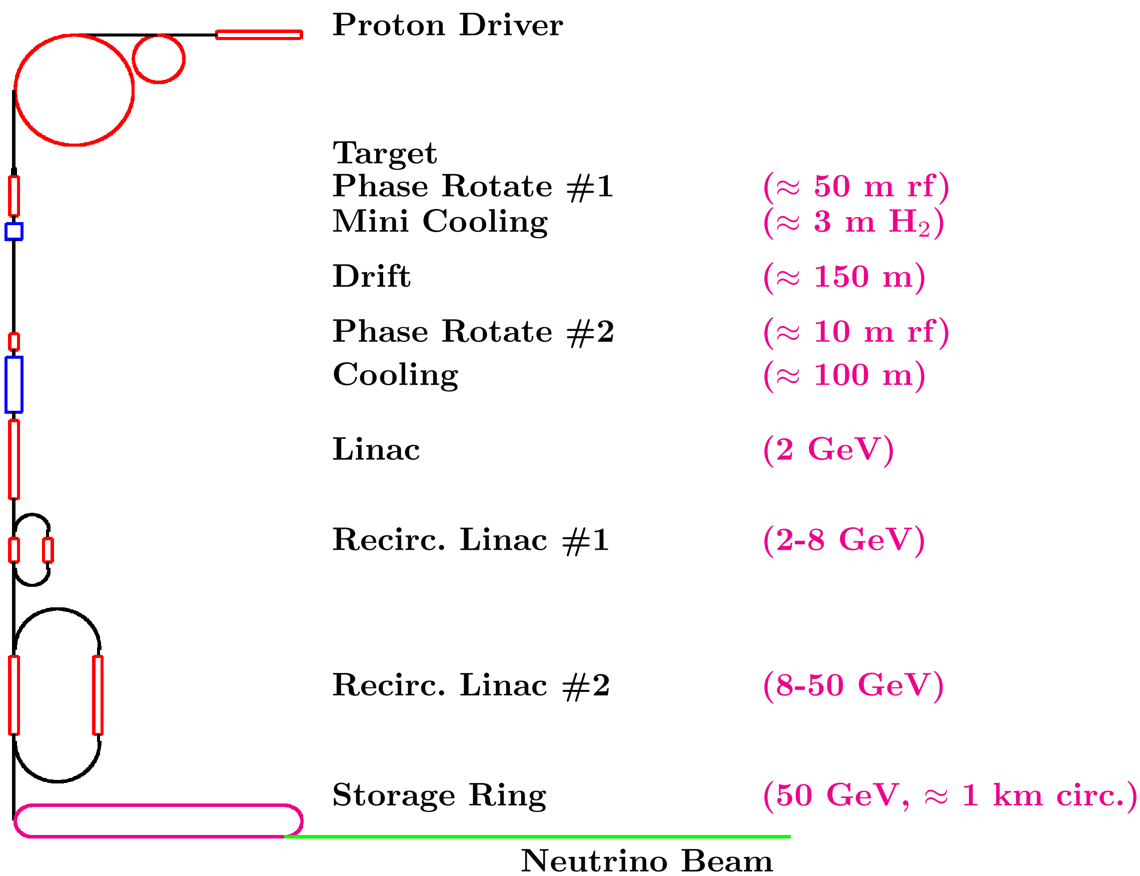
Targetry and Capture Issues at a Neutrino-Factory/Muon-Collider Source



Kirk T. McDonald

Princeton U.

`mcdonald@puphep.princeton.edu`

November 17, 1999

ACCAPP'99, Long Beach, CA

`http://puhep1.princeton.edu/mumu/target/`

Muon Requirements

- $\approx 10^{14}\ \mu^{\pm}/\mathrm{s}$ for either a muon collider or a neutrino factory.
- The muons come from the decay of soft pions produced in p-nucleus collisions.
- **Our strategy is to maximize the ratio of captured muons per proton.**

  i.e., to minimize the proton requirements.
- Goal: $0.1\mu/p$ delivered for physics use.

The Source

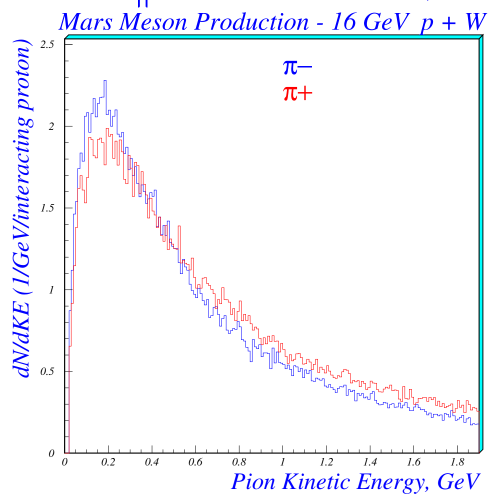
- The muons come from the decay of soft pions produced in p-nucleus collisions.
- Need at least $1.5 \times 10^{15}\ p/\mathrm{s}$ at 16-24 GeV

  $\Leftrightarrow$ 4 MW beam power.
- Initial muon emittance is about 10^6 larger than desired

  $\Rightarrow$ Need fast cooling.
- [Our muon beam is 10^6 times hotter than existing beams.]

