# GPDs (and DAs) from (semi-) exclusive DY processes

KEK, March 12, 2015

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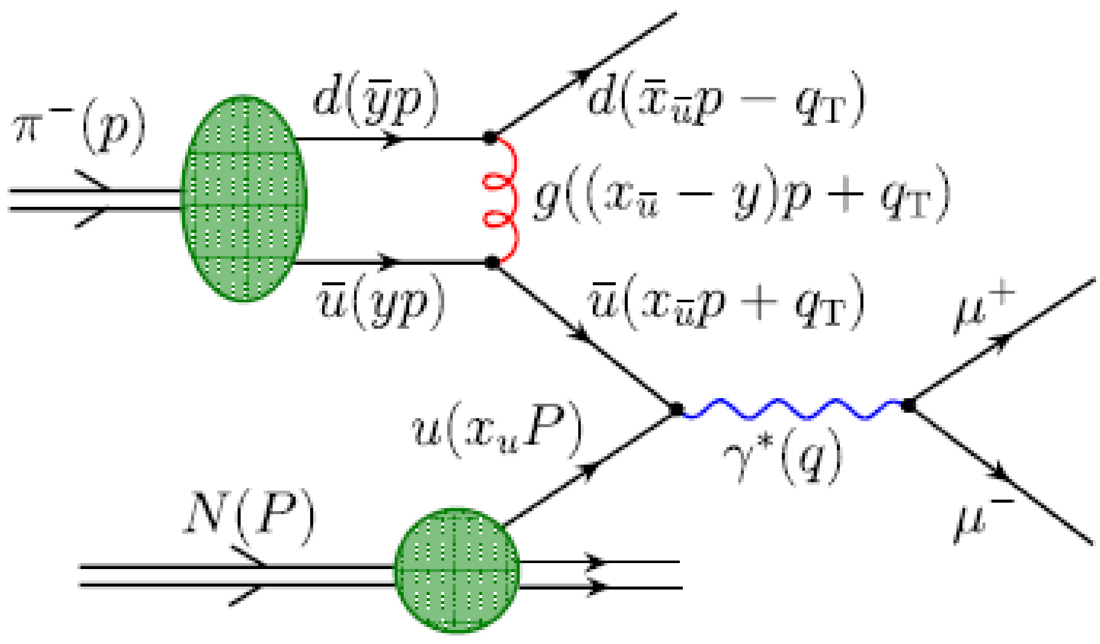
# Outline

How GPDs are manifested at large xF? Is it possible to separate SE (Brandenburg,Brodsky,Khoze,Muller) from E (Berger,Diehl,Pire)? (thanks to Wen-Chen Chang)

- Semi-exclusive pion-nucleon DY (COMPASS) and pion DA
- Exclusive DY and GPDs
- Role of $X_F$ for E and $Q_T$ for SE
- Role of angular distribution

