Leptoquark Pair Production

in $\gamma\gamma$ Scattering

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DESY

1. Introduction
2. Classification of Leptoquark States
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4. QCD Corrections
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1. Classification of Leptoquark States

B and L conserving

BUCHMÜLLER, RÖCKL, WYLER '87

family–diagonal

$SU(3)_c \times SU(2)_L \times U(1)_Y$ invariant couplings

leptoquark (Φ)	spin	F	colour	T_3	Q_{em}	$\lambda_L(lq)$	$\lambda_R(lq)$	$\lambda_L(\nu q)$
S_1	0	-2	$\bar{3}$	0	1/3	g_{1L}	g_{1R}	$-g_{1L}$
$\tilde{S}_1$	0	-2	$\bar{3}$	0	4/3	0	$\tilde{g}_{1R}$	0
$\vec{S}_3$	0	-2	$\bar{3}$	$+1$	4/3	$-\sqrt{2}g_{3L}$	0	0
				0	1/3	$-g_{3L}$	0	$-g_{3L}$
				-1	$-2/3$	0	0	$\sqrt{2}g_{3L}$
R_2	0	0	3	1/2	5/3	h_{2L}	h_{2R}	0
				$-1/2$	2/3	0	$-h_{2R}$	h_{2L}
$\tilde{R}_2$	0	0	3	1/2	2/3	$\tilde{h}_{2L}$	0	0
				$-1/2$	$-1/3$	0	0	$\tilde{h}_{2L}$
$V_{2\mu}$	1	-2	$\bar{3}$	1/2	4/3	g_{2L}	g_{2R}	0
				$-1/2$	1/3	0	g_{2R}	g_{2L}
$\tilde{V}_{2\mu}$	1	-2	$\bar{3}$	1/2	1/3	$\tilde{g}_{2L}$	0	0
				$-1/2$	$-2/3$	0	0	$\tilde{g}_{2L}$
$U_{1\mu}$	1	0	3	0	2/3	h_{1L}	h_{1R}	h_{1L}
$\tilde{U}_{1\mu}$	1	0	3	0	5/3	0	$\tilde{h}_{1R}$	0
$\vec{U}_{3\mu}$	1	0	3	$+1$	5/3	$\sqrt{2}h_{3L}$	0	0
				0	2/3	$-h_{3L}$	0	h_{3L}
				-1	$-1/3$	0	0	$\sqrt{2}h_{3L}$

$$\mathcal{L} = \mathcal{L}^f_{|F|=2} + \mathcal{L}^f_{F=0} + \mathcal{L}^{\gamma,Z,g}$$

$$\mathcal{L}^{\gamma,Z,g} = \sum_{scalars} \left[(D^\mu\Phi)^\dagger(D_\mu\Phi) - M^2\Phi^\dagger\Phi\right] + \sum_{vectors}\left[-\frac{1}{2}G^\dagger_{\mu\nu}G^{\mu\nu} + M^2\Phi^{\mu\dagger}\Phi_\mu\right]$$

$$D_\mu = \partial_\mu - ieQ^\gamma A_\mu - ieQ^Z Z_\mu - ig_s\frac{\lambda_a}{2}A^a_\mu$$

$$\begin{aligned}
\mathcal{L}^f_{F=0} &= (h_{2L}\bar{u}_R l_L + h_{2R}\bar{q}_L i\tau_2 e_R)R_2 + \tilde{h}_{2L}\bar{d}_R l_L \tilde{R}_2 \\
&+ (h_{1L}\bar{q}_L\gamma^\mu l_L + h_{1R}\bar{d}_R\gamma^\mu e_R)U_{1\mu} \\
&+ \tilde{h}_{1R}\bar{u}_R\gamma^\mu e_R\tilde{U}_{1\mu} + h_{3L}\bar{q}_L\vec{\tau}\gamma^\mu l_L\vec{U}_{3\mu} + h.c.
\end{aligned}$$

$$\begin{aligned}
\mathcal{L}^f_{|F|=2} &= (g_{1L}\bar{q}^c_L i\tau_2 l_L + g_{1R}\bar{u}^c_R e_R)S_1 \\
&+ \tilde{g}_{1R}\bar{d}^c_R e_R\tilde{S}_1 + g_{3L}\bar{q}^c_L i\tau_2\vec{\tau} l_L\vec{S}_3 \\
&+ (g_{2L}\bar{d}^c_R\gamma^\mu l_L + g_{2R}\bar{q}^c_L\gamma^\mu e_R)V_{2\mu} \\
&+ \tilde{g}_{2L}\bar{u}^c_R\gamma^\mu l_L\tilde{V}_{2\mu} + h.c.,
\end{aligned}$$

PRESENT LQ BOUNDS

95% CL

1ST GENERATION $m > 242$ GeV

2ND GENERATION $m > 202$ GeV

3RD GENERATION $m > 93$ GeV $\left(|Q| = \frac{1}{3}\right)$
99 GeV

TEVATRON

→ SEARCH CONTINUES

- TEVATRON
- LHC

} BEFORE TESLA STARTS

MEASURABLE: κ_G, λ_G BUT NOT: $\kappa_\gamma, \lambda_\gamma$

Decay Pattern for Pair Production

states	$l^+l^- + 2jets$	$l\nu + 2jets$	$\nu\overline{\nu} + 2jets$
S_1 U_1	$\frac{4}{9}$ 1 $\frac{1}{4}$	$\frac{4}{9}$ 0 $\frac{1}{2}$	$\frac{1}{9}$ 0 $\frac{1}{4}$
$R_2^{2/3}$ $V_2^{1/3}$	$\frac{1}{4}$ 1 0	$\frac{1}{2}$ 0 0	$\frac{1}{4}$ 0 1
$S_3^{1/3}$ $U_3^{2/3}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$
$\tilde{S}_1$ $S_3^{4/3}$ $R_2^{5/3}$ $\tilde{R}_2^{2/3}$ $V_2^{4/3}$ $\tilde{V}_2^{1/3}$ $\tilde{U}_1$ $U_3^{5/3}$	1	0	0
$S_3^{-2/3}$ $\tilde{R}_2^{-1/3}$ $\tilde{V}_2^{-2/3}$ $U_3^{-1/3}$	0	0	1

Table 3: Branching ratios for final states arrising from the decays of leptoquarks associated with the first ($l = e$) and second ($l = \mu$) family. The sequence of branching fractions given in the second and third row refers to the assumptions $\lambda_L = \lambda_R, \lambda_L = 0$, and $\lambda_R = 0$, respectively.

