Photon collider at TESLA: parameters and IR issues

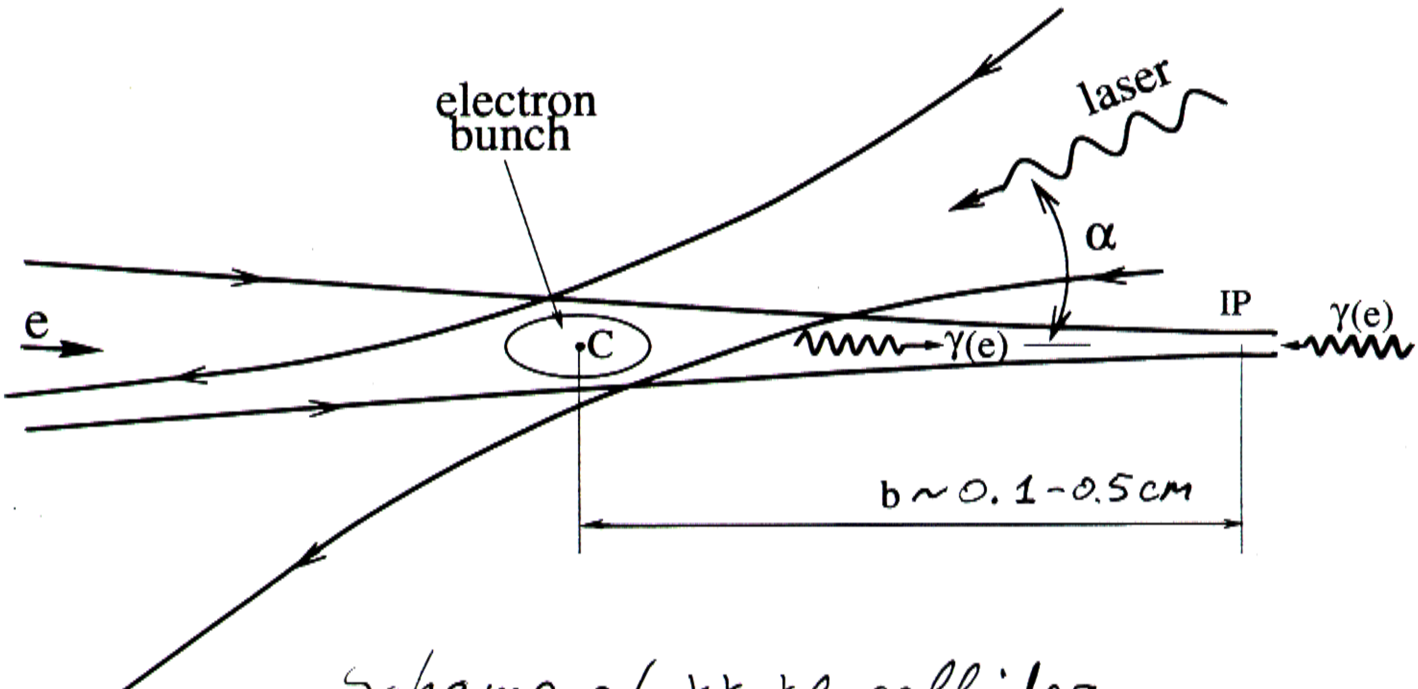
V. Telnov

LCWS 2000

FNAL, 25.10.2000

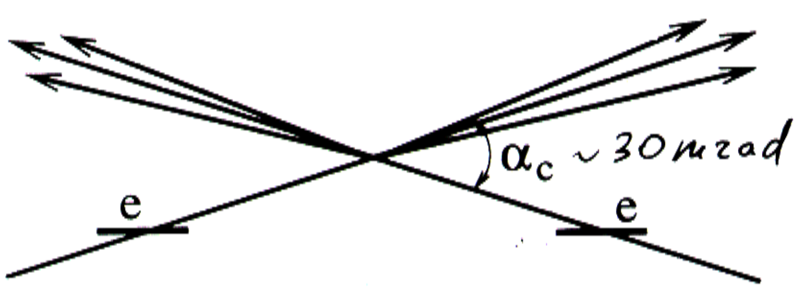
- 1. Introduction
- 3. Parameters of $\gamma\gamma$, γe collider at TESLA
- 2. Physics motivation
- 4. Lasers, optics
- 5. Specific features of detector for PC.
- 6. Conclusion

Photon colliders



Scheme of γγ, γe collider

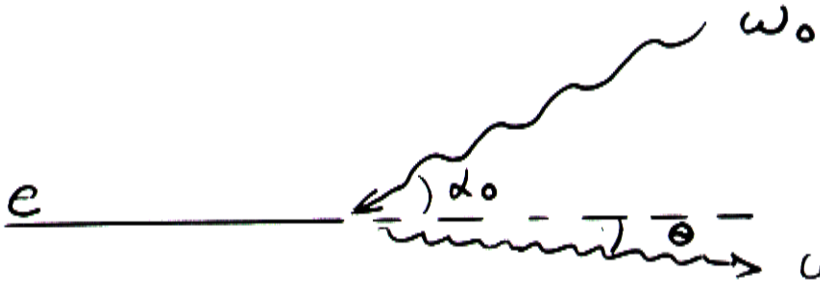
a)



b)

crab crossing

Compton scattering



– energy
$\hbar \equiv 1$

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

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

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

Example: $E_0 = 250$ GeV
$\omega_0 = 1.17$ eV ($\lambda = 1.06\,\mu m$)
(Nd: Glass)

$\rightarrow x = 4.5$

$\dfrac{\omega_m}{E_0} \sim 0.82$

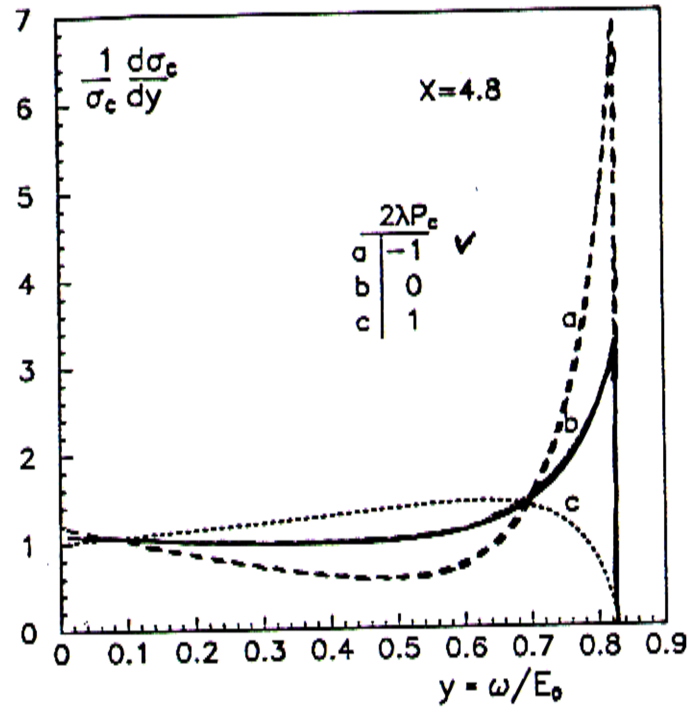
$x \simeq 4.8$ is threshold for $\gamma_{laser}\,\gamma_{high\,energy} \rightarrow e^+e^-$

Cnergy spectrum of scattered photons (6

λ - long. polar. of electr

P_c - helicity of laser pho

(6)



$$X = \frac{4E_0\omega_0}{m^2c^4}$$

at $X \gg 1$

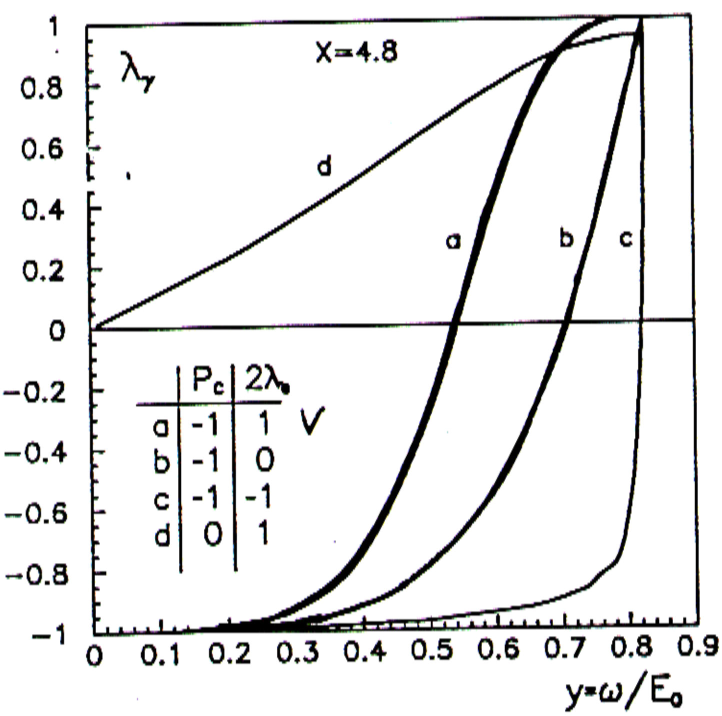
$$\theta \sim \frac{1}{\gamma} \Leftrightarrow \frac{\Delta y}{y_m} \sim \frac{1}{X}$$

