Resonance Formation in $\gamma\gamma$ Collisions with the L3 Detector at LEP

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L3 Collaboration

Results by

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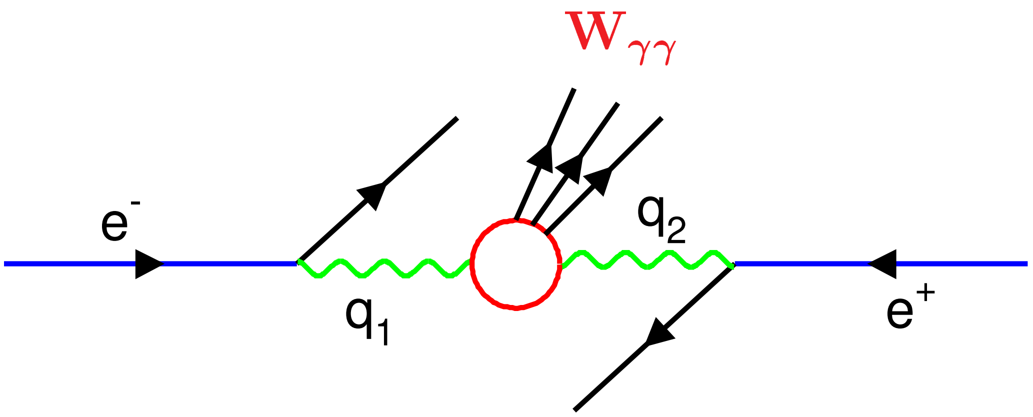
Outline

- Introduction
- The L3 detector
- η' production and form factor
- The $\pi^+\pi^-\pi^0$ final state
- $\gamma\gamma \to \pi^+\pi^-$, $\mathrm{K}^+\mathrm{K}^-$ (Preliminary)
- The $\mathrm{K}^0_S\mathrm{K}^0_S$ final state
- Summary & Conclusions



$$Q^2 \simeq \max(-q_1^2, -q_2^2)$$

$$P^2 \simeq \min(-q_1^2, -q_2^2)$$

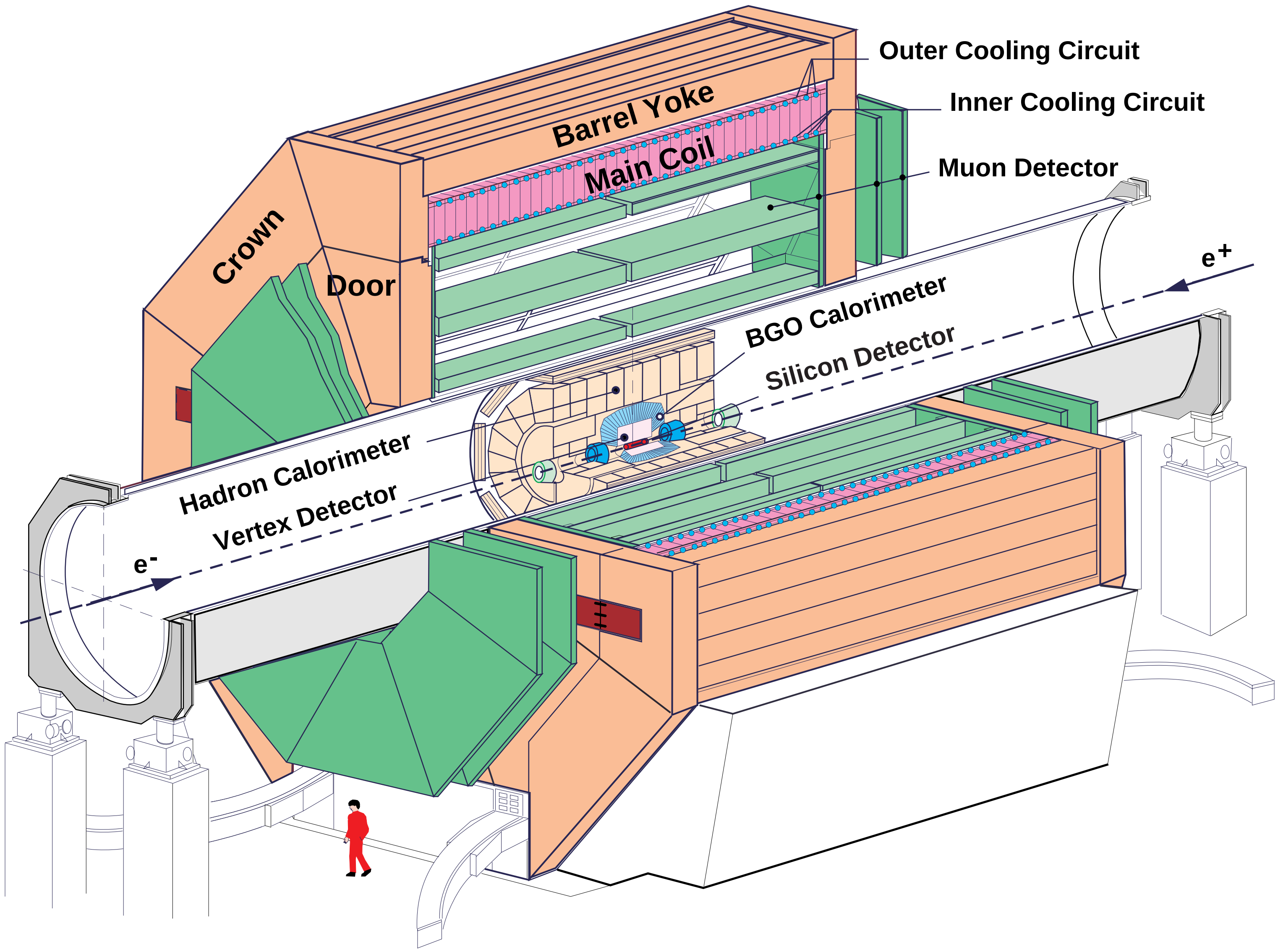
$$\vec{p}_T(\gamma\gamma \text{ System})^2 \simeq Q^2$$

Resonance formation :

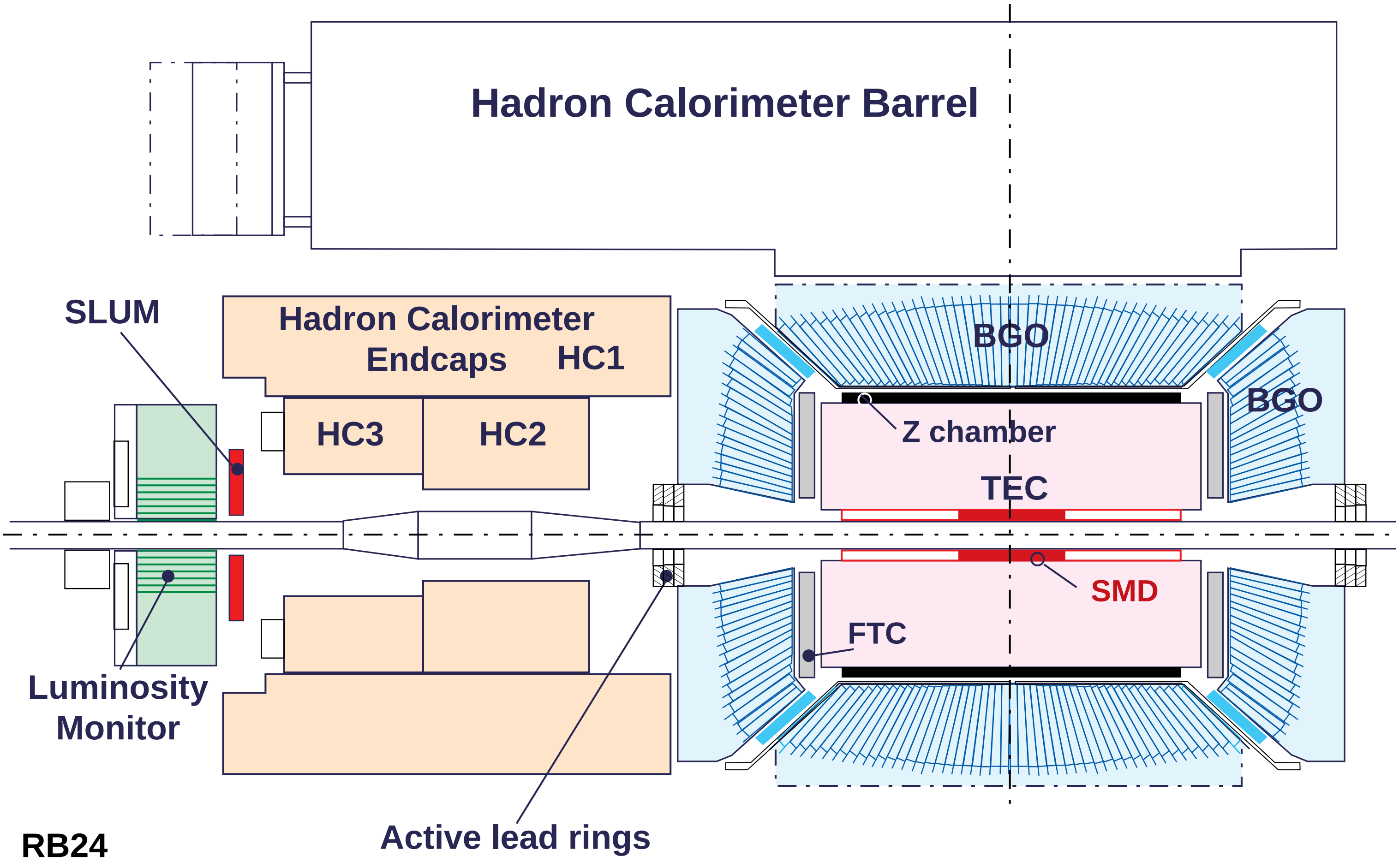
$$d\sigma(W_{\gamma\gamma}, 0, 0) = 2\pi(2J+1)\frac{m_R}{W_{\gamma\gamma}^2}\frac{\Gamma_{\gamma\gamma}}{(m_R{}^2 - W_{\gamma\gamma}^2)^2 + m_R{}^2\Gamma_R{}^2} \times \mathcal{T} \times d(\text{LIPS})$$

