Muon Collaboration

Muon Collaboration R&D at Fermilab

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DOE Program Review. Fermilab, March 2003

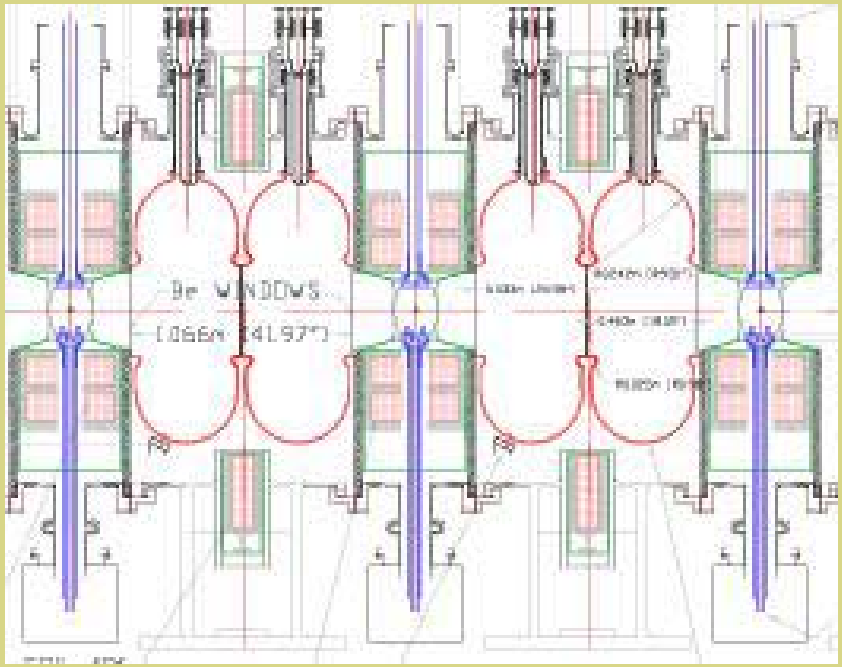
INTRODUCTION

1. Fermilab is one of the three lead-laboratories for the Neutrino Factory and Muon Collider Collaboration (Muon Collaboration).

2. Within the framework of the Muon Collaboration, Fermilab is host to the MUCOOL sub-activity, which is the R&D program to develop the technology required for a muon ionization cooling channel.

3. The Fermilab group also makes contributions central to the design & simulation studies focused on significantly reducing the cost of a neutrino factory.

MUCOOL R&D



70 Physicists from 16 Institutions

Mission: To prototype and test all the components needed for a muon ion-ization cooling channel.

High-gradient RF Cavities operating in a multi-Tesla magnetic field.

Liquid hydrogen absorbers with very thin windows, operating safely next to an RF cavity within a lattice of solenoids.

→ Engineering test of a short cooling section in a high-intensity beam at the 400 MeV Fermilab Linac.

External technical review (MUTAC) Report:

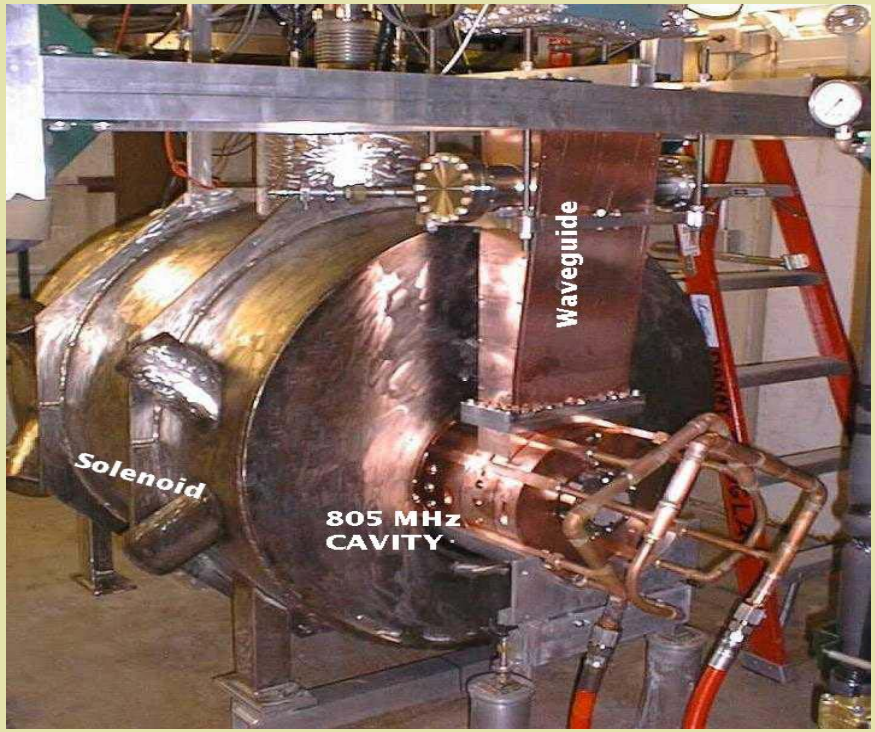
"Ionization cooling remains the primary R&D issue for the (muon) collab-oration. The most difficult part is the development and integration of the hardware, which is the goal of the MUCOOL efforts."

805 MHz RF R&D - 1

Need high gradient cavities to operate in multi-Tesla solenoid field

The magnetic field focuses the dark current electrons
→ high current densities

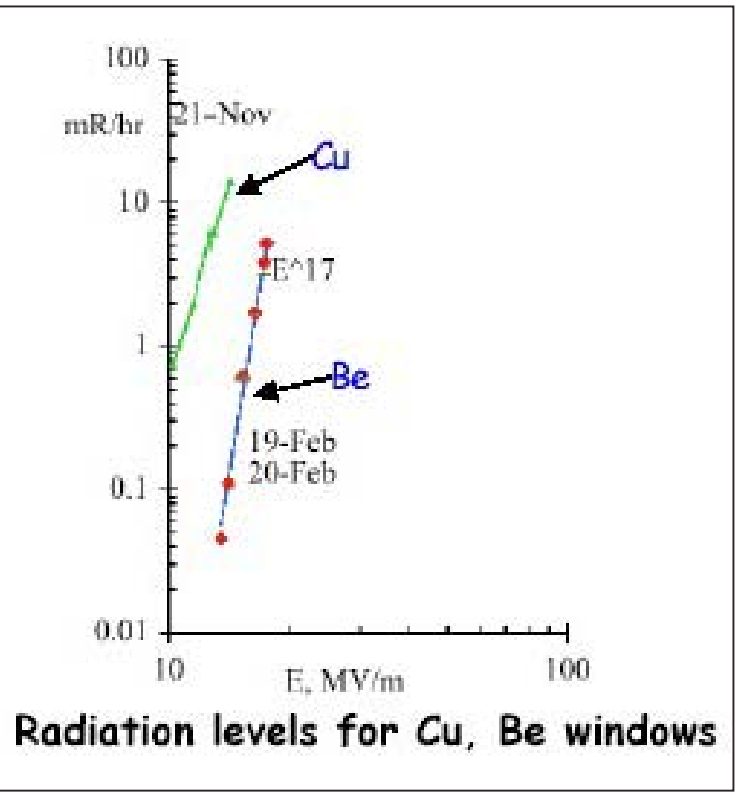
Would like to use a pillbox-type Cavity (at fixed peak power doubles gradient on-axis) using, for example thin Be foils to close the aperture:
→ Multipactoring ?
→ Cavity detuning due to RF heating ?



