$F_{2,hadr}^{\gamma}$ and $\sigma_{\gamma^*\gamma^*}$

Results from L3 and Opal

Daniel Haas
University of Basel

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Overview

- ☐ $F_{2,hadr}^{\gamma}$ at L3 (Single Tag)
  - Available x – Q^2-range
  - Unfolding
  - Monte Carlo
  - Modeling Dependence
  - Results from L3 - Low and Medium Q^2
  - Results from L3 - High Q^2
- ☐ $\sigma_{\gamma^*\gamma^*}$ (Double-Tag)
  - Kinematics
  - BFKL
  - Results from L3
- ☐ Conclusions

F_2^γ : $x - Q^2$ **at L3**

Accessible Region

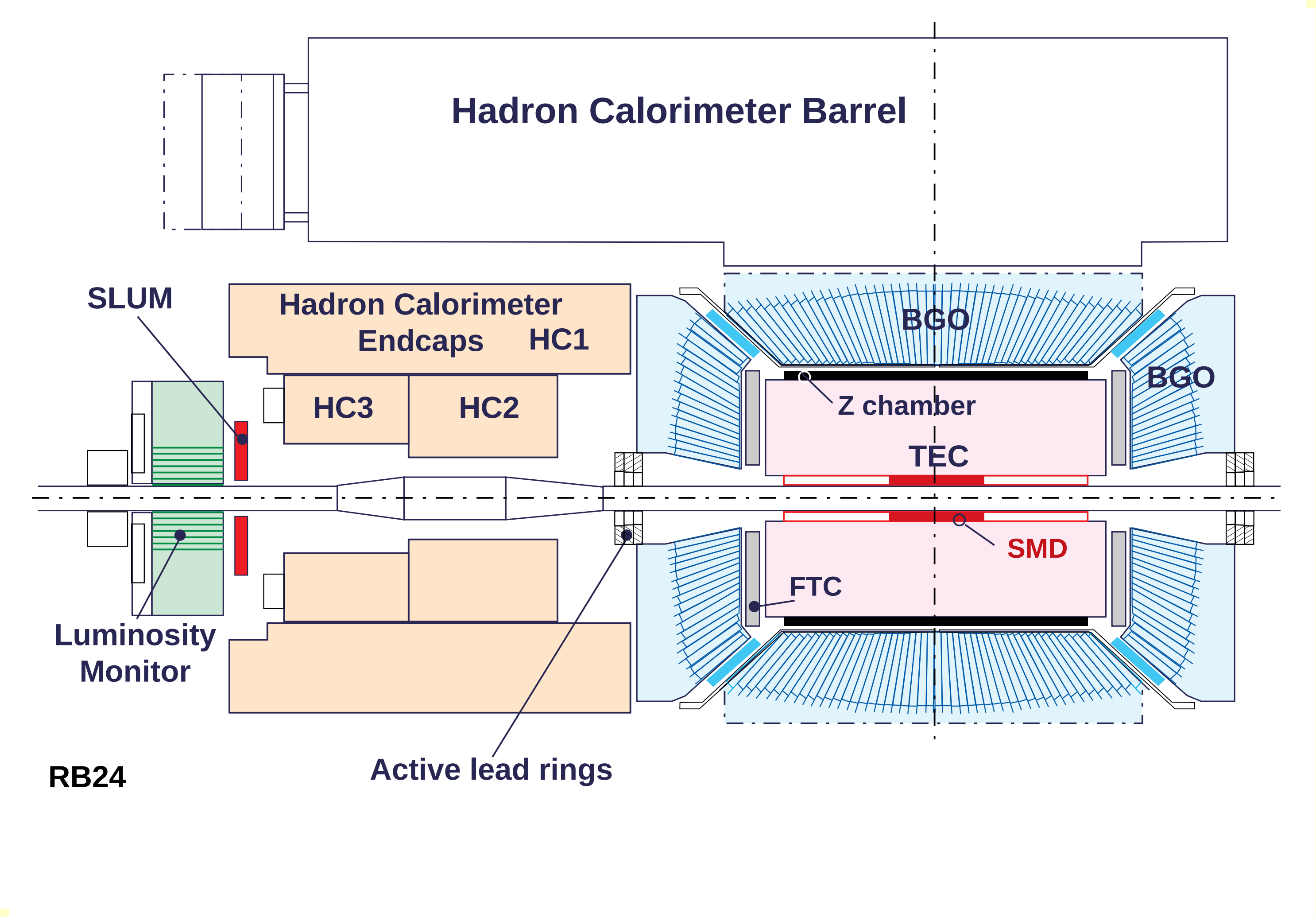
	$\sqrt{s}$ GeV	Q^2 GeV^2	$< P^2 >$ GeV^2	θ_{tag} mrad	x
L3 Low Q^2 (1)	91	1.2 - 9	0.08	26 - 66	0.002 - 0.2
L3 Medium Q^2 (2)	183	9 - 30	0.08	30 - 66	0.01 - 0.3
L3 High Q^2 Single Tag (3)	91	40 - 500	0.014	200 - 600	0.05 - 0.98
L3 High Q^2 Double Tag (3)	91	40 - 500	1 - 8	200 - 600	0.05 - 0.98

Used Sample and Cuts

	$\mathcal{L}$ pb^{-1}	Evts	Bkg	E_{tag} GeV	W_{vis} GeV
L3 Low Q^2	140	9928	355	> 35	3 - 40
L3 Medium Q^2	52	1694	71	> 70	> 3
L3 High Q^2 Single Tag	120	496	40	> 14	> 3
L3 High Q^2 Double Tag	120	43	< 2	> 14	> 3

(1) Phys. Lett. B436 (1998) 403 (2) Phys. Lett. B447 (1999) 147
(3) CERN EP 2000-044 (subm. to Phys. Lett.)

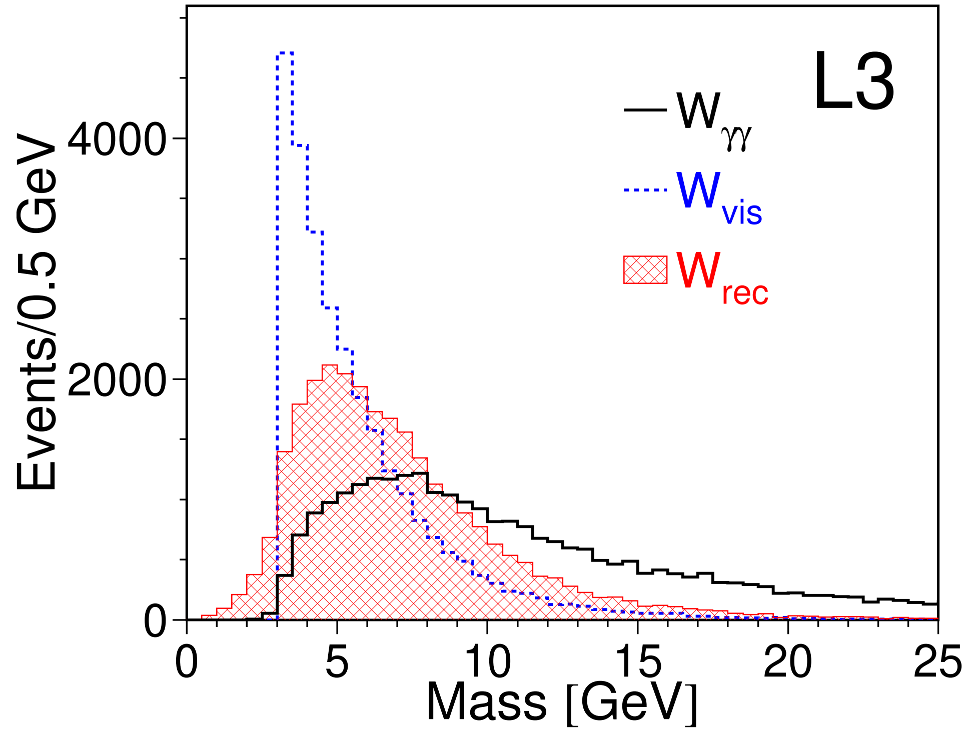
F_2^γ : Tagging in the L3-Detector



- ❑ Tagging done in the Luminosity Monitor or in the Endcaps

F_2^{γ} : Unfolding

- ❑ Problem: The final state is not completely reconstructed due to detector acceptance
  - ➪ $W_{vis} < W_{\gamma\gamma}$ and $x_{vis} < x$
- ❑ Using kinematics of the tagged electron and transverse momentum conservation can help...
  - ➪ $W_{vis} \rightarrow W_{rec}$
- ❑ ... BUT unfolding is still needed!
  - ➪ $W_{rec} \rightarrow W_{\gamma\gamma}$
  - ➪ Dependencies of the used Monte Carlos