- **Resonance Parameters:**
  J Spin
  m_R Mass
  $\Gamma_{\gamma\gamma}$ Two-photon width
  Γ_R Total width
- $\mathcal{T}$ Angular Distribution Dependence
- d(LIPS) Lorentz Invariant Phase Space

The L3 Detector



The L3 Detector

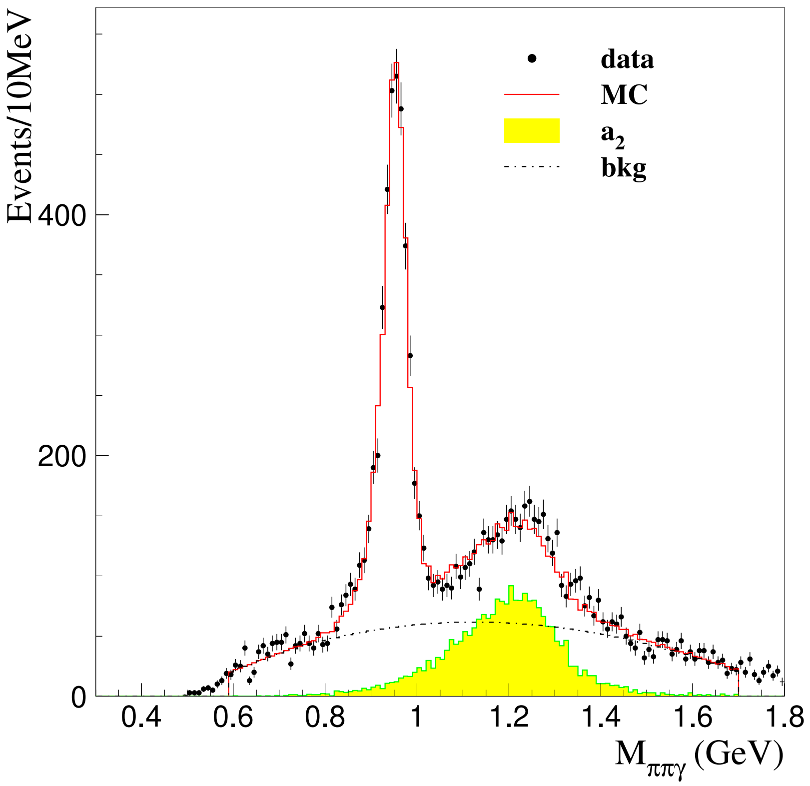


Devices mainly used for $\gamma\gamma \rightarrow$Resonance studies:

- Central tracking system:
  Silicon Microvertex Detector + Time Expansion Chamber
- Electromagnetic Calorimeter:
  BGO - High resolution (5% at 100 MeV, 1.4% above 2 GeV)
- Charged-track Trigger:
  Low p_T threshold 150 MeV.

Event selection :

- **Two "good" tracks and one isolated electromagnetic cluster.**
- $|\vec{p}_T(\pi^+\pi^-\gamma)|^2 < 0.01\ \mathrm{GeV}^2$
- $E(\gamma) > 140$ MeV
- $|\vec{p}_T(\pi^+\pi^-)|^2 > 0.001\ \mathrm{GeV}^2$
- $|\cos\theta_{\rho CMS}(\pi^+)| < 0.94$ (z axis $\parallel \vec{p}_\gamma$)

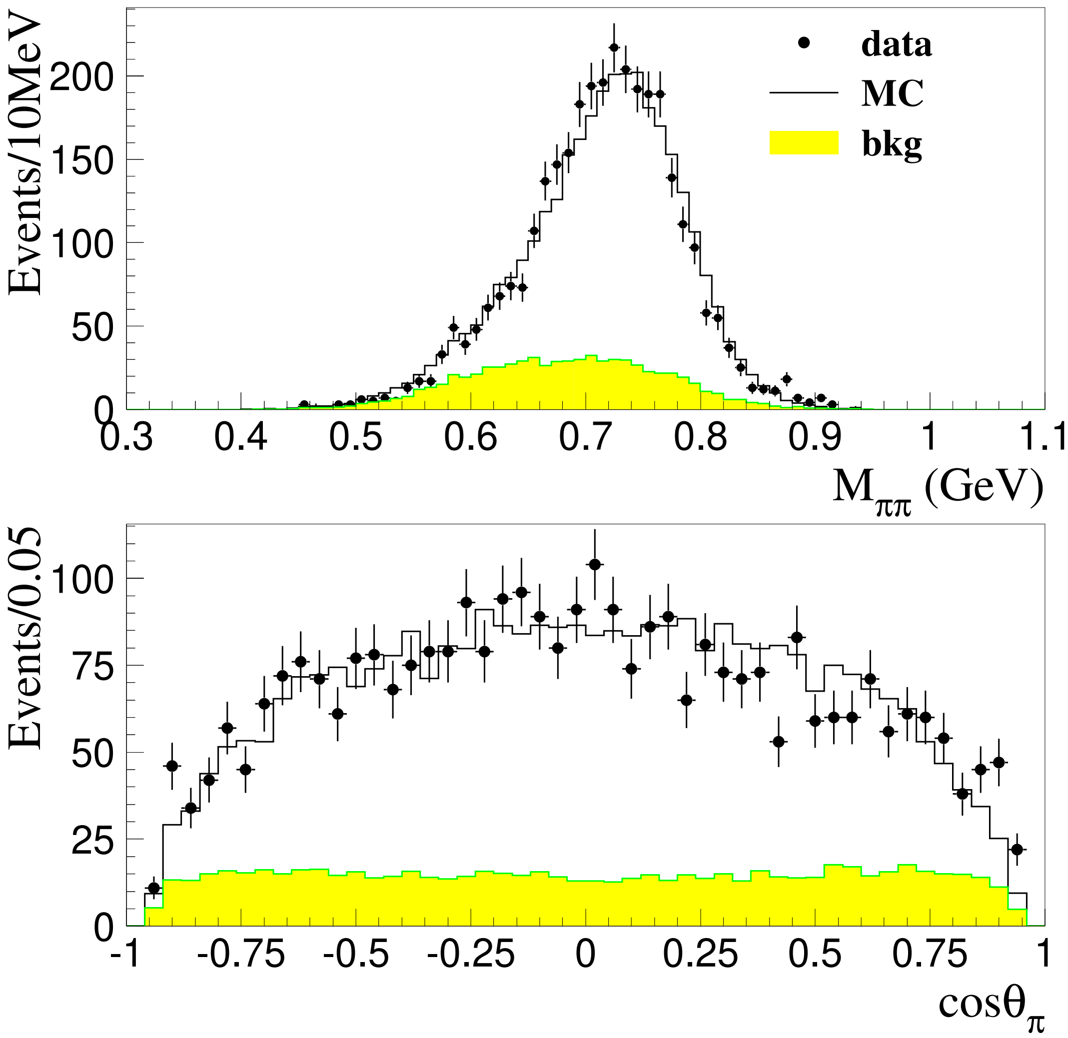


Fit to MC η', inclusive $a2$, background

$$\Gamma_{\gamma\gamma} = (4.17 \pm 0.10 \pm 0.21)\mathrm{keV}$$

$\eta' \to \pi^+\pi^-\gamma$ is dominated by $\eta' \to \rho\gamma$

- η' selection: $0.85 < m(\pi^+\pi^-\gamma) < 1.05$ GeV
- $m(\pi^+\pi^-)$ is consistent with MC of pure $\rho\gamma$
- $\cos\theta^*(\pi)$ distribution dominated by ρ (spin 1) $|\mathcal{M}|^2 \propto \sin^2\theta^*(\pi)$ in ρ CMS



