Double Tag events in Two-Photon Collisions at LEP

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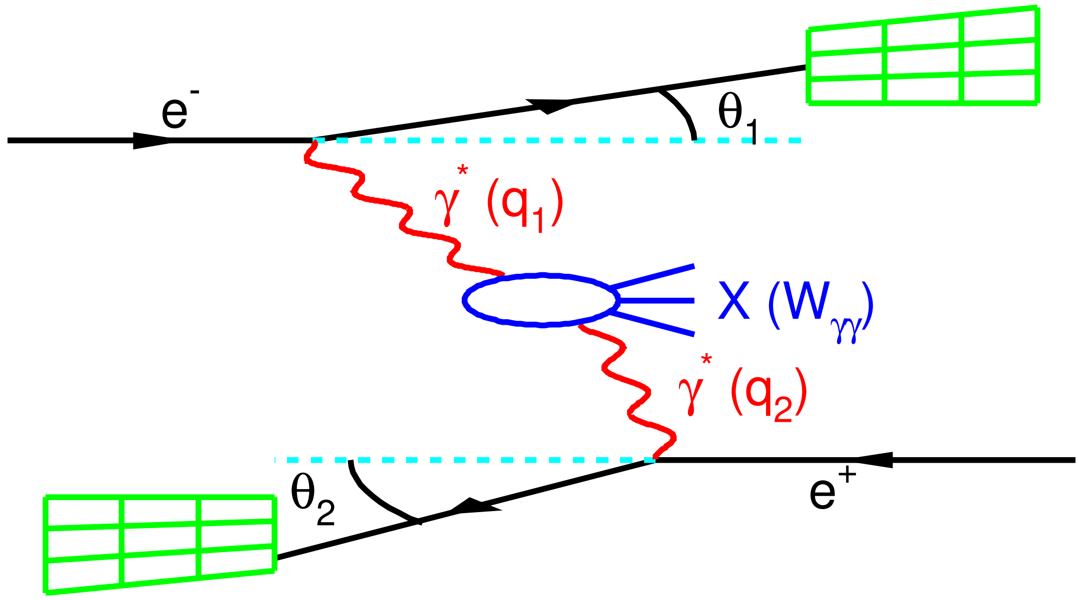
Representing
L3 Collaboration

- $\gamma^*\gamma^*$ Physics
- Motivation (BFKL Physics)
- Cross-section Measurements
- Conclusions

$e^+e^- \rightarrow e^+e^-\text{hadrons}$

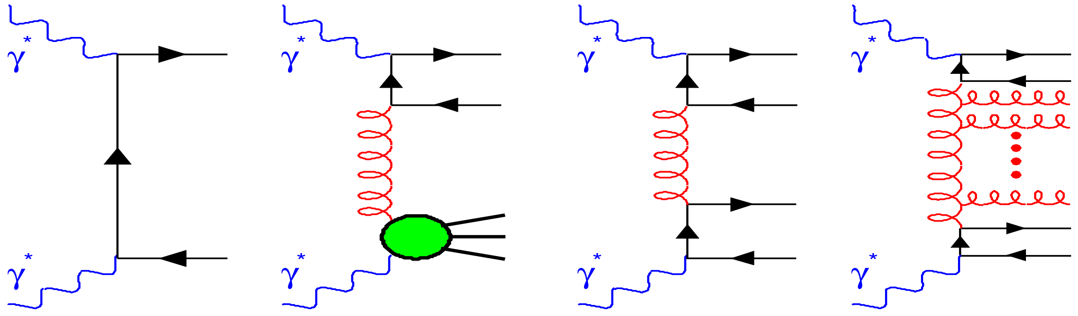


- The virtualities of photons:
  $Q^2 = -q_1^2 \simeq -q_2^2 = 2\sqrt{s}\,E_{tag}\,(1 - cos\theta)$

- The $\gamma\gamma$ center of mass energy
  $\mathrm{W}_{\gamma\gamma} = \sqrt{(q_1 + q_2)^2}$
  can be measured directly from the $e^\pm$.

- Luminosity Monitor $\frac{\Delta E}{E} = 1.3\%$

BFKL physics and $\gamma^*\gamma^*$



- J. Bartels et al. (PLB 389 742) and S.J. Brodsky et al. (PRD 56 6957) pointed out that the BFKL Pomeron can be investigated in $\gamma^*\gamma^*$ collisions.

