Final States in $\gamma\gamma$ and γp interactions

Vancouver

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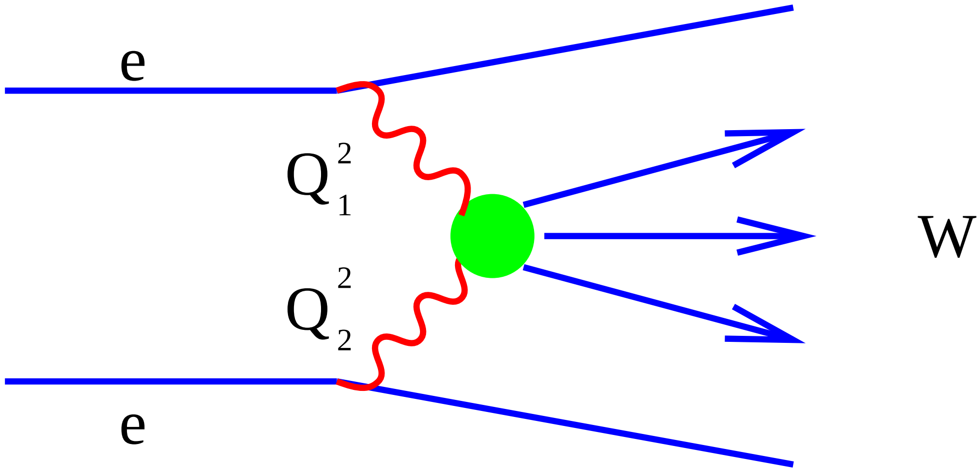
on behalf of the H1, L3 and OPAL collaborations

1. Total hadronic cross-section (L3, OPAL)
2. Jet production (OPAL)
3. Hadron production (OPAL, H1)
4. Baryon-Antibaryon asymmetry (H1)
5. Glueball searches (L3)

many thanks to H1 and L3, especially to Martin Erdmann, Maria Kienzle, Andrey Rostovtsev, Martin Swart

photon-photon (mainly LEP2):

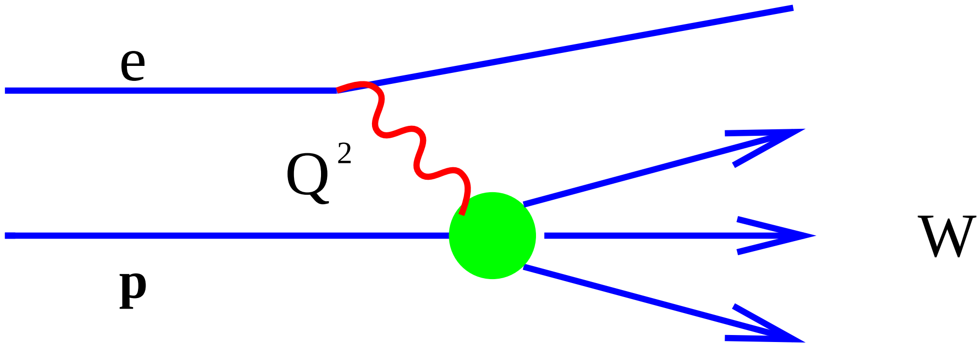


$$W_{\gamma\gamma} = \sqrt{s}_{\gamma\gamma} = \sqrt{(\sum E_h)^2 - (\sum \vec{p}_h)^2}$$

$10 < W_{\gamma\gamma} < 120$ GeV

$Q_1^2, Q_2^2 < 5$ GeV^2

photon-proton (HERA):

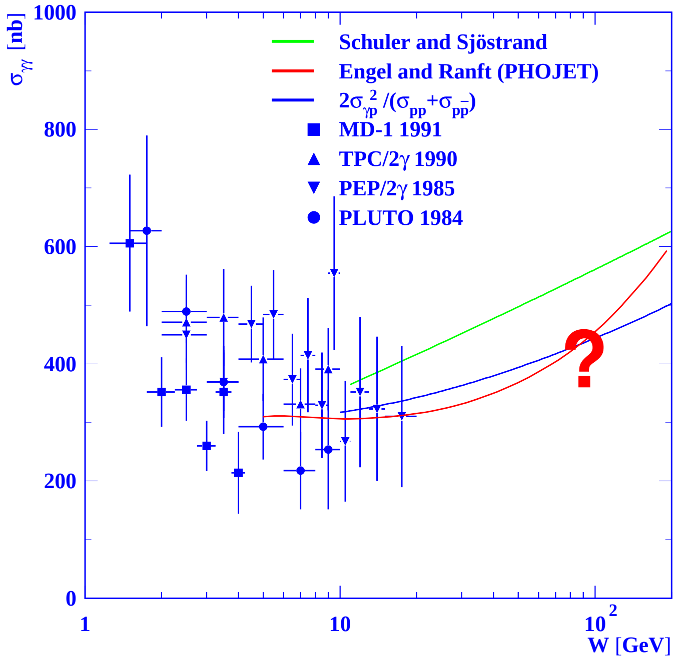


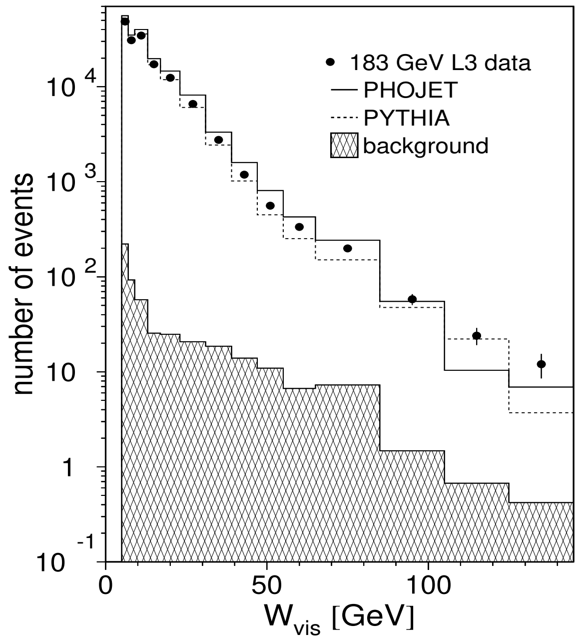
$40 < W_{\gamma p} < 300$ GeV

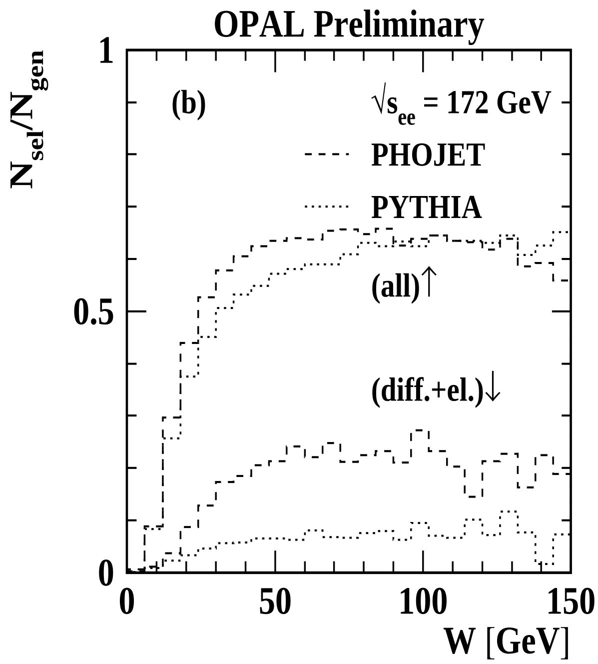
$Q^2 < 4$ GeV^2

1.) Total hadronic $\gamma\gamma$ cross-section

Pre-LEP2:







Use unfolding for $\mathrm{d}N_{\mathrm{ev}}/\mathrm{d}W_{\mathrm{vis}} \rightarrow \mathrm{d}\sigma_{\mathrm{ee}}/\mathrm{d}W$

Extracting $\sigma_{\gamma\gamma}$ from $\mathrm{d}\sigma_{\mathrm{ee}}/\mathrm{d}W$

$\longrightarrow$ luminosity function $L_{\gamma\gamma}$

$\longrightarrow$ form factors $F(Q^2)$

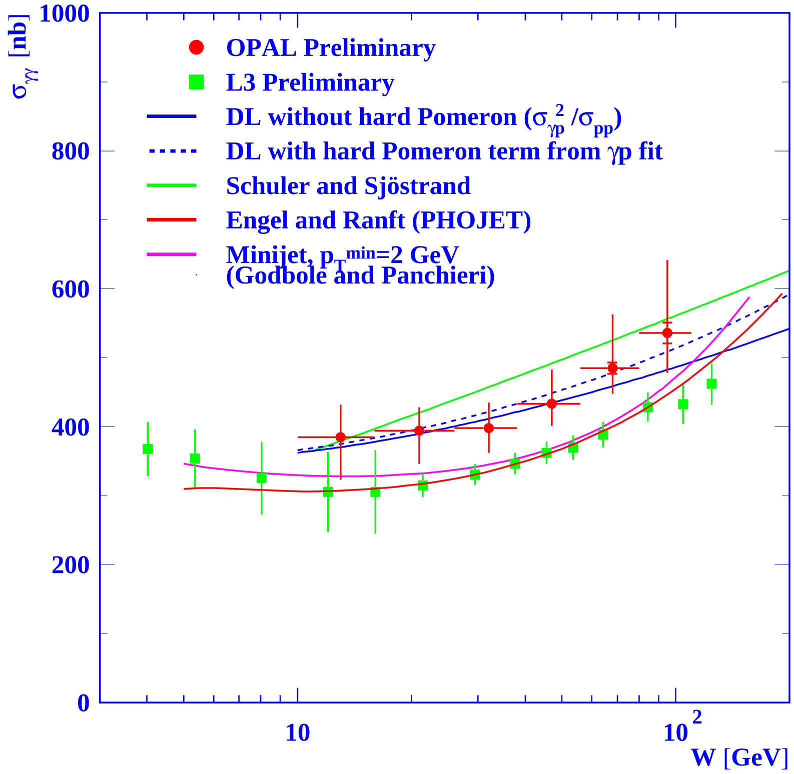
$$\frac{\mathrm{d}\sigma_{\mathrm{ee}}}{\mathrm{d}y_1\mathrm{d}Q_1^2\mathrm{d}y_2\mathrm{d}Q_2^2} = \frac{\mathrm{d}L_{\gamma\gamma}}{\mathrm{d}y_1\mathrm{d}Q_1^2\mathrm{d}y_2\mathrm{d}Q_2^2}\sigma_{\gamma\gamma}(W, Q_1^2, Q_2^2)$$

