Hadron structure and spectroscopy with COMPASS

using π and μ beams the unusual way

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based on works with

IV Anikin, M. Diehl, L. Szymanowski, J.P. Lansberg, OV Teryaev, S Wallon

a simplistic outsider view

➭ **Success of π beams : spectroscopy**

$\longrightarrow$ **beautiful $\pi_1(1600)$ discovery**

➭ **Success of μ beams : hadronic structure**

$\longrightarrow$ **$\Delta G(x)$ historical measurements , TMDs**

near future : GPDs through DVCS and other exclusive channels

MY PROPOSAL :

➭ **use π beams to explore the structure of proton in exclusive processes (= one limit of the Drell Yan program)**

➭ **use μ beams to analyze the hybrid meson $\pi_1(1600)$ (= one limit of the DEMP program)**

Plan of the talk

➭ use π beams to explore the structure of proton in exclusive processes (= two limits of Drell Yan)

$\longrightarrow$ Forward exclusive $\pi N \to \mu^+\mu^- N'$ Accessing GPDs $\tilde{E}$ and $\tilde{H}$

$\longrightarrow$ Backward exclusive $\pi N \to \mu^+\mu^- N'$ Accessing $\pi \to N$ TDAs

$\longrightarrow$ discover the exclusive K factor

➭ use μ beams to analyze the 1^{-+} hybrid meson $\pi_1(1600)$

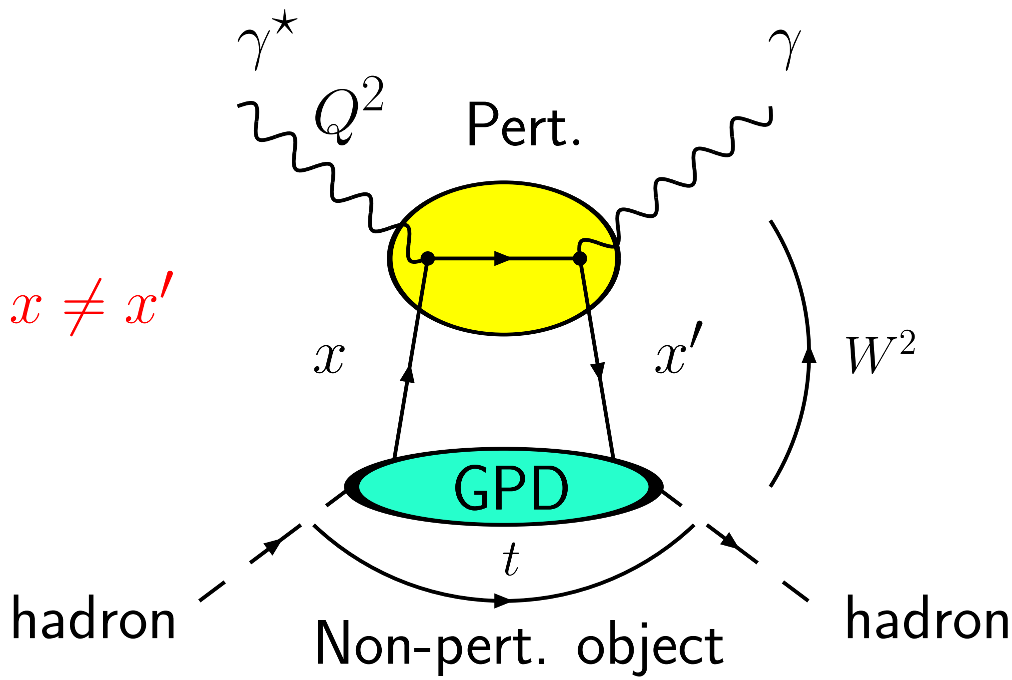
$\longrightarrow$ scrutenize the hybrid DA, namely its $\bar{q}q$ Fock state *(sic)*

➭ use quasi real γ beams for Drell Yan pairs on transv. pol. target

$\longrightarrow$ scrutenize the γ chiral odd DA and $h_1(x)$

Success of factorized description of DVCS/TCS

$\gamma^* N \to \gamma^* N'$ in terms of Generalized Parton Distributions



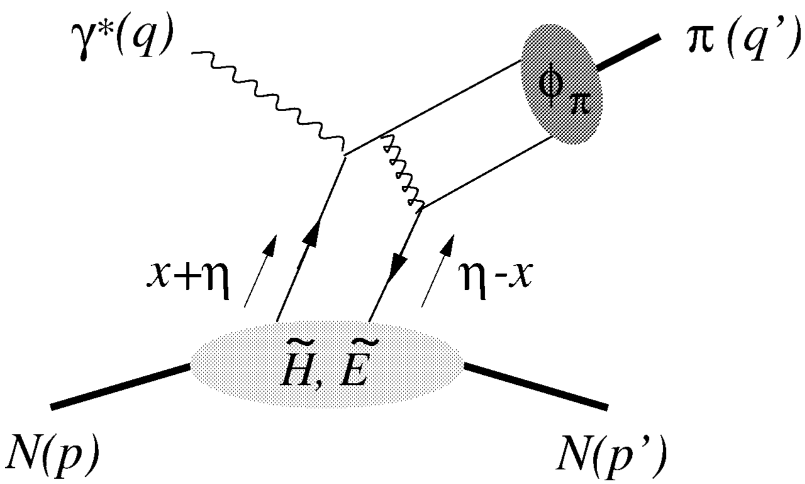
$\gamma^* N \to \gamma N'$ and $\gamma N \to \gamma^* N'$ in terms of the same GPDs, the same LO coeff. function and different NLO contributions

BP, L.Szymanowski, J.Wagner : Phys Rev. D83,034009(2011)

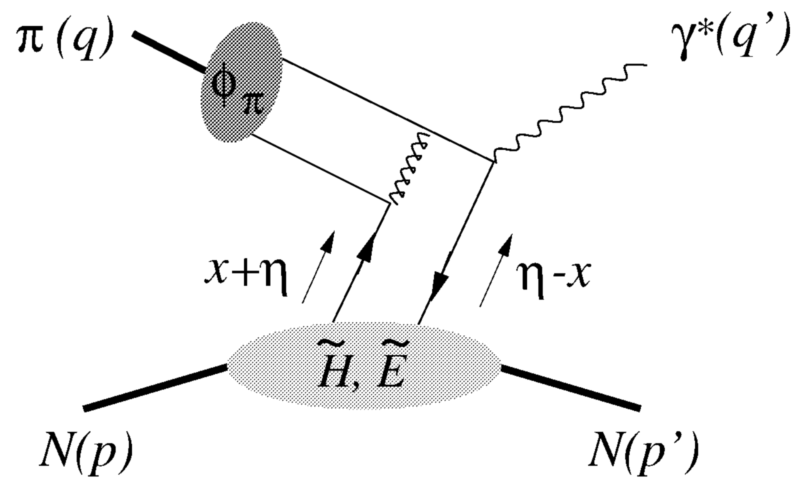
$\gamma^* N \to \pi N'$ and $\pi N \to \gamma^* N'$

E.Berger,M.Diehl,BP,Phys Lett.B523

Pion beams reveal $\tilde{H}, \tilde{E}$ Generalized Parton distributions



(a)



(b)

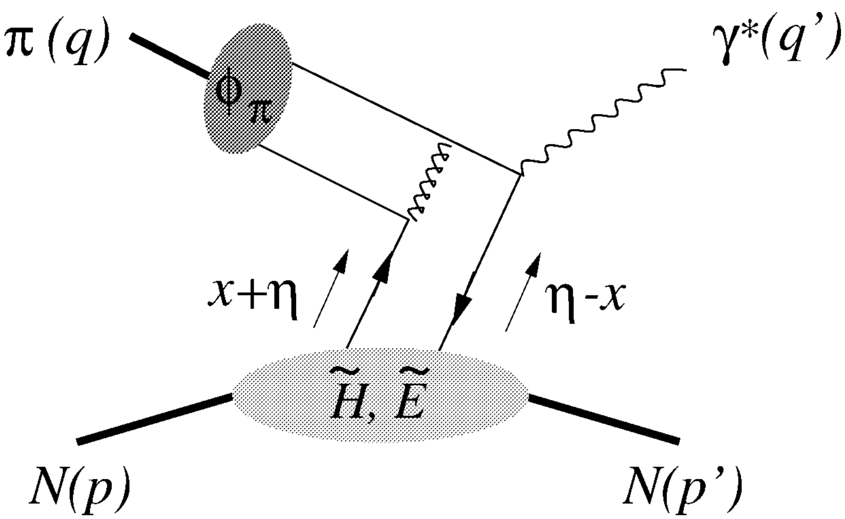
spacelike

timelike
(= Exclusive Limit of Drell Yan process)

COMPASS with μ beams $\Longleftrightarrow$ COMPASS with π beams

Exclusive lepton pair production in πN scattering

$$\pi^- p \to \gamma^* n \to \mu^+ \mu^- n$$



(b)

Bjorken variable $\tau = \frac{Q'^2}{s - M^2}$

skewness $\eta = \frac{(p-p')^+}{(p+p')^+} = \frac{\tau}{2-\tau}$

$$\frac{d\sigma}{dQ'^2\, dt\, d(\cos\theta)\, d\varphi} = \frac{\alpha_{\rm em}}{256\,\pi^3} \frac{\tau^2}{Q'^6} \sum_{\lambda',\lambda} |M^{0\lambda',\lambda}|^2 \sin^2\theta$$

