Inclusive Jet Production in Photon-Photon Collisions at $\sqrt{s_{ee}} = 130 - 136\,\mathrm{GeV}$

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- Introduction

1. Energy flows
2. Jet cross-sections

- Conclusions

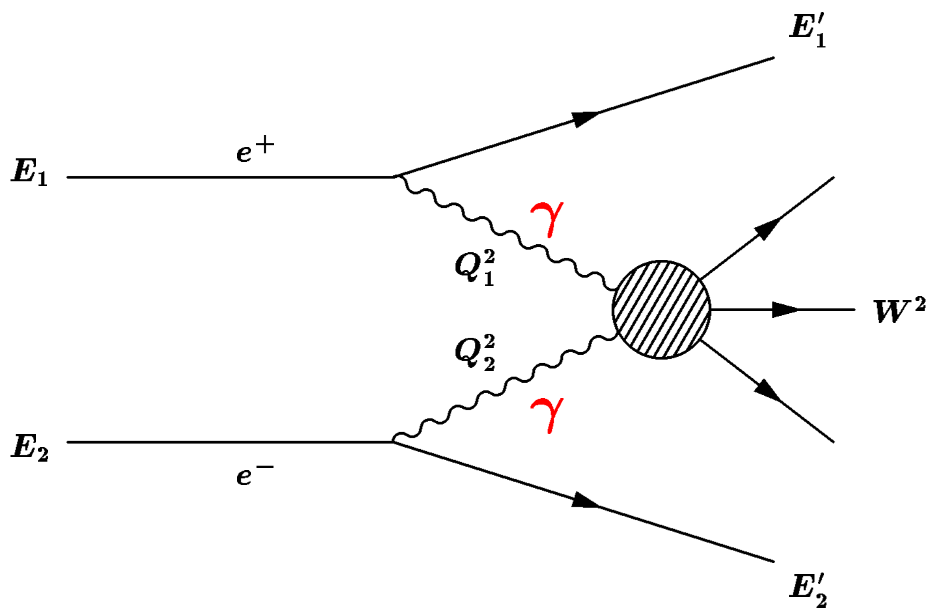
For the Collaboration

Motivations

The study of jet production in $\gamma\gamma$ interactions is a good tool to:

1. Study the structure of the photon and its interactions
2. Test the new $\gamma\gamma$ Monte Carlo generators (PYTHIA and PHOJET)
3. Compare with NLO perturbative QCD calculations

Photon–photon scattering



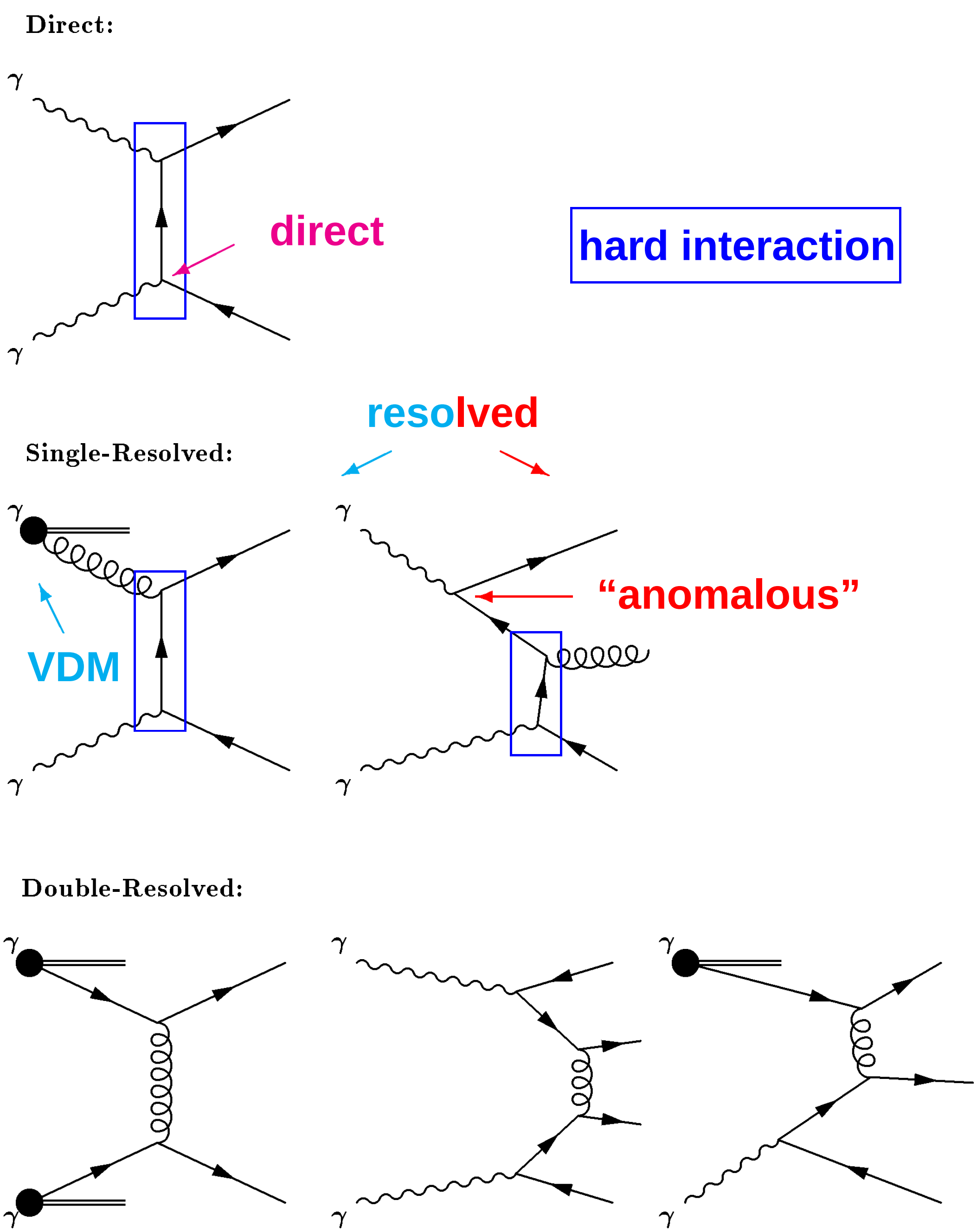
Exchange of two quasi-real photons (γ)

