Exclusive baryon-antibaryon production in $\gamma\gamma$ at e^+e^- colliders

Teresa Barillari

Duality 2005 Frascati, 7 June 2005

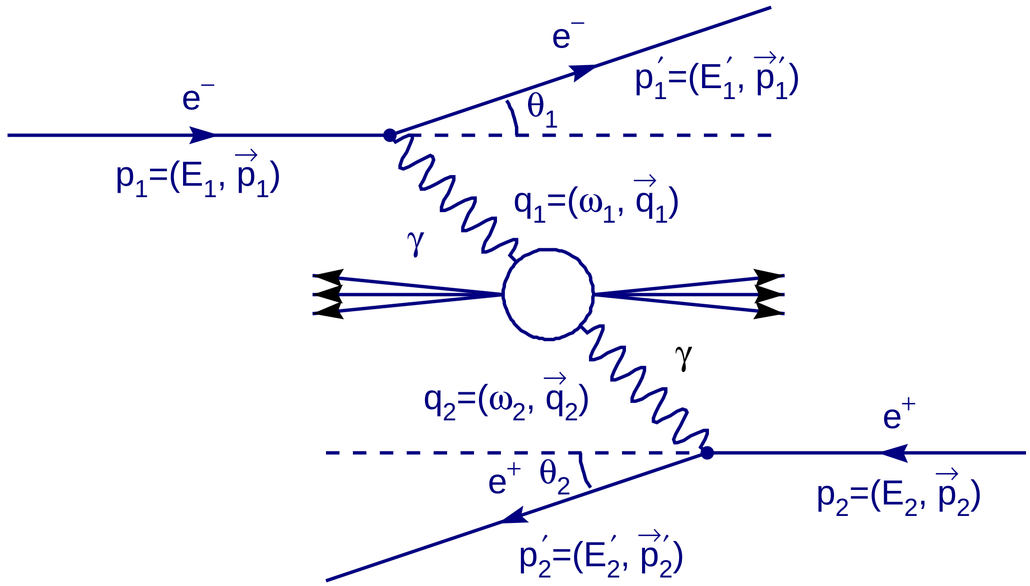
- Introduction
- Kinematics
- Theory
- Experimental results on $\gamma\gamma \rightarrow p\bar{p}$ processes
- Experimental results on $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ and $\gamma\gamma \rightarrow \Sigma^0\overline{\Sigma^0}$ processes
- Conclusions

Introduction

- The exclusive production of baryon-antibaryon pairs ($B\overline{B}$) in the collision of two quasi-real photons can be used to test predictions of QCD
- The QCD application to exclusive $\gamma\gamma$ reactions is based on the work of:
  - G. P. Lepage et S. J, Brodsky Phys. Rev. D22 (1980);
G. R. Farrar et al., Nucl. Phys. B259 (1985),
V. L. Chernyak et al., Nucl. Phys. B246 (1984)
- These calculations yield cross-sections about one order of magnitude smaller than the experimental results for $W > 2.5$ GeV
- To model non-perturbative effects, the introduction of quark-diquark systems has been proposed:
  - C. F. Berger, W. Schweiger, arXiv:hep-ph/0411123 (2004); C. F. Berger, W. Schweiger, Eur. Phys. J C28 (2003) [arXiv:hep-ph/0212066];
M. Anselmino et al., Int. J. Mod. Phys. A4 (1989)
- There exists an alternative description for the $\gamma\gamma \to B\overline{B}$, processes, the handbag model:
  - M. Diehl, P. Kroll and C. Vogt, Eur. Phys. J C26 (2003) [arXiv:hep-ph/0206288]
- In this presentation the existing $\gamma\gamma \to B\overline{B}$ cross-section measurements are discussed

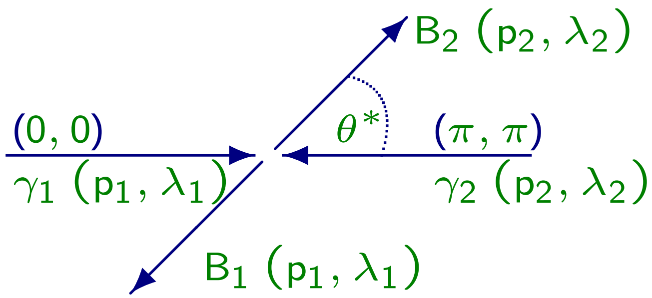
Kinematics

$e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-X$ $X = p\bar{p}, \Lambda\bar{\Lambda}, \ldots$ (Baryons)



$$Q_i^2 \approx 2E_iE_i^{'}(1 - \cos\theta_i)$$
$$Q_i^2 = (q_i^2 - \omega_i^2)$$

$\gamma\gamma$ center-of-mass system (CMS)



W, invariant mass in the $\gamma\gamma$ CMS

θ^*, polar angle in the $\gamma\gamma$ CMS

Untagged $\gamma\gamma$ events

In the two-photon events it is possible to distinguish:

- Double-tag $\gamma\gamma$ events:
  - Both scattered electrons are detected
- Single-tag $\gamma\gamma$ events:
  - One of the scattered electrons is detected
- No-tag $\gamma\gamma$ events:
  - No electron is detected

Hard scattering picture (HSP)

In pQCD (or HSP) an exclusive process: $A + B \to C + D$
is described by the exclusive hadronic amplitude

see: Brodsky et al., Phys. Rev. D24 (1981); Brodsky et al., ECFA 87/108 (1987)

$$\mathcal{M} = \int T_H(x_j, p_\perp) \prod_{H_i} \left(\phi_{H_i}(x_j, \tilde{p}_\perp) \delta(1 - \sum_{k=1}^{n_i} x_k) \prod_{j=1}^{n_i} d\,x_j \right)$$

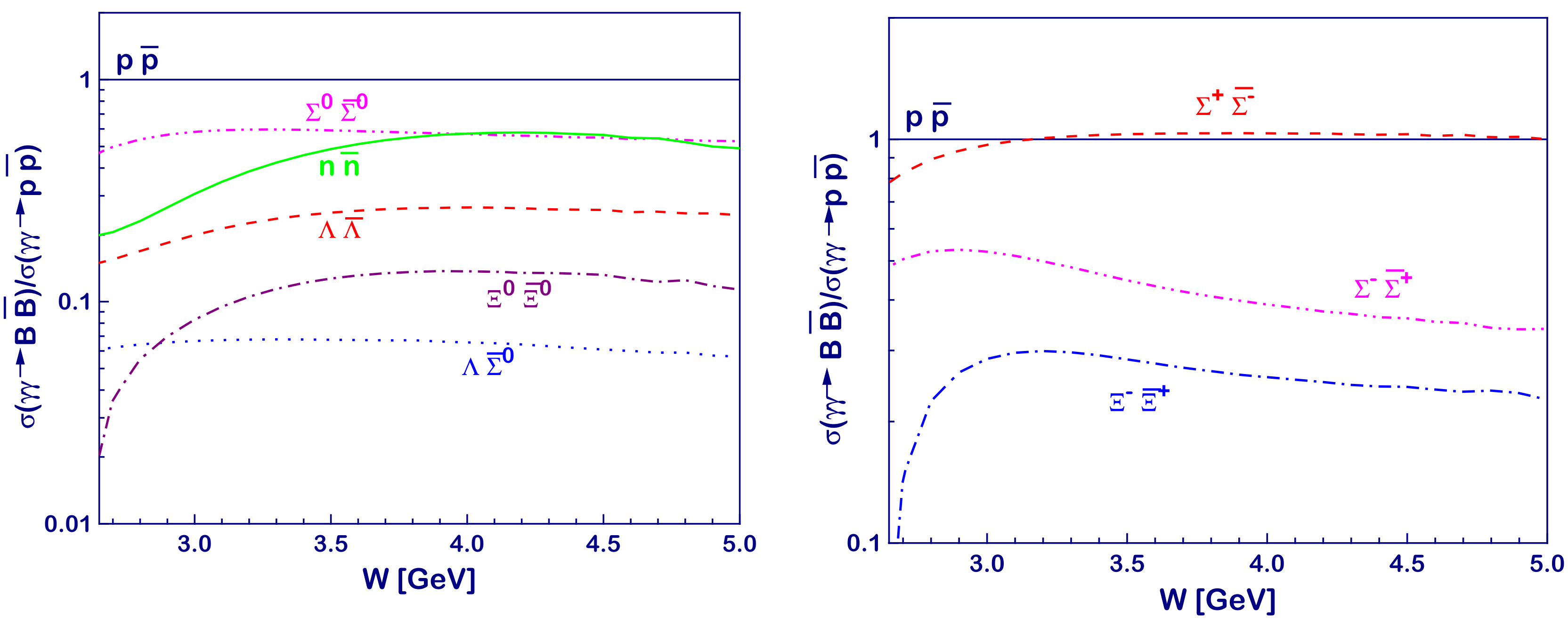
$\mathcal{M}$ separates:“short-range” from “long-range” phenomena

- ϕ_{H_i}: Process-independent, non-perturbative parton distribution amplitude (DA)
- T_H: Process-dependent, perturbative hard scattering amplitude
- $\tilde{p}_\perp \approx min(x, 1 - x)\sqrt{s}|\sin\theta|$
- x_j: Longitudinal momentum fraction carried by the valence partons in the hadron

$\mathcal{M}$ has been computed only for some reactions like exclusive $\gamma\gamma$ reactions. For other processes such calculation is too difficult

Quark-Diquark model

- There are applications of the quark-diquark model to the reactions:
  $\gamma\gamma \to B\overline{B}$ where $B = p, \Lambda, \Xi^-, \Sigma, \Delta,$, etc.
- Within this model baryons are treated as quark-diquark systems. The composite nature of the diquarks is taken into account by diquark form factors which are parameterized such that asymptotically the pure quark HSP emerges.

