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

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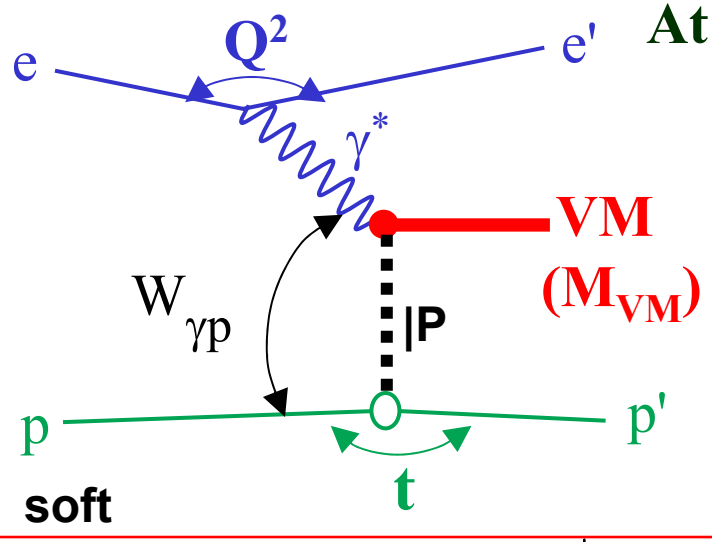
Outline:

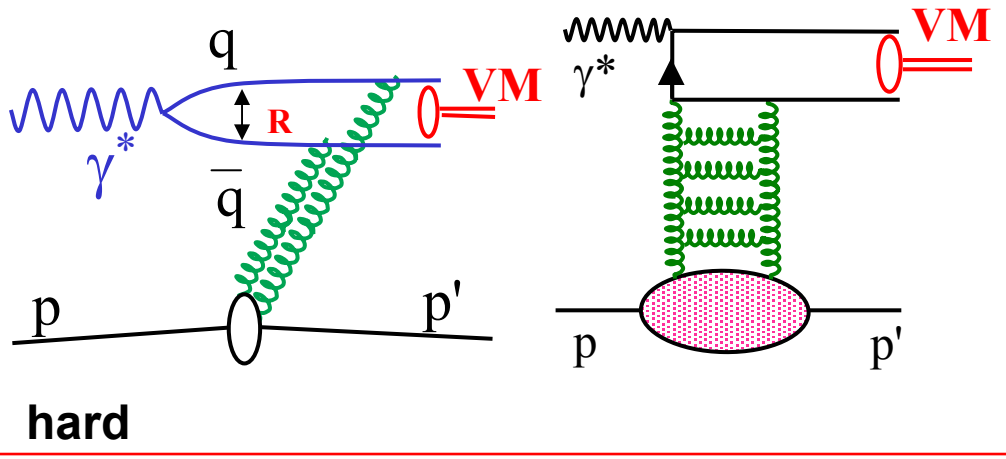
- ¥ Exclusive vector meson production
- ¥ Summary
- First observation of resonances in inclusive $K_S^0 K_S^0$ final state in DIS
- Summary

Exclusive Vector Meson Production

At HERA:

VM = ρ, ω, ϕ, J/y , ψ(2S), etc





Soft (Regge + VDM)		Hard (pQCD)
$d\sigma/dt \propto W^{4(\alpha_P(t)-1)} e^{-b(W)\|t\|}$ $\alpha_P(t) = \alpha_P(0) + \alpha'_P\, t$ At low |t| ⇒ $\sigma(W) \propto W^{0.22}$	Cross section $\sigma(W) \propto W^{\delta}$	$\sigma \propto \left[xg(x, Q^2_{eff})\right]^2$ $x \approx 1/W^2$ Gluon from fit to F_2 scaling violation ⇒ $\sigma(W) \propto W^{0.8}$
———	Scale	Q^2 , |t| , M_{VM}^2
$b(W) = b_0 + 4\alpha' \ln W$ $b \propto R^2$	Transv. size of the interaction region	Small size. No W dependence.

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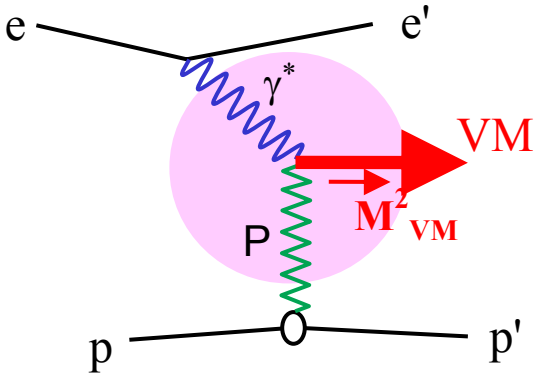
Exclusive Vector Meson Production

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



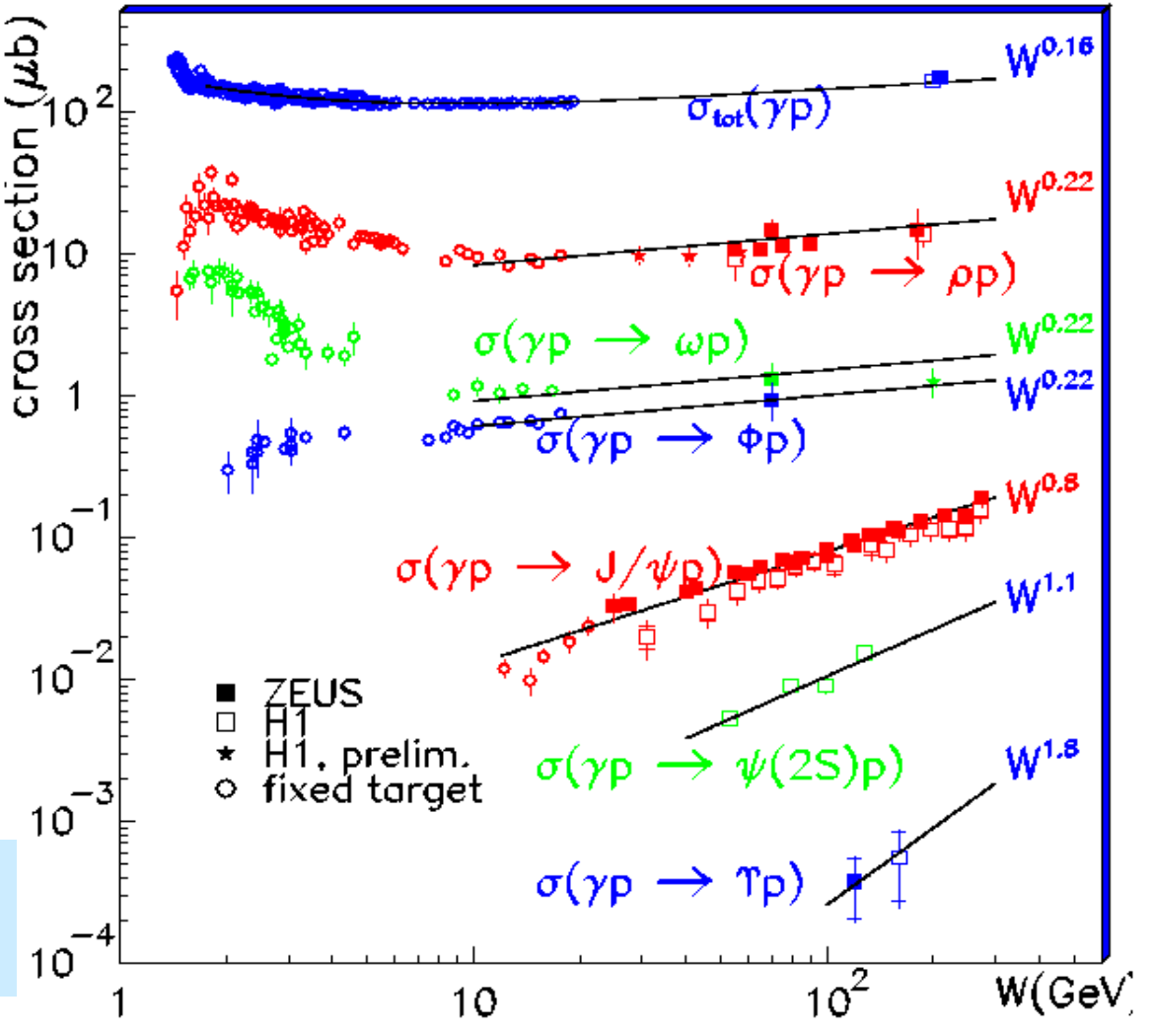
Fit $\sigma \propto W^{\delta}$:

$\delta \approx 0.22$ for ρ^0, ω, ϕ

$\delta \approx 0.8$ for J/ψ

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

A first look:



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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 ⇐ previous slide)

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

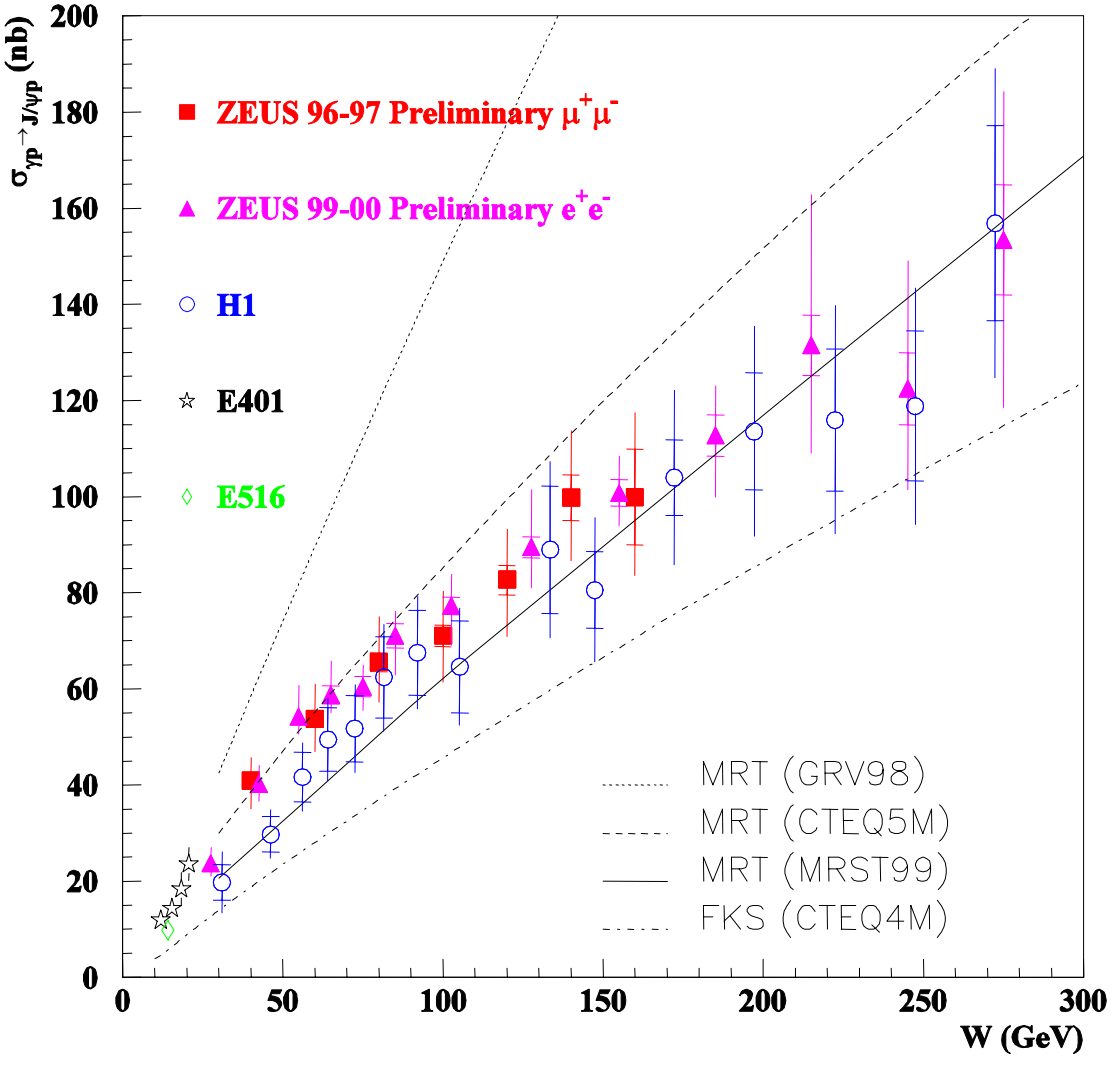
Models sensitive to input parametrisation of the gluon density

