EXCLUSIVE $\gamma\gamma$ ANNIHILATION

AT LARGE ENERGY

OR LARGE VIRTUALITY

M. DIEHL

DESY HAMBURG

1. $\gamma\gamma \to \pi\pi$, $\gamma\gamma \to p\bar{p}$, ETC. AT LARGE s

2. $\gamma^*\gamma^* \to \pi^0$ WITH TWO OFF-SHELL PHOTONS

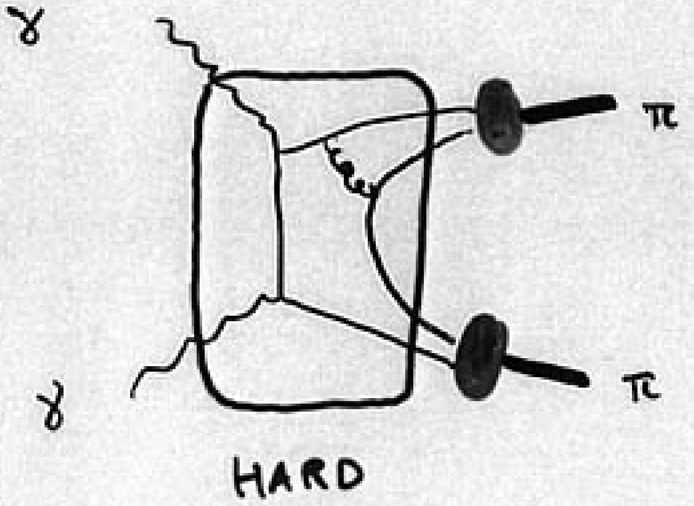
WORK WITH P. KROLL
C. VOGT

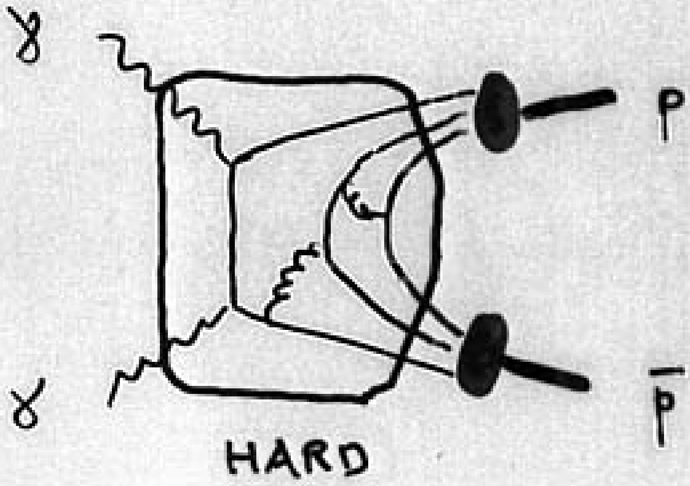
- $\gamma\gamma \to \pi\pi$, KK , ...

  $\to p\bar{p}$, $\Lambda\bar{\Lambda}$, ...

AT LARGE ENERGY

HARD SCATTERING MECHANISM (BRODSKY , LEPAGE)





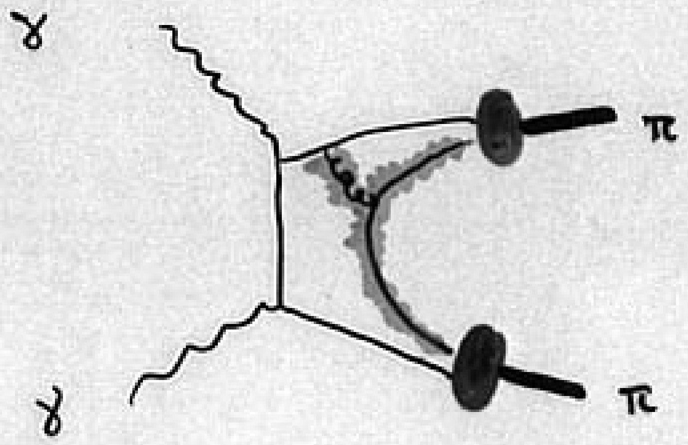
IN LIMIT $s \to \infty$ AT t/s , u/s FIXED

