EXCLUSIVE PRODUCTION OF MESONS AND PHOTONS

THEORY ASPECTS

MARKUS DIEHL, SLAC

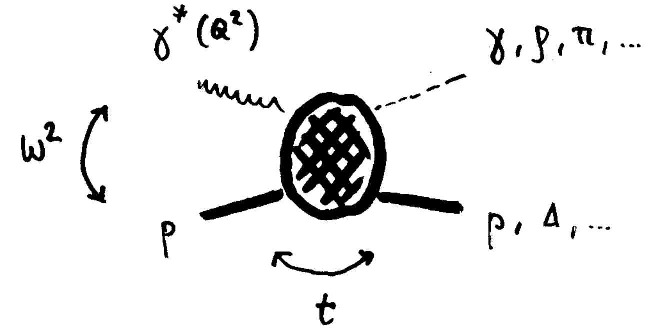
- PRODUCTION OF MESONS ($\rho, \pi, \ldots$) AND PHOTONS
  AT LARGE Q^2 AND SMALL t
  SKEWED PARTON DISTRIBUTIONS
- COMPTON SCATTERING AT LARGE t

→ REMINDER OF BASIC THEORY RESULTS
"WHAT DO WE WANT TO LEARN"

→ WHY HIGH ENERGY IS IMPORTANT

PHOTON AND MESON PRODUCTION IN THE BJORKEN REGIME

D. MÜLLER et al. '94
X. JI '96
A. RADYUSHKIN '96
J. C. COLLINS et al. '96 '98



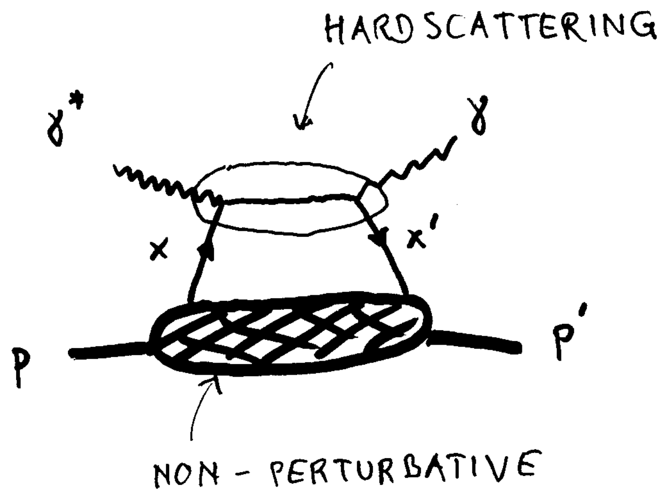
- IN THE LIMIT $Q^2 \to \infty$ (LARGE)

  $x_B \simeq \dfrac{Q^2}{Q^2 + W^2}$ FIXED

  t FIXED (SMALL)

  HAVE FACTORIZATION

- FOR DVCS :



$x \neq x'$

$x - x' = x_B$

SKEWED PARTON DISTRIBUTION

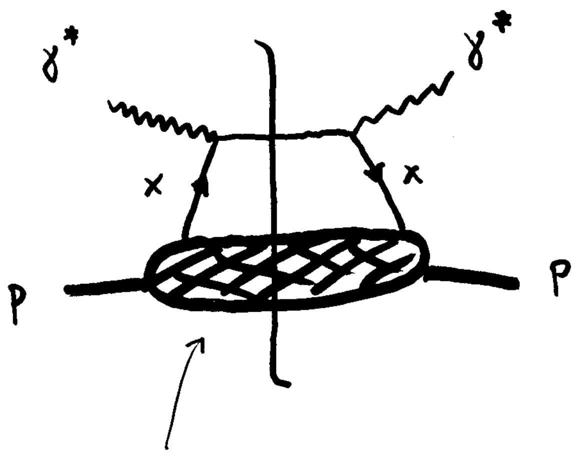
WANT TO MEASURE

- CLOSE ANALOGY WITH INCLUSIVE DIS :

$$\sigma(\gamma^* p \to X) \quad \propto \quad \mathrm{Im}\ \mathcal{A}(\gamma^* p \to \gamma^* p)$$