Models with

$$\sigma \propto \left[xg(x,Q^2_{eff})\right]^2$$

in reasonable agreement with data

Indeed, M_{VM} is a hard scale



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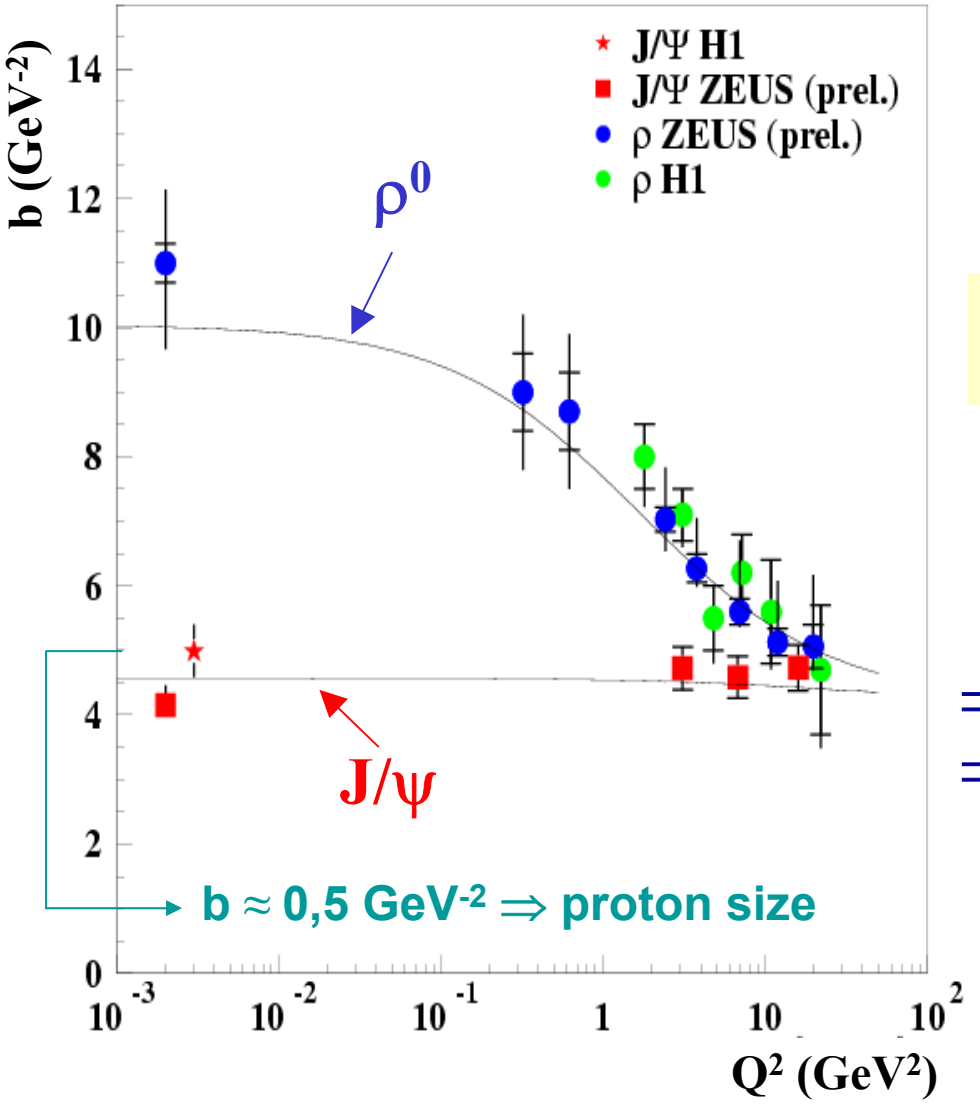
Exclusive Vector Meson Production

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



Can Q2 provide a hard scale?

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

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

R is the transverse size of the interaction region

⇒ **R** decreases with Q^2 for ρ^0

⇒ **R** already small for **J/ψ** at small Q^2

And the power-law W^δ dependence? ⇒

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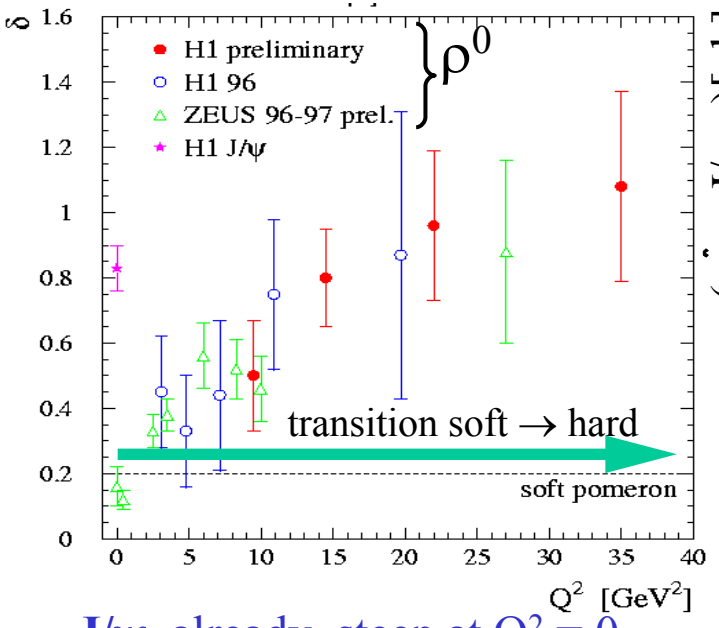
Exclusive Vector Meson Production

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

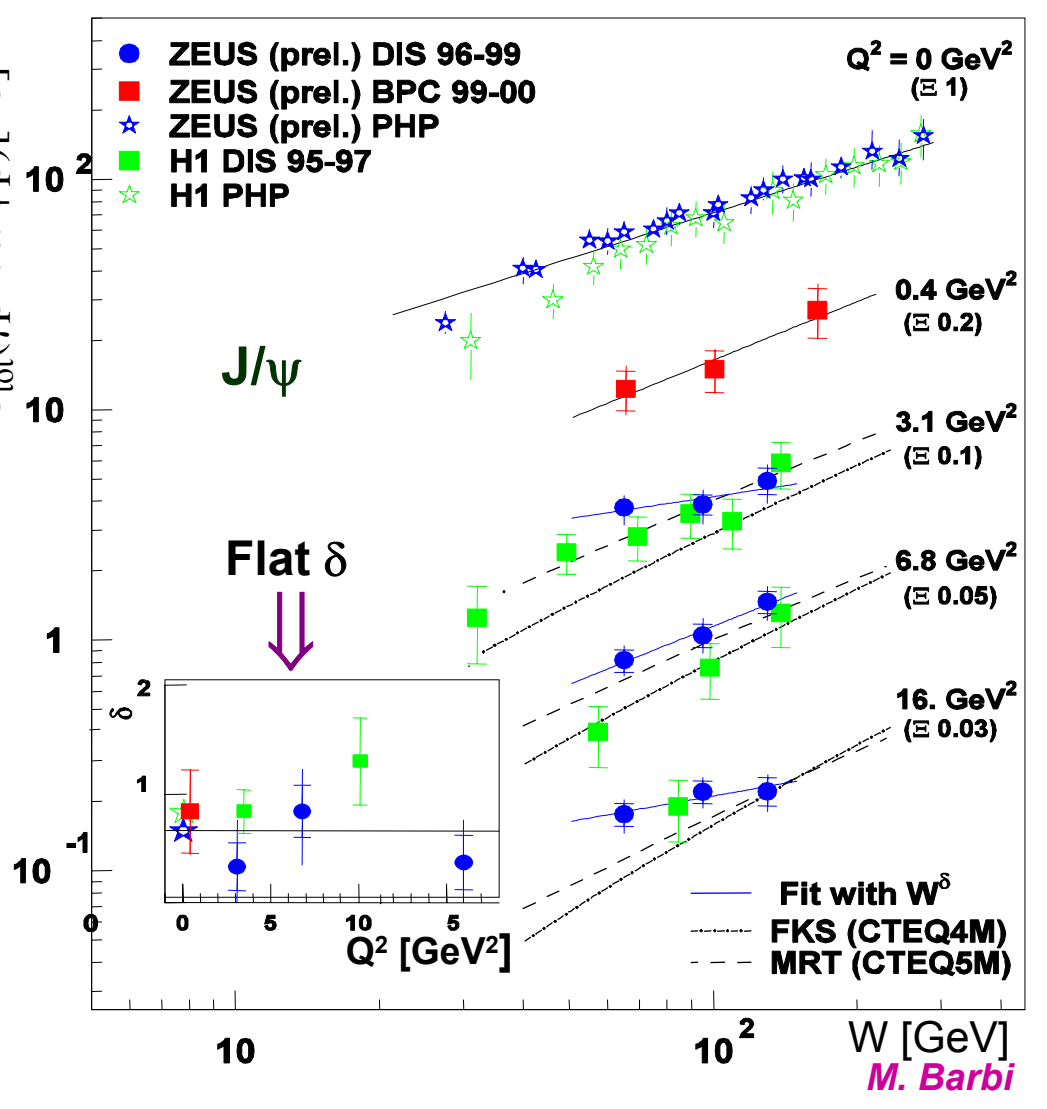
Can Q^2 provide a hard scale?



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.



