Exclusive $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^0\pi^-\pi^0$ production in two photon collisions at L3

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Outline

$e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$
$e^+e^- \to e^+e^-\pi^+\pi^0\pi^-\pi^0$

- Exclusive $\rho^0\rho^0$ and $\rho^+\rho^-$ production at $Q^2 \approx 0$
- Exclusive $\rho^0\rho^0$ production for $1.2 < Q^2 < 30$ GeV^2 [Subm. to Phys. Lett.]
- $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^0\pi^-\pi^0$ at $W_{\gamma\gamma} > 2.4$ GeV

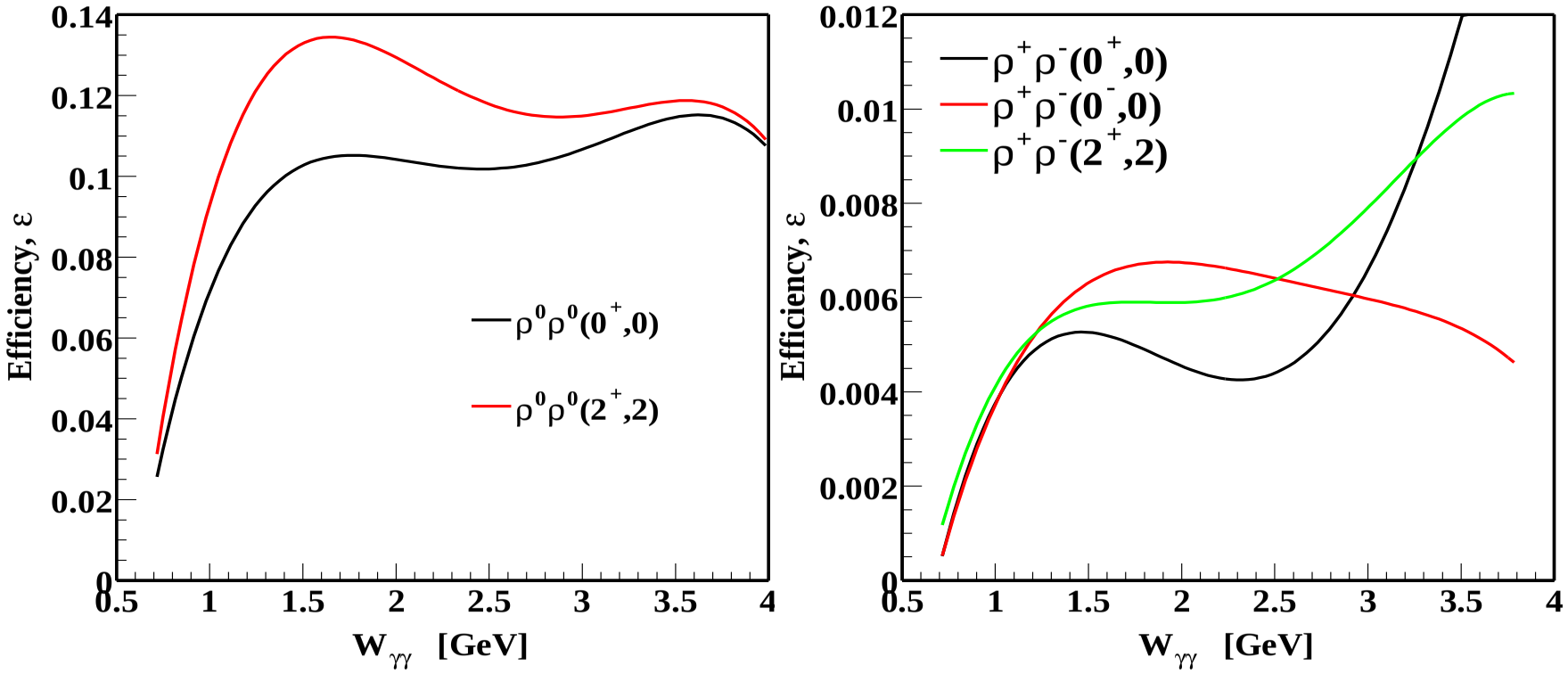
Exclusive $\rho\rho$ production at $Q^2 \approx 0$

- high energy data ($161 < \sqrt{s} < 208$ GeV), integrated luminosity $\mathcal{L}_{e^+e^-} = 686.7$ pb^{-1}
- $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$
  - 4 tracks with zero charge
  - no photons
  - dE/dx CL$(4\pi) > 6\%$
- $e^+e^- \to e^+e^-\pi^+\pi^0\pi^-\pi^0$
  - two tracks with zero charge
  - dE/dx CL$(2\pi) > 6\%$
  - 4 photons $E_\gamma > 100$ MeV
  - two best π^0 from constraint fit
- $p_t^2(4\pi) < 0.02$ GeV^2

Sample of $\pi^+\pi^-\pi^+\pi^-$ — 69542 events (66838 in $1.0 < W_{\gamma\gamma} < 3.0$ GeV)
Sample of $\pi^+\pi^0\pi^-\pi^0$ — 5263 (4740 in $1.0 < W_{\gamma\gamma} < 3.0$ GeV).

Efficiency and detector acceptance

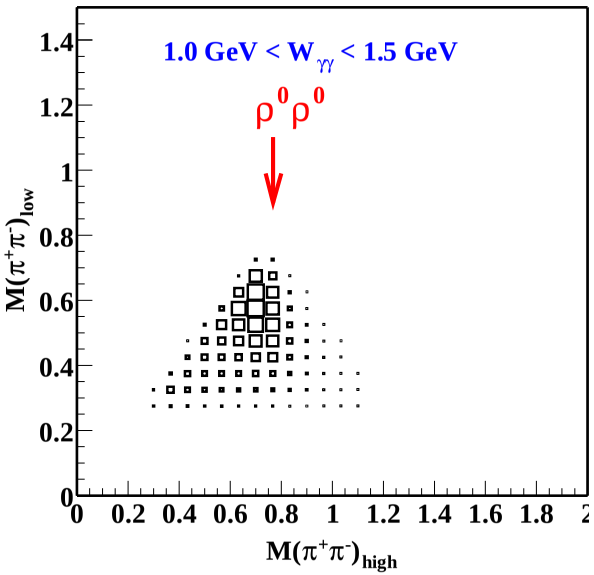
Detector acceptance and selection efficiency ε determined from MC (EGPC generator [F. Linde, Ph.D Thesis, 1988])

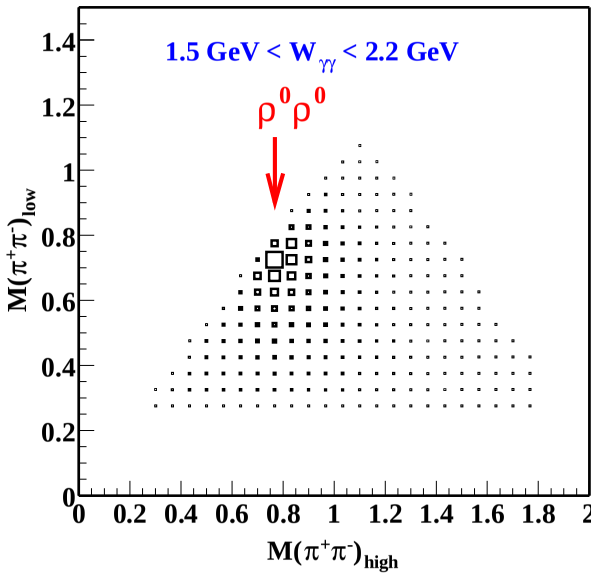


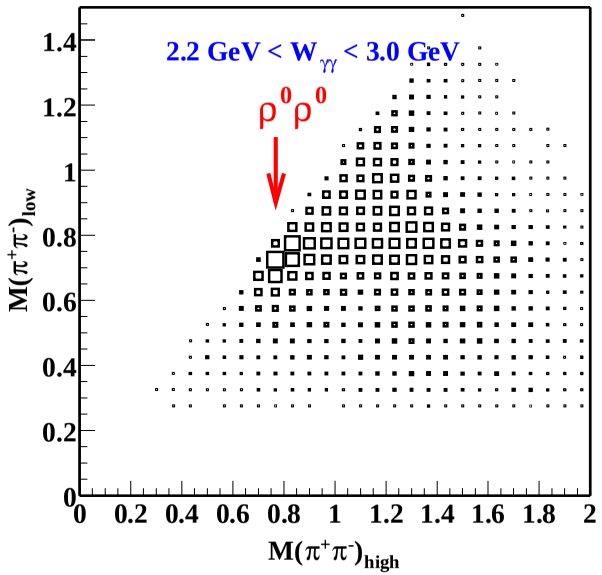
Trigger efficiency calculated from the data:

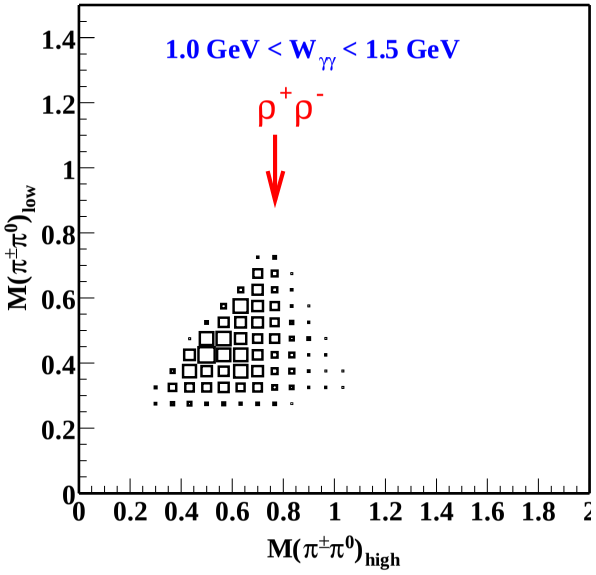
- 91.8% for $\pi^+\pi^-\pi^+\pi^-$
- 51.8% for $\pi^+\pi^0\pi^-\pi^0$

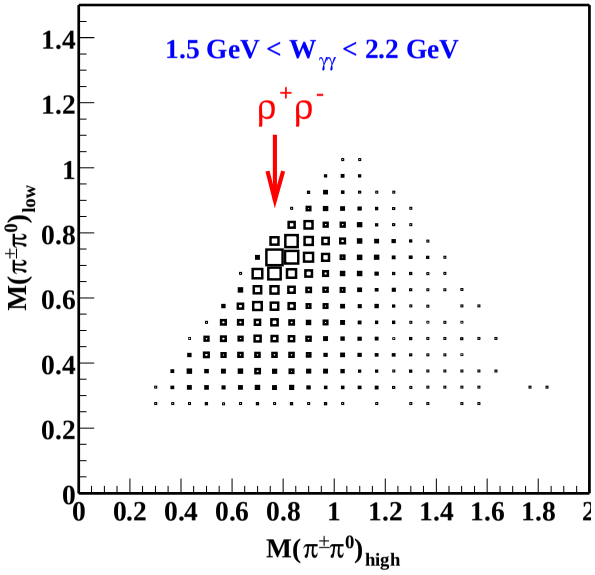
Two pion mass spectra

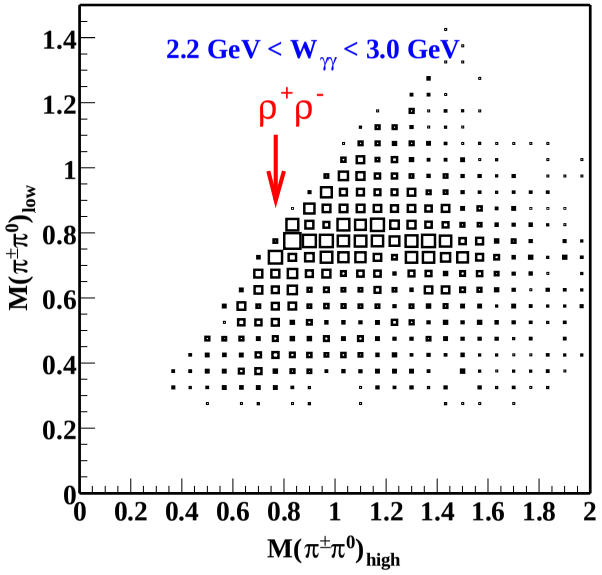




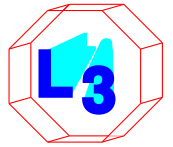








Partial Wave Analysis method

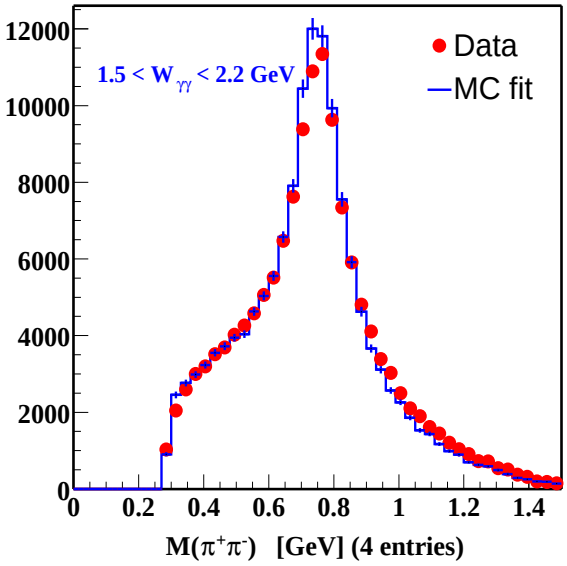


- Performed in $1.0 < W_{\gamma\gamma} < 3.0$ GeV
- Model with $\rho\rho$ in different spin-parity states and isotropic 4π [M.Althoff et al. Z.Phys.**C16**,1982]
  - $A_{\rho\rho} \sim BW_{12} BW_{34} \Psi_{J^P\, J_z}$+perm.
  - $A_{4\pi} \sim 1$
- $\rho\rho(J^P, J_z) =$ $(0^+,0),(2^+,2),(0^-,0),(2^+,0),(2^-,0(1,2))$ and 4π isotropic, no interference, significant $\rho\rho$ only 0^+ and $(2^+,2)$; 4π isotropic is effective background
- MC integration of $|A_{\rho\rho}|^2$
- Likelihood fit to the data in each $W_{\gamma\gamma}$ bin

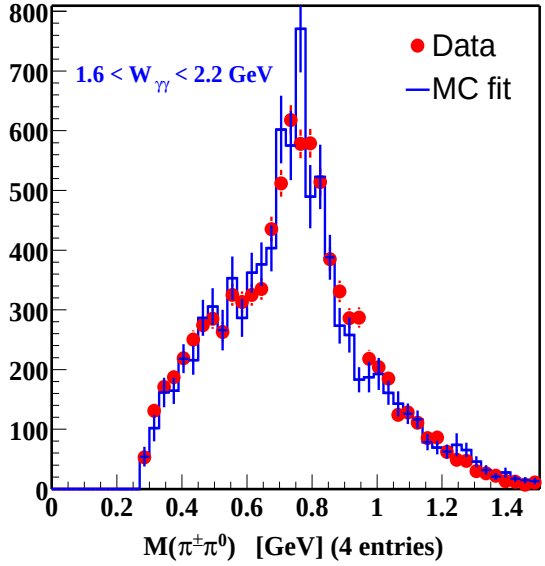
Fit results for $\rho\rho$

- $M(\pi^+\pi^-)$ and $M(\pi^\pm\pi^0)$

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

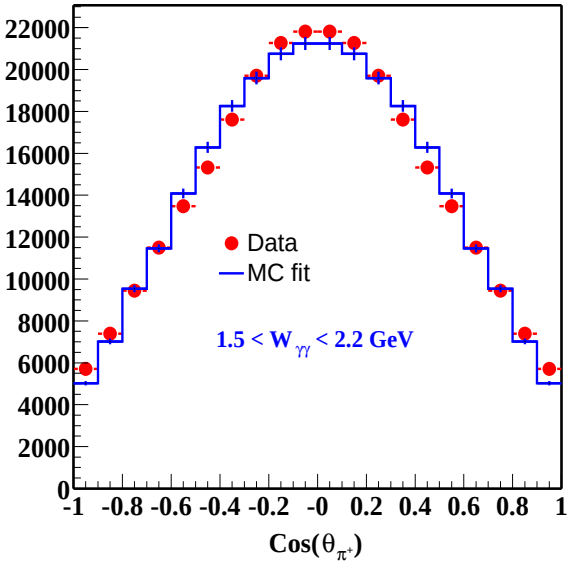


$M(\pi^\pm\pi^0)$ spectrum

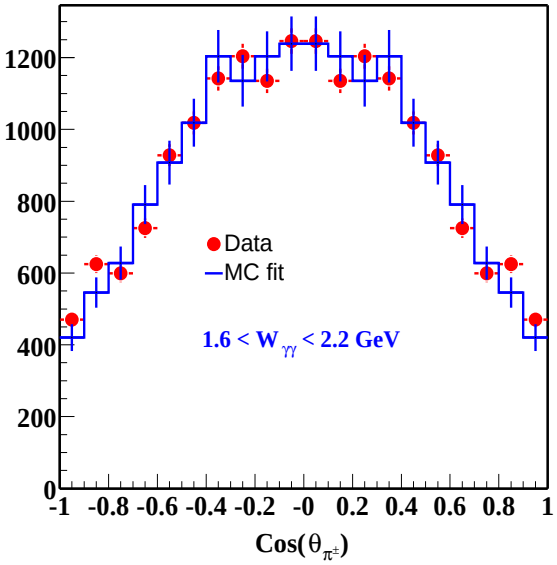


- Angle of pion in C.M.S. of ρ with respect to the beam axis (Adair angle)

