Search for Single Leptoquark Production in Electron-Photon Scattering at $\sqrt{s} = 161$ and 172 GeV

PHOTON '97, Egmond aan Zee

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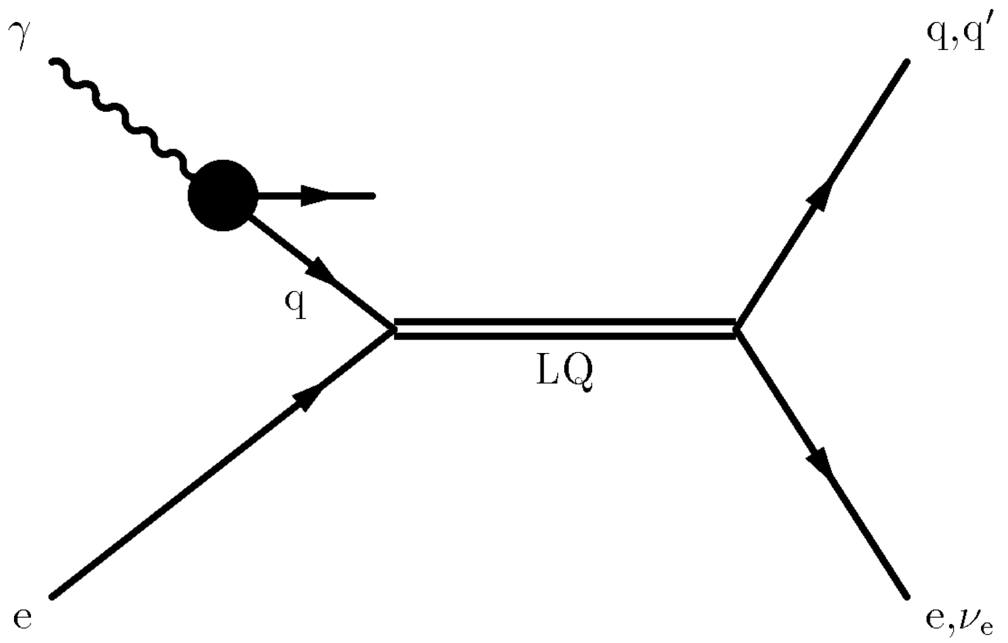
for the -Collaboration

- Introduction
- The electron plus hadronic jet channel
- The neutrino plus hadronic jet channel
- Mass limit for a scalar leptoquark
- Conclusion

Introduction

- Some theories beyond the SM predict Leptoquarks
- Leptoquarks carry baryon and lepton numbers

Electron-Photon-Scattering at LEP:



$$\sigma(e^+e^- \to \mathrm{LQ} + \mathrm{X}) = \frac{\lambda^2\pi}{2s}\int_{M^2/s}^{1}\frac{dz}{z} f_{\gamma/e}(z) f_{q/\gamma}\left(\frac{M^2}{zs}, M^2\right)$$

$f_{\gamma/e}(z)$	Weizsäcker-Williams photon flux
$f_{q/\gamma}(\frac{M^2}{zs}, M^2)$	parton distribution function
λ, M	Yukawa coupling, LQ mass

J. Kalinowski, R. Rückl, H. Spiesberger, P. M. Zerwas, hep-ph/9703288:

LQ	Q	Decay Mode	BR $e^{\pm} j$	Coupling	Limits Ref. [11, 12]	HERA estimates	$e_i^- e^+ \to q_k \bar{q}$ ik
S_0 ($\tilde{d}_R$)	$-1/3$	$e_L u$	$\frac{1}{2}$	g_L	$g_L < 0.06$	0.40	LL
		$\nu_L d$		$-g_L$			–
		$e_R u$	1	g_R	$g_R < 0.1$	0.28	RR
$\tilde{S}_0$	$-4/3$	$e_R d$	1	g_R	$g_R < 0.1$	0.30	RR
S_1	$+2/3$	$\nu_L u$	0	$\sqrt{2} g_L$	$g_L < 0.09$	–	–
	$-1/3$	$\nu_L d$	$\frac{1}{2}$	$-g_L$		0.40	–
		$e_L u$		$-g_L$			LL
	$-4/3$	$e_L d$	1	$-\sqrt{2} g_L$		0.21	LL
$V_{1/2}$	$-1/3$	$\nu_L d$	0	g_L	$g_L < 0.09$	–	–
		$e_R u$	1	g_R		0.30	RL
	$-4/3$	$e_L d$	1	g_L	$g_R < 0.05$	0.32	LR
		$e_R d$		g_R		0.32	RL
$\tilde{V}_{1/2}$	$+2/3$	$\nu_L u$	0	g_L	$g_L < 0.09$	–	–
	$-1/3$	$e_L u$	1	g_L		0.32	LR
$S_{1/2}$	$-2/3$	$\nu_L \bar{u}$	0	g_L	$g_L < 0.1$	–	–
		$e_R \bar{d}$	1	$-g_R$		0.052	RL
	$-5/3$	$e_L \bar{u}$	1	g_L	$g_R < 0.09$	0.026	LR
		$e_R \bar{u}$		g_R		0.026	RL
$\tilde{S}_{1/2}$ * ($\tilde{\bar{d}}_L$)	$+1/3$	$\nu_L \bar{d}$	0	g_L	$g_L < 0.1$	–	–
($\tilde{\bar{u}}_L$)	$-2/3$	$e_L \bar{d}$	1	g_L		0.052	LR
V_0	$-2/3$	$e_L \bar{d}$	$\frac{1}{2}$	g_L	$g_L < 0.05$	0.080	LL
		$\nu_L \bar{u}$		g_L			–
		$e_R \bar{d}$	1	g_R	$g_R < 0.09$	0.056	RR
$\tilde{V}_0$	$-5/3$	$e_R \bar{u}$	1	g_R	$g_R < 0.09$	0.027	RR
V_1	$+1/3$	$\nu_L \bar{d}$	0	$\sqrt{2} g_L$	$g_L < 0.04$	–	–
	$-2/3$	$e_L \bar{d}$	$\frac{1}{2}$	$-g_L$		0.080	LL
		$\nu_L \bar{u}$		g_L			–
	$-5/3$	$e_L \bar{u}$	1	$\sqrt{2} g_L$		0.019	LL

Also sensitive to R-parity violating squarks

Published limits

First generation scalar leptoquarks:

- ep scattering (single production)

  H1: $M > 275$ GeV and ZEUS: $M > 168$ GeV

  for Yukawa coupling $\lambda > \sqrt{4\pi\alpha_{\rm em}}$

  Limits assume a 50 % branching of the LQ into eq

  and ν_eq final states $(\beta = 0.5)$

- $\bar{\rm p}$p scattering (pair production)

