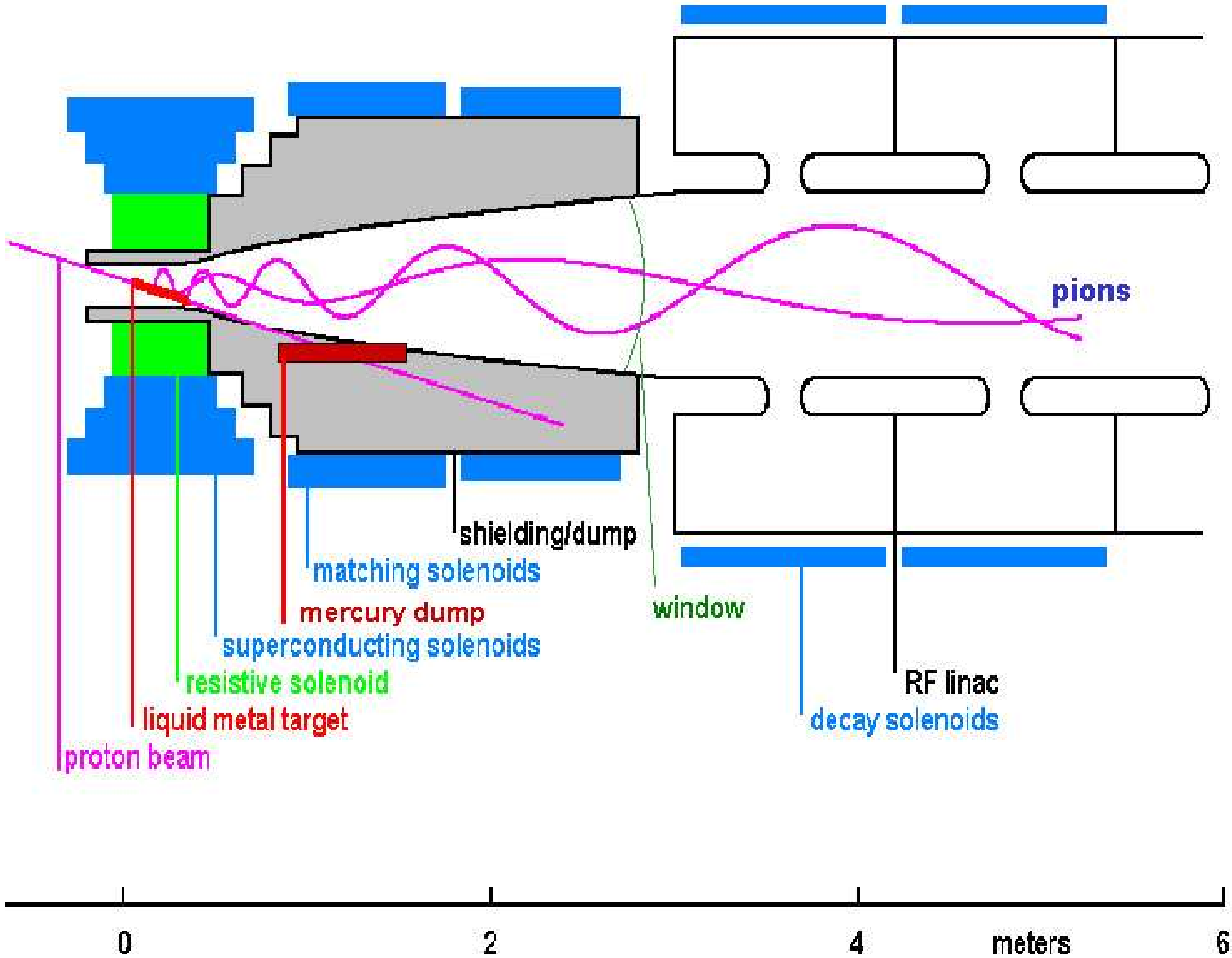
The R&D Program for Targetry and Capture at a Neutrino Factory/Muon-Collider Source



Spokesperson: Kirk T. McDonald

Princeton U.

Targetry Group Meeting

BNL, January 24, 2000

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

The Opportunity of a Neutrino Factory

- The next generation of neutrino experiments will firm up present indications of couplings of pairs of neutrinos – but will not explore simultaneous effects of 3 neutrinos.
- Many of the neutrino oscillation solutions permit complete study of the couplings between 3 (4?) neutrinos at a neutrino factory.
- But, $> 10^{21}$ ν's/year are needed for this!
- A neutrino factory is a path to a muon collider.

However, there are at present too many explanations of neutrino oscillation data to define an optimal parameter set for a neutrino factory: energy, distance to remote detectors....

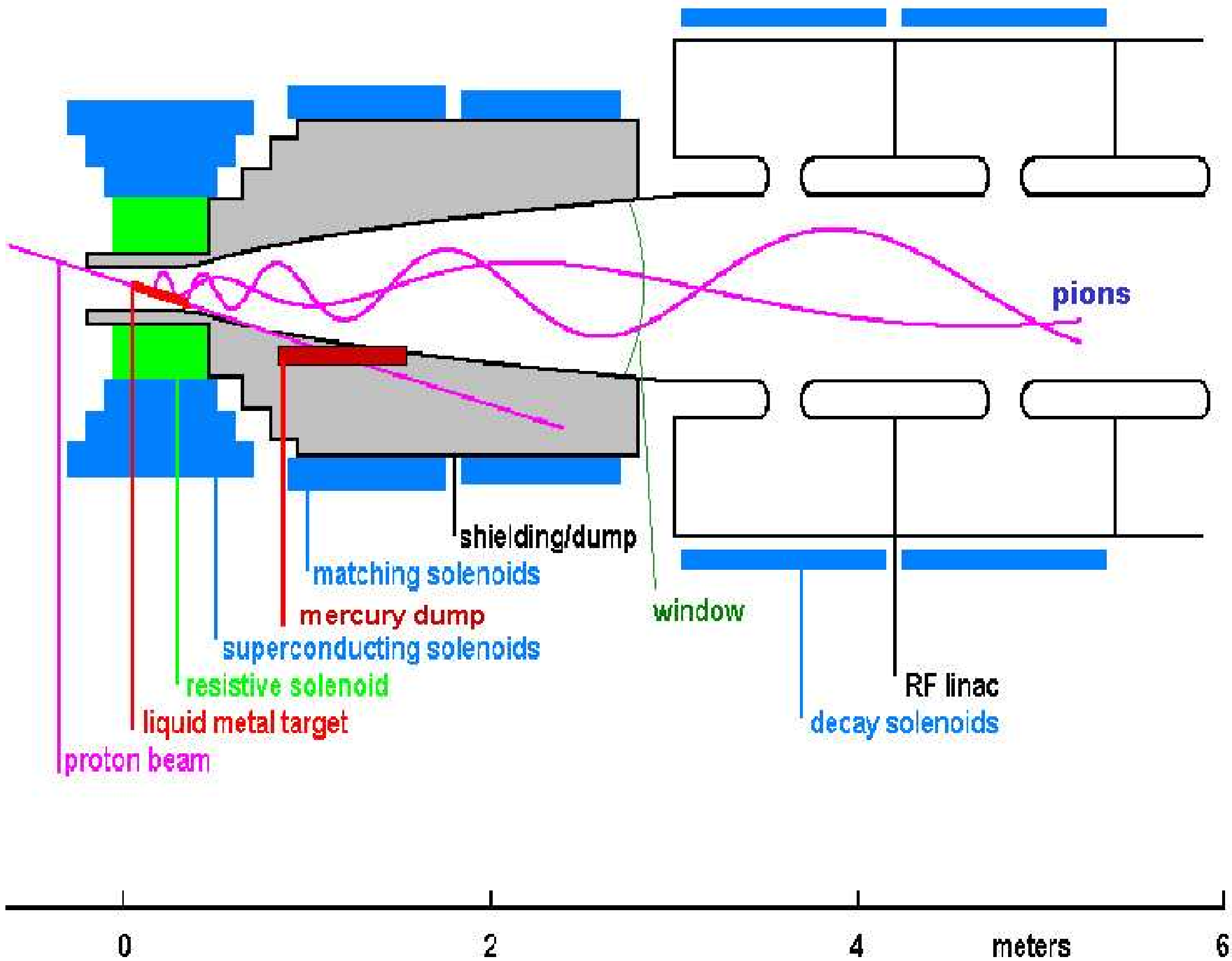
It will take several years for the physics to be clarified enough to make a wise choice of parameters for an initial neutrino factory.

