Two Photon Physics at a Linear Collider

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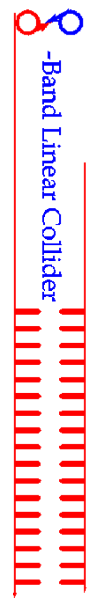
Lund, 13 September 1998

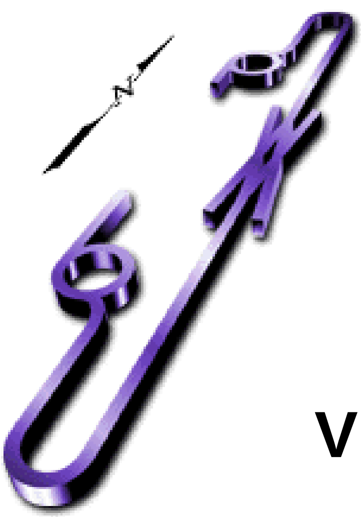


Introduction

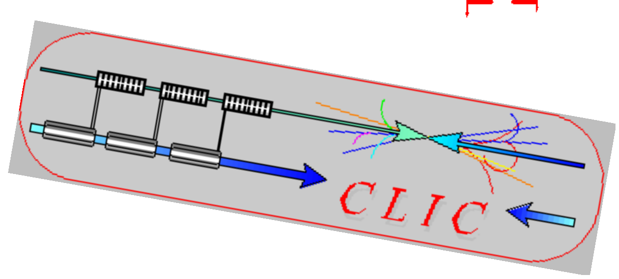
1. The instruments

2. The physics

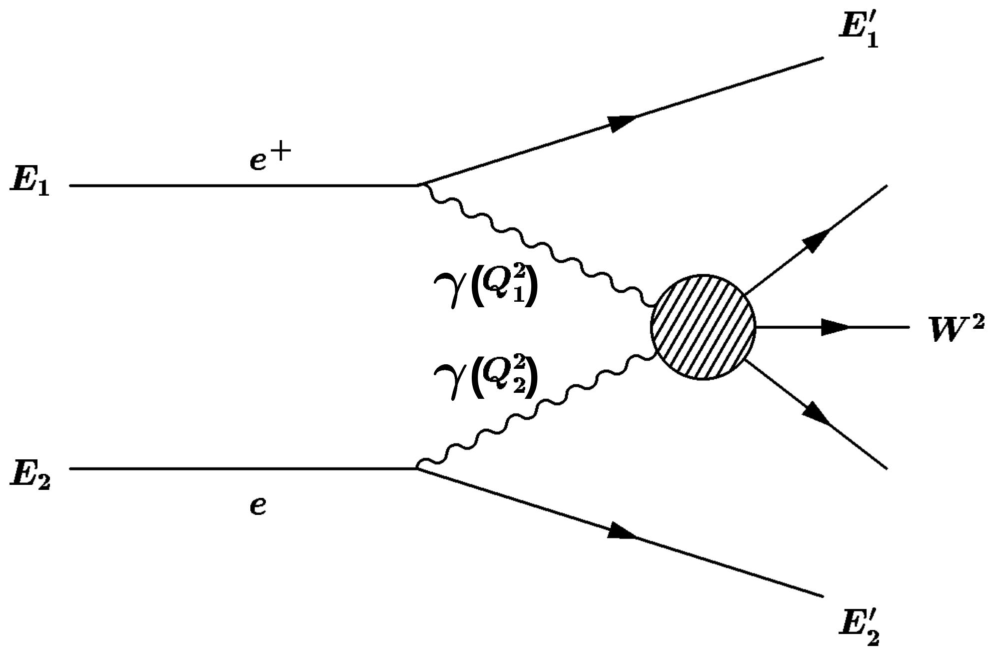
Conclusions



VLEPP



Photon — photon scattering



Interaction of two quasi-real photons

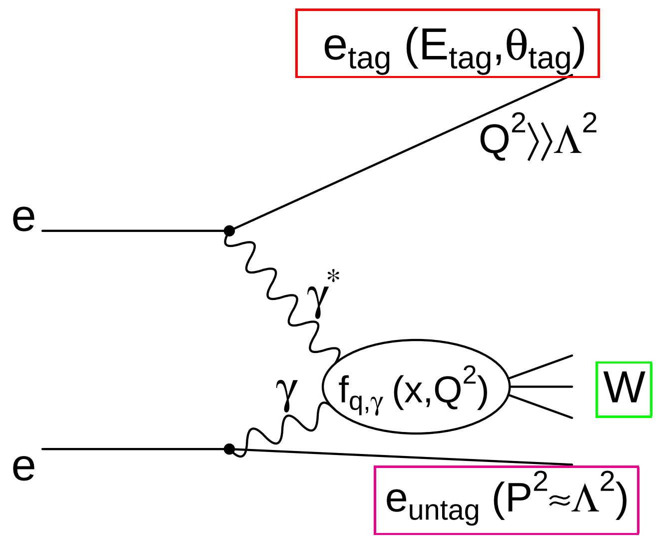
$$\gamma\gamma \to X$$

e.g. $X(s_{\gamma\gamma}) = \ell^+\ell^-, \mathrm{q\bar{q}}, \mathrm{Q\bar{Q}}, \mathrm{Z^0Z^0}, \mathrm{W^+W^-}, H$

$$Q_i^2 = 2E_iE_i'(1-\cos\theta_i) \approx 0$$

$$W^2 = s_{\gamma\gamma} = \left(\sum_h E_h\right)^2 - \left(\sum_h \vec{p}_h\right)^2$$

Electron-Photon Scattering



$$\frac{d^2\sigma_{e\gamma\to eX}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\cdot$$

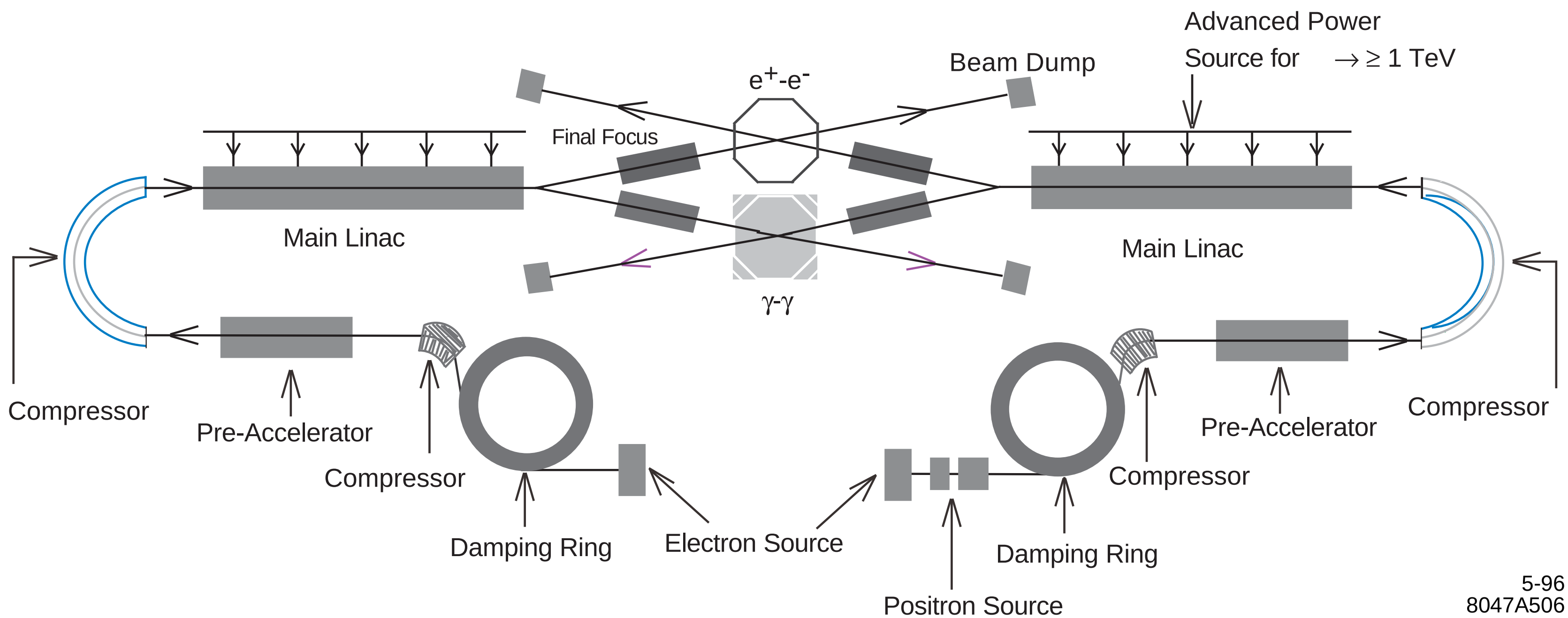
$$\left[(1+(1-y)^2)\,F_2^\gamma(x,Q^2) - \underbrace{y^2 F_L^\gamma(x,Q^2)}_{\to 0}\right]$$

$$Q^2 = 2\,E_b\,E_{tag}\,(1-\cos\theta_{tag}) \gg P^2$$

$$x = \frac{Q^2}{Q^2+W^2+P^2}$$

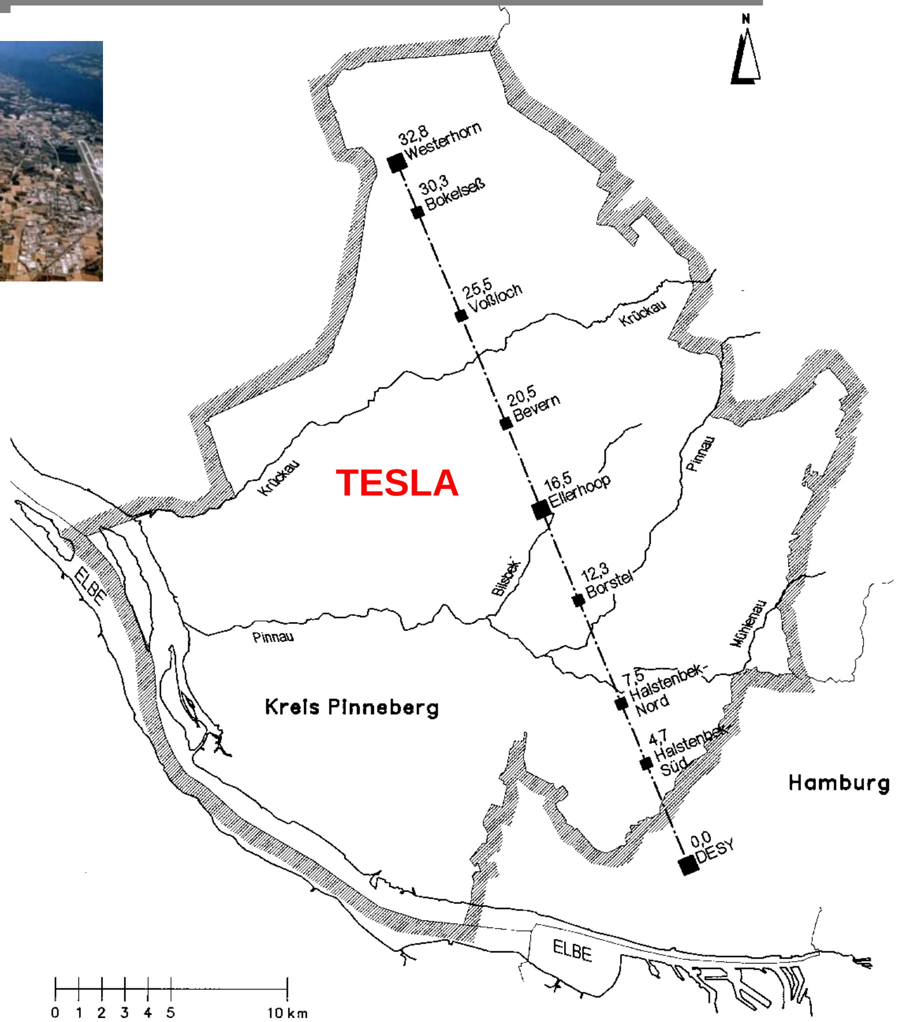
$$y = 1-\frac{E_{tag}}{E_b}\cos^2\left(\frac{\theta_{tag}}{2}\right) \ll 1$$

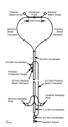
The general layout of a future Linear Collider



