UNKOWN FOR EVER ?

OVVERO

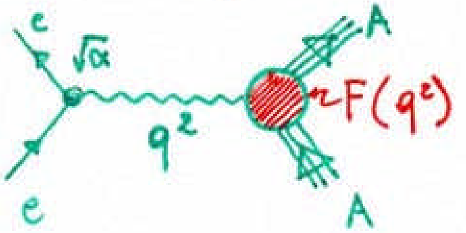
COSA NON SAPREMO SENZA

$1.2 \lesssim W_{e^+e^-} \lesssim 2 \div 3$ GeV

- FATTORI DI FORMA NUCLEONE (n)
- STATI ECCITATI SECONDO QCD

FATTORI DI FORMA E.M.

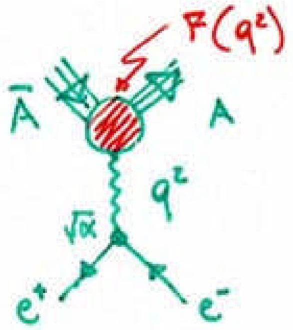
- **Scattering elastico**: $\sigma(eA \to eA) = \sigma_{punt} \cdot |F(q^2)|^2$



$$q^2 = (E_e^f - E_e^i)^2 - |\vec{P}_e^f - \vec{P}_e^i|^2 < 0$$

(space - like)

- **Annichilazione e^+e^-**: $\sigma(e^+e^- \to A\bar{A}) = \sigma_{punt} \cdot |F(q^2)|^2$



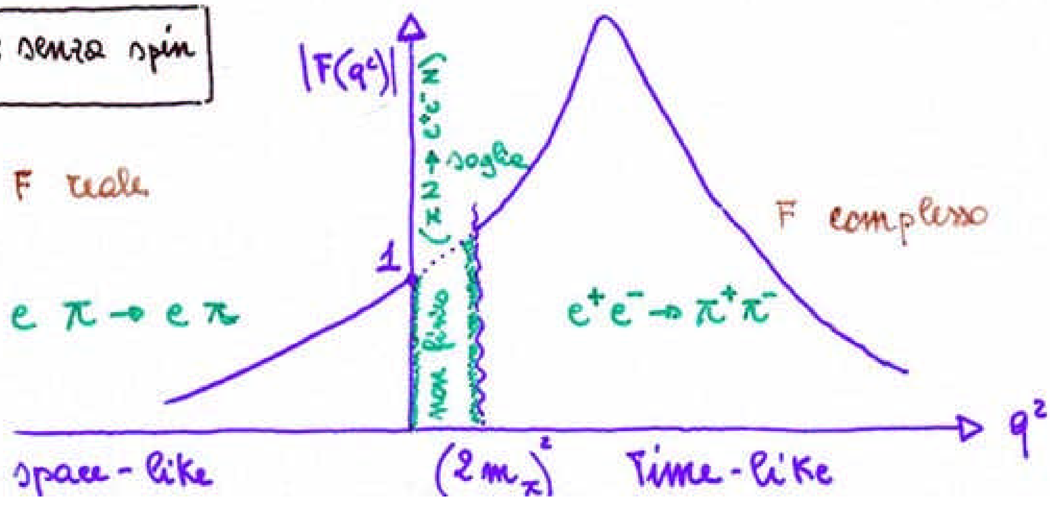
$$q^2 = W^2 > 0$$

(Time - like)

- **Analiticità (continuità)**: la stessa funzione $F(q^2)$

π : senza spin

F reale



$$\begin{cases} q^2 = 0 & : F(0) = 1 \quad \text{(Def. di puntiforme)} \\ |q^2| \to \infty & : F(+\infty) = F(-\infty) \to 0 \quad (\text{" struttura}) \end{cases}$$

- Spin del N $\Rightarrow$ 2 FF
- Sc. elastico :

$$\begin{cases} \text{Interaz. elettrica : non cambia direz. } \vec{S} & : G_E(q^2) \\ \quad \text{" magnetica : ribalta} \quad \text{"} & : G_M(q^2) \end{cases}$$

$$\begin{cases} G_E^p(q^2) \sim 1/\left(1+\frac{q^2}{m_e^2}\right)^2 \\ G_E^n(q^2) \sim 0 \end{cases} \qquad \begin{cases} G_M^p \sim \mu_p G_E^p \\ G_M^n \sim \mu_n G_E^p \end{cases}$$

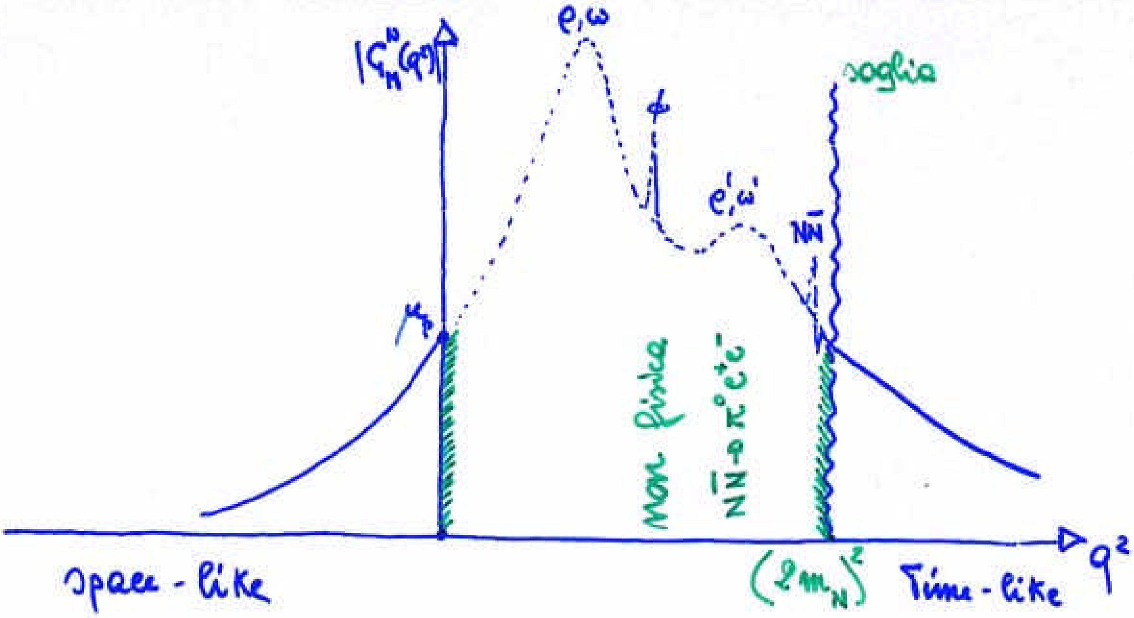
- Annichilazione e^+e^- :

$\bar{N}$ uscente spin up $\leftrightarrow$ N entrante spin down $\Rightarrow$ corrisp. G

$$\frac{d\sigma}{d\Omega}(e^+e^- \to N\bar{N}) = \frac{\alpha^2 \beta_N C}{4\,Q^2}\left\{|G_M(Q^2)|^2(1+\cos^2\theta_N^*) + \frac{4m_N^2}{Q^2}\cdot|G_E(Q^2)|^2 \sin^2\theta_N^*\right\}$$

$$C \simeq \frac{\pi\alpha}{\beta_N}\Big/\left(1 - e^{-\pi\alpha/\beta}\right) \qquad \text{corr. coulomb. (?)}$$

Misura pol. N / fasci pol. $\Rightarrow$ Fase relativa G_E/G_M



~ 1.88 GeV

- A soglia $(W = 2m_N)$:

$$\sigma(4m_N^2) \simeq \pi^2 \alpha^3 |G_E(4m_N^2)|^2 \sim 0.1 \text{ nb} \quad (?)$$

Solo onda S: $G_E(4m_N^2) = G_M(4m_N^2)$ (isotropia)

PREDIZIONI PER I F.F. TIME-LIKE

Q.C.D.

- Adroni : quarks ($s = \frac{1}{2}$, $q \begin{cases} q_u = 2/3 \\ q_d = q_s = -1/3 \end{cases}$) + gluoni ($g$)

3 cariche di colore
confinamento "
libertà asintotica

$$V_{q\bar{q}}(r) \sim \frac{\alpha_s(q^2)}{r} + k\,r$$

- Prediz. quantitative solo per $Q^2 \to \infty$ (QCD perturbativa)
  " semiquant. statiche (non relat., $m_q \sim 300$ MeV)
  Lattice Th. x futuro

- Mesoni : $q\bar{q}$ ($+ \Sigma q\bar{q}$) : analogia con Q.E.D.
  Barioni : qqq : pura QCD

- $p \equiv u\,u\,d$
  $n \equiv d\,d\,u$

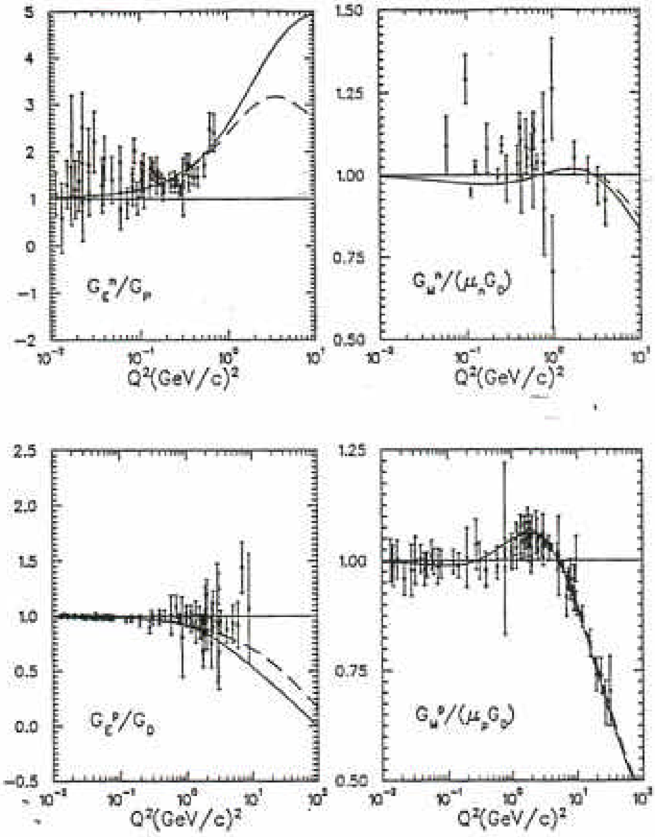
$$\sigma(e^+e^- \to n\bar{n}) \sim \left(\frac{q_d}{q_u}\right)^2 \sigma(e^+e^- \to p\bar{p})$$

- e polarizzati su p (n) polarizzati $\Rightarrow$ misura diretta spin costituenti in DIS
  Crisi spin del Nucleone : $s \sim 0$

