



Exclusive Production of Hadron Pairs in Two-Photon Interactions

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on behalf of the LEP collaborations

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Outline



□ π and K pair production

- ▶ π and K meson pair production [ALEPH: CERN-EP:2003-030]

□ Baryon pair production

- ▶ $p\bar{p}$ [L3: CERN-EP:2003-014 OPAL: Eur. Phys. J. C28 (2003) 45]
- ▶ $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ [L3: PLB 536 (2002) 24]

□ $\rho^0\rho^0$ and $\rho^+\rho^-$ pair production

- ▶ $\rho^0\rho^0$ and $\rho^+\rho^-$ pair production at $Q^2 \approx 0$ [L3: submitted to EPS]
- ▶ $\rho^0\rho^0$ pair production at high Q^2 [L3: CERN-EP:2003-020]



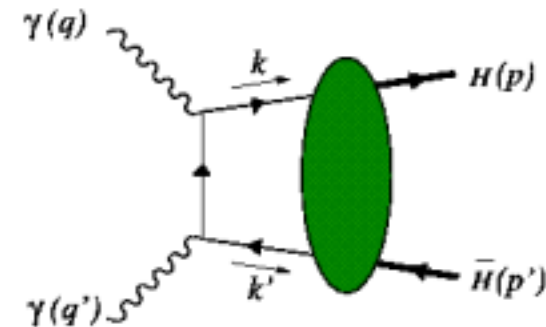
Hadron pair production in $\gamma\gamma$ collisions

Tests of QCD calculations

□ π and K pair production

- ▶ Handbag model ⁽¹⁾
based on the Brodsky
and Lepage approach ⁽²⁾

Handbag model



Amplitude $\gamma\gamma \rightarrow H\bar{H}$ factorized into:

- ▶ Hard part : $\gamma\gamma \rightarrow q\bar{q}$ scattering
- ▶ Soft part: $q\bar{q} \rightarrow H\bar{H}$ transition

(1) M. Diehl, P. Kroll and C. Vogt, PLB 532 (2002) 99, hep-ph/0112274.

(2) S. J. Brodsky and J. P. Lepage, PRD 22 (1980) 2157 .



Hadron pair production in $\gamma\gamma$ collisions

Tests of QCD calculations

□ Baryon pair production

- ▶ Handbag model ⁽¹⁾
- ▶ Three quark model ⁽²⁾
- ▶ Quark-diquark model ⁽³⁾

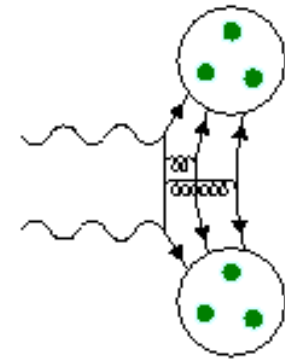
(1) M. Diehl, P. Kroll and C. Vogt, hep-ph/0206288.

(2) G. Farrar *et al.*, Nucl Phys B 259 (1985) 702.

(3) C. F. Berger, B. Lechner and W. Schweiger, Fizika B8 (1999) 371; C. F. Berger and W. Schweiger hep-ph/0212066.

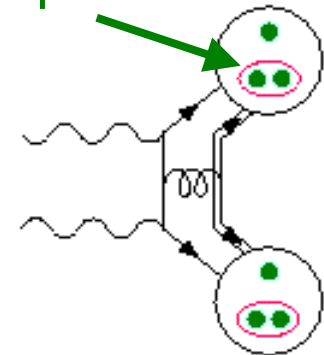
Three quark & Diquark models

Three quark model



Diquark

Quark-diquark model





π and K pair selection

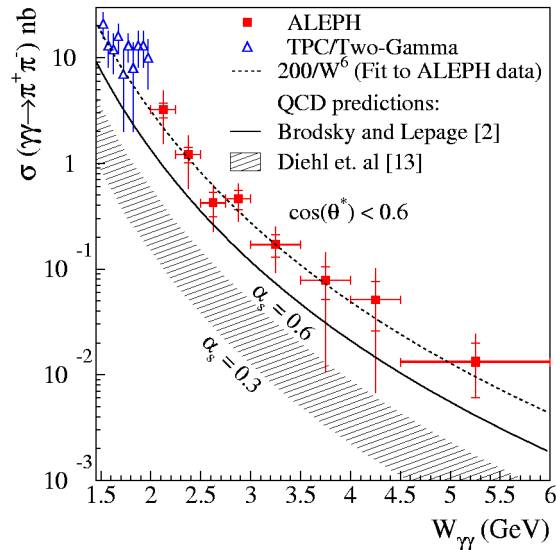
ALEPH event selection:

- ▶ 2 tracks of opposite charge
- ▶ Electron rejection criteria
- ▶ Muon rejection criteria
- ▶ Cut on dE/dx to select pions and kaons
- ▶ Exclusive event selection cut



$\gamma\gamma \rightarrow \pi^+\pi^-$ and $\gamma\gamma \rightarrow K^+K^-$ cross sections