  CDF: $M > 80$ GeV and D0: $M > 116$ GeV

  for $\beta = 0.5$

- e$^+$e$^-$ scattering (single production)

  DELPHI: $M > 65$ GeV

  single production in Z^0 $\rightarrow$ LQ $+$ e $+$ jet

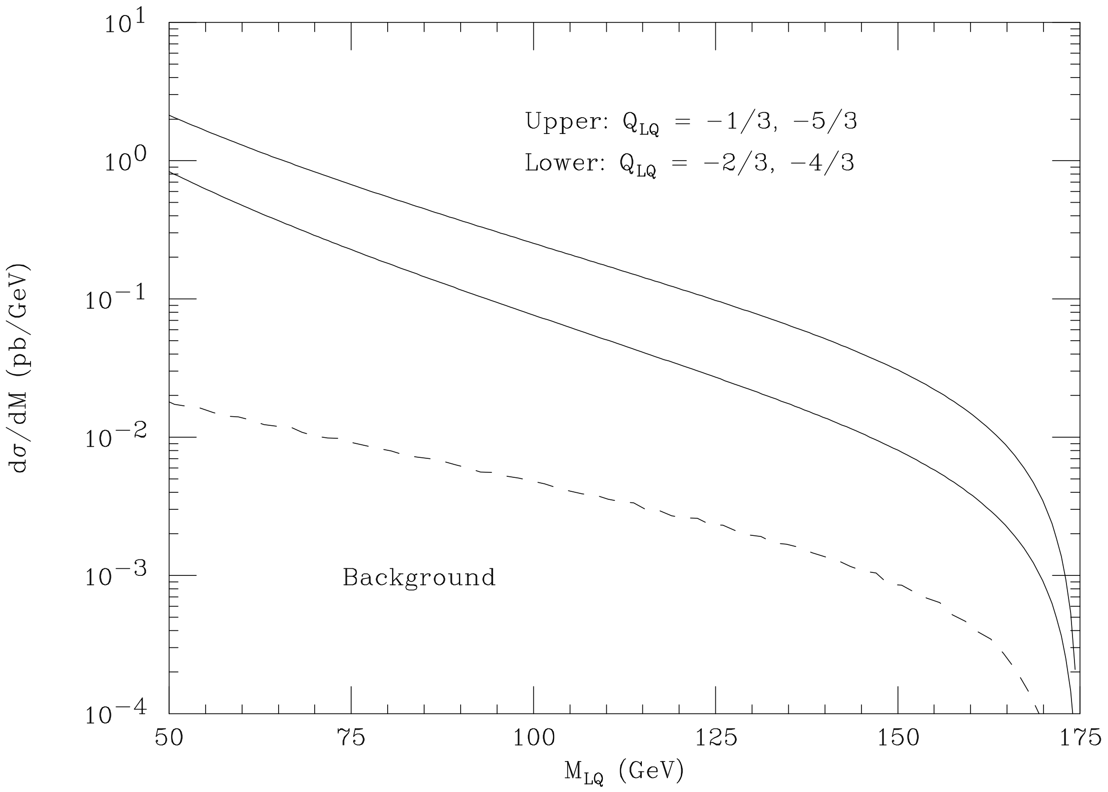
  for $\beta = 2/3$

- e$^+$e$^-$ scattering (pair production)

  All LEP collaborations at $M \approx M_Z/2$

M. A. Doncheski and S. Godfrey

Phys. Lett. B393 (1997) 355 ($\sqrt{s} = 175$ GeV)



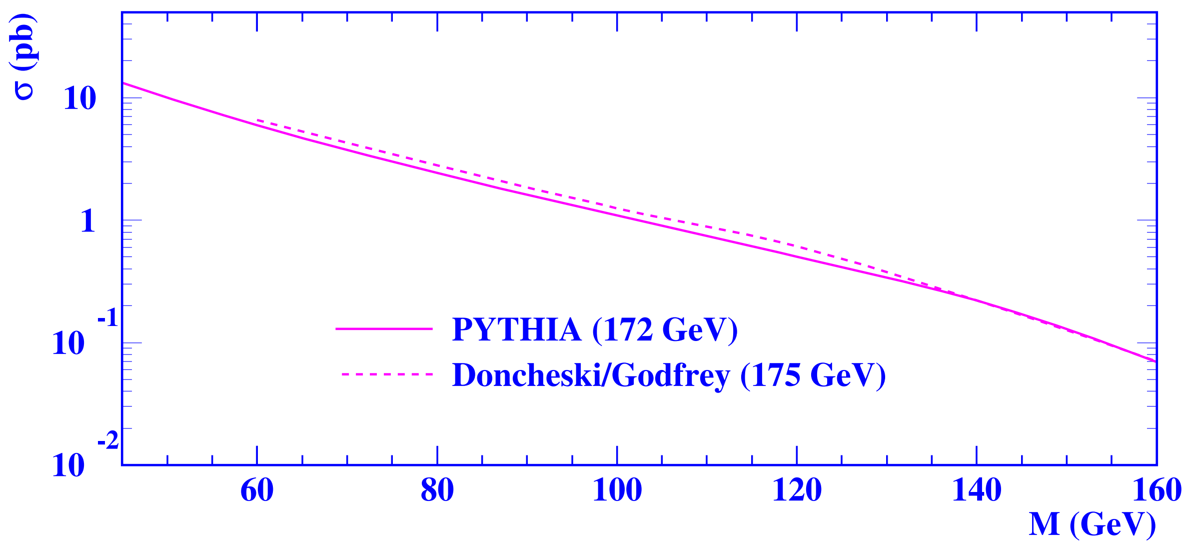
- **At HERA (ep) main contribution from**
  u,d valence quarks
- **At LEP (eγ) main contribution from**
  up-type quarks and anti-quarks ($e^{\pm}u, e^{\pm}\bar{u}$),

$$\text{since} \quad \frac{e_u^2}{e_d^2} = 4 \qquad (\gamma \to q\bar{q})$$

Monte Carlo simulation

- Generator used: PYTHIA 5.722
- Only scalar LQ
- Standard PYTHIA modified to allow $\nu q'$ final states
- JETSET fragmentation
- Small differences between structure function parametrisations (used GRV-LO)

cross-sections ($\lambda = \sqrt{4\pi\alpha_{\rm em}}$):



Event Analysis

- Cone jet finding algorithm

  Cone size:

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 1$$

  Transverse energy:

$$E_{\mathrm{T}} > 15 \text{ GeV}$$

- Matching algorithm uses
  - calorimeter clusters
  - charged tracks
- Electron identification using a Neural Net algorithm.
- Electron is used in jet search

