Hadron Production and Cross Sections in $e\gamma$ and $\gamma\gamma$ Collisions at LEP

INTERNATIONAL EUROPHYSICS CONFERENCE
ON HIGH ENERGY PHYSICS

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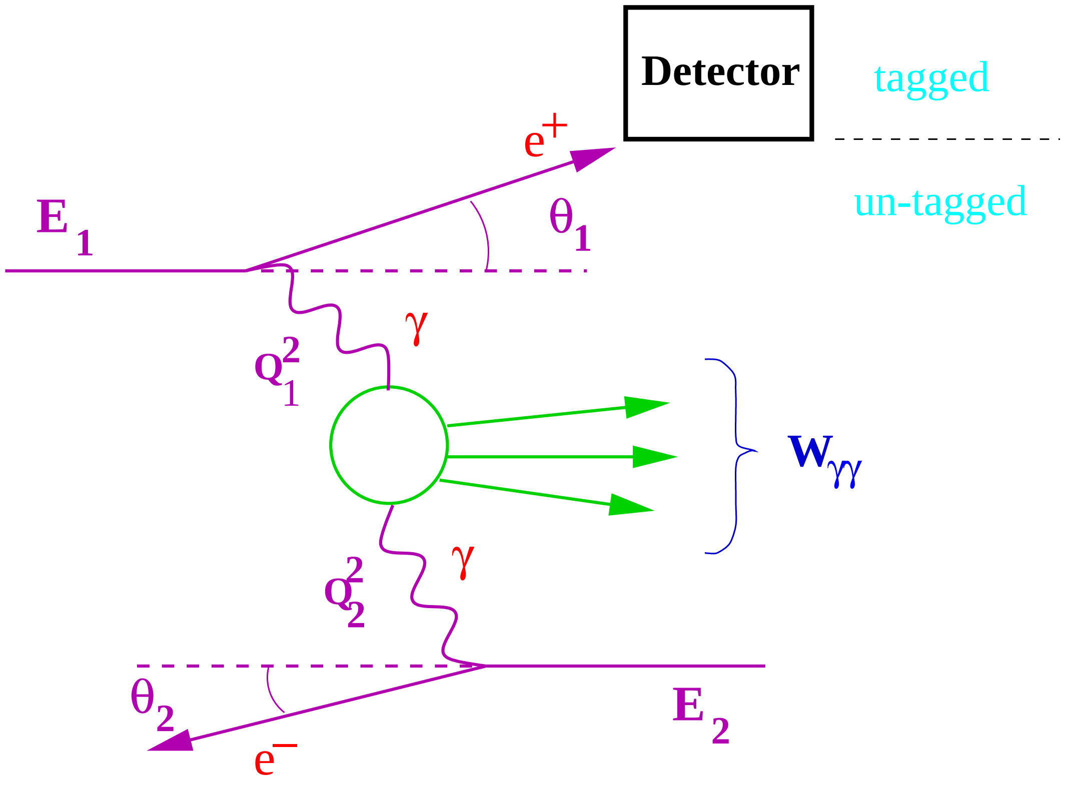
EPS 97

$\gamma\gamma$ and $e\gamma$ scattering

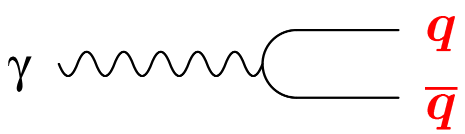
$$Q_i^2 = 2 \cdot E_{beam} \cdot E_i \cdot (1 - \cos\theta_i)$$

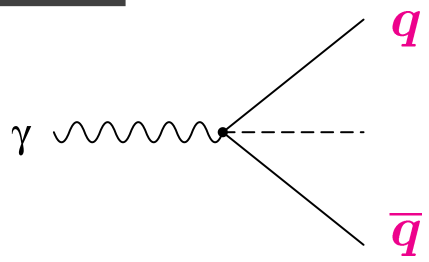


anti-tagged $\longrightarrow$ $\gamma\gamma$ **scattering**

single/double-tagged $\longrightarrow$ $e\gamma$ **scattering**

Event Types



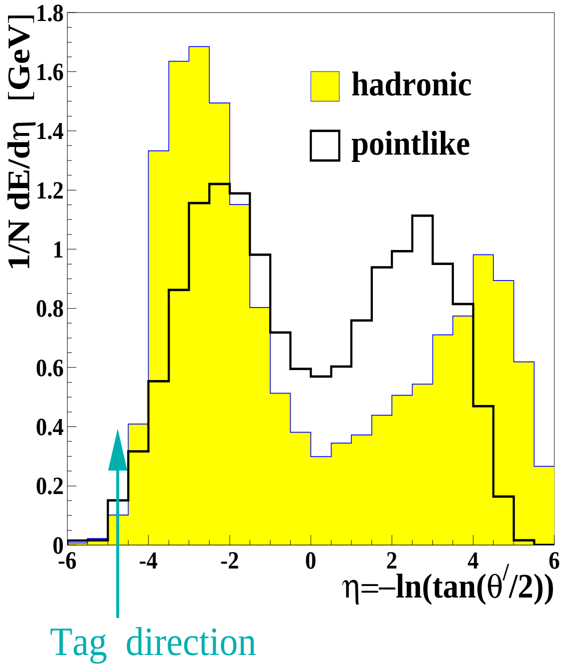


'hadronic', p_T = "small"
non–perturbative
VDM (ρ, ω, ϕ)

'pointlike', p_T = "large"
perturbative

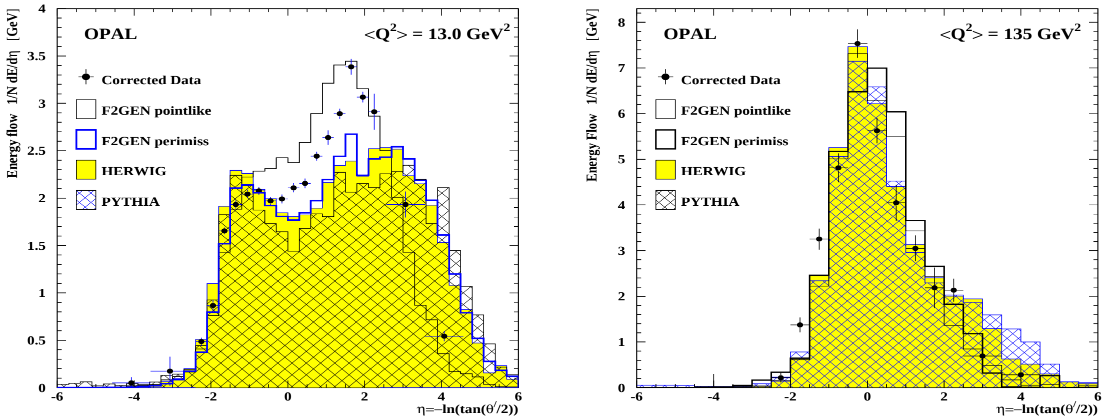
Hadronic and pointlike events have different angular distributions of the the final state hadrons:

Energy flow vs. pseudorapidity in $e\gamma$ events:



- **hadronic events lie closer to the beam direction**
  (= higher η)