$\gamma\gamma \rightarrow \pi^+\pi^-$

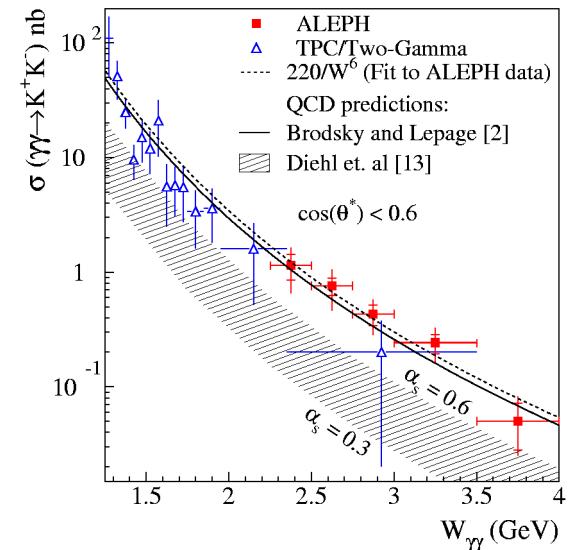


Fit with power law: $A W^{-6}$

► $\pi^+\pi^-$: $A = 200 \pm 40 \text{ nb} \cdot \text{GeV}^6$

► K^+K^- : $A = 220 \pm 40 \text{ nb} \cdot \text{GeV}^6$

$\gamma\gamma \rightarrow K^+K^-$



□ $\sigma(\gamma\gamma \rightarrow \pi^+\pi^-) = \sigma(\gamma\gamma \rightarrow K^+K^-)$ within uncertainty

□ Shape well described by QCD predictions

□ Disagreement in normalization and ratio K/π
(QCD: $\sigma(\gamma\gamma \rightarrow K^+K^-) / \sigma(\gamma\gamma \rightarrow \pi^+\pi^-) \approx 2$)



Proton-antiproton pair selection

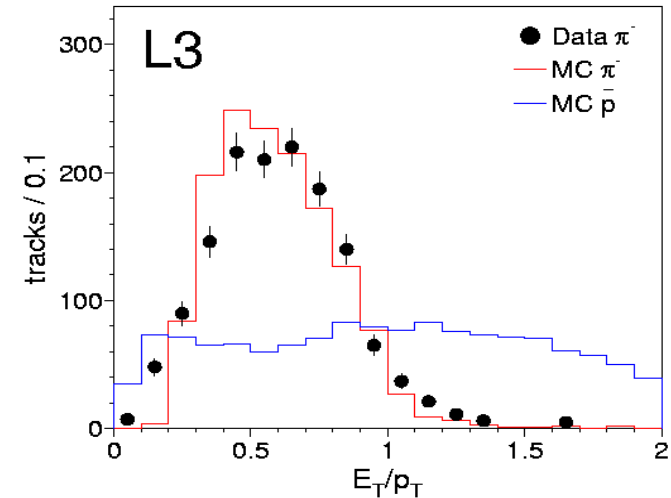
□ L3:

▶ Antiproton

Neural network: P , dE/dx , E_t/p_t
& shower shape

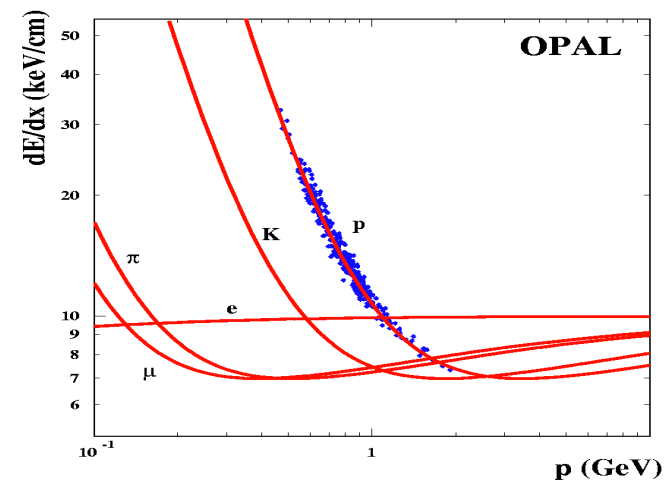
▶ Proton

dE/dx and E_t/p_t

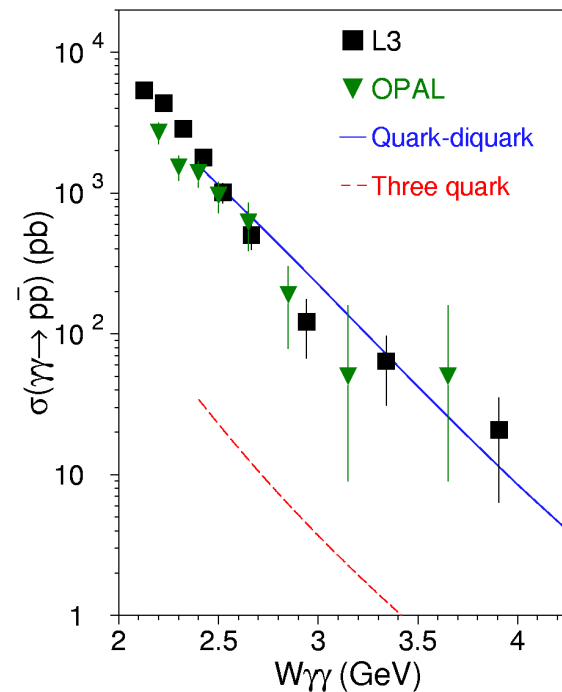
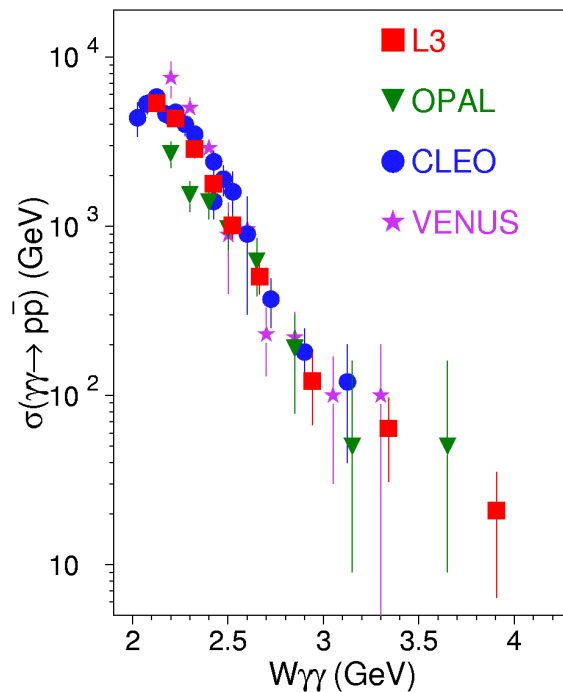