From LEP/ SLC to TESLA

LEP



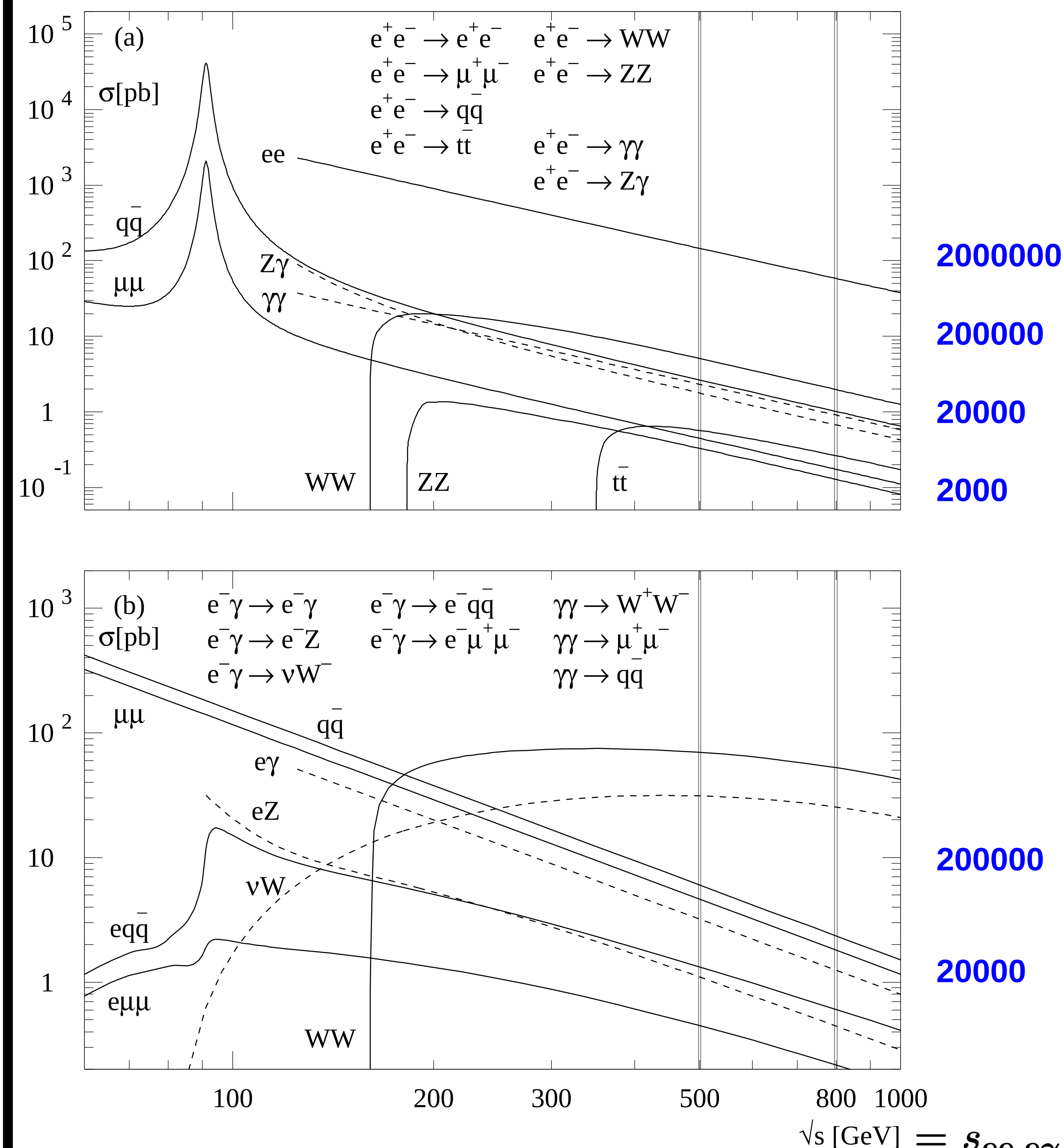


← SLC

		LEP	SLC	TESLA
radius	[km]	8.5	∞	∞
length	[km]	26.7	4	33
gradient	[MV/m]	6	10	25
σ_x/σ_y	[μm/μm]	110 / 5	1.4 / 0.5	0.845/0.019
energy	[GeV]	100	50	250
luminosity	[10^{31}cm^{-2}s]	7.4	0.1	5000-10000
$\mathcal{L}_{int}$	[1/pb y]	100	15	20000

The expected cross sections

$\mathcal{L}_{int} = 20 fb^{-1}/y \quad \Rightarrow$ Events/y

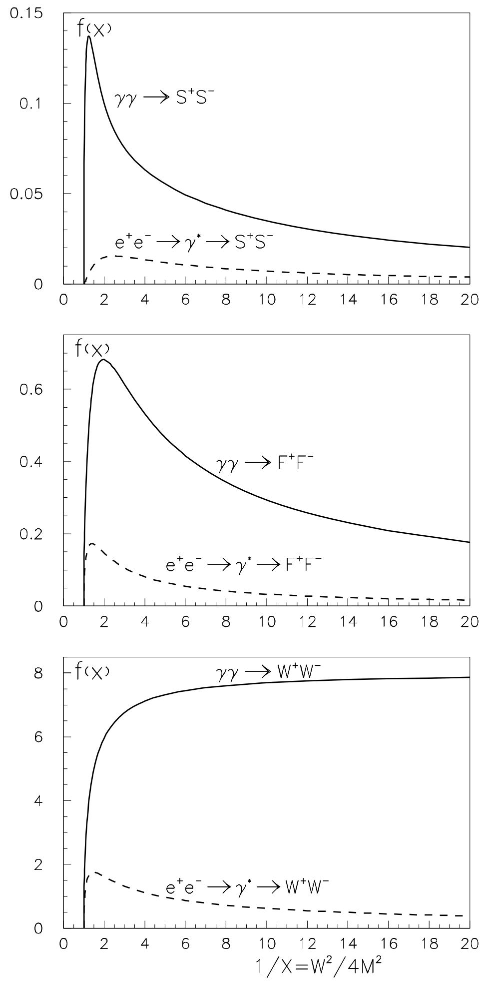


$= s_{ee,e\gamma,\gamma\gamma}$

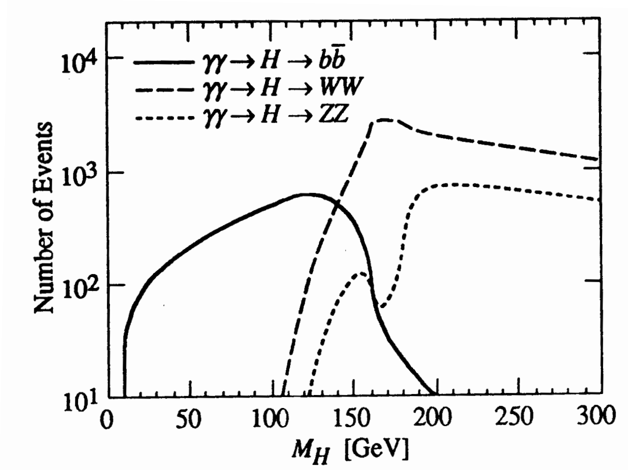
$10 < \theta_i < 170$ deg, $M_{\mu^+\mu^-,q\bar{q}} > 50$ GeV

Some advantages of photon colliders

$f(x) = \sigma \cdot \frac{M^2}{\pi\alpha},\ W^2 = s_{ee}, s_{\gamma\gamma}$

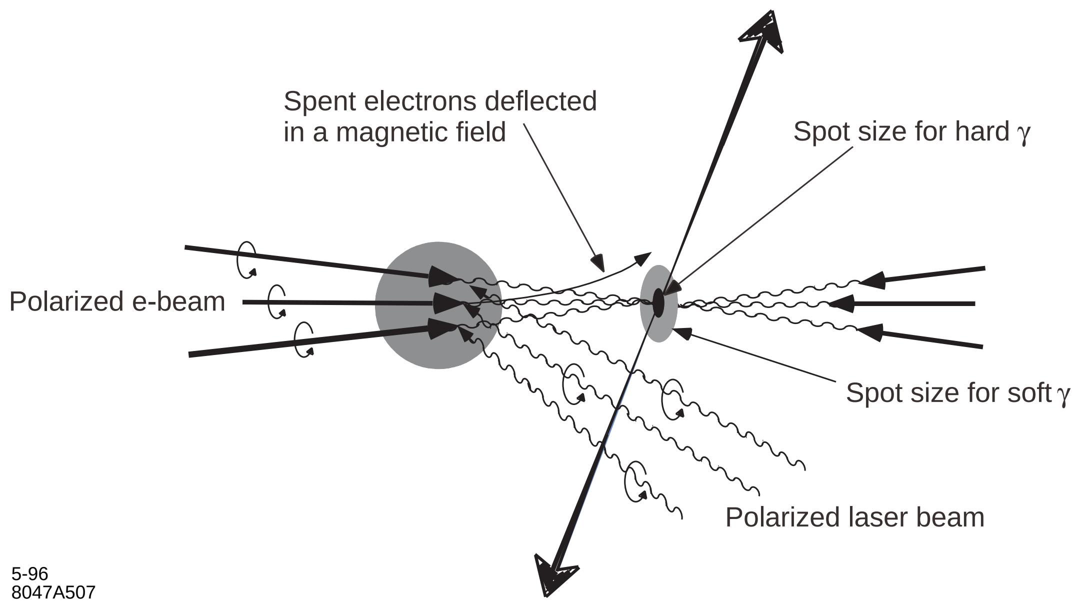


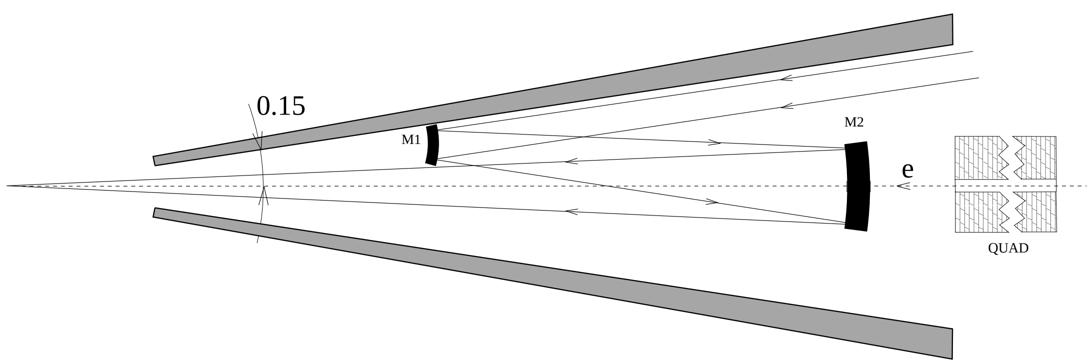
$\frac{dL^{\gamma\gamma}}{dW_{\gamma\gamma}} = 4 \cdot 10^{-2}$ / fb GeV

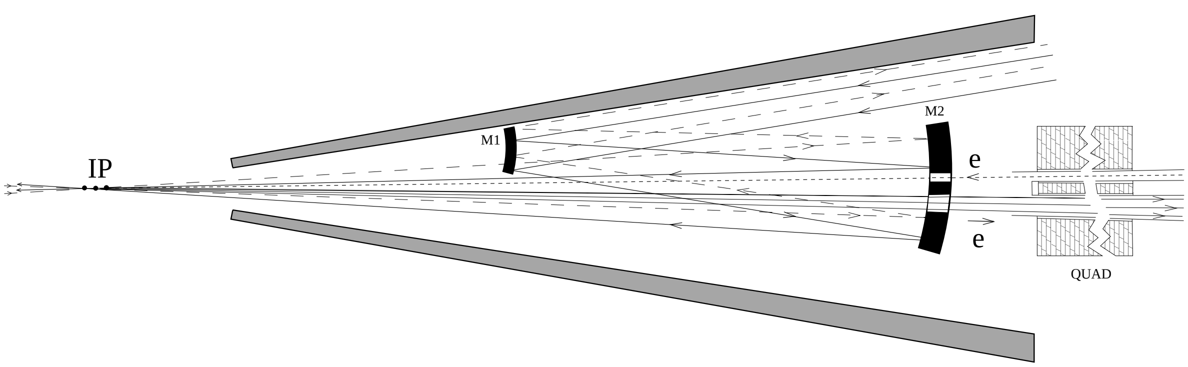


- Larger cross sections than e^+e^- for several final states, e.g. W^+W^- pairs.
- Good prospect for two photon production of Higgs bosons.
- Replace the Weizsäcker Williams Photons in $\gamma\gamma$ collisions by high energy compton scattered photons $\Rightarrow$ larger $W_{\gamma\gamma}$.
- Single production of Leptoquarks, Higgs bosons, etc. gives access to larger masses.