Hadron production in $e\gamma$



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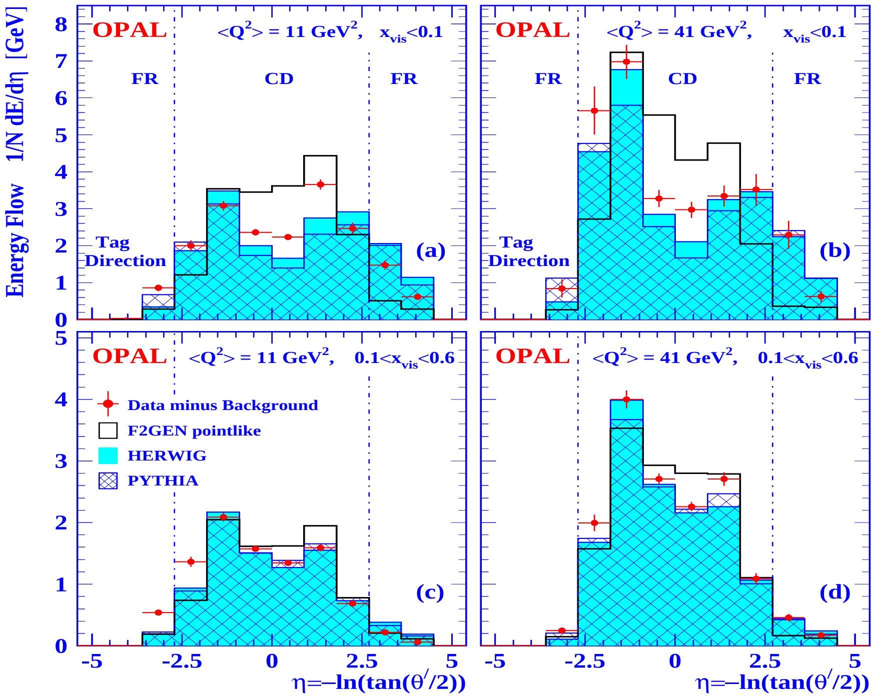
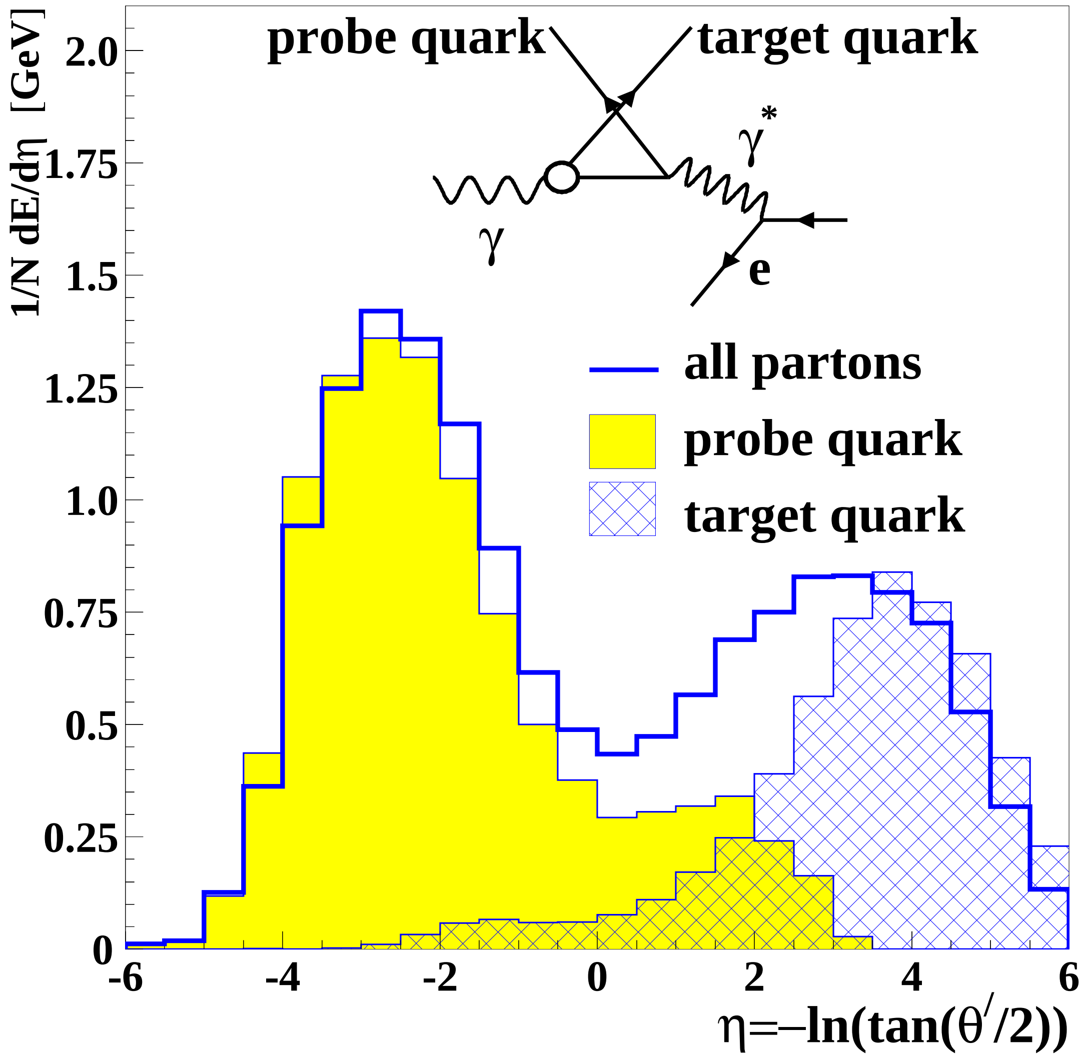
- bad agreement at low Q^2 and low x
- photon more pointlike than expected from MC



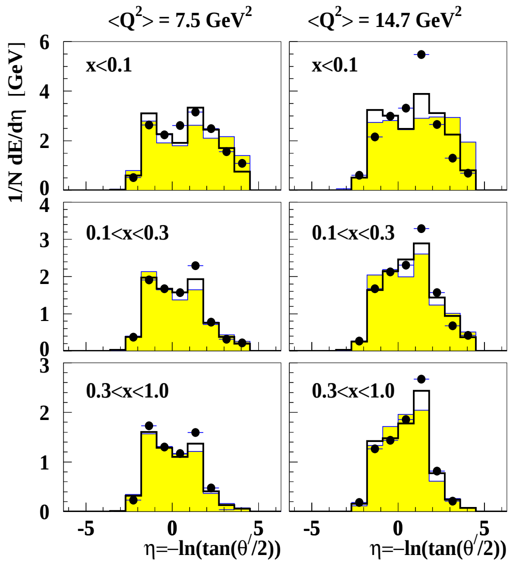
- OPAL (LEP2) $\mathcal{L} = 18.1\mathrm{pb}^{-1}$ (sub. to Phys. Lett. B)
- Discrepancies persist at higher c.m. energies

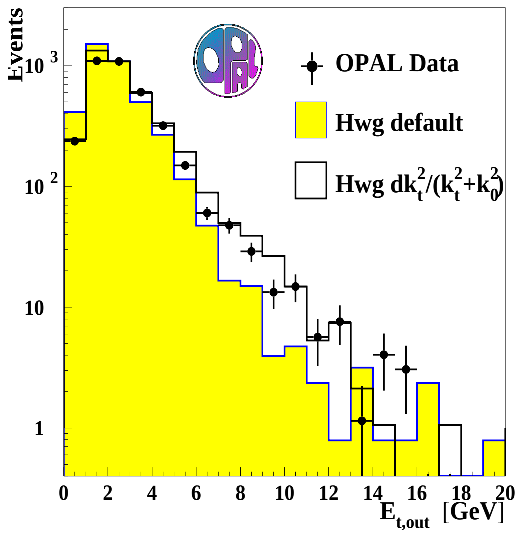
More Energy flows



- Tune the k_T distribution of the "target" quark from a gaussian to a power-like shape of the form $dk_T^2/(k_T^2+k_0^2)$; $\quad k_0 = 0.66\ \mathrm{GeV}$

Tuning Monte Carlos





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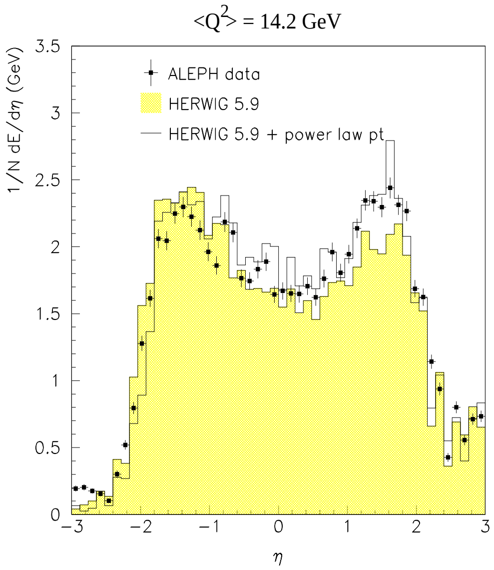