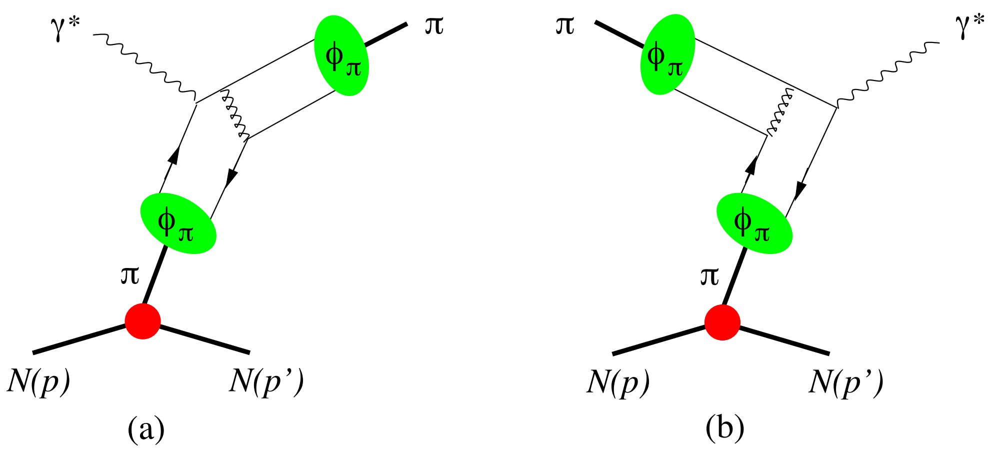
$$M^{0\lambda',\lambda}(\pi^- p \to \gamma^* n) = -ie\,\frac{4\pi}{3}\,\frac{f_\pi}{Q'}\,\frac{1}{(p+p')^+}\,\bar{u}(p',\lambda')\left[\gamma^+\gamma_5\,\tilde{\mathcal{H}}^{du}(\eta,t) + \gamma_5\frac{(p'-p)^+}{2M}\,\tilde{\mathcal{E}}^{du}(\eta,t)\right] u(p,\lambda)$$

$$\tilde{\mathcal{H}}^{du}(\eta,t) = \frac{8\alpha_S}{3}\int_{-1}^{1} dz\,\frac{\phi_\pi(z)}{1-z^2}\int_{-1}^{1} dx\left[\frac{e_d}{-\eta-x-i\epsilon} - \frac{e_u}{-\eta+x-i\epsilon}\right]\left[\tilde{H}^d(x,\eta,t) - \tilde{H}^u(x,\eta,t)\right]$$

$\tilde{H}$ and $\tilde{E}$ GPDs

➯ $\tilde{H}(x, \xi = 0, t = 0) = \Delta q(x)$

➯ $\tilde{E}$ **unknown : Pion pole dominance often assumed**

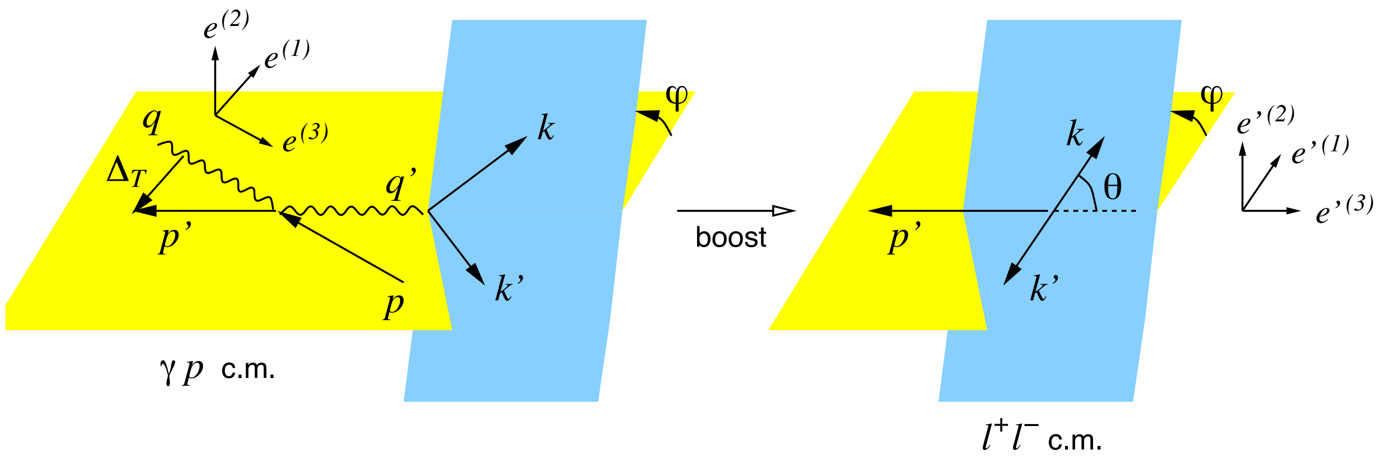


to be tested

➯ $t-$**dependence** $\rightarrow$ **proton femtophotography**

Lepton angular distribution

Dominant Amplitude : longitudinal γ^*



$$\frac{d\sigma}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} = \frac{\alpha_{\mathrm{em}}}{256\,\pi^3}\,\frac{\tau^2}{Q'^6}\,\sum_{\lambda',\lambda} |M^{0\lambda',\lambda}|^2 \sin^2\theta$$

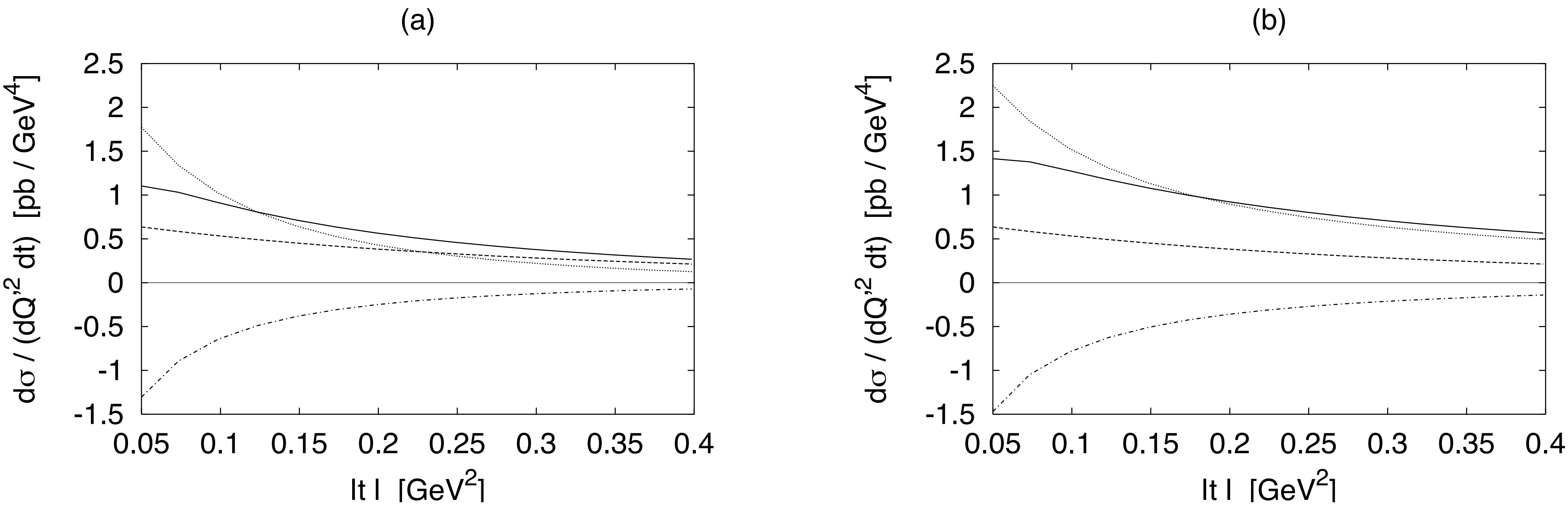
Crucial Test of the validity of the twist expansion

if σ_T not small, extract GPDs from σ_L only !

LO Estimates

E.Berger,M.Diehl,BP,Phys Lett.B523

$Q'^2 = 5GeV^2 \qquad \tau = 0.2$



(dashed) $= |\tilde{\mathcal{H}}|^2$; **(dash-dotted)** $=$ **Re**$(\tilde{\mathcal{H}}^* \tilde{\mathcal{E}})$; **(dotted)** $= |\tilde{\mathcal{E}}|^2$.

