Muons for a Neutrino Factory and a Muon Collider

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Muon Collider main page:

`http://www.cap.bnl.gov/mumu/mu_home_page.html`

Muon Collider R&D Status Report:

`http://www.cap.bnl.gov/mumu/status_report.html`

Muon Collider Targetry page:

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

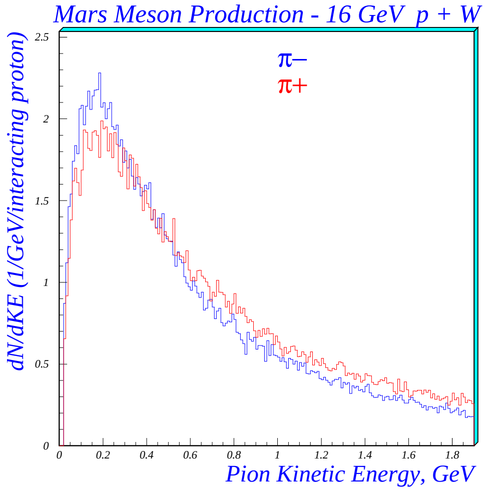
Muon Requirements

- $\approx 10^{14}\ \mu^{\pm}/\mathrm{s}$ 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 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.

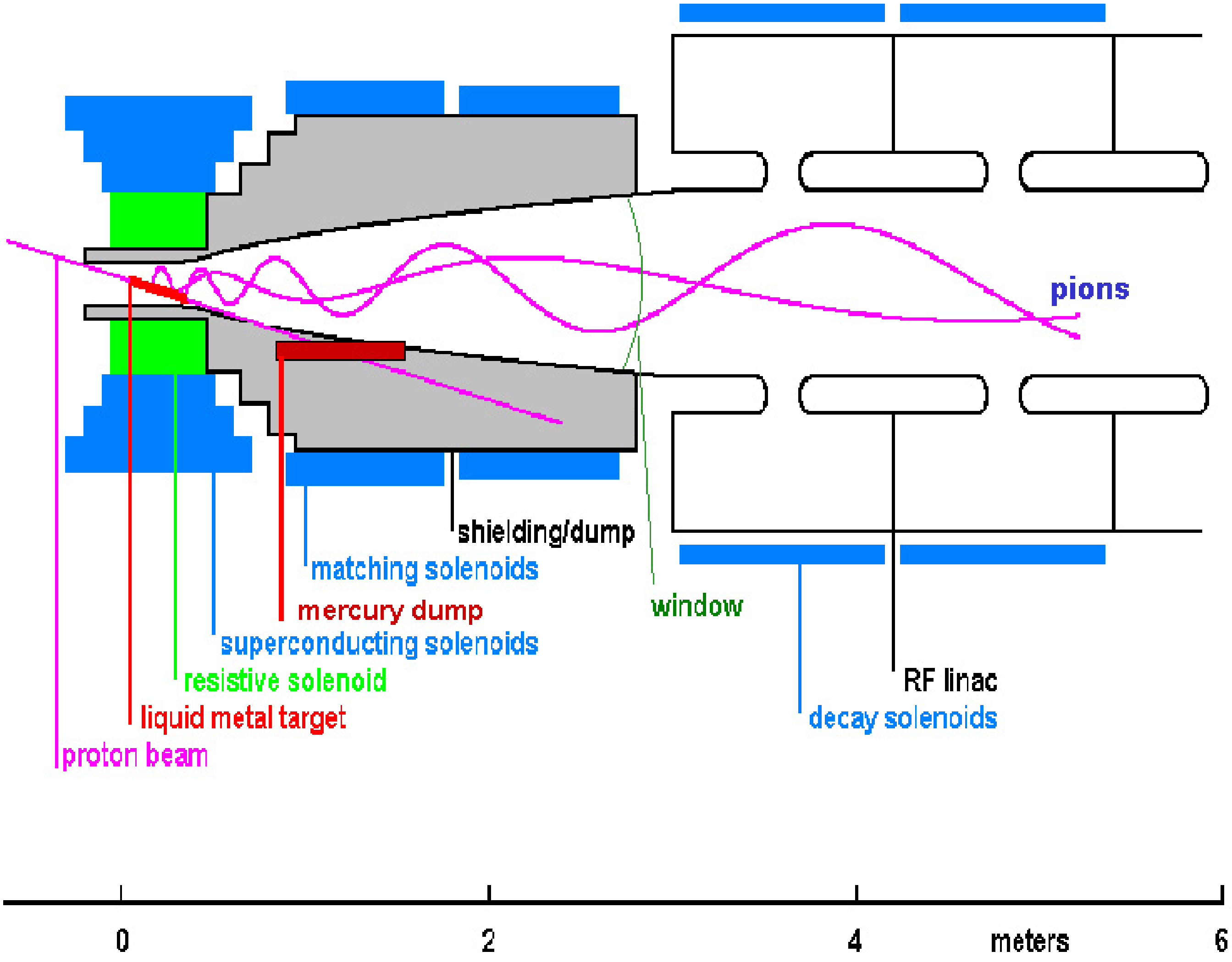
- Capture efficiency improved with a stronger (20 T) field on the target than in the main channel (1.25 T). [Adiabatic invariance reduces the pion $P_{\perp}$ when going from high to low B.]

- $\Rightarrow$ 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).

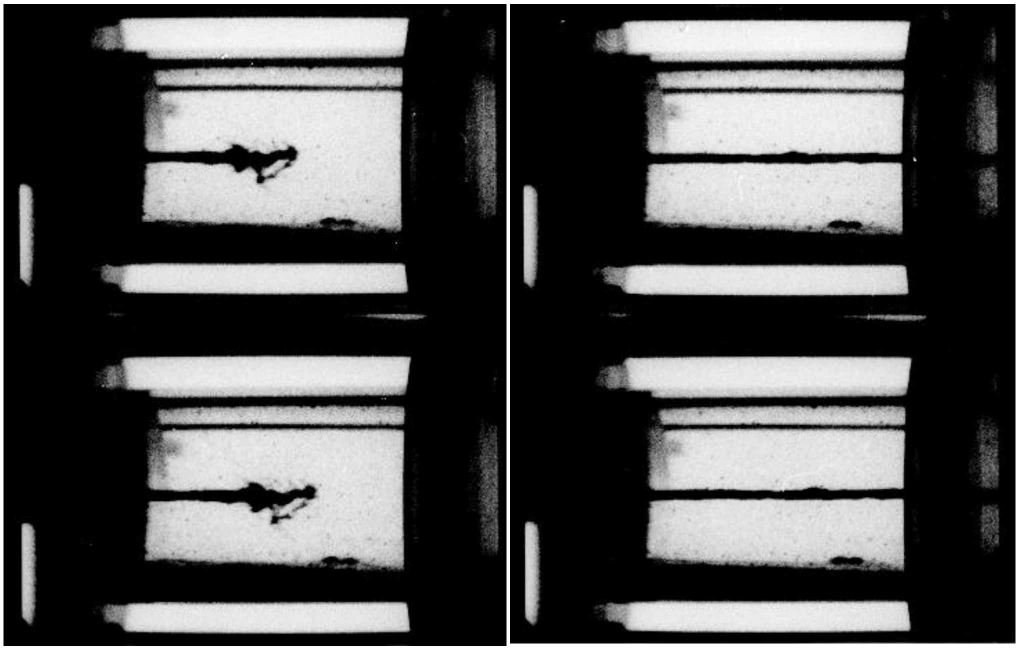
Overview of Targetry for a Muon Collider



- 1.2×10^{14} $\mu^{\pm}$/s via π-decay from a 4-MW proton beam.
- Proton pulse $\approx$ 1 ns rms for a muon collider.
- 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 Issues

- Is a liquid jet target viable?
  - 1-ns beam pulse ⇒ 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