□ OPAL:

▶ dE/dx and E/P



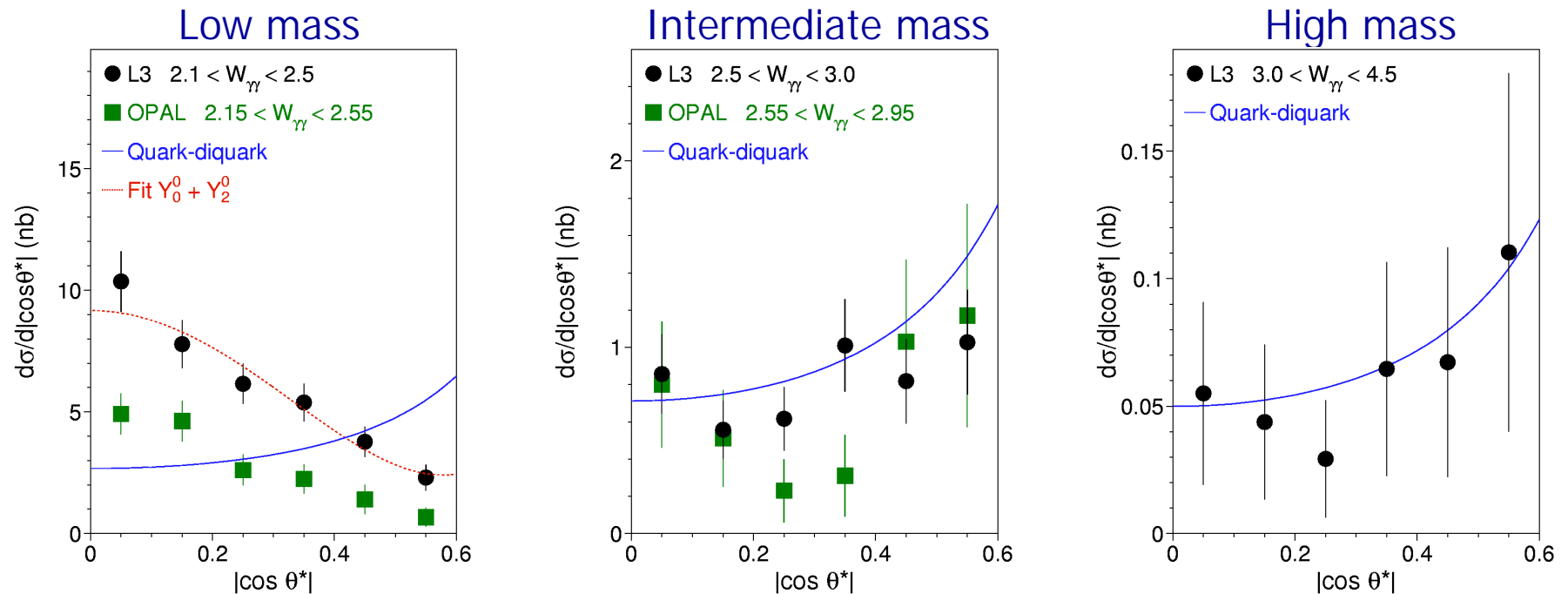
$\gamma\gamma \rightarrow p\bar{p}$ cross section



- Results compatible with previous measurements
- Extend $W_{\gamma\gamma}$ range