Target Transverse Spin asymmetry

At the twist 2 level : $\dfrac{d^{\uparrow}\sigma - d^{\downarrow}\sigma}{d^{\uparrow}\sigma + d^{\downarrow}\sigma} = A_{\mathrm{UT}}^{\sin(\phi-\phi_S)} \sin(\phi - \phi_S) + \text{other harmonics}$

$$A_{UT} = \frac{-2\sqrt{\frac{t-t_{min}}{t_{min}}}\,\eta^2\,\mathcal{I}m\,(\,\tilde{\mathcal{H}}\,\tilde{\mathcal{E}}^*\,)}{(1-\eta^2)|\tilde{\mathcal{H}}|^2-\frac{t}{4M^2}|\eta\tilde{\mathcal{E}}|^2-2\eta^2\mathcal{R}e(\tilde{\mathcal{H}}\tilde{\mathcal{E}}^*)}$$

➪ New information on GPDs.

e.g. if $\tilde{E}$ is well modelized by pion pole, $\tilde{\mathcal{E}}$ is real $\rightarrow A_{UT} \sim \tilde{H}(x, \xi = x, t)$

$\boxed{\text{NLO analysis not done}}$

At LO, space - and timelike amplitudes are related

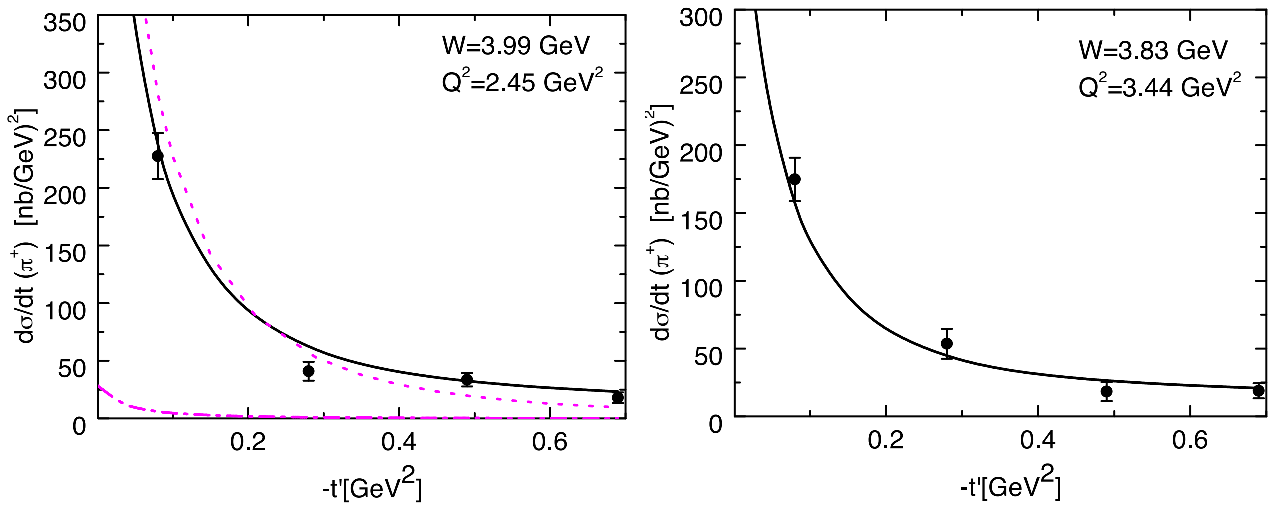
$$M^{0\lambda',\lambda}(\pi^- p \to \gamma^* n) = \left[M^{\lambda',0\lambda}(\gamma^* p \to \pi^+ n)\right]^*$$

At higher orders, significant differences expected

$\to$ critical check of the universality of GPDs and of factorization.

Status of spacelike $\gamma^*(Q)p \to \pi N$

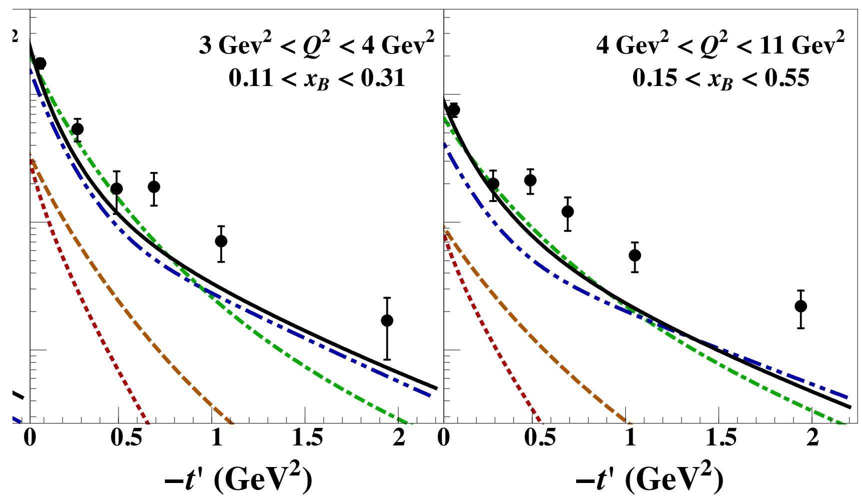
Data from HERMES :



$\sigma_T + \epsilon\sigma_L$ σ_T **vs** σ_L **?**

(also data from JLab)

2 contradictory phenom. analysis



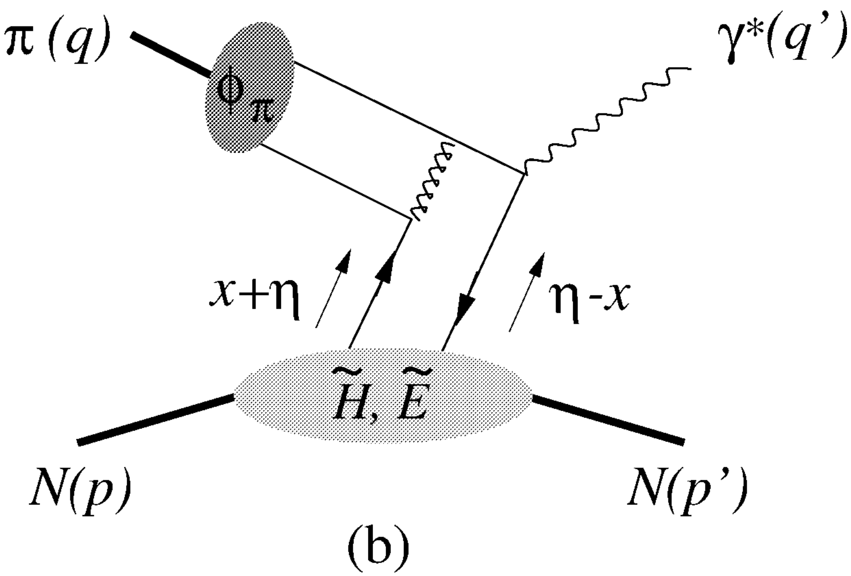
π**-exchange with exp FF ;**

S. Goloskokov and P.Kroll, EPJ, C65

QCD with $\alpha_S = .8$

C. Bechler, D. Muller, ArXiv 0906.2571

Compass Opportunity



Sufficient rates ($O(1-10$/hour)

Transverse spin asymmetry

$1 < q'^2 < 10\, GeV^2$, **small** $t = (q - q')^2$, **fixed** $\xi = \frac{p_N^+ - p_{N'}^+}{p_{N'}^+ + p_N^+}$

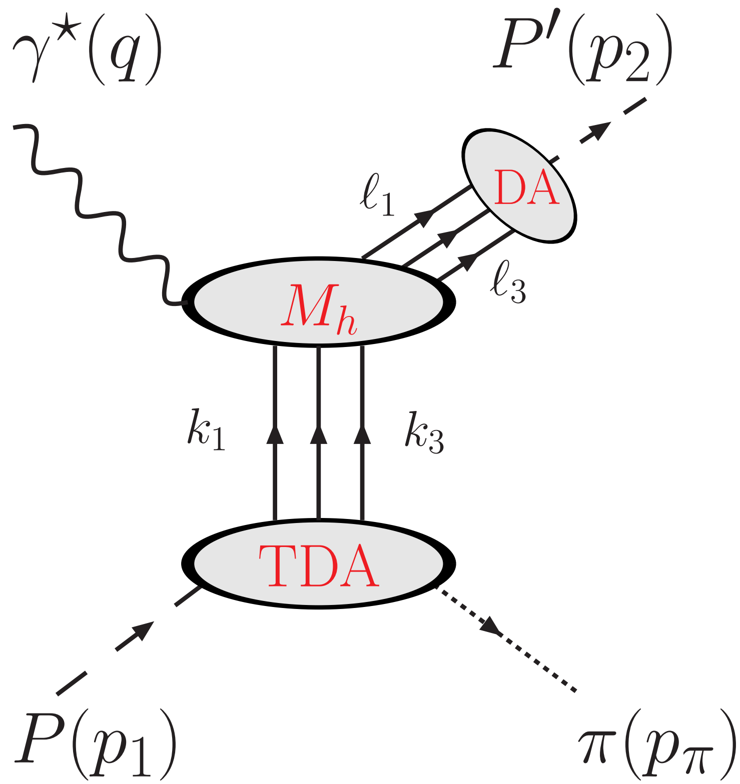
Measure lepton pair momentum ; deduce missing mass$^2 = \bar{M}^2$.

Select small $\bar{M}^2 \approx M_p^2$. (*(or detect final proton with recoil detector ?)*

Small ξ : lepton pair forward.

