Two photon collisions: physics at CEPC energies

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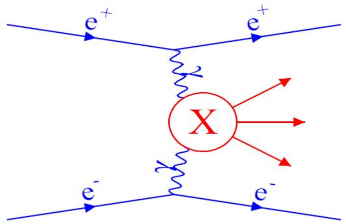
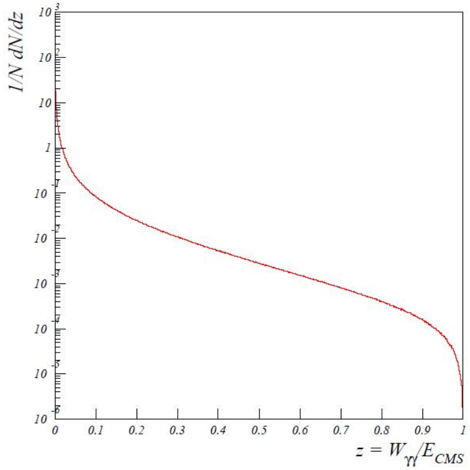
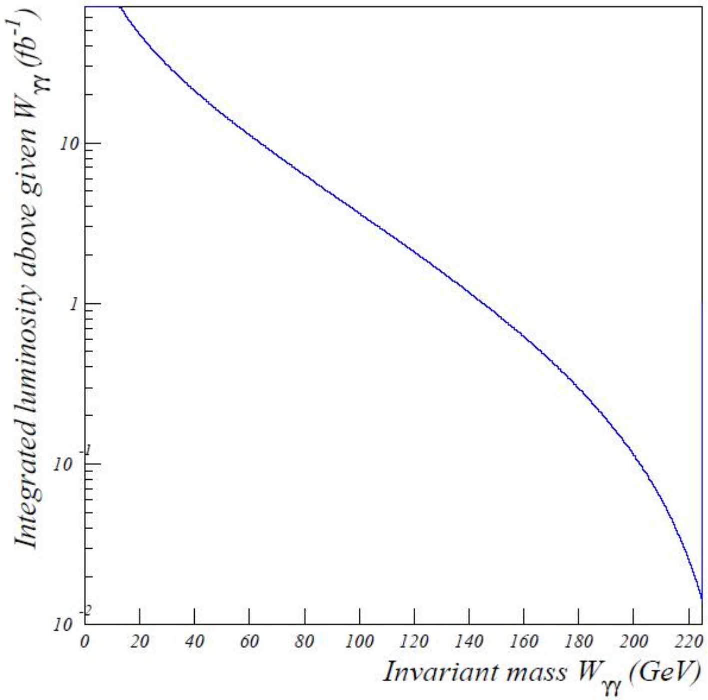
Every ee collider is at the same time a gamma-gamma collider!







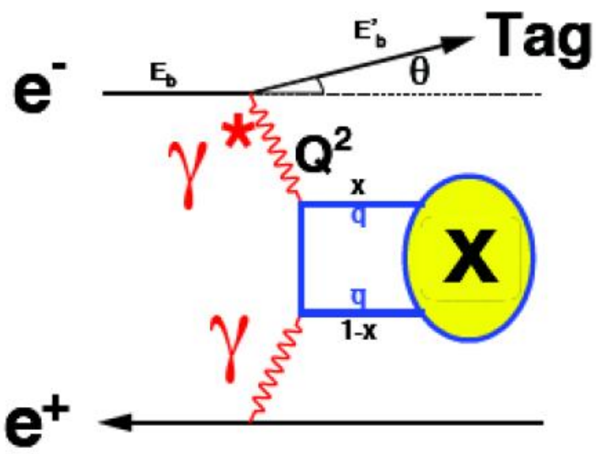
$$\sigma(e^+e^- \rightarrow e^+e^-X) \sim \alpha^4 \log^2(E)/m_e$$

to be compared with annihilation:

$$\sigma(e^+e^- \rightarrow X) \sim \alpha^2/E^2$$

- CEPC will provide several fb^{-1} at $\gamma\gamma$ collision energy >100GeV
- It is our duty to produce good physics from this "free" statistics

Kinematics



Photon virtuality:

$Q^2 = 4E_B E'_B \sin^2(\theta/2)$

Gamma-gamma mass:

$W = M(\gamma\gamma)$

Bjorken x:

$x = Q^2/(Q^2+W^2)$

- Untagged events: collisions of quasi-real photons (low Q^2)
- Single-tag events: collision of a quasi-real photon with a highly virtual one. One beam particle detected in the calorimeter
- Double-tag: 2 high-virtuality photons, both beam particles detected, event kinematics fully reconstructed

How to select $\gamma\gamma$ events

- Good P_T balance
- Quite strong imbalance in P_Z
  - Tracks tend to be in the forward region
- Small visible invariant mass
  - Well separated from the radiative return to Z
- Single-tag (and especially double-tag) simplify selection a lot

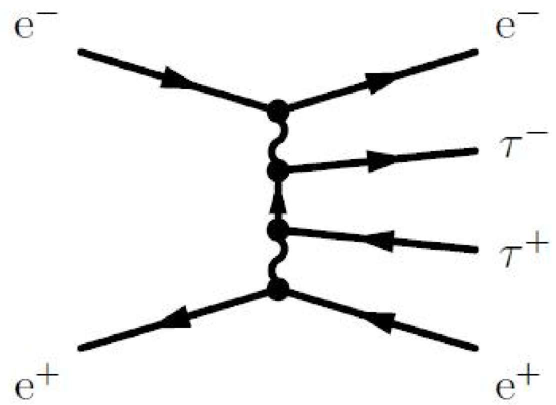
What can we study at CEPC?

