E_6 GUT model & the Higgs boson search

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Flavour at the LHC workshop

Recall the model

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

D, S, B: New iso-singlet quarks (Q=−⅓)

$$\begin{aligned} \mathrm{L}_{\mathcal{D}} &= \frac{\sqrt{4\pi\alpha_{em}}}{2\sqrt{2}\sin\theta_W}\left[\bar{u}^{\theta}\gamma_\alpha\left(1-\gamma_5\right)d\cos\phi + \bar{u}^{\theta}\gamma_\alpha\left(1-\gamma_5\right)D\sin\phi\right]W^\alpha \\ &- \frac{\sqrt{4\pi\alpha_{em}}}{4\sin\theta_W}\left[\frac{\sin\phi\cos\phi}{\cos\theta_W}\bar{d}\gamma_\alpha\left(1-\gamma_5\right)D\right]Z^\alpha \\ &- \frac{\sqrt{4\pi\alpha_{em}}}{12\cos\theta_W\sin\theta_W}\left[\bar{D}\gamma_\alpha\left(4\sin^2\theta_W - 3\sin^2\phi(1-\gamma_5)\right)D + \bar{d}\gamma_\alpha\left(4\sin^2\theta_W - 3\cos^2\phi(1-\gamma_5)\right)d\right]Z^\alpha + h.c. \end{aligned} \tag{1}$$

The measured values of CKM elements & unitarity of the 3x4 CKM rows constrains ϕ : *sin* ϕ < *0.07* .

θ : CKM mixing angle
ϕ : d - D mixing angle

Assumptions:

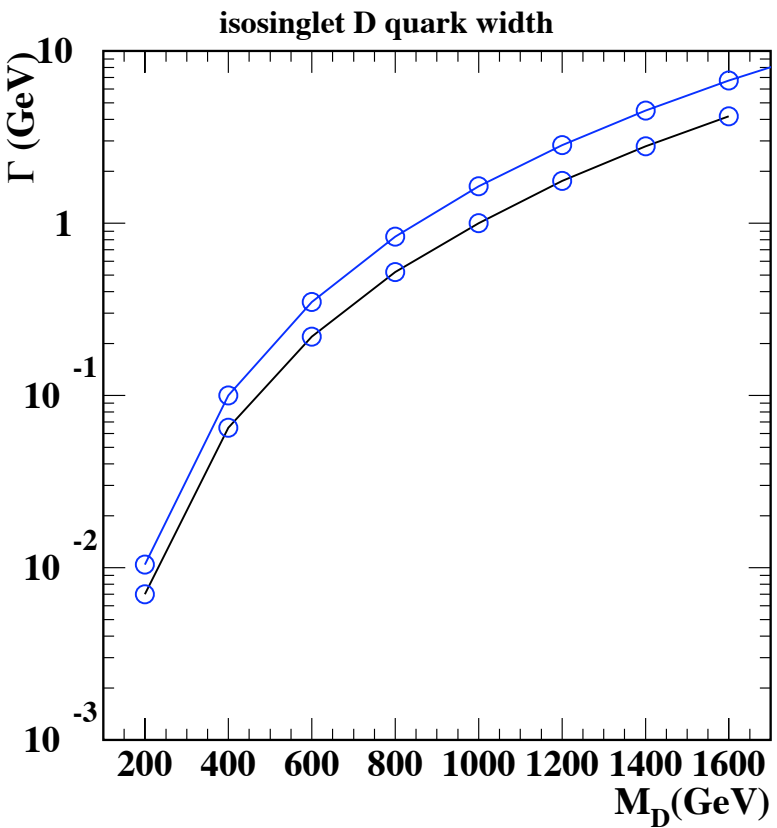
1. In-family mixing bigger than between family mixing
2. D quark is the lightest, like SM: most accessible in LHC
3. E_6 gauge bosons heavy & don't interact w/ SM bosons

Higgs Interaction

- The D-d mixing, before the SSB,will introduce D-h interaction.
- A straightforward calculation gives:

$$
\begin{aligned}
L_h^M &= \frac{m_D}{\nu}\sin^2\phi_L \bar{D}^M D^M h \\
&- \frac{\sin\phi_L\cos\phi_L}{2\nu}\bar{D}^M\left[(1-\gamma^5)m_D+(1+\gamma^5)m_d\right]d^M h \\
&- \frac{\sin\phi_L\cos\phi_L}{2\nu}\bar{d}^M\left[(1+\gamma^5)m_D+(1-\gamma^5)m_d\right]D^M h \\
&+ \frac{m_d}{\nu}\cos^2\phi_L \bar{d}^M d^M h
\end{aligned}
$$

