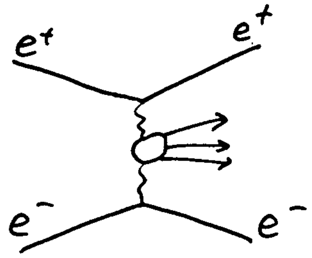
Problems (and show-stoppers) for $\gamma\gamma$, $\gamma\mu$, μp using very high energy muons

V. Telnov

Montauk, 1.10.1999

1. Introduction.
   $\gamma\gamma$, γe based on linear e^+e^- colliders
2. $\gamma\gamma$ at muon colliders
3. $\gamma\mu$ —"— —"—
4. μp —"— —"—

$\gamma^*\gamma^*$ at storage rings (since ~1970)



$dn_\gamma \sim 0.035\, d\omega/\omega$

$\gamma\gamma \to e^+e^-$ (1969)
$\gamma\gamma \to \eta', f_2$ (1979)

$L_{\gamma\gamma} \sim 10^{-2} L_{ee}$ at $W_{\gamma\gamma}/2E > 0.1$
$\sim 10^{-4} L_{ee}$ " " > 0.5

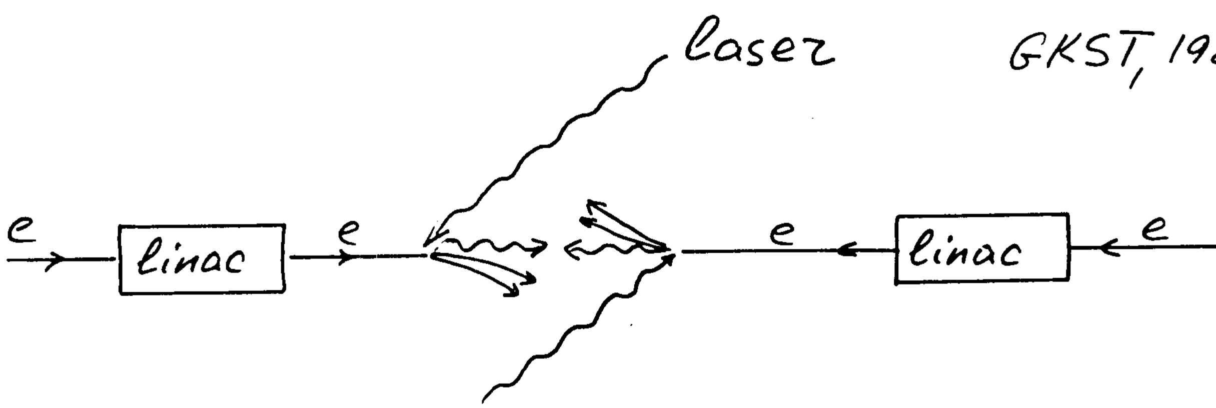
$\gamma\gamma$, γe at linear colliders

$2E_0 \approx 0.2 - 2$ TeV
$e^+e^- + e^-e^-$
$+$ $\gamma\gamma$, γe-colliders

CDR
- TESLA/SBLC
- NLC } → ILC
- JLC }

CLIC
VLEPP

GKST, 1981



$N_\gamma \sim N_e$, $E_\gamma \sim E_e$ $\Rightarrow$ $L_{\gamma\gamma} \sim L_{ee}$
$\sim 0.1 - 1$ TeV
$>$?
$10^{33} \to 10^{34} \to 10^{35}$ (?) !!!

Photon colliders

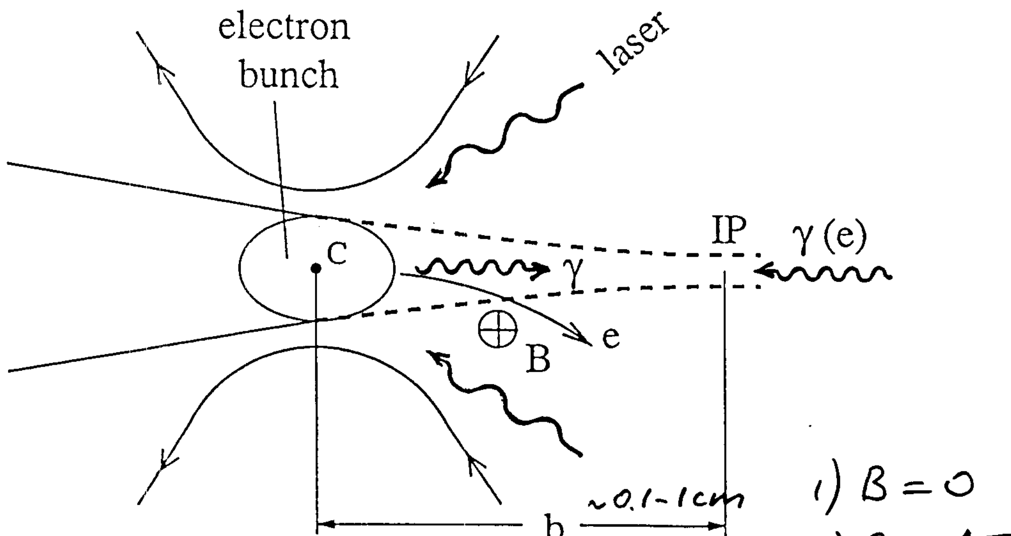


Figure 1:

