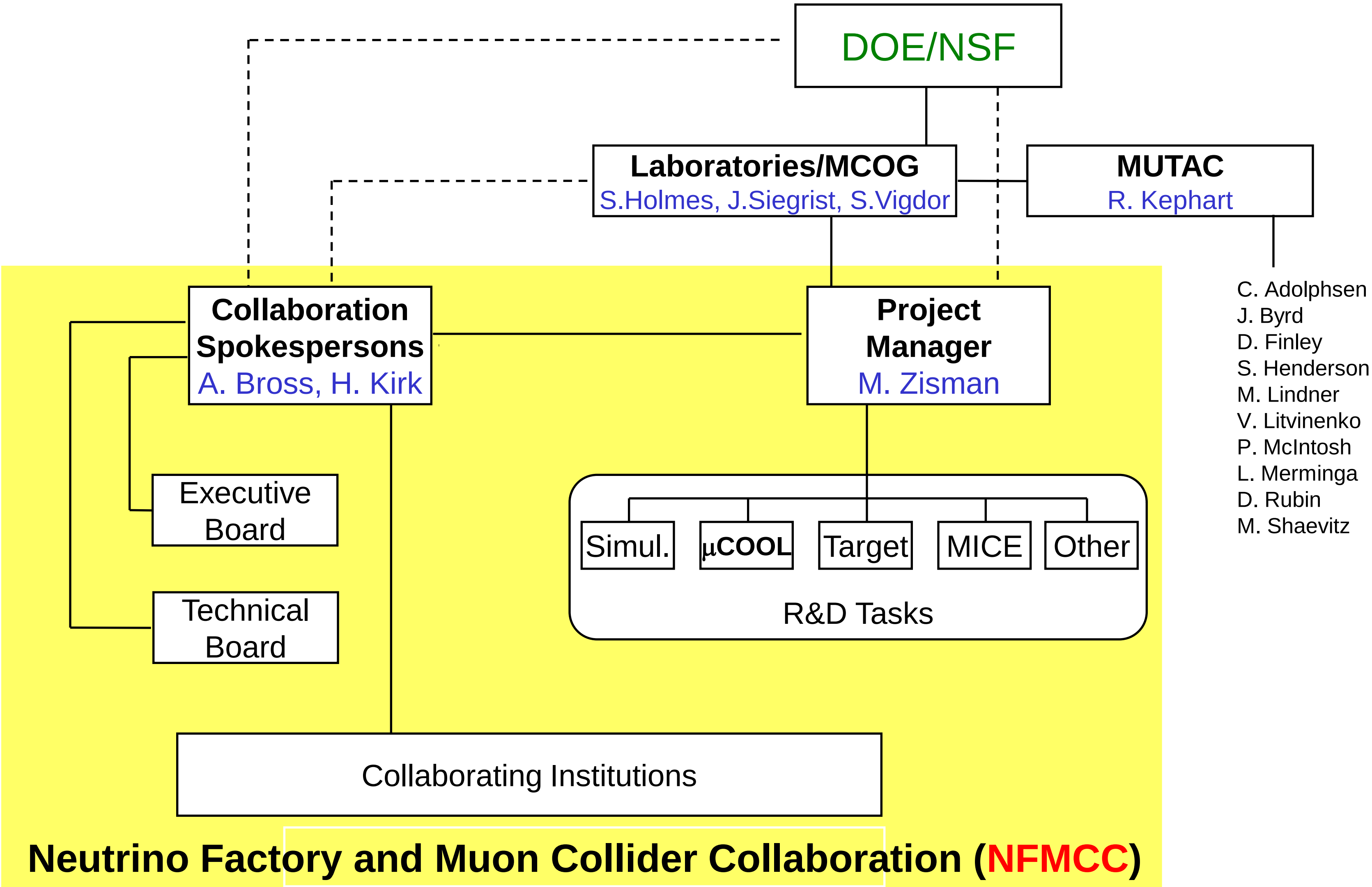
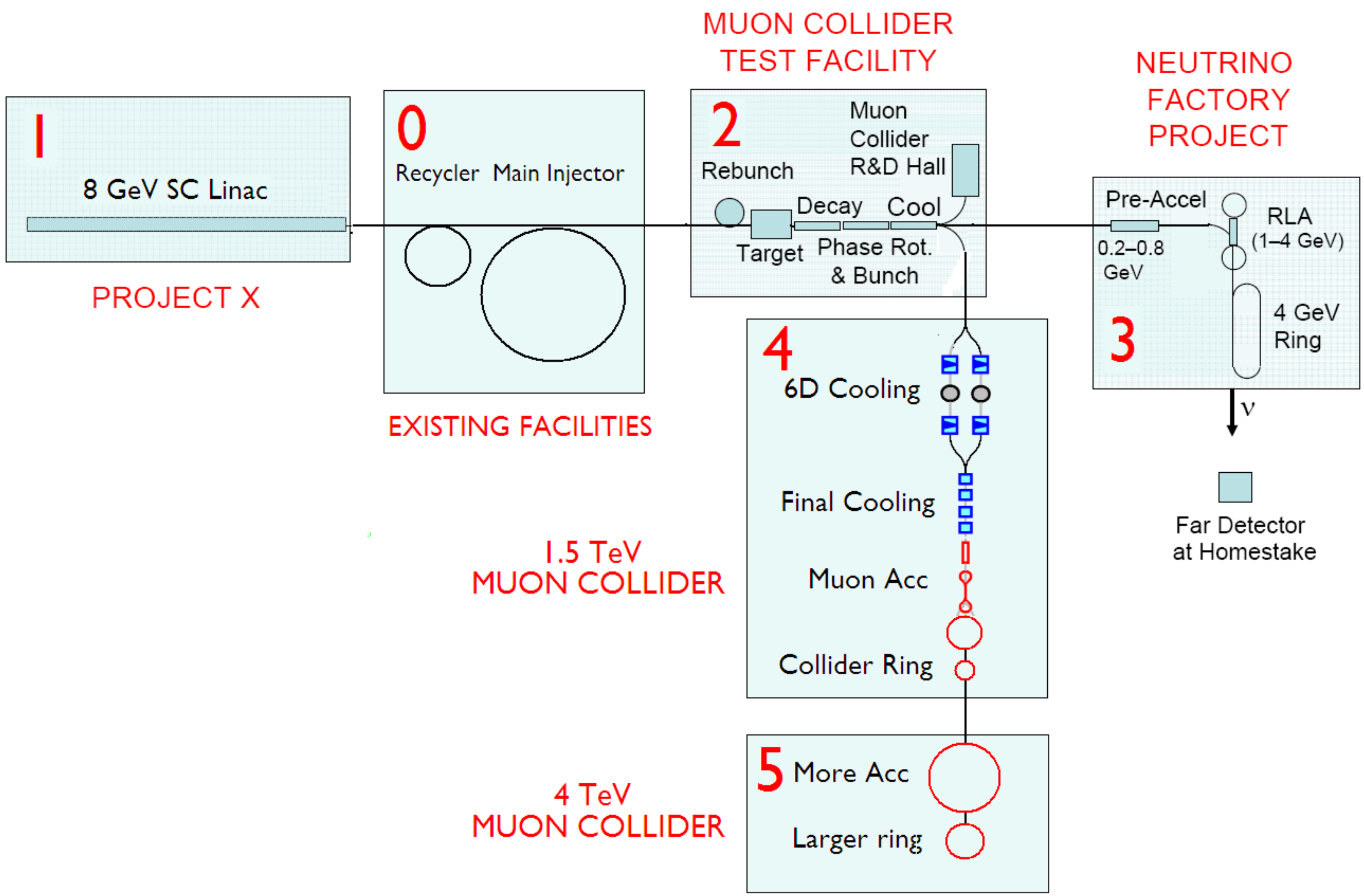
Neutrino Factory and Muon Collider Collaboration R&D

Alan Bross
Accelerator Physics Center
Fermilab AAC Meeting
May 6, 2008

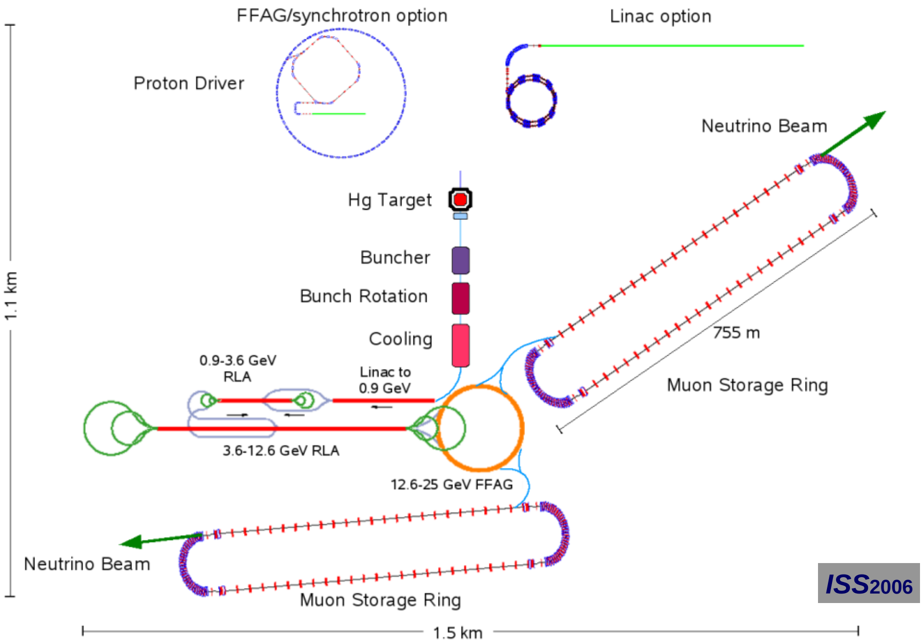
Current Organization

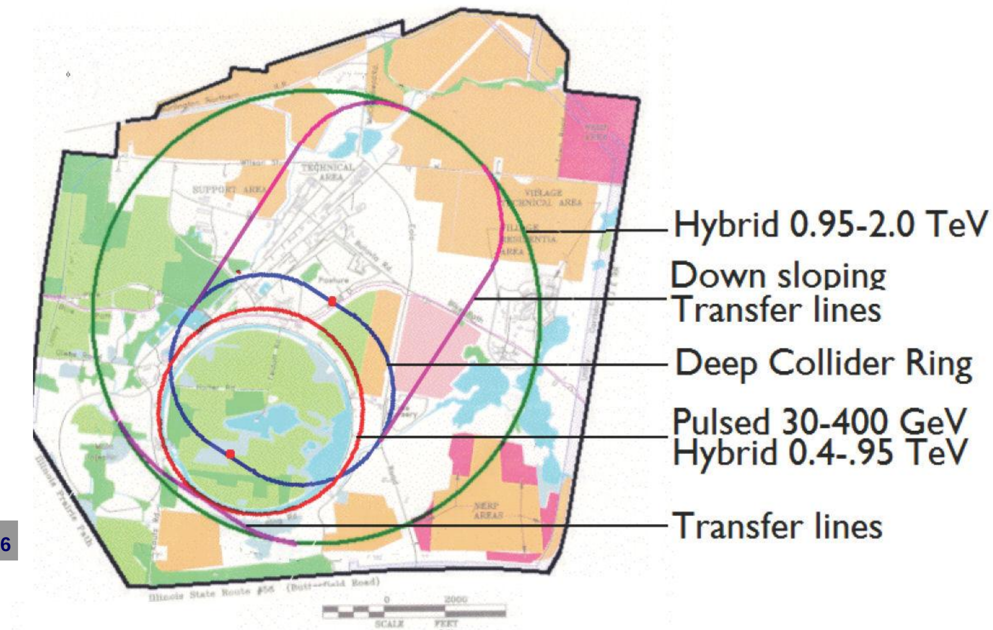


Muon Complex Evolution



NF & MC
Although Very Different – Front End Can be the Same





- Neutrino Factory
  - IDS Basline (FS1, FS2(a)(b), ISS)
    - 25 GeV μ storage ring
    - 4 GeV Option under study
- MC: One Concept
  - 4 TeV Center-of-Mass
    - Rapid-Cycling Synchrotron Acceleration

SMALL FOOTPRINT

The Future - The Planets Will Be In Alignment?