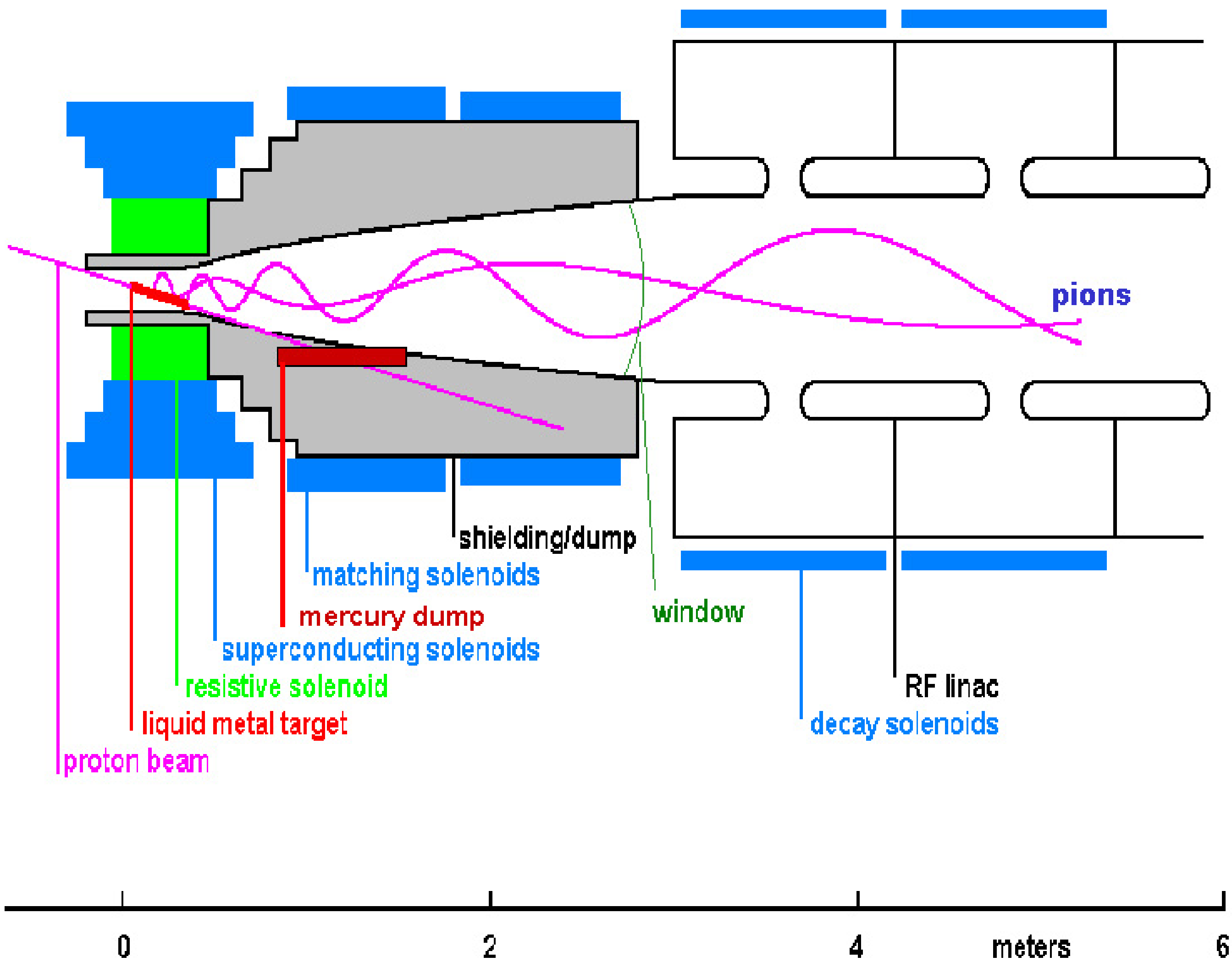
The Muon Source

- Pion production peaks at $P_{\|} \approx 350$ MeV$/c$; $P_{\perp} \lesssim 200$ MeV$/c$.



- $\Rightarrow$ Capture the soft pions in a solenoid magnet channel.
- Capture efficiency improved with a stronger (20 T) field on the target than in the main channel (1.25 T). [Adiabatic invariance reduces the pion $P_{\perp}$ when going from high to low B.]
- $\Rightarrow$ High-Z target without nearby cooling structure that would absorb pions.
- $\Rightarrow$ Liquid mercury jet target.
- Soft pions have $v/c < 1$, $\Rightarrow$ Disperse while drifting
  $\Rightarrow$ Begin RF manipulation as soon as possible to form a bunch with reduced energy spread (Phase Rotation).

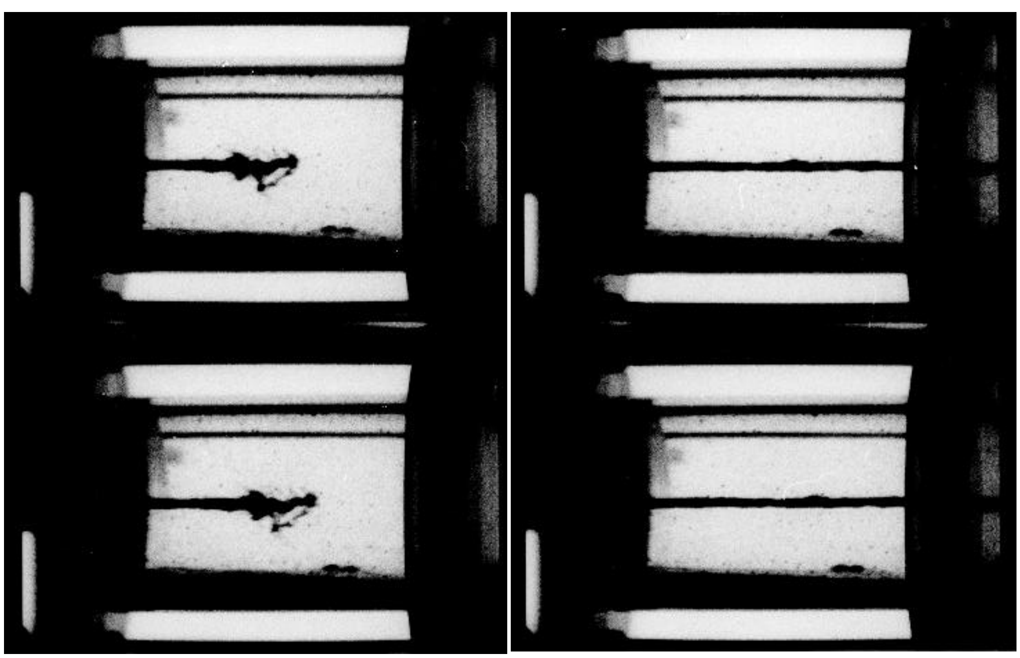
Overview of Targetry and Capture



- 1.2×10^{14} $\mu^{\pm}$/s via π-decay from a 4-MW proton beam.
- Proton pulse ≈ 1 ns rms.
- Mercury jet target.
- 20-T capture solenoid followed by a 1.25-T π-decay channel with phase-rotation via rf (to compress energy of the muon bunch).

Targetry and Capture Issues

- Is a liquid jet target viable?
  - 1-ns beam pulse $\Rightarrow$ shock heating of target.
  - Resulting pressure wave may disperse liquid (or crack solid).
  - Damage to target chamber walls?
  - Magnetic field will damp effects of pressure wave.
  - Eddy currents arise as metal jet enters the capture magnet.
  - Jet is retarded and distorted, possibly dispersed.
  - Hg jet studied at CERN, but not in beam or magnetic field:



High-speed photographs of mercury jet target for CERN-PS-AA (laboratory tests)

4,000 frames per second, Jet speed: 20 ms-1, diameter: 3 mm, Reynold's Number:>100,000

A. Poncet

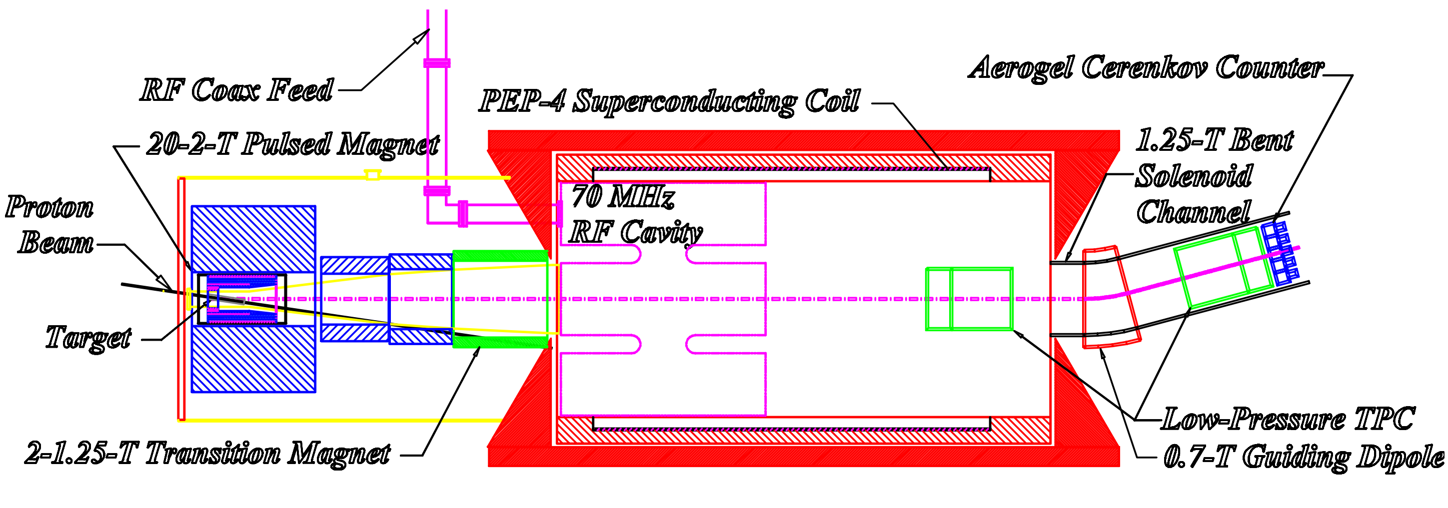
- Is the first rf cavity viable?
  - High-gradient (5 MeV/m), low-frequency ($\approx$ 70 MHz) rf cavity only 3 m downstream of target.
  - $> 10^{14}$ particles traverse the cavity each proton pulse; many hit the cavity wall.
  - Cavities tested against breakdown from beam-induced showers only up to $\approx 10^{12}$ particles/pulse.
- Is the 20-T Solenoid viable?
  - Even with water-cooled tungsten inserts, this hybrid (copper/superconductor) magnet will experience a very high radiation dose.
  - LANL, MSU have experience with superconducting magnets in high radiation areas.
- Other Radiological Issues
  - A 4-MW beam leads to activation issues characteristic of neutron spallation sources.
  - Remote handling of activated liquid target material is under study at CERN ISOLDE, the ORNL NSNS, ...

