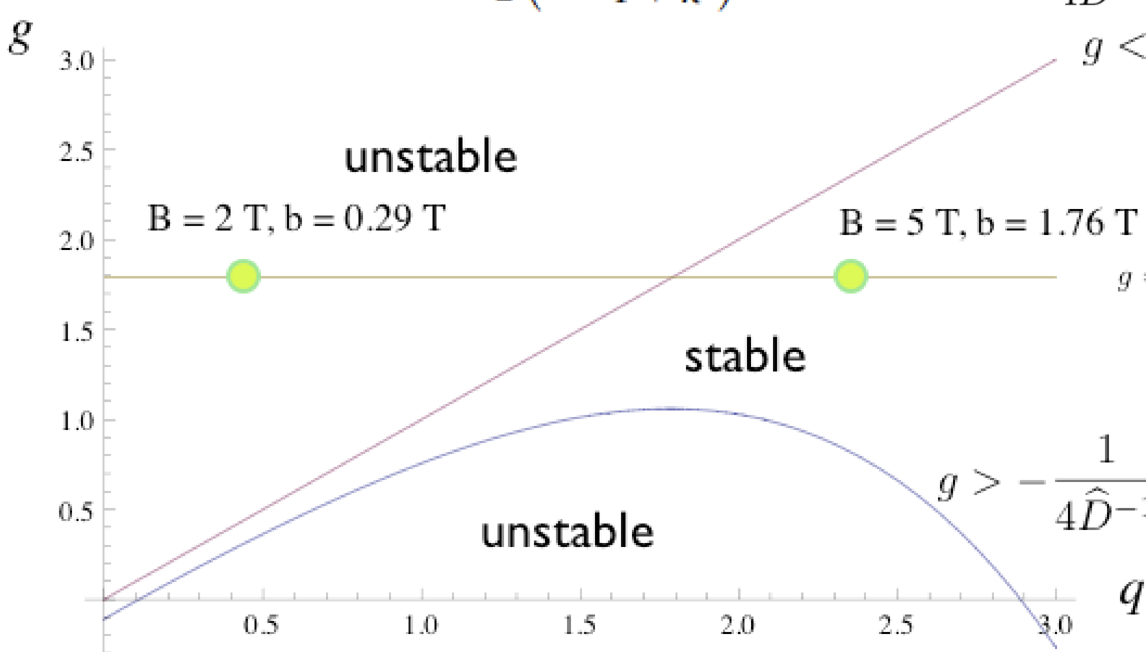
$$R \equiv \frac{1}{2}\left(1 + \frac{q^2}{1+\kappa^2}\right).$$

Stability condition is, therefore

$$0 < G < R^2$$

Stability condition can be represented by g (field index) and q (= k_c/k-1)

$$g > -\frac{1}{4\widehat{D}^{-1}}\left(1+\frac{q^2}{1+\kappa^2}\right)^2 + q \qquad g < q \qquad q > 0$$



