

Muon Collider main page:

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

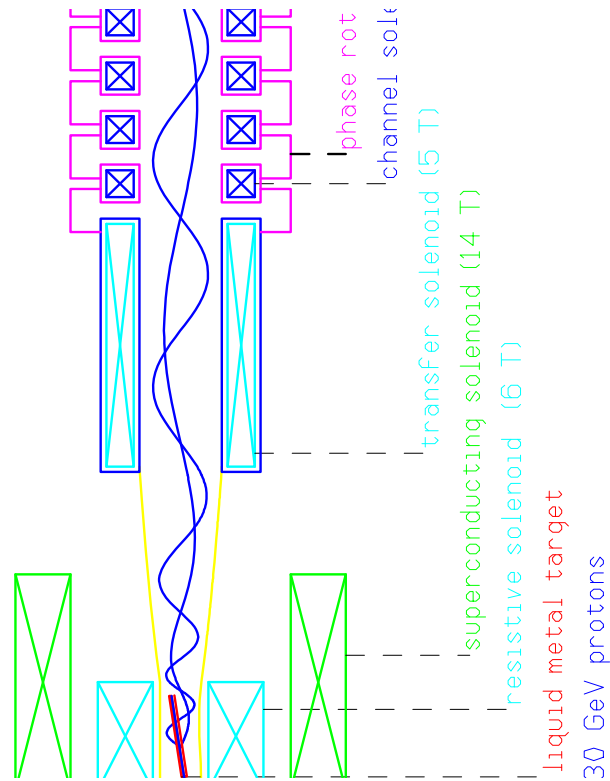
My muon collider page:

<http://www.hep.princeton.edu/~mcdonald/mumu>

Overview of Targetry for a Muon Collider

- Get muons from pion decay: $\pi^\pm \rightarrow \mu^\pm \nu$.
- Pions from proton-nucleus interactions in a **target**.
- Goal: $1.2 \times 10^{14} \mu^\pm/\text{s}$.
- \Rightarrow High- Z target,
High-energy proton beam,
High magnetic field around target to capture soft pions.
- $\mu/p = 0.08$ at 16 GeV $\Rightarrow 1.5 \times 10^{15} p/\text{s}$.
- 15-Hz proton source.
- 4 MW power in p beam.
- Compare: 0.1 MW in 900-GeV extracted p beam at FNAL;
0.25 MW in 30-GeV extracted beam at BNL AGS.

Baseline Scenario

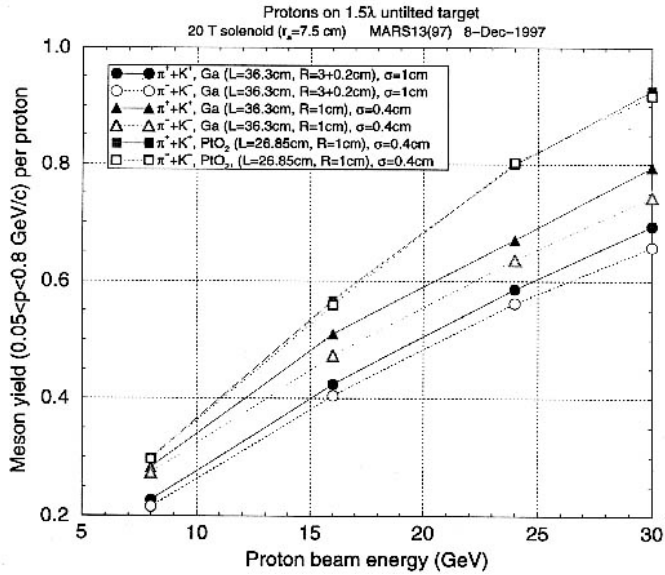


- Liquid metal target: Ga, Hg, or solder (Bi/In/Pb/Sn alloy)
- 20-T capture solenoid followed by 5-T phase-rotation channel.
- 20 T = 8-T, 8-MW water-cooled Cu magnet
+ 12-T superconducting magnet.
- Cost of 12-T magnet $\approx 0.8 \text{ M\$ } (B[\text{T}] R[\text{m}])^{1.32} (L[\text{m}])^{0.66}$
 $\approx \$6\text{M}$.