$$Q_i^2 = 2E_iE'_i(1-\cos\theta_i) \approx 0$$

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

At $\sqrt{s_{ee}} = 130\,\mathrm{GeV}$, for $W^2 > 4\,\mathrm{GeV}^2$ and $Q_i^2 < 1\,\mathrm{GeV}^2$:
$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^- + hadrons) \approx 14\,nb \approx 40 \cdot \sigma(\mathrm{e}^+\mathrm{e}^- \to (\gamma, \mathrm{Z}^0) \to hadrons)$

Leading order diagrams



Monte Carlo models

PYTHIA 5.721 and PHOJET 1.05

Monte Carlo ingredients:

1. Leading order (LO) QCD matrix elements
2. Hard and soft processes
3. Total cross sections from Regge models
4. Initial state parton radiation
5. Fragmentation based on by JETSET 7.408
6. Multiple interactions

NLO calculations

- NLO calculations for inclusive jet cross sections by T. Kleinwort and G. Kramer, DESY-96-035 (1996), hep-ph/9509321 and Phys. Lett. B370 (1996) 141, hep-ph/9602418.

Event selection

- $W_{\mathrm{ECAL}} > 3$ GeV
- Energy sum in all calorimeters less than 50 GeV
- Missing transverse energy less than 5 GeV
- Number of tracks $n_{\mathrm{ch}} > 4$, sum of all charges less than 4
- Maximum momentum of any charged track less than 15 GeV
- No electron tags in forward calorimeters

