Prospects for a Muon Collider

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July 17, 1998

BNL AGS/RHIC User's Meeting

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

Princeton muon collider page:

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

Future Frontier Facilities

(Will the U.S. have one?)

- Hadron collider (LHC, SSC): $\approx$ \$100k/m [magnets].

  $\approx$ 2 km per TeV of CM energy.

  Ex: LHC has 14-TeV CM energy, 27 km ring, $\approx$ \$3B.

- Linear e^+e^- collider (SLAC, NLC(?)): $\approx$ \$200k/m [rf].

  $\approx$ 20 km per TeV of CM energy;

  But a lepton collider needs only $\approx 1/10$ the CM energy to have equivalent physics reach to a hadron collider.

  Ex: NLC, 1.5-TeV CM energy, 30 km long, $\approx$ \$6B (?).

- Muon collider: $\approx$ \$1B for source/cooler + \$100k/m for rings

  Well-defined leptonic initial state.

  $m_\mu/m_e \approx 200 \Rightarrow$ Little beam radiation.

  $\Rightarrow$ Can use storage rings.

  $\Rightarrow$ Smaller footprint.

  Technology: closer to hadron colliders.

  $\approx$ 6 km of ring per TeV of CM energy.

  Ex: 3-TeV muon collider $\approx$ \$3B (?).

