Possible dualities between mechanisms of hadronic exclusive processes

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Outline

Solvable example for pion pair photoproduction

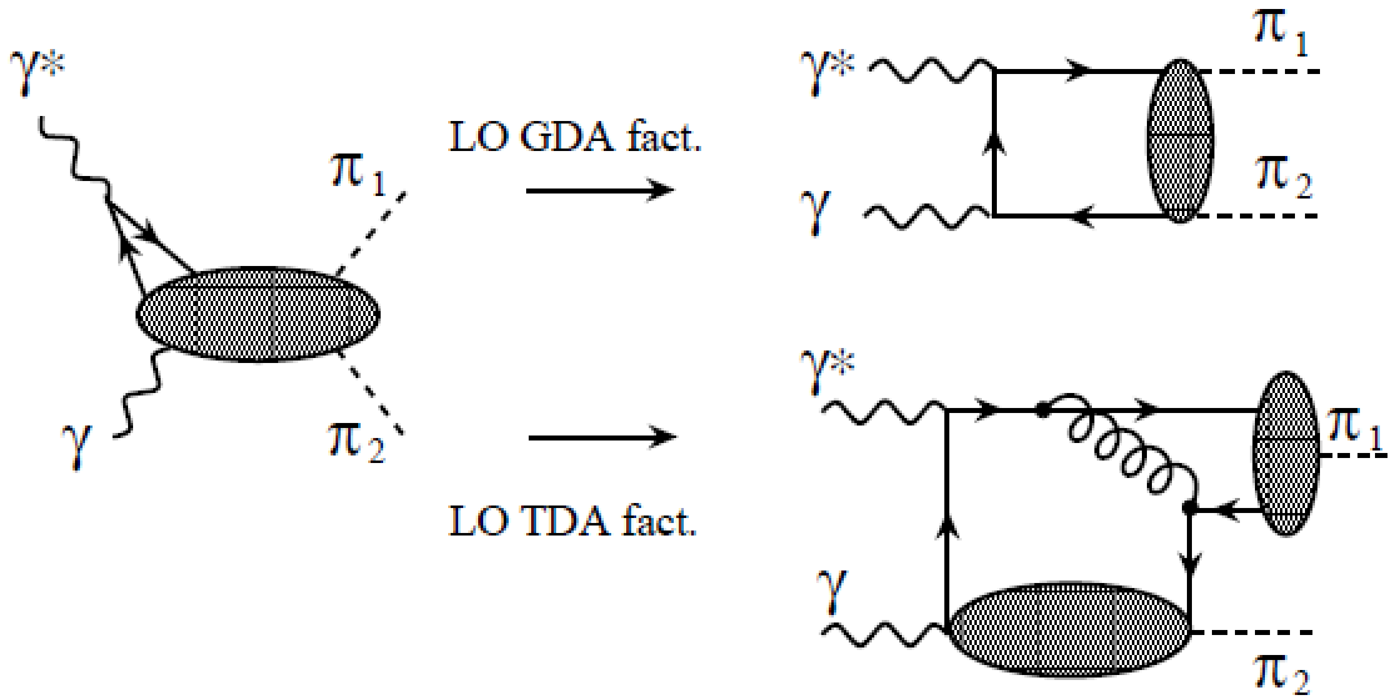
Exclusive limits for Drell –Yan type processes

- Angular distributions, positivity,LT
- Semi-exclusive pion-nucleon DY (COMPASS) and pion DA
- Exclusive DY (COMPASS,NICA) and TDA
- BG-type duality in DY(@COMPASS&PANDA): Sivers function and time-like formfactors

QCD factorization mechanisms

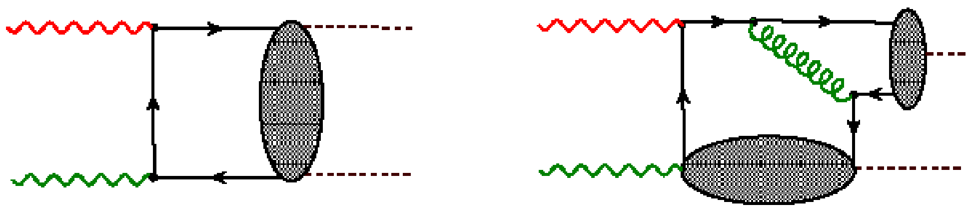
- Hard and Soft parts may change simultaneously for transition to diffferent kinematical domains
- Various factorization mechanisms (duality, matching,…)
- Exclusivity for DY (TMD)pdf's->GPDs
- q-H, H-H, q-q dualities

Two mechanisms for 2 pion production by real and virtual photons



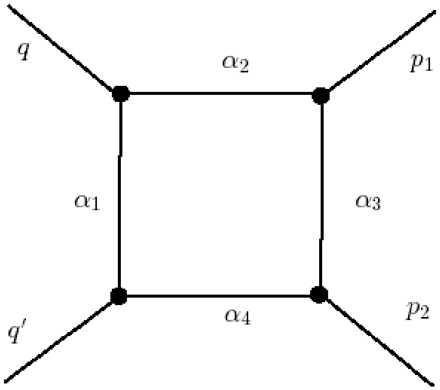
Solvable example for duality of mechanisms (Anikin, Cherednikov, Stefanis, OT, 08) (~s<->t in QCD factorization)

- 2 pion production : GDA (small s) vs TDA+DA (small t)



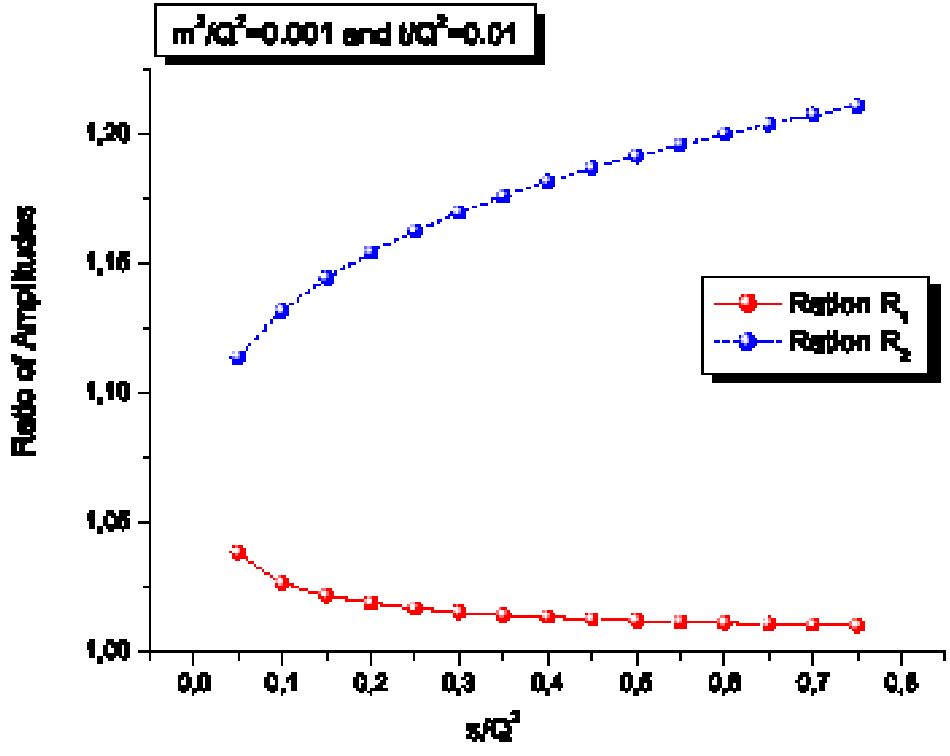
- Scalar model - asymptotics(Efremov,

Ginzburg, Radyushkin…)



