Axial Anomaly and Strange Quarks

FOURTEENTH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

Moscow, MSU, August 21 2009

Oleg Teryaev
JINR, Dubna

Outline

- Axial anomaly for massless and massive fermions: decoupling
- Axial anomaly and Heavy quarks polarization in nucleon
- When strange quarks can be heavy: multiscale hadrons
- Support: small higher twist with IR QCD coupling
- Charm/strange universality?
- Chiral magnetic effect for strangeness in Heavy Ions collisions
- Conclusions

Heavy strange quark?!

- With respect to WHAT?
- Light with respect to hadron mass
- BUT
- Heavy with respect to higher twists parameters
- Multiscale nucleon
- Possible origin – small correlations of gluon (and quark) fields

Symmetries and conserved operators

- (Global) Symmetry -> conserved current ($\partial^\mu J_\mu = 0$)
- Exact:
- U(1) symmetry – charge conservation - electromagnetic (vector) current
- Translational symmetry – energy momentum tensor $\partial^\mu T_{\mu\nu} = 0$

Massless fermions (quarks) – approximate symmetries

- Chiral symmetry (mass flips the helicity)

$$\partial^{\mu} J^{5}{}_{\mu} = 0$$

- Dilatational invariance (mass introduce dimensional scale – c.f. energy-momentum tensor of electromagnetic radiation)

$$T_{\mu\mu} = 0$$

Quantum theory

- Currents -> operators
- Not all the classical symmetries can be preserved -> anomalies
- Enter in pairs (triples?...)
- Vector current conservation <-> chiral invariance
- Translational invariance <-> dilatational invariance

Massive quarks

- One way of calculation – finite limit of regulator fermion contribution (to TRIANGLE diagram) in the infinite mass limit
- The same (up to a sign) as contribution of REAL quarks
- For HEAVY quarks – cancellation!
- Anomaly – violates classical symmetry for massless quarks but restores it for heavy quarks

Decoupling

- Happens if the symmetry is broken both explicitly and anomalously
- Selects the symmetry in the pair of anomalies which should be broken (the one which is broken at the classical level)
- For “non-standard” choice of anomalous breakings (translational anomaly) there is no decoupling
- Defines the Higgs coupling, neutralino scattering…

M. V. POLYAKOV, A. SCHÄFER, AND O. V. TERYAEV

PHYSICAL REVIEW D 60 051502

Heavy quarks polarisation

- Non-complete cancellation of mass and anomaly terms (97)

$$\partial^\mu j^c_{5\mu} = \frac{\alpha_s}{48\pi m_c^2}\partial^\mu R_\mu ,$$

$$R_\mu = \partial_\mu (G^a_{\rho\nu}\tilde{G}^{\rho\nu,a}) - 4(D_\alpha G^{\nu\alpha})^a \tilde{G}^a_{\mu\nu}$$

$$\begin{aligned}\langle N(p,\lambda)|j^{(c)}_{5\mu}(0)|N(p,\lambda)\rangle &= \frac{\alpha_s}{12\pi m_c^2}\langle N(p,\lambda)|g\sum_{f=u,d,s}\bar{\psi}_f\gamma_\nu\tilde{G}_\mu{}^\nu\psi_f|N(p,\lambda)\rangle \\ &= \frac{\alpha_s}{12\pi m_c^2}2m_N^3 s_\mu f_S^{(2)} .\end{aligned}$$

- Gluons correlation with nucleon spin – twist 4 operator NOT directly related to twist 2 gluons helicity BUT related by QCD EOM to singlet twist 4 correction (colour polarisability) f2 to g1
- “Anomaly mediated” polarisation of heavy quarks

Numerics

- Small (intrinsic) charm polarisation

$$\overline{G}_A^c(0) = -\frac{\alpha_s}{12\pi} f_S^{(2)} \left(\frac{m_N}{m_c}\right)^2 \approx -5\times10^{-4}$$

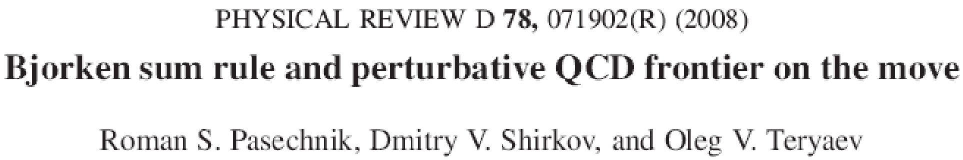
- Consider STRANGE as heavy! – CURRENT strange mass squared is ~100 times smaller – -5% - reasonable compatibility to the data! (But problem with DIS and SIDIS – talk of D. Peshekhonov)
- Current data on f2 – somewhat larger

Can s REALLY be heavy?!

