From pion formfactor to exclusive Drell-Yan processes

XXII Baldin ISHEPP, ***Session in Honor of the 80th Anniversary of Professor Anatoly Efremov***

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Outline

- AV and pion formfactor
- From pion FF to Exclusive DY
- GPDxDA vs GPDxGPD
- Factorization vs dispersion relations
- Similarity to twist-3 semiinclusive SSA
- Gluons GPDs case and quarkonia/Higgs CEP
- Conclusions

V.Efremov, A.V.Radyushkin

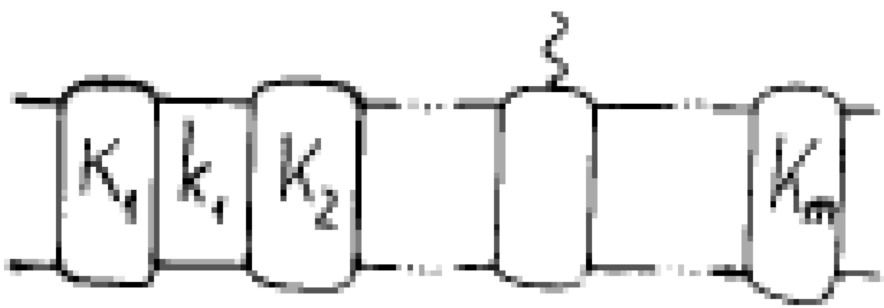

Fig.2

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E2 - 9717

A.V.Efremov, A.V.Radyushkin

ASYMPTOTICS OF PION ELECTROMAGNETIC FORM FACTOR IN SCALE INVARIANT QUARK MODEL

1976

[Factorization and Asymptotical Behavior of Pion Form-Factor in QCD](#) (In Russian)
A.V. Efremov, A.V. Radyushkin (Dubna, JINR). Nov 1979. 12 pp.
Published in **Phys.Lett. B94 (1980) 245-250**
JINR-P2-12900
DOI: 10.1016/0370-2693(80)90869-2

- QCD

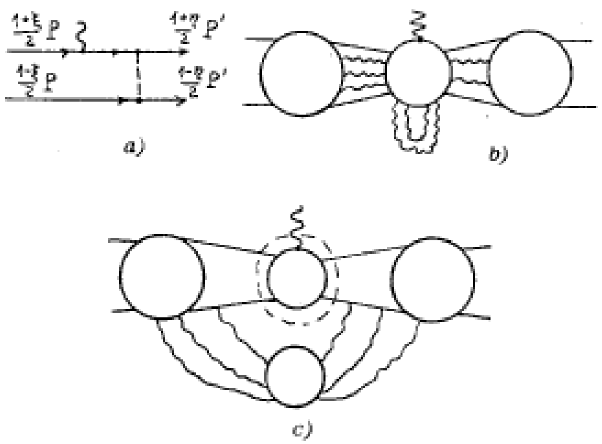
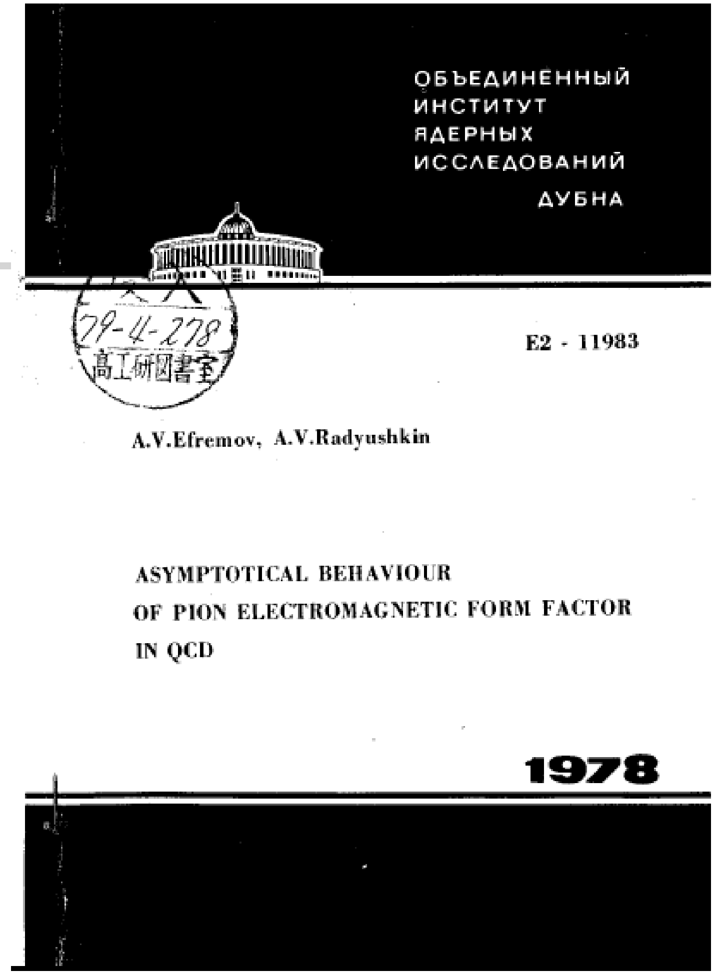