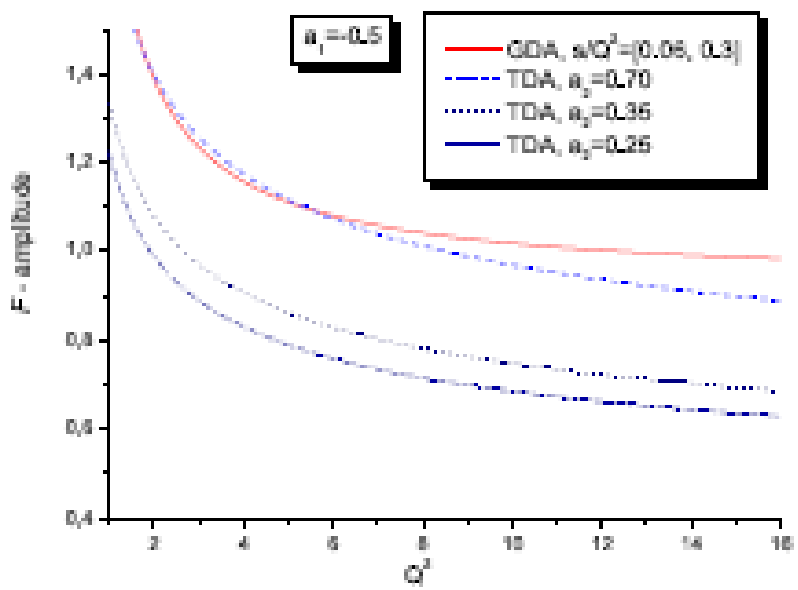
Duality in scalar model

- "Right" (TDA, red) and "wrong" (GDA, blue) asymptotics / exact result (>1- negative "Higher Twist"



Duality in QCD (same helicity amplitude)

- Qualitatively- surprisingly good, quantitatively - model-dependent



Selection between models of GDA's

- PW expansion

$$\Phi_1(z,\zeta,W^2) = 9N_f\, z\bar{z}(2z-1)\left(\tilde{B}_{10}(W^2)e^{i\delta_0(W^2)} + \tilde{B}_{12}(W^2)e^{i\delta_2(W^2)}P_2(\cos\theta_\pi)\right)$$

- Resonances (recall Veneziano duality)-f2 dominance

$$\tilde{B}_{12}(W^2) = \frac{10}{9}\frac{g_{f_2\pi\pi}\, f_{f_2}\, M_{f_2}^3\, \Gamma_{f_2}}{(M_{f_2}^2 - W^2)^2 + \Gamma_{f_2}^2 M_{f_2}^2}$$

$$f_{f_2} = 0.056\,\mathrm{GeV},\ M_{f_2} = 1.275\,\mathrm{GeV},\ \Gamma_{f_2} = 0.185\,\mathrm{GeV}$$

- Simple – works much worse

$$\tilde{B}_{12}(0) = \beta^2 \frac{10}{9N_f} R_\pi$$

From 2 pion production to DY

- Angular distribution

$$d\sigma \propto 1 + \lambda \cos^2\theta + \mu \sin 2\theta \cos\phi + \frac{\nu}{2} \sin^2\theta \cos 2\phi + \rho \sin 2\theta \sin\phi + \sigma \sin^2\theta \sin 2\phi$$

- Positivity of the matrix (= hadronic tensor in dilepton rest frame)

$$M_0 = \begin{pmatrix} \frac{1-\lambda}{2} & \mu & \rho \\ \mu & \frac{1+\lambda-\nu}{2} & \sigma \\ \rho & \sigma & \frac{1+\lambda+\nu}{2} \end{pmatrix}$$

$$|\lambda| \le 1,\ |\nu| \le 1+\lambda,\ \mu^2 \le \frac{(1-\lambda)(1+\lambda-\nu)}{4}$$

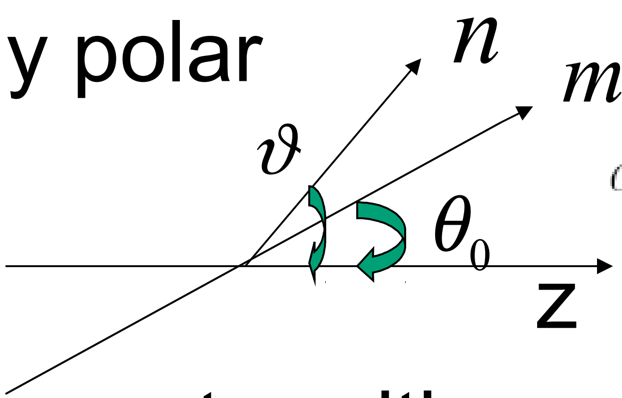
$$\rho^2 \le \frac{(1-\lambda)(1+\lambda+\nu)}{4},\ \sigma^2 \le \frac{(1+\lambda)^2-\nu^2}{4}$$

cubic – det $M_0 > 0$

- 1st line – Lam&Tung by SF method

Kinematic azimuthal asymmetry from polar one by rotation ($\sim k_T$)

Only polar



$$d\sigma \propto 1 + \lambda_0 (\vec{n}\vec{m})^2 = 1 + \lambda_0 \cos^2 \theta_{nm}^2$$

asymmetry with respect to m!

$$\cos\theta_{nm} = \cos\theta\cos\theta_0 + \sin\theta\sin\theta_0\cos\phi$$

azimuthal angle appears with new

$$\lambda = \lambda_0 \frac{2 - 3\sin^2\theta_0}{2 + \lambda_0 \sin^2\theta_0}$$

$$\nu = \lambda_0 \frac{2sin^2\theta_0}{2 + \lambda_0 \sin^2\theta_0}$$

Generalized Lam-Tung relation (OT'05)

- Relation between coefficients (high school math sufficient!)

