Workgroup-1 exotics subgroup summary -I

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Flavour in the era of the LHC
26-28 March 2007

Exotics group

- 5 meetings between November 2005 and March 2007
- Non-supersymmetric models beyond SM
  - 20 contributions,
  - Both theoretical and phenomenological studies,
  - ~50 pages for the yellow report

contributors

Non-SUSY BSM Chapter

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- Thank you to all ..

Motivations

- SM is like your old car: *you know it has problems!*
  - Hierarchy problem: $\delta H \sim M_H$
  - Non-unification for EW and Strong Forces
  - Seemingly arbitrary fermion mass & mixings
  - Unknown source of baryogenesis
- LHC is to start soon:
  - at the end of 2007 $\sqrt{s}$=0.9 TeV
  - In 2008 LHC will provide $\sqrt{s}$=14 TeV,
    - few years at 10 fb^{-1} /yr: low luminosity
    - then 100 fb/yr : nominal or design luminosity
- What flavour physics can be done at this new era?
  - What are the extensions to SM?

“Exotic” models

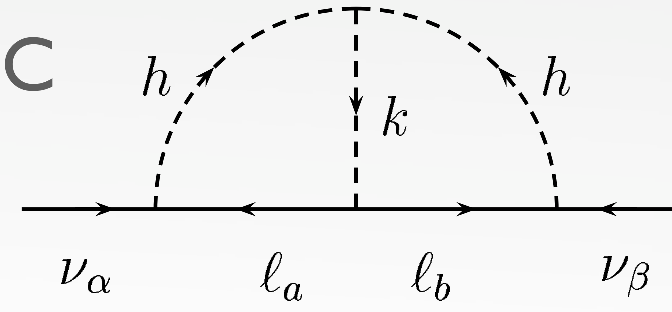
- A brief summary of popular models:
  - Grand Unified Theories:
    - SM gauge group is embedded into a larger one like SO(10), to unify EW and QCD.
    - additional fermions and bosons predicted.
  - Little Higgs models:
    - spontaneously broken global symmetry to impose a cut-off ~10 TeV.
    - additional bosons and quarks introduced to cure the hierarchy problem.
  - Extra Dimensions:
    - Low Planck scale in d dimensional theory solves the hierarchy problem between EW and Gravitational couplings.
    - Excitations of SM bosons and fermions are predicted.
- *These models do **not** exclude supersymmetry.*

Contents

I. Searches for scalars

Relevant Models

- 2HDM
  - A 2nd Higgs doublet to induce baryogenesis
  - CPV H can be searched via top quarks *(see top sub-group report)*
- Little Higgs
  - A Higgs triplet to cancel its own loop contribution to m_H
  - Higgs correction is small, new Higgs might be inaccessible
- Babu-Zee model
  - Two new scalars to induce the ν masses at 2-loop level.
  - New scalars can be accessible at the LHC



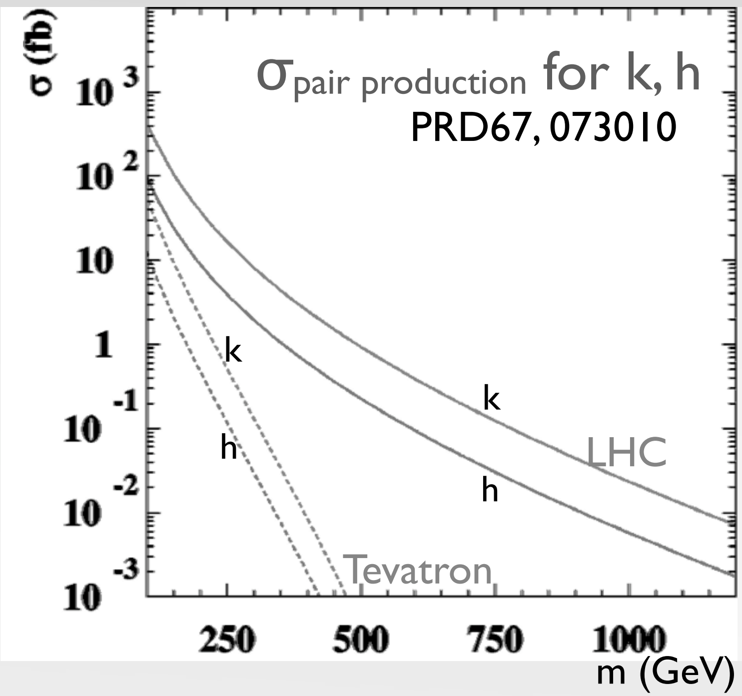
1.1 Babu-Zee model

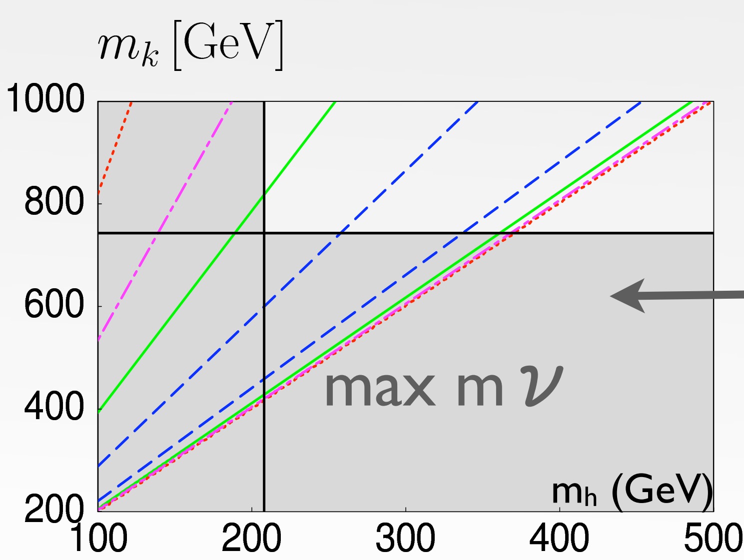
- h^+ and k^{++}, couple to leptons, give Majorana ν mass.
- ν data predicts $M_{h,k}$ ~O(0.1 - 1.0 TeV)
- Signature: $q\bar{q} \to \gamma^*, Z^* \to k^{--}k^{++}$

$$k^{\pm\pm} \to h^{\pm}h^{\pm}$$
$$k^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$$

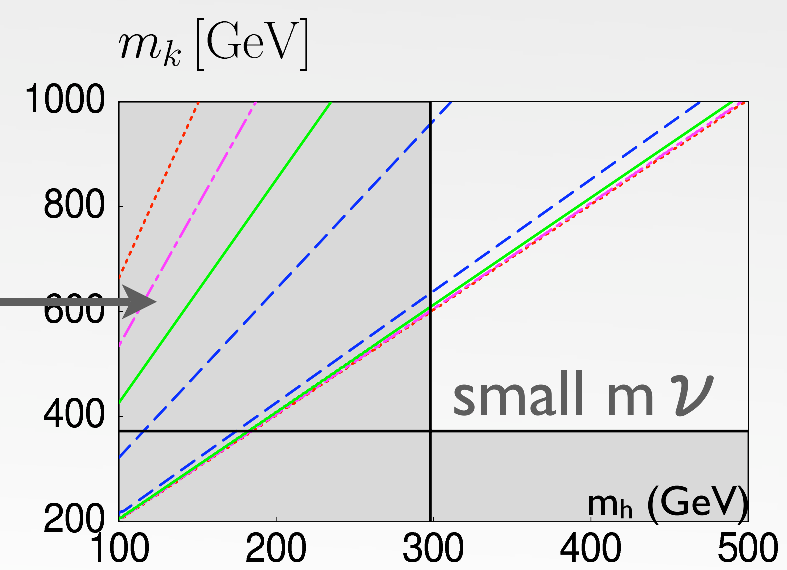
BR(k→hh) model dependent values [0.1 - 0.8] scanned

