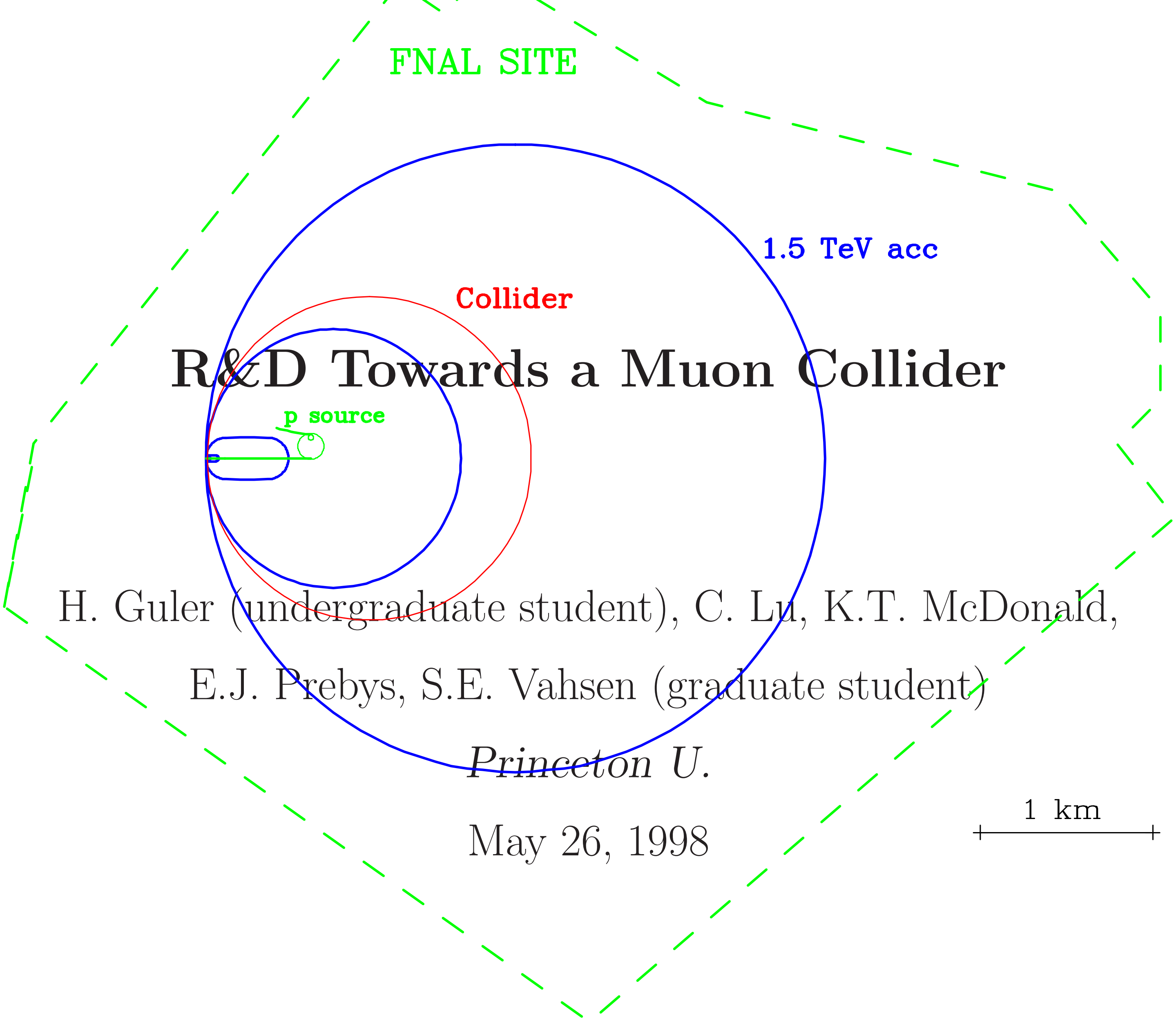

R&D Towards a Muon Collider

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Muon Collider main page:

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

Princeton muon collider page:

`http://www.hep.princeton.edu/~mcdonald/mumu`

Options for Future Colliders

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

  ≈ 2 km per TeV of CM energy.

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

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

  ≈ 20 km per TeV of CM energy;

  But a lepton colliders needs only ≈ 1/5 the CM energy to have equivalent physics reach to a hadron collider.

  Ex: NLC has 3-TeV CM energy, 30 km long, ≈ \$6B (?).

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

  Well-defined leptonic initial state.

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

  ⇒ Can use storage rings.

  ⇒ Smaller footprint.

  Technology: closer to hadron colliders.

  ≈ 6 km of ring per TeV of CM energy.

  Ex: 3-TeV muon collider ≈ \$3B (?).

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.
- 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.