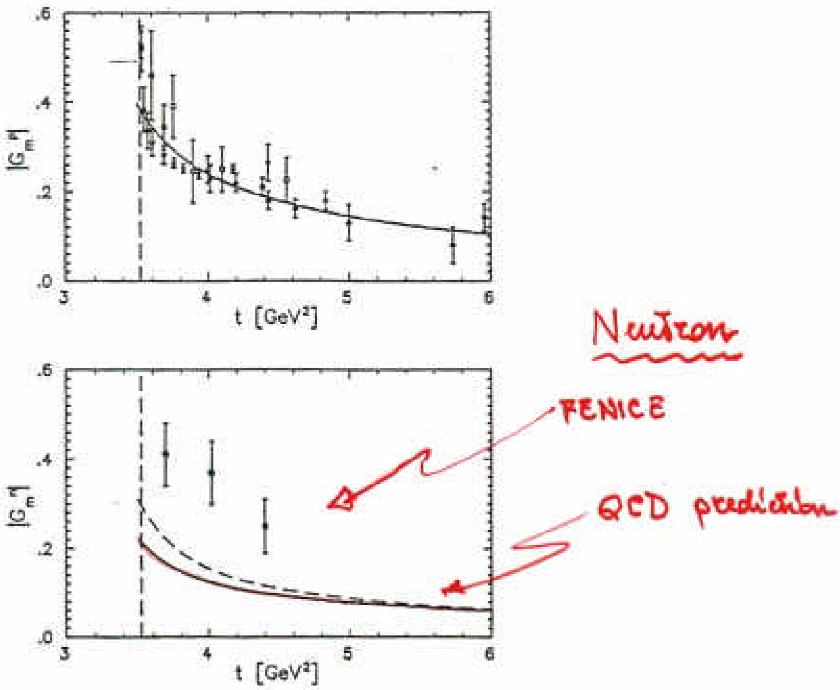
Dispersion-theoretical analysis of the nucleon electromagnetic form factors: Inclusion of time-like data[#1]

H.-W. Hammer[‡#2], Ulf-G. Meißner[‡#3#4], D. Drechsel[‡#5]

(1996)



The space-like nucleon em form factors. Dashed lines: Fit 1, space-like data only. Solid lines: Fit 2, including also the time-like data.



The time-like nucleon em form factors. Solid lines: Fit 2. Dashed lines: including in addition the $\phi(1680)$.

TEORIA DI SKYRME

- No quarks
- π puntiforme, ma interagisce con se stesso
- Stato stabile di molti π (solitone) con $J = \frac{1}{2}$
  (Rotaz. 2π $\psi \to -\psi$)
  ($\sum l$ pari $+ \sum l$ dispari $= \frac{1}{2}$)
- Num. quantico Topologico = Num. barionico
- Con 1 solo parametro libero (f_π: dec. debole del π):

Nucleone	Exp	Skyrme
M_N	939 MeV	~ 1 GeV
M_Δ	1232	~ 1.5
$\sqrt{r^2}$	0.79 fm	0.6 fm
μ_p	2.79	1.9
μ_n	−1.91	−1.3
μ_Δ	3.3	2.3
g_A	1.23	0.6

- $N_{colori} \to \infty$: QCD → "Skyrme"
- $\sigma(e^+e^- \to n\bar{n}) \gtrsim \sigma(e^+e^- \to p\bar{p})$

Studio dei fattori di forma e risultati di **Fenice**

Esperimento Fenice:

- Dati presi tra il **1990** ed il **1993**
- Adone singolo bunch: $\langle L \rangle =$ **5×10^{28} cm^{-2} s^{-1}** ; $L_{picco} =$ **10^{29} cm^{-2} s^{-1}**
- In totale integrata $L_{int} =$ **480 nb^{-1}**

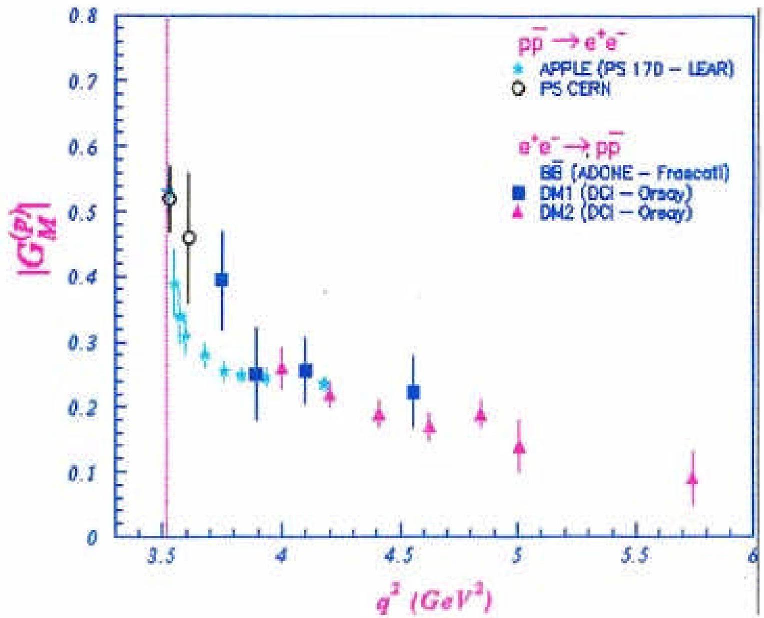
- Dati presi alle energie ($\sqrt{s}$ in GeV):

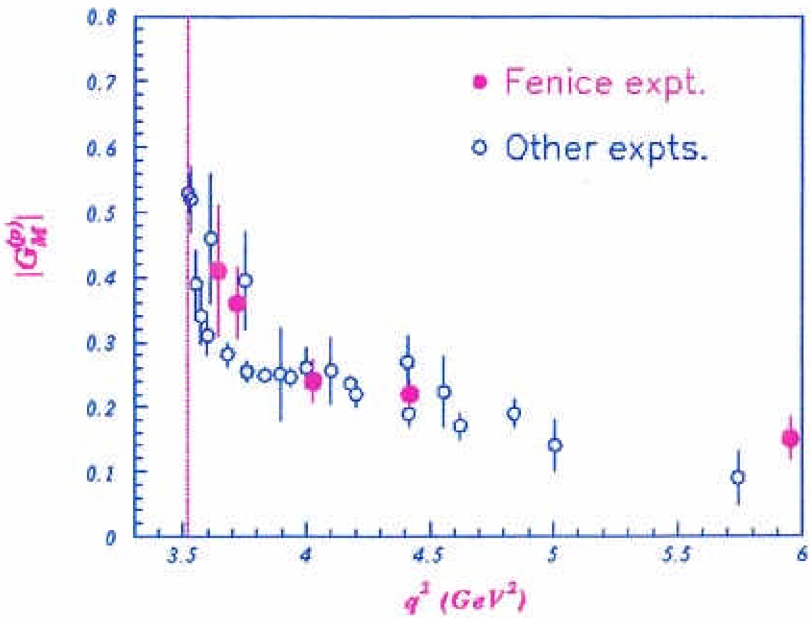
→ **1.82 – 1.84 – 1.86 – 1.88**	studio fondo sottosoglia + multiadronica	**35 nb^{-1}**
→ **1.90 – 1.92 – 2.0 – 2.1 – 2.44**	studio fattori di forma time-like + multiadronica	**365 nb^{-1}**
→ **3.1**	decadimenti J/psi	**80 nb^{-1}**

- Apparato: scintillatori + tubi a streamer + RPC (veto cosmico):
  Nucl.Instr. And Meth. A337 (1993) 34;
  → No campo magnetico
  → Copertura angolare **76% di 4π**
  → Rivelazione di stati finali neutrone - antineutrone
    → Efficienza per annichilazione di antineutroni: tra il **20%** ed il **27%**
    → Efficienza per neutroni: tra il **10%** ed il **20%**
    → ➔ Esperimento di "singola" con problemi di fondo (cosmici / fondi macchina)

Fattore di Forma del Protone

$\sqrt{s}$(GeV)	L(nb^{-1})	$N_{cand} - N_{bckg}$	ε	σ(nb)
1.90	34.2±2.0	7±3	0.21±0.07	0.97±0.53
1.92	79.6±4.8	16.0±4.5	0.21±0.02	0.96±0.27
2.00	93.9±5.6	18.0±4.7	0.31±0.03	0.62±0.17
2.10	99.9±6.0	28.0±5.3	0.45±0.03	0.62±0.12
2.44	57.1±3.4	7.0±2.6	0.44±0.03	0.28±0.12