ARISTIZABAL-SIERRA





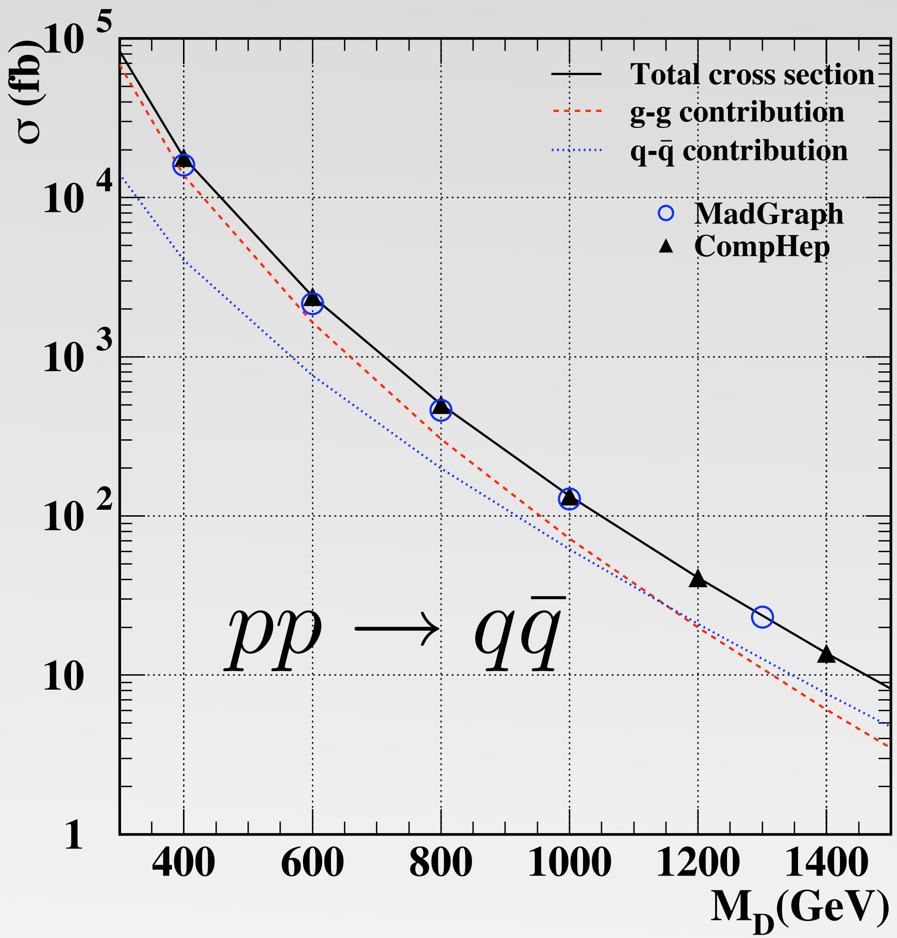
excluded by
$\mu \to e\gamma \quad \tau \to 3\mu$



2. Searches for quarks

Relevant Models

- Iso-singlets predicted in
  - GUTs, Little Higgs, EDs
  - W,Z,H vertex modified
  - γ,g vertex same as SM
- Iso-doublets: the 4th SM-like family
  - not yet ruled out for $m_\nu > m_Z/2$
- Extra Dimensions
  - KK excitations of known quarks
  - additional quarks with Q= 1/3, 2/3, 5/3



Iso-singlet quark pair production at LHC (tree level)

classification

Q_e	$I_3=0$ singlet	$I_3=\pm 1/2$ doublet
-1/3	E6, *D*	4^{th} Fam, d_4/b'
2/3	LH, *T*	4^{th} Fam* u_4
5/3	EDs,	

$Q_e = I_3 + \frac{1}{2} Y$

$g_V = I_3 - 2\sin^2\theta_w$

$g_A = I_3$

*LHC relevant material is also in ATLAS TDR

2.1 Iso-singlets Q=−1/3

Mehdiyev, Sultansoy, Unel, Yilmaz

- E6 model introduces new particles:

$$SU_C(3) \times SU_W(2) \times U_Y(1) \subset E_6$$

- one iso-singlet quark per family :

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

Assumptions:

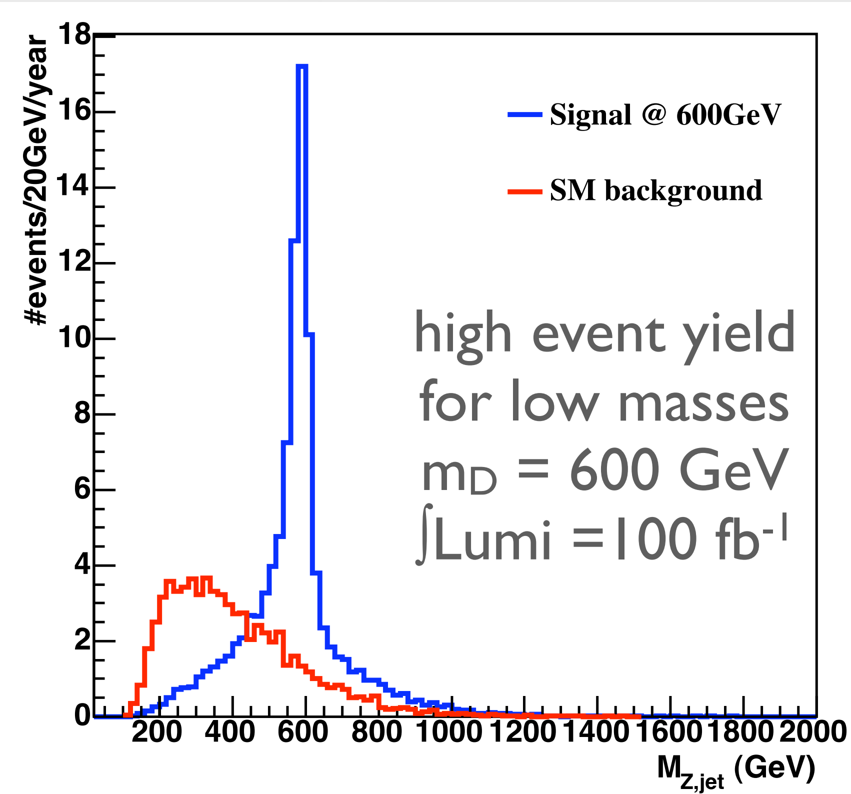
1. In-family mixing bigger than between family mixing
2. D quark is the lightest, like SM: most accessible in LHC
3. E6 gauge bosons heavy & don't interact w/ SM bosons

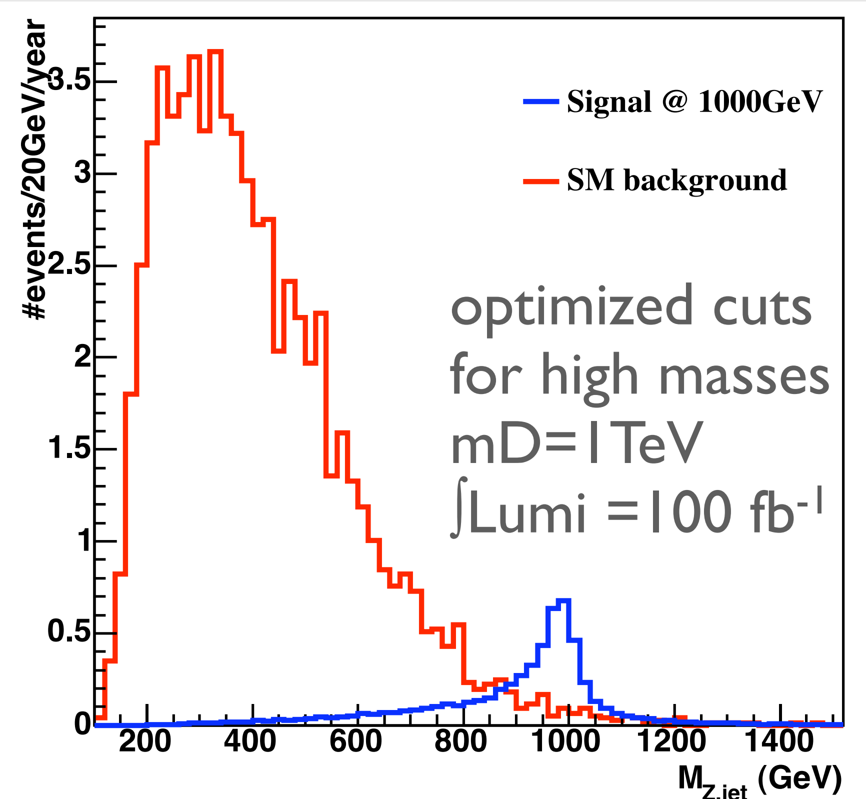
	$D \to Zd$	$D \to Wu$	
BR	33%	66%	if there is no Higgs
	25%	50%	if Higgs is light