How to factorize backward leptoproduction $\gamma^* N \to N' \pi$

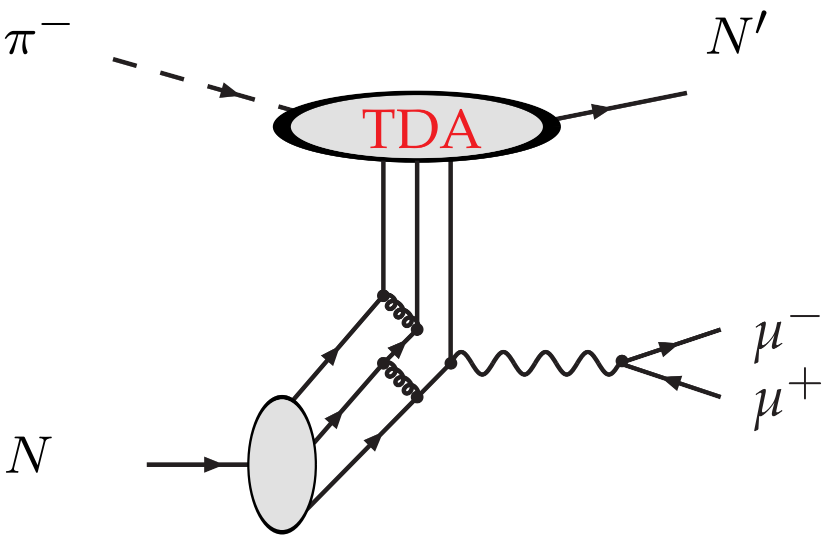
BP, L Szymanowski, PRD71 and PLB622

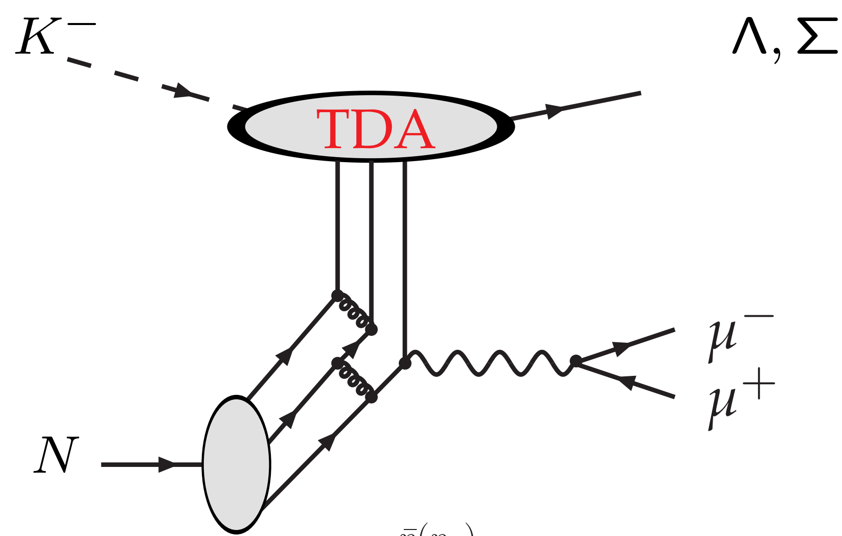


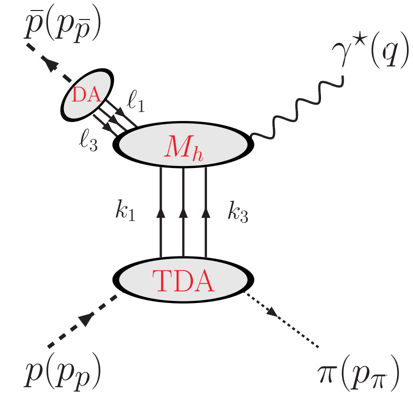
at large q^2, *small* $u = (p_1 - p_\pi)^2$, *fixed* $\xi = \frac{p^+_{N'} - p^+_\pi}{p^+_{N'} + p^+_\pi}$

$\rightarrow$ factorize timelike versions of backward $\gamma^* N \rightarrow N'\pi$

$\pi N \rightarrow N'\gamma^*(Q')$ $\qquad\qquad$ $K^- N \rightarrow \Lambda\gamma^*(Q')$







$\bar{N}N \rightarrow \pi\gamma^*$

at large Q'^2, **small** $u = (p_{N'} - p_\pi)^2$, **fixed** ξ

Interpretation of the $(\pi \to N) or (N \to \pi)$ TDAs

Develop proton wave function as (schematically) $|qqq> + \;\; |qqq\pi> + ...$

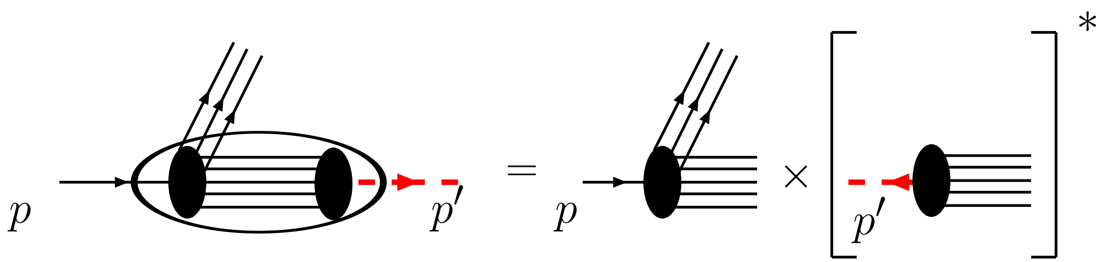
$|qqq>$ **is described by proton DA :** $\langle 0|\, \epsilon^{ijk} u^i_\alpha(z_1\, n) u^j_\beta(z_2\, n) d^k_\gamma(z_3\, n)\, |p(p,s)\rangle \Big|_{z^+=0,\, z_T=0}$

Define matrix elements sensitive to $|qqq\;\pi>$ **part : the TDAs**

$$\langle \pi(p')|\, \epsilon^{ijk} u^i_\alpha(z_1\, n) u^j_\beta(z_2\, n) d^k_\gamma(z_3\, n)\, |p(p,s)\rangle \Big|_{z^+=0,\, z_T=0}$$

light cone matrix elements of operators obeying usual RG evolution equations

➩ The $\pi \to N$ TDAs provides information on the next to minimal Fock state in the baryon



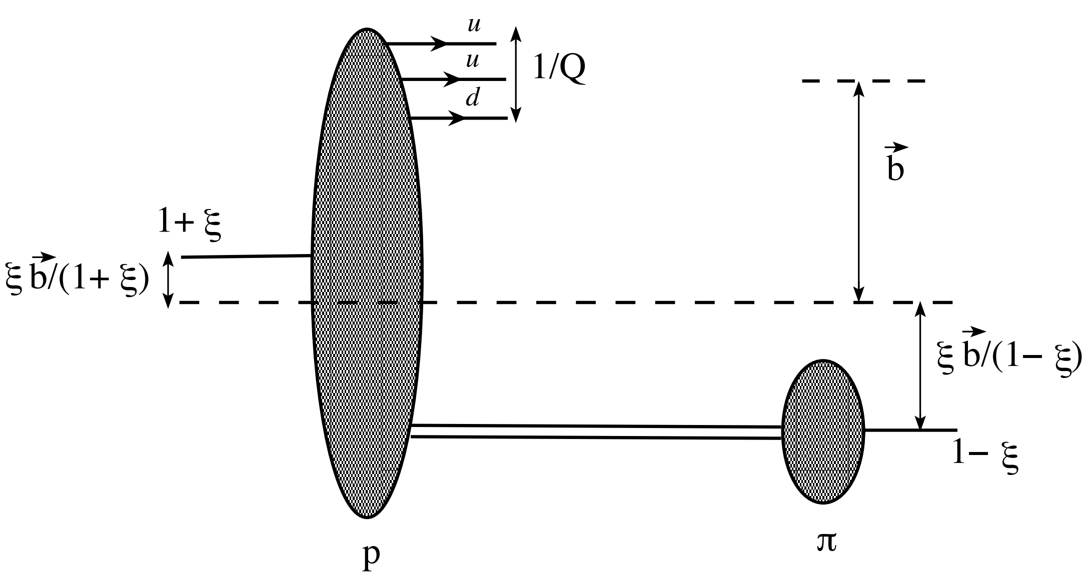
$Proton = |u\; d\; d\; \pi^+ >$ with small transverse separation for the quark triplet

Impact parameter interpretation

- As for GPDs Fourier transform $\Delta_T \to b_T$

$$F(x_i, \xi, u = \Delta^2) \to \tilde{F}(x_i, \xi, b_T)$$

$\longrightarrow$ Transverse picture of pion cloud in the proton



if factorization works

Define Transition Distribution Amplitudes

- **Dirac decomposition at leading twist :**

$$4\langle\pi^0(p')|\,\epsilon^{ijk}u^i_\alpha(z_1)u^j_\beta(z_2)d^k_\gamma(z_3)\,|p(p,s)\rangle\Big|_{z^+=0,\,z_T=0} =$$

$$\frac{-f_N}{2f_\pi}\Big[V_1^0(\hat{P}C)_{\alpha\beta}(B)_\gamma + A_1^0(\hat{P}\gamma^5C)_{\alpha\beta}(\gamma^5B)_\gamma - 3T_1^0(P^\nu i\sigma_{\mu\nu}C)_{\alpha\beta}(\gamma^\mu B)_\gamma] +$$
$$V_2^0(\hat{P}C)_{\alpha\beta}(\hat{\Delta}_TB)_\gamma + A_2^0(\hat{P}\gamma^5C)_{\alpha\beta}(\hat{\Delta}_T\gamma^5B)_\gamma + T_2^0(\Delta_T^\mu P^\nu\sigma_{\mu\nu}C)_{\alpha\beta}(B)_\gamma$$
$$+T_3^0(P^\nu\sigma_{\mu\nu}C)_{\alpha\beta}(\sigma^{\mu\rho}\Delta_T^\rho B)_\gamma + \frac{T_4^0}{M}(\Delta_T^\mu P^\nu\sigma_{\mu\nu}C)_{\alpha\beta}(\hat{\Delta}_TB)_\gamma$$

