$d$-$D$ quark mixing angle in the $E_6$ model

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Recall the model

\[
\begin{pmatrix}
u_L \\
d_L
\end{pmatrix}, u_R, d_R, D_L, D_R \begin{pmatrix}c_L \\
S_L
\end{pmatrix}, c_R, s_R, S_L, S_R \begin{pmatrix}t_L \\
b_L
\end{pmatrix}, t_R, b_R, B_L, B_R
\]

**D, S, B:** New iso-singlet quarks \((Q = -\frac{1}{3})\)

\[
L_D = \frac{\sqrt{4\pi\alpha_{em}}}{2\sqrt{2}\sin\theta_W} [\bar{u}^\theta \gamma_\alpha (1 - \gamma_5) d \cos \phi + \bar{u}^\theta \gamma_\alpha (1 - \gamma_5) D \sin \phi] W^\alpha - \frac{\sqrt{4\pi\alpha_{em}}}{4\sin\theta_W} \left[\frac{\sin \phi \cos \phi}{\cos \theta_W} \bar{d} \gamma_\alpha (1 - \gamma_5) D\right] Z^\alpha - \frac{\sqrt{4\pi\alpha_{em}}}{12\cos\theta_W \sin\theta_W} \left[\bar{D} \gamma_\alpha (4\sin^2 \theta_W - 3\sin^2 \phi (1 - \gamma_5)) D + \bar{d} \gamma_\alpha (4\sin^2 \theta_W - 3\cos^2 \phi (1 - \gamma_5)) d\right] Z^\alpha + h.c.
\]

The measured values of CKM elements & unitarity of the 3x4 CKM rows constrains \(\phi: \sin \phi < 0.07\).

**Assumptions:**
1. In-family mixing bigger than between family mixing
2. D quark is the lightest, like SM: most accessible in LHC
3. E_6 gauge bosons heavy & don’t interact w/ SM bosons

\(\theta:\) CKM mixing angle
\(\phi:\) d - D mixing angle
Mixing angle with SM quark

- d-D mixing angle can only be extracted from the single production of D quark since the cross section depends linearly on $(\sin \Phi)^2$

- Cross section for $pp \rightarrow D + \text{jet}$ as a function of $m_D$ and for various values of the mixing angle (0.015 ... 0.065)

$D$ quark + jet production and decay @ LHC should be studied
• Decays involving Z would be easiest to reconstruct:

\[ m_D = 400 \ldots 2000 \text{ GeV} \] cases are considered using generator level MC (CompHEP) with 2j+Z as the signal (\(\sin\Phi=0.045\))

- All SM processes yielding 2j+Z are also considered as background events where j can be any light jet.
Event selection

- Trigger and detector driven common cuts for all mD values:
  
  \[ P_{Tp} > 15 \text{ GeV} \]
  \[ |\eta_p| < 3.2 \]
  \[ |\eta_Z| < 3.2 \]
  \[ R_p > 0.4 \]
  \[ M_{Zp} = M_D \pm 20 \text{ GeV} \]

✓ Signal & Bg can be separated using the PT of the most energetic jet:
Further details

• Cut values were optimized by maximizing the signal significance, $\sigma = S/\sqrt{B}$

• Effective signal and bg cross sections for 2j+Z:

- Number events from Z leptonic decays after 100fb$^{-1}$ integrated luminosity:
Mixing angle reach

• cross section at a given $m_D$ depends linearly on $(\sin\Phi)^2$

• the signal significances obtained at the example $\sin\Phi=0.045$ can be converted to $3\sigma$ exclusion plots for angular reach at fixed mass values
Mixing angle reach

$3\sigma$ signal / exclusion curves

- Cross section at a given $m_D$ depends linearly on $(\sin\Phi)^2$

- The signal significances obtained at the example $\sin\Phi=0.045$ can be converted to $3\sigma$ exclusion plots for angular reach at fixed mass values

**BUT:** gluon jets were forgotten

$\sigma_{BG}$ should be $\sim *3.4$
Outlook

• Fix the BG problem, re-optimize, recalculate

• We can use the jet associated production of the $D$ quark to make a measurement on its mixing angle to the SM quarks.

• If there is no signal observation a limit curve on the $\sin \Phi$ vs $m_D$ plane can be imposed.

• If the mixing angle is not so small, the single production might become more efficient than the double production for the discovery as well.