Fig. 5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E2 - 11983

A.V.Efremov, A.V.Radyushkin

ASYMPTOTICAL BEHAVIOUR
OF PION ELECTROMAGNETIC FORM FACTOR
IN QCD

1978

- Note symmetric
kinematics – most convenient for GPDs

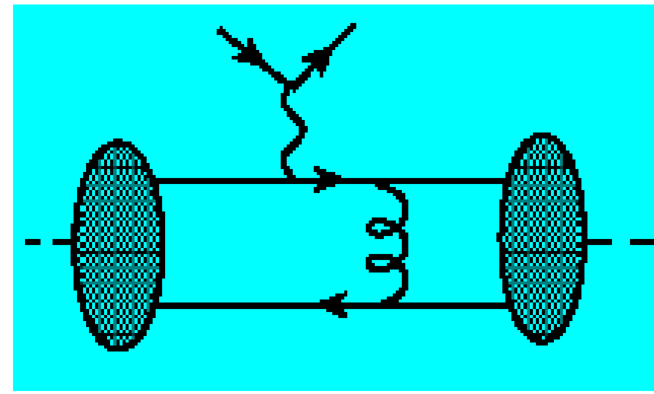
Way to (semi) exclusive DY

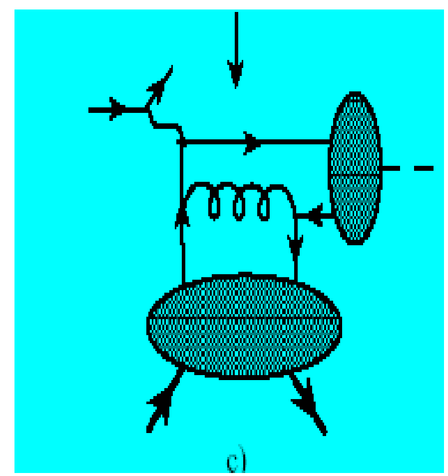
- Starting from (Pion) form factor- 2 DA's

$$F \sim \left(\int dx \frac{\phi(x)}{1-x}\right)^2$$

- 1 DA -> GPD :Exclusive mesons production (Frankfurt, Strikman) / DY ("classical" mechanism – Pire, Schymanowski, Wagner)

$$M \sim \int dx \frac{\phi(x)}{1-x} \int dx \frac{H(x,\xi)}{x-\xi+i\varepsilon}$$





