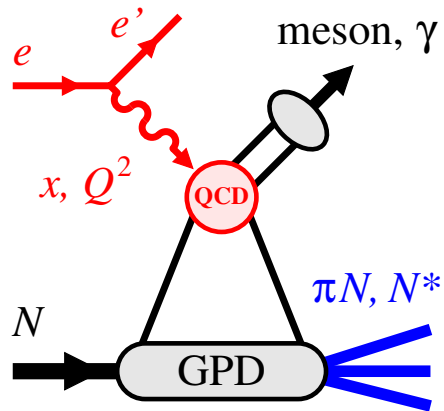


Exploring resonance structure with transition GPDs

Joint Workshop ECT* - APCTP, ECT* Trento, 21-25 Aug 2023 [\[Webpage\]](#)

Vladimir Braun, Stefan Diehl, Kyungseon Joo, Chang-Hwan Lee, Charlotte Van Hulse, Christian Weiss (Organizers)



- Welcome
- Context and topics
- Workshop goals and agenda



Yongseok Oh

Kyungpook National University & APCTP

Eminent theoretical nuclear physicist

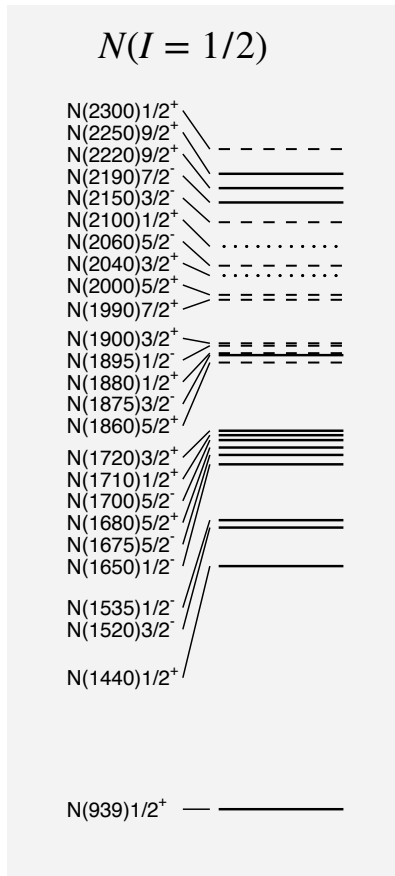
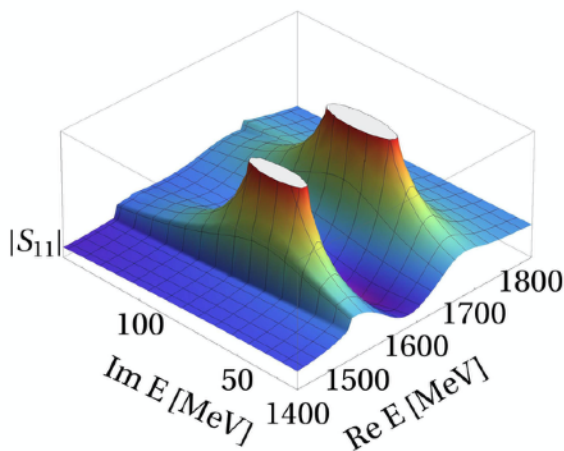
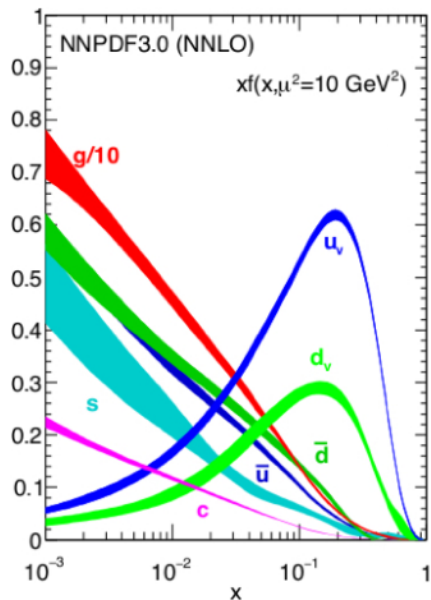
Great community leader and excellent administrator

