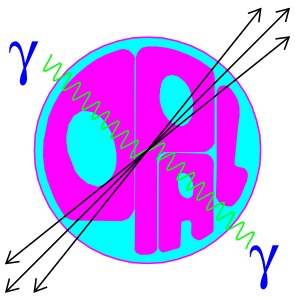
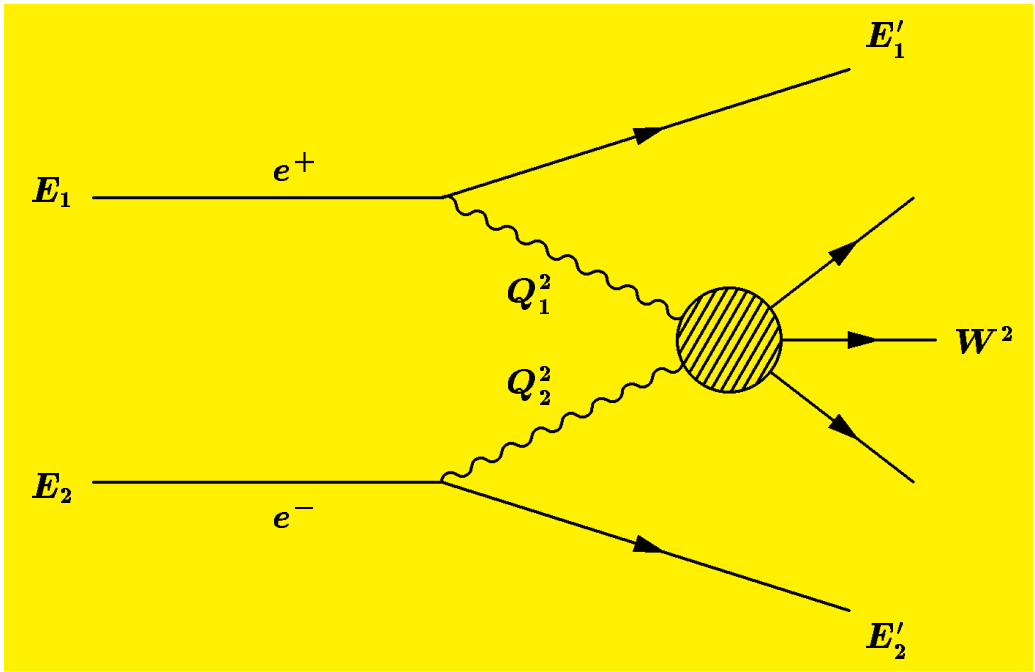
Dijet Production in Photon-Photon Collisions at $\sqrt{s_{ee}} = 161$ and 172 GeV

PHOTON '97, Egmond aan Zee

Roland Bürgin, Freiburg University

for the  -Collaboration

- Introduction
- Separation of event classes
- Angular distributions
- Inclusive two-jet cross-section
- Conclusions



$$Q_i^2 \approx 2E_i E_i'(1 - \cos\Theta_i)$$

$$W^2 = s_{\gamma\gamma} = \left(\sum_h E_h\right)^2 - \left(\sum_h \vec{p}_h\right)^2$$

1. $e\gamma$ scattering ("single tagged")

   $Q_1^2 >> 0$ and $Q_2^2 \approx 0$ (or v. v.)

2. $\gamma\gamma$ scattering ("anti-tagged")

   $Q_1^2 \approx 0$ and $Q_2^2 \approx 0$

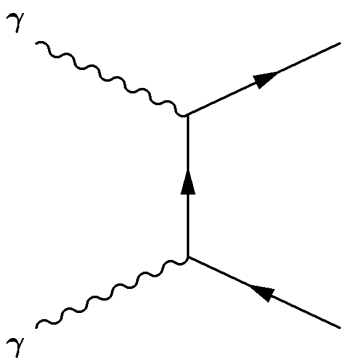
Monte Carlo Generators

PYTHIA 5.722 and PHOJET 1.05

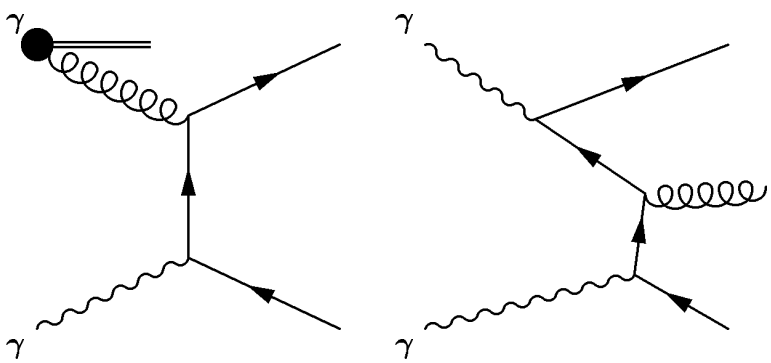
- Photon energy spectrum with the Equivalent Photon Approximation (EPA)
- Leading order (LO) QCD matrix elements
- Hard and soft processes
- Total cross sections from Regge models
- Initial and final state parton radiation
- Fragmentation done by JETSET 7.408
- Multiple interactions

