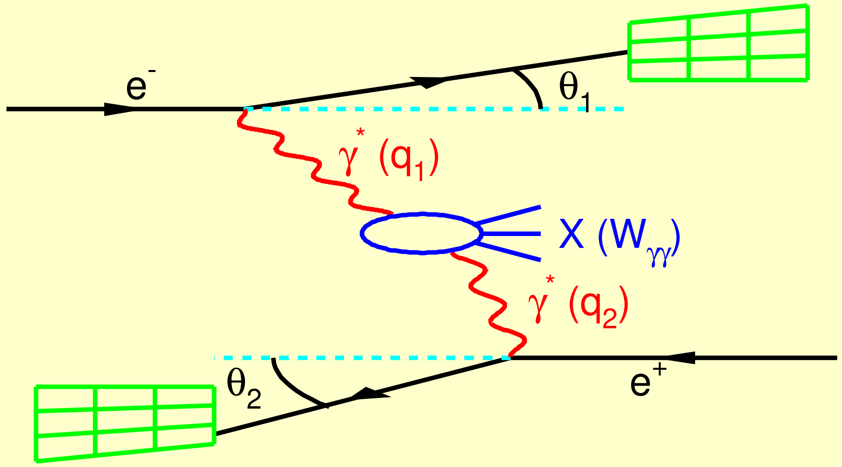
Measurement of $\gamma^*\gamma^*$ collisions at LEP

Chih-Hsun LIN

National Central Univ., TAIWAN

XXXVth Rencontres De Moriond

Two-photon Physics

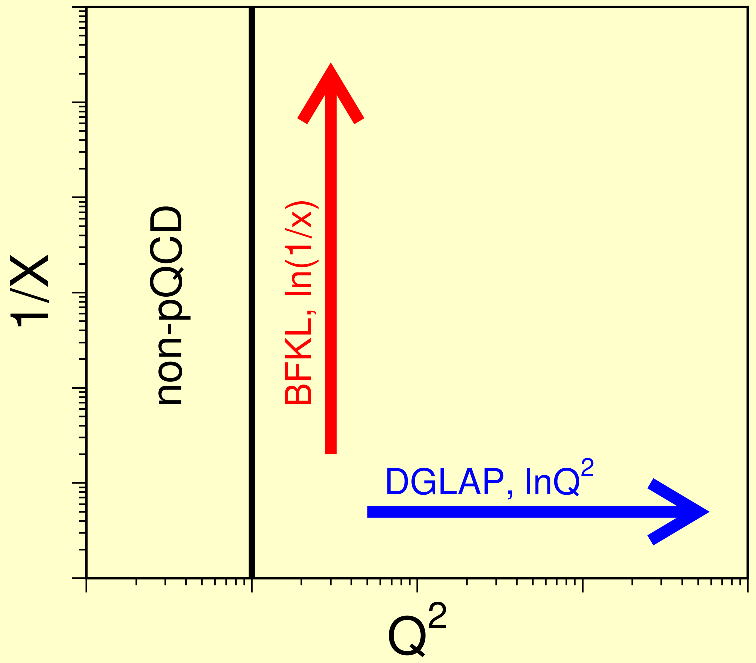


$$Q_i^2 = -q_i^2 = 2E_b E_{tag}^i (1 - \cos\theta_i)$$

$$W_{\gamma\gamma} = \sqrt{(q_1 + q_2)^2}$$

- Both scattered electrons are seen in the detector.
  ➜ $\gamma^*\gamma^*$ collisions (double-tag)
- $W_{\gamma\gamma}$ can be measured directly.
- Include QED (QPM), non-pQCD (VDM) and pQCD processes.