R&D Goals

Long Term: Provide a facility to test key components of the front-end of a neutrino factory/muon collider in realistic beam conditions.

Near Term (1-2 years): Explore viability of a liquid metal jet target in intense, short proton pulses and (separately) in strong magnetic fields.
(Change target technology if encounter severe difficulties.)

Mid Term (3-4 years): Add 20-T magnet to AGS beam tests;
Test 70-MHz rf cavity (+ 1.25-T magnet) downstream of target;
Characterize pion yield.



An R&D Program for Targetry and Capture at a Muon Collider Source

A Proposal to the BNL AGS Division

James Alessi,[b] John Corlett,[e] D. Duncan Earl,[f] Richard C. Fernow,[b] Yasuo Fukui,[e] Tony A. Gabriel,[f] Juan C. Gallardo,[b] Michael A. Green,[e] John R. Haines,[f] Jerry Hastings,[b] Ahmed Hassanein,[a] Colin Johnson,[c] Stephen A. Kahn,[b] Bruce J. King,[b] Harold G. Kirk,[b] Paul Lebrun,[d] Vincent LoDestro,[b] Changguo Lu,[g] Kirk T. McDonald,[g,1] Nikolai V. Mokhov,[d] Alfred Moretti[d], James H. Norem,[a] Robert B. Palmer,[b] Eric J. Prebys,[g] Claude Reed,[a] Thomas Roser,[b] Ronald M. Scanlan,[e] Dale L. Smith,[a] Yağmur Torun,[b,h] Andy van Ginneken,[d] Haipeng Wang,[b] Robert Weggel,[b] Yongxiang Zhao[b]

[a]*Argonne National Laboratory, Argonne, IL 60439*
[b]*Brookhaven National Laboratory, Upton, NY 11973*
[c]*CERN, 1211 Geneva 23, Switzerland*
[d]*Fermi National Laboratory, P. O. Box 500, Batavia, IL 60510*
[e]*Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720*
[f]*Oak Ridge National Laboratory, Oak Ridge, TN 37831*
[g]*Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544*
[h]*Department of Physics and Astronomy, SUNY, Stony Brook, NY 11790*

(Submitted Sept. 28, 1998; approved as BNL E951 Oct. 1, 1999)

[1]Spokesperson. Email: mcdonald@puphep.princeton.edu

The 8 Steps in the R&D Program

1. Simple tests of liquid (Ga-Sn, Hg) and solid (Ni) targets with AGS Fast Extracted Beam (FEB).

2. Test of liquid jet entering a 20-T magnet (20-MW cw Bitter magnet at the National High Magnetic Field Laboratory).

3. Test of liquid jet with 10^{14} ppp via full turn FEB (without magnet).

4. Add 20-T pulsed magnet (4-MW peak) to liquid jet test with AGS FEB.

5. Add 70-MHz rf cavity downstream of target in FEB.

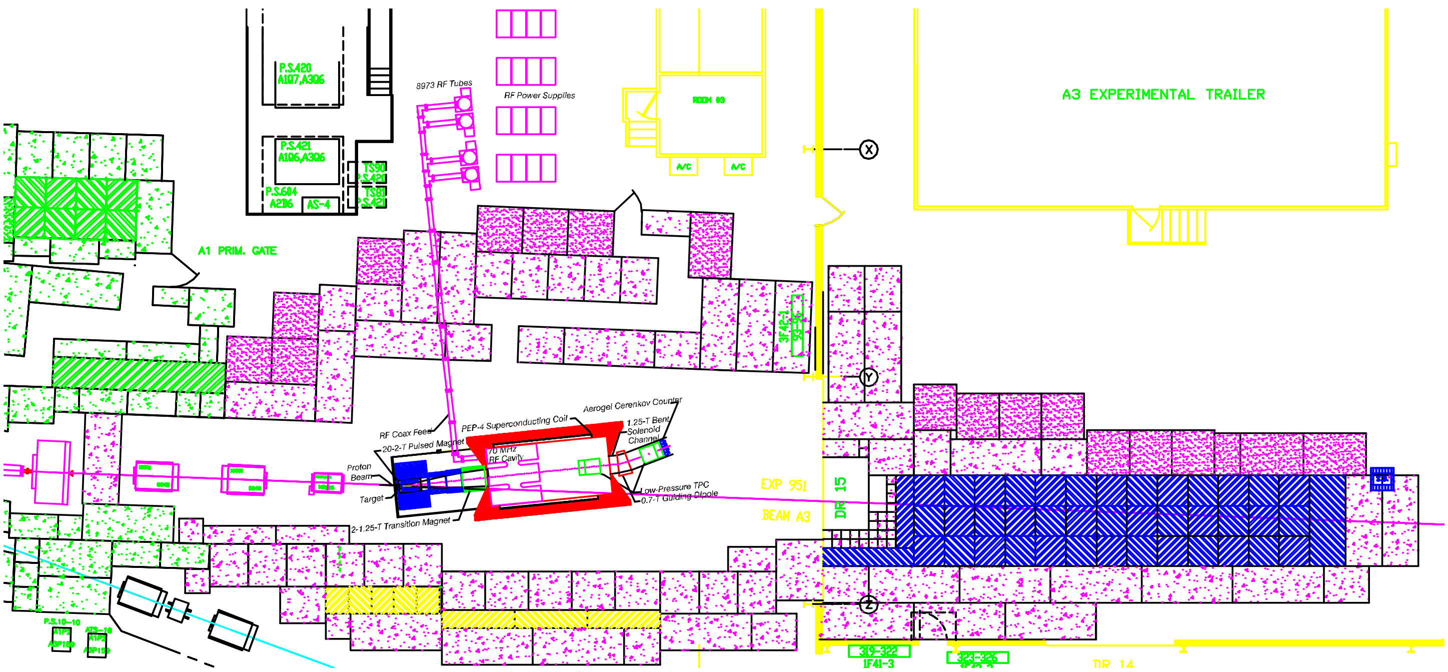
6. Surround rf cavity with 1.25-T magnet. At this step we have all essential features of the source.

