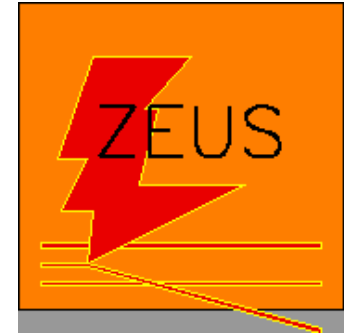


Exclusive Vector Meson Production and Inclusive $K_S^0 K_S^0$ Final State in DIS at HERA

Photon2003,
Frascati
07-11/04



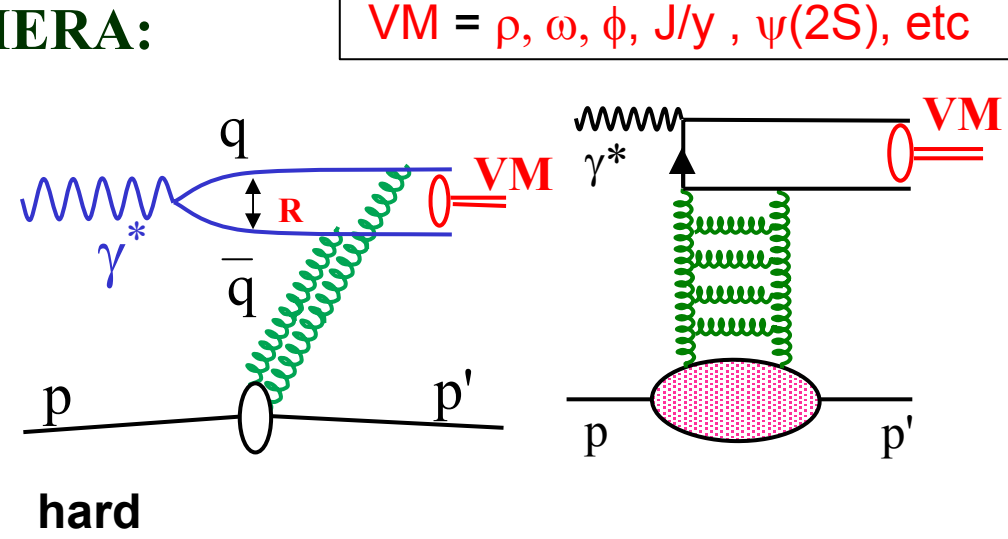
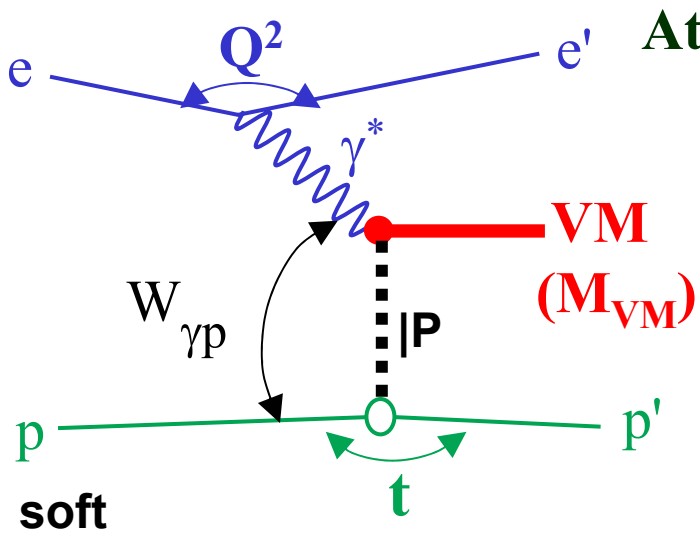
M. Barbi
McGill University
For the H1 and Zeus
Collaboration



Outline:

- ¥ Exclusive vector meson production
- ¥ Summary
- First observation of resonances in inclusive
 $K_S^0 K_S^0$ final state in DIS
- Summary

Exclusive Vector Meson Production



$VM = \rho, \omega, \phi, J/\psi, \psi(2S), \text{ etc}$

Soft (Regge + VDM)

$$\frac{d\sigma}{dt} \propto W^{4(\alpha_p(t)-1)} e^{-b(W)|t|}$$

$$\alpha_p(t) = \alpha_p(0) + \alpha'_p t$$

At low $|t| \Rightarrow \sigma(W) \propto W^{0.22}$

Cross section

$$\sigma(W) \propto W^\delta$$

Hard (pQCD)

$$\sigma \propto [xg(x, Q_{eff}^2)]^2 \quad x \approx 1/W^2$$

Gluon from fit to F_2 scaling violation $\Rightarrow \sigma(W) \propto W^{0.8}$

Scale

$$Q^2, |t|, M_{VM}^2$$

$$b(W) = b_0 + 4\alpha' \ln W \quad b \propto R^2$$

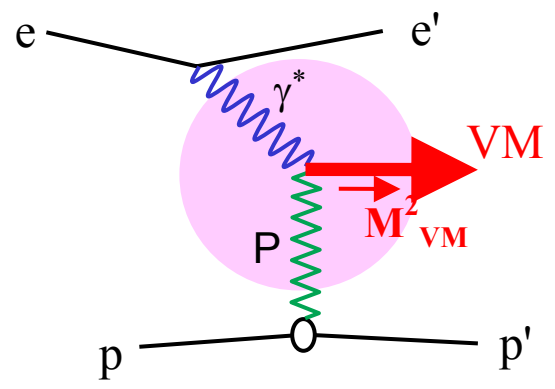
Transv. size of the interaction region

Small size. No W dependence.

Exclusive Vector Meson Production

Elastic VM in photoproduction ($Q^2 = 0$)

A first look:

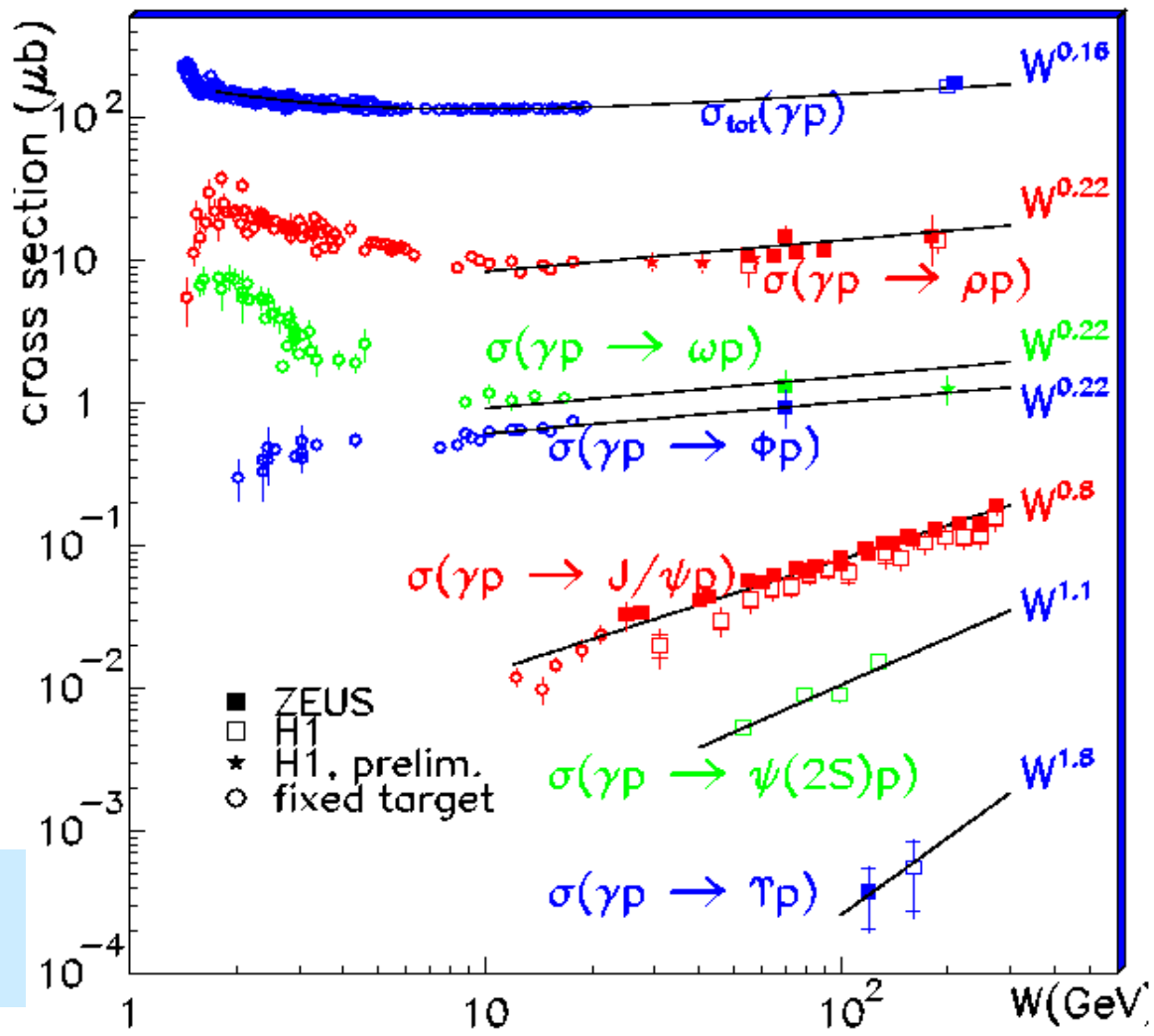


Fit $\sigma \propto W^\delta$:

$\delta \approx 0.22$ for ρ^0, ω, ϕ

$\delta \approx 0.8$ for J/ψ

\Rightarrow high M_{VM}^2 sets hard scale



Exclusive Vector Meson Production

J/ψ Photoprod. in bins of W and comparison to LLA calculations

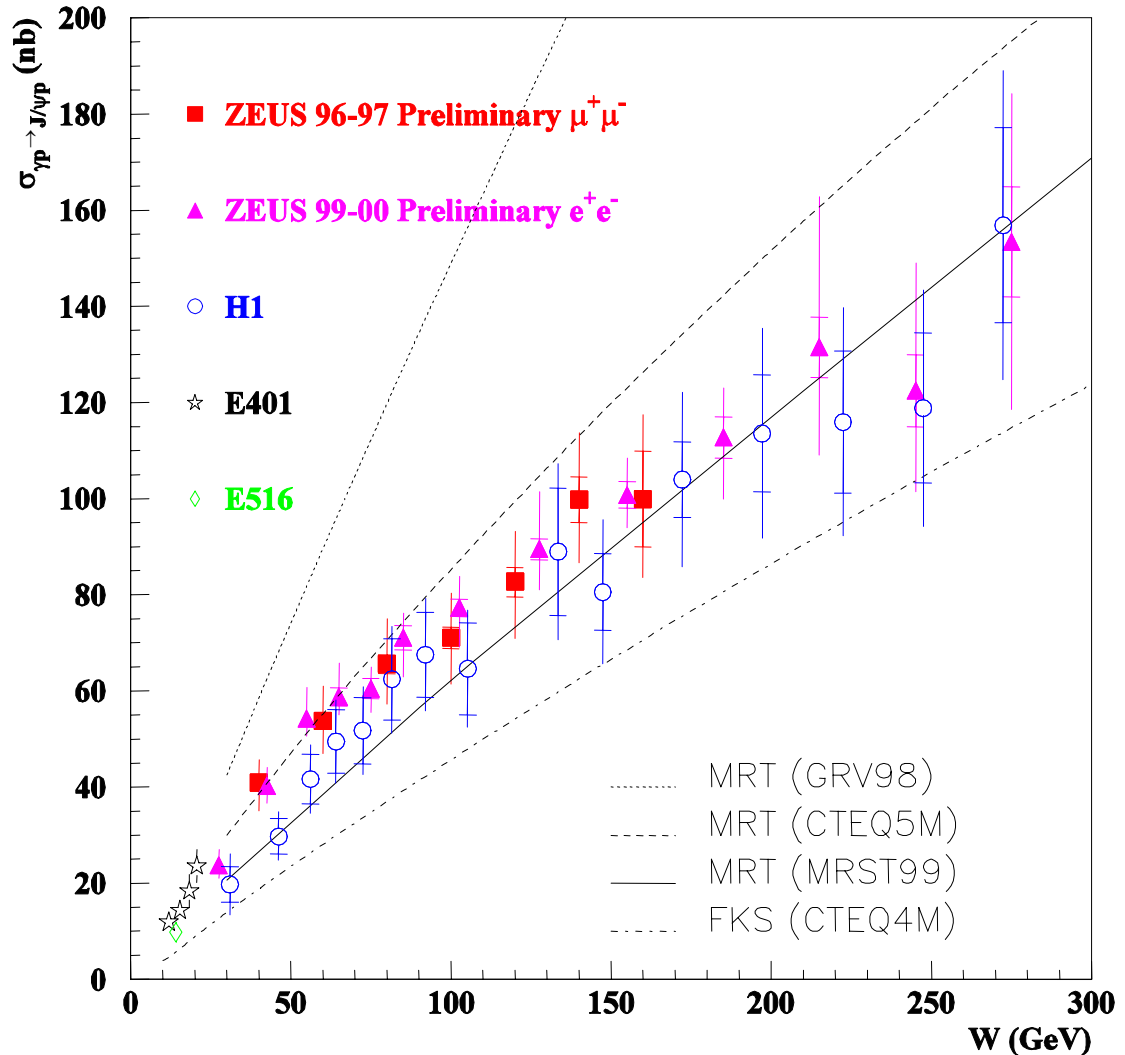
Looking at high M_{VM}
(consistent with hard
regime \leftarrow previous
slide)