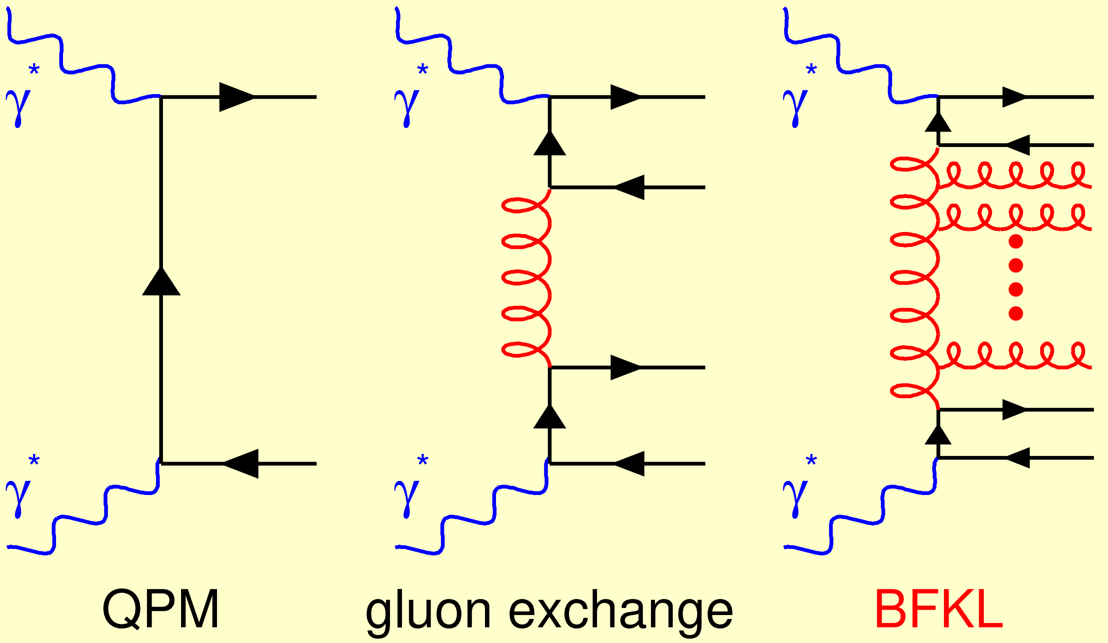
QCD scheme



- DGLAP evolution scheme :
  - ➜ $\sigma \propto \ln Q^2$
  - ➜ Strong ordering in Q^2
  - ➜ A good description to the structure function

- BFKL evolution scheme :
  - ➜ At fix Q^2, small $x = Q^2/s$
  - ➜ $\sigma \propto s^{0.53}$ (Regge like)
  - ➜ No ordering in Q^2

BFKL



- With $Q_1^2 \sim Q_2^2$, DGLAP ⇨ one-gluon exchange
- Non-Perturbative part (VDM) is vanished with large Q^2.
- QED (QPM) process is well known.

➜ Good test to BFKL

LO BFKL

❒ In LO approximation (asymptotic formula):

*Brodsky, Hautmann and Soper, PRD 56 6957

*Bartel, Roeck and Lotter, PLB 389 742

$$\sigma_{\gamma^*\gamma^*} = \frac{\sigma_0}{Q^2 * Y}\left(\frac{s}{s_0}\right)^{\alpha_P - 1} \simeq \frac{\sigma_0}{Q^2 * Y}\left(\frac{W^2_{\gamma^*\gamma^*}}{Q^2}\right)^{\alpha_P - 1}$$

$$\alpha_P - 1 = 4\ln 2\frac{N_c\alpha_s}{\pi} \quad , \quad Y = \ln(s/s_0)$$

$$s_0 = Q^2/y^2 \quad , \qquad y = 1 - (E_{tag}/E_b)\cos^2(\theta_{tag}/2)$$

❒ Using $N_c = 3$, $\alpha_s = 0.2$ $(\Lambda_{\mathrm{LO}} = 0.16\ \mathrm{GeV}, Q^2 = 15\ \mathrm{GeV}^2)$

➜ $\alpha_P - 1 \simeq 0.53 > 0.079$

NLO BFKL

- NLO corrections to $\alpha_P - 1$:
  - ➜ NLO corrections are negative.
  - ➜ $\alpha_P^{NLO} - 1 < 0$ when $\alpha_S > 0.16$.
- Improve resummation :
  - ➜ NLO BFKL + BLM optimal scale
    (Brodsky, Fadin, Kim, Lipatov and Pivovarov, hep-ph/9901229)
  - ➜ Color dipole BFKL
    (Nikolaev, Speth and Zoller, hep-ph/0001120)
  - ➜ Double logs resummations
    (Ciafaloni, Colferai and Salam, PRD 60, 114036)

