SEARCH FOR SCALAR AND VECTOR DIQUARKS AT THE LHC

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Contents

Introduction

- We examined scalar and vector diquarks at the LHC.
- Diquarks can occur beyond the standard model (SM).
- Models: composite model [Wudka86] and superstring-inspired E_6 models [Hewett et al.89].
- Diquarks are anti-triplet (3*) or sextet (6) under SU(3).

- Diquarks carry baryon number |B|=2/3 and couple to a pair of quarks.
- Diquarks have spin-1 (vector) [Arık et al.02] and spin-0 (scalar) [Atag et al.99].
- Diquarks have electrical charges |Q|=1/3, 2/3, 4/3.

Limits on Diquarks

- Fermilab (CDF) sets limits on the masses of scalar diquarks decaying to dijets with the exclusion of mass range $290 < m_{DQ} < 630$ GeV [CDFNote9246].
- Which are expected to be approximately valid for other scalar diquarks.
- There are also indirect bounds imposed on couplings from electroweak precision data from LEP e^+e^- collider. These bounds allow diquark-quark couplings up to a value $\alpha_{DQ} \sim 0.1$ [Bhattacharyya et al., 1995].

Interaction Lagrangian

$$L_{|B|=0} = f_{1L}\bar{q}_L\gamma^\mu q_L DQ^C_{1\mu} + (f_{1R}\bar{d}_R\gamma^\mu d_R + f'_{1R}\bar{u}_R\gamma^\mu u_R)DQ'^C_{1\mu}$$

$$+ \bar{f}_{1R}\bar{u}_R\gamma^\mu d_R \tilde{DQ}^C_{1\mu} + f_{3L}\bar{q}_L\tau\gamma^\mu q_L . DQ^C_{3\mu} + f_2\bar{q}_L i\tau_2 u_R DQ^C_2$$

$$+ \bar{f}_2\bar{q}_L i\tau_2 d_R \tilde{DQ}^c_2 + H.c.$$

$$L_{|B|=2/3} = (g_{1L}\bar{q}^C_L i\tau_2 q_L + g_{1R}\bar{u}^C_R d_R)DQ^C_1 + \tilde{g}_{1R}\bar{d}^C_R d_R \tilde{DQ}^c_1$$

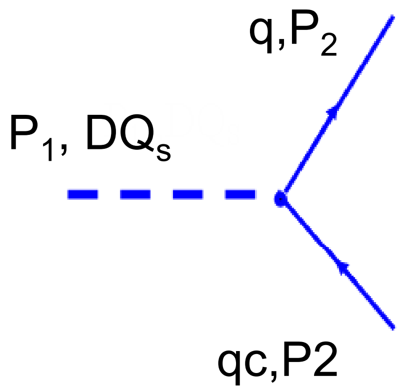
$$+ \tilde{g}'_{1R}\bar{u}^C_R u_R \tilde{DQ}'^C_1 + g_{3L}\bar{q}^C_L i\tau_2\tau q_L . DQ^C_3 + g_2\bar{q}^C_L\gamma^\mu d_R DQ^C_{2\mu}$$

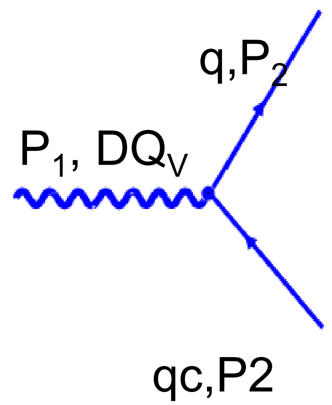
$$+ \tilde{g}_2\bar{q}^C_L\gamma^\mu u_R \tilde{DQ}^c_{2\mu} + H.c.$$

