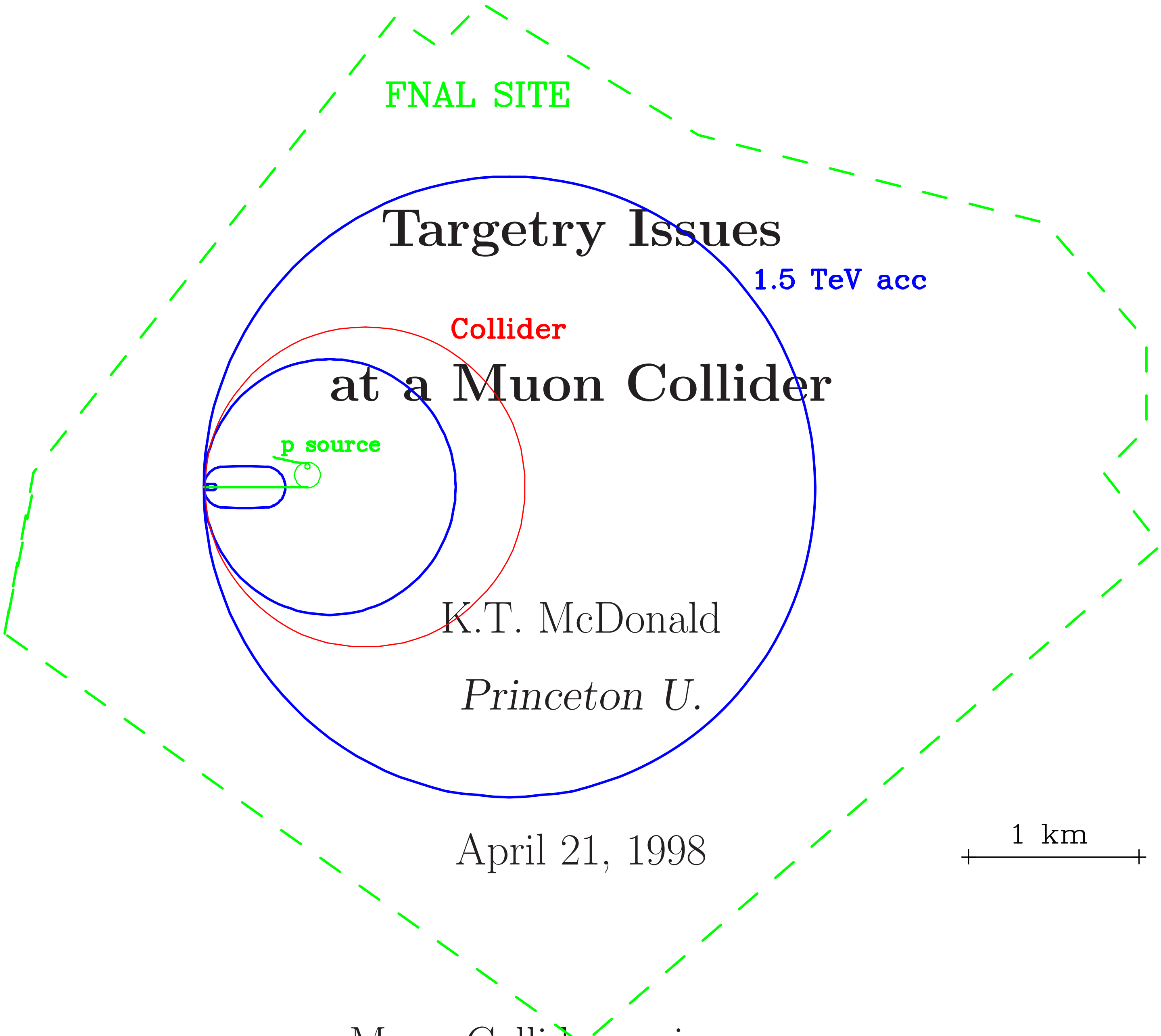

Targetry Issues at a Muon Collider

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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

