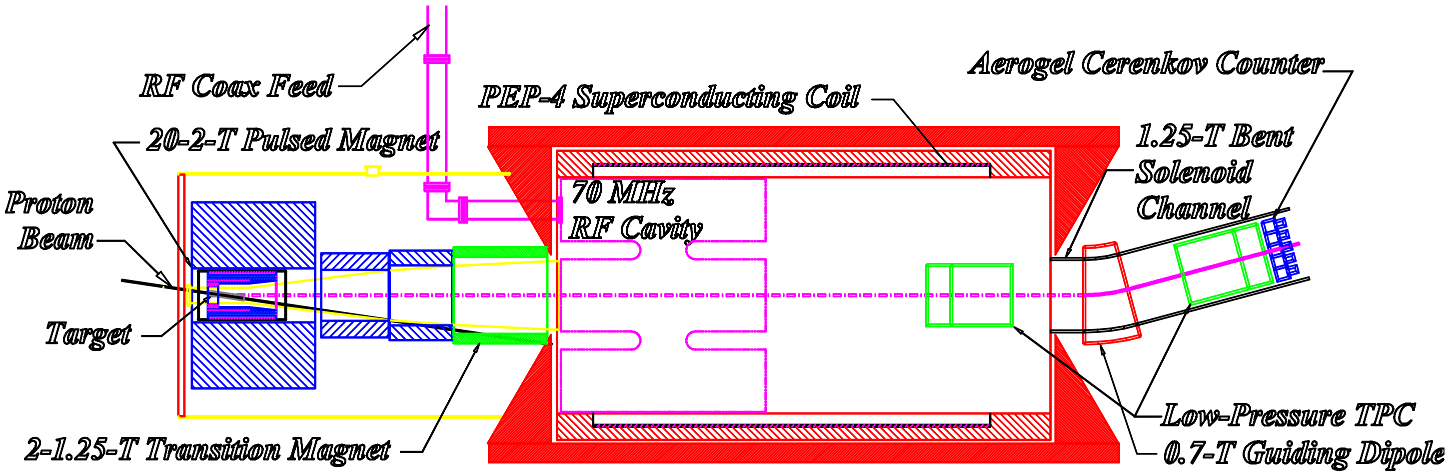

An R&D Program for Targetry and Capture at a Muon-Collider Source

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July 22, 1999

Muon Collider Targetry page:

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

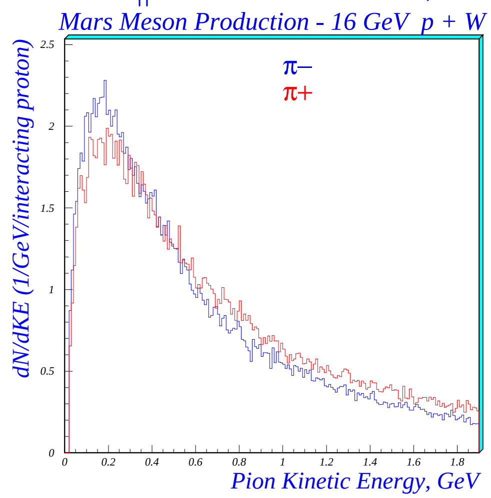
Muon Requirements

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

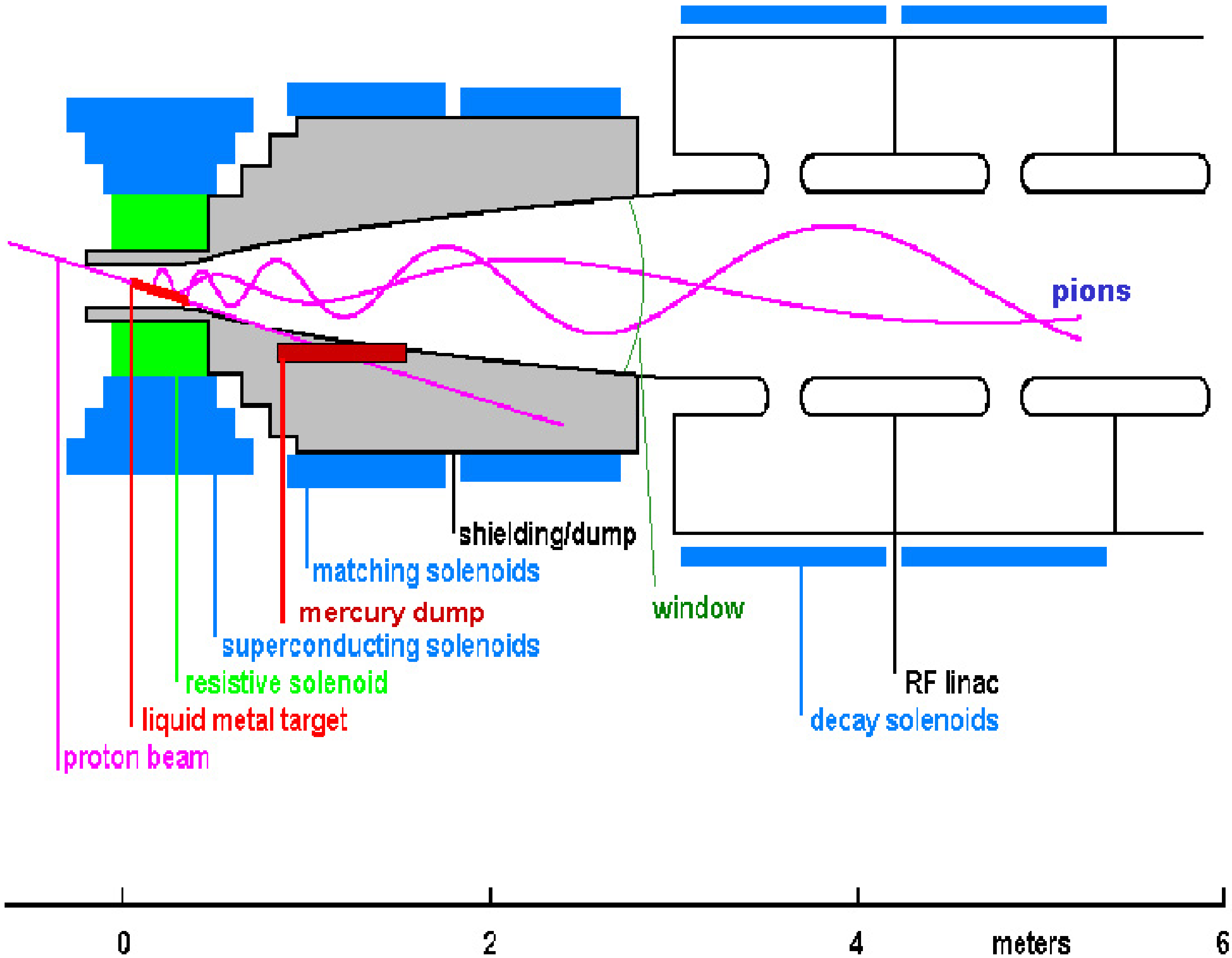
The Muon Source

- 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).

