MuCool Test Area Update

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MTA Program Overview

• Goal: Demonstrate a working solution to RF cavity operation in high external magnetic field for muon cooling

• Major MAP deliverable
  – and near-term technical risk for MICE

• Major impact on cooling channel design and future system tests

• A multipronged approach has been followed
  ⇝ Identify most promising paths for detailed study
805-MHz Pillbox Button Cavity Program (Magnetic Field, Materials, Windows)

- Pillbox geometry with thin curved Be windows
- Button holder for removable electrode inserts
- Used to
  - Quantify magnetic field dependence of gradient
  - Establish feasibility of thin windows (Cu, Be)
  - Test potential cavity materials (Cu, Be, Mo, W)
Fermilab 805-MHz Pillbox Button Cavity Program

- Most recent test: Be vs Cu buttons & flat Cu endplates
  - Higher gradient with Be buttons
  - Minimal surface damage on Be
  - Surface microscopy complete
- Will also be used to test grid-tube windows
Magnetic Field Dependence

“All-season” Cavity (Muons Inc, LANL)

- Modular pillbox with replaceable endplates
- Designed for both vacuum and high pressure
- Made of 316SS with 25µ Cu plating
- 3.9/6.6/2.7cm-thick center ring/inner/outer plates
- RF volume $\phi 29.1 \times 12.9$ cm
- 1-5/8” coax coupler
- $f=810.375$ MHz under vacuum, $Q=28k$
- Power: 1.2MW @ 25 MV/m
- No cooling included in design
- Operated in magnet
  - 25 MV/m at $B=0$ and 3 T
- Re-run with RF pickup (>3M pulses)
  - Confirmed at $B=0$ (29 MV/m)
  - 21+ MV/m at $B\neq 0$
  - Data analysis in progress
Magnetic Field Dependence

“All-season” Cavity (Muons Inc, LANL)

- Inspection
  - Damage spots on endplates (about same # as sparks)
  - Spot size (mm) similar to those in other Cu cavities
  - Evidence of arcing at coupler center conductor
  - Testing to continue with B up to 5T
Future Vacuum Pillbox Cavity R&D
805-MHz Modular Cavity (SLAC/LBNL)

- New R&D vehicle for detailed systematic studies
  - Modular design for easy assembly, parts replacement
  - Removable endplates (Cu, Be, other materials, treated surfaces)
  - Coupling iris moved to center ring and field reduced (*more realistic design*)
  - RF design validated by detailed simulation
  - Ports for instrumentation
  - Fabrication in progress
  - Expected delivery to MTA: Fall `13
• HPRF concept previously tested at the MTA (Hanlet et al., EPAC06)
  – Dense H\(_2\) gas buffers dark current while serving as cooling medium
  – Allows gradients up to the surface breakdown limit with no B-field effect
  – H\(_2\) supports 1 MV/m per atm
• Response to high-intensity beam
  – Electron-ion pairs produced by beam
  – Beam-induced plasma loads the cavity
  – Mitigate with electronegative dopant gas
• 2 beam tests performed to evaluate plasma dynamics in the cavity
  – Fermilab Linac beam (400-MeV \(p\))
  – \(dE/dx\) per \(p\) similar to 100-MeV/c \(\mu\)
  – \(\sim 10^9\) protons per bunch
• Wide range of parameters
  – $10^{10}$-3x$10^{11}$ ppp, 0-50 MV/m
  – 300-1520 psi H2, B=0 and 3T
  – Electronegative Dopant Studies: SF6 & dry air effect vs. concentration
  – Ion Mobility Studies: He+air, N2+air, D2

• Publication to be submitted this week
  – Quantitative theory validated by measurement of energy in H2/D2+dopant (B. Freemire thesis)
  – Electronegative dopants turn mobile ionization electrons into heavy ions, reducing RF losses by large factor

• Results extrapolate well to Neutrino Factory operation and a range of Muon Collider beam parameters
  – Plasma loading < beam loading
  – Bunch intensity limits being evaluated

