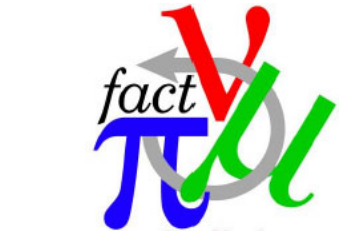


MuCool Overview and Plans

Daniel M. Kaplan

MuTAC Review
Fermilab
Jan. 14–15, 2003

MuCool-related talks at this Review:

This afternoon:

MUCOOL Overview and Plans	Kaplan	30’
NCRF R&D Program and Plans	Li	30’
RF Background Studies and Plans	Torun	15’
ICAR Program Overview and Plans	Morrison	10’
LH2 Absorber Program and Plans	Cummings	25’
Cooling Channel Instrumentation	Errede	10’

Tomorrow:

MICE Overview and Approach	Blondel	45’
MICE Technical Update and RAL Plans	Drumm	30’

Outline of this talk:

1. MuCool Collaboration and Mission
2. High-gradient normal-conducting RF R&D
3. High-power LH_2-absorber R&D
4. Gaseous-absorber option
5. MuCool Test Area
6. Detector R&D
7. Simulations
8. Support for MICE
9. Plans
10. Summary

MuCool Collaboration

18 institutions from US, Europe, and Japan:

RF Development
- ANL
- FNAL
- IIT
- LBNL
- Univ. Mississippi

Beam Diagnostics
- ANL
- FNAL
- IIT
- Princeton
- Univ. Chicago

Absorber R&D
- FNAL
- IIT
- KEK
- NIU
- UIUC
- Univ. Mississippi
- Univ. Osaka
- Univ. Oxford

Solenoids
- LBNL

Cooling Experiment
- ANL
- BNL
- FNAL
- Fairfield
- IIT
- Iowa
- JLab
- LBNL
- NIU
- UCLA
- UCR
- Univ. Chicago
- Univ. Mississippi

Mission:
- Design, prototype, & bench-test all cooling-channel components
- Make an engineering beam test of a cooling section
- Support cooling demonstration in muon beam (MICE)

MuCool Organization

Acting Spokesperson:	Dan Kaplan*
BNL Contact:	Rick Fernow
LBNL Contact:	Derun Li

*Replacement for Steve Geer (following his election as Muon Collaboration co-spokesperson) until a successor can be named

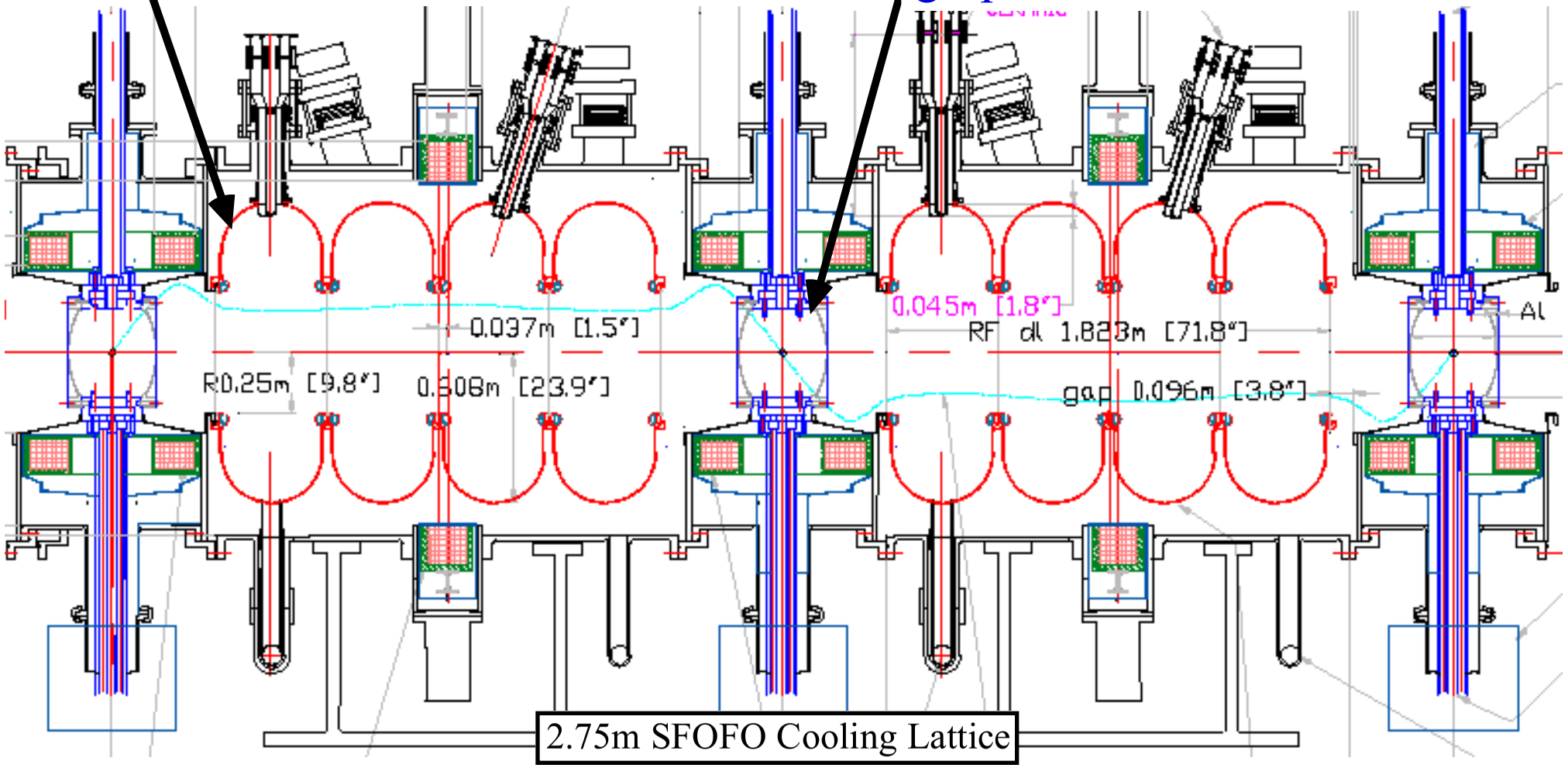
R&D Coordinators:

RF:	D. Li, LBNL A. Moretti, FNAL
Absorbers:	M. A. Cummings, NIU
Cavity Diagnostics:	Y. Torun, IIT
MuCool Test Area:	M. Popovic, FNAL

Website: http://www.fnal.gov/projects/muon_collider/cool/cool.html

MuCool R&D Projects & Facilities

- High-gradient normal-conducting RF
- High-power LH2 absorbers



- Test facilities for the above:
  - FNAL Lab G
  - FNAL MuCool Test Area
- Simulation studies in support of cooling R&D

Key R&D Issues

1. Can NCRF cavities be built that provide the required accelerating gradients, operating in multi-tesla fields?

2. Can the heat from dE/dx losses be adequately removed from the absorbers?

3. Can the channel be engineered with an acceptably low thickness of non-absorber material (absorber, RF, & safety windows) in the aperture?