- Higgs production!
- QED test: anomalous magnetic moment from $\gamma\gamma \longrightarrow \tau\tau$
- Spectroscopy of heavy quarkonia
- Photon structure function

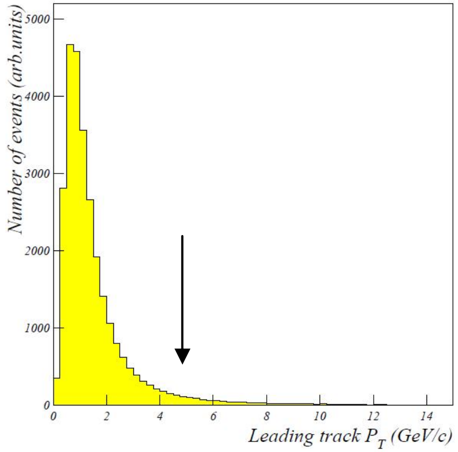
Anomalous magnetic moment of the tau lepton

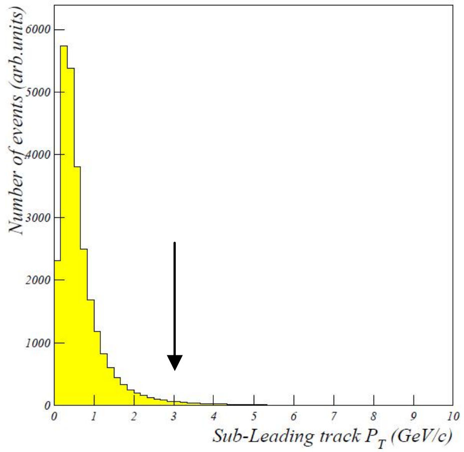
- Anomalous magnetic moments of electron and muon (a_e and a_μ) are known with astonishing precision of 10^{-12} and 10^{-9}
- a_τ is known only at 10^{-2} level (LEP2)
- Sensitivity to the new physics growth typically as M^2

- At LEP the magnetic moment of tau lepton has been measured via the cross-section of untagged events **$ee \rightarrow ee\tau\tau$**



$\gamma\gamma\to\tau\tau\to e\mu$ events at 240 GeV

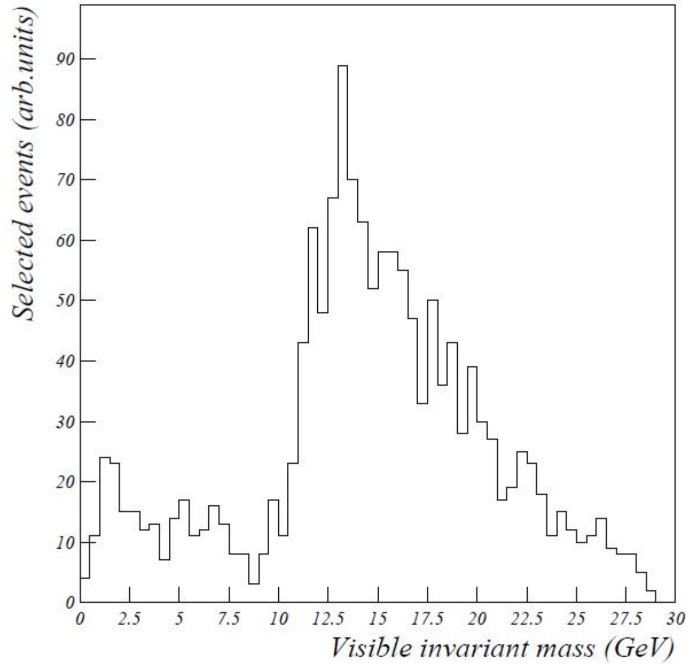




- 570 pb will provide 3B events with 5 ab^{-1}, or 165M events in $e\mu$ final state
- We assume extremely severe kinematic cuts: P_T above 5 GeV/c for the leading track, and 3 GeV/c for the second track
- Tracks with $\theta>20^{\circ}$, total energy E<30 GeV to remove annihilation events

Estimation of sensitivity

- Selection efficiency: 0.42% (at LEP: 15-20%).
- Number of events at CEPC: 700K
- Statistical error at permille level.
- Systematics:
  - tracking 0.15% per track;
  - PID 0.15% per track;
  - luminosity: 0.1%;
  - trigger efficiency: 0.1%
- Total systematics: 0.5%