The creation of the Photon beam

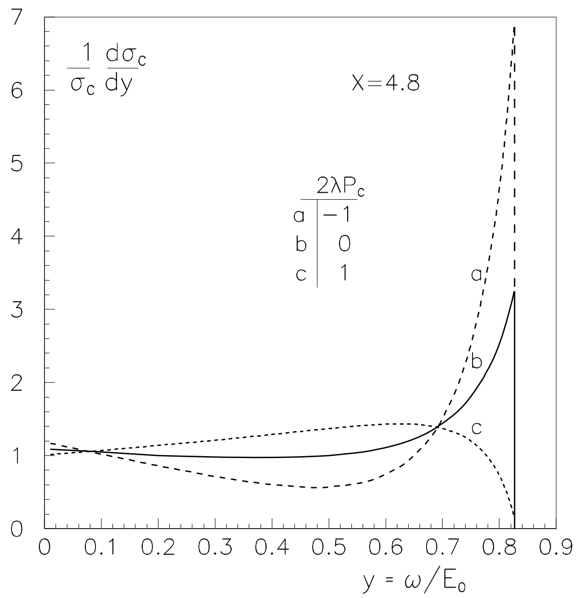


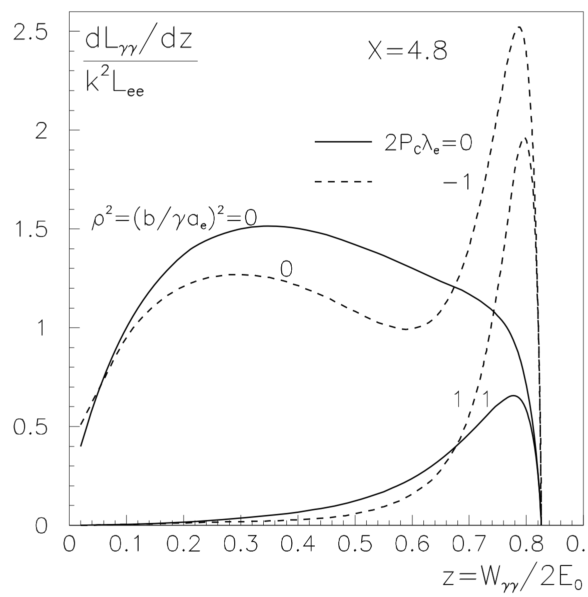




Critical parameters for $\gamma\gamma$ collisions

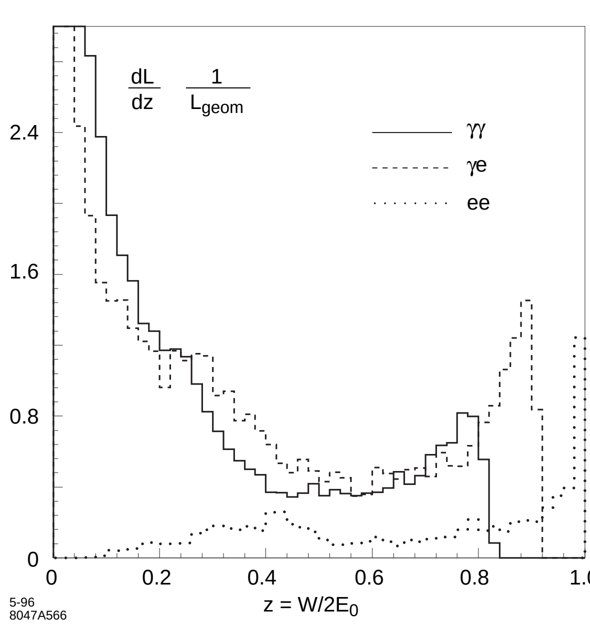
beam energy spread

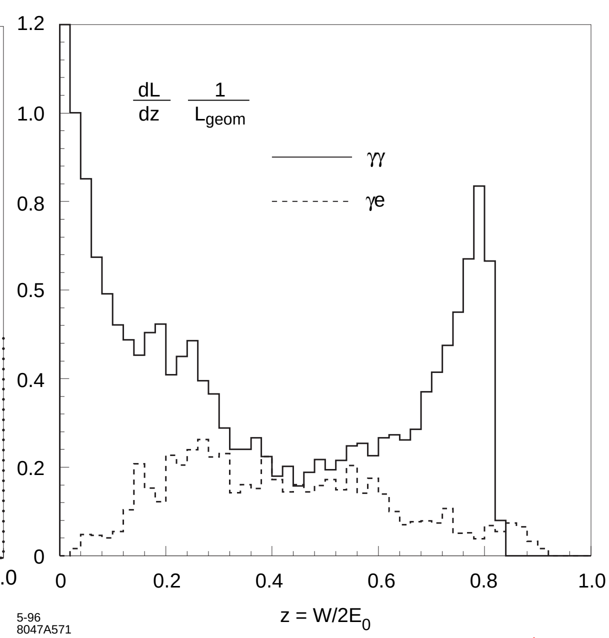




helicities **conversion point**

Remaining $e\gamma$ and e^+e^- luminosities

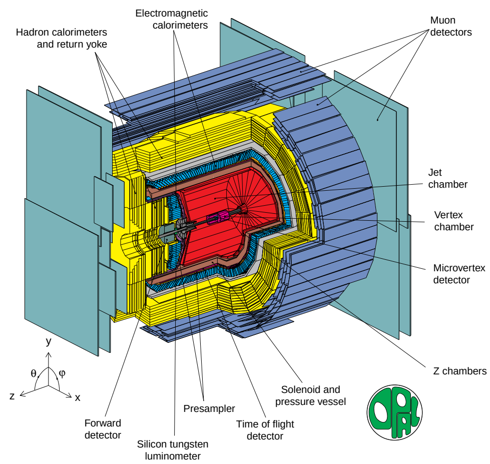


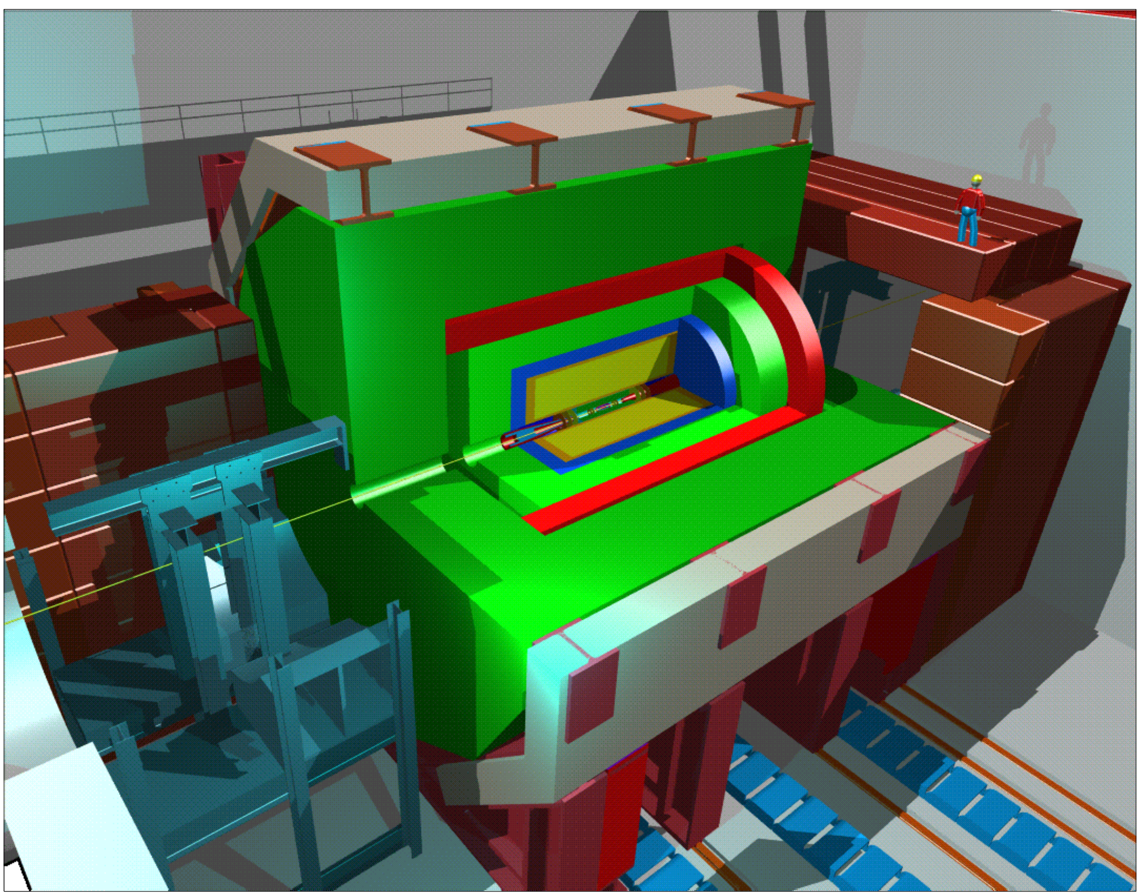


no deflection of $e^{\pm}$ **deflection of $e^{\pm}$**

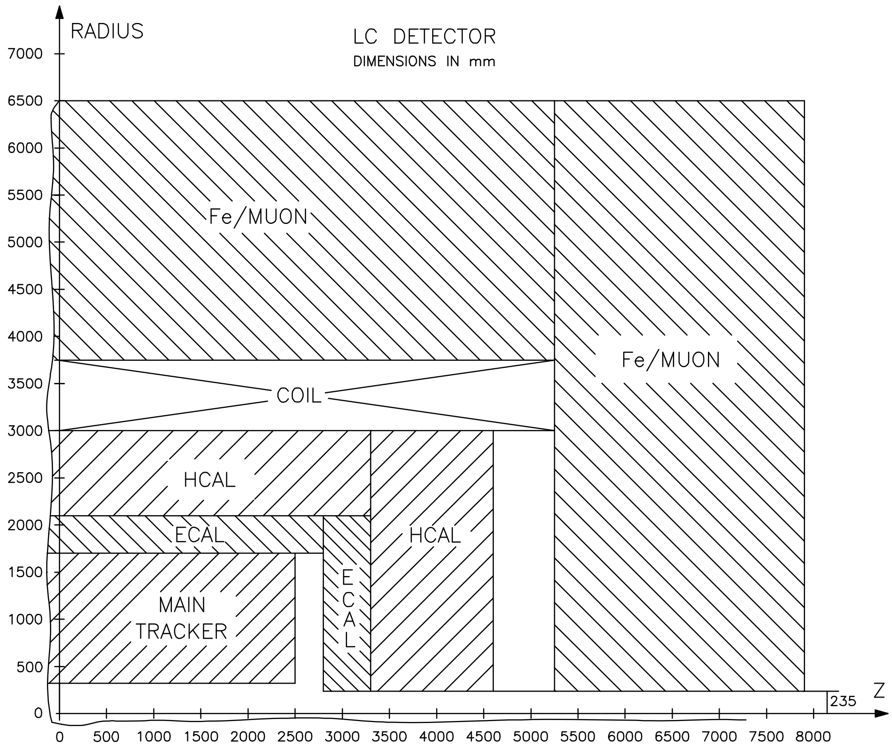
From LEP to TESLA

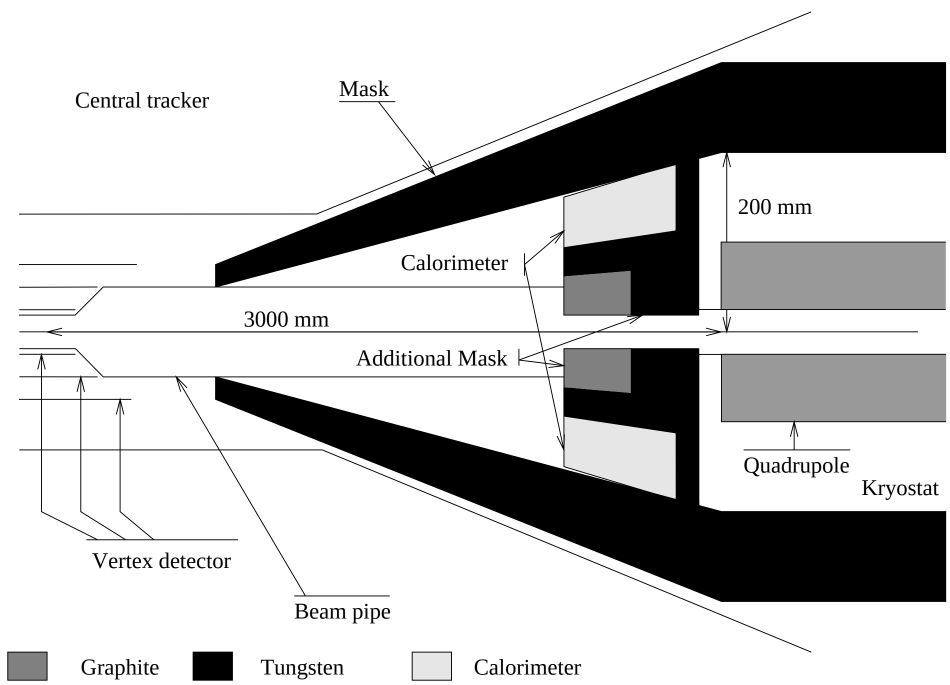
the detector



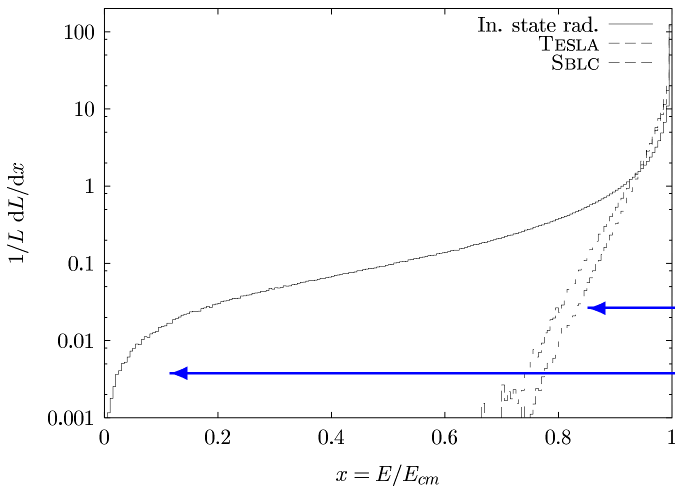


The general detector concept



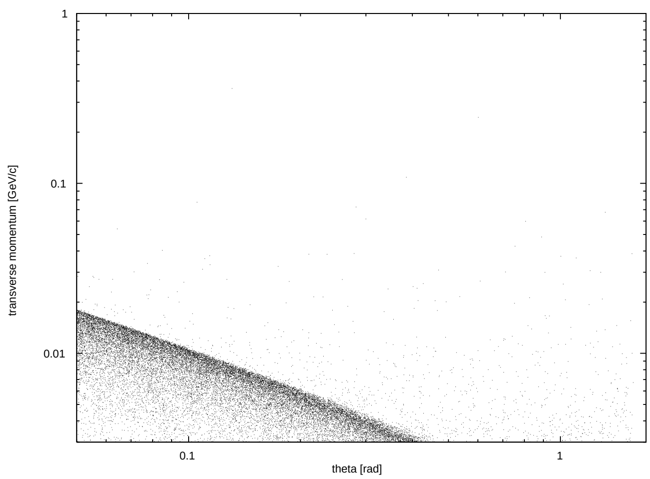


Some features of the background



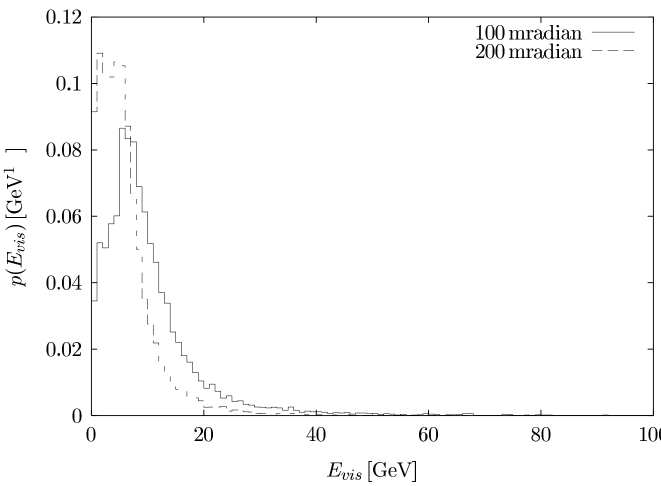
beamstrahlung

initial state radiation



$$\frac{N_{e^+e^-}}{BX} = 10^5$$

$$E_{tot} = 1.5 \cdot 10^5 \text{ GeV}$$



$$\frac{N_{had}(W_{had}>5GeV)}{BX} = 0.13$$

$$\langle E_{vis} \rangle = 10 \text{ GeV}$$

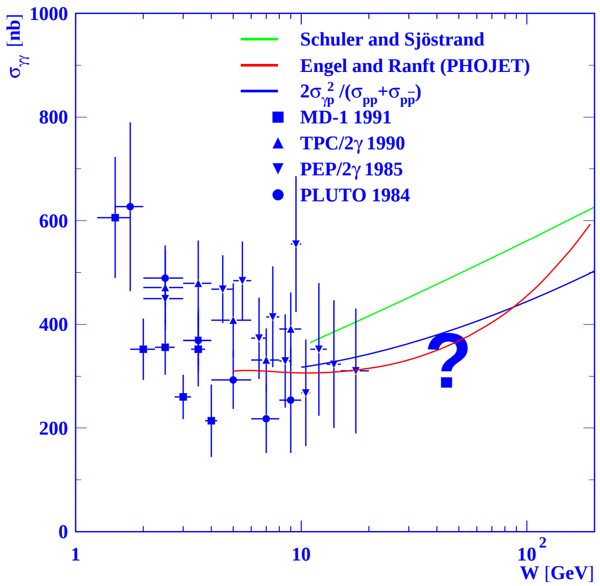
From LEP to TESLA the physics

1. Total $\gamma\gamma$ cross section
2. Jet production in $\gamma\gamma$, $\gamma^{\star}\gamma$ and $\gamma^{\star}\gamma^{\star}$ collisions
3. QED and QCD Structure Functions of the photon
4. Heavy Quark production
5. BFKL signatures in $\gamma^{\star}\gamma^{\star}$ collisions
6. Production of W pairs
7. Higgs Production using $\gamma\gamma \rightarrow H$
8. Resonances
9. Searches for new particles
10. Diffraction
11. Production of Z pairs and photon pairs