- Strange quark mass close to matching scale of heavy and light quarks – relation between quark and gluon vacuum condensates (similar cancellation of classical and quantum symmetry violation – now for trace anomaly). BUT - common belief that strange quark cannot be considered heavy,
- In nucleon (no valence “heavy” quarks) rather than in vacuum - may be considered heavy in comparison to small genuine higher twist – multiscale nucleon picture

Are higher twists small?

- More theoretically clear – non singlet case – pQCD part well known (Bjorken sum rule)
- Low Q region – Landau pole – IR stable coupling required (Analytic,freezing…)
- Allows to use very accurate JLAB data to extract HT



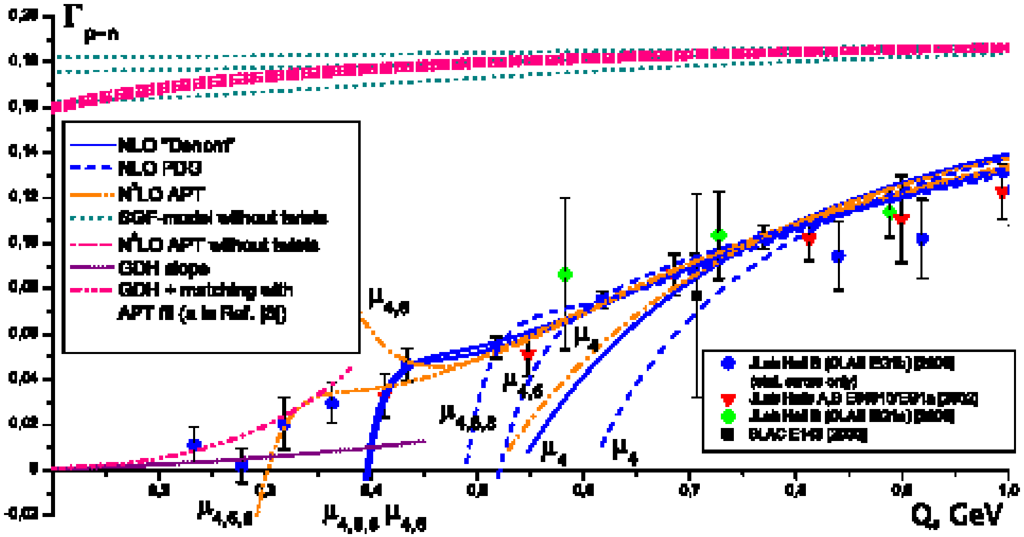
PHYSICAL REVIEW D **78,** 071902(R) (2008)

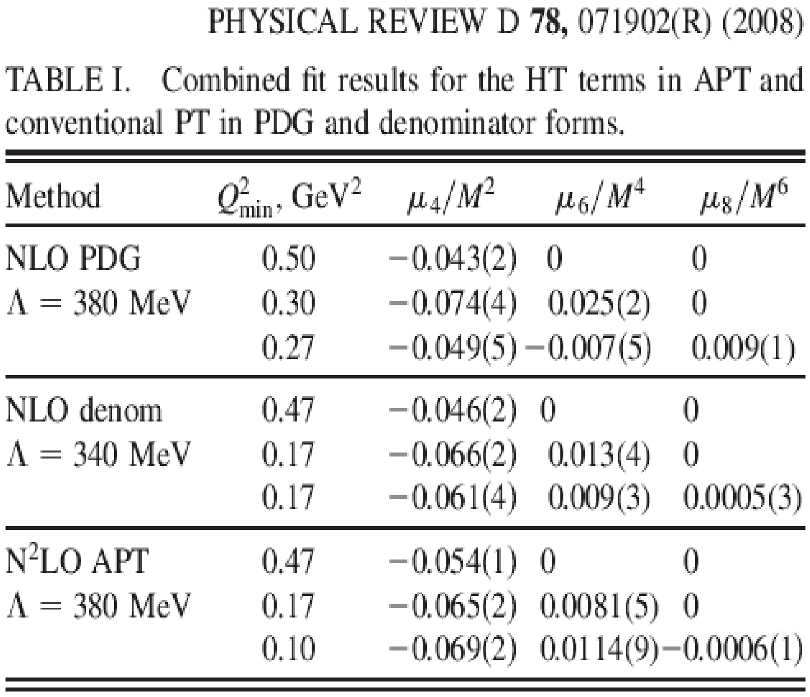
Bjorken sum rule and perturbative QCD frontier on the move

Roman S. Pasechnik, Dmitry V. Shirkov, and Oleg V. Teryaev

Higher twists from Bjorken Sum Rule

- Accurate data + IR stable coupling -> low Q region





PHYSICAL REVIEW D **78,** 071902(R) (2008)

TABLE I. Combined fit results for the HT terms in APT and conventional PT in PDG and denominator forms.

