

# Non-diagonal DVCS, Transitional Gravitational Form Factors and Transitional GPDs

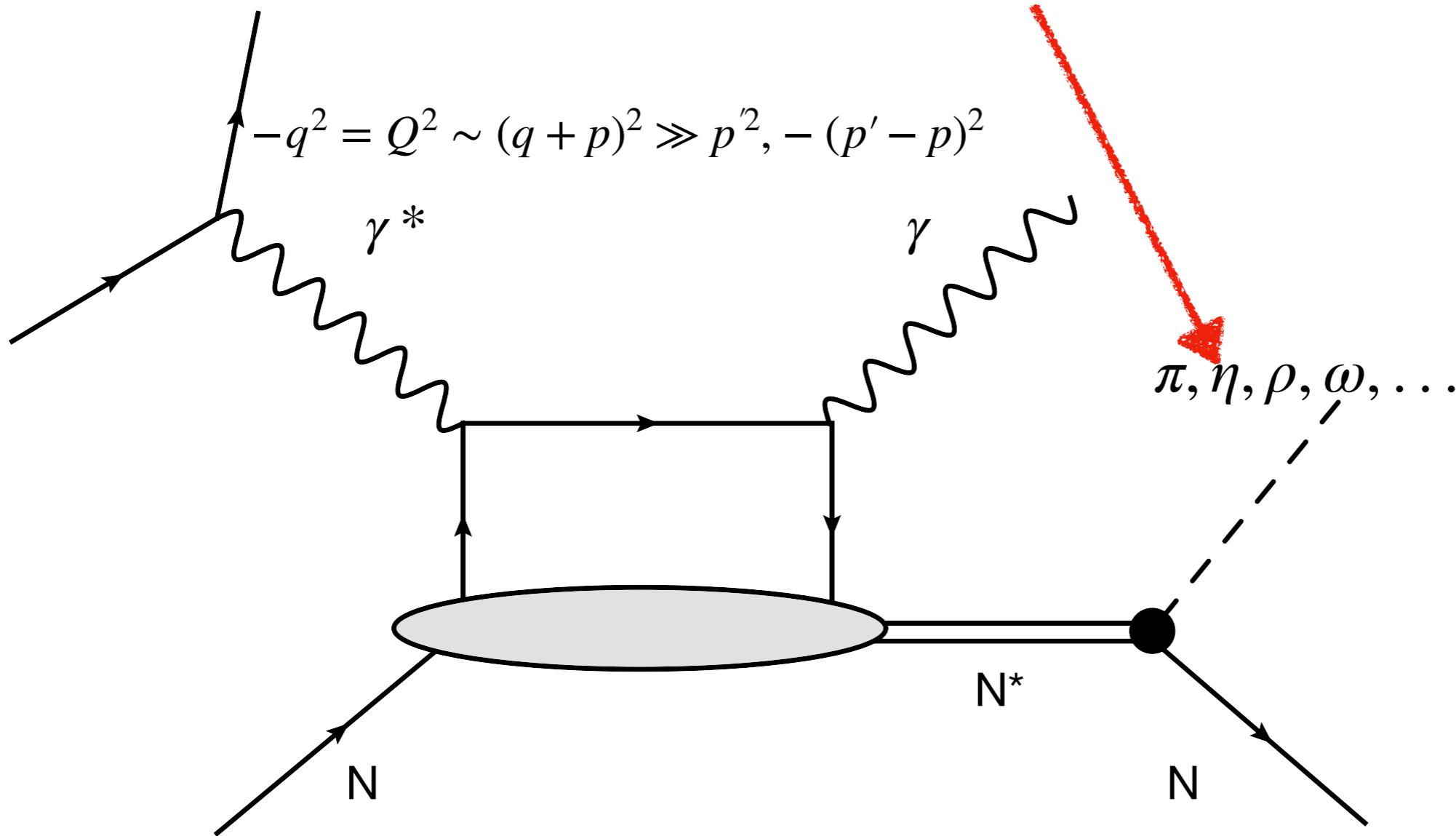
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# Outline

- Non-Diagonal DVCS
- Accessible Physics
- $N \rightarrow \pi N$  Transition GPDs
- PWA to  $N \rightarrow N^*$
- Relation between Transition GPD and Transition Gravitational Form Factors