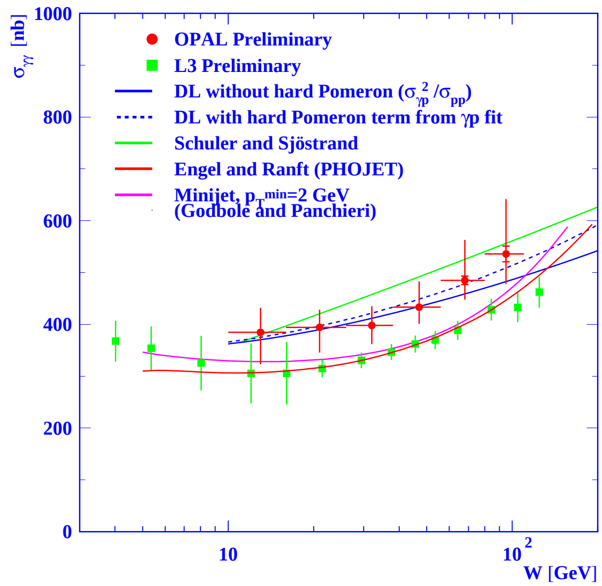
... and much more

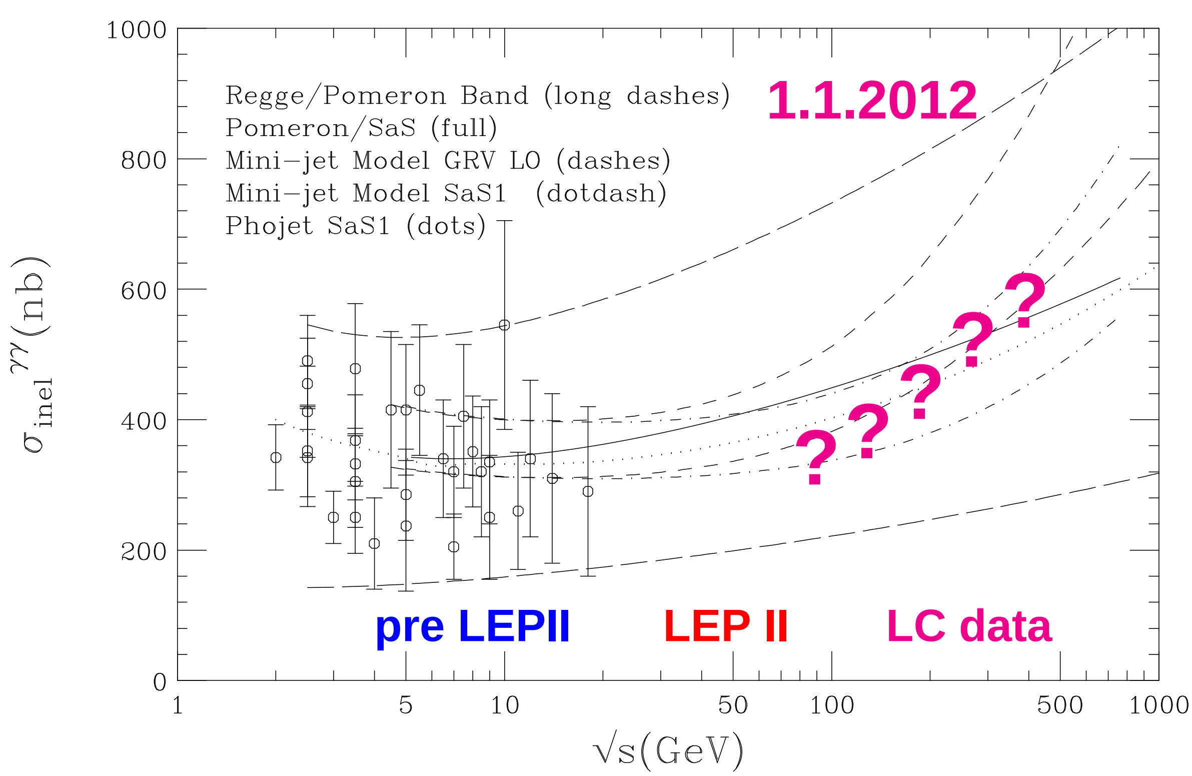
The total γ-γ cross section

1995 pre LEPII

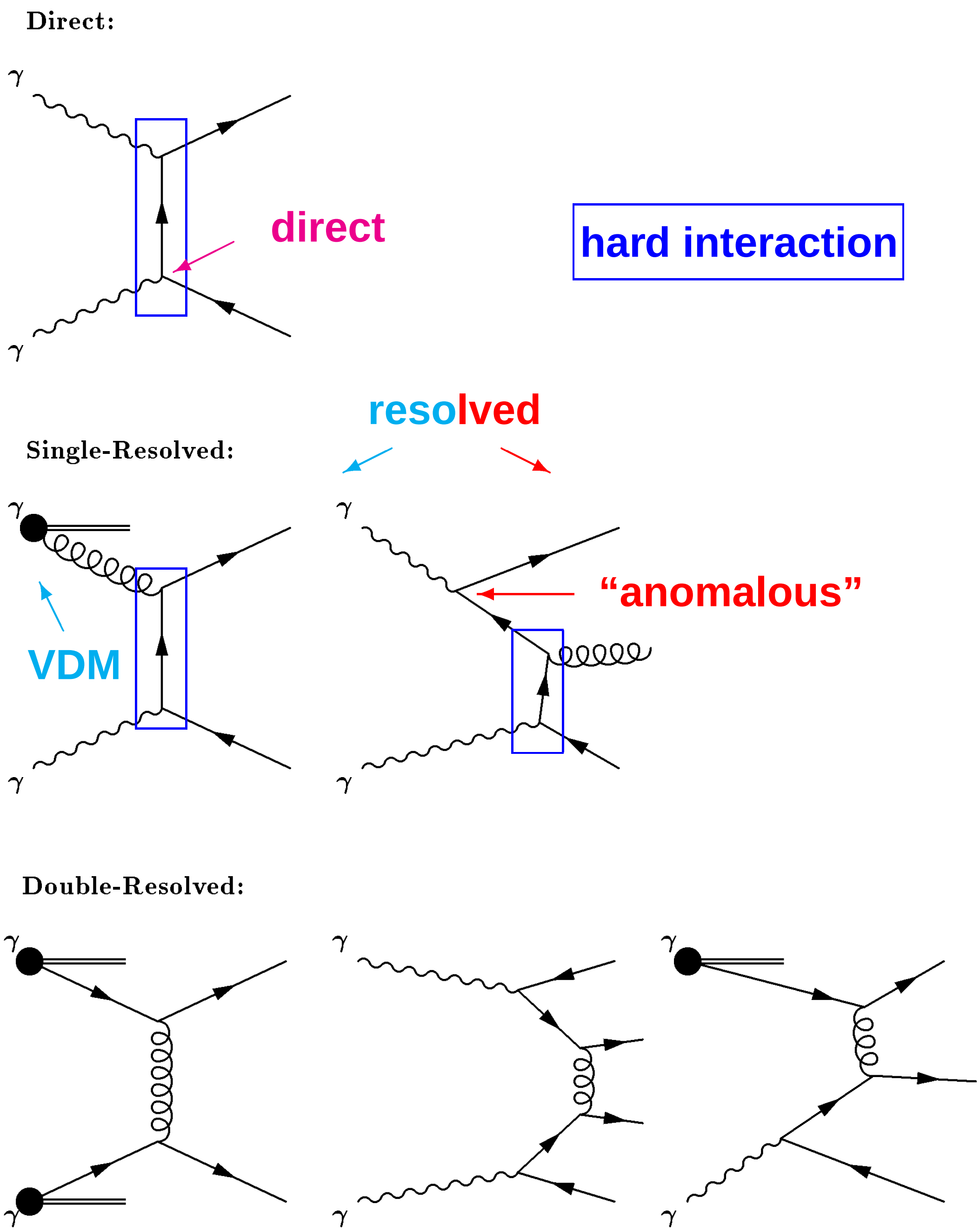


1998 LEPII data

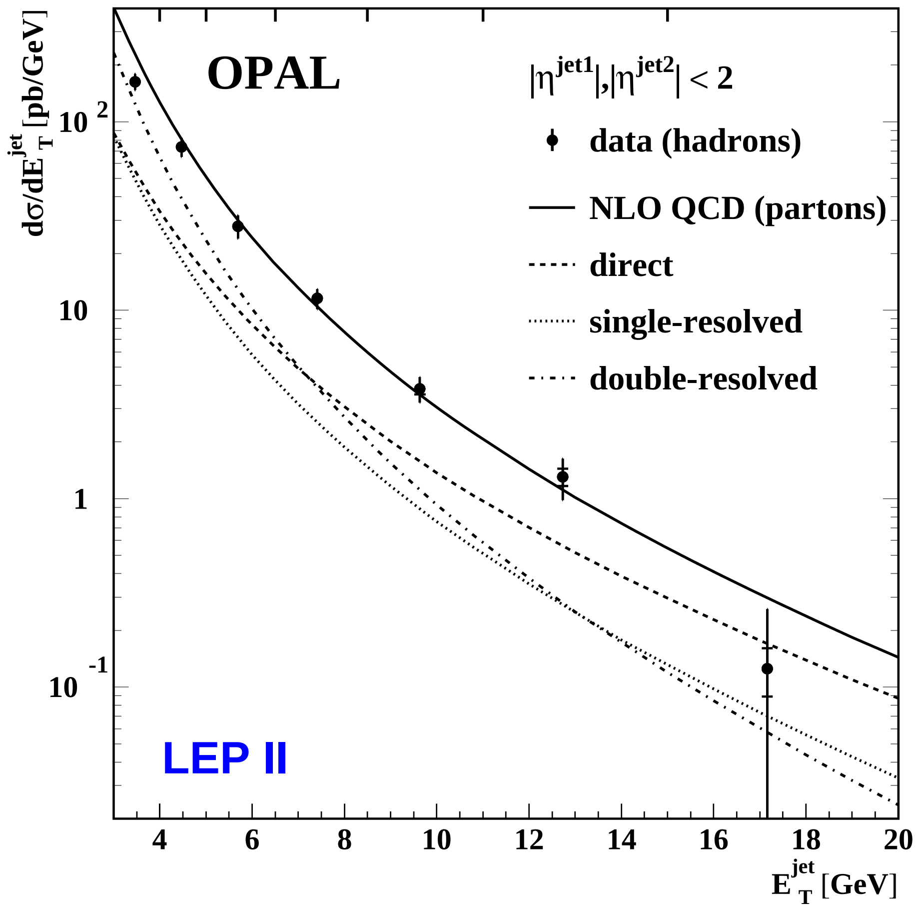


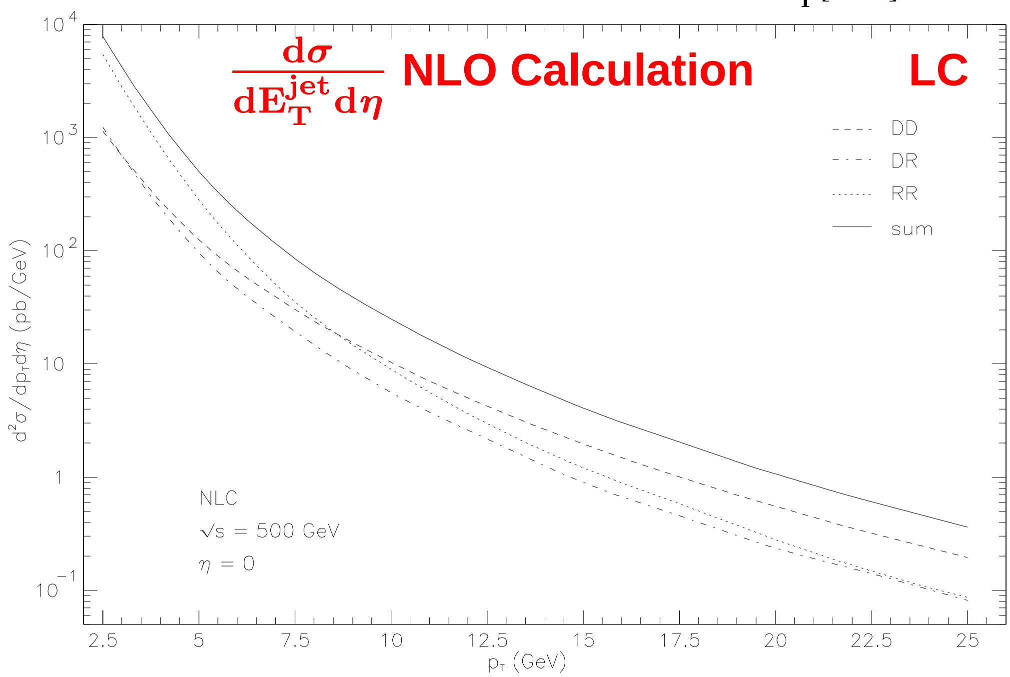


Leading order diagrams

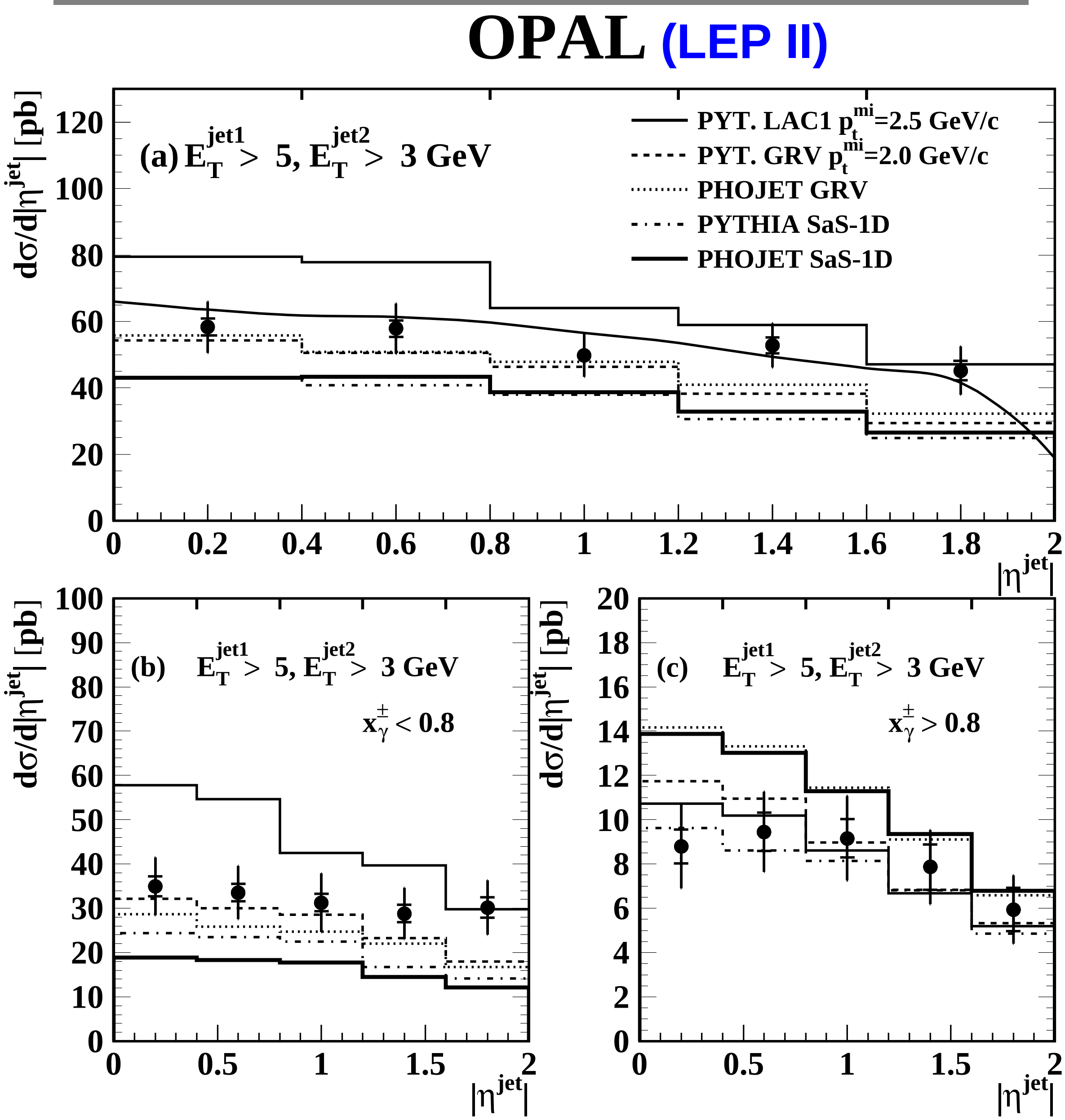


The inclusive jet cross-sections





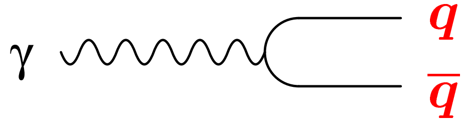
The sensitivity to parton densities