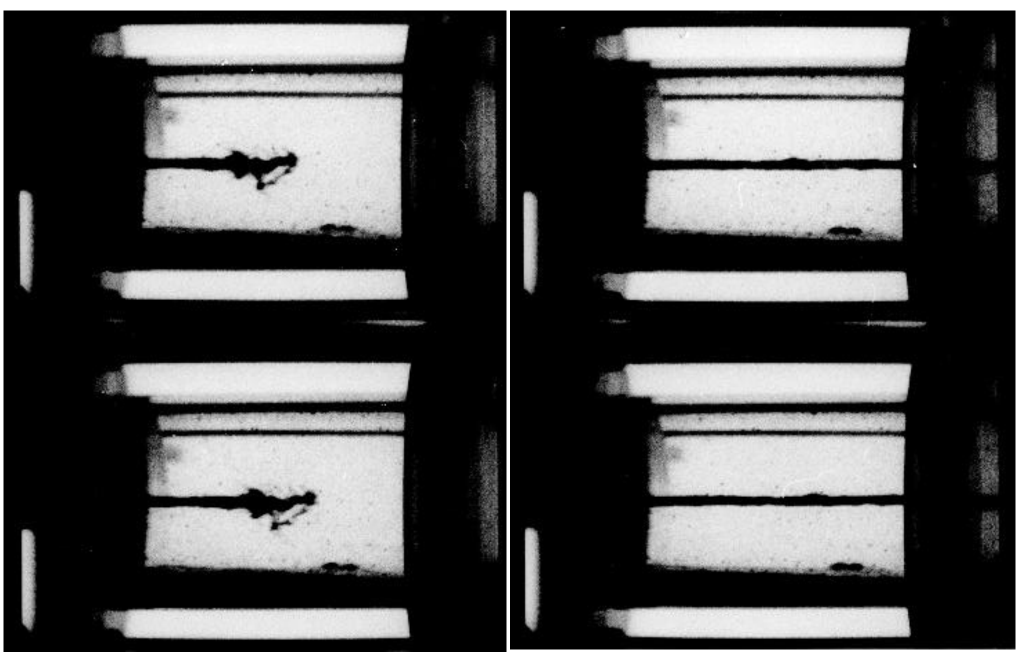
Overview of Targetry for a Muon Collider



- 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

A. Poncet

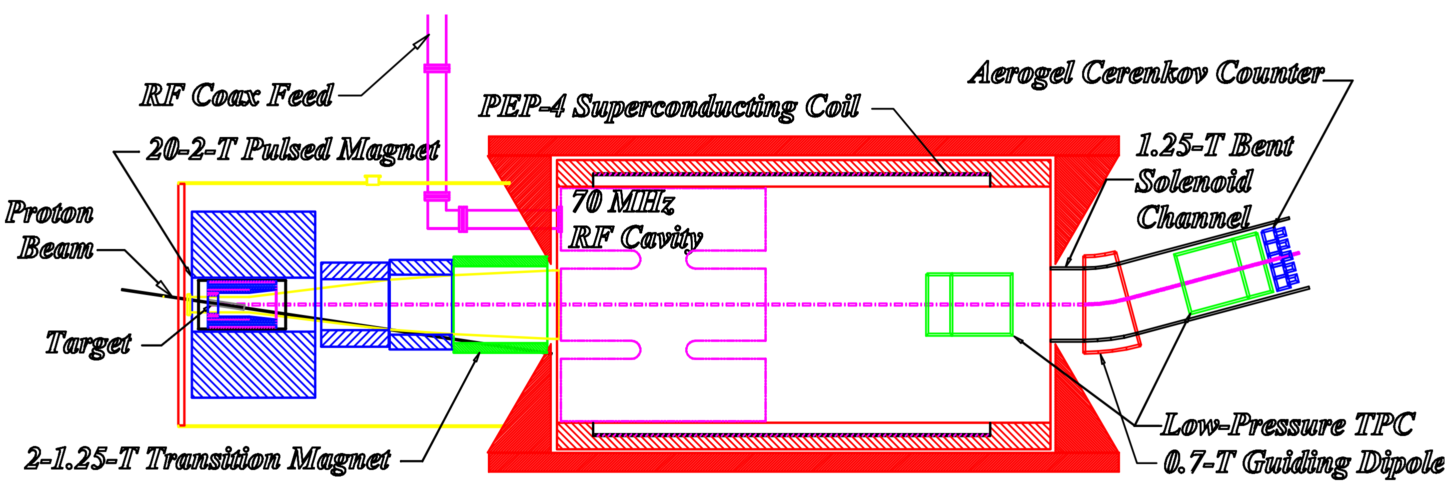
- Is the first rf cavity viable?
  - High-gradient (5 MeV/m), low-frequency ($\approx$ 70 MHz) rf cavity only 3 m downstream of target.
  - $> 10^{14}$ particles traverse the cavity each proton pulse; many hit the cavity wall.
  - Cavities tested against breakdown from beam-induced showers only up to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

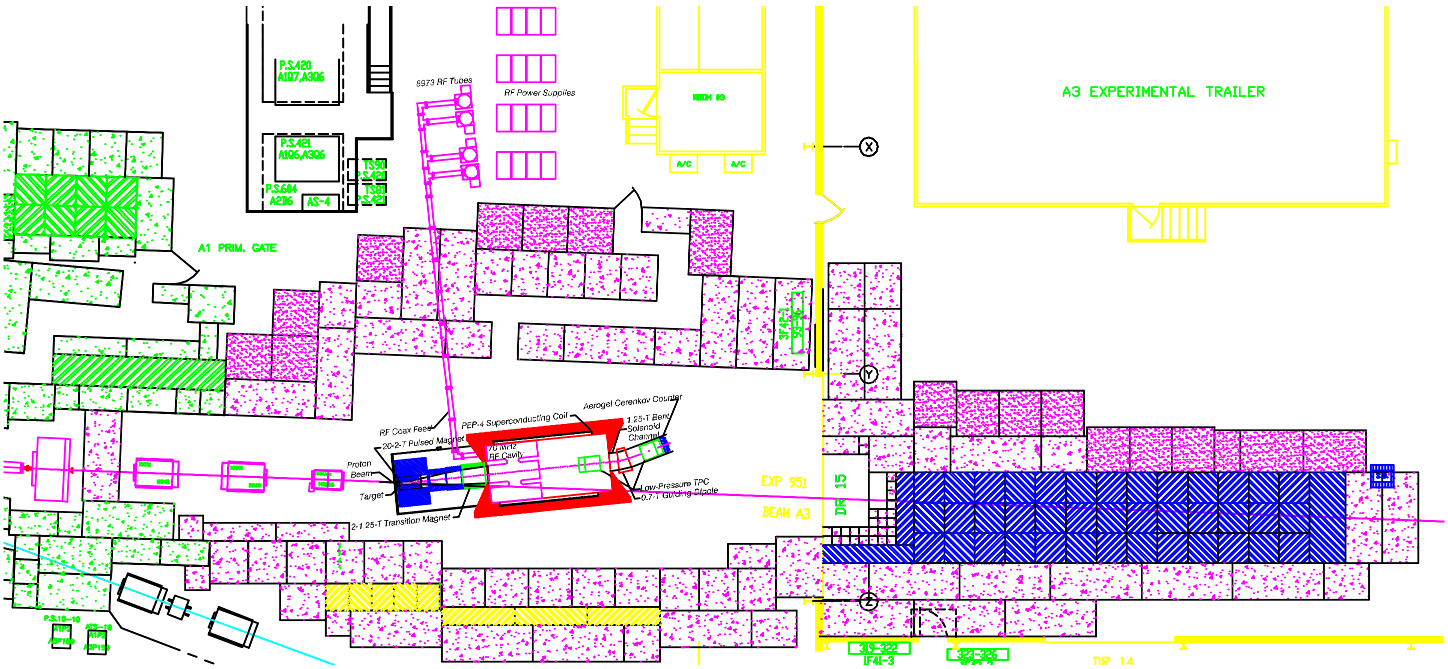
Parameter	Muon Collider	BNL AGS	FNAL Booster	CERN PS	LANSCE PSR
Proton Energy (GeV)	16-24	24	8.9	24	0.8
p/bunch	5×10^{13}	1.6×10^{13}	6×10^{10}	4×10^{12}	3×10^{13}
No. of bunches	2	6	84	8	1
p/cycle	1×10^{14}	1×10^{14}	5×10^{12}	3×10^{13}	3×10^{13}
Bunch spacing (ns)	≈ 1000	440	18.9	250	–
Bunch train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