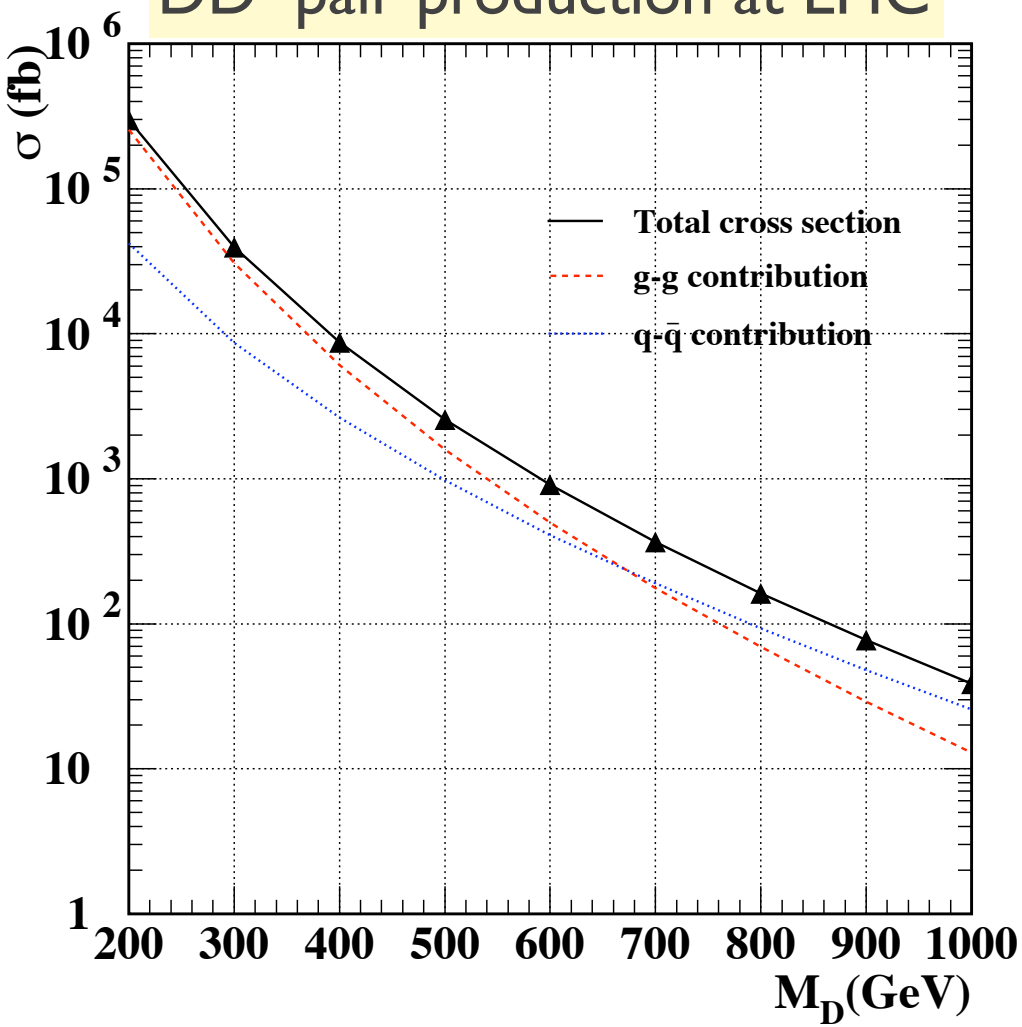
- New width calculation

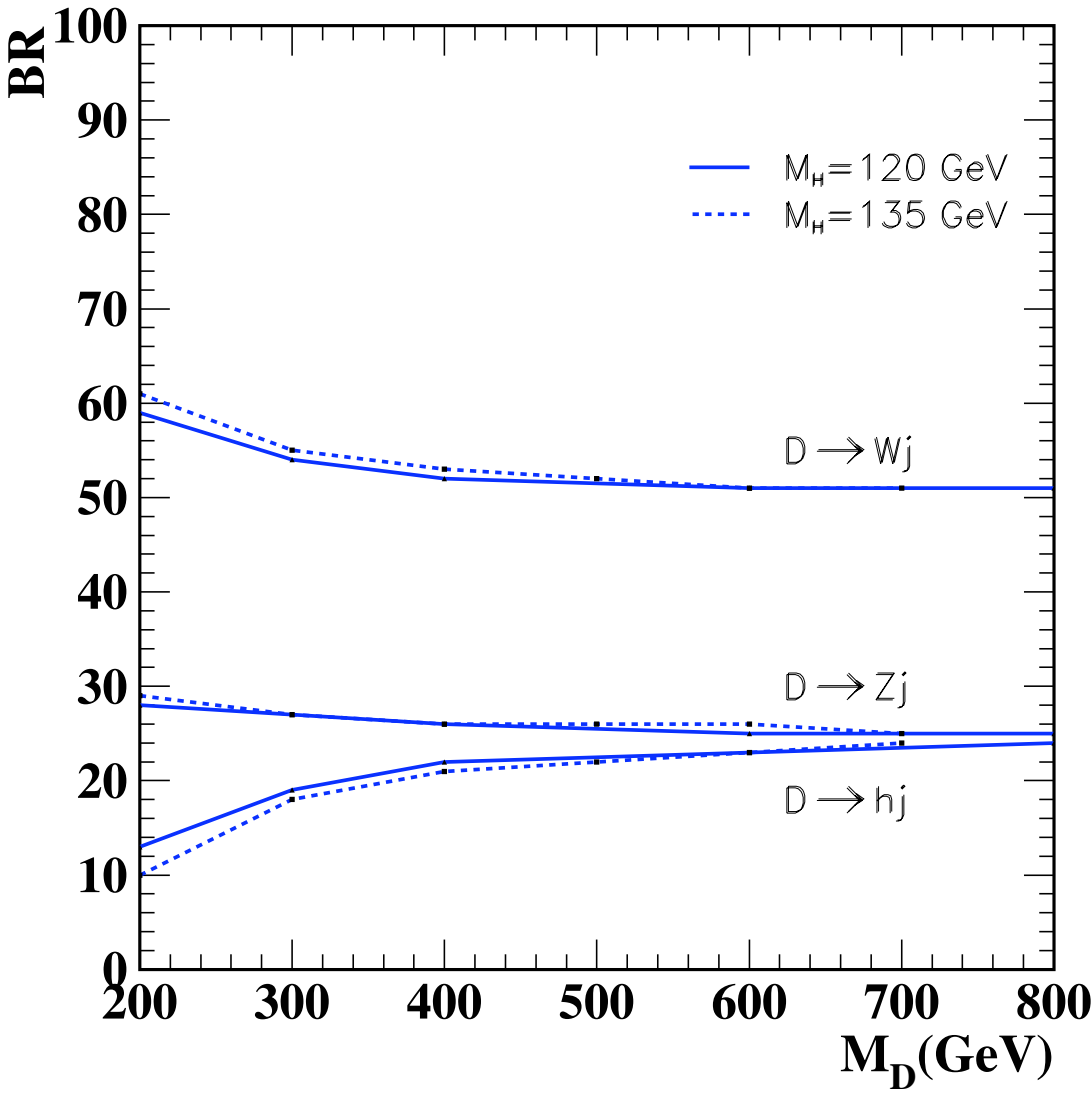


Illustrative case: mH=120 GeV, sinϕ=0.045,
blue=w/ Higgs IA,
black=w/o Higgs IA

New cross sections & BRs

DD pair production at LHC



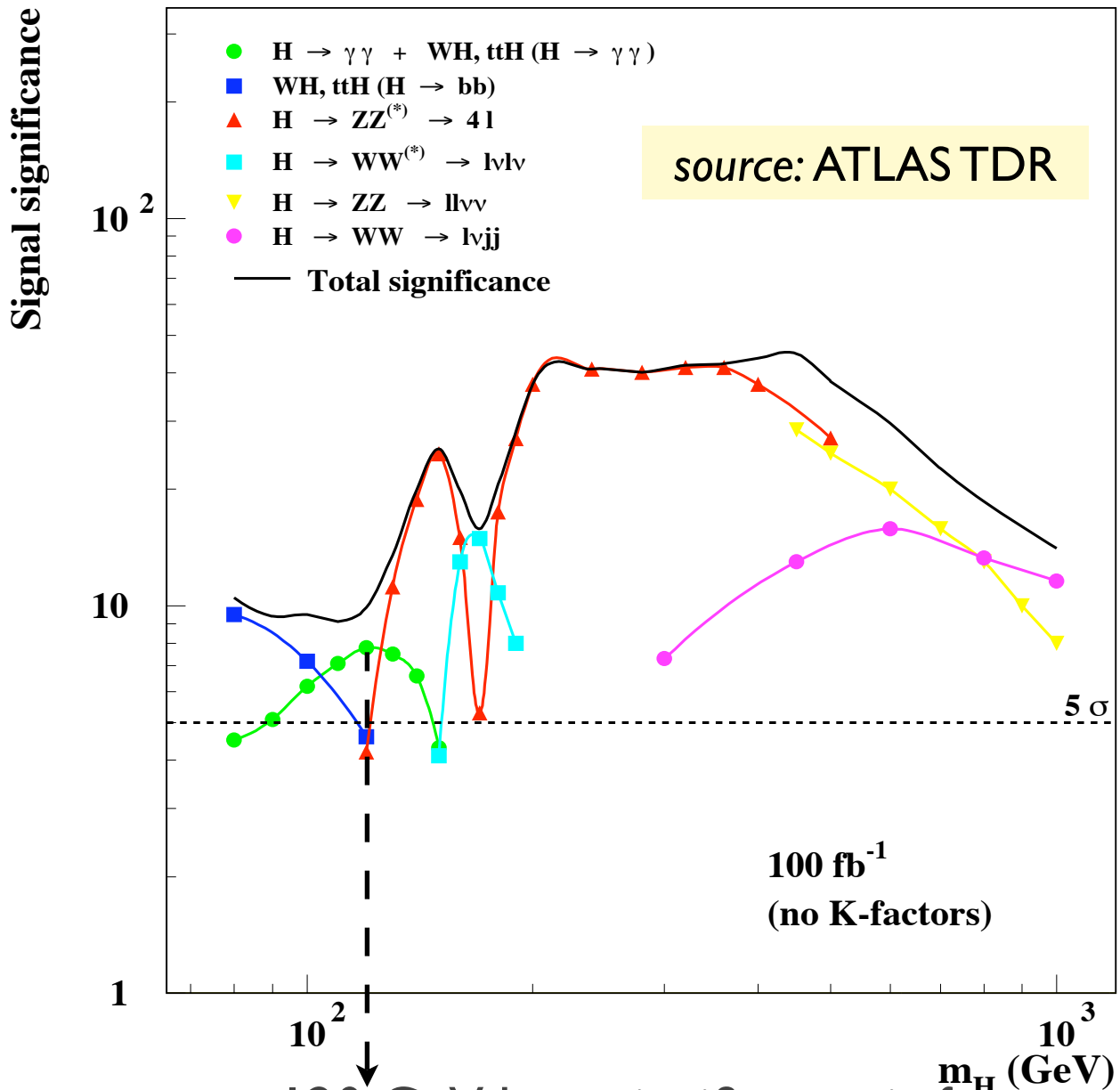


- if m_D ~250 GeV, then pair production $\sigma \sim 10^5$ fb.
- D decay BRs for a light Higgs (120..135GeV), depend on m_D. For high m_D (>700GeV) 50, 25 & 25% for W, Z & h modes.

Impact on Higgs searches

- Could we use the D quarks to improve the Higgs search potential of ATLAS?

- Consider:
  - D quark pair production
  - a light Higgs

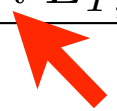


at m_H=120 GeV, best significance is from H→γγ channel, 8σ at 100fb^{-1}

$BR(H \to \gamma\gamma) = 0.2\%$

MC study on h discovery

D_1	D_2	BR	#expected Higgs/100fb^{-1}	expected final state
$D \to h\,j$	$D \to h\,j$	0.029 (0.053)	$0.58\times10^6(2.65\times10^4$)	$2j\ 4j_b$
$D \to h\,j$	$D \to Z\,j$	0.092 (0.120)	$0.92\times10^6(3.0\times10^4)$	$2j\ 2j_b\ 2l$
$D \to h\,j$	$D \to W\,j$	0.190 (0.235)	$1.9\times10^6(\ 5.88\times10^4)$	$2j\ 2j_b\ l\ E_{T,miss}$