Data: $e^+e^- \rightarrow e^+e^-$ *hadrons*

❒ L3 : measured at 91 GeV ($\mathcal{L} = 140\ pb^{-1}$), 183 GeV ($\mathcal{L} = 53\ pb^{-1}$) and 189 GeV - 202 GeV ($\mathcal{L} = 401\ pb^{-1}$)

➜ $E_{tag} > 30$ GeV and 30 mrad $< \theta_{tag} <$ 66 mrad

➜ $2 < Y = \ln(S/S_0) < 6$ (7 at 189-202GeV)

❒ OPAL : measured at 189 GeV ($\mathcal{L} = 169\ pb^{-1}$)

➜ $E_{tag} > 65$ GeV and 34 mrad $< \theta_{tag} <$ 54 mrad

➜ $2 < Y = \ln(S/S_0) < 6$

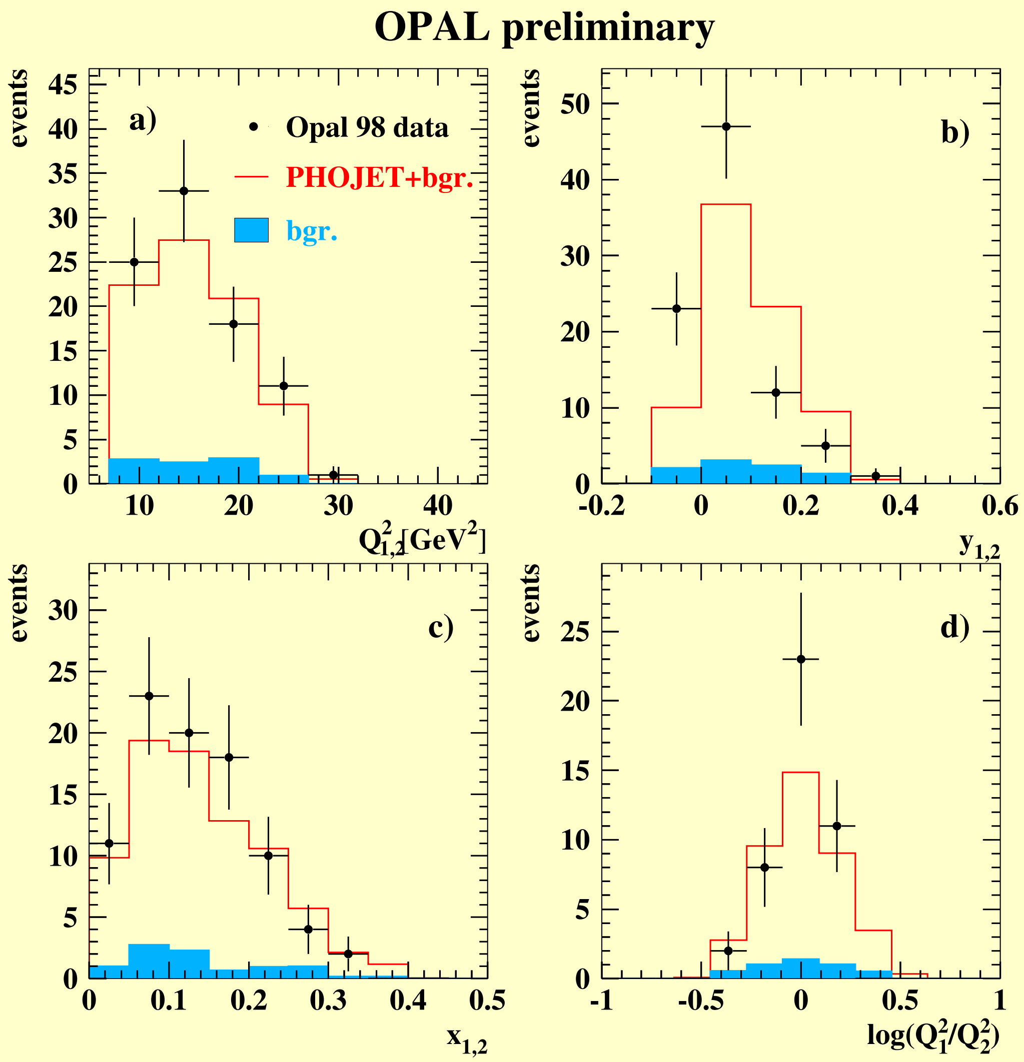
❒ Backgrounds :