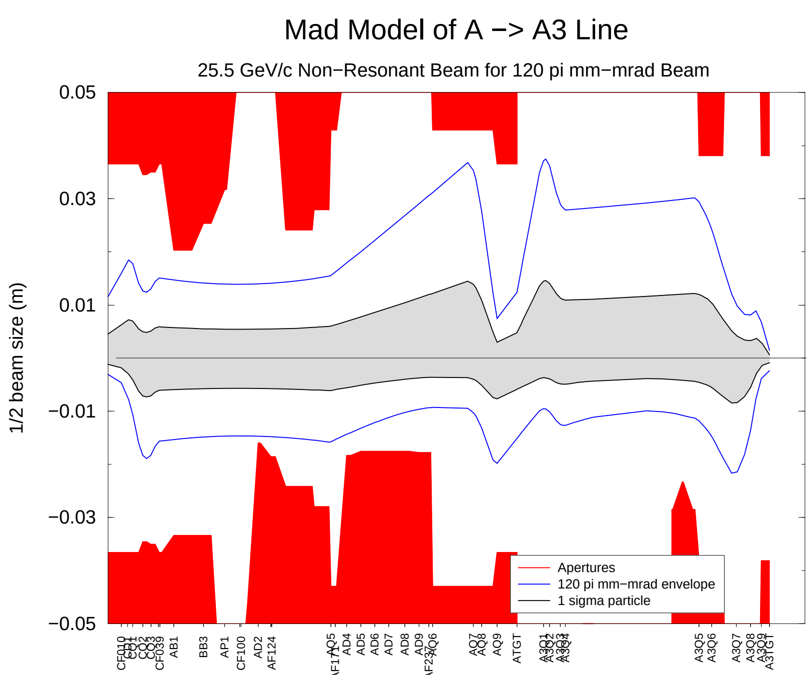
1. Simple tests of liquid (Ga-Sn, Hg) and solid (Ni) targets with AGS Fast Extracted Beam (FEB).
2. Test of liquid jet entering a 20-T magnet (20-MW cw Bitter magnet at the National High Magnetic Field Laboratory).
3. Test of liquid jet with 10^{14} ppp via full turn FEB (without magnet).
4. Add 20-T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

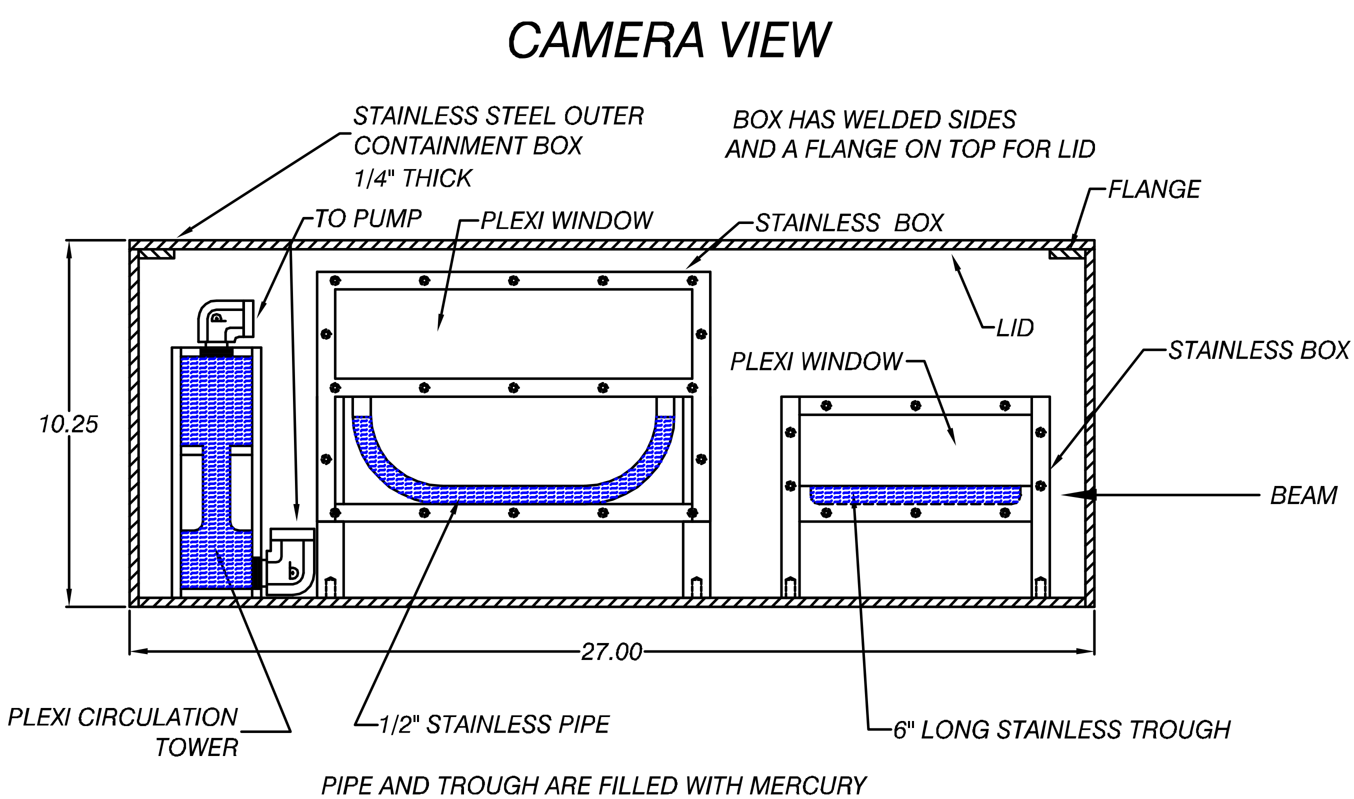
- Site presently under consideration: A3 line.



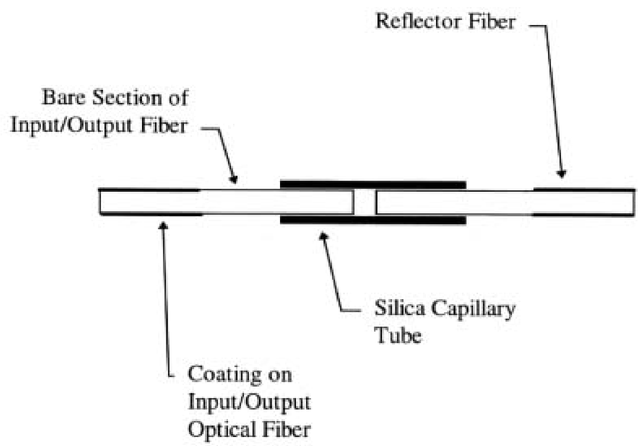
- What beamline upgrades are needed to bring a 100 mm-mrad beam to a spot with $\sigma_r = 1$ mm? (Kevin Brown)