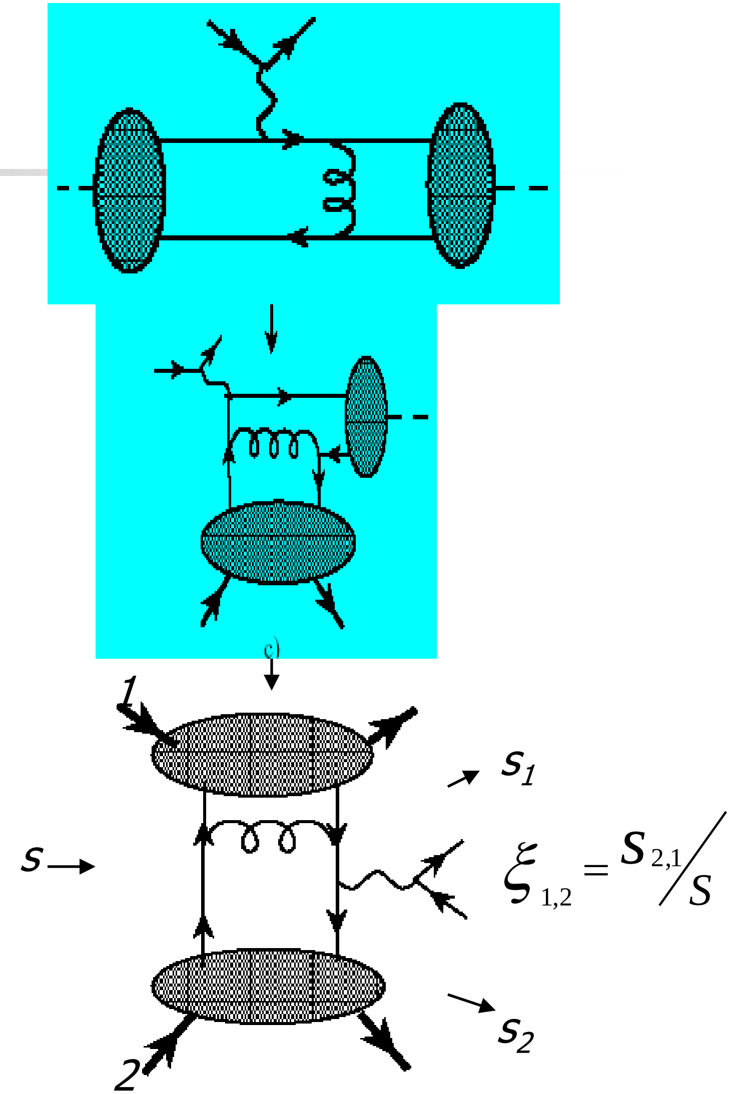
Next step: 2 DA's -> 2 GPD's

- Exclusive double diffractive DY process
- Analytic continuation:

$$M \sim \int dx \frac{H(x,\xi_1)}{x-\xi_1 \pm i\varepsilon} \int dy \frac{H(y,\xi_2)}{y-\xi_2 \mp i\varepsilon}$$

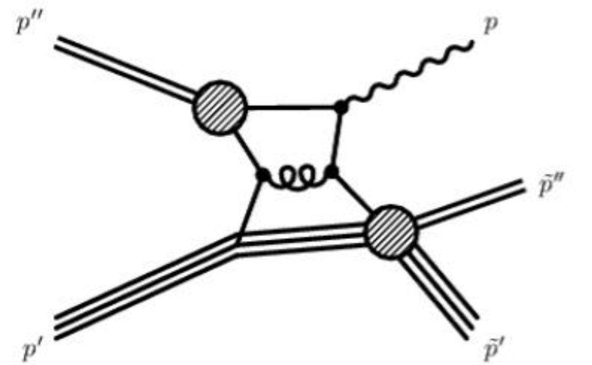
- DIFFERS from direct calculation – NO factorization in physical region

$$M \sim \int\int dxdy \frac{H(x,\xi_1)H(y,\xi_2)}{(x-\xi_1)(y-\xi_2)+i\varepsilon}$$

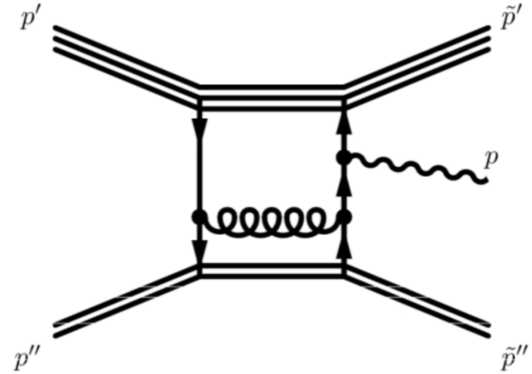


Comparison of different "handbag" contributions for pion-nucleon diffractive DY (AP,OT, in progress)