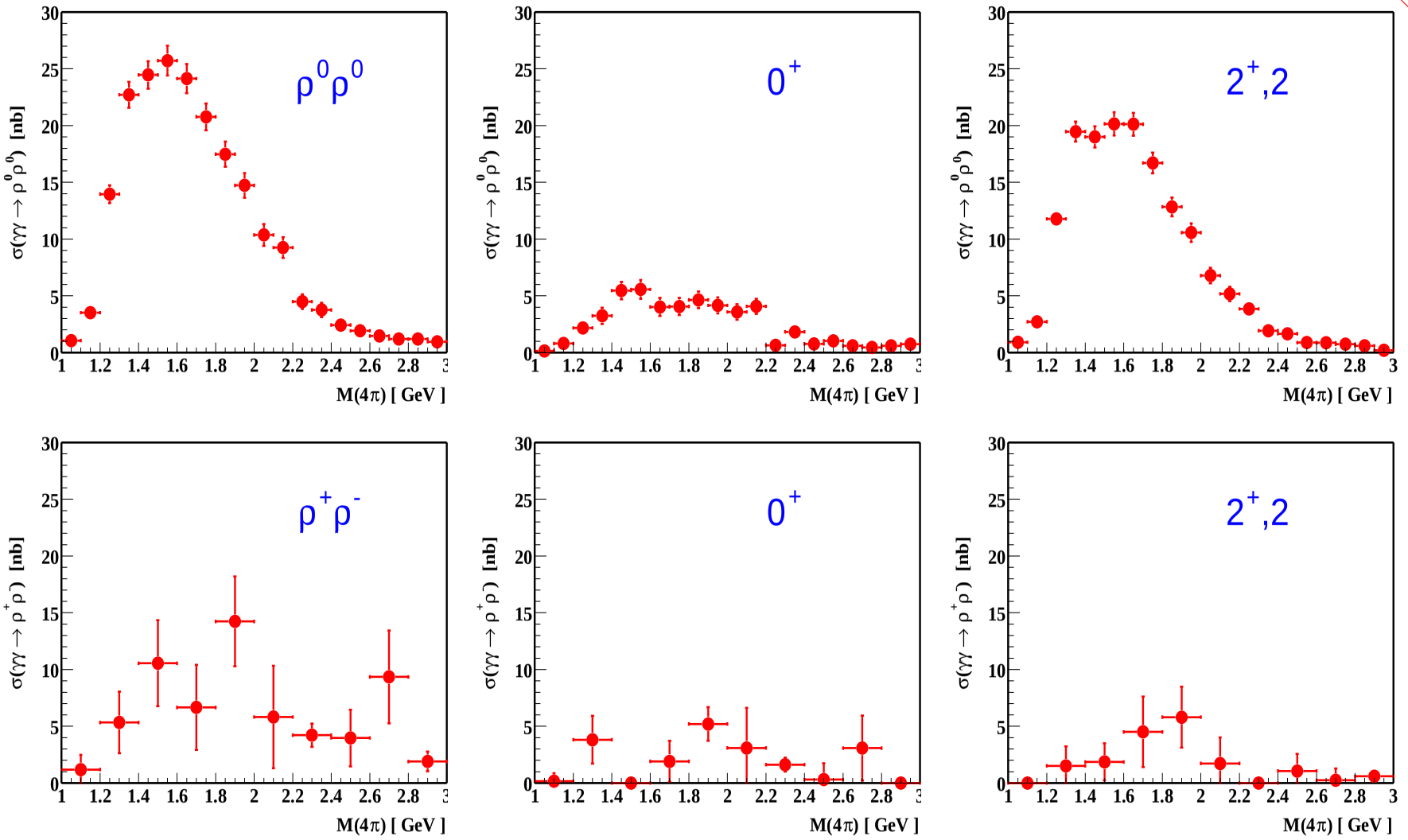
angle of π^+ in ρ^0 CMS



angle of $\pi^\pm$ in $\rho^\pm$ CMS

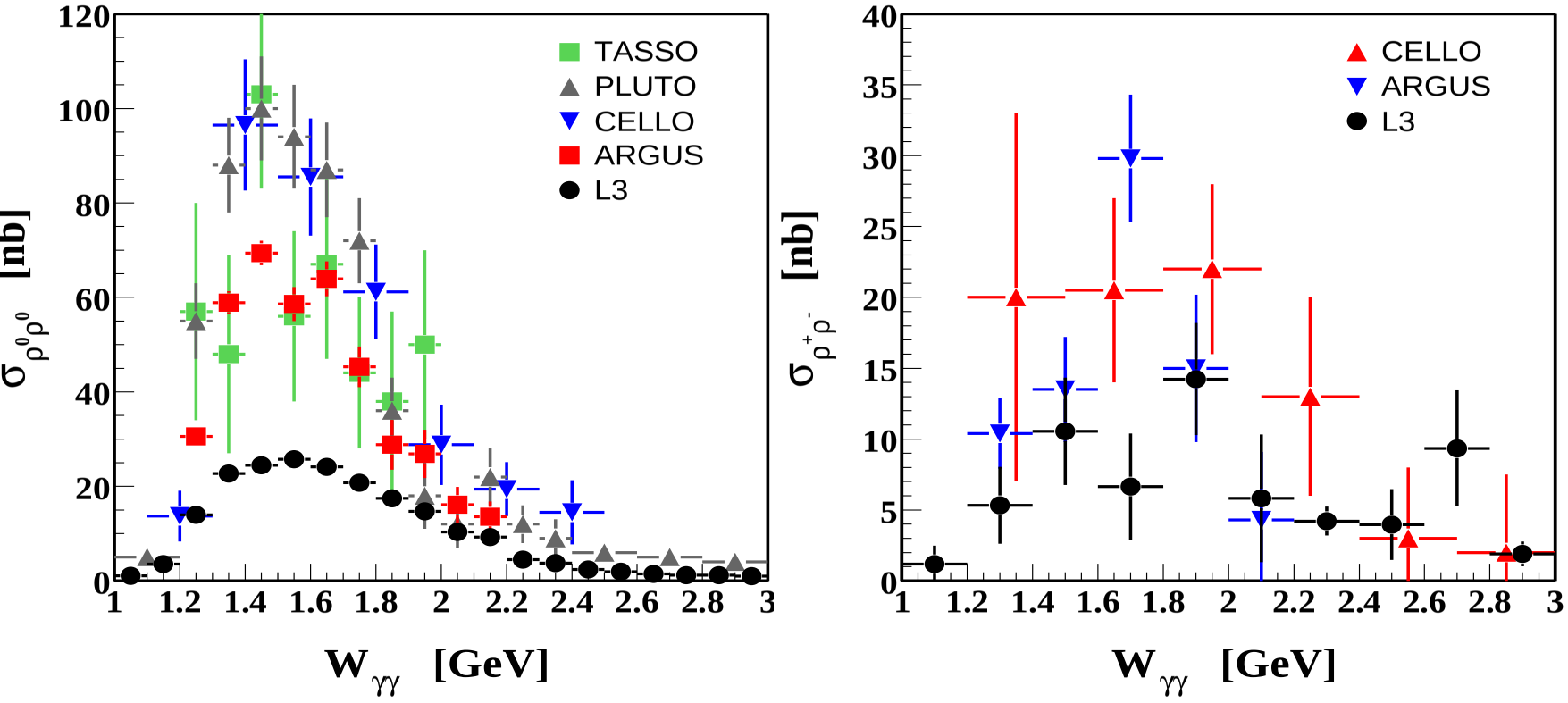


Cross section for $\gamma\gamma \to \rho\rho$



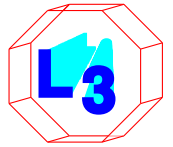
- Total $\rho\rho$ and dominant partial waves cross sections
- Isospin ratio of the $\rho\rho$ cross sections is incompatible with $I = 0, 1$

