Double Tag events in Two-Photon Collisions at LEP

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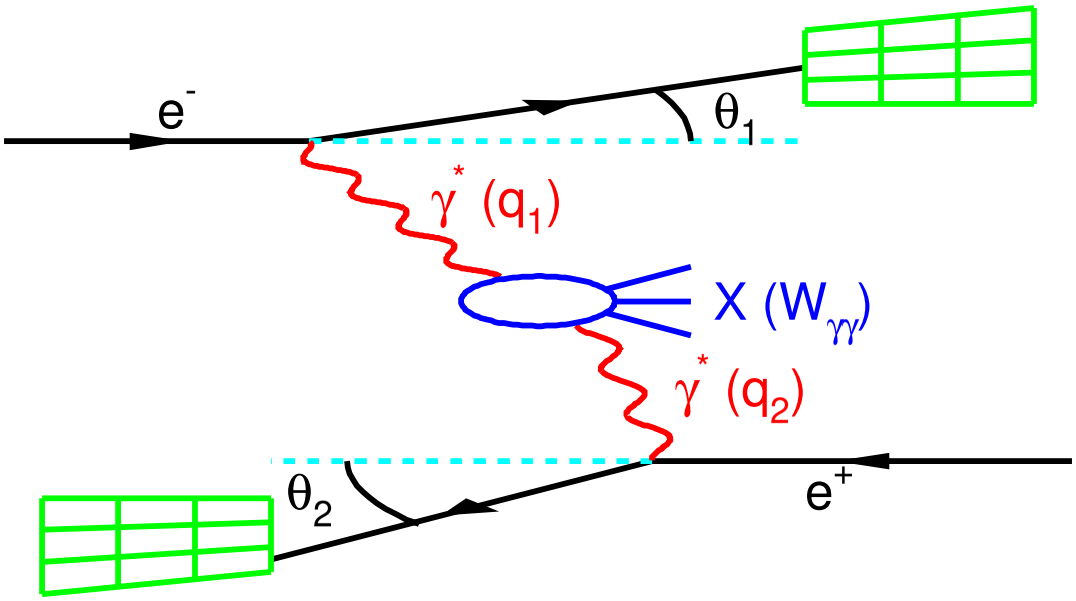
Representing
L3 Collaboration

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

$e^+e^- \rightarrow e^+e^-hadrons$

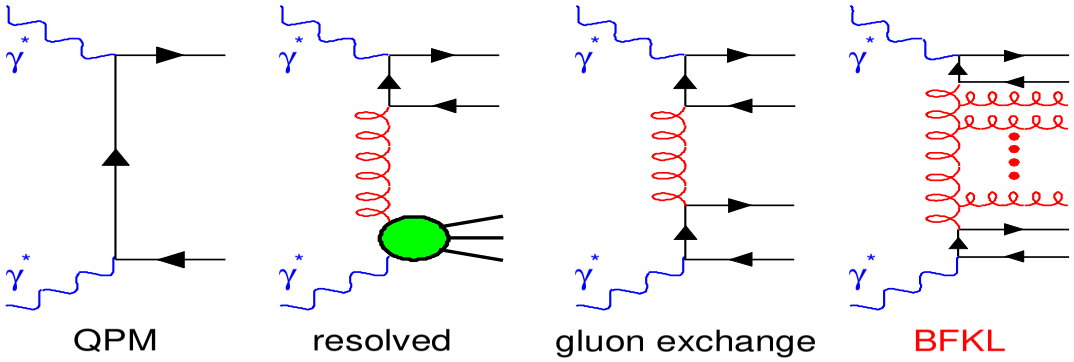


- The virtualities of photons:
  $Q^2 = -q_1^2 \simeq -q_2^2 = 2\sqrt{s}\,E_{tag}\,(1 - cos\theta)$

- The $\gamma\gamma$ center of mass energy
  $W_{\gamma\gamma} = \sqrt{(q_1 + q_2)^2}$
  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 $W^2_{\gamma^*\gamma^*} >> Q^2 >> m^2_\rho$.