- Exclusive process $p\pi^0 \rightarrow p\pi^0\gamma^*$:
  - Classical



  - Double diffractive



GPDxGPD

- Probability amplitude:

$$S_{p\pi 1} = i\frac{(2\pi)^4}{2N_c^2}\frac{eg_{(s)}^2}{(2V)^{\frac{5}{2}}\sqrt{\varepsilon'\varepsilon''\tilde{\varepsilon}'\tilde{\varepsilon}''\varepsilon}}\cdot e_\lambda^* \cdot \frac{1}{(\bar{P}',\bar{P}'')}\cdot\left(\frac{\bar{P}'^\lambda}{\xi_2}-\frac{\bar{P}''^\lambda}{\xi_1}\right)\cdot I_1 \cdot$$

$$\cdot\delta(p'+p''-\tilde{p}'-\tilde{p}''-q)$$

$$\xi_1,\xi_2\in[0,1] \qquad \bar{P}'=\frac{p'+\tilde{p}'}{2} \qquad \bar{P}''=\frac{p''+\tilde{p}''}{2}$$

- Longitudinal polarisation

Compton FFs

$$I_1 = \int_{-1}^{1} \frac{e_u H_p^{(u)}(x) H_\pi^{(u)}(y)}{(x+\xi_1)(y-\xi_2) - i\varepsilon_g} \mathrm{d}x\mathrm{d}y - \int_{-1}^{1} \frac{e_u H_p^{(u)}(x) H_\pi^{(u)}(y)}{(x-\xi_1)(y+\xi_2) - i\varepsilon_g} \mathrm{d}x\mathrm{d}y +$$
$$+ \int_{-1}^{1} \frac{e_d H_p^{(d)}(x) H_\pi^{(d)}(y)}{(x+\xi_1)(y-\xi_2) - i\varepsilon_g} \mathrm{d}x\mathrm{d}y - \int_{-1}^{1} \frac{e_d H_p^{(d)}(x) H_\pi^{(d)}(y)}{(x-\xi_1)(y+\xi_2) - i\varepsilon_g} \mathrm{d}x\mathrm{d}y$$

$$H_p^{(q)}(x) = \begin{cases} H_p^q(x) & x > 0 \\ -H_p^{\bar{q}}(-x) & x < 0 \end{cases}$$

Classical mechanism

- Probability amplitude:

$$S_{p\pi 2} = i\frac{(2\pi)^4}{2N_c^2}\frac{ee_q g_{(s)}^2}{(2V)^{\frac{5}{2}}\sqrt{\varepsilon'\varepsilon''\tilde{\varepsilon}'\tilde{\varepsilon}''\varepsilon}} \cdot e_\lambda^* \cdot \frac{1}{(\bar{P},p'')} \cdot \left(2\bar{P}^\lambda - \frac{p''^\lambda}{\xi}\right) \cdot I_2 \cdot$$

$$\cdot \delta(p' + p'' - \tilde{p}' - \tilde{p}'' - q)$$

$$\xi \in [0,1] \qquad \bar{P} = \frac{p' + \tilde{p}' + \tilde{p}''}{2}$$

- Also longitudinal polarisation

Compton FF

$$I_2 = \int_{-1}^{1} \mathrm{d}x \int_0^1 \frac{H_{p\pi}(x)\Phi(y)}{(x+\xi)y + i\varepsilon_g} \mathrm{d}y + \int_{-1}^{1} \mathrm{d}x \int_0^1 \frac{H_{p\pi}(x)\Phi(y)}{(x-\xi)y - i\varepsilon_g} \mathrm{d}y$$

$$H_{p\pi}(x) = \frac{1}{\sqrt{2}} \left[e_u H_{p\pi}^{(u)}(x) - e_d H_{p\pi}^{(d)}(x) \right]$$

$\Phi(y)$ – distribution amplitude of pion

Pion decay constant cansel in DA and TDA (natural normalization in accordance wih soft-pion theorems)

Comparison of the processes

- Ratio of the cross-sections (prefactor due to EM GI):

$$\frac{A_1}{A_2} = \frac{2(1+\xi_1)(1+\xi_2)}{2(1+\xi)\xi_1\xi_2} \cdot \frac{|I_1|^2}{|I_2|^2} = \frac{s(s_1+s_2-s)}{s_1 s_2} \cdot \frac{|I_1|^2}{|I_2|^2}$$

$$s = (p' + p'')^2 \qquad s_1 = (\tilde{p}' + q)^2 \qquad s_2 = (\tilde{p}'' + q)^2$$