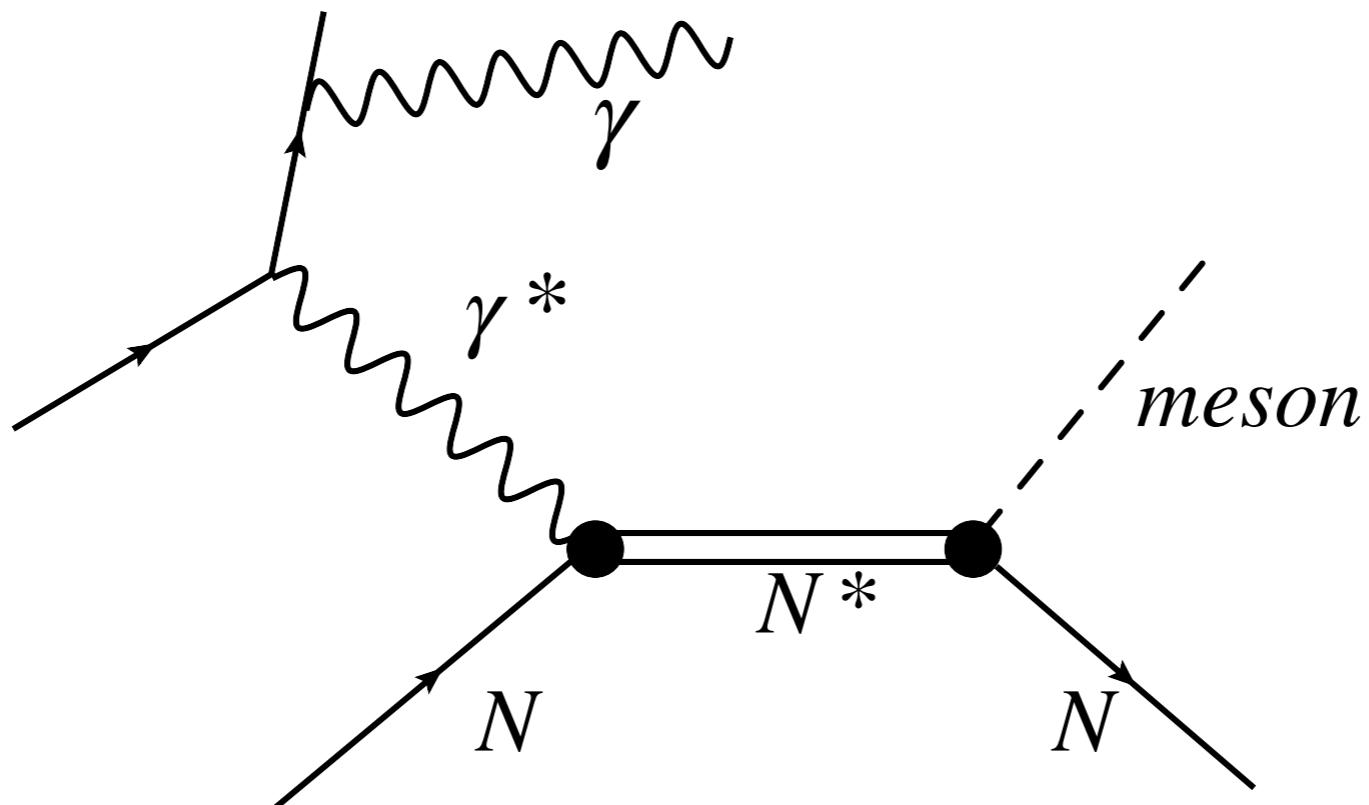
# Non-Diagonal DVCS

$$\gamma^*(q) + N(p) \rightarrow \gamma(q) + [ \underbrace{M(k)}_{\gamma} \ N(p' - k)]$$



Key requirement to the detector is the large coverage in the cm angle of final meson+nucleon system

# Interference with B-H.



- Enhance possible weak  $N^*$  signals
- Direct access to the amplitude of the string excitation process: QCD string + $N \rightarrow N^*$

# Accessible Physics

- Transitional  $N \rightarrow N^*$  GPDs [arXiv:hep-ph/0609045 ]
- Transitional  $N \rightarrow N^*$  gravitational Form Factors
- Chiral perturbation theory on light cone and chiral dynamics in gravitational interactions
- Baryon resonance spectroscopy with fundamental probes of any spin (in particular graviproduction of resonances)