- We believe ~2012 will be a pivotal time in HEP
  - LHC Physics Results
  - Neutrino Data from Reactor and Accelerator Experiments
    - Double Chooz Daya Bay
    - MINOS, T2K ,Nova
  - Major Studies for Frontier Lepton-Colliders Completed
    - ILC EDR
    - CLIC CDR
- Collaboration Goals
  - Through
    - Simulation Effort
    - Component Development
    - Experiment Studies
  - Deliver RDR for Neutrino Factory (IDS)
  - Deliver ZDR for Muon Collider

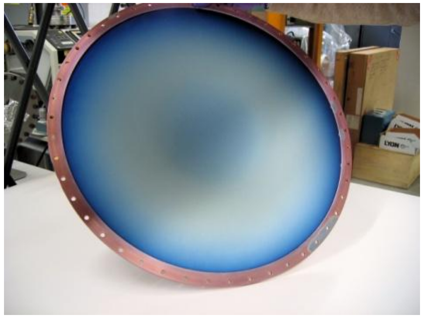
R&D Program

Focusing on Fermilab Activities

Muon Cooling: MuCool and MICE

Component R&D and Cooling Experiment

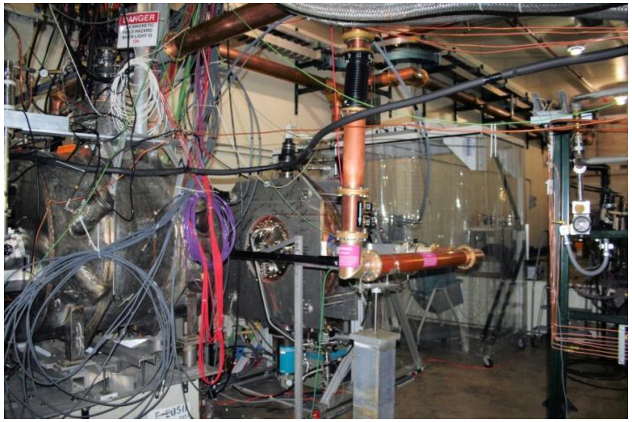
- MuCool
  - Component testing: RF, Absorbers, Solenoids
    - With High-Intensity Proton Beam
  - Uses Facility @Fermilab (MuCool Test Area -MTA)
  - Supports Muon Ionization Cooling Experiment (MICE)
  - 10 institutions from the US, UK and Japan participate



50 cm ∅ Be RF window

MuCool Test Area

MuCool 201 MHz RF Testing



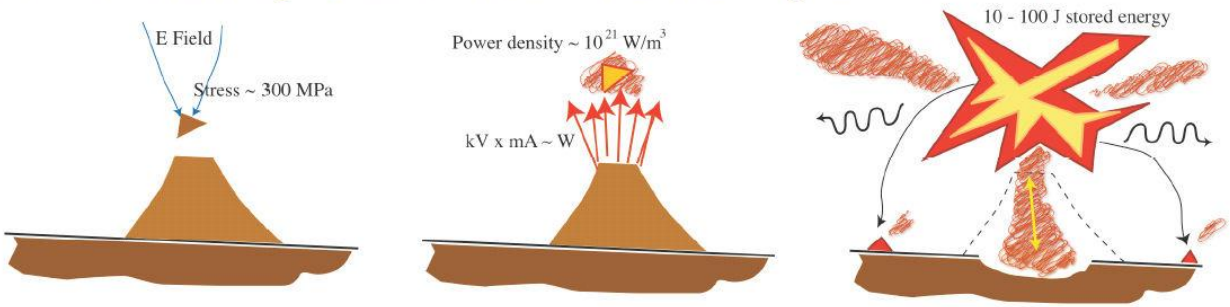
MuCool LH_2 Absorber Body

Fundamental Focus Of RF R&D

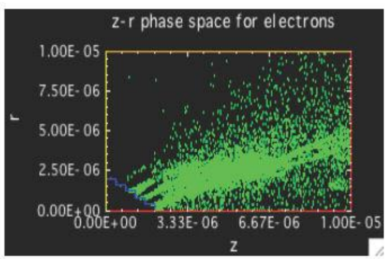
- Study the limits on Accelerating Gradient in NCRF cavities in magnetic field
- It has been proposed that the behavior of RF systems in general can be accurately described (predicted) by universal curves
  - Electric Tensile Stresses are important in RF Breakdown events
- This applies to all accelerating structures
- Fundamental Importance to both NF and MC
  - Muon capture, bunching, phase rotation
  - Muon Cooling
  - Acceleration

Detailed Modeling Code Now Available

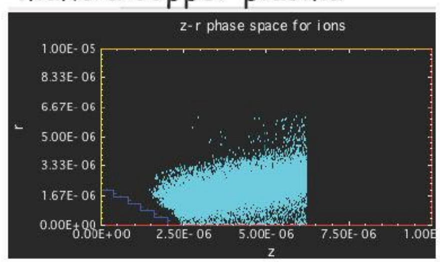
Detailed modeling of breakdown is underway at Tech-X.

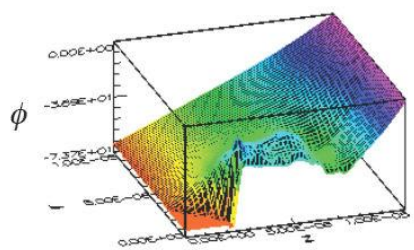


field emitted electrons

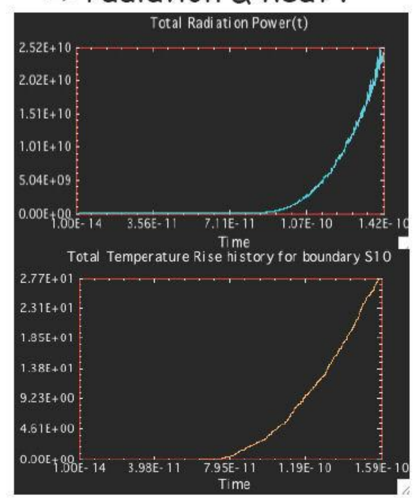


make a copper plasma





⇒ radiation & heat .



Preliminary results.

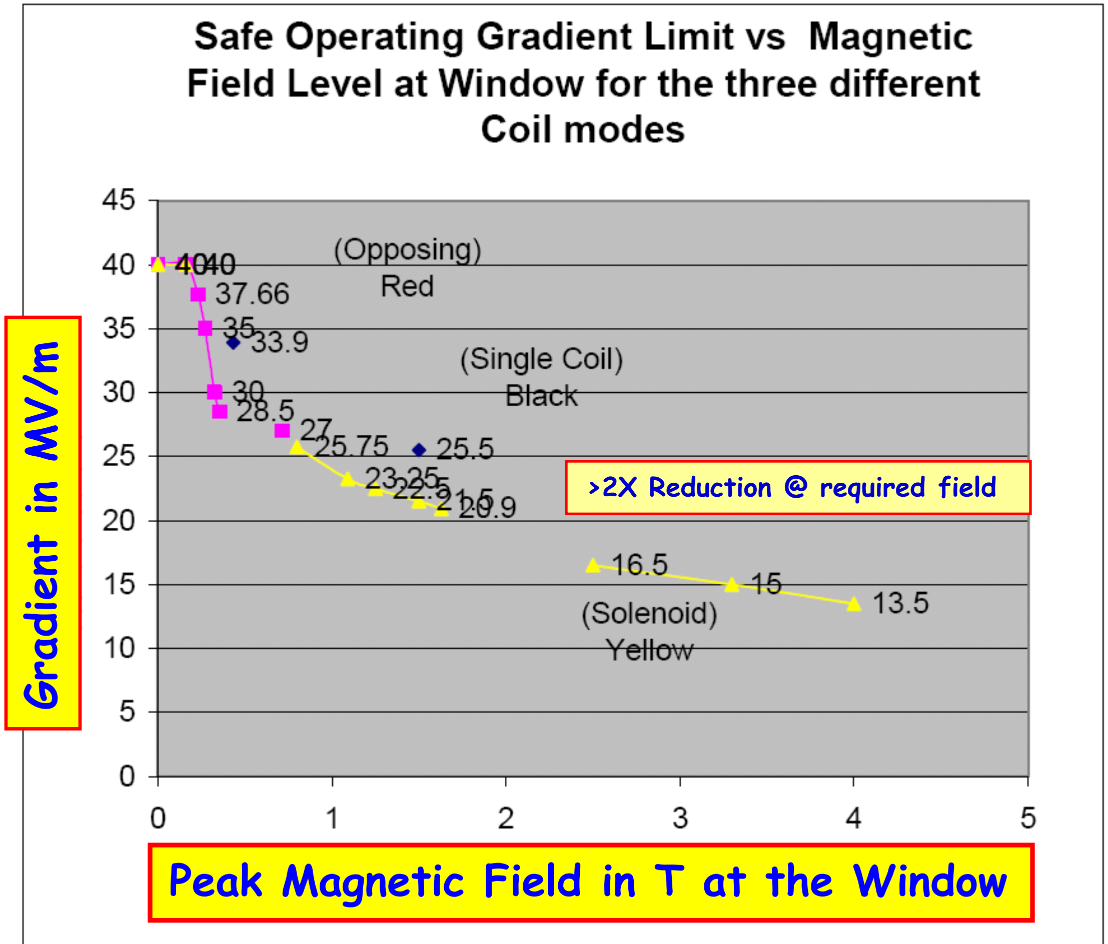
Must define experiments to vet this code

NCRF Model Extended to SCRF

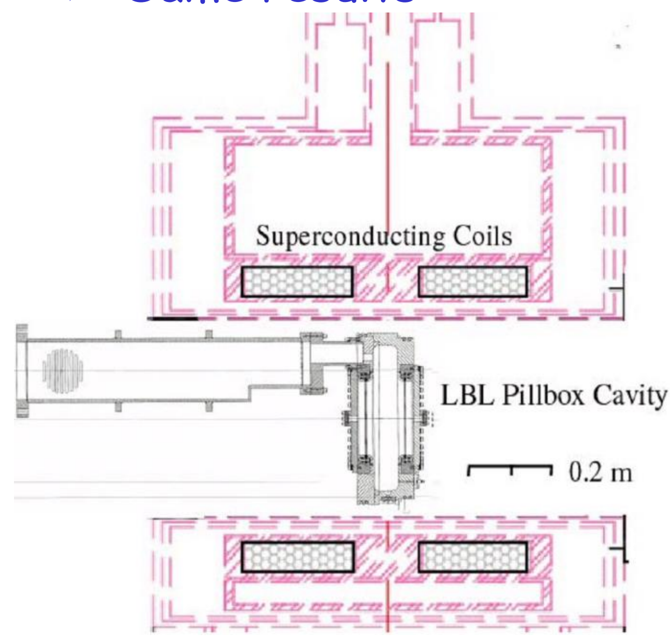
- We have extended this model to SCRF and high frequency problems.
- We are working with the Argonne Materials Science Division to develop:
  - *A materials science program to understand chemical, morphology and electronic properties of rf SCRF and NC materials*
  - Cavity tests to determine optimum procedures and performance.
- This program is underway and, using Argonne internal funding, and has produced important results:
  - We have developed a model of High Field Q-Slope based on magnetic oxides, that seems to explain SCRF cavity data.
  - We have developed a new procedure to produce niobium surfaces without complex oxides.
  - We are beginning a program of cavity testing with JLab.
- Using Atomic Layer Deposition and other newly developed materials science techniques we can synthesize and analyze surfaces with unprecedented precision.
    - Limits maximum gradient

The Basic Problem – B Field Effect

805 MHz Studies



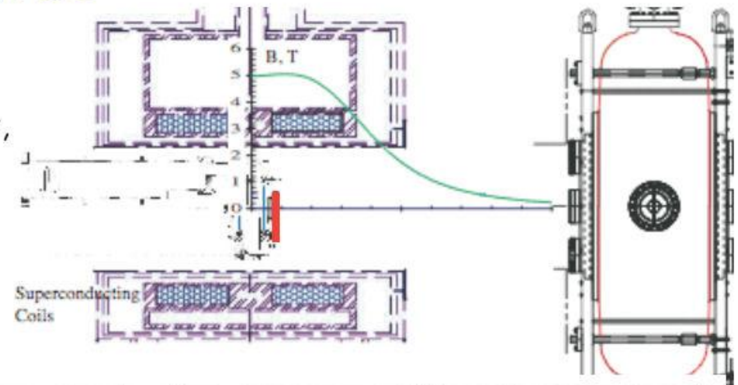
- Data seem to follow universal curve
  - *Max stable gradient degrades quickly with B field*
- Remeasured
  - *Same results*



805 MHz Imaging

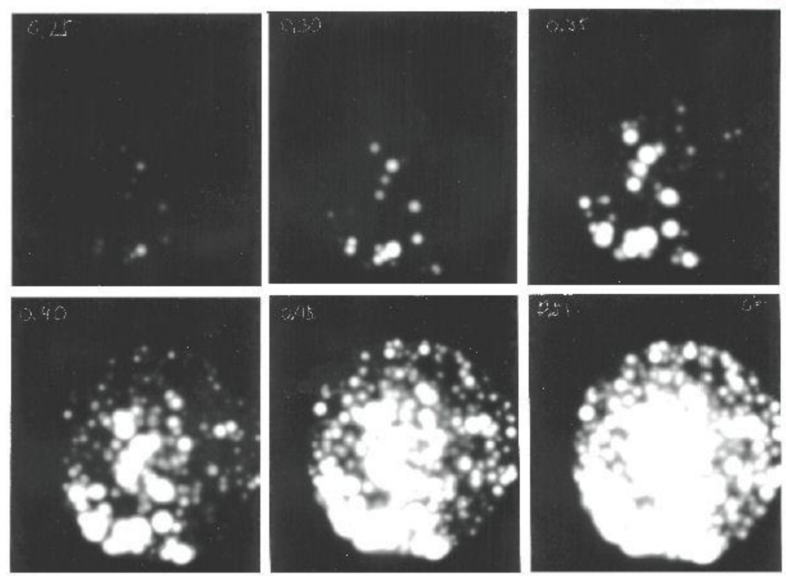
Polaroid Pictures of Field emitters

- Inserting polaroids near the window,



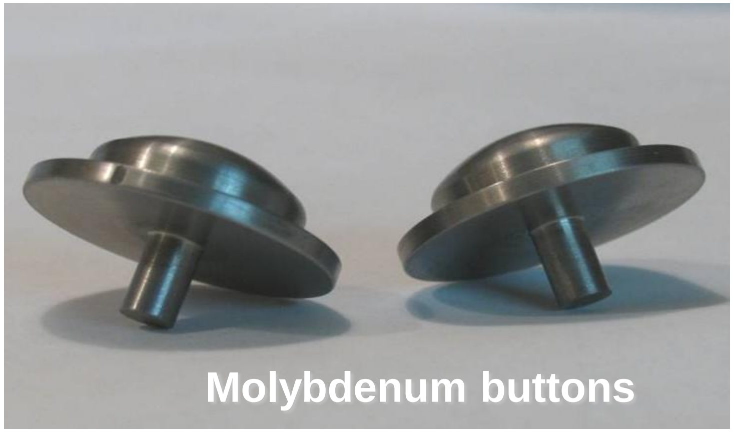
- Gives a picture of how the field emitters change with rf field.

