Double-tag events study with L3 at $\sqrt{s} = 189\,GeV$

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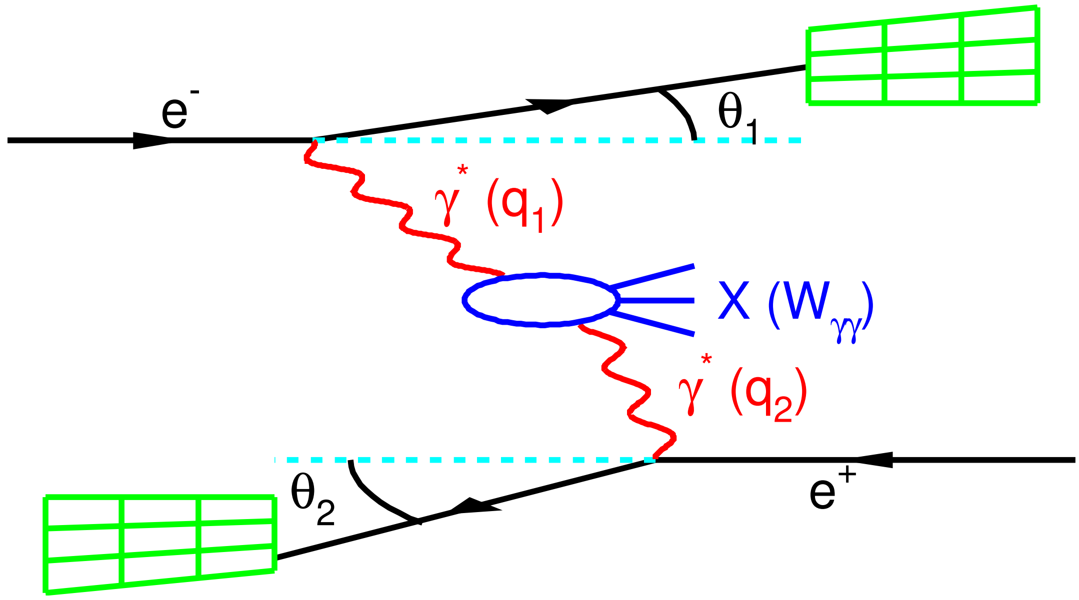
Freiburg

- $\gamma^*\gamma^*$ physics
- Data and Monte-Carlo selection and quality
- Cross-sections
- $\gamma^*\gamma^*$ and the BFKL Pomeron
- Conclusions and outlook