Cross section for $\gamma\gamma \to \rho\rho$



$\Rightarrow$ Broad enhancement near threshold of $\gamma\gamma \to \rho\rho$

Exclusive $\rho^0\rho^0$ production for $1.2 < Q^2 < 30$ GeV^2



- Single tag $e^+e^- \to e^+e^-_{\rm tag}\gamma\gamma^* \to e^+e^-_{\rm tag}\rho^0\rho^0$
  - tagged electron 25 mrad $< \theta <$ 68 mrad
  - $p_{\rm t}^2(e_{\rm tag}\pi^+\pi^-\pi^+\pi^-) < 0.2$ GeV^2
  - $E_{\rm tag} > 80\%\ E_{\rm beam}$

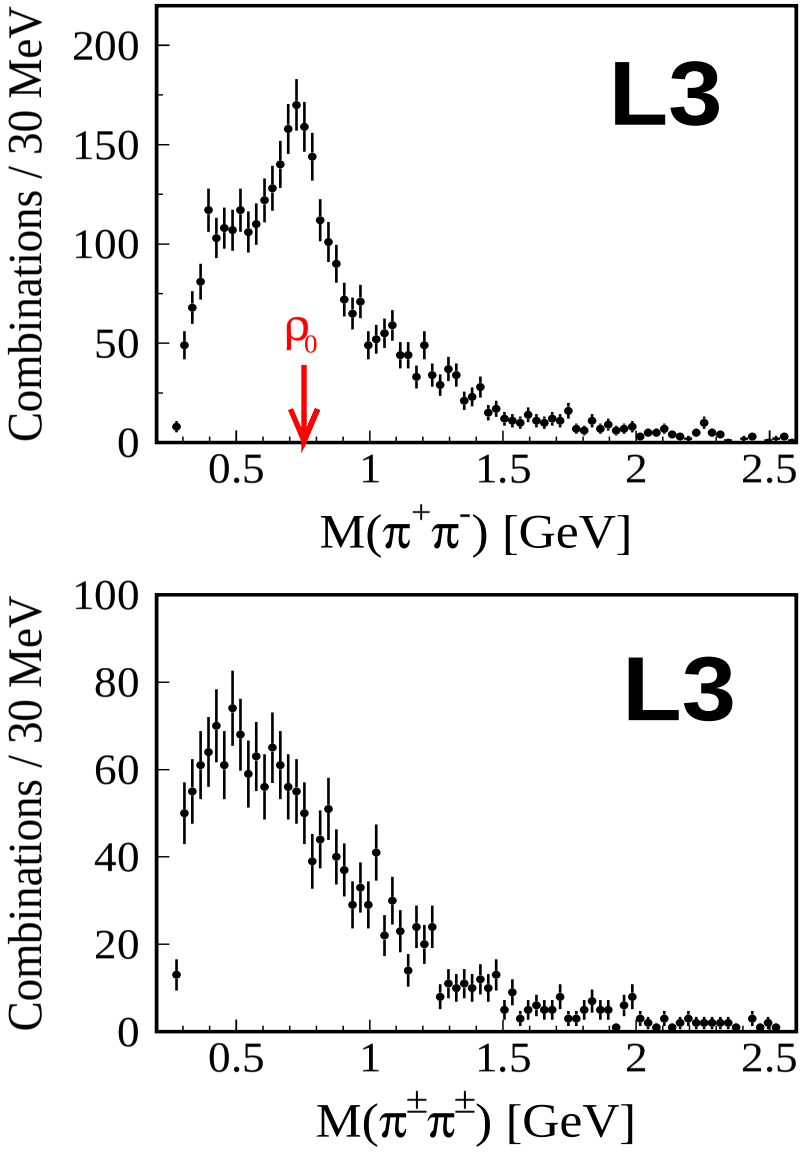
$\Rightarrow$ Z-pole ($\sqrt{s} \approx 91$ GeV) $1.2 < Q^2 < 8.5$ GeV^2, $\mathcal{L}_{e^+e^-} = 148.7$ pb^{-1}

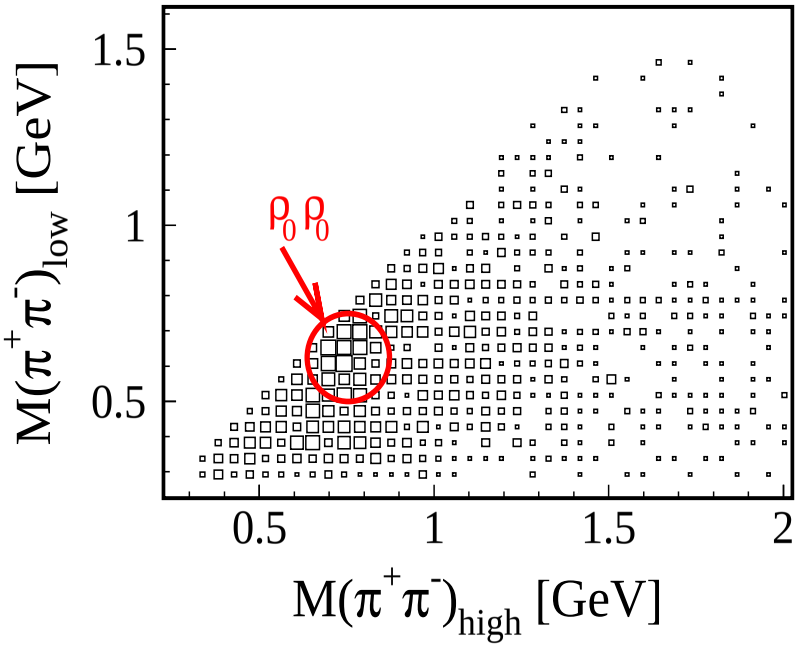
$\Rightarrow$ high energy data ($\sqrt{s} \approx 195$ GeV) $8.8 < Q^2 < 30$ GeV^2, $\mathcal{L}_{e^+e^-} = 706.0$ pb^{-1}

$\Rightarrow$ at Z-pole sample of 851 events with $W_{\gamma\gamma} > 1$ GeV

$\Rightarrow$ at high energy sample of 498 events with $W_{\gamma\gamma} > 1$ GeV