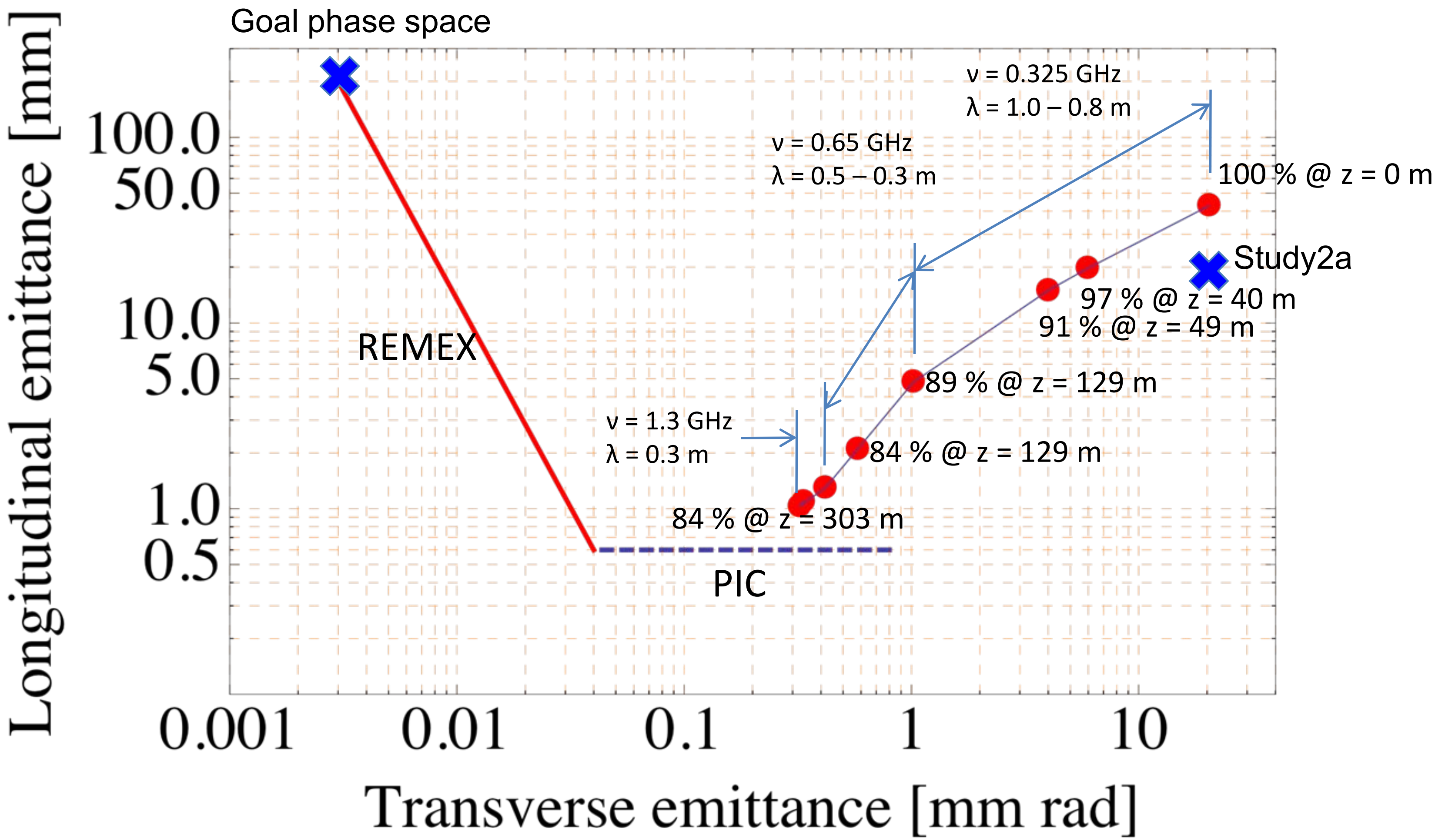
$$g < q$$

$$g = -\frac{\kappa^2 + (1-\kappa^2)q}{1+\kappa^2} + \widehat{D}^{-1} = 1.79$$

$$g > -\frac{1}{4\widehat{D}^{-1}}\left(1+\frac{q^2}{1+\kappa^2}\right)^2 + q$$

New Fernow-Neuffer plot

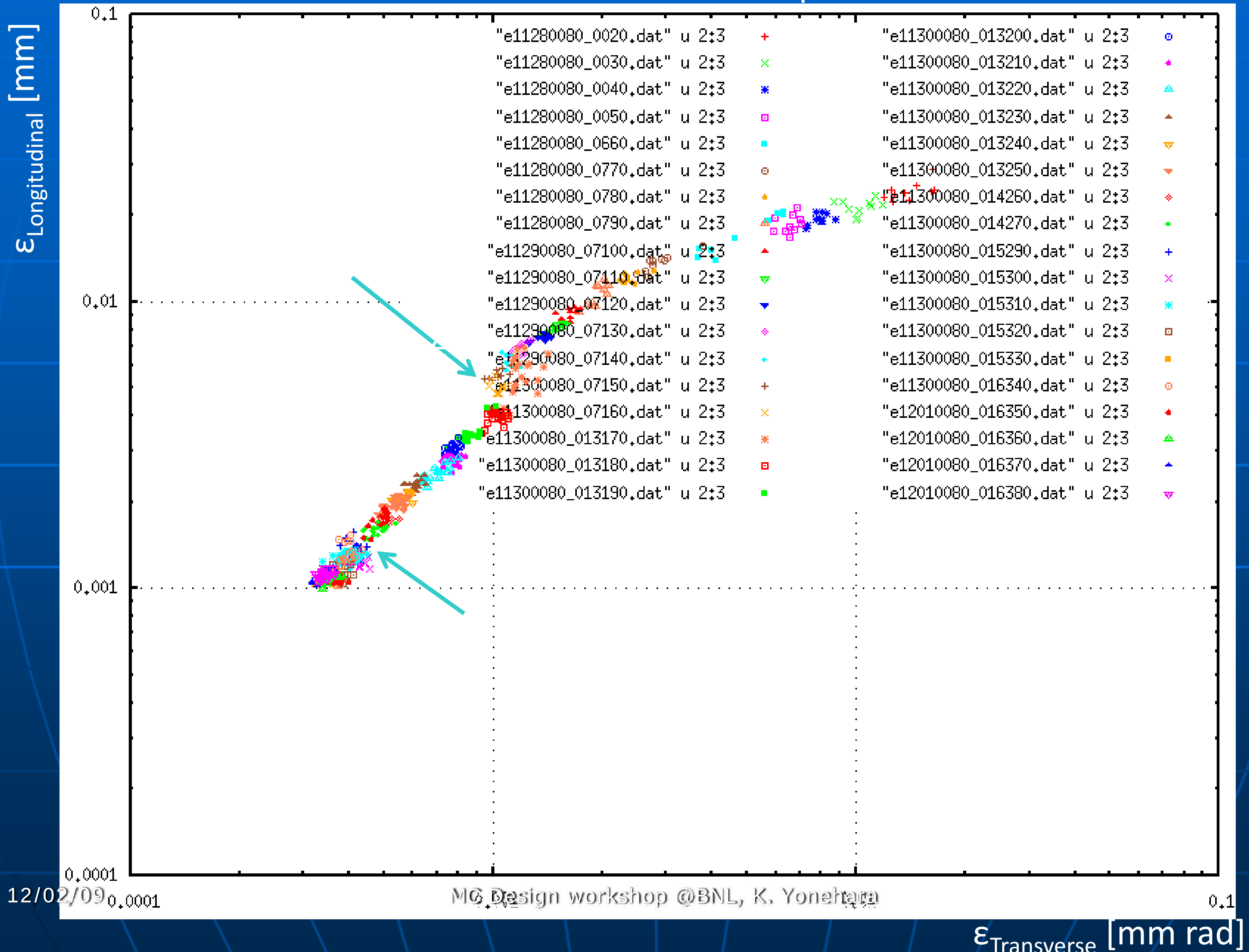
MC Design workshop @BNL, K. Yonehara



- GH2 pressure = 160 atm
- 60 μm Be RF window
- E ~ 27 MV/m
- Detailed parameter will be given in later slide (slide 15)

Emittance evolution in HCC

Let us revisit new Fernow Neuffer plot on slide 3



Parameter list

	Z	±Δr	±Δp/p	b	b'	bz	ν	κ	λ	N_μ	ε_T	ε_L	ε_{6D}
unit	m	cm	%	T	T/m	T	GHz		m		mm rad	mm	mm^3
	Channel length	Full Width	Full width	@ ref	@ ref	@ ref	RF						
1	0	15	22	1.3	-0.5	-4.2	0.325	1.0	1.0	388	20.4	42.8	12900
2	40	8	10	1.3	-0.5	-4.2	0.325	1.0	1.0	375	5.97	19.7	415.9
3	49	7	10	1.4	-0.6	-4.8	0.325	1.0	0.9	354	4.01	15.0	10.8
4	129	3	2.5	1.7	-0.8	-5.2	0.325	1.0	0.8	327	1.02	4.8	2.0
5	219	1.7	1.8	2.6	-2.0	-8.5	0.65	1.0	0.5	327	0.58	2.1	3.2
6	243	1.6	1.3	3.2	-3.1	-9.8	0.65	1.0	0.4	327	0.42	1.3	0.14
7	273	1.3	1.3	4.3	-5.6	-14.1	0.65	1.0	0.3	327	0.32	1.0	0.08
8	303	1.2	1.1	4.3	-5.6	-14.1	1.3	1.0	0.3	327	0.34	1.1	0.07

