MAP RF R&D

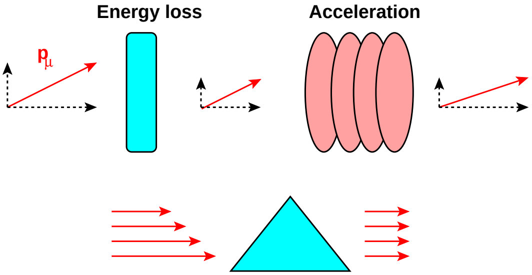
Yağmur Torun

Illinois Institute of Technology

Muon Collider Italian Briefing
Oct 6, 2010 - Fermilab

Ionization Cooling

The only muon cooling scheme that appears practical within the muon lifetime (2.2μs).



Mainly transverse; longitudinal cooling requires momentum-dependent path-length through the energy absorbers

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Ionization Cooling

Normalized transverse emittance ε of muon beam in solenoidal channel

$$\frac{d\varepsilon}{ds} \simeq \frac{\left\langle \frac{dE}{ds} \right\rangle}{\beta^2 E} (\varepsilon - \varepsilon_0), \quad \varepsilon_0 \simeq \frac{0.875\text{MeV}}{\left\langle \frac{dE}{ds} \right\rangle X_0} \frac{\beta_\perp}{\beta}$$

ε_0: equilibrium emittance (multiple scattering $\sim$ cooling)

- Energy absorbers with large *dE* per radiation length (LH2: 29MeV/m x 8.9m; LiH: 151MeV)
- Strong focusing (large B-field), $\beta_\perp \sim p/B$
- High-gradient rf cavities to replace longitudinal momentum and for phase focusing
- tight packing to minimize decay losses
- low muon momentum
- emittance exchange for 6D cooling (or twisted field – Guggenheim, HCC, snake)

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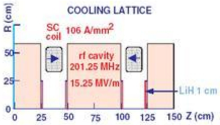

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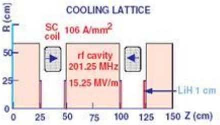

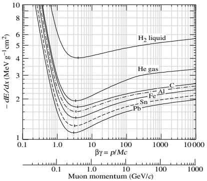

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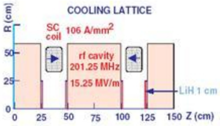

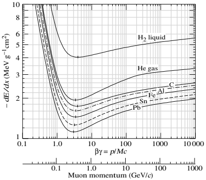

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MuCool R&D Project at Fermilab

Mission

- design, prototype and test components for ionization cooling
  - Energy absorbers
  - RF cavities
  - Magnets
  - Diagnostics
- including associated simulation and theoretical studies
- support system tests

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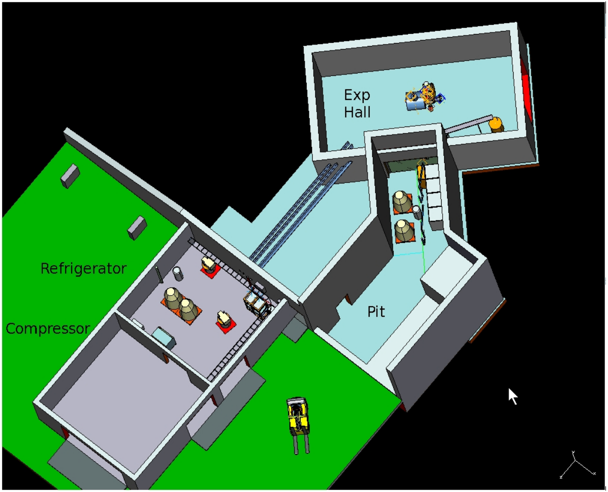
MuCool now folded into Muon Accelerator Program.

Dedicated facility at the end of the Linac built to address MuCool needs

- RF power (13 MW at 805 MHz, 4.5 MW at 201 MHz)
- Superconducting magnet (5 T solenoid)
- Large coupling coil under construction
- 805 and 201 MHz cavities
- Radiation detectors
- Cryo plant (commissioned this year)
- 400 MeV p beamline (commissioned to upstream of hall)

MuCool Test Area (MTA)



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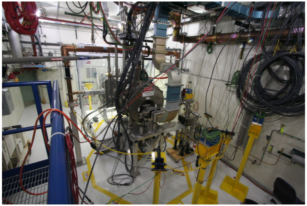
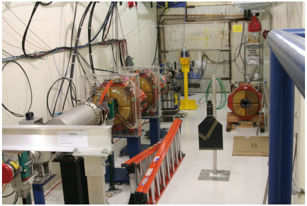
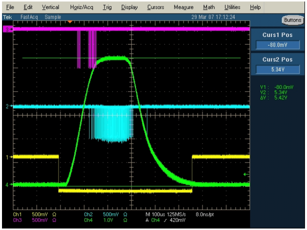
Experimental Hall



Beamline





X-rays at high gradient

Compressor Room

RF R&D Program

- Initial studies with 6-cell 805 MHz cavity hinted at limits of Cu surface and effect of magnetic field
  - strong dark current soaking up all rf power beyond 55 MV/m surface field
  - field emission beamlets focused by magnetic field (enough to drill holes in windows)
- 805 MHz pillbox cavity used to
  - quantify magnetic field dependence of gradient
  - establish feasibility of thin windows
  - test buttons with different materials/coatings
  - Back after rebuild at JLab

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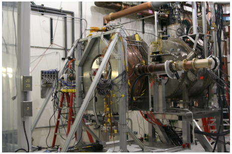
201 MHz MICE prototype cavity