Scheme of $\gamma\gamma$,γe collider

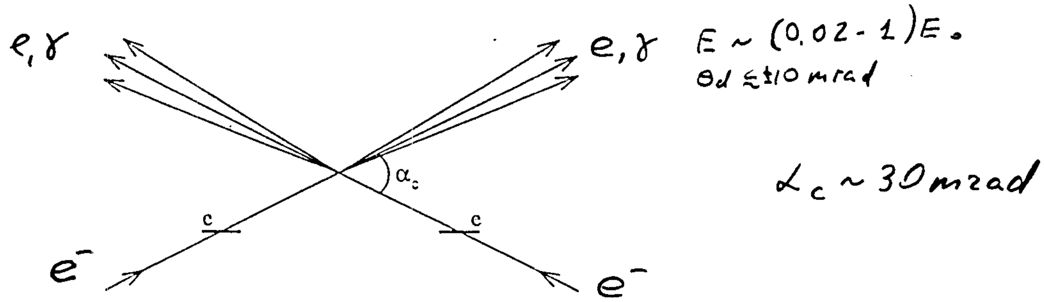
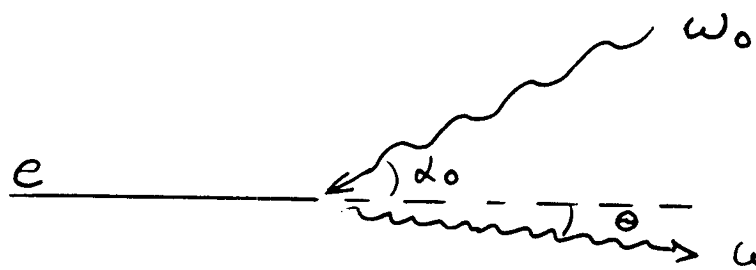


Figure 2:

Crab crossing scheme

Compton scattering



– energy
$\hbar \equiv 1$

$\omega_m \sim 4\gamma^2 \omega_0$ at $x \ll 1$

$$\omega = \frac{\omega_m}{1 + (\vartheta/\vartheta_0)^2}, \quad \omega_m = \frac{x}{x+1} E_0; \quad \vartheta_0 = \frac{mc^2}{E_0}\sqrt{x+1};$$

$$x = \frac{4E\omega_0}{m^2c^4} \simeq 15.3 \left[\frac{E_0}{\mathrm{TeV}}\right] \left[\frac{\omega_0}{eV}\right] = 19 \left[\frac{E_0}{\mathrm{TeV}}\right] \left[\frac{\mu m}{\lambda}\right],$$

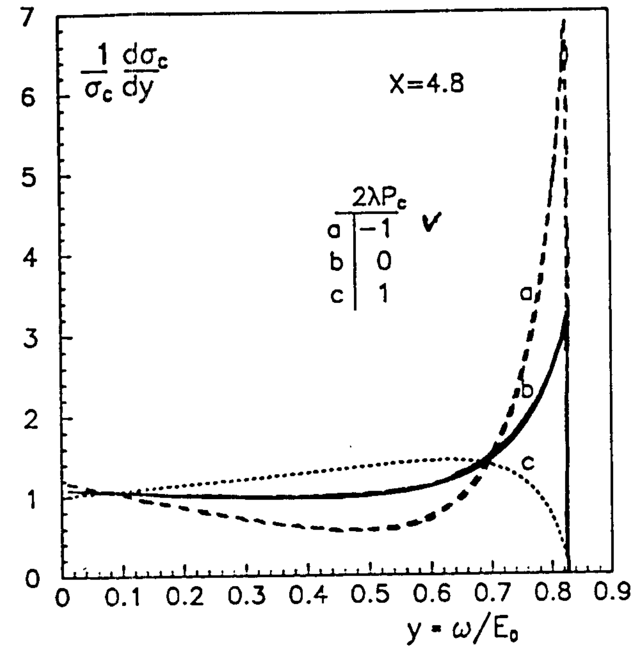
Example: $E_0 = 250$ GeV
$\omega_0 = 1.17$ eV ($\lambda = 1.06 \mu m$)
(Nd: Glass)
$\Rightarrow x = 4.5$
$\frac{\omega_m}{E_0} \sim 0.82$

$x \simeq 4.8$ is threshold
for $\gamma_{laser}\,\gamma_{high\,energy} \to e^+e^-$

Energy spectrum of scattered photons

λ – long. polar. of electr.
P_c – helicity of laser phot.

(6)



at $x \gg 1$

$\theta \sim \frac{1}{\gamma} \Leftrightarrow \frac{\Delta y}{y_m} \sim \frac{1}{x}$

$\sigma_c = \sigma_c^{np} + \lambda_e P_c \sigma_1$

Figure 2: Photon energy spectrum (for small conversion coefficients)