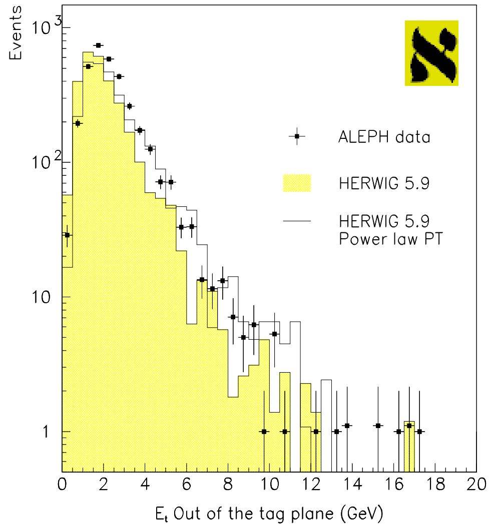

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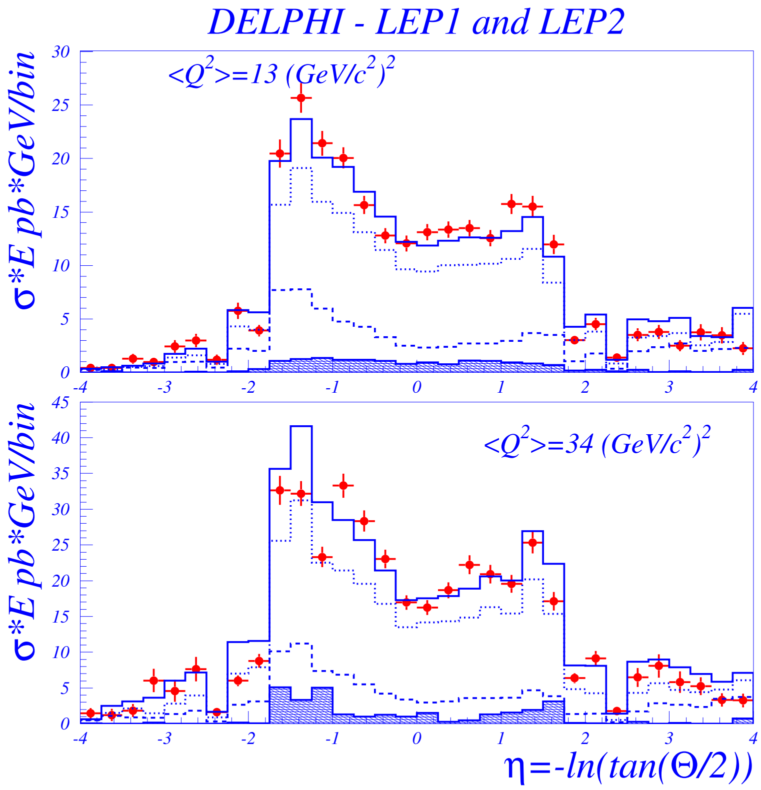
- Tuning parton k_T in HERWIG improves agreement
- More work on underlying problem needed

Tuned Monte Carlos



DELPHI Monte Carlo: TWOGAM

Solid line:

QPM + GVDM + RPC (“resolved photon component”)

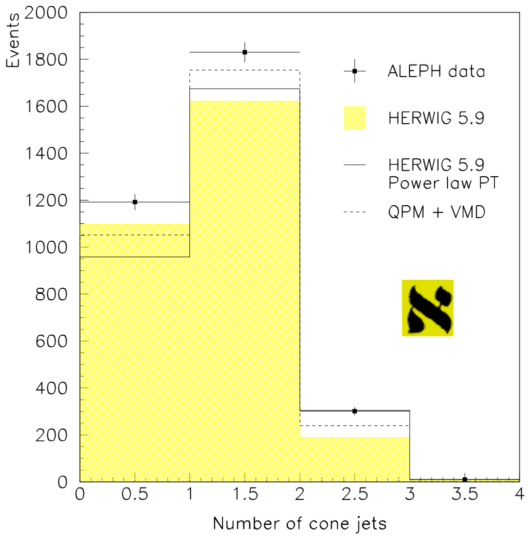
tuning the relative amounts or GVDM and RPC to the data

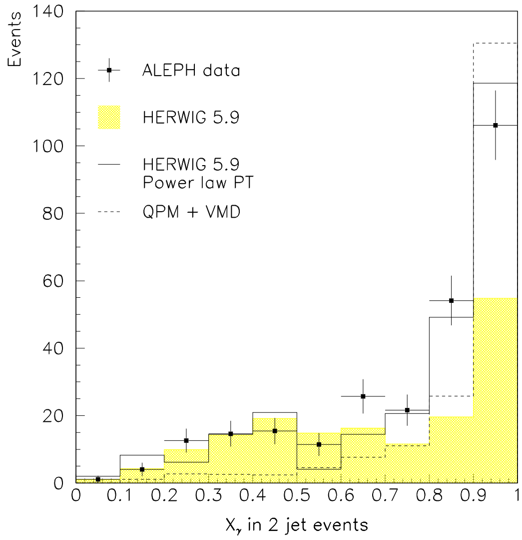
Jets in $e\gamma$ Events

The number of jets is sensitive to the hadron distribution

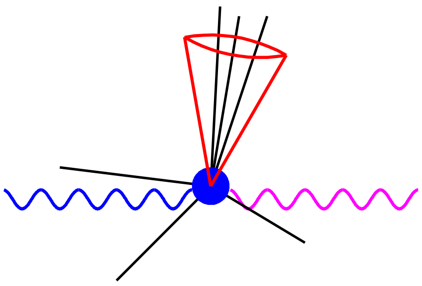
$$x_\gamma = \frac{\sum_{jets}(E+p_z)}{\sum_{hadrons}(E+p_z)}$$

$x_\gamma \sim 1$ **= direct** $x_\gamma \ll 1$ **= resolved**





Cone Jets



$E_T^{jet} > 3\mathrm{GeV}$

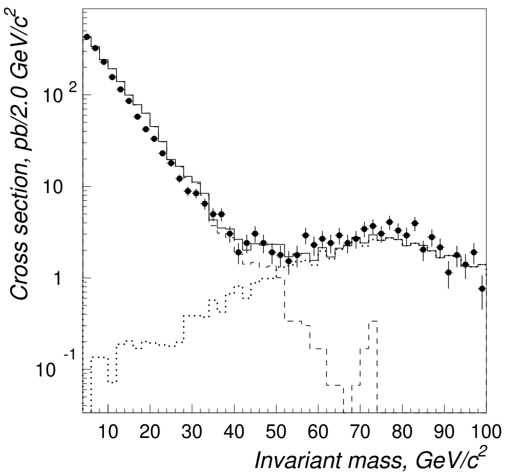
$|\eta_{jet}| < 2$

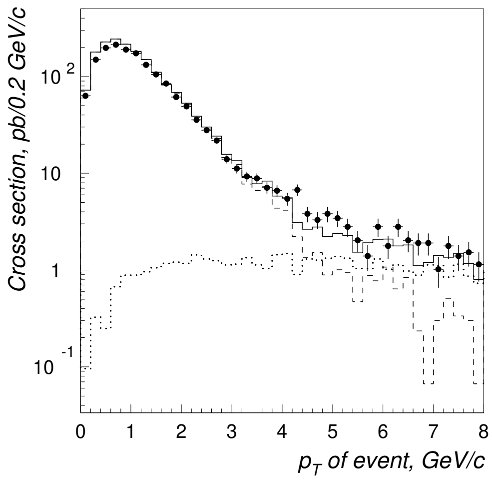
$\rightarrow$ **Number of Jets:**

OPAL	0 jet	1 jet	2jet
Data	30.7%	63.8%	5.4%
Herwig	33.9%	63.6%	2.4%
k_{T}	31.0%	63.0%	5.9%

Hadron production in $\gamma\gamma$ events

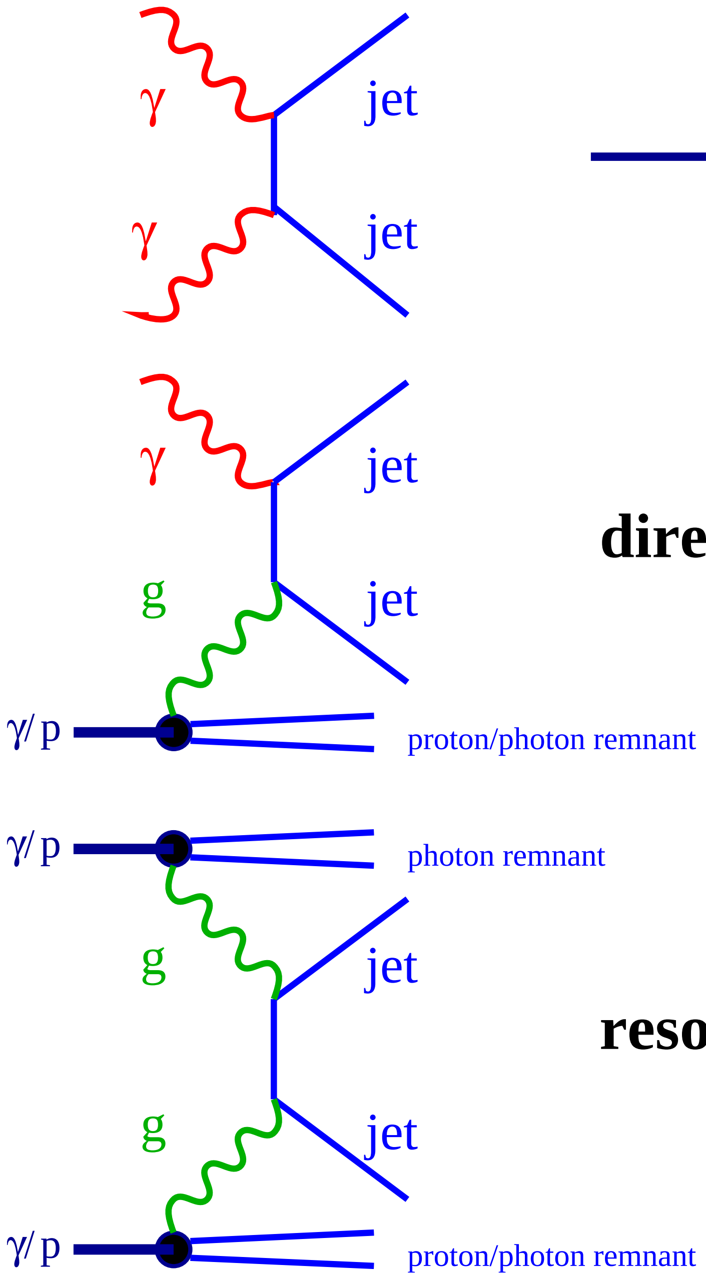
- Select anti-tagged events
  $\Rightarrow$ low Q^2 ($Q^2 < 1$GeV^2), quasi-real photons
- LO QCD: $\gamma\gamma$ events modeled in 3 classes:
  direct,
  single-resloved and
  double-resloved