Method	$Q^2_{\min}$, GeV^2	μ_4/M^2	μ_6/M^4	μ_8/M^6
NLO PDG	0.50	−0.043(2)	0	0
Λ = 380 MeV	0.30	−0.074(4)	0.025(2)	0
	0.27	−0.049(5)	−0.007(5)	0.009(1)
NLO denom	0.47	−0.046(2)	0	0
Λ = 340 MeV	0.17	−0.066(2)	0.013(4)	0
	0.17	−0.061(4)	0.009(3)	0.0005(3)
N^{2}LO APT	0.47	−0.054(1)	0	0
Λ = 380 MeV	0.17	−0.065(2)	0.0081(5)	0
	0.10	−0.069(2)	0.0114(9)	−0.0006(1)

- HT – small indeed

Comparison : Gluon Anomaly for massless and massive quarks

- Mass independent
- Massless – naturally (but NOT uniquely) interpreted as (on-shell) gluon circular polarization
- Small gluon polarization – no anomaly?!
- Massive quarks – acquire "anomaly polarization"
- May be interpreted as a kind of circular polarization of OFF-SHELL (CS projection -> GI) gluons
- Very small numerically
- Small strange mass – partially compensates this smallness and leads to % effect

Unpolarized strangeness – can it be considered as heavy?

- Heavy quark momentum – defined by <p|GGG|p> matrix element (Franz,Polyakov,Goeke)

$$\frac{\langle N(P)|n^\mu n^\nu i g_s^3(\mu)\,\mathrm{tr}_c G_{\alpha\nu} G_{\beta\mu} G^{\alpha\beta}|N(P)\rangle}{\langle N(P)|n^\mu n^\nu g_s^2(\mu)\,\mathrm{tr}_c G^\alpha_\nu G_{\alpha\mu}|N(P)\rangle} = \Lambda^2$$

$$M_2^{(c),\ \mathrm{intrinsic}}(\mu) = \frac{\alpha_s(\mu)}{30\pi}\frac{\Lambda^2}{m_c^2} M_2^G(\mu) + \mathcal{O}\left(\frac{1}{m_c^4}\right).$$

- IF no numerical suppression of this matrix element – charm momentum of order 0.1%
- IF strangeness can be also treated as heavy – too large momentum of order 10%

Heavy unpolarized Strangeness: possible escape

- Conjecture: $\langle p|GGG|p\rangle$ is suppressed by an order of magnitude with respect to naïve estimate
- Tests in models/lattice QCD (Done)
- Charm momentum of order 0.01%
- Strangeness momentum of order of 1%

Heavy unpolarized Strangeness: vector current

- Follows from Heisenberg-Euler effective lagrangian (confirmed: A. Moiseeva, M. Polyakov)
- FFFF -> FGGG -> Describes strangeness contribution to nucleon magnetic moment and pion mean square radius
- FFFF->FFGG -> perturbative description of chiral magnetic effect for haeavy (strange) quarks in Heavy Ion collisions

Charm/Strangeness universality

- Universal behaviour of heavy quarks distributions - from non-local (C-even) operators
- c(x)/s(x) = $(m_s / m_c)^2 \sim 0.01$
- Delta c(x)/Delta s(x)= $(m_s / m_c)^2 \sim 0.01$
- Delta c(x)/c(x) = Delta s(x)/s(x)
- Experimental tests – comparison of strange/charmed hadrons asymmetries

Higher corrections

- Universality may be violated by higher mass corrections
- Reasonable numerical accuracy for strangeness – not large for s –> negligible for c
- If so, each new correction brings numerically small mass scale like the first one
- Possible origin – semiclassical gluon field
- If not, and only scale of first correction is small, reasonable validity for s may be because of HT resummation

Conclusions

- Heavy quarks – cancellation of anomalous and explicit symmetry breaking
- Multiscale picture of nucleon - Strange quarks may be considered are heavy sometimes
- Possible universality of strange and charmed quarks distributions – similarity of spin asymetries of strange and charmed hadrons
- Chiral magnetic effect for stange quarks – straightforward modification of Heisenberg-Euler lagrangian