Background by $\pi^+\pi^-\gamma$ phase space

η' Cross Section

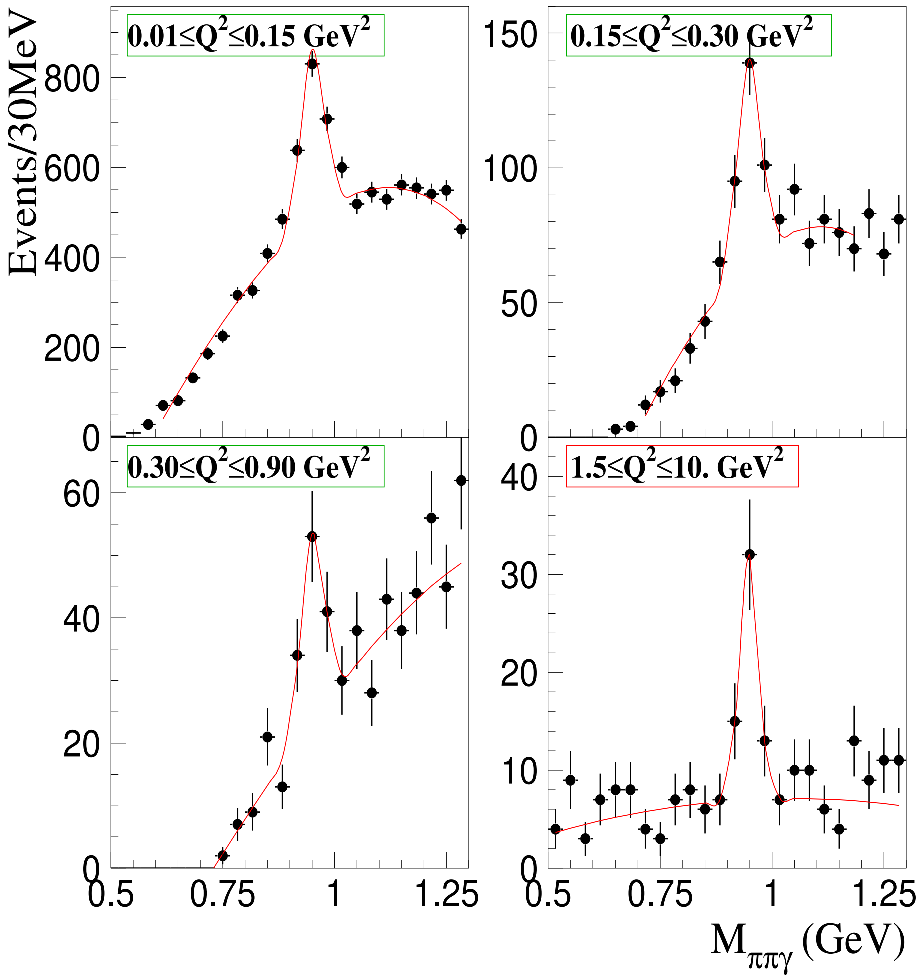
Cross section :

$$\sigma_{TT}(W_{\gamma\gamma}, Q^2, P^2) = \frac{\pi}{4}\sqrt{X} \cdot F^2(Q^2, P^2) \cdot \sigma(W_{\gamma\gamma}, 0, 0)$$

$$\frac{F^2(Q^2,P^2)}{F^2(0,0)} = \left(\frac{1}{1+Q^2/\Lambda^2}\right)^2 \cdot \left(\frac{1}{1+P^2/\Lambda^2}\right)^2$$

- **Untagged** : $0.01 < Q^2 < 0.9$ GeV^2
  $Q^2 \simeq |\vec{p}_T(\pi^+\pi^-\gamma)|^2$

- **Single Tagged** : $1.5 < Q^2 < 10$ GeV^2
  $Q^2 \simeq 2E_{beam}E_{tag}(1 - \cos\theta_{tag})$



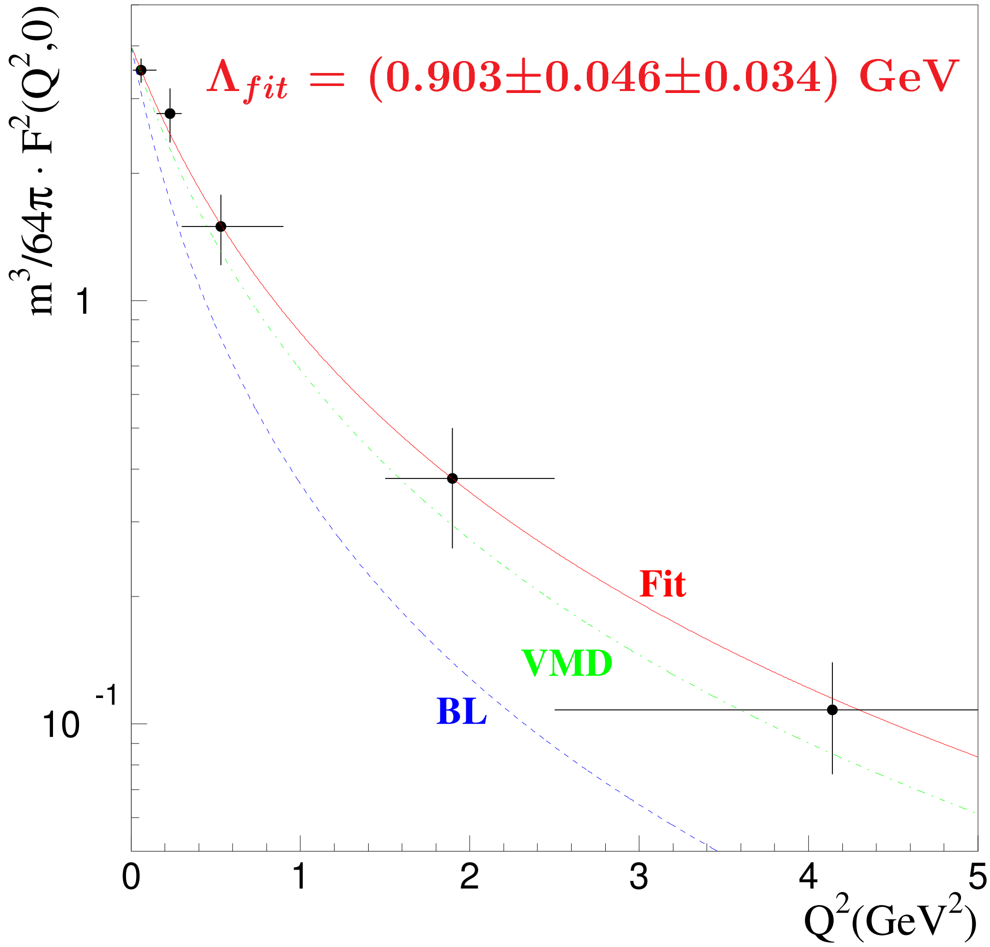
η' Form Factor

In each Q^2 interval :

$$F^2(\langle Q^2 \rangle) = \frac{\Delta\sigma_{data}(\langle Q^2 \rangle)}{\Delta\sigma_{MC}(\langle Q^2 \rangle, F^2(Q^2=0))}$$

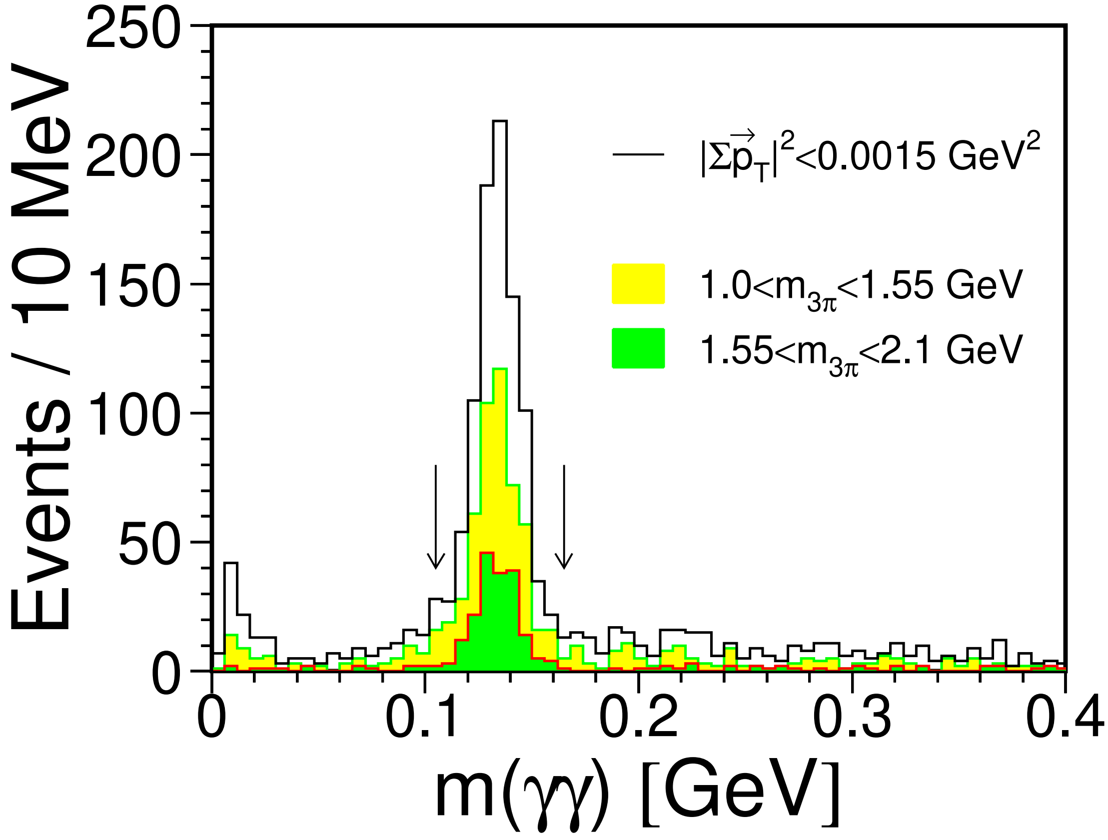
Fit to the distribution:

$$F^2(\langle Q^2 \rangle) = \left(\frac{1}{1 + \langle Q^2 \rangle / \Lambda^2} \right)^2$$