- Good agreement with quark-diquark model
- Three quark model excluded

$\gamma\gamma \rightarrow p\bar{p}$ angular distribution

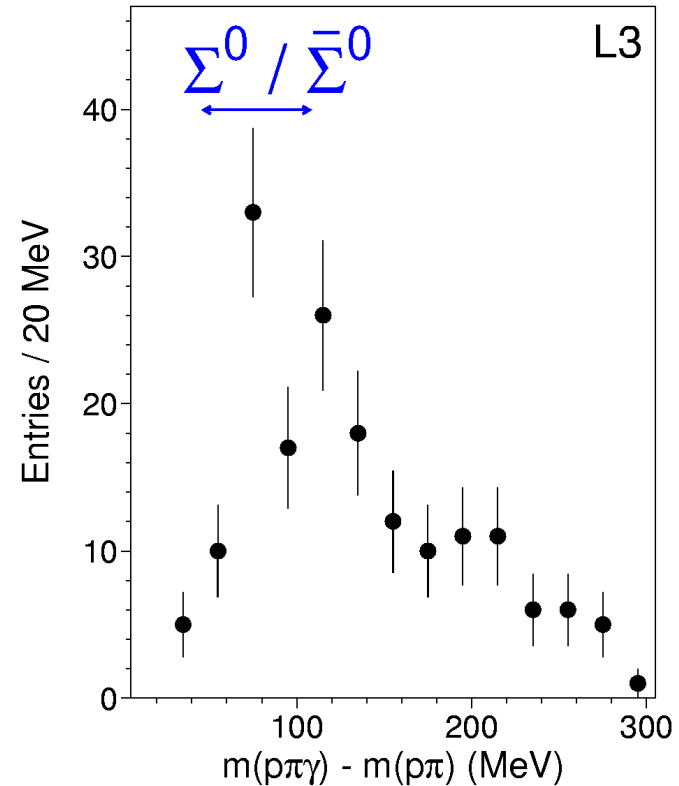
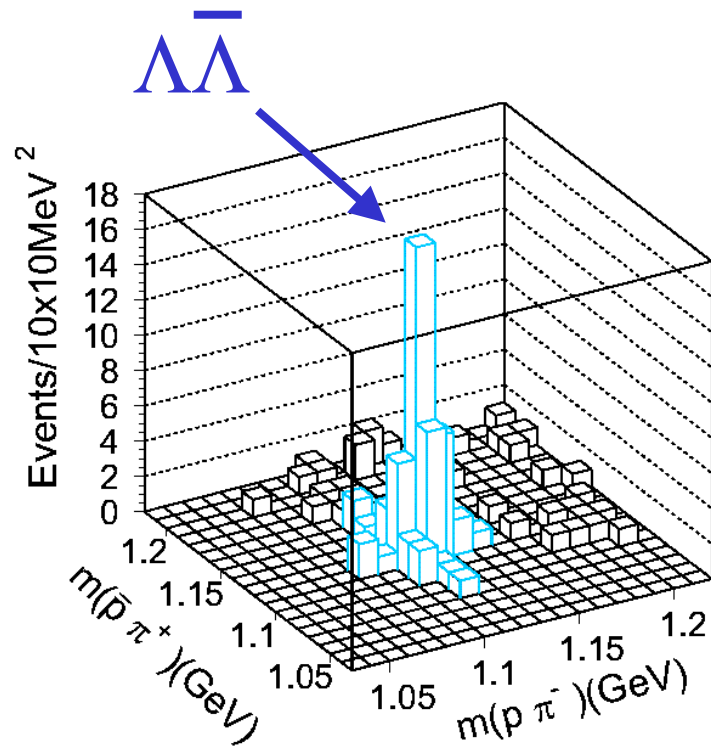


- Agreement in the intermediate and high $W_{\gamma\gamma}$ region
- Disagreement with diquark model in the low $W_{\gamma\gamma}$ region
- Low mass region well described by spherical harmonics : 92% Y_2^0 and 8% Y_0^0



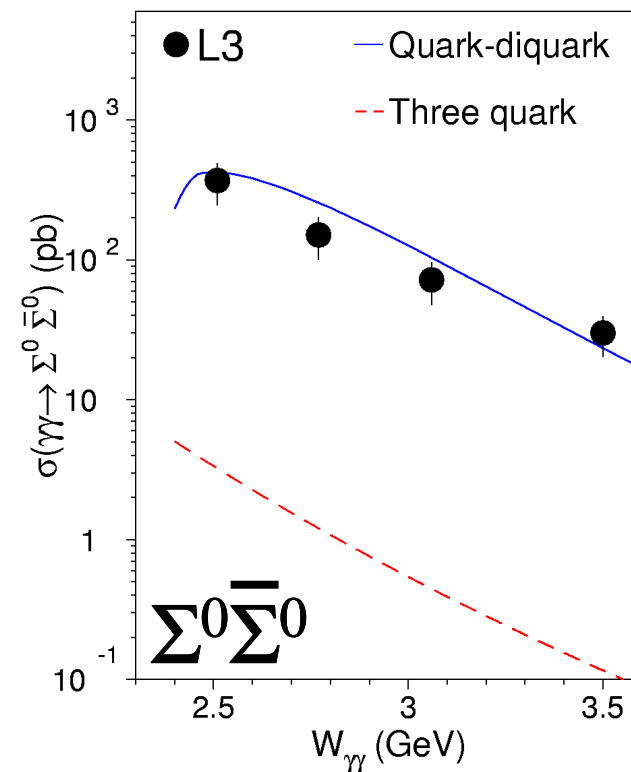
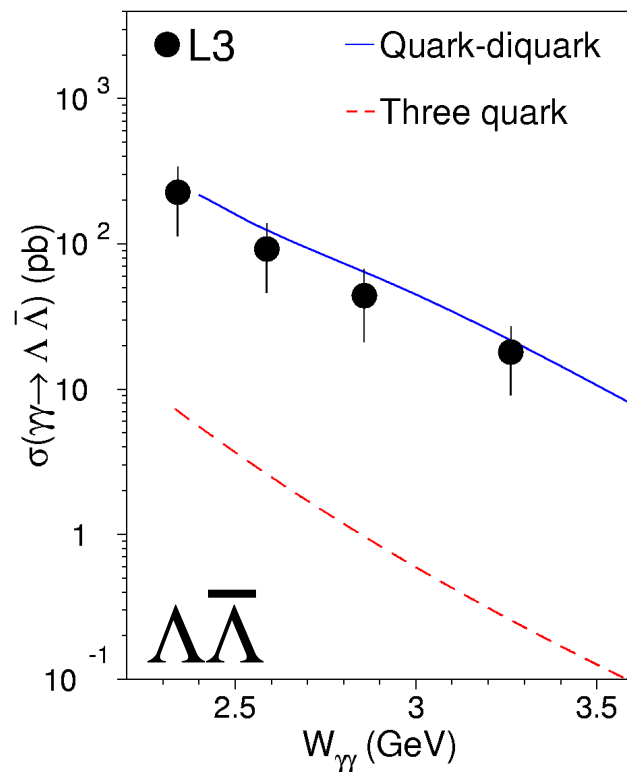
Λ and Σ^0 -pair selection