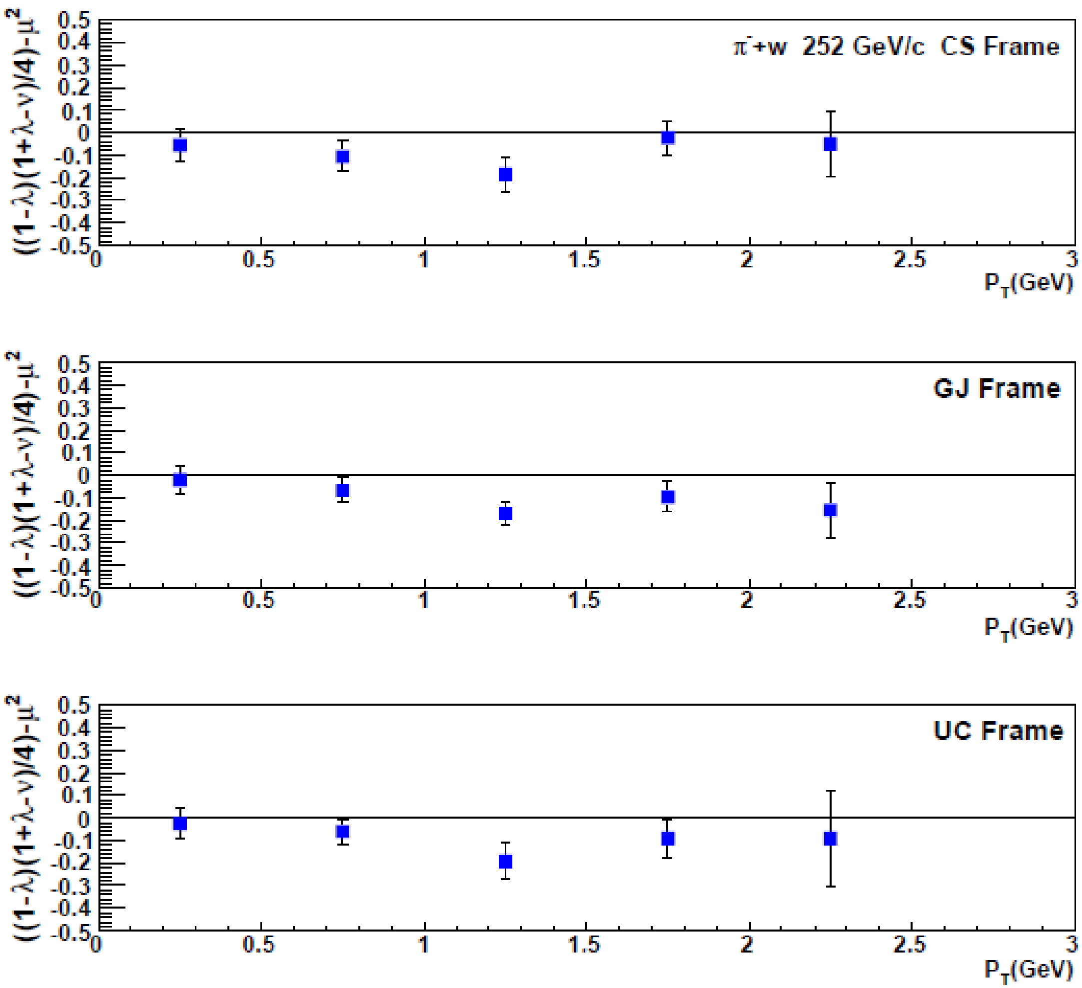
$$\lambda_0 = \frac{\lambda + \frac{3}{2}\nu}{1 - \frac{1}{2}\nu}$$

- Reduced to standard LT relation for transverse polarization (λ_0 =1)
- LT - contains two very different inputs: kinematical asymmetry+transverse polarization

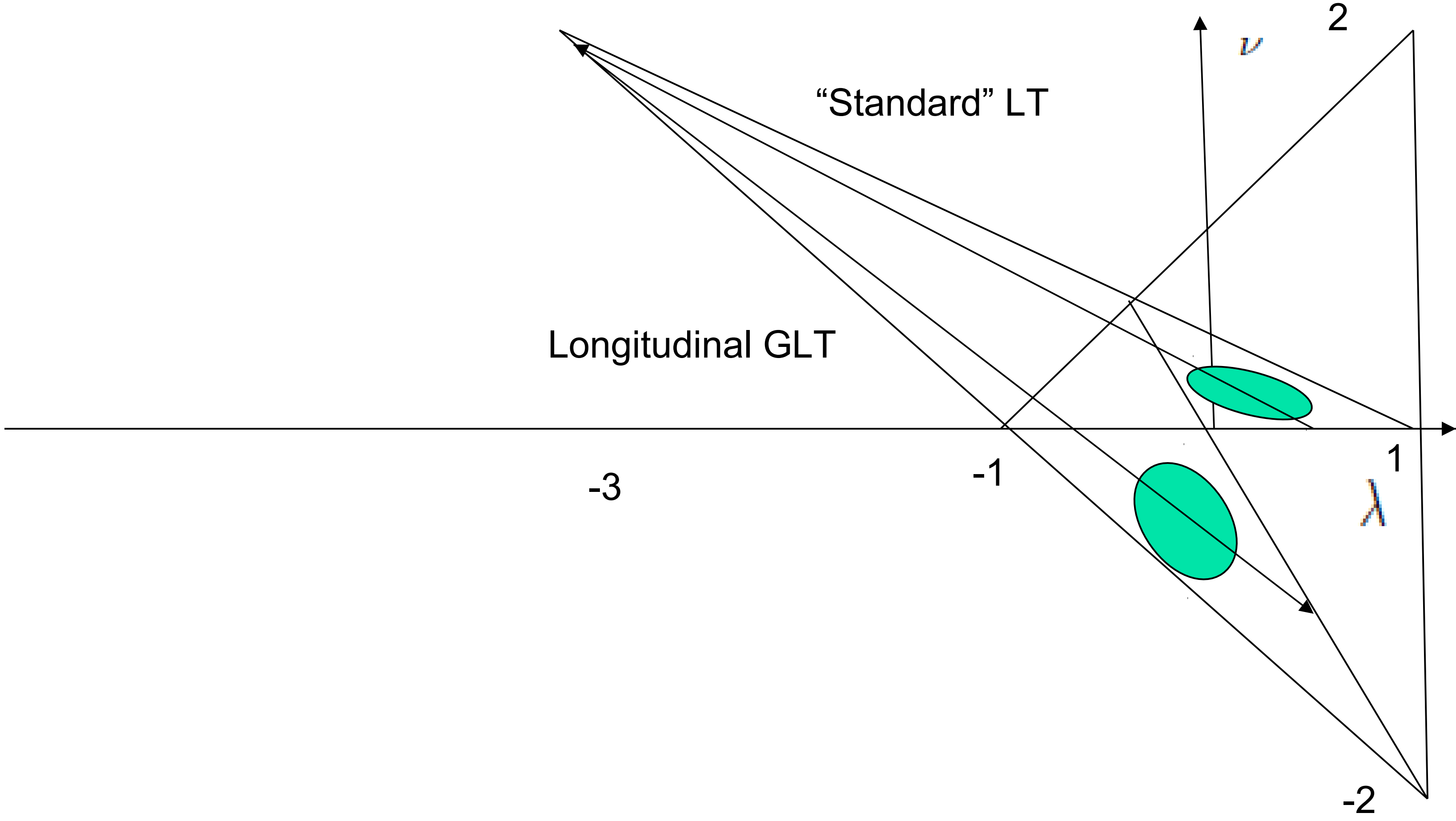
Matching with pQCD results (J. Collins, PRL 42,291,1979)

- Direct comparison: $\tan^2 \theta_0 \, (k_T/Q)^2$
- Off-shellness effects for colliding (anti)quarks – cancel in GI set
- New ingredient – expression for μ
- Linear in k_T
- Saturates positivity constraint!
- Tests by J.-C. Peng,J.Roloff:often close to saturation
- Extra probe of transverse momentum

Close to saturation – helpful (Roloff,Peng,OT,in preparation)!