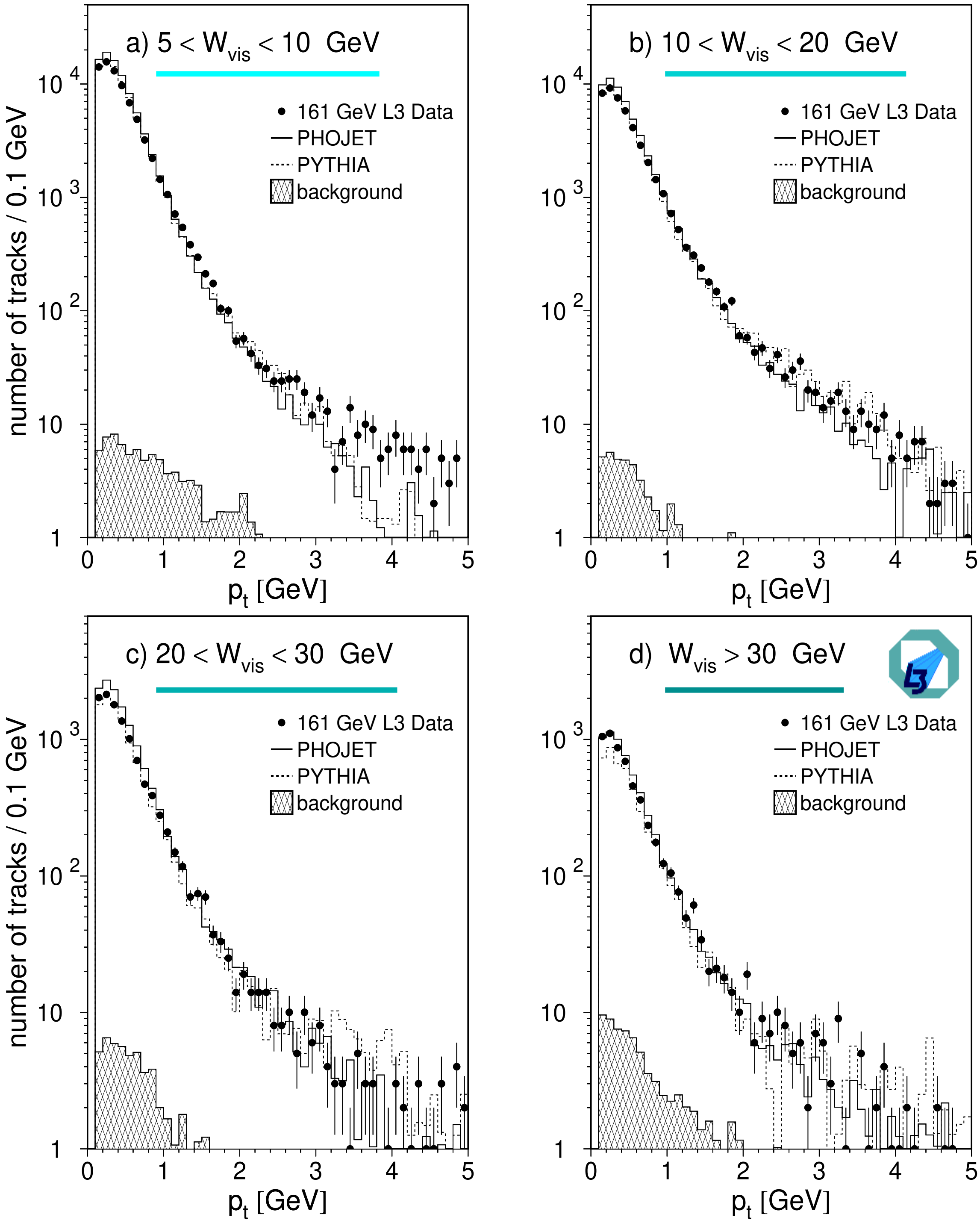
- DELPHI: LEP1 and LEP2
- $e^+e^- \to \gamma\gamma \to$ hadrons
  and $e^+e^- \to \gamma/Z \to$ hadrons background

Leading order $\gamma\gamma$ and γp



	HERA	LEP
1	—	direct
2	direct	single-resolved
3	resolved	double-resolved

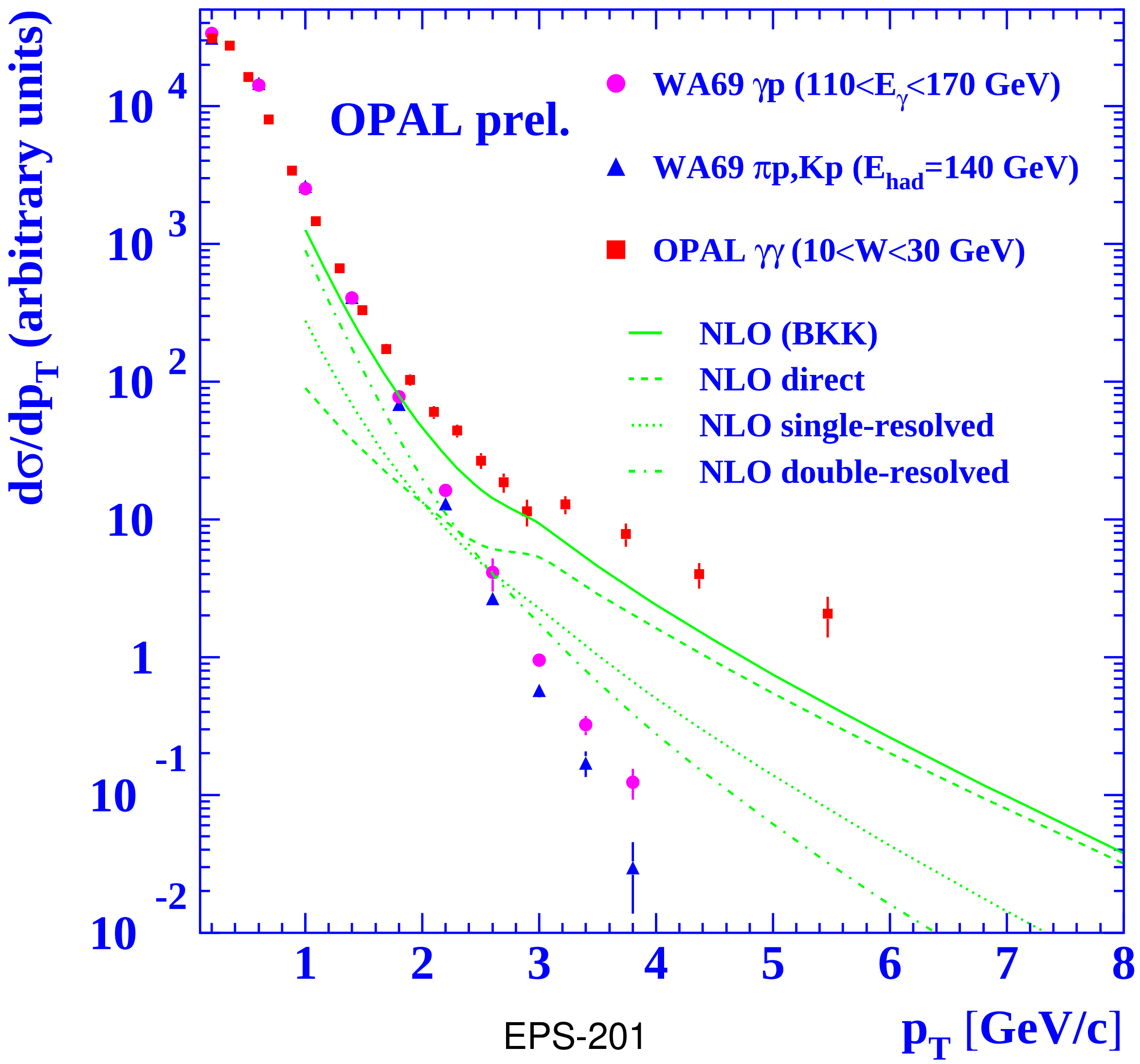
Hadron production in $\gamma\gamma$ events



