Leptoquark signal from global analysis

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Outline

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- Leptoquark models
- Global analysis
- Leptoquark limits
- Summary

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Introduction

New determination of APV in cesium

Parity non-conservation in cesium atoms caused by exchange of the Z° boson between atomic electrons and quarks in the nucleus.

New data and improved theoretical calculations (1999):

$$\Delta Q_W^{Cs} \equiv Q_W^{meas} - Q_W^{SM} = 1.13 \pm 0.46$$

$$\text{previously :} \quad 0.71 \pm 0.84$$

⇒ 2.5 σ deviation from the Standard Model

Unitarity of the CKM matrix

The Review of Particle Physics, 2000 edition, Euro. Phys. J. C15, 1.

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9959 \pm 0.0019$$

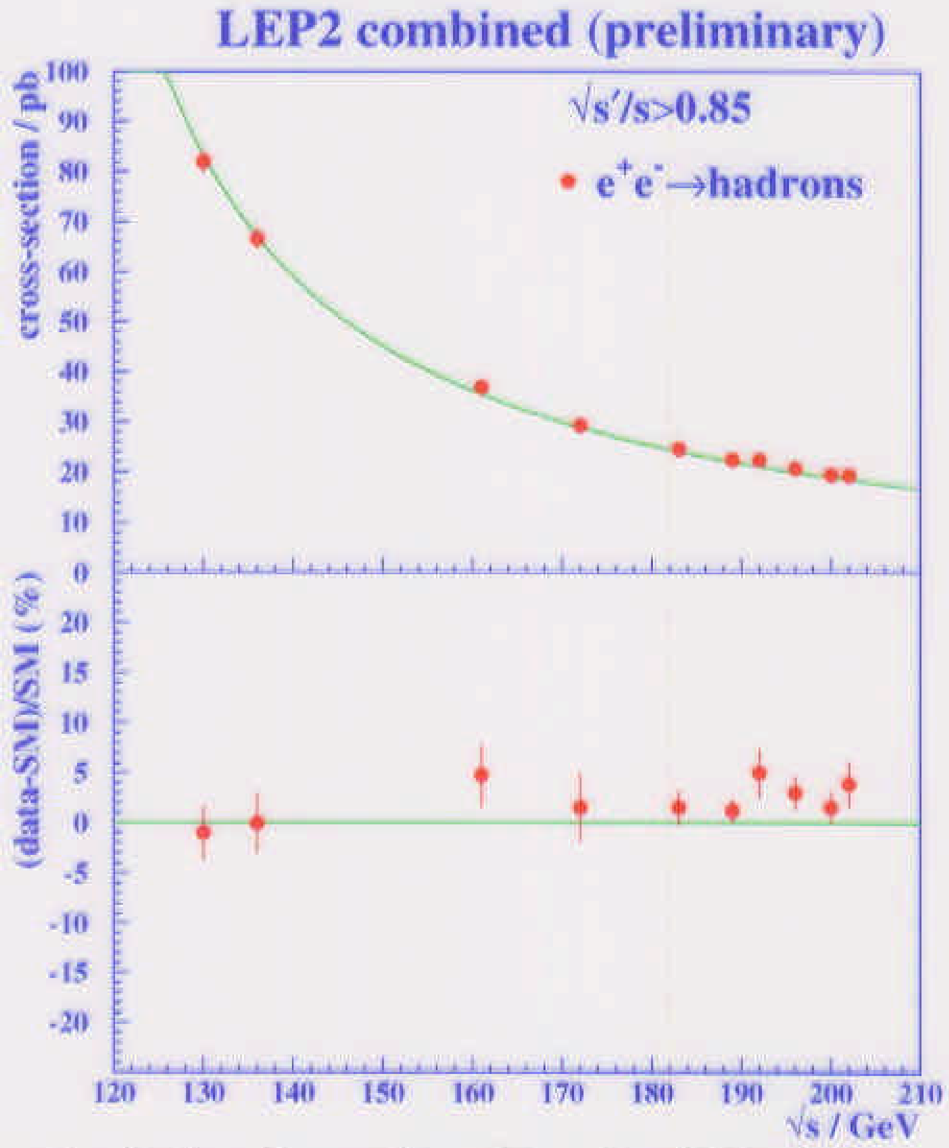
$$\text{previously :} \quad 0.9969 \pm 0.0022$$

⇒ 2.2 σ deviation from the Standard Model

Introduction

New results from LEP2

Hadronic cross-section measurements presented in Moriond



⇒ 2.3 σ deviation from the Standard Model

Possible sign for "new physics" ???

