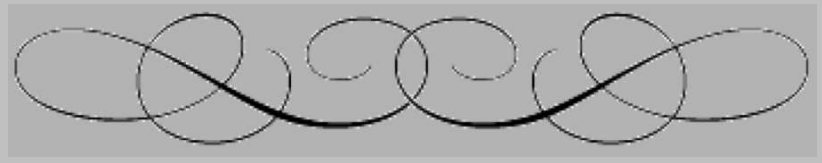
Spanning from exotic quarks to Higgs boson with ATLAS



N. Gökhan Ünel
University of California, Irvine

On Behalf of the ATLAS Collaboration

International Conference on Particle Physics, 27-31 October, 2008.
in memoriam of Prof. E. Arik and Her Colleagues

Contents

- ATLAS experiment
- SM and beyond
  - Models w/ additional quarks
- ATLAS prospects for
  - Fourth Family model
    - quark searches
    - impact to Higgs hunt
  - E6 GUT model
    - quark searches
    - impact to Higgs hunt
- Conclusions

i n m e m o r i a m


Prof. Fatma Şenel Boydağ
CAST


Prof. İskender Hikmet,
CAST


Mustafa Fidan
CAST


Engin Abat
ATLAS


Berkol Doğan
ATLAS


Prof. Engin Arik
14 Oct. 1948 - 30 Nov. 2007
Participated CERN experiments: Charm-2, Chorus, SMC, CAST, ATLAS

SM and beyond

- SM explains all the experiments conducted so far,
  - BUT:
- What are the fundamental constituents of the matter?
  - Why do we have mass? Why do we exist?
- Is the there a basic symmetry between the matter particles and the force carriers?
  - Are there really 4 forces governing the universe?
  - Can they be explained by a Unified Theory?
- Are there 3+1 dimensions in the universe we live in?
- What is the dark matter & blackholes we hear about?
  - Can they be produced in the lab?

What are the options?

SUSY looks as a promising candidate for a general theory

What if there is no SUSY ??

Little Higgs with T-parity? ★

*Fourth Family ? ★

UED ? ☆

Technicolor ? ★

Compositeness ? ☆

*GUT-inspired E_6 ? ★

★ Models predicting additional quarks

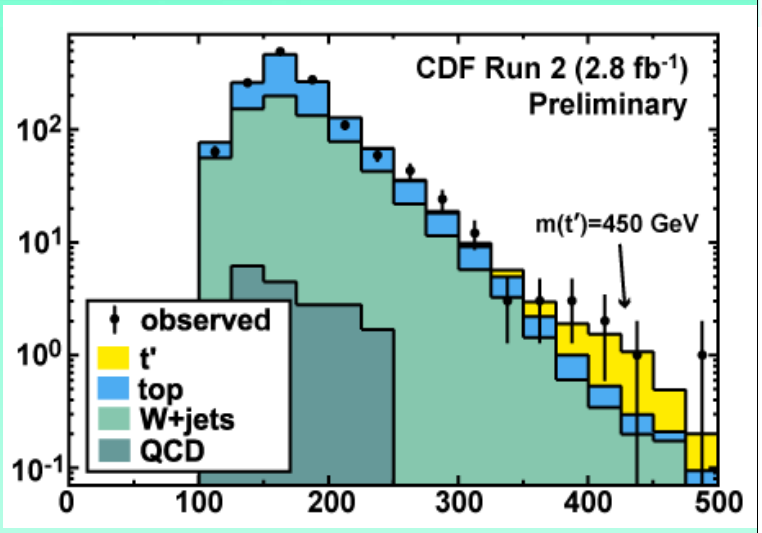
☆ Models predicting additional quarks in some cases

*In this talk, we focus on these models

Recent Hints

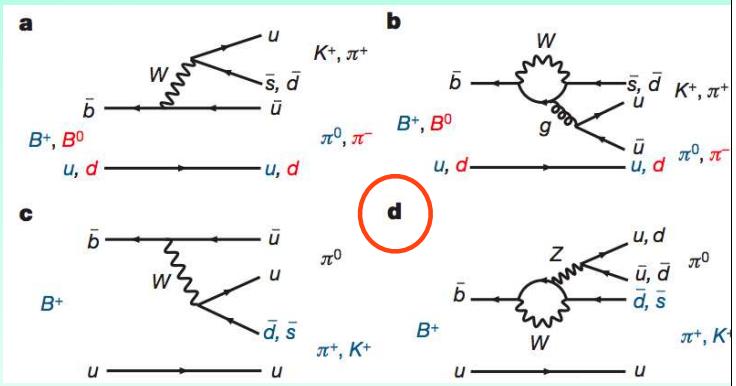
Tevatron results (CDF @ ICHEP)

- Q→W+jet channel, pair production (no b-tagging)
- 2σ "fluctuation" in direct searches at high mass tail.
- current limit m_Q>311GeV



Belle Kπ puzzle (Nature V452, 03/2008)

- Asym(B^+->$K^+\pi^0$) vs Asym(B^0->$K^+\pi^-$) : difference in SM = 0
- new CP source: needed for BAU!
  - explainable with an extra quark in EW penguin?