Ingredients of a Muon Collider

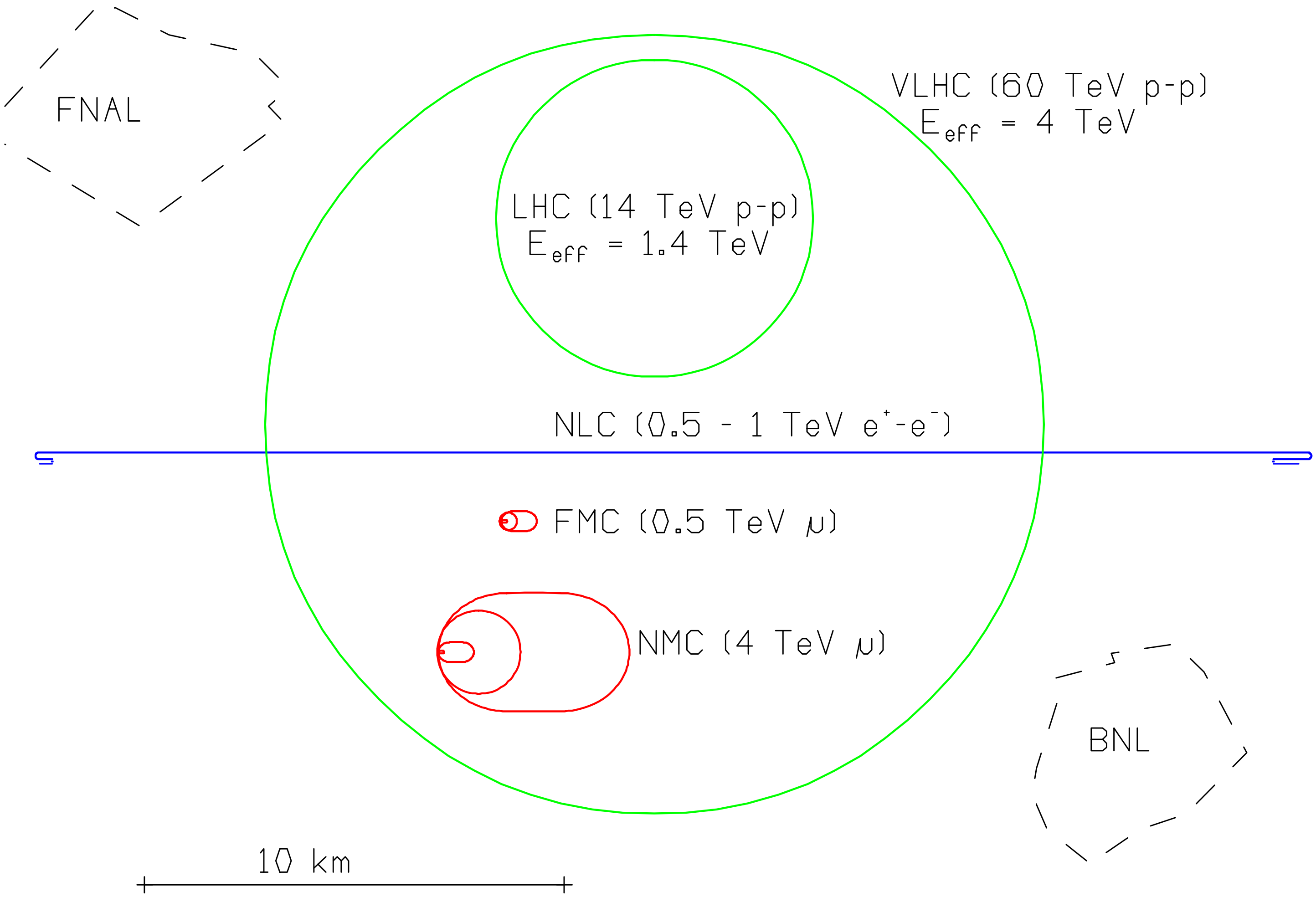
An accelerator complex in which

- 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.

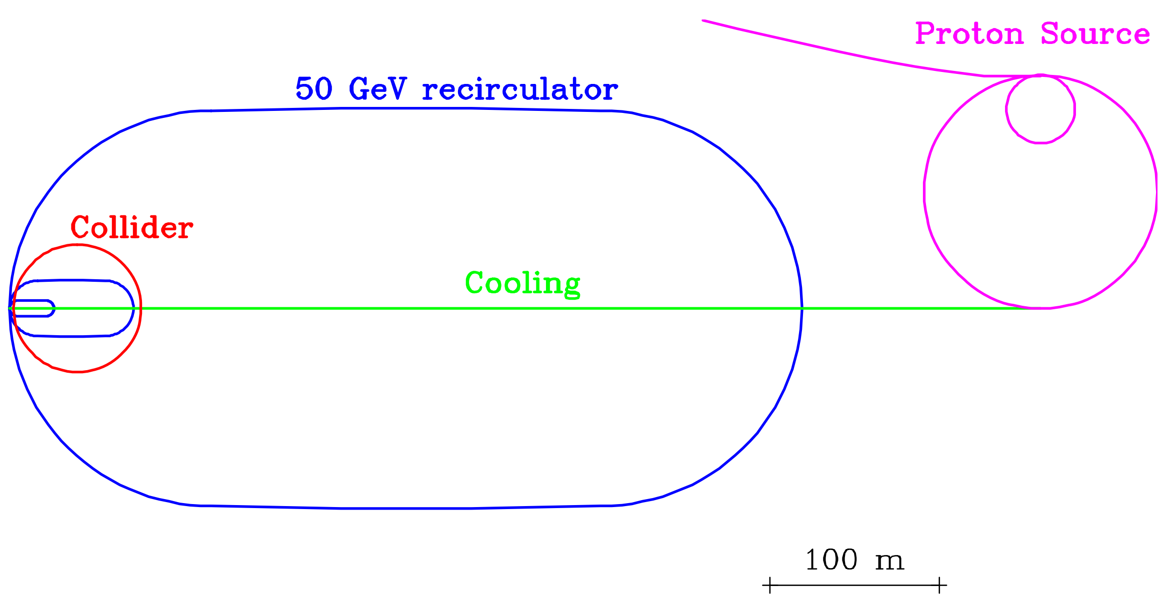
Muons decay: $\mu \to e\nu \qquad \Rightarrow$