Very Recent HCC Progress

- HCC Technology Development
  - Magnets
    - 1st HCC magnets with NbTi built, iterations underway
    - Final HCC magnets using HTS engineered based on HS
    - Two-coil HS about to be built with YBCO (~$25k YBCO due in 2 weeks)
    - Fiber optic quench protection to be experimentally developed ($100k OBR)
    - High field magnet development funded (2 SBIR-STTR projects, +Alvin et al.)
  - RF Cavities
    - SF6 doping studies support models (which imply beam capability) (new)
    - Beam to the MTA soon?
    - Dielectric loaded RF to be tested (Milorad talk)
    - Engineering solutions for HTS HCC with integrated RF (new)
  - Integration of Magnets, RF, HP GH2, cryogenics, and power sources (new)
    - Phase and frequency locked magnetron prototype being built (new)
    - Power requirements for RF in HCC (new)
    - Hyperconductivity and T dependence for RF Power in HCC (new)

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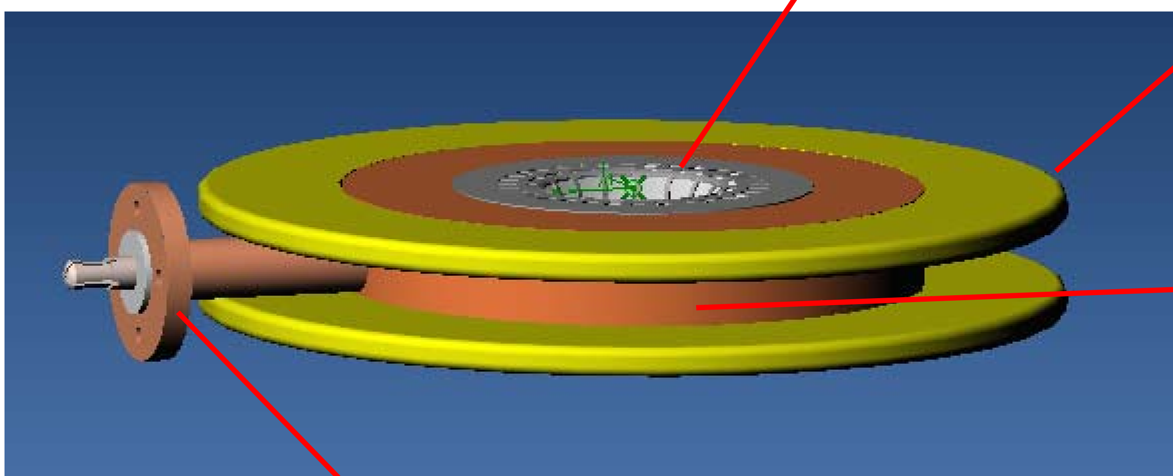
Cavity Module Concept

- Single pill-box cavities are made that are aligned to create an HCC.
- Each Cavity has it's own set of magnet coils at 50% fill factor