Leading order $\gamma\gamma$ interactions

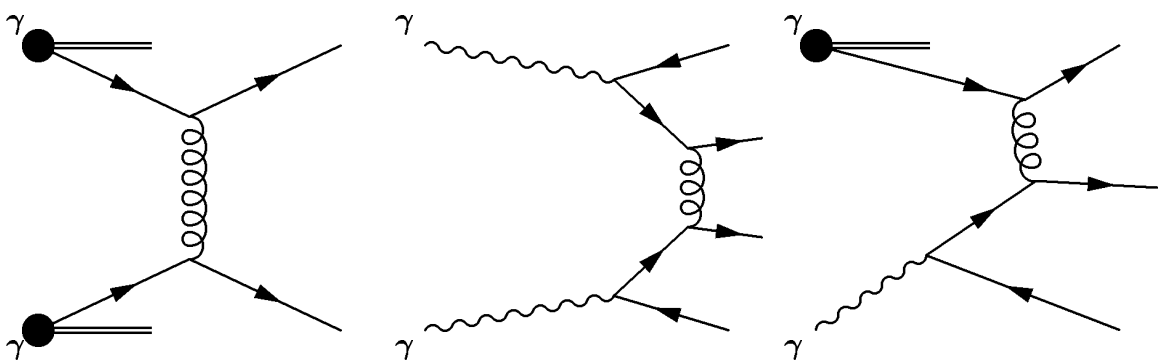
Direct:



Single-Resolved:



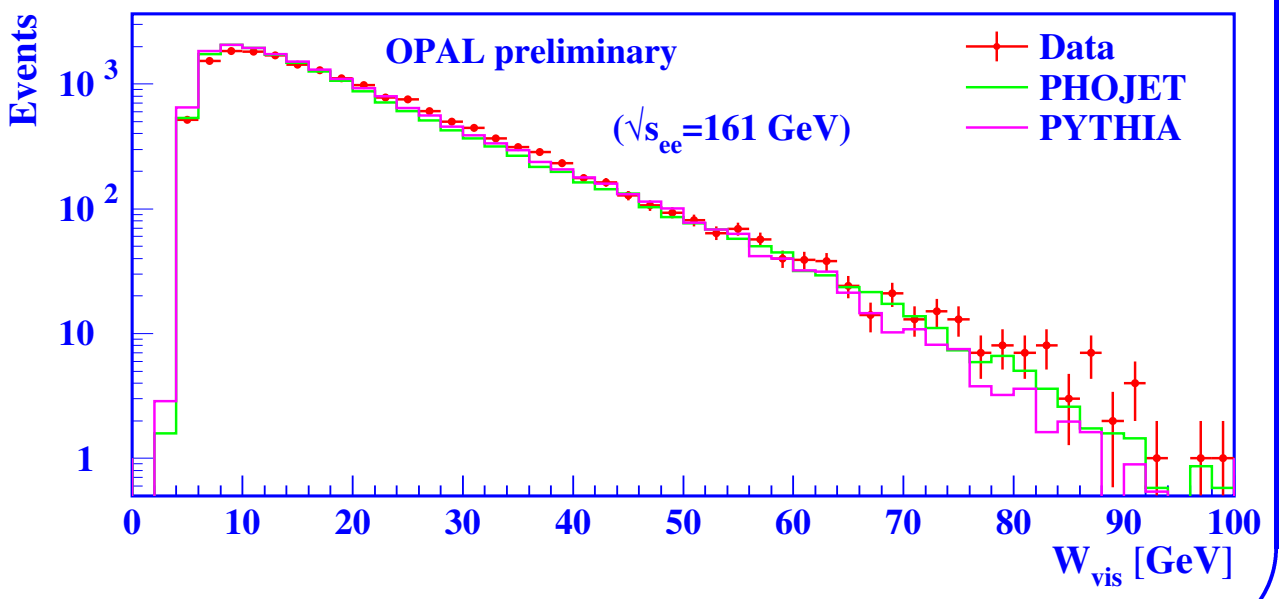
Double-Resolved:



Event Selection at LEP 2

- $W_{\mathrm{ECAL}} > 3$ GeV
- Energy sum in calorimeters less than 45 GeV
- Missing transverse energy less than 5 GeV
- $n_{\mathrm{ch}} > 4$
- No electron tags in forward calorimeters

$$W_{\mathrm{vis}} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i\right)^2}$$



Cone jet algorithm

Cone radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

pseudo-rapidity $\eta = -\ln \tan \frac{\theta}{2}$

azimuthal angle ϕ

$$R = 1 \quad E_T^{\text{jet}} > 3 \text{ GeV} \quad |\eta^{\text{jet}}| < 2$$

- **Detector:**
  - **charged tracks**
  - **calorimeter clusters**
- **Monte Carlo Generator:**
  - **primary hadronic multiplicity**

Selected dijet events

After event selection and jet finding

2681 dijet events remain in 20.0 pb^{-1}

background processes:

- **e$^+$e$^-$** $\rightarrow (\gamma^*, \mathrm{Z}^0)$

  $\rightarrow$ **hadrons**(γ)**: 1.2 %**

- $e\gamma \rightarrow e+$**hadrons**

  $(Q^2 > 1.0\ \mathrm{GeV}^2)$**: 0.2 %**

- **Negligible background from beam-gas and beam-wall interactions**

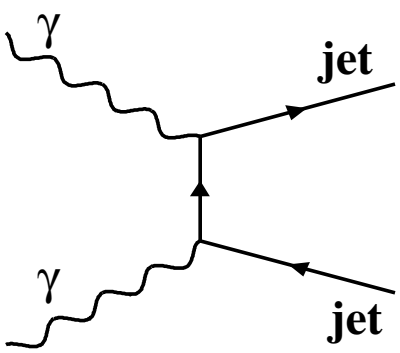
$\langle Q^2 \rangle$ **of selected Monte Carlo events:**

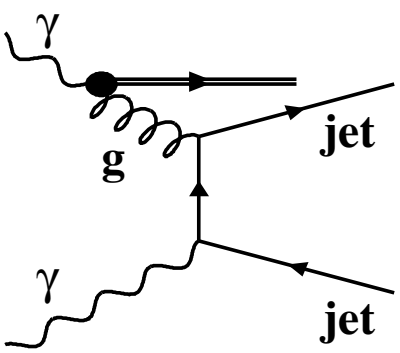
0.06 **GeV**^{2}

Direct and resolved processes

$$x_\gamma^{\pm} = \frac{\sum_{\text{jets=1,2}} (E \pm p_z)}{\sum_{\text{hadrons}} (E \pm p_z)}$$

