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

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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/

AIP Conference Proceedings, Vols. 352, 372, 435 & 441

The Y2K Problem for Particle Physics

- Can elementary particle physics prosper for a 2nd century with laboratory experiments based on innovative particle sources?
- Can a full range of new phenomena be investigated:
  - Neutrino mass $\Rightarrow$ a 2nd 3×3 (or larger?) mixing matrix.
  - Precision studies of Higgs bosons.
  - A rich supersymmetric sector (with manifestations of higher dimensions).
  - ... And more ....
- Will our investment in future accelerators result in more cost-effective technology, that is capable of extension to 10's of TeV of constituent center-of-mass energy?

The Solution...

- A **Muon Collider** is the best option to accomplish the above!

What is a Muon Collider?

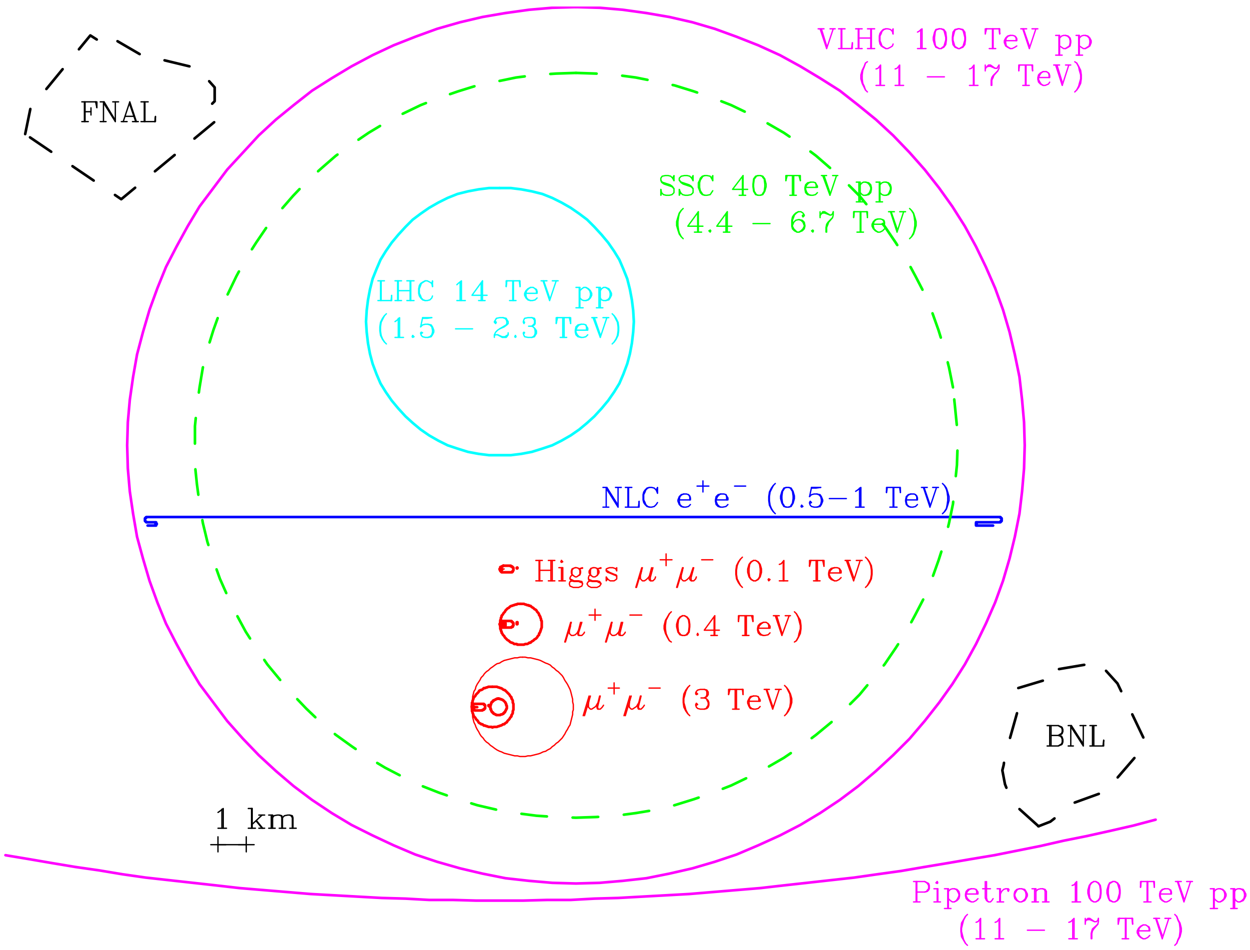
An accelerator complex in which

- Muons (both μ^+ and μ^-) are collected from pion decay following a pN interaction.
- Muon phase volume is reduced by 10^6 by ionization cooling.
- The cooled muons are accelerated and then stored in a ring.
- $\mu^+\mu^-$ collisions are observed over the useful muon life of ≈ 1000 turns at any energy.
- Intense neutrino beams and spallation neutron beams are available as byproducts.

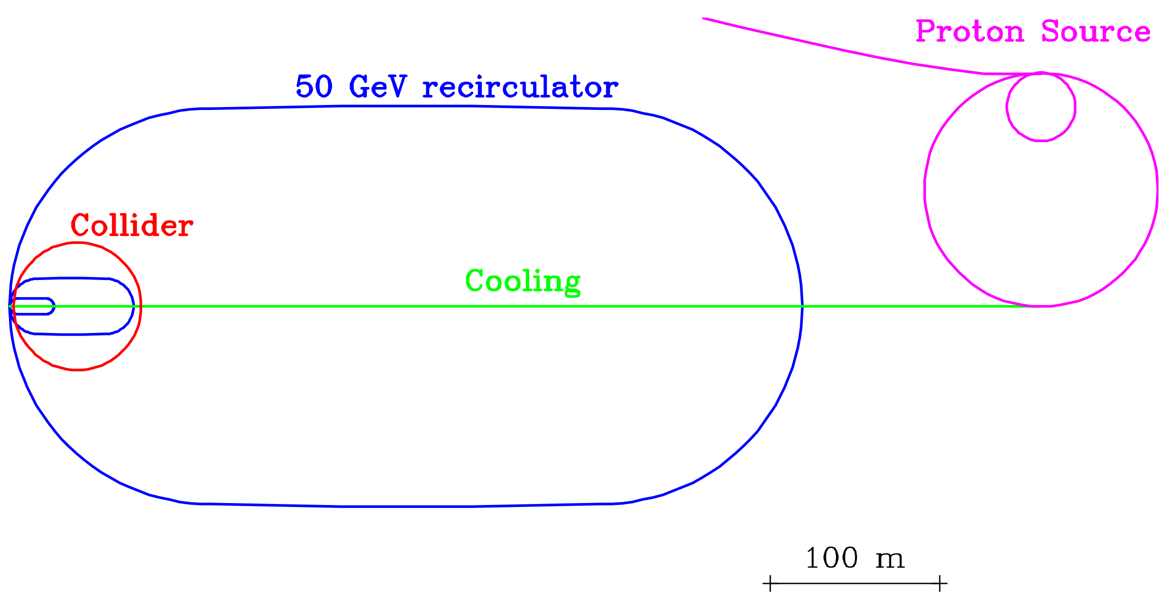
Muons decay: $\mu \to e\nu \qquad \Rightarrow$

- Must cool muons quickly (stochastic cooling won't do).
- Detector backgrounds at LHC level.
- Potential personnel hazard from ν interactions.

Footprints



A First Muon Collider to study light-Higgs production:



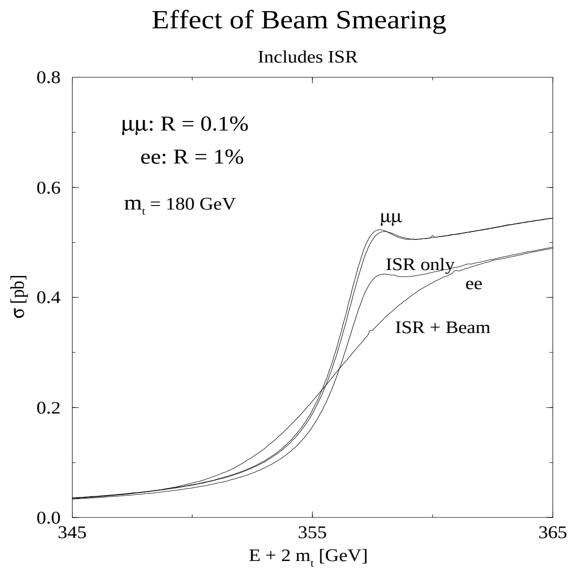
The Case for a Muon Collider

- More affordable than an e^+e^- collider at the TeV (LHC) scale.
- More affordable than either a hadron or an e^+e^- collider for (effective) energies beyond the LHC.
- Precision initial state superior even to e^+e^-.