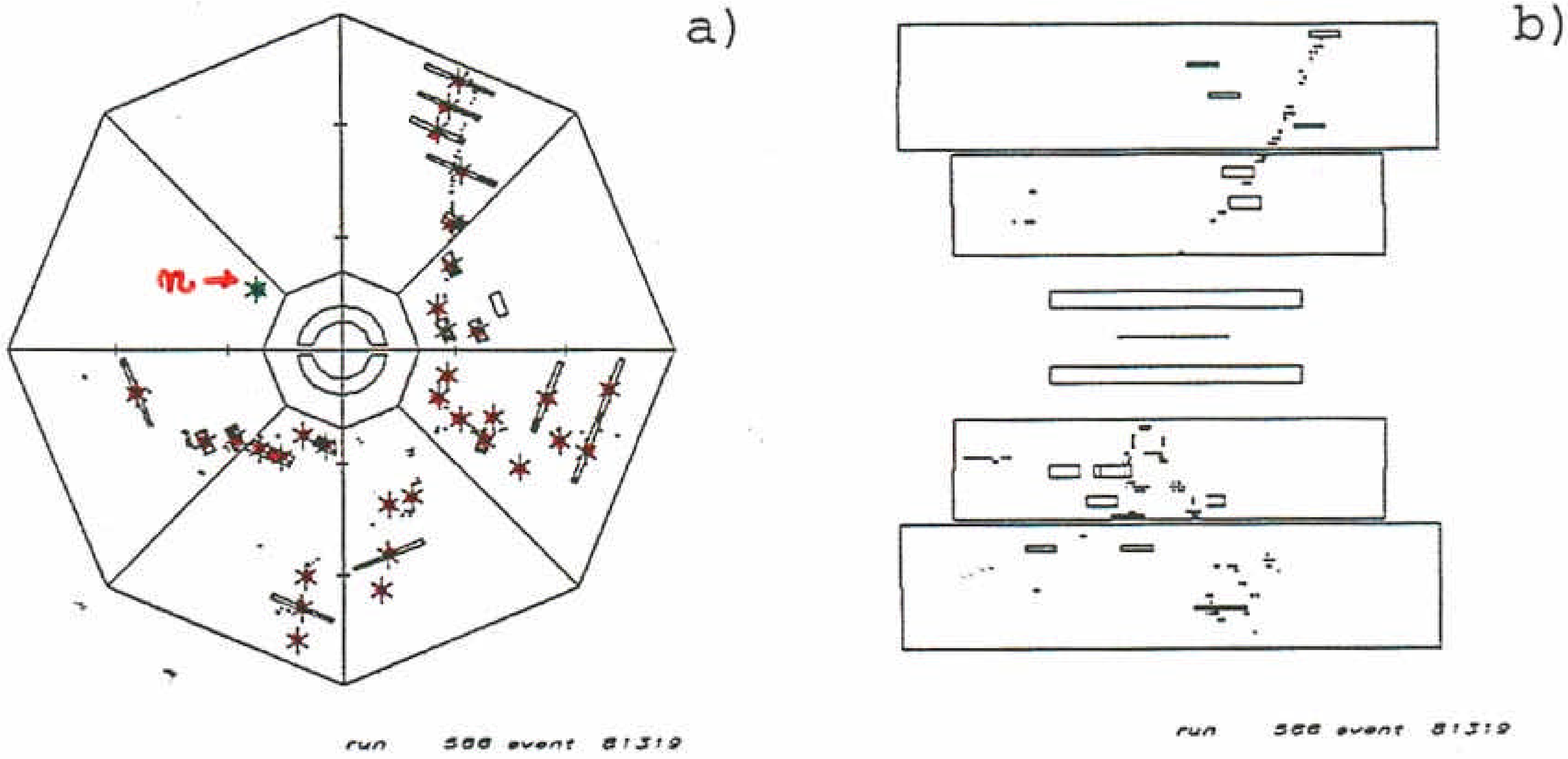
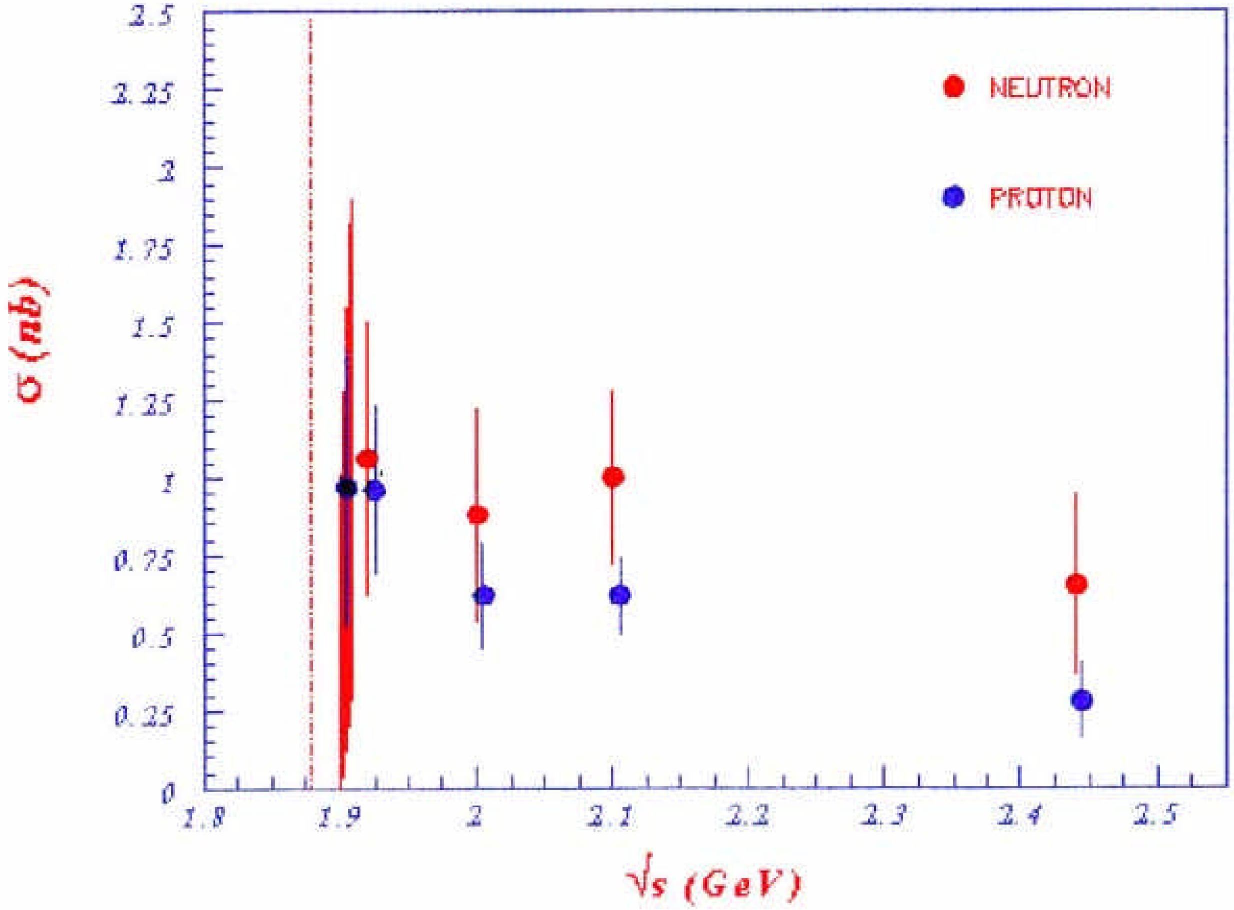
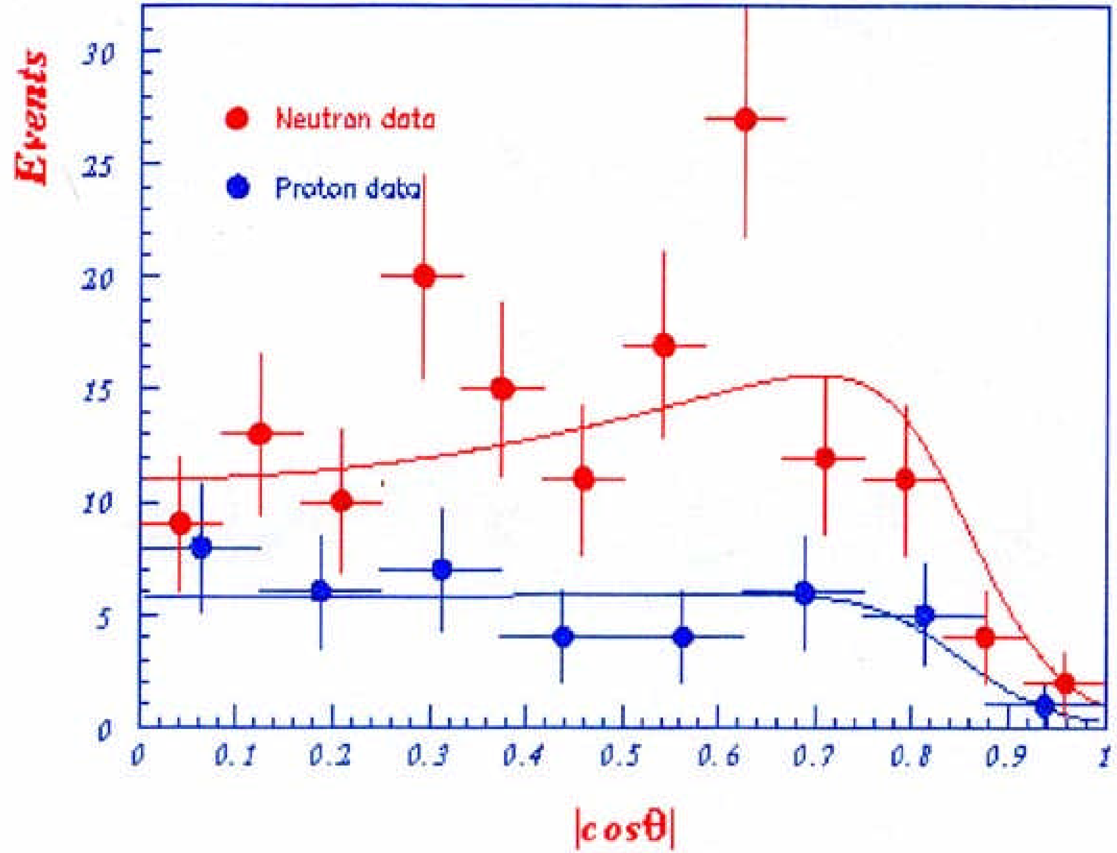


Figure 11: Example of candidate $n\overline{n}$ event as shown by the FENICE event display. (a) $R-\phi$ view orthogonal to the beams, and (b) $R-Z$ view.

$e^+e^- \rightarrow n\bar{n}$ (FENICE)

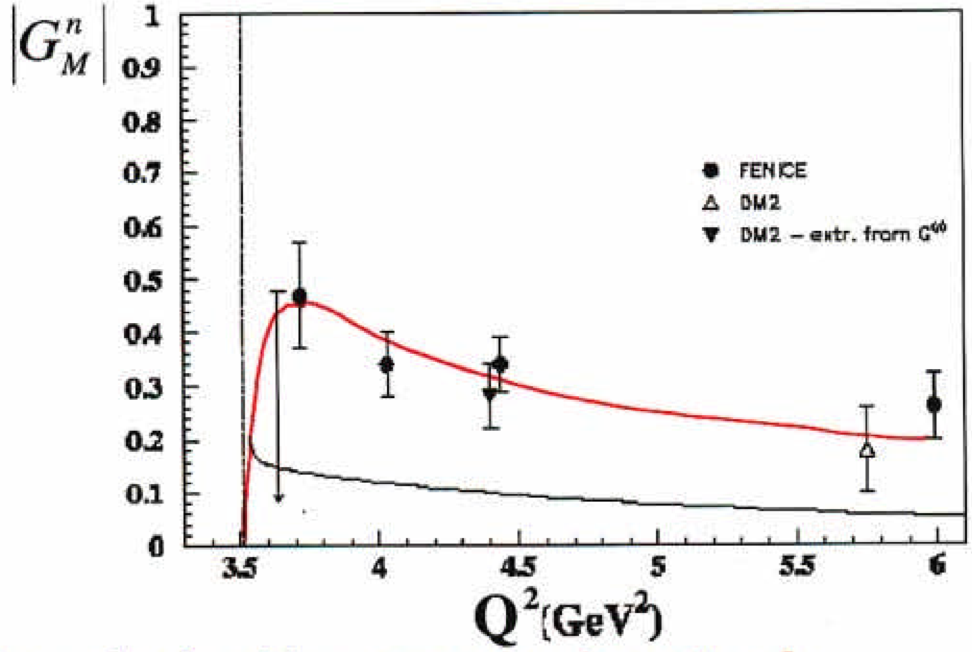


G_E vs G_M (FENICE)



$$|G_E^{(n)}| << |G_M^{(n)}|$$

Ratio between neutron and proton form factors



Data obtained by **one experiment only**

(FENICE at ADONE , $\int L dt = 0.4\ pb^{-1}$, ~ 80 events).