$B =$ **nucleon spinor** $\qquad V_i(z_i), A_i(z_i), T_i(z_i)$ **are the TDAs**

V_1 **and** T_1 **dominant . If isospin = 1/2,** $T_1 = f(V_1)$

- **Fourier transform each TDA, → momentum fractions representation**

$$F(z_i) = \int_{-1+\xi}^{1+\xi} d^3x\,\delta(\sum x_i - 2\xi)e^{-iPn\Sigma x_iz_i}\,F(x_1,x_2,x_3,\xi,t,Q^2)$$

$$F = V_i, A_i, T_i$$

➯ **Write the Amplitude** $(\pi N(p_2) \to N'(p_1)\mu^+\mu^-)$

$$\mathcal{M}^{\lambda}_{s_1 s_2} = -i\frac{(4\pi\alpha_s)^2\sqrt{4\pi\alpha_{em}}f_N^2}{54 f_\pi Q^4}\Bigg[\underbrace{\bar{u}(p_2,s_2)\not{\varepsilon}(\lambda)\gamma^5 u(p_1,s_1)}_{\mathcal{S}^{\lambda}_{s_1 s_2}}\underbrace{\int_{-1+\xi}^{1+\xi} d^3x \int_0^1 d^3y \Big(2\sum_{\alpha=1}^{7} T_\alpha + \sum_{\alpha=8}^{14} T_\alpha\Big)}_{I}$$

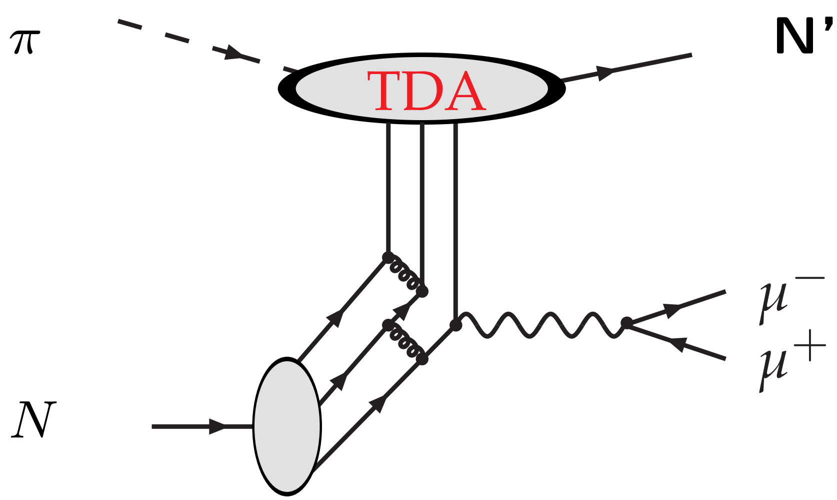
$$-\underbrace{\varepsilon(\lambda)_\mu \Delta_{T,\nu}\bar{u}(p_2,s_2)(\sigma^{\mu\nu}+g^{\mu\nu})\gamma^5 u(p_1,s_1)}_{\mathcal{S}'^{\lambda}_{s_1 s_2}}\underbrace{\int_{-1+\xi}^{1+\xi} d^3x \int_0^1 d^3y \Big(2\sum_{\alpha=1}^{7} T'_\alpha + \sum_{\alpha=8}^{14} T'_\alpha\Big)}_{I'}\Bigg],$$

= baryon helicity conserving + baryon helicity violating amplitudes

➯ The Hard Amplitude is calculated from 21 Feynman diagrams

Interference of $\mathcal{S}$ and $\mathcal{S}'$ → Transverse spin asymmetry

Compass Opportunity



also with Kaon beam $(N' \to \Lambda)$

$1 < Q^2 < 10 GeV^2$, **small** $u = (p_\pi - p_{N'})^2$, **fixed** $\xi = \frac{p_\pi^+ - p_{N'}^+}{p_{N'}^+ + p_\pi^+}$

Measure lepton pair momentum ; deduce missing mass^2 = $\bar{M}^2$.

Select small $\bar{M}^2 \approx M_p^2$.

Small $u = (p_{target} - q)^2$: lepton pair almost at rest in lab frame

Transverse Target spin asymmetry

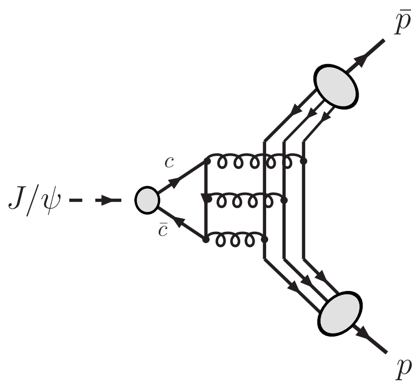
Recall $\mathcal{M} = \mathcal{S}T_i + \mathcal{S}'T_i'$; $\mathcal{S}(\mathcal{S}')$ is Nucleon helicity conserving (violating)

- Comes from Interference of $\mathcal{S}$ and $\mathcal{S}$'
- Leading twist (i.e. not $1/Q^2$) in eN and $\bar{N}N$ reactions
- zero in πN reaction
- Proportionnal to $\mathcal{I}$m $(T_i T_j^{\prime *})$
  - absent in a hadronic (nucleon exchange) description
  - i.e. specific to a partonic (TDA) description

$\rightarrow$ transversally polarized Λ in $KN \rightarrow \Lambda\, \mu^+ \mu^-$

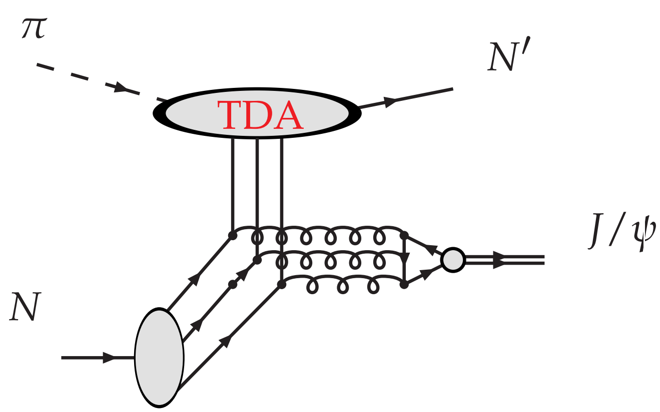
Extending Drell Yan to charmonium case : $\pi N \to N'\psi$

➭ Recall $\psi \to \bar{p}p$ decay



the amplitude of which is described with the help of proton (and $\bar{p}$) DAs

➭ Replace antiproton DA by $\pi \to N$ TDA $\qquad \xi \approx \dfrac{M_\psi^2}{2 s_{\pi N}}$



ψ is isoscalar $\to$ Isospin $\frac{1}{2}$ part of $\pi \to N$ TDA selected by hard amplitude

Tests of the applicability of the TDA framework

The process amplitude Factorizes at large enough Q^2 :

$$\mathcal{M}(Q^2,\xi,t) = \int dx dy \phi(y_i) T_H(x_i,y_i,Q^2) F(x_i,\xi,t)$$

You know that you reach the right domain if you check :

- scaling law for the amplitude : $\mathcal{M}(Q^2,\xi) \sim \frac{\alpha_s(Q^2)^2}{Q^4}$, (up to log corrections)

- Dominance of transversely polarized virtual photon $\sigma_T >> \sigma_L$

➩ crucial test : Universality of TDAs $\rightarrow$ this description applies as well to spacelike and timelike reactions

$\rightarrow$ Backward DEMP $\gamma^* P \rightarrow P'\pi$ and Backward $\pi N \rightarrow N'\gamma^*$

Data exist (JLab) for Q^2 up to a few GeV^2 $\longrightarrow$ More to come !

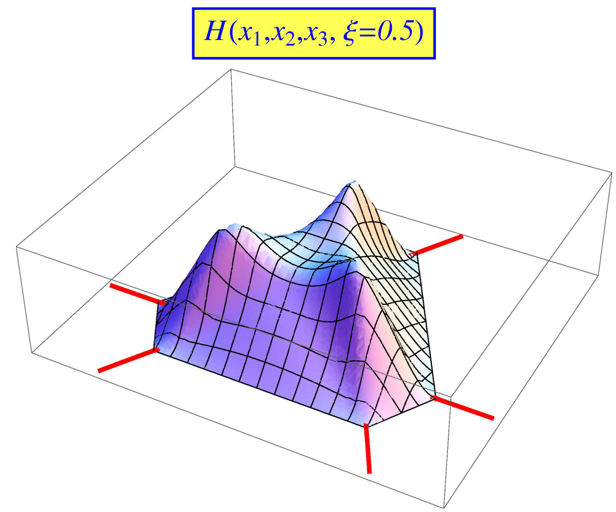
Conclusions

➩ Exclusive limit of Drell Yan reactions with π (K and $\bar{p}$?) beams will yield crucial information on GPDs and TDAs!