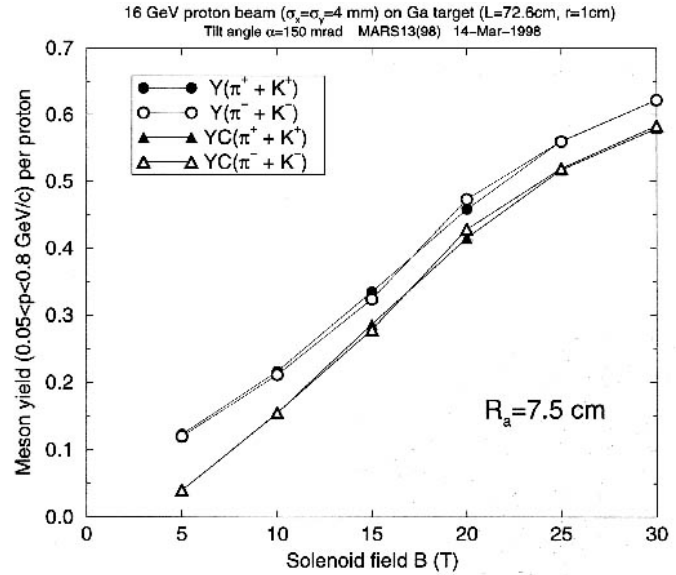
- Capture pions with $P_{\perp} < 220 \text{ MeV}/c$.
- Adiabatic invariant: $\Phi = \pi r^2 B$ as B drops from 20 to 5 T.
- $r = P_{\perp}/eB =$ radius of helix.
- $\Rightarrow P_{\perp,f} = P_{\perp,i} \sqrt{B_f/B_i} = 0.5$ (and $P_{\parallel,f} > P_{\parallel,i}$).
- Tilt target by ≈ 0.1 rad to minimize absorption of spiralling pions (factor of 2 effect).
- Target should be short and narrow,
 \Rightarrow high density; no cooling jacket.
- High power of beam + radiation damage would crack stationary target.
 - 10% of beam energy deposited in target $\Rightarrow 30 \text{ kJ/pulse}$.
 - $M_{\text{target}} = \pi r^2 l \rho \approx 10 \text{ kg} \Rightarrow \approx 0.1 \text{ eV/atom/pulse}$.
 - 10% of TNT \Rightarrow Shock damage.
 - 1% of atoms ionized each pulse \Rightarrow embrittlement....
- \Rightarrow **Pulsed heavy-metal liquid jet** as target.