Decay channel: $\Lambda \rightarrow p\pi^-$ $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ $\Sigma^0 \rightarrow \Lambda\gamma$





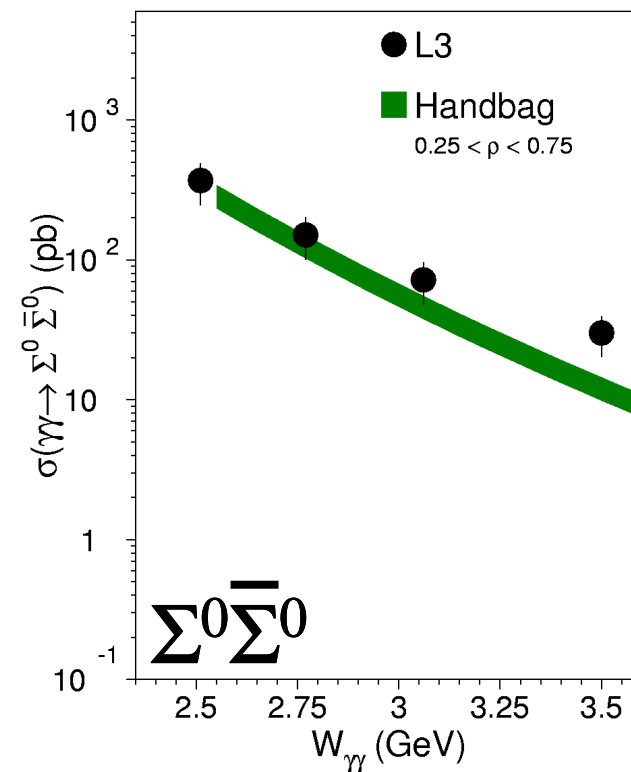
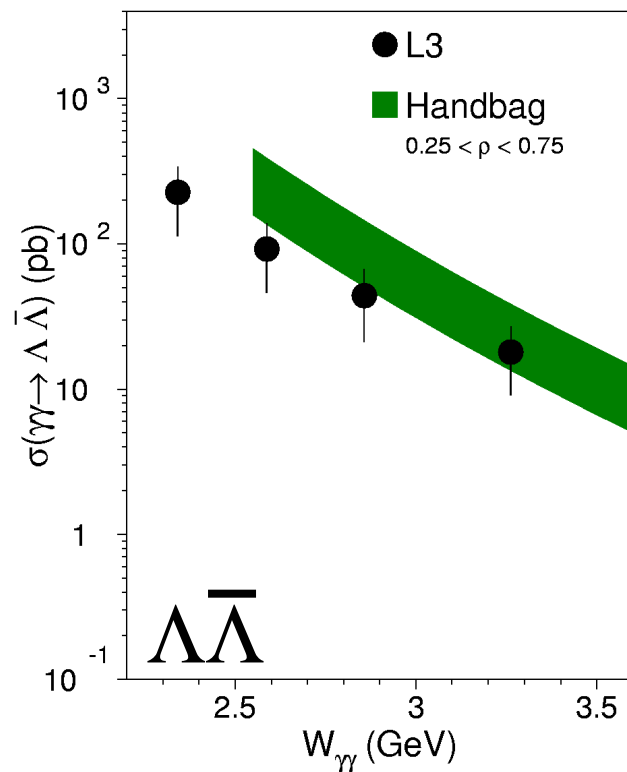
$\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ and $\gamma\gamma \rightarrow \Sigma^0\bar{\Sigma}^0$ cross sections



- Good agreement with diquark model predictions
- Three quark model excluded



$\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ and $\gamma\gamma \rightarrow \Sigma^0\bar{\Sigma}^0$ cross sections



- Agreement with the handbag model predictions using $\gamma\gamma \rightarrow p\bar{p}$ as input data