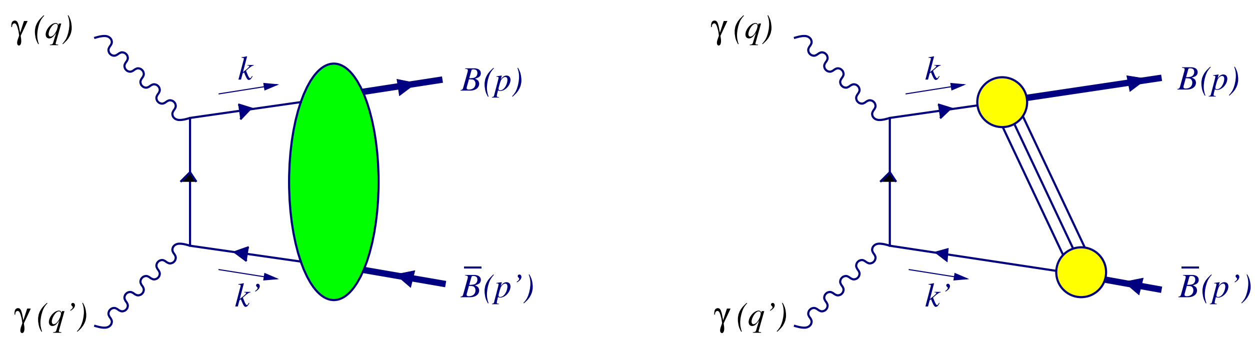


Diquark model predictions for integrated cross-sections (for $|\cos\theta^*| < 0.6$) for neutral and charged baryons

see C. F. Berger, W. Schweiger, arXiv:hep-ph/0411123 (2004); C. F. Berger, W. Schweiger, Eur. Phys. J C28 (2003); M. Anselmino et al., Int. J. Mod. Phys. A4 (1989)

The handbag mechanism

- The handbag mechanism studies the annihilation of two photons into baryon-antibaryon pairs (see M. Diehl, P. Kroll and C. Vogt, Eur. Phys. J C26 (2003))
- In this model the amplitude of the process $\gamma\gamma \to \mathrm{B\overline{B}}$ is factorized (see fig. (a)) into:
  - **Hard part** $\gamma\gamma \to \mathrm{q\overline{q}}$ scattering
  - **Soft part** (see fig. (b)) $\mathrm{q\overline{q}} \to \mathrm{B\overline{B}}$ transition described by form factors



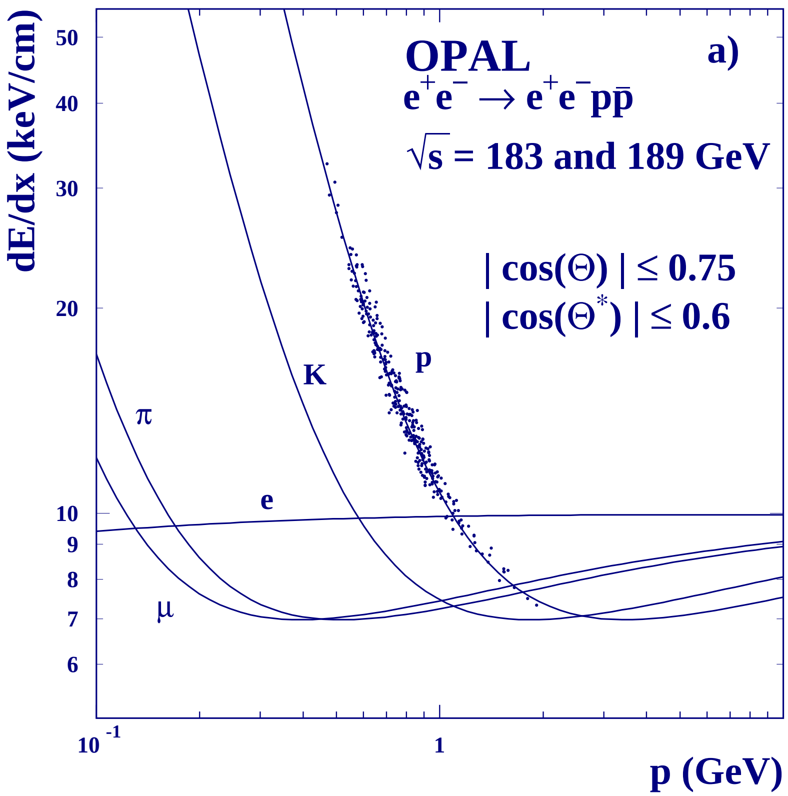
- This model:
  - Assumes that $(\overline{q})\ q$ hadronizes into $(\overline{\mathrm{B}})\mathrm{B}$ with any number of soft partons connecting the two parton-hadron vertices. The $(\overline{q})\ q$ carries the full momentum of the $(\overline{\mathrm{B}})\mathrm{B}$
  - Use $\gamma\gamma \to \mathrm{p\overline{p}}$ measurements to fit the parameters of the model
  - Predictions for other baryon octet members depend on a parameter ρ

Features of the untagged $e^+e^- \to e^+e^-X$ *events*

- The final state X has small $p_\perp$ and low mass
- The charged track particles coming from X are detected at small angles with respect to the beam
- They are almost back-to-back in the $r-\phi$ plane but not in the $r-z$ plane
- The $\gamma\gamma$ CMS is boosted along the beam axis

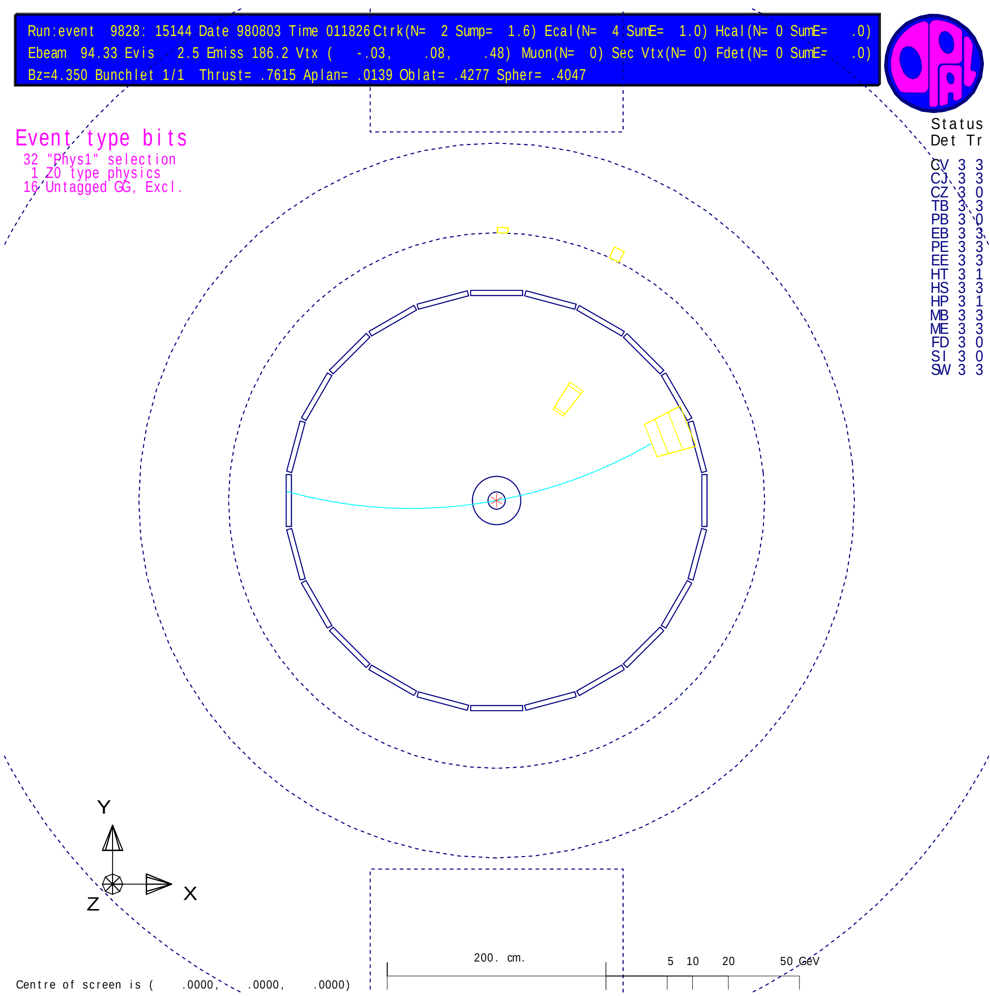
Exclusive untagged $\gamma\gamma \rightarrow \mathrm{p\bar{p}}$ event selection