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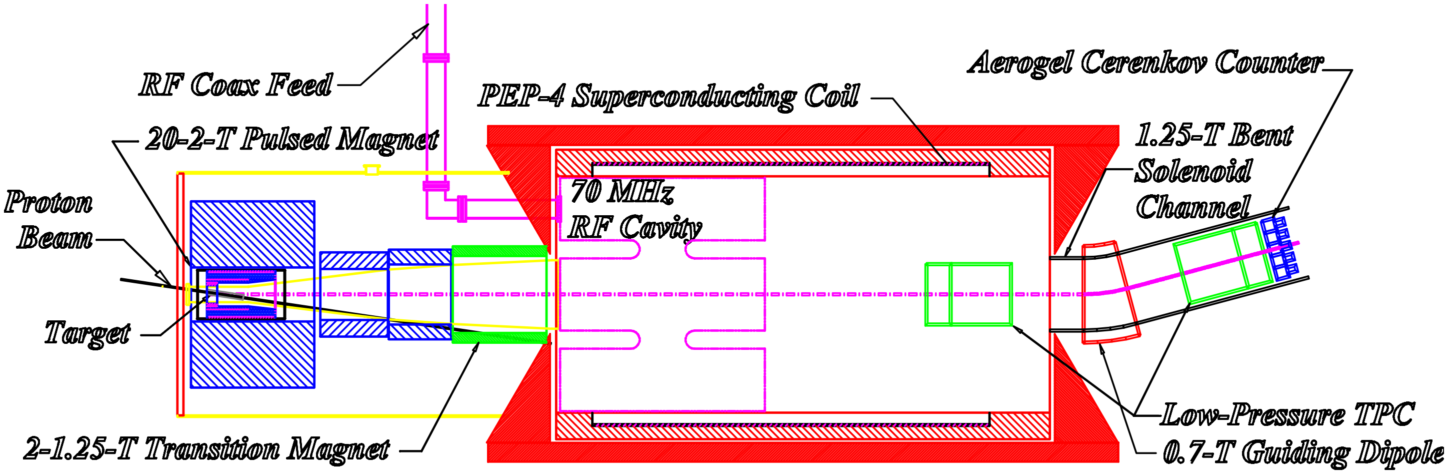
- Is the first rf cavity viable?
  - High-gradient (5 MeV/m), low-frequency ($\approx$ 70 MHz) rf cavity only 3 m downstream of target.
  - $> 10^{14}$ particles traverse the cavity each proton pulse; many hit the cavity wall.
  - Cavities tested against breakdown from beam-induced showers only up to $\approx 10^{12}$ 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 has 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 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 (P951)

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(Submitted Sept. 28, 1998)

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Beam Tests at BNL

The BNL AGS has proton beam parameters closest to those desirable for a muon collider source.

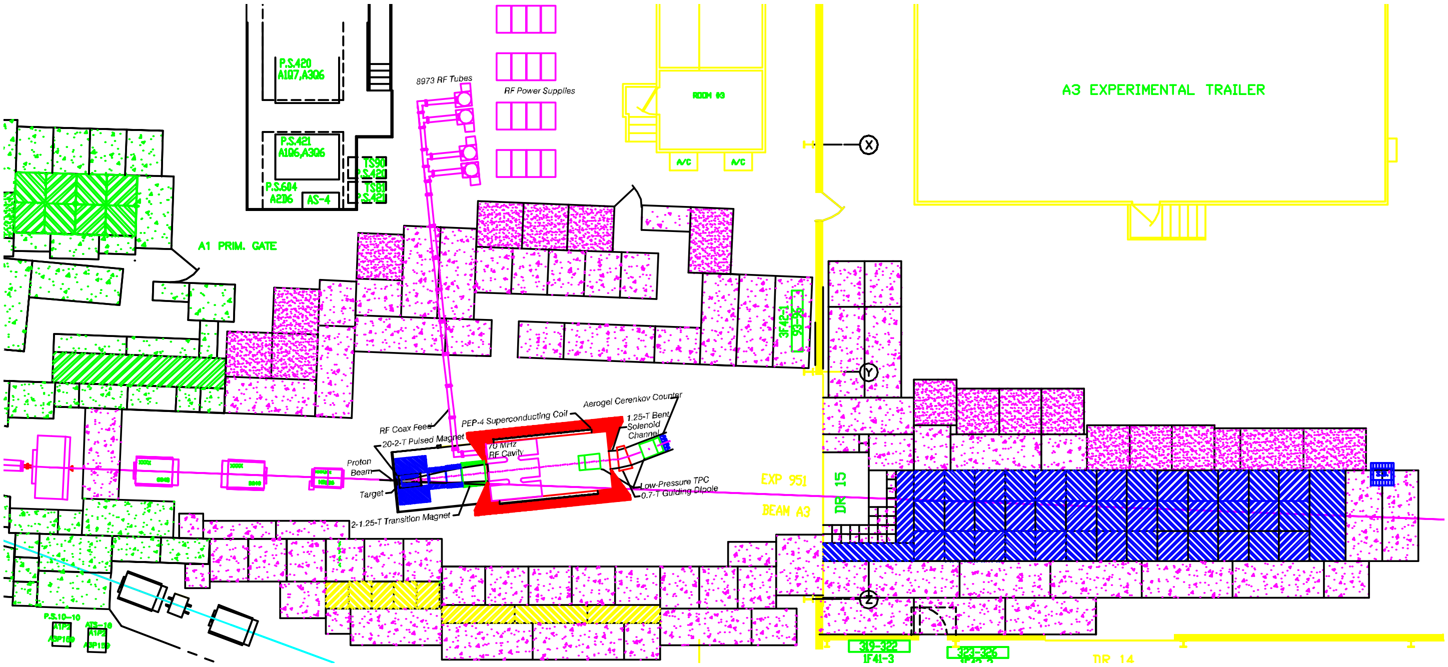
Parameter	Muon Collider	BNL AGS	FNAL Booster	CERN PS	LANSCE PSR
Proton Energy (GeV)	16-24	24	8.9	24	0.8
p/bunch	5×10^{13}	1.6×10^{13}	6×10^{10}	4×10^{12}	3×10^{13}
No. of bunches	2	6	84	8	1
p/cycle	1×10^{14}	1×10^{14}	5×10^{12}	3×10^{13}	3×10^{13}
Bunch spacing (ns)	≈ 1000	440	18.9	250	–
Bunch train length (μs)	≈ 1	2.2	1.6	2.0	0.25
RMS Bunch length (ns)	≈ 1	≈ 10	≈ 1	≈ 10	≈ 60

The 8 Steps in the R&D Program

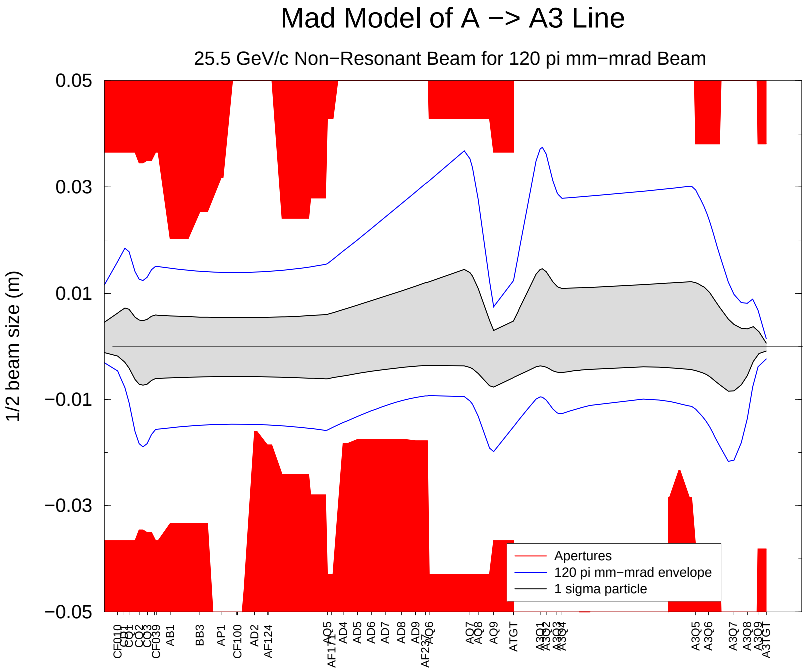
1. Simple tests of liquid (Ga-Sn, Hg) and solid (Ni) targets with AGS Fast Extracted Beam (FEB).
2. Test of liquid jet entering a 20-T magnet (20-MW cw Bitter magnet at the National High Magnetic Field Laboratory).
3. Test of liquid jet with 10^{14} ppp via full turn FEB (without magnet).
4. Add 20-T 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.