$$\sigma_{\gamma\gamma}(W, Q_1^2, Q_2^2) = F(Q_1^2)F(Q_2^2)\sigma_{\gamma\gamma}(W, 0, 0)$$

with $y_i = E_{\gamma_i}/E_{\mathrm{e}}$

Main systematic errors

	L3	OPAL
unfolding with PHOJET or PYTHIA		5%
calorimeter energy scale	$1-3\%$	$1-10\%$
trigger efficiency	$4-15\%$	2%
multiplicity cuts	$1-5\%$	$2-15\%$
beam-gas (beam-wall) background		2%



Donnachie-Landshoff[a]

(soft Pomeron + Reggeon exchange)

$$\sigma(s) \approx Xs^{0.08} + Ys^{-0.46}$$

(plus possible hard Pomeron term $\propto s^{0.4}$)

Models use factorisation to predict soft part of total cross-section from γp and pp data (with $\sqrt{s}_{\gamma\gamma} = \sqrt{s}_{\gamma \mathrm{p}} = \sqrt{s}_{\mathrm{pp}}$)

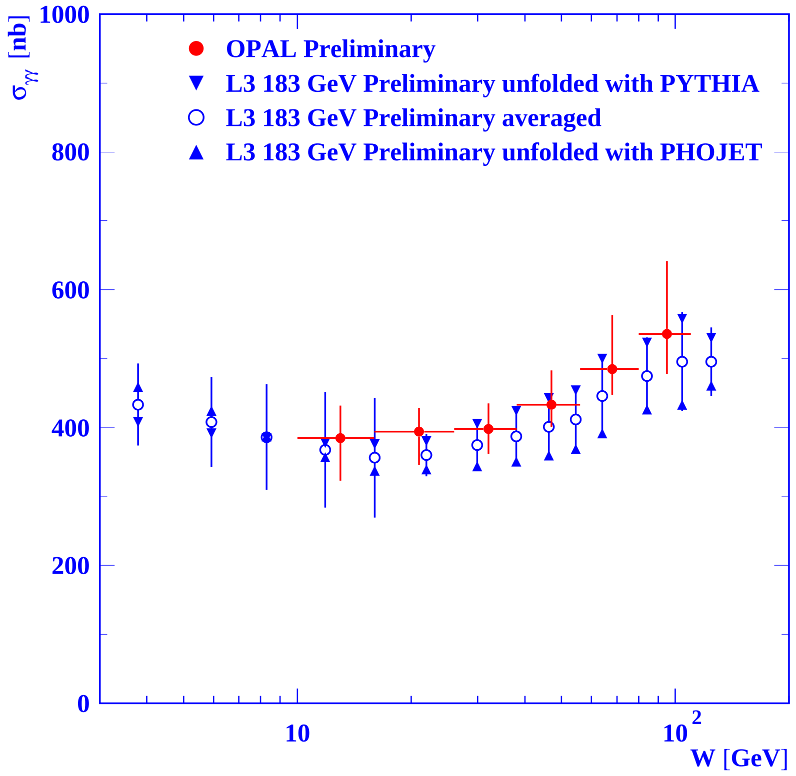
Models predict stronger high energy rise of $\gamma\gamma$ total cross-section compared to γp and pp total cross-section

[a] "Regge theory is one of the great truths of particle physics"

Is there a L3/OPAL discrepancy ?

L3 uses PHOJET for unfolding central values and gives no model dependent systematic error

OPAL shows the average of the results obtained with PHOJET and PYTHIA and takes difference between models as systematic error



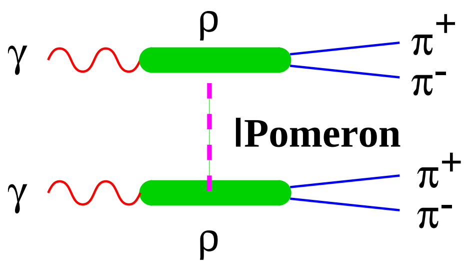
Errors are highly correlated

$\Rightarrow$

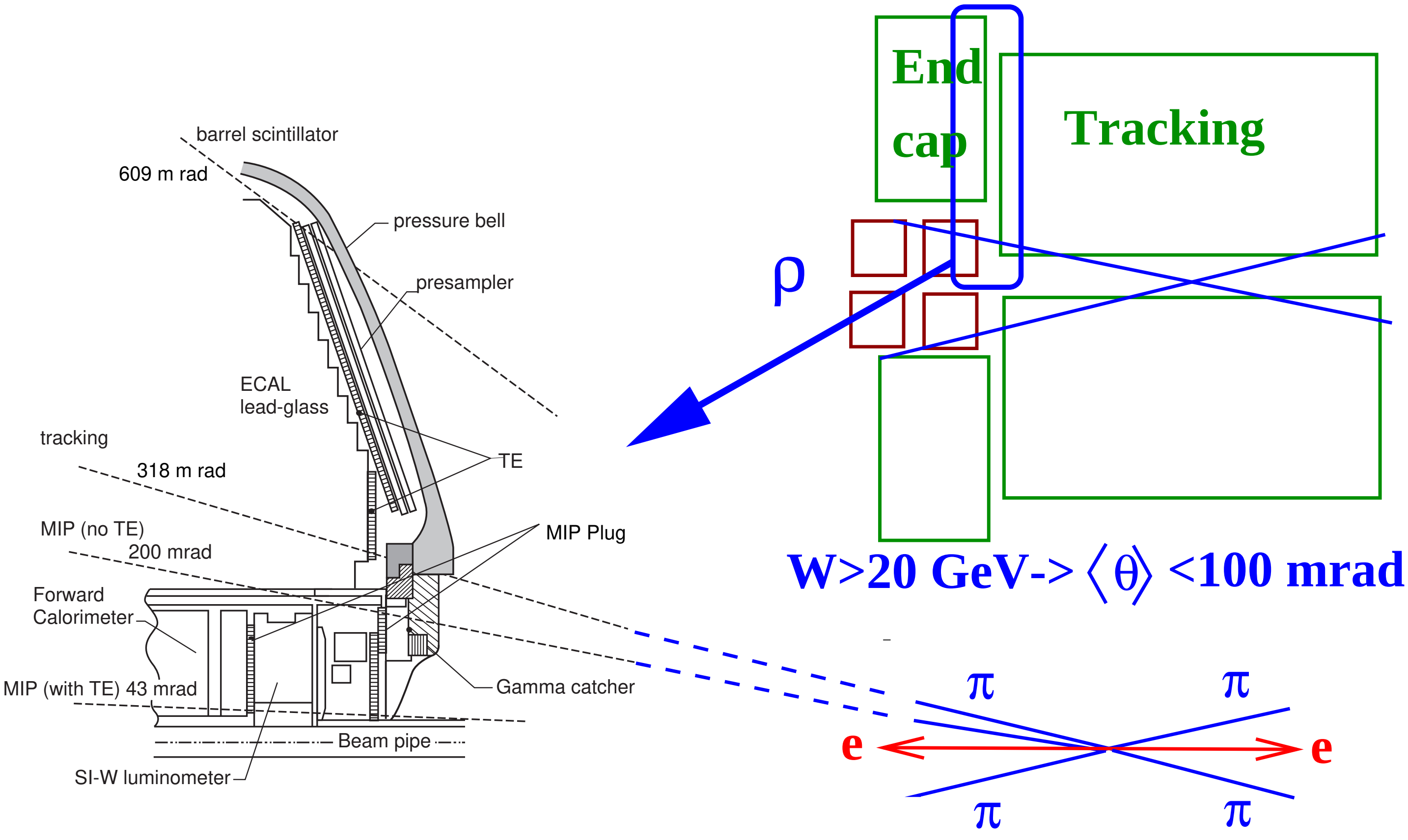
No significant discrepancy

quasi-elastic: $\gamma\gamma \rightarrow \rho\rho$ **diffractive** $\gamma\gamma \rightarrow \rho X$

HERA data $\&$ **factorisation** $\Rightarrow 20 - 40\%$ **of total rate**



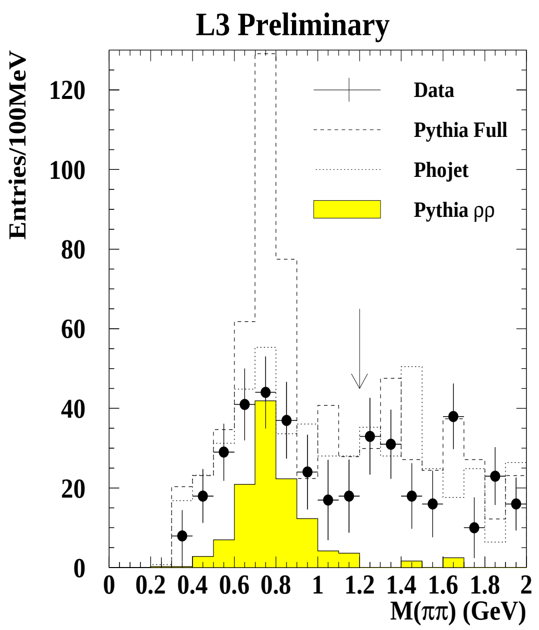
e.g. OPAL:

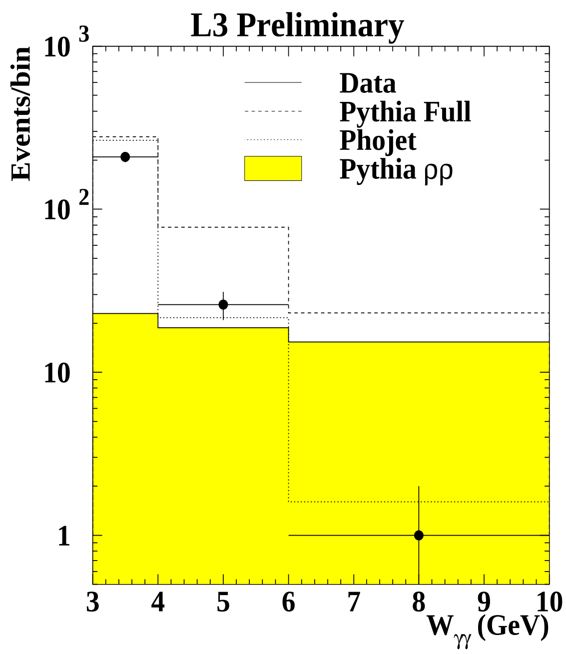


tracking down to 318 mrad

$\gamma\gamma \to \rho\rho$

'largest single process hadronic cross-section at LEP'



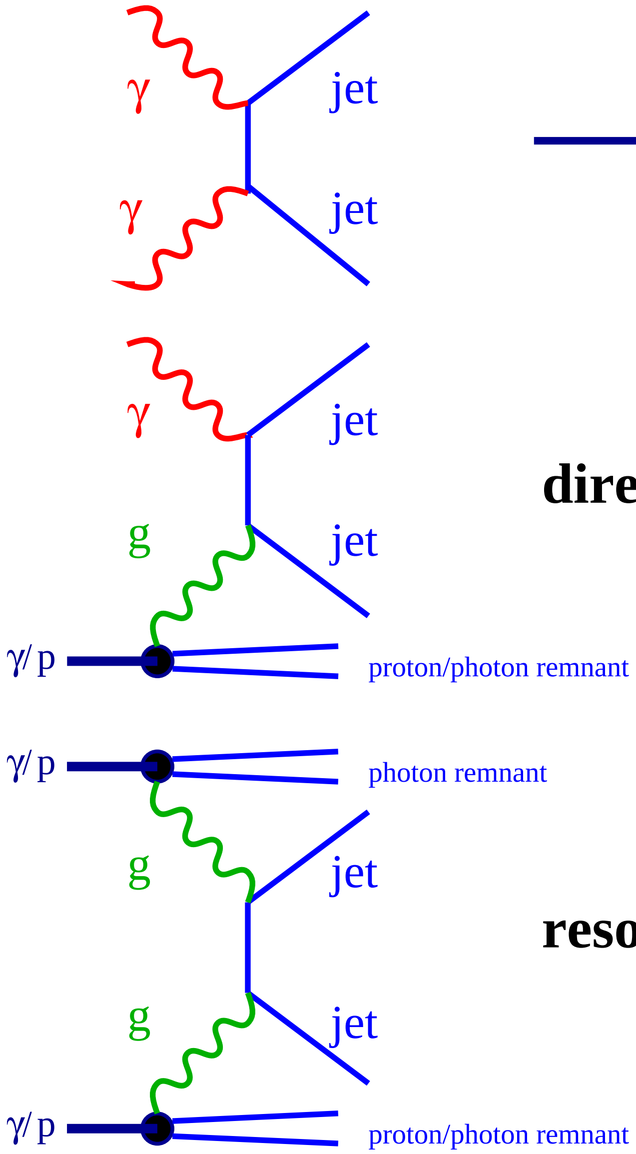


For $W < 10$ GeV:

- quasi-elastic cross-section in PYTHIA too large
- energy dependence of quasi-elastic cross-section incorrect for PYTHIA

measurements for $W > 10$ GeV difficult, but important

$\gamma\gamma$ and γp in leading order



	HERA	LEP
(upper diagram)	—	direct
(middle diagram)	direct	single-resolved
(lower diagram)	resolved	double-resolved

- All matrix elements involving γ, q, g contribute
- sensitive to $g^{\gamma}(x, Q^2)$

2.) Jets in $\gamma\gamma$

jets $\Leftrightarrow$ parton dynamics

hard scale available (normally E_{T} of the jets)

$\Rightarrow$ parton densities $f(x_\gamma, E_{\mathrm{T}}^2)$

Cone Algorithm with cone size R

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

($\eta = -\ln\tan\theta/2$ and azimuth ϕ)

compare to

- LO QCD Monte-Carlo models with LO parton densities:

  PYTHIA, (HERWIG), PHOJET with GRV, SaS, LAC...

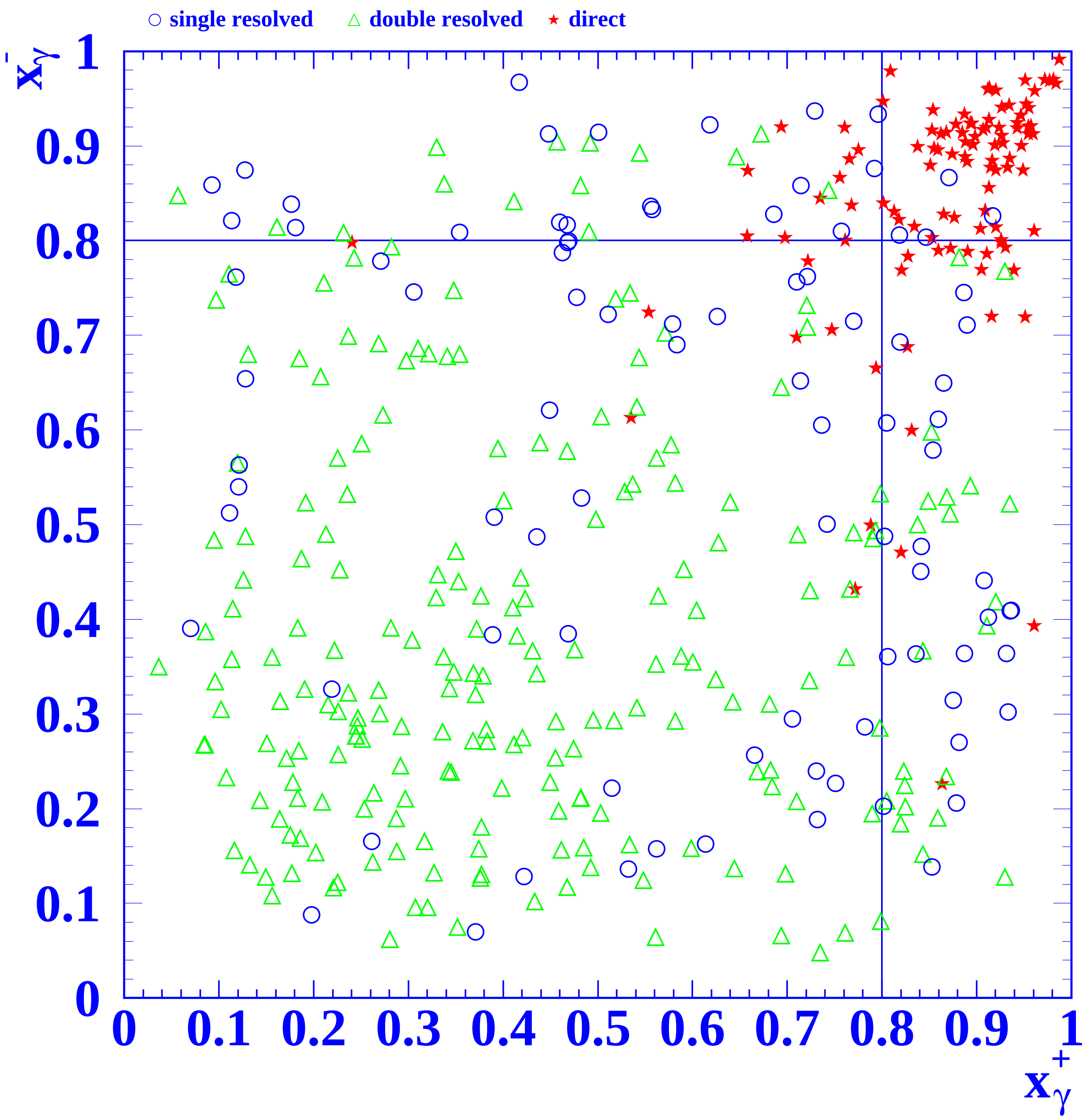
- NLO QCD calculations:

  (P.Aurenche et al.)