Atağ et al, 1999.; Arik et al., 2002

Decay Channels

Decay channels for scalar and vector diquarks





Squared Matrix elements for Scalar and vector diquarks

$$\langle |M_S|^2 \rangle = 2(a^2 + b^2) C_{Sf}\, g^2\, m_{QD}^2$$

$$\langle |M_V|^2 \rangle = \frac{4}{3}(a^2 + b^2) C_{Vf}\, g'^2\, m_{QD}^2$$

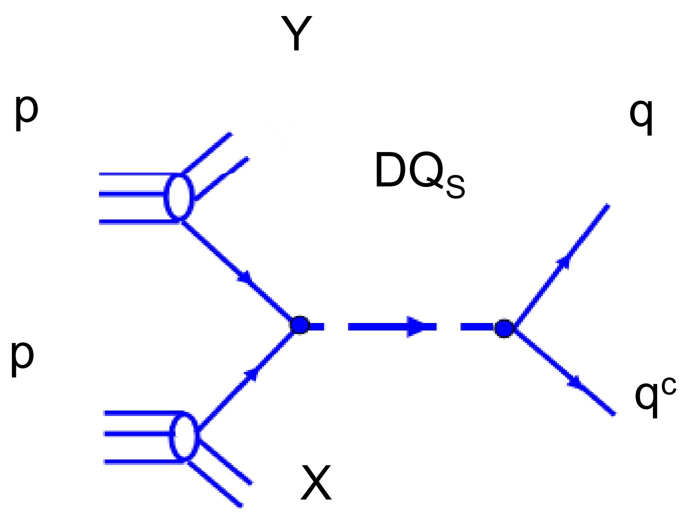
$\alpha_{DQ} = 0.1 = \alpha_s$ and a = b = ½ ,

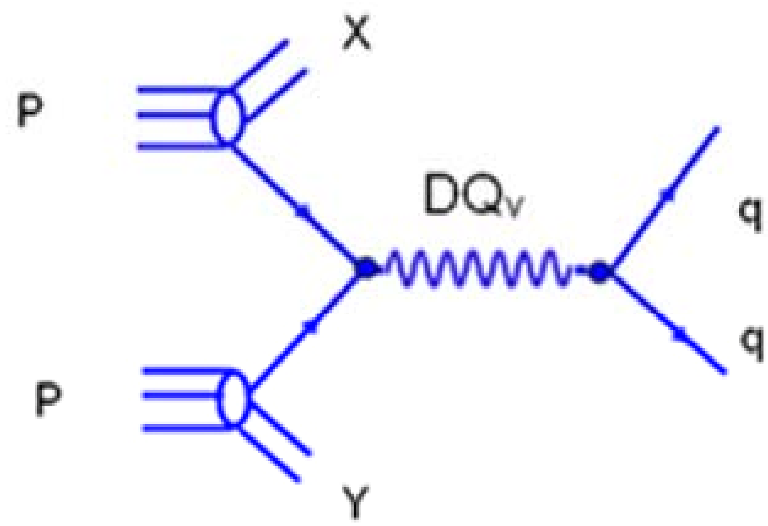
$$\Gamma_{DQ}^{S} = \frac{F_S\, g^2\, m_{DQ}}{16\pi} \cong 25 GeV \left(\frac{F_S\, m_{DQ}}{1 TeV}\right)$$

$$\Gamma_{DQ}^{V} = \frac{F_S\, g^2\, m_{DQ}}{24\pi} \cong 17 GeV \left(\frac{F_S\, m_{DQ}}{1 TeV}\right)$$

Resonant Production of Diquarks at LHC

- Schematic view of scalar and vector diquark resonant production (contributing to dijet final state)





Differential cross sections for scalar and vector diquarks:

$$\frac{d\hat{\sigma}^S}{d\hat{t}}(q_i q_j \to DQ \to q_i q_j) = \frac{F_S g^4}{64\pi[(\hat{s}-m_{DQ}^2)^2 + (m_{DQ}\Gamma_{DQ}^S)^2]}$$

$$\frac{d\hat{\sigma}^V}{d\hat{t}}(q_i q_j \to DQ \to q_i q_j) = \frac{F_S g^4}{16\pi[(\hat{s}-m_{DQ}^2) + (m_{DQ}\Gamma_{DQ}^V)^2]}$$

- In the narrow width approximation ($\Gamma_{DQ}/m_{DQ}<0.1$), the cross section of s-channel diquark production can be obtained as:

$$\frac{1}{(\hat{s}-m_{DQ}^2)^2+m_{DQ}^2\Gamma_{DQ}^2} \cong \frac{\pi}{m_{DQ}\Gamma_{DQ}}\delta(\hat{s}-m_{DQ}^2)$$

$$\hat{\sigma}_R^S = \frac{F_S g_{DQ}^4 \hat{s}}{64 m_{DQ}\Gamma_{DQ}^S}\delta(\hat{s}-m_{DQ}^2)\ , \quad \hat{\sigma}_R^V(\hat{s}) \cong \frac{F_S g_{DQ}^4 \hat{s}}{24 m_{DQ}\Gamma_{DQ}^V}\delta(\hat{s}-m_{DQ}^2)$$

- The total cross section for the resonance production of scalar diquarks at pp collider is given by;

$$\sigma = \int_{m_{DQ}^2/s}^{1} \frac{dx}{x} f_{q/p}(x, Q_p^2) f_{q'/p}(m_{DQ}^2/xs, Q_p^2) \widehat{\sigma}(\widehat{s})$$