- In Leading order at saddle point approximation :

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

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

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

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

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

➠ Attempts to include NLO are still not conclusive

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 (CERN 96-01 (1996), Volume 2)

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)

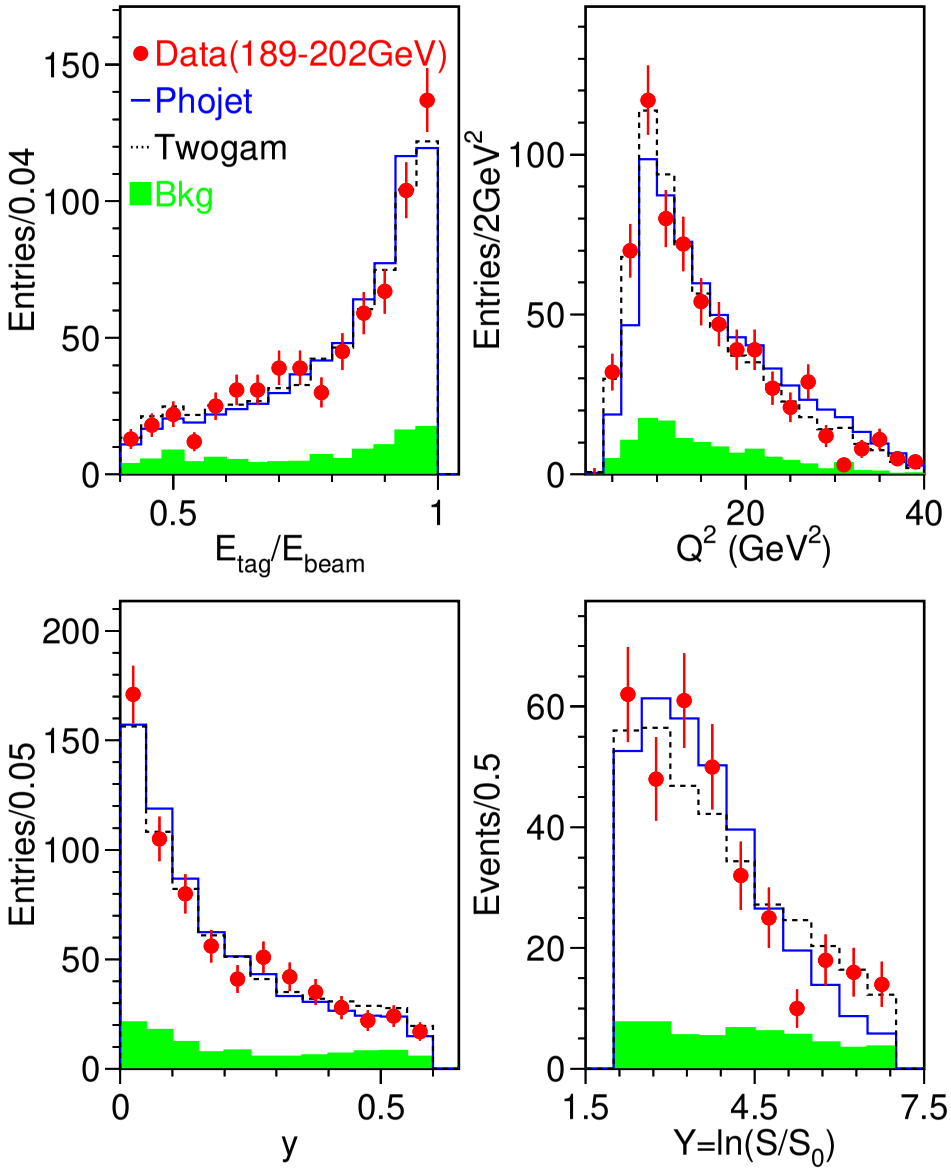
JAMVG describes the direct process $\gamma\gamma \rightarrow q\bar{q}$

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

- Two tagged electrons are identified :
  - $E_{tag} > 40$ GeV
  - $30 \text{ mrad} < \theta_{tag} < 66 \text{ mrad}$ (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 :
  - $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ $\approx 6.3\%$
  - misidentified single-tag two-photon events $\approx 9.3\%$
  - $e^+e^- \rightarrow q\bar{q}$ $\approx 1\%$