$\Rightarrow$ **7663 events in 4.9 pb^{-1}**

Cone jet algorithm

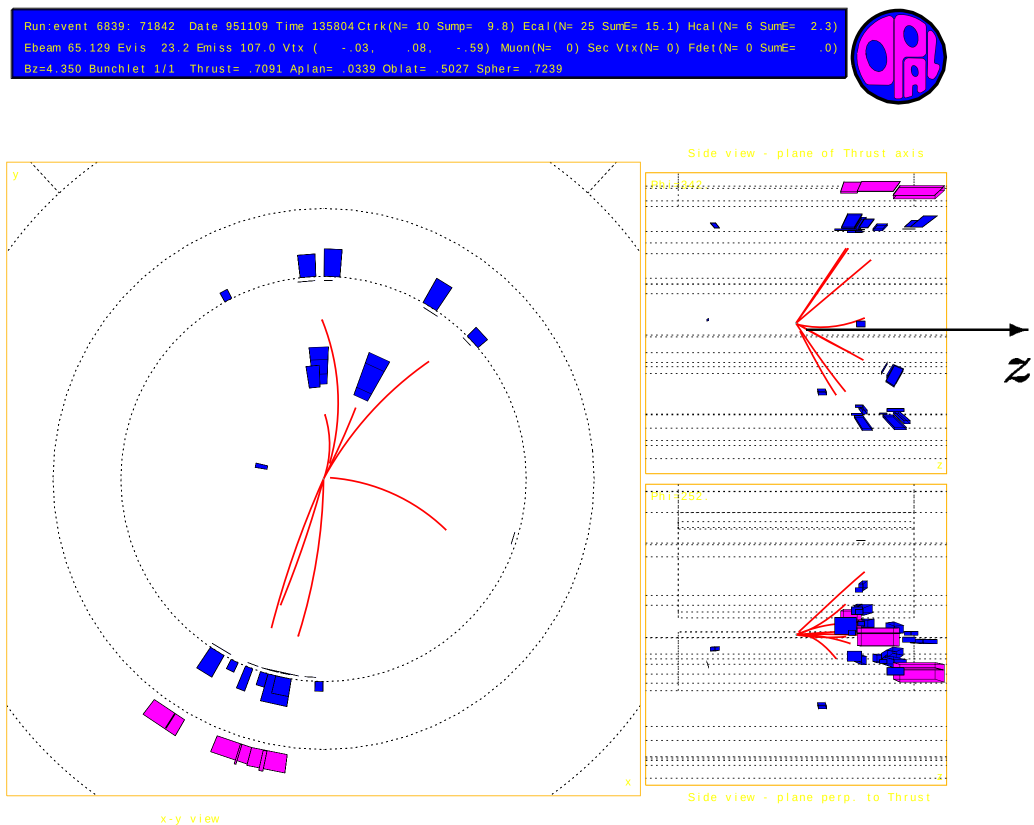
- **Detector:** tracks and calorimeter clusters
- **Monte Carlo Generator:** primary hadrons

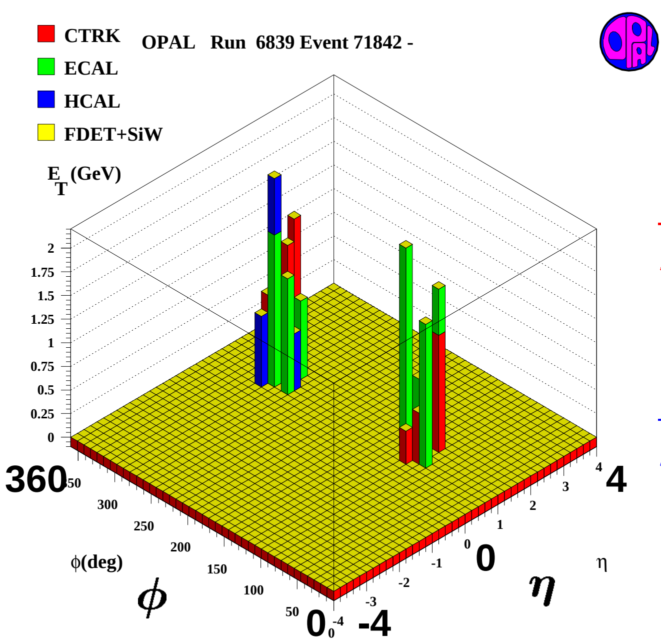
Cone radius: $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

pseudo-rapidity $\eta = -\ln\tan\frac{\theta}{2}$, azimuthal angle ϕ

Choice: $R = 1,\ \left|\eta^{\mathrm{jet}}\right| < 1,\ E_{\mathrm{T}}^{\mathrm{jet}} > 3\,\mathrm{GeV}$

A direct two-jet event





***Jet* 1 :**

$$\eta = 0.9, \; E_T^{\rm jet} = 6.6 \; \rm GeV$$

***Jet* 2 :**

$$\eta = 0.7, \; E_T^{\rm jet} = 6.9 \; \rm GeV$$

Jet multiplicity and background contribution

	0-jet	1-jet	2-jet
data	6813	709	132
$\gamma\gamma \to \tau\tau$	2.7 ± 0.7	1.9 ± 0.6	0.6 ± 0.4
e$\gamma \to$ e + had (single tagged)	60.5 ± 5.5	1.0 ± 0.7	< 0.5
$e^+e^- \to$ had(γ)	4.3 ± 0.3	3.8 ± 0.3	1.1 ± 0.2
$e^+e^- \to \tau\tau(\gamma)$	0.06 ± 0.01	0.09 ± 0.02	0.06 ± 0.01