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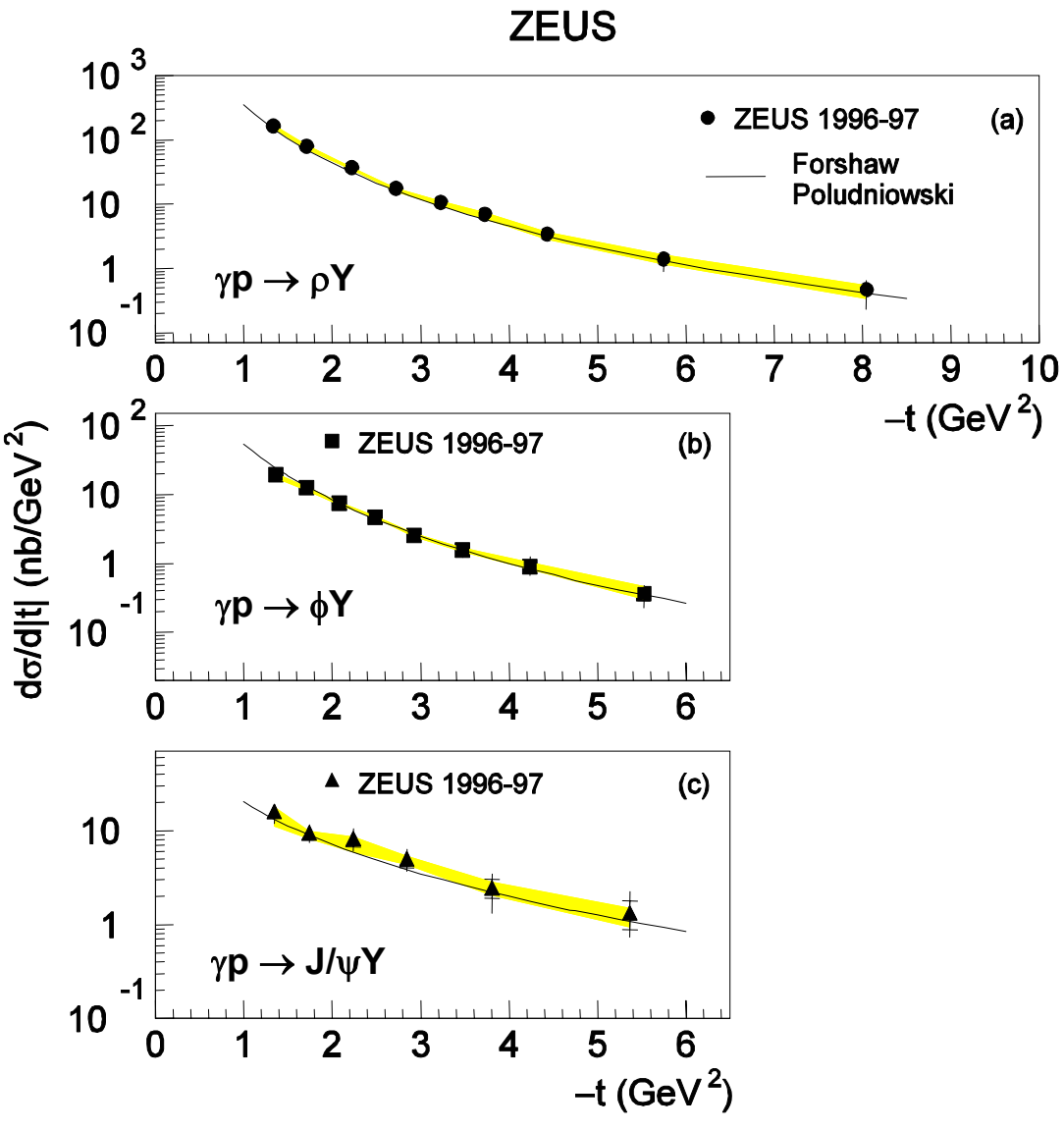
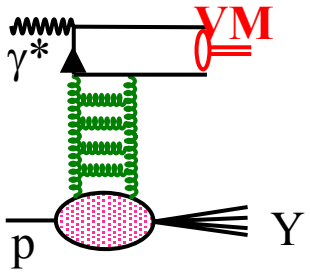
Exclusive Vector Meson Production

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



What about |t|?

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

⇓

⇒ **|t| sets a hard scale**

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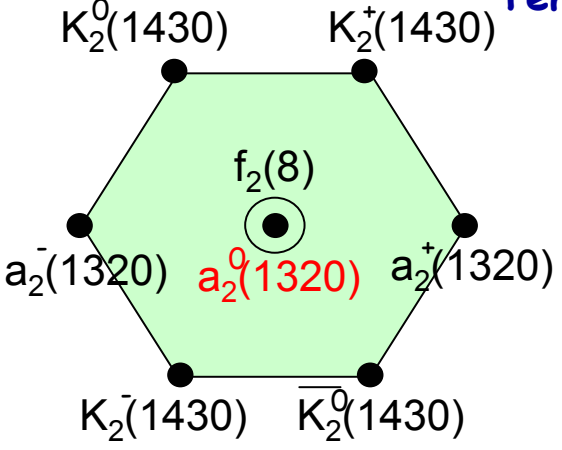
Summary

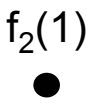
- Q^2 , M_{VM}^2 and $|t|$ set a hard scale.
- Perturbative QCD predictions agree with data

Inclusive $K_S^0K_S^0$ 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.**
- $K_S^0K_S^0$ couples to meson states with $J^{CP}=(even)^{++}$

Tensor $J^{CP}=2^{++}$ Nonet



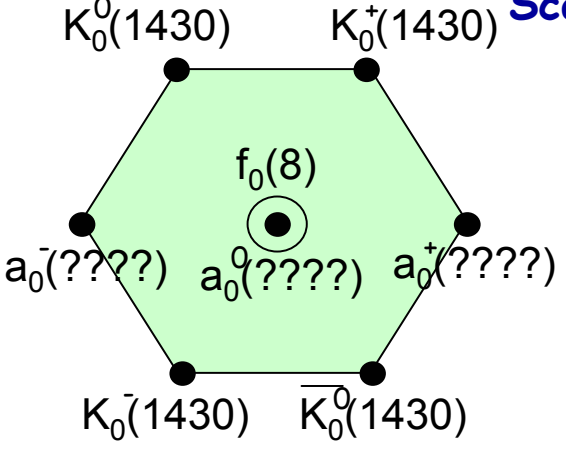


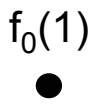
$f_2(8)$ → $f_2(1270) \sim u\bar{u}+d\bar{d}$

$f_2(1)$ → $f_2(1525) \sim s\bar{s}$

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

Scalar $J^{CP}=0^{++}$ Nonet **3 candidates for 2 spots**





$f_0(8)$ → $f_0(1370) \sim u\bar{u}+d\bar{d}$

$f_0(1)$ → $f_0(1500) \sim ??$

$f_0(1710) \sim s\bar{s}$

$f_0(1710)$ is a glueball candidate

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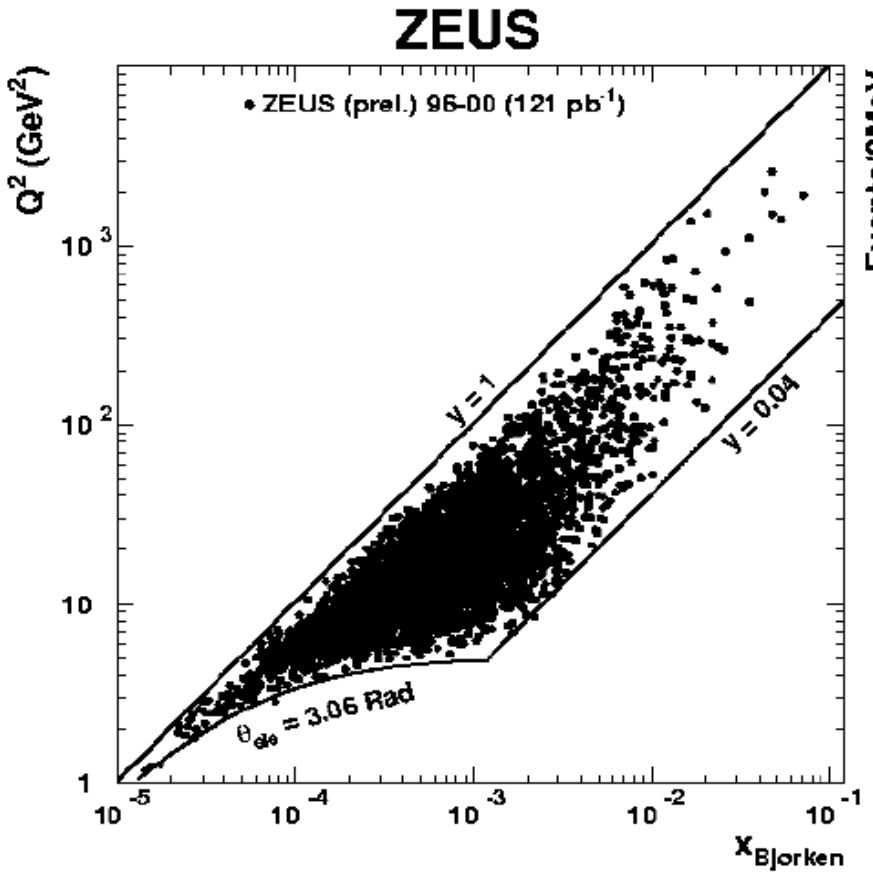
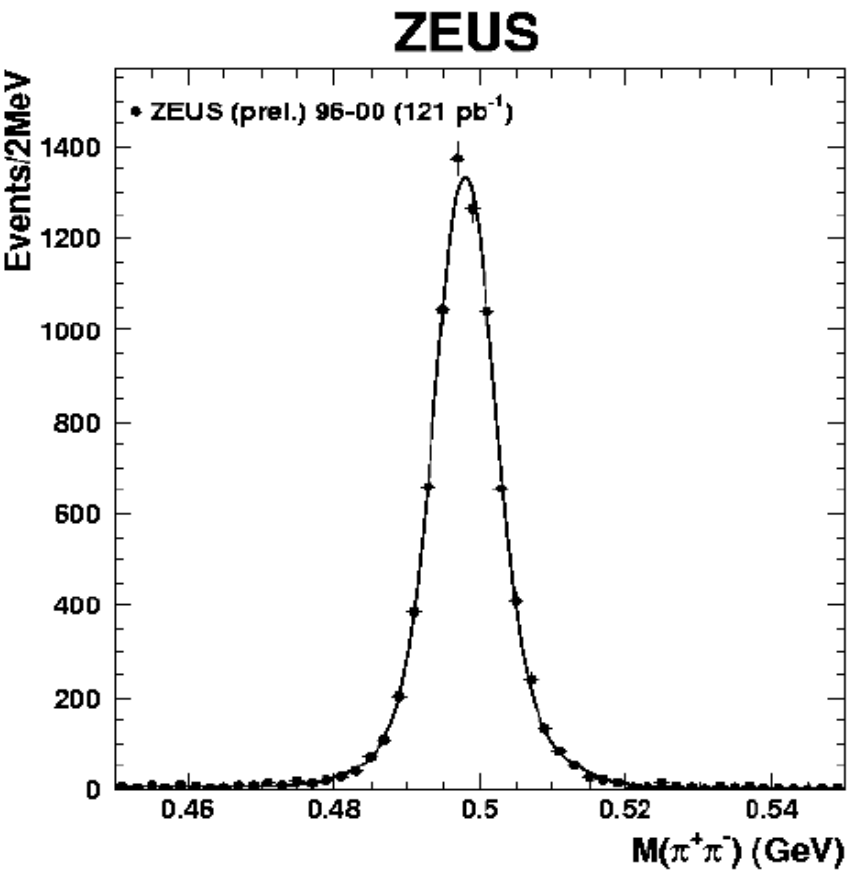
Inclusive $K_S^0 K_S^0$ final state in DIS