4. Can the channel be designed & engineered to be cost effective?

High-Gradient-RF-Cavity R&D

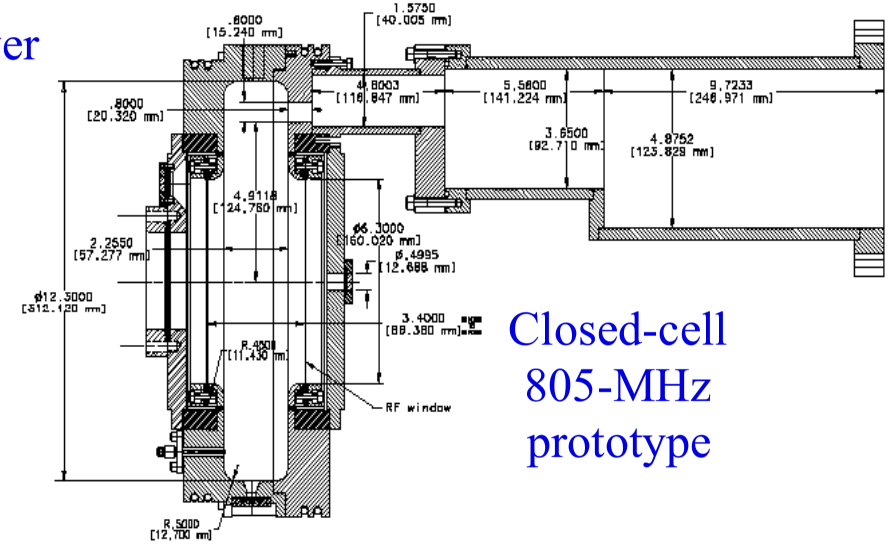
ANL / FNAL / IIT / LBNL / UMiss

- Goal:

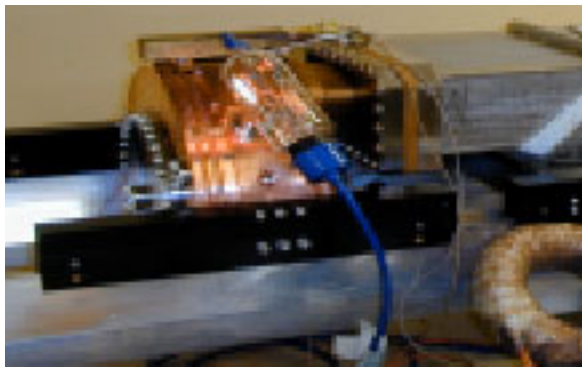
  201-MHz Cu cavity with > 15-MV/m on-axis accelerating gradient, operable in few-T solenoidal magnetic field

  – But rapid progress easier with smaller-scale prototypes → initial tests at 805 MHz
  – Pillbox cavity (cells closed with conducting windows) can save ≈ 50% in peak power
  – Open-cell tests were Ph.D. project of U. Cincinnati student V. Wu (now on FNAL staff)

Open-cell 805-MHz prototype under high-power test in Lab G superconducting solenoid



Closed-cell 805-MHz prototype

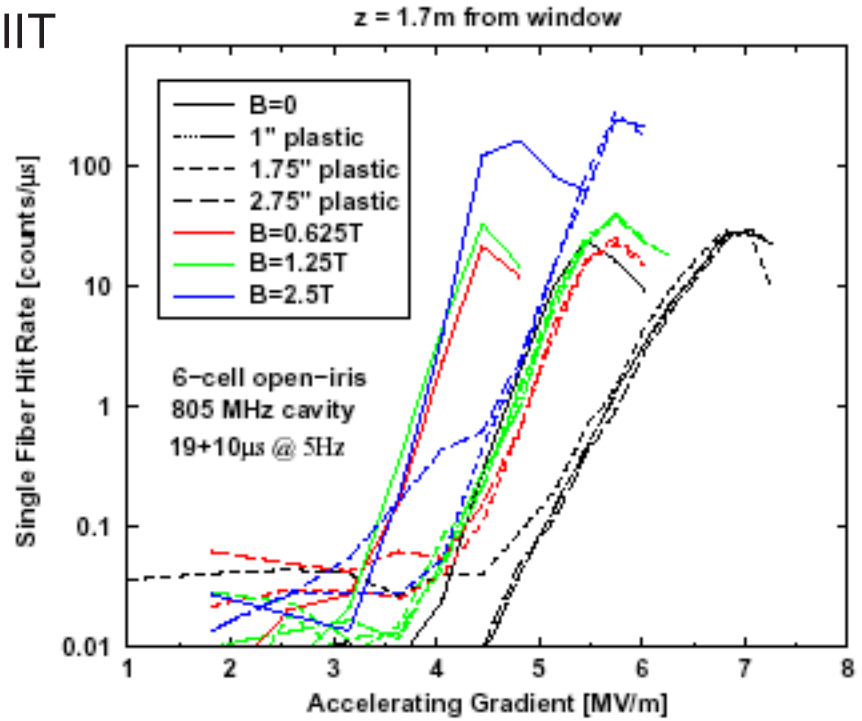


During bake-out last winter at LBL (now under high-power test in Lab G)

805-MHz Cavity Emission Studies

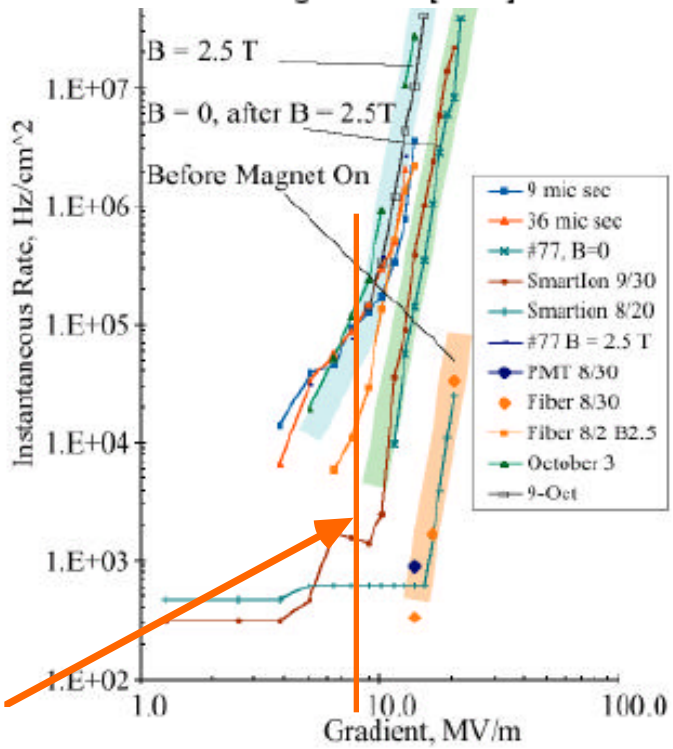
ANL / FNAL / IIT

- Studies with open-cell cavity in 2001 reached 54 MV/m surface field (25 MV/m on-axis accelerating gradient)
  - Revealed large dark current, enhanced by solenoidal **B** field
  - Emissions from sparks melted plexiglas and titanium windows
  - Paper submitted to Phys. Rev. ST AB



- Tests now in progress with closed-cell prototype → $E_{surf} \approx E_{acc}$
  - 1st tests with Cu windows, $B = 0$ → easy conditioning to 34 MV/m (allaying multipactor concern)
  - With $B = 2.5$ T, conditioning harder, large dark currents
  - Now embarking on studies of surface treatment

  →See Li, Torun talks
  - TiN-coated Be windows installed last month
- MICE: $E_{acc} \leq 8$ MV/m ⇒ bkg rate manageable

