Introduction

We'll see that:

- Laser cooling, by Compton scattering, works very well in theory
- Power needed scales as $1/E^2$ of muon beam

⇒ Might be feasible for ≥1.5 TeV beam
$\geq \times 1000$ increase in luminosity per muon
relative to parameters in status report

Scenario:
~~Go directly to~~ 3 TeV c.o.m. COLLIDER IN STATUS REPORT
Still need front–end cooling, but looser requirements:

- Lower repitition rate
- Less cooling– just good enough to get into accelerator
- Lower muon acceptance

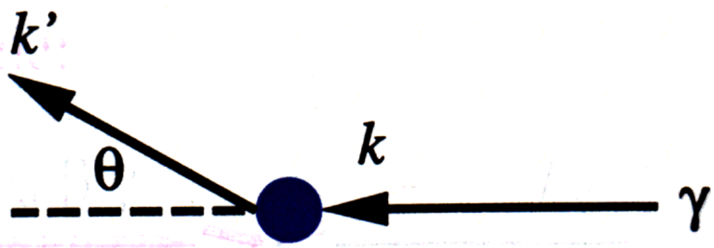
Other benefits

- Reduced radiation problem
- Reduced detector backgrounds
- Possibility for ultra–high luminosity

New set of technical miracles needed, but:

- Net improvement in feasibility?
- Net reduction in power consumption?

Compton Scattering



μ in rest frame

$$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha^2}{2m^2}\right)\left(\frac{k'}{k}\right)^2\left(\frac{k'}{k} + \frac{k}{k'} - \sin^2\theta\right)$$

$$k' = \frac{k}{1+(k/m)(1-\cos\theta)}$$

For $k << m$:

$$k' \approx k$$

$$\frac{d\sigma}{d\Omega} = 1 + \cos^2\theta$$

$$\sigma = \frac{8\pi}{3} r_\mu^2$$

r_μ^2 is the classical muon radius, $\frac{\alpha^2}{m^2}$

σ reduced by 4×10^4 relative to e

For 0.1 eV γ: 1 collision $\Leftrightarrow$ 10 J / $(\mu m)^2$

Laser Cooling of 1.5 TeV Muon Beams

Fritz DeJongh

- Introduction
- Compton scattering
- Transverse cooling effect
- Longitudinal cooling effect
- Configuration with storage ring
- Conclusions

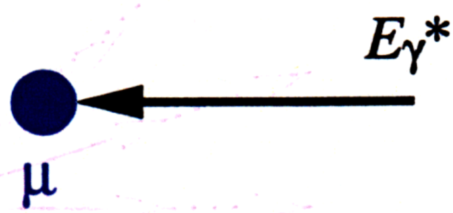
Application to e^+e^- beams for $\gamma\gamma$ collider

Palmer
Telnov
Ohsagi

Lab frame:

$\beta \approx 1$

μ frame:



$$E_\gamma{}^* = \gamma\, E_\gamma\,(1 + \beta) \approx 2\,\gamma\, E_\gamma$$

- On average:
- In μ frame:

  γ transfers energy $E_\gamma{}^*$ to μ

Average E_μ loss in lab frame:

$$E_\mu \rightarrow E_\mu - 2\,\gamma^2\, E_\gamma$$

Average transverse kick:

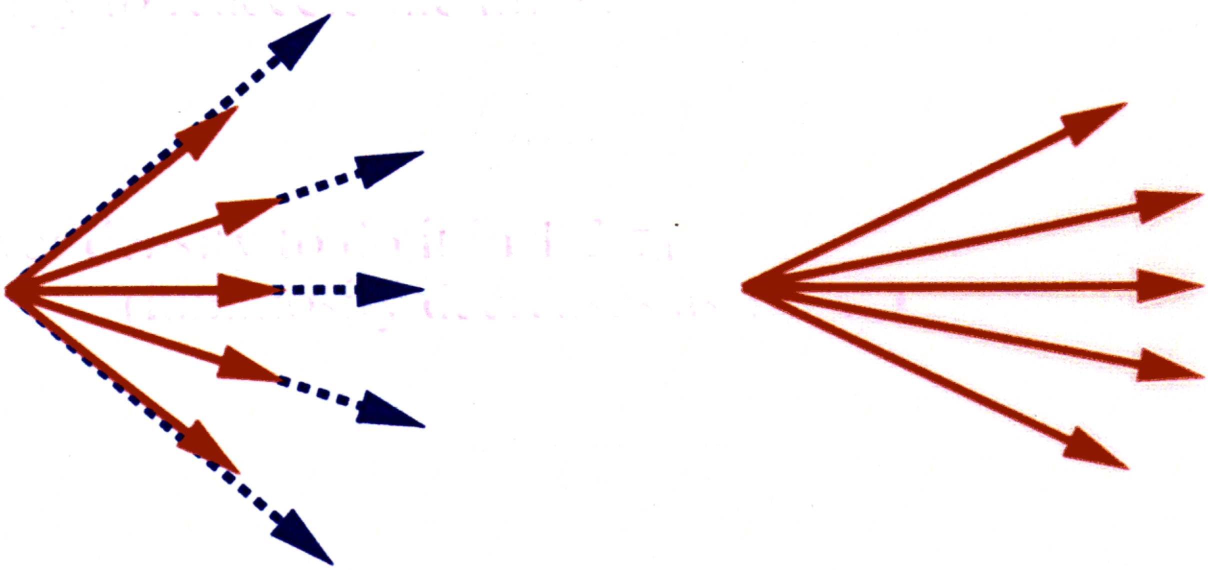
$$p_{T\mu} \sim \gamma\, E_\gamma$$

$\Rightarrow$For large γ,
μ slows down without changing direction.

Transverse Cooling Effect

Cooling effect:
Compton scatter a set of muons and reaccelerate:

$$\sigma_\alpha \to \sigma_\alpha \left(1 - 2\,\gamma\, E_\gamma / m\right)$$



Heating effect:
From transverse kick

Poisson stat

$$\sigma_\alpha^2 \to \sigma_\alpha^2 + 2\,\frac{15}{16}\left(\frac{E_\gamma}{m}\right)^2$$

Equilibrium:

$$\sigma_\alpha = \left(\frac{15}{32}\,\frac{E_\gamma}{E_\mu}\right)^{1/2}$$

To decrease $\sigma\alpha$ by $1/e$

Number of scatterings

$$n = \frac{m}{2\gamma E_\gamma}$$

Energy to reaccelerate muon

$$E_{reacc} = E_\mu$$

Power density to do it in $1/2\ \tau_\mu$
(luminosity decreases as $1/2\ \tau_\mu$)

$$p = \frac{3m}{8\pi\, \gamma^2\, \tau_\mu\, r_\mu^2}$$

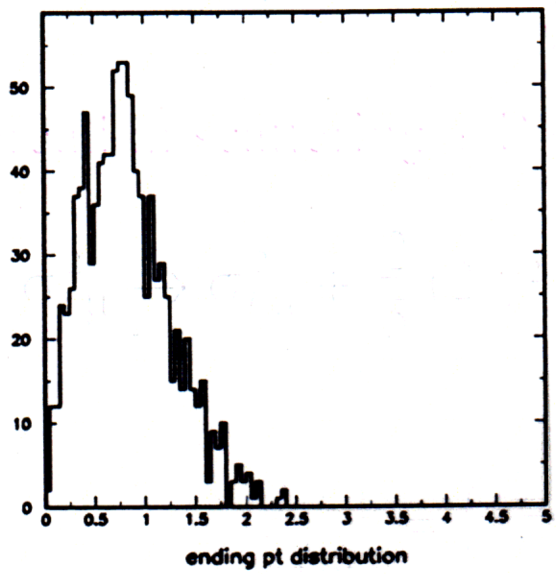
Decreases as the square of E_μ increases!

For $E_\mu = 1.5$ TeV:

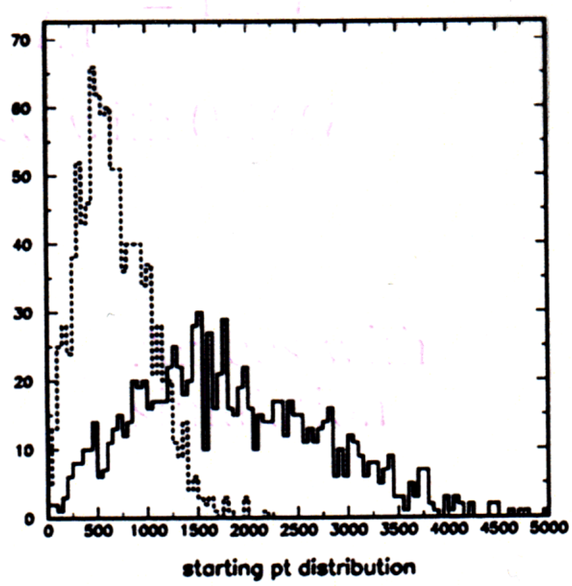
$$p = 2.4 \times 10^7\ \mathrm{W} / \mu\mathrm{m}^2$$