Lab G High Power 805 MHz Test Facility
12 MW klystron
Linac-type modulator & controls
X-Ray cavern
5T two-coil SC Solenoid
Dark-current & X-Ray instrumentation

805 MHz RF R&D - 2

Window damage at high gradients in multi-Tesla field



Radiation levels for Cu, Be windows

Concept 1 – open cell cavity with high surface field

805 MHz Cavity built & tested
→Surface fields 53 MV/m achieved
→Large dark currents observed
→Breakdown damage at highest gradients in 2T field
→Ph.D Thesis: Vincent Wu (U. Cincinnati)

Concept 2 – pillbox cavity with thin conducting Be foil

805 MHz single cell cavity (LBNL, U. Mississippi) tested
→Breakdown problems with Cu windows
→Be windows operated OK at 17 MV/m in 2T field …
but breakdown with higher magnetic fields.
→no serious multipactoring problems
→no serious cavity detuning due to RF heating of foil

Concept 2 – pillbox cavity with grid of hollow tubes

Design studies in progress →
Thesis topic: M. Sharoa (IIT)

Liquid Hydrogen Absorber R&D

Led by consortium of Illinois Universities (ICAR)

Thin absorber windows
Tested – new technique
– ICAR Universities

Window burst tests
– ICAR Universties

Fermilabs main contributions: safety oversight and cryo design.

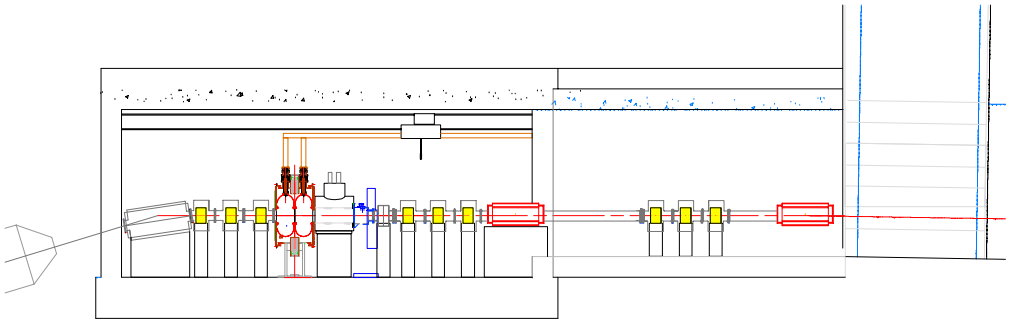
Designed (IIT, U. Oxford), & manufactured very thin Al windows (U. Mississippi) , subsequently measured (FNAL), & pressure tested (NIU) including required safety tests (destructive) at LN2 temperature.

Designed LH2 absorber filling system (FNAL)

Designed 2 different absorbers (IIT, U. Osaka/KEK) to be built and filled at Fermilab.

Understanding of safety issues and solutions is advancing.

MUCOOL Test Area at the end of the Linac



ELEVATION

Test Program

- Fill Liq. H absorbers: U.S. & Japanese prototypes
- High-Power tests of 201 MHz & 805 MHz Cavities
- Engineering test: Absorber–Cavity–Solenoid system
- Development of new beam diagnostics
- Eventual engineering test in high-intensity beam

Cost Reduction Design Work : Phase Rotation & Bunching

Phase Rotation:

Induction Linac replaced with NCRF system with multiple frequencies.