FORWARD
COMPTON AMPLITUDE

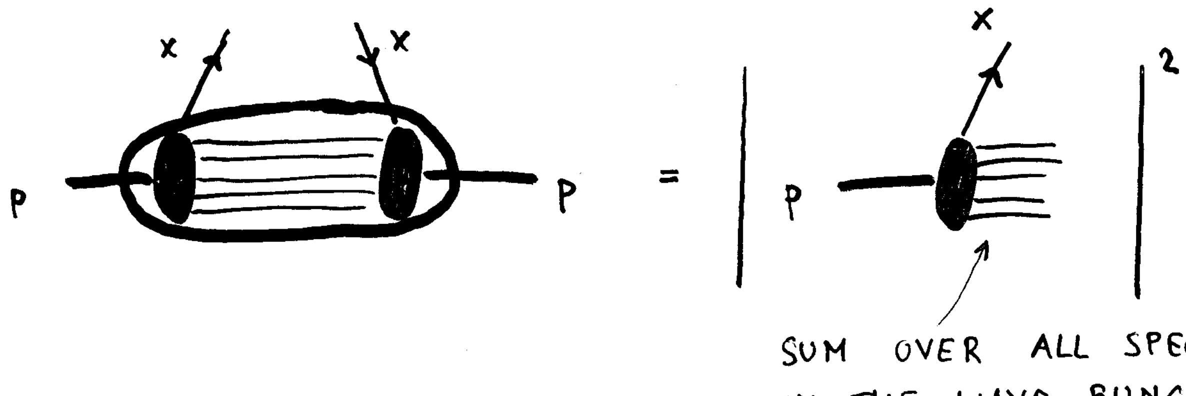
- IN BJ LIMIT :



THE USUAL PARTON DISTRIBUTIONS

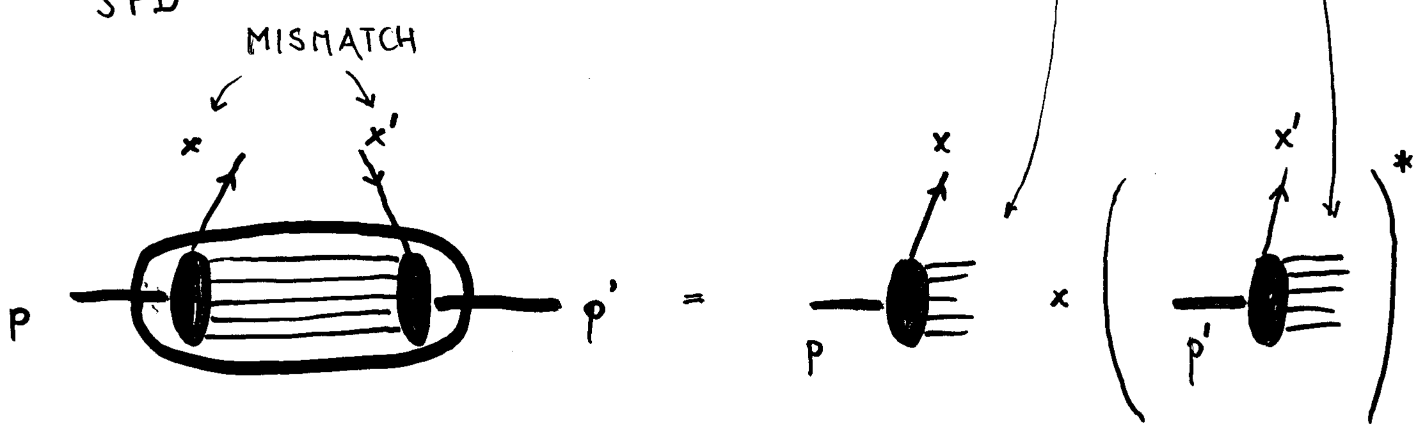
WHAT IS INTERESTING ABOUT SPDs ?

* USUAL PARTON DIST'N = PROBABILITY TO FIND PARTON WITH x



SUM OVER ALL SPECTATORS IN THE WAVE FUNCTIONS

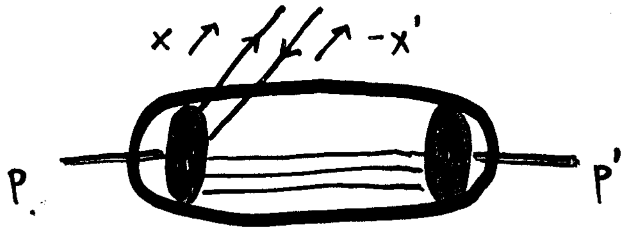
* SPD



INTERFERENCE OF DIFFERENT WAVE FUNCTIONS

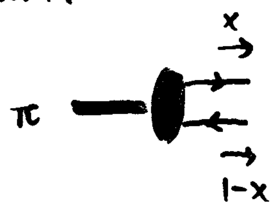
* IN SPD CAN HAVE $x > 0$, $x' < 0$

↳ ANTIPARTON WITH FRACTION $-x'$



- PROBE $q\bar{q}$ COMPONENT IN WAVE FUNCTION

SIMILAR TO MESON W. F.



