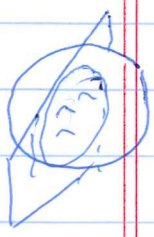
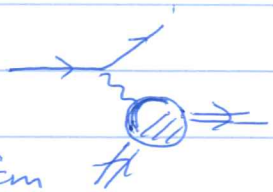
Nucleon Tomography



- New major physics issue; leap in hadron structure
- Could not be done/asked before
- Know how to do it (in principle)
- Many issues (in practice)
- Outreach / Outlook

- Elastic form factors



Hofstadter, '56 $R_p \sim 0.8$ fm

- $G_M^p \neq G_{dipole}$
- $G_E^p / G_M^p \searrow$ with Q^2

- Flavor separation

~~$F_2^{(u)}$~~ ~~$=$~~ $F_2^{(d)}$ (w/ $F_1^d / F_1^u \searrow$ with Q^2 (factor ~)

- Transverse structure is not dull!

- Inclusive reactions (Parton distributions)

Big sucess: Universality (DIS, jets, top, higgs)

4 loop theory.

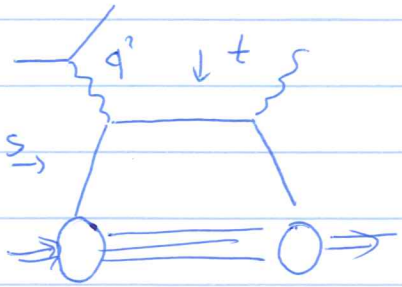
$u(x,Q^2)$ $d(x,Q^2)$, $g(x)Q^2)$

Accuracy ~ 10% valence

gluon at large x?

small x ?

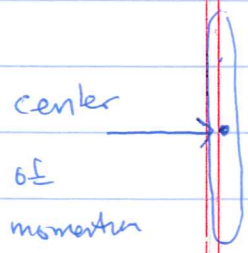
- Tomography $(x, \cancel{t})$ ~ $(x, b_\perp)$
  → Hard exclusive scattering in Bjorken limit



- Amplitude, not cross section
- t - dependence
- $q^2/s \sim O(1)$, $t \ll |q^2|$

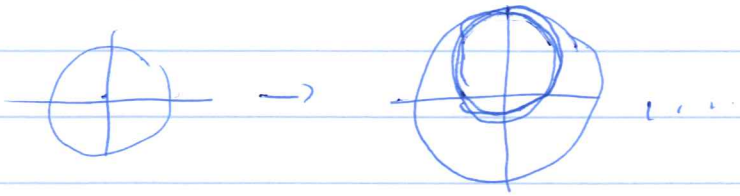
? Exclusivity ↦ Detectors
? Very small cross sections ↦ Luminosity
? Bad experience with Bjorken-Lepage Theory
↦ New factorizations theorems

- What would be immediate insights ?



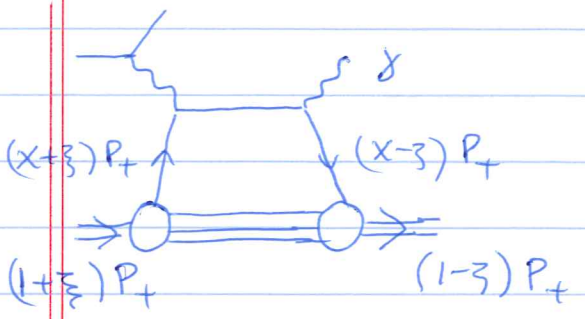
$\langle p | T_{\mu\nu} | p' \rangle$ energy-mom. tensor

- matter radius (gluon) vs charge radius
- helicity sum rule Orbital ang. momentum
- scaling with $b^2/(1-x)$
- spin degrees of freedom



- Theory issues / status - this talk

(V) Factorization (DVCS - golden mode)



$x-\xi > 0$ ~ DIS

$x<\xi$ ~ FF

$x=\xi$?

$$\xi \sim \frac{x_B}{2-x_B}$$

$$\mathcal{H} \sim \int_{-1}^{1} dx \frac{1}{x-\xi+i\varepsilon} H(x,\xi,\Delta_T^2)$$

$\mathcal{H}$ ↑ Compton FF

$H(x,\xi,\Delta_T^2)$ ↑ GPD

$$\langle P' | \bar{q}(\boxtimes)[n,-n]\gamma_+ q(-n) | P \rangle \mapsto H, E (\tilde{H}, \tilde{E})$$

$$\int d^2\Delta_T e^{i b_\perp \Delta_T} H(x,0,\Delta_T^2) \sim \underline{q(x, b_T)}$$

Conformal symmetry

$$\frac{\beta(g)}{g} \sim \varepsilon - \frac{\beta_{QCD}(g)}{g}$$

$$T\{J(x)J(0)\} = \sum_n C_n O_n + \sum C_n' \partial O_n + \dots$$

↑ fixed by algebra

- mixing with operators containing total derivatives
  NLO → NNLO
- "Invisible operators"
  $\partial_{\mu_1} O^{\mu_1 \mu_2 \dots \mu_n}$ – vanishes on free quarks

→ $\frac{t}{Q^2}, \frac{m_N^2}{Q^2}$

↳ Interpretation

Phenomenology

Wanted:

- Several functions of several variables
- Will need many observables and high statistics
  (transversely polarized targets, e.g.)
- Cannot wait XXX years to have full experiment

→ Need Hierarchy of goals / contributions, etc.