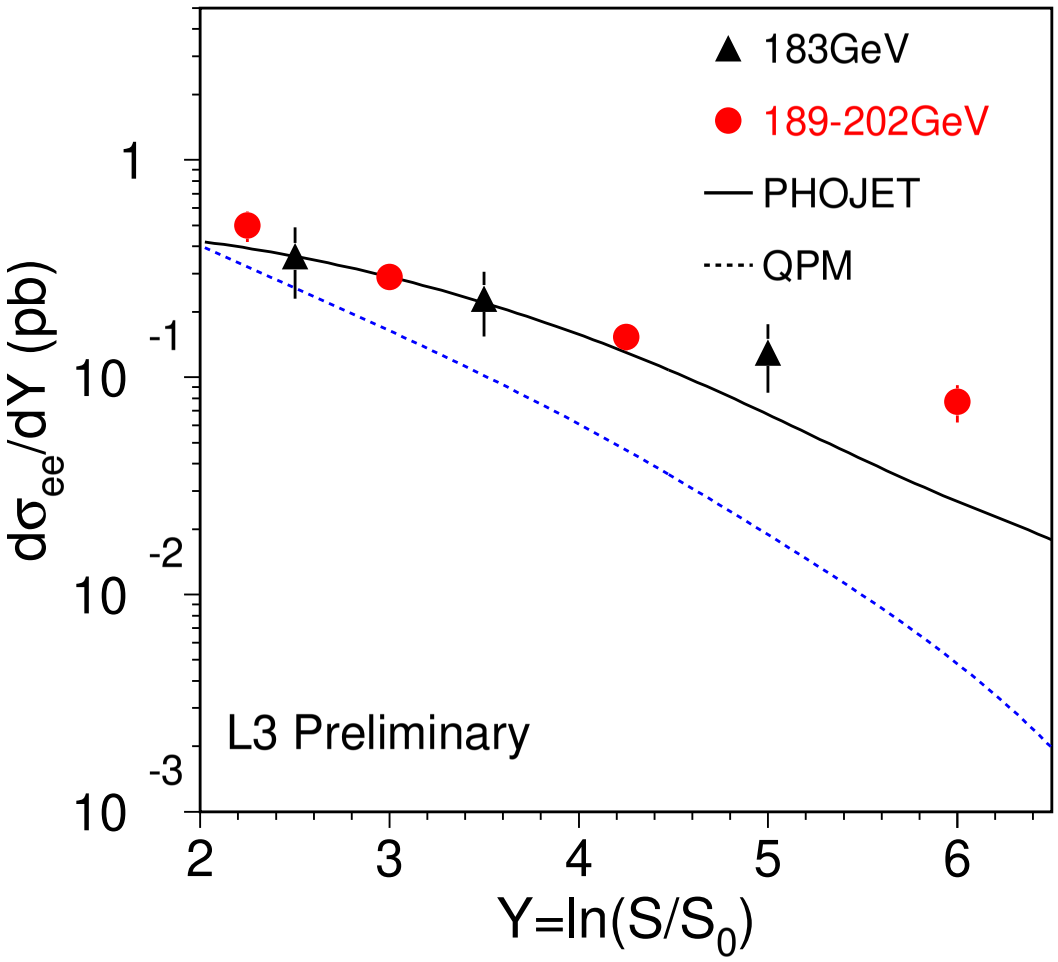
L3: MC/Data



- Reasonable agreement with PHOJET and TWOGAM.
- Select :
  - 137 events at 91 GeV ($\langle Q^2 \rangle = 3.5$ GeV^2)
  - 34 events at 183 GeV ($\langle Q^2 \rangle = 14$ GeV^2)
  - 336 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 :

➜ 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)