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

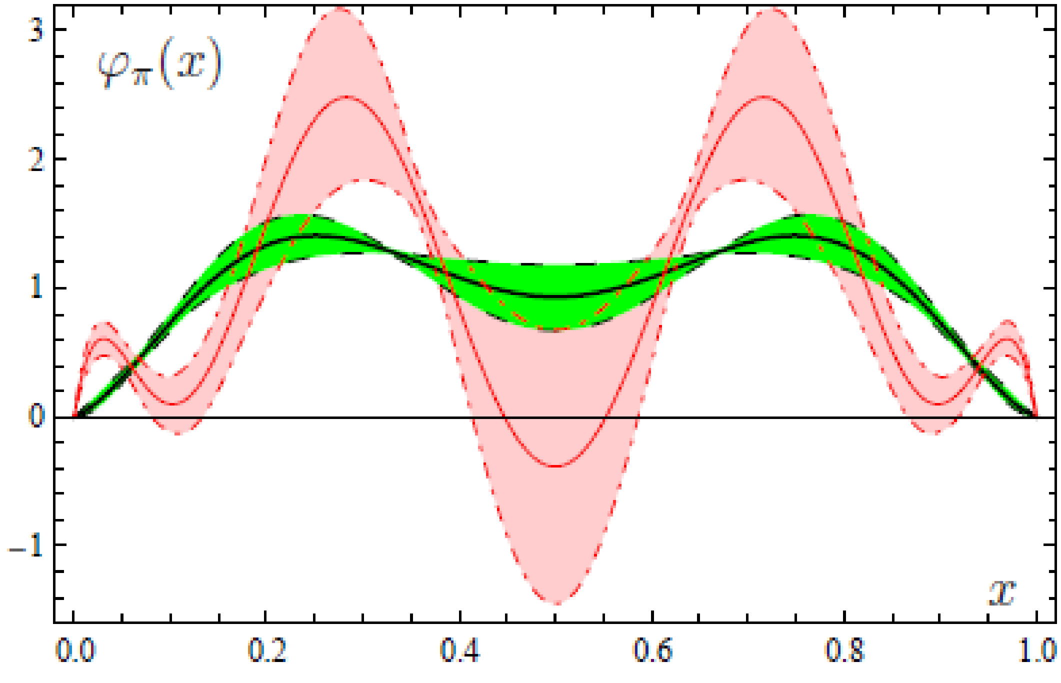


# Pion DA

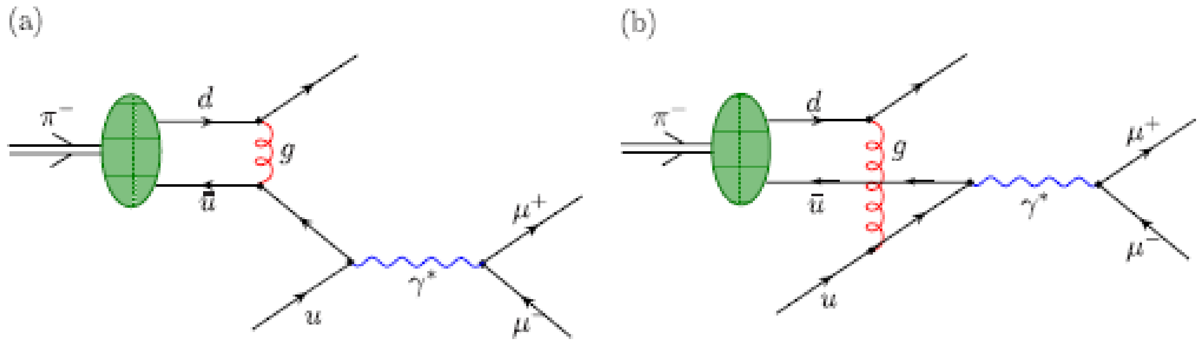
- Element of ERBL factorization
- Describes probability amplitude for the (anti) quark carrying given light-cone momentum fraction
- Interest recently increased due to BaBar/BELLE data for pion-photon transition formfactor-simplest exclusive process

