

LEPTOQUARKS AT LHC*

Ilja Doršner

University of Split

*Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split
(FESB)*

LHC Days in Split

29 September – 4 October, 2014

*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

OUTLINE

- **FRAMEWORK**

- **LEPTOQUARK (LQ) PRODUCTION AT LHC**

(SINGLE AND PAIR PRODUCTION OF LEPTOQUARKS)

- **FLAVOR CONSTRAINTS**

- **THE CMS LEPTOQUARK SEARCH RECAST**

(SECOND GENERATION LEPTOQUARKS)

- **CONCLUSIONS**

FRAMEWORK

$SU(3) \times SU(2) \times U(1)$ MULTIPLETS

SCALAR LEPTOQUARKS (LQs):

$$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$(\mathbf{3}, \mathbf{2}, 7/6)$$

$$(\mathbf{3}, \mathbf{2}, 1/6)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 4/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$$

FRAMEWORK

$SU(3) \times SU(2) \times U(1)$ MULTIPLETS

SCALAR LEPTOQUARKS (LQs):

$$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$(\mathbf{3}, \mathbf{2}, 7/6)$$

$$(\mathbf{3}, \mathbf{2}, 1/6)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 4/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$$

W. Buchmuller, R. Ruckl and D. Wyler, Phys. Lett. B 191, 442 (1987).

FRAMEWORK

$SU(3) \times SU(2) \times U(1)$ MULTIPLETS

SCALAR LEPTOQUARKS (LQs):

$$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$(\mathbf{3}, \mathbf{2}, 7/6)$$

$$(\mathbf{3}, \mathbf{2}, 1/6)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 4/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$$

I. Doršner, S. Fajfer and N. Košnik, Phys. Rev. D 86, 015013 (2012).

FRAMEWORK

$SU(3) \times SU(2) \times U(1)$ MULTIPLETS

SCALAR LEPTOQUARKS (LQs):

$$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$(\mathbf{3}, \mathbf{2}, 7/6)$$

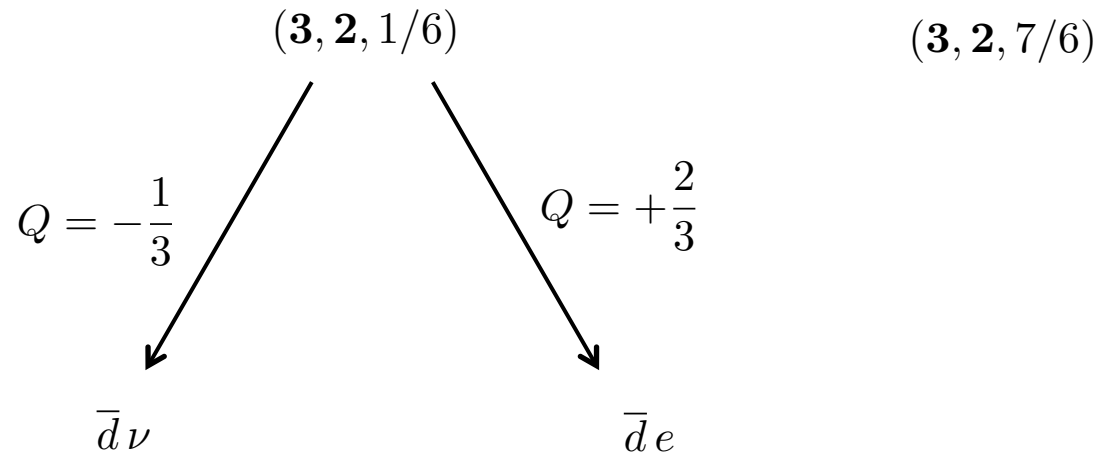
$$(\mathbf{3}, \mathbf{2}, 1/6)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$$

$$(\bar{\mathbf{3}}, \mathbf{1}, 4/3)$$

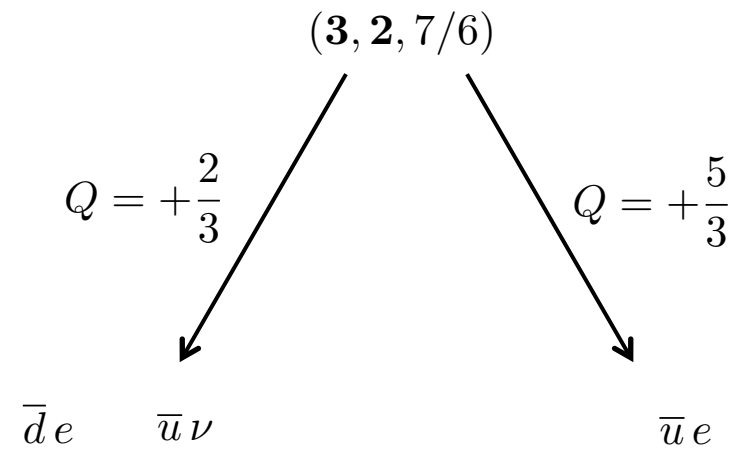
$$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$$