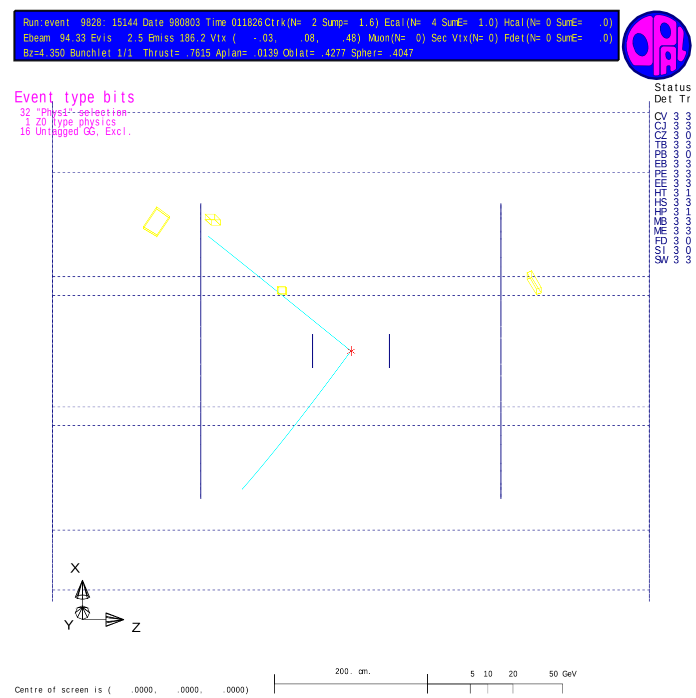
- Main selection cuts:
  - 2 tracks with zero total charge
  - $\mathrm{d}E/\mathrm{d}x$ cuts to eliminate background and to identify (anti)protons
  - Neural networks, $\mathrm{d}E/\mathrm{d}x$, E/p to identify antiprotons
  - $|\sum \vec{\mathrm{p}}_\perp|^2$ cut for exclusive events
  - $|\cos\theta^*| < 0.6$



The $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-p\bar{p}$ *events*

A typical $\gamma\gamma \to p\bar{p}$ event selected with the OPAL detector at LEP2





$\gamma\gamma \to p\bar{p}$ *cross-section measurements*

- The $e^+e^- \to e^+e^- p\bar{p}$ differential cross section is given by:

$$\frac{d\sigma(e^+e^- \to e^+e^- p\bar{p})}{dW\, d|\cos\theta^*|} = \frac{N_{ev}(W, |\cos\theta^*|)}{\mathcal{L}_{e^+e^-}\, \varepsilon_{TRIG}\, \varepsilon_{DET}(W, |\cos\theta^*|)\, \Delta W\, \Delta|\cos\theta^*|}$$

  - $\mathcal{L}_{e^+e^-}$ = Measured integr. luminosity

- The total cross section $\sigma(\gamma\gamma \to p\bar{p})$ is given by:

$$\sigma(\gamma\gamma \to p\bar{p}) = \frac{d\sigma(e^+e^- \to e^+e^- p\bar{p})}{dW} \Bigg/ \frac{d\mathcal{L}_{\gamma\gamma}}{dW}$$

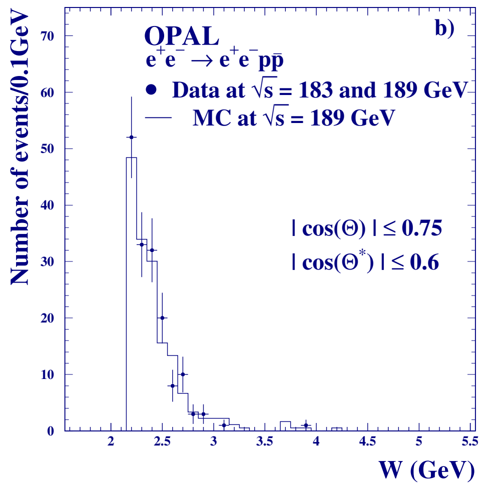
  - $d\mathcal{L}_{\gamma\gamma}/dW$ = GALUGA $\gamma\gamma$ luminosity function

    see e.g.: G. Schuler, hep-ph/9610406 (1996); G. Schuler, hep-ph/9710506 (1997)

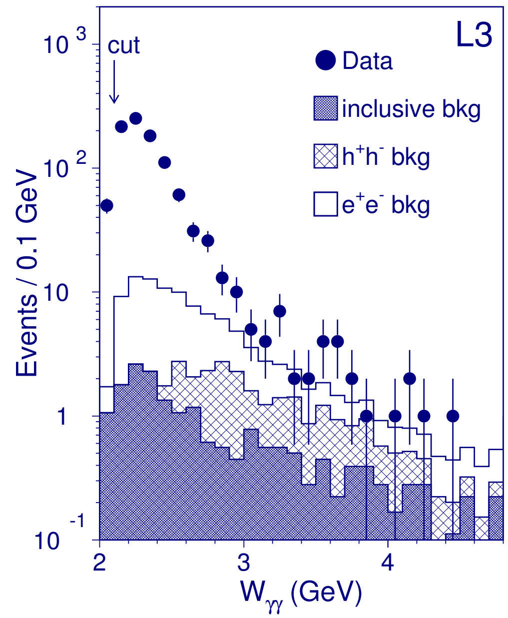
Existing $\gamma\gamma \rightarrow p\bar{p}$ *cross-section measurements*

e^+e^- Experiments	Year	E_{Beam} (GeV)	Integrated Luminosity (pb^{-1})	W (GeV)	Number of $p\bar{p}$ events
TASSO (DESY)	1982	$15 - 18.3$	19.685	$2.0 - 2.6$	8
TASSO (DESY)	1983	17	74	$2.0 - 3.1$	72
JADE (DESY)	1986	$17.4 - 21.9$	$59.3 + 24.2$	$2.0 - 2.6$	41
TPC/2γ (SLAC)	1987	14.5	75	$2.0 - 2.8$	50
ARGUS (DESY)	1989	$4.5 - 5.3$	234	$2.6 - 3.0$	60
CLEO (CESR)	1994	5.29	1310	$2.0 - 3.25$	484
VENUS (TRISTAN)	1997	$57 - 64$	331	$2.2 - 3.3$	311
OPAL (LEP)	2003	$91.5 - 94.5$	249	$2.15 - 3.95$	163
L3 (LEP)	2003	$91.5 - 104.5$	667	$2.1 - 4.5$	989
BELLE (KEKB)	2005	$8\,(e^-) \times 3.5\,(e^+)$	89000	$2.025 - 4.0$	36094

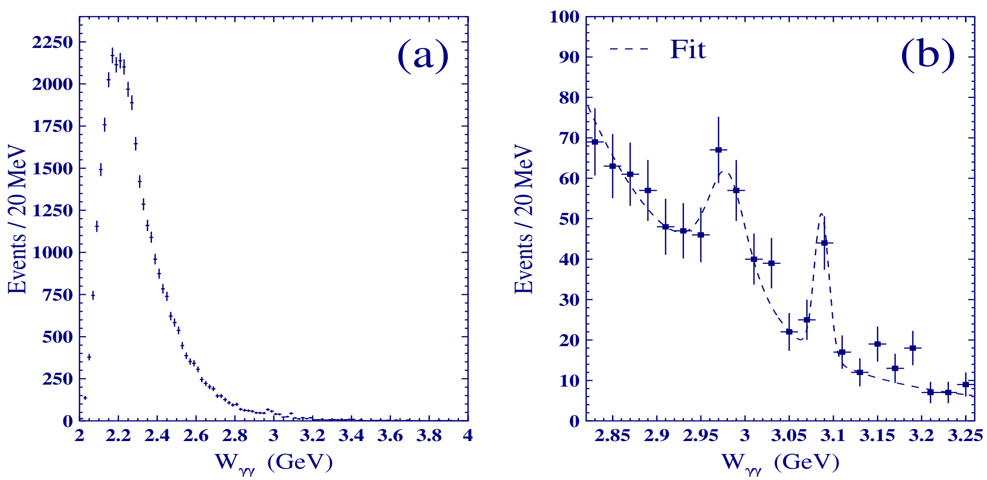
$\gamma\gamma \rightarrow p\bar{p}$ *invariant mass distributions*