Simple simulation – quantitative agreement

$E_\gamma = 1$ eV, $E_\mu = 1.5$ TeV $\Rightarrow$ $\sigma_\alpha = 5.6 \times 10^{-7}$ rad
compared with 10^{-3} rad



Equilibrium p_T



p_T reduction

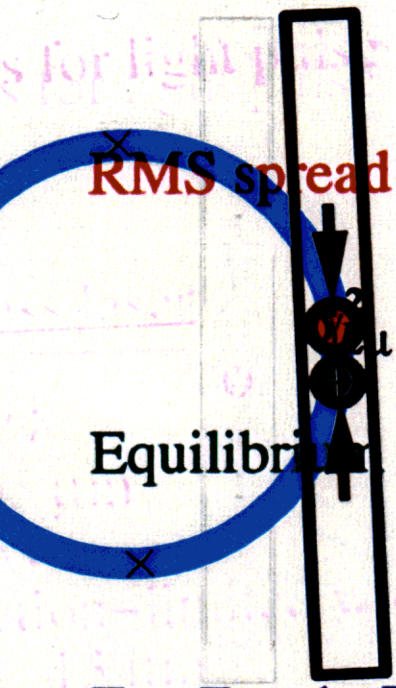
Dashed: ending p_T distribution

torage Ring

Longitudinal Cooling Effect

Energy loss $\propto E_\mu^2$

$$\sigma_{E\mu} \to \sigma_{E\mu} - \frac{\sigma_{E\mu}}{E\mu} 4\gamma^2 E_\gamma$$



RMS spread in scattering + Poisson term

$$\sigma_{E\mu}^2 \to \sigma_{E\mu}^2 + \frac{2}{5}(2\,\gamma^2 E_\gamma)^2 + (2\,\gamma^2 E_\gamma)^2$$

Equilibrium

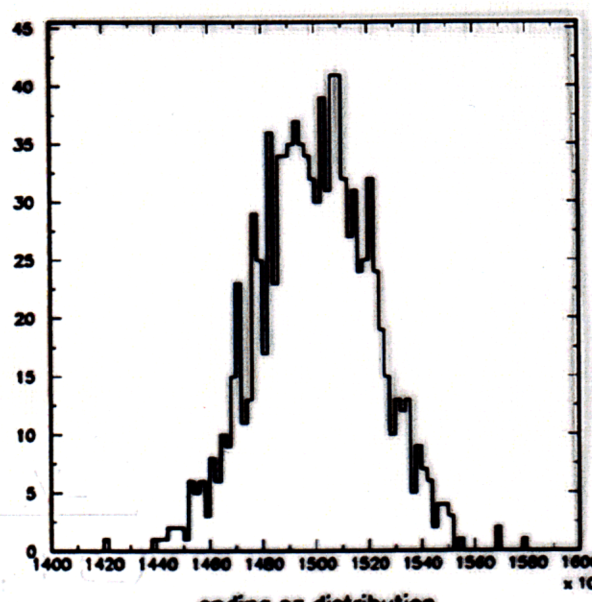
$$\frac{\sigma_{E\mu}}{E\mu} = \left(\frac{7\gamma E_\gamma}{5m}\right)^{1/2}$$