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



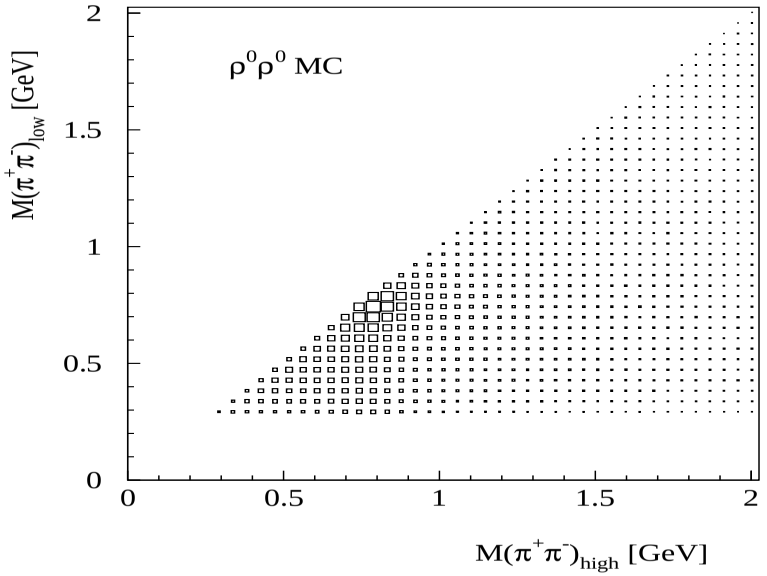


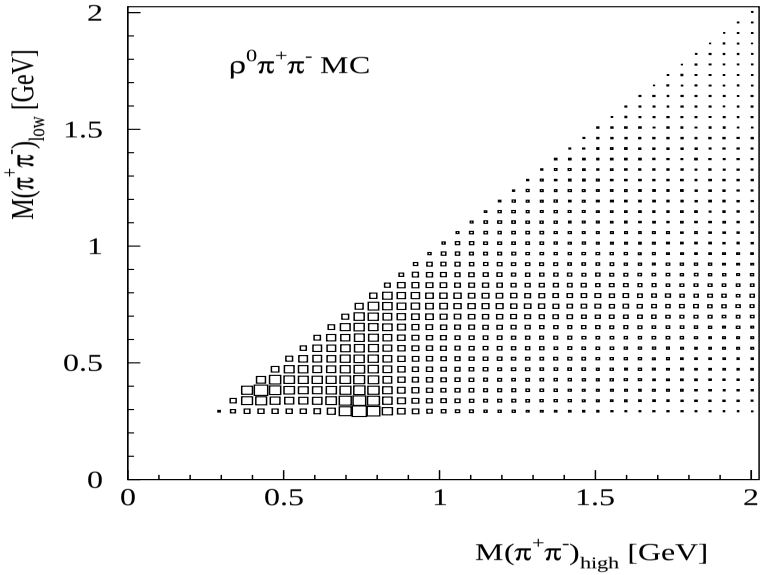
Box method [D.M.Schmidt et al. NIM A328(1993)]

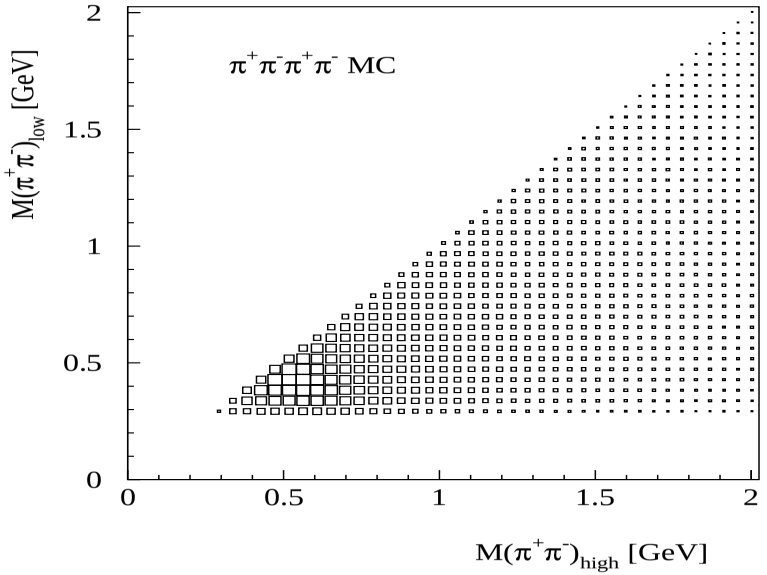
2 million MC events for channel

- $\gamma\gamma^* \to \rho^0\rho^0$
- $\gamma\gamma^* \to \rho^0\pi^+\pi^-$
- $\gamma\gamma^* \to \pi^+\pi^-\pi^+\pi^-$