GPD and TDA physics explore confinement dynamics in hadrons

➩ Recent theoretical progress

- Quadruple distribution representation
- Isospin relations
- N and Δ exchange models



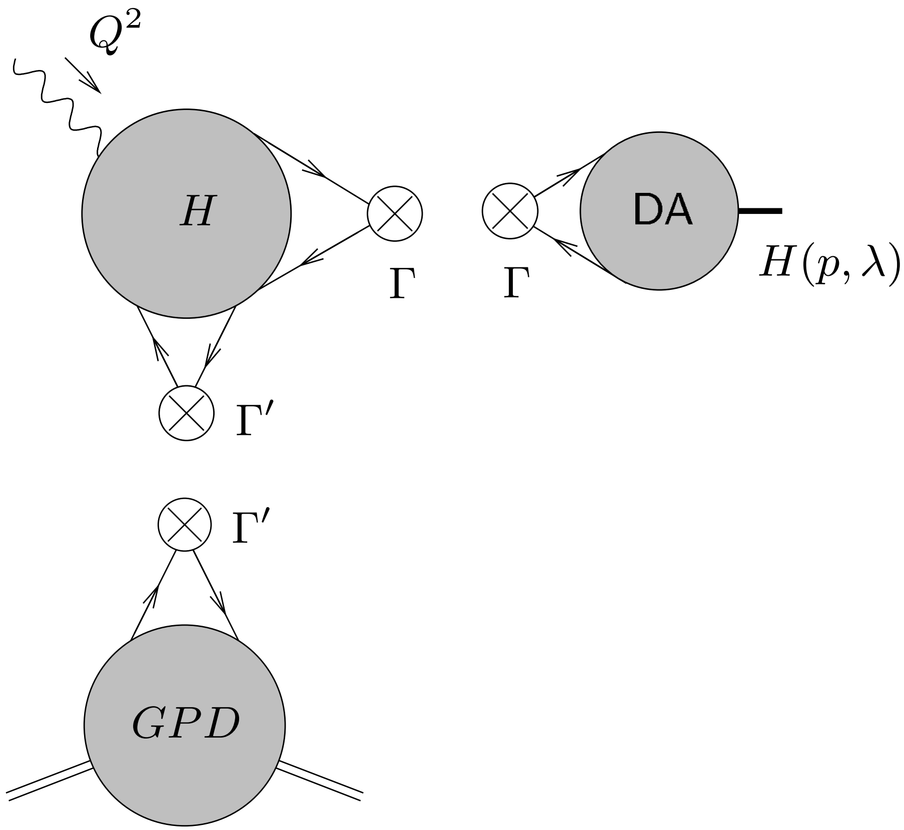
➩ Experimental breakthrough expected from COMPASS :

- first measurements of $\tilde{H}(x,\xi,t)$, $\tilde{E}(x,\xi,t)$ at small ξ in spacelike and timelike cases
- first measurements of TDA in a timelike regime

HARD muoPRODUCTION OF EXOTIC HYBRID

IV Anikin, BP, L.Szymanowski, OV Teryaev, S Wallon, Phys. Rev D70 and D71

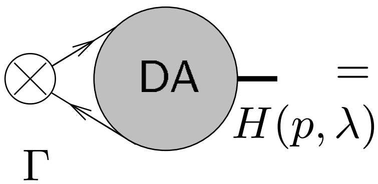
Factorization framework



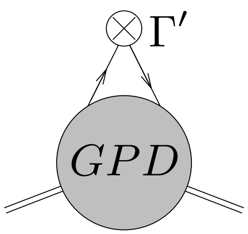
➩ **AIM : measure DA of the hybrid already discovered**

(we discussed $\pi_1(1400) \to \pi\eta$ specific case ; also applicable to $\pi_1(1600)$)

The crucial non perturbative parts



$= \langle H(p,\lambda)|\mathcal{O}(\Psi,\,\bar{\Psi}\,A)|0\rangle$ matrix element of a non-local light-cone operator

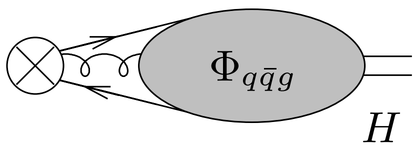


$= \langle N(p')|\mathcal{O}'(\Psi,\,\bar{\Psi}\,A)|N(p)\rangle$ matrix element of a non-local light-cone operator

The TWIST 2 DA of the EXOTIC HYBRID

Distribution amplitude of exotic hybrid mesons at twist 2

- One may think that to produce $|q\bar{q}g\rangle$, the fields Ψ, $\bar{\Psi}$, A should appear explicitely in the non-local operator $\mathcal{O}(\Psi,\, \bar{\Psi}\, A)$



- If one tries to produce $H = 1^{-+}$ from a local operator, the dominant operator should be $\bar{\Psi}\gamma^\mu G_{\mu\nu}\Psi$ of twist = dimension - spin = 5 - 1 = 4
- It means that there should be a $1/Q^2$ suppression in the production amplitude of H with respect to usual ρ-production (which is twist 2)
- But one of the main progress is the understanding of hard exclusive processes in terms of non-local light-cone operators, like the twist 2 operator

$$\bar{\psi}(-z/2)\gamma_\mu[-z/2; z/2]\psi(z/2)$$

where $[-z/2; z/2]$ is a Wilson line which thus hides gluonic degrees of freedom: the needed gluon is there, at twist 2. This does not requires to introduce explicitely A!

Feasibility - step 1

Counting rates for H versus ρ electroproduction: order of magnitude

- Ratio:

$$\frac{d\sigma^H(Q^2,x_B,t)}{d\sigma^\rho(Q^2,x_B,t)} = \left| \frac{f_H}{f_\rho} \frac{(e_u \mathcal{H}^-_{uu} - e_d \mathcal{H}^-_{dd})\,\mathcal{V}^{(H,-)}}{(e_u \mathcal{H}^+_{uu} - e_d \mathcal{H}^+_{dd})\,\mathcal{V}^{(\rho,+)}} \right|^2$$

- Rough estimate:
  - neglect $\bar{q}$ *i.e.* $x \in [0,1]$

    $\Rightarrow ImA_H$ and ImA_ρ are equal up to the factor $\mathcal{V}^M$
  - Neglect the effect of $Re\mathcal{A}$

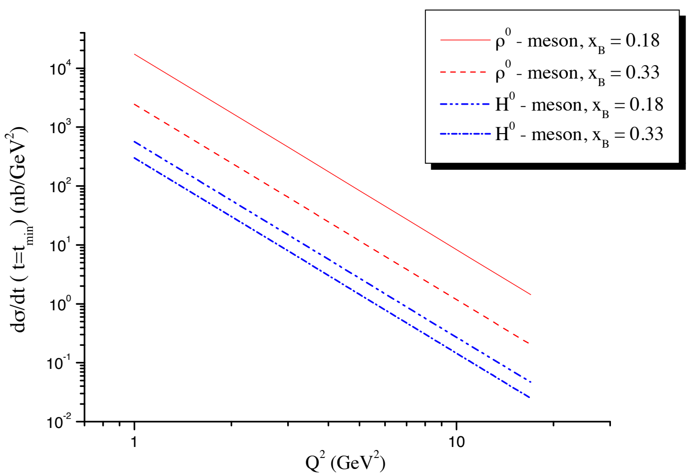
$$\frac{d\sigma^H(Q^2,x_B,t)}{d\sigma^\rho(Q^2,x_B,t)} \approx \left(\frac{5f_H}{3f_\rho}\right)^2 \approx 0.15$$

Feasibility - step 2

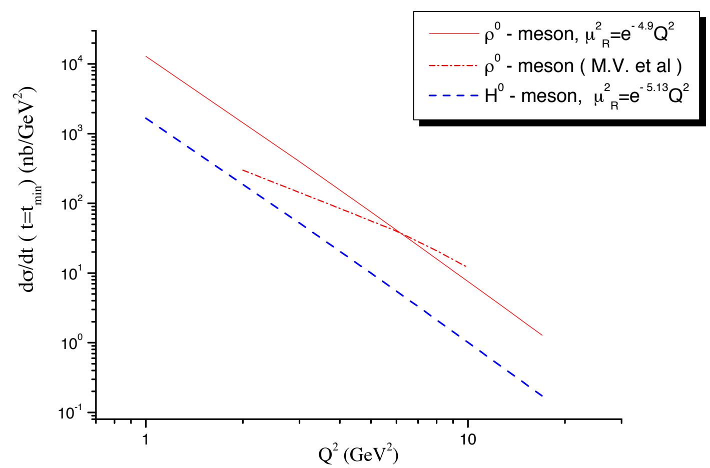
Counting rates for H versus ρ electroproduction: more precise study

- use standard description of GPDs based on Double Distributions
- $\mu_R^2 = Q^2$ versus BLM scale from NLO (at the level of cross-section)