➜ $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$

➜ misidentified single-tag two-photon events

➜ $e^+e^- \rightarrow q\bar{q}$

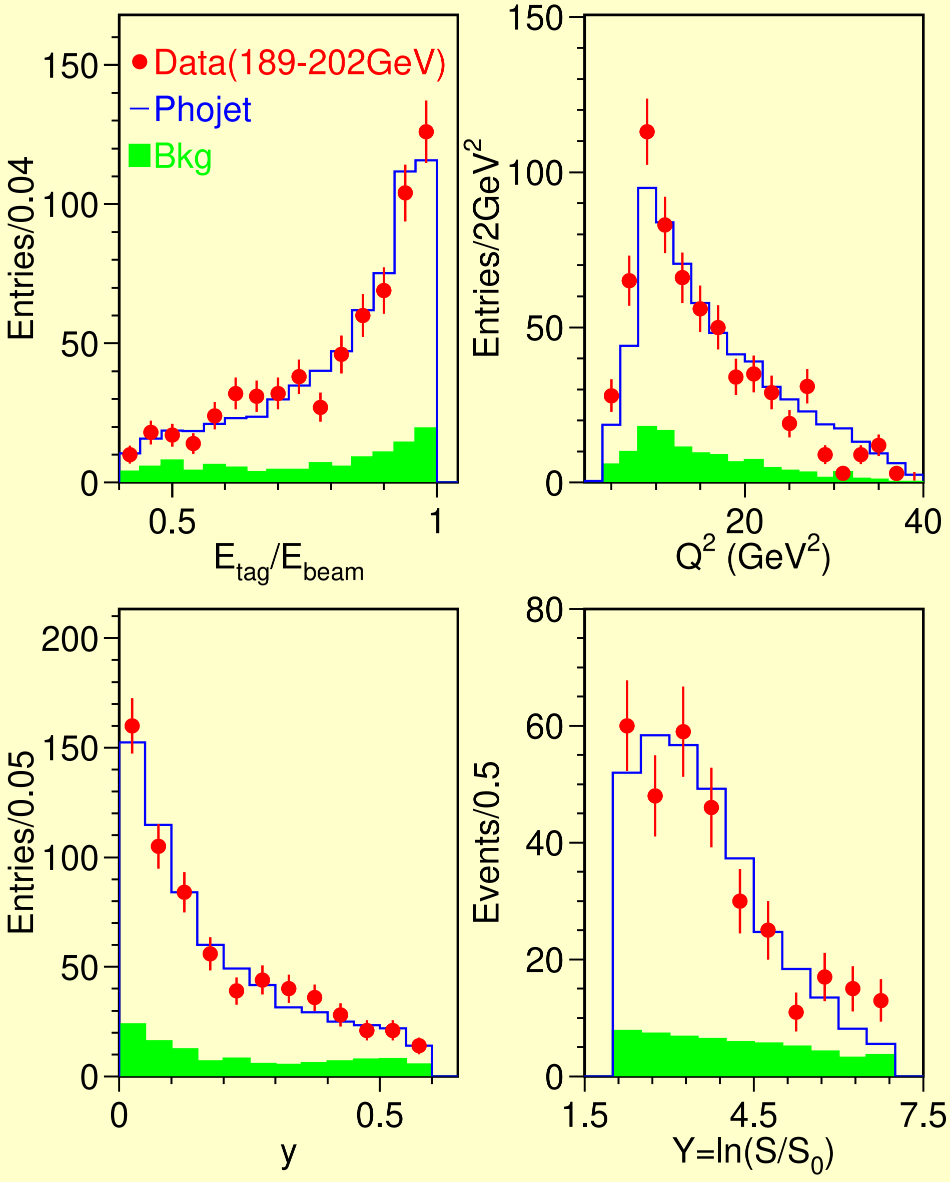
OPAL: MC/Data



➜ Reasonable agreement with PHOJET.

➜ Select 44 events at 189 GeV.