FRAMEWORK

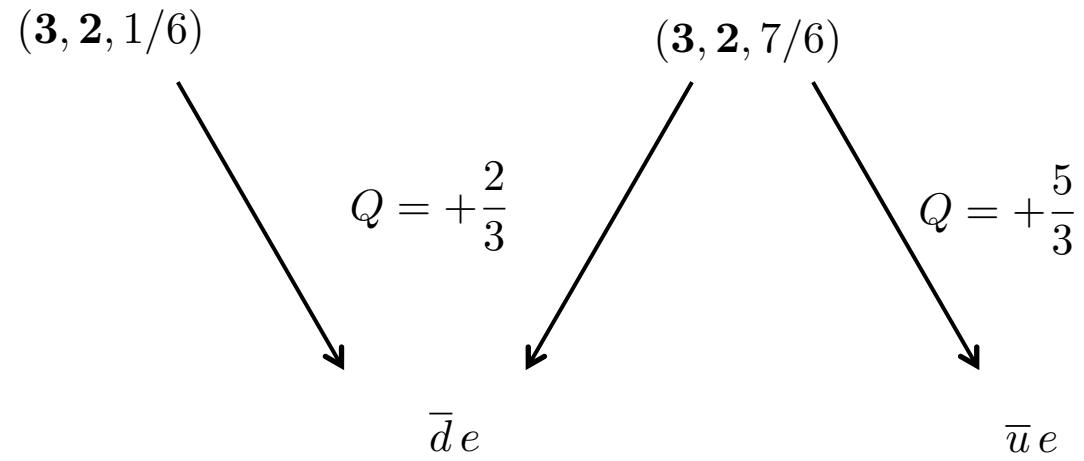


FRAMEWORK

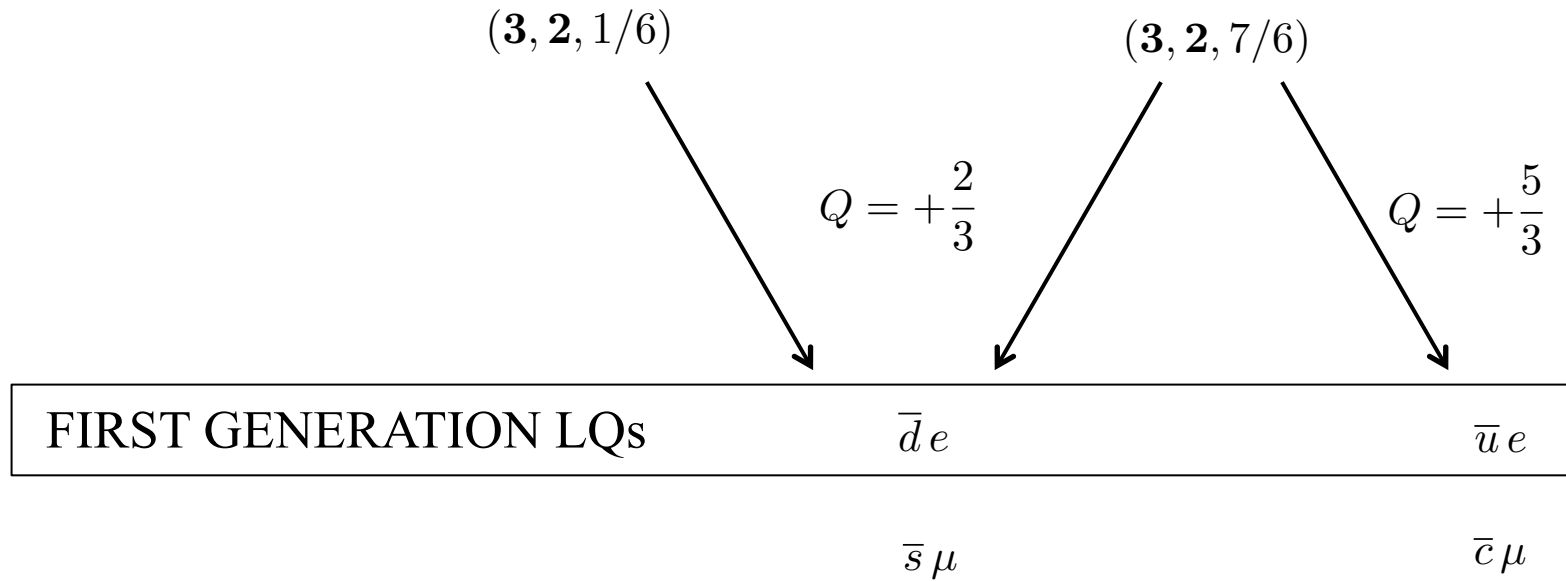
$(\mathbf{3}, \mathbf{2}, 1/6)$



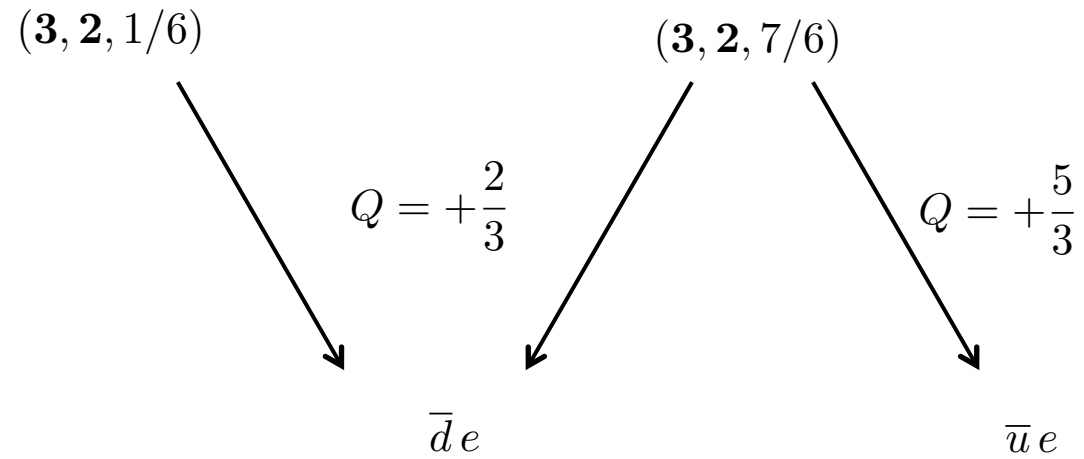
FRAMEWORK



FRAMEWORK



FRAMEWORK



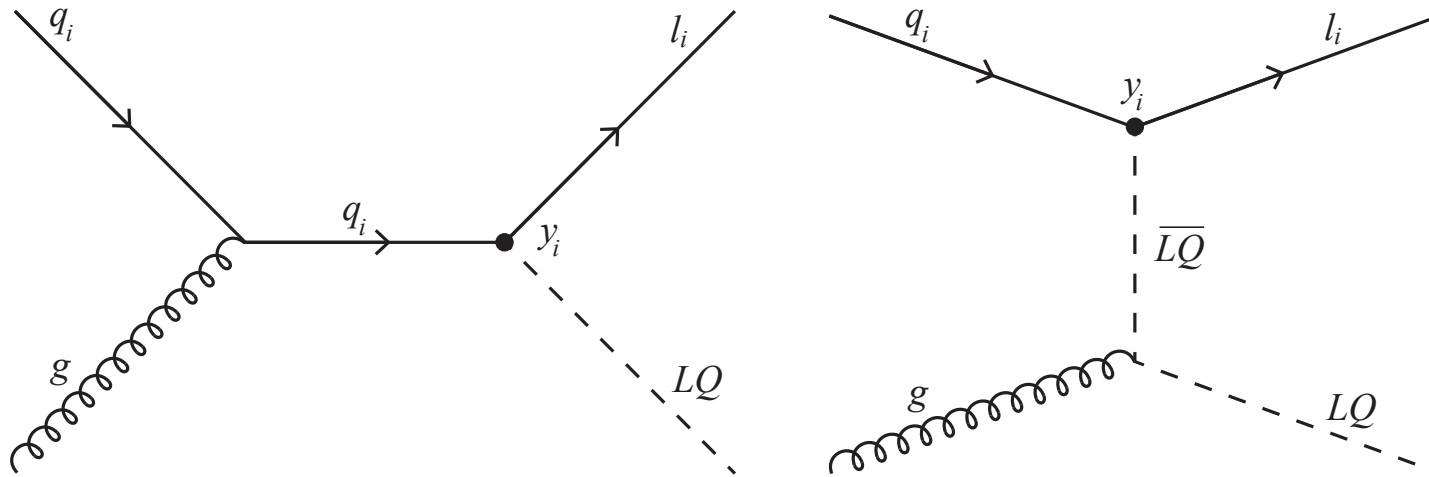
SECOND GENERATION LQs

$\bar{s}\mu$

$\bar{c}\mu$

LEPTOQUARK PRODUCTION AT LHC

SINGLE SCALAR LQ PRODUCTION:

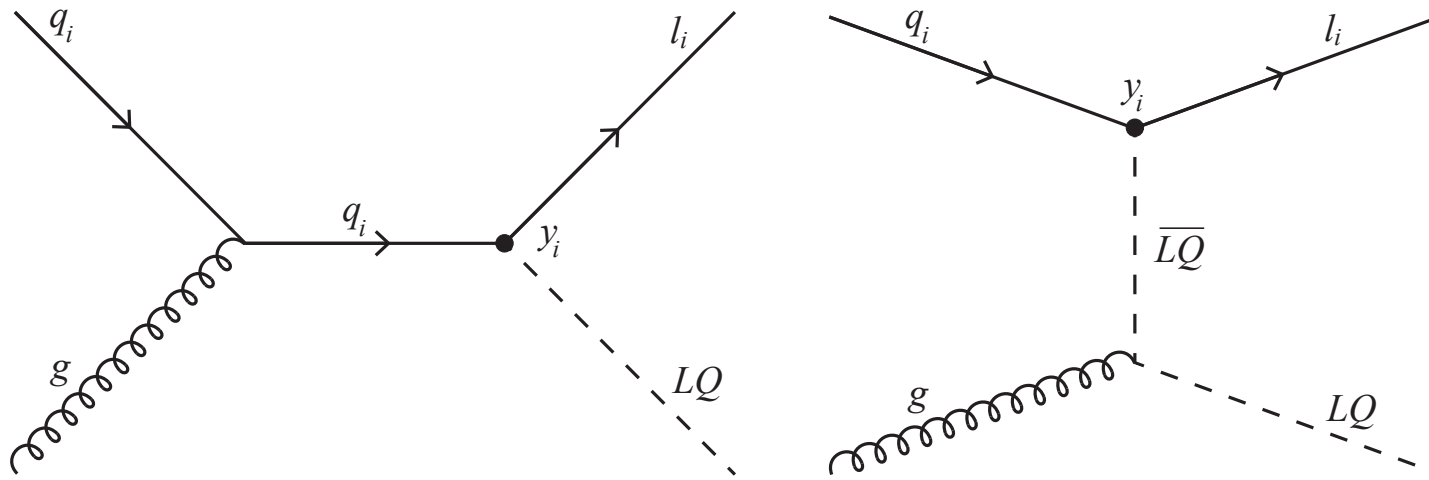


s-channel

t-channel

LEPTOQUARK PRODUCTION AT LHC

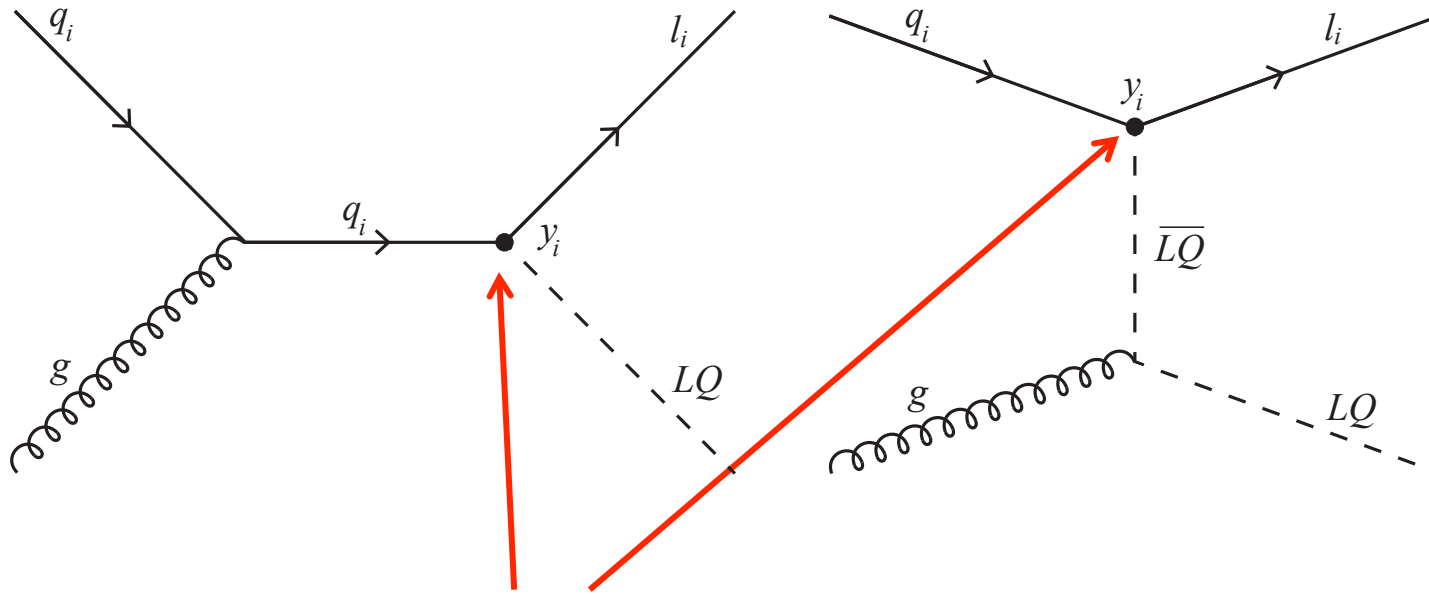
SINGLE SCALAR LQ PRODUCTION:



$$l_i = e, \mu$$
$$q_i = (u, d), (c, s)$$

LEPTOQUARK PRODUCTION AT LHC

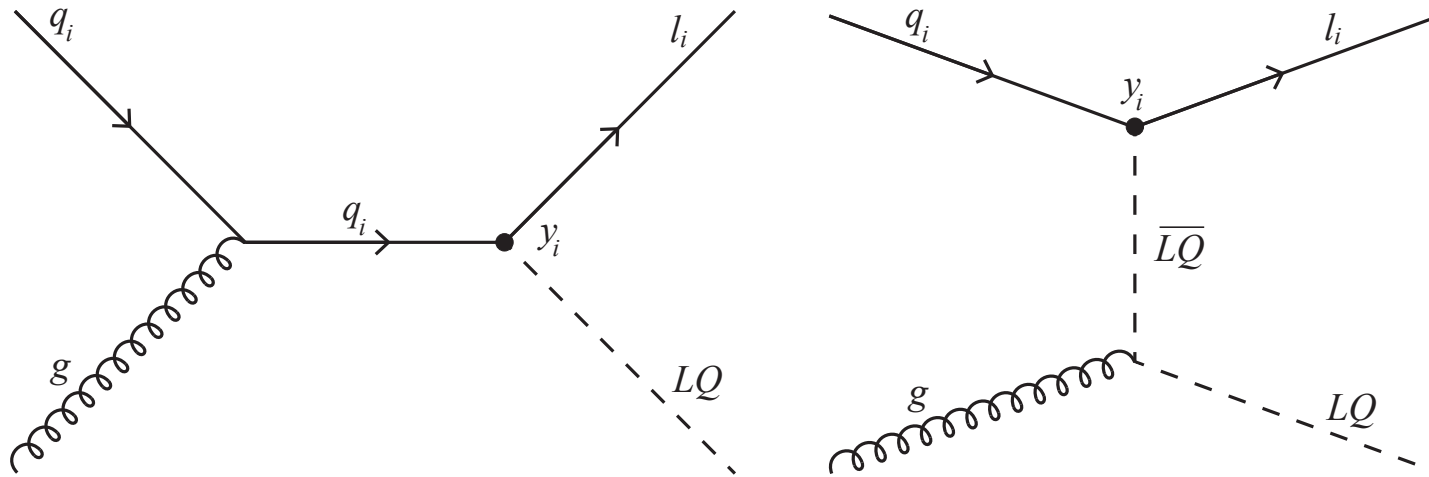
SINGLE SCALAR LQ PRODUCTION:



Yukawa (lepton-quark-leptoquark) coupling

LEPTOQUARK PRODUCTION AT LHC

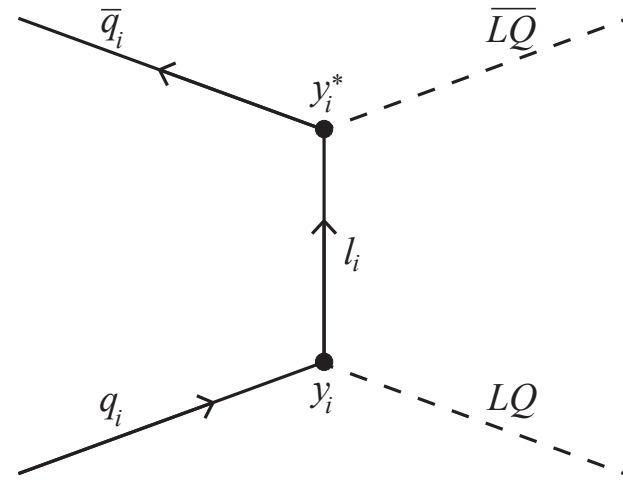
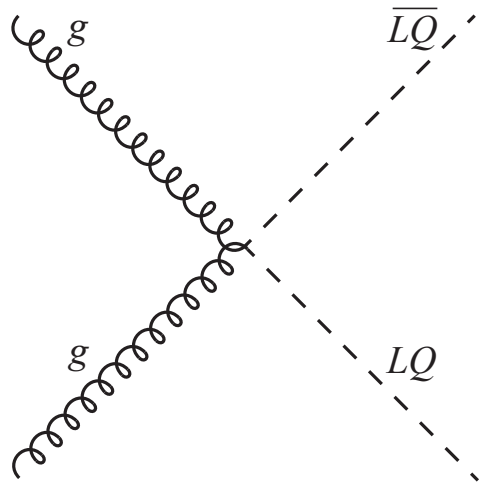
SINGLE SCALAR LQ PRODUCTION:



J. L. Hewett and S. Pakvasa, Phys. Rev. D 37, 3165 (1988); O. J. P. Eboli and A. V. Olinto, Phys. Rev. D 38, 3461 (1988); M. De Montigny and L. Marleau, Phys. Rev. D 40, 2869 (1989); J. Ohnemus, S. Rudaz, T. F. Walsh and P. M. Zerwas, Phys. Lett. B 334, 203 (1994); O. J. P. Eboli and T. L. Lungov, Phys. Rev. D 61, 075015 (2000); A. Belyaev, C. Leroy, R. Mehdiyev and A. Pukhov, JHEP 0509, 005 (2005).