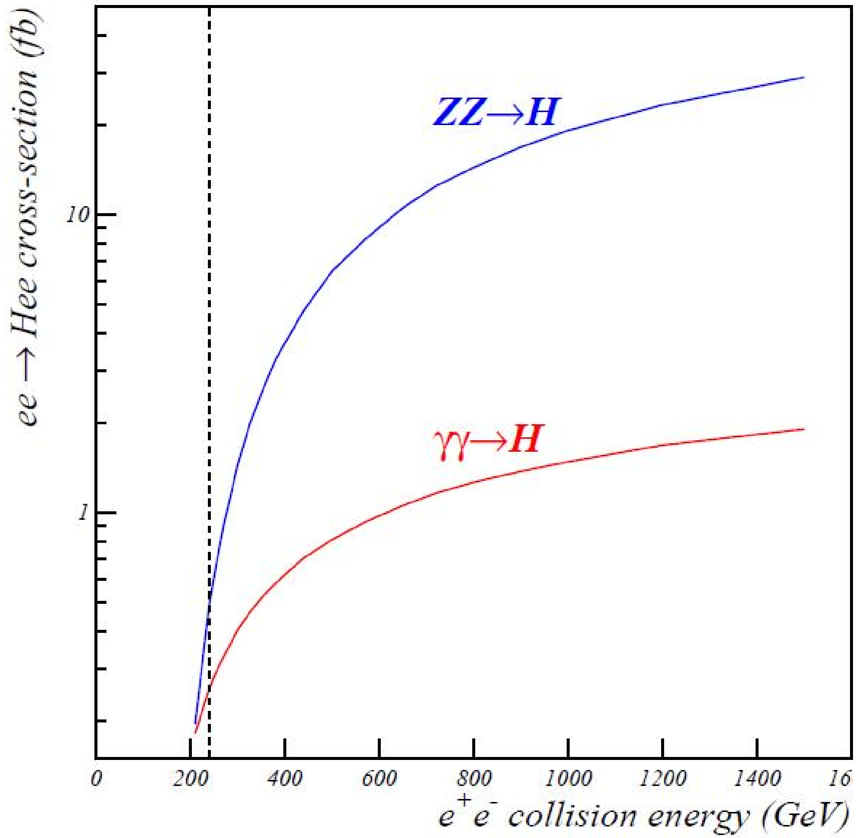


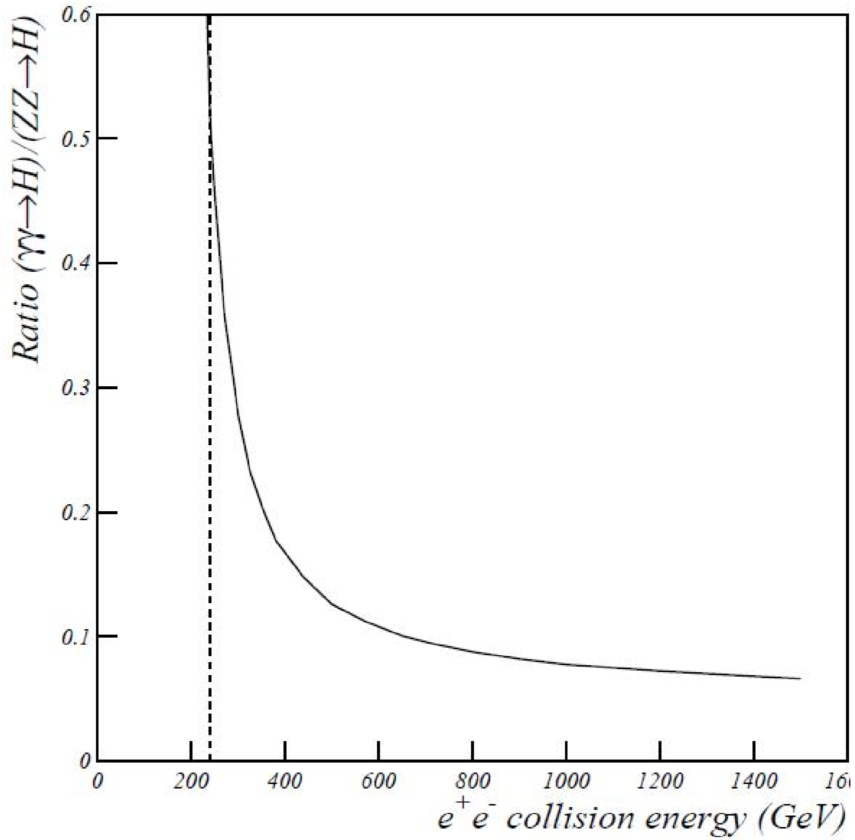
DELPHI measurement: ± 4%
CEPC will improve tau magnetic moment by order of magnitude
Systematics-dominated after just 1/10 of the total luminosity

Higgs photoproduction

- Never has been observed
- $H\gamma\gamma$ vertex forbidden in SM at tree level
- We know for sure that $\gamma\gamma \rightarrow H$ does occur, because $H \rightarrow \gamma\gamma$ decay was observed
- Predicted cross-section 0.26fb @240 GeV
  - O(1000) events expected at CEPC
- Background:
  - $ZZ \rightarrow H$: 0.50fb
  - $\gamma\gamma \rightarrow$ bb: 1000 fb (background for channel $H \rightarrow$ bb)
  - $\gamma\gamma \rightarrow$ cc: 240000 fb (wrong tagging c as b)