  8.8 – 17.6 MV/m

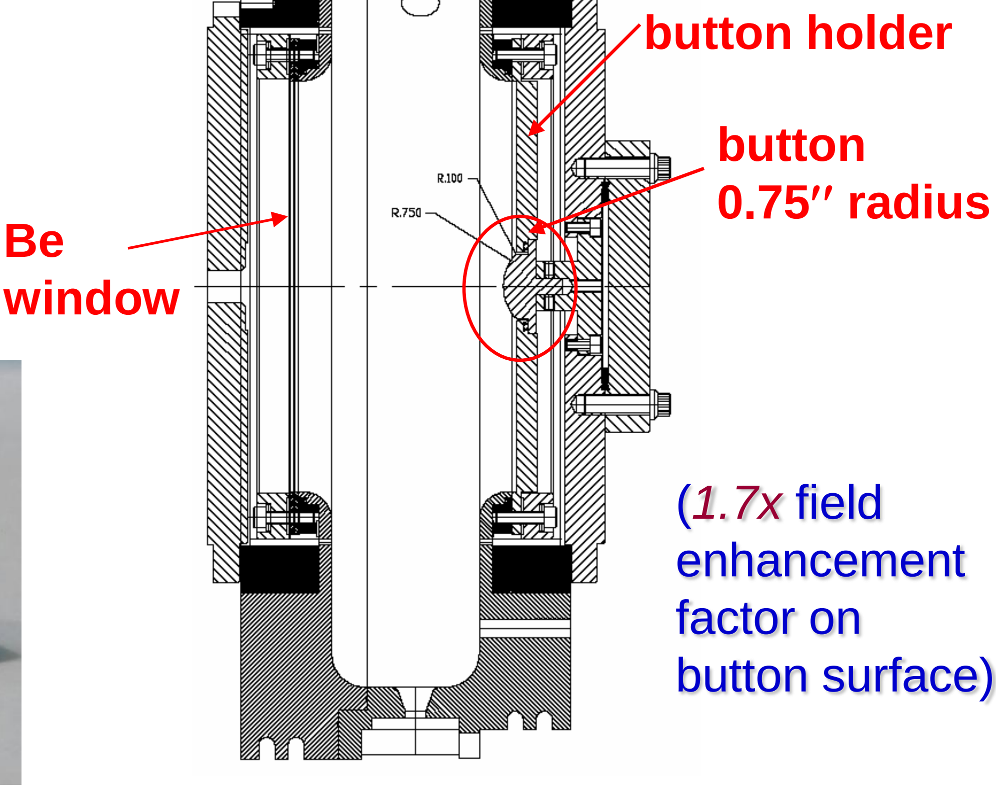


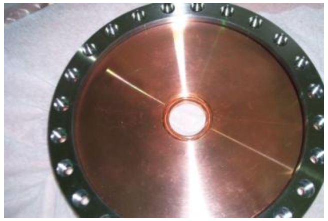
Cavity material ("Button") test

- "Button" system in pillbox cavity designed for easy replacement of test materials
- Tested so far: TiN-coated Cu & Mo, bare Mo and W
- To be tested: Cu (electro-polished & unpolished), Be
- Results to date indicate that TiN can improve performance at a given B field by somewhat more than 50%
  - 16.5MV/m → 26MV/m



Molybdenum buttons



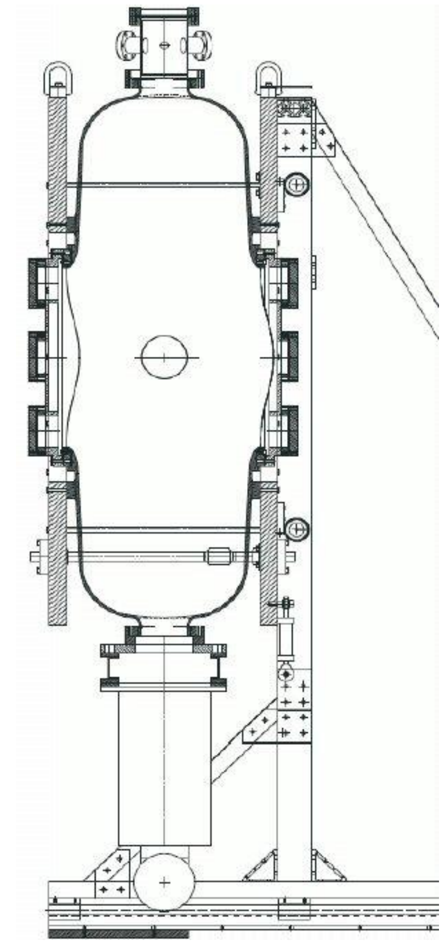


(*1.7x* field enhancement factor on button surface)

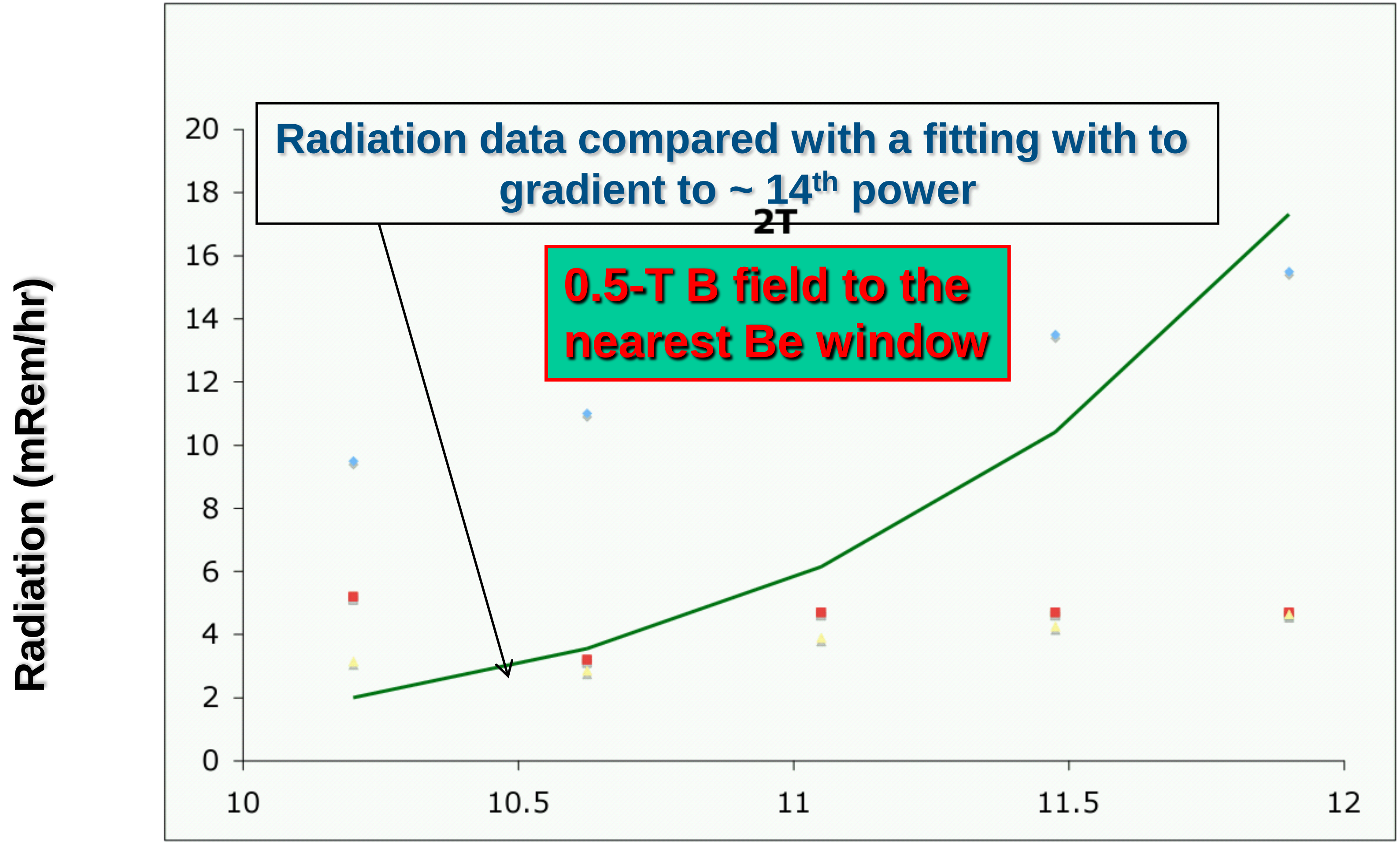
RF R&D – 201 MHz Cavity Test

The 201 MHz Cavity – *19 MV/m Gradient Achieved* (Design – 16MV/m)

- At 0.75T reached 14MV/m (multipactoring observed)



Radiation at 0.5-T Field

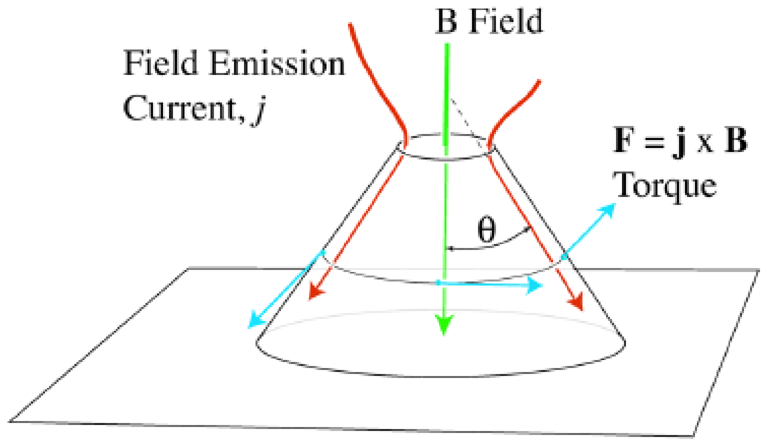


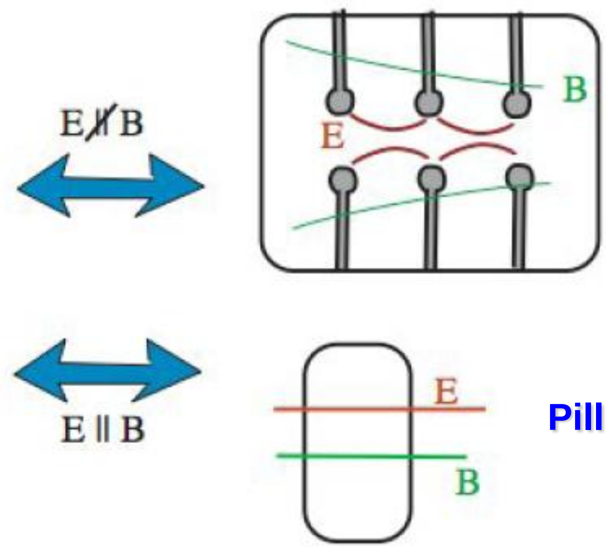
Cavity Gradient (MV/m)

■ ◆ ▲ **Represent Chipmonk #1, #2 and #3, respectively**

E × B study: Concept

- **Stress on emitter *F* ~ *j* × *B***
  - Stress can be ~ 10 GPa, sufficient to trigger fracture
- **In open-cell cavity (studied in ≈ 2000, lower-right), *E* generally not parallel to *B*, whereas in pillbox cavity, *E // B***
- **In order to reveal the relationship between field emission and orientations of *E* and *B* field, *E* × *B* study is planned.**