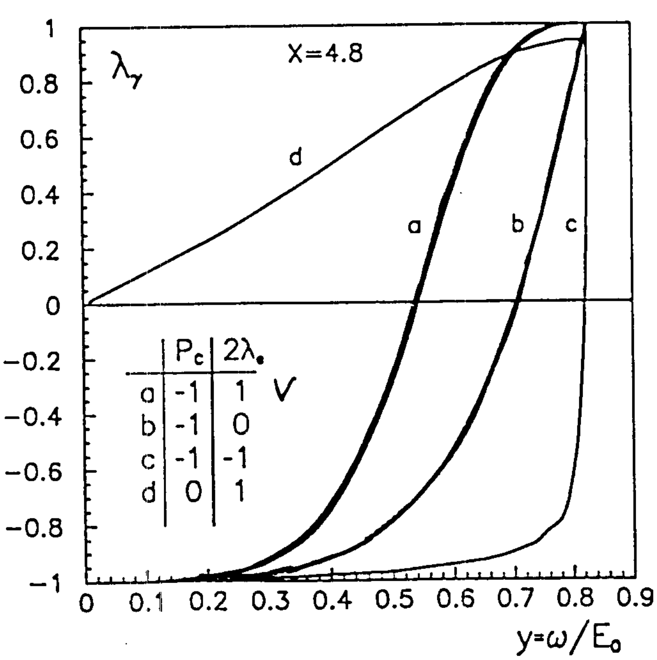
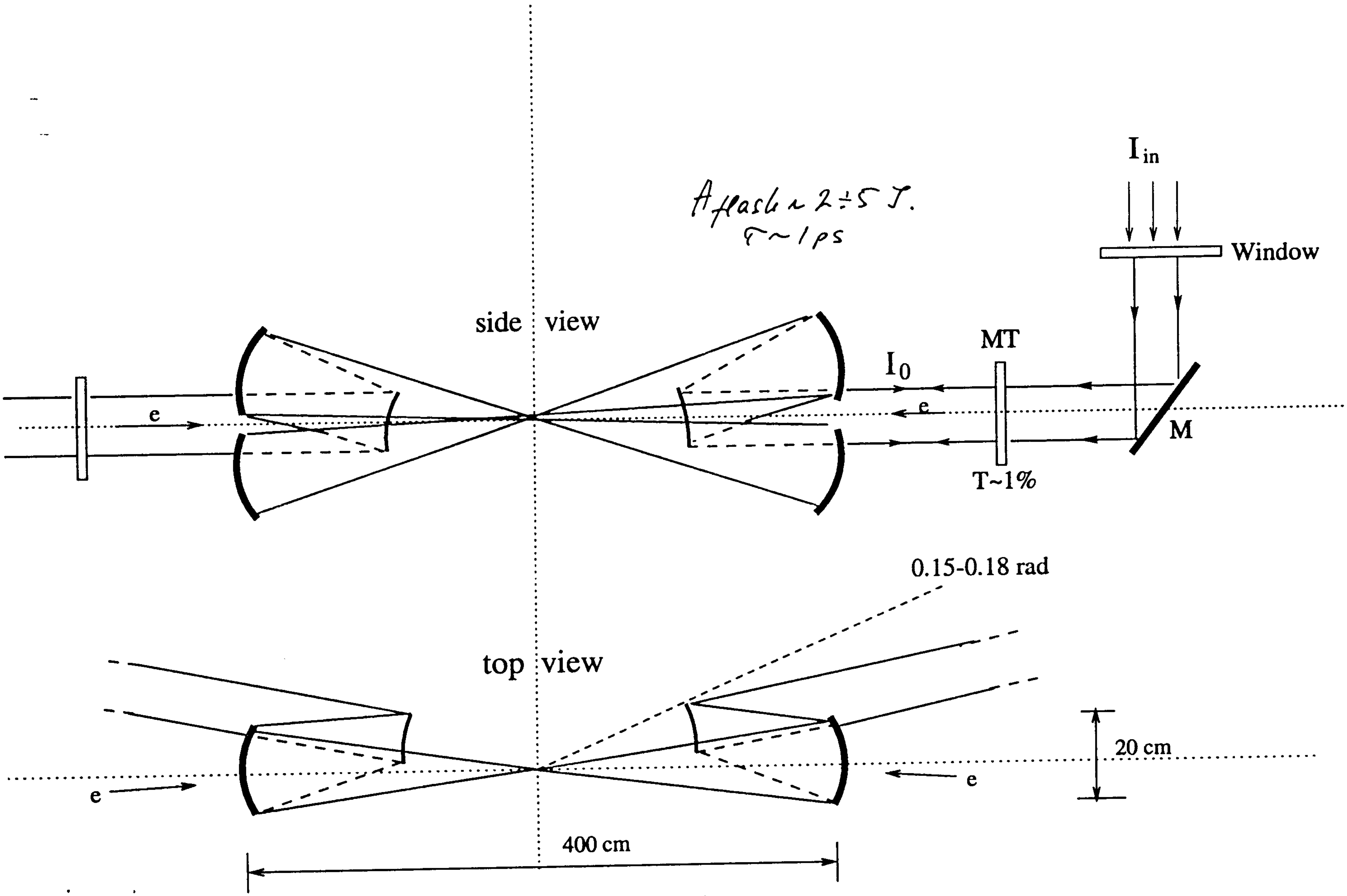


Figure 3: Mean helicity of the scattered photons.



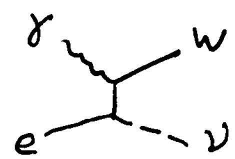
A flash ~ 2÷5 J.
τ ~ 1 ps
I in
Window
side view
MT
I0
e
M
T~1%
0.15-0.18 rad
top view
20 cm
e
e
400 cm

Physics (some examples)

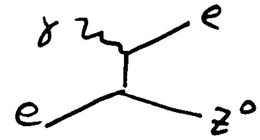
(γe)

1) $\gamma e \to W\nu$

$\sigma \sim (1-2\lambda)\cdot 5\cdot 10^{-35}\,cm^2$



2) $\gamma e \to Z^0 e$



3) $\gamma e \to e^* \to \gamma e$

4) $\gamma e \to \tilde{\gamma}\tilde{e} \to \tilde{\gamma}\tilde{\gamma} e$ ($\tilde{e}$ with $M_{\tilde{e}} > E_0$ can be observed)

($\gamma\gamma$)

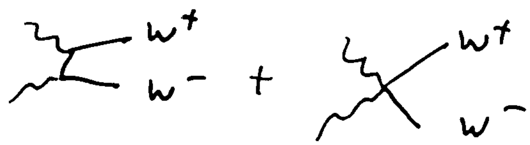
1) $\gamma\gamma \to hadr$

$\sigma > 3\cdot 10^{-31}\,cm^2$

background

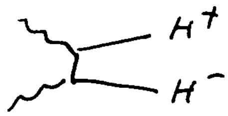
2) $\gamma\gamma \to W^+W^-$

$\sigma \sim 8\cdot 10^{-35}\,cm^2$



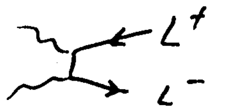
W-factory

3) $\gamma\gamma \to H^+H^-$



$\underline{\sigma_{\gamma\gamma\to H^+H^-} \sim 6\,\sigma_{e^+e^-\to H^+H^-}}$

4) $\gamma\gamma \to L^+L^-$

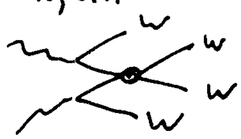


$\sigma_{\gamma\gamma} > \sigma_{e^+e^-}$
(cm. fig.)

5)

$$\begin{cases} H \to b\bar{b} & M_H < 150 \\ H \to Z_0 Z_0 & M_H = 120 - 350 \\ H \to WW & M_H = 100 - 200 \end{cases}$$

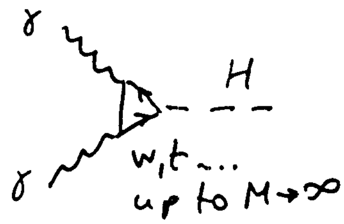
6)



- Many processes unique and complementary to e^+e^-.