Target Optimization via MARS Code

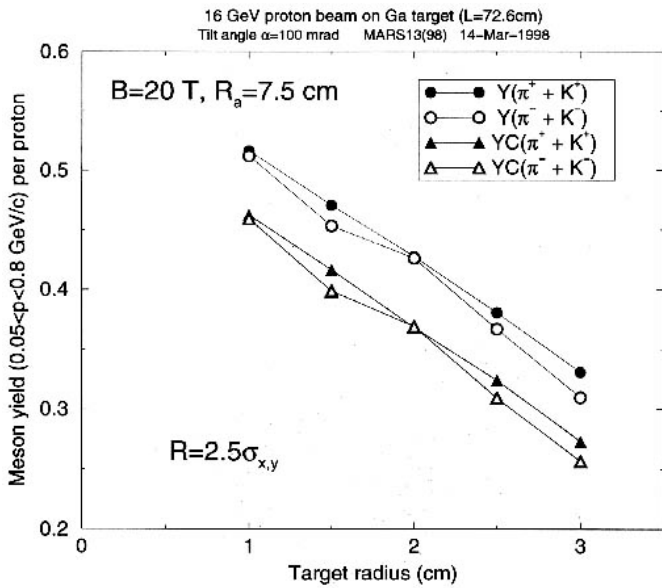
Yield *vs.* Beam Energy



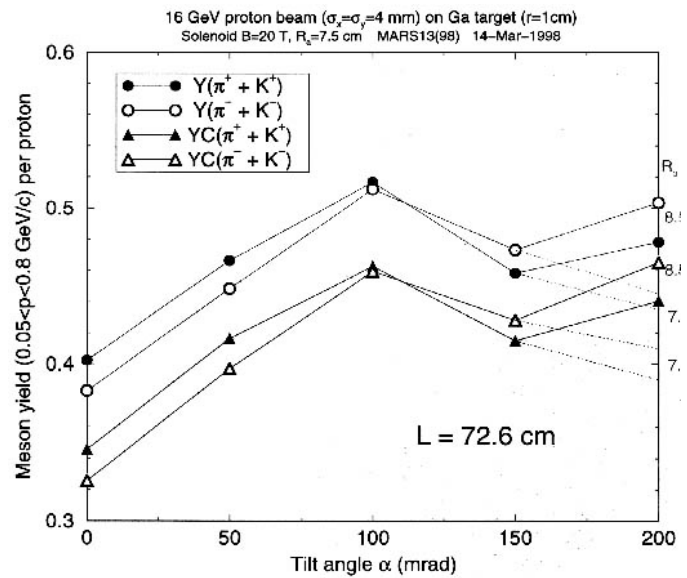
Yield *vs.* Magnetic Field



Yield *vs.* Target Radius

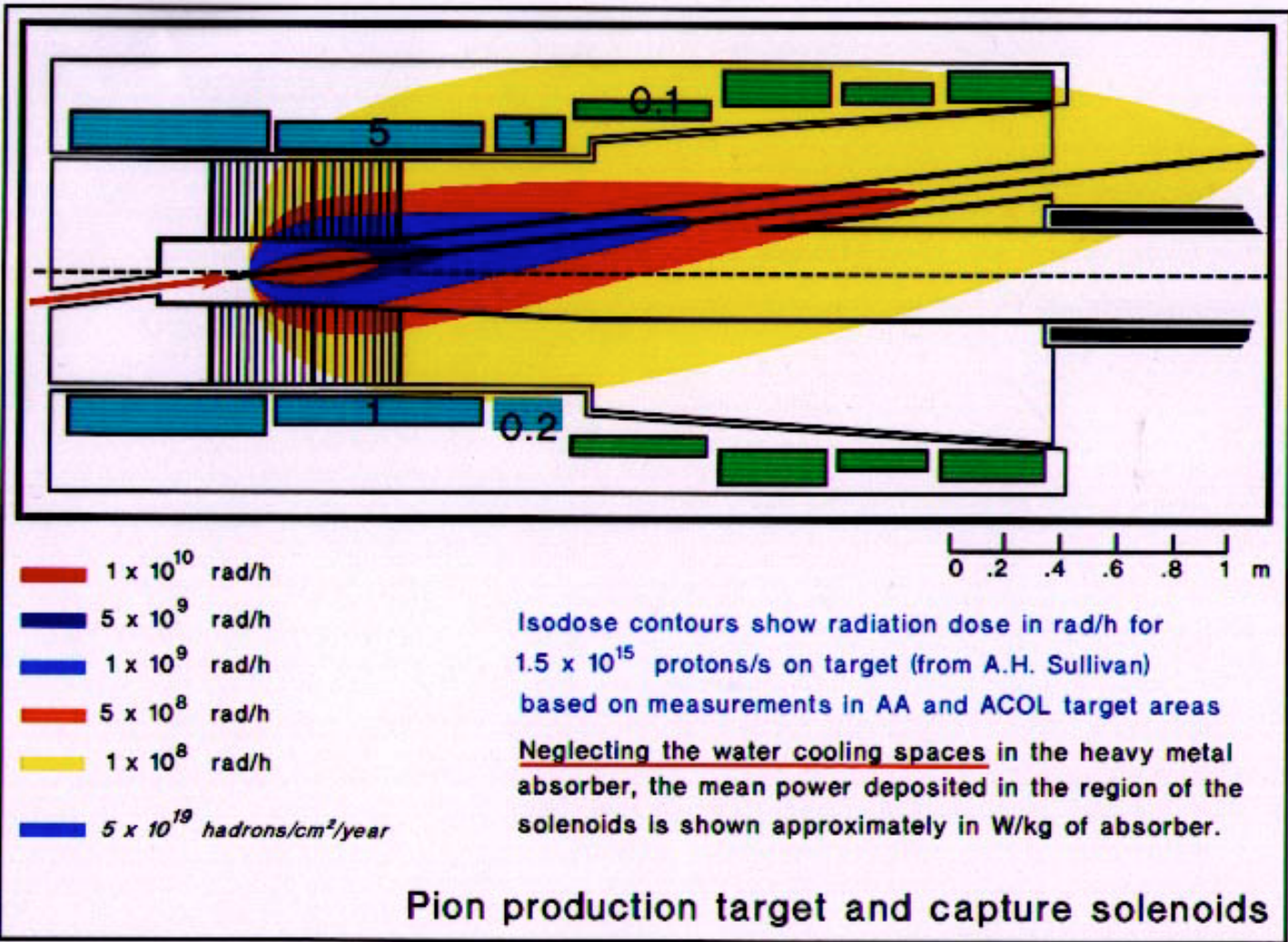


Yield *vs.* Target Angle

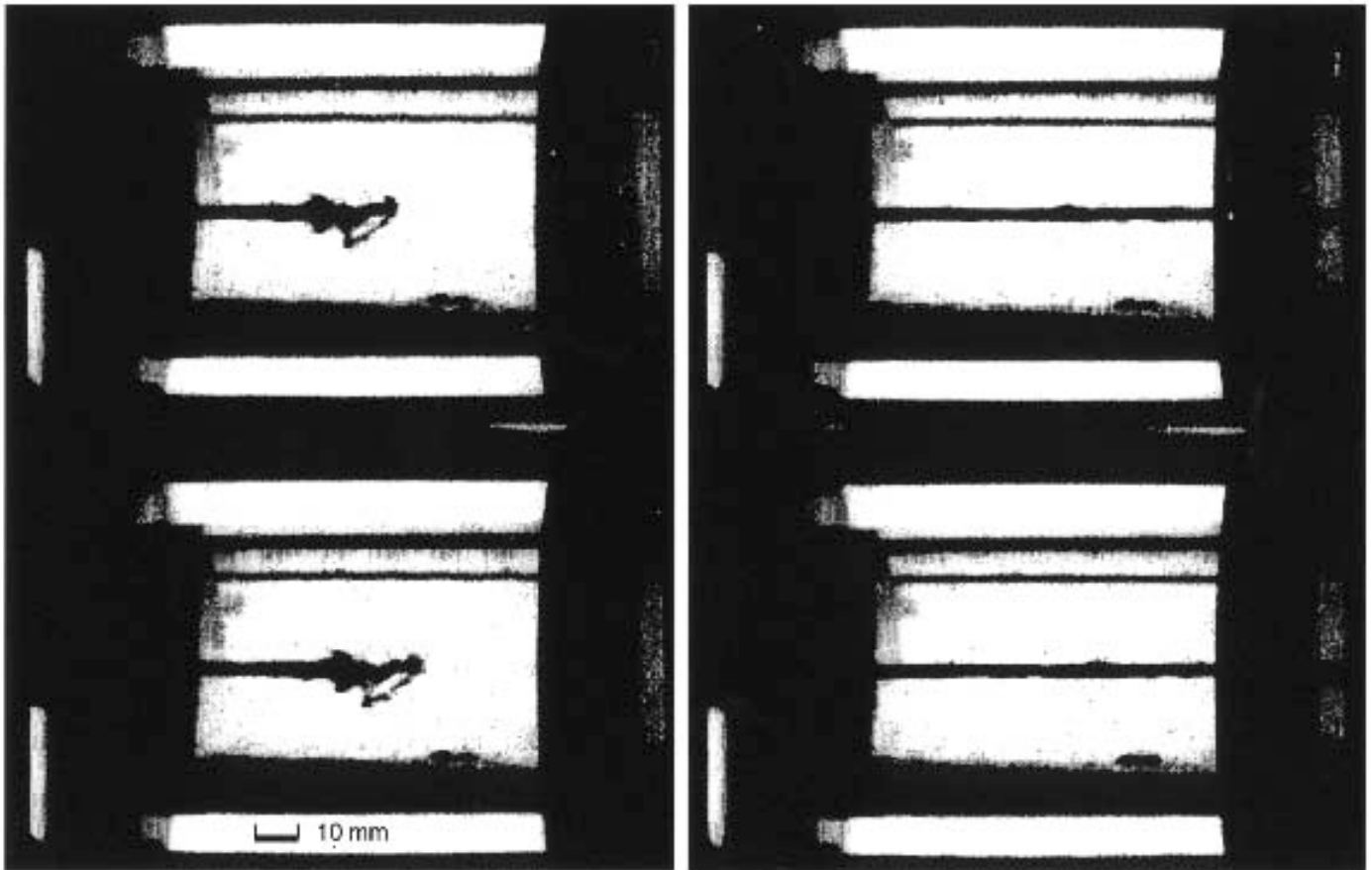


[Nikolai Mokhov, <http://www-ap.fnal.gov/MUMU/mumu.html>]

High Radiation Dose Around Target



Mercury Jet Studied at CERN



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. Poncelet

Colin Johnson has joined the muon collider targetry group.

Eddy Current Effects on Conducting Liquid Jets

- In frame of jet, changing magnetic field induces eddy currents.
- Lenz: Forces on eddy current oppose motion of jet.
- Longitudinal drag force \Rightarrow won't penetrate magnet unless jet has a minimum velocity: $\sigma = \sigma_{\text{Cu}}/60$, $\rho = 10 \text{ g/cm}^3$, \Rightarrow

$$v_{\min} > 60 \text{ m/s} \left[\frac{r}{1 \text{ cm}} \right] \left[\frac{r}{D} \right] \left[\frac{B_0}{20 \text{ T}} \right]^2.$$

Ex: $B_0 = 20 \text{ T}$, $r = 1 \text{ cm}$, $D = 20 \text{ cm}$, $\Rightarrow v_{\min} = 3 \text{ m/s}$.