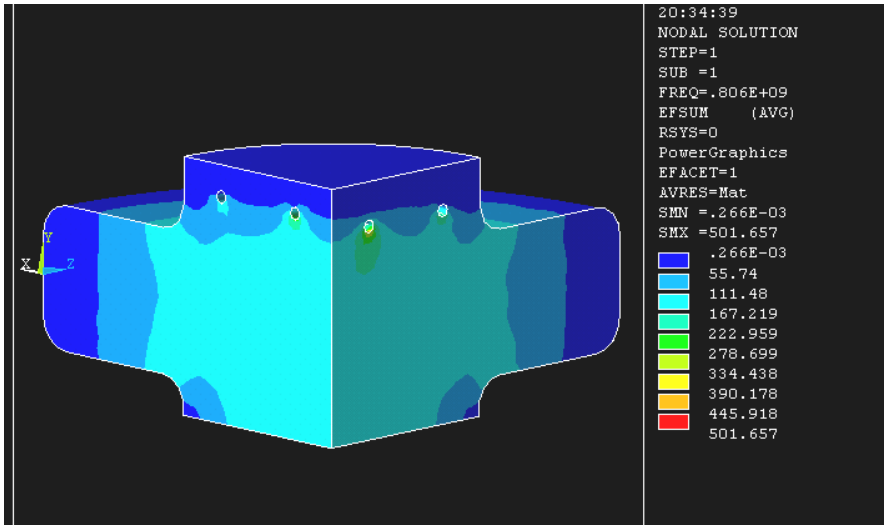


Tube Grid Design Studies

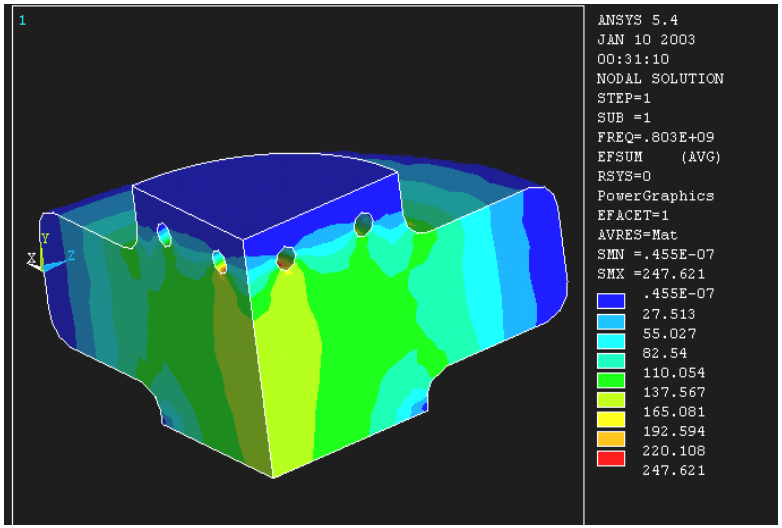
LBNL / FNAL / IIT

- To handle RF heat load with large (≈20-cm-radius) iris without buckling, Be windows need to be quite thick (> 1 mm)
- Grids of gas-cooled Al tubing might be thinner (in rad. len.) & cheaper
- Finite-element-analysis studies in progress at LBNL, IIT
  - Thesis project for IIT Mechanical Engineering Ph.D. student M. Alsharo'a under Moretti's direction
  - Current goal: find manufacturable grid configuration with manageable field enhancement factor at tube surface (work in progress)

4x4 grid of 0.5-cm x & y tubes
field enhancement = 3.6



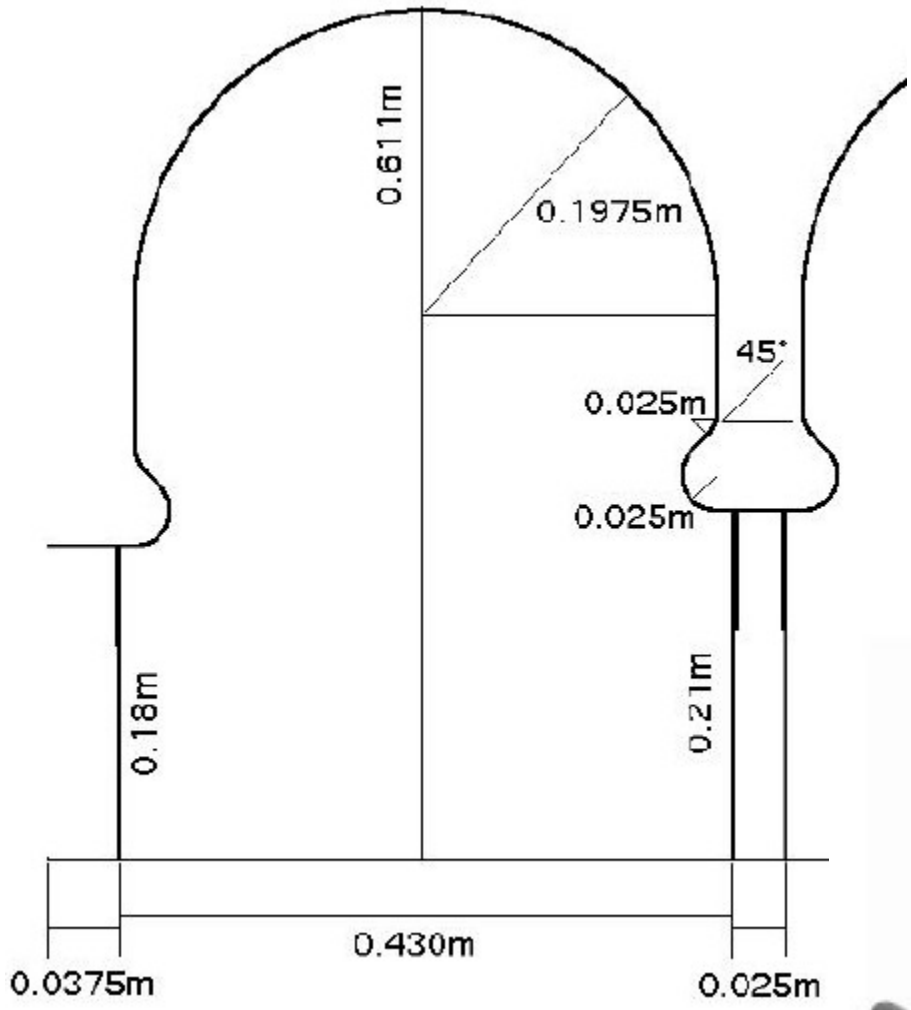
4x4 "waffle" grid of 1-cm tubes
field enhancement = 1.8