'Fraction of photon momentum participating in the hard interaction'



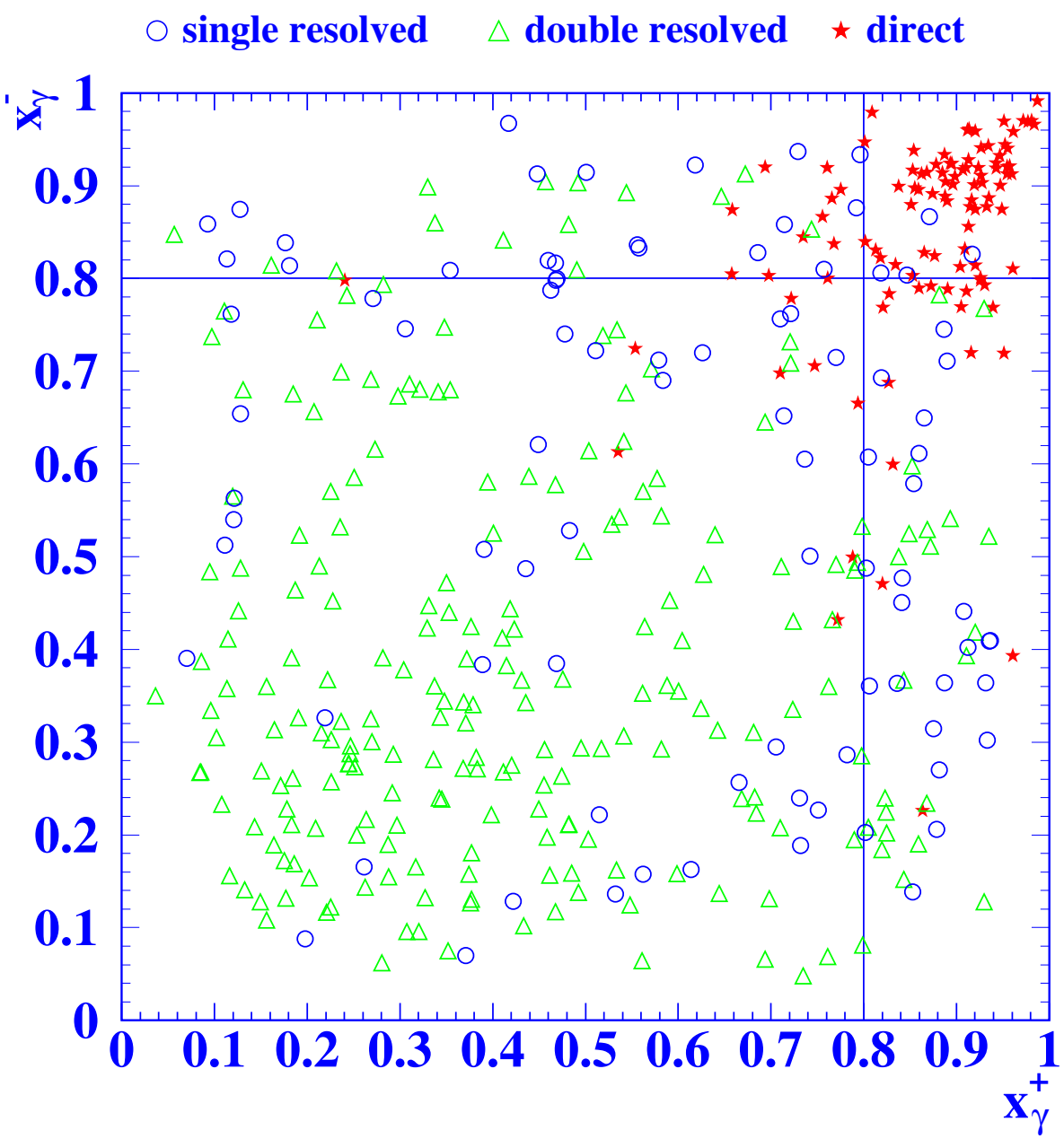


$x_\gamma^+ = 1$ — **Direct events (no remnant jet)**

$x_\gamma^+ < 1$ — **Resolved events**

Smearing due to detector, hadronization and higher order QCD (gluon radiation)