# $N \rightarrow \pi N$ Transition GPDs

- Parametrization

$$\Gamma_1 = \gamma_5 \quad \Gamma_2 = \frac{M \cdot h}{n \cdot \bar{p}} \gamma_5 \quad \Gamma_3 = \frac{k}{M} \gamma_5 \quad \Gamma_4 = \frac{\not{k} \cdot \not{h}}{M} \gamma_5$$

- Unpolarized GPDs (isoscalar)

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x\bar{p}\cdot n} \langle N(p') \pi^a(k) | \bar{\psi}(-\lambda n/2) h \psi(\lambda n/2) | N(p) \rangle = \frac{ig_A}{M f_\pi} \sum_{i=1}^4 \bar{U}(p') \Gamma_i \tau^a H_i^{(0)} U(p)$$



- Polarized GPDs (isoscalar)

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x\bar{p}\cdot n} \langle N(p') \pi^a(k) | \bar{\psi}(-\lambda n/2) h \gamma_5 \psi(\lambda n/2) | N(p) \rangle = \frac{ig_A}{M f_\pi} \sum_{i=1}^4 \bar{U}(p') \Gamma_i \gamma_5 \tau^a H_i^{(0)} U(p)$$

[Polyakov, Stratmann, 2018]

# $N \rightarrow \pi N$ Transition GPDs

- Unpolarized GPDs (isovector)

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x \bar{p} \cdot n} \langle N' \pi^a | \bar{\psi}(-\lambda n/2) \not{h} \tau^b \psi(\lambda n/2) | N \rangle = \frac{ig_A}{M f_\pi} \sum_{i=1}^4 \bar{U}' \Gamma_i (\delta^{ab} H_i^{(+)} + i \epsilon^{abc} \tau^c H_i^{(-)}) U$$

- Polarized GPDs (isovector)

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x \bar{p} \cdot n} \langle N' \pi^a | \bar{\psi}(-\lambda n/2) \not{h} \gamma_5 \tau^b \psi(\lambda n/2) | N \rangle = \frac{ig_A}{M f_\pi} \sum_{i=1}^4 \bar{U}' \Gamma_i \gamma_5 (\delta^{ab} \tilde{H}_i^{(+)} + i \epsilon^{abc} \tau^c \tilde{H}_i^{(-)}) U$$

- Gluon GPDs

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x \bar{p} \cdot n} \langle N' \pi^a | F^{\mu\rho}(-\lambda n/2) F_\rho^\nu(\lambda n/2) n_\mu n_\nu | N \rangle = \frac{ig_A}{M f_\pi} \frac{n \cdot \bar{p}}{2} \sum_{i=1}^4 \bar{U}' \Gamma_i \tau^a x H_i^{(G)} U$$

# Transition GPD $H_i^{(0)}$

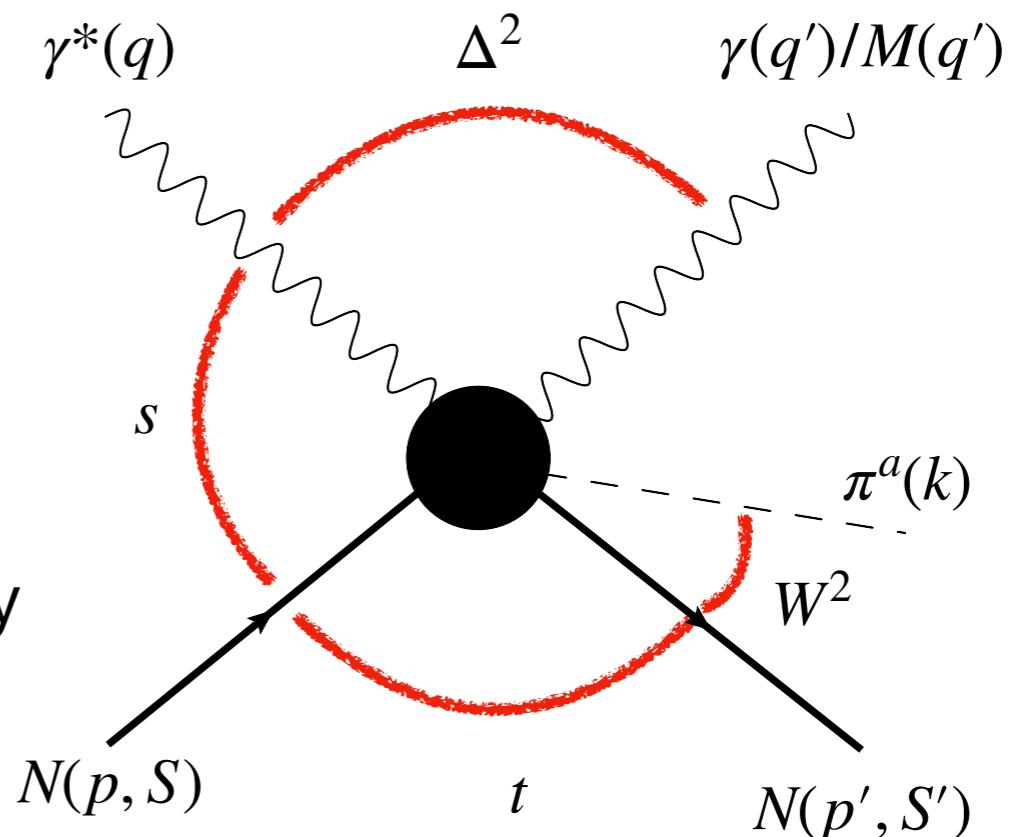
- Transition GPD  $H_i^{(0)}$  depends on  
 $H_i^{(0)}(x, \xi, \alpha, t, W^2)$