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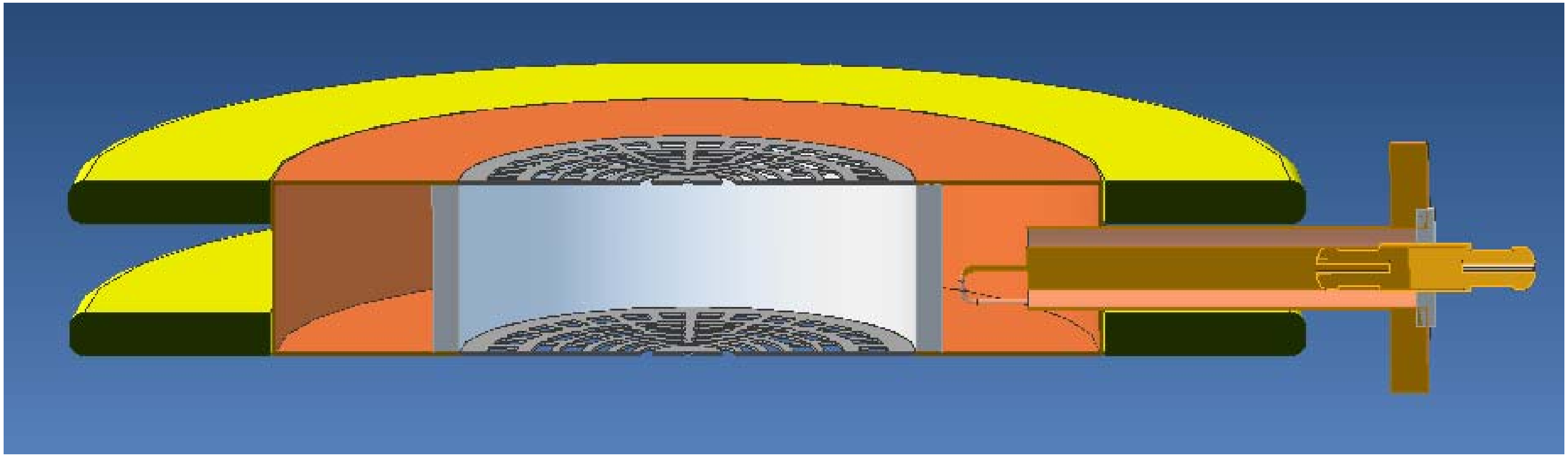
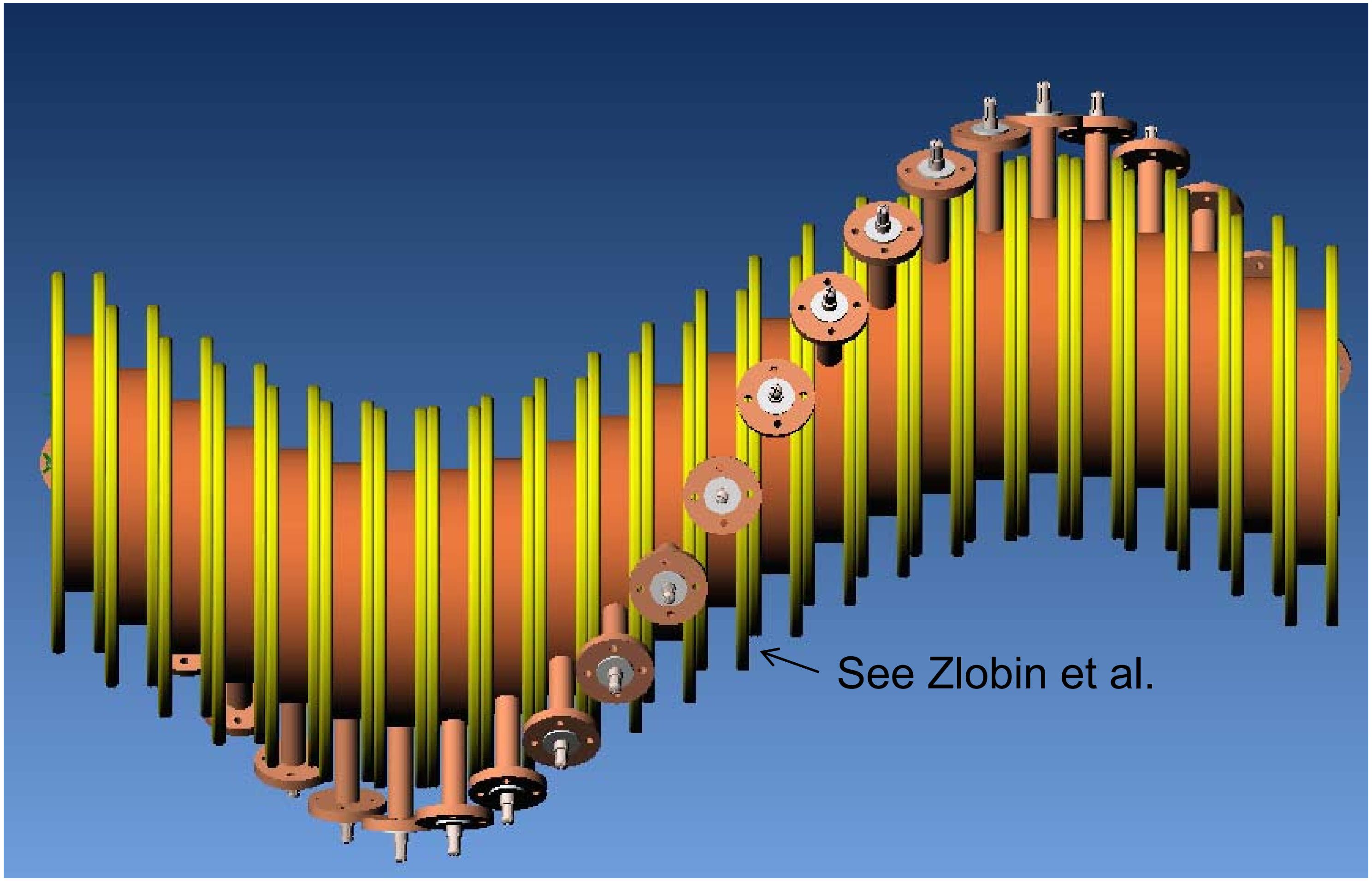
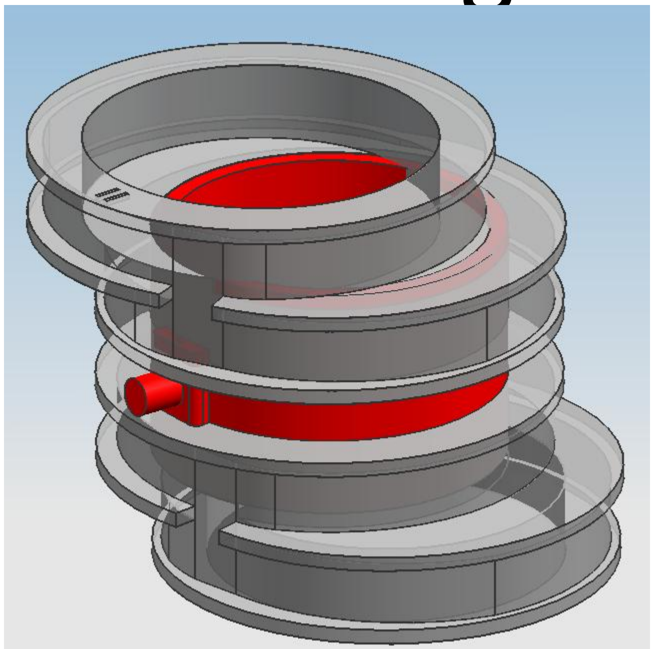
Cavity Detail