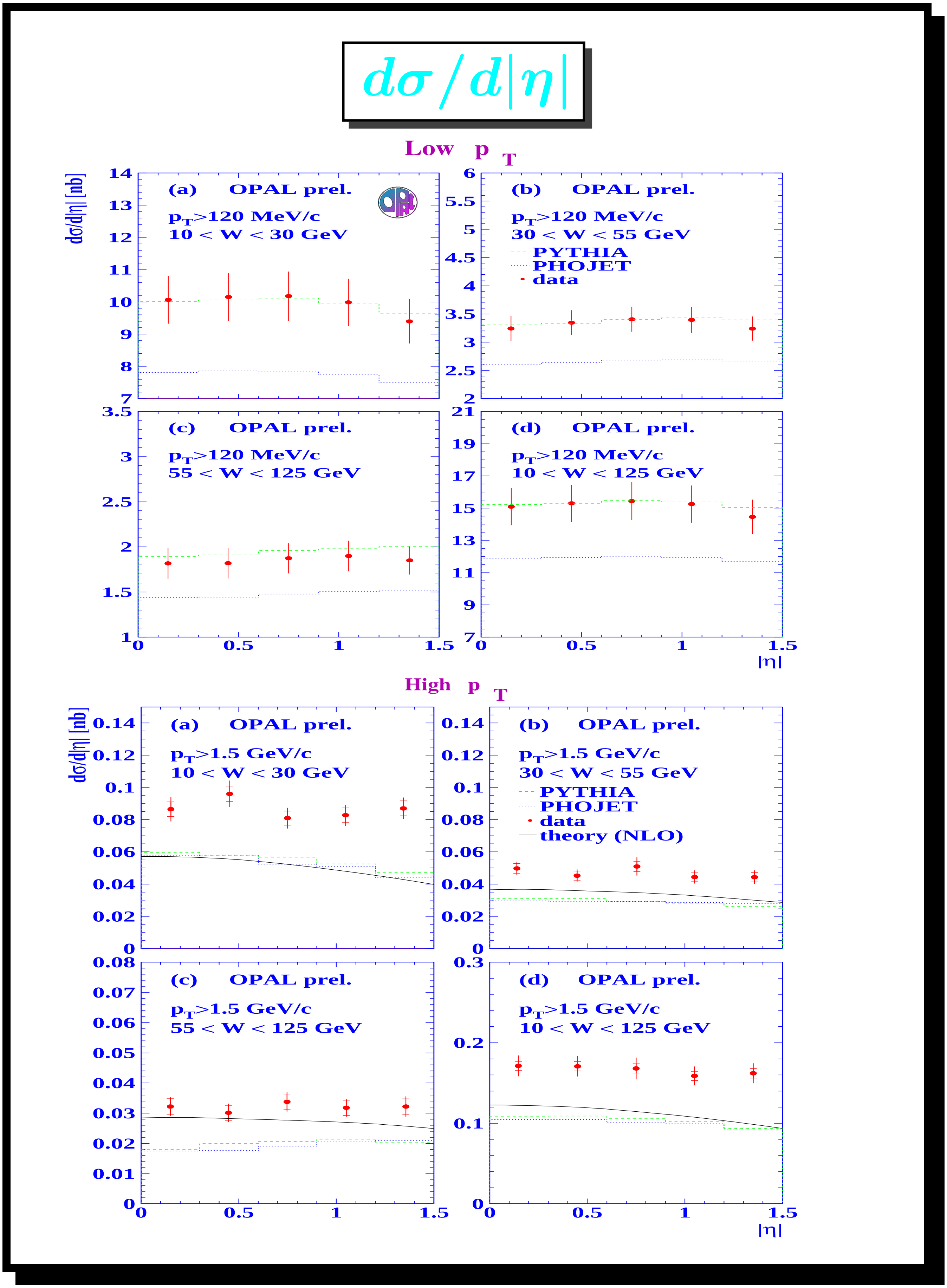
- p_T **of tracks measured by L3 and compared to M.C.**

Hadron production: $d\sigma / dp_T$

- $\gamma\gamma$ (anti-tagged) events:

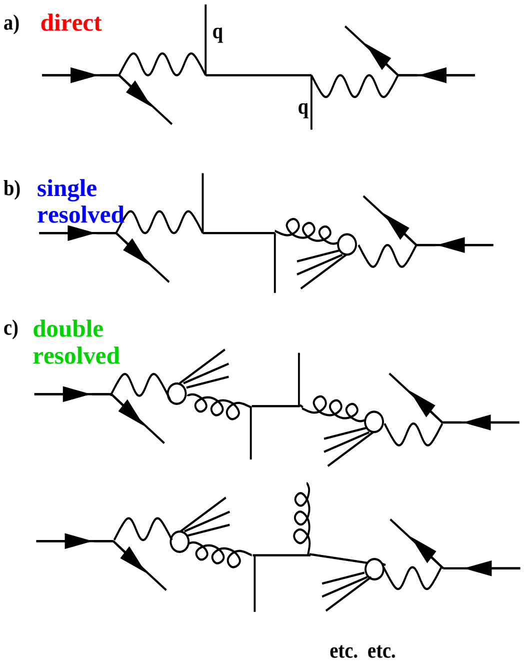


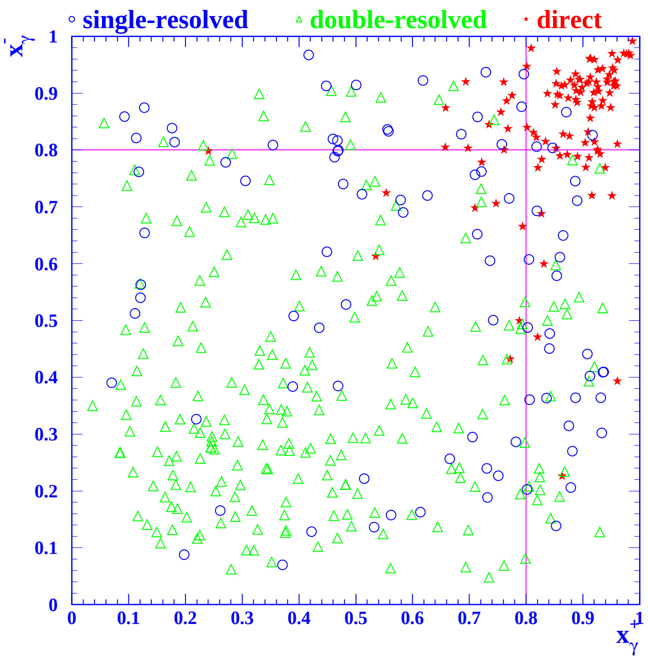
- WA69 hp and γp data normalised to $\gamma\gamma$ data
- $\gamma\gamma$ spectrum "harder" due to direct component
- NLO calculations lie significantly below data



dσ/d|η|
Low p T
dσ/d|η| [nb]
(a) OPAL prel.
pT>120 MeV/c
10 < W < 30 GeV
(b) OPAL prel.
pT>120 MeV/c
30 < W < 55 GeV
PYTHIA
PHOJET
data
(c) OPAL prel.
pT>120 MeV/c
55 < W < 125 GeV
(d) OPAL prel.
pT>120 MeV/c
10 < W < 125 GeV
|η|
High p T
dσ/d|η| [nb]
(a) OPAL prel.
pT>1.5 GeV/c
10 < W < 30 GeV
(b) OPAL prel.
pT>1.5 GeV/c
30 < W < 55 GeV
PYTHIA
PHOJET
data
theory (NLO)
(c) OPAL prel.
pT>1.5 GeV/c
55 < W < 125 GeV
(d) OPAL prel.
pT>1.5 GeV/c
10 < W < 125 GeV
|η|

Two Jet $\gamma\gamma$ Events

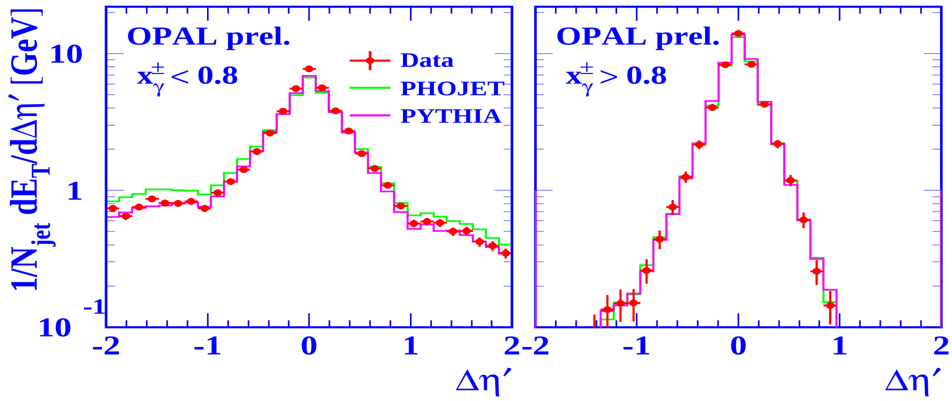




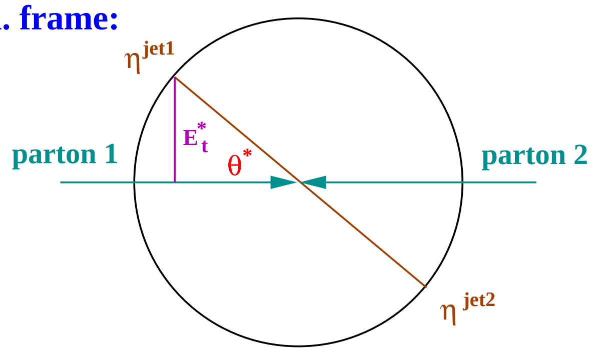
$$x_\gamma^+ = \frac{\sum_{jets}(E+p_z)}{\sum_{had}(E+p_z)} \quad \text{and} \quad x_\gamma^- = \frac{\sum_{jets}(E-p_z)}{\sum_{had}(E-p_z)}$$