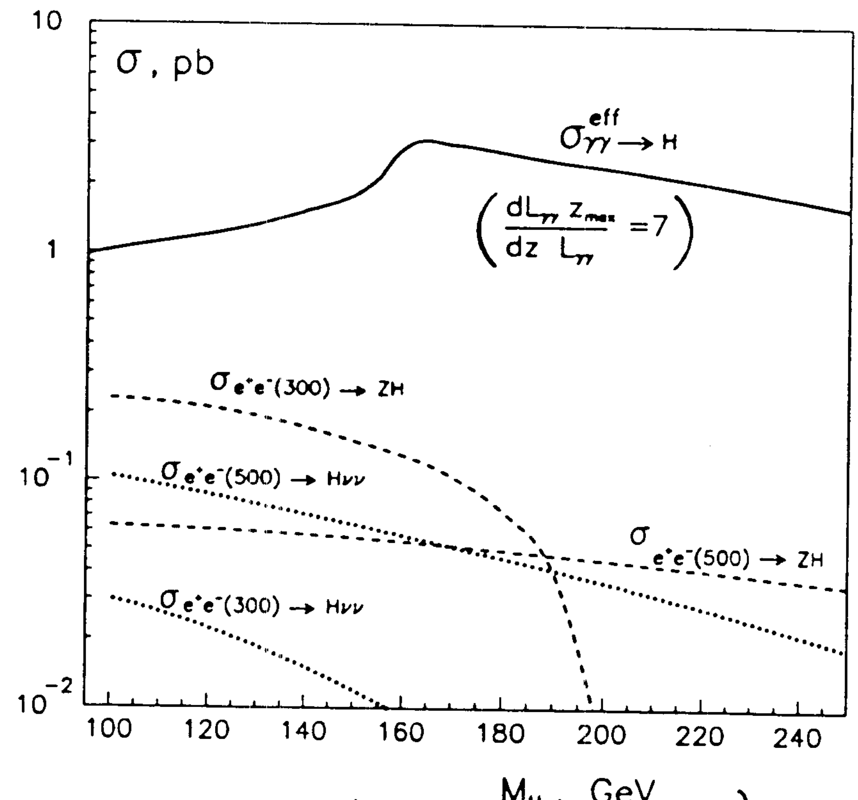
  >1000 theor. papes

SM Higgs production in $\gamma\gamma$ and e^+e^- coll.



$\Gamma_{H\to\gamma\gamma}$ is very sensitive to each new W', L', q'

V. Telnov
Int. J. Mod. Phys A 13 (1998) 2399



$$\frac{\sigma^{eff}_{\gamma\gamma\to H}}{\sigma_{e^+e^-\to HZ}} \approx$$

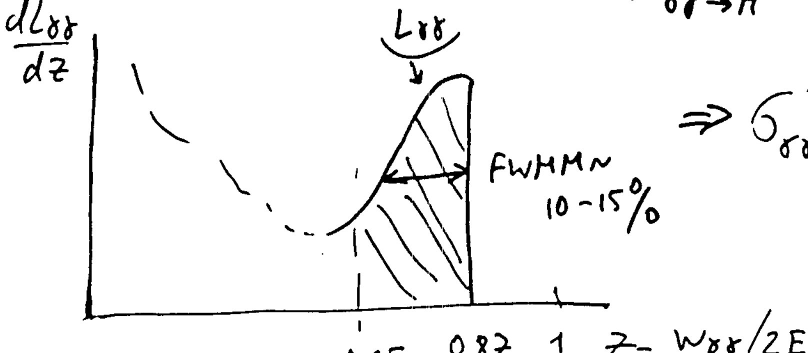
$\approx 6 - 40$!!!

for $M_H = 120 - 250$

Definition of $\sigma^{ef}_{\gamma\gamma\to H}$ (for $\Gamma_H \ll \Delta W_{\gamma\gamma}$)

$$N_{\gamma\gamma\to H} = \frac{dL}{dW}\,\frac{4\pi^2\Gamma_{\gamma\gamma}}{M_H^2} = \sigma^{ef}\cdot L$$

$$\Rightarrow \sigma^{eff}_{\gamma\gamma\to H} = \frac{dL}{dz}\,\frac{z_m}{L}\cdot\frac{4\pi\,\Gamma_{\gamma\gamma\to H}}{M_H^3}$$