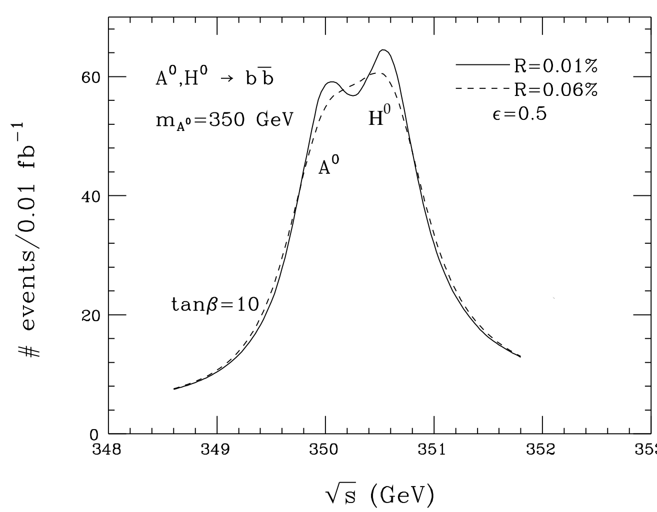
  Muon polarization $\approx 25\%$,

  $\Rightarrow$ Can determine $E_{\rm beam}$ to 10^{-5} via $g-2$ spin precession.

$t\bar{t}$ threshold:



Nearly degenerate A^0 and H^0:



- Initial machine could produce light Higgs via s-channel:

  Higgs coupling to μ is $(m_\mu/m_e)^2 \approx 40,000\times$ that to e.

  Beam energy resolution at a muon collider $< 10^{-5}$,

  $\Rightarrow$ Measure Higgs width.

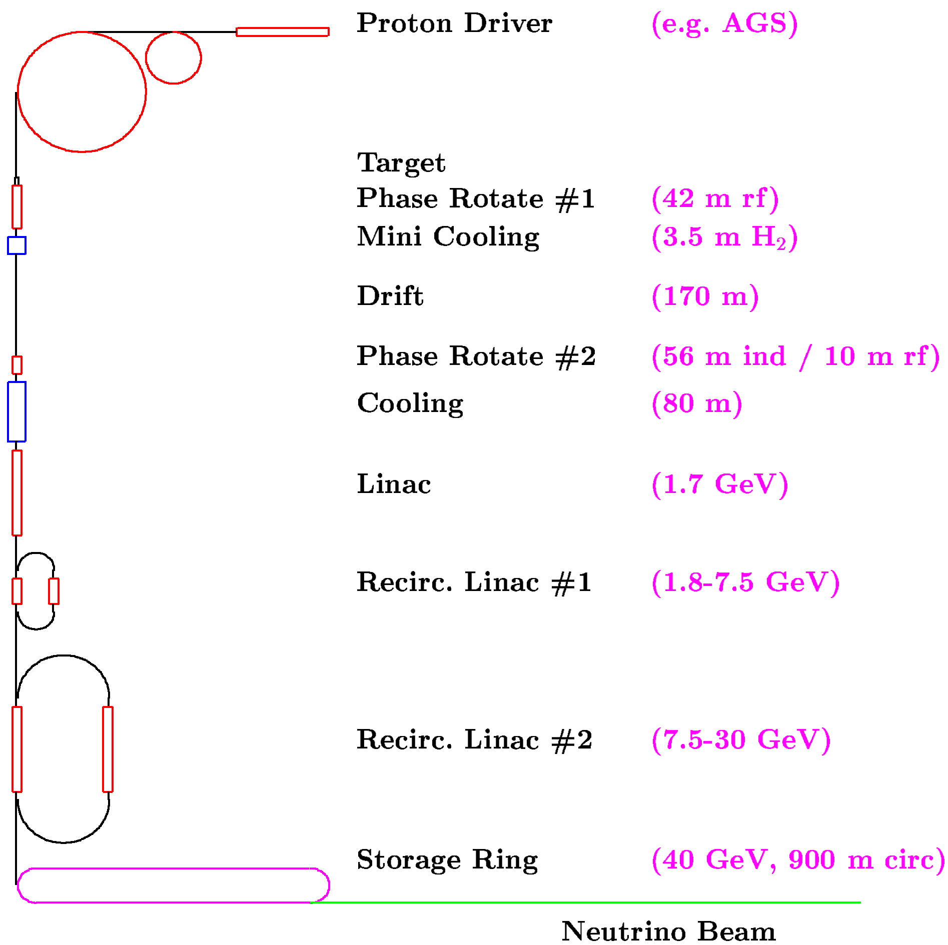
  Add rings to 3 TeV later.

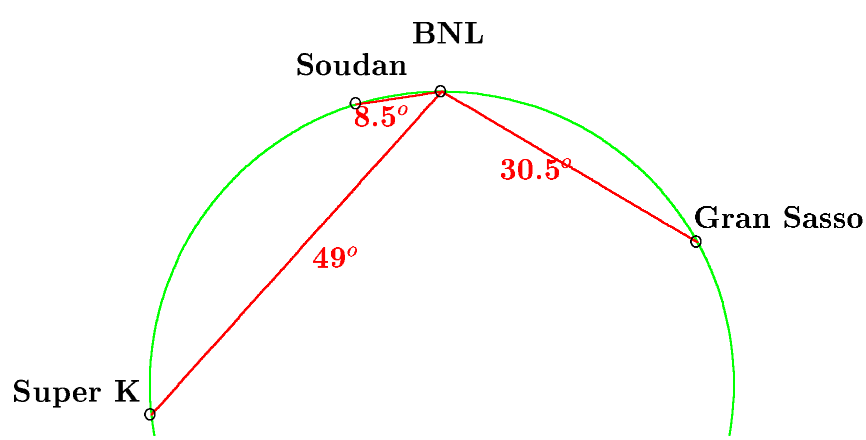
- Neutrino beams from μ decay about 10^4 hotter than present.

  Initial scenario in a low-energy muon storage ring.

  Study CP violation via CP-conjugate initial states:

$$\mu^+ \to e^+ \overline{\nu}_\mu \nu_e, \qquad \mu^- \to e^- \nu_\mu \overline{\nu}_e.$$





HEPAP Subpanel Report on PLANNING FOR THE FUTURE OF U.S. HIGH-ENERGY PHYSICS

February 1998

Recommendation on R&D for a Muon Collider

The Subpanel recommends that an expanded program of R&D be carried out on a muon collider, involving both simulation and experiments. This R&D program should have central project management, involve both laboratory and university groups, and have the aim of resolving the question of whether this machine is feasible to build and operate for exploring the high-energy frontier. The scale and progress of this R&D program should be subject to additional review in about two years.

CERN-EP/98-03
CERN-SL 98-004 (AP)
CERN-TH/98-33

Options for Future Colliders at CERN

J. Ellis, E. Keil, G. Rolandi

January 23, 1998

6 RECOMMENDATIONS

3. CERN should launch technical studies of $\mu^+\mu^-$ colliders, notably in the areas of the source and beam cooling, and should explore the possibility of locating such machines on or in the neighbourhood of the CERN site.

6. These studies should be carried out in collaborations with other laboratories, since most technical problems do not depend on the site. CERN's goal in these collaborations should be to contribute to the global pool of technologies for future collider options. It should confirm its reputation as a valuable and reliable partner in the international collaborations that will form to develop proposals for future collider projects.

The Muon Collider Collaboration

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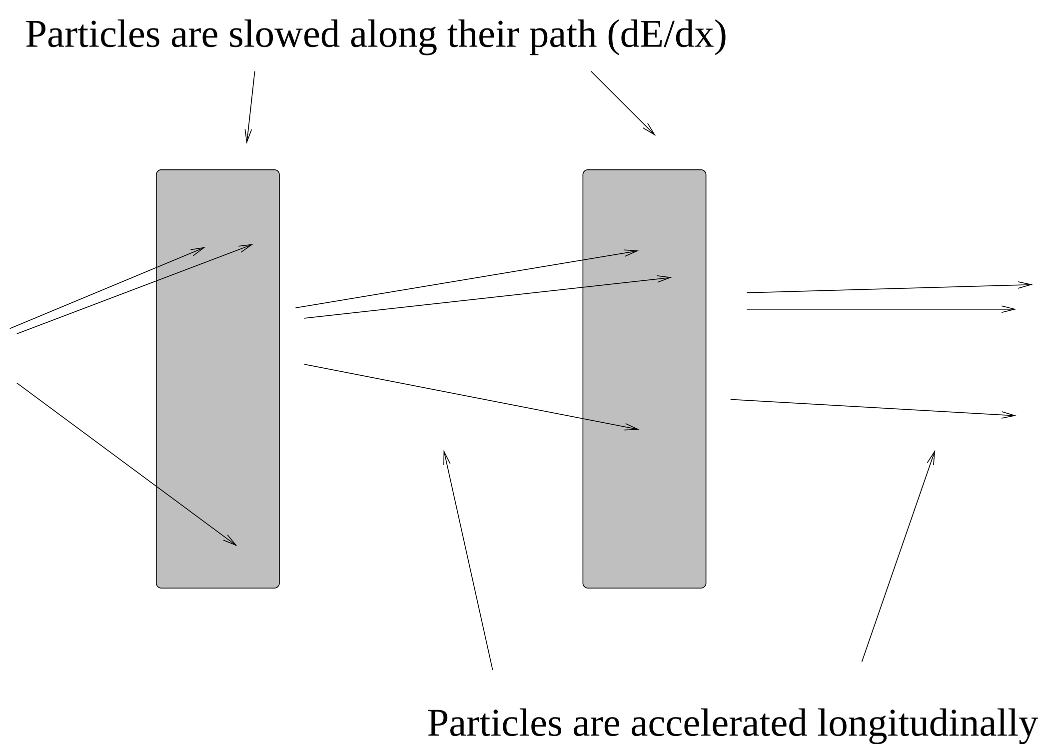
Spokesperson: R.B. Palmer