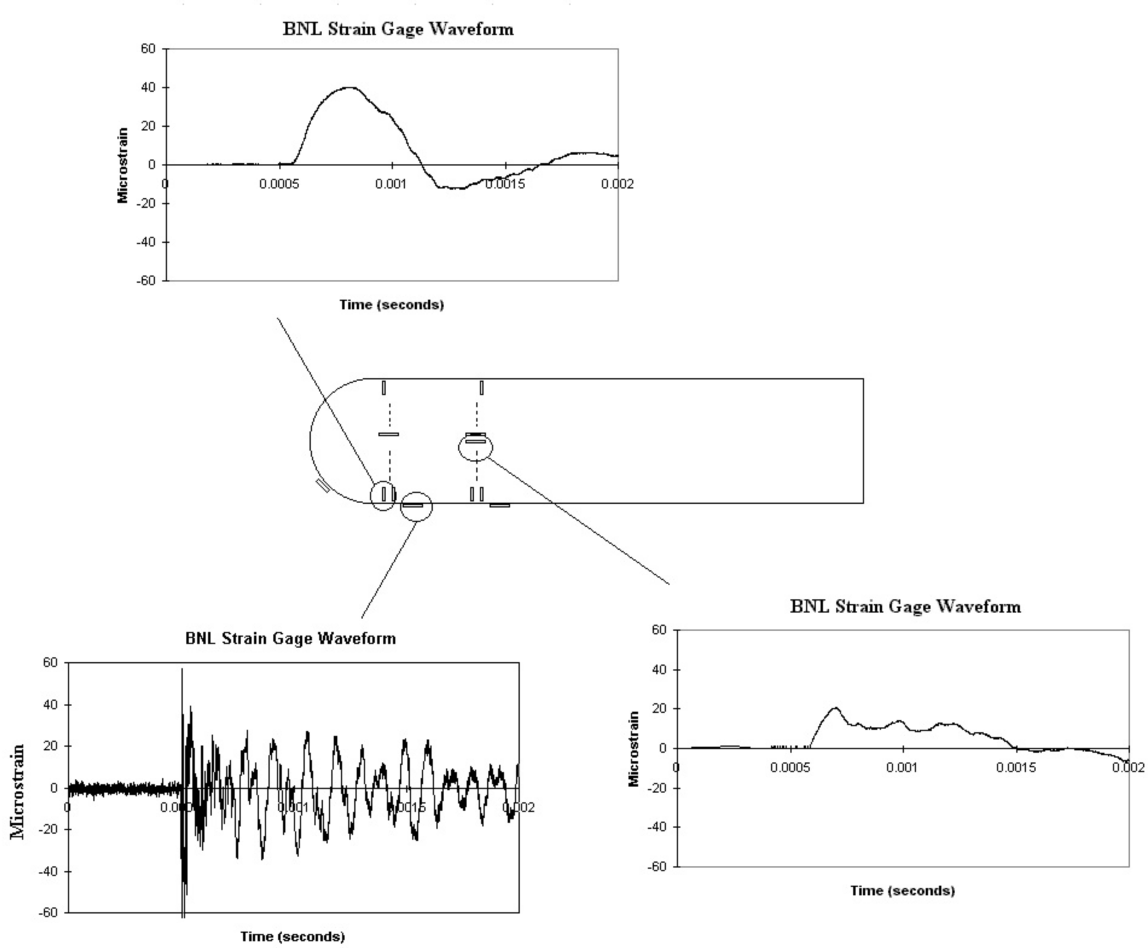


- Beamline instrumentation upgrades: spot size, beam current, FEB radiation monitoring.
- Run first tests parasitic to $g-2$ expt. in Mar/Apr 2000.
- Data taking via pulse-on-demand once every few minutes; but desire 1-Hz running for beam tuning.
- Shielding needed for 1-Hz running with 10^{14} ppp =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



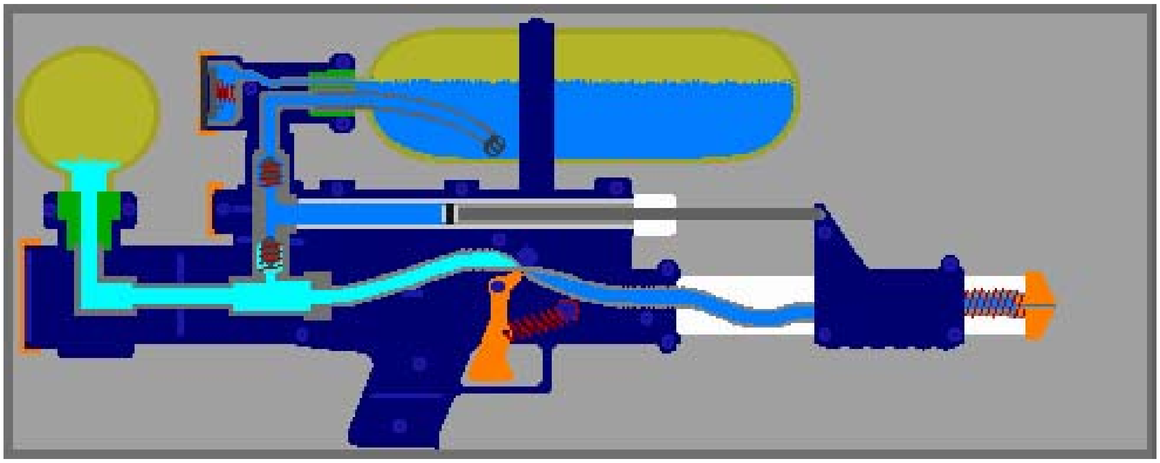
- Instrumentation: high-speed camera, fiberoptic strain sensors (Duncan Earl, ORNL).



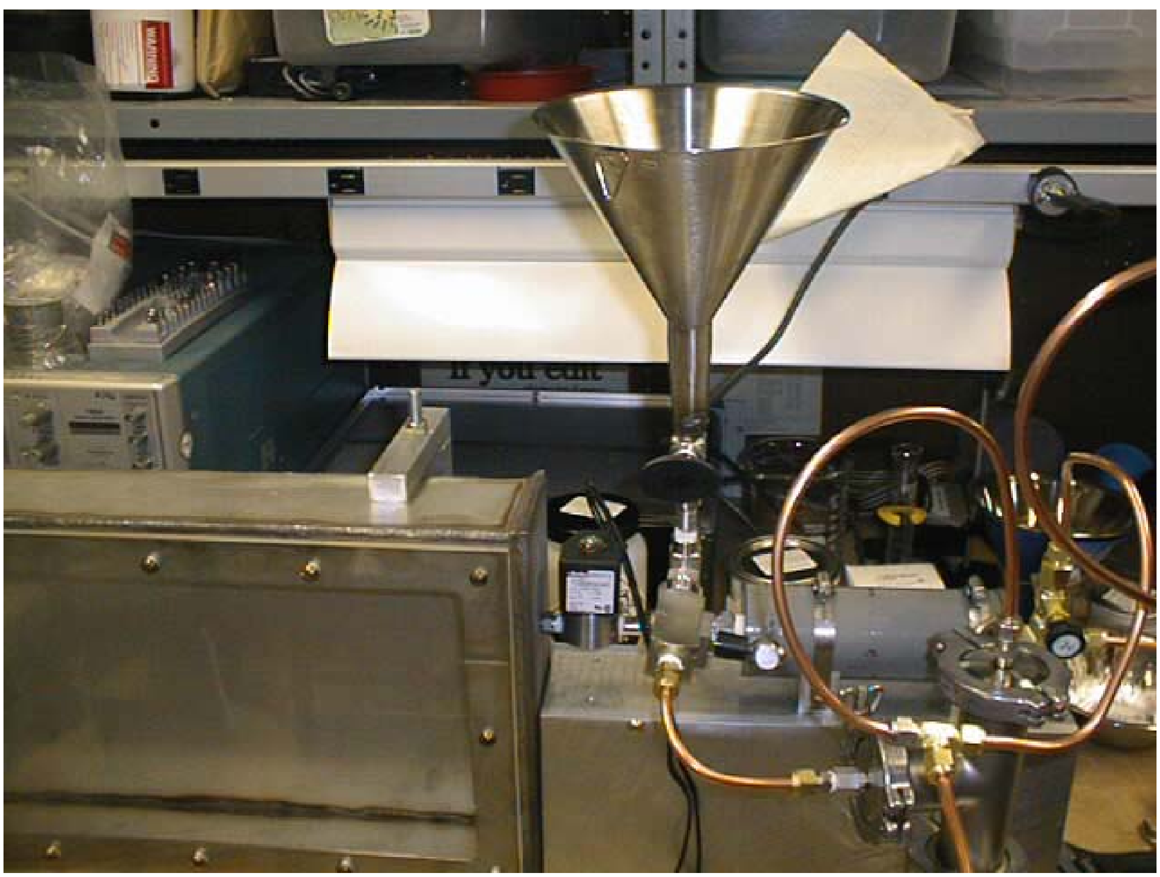


Issues, 2: Pulsed Liquid Jet

- Inspiration:

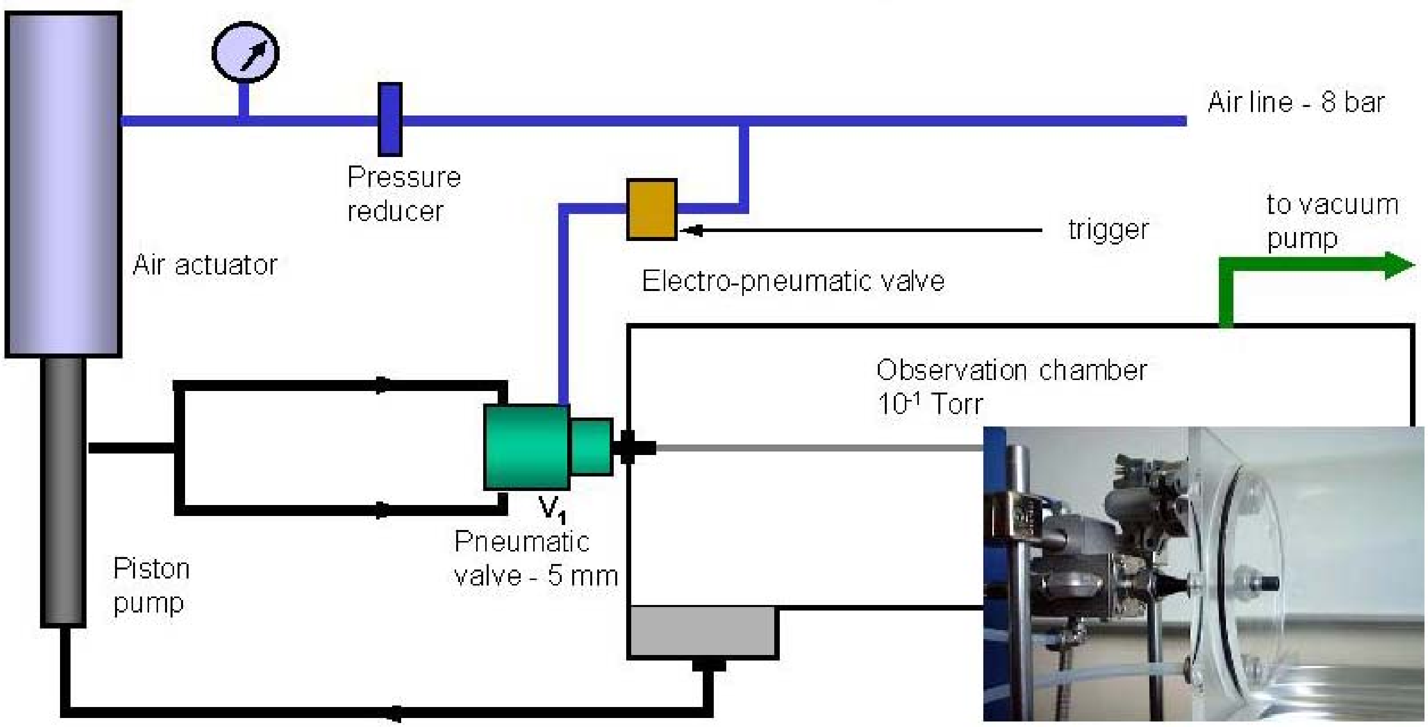


- Prototype jet using Ga-Sn, a room temperature liquid (Princeton).



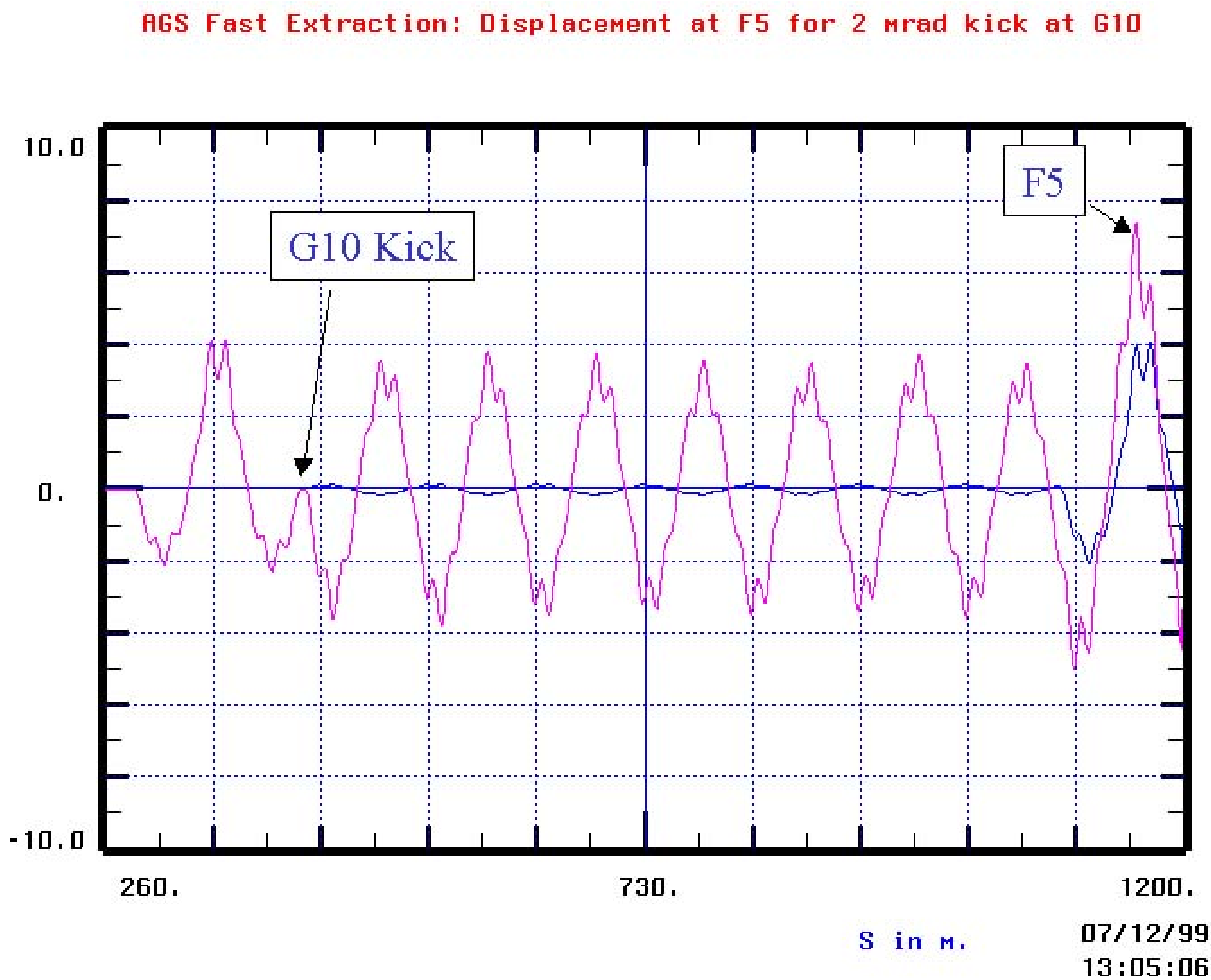
- May 18, 1999: Ga-Sn jet breaks up too quickly, forms oxide scum:

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



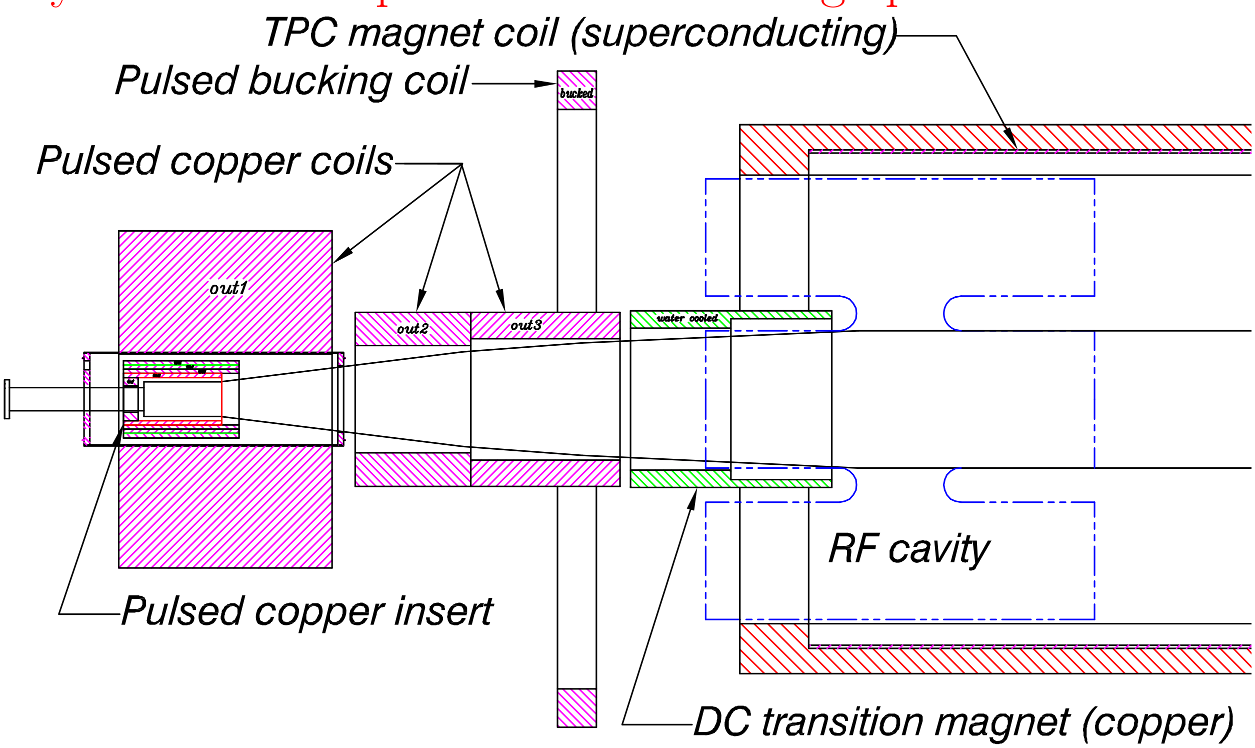
Issues, 3: Full Turn Extraction

- 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.



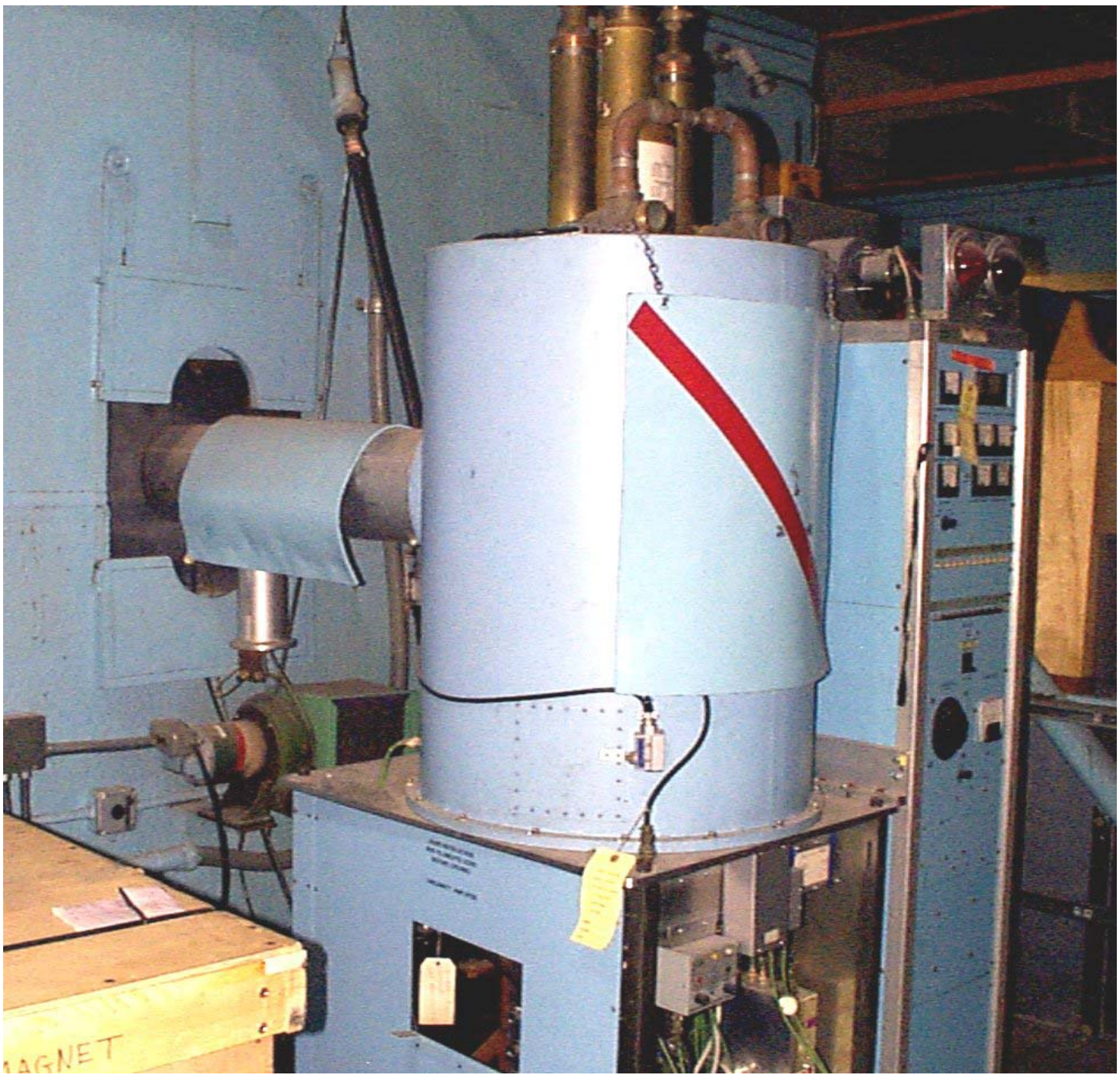
Issues, 4: Pulsed 20-T Magnet

- 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.