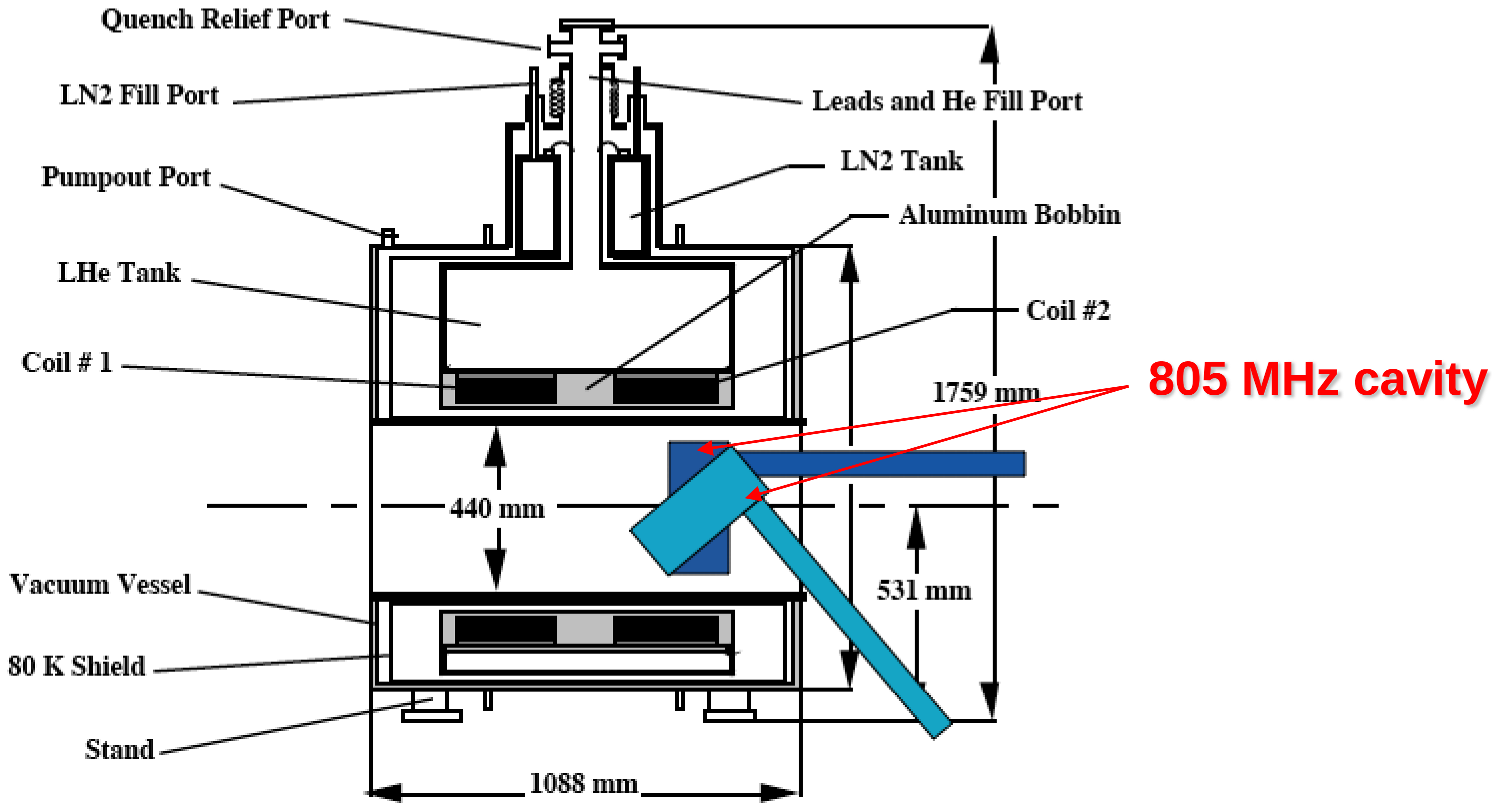




Open Cell

Pillbox

E × B study: Experiment schematic



A Cross-section view of the RF Solenoid from the side

MuCool Absorber Program

Absorber Design Issues

- 2D Transverse Cooling

$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu L_R}$$

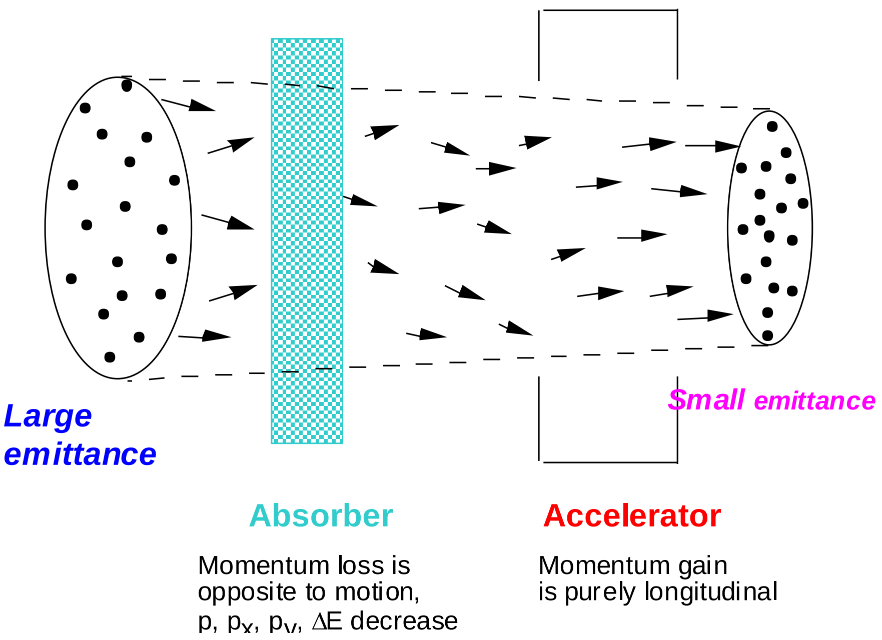
and

$$\epsilon_{N,\min} = \frac{\beta_\perp (14\ \mathrm{MeV})^2}{2\beta m_\mu \frac{dE_\mu}{ds} L_R}$$

- Figure of merit: $M=L_R dE_\mu/ds$

M^2 (4D cooling) for different absorbers

Material	$\langle dE/ds\rangle_{\min}$ (MeV g^{-1}cm^2)	L_R (g cm^{-2})	Merit
GH_2	4.103	61.28	1.03
LH_2	4.034	61.28	1
He	1.937	94.32	0.55
LiH	1.94	86.9	0.47
Li	1.639	82.76	0.30
CH_4	2.417	46.22	0.20
Be	1.594	65.19	0.18

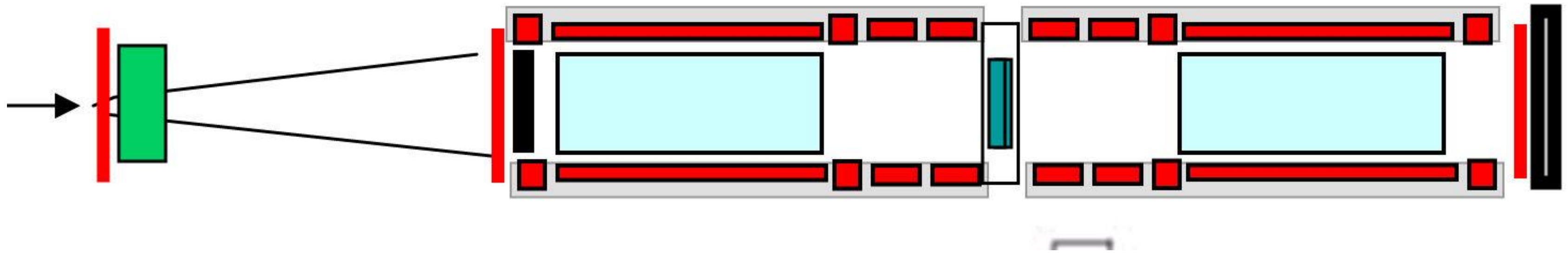


H_2 is clearly Best - Neglecting Engineering Issues Windows, Safety

LiH Discs

We want to Procure:

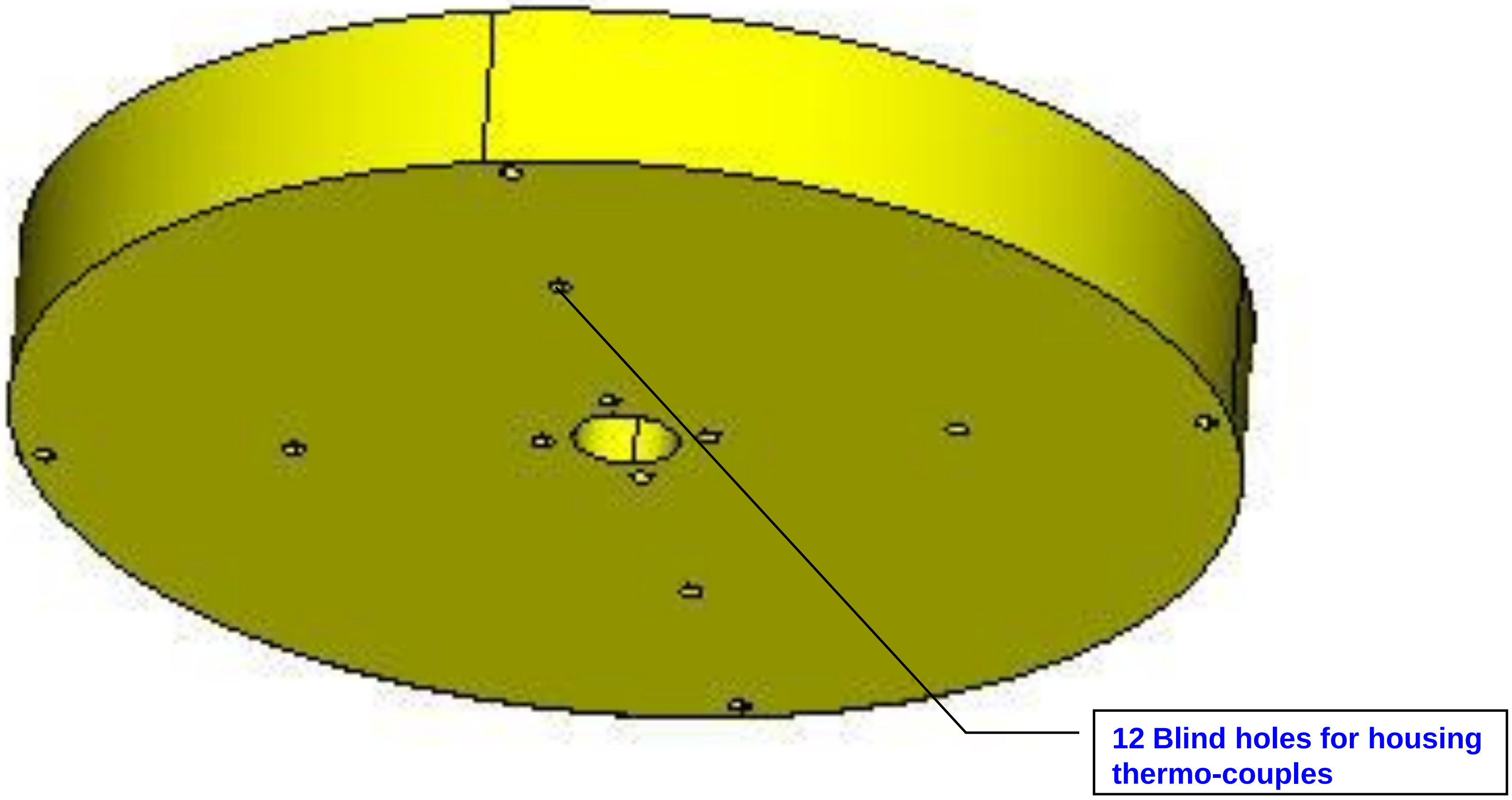
- An instrumented LiH disc (30 cm diameter, 4 cm thick) for measuring thermal properties
- Two small (1.25" diameter X 0.25" thick) samples for radiation stability tests
- One or Two LiH discs (50 cm diameter, 6.5 cm thick)
  - For use in MICE Step III.1