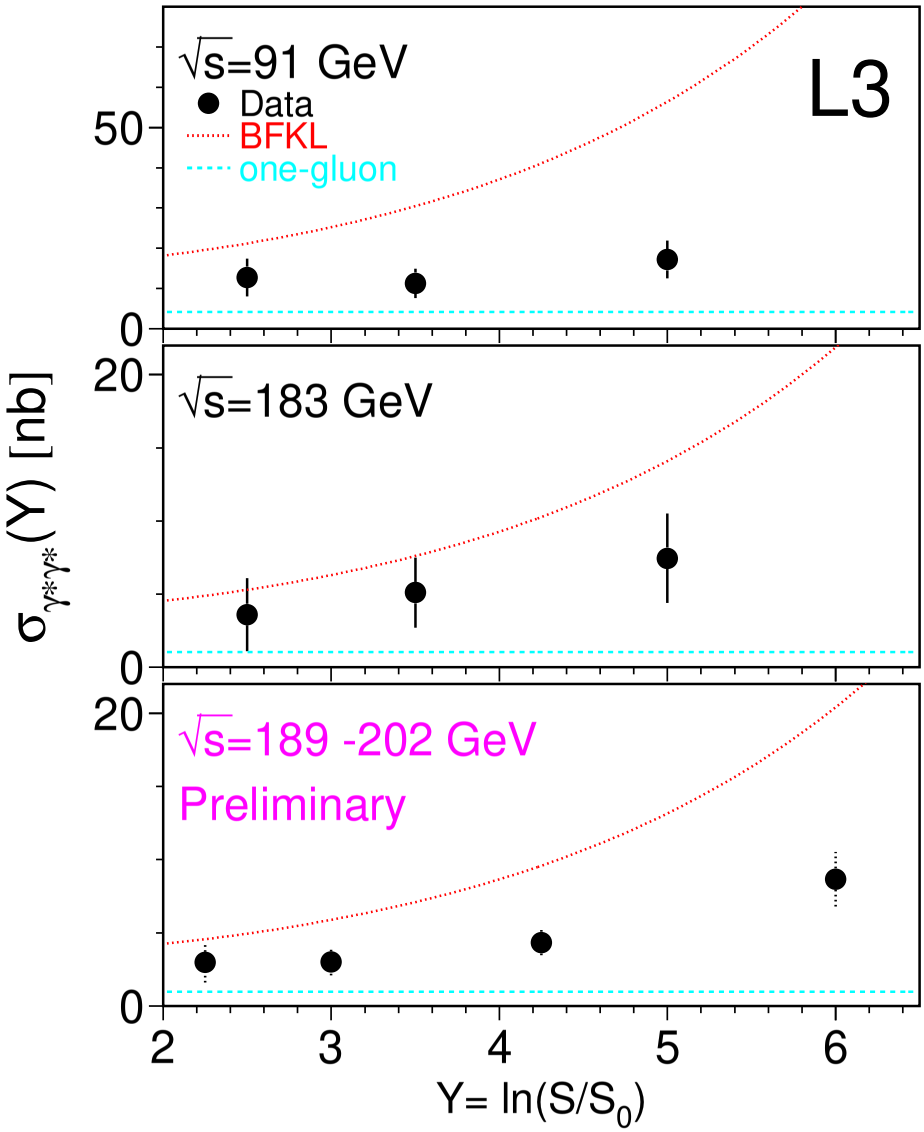
➜ Charm production is suppressed in PHOJET due to high p_t^{cut}.

➜ 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.