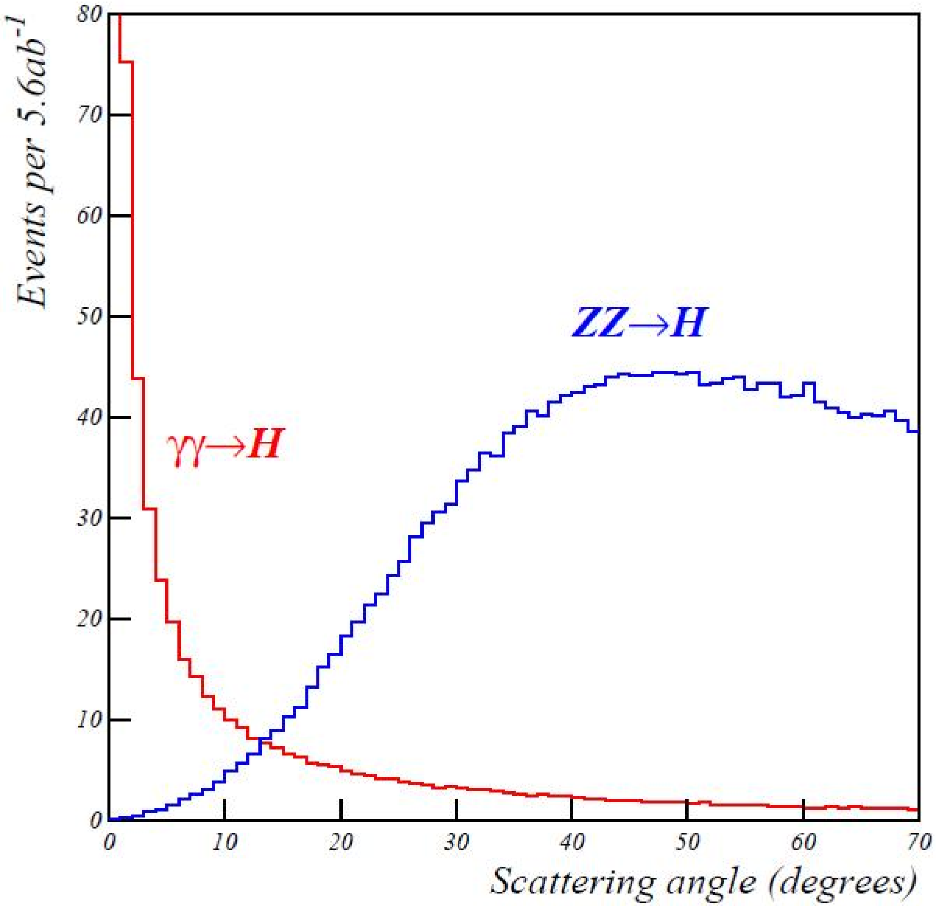
ZZ fusion background





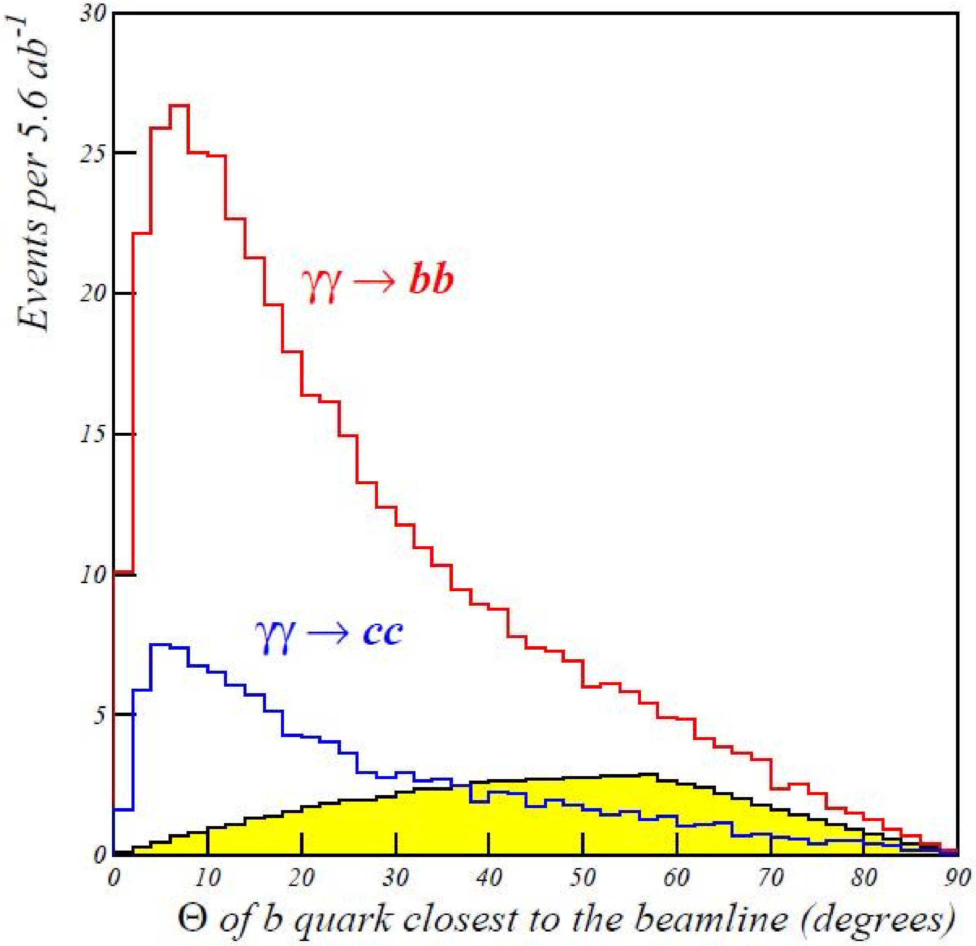
CEPC is the ideal place to study $\gamma\gamma \to H$!!