  ⇨ The BFKL diagram is dominant at high Q^2 and high $W_{\gamma^*\gamma^*}$.

- In Leading order at saddle point approximation :

$$\sigma_{\gamma^*\gamma^*} = \frac{\sigma_0}{\sqrt{Q_1^2 Q_2^2 Y}} \left(\frac{s}{s_0}\right)^{\alpha_P - 1} \simeq \frac{\sigma_0}{\sqrt{Q_1^2 Q_2^2 Y}} \left(\frac{W^2_{\gamma^*\gamma^*}}{Q^2}\right)^{\alpha_P - 1}$$

$$s_0 = \frac{K\sqrt{Q_1^2 Q_2^2}}{y_1 y_2}, \quad y = 1 - (E_{tag}/E_b)\cos^2(\theta_{tag}/2)$$

$$\alpha_P - 1 = 4\ln 2 \frac{N_c \alpha_s}{\pi} \quad , \quad Y \approx \ln\left(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}}\right)$$

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

$\alpha_P - 1 \simeq 0.53 > 0.094$ ("soft Pomeron")

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)

$$0.17 < \alpha_P^{NLO} - 1 < 0.33$$

Used data and MC

- Data :

$\sqrt{s}$	$< Q^2 >$	$\int \mathcal{L}.dt$
189–202 GeV	15 GeV^2	401 pb^{-1}
183 GeV	14 GeV^2	52 pb^{-1}
91 GeV	3.5 GeV^2	140 pb^{-1}

L3 collab., Phys. Lett. B 453 (1999) 333

- Monte Carlo :

PHOJET: Engel and Ranft (Phys. Rev. D54 4246 (1995))

TWOGAM: Nova, Oleshevski and Todorov

JAMVG: J.A.M. Vermaseren (Nucl. Phys. B229 347 (1983))

PHOJET and TWOGAM reproduce quite well single-tagged and untagged events using the parton density function of the photon (GRV)

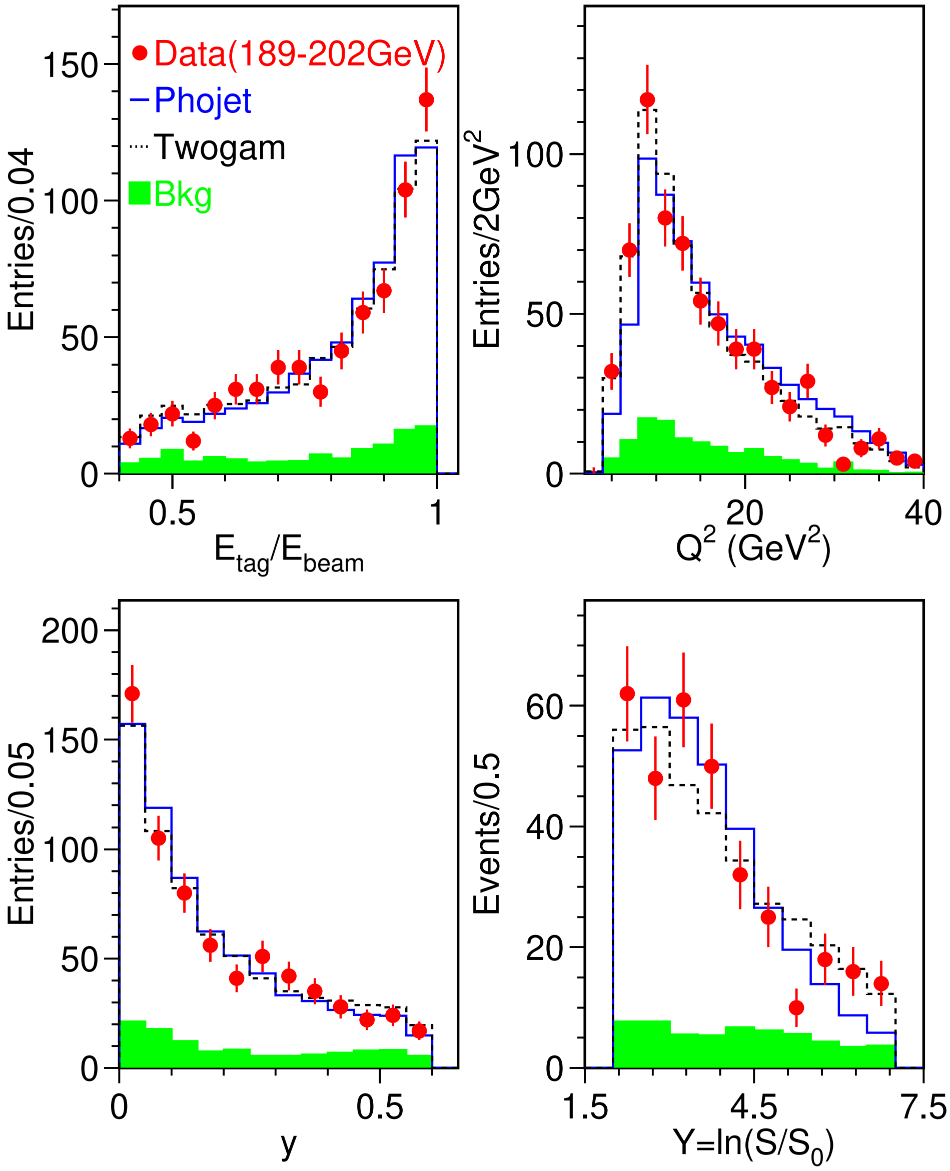
JAMVG describes the direct process $\gamma\gamma \rightarrow \mathrm{q}\bar{\mathrm{q}}$