F_2^γ : MC - Overview

Used Monte Carlo-Programs

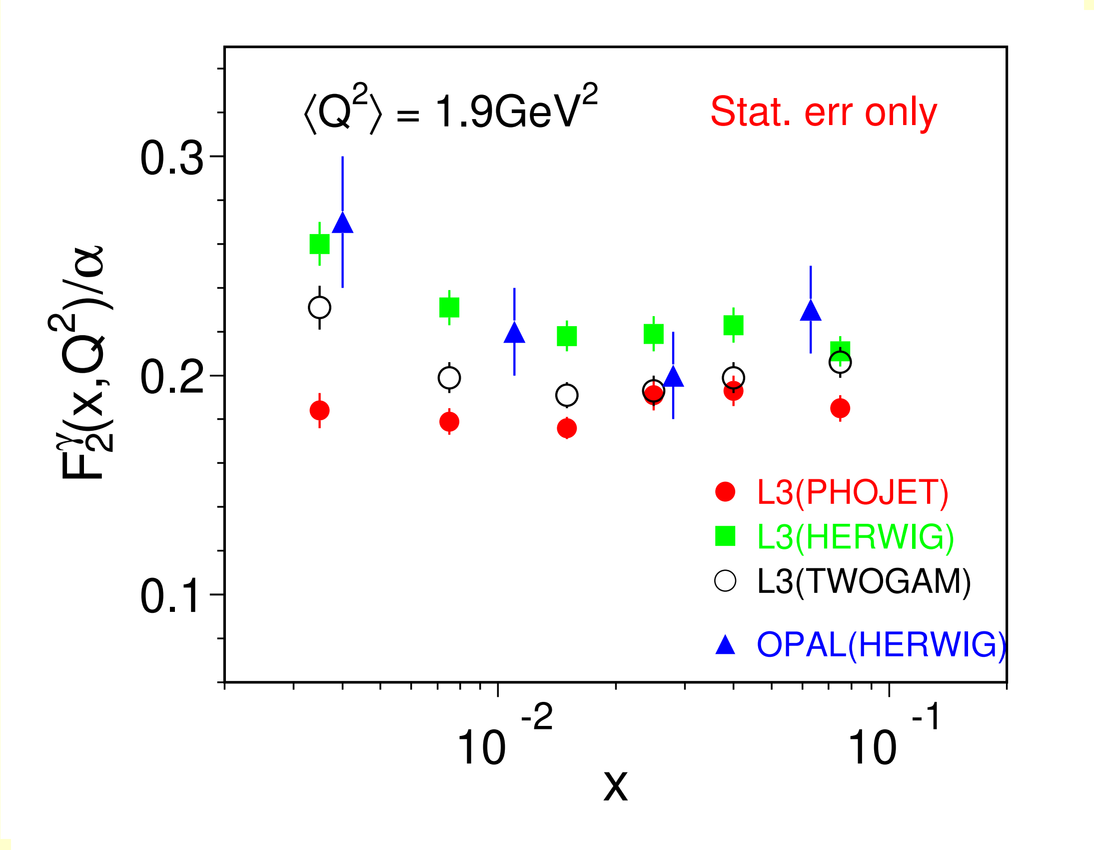
- JAMVG – Vermaseren
- TWOGAM (v1.71) – Nova, Olshevski and Todorov
- PHOJET (v1.05c) – Engel and Ranft
- HERWIG (v5.9) – Marchesini et al.

Parametrisations

- GRV-HO, Glück, Reya and Vogt (1992)
- SaS-1d, Schuler and Sjöstrand (1995, 1996)
- LAC, Levy, Abramovicz and Charchula (1991)

- All Monte Carlos contain different physical models
  - ➪ Unfolding depends on the used MC
- This is the main systematic error

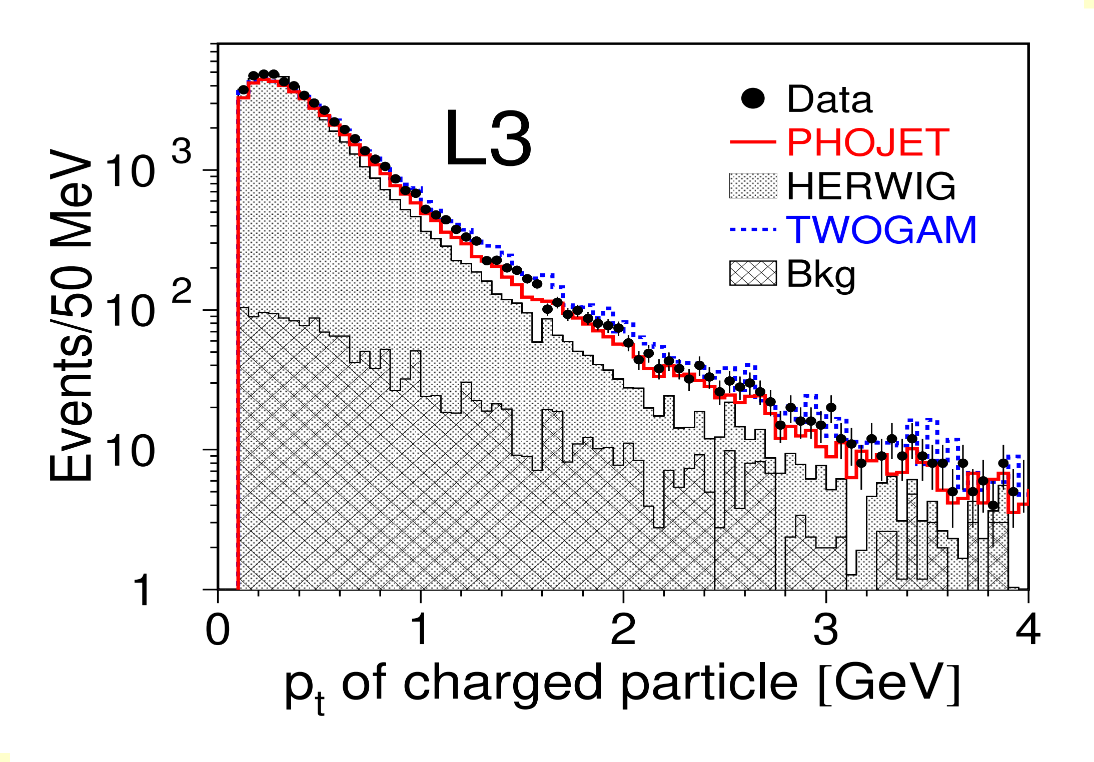
F_2^γ : Modeling Dependence



- ☐ Unfolding Matrix is specific for the used Monte Carlo
- ☐ L3 and OPAL agree well IF the same model is used
- ☐ At low x (high mass) the use of different MC's leads to differences in the unfolded values of F_2^γ of 10 to 30 %