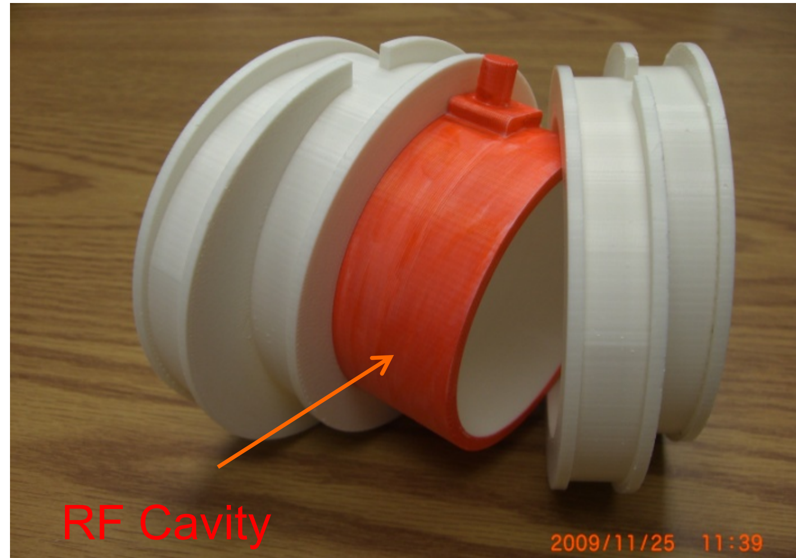


Complete HCC---Single Period

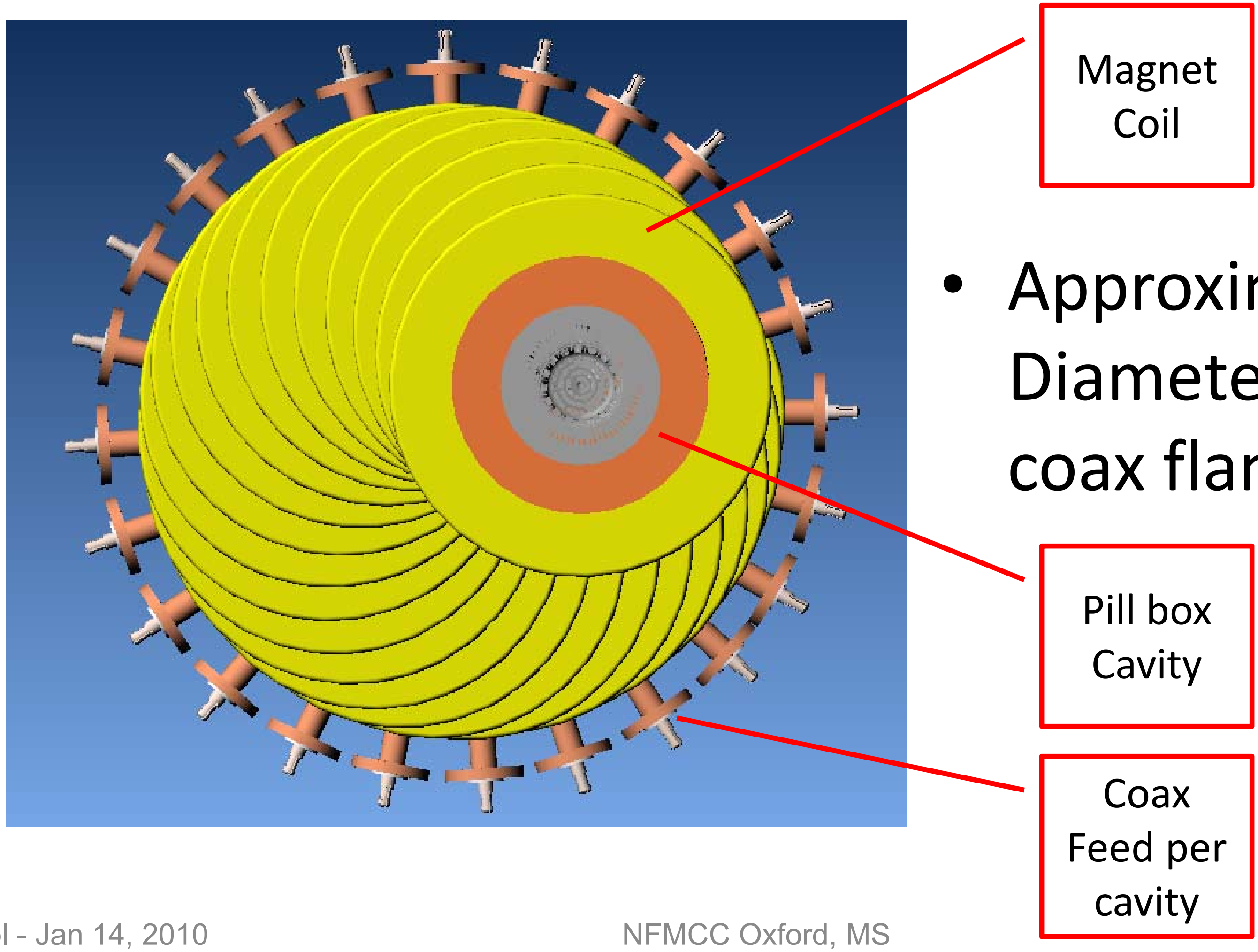


Modeling HTS section with RF





This is a 24 cavity per period 400 MHz design



- Approximate Diameter at the coax flange is 40”

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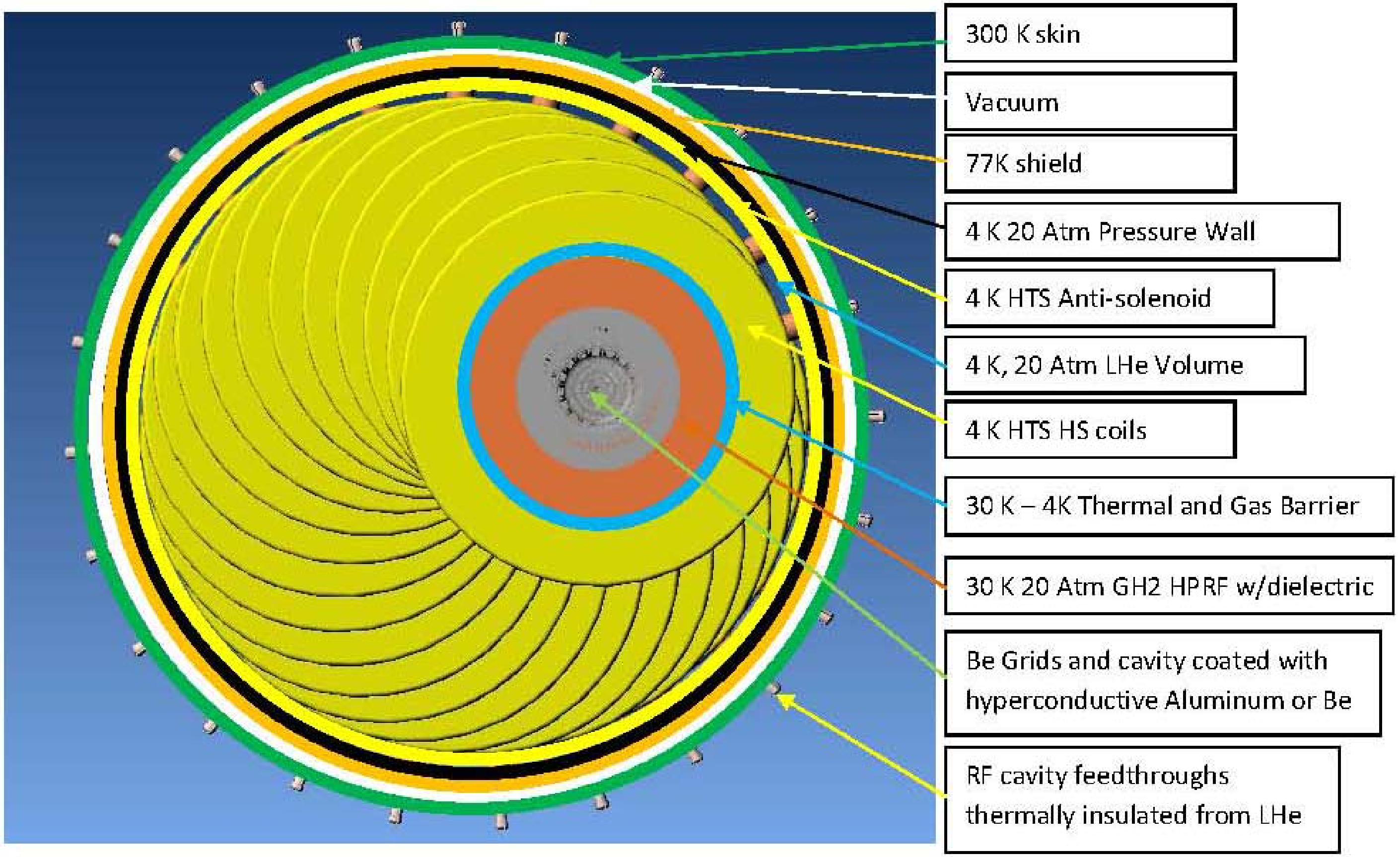
Dear HCC Aficionados, Dec. 21, 2009