LEPTOQUARK PRODUCTION AT LHC

SCALAR LQ PAIR PRODUCTION:



y_{ue}

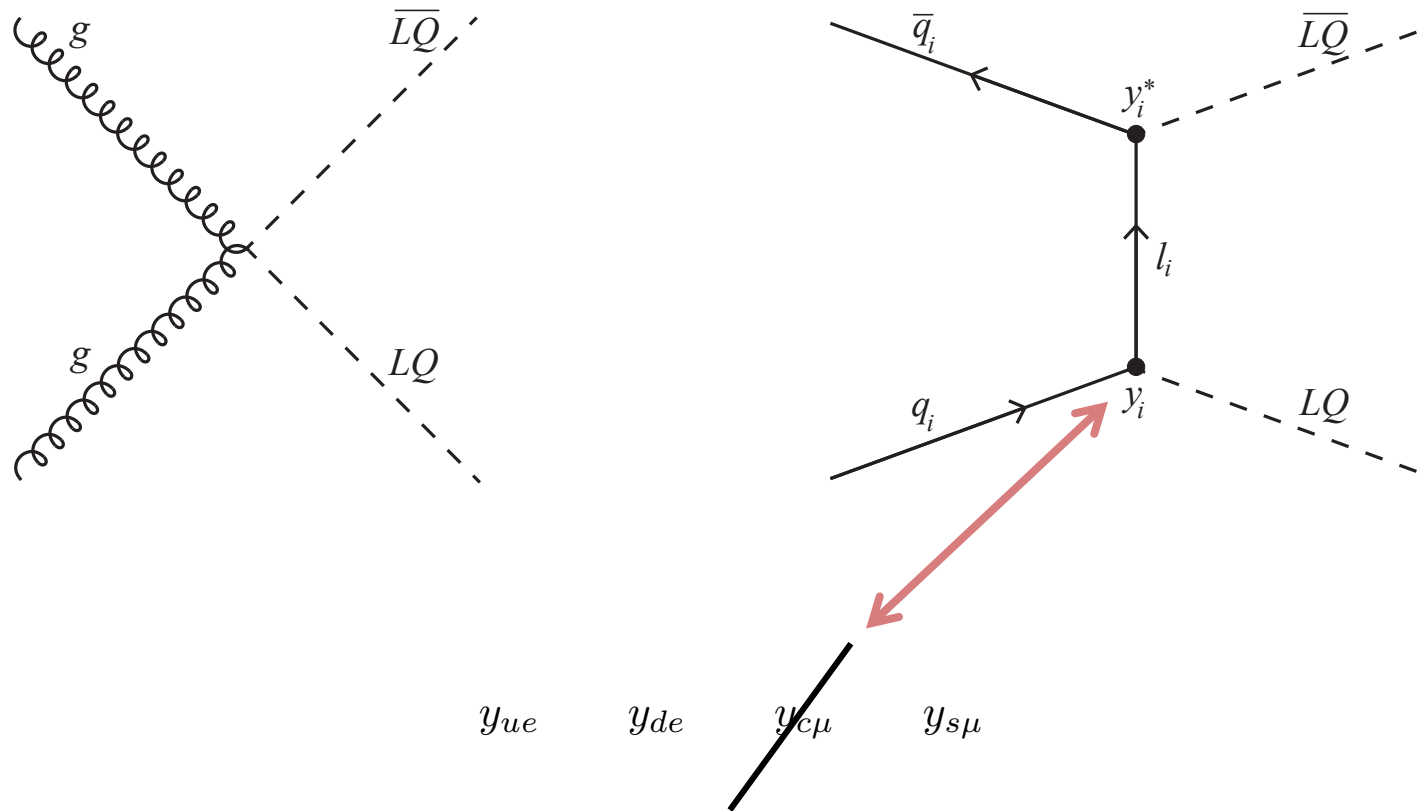
y_{de}

$y_{c\mu}$

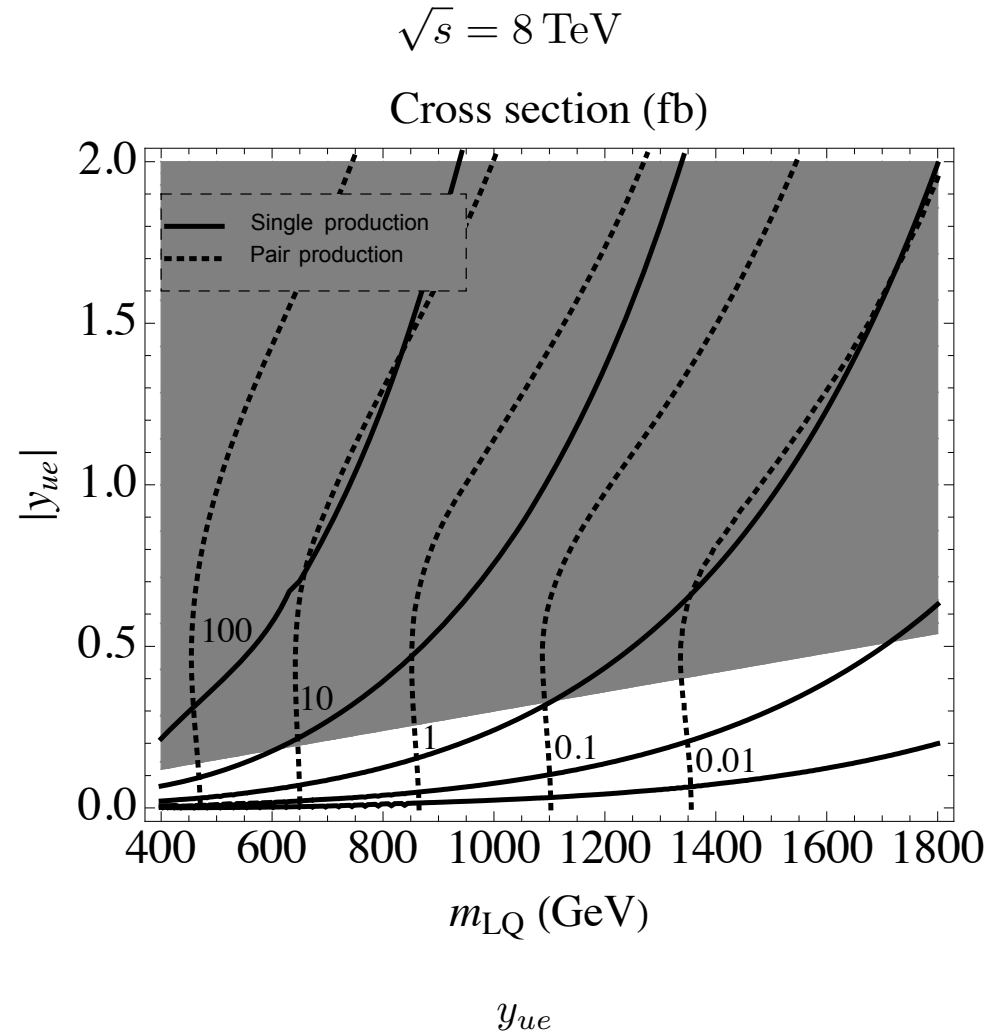
$y_{s\mu}$

LEPTOQUARK PRODUCTION AT LHC

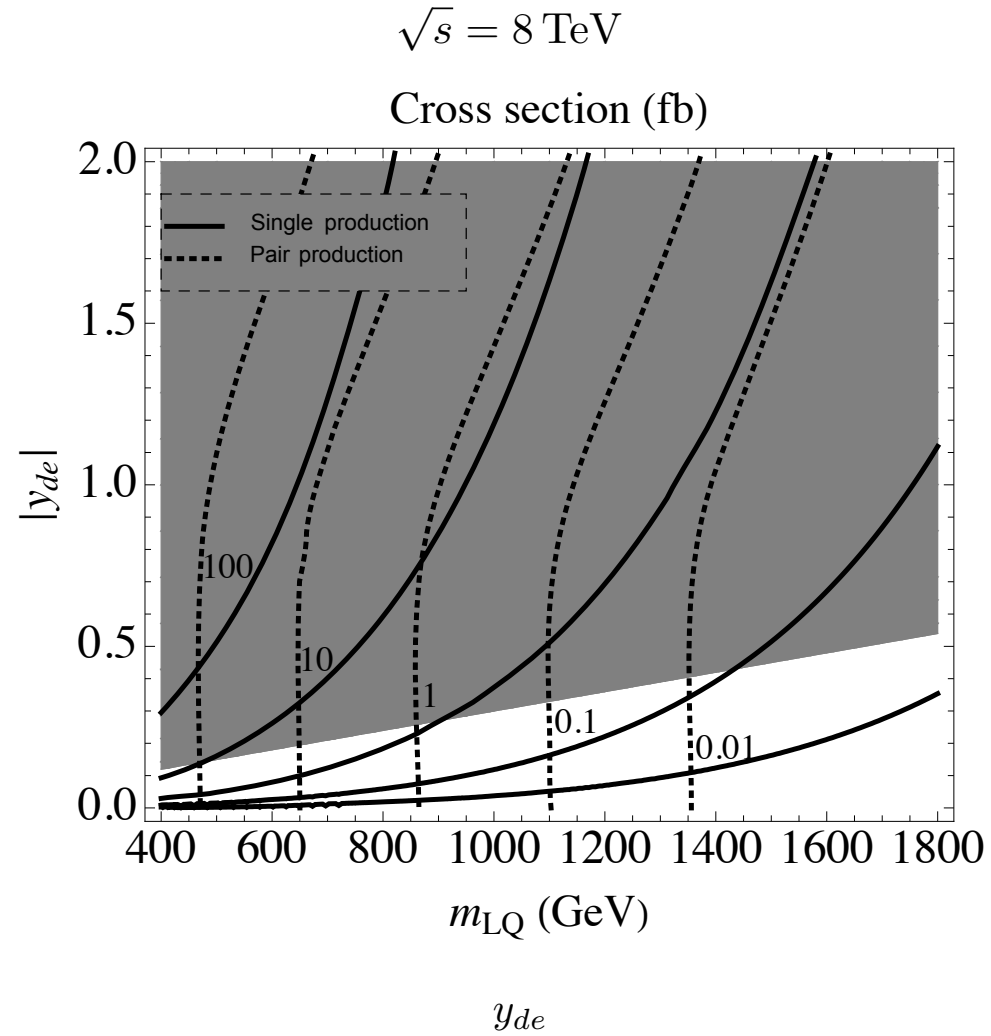
SCALAR LQ PAIR PRODUCTION:



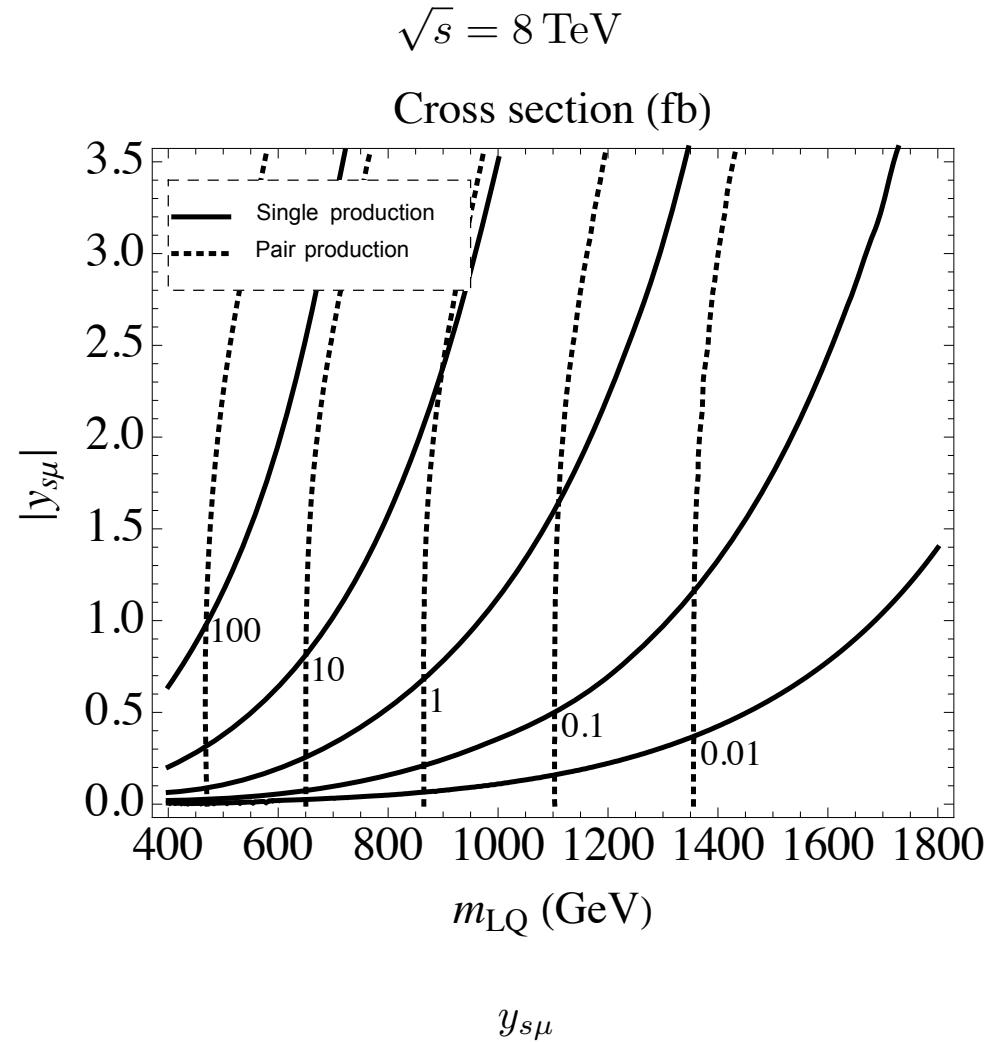
LEPTOQUARK PRODUCTION AT LHC



LEPTOQUARK PRODUCTION AT LHC



LEPTOQUARK PRODUCTION AT LHC



FLAVOR CONSTRAINTS

ATOMIC PARITY VIOLATION



$$|y_{de}| \leq 0.34 \left(\frac{m_{LQ}}{1 \text{ TeV}} \right)$$