Positivity domain with (G)LT relations



LT violation

- Azimuthal asymmetries at fundamental level required
- Privileged plane
- NLO-gluon emission
- BM-quark spins

- Off-shell quarks (NLO,HT)

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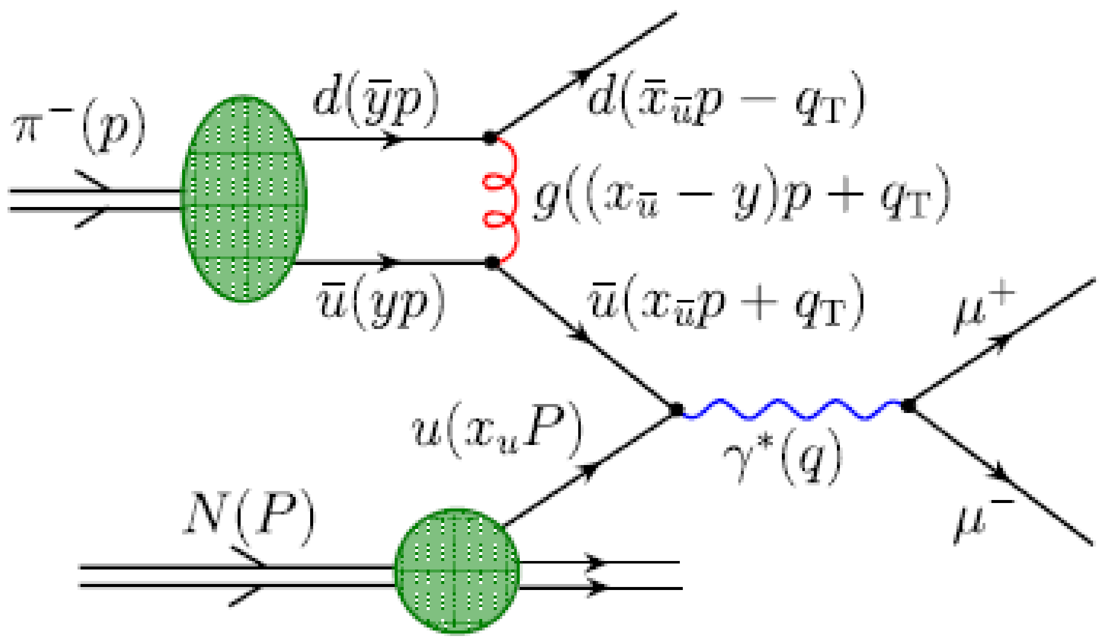
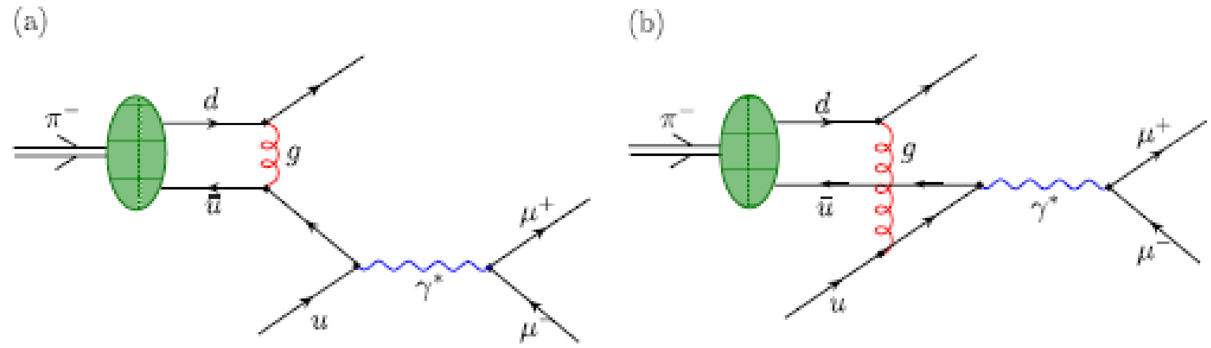
Semi-Exclusive DY (large x_F) - Pion participates through Distribution Amplitude (Light-cone WF)



GI -> p



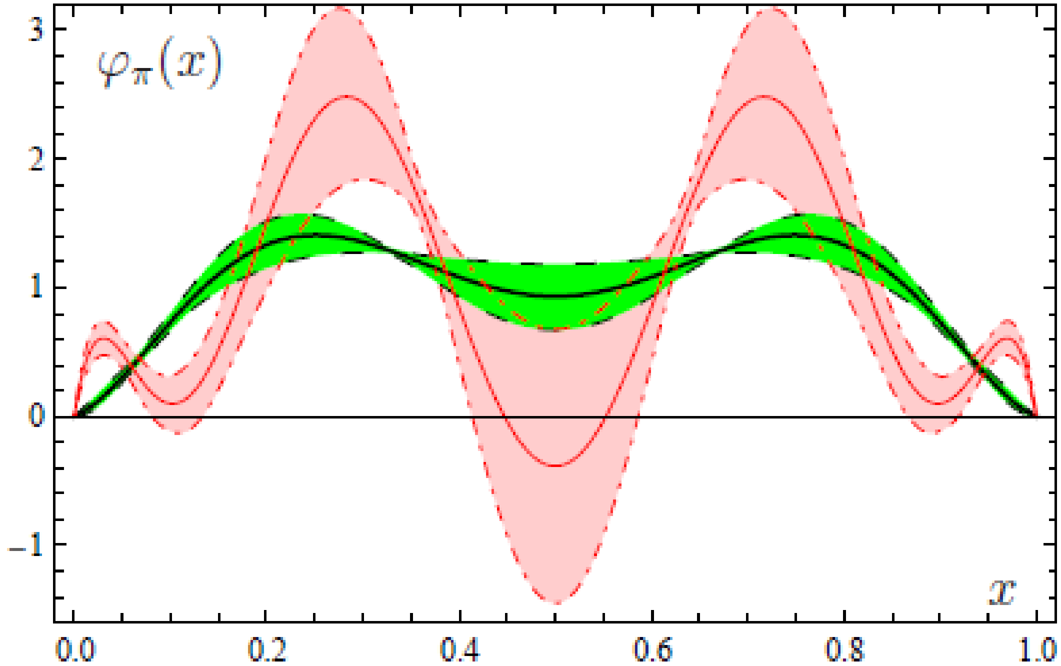
- Colour GI -> second diagram -> phase
- Unpolarized – Brandenburg, Brodsky, Mueller(94)
- Longitudinally polarized –> SSA – Brandenburg, Mueller, OT(95)
- Refined DA – Bakulev, Stefanis,OT(07)