Likelihood fit to the data

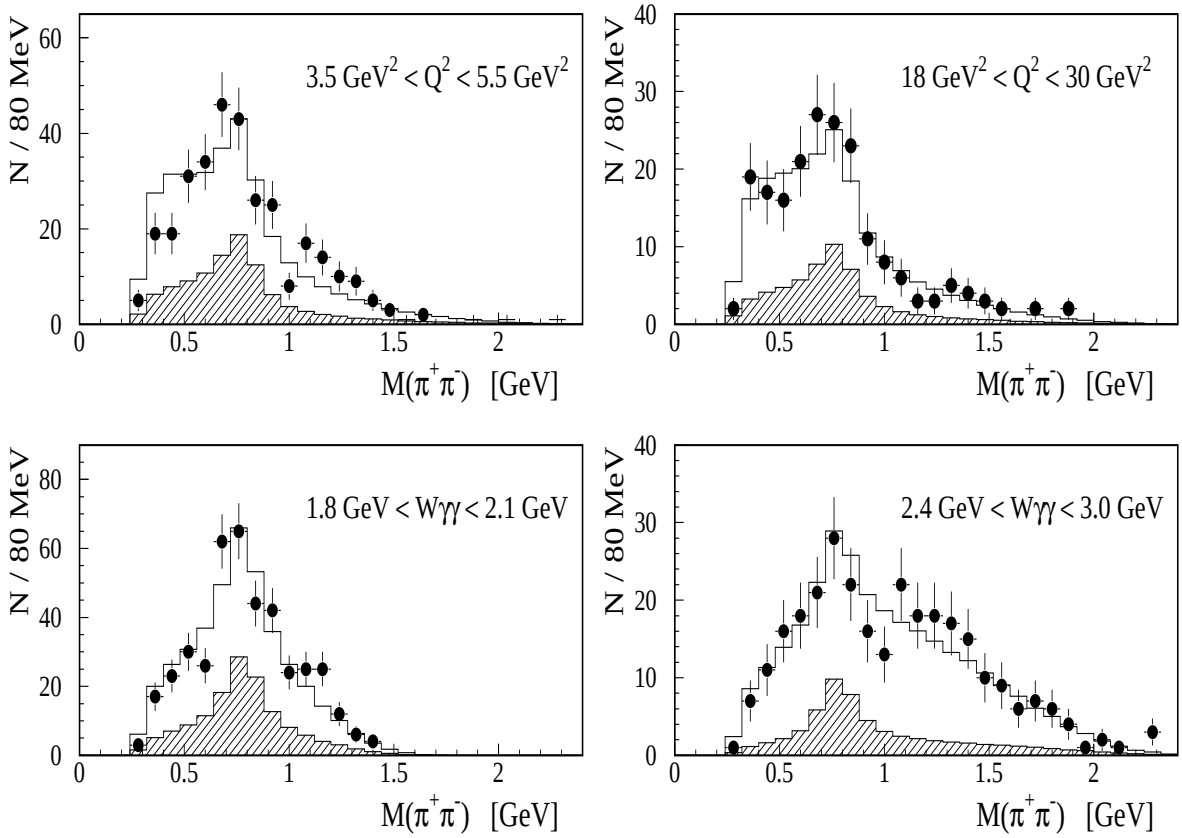




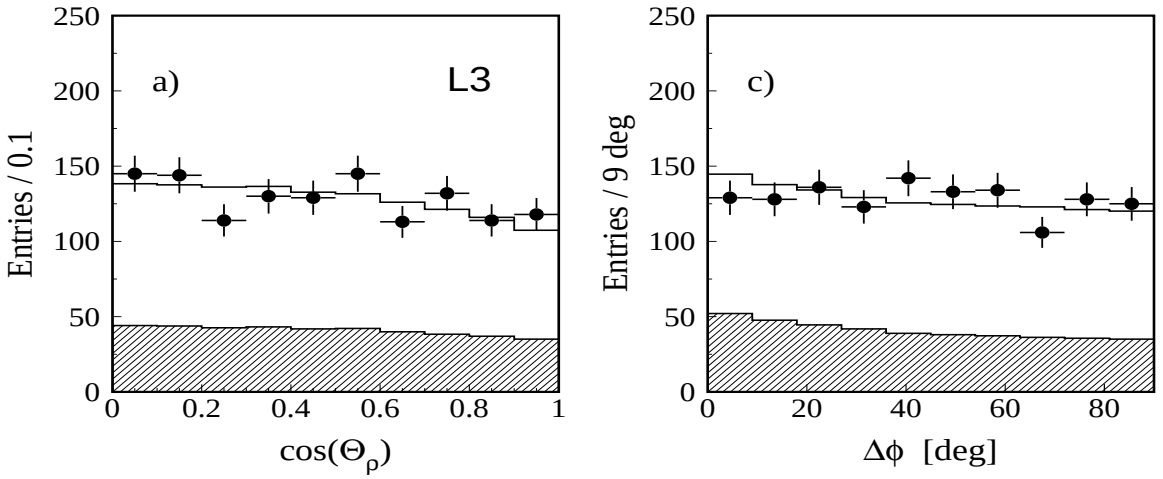


Fit results for $\rho^0\rho^0$

- $M(\pi^+\pi^-)$ in different Q^2 and $W_{\gamma\gamma}$ regions

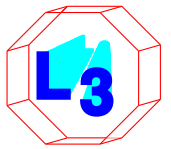


- Production angle and angle between decay planes

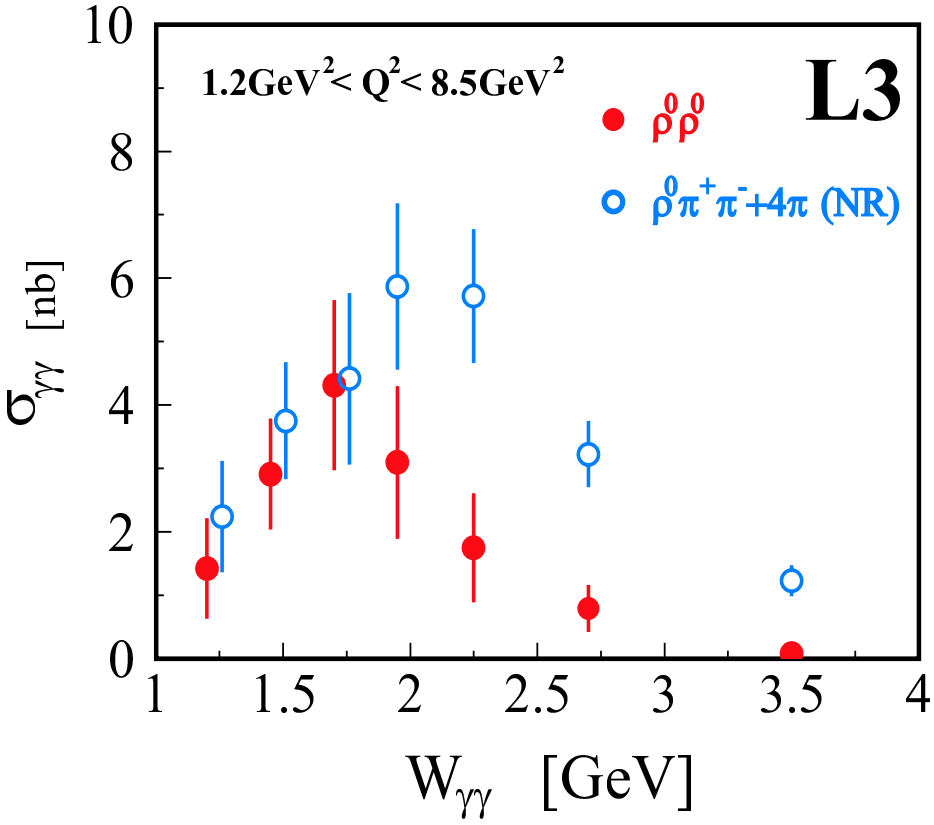


Points represent the data, histogram shows fit results, hatched area shows $\rho^0\rho^0$ component

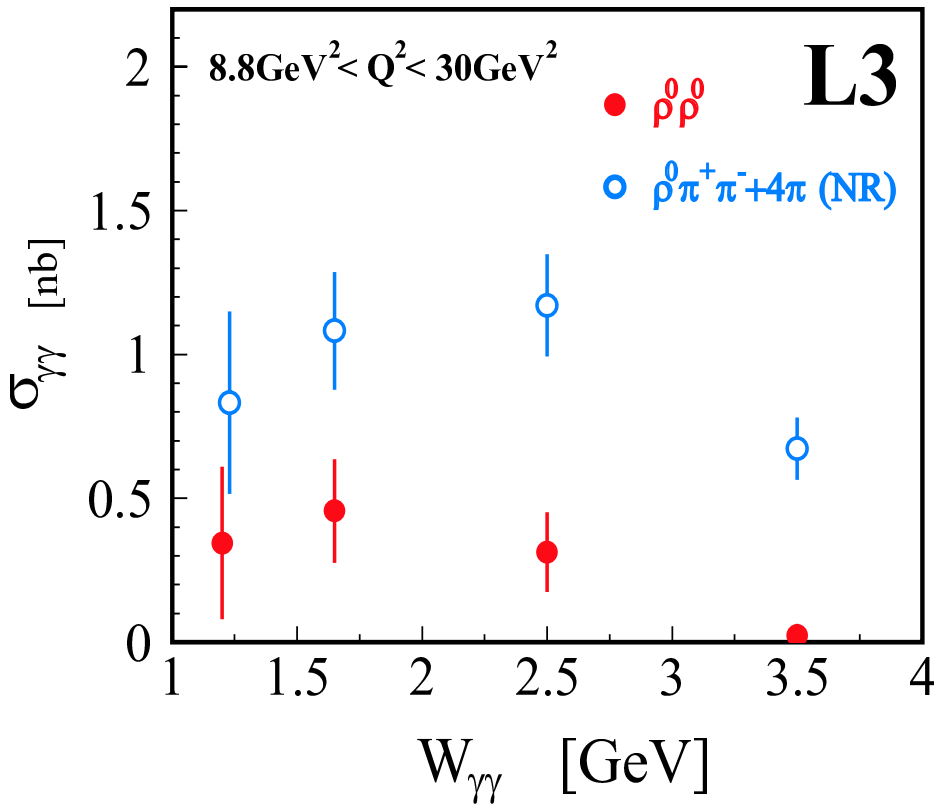
Cross-section of $\gamma\gamma^* \to \rho^0\rho^0$