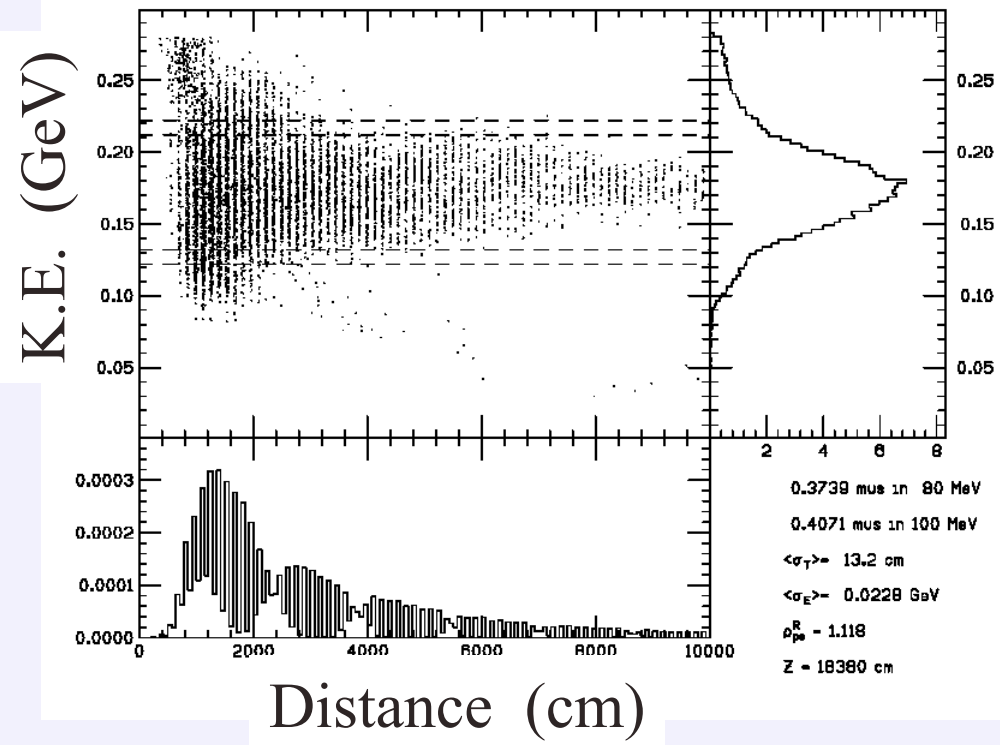
Idea: D. Neuffer (FNAL)

New Ph.D Student:
Alexey Poklonskiy (MSU)

→ Cheaper Technology
→ Shorter Length
→ Better Performance

	Study II	NOW	FACTOR
Total Length (m)	328	166	0.51
Acc. Length (m)	269	35	0.13
Acc. Type	Ind. LINAC	NCRF	

Bunch Train After Phase Rotation



Cost Reduction Design Work : Ring Cooler

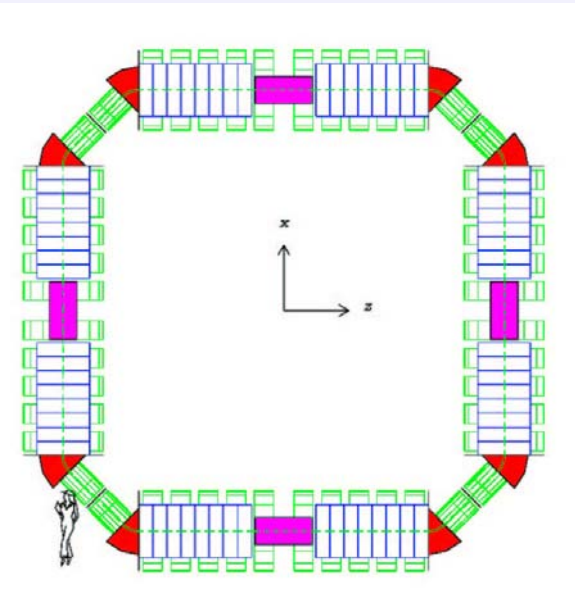
Cooling Channel:

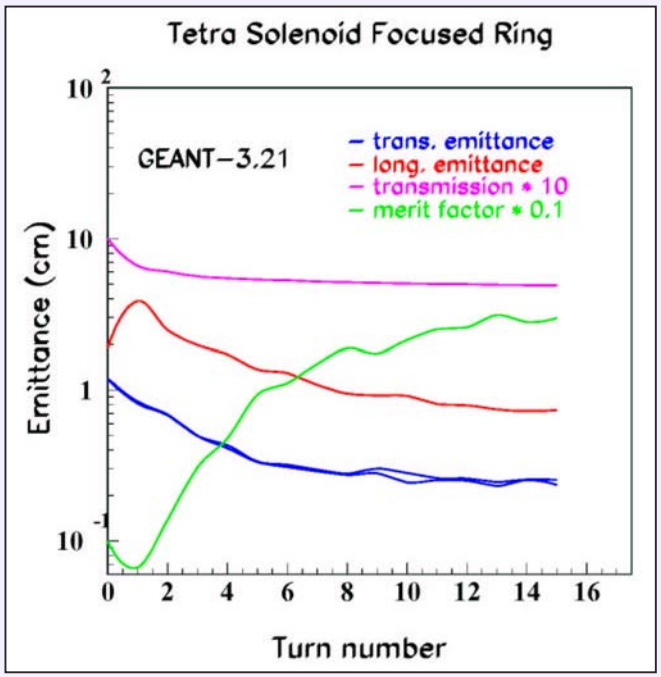
Replace Linear Cooling Channel with a Cooling Ring