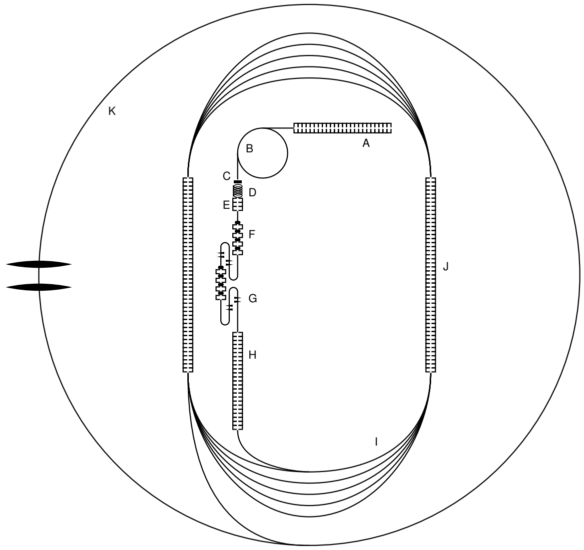
Technical Challenges

- Proton Driver, 16-GeV, 15 Hz, 4MW, 1-ns bunch
- **Targetry and Capture**
- Muon Cooling
  - Ionization: takes momentum away.
  - RF acceleration: puts momentum back along z axis.
  - $\Rightarrow$ Transverse "cooling".

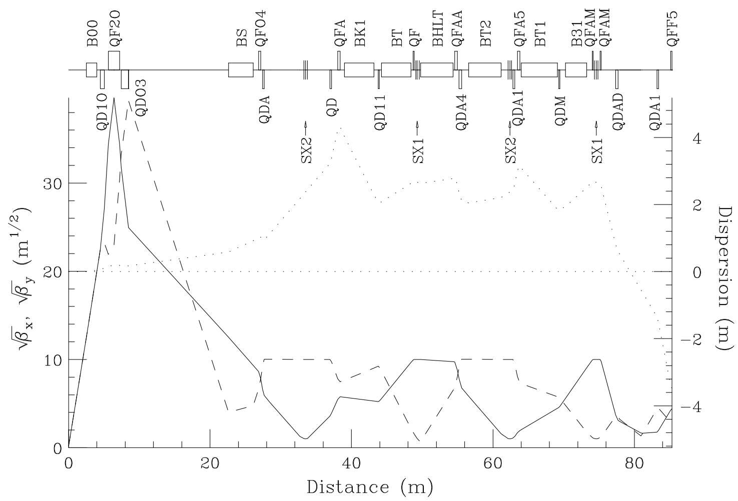


  - Origin: G.K. O'Neill, Phys. Rev. **102**, 1418 (1956).
  - Won't work for electrons or protons: use muons.
  - Lab test of ionization cooling: Fermilab P904.

- Acceleration

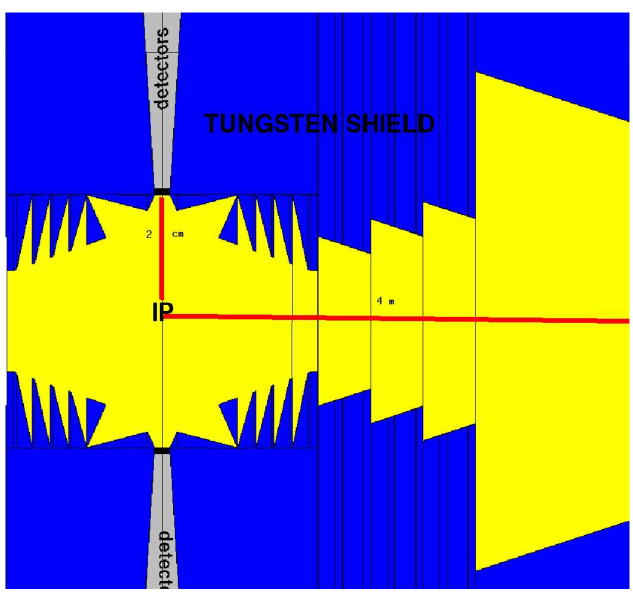


- Storage rings

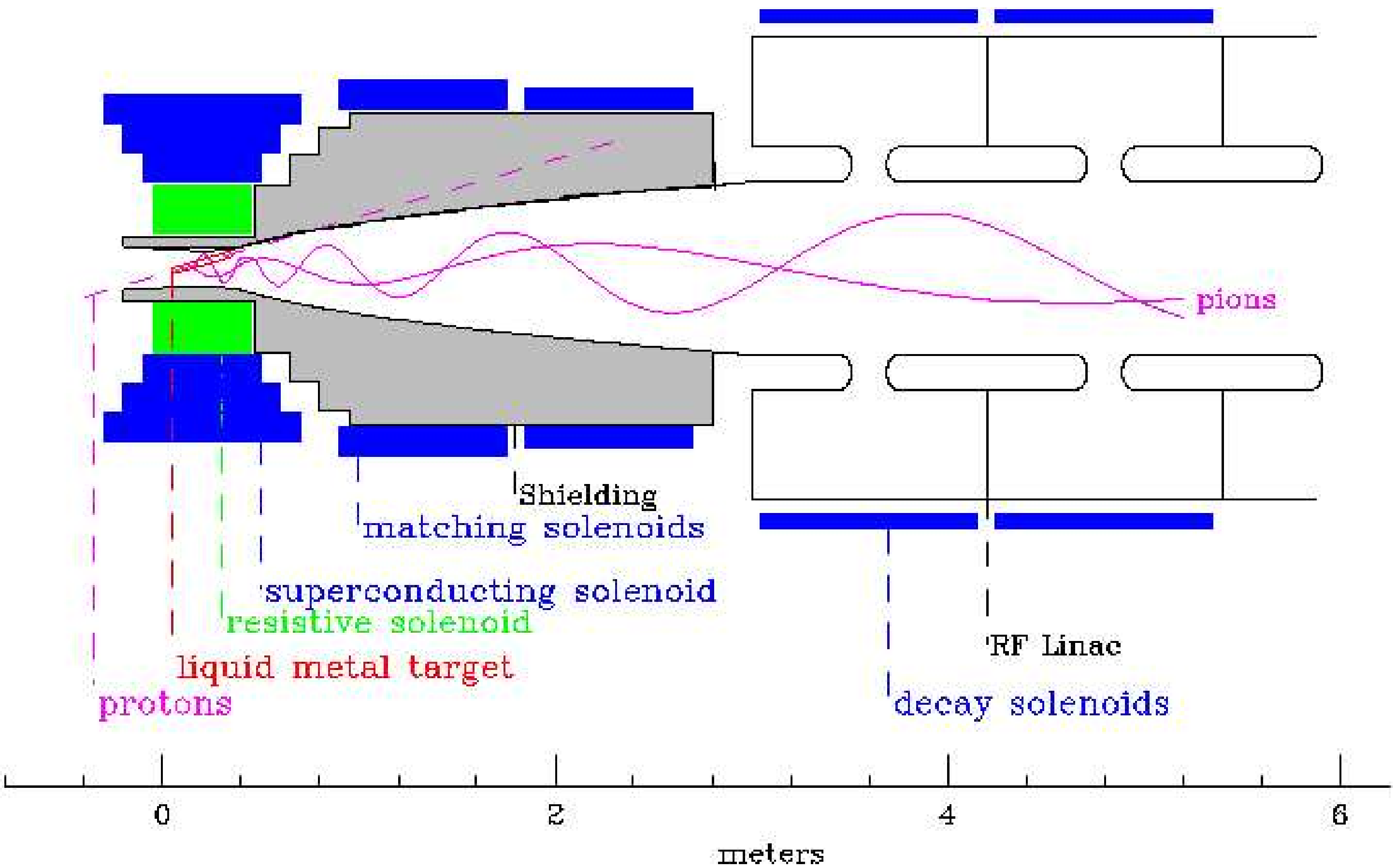


- Interaction region and detector design.

