# Quark-Hadron Duality and Time-like fomfactors

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February 21, 2013

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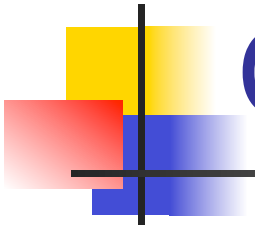
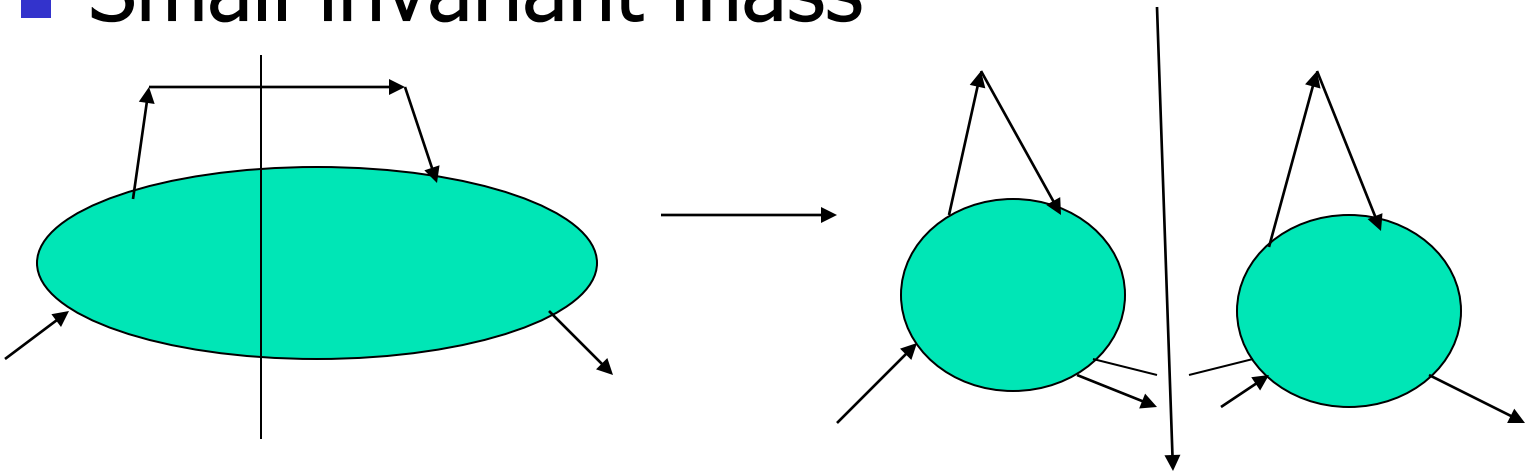


# Outline

- Nucleon structure: inclusive vs exclusive
- Space-like FFs and pdf's
- Time-like FFs and squared pdf
- BG-type duality and DYW-type relations in DY(@COMPASS&PANDA): Sivers function and time-like formfactors
- Time-like gravitational formfactors: similarity of annihilation and inflation