Ingredients of a Muon Collider

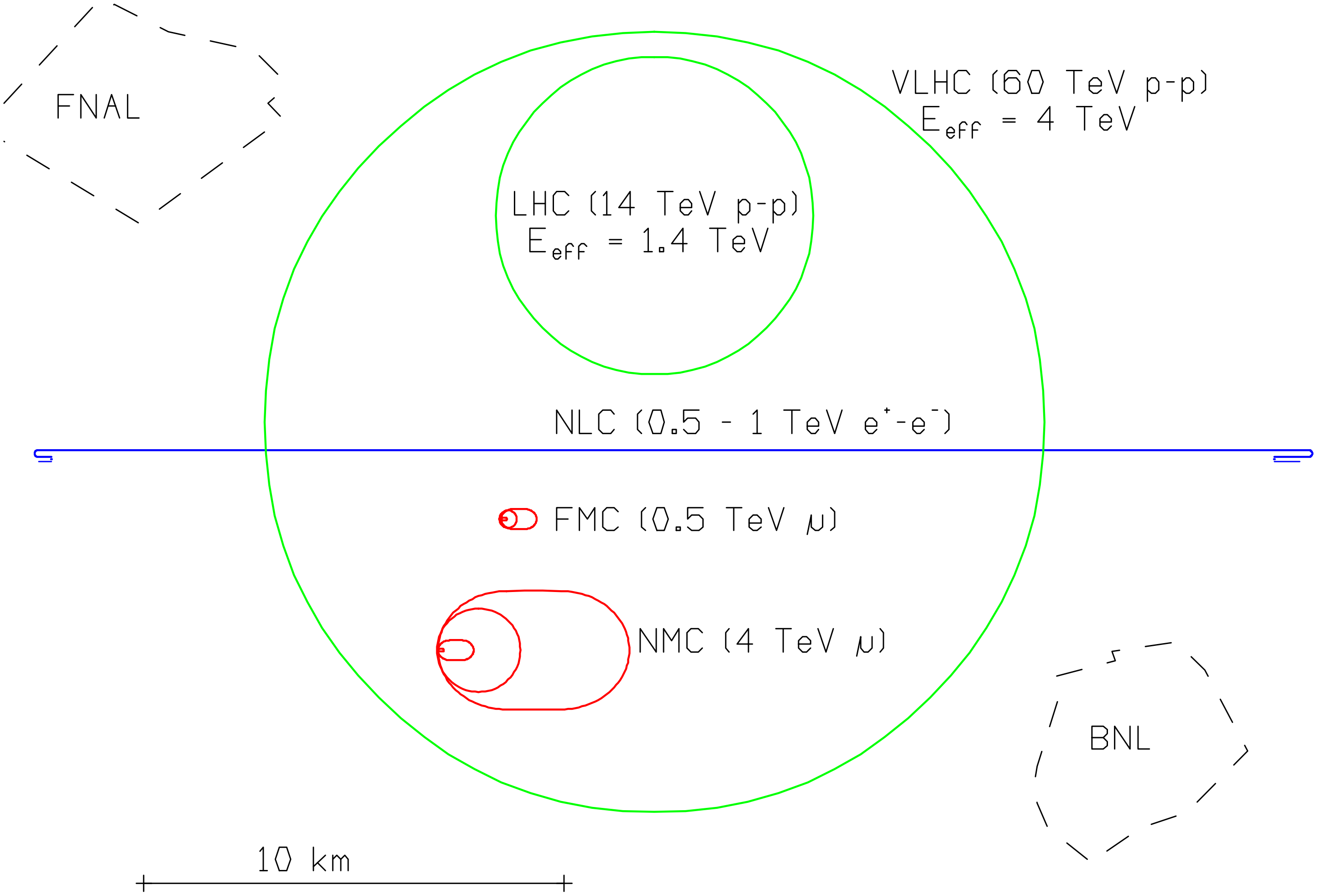
An accelerator complex in which

- Muons (both μ^+ and μ^-) are collected from pion decay following a pN interaction.
- The muon phase volume is reduced 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.