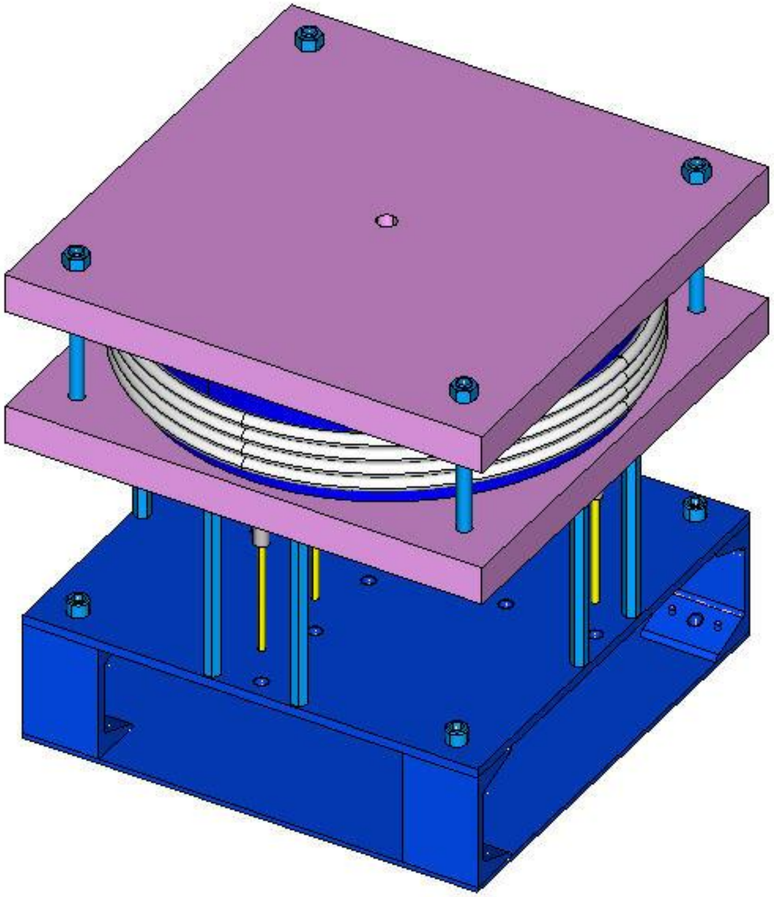
Production of LiH Disks

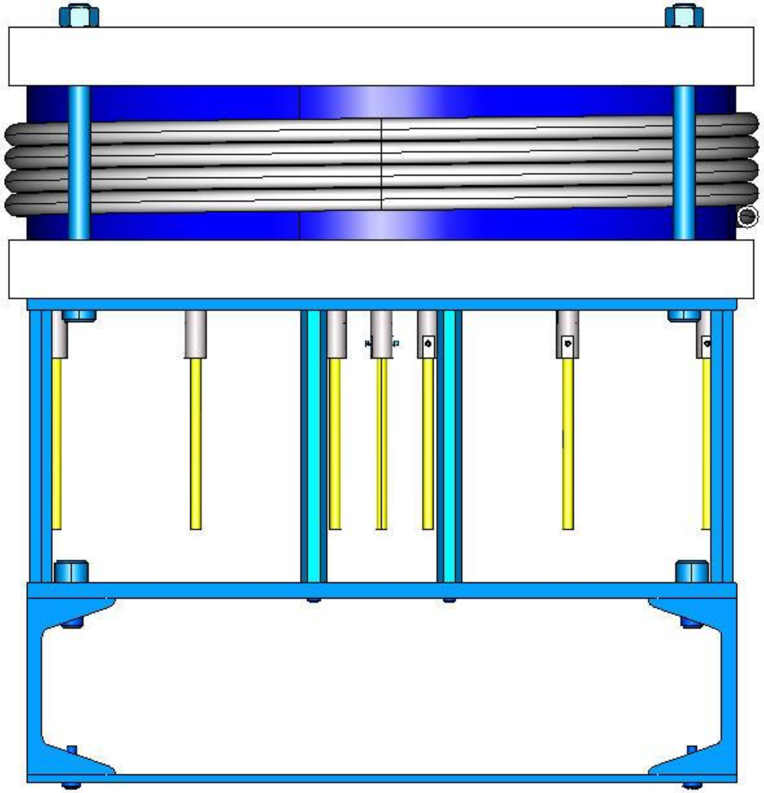
- Only 1 vendor was found that would cast LiH
  - After some reflection (and some input from Chemists from Argonne Lab), the vendor decided casting LiH was too dangerous (production of H_2 gas)
- Work with Y12 (Oakridge)
  - Found the engineer in charge of their LiH work and he suggested that they press (Hot 150C, Isostatic (30,000 psi) a "loaf" and machine parts to our specification from the loaf
    - They have achieved 98% theoretical density using this technique
    - They are doing R&D on casting LiH for their internal programs, but do not recommend it for our application.
      - It is very tricky due to the high temperature (700C +) and the large (30%) shrinkage on cooling
- We are in the process of setting up a contract with them to make a disk for temperature studies and 1 or 2 disks for MICE
  - Note: The Li in their LiH is ^{6}Li
    - For the mass we will receive, our parts will be considered nuclear material

Instrumental Disc

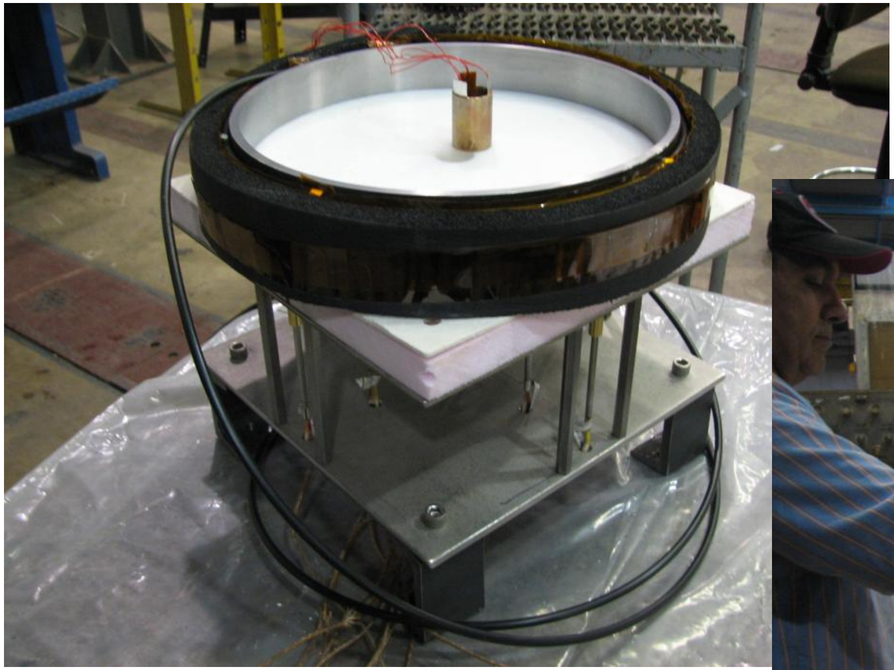


The Set Up Ready for the Thermal Test

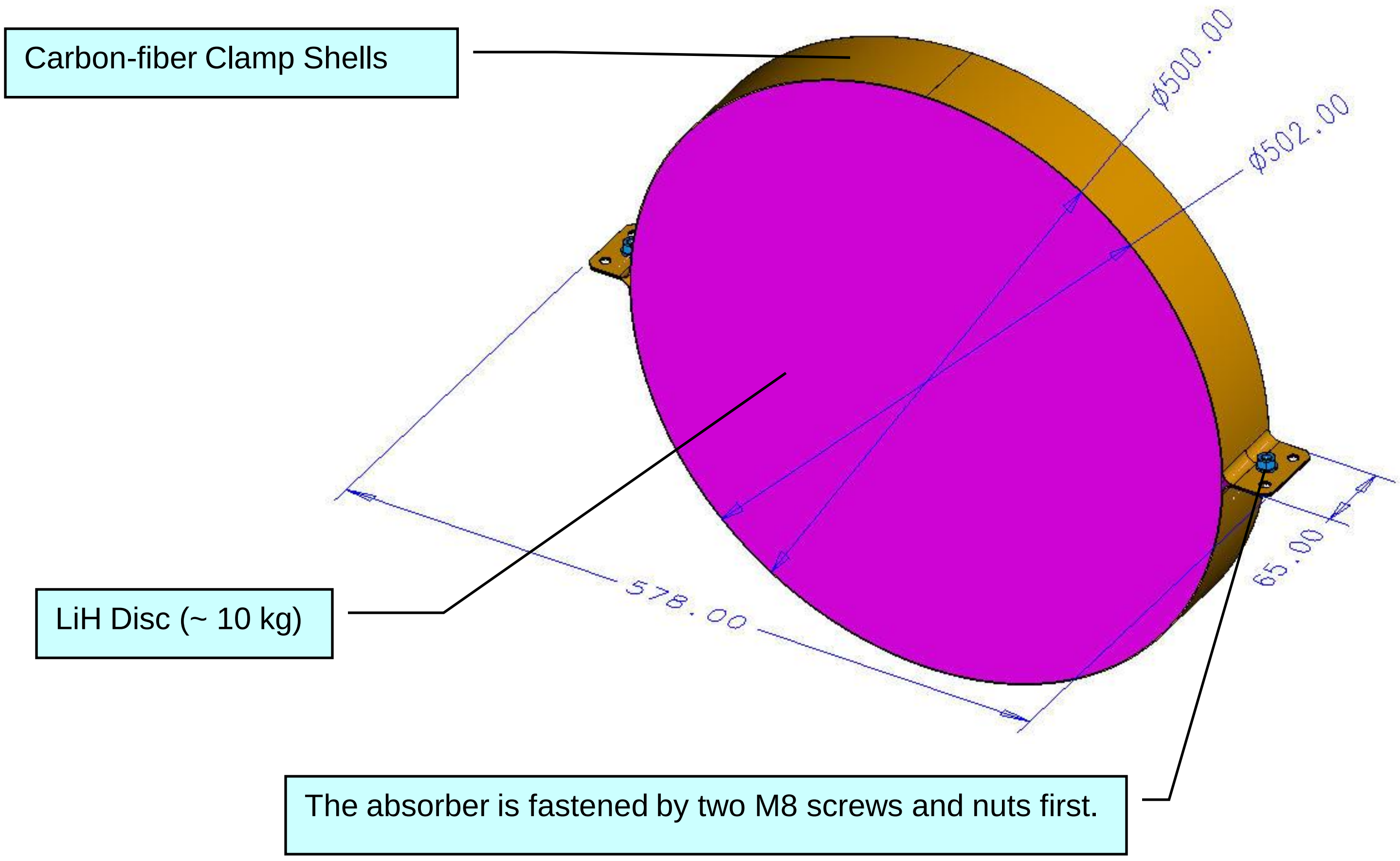




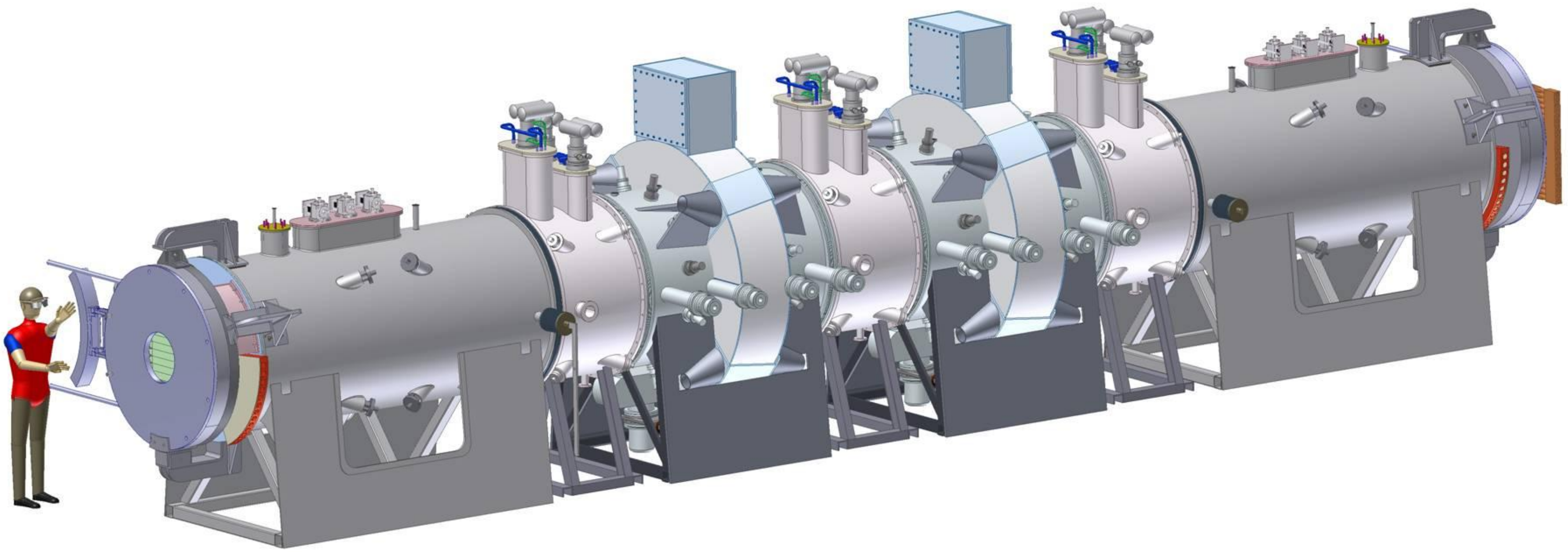
The Hardware Ready to take the Disc



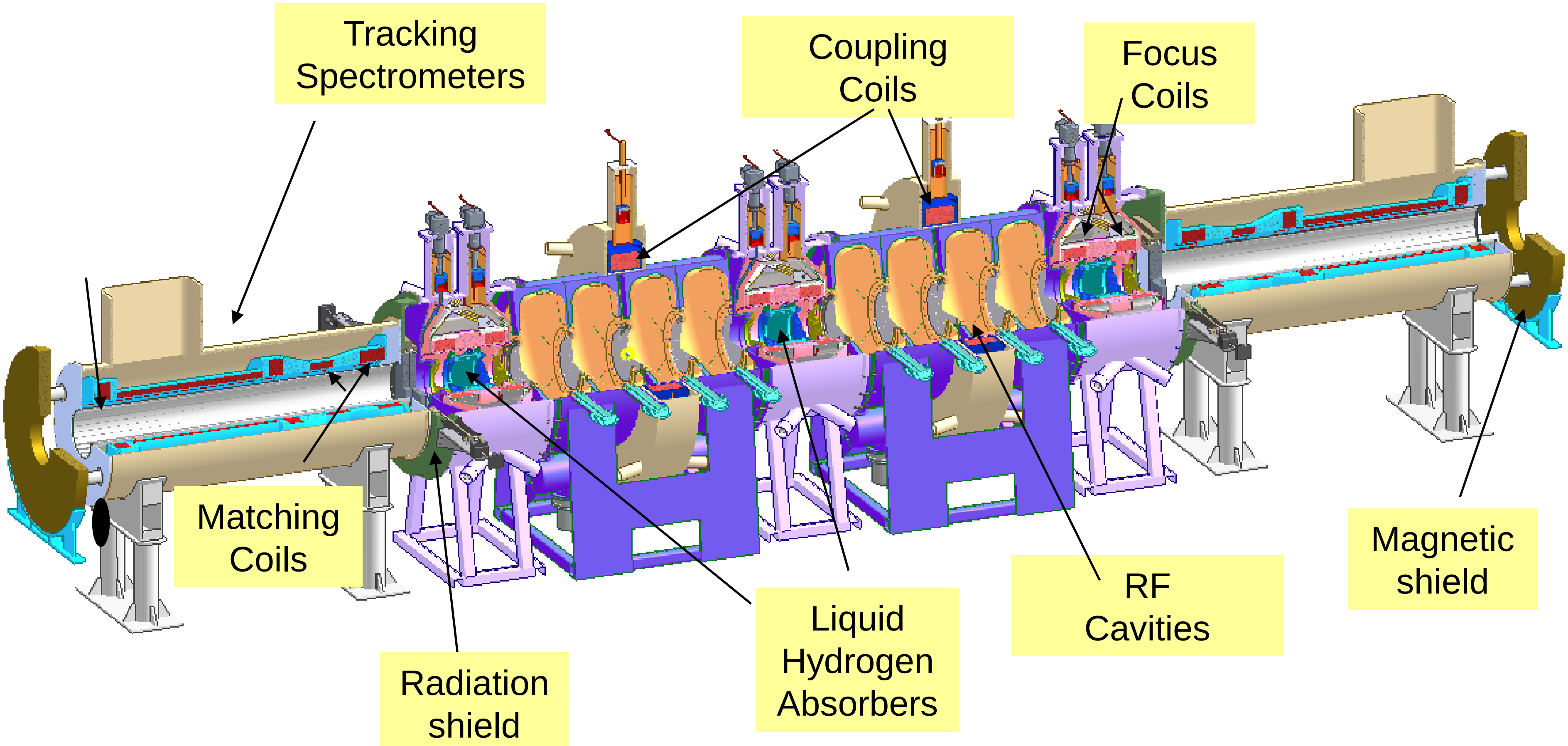
The MICE Energy Absorber



Muon Ionization Cooling Experiment (MICE)