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

Footprints

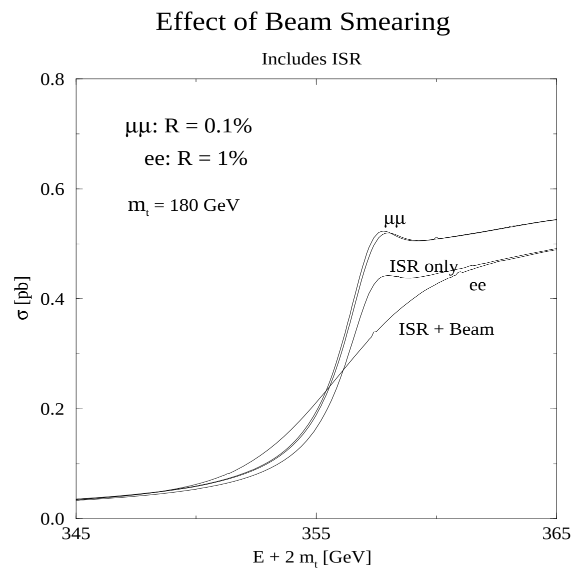


A First Muon Collider to study light-Higgs production:



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^-.



- 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.

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

Meetings and Workshops

Subject	Organizer	Place	Date	Additional Information
Targetry	H. Kirk and K. McDonald	BNL	Aug. 3, 1998	Contact K. McDonald (mcdonald@puphep.princeton.eduH.)/ Kirk (hkirk@bnl.gov)
Acceleration	S. Berg and D. Neuffer	Bloomington, IN	Aug. 10-11, 1998	Contact S. Berg (jsberg@indiana.edu)
Neutrino Physics	B. King	BNL	Aug. 13-14 1998	Contact B. King (bking@bnl.gov)
Cooling Theory & Expt	R. Fernow and S. Geer	BNL	Aug. 31-Sep. 2, 1998	Contact R. Fernow (fernow@bnl.gov) or S. Geer (sgeer@fnal.gov)
Collaboration Meeting	A. Sessler	LBNL	Oct. 8-13, 1998	Contact A. Sessler (amsessler@lbl.gov)
Cooling Theory & Expt	R. Fernow and S. Geer	FNAL	Dec. 7 - 9, 1998	Contact R. Fernow (fernow@bnl.gov) or S. Geer (sgeer@fnal.gov)
Collaboration Meeting	B. Palmer	BNL	Tentative May 19-26, 1999	Contact J. Gallardo (gallardo@bnl.gov)

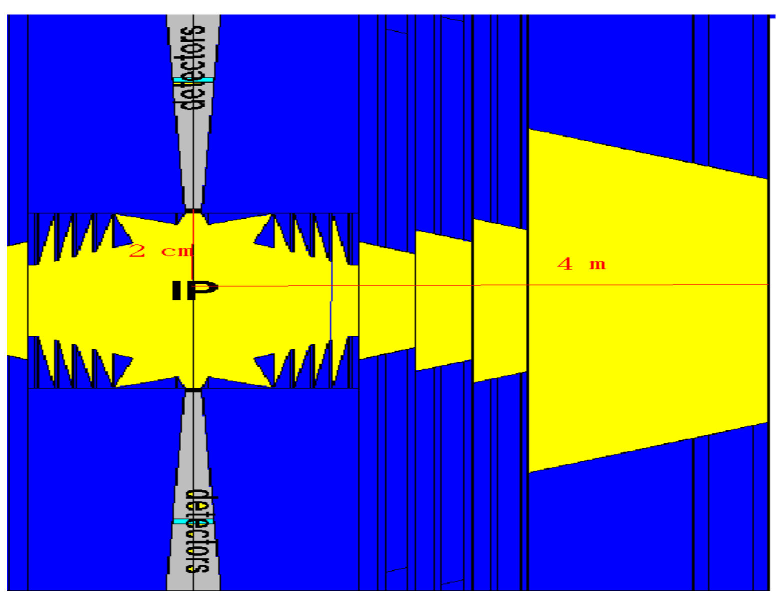
- PROSPECTIVE STUDY OF MUON COLLIDERS

  Introductory meeting
  Monday, July 20 1998 at 14 hrs
  CERN PS Auditorium, Bdg 6-2-024