Issues, 1: Initial Tests with FEB

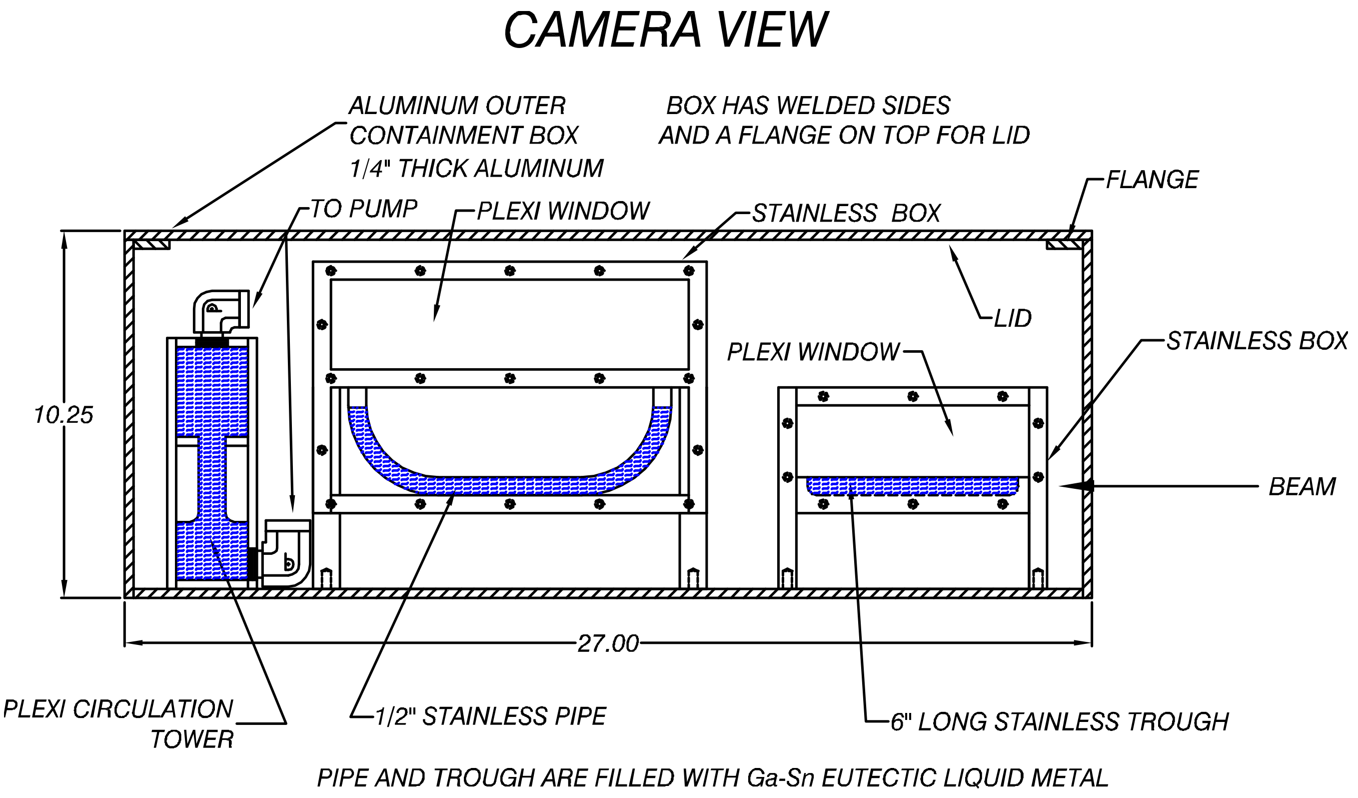
- Site presently under consideration: A3 line.



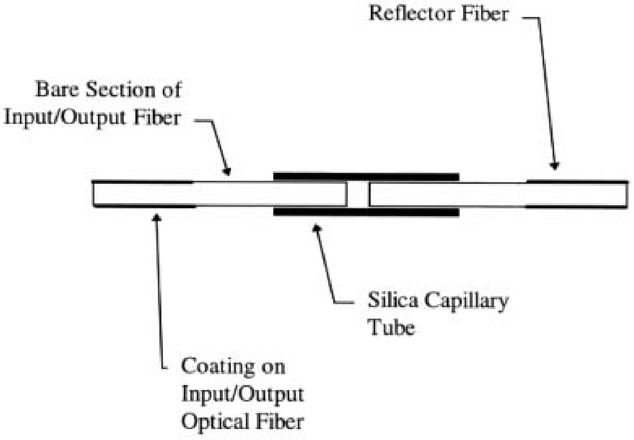
- What beamline upgrades are needed to bring a 100 mm-mrad beam to a spot with $\sigma_r = 1$ mm? (Kevin Brown)

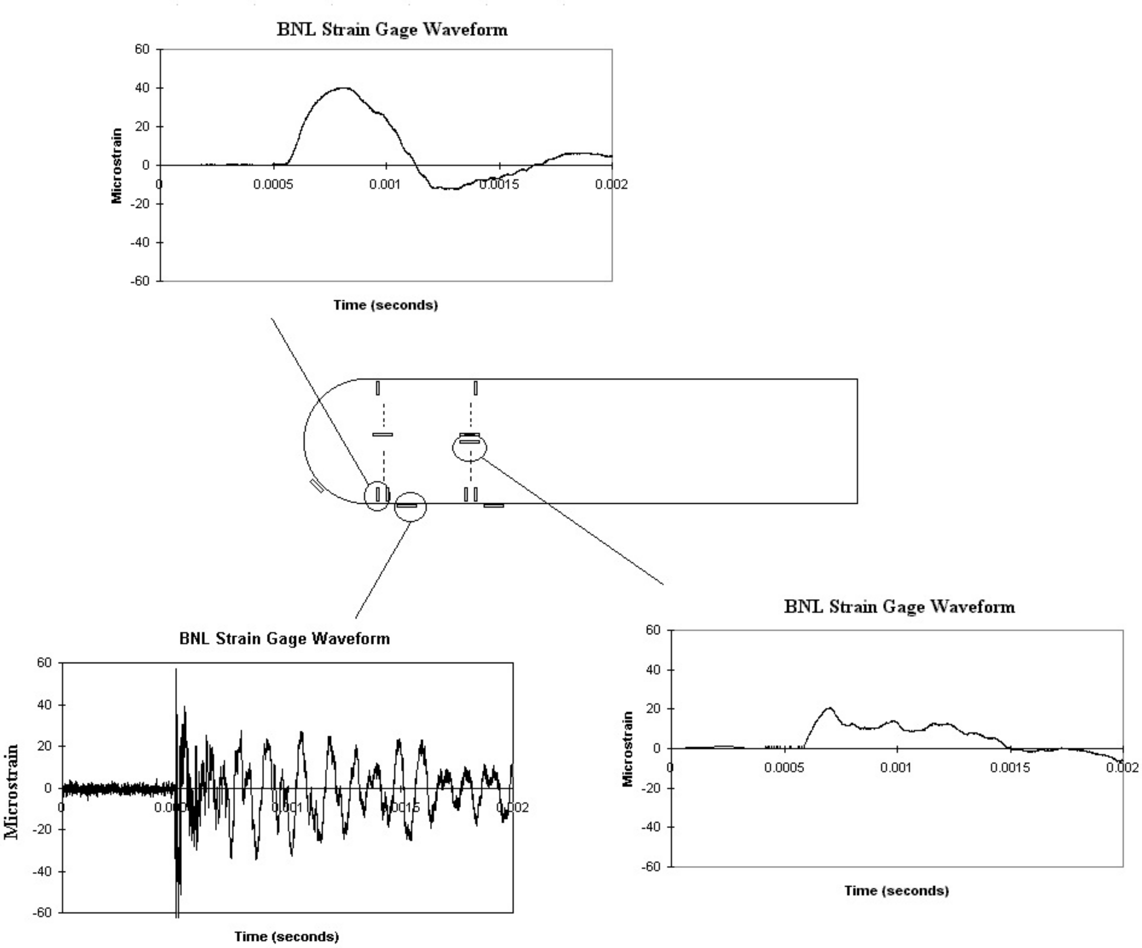


- Beamline instrumentation upgrades: spot size, beam current, FEB radiation monitoring.
- Run first tests parasitic to $g-2$ expt. in Mar/Apr 2000.
- Data taking via pulse-on-demand once every few minutes; but desire 1-Hz running for beam tuning.
- Shielding needed for 1-Hz running with 10^{14} ppp = 100 TP (Ripp Bowman, Ralf Prigl).
- First test: liquid metal in a trough, a pipe and in free flow (Princeton).



