Update on Targetry and Capture at a Muon Collider Source

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Targetry Meeting at LBNL

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

Overview

- Targetry & Capture proposal submitted to BNL, Sept. 28, 1998.
- Of $2M FY99 R&D funds, $555 allocated to targetry:

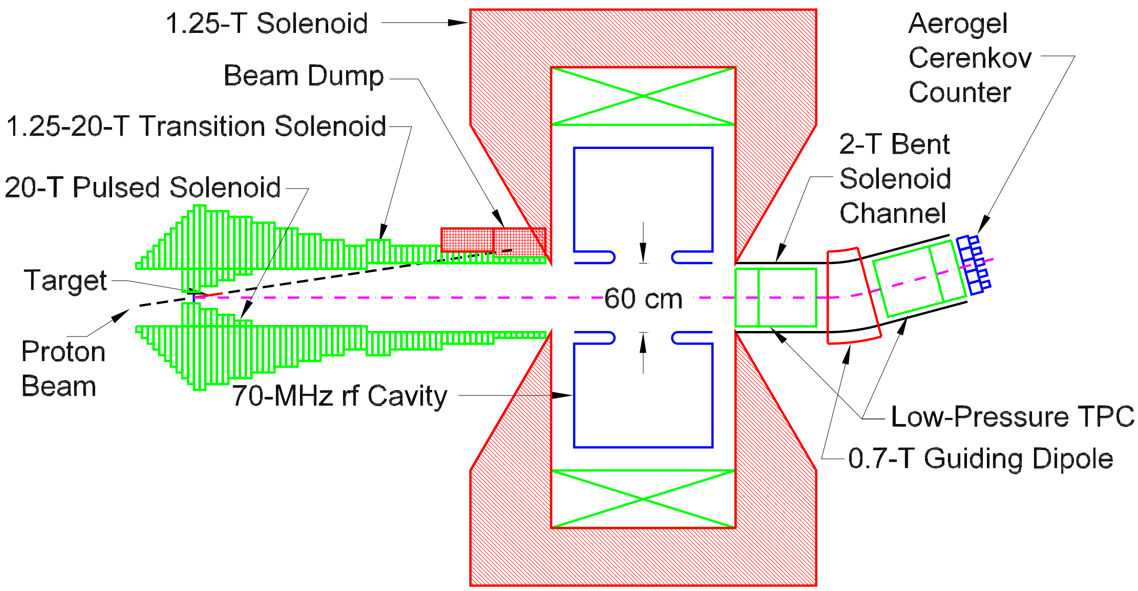
  BNL $365k, Princeton $90k, ANL $75k, LBNL $25k.
- Spot-size test in FEB U-line, Nov. 17, 1998.
- KTM visited Oak Ridge Lab, Feb. 5, 1999.
- Now interviewing candidates for magnet design engineer to assist B. Weggel.
- To be discussed at this meeting: Site, Target, RF.
- More simulation needed:

  Thermal hydraulics and magnetohydrodynamics of liquid metal jets.

  MARS + ICOOL for better evaluation of target + capture scenarios.

Site for the AGS Beam Studies

- Desire to test target, pulsed magnet, and low-frequency RF cavity in a 24-GeV beam with single-turn extraction of the full AGS beam ($\approx 10^{14}$ protons in 6 booster batches over 1 μs).



- First suggestion was to use the FEB U-line (old neutrino line).

- Tests on Nov. 19, 1999, indicate that cannot focus the beam to better than 3 mm (rms) without quad upgrades;