$\frac{n_B}{n_\gamma} = (5.1^{+0.3}_{-0.2}) \times 10^{-10}$ WMAP

KM ~ 10^{-20}

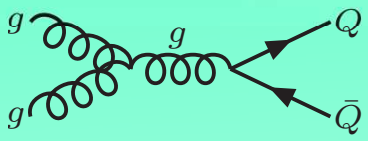
Too Small in SM

$m_{b'}, m_{t'} \cong 300\text{GeV}$ 10^{+13}

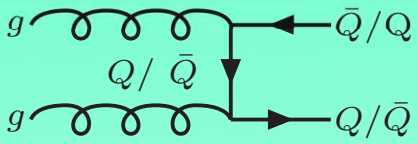
$\sim 600\text{GeV}$ 10^{+15}

$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0)$
$= -0.147 \pm 0.028$ @ **5.3σ**

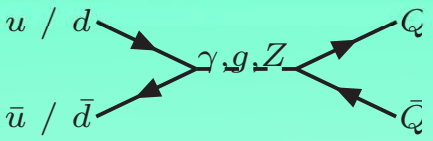
LHC: a gluon collider



gluons, s channel

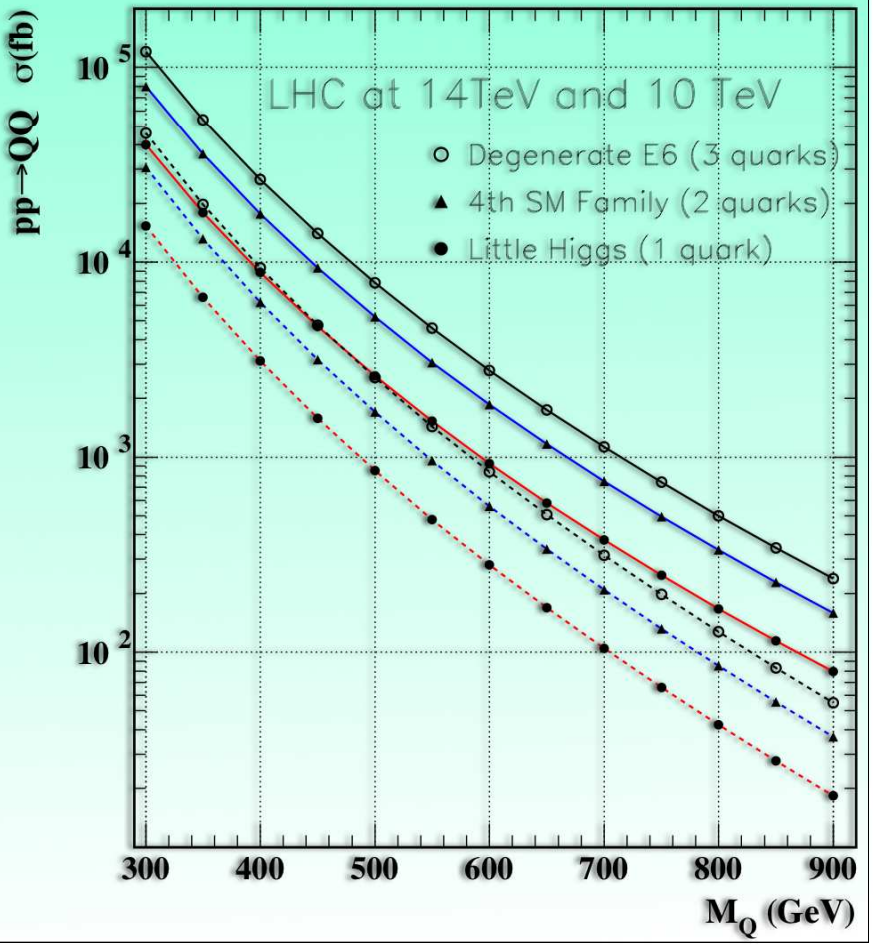


gluons, t channel



quarks, s channel

- LHC is mostly a gluon collider
  - quarks are pair produced with large σ.
  - quarks will be "easy" to discover:
    - small MET, can distinguish from susy
    - can fully reconstruct the event,
  - First searches will look for Q