We have used CTEQ5L (Lai et al., 2000) parametrization with $Q_p^2 = \hat{s}$

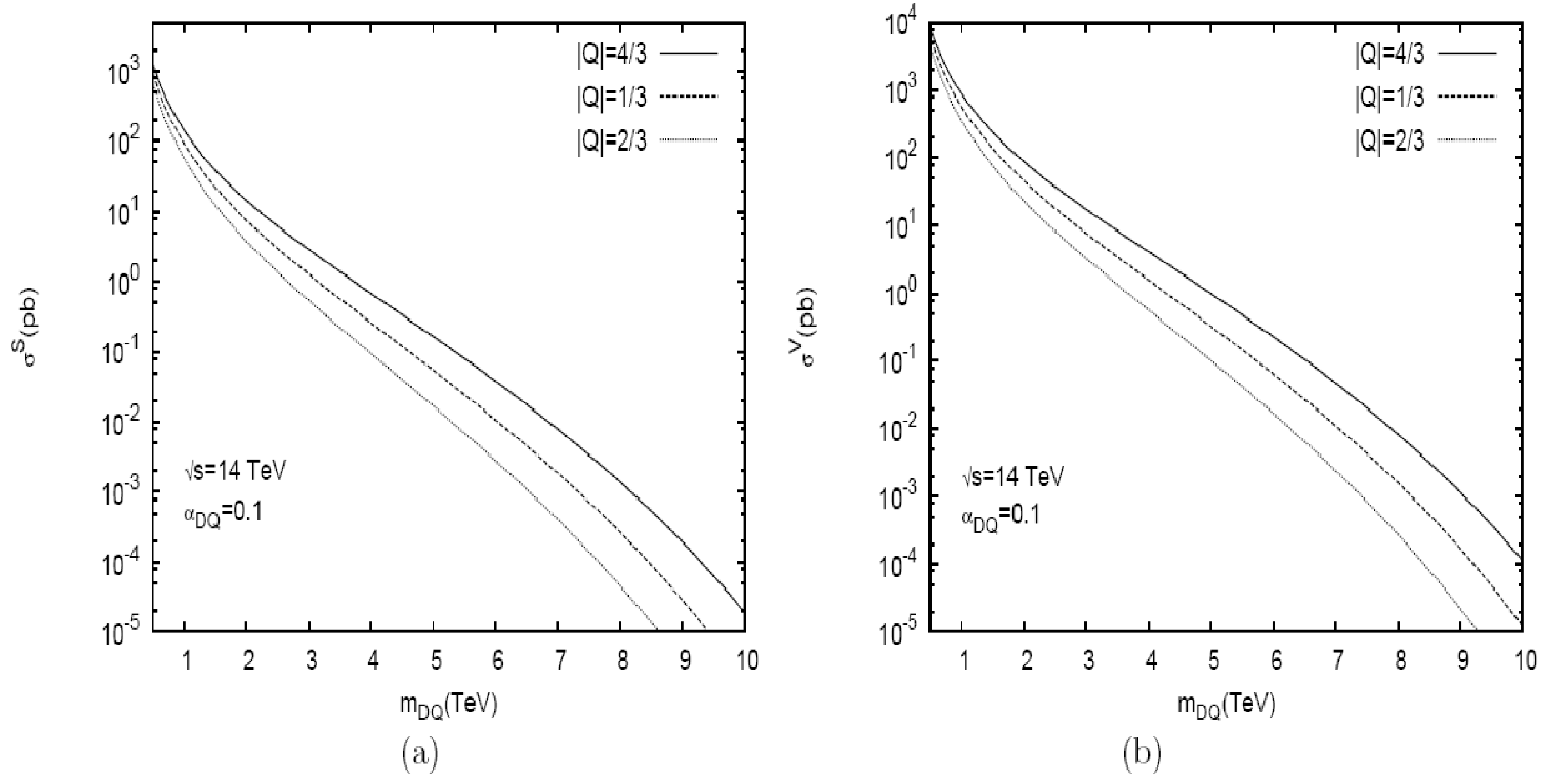
- Using narrow width approximation;

$$\sigma_R^S(m_{DQ}^2) = \frac{F_S g_{DQ}^4}{64 m_{DQ} \Gamma_{DQ}^S} \qquad \sigma_R^V(m_{DQ}^2) = \frac{F_S g_{DQ}^4}{24 m_{DQ} \Gamma_{DQ}^V}$$

- The total cross section for the resonance production of vector diquarks at pp collider is given by

$$\sigma^V = \int_{m_{DQ}^2/s}^{1} \frac{dx}{x} f_{q/p}(x, Q_p^2) f_{q'/p}(m_{DQ}^2/xs, Q_p^2) \sigma_R^V(m_{DQ}^2)$$

The cross section is plotted against the diquark mass.