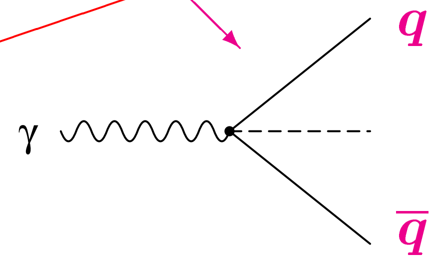


- The gluon density $f_{g/\gamma}$ in the photon can be constrained.
- The simulation of hadronic final states has be be improved.

The contributions to $F_2^\gamma(x, Q^2)$

$$F_2^\gamma(x, Q^2) = x \sum_{c,f} e_q^2 \, \underline{f_{q,\gamma}(x, Q^2)}$$





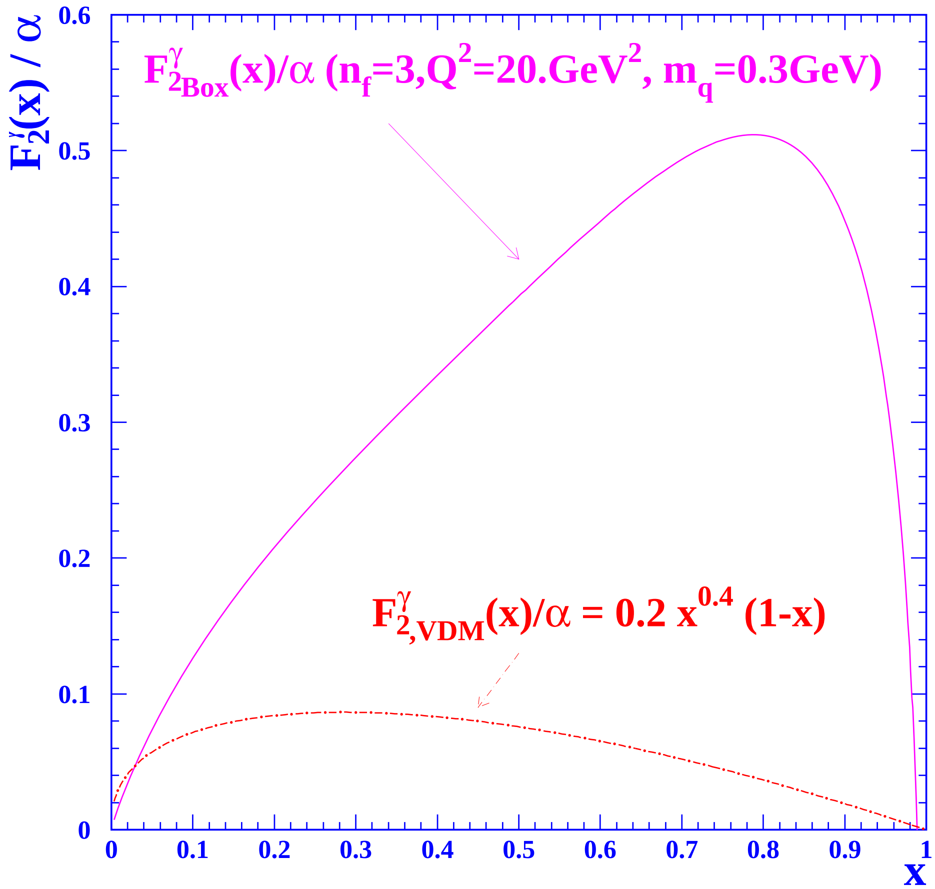
'hadronic', p_T = "small"

non–perturbative

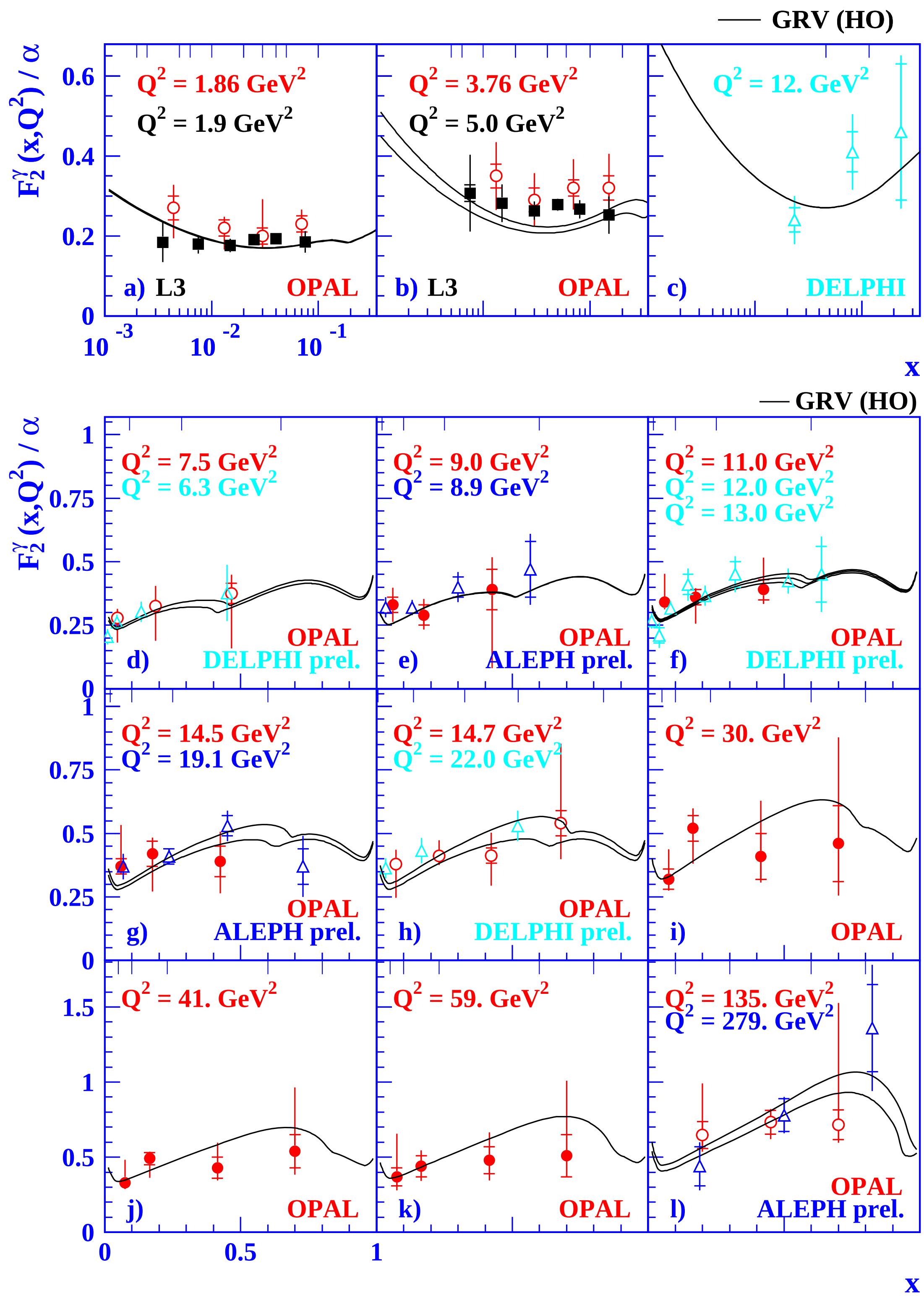
VDM (ρ, ω, ϕ)