Separation of event classes



select double-resolved events: $x_\gamma^\pm < 0.8$

select direct events: $x_\gamma^\pm > 0.8$

Energy flow around jet axes

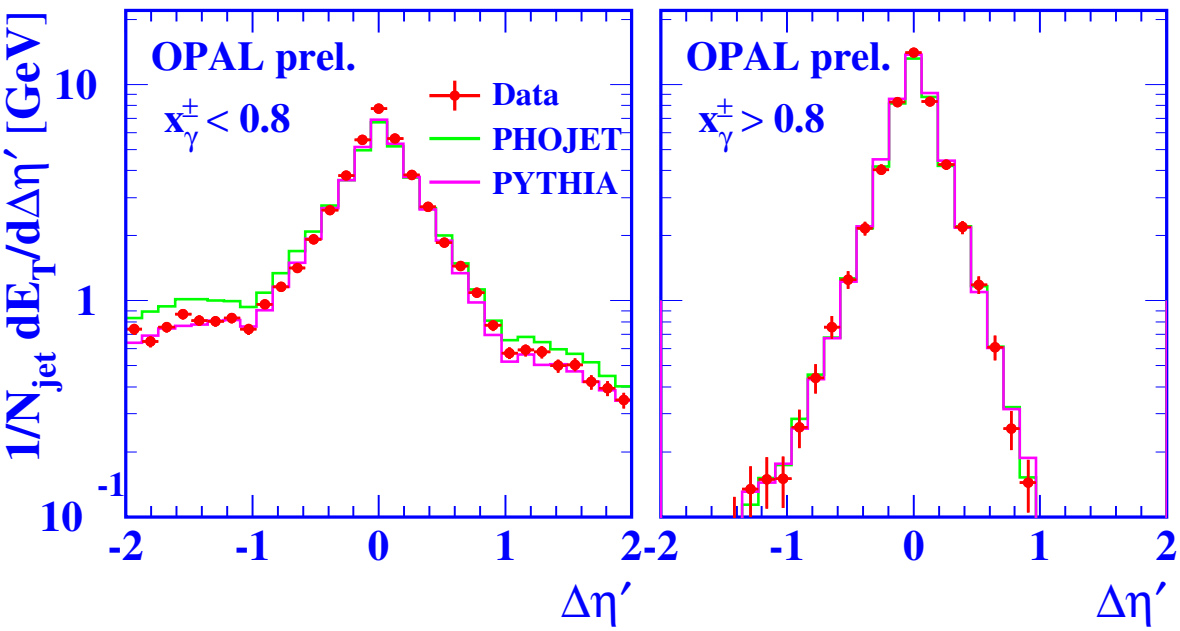
$$\frac{1}{N_{\mathrm{jet}}}\frac{dE_T}{d(\Delta\eta')}$$

$$\Delta\eta' = \pm(\eta - \eta^{\mathrm{jet}})$$

Always more remnant at $\Delta\eta' < 0$

"double resolved" $x_\gamma^{\pm} < 0.8$

"direct" $x_\gamma^{\pm} > 0.8$

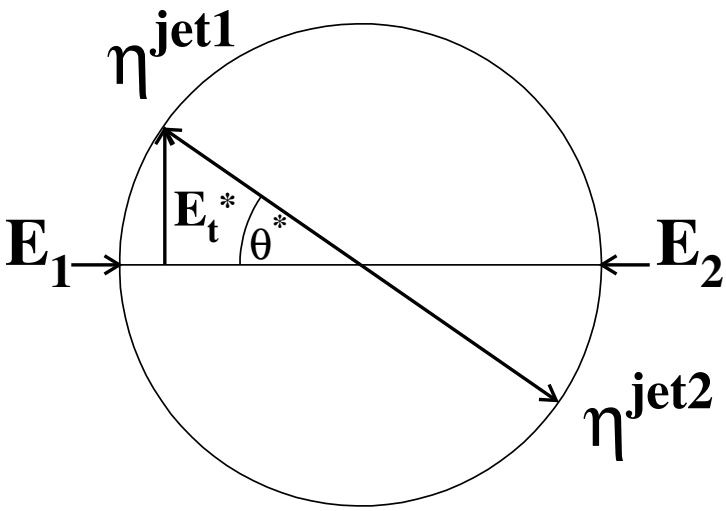


Integrated over $|\Delta\phi| < \pi/2$

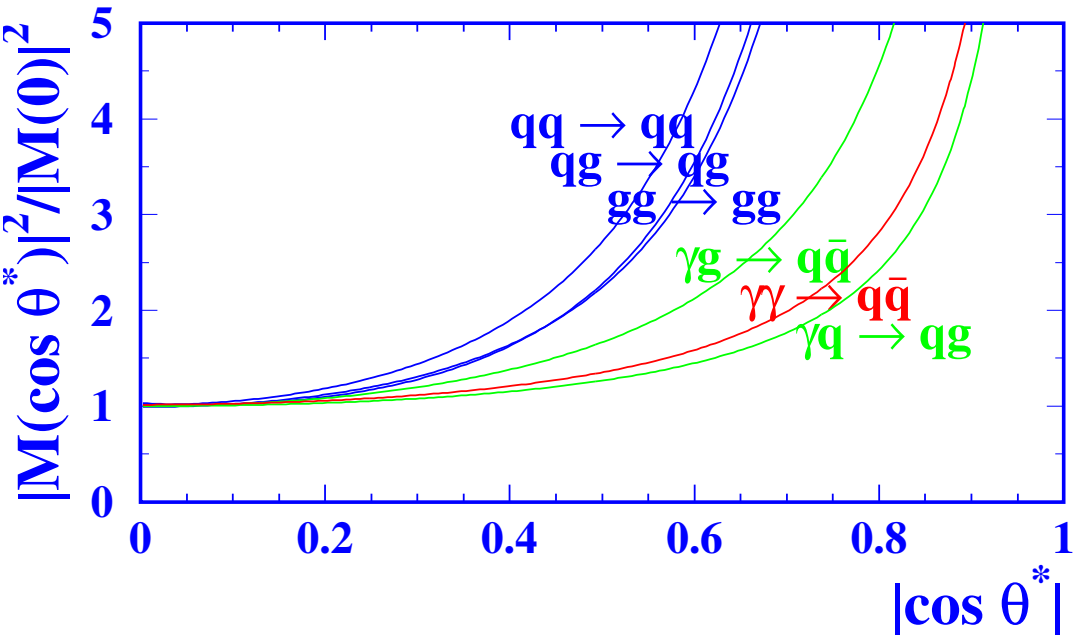
Parton dynamics

Parton scattering angle θ^*:

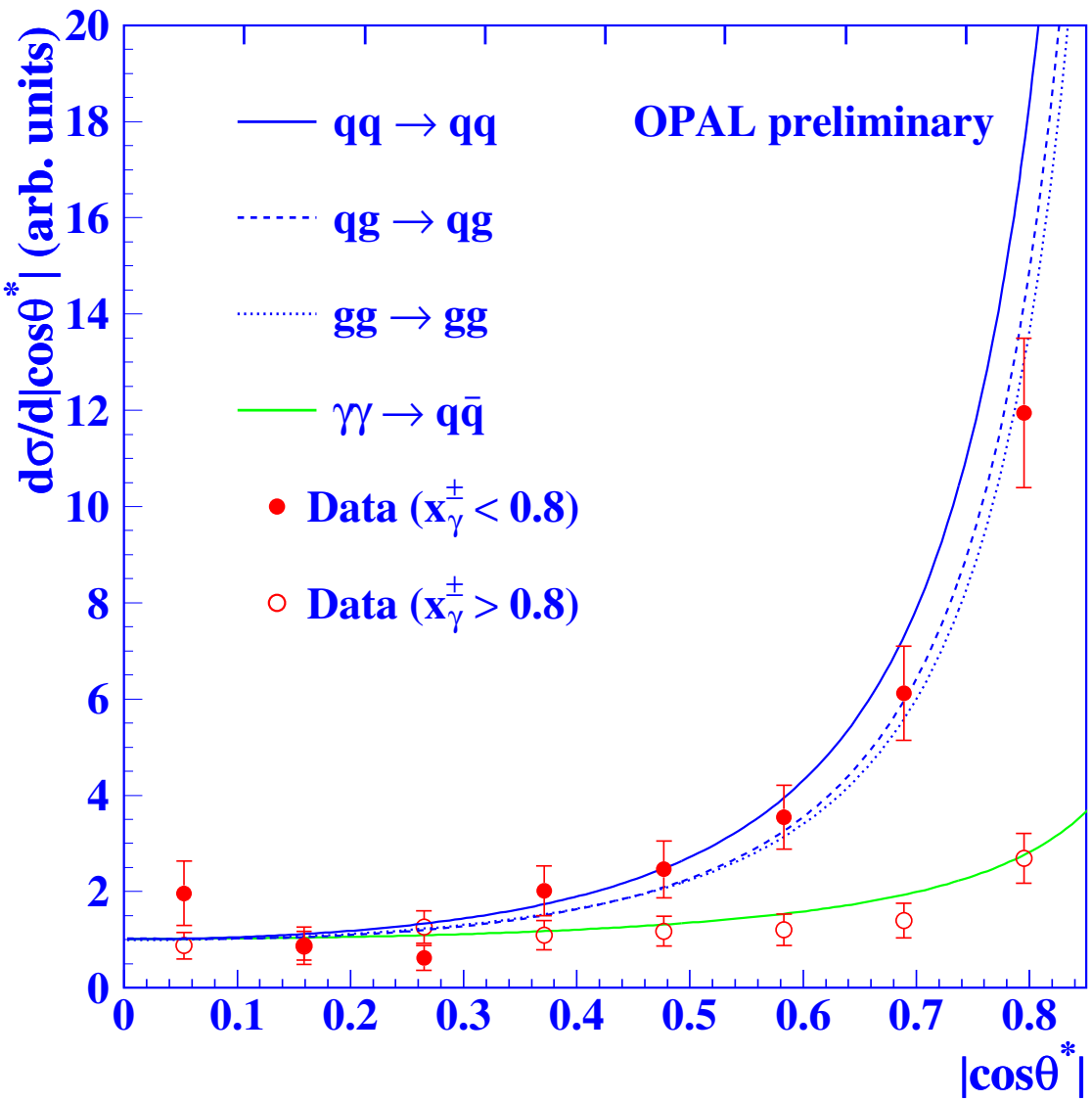
$$\cos\theta^* = \tanh\frac{\eta^{jet1}-\eta^{jet2}}{2}$$