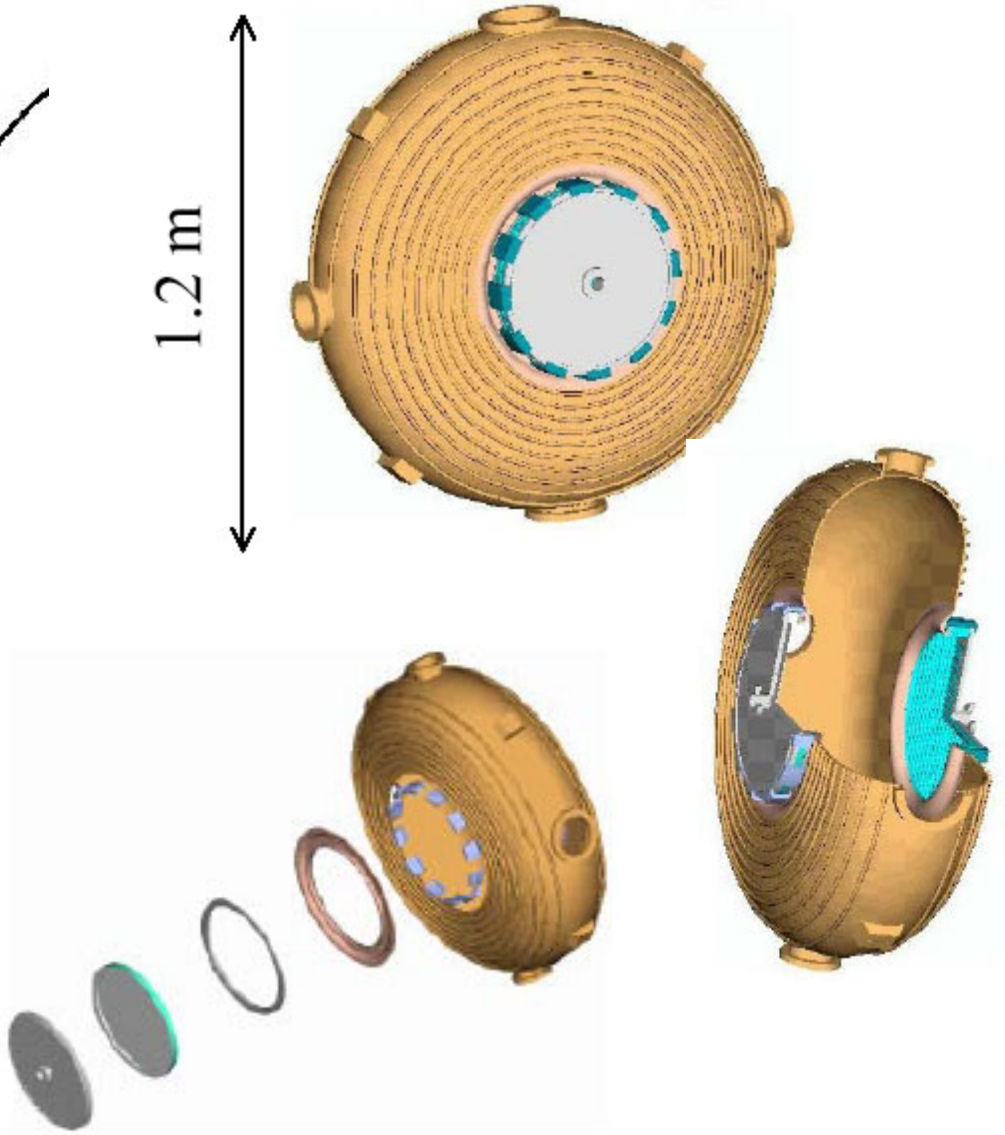


201-MHz Design Work

A. Ladran, D. Li, R. Rimmer (now at JLab), LBNL

- Both electrical and mechanical design essentially complete:

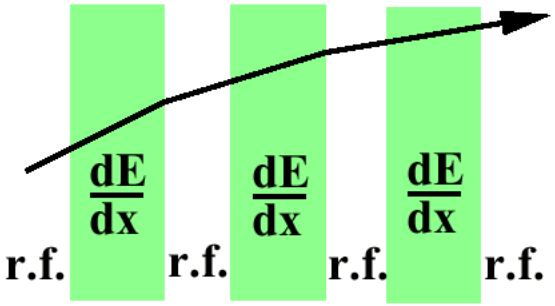




- Now ready for prototyping
  - held up this year for lack of funds

Absorber R&D

- 2D transverse-cooling rate:

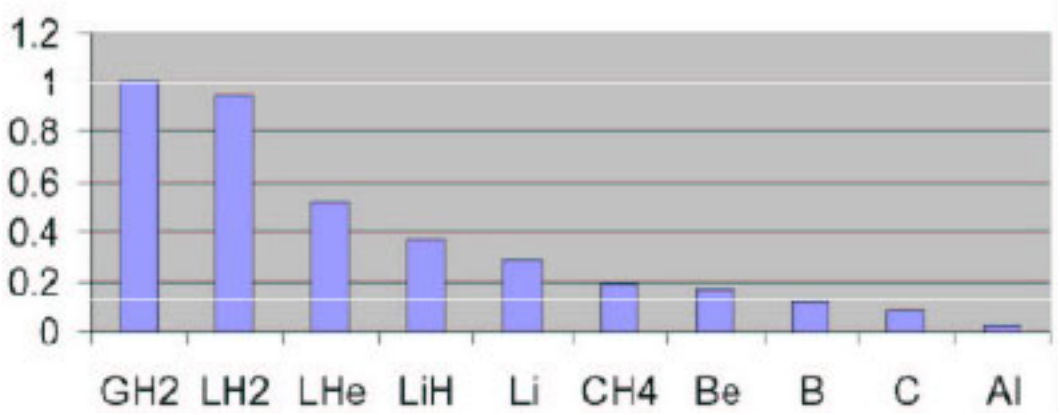


$$\frac{d\varepsilon_{x,N}}{dz} \approx -\frac{1}{\beta^2}\frac{\varepsilon_{x,N}}{E}\left|\frac{dE}{dz}\right| + \beta_\perp \frac{(0.014\,\mathrm{GeV})^2}{2\beta^3 E m_\mu L_R}$$

Competition between energy loss and Coulomb scattering

⇒ Absorber material comparison:

Transverse cooling merit factor $\propto (L_R\, dE/dx)^2$



- Hydrogen is best material by factor $\gtrsim 2$

(...all other things being equal, e.g., neglecting effect of containment windows)

Absorber Power Handling

- Need to handle 100s of watts per absorber in Study-II scenario

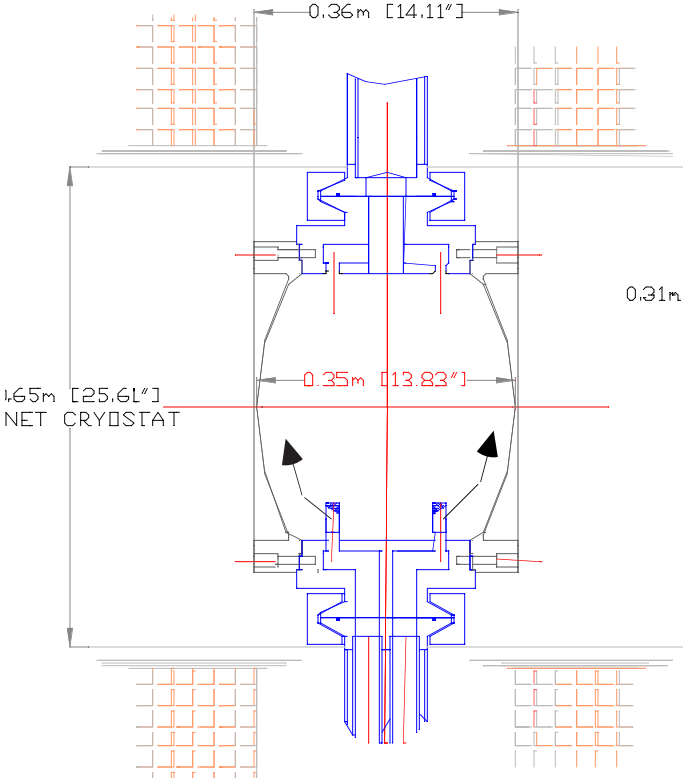
  → ~ kW with more ambitious Proton Driver (4 MW instead of 1 MW) and/or Neuffer phase rotation (keeps both μ^+ and μ^- simultaneously)

  → ~ 10 kW in ring cooler with ≈10 passes

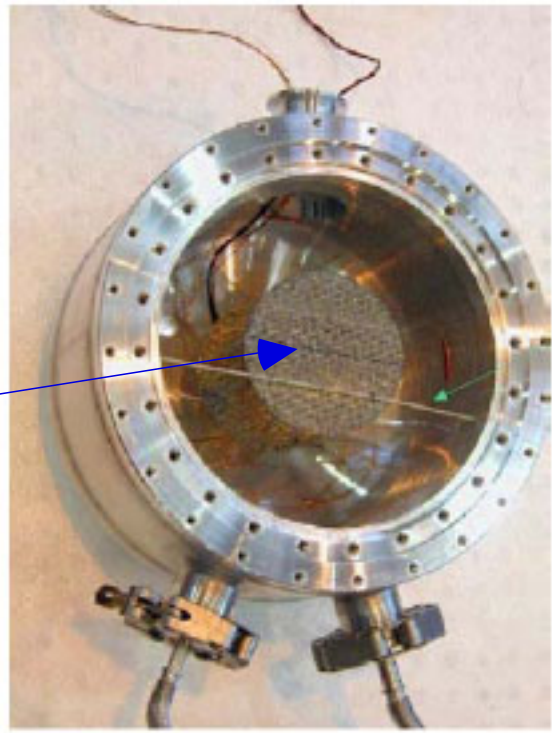
  – State of the art is several hundred W in e.g. SLAC E-158 LH_2 target