Cools both Transverse & Longitudinal Emittances)

Original concept: V. Balbekov (FNAL)
Co-ordination: R. Raja (FNAL)
Simulation: Z. Usubov

	Study II	NOW	FACTOR
Total Length (m)	108	33	0.30
Acc. Length (m)	54	37	0.21
Acc. Grad. (MV/m)	16	12	0.66





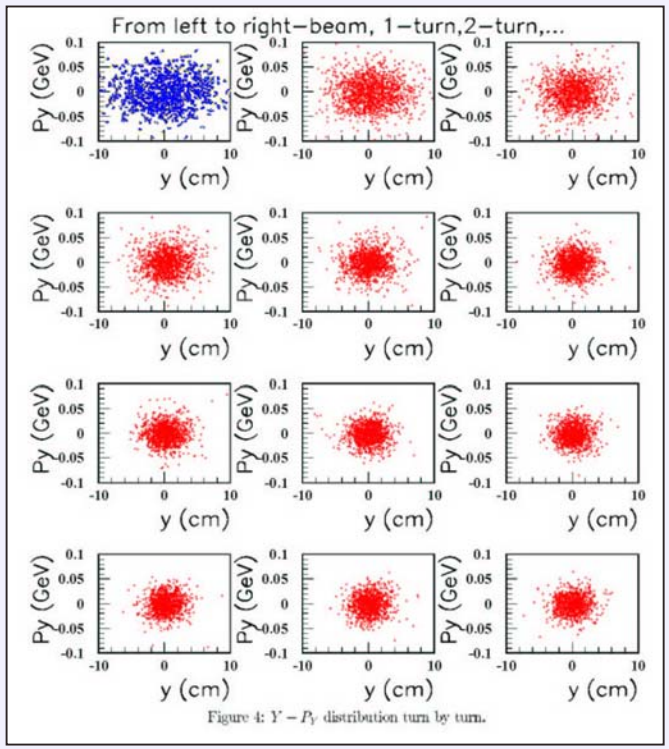


Figure 4: $Y - P_Y$ distribution turn by turn.

→ Shorter Length
→ Better Performance

Cost Reduction Design Work : Acceleration

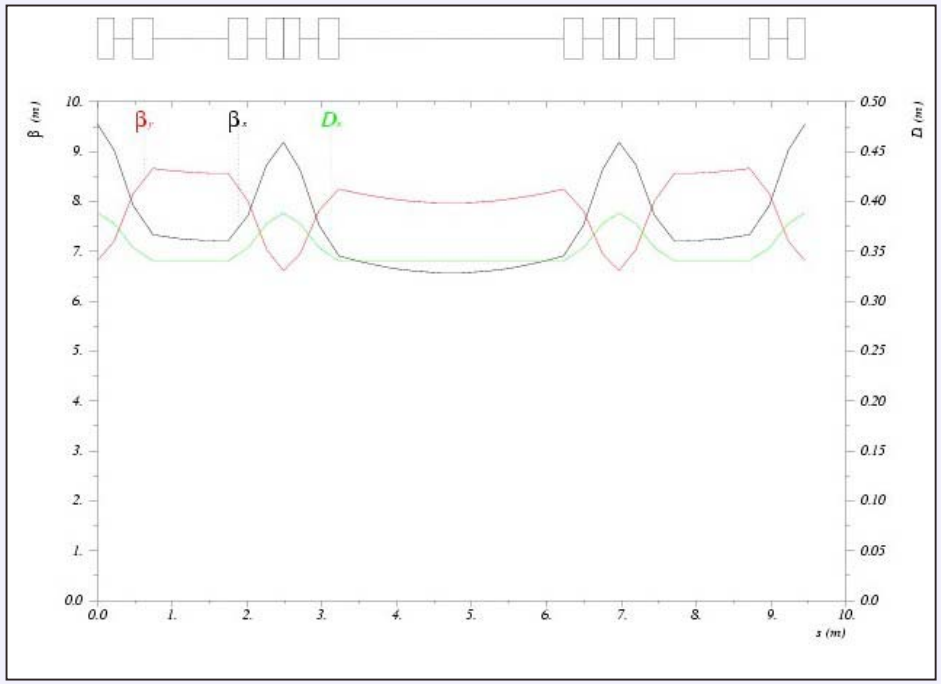
Acceleration:

RLA replaced with a new type of FFAG accelerator ("non-scaling FFAG")

	Study II	NOW	FACTOR
Vac Length (m)	3261	730	0.22
Turn Length (m)	1494	730	0.49
Acc. Length (m)	288	102	0.35
Acc. Grad. (MV/m)	16	8	0.50

Idea: C. Johnstone (FNAL)

→ Single Arcs (vs. 4 in RLA)
→ Less RF



Accomplishments in the last year

1. MUCOOL Test Area design complete, contract signed, construction begun.
2. Open cell cavity operation in multi-Tesla field studied at Lab G … dark current characterized and breakdown issues identified.
3. Pillbox cavity tested at Lab G with Cu and Be windows. High gradient achieved with fields up to 2 Tesla with Be windows, no multipactoring or serious detuning issues encountered.
4. Liquid hydrogen absorber R&D (pursued by a consortium of Illinois Universities) supported, with safety issues under study & cryo design work advanced. Thin windows successfully tested.
5. New ideas for phase rotation, cooling rings, and acceleration developed – may well lead to a significantly more cost effective neutrino factory design.

MUTAC Review

Every year the Muon Collaborations R&D is reviewed by an external technical committee (MUTAC: H. Edwards (chair), M. Breidenbach, G. Dugan, M. Harrison, J. Hastings, Y.-K. Kim, J. Lykken, A. McInturff, R. Ruth, K. Yokoya), that reports to a multi-laboratory directorate level oversight group (MCOG).

The review this year was in January, and resulted in a very positive report. In their transmittal letter to the laboratory directors, MCOG say:

The successful record of progress is epitomized by the summary judgment in the report, namely that "Overall, MUTAC was impressed by the accomplishments since the last meeting, particularly given the strained financial situation. MUTAC can enthusiastically assure MCOG that the limited funding is being well and carefully utilized."

MCOG has concluded that it is imperative that DOE seek to provide enhanced R&D funding for this work if it is to meet either the intent or the recommendations of the Long Range Plan laid out in the 2002 Gilman Report of HEPAP.

Future Plans

FY04
Equip MUCOOL Test Area
Continue 805 MHz studies at Lab G
Fill first absorber with Liq. H2
Continue preparation for Feasibility Study III
FY05
201 MHz High Power Tests
Fill absorber next to operating cavity
Prepare 400 MeV beam capability
Initiate Feasibility Study III (cost effective design)
FY06 and Beyond
Complete Feasibility Study III
Cooling component engineering tests with Linac beam
Production of components for the MICE experiment

Summary

1. Given the very limited resources, the Muon Collaboration hardware R&D is making good progress.

2. There are new concepts for phase rotation, cooling, and acceleration that promise significant cost reductions. We will need a "Study III" in about 2 years.

3. The resources we have are far less than recommended by the HEPAP sub-panel … in spite of good technical reviews, & growing excitement in neutrino oscillation physics.

4. The Muon Collaboration provides a new model for accelerator R&D involving many laboratory and University institutions, particle- and accelerator-physicists and engineers. The model is succeeding.