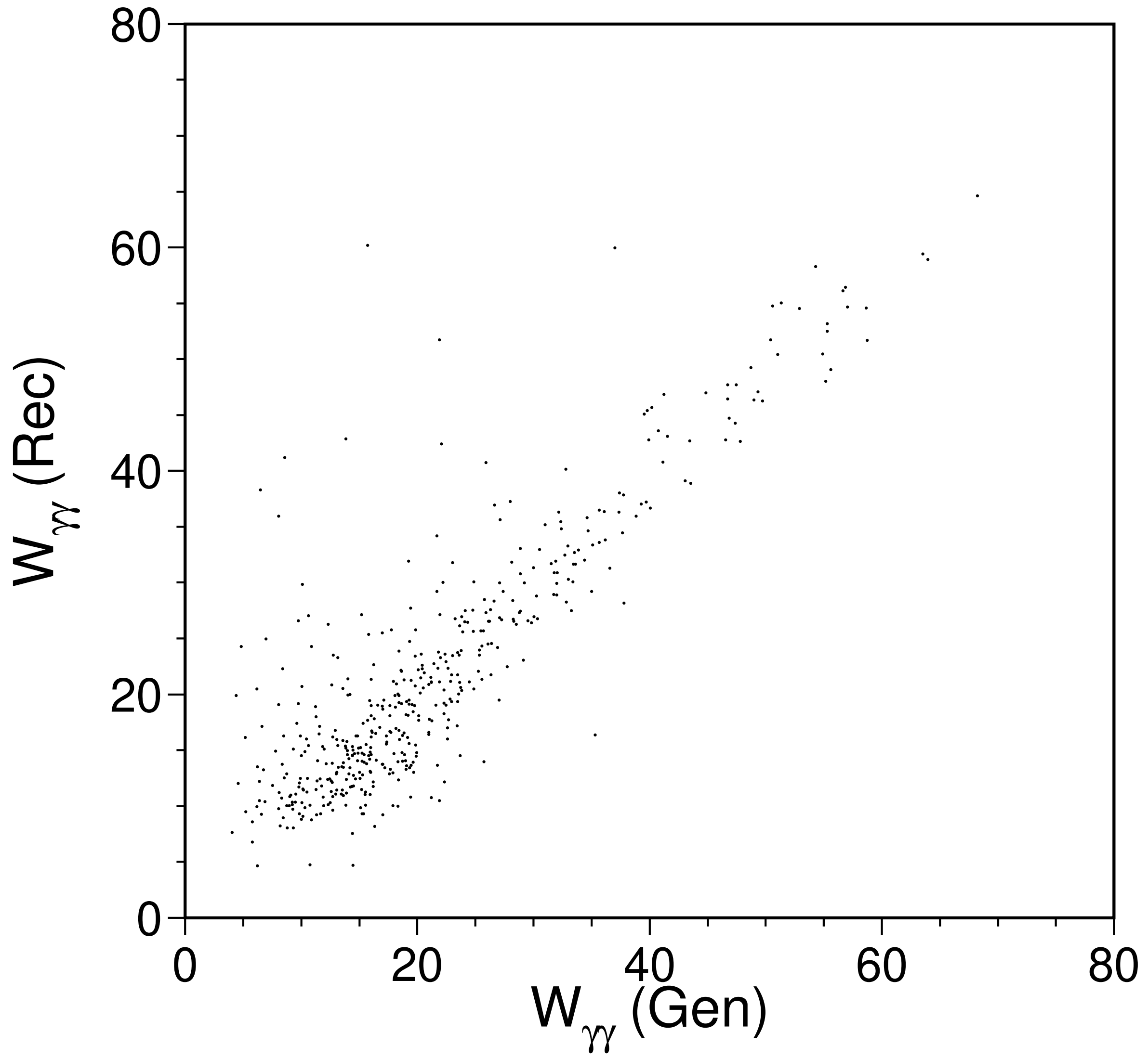
$\gamma^*\gamma^*$ physics



- 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

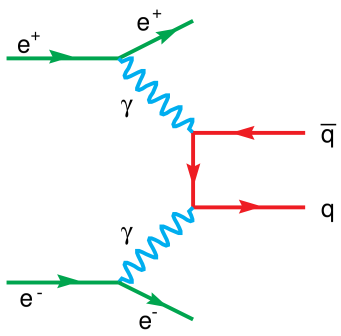
Generated versus reconstructed events

Using PHOJET :

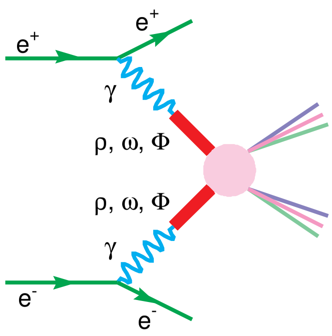


⇨ no unfolding

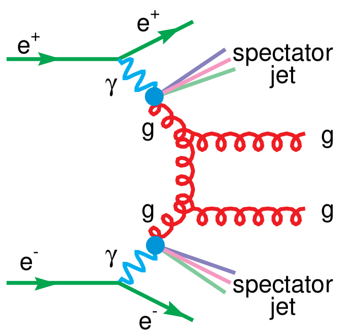
Diagrams contributing to: $\gamma^*\gamma^* \to \text{hadrons}$



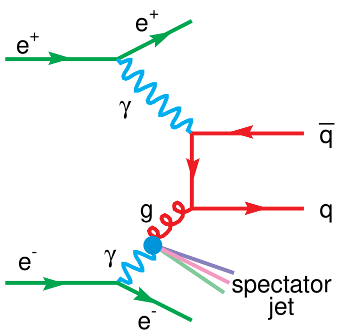
Direct



VDM



Double Resolved



Single Resolved

➩ In $\gamma^*\gamma^*$ collisions, the VDM process is highly suppressed because of VDM form factors when $Q^2 \gg m_\rho^2$

Used data and MC

- Data :

L3 :	189 GeV,	176. pb^{-1}
already published :	183 GeV,	52. pb^{-1}
(L3 coll., CERN-EP/98-205)	91 GeV,	140. pb^{-1}

- Monte Carlo :

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

TWOGAM: Nova, Oleshevski and Todorov (Nucl. Phys. B229 347 (1983))

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 $\gamma\gamma \to q\bar{q}$

189 GeV events selection

- The two tagged electrons are identified by :
  $E_{tag} > 40$ GeV
  $30 \text{ mrad} < \theta_{tag} < 66 \text{ mrad}$

- The number of tracks > 2

- $2 < Y < 6$; $\quad Y = \ln(\frac{s}{s_0}) \approx \ln(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}})$

$Y \approx ln(\frac{(q_1+q_2)^2}{\sqrt{q_1^2 q_2^2}}) = ln(\frac{q_1^2+2q_1.q_2+q_2^2}{q_1 q_2})$
as $E_{tag1} \simeq E_{tag2} \simeq \sqrt{s}/2$ and $m_e \simeq 0$
$Y \approx ln(\frac{2-cos\theta_{\gamma_1\gamma_2}}{2\sqrt{(1-cos\theta_1)(1-cos\theta_2)}})$

$\Rightarrow$ Y is independent of $\sqrt{s}$

Data samples

$\sqrt{s}$	91 GeV	183 GeV	189 GeV

$W_{\gamma\gamma}$ range	2 - 30 GeV	5 - 70 GeV	5 - 75 GeV
Q^2 range	1 - 9 GeV^2	2 - 35 GeV^2	3 - 37 GeV^2
$< Q^2 >$	3.5 GeV^2	14 GeV^2	14.5 GeV^2