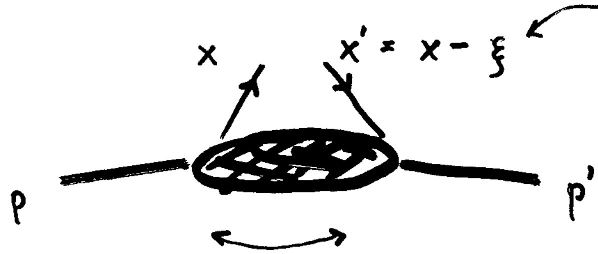
- NO COUNTERPART IN USUAL PARTON DIST'S

* RELATION TO FORM FACTORS VIA SUM RULES

$$\int dx \; H(x, \xi, t) = F_1(t) \quad \text{DIRAC} \qquad \xi = x - x'$$

$$\int dx \; E(x, \xi, t) = F_2(t) \quad \text{PAULI}$$

DIFFERENT SPIN STRUCTURES



LONGITUDINAL MOMENTUM MISMATCH

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

t ↔ ALSO TRANSVERSE MOMENTUM TRANSFER

- SPDs PROBE **LONGITUDINAL** AND **TRANSVERSE** STRUCTURE IN A CORRELATED WAY

* RICH SPIN STRUCTURE

H E → QUARK SPIN AVERAGE
AS $q(x)$

$\tilde{H}$ $\tilde{E}$ → ... DIFFERENCE
AS $\Delta q(x)$

↓ ↓

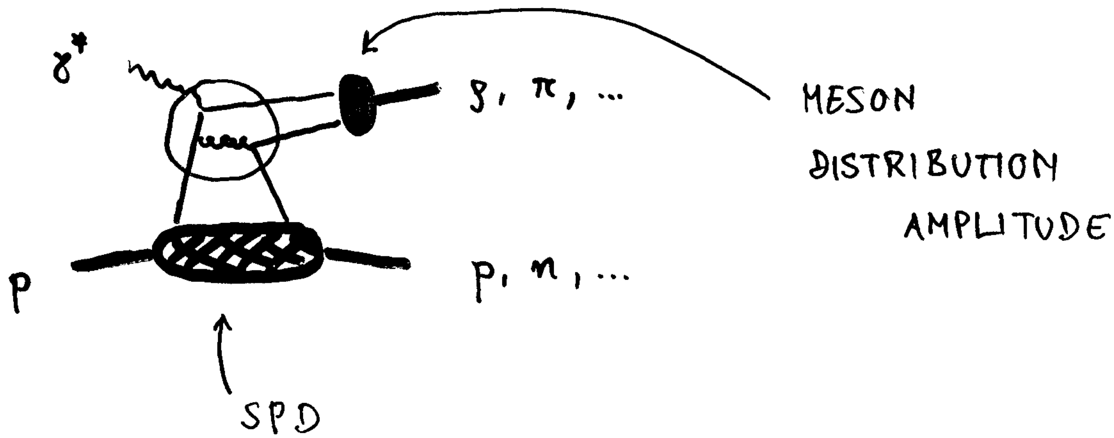
PROTON SPIN
NO FLIP FLIP

AS $F_1(t)$ ... $F_2(t)$

↳ ORBITAL ANGUAR MOMENTUM
OF PARTONS

JI'S SUM RULE '96

- FACTORIZATION FOR MESON PRODUCTION

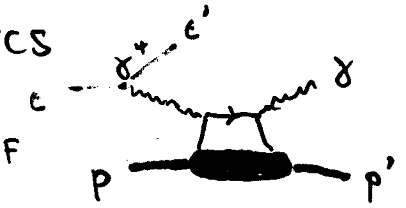


H, E FOR VECTOR MESONS

$\tilde{H}$, $\tilde{E}$ — PSEUDOSCALAR ...

COMLEMENTARITY OF MESON PRODUCTION AND DVCS

MESON PROD. | DVCS

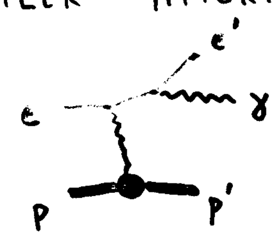


- DIFFERENT IMPORTANCE OF POWER CORRECTIONS

POWER CORR. CAN BE IMPORTANT

EXPECT BJ. REGION AT LOWER Q^2

+ CAN STUDY AT AMPLITUDE LEVEL THROUGH BETHE-HEITLER INTERFERENCE



− TWO UNKNOWNS : (G)DA AND SPDs

+ VARIETY OF CHANNELS DISENTANGLE FLAVOURS, $q, \bar{q}, g$, H, E AND $\tilde{H}, \tilde{E}$

+ LARGE COUNTING RATES FOR SOME CHANNELS (ρ)