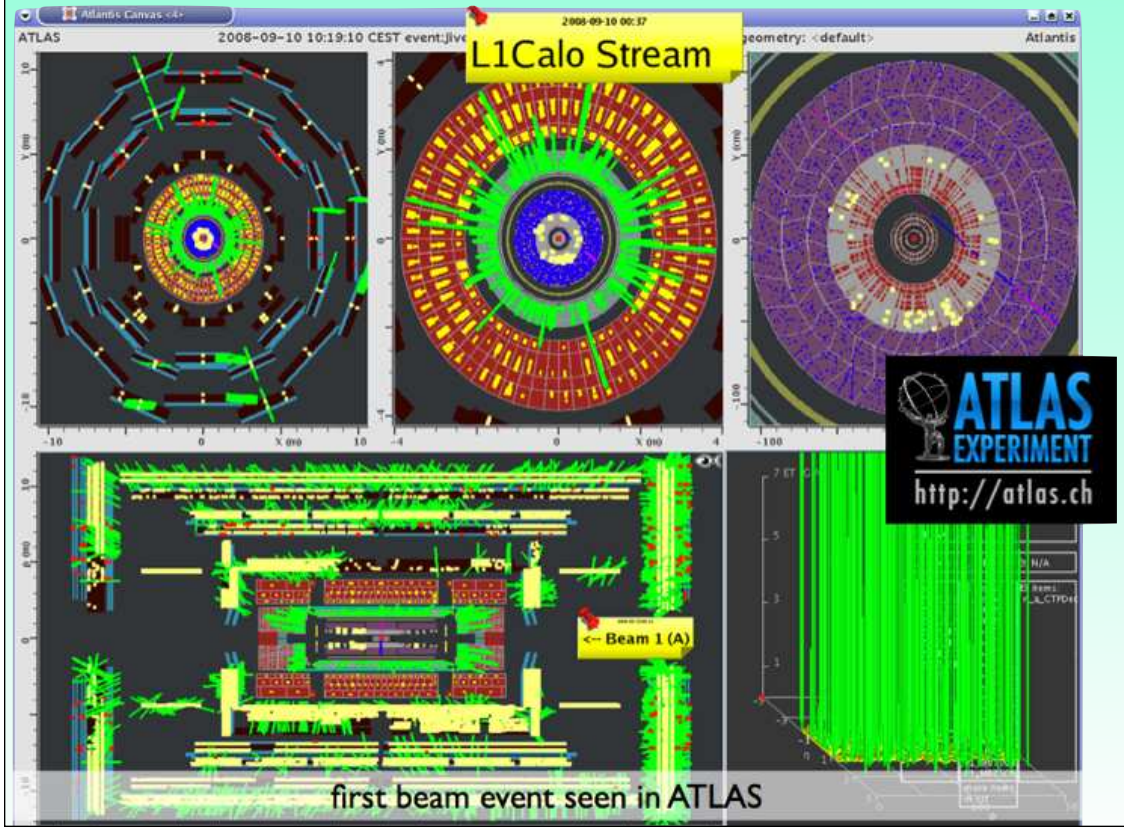


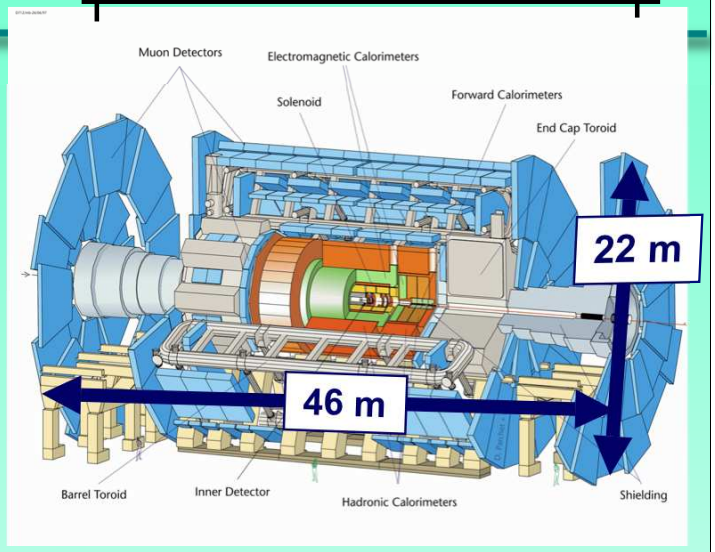
ATLAS currently

For further details see talk by P.Jenni in this conference

is well and taking data

- with cosmic rays...
- LHC beam expected in April 2009





- Inner Tracking ($|\eta|<2.5$, 2T solenoid) :
  - Silicon pixels and strips
  - Transition Radiation (e/π separation)
- Calorimetry ($|\eta|<5$) :
  - EM : Pb-LAr, Accordion shape
  - HAD: Fe/scintillator (centr), Cu/W-LAr (fwd)
- Muon Spectrometer ($|\eta|<2.7$, 4T toroid) :
  - air-core toroids with muon chambers

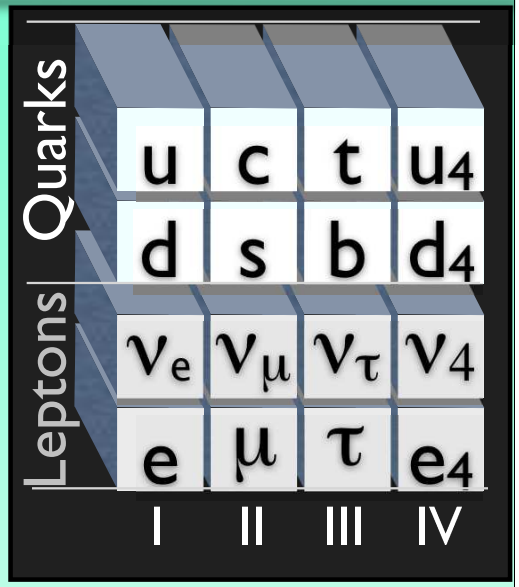
ID:	$\sigma/p_T \approx 5 \times 10^{-4}\ p_T \oplus 0.001$
	$\sigma(d_0)=15\mu m$ at 20GeV
ECAL:	$\sigma/E \approx 10\%/\sqrt{E(GeV)} \oplus 0.7\%$
HCAL:	$\sigma/E \approx 50\% / \sqrt{E(GeV)} \oplus 3\%$
Muon:	$\sigma/p_T \approx 10\%$ at 1 TeV/c