p_z: **momentum in z-direction**

$x_\gamma^\pm$: **Fraction of photon momentum in hard process**

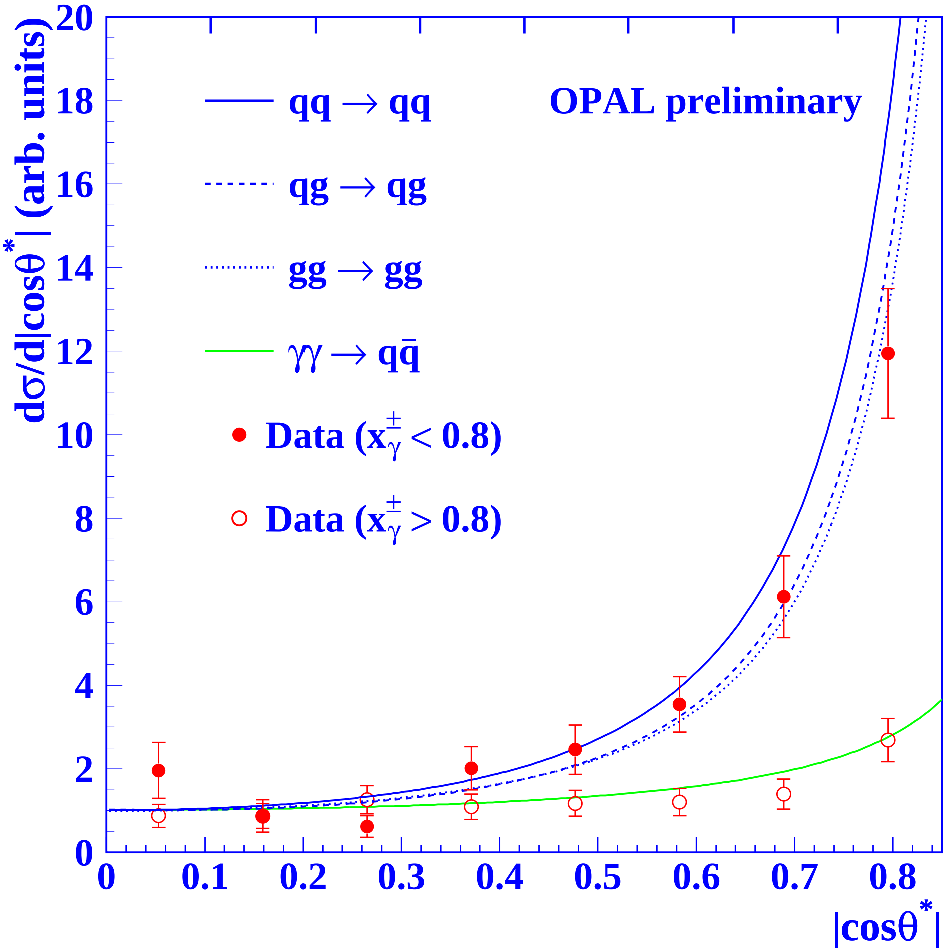


Parton scattering angles



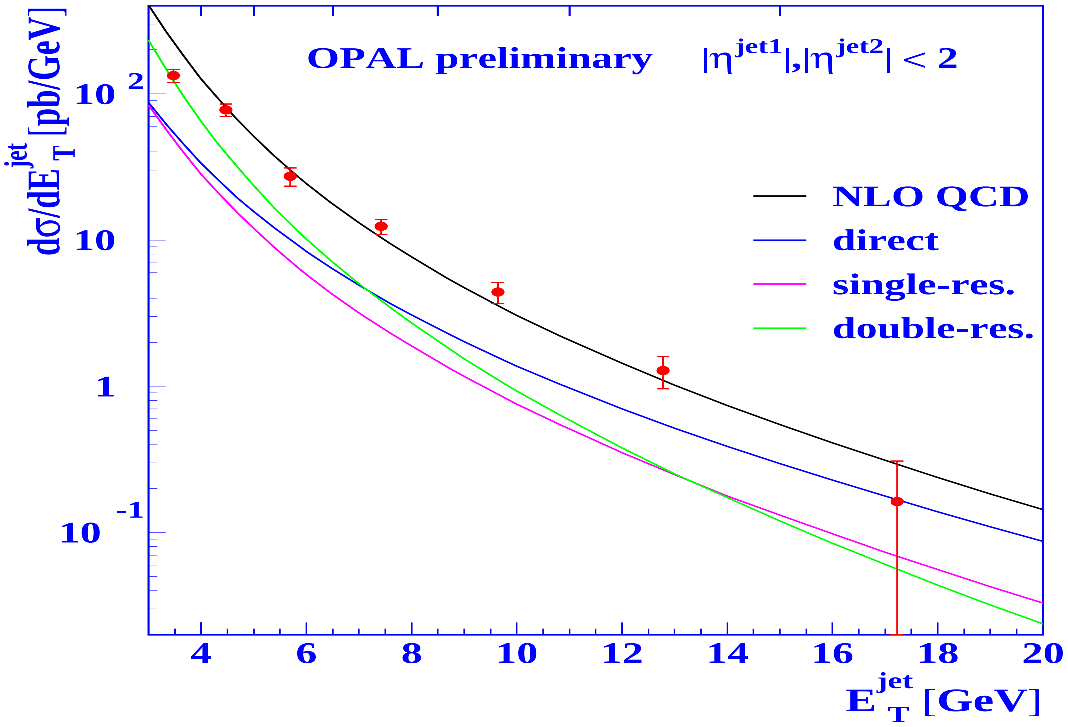
quark (fermion) exchange dominates direct $\propto |1-\cos^2\theta^*|^{-1}$

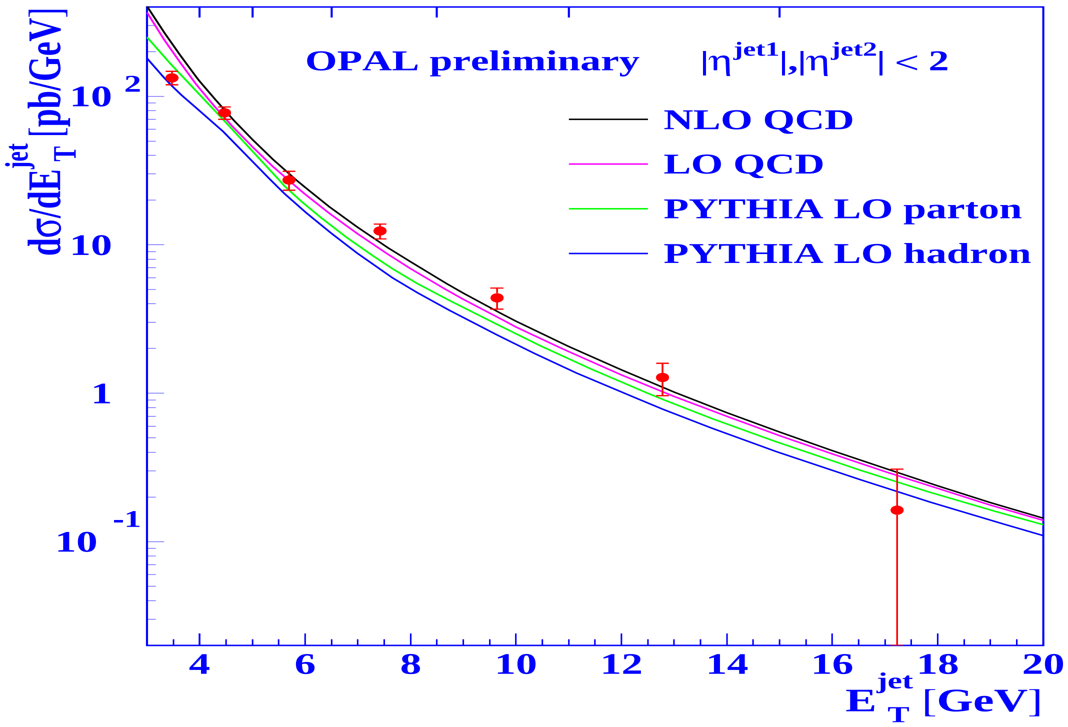
gluon (boson) exchange dominates resolved $\propto |1-\cos\theta^*|^{-2}$