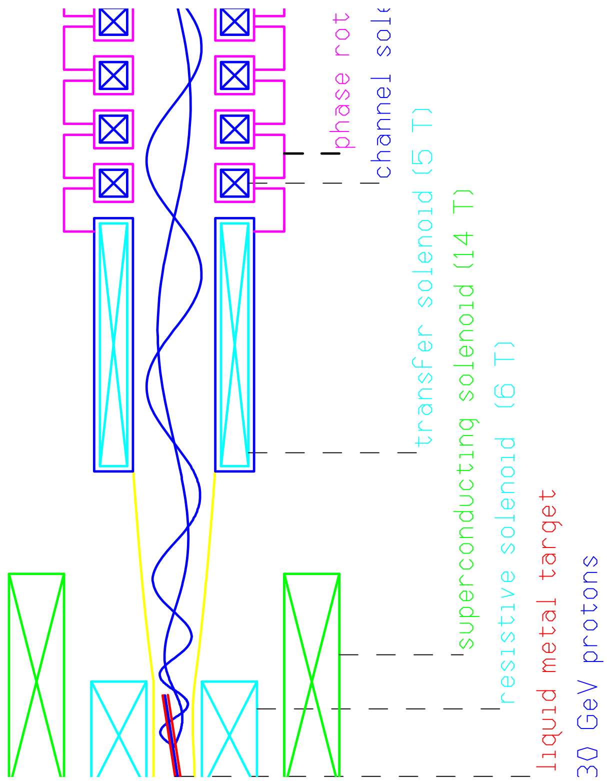
Overview of Targetry for a Muon Collider

- Get muons from pion decay: $\pi^\pm \rightarrow \mu^\pm \nu$.
- Pions from proton-nucleus interactions in a **target**.
- Goal: 1.2×10^{14} $\mu^\pm$/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/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.

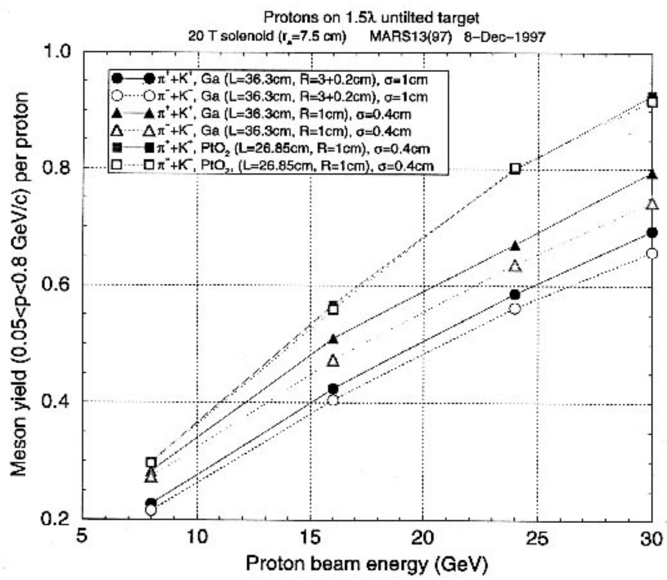
- Cost of 12-T magnet $\approx$ 0.8 M\$ $(B[\mathrm{T}]\ R[\mathrm{m}])^{1.32}(L[\mathrm{m}])^{0.66}$

  $\approx$ \$6M.

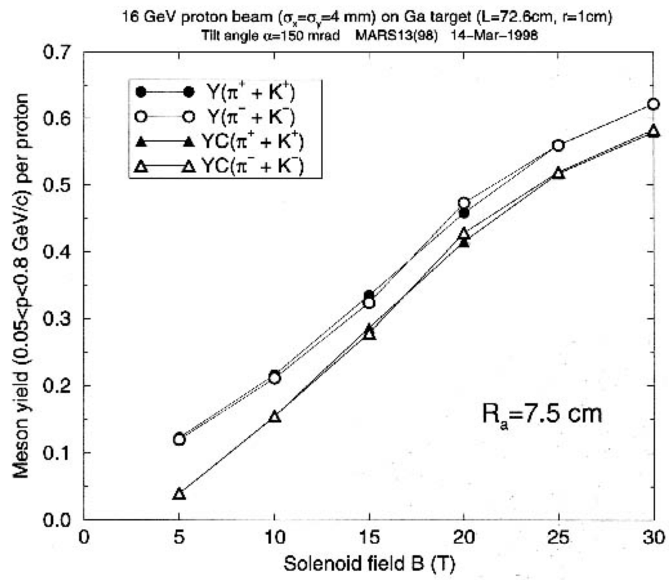
- Capture pions with $P_\perp < 220$ MeV/c.
- Adiabatic invariant: $\Phi = \pi r^2 B$ as B drops from 20 to 5 T.
- $r = P_\perp / eB$ = radius of helix.
- $\Rightarrow P_{\perp,f} = P_{\perp,i}\sqrt{B_f/B_i} = 0.5$ (and $P_{\|,f} > P_{\|,i}$).
- Tilt target by ≈ 0.1 rad to minimize absorption of spiralling 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 kJ/pulse.
  - $M_{\rm target} = \pi r^2 l \rho \approx 10$ kg $\Rightarrow \approx 0.1$ 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