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

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

Footprints



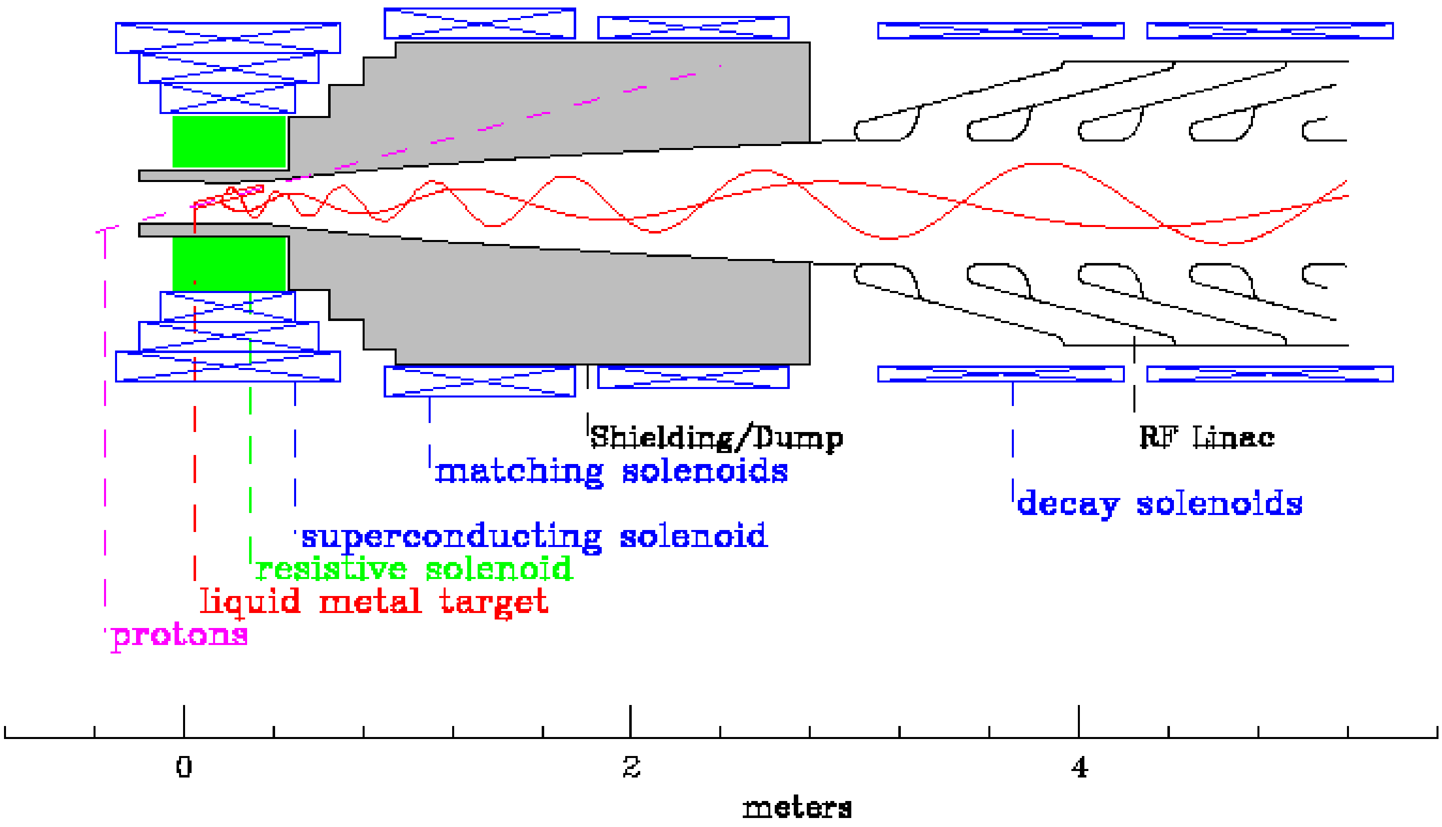
Muon collider:

- Significant base cost (≈ \$1B) at any energy, plus 'modest' cost (≈ \$100k/m) for storage rings.
- Up to 4 TeV on existing sites at cost below LHC.
- Technology path to ≈ 100 TeV before limited by radiation losses.

Technical Challenges

- 16-GeV proton driver, 15 Hz, 4-MW beam power,
  1-ns bunch length.
- **Targetry and Capture**
- **Muon Cooling**
- Storage rings have beautiful, highly corrected solutions due to heroic work of Al Garren, Carol Johnstone and Dan Trbojevič.

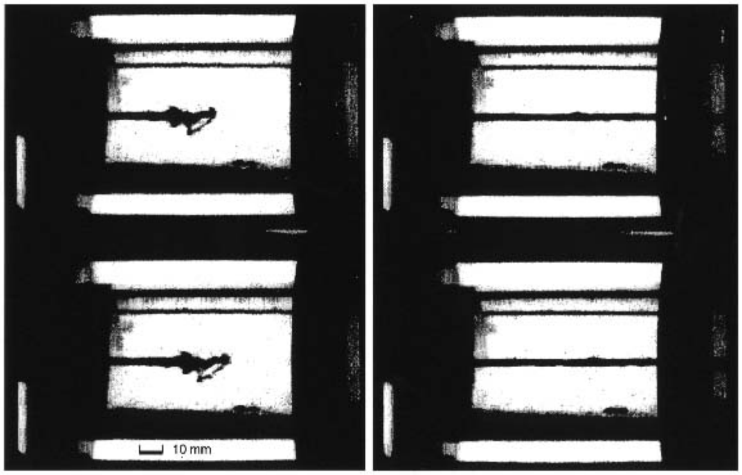
Overview of Targetry for a Muon Collider



- 1.2×10^{14} $\mu^{\pm}$/s via π-decay from 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 1.5-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, possible 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)