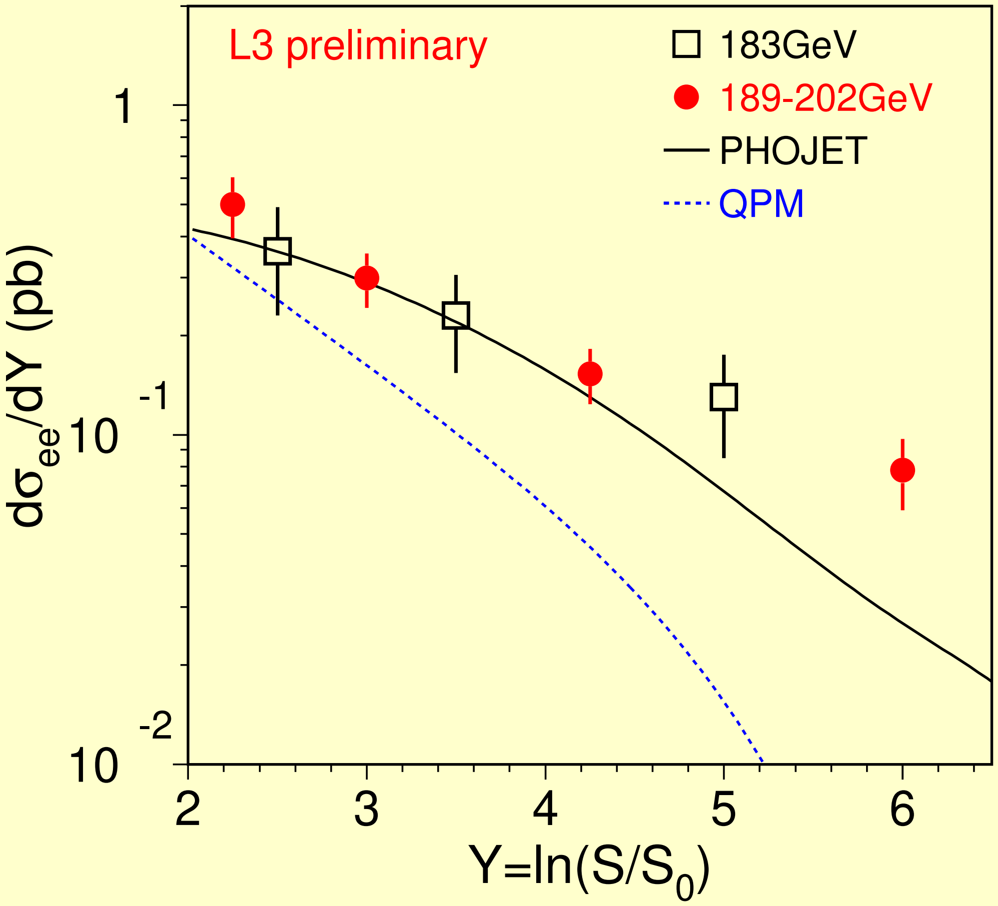
L3: MC/Data



- ❑ Reasonable agreement with PHOJET.
- ❑ Select :
  - ➜ 137 events at 91 GeV ($\langle Q^2 \rangle = 3.5$ GeV^2)
  - ➜ 34 events at 183 GeV ($\langle Q^2 \rangle = 14$ GeV^2)
  - ➜ 324 events at 189-202 GeV ($\langle Q^2 \rangle = 15$ GeV^2)

$\sigma(e^+e^- \to e^+e^- hadrons)$

$\sigma(e^+e^- \to e^+e^- hadrons)$ in defined phase space.