Discovery for Q=−1/3

Mehdiyev, Sultansoy, Unel, Yilmaz

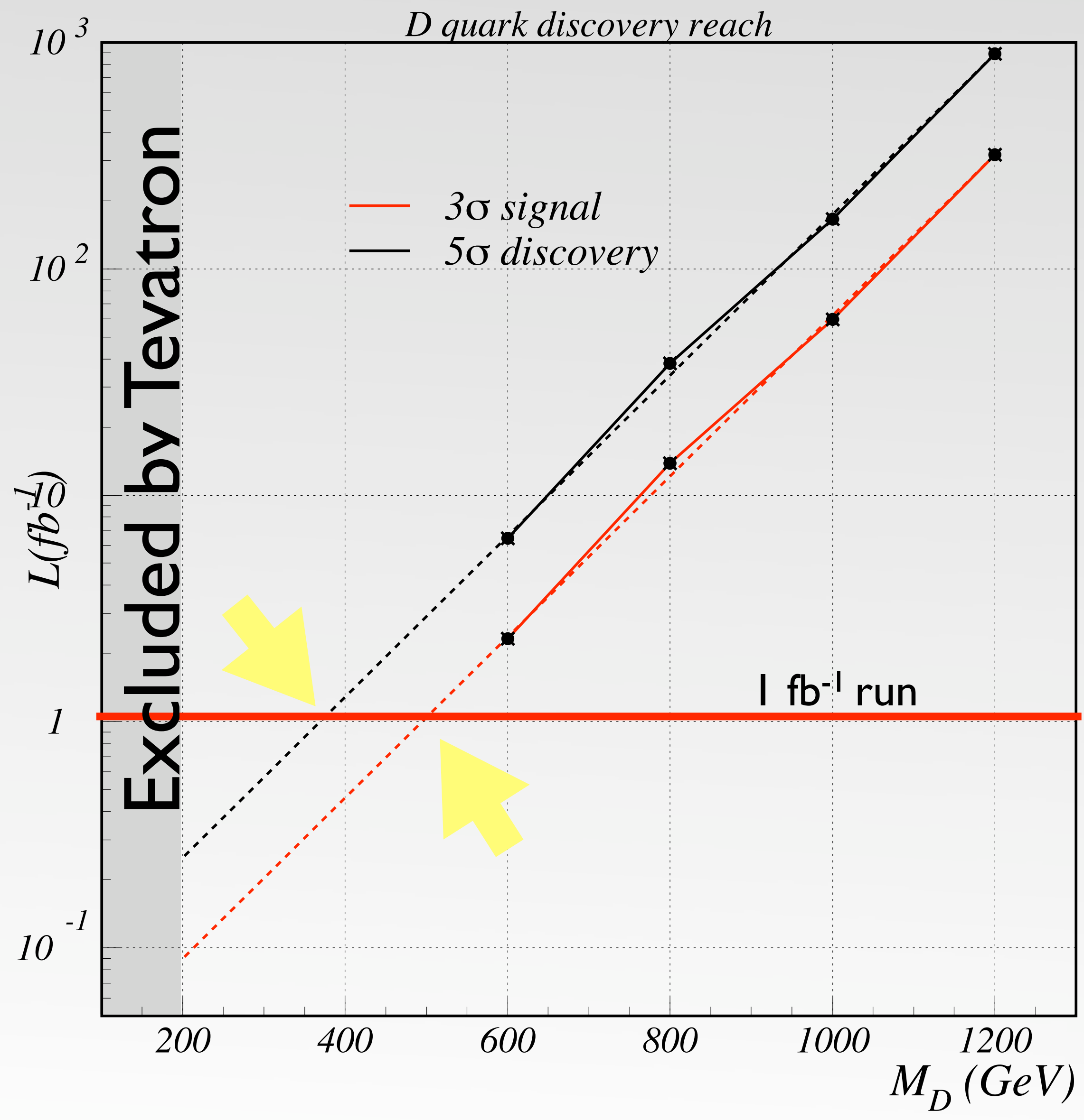
- uses pp→DD pair production
  - independent of d-D mixing angle
  - with both the D→Zd and Z decays leptonically (e,μ)
  - signal is 4 leptons + 2 jets
- ATLAS FastMC based study with simple cuts
- m_D scan up to 1.2 TeV, channel efficient up to ~1 TeV





D quark mass reach

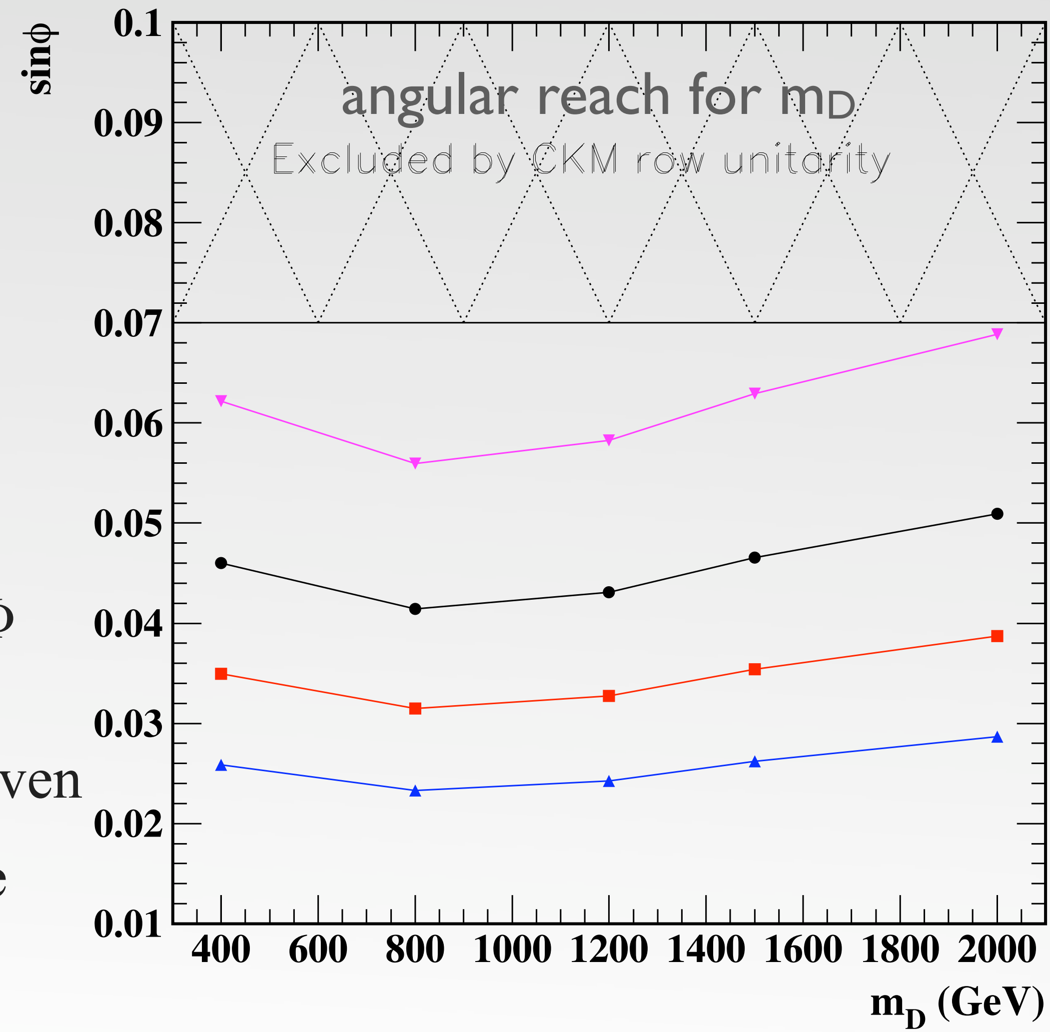
- Estimation for other D mass values using only D→Zd channel
- 1fb^{-1}
  - 3σ : m_D~500 GeV
  - 5σ : m_D~350 GeV
- 10fb^{-1}
  - 3σ : m_D~750 GeV
  - 5σ : m_D~650 GeV
- 100fb^{-1}
  - 3σ : m_D~940 GeV
  - 5σ : m_D~1050 GeV



Mixing for Q=−1/3

Sultansoy, Unel, Yilmaz

- Jet associated single production & decay
  - pp→jD→jjZ where leptonic Z decays are considered
- production σ ~ $(\sin\Phi)^2$, where Φ=d-D mixing angle
  - good for measuring sinΦ
- generator level study with cuts



- 3σ signals can be rescaled for different sinΦ values at any mass
- 30, 100, 300 & 1000 fb^{-1} reach limits are given
- with 300 fb^{-1} current mixing limits could be enhanced 2 times