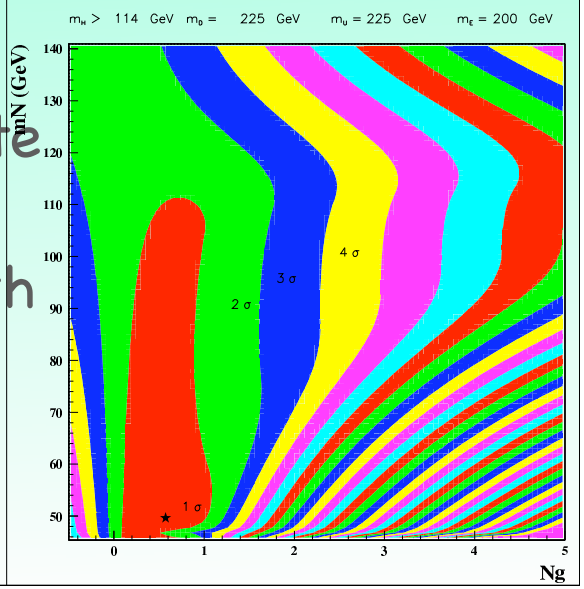
Fourth Family (FF)

For further details see talk by S.Sultansoy in this conference

- FF is the simplest "modification" to SM as we know it today
  - predicts 4 new heavy leptons m > 100GeV
    - quarks are to be searched for,
    - quasi-degenerate u_4 , d_4 masses expected:

      $|m_{d4}-m_{u4}| < m_W/2$
  - heavy FF quark condensate may play the Higgs role and give mass to fermions
  - heavy neutrinos may be the DM candidate we are looking for.
  - EW precision data equally compatible with 3SM and 4SM cases.
- FF is an economical solution to SM problems.

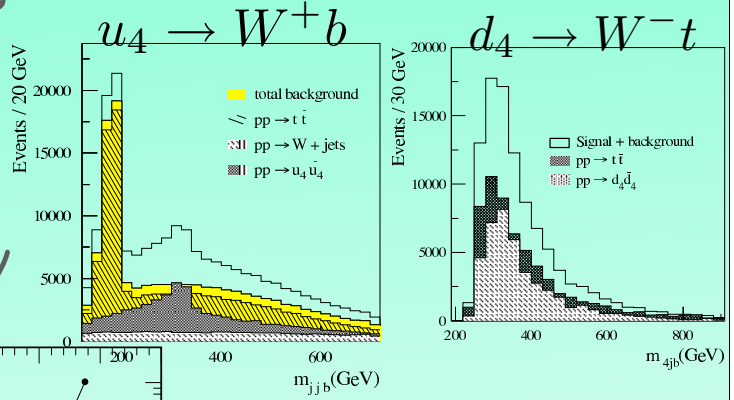


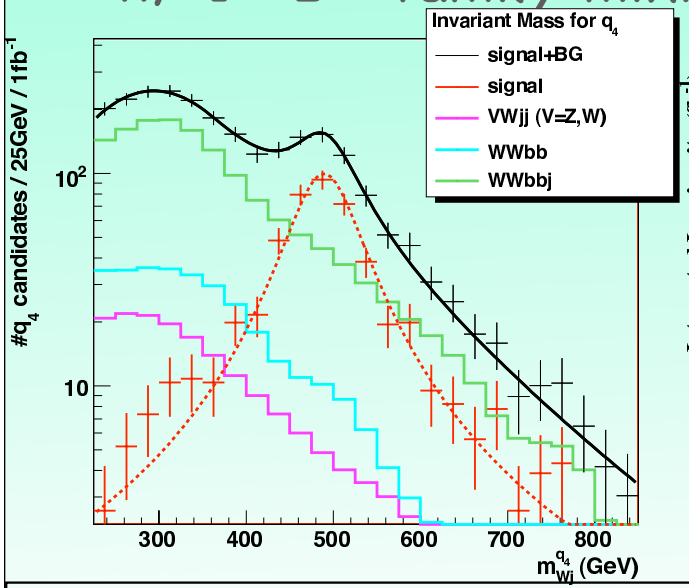


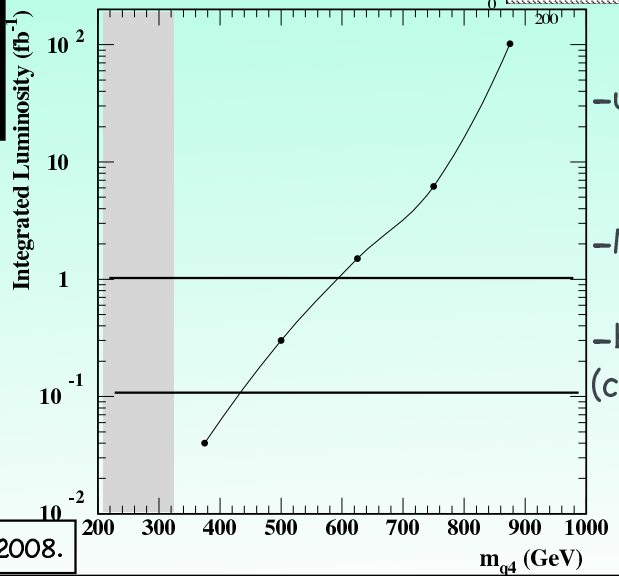
prospects for FF quarks

Search channels (No FCNC at tree level):

- Q→Wj depending on 4x4 CKM, j is from 1st, 2nd or 3rd family
- case w/ dominant 3rd family mixing was studied before
  - u4 easy, d4 not so easy
  - 10 year old work, can be improved.
- w/ 1st 2nd family mixing: recent study







Ozcan, Sultansoy, Unel, SN-ATLAS-2008-069, EPJC, 2008.