Leading Log. Approx.
(LLA) pQCD
with different gluon
parametrisations

Models sensitive to
input parametrisation
of the gluon density

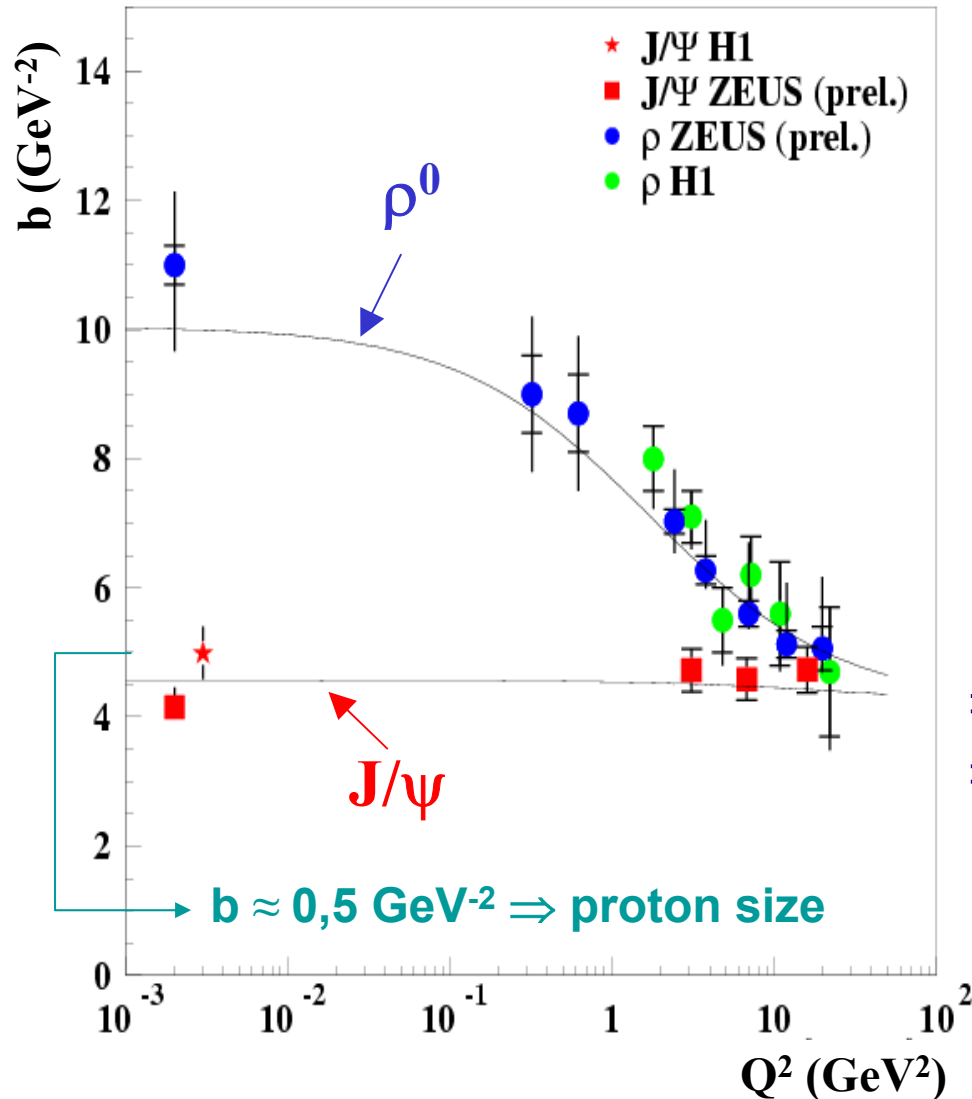
Models with
 $\sigma \propto [xg(x, Q_{eff}^2)]^2$
in reasonable
agreement with data

Indeed, M_{VM} is a hard scale



Exclusive Vector Meson Production

Steepness of ρ^0 and J/ψ cross-section



Can Q^2 provide a hard scale?

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

$$b \propto R^2 \approx R_p^2 + R_{VM}^2$$

R is the transverse size of the interaction region

- $\Rightarrow R$ decreases with Q^2 for ρ^0
- $\Rightarrow R$ already small for J/ψ at small Q^2

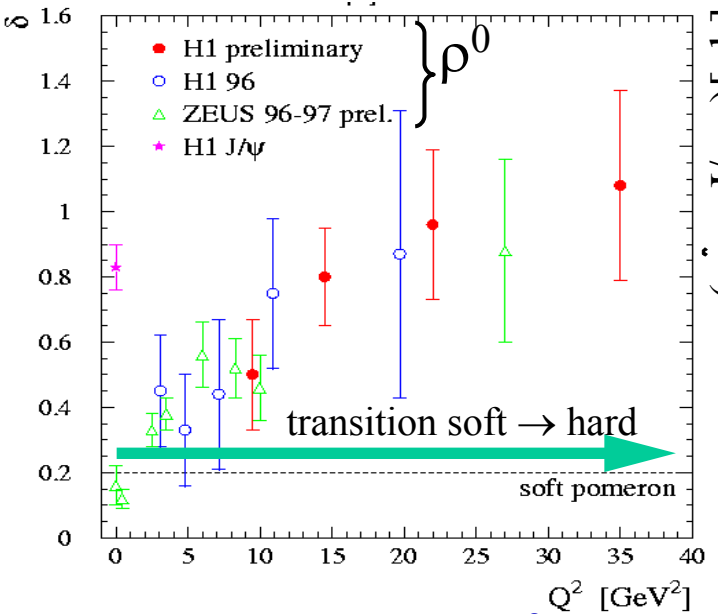
And the power-law W^δ dependence? \Rightarrow

Exclusive Vector Meson Production

W-dependence of elastic ρ^0 and J/ψ in bins of Q^2 (PhP and DIS)

ZEUS

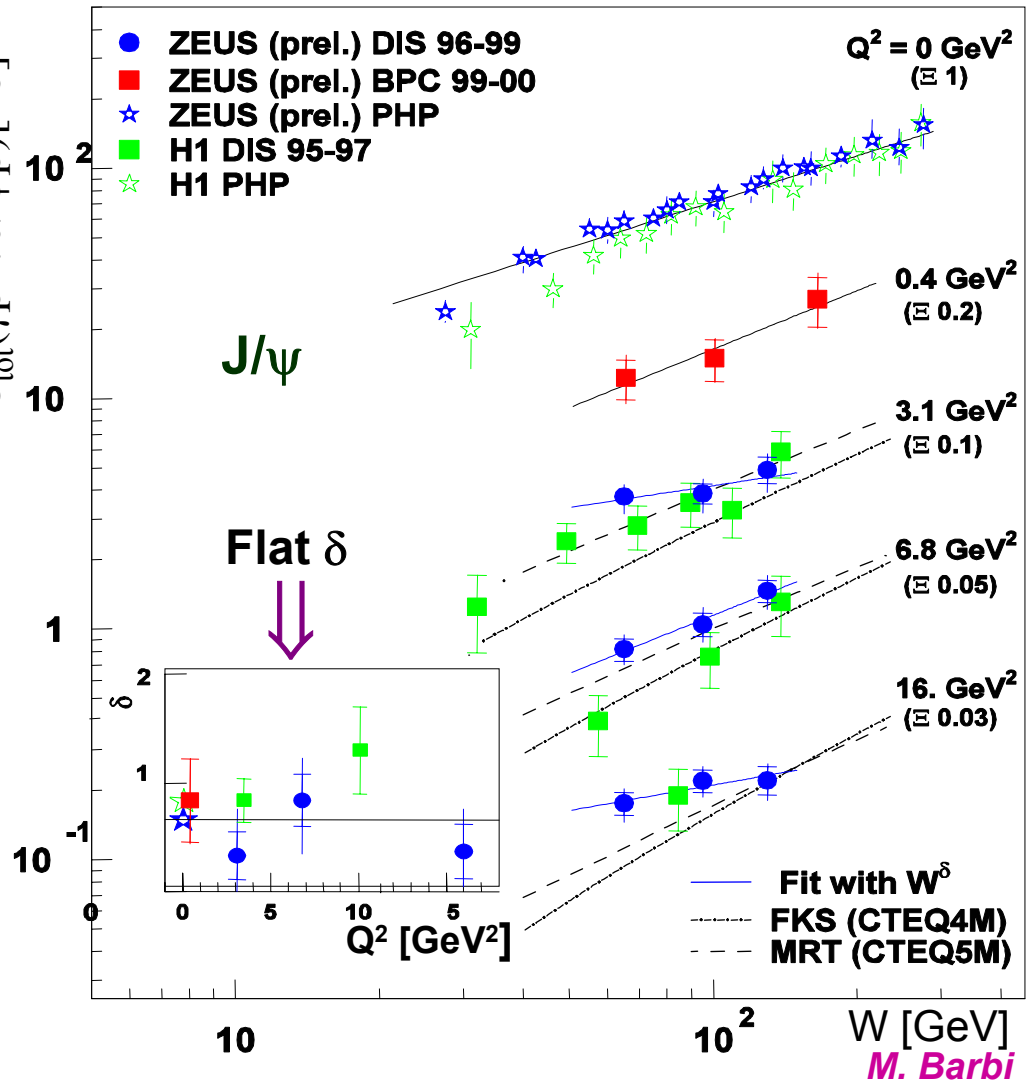
Can Q^2 provide a hard scale?



J/ψ already steep at $Q^2 = 0$

- Data fitted with W^δ
- pQCD models consistent with data

Q^2 also provides a hard scale.