⇒ 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





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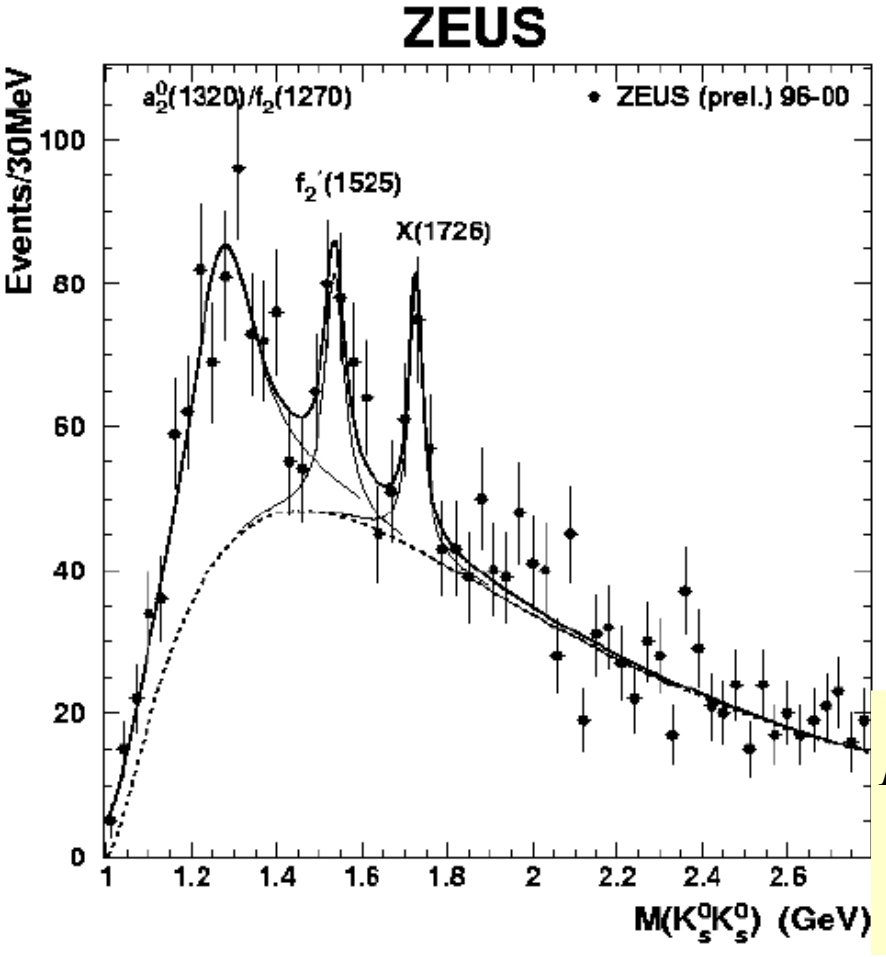
Inclusive $K_S^0 K_S^0$ final state in DIS

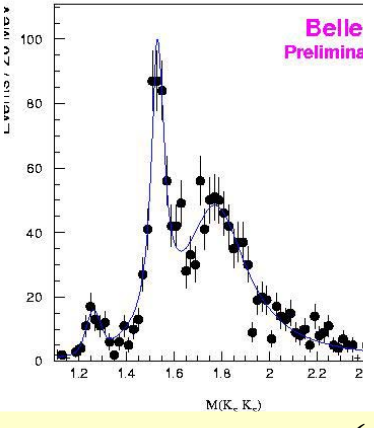
First observation of $J^{CP}=(even)^{++}$ in DIS. Two states are observed

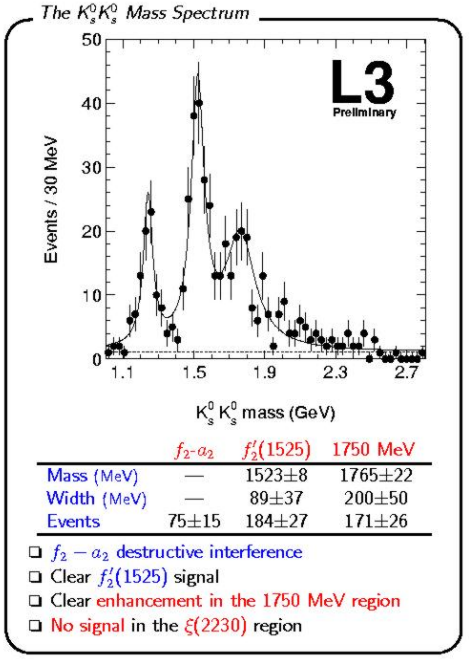
- **a state consistent with $f_2'(1525)$**
- **X(1726) (is this the $f_0(1710)$?)**

A third state is observed in the (problematic) 1300 MeV mass region, consistent with the f2(1270)/a2(1320) interference



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





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

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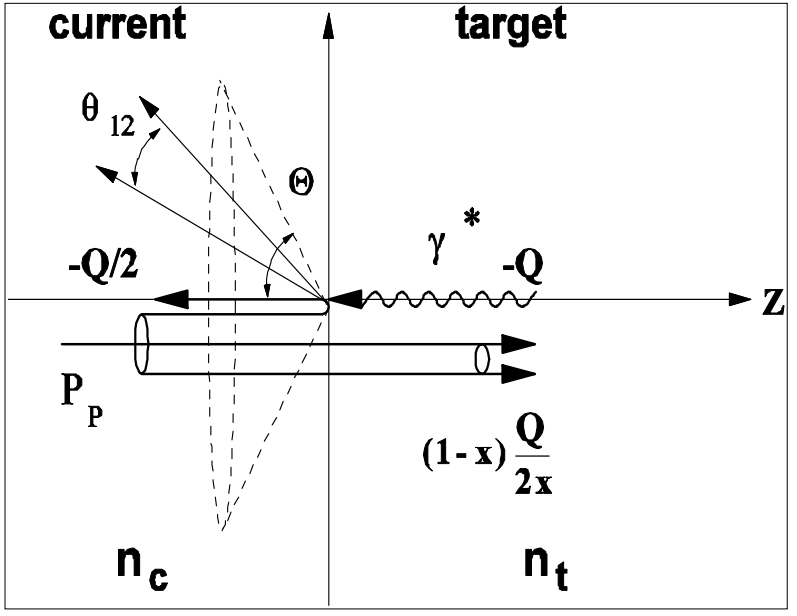
Inclusive $K_S^0K_S^0$ final state in DIS

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

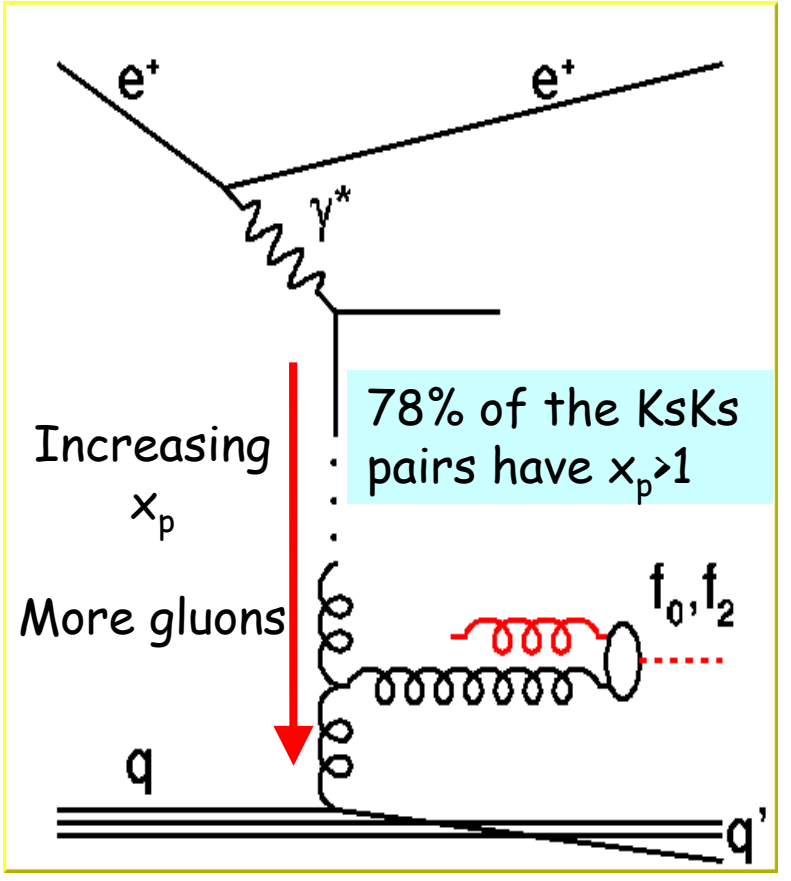
Current region in DIS is equivalent to an e^+e^- hemisphere

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



$P_z(KsKs)<0$ (7%) $P_z(KsKs)>0$ (93%)

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



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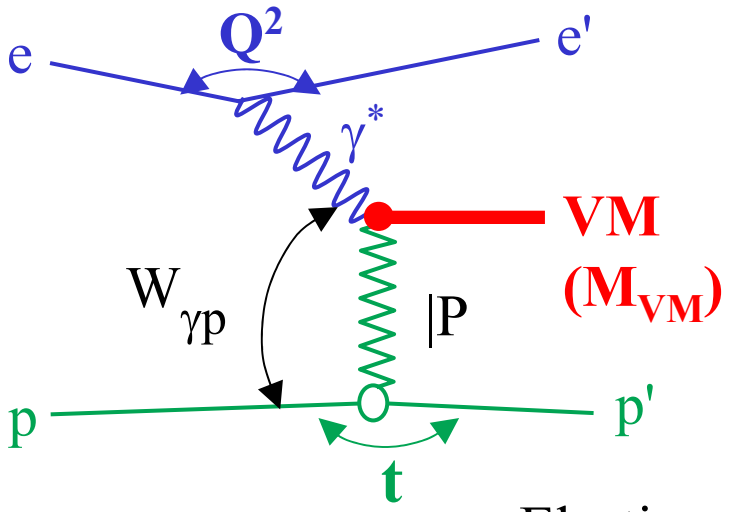
Inclusive $K_S^0 K_S^0$ final state in DIS