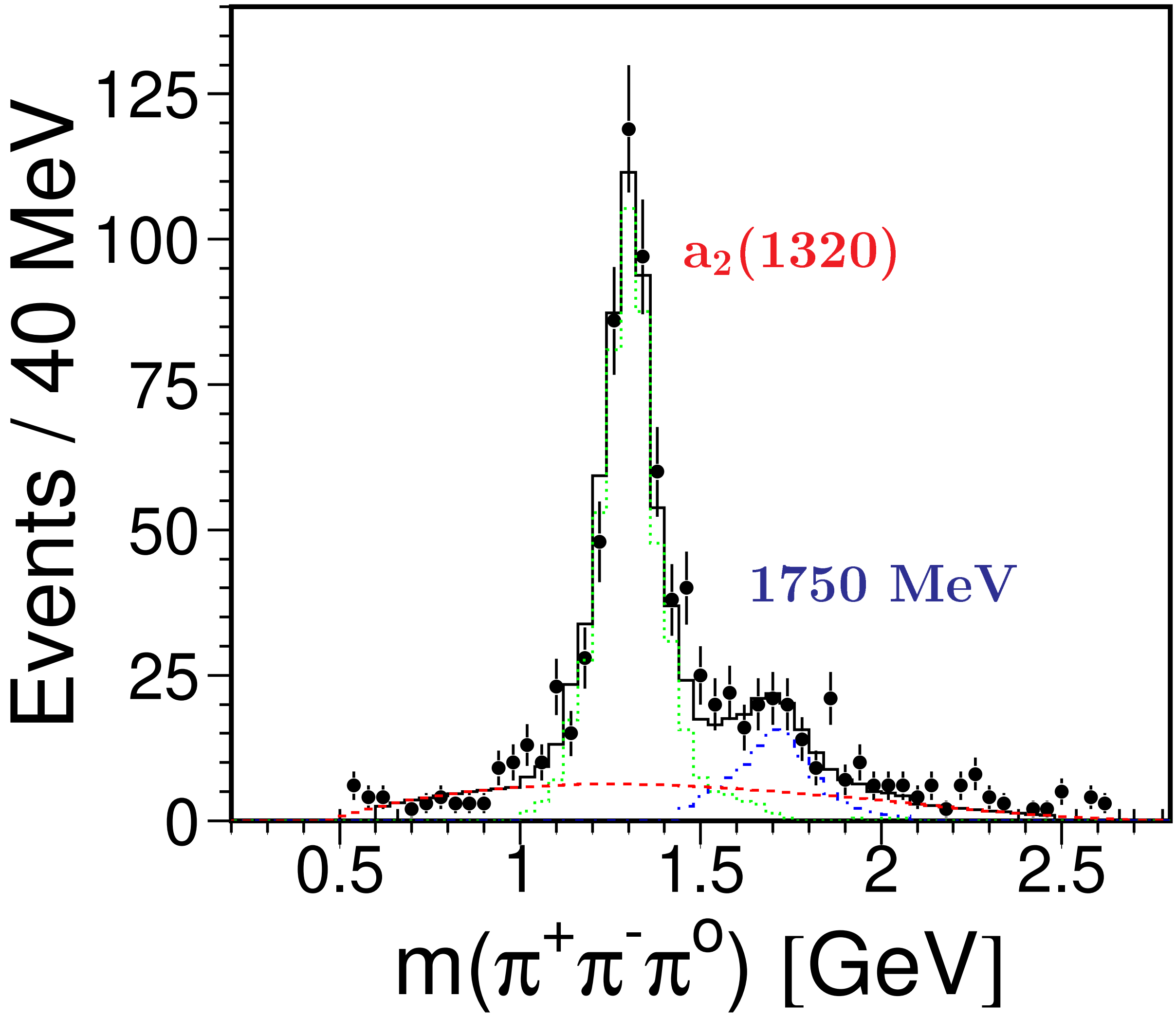


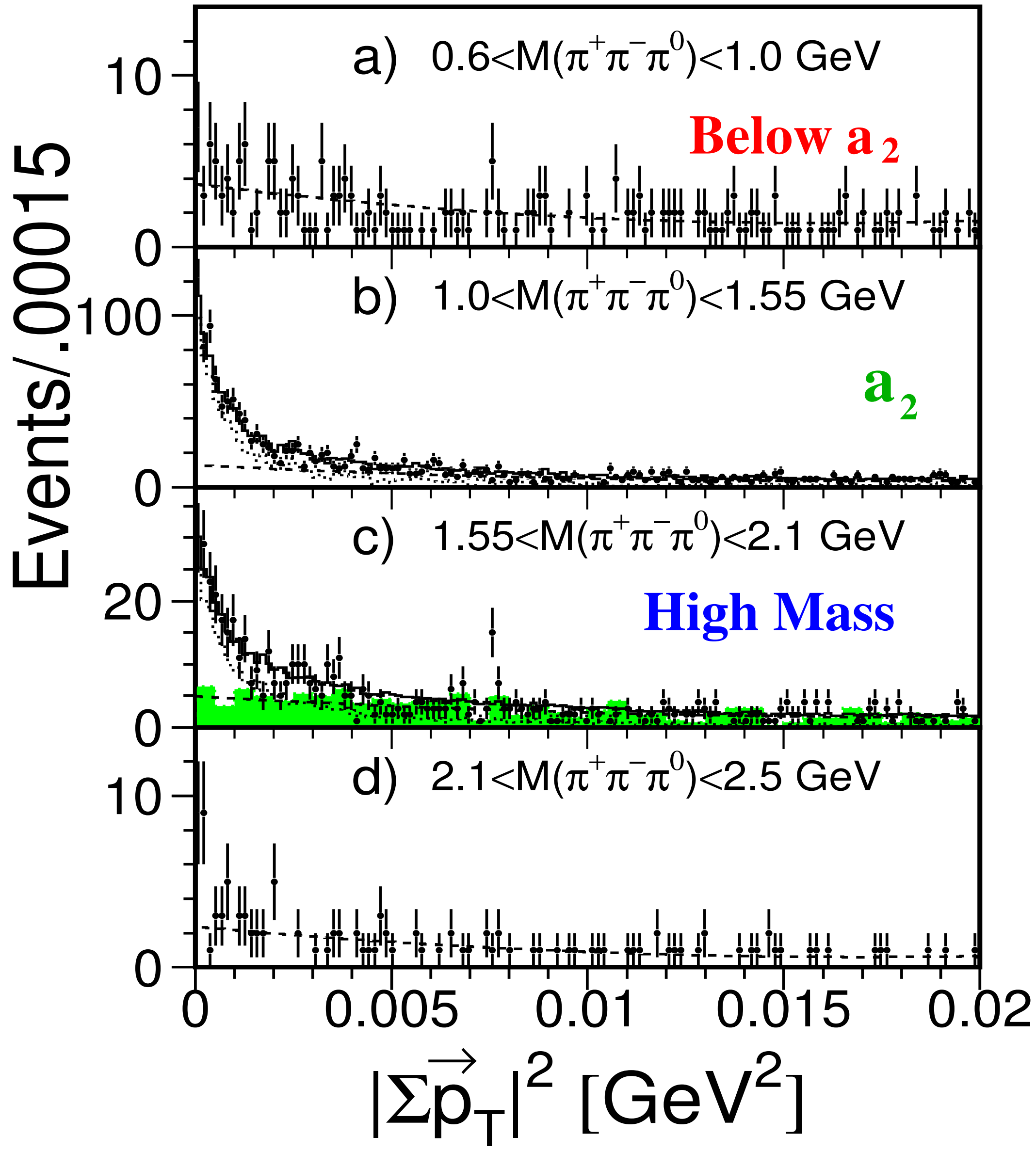
• VMD($\rho\omega$): Λ=0.83
Brodsky-Lepage: Λ=0.66
(Ll.Ametller et al.,Phys.Rev.D45(1992),986.)

- **Two "good" tracks and two isolated electromagnetic clusters.**
- π^0 **selection :**
  BGO $E_\gamma > 80$ **MeV,**
  105 $< m(\gamma\gamma) <$ **165 MeV**



- **Exclusive production :**
  $|\vec{p}_T(\pi^+\pi^-\pi^0)|^2 < 0.0015\ \mathrm{GeV}^2$





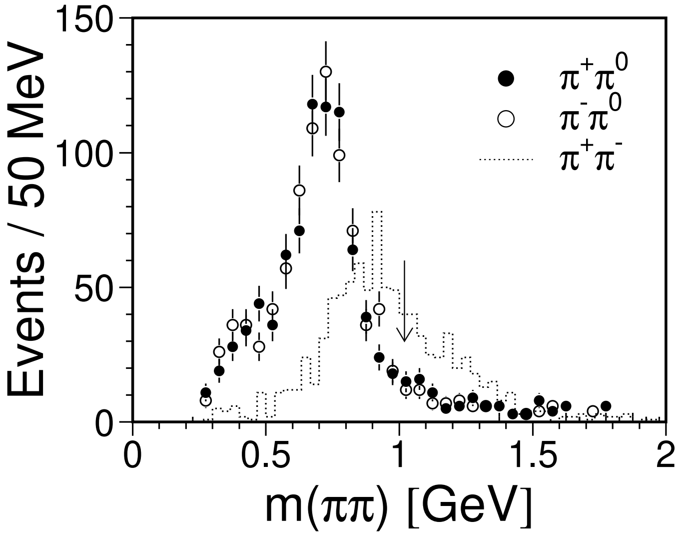
Background fractions :

mass [GeV]	0.60 — 1.00	1.00 — 1.55	1.55 — 2.10	2.10 — 2.50
Fraction [%]	—	19±0.5	25±3	—
Total ev.	42	618	184	38
Bkgd ev.	—	120	46	—