Event selection $e^+e^- \to e^+e^-$hardons

- Two tagged electrons are identified :
  - ➜ $E_{tag} > 40$ GeV
  - ➜ 30 mrad $< \theta_{tag} <$ 66 mrad (Luminosity Monitor)
  - ➜ $2 < Y < 7$; $Y = \ln(\frac{s}{s_0}) \approx \ln(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}})$

- Backgrounds :
  - ➜ $e^+e^- \to e^+e^-\tau^+\tau^-$ $\approx 6.3\%$
  - ➜ misidentified single-tag two-photon events $\approx 9.3\%$
  - ➜ $e^+e^- \to q\bar{q} \approx 1\%$

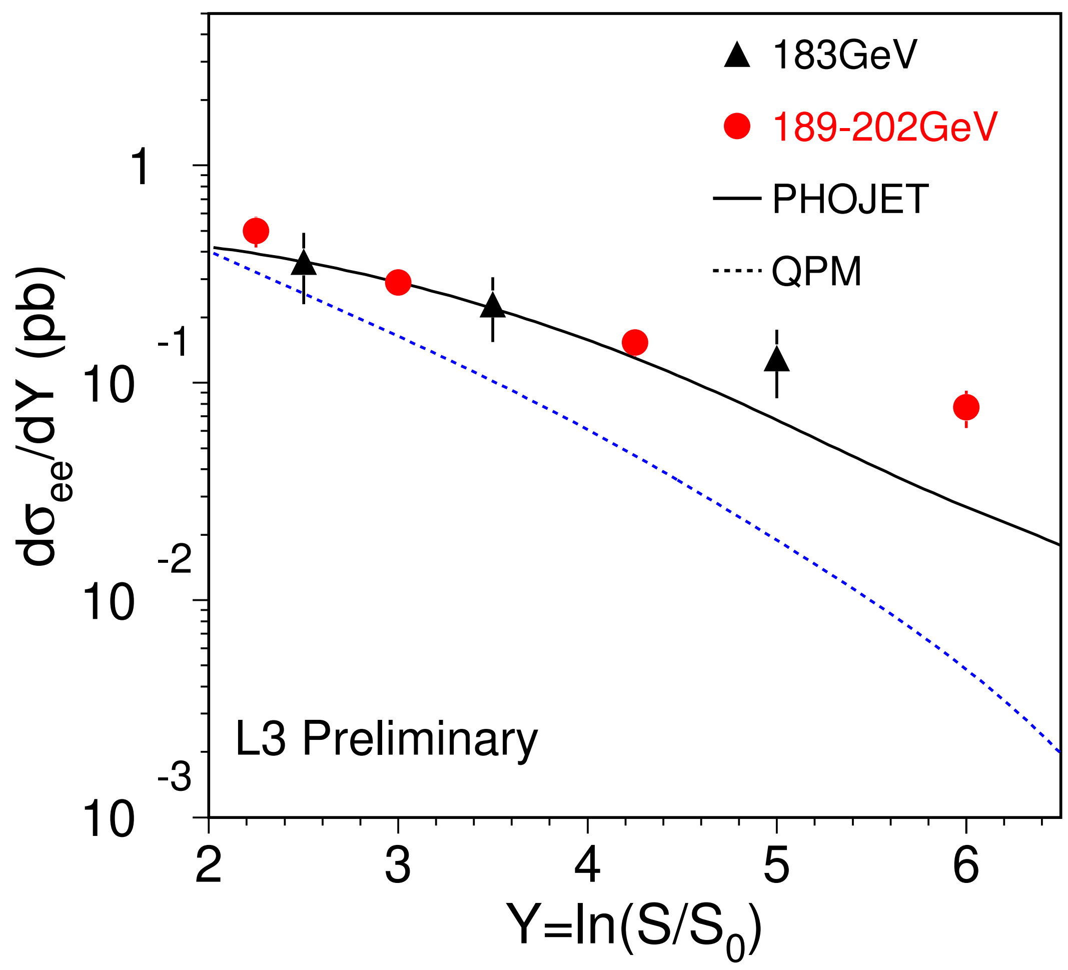
L3: MC/Data



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

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

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



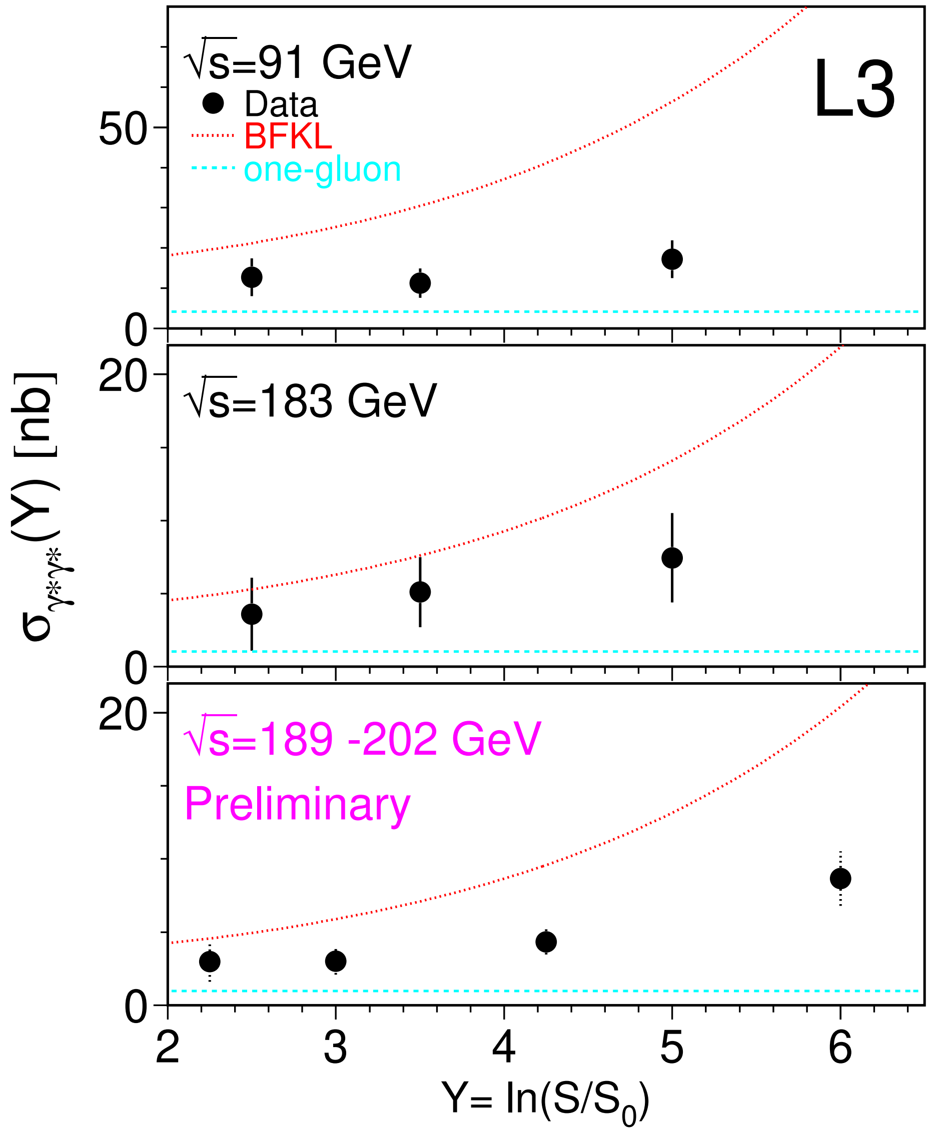
- L3 :
  - ➜ QPM is insufficient ($\sigma_{ee} = 0.42$ pb)