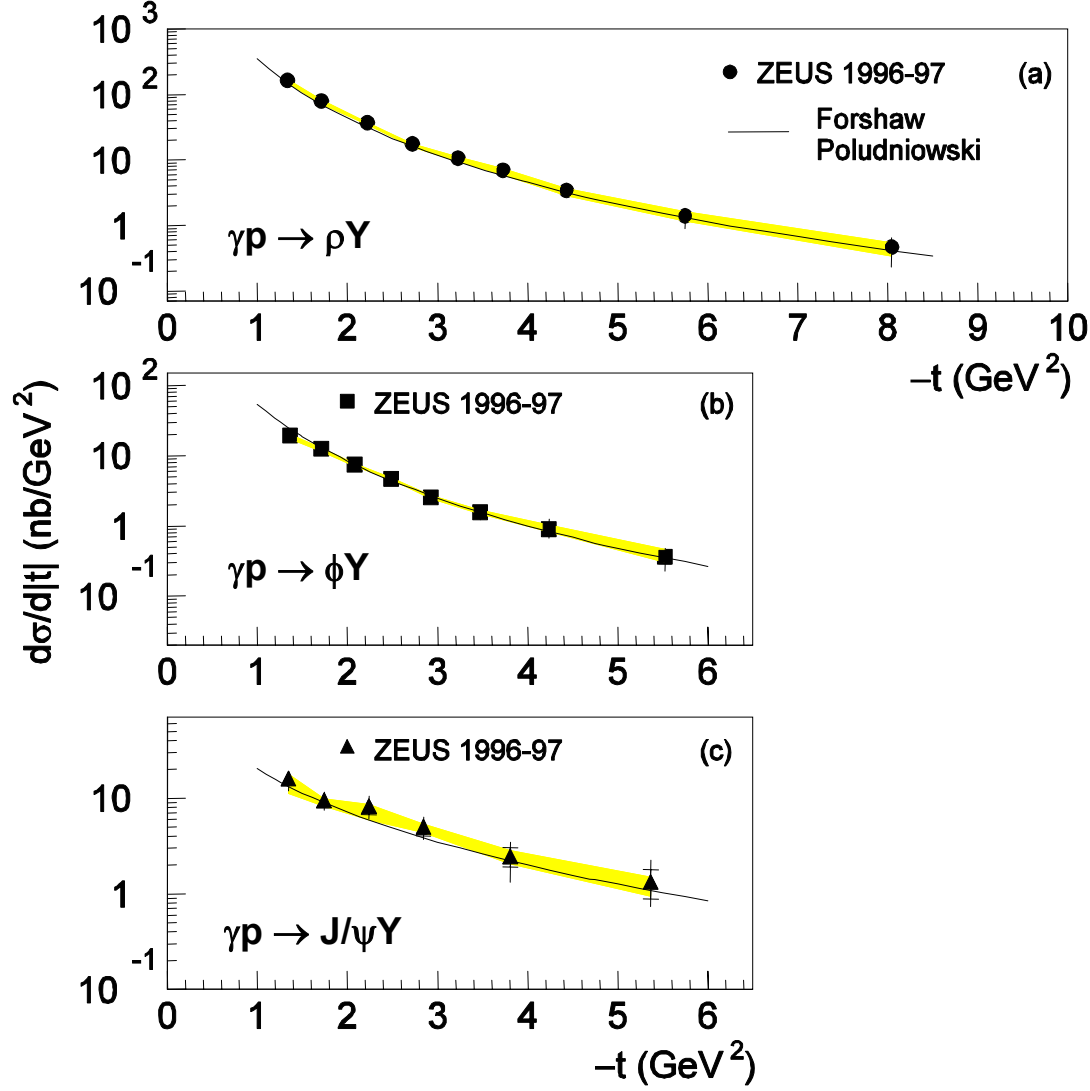
M. Barbi

Exclusive Vector Meson Production

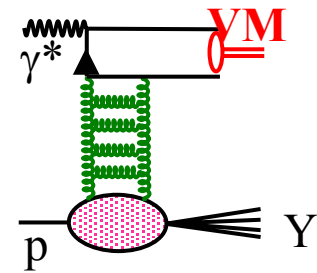
Photoproduction of proton-dissoc. VM at high $|t|$

What about $|t|$?

ZEUS



Typical elastic VM production has $|t| < 1 \text{ GeV}^2$.
Use proton dissociation to reach higher $|t|$



Use BFKL LLA approach to fit data (Forshaw and Poludniowski)

BFKL LLA approach is in agreement with data



$\Rightarrow |t|$ sets a hard scale

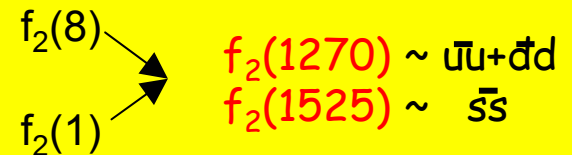
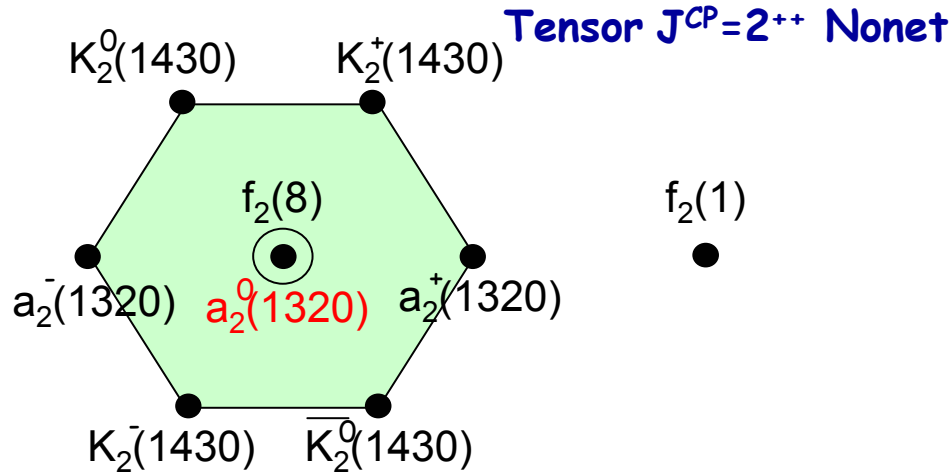
Summary

- Q^2 , M_{VM}^2 and $|t|$ set a hard scale.
- Perturbative QCD predictions agree with data

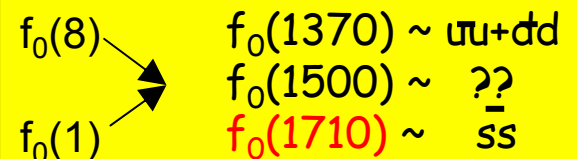
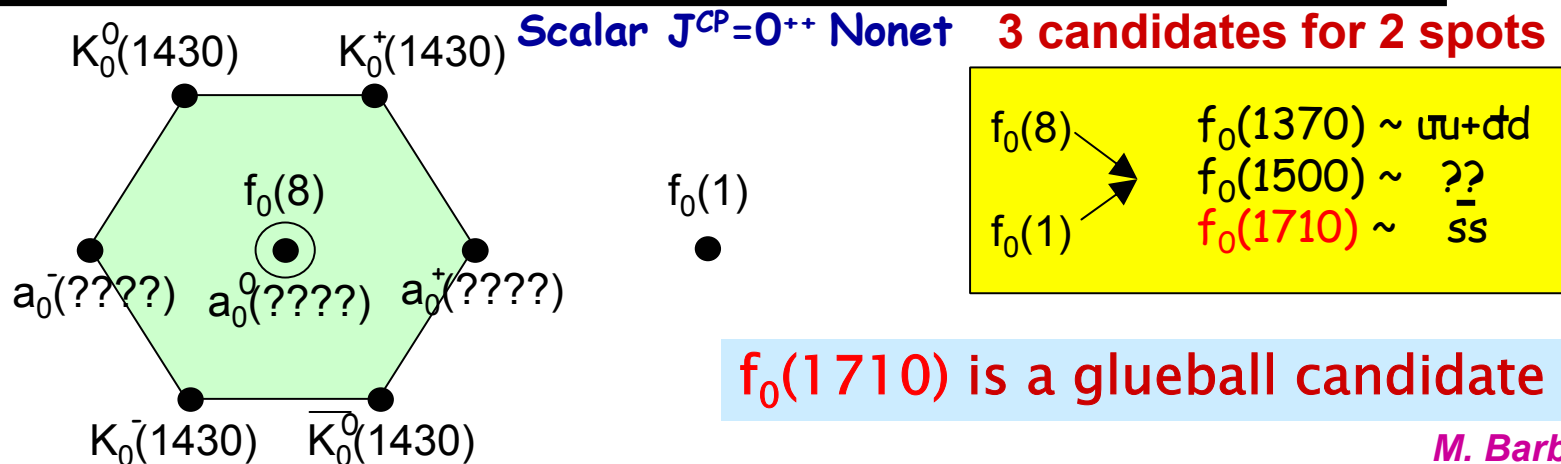
Inclusive $K_S^0 K_S^0$ final state in DIS

• QCD predicts the existence of hadrons made up by gluons (glueballs).
 From Lattice QCD calculations, the lightest **glueball** has $J^{CP}=0^{++}$ with a mass **1730 ± 100 MeV**.

• $K_S^0 K_S^0$ couples to meson states with $J^{CP}=(\text{even})^{++}$



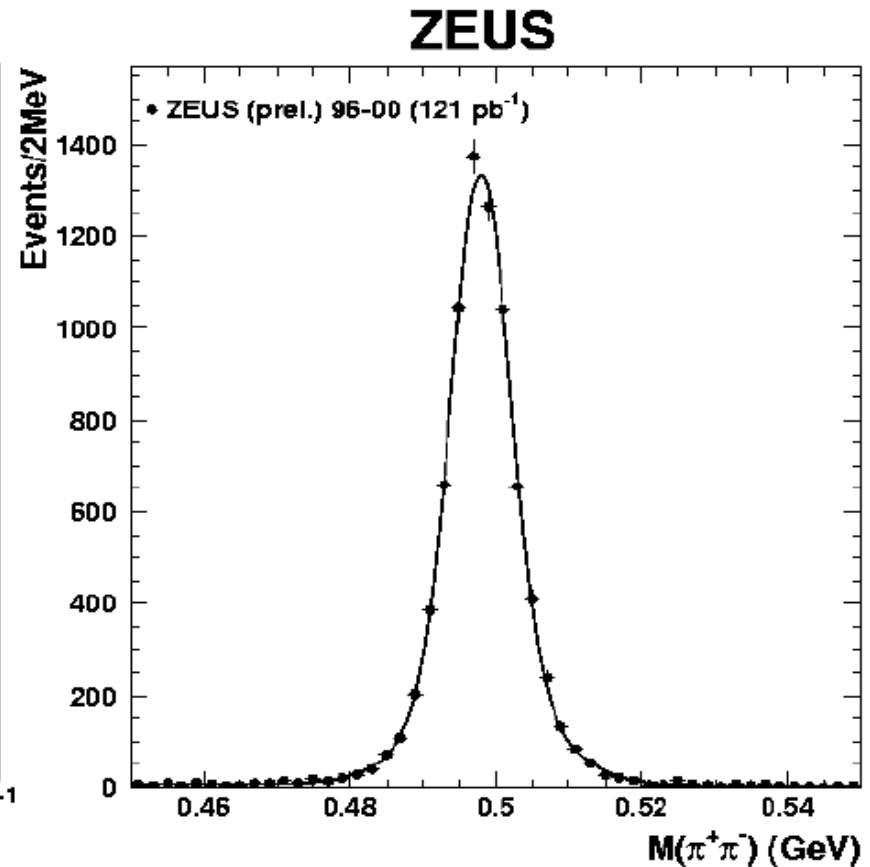
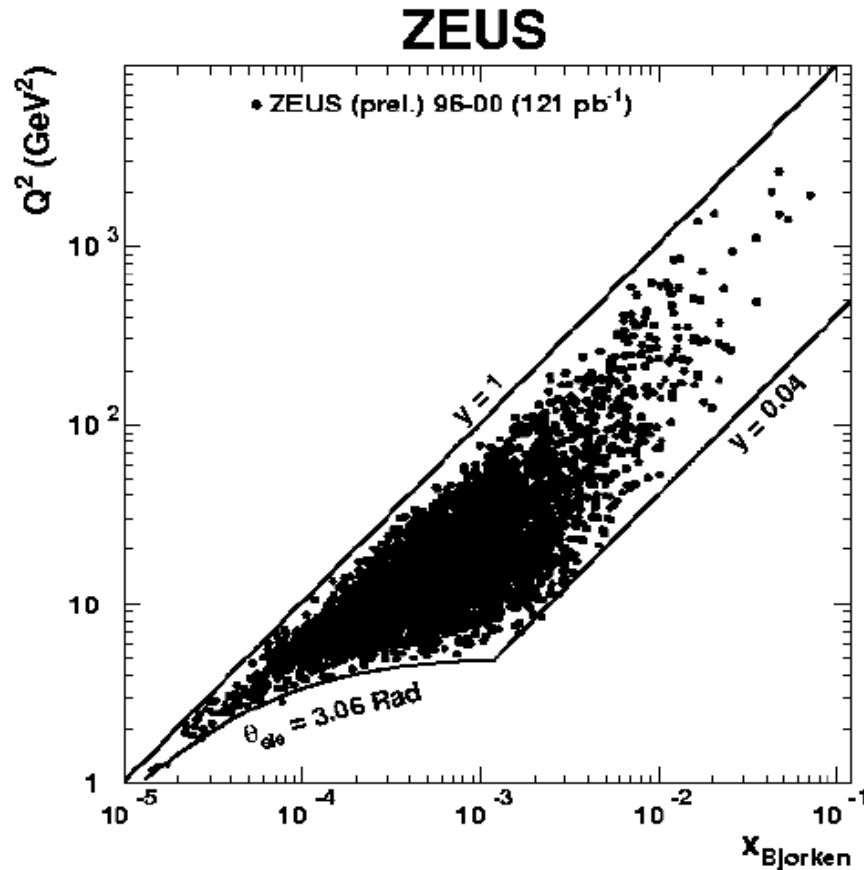
$$a_2^0(1320) \sim u\bar{u} - d\bar{d}$$