'pointlike', p_T = "large"

perturbative

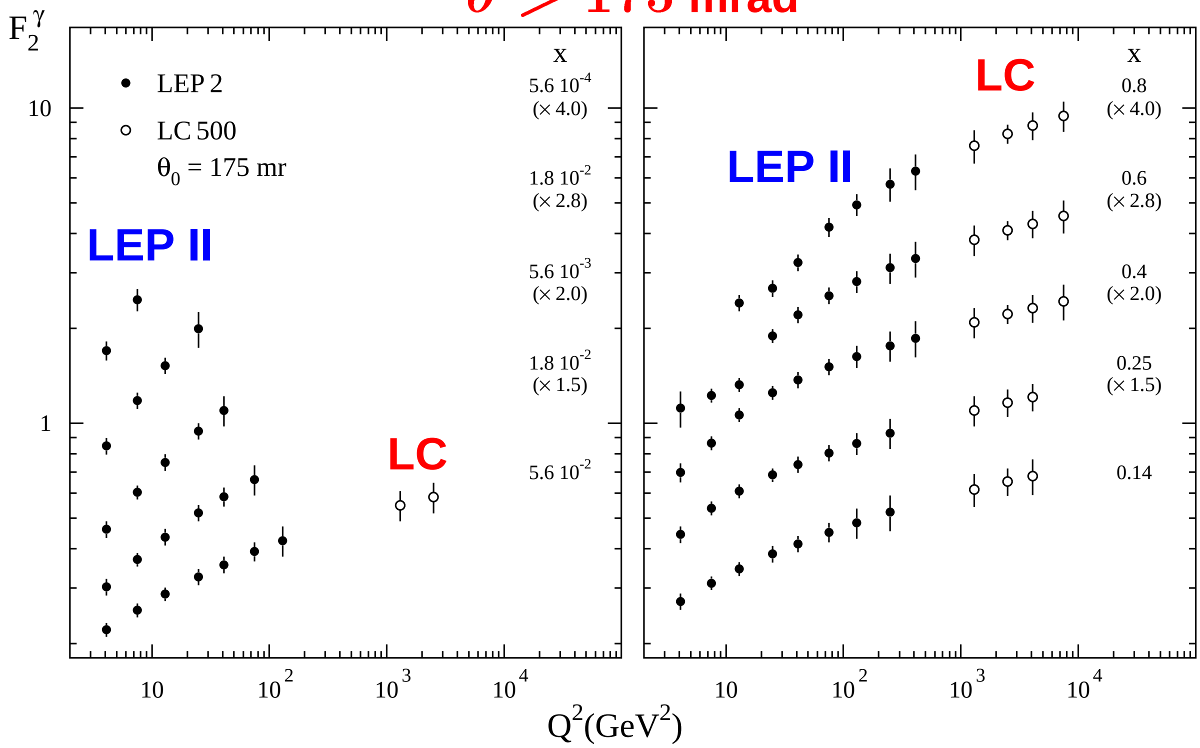


The LEP data on F_2^{γ}

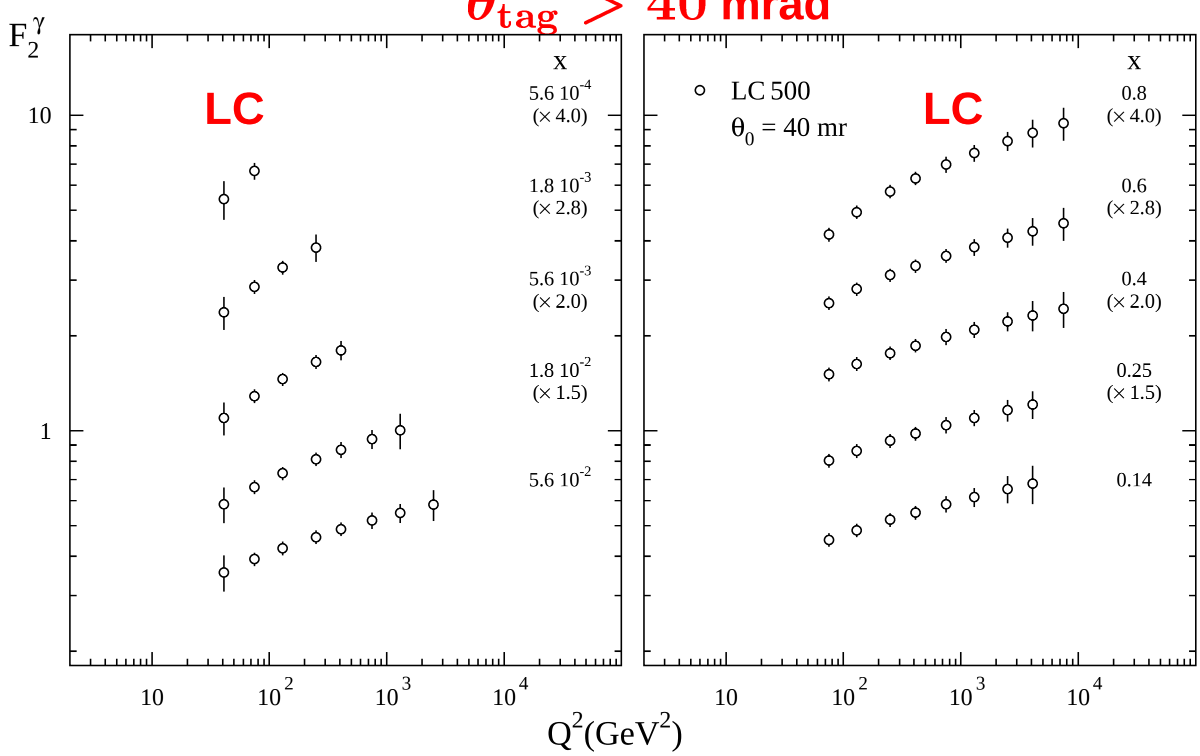


F_2^γ prospects for a LC

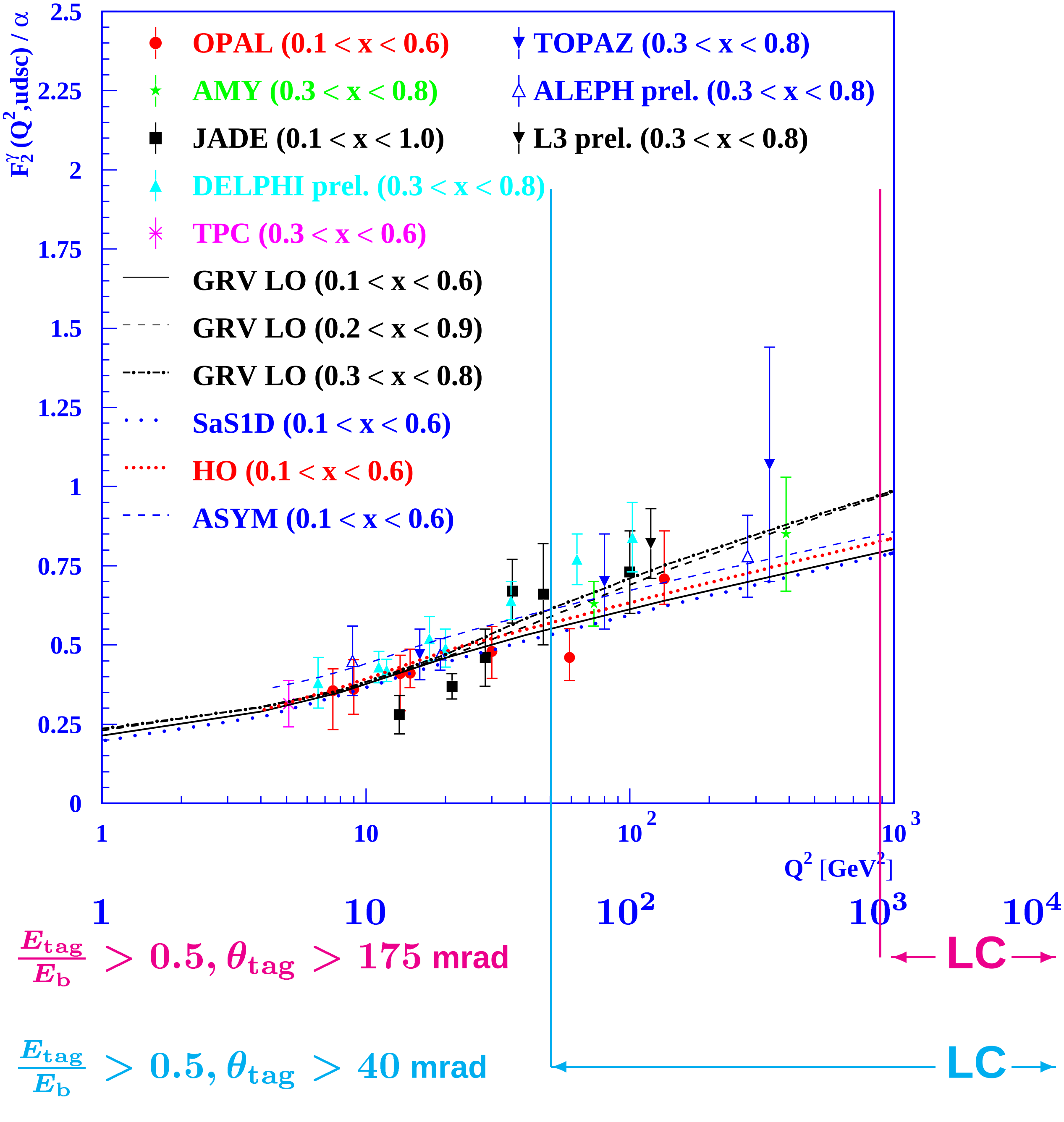
$\theta > 175$ mrad



$\theta_{tag} > 40$ mrad

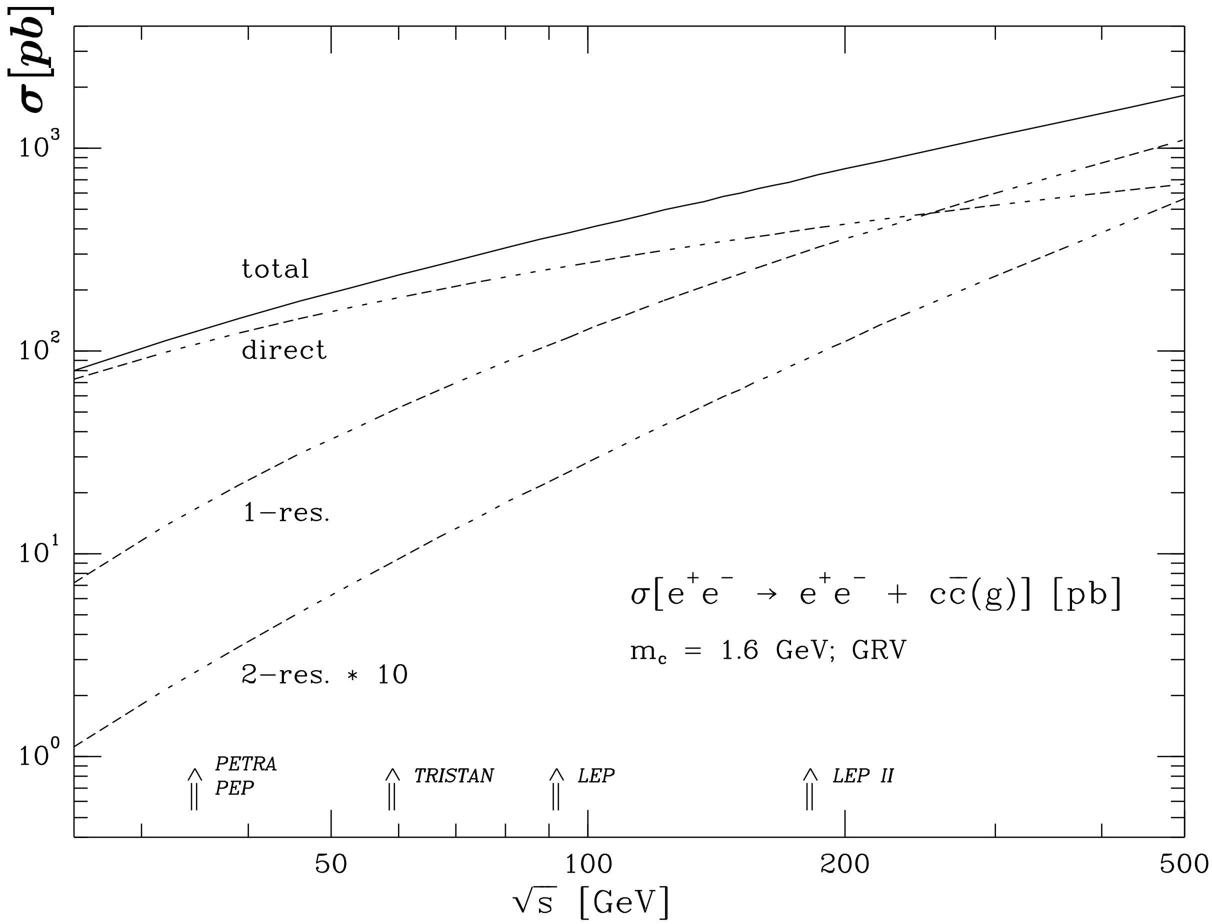


The Q^2 evolution of F_2^γ



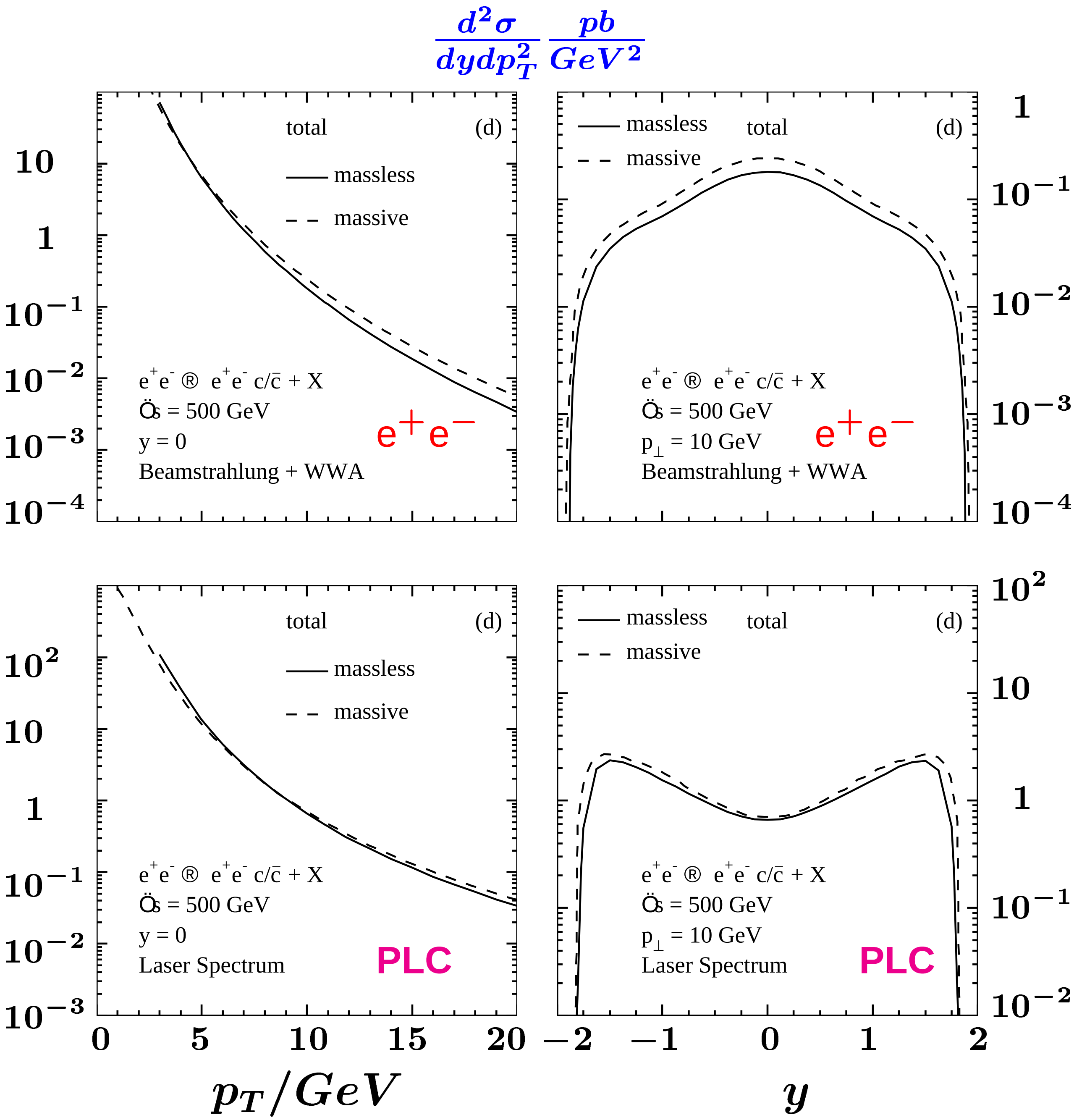
To achieve overlap with LEP II data the mask has to be instrumented.