$$\boxed{\omega_m = \frac{X}{X+1} E_0}$$

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

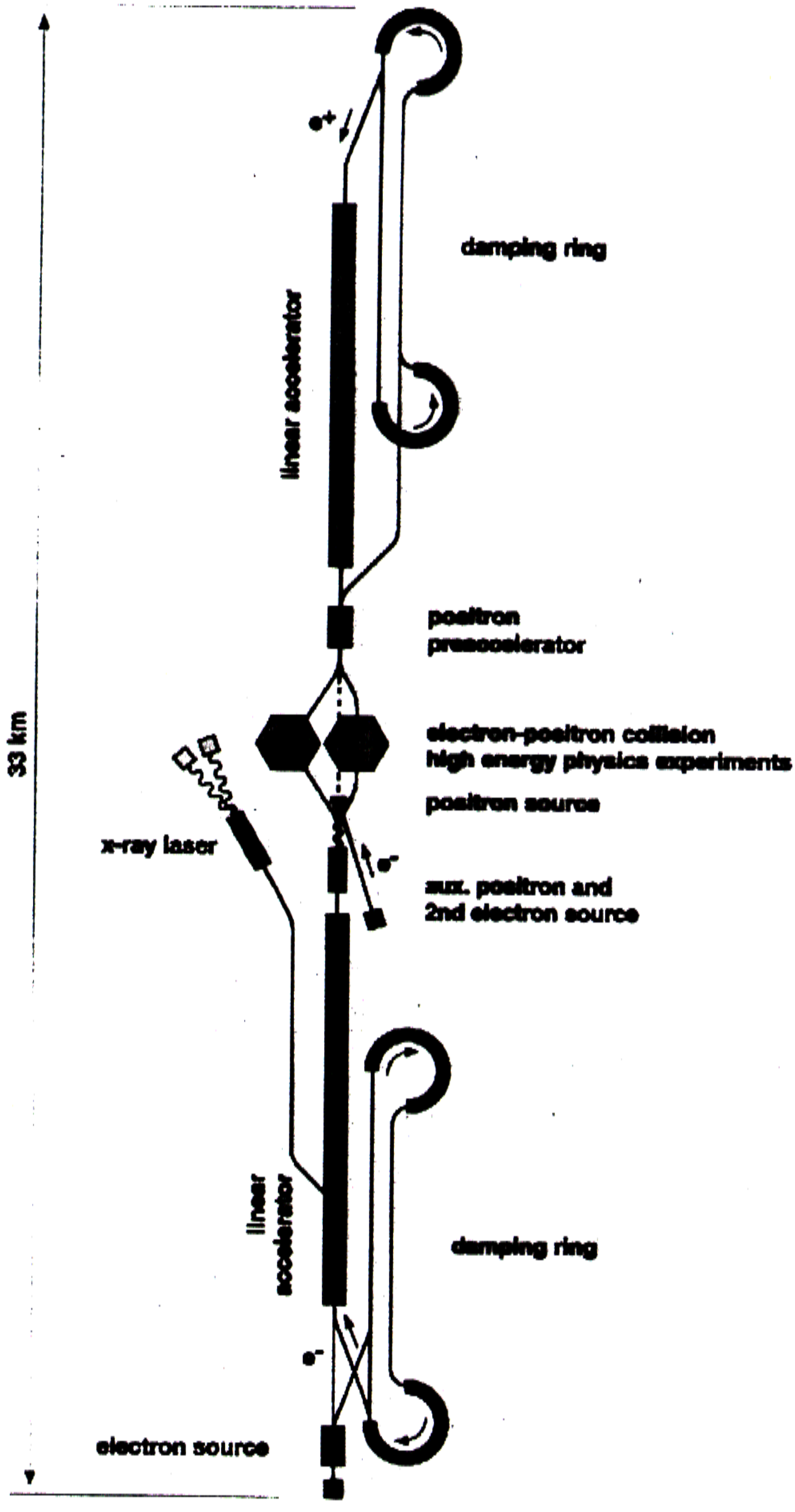
$E = 250$ GeV, $\lambda = 1.06\,\mu m$ (Nd: glass) $\to X \sim 4.7$.

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



$y = y_m \quad \lambda_\gamma = -P_c$

Figure 3: Mean helicity of the scattered photons.


33 km
e+
damping ring
linear accelerator
positron
preaccelerator
electron-positron collision
high energy physics experiments
positron source
x-ray laser
e-
aux. positron and
2nd electron source
linear
accelerator
damping ring
e-
electron source

International Workshop on
High Energy Photon Colliders

14-17 June, 2000
DESY, Hamburg, Germany

Topics

Physics in high energy $\gamma\gamma$ and γe collisions
Lasers and optical systems for photon colliders
Processes in the conversion region
Production of polarized electrons with very low emittances
Optimization of $\gamma\gamma$ and γe luminosities
Removal of disrupted beams, backgrounds
Interaction region layout, crab crossing, final focus
Detector issues specific for photon colliders

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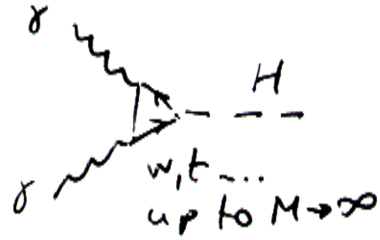
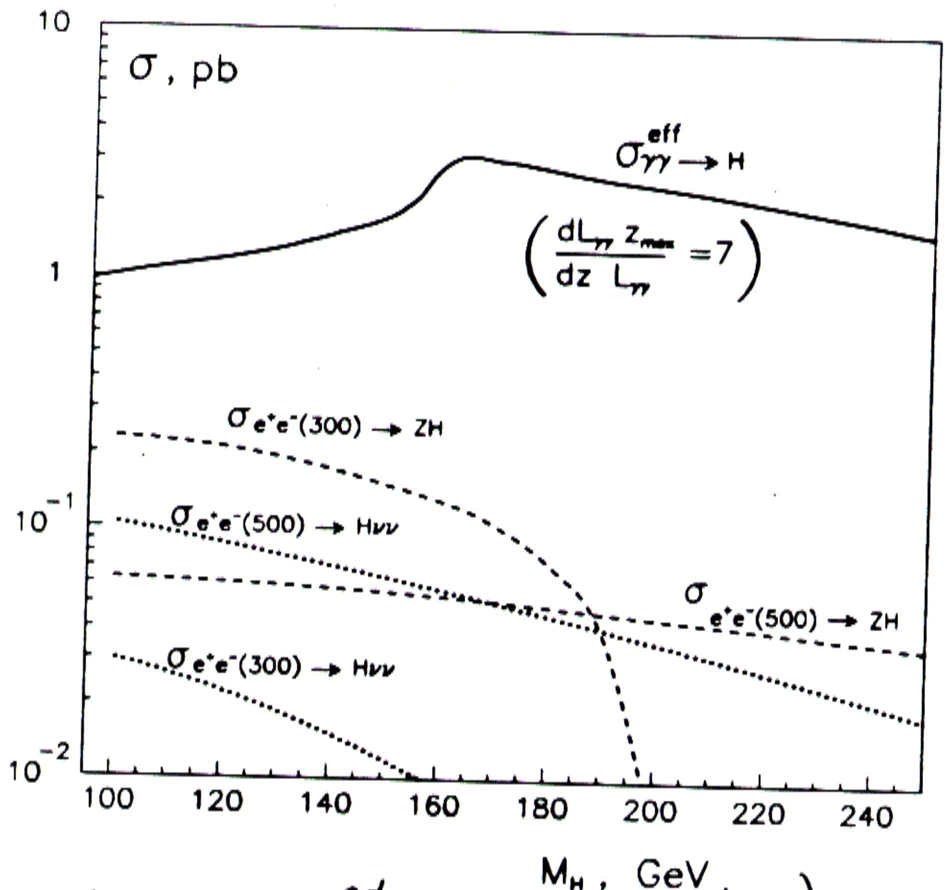
SM Higgs production in $\gamma\gamma$ and e^+e^- coll.



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

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

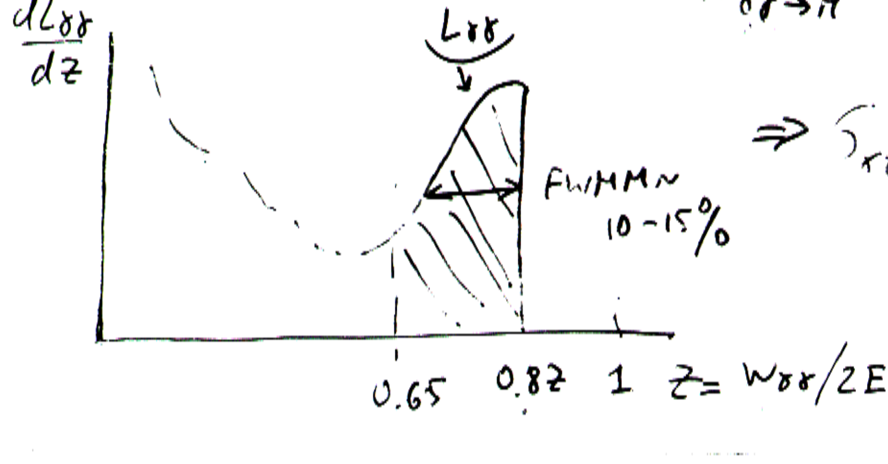


$$\frac{\sigma^{eff}_{\gamma\gamma\to H}}{\sigma_{e^+e^-\to HZ}} \approx \approx 6-40 \; !!!$$