Electron scattering angle



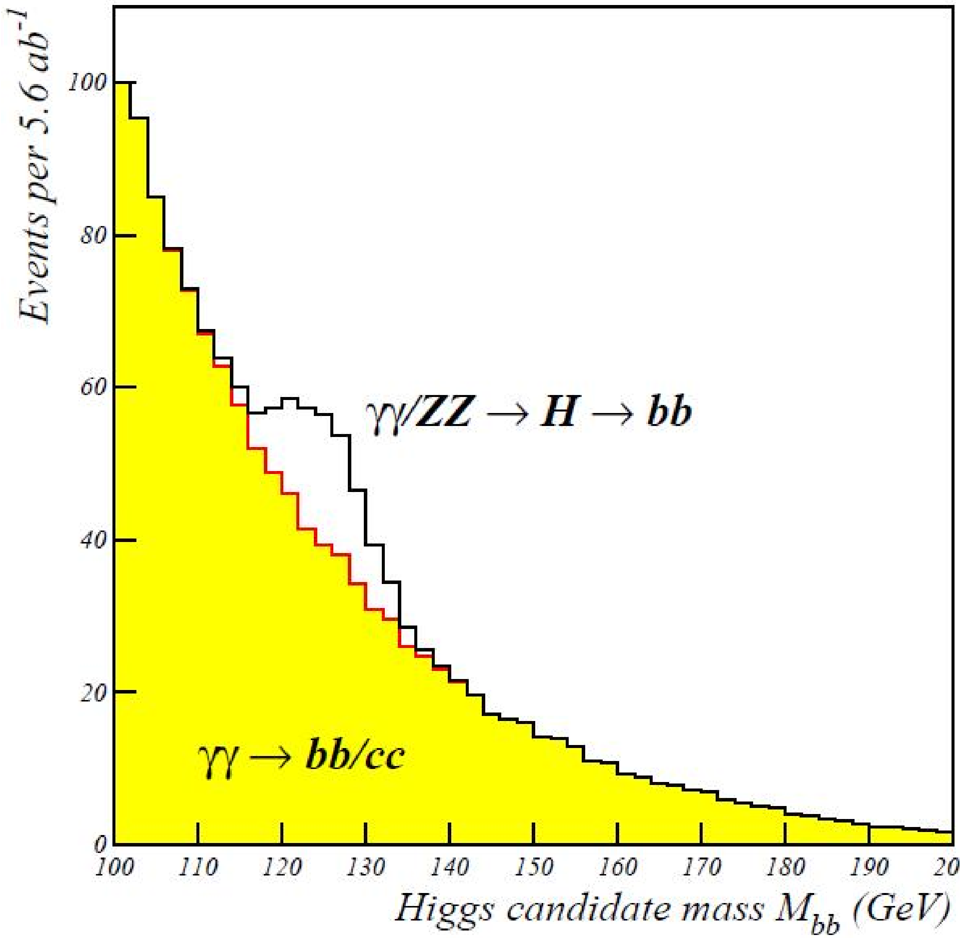
- Single tag (Θ>30mrad) reduces signal by ~5 and γγ→ bb by ~15
- For ZZ→H electrons are scattered at a very large angle in nearly all events
- We cut 30mrad<Θ<24º
- The lower cut is dictated by the lumical acceptance; upper is from S/√B optimization

Detector acceptance



- Cut on jet angle Θ>20º reduces qq background by factor of 2, almost “for free”, since efficiency in Very Forward will be low anyway
- We assume that cc background is reduced by factor of 100 with 64% signal efficiency (CDR numbers)
- Within the acceptance (Θ_{jet}>20º) we assume 75% efficiency to reconstruct both jets

The Higgs signal



- Assuming 5 GeV mass resolution (CDR), we expect for 118<Mbb<132:
  - Signal: 57 events
  - ZZ→H : 33 events
  - γγ→ bb : 223 events
  - γγ→ cc: 55 events
- Signal significance: 4.1σ from H→bb alone
- Including other Higgs decay channels, the signal will be reliably observed (even 5σ discovery possible)

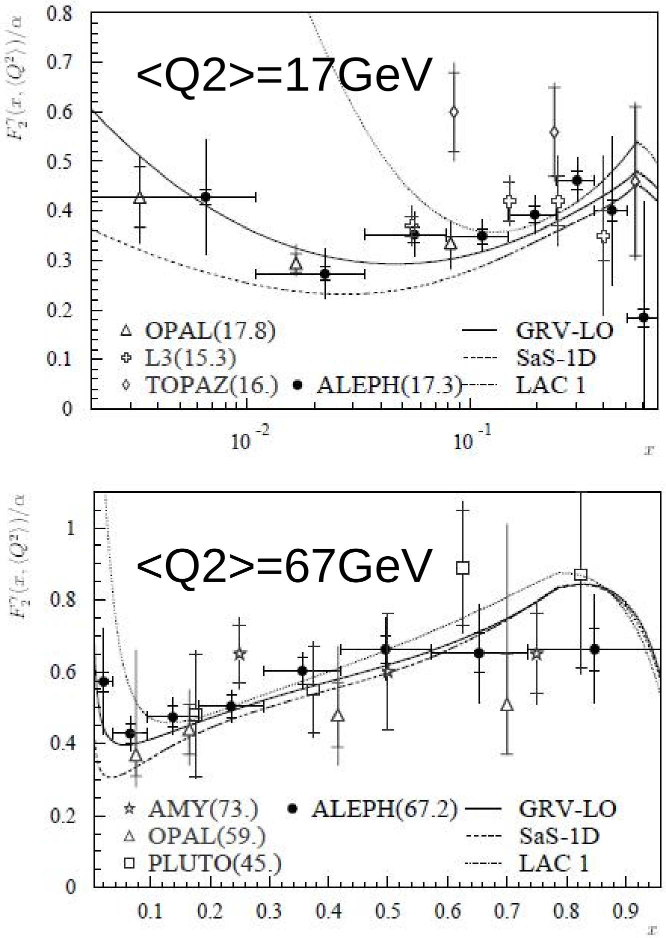
Photon structure function $F_2^\gamma(x, Q^2)$