Pion DA

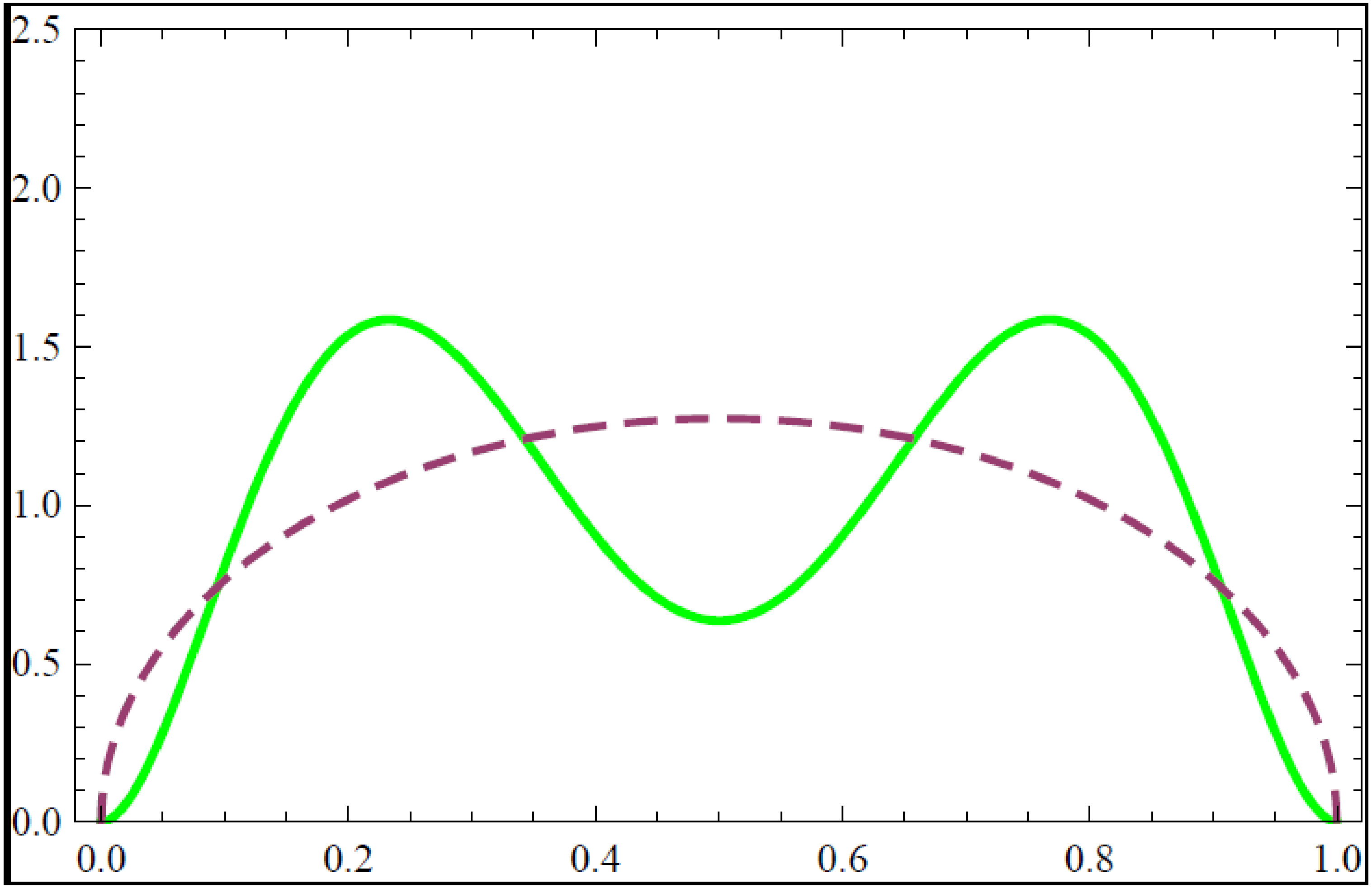
- Element of ERBL factorization
- Describes probability amplitude for the (anti) quark carrying given light-cone momentum fraction
- Interest recently increased due to BaBar data for pion-photon transition formfactor-simplest exclusive process

Pion DA

- (Conservative) model of Bakulev, Mikhailov, Stefanis vs (3D) fit



Comparison to holographic model



Angular distributions – probes of DA

- Unpolarized

$$\lambda(\tilde{x}, \rho) = \frac{2}{N}\{(1-\tilde{x})^2[(>\mathrm{Im}I(\tilde{x}))^2 + (F + \mathrm{Re}I(\tilde{x}))^2] - (4-\rho^2)\rho^2\tilde{x}^2F^2\}, \quad (2.19)$$

$$\mu(\tilde{x}, \rho) = -\frac{4}{N}\rho\tilde{x}F\{(1-\tilde{x})[F + \mathrm{Re}I(\tilde{x})] + \rho^2\tilde{x}F\}, \quad (2.20)$$

$$\nu(\tilde{x}, \rho) = -\frac{8}{N}\rho^2\tilde{x}(1-\tilde{x})F[F + \mathrm{Re}I(\tilde{x})], \quad (2.21)$$

$$N(\tilde{x}, \rho) = 2\{(1-\tilde{x})^2[(\mathrm{Im}I(\tilde{x}))^2 + (F + \mathrm{Re}I(\tilde{x}))^2] + (4+\rho^2)\rho^2\tilde{x}^2F^2\} \quad (2.22)$$

$$F = \int_0^1 dy \frac{\varphi(y, \tilde{Q}^2)}{y},$$

$$I(\tilde{x}) = \int_0^1 dy \frac{\varphi(y, \tilde{Q}^2)}{y(y + \tilde{x} - 1 + i\varepsilon)}$$

$$\tilde{x}(x_L, \rho) \equiv \frac{x_L + \sqrt{x_L^2 + 4(1+\rho^2)\tau}}{2(1+\rho^2)}.$$