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• Magnet apertures in HCC with RF inside helical solenoids lead to large fields on conductors
• Dielectric loading to shrink RF cavities
• High-pressure gas to suppress dielectric surface breakdown

• Muons Inc. grant for HCC engineering design (G. Flanagan, K. Yonehara)
• Hardware in hand
• Initial test with Al2O3 carried out
201-MHz Program
(Surface treatment, NF channel, MICE)

• 201-MHz MICE prototype cavity with SRF-like surface treatment (EP, HP rinse)
  – Conditioned to design gradient quickly
  – Demonstrated operation with large curved Be windows
  – Somewhat reduced performance in fringe field of solenoid
  – No surface damage seen on cavity interior
  – Some evidence for sparking in the coupler
    • Multi-pacting studied
    • Design now modified
    • Also looking into TiN coating
  – Radiation output measured (MICE detector backgrounds)

• Future
  – Install/operate single-cavity vessel
  – Large diameter magnet (coupling coil) needed for field configuration closer to MICE/cooling channel
• MICE cavity in vacuum vessel for MTA test
• Components
  – 1\textsuperscript{st} MICE cavity EP’ed at LBNL
  – Vacuum vessel built at Keller Technology
  – Be windows in hand
  – Actuators built at LBNL
  – Tuner forks built at FNAL
  – Fabrication of new couplers started at LBNL
201-MHz Single-Cavity Module

- Assembly/integration
  - Cavity and vessel at Lab-6
  - Clean room prepared
  - Assembly fixtures built
  - Tuner control bench tested
  - Plan in place for handling and transport

- Expect operation Fall 2013
  - Option for beam test

- Ultimately will be tested with the first Coupling Coil Magnet
  - Requires 6-month MTA shutdown
Components in Lab-6

Vacuum vessel on transport stand

Cavity

Tuner installation fixture (horizontal stand)

Tuner forks
Outlook

• Experimental program
  – HPRF beam tests successfully concluded
    • Looks promising for Neutrino Factory and Muon Collider application
    • Dielectric loading tests started
  – Vacuum cavity R&D bearing fruit
    • 20+ MV/m @ 3T demonstrated in Cu pillbox (all-season cavity), follow-on testing underway
    • Alternative window geometry to be explored
    • New modular cavity in fabrication for detailed systematic studies (Cu/Be walls, gradient vs B)
    • Beam tests will be included in experimental program
    • 201-MHz single-cavity module (MICE) tests
      – Tests with Coupling Coil Magnet will follow when magnet prototype ready

• Infrastructure upgrades (beamline, RF, magnets)
  • R&D program now pointing the way to RF solutions for ionization cooling channels!
Recent publications
http://mice.iit.edu/mta/papers.html