Higgs searches & Q=−1/3

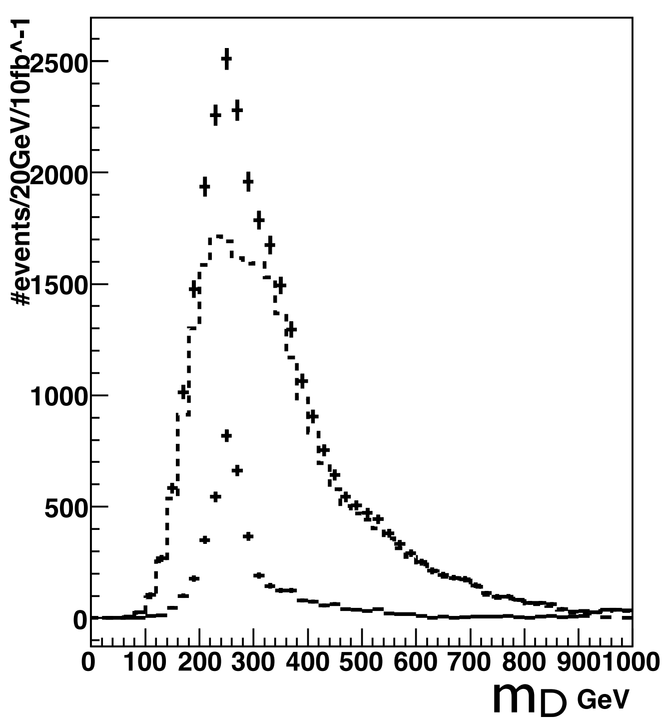
SULTANSOY, UNEL

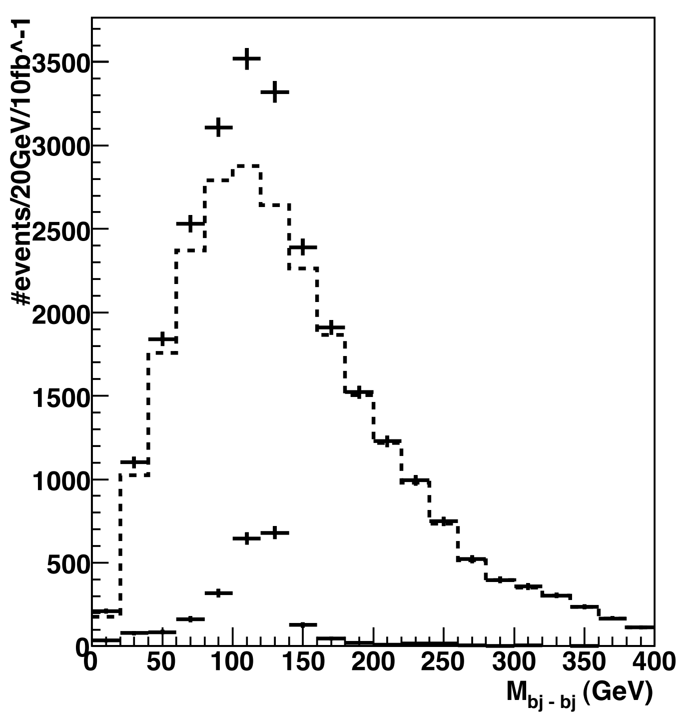
- d-D mixing leads to dDh vertex at tree level
- this can be exploited for a double discovery: light H & D
- pair production mode considered for ATLAS using FastMC
  - m_D =250 -1000 GeV range scanned

example:
$\int$Lumi =10 fb^{-1}
$m_D = 250\, GeV$
$m_H = 120\, GeV$

m_D=250 (500) GeV

D_1	D_2	BR	expected final state
$D \to h\,j$	$D \to h\,j$	0.029 (0.053)	$2j\;4j_b$
$D \to h\,j$	$D \to Z\,j$	0.092 (0.120)	$2j\;2j_b\;2l$
$D \to h\,j$	$D \to W\,j$	0.190 (0.235)	$2j\;2j_b\;l\;E_{T,miss}$





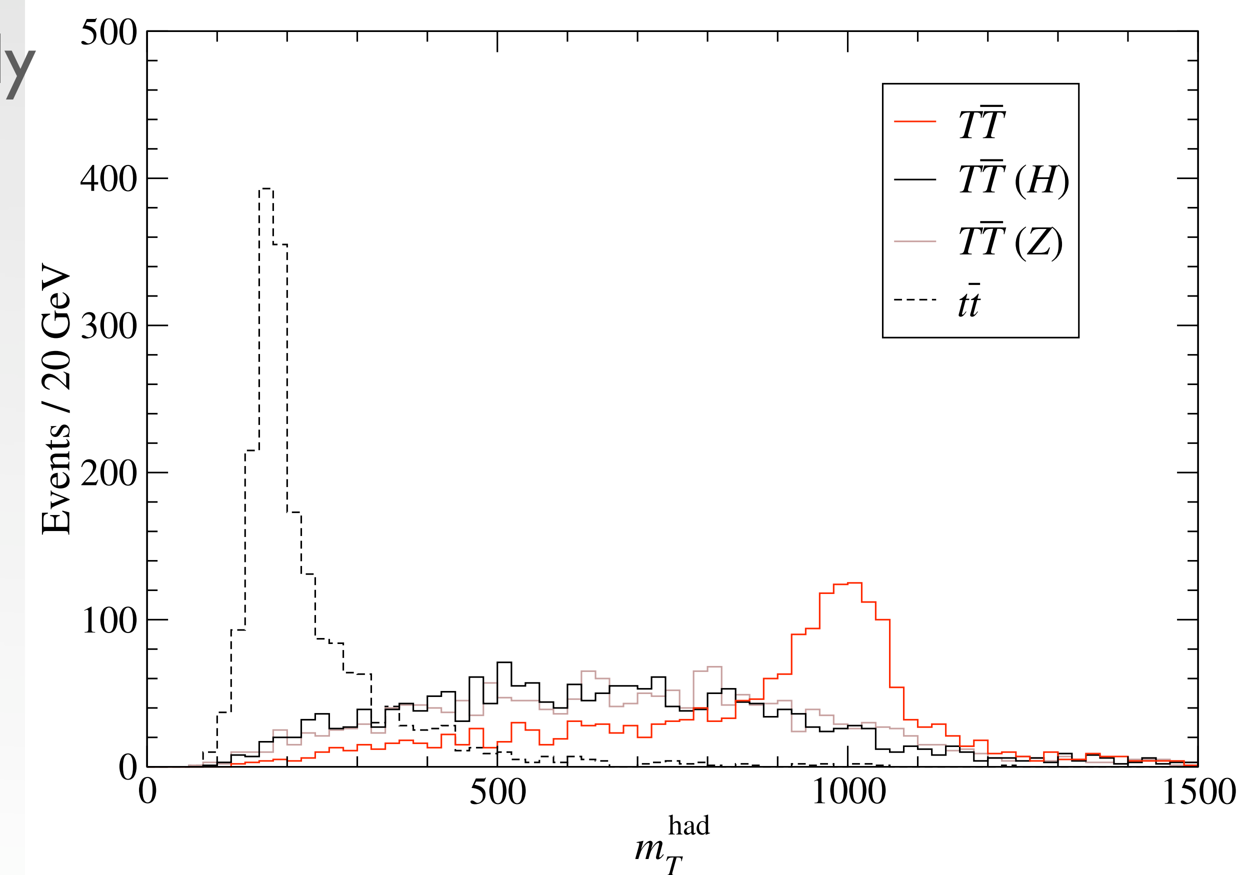
- 5σ Higgs discovery in DD→Whjj channel can be made using 100 fb^{-1} if m_D <700 GeV
- If m_D<630 GeV, this channel becomes as efficient as h→γγ .
  (i.e. 8σ in 100 fb^{-1})

Q=2/3 Iso-singlets: discovery

Aguilar-Saavedra

- Up type quark T, predicted by LH & GUT models
- T decays via W,Z & H (BR similar to -1/3 quark) to *b* and *t* quarks.
- pair production considered with all decay modes with at least 1 W decaying leptonically
- ATLAS FastMC based study for m_T = 1 TeV and light Higgs
- main background from tt only