# Exclusive limit of DIS and space-like (transitional and elastic) FFs

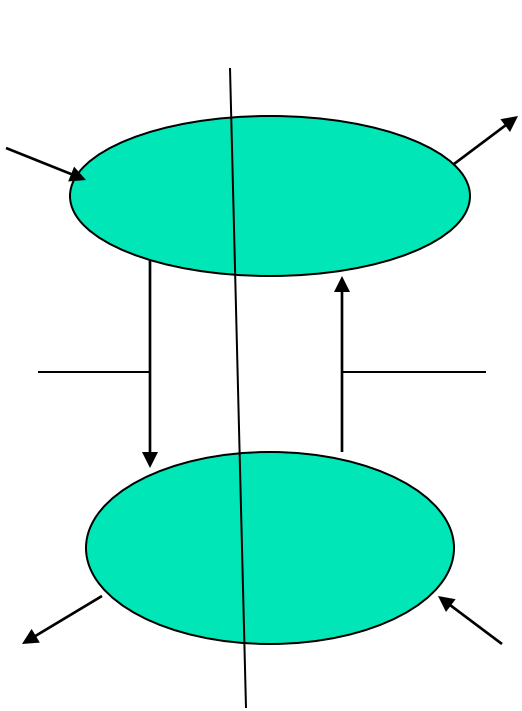
- Small invariant mass

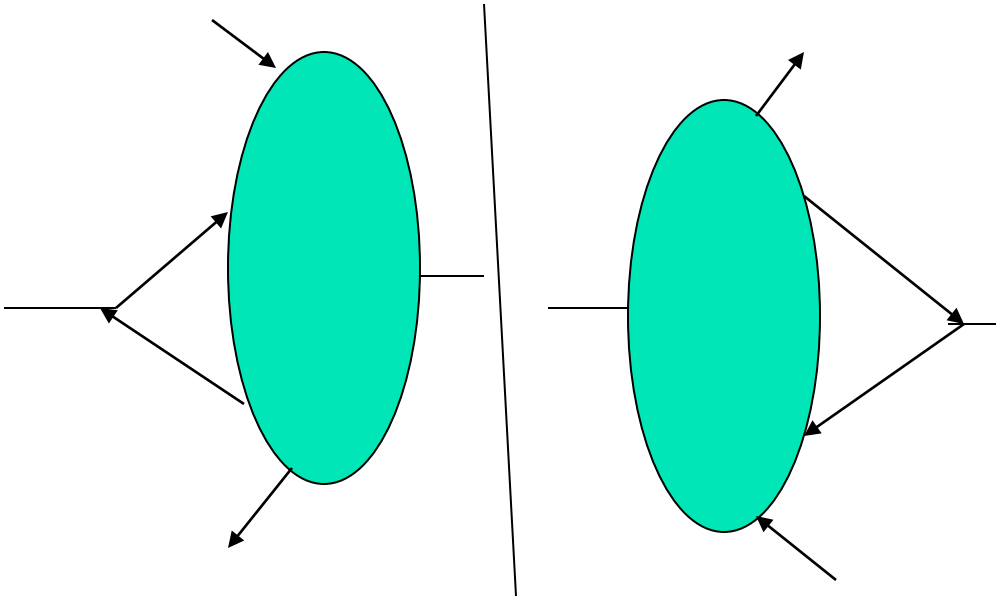


- Relation between x ->1 and large $Q^2$
- pdf ~ $(FF)^2$

# Exclusive limit of DY and time-like FFsTime-like FFs

- (Proton-antiptroton) DY at small s-$Q^2$





- $(pdf)^2 \sim$ (Dirac) $(FF)^2$
- ??!

# Comparing space-like and time-like FFs

- "Duality intervals" - from mass to x-space
- DIS: $(P+q)^2 = (P_f + \delta P_{DIS}))^2 = (M + \mu_{DIS})^2$ $\mu_{DIS}$ ~ pion mass
- Deviation of $x_B (\equiv 1 - \delta_{DIS})$ from 1

$$\delta_{DIS} \sim 2M\mu_{DIS}/Q^2.$$

- DY: $(P_1 + P_2)^2 = (q + \delta P_{DY})^2$

- Deviation of $\tau = Q^2/s (\equiv 1 - \delta_{DY})$ from 1

$$\delta_{DY} \sim 2\mu_{DY}/Q$$

# FFs from dualityh intervals

- DIS: $F_{SL}^2 \sim \int_0^{\delta_{DIS}} d\bar{x} f(\bar{x}) \quad x = 1 - \bar{x}$

- DY: $F_{TL}^2 \sim \int_0^{\delta_{DY}} d\bar{x}_1 d\bar{x}_2 f(\bar{x}_1) f(\bar{x}_2) \delta(\delta_{DY} - \bar{x}_1 - \bar{x}_2)$
- Proton-antiproton DY –same parton distributions $f(\bar{x}) = C\bar{x}^a$

$$F_{SL}^2(Q^2) \sim \frac{C}{a+1}\left(\frac{2M\mu_{DIS}}{Q^2}\right)^{a+1}; \; F_{TL}^2(Q^2) \sim \frac{C^2}{2(a+1)}\left(\frac{4\mu_{DY}^2}{Q^2}\right)^{a+1}$$

# SL vs TL

- Same Q-dependence

- Normalization –defined by distribution scale (~5) and duality intervals
- Asymptotically coincide – larger duality interval for DY!?
- Experimental tests – like BG tests in DIS@Jlab
- Suppression of single pion production together with DY dilepton  pair?