These facts afford both an opportunity and a need for an ambitious R&D program.

We Need a High Performance Source

- We need lots of protons: several megawatts desired, perhaps only 1 MW initially.
- We need to maximize the yield of ν's, and hence μ's per proton.
- For advanced neutrino studies (ν_e in final state), and for a muon collider, we desire controlled muon polarization.
- High yield seems best accomplished in a solenoidal capture system with a dense target and little support structure.
- Solid targets extremely marginal in multimegawatt beams with 10^8 cycles/year.
- A "disposable" target may be preferable; use once and throw away.
- $\Rightarrow$ Mercury jet target.
- Maximal capture + polarization control
  $\Rightarrow$ High-gradient, low-frequency rf close to target.

The Baseline Targetry/Capture Scenario



Choices:

- Liquid or solid target?
- Phase rotation or drift after target?

High performance neutrino factory and muon collider favor the first choices.

May be expedient to start with the second choices.

Two Classes of Issues

1. Viability of targetry and capture for a single pulse.
   - Effect of pressure wave induced in target by the proton pulse.
   - Interaction of a moving metal target with the solenoid field.
   - Operation of the first rf cavity in a magnetic field and in large particle flux.
2. Long-term viability of the system in a high radiation area.

   [Issues for solid target & magnet coils are of this type.]

The most novel issues (1) are addressable in studies with low rep. rate but a large number of protons/pulse (up to 10^{14} $p$pp in BNL E951).

Long-term issues, including solid targets, may require study in a high-rep.-rate, high-average-power beam (Los Alamos Spallation Radiation Damage Facility, 0.8 MW, 20 Hz; a DOE Category 3 Nuclear Facility).

R&D Goals

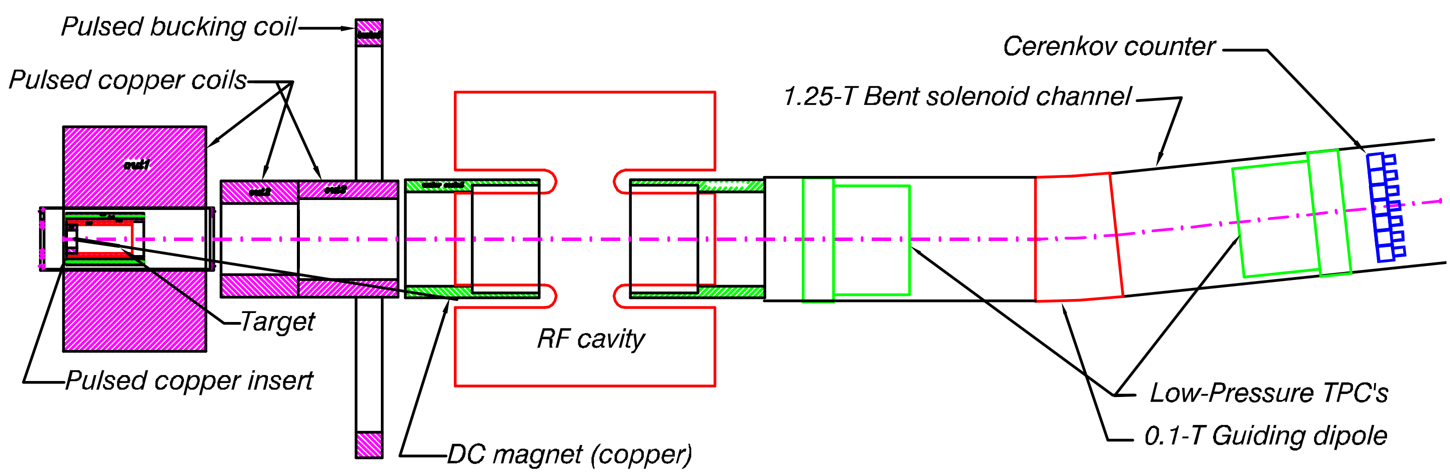
1. Single pulse studies (BNL E951).

   Overall: Test key components of the front-end of a neutrino factory in realistic single-pulse 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 beam tests; Test 70-MHz rf cavity (+ 1.25-T magnet) 3 m from target; Characterize pion yield.



2. Long Term Survivability

Define needed R&D program during 2nd half of FY00.

Example: survival of a carbon target:

- Cylindrical geometry focuses reflected pressure wave to very high values on axis, even for diffuse energy deposition.
- 10-100 J/gm/pulse, $> 10^8$ pulse/year, $\Rightarrow > 10^5$ eV/atom/yr.
- $\Rightarrow$ Every interatomic bond broken $\gtrsim 10^3$ times/year.
- 4 MW $\Rightarrow 10^{22}$ p/year $\approx$ 30 dpa/year.
- Graphite lifetime is about 10 dpa.

90% of beam energy deposited in the liner of the superconducting magnets.

Is a solid liner viable; should the beam hit a mercury pool?

Are the superconducting coils viable? (Peter Wanderer, Al Zeller)

We must operate a high-radiation facility. (Michael Todosow, Phil Spampinato)

The 8 Steps in the E951 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.

E951 Schedule

- FY99:

  Prepare A3 area;

  Begin work on liquid jets, magnet systems, and rf systems.

- FY00:

  Complete A3 line;

  Continue work on magnet and rf systems;

  Begin work on extraction upgrade.

- FY01:

  First test of targets in A3;

  Liquid jet test in 20-T magnet at NHMFL;

  Continue work on extraction magnet and rf systems.