$$|y_{ue}| \leq 0.36 \left(\frac{m_{LQ}}{1 \text{ TeV}} \right)$$

FLAVOR CONSTRAINTS

$$K_L \rightarrow \mu^- e^+$$



$$|y_{s\mu} y_{de}^*| < 2.1 \times 10^{-5} \left(\frac{m_{LQ}}{1\text{TeV}} \right)^2$$

FLAVOR CONSTRAINTS

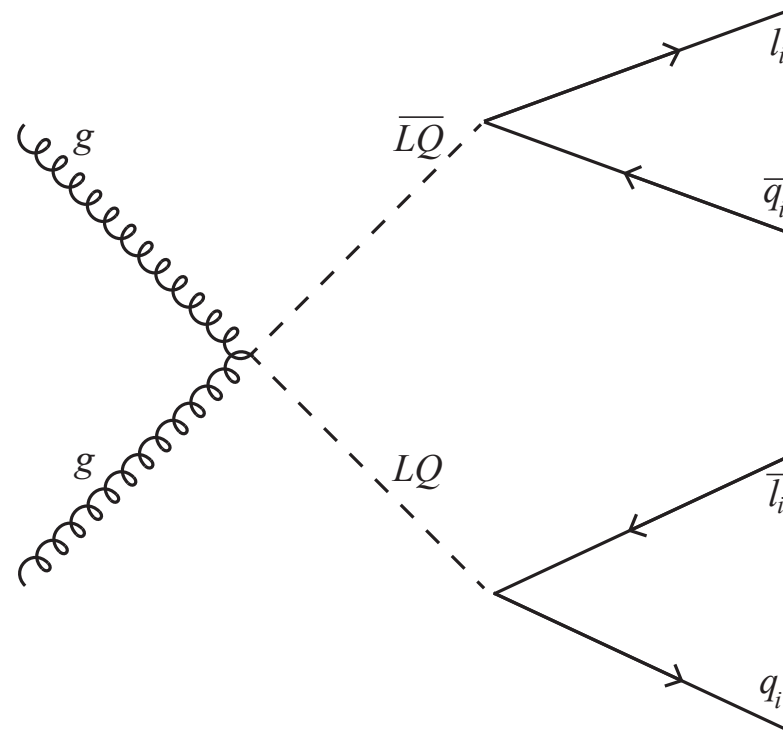
$$D^0 \rightarrow \mu^- e^+$$



$$|y_{c\mu} y_{ue}^*| < 0.6 \left(\frac{m_{LQ}}{1\text{TeV}} \right)^2$$

THE CMS SEARCH

(FIRST GENERATION LEPTOQUARK)*
(SECOND GENERATION LEPTOQUARK)^



*CMS PAS EXO-12-041.