EXPERIMENTAL REQUIREMENTS

- NEED HIGH Q^2 → BEAM ENERGY ↘ LUMINOSITY

- MAKE SURE THAT IS EXCLUSIVE → "HERMETIC" DETECTOR AND/OR ↘ GOOD MOMENTUM RESOLUTION

- VARIETY OF CHANNELS → PARTICLE I.D. ↘ LUMINOSITY

- ANGULAR DISTRIBUTIONS ↗ LUMINOSITY

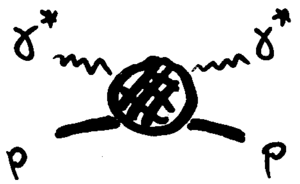
SOME REASONS WHY NEED LARGE Q^2

- THE PICTURE DISCUSSED SO FAR CAN BE DERIVED FROM QCD FOR LARGE ENOUGH Q^2

  AT FINITE Q^2 : POWER CORRECTIONS / HIGHER TWIST EFFECTS

  MUST LEARN FROM DATA IF THESE ARE SMALL

* ALREADY IN DIS : FACTORIZATION PREDICTS SCALING BEHAVIOR



=

$\frac{1}{Q^0}$ × (corrections in $\log Q^2$)

+ power corrections $\frac{1}{Q^n}$ × (logs)

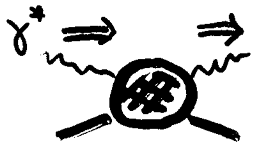
- AT FIXED x_B FORM OF $\log Q^2$ CORRECTIONS NOT PREDICTED (ONLY FOR MOMENTS IN x_B)

→ TO DISTINGUISH $\log Q^2$ AND $1/Q^n$ CORRECTIONS NON-TRIVIAL

* SAME IS TRUE FOR DVCS

  BUT HERE HAVE ONE MORE EXPERIMENTAL HANDLE :

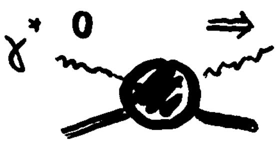
- HELICITY OF PHOTON



$=$

$\frac{1}{Q^0} \times (\text{logs})$

$+$ corrections $\frac{1}{Q} \times (\text{logs})$



$=$ power suppressed $\frac{1}{Q} \times (\text{logs})$

$+ \ldots$

- CAN SEPARATE THESE THROUGH ANGULAR DISTRIBUTIONS

  ... STUDY Q^2 DEPENDENCE OF LEADING- AND OF NONLEADING TWIST QUANTITIES

GOOD, BUT FOR THIS NEED LEVER ARM IN Q^2

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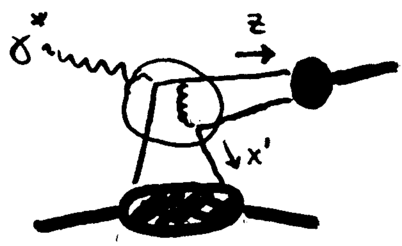
* IN MESON PRODUCTION EXPECT ONSET OF SCALING REGIME FOR <u>HIGHER Q^2</u> THAN IN DVCS :

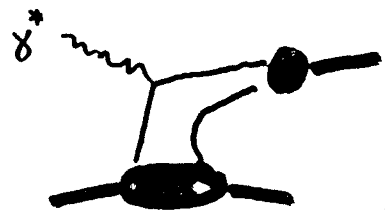
HAVE ADDITIONAL SOURCES OF POWER CORRECTIONS :

→ ENDPOINT REGIONS

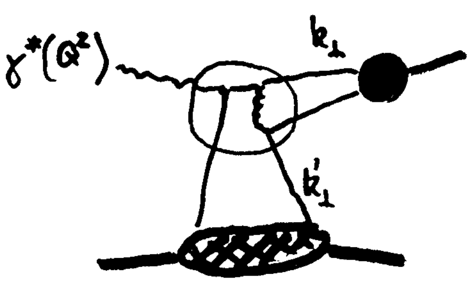


• IF $\begin{cases} x' \to 0 \\ z \to 1 \end{cases}$ THE GLUON BECOMES SOFT AND BELONGS IN THE MESON W.F.