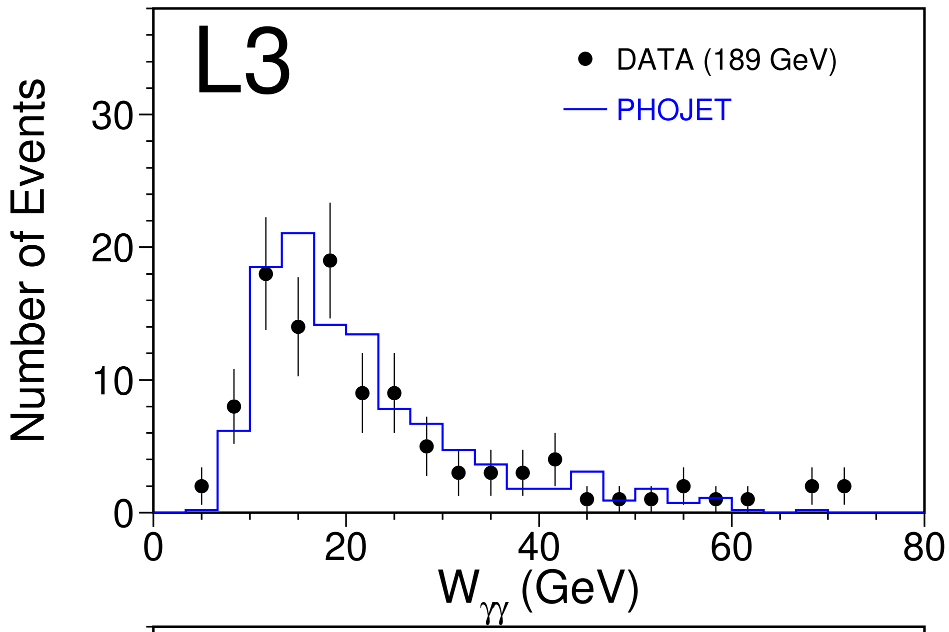
Luminosity	140. pb^{-1}	52. pb^{-1}	176. pb^{-1}
Events	137	34	108
Bkg	12	4	14

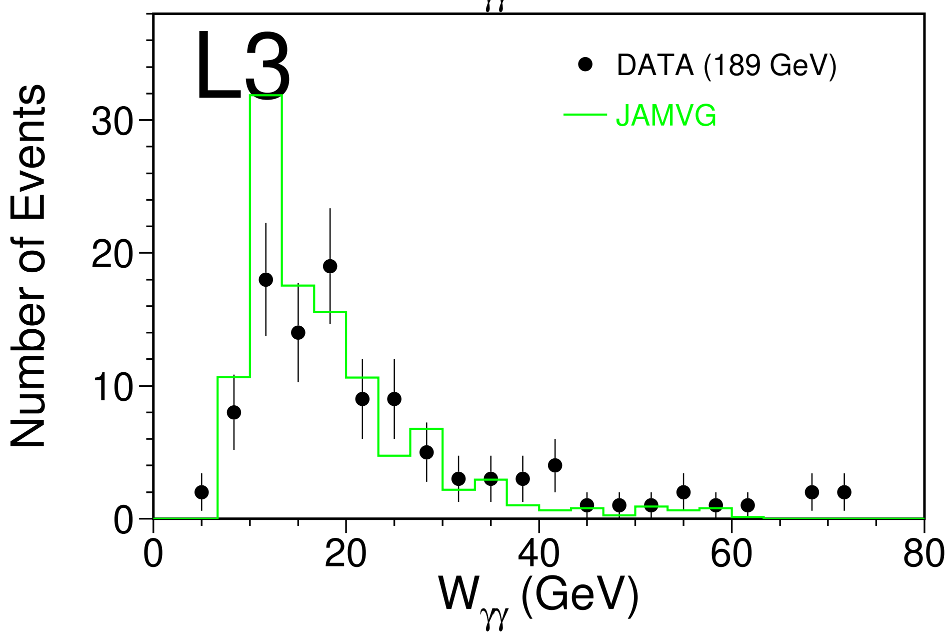
Typical efficiencies calculated at 189 GeV:
with PHOJET: 64.8 ± 2.7 %
with JAMVG: 64.3 ± 3.0 %

Trigger efficiency is $\simeq 100$ %

The backgrounds come from $e^+e^- \to e^+e^-\tau^+\tau^-$ and single tagged events.