F_2^{γ} : MC Comparison at Low Q^2

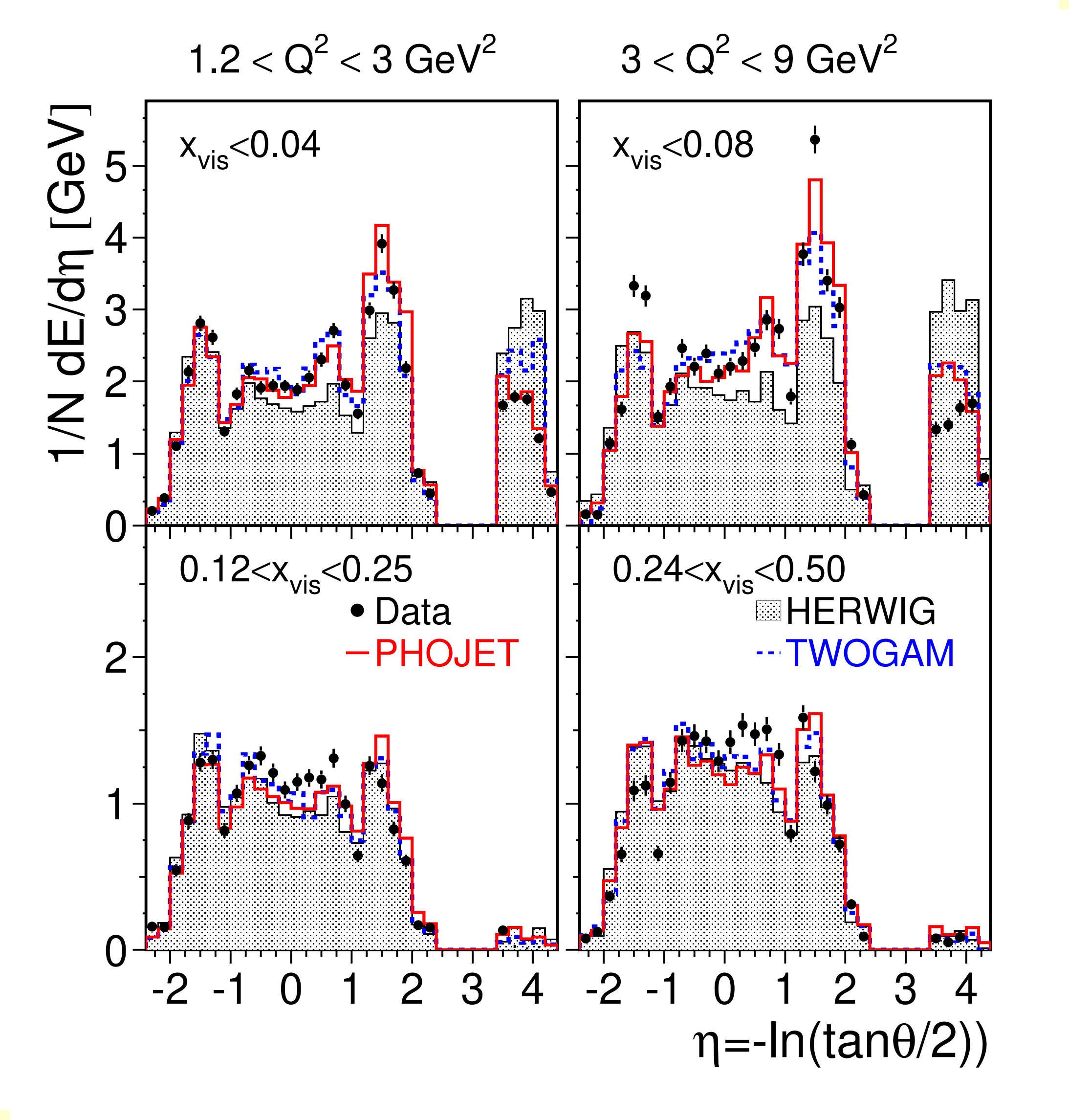
Transverse Momentum



- $1.2 < Q^2 < 9$ GeV^2
- PHOJET and TWOGAM describe well the DATA
- HERWIG will not be used

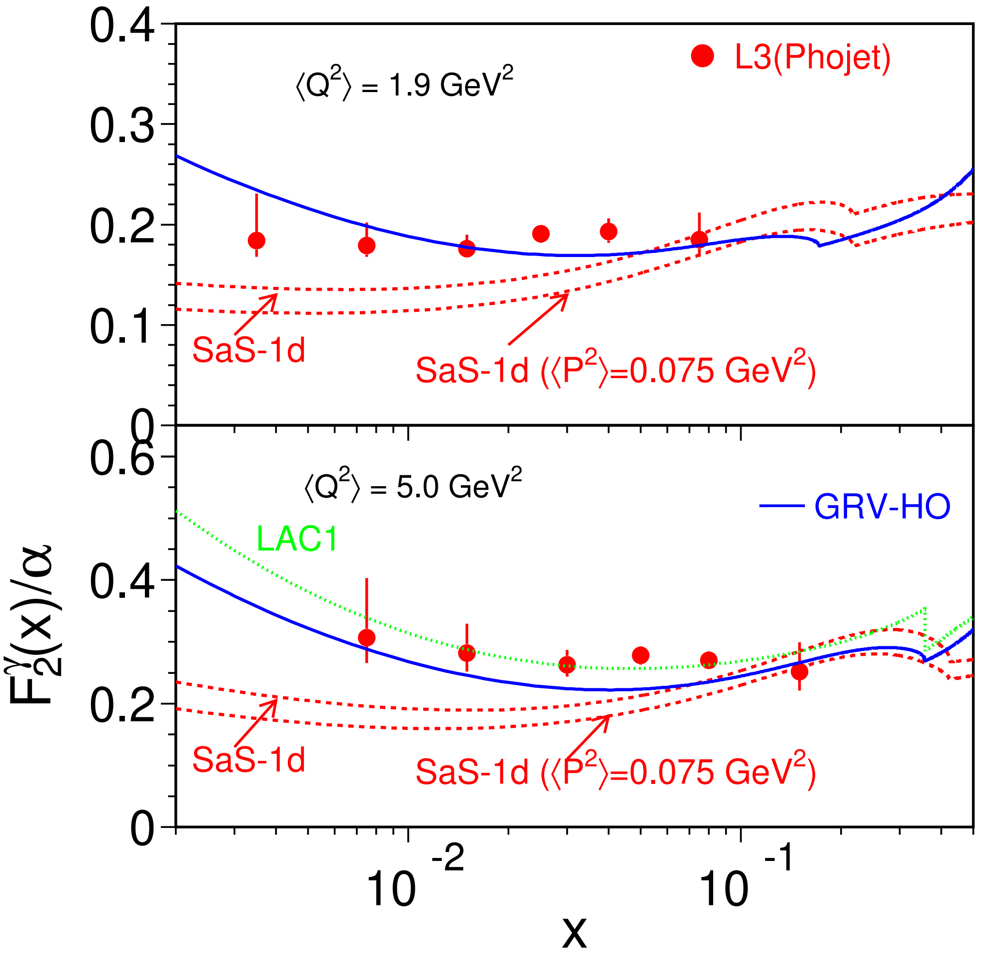
F_2^γ : MC Comparison at Low Q^2

Energy Flow



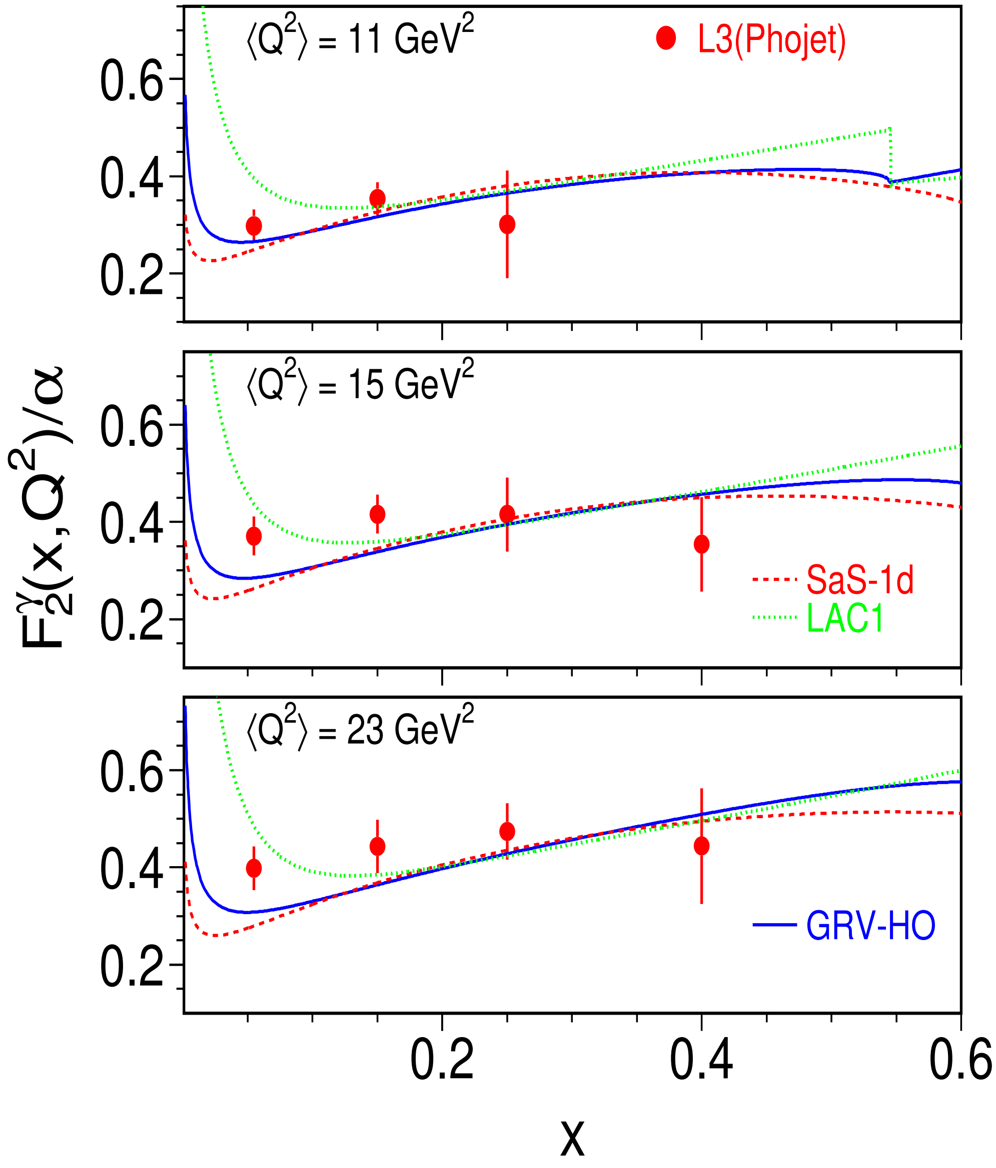
- ☐ Again PHOJET and TWOGAM describe well the DATA
- ☐ HERWIG agrees better at high x