OPAL background negligible

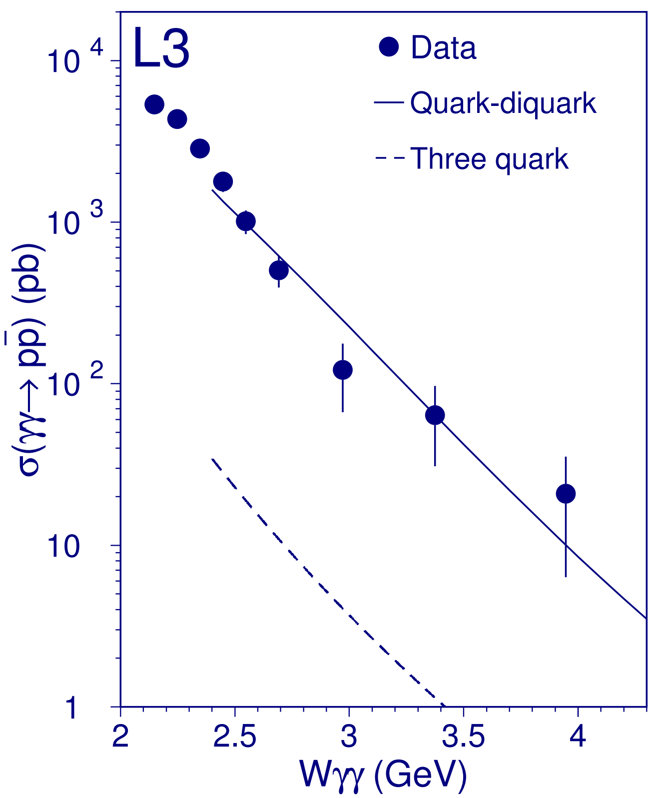


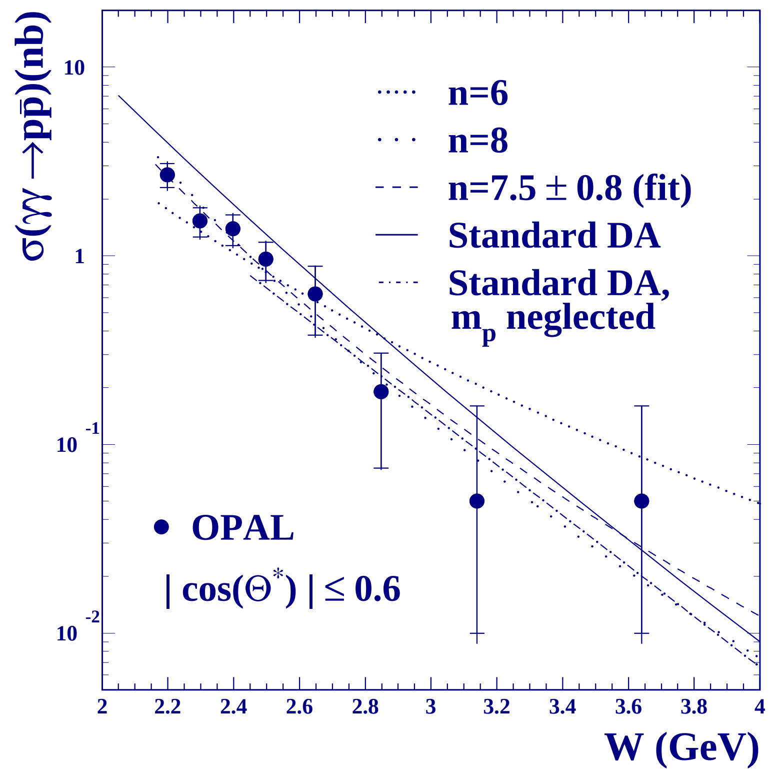
L3 background level between 4% and 69%



Belle, $\eta_c(2980)$ and J/Ψ peaks found in the data

$\gamma\gamma \rightarrow p\bar{p}$ *cross-section measurements I*

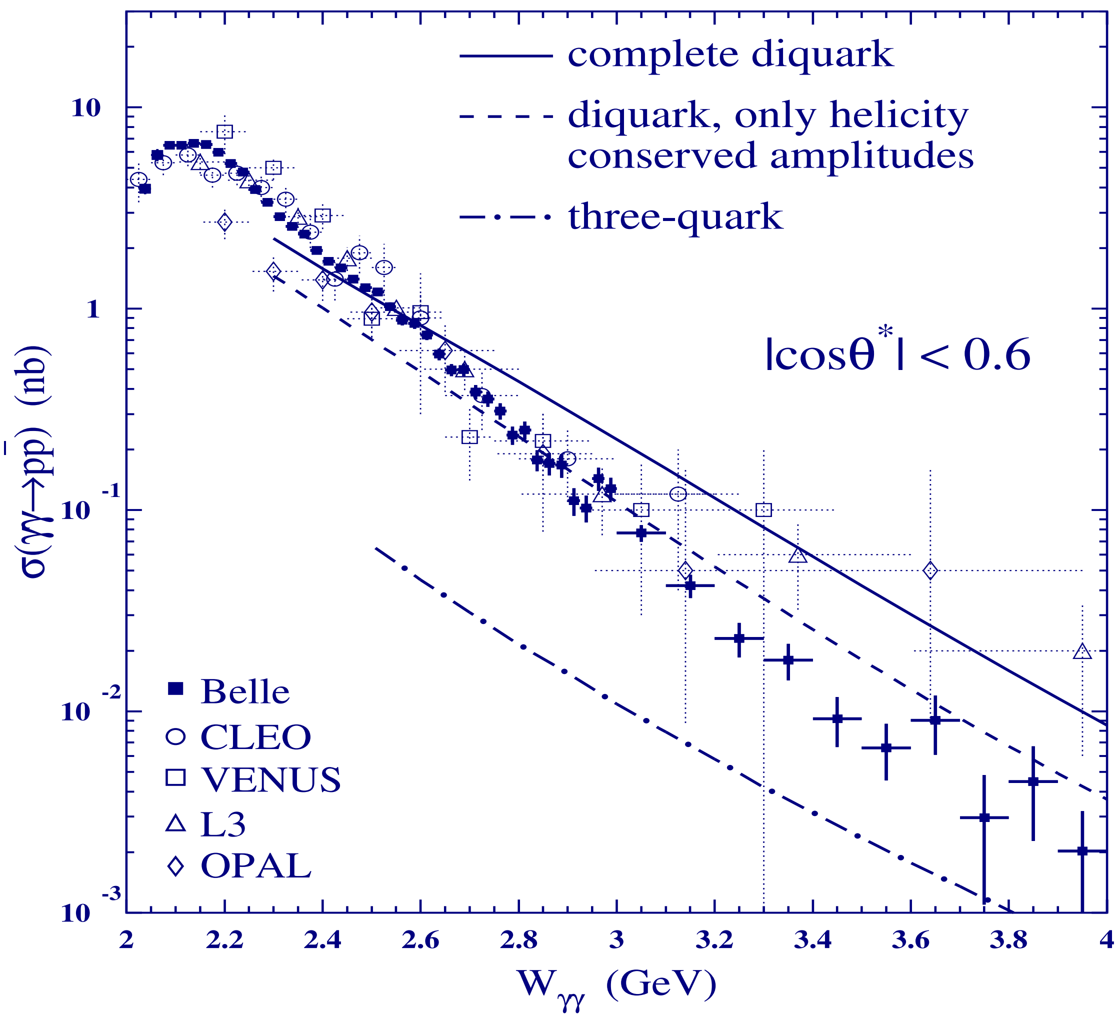




- ► L3 data described by the quark-diquark model
- ► Three quark model excluded

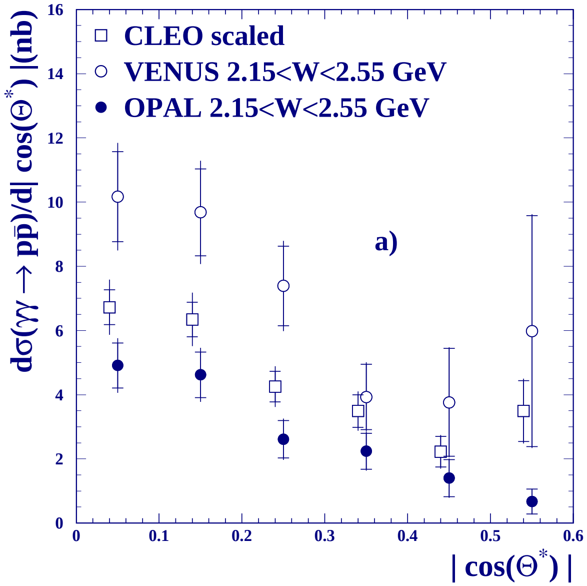
- ► OPAL data described by the quark-diquark models
- ► Power law compared to the data with $\sigma(\gamma\gamma \rightarrow p\bar{p}) \approx -W^{-2(n-3)}$ for three values of n. For data with $W > 2.5\text{GeV}$, $n = 9 \pm 2$