- GPDxGPD – dominant in forward region

Interference

- Cross section:

$$\frac{d\sigma}{\mathrm{d}^3\tilde{p}'\mathrm{d}^3\tilde{p}''} = \frac{\alpha_{(em)}\alpha^2_{(s)}}{2^6 N_c^4 \pi^2 \tilde{\varepsilon}'\tilde{\varepsilon}''} \cdot \frac{1}{(p',p'')^2} \cdot$$

$$\cdot \left[\frac{8s^2}{s_1 s_2}|I_1|^2 + \frac{8s}{s_1+s_2-s}|I_2|^2 + 4s\left(\frac{1}{s_2} + \frac{s}{s_1(s_1+s_2-s)}\right)(I_1^* I_2 + I_2^* I_1)\right] \cdot$$

$$\cdot \delta(q^2 - m_\gamma^2)$$

- Interference term – nonsymmetric wrt $s_{1,2}$ interchange

Compton FFs: analytic continuation and IR regularization

- Pole prescription unclear – cuts in s and $s_{1,2}$ produce different signs
- Similar to pion dissosiation to dijet (D. Ivanov et al)
- $s_{1,2}/s$ the same when both positive or both negative – cancellation of cuts
- Similar to cancellation of cuts in s and Q^2 for semi-inclusive annihilation
- Suhggestion for time-like DVCS: Q^2/s – cancel; Q^2/u due to Q^2 cut: different duality properties with – resonances in vector rather than s- channel (BG-type ones)
- Direct calculation: IR regularization (of imaginary part) like in GK model

Similarity to twist 3 Single Spin Asymmetries

- Another direction of AV activity at about the same time

AV

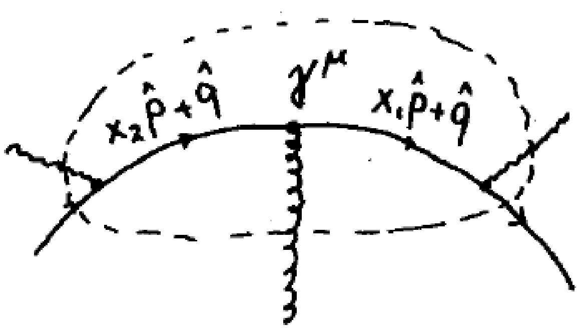


Fig.3

[QCD Asymmetry and Polarized Hadron Structure Functions](#) (In Russian)
A.V. Efremov, O.V. Teryaev (Dubna, JINR). Aug 1984. 6 pp.
Published in **Phys.Lett. B150 (1985) 383**
JINR-P2-84-603
DOI: 10.1016/0370-2693(85)90999-2
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
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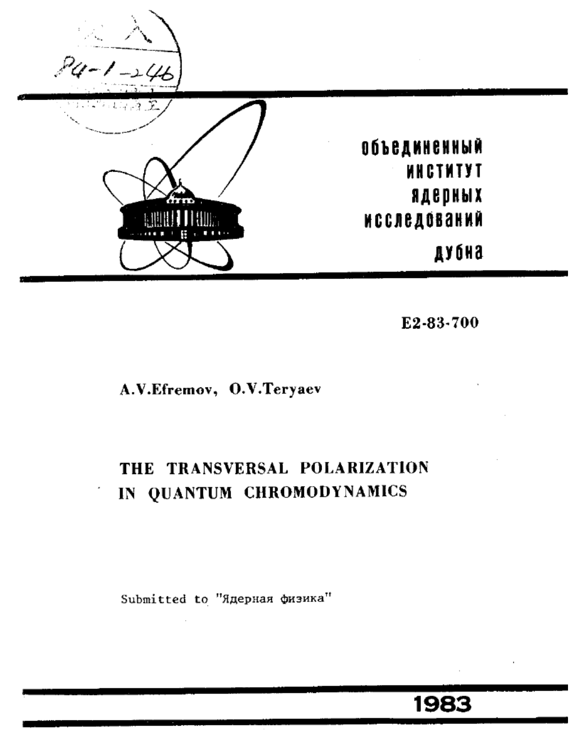
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E2-83-700