F_2^γ : Results at Low Q^2



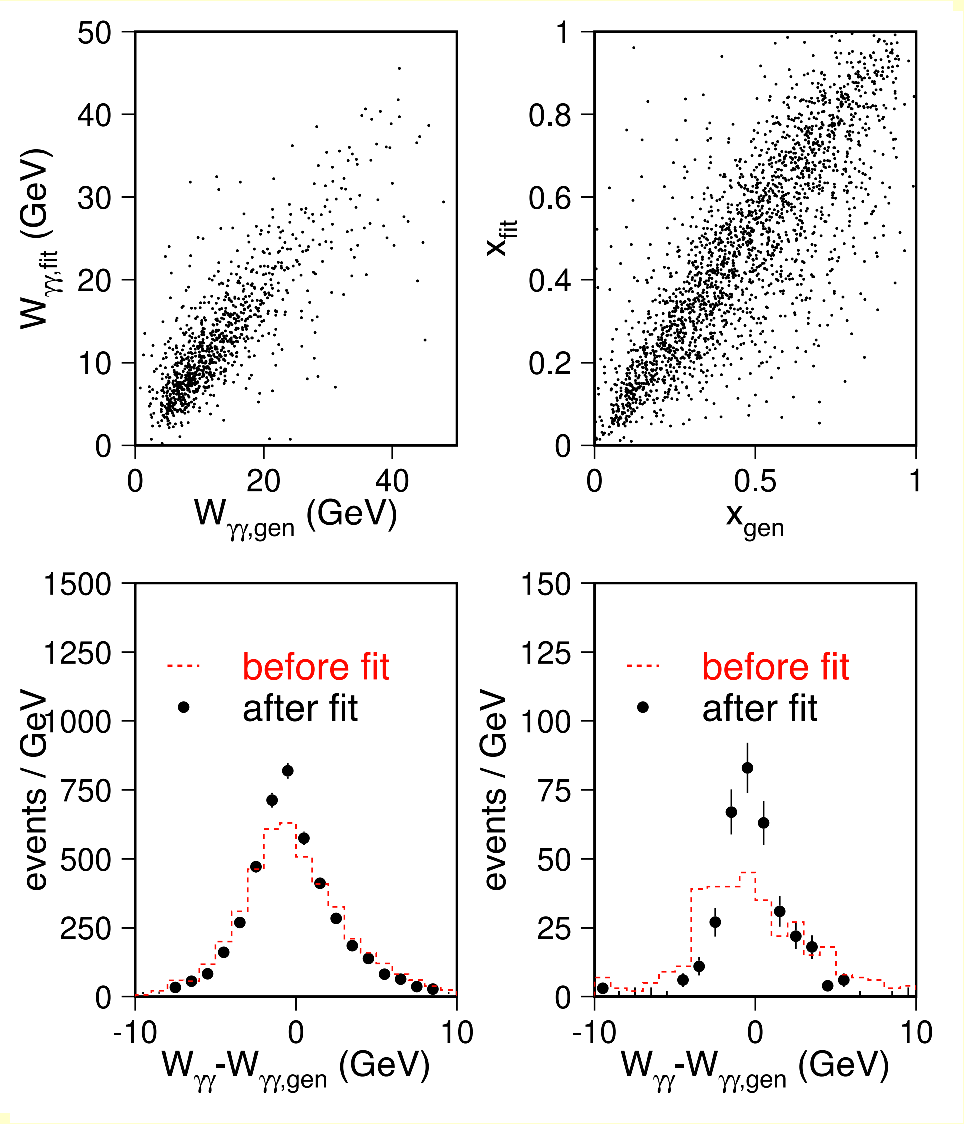
- ❑ SaS-1d lies below the data
- ❑ SaS-1d with nonzero $< P^2 >$ is even lower
- ❑ GRV-HO gives a good description at low x
- ❑ LAC1 agrees with the data at $Q^2 = 5$ GeV^2

F_2^γ : Results at Medium Q^2



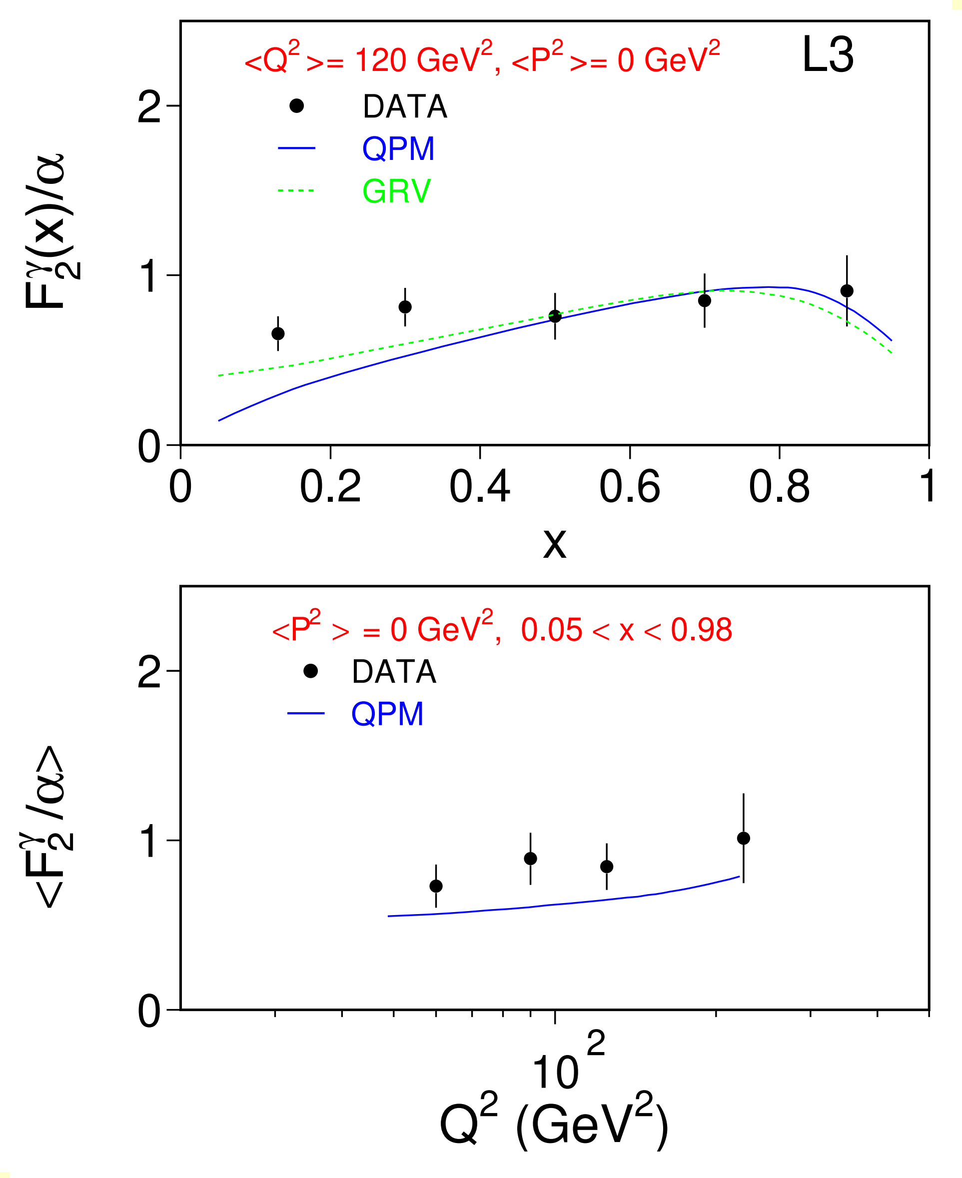
- ❑ $x > 0.1$: good agreement between data and GRV-HO, SaS-1d and LAC1
- ❑ $x < 0.1$: data lie between LAC1 and GRV-HO