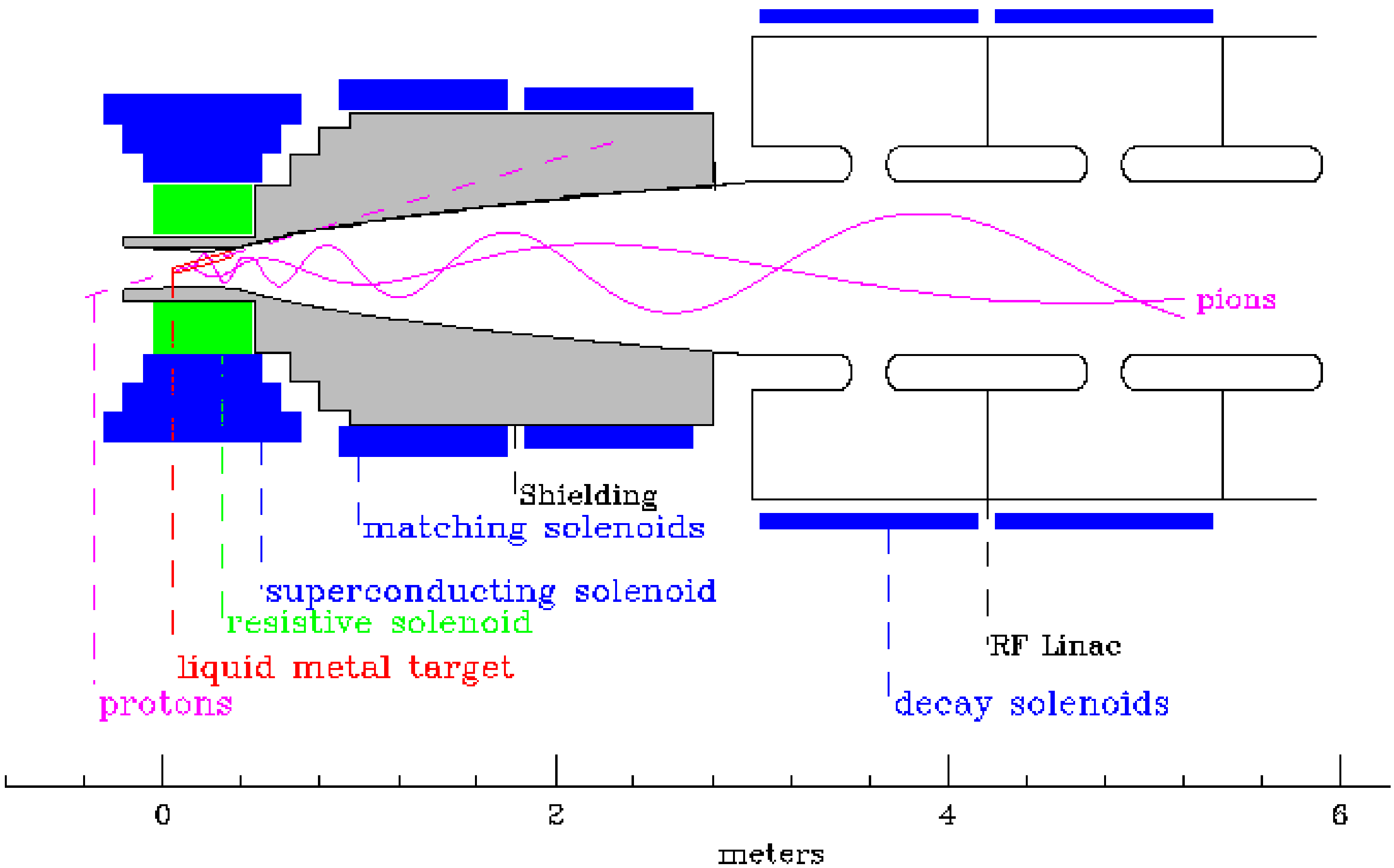
Technical Challenges

- 16-GeV proton driver, 15 Hz, 4-MW beam power, 1-ns bunch length (C. Ankenbrandt, T. Roser...).
- **Targetry and Capture**
- **Muon Cooling**
- Acceleration – more work needed (S. Berg...)
- Storage rings have beautiful, highly corrected solutions due to heroic work of Al Garren, Carol Johnstone and Dan Trbojevič.
- Interaction region and detector design – more work needed (I. Stumer...)