- Drag force is larger at larger radius \Rightarrow planes deform into cones:

$$\frac{\Delta z(r)}{r} \approx -3\alpha \left[\frac{r}{1 \text{ cm}} \right] \left[\frac{B_0}{20 \text{ T}} \right]^2 \left[\frac{10 \text{ m/s}}{v} \right].$$

Ex: $\alpha = L/D = 2$, $r = 1 \text{ cm}$, $v = 10 \text{ m/s}$ $\Rightarrow \Delta z = 6 \text{ cm}$.

- Radial pressure: compression as jet enters magnet, expansion as it leaves:

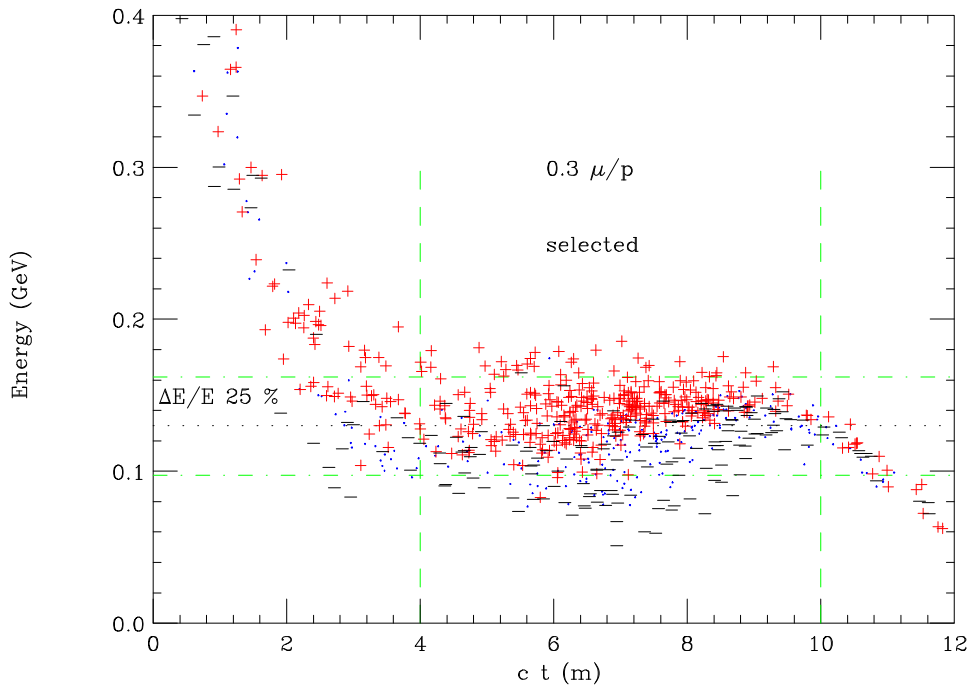
$$P \approx 50 \text{ atm.} \left[\frac{r}{1 \text{ cm}} \right] \left[\frac{r}{D} \right] \left[\frac{B_0}{20 \text{ T}} \right]^2 \left[\frac{v}{10 \text{ m/s}} \right].$$

Ex: $P = 2.5 \text{ atm}$ for previous parameters.

- Will the jet break up into droplets?
- Need both FEA analysis and **lab tests**.

Phase Rotation Channel

- Capture pions with large ΔE about $E \approx 150$ MeV.
- Squeeze energy in linac phased for zero gain at 150 MeV.
- RF cavities interspersed with 5-T magnets.



[+ \leftrightarrow positive polarization, - \leftrightarrow negative]

Linac	Length m	Frequency MHz	Gradient MeV/m
1	3	60	5
2	29	30	4
3	5	60	4
4	5	37	4

Targetry R&D Program

- Simulations:

 - Target shock damage.

 - Magnetohydrodynamics of liquid metal jets.

 - Beam transport in the phase rotation channel.

- Liquid metal dynamics:

 - Lab tests of jets entering 6-20 T magnets.

- Beam + target tests:

 - Liquid (solid) targets in BNL beam of 10^{14} protons/pulse.

 - RF cavity close to target: radiation induced breakdown?

- Workshop: May 1 at BNL to formulate R&D plan.