EPS-200

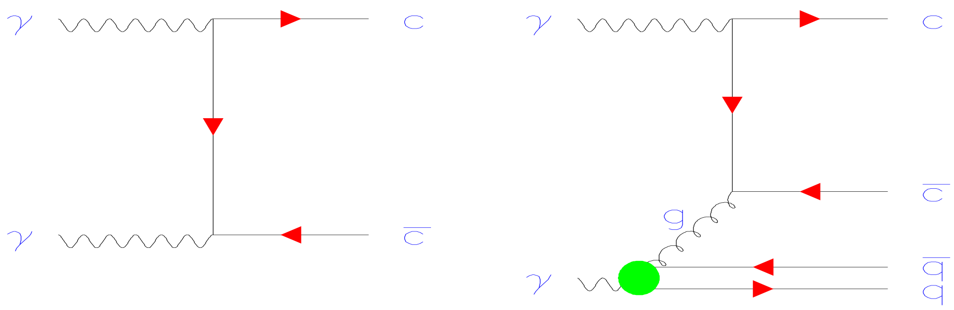
Jet cross-section





Charm in (or from) the Photon

- Heavy quark production in $\gamma\gamma$ tests pQCD
- Extention of measurements at PEP, PETRA and TRISTAN



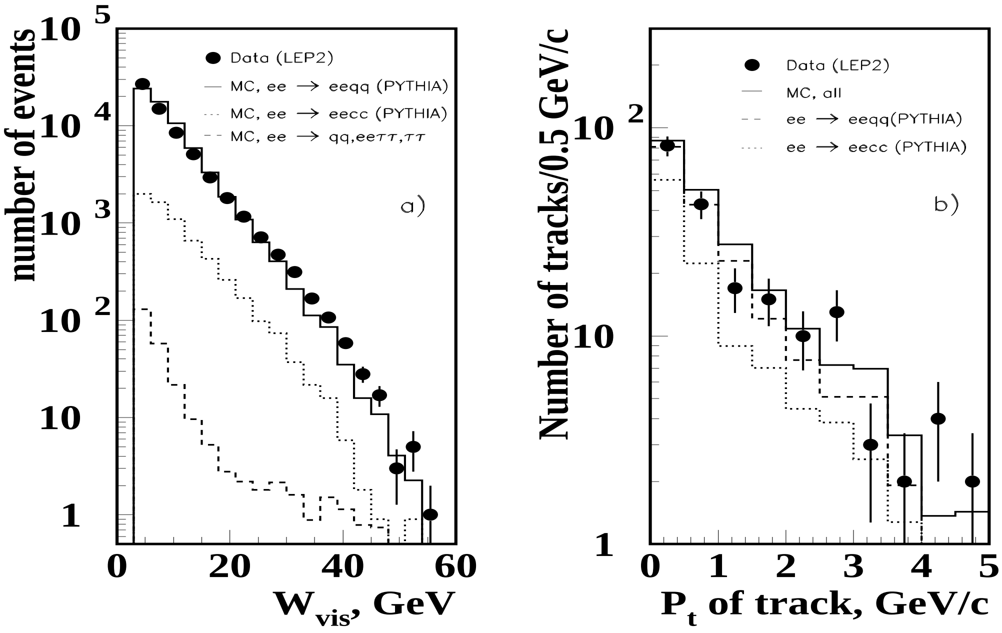
- L3: From $\sim$20k $\gamma\gamma$ events at LEP1 and LEP2

  72 μ events are selected (expect 34 background)

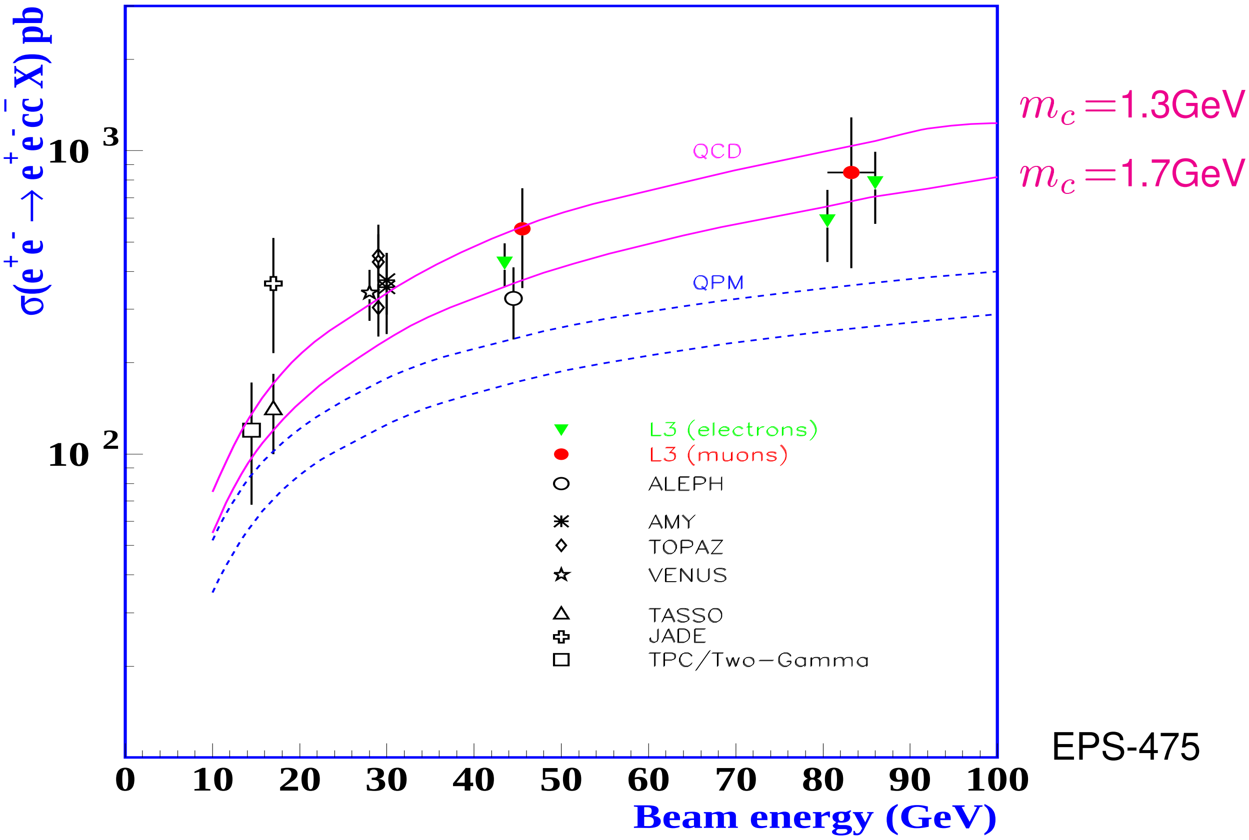
  $\rightarrow$ selection efficiency $(0.6-0.7)\times10^{-3}$, and

  732 e events are selected (expect 365 background)