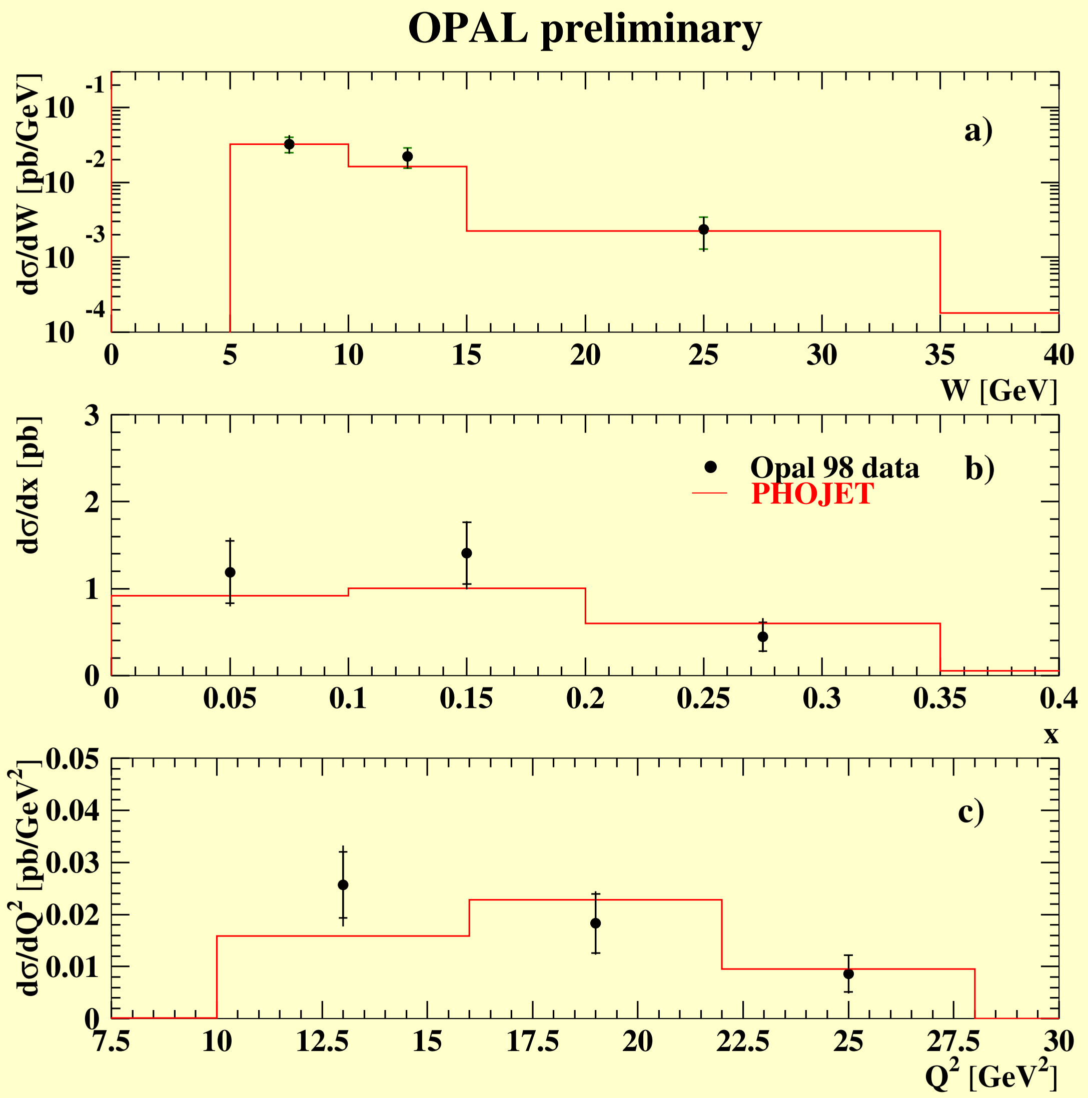
- L3 :
  - ➜ The data are consistent.
  - ➜ QPM is insufficient.

$\sigma_{ee} = 0.94 \pm 0.05 \pm 0.14$ pb $\quad (\sigma_{Phojet} = 0.75$ pb$)$

- OPAL :