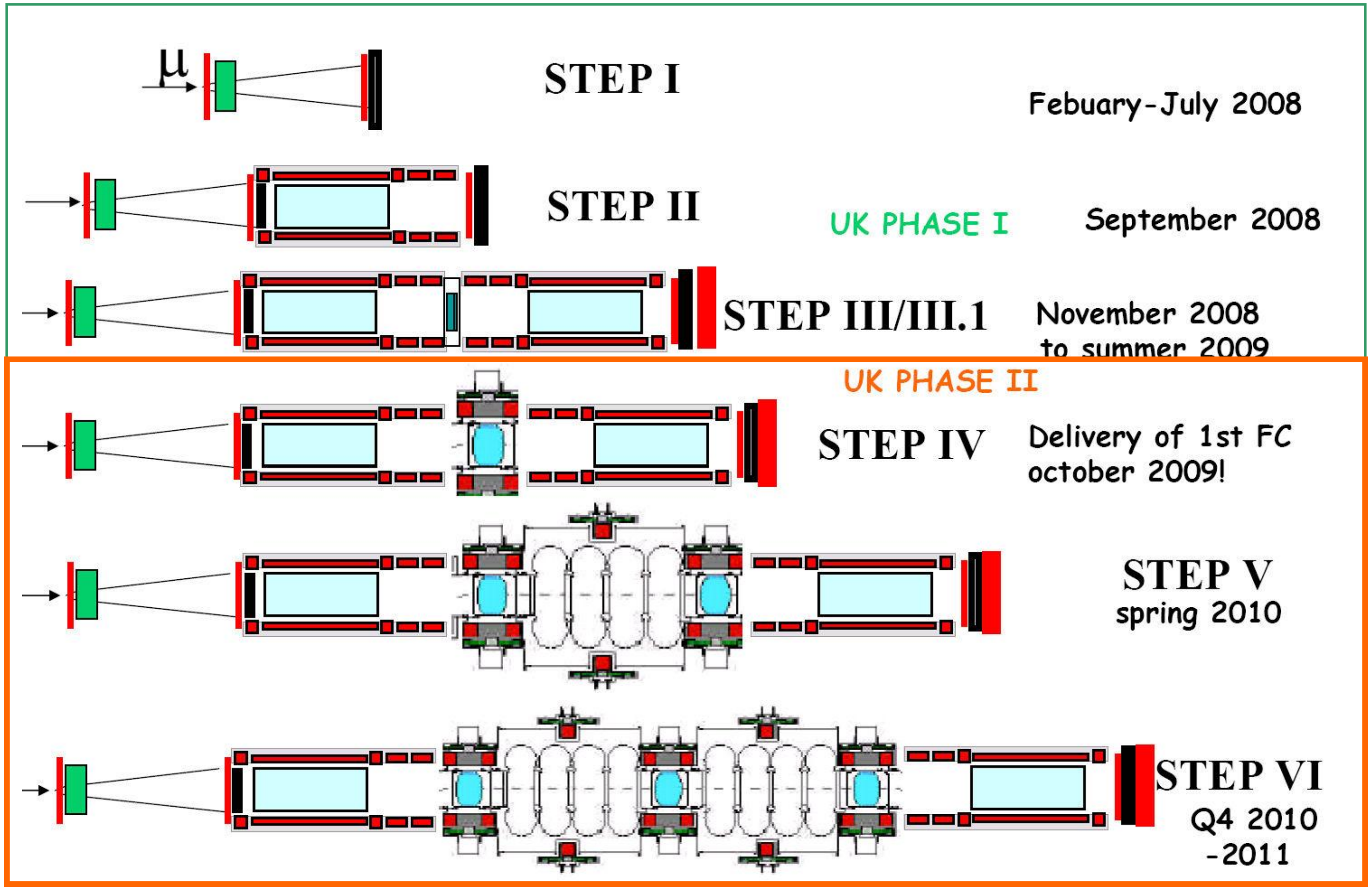
Muon Ionization Cooling Experiment



Muon Ionization Cooling Experiment (MICE)

MICE
Measurement of Muon Cooling - Emittance Measurement @ 10^{-3}

Aspirational MICE Schedule as of April 2008



MICE Milestone

First Beam Measured in MICE Beam Line

View Through Two of the Quads in the MICE Beam Line

Progress on MICE

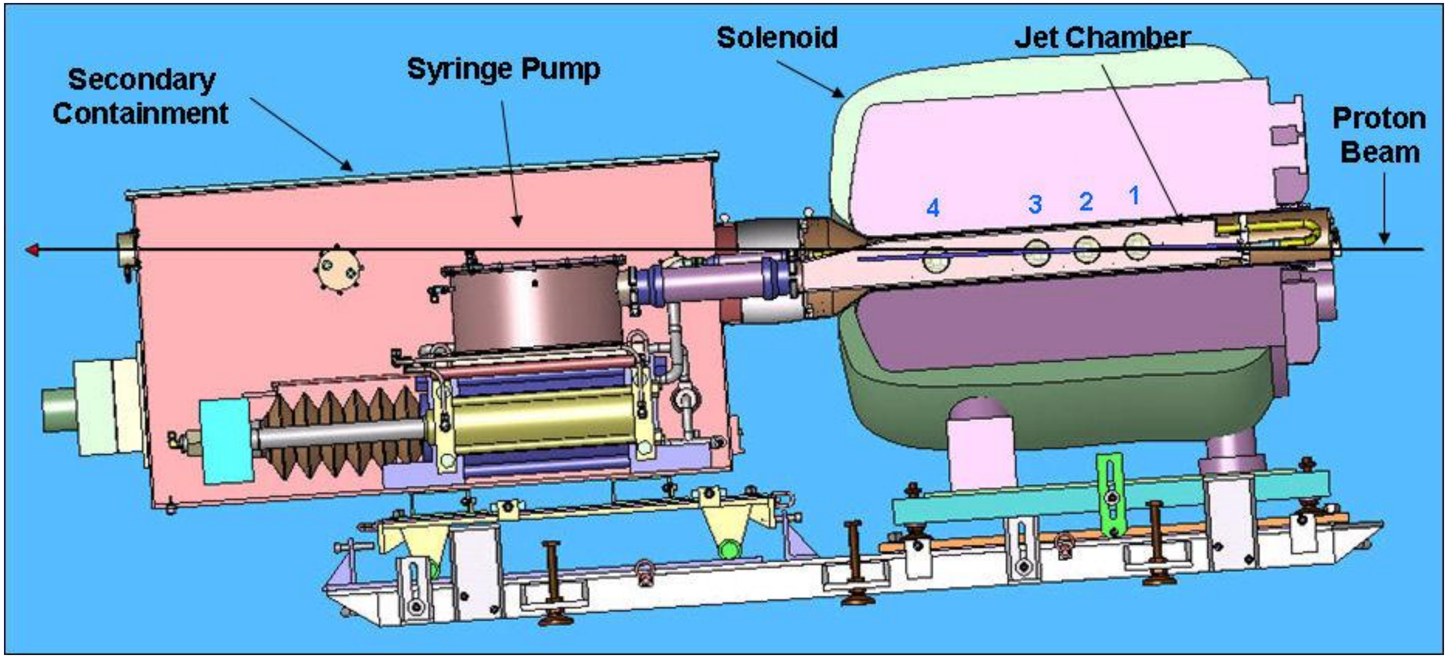
- Beam Line Complete
  - First Beam March 30th!
    - Beam Monitors (FNAL)
- First Spectrometer Summer

Fermilab Responsibilities in MICE

- Beam Line
  - Beam Line monitors (scintillating fiber detectors)
- Spectrometers
  - Fiber ribbons for Fiber Tracker
  - Fiber Readout
    - VLPC and cryogenics
    - Analog Front-end Board
  - Field mapping of Spectrometer magnets
    - Using upgraded ZipTrack System
- Absorbers
  - Supported testing of prototype (KEK design) LH_2 @MTA
  - Provide LiH disks for step III.1

MERIT -Mercury Intense Target

- Test of Hg-Jet target in magnetic field (15T)
- Located in TT2A tunnel to ISR, in nTOF beam line
- Beam run was in October, 2007
  - Test the principle of 50 Hz operation at 24 GeV ⇒ 4 MW

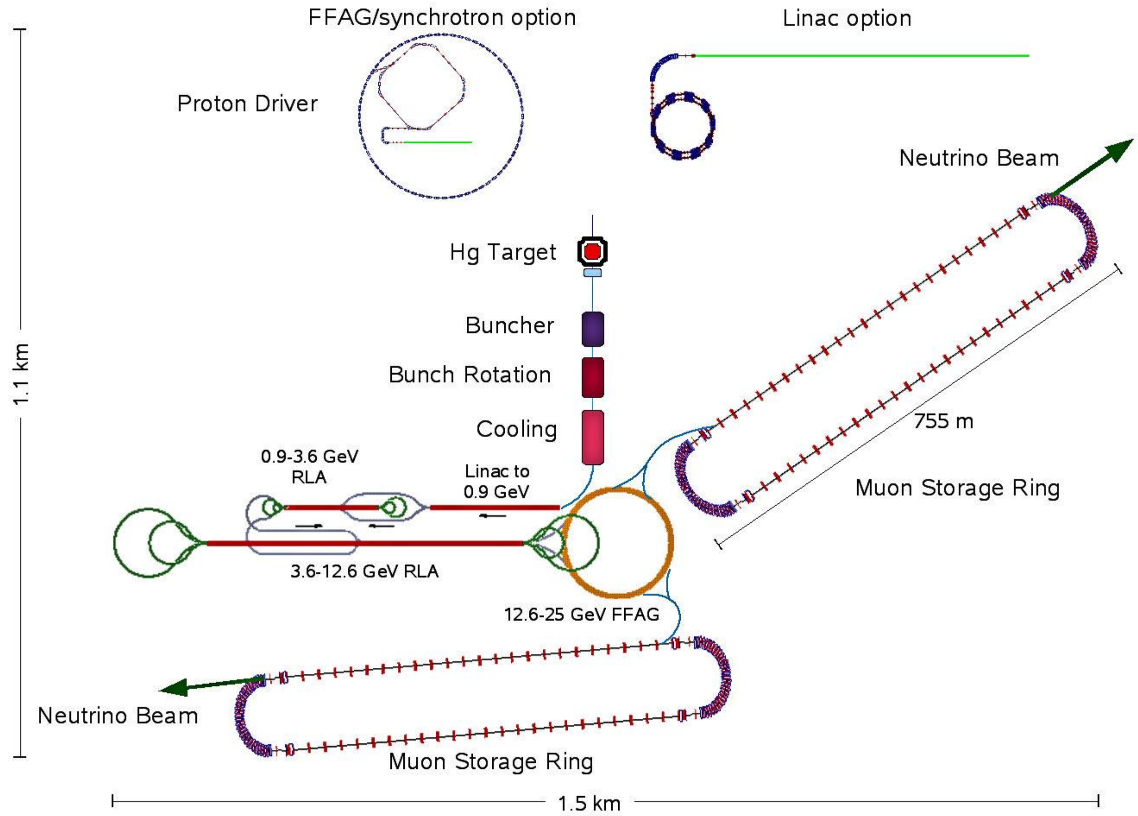


The MERIT Experiment Results

- The Neutrino Factory/Muon Collider target concept has been validated for 4MW 50Hz operations.
  - Tremendous work by the MERIT Team
- Data Analysis continues
  - APC – Energy Deposition Group
    - Particle production/flux simulations and compare to data