  $\sigma_{ee} = 0.93 \pm 0.05 \pm 0.14$ pb (PHOJET: $\sigma_{ee} = 0.76$ pb)

  - ➜ Charm production is suppressed in PHOJET due to high p_t^{cut}.
  - ➜ At 5$< Y <$ 7, cross section exceeds $\approx 3.5\sigma$ above the prediction
  - ➜ Opens a room for BFKL

$\gamma^*\gamma^*$ collisions

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

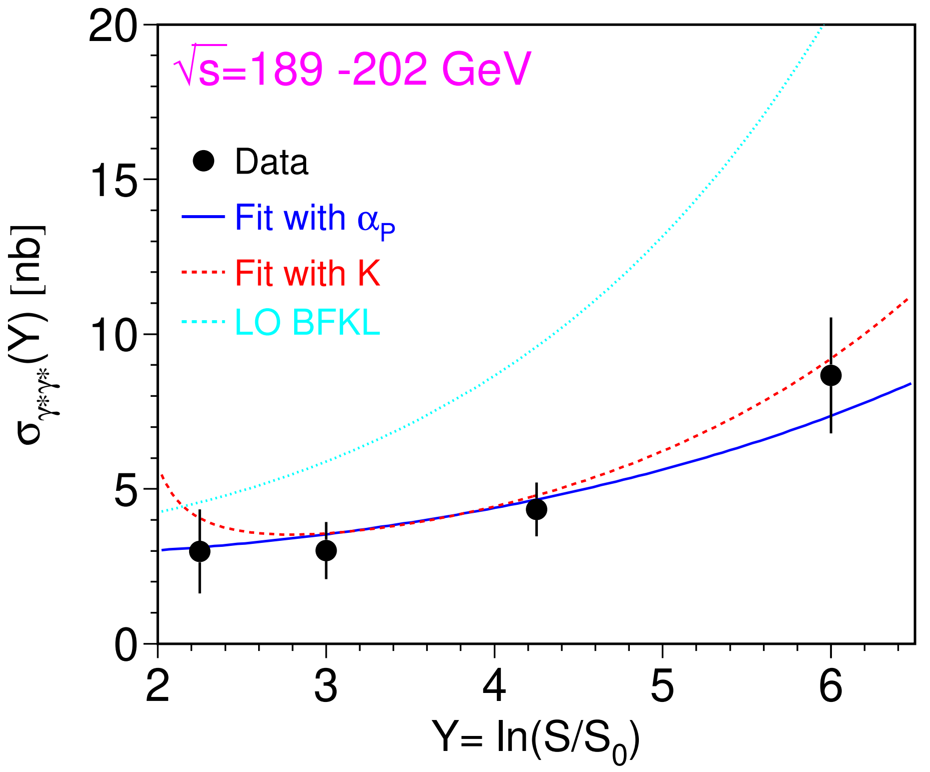


➜ Rise of $\gamma^*\gamma^*$ cross-section is observed

➜ One gluon exchange process is insufficient.

➜ LO BFKL prediction (saddle point approx.) 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 $K = 1.$