Total cross sections in pp collisions for a) scalar and b) vector diquarks for different charges, with coupling strength α_{DQ}=0.1, depending on their mass (Çakır et al. 2005).

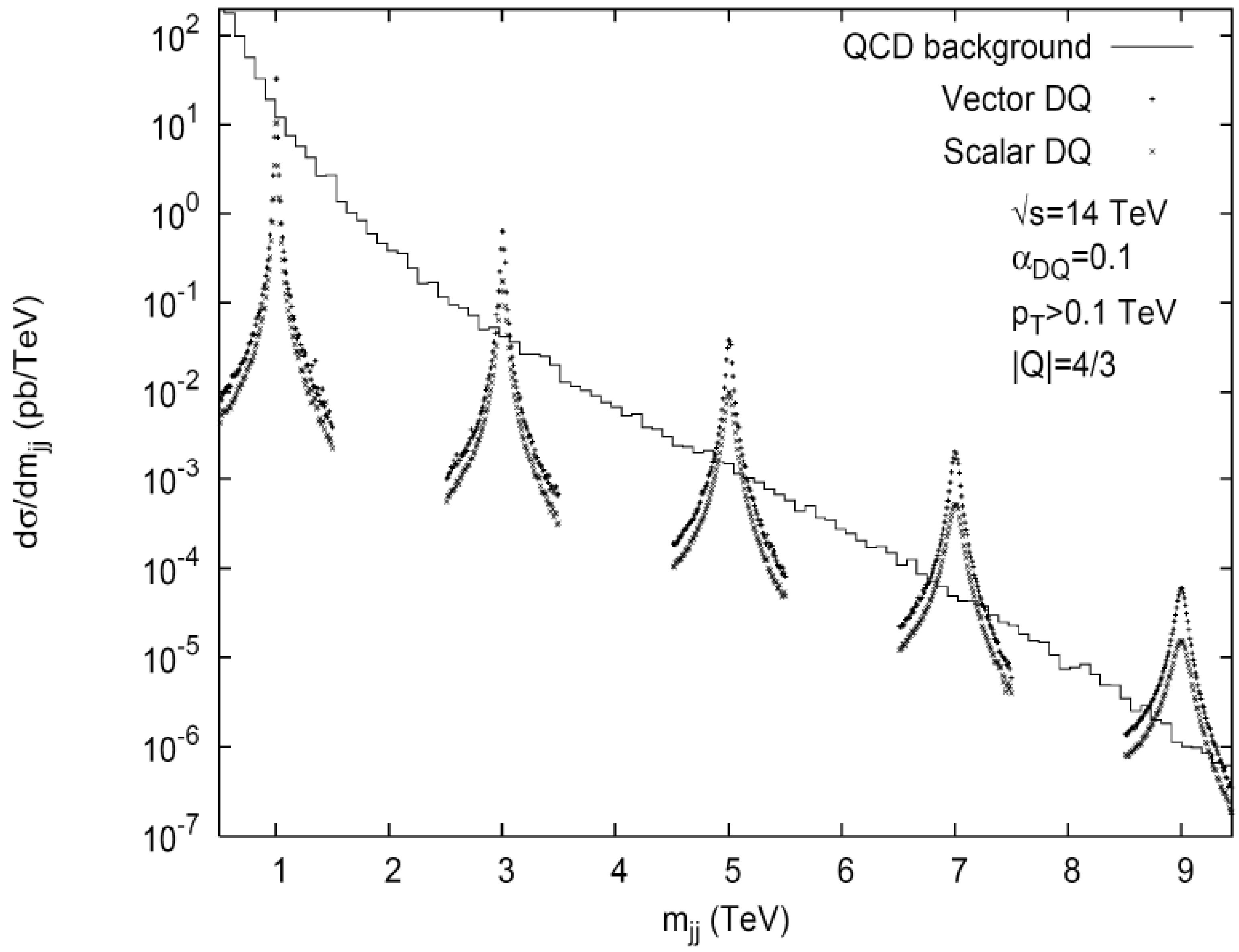
Signal and Background

- The cross sections (in pb) for QCD backgrounds contributing to two jets final states at parton level generated by CompHEP (Boos et al., 2004) with various P_T cuts