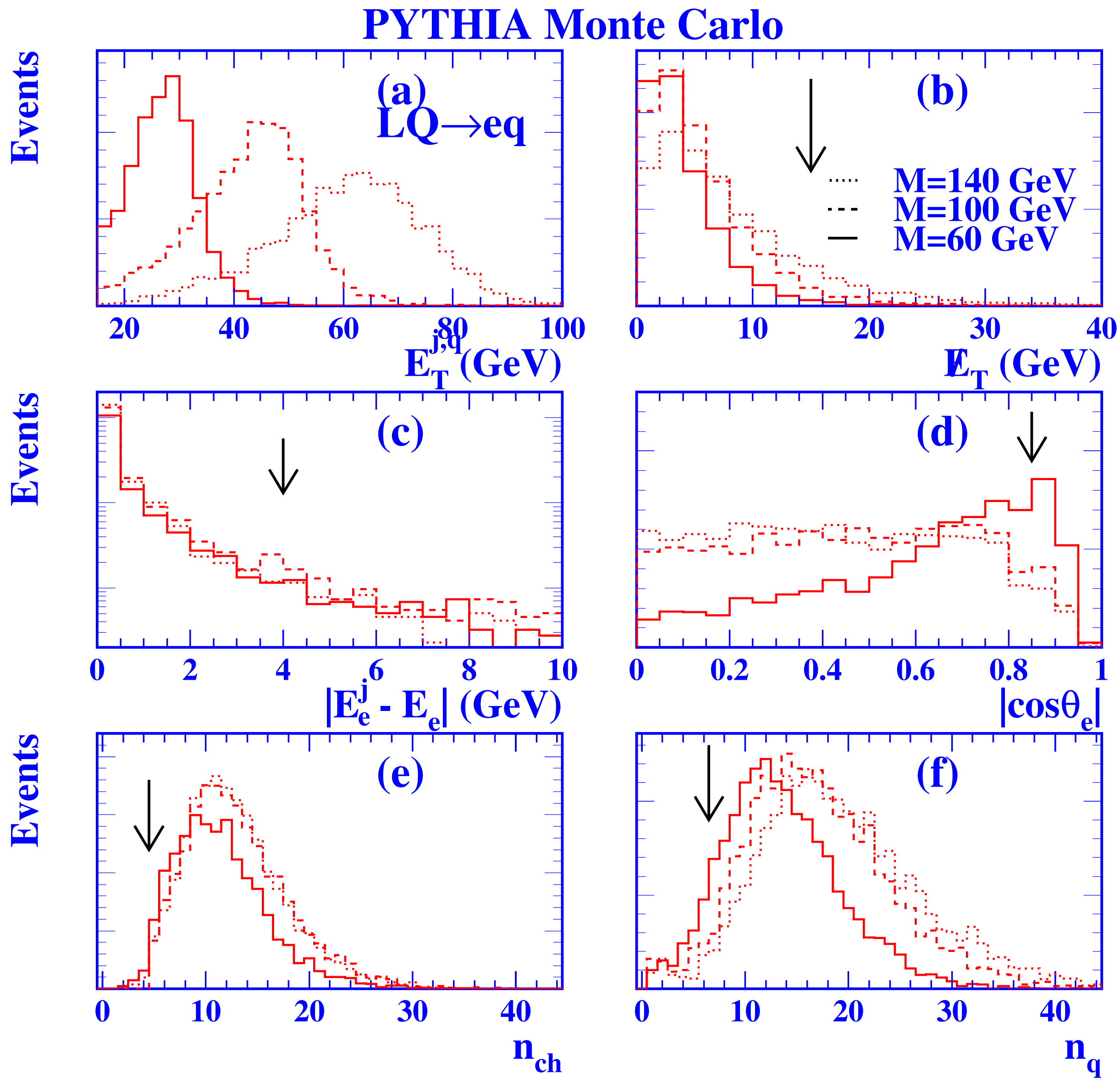
$$L = 20.5 \text{ pb}^{-1} \text{ at } \sqrt{s} = 161 \text{ and } 172 \text{ GeV.}$$

Electron plus hadronic jet

Preselection Cuts:

$$n_{\mathrm{j}} = 2$$

$$E_{\mathrm{e}} > 2 \text{ GeV}$$



Data vs Monte Carlo I

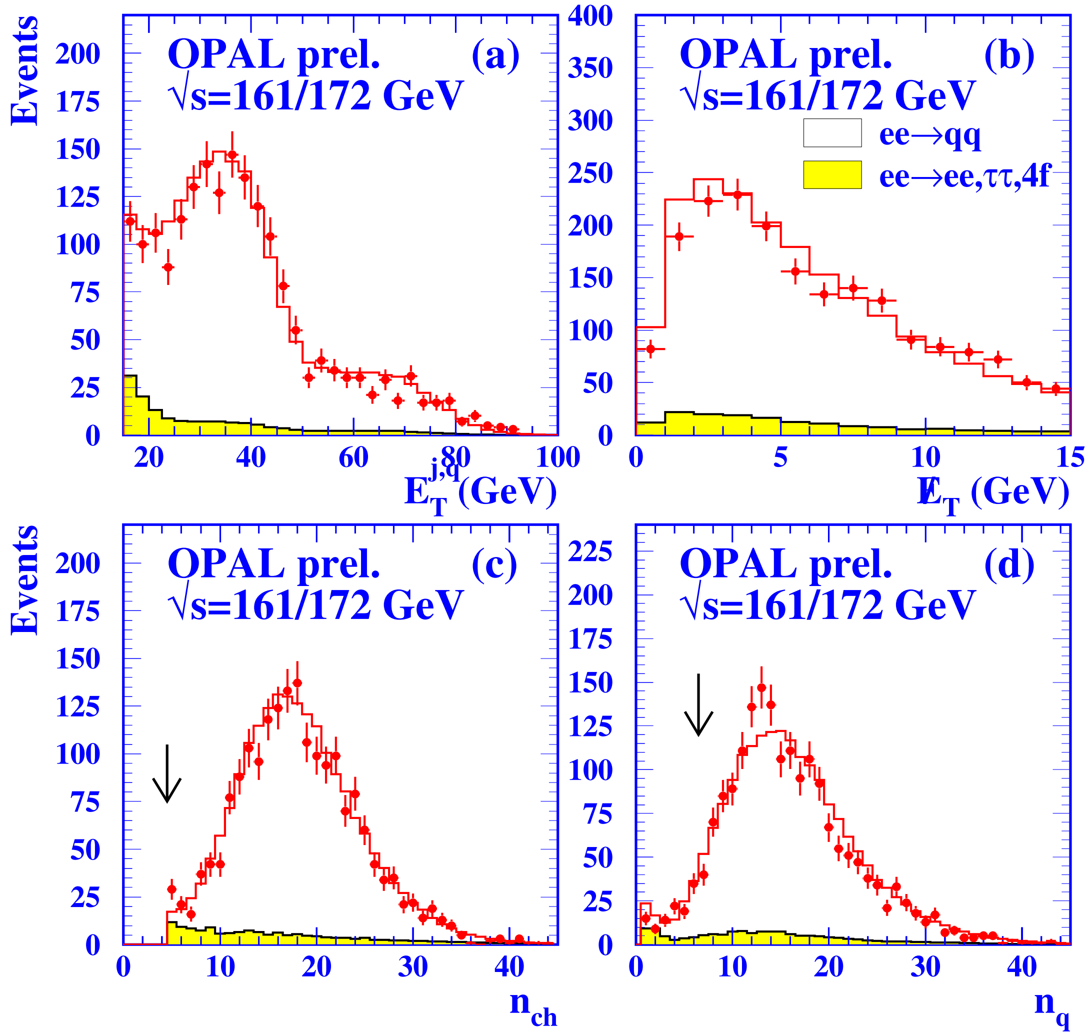
Cuts (A1):