International Design Study for a Neutrino Factory

Neutrino Factory - IDS Starting Point

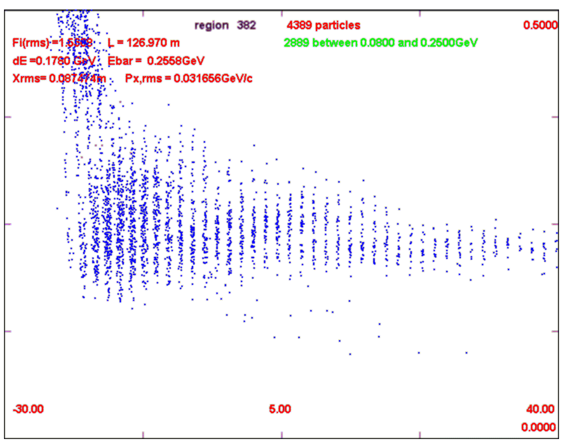


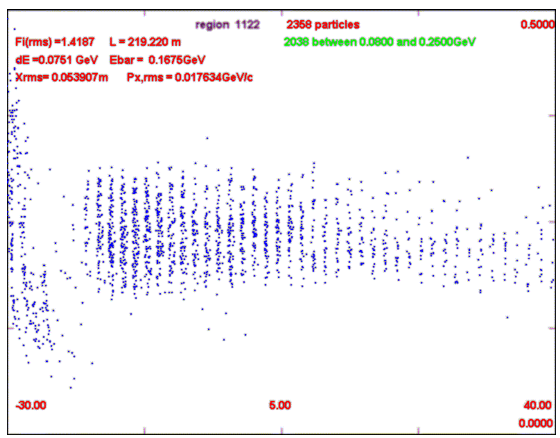
- Proton Driver
  - 4 MW, 2 ns bunch
- Target, Capture & Phase Rotation
  - Hg Jet
  - 200 MHz train
- Cooling
  - 30 πmm ($\perp$)
  - 150 πmm (L)
- Acceleration
  - 103 MeV $\rightarrow$ 25 GeV
- Storage/Decay ring

MCTF

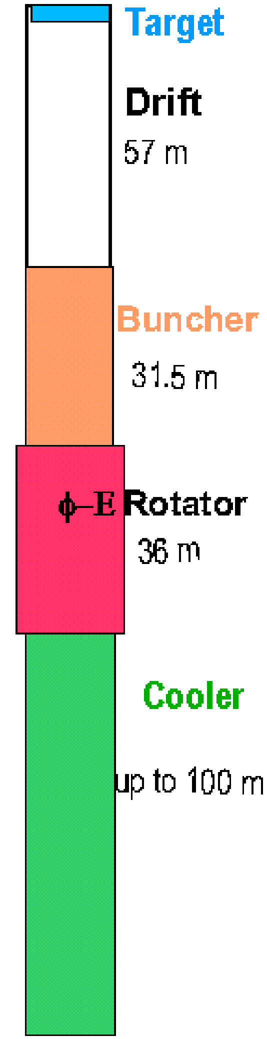
Front-End Simulation

- Reduce drift, buncher, rotator to get shorter bunch train:
  - 217m ⇒ **125m**
  - **57m drift, 31.5m buncher, 36m rotator**
  - **Rf voltages up to 15MV/m (×2/3)**
- **Obtains** ~0.26 μ/p_{24} **in ref. acceptance**
  - **Slightly better ?**
    - **~0.24 μ/p for Study 2B baseline**
- **80+ m bunchtrain reduced to < 50m**
  - **Δn: 18 -> 10**





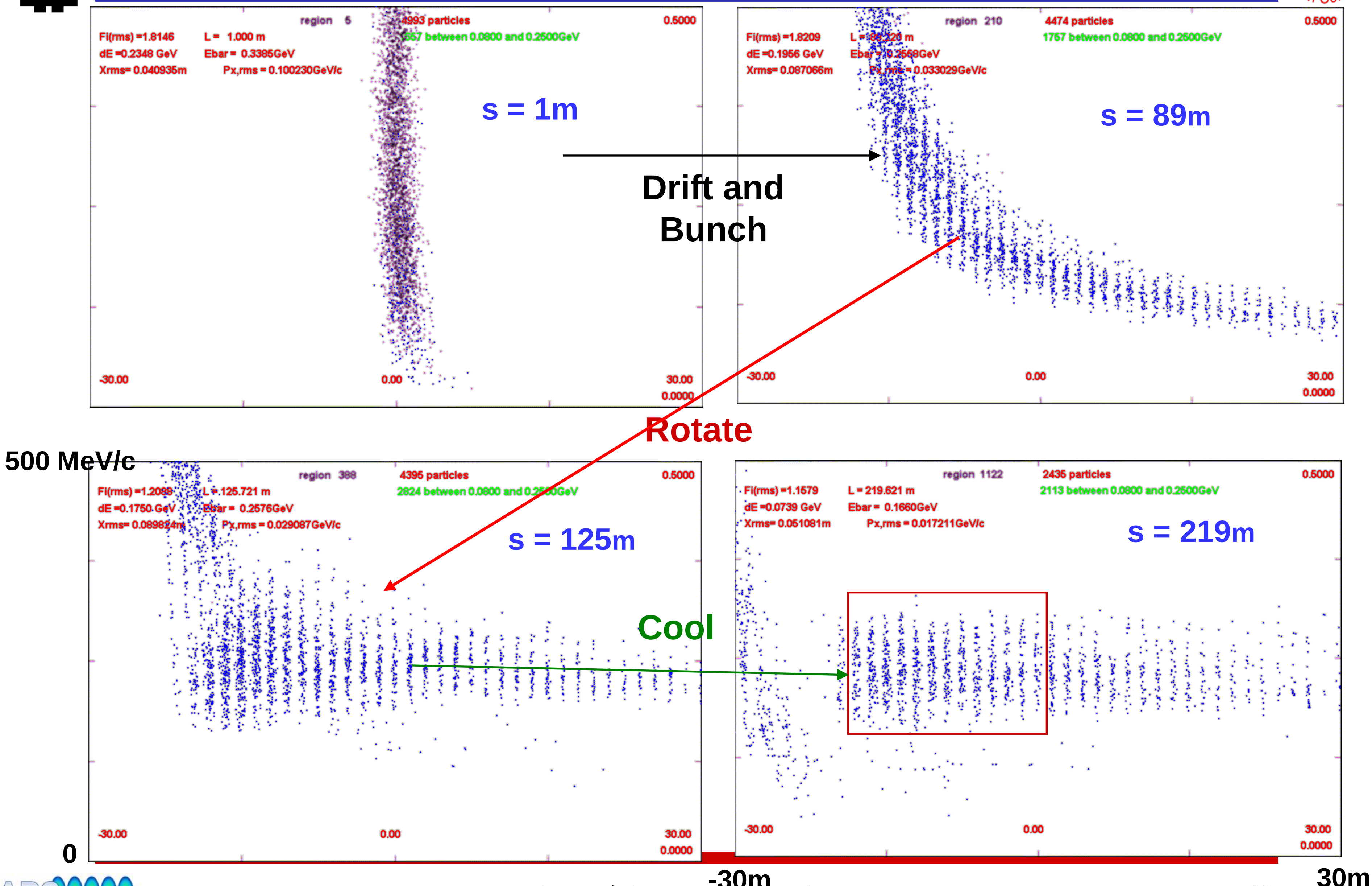
500MeV/c



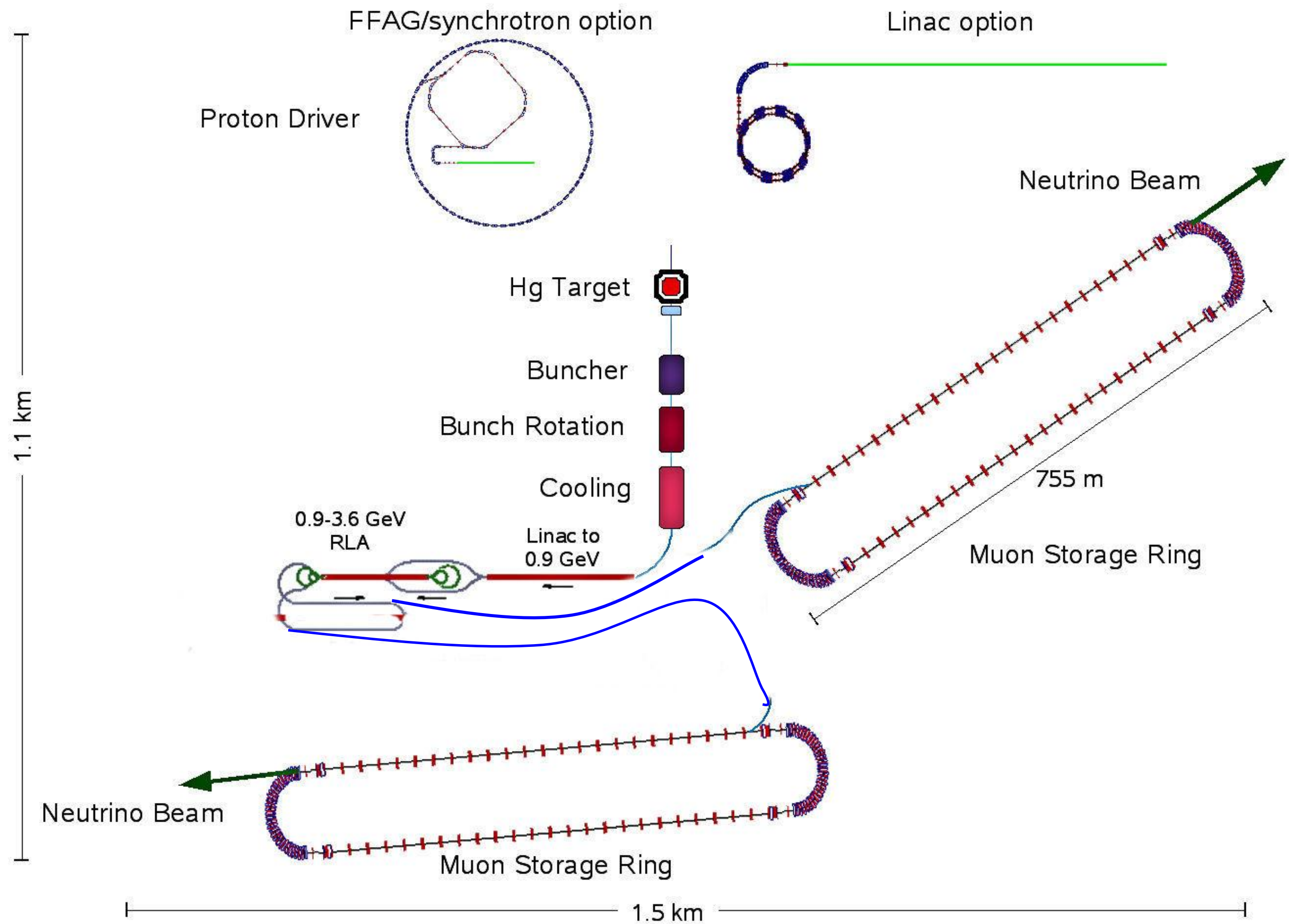
-30

40m

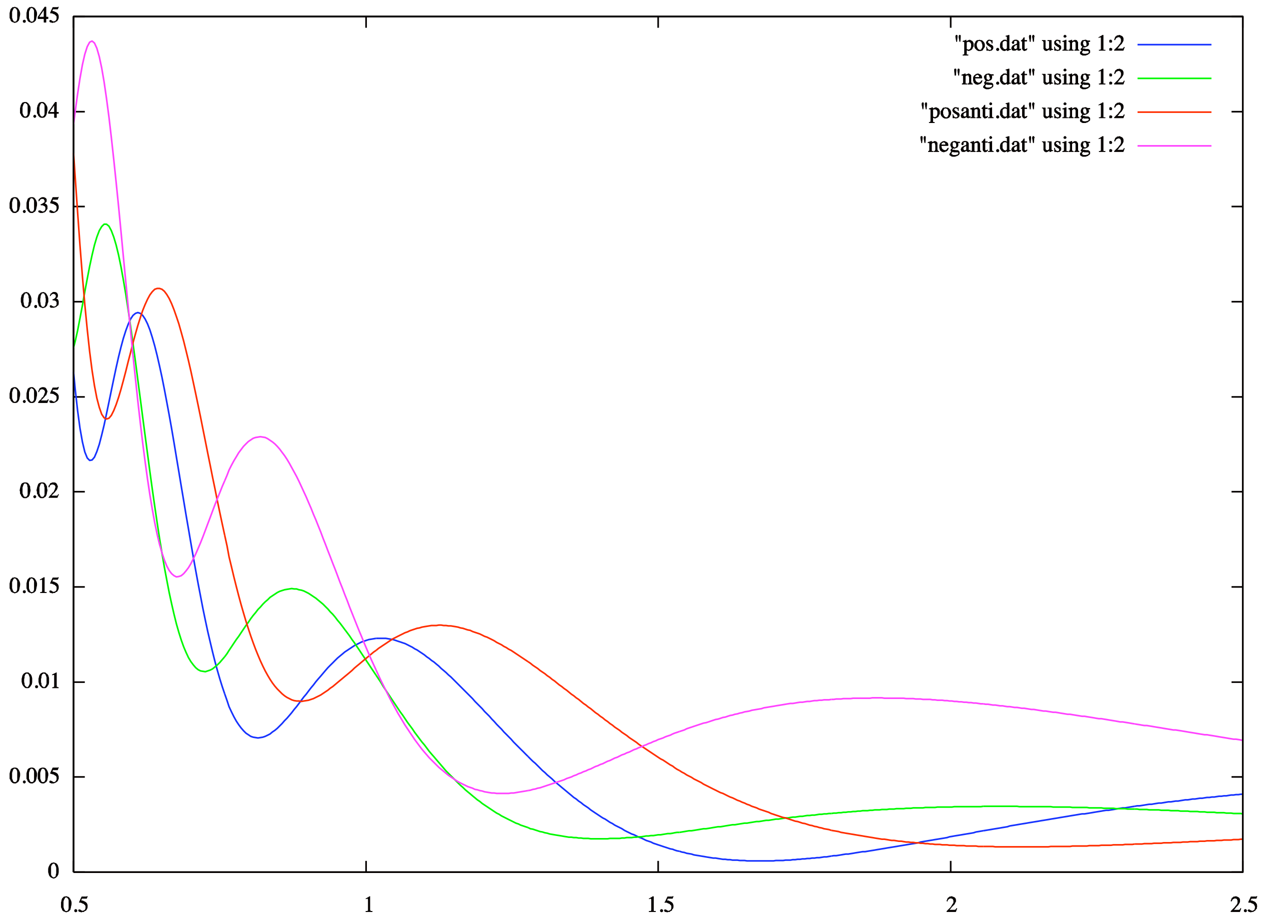
Simulations (N_B=10)