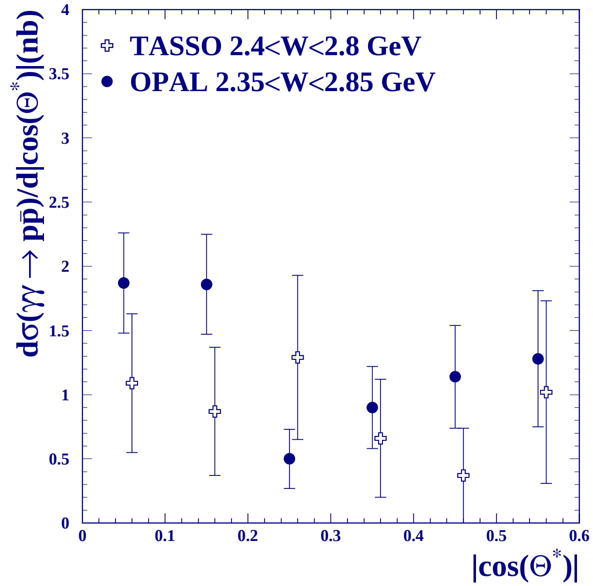
$\gamma\gamma \to p\bar{p}$ *cross-section measurements II*

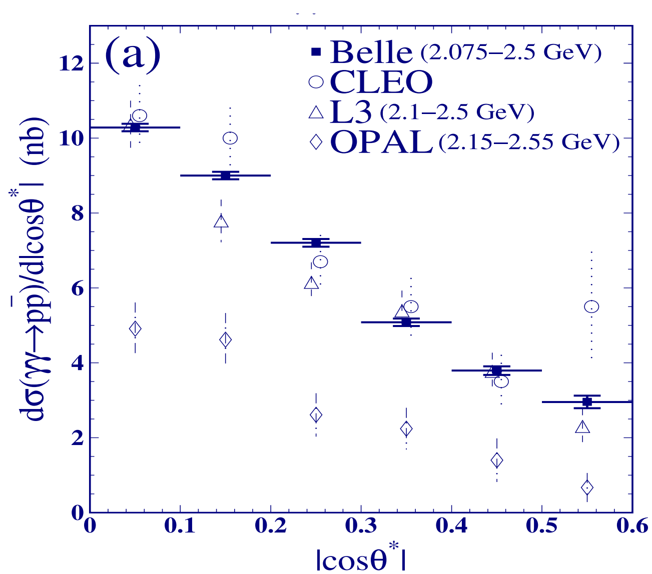


- Good agreement between different experiments
- Belle results: at higher W the data fall below the diquark predictions and approach the three-quark model predictions