$f_0(1710)$ is a glueball candidate

Inclusive $K_S^0 K_S^0$ final state in DIS

- ⇒ A total luminosity of 121 pb^{-1} was used
- ⇒ Only events with at least 2 K_S^0 were selected
- ⇒ Clean K_S^0 sample

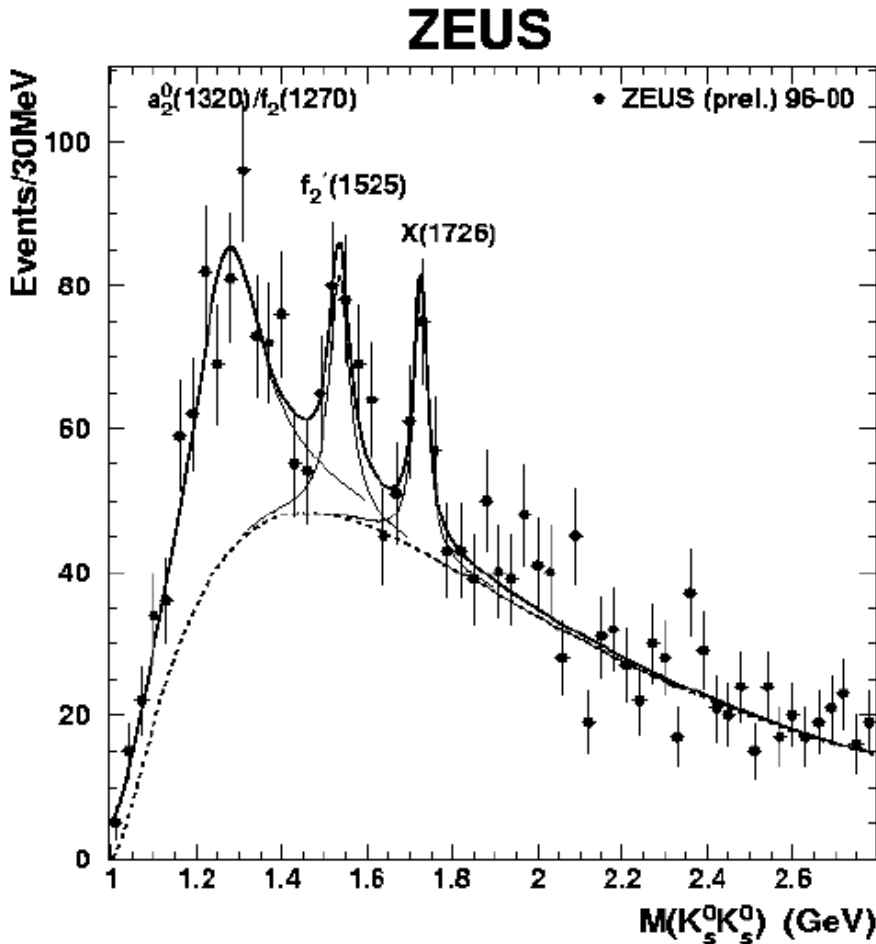


Inclusive $K_S^0 K_S^0$ final state in DIS

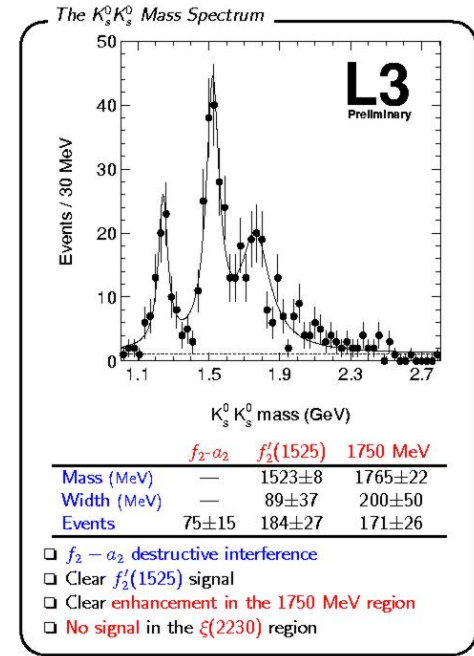
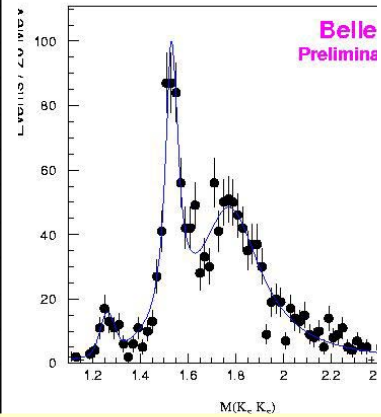
First observation of $J^{CP}=(\text{even})^{++}$ in DIS. Two states are observed

- a state consistent with $f_2'(1525)$
- $X(1726)$ (is this the $f_0(1710)$?)

A third state is observed in the (problematic) 1300 MeV mass region, consistent with the $f_2(1270)/a_2(1320)$ interference



Several states have been observed in the 2GeV region (see PDG02)



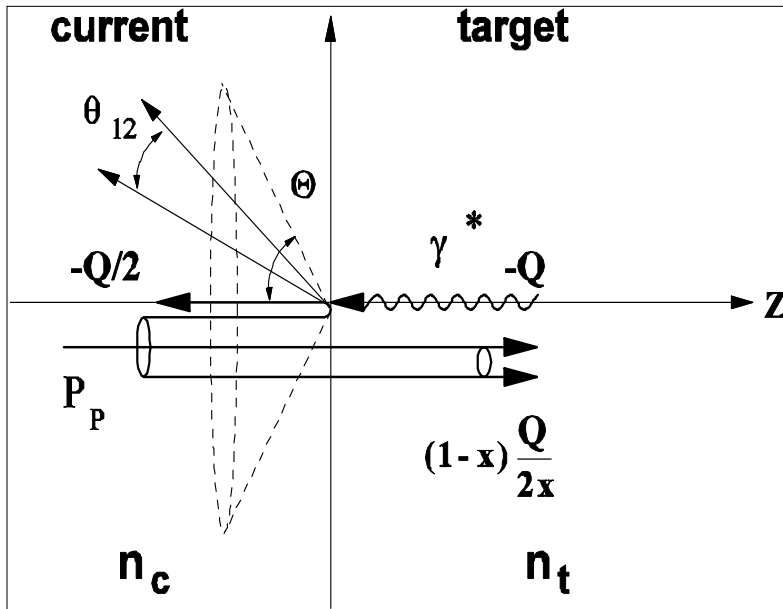
$$F(M) = \frac{dN}{dM} = \sum_{i=1}^3 \left(\frac{N_i}{2\pi} \frac{\Gamma_i}{(M - M_{0,i})^2 + \Gamma_i^2 / 4} \right) + A(M - 2m_{K_S})^B e^{-C\sqrt{M-2m_{K_S}}}$$

Inclusive $K_S^0 K_S^0$ final state in DIS

$\Rightarrow K_S^0 K_S^0$ in the Breit-frame

Current region in DIS is equivalent to an e^+e^- hemisphere

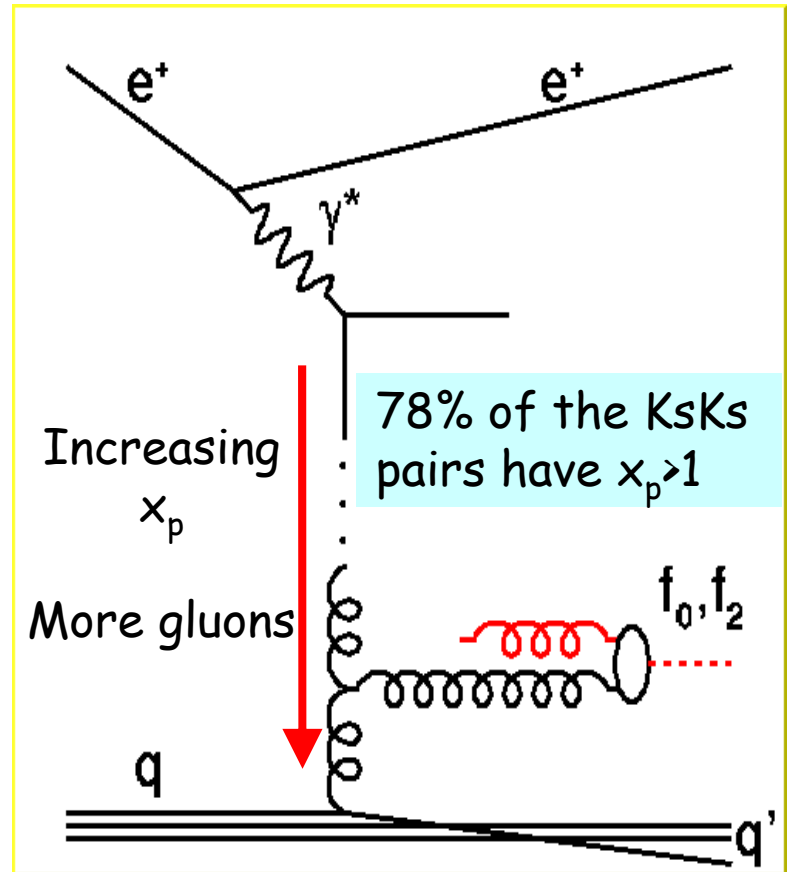
$$2x\vec{p} + \vec{q} = 0$$



$P_z(K_S K_S) < 0$ (7%)

$P_z(K_S K_S) > 0$ (93%)

$$P_q = \frac{Q}{2}, \quad x_p^{MAX} = \frac{P_{K_S K_S}^{MAX}}{P_q} = \frac{1-x}{x}$$

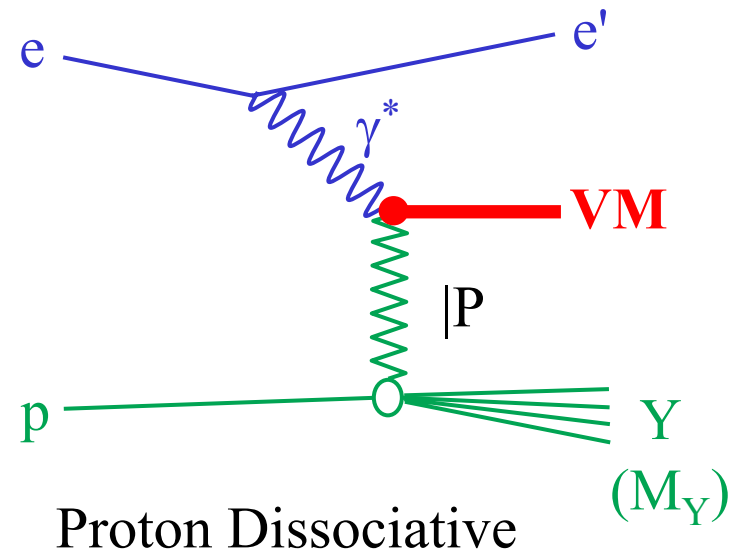
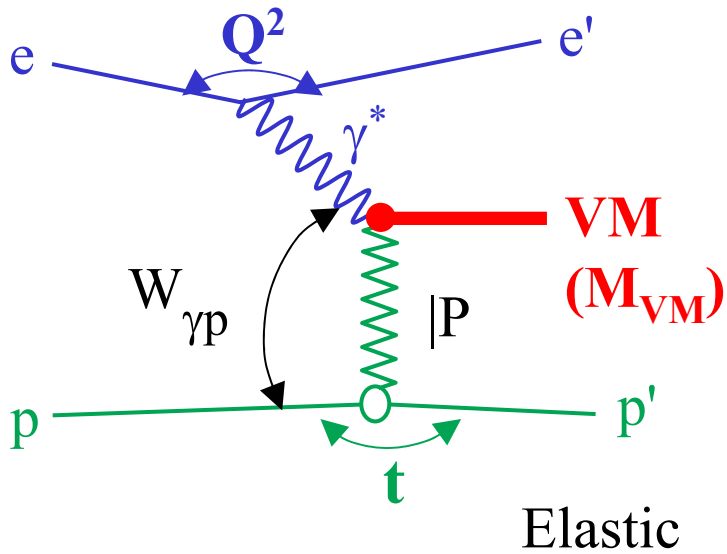