$$\rho \equiv Q_T/Q$$

$$x_L = 2Q_L/\sqrt{s} < 1$$

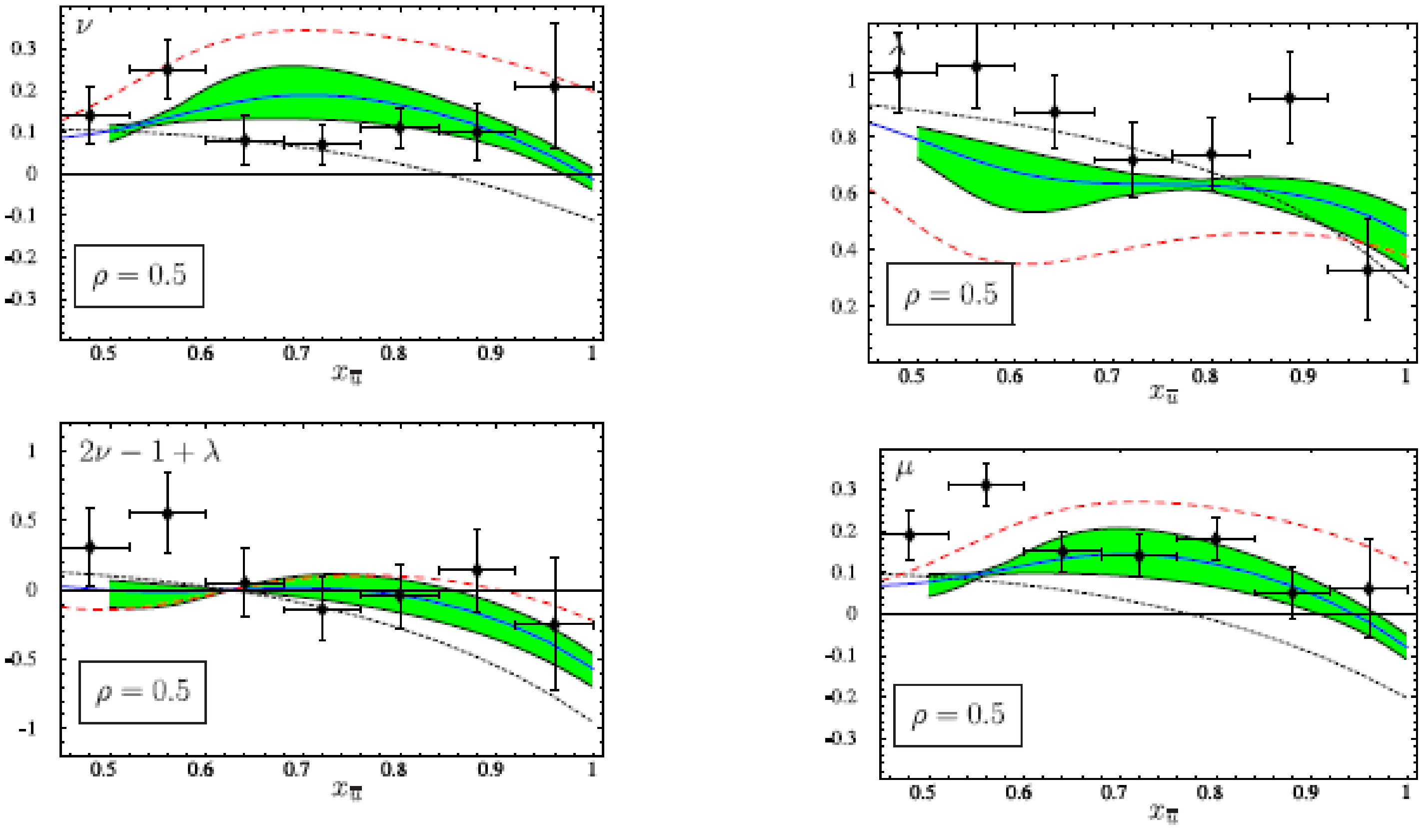
- Polarized

$$\bar{\mu}(\tilde{x}, \rho) = \frac{-2\pi s_\ell \rho\tilde{x}F\varphi(\tilde{x}, \tilde{Q}^2)}{(1-\tilde{x})^2[(F + \mathrm{Re}I(\tilde{x}))^2 + \pi^2\varphi(\tilde{x})^2] + (4+\rho^2)\rho^2\tilde{x}^2F^2}\bar{\mu}_{\mathrm{nucl}},$$

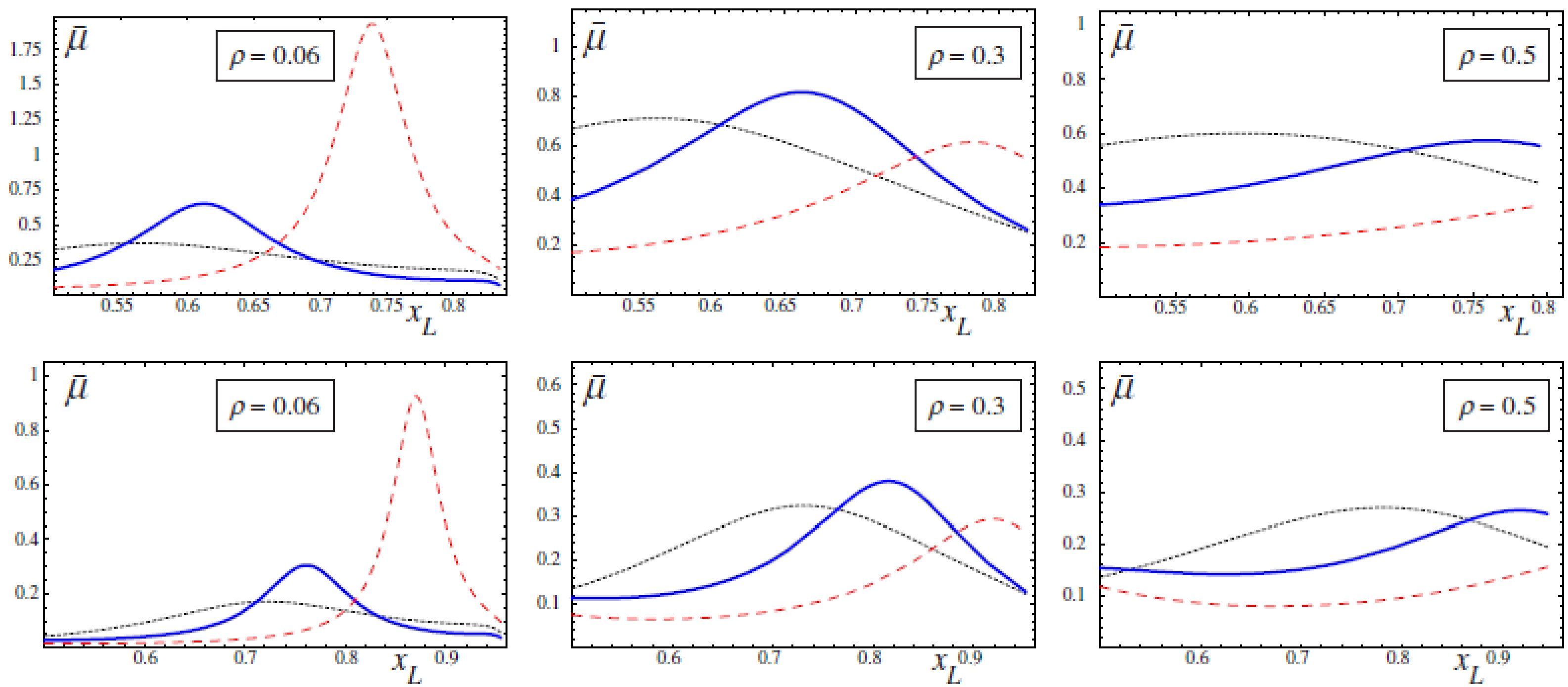
$$\bar{\mu}_{\mathrm{nucl}} \equiv \frac{\frac{4}{9}\Delta q_u^v(x_p;\mu^2) + \frac{4}{9}\Delta q_u^s(x_p;\mu^2) + \frac{1}{9}\Delta q_d^s(x_p;\mu^2)}{\frac{4}{9}q_u^v(x_p;\mu^2) + \frac{4}{9}q_u^s(x_p;\mu^2) + \frac{1}{9}q_d^s(x_p;\mu^2)},$$