$$n_{\mathrm{j}} = 2$$

$$n_{\mathrm{ch}} \geq 5$$

$$E_{\mathrm{ECAL}}/\sqrt{s} < 0.9$$

$$\not{E}_{\mathrm{T}} < 15 \text{ GeV}$$



Data vs Monte Carlo II

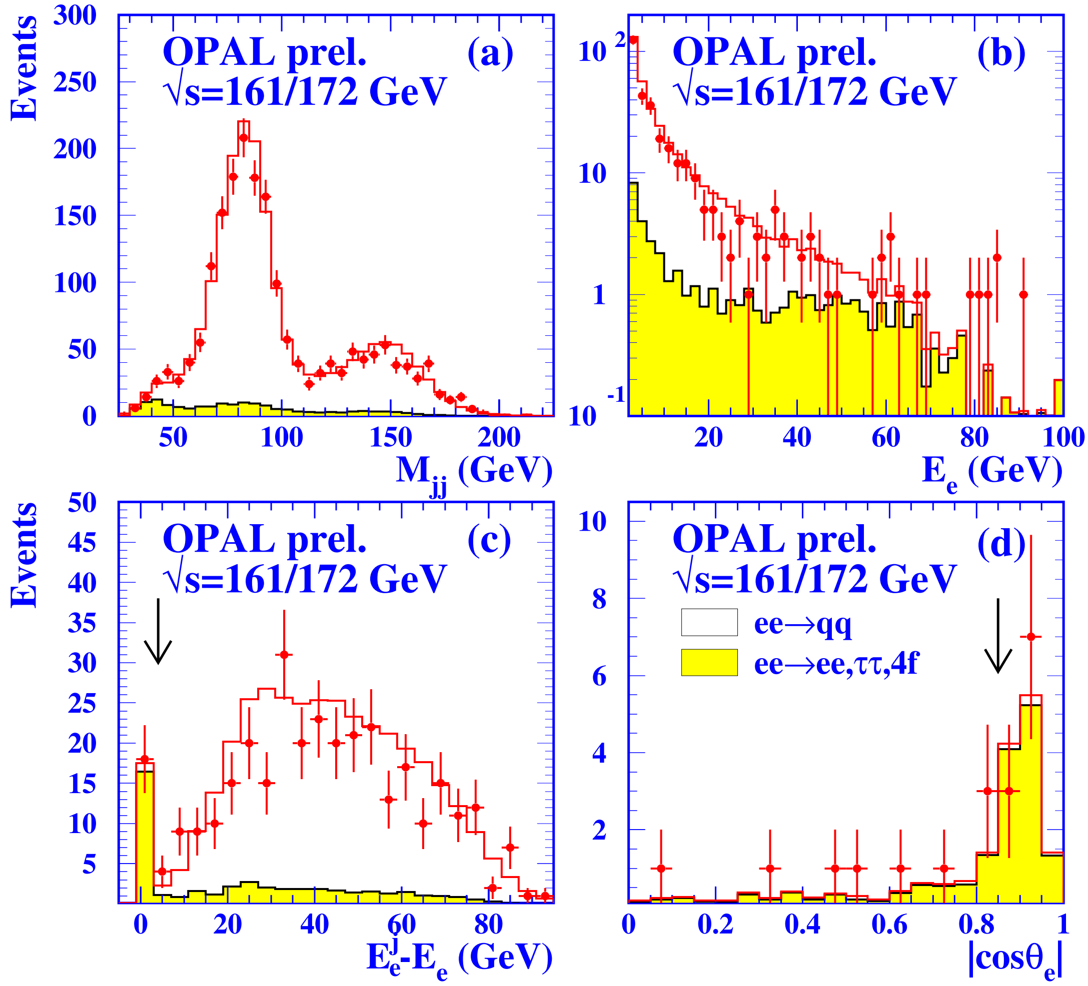
Cuts (A1):

$$n_{\mathrm{j}} = 2$$

$$n_{\mathrm{ch}} \geq 5$$

$$E_{\mathrm{ECAL}}/\sqrt{s} < 0.9$$

$$\not{E}_{\mathrm{T}} < 15 \text{ GeV}$$



(c) $E_{\mathrm{e}} > 2$ GeV (d) $|E_{\mathrm{e}}^{\mathrm{j}} - E_{\mathrm{e}}| < 4$ GeV

Electron plus hadronic jet

(A1) $n_{\mathrm{j}} = 2$ (includes electron)

$n_{\mathrm{ch}} \geq 5$

$E_{\mathrm{ECAL}}/\sqrt{s} < 0.9$ (against $e^+e^- \rightarrow e^+e^-$)

$\not{E}_{\mathrm{T}} < 15$ GeV

(A2) Jet with the smallest angular distance to the identified electron is chosen to be the electron jet.