- Two possible solutions being pursued:

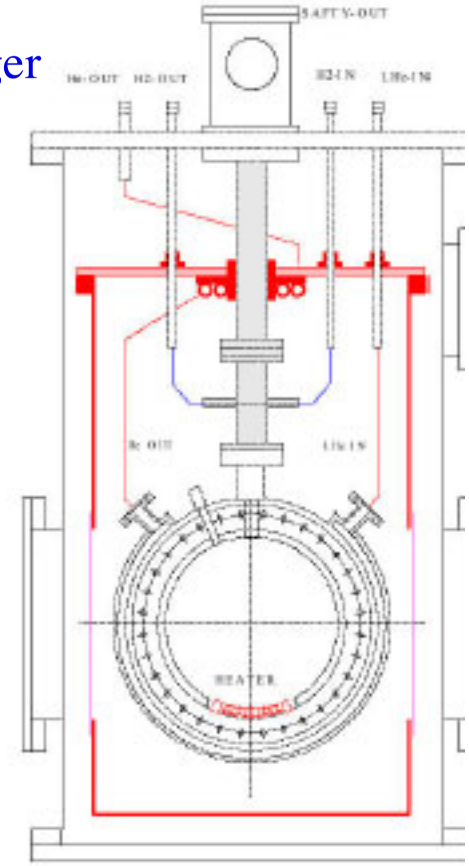
IIT/NIU: Forced-flow absorber with external cooling loop



KEK/Osaka: Convection-cooled absorber with internal heat exchanger



Array of heating wires



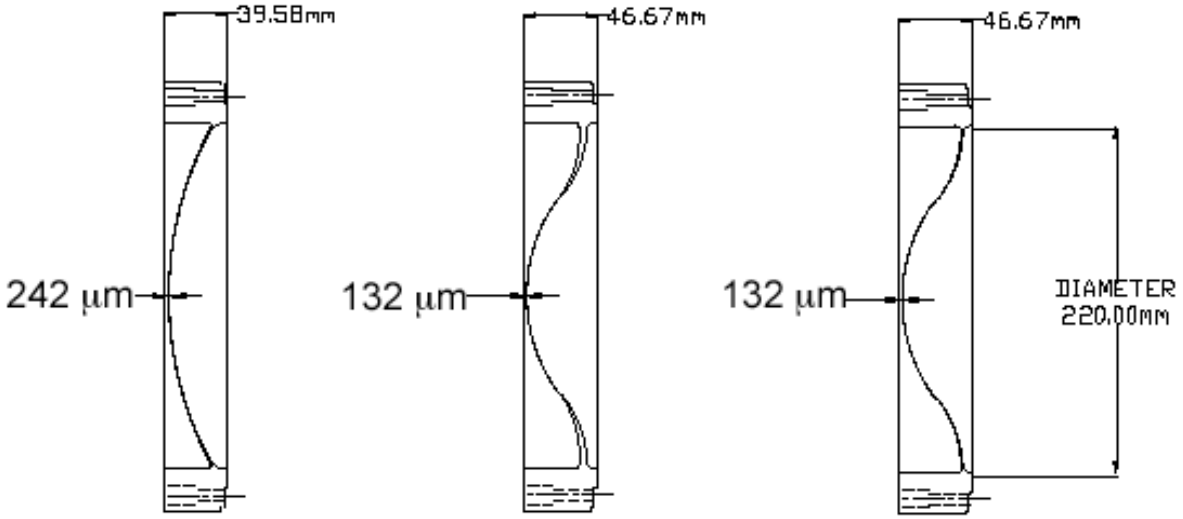
- Power-handling limit yet to be established for either approach

Progress in Absorber Windows: 1

IIT / NIU / Oxford / UMiss

- To avoid compromising hydrogen's low Coulomb scattering, need containment windows as thin as possible:

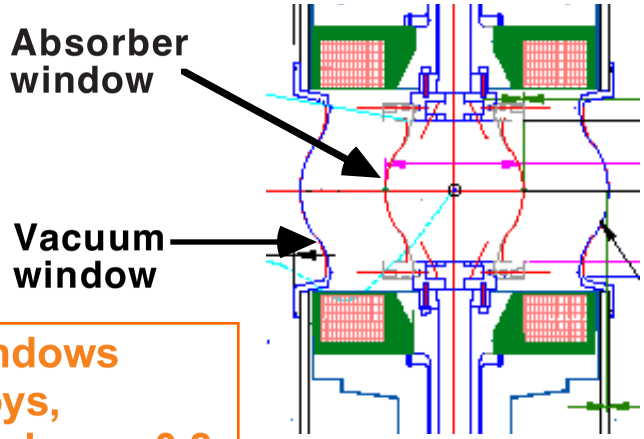
3 iterations of absorber window design:



Windows machined w/ integral flange out of single disk of Al alloy

Developed non-contact "photogrammetry" for window measurement and certification

Established need for containment vacuum surrounding absorber, to satisfy safety guidelines



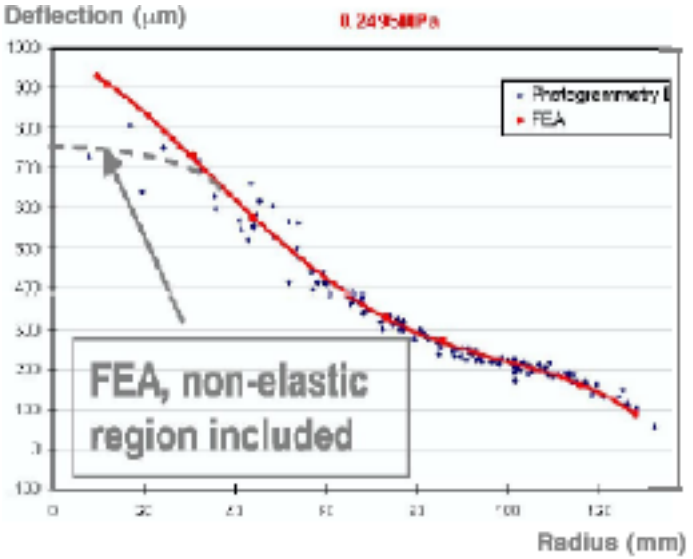
With "inflected" windows & modern Al alloys, merit factor can be as high as ≈ 0.8

Progress in Absorber Windows: 2

- FNAL requirement for nonstandard LH_2 containment windows:
  - Series of 4 windows must be destructively pressure-tested
- This was carried out for windows of the "1st-iteration" design:

- Reliability of photogrammetry established
  - Good agreement w/ FEA predictions
  - Good agreement w/ strain-gage data
  - Good agreement w/ CMM data
  - Good agreement w/ micrometer measurements

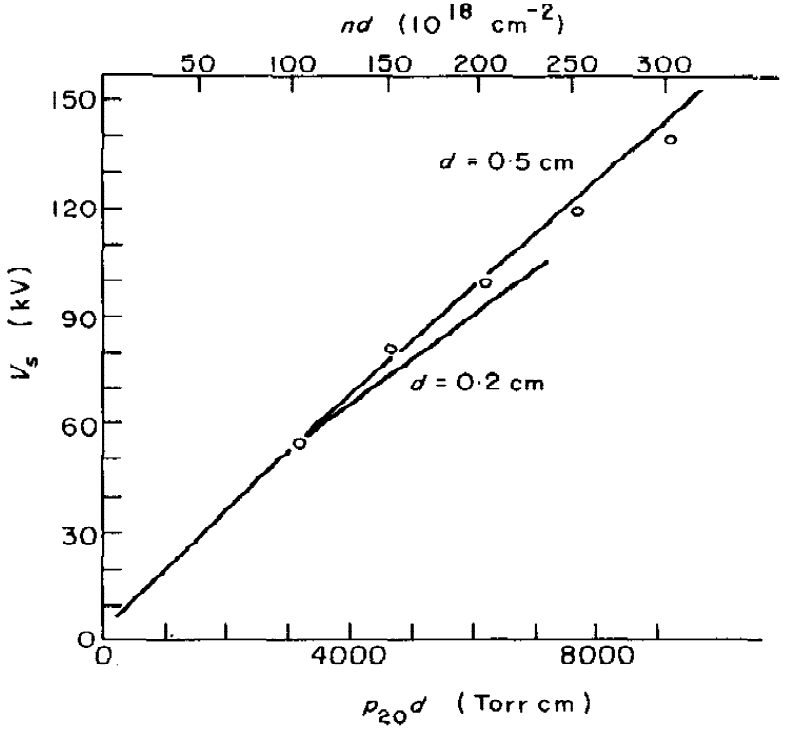
→ See Cummings & Errede talks



Gaseous Absorber?