A.V.Efremov, O.V.Teryaev

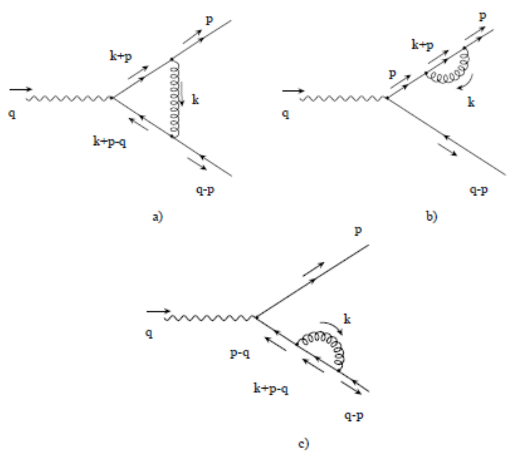
THE TRANSVERSAL POLARIZATION IN QUANTUM CHROMODYNAMICS

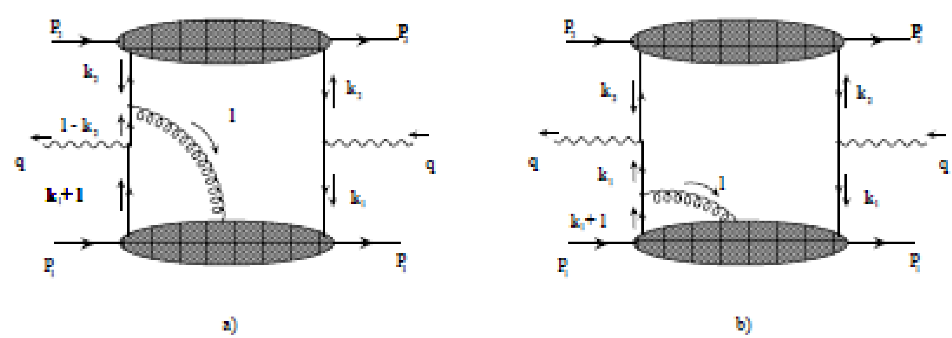
Submitted to "Ядерная физика"

1983

Electromagnetic Gauge Invariance in DY process (IA,OT)

- Extra diagram – factor 2 in transverse (TM integrated) asymmetry
- Absent in pQCD



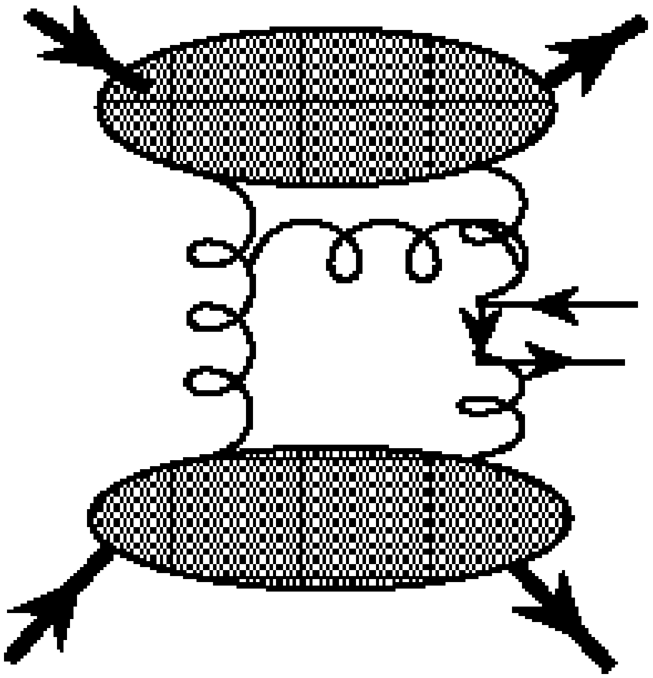


Comparison

- DY: imaginary part of EOM poles <..G(x)..>/x~<..A(x)..>
- Gluon DVMP – also!
- For free quarks target (recent discussion with D.Ivanov) – from gluon propagator: GI but much simpler in axial gauge with correct phase prescription
- One should expect similar situation with cuts for twist 3 SSA (for free quark? Onium??)
- Pion to 2 jets – poles with different prescriptions and claimed factorization breaking similar to that for Sivers function?
-