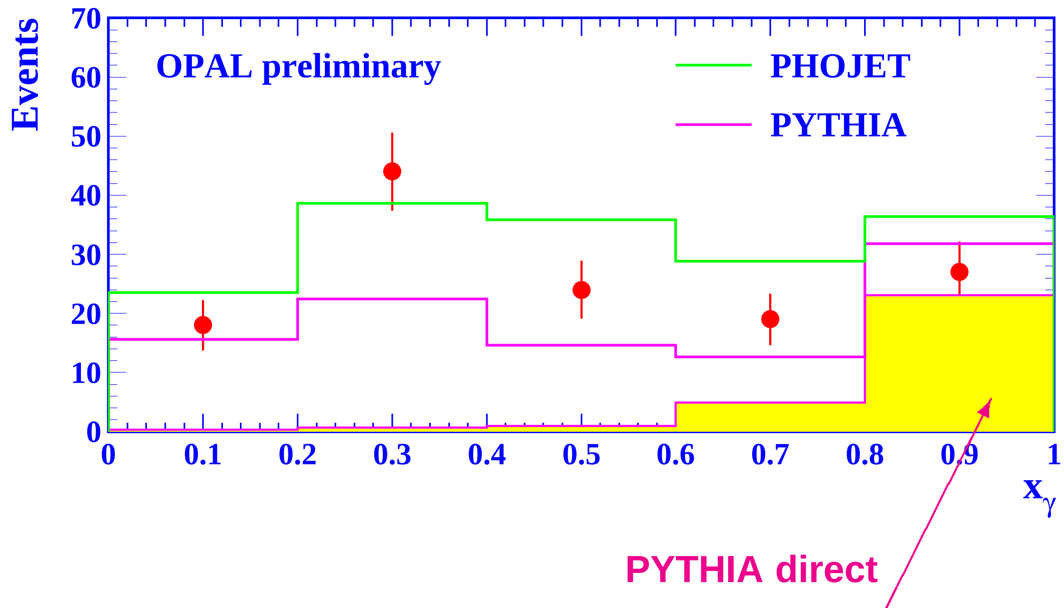
	3-jet	4-jet
data	8	1
$\gamma\gamma \to \tau\tau$	< 0.3	< 0.3
e$\gamma \to$ e + had	< 0.5	< 0.5
$e^+e^- \to$ had(γ)	0.1 ± 0.1	< 0.1
$e^+e^- \to \tau\tau(\gamma)$	< 0.01	< 0.01

Total background less than 1%

The x_γ distribution for 2–jet events

x_γ is the fraction of the photon momentum participating in the hard interaction

$$x_\gamma = \max\left\{\frac{\sum_{\text{jets}}(E+p_z)}{\sum_{\text{hadrons}}(E+p_z)}, \frac{\sum_{\text{jets}}(E-p_z)}{\sum_{\text{hadrons}}(E-p_z)}\right\}$$