7. Characterize pion yield from target + magnet system with slow extracted beam (SEB).

8. Ongoing simulation of the thermal hydraulics of the liquid-metal target system.

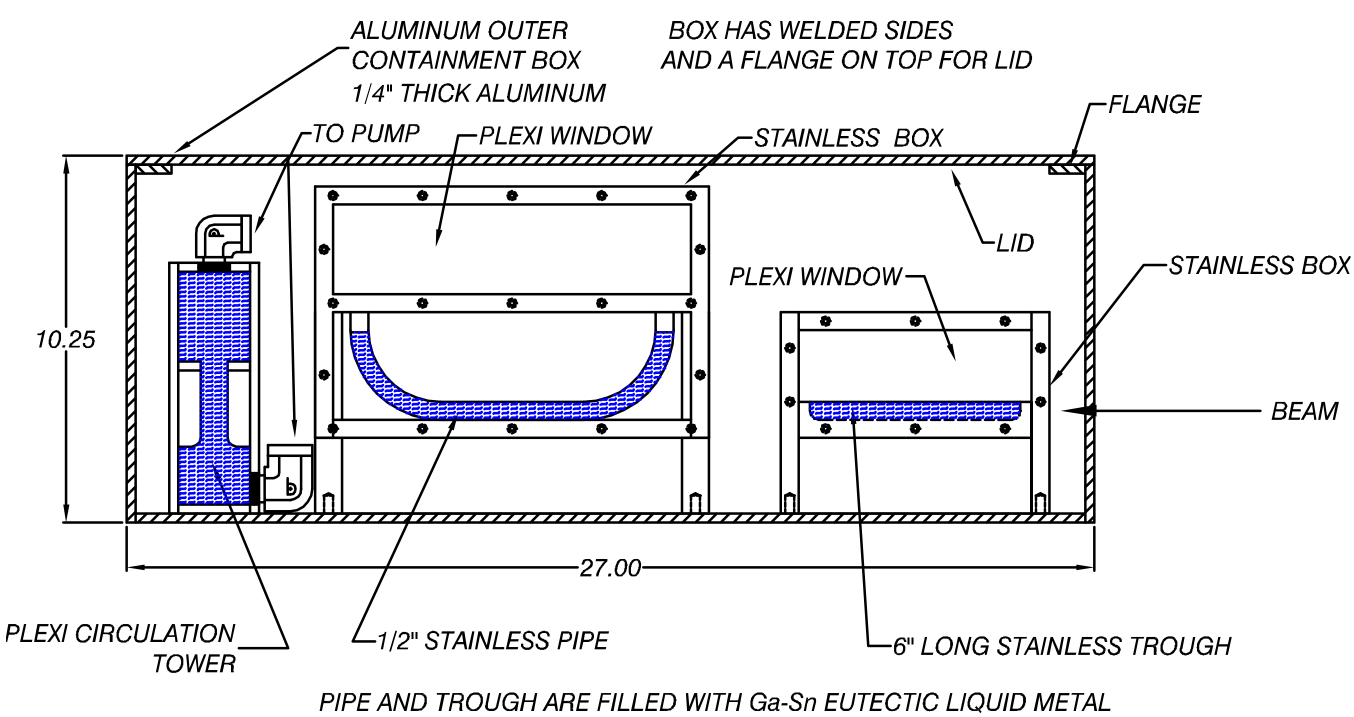
Step 1: Initial Tests with FEB

- Site presently under consideration: A3 line.

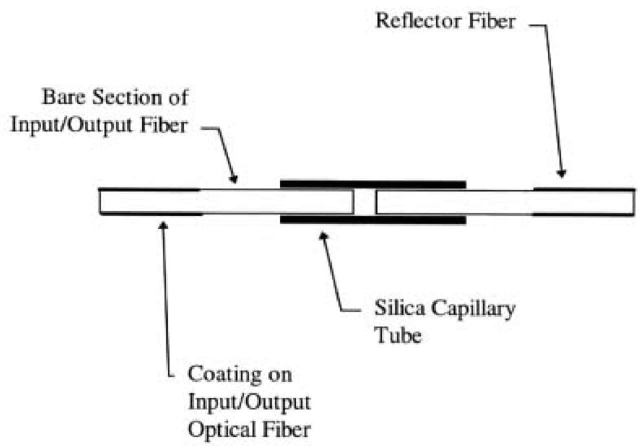


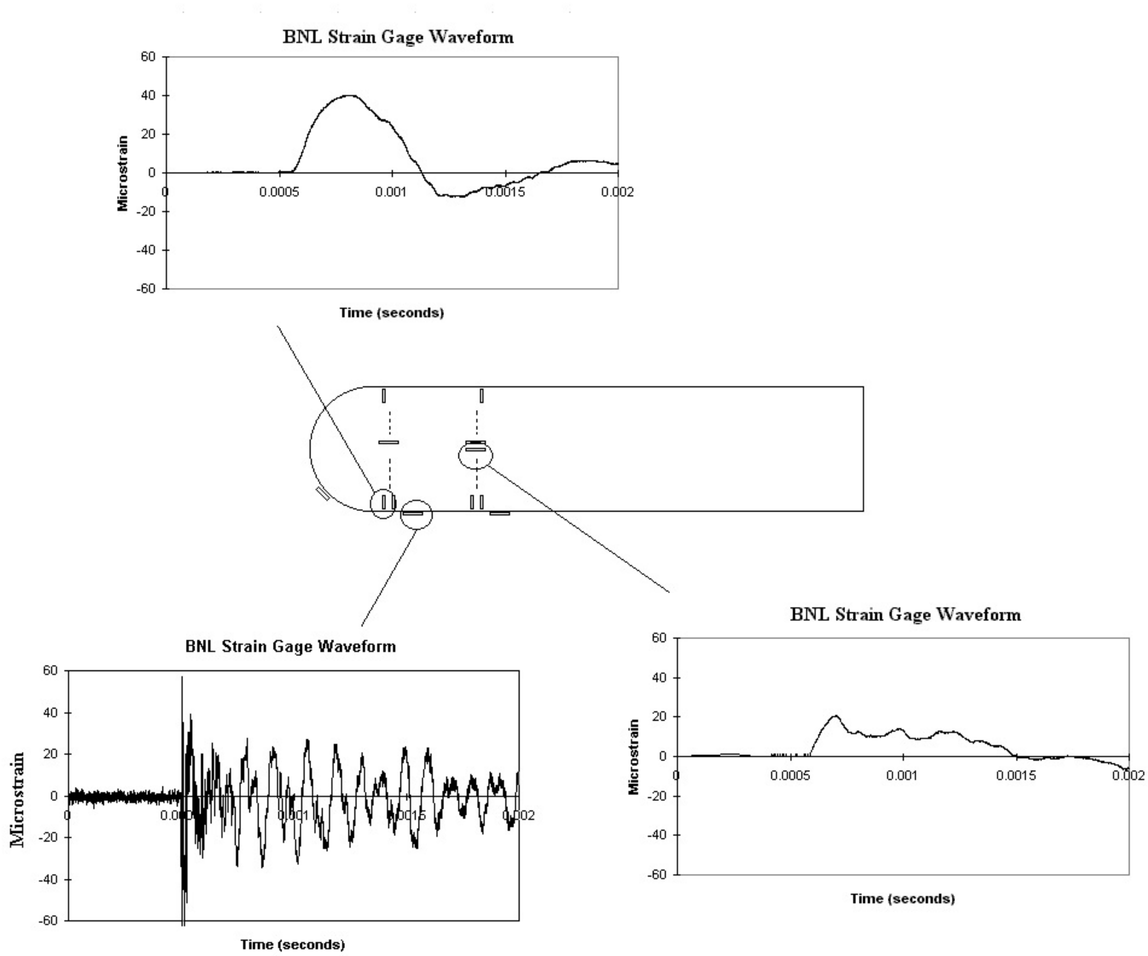
- First test: liquid metal in a trough, a pipe and in free flow.