Process	$p_T > 0.1$ TeV	$p_T > 0.5$ TeV	$p_T > 1$ TeV	$p_T > 2$ TeV
$gg \to gg$	6.3×10^5	2.0×10^2	2.3×10^0	5.7×10^{-3}
$qg \longrightarrow qg$	6.4×10^5	4.8×10^2	1.0×10^1	5.7×10^{-2}
$qq' \to qq'$	1.0×10^5	1.8×10^2	6.7×10^0	8.8×10^{-2}
$gg \to q\overline{q}$	2.4×10^4	9.8×10^0	1.0×10^{-1}	2.9×10^{-4}
$q\overline{q} \longrightarrow q'\overline{q'}$	1.6×10^3	2.8×10^0	1.3×10^{-1}	1.1×10^{-3}
$q\overline{q} \longrightarrow gg$	1.5×10^3	2.5×10^0	6.7×10^{-2}	8.5×10^{-4}
Total	1.4×10^6	8.8×10^2	1.9×10^1	1.5×10^{-1}

Signal and Background

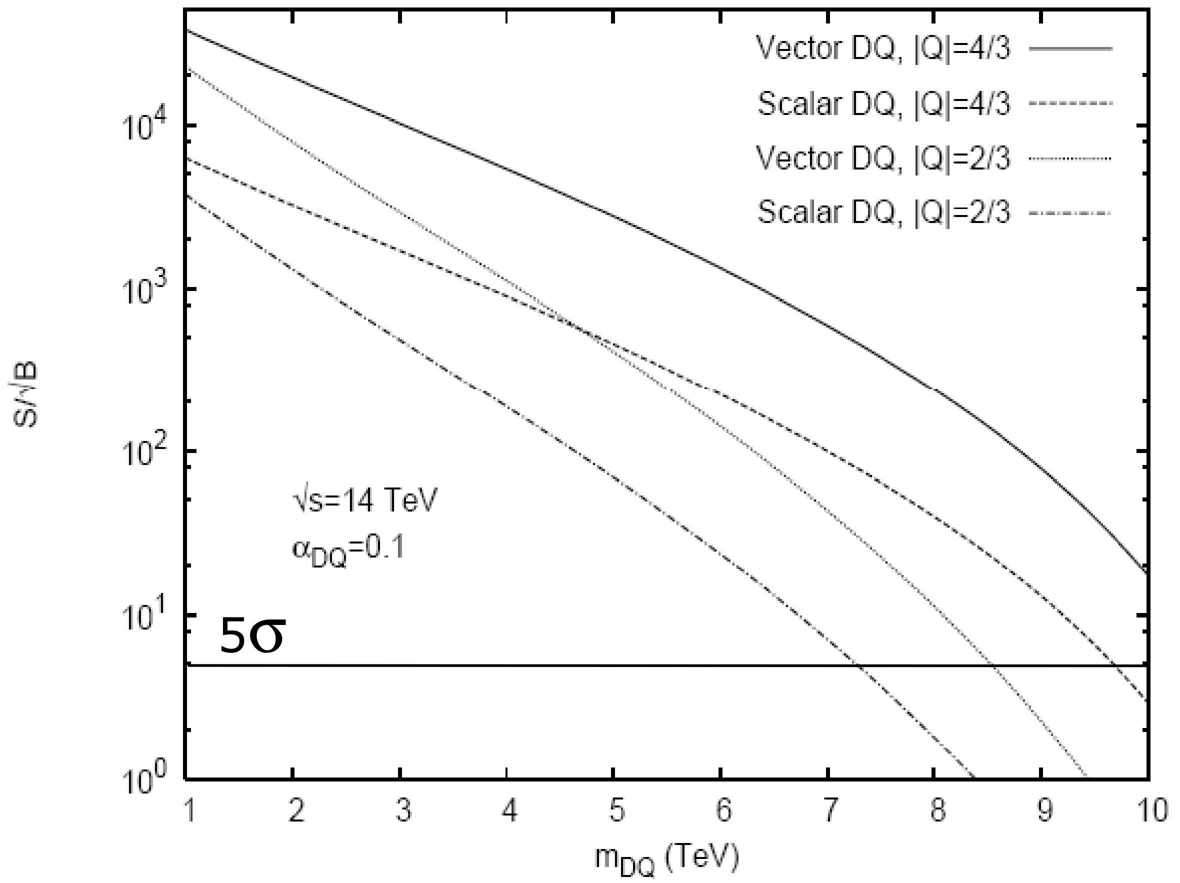
- The dijet invariant mass distribution for the process $pp \rightarrow 2j+X$ including the signal and the QCD backgrounds at the LHC.
- For comparison signal peaks for scalar and vector diquark with masses $m_{DQ}=1,3,5,7,9$ TeV and $\alpha_{DQ}=0.1$ are shown over the dijet background distribution.