$\gamma\gamma \rightarrow p\bar{p}$ *differential cross-section measurements I*

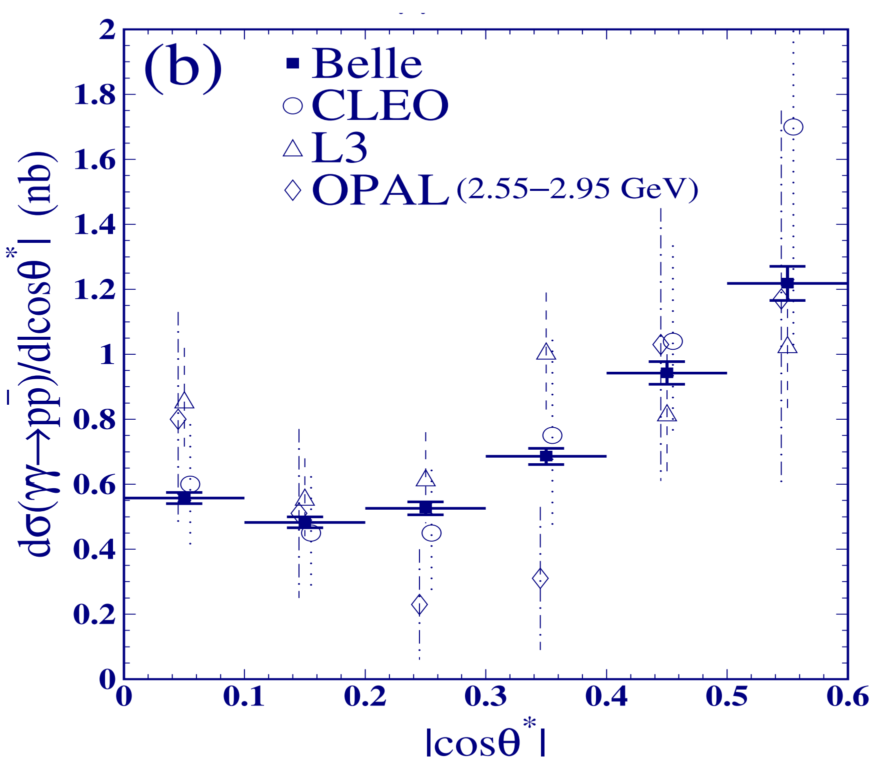




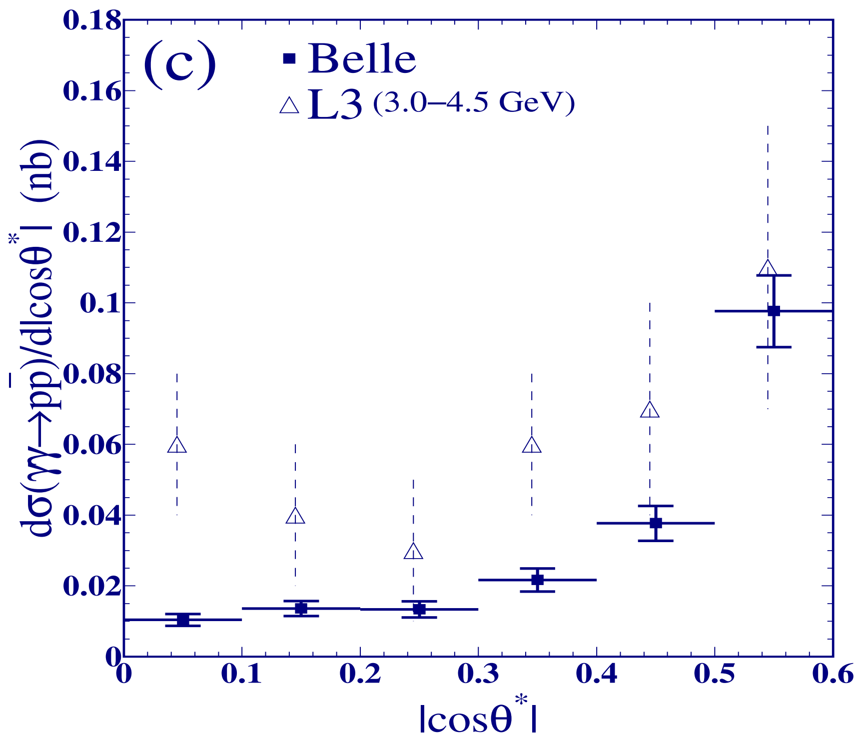


Low W range: comparison between different experiments

$\gamma\gamma \to p\bar{p}$ *differential cross-section measurements II*



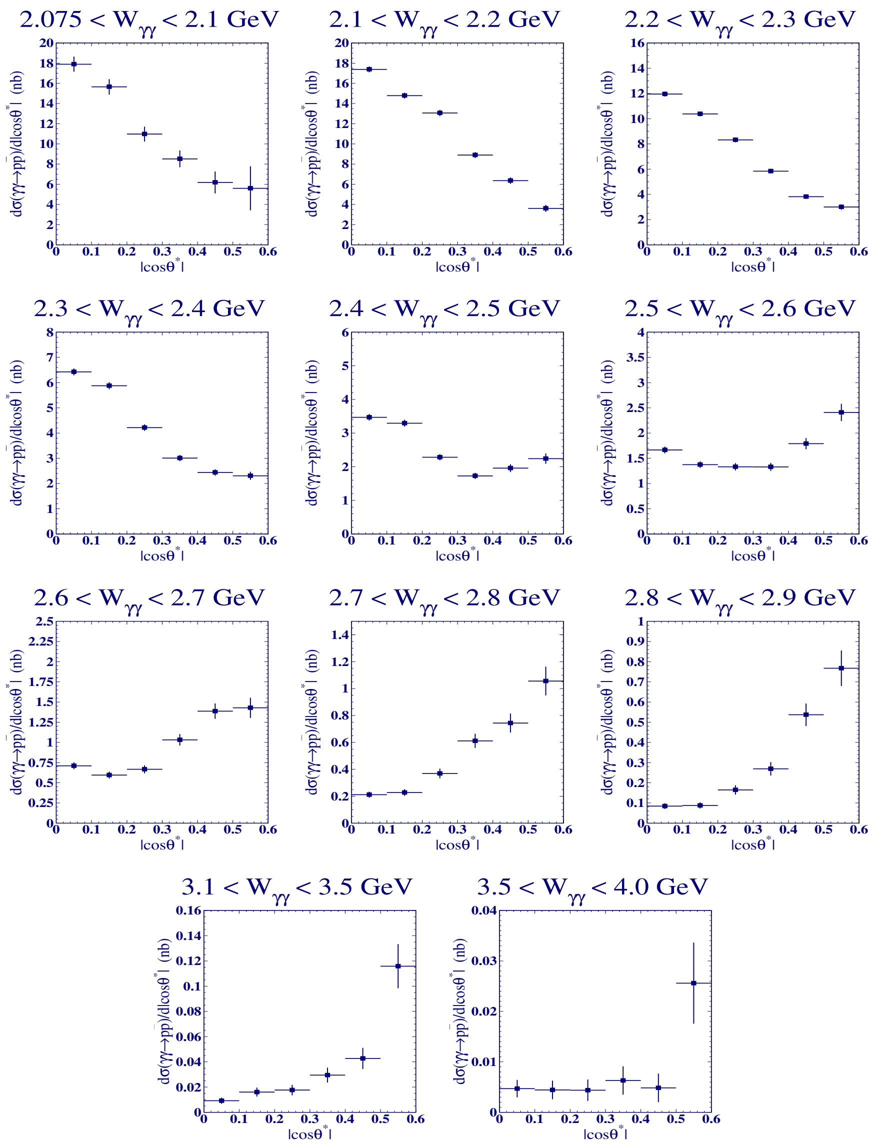
$2.5 < W < 3.0$GeV



$3.0 < W < 4.0$GeV

- High W range: comparison between different experiments

$\gamma\gamma \to p\bar{p}$ *differential cross-section measurements III*

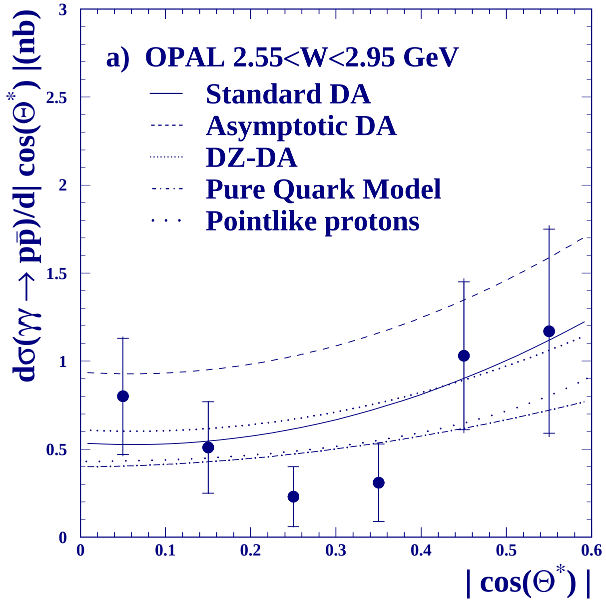


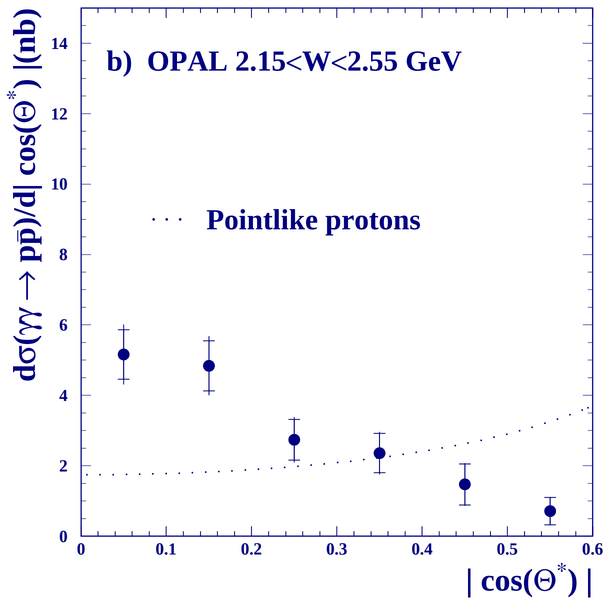
Belle results: at $W < 2.4$ GeV the differential cross-section decrease as $|\cos\theta^*|$ increases; for $W > 2.6$ GeV the opposite trend is observed. The transition occurs at $W \approx 2.5$ GeV

Angular dependence of the $\gamma\gamma \rightarrow p\bar{p}$ cross-section I

QED angular distribution for massless and point-like fermions

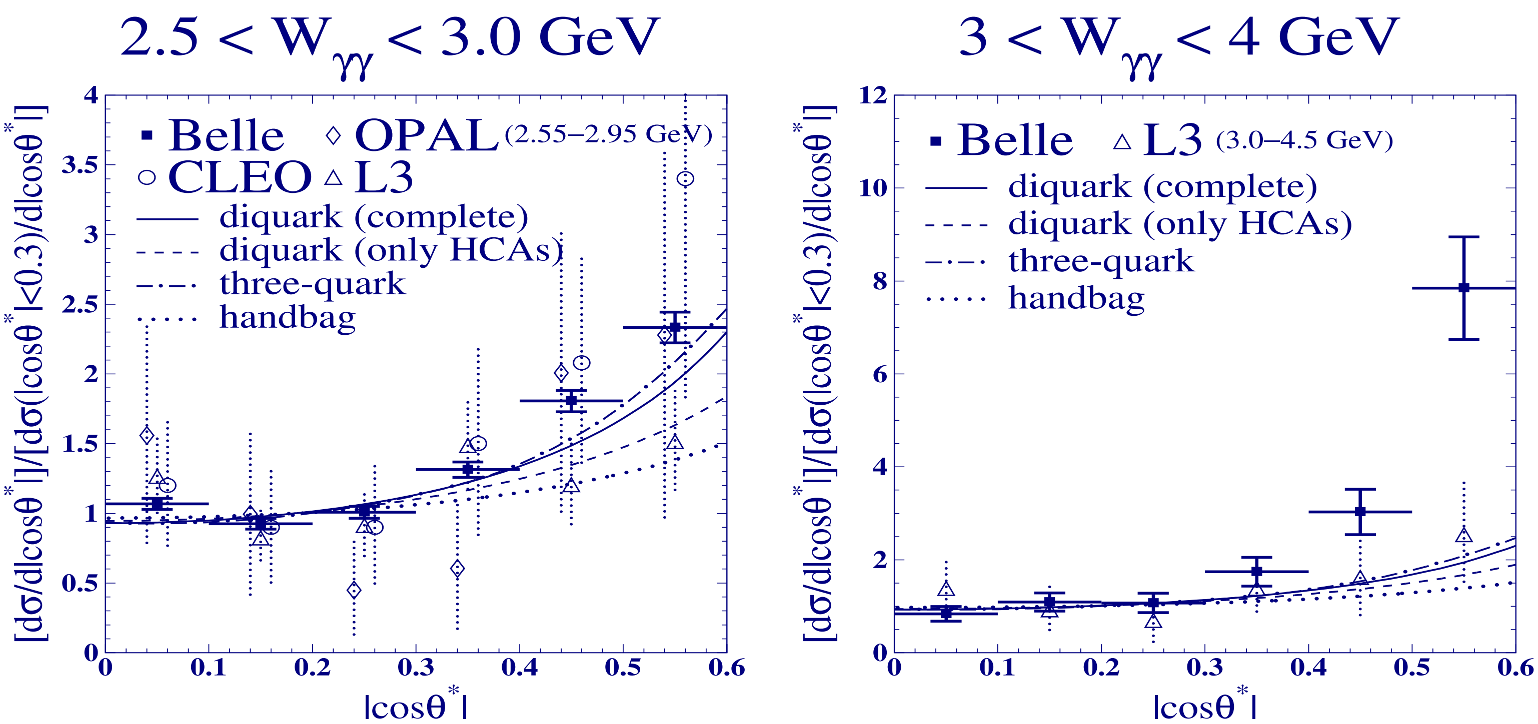
$$\frac{d\sigma(\gamma\gamma\rightarrow p\bar{p})}{d|\cos\theta|} \propto \frac{(1+\cos^2\theta)}{(1-\cos^2\theta)}$$





- At high W, the point-like p approximation agrees with the data, the diquark and the pure quark model curves.
- At low W, point-like p approximation not valid anymore.