A muon's view of the interaction region:



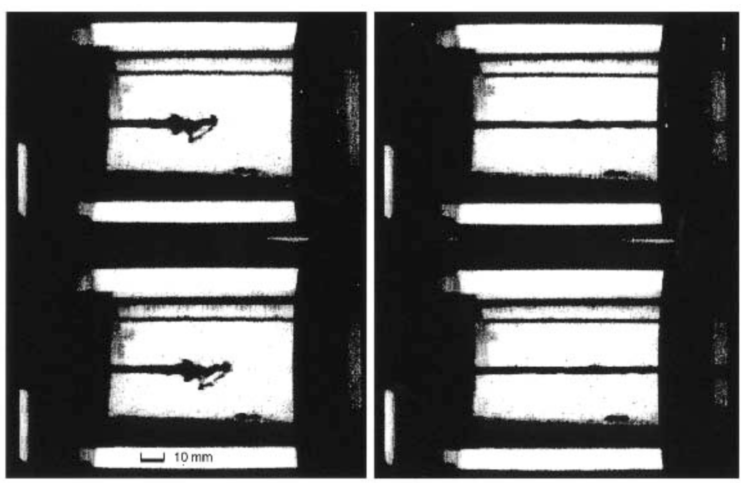
Overview of Targetry for a Muon Collider



- 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 test)
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.

An R&D Program for Targetry

at a Muon Collider

A Proposal to the BNL AGS Division

David Brashears,[h] Kevin Brown,[b] Michael Cates,[h] John Corlett,[f] Adrian Fabich,[d] Richard C. Fernow,[b] Charles Finfrock,[b] Yasuo Fukui,[c] Tony A. Gabriel,[f] Juan C. Gallardo,[b] Michael A. Green,[f] George A. Greene,[b] John R. Haines,[h] Jerry Hastings,[b] Ahmed Hassanein,[a] Colin Johnson,[d] Stephen A. Kahn,[b] Bruce J. King,[b] Harold G. Kirk,[b,1] Jacques Lettry,[d] Vincent LoDestro,[b] Changguo Lu,[i] Kirk T. McDonald,[i,2] Nikolai V. Mokhov,[e] Alfred Moretti,[e] James H. Norem,[a] Robert B. Palmer,[b] Ralf Prigl,[b] Helge Ravn,[d] Bernard Riemer,[h] James Rose,[b] Thomas Roser,[b] Joseph Scaduto,[b] Peter Sievers,[d] Nicholas Simos,[b] Philip Spampinato,[h] Iuliu Stumer,[b] Peter Thieberger,[b] James Tsai,[h] Thomas Tsang,[b] Haipeng Wang,[b] Robert Weggel,[b] Albert F. Zeller,[g] Yongxiang Zhao[b]

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To be submitted Sept. 1,1998.