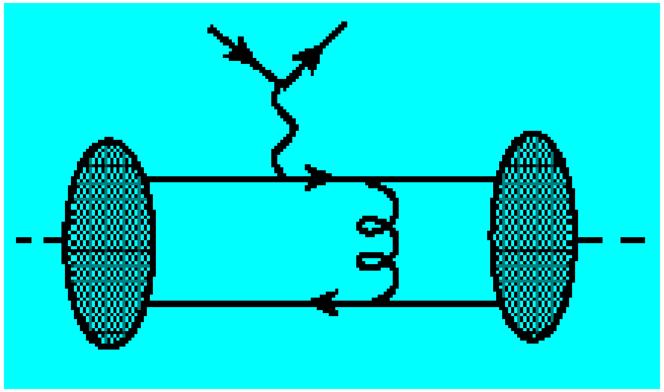
Double Diffraction: gluons

- One or both GPDs may be gluonic
- Complementary description of LHC DD (Higgs, Quarkonia, dijets)



Comparing collinear and (benchmark) KMR mechanisms

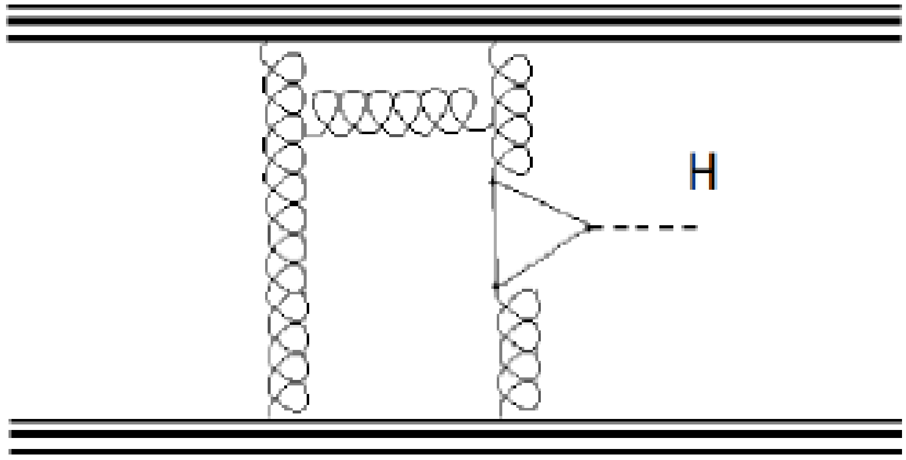
- Recall starting point – pion FF



- KMR analog for pion FF: Feynman mechanism
- Collinear – dominant for large Q2
- Is something remained from this property after transition to GPDxGPD (wf overlap -> screening gluon)?!
- Collinear – no gap survival probability? Substituted by hard gluon?

Higgs boson production (AP,OT, in progress)

- Collinear factorization – hard gluon exchange



Gauge

- Axial gauge:

$$D_{\mu\nu}(k) = \frac{1}{k^2}\left[g_{\mu\nu} + (n^2 + \alpha k^2)\frac{k_\mu k_\nu}{(k,n)^2} - \frac{k_\mu n_\nu + k_\nu n_\mu}{(k,n)}\right]$$

- Partly fixing gauge:

$$n = p' + ap''$$

Probability amplitude

- Approximation of small skewnesses:

$$S_{fi} = -i\frac{10\pi^2 g_{(s)}^4}{(2V)^{\frac{5}{2}} v\sqrt{p'^0 p''^0 \tilde{p}'^0 \tilde{p}''^0} p^0} \cdot \int_0^1 f(x) f(y) \mathrm{d}x \mathrm{d}y \cdot$$

$$\cdot \delta(p' + p'' - \tilde{p}' - \tilde{p}'' - p)$$

- Gauge dependence cancelled

Conclusions

- AV ideas work, develop and lead to new relations between their consequences
- Imaginary parts in twist 3 transverse spin-dependent DY and exclusive DY amplitude have similar properties
- Non-universality and factorization breaking for inclusive and exclusive processes – similar?