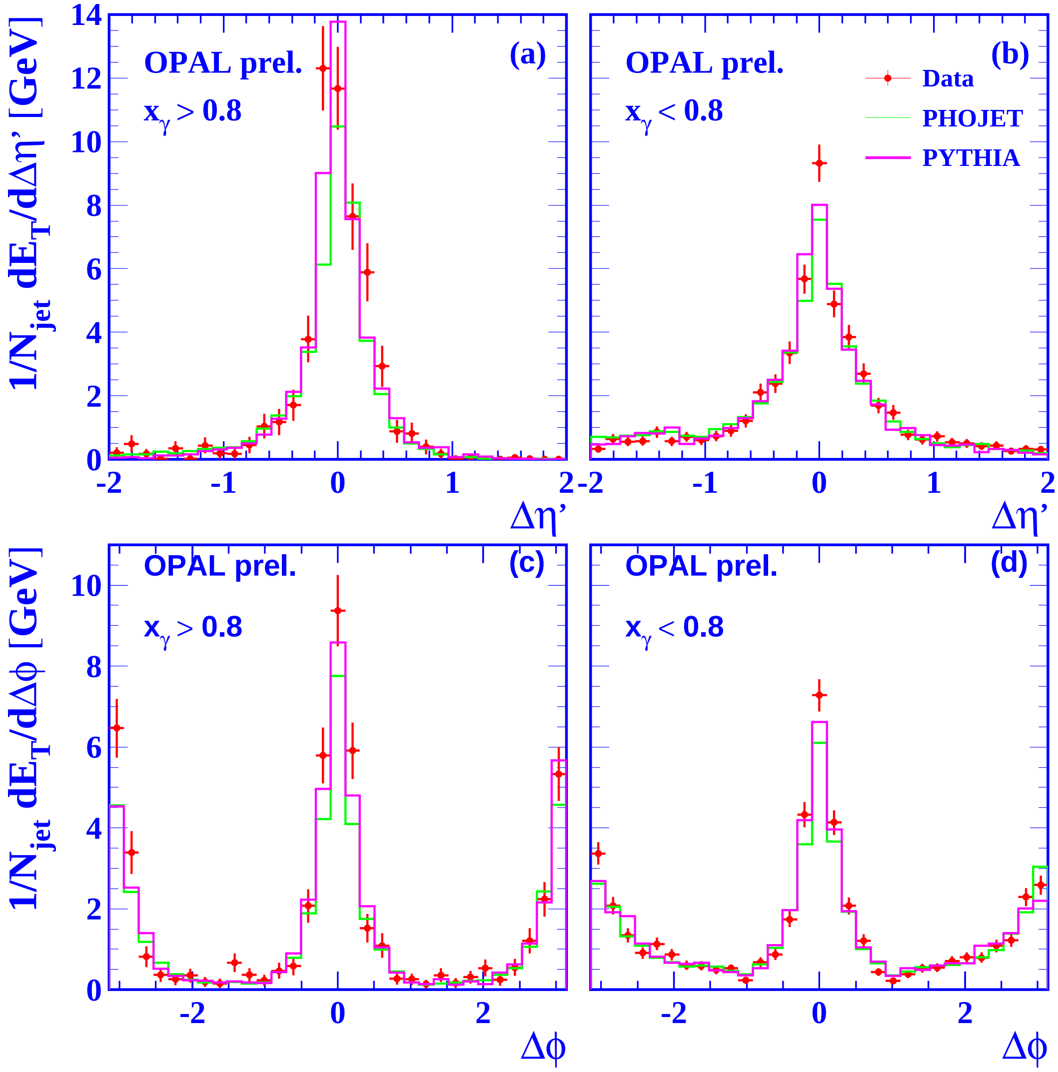


Direct events : $x_\gamma \equiv 1$ no remnant jet

Resolved events : $x_\gamma < 1$ remnant jets possible

The energy flow for 2–jet events

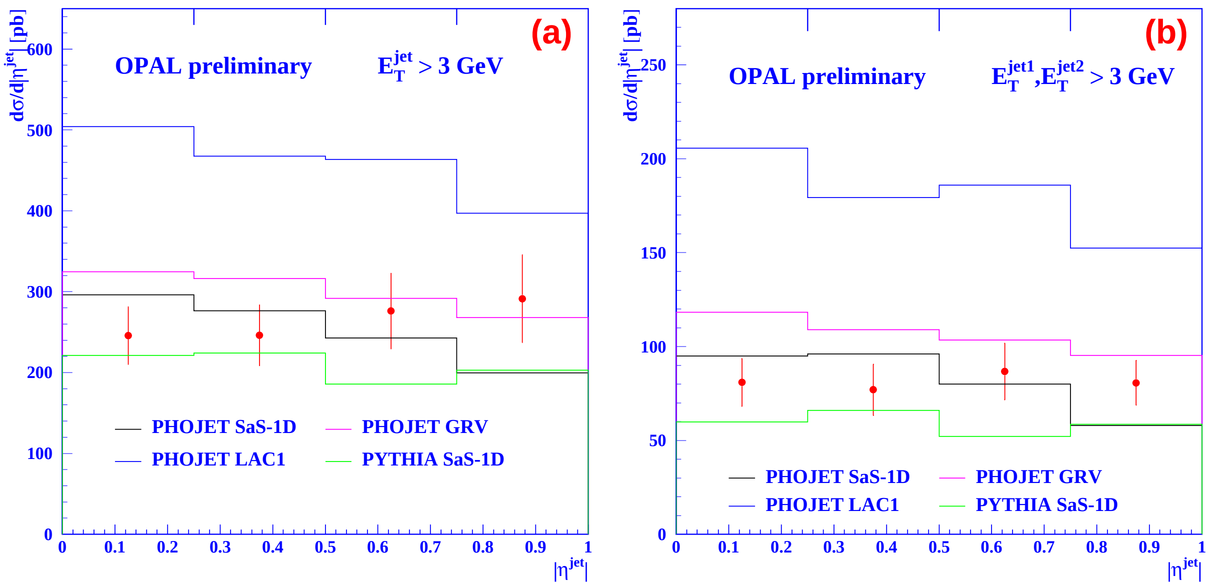
$$\Delta\eta' = \pm(\eta - \eta_{\rm jet})$$