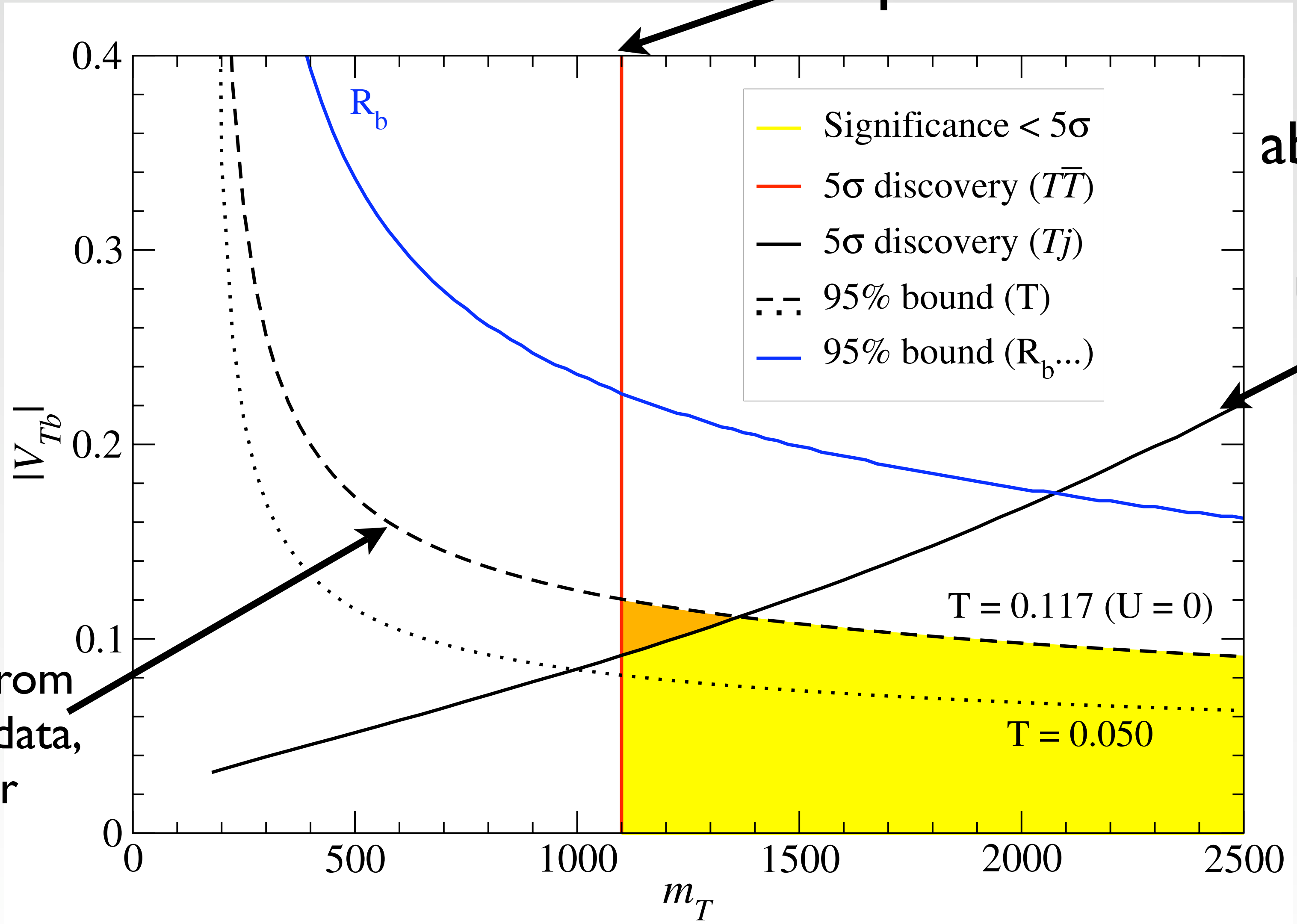
TT decay	signature
WbWb	$\ell\nu$ bb jj
WbHt	$\ell\nu$ bbbb jj
WbZt	$\ell\nu$ bb jjjj



5σ reach for T mass

- TT & Tj used for ∫L=300 fb^{-1} data for only T→Wb
    - $\sigma_{Tj} \sim |V_{Tb}|^2$ where $V_{Tb} \sim O(m_t/m_T)$
    - background tt only

up to 1.1 TeV using TT



above this curve using Tj

upper bound from EW precision data, T parameter

T quark and the Higgs

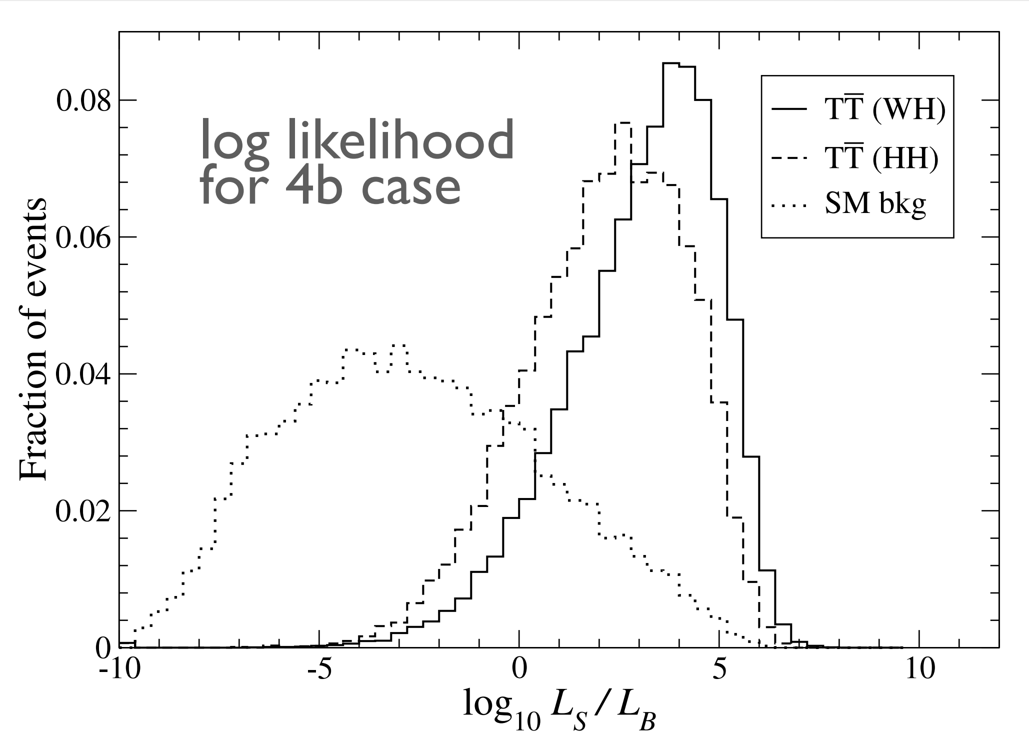
AGUILAR-SAAVEDRA

- For a light Higgs T quark's decays provide a large σ enhancement.
- pair production study with pythia using signals: $T\bar{T} \to WbHt$
- main background tt & tt nj where n=1,2,3,4,5. $T\bar{T} \to HtHt$