  (600 hours).

- FY02:

  Complete extraction upgrade, magnet and rf systems;

  Test targets with 10^{14} $p$pp;

  Begin work on pion yield diagnostics;

  Option to study mercury dump in vertically pitched beam.

  (600 hours).

- FY03:

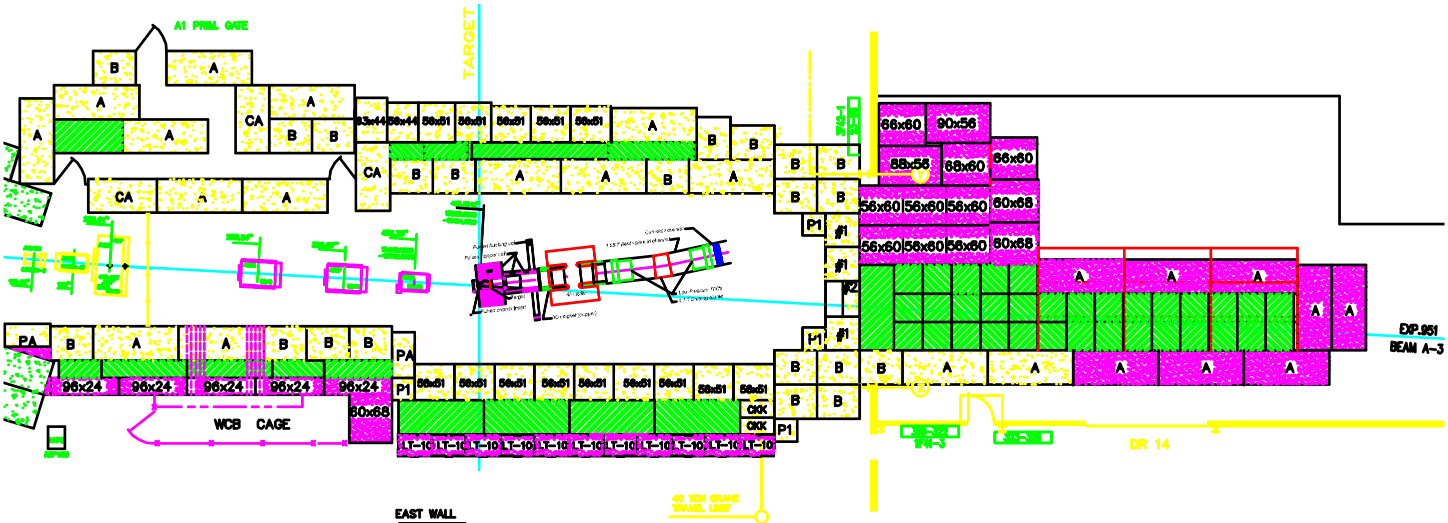
  Beams tests of target + 20-T pulsed magnet + rf cavity;

  Complete pion detectors; test yield with low intensity SEB.

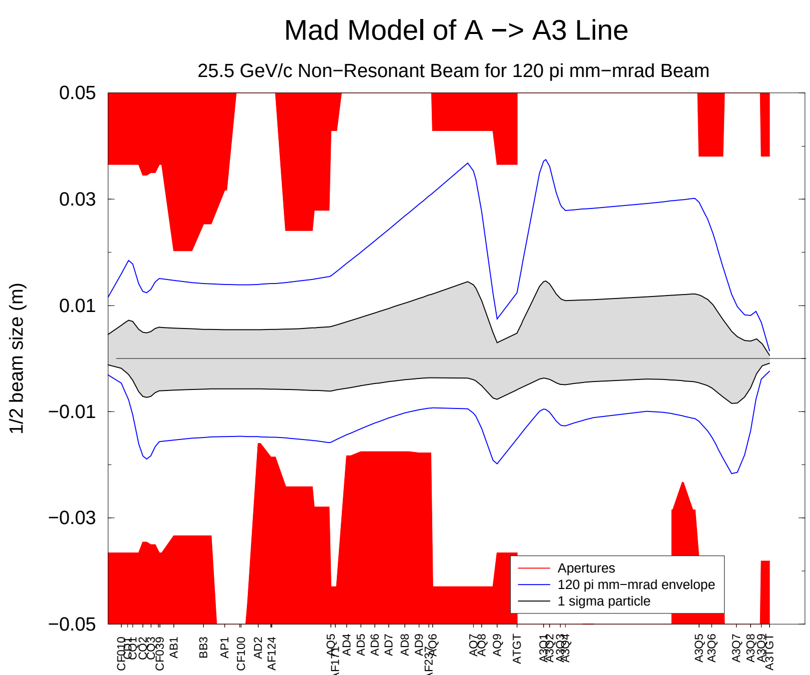
  (1800 hours).

Issues, 1: Initial Tests with FEB

- A3 line now being prepared for E951 (Joe Scaduto).



- Beamline upgrades needed to bring a 100 mm-mrad beam to a spot with $\sigma_r = 1$ mm? (Kevin Brown)



Option for vertically pitched beam.

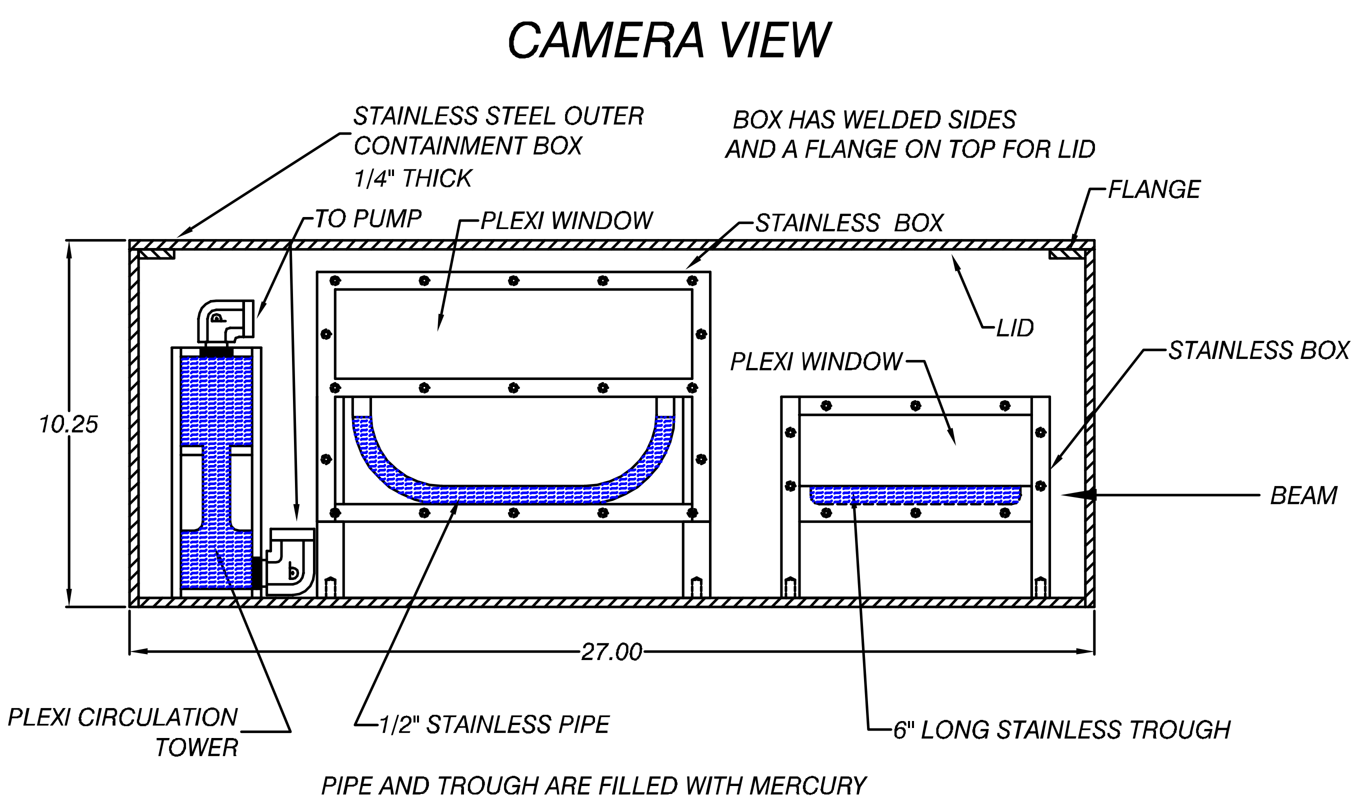
- Beamline instrumentation upgrades: spot size, beam current, FEB radiation monitoring.