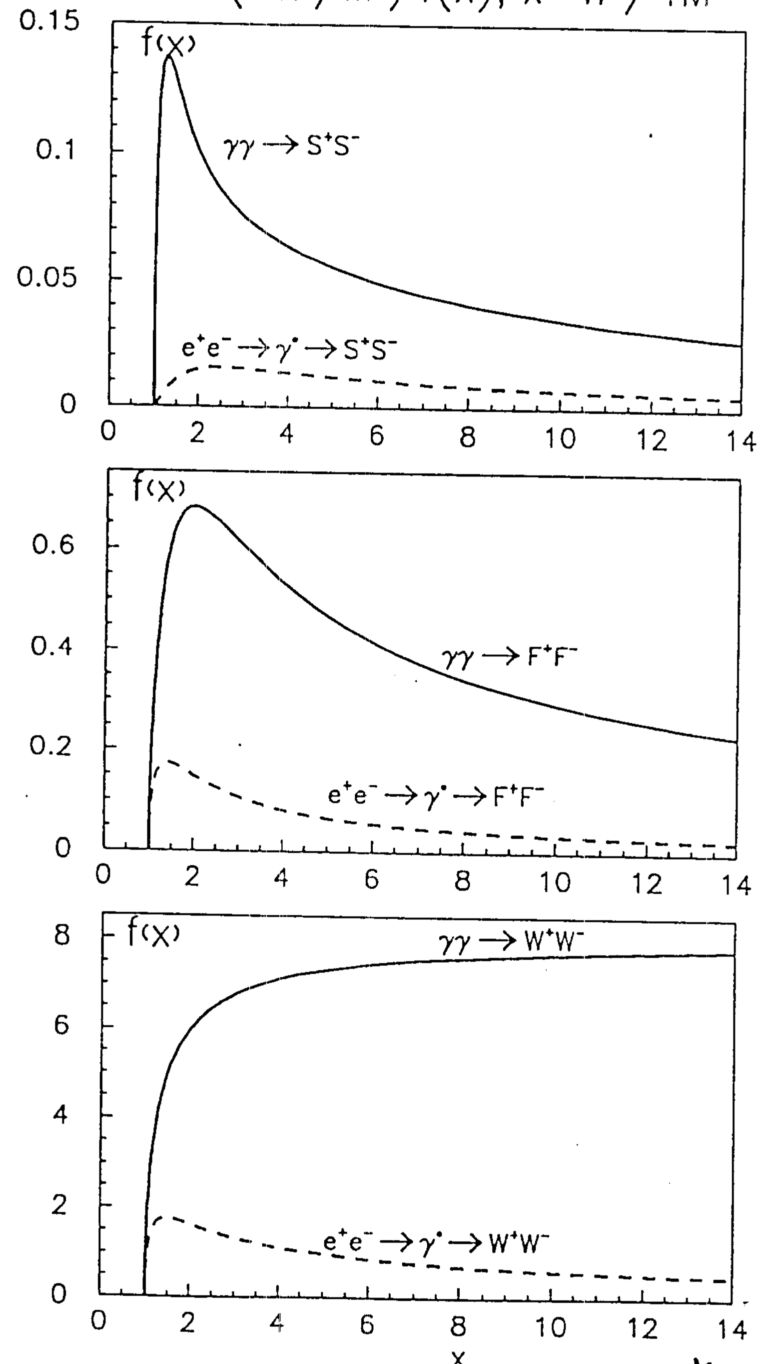


$$\frac{dL}{dz}\,\frac{z_m}{L} \sim 7$$

Charged particle production in $\gamma\gamma$ and e^+e^--collisions

unpolirized beams

$\sigma = (\pi\alpha^2/M^2)\, f(x),\ x = W^2/4M^2$



scalars

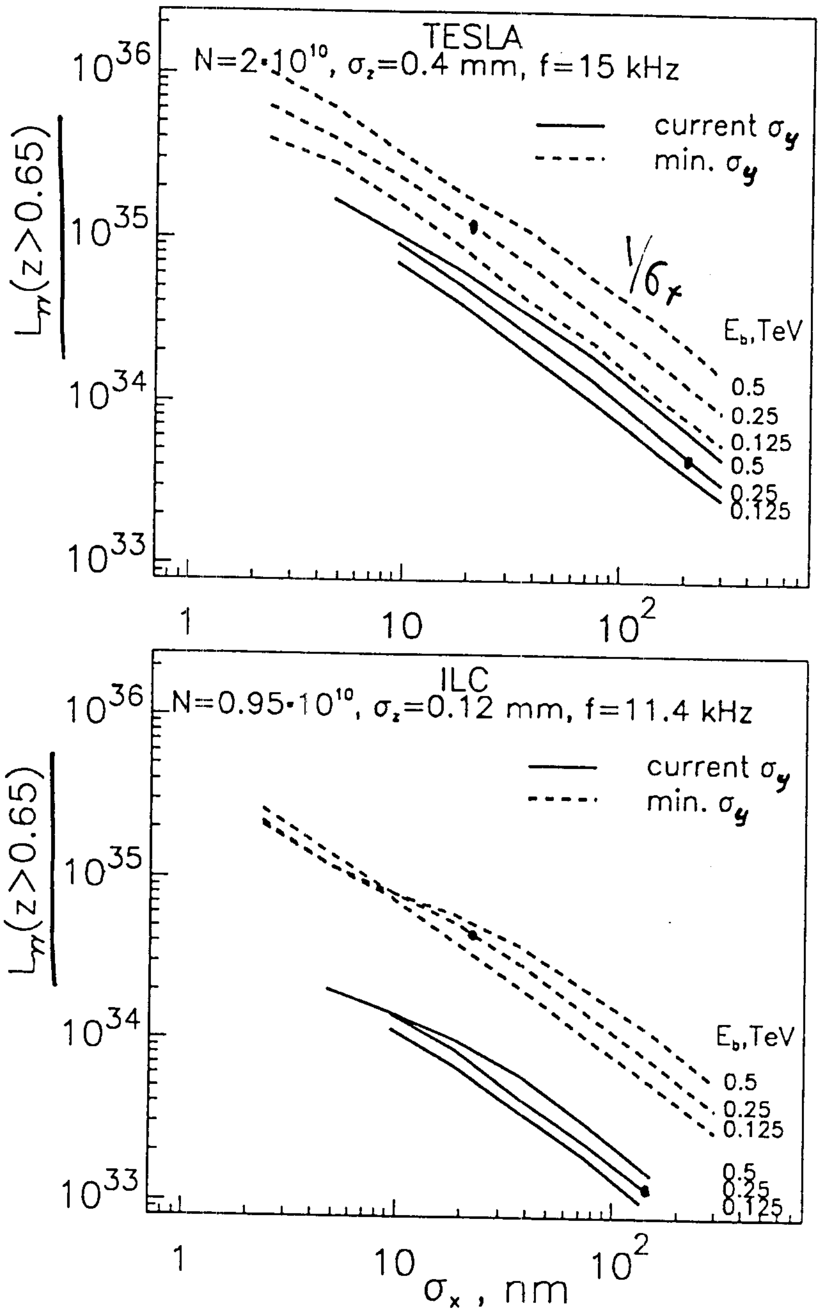
leptons

w-bosons

$$x = \frac{W_{\gamma\gamma}^2}{4M^2}$$

$$\sigma_{\gamma\gamma} \sim 5 \div 20\ \sigma_{e^+e^-}$$

$L_{\gamma\gamma}(z>0.65)$ vs σ_x



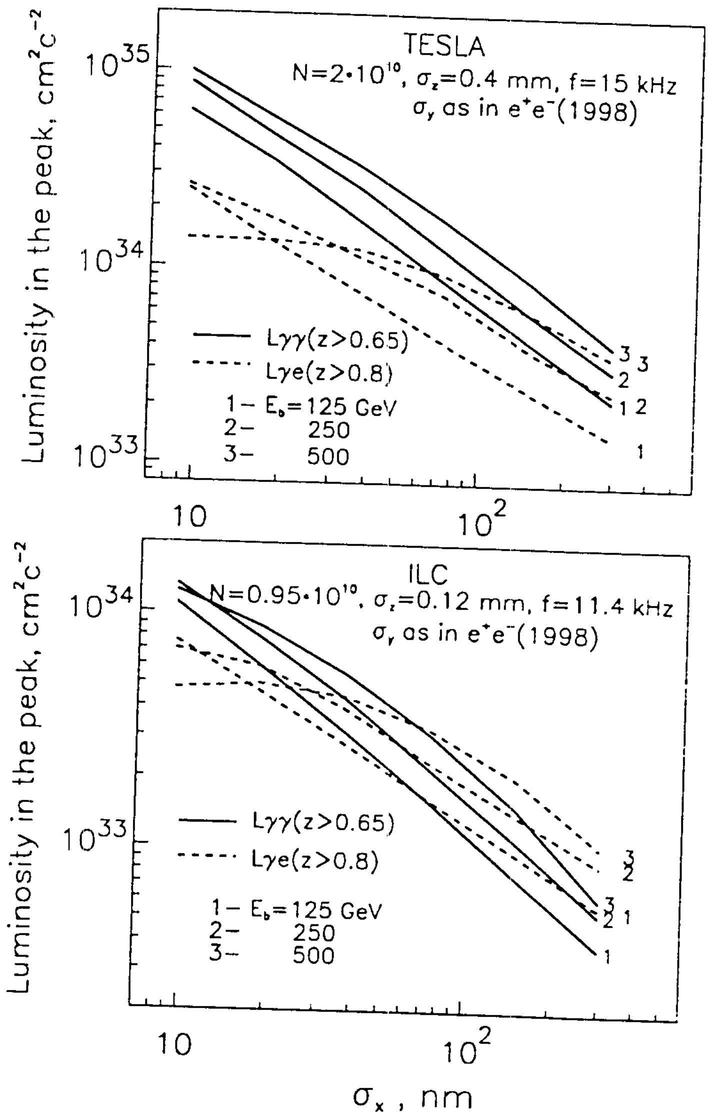
—— „current" σ_y

- - - - minimum σ_y ($\sim \beta/\gamma$)

Resume:

$L_{\gamma\gamma}(z>0.65)$, $2E = 500$ GeV ($\sigma_x > 10$ nm)

	„now"	possible		
TESLA	$4.5\cdot10^{33}$	$2\cdot10^{35}$	!!	~ 50