LINEAR COLLIDER:

$e^+e^- \rightarrow \phi\bar{\phi}$
$\gamma\gamma \rightarrow \phi\bar{\phi}$
} WIDELY INDEPENDENT OF $\lambda_{\ell q}$

$\longrightarrow$ GAUGE COUPLINGS

e^+e^- ANNIHILATION:

HEWETT, RIZZO, ZERWAS, JB RÜCKL
JB BOOS KRYUKOV

MASS BOUNDS: $m_\phi \lesssim \frac{1}{2}\sqrt{s}$

LOSSES: BEAMSTRAHLUNG, QED JB '93
$-\Delta\sigma \sim 40\%$ $O(\alpha^2)$ needed

ENHANCEMENT: QCD FS $\frac{1}{\beta}$ JB '93

$\longrightarrow$ NEARLY BALANCED UP TO $\sqrt{s} \sim 1\,\text{TeV}$.

2. $\gamma\gamma$ Scattering

$U_{em}(1)$ invariant Lagrangian:

$$\mathcal{L} = \mathcal{L}_s + \mathcal{L}_v \tag{1}$$

with

$$\mathcal{L}_s = \sum_{scalars} \left[(D^\mu \Phi)^\dagger (D_\mu \Phi) - M_s^2 \Phi^\dagger \Phi \right] \tag{2}$$

and

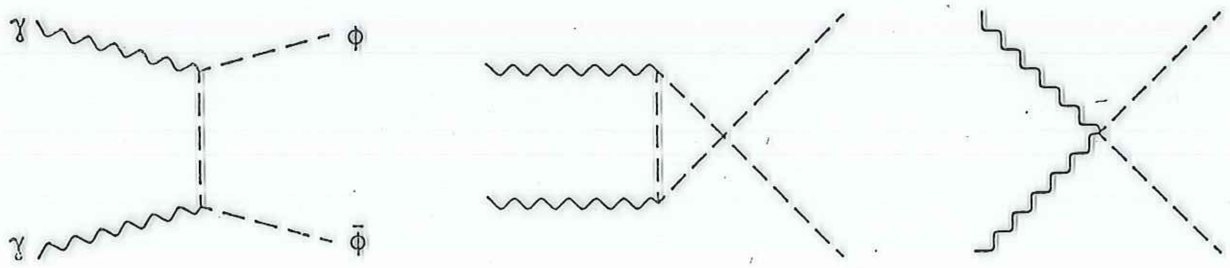
$$\mathcal{L}_v = \sum_{vectors} \left\{ -\frac{1}{2} G^\dagger_{\mu\nu} G^{\mu\nu} + M_v^2 \Phi^\dagger_\mu \Phi^\mu - ie \left[(1 - \kappa_A) \Phi^\dagger_\mu \Phi_\nu F^{\mu\nu} + \frac{\lambda_A}{M_v^2} G^\dagger_{\sigma\mu} G^\mu_\nu F^{\nu\sigma} \right] \right. \tag{3}$$

Field strength tensors:

$$\begin{aligned} F_{\mu\nu} &= \partial_\mu A_\nu - \partial_\nu A_\mu, \\ G_{\mu\nu} &= D_\mu \Phi_\nu - D_\nu \Phi_\mu \end{aligned} \tag{4}$$

Covariant derivative:

$$D_\mu = \partial_\mu - ieQ^\gamma A_\mu \tag{5}$$



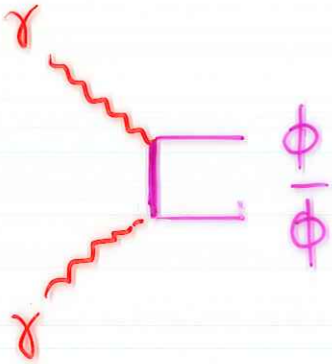
Anomalous couplings: κ_A and λ_A

$\Updownarrow$

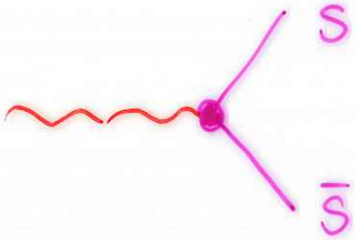
anomalous magnetic moment μ_Φ and electric quadrupole moment q_Φ of leptoquarks:

$$\begin{aligned} \mu_{\Phi,A} &= \frac{eQ_\gamma}{2M_\Phi} (2 - \kappa_A + \lambda_A) \\ q_{\Phi,A} &= -\frac{eQ_\gamma}{M_\Phi^2} (1 - \kappa_A - \lambda_A) \end{aligned} \tag{6}$$

WHY TO SEARCH FOR $\phi\bar{\phi}$ IN $\gamma\gamma$-SCATTERING?

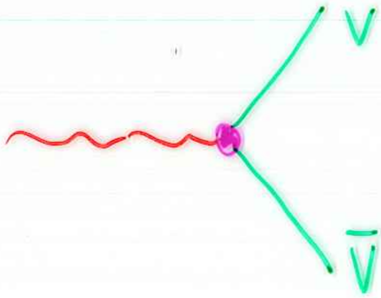


SCALARS & VECTORS



$\sigma \sim Q_\phi^4 \qquad |Q_\phi| = \frac{1}{3} \; \ldots \; \frac{5}{3} \; !$

$\sigma = O(1) \; \ldots \; O(625).$



$\sigma_V = \sigma_V(\kappa_\gamma, \lambda_\gamma)$

ANOMALOUS COUPLINGS.

Sensitivity to Quantum Numbers

Process	LQ	Quantum Numbers
e^+e^- Annihilation	S,V	$Q^\gamma_\Phi, Q^Z_\Phi, \lambda_{L,R}$
$\gamma\gamma$ Collider	S	Q^γ_Φ
	V	$Q^\gamma_\Phi, \kappa_A, \lambda_A$
$e\gamma$ Collider	S,V	$\lambda_{L,R}, Q^\gamma_\Phi$
ep Collider	single LQ	$\lambda_{L,R}$
	pairs : S	Q^γ_Φ
	pairs : V	$Q^\gamma_\Phi, \kappa_A, \kappa_G, \lambda_A, \lambda_G$
$p\overline{p}$ Collider	V	κ_G, λ_G

$\sigma \sim Q^4_\Phi$

2. CROSS SECTIONS

BORN:

J. BLÜMLEIN, E. BOOS, NUCL. PHYS (P.S.) 37B (1994) 181

J. BLÜMLEIN, E. BOOS, A. KRYUKOV, Z. PHYS. C76 (1997) 137

CODE: LQPAIR 1.0 : J. BLÜMLEIN, E. BOOS, A. KRYUKOV '99.