for $M_H =$ 120 – 250

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

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

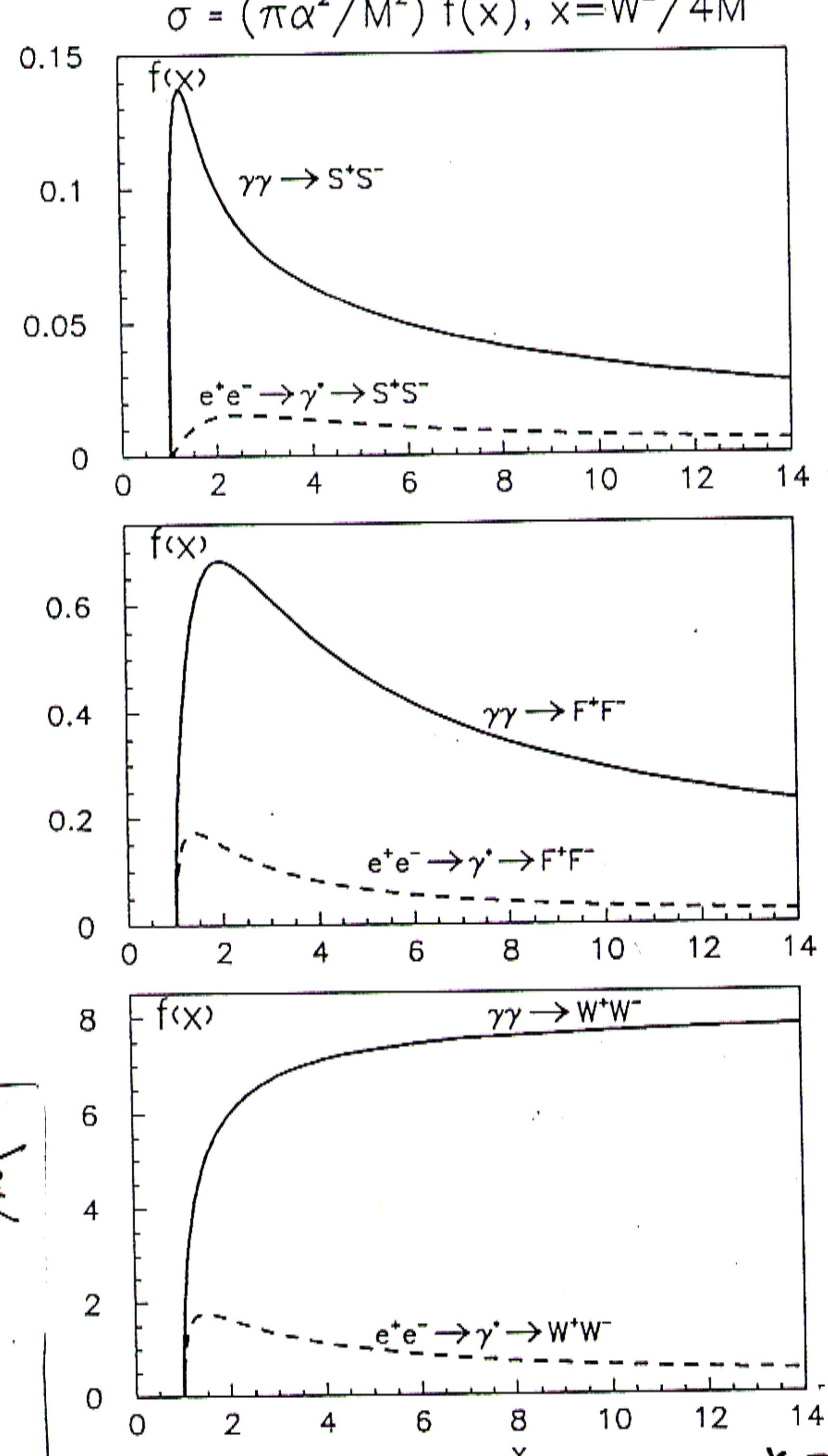


$$\Rightarrow \sigma^{eff}_{\gamma\gamma\to H} = \frac{dL}{dz}\frac{z_m}{L}\cdot\frac{4\pi\Gamma_{\gamma\gamma\to H}}{M_H^3}$$

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

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

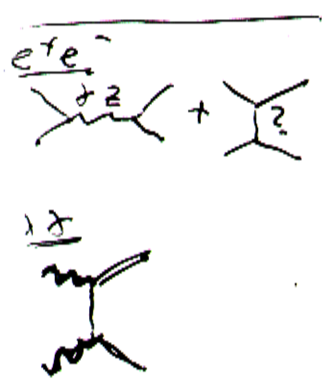
unpolarized beams



scalars

leptons

w-bosons

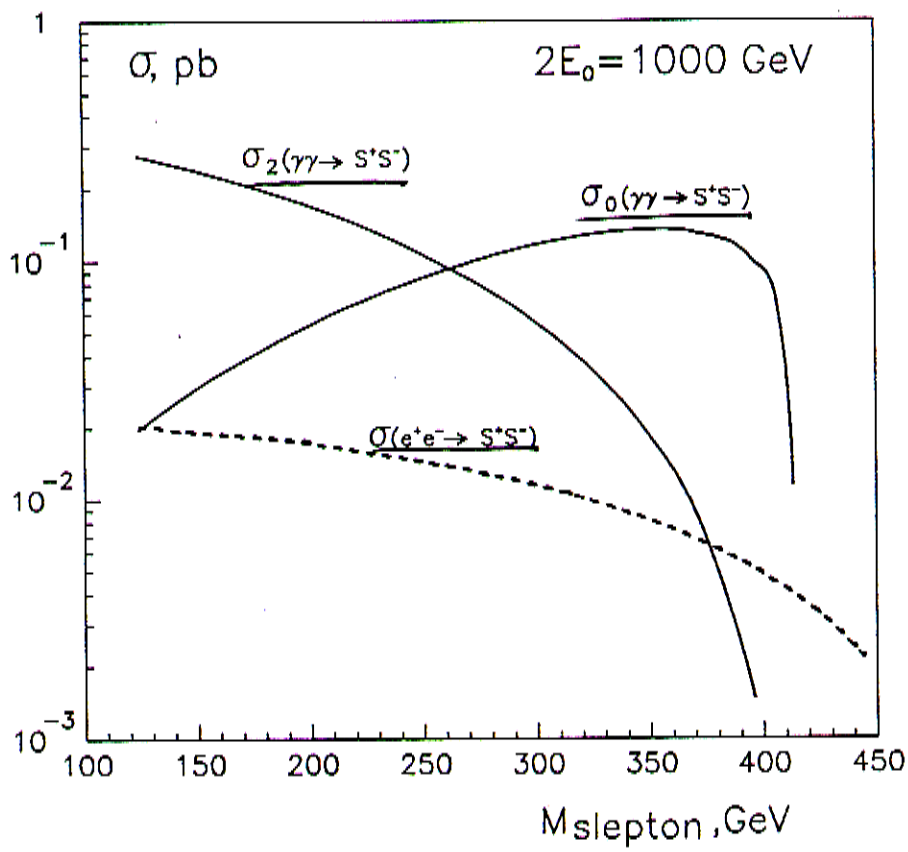


QED
direct meas. of charge.

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

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

Production of charged scalar pairs in e^+e^- and polarized $\gamma\gamma$ collisions



For heavy particles $\sigma_{\gamma\gamma} \sim 15\text{-}20\, \sigma_{e^+e^-}$

(Note: $\sigma_{e^+e^- \to SS}$ is valid for all sleptons, except selectron)

Gold-plated processes for $\gamma\gamma$, γe collider

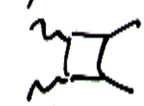
$\gamma\gamma \to$ light Higgs ($\Gamma_{H\to\gamma\gamma}$), $b\bar{b}$, $c\bar{c}$, $\tau\bar{\tau}$, WW^*, ZZ^* . . .

$\gamma\gamma \to H, A \to t\bar{t}, b\bar{b}$ (CP, etc.), higher acces. mas.

$\gamma\gamma \to W^+W^-$ (anomalous coup., extra dimensions)

$\gamma\gamma \to S\bar{S}, F\bar{F} \ldots H^+H^-, H^{++}H^{--} \ldots$ – 2ch

$\gamma\gamma \to t\bar{t}$, $\tilde{t}, \bar{\tilde{t}}$, stoponium

$\gamma\gamma \to \gamma\gamma, \gamma Z, ZZ$ 

$\gamma e \to \tilde{e}\tilde{\gamma}$ higher accessible masses (than in e^+e^-)