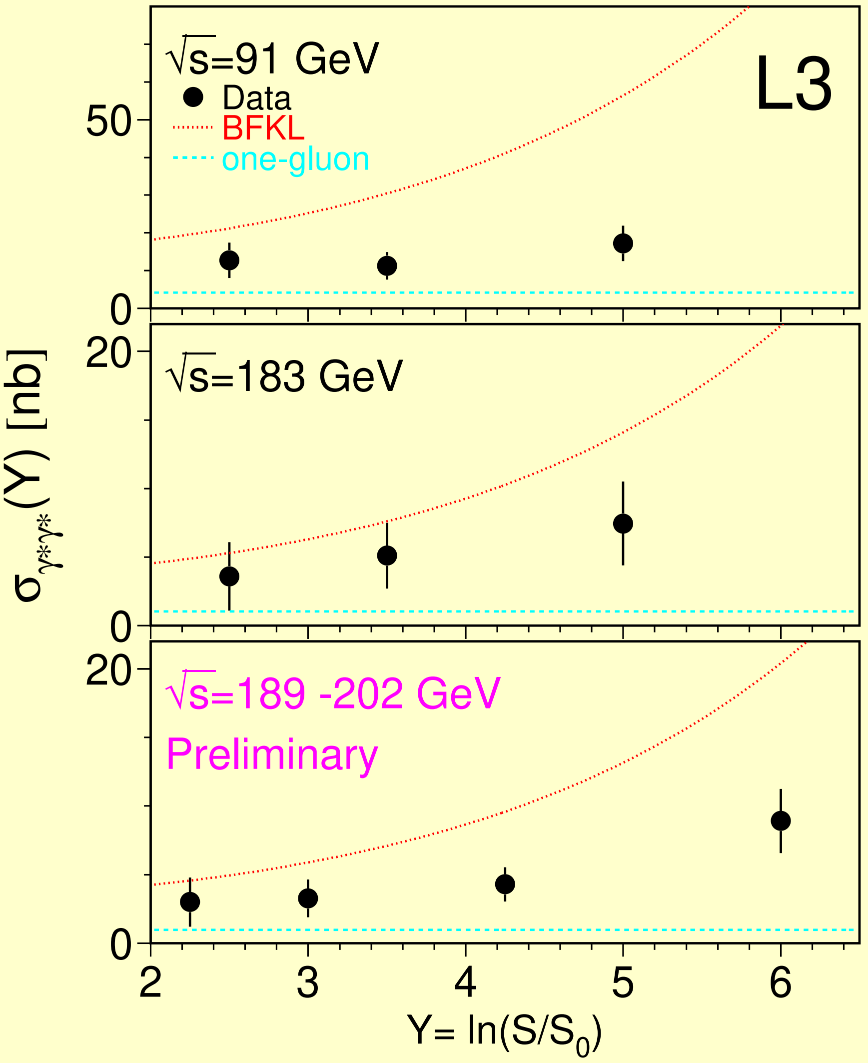
$\sigma_{ee} = 0.15 \pm 0.05^{+0.03}_{-0.02}$ pb $\quad (\sigma_{Phojet} = 0.17$ pb$)$

$\sigma(\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-}\,hadrons)$



$\gamma^*\gamma^*$ collisions

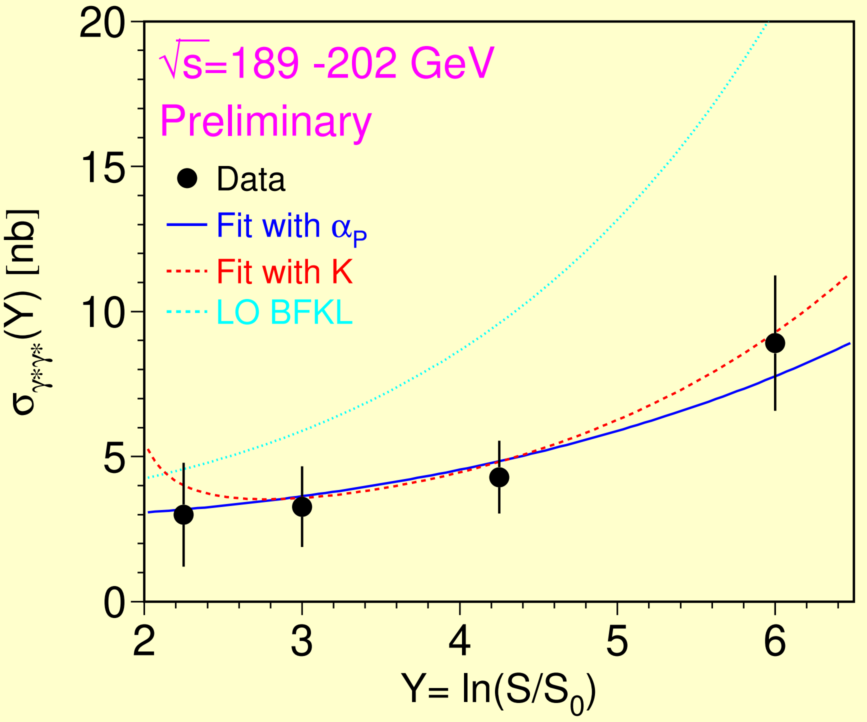
- ❑ $\sigma_{ee} = \mathcal{L}_{TT} \times \sigma_{\gamma^*\gamma^*}$
- ❑ Subtract the QPM contribution.



➜ One gluon exchange process is insufficient.