→ CONVOLUT WITH COMPTON LASER SPECTRA

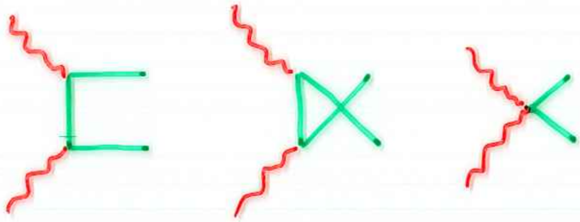
THREE CONTRIBUTIONS:

MOST IMPORTANT TERM → $\gamma_{DIR} \times \gamma_{DIR}$

$\gamma_{DIR} \times \gamma_{RESOLVED}$ ← HADRONIC.

$\gamma_{RESOLVED} \times \gamma_{RESOLVED}$

DIRECT TERMS:



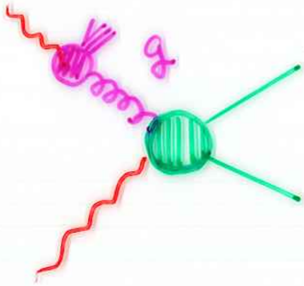
$S \quad V$

$\bar{S} \quad \bar{V}$

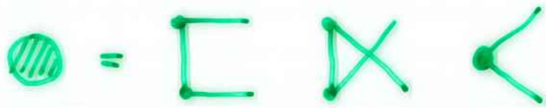
V: K_A, λ_A

DIRECT-RESOLVED CONTRIBUTIONS:

①



②



assume: $\lambda_{ge} \ll 1$.

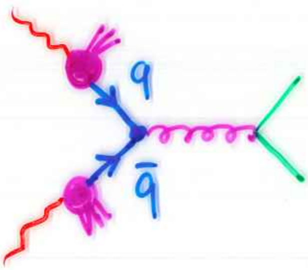
+ ① ↔ ②.

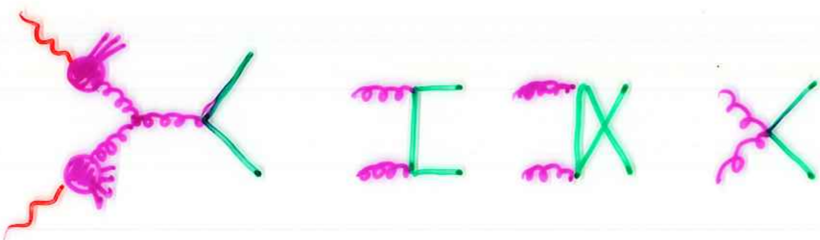
V: $\underline{\gamma} \quad \underline{g}$

K_A, K_G

λ_A, λ_G

RESOLVED-RESOLVED TERM:





V: K_G, λ_G

V: direct.

$$
\begin{aligned}
\widetilde{F}_0 &= \beta\left(\frac{11}{2}-\frac{9}{4}\beta^2+\frac{3}{4}\beta^4\right)-\frac{3}{8}\left(1-\beta^2-\beta^4+\beta^6\right)\ln\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_1 &= -8\beta-\frac{3}{2}\left(1-\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_2 &= 3\beta+\frac{1}{4}\beta\frac{\hat{s}}{M_\Phi^2}+\left(\frac{7}{2}-2\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_3 &= -\frac{1}{4}\beta\frac{\hat{s}}{M_\Phi^2}+\left(-2+\frac{3}{4}\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_4 &= -\frac{1}{96}\beta+\frac{5}{48}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{4-\beta^2}{16}\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_5 &= -\left(1-\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_6 &= -\frac{1}{6}\beta+\frac{17}{12}\beta\frac{\hat{s}}{M_\Phi^2}+\left(-3-\frac{\beta^2}{2}+\frac{1}{2}\frac{\hat{s}}{M_\Phi^2}\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_7 &= -\beta+\frac{11}{6}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1}{3}\beta\frac{\hat{s}^2}{M_\Phi^4}-\frac{3+\beta^2}{4}\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_8 &= -\frac{1}{96}\beta+\frac{59}{80}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{113}{320}\beta\frac{\hat{s}^2}{M_\Phi^4}+\frac{43}{960}\beta\frac{\hat{s}^3}{M_\Phi^6}+\left(-\frac{1}{2}-\frac{1}{16}\beta^2+\frac{1}{8}\frac{\hat{s}}{M_\Phi^2}\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_9 &= 2\beta+(2+\beta^2)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_{10} &= 2\beta-\frac{7}{3}\beta\frac{\hat{s}}{M_\Phi^2}+\left(3+\frac{5}{4}\beta^2-\frac{1}{2}\frac{\hat{s}}{M_\Phi^2}\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_{11} &= \frac{1}{24}\beta-\frac{59}{48}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{5}{32}\beta\frac{\hat{s}^2}{M_\Phi^4}+\frac{5+\beta^2}{4}\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_{12} &= -\beta-\frac{1}{2}\beta\frac{\hat{s}}{M_\Phi^2}+\left(-\frac{1}{4}-\frac{7}{4}\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_{13} &= \frac{1}{24}\beta+\frac{1}{3}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1}{4}\left(1-\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \\
\widetilde{F}_{14} &= -\frac{1}{16}\beta+\frac{11}{96}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{17}{192}\beta\frac{\hat{s}^2}{M_\Phi^4}+\left(\frac{1}{8}\frac{\hat{s}}{M_\Phi^2}-\frac{3}{4}-\frac{3}{8}\beta^2\right)\log\left\|\frac{1+\beta}{1-\beta}\right\| \qquad (12)
\end{aligned}
$$

Tree–level unitarity:

$$\lambda_A = 0$$

$$\kappa_A^2\left[\left(\kappa_A-\frac{6}{5}\right)^2+\frac{24}{25}\right] = 0. \qquad (13)$$

Since κ_A, λ_A real $\to \kappa_A \equiv \lambda_A \equiv 0$.