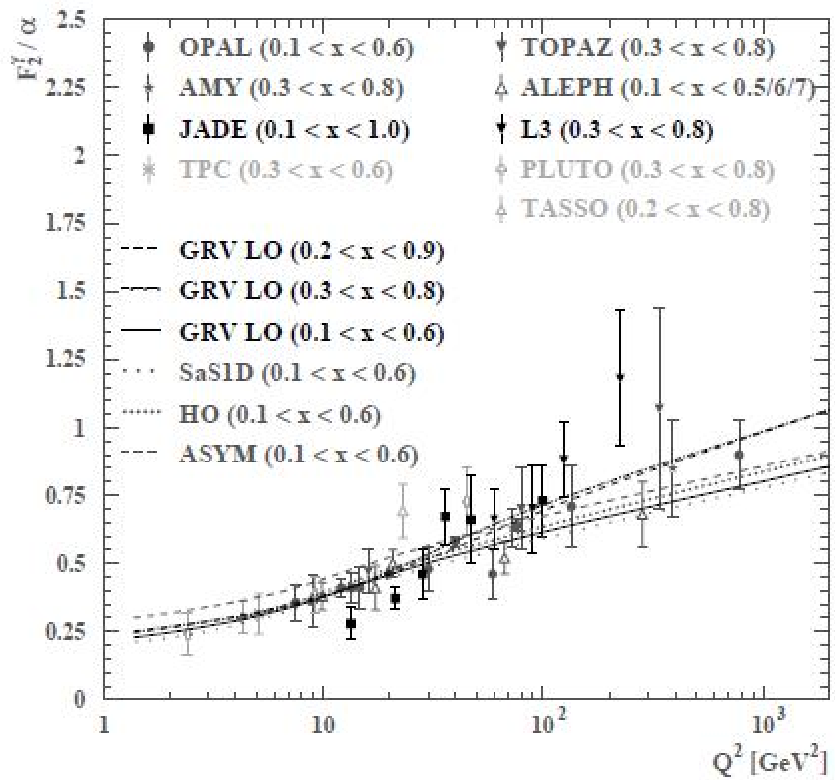
- Hadronic structure function in single-tag
- Can be extracted from $d^3\sigma/dQ^2dxdy$

$$Q^2 = 2E_{beam}E_{tag}(1 - \cos\theta_{tag}),\ x = Q^2/(Q^2 + W^2)$$

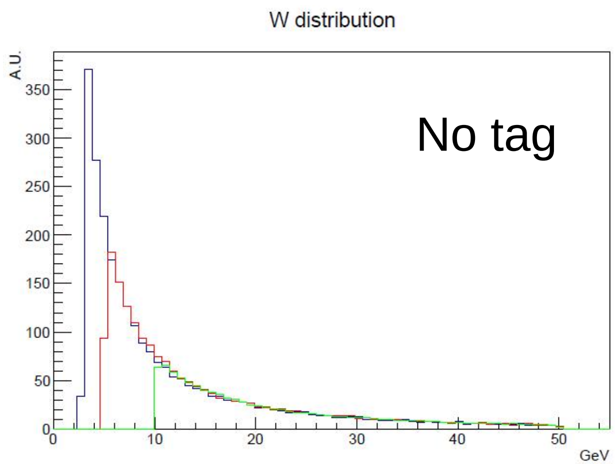
- Most difficult part is the reconstruction of the hadronic invariant mass W
- Required complicated unfolding procedure, detailed understanding of the detector