- Analysis of Breakdown Damage in an 805 MHz Pillbox Cavity for Muon Ionization Cooling R&D, D. Bowring et al., IPAC13
- A Modular Cavity for Muon Ionization Cooling R&D, D. Bowring et al., IPAC13
- Transient Beam Loading Effects in Gas-filled RF Cavities for a Muon Collider, M. Chung et al., IPAC13
- Beam Induced Plasma Dynamics in a High Pressure Gas-Filled RF Test Cell for use in a Muon Cooling Channel, B. Freemire et al., IPAC13
- Multipacting Simulation of the MICE 201 MHz RF Cavity, T. Luo et al., IPAC13
- High Power Tests of Alumina in High Pressure RF Cavities for Muon Ionization Cooling Channel, L. Nash et al., IPAC13
- The RF System for the MICE Experiment, K. Ronald et al., IPAC13
- RF Cavity Spark Localization Using Acoustic Measurement, P. Snopok et al., IPAC13
- Simulation of Beam-induced Gas Plasma in High Gradient RF Field for Muon Colliders, K. Yonehara et al., IPAC13
- Summary of Dense Hydrogen Gas Filled RF Cavity Tests for Muon Acceleration, K. Yonehara et al., IPAC13
- Progress on a Cavity with Beryllium Walls for Muon Ionization Cooling Channel R&D, D. Bowring et al., IPAC12 proceedings
- Electron Recombination in a Dense Hydrogen Plasma, B. Freemire et al., IPAC12 proceedings
- Study of Electronegative Gas Effect in Beam-Induced Plasma, B. Freemire et al., IPAC12 proceedings
- Beam Profile Measurement in MTA Beam Line for High Pressure RF Cavity Beam Test, M. Jana et al., IPAC12 proceedings
- Conditioning and Future Plans for a Multi-purpose 805 MHz Pillbox Cavity for Muon Acceleration Studies, G. Kazakevich et al., IPAC12 proceedings
- Improved RF Design for an 805 MHz Pillbox Cavity for the US MuCool Program, Z. Li et al., IPAC12 proceedings
- Progress on the MICE 201 MHz RF Cavity at LBNL, T. Luo et al., IPAC12 proceedings
- Progress in Modeling Arcs, J. Norem et al., IPAC12 proceedings
- Kinetic Modeling of RF Breakdown in High-Pressure Gas-filled Cavities, D. Rose et al., IPAC12 proceedings
- Beam Tests of a High Pressure Gas-Filled Cavity for a Muon Collider, T. Schwarz et al., IPAC12 proceedings
- Influence of Intense Beam in High Pressure Hydrogen Gas Filled RF Cavities, K. Yonehara et al., IPAC12 proceedings
- An Automated Conditioning System for the MUCOOL Experiments at Fermilab, A. Kurup, IPAC11 proceedings
- High Pressure RF Cavity Test at Fermilab, B. T. Freemire et al., PAC11 proceedings
- Multi-purpose 805 MHz Pillbox RF Cavity for Muon Acceleration Studies, G. M. Kazakevich et al., PAC11 proceedings
- Vacuum Arcs and Gradient Limits, J. Norem et al., PAC11 proceedings
- Enhancement of RF Breakdown Threshold of Microwave Cavities by Magnetic Insulation, D. Stratakis et al., PAC11 proceedings
- Beam Test of a High Pressure Cavity for a Muon Collider, M. Chung et al., IPAC10 proceedings, p3494
- Beam-induced Electron Loading Effects in High Pressure Cavities for a Muon Collider, M. Chung et al., IPAC10 proceedings, p3497
- The US Muon Accelerator Program, Y. Torun et al., IPAC10 proceedings, p3491
- The MuCool Test Area and RF Program, Y. Torun et al., IPAC10 proceedings, p3780
- Rectangular Box Cavity Tests in Magnetic Field for Muon Cooling, Y. Torun et al., IPAC10 proceedings, p3795
- Study of Electron Swarm in High Pressure Hydrogen Gas Filled RF Cavities, K. Yonehara et al., IPAC10 proceedings, p3503
Recent student projects
http://mice.iit.edu/mta/students/

- Luca Somaschini (Pisa) – 201-MHz tuner system and instrumentation
- Logan Rowe (Kettering) – 201-MHz module assembly
- John Sobolewski (Marquette) – adapters for inspection/microscopy
- Jared Gaynier (Kettering) – circulator & CC installation
- Lisa Nash (U. Chicago) – dielectric loaded HPRF
- Adam Sibley (Trinity) – HPRF breakdown study
- Oleg Lysenko (U. Chicago) – HPRF beam test
- Jessica Cenni (Pisa) – dielectric loaded cavity
- Tom Mclaughlin (Valparaiso) – magnet mapping, circulator installation
- Ivan Orlov (Moscow State) – HPRF beam test simulation
- Raul Campos (NC State) – beamline magnet support
- Peter Lane (IIT) – acoustic sensors for RF breakdown
- Timofey Zolkin (U. Chicago) – dark current instrumentation
- Giulia Collura (Torino) – HPRF beam test
- Ben Freemire (IIT) – HPRF beam test (Ph. D.), other tests
- Last Feremenga (U. Chicago) – magnetic field mapping
- Anastasia Belozertseva (U. Chicago) – magnet mapping