$$\alpha_P - 1 = 0.36 \pm 0.02 < 0.53 \quad \chi^2/dof = 0.98/3$$

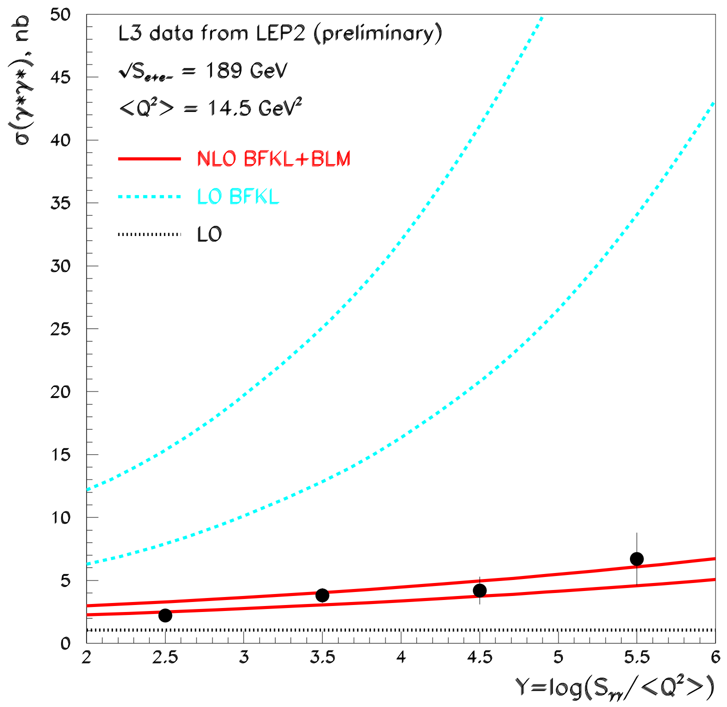
$$\alpha_P^{NLO} - 1 = 0.29 - 0.31 \quad (Q^2 = 14\ \mathrm{GeV}^2)$$

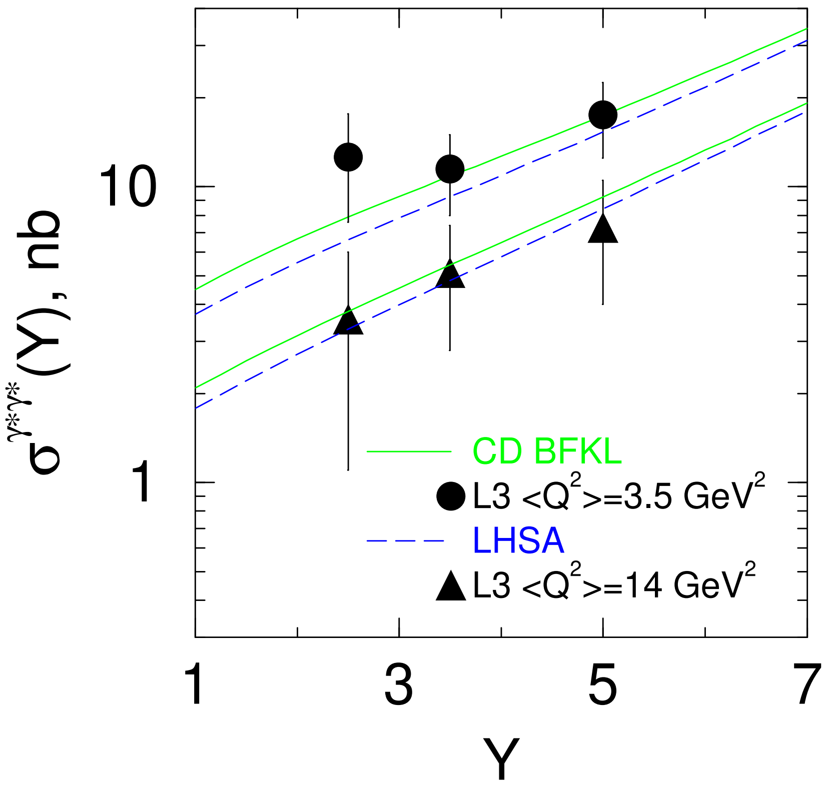
(Ciafaloni, Colferai and Salam, PRD 60, 114036)

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

$$K = 6.4 \pm 1.0 > 1 \quad \chi^2/dof = 1.34/3$$

NLO BFKL





➜ Agree with the data !

Conclusions

- $\gamma^*\gamma^*$ collisions have been measured up to $\langle Q^2 \rangle = 15\ \mathrm{GeV}^2$ and Y$\approx \ln(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}}) = 7$ at L3
- The QPM is not sufficient to describe the data
  QCD diagrams are necessary.
- Agreement between data and PHOJET Monte-Carlo model using GRV-LO parton density function is reasonable for Y$<$5

  ➜ $\approx 3.5\sigma$ above the prediction 5$<$Y$<$7

- Cross-sections of $\gamma^*\gamma^*$ collisions
  - ⇨ LO BFKL predicts too large cross-sections

    ➜ sensitive to the energy scale s_0.
  - ⇨ Improved NLO BFKL calculations are necessary.