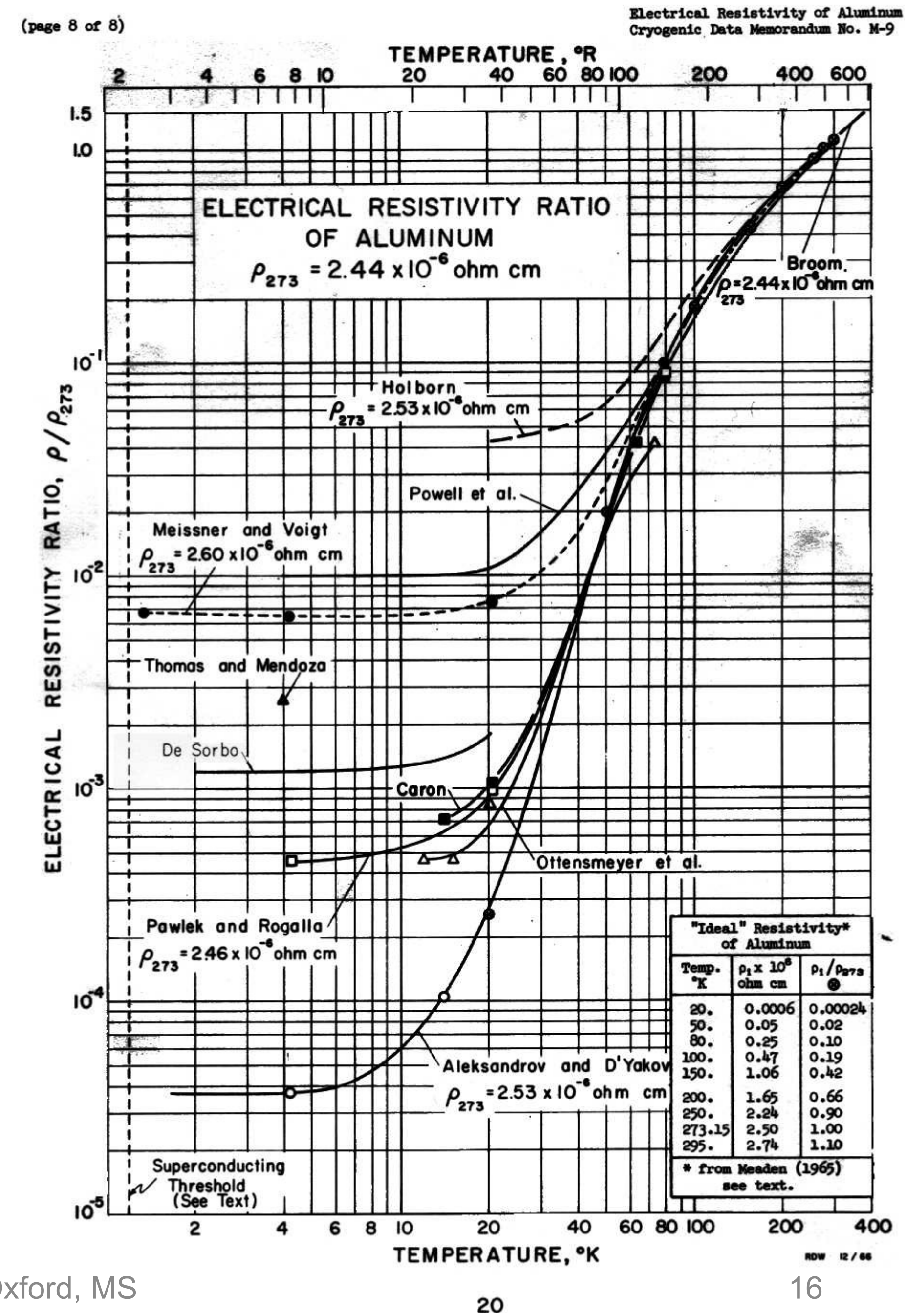
Here is an engineering concept for a HCC with cooling by High Pressure hydrogen for RF and High Pressure LHe for HTS or LTS:



Here we have one pressure vessel (black) that contains the RF and magnets at 20 Atm, where the RF is cooled at ~30 K by GH2 and the magnets at 4 K by LHe. At 30 K and 20 Atm, the hydrogen density is approximately the same as the 200 Atm at STP that has been used in many simulations. The thermal barrier (blue) between the two systems does not have to be very efficient since heat leaks from the LHe can help cool the GH2 which will be heated by the RF and the Beam. Since everything inside the black pressure wall is at the same pressure, the RF cavities can be thin, perhaps made of the SS HTS support structure. The RF feedthroughs will have to be insulated from the LHe. I am not sure how to tune the individual RF cavities other than to set them all to be the same on the bench and do the fine tuning with GH2 pressure.