QCD background
Vector DQ
Scalar DQ
√s=14 TeV
α_{DQ}=0.1
p_T>0.1 TeV
|Q|=4/3
$d\sigma/dm_{jj}$ (pb/TeV)
m_{jj} (TeV)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
2
3
4
5
6
7
8
9

Signal Significance

- In order to obtain the observability of diquarks at the LHC we have calculated signal (S) and background (B) event estimations for an integrated luminosity of 10^5 pb^{-1}.
- We present $S/\sqrt{B}$ as a function of diquark mass for scalar and vector diquarks with charges |Q|=4/3, 2/3.



The signal significances $S / \sqrt{B}$ for diquarks as a function of diquark mass m_{DQ} at the LHC with L= 10^5 pb^{-1} (Çakır et al.,2005) .

Conclusions

- The resonant production of scalar and vector diquarks at LHC have large cross section, eg. O(1pb) at m=3 TeV.

- With reasonable cuts, it may be possible to cover mass ranges up to 10 TeV for coupling $\alpha_{DQ}=0.1$.

- If we take at least 25 signal events and $S/\sqrt{B}\geq 5$ as discovery criteria;

Scalar (vector) diquarks with charge $|Q|=2/3$ can be observed up to 7.5 (8.5) TeV at the LHC.

- For the diquarks with charge |Q|=4/3 it is possible to cover mass ranges up to 9.5 (10) TeV at the LHC with $L_{int}= 10^5$ pb^{-1}.
- For this luminosity, 10^7 scalar diquark events/year and 10^8 vector diquark events/year are expected for m_{DQ}=1 TeV.
- Our results show that even for much lower coupling constants such as 10^{-3}, diquarks can be seen at the LHC.