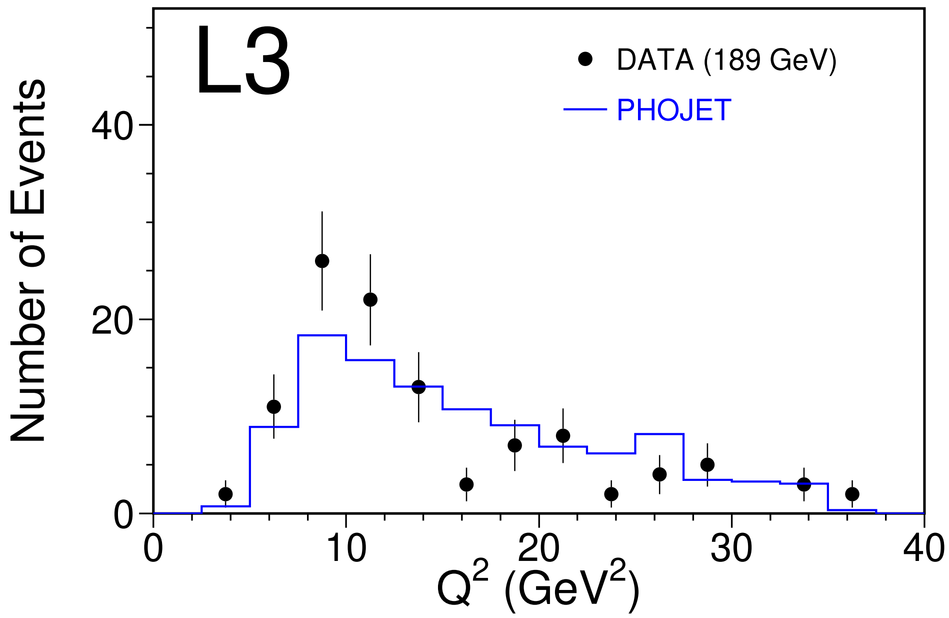
Data/MC Comparison

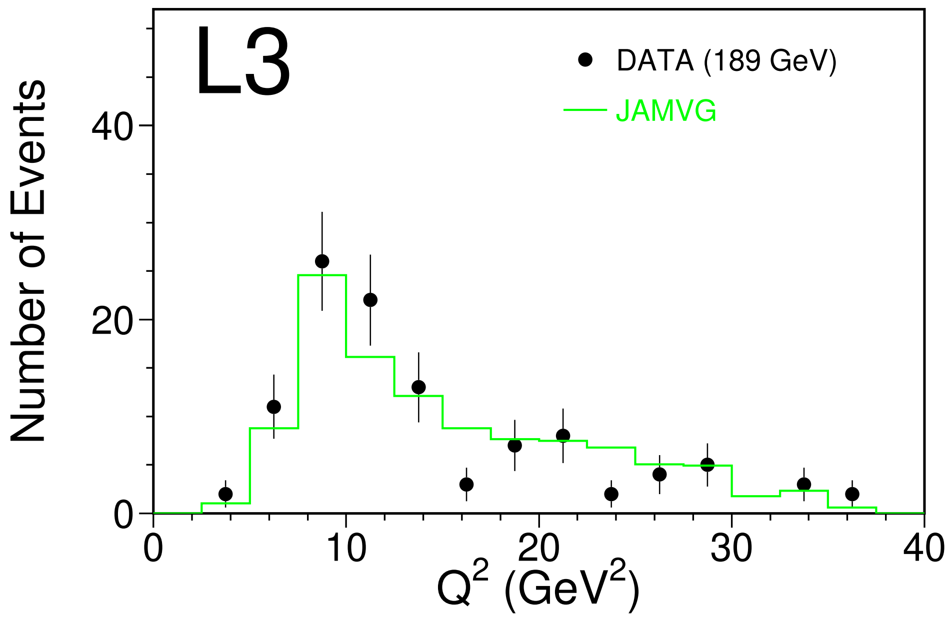




normalised to the number of events

Data/MC Comparison





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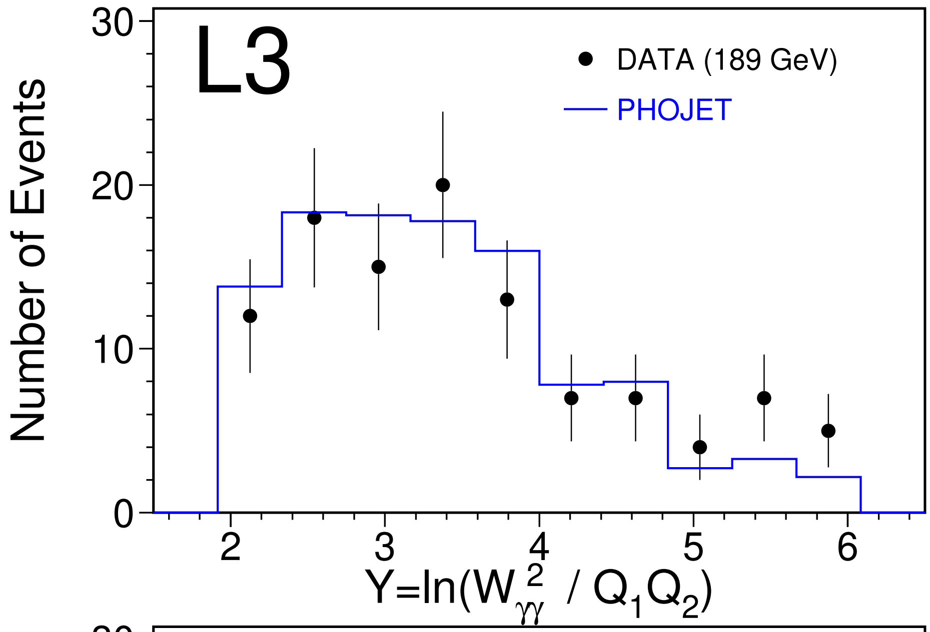
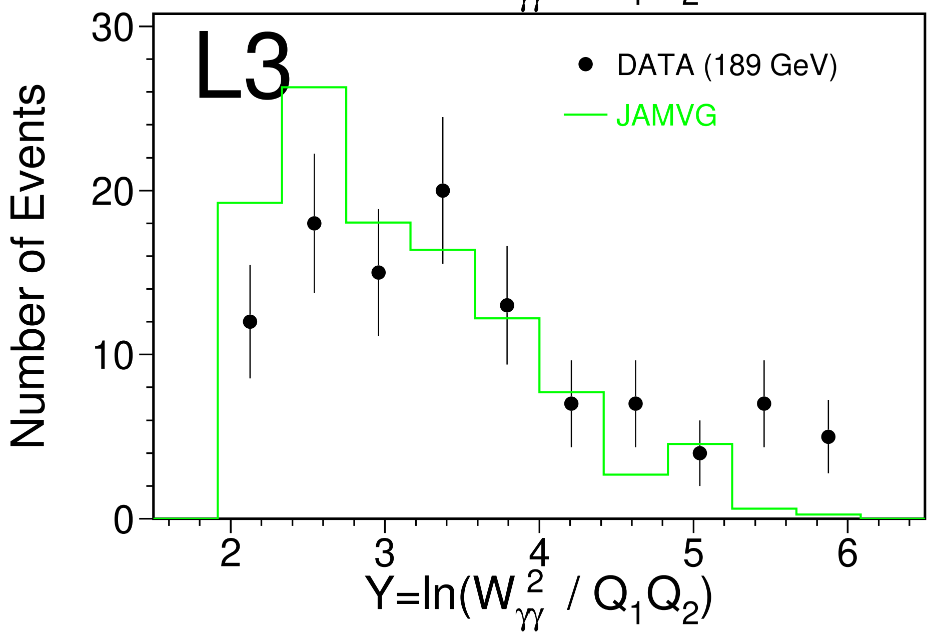