A muon's view of the interaction region:



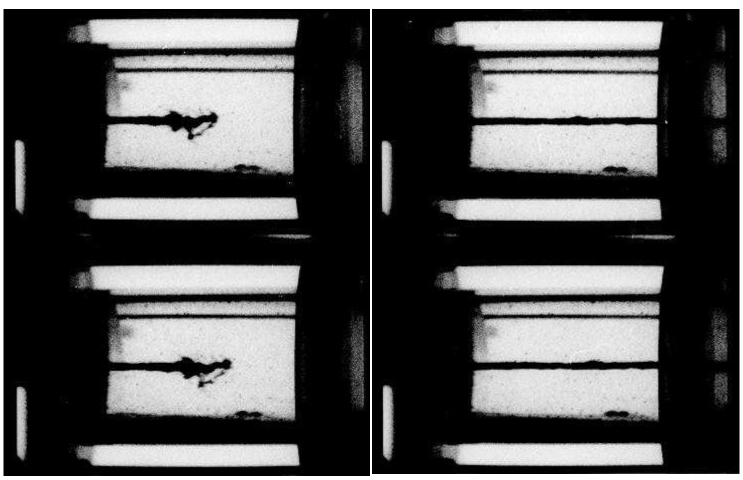
Overview of Targetry for a Muon Collider



- 1.2×10^{14} $\mu^{\pm}$/s via π-decay from a 4-MW proton beam.
- Cooling jacket around stationary target would absorb too many pions.
- Liquid-metal jet target: Ga, Hg, or solder (Bi/In/Pb/Sn).
- 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

- 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

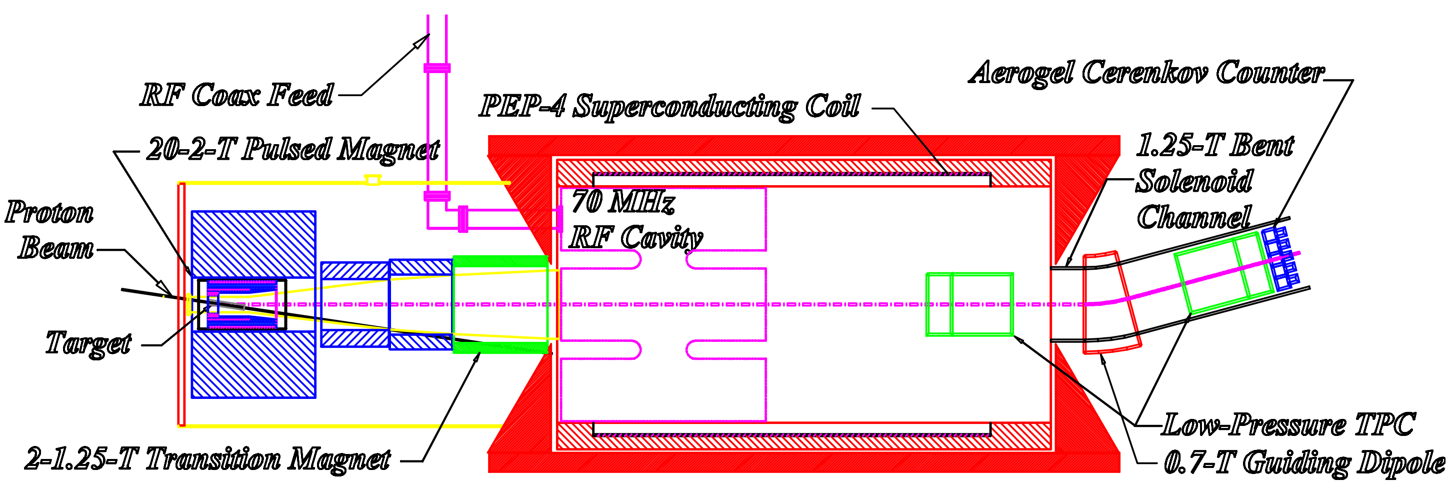
- Targetry area also contains beam dump.
  - Need 4 MW of cooling.
  - Harsh radiation environment for magnets and rf.

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.



The 8 Steps in the R&D Program

1. Simple tests of liquid (Ga-Sn) 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 Field Magnet 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 extract beam (SEB).

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

Draft of AGS Impact Statement

P951 AGS Impact Statement 5/16/99-DRAFT

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

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Institutions: **ANL,BNL,CERN,Fermilab,LBNL,ORNL,Princeton,SUNY-Stony Brook**

Propose to study the effects of an intense FEB from the AGS on liquid and solid target materials. A test was conducted in early FY 1999 in the FEB U-line, that showed a beam with an appropriate size could be delivered if some modifications are made to the beam transport. Alternative locations are being considered, in particular the A3 location on the present SEB floor.

The proposed R&D program into these targetry issues for a muon-collider source consists of eight parts:

1. Initial studies of liquid (and solid) target materials with a proton beam at the AGS.
2. Studies of a liquid-metal jet entering a 20-T magnet at the national High Magnetic Field Laboratory (NMFL) in Florida.
3. Studies of a full-scale liquid-metal jet in a beam of 100 TP protons per pulse, but without magnetic field.
4. Studies of a liquid-metal jet + proton beam + 20-T pulsed solenoid magnet.
5. Studies of a 70 MHz RF cavity downstream of the target in the proton beam but without a magnet around the cavity.
6. Continuation of topic 5, with the addition of a 1.25-T, 1.25-m-radius solenoid surrounding the RF cavity.
7. Characterization of the pion yields downstream of the target with RF cavity.
8. Simulation of the performance of liquid-metal targets: thermal shock, eddy current. Validation of the simulation by exploding-wire studies.

Topic 1 and 3-7 are planned activities that would use the AGS.

Topic	**Beam**					**Remarks**	**Hours**	**Run Year**	**AGS Work**
	GeV/c	**Bunch structure**	**#Bunches**	**TP**	**Beam Size**				
1	24	**FEB**	1	10	1mm		600	FY00	Remove E864 and prepare A3 for FEB
2									None
3	24	**FEB**	6	100	1mm		600	FY01	Upgrade AGS kicker for Single-turn extraction
4	24	**FEB**	6	100	1mm		200	FY02	Install pulsed magnet
5	≥7	**FEB**	1	100	2mm, 2ns		200	FY02	Install RF Cavity
6	≥7	**FEB**	1	100	2mm, 2ns		200	FY02	Install Solenoid (probably superconducting)
7	16-24	**SEB**		1	1mm	Secondary Beam	600	FY03	Install secondary beam instrumentation
8									None

Conflicts with other experiments:

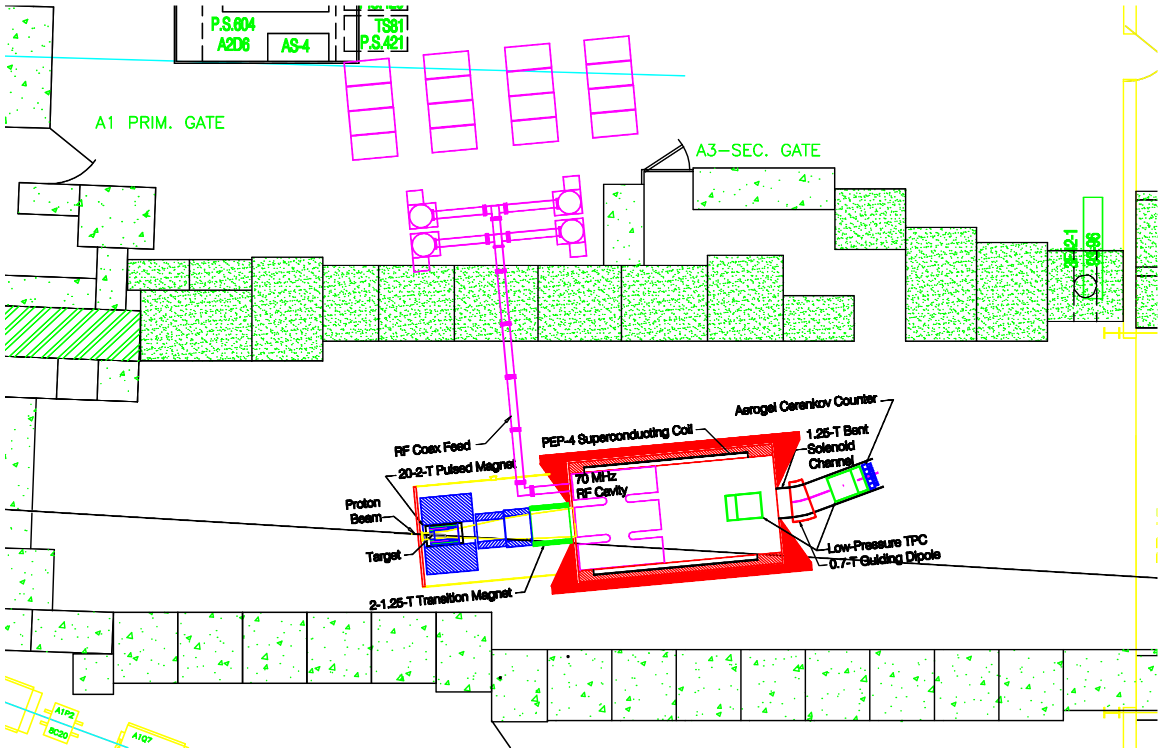
•

Some Issues:

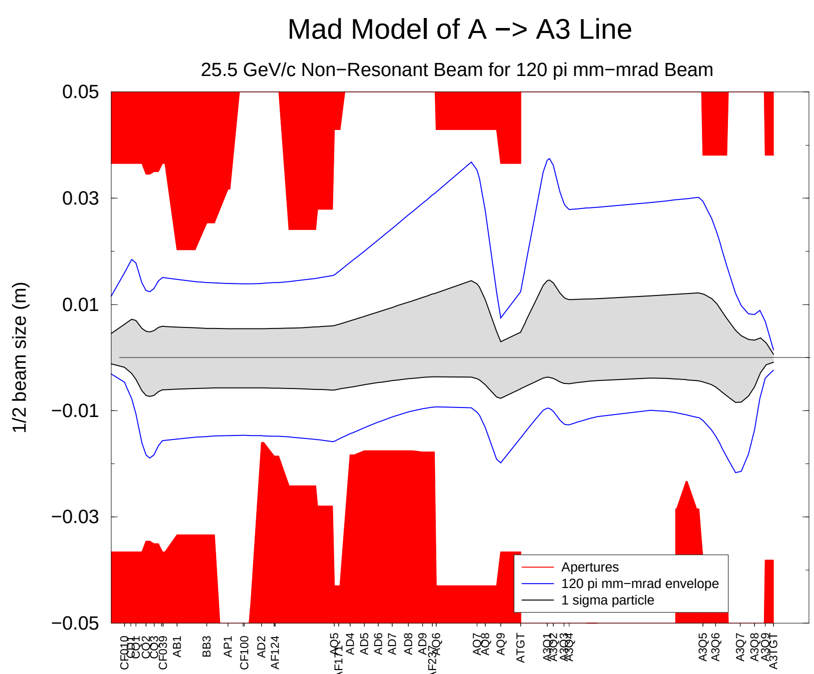
- **1** Initial Studies
  - Add quads in A3 line to deliver spot with sigma_x = sigma_y = 1mm @24 GeV.
  - Revise radiation safety monitors for FEB operation.
  - FEB running requires 1 Hz rate only for beam tuning; data taking is pulse-on-demand, about 1 per 10 min.
- **3** Single-turn Extraction
  - Muon-collider test goal is 10^14 protons in a sinlge pulse. 10^14 protons in 6 bunches + single-turn extraction is acceptable.
- **4** Pulsed magnet system
  - Bus MPS supply to A3 area.
  - Pulsed magnet is LN_2 cooled; 100 liter of LN_2 blown off each pulse (~ every 10 min); vent outside cave.
  - System includes conventional 'transition' magnets with ~ 1MW power.
  - Beam will strike the transition magnet, which must incorporate some features of a beam dump.
- **5** RF Cavity
  - The RF power supplies will arrive in FY00; establish RF test area adjacent to A3 line.
  - RF power transmitted into cave via 4 6"-coax lines => shielding penetrations and/or chicane.
  - RF power tubes may require magnetic shielding from stray fields of the E-951 magnets.
- **6** RF Solenoid
  - PEP-4 (TPC) solenoid to be transported to BNL in FY00 (without steel).
  - Use 100-W LHe refrigerator from E850
  - A3 cave must be high enough to clear magnet + cryo facilities.
- **7** Characterization of Pion Production
  - Bent solenoid spectrometer probably superconducting; add to refrigetator load.
  - Beam intensity < 10^6 Hz; long spill

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)



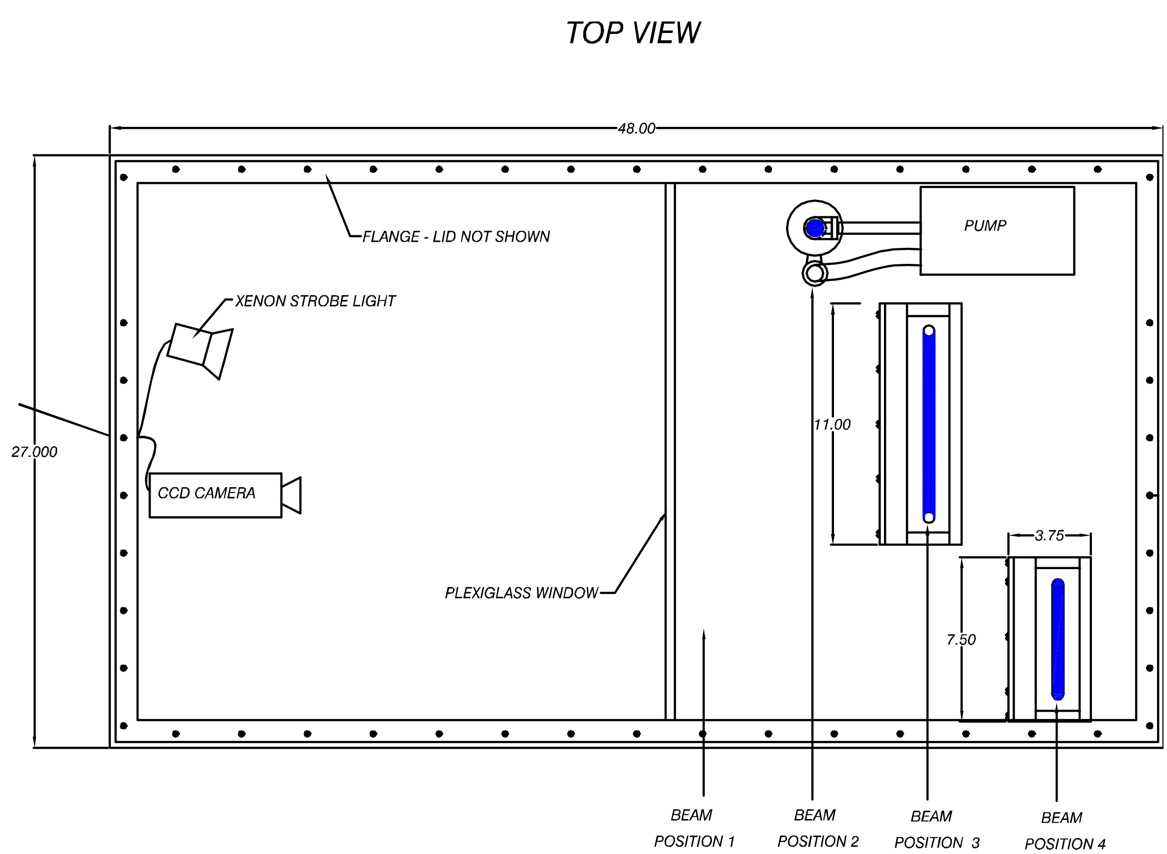
- Beamline instrumentation upgrades: spot size, beam current, FEB radiation monitoring.

- Run first tests parasitic to $g-2$ in Mar/Apr 2000.

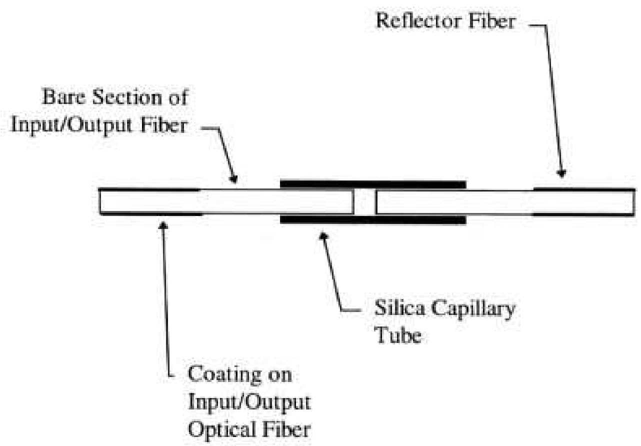
- Data taking via pulse-on-demand once every few minutes; but desire 1-Hz running for beam tuning.

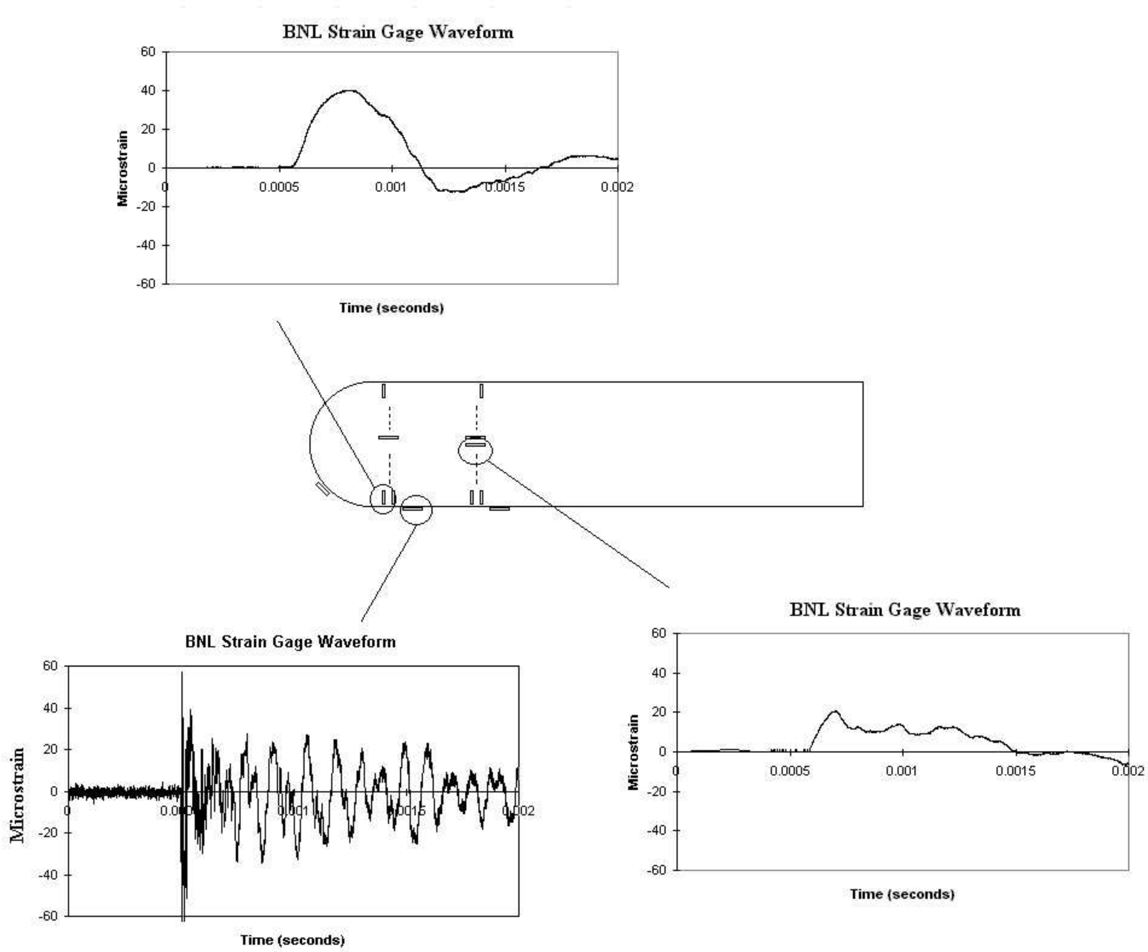
- Shielding needed for 1-Hz running with 10^{14} ppp = 100 TP (Ripp Bowman, Ralf Prigl).