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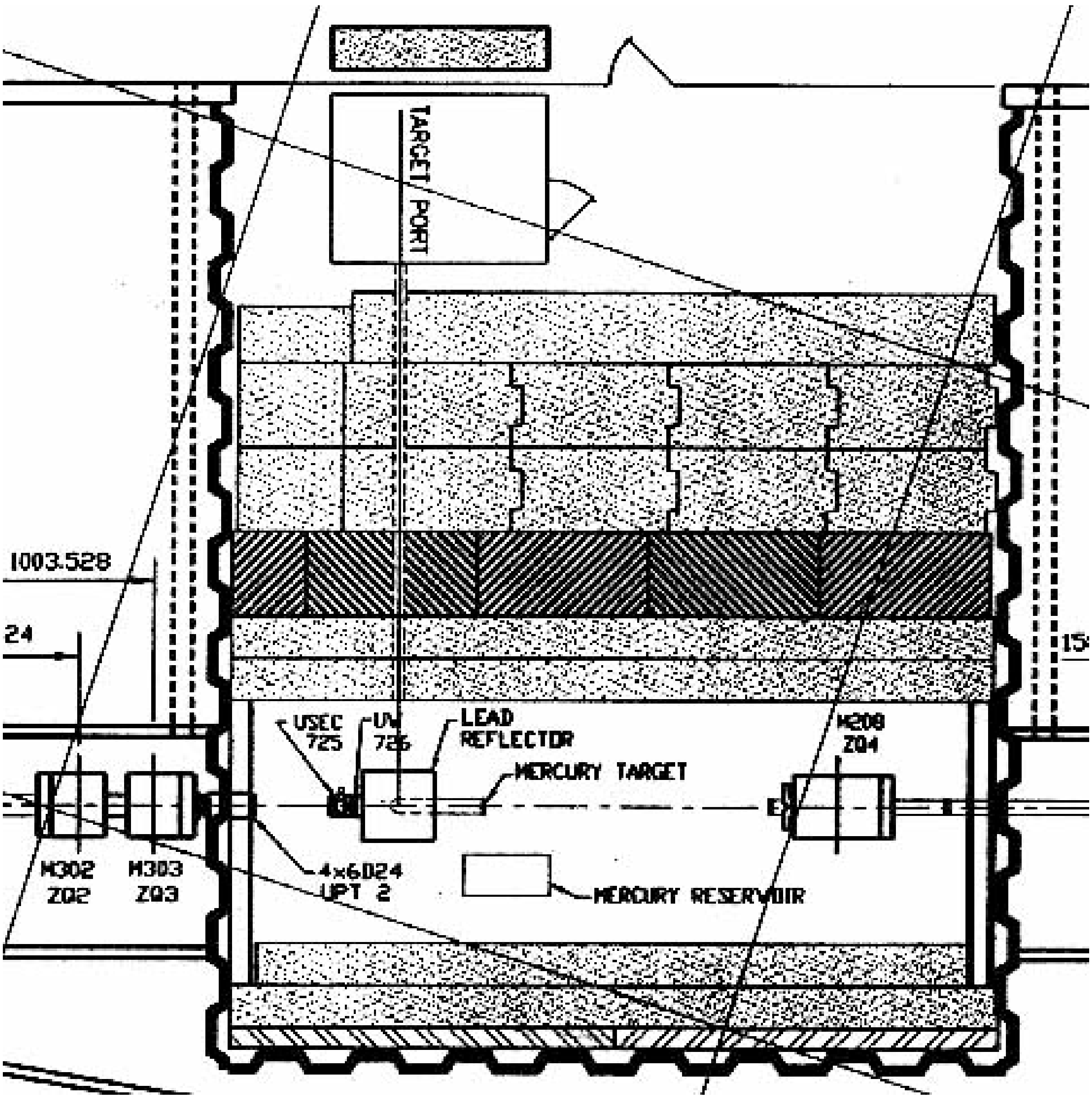
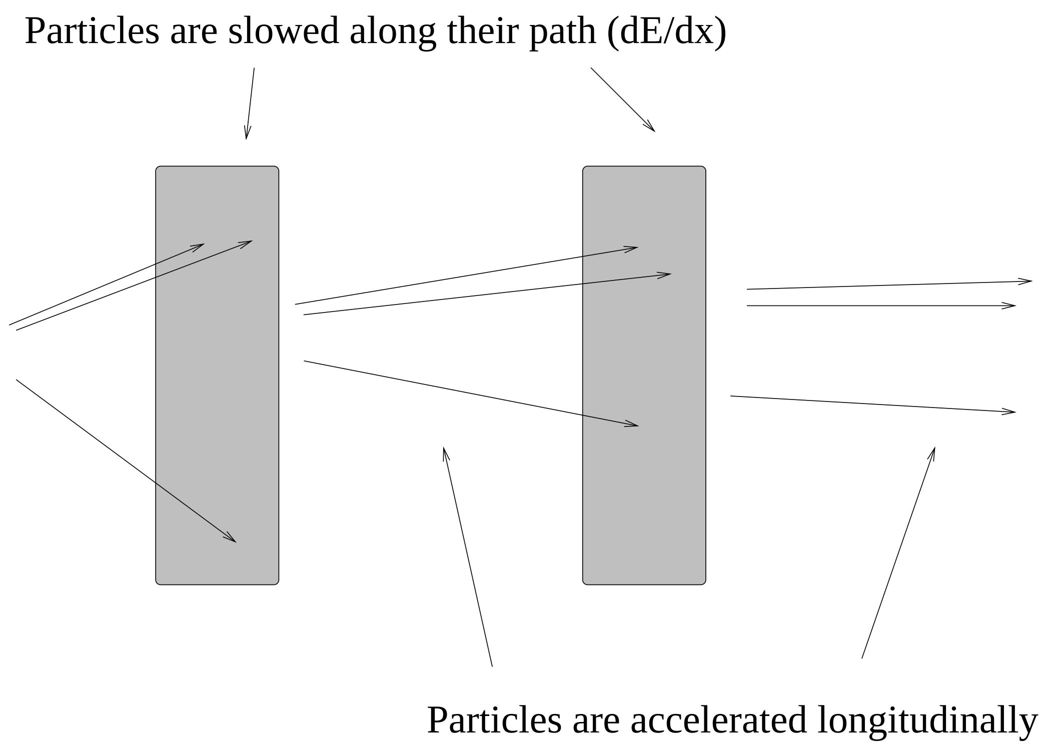
Studies to be performed in the AGS F.E.B. U-line.