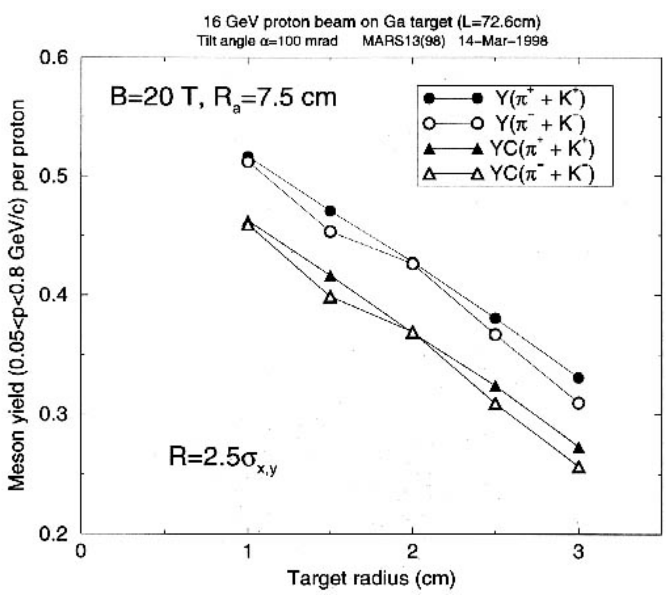
Yield *vs.* Beam Energy



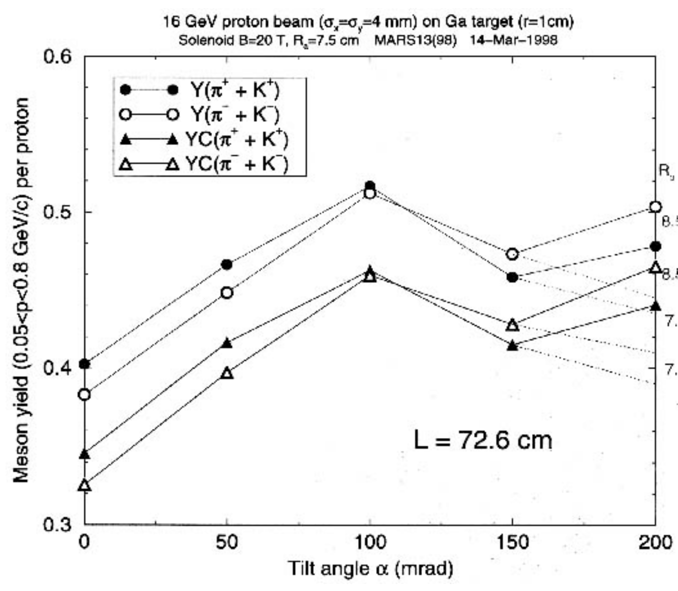
Yield *vs.* Magnetic Field



Yield *vs.* Target Radius

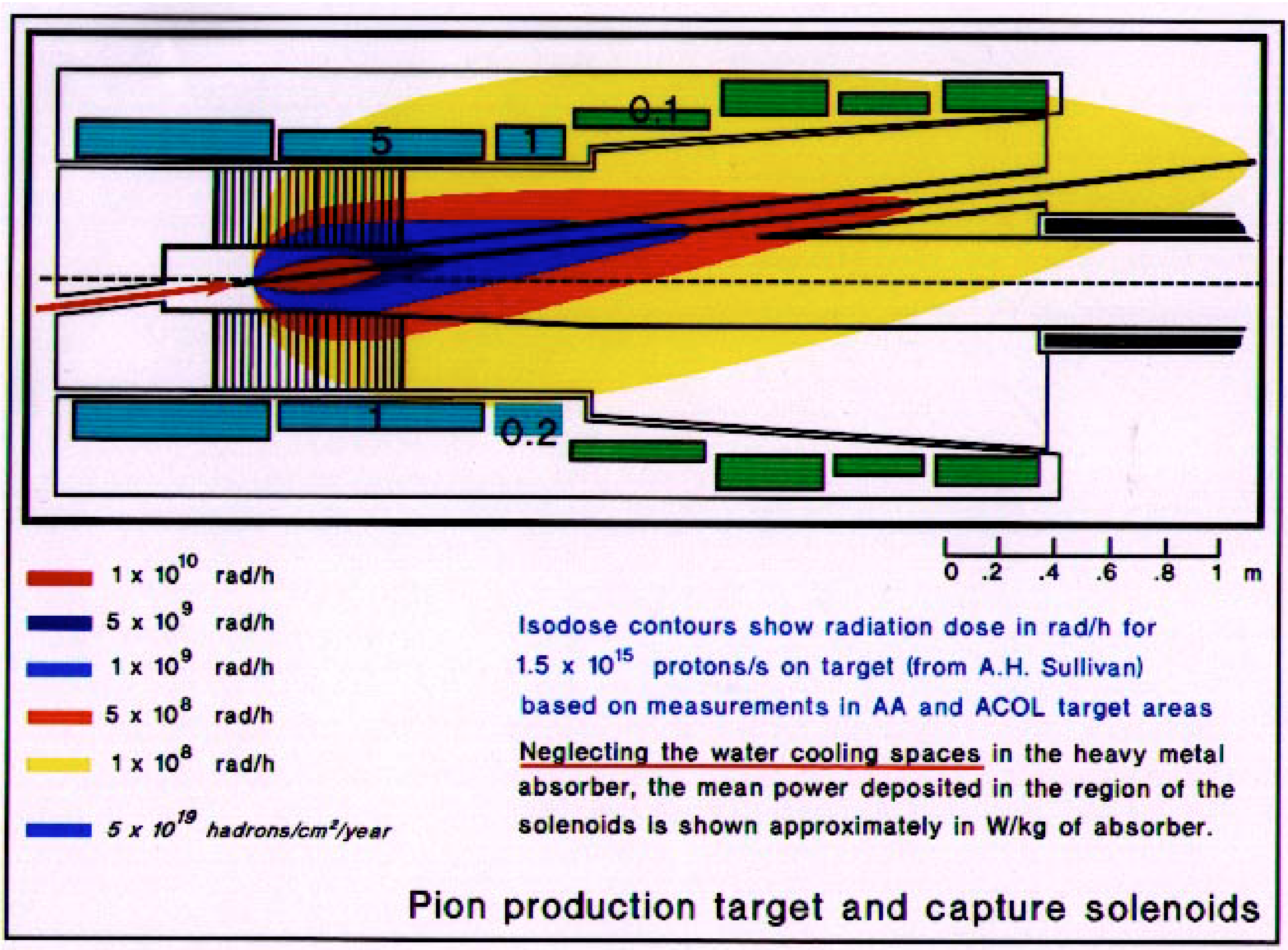


Yield *vs.* Target Angle

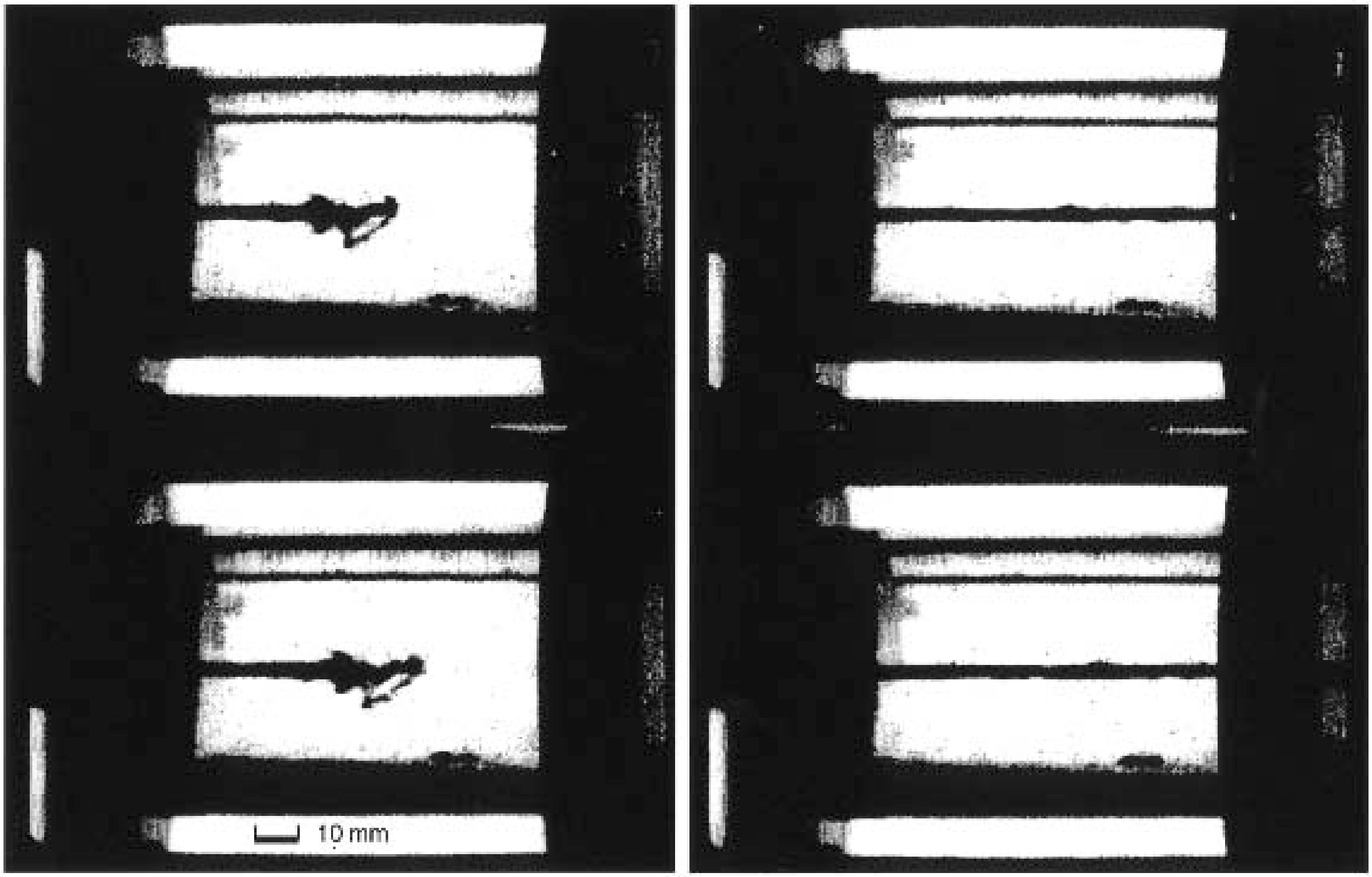


[Nikolai Mokhov, `http://www-ap.fnal.gov/MUMU/mumu.html`]

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. Poncet