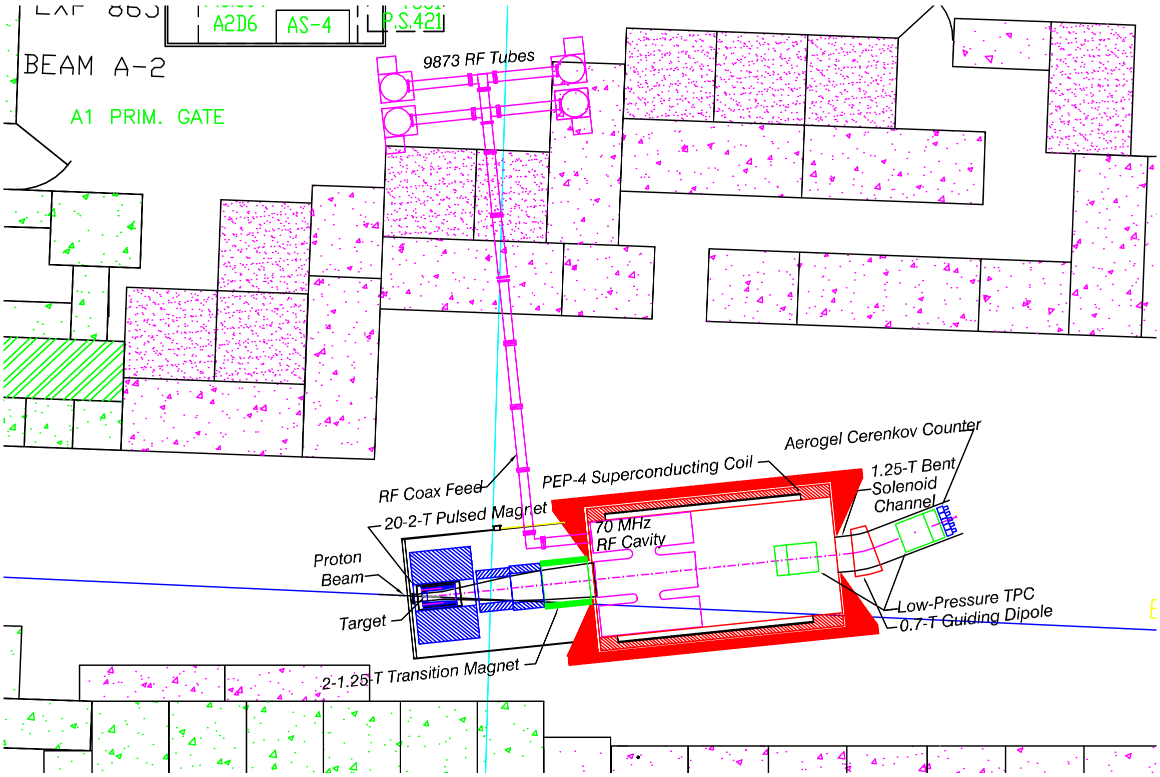


Issues, 5: 70-MHz RF Cavity

- 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).



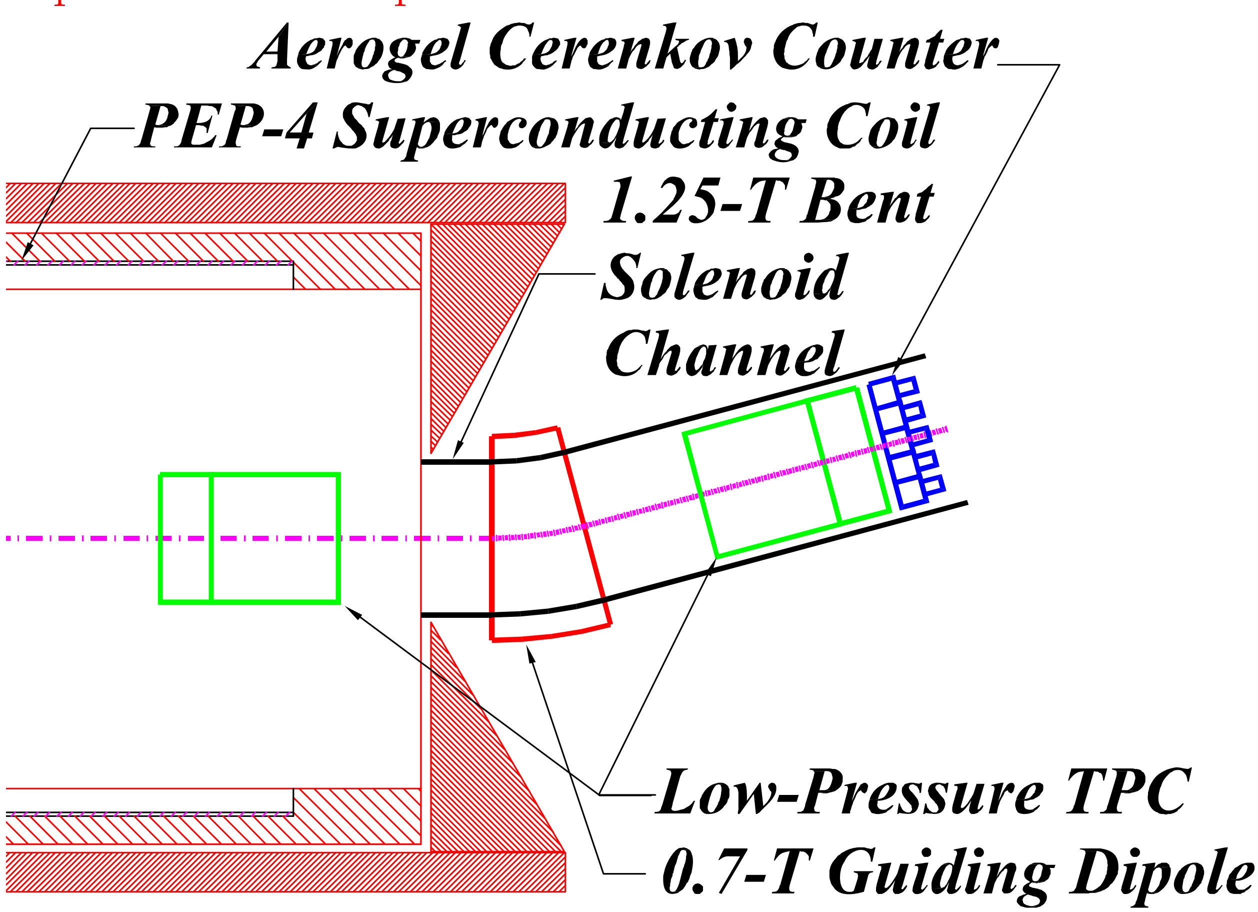
- The tubes and electronics should arrive at BNL early FY00.
- Ideal test site would be just outside A3 cave, close to final location.
- The 8973 tubes may need magnetic shielding.
- We are also embarking on an R&D program with industry to develop a 50-MW peak power, 70-MHz power supply (EEV, Eimac, 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.

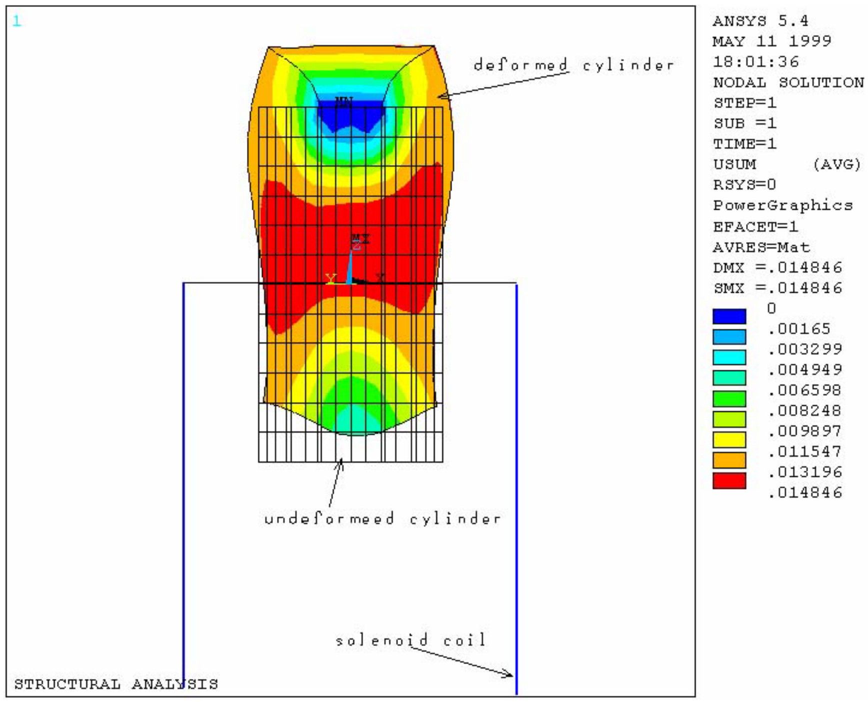
Issues, 7: Characterization of Pion Yield

- 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.