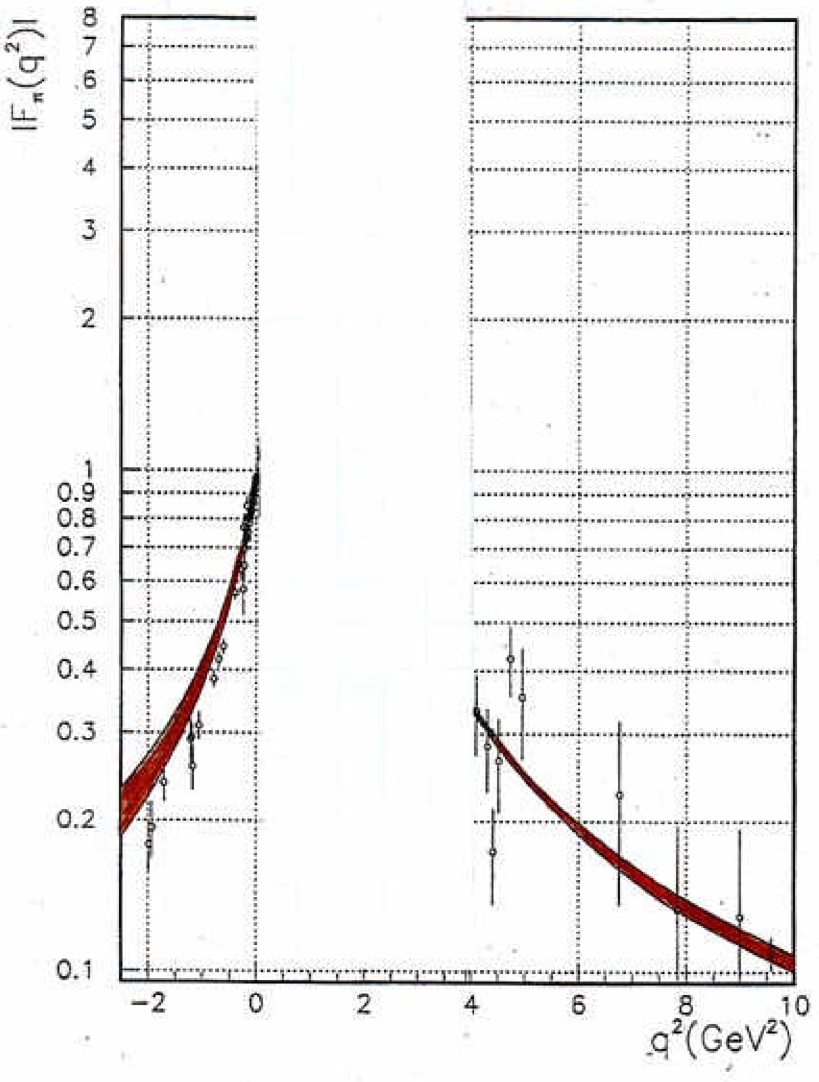
$G_M^n > G_M^p$!!!

Assumes G_E=G_M for both proton and neutron.

High-statistics measurement needed:

- to separate electric and magnetic form factors
- to measure their relative phase
  to get Dirac and Pauli ff.

F.F. IN THE UNPHYSICAL REGION



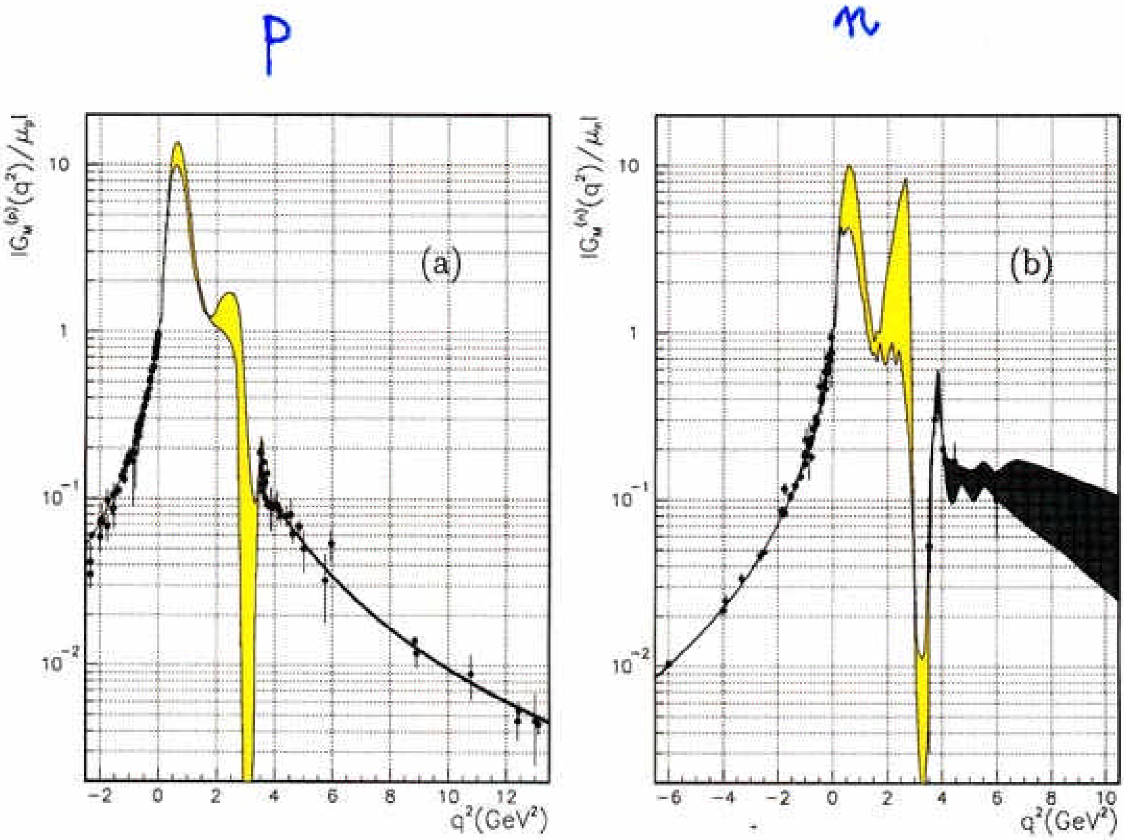
: Pion form factor. The black shaded area is the solution of eq. , the gray shaded area is the input of the equation.

$$\log G(Q^2) = \frac{Q^2}{\pi}\sqrt{Q_0^2 - Q^2}\int_{Q_0^2}^{\infty} \frac{\log|G(t)|}{t\,(t-Q^2)\sqrt{t-Q_0^2}}\,dt$$

(Eur. Phys. J C 11 (1999) 709)

FF IN THE UNPHYSICAL REGION

BY DISPERSION RELATION ON log(G)



$\Gamma_\rho \sim 350$ MeV (?)

SPETTROSCOPIA ADRONICA

- Confinamento colore ⇒ Adrone ~ Scatola

- Stati "esotici" previsti dalla QCD:
  - Solo gluoni ("Glueballs") gg
  - Massa eff. × q ⇒ Massa eff. × g ⇒ "Hybrids" $q\bar{q}g$
  - Eccitazioni collettive

⇓

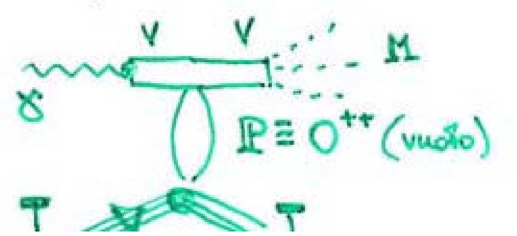
- Una pletora di stati (non visti sinora?)

Masse ~ $1.5 \div 2.5$ GeV (eccetto ggg: $J^{PC} = 1^{--}$ $M \sim 4$ GeV)

Larghezze; Sezioni d'urto di produzione } ?? (isoscalari ⇒ $\sigma(e^+e^- \to V) \lesssim 0.1 \div 1$ nb