Isolation cut: $|E^{\mathrm{j}}_{\mathrm{e}} - E_{\mathrm{e}}| < 4$ GeV

(A3) $|\cos\theta_{\mathrm{e}}| < 0.85$

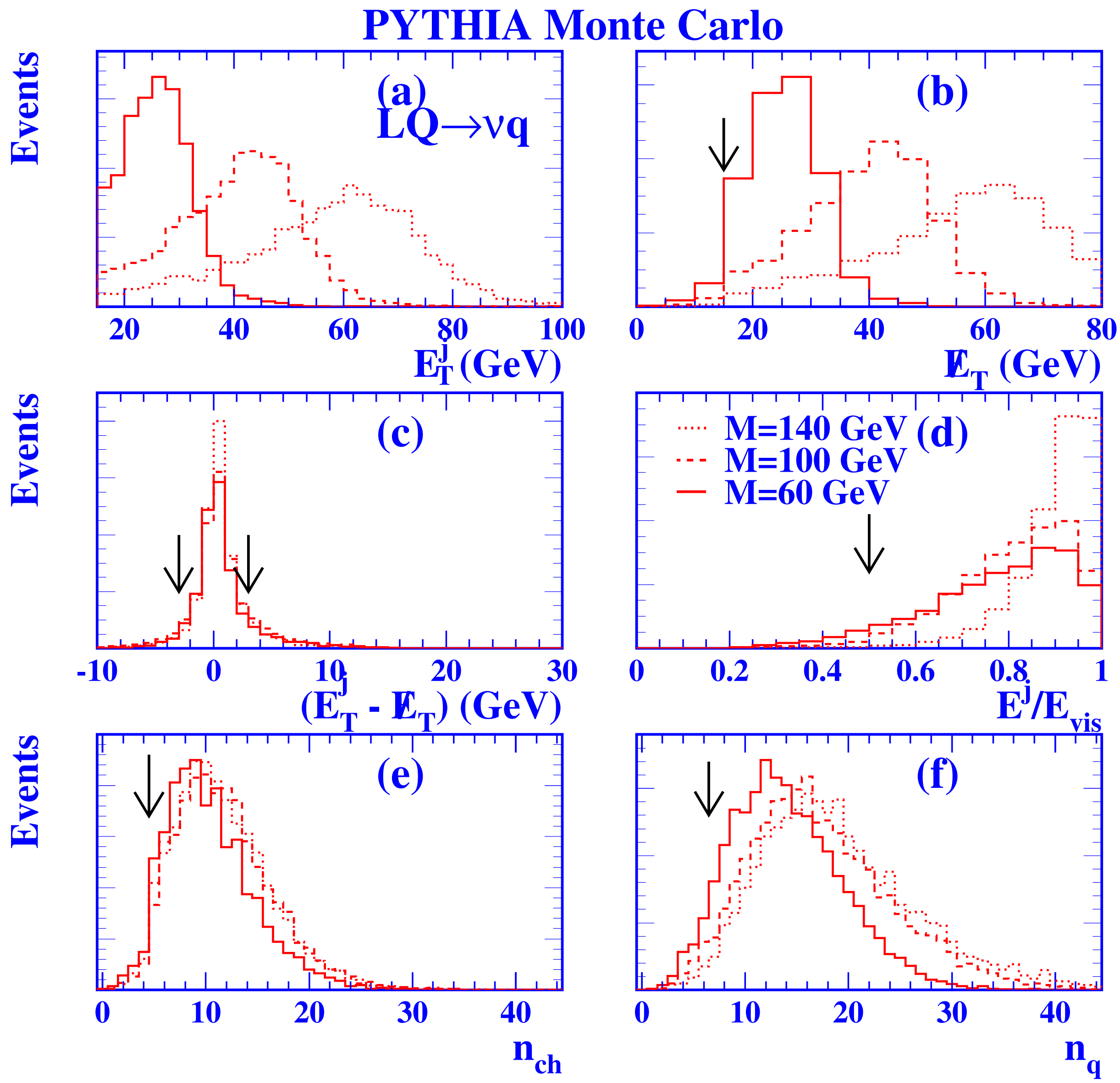
(A4) Total multiplicity n_{q} of the quark jet (neutral plus charged): $n_{\mathrm{q}} \geq 7$

	A1	A2	A3	A4
ee$\longrightarrow$ q$\bar{\mathrm{q}}$	2031	1.3	0.8	0.80 ± 0.07
ee$\longrightarrow$ $\tau\tau$,ee	13	1.4	1.2	0.25 ± 0.05
ee$\longrightarrow$ 4 f	200	15.0	4.7	4.18 ± 0.44
sum (MC)	2244	17.8	6.7	5.23 ± 0.44
data	2246	19	9	4
$M = 60$ GeV	75 %	50 %	40 %	38 %
$M = 140$ GeV	87 %	59 %	56 %	55 %

Neutrino plus hadronic jet

Preselection Cuts:

$$n_{\mathrm{j}} = 1$$



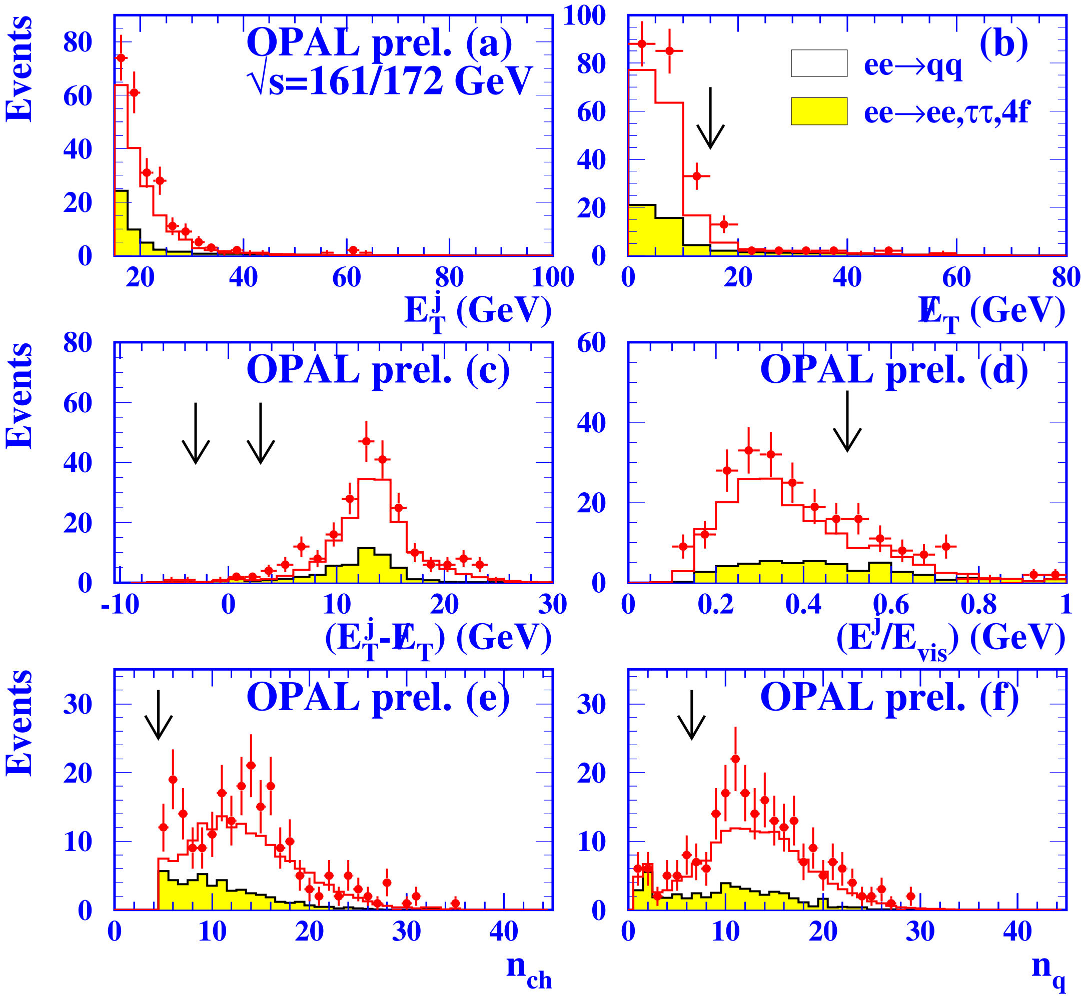
Data vs Monte Carlo III

Cuts:

$$n_{\mathrm{j}} = 1 \quad \text{with } |\eta^{\mathrm{jet}}| < 2$$

$$n_{\mathrm{ch}} \geq 5$$

$$E_{\mathrm{ECAL}} / E_{\mathrm{vis}} > 0.2$$



- Normalisation problem due to SM eγ Monte Carlo
- No effect on search region

Neutrino plus hadronic jet

(B1) $E_{\mathrm{ECAL}}/E_{\mathrm{vis}} > 0.2$

$n_{\mathrm{j}} = 1$ with $|\eta^{\mathrm{jet}}| < 2$

$n_{\mathrm{ch}} \geq 5$

(B2) $\not{E}_{\mathrm{T}} > 15$ GeV

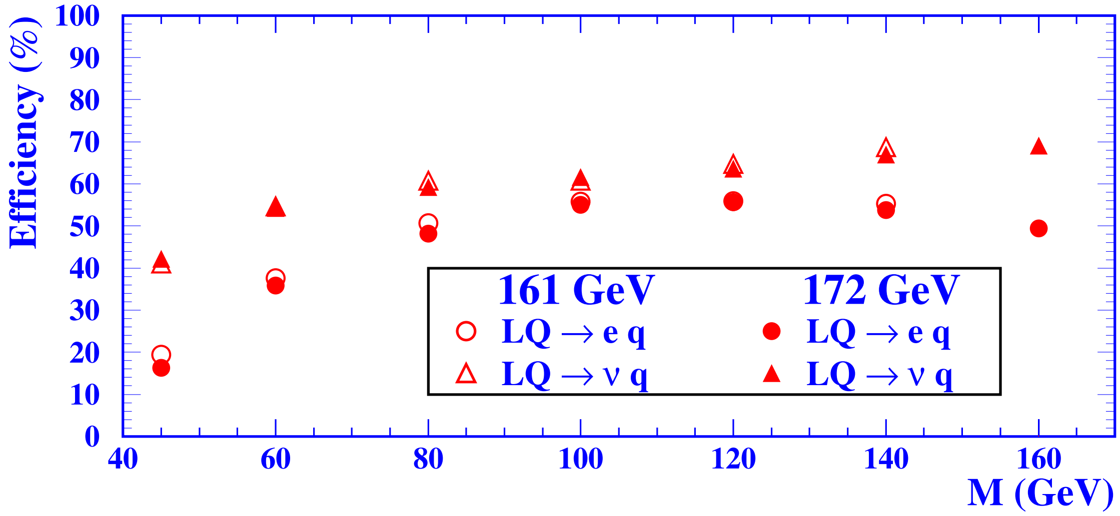
(B3) $|E_{\mathrm{T}}^{\mathrm{j}} - \not{E}_{\mathrm{T}}| < 3$ GeV

(B4) $E^{\mathrm{j}}/E_{\mathrm{vis}} > 0.5$

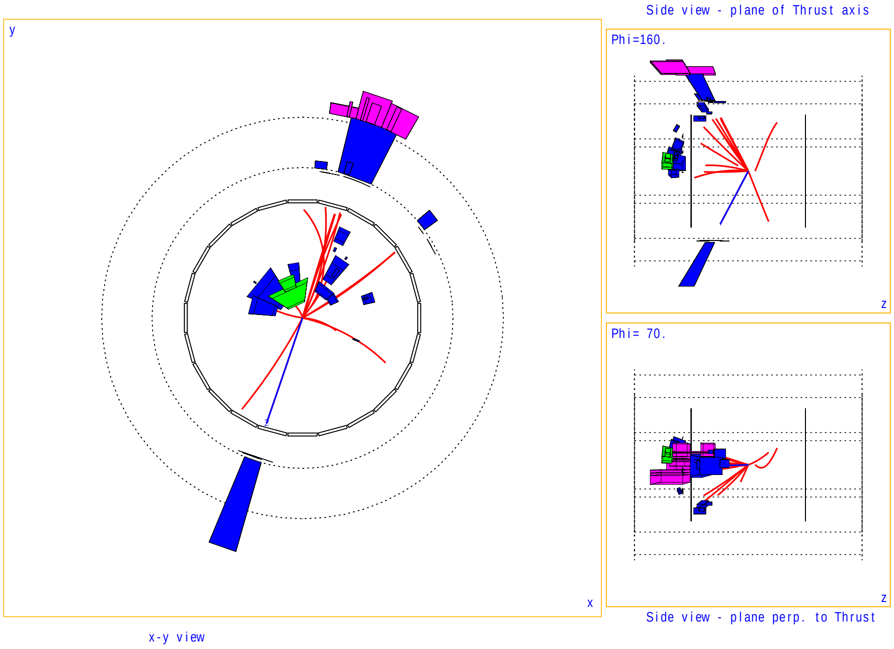
(B5) Total multiplicity n_{q} of the quark jet (neutral plus charged): $n_{\mathrm{q}} \geq 7$

	B1	B2	B3	B4/B5
ee$\rightarrow$ q$\bar{\mathrm{q}}$	122	5.7	0.20	0.04 ± 0.01
ee$\rightarrow$ $\tau\tau$	3	1.6	0.22	0.12 ± 0.01
ee$\rightarrow$ 4 f	48	7.5	2.27	1.65 ± 0.05
sum (MC)	172	14.9	2.69	1.81 ± 0.05
data	131	25	3	2
$M = 60$ GeV	73 %	70 %	59 %	55 %
$M = 140$ GeV	83 %	83 %	70 %	69 %