Z-pole data

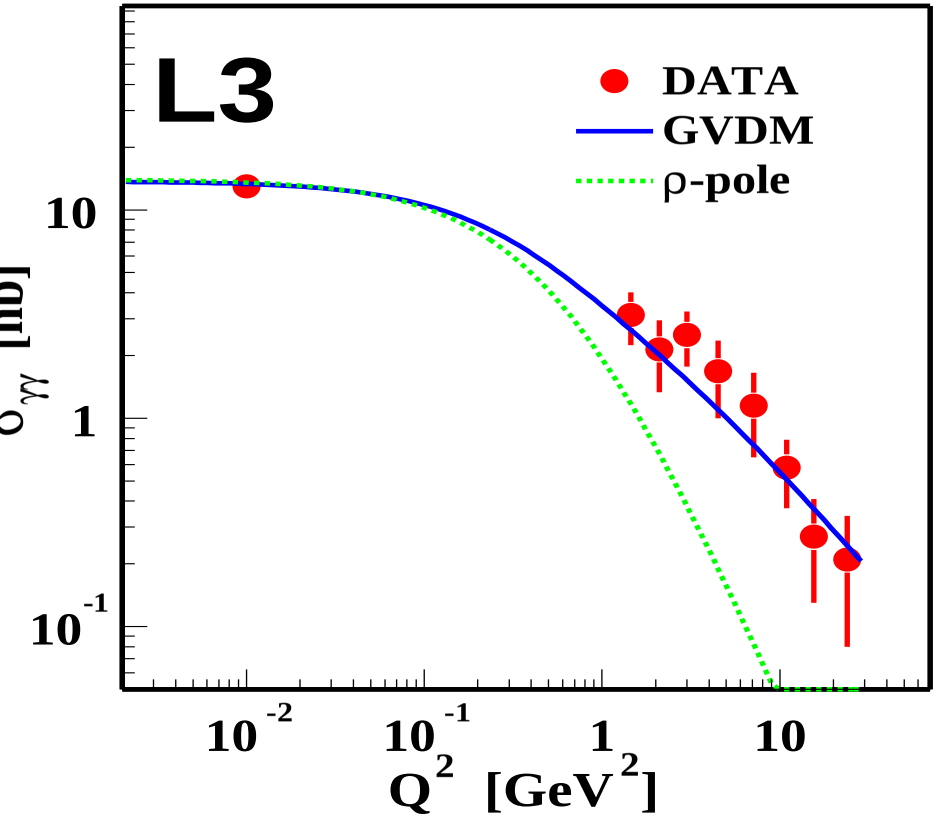


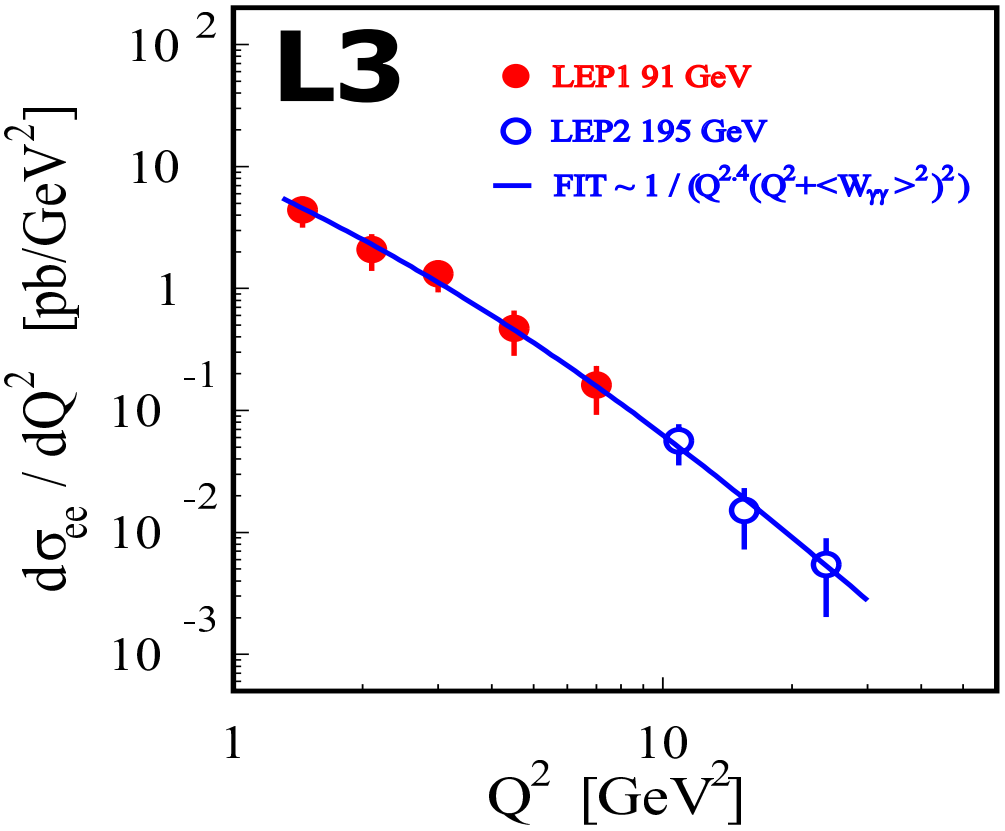
High energy data



- Broad enhancement near threshold of $\gamma\gamma \to \rho^0\rho^0$ as seen in measurement at $Q^2 \approx 0$
- Interval $1.1 < W_{\gamma\gamma} < 3.0$ GeV is chosen for Q^2-dependence

Cross-section of $\gamma\gamma^* \to \rho^0\rho^0$



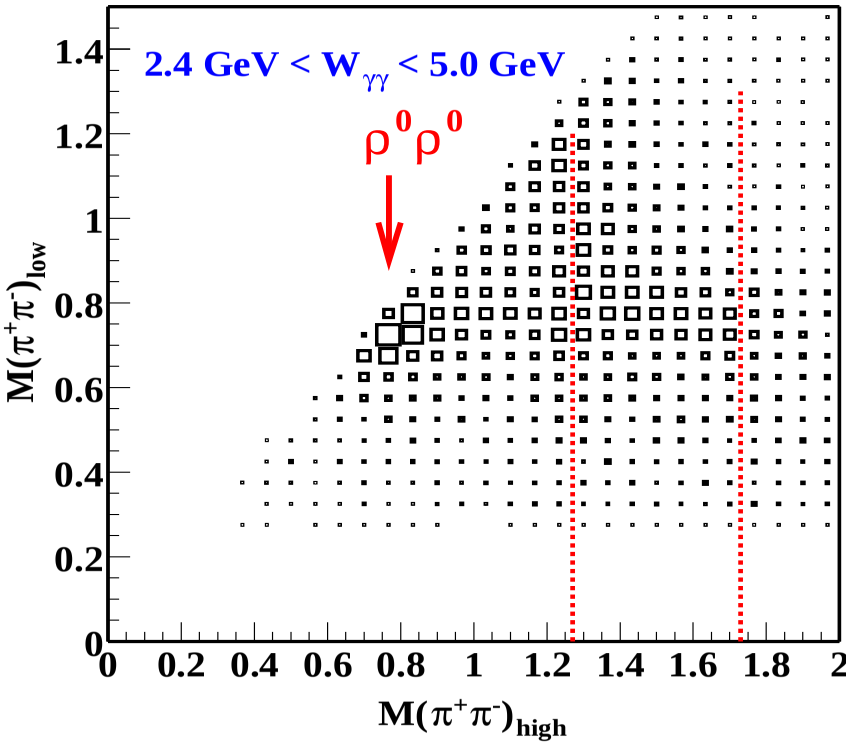


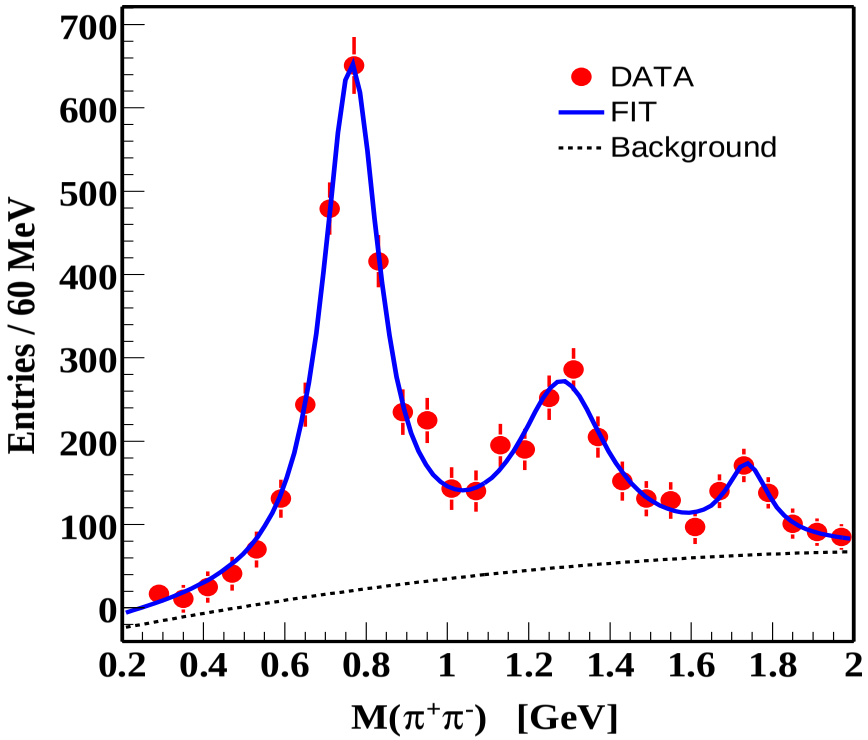
- Agrees well with GVDM form factor, ρ-pole is not sufficient

- Fit with $1/(Q^m(Q^2 + \langle W\rangle^2)^2)$
  - $m = 2.4 \pm 0.3$ ($\langle W\rangle = 1.945$)
  - Agrees with QCD expectation

  $m = 2$ [M. Diehl et al. PRD 62 073014]