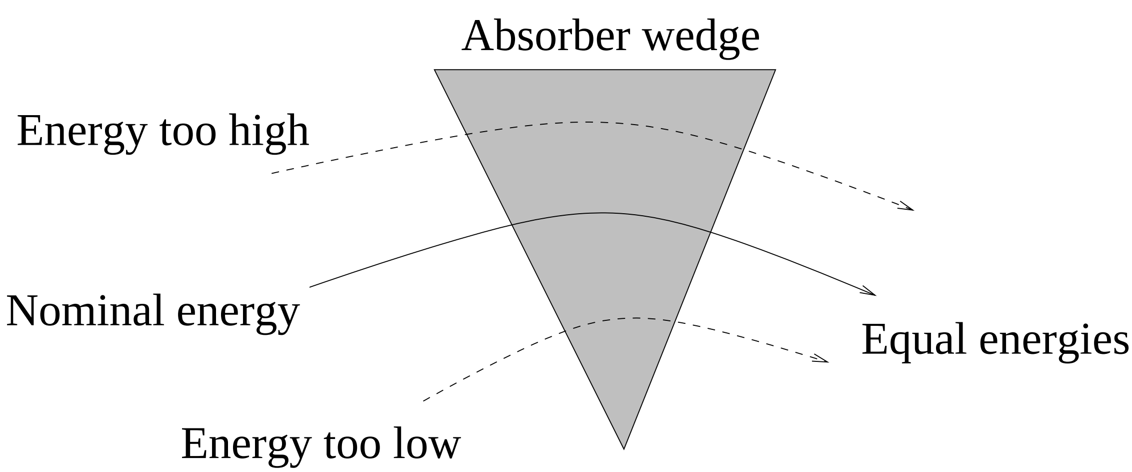
Ionization Cooling

- Ionization: takes momentum away.
- RF acceleration: puts momentum back along z axis.
- $\Rightarrow$ Transverse cooling.



- Use channel of LH_2 absorbers, rf cavities and alternating solenoids (to avoid buildup of angular momentum).