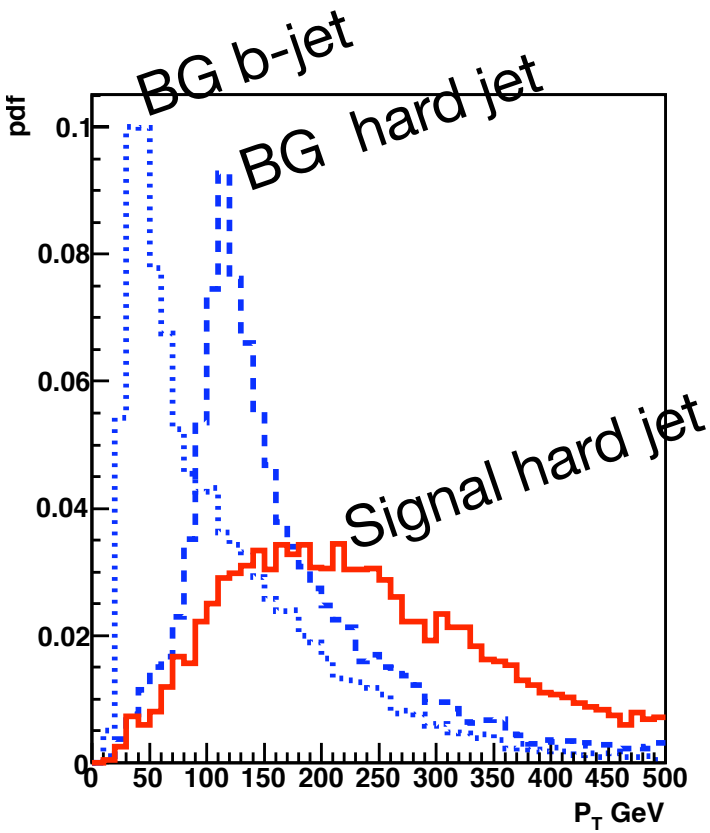


- >3x10^6 (>1x10^5) additional Higgs bosons at LHC, if m_D=250 (500) GeV
  - enough to motivate a study for 250, 500, 750 & 1000 GeV quarks using the 2j 2j_b l E_T^{miss} signal
  - SM background: W j_b j_b j j events, 80% from t-t background
  - Signal implemented in CompHEP, bg from MadGraph, simulation in athena 11.0.41 using ATLfast
  - Final analysis done with physics objects in Root
  - Generator level cuts are:

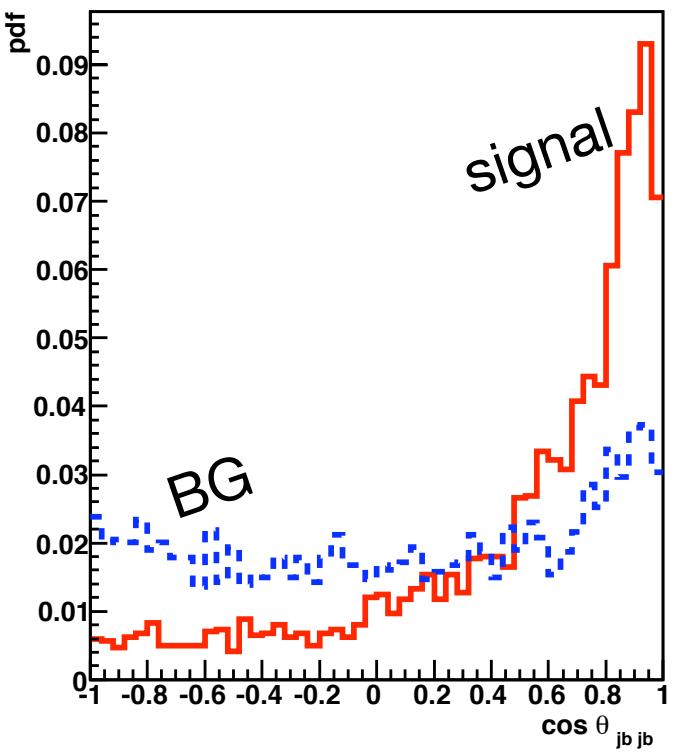
$$\begin{aligned} |\eta_p| &\leq 3.2 \quad , \\ P_{T\,p} &\geq 20\,GeV \quad , \\ R_p &> 0.4 \end{aligned}$$