^CMS PAS EXO-12-042.

THE CMS SEARCH

(FIRST GENERATION LEPTOQUARK)*
(SECOND GENERATION LEPTOQUARK)^

- PAIR PRODUCTION IS QCD DRIVER;
- SINGLE LQ PRODUCTION DOES NOT CONTRIBUTE;

*CMS PAS EXO-12-041.

^CMS PAS EXO-12-042.

THE CMS SEARCH

(FIRST GENERATION LEPTOQUARK)*
(SECOND GENERATION LEPTOQUARK)^

$M_{\mu\mu} \equiv$ the invariant mass of the two **electrons** (muons);

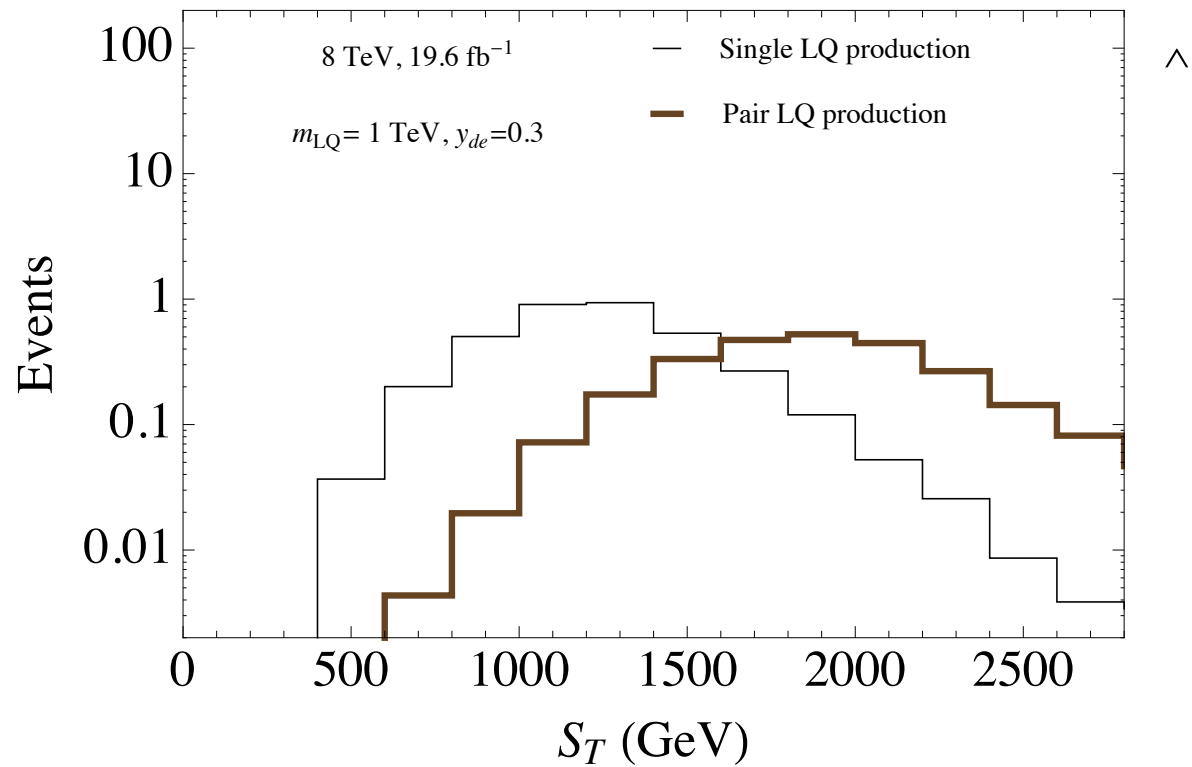
$$S_T = p_T(\mu_1) + p_T(\mu_2) + p_T(jet_1) + p_T(jet_2)$$

$M_{\min}(\mu, jet) \equiv$ the smallest of the two **electron-jet** (muon-jet) invariant masses which minimizes the $LQ - \overline{LQ}$ invariant mass difference;

*CMS PAS EXO-12-041.

^CMS PAS EXO-12-042.

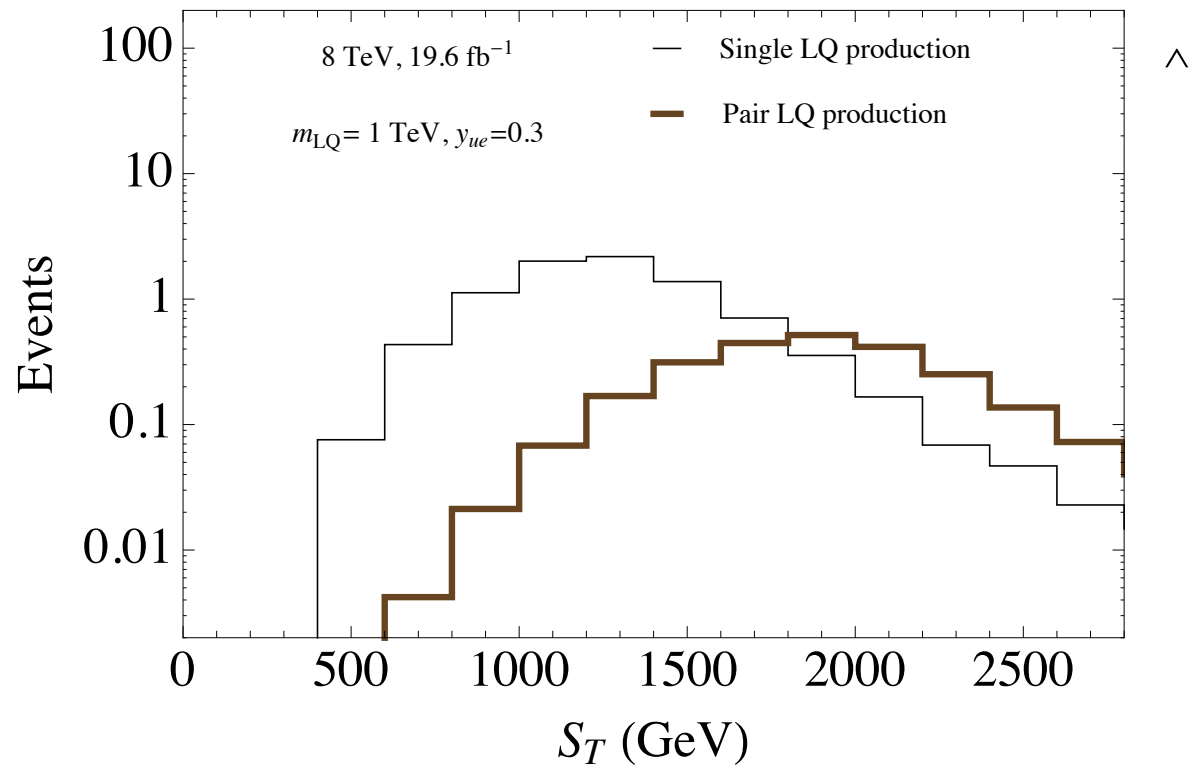
THE CMS SEARCH* (FIRST GENERATION LEPTOQUARK)



*CMS PAS EXO-12-041.

^V. Brigljević, I. Doršner, A. Greljo and U. Langenegger, work in progress.

THE CMS SEARCH* (FIRST GENERATION LEPTOQUARK)



*CMS PAS EXO-12-041.

^V. Brigljević, I. Doršner, A. Greljo and U. Langenegger, work in progress.