ILC	$1.1\cdot10^{33}$	$8\cdot10^{34}$ *( )		



— $L_{\gamma\gamma}$

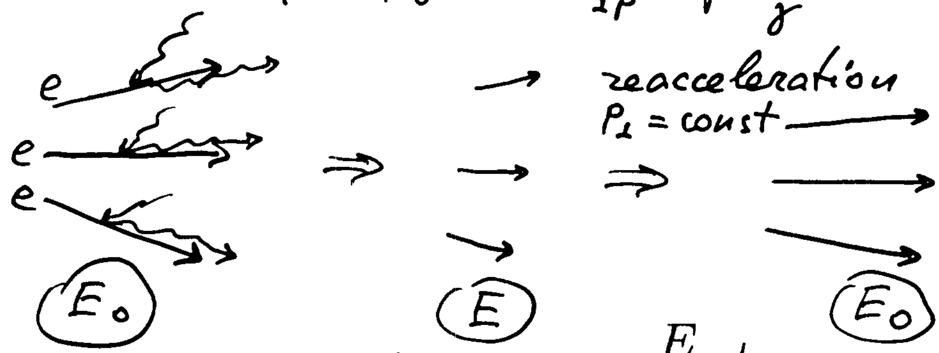
--- $L_{\gamma e}$

Laser cooling

Principle: electrons with the energy about 5 GeV colliders with powerful laser pulse and loss their longitudinal and transverse momenta. As result, normalize emittance is decreased.

$\varepsilon = \sigma_i \alpha_i$

$\varepsilon_n = \varepsilon / \gamma \qquad \sigma_{IP} \sim \sqrt{\dfrac{\varepsilon_n \sigma_z}{\gamma}}$



laser cooling can be repeated 2-3 times (if necessary)

$$\boxed{\epsilon_n = \epsilon_{n0} \frac{E}{E_0}.} \sim \frac{1}{10} \varepsilon_{n0}$$

V.Telnov, Phys.Rev.Lett. 78 (1997) 4757, err. 80 (1998) 2747

Issues:

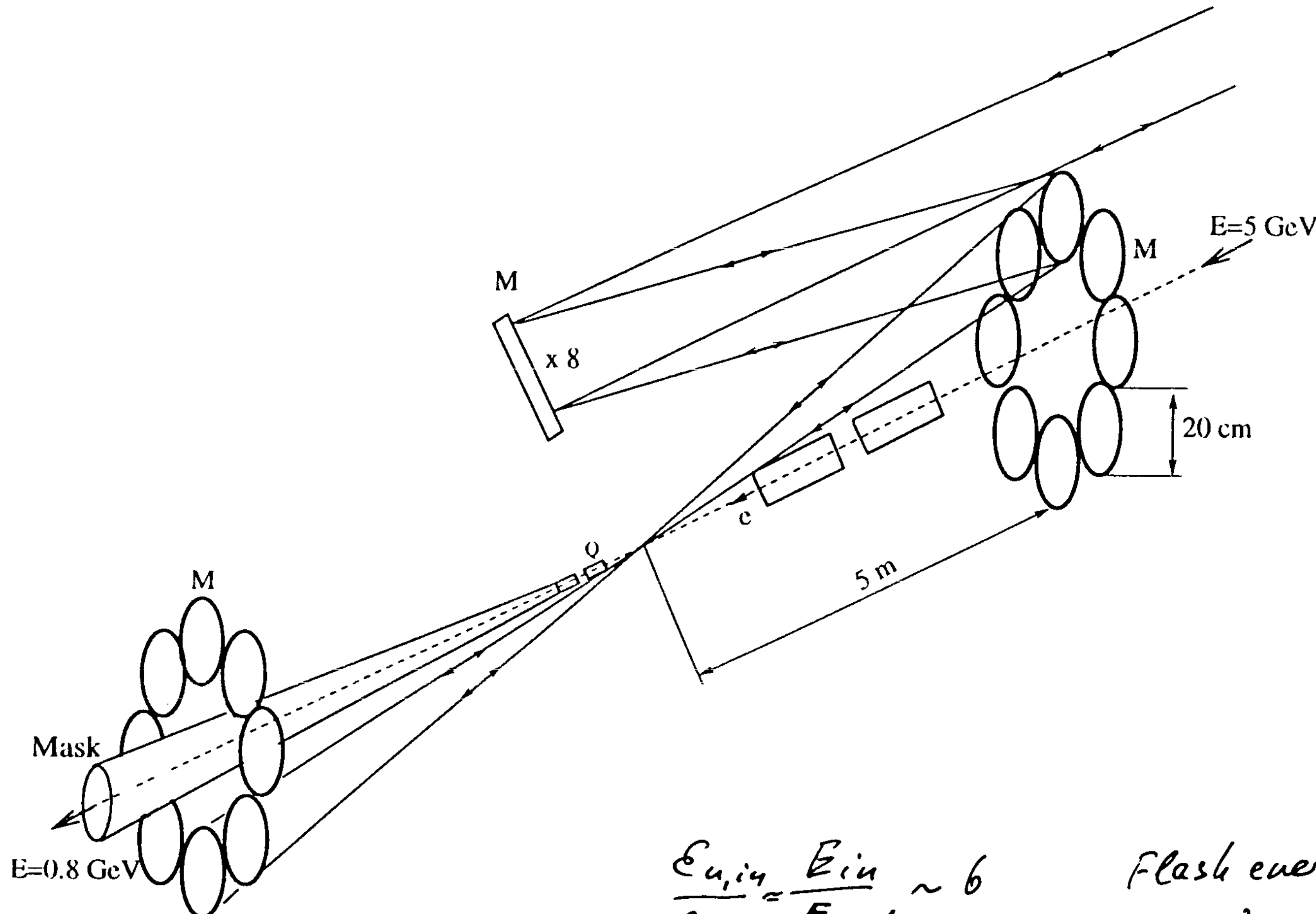
1. Energy of laser flash. About 10 J.

2. Energy spread. About 15% after collision and 1.5% afrer reacceleration to the initial energy. Two-three stages are possible.

3. Beam heating, ultimate emittance. $\varepsilon_{xn}(\varepsilon_{yn})$ About 1000(10) times better in x(y) directions than after damping rings. !

4. Depolarization. About 15% (optimization is possible).

This is the most straightforward method to (very) high luminosities photon colliders.



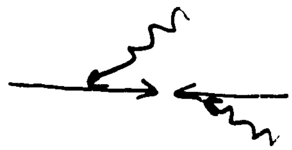
$\frac{\mathcal{E}_{u,in}}{\mathcal{E}_{u,out}} = \frac{E_{in}}{E_{out}} \sim 6$

Flash energy 25 x 8 J
$\nu \sim 15$ kHz
$\bar{P} \sim 3$ MW
but if $Q \sim 10^3 = \bar{P}_{laser} \sim 3$
$P_1 \sim \frac{3}{8} \sim 0.4$ k

$\gamma\gamma$, $\gamma\mu$, μp at HE muon colliders

($\gamma\gamma$)

There are 5 stoppers: 5 x 

(1.) 

$N_\gamma = k N_{\mu\mu}$

$L_{\gamma\gamma}$ is max when $k \sim 1$ (only one collision),
then

$$\boxed{L_{\gamma\gamma} < \frac{L_{\mu\mu}}{1000}} \leftarrow \text{the number of coll. at } \mu\mu \text{ colliders}$$

(2.) $\underline{\sigma_c \propto \frac{1}{m^2}}$

$\Rightarrow$ for $\mu \to \gamma$ conversion The number of photons in a laser target should be $\sim$ 40000 times larger than at ee lin. collid.

(3.) $E_{\gamma,max} = \frac{x}{x+1} E_0$; $x = \frac{4E_0\omega_0}{m^2c^4}$

To have $E_\gamma \sim E_0$ we need $x > 1$

$$\Rightarrow \frac{\omega_0(\text{for } \mu)}{\omega_0(\text{for } e)} \sim \frac{m_\mu^2}{m_e^2}\frac{E_e}{E_\mu}$$

Even for $E_0 = 50$ TeV (μ) $\omega_0 \sim 100$ eV
x-ray laser

The required flash energy

$$A \propto \frac{m^3}{E} \sim 10\text{ MJ} \quad (1\text{ps pulse})$$

This is impossible.

(4) $\gamma\mu \to \mu e^+e^-$ — is competing process at the CP

$$\frac{\sigma_{\gamma\mu \to \mu e^+e^-}}{\sigma_{\dots}} \sim \frac{\frac{28\alpha\sigma_0}{9\pi}\ln\frac{4E_0\omega_0}{m_\mu m_e}}{\dots} \sim 550 \text{ at } x \sim 1$$

(5.) $\gamma \to e^+e^-$ conversion in μ-beam field

The threshold $\Upsilon \sim \frac{\omega}{mc^2}\frac{B}{B_0}$ $\quad B_0 = \frac{\alpha e}{r_e^2} \sim 4.4\cdot 10^{13}G$

For $\omega \sim 40$ TeV, and "evolutionary" $\mu\mu$ $2E = 100$ TeV

$\Upsilon \sim 180$

The probab. of conversion on the length $\sigma_z \sim 5$ mm

$p \sim 250$! Only $< 0.5\%$ of γ's servive

All together!

a) $A \sim 10$ MJ, $\omega_0 \sim 100$ eV at $2E = 100$ TeV
(impossible)

b) $L_{\gamma\gamma} \sim \underbrace{\frac{1}{1000}}_{\text{one pass}} \underbrace{\left(\frac{1}{500}\right)^2}_{\substack{\text{due to}\\ e^+e^- \text{ in CP}}} \underbrace{\left(\frac{1}{200}\right)^2}_{\substack{\text{due to}\\ \gamma \to e^+e^- \text{ at IP}}} \sim 10^{-13} L_{\mu\mu}$!!!