Summary

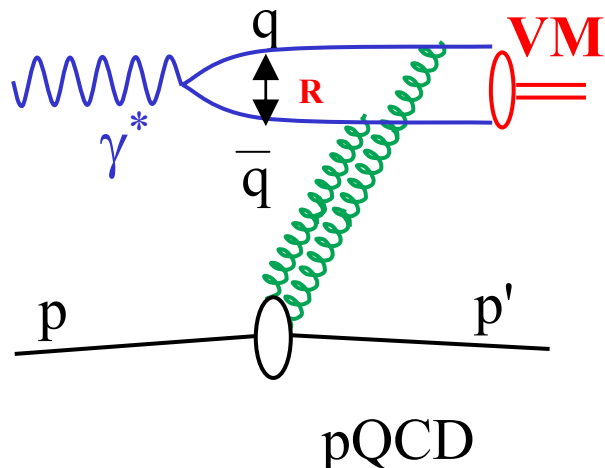
- First observation of resonances in $K_S^0 K_S^0$ final state in DIS was reported
- Two states are observed in the 1300 MeV, 1500 MeV mass region consistent with $f_2(1270)/a_2(1320)$ and $f_2'(1525)$
- Another state X(1726) is observed, probably the $f_0(1710)$ (a glueball candidate)
- States are produced in a gluon rich environment



Vector Meson Production



Hard regime (pQCD)



$$Q^2 = \gamma^* \text{ virtuality; } Q^2 < 100 \text{ GeV}^2$$

$$W_{\gamma p} = \gamma^* p \text{ CMS energy; } 20 < W_{\gamma p} < 290 \text{ GeV}$$

$$t = 4\text{-mom. transf. squared; } |t| < 20 \text{ GeV}^2$$

$$VM = \rho, \omega, \phi, J/\psi, \psi', Y$$

$$R = 1/[z(1-z)Q^2 + m_q^2]^{1/2}; z = E_q / E_{\gamma^*}$$

M. Barbi

Vector Meson Production

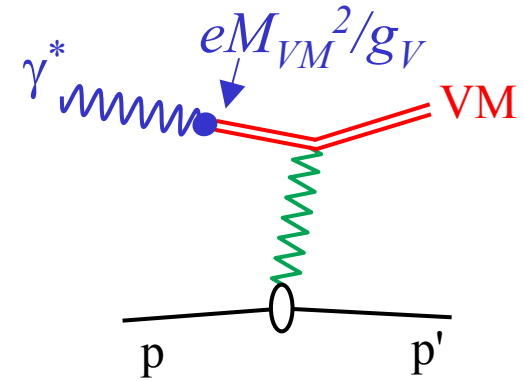
Soft regime (Regge + VMD)

Photon transversally polarized ; low Q^2 or $|t|$

$$\frac{d\sigma}{dt} \propto \left(\frac{W^2}{W_0^2} \right)^{2[\alpha_P(t)-1]} e^{-b_0|t|}$$

$$\alpha_P(t) = \alpha_P(0) + \alpha'_P t = 1.08 + 0.25 t$$

(Donnachie-Landshoff)



$$b(W) = b_0 + 2\alpha'_P \ln \left(\frac{W^2}{W_0^2} \right)$$

(Shrinkage)

σ rising weakly with W :

At low $|t|$, $|t| < 1.5 \text{ GeV}^2$

$$\delta = 0.22$$

$$\sigma(W) \propto W^\delta, \quad \delta \approx 4(\alpha_P(0) - 1 - \alpha'_P/b)$$

σ steep exponential t dependence (shrinkage):

$$\frac{d\sigma}{dt} \propto e^{-b(W)|t|}$$

Vector Meson Production

Hard regime (pQCD)

Photon mainly longitudinally polarized

Large Q^2 , M_{VM} or $|t|$ $\bar{q}q$ system is small, probes the proton

Two-gluon-exchange approach at LO

Gluon ladder (LLA approach)

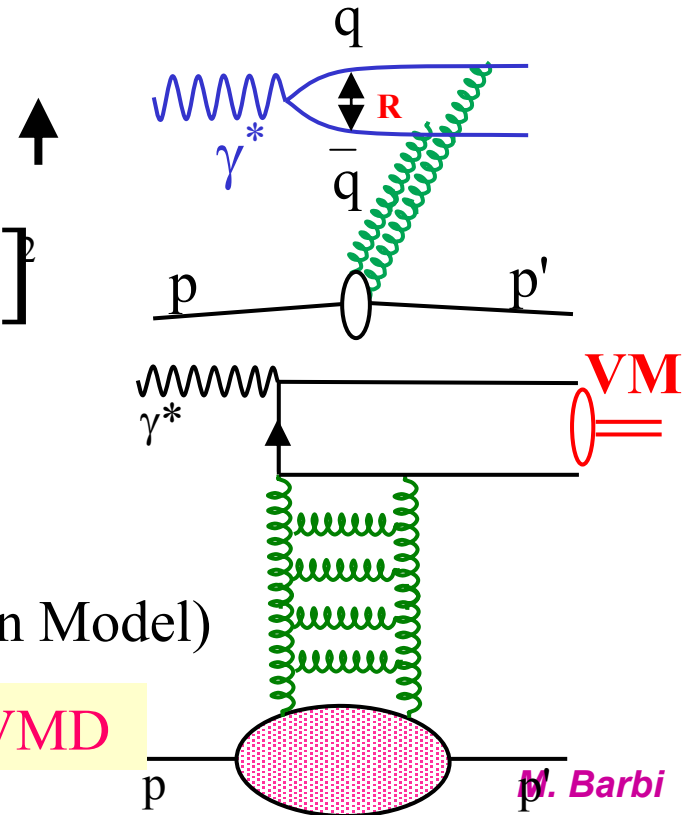
$$\sigma_L \propto \left[\frac{1}{Q^6} \right] \alpha_s^2(Q_{eff}) \left[xg(x, Q_{eff}^2) \right]^2 \approx \left[x^{0.2} \right]^2$$

$$\approx W^{0.8}, \quad \left(x \approx 1/W^2 \right) \quad \text{Gluon from } F_2 \text{ scaling violations}$$

At which scale Q_{eff}^2 should xg be evaluated ?

For ex.: $Q_{eff}^2 = \frac{1}{4} \cdot (Q^2 + M_{VM}^2 + |t|)$ (Ryskin Model)

σ rising steeper than expected from Regge+VMD

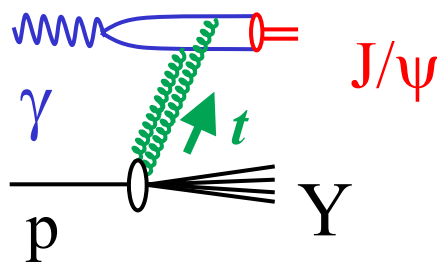


Vector Meson Production

Photoprod. of proton-dissoc. VM at high $|t|$

Dependence at large $|t|$ not exponential:

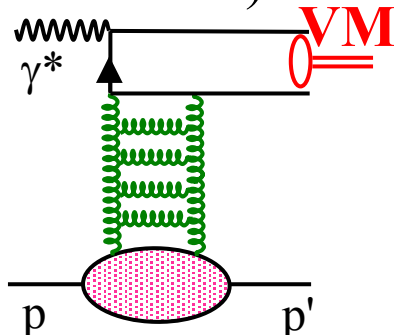
$$\frac{d\sigma}{d|t|} \propto |t|^{-n}$$



\Rightarrow indication that large $|t|$ may provide a hard scale to apply perturbative QCD

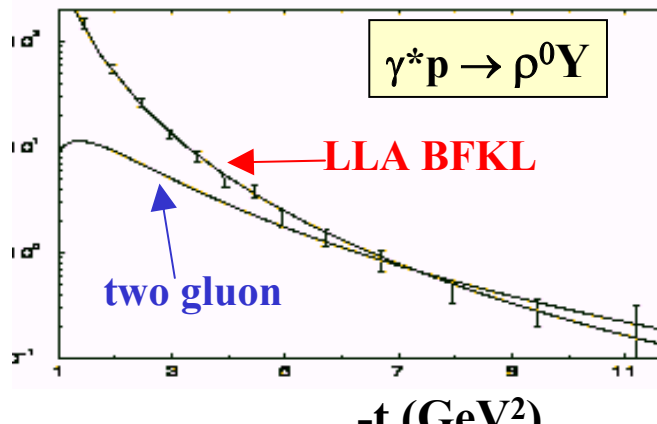
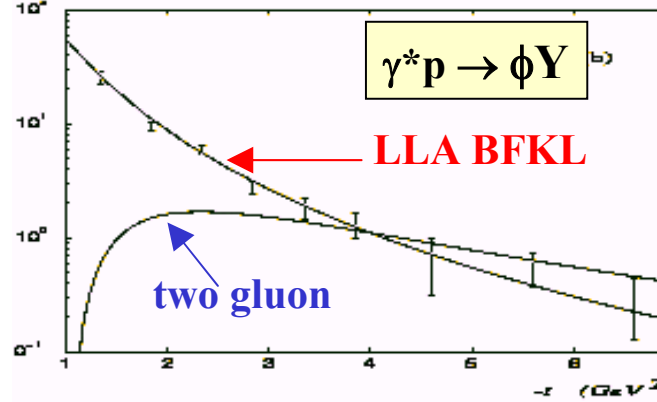
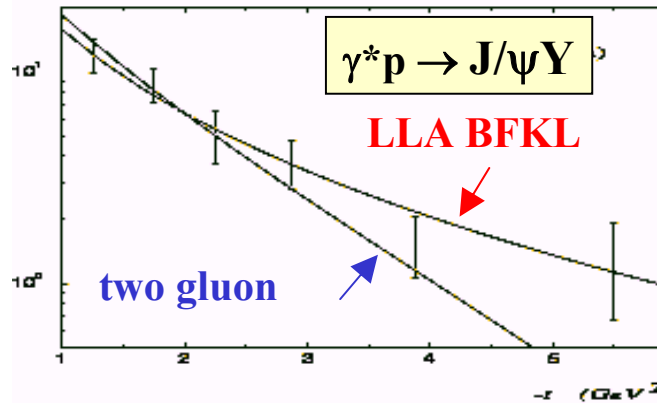
Forshaw and Poludniowski fitted the ZEUS data for p-dissociative photoproduction of ρ^0 , ϕ and J/ψ mesons (hep-ph/0107068):