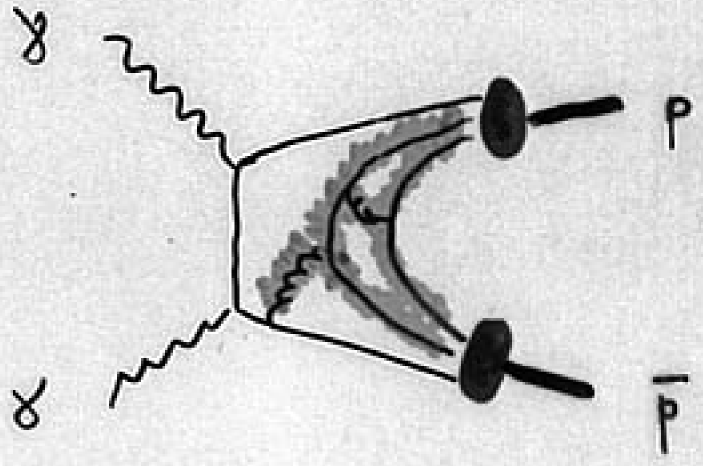
• $\gamma\gamma \to \pi\pi$, KK , ...

$\to p\bar{p}$, $\Lambda\bar{\Lambda}$, ...

AT LARGE ENERGY

HARD SCATTERING MECHANISM (BRODSKY , LEPAGE)





• REGION WHERE YELLOW LINES ARE SOFT
(MOMENTA ~ 100 MeV IN c.m.)

→ IN LIMIT $s \to \infty$ AT t/s , u/s FIXED
IS POWER SUPPRESSED

→ APPROXIMATIONS OF HARD-SCATTERING CALCULATION
BREAK DOWN

→ FOR $s \sim$ few GeV^2 ... few 10 GeV^2

CALCULATION EITHER

- UNDERSHOOTS DATA

OR

- HAS SUBSTANTIAL CONTRIBUTION FROM SOFT REGION ↯

↖ DEPENDS ON WAVE FUNCTION ↙

RESULTS : MESON PAIRS

$\gamma\gamma \to \pi^+\pi^-$: $$\frac{d\sigma}{dt} = \frac{8\pi\alpha_{e.m.}^2}{s^2} \frac{1}{\sin^4\theta} \left| R_{\pi\pi}(s) \right|^2$$

$\updownarrow$ FORM FACTOR OF QUARK ENERGY – MOMENTUM TENSOR

- CAN DESCRIBE PRELIM. ALEPH + DELPHI DATA (PHOTON '01) WITH

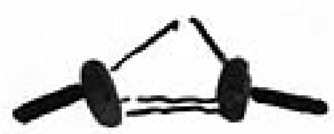
$$|R_{\pi\pi}(s)| \sim \frac{(0.75 \pm 0.07)\ \mathrm{GeV}^2}{s} \qquad \text{FOR } s = 6.2 \div 30\ \mathrm{GeV}$$

COMPARE WITH TIMELIKE ELECTROMAG. FORM FACTOR

$$|F_\pi(s)| \sim \frac{(0.93 \pm 0.12)\ \mathrm{GeV}^2}{s} \qquad \text{FOR } s = 4 \div 9\ \mathrm{GeV}^2$$

- SOFT OVERLAP CAN MIMIC PERTURB $1/s$ **BEHAVIOR** OVER A FINITE s RANGE

[EXPLICITLY SEEN FOR MODELS IN SPACELIKE REGION]



M.D. ET AL. PLB 460, 204

- PREDICT θ DEPENDENCE

FOR $|\cos\theta|$ NOT ~ 1

s, t, u NOT TOO SMALL

RESULTS : BARYON PAIRS

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha_{em}^2}{s^2}\frac{1}{\sin^2\theta}\left[|R_{eff}(s)|^2 + \cos^2\theta \, |R_V(s)|^2 \right]$$

$|R_{eff}(s)|^2$ ↕ AXIAL CURRENT; $|R_V(s)|^2$ ↕ VECTOR CURRENT

- $p\bar{p}$ CLEO, VENUS DATA ⇝

$$|R_{eff}(s)| = \frac{(6.5 \pm 0.05)\,GeV^4}{\sqrt{s}^4}$$ FOR $s = 6.5 \div 11\ GeV^2$

COMPARE WITH $|G_M(s)| \simeq \frac{3\,GeV^4}{s^2}$ $s = 8.9 \div 13\ GeV^2$

- ANGULAR DEPENDENCE

NOW DEPENDS ON R_V/R_{eff}

- DIFFERENT CHANNELS (BARYON OCTET STATES)

WITH $SU(3)_F$, NEGLECT $s\bar{s} \to p\bar{p}$

GET RATIOS OF ALL CHANNELS IN TERMS OF

$$\rho = \frac{d\bar{d} \to p\bar{p}}{u\bar{u} \to p\bar{p}}$$

→ WITH $\rho \simeq 0.25 \div 0.75$ IN GIVEN s-RANGE

CLEO, LS DATA FOR $\Sigma^0\bar{\Sigma}^0$, $\Lambda\bar{\Lambda}$ ✓

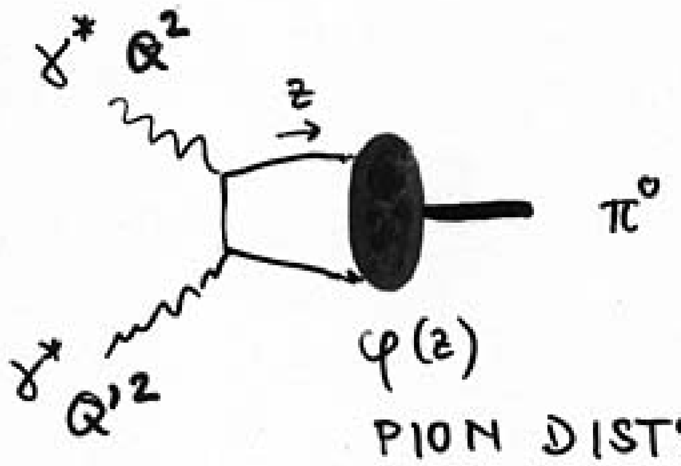
→ $$\sigma(\Lambda\bar{\Sigma}^0 + \Sigma^0\bar{\Lambda}) \simeq \frac{3}{2}\left(\frac{1-2\rho}{4+\rho}\right)^2 \sigma(p\bar{p})$$

SMALL

... SAME DIAGRAMS, DIFFERENT KINEMATICS, DIFFERENT PHYSICS :

M.D. ET AL. EPJC 22, 439

$\gamma^* \gamma^* \to \pi^0$ AT LARGE Q^2



PION DISTRIBUTION AMPLITUDE

→ LEADING MECHANISM AT LARGE $Q^2 + Q'^2$

HARD SCATTERING : ANALYSES INCLUDING $O(\alpha_s)$ CORR'S

RECENTLY $O(\alpha_s^2)$ B. MELIČ ET AL. hep-ph/0212346

→ EVEN WITH $Q'^2 = 0$ POWER CORRECTIONS ESTIMATED MODERATE $\sim -10\%$ @ $Q^2 = 4$ GeV^2

$$\varphi(z) = 6z(1-z) \left[1 + \sum_{n=2,4,\dots} B_n(\mu^2) \, C_n^{3/2}(2z-1) \right]$$

$Q'^2 = 0$: $$F_{\gamma\pi}(Q^2) \propto \frac{1}{Q^2} \int dz \, \frac{\varphi(z;Q^2)}{z(1-z)} \propto 1 + \sum_{n=2,4,\dots} B_n(Q^2)$$

TO LO(α_s)

CLEO DATA : $\sum_{n=2,4,\dots} B_n$ IS SMALL

- CONSISTENT WITH ANALYSIS OF F_π, $\pi p \to 2$ jets $+ p$

- SOME SENSITIVITY TO INDIVIDUAL B_n AT NLO(α_s)

WHAT CAN WE LEARN WITH TWO OFF-SHELL PHOTONS ?

$$\bar{Q}^2 = \frac{1}{2}\left(Q^2 + Q'^2\right) \qquad \omega = \frac{Q^2 - Q'^2}{Q^2 + Q'^2}$$

$$F_{\pi\gamma^*} \propto \frac{1}{\bar{Q}^2}\left[c_0(\omega) + \sum_{n=2,4,\ldots} c_n(\omega)\, B_n \right]$$

AS ω GOES AWAY FROM $\omega = 1$ ...

SOMETHING FUNNY HAPPENS → PLOTS