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



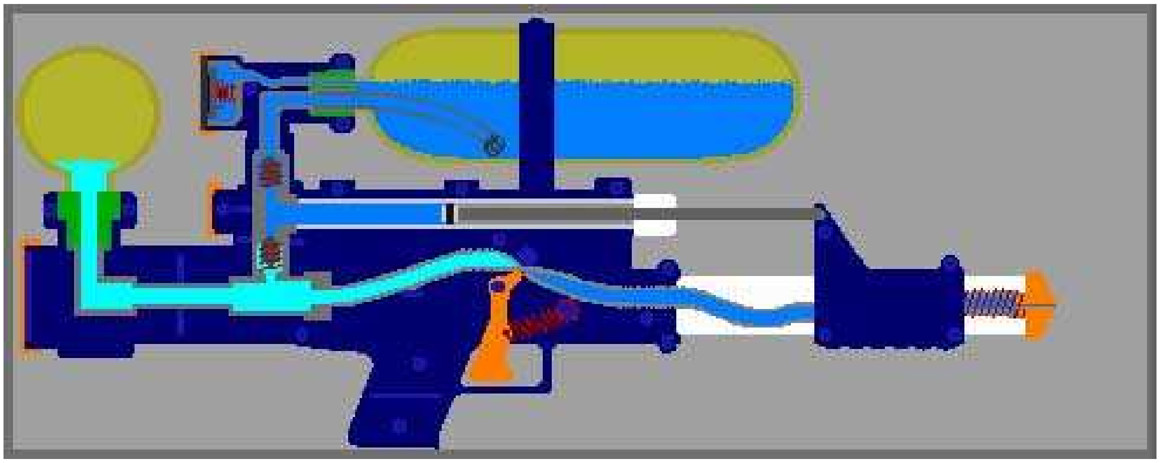
- Instrumentation: high-speed camera, fiberoptic strain sensors (Duncan Earl, ORNL).



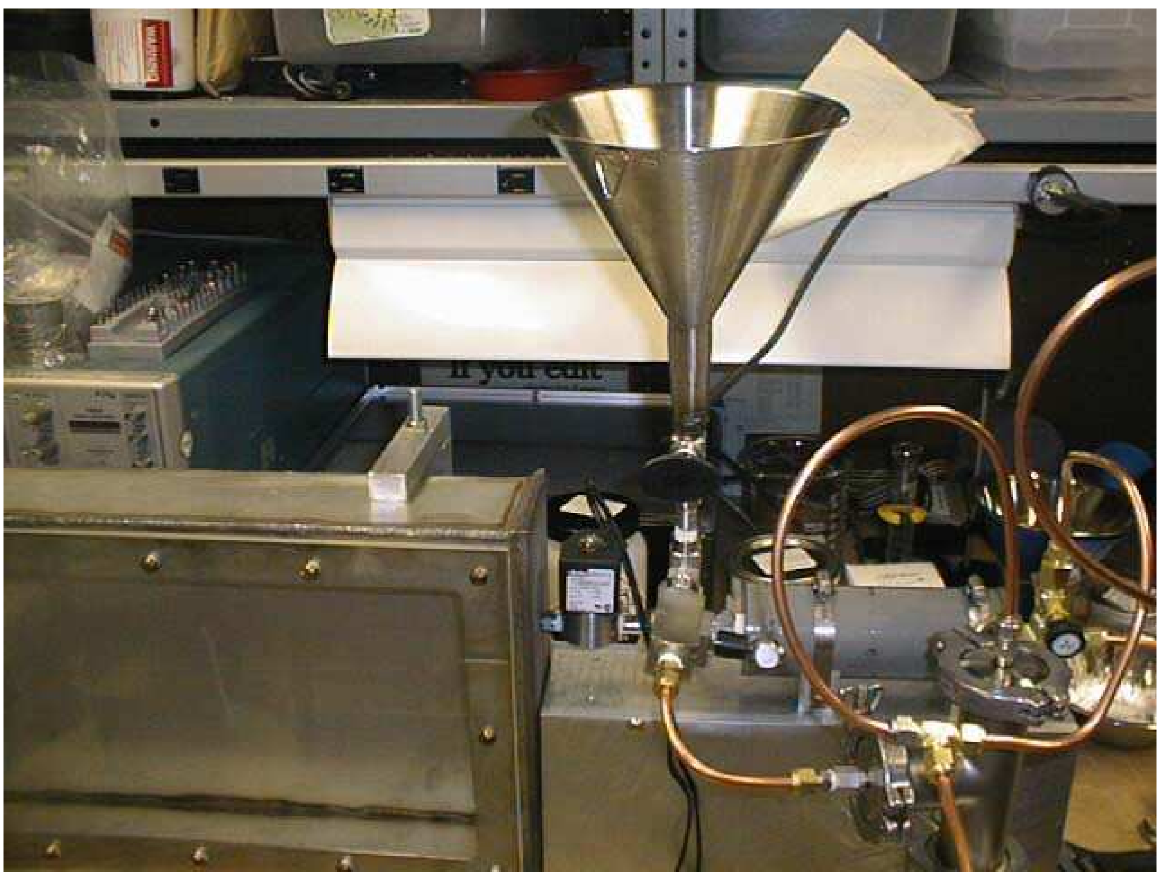


Issues, 2: Pulsed Liquid Jet

- Inspiration:



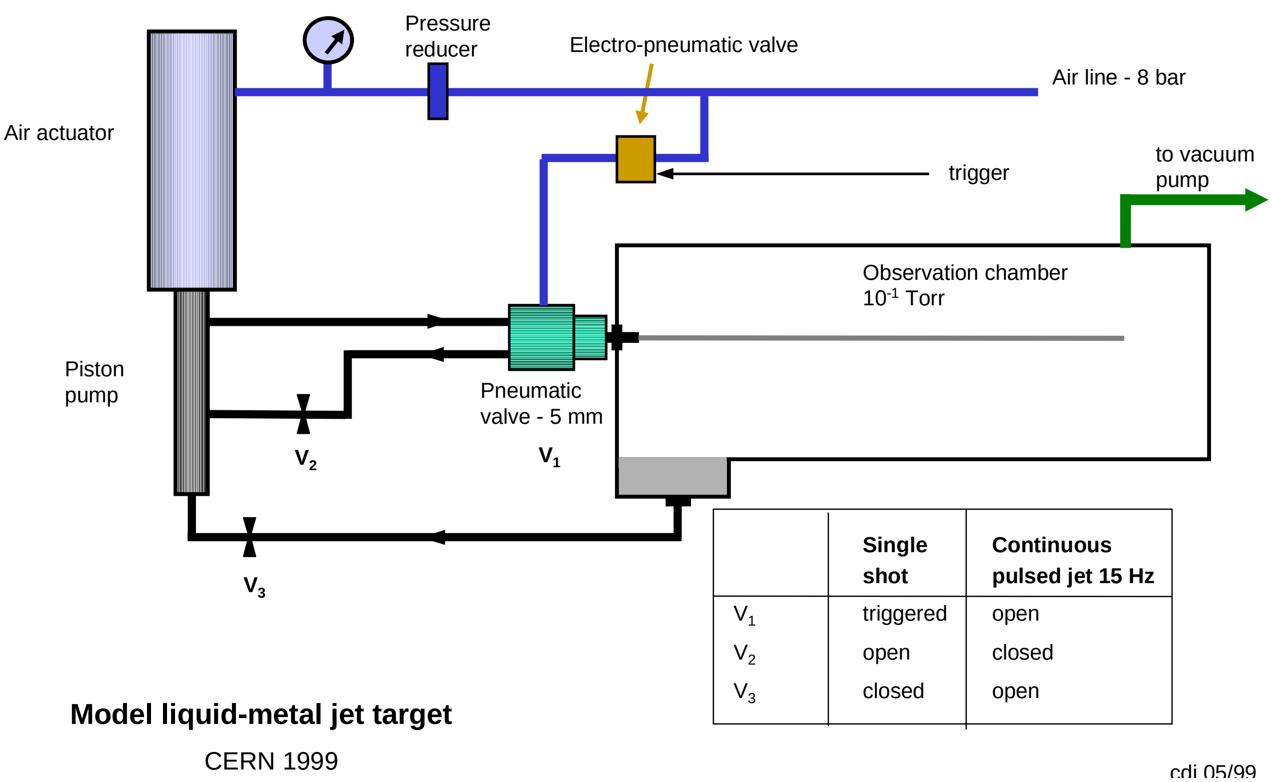
- Prototype jet using Ga-Sn, a room temperature liquid (Princeton).