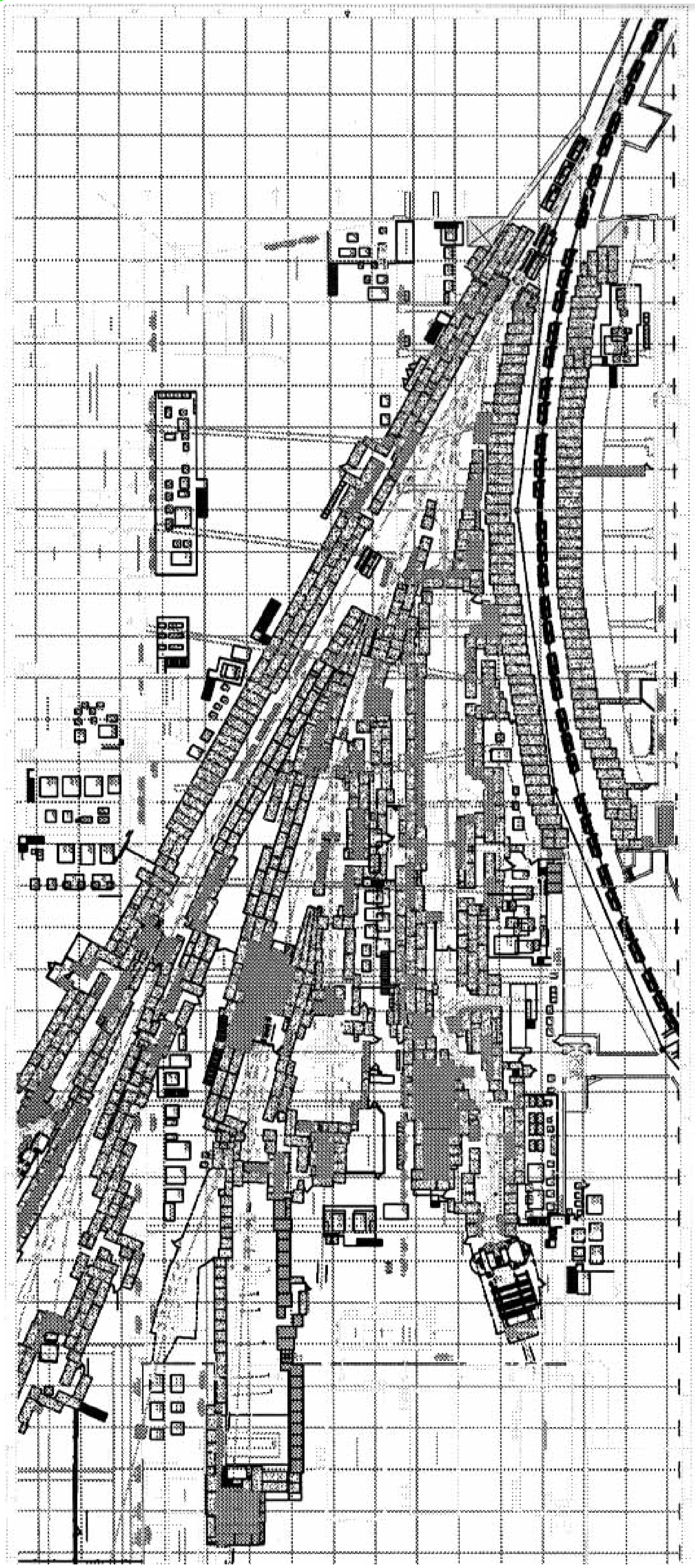
  But desire 1 mm rms;

