collisions at L3
production in two photon
exclusive $\mu^+ \mu^- + \mu^- \mu^-$ and $\nu^0 + \nu^0 - \nu^0 - \nu^0$
$\sqrt{s} < 2.4 \text{ GeV}$

$1.2 \, \sigma > 30 \, \text{ GeV}^2$

Exclusive production for $d_0 d_0$ and $d_+ d$ production at 0

$0 \approx \sigma$
Sample of \( \nu + \bar{\nu} \) events (66838 in 1.0 \( M^2 > 3.0 \text{ G\text{eV}} \))

Sample of \( \nu + \bar{\nu} \) events (5263 in 1.0 \( M^2 > 3.0 \text{ G\text{eV}} \))

\[
\left( \frac{d^2 p}{d^2 \eta} \right) \geq 0.02 \text{ G\text{eV}^2} \]

two best \( \nu_0 \) from constraint fit *

\( \nu_0 \) photons \( E < M^2 \)

\( \text{dE/dx} \cdot \text{CL}(\nu_0) < 6\% \)

two tracks with zero charge *

\( -e + e \leftrightarrow e - e \)

\( \text{dE/dx} \cdot \text{CL}(\nu_0) < 6\% \)

no photons *

\( \text{4 tracks with zero charge} \)

\( -e + e \leftrightarrow e - e \)

Integrated luminosity \( \mathcal{L} = 686.7 \text{ pb}^{-1} \)

High energy data (161 \( \sqrt{s} > 208 \text{ G\text{eV}} \))

\( 0 \approx 0 \) at production \( d\sigma \)
Collisions at 15 (Page 4)

Exclusive \( e^{+} \mu^{-} e^{-} \mu^{+} \) and \( e^{+} \mu^{-} e^{-} \mu^{+} \) 0

51.8\% for \( e^{+} \mu^{-} e^{-} \mu^{+} \) 0

91.8\% for \( e^{+} \mu^{-} e^{-} \mu^{+} \) 0

Trigger efficiency calculated from the data:

Detector acceptance and selection efficiency & determined

From MC (ECPG generator) [P. Lind, Ph.D. thesis, 1988]
Two pion mass spectra

Exclusive \( \mu^+\mu^- + \mu^+\mu^- \) and \( \mu^+\mu^- + \mu^+\mu^- \) production in two photon collisions at low energy.
Likelihood fit to the data in each $W$ bin

$|dA_p^d| \sim \frac{dA_{pp}^d}{|dA_p^d|_p^d}$

MC integration of $|dA_p^d|$

Background

only $0^+ \text{ and } (2^+, 2)$, $4\pi$ isotropic is effective

$4\pi$ isotropic, no interference, significant $pp$

and isotropic $4\pi$

Model with $dA_{pp}^d$ in different spin-parity states

Perform in $1.0 < W < 3.0$ GeV

Partial Wave Analysis method
Fit results for $\rho\rho$

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

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

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

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

  angle of $\pi^+$ in $\rho^0$ CMS

  angle of $\pi^\pm$ in $\rho^{\pm}$ CMS
IJossspin ratio of the $pp$ cross sections is incompatible with $I = 0'1$.

Total and dominant partial waves cross sections

Cross section for $pp \rightarrow$ \( \gamma \gamma \)
$d\bar{d} \leftrightarrow \gamma\gamma$ near threshold $\Rightarrow$ Broad enhancement

Cross section for $d\bar{d}$
at high energy sample of 48 events with $W < 1$ GeV
at Z-pole sample of 851 events with $W < 1$ GeV

$J^{\pm} = 706.0 \pm 1$ pb$^{-1}$

$8.8 > \sqrt{s} > 30$ GeV $\approx 195$ GeV

high energy data (Z) $\approx 8.5$ GeV

$\approx 148.7 \pm 1$ pb$^{-1}$

$\sqrt{s} > 8.9$ GeV (Z) $\approx 59$ GeV

$\approx 0.2$ GeV

$\leq 80\%$ beam

$0 > \theta > 68$ mrad

tagged electron 2$\pi$ mrad

$3 \pi$ tagged $e^+ e^-$

Single tagged $e^+ e^-$

Exclusive production for $\sqrt{s}$ $\approx 30$ GeV
Collisions at L3 (Page 12)

Production in two photon

Exlusive \( \mu^- \mu^+ \) and \( \mu^- \mu^- \) and \( \mu^+ \mu^+ \) and \( \mu^+ \mu^- \)

\[ M(\mu^- \mu^+) \text{ [GeV]} \]

Likehood fit to the data

\(-\mu^- \mu^- \mu^- \mu^- \) \( \star \star \)

\(-\mu^- \mu^- d \) \( \star \star \)

\( d_0 d \) \( \star \star \)

2 million MC events for channel

Box method [D. M. Schmidt et al. NIM A328 (1993)]
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
$\theta^2$-dependence

Interval $1.1 < M < 3.0 \text{ GeV}$ is chosen for $0 \approx \theta^2 \approx 0$

Broad enhancement near threshold of

High energy data

Cross-section of

$\sigma_{00} \propto \mu^2$
\[ m = 2 \] agrees with QCD expectation.

- \( m = 2.4 \pm 0.3 \) \( (\langle M \rangle + \langle \tilde{Q} \rangle)m_{\tilde{Q}} \) / fit with I.

- \( m \) with factor, \( p \)-pole is not sufficient.

\[ \text{L3} \]

\[ \text{GDDM} \]

Cross-section of data.
Exclusiv e $\mu^+ \mu^- \mu^+ \mu^-$ and $\mu^+ \mu^- \mu^+ \mu^-$ are clearly seen: $A^\Lambda$ = 130 \pm 61 \text{ GeV}$, $M^\Lambda = 1270 \pm 19 \text{ GeV}$, $A^\Lambda = 130 \pm 70 \text{ GeV}$, $M^\Lambda = 1270 \pm 24 \text{ GeV}$.

High $W$ two pion mass spectra.
Breit-Wigner fit for high $W_{\gamma\gamma}$

$M_\rho = 773 \pm 8$ GeV \quad \Gamma_\rho = 191 \pm 25$ GeV

$M_{f_2} = 1273 \pm 14$ GeV \quad \Gamma_{f_2} = 112 \pm 67$ GeV

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Exclusive $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^0\pi^-\pi^0$ production in two photon collisions at L3 (page 17)
collisions at L3 (page 18)
production in two proton
$\sqrt{s} = 1.27 (1.770) \pm f_{0} \%$ and $f_{0} \%$ are seen
$\sqrt{s} = 1.770 (1.270) \pm f_{0} \%$ and $f_{0} \%$ are clearly seen

High MT

Region

Low and High $p_{T}$ data are consistent with the same QCD

consistent

Measurements of the $\omega$ at $0 < \sqrt{s} < 1.2 GeV$ are

QCDM form factor describes well dependence of $\omega$ on $p_{T}$

section $d\sigma_{t}/d\cos\theta$

good agreement with the QCD expectation for differential cross

0 $\sim \omega$ production at high $p_{T}$

Exclusively $d_{0}d_{0}$ production at $\omega$

with isospin $I = 0, 1$ is incompatible

Cross section ratio of $d_{+}d_{-}/d_{0}d_{0}$ is incompatible

Broad enhancement of near threshold $d\sigma_{t}/d\cos\theta$

Dominance of $p_{T}$ of spin-parity state

0 $\sim \omega$ production at $dd$

Summary
Cross section for $\nu + \bar{\nu} - \nu + \bar{\nu}$, comparison of total cross section $\sim$