  $\rightarrow$ selection efficiency $(0.7-1.3)\times10^{-2}$



Charm cross section



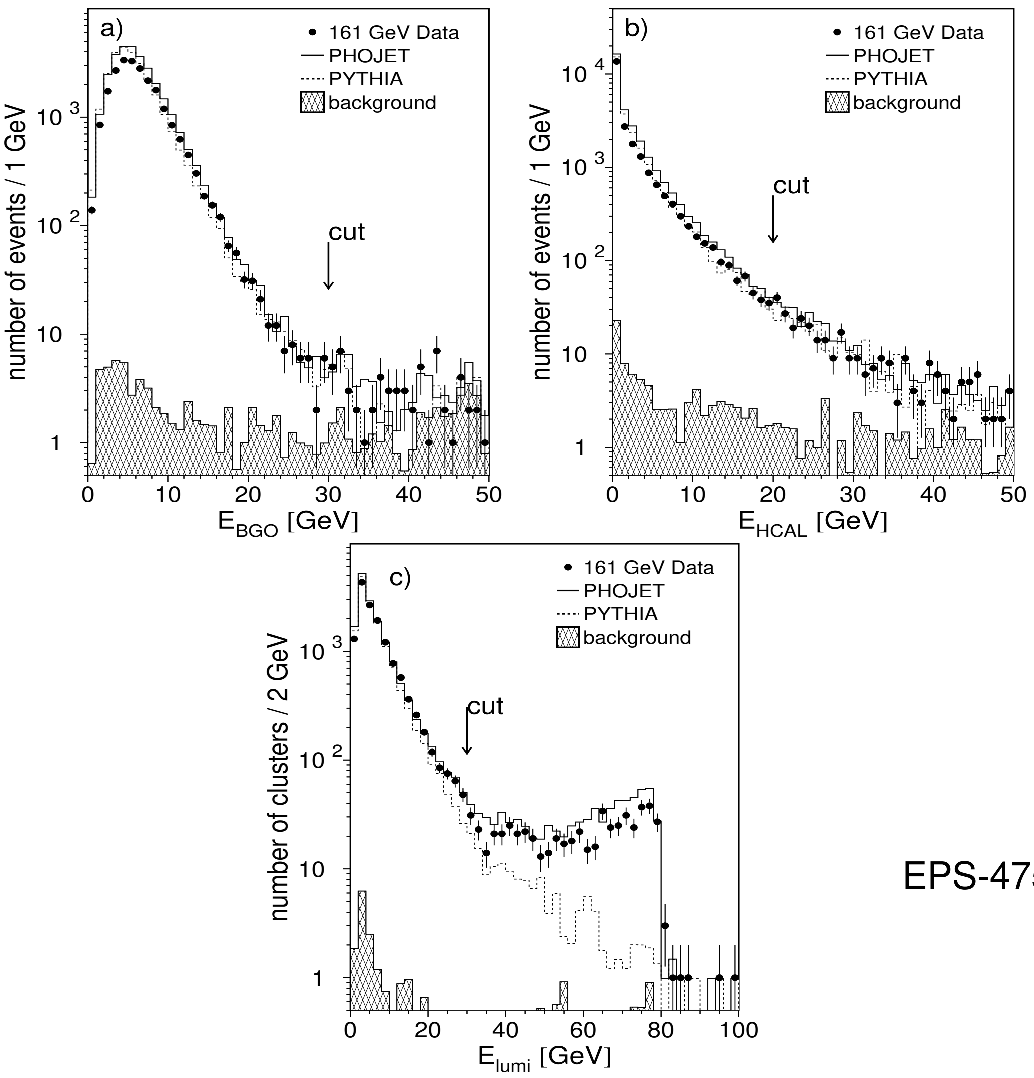
L3: Leptons from semi-leptonic charm decays

$\Rightarrow$	μ	$\sigma_{LEP1}^{ee\to eeccX} = 553 \pm 200$ pb
	μ	$\sigma_{LEP2}^{ee\to eeccX} = 848 \pm 439$ pb
	e	$\sigma_{91}^{ee\to eeccX} = 425 \pm 70$ pb
	e	$\sigma_{161}^{ee\to eeccX} = 586 \pm 156$ pb
	e	$\sigma_{172}^{ee\to eeccX} = 783 \pm 210$ pb

- **Extrapolate cross section to $p_T = 0$**

  $\Rightarrow$ **Large modeling error**

Total cross section measurement



EPS-475

- **To measure the total cross section one needs to apply large corrections for events lost due to limited detection and/or trigger acceptance**
- $\gamma\gamma \to \rho\rho \sim 10\%$ **of** σ_{tot}

$\Rightarrow$ **big uncertainties from M.C. corrections**

Total cross section measurement

- **Measure** $d\sigma/dW_{\gamma\gamma}$, **calculate** $\mathcal{L}_{\gamma\gamma}$ **and extrapolate to** $Q^2 = 0$
- **Gribov factorisation (hadronic photon):**

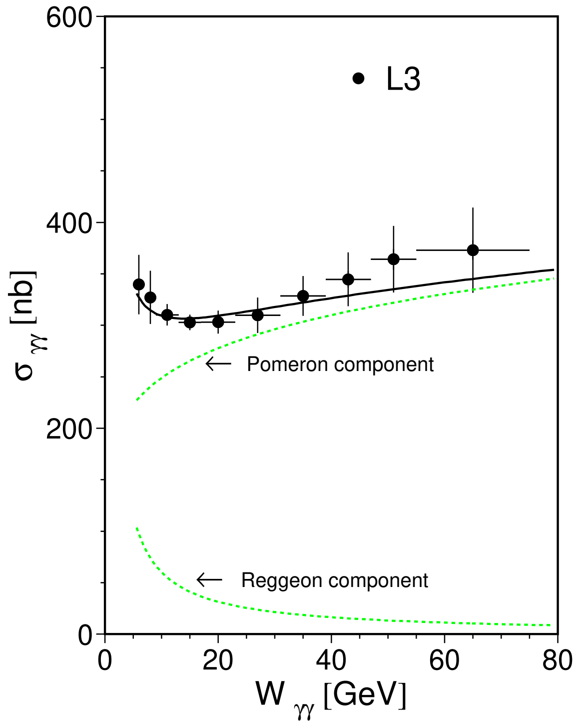
  $\sigma_{\gamma\gamma} = \frac{(\sigma_{\gamma p})^2}{\sigma_{pp}} \approx 250 - 400\text{nb}$
- **Regge parameterisation:**

  $\sigma(s) = X s^{\epsilon} + Y s^{-\eta}$; $\qquad X = 173 \pm 7$

  $Y = 519 \pm 125$

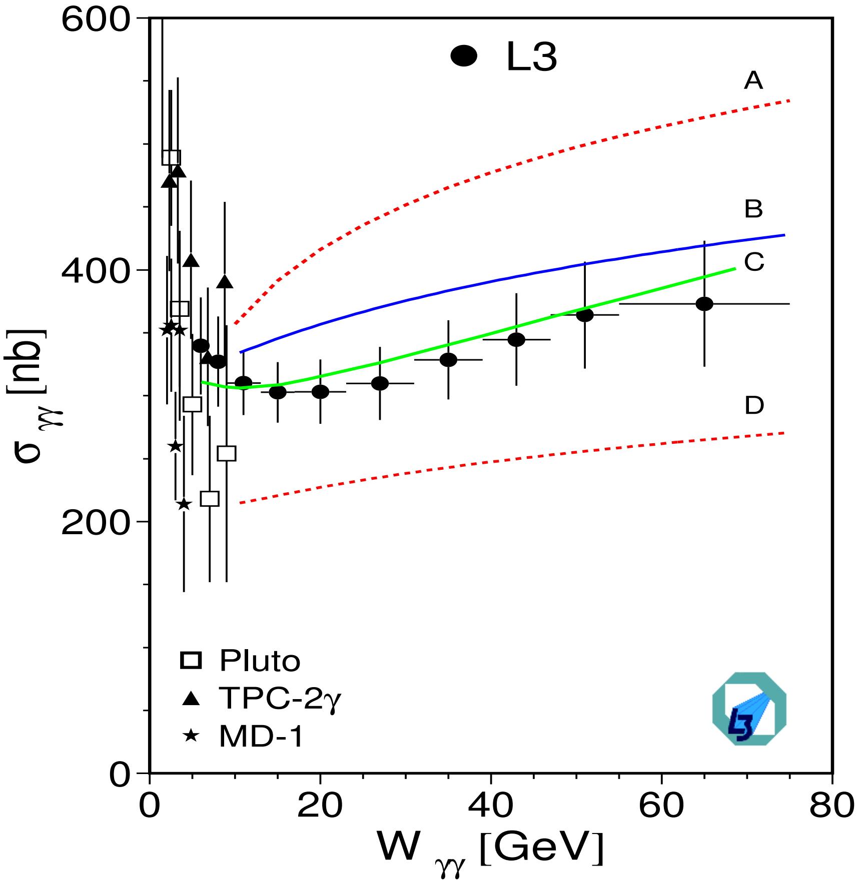
  (Donnachie-Landshoff) $\quad \eta, \epsilon$ **from PDG**

  ($\epsilon = 0.079 \pm 0.001$ **and** $\eta = 0.468 \pm 0.006$**)**



- $5\,GeV < W_{\gamma\gamma} < 75\,GeV$

Total $\gamma\gamma$ Cross Section



EPS-475

A	- - - - -	***Max. estimate from photo-production***
B	——	***Schuler and Sjöstrand***
C	——	***Dual Parton Model (Engel & Ranft)***
D	- - - - -	***VMD contribution***

- $\sigma_{tot}^{\gamma\gamma}$ **Results forthcoming form other LEP experiments**
- **For a conclusive result a 0°-angle tagger is needed.**

Conclusion and Outlook

- Hadron production in $e\gamma$ events: better agreements with data achieved by tuning parton k_T (ALEPH,OPAL) or adding "resolved photon component" (DELPHI)
- More work needed to understand origin of discrepancies (γ more pointlike? BGF?)
- Hadron production in $\gamma\gamma$ events compared to NLO calculations (OPAL) – harder spectrum than γ**p** and **hp** scattering
- Charm production and cross sections (L3) measurement extended to higher energies
- L3 has demonstrated for the first time the $\sqrt{s}_{\gamma\gamma}$ behaviour of $\sigma^{tot}_{\gamma\gamma\rightarrow\mathrm{hadrons}}$
- Most LEP experiments have upgraded their far-forward calorimeters
  double-tag results forthcoming