Leptoquark Models

Consider leptoquark states described by
the Buchmüller-Rückl-Wyler (BRW) effective model

BRW model

First-generation leptoquarks:

- respect $SU(3)_C \times SU(2)_L \times U(1)_Y$ symmetry of the Standard Model
- only family diagonal couplings
  (to avoid FCNC processes)
- couplings conserve lepton and baryon numbers
  (to avoid rapid proton decay)
- couple either to left- or right-handed leptons
  (very strong bounds from rare decays)

$\Rightarrow$ 14 possible states (7 scalar and 7 vector)

(6 isospin singlets, 6 doublets and 2 triplets)

Additional (simplifying) assumptions:

- different states within isospin multiplets have the same mass
- only one of the leptoquark types contribute

Leptoquark Models

Aachen notation

Model	Fermion number F	Charge Q	$BR(LQ \to e^{\pm}q)$ β	Coupling		Squark type
$S_\circ^L$	2	$-1/3$	1/2	$e_L u$	νd	$\tilde{d}_R$
$S_\circ^R$	2	$-1/3$	1	$e_R u$		
$\tilde{S}_\circ$	2	$-4/3$	1	$e_R d$		
$S_{1/2}^L$	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	0		$\nu \bar{u}$	
$S_{1/2}^R$	0	$-5/3$	1	$e_R \bar{u}$		
		$-2/3$	1	$e_R \bar{d}$		
$\tilde{S}_{1/2}$	0	$-2/3$	1	$e_L \bar{d}$		$\bar{\tilde{u}}_L$
		$+1/3$	0		$\nu \bar{d}$	$\bar{\tilde{d}}_L$
S_1	2	$-4/3$	1	$e_L d$		
		$-1/3$	1/2	$e_L u$	νd	
		$+2/3$	0		νd	
$V_\circ^L$	0	$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
$V_\circ^R$	0	$-2/3$	1	$e_R \bar{d}$		
$\tilde{V}_\circ$	0	$-5/3$	1	$e_R \bar{u}$		
$V_{1/2}^L$	2	$-4/3$	1	$e_L d$		
		$-1/3$	0		νd	
$V_{1/2}^R$	2	$-4/3$	1	$e_R d$		
		$-1/3$	1	$e_R u$		
$\tilde{V}_{1/2}$	2	$-1/3$	1	$e_L u$		
		$+2/3$	0		νu	
V_1	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
		$+1/3$	0		$\nu \bar{d}$	

Leptoquark Models

CI limit

In the limit $M_{LQ} \gg \sqrt{s}$ leptoquark production or exchange is described by effective vector $eeqq$ contact interactions:

$$\mathcal{L}_{CI} = \sum_{\substack{\alpha,\beta=L,R \\ q=u,d}} \eta^{eq}_{\alpha\beta} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$

⇒ Contribution to the scattering amplitude: $\eta^{eq}_{ij} \sim \left(\frac{\lambda_{LQ}}{M_{LQ}}\right)^2$.