- May 18, 1999: Jet breaks up too quickly:

- Hg jet under construction at CERN

  (Colin Johnson, Helge Ravn).



	Single shot	Continuous pulsed jet 15 Hz
V_1	triggered	open
V_2	open	closed
V_3	closed	open

Model liquid-metal jet target

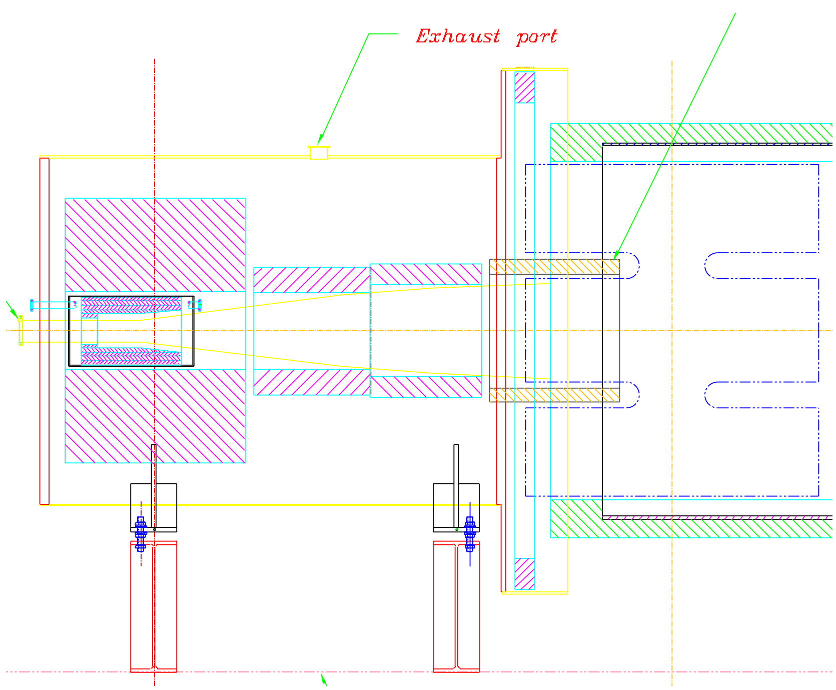
CERN 1999

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 $\approx \$600k$, ≈ 18 months.
- Initiate design work in FY99 to complete upgrade in early FY01.

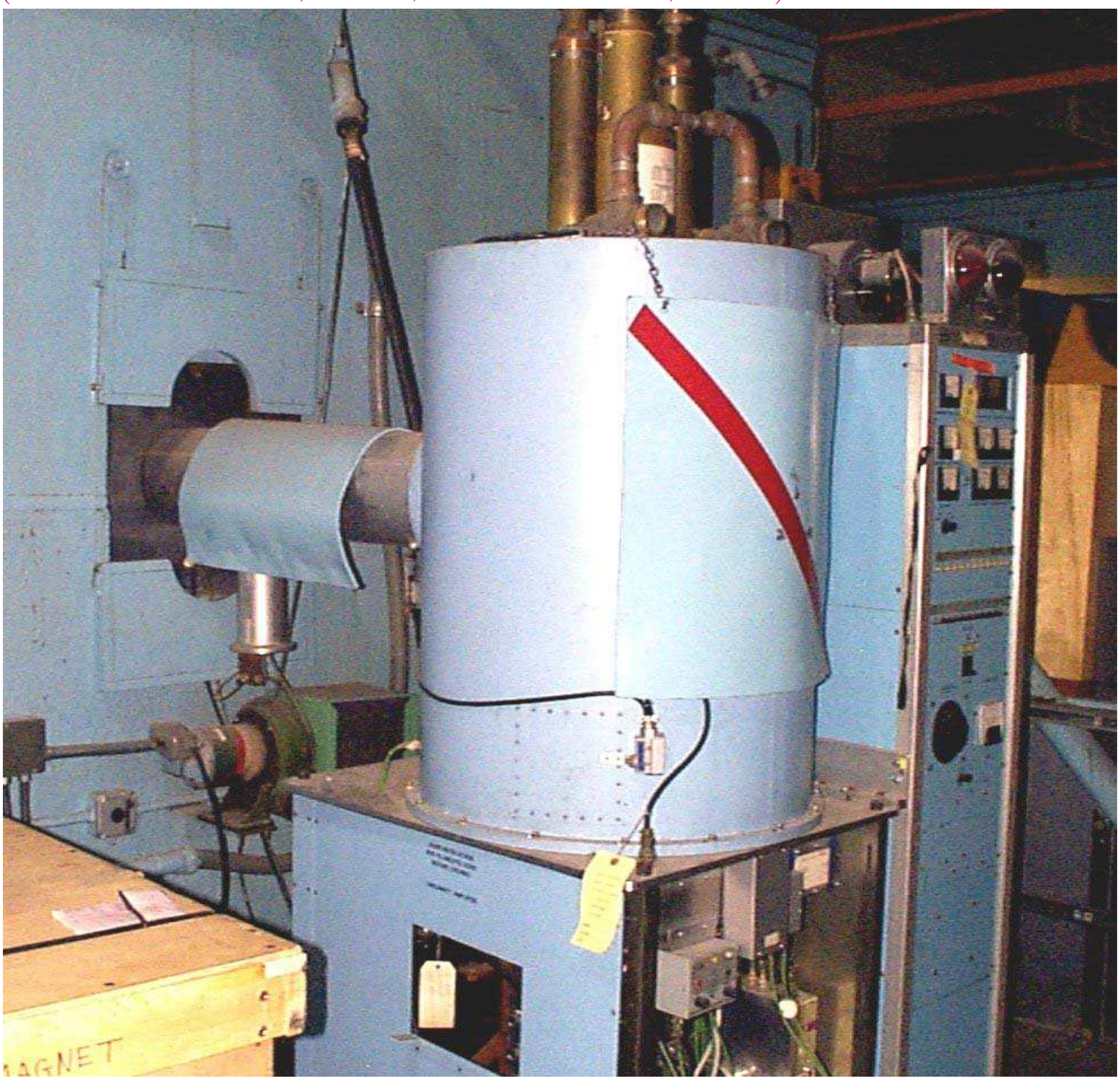
Issues, 4: Pulsed 20-T Magnet

- The copper magnet will be cooled by LN_2, and can be pulsed once every 10 minutes. Pulse duration ≈ 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 ≈ 1 MW average power.



Issues, 5: 70-MHz RF Cavity

- Cavity has 60-cm-diameter iris, 2-m outer diameter.
- 4-6 MW peak power to be supplied by four 8973 tubes recomissioned 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).

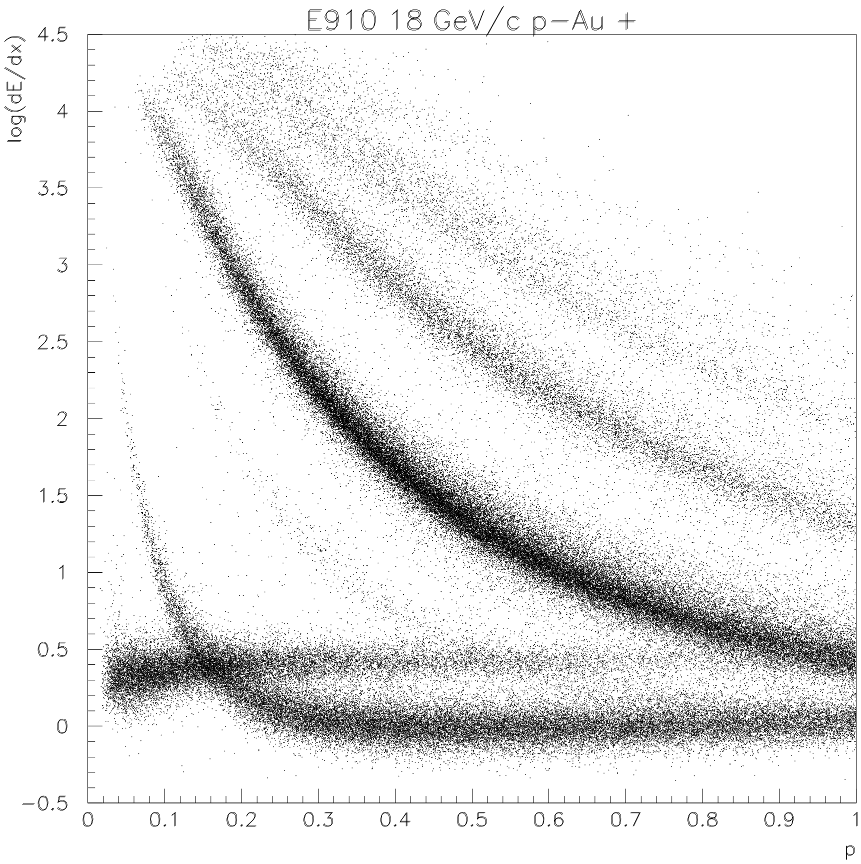
Issues, 6: 1.25-T Solenoid Around RF Cavity

- 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.