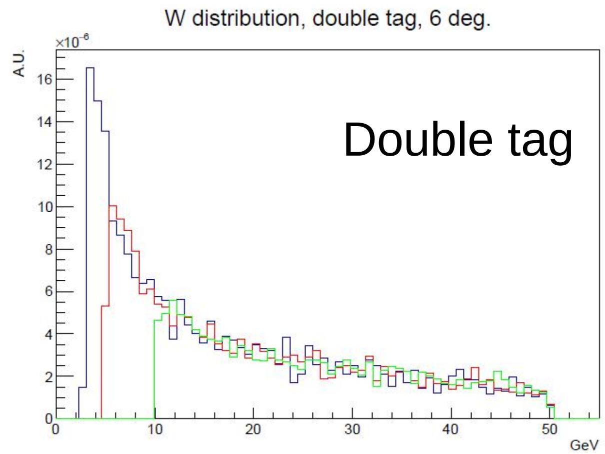
Structure function at LEP

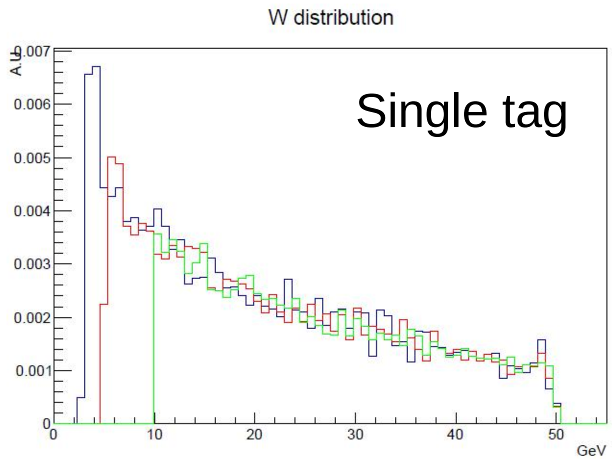




Statistics estimation with Galuga

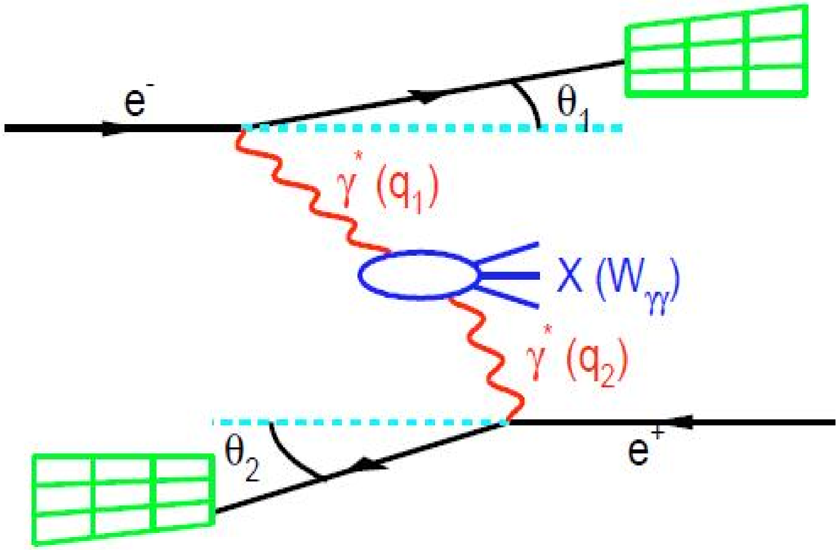


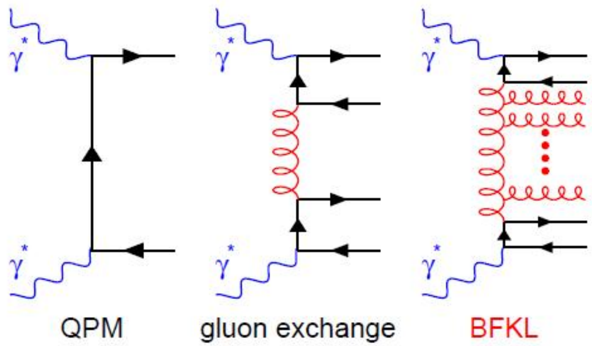




- W > 3 / 5 / 10 GeV:
- No tag: 70B/50B/25B events
- Single tag: 4M/3.5M/3M
- Double tag: 6K/5K/3.5K events
- Note: tags assuming $\theta>6^o$
- Much, much more double tags within luminosity monitor

Double-tag $\gamma^*\gamma^*$ collisions





- Kinematics is fully defined by the tagged electrons
- No need of sophisticated unfolding procedure
- Statistics! Must tag electrons as close as possible to the beam line

Double-tag from L3

- BFKL prediction:

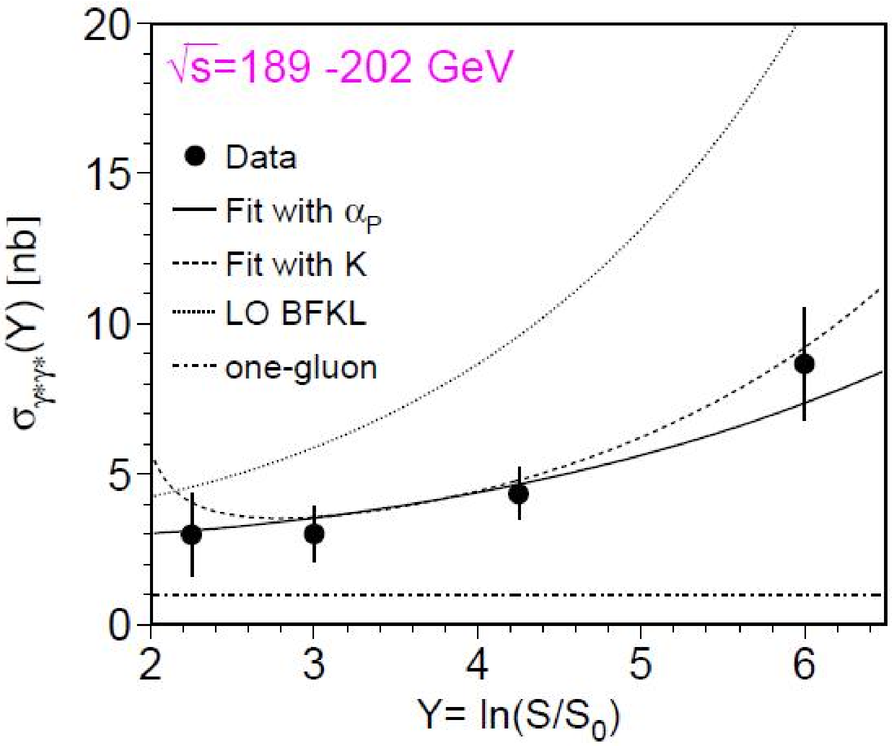
$$\sigma_{\gamma^*\gamma^*} = \frac{\sigma_0}{Q_1 Q_2 Y}\left(\frac{s}{s_0}\right)^{\alpha_P - 1}$$

$$s_0 = \frac{K Q_1 Q_2}{y_1 y_2} \quad , \quad Y = \ln(s/s_0)$$

$$y_i = 1 - (E_i/E_b)\cos^2(\theta_i/2)$$

- “Hard pomeron intercept”