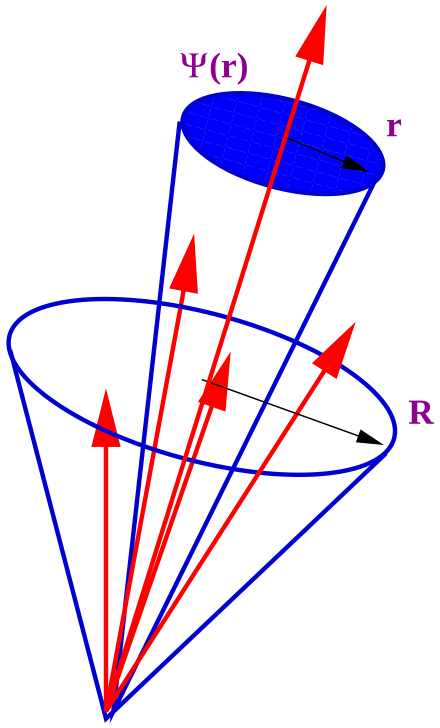
  T.Kleinwort, M.Klasen, G.Kramer with GRV, GS...

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

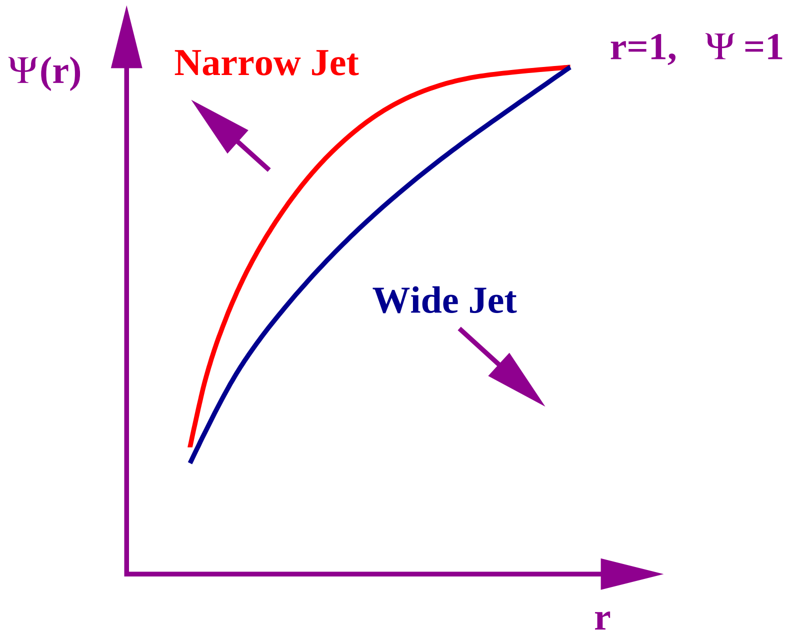
'fraction of photon's momentum participating in the hard interaction'

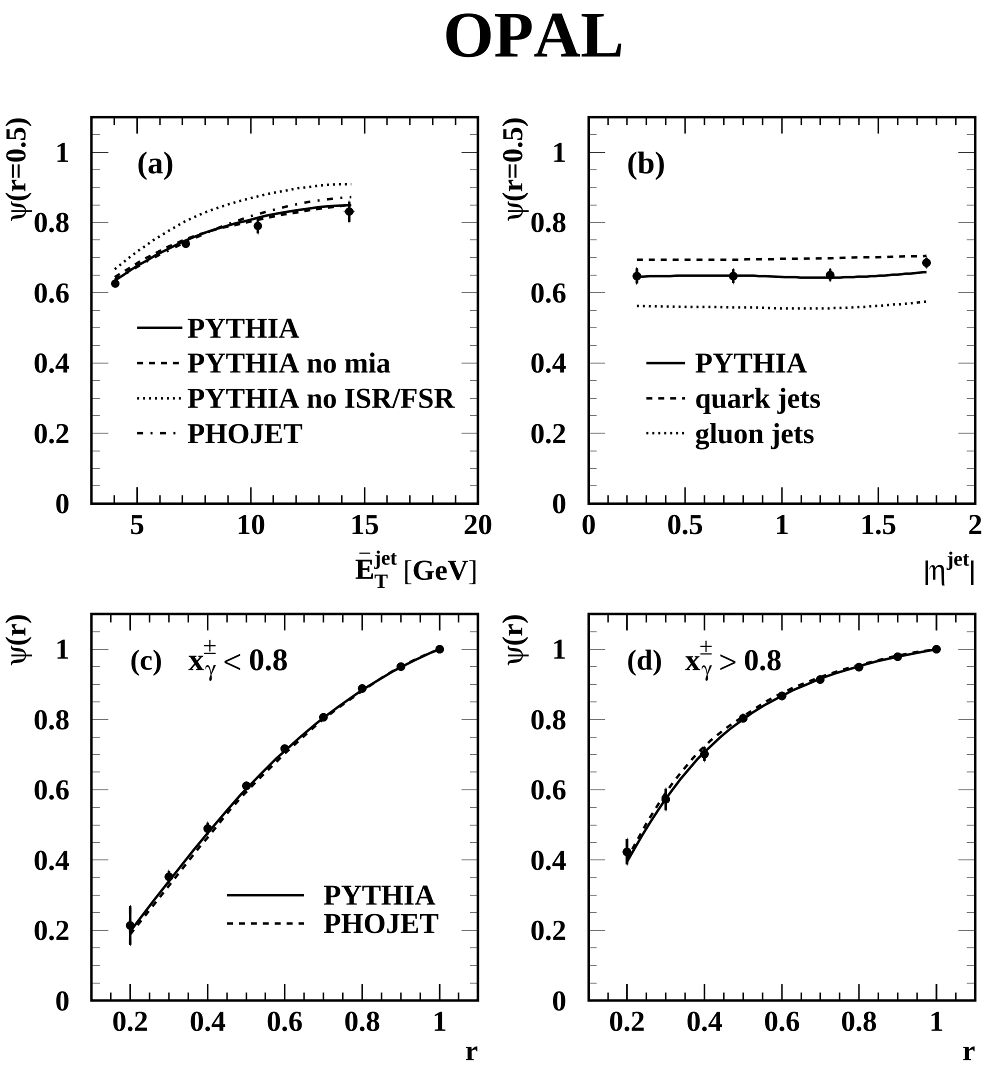


Jet Shapes



$$\psi(r) = \frac{1}{N_{\mathrm{jets}}} \sum_{\mathrm{jets}} \frac{E_{\mathrm{T}}(r)}{E_{\mathrm{T}}(r=R)}$$





jets become narrower at high $\bar{E}_{\mathrm{T}}^{\mathrm{jet}}$

multiple interactions have little influence

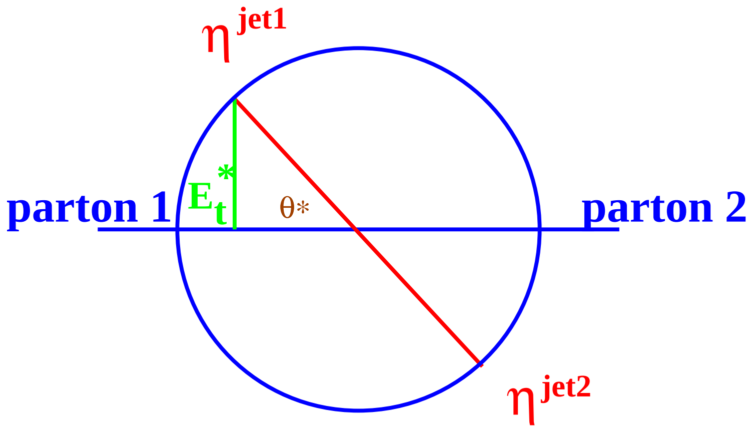
ISR and FSR (parton shower) needed

gluon jets broader than quark jets

jets from resolved events (more gluon jets) are broader than jets from direct events (more quark jets)

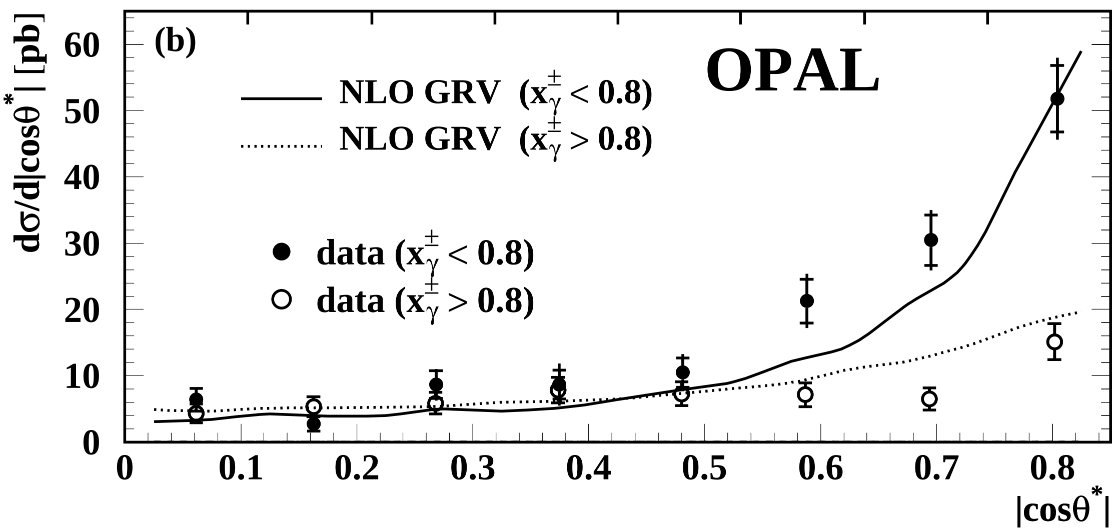
Parton scattering angle θ^*:

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



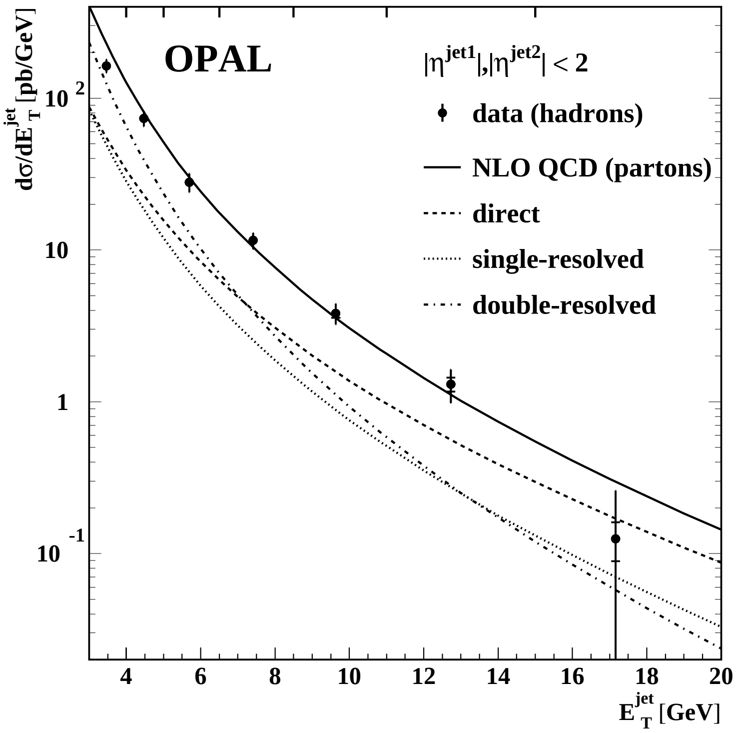
quark exchange (fermion) dominates direct $\propto |1-\cos^2\theta^*|^{-1}$

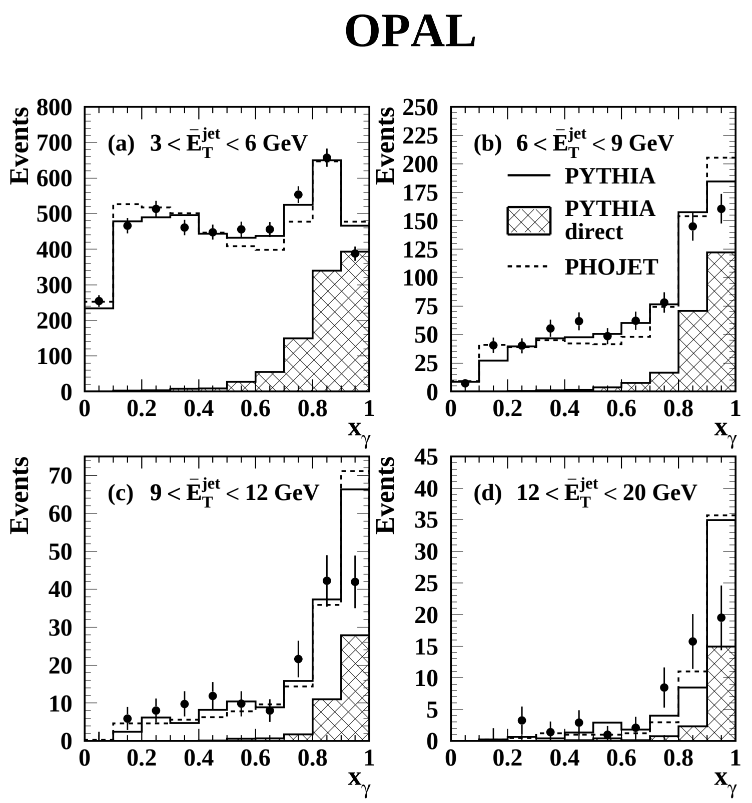
gluon exchange (boson) dominates resolved $\propto |1-\cos\theta^*|^{-2}$



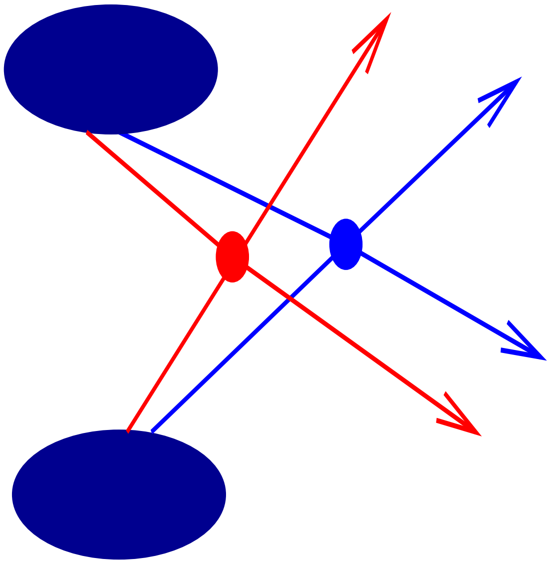
$$\bar{\eta} = \frac{\eta^{jet1}+\eta^{jet2}}{2} < 1\ ,\ M_{jj} > 12\ \text{GeV}$$

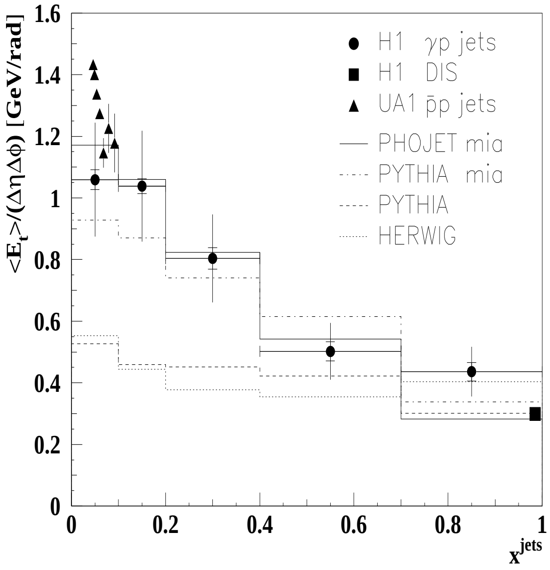
Di-jet cross-section compared to NLO-QCD by Klasen, Kleinwort & Kramer (GRV-NLO)





Transverse energy flow (wrt to beam) outside the jets in the central rapidity region $|\eta^*| < 1$

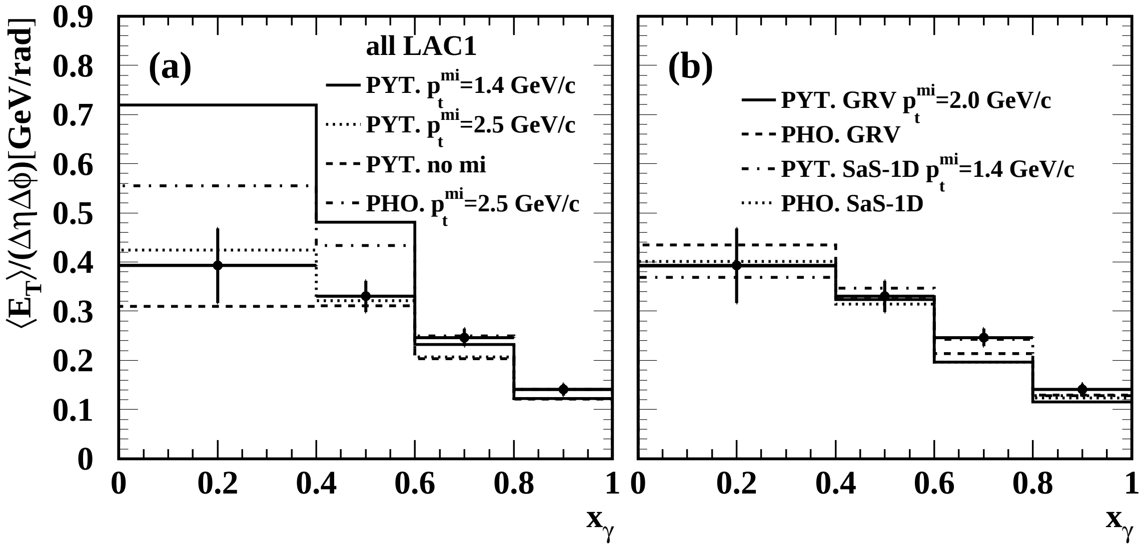




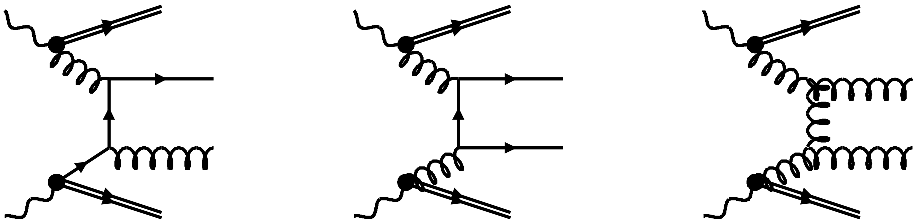
PHOJET and PYTHIA use multiple interaction (mi) model for underlying event