Summary

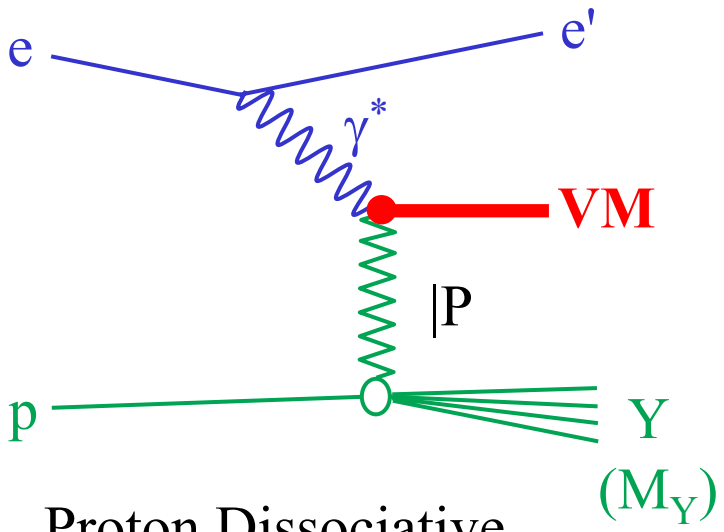
- First observation of resonances in $K_S^0 K_S^0$ final state in DIS was reported
- Two states are observed in the 1300 MeV, 1500 MeV mass region consistent with $f_2(1270)/a_2(1320)$ and $f_2'(1525)$
- Another state X(1726) is observed, probably the $f_0(1710)$ (a glueball candidate)
- States are produced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


Extra Slides

Vector Meson Production

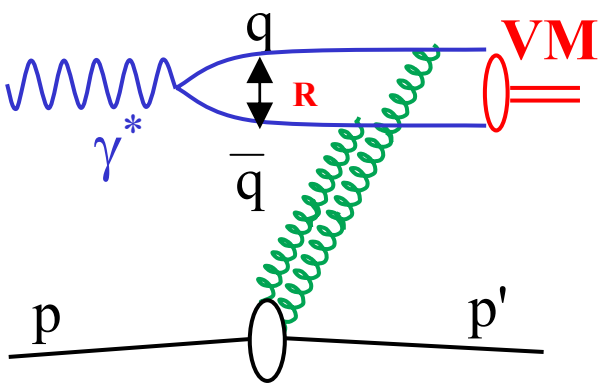


Elastic



Proton Dissociative

Hard regime (pQCD)



pQCD

Q^2 = γ^* virtuality; $\mathbf{Q^2 < 100\ GeV^2}$

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

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

VM = ρ, ω, ϕ, J/ψ , ψ', Υ

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

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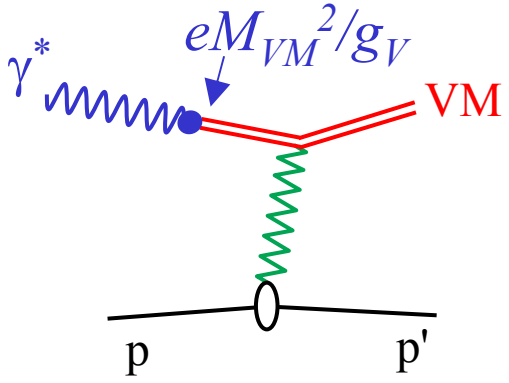
Vector Meson Production

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)

$$b(W) = b_0 + 2\,\alpha'_P \ln\left(W^2/W_0^2\right)$$

(Shrinkage)

σ rising weakly with W:

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

At low |t|, $|t| < 1.5$ GeV^2

$\delta = 0.22$

σ steep exponential t dependence (shrinkage):

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

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Vector Meson Production

Hard regime (pQCD)

Photon mainly longitudinally polarized

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

Two-gluon-exchange approach at LO

Gluon ladder (LLA approach)

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

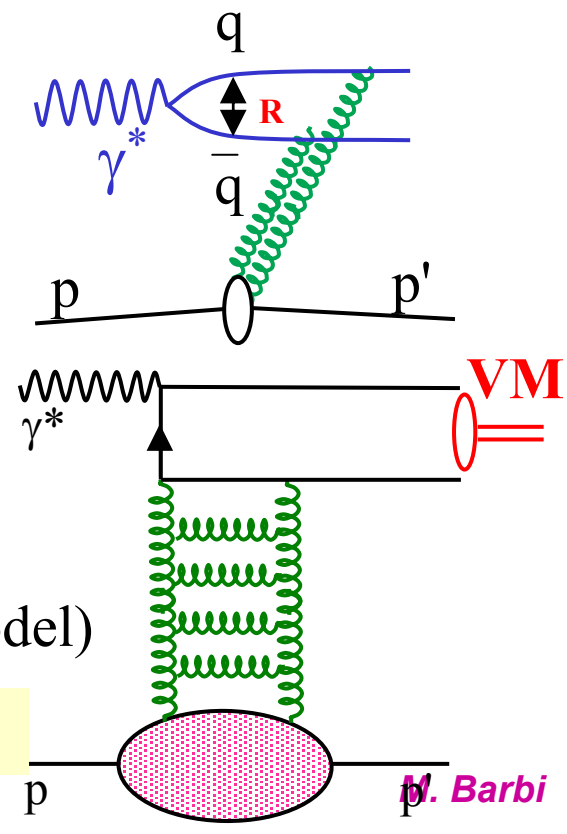
$$\approx W^{0.8}, \quad \left(x \approx 1/W^2 \right)$$

Gluon from F_2 scaling violations

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

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

σ rising steeper than expected from Regge+VMD



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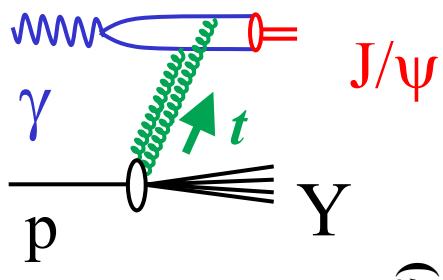
Vector Meson Production

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

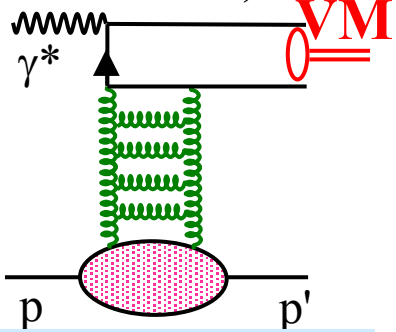
Dependence at large |t| not exponential:

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



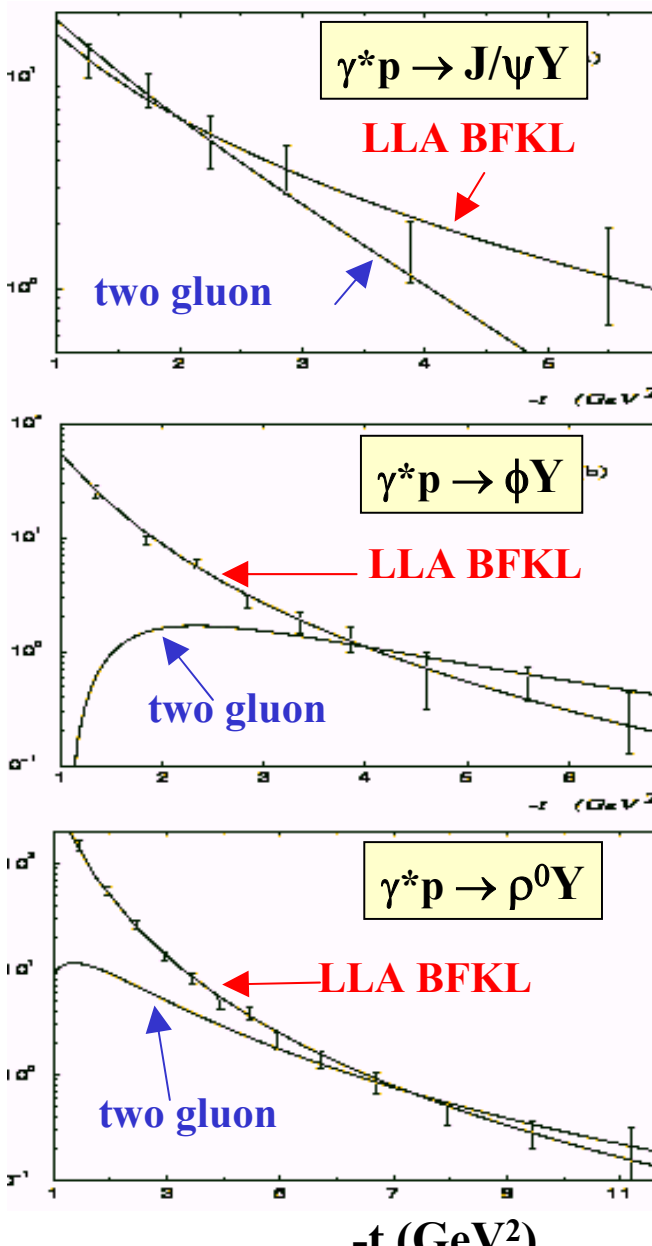
⇒ indication that large |t| may provide a hard scale to apply perturbative QCD