- Run first tests parasitic to $g-2$ expt. in Oct/Nov 2000.

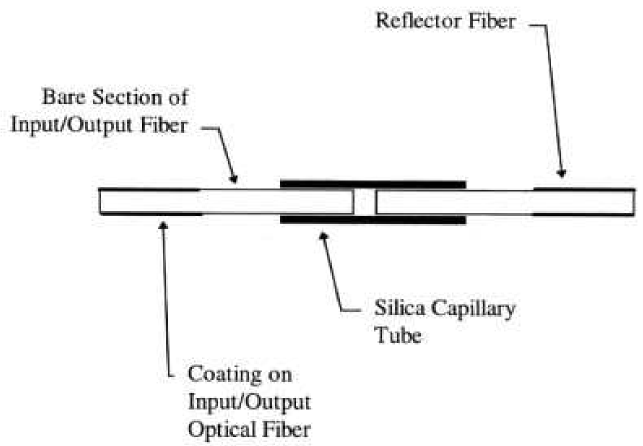
- Data taking via pulse-on-demand once every few minutes; but desire 1-Hz running for beam tuning.

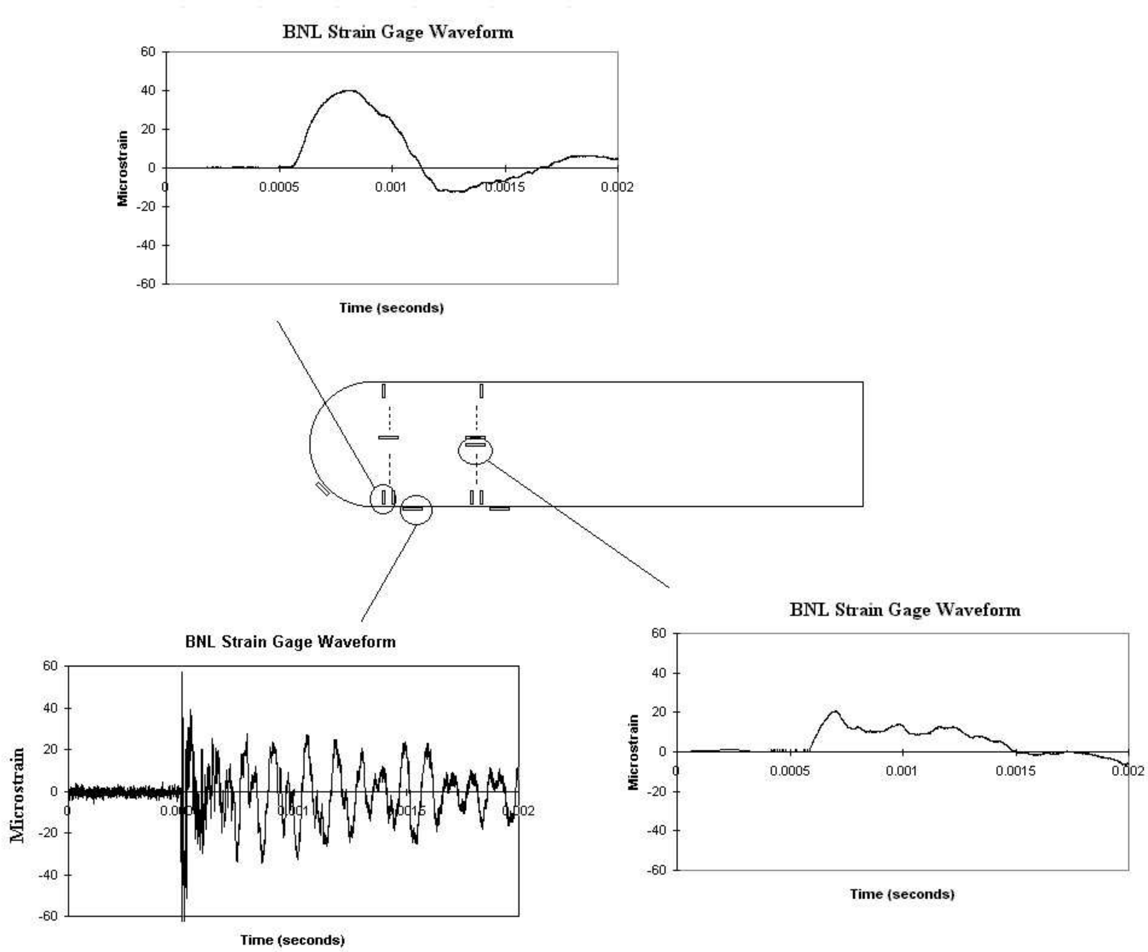
- Shielding needed for 1-Hz running with 10^{14} ppp = 100 TP (Ripp Bowman, Ralf Prigl).