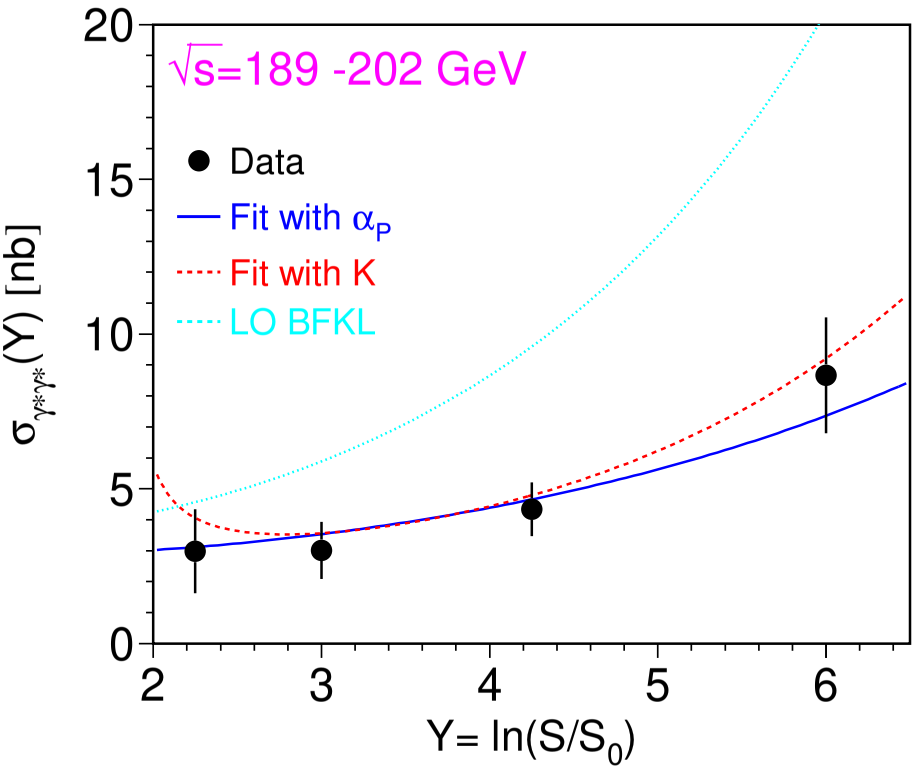


➜ Rise of $\gamma^*\gamma^*$ cross-section is observed

➜ 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 $K = 1$.

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

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

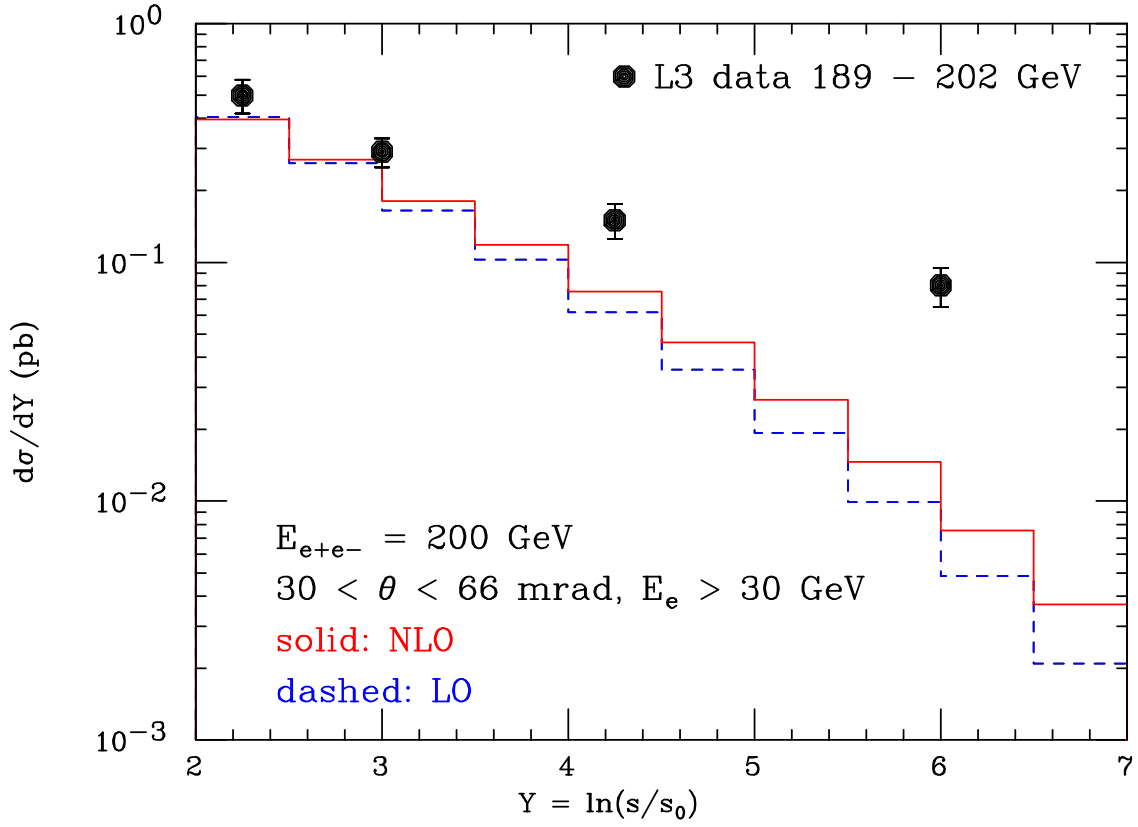
(**Ciafaloni, Colferai and Salam, PRD 60, 114036**)