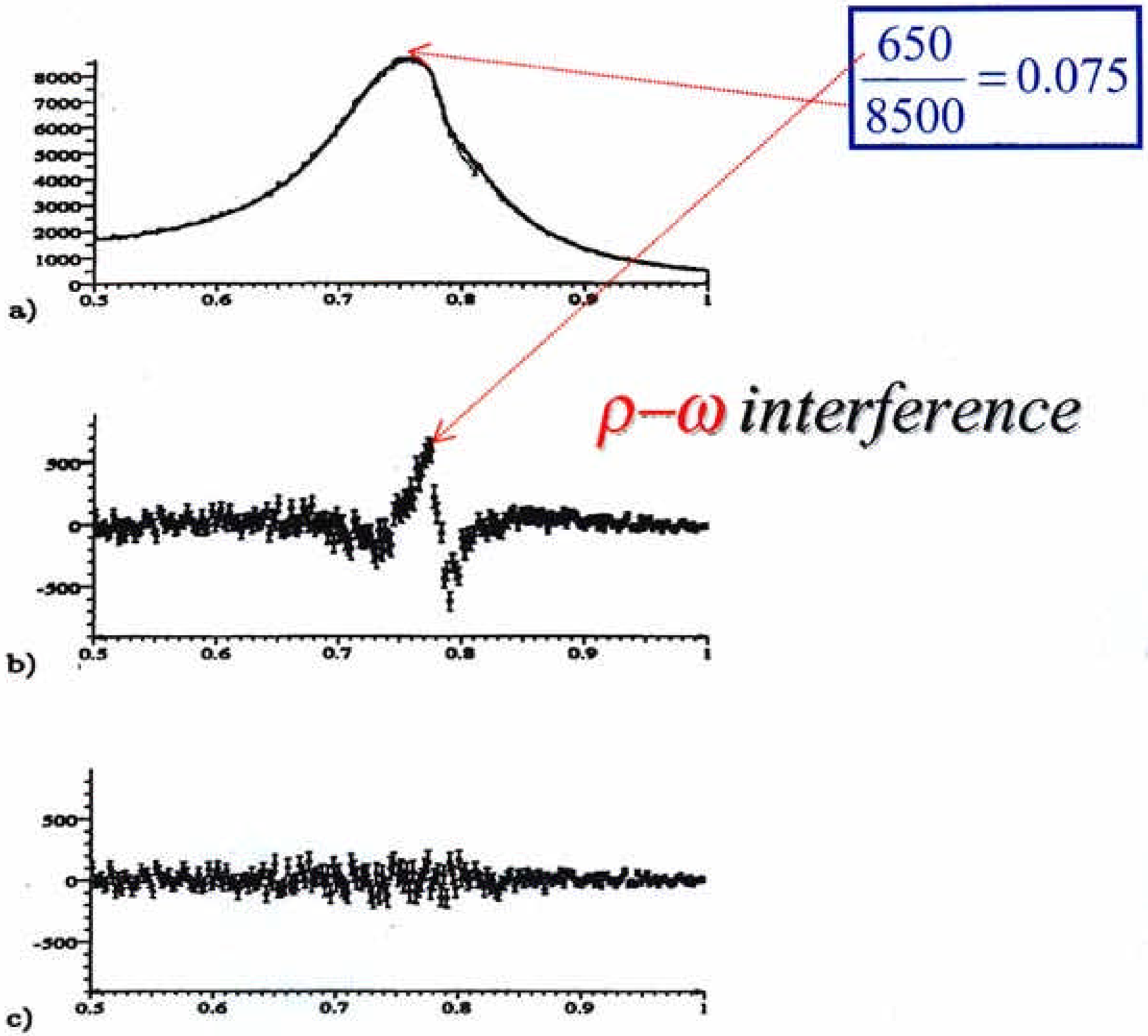
Di fatto annegati nel continuo

- In e^+e^- solo $J^{PC} = 1^{--}$
- Fotoproduzione diffrattiva ≈ e^+e^-



m.q. del γ ⇒ masse prodotte M

E687 $\pi^+\pi^-$ diffractive photoproduction

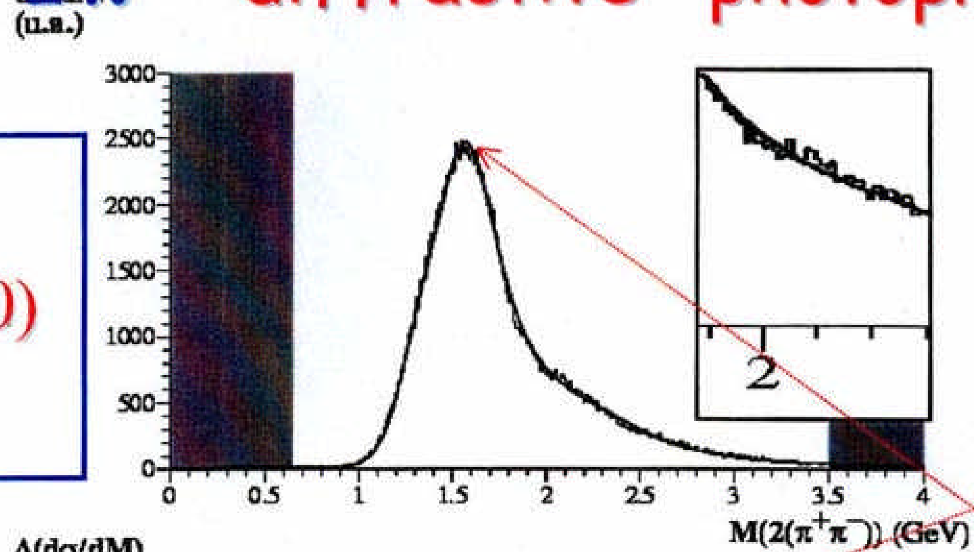


E687 $2\pi^+ 2\pi^-$ diffractive photoproduction

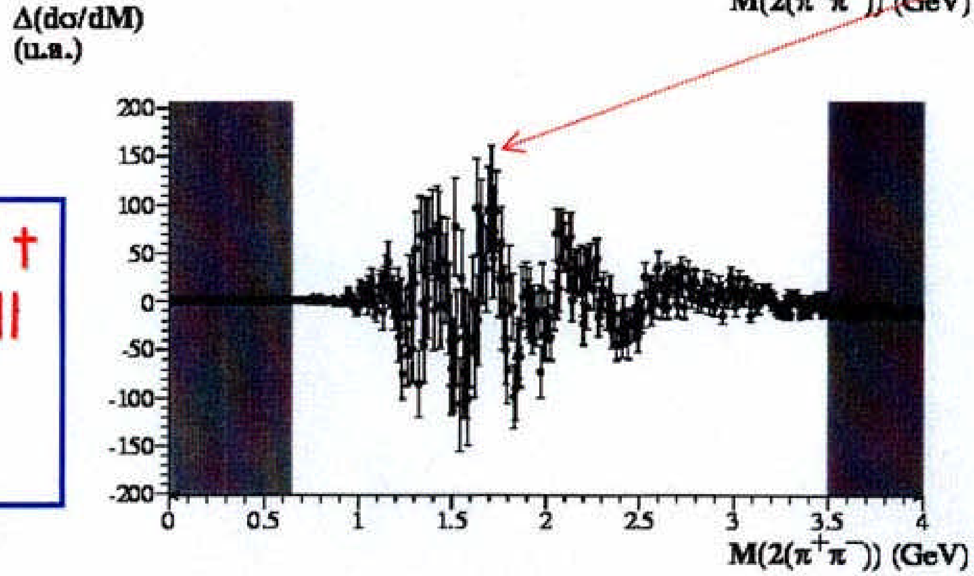
Fit amplitudes :

$\rho(1450), \rho(1700)$

$(\chi^2 = 467/274)$

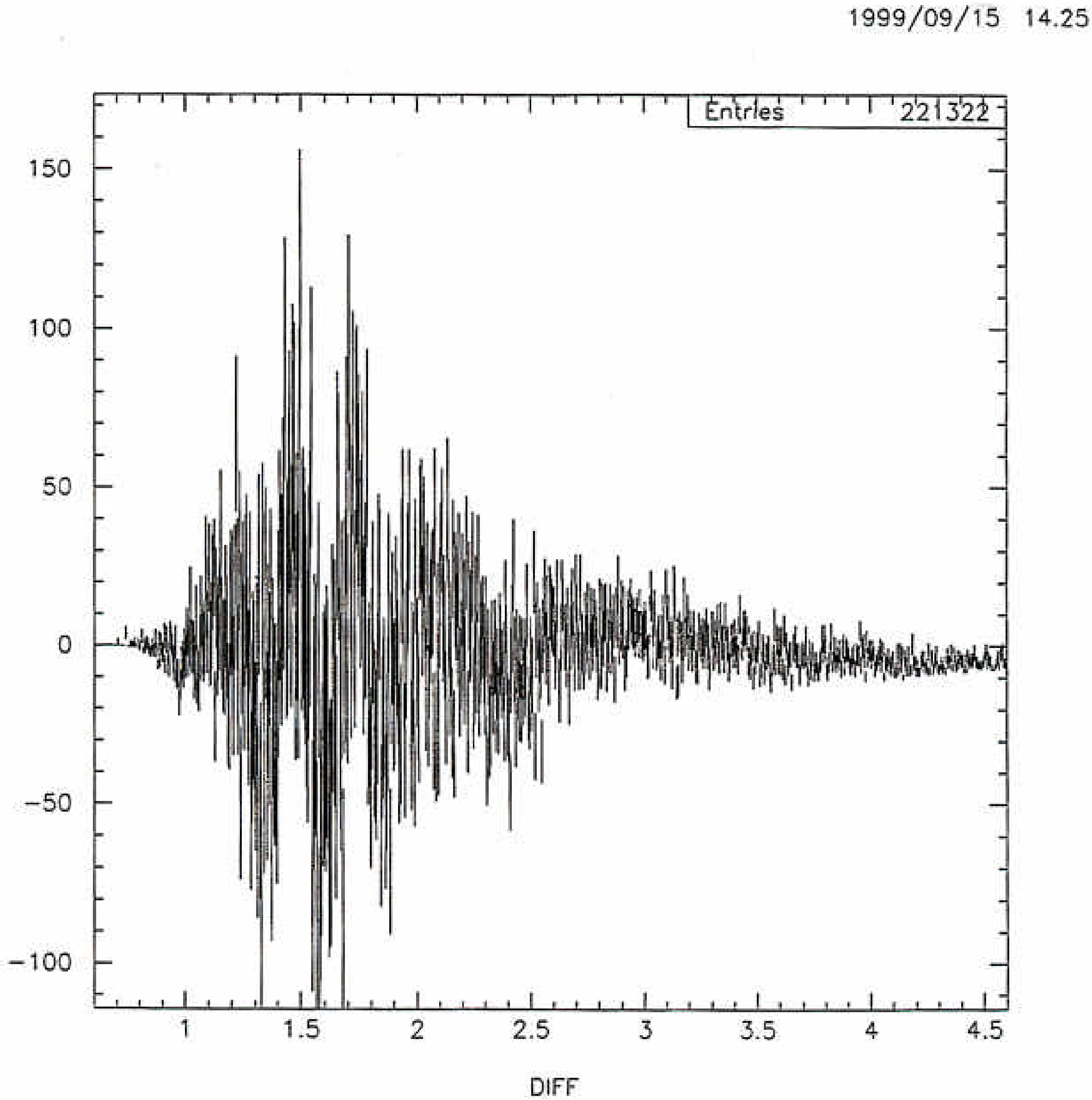


$\frac{150}{2500} = 0.06$



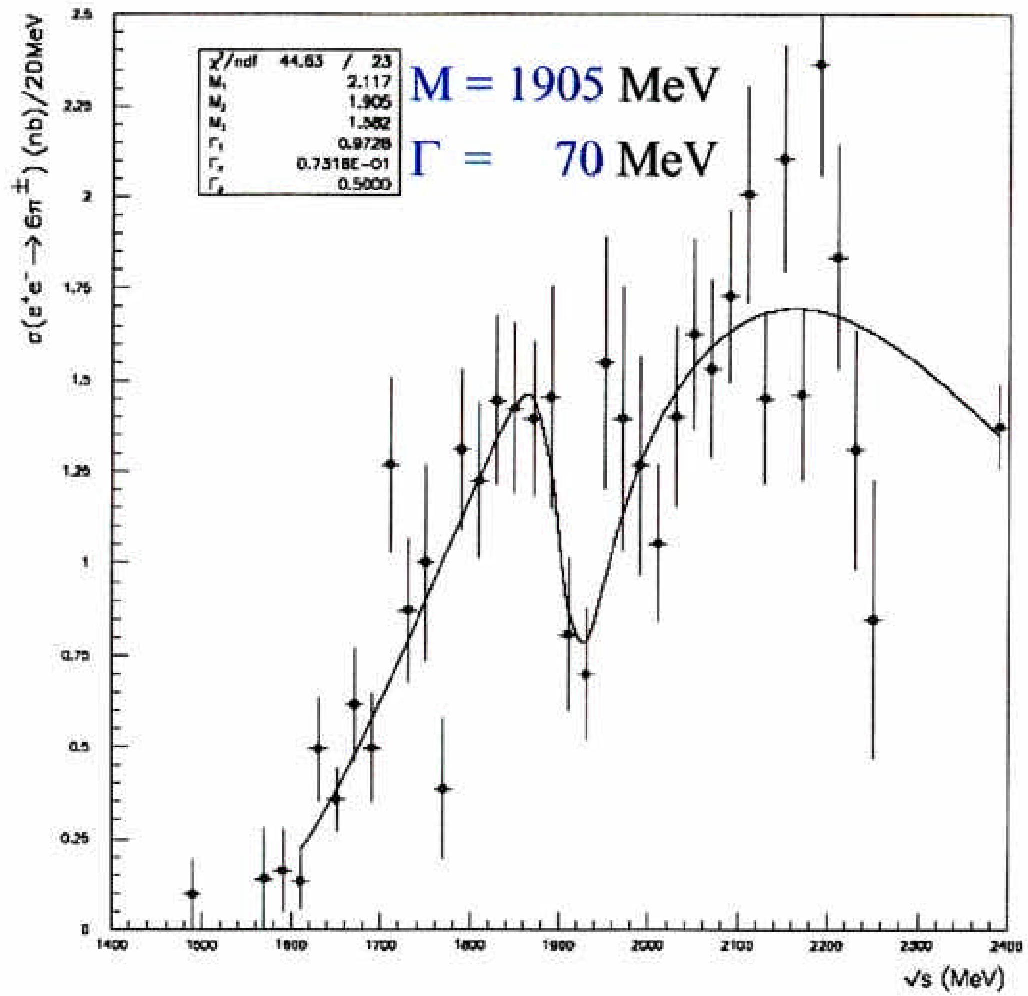
The fit doesn' t account for all observed structures