$T\bar{T} \to HtZt$

expected signature: $\ell\,\nu \; \geq 4b_j\,2j$

example at m_T=500 GeV, M_H=115 GeV, $\int L$=30 fb^{-1}

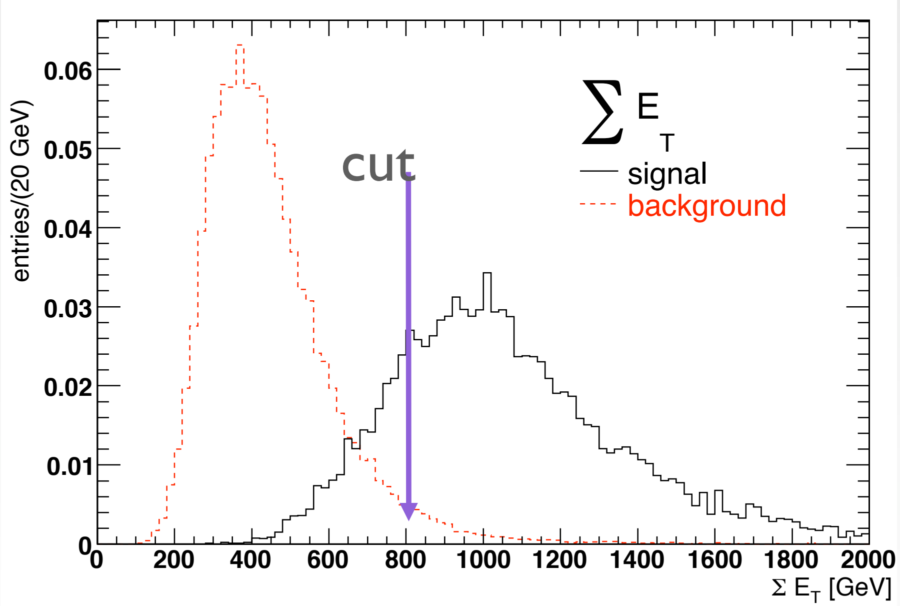


$\#b_j$	Higgs signal significance
4	6.43
5	6.02
6	5.63
combined	10.45

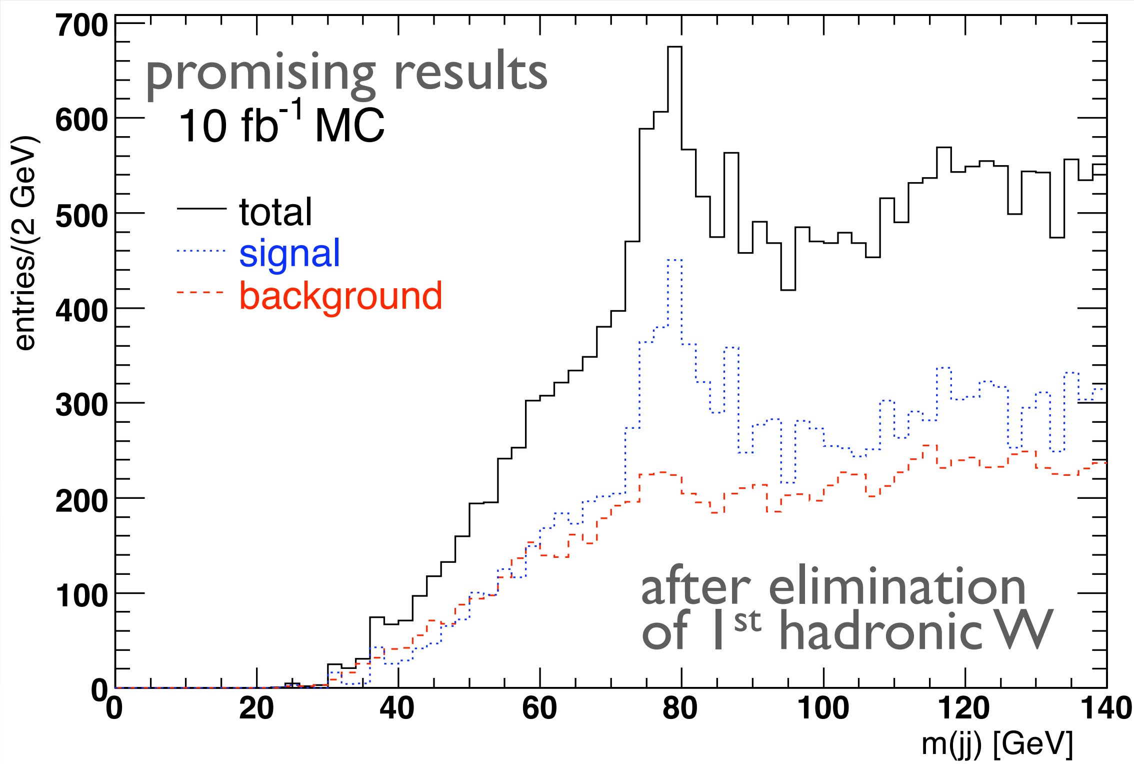
singlets from EDs

DENNIS, SERVANT, TSENG, KARAGOZ-UNEL

- RS model with extended EW gauge group
- additional symmetries allows quarks m~O(100)GeV w/ Q=-1/3, 2/3, 5/3
  - *q*: KK excitation of *b* with BR($q \to W\ t$)~50% for m_H~300GeV
- Focus on *qq* pair prod.: 2x($q \to Wt$)$\to$4W 2b
  - pythia level study w/ at least 1 W decaying leptonically
  - main SM background has 2 W
  - m_q=500 GeV & m_H=300 GeV



bg from tt and ttH events



2.2 Iso-doublets

- a 4th family with heavy quarks and leptons (>200GeV)
- could explain the observed fermion mixing & mass values, CP violation in b-s transitions
    - not yet ruled out experimentally
- Study of channels of interest for new quark

mixing	pair prod. signal	comment
$b' \to c/u\, W$	cc/uu WW	*see next slide*
$b' \to cW$, bZ/H	cbWZ/H	*FCNC, could get H as a bonus*
$b' \to tW$	ttWW or bb4W	*same signal as ED KK quarks*
$b' \to tW$, bZ/H	bb WW Z/H	*b-jet to distinguish from row 2*

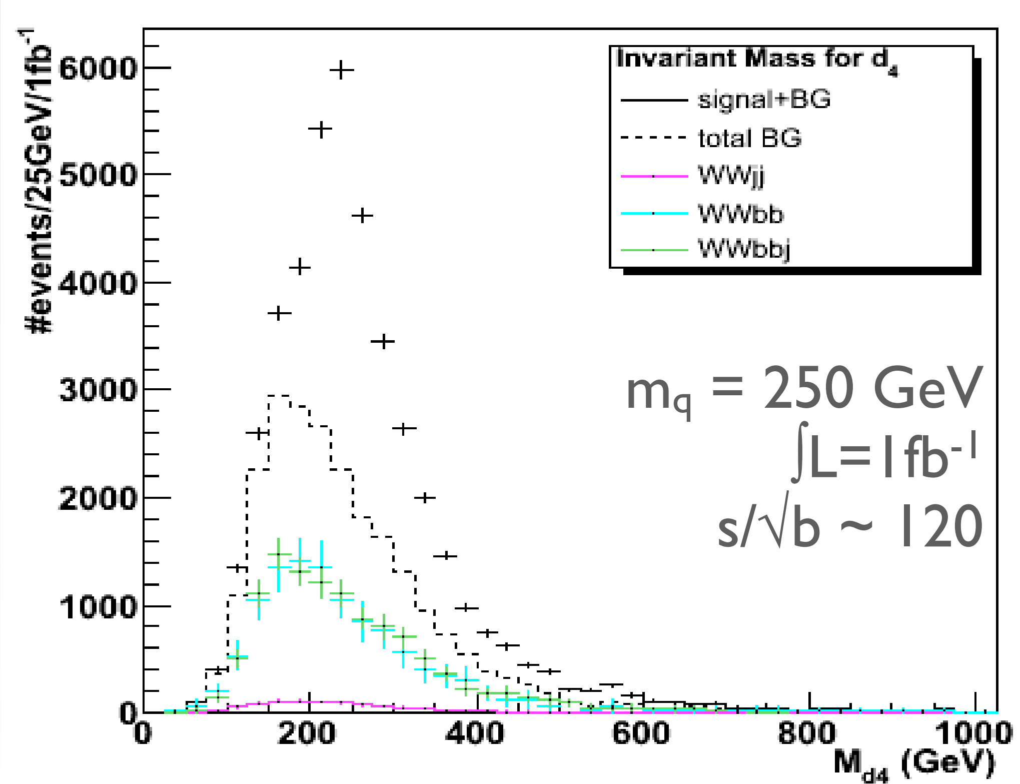
4th family - discovery

OZCAN, SULTANSOY, UNEL

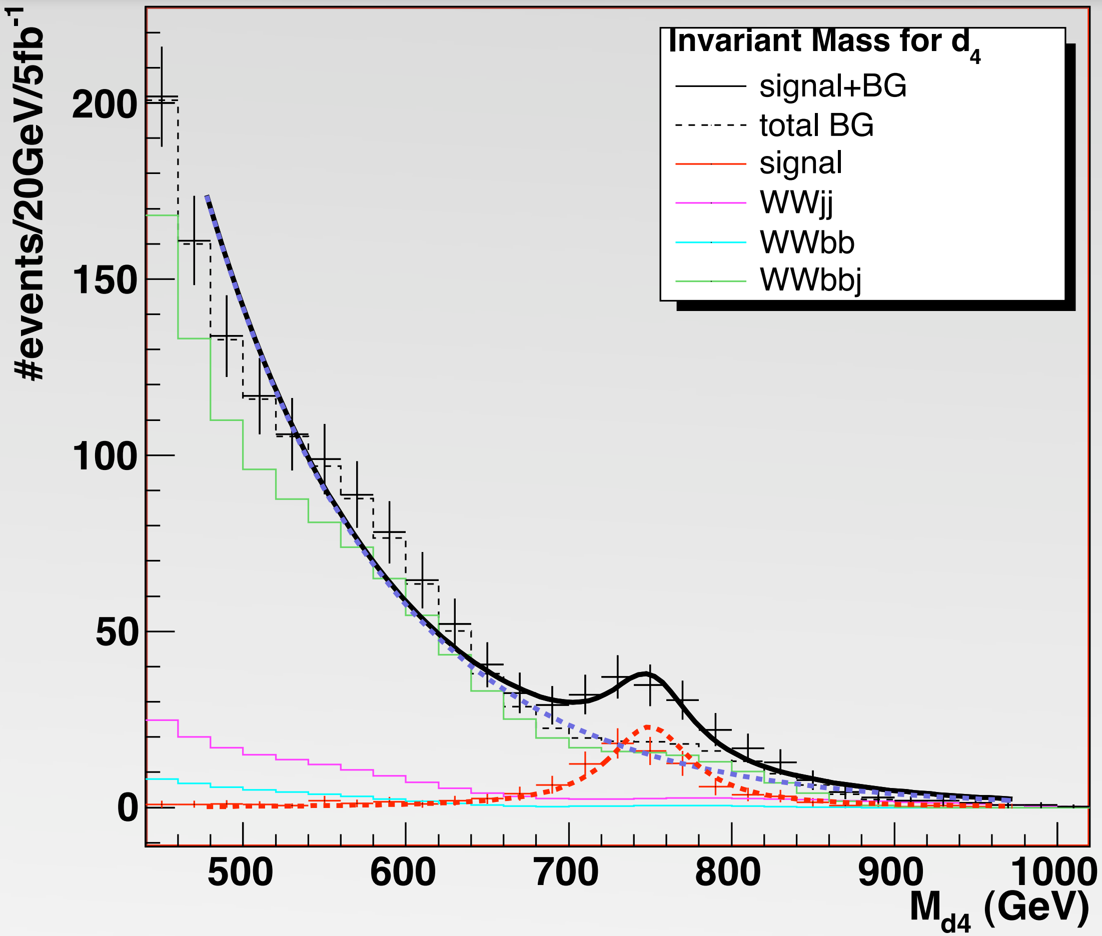
- pair production of the quarks: d_4 , u_4
  - $m_{u4} \sim m_{d4}$ from DMM approach
- scenario with mixing to 1st or 2nd generations,
  - $pp \rightarrow d_4 d_4 / u_4 u_4 \rightarrow W W j j$
    - one W decays via e/μ the other via non-b jets: $e/\mu+4j+E^T_{miss}$
- ATLAS fastMC study scanning m= 250 - 750 GeV