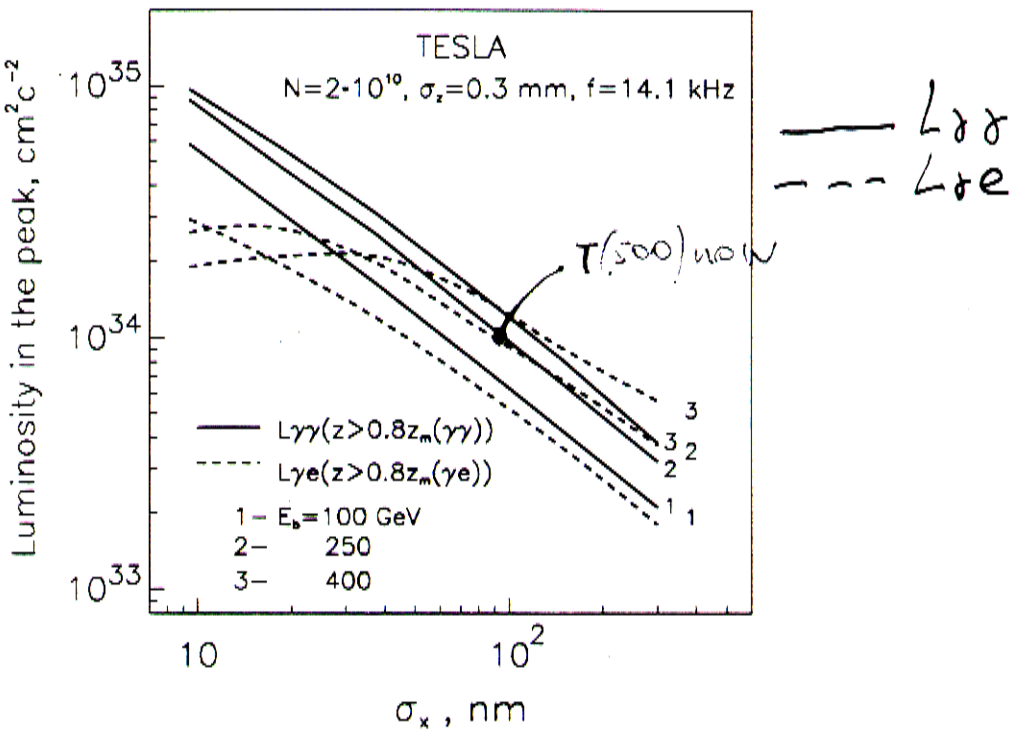
$\gamma e \to e^*$

$\gamma e \to t b \nu$ (Wtb-coupling)

$\gamma e \to eH$ 

$\gamma\gamma, \gamma e \to$ QCD

$L_{\gamma\gamma}$ and $L_{\gamma e}$ $(z > 0.8 z_m)$ vs σ_x



Having e-beams with smaller emittances we can further increase luminosity by one order

Laser cooling of electron beam for LC

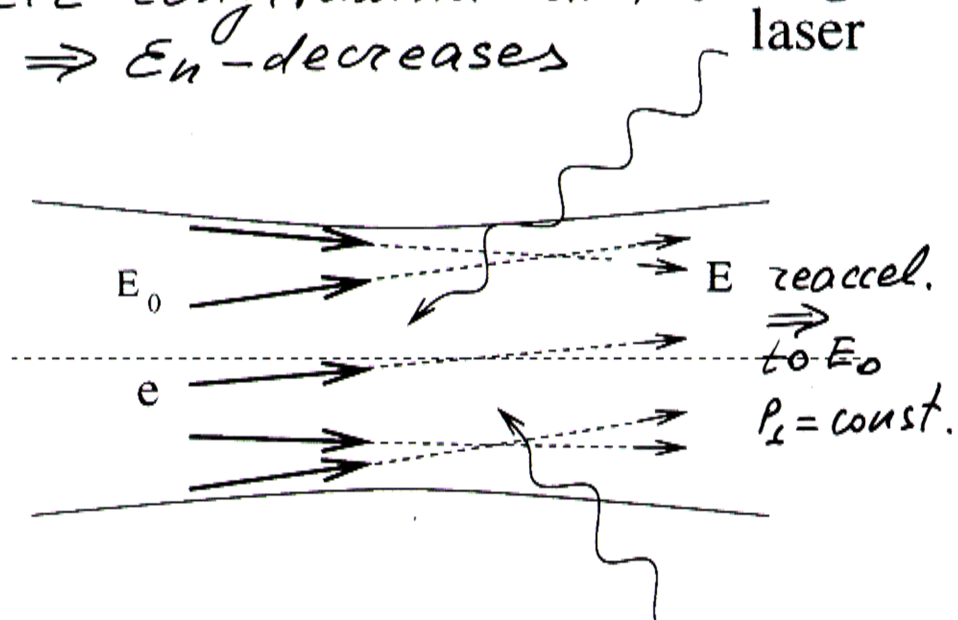
V. Telnov

V. Telnov
PRL 78(1997) 4757
80 (1998) 2747 (er)

$\varepsilon_i = \sigma_i \cdot \theta_i \qquad \varepsilon_{n,i} = \varepsilon\gamma$

$\sigma_{IP} \sim \sqrt{\dfrac{\varepsilon_n \sigma_z}{\gamma}}$ $\qquad \varepsilon_n$ – normalized emittance.

Principle: electrons with the energy ~5 GeV are collided with powerful laser pulse and lose their longitudinal and transverse momenta ⇒ ε_n – decreases



$$\varepsilon_{n,out} \sim \varepsilon_{n,in} \frac{E}{E_0}$$

$$\sim \left(\frac{1}{10} \div \frac{1}{5}\right) \varepsilon_{n,in}$$

Problems, issues

1. Flash energy
2. Energy spread
3. Ultimate emittance
4. Depolarization
5. Ponderomotive forces

$\mathcal{H}(130)$ hep-ex/0010033

Parameters of the $\gamma\gamma$ collider at TESLA

	2E=500, x=4.6	2E=200, x=1.8	2E=158, x=4.6
$N/10^{10}$	2	2	2
σ_z, mm	0.3	0.3	0.3
$f_{rep}\, n_b$, kHz	14.1	14.1	14.1
$\gamma\varepsilon_{x/y}/10^{-6}$, m rad	2.5/0.03	2.5/0.03	2.5/0.03
$\beta_{x/y}$, mm, IP	1.5/0.3	1.5/0.3	1.5/0.3
$\sigma_{x/y}$, nm	88/4.3	140/6.8	160/7.6
b, mm	2.1	1.3	1.2
$L_{ee, geom}$, 10^{33}	120	48	38
$L_{\gamma\gamma}(z>0.8z_{m,\gamma\gamma})$, 10^{33}	11.5	3.5	3.6
$L_{\gamma e}(z>0.8z_{m,\gamma e})$, 10^{33}	9.7	3.1	2.7
θ_{max}, mrad	9	8.5	16

$L_{\gamma\gamma} \propto E$ (assumed), $N, f n_b, \sigma_z, \varepsilon_n = const$

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.4\, L_{e^+e^-}$ (for present beam param.)

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.1\, L_{geom}$ ($k^2=0.4$)

Some numbers

If $L_{geom} \propto E$

$M_H = 120$ GeV $\qquad$ 160 GeV

$$\frac{N_{\gamma\gamma\to H}}{N_{e^+e^-\to ZH,\,\nu\bar{\nu}H\,(500\,\mathrm{GeV})}} = 0.9 \qquad = 3$$

$$\frac{N_{\gamma\gamma\to H^+H^-}}{N_{e^+e^-\to H^+H^-}} \sim 8$$

$\gamma\gamma$, γe colliders based on TESLA(2x250)

	~DR 1997	1998	2000
$N/10^{10}$	3.63	2	2
σ_z, mm	0.5	0.4	0.3
$f_{rep} \times n_b$, kHz	5.65	14.1	14.1
$\gamma\epsilon_{x,y}/10^{-6}$,m·rad	14/0.25	10/0.03	2.5/0.03
$\beta_{x,y}$,mm at IP	3.2/0.5	2/0.4	(1.5) 1/0.3 ?
$\sigma_{x,y}$,nm	303/16	200/5	70/4.3
b, mm	11.5	2.4	2.1
$L(geom)$, 10^{33}	12	45	145 (120)
$L_{\gamma\gamma}(z>0.65), 10^{33}$	1.2	4.2	14 (11.5)
$L_{\gamma e}(z>0.65), 10^{33}$	2	6.5	11

$\beta_x = 1.5\,mm$

$L_{\gamma\gamma}(z > 0.65) \sim (0.4-0.5) L_{e^+e^-}$

$\gamma\gamma$ luminosity spectrum

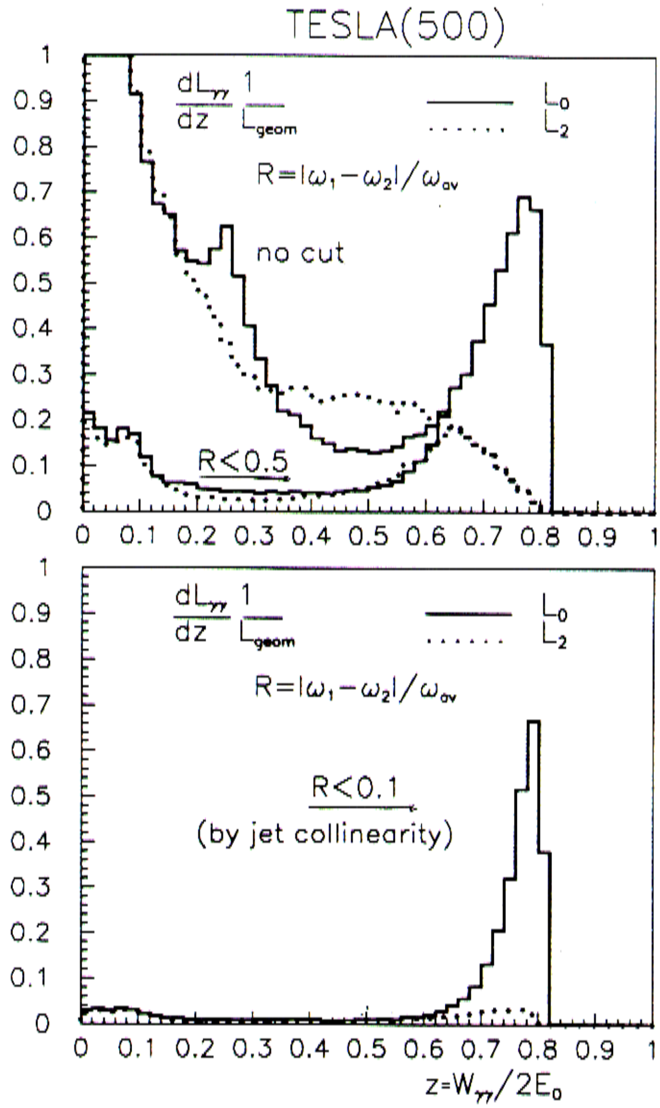
with cuts on $\frac{p_{\parallel} c}{0.5\, E_{tot}} \equiv R$