FNAL/E831 (PRELIMINARY)

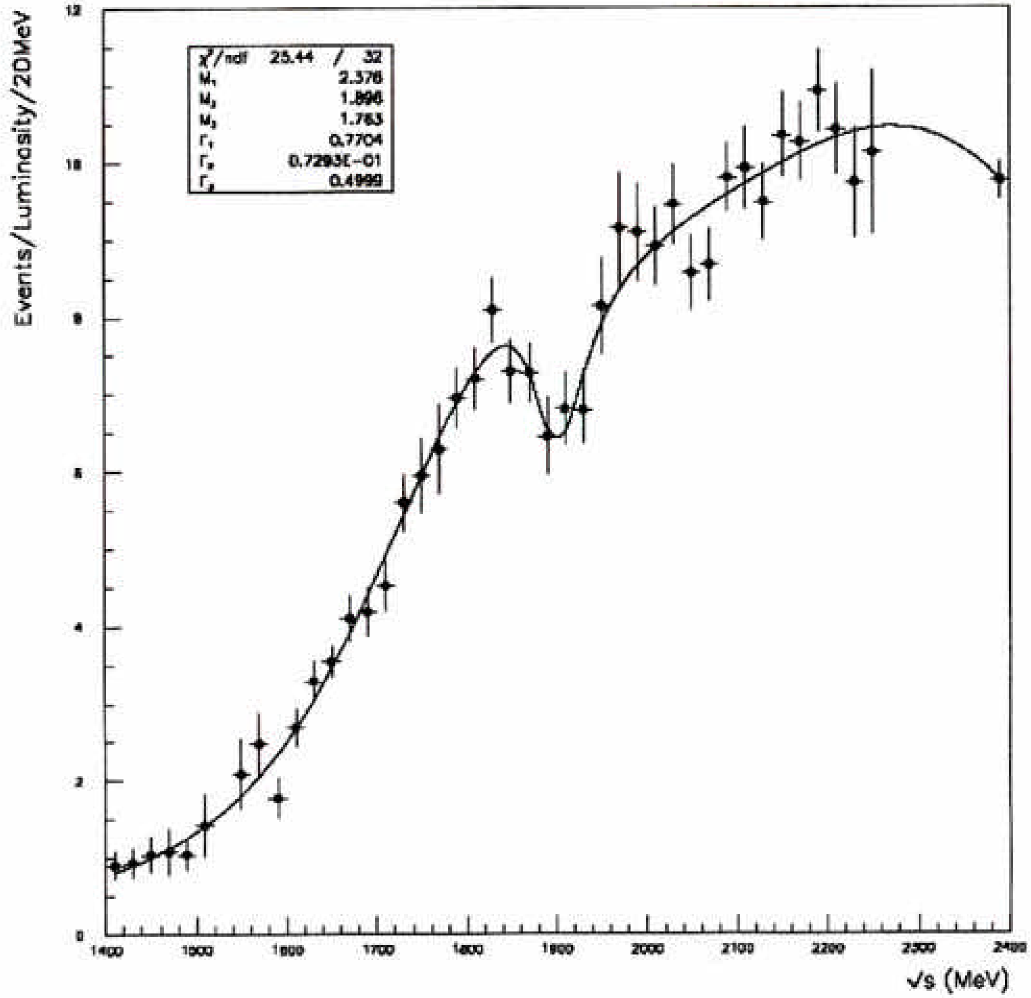


$2\pi^+ 2\pi^-$ DIFFRACTIVE PHOTOPROD.

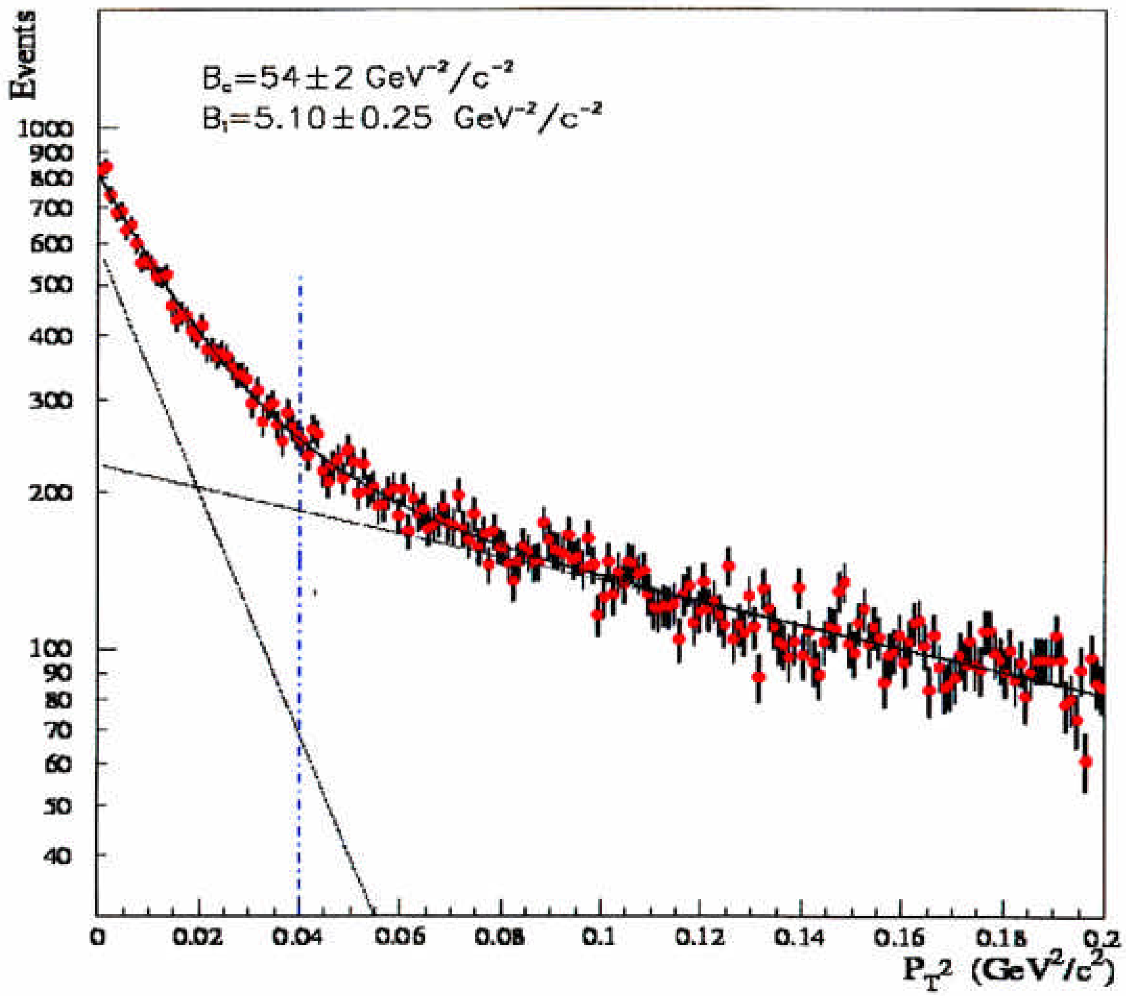
(DM2 unpublished) $e^+ e^- \rightarrow 3\pi^+ 3\pi^-$



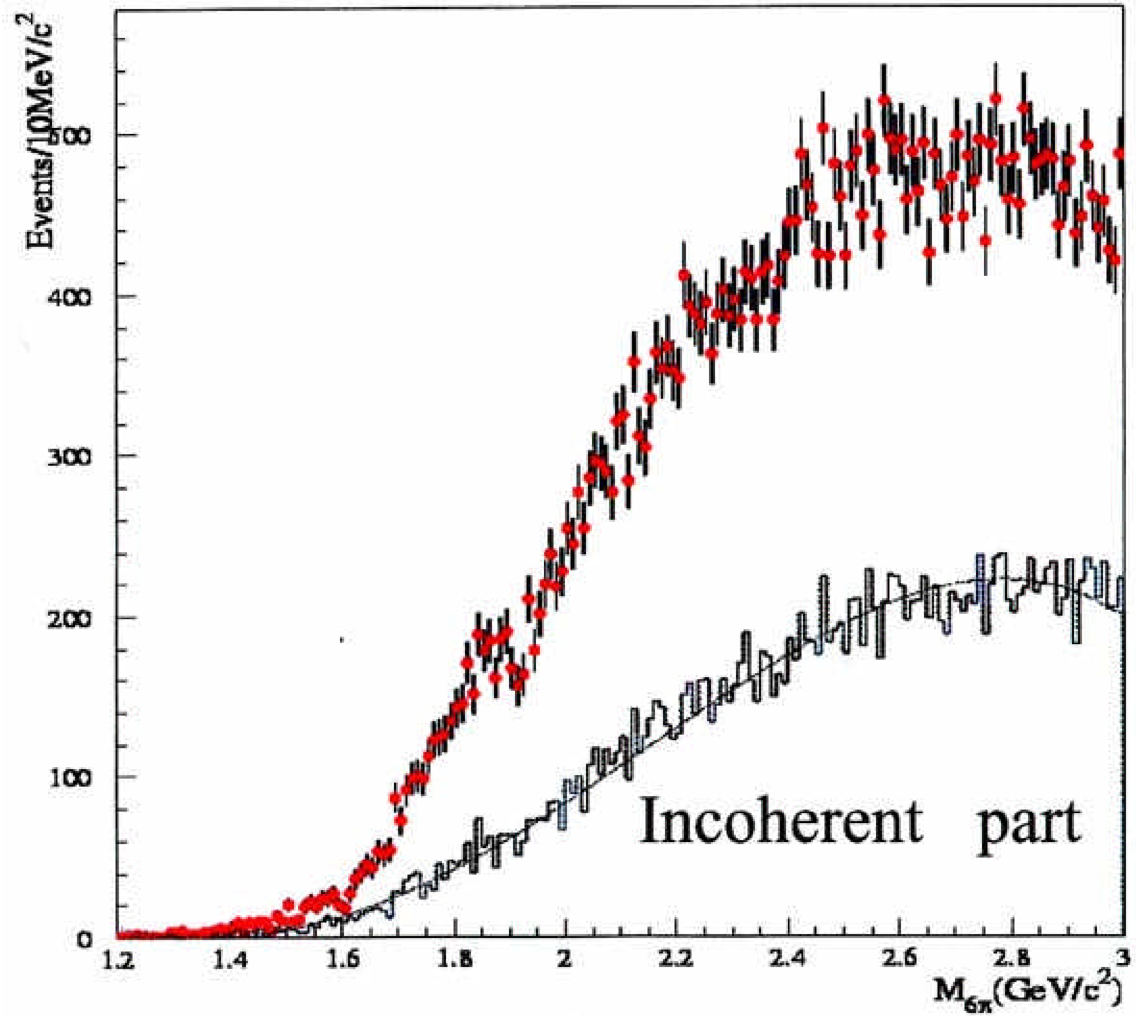
$e^+ e^- \to 4\,\pi^\pm\, 2\pi^0$, $3\pi^+ 3\pi^-$, $\geq 6\pi$