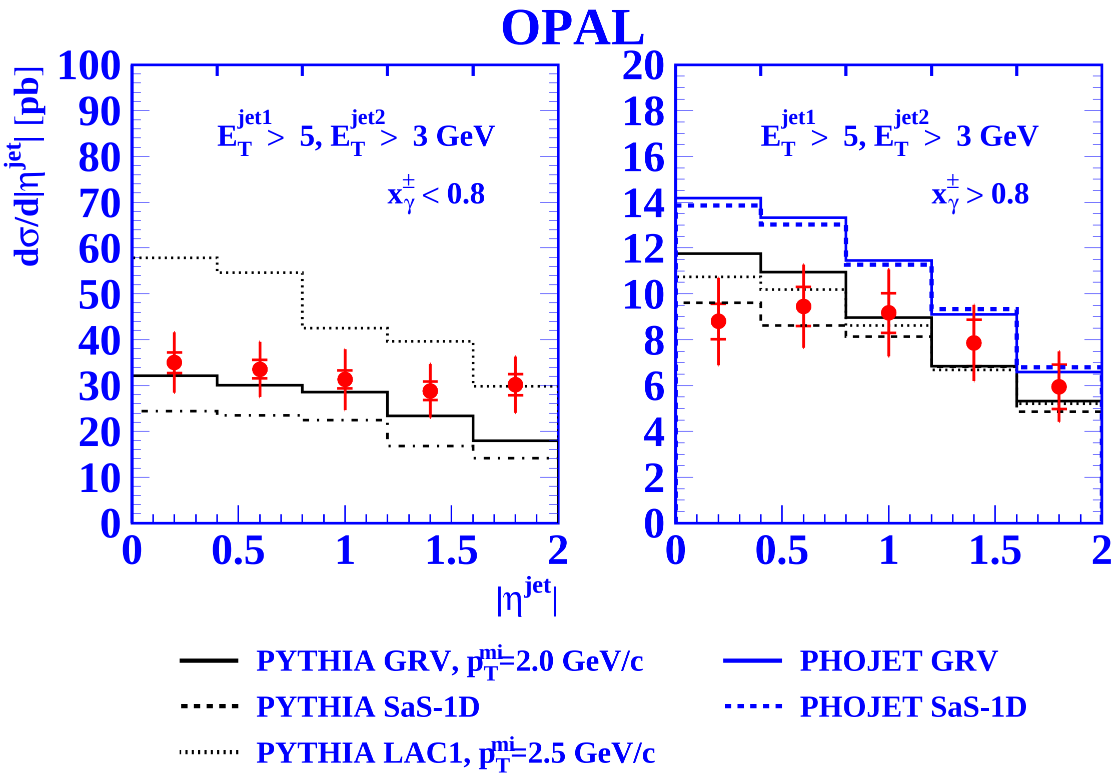
$p_{\mathrm{T}}^{\mathrm{mi}}$: **transverse momentum cut-off**

OPAL



Double-resolved processes ⇒ gluons in the photon



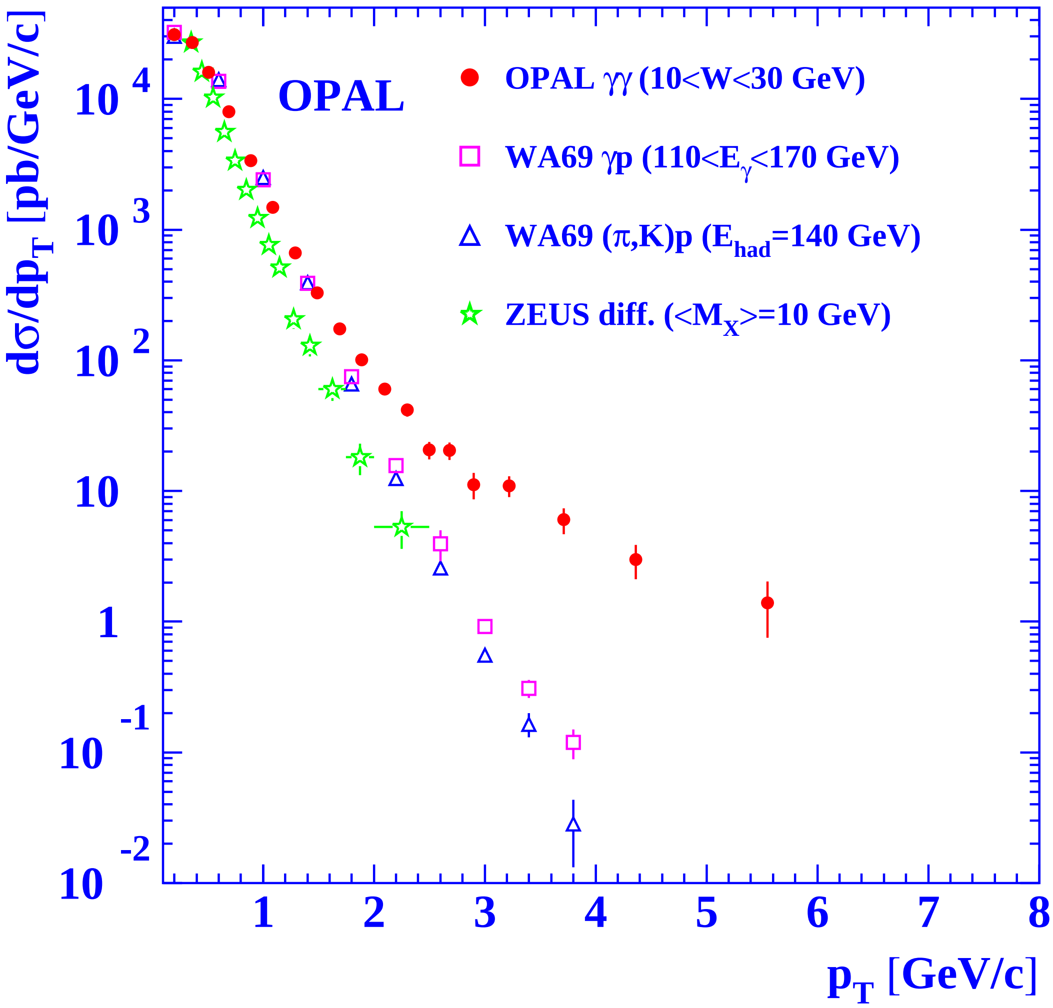


for $x_\gamma^\pm < 0.8$ (mainly resolved) sensitive to gluon content of the parametrisation

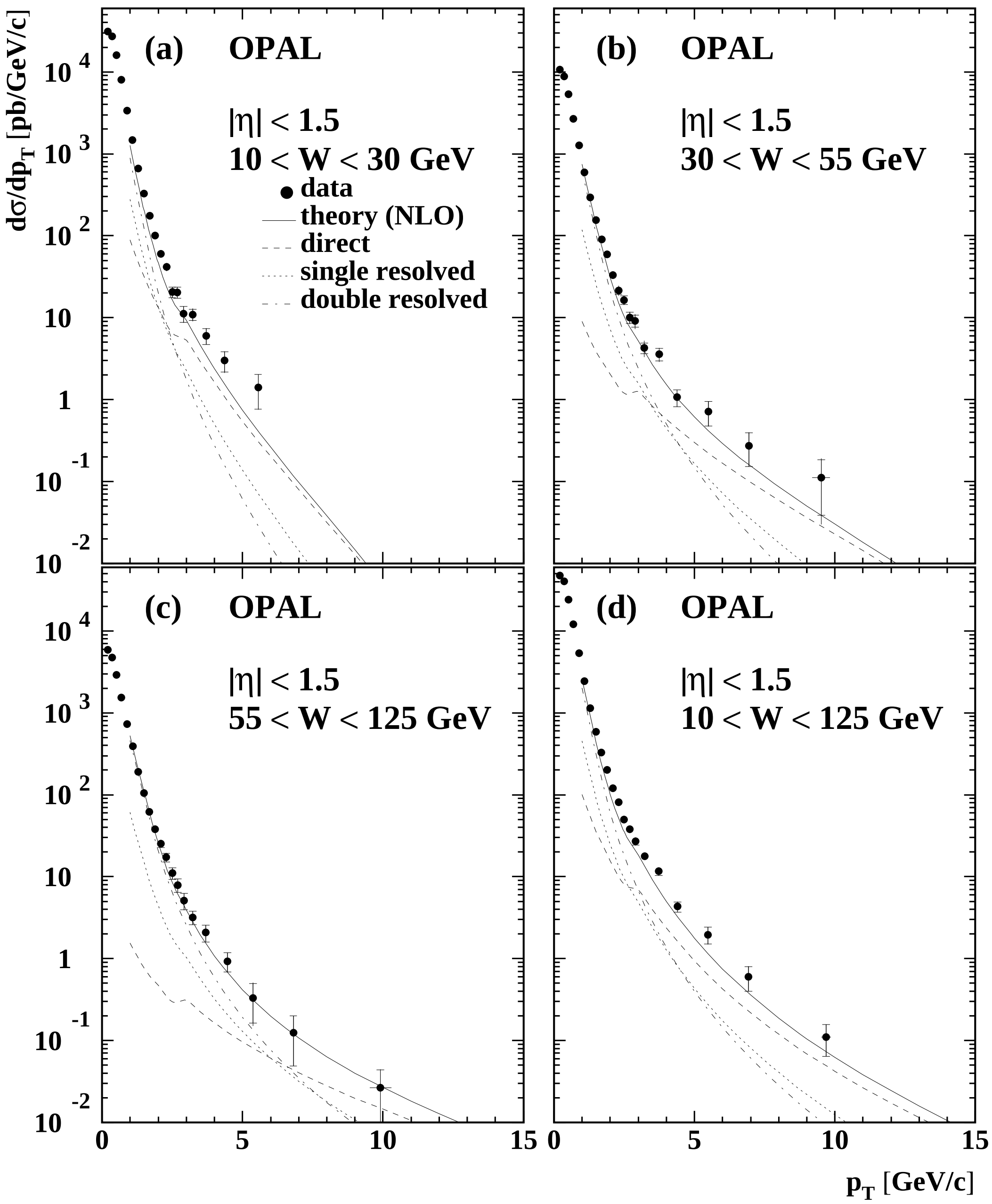
for $x_\gamma^\pm > 0.8$ (mainly direct) no dependence on parametrisation used, but models (PHOJET and PYTHIA) differ