V : RESOLVED - DIRECT.

$$F_{18} = 2(5-\beta^2\cos^2\theta) - \frac{\hat{s}}{M_\Phi^2}\frac{11-15\beta^2\cos^2\theta+4\beta^4\cos^4\theta}{4} - \frac{\hat{s}^2}{M_\Phi^4}\frac{(1-\beta^2\cos^2\theta)^2}{4},$$

$$F_{19} = 3-\beta^2\cos^2\theta - \frac{\hat{s}}{M_\Phi^2}\frac{7-8\beta^2\cos^2\theta+\beta^4\cos^4\theta}{4} + \frac{\hat{s}^2}{M_\Phi^4}\frac{11-13\beta^2\cos^2\theta+\beta^4\cos^4\theta+\beta^6\cos^6\theta}{32} + \frac{\hat{s}^3}{M_\Phi^6}\frac{5-7\beta^2\cos^2\theta-\beta^4\cos^4\theta+3\beta^6\cos^6\theta}{128}, \tag{A.1}$$

$$F_{20} = -\frac{3-\beta^2\cos^2\theta}{2} + \frac{\hat{s}}{M_\Phi^2}\frac{(1-\beta^2\cos^2\theta)^2}{8} + \frac{\hat{s}^2}{M_\Phi^4}\frac{11-23\beta^2\cos^2\theta+13\beta^4\cos^4\theta-\beta^6\cos^6\theta}{64}.$$

The functions $\widetilde{F}_i(\hat{s},\beta)$, which describe the different contributions to the integrated cross-section (13), are:

$$\widetilde{F}_0 = \beta\left(\frac{11}{2}-\frac{9}{4}\beta^2+\frac{3}{4}\beta^4\right) - \frac{3}{8}\left(1-\beta^2-\beta^4+\beta^6\right)\ln\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_1 = -4\beta - \frac{3}{4}(1-\beta^2)\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_2 = \frac{1}{16}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{3-\beta^2}{4}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_3 = 3\beta + \frac{1}{8}\beta\frac{\hat{s}}{M_\Phi^2} + \left(2-\frac{3}{2}\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_4 = -\frac{1}{8}\beta\frac{\hat{s}}{M_\Phi^2} + \left(-1+\frac{3}{8}\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_5 = -\frac{1}{96}\beta + \frac{5}{48}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{4-\beta^2}{16}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_6 = -\frac{1}{2}(1-\beta^2)\log\left|\frac{1+\beta}{1-\beta}\right|.$$

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$$\widetilde{F}_7 = \frac{7}{12}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{1}{24}\beta\frac{\hat{s}^2}{M_\Phi^4} - \frac{5+\beta^2}{4}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_8 = -\frac{1}{6}\beta + \frac{1}{4}\beta\frac{\hat{s}}{M_\Phi^2} - \frac{1}{12}\beta\frac{\hat{s}^2}{M_\Phi^4} + \left(-\frac{1}{2}+\frac{1}{2}\frac{\hat{s}}{M_\Phi^2}\right)\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_9 = -\frac{1}{2}\beta + \frac{11}{12}\beta\frac{\hat{s}}{M_\Phi^2} - \frac{1}{6}\beta\frac{\hat{s}^2}{M_\Phi^4} - \frac{3+\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{10} = -\frac{1}{96}\beta + \frac{59}{80}\beta\frac{\hat{s}}{M_\Phi^2} - \frac{113}{320}\beta\frac{\hat{s}^2}{M_\Phi^4} + \frac{43}{960}\beta\frac{\hat{s}^3}{M_\Phi^6} + \left(-\frac{1}{2}-\frac{1}{16}\beta^2+\frac{1}{8}\frac{\hat{s}}{M_\Phi^2}\right)\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{11} = \frac{1}{2}(1+\beta^2)\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{12} = \beta + \frac{1}{2}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{13} = \beta - \frac{5}{12}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{1}{24}\beta\frac{\hat{s}^2}{M_\Phi^4} + \left[-\frac{1}{4}\frac{\hat{s}}{M_\Phi^2} + \left(\frac{3}{8}+\frac{1}{4}\beta^2\right)\right]\log\left|\frac{1+\beta}{1-\beta}\right|, \tag{A.2}$$

$$\widetilde{F}_{14} = -\frac{11}{24}\beta\frac{\hat{s}}{M_\Phi^2} - \frac{1}{24}\beta\frac{\hat{s}^2}{M_\Phi^4} + \frac{9+3\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{15} = \frac{1}{48}\beta - \frac{59}{96}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{5}{64}\beta\frac{\hat{s}^2}{M_\Phi^4} + \frac{5+\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{16} = -\frac{1}{2}\beta - \frac{1}{8}\beta^2\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{17} = -\frac{1}{96}\beta + \frac{1}{48}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{1}{48}\beta\frac{\hat{s}^2}{M_\Phi^4} - \frac{2+\beta^2}{16}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

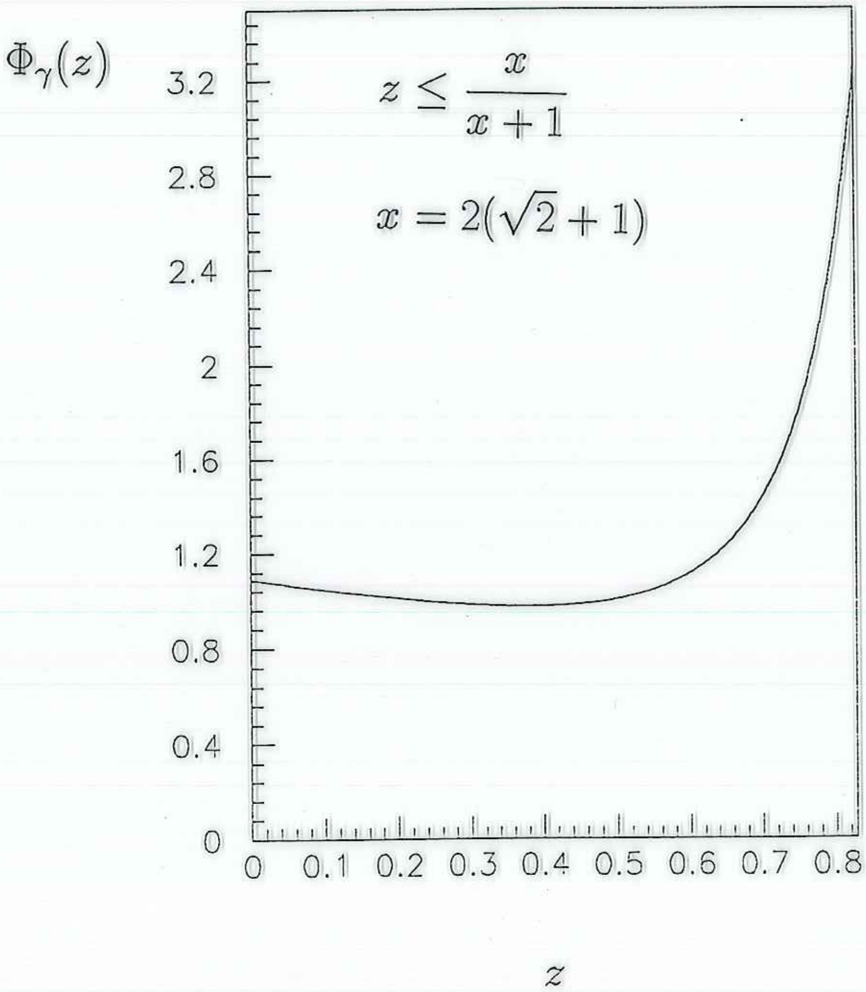
$$\widetilde{F}_{18} = -\frac{1}{4}\beta\frac{\hat{s}}{M_\Phi^2} - \frac{1-6\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{19} = -\frac{1}{24}\beta + \frac{7}{96}\beta\frac{\hat{s}}{M_\Phi^2} + \frac{3}{64}\beta\frac{\hat{s}^2}{M_\Phi^4} + \left[\frac{1}{8}\frac{\hat{s}}{M_\Phi^2} - \frac{2+\beta^2}{4}\right]\log\left|\frac{1+\beta}{1-\beta}\right|,$$