Colleague and friend to many of us

We will miss him dearly

Meetings organized by Yongseok in last two years:

1. APCTP Focus Program: Nuclear Physics 2021 Part II: Science Opportunities with EIC, 19-24 July 2021, Hilton Gyeongju, Gyeongju, Gyeongsang-pook Do, South Korea; <https://indico.knu.ac.kr/event/494/>.
2. Light Cone 2021: Physics of Hadrons on the Light Front, Nov. 28 – Dec. 4, 2021, Jeju Island, South Korea; <https://indico.cern.ch/event/938795/>.
3. APCTP Focus Program: Physics of Excited Hadrons in the Present and Future Facilities, 11 – 16 July 2022, South Korea: <https://indico.knu.ac.kr/event/566/>
4. APCTP Workshop: Hadron Physics Opportunities with JLab Energy and Luminosity Upgrade, 18 – 23 July 2022, Pohang, South Korea: <https://indico.knu.ac.kr/event/566/>.
5. APCTP Workshop: The Physics of Electron Ion Collider, 2-4 November 2022, Howard Johnson Incheon Airport Hotel Incheon, South Korea; <https://indico.knu.ac.kr/event/592/>.
6. NCU workshop: EIC physics and detectors, 9-10 December 2022, Department of Physics, National Central University, Taipei, Taiwan; <https://indico.phys.sinica.edu.tw/event/67/>.
7. EIC Asia Workshop, 16-18 March, 2023, Okochi-hall at RIKEN, Wako, Saitama, Japan; <https://indico2.riken.jp/event/4389/>.
8. Electron-Ion Collider Resource Review Board (RRB) Meeting, 3-4 April 2023, Stony Brook University, Stony Brook, NY, U.S.A.; <https://www.bnl.gov/eic-rrbmeeting/>.
9. ECT*-APCTP Joint Workshop: Exploring resonance structure with transition GPDs, 21 – 25 August 2023, Trento, Italy ←



[Image credits: NNPDF 3.0, PDG 2016, Roenchen - FZ Jülich]

Structure of nucleon

High-momentum-transfer processes

QCD factorization

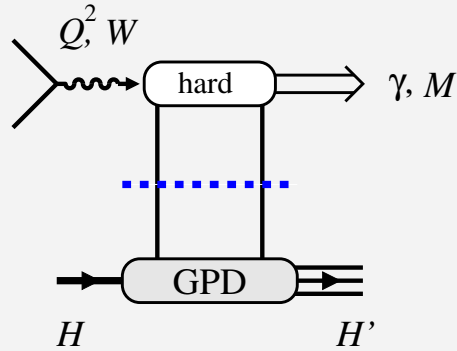
Quark/gluon distributions 1D \rightarrow 3D

Structure of interacting/excited states?

Multihadron states $\pi N, \pi\pi N, KY$

Resonances N^*, Δ, Y^*

Limited information from $\langle \pi N | V^\mu, A^\mu | N \rangle$



Factorization

Asymptotic regime $Q^2, W^2 \gg \mu_{\text{had}}^2$, $|t| \sim \mu_{\text{had}}^2$

Production process communicates with target through QCD light-ray operators $\mathcal{O}(z) = \bar{\psi}(0) \dots \psi(z)_{z^2=0}$

Hadronic matrix elements $\langle H' | \mathcal{O}(z) | H \rangle \leftrightarrow \text{GPDs}$