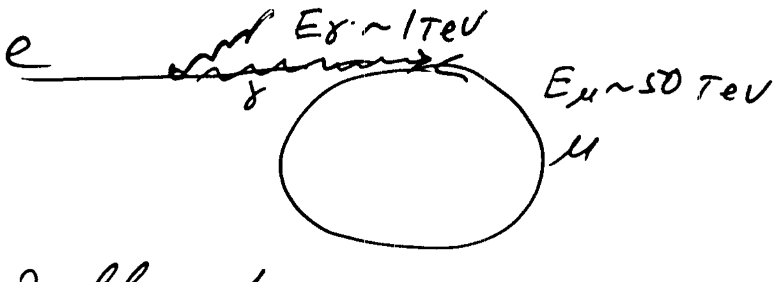
However: $\gamma\gamma$ interactions can be studied in $\gamma^*\gamma^*$ interactions (without $\mu \to \gamma$ convers.)

$L_{\gamma^*\gamma^*} \sim 10^{-2} L_{\mu\mu}$ $\quad W_{\gamma\gamma} > 0.1 * 2E_0$

$\sim 10^{-4} L_{\mu\mu}$ $\quad W_{\gamma\gamma} > 0.5 \times 2E_0$

$\gamma\mu$ 1) γ from Compton conversion on μ — impossible (see $\gamma\gamma$)

2) γ from e (LC) may be



Problem 1.

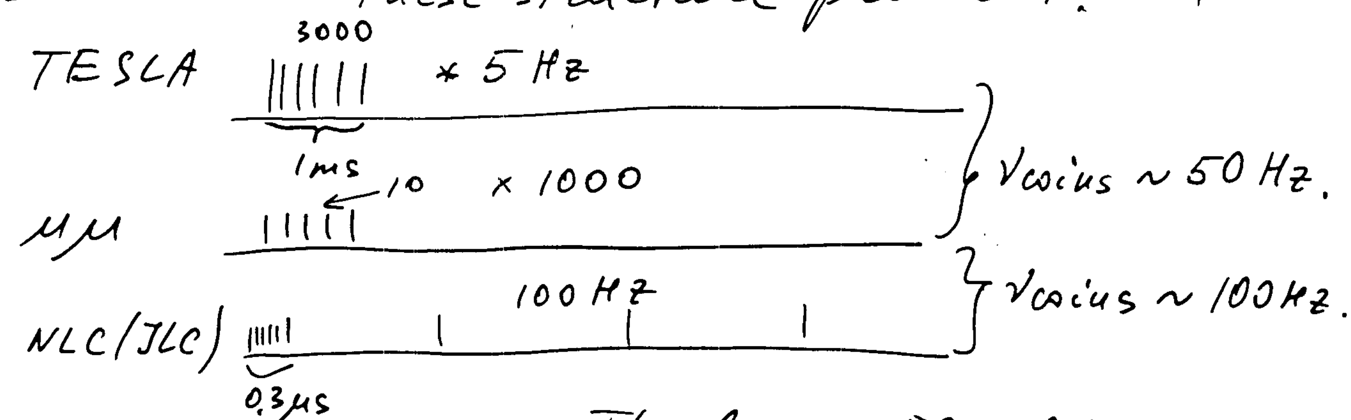
$$L_{\gamma\mu} \le \frac{N_\mu N_\gamma f}{2\pi\sigma^2} \qquad t_\mu \sim t_{ee} \sim 10^4 \text{ is possible.}$$

$$N_{\gamma\,(E>0.6E_{\gamma max})} \sim 0.25 N_e\ ; \quad N_e \sim 10^{-2} N_\mu$$

$$N_e \sim 2\cdot 10^{10} \text{ (TESLA)}$$
$$0.7\cdot 10^{10} \text{ (NLC)}$$

$$\Rightarrow L_{\gamma\mu} \lesssim \frac{1}{500} L_{\mu\mu}$$

Problem 2. Pulse structure problem.



$$\text{The loss} \sim \frac{50-100}{10^4} \sim 10^{-2}$$

Problem 3. $\gamma \to e^+e^-$ conversion in the μ-beam field

For $\mu\mu$ (100) evolut. only 10% of γ survive

Conclusion: $L_{\gamma\mu} \sim \underbrace{\frac{1}{100}}_{N_e} \cdot \underbrace{\frac{1}{100}}_{\text{pulse}} \cdot \frac{1}{10} L_{\mu\mu} \sim 10^{-5} L_{\mu\mu}$.

pulse str. ... conv...

However $\gamma\mu$ interactions can be studied in $\gamma^*\mu$ interactions.

$L_{\gamma^*\mu} \sim 0.15\, L_{\mu\mu}$ $\quad W_{\gamma\mu} > 0.1 \times 2E_0$

$\sim 0.05\, L_{\mu\mu}$ $\quad W_{\gamma\mu} > 0.5 \times 2E_0$

μp Collisions of μ with LHC, ... SSC bunches give very low $L_{\gamma\mu}$ due to

$$\left.\begin{array}{l} a)\ \sigma_{xp} \gg \sigma_{x\mu} \\ b)\ f_\mu \ll f_p \\ c)\ N_p \lesssim 0.1 N_\mu \end{array}\right\} \quad L_{\mu p} < 5 \cdot 10^{30}$$

no sense.

However, one can build a special source of protons with the same parameters as μ (using several stages of electron cooling at different energies.)

then

$$L_{\mu p} = L_{\mu\mu}!$$

- The main problems: $\gamma^* p$ reactions - background

at $L_{\mu p} \sim 10^{36}$ it will be ~ 5000 reactions / crossing.

$\nu \sim 10^4$

Solutions: a) increase ν

b) increase low θ dead region

at large angle: signal $\propto E_0$

background $\propto \ln E_0$!

Physics program for μp is less interesting than $\mu^+\mu^-$ but certainly has sense if $\mu\mu$ is built.

One can get pp in the same rings (with a higher ...