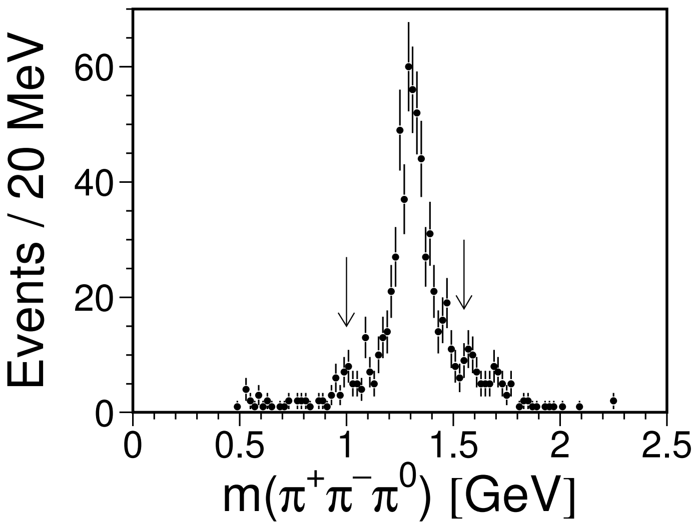
$a_2(1320) \to \rho^{\pm}\pi^{\mp}$

- **Selection :**
  - $|\sum \vec{p}_T|^2 < 0.0015$ **GeV^2**
  - **1.0** $< m(\pi^+\pi^-\pi^0) <$ **1.55 GeV**
  - $m(\pi^{\pm}\pi^0) < m_\rho +$ **250 MeV**

- ρ **effective mass :**

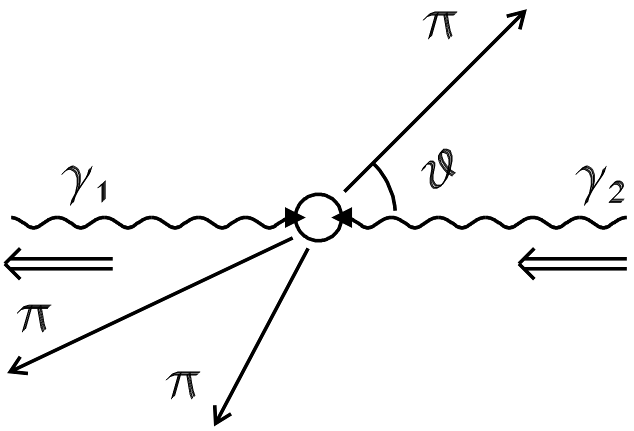


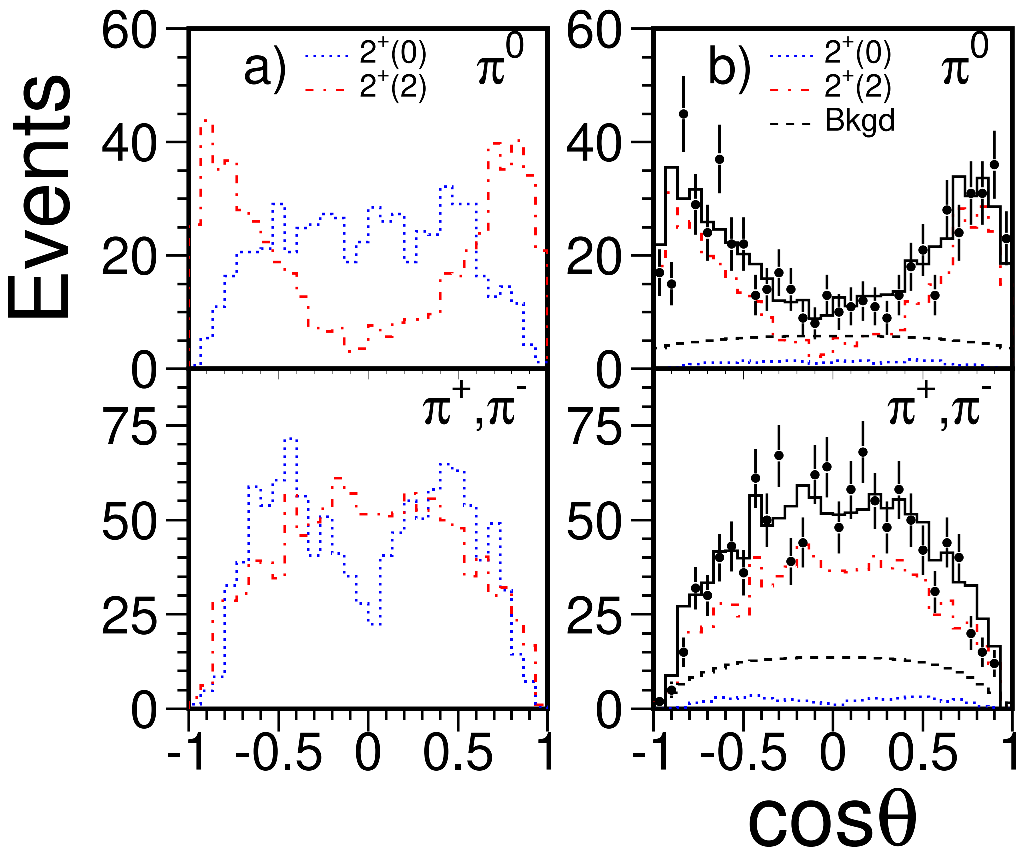
- $a_2(1320)$ **effective mass :**



$a_2(1320)$ Helicity

- $J^P = 2^+$: helicity λ can be 0 or 2.