Works for any transition with $m_{H'} - m_H \sim \mu_{\text{had}}$

New operators for hadronic excitation

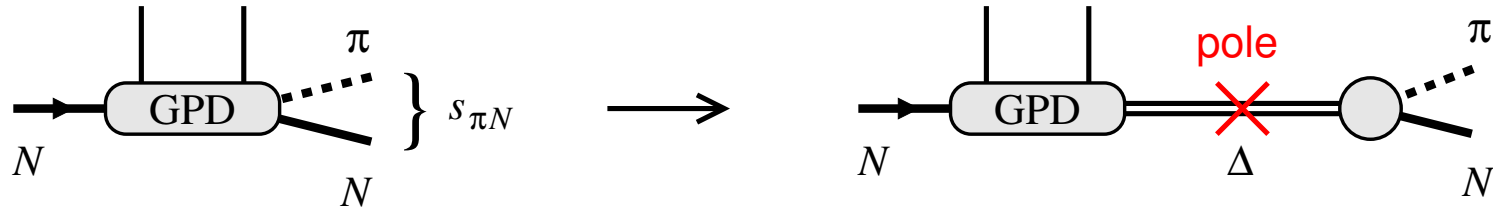
Well-defined QCD operators: Renormalization, scale dependence, universality \rightarrow LQCD, nonpert. methods

Operators with “new” quantum numbers:

Spin ≥ 2 – QCD energy momentum tensor

Quark spin/ flavor dependence, chiral even/odd

Gluonic operators



$$\langle \pi N | \mathcal{O} | N \rangle = \frac{\langle \pi N | \Delta \rangle \langle \Delta | \mathcal{O} | N \rangle}{s_{\pi N} - M_{\Delta}^2} + \text{less singular}$$

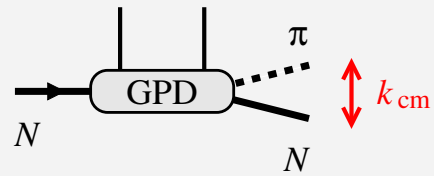
Definition of resonance GPDs

Multihadron final state, e.g. πN , partial-wave projection

Analytic continuation in invariant mass $s_{\pi N}$: Pole at $s_{\pi N} = M_{\Delta}^2$, resonance structure defined at pole

Physical region: Resonant + non-resonant contributions, needs theory

Chiral dynamics



Near-threshold region $k_{\text{cm}} \sim M_\pi$

Soft-pion theorems relate $N \rightarrow \pi N$ and $N \rightarrow N$ matrix elements

Pobylitsa, Polyakov, Strikman 2001; Guichon, Mossé, Vanderhaeghen 2003; Chen, Savage 2004; Birse 2004; Klivel, Polyakov 2004

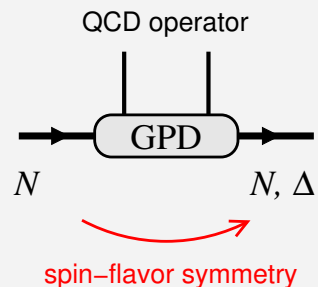
Models of effective dynamics

Chiral soliton — realizes large- N_c with effective dynamics
→ Talk Son

Light-front quark models
Lorce; Pasquini et al; J.-Y. Kim

Holography — based on gauge-string duality;
close connection between structure and spectrum
Mamo, Zahed

$1/N_c$ expansion



Large- N_c — semiclassical limit of QCD

Organization scheme for nonpert. dynamics

Emergent spin-flavor symmetry $SU(2N_f)$ connects N and Δ matrix elements

Systematic expansion in $1/N_c$:
Spin-flavor components of GPDs

Börnig et al. 1998; Frankfurt, Polyakov, Strikman 1998; Goeke, Polyakov, Vanderhaeghen 2001

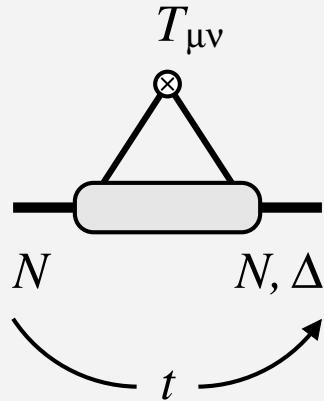
Lattice QCD

Partonic structure from large-momentum Euclidean correlation functions: Quasi/pseudo distributions