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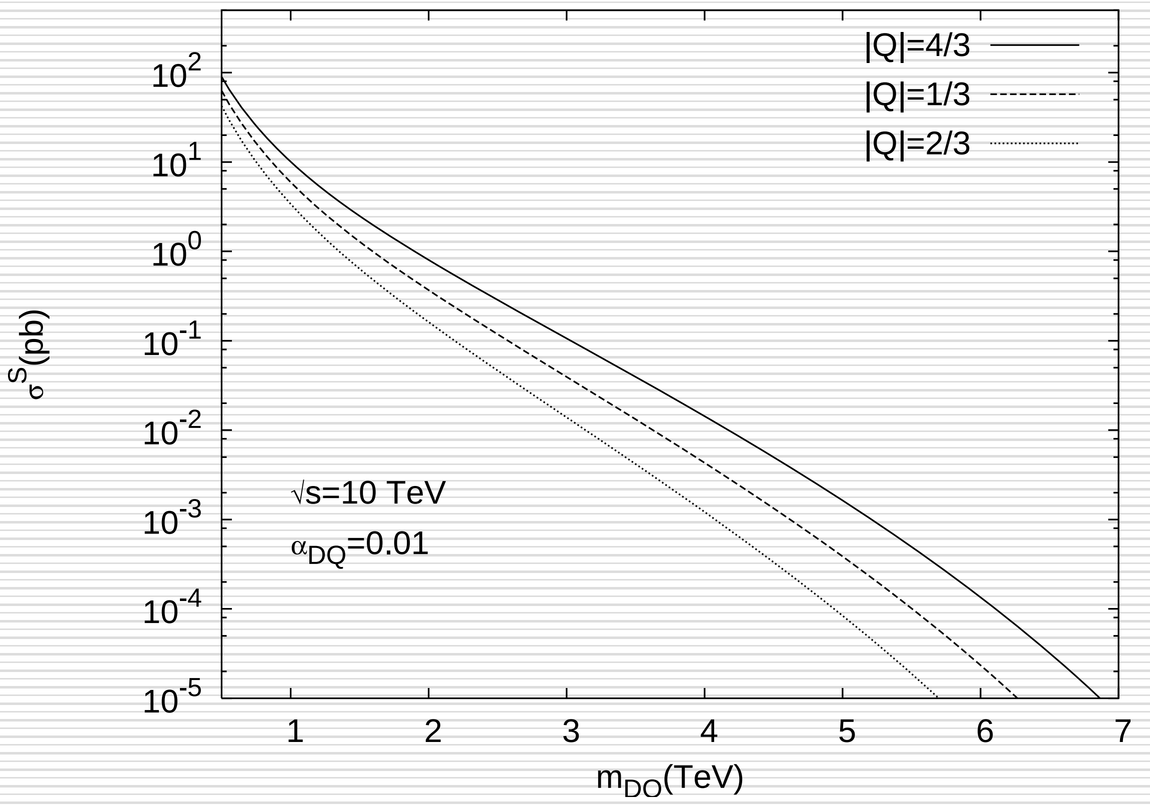
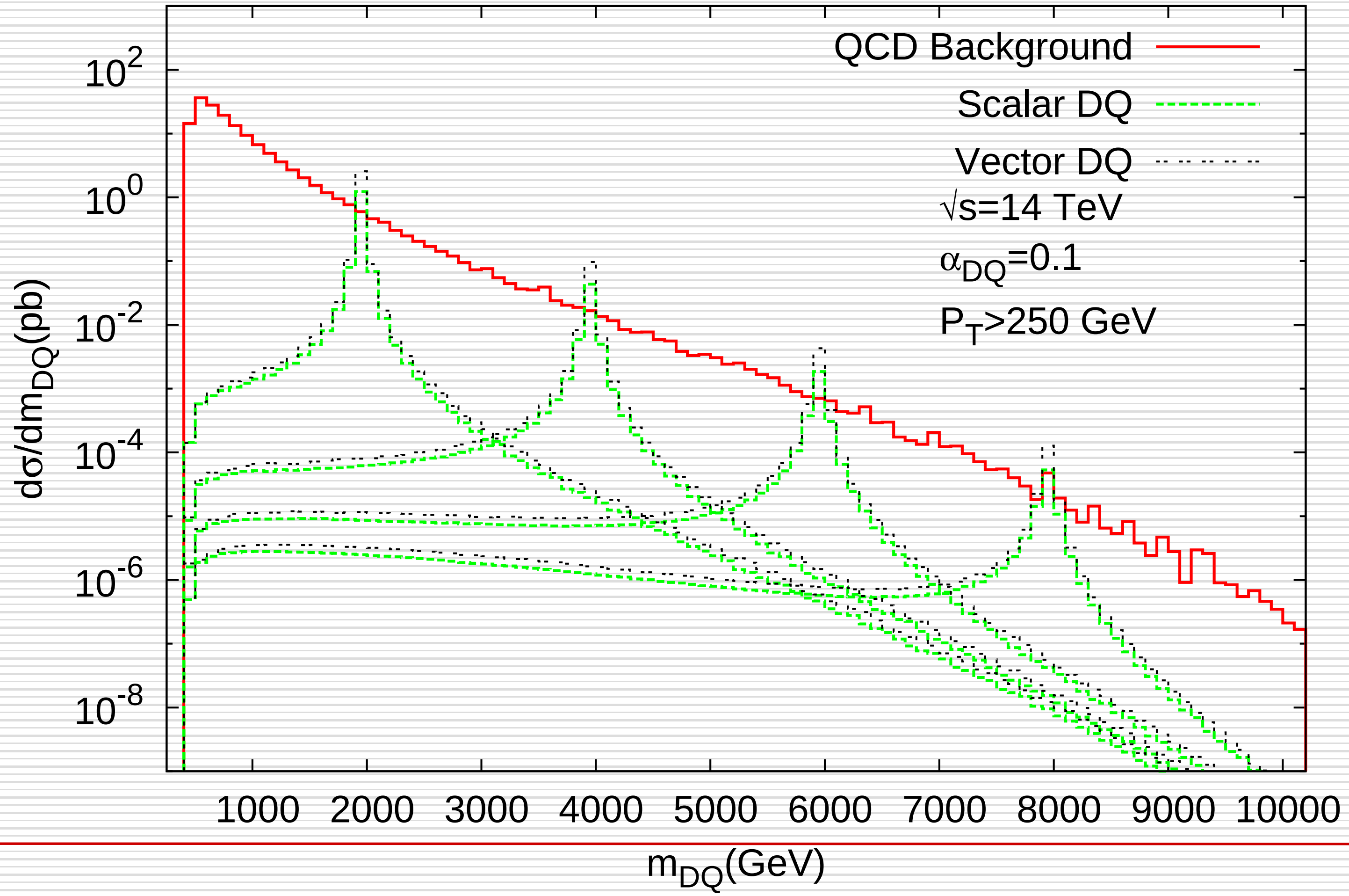
THANKS…