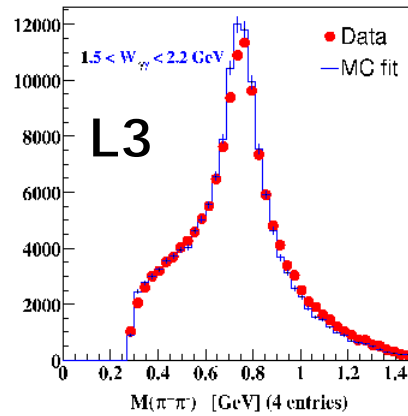


$\rho^0\rho^0$ and $\rho^+\rho^-$ pair production at $Q^2 \approx 0$

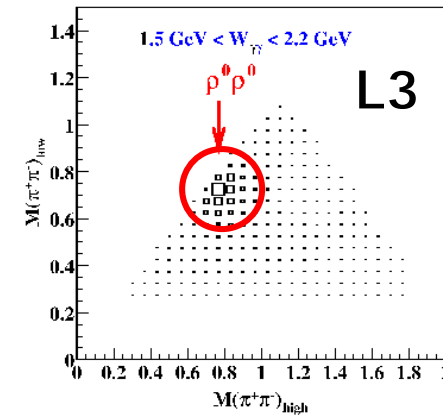
$\rho^0\rho^0$ channel

- ▶ High statistics (~70000 events)
- ▶ Clear $\rho^0\rho^0$ peak

$m(\pi^+\pi^-)$ spectrum



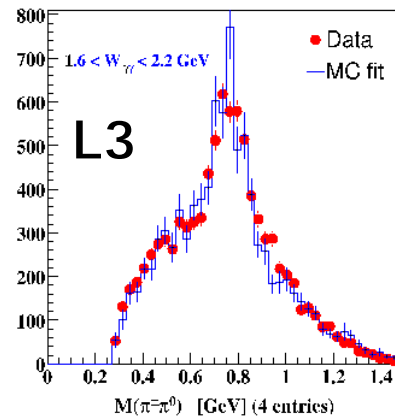
$\rho^0\rho^0$ mass spectrum



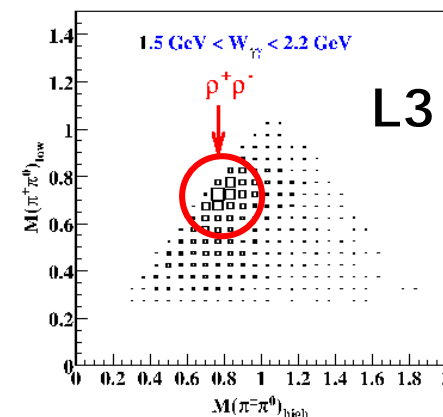
$\rho^+\rho^-$ channel

- ▶ Less statistics (~5000 events)
- ▶ Clear $\rho^+\rho^-$ peak

$m(\pi^\pm\pi^0)$ spectrum



$\rho^+\rho^-$ mass spectrum





$\rho^0\rho^0$ and $\rho^+\rho^-$ pair production at $Q^2 \approx 0$

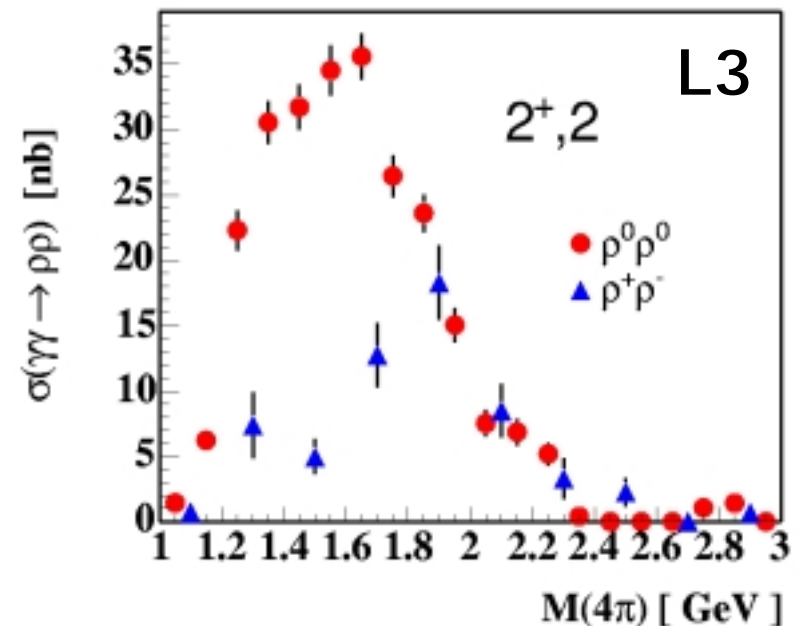
Partial Wave Analysis:

Model with $\rho\rho$ in different spin-parity-helicity states and isotropic 4π

$$A_{\rho\rho} = BW_{12} BW_{34} \Psi_{J^P, J_z} + \text{permutations}$$

$$A_{4\pi} = 1$$

- ▶ $(J^P, J_z) = (2^+, 2)$ dominant state
- ▶ $(0^+, 0)$ small contribution
- ▶ $(0^-, 0), (2^+, 0), (2^-, 0(1, 2))$ negligible



- ❑ Broad enhancement near threshold of $\gamma\gamma \rightarrow \rho^0\rho^0$
- ❑ Ratio of $\rho^+\rho^- / \rho^0\rho^0$ cross sections incompatible with formation of one Isospin 0 or 1 resonance