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: $\sigma = \sigma_{\rm Cu}/60,\ \rho = 10$ g/cm^3, $\Rightarrow$

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

Ex: $B_0 = 20$ T, $r = 1$ cm, $D = 20$ cm, $\Rightarrow v_{\rm min} = 3$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: $\alpha = L/D = 2,\ r = 1$ cm, $v = 10$ m/s $\Rightarrow \Delta z = 6$ cm.

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

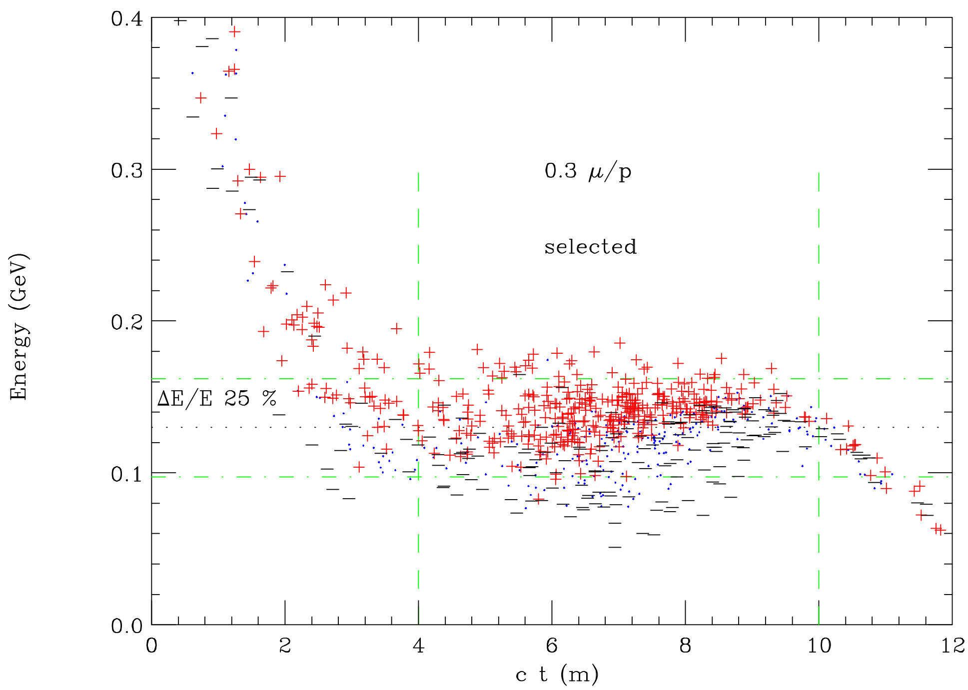
$$P \approx 50 \text{ atm.} \left[\frac{r}{1 \text{ cm}}\right] \left[\frac{r}{D}\right] \left[\frac{B_0}{20 \text{ T}}\right]^2 \left[\frac{v}{10 \text{ m/s}}\right].$$

Ex: $P = 2.5$ 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.



[+ ↔ positive polarization, − ↔ 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.