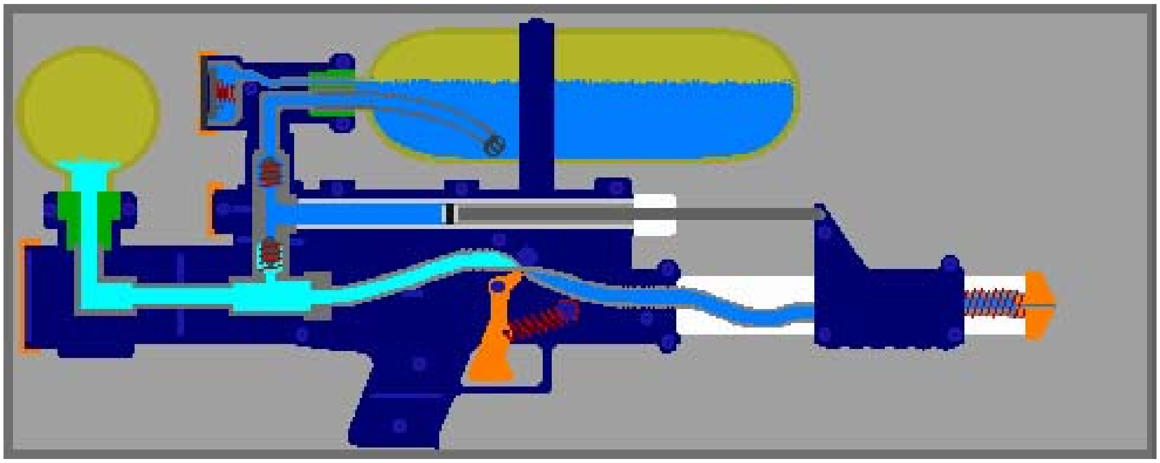
- Instrumentation: high-speed camera, fiberoptic strain sensors (Duncan Earl, ORNL).



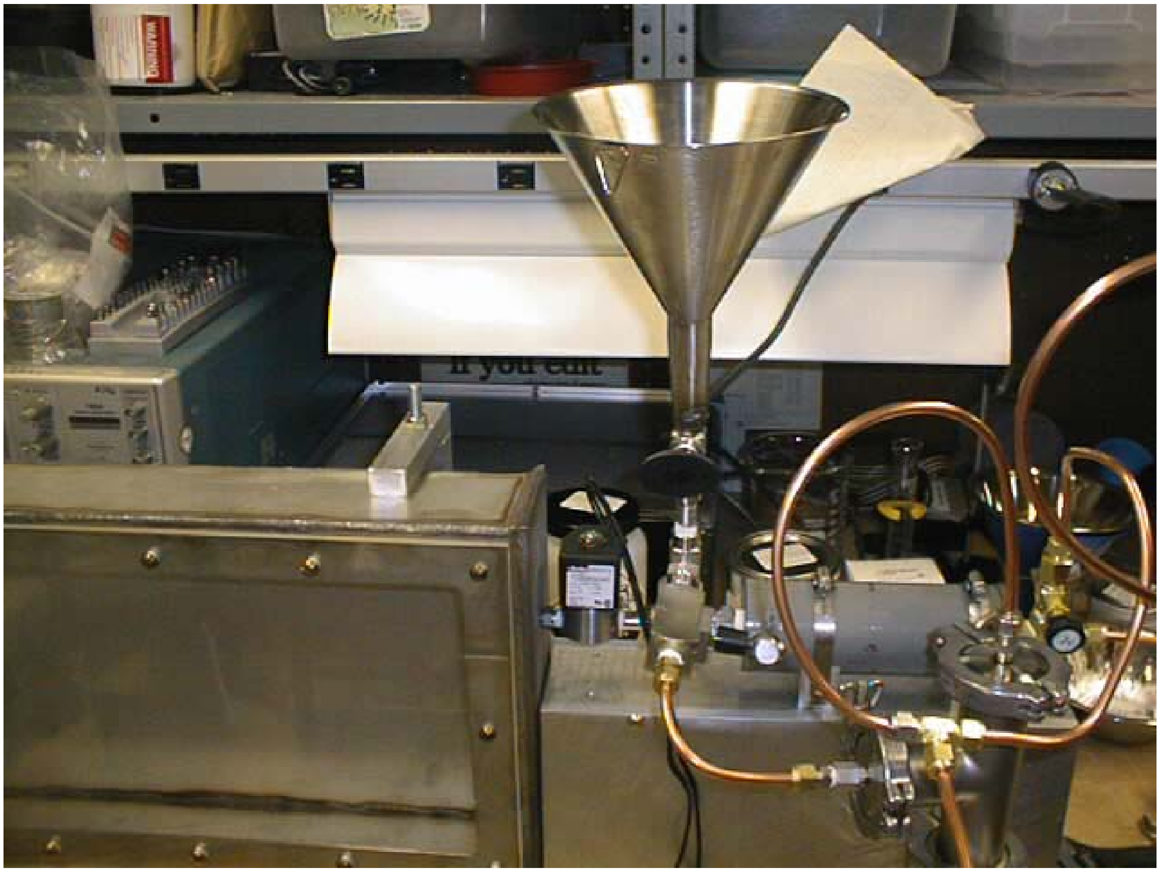


Issues, 2: Pulsed Liquid Jet

- Inspiration:

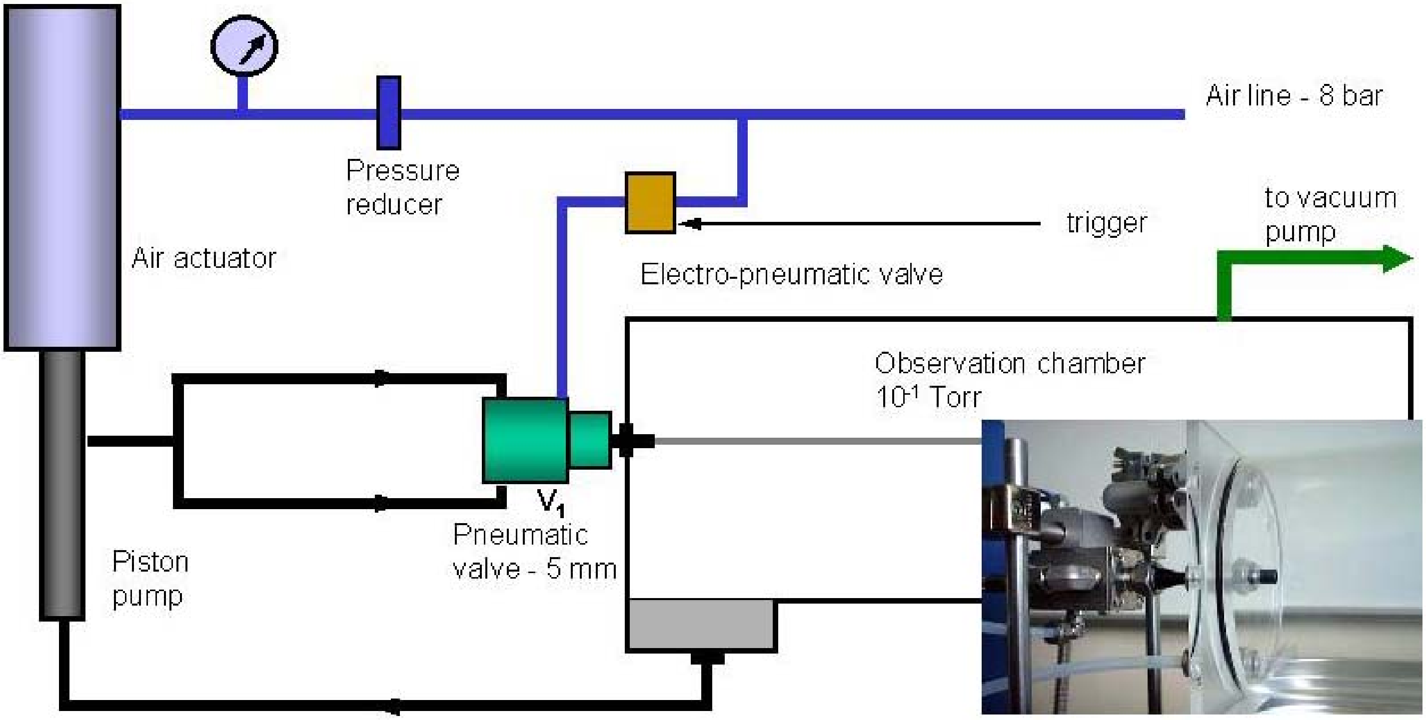


- Prototype jet using Ga-Sn, a room temperature liquid (Princeton).