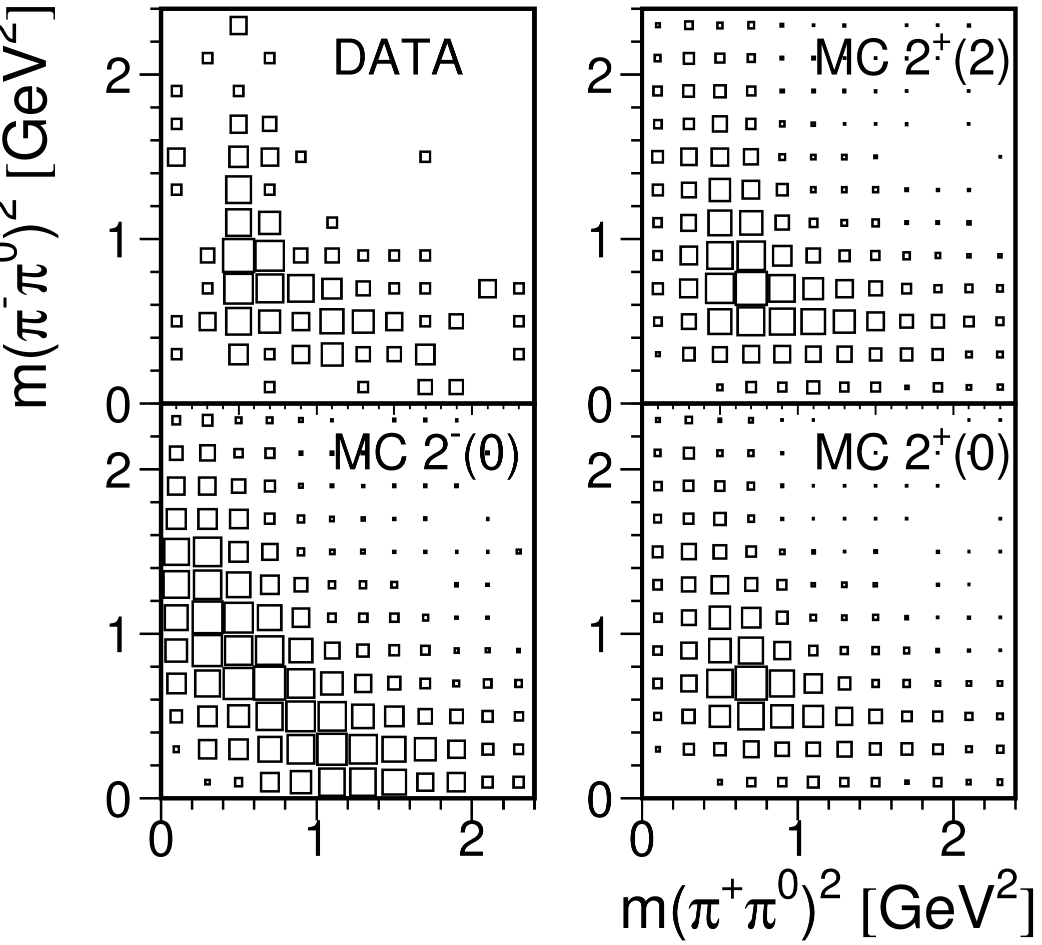


- $\lambda = 2$ fraction : $0.92 \pm 0.05 \pm 0.05$

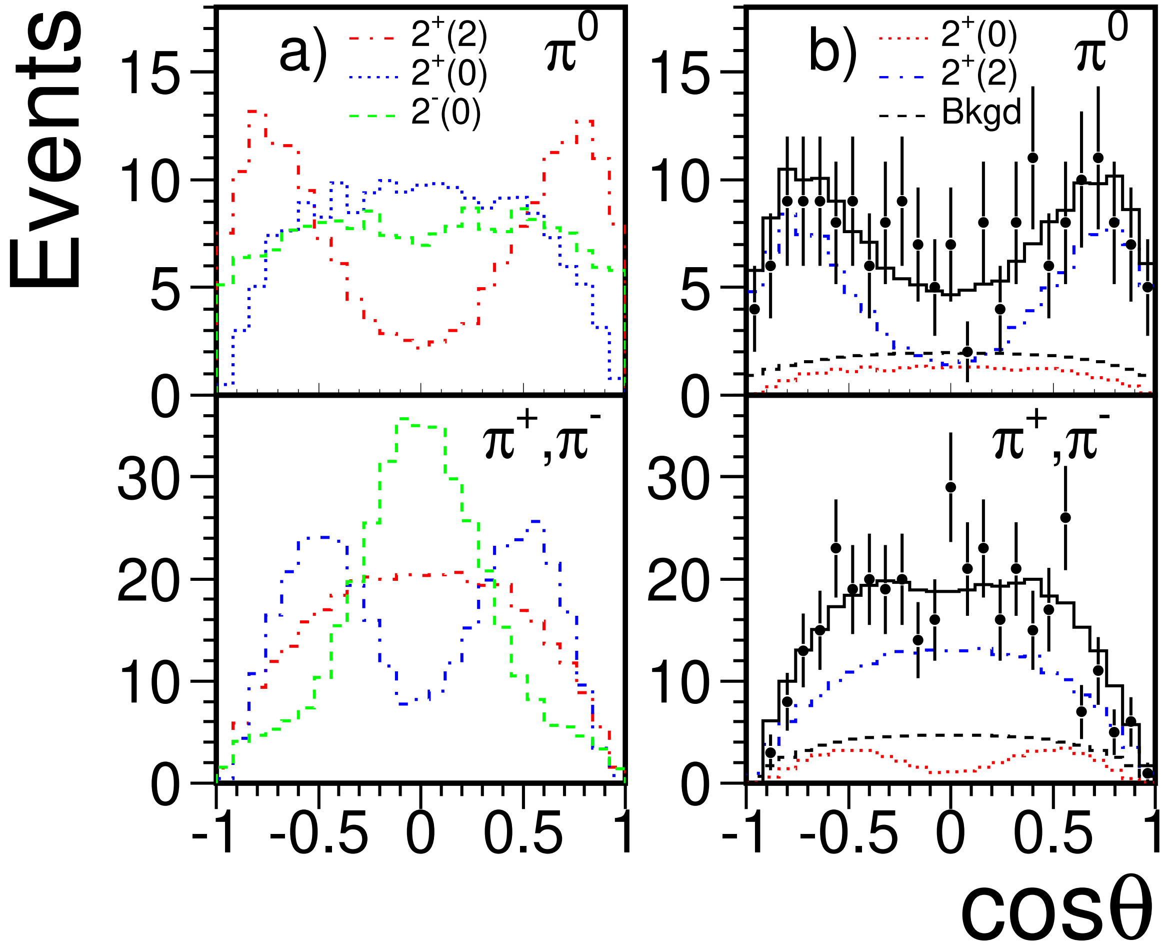
The $\pi^+\pi^-\pi^0$ High-mass Region

- $|\sum \vec{p}_T|^2 < 0.0015$ GeV^2
- $1.55 < m(\pi^+\pi^-\pi^0) < 2.1$ GeV

- **Spin-Parity Analysis :**
  - $R \to \rho\pi, f_2\pi$
  - $J^P(\lambda) = 2^-(0), 2^+(0), 2^+(2)$



High-mass Sample Helicity

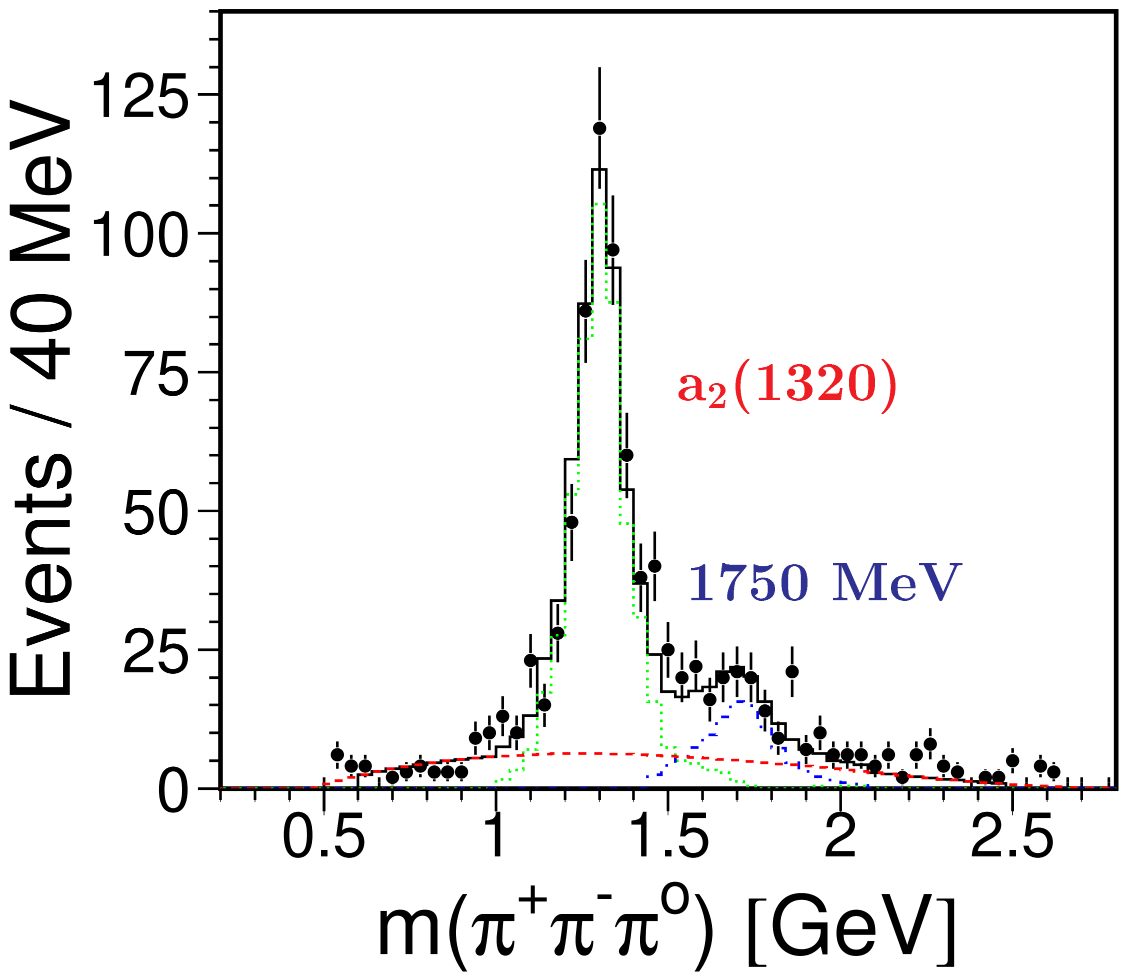


- $\mathbf{J^P(\lambda)=2^-(0)}$ **fraction : 12±11 % !**

  $\mathbf{\Gamma_{\gamma\gamma}(\pi_2)BR(\pi^+\pi^-\pi^0) < 0.072}$ **keV (90% CL)**

- $\mathbf{J^P(\lambda)=2^+(2)}$ **fraction : 74±13 % (Dominant!)**

Resonance Parameters



	$a_2(1320)$	High mass region
$\Gamma_{\gamma\gamma}$ (keV)	$0.98 \pm 0.05 \pm 0.09$	–
$\Gamma_{\gamma\gamma} \cdot BR$ (keV)	–	$0.29 \pm 0.04 \pm 0.02$
m (MeV)	$1323 \pm 4 \pm 3$	$1752 \pm 21 \pm 11$
Γ (MeV)	$105 \pm 10 \pm 11$	$150 \pm 110 \pm 34$

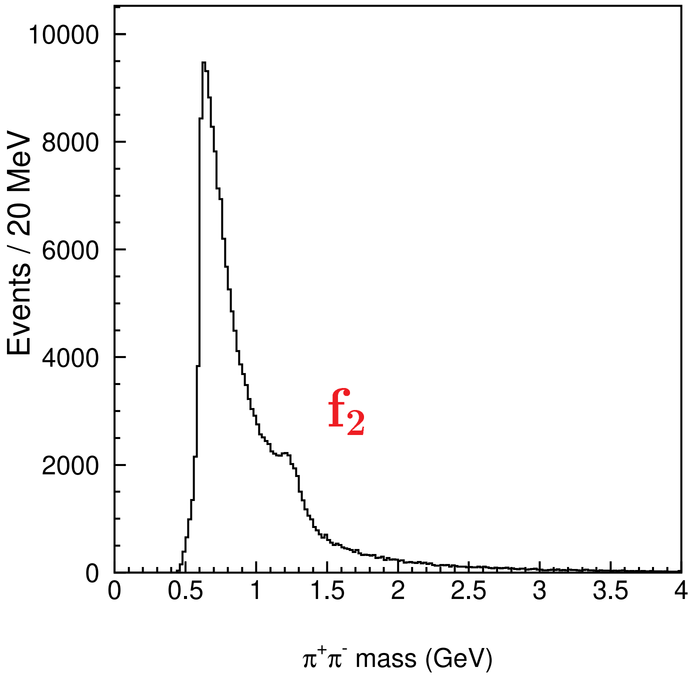
OGE-SRM : (C. R. Münz, Nucl.Phys.A609:364-376,1996)

	Mass (MeV)	$\Gamma_{\gamma\gamma}$
$a_2(1320)$	1280	0.900
a_2'	1740	0.376
a_2''	1820	0.353