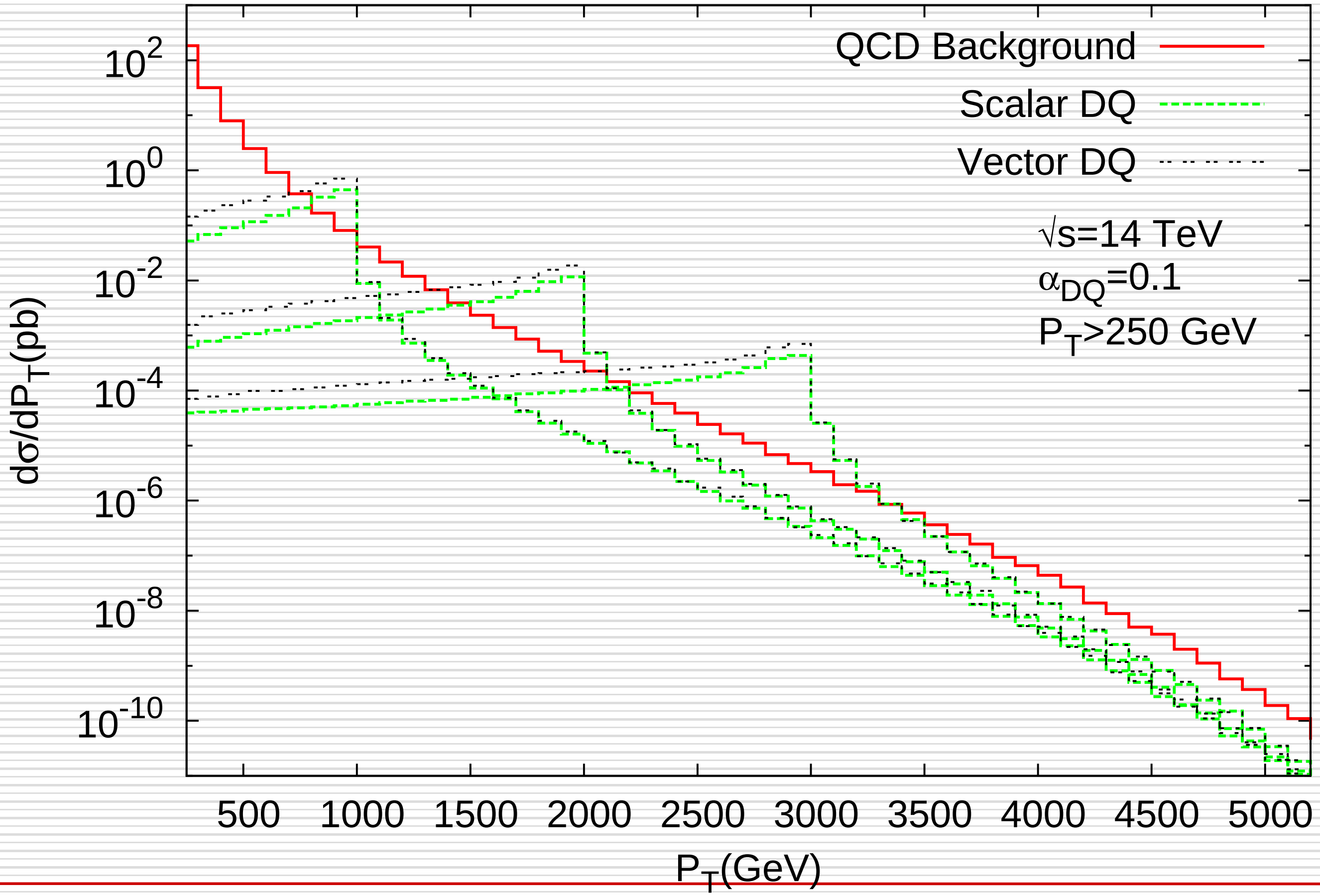


|Q|=4/3
|Q|=1/3
|Q|=2/3
√s=10 TeV
α_DQ=0.01
σ^S(pb)
m_DQ(TeV)
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1
2
3
4
5
6
7

- From these figures we find that diquarks with charge $|Q| = 4/3$ have the largest cross sections whencompared to the other types. The reach for the diquark mass is approximately 7 TeV.
- If we take $\alpha_{DQ} = 0.1$ and the LHC nominal energy of ($\sqrt{S} = 14$TeV) diquark production cross sections becomes approximately 10 times larger and the potential for the discovery of vector diquarks increases to m_{DQ} 10 TeV.

Another calculations





QCD Background
Scalar DQ
Vector DQ
√s=14 TeV
α_DQ=0.1
P_T>250 GeV
dσ/dP_T(pb)
P_T(GeV)
10^2
10^0
10^-2
10^-4
10^-6
10^-8
10^-10
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

- For the diquarks with charge $|Q|=4/3$ it is possible to cover mass ranges up to 8.9 (10) TeV at the LHC with Lint= 10^4 pb^{-1}.

- For this luminosity, 10^6 scalar diquark events/year and 10^7 vector diquark events/year are expected for $m_{DQ}=1$ TeV.