$$\widetilde{F}_{20} = \frac{1}{48}\beta + \frac{1}{6}\beta\frac{\hat{s}}{M_\Phi^2} - \frac{1}{8}(1-\beta^2)\log\left|\frac{1+\beta}{1-\beta}\right|.$$

$$\Phi_\gamma(z) = \frac{1}{N(x)}\left[1 - z + \frac{1}{1-z} - \frac{4z}{x(1-z)} + \frac{4z^2}{x^2(1-z)^2}\right]$$

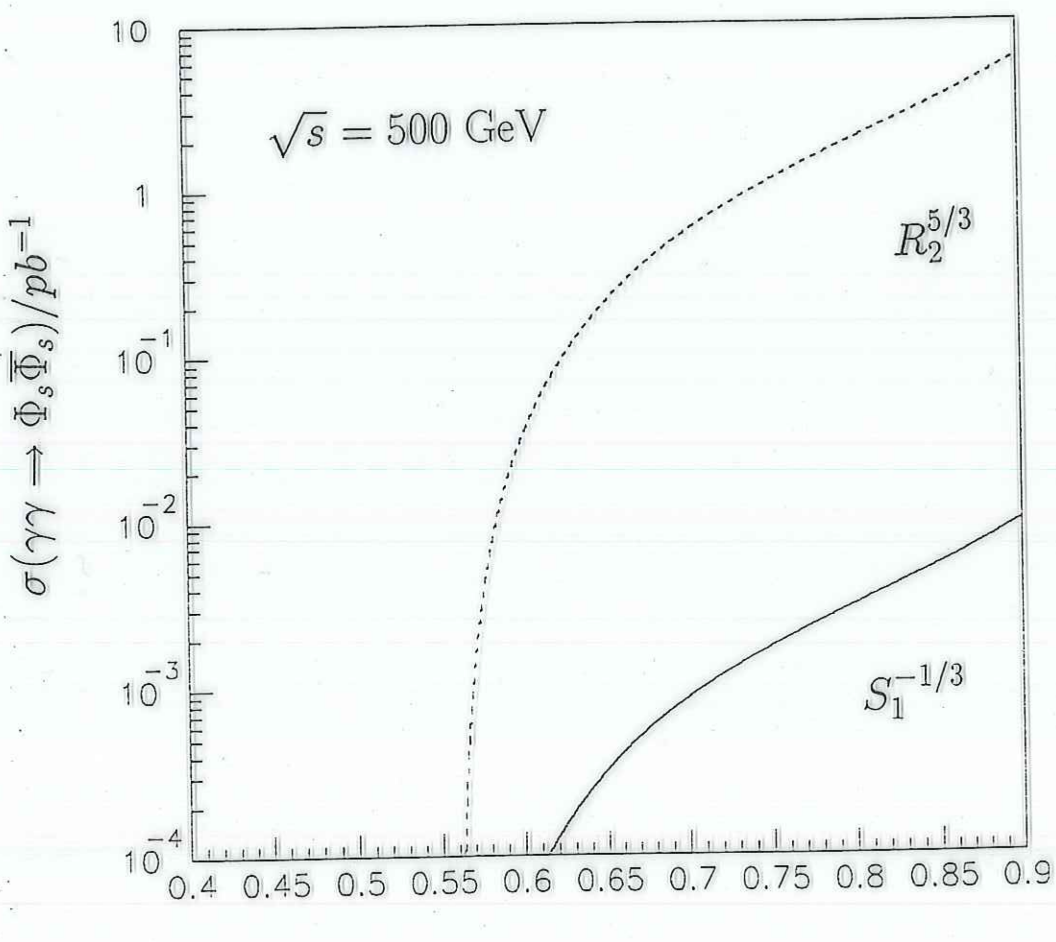
$$N(x) = \frac{16 + 32x + 18x^2 + x^3}{2x(1+x)^2} + \frac{x^2 - 4x - 8}{x^2}\ln(1+x)$$