normalised to the number of events

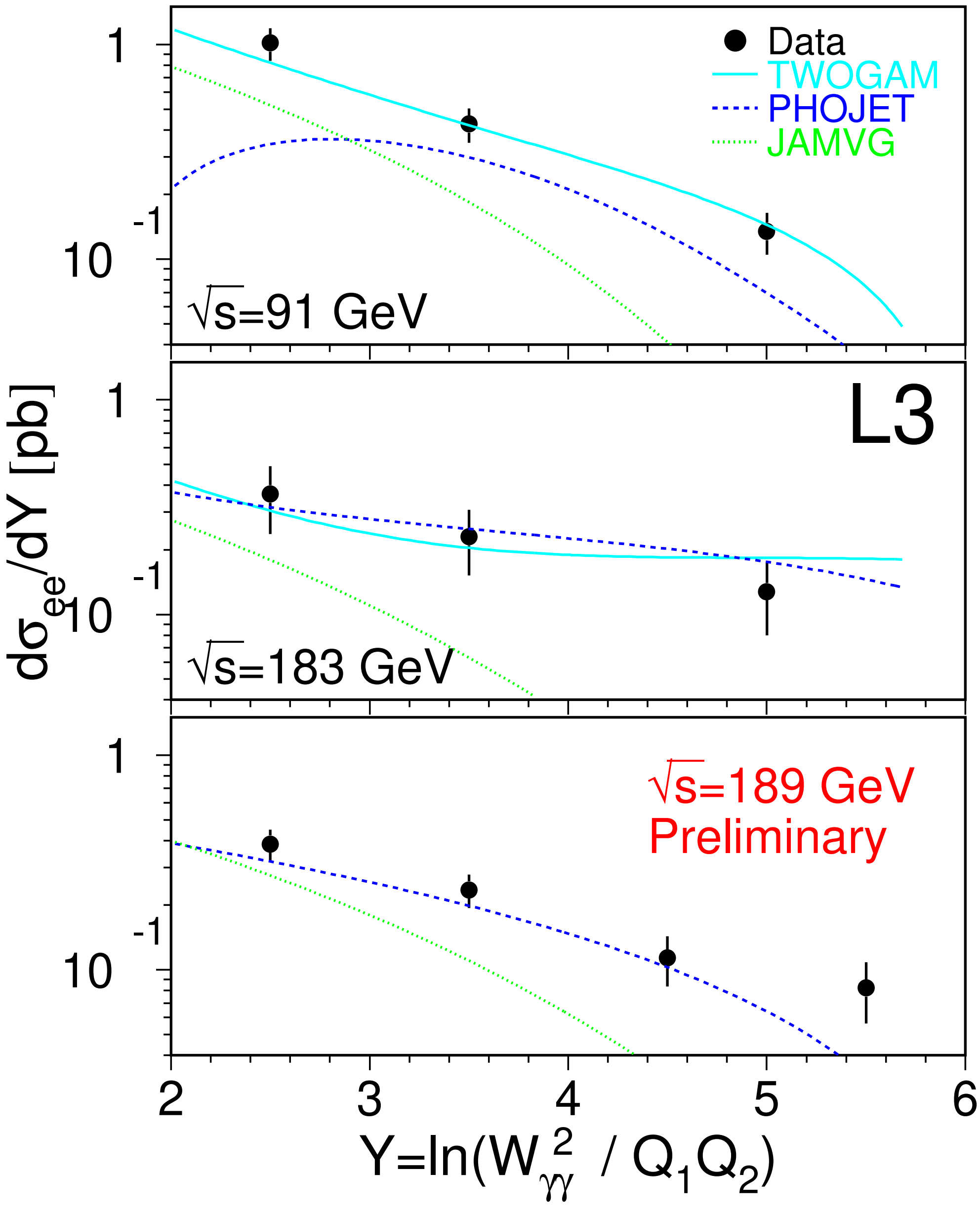
$\sigma_{\rm ee}$: Results

189 GeV				
	DATA corrected with PHOJET	PHOJET	DATA corrected with JAMVG	JAMVG
ΔY	$\mathrm{d}\sigma/\mathrm{d}Y$	$\mathrm{d}\sigma/\mathrm{d}Y$	$\mathrm{d}\sigma/\mathrm{d}Y$	$\mathrm{d}\sigma/\mathrm{d}Y$
$2-3$	0.386 ± 0.064	0.316	0.394 ± 0.065	0.274
$3-4$	0.236 ± 0.042	0.208	0.219 ± 0.039	0.114
$4-5$	0.114 ± 0.030	0.093	0.081 ± 0.022	0.028
$5-6$	0.082 ± 0.026	0.035	0.074 ± 0.022	0.008

Data are corrected in acceptance and efficiency with the MCs

Results are rather insensitive to MC corrections

σ_{ee} : Results