Angular dependence of the $\gamma\gamma \rightarrow p\bar{p}$ cross-section II



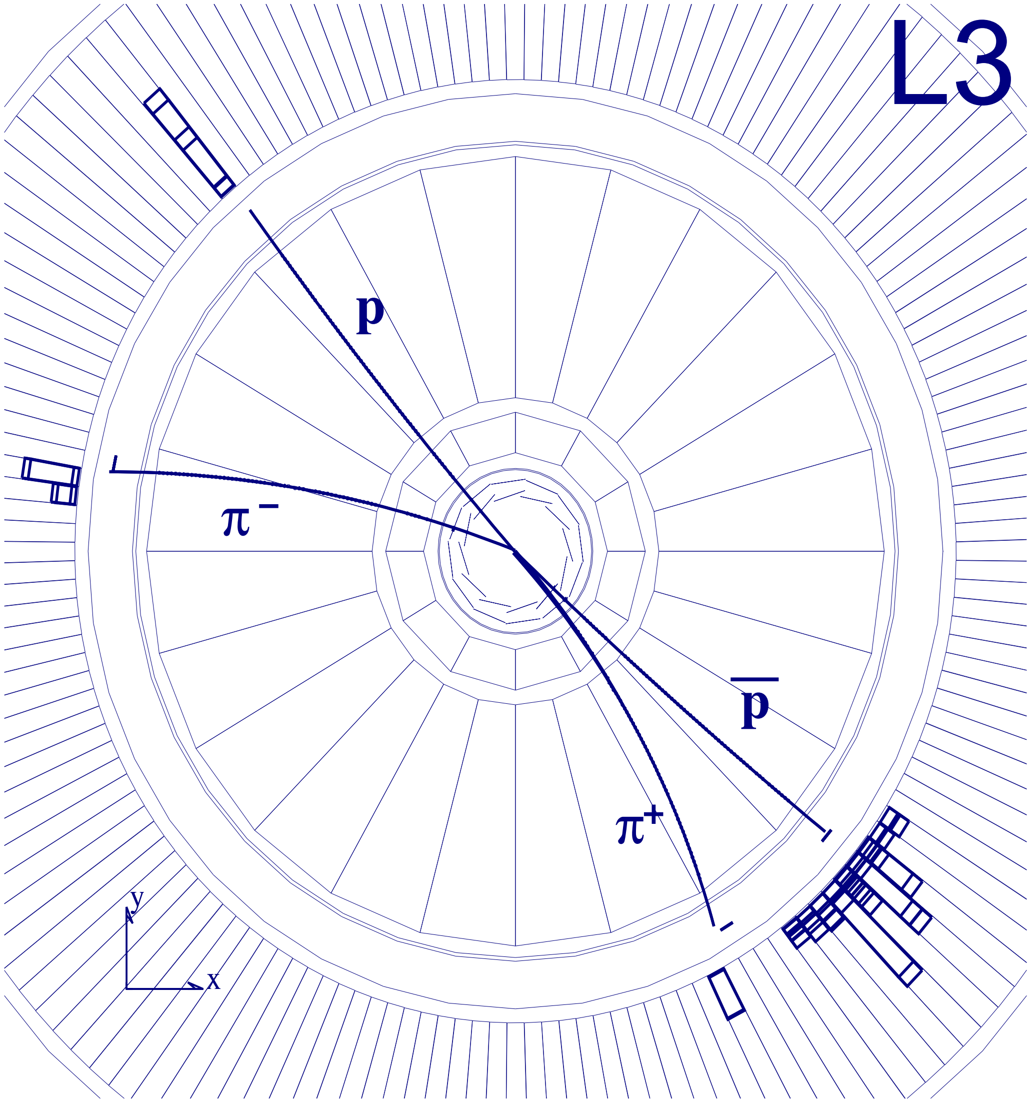
- Belle: differential cross-section as function of $|\cos\theta^*|$, normalized to that averaged within $|\cos\theta^*| < 0.3$ for two higher W ranges
- At higher energies the data rise more sharply than the the current models predictions

$\gamma\gamma \to \Lambda\overline{\Lambda}$ *and* $\gamma\gamma \to \Sigma^0\overline{\Sigma^0}$ *events selection*

- Main cuts to select $\gamma\gamma \to \Lambda\overline{\Lambda} \to p\pi^-\overline{p}\pi^+$ and $\gamma\gamma \to \Sigma^0\overline{\Sigma^0} \to \Lambda\gamma\overline{\Lambda}\gamma$ events
  - 4 tracks with zero total charge
  - 2 secondary vertices at a distance from the primary interaction vertex $> 3\,\text{mm}$ in the transverse plane
  - dE/dx cuts to eliminate background and to identify $(\overline{p})p$ and $(\pi^+)\pi^-$
  - E/p to identify antiprotons
  - Transverse momentum of the 4 tracks, $P_\perp < 4\,\text{GeV}$ for exclusive events
  - $|\cos\theta^*| < 0.6$
  - Combining the selected Λ and $\overline{\Lambda}$ with photon candidates, defined in the EM calorimeter, for $\Sigma^0\overline{\Sigma^0}$ reconstruction
  - Use a maximum extended likelihood fit to find the fractions of the different channels ($\Lambda\overline{\Lambda}$, $\Sigma^0\overline{\Sigma^0}$, and $\Lambda\overline{\Sigma^0} + \overline{\Lambda}\Sigma^0$)

$e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-\Lambda\bar{\Lambda}$ *event*

A typical $\gamma\gamma \to \Lambda\bar{\Lambda}$ event selected with the L3 detector at LEP