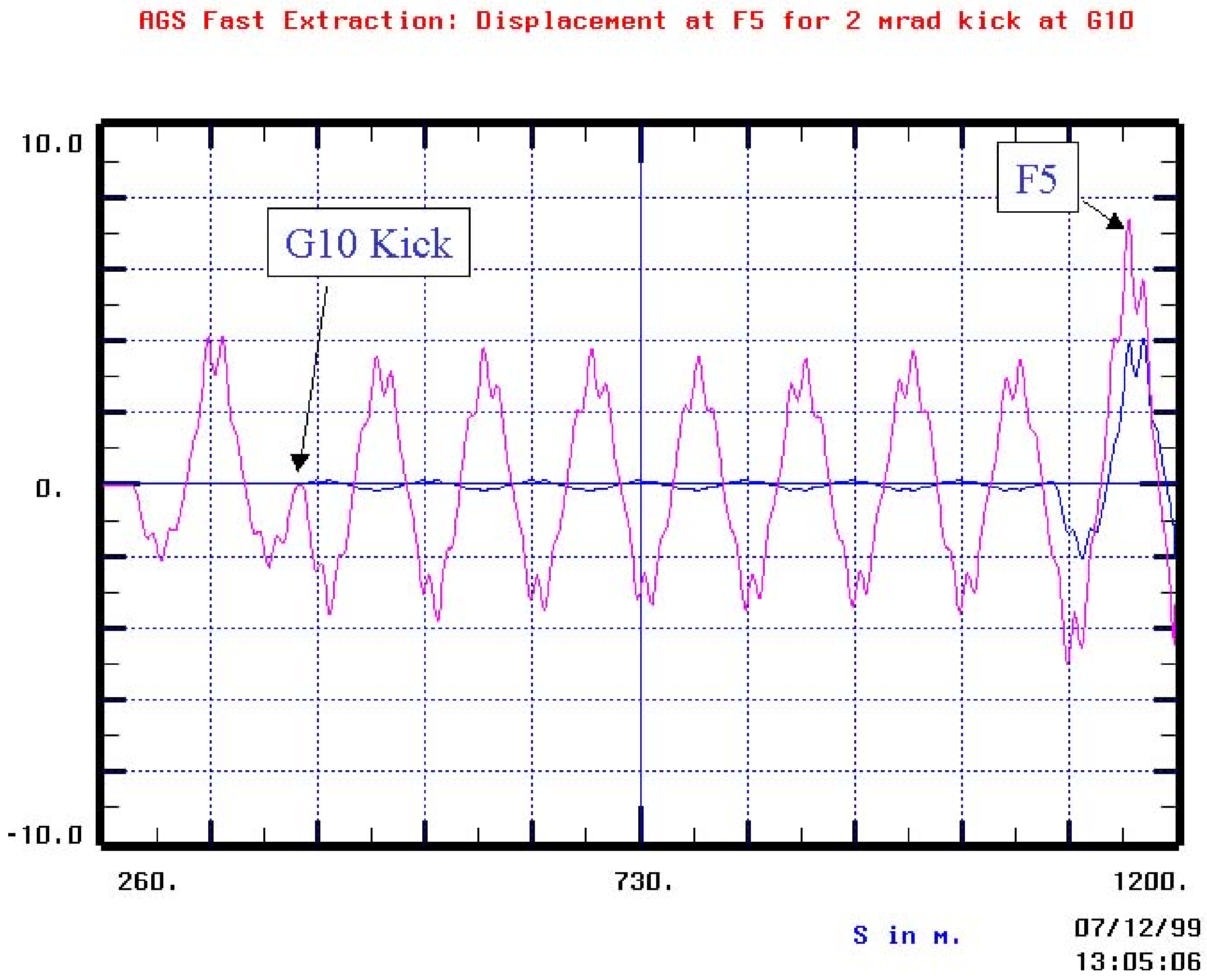
- May 18, 1999: Ga-Sn jet breaks up too quickly, forms oxide scum:

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



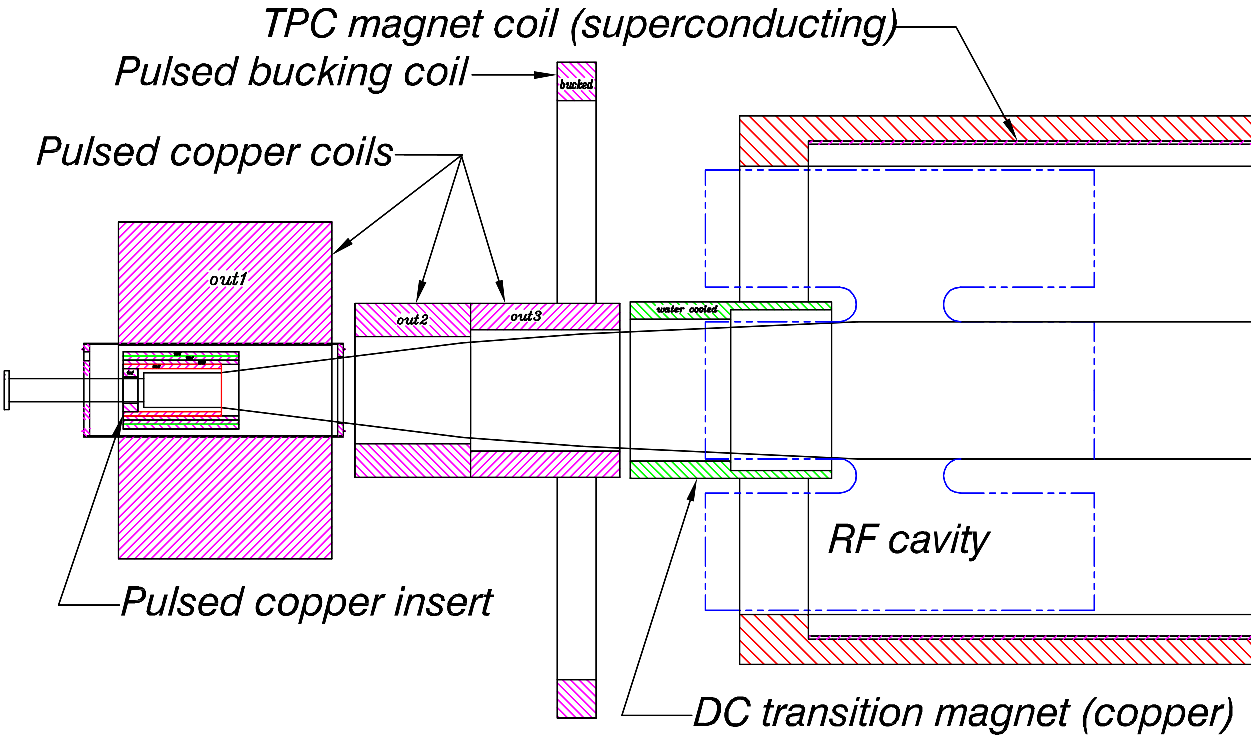
Issues, 3: Full Turn Extraction

- 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 FY99 to complete upgrade in early FY01.