IDS - Lite


FFAG/synchrotron option
Linac option
Proton Driver
Neutrino Beam
Hg Target
Buncher
Bunch Rotation
Cooling
1.1 km
755 m
0.9-3.6 GeV
RLA
Linac to
0.9 GeV
Muon Storage Ring
Neutrino Beam
Muon Storage Ring
1.5 km

Low Energy ν Oscillation Pattern

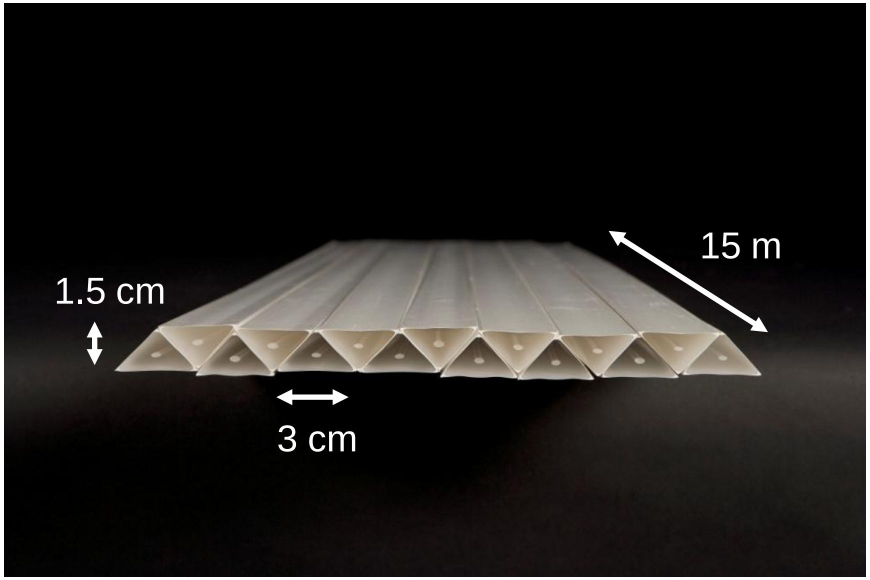


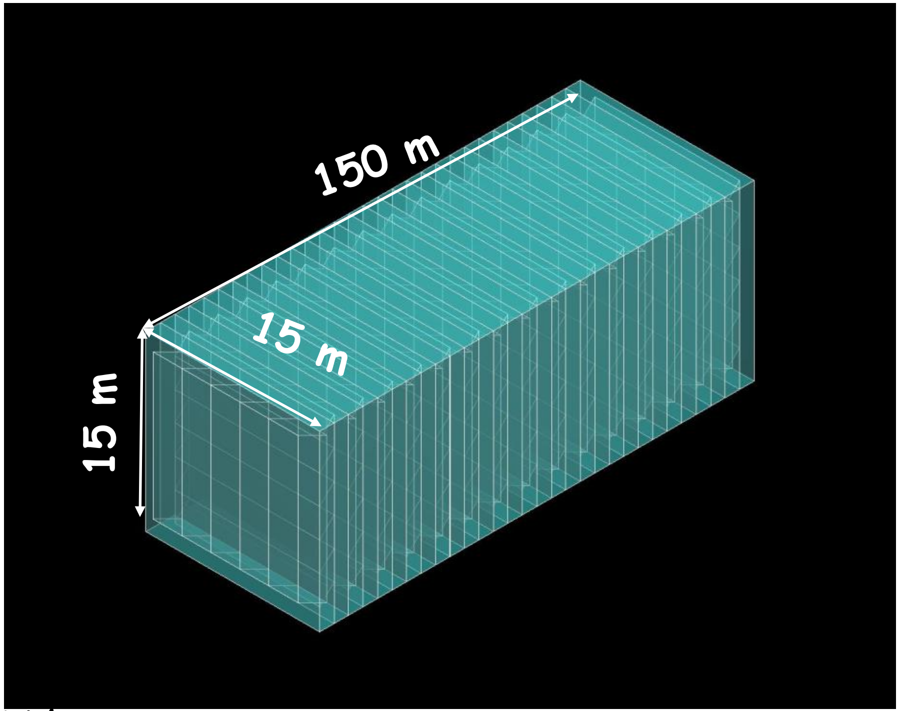
- If the TASD can fully exploit the rich oscillation pattern at low energy → 0.5 to 1.5 GeV (and go to E_ν threshold of 0.5 GeV)

Fine-Resolution Totally Active Segmented Detector

Simulation of a Totally Active Scintillating Detector (TASD) using Nova and Minerva concepts with Geant4

- 3333 Modules (X and Y plane)
- Each plane contains 1000 slabs
- Total: 6.7M channels

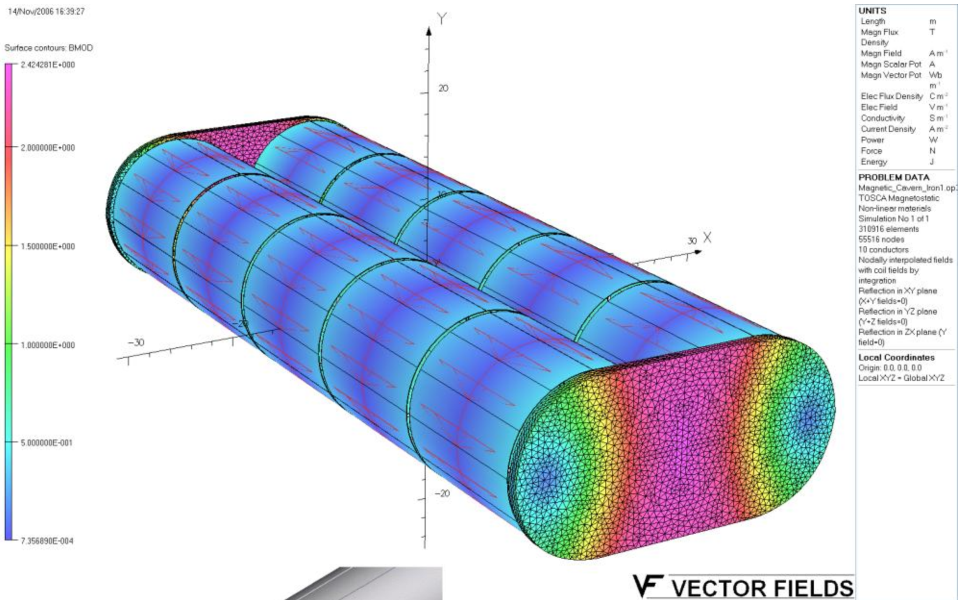


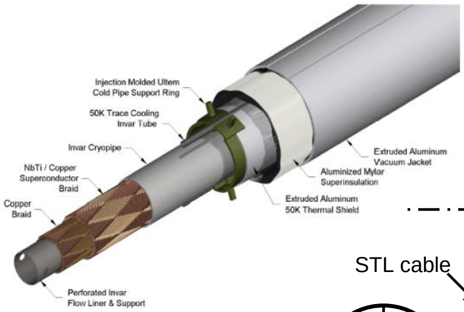


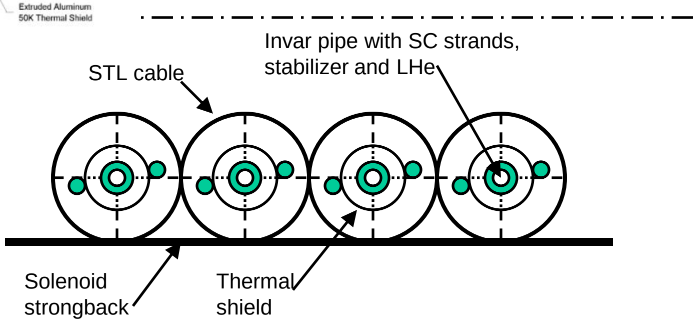
- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

B = 0.5T

Very-Large Magnets: NF Detector R&D
The Magnetic Cavern







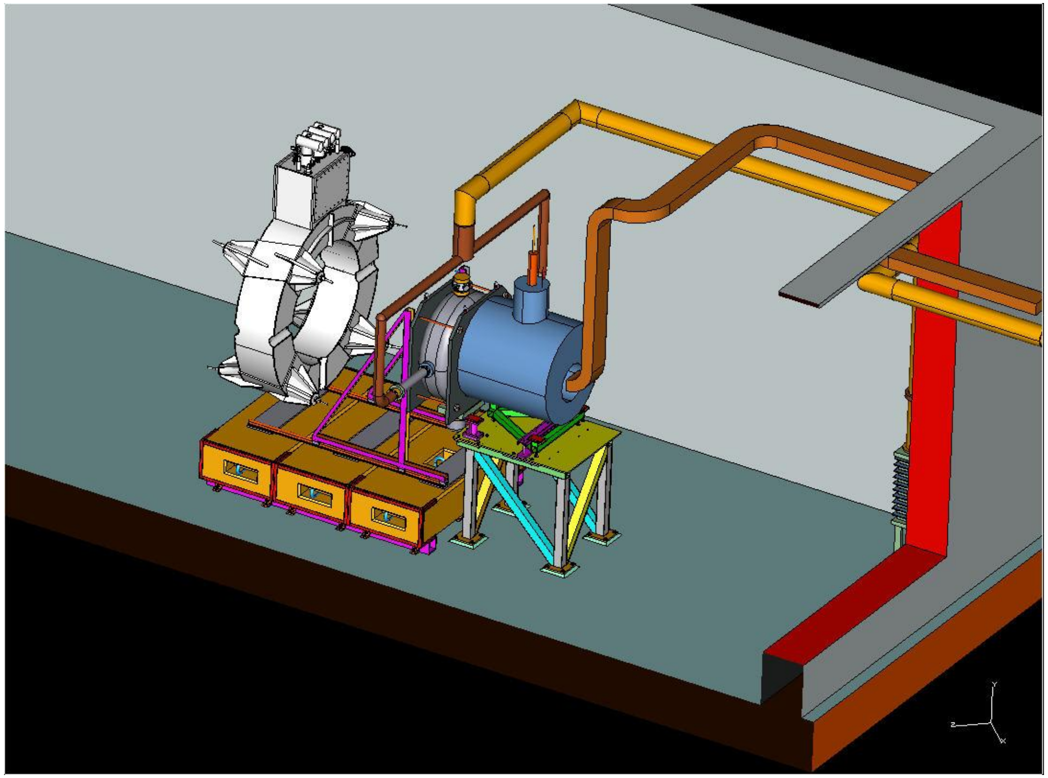
- Based on Superconducting Transmission Line (SCTL) for VLHC (Fermilab)
- Features
  - 25 X 10^3 m^3
  - 10 solenoids
  - 15-m long 15 m ID each
  - B_{nom}~0.5 T (@50% critical current)
  - 1 m iron wall, B~2.4 T
  - *Good field uniformity*
- Re-engineer SCTL for tighter bend radius
  - 7.5m vs. 37km
- 2-3 Turn full-scale prototype tests
  - *Verify forces, etc*

MuCool Phase II

MTA Cryo-Infrastructure

- MTA Reconfiguration
  - Commission Cryo-Plan (April/May 2008)
  - Install Transfer Line system
  - Raise Equipment to beam height
  - New shield wall
- Working on Project Plan
  - ≈ 3 month effort with adequate technician resources
    - Need 5 technicians full time (estimate is about 2000 hours)
    - Plus 5 weeks of a welder
    - Plus $50k in M&S (Does not include rerouting of RF power)
- Need to complete before the 2008 Accelerator Shutdown
  - But shutdown now delayed until March 09
  - Now driven by experimental program

MuCool Phase II



- Commission Linac Beam Line to MTA
- Reconfigure Equipment
- First Beam Experiment (Muon's Inc HP RF Test Cell) by end of 2008
- Tests of 201 MHz cavity in full field
  - New SC coil
    - MICE CC prototype

MTA Beam Status/Commissioning

- Beam Line Installation
  Complete except for installation of C magnets
- Beam Line commissioning to first beam stop (Linac side of shield wall) may start as early as June
- Still doing radiation shielding assessments
  - Rerouting RF Power required
    - Final configuration for this still being developed
- Will start at low intensity
  - Need Shielding upgrade (over-burden) for high-intensity
    - Full pulse intensity, limited #pulses/min

Outlook and Plans

- Although this has been a stressful year due to funding limitations, much progress has been made
  - MuCool –
    - 19MV/m @ 201MHz
    - Making progress on understanding/mitigated B Field Effect
      - Button studies (material tests, surface treatments, E X B effects
      - First 201 MHz measurements in large B field
    - Begin thermal and mechanical tests on HIP LiH absorber prototypes
    - Complete MTA cryo infrastructure installation and commission system
    - Commission Beam Line
    - First tests with Beam Complete by year's end
      - Test of HP H_2 RF test cell with beam
  - MERIT – 4MW Targetry demonstration
  - MICE – First beam
    - By end of the year have first cooling measurement (no RF)
  - IDS-NF has been launched
    - Fermilab simulation efforts aimed at front end
    - Low-Energy NF physics/detector studies
  - Developing the plan on how to deliver a feasibility study (ZDR) for a Muon Collider by around 2012