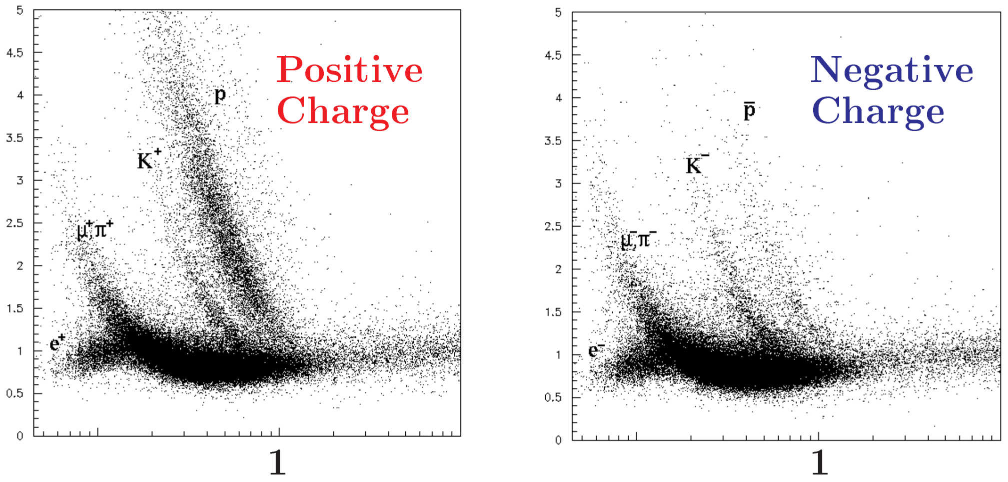
$\gamma\gamma \to \pi^+\pi^-, K^+K^-$

Event Selection :

- Two "good" tracks of opposite charge
- $|\Sigma\vec{p}_T|^2 < 0.06\ \mathrm{GeV}^2$



- Spectrum dominated by $\gamma\gamma \to e^+e^-, \mu^+\mu^-$
- Search for $\gamma\gamma \to \pi^+\pi^-, K^+K^-$ and $p\bar{p}$

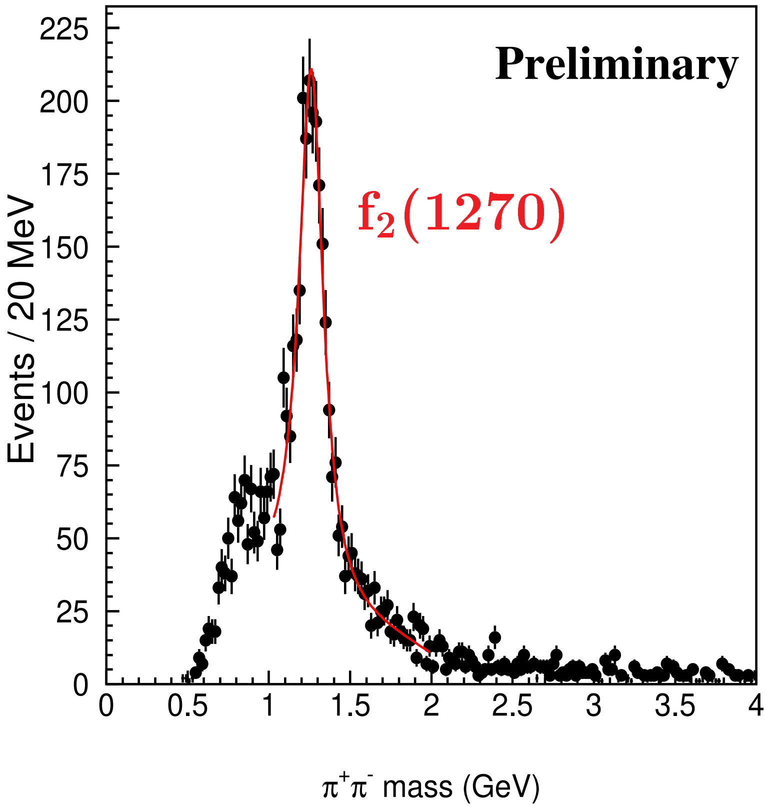


dE/dx vs P (GeV)

Particle ID by Artificial Neural Network:

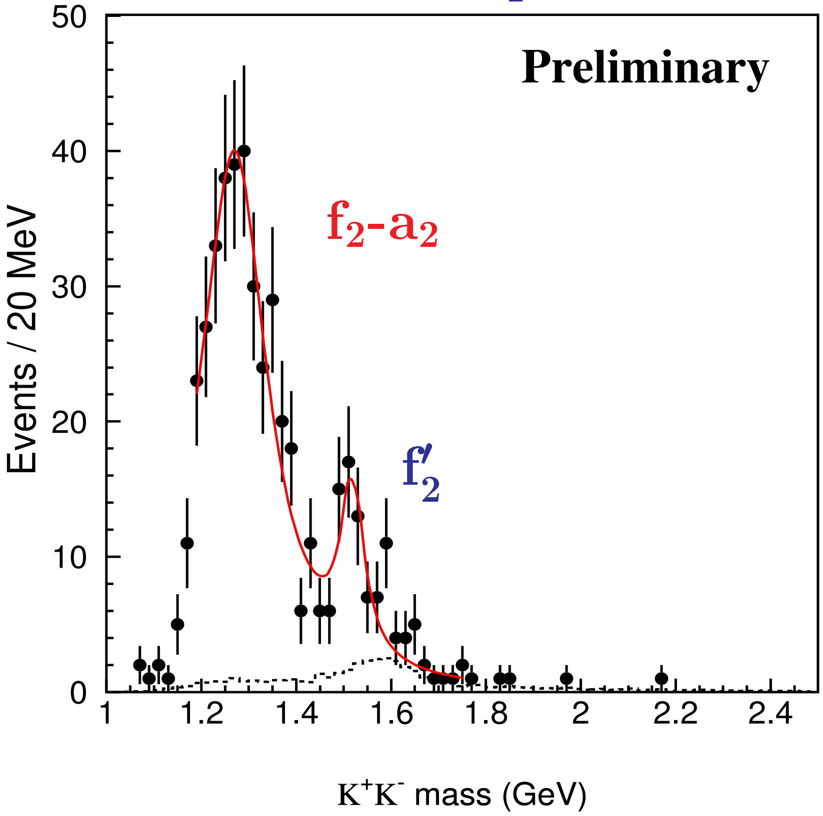
- Track momentum
- Ionization loss (dE/dx)
- Electromagnetic calorimeter (3 quantities)
- Hadron calorimeter (1 quantity)

$\pi^+\pi^-$ mass spectrum



	Mass (MeV)	Width (MeV)
$f_2(1270)$	1260 ± 7	184 ± 12

K^+K^- mass spectrum



Constructive f_2-a_2 interference

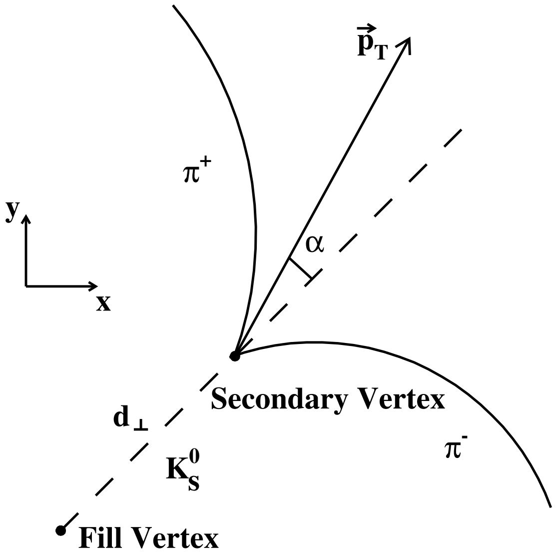
(H.J.Lipkin,Nucl.Phys.B7(1968)321)

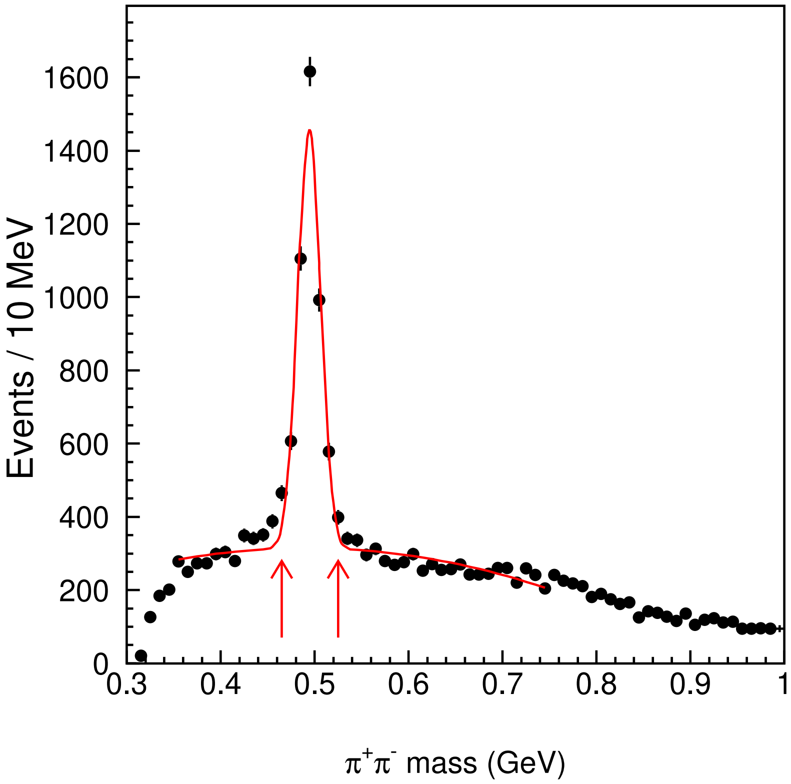
	Mass (MeV)	Width (MeV)
$f_2(1270)$-$a_2(1320)$	1271 ± 8	158 ± 23
$f'_2(1525)$	1522 ± 9	79 ± 32

$\gamma\gamma \rightarrow K_s^0 K_s^0$

- **Only the $K_s^0 \rightarrow \pi^+\pi^-$ decay is considered.**
- **Search for secondary vertices in four “good” track events with charge balance.**