F_2^γ : W_{fit} and x_{fit} at High Q^2



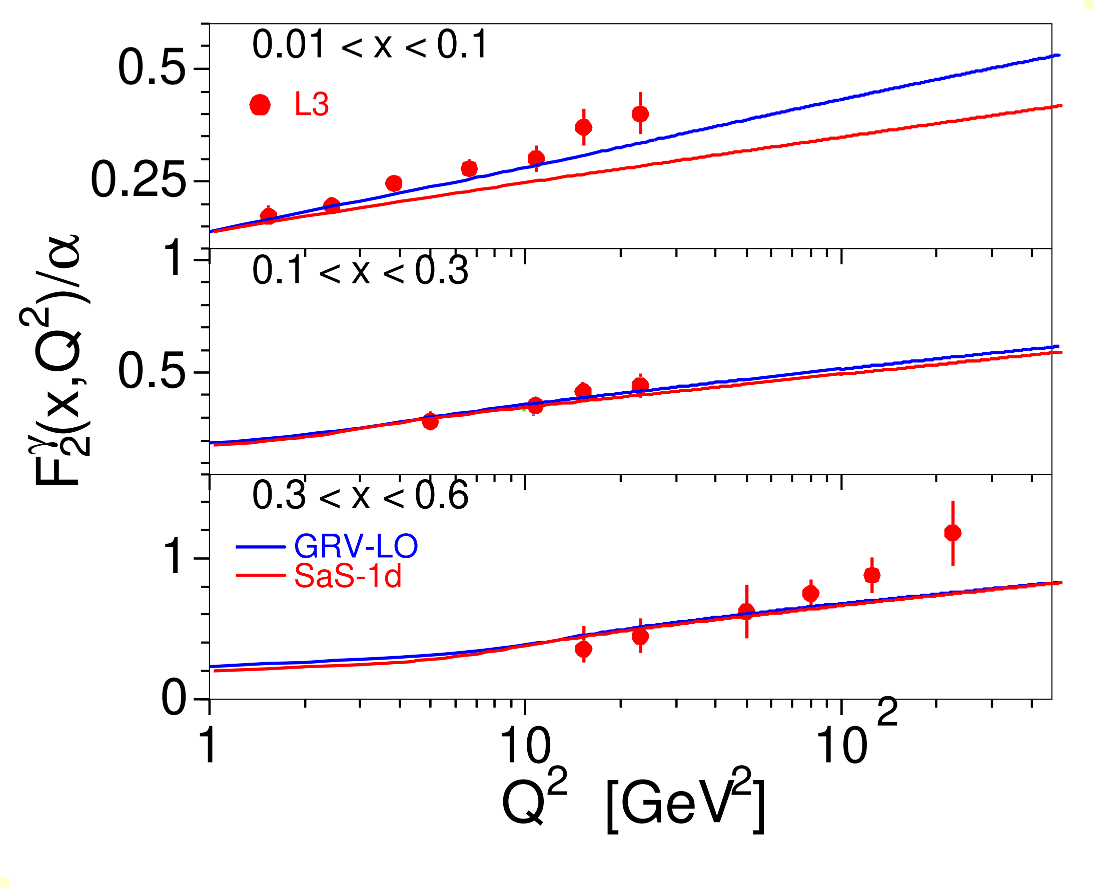
- Vermaseren Monte Carlo is used at $\sqrt{s} = 91$ GeV, $< Q^2 >= 120$ GeV^2, $P^2 = 0$
- Linear Relation simplifies unfolding
  - ➪ Little extrapolation is needed!
- PHOJET and TWOGAM produce similar correlations

F_2^γ : Results at High Q^2



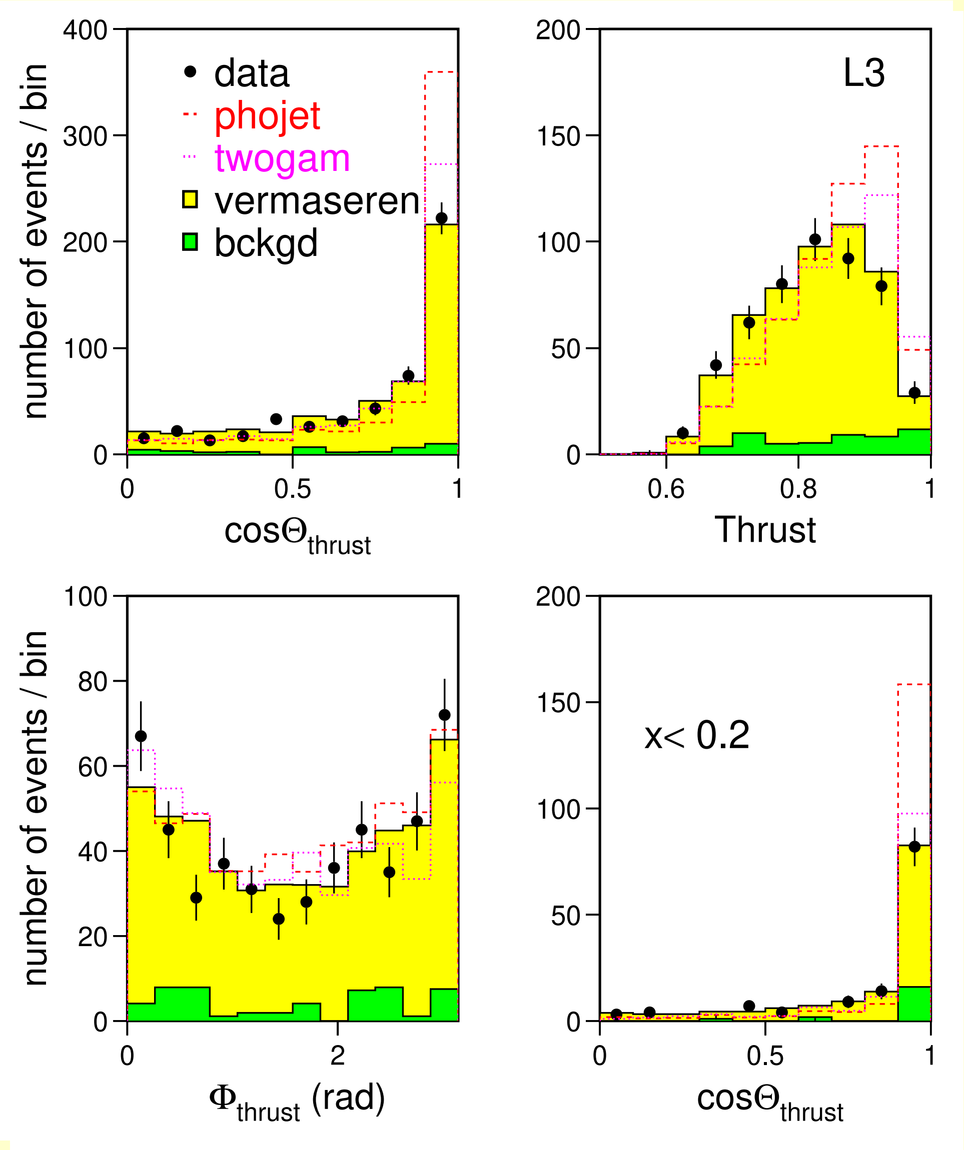
- QPM describes F_2^γ for $x > 0.4$, is insufficient for low x
- GRV-HO lies below the data for $x < 0.4$
- Q^2-dependence is described, but data is higher (QPM model depends on the assumed quark masses)