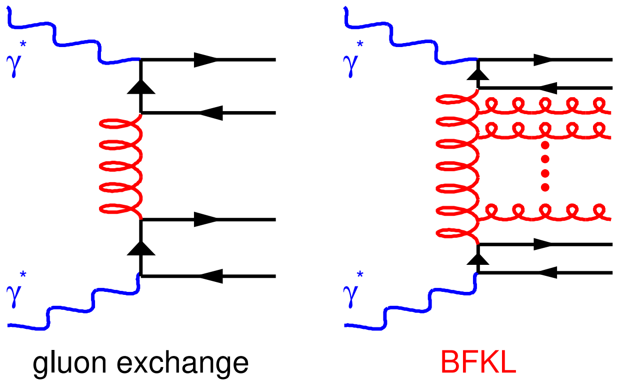


Direct process (JAMVG) is insufficient

but

PHOJET and TWOGAM agree quite well

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



- J. Bartels et al. (Phys. lett. B389 742, 1996) and S.J. Brodsky et al. (Phys. Rev. D56 6957, 1997) 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 approximation :

$$\sigma_{\gamma^*\gamma^*} = \sigma_0(Q^2, Y)\left(\frac{s}{s_0}\right)^{\alpha_P - 1} = \sigma_0(Q^2, Y)\, e^{Y.(\alpha_P - 1)}$$

$$\alpha_P - 1 = 4 \ln 2 \frac{N_c \alpha_s}{\pi}$$

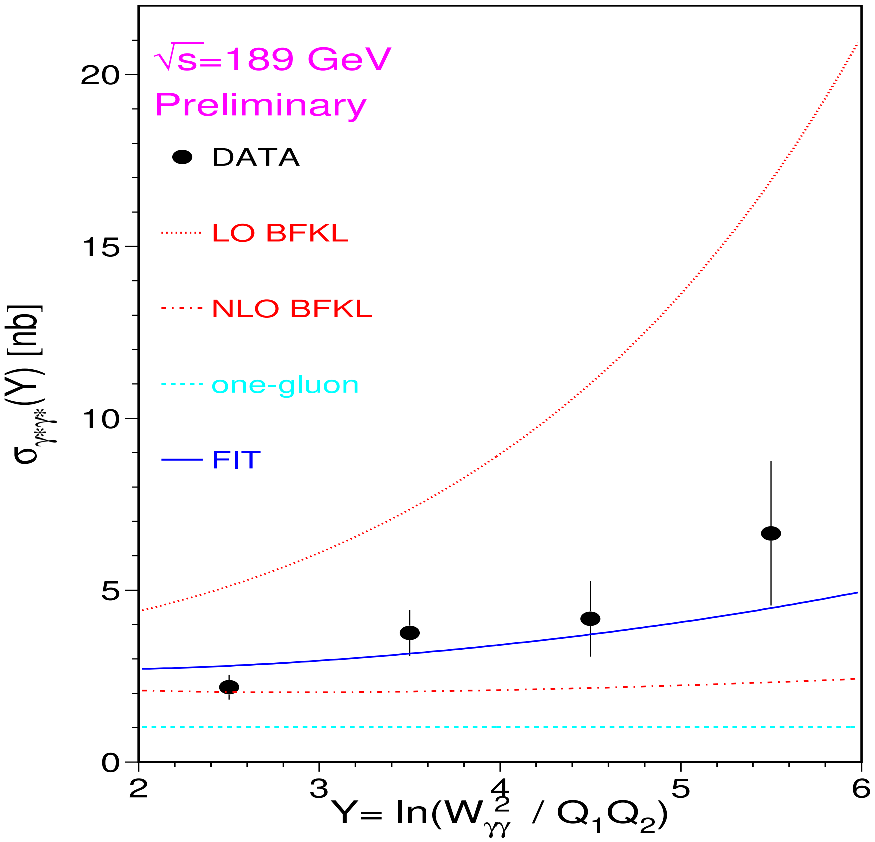
Using $N_c = 3$, $\alpha_s = 0.2$ ➜ $\alpha_P - 1 \simeq 0.53$
(> 0.095 "soft Pomeron")