> **BFKL LLA approach: consistent with data**



> **two-gluon-exchange approach at LO: inadequate**

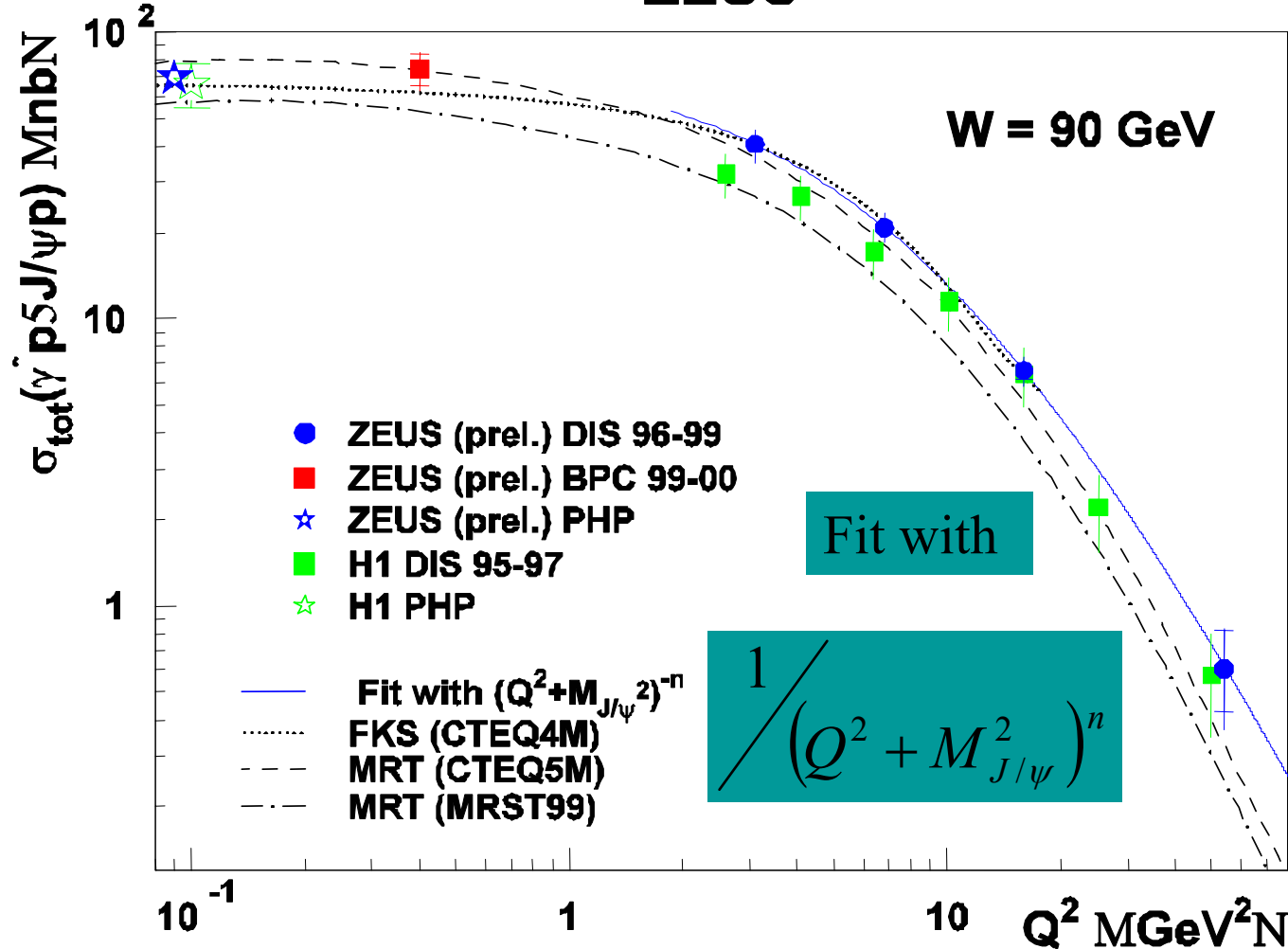
$d\sigma/dt$ (nb/GeV²)



Vector Meson Production

J/ ψ cross-section and QCD models (PhP and DIS)

ZEUS



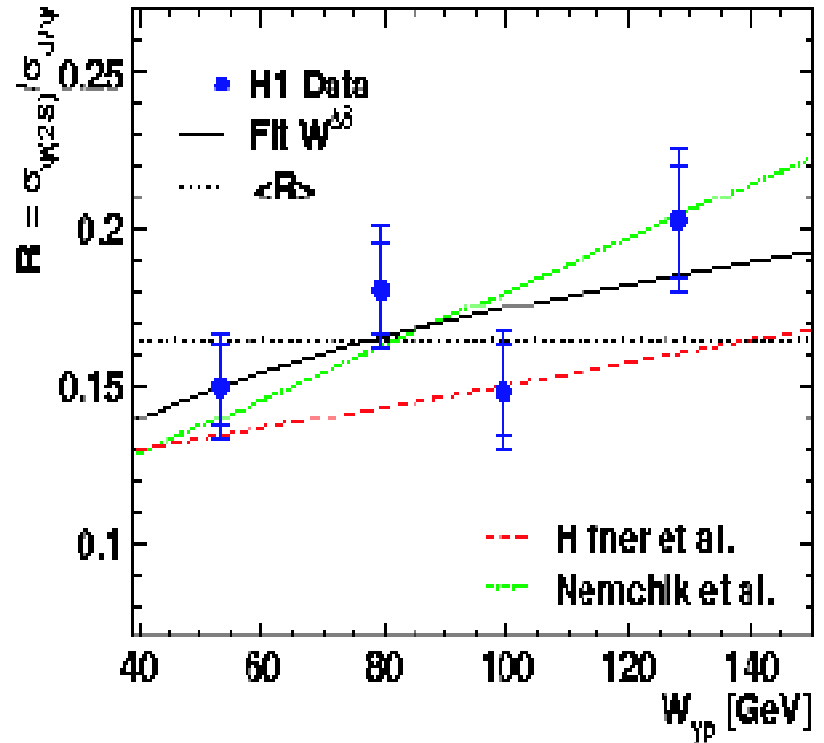
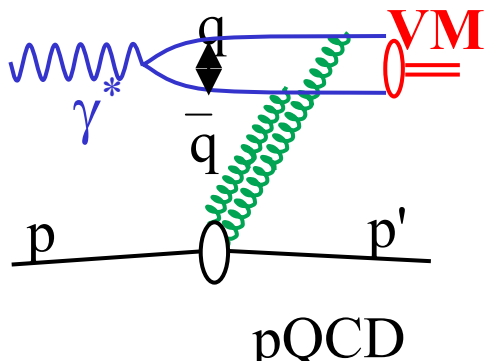
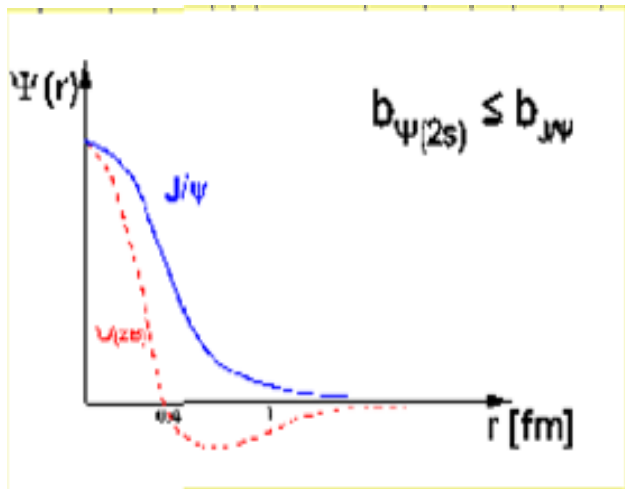
⇒ QCD models FKS and MRT(CTEQ5M) are in good agreement with data M. Barbi

Vector Meson Production

Diffractive Photoproduction of $\psi(2S)$ - pQCD

- Cross-section suppressed with respect to that of J/ψ
- Steeper W dependence

$\psi(2S)$ wavefunction has a node

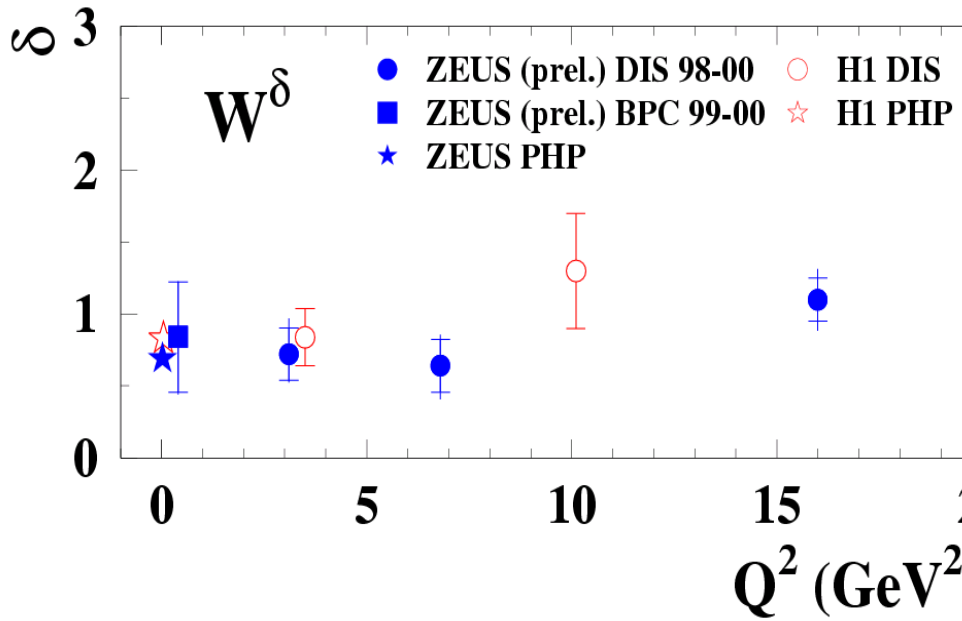
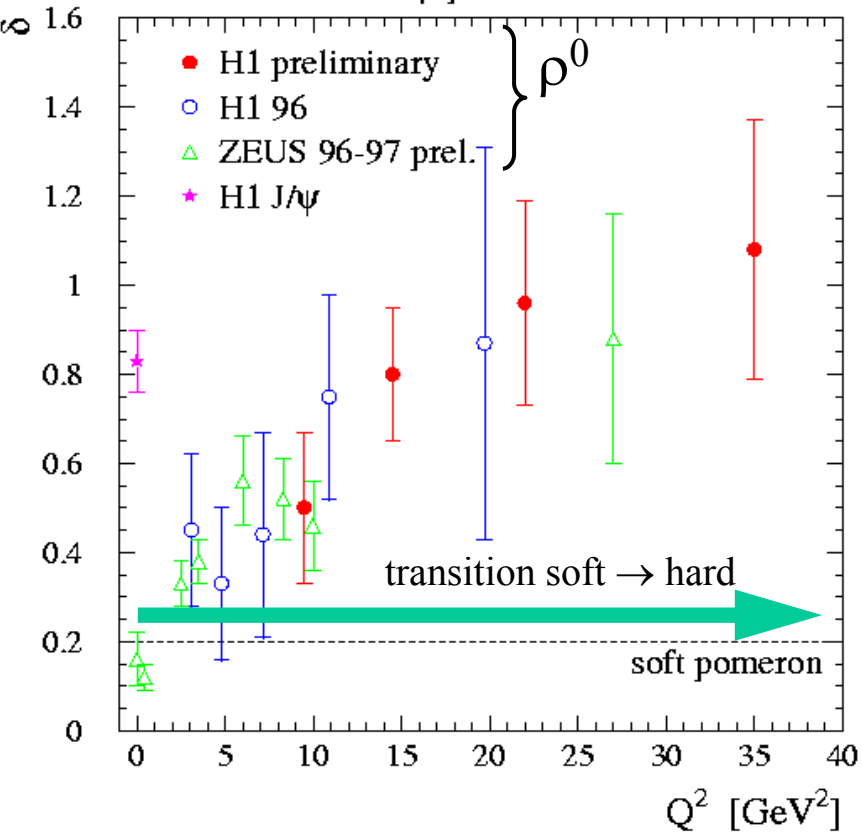


- Overall $R \approx 0.166$ consistent with pQCD prediction
- Fit $W^{\Delta\delta} \Rightarrow \Delta\delta \approx 0.24$ consistent with W dependence for $\psi(2S)$

Vector Meson Production

W-dependence of elastic ρ^0 and J/ψ in bins of Q^2 (PhP and DIS)

Fit $\sigma \propto W^\delta$:

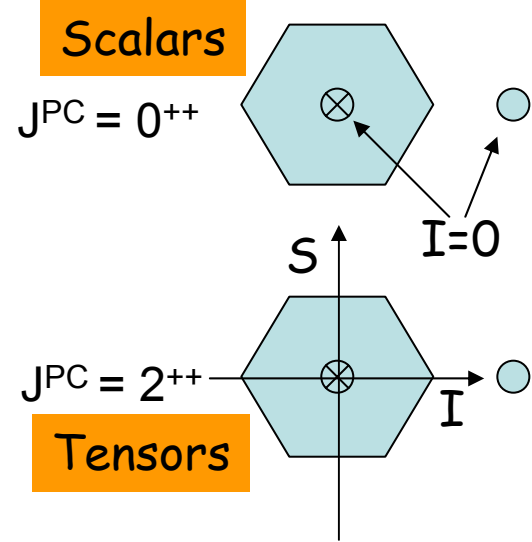
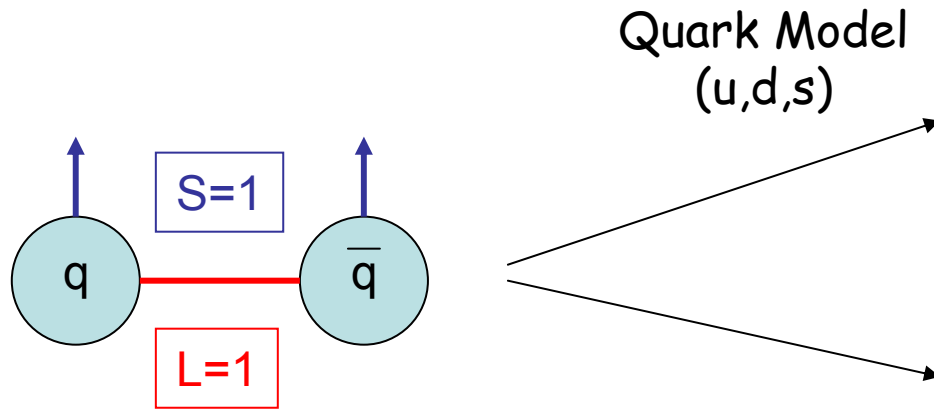


J/ψ already steep at $Q^2 = 0$

$\Rightarrow Q^2$ provides a hard scale

Extras..... KsKs final state

Scalar and Tensor Mesons



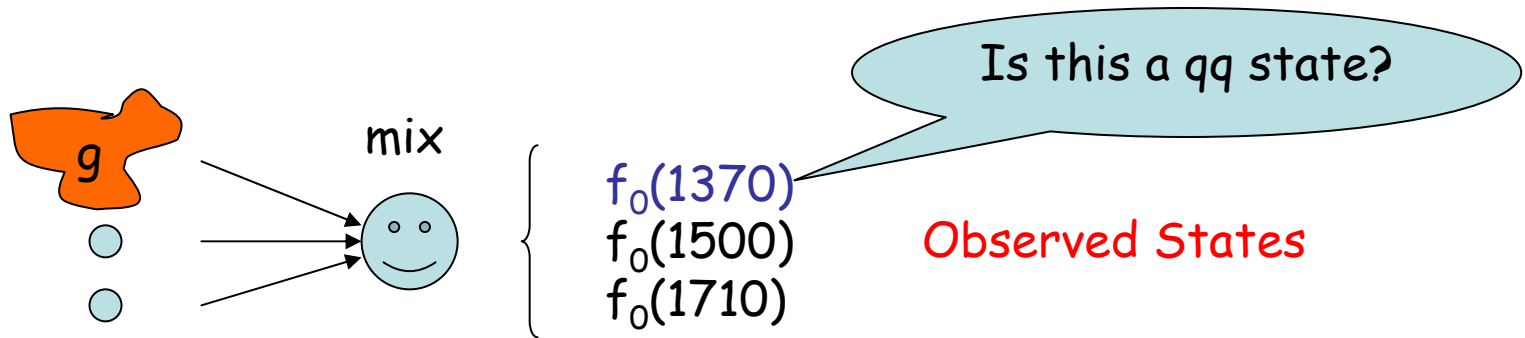
$$P = (-1)^{\chi(+1)\chi(-1)^L} = (-1)^{L+1}$$

$$C = (-1)^{L+S}$$

$$J = 0 \text{ or } 2$$

Masses 1-2 GeV, scalar and tensor mesons *much heavier* than the pseudoscalars

QCD: richer than Quark Model, predicts gluon states with $J^{PC} = 0^{++}, 2^{++}, I=0$



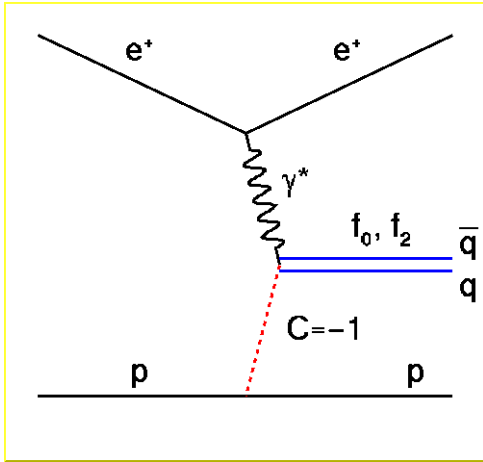
Ks: has $S=L=0, P=-1, C=+1$

KsKs: has $P=+1, C=+1 \rightarrow J=\text{even}$

KsKs final state couples only to $J^{PC}=(\text{even})^{++}$ and it is CLEAN.
This is the golden channel (given statistics) to look for scalar
and tensor meson resonances

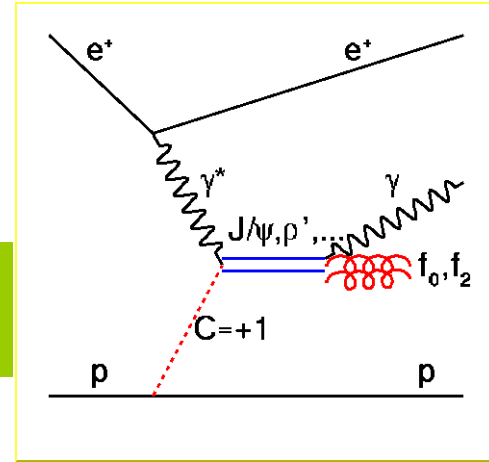
Production mechanisms in DIS

Gluon poor processes

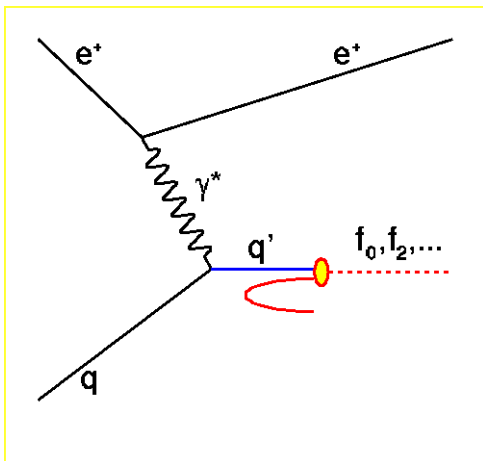


Odderon Exchange

VM Radiative decays

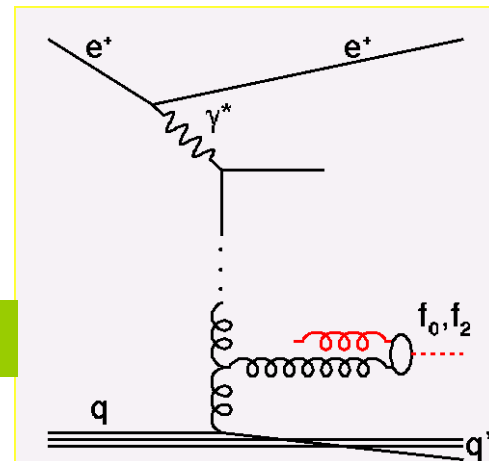


Gluon rich processes



In quark Jets

In gluon jets

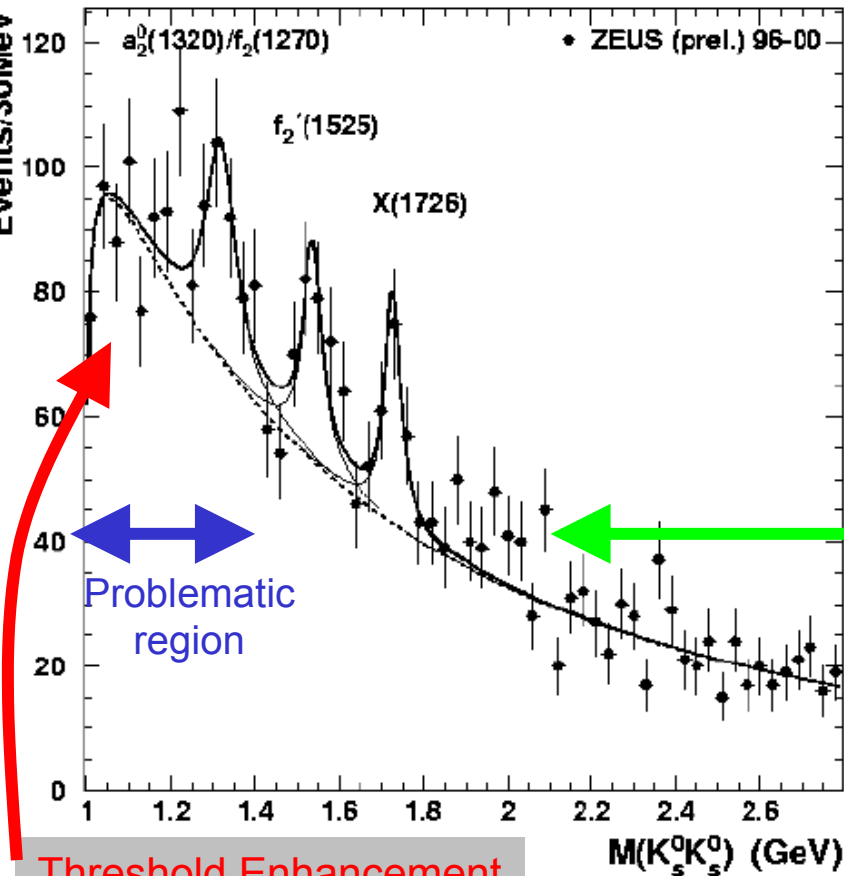


$K_S^0 K_S^0$ final state in DIS

First observation of $J^{CP}=(\text{even})^{++}$ in DIS. Two states are observed:

- a state consistent with $f_2(1525)$
- $X(1726)$ (is this the $f_0(1710)$?)

ZEUS



Fit 3 Breit-Wigner and a backg. function

$$F(M) = \frac{dN}{dM} = \sum_{i=1}^3 \left(\frac{N_i}{2\pi} \frac{\Gamma_i}{(M - M_{0,i})^2 + \Gamma_i^2 / 4} \right) + A(M - 2m_{K_S})^B e^{-C\sqrt{M-2m_{K_S}}}$$

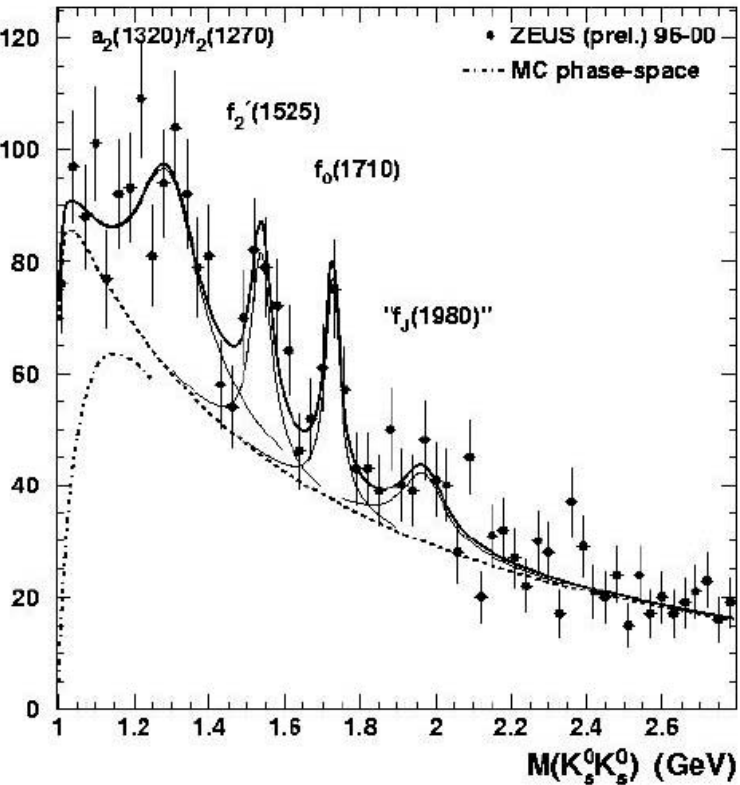
Several states have been observed in the 2GeV region (see PDG02)

$f_0(980)/a_0(980)$ gives K_S pair with very small opening angle in the lab. We would like to remove collinear K_S pairs and then fit the spectrum.