What we know to this point?

(Reaction mechanism)

- "Handbag" dominance confirmed by data

Big help:

$$d\sigma^{\rightarrow} + d\sigma^{\leftarrow} \sim |BH|^2 + 2\,\mathrm{Re}\,|\mathcal{H}\cdot BH| + |DVCS|^2$$

$$d\sigma^{\leftarrow} - d\sigma^{\leftarrow} \sim \mathrm{Im}\,|\mathcal{H}\cdot BH|$$

Other processes →

- Different observables emphasize different GPDs
- "Realistic" models of GPDs
- Machinery:

  Factorization → Amplitudes → Observables

  "PARTONS" Project

- Constraints from lattice calculations
  (gold-plated: D-term)
  starting to arrive
- Other processes (later)

Interpretation

Usual paradigm - light-front wave functions

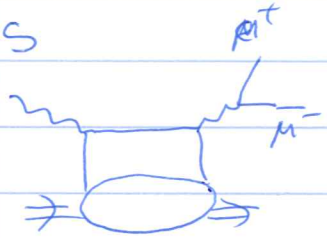
- GPDs are not parton densities

- $H(x, \xi, \Delta_\perp^2) \not\to H(x, 0, \Delta_\perp^2)$
  - $H(x, \xi, \Delta_\perp^2)$: LO
  - $H(x, 0, \Delta_\perp^2)$: Tomography

[need NLO and lever-arm in Q^2]

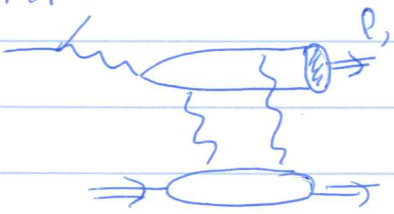
Other processes

TCS

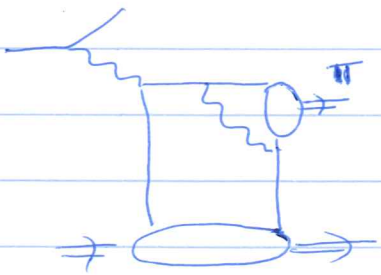


Analytic continuation (LT)
Universality, nontrivial signs

DVMP



Gluon GPD

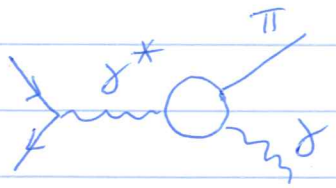


Flavor separation

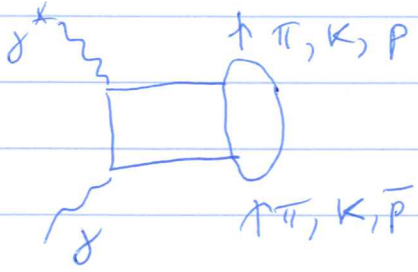
"More data = less theory"

Outlook / Outreach

- t-channel reactions at e^+e^- facilities



space- and time-like (ISR)



- TMDs and Wigner distributions

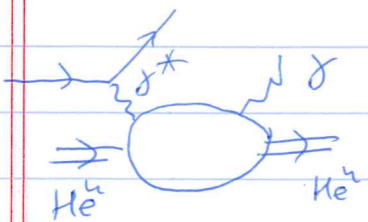
$$f\left((p-p')^2, np, b_\perp^2\right) \langle p' | \bar{\psi}(n_- + b_\perp)\, \gamma_+\, \psi(-n_- - b_\perp) | p \rangle$$

F ↓ ↓ ↓ F

$b_\perp^2 \times k_\perp^2 \rightarrow W(x, b_\perp, k_\perp)$

- Lattice experiments — position space ~~time~~ vs. momentum-space

- Coherent DVCS from nuclei



- Tomography of nuclei with 0.2 fm resolution in $b_\perp$ ~~at wavelength 0.05 fm~~
  Deformed nucleons or ~~what~~ quark-gluon degrees of freedom or what

Will see quarks and gluons (wavelength ~ 2-3 GeV) with ~ 1/2 fm resolution in ~~transverse~~ position