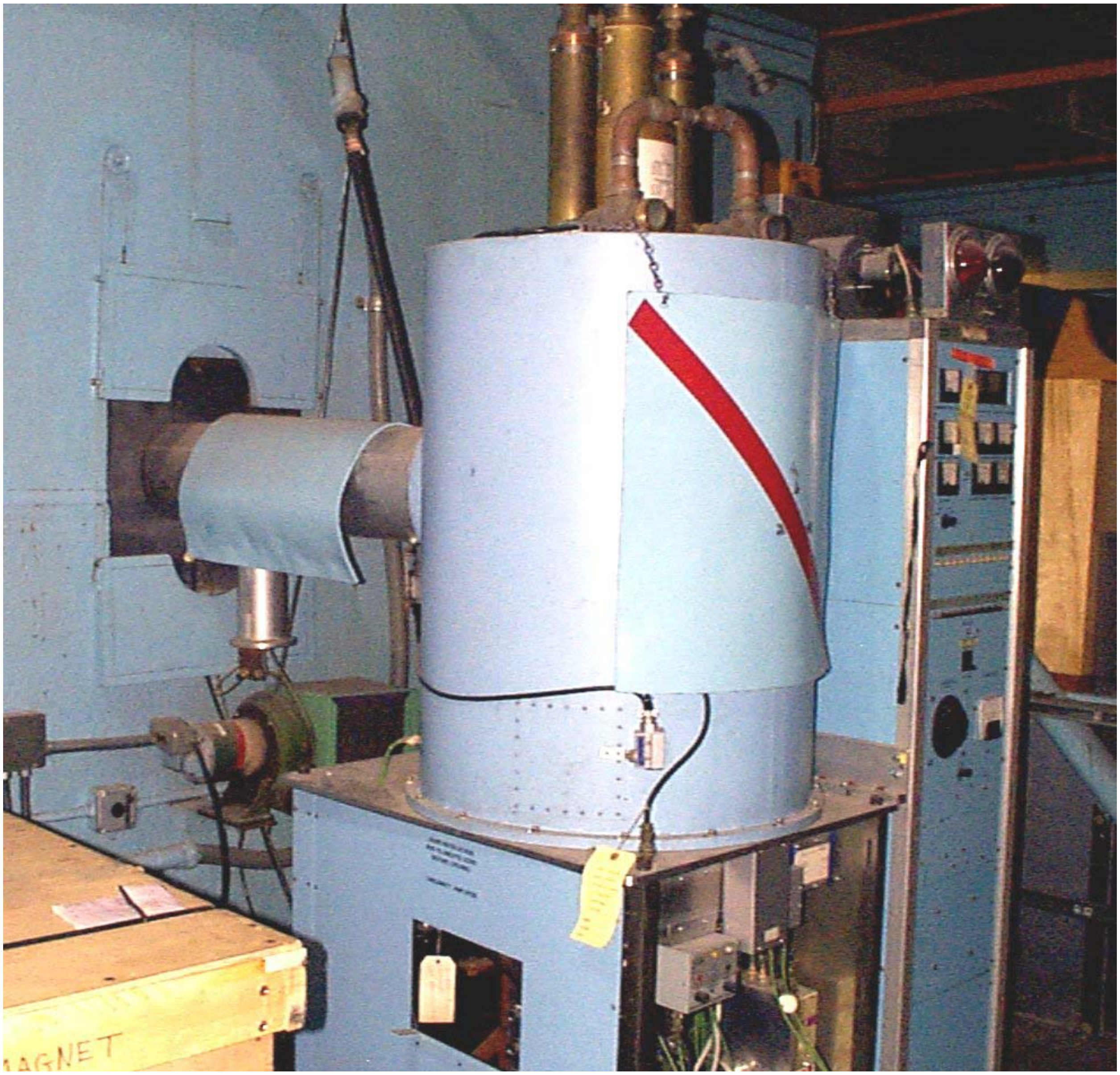
Issues, 4: Pulsed 20-T Magnet

- The copper magnet will be cooled by LN_2, and can be pulsed once every 10 minutes. Pulse duration $\approx$ 1 s.
- Engineer: Bob Weggel, 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.

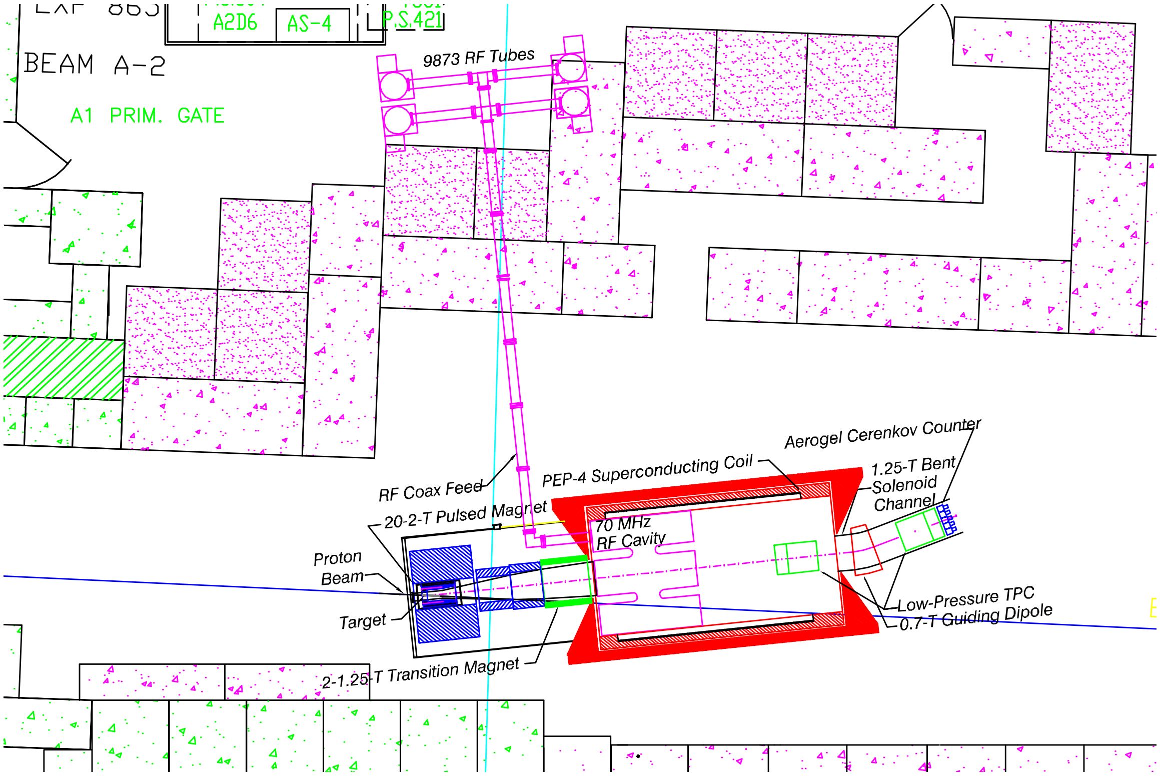


Issues, 5: 70-MHz RF Cavity

- Cavity has 60-cm-diameter iris, 2-m outer diameter.
  (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)



- Transmit rf power to the cavity via four 6″-diameter coax lines. Couple to upstream face of cavity (to avoid need for power combiner).



- The tubes and electronics should arrive at BNL early FY00.

- Ideal test site would be just outside A3 cave, close to final location.

- The 8973 tubes may need magnetic shielding.