- u4/d4 pair →WjWj , light jets
  - semi leptonic mode
  - both q_4 reconstructed
- MLM matching not done
  - pessimistic results
- background estimated from fit (crystal ball function)

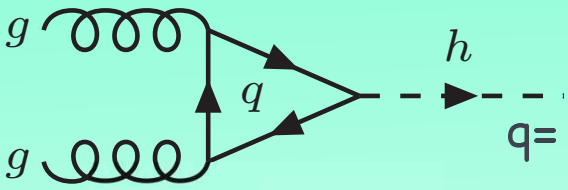
discovery limits:
- 100 pb^{-1} up to 450 GeV
- 1 fb^{-1} up to 600 GeV

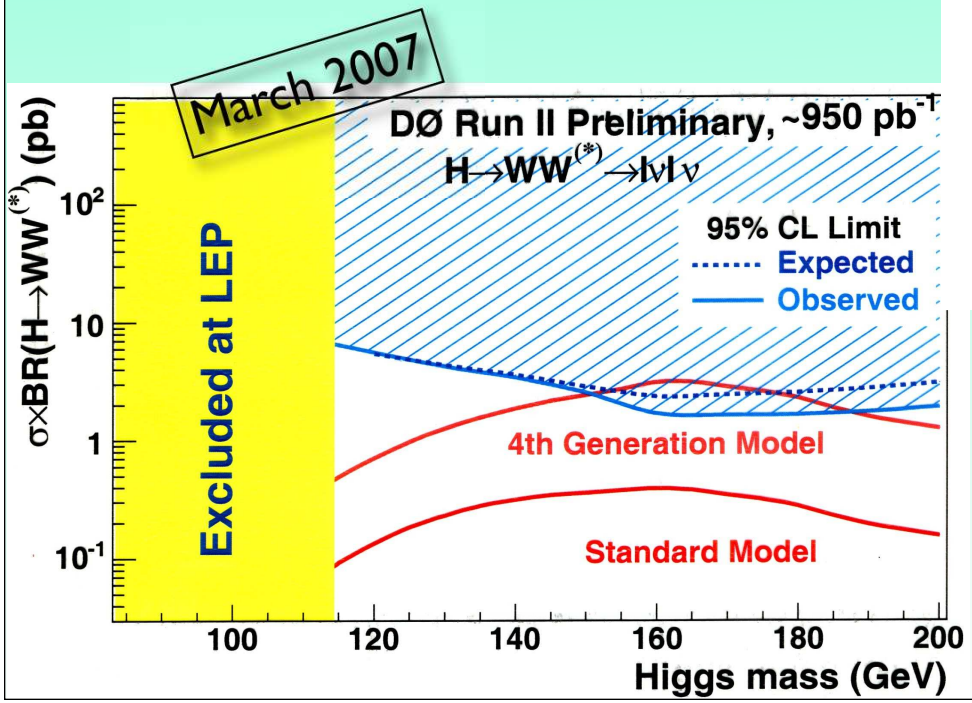
FF and Higgs .

Enhancement to Higgs production from FF quarks

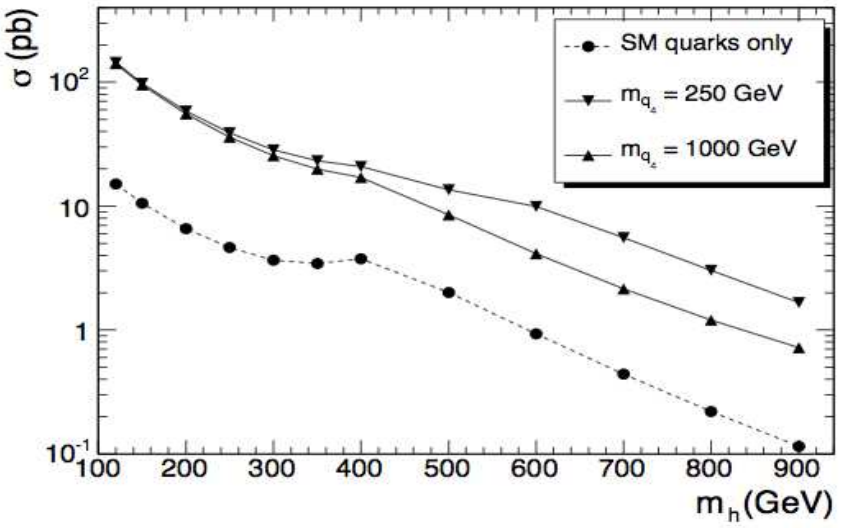
- from to gluon fusion loop $\sigma_{4th}(gg\to h) \simeq 9\,\sigma_{SM}(gg\to h)$

  – indirect searches at Tevatron & LHC





LHC @ 14TeV



indirect searches limit the mass of Higgs and the mass of q_4.
-> D0 analysis being updated!

FF and Higgs ..

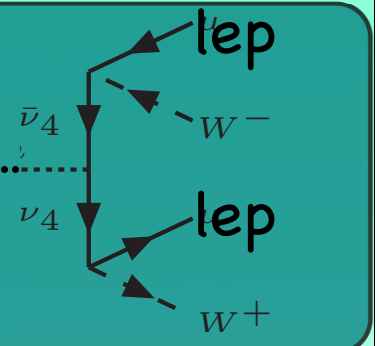
What about the Higgs decays to FF members ?