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



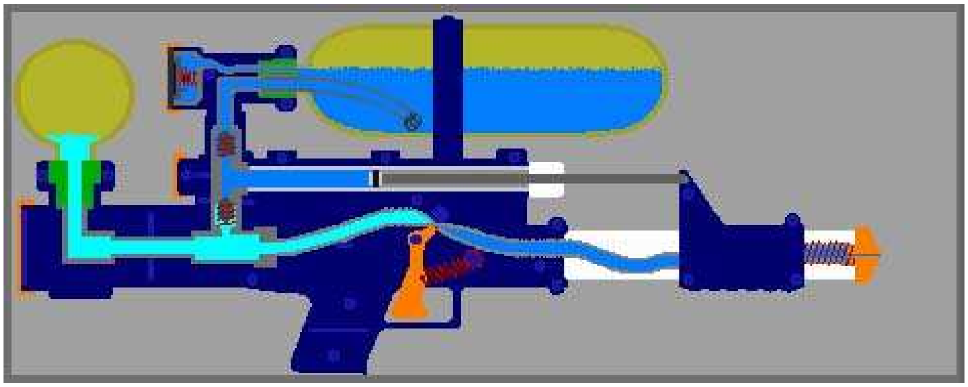
- Instrumentation: high-speed camera, fiberoptic strain sensors (Duncan Earl, ORNL).



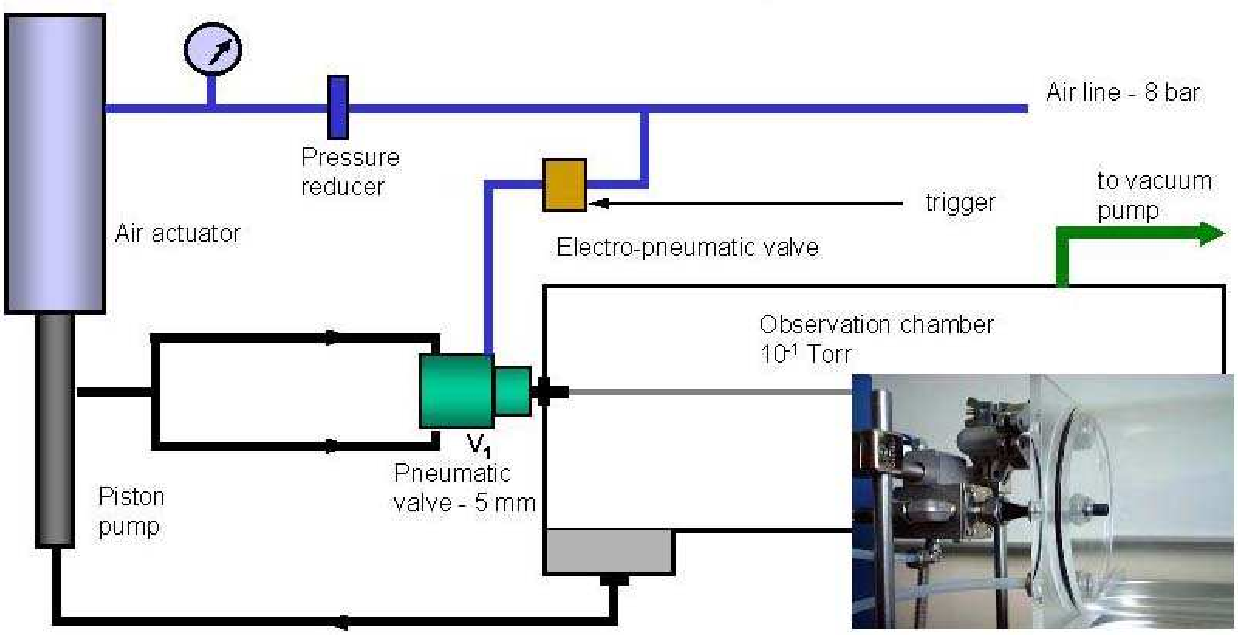


Issues, 2: Pulsed Liquid Jet

- Inspiration:



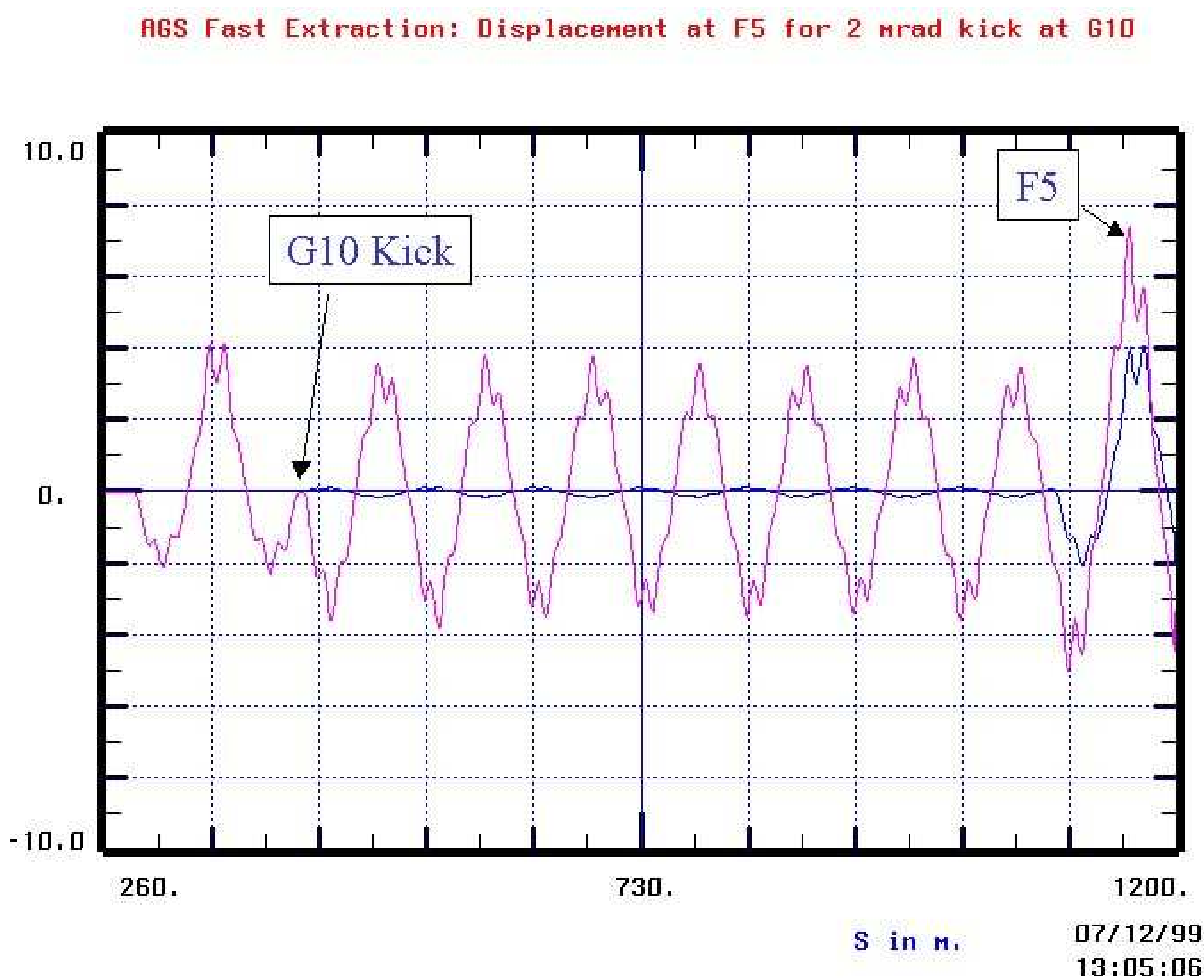
- Hg jet under construction at CERN (Colin Johnson, Helge Ravn), and at Princeton.