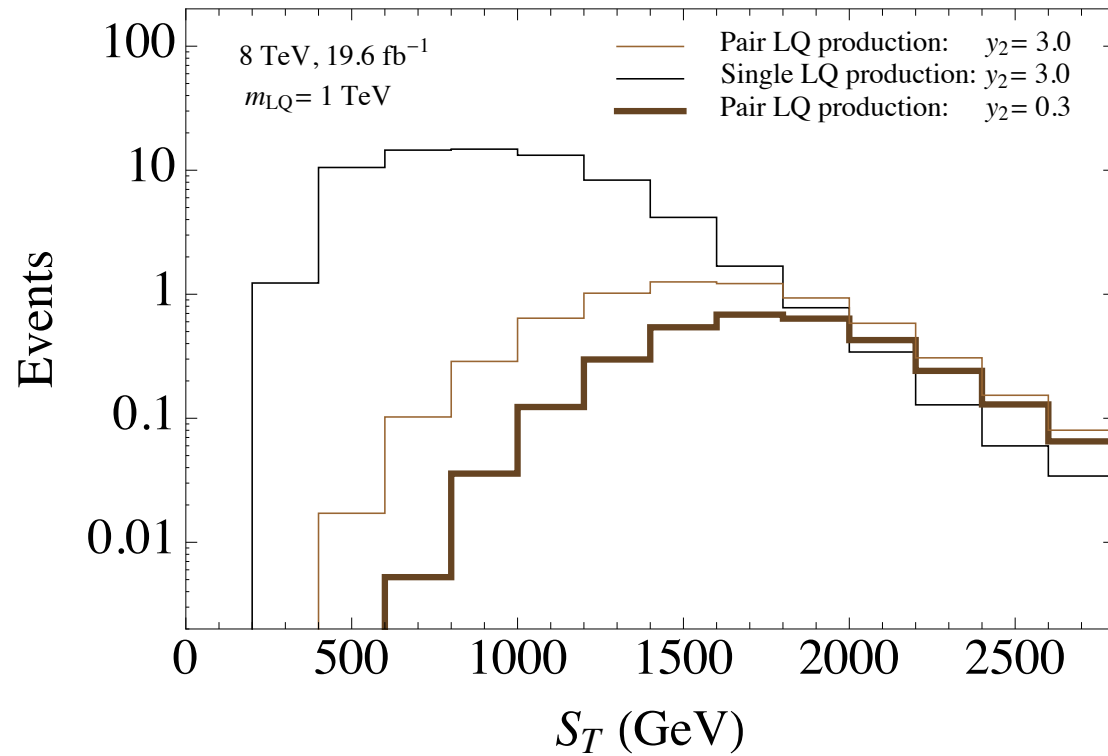
THE CMS SEARCH RECAST*

(SECOND GENERATION LEPTOQUARK)

m_{LQ} (GeV)	500	700	900	950	≥ 1000
$S_T >$ (GeV)	685	935	1135	1175	1210
$M_{\mu\mu} >$ (GeV)	150	195	230	235	245
$M_{\min}(\mu, j) >$ (GeV)	155	295	535	610	690
Signal yield < at 95% CL	34	9.8	5.6	3.5	1.8

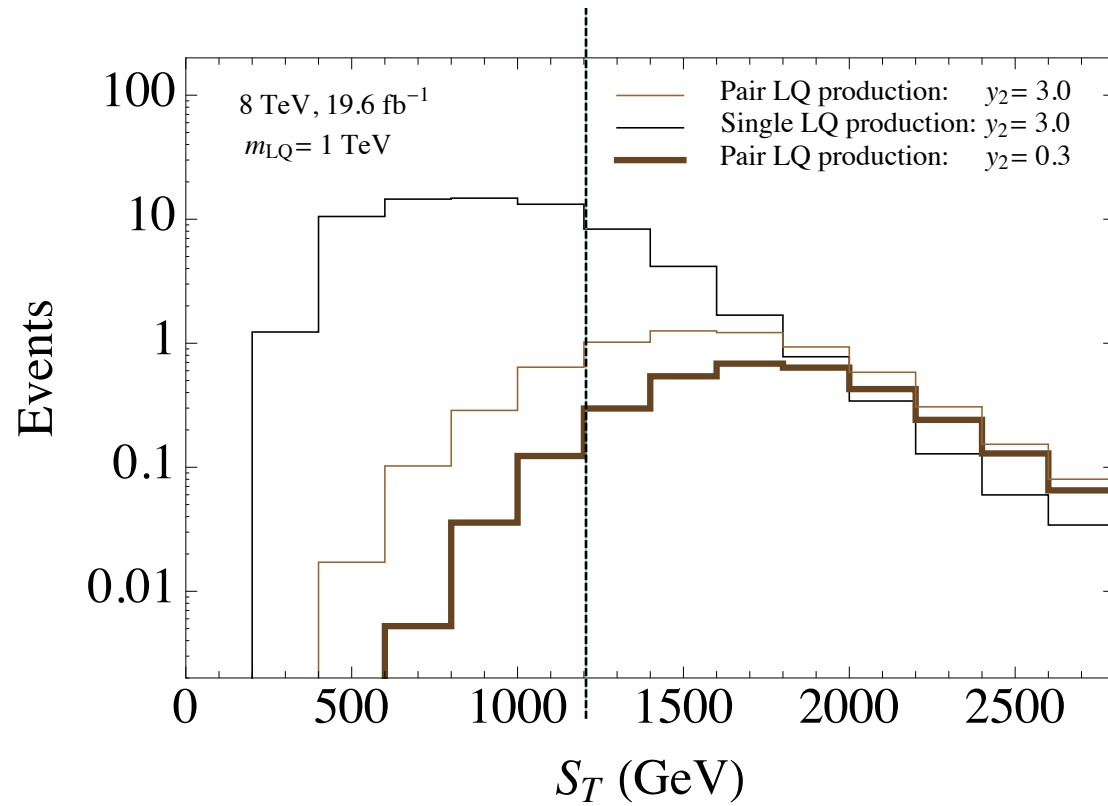
*CMS PAS EXO-12-042.

THE CMS SEARCH RECAST*



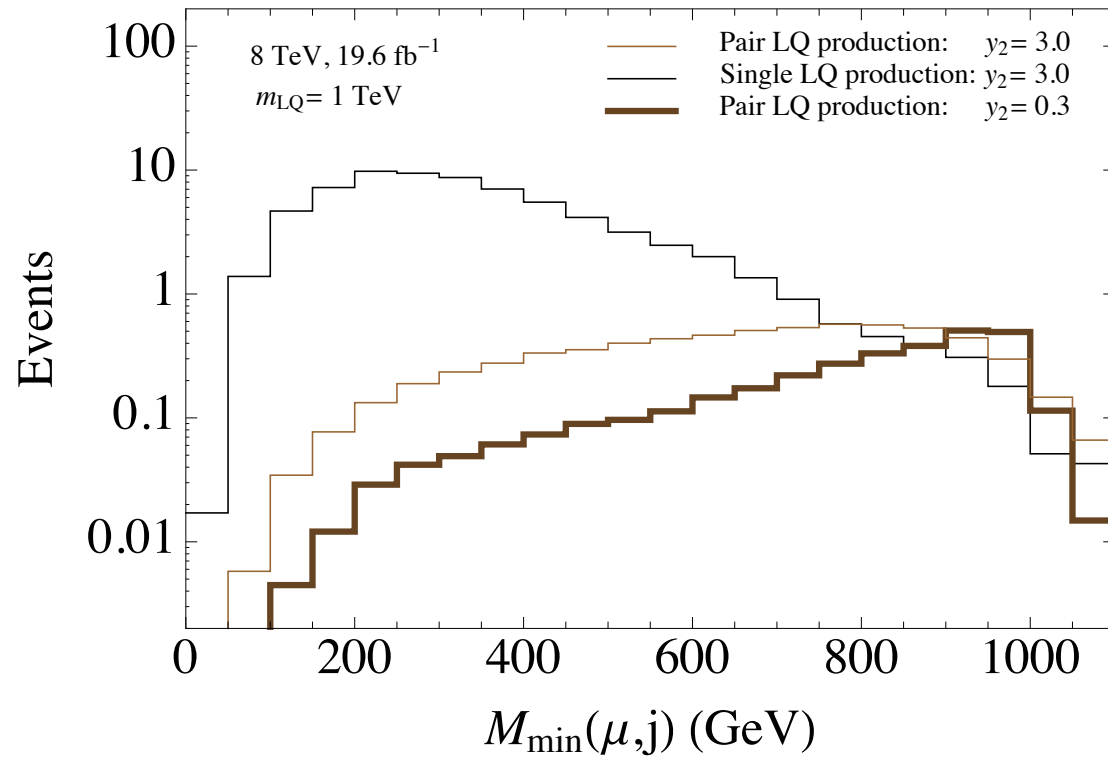
*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