$\xi = 0.2$	$\mu_R^2 = e^{-4.9} Q^2$	ρ	$\xi = 0.1$	$\mu_R^2 = e^{-4.68} Q^2$	ρ
(or $x_B \approx 0.33$)	$\mu_R^2 = e^{-5.13} Q^2$	H	(or $x_B \approx 0.18$)	$\mu_R^2 = e^{-5.0} Q^2$	H



$\mu_R^2 = \mu_F^2 = Q^2$



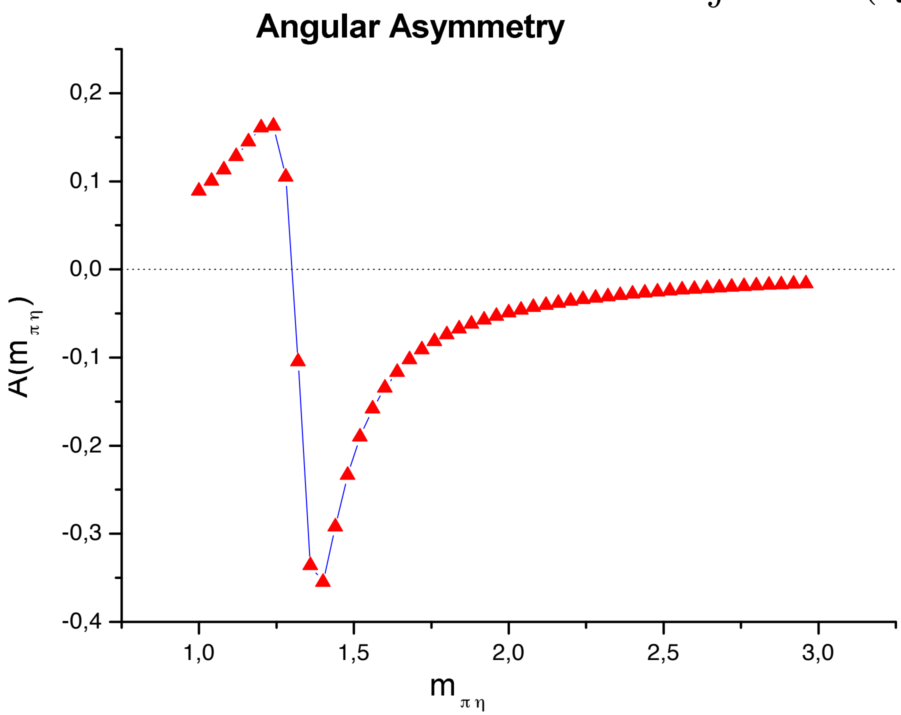
$\mu_R^2 = \mu_F^2 = \mu_{BLM}^2 \quad x_B \approx 0.33$

An asymmetry to mimic phase shift analysis

Angular asymmetry to unravel the hybrid meson

- π_1 has rather small amplitude with respect to the a_2 background
- Asymmetry sensitive to their interference:

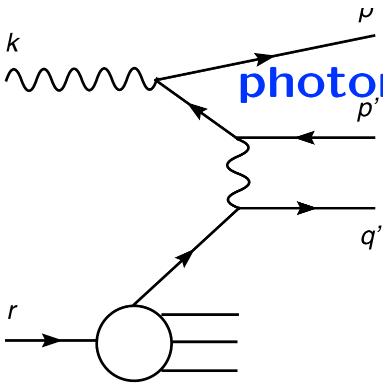
$$A(Q^2, y_l, \hat{t}, m_{\pi\eta}) = \frac{\int \cos\theta_{cm}\, d\sigma^{\pi^0\eta}(Q^2, y_l, \hat{t}, m_{\pi\eta}, \cos\theta_{cm})}{\int d\sigma^{\pi^0\eta}(Q^2, y_l, \hat{t}, m_{\pi\eta}, \cos\theta_{cm})}$$



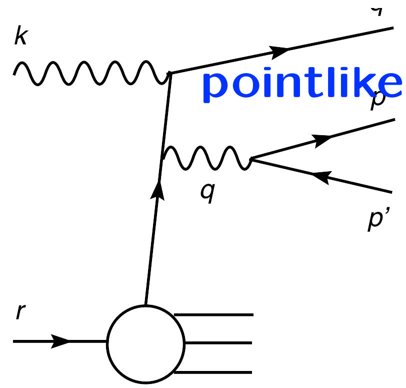
$$= \frac{\frac{8}{15}\mathcal{R}e\left[B_{11}(m_{\pi\eta}^2)B_{12}{}^*(m_{\pi\eta}^2)\right]}{\frac{2}{3}\left|B_{11}(m_{\pi\eta}^2)\right|^2 + \frac{2}{5}\left|B_{12}(m_{\pi\eta}^2)\right|^2}$$

PHOTOPRODUCTION OF DRELL YAN PAIRS

$$\gamma N -> l^+ l^- X$$



(a)



(b)

Bethe - Heitler process **Drell Yan process**

- ➪ **Quasi real photon beam**
- ➪ **Transversely polarized target**
- ➪ **A difficult but rewarding experiment**

BP, L.Szymanowski, Phys. Rev. Lett. 103, 072002

MOTIVATION

Transverse spin structure of nucleon is very badly known !

Even at the usual (integrated) parton distribution level :

interesting but indirect knowledge of $\Delta_T q(x) = h_1^q(x)$

Basic reason transversity distribution is CHIRAL ODD

An observable quantity contains an even number of chiral-odd objects

➩ Drell Yan double polarized cross section $h_1^q(x_1)h_1^{\bar{q}}(x_2) \rightarrow$ PAX

➩ Use another chiral-odd object : fragmentation, TMD ...

BASIC IDEA

Leading Twist Photon Distribution Amplitude and

Transversely polarized Vector Meson Distribution Amplitude

are CHIRAL ODD

Recall Distribution Amplitude = hadron light cone wave function

$$\int dx^- \, e^{-iz(P.x)} \, \langle 0|\bar{q}_\alpha(0) q_\beta(x)|H(P)\rangle\Big|_{x^+=0,\, x_T=0}$$

($\rightarrow$ Fourier Transform $\int dk^- d\,\vec{k}_T$)

The photon Distribution Amplitude

Non-triviality of the QCD vacuum $\longrightarrow \langle \bar{q} q \rangle \neq 0$

Magnetic susceptibility $\chi \neq 0$

Photon couples to quarks through *em* coupling and through a twist 2 photon distribution amplitude (DA) $\phi_\gamma(u)$

$$\langle 0|\bar{q}(0)\sigma_{\alpha\beta}q(x)|\gamma^{(\lambda)}(k)\rangle = i\, e_q\, \chi\, \langle \bar{q} q \rangle \left(\epsilon_\alpha^{(\lambda)} k_\beta - \epsilon_\beta^{(\lambda)} k_\alpha\right) \int_0^1 dz\, e^{-iz(kx)}\, \phi_\gamma(z)\,,$$

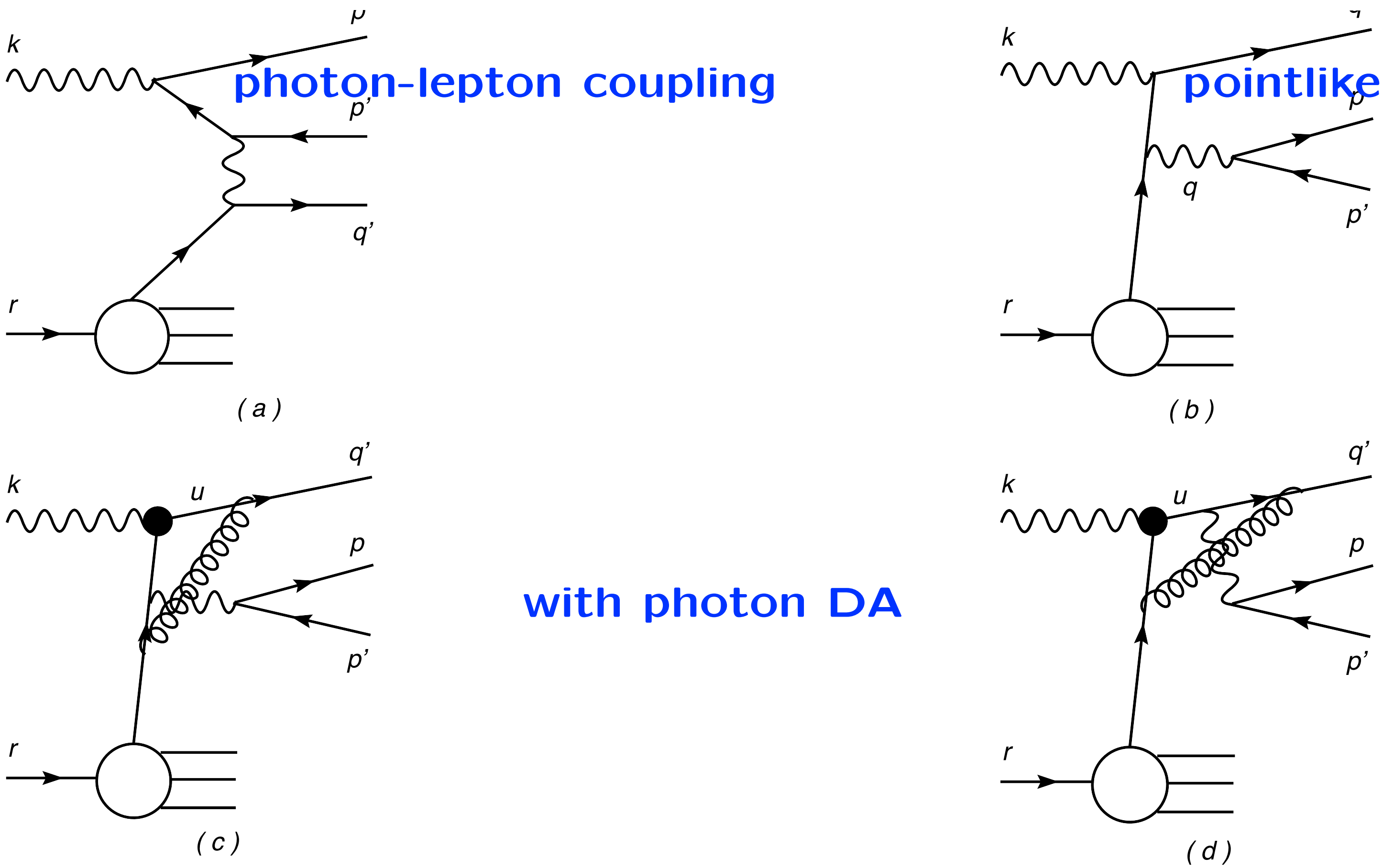
➫ **normalization :** $\int dz\, \phi_\gamma(z) = 1$**,**