QCD prediction of different matrix elements



Parton scattering angle



LO QCD prediction agrees well with data

samples of direct and double resolved events

Inclusive NLO jet cross sections

T. Kleinwort and G. Kramer,

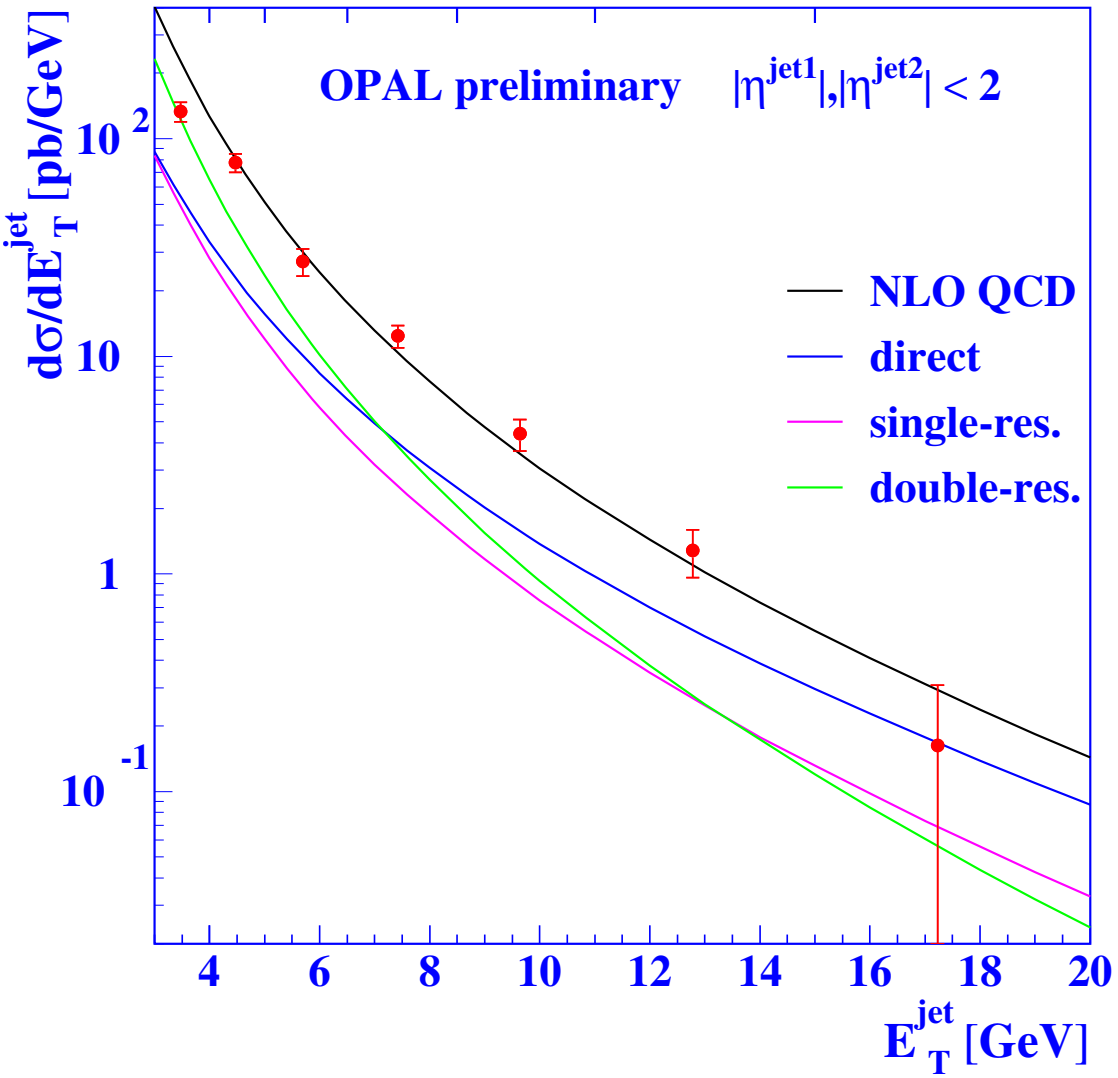
DESY-96-035 (1996) and Phys. Lett. B370 (1996) 141

$$\frac{d\sigma^D}{dE_T d\eta} = \left(\frac{d\sigma^{\gamma\gamma\to jet+jet}}{dE_T d\eta}\right)_{LO} + \frac{\alpha_s(\mu)}{2\pi} K^D(R,M)$$

$$\frac{d\sigma^{SR}}{dE_T d\eta} = \sum_{i=q,G} \int dx_1 F_{i/\gamma}(x_1) \left(\left(\frac{d\sigma^{i\gamma\to jet+jet}}{dE_T d\eta}\right)_{LO} + \frac{\alpha_s(\mu)}{2\pi} K^{SR}_{i\gamma}(R,M)\right)$$

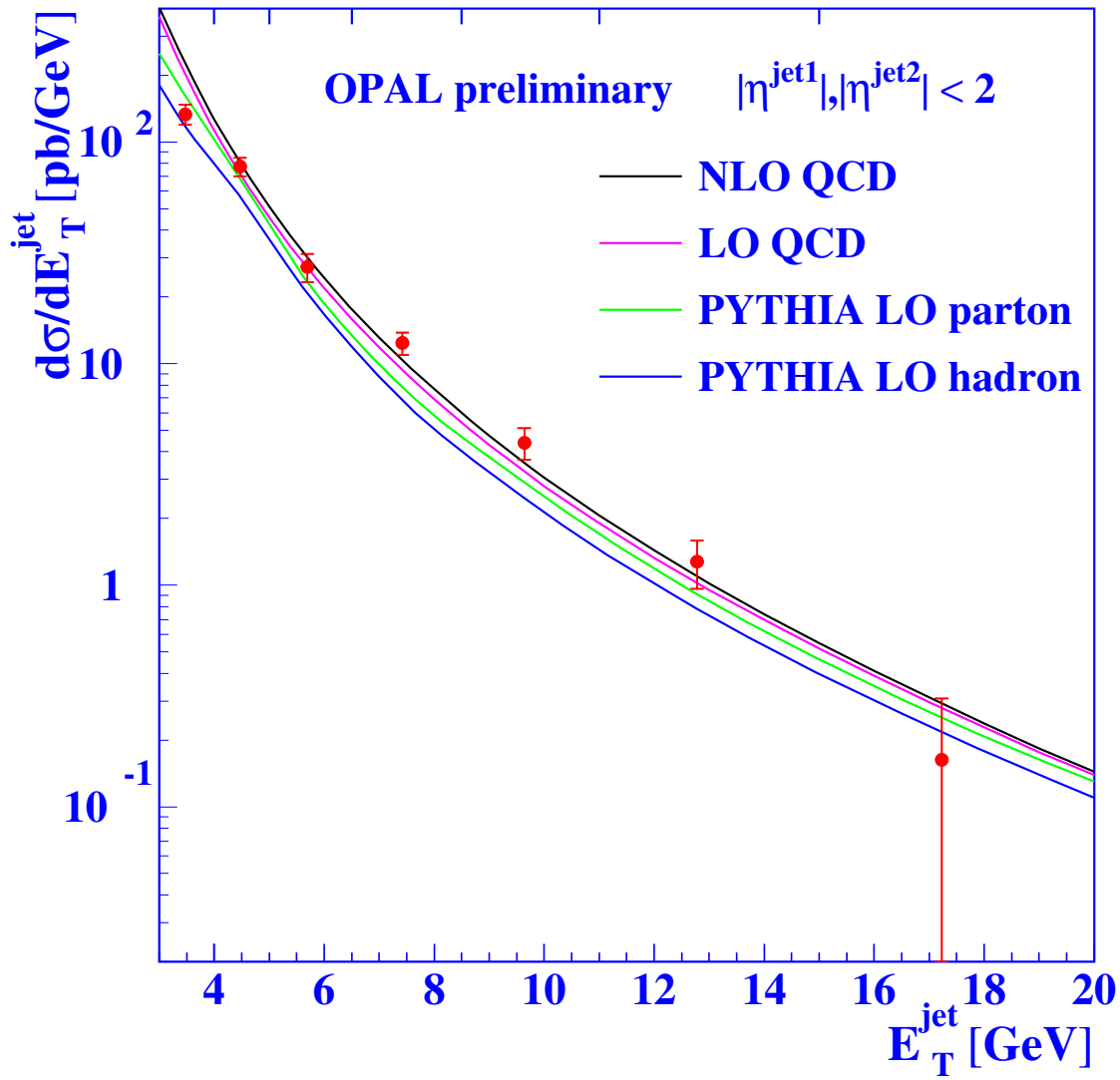
$$\frac{d\sigma^{DR}}{dE_T d\eta} = \sum_{i,j=q,G} \int\int dx_1 dx_2 F_{i/\gamma}(x_1) F_{j/\gamma}(x_2) \left(\left(\frac{d\sigma^{ij\to jet+jet}}{dE_T d\eta}\right)_{LO} + \frac{\alpha_s(\mu)}{2\pi} K^{DR}_{ij}(R,M)\right)$$