- $\xi = -\frac{n \cdot \Delta}{2n \cdot \bar{p}}$

- $\alpha = \frac{n \cdot k}{n \cdot (p' + k)}$  (related to decay angle)

- $t = (p' - p)^2$  (virtuality of  $\gamma^*$ )

- $W^2 = (p' + k)^2$  (inv. mass of m+N)



# PWA $\rightarrow(N \rightarrow N^*)$

- In order to simplify the analysis,  $H_i(x, \xi, \alpha, t, W^2) \rightarrow H_i^{I JL}(x, \xi, t, W^2)$  by isospin decomposition and partial wave decomposition

$$H_i^{ab} = \delta^{ab} H_i^{I=(-)} + i\epsilon^{abc}\tau^c H_i^{I=(+)}$$

$$H_i^{IL}(x, \xi, t, W^2) = \int_{-1}^1 d\alpha H_i^I(x, \xi, \alpha, t, W^2) P_L(\alpha)$$

where  $\int_{-1}^1 dx x^{N-1} H^{IJL} = 0, \text{ for } N < L,$

N>L:transition FF of the operator of twist-2 and spin N

- $H^{IJL}$ 's are complex functions and the imaginary part is related to the  $\pi N$  scattering amplitude

$$\text{Im} H^{IJL} = \tan[\delta_{\pi N}^{IJL}(W^2)] \text{Re} H^{IJL} \quad \pi N \text{ phase shift obtained from PWA}$$

[Polyakov, 1998]

# PWA $\rightarrow (N \rightarrow N^*)$

Obtained by PWA

- $W^2$ -dependence of  $\pi N$  is given by Omnes solution

$$H^{IJK}(x, \xi, t, W^2) = H^{IJK}(x, \xi, t, W^2) \exp \left\{ \sum_{k=1}^{N-1} c_k W^{2k} + \frac{W^{2N}}{\pi} \int_{2m_\pi m_N}^\infty ds \frac{\delta_{\pi N}^{IJK}(s)}{s^N (s - W^2 - i0)} \right\}$$



Fixed by EFT methods

- $N \rightarrow N^*$  GPDs are obtained at  $W^2$  corresponding to the resonance where the phase shift crosses  $\pi/2$

# Relation between transition GPDs and transition gravitational FF

- Transition gravitational FFs

$$\langle N(p') \pi^a(k) | T^{\mu\nu} | N_i(p) \rangle = \frac{ig_A}{M f_\pi} \sum_{i=1}^{20} \bar{U}(p') \tau^a \Gamma_i^{\mu\nu} B_i U(p)$$

- Due to the conservation of EMT only **12 FFs** are independent.
- From current conservation and polynomiality, transition gravitational form factors can be determined from the second moment of transition GPDs

- Example:  $\int_{-1}^1 dx x \left( H_4^{(0)} + \frac{1}{2} H_4^{(G)} \right) = B_{18} + B_{19}(-2\xi) + B_{20}\bar{\alpha}$

*Thank you!*