- Next to leading order calculations by S.J. Brodsky et al. (hep-ph/9901229) give $\alpha_P - 1 \leq 0.175$

$\sigma_{\gamma^*\gamma^*}$: Results

After subtraction of the direct part :

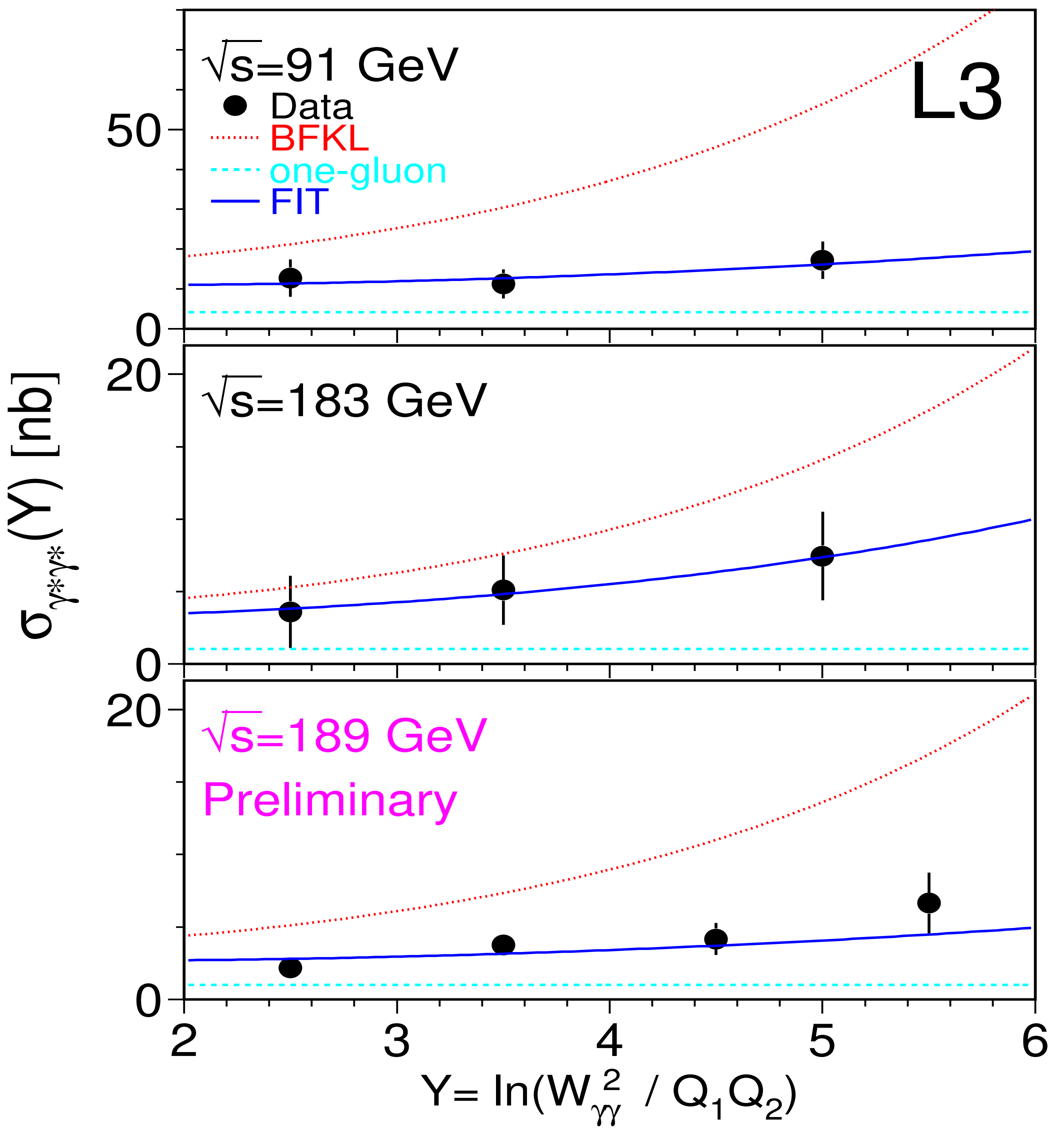
$\sigma_{\text{ee}} = L_{TT} \otimes \sigma_{\gamma^*\gamma^*}$



- The measured cross-section is much lower than the LO BFKL Pomeron prediction, and higher than the NLO one.
- Fit to the data, leaving α_P as a free parameter:

  $\alpha_P - 1 = 0.29 \pm 0.032 \quad < 0.53$ but > 0.175 !