Inclusive two-jet cross section



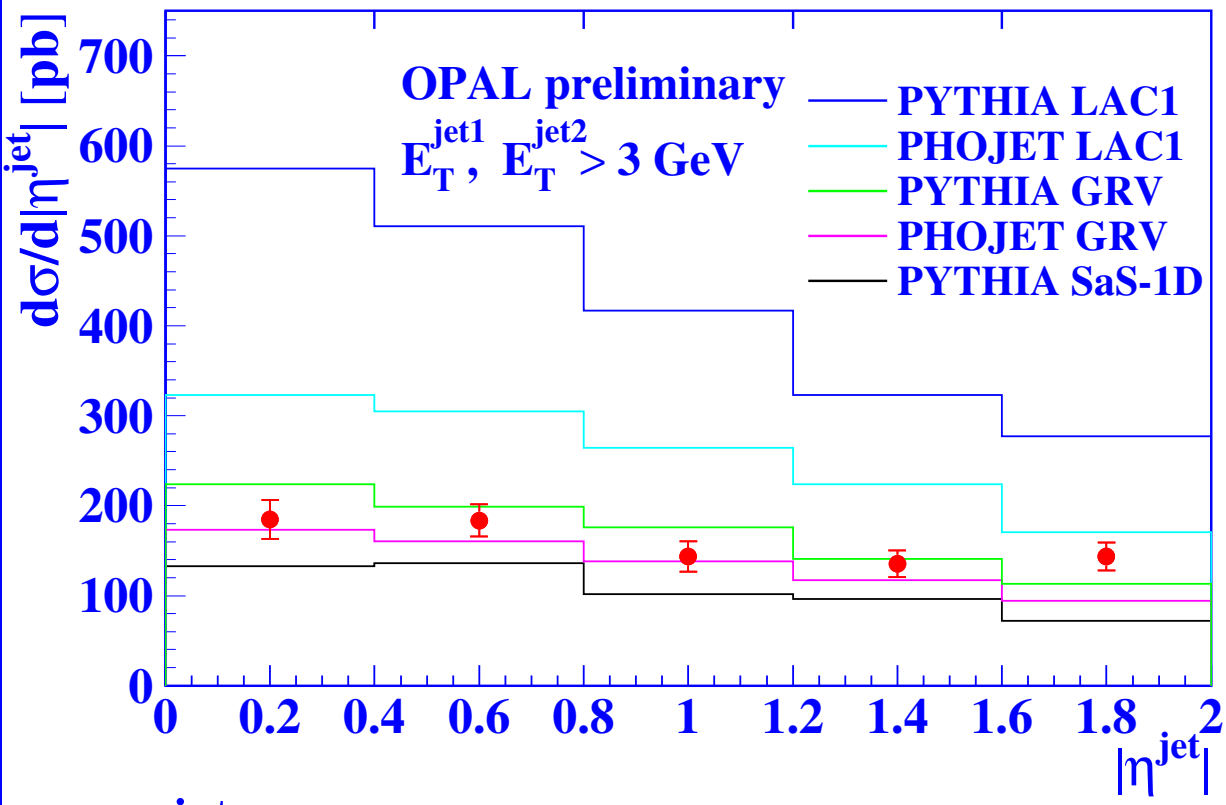
- Regularized unfolding (method of V. Blobel)
- Direct contribution dominates at $E_T^{\mathrm{jet}} > 8$ GeV
- Fraction of hard interactions increases from $\bar{p}p$ to γp to $\gamma\gamma$

Parton Hadron corrections



- NLO calculation uses NLO-GRV photon structure function and $\Lambda^{(5)}_{\overline{\rm MS}} = 130$ MeV
- Parton calculation compared to hadron level cross section
- $\sigma_{\rm NLO}/\sigma_{\rm LO} \sim 1.1$