- Solid target options: C (NUMI), W (LANSCE), Cu bands (King, Drumm).

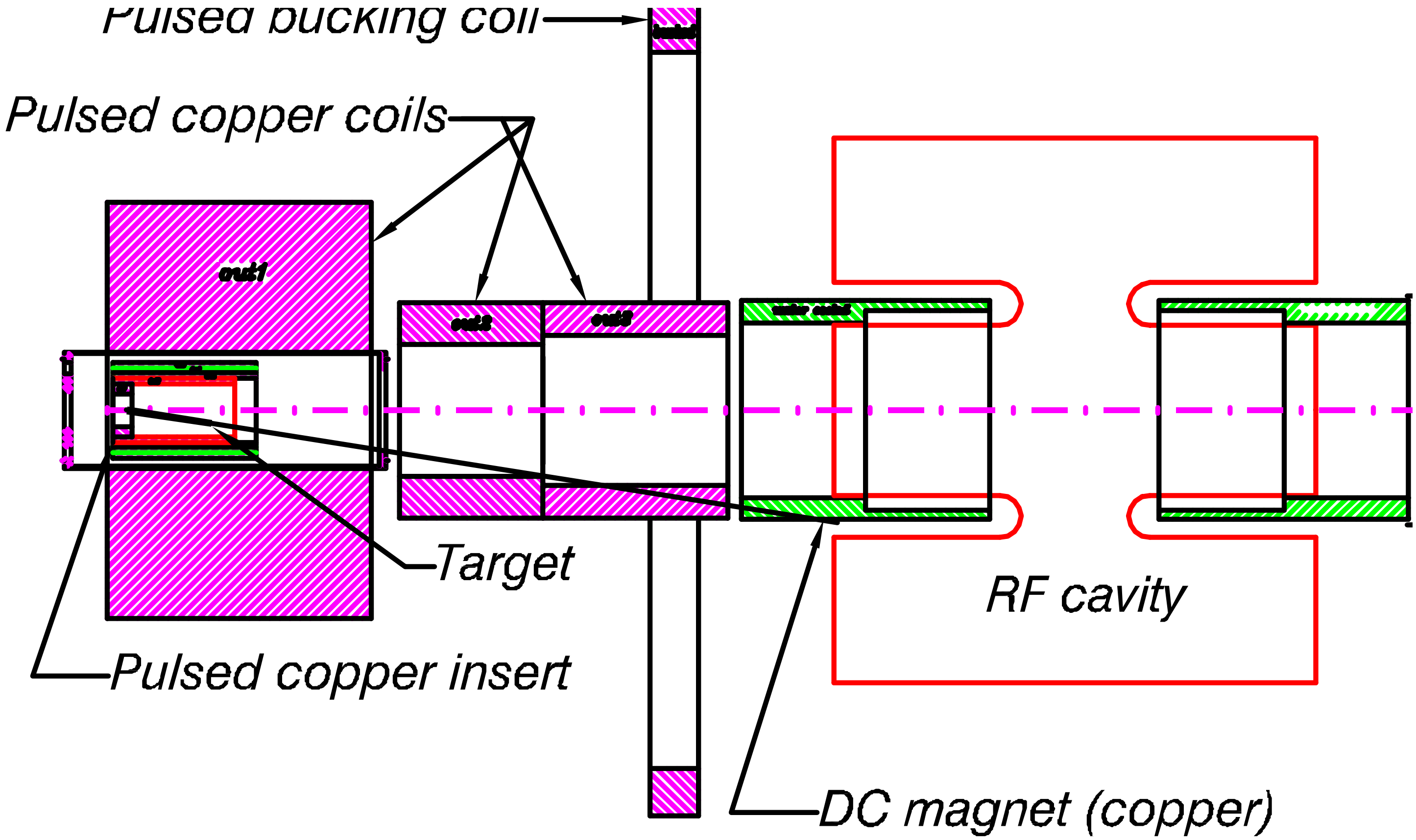
Issues, 3: Full Turn Extraction

- 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 early FY02.



Issues, 4: Pulsed 20-T Magnet

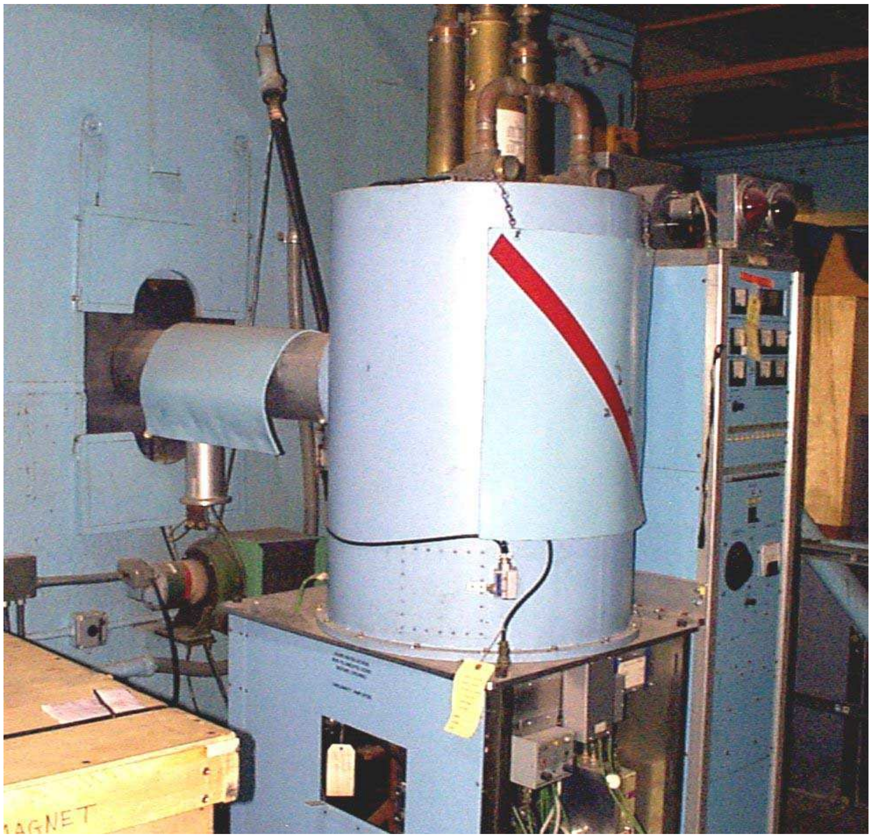
- The copper magnet will be cooled by LN_2, and can be pulsed once every 10 minutes. Pulse duration ≈ 1 s. (Bob Weggel)



- 5 MW (peak) power from a new power supply (Jon Sandberg).
- 100 liters of LN_2 boiled off each pulse; vent outside of cave.
- For a neutrino factory source, need 20-T hybrid superconducting magnet (John Miller).