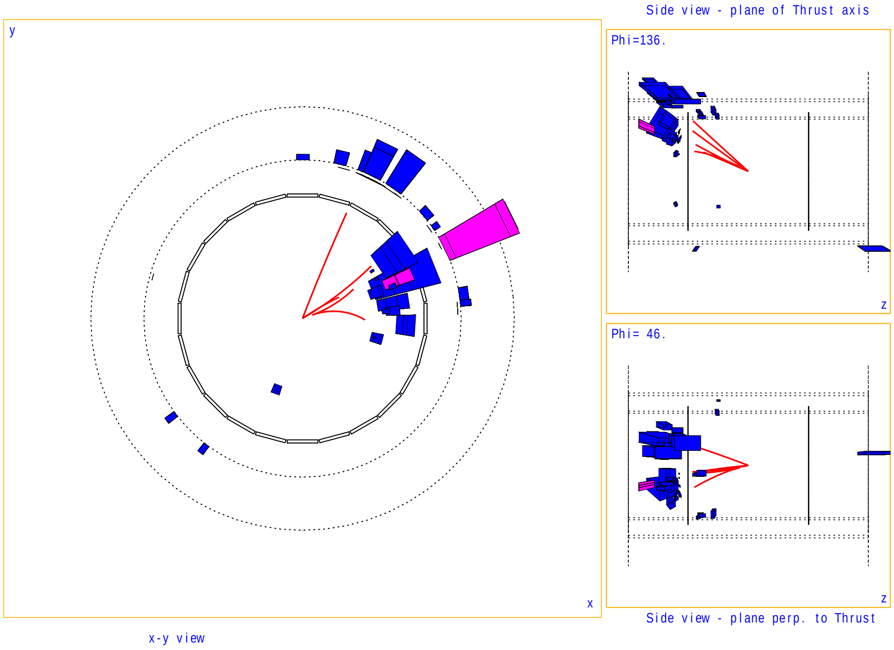
Efficiency vs. Leptoquark Mass



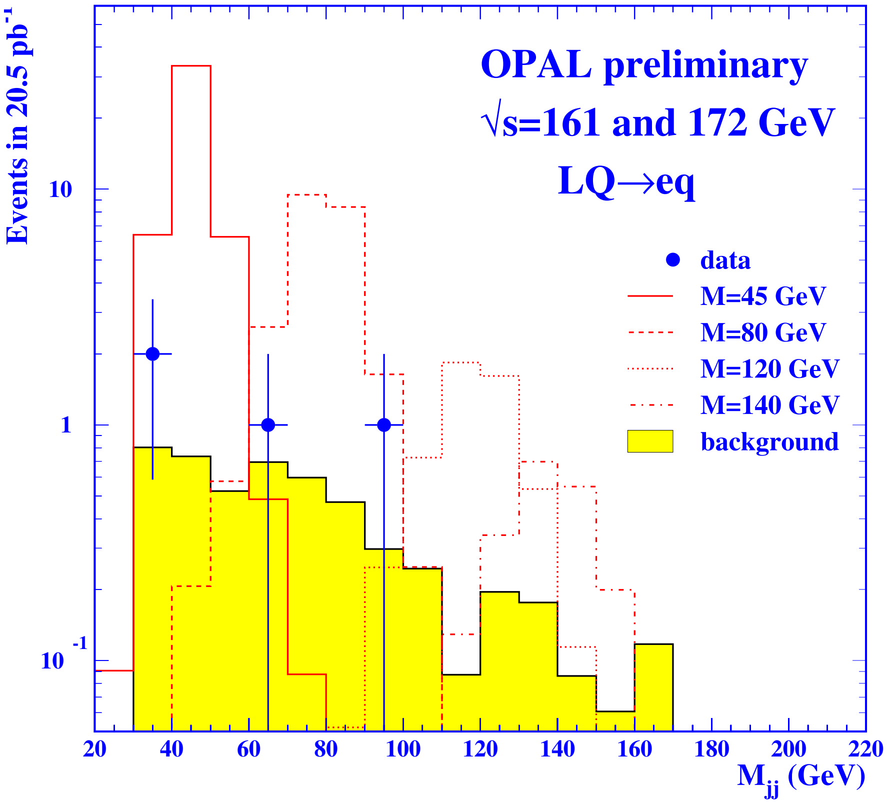
- Cuts not optimized for $M < M_Z/2$
- Efficiency at low M drops due to jet finding
- Efficiency $\approx$ flat for $M > 80$ GeV
- $\not{E}_T$ cuts create differences at large M

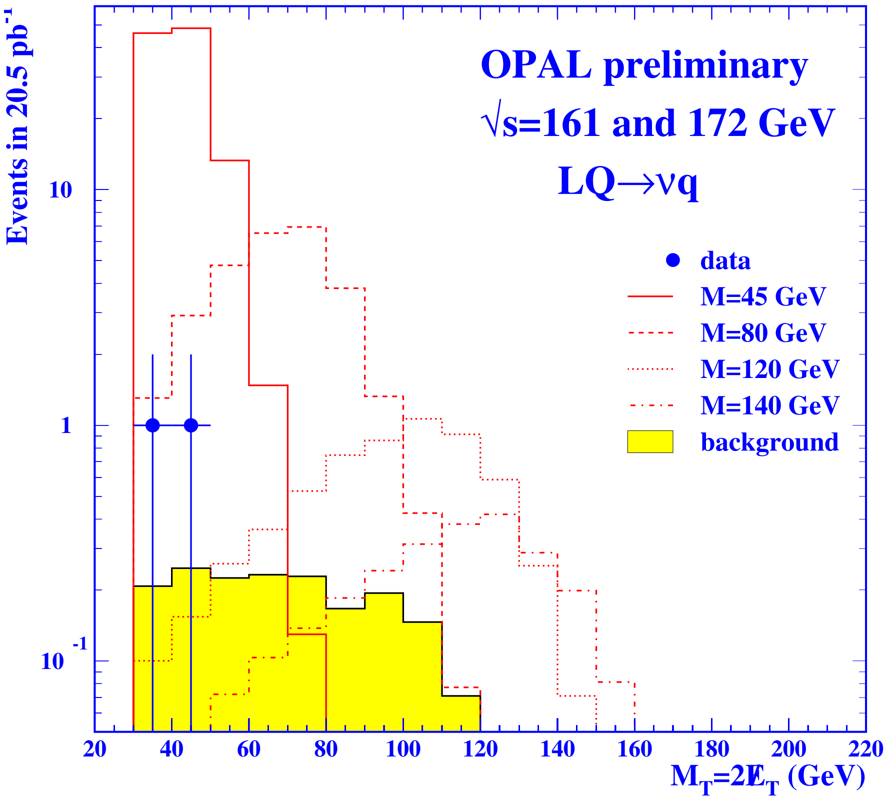


$$M = 62 \text{ GeV}$$



$$\not\!\!E_{\mathrm{T}} = 22 \text{ GeV} \Rightarrow M_{\mathrm{T}} = 2\not\!\!E_{\mathrm{T}} = 44 \text{ GeV}$$