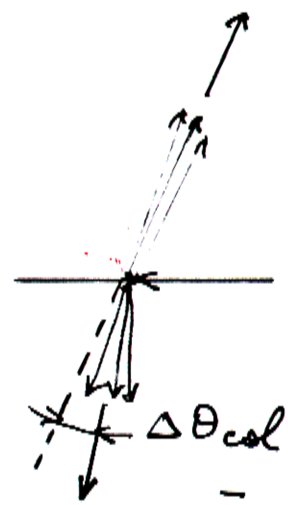
new beam parameters

$\varepsilon_{nx} = 2.5 \cdot 10^{-4}$ cm

$\beta_x = 1.5$ mm

$x = 4.6$

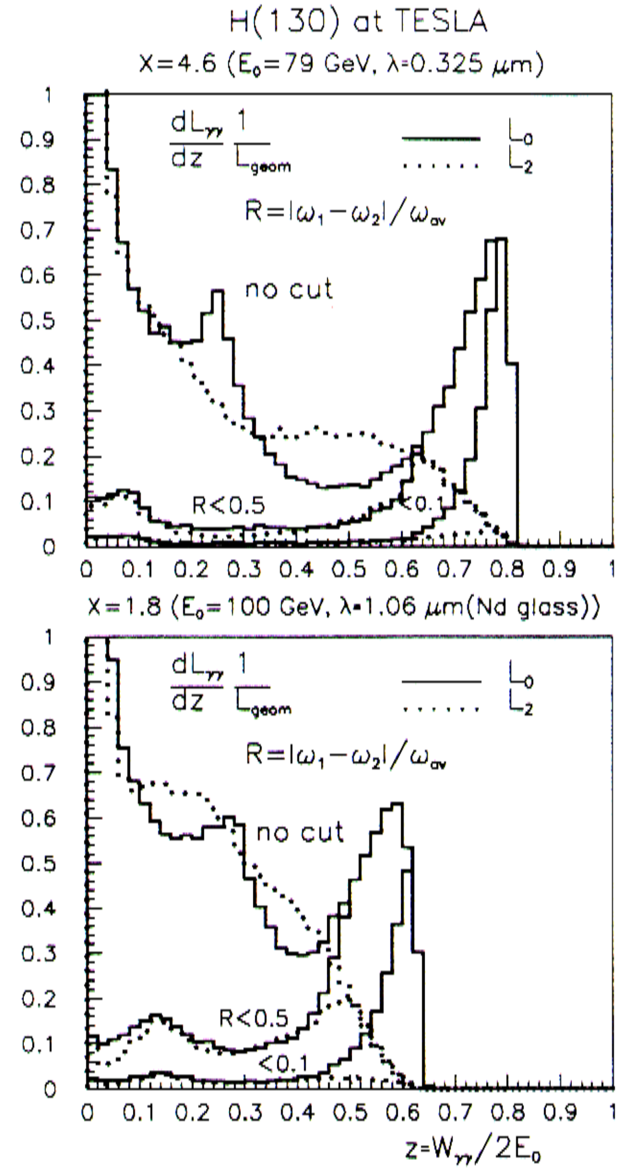




$\gamma\gamma \to H \to b\bar{b}$

$\to H \to \tau^+\tau^-$

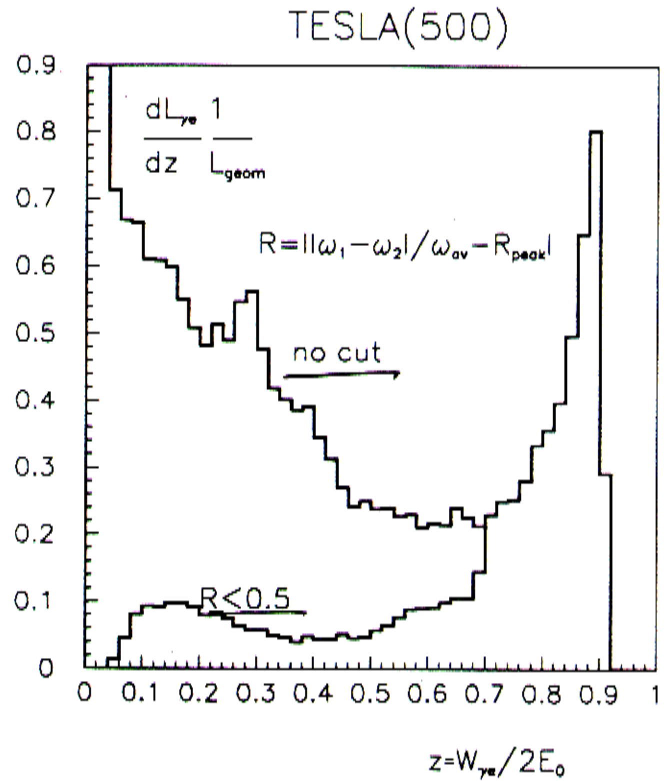
$\gamma\gamma$ luminosity spectra for H(130)



$x = 4.6$ $E_e = 79$ Ge
($\lambda = 0.325\ \mu m$)

$X = 1.8$ $E_e = 100$ GeV
($\lambda \sim 1\ \mu m$).