$$\bar{\nu}(\tilde{x}, \rho) = 2\rho\bar{\mu}(\tilde{x}, \rho),$$

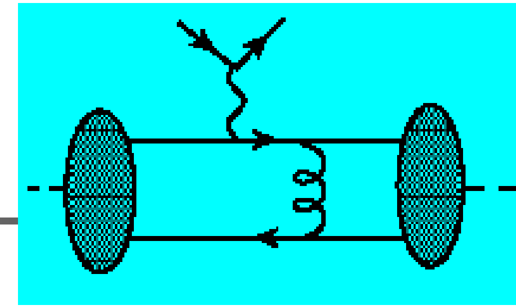
Asymmetries vs data



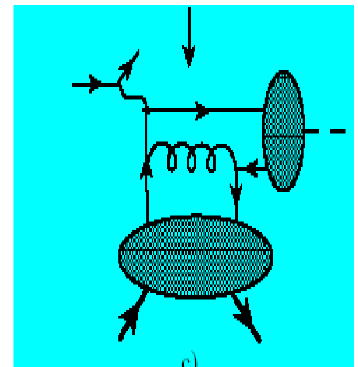
Polarization -> scanning of DA

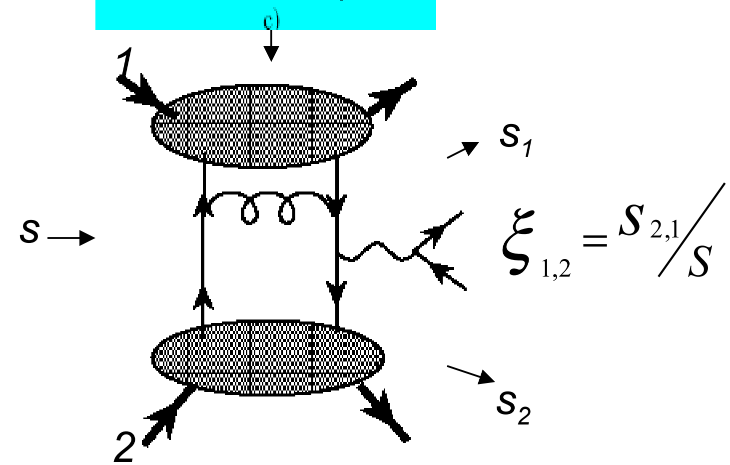


From semi-
to pure exclusive



- Simplest case - pion FF(ERBL)
- Change DA to GPD-exclusive electroproduction – talk
- Time from right to left-exclusive DY (DAxGPD) – cf talk of J. Wagner
- Second DA->GPD-another mechanism- OT’05 (problems with factorization -analytic continuation to be performed)



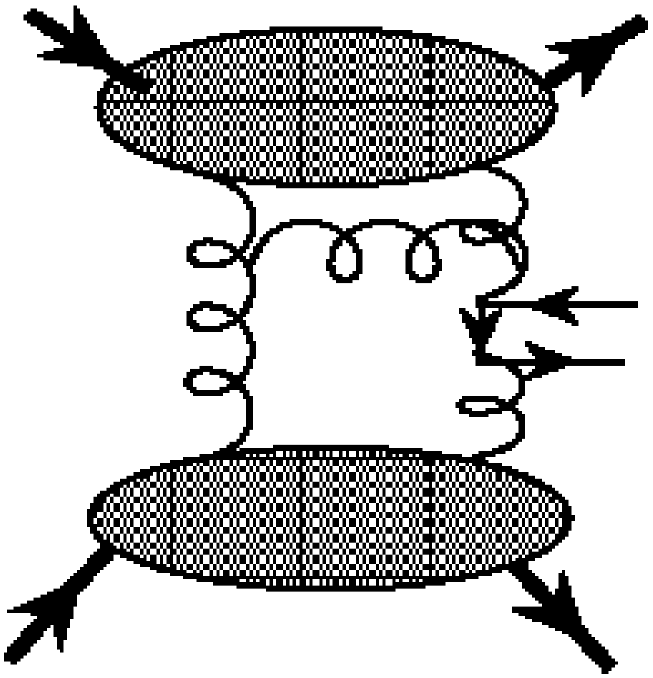


Analytic continuation

- Try to calculate in they unphysical region
- $|\xi_{1,2} = s_{2,1}/S| > 1$
- How to continue?
- Solved for hard SPE –type amplitudes (LO - OT, Blois'05; Anikin, OT;Polyakov, Semenov-Tian-Shansky; Muller,Kumericky; NLO – Diehl, Ivanov)

Implications for Higgs

- Already at the crossing level – GPD ->GDA
- Higgs production amplitude (GPD) -
- Higgs EXCLUSIVE DECAY amplitude to 2 hadron pairs (MC)
- More general property than collinear factorization framework

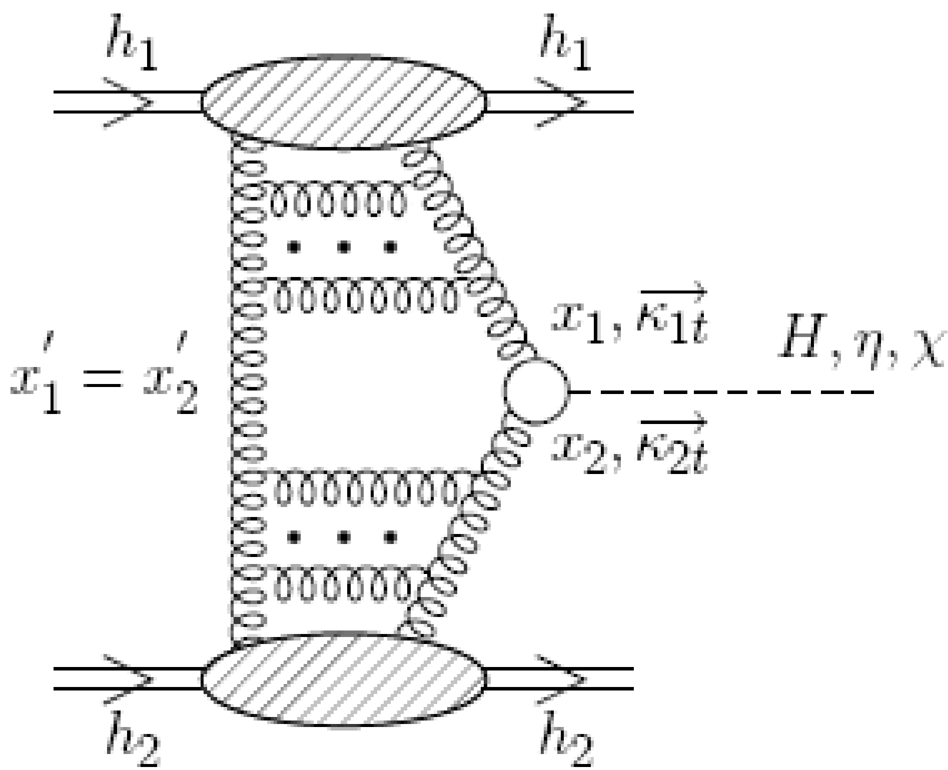


Status of factorization

- For pion FF – Brodsky-Lepage ratio (now – BABAR data problem…)
- Analogy - ratio of VM amplitude squared to exclusive DY one
- Duality to Durham? Hard exchange – (part of) survival probability?