3.) Hadron production

Compare meson-p and γp to $\gamma\gamma$ data at similar centre-of-mass energies W (charged hadrons)



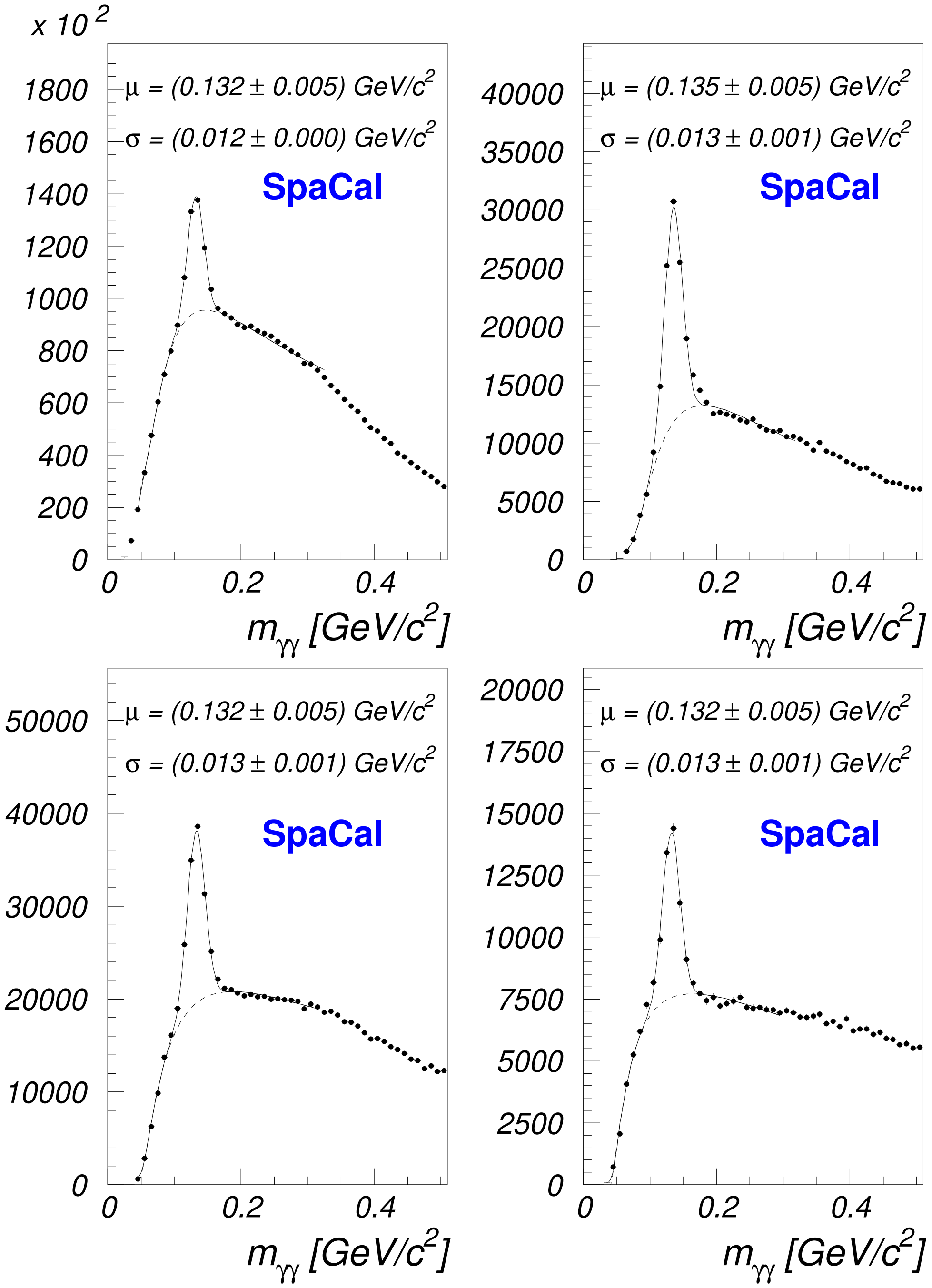
- WA69 and ZEUS data normalized to $\gamma\gamma$ data at low p_{T}
- $\gamma\gamma$ harder due to direct component

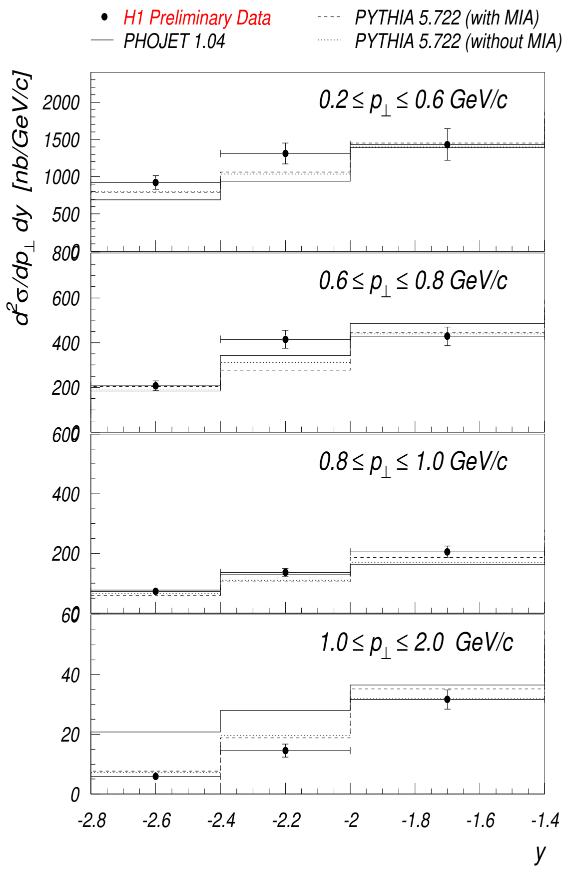


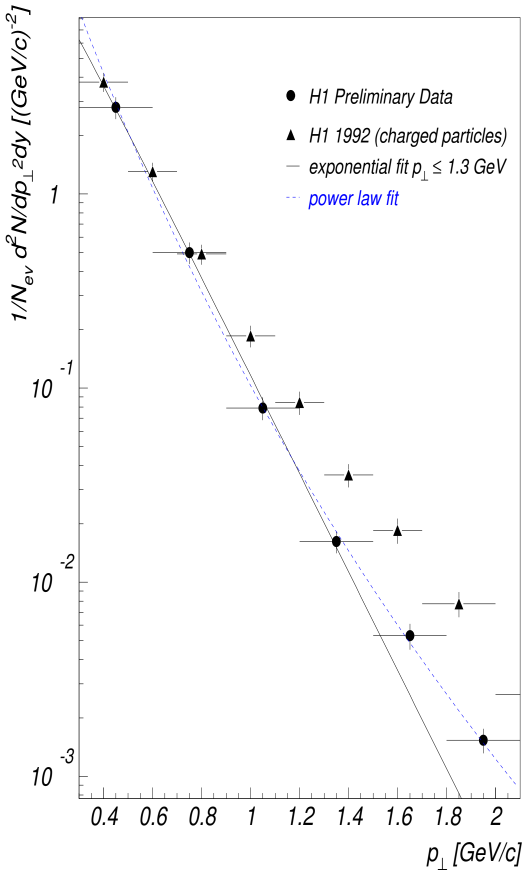
NLO calculations by Binnewies, Kniehl and Kramer use e^+e^- fragmentation functions and GRV-NLO parton densities with $\mu^2 = p_T^2$

H1: Inclusive π^0 production in photon hemisphere (backward):

$-2.8 \leq y \leq -1.4$ and $0.2 \leq p_\perp \leq 1.0$ GeV$/c^2$







- **spectra well described by PHOJET and PYTHIA**
- **accuracy not sufficient to distinguish between multiple interactions models**
- **no separation of diffractive and non-diffractive events**
- **$p_\perp$ spectrum well described by exponential**

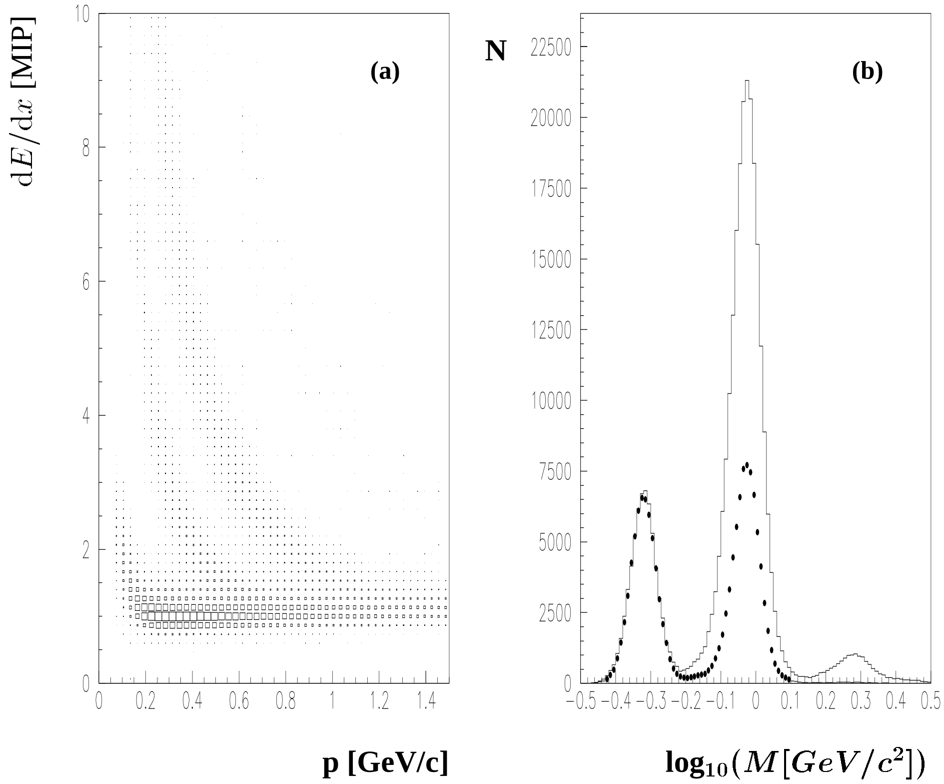
$$f(p_\perp) = \exp(a - b \cdot \sqrt{p_\perp^2 + m_{\pi^0}^2})$$