High $W_{\gamma\gamma}$ two pion mass spectra





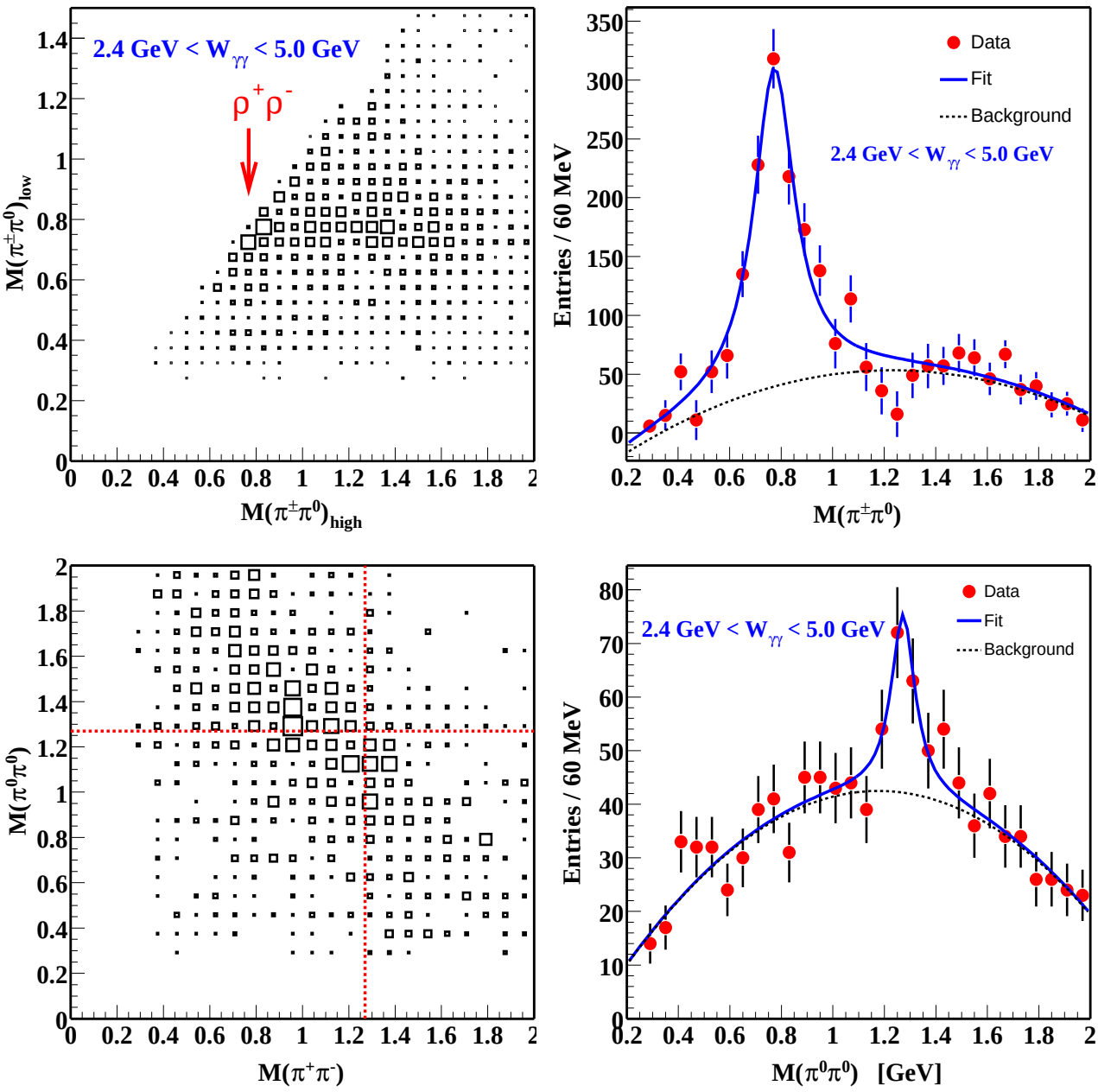
$M_\rho = 763 \pm 4$ GeV $\quad \Gamma_\rho = 170 \pm 21$ GeV

$M_{f_2} = 1282 \pm 15$ GeV $\quad \Gamma_{f_2} = 273 \pm 130$ GeV

$M_{\rho'} = 1738 \pm 19$ GeV $\quad \Gamma_{\rho'} = 130 \pm 61$ GeV

- $\rho(770)$, $f_2(1270)$,$\rho'(1700)$ are clearly seen

Breit-Wigner fit for high $W_{\gamma\gamma}$

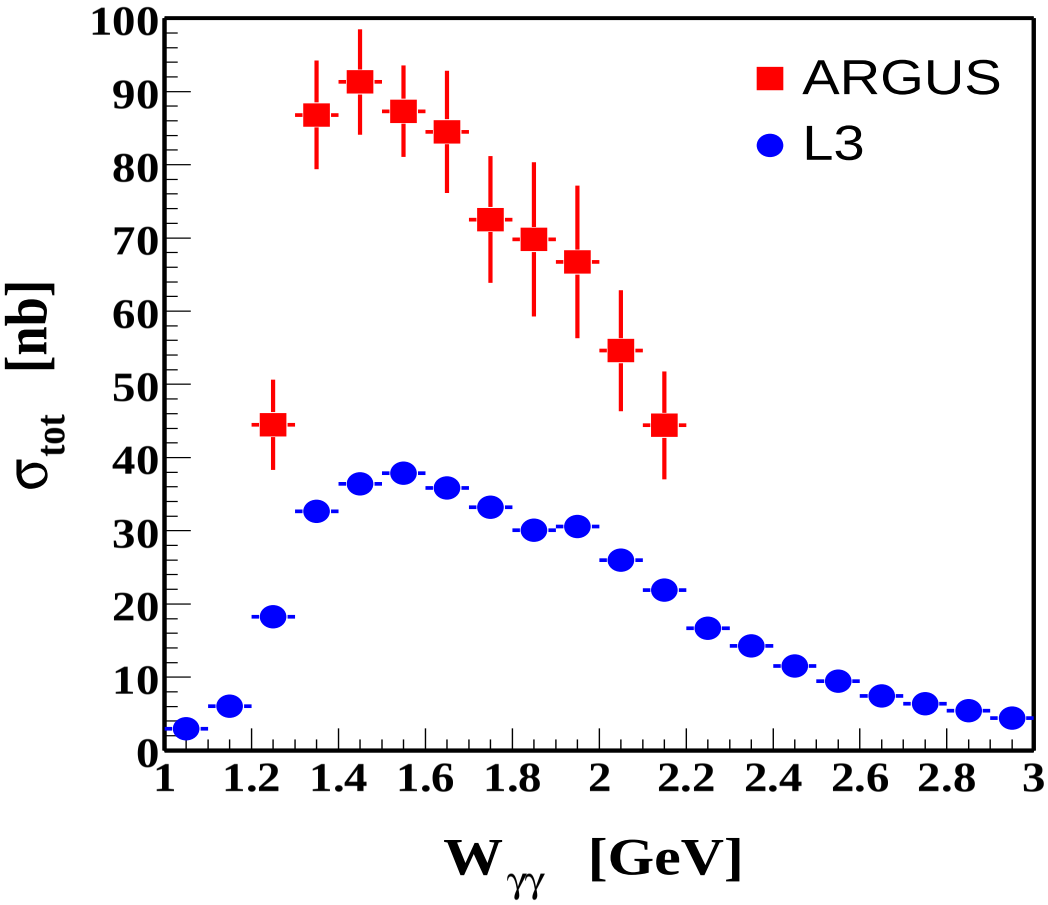


$$M_\rho = 773 \pm 8 \text{ GeV} \qquad \Gamma_\rho = 191 \pm 25 \text{ GeV}$$
$$M_{f_2} = 1273 \pm 14 \text{ GeV} \qquad \Gamma_{f_2} = 112 \pm 67 \text{ GeV}$$

Summary

- Exclusive $\rho\rho$ production at $Q^2 \approx 0$
  - Dominance of $(J^P, J_z) = (2^+, 2)$ spin-parity state
  - Broad enhancement of $\rho\rho$ near threshold
  - Cross section ratio $\sigma(\rho^0\rho^0)/\sigma(\rho^+\rho^-)$ is incompatible with isospin $I = 0, 1$
- Exclusive $\rho^0\rho^0$ production at high Q^2
  - Broad enhancement of $\rho^0\rho^0$ near threshold as for $Q^2 \sim 0$
  - Good agreement with the QCD expectation for differential cross section $d\sigma_{e^+e^-}/dQ^2$
  - GVDM form factor describes well Q^2 dependence of $\sigma_{\gamma\gamma}$
  - Measurements of the $\sigma_{\gamma\gamma}$ at $Q^2 \sim 0$ and for $Q^2 > 1.2$ GeV^2 are consistent
  - Low and high Q^2 data are consistent with the same QCD prediction
- High $W_{\gamma\gamma}$ region
  - In $\pi^+\pi^-\pi^+\pi^-$ $\rho^0(770)$, $f_2(1270)$ and $\rho'(1700)$ are clearly seen
  - In $\pi^+\pi^0\pi^-\pi^0$ $\rho^{\pm}(770)$ and $f_2(1270)$ are seen

Cross section for $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$



$\Rightarrow$ Comparison of total $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ cross section