Standart approach - Durham (KKMR) Model

- Generalized UGDF
- FF analogy- Feynman mechanism



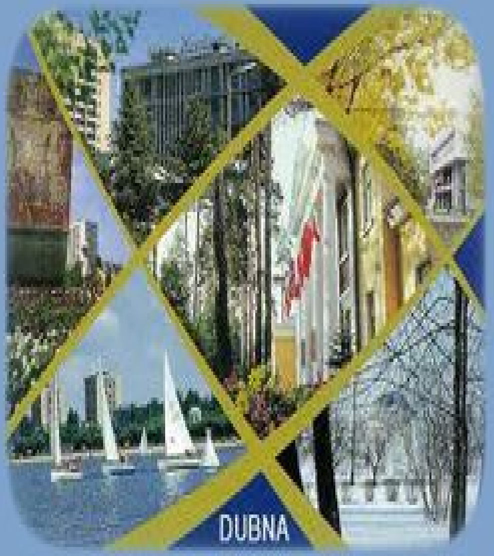
Properties of exclusive DY

- Polarization T->L
- Difference in sign between imaginary parts of electroproduction and DY-> exclusive analog of famous Sivers function sign change
- Final proton is not mandatory – small missing mass ~at rest for fixed target-possible at COMPASS
- PP(NICA): TDA p->pp (to be compared with p->D)
- Test of scaling in various momenta
- Estimates for COMPASS ~ 10^3 events
- Exclusive limit with antiproton beam – relation to time-like FF's

Conclusions

- (Semi)exclusive limits of DY – interesting theoretically
- Feasibility at various experiments remains to be studied

- NICA@JINR has a possibility studies of various spin physics in hadronic and HIC
- New suggestions welcomed
- Better to see once than to hear 100 times; WELCOME to SPIN 2012



The 20th INTERNATIONAL SYMPOSIUM on
Spin Physics (SPIN2012)
JINR, Dubna, Russia
September 17 - 22, 2012

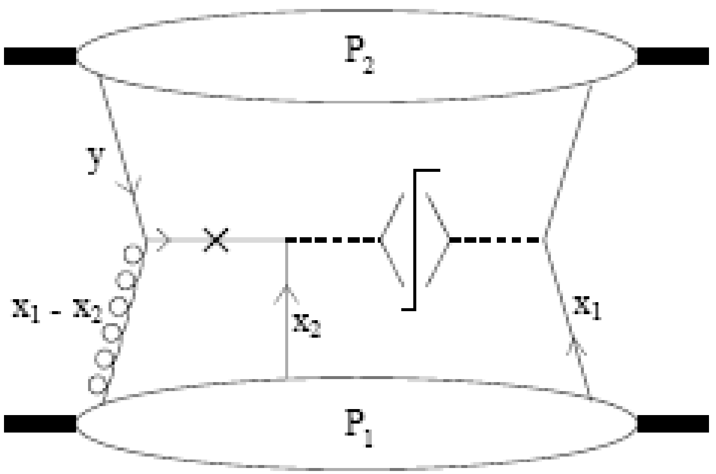
http://theor.jinr.ru/~spin2012/

SSA in DY

- TM integrated DY with one transverse polarized beam – unique SSA – gluonic pole (Hammon, Schaefer, OT) – “factor 2” problem

$$A = g\,\frac{\sin 2\theta\ \cos\phi \left[T(x,x) - x\frac{dT(x,x)}{dx}\right]}{M\left[1+\cos^2\theta\right] q(x)}$$

- Positivity: twist 4 denominator



$+$ c. c.

Contour gauge in DY: (Anikin,OT arXiv:1003.1482 and PLB)

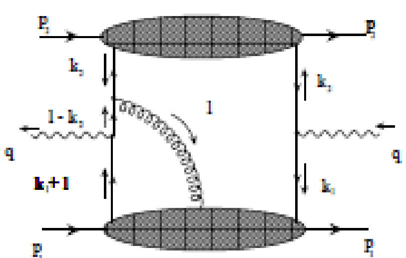
- Motivation of contour gauge – elimination of link $[-\infty^-, 0^-] = 1$

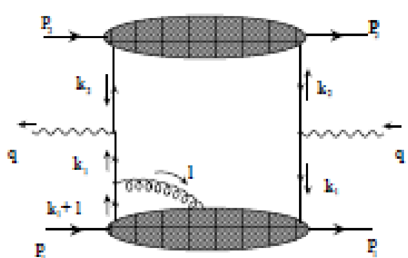
$$[-\infty^-, 0^-] = Pexp\Big\{-ig\int_{-\infty}^{0} dz^-\, A^+(0,z^-,\vec{0}_T)\Big\}$$

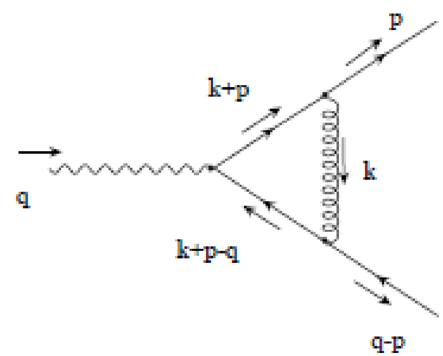
- Appearance of infinity – mirror diagrams subtracted rather than added
- Field $A^\mu(z) = \int_{-\infty}^{\infty} d\omega^- \theta(z^- - \omega^-) G^{+\mu}(\omega^-) + A^\mu(-\infty)$
- Gluonic pole appearance $B^V(x_1,x_2) = \frac{T(x_1,x_2)}{x_1 - x_2 + i\epsilon}$
- cf naïve expectation $B^V(x_1,x_2) = \frac{\mathcal{P}}{x_1 - x_2} T(x_1,x_2)$
- Source of phase?!

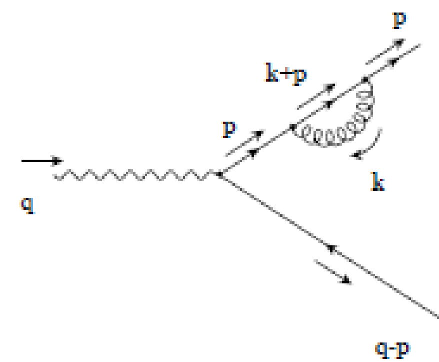
Phases without cuts

- EM GI (experience from q2 DVCS) – 2 contributions









- Cf PT – only one of two diagrams contribute to SSA and required for GI
- NP tw3 analog - GI only if
  GP absent
- GI with GP – “phase without cut”

Analogs/implications

- Analogous pole – in gluon GPD
- Prescription – also process-dependent: 2-jet diffractive production (Braun et al.)
- Analogous diagram for GI – Boer, Qiu(04)
- Our work besides consistency proof – factor 2 for asymmetry (missed before)
- GI $Z_\mu = \hat{p}_{1\,\mu} - \hat{p}_{2\,\mu}$ (zq)=0
- Naïve $\hat{p}_{1\,\mu} \Longrightarrow \hat{p}_{1\,\mu} - q_\mu \frac{\hat{p}\cdot q}{Q^2} = \frac{p_{1\,\mu} - p_{2\,\mu}}{2}$.
- But! Metz&Zhou 2->1/2 ("factor of 2 puzzle" in addition to sign puzzle)

Sivers function and formfactors

- Relation between Sivers function and AMM known on the level of matrix elements (Brodsky, Schmidt, Burkardt)
- Phase?
- Duality for observables?

BG/DYW type duality for DY SSA in exclusive limit

- Proton-antiproton DY – valence annihilation - cross section is described by Dirac FF squared
- The same SSA due to interference of Dirac and Pauli FF's with a phase shift (Rekalo,Brodsky)
- Exclusive large energy limit; x -> 1 :

  $$T(x,x)/q(x) \to \text{Im } F2/F1$$

- Both directions – estimate of Sivers at large x and explanation of phases in FF's