# Pion DA

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



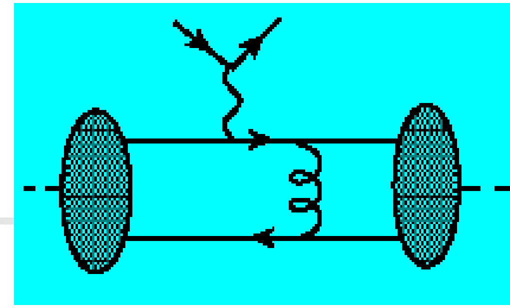
# GI ->

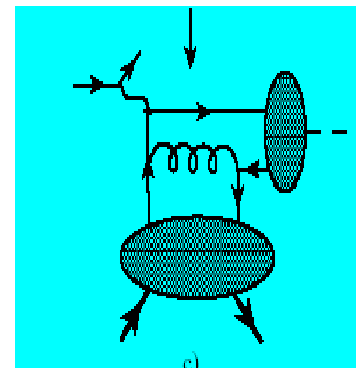


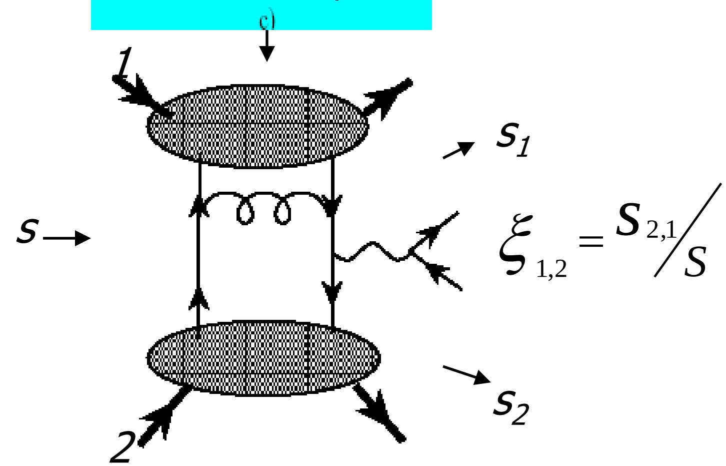

- Colour GI -> second diagram -> phase
- Unpolarized – Brandenburg, Brodsky, Khoze, Mueller(94)
- Longitudinally polarized –> SSA – Brandenburg, Mueller, OT(95)
- Refined DA – Bakulev, Stefanis,OT(07)

# From semi-to pure exclusive

- Simplest case - pion FF(ERBL)
- Change DA to GPD- exclusive electroproduction (Frankfurt,Strikman)
- $M_{DY} \sim M_{DVCS} F_{pi\ g\ g^*}$
- Time from right to left- exclusive DY (DAxGPD)- Berger,Diehl,Pire
- Phase sign change: c.f. Sivers for SIDIS/DY
- Analytic properties ~ factorization (not completely lear yet)
- Second DA->GPD-another mechanism- OT'05 (problems with factorization -analytic continuation to be performed)







# Backward DY –qqq TDA – transition from nucleon to meson

- J.P. Lansberg, B.Pire, K. Semenov-Tian-Shansky and L. Szymanowski, Phys. Rev. D86 (2012) 114033 [arXiv:1210.0126 [hep-ph]].

- Are negative x accessible?

# Kinematical regions for exclusive and semi-exclusive DY

- $(x_1 p_1 + x_2 p_2 + Q_T)^2 = Q^2$
- $x_1 x_2 = (Q_T^2 + Q^2)/s$
- $x_1 - x_2 = x_F$
- (Sudakov) Variables:
- $x_F$, $Q_T^2$, $Q^2$ <-> $x_1$, $x_2$, $Q_T^2/Q^2$
- Semi-exclusive: $x_1 \to 1$
- Exclusive: $x_1 \to 1$ ($x_2 \to$ skewness), $Q_T^2(t) \to 0$

# E/SE DY

- SE – may be accessed at relatively large $Q_T$ (supportive, moves x's to larger values)
- E requires selection of low $Q_T$
- S/SE separation at low $Q_T$ - (tensor) polarization