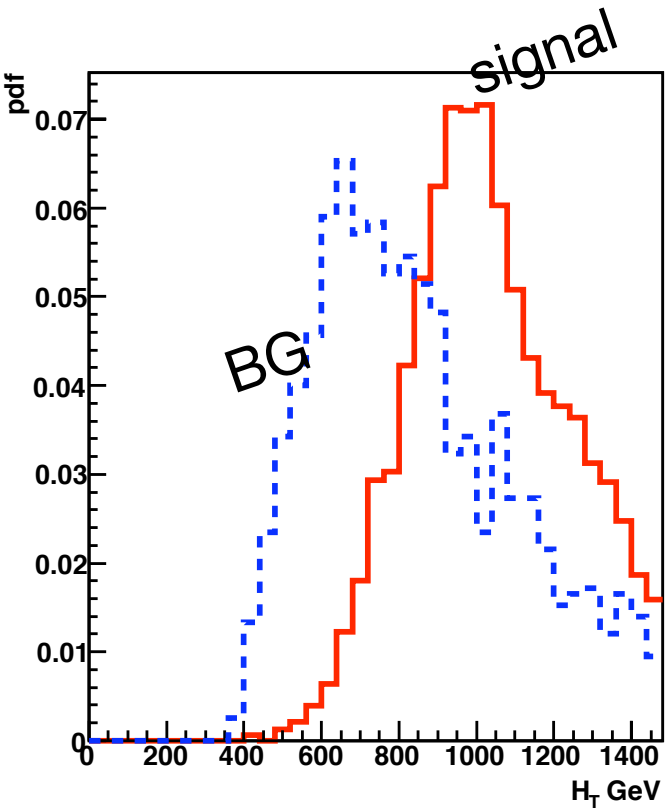
Event Kinematics

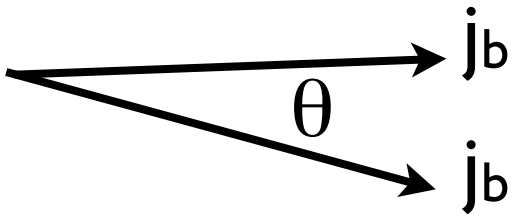
- Example for m_D = 500 GeV



P_T jet





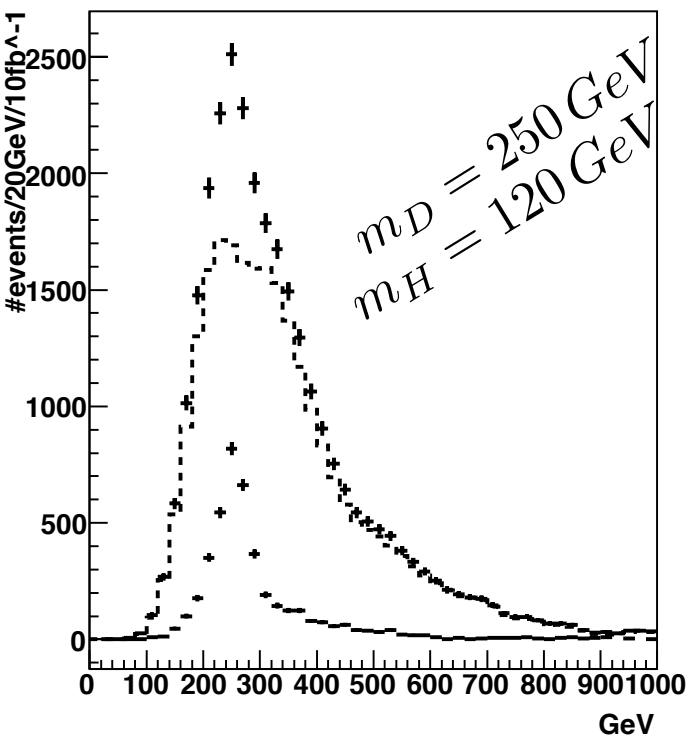


$$H_T = \sum_{particles} |P_T|$$

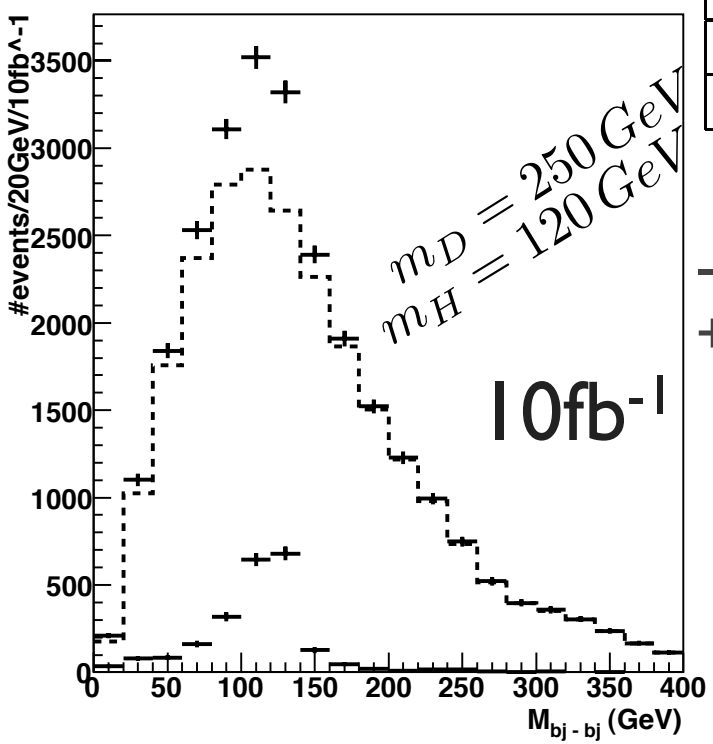
D and H Reconstruction 1/2

- Only e & μ are considered for W decays
- Missing E_T is assumed to come from ν
- Analysis cuts (example at m_D = 750 GeV) are :
  - only H_T & P_{Tjet} optimized

cut value	$\%\epsilon_{si}$	$\%\epsilon_{bg}$
#lep = 1	82.6	79.1
#jet = 4	98.7	99.4
$\#b_{jet}$=2	33.7	36.2
$P_T lep$>20 GeV	96.0	93.5
$P_T jet$>140 GeV	86.3	36.2
$\cos\theta_{jet} > -0.8$	97.8	90.4
$M_{jet-jet} > 90$ GeV	99.9	83.1
$H_T > 1300$ GeV	77.0	20.2
$\Delta m_D < 100$ GeV	55.7	32.9
combined	9.54	0.48