$$(\alpha_P - 1) = (4\ln 2) N_c \alpha_s / \pi$$



- LO BFKL: $\alpha_P \sim 0.53$
- NLO BFKL: $\alpha_P \sim 0.17$

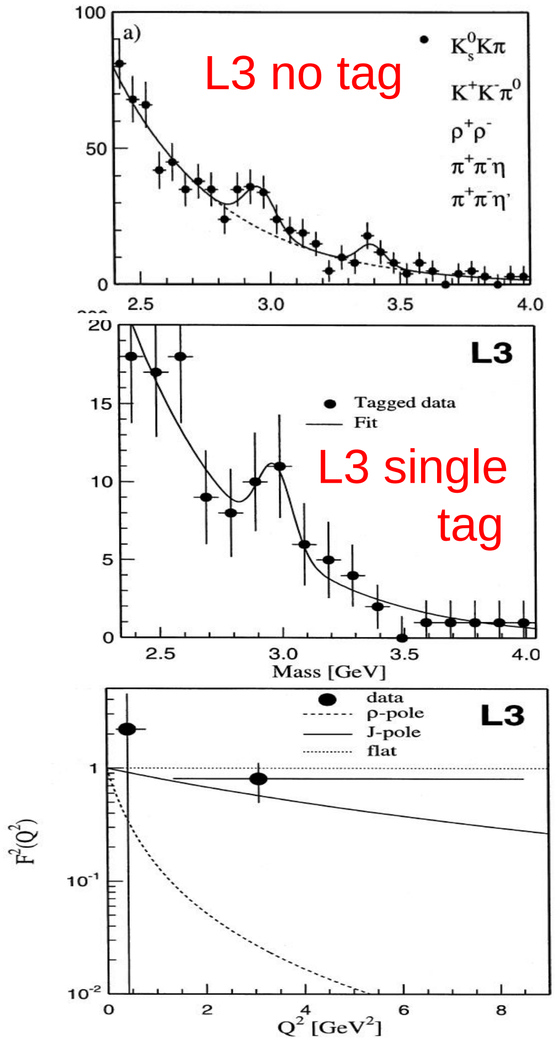
- L3 result (30<θ<66mrad)
- $\alpha_P = 0.36 \pm 0.02$

Charmonium substructure

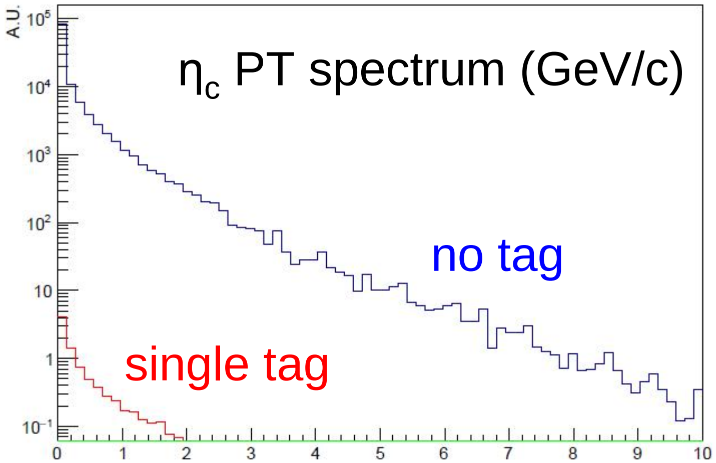
- Exclusive charmonium production in single-tag events can be used to measure the transition form-factor
- $\sigma(\gamma\gamma \rightarrow R) \sim \Gamma_{\gamma\gamma} F^2(Q^2) BW(W)$
- In VDM:

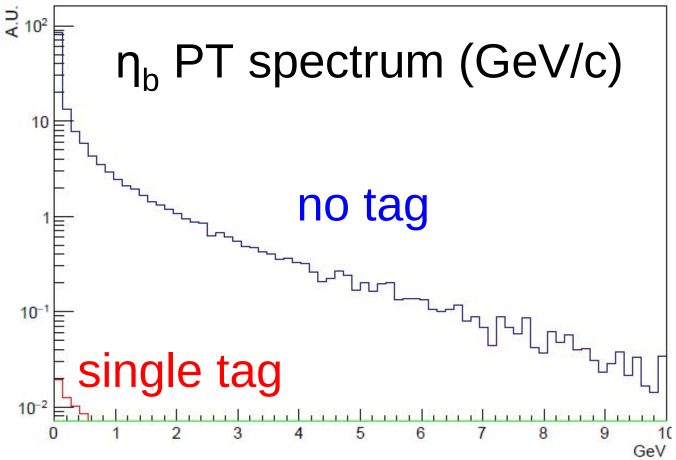
$$F(Q^2) = \frac{1}{1 + Q^2/\Lambda^2},$$

$$\text{with} \quad \Lambda^2 = M_V^2, \quad V = \rho, \omega, \phi, \text{J} \ldots$$



Quarkonium statistics from Galuga





- Expected event number for no tag/single tag/double tag:
- η_c : 1G / 85K / 90
- η_b : 1.2M / 1K / 15
- Note: tags assuming $\theta > 6^o$
- Enormous number of no-tag events, but very difficult to select
- Single tag: nice statistics of η_c and η_b

Summary

- The abundant gamma-gamma collisions will be not only background, but a rich source of physics studies
  - QED tests
  - Perturbative QCD
  - Non-perturbative QCD
  - Hadron structure
- Many studies have been done at LEP, mostly statistically dominated
- Enormous CEPC luminosity will improve our knowledge by a huge factor
- It is vital to have the luminosity tagger as close as possible to the beam line