Mass effects

Contribution to the scattering amplitude for $M_{LQ} \sim \sqrt{s}$:

⇒ for u-channel exchange:

$$\eta^{eq}_{\alpha\beta} \sim \frac{\lambda^2_{LQ}}{M^2_{LQ} - \hat{u}}$$

LEP, HERA, Tevatron

⇒ for t-channel exchange:

$$\eta^{eq}_{\alpha\beta} \sim \frac{\lambda^2_{LQ}}{M^2_{LQ} - \hat{t}}$$

LEP, Tevatron

⇒ for s-channel production:

$$\eta^{eq}_{\alpha\beta} \sim \frac{\lambda^2_{LQ}}{M^2_{LQ} - \hat{s} - i\hat{s}\frac{\Gamma_{LQ}}{M_{LQ}}}$$

HERA

Global analysis

High energy data

- LEP2 results
  - ⇒ quark-pair production cross-section $\sigma(e^+e^- \to q\bar{q})$
    sensitive to all leptoquark states
  - ⇒ forward-backward asymmetries A^b_{FB}, A^c_{FB}, A^{uds}_{FB}
  - ⇒ heavy quark production ratios R_b, R_c
    little sensitive to first-generation leptoquarks
- HERA $\frac{d\sigma}{dQ^2}$ results
  - ⇒ NC e^+p DIS data 1994-97
    most sensitive to $F = 0$ leptoquarks
  - ⇒ NC e^-p DIS data 1998-99
    most sensitive to $F = 2$ leptoquarks
  - ⇒ CC $e^{\pm}p$ DIS data 1994-99
    sensitive to $S^L_\circ$, S_1, $V^L_\circ$, V_1
- Tevatron results
  - ⇒ data on high-mass Drell-Yan electron pair production
    sensitive to all first-generation leptoquarks
  - ⇒ direct search results for first-generation leptoquarks
    $M_{LQ} > 242$ GeV for scalar LQ (CDF+D∅)
    $M_{LQ} > 245$ GeV for vector LQ (D∅)

Global analysis

Low energy data

- Atomic Parity Violation experiments

$$\Delta Q_w(Cs) = 1.13 \pm 0.46$$
$$\Delta Q_w(Tl) = 1.9 \pm 3.6$$
$$\text{CI}: \quad \Delta Q_w \sim \sum_{q=u,d} \sum_{\beta} (\eta^{eq}_{L\beta} - \eta^{eq}_{R\beta})$$

- Unitarity of the Cabibbo-Kobayashi-Maskawa matrix

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9959 \pm 0.0019$$
$$\text{CI}: \quad V_{ud} = V^{SM}_{du} \cdot \left(1 - \frac{\eta^{ed}_{LL} - \eta^{eu}_{LL}}{4\sqrt{2}G_F}\right)$$

- electron-muon universality

$$R = \frac{\Gamma(\pi^- \to e\bar{\nu})}{\Gamma(\pi^- \to \mu\bar{\nu})} = 0.9966 \pm 0.030 \, R_{SM}$$
$$\text{CI}: \quad \frac{R_{meas}}{R_{SM}} = \left(1 - \frac{\eta^{ed}_{LL} - \eta^{eu}_{LL}}{4\sqrt{2}G_F}\right)^2$$

- Polarization Asymmetry in low energy scattering
  results from eD, eBe, eC and $\mu^{\pm}C$ scattering
  direct measurement of the parity non-conservation

- neutrino-nucleus scattering
  constraints derived from the precise measurement of

$$R^{\nu} = \frac{\sigma^{\nu N}_{NC}}{\sigma^{\nu N}_{CC}}$$

Global analysis

Method

Consider global probability function:

$$\mathcal{P}(\vec{\eta}) = \prod_i P_i(\vec{\eta})$$

where the product runs over all experimental data points i.

For low-energy experiments and LEP data:
Gaussian probability distribution is used for $P_i(\vec{\eta})$.

For HERA high-Q^2 and Tevatron results:
Poisson distribution for the observed number of events.