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

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

Recent Update: NLO QPM

- Running α_{em} is used depending upon the Photon Virtuality ➠ increases σ_{ee} more than 10%
- Quark Mass effects are included



M.Cacciari, V. Del Duca, S. Frixione and Z. Torcsanyi

Presented QCD'00, Montpellier

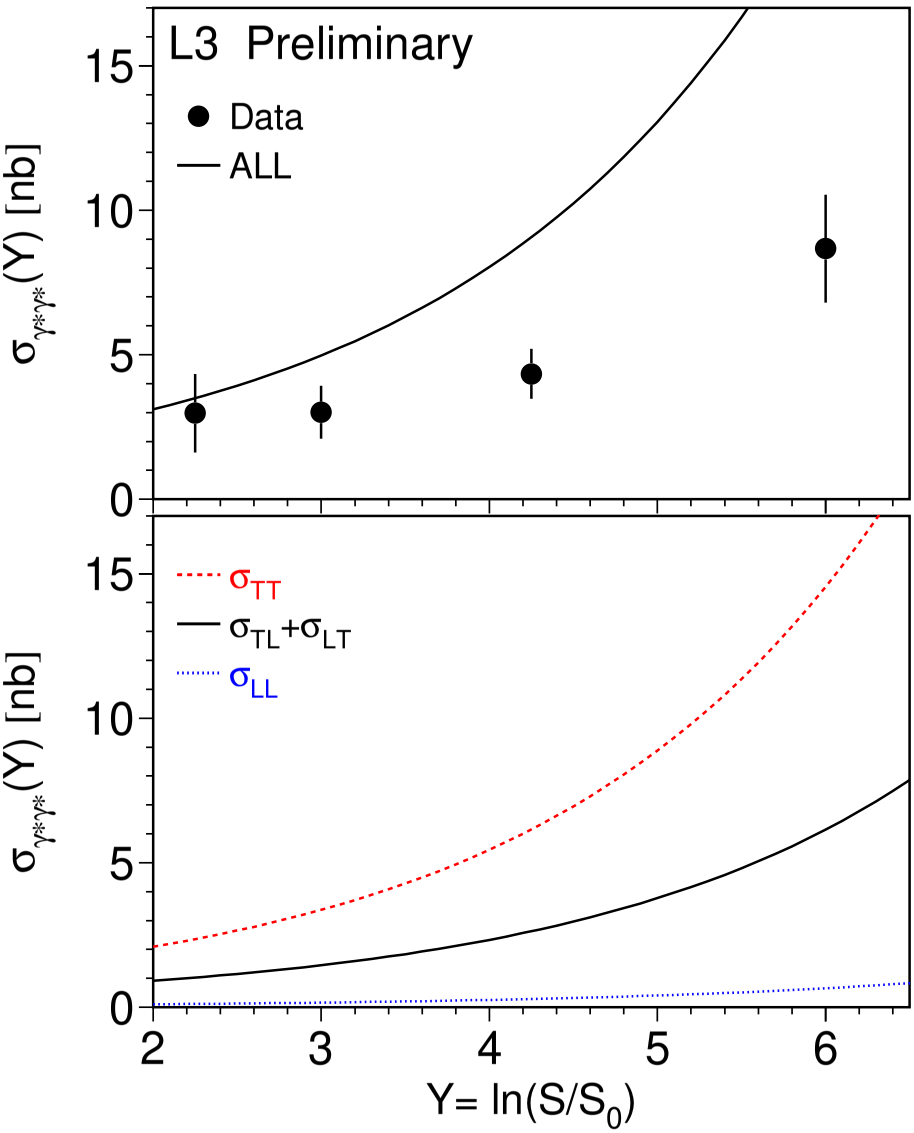
NLO QPM Calculation is not sufficient to describe the data

Recent Update: Improvements to LO BFKL

J. Bartels, C. Ewerz, R. Staritzbichler, hep-ph/0004029

- Massive Charm quark reduces $\sigma_{\gamma^*\gamma^*}$ by 20%
- Longitudinal Polarisation increases $\sigma_{\gamma^*\gamma^*}$ by 40%