For $E_\gamma = 1$ eV, $E_\mu = 1.5$ TeV

$$\frac{\sigma_{E\mu}}{E\mu} = 1.4\%$$

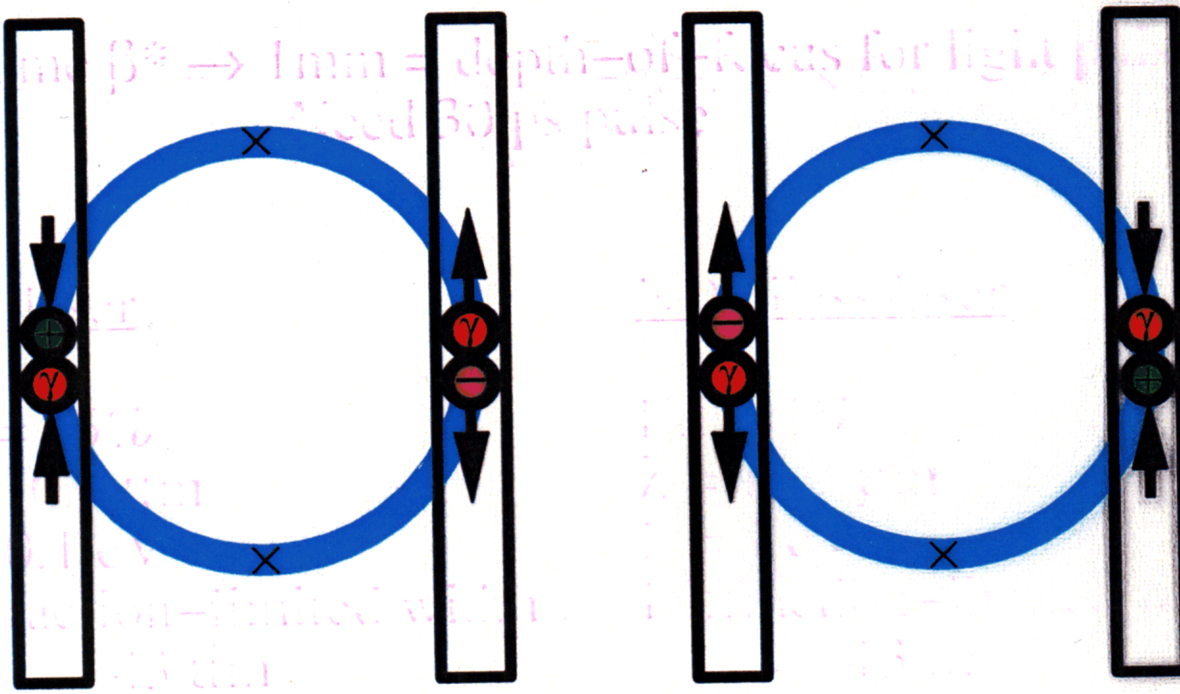
compared with 0.16%

Agrees with simulation



Use with 1.5 TeV/beam Storage Ring

Assume 4 bunches $\rightarrow$ 1 bunch



Parameters from status report:

- circumference = 6 km
- $\beta^* = 3$ mm
- $\sigma_z = 3$ mm
- $\sigma_r = 3.2\ \mu$m
- $\sigma_\theta = 1.1$ mrad
- $L = 7 \times 10^{-34}$ / cm² sec

$$L \propto \frac{N_+ N_-}{\beta^* (\varepsilon_+ + \varepsilon_-)}$$

To cool in 1 τ_L: (1/e)

- 15 msec
- 750 turns

$\Rightarrow$ Q = 1000, reasonable

Assume $\beta^* \rightarrow$ 1mm = depth–of–focus for light pulse
Need 30 ps pulse

$p \propto \beta^*$ OK IF σ_E INCREASES

<u>CO_2 laser</u>

Eff = 25%
λ = 10.6 μm
E = 0.1 eV
Diffraction–limited width
43 μm
F–stop = 7
Lum factor: 5600
Energy spread: 0.4%
Energy in pulse:
0.5 MJ

X 8.6 FOR eq.

<u>ND:Glass laser</u>

Eff = 1%
λ = 1.05 μm
E = 1 eV
Diffraction–limited width
13 μm
F–stop = 22
Lum factor: 1770
Energy spread: 1.4%
Energy in pulse:
0.05 MJ

X 7.5 FOR eq.

Conclusions

$> \times 1000$ in luminosity
~10 MW of power

$\Rightarrow$ Can in principle be done with reasonable power consumption, and result in looser requirements on other components.

CO_2 laser seems preferable
- Better cooling
- Lower energy spread

Can a laser be made with
- short enough pulses?
- high enough power

Can good enough optics be made?

Can we get the light to the IP?

Can we make muon bunches shorter?