Probability function is normalized to the Standard Model probability:

$$\mathcal{P}(0) \equiv \mathcal{P}_{SM} = 1$$

Maximum probability value $\mathcal{P}_{max}$ is found using MINUIT

Limit setting

- 95% CL **exclusion** limits:

$$\begin{aligned} \mathcal{P}(\vec{\eta}) &< 0.05 \cdot \mathcal{P}_{SM} \\ \text{or} \quad \ln \mathcal{P}(\vec{\eta}) &< -3.0 \end{aligned}$$

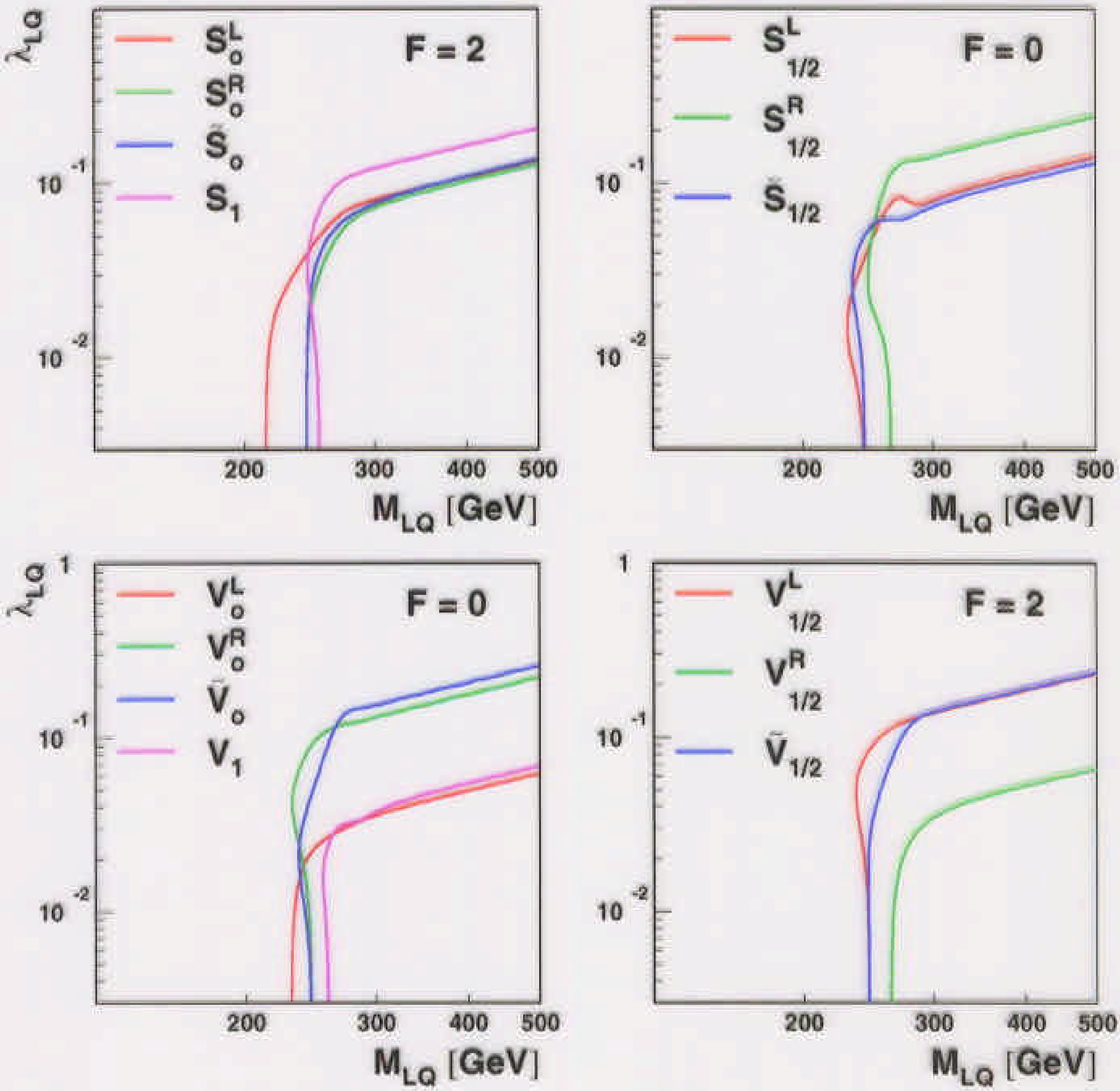
For $\mathcal{P}_{max} \gg 1$:

- 95% CL **signal** limits:

$$\begin{aligned} \mathcal{P}(\vec{\eta}) &> 0.05 \cdot \mathcal{P}_{max} \\ \text{or} \quad \ln \mathcal{P}(\vec{\eta}) &< \ln \mathcal{P}_{max} - 3.0 \end{aligned}$$

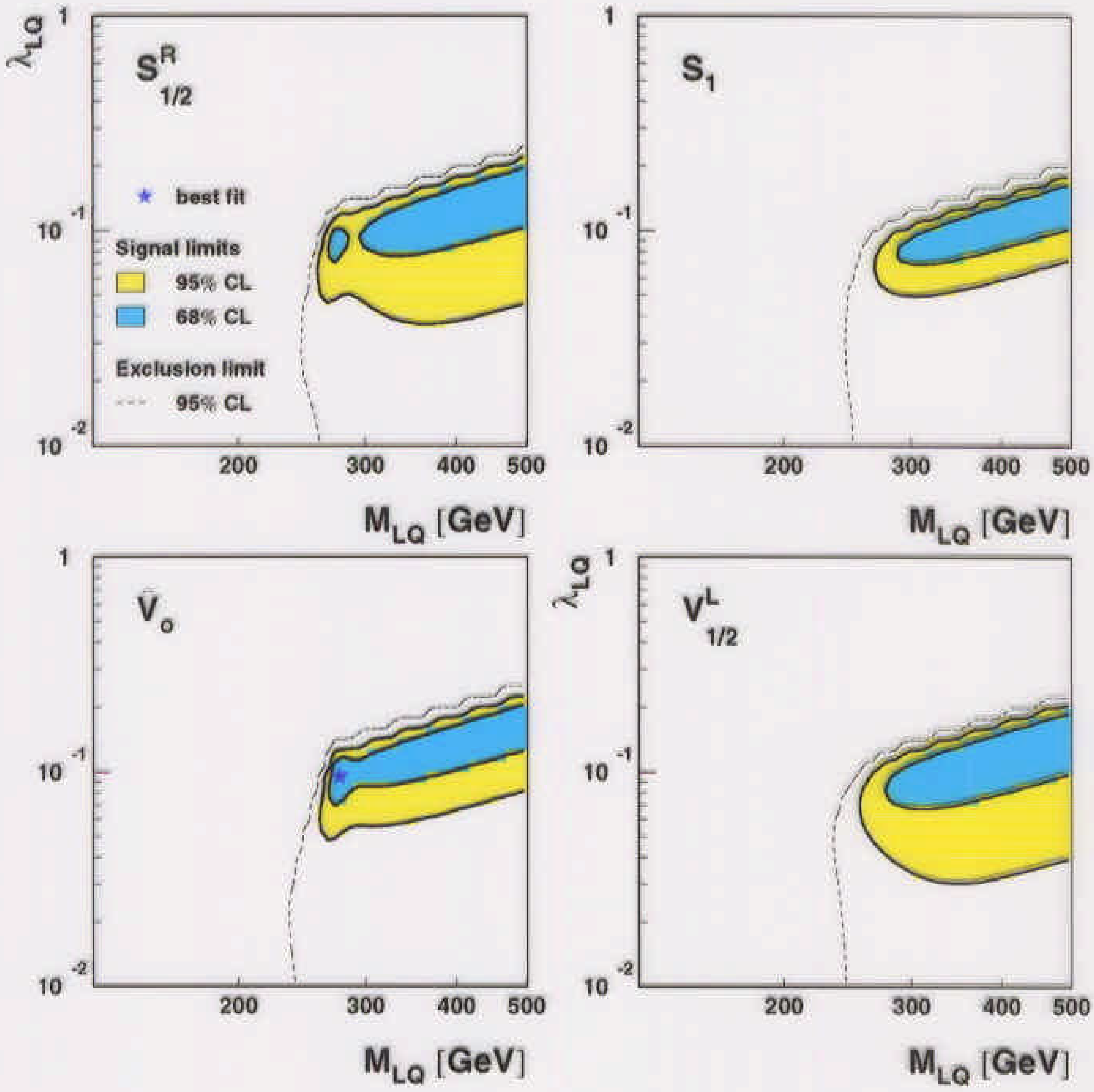
Leptoquark limits

Exclusion limits



Leptoquark limits

Signal limits



Leptoquark limits

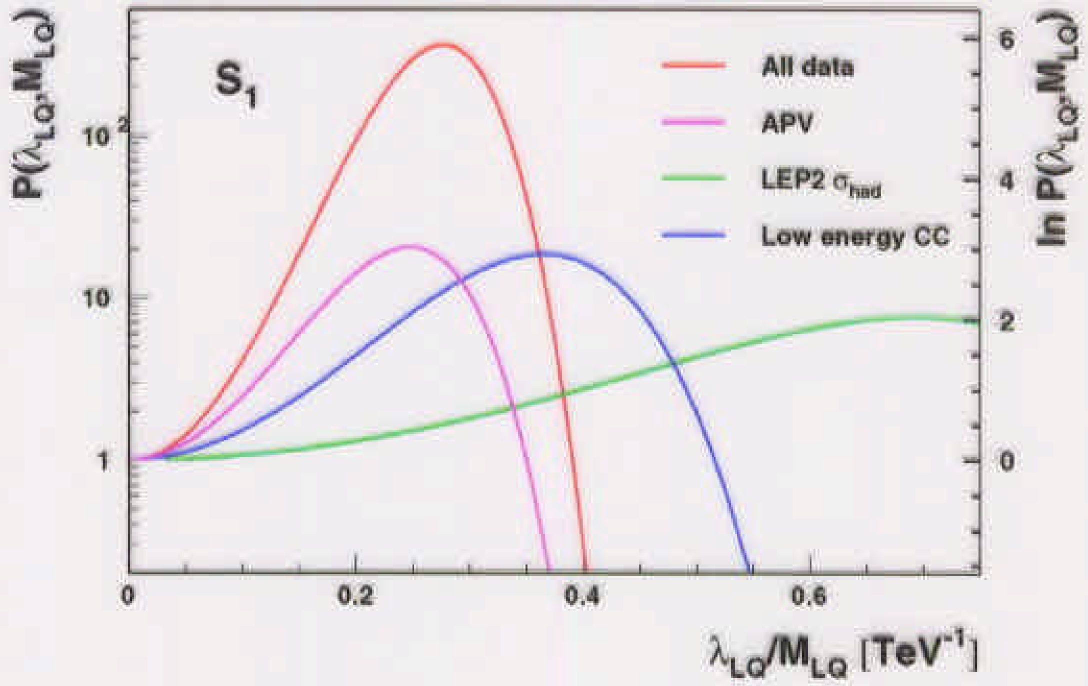
Summary of results

	95% CL excl. limits		best description		95% CL signal limits	
Model	$\frac{\lambda_{LQ}}{M_{LQ}}$ [TeV^{-1}]	M_{LQ} [GeV]	$\left(\frac{\lambda_{LQ}}{M_{LQ}}\right)_{max}$ [TeV^{-1}]	$\mathcal{P}_{max}$	$\frac{\lambda_{LQ}}{M_{LQ}}$ [TeV^{-1}]	M_{LQ} [GeV]
$S_\circ^L$	0.27	213				
$S_\circ^R$	0.25	242				
$\tilde{S}_\circ$	0.28	242				
$S_{1/2}^L$	0.29	229				
$S_{1/2}^R$	0.49	245	0.32 ± 0.06	35.8	0.09–0.44	258
$\tilde{S}_{1/2}$	0.26	233				
S_1	0.41	245	0.28 ± 0.04	367.	0.15–0.36	267
$V_\circ^L$	0.12	230				
$V_\circ^R$	0.44	231	0.28 ± 0.07	11.7		
$\tilde{V}_\circ$	0.52	235	0.34 ± 0.06	122.	0.16–0.46	259
$V_{1/2}^L$	0.47	235	0.30 ± 0.06	31.7	0.08–0.42	254
$V_{1/2}^R$	0.13	262				
$\tilde{V}_{1/2}$	0.47	244	0.30 ± 0.07	14.8		
V_1	0.14	254				