γe luminosity spectrum

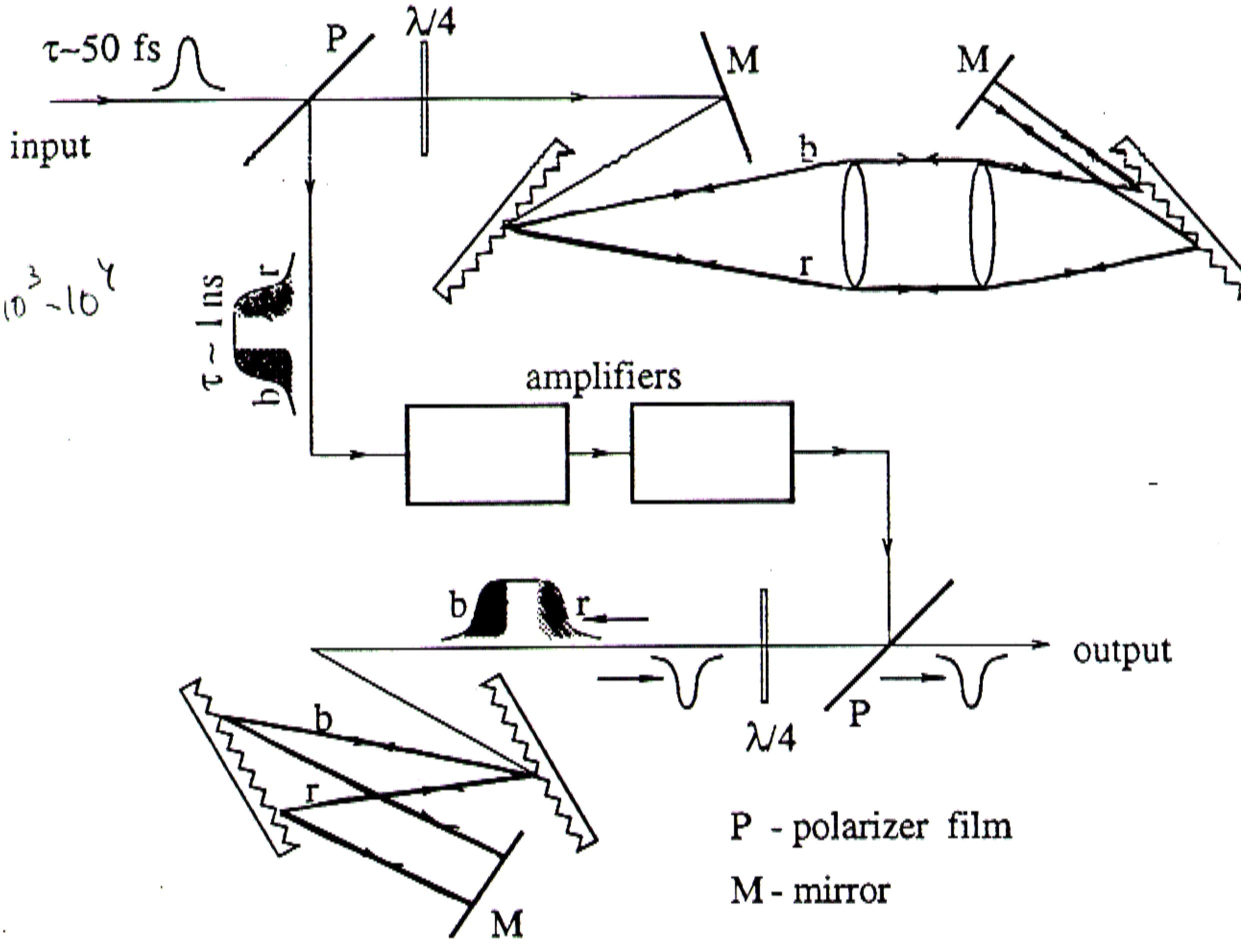


Solid state lasers

chirped pulse amplification

10^{15} W has been reached

$\frac{\tau_r}{\tau_0} \sim 10^3 - 10^4$

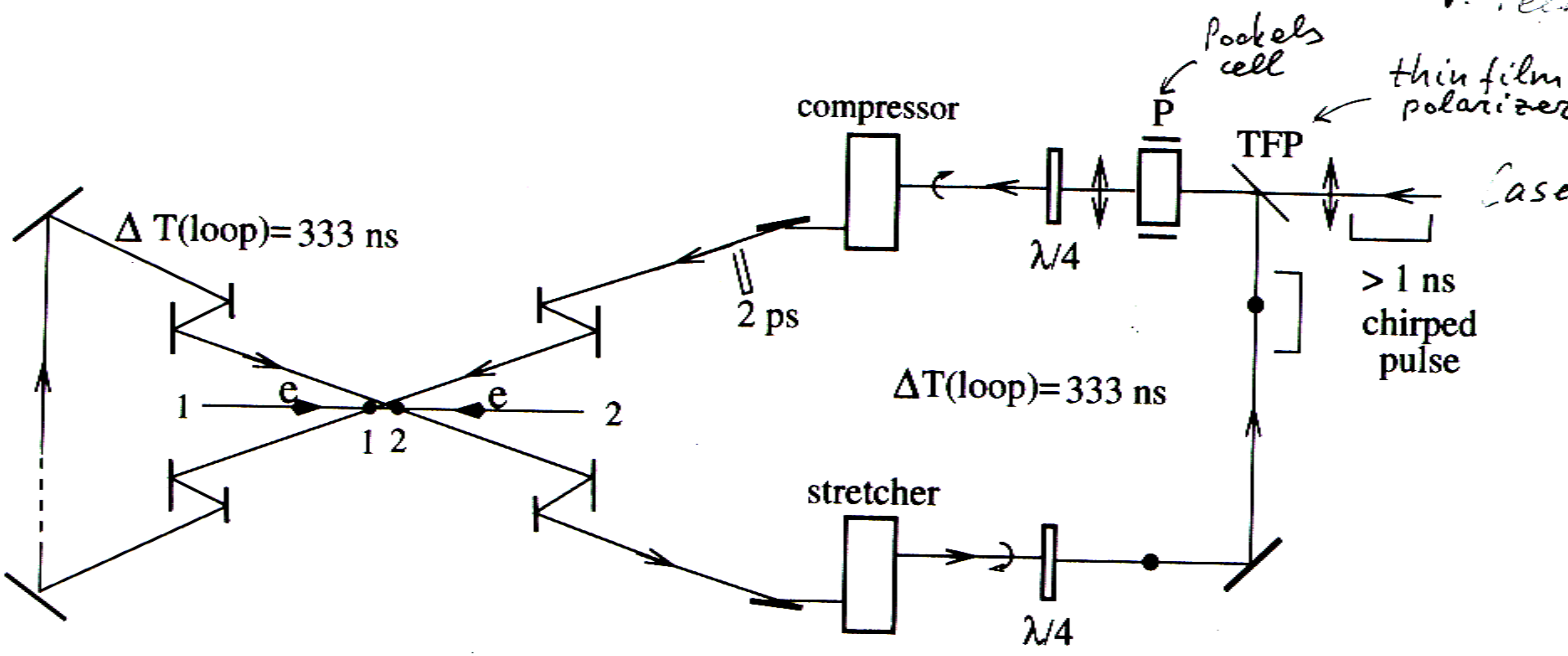


solid state lasers (Nd: glass and other) with the required parameters exist, problem – rep. rate (~1 Hz)
diode (semiconductor) laser pumping
increase rep. rate by a factor 100
Opinion of experts:
20–30 kW solid state laser system

Optical scheme for photon collider at TESLA

o) optical „storage ring"
optical trap

hep-ex/0010035
V. Tel.



Cost of diodes
5 \$/W - now
1 \$/W - planing exper.
0.07 \$/W - fusion

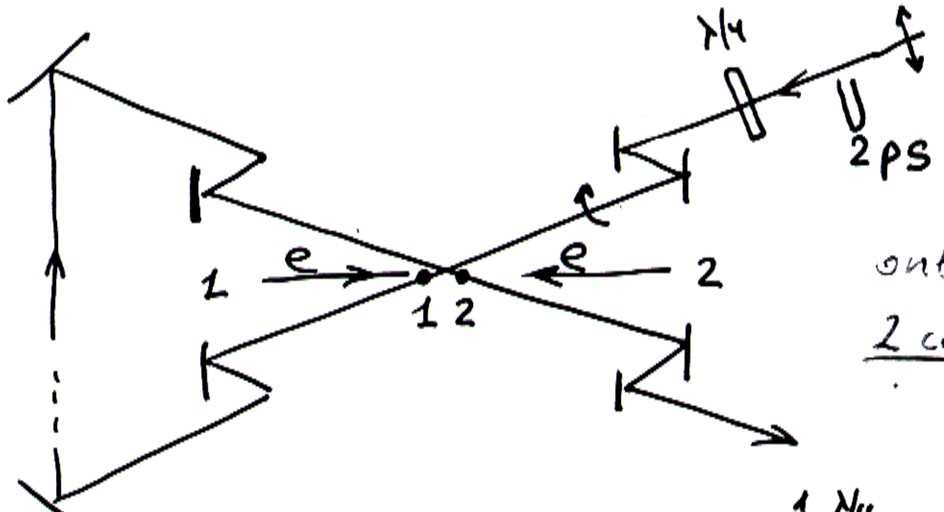
Each 5 J, 2ps laser bunch makes ~ 10 round trips in the "optical storage ring" and 2×10 times collide with electron beams

$\bar{P}_{laser} \sim 7 kW$ (~ 8 lasers) diode pumped

P_{peak}(diodes) = 3 M
× 5 \$/
15 M\$

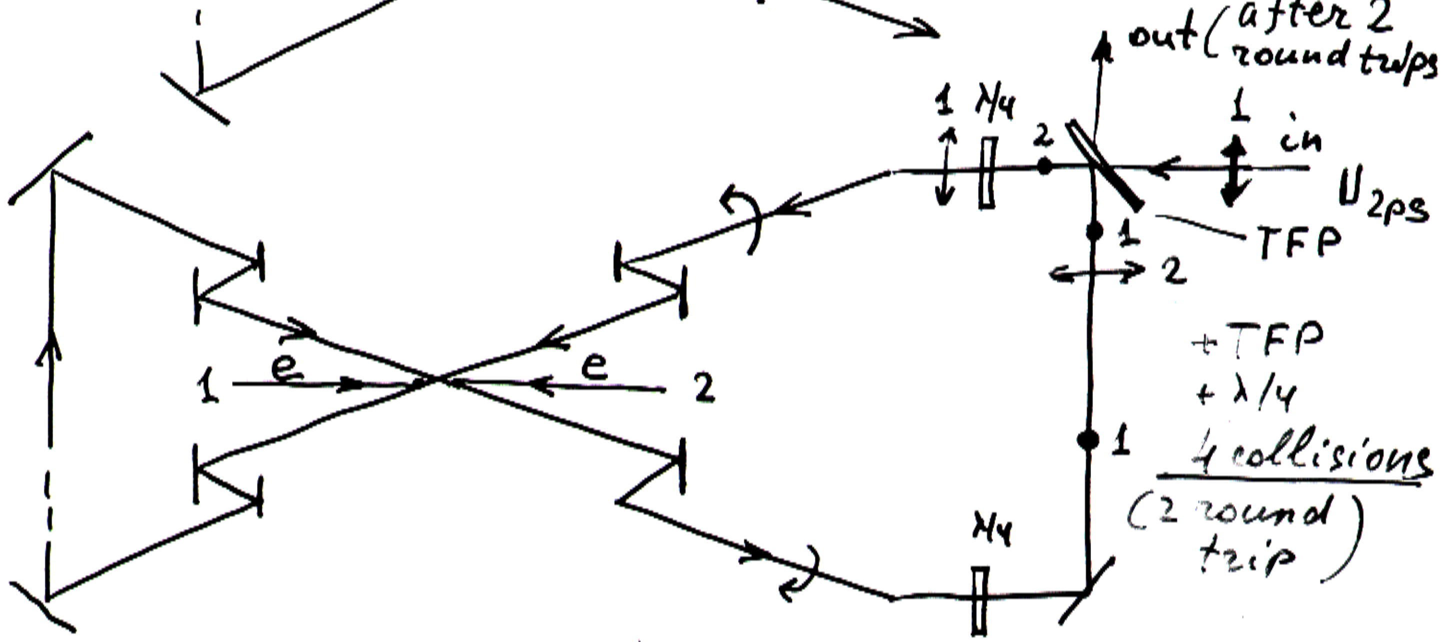
Possible variations of the optical scheme
(see previous fig.)

• 1.



only mirrors
2 collisions

• 2.