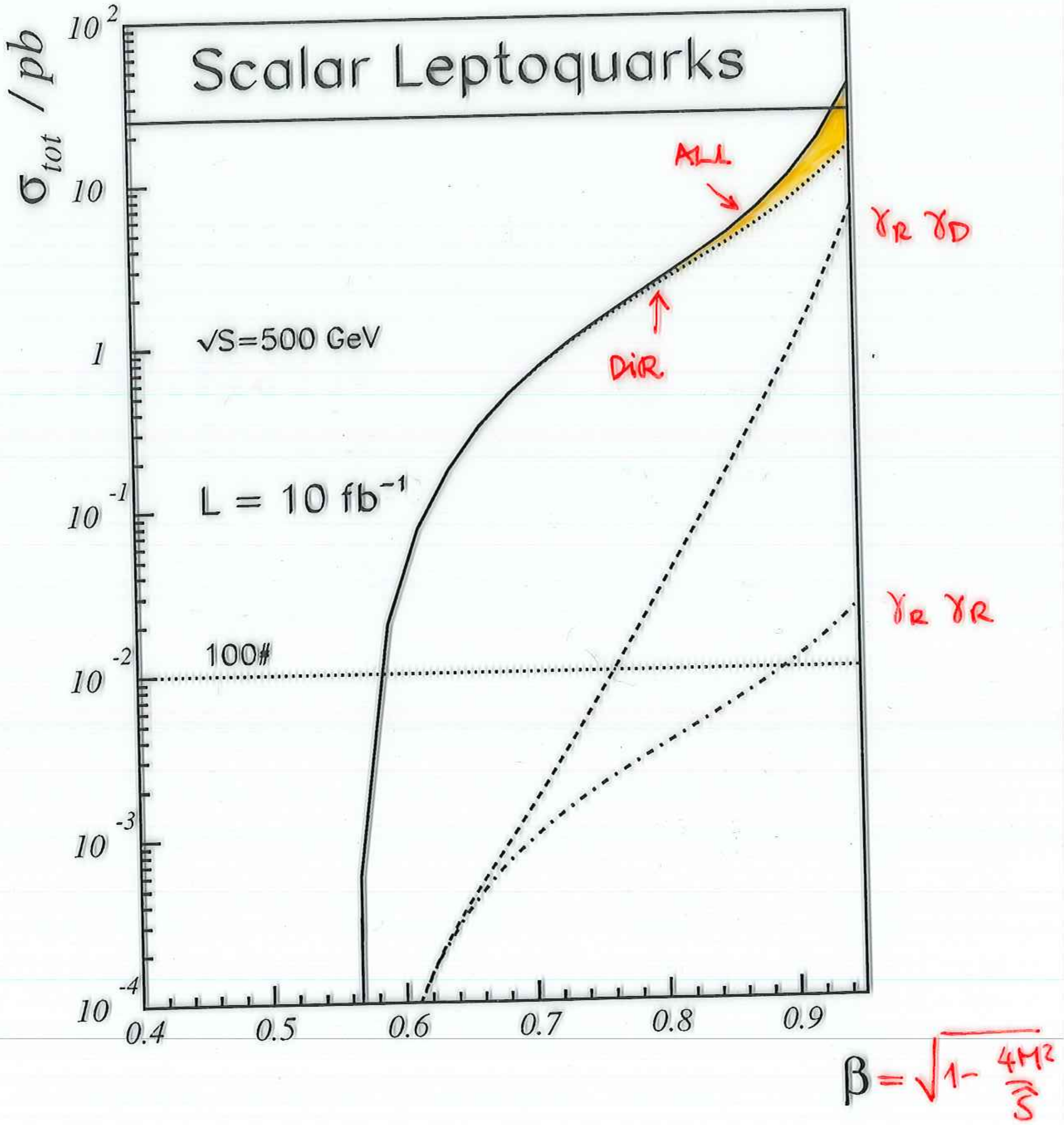


COMPTON -
CONVERSION
SPECTRUM

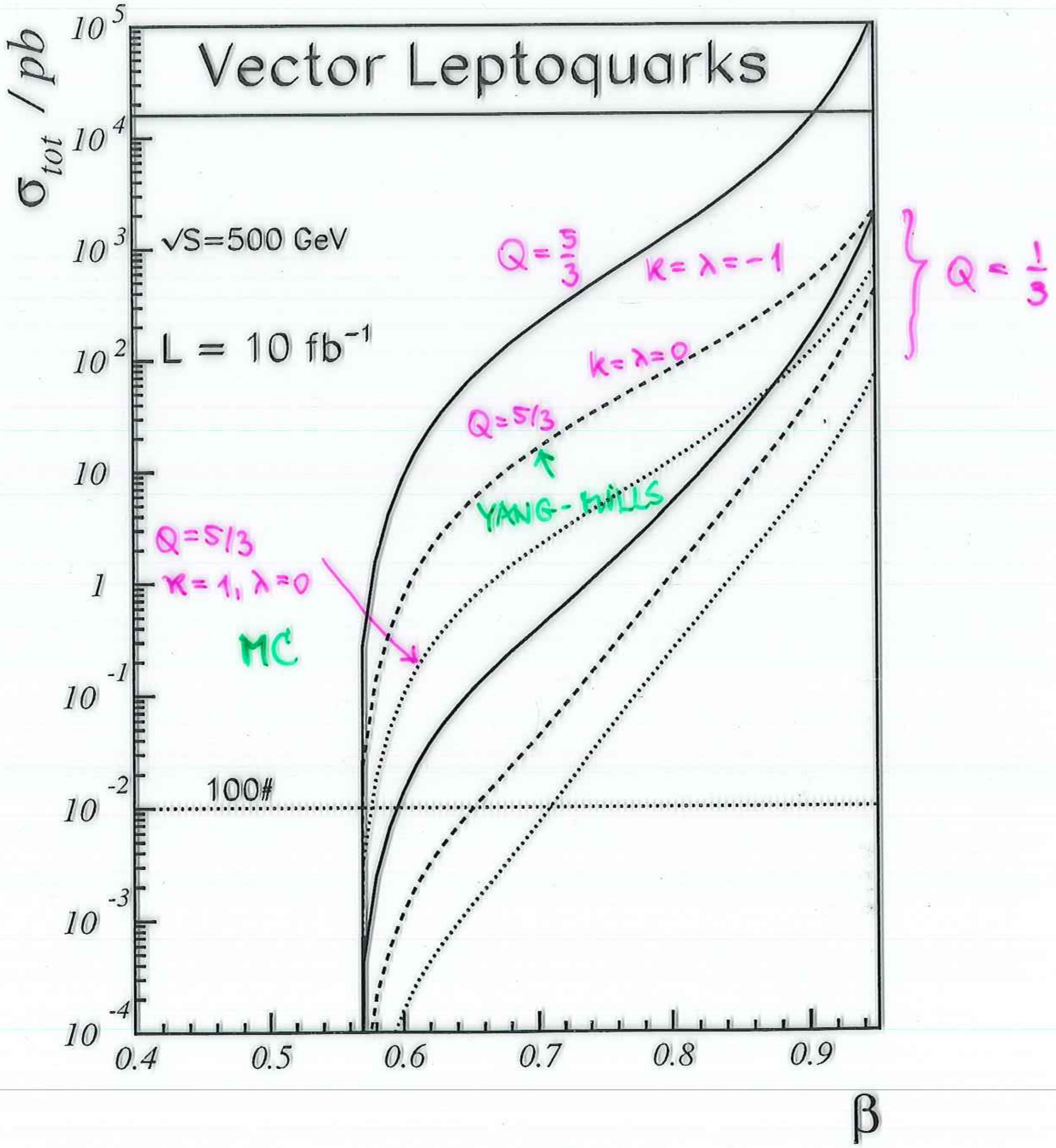
$$\sigma_{scalar}(s) \;=\; \frac{\pi\alpha^2}{s} Q_\Phi^4 \left\{ 2(2-\beta^2)\beta - (1-\beta^4)\ln\left|\frac{1+\beta}{1-\beta}\right| \right\}$$

$$\sigma = \int_0^{z_{max}} dz_1 \int_0^{z_{max}} dz_2 \Phi_\gamma(z_1)\Phi_\gamma(z_2)\hat{\sigma}(\hat{s})\theta\left(\hat{s} - 4M_\Phi^2\right)$$