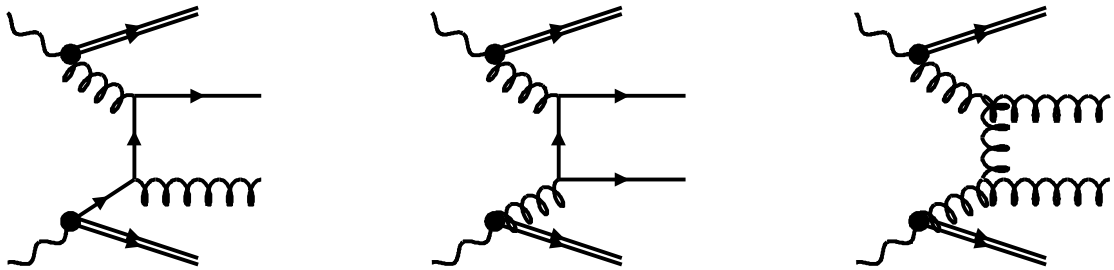
Inclusive two-jet cross section



- $\eta^{\rm jet}$ measured in lab frame
- Boost from lab to $\gamma\gamma$ frame varies event-by-event
- Within errors the cross section is independent of $\eta^{\rm jet}$ for $|\eta^{\rm jet}| < 2$
- PHOJET and PYTHIA describe data with GRV and SaS-1D, LAC1 too high

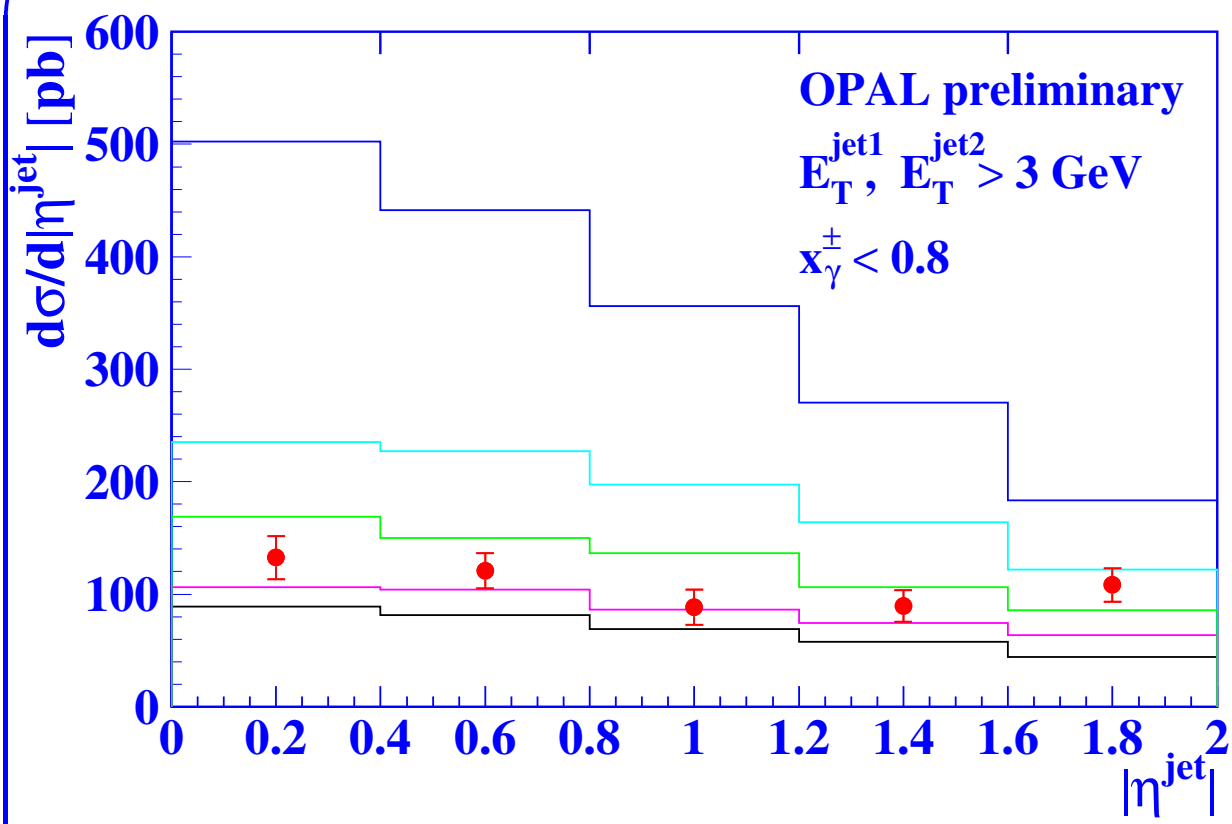
Jet cross section of resolved events

Double-resolved processes sensitive to the gluon content of the photon



	PYTHIA SaS-1D	
	no $x_\gamma^\pm$ cut	$x_\gamma^\pm < 0.8$
0 gluons	61.9 %	43.9 %
$\geq$ 1 gluon	38.1 %	56.1 %

	PYTHIA LAC1	
	no $x_\gamma^\pm$ cut	$x_\gamma^\pm < 0.8$
0 gluons	38.8 %	20.5 %
$\geq$ 1 gluon	61.2 %	79.5 %



- Monte Carlo in reasonable agreement using SaS-1D and GRV, but not LAC1
- agreement of direct events with $x_\gamma^\pm > 0.8$ for all photon structure functions

Conclusions

Dijet production in $\gamma\gamma$ interactions at $\sqrt{s}_{\mathrm{ee}} = 161$ and 172 GeV was measured using a cone algorithm with $E_T^{\mathrm{jet}} > 3$ GeV and $|\eta^{\mathrm{jet}}| < 2$.

Direct and double-resolved events separated with $x_\gamma^{\pm}$

Good agreement of parton scattering angle with LO QCD calculations

Good agreement of inclusive two-jet cross section with NLO calculations

PYTHIA and PHOJET with SaS-1D or GRV are in reasonable agreement with data.

Two-jet cross section with LAC1 is too large.