Using $N_c = 3$, $\alpha_s = 0.208$ ($< Q^2 >= 15$ GeV^2)



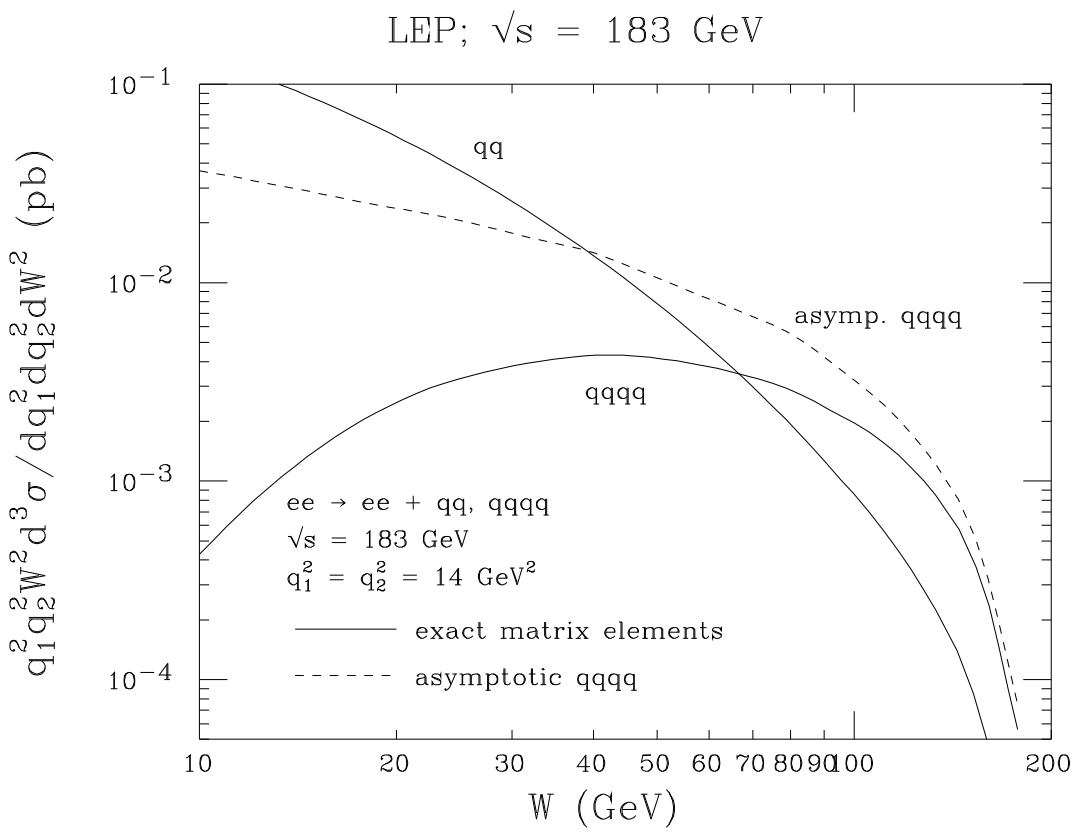
Recent Update: Improvements to LO BFKL

L.H. Orr and W.J. Stirling, ICHEP2000, Osaka

Analytical BFKL solution have

- Sum over arbitrary number of gluons
- Leading order kinematics only
  - No kinematics cost to emit gluons
  - Energy and Momentum not Conserved