→ OVERLAP CONTRIBUTION



→ FINITE $k_\perp$



• TO BE IN SCALING REGIME NEED

OFF-SHELLNESS IN HARD SCATTERING = FRACTION OF Q^2 ≫ $k_\perp, k_\perp'$ IN MESON AND PROTON

SCALE Q^2 "DILUTED" (LIKE IN ELASTIC FORM FACTORS) MORE THAN FOR DVCS

- PREDICTIONS FOR POLARIZATION IN SCALING REGIME :

  BOTH γ^* AND MESON HAVE $J_z = 0$

  e.g. FOR ρ : $\gamma^*_L\ p \to \rho_L\ p$ LEADING

  $\gamma^*_T\ p \to \rho_T\ p$ } SUBLEADING
  AND HELICITY CHANGING TRANSITIONS

BUT EXISTING DATA SHOW STRONG CONTRIBUTION FROM ρ_T EVEN AT $Q^2 \simeq 5$ to $10\ GeV^2$

→ FOR HIGH Q^2 ARE AT SMALL x_B

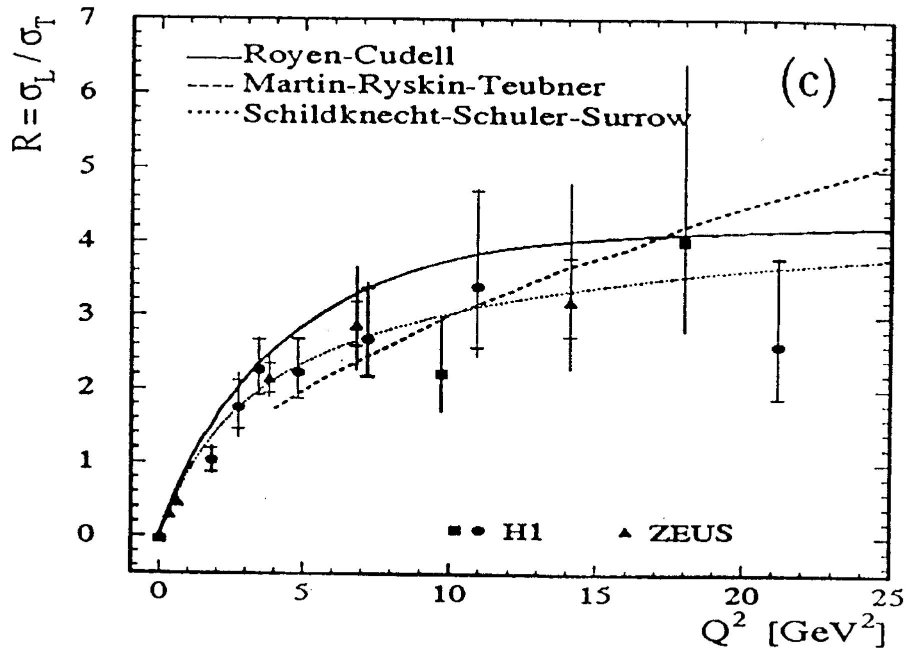
- EXPLANATION IN QCD FRAMEWORK
  A.D. MARTIN et al. '97, '99
  RELIES ON SMALL x_B GLUON EXCHANGE

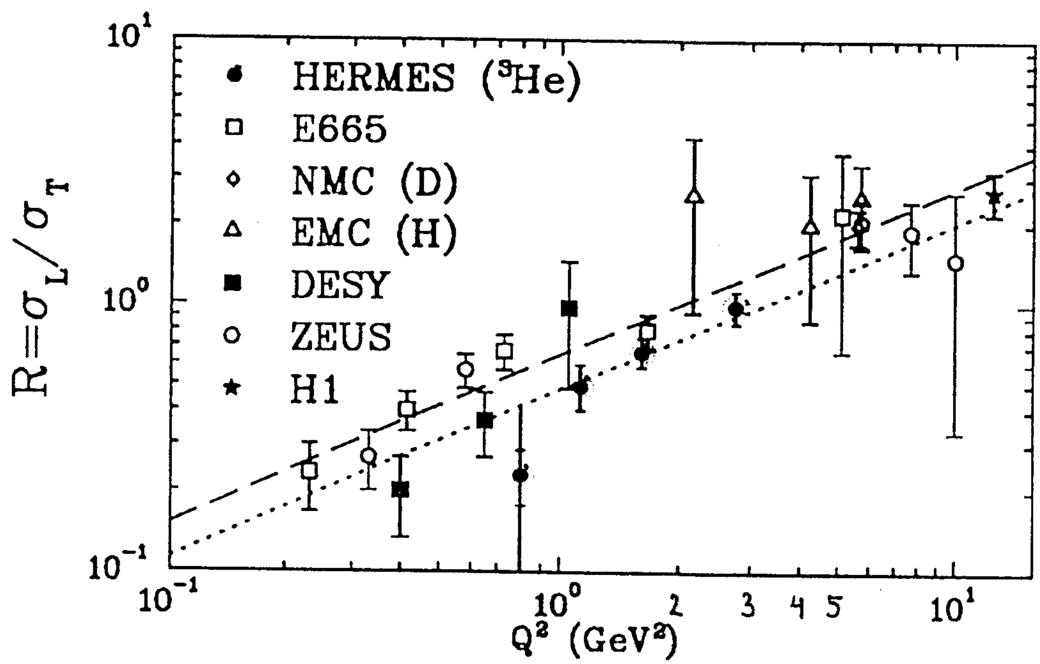
→ TO CLARIFY SITUATION NEED DATA IN VALENCE REGION OF x_B AND AT HIGH Q^2