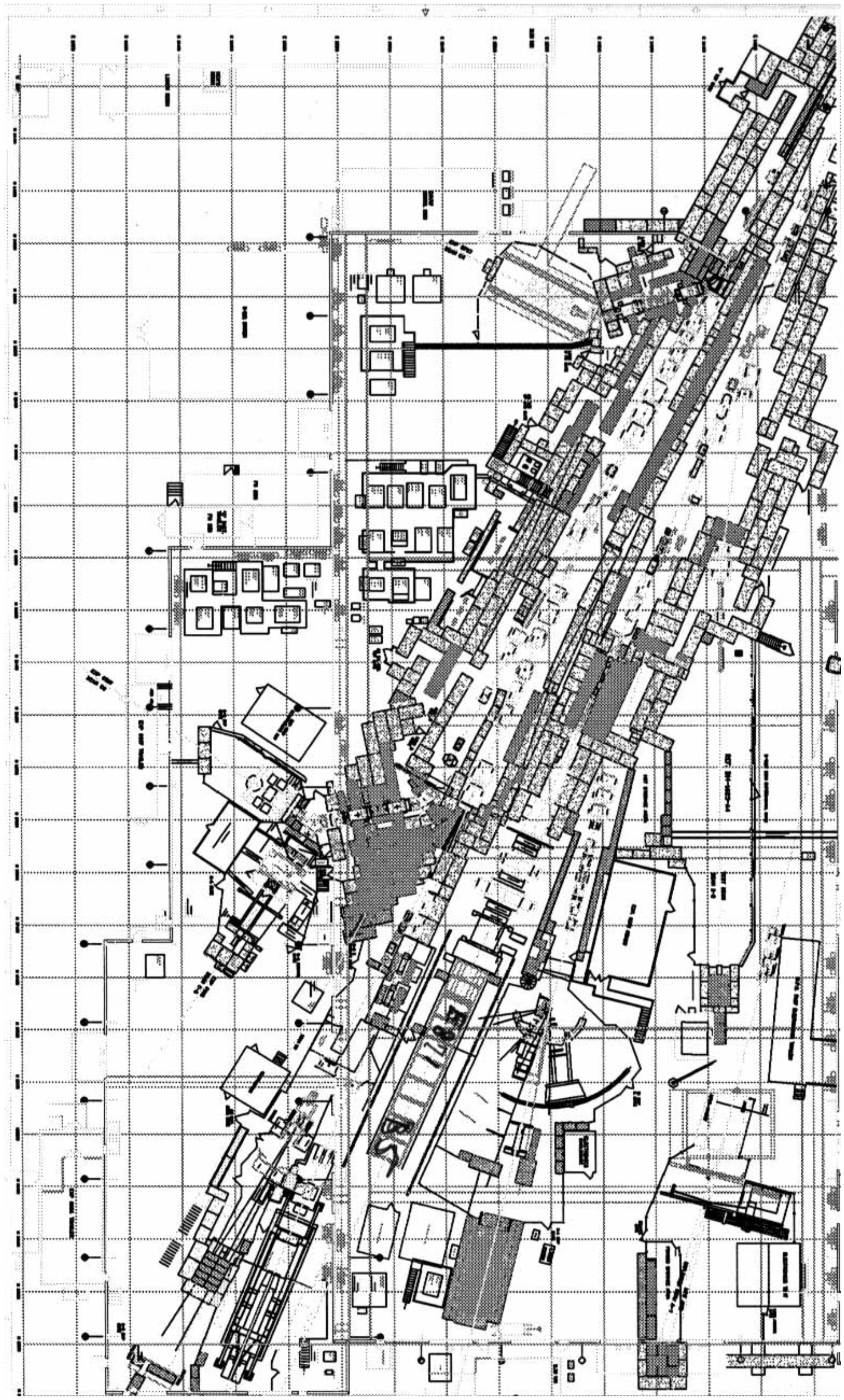
  Infrastructure in the U-line is minimal.

  http://ad1.ags.bnl.gov/~kbrown

  http://puhep1.princeton.edu/mumu/target/mumu-98-16.ps

- P. Pile suggests we consider a beam line in the Main AGS hall.





- K. Brown claims 100π mm-mrad will fit thru AGS switchyard.
- T. Roser claims can do fast ejection in main AGS hall.

Target Issues

- Baseline design: pulsed jet of liquid metal (Hg).
- Initial tests with GaSn, a room-temperature liquid:

  5 kg purchased.

  Fast 3-mm valve in hand.

  But, serious tests not yet begun.
- **Why won't a passive solid target work?**

  Dismissed in one sentence in the Snowmass book.

  M. Green's Orcas Island notes are lost.
- H. Kirk will describe a distributed target option.
- Here we (re)consider a water-cooled nickel target.