# Duality and axial FFs

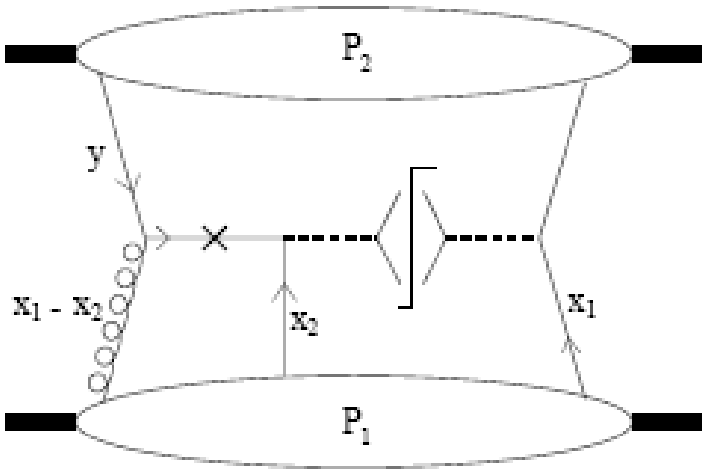
- Duality - -> similarity of axial and vector (Dirac) FFs – gamma_5 annihilate (OT’05)
- Recent analysis of neutrino data (V.Naumov,K.Kuzmin, O. Petrova) – small axial mass – closeness to standard dipole EM FF

# SSA in DY

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

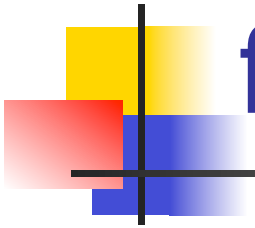
$$A = g\,\frac{\sin 2\theta\ \cos\phi\left[T(x,x) - x\frac{dT(x,x)}{dx}\right]}{M\left[1+\cos^2\theta\right]q(x)}$$

- Related to the moment of Sivers function




+ c. c.

# 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 dilepton mass) limit; x -> 1 : T(x,x)/q(x) -> Im $F_2/F_1$ (Q ~ 1 /(1-x))
- Both directions – estimate of Sivers at large x and explanation of phases in FF's
- Compatible with models for Sivers $\sim(1-x)^{4-5}$
- Possibilities; estiamate SCALE of Sivers
- Common fits of Sivers and FF's?

# Gravitational Formfactors: EM current -> Energy-Momentum Tensor

$$\langle p'|T^{\mu\nu}_{q,g}|p\rangle = \bar{u}(p')\Big[A_{q,g}(\Delta^2)\gamma^{(\mu}p^{\nu)} + B_{q,g}(\Delta^2)P^{(\mu}i\sigma^{\nu)\alpha}\Delta_\alpha/2M\Big]u(p)$$

- Conservation laws - zero Anomalous Gravitomagnetic Moment : $\mu_G = J$ (g=2)

$$P_{q,g} = A_{q,g}(0) \qquad A_q(0) + A_g(0) = 1$$

$$J_{q,g} = \frac{1}{2}\left[A_{q,g}(0) + B_{q,g}(0)\right] \qquad A_q(0) + B_q(0) + A_g(0) + B_g(0) = 1$$

- May be extracted from high-energy experiments/ NPQCD calculations
- Describe the partition of angular momentum between quarks and gluons
- Describe interaction with both classical and TeV gravity

# Time-like gravitational FFs and D-term

- Negative sign of D-term -> positive C- quadrupole GrFF
- “Stability” arguments – Polyakov, Schweizer
- Holds for hadrons (also in nuclear media) , “Q-balls”, photons…
- Let us compare hadronic $\langle p|T|p'\rangle$ and vacuum $\langle 0|T|0\rangle$ matrix elements of EMT
- C –> “effective” cosmological constant ~ C $q^2$ : unusual dimension (2 instead of 4) due to normalization of states |p>
- Negative in SL region: scattering ~ deceleration
- Positive in TL region: annihilation ~ acceleration/inflation (“little bang”)
- Application to heavy-ion collisions?
- Can real Big Bang be considered as a result of annihilation (in extra dimensions)?!

# Conclusions

- Exclusive limit of proton-antiproton DY – duality to TL FFs
- Similar Q-dependence to SL normalization – deopends on pdfs and duality intervals
- Experimental tests of duality in proton-antiproton annnihilation similar to BG duality studies @JLab.
- Sivers function <-> partonic picture of phase shift between Dirac and Pauli FFs
- Time-like GrFF's : Annihilation ~Inflation?!