# Dilepton angular distribution

- 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

# Angular distributions – probes of DA

- Unpolarized

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

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

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

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

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

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

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

$$\rho \equiv Q_T/Q;$$

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

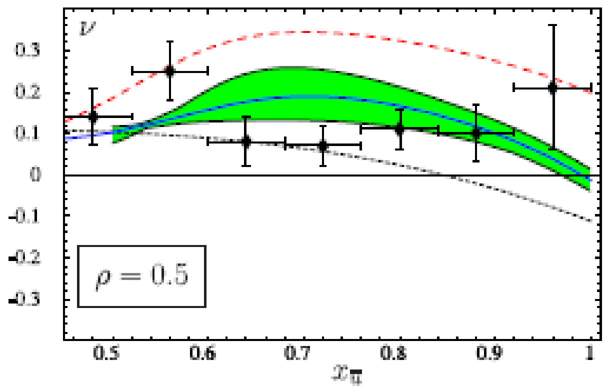
- Polarized

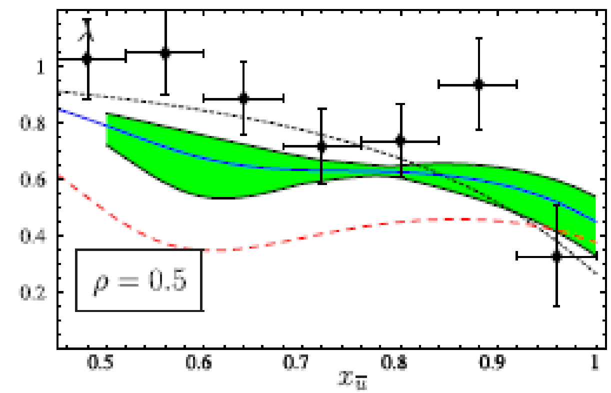
$$\bar{\mu}(\tilde{x},\rho) = \frac{-2\pi s_\ell \rho\tilde{x}F\varphi(\tilde{x},\tilde{Q}^2)}{(1-\tilde{x})^2[(F+\mathrm{Re}I(\tilde{x}))^2 + \pi^2\varphi(\tilde{x})^2] + (4+\rho^2)\rho^2\tilde{x}^2F^2}\,\bar{\mu}_{\mathrm{nucl}},$$

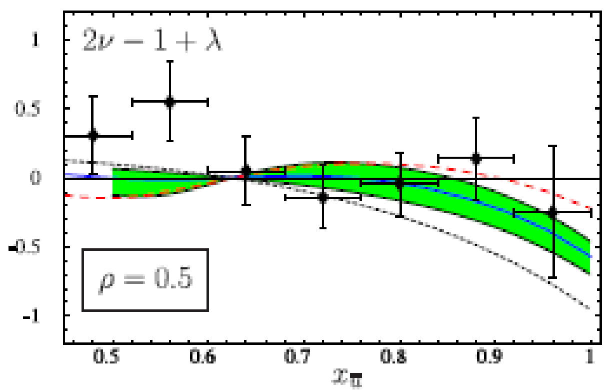
$$\bar{\mu}_{\mathrm{nucl}} \equiv \frac{\frac{4}{9}\Delta q_u^v(x_p;\mu^2) + \frac{4}{9}\Delta q_u^s(x_p;\mu^2) + \frac{1}{9}\Delta q_d^s(x_p;\mu^2)}{\frac{4}{9}q_u^v(x_p;\mu^2) + \frac{4}{9}q_u^s(x_p;\mu^2) + \frac{1}{9}q_d^s(x_p;\mu^2)},$$

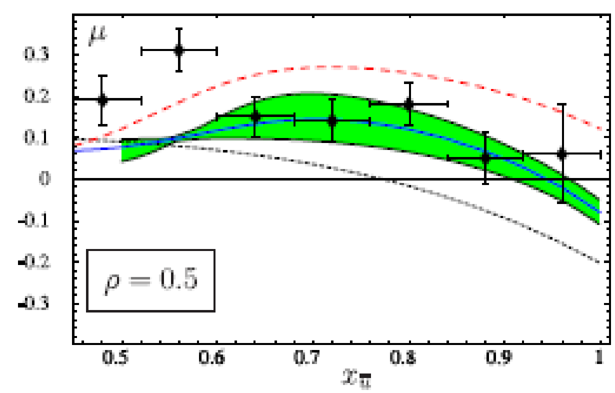
$$\bar{\nu}(\tilde{x},\rho) = 2\rho\bar{\mu}(\tilde{x},\rho),$$