Scalar Leptoquarks
σ_{tot} / pb
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
ALL
DiR
$\gamma_R \gamma_D$
$\gamma_R \gamma_R$
√S=500 GeV
L = 10 fb^{-1}
100#
0.4
0.5
0.6
0.7
0.8
0.9
$\beta = \sqrt{1 - \frac{4M^2}{\hat{s}}}$


Vector Leptoquarks
√S=500 GeV
L = 10 fb⁻¹
σ_tot /pb
β
100#
Q = 5/3
κ = λ = -1
κ = λ = 0
Q=5/3
YANG-MILLS
Q=5/3
κ = 1, λ = 0
MC
Q = 1/3

BIGI, GABBIANI '91

FADIN, KHOZE '87, '88
BIGI, FADIN, KHOZE '91

PESKIN, STRASSLER '91.

$$d\sigma = d\sigma_B \cdot \frac{K_S(E)}{K_S^{(B)}(E)}$$

$$K_{(B)}(E) = \frac{M_S}{4\pi}\sqrt{M_S E}$$

$$K_S(E) = \frac{M_S^2}{4\pi}\left\{ \frac{k_+}{M_S} + \frac{2K_1}{M_S}\arctan\left(\frac{k_+}{k_-}\right) + \sum_{n=1}^{\infty}\frac{2k_1^2}{M_S^2 n^4}\,\frac{\Gamma_S k_1 \cdot n + K_+\left[n^2\sqrt{E^2+\Gamma_S^2} + \frac{k_1^2}{M_S}\right]}{\left[E + (k_1^2/M_S^2 n^2\right]^2 + \Gamma_S^2}\right\}$$

$$k_1 = \frac{2}{3}\alpha_S \cdot M_S$$

$$K_\pm = \sqrt{\frac{M_S}{2}\left[\sqrt{E^2+\Gamma_S^2} \pm E\right]}$$

we assumed:

$E = W - 2M_S$, $\Gamma_S \simeq 1\,\mathrm{GeV}$, $\alpha_S = \alpha_S(M_S^2)$ fixed

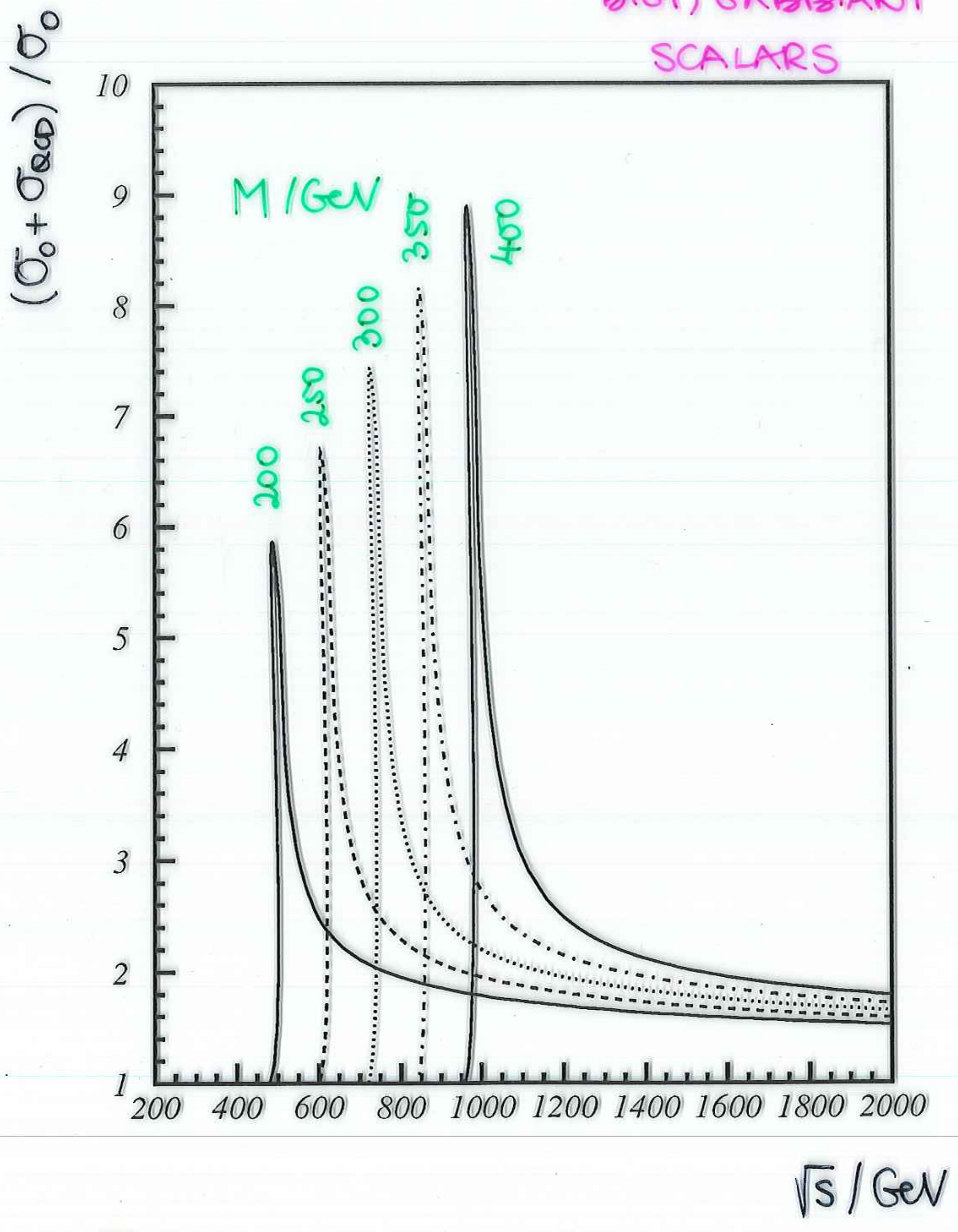
(hadronic width of S's)

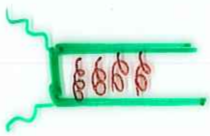
3. QCD CORRECTIONS

(LIT: BIGI, FADIN, KHOZE)

BIGI, GABBIANI '91

SCALARS





↳ LEPTOQUARKONIUM ?

(JB '93)

Formation of Bound States ?