P^2_T Distribution ($3\pi^+ 3\pi^-$)



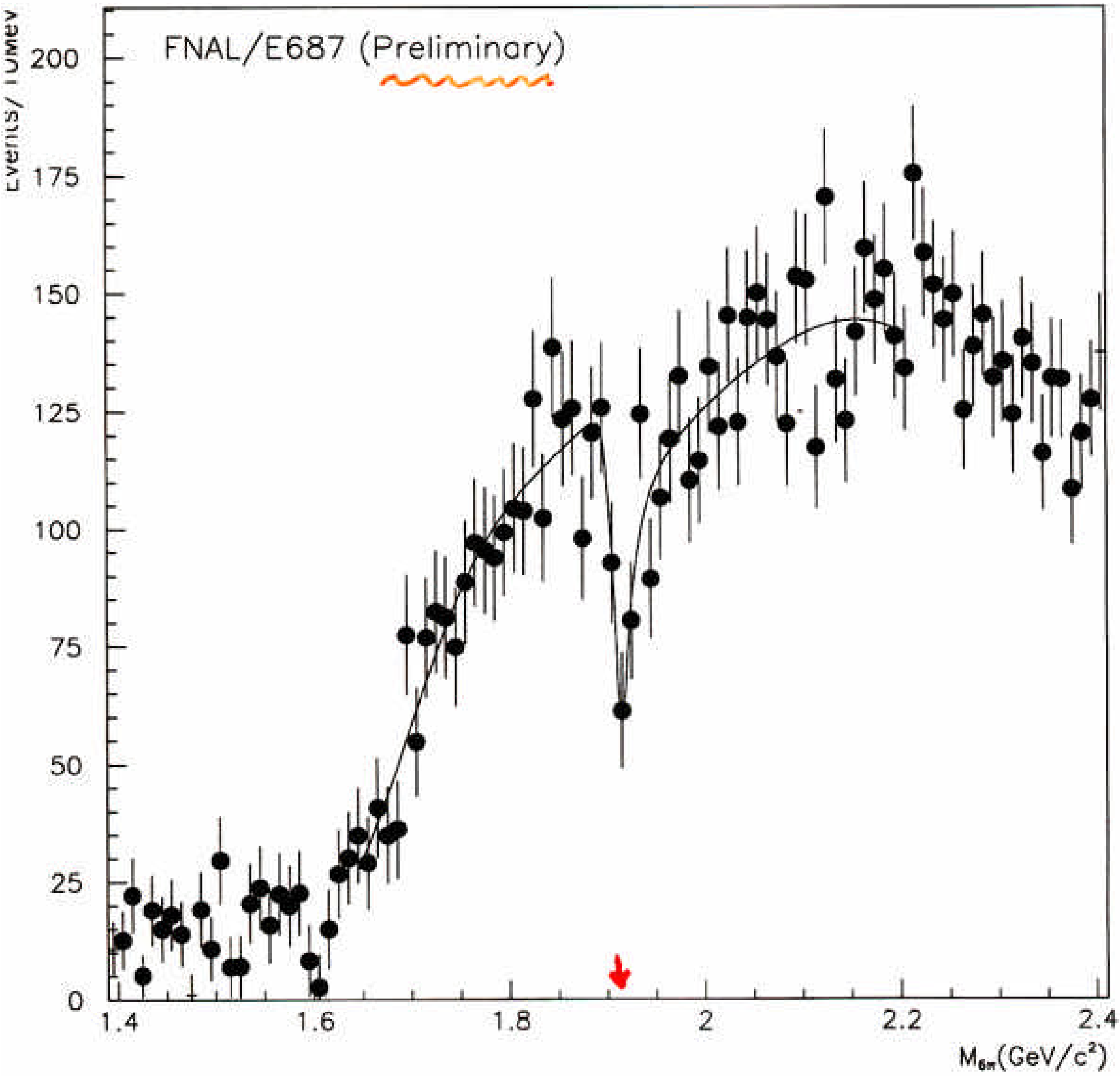
E687 $3\pi^+ 3\pi^-$ Mass Distribution



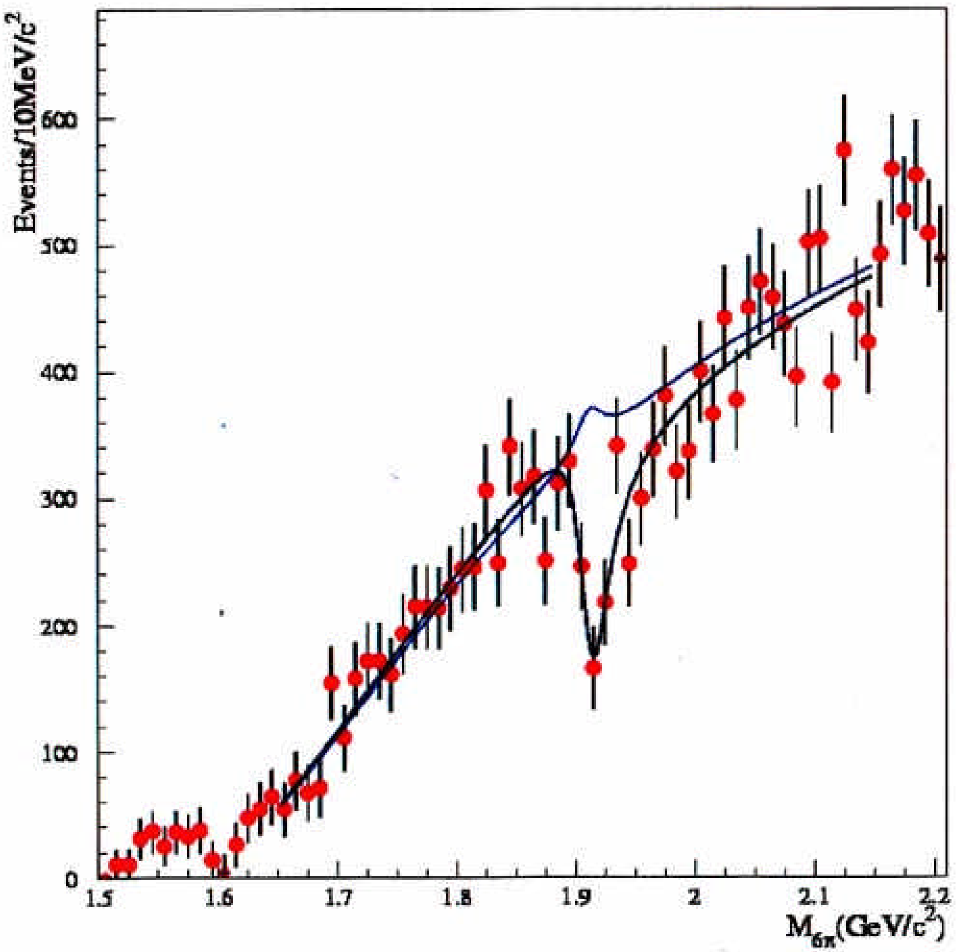
FNAL / E687

DIFFRACTIVE PHOTOPR.

$\sigma(\gamma A \to 3\pi^+ 3\pi^- A)$ $t \leq 40$ MeV^2



Expected yield without interference



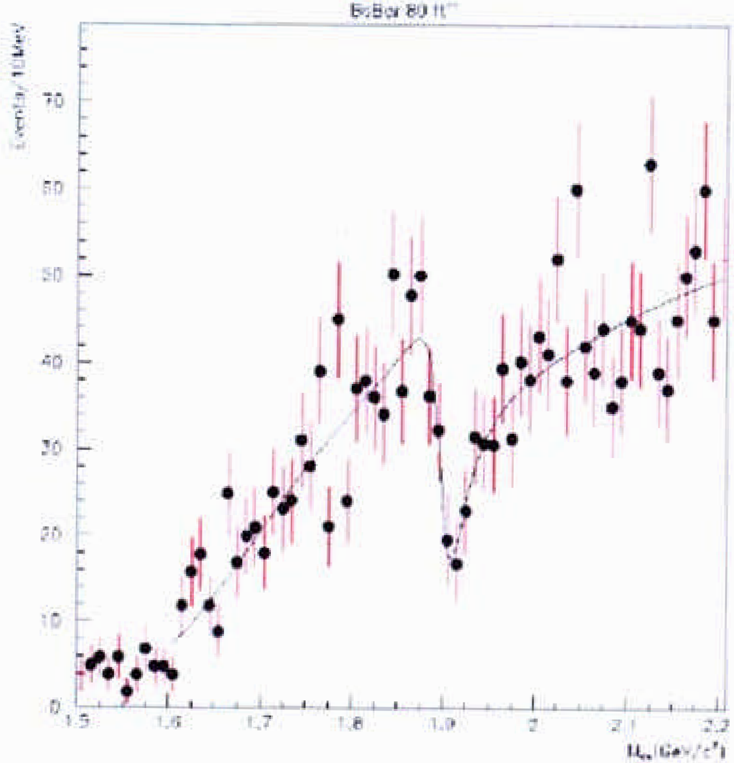
$e^+ e^- \rightarrow 3\pi^+ 3\pi^- + \gamma$

(BaBar 80ft $^{-1}$)

$M = 1900 \pm 10$ MeV

$\Gamma = \ \ 32 \pm 5$ MeV

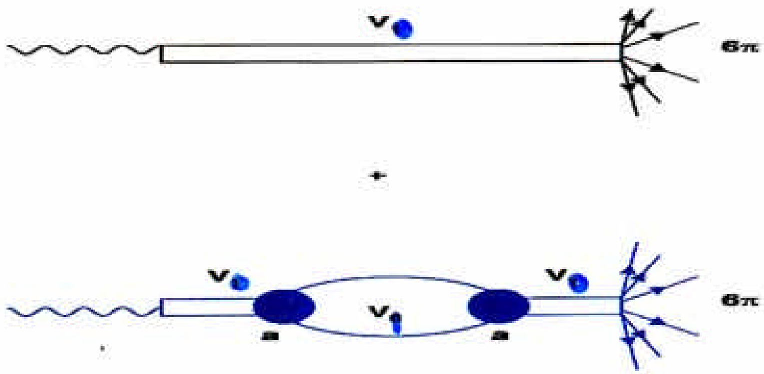
Preliminary



Structure has been observed by DM2 and FOCUS – no explanation!

Why a destructive interference

- A narrow resonance V_0, weakly coupled to e^+e^- and to the hadron final state via mixing with a nearby broad vector meson V_1, has to be seen as a destructive interference (P.J.Franzini and F.J. Gilman, Phys. Rev.D32,237,1985) .