width and $\sigma_{\text{pair production}}$

M_{q4} (GeV)	250	500	750
Γ (MeV)	0.01	0.08	0.28
σ (pb)	99.8	2.59	0.25



4th family & intermezzo



High mass also seems to be feasible:

m_q = 750 GeV & $\int L = 5 fb^{-1}$

$s/\sqrt{b} \sim 5$

Necessary ∫Luminosity for 5σ signal

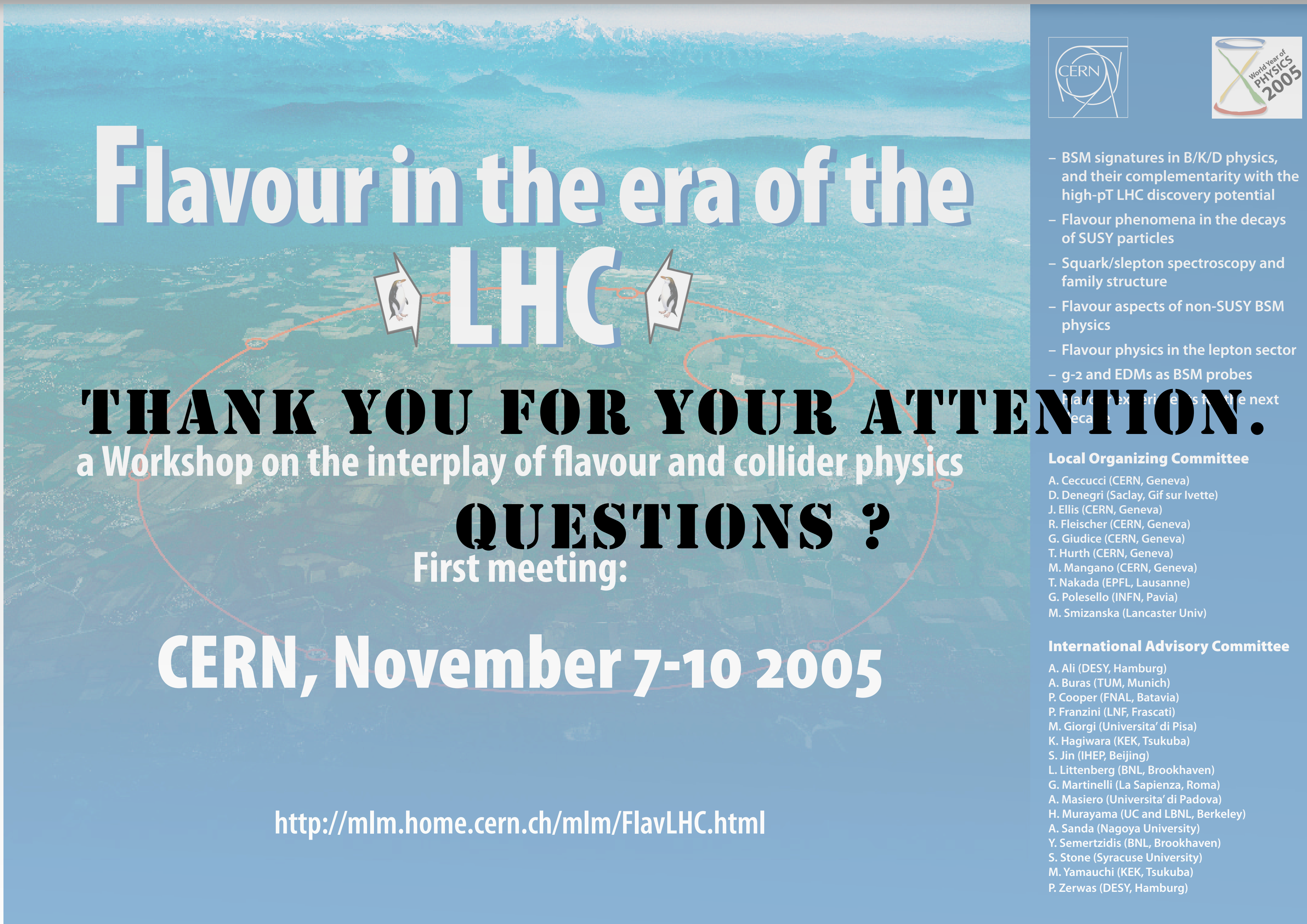
M_q (GeV)	250	500	750
$\int L$ (fb^{-1})	0.002	1.95	5

- quark searches seem promising in LHC;
  - Still unexplored channels, unconsidered models, omitted backgrounds & ongoing collaborative work.
- what about new leptons & vector bosons? see *part* 2..

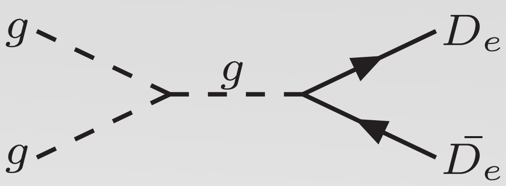
Backup slides

THANK YOU FOR YOUR ATTENTION.

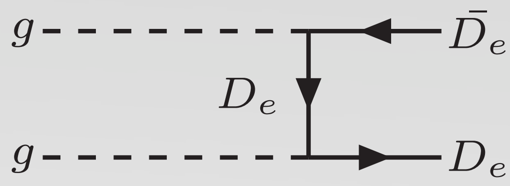
QUESTIONS ?