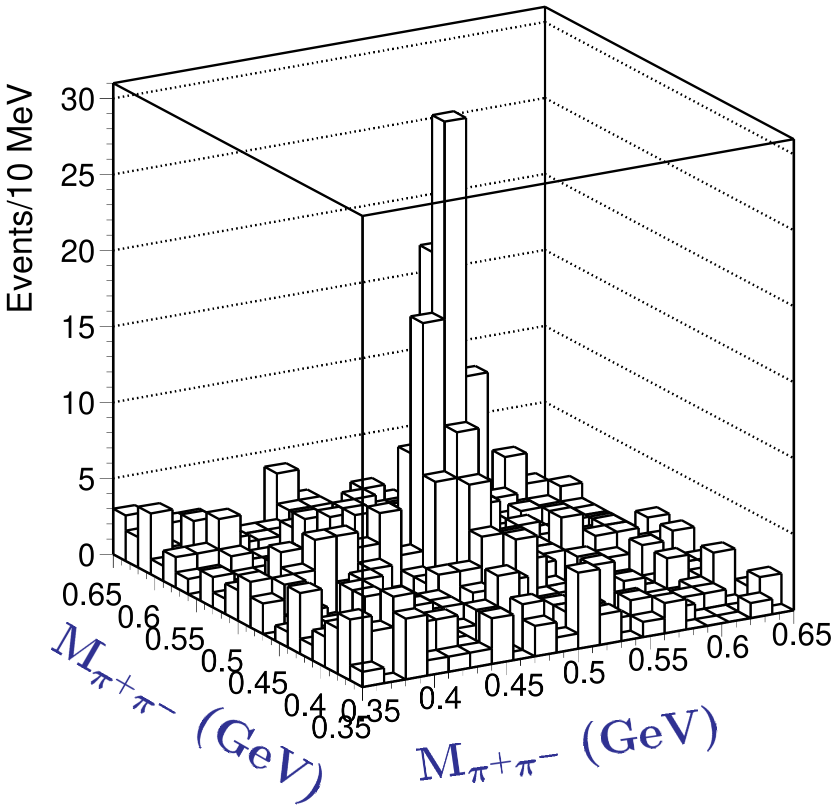
- **$|\alpha| < 0.3$ rad**
- **$d_\perp > 3$ mm**





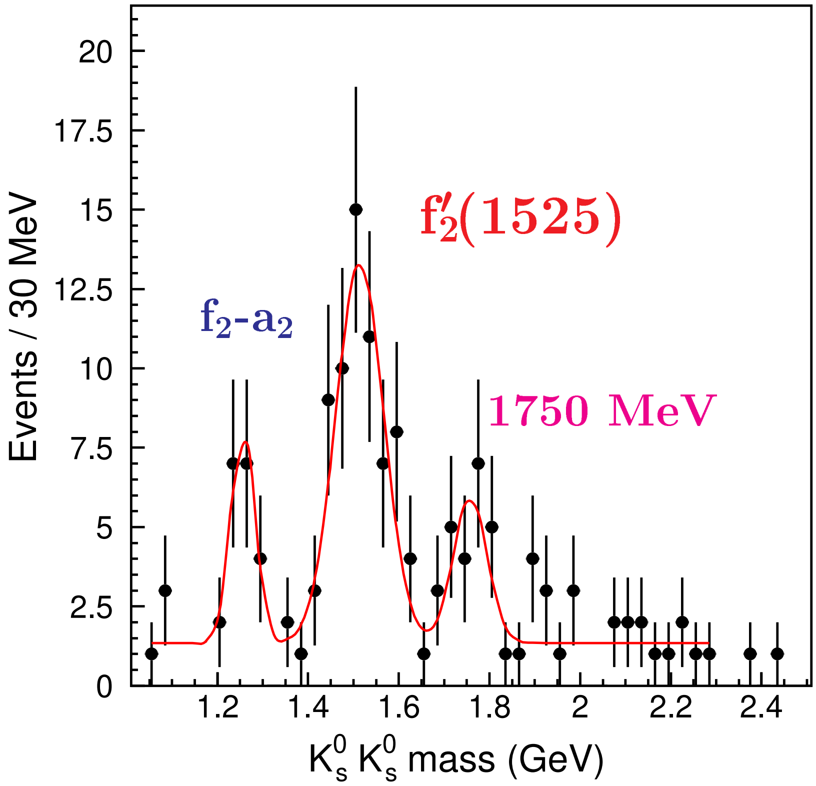
The $K_s^0 K_s^0$ Final State

- $|\Sigma\vec{p}_T|^2 < 0.1\ \mathrm{GeV}^2$
- **Events with photons are rejected.**



- $M_{\pi^+\pi^-}$ **within** ± 30 **MeV of** K_s^0 **mass.**
- $\mathcal{L} = 160\ \mathrm{pb}^{-1}$ **(LEP1 and LEP2)**
- **148 events are selected.**

The $K_s^0 K_s^0$ Mass Spectrum



Maximum Likelihood fit:

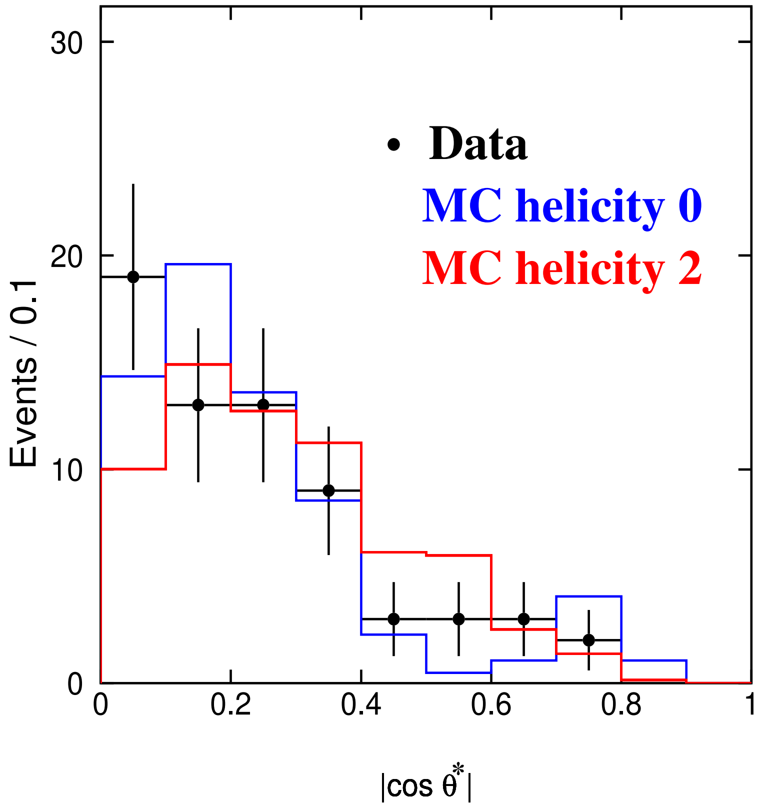
	Mass (MeV)	Width (MeV)	Events
$f_2'(1525)$	1515±10	112±19	57.4±9.2
1750 MeV Region	1760±14	119±26	17.4±5.6

- **f_2-a_2 destructive interference**
- **Enhancement around 1750 MeV (3 σ effect)**
- **OGE-SRM : (C.R.Münz, Nucl.Phys.A609:364,1996)**
  f_2'', M=1740 Mev, $\Gamma_{\gamma\gamma}$= 1.040 KeV
  f_2''', M=1820 Mev, $\Gamma_{\gamma\gamma}$= 0.982 KeV

Full LEP1 statistics: $\mathcal{L}$=140 pb^{-1}

	Helicity 0	Helicity 2
Total Efficiency (%)	1.94	4.13
$\Gamma_{\gamma\gamma}(f_2') \times Br(f_2' \to K\bar{K})$ (keV)	0.19±0.04±0.05	0.09±0.02±0.02

Angular distribution
in the two-photon cms for the f_2'



ndf=8	Helicity 0	Helicity 2
χ^2	29.9	12.3

Helicity 2 is favoured.

Summary

Resonance	Decay Channel	$\mathcal{L}$ pb^{-1}	Mass (MeV)	$\Gamma_{\gamma\gamma}$ (keV)
$\eta'(958)$	$\pi^+\pi^-\gamma$	129	952±1	4.17±0.10±0.21
$a_2(1320)$	$\pi^+\pi^-\pi^0$	140	1323±4	0.98±0.05±0.09
$f'_2(1525)$	$K\bar{K}$	140	1515±10	(0.09±0.02±0.02)/BR
$f_2(1270)$	$\pi^+\pi^-$	50	1260±7	
a'_2	$\pi^+\pi^-\pi^0$	140	1752±21	(0.029±0.04±0.02)/BR

Conclusions

- η'
  Very high precision measurement of the

  $$\Gamma_{\gamma\gamma} = (4.17 \pm 0.10 \pm 0.21)\mathrm{keV}$$

  and study of its form factor.

- $\pi^+\pi^-\pi^0$ final state
  Exclusive production at 1750 MeV.
  Spin parity: J^P=2^- excluded,
  J^{PC}=2^{++} dominates.
  Radial recurrence of the a_2.

- f_2-a_2 interference in $K\bar{K}$.

- Enhancement of the $K^0_sK^0_s$ final state at 1750 MeV. Possible signal from a radial recurrence of the f'_2.

- L3, with $\mathcal{L}$=500 pb^{-1} form LEP2, will allow tests of QCD and searches for new states.