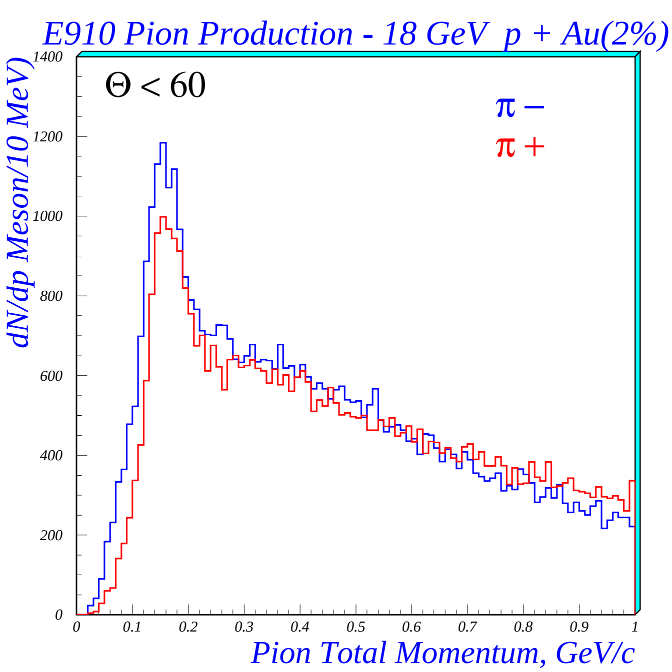
Issues, 7: Characterization of Pion Yield

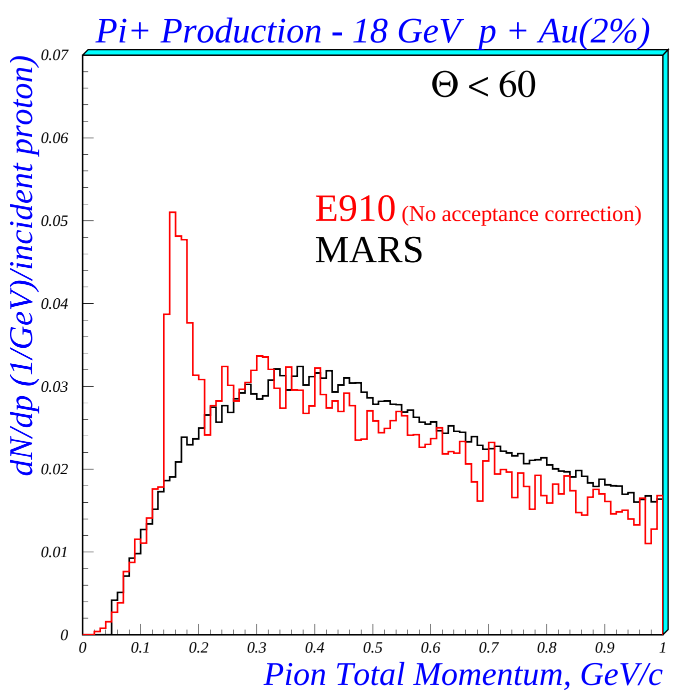
- The final measure of system performance is the capture of soft pions that later decay to muons.
- Add bent solenoid spectrometer downstream of TPC magnet.
- Instrument with low-pressure TPC's and aerogel Čerenkov counters.
- Collect data with slow beam, $< 10^6$ ppp.
- Compare with extrapolations from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

Results from E-910 (Still Preliminary)



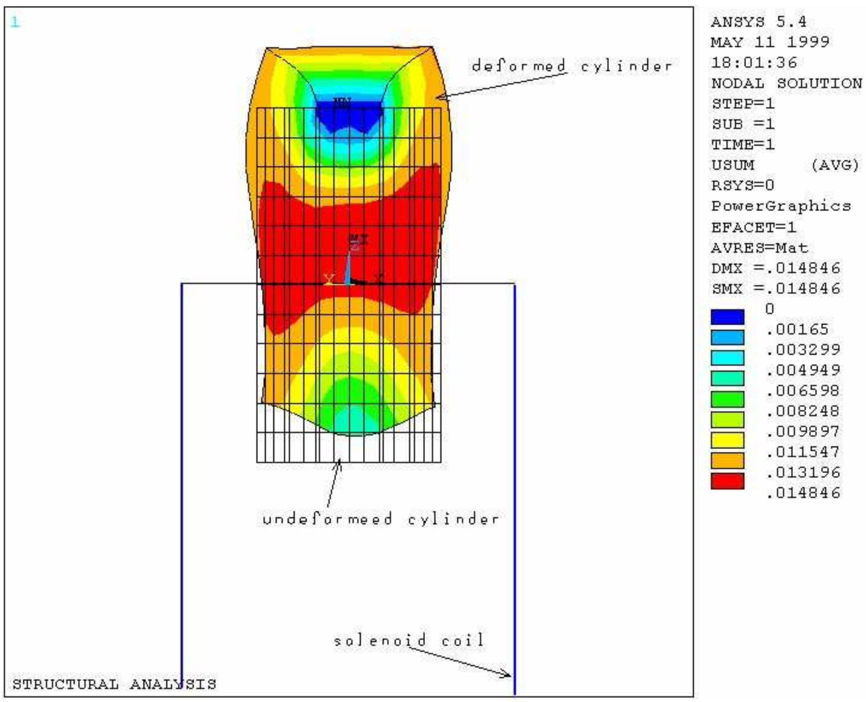
π band and e bands overlap at ≈ 160 Mev/c; not yet subtracted.



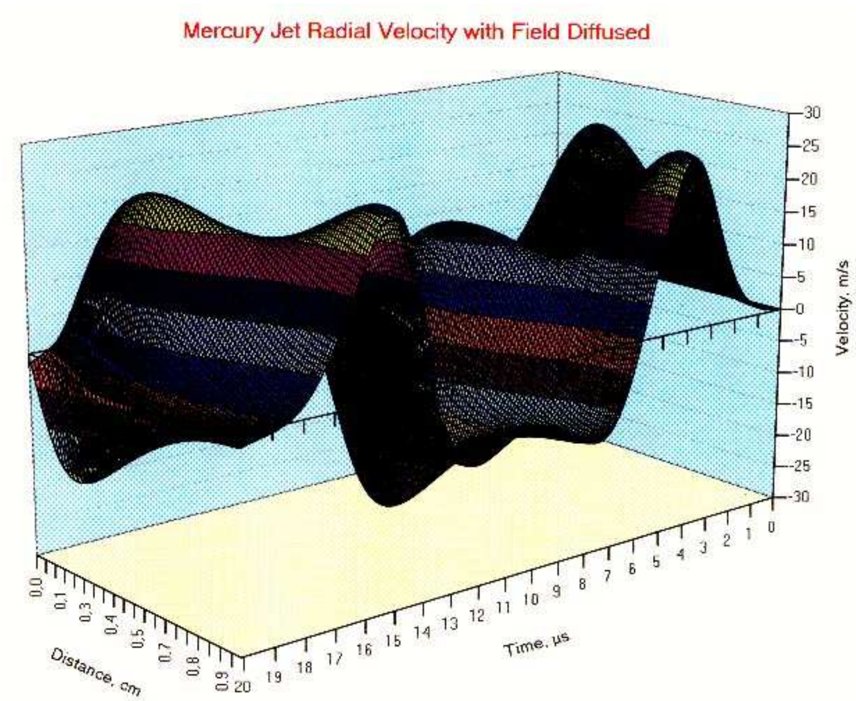


Issues, 8: Simulation of Beam-Jet-Magnet

- ANSYS simulation (Changguo Lu, Princeton):



- HEIGHTS simulation (Ahmed Hassanein, ANL):



Budgets

FY99

Task	ANL	BNL	LBL	Princeton	Total
Initial Jet Studies		20		85	105
AGS Beamline Upgrades		100			100
Pulsed Solenoid Design		50			50
RF Systems		115	75		190
Simulation Studies	75			5	80
Total	75	285	75	90	**$525k**

FY00 (Projected)

Task	ANL	BNL	LBL	Princeton	Total
Initial Jet Studies		100		100	200
AGS Beamline Upgrades		400			400
Magnet Systems		300			300
RF Systems		375	75		450
Simulation Studies	150			10	160
Total	150	1175	75	110	**$1510k**

FY01: \$2M, FY02: \$2M, FY03: \$1M; Total: \$7M.

Schedule

- FY99:

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

- FY00:

  Initial tests in A3 line.

  (600 hours).

- 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).