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



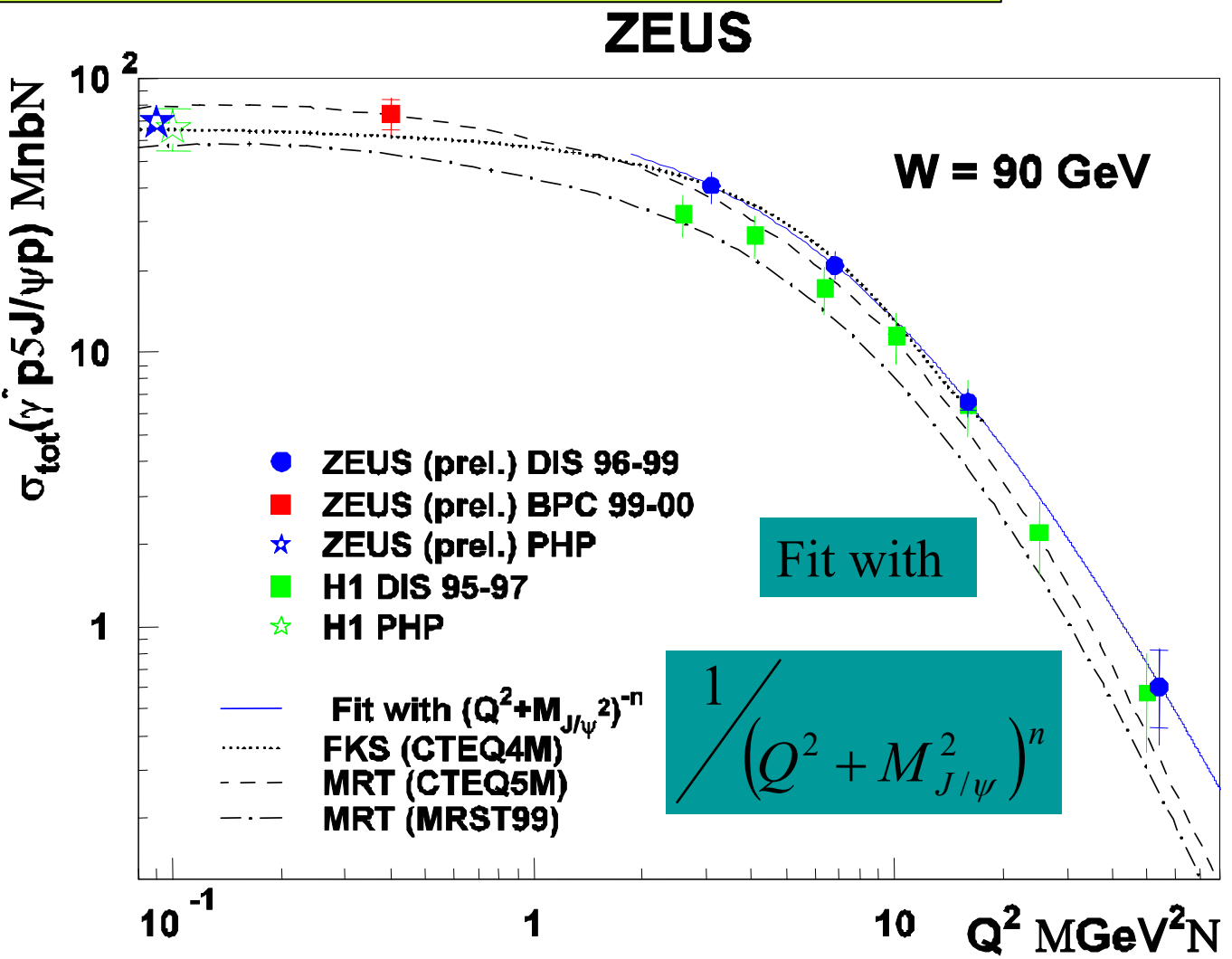
> **BFKL LLA approach: consistent with data**

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



Vector Meson Production

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



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

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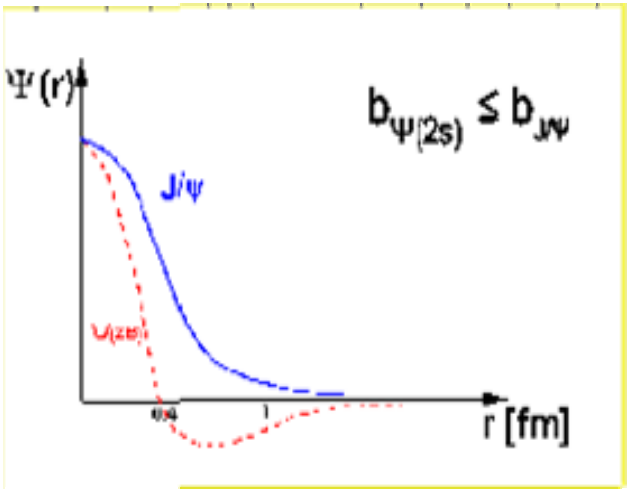
Vector Meson Production

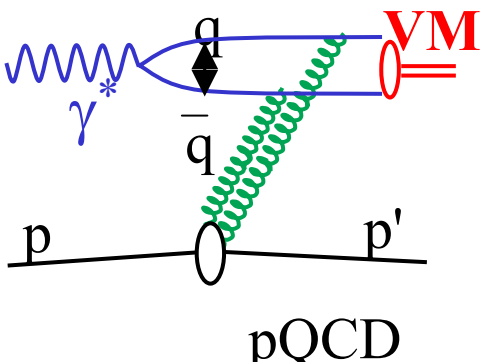
Diffractive Photoproduction of ψ(2S) - pQCD

–> Cross-section suppressed with respect to that of J/y

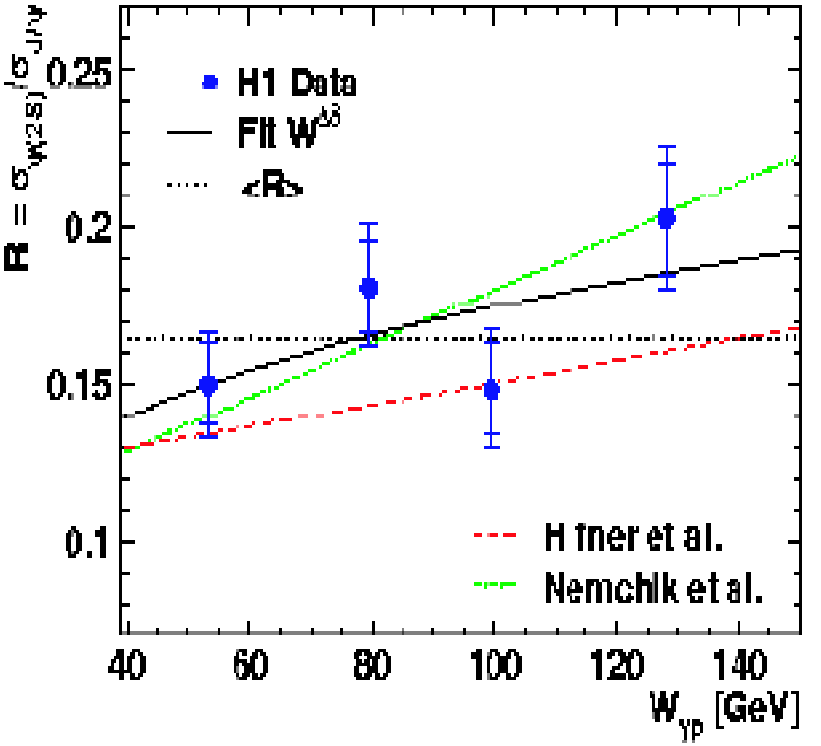
–> Steeper W dependence

ψ(2S) wavefunction has a node





pQCD



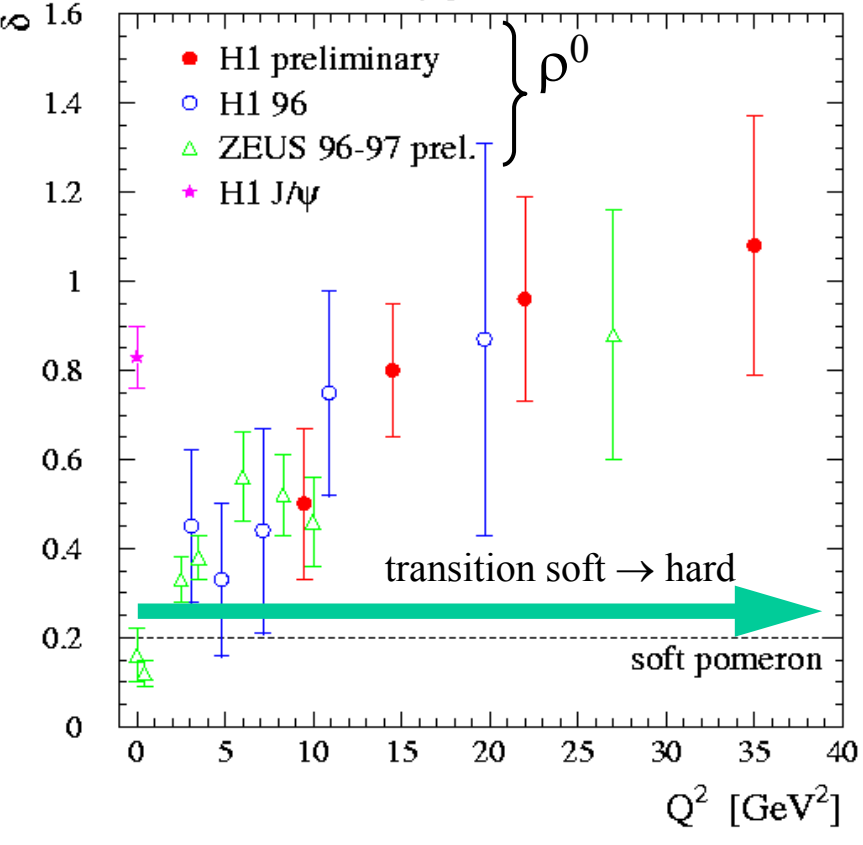
–> Overall R ≈ 0.166 consistent with pQCD prediction

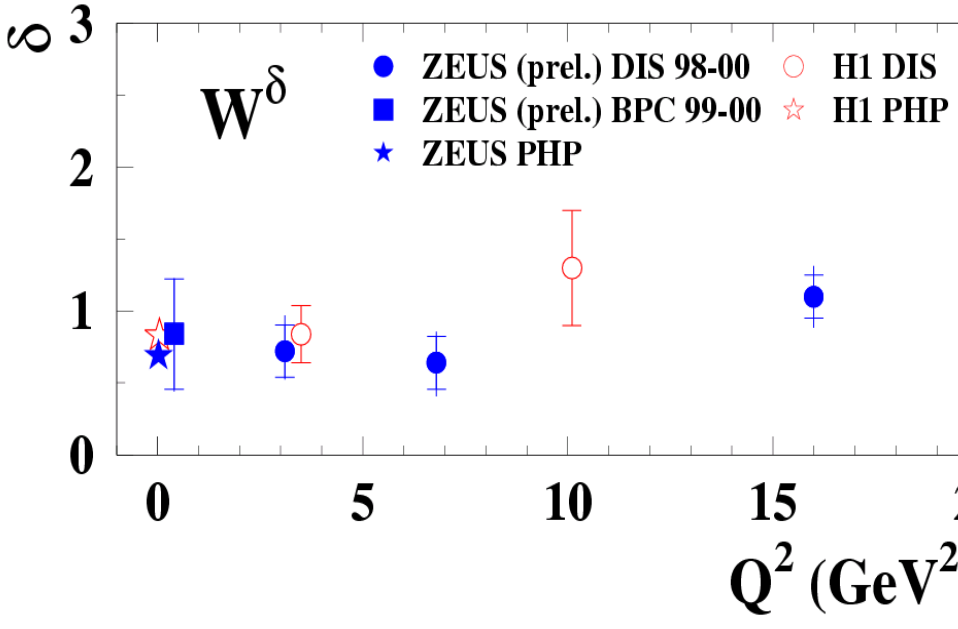
–> Fit $W^{\Delta\delta} \Rightarrow \Delta\delta \approx 0.24$ consistent with W dependence for **ψ(2S)**