Issues, 5: 70-MHz RF Cavity

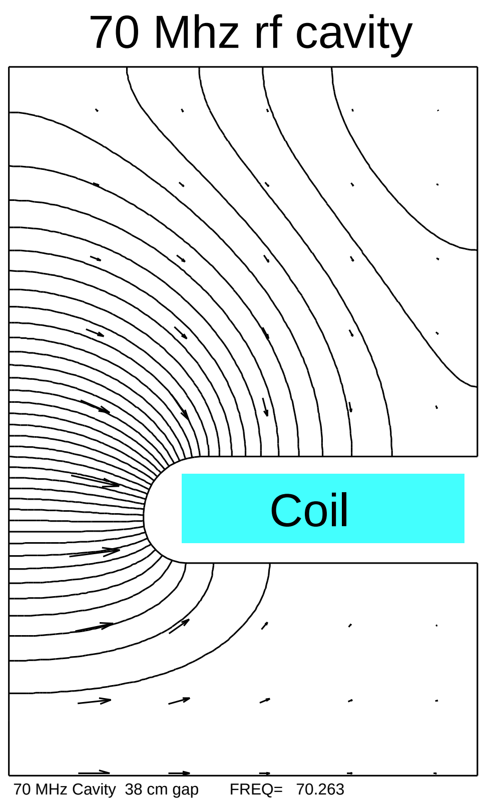
- Cavity has 60-cm-diameter iris, 2-m outer diameter.
  (Jim Rose)
- 4-6 MW peak power to be supplied by four 8973 tubes
  recommissioned from the LBL Hilac.
  (John Corlett, Don Howard, LBL)



- 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).

Issues, 6: 1.25-T Solenoid Inside RF Cavity

- 1.25-T coils in cavity "nose pieces" do not produce momentum stop bands (Harold Kirk).

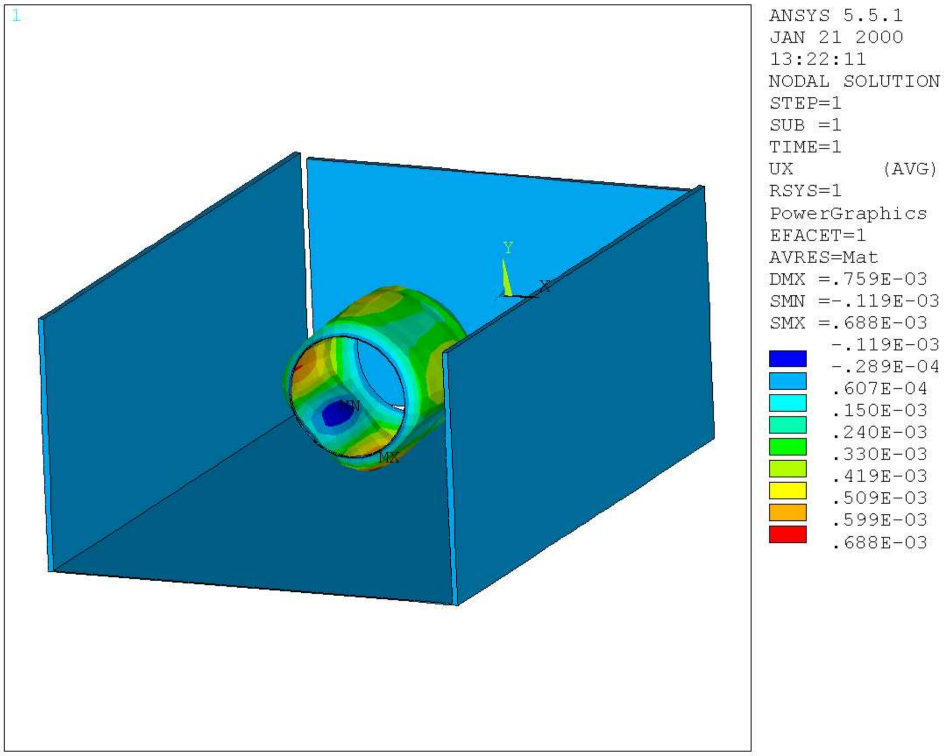


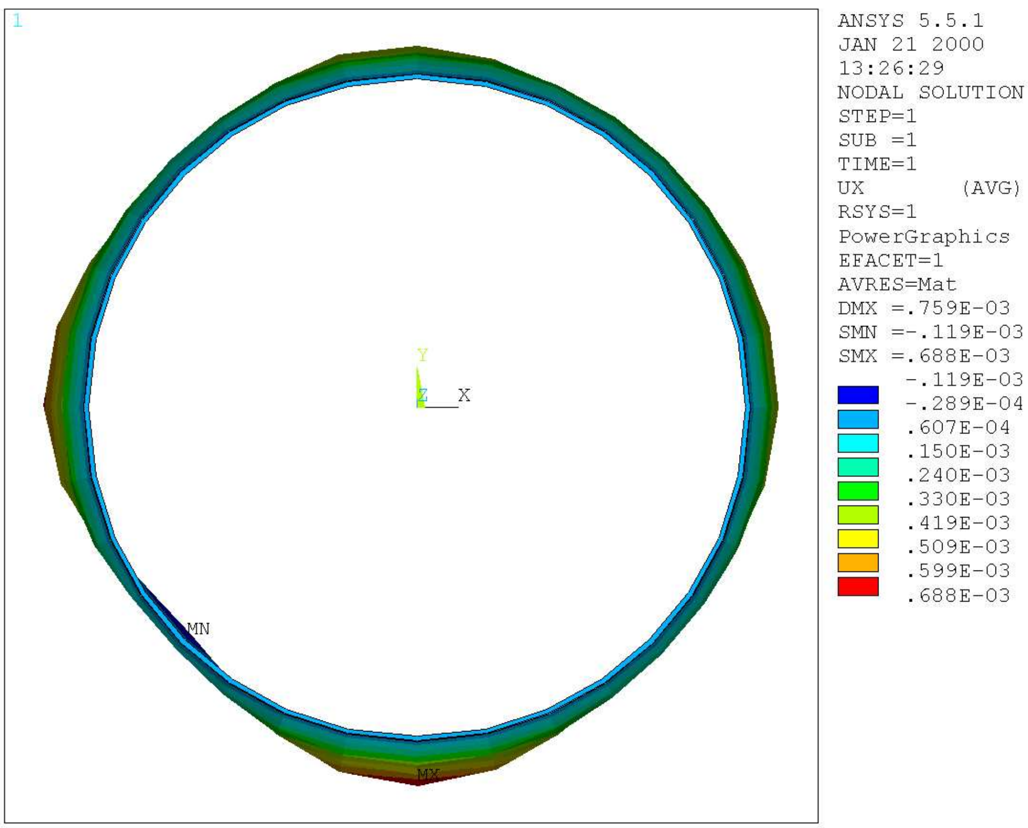
- Superconducting coils can be built in this geometry. (Mike Green)

- May use copper coils in E951 (Bob Weggel).