An opportunity to operate the RF cavities with ultrapure metallic coating needs to be investigated. If anomalous skin depth and magnetostrictive uncertainties can be overcome, we could imagine the most efficient RF system possible in strong magnetic fields. Both Be and Al are excellent candidates, where the extremely low resistivity of Al has been called hyperconductivity. Also, an appropriate dielectric to adjust the RF frequency should have very low loss tangent at 30 K. We need some experiments!

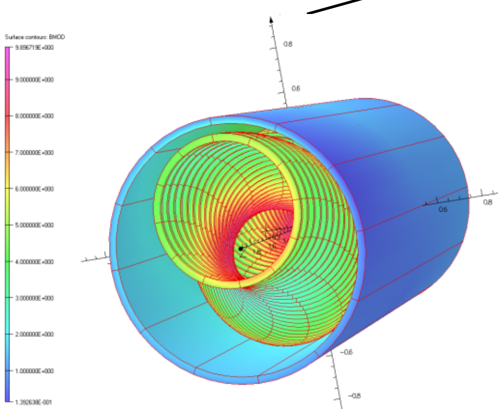
Many challenges! Reducing T reduces resistivity. As resistivity goes down, Q and filling time increase. Power must be removed which is less efficient at lower T.



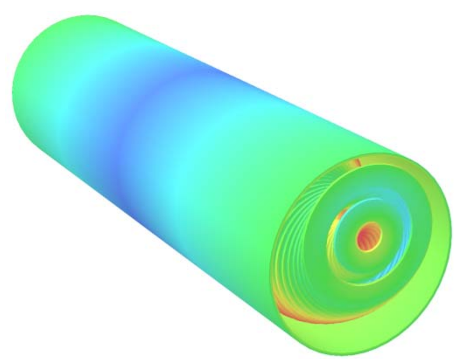
6D cooling: Helical Cooling Channel

K. Yonehara, S. Kahn, R. Johnson et al.

Parameter			Section			
			1st	2nd	3rd	4th
Total length		m	50	40	30	40
Period		mm	1000	800	600	400
Orbit radius		mm	159	127	95	64
Solenoidal field	B_z	T	-6.95	-8.69	-11.6	-17.3
Helical dipole	B_t	T	1.62	2.03	2.71	4.06
Helical gradient	G	T/m	-0.7	-1.1	-2	-4.5



V.S. Kashikhin et al.



M. Lopes et al.

Multi-section HCC

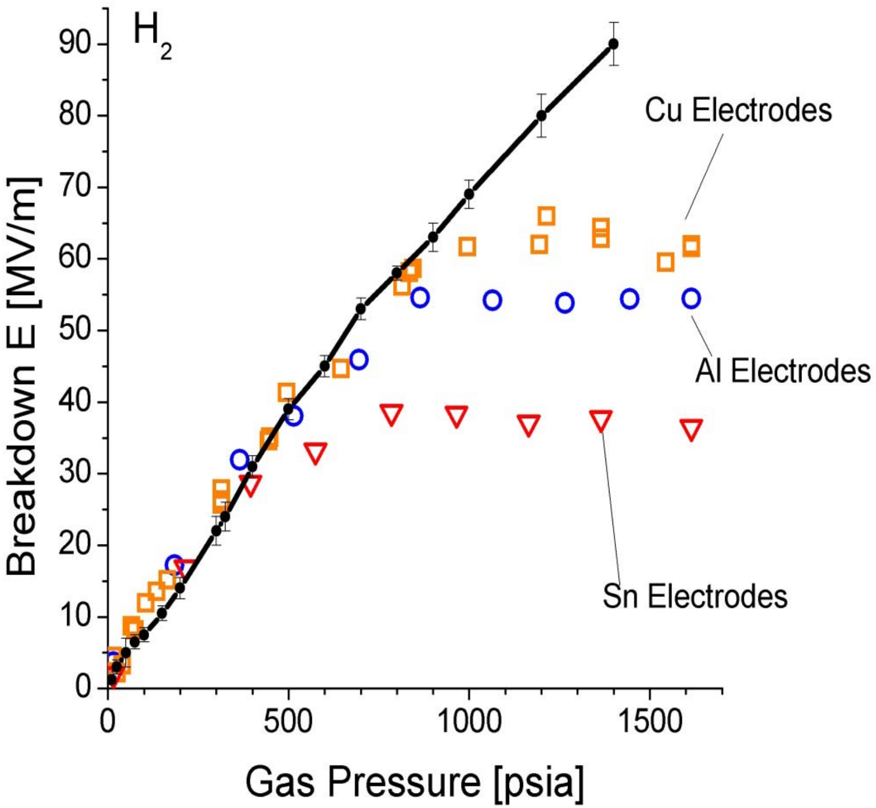
- Wide range of fields, helical periods, apertures
- Room for RF system and absorber
- Field tuning more complicate at high fields

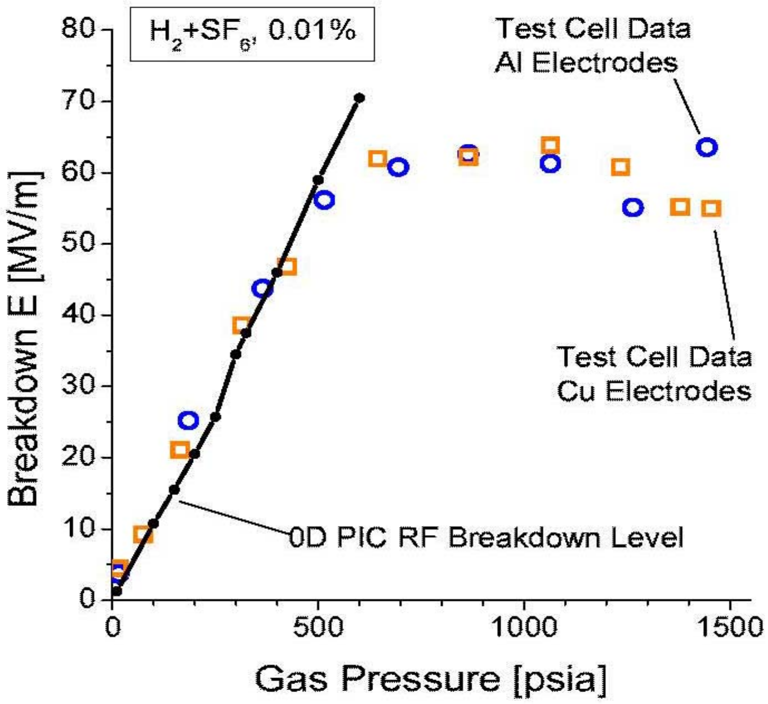
HS concept (FNAL/Muons Inc.)