B. CLERBAUX

(H1)

DIS 99, ZEUTHEN



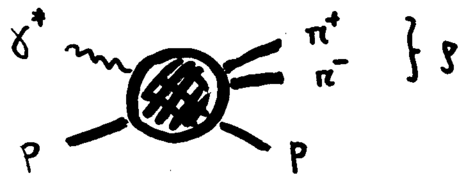


A. BORISSOV (HERMES)

DIS 99, ZEUTHEN

- FOR $\gamma^* p \to \rho p$ ALSO NEED **LARGE W^2**
  $\quad \hookrightarrow \pi^+\pi^-$

ρ – PRODUCTION



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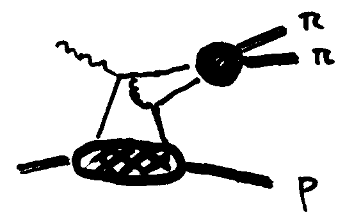
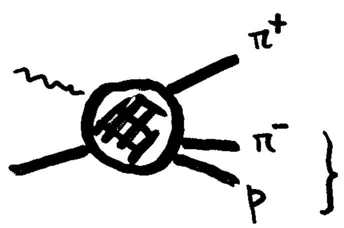


\+ corrections

SAME FINAL STATE AS



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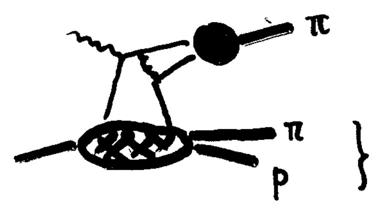


\+ corrections

→ BOTH PROCESSES INTERESTING, BUT TO SEPARATE THEM NEED SUFFICIENT PHASE SPACE
... W^2

MESONS AND PHOTONS IN THE BJORKEN REGIME

- PROVIDE ACCESS TO SPDs

  SPDs CONTAIN INFO ON PROTON STRUCTURE WHICH RELATES TO, BUT CANNOT BE OBTAINED FROM USUAL PARTON DIST'S AND FORM FACTORS

- DVCS HAS HANDLES TO EXPLORE WHETHER SCALING REGIME IS ATTAINED

  WITH POSSIBLE BENEFITS FOR UNDERSTANDING DIS A BIT BETTER

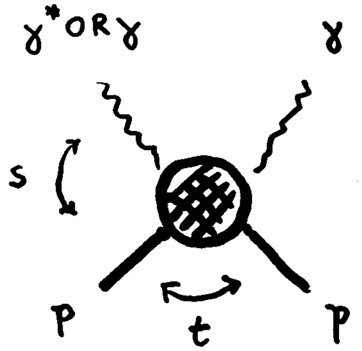
  NEED LEVER ARM IN Q^2

- FOR MESON PRODUCTION, ESPECIALLY FOR ρ, EXPECT THAT WILL NEED LARGE Q^2

  SUFFICIENTLY LARGE W^2 NEEDED FOR SEPARATION OF "PROTON" AND "MESON SIDE" OF PROCESS

COMPTON SCATTERING AT LARGE t

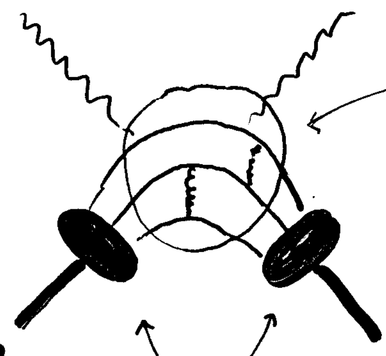
($Q^2 = 0$ OR NOT)



- IN THE LIMIT $\quad s, t, u \rightarrow \infty$

  t/s FIXED $\quad$ = FIXED SCATTERING ANGLE

HAVE FACTORIZATION :



BRODSKY, LEPAGE

- PREDICTS **SCALING**

$$\frac{d\sigma}{dt} \sim \frac{1}{s^6} f(s/t)$$

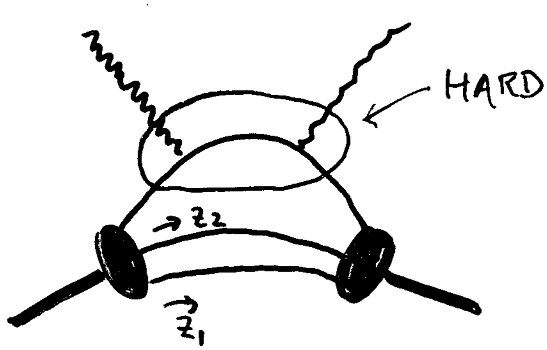
- BUT

EXTERNAL HARD SCALE t "DILUTED"

PROBLEMS WITH END-POINT REGIONS OF W.F.