# Asymmetries vs data

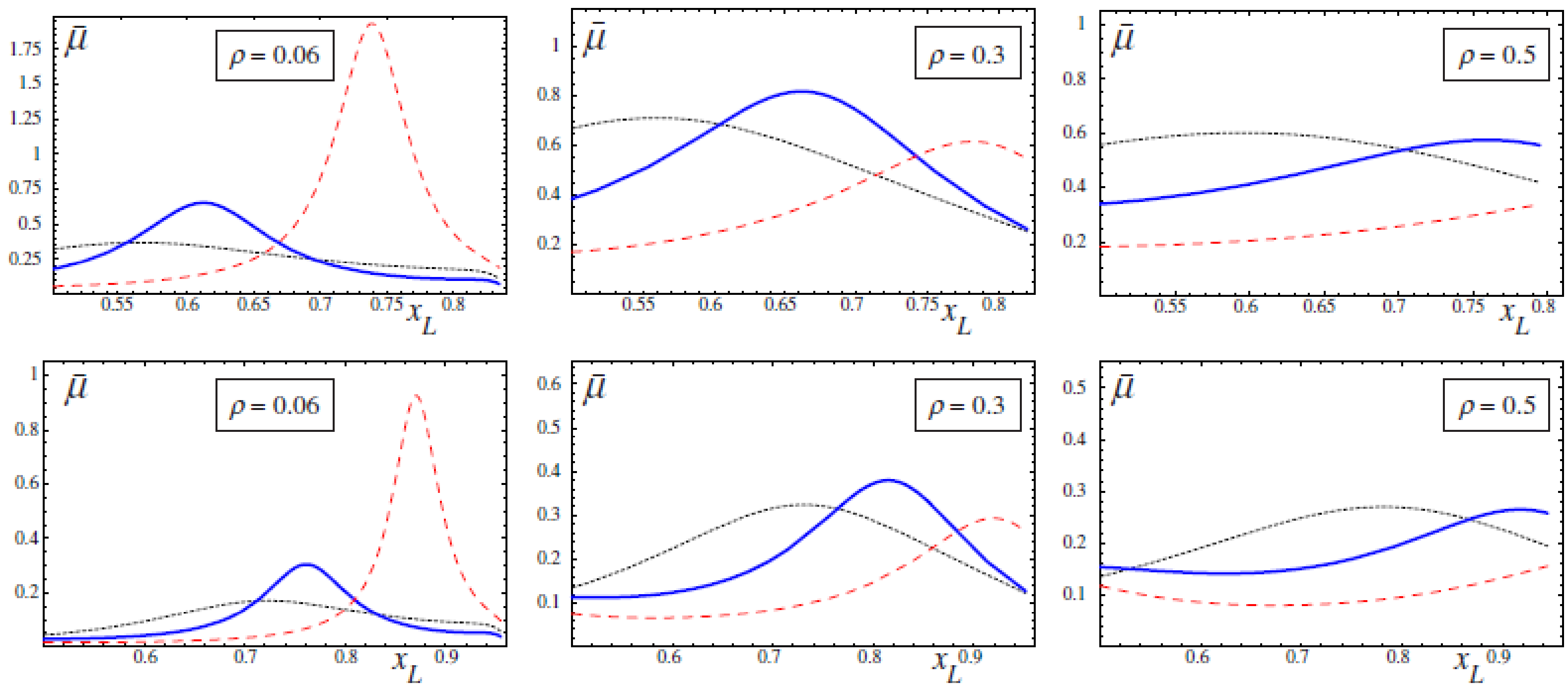


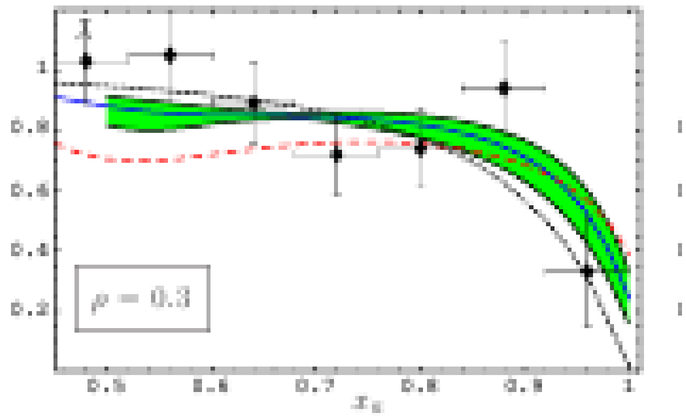
# Longitudinal Target Polarization (no at COMPASS, possible at J-PARC?) -> scan of DA




The upper row corresponds to a center-of-mass energy $s = 100\ \mathrm{GeV}^2$.

# Properties of exclusive DY

- Polarization T->L (collinear limit)




- More detailed calculations of angular distributions required

# CONCLUSIONS

- SE/E – various reagion of transverse momentum
- Small transverse momentum – angular distributions crucial

# Polarizabilities of pions, kaons..?

- Lattice studies for pions, rho (kaons are planned) Magnetic polarizabilities of light mesons in *SU*(3) lattice gauge theory
E.V. Luschevskaya (Moscow, ITEP), O.V. Teryaev (Dubna, JINR), O.A. Kochetkov (Moscow, ITEP & Regensburg U.). Nov 16, 2014. 8 pp.
e-Print: **arXiv:1411.4284 [hep-lat]**

- **g ~ 2**
- **polarizabilities**
- **No tachyonic mode**