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 $Q^2 = 0$

⇒ Q^2 provides a hard scale

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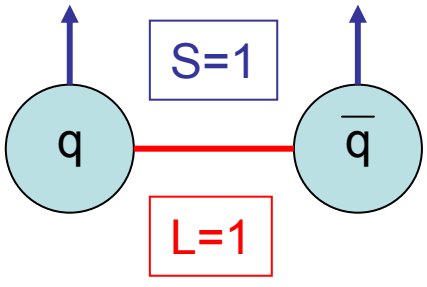
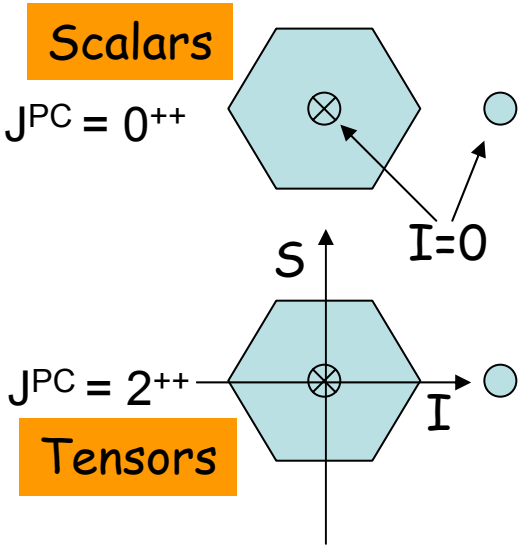
Extras….. KsKs final state

Scalar and Tensor Mesons



Quark Model
(u,d,s)



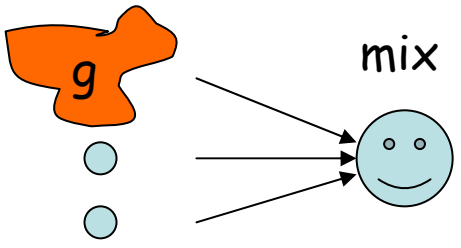
$P = (-1)x(+1)x(-1)^L = (-1)^{L+1}$

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

$J = 0$ 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



mix

$f_0(1370)$
$f_0(1500)$
$f_0(1710)$

Is this a qq state?

Observed States

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

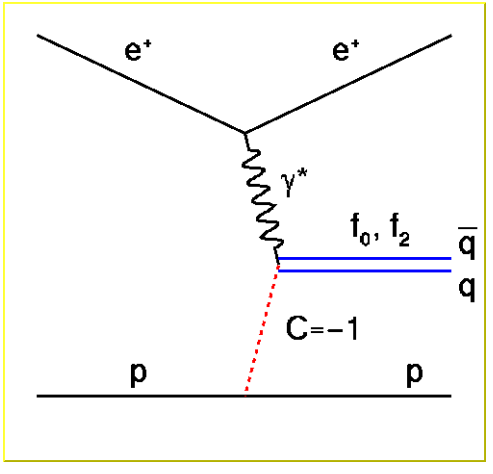
KsKs: has P=+1, C=+1 → J=even

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

M. Barbi

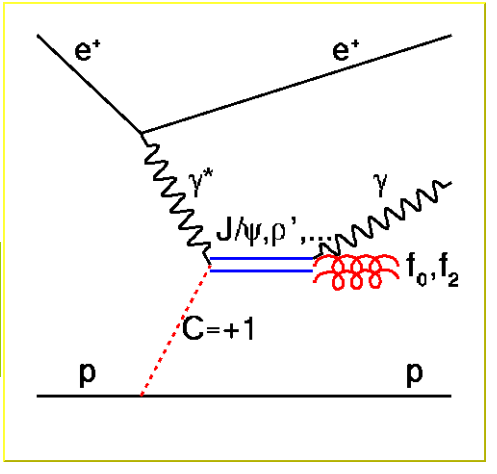
Production mechanisms in DIS

Gluon poor processes

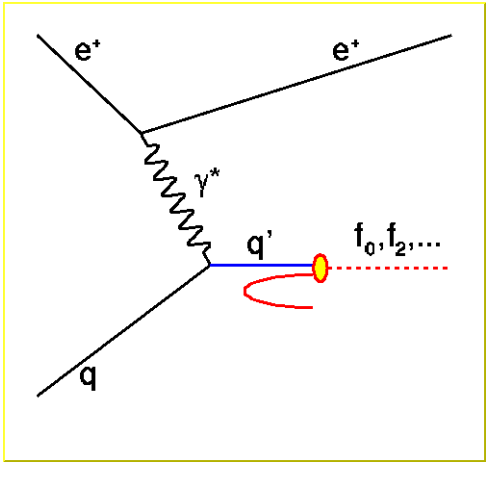


Odderon Exchange

VM Radiative decays

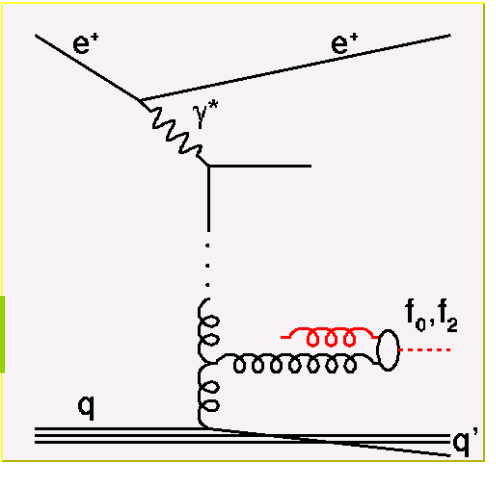


Gluon rich processes



In quark Jets

In gluon jets

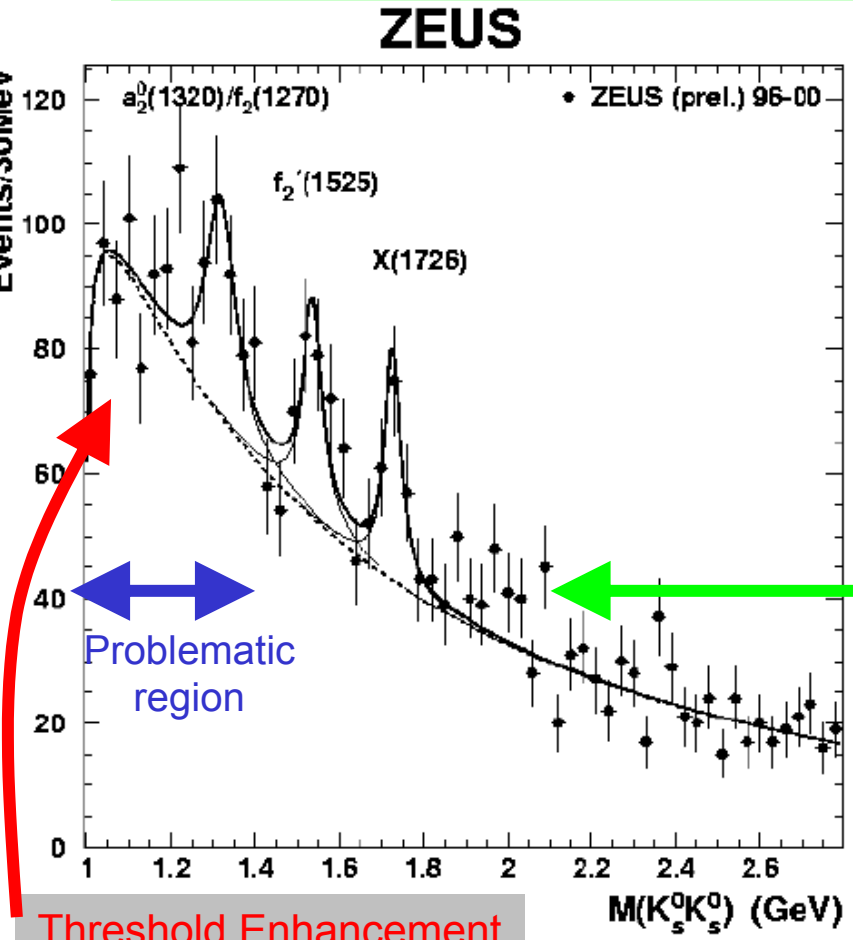


M. Barbi

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

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

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



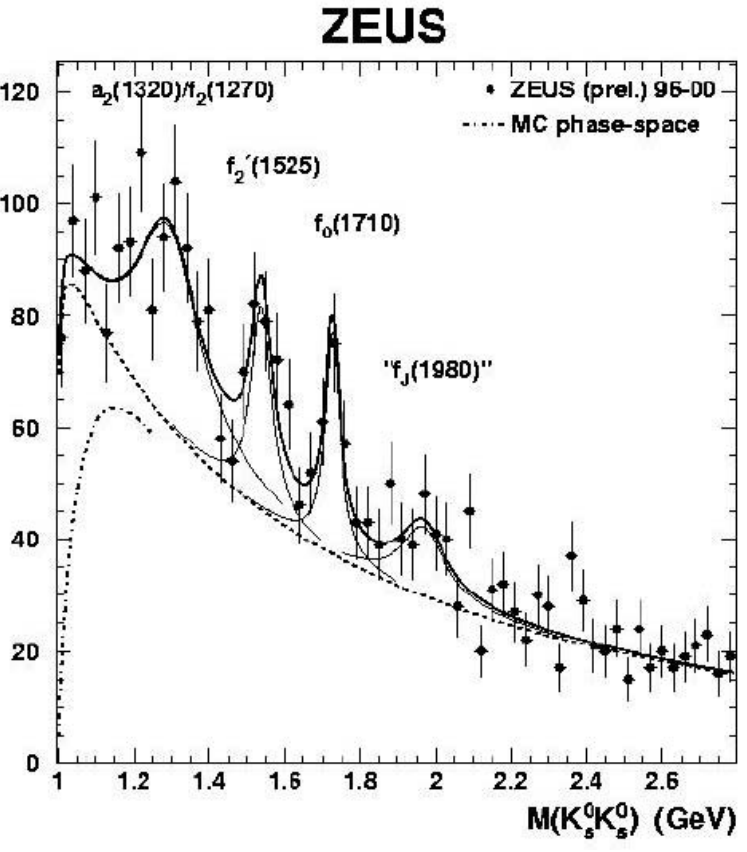
Fit 3 Breit-Wigner and a backg. function