Reconstructed invariant mass of D



Reconstructed invariant mass of h

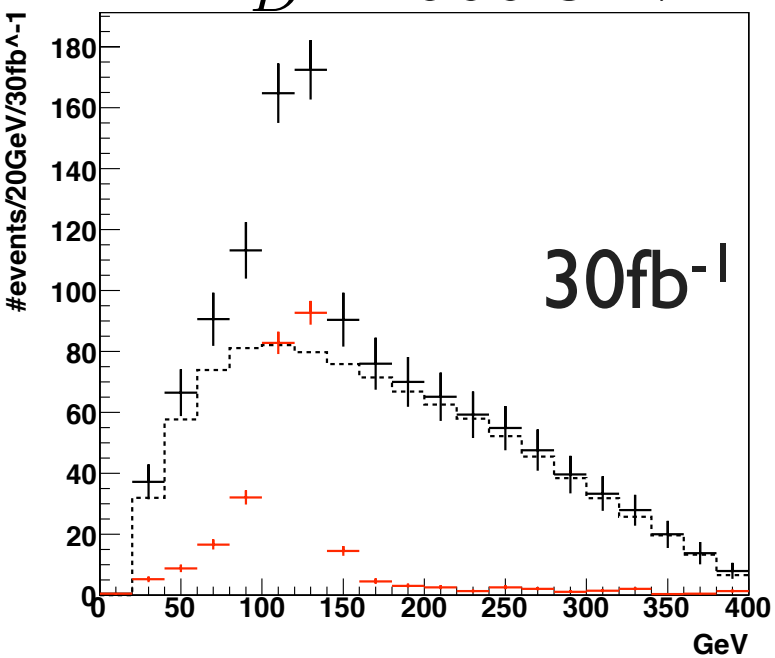
--- SM background
++ Signal

✓ *With these parameters, using 10fb^{-1} integrated luminosity, both the Higgs boson and the D quark can be discovered.*

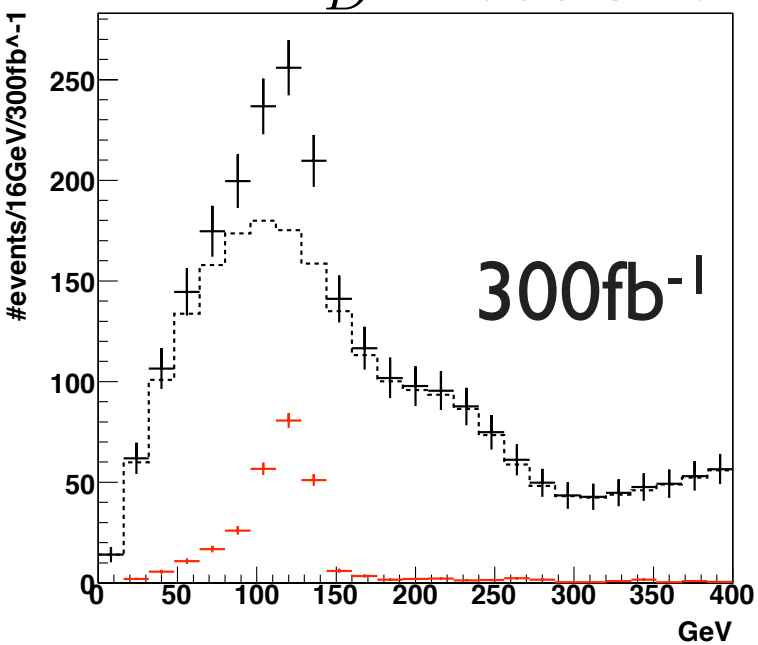
D and H Reconstruction 2/2

- For higher *D* quark masses lets concentrate only on Higgs searches:

$m_D = 500\,GeV$



$m_D = 750\,GeV$

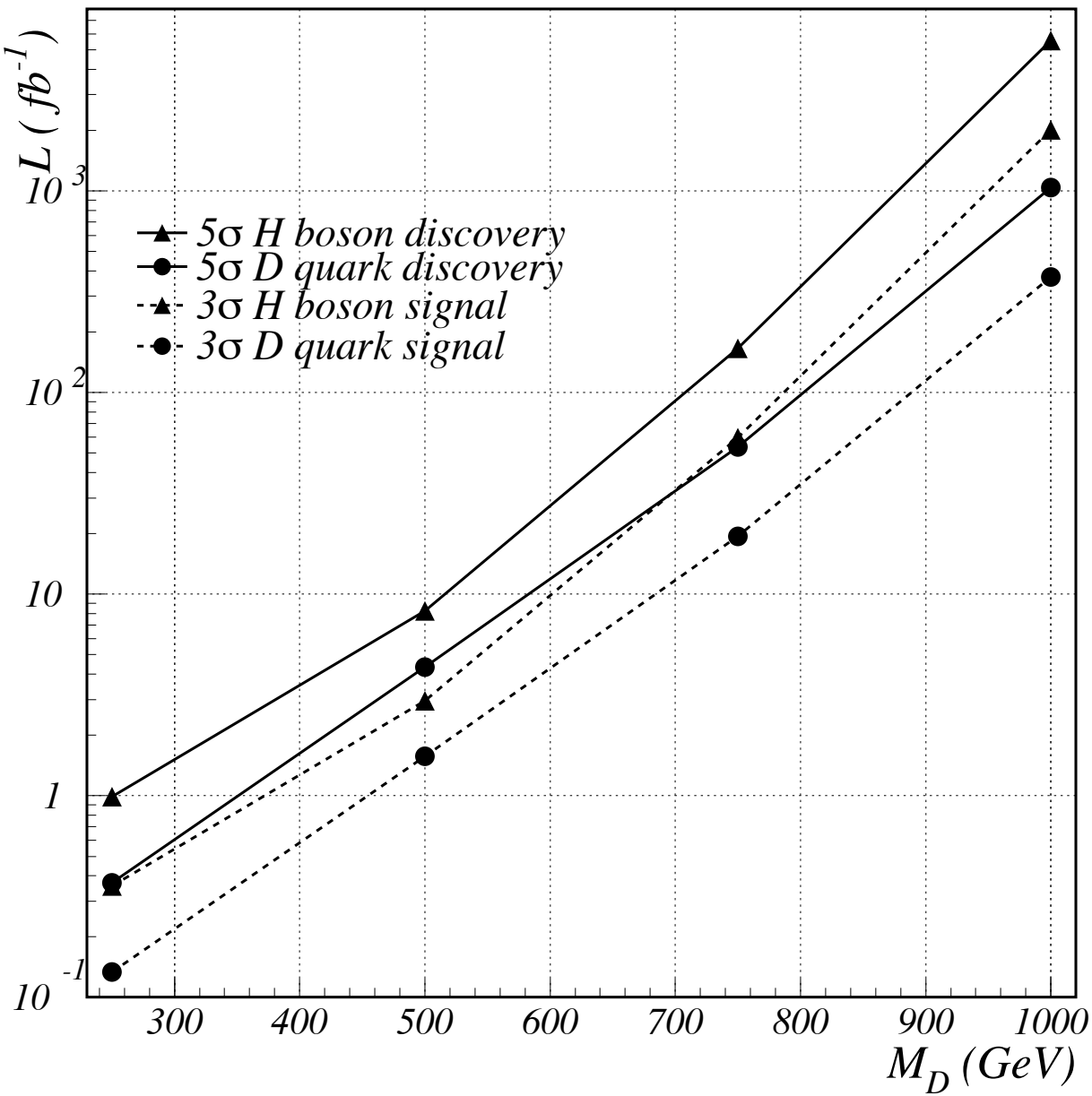


- 30fb^{-1} ∫Luminosity yields:

M_D(GeV)	250		500		750		1000	
S	8802	5303	336	222	27	19	1.9	1.4
B	29379	31717	313	321	32	56	3.1	10.6
$S/\sqrt{B+S}$	45.1	27.6	13.2	9.5	3.5	2.1	0.84	0.42

Higgs and D signal reach

- 5σ Higgs discovery from DD→Whjj channel can be made in <u>one</u> year of running at design luminosity if m_D <700 GeV
- If m_D<630 GeV, this channel becomes as efficient as H→γγ . (i.e. 8σ in 100 fb^{-1})



Outlook

- The 3 sigma signal from a light Higgs, can be seen within a year (100 fb^{-1}) via the E_6 quarks if $m_Q < 800$ GeV.
- The outcome should be checked against the full simulation (Geant) results. (working for a CSC note)
- The impact of the heavy quark(s) to the Higgs production via loop diagrams could be interesting.
- BG in this analysis is ~20% overestimated: we did $\sigma = 2*(W^+4j)$ but $\sigma(W^- 4j) = 0.8*\sigma(W^+ 4j)$
- Multi jet background to be checked. (*thanks to Juan Antonio for the hint!*)