F_2^γ : Q^2-Evolution



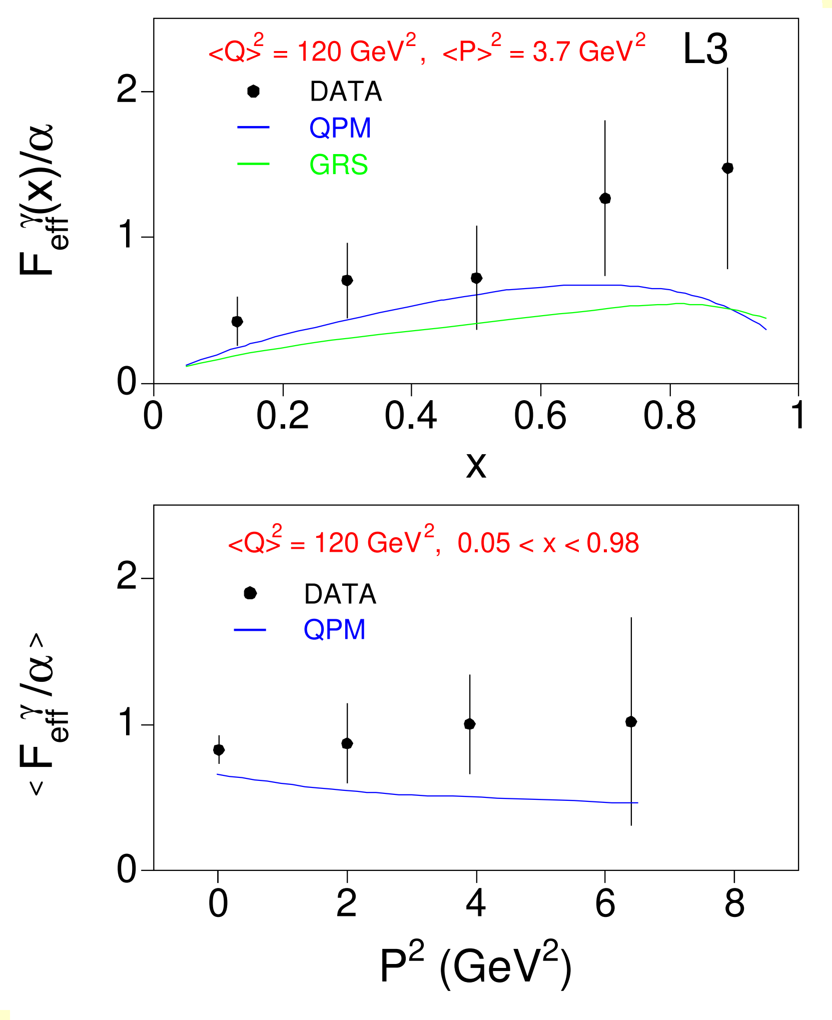
- ☐ The Q^2 evolution agrees with the QCD prediction

F_2^γ : Diffraction



- ❑ MC normalized to Data - Background
- ❑ Thrust is well described by Vermaseren
- ❑ PHOJET and TWOGAM align the particles along the thrust axis
- ❑ Less forward activity is seen in the data then predicted by PHOJET and TWOGAM

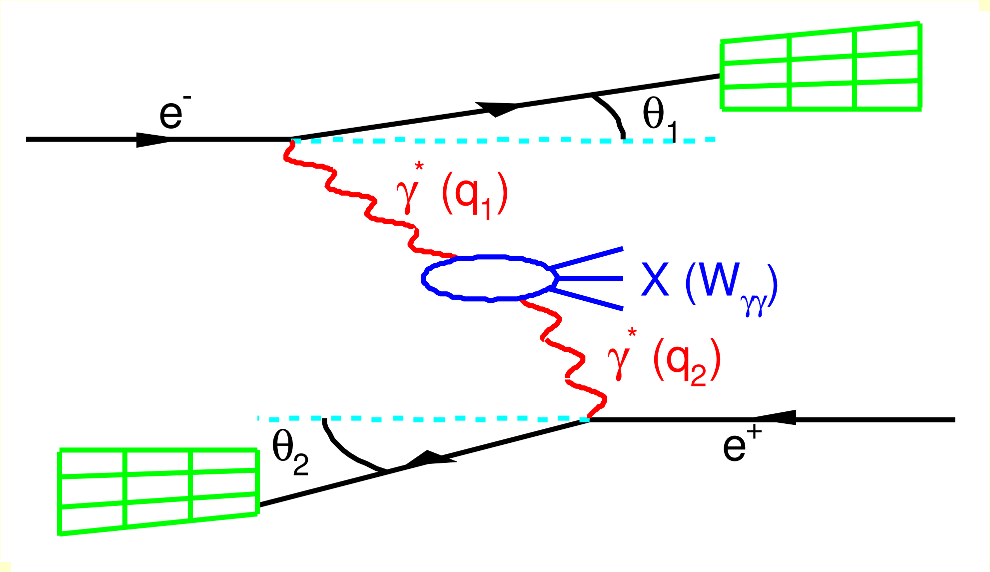
F_{eff}^{γ} : Double Tag



- ☐ $F_{eff}^{\gamma} \propto (\sigma_{TT} + \sigma_{LT} + \sigma_{TL} + \sigma_{LL})$
- ☐ An 'asymmetric' double tag is used
  ($< Q^2 >= 120$ GeV², $< P^2 >= 3.7$ GeV²)
- ☐ The QCD-calculation (GRS) contains only transverse photons
- ☐ Overall the data lie somewhat above the predictions from QPM and GRS

$\sigma_{\gamma^*\gamma^*}$: Double Tag

Kinematics

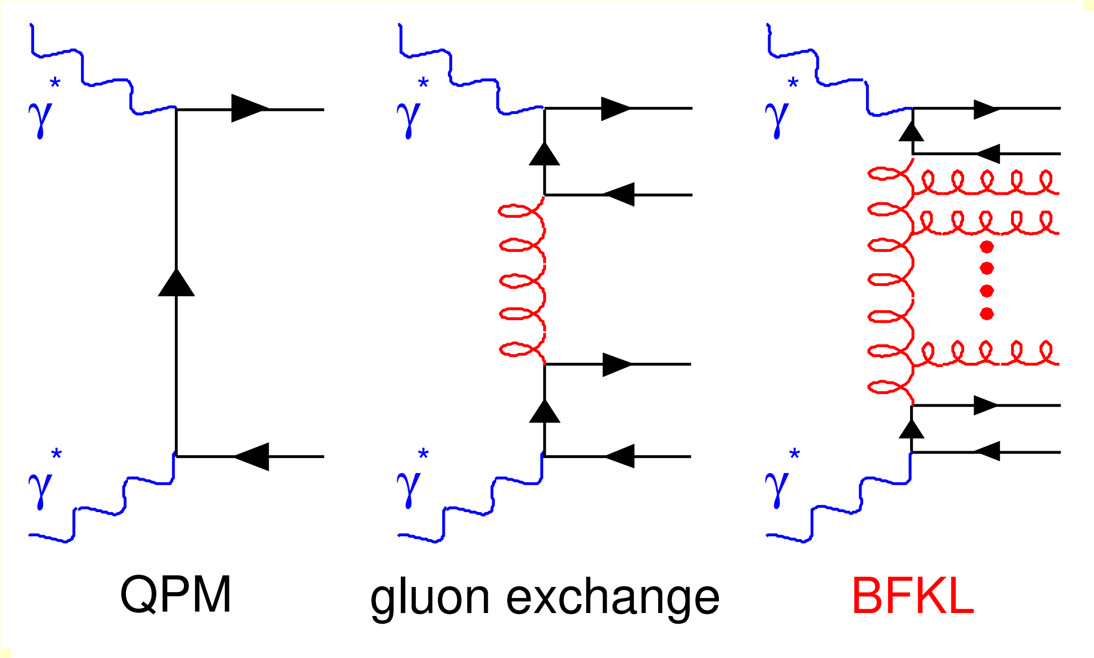


$$Q_i^2 = -q_i^2 = 2E_b E^i_{tag}\,(1-\cos(\theta_i))$$

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

- ❑ Both electrons are seen in the detector
  - ➪ $\gamma^*\gamma^*$ collisions (double tag)
- ❑ $W_{\gamma\gamma}$ can be measured directly
  - ➪ No unfolding needed
- ❑ Models include QED (QPM), non-perturbative QCD (VDM) and perturbative QCD

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



- Non-Perturbative part (VDM) vanishes with large Q^2
- QED (QPM) process is well known
- pointlike coupling, no unknown parameters
  - We can calculate the process
  - In Leading order approximation:

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

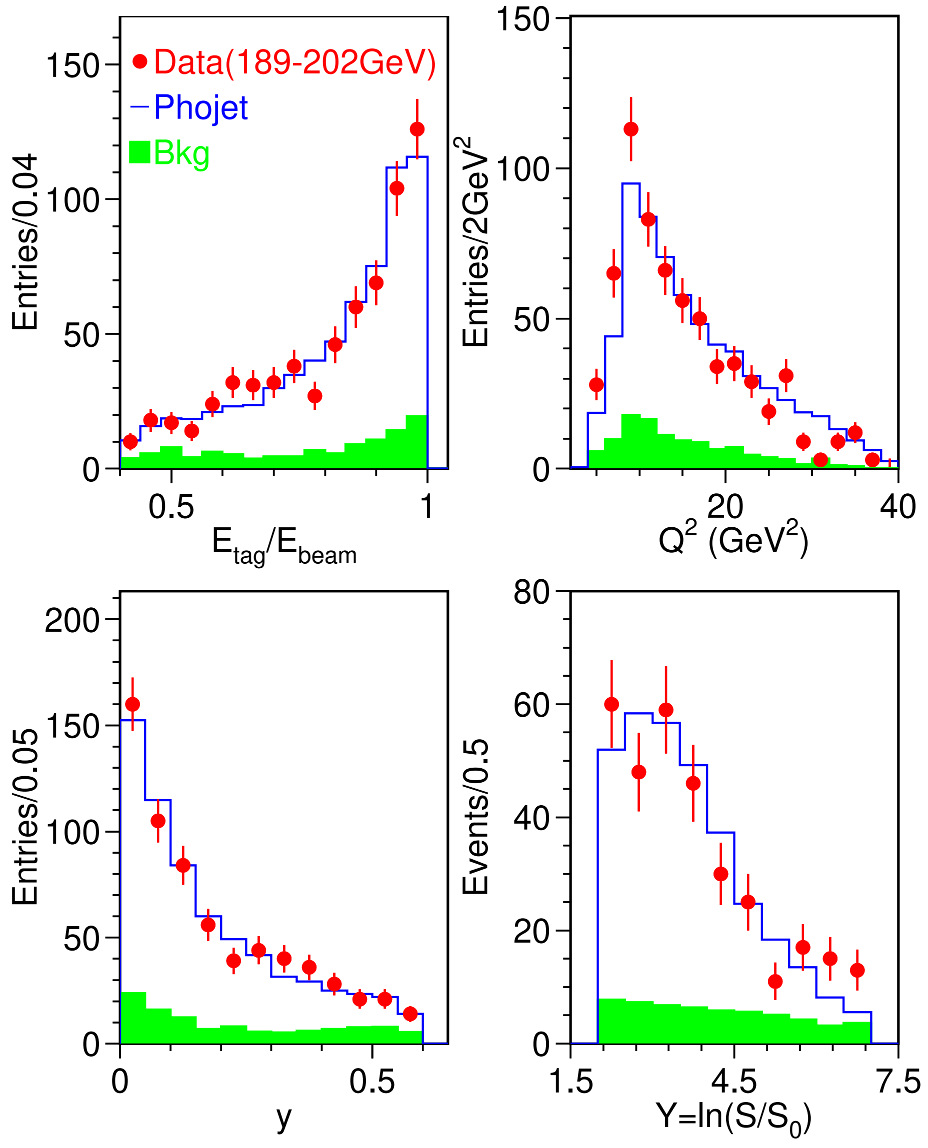
with $s_0 = \frac{\sqrt{Q_1^2 Q_2^2}}{y_1 y_2}$ and $\alpha_P - 1 = 4 \ln 2 \frac{N_c \alpha_s}{\pi}$

- Good scenario to test BFKL!

$\sigma_{\gamma^*\gamma^*}$: Available Data

- ❑ L3: 3 datasets
  91 GeV, $\mathcal{L} = 140$ pb^{-1} (Phys. Lett B453 (1999) 94);
  183 GeV, $\mathcal{L} = 53$ pb^{-1} (ditto);
  NEW DATA: 189 - 202 GeV, $\mathcal{L} = 401$ pb^{-1}
  - ➪ Used Cuts:
  - ➪ $E_{tag} > 30$ GeV and 30 mrad $< \theta_{tag} <$ 66 mrad
  - ➪ $2 < Y = \ln(s/s_0) < 6$ (7 at 189 - 202 GeV)
- ❑ OPAL:
  - ➪ Ongoing analysis, results to be expected soon
- ❑ Backgrounds
  - ➪ $e^+e^- \to e^+e^-\tau^+\tau^-$
  - ➪ misidentified single tag two-photon events
  - ➪ $e^+e^- \to q\bar{q}$

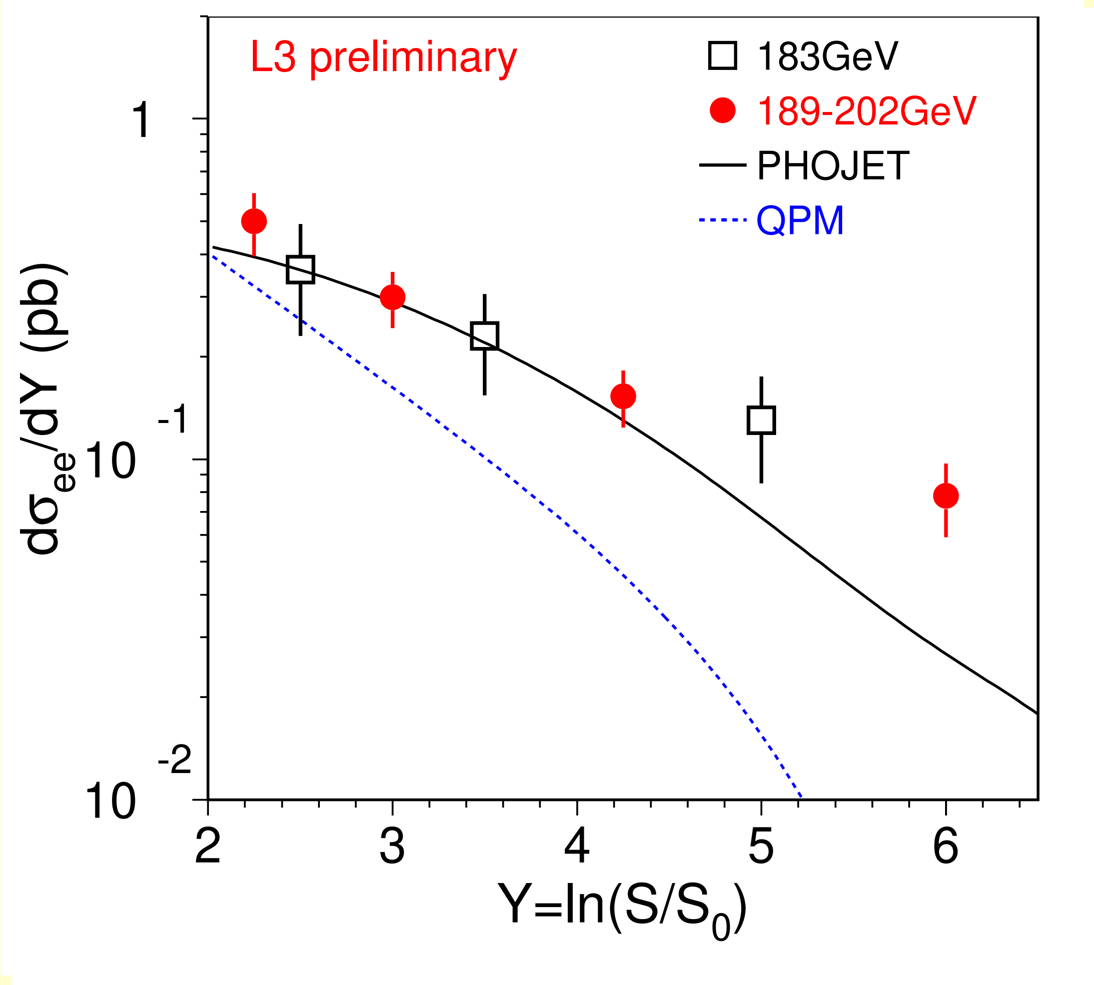
$\sigma_{\gamma^*\gamma^*}$: L3 - MC/DATA