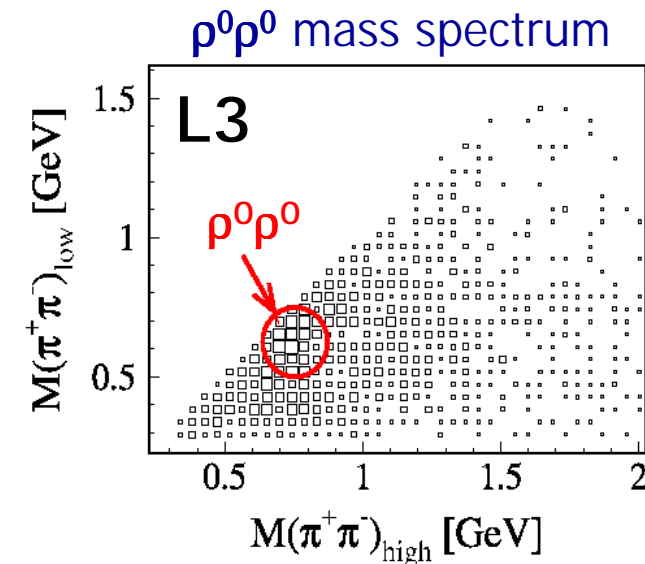
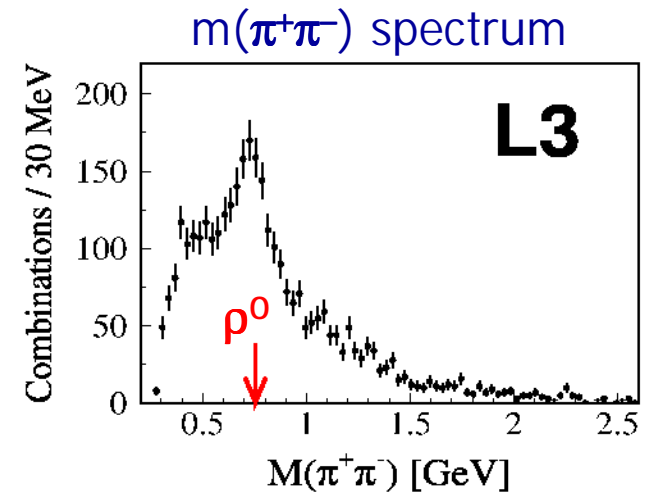
$\rho^0\rho^0$ pair production at high Q^2

□ Select 4π + tagged electron:

- ▶ $\gamma\gamma^* \rightarrow \rho^0\rho^0$
- ▶ $\gamma\gamma^* \rightarrow \rho^0\pi^+\pi^-$
- ▶ $\gamma\gamma^* \rightarrow \pi^+\pi^-\pi^+\pi^-$ non-resonant
- ▶ Separated by a box method

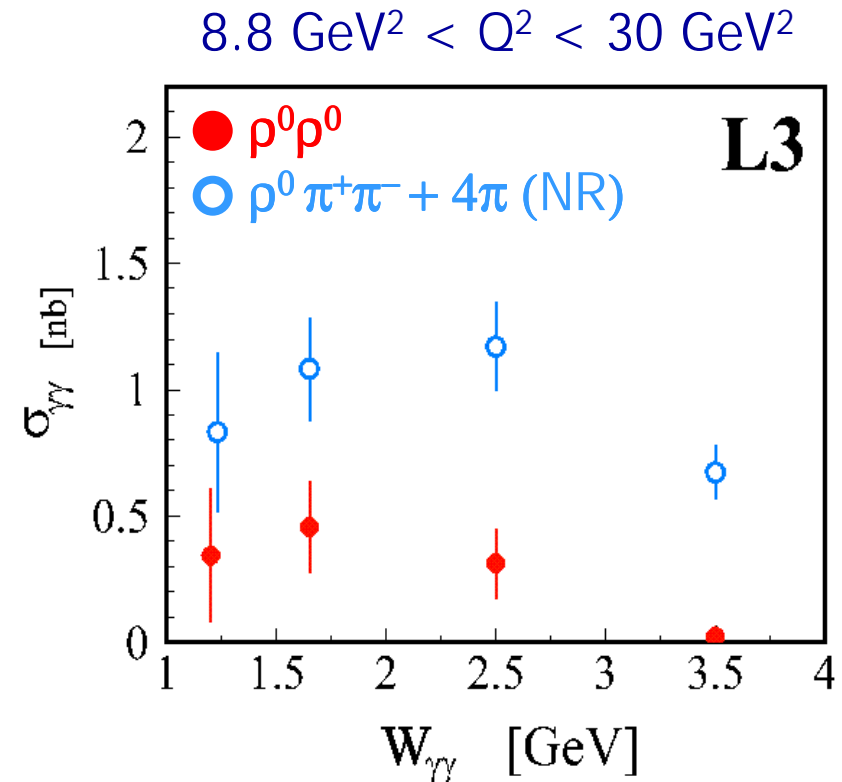
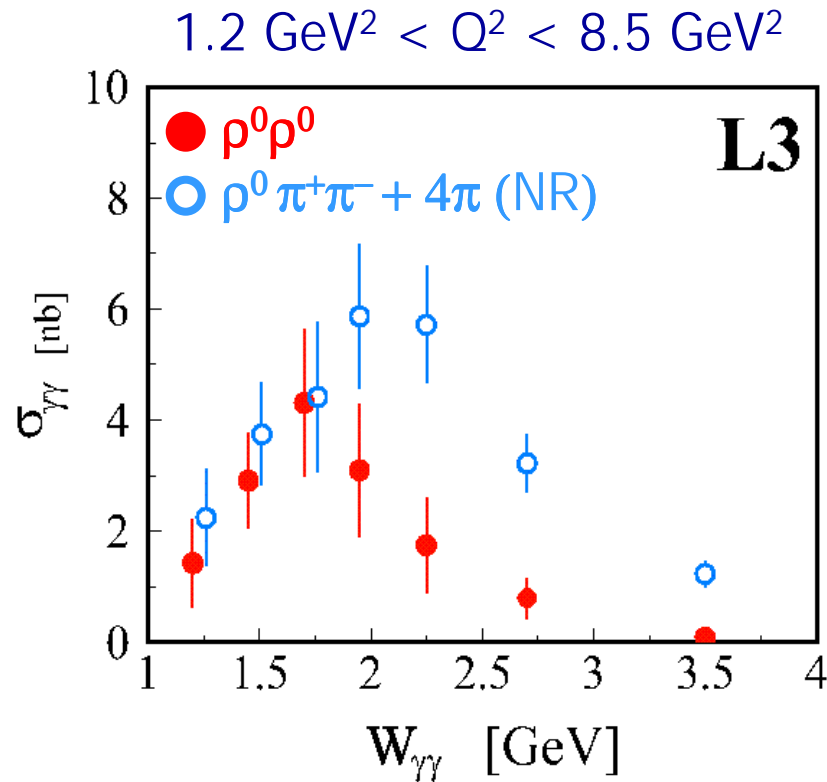
□ Q^2 interval:

$$1.2 \text{ GeV}^2 < Q^2 < 30 \text{ GeV}^2$$





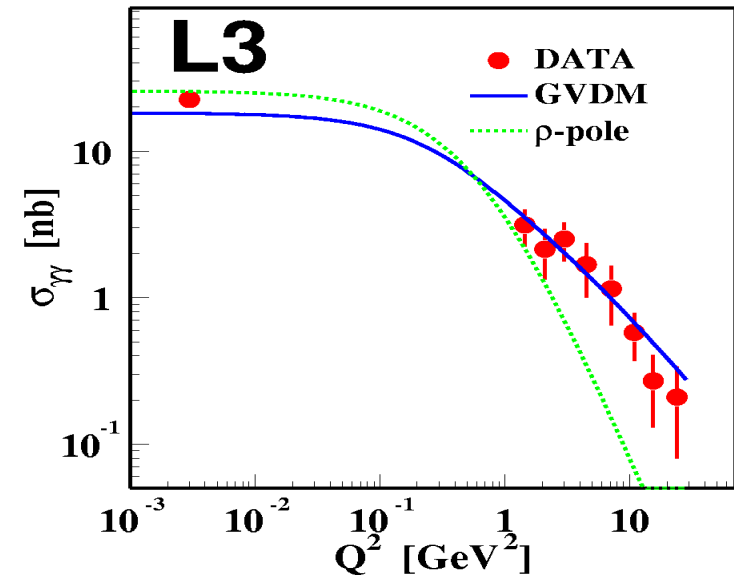
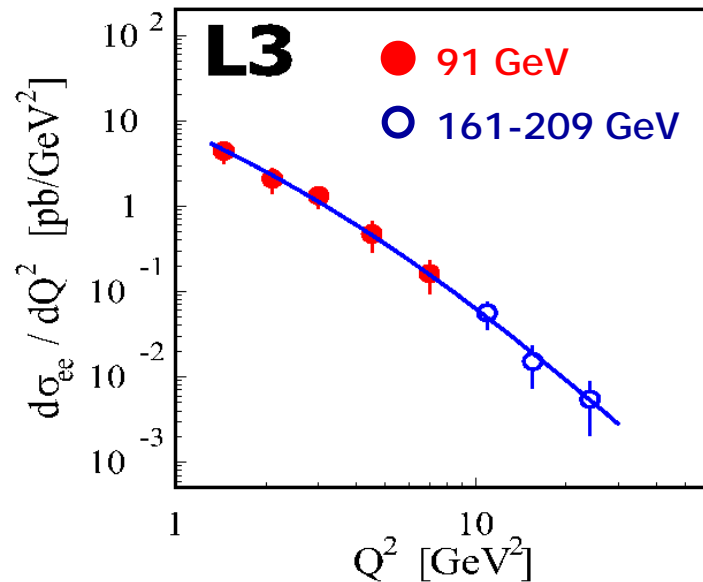
$\rho^0\rho^0$ pair production at high Q^2



- Broad enhancement near threshold of $\gamma\gamma \rightarrow \rho^0\rho^0$ as observed in $Q^2 \approx 0$ measurement



$\rho^0\rho^0$ pair production at high Q^2



□ Fit with $1/(Q^m(Q^2 + \langle W \rangle^2)^2)$:

▶ QCD prediction⁽¹⁾ : $m=2$

▶ Data: $m=2.4 \pm 0.3$ ($\langle W_{\gamma\gamma} \rangle = 1.95$)

□ Low and high Q^2 data are well described by GDVM form factor

□ ρ-pole not sufficient

(1) M. Diehl *et al.* PRD 62 073014 (2000); hep-ph/0003233

Conclusions



□ π and K pair production

- ▶ $\sigma(\gamma\gamma \rightarrow \pi^+\pi^-) = \sigma(\gamma\gamma \rightarrow K^+K^-)$
- ▶ Only $W_{\gamma\gamma}$ dependence agrees with QCD predictions
- ▶ Normalization and K/π ratio disagree with QCD predictions

□ Baryon pair production

- ▶ Data can be described by diquark model and handbag model
- ▶ Three quark model excluded

□ $\rho^0\rho^0$ and $\rho^+\rho^-$ pair production

- ▶ Dominance of $(J^P, J_z) = (2^+, 2)$ for $Q^2 \approx 0$
- ▶ Broad enhancement near threshold of $\gamma\gamma \rightarrow \rho^0\rho^0$
- ▶ Good agreement with QCD predictions for $d\sigma_{e^+e^-}/dQ^2$
- ▶ GVDM form factor also describes well the Q^2 dependence of $\sigma_{\gamma\gamma}$