Leptoquark limits

Possible S_1 signal

Contributions to the probability function, $M_{LQ} \gg \sqrt{s}$



Maximum probability $\mathcal{P}_{max}$ = 367. (ln $\mathcal{P}_{max}$ = 5.9)

corresponds to 3.4 σ deviation from the Standard Model:

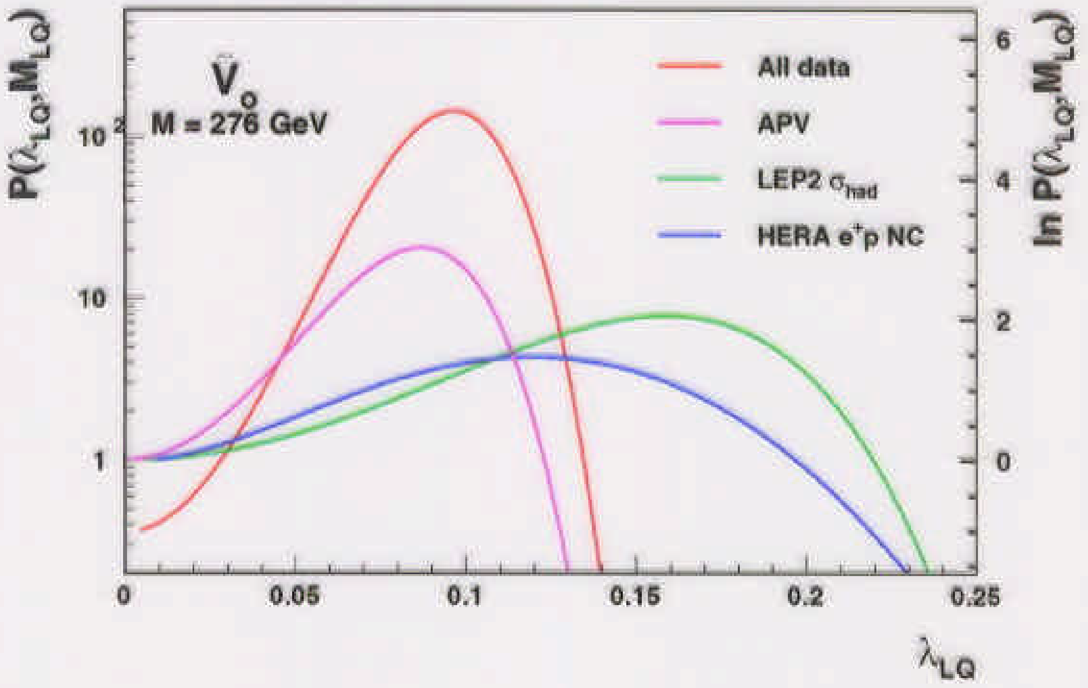
- ⇒ APV measurement: P = 19.5 2.4 σ
- ⇒ LEP σ_{had}: P = 1.7 1.0 σ
- ⇒ Low energy CC (CKM and e/μ): P = 10.9 2.2 σ

$$\lambda/M = 0.28 \pm 0.04 \,\text{TeV}^{-1}$$

Leptoquark limits

Possible $\tilde{V}_\circ$ signal

Contributions to the probability function, $M_{LQ} = 276$ GeV



Maximum probability $\mathcal{P}_{max}$ = 142. (ln $\mathcal{P}_{max}$ = 5.0)

corresponds to 3.1 σ deviation from the Standard Model:

- ⇒ APV measurement: P = 20.1 2.4 σ
- ⇒ LEP σ_{had}: P = 3.3 1.5 σ
- ⇒ HERA NC e^+p DIS: P = 3.9 1.7 σ
- ⇒ Tevatron direct search: P = 0.36

M = 276 ± 7 GeV λ = 0.095 ± 0.015

Summary

- Some recent data indicate possible deviations from the Standard Model predictions...
- Data from HERA, LEP, Tevatron and low energy experiments were combined in search for first-generation leptoquarks.
- Possible signal for "new physics" observed for:
  - ⇒ d_{LL} contact interaction model
    $\Lambda = 13.2 \pm 1.8$ TeV
  - ⇒ S_1 leptoquark model
    $\lambda/M = 0.28 \pm 0.04$ TeV^{-1}
  - ⇒ $\tilde{V}_\circ$ leptoquark model
    $M = 276 \pm 7$ GeV
    $\lambda = 0.095 \pm 0.015$
- Leptoquark "signal" region accessible in many future experiments (Tevatron, LHC, TESLA/NLC, THERA...)