Charm cross section in $\gamma\gamma$



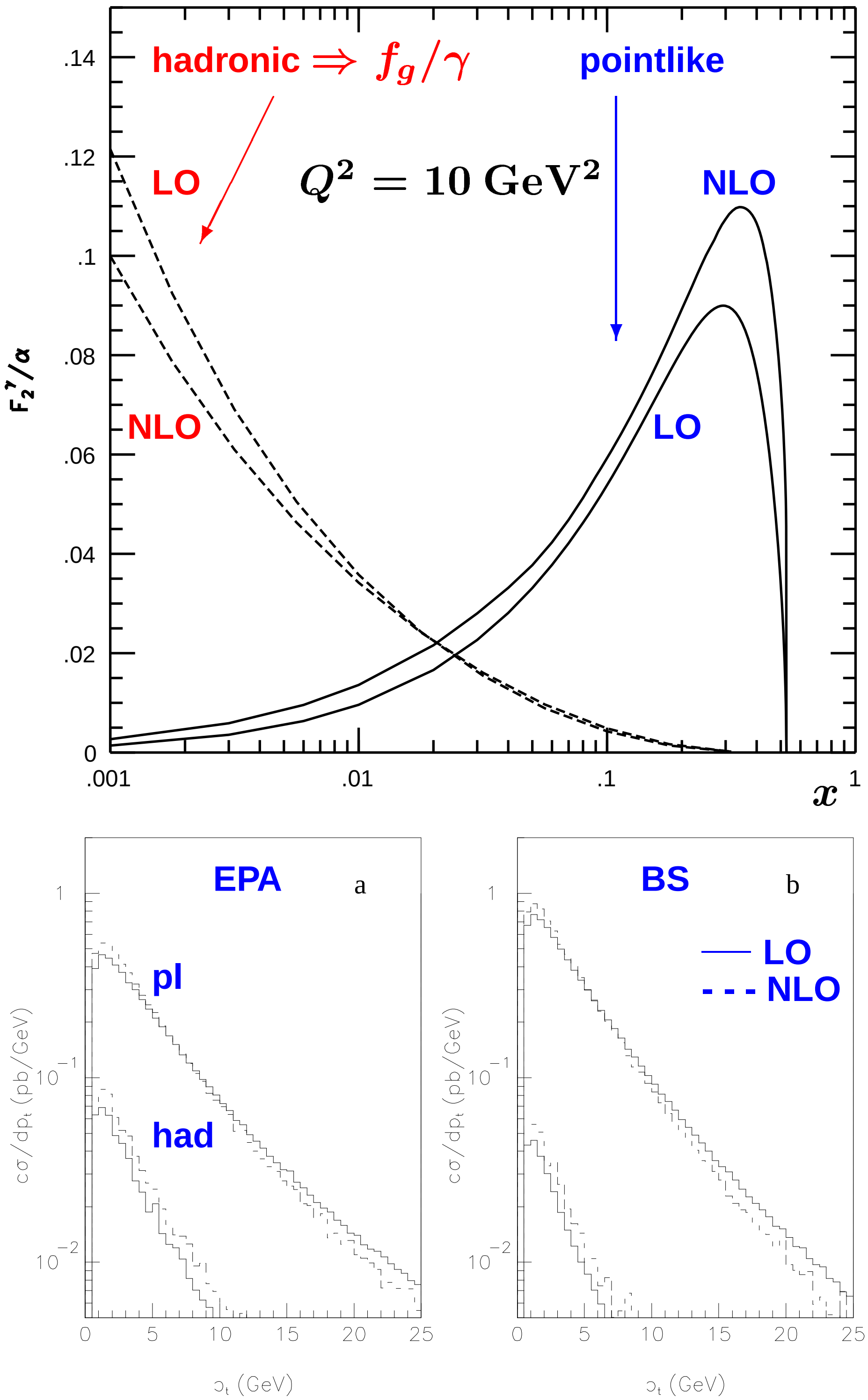
- **Direct and 1-res (NLO), 2-res (LO) calculation, all based on the EPA**
- $\mu = \sqrt{2}m_c, m_c = 1.6$ **GeV** $W_{min} = 3.8$ **GeV**
- 10^7 $c\bar{c}$ **events/year**
- **Direct process is pure QCD prediction**
  $\sigma = f(m_c, \alpha_s)$

Charm production in $\gamma\gamma$



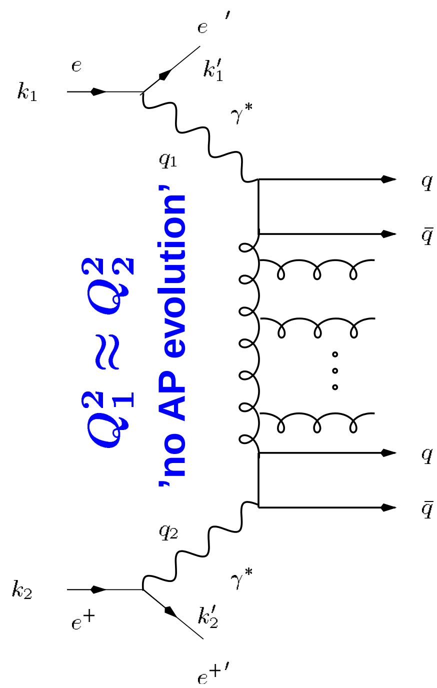
NLO calculation, EPA integrated up to θ_{tag} = 175 mrad, m_c = 1.5 GeV