Water Cooling

- We expect about 400 kW = 100 kCal/s of energy deposited in our target.
- If allow water temp. rise of 100C, need 1kg/s = 1 liter/s flow.
- Various estimates of heat transfer at water/metal boundary:
  Snowmass book, C. Johnson: 200 W/cm^2.
  B. Weggel: 1 kW/cm^2.
  J. Haines (ORNL): 2 kW/cm^2.
- If accept 1 kW/cm^2, would need 400 cm^2 surface area.
- Nominal target size is $R = 1$ cm, $L = 30$ cm, $\Rightarrow A = 2\pi RL =$ 188 cm^2.
- $\Rightarrow$ Add fins, or run longitudinal or transverse water channels thru the target.

Properties of Nickel

- Z = 28, A = 58.7, $\rho = 8.9$ g/cm^3.
- Young's modulus, $E = 200$ GPa,

  Yield strength, $P \approx 0.2$ GPa $\approx 0.001E$,

  Poisson's ratio = 0.31.
- Electrical resisitvity = 6.8 $\mu\Omega$-cm = 4 $\times$ Cu.
- Melting point = 1453C, boiling = 2730C.
- Thermal expansion coef, $\alpha = 1.3 \times 10^{-5}$/C @ 20C.
- Specific heat, $C = 0.44$ J/g-C.
- Thermal conductivitiy, $\kappa = 90$ W/m-C = 0.9 W/cm-C.
- Permanickel 300 alloy has tensile strength $\approx$ 0.6 GPa, but $\kappa = 60$ W/m-C.
- Nickel is known to have good resistance to thermal shock.

Effect of a Single Beam Pulse on Nickel

- $\Delta U \approx 30$ J/g deposited in each beam pulse ($@f = 15$ Hz).
- $\Delta T = \Delta U / C = 30/0.44 = 68$C.
- Estimate thermal shock as

$$\Delta U = C\Delta T = \frac{C}{\alpha}\frac{\Delta l}{l} = \frac{C}{\alpha}\frac{P}{E},$$

$$\Rightarrow P = E\alpha\Delta T = 1.3 \times 10^{-5} \cdot 68 \cdot 200 = 0.18 \text{ GPa}.$$

- At or below yield strength for nickel/nickel alloy.
- Lore: the heat generated in a nickel target anneals it to a state of high yield strength, favorable for shock resistance.

Steady-State Thermal Stress

- Steady-state thermal gradients $\Rightarrow$ stress.

- Simplified model:

  Thermal gradient $T(z) \Rightarrow$ differential expansion $\Delta l(z)$.

  $$\frac{\delta \Delta l}{l} = \alpha[T(l) - T(0)] \equiv \alpha \Delta T.$$

  Relate the differential strain to stress via

  $$\frac{\delta \Delta l}{l} \approx \frac{P}{E}.$$

  Then, $P = \epsilon E \alpha \Delta T$, independent of length scale!

  Detailed calculations show $\epsilon = 0.3$-0.5.

- To avoid material failure, keep $P/E \leq 0.001$,

  $\Rightarrow$ Maximum thermal gradient $\Delta T = 0.001/\alpha\epsilon \approx 150$C.

- [$\Rightarrow$ Bandsaw must move fast enough that no more than 2 beam pulses hit any given spot.]

- If desire $\Delta T = 100$C along length l of a volume that presents area A to the cooling water, must have heat transfer rate

$$\frac{\kappa A \Delta T}{l} = \Delta U f \rho A l,$$

$$\Rightarrow l^2 = \frac{\kappa \Delta T}{\Delta U f \rho} = \frac{0.9 \cdot 100}{30 \cdot 15 \cdot 8.9} = 0.023, \Rightarrow l = 0.15 \text{ cm}.$$

- $\Rightarrow$ No material can be more than 1.5 mm from a water channel.
- Possible solution: slice target into 100 3-mm-thick disks,
  $\Rightarrow$ 600 cm^2 surface area, $\Rightarrow$ need 700 W/cm^2 cooling.
  Flow water transversely thru gaps of 1.5-3 mm between disks.
- Questions:
  What water pressure is needed?
  How massive is the pressure vessel?
  Will beam energy deposited in water lead to cavitation damage?
  What is pion yield?
- To go much farther, need professional engineering.