R. Johnson et al., Muons, Inc. / FNAL / IIT

- Idea: why not eliminate (almost) all the windows?
  - Cooling channel becomes series of RF cavities (in suitable focusing field) filled with high-pressure gaseous H_2, protected against breakdown by the Paschen effect:



Breakdown voltages in hydrogen (Müller, 1966. permission of Springer–Verlag)

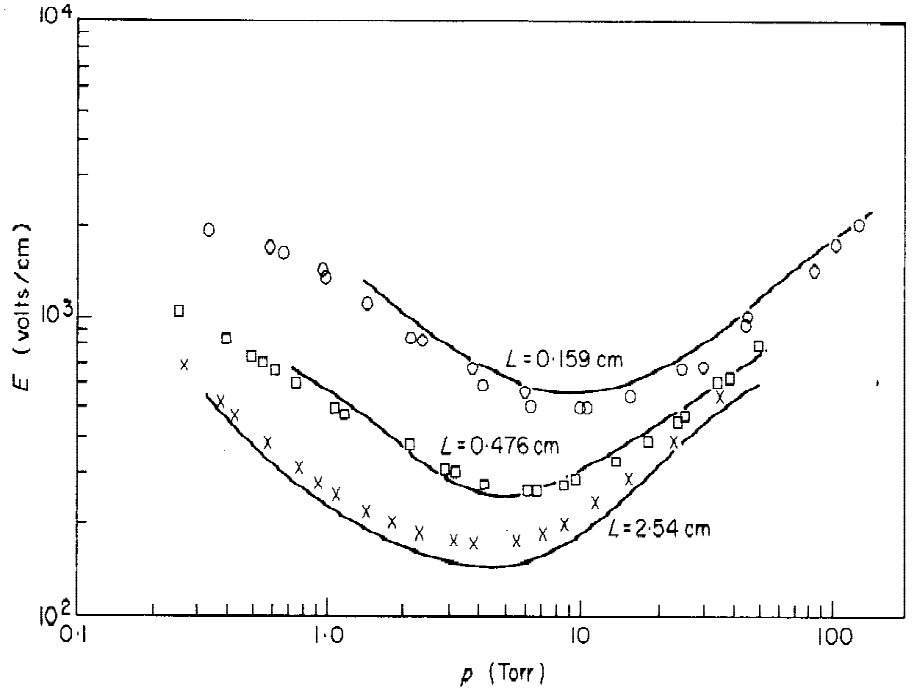


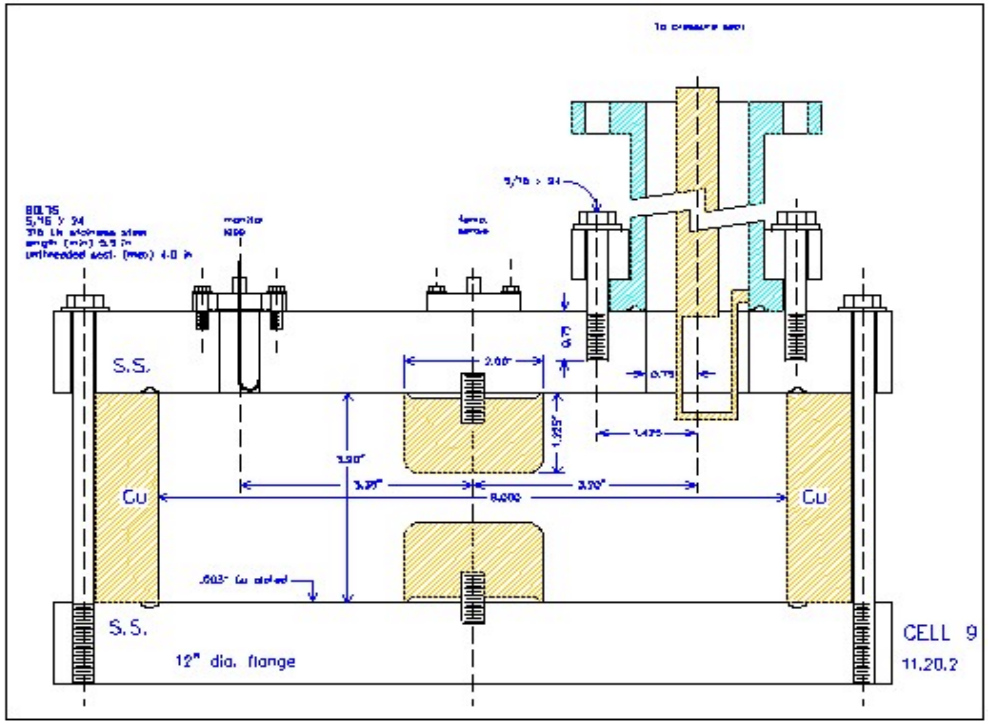
Figure 8.13. Theory and experiment compared for hydrogen at 2·8 GHz (MacDonald and Brown, 1949. Reproduced by permission of The American Physical Society)

- With low-temp operation, could take advantage of reduced Cu resistivity
- Could lead to higher-performance, shorter, cheaper cooling channel with higher-gradient RF cavities

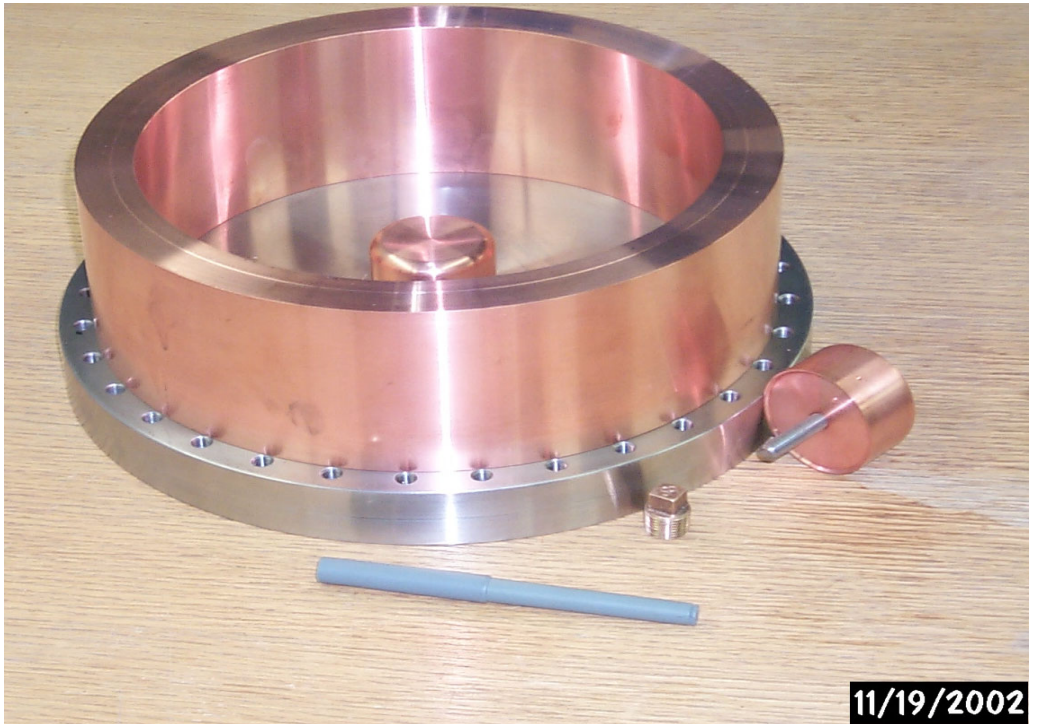
Current Status

- Muons, Inc. formed, Phase I STTR funding obtained from DOE ($100k)
  - Goal: Build a test cell and use it at FNAL Lab G to measure the Paschen curve (breakdown voltage vs. pressure) of helium (at least) at 805 MHz at 80K over many-atmosphere range in *P*
  - After some work, solutions found for high-pressure seals

