Deep Virtual Production of ππ Pairs

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In Our Project...

• We are mainly considering two reactions, Charged and Neutral Pion Pairs

•ep \rightarrow e'p' $\pi^+\pi^-$

• $\pi\pi$ Isospin I=1, angular momentum J=1

- *ρ*(770)
- Isospin I=0, angular momentum J=0
 - f₀(500), f₀(980)

•ep \rightarrow e'p' π^0 π^0

Isospin zero, spin zero channel (I:J=0:0)

• f₀(500), f₀(980)

Deep Virtual Factorization: low-mass hadronic final state



- B. Lehmann-Dronke *et al.*, Phys Lett B **475** (2000) 147
- B. Lehmann-Dronke et al., Phys Rev D, 63 (2001) 114001
- Neutral mesonic final state: $\pi^+\pi^-$ or $\pi^0\pi^0$
 - a) [Flavor-Diagonal quark-GPD] ⊗ [qq-Two-Pion Distribution Amplitude (DA)]
 - b) [Flavor-Diagonal quark-GPD] © [gluon-Two-Pion Distribution Amplitude (DA)]
 - c) [Gluon-GPD] ⊗ [qq-Two-Pion Distribution Amplitude (DA)]

Deep sigma

- σ -meson: $f_0(500)$ well established
 - $Pole = (450\pm 20)MeV i(275\pm 12)MeV)$
- Microscopic structure of $f_0(500)$ not well understood.
 - $q\overline{q}: {}^{3}P_{0}$
 - tetraquark, ππ-molecule
 - glueball
 - superposition of all of the above



- σ -meson Asymptotic Distribution Amplitudes: $\phi_{gluon} = 2 \phi_{qq}$
- Deep sigma-production offers intringing evidence for gluonic content of $f_0(500)$





Deep Virtual ππ Production Amplitude

$$\mathcal{M} \sim \sum_{\lambda_N, \lambda_\pi \in \{q\overline{q}, g\}} \int d au dz \operatorname{GPD}_{\lambda_N}(au, \xi, t) \cdot S_{\lambda_N \lambda_\pi}(au, z, \xi) \cdot \operatorname{DA}^I_{\lambda_\pi}(z, \zeta; m_{\pi\pi})$$

$$\sim \sum_{J^{\pi};I \atop \lambda_{N}, \lambda_{\pi} \in \{q\overline{q},g\}} \int d\tau dz \operatorname{GPD}_{\lambda_{N}}(\tau,\xi,t) \cdot S_{\lambda_{N}\lambda_{\pi}}(\tau,z,\xi) \cdot \operatorname{DA}_{\lambda_{\pi}}^{J^{\pi};I}(z,\zeta) P_{J}(\cos\theta^{*})\Omega_{J;I}(m_{\pi\pi})$$

$$\xi \sim \underline{x_{B}}$$

• Kinematics:

$$t = (q - p_{\pi\pi})^2 = (P'_p - P_p)^2$$

$$\zeta, (1 - \zeta) = \frac{1}{2} [1 \pm \beta^* \cos \theta^*] = \text{ pion lightcone momentum fractions}$$

$$\beta^* = \text{ pion velocity in } \pi\pi \text{ rest frame}$$

$$\theta^* = \text{ pion polar angle in } \pi\pi \text{ rest frame}$$

• Dynamics:

- $S(\tau, z; \xi)$ = Hard scattering amplitude (quark-gluon propagators)
- $\Omega_{J;I} = Omnès$ -function, derived from $\pi\pi$ phase shifts
- τ = average momentum fraction of parton in nucleon
- z = momentum fraction of parton in $\pi\pi$ DA

$\pi\pi$ Mass Distribution (Omnès F'n)



ππ Omnès F'n I;J = 1;1 (*ρ*-meson)



$$\Omega_l^I(m_{\pi\pi}) = \exp\left\{i\delta_l^I(m_{\pi\pi}) + \frac{m_{\pi\pi}^2}{\pi} \Re \left[\int_{4m_{\pi}^2}^{\infty} ds \frac{\delta_l^I(s)}{s(s-m_{\pi\pi}^2-i\epsilon)}\right]\right\}$$

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Deep Meson Production

- Corrections up to factor of 10 to leading-order factorization at Jlab kinematics
- Successful phenomenology with finite-size/ χ SB in $\gamma \rightarrow$ meson amplitude and kinematic higher twist in proton GPD.
 - Deep π⁰, η: χSB Twist-3 DA⊗GPD_T
 - $d\sigma_T >> d\sigma_L$
 - (Recent Hall A and CLAS results)
 - Deep φ : Sudakov form factor (finite-size) suppression:
 - CLAC/HERMES/HERA data → →



The Deep ρ Problem

s-channel helicity-conservation violated

• Cross section is anomalously large at low *W*.



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CLAS12 Deep Processes WG

3/30/2017

Conclusions

- Deep ρ is a background to deep σ in the $\pi^+\pi^-$ channel.
 - Theory work on deep *ρ*:
 - Goloskokov-Kroll: Transversity
 - C.Weiss: Instanton dynamics study in progress.
- Detecting deep σ in the $\pi^0\pi^0$ channel is free of ρ background, but is challenging in CLAS12.
- We would like to analyse these data from CLAS12 Run Group A
- We have started to write a MC generator based on the Lehmann-Dronke formalism.
 - Comments, suggestions welcome.

Thank You

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3/30/2017



ππ Final State Quantum Numbers

J ^π ; Ι	Resonance	Re[Pole]	Im[Pole]= –Г
0+; 0	σ, f ₀ (500)	450±20	-275±12
	f ₀ (980)	990±20	-40±20
1-; 1	ρ (770)	770±5	-148 ± 1
2+; 0	f ₂ (1270)	1275±1	-185±3
J ^π ; 2		Non-Resonant	

- J. Peláez: "From controversy to precision on the sigma meson: a review on the status of the non-ordinary f₀(500) resonance", <u>Phys.Rept. 658 (2016) 1</u>
 - The entire history, and struggle, to understand the strong interactions can be found in this story of the σ -meson