CAMERA VIEW



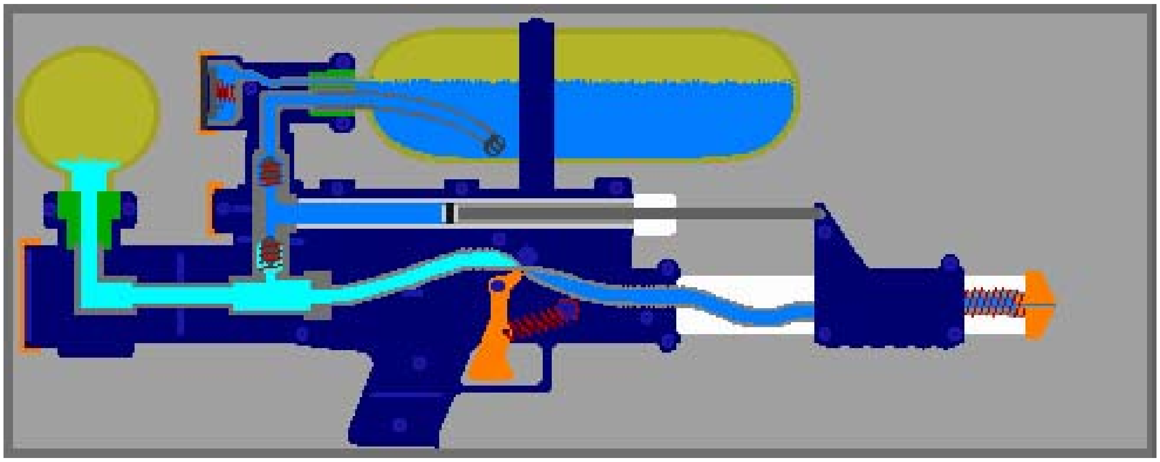
- Instrumentation: high-speed camera, fiberoptic strain sensors (Duncan Earl, ORNL).



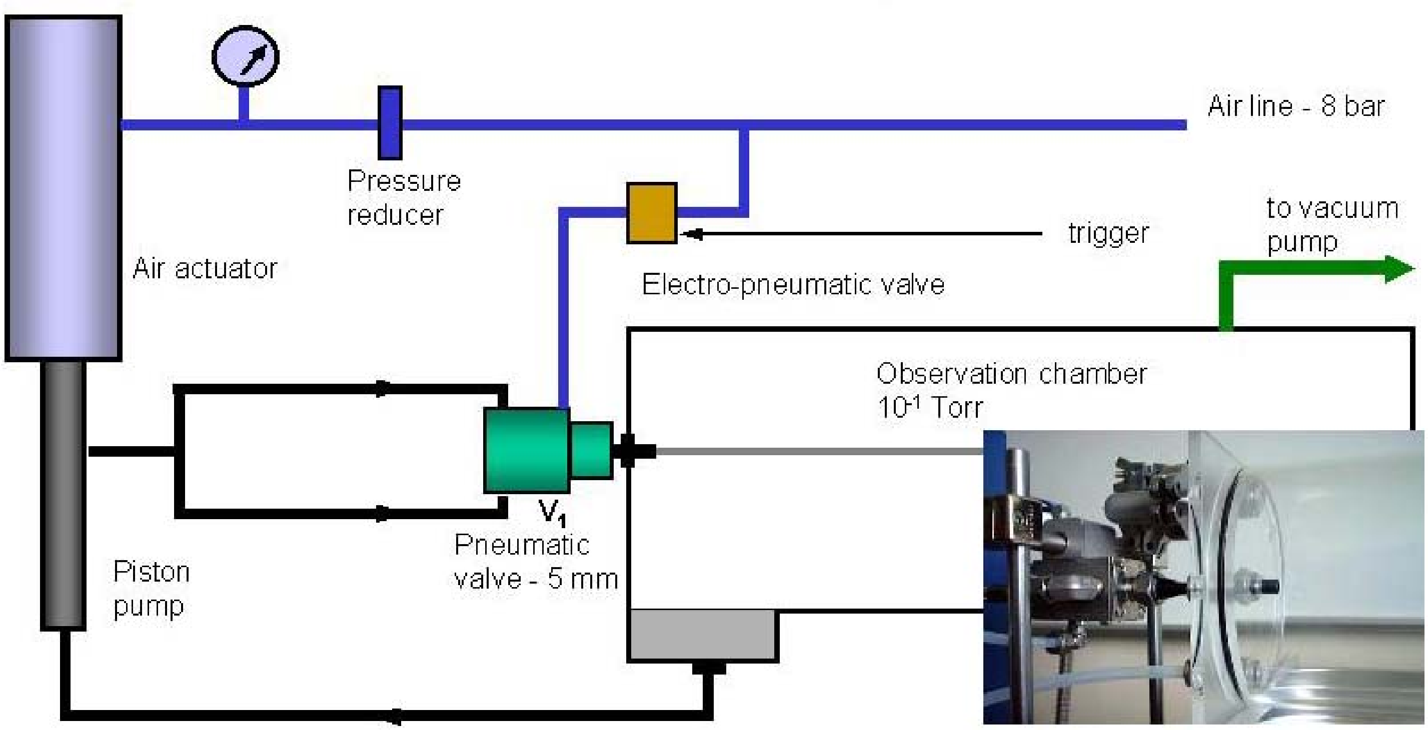


Step 2: Pulsed Liquid Jet

- Inspiration:

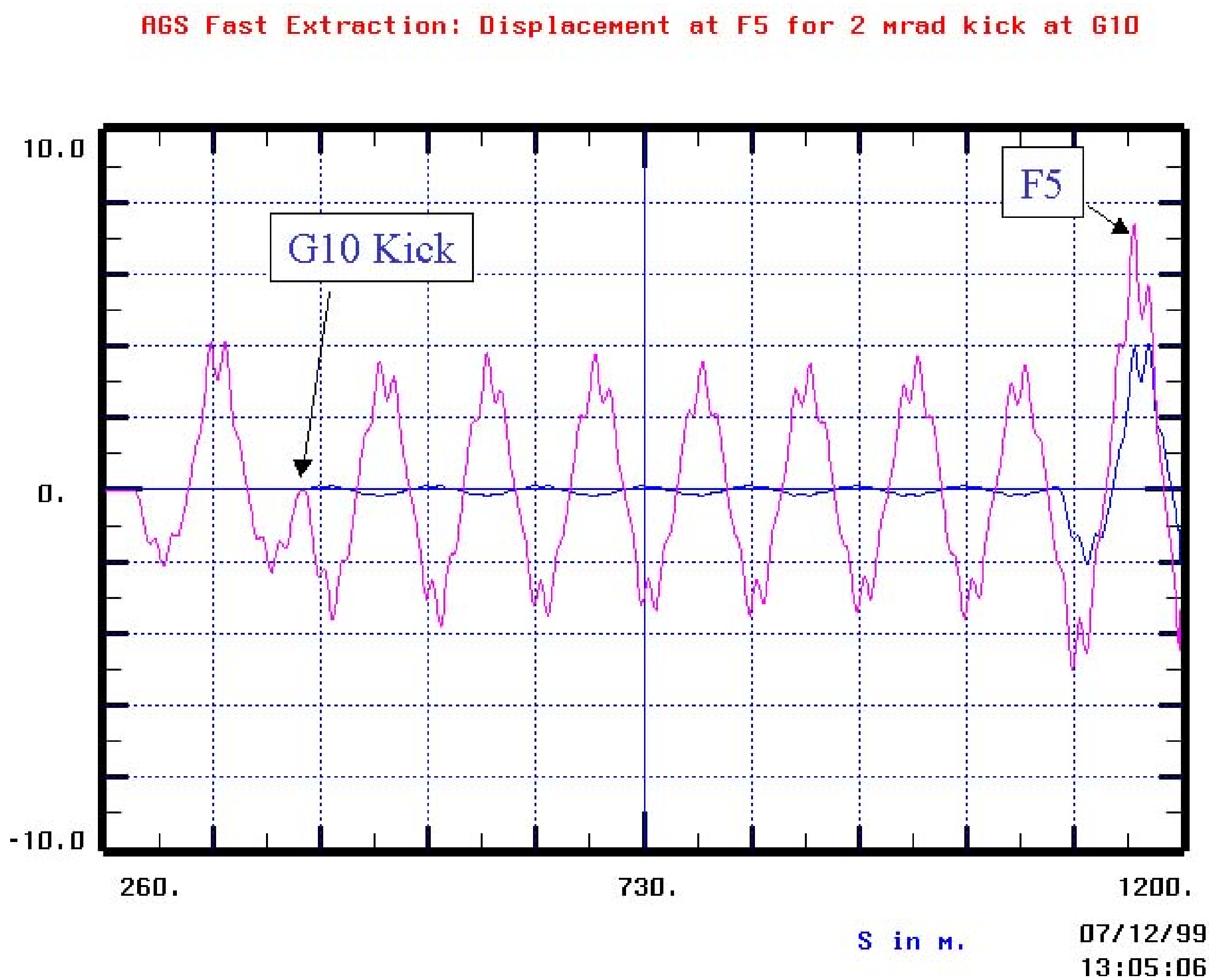


- Hg jet under construction at CERN (Colin Johnson, Helge Ravn), and at Princeton.



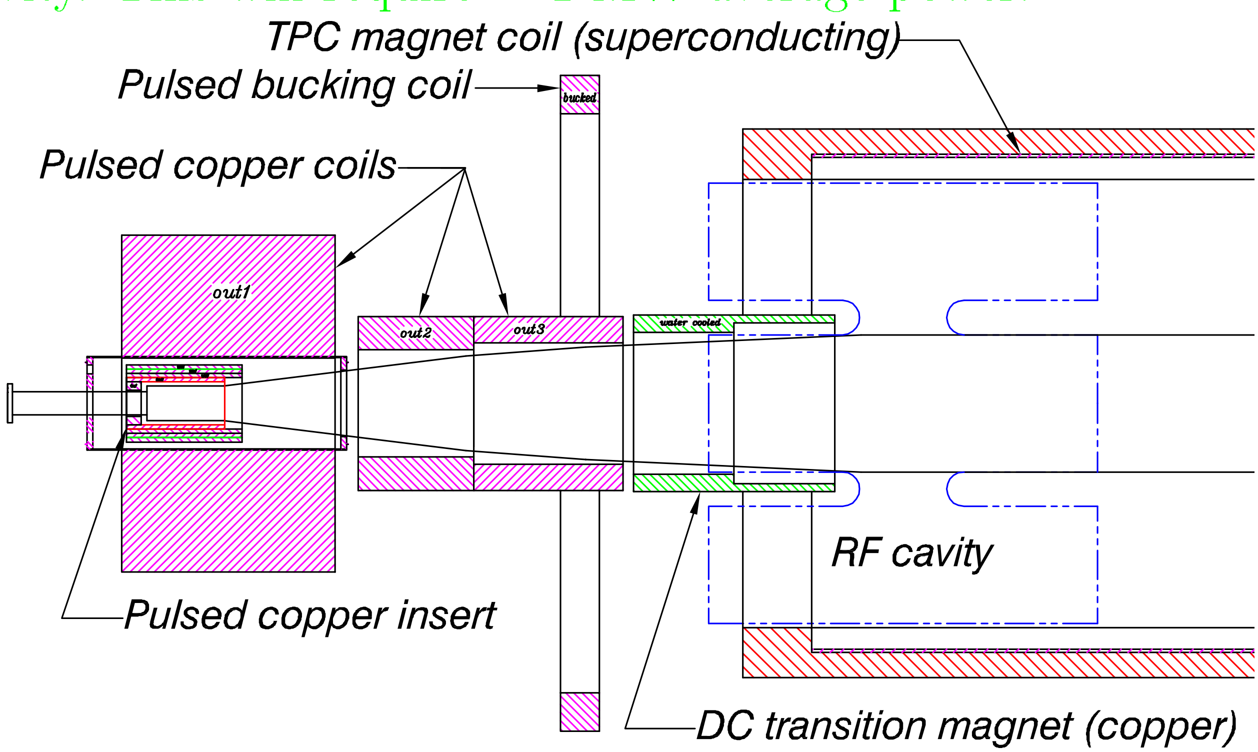
Step 3: Full Turn Extraction

- G10 kicker can deliver beam to A-C lines as well as to U line.
- Present power supply sufficient to kick out only 1 bunch.
- Upgrade to kick out all 6 bunches requires ≈ 18 months.
- Initiate design work in FY00 to complete upgrade in FY01.



Step 4: Pulsed 20-T Magnet

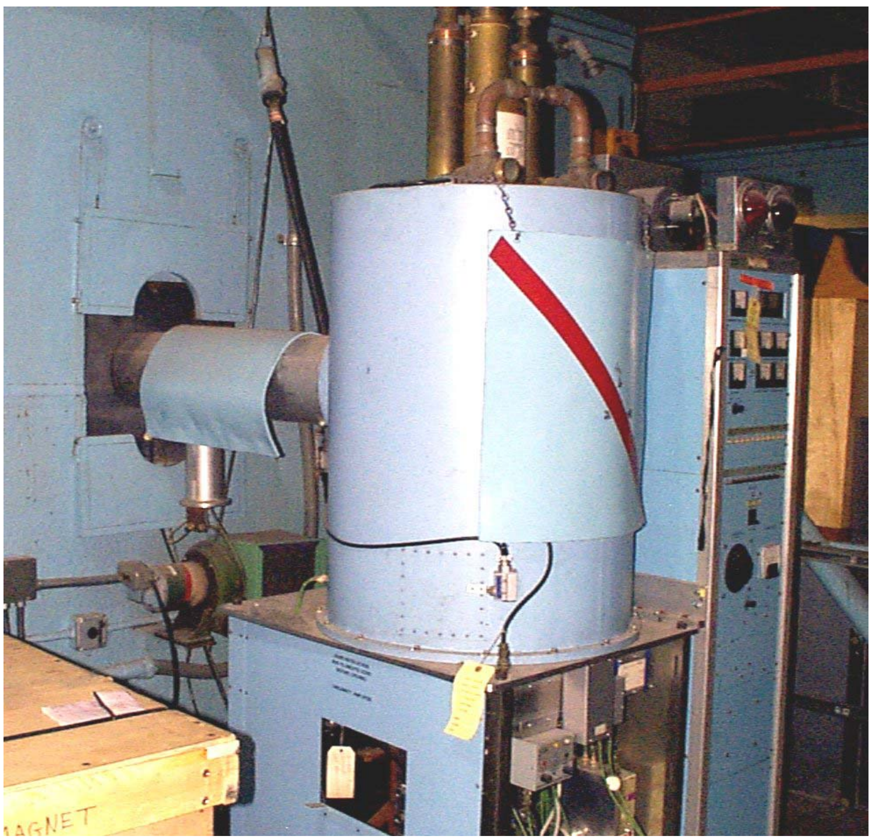
- The copper magnet will be cooled by LN_2, and can be pulsed once every 10 minutes. Pulse duration $\approx$ 1 s.
- Engineers: Bob Weggel, Bill Sands, designer: Bob Duffin.
- 4 MW (peak) power to be bussed from the MPS power supply house to the A3 line (Andy Soukas).
- 100 liters of LN_2 boiled off each pulse; vent outside of cave.
- A DC magnet is required as a transition between the pulsed magnet and the DC superconducting magnet around the rf cavity. This will require $\approx$ 1 MW average power.