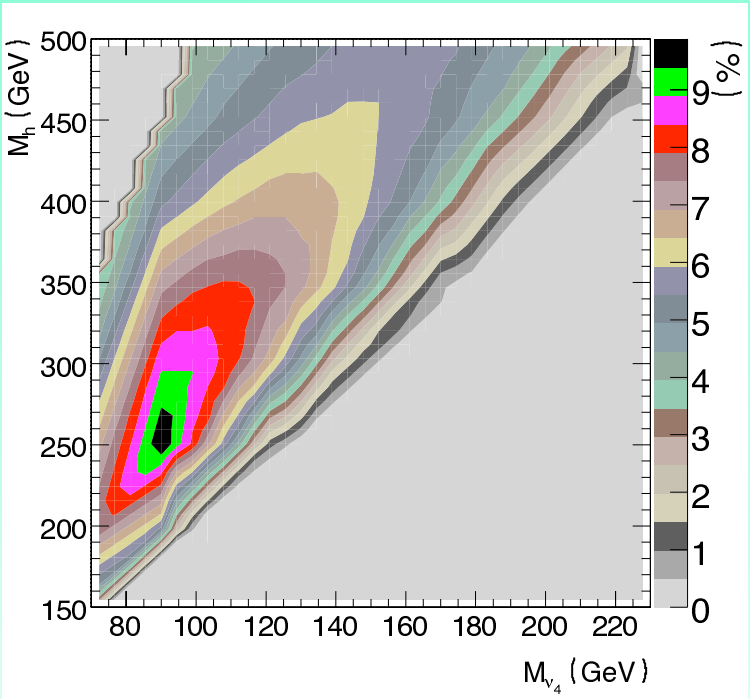
- In particular to ν_4

Sultansoy, Unel, hep-ph/0707.3266 & Turkish J. Phys. 31, (2007) 295-298

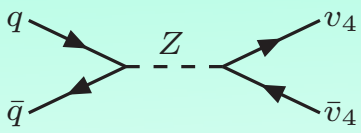
new search channel: h.....

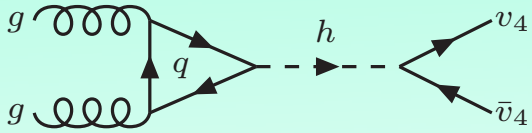
"Silver & platinum modes" of Higgs search





Cuhadar-Donszelmann , Karagoz Unel, Ozcan, Sultansoy, Unel, arXiv:0806.4003 [hep-ph], JHEP10(2008)074





Define 3 benchmark points with different mass values all in the 2μ+4j final state BR (ν4 → μW) = 68% (PRD72,2005, 053006)

	$\sigma_{pp\to Z\to\nu_4\bar{\nu}_4}$ (fb)	m_h (GeV)	$\sigma_{gg\to h}$ (pb)	m_{ν_4} (GeV)	BR($h\to\nu_4\bar{\nu}_4$)	$\sigma_{pp\to\nu_4\bar{\nu}_4\to WW\mu\mu}$ (fb)
S1	782	N/A	N/A	100	N/A	362
S2	782	300	30	100	0.088	1583
S3	144	500	10	160	0.055	321

Higgs & ν_4 .

PGS based study

Initially same, later on separate cuts for Dirac & Majorana cases

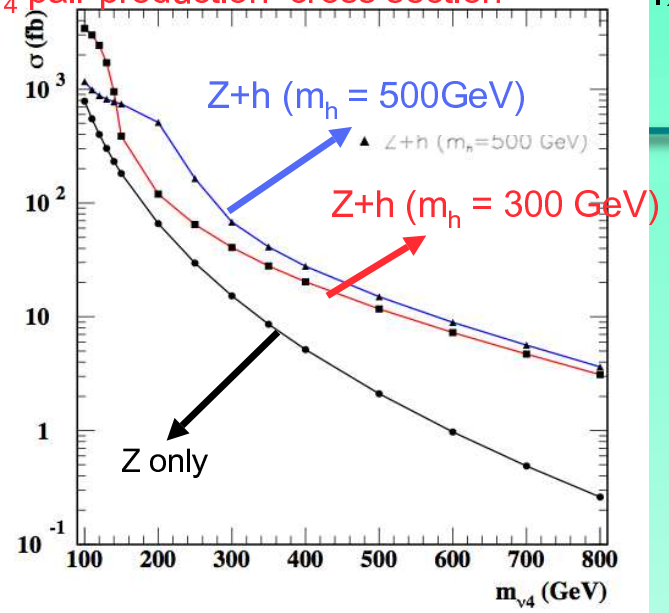
Backgrounds:

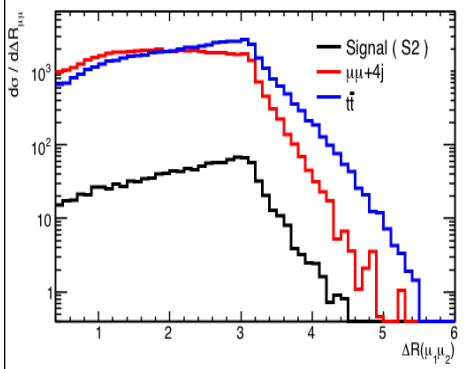
2V+2μ, V=W, Z = 5fb

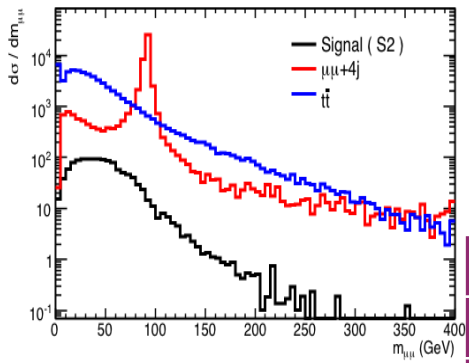
Z/γ +4j = 57pb

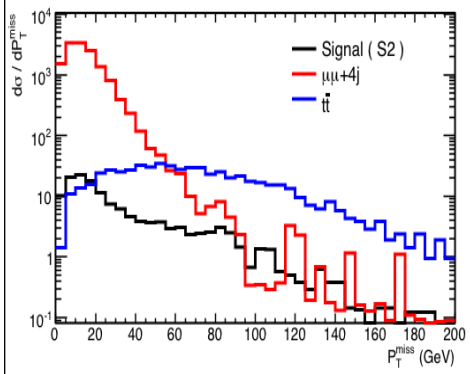
ttbar =755pb

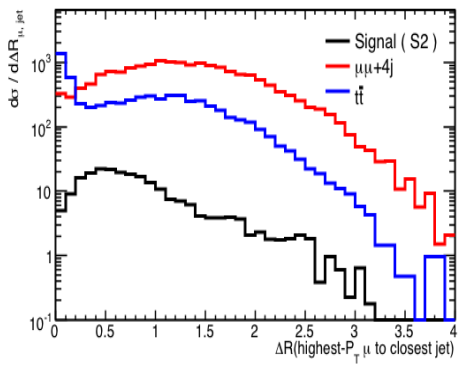
ν_4 pair production cross section









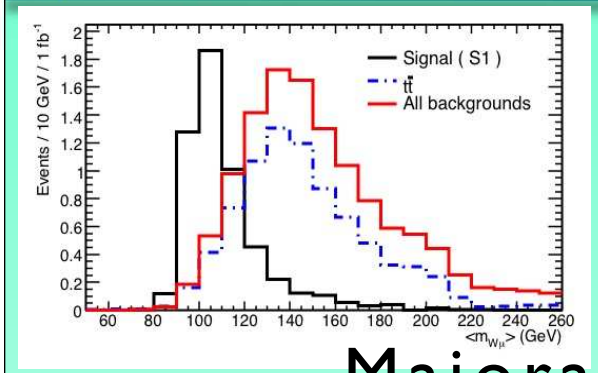


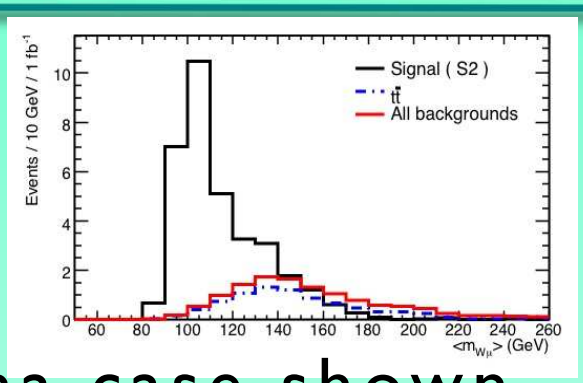
$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

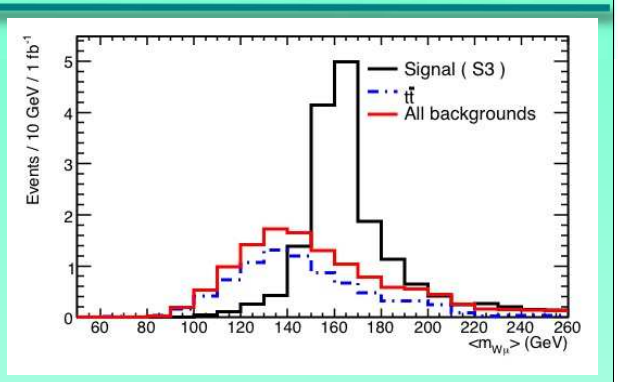
Selection cut	S1	S2	S3	2μ4j	tt
At least 2μ	63.6	77.9	84.1	93.3	8.1
$p_T(\mu) > 15$ GeV	50.7	55.1	95.1	88.8	29.5
At least 4j	73.6	82.3	82.6	86.0	88.7
$p_T(j) > 15$ GeV	53.3	65.6	72.2	70.4	76.0
$\lvert M_{jj} - M_W \rvert < 20$ GeV	63.1	60.5	60.3	45.9	52.8
$\Delta R_{\mu j} > 0.4$	64.5	65.9	77.4	83.0	17.4
No j_b	93.6	92.0	91.5	93.6	53.4
$ME_T < 30$ GeV	74.4	64.9	68.7	79.4	15.4
Common ε_{reco}	3.7	5.7	13.4	24.2	0.012

Higgs & ν4 ..