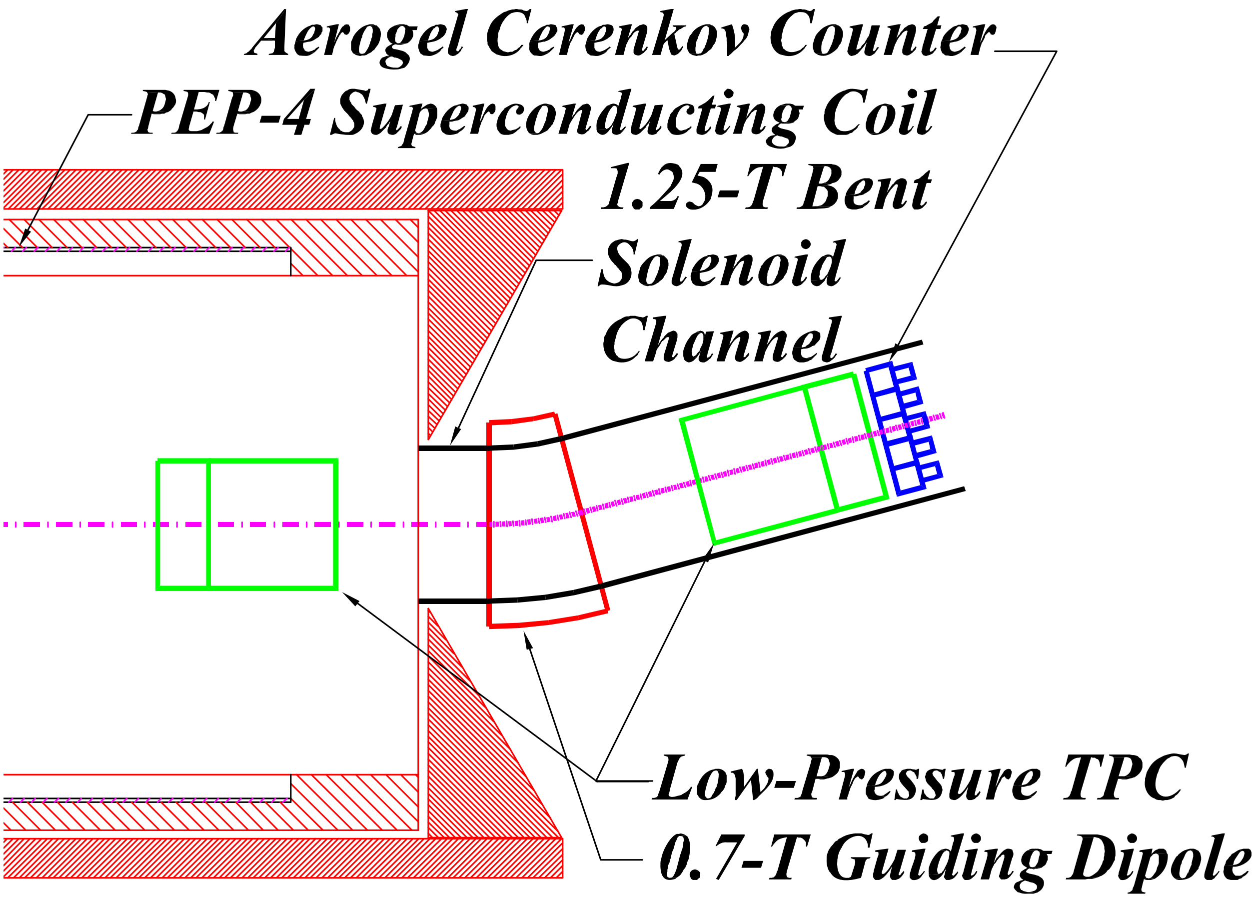
- We are also embarking on an R&D program with industry to develop a 50-MW peak power, 70-MHz power supply (EEV, Eimac, Litton, Thomson).

Issues, 6: 1.25-T Solenoid Around RF Cavity

- Present plan: use PEP-4 TPC superconducting solenoid (Mike Green, LBL).
- Use 100-W LHe refrigerator from E-850.
- Need DC transition magnet to protect the superconducting magnet from quenching during pulsing of the 20-T magnet (Bob Weggel).
- Need end plate steel and/or bucking coils to complete the isolation of the superconducting magnet.
- The magnet fringe fields will extend a considerable distance.

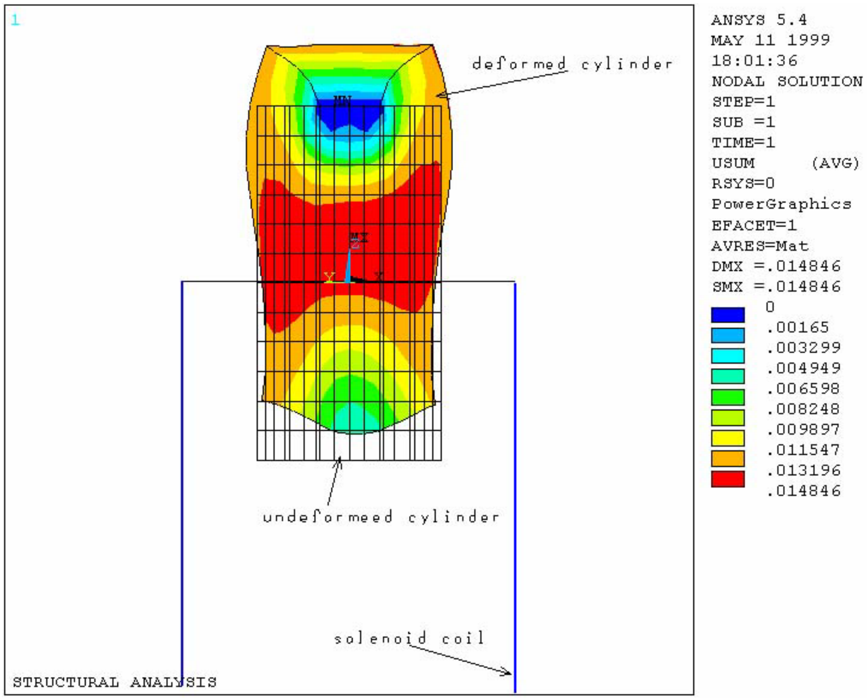
Issues, 7: Characterization of Pion Yield

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



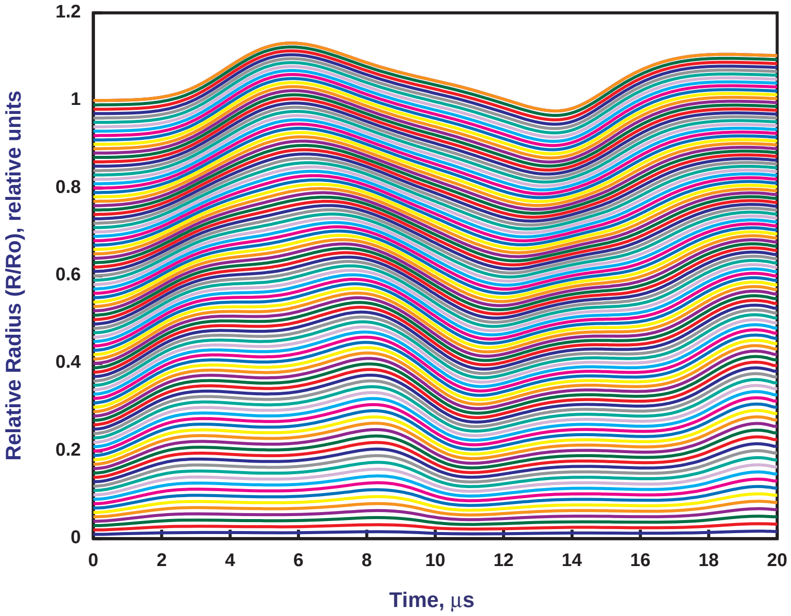
Issues, 8: Simulation of Beam-Jet-Magnet

- ANSYS simulation (Changguo Lu, Princeton):