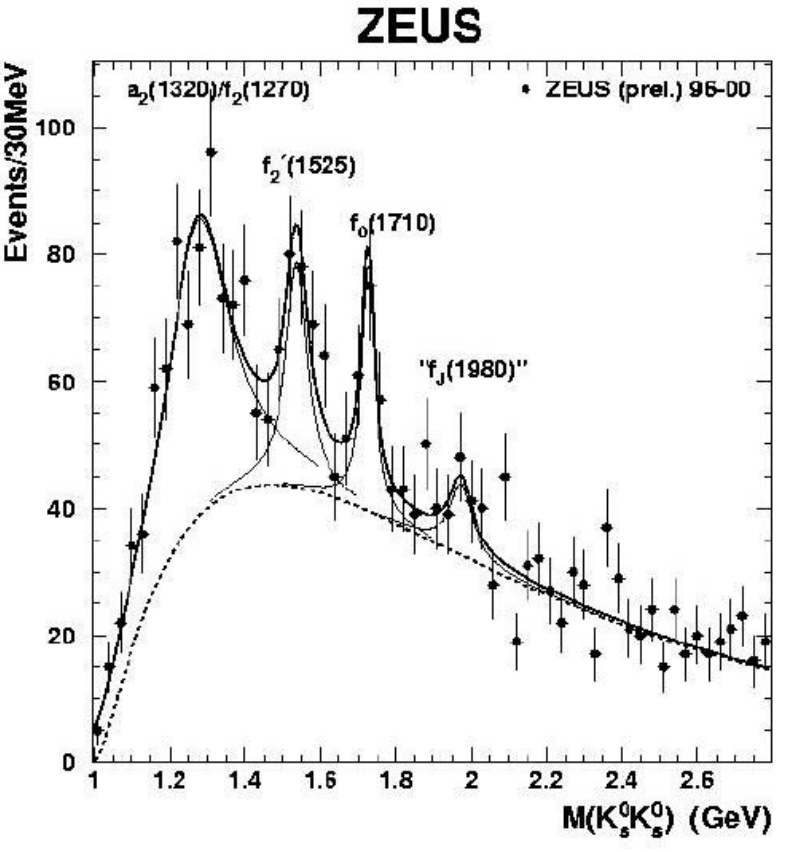
$$F(M)=\frac{dN}{dM}=\sum_{i=1}^{3}\left(\frac{N_i}{2\pi}\frac{\Gamma_i}{(M-M_{0,i})^2+\Gamma_i^2/4}\right)+A\left(M-2m_{K_s}\right)^B e^{-C\sqrt{M-2m_{K_s}}}$$

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.

Observation of J=even meson resonances in ep

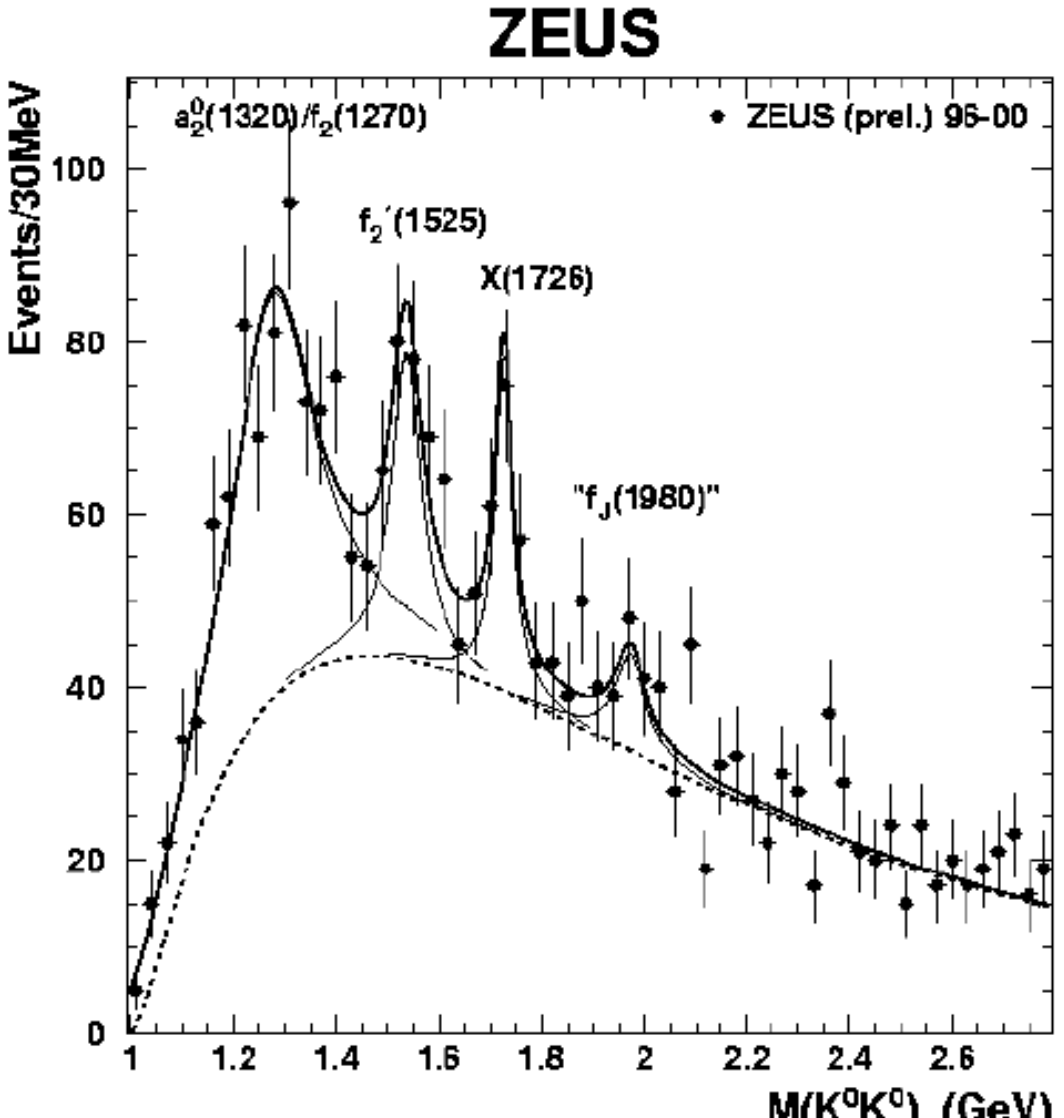




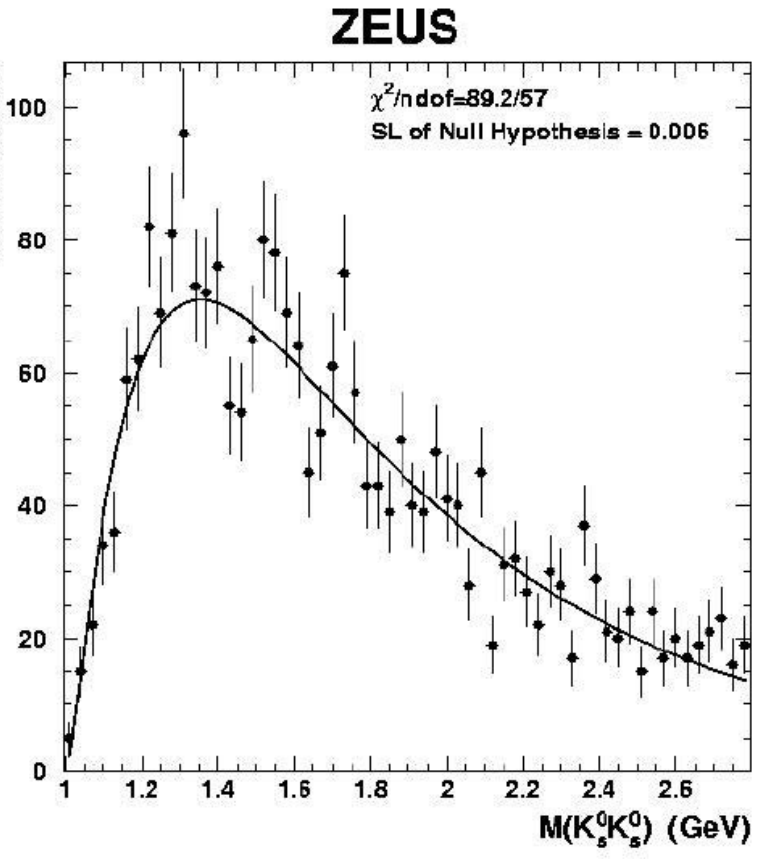
cosKK < 0.92 cut

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

⇒ Attempt to include the 1980 MeV mass region



How well a smooth background describes the data:

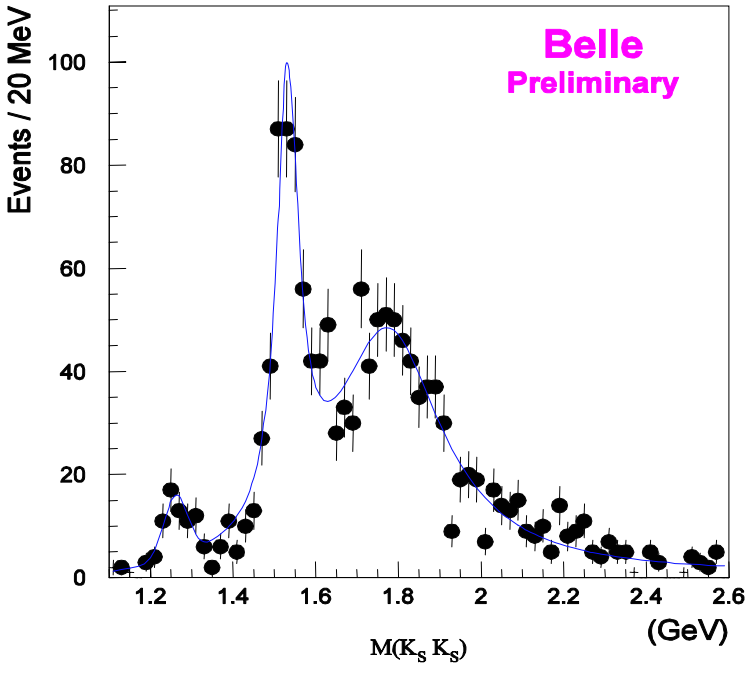


$$SL \approx \frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\chi^2}-\sqrt{2n-1}}^{\infty} e^{-x^2/2} dx$$

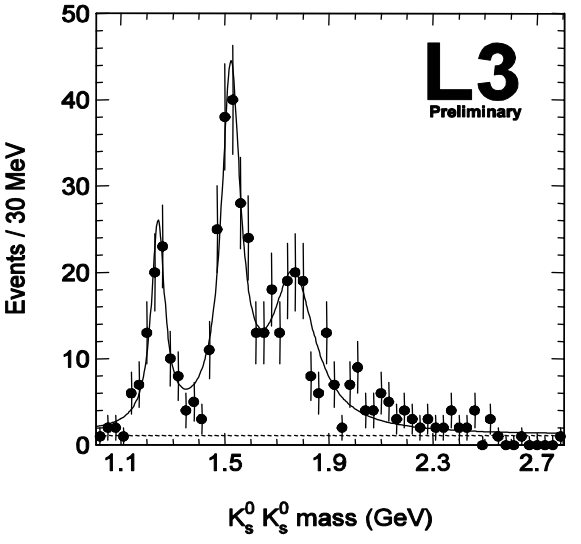
It is less than 1% likely that a smooth distribution describes the data.

$e^+e^- \to \gamma\gamma \to K_S K_S$

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