805-MHz test cell designed



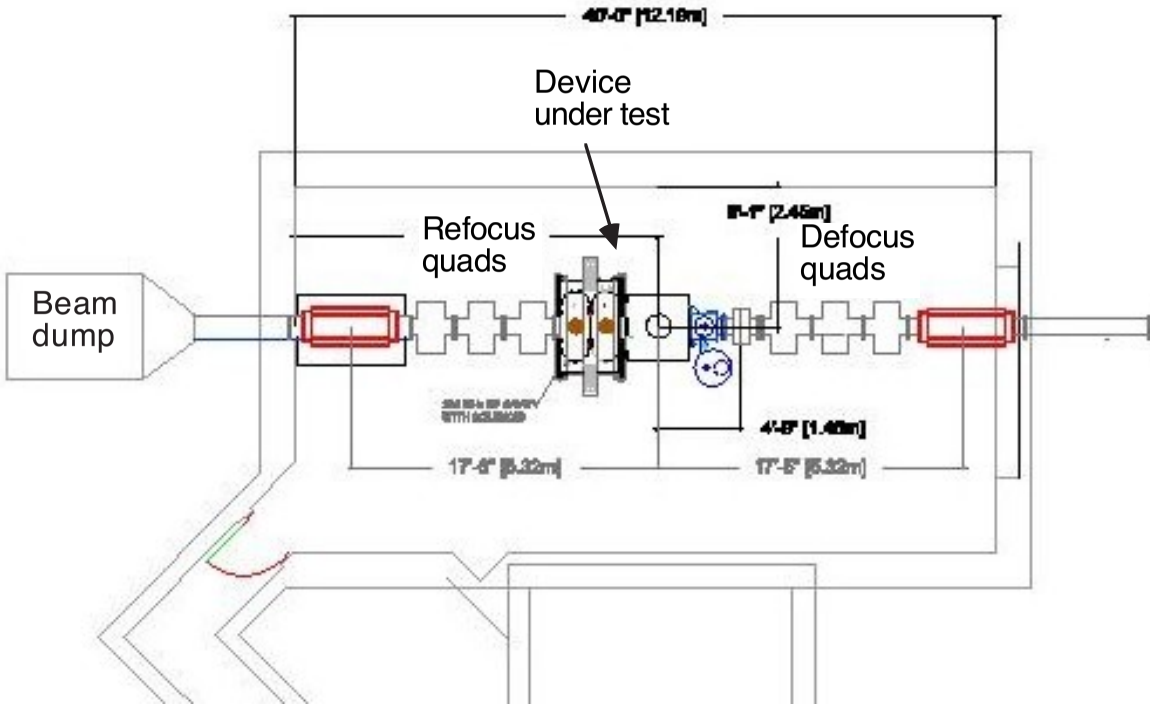
Assembly in progress



- Now seeking safety approval for high-pressure test-cell operation
- STTR proposals in preparation for other possible applications of high-pressure RF cavities

MuCool Test Area

- Need facility in which to test
  - absorbers
  - RF cavities
  - solenoids
- Show that cooling cell is operable in an intense beam
  (engineering test, not cooling demo)
- ∃ convenient location:
  end of Linac has
  - sufficient space
  - 201 & 805 MHz RF power sources (Linac RF test stands)
  - 400 MeV beam up to 2.4×10^{14} p/s → 570 W in 35-cm LH_2 absorber (higher at lower E)



MTA Current Status

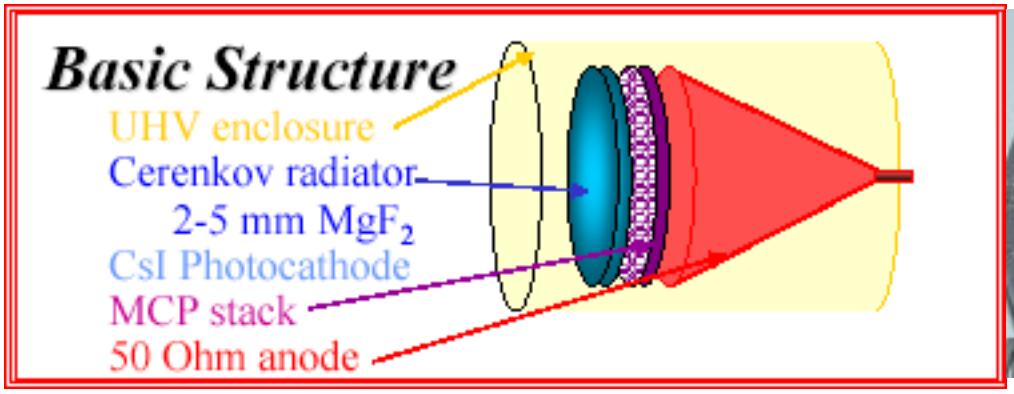
Demolition of existing access ramp and walls:

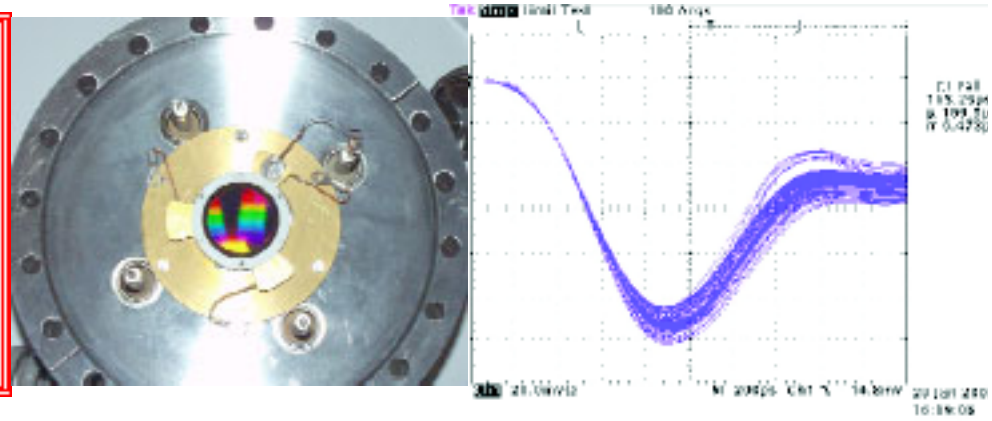
Next: excavation begins...