($b = 5.80 \pm 0.20$ (GeV/c)$^{-1}$ for $p_\perp < 1.3$ GeV)

and a power law at higher $p_\perp$

4.) Baryon-Antibaryon asymmetry

- tagged photoproduction ($150 < W < 260$ GeV)
- identify (anti-)protons with Central Jet Chamber
- $\mathrm{d}E/\mathrm{d}x(\mathrm{meas}) > 2 \cdot \mathrm{dE/dx(mip)}$
- $0.3 < p < 0.6$ GeV/c

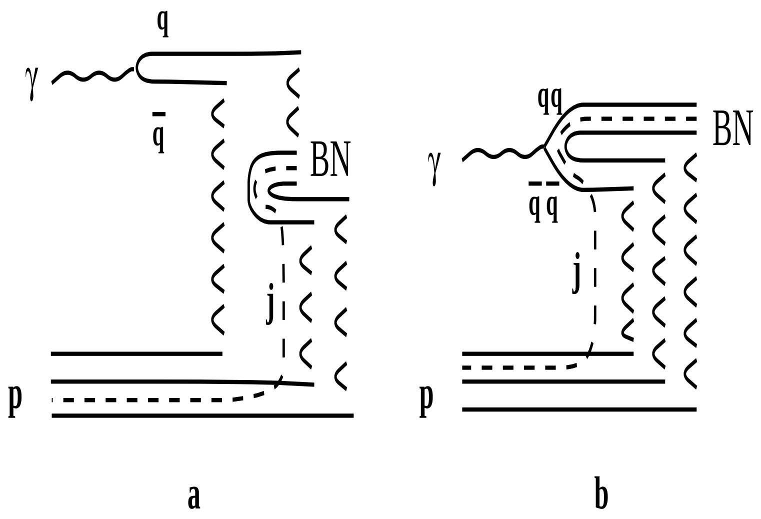


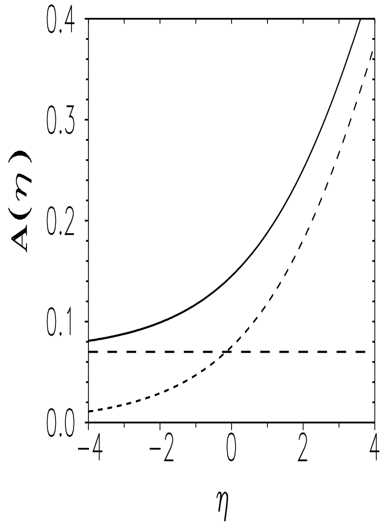
points: negative charge, histogram: positive charge

further cuts against beam-gas and beam-wall

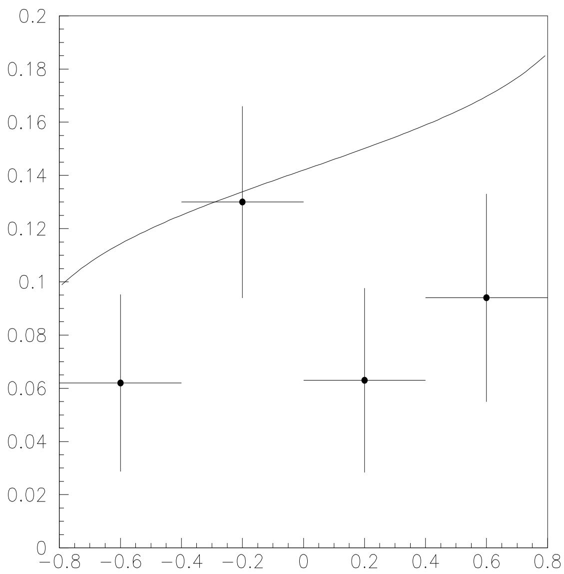
B.Z.Kopeliovich and B.Povh, Z.Phys.C75 (1997) 693, predict

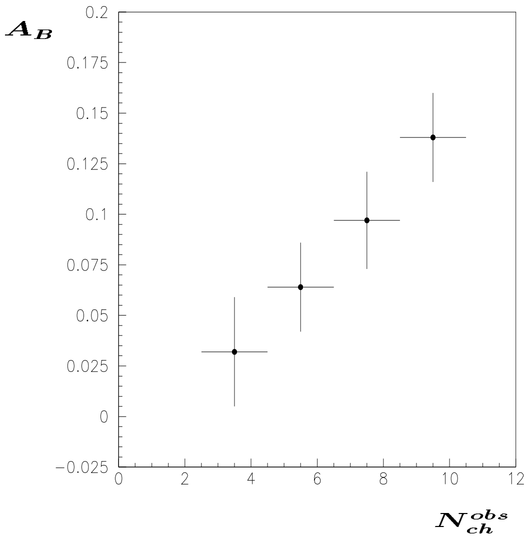
$$A_{\rm B} = 2\frac{N_{\rm p} - N_{\overline{\rm p}}}{N_{\rm p} + N_{\overline{\rm p}}} \approx 7\% \text{ at low x}$$





$A_{\rm B}$ vs. $\cos\theta$ $\qquad A_{\rm B} = (8.0 \pm 1.0 \pm 2.5)\%$

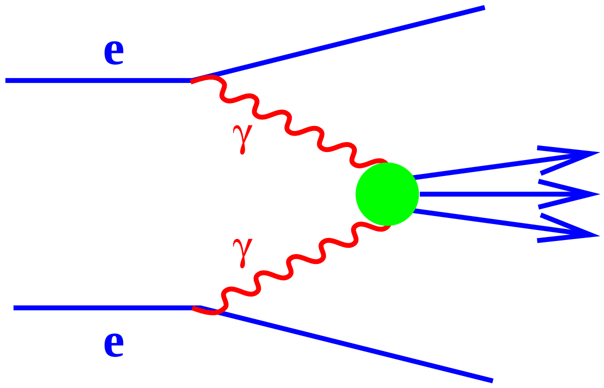




data in qualitative agreement with model

(not directly comparable, measurement restricted to $0.3 < p < 0.6$ GeV/c and $|\cos\theta| < 0.8$)

5.) Glueball search

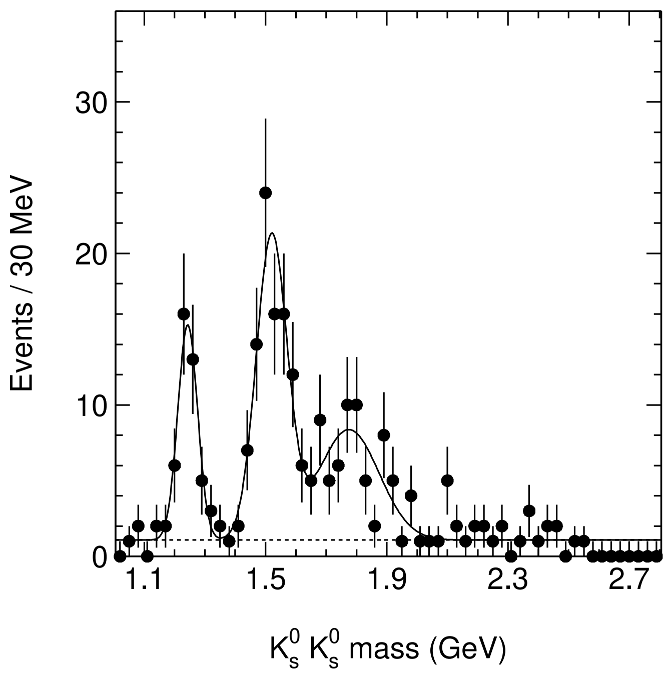


$J^{PC} = 0^{-+}, 0^{++}, 2^{++}$

(for real photons)

Stickiness $S_X = \frac{|\langle X|gg\rangle|^2}{|\langle X|\gamma\gamma\rangle|^2}$

- CLEO: Stickiness S of 102 (at 95 % CL) for $\xi(2230) \rightarrow K_S K_S, \pi^+, \pi^-$ decays
- L3: Stickiness S of 28.6 (at 95 % CL) for glueball candidate in $\xi(2230) \rightarrow K_S K_S$ decays



Conclusions

L3 and OPAL measure total hadronic $\gamma\gamma$ cross-section in the range $5 < W < 130$ GeV. Large systematic error from model dependence, but L3 and OPAL are consistent! Does $\gamma\gamma$ cross-section rise faster at high W than hadronic cross-sections ?

OPAL measurements of $\gamma\gamma$ jet cross-sections can constrain gluon content of the photon.

Hadron production in $\gamma\gamma$ harder than in γp or meson-p scattering (OPAL). π^0 production measured by H1 in the photon hemisphere is in satisfactory agreement with models.

A non-vanishing baryon asymmetry has been measured in photoproduction by H1 at a distance of about 7 rapidity units from the leading baryon production region.

Possible tensor glueball state $\xi(2230)$ not seen in $\gamma\gamma$ (L3 and CLEO), this is additional evidence for glueball interpretation.