THE CMS SEARCH RECAST*



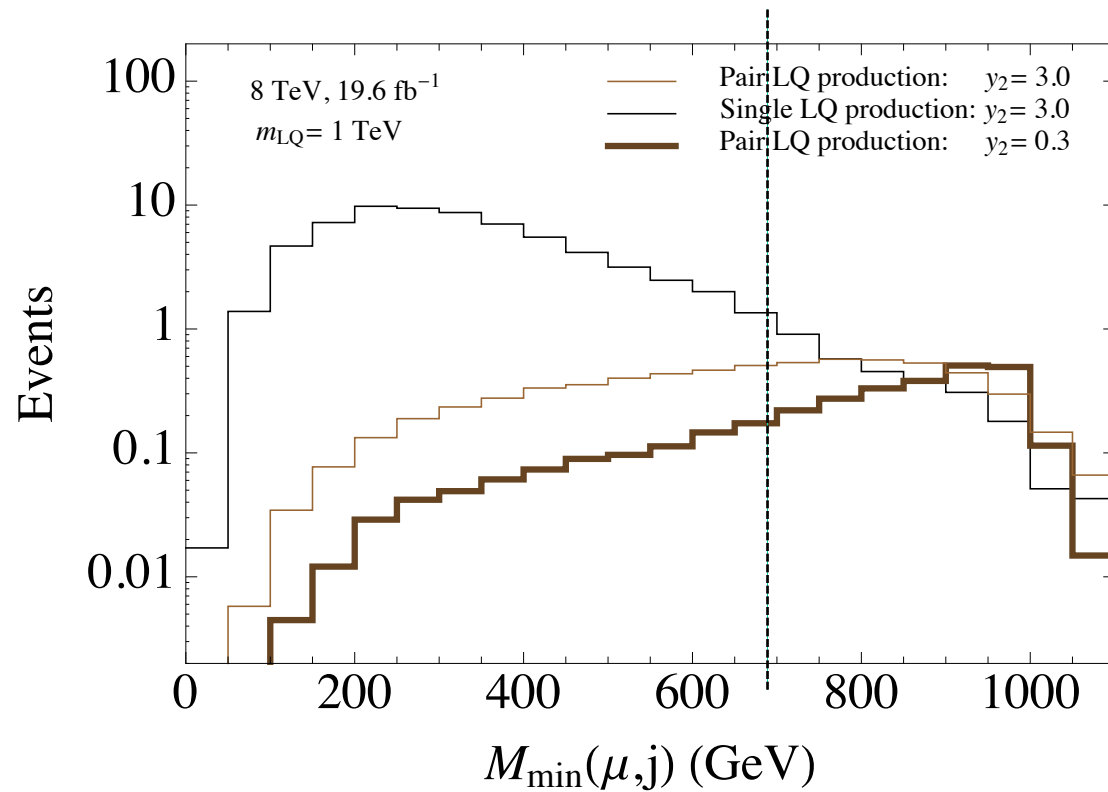
*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

THE CMS SEARCH RECAST*



*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

THE CMS SEARCH RECAST*



*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

THE CMS SEARCH RECAST*

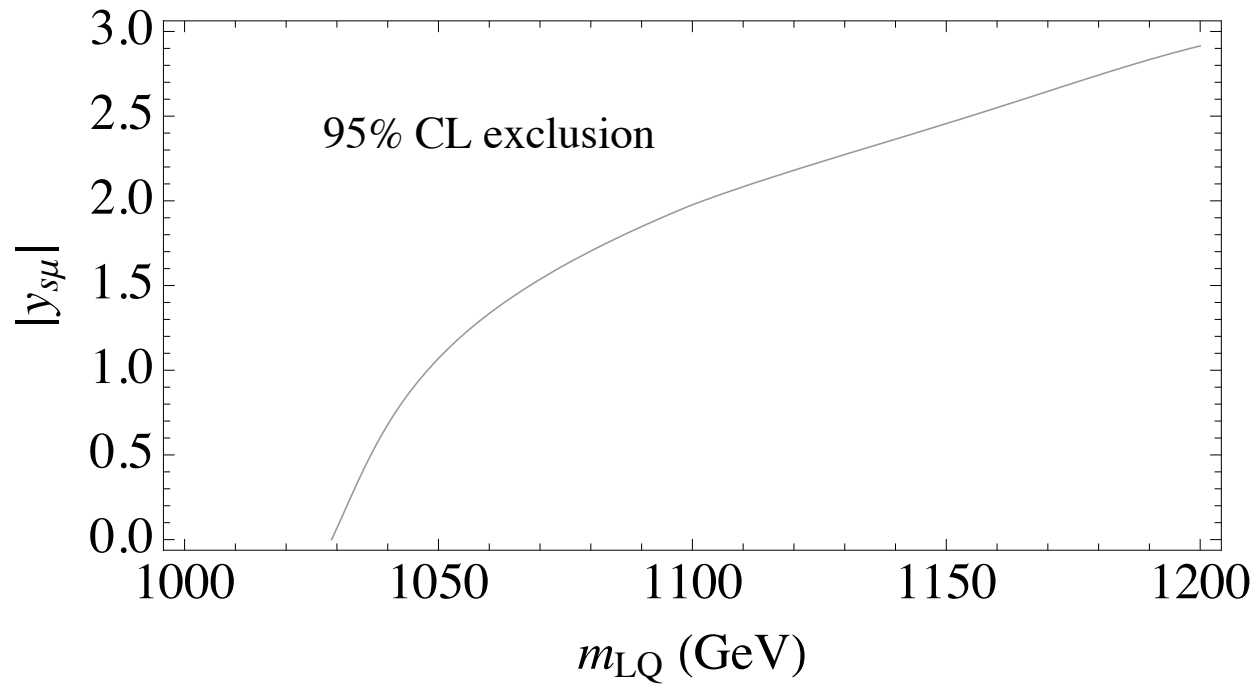
(SECOND GENERATION LEPTOQUARK)

$m_{LQ}(\text{GeV})$	$N_{\text{evs}}(\text{Pair production}) + N_{\text{evs}}(\text{Single production})$			
	$y_2 = 0.3$	$y_2 = 1.0$	$y_2 = 2.0$	$y_2 = 3.0$
500	600 + 8.2	600 + 89	720 + 330	1300 + 700
700	55 + 0.98	56 + 11	64 + 41	110 + 81
900	6.5 + 0.10	6.5 + 1.2	7.0 + 4.5	11 + 8.4
1000	2.2 + 0.03	2.2 + 0.33	2.3 + 1.1	3.1 + 2.3
1050	1.5 + 0.02	1.5 + 0.27	1.5 + 1.0	2.1 + 2.1
1100	0.96 + 0.02	0.96 + 0.21	1.0 + 0.82	1.4 + 1.6
1150	0.62 + 0.02	0.62 + 0.17	0.66 + 0.75	0.92 + 1.4
1200	0.41 + 0.01	0.41 + 0.14	0.44 + 0.55	0.60 + 1.3
1300	0.17 + 0.01	0.17 + 0.09	0.19 + 0.37	0.26 + 0.74
1400	0.07 + 0.00	0.07 + 0.06	0.08 + 0.24	0.12 + 0.52

*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

THE CMS SEARCH RECAST*

(SECOND GENERATION LEPTOQUARK)



*I. Doršner, S. Fajfer and A. Greljo, arXiv:1406.4831.

CONCLUSIONS

Large lepton-quark-leptoquark couplings contribute to leptoquark production at LHC.

A t -channel pair production and a single leptoquark production both need to be taken into consideration if the leptoquark Yukawa coupling cannot be neglected.

Existing flavor constraints allow for sizeable Yukawa couplings of the Standard Model fermions of a single generation to leptoquarks.

CONCLUSIONS

A recast of an existing CMS search for the second generation leptoquark yields the best limit on Yukawa coupling between the leptoquark, a muon and a strange quark to date.

A recast of an existing CMS search for the first generation leptoquark could yield very stringent limit on Yukawa coupling[^] of the leptoquark that couples to an electron and an up quark or a down quark.

[^]V. Brigljević, I. Doršner, A. Greljo and U. Langenegger, work in progress.

THANK YOU

dorsner@fesb.hr