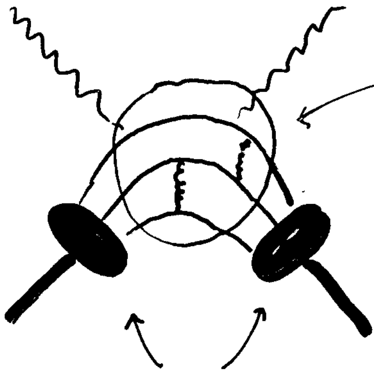
CANNOT CONSISTENTLY ACCOUNT FOR NORMALIZATION OF DATA

→ OVERLAP CONTRIBUTION / FEYNMAN MECHANISM



z_1, z_2 SMALL , "WEE" PARTONS

- FORMALLY A POWER CORRECTION TO BL
  CAN DOMINATE AT ACCESSIBLE s, t, u



P P

HARD SCATTERING

PROTON DISTRIBUTON AMPL.

BRODSKY, LEPAGE

• PREDICTS **SCALING**

$$\frac{d\sigma}{dt} \sim \frac{1}{s^6} f(s/t)$$

• BUT

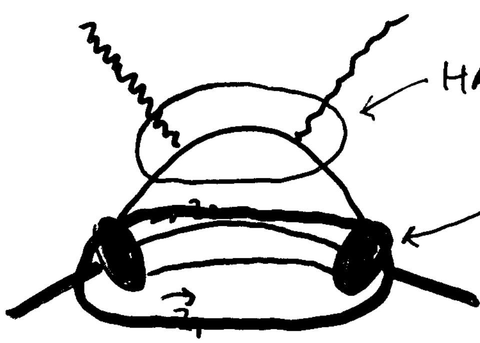
EXTERNAL HARD SCALE t "DILUTED"

PROBLEMS WITH END-POINT REGIONS OF W.F.

CANNOT CONSISTENTLY ACCOUNT FOR NORMALIZATION OF DATA

CAN DESCRIBE EXISTING DATA

→ OVERLAP CONTRIBUTION / FEYNMAN MECHANISM



HARD

SOFT, WRITE AS MOMENT

$$\int \frac{dx}{x} \; H(x, \xi = 0, t)$$

↑ AND OTHER SPDS

A. RADYUSHKIN '98

M. D. et al. '99

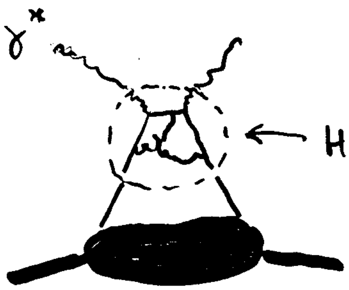
z_1, z_2 SMALL, "WEE" PARTONS

• FORMALLY A POWER CORRECTION TO BL

CAN DOMINATE AT ACCESSIBLE s, t, u

WARNING :

HANDBAG IN DVCS MEANS

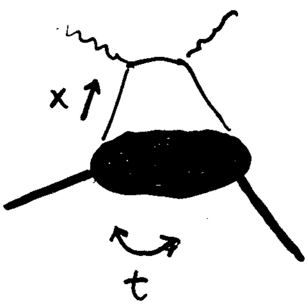


- OUT OF ALL POSSIBLE DIAGRAMS ONLY TAKE HANDBAG ONES
- IN HARD SCATTERING SET $t = 0$

  (SO WE NEED $|t| \ll Q^2$)
- HAVE FACTORIZATION THEOREM FOR ASYMPTOTIC Q^2

$\neq$

HANDBAG AT LARGE t



- PRE - ASYMPTOTIC
- DIFFERENT APPROXIMATIONS $x = 1$ IN HARD SCATT.
- COMPETES WITH BRODSKY - LEPAGE MECHANISM

  CONTROVERSIAL WHICH IS MORE IMPORTANT
- NO SMOOTH TRANSITION TO DVCS APPROXIMATIONS

A.V. RADYUSHKIN 1998

M.D. ET AL 1999

- ONGOING DEBATE HARD SCATTERING ↕ SOFT OVERLAP

  FOR PROTON FORM FACTOR $F_1(t)$

- COMPTON SCATTERING OFFERS CHANCES TO MAKE PROGRESS

  → POLARIZATION OBSERVABLES (TARGET OR RECOIL p AND INCIDENT γ)

