

EXCLUSIVE $\gamma\gamma$ ANNIHILATION

AT LARGE ENERGY

OR LARGE VIRTUALITY

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DESY HAMBURG

1. $\gamma\gamma \rightarrow \pi\pi$, $\gamma\gamma \rightarrow p\bar{p}$, ETC. AT LARGE S

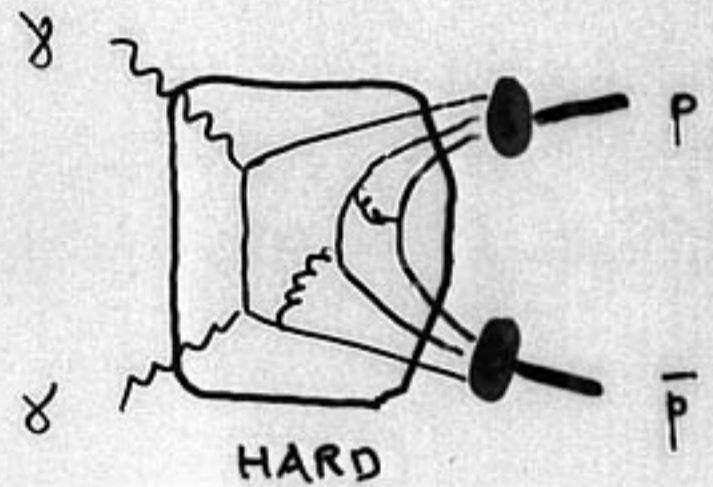
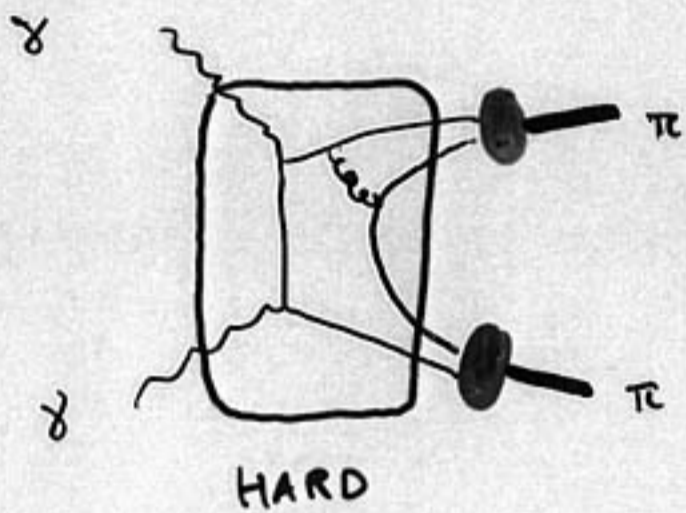
2. $\gamma^* \gamma^* \rightarrow \pi^0$ WITH TWO OFF-SHELL PHOTONS

WORK WITH P. KROLL
C. VOGT

- $\gamma\gamma \rightarrow \pi\pi, KK, \dots$
 $\rightarrow p\bar{p}, \Lambda\bar{\Lambda}, \dots$

AT LARGE ENERGY

HARD SCATTERING MECHANISM (BRODSKY , LEPAGE)



IN LIMIT $s \rightarrow \infty$

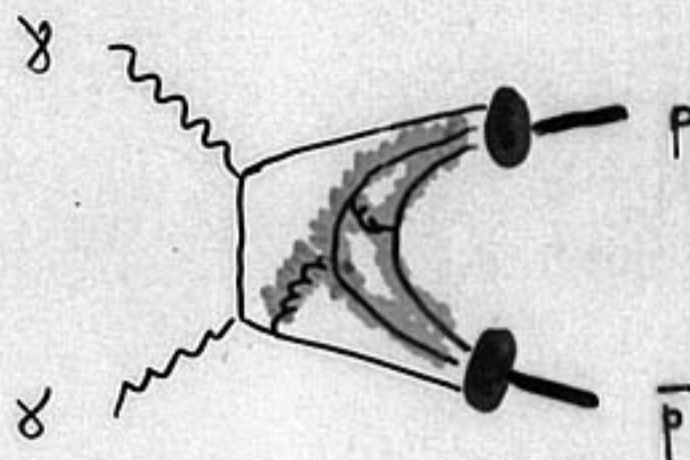
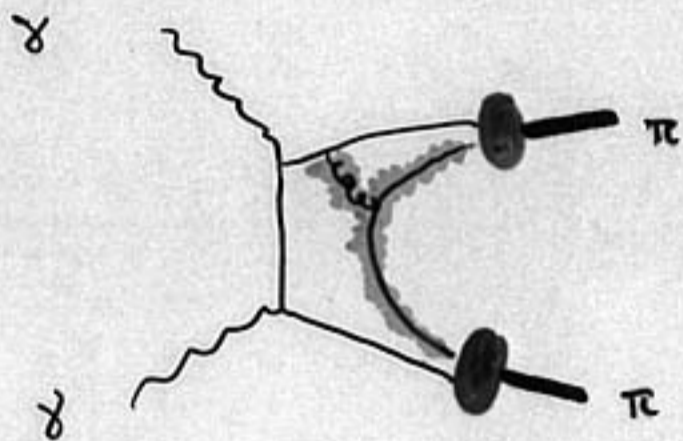
AT $t/s, u/s$ FIXED

• $\gamma\gamma \rightarrow \pi\pi, KK, \dots$

$\rightarrow p\bar{p}, \Lambda\bar{\Lambda}, \dots$

AT LARGE ENERGY

HARD SCATTERING MECHANISM (BRODSKY , LEPAGE)



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

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

\rightarrow APPROXIMATIONS OF HARD-SCATTERING CALCULATION
BREAK DOWN

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

CALCULATION EITHER

• UNDERSHOOTS DATA

OR

• HAS SUBSTANTIAL CONTRIBUTION
FROM SOFT REGION ζ

\nwarrow DEPENDS
ON
WAVE
FUNCTION

RESULTS : MESON PAIRS

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

↑
FORM FACTOR OF
QUARK ENERGY-MOMENTUM
TENSOR

- CAN DESCRIBE PRELIM. ALEPH + DELPHI DATA (PHOTON '01)
WITH
 $|R_{\pi\pi}(s)| \sim \frac{(0.75 \pm 0.07) \text{ GeV}^2}{s}$ FOR $s = 6.2 \div 30 \text{ GeV}^2$

COMPARE WITH TIMELIKE ELECTROMAG. FORM FACTOR

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

- 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 : ISAKYON PAIRS

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha_{em}^2}{s^2} \frac{1}{\sin^2\theta} \left[\underset{\substack{\updownarrow \\ \text{AXIAL CURRENT}}}{|R_{eff}(s)|^2} + \cos^2\theta \underset{\substack{\updownarrow \\ \text{VECTOR CURRENT}}}{|R_v(s)|^2} \right]$$

- $p\bar{p}$ CLEO, VENUS DATA \leadsto
 $|R_{eff}(s)| = \frac{(6.5 \pm 0.05) \text{ GeV}^4}{\sqrt{s}^4}$ FOR
 $s = 6.5 \div 11 \text{ GeV}^2$
COMPARE WITH $|G_H(s)| \approx \frac{3 \text{ GeV}^4}{s^2}$ $s = 8.9 \div 13 \text{ GeV}^2$

• ANGULAR DEPENDENCE

NOW DEPENDS ON R_v/R_{eff}

• DIFFERENT CHANNELS (BARYON OCTET STATES)

WITH $SU(3)_F$, NEGLECT $s\bar{s} \rightarrow p\bar{p}$
GET RATIOS OF ALL CHANNELS IN TERMS OF

$$\beta = \frac{d\bar{d} \rightarrow p\bar{p}}{u\bar{u} \rightarrow p\bar{p}}$$

\rightarrow WITH $\beta \approx 0.25 \div 0.75$ IN GIVEN s -RANGE

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

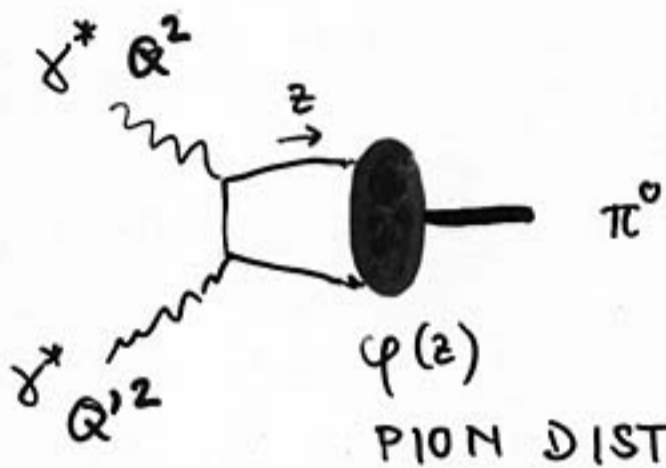
$$\rightarrow \sigma(\Lambda \bar{\Sigma}^0 + \Sigma^0 \bar{\Lambda}) \approx \frac{3}{2} \left(\frac{1-2\beta}{4+\beta} \right)^2 \sigma(p\bar{p})$$

SMALL

M.D. ET AL.

EPJC 22, 439

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



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

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

RECENTLY $O(\alpha_s^2)$

B. MELIĆ ET AL.

hep-ph/0212346

→ EVEN WITH $Q'^2 = 0$ POWER CORRECTIONS

ESTIMATED MODERATE

$\sim -10\%$ @ $Q^2 = 4 \text{ GeV}^2$

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

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

TO $LO(\alpha_s)$

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

• SOME SENSITIVITY TO INDIVIDUAL B_n AT NLO(α_s)

• CONSISTENT WITH ANALYSIS OF

F_π , $\tau_p \rightarrow 2 \text{ jets} + p$

WHAT CAN WE LEARN WITH

TWO OFF-SHELL PHOTONS ?

$$\bar{Q}^2 = \frac{1}{2} (Q^2 + Q'^2)$$

$$w = \frac{Q^2 - Q'^2}{Q^2 + Q'^2}$$

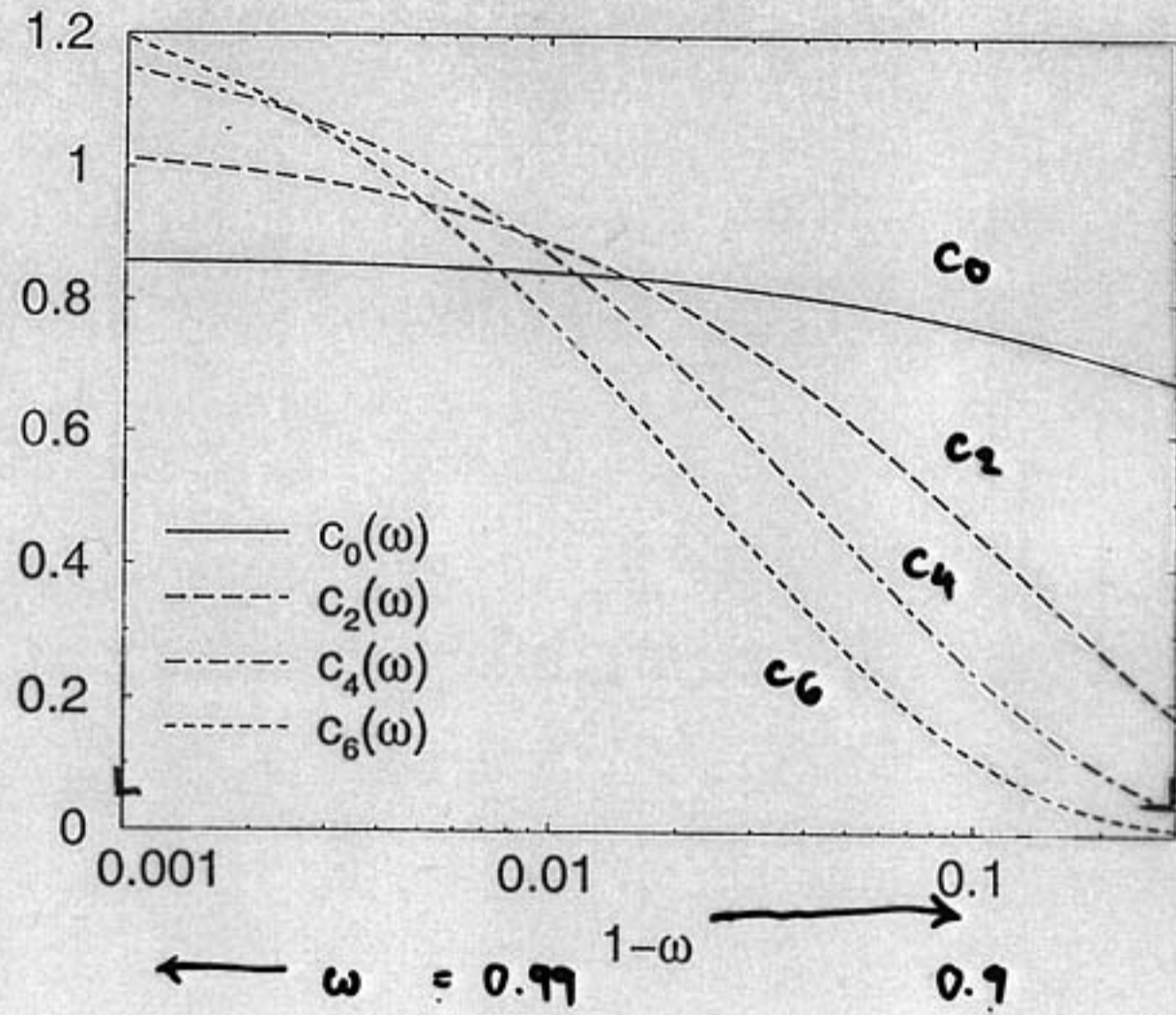
$$F_{\pi\gamma^*} \propto \frac{1}{\bar{Q}^2} \left[c_0(w) + \sum_{n=2,4,\dots} c_n(w) B_n \right]$$

AS w GOES AWAY FROM $w = 1 \dots$

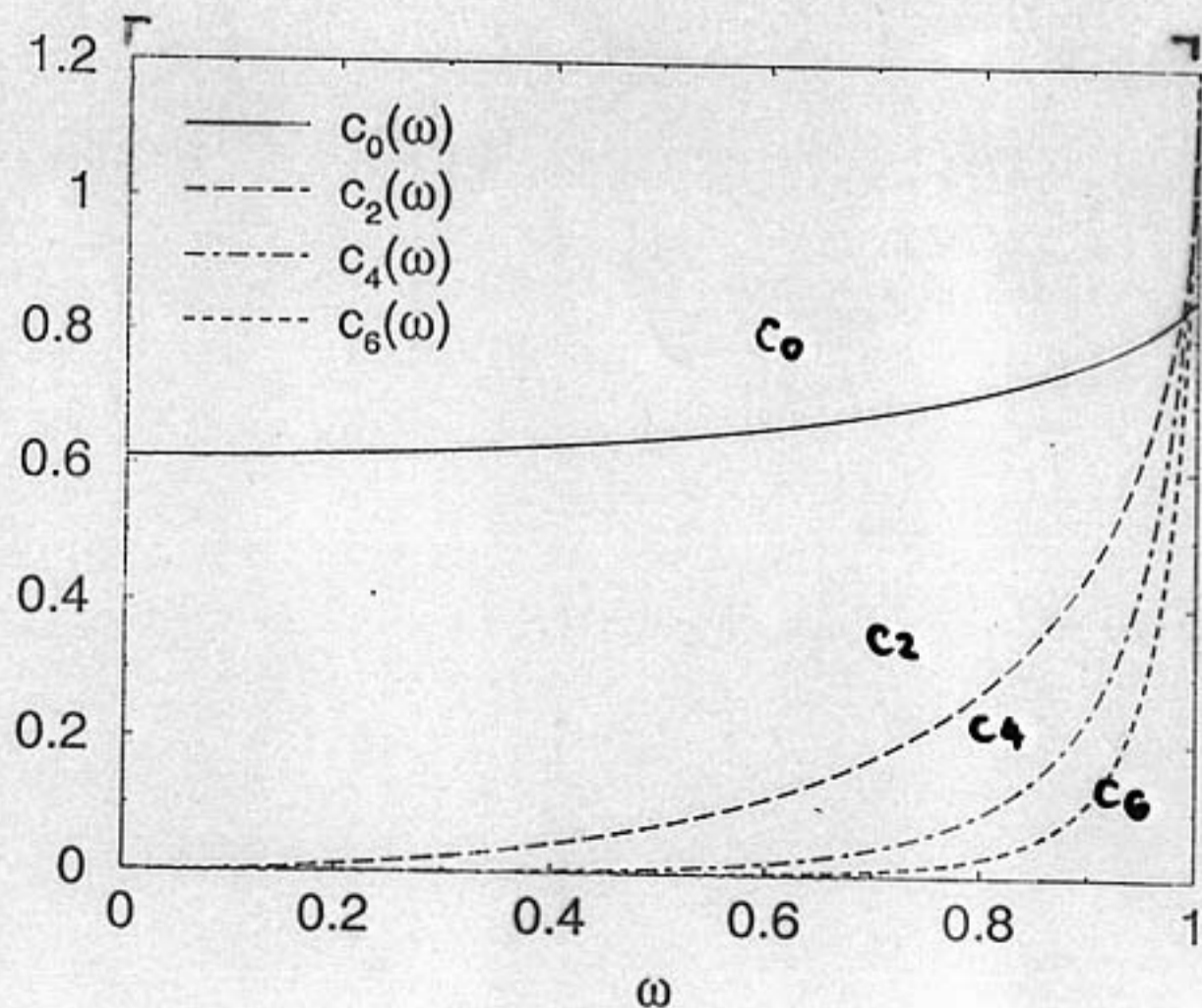
SOMETHING FUNNY HAPPENS \rightarrow PLOTS

$$F_{y^*n} \propto c_0(\omega) + \sum_{n=2,4,\dots} c_n(\omega) B_n$$

→ IN REGION $1-\omega \approx 10^{-3} \dots 0.3$ FIND SOME SENSITIV.
TO B_2, B_4 SEPARATELY



COEFFICIENTS
INCLUDE
 $O(\alpha_s)$ CORR'S



→ IN WIDE RANGE OF ω AROUND $\omega=0$

≈ NO SENSITIVITY TO B_4, B_6, \dots

LITTLE SENS. TO B_2

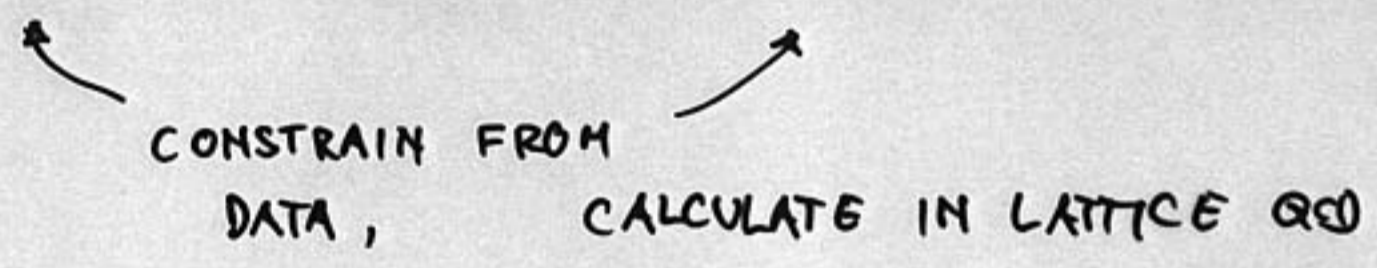
$$F_{\pi\gamma^*} = \frac{\sqrt{2} f_\pi}{3 \bar{Q}^2} \left[1 - \frac{\alpha_s}{\pi} - 3.583 \left(\frac{\alpha_s}{\pi}\right)^2 - 20.215 \left(\frac{\alpha_s}{\pi}\right)^3 \right. \\ \left. + \frac{1}{5} \omega^2 \left(1 - \frac{5}{3} \frac{\alpha_s}{\pi}\right) + \frac{12}{35} \omega^2 B_2 + \dots \right]$$

- GEGENBAUER MOMENTS APPEAR AS $\omega^n B_n (1 + \dots \omega^2 + \dots \omega^4 + \dots)$

- $F_{\pi\gamma^*}$ KNOWN UP TO CORRECTIONS IN

$$\alpha_s^4, \quad \alpha_s^3 \omega^2, \quad \omega^4, \quad \frac{1}{\bar{Q}^6}$$

IF GIVEN B_2 AND ONE TWIST-4 MATRIX ELEM.



→ AN (ALMOST) PARAMETER FREE PREDICTION OF QCD

→ FUNDAMENTAL TEST

→ MEASURE α_s ?

VERY SIMILAR TO BJORKEN SUM RULE IN DIS

THE BAD NEWS : SMALL X SECTION for $e^+e^- \rightarrow e^+e^- \pi^0$

$$\bar{Q}^2 = 4 \text{ GeV}^2, \quad |\omega| \leq 0.5 \quad \rightarrow \quad \frac{d\sigma_{e^+e^-}}{d\bar{Q}^2} \approx 0.5 \text{ fb/GeV}^2$$

... HIGH-LUMINOSITY UPGRADES OF B-FACTORIES ?

SUMMARY

- $\gamma\gamma \rightarrow \pi^+\pi^- , \pi^0\pi^0 , K^+K^- , \dots$
 $\gamma\gamma \rightarrow p\bar{p} , \Sigma^0\bar{\Sigma}^0 , \dots$

SOFT "HANDBAG" MECHANISM :

TESTABLE PREDICTIONS

HOPE TO CLARIFY WHAT IS REACTION
MECHANISM

- $\gamma^*\gamma^* \rightarrow \pi^0$

→ AT $Q'^2 \ll Q^2$ SOME (THEORETICALLY CLEAN!)
EXTRA INFORMATION ON
PION DISTRIBUTION
AMPLITUDE

→ AT $Q'^2 \sim Q^2$ POTENTIAL FOR PRECISION TEST OF QCD
DETERMIN. OF α_s

PHYSICS FOR HIGH-LUMINOSITY e^+e^-
MACHINES

EXCLUSIVE $\gamma\gamma$ ANNIHILATION

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