Excited states from correlation functions of sets of multiparticle operators: generalized eigenvalue problem, distillation

Long-term prospect of GPD and transition GPD calculations

→ Talks Constantinou, Braun



EMT operator as 2nd x-moment of light-ray operator

EMT form factors describe distributions of momentum, angular momentum, forces in system

Ji 1996, Polyakov 2003, Lorce et al. 2013+

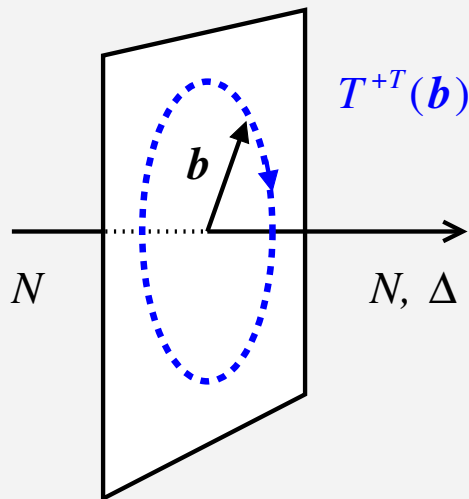
$N \rightarrow N$: Extensive studies, “mechanical properties”

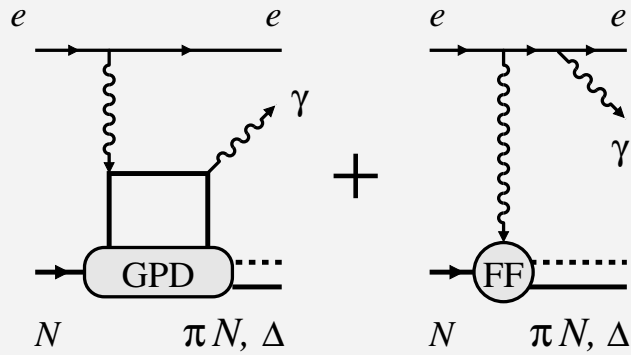
$N \rightarrow \Delta, N^*$: Concepts and structures can be generalized!

EMT transition form factors: Multipoles, interpretation, $1/N_c$ expansion

Example: Isovector angular momentum in $N \rightarrow \Delta$ transitions

→ Talk J.Y. Kim





DVCS

Probes chiral-even GPDs

Theory predictions for transition GPDs

Goeke, Vanderhaeghen, Polyakov 2001, Semenov-Tian-Shansky, VdH 2023

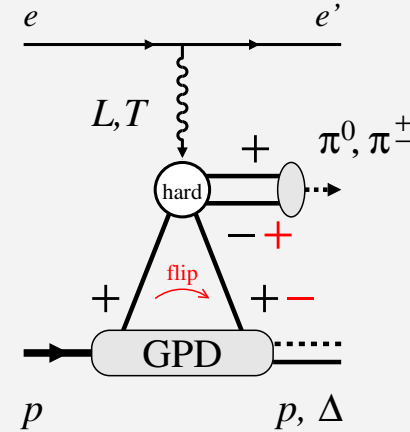
HERMES: Beam spin asymmetry A_{LU}

JLab12: First results from CLAS12 Δ^+

→ Yo, Diehl

EIC: Far-forward Delta reconstruction?