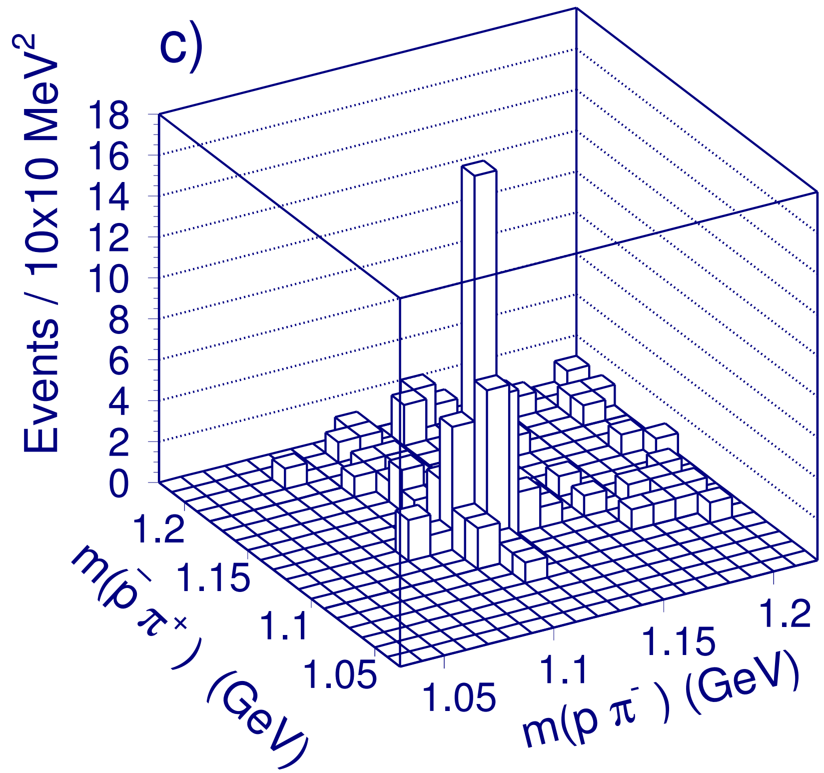


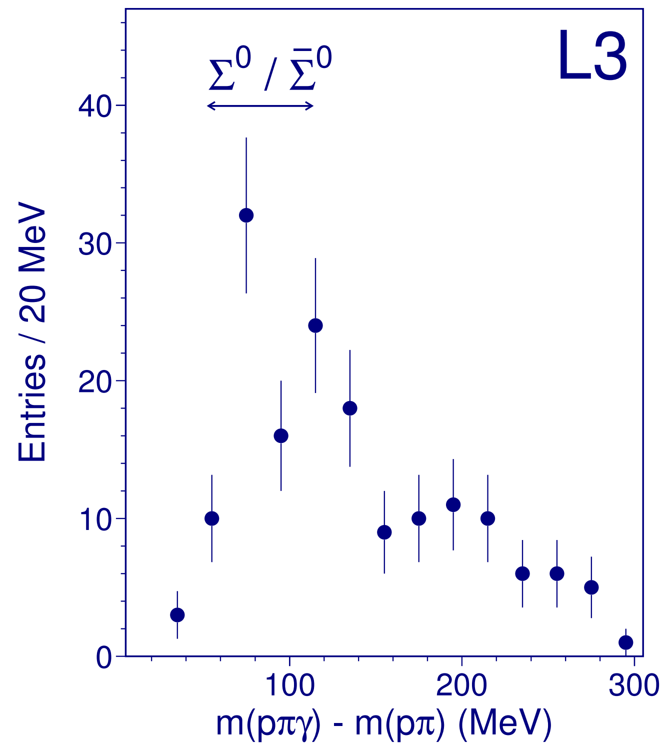
$\gamma\gamma \to \Lambda\overline{\Lambda}$ & $\gamma\gamma \to \Sigma^0\overline{\Sigma^0}$ *cross-section measurements*

e^+e^- Experiments	Year	E_{Beam} (GeV)	Integrated Luminosity (pb^{-1})	W (GeV)	Number of $\Lambda\overline{\Lambda}$ events
CLEO (CESR)	1997	5.29	3500	$2.25 - 3.6$	51
L3 (LEP)	2002	$45.5 - 104.5$	844	$2.2 - 3.5$	19

e^+e^- Experiments	Year	E_{Beam} (GeV)	Integrated Luminosity (pb^{-1})	W (GeV)	Number of $\Sigma^0\overline{\Sigma^0}$ events
L3 (LEP)	2002	$45.5 - 104.5$	844	$2.24 - 3.8$	14

$\gamma\gamma \to \Lambda\overline{\Lambda}$ and $\gamma\gamma \to \Sigma^0\overline{\Sigma^0}$ results I

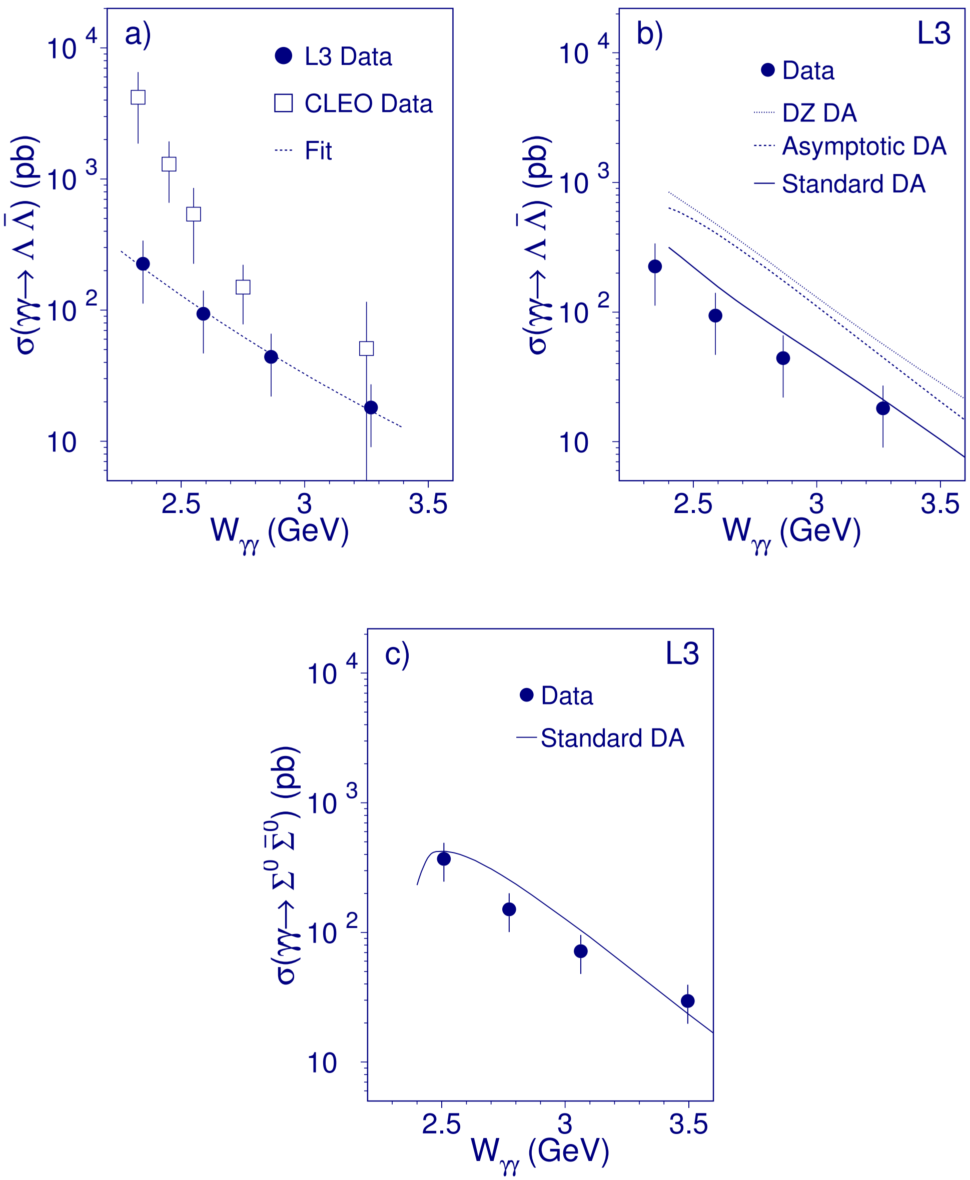




- L3 data: clean peak, 33 events selected
- Estimated background $< 1\%$

- L3 data: clear $\Sigma^0/\overline{\Sigma^0}$ peak

$\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ *and* $\gamma\gamma \rightarrow \Sigma^0\overline{\Sigma^0}$ *results II*



- L3 data with limited statistics
- L3 $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ cross-section measurements disagree with the results obtained by CLEO at low W
- L3 $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ and $\gamma\gamma \rightarrow \Sigma^0\overline{\Sigma^0}$ measurements in agreement with quark-diquark model predictions

Conclusions

- There are results for $\gamma\gamma \to p\bar{p}$, $\gamma\gamma \to \Lambda\bar{\Lambda}$, and $\gamma\gamma \to \Sigma^0\overline{\Sigma^0}$ cross-section measurements
- For the $\sigma(\gamma\gamma \to p\bar{p})$ cross-section measurements all experimental results agree within each other
  - The OPAL and L3 results are in agreement with the quark-diquark model predictions
  - Belle results are in agreement with the quark-diquark model for $2.5 < W < 3.0\,\mathrm{GeV}$. At higher energies the data exhibit a gradual approach to the three quark model predictions
  - The shape of $d\sigma(\gamma\gamma \to p\bar{p})/d|\cos\theta|$ agrees within all the experiments results, in comparable W range
  - At low W values the $d\sigma(\gamma\gamma \to p\bar{p})/d|\cos\theta|$ does not agree with the models.
  - Belle results show that the descending trend of the $d\sigma(\gamma\gamma \to p\bar{p})/d|\cos\theta|$ change to an ascending one with the increase of energies.
- CLEO and L3 $\gamma\gamma \to \Lambda\bar{\Lambda}$ cross-section measurements agree at high W.
- More experimental investigations needed.
- L3 $\gamma\gamma \to \Lambda\bar{\Lambda}$ and $\gamma\gamma \to \Sigma^0\overline{\Sigma^0}$ cross-section measurements agree with the quark-diquark model predictions
- Existing models don't provide satisfactory description of the angular dependence of the cross-section, expecially in the low W region