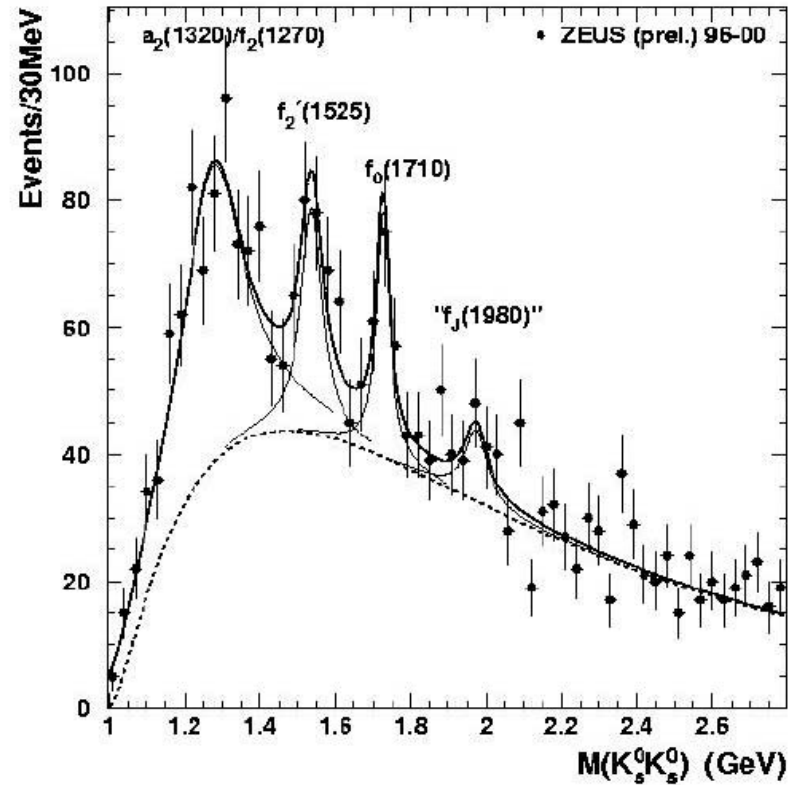
Threshold Enhancement due to $f_0(980)/a_0(980)$

Observation of J -even meson resonances in ep

ZEUS



ZEUS

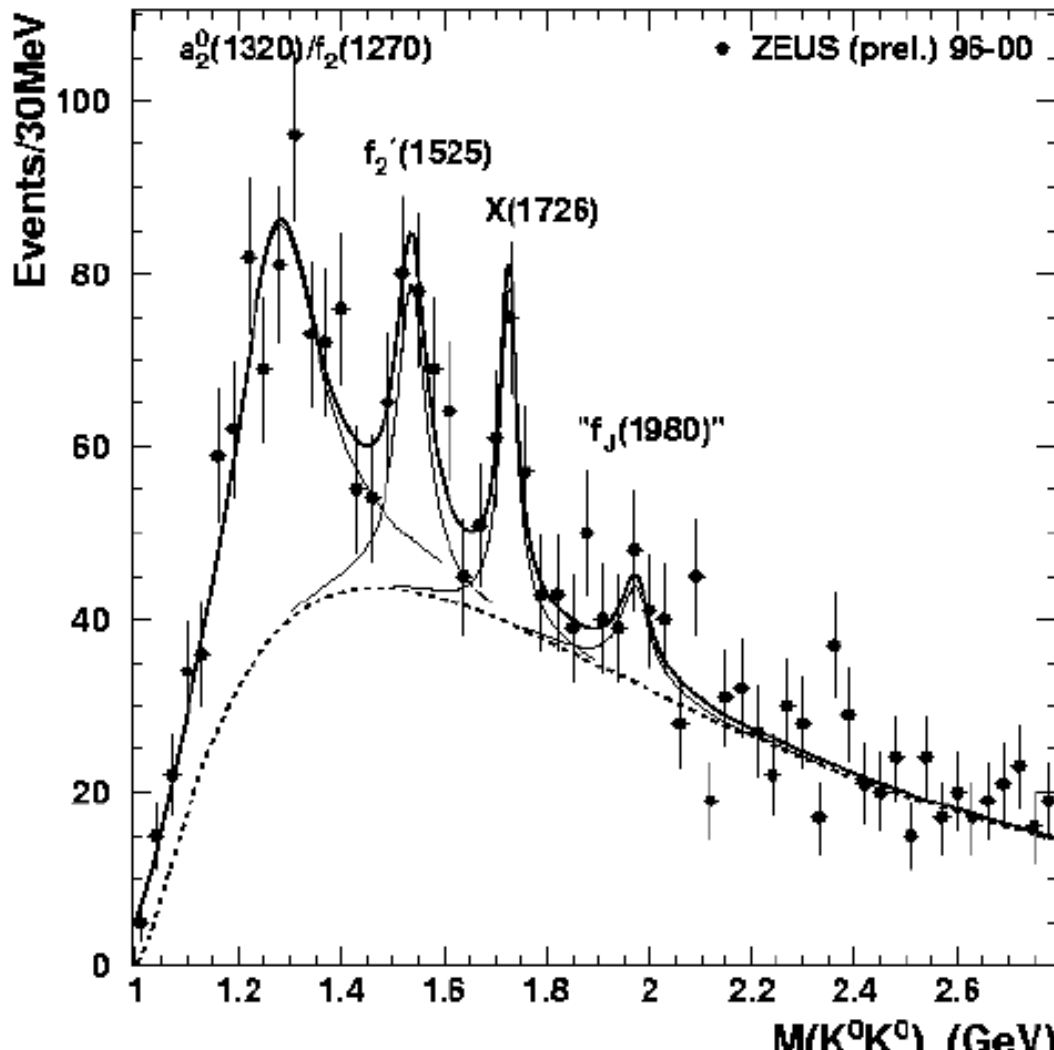


$\cos KK < 0.92$ cut

$K_S^0 K_S^0$ final state in DIS

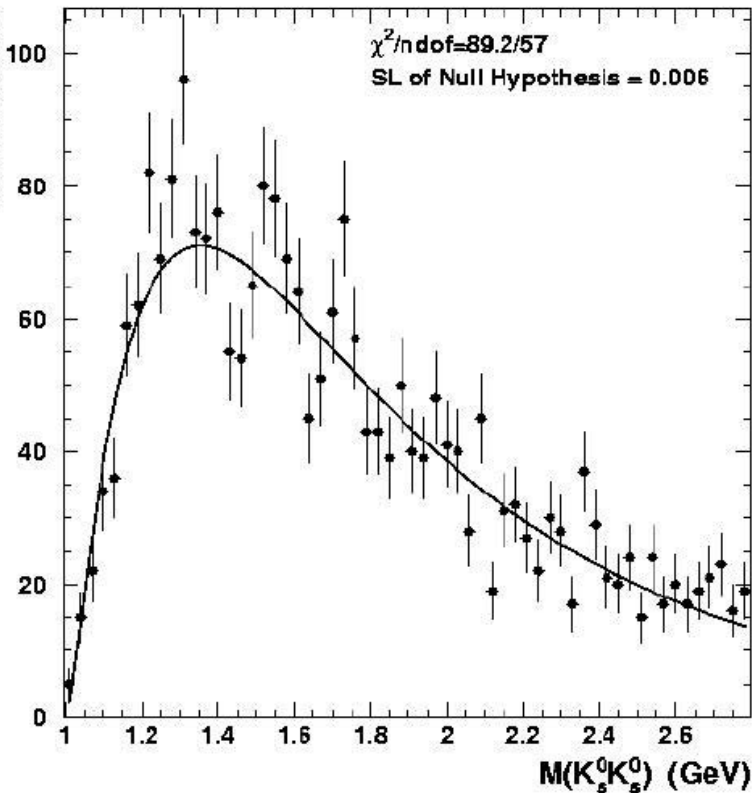
⇒ Attempt to include the 1980 MeV mass region

ZEUS



How well a smooth background describes the data:

ZEUS

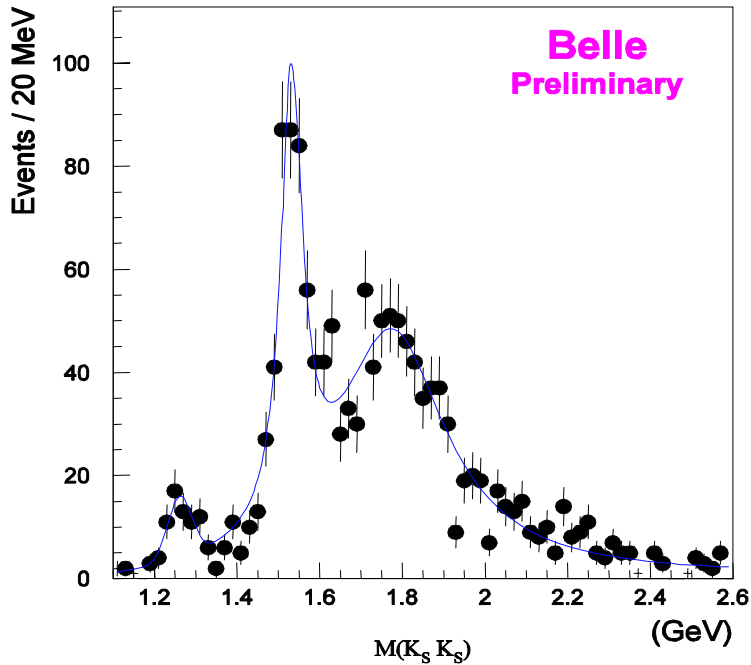


$$SL \approx \frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\chi^2} - \sqrt{2n-1}}^{\infty} e^{-x^2/2} dx$$

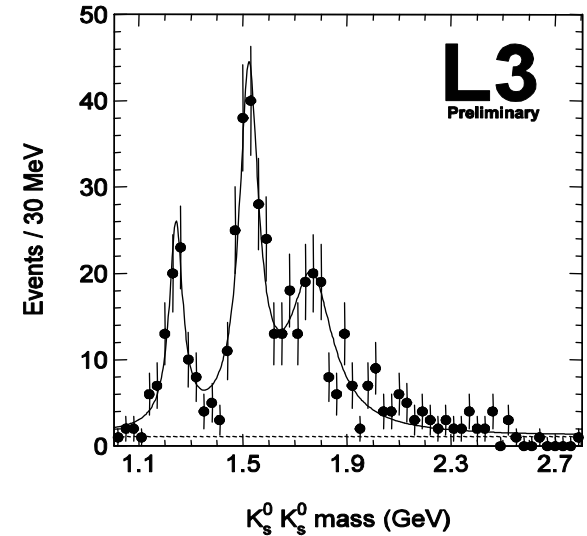
It is less than 1% likely that a smooth distribution describes the data.

$$e^+e^- \rightarrow \gamma\gamma \rightarrow K_s K_s$$

If $f(1710)$ is a glueball it should have small coupling to $\gamma\gamma$



The $K_s^0 K_s^0$ Mass Spectrum



	$f_2 - a_2$	$f_2'(1525)$	1750 MeV
Mass (MeV)	—	1523 ± 8	1765 ± 22
Width (MeV)	—	89 ± 37	200 ± 50
Events	75 ± 15	184 ± 27	171 ± 26

- $f_2 - a_2$ destructive interference
- Clear $f_2'(1525)$ signal
- Clear enhancement in the 1750 MeV region
- No signal in the $\xi(2230)$ region