→ Jentsch



Pseudoscalar meson production

Twist-2 mechanism: Chiral-even GPDs + DA, L photon

Frankfurt, Poblitsa, Polyakov, Strikman 1998

Large twist-3 mechanism: Chiral-odd GPDs + DA, T photon

Goldstein, Liuti et al 08+, Goloskokov, Kroll 09+

Describes well JLab 6 GeV $N \rightarrow N$ data

Theory predictions for $\pi^- \Delta^{++}$ using $1/N_c$

Kroll, Passek-Kumericki 2023

JLab12: First results on $\pi^- \Delta^{++}$ and $\pi^+ \Delta^0$

→ Diehl, Usman

Strange pseudoscalar meson electroproduction

$$\gamma^* p \rightarrow K\Lambda, K\Sigma, K\Sigma^*$$

Expect chiral-odd mechanism as in pion production

Transition GPDs from SU(3) flavor symmetry, $1/N_c$ expansion

JLab12: Final states in CLAS12 data

Vector mesons at large x

→ A. Kim

$$\gamma^* p \rightarrow \rho^0 p, \omega p, \rho^+ n, K^* N, \dots$$

Many possibilities for 1/2 and 3/2 baryon final states

GPD-based description still poorly understood

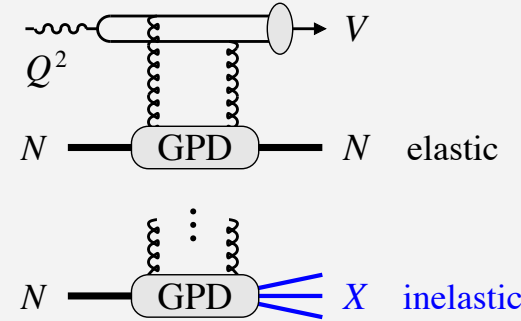
GPDs in photo- and hadroproduction

Dilepton photoproduction - timelike Compton scattering

Dilepton hadroproduction - exclusive Drell-Yan process

New possibilities for transition GPDs → Kumano, Chang, Chatagnon

Vector mesons at small x



Diffractive scattering,
no quantum number
exchange

GPD-based description: Gluon GPDs + finite-size effects

Describes well HERA $\rho^0, \phi, J/\psi$ data

→ Van Hulse

Transitions $p \rightarrow X(\text{low-mass})$: Inelastic diffraction

Connected with quantum fluctuations of gluon density in proton

Frankfurt et al 2008; Schlichting, Schenke, Mäntisaari 2014/2016

LHC ultraperipheral pA/AA: Highest energies in photoproduction

EIC: Diffraction program with far-forward detectors

→ Winn, McNulty, Jentsch

- Review status of theory/analysis/experiments in $N \rightarrow N$ GPDs
- Explore extension to transition GPDs $N \rightarrow \pi N, \Delta, N^*, \dots$
with upcoming experimental and theoretical results
- Formulate future program with JLab12 + beyond, EIC far-forward,
and photon/hadron beams

Mon 21 Aug

GPD analysis

S. Liuti, P. Sznajder, V. Bertone, Y. Guo

DVCS and transition GPDs

H. Yo, M. Vanderhaeghen, S. Diehl

Tue 22 Aug

Lattice calculations of GPDs

M. Constantinou, V. Braun

Transition GPD properties and models

K. Semenov-Tian-Shansky, Y.-D. Son,
J.-Y. Kim, C. Weiss

Wed 23 Aug

GPDs with hadron and photon beams

S. Kumano, W.-C. Chang, P. Chatagnon,

Baryon resonances

K. Joo, D. Roenchen

Thu 24 Aug

Meson production and transition GPDs

P. Kroll, A. Kim, S. Diehl, A. Usman

APCTP activities

C.-H. Lee

GPDs at collider experiments

C. Van Hulse, M. Winn, R. McNulty, A. Jentsch

Fri 25 Aug

Future program in experiment and theory

All participants

Presentations 30 + 10 mins

Group discussion after each topic

Reception Monday 1730-1900

Workshop Dinner Thursday 1900-2100



ECT* Trento celebrating 30 years in 2023

Outstanding service to nuclear theory and experiments,
especially JLab community

More information on activities and funding on webpage:

[\[ECT*\]](#)