$\sigma_{\gamma^*\gamma^*}$: Results



combined fit:

$$\alpha_P - 1 = 0.29 \pm 0.025$$

$$\chi^2/d.o.f. = 7/10 \qquad C.L. = 72.5\%$$

$$\chi^2_{LO-BFKL}/d.o.f. = 263/10$$
$$\chi^2_{NLO-BFKL}/d.o.f. = 21/10$$

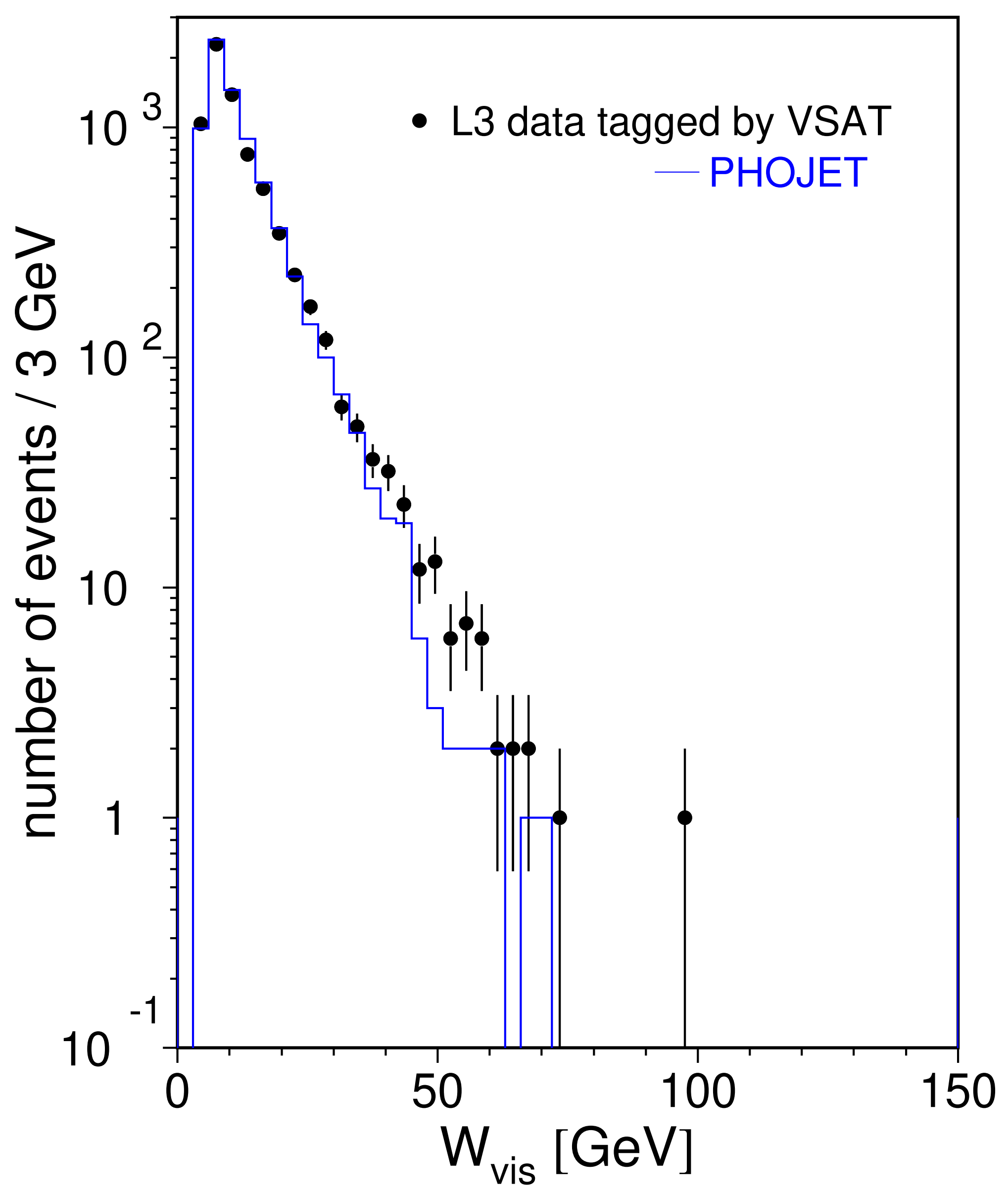
Conclusions

- Agreement between data and Monte-Carlo using GRV-LO parton density function is fairly good.
- Cross-sections of $\gamma^*\gamma^*$ collisions
  - Measured at $\sqrt{s} \simeq 91, 183$ and 189 GeV.
  - The direct part is not sufficient to describe the data. Resolved diagrams are necessary.
  - Data are lower than the LO BFKL Pomeron prediction and higher than the NLO prediction.

Outlook

- LEP will run until year 2000
  ➜ (twice ?) more data are coming !
  Even more precise results are foreseen !
- Our very small angle calorimeter can be used to explore the low Q^2 region: $0.2\,GeV^2 < Q^2 < 0.8\,GeV^2$

Outlook



number of events / 3 GeV
10^{3}
10^{2}
10
1
10^{-1}
0
50
100
150
W_{vis} [GeV]
L3 data tagged by VSAT
PHOJET