- Hope for beneficial occupancy ≈Fall '03
- Install LH_2 cryo & 201-MHz RF power in FY04 (if funding permits)

Detector R&D

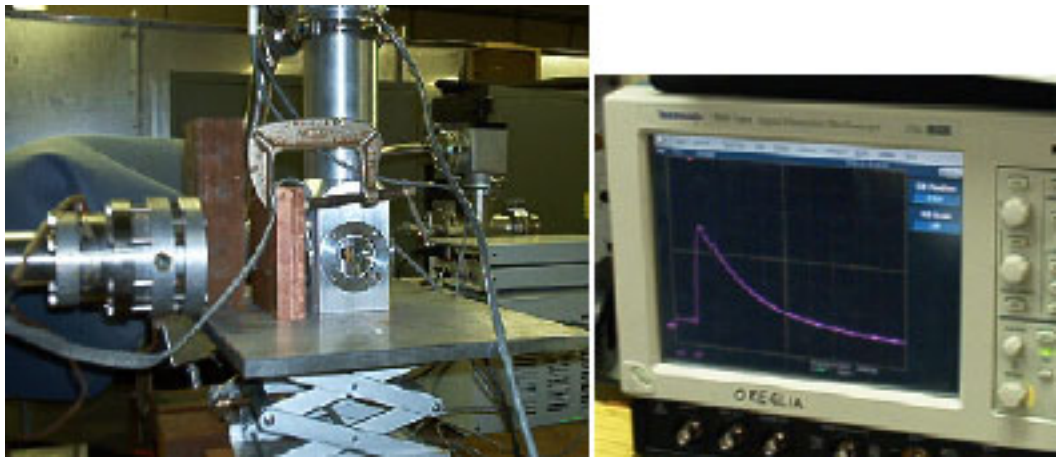
- Fast-timing detector: A Bross (FNAL) et al.





  - σ_t = 6.5 ps demonstrated! PC stability needs more work – \$0 in FY02 → slow progress

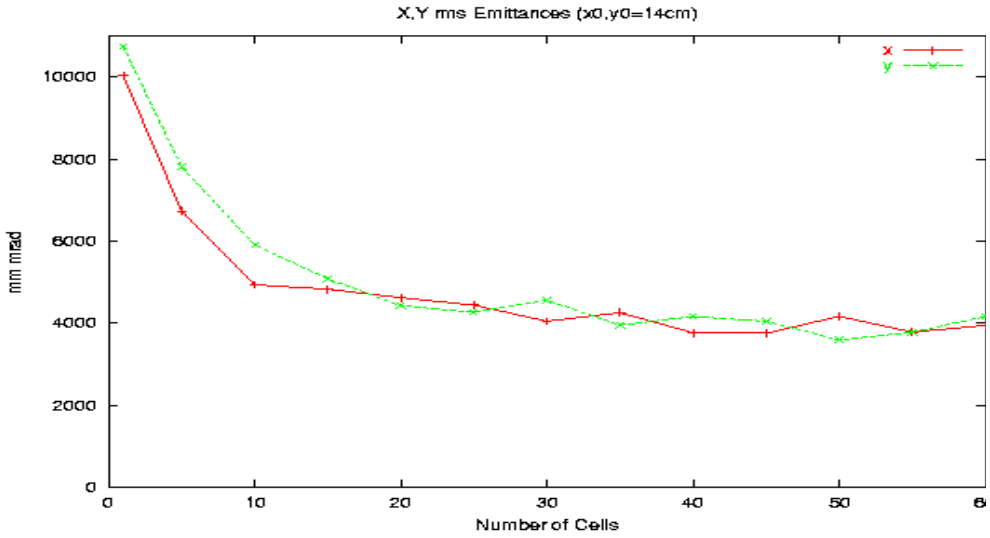
- Bolometric beam-profile monitor: K. Hoffman (U of C) et al.
  - Principle: muon-beam heat deposition changes resistivity of a film deposited e.g. on absorber window
  - Slow signal immune from RF noise



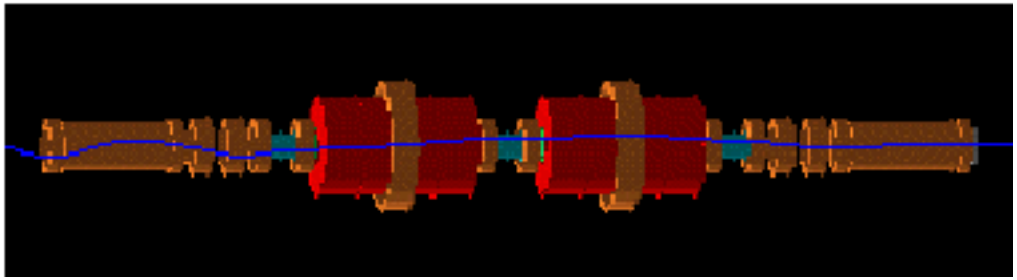
Beam test in progress at ANL in 20-MeV electron beam

MuCool Simulations

- Quadrupole-focused cooling channel:
  D. Errede (UIUC), C. Johnstone (FNAL), M. Berz (MSU) et al.
  - Quads can be more cost-effective at large $\beta_\perp$ values appropriate at start of cooling
  - Might be compatible with SC RF, reducing RF power cost



- Geant Study-II simulation with realistic windows: Y. Torun, T. Roberts (IIT)
  - 1st study confirmed that "iteration 2" window design was improvement over Study-II performance (not obvious → window was thinner at center but much thicker at edges)
  - Code improvements in progress (speed, usability)
  - Result imminent with "iteration 3" design including vacuum windows
- MICE Geant simulation:
  - IIT's Y. Torun serves as MICE co-team leader for simulations (as well as Webmaster and Steering Group Secretary)
  - Developed Geant4 framework and coordinated contributions from other collaborators



MuCool support for MICE

- Cooling demonstration too ambitious for any one of world's regions
  ⇒ MuTAC advised seeking int'l participation
  - Strong interest in cooling exp't in EU, UK, Japan as well as US
    → see Blondel, Drumm talks
  - Attitude of funding agencies TBD
- MuCool Collaboration is providing to MICE
  - concept development (MICE based on Study-II cooling channel)
  - engineering integration
  - simulations
  - RF cavity development & testing
  - absorber development & testing
  - fast-timing detector (will permit detailed exploration of longitudinal phase space)
- How to draw the line between MuCool & MICE:
  - MuCool will prototype & test each piece of cooling hardware, including MICE pieces for which we are responsible
  - "Production" units for MICE will be built with MICE funds
- MuCool engineering & high-intensity tests fully complementary to MICE "one muon at a time" cooling demo → both are essential!

Plans

- Continue 805-MHz tests to determine how best to minimize dark current & breakdown
- Finish MTA construction in FY03
- Start building 1st 201-MHz cavity prototype in FY03
- Install MTA absorber cryo support and/or 201-MHz RF in FY04 as funding permits
  - Carry out 1st test of absorber with LH_2 fill
  - Carry out 1st test of 201-MHz cavity
  - Test absorber in dark-current flux from cavity
- Build coupling-coil prototype (surrounds RF cavities) when funding available (FY05?)
- Install 400-MeV *p* beamline from Linac when funding available (FY05?)
  - Test absorber power-handling capability
  - Test cavity in solenoid irradiated by intense beam
  - Test complete set of integrated cooling elements in intense beam

Summary

- Continued progress developing components for a cooling channel (slowed but not stopped by FY03 DOE funding cut)
- Ongoing 805 MHz RF R&D program developing techniques required for low-dark-current, high-gradient NCRF cavities operable at high *B*
- Healthy progress developing LH_2 absorbers with thin windows (largely funded by State of Illinois via ICAR)
- MuCool Test Area under construction
- Contributed to MICE Technical Proposal and MICE NSF proposal
- Opportunities for Ph.D. and M.S. students in beam physics & engineering
  - already 1 Ph.D. & 1 M.S. completed, 1 Ph.D. in progress
- Benefiting from international collaboration
  - Japan contribution to absorbers
  - UK contribution to absorber windows
  - Cooling experiment proceeding via international MICE Collaboration
- Rate of continued progress will depend on budgets in FY04 and beyond