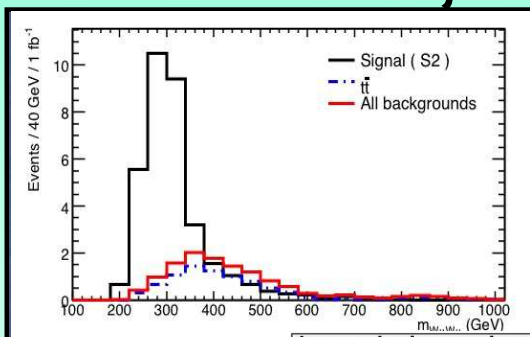
$$\mathcal{S} = \sqrt{2 \times [(s+b)\ln(1+\frac{s}{b}) - s]}$$

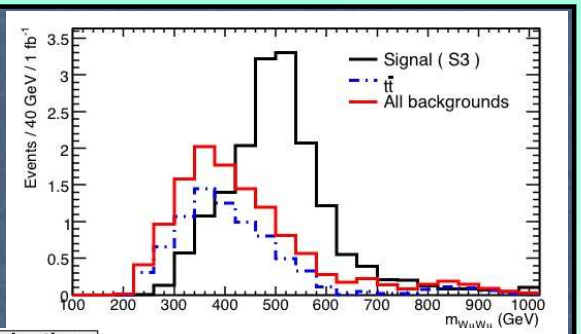




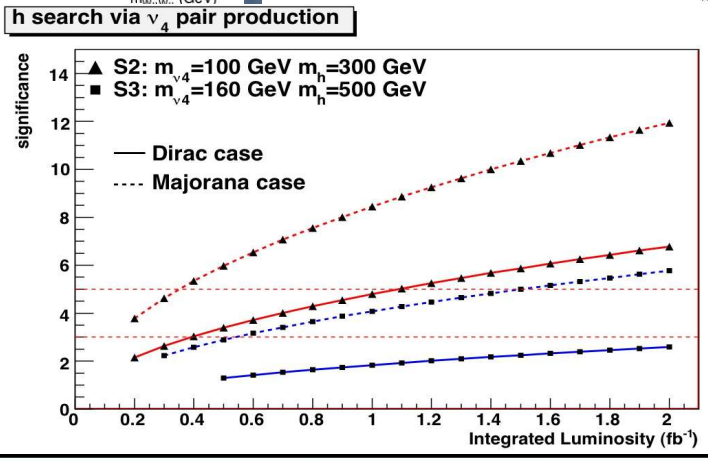


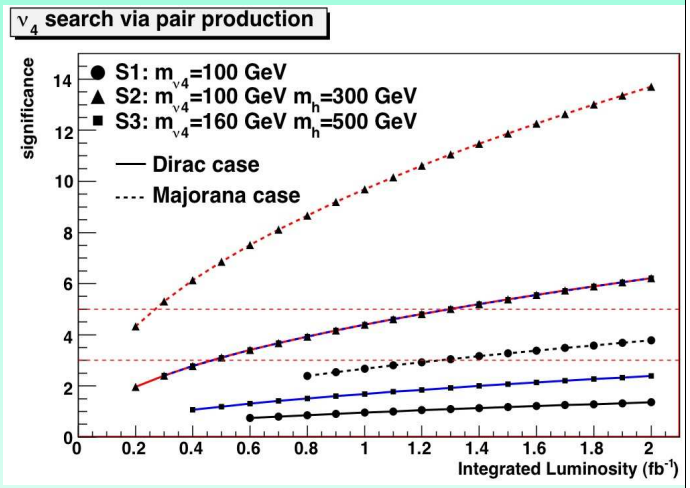
Majorana case shown





Higgs





- 1 fb or less for Majorana
- about 2 fb for Dirac
- if no Higgs Dirac v4 can stay undetected

prospects for E6 inspired quarks

- E6 GUT, initially suggested by F. Gürsey in 70s
  - predicts one iso-singlet quark per family (assume D lightest)

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

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

Mehdiyev, Sultansoy, Unel, Yilmaz, EPJC 49 2007.

- Higgs boson could also be in the game:
  - if $m_h < m_D$, D->hd is possible:

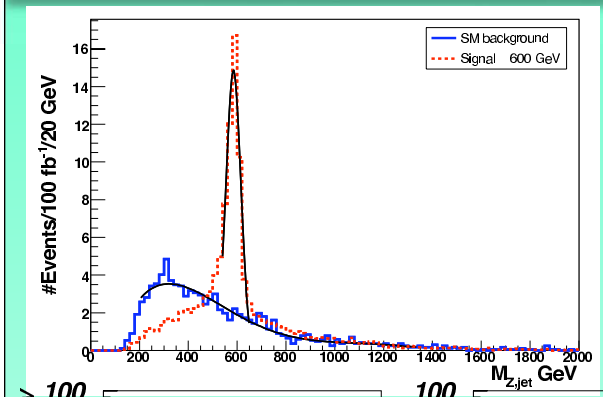
$$\begin{aligned} L_h^M &= \frac{m_D}{\nu}\sin^2\phi_L\bar{D}^M D^M h \\ &- \frac{\sin\phi_L\cos\phi_L}{2\nu}\bar{D}^M\left[\left(1-\gamma^5\right)m_D+\left(1+\gamma^5\right)m_d\right]d^M h \\ &- \frac{\sin\phi_L\cos\phi_L}{2\nu}\bar{d}^M\left[\left(1+\gamma^5\right)m_D+\left(1-\gamma^5\right)m_d\right]D^M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

- Branching Fractions:
  - w/o Higgs : D→Wq (66%) D→Zq (33%)
  - with Higgs: D→Wq (50%) D→Zq (25%) D→hq (25%)

Sultansoy, Unel, SN-ATLAS-2007-066, PLB, 669, 1,2008.