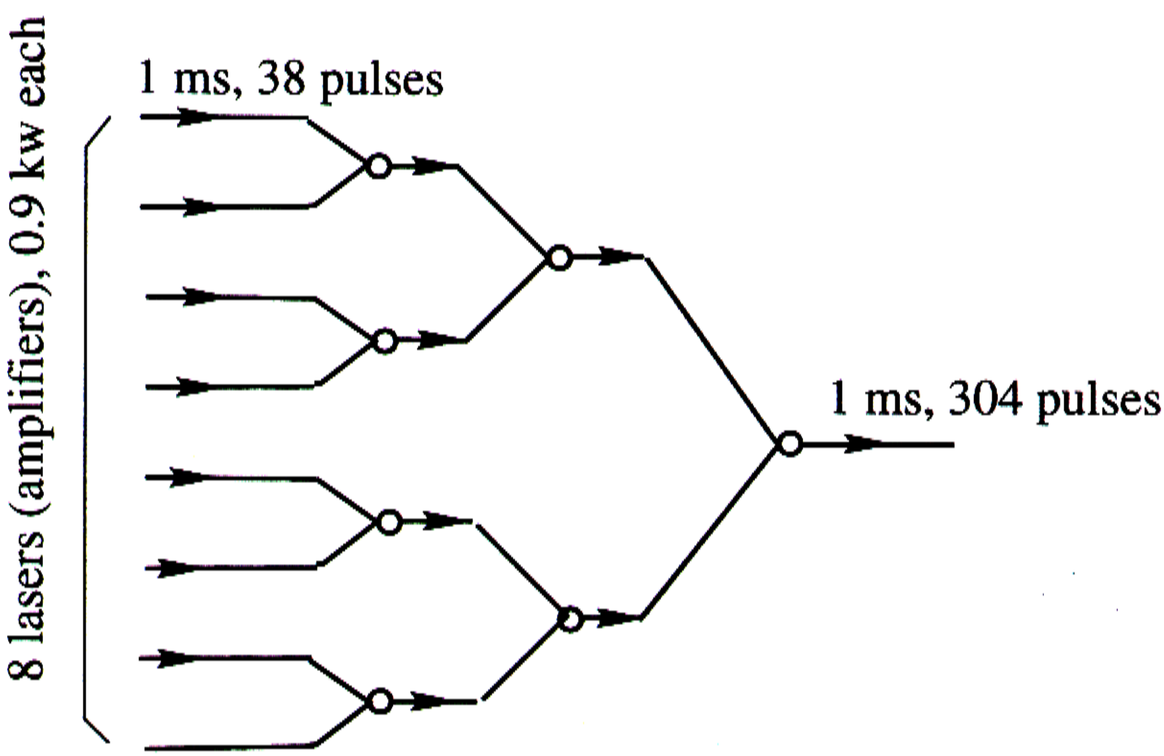
+TFP
+ λ/4
4 collisions
(2 round trip)

• 3. Same as 2
+ 1 Pockels cell with large diameter
just after TFP

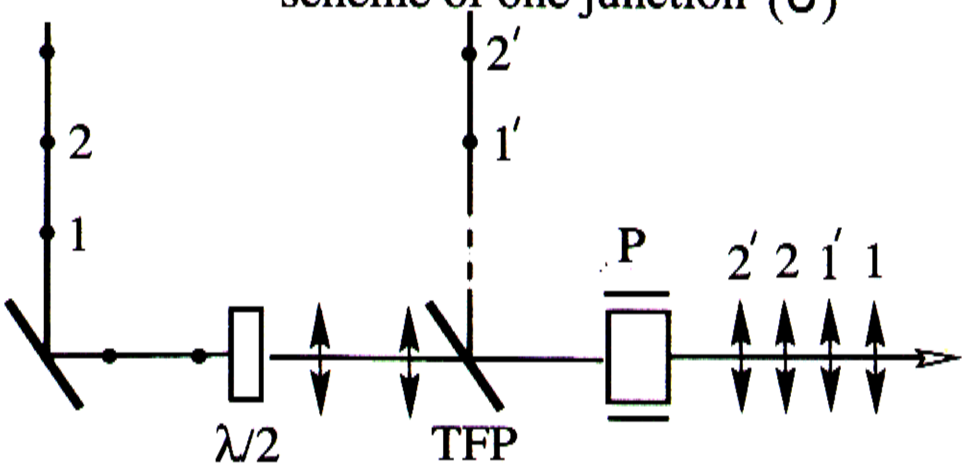
the number of round trips is limited only by attenuation of the laser pulse and ~~the~~ „nonlinear" integral (due to short pulse, ~ 5–10 round trips (10–20 collisions) seems possible.

(in comparison with scheme 0, there is no absorb-

Combining of pulses from several lasers to one train



scheme of one junction (o)



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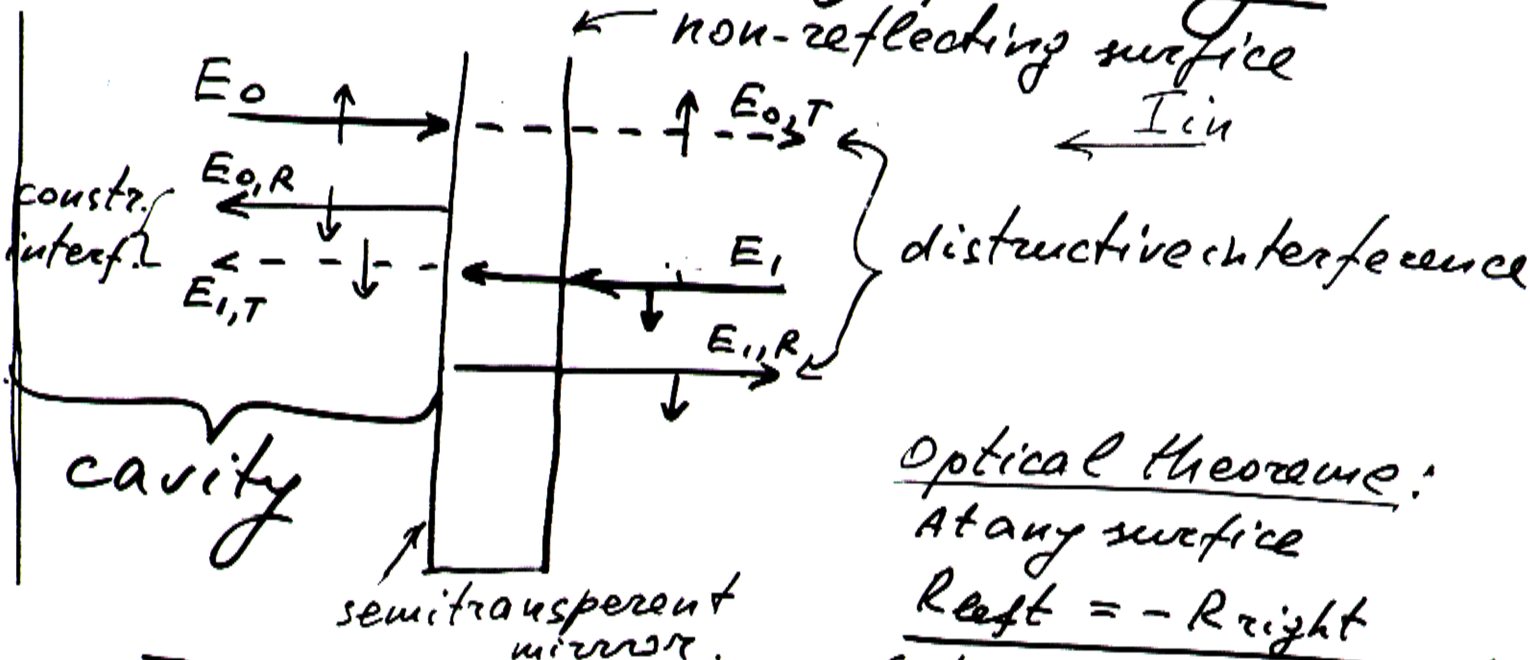
„External" optical cavity

Physics of cavity pumping



Optical theoreme:
At any surface
$R_{left} = -R_{right}$
(phase sign is opposite)