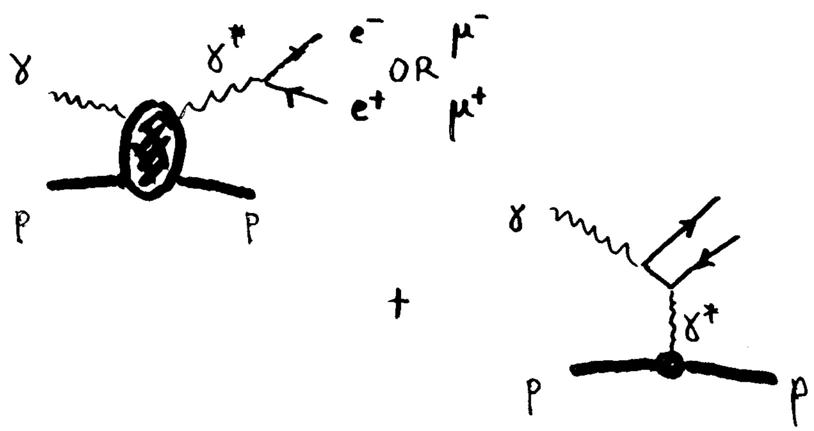
  VERY DIFFERENT PREDICTIONS IN TWO DESCRIPTIONS
  M.D. et al. '99

  → FOR VCS $\gamma^* p \to \gamma p$ CAN ACCESS PHASE (*) OF COMPTON AMPLITUDE THROUGH BETHE-HEITLER INTERFERENCE

  SOFT OVERLAP : IS PURELY REAL
  HARD SCATT : HAS IMAGINARY PART

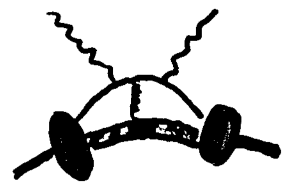
  (*) ALSO IN $\gamma p \to \gamma^* p$

... AND



- ONGOING DEBATE HARD SCATTERING ↔ SOFT OVERLAP FOR PROTON FORM FACTOR $F_1(t)$

← ALSO: DIQUARK PICTURE



- MORE NON-PERTURB. ELEMENTS
- LESS PROBLEM AT ENDPOINTS

- COMPTON SCATTERING OFFERS CHANCES TO MAKE PROGRESS

→ POLARIZATION OBSERVABLES (TARGET OR RECOIL p AND INCIDENT γ)

VERY DIFFERENT PREDICTIONS IN TWO DESCRIPTIONS
M.D. et al. '99

→ FOR VCS $\gamma^* p \to \gamma p$ CAN ACCESS PHASE OF COMPTON AMPLITUDE THROUGH BETHE-HEITLER INTERFERENCE

SOFT OVERLAP : IS PURELY REAL

HARD SCATT : HAS IMAGINARY PART

... AND

→ HARD-SCATT. MECHANISM :

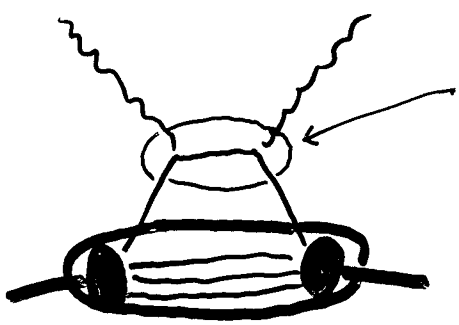
SCALING IN TWO VARIABLES

$$\frac{d\sigma}{dt}(s,t) \sim \frac{1}{s^6} f(t/s) \times (\text{logs})$$

- SCALING BEHAVIOR IN SOFT OVERLAP IS APPROXIMATE ONLY HOLDS IN LIMITED t INTERVAL

- PRECISE DATA <u>MAY DISTINGUISH MECHANISMS</u> BUT NEED <u>LEVER ARM IN s, t</u>

- IN ORDER TO WORK, SOFT OVERLAP ALSO NEEDS <u>SUFFICIENTLY LARGE s,t,u</u> (UNLIKE IN THE CASE OF $F_1(t)$)



HARD SCATTERING NEED OFF-SHELLNESS » HADRONIC SCALES

ELSE APPROX. BREAK DOWN

→ AT TOO LOW s,t,u, NEITHER SOFT OVERLAP NOR HARD-SCATTERING MECHANISM WILL WORK

FIXED ANGLE RCS, VCS

- DATA AT SUFFIC. LARGE s, t, u
  WITH SUFFIC. LEVER ARM

  MAY HELP RESOLVE THE LONG STANDING CONTROVERSY

  HARD SCATTERING ↔ SOFT OVERLAP

- IF ADEQUATE THEOR. DESCRIPTION IDENTIFIED

  DATA WILL PROVIDE NEW INFORMATION ON PROTON STRUCTURE