OPAL preliminary
√s=161 and 172 GeV
LQ→eq
data
M=45 GeV
M=80 GeV
M=120 GeV
M=140 GeV
background
Events in 20.5 pb-1
10
1
10 -1
20 40 60 80 100 120 140 160 180 200 220
Mjj (GeV)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Events in 20.5 pb-1
10
1
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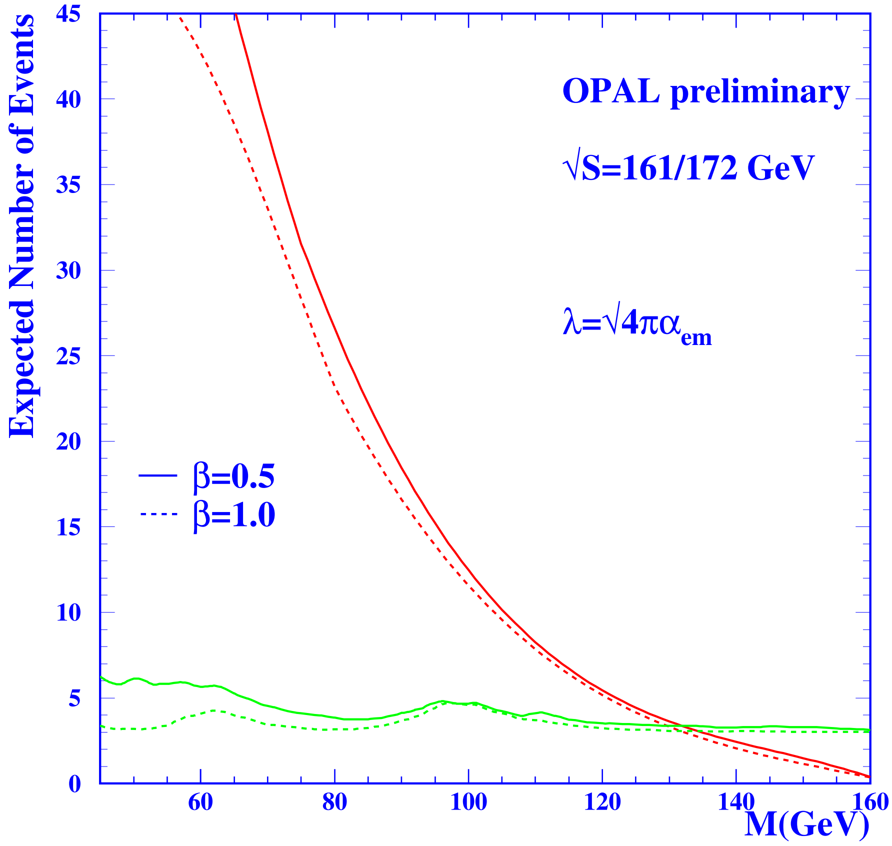
20 40 60 80 100 120 140 160 180 200 220
MT=2ET (GeV)



$$\beta = \mathbf{BR}(\mathbf{LQ} \rightarrow \mathbf{eq})$$

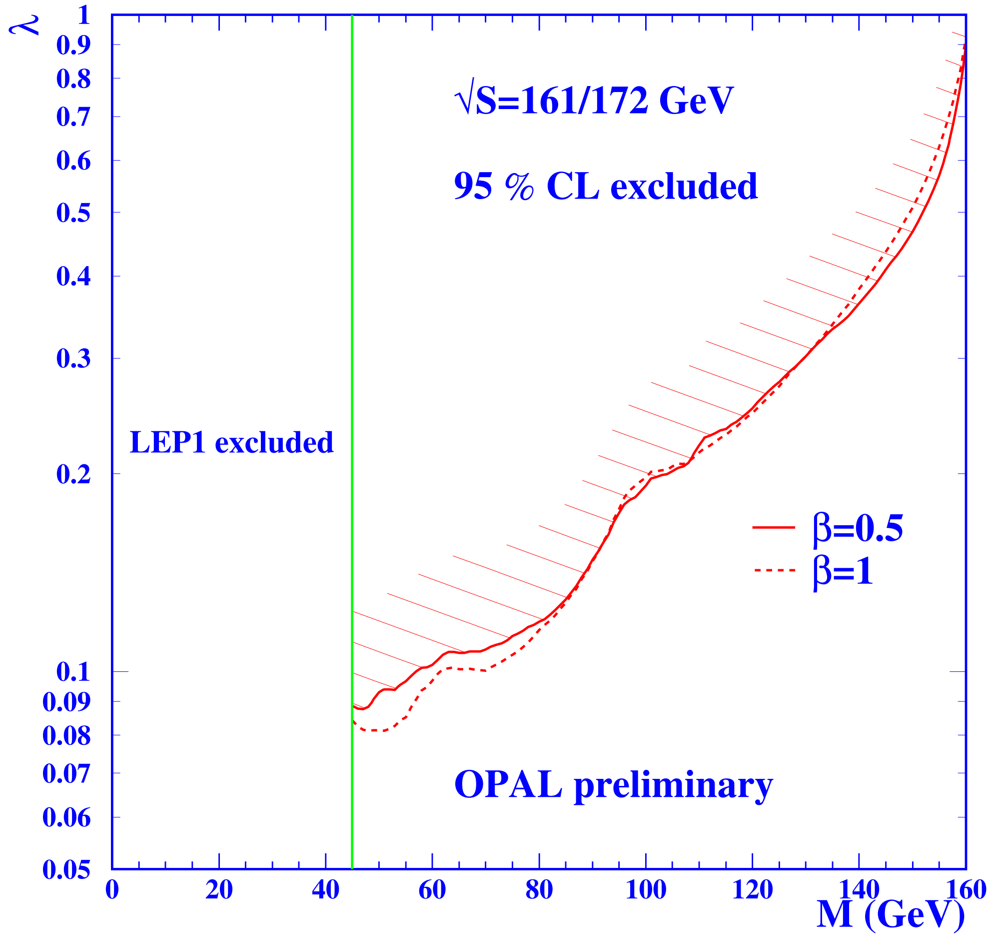
— 95 % confidence level

Limit calculation takes into account:

- candidates
- background
- resolution
- systematic errors

systematic errors:

luminosity measurement	$<$1 %
model dependence	
of the leptoquark fragmentation	4 %
electron identification	2 %
Monte Carlo statistics	1 %



$$\lambda = \sqrt{4\pi\alpha_{\rm em}} \Rightarrow M > 131 \text{ GeV at } 95\% \text{ CL}$$

Conclusion

Weizsäcker-Williams photons

are not always 'soft'....

$M = 131$ GeV first generation scalar leptoquark of charge -1/3 or -5/3 excluded at 95 % CL for $\beta = 0.5$ and $\lambda = 0.31$

Significantly higher limit expected with 184 GeV data

Better limit than from LQ pair production at LEP, but more model dependence due to the Yukawa coupling λ