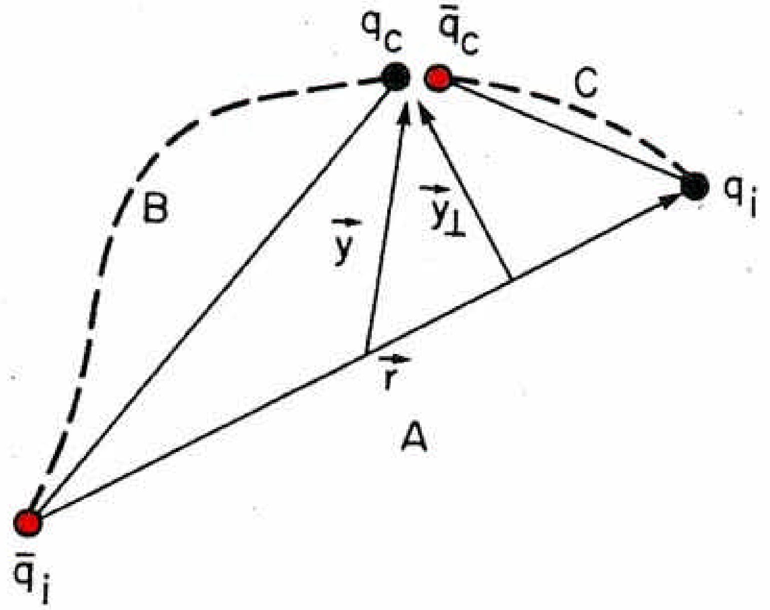


$$A \propto \frac{1}{M^2 - M_{V_0}^2}\left(1 + a\frac{1}{M^2 - M_{V_1}^2}a\frac{1}{M^2 - M_{V_0}^2} + \ldots\right)$$

$$\propto \frac{M^2 - M_V^2}{(M^2 - M_{V_0}^2)(M^2 - M_{V_1}^2) - a^2}$$

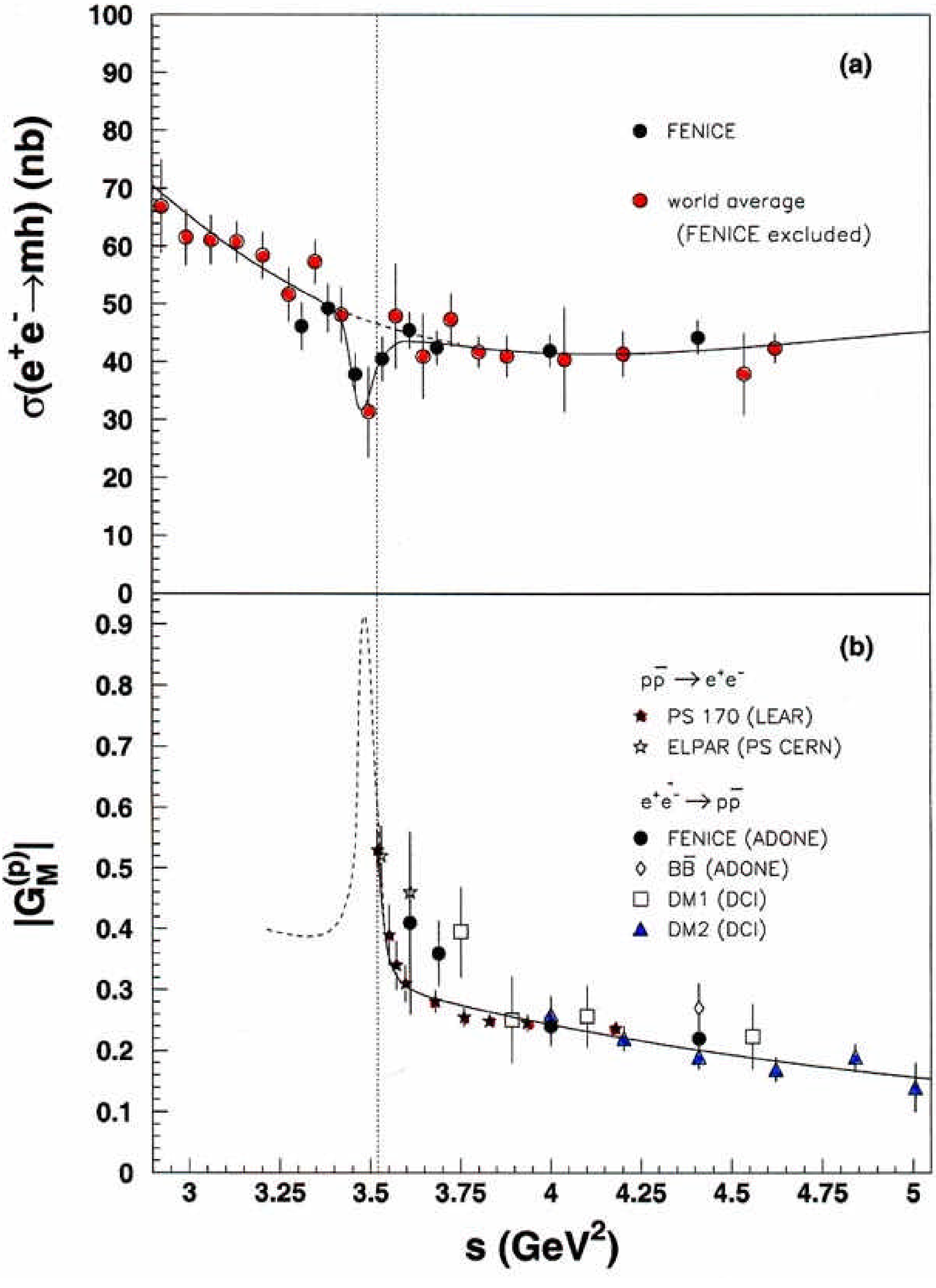
- This amplitude has a dip at the V mass pole.

N. ISGUR et al. P.R.L. 54 (1985) 869



Hybrid state[a]	J^{PG}	(Decay mode)$_{L \text{ of decay}}$	Partial width (MeV)
x_2^{+-} (1900)	2^{++}	$(\pi A_2)_P$	450
		$(\pi A_1)_P$	100
		$(\pi H)_P$	150
y_2^{+-} (1900)	2^{+-}	$(\pi B)_P$	500
z_2^{+-} (2100)	2^{+-}	$[\bar{K}K^*(1420)+\text{c.c.}]_P$	250
		$(\bar{K}Q_2+\text{c.c.})_P$	200
x_1^{-+} (1900)	1^{--}	$(\pi B)_{S,D}$	100,30
		$(\pi D)_{S,D}$	30,20
y_1^{-+} (1900)	1^{-+}	$(\pi A_1)_{S,D}$	100,70
		$[\pi\pi(1300)]_P$	100
		$(\bar{K}Q_2+\text{c.c.})_S$	~100
z_1^{-+} (2100)		$(\bar{K}Q_1+\text{c.c.})_D$	80
		$(\bar{K}Q_2+\text{c.c.})_S$	250
		$[\bar{K}K(1400)+\text{c.c.}]_P$	30
x_0^{+-} (1900)	0^{++}	$(\pi A_1)_P$	800
		$(\pi H)_P$	100
		$[\pi\pi(1300)]_S$	900
y_0^{+-} (1900)	0^{+-}	$(\pi B)_P$	250
z_0^{+-} (2100)	0^{+-}	$(\bar{K}Q_1+\text{c.c.})_P$	800
		$(\bar{K}Q_2+\text{c.c.})_P$	50
		$[\bar{K}K(1400)+\text{c.c.}]_S$	800

Resonant Structures



$p^+p^-\gamma$

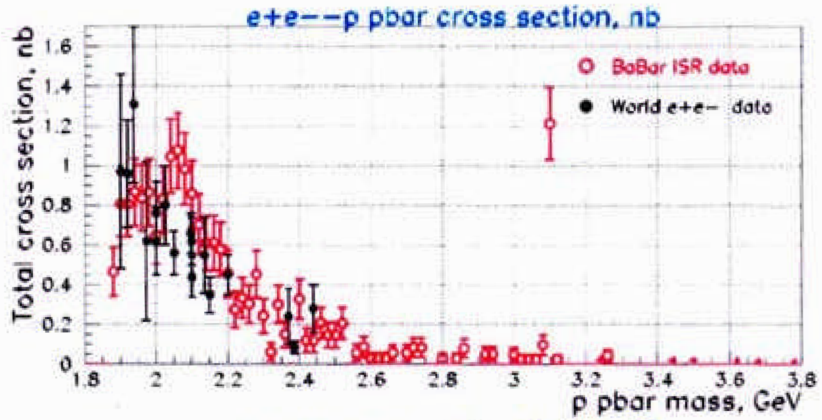
topology: 2 charged tracks, 2 proton ID, No μ ID + 1C fit in pp hyp.

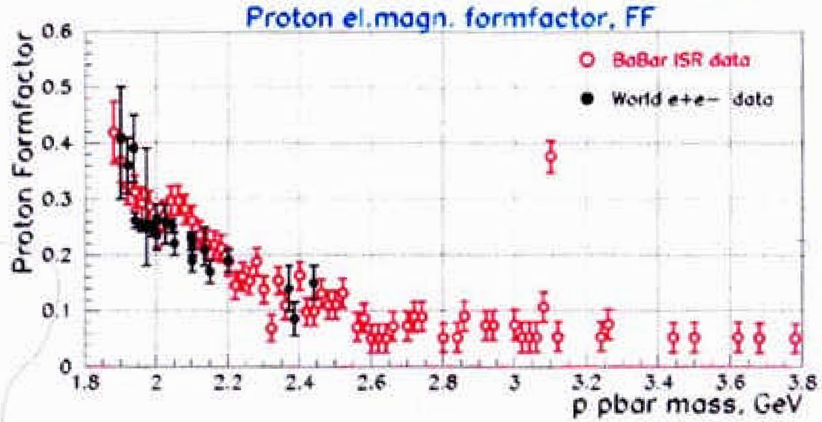
main background: $\mu\mu\gamma$, $\pi\pi(\rho)\gamma$, $KK(\phi)\gamma$

tight cuts keep background at the <5% level

$B(j/\psi \to p^+p^-) = 0.0028 \pm 0.0005$

PDG2002 -- 0.00214 ± 0.00010





BAD in preparation (S. Serednyakov)

PROSPETTIVE

- B-Factory, mediante Initial State Radiation:
  - $\mathcal{L}_{eq} \propto \Delta M$. Se $\Delta M \sim \pm 50\,MeV \Rightarrow \mathcal{L}_{eq} \sim 10^{28}\,cm^{-2}s^{-1}$
  - Raccolta contemporanea $\Rightarrow \mathcal{L}_{eq} \sim 10^{29}\,cm^{-2}s^{-1}$
  - $n\bar{n}$ molto difficile
  - $\sigma < 0.1\,nb$ " "
  - Ris. $\Delta M \sim 10\,MeV$

- Cornell (τ/charm), Se $W_{min} \simeq M_{J/\psi} \Rightarrow$ Stesse conclusioni

- BEPC:
  - $\mathcal{L} \sim 10^{29}\,cm^{-2}s^{-1}$
  - $n\bar{n}$ molto difficile

- VEPP 2000

- DAΦNE 2