- But the **energy spread rises**.
- $\Rightarrow$ Must exchange longitudinal and transverse emittance frequently to avoid beam loss due to bunch spreading.
- Can reduce energy spread by a wedge absorber at a momentum dispersion point:



- Emittance exchange via wedges + bent solenoids:

April 15, 1998

PROPOSAL

Ionization Cooling Research and Development Program for a High Luminosity Muon Collider

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The MUCOOL Collaboration

[†] Spokesperson

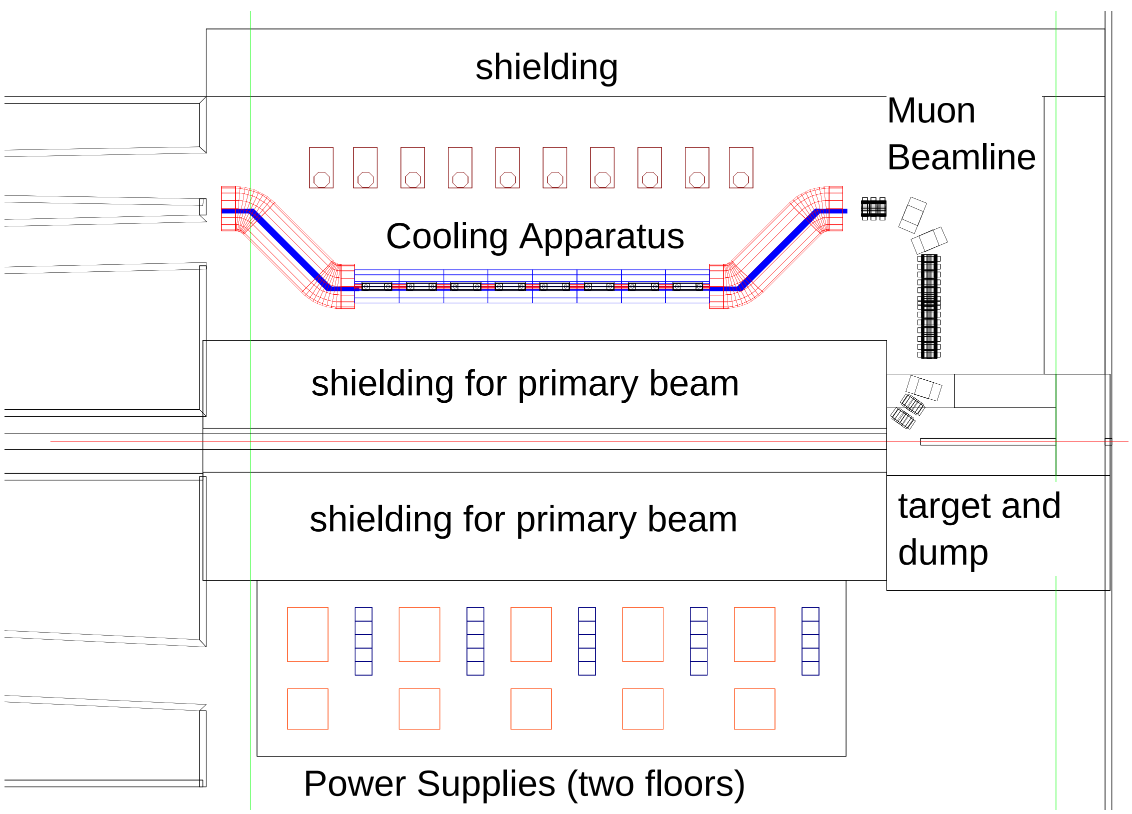
Cooling Demonstration Experiment

Test basic cooling components:

- Alternating solenoid lattice, RF cavities, LH_2 absorber
- Lithium lens (for final cooling).
- Dispersion + wedge absorbers to exchange longitudinal and transverse phase space.

Track individual muons; simulate a bunch in software.

Possible site: Meson Lab at Fermilab:



Summary

- A muon collider offers the prospect of a more cost-effective technology for high-energy accelerators.
- Cooling the beams is the key.
- The concepts of a muon collider are still in a formative stage.
- ⇒ Join us in exploring the physics opportunities and solving the technical challenges of a muon collider!