More details:

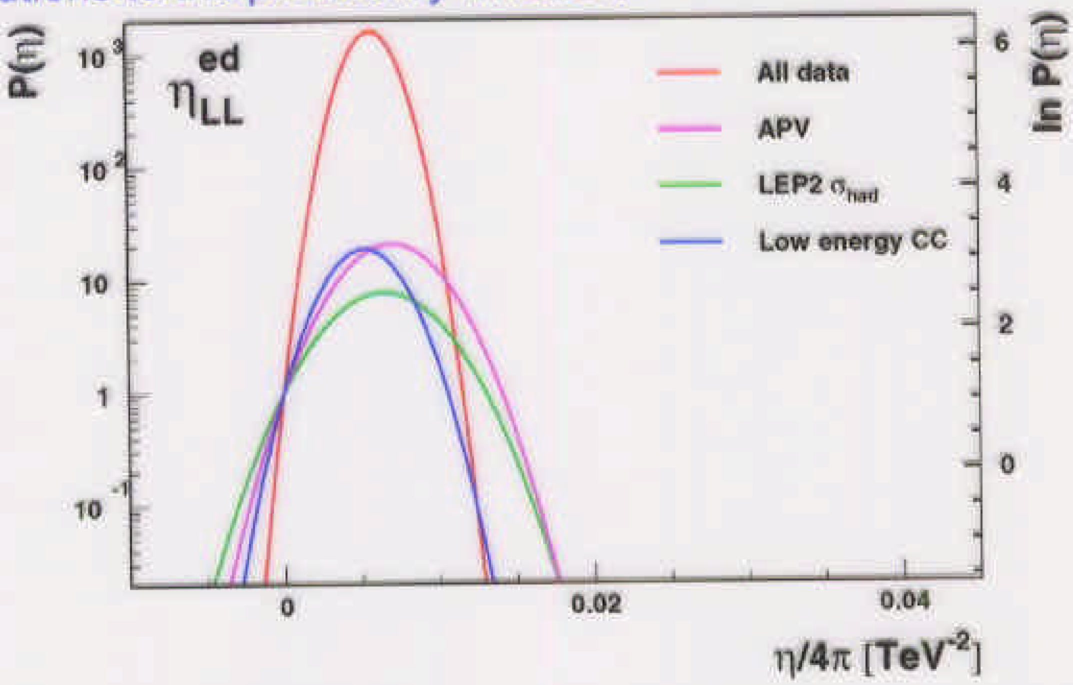
Global CI analysis	• hep-ph/9904334 Euro.Phys.J. C11 (1999) 539
Leptoquark analysis	• hep-ph/0003271
Updated CI results	• hep-ph/0006196
LQ in future experiments	• hep-ph/0006335

Global Analysis

Possible CI signal

Best description of all data –
model with $e_L d_L$ contact interaction

Contributions to the probability function:



Maximum probability $\mathcal{P}_{max}$ = 1570. (ln $\mathcal{P}_{max}$ = 7.4)

corresponds to 3.8 σ deviation from the Standard Model:

- ⇒ APV measurement: P = 21.1 2.5 σ
- ⇒ LEP σ_{had}: P = 7.4 2.0 σ
- ⇒ Low energy CC (CKM and e/μ): P = 18.1 2.4 σ

Contact Interaction mass scale: $\eta = \frac{4\pi}{\Lambda^2}$

$$\Lambda_{LL}^{ed} = 13.2 \pm 1.8 \text{ TeV}$$

Searches at Future Colliders

hep-ph/0006335