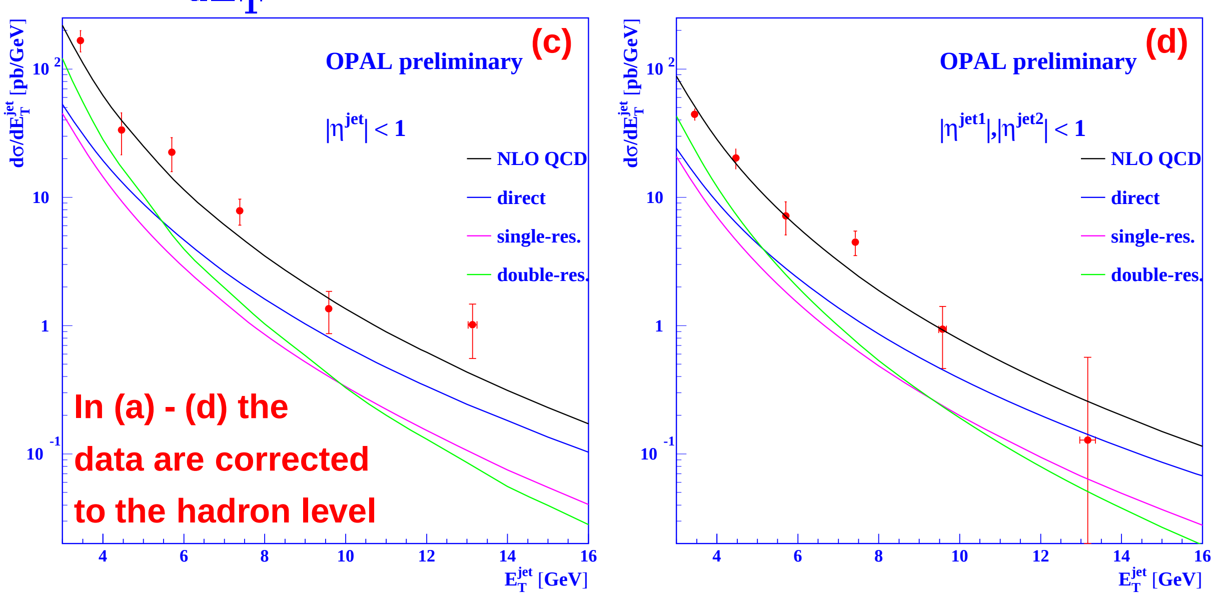
"direct" $x_\gamma > 0.8$ "resolved" $x_\gamma < 0.8$

The inclusive jet cross sections

$\frac{d\sigma}{d\eta^{jet}}$ compared to *Monte Carlo models*



$\frac{d\sigma}{dE_T^{jet}}$ compared to *NLO Calculations*



1–jet ⟷ **2–jet**

Systematic error determination

1. ECAL energy scale varied by $\pm 5\%$
2. Degradation of track resolution in MC
3. Unfolding using PYTHIA and PHOJET

$\langle E_T^{jet} \rangle$ (GeV)	$d\sigma/dE_T^{jet}$ (pb/GeV)
3.45 ± 0.02	$167.2 \pm 6.8 \pm 31.0$
4.46 ± 0.02	$33.5 \pm 2.4 \pm 11.8$
5.70 ± 0.03	$22.5 \pm 2.0 \pm 6.3$
7.39 ± 0.04	$7.8 \pm 1.1 \pm 1.5$
9.59 ± 0.08	$1.4 \pm 0.3 \pm 0.4$
13.14 ± 0.11	$1.0 \pm 0.3 \pm 0.4$

$\Rightarrow$ Need to improve on the systematic error

Conclusions

Jet production in $\gamma\gamma$ interactions at $\sqrt{s_{ee}} = 130 - 136$ GeV was studied using a cone algorithm with $E_{\mathrm{T}}^{\mathrm{jet}} > 3$ GeV and $|\eta^{\mathrm{jet}}| < 1$, leading to the following results.

1. Direct and resolved events can be separated by measuring x_γ.
2. The PYTHIA and PHOJET Monte Carlo models with the SaS-1D or GRV parton density functions are in reasonable agreement with the data. The jet cross section using the LAC1 parton density function is too large.
3. NLO calculations on the parton level are found to be in good agreement with the data corrected to the hadron level.