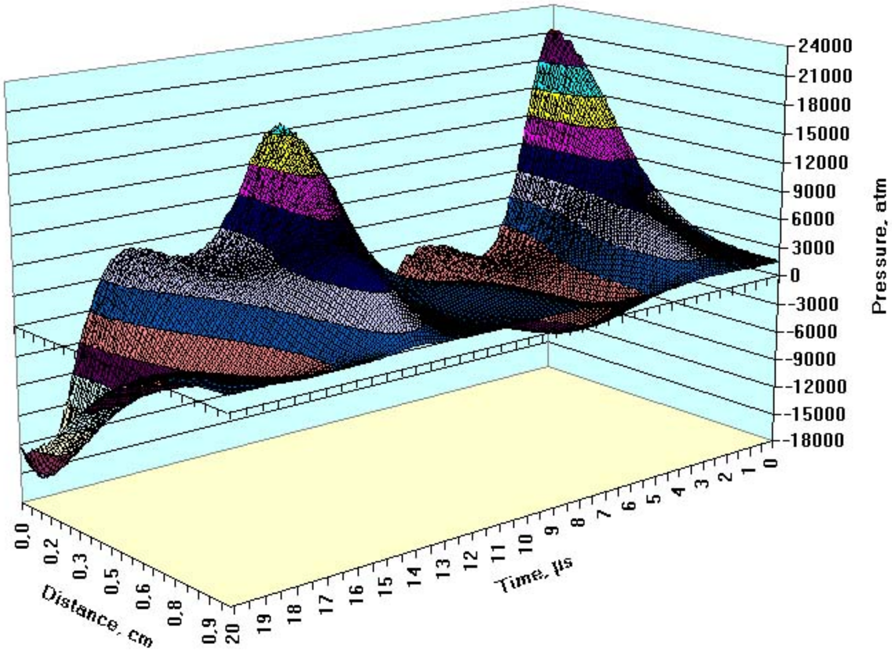
- HEIGHTS simulation (Ahmed Hassanein, ANL):

Mercury Jet with 4 mm Beam and B-field Diffused in

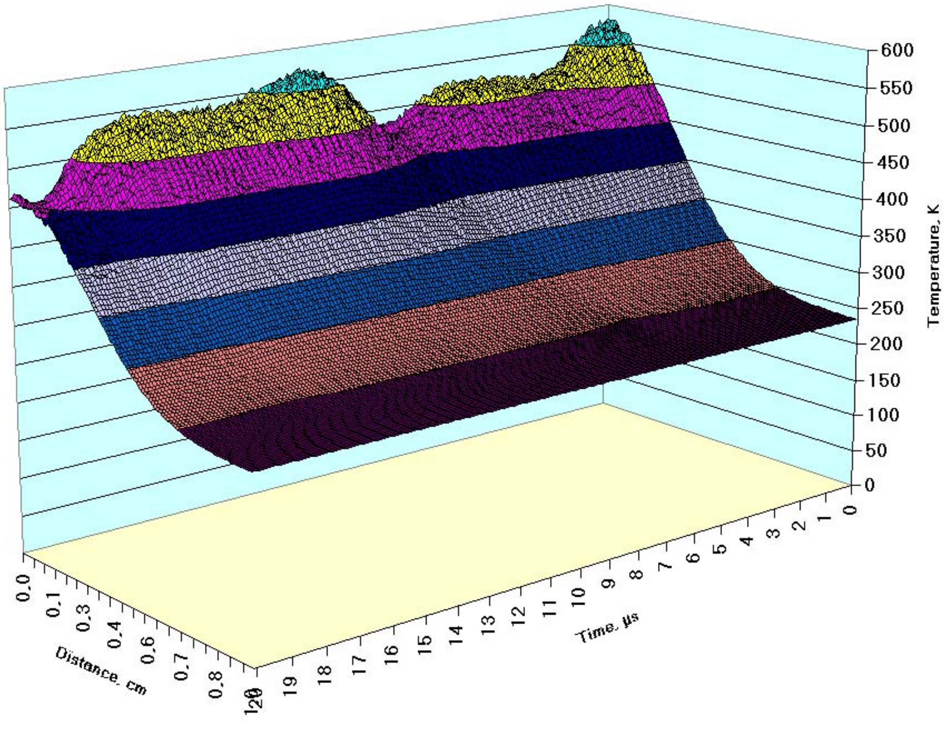


Pressure and Temperature Profiles

Pressure inside Hg Jet with Field Diffused

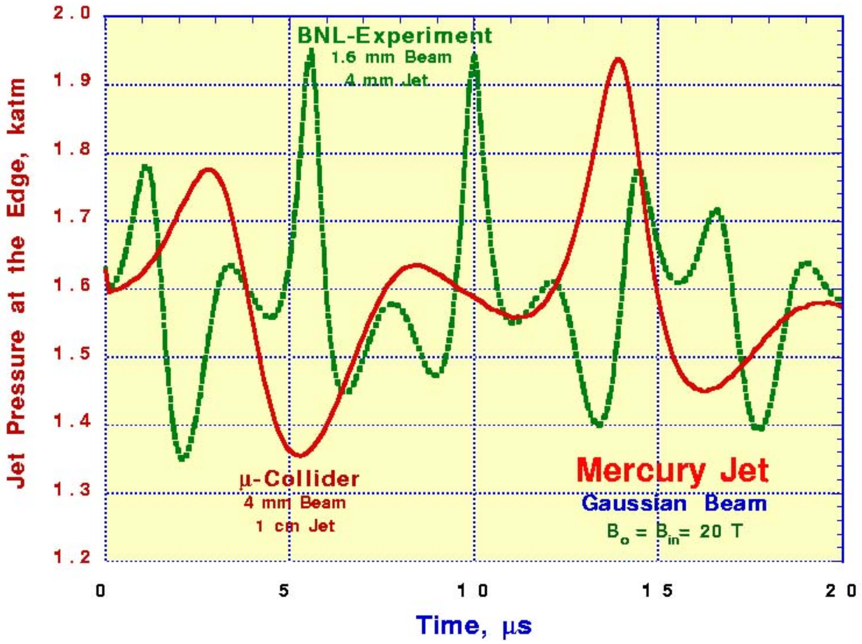


Temperature Inside Hg Jet with Field Diffused

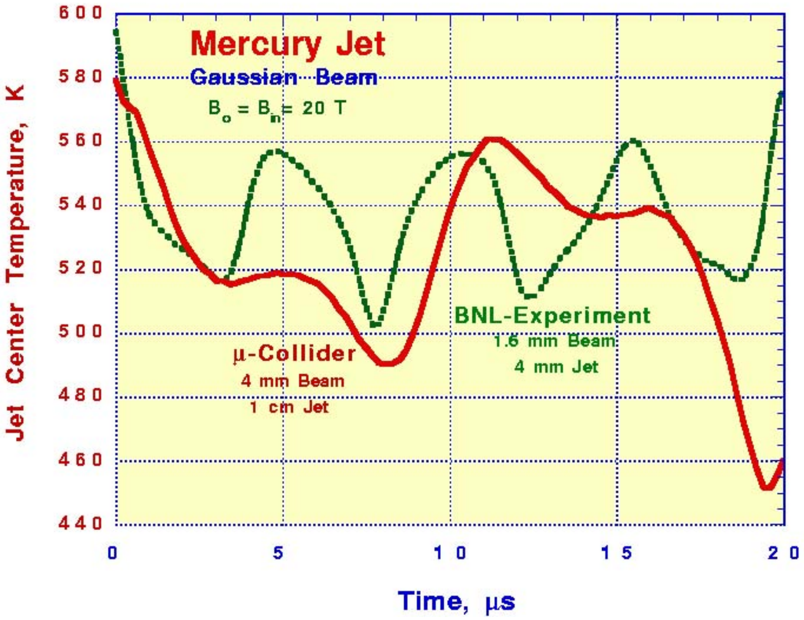


Effect of a Scaled-Down Target

HEIGHTS Analysis of Total Edge Pressure Inside Mercury Jet



HEIGHTS Analysis of Jet Center Temperature Inside Mercury Jet



Schedule

- FY99:

  Prepare A3 area; begin work on liquid jets, extraction upgrade, magnet systems, and rf systems.

- FY00:

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

  (600 hours of AGS beamtime).

- 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).

AGS Operations Issues

- In FY00/01, HEP operation of AGS is only for the $g - 2$ experiment, with fast extraction. P951 is very compatible with parasitic running in this condition.
- After FY01, no DOE approved HEP operation of the AGS.
- The AGS2000 program proposes running slow extracted proton beam 30-35 weeks/yr, for 16-20 hours/day during RHIC operation.
- P951 requires fast extracted beam, so cannot parasite off the AGS2000 program; we must interleave running with AGS2000, but seek $\lesssim 6$ weeks/yr.
- If there is no other HEP operation of the AGS after FY01, P951 would then bear the full incremental cost of proton beam running.