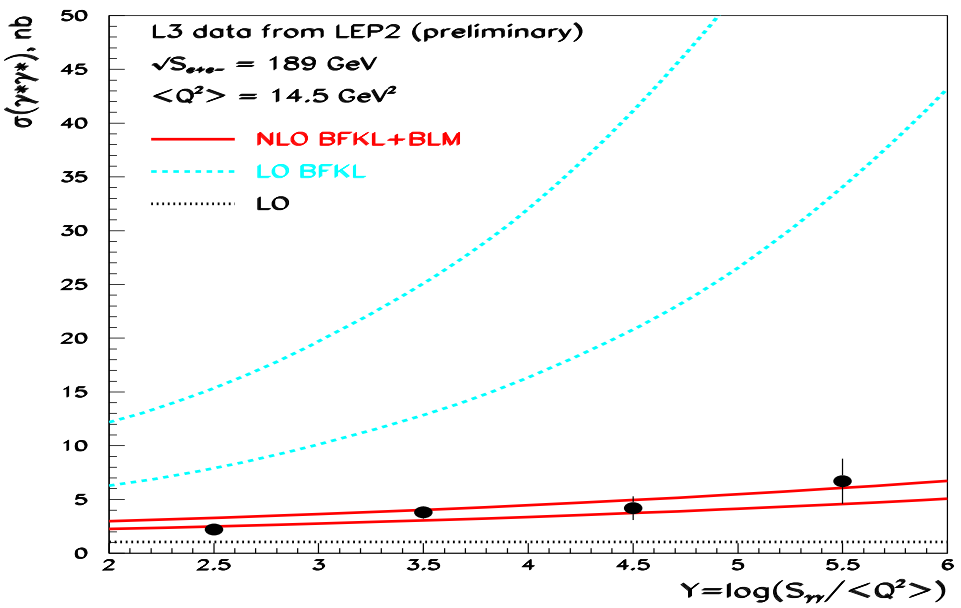
Monte Carlo calculation of the BFKL process including energy and momentum



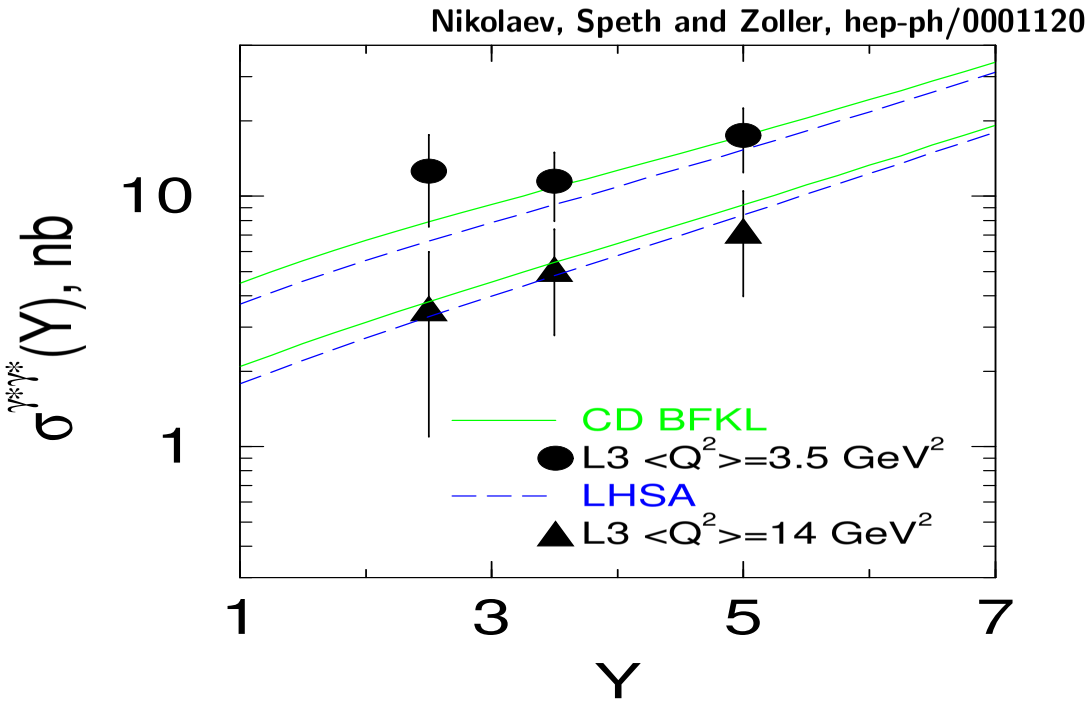
Effect of Kinematic constraints can be large

NLO BFKL

Brodsky, Fadin, Kim, Lipatov and Pivovarov, hep-ph/9901229



Nikolaev, Speth and Zoller, hep-ph/0001120



➜ 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 ➜ **BFKL ?**

- 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.