Charm production $\gamma^\star\gamma$



$\frac{E_{tag}}{E_b} > 0.5, \theta_{tag} > 40$ mrad, $m_c = 1.5$ GeV, $\mu = Q$

BFKL signature in $\sigma_{\gamma^\star\gamma^\star}$



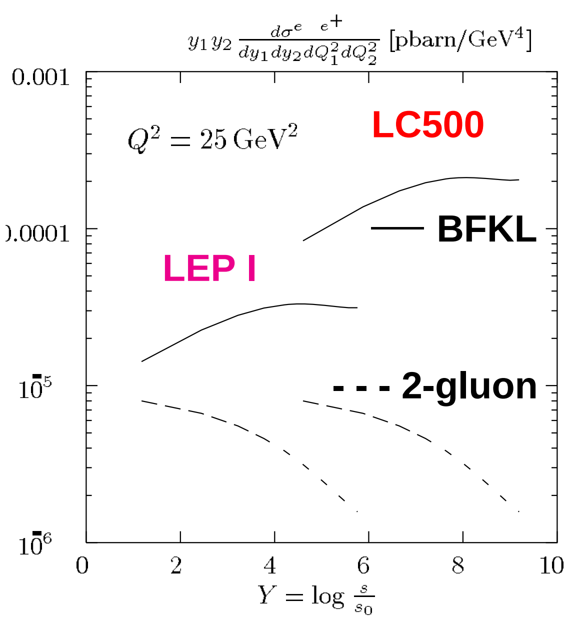
$$y_1 = \frac{q_1 k_2}{k_1 k_2}$$

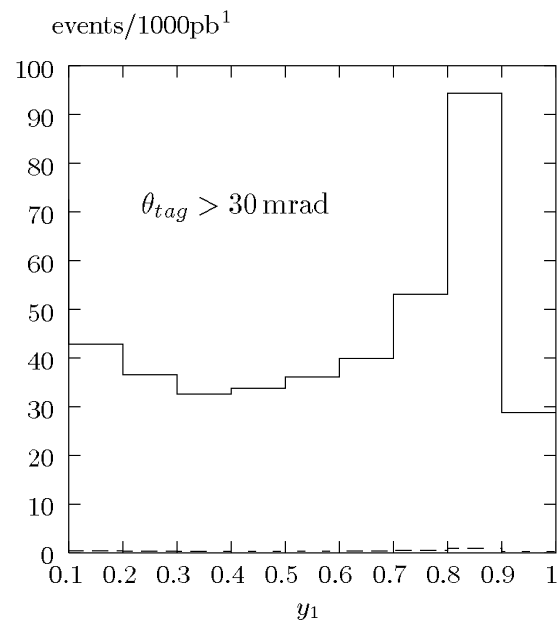
$$Q_1^2 = -q_1^2$$

$$s = (k_1 + k_2)^2$$

$$\hat{s} = s y_1 y_2, \quad s_0 = \frac{\sqrt{Q_1^2 Q_2^2}}{y_1 y_2}$$

$$\hat{s} \gg Q_i^2$$





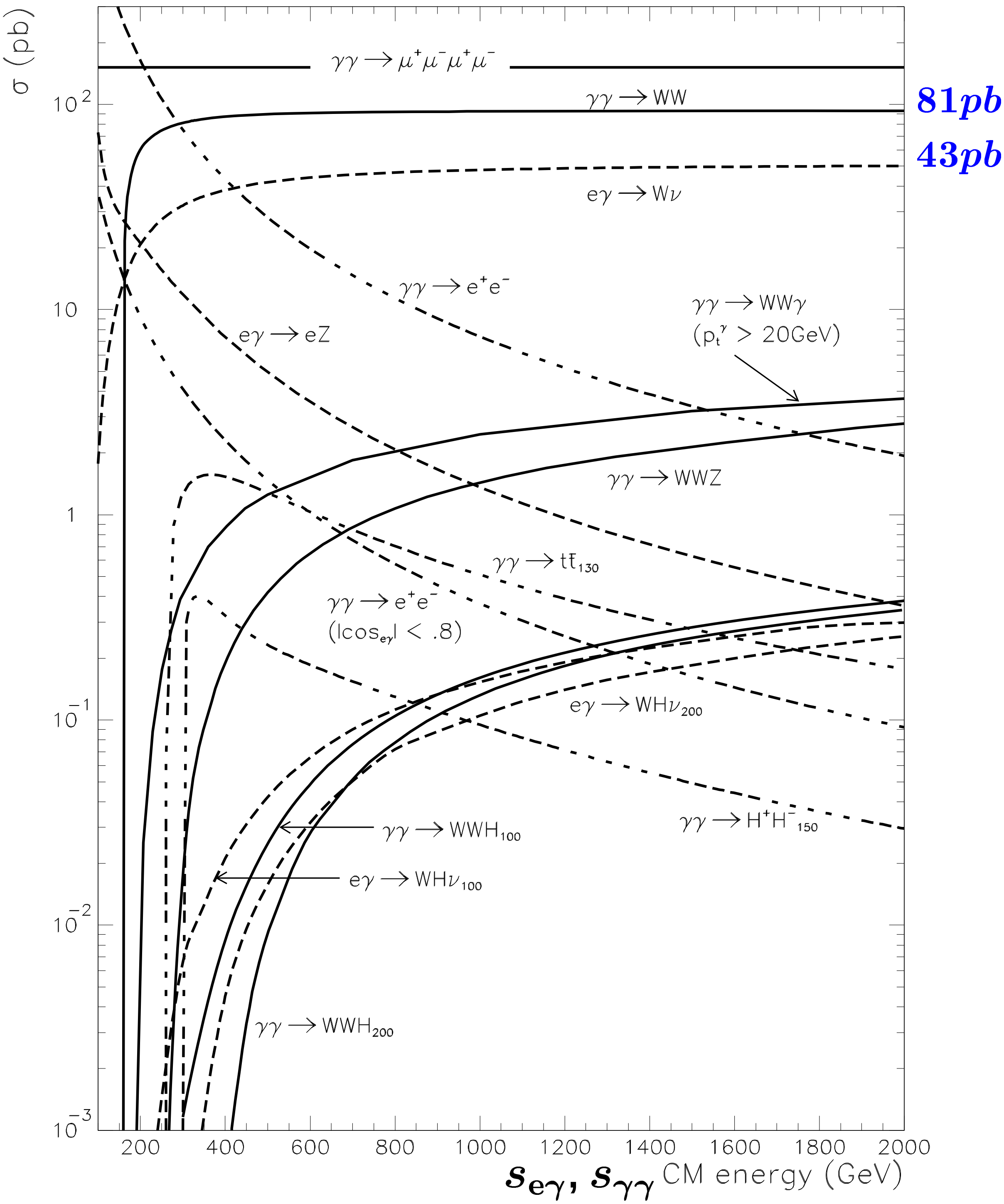
$E_{tag} > 20$ GeV

$\log(\frac{s}{s_0}) > 2$

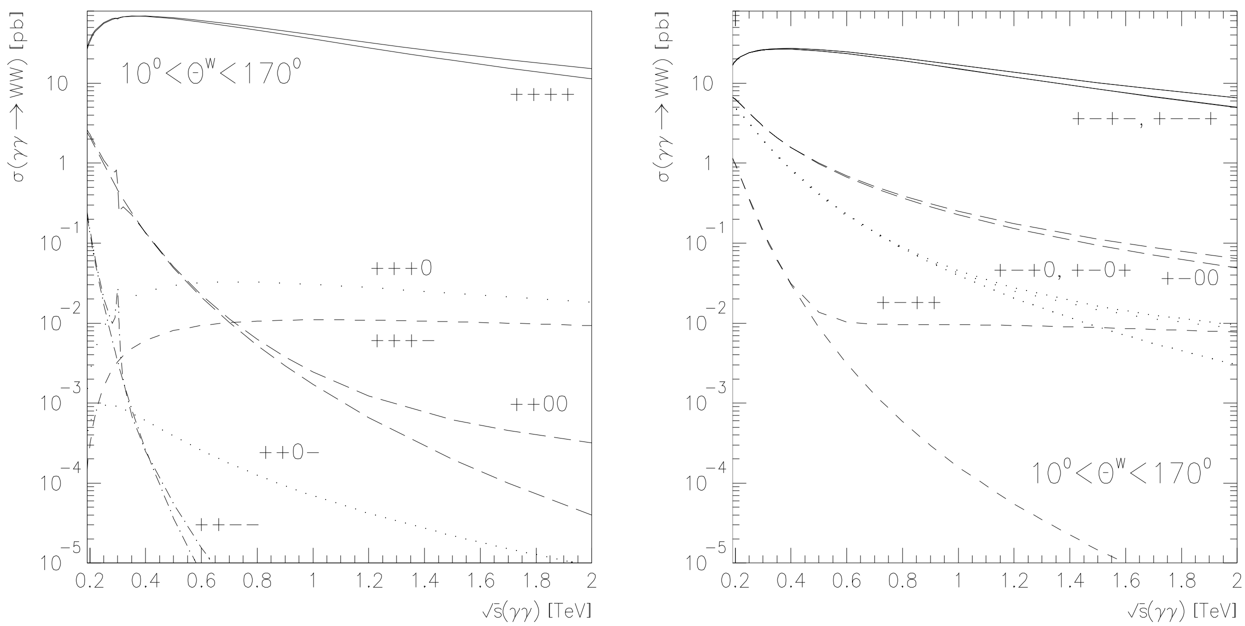
$2.5 < Q_i^2 < 200$

$\Rightarrow \mathcal{O}(6000)$ events/y

Some γγ and eγ cross sections



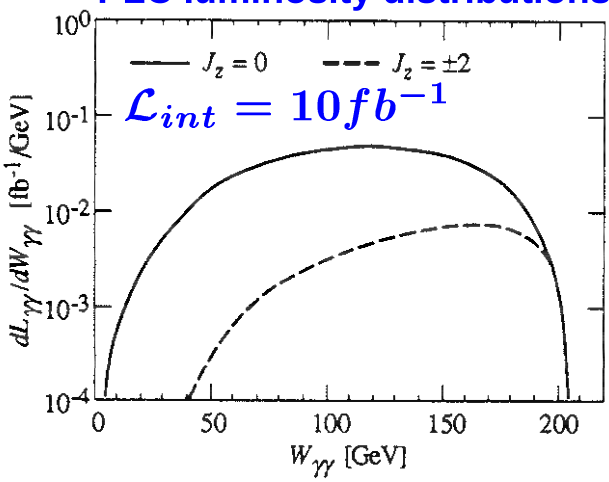
W - pair production in $\gamma\gamma$

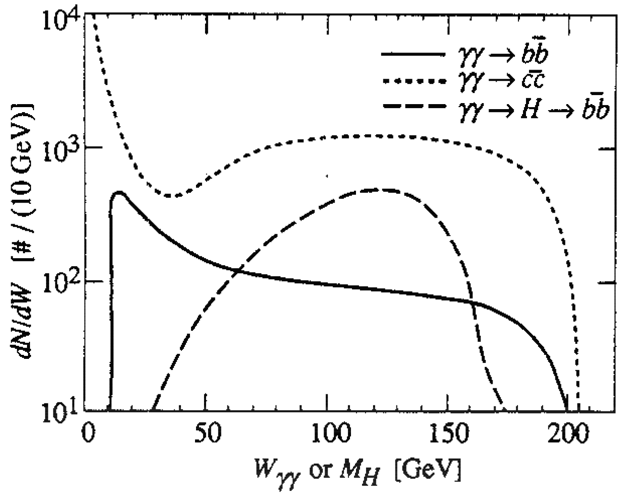


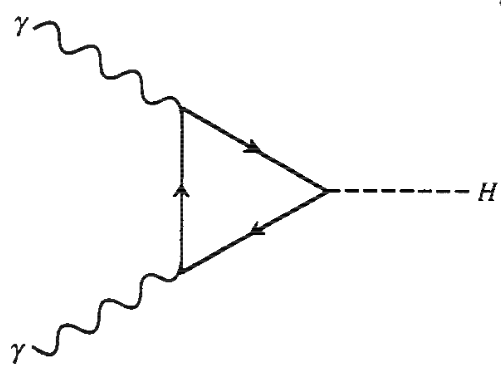
- **Cross sections for WW and WWγ final states, Born + $\mathcal{O}(\alpha)$ corrections.**
- **$\sigma_{\gamma\gamma} = 61$ pb, $\sigma_{ee} = 6.6$ pb within cuts using the PLC photon energy spectrum.**
- **The radiative corrections are moderate but do strongly depend on θ^W.**
- **$\mathcal{O}(10^6)$ $\mathrm{W^+W^-}$ pairs per year are produced. A sample well suited to study the anomalous couplings of the W.**

Higgs search in $\gamma\gamma \to H \to \mathrm{b\bar{b}}$

PLC luminosity distributions **event rates**



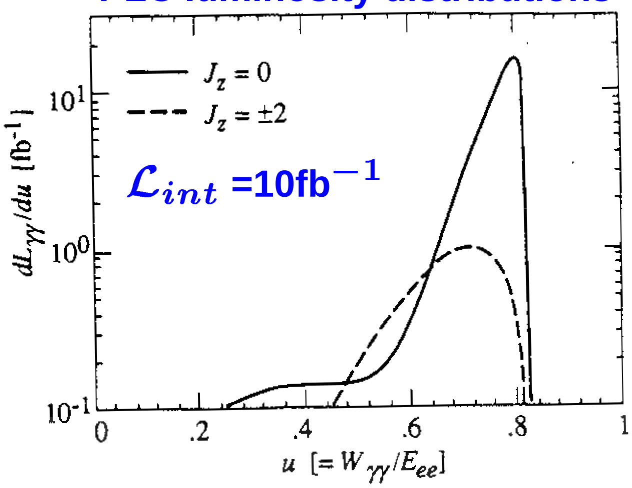




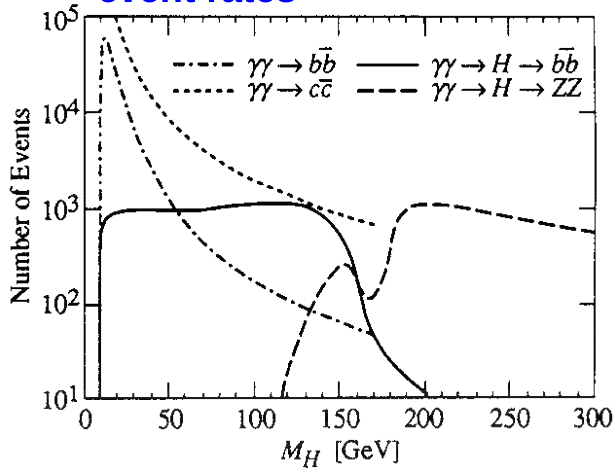
1. **The Higgs is produced as an s-channel resonance.**
2. **To suppress the continuum production of $\mathrm{b\bar{b}}$ and $\mathrm{c\bar{c}}$ one needs to select $J_z = 0$, good b tagging ($\epsilon_b > 90\%$) and c suppression ($\epsilon_{c\to b} < 5\%$).**
3. **With a mass resolution of 10% M_H (FWHM) a signal with larger than 10 σ significance can be established in the range $80 < M_H < 140$ GeV for $\mathcal{L}_{int} = 10 fb^{-1}$.**

Determination of $\Gamma(H \to \gamma\gamma)$

PLC luminosity distributions

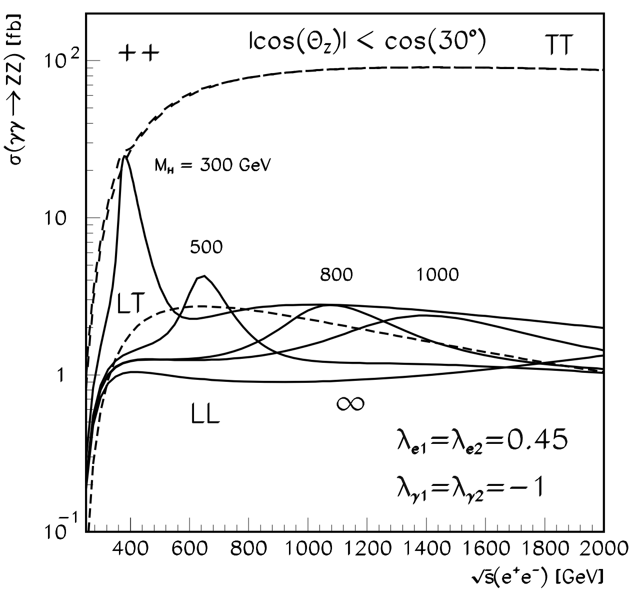


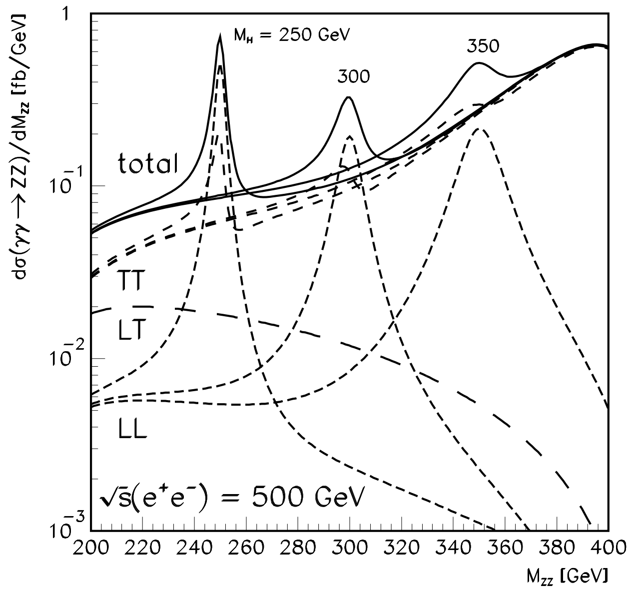
event rates



1. A measurement of $\Gamma(H \to \gamma\gamma)$ is very fundamental as it is sensitive to all new particles in the loop which couple to the Higgs.
2. The expected event rates are calculated for $|\cos\theta| < 0.7$ and a resolution of $\sigma_{M_H} = 0.1 M_H$.
3. $\Gamma(H \to \gamma\gamma)$ can be determined with an $\mathcal{O}$(10%) error for $\mathcal{L}_{int} = 10 fb^{-1}$.

ZZ final states





- The cross sections are based on the PLC photon energy spectrum.
- The cross section strongly depend on the helicities of the Z bosons.
- Higgs signals up to $M_H = 350$ GeV can be observed, for higher masses the background from the continuum $Z_T Z_T$ production is too high.

Conclusions

1. The LC is an unique tool to investigate two photon physics at the highest energies.
2. Due to the high centre-of-mass energy, especially in the PLC mode new channels (Higgs, W, Z, LQ,...) are open to be copiously produced in the two photon mode.
3. The tagging of electrons down to the lowest possible angles is a challenging task, but it is mandatory in order to achieve overlap with the two photon physics results from LEP II in several areas, i.e structure function measurements.
4. In all physics channels a careful determination of the $\gamma\gamma$, $e\gamma$ and e^+e^- luminosity distribution is essential.

Lots of work is in front of us to bring a LC to life, but it should be fun and the physics potential is certainly worth the effort.

slides:

http://wwwinfo.cern.ch/~nisius/