- Reasonable Agreement with PHOJET
- 137 events at 91 GeV ($< Q^2 >= 3.5$ GeV^2)
- 34 events at 183 GeV ($< Q^2 >= 14$ GeV^2)
- 324 events at 189 - 202 GeV ($< Q^2 >= 15$ GeV^2)

$\sigma_{\gamma^*\gamma^*}$: L3-Results

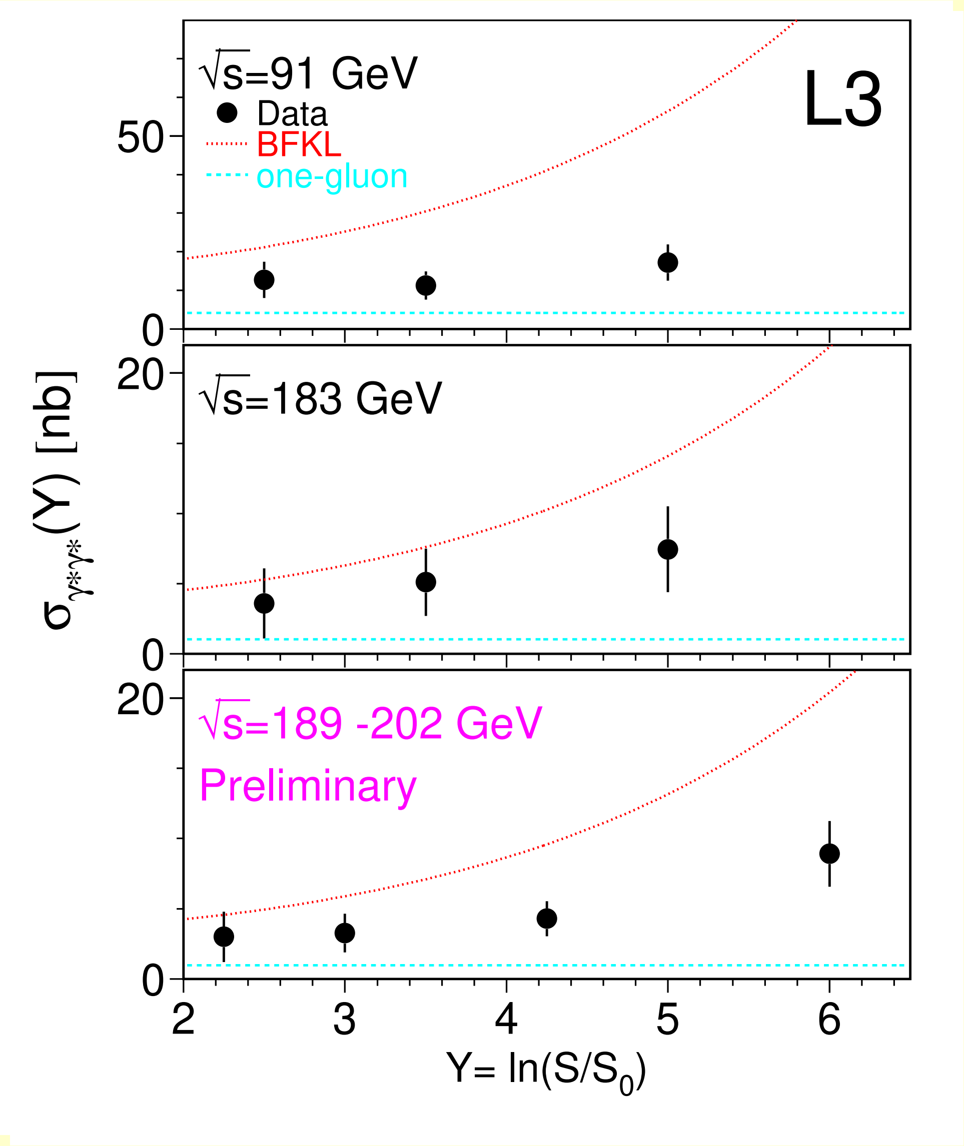
$\sigma(e^+e^- \to e^+e^-$hadrons$)$



- ❑ Data is consistent with PHOJET
  - ➪ i.e. LO QCD with Structure Functions
  - ➪ only high Y region shows some discrepancy
- ❑ QPM is insufficient to describe the Data
- ❑ $\sigma_{ee} = 0.94 \pm 0.05 \pm 0.14$ pb $(\sigma_{PHOJET} = 0.75$ pb$)$

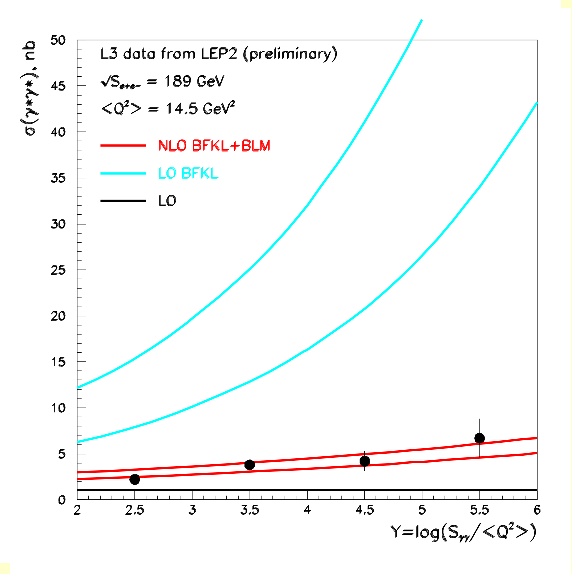
$\sigma_{\gamma^*\gamma^*}$: L3-Results

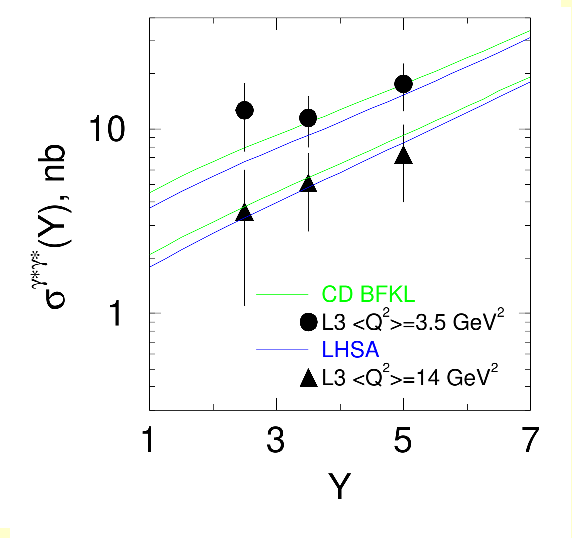
$\sigma_{\gamma^*\gamma^*}$



- ❑ $\sigma_{ee} = \mathcal{L} \times \sigma_{\gamma^*\gamma^*}$
- ❑ We subtract the QPM contribution
- ❑ One gluon exchange process is insufficient
- ❑ LO BFKL (asymptotic) is too high

$\sigma_{\gamma^*\gamma^*}$: L3-Results





- ☐ Improved NLO BFKL calculations agree with L3-Data!
  - Calculations provided by V. Kim
  - NLO BFKL + BLM optimal scale – Brodsky, Fadin, Kim, Lipatov and Pivovarov hep-ph/9901229
  - Color Dipole BFKL – Nikolaev, Speth and Zoller hep-ph/0001120

F_2^γ : Conclusions

❑ The Hadronic Photon Structure Function F_2^γ has been measured at L3 in the range of
1 GeV$^2 < Q^2 <$ 500 GeV^2
and $0.002 < x < 1$

❑ Unfolding is needed to get the 'true' $W_{\gamma\gamma}$ out of W_{vis}
Use of p_t (low - medium Q^2) or kinematic fitting (high Q^2) improve the description significantly

❑ In the low and medium Q^2-range, GRV-HO is able to describe the data, but is too low for $x < 0.1$

❑ At high Q^2 and low x the perturbative theory is lower than the data

❑ The Q^2 evolution of F_2^γ and F_{eff}^γ agrees with QCD

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

- ❑ Double tag $\gamma^*\gamma^*$ collisions have been measured at L3 up to
  $< Q^2 >= 15$ GeV^2 and $\ln(s/s_0)(\approx \frac{W^2_{\gamma^*\gamma^*}}{Q^2}) = 7$
- ❑ The MC model PHOJET (containing direct and resolved processes) gives a reasonable description of the data
- ❑ LO BFKL predictions are too high
  - ➪ very sensitive to the energy scale s_0
- ❑ Improved NLO BFKL calculations agree with the data