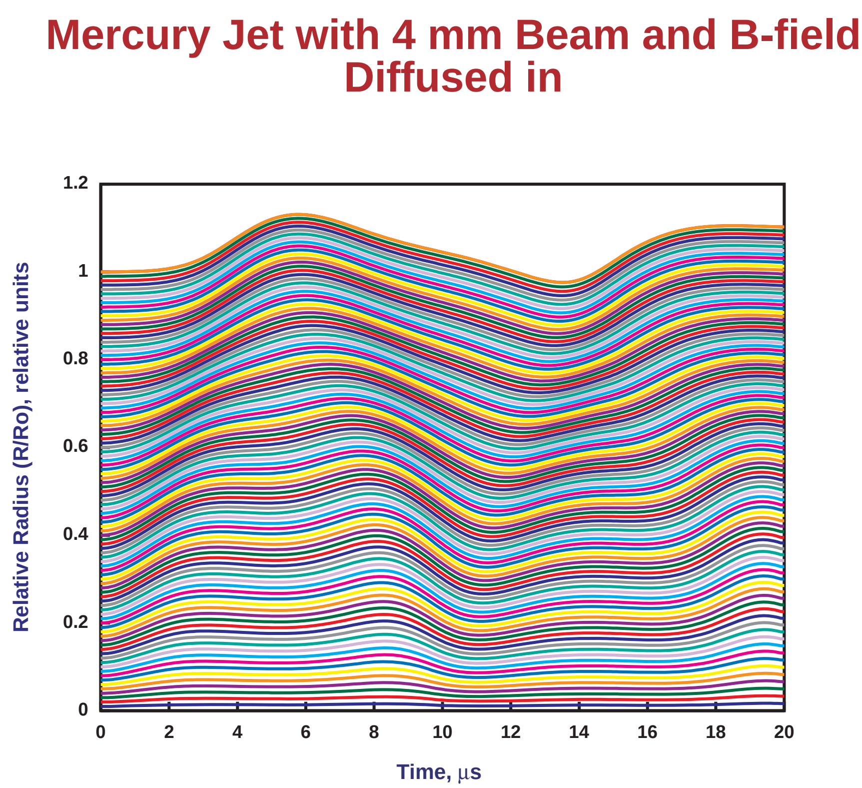


Issues, 8: Simulation of Beam-Jet-Magnet

- ANSYS simulation (Changguo Lu, Princeton):

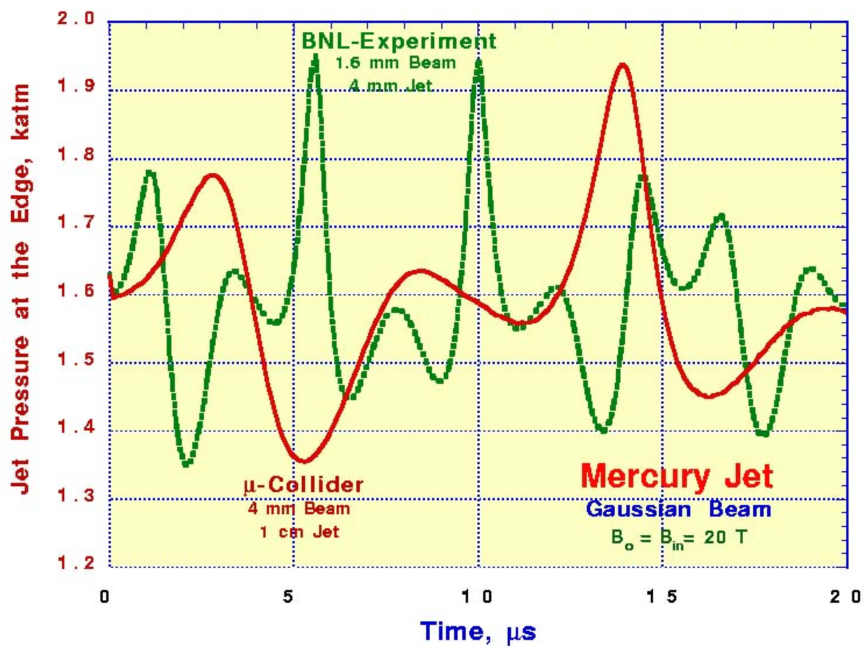


- HEIGHTS simulation (Ahmed Hassanein, ANL):

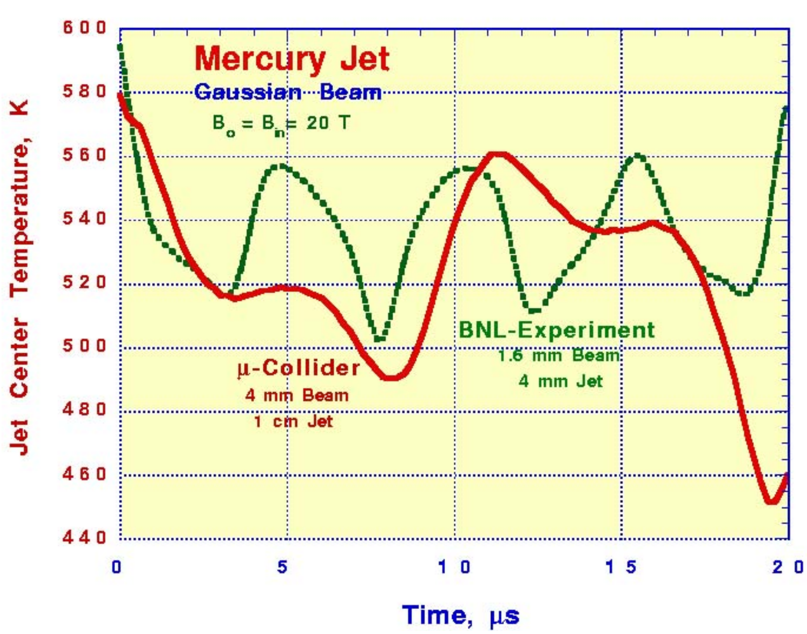


Effect of a Scaled-Down Target

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.

Budgets

Yearly Summary

Category	FY99	FY00	FY01	FY02	FY03	Total
Base Program	$0.5M	$1.5M	$2M	$2M	$1M	$7M
AGS Operations		$1M	$1M	$1M	$1M	$4M
RF Power Source	$0.05M	$0.5M	$1M	$1M	$1M	$3.5M

FY99

Task	ANL	BNL	LBL	Princeton	Industry	Total
Initial Jet Studies		20		85		105
AGS Beamline Upgrades		100				100
Pulsed Solenoid Design		50				50
RF Systems		65	75		50	190
Simulation Studies	75			5		80
Total	75	285	75	90	50	**$525k**

FY00 (Projected)

Task	ANL	BNL	LBL	Princeton	Industry	Total
Initial Jet Studies		100		90		190
AGS Beamline Upgrades		400				400
AGS Operations		1000				1000
Magnet Systems		300				300
RF Systems		375	75		500	950
Simulation Studies	150			10		160
Total	150	2175	75	100	500	**$3000k**

Closing Remarks

- We seek a timely recommendation of approval for the proposed R&D program on targetry and capture.

- Proposal P951 submitted to BNL AGS Division Sept. 1998.

- Presented to the AGS/RHIC PAC on May 25, 1999:

  "The PAC recognizes that future progress in elementary particle physics will require accelerators of higher energy than those currently operating or under construction.

  There are only a few possible paths to this higher energy. Of these, the muon collider offers interesting and promising features. However, it is clear that before a decision could be made to choose this option, substantial research and development must demonstrate that the muon collider approach is realistic.

  The AGS offers significant and unique capabilities as a test facility for the targeting and capture phase of the muon collider R&D. We were pleased to hear that members of the muon collider collaboration are pursuing these directions. We encourage the proponents of P951 and others to continue their work.

  Additional technical study is needed to determine what is required for the lab to make a significant contribution to the muon collider R&D program within the frame work of a national, possibly international, effort. Such a study should maintain a broad perspective and take technical, cost, schedule and safety issues into account."

- Presented to the BSA Science and Technology Steering Committee on June 4, 1999.