Step 5: 70-MHz RF Cavity

- Cavity has 60-cm-diameter iris, 2-m outer diameter.
  (Jim Rose, BNL, Werner Pirkl, CERN)

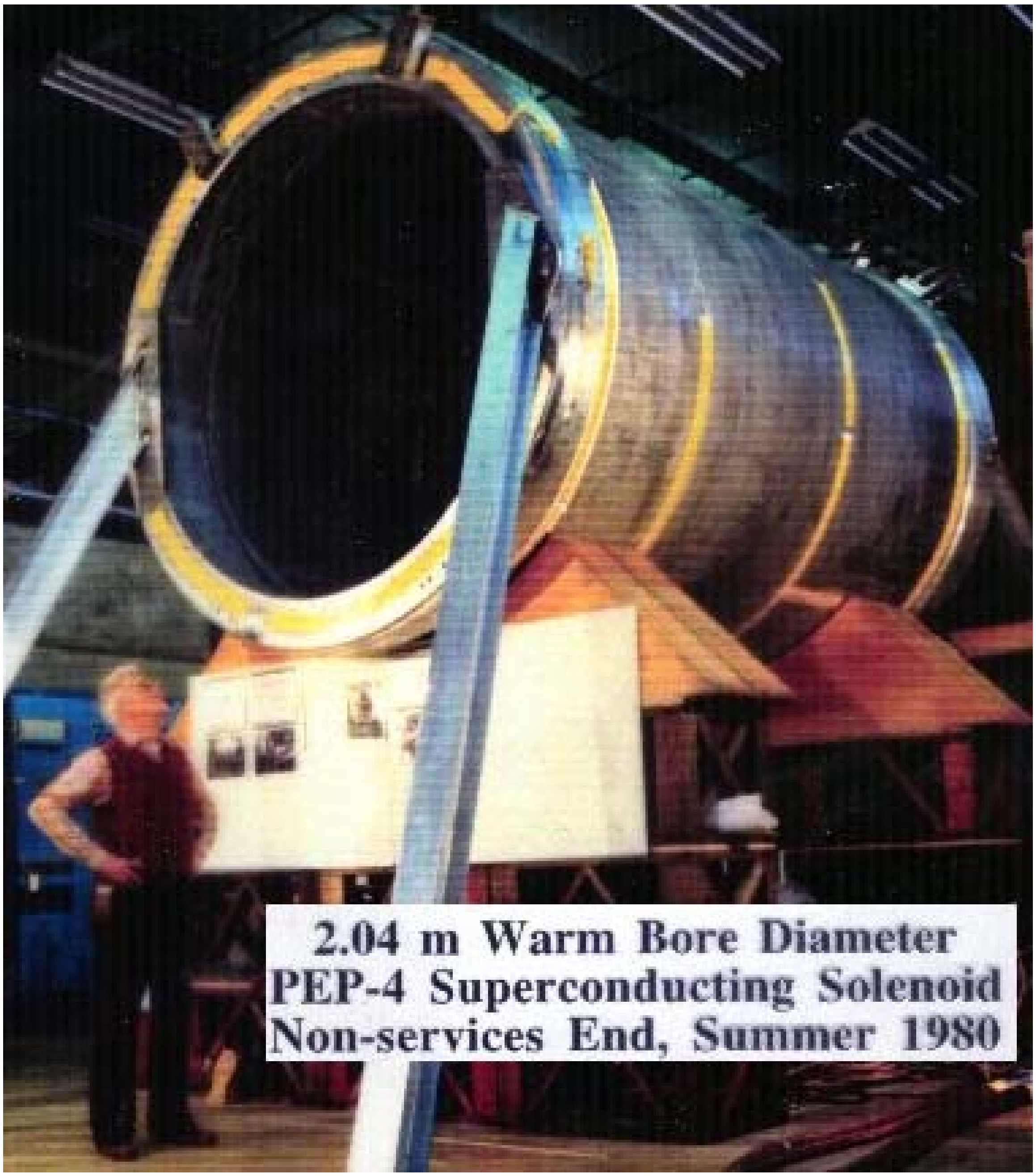
- 4-6 MW peak power to be supplied by four 8973 tubes recommissioned from the LBL Hilac.
  (Vince LoDestro, BNL; Don Howard, LBL)



- We are also embarking on an R&D program with industry to develop a 50-MW peak power, 70-MHz power supply (EEV, Eimac, Litton, Thomson).