In equilibrium

$$E_{0,R} + E_{1,T} = E_0$$

$$E_0^2 = E_1^2 T / (1-\sqrt{R})^2$$

$$R + T + \delta = 1$$

$$\sqrt{R} \sim 1 - \frac{T}{2} - \frac{\delta}{2}$$

$$E_0^2 = E_1^2 \frac{4T}{(T+\delta)^2}$$

$$\boxed{\frac{I_0}{I_{in}} = \frac{4T}{(T+\delta)^2}}$$

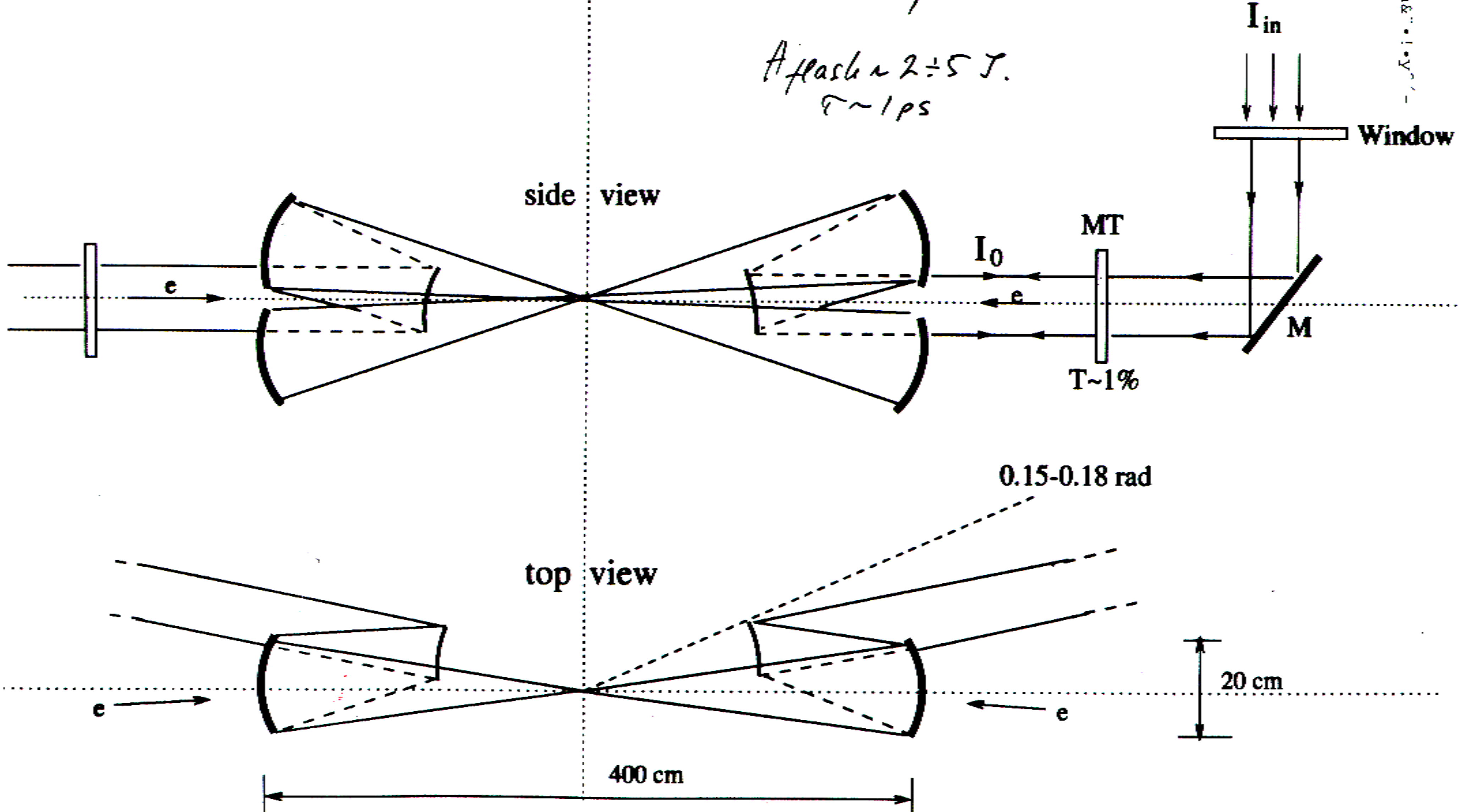
I_0

"External" optical cavity at photon collider

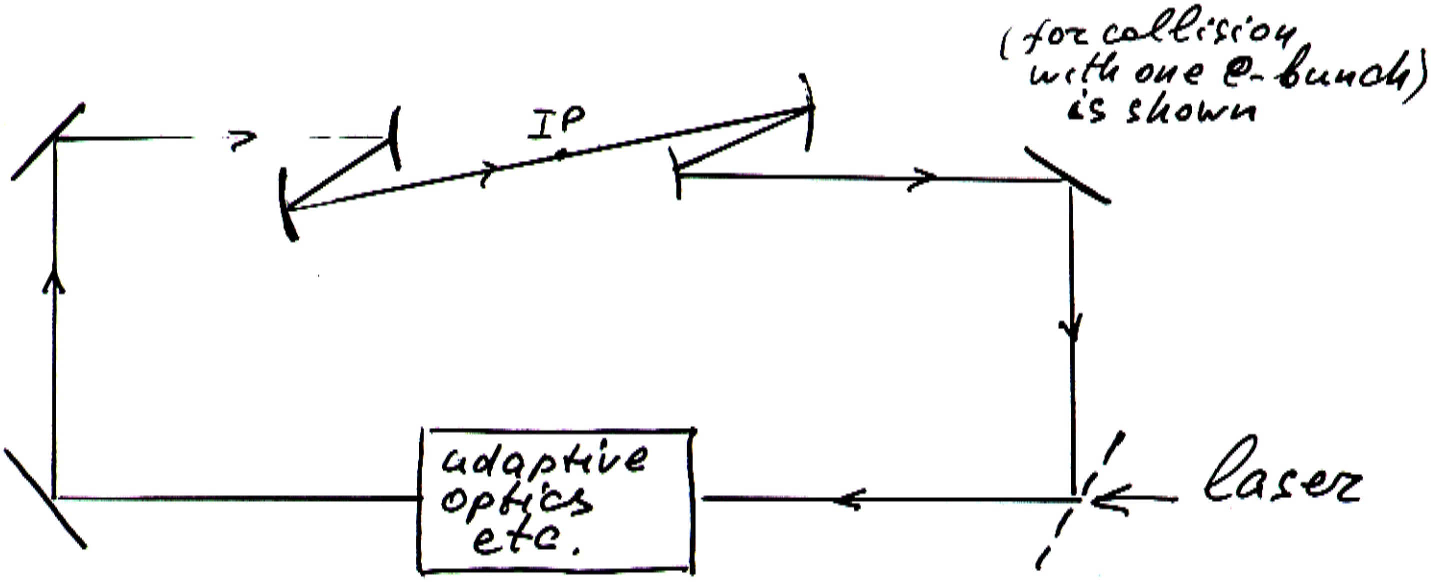
V. Telnov

$I_0 \sim Q I_{in}$, $Q \sim 20-100$

$A_{flash} \sim 2 \div 5$ J, $\tau \sim 1$ ps



Ring-type „external" optical cavity
(the same principle)



all as in „linear" cavity but no problem with backreflected light.

„External" cavity is very attractive approach but very high tolerances

$$\Delta X \sim \frac{\lambda}{2\pi Q}$$

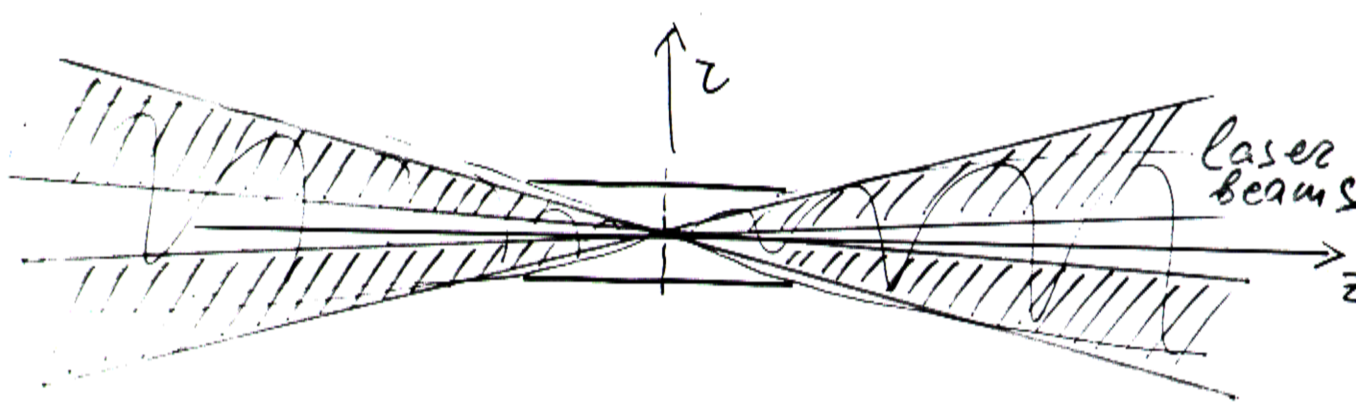
While in the „optical trap" (storage ring)

$$\Delta X \sim \frac{0.1\,\sigma_z}{Q}$$

Difference $\sim \frac{\sigma_z}{\lambda} \sim 300$!

Specific detector aspects

1)



In absence of laser optics the size of the vertex detector is determined by the e^+e^- background which occupy the region

$$r^2_{max} \approx \frac{25 N e}{\sigma_z B} z \sim 0.12 \frac{N}{10^{10}} \frac{z[cm]}{\sigma_z[mm] B[T]} \; cm^2$$

For TESLA, $N = 2 \cdot 10^{10}$, $\sigma_z = 0.3$ mm, $B = 3T$

$$r[cm] = 0.52 \sqrt{z[cm]}$$

For $r = 2$ cm $\quad z_m = \pm 15$ cm

$\Rightarrow$ clear angle $= 130$ mrad

Laser beam has r.m.s. divergence

$$\alpha_{\gamma, x} \approx \sqrt{\frac{\lambda}{4\pi \beta_\gamma}} \sim \sqrt{\frac{10^{-4}}{4\pi \cdot 0.05}} = 0.013$$

The required clear angle

$$\Delta\theta \sim 2 \times 3 \times 0.013 = 80 \text{ mrad}$$

that is less than due to backgrounds (130)

2) Mirrors occupy ...

Conclusion

- 1. $L_{\gamma\gamma}(z>0.8 z_m) \sim 40\% L_{e^+e^-}$
- 2 $\sigma_{\gamma\gamma} \sim 10\, \sigma_{e^+e^-}$
- 3 = 1×2 → physics motivation is clear: many processes can be studied in $\gamma\gamma, \gamma e$ coll. better than anywhere.
- 4. The second IP and specific accelerator aspects are included in TESLA TDR
- 5. Laser system can be (build) made using existed technologies!
- 6. ⇒ $\gamma\gamma, \gamma e$ collider is very essential part of LC, not less interesting than e^+e^-, its development should have high(er) priority in HEP program!