- Ring coils follow the helical beam orbit producing all required field components
- Straight solenoid concept does not work for high-field/small-aperture sections

Time-Dependent Zero-Dimensional Kinetic Simulations of RF Breakdown in High Pressure H2 with Small Admixtures of SF6

D. V. Rose, C. Thoma, D. R. Welch, K. Yonehara, R. P. Johnson





900 MHz magnetron prototype
(Ph I STTR with Milorad Popovic
and Al Moretti)

recent progress (cntd)

- Simulations, Models, and Inventions

  - New HCC simulations show impressive 6-D cooling
    - More conservative frequencies and apertures – 10^{34} still looking good

  - Parametric-resonance Ionization Cooling – key to LEMC!
    - Epicyclic PIC invention seems to overcome fringe field and D problems
    - G4Beamline model working, ready for development
    - New person (Vasiliy Morozov) addressing this problem
      - (new correlated optics)

    Same lattice (with opposite wedge angle) will allow REMEX

  - Ramping RLA Magnets to enable more RF cavity traversals
    - variations on and extensions to Don Summers (Olemiss) concept
    - See Bogacz and Beard

  - 3 GeV CW Project-X will be upgradable for MC and NF
    - Report available next week. Inventions by Popovic and Ankenbrandt

recent progress (cntd)

- New Synergies
  - Project-X heeding MC and NF needs
    - Contributing to: H^- Source, laser stripping, magnetron, couplers,
  - Mu2e experiment P-X upgrade uses muon cooling techniques,
    - Favorable reviews, but still awaiting Fermilab response to “MANX following MICE” and “Mu2e Upgrade” proposals
    - My lesson – need to have at least two competitors
  - Homeland Security
    - Muons for Special Nuclear Material (SNM) detection
  - Advanced Research Project Administration – Energy (ARPA-E)
    - Accelerator-Driven Subcritical (ADS) Power Generation, and Nuclear Waste Disposal (ATW)
    - Can ARPA-E help fund and expedite more powerful Project-X, to make sure MC and NF needs are met?

Muons, Inc. Status

7 New Phase I awards.

- HOM Absorbers (Cornell),
- Quasi-isochronous Decay Channels (Fermilab),
- DC Gun Insulators (JLab),
- H-minus Ion Source (SNS),
- High-power Coaxial Couplers (JLab),
- High-field YBCO Magnets (FSU),
- Phase and Frequency-locked Magnetrons for SRF (Fermilab)

2 New Phase II awards:

- Fiber Optics for HTS (FSU)
- Pulsed RLAs (JLab)

2 Phase II awards continued

- HCC Magnets (Fermilab)
- Stopping muon beams (ODU)

3 Contracts :

- Fermilab - to help with Project-X development
- PNNL - to help develop a photon beam concept for Homeland Security (2nd)
- ANL/UC - ps counter development

21 New SBIR-STTR Proposals submitted

1 DTRA proposal with Hampton U announced soon

BES

Dudnikov.Stockli 15b ORNL 15 b High Brightness Sources of Negative Hydrogen Ions
Rol Danilov 16d ORNL Laser Stripping for H^- Injection
Mike-Nasiri 14d ANL Adjustable High Power Coax RF Coupler

NP

Dudnikov-Zhang 45e JLab Highly Polarized Ion Sources
Mike-Rimmer 45c- JLab Novel Crab Cavity RF Design
Mike Milorad 45a FNAL Compact, Tunable RF Cavities
Mike Milorad 45a FNAL Dielectric Loaded RF Cavities
Tom Dan 45d IIT Particle Refrigerator

HEP

MACC Hedin NIU 61a Integrated Low Beta Region Muon Collider Detector Design
Rol Justin NCSU 62a YBCO Roebel Cable for High-field Low-loss Accelerator Magnets
Rol SlavaD 64b JLab Epicyclic channels for PIC
Tom Dan 64g IIT Advanced Multi-Program GUI for Accelerator Modeling
Kahn Hedin 64g NIU Simulation of Accelerator Based Backgrounds in a Muon Collider
Kahn Palmer 63f BNL High Gradient Final Focusing Quadrupoles for Lepton Colliders
Abrams Hauptman 64a ISU Gas-Cherenkov Calorimeter for High Intensity Beams
Abrams Frisch 64b UC Fast Time-of-Flight System for Muon Cooling Experiments
Mike-Moretti 65c FNAL RF Pulse Compressors for Muon Beams
Rol Dan IIT 65a Gridded-Wire Windows for High Pressure RF Cavities
Rol-Zeke 65a Buckyball Dopants for High Pressure RF Cavities

FES

Mike-Kwan LBNL 68a High Currently Density Lithium Ion Source
Rol Justin NCSU 66c Fiber Optics Sensors for Cable-Wound SC Magnets for Fusion

Ultimate Goal: High-Energy High-Luminosity Muon Colliders

- precision lepton machines at the energy frontier
- achieved in physics-motivated stages that require developing inventions and technology, e.g.
  - high-power 8-GeV H^- Linac (CW with AR & BRs)
  - stopping muon beams (HCC, EEXwHomogeneous absorber)
  - neutrino factory (HCC with HPRF, RLA in CW Proj-X)
  - Z' factory (low Luminosity collider, HE RLA)
  - Higgs factory (extreme cooling, low beta, super-detectors)
  - Energy-frontier muon collider (more cooling, lower beta)
    - Muons, Inc. stops being non-profit?