➜ LO BFKL prediction (asymtotic) is too high.

$\gamma^*\gamma^*$ collisions



❒ Fit with

$$\sigma_{\gamma^*\gamma^*} = \frac{\sigma_0}{Q^2 * \ln[s/(K \times s_0)]} \left(\frac{s}{K \times s_0} \right)^{\alpha_P - 1}$$

➜ α_P is free parameter and $K = 1$.

$\alpha_P - 1 = 0.37 \pm 0.04 < 0.53 \quad \chi^2/dof = 0.51/3$

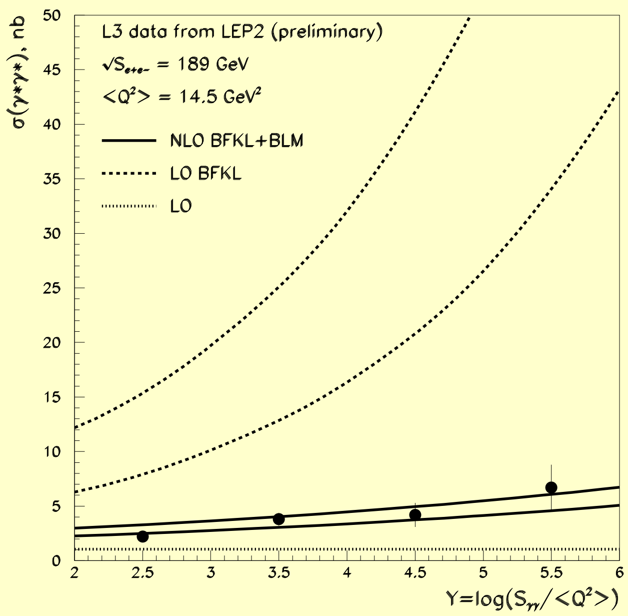
$\alpha_P^{NLO} - 1 = 0.29 - 0.31 \quad (Q^2 = 14 \text{ GeV}^2)$

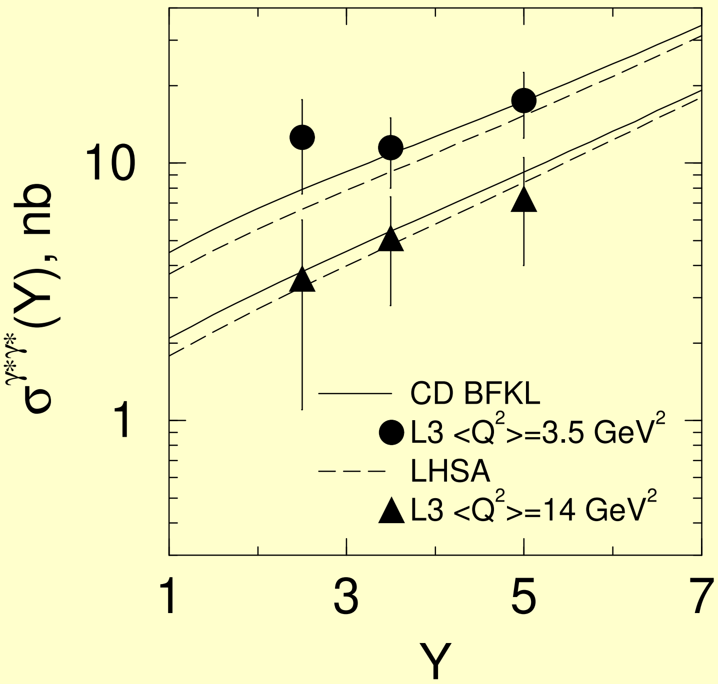
(Ciafaloni, Colferai and Salam, PRD 60, 114036)

➜ K is free parameter and $\alpha_P - 1 = 0.53$

$K = 6.2 \pm 1.7 > 1 \quad \chi^2/dof = 0.57/3$

NLO BFKL





➜ Agree with the data !

Conclusion

- $\gamma^*\gamma^*$ collisions have been measured up to $\langle Q^2\rangle = 15$ GeV^2 and $\ln(s/s_0) = 7$ at LEP.
- The LO MC model PHOJET gives a reasonable description of the data.
- LO BFKL predicts too large cross-sections.

  ➜ sensitive to the energy scale s_0.
- Improved NLO BFKL calculations agree with the data.