➫ $z =$ **momentum light-cone fraction carried by the quark.**

Here the photon is real ; not much change if slightly virtual.

How to access the transversity PDF

Consider $\gamma N -> l^+ l^- X$



photon-lepton coupling

pointlike photon-quark coupling

with photon DA

Kinematics

$$\gamma(k)q(x\,r) \to l(p)l(p')q(q')$$

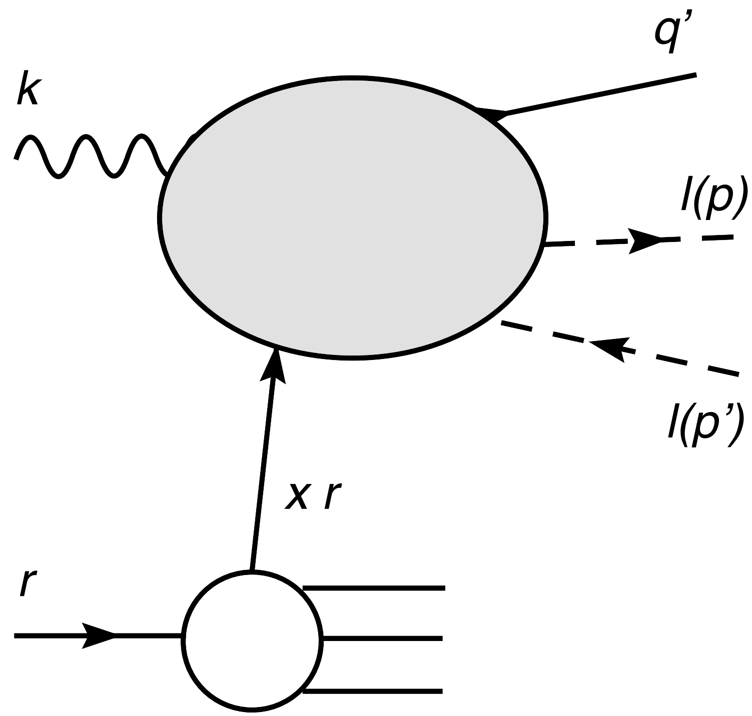
$$p + p' = q = \alpha k + \frac{Q^2 + \mathbf{Q_T}^2}{\alpha s} r + Q_\perp$$

$$q' = \bar{\alpha} k + \frac{\mathbf{Q_T}^2}{\bar{\alpha} s} r - Q_\perp$$

$$p = \gamma\alpha k + \frac{(\gamma\mathbf{Q_T} + \mathbf{l_T})^2}{\gamma\alpha s} r + \gamma Q_\perp + l_\perp$$

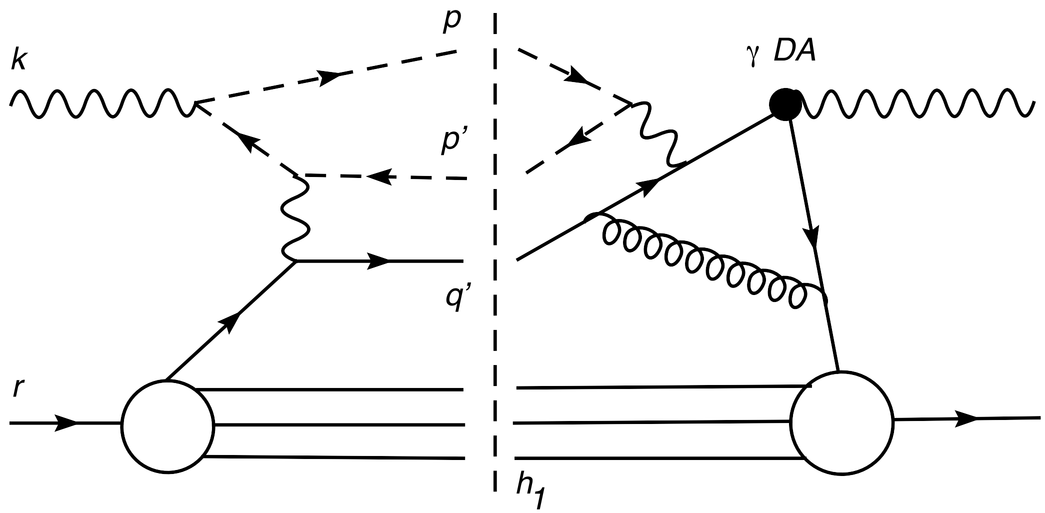
$$p' = \bar{\gamma}\alpha k + \frac{(\bar{\gamma}\mathbf{Q_T} - \mathbf{l_T})^2}{\bar{\gamma}\alpha s} r + \bar{\gamma} Q_\perp - l_\perp$$

$$x = \frac{\bar{\alpha} Q^2 + \mathbf{Q_T}^2}{\alpha\bar{\alpha} s} \qquad Q^2 = \frac{\mathbf{l_T}^2}{\gamma\bar{\gamma}}$$



Interference effects

Remember BH-DVCS interference BP, L.Szymanowski, Phys. Rev. Lett. 103, 072002



➩ Chiral-oddity of photon DA $\longrightarrow$ Interference builds a proton transversity dependent contribution

➩ Charge conjugation properties : $\frac{d\Delta_T\sigma(l^-)-d\Delta_T\sigma(l^+)}{d^4Q\,d\Omega} = \frac{d\sigma_{\phi BH}}{d^4Q\,d\Omega}$

Crucial point : CHIRAL-ODD amplitude has an absorptive part :

$$\textbf{Amplitude}\ \mathcal{A}_\Phi \sim \int_0^1 du \frac{\phi_\gamma(u)}{u-\frac{Q^2\alpha}{Q^2+\mathbf{Q}^2}-i\epsilon} = PV\int_0^1 du \frac{\phi_\gamma(u)}{u-\frac{Q^2\alpha}{Q^2+\mathbf{Q}^2}} + i\pi\phi_\gamma\left(\frac{Q^2\alpha}{Q^2+\mathbf{Q}^2}\right)$$

Cross section difference

$$d\bar{\sigma}_{\phi BH} = \frac{(4\pi\alpha_{em})^3}{4s}\frac{C_F 4\pi\alpha_s}{2N_c}\cdot\frac{\chi\langle\bar{q}q\rangle}{\vec{Q}_\perp^2}\int dx\sum_q Q_l^3 Q_q^3 h_1^q(x) 2\mathcal{R}e(\mathcal{I}_{\phi BH})\, dLIPS$$

$$2\mathcal{R}e(\mathcal{I}_{\phi BH}) = \phi_\gamma[\frac{\alpha Q^2}{Q^2+\vec{Q}_\perp^2}]\frac{32\pi\alpha^2\bar{\alpha}}{xs(\bar{\alpha}Q^2+\vec{Q}_\perp^2)^2}\cdot(Q^2+\vec{Q}_\perp^2)[\epsilon^{rks_T Q_T}A_1+\epsilon^{rks_T l_T}A_2]$$

Result : INTERFERENCE DOESN'T VANISH

$$\sim \quad \chi\,\phi_\gamma(\frac{Q^2\alpha}{Q^2+\mathbf{Q_T}^2})\cdot h_1(\frac{\bar{\alpha}Q^2+\mathbf{Q_T}^2}{\alpha\bar{\alpha}s})$$

- ➩ **may be singled out by the lepton azymuthal distribution**
- ➩ **allows to scan $h_1(x)$ and $\Phi_\gamma(z)$**
- ➩ **only nucleon is polarized, i.e. SINGLE SPIN EFFECTS**

CONCLUSION

THERE IS MUCH PHYSICS TO BE STUDIED WITH COMPASS, BOTH WITH HADRON and MUON BEAMS

there is EVEN MORE than in the existing PROPOSALS

Thank you for your attention