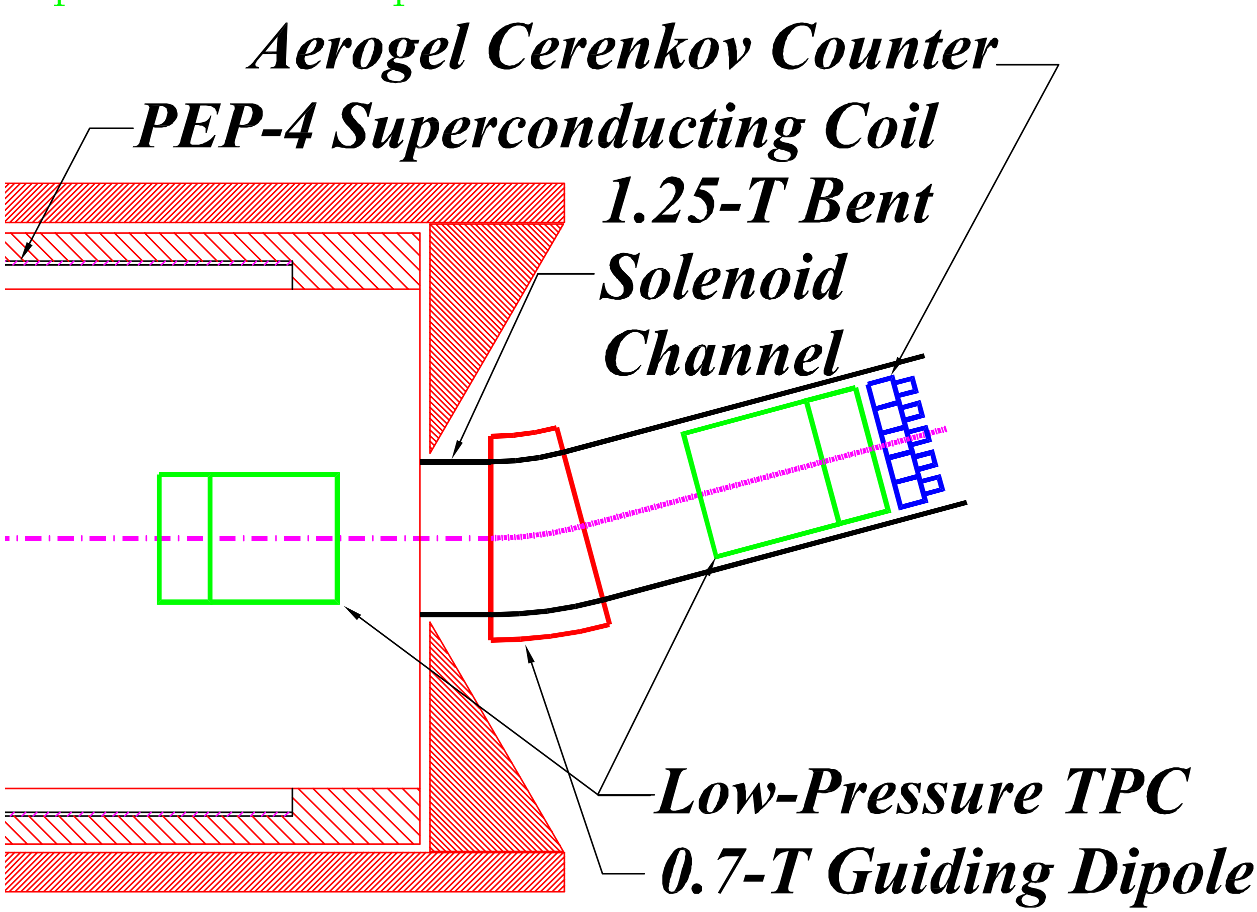
Step 6: 1.25-T Solenoid Around RF Cavity

- Present plan: use PEP-4 TPC superconducting solenoid (Mike Green, LBL).



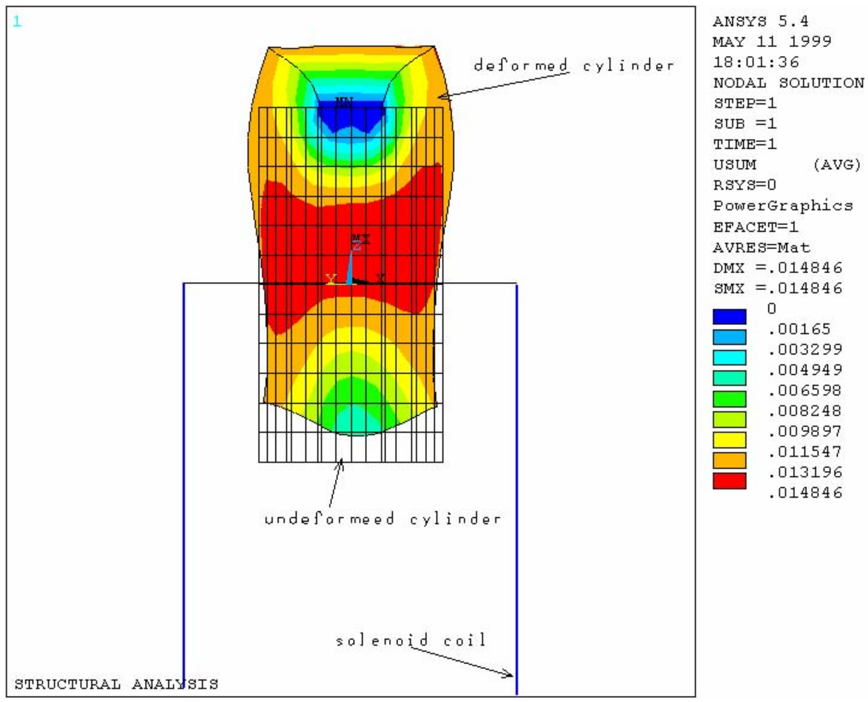
Step 7: Characterization of Pion Yield

- The final measure of system performance is the capture of soft pions that later decay to muons.
- Add bent solenoid spectrometer downstream of TPC magnet.
- Instrument with low-pressure TPC's and aerogel Čerenkov counters.
- Collect data with slow beam, $< 10^6$ ppp.
- Compare with extrapolations from data of E-910.

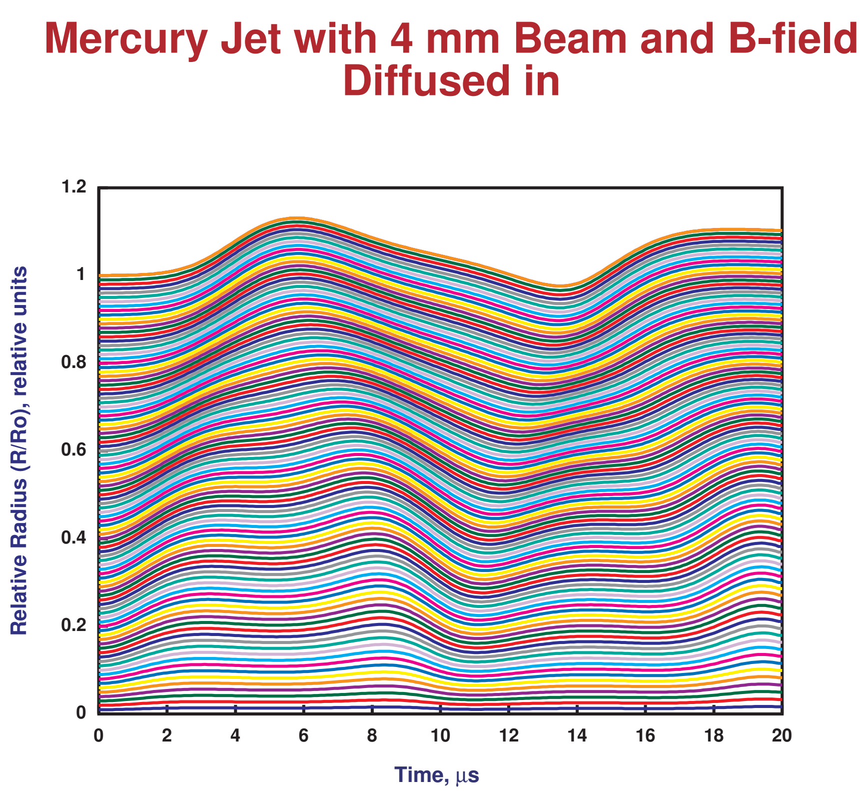


Step 8: Simulation of Beam-Jet-Magnet

- ANSYS simulation (Changguo Lu, Princeton):



- HEIGHTS simulation (Ahmed Hassanein, ANL):



Schedule of Targetry & Capture R&D

- FY99:

  Begin preparations of BNL A3 area; begin work on liquid jets.

- FY00:

  Initial beam tests in A3 line. Liquid jet test at NHMFL.

  (600 hours of AGS beamtime);

  Begin work on extraction upgrade, magnet systems,

  and rf systems.

- FY01:

  Complete extraction upgrade; test of liquid jet + beam.

  (600 hours).

- FY02:

  Complete magnet and rf systems; test with 2 ns beam.

  (600 hours).

- FY03:

  Complete pion detectors; test with low intensity SEB.

  (600 hours).