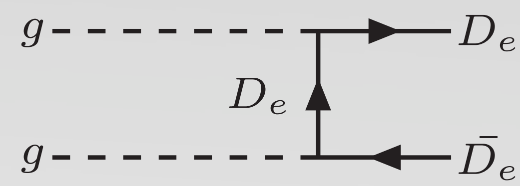
D quark pair production



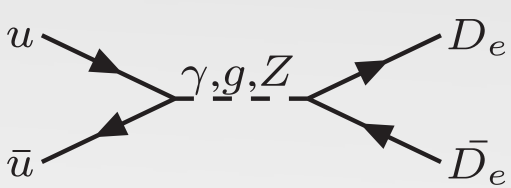
gluons, s channel



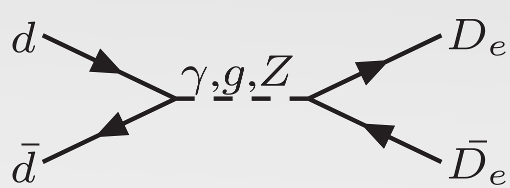
gluons, t channel 1



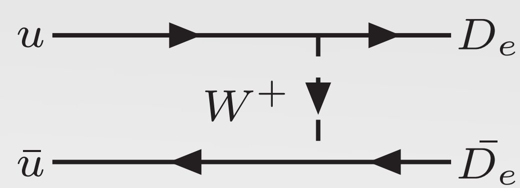
gluons, t channel 2



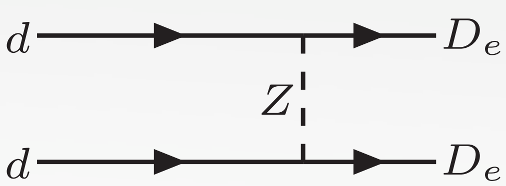
up quarks, s channel



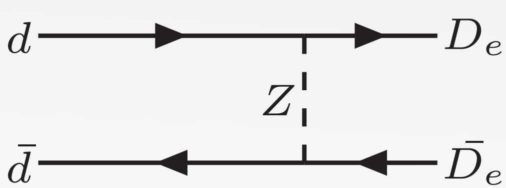
down quarks, s channel



up quarks, t channel



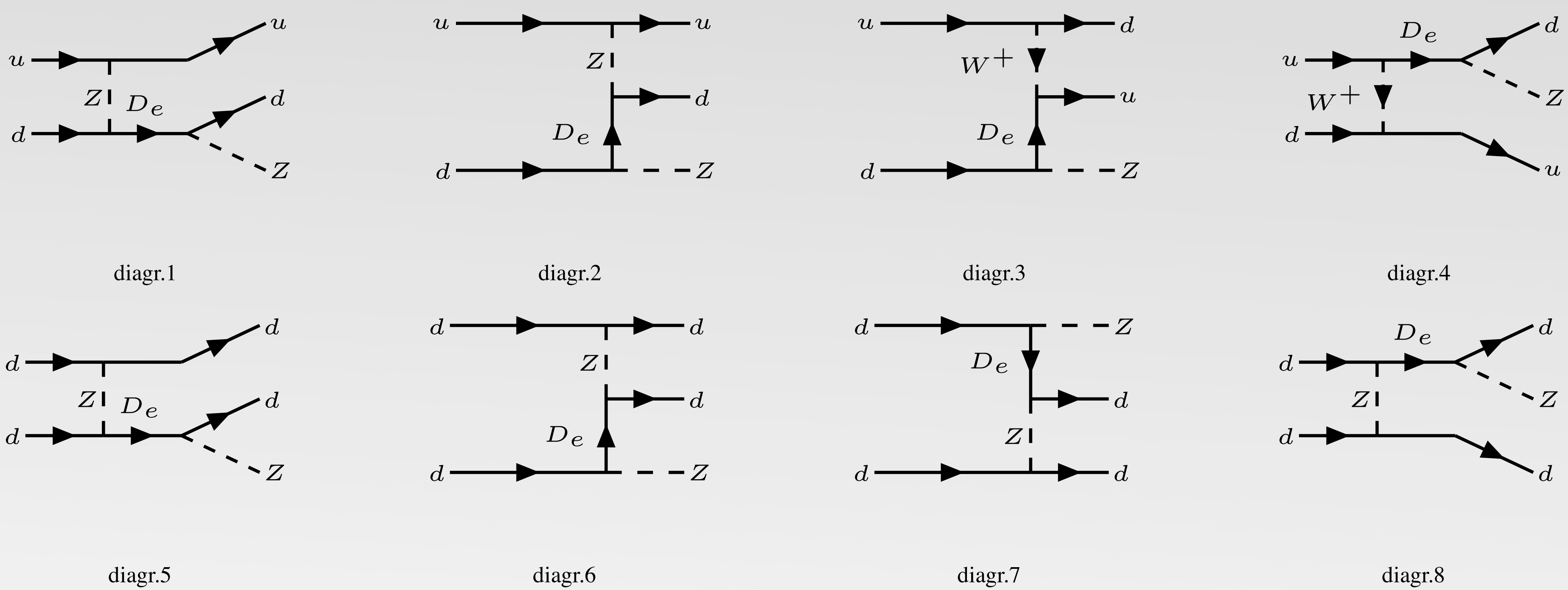
down quarks, t channel 1



down quarks, t channel 2

Single D quark production

- Decays involving Z would be easiest to reconstruct:

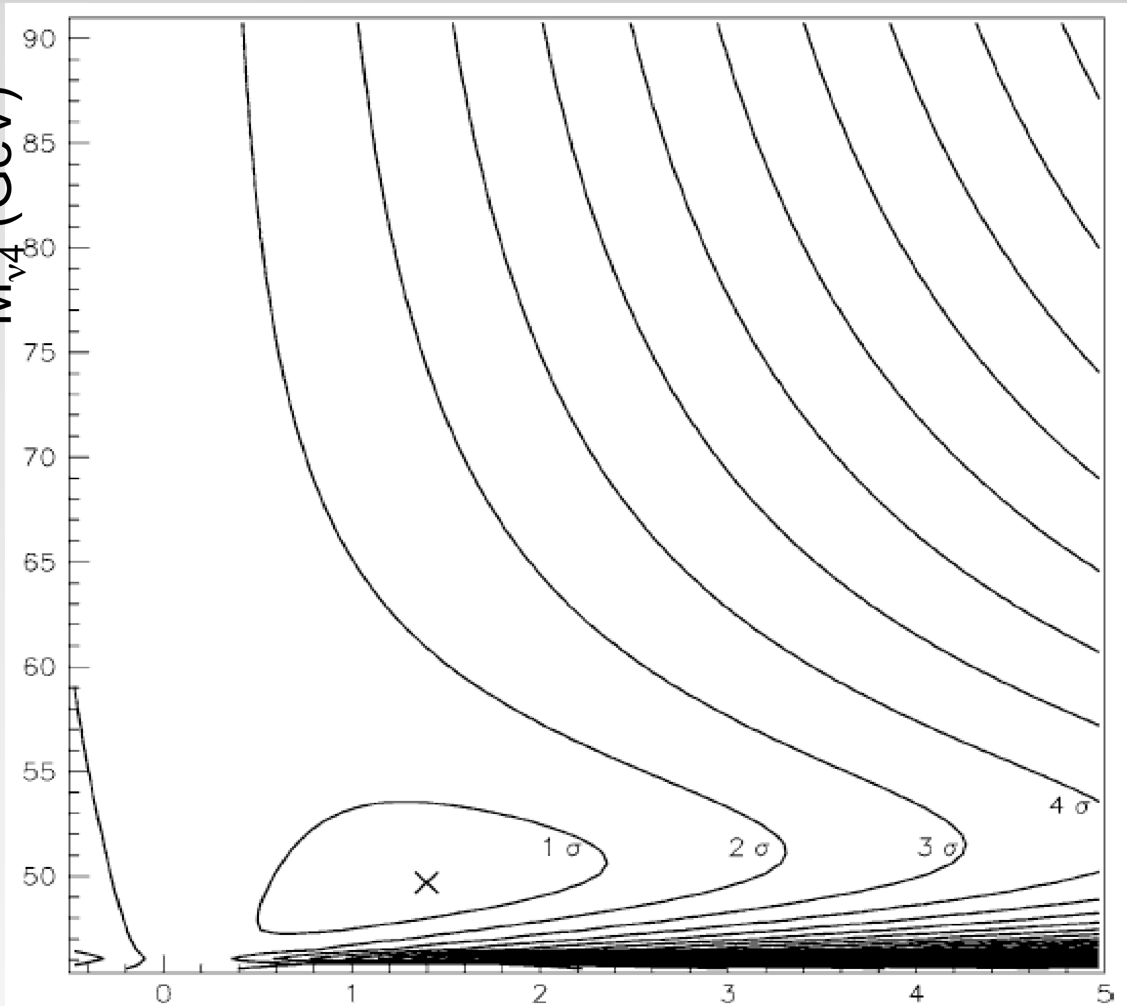


➡m_D = 400 … 2000 GeV cases are considered using generator level MC (CompHEP) with 2j+Z as the signal (sinΦ=0.045)

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

is 4th SM family Possible?

$M_{\nu 4}$ (GeV)



Number of extra generations

Precision EW data consistent with fourth generation with a heavy neutrino.

Example exclusion plot from Novikov, Okun, Rozanov, Vysotsky, PLB 529, 2002, for:

M_{d4} = 200 GeV

M_{u4} = 220 GeV

M_{e4} = 100 GeV

At the minimum,

$\chi 2$ /#d.o.f. = 21.6/12, Ng=1.4,

$M_{\nu 4}$= 50 GeV, M_H= 116 GeV.

$$a^d \approx a^u \approx a^\ell \approx a^\nu \qquad \approx \qquad a$$

$$e = g_W \sin\theta_W \quad < a/\sqrt{(2)} < \quad g_Z = g_W / \cos\theta_W$$