- The PEP-4 TPC superconducting magnet coil, previously proposed, interacts badly with iron in the A3 cave. (Steve Kahn, Changguo Lu)

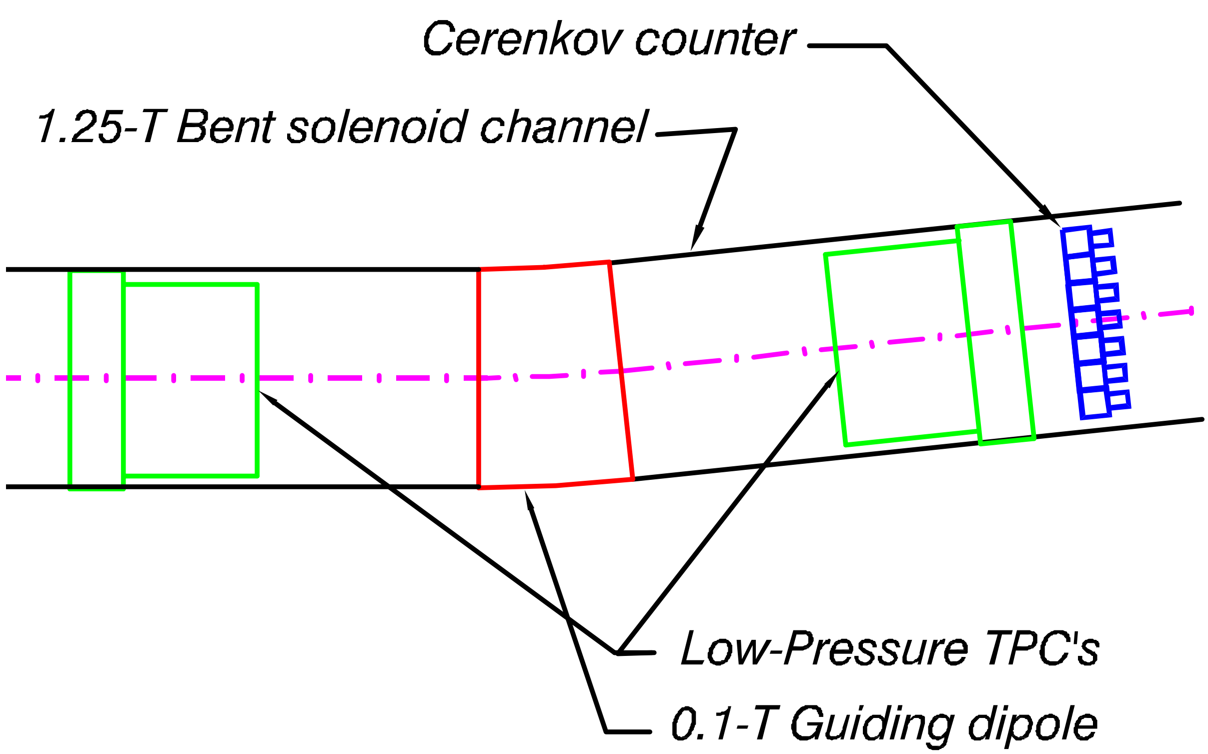
ANSYS Simulation of PEP-4 Coil in A3 Cave





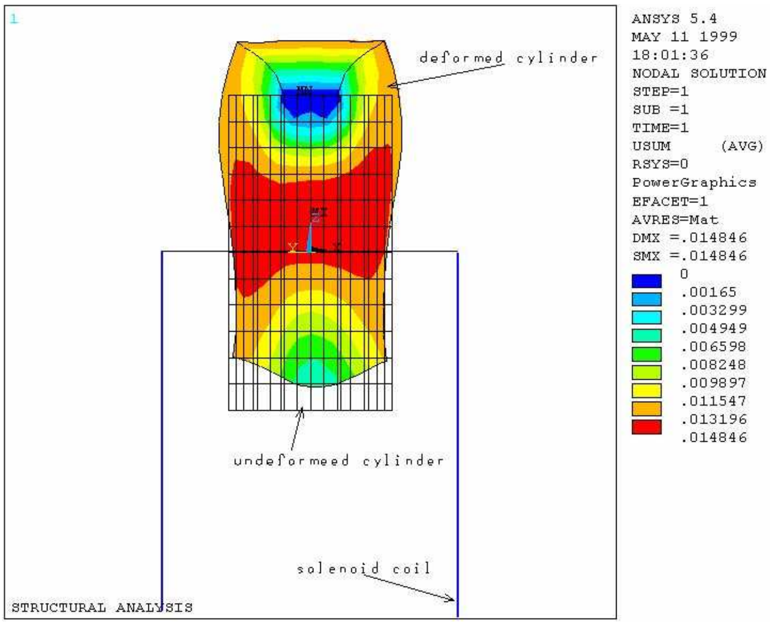
Issues, 7: Characterization of Pion Yield

- 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, $< 10^6$ $p$pp.
- Compare with extrapolations from data of E-910.

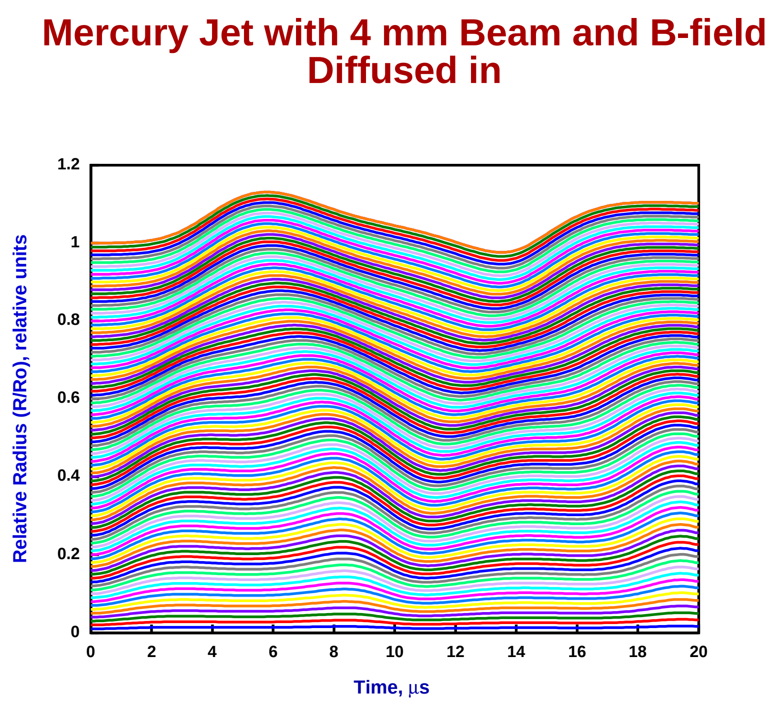


Issues, 8: Simulation of Beam-Jet-Magnet

- ANSYS simulation (Changguo Lu):



- HEIGHTS simulation (Ahmed Hassanein):



- Other simulations: Steve Kahn, Yasuo Fukui, Roman Samulyak.