- built very clean (electropolished, etc.)
- conditioned to design gradient very quickly
- ran successfully with thin curved Be windows
- operated in stray magnetic field
- radiation output measured (MICE detector backgrounds)
- large diameter coil needed for field configuration closer to MICE
- No surface damage seen in visual inspection



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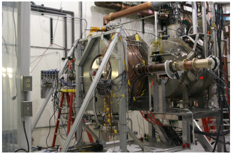

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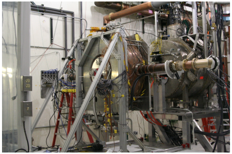

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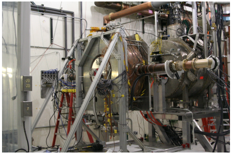

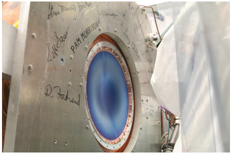

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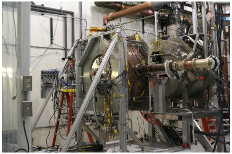

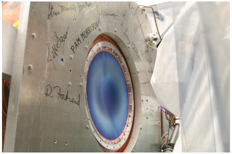

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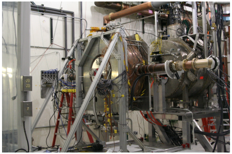

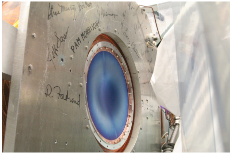

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RF R&D Program

201 MHz MICE prototype cavity

- built very clean (electropolished, etc.)
- conditioned to design gradient very quickly
- ran successfully with thin curved Be windows
- operated in stray magnetic field
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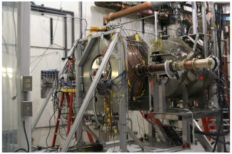

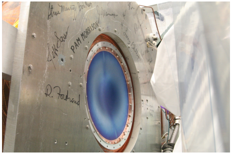

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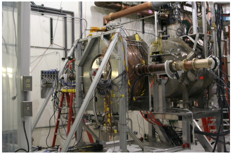

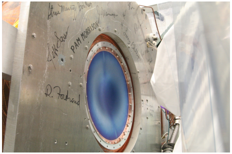

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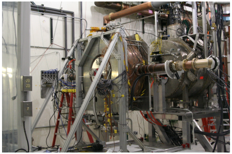

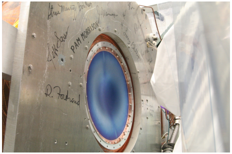

Effect of Magnetic Field

- External magnetic fields can significantly modify the performance of rf cavities by deflecting electrons coming off the surface at field emission sites and/or any plasma cloud that might form near the surface
- When $\vec{B}_{\text{ext}} \parallel \vec{E}_{\text{rf}}$, electrons can ride magnetic field lines between the accelerating gap and cause damage due to the focused current density
- When $\vec{B}_{\text{ext}} \perp \vec{E}_{\text{rf}}$, electrons can be deflected into grazing angles to the surface before being accelerated
- Must develop understanding to mitigate problem in cooling channel designs
- Need experimental data with $\vec{B}_{\text{ext}} \perp \vec{E}_{\text{rf}}$
- Also want to study the effect as a function of angle between fields

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Potential Solutions

- Better materials: more robust against breakdown (melting point, energy loss, skin depth, thermal diffusion length, etc.)
- Surface processing: suppress field emission (superconducting RF techniques, coatings, atomic layer deposition)
- Magnetic shielding: at cavity locations
- Magnetic insulation: modified cavity/coil designs to keep $B \perp E$ on cavity surfaces
- High-pressure gas: suppress breakdown by moderating electrons (Tollestrup talk)

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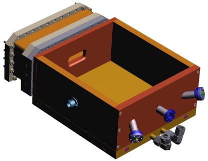
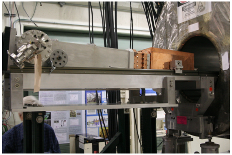
Box Cavity

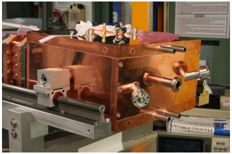
- Rectangular geometry chosen for test cavity to allow fast fabrication and simplify analysis
- Interior dimensions: 276.5 x 250 x 123.8 mm
- Made of 101 OFE copper plates
- Attached in two hydrogen brazing cycles
- Support system designed to rotate cavity pivoting around magnet center by up to 12^o
- Rectangular coupling aperture with rounded edges and a coupling cell built to match the power coupler to waveguide
- Three CF flange tubes for rf pickups and optical diagnostics
- $f_0 = 805.341$ MHz, $Q_0 = 27.9 \times 10^3$, coupling factor 0.97

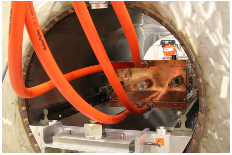




Box Cavity

- Operating in the MTA magnet since mid-March
- Automated control program, optical diagnostics
- Commissioned to 49MV/m at B=0
- Took data at 0, ± 1, 3, 4^o wrt B axis (3T)
- Large effect seen at 3-4^o (stable gradient down to about 25MV/m)
- Some degradation even at 1^o
- Visual inspection of interior, no spark damage
- RF and optical signals during sparks saved for analysis





Outlook

- 805 MHz rectangular box cavity run with B⊥E complete
- Data should provide insight into effect of magnetic field
- Another box cavity with B||E also built
- 805 MHz pillbox cavity will be running again to study breakdown resistance of different surfaces using buttons
  - Be
  - ALD coating
- 201 MHz pillbox cavity to be tested again
- High pressure RF tests to continue (with beam when available)
- Be-walled cavity being designed
- We hope to demonstrate a viable solution to RF in magnetic field for muon cooling within the next couple of years at the MTA