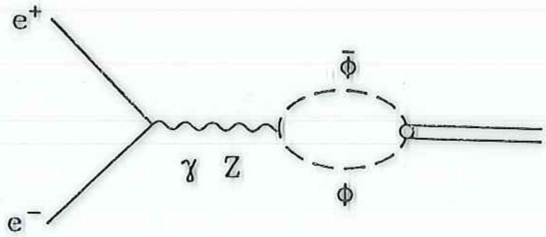
'Leptoquarkonia'

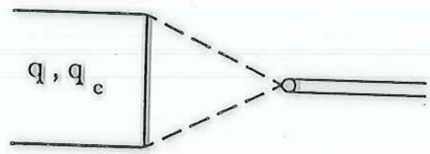
JB '93

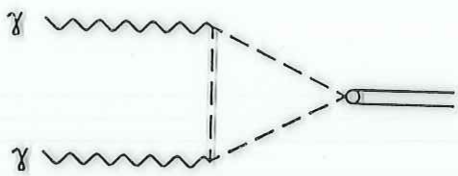
BOWSER-CHAO et al '98

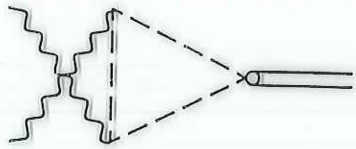
KISELEV '98

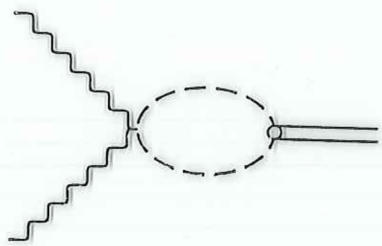
$$\beta \ll 1$$







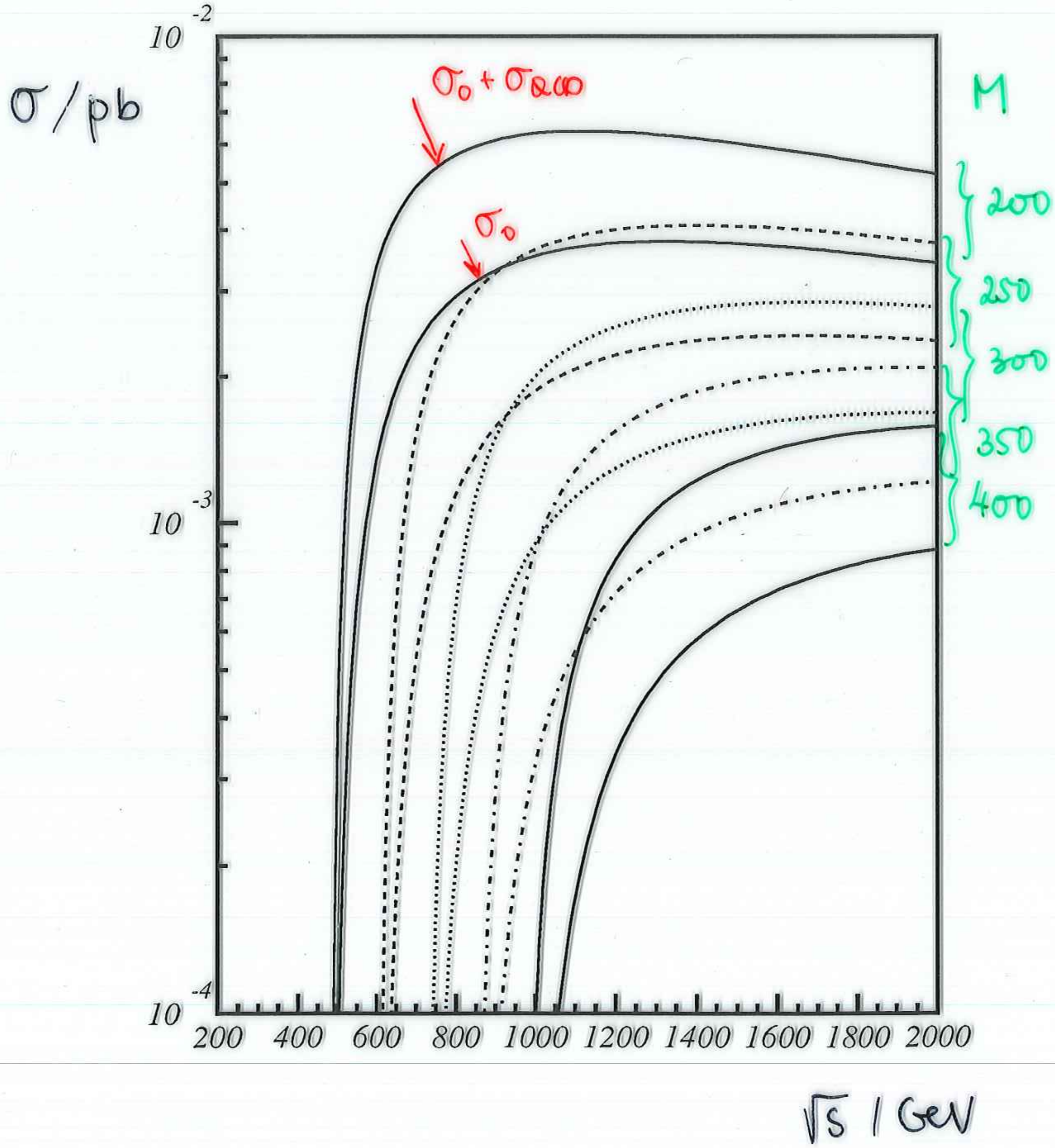




$$\begin{aligned}
\sigma(e^+e^- \to \Phi_s\overline{\Phi}_s) &\propto \beta^3 \\
\sigma(e^+e^- \to \Phi_v\overline{\Phi}_v) &\propto \beta^3 \\
\sigma(\gamma\gamma \to \Phi_s\overline{\Phi}_s) &\propto \beta \\
\sigma(\gamma\gamma \to \Phi_v\overline{\Phi}_v) &\propto \beta
\end{aligned} \tag{14}$$

pre ferred !

$$\Gamma_\Phi \sim \lambda_{eq}^2 M_\Phi \lesssim 100 \text{ MeV}$$



- IMPORTANT THRESHOLD FACTOR!
- COULOMB-SINGULARITY

Conclusions

1. $\sigma_{S,V}(\gamma\gamma \rightarrow \Phi\overline{\Phi}) \propto Q_{\Phi}^{4}$
2. Background free window to measure κ_A, λ_A iff vector LQ's exist (then found by LHC before)
3. Strong threshold enhancement $O(5)$
4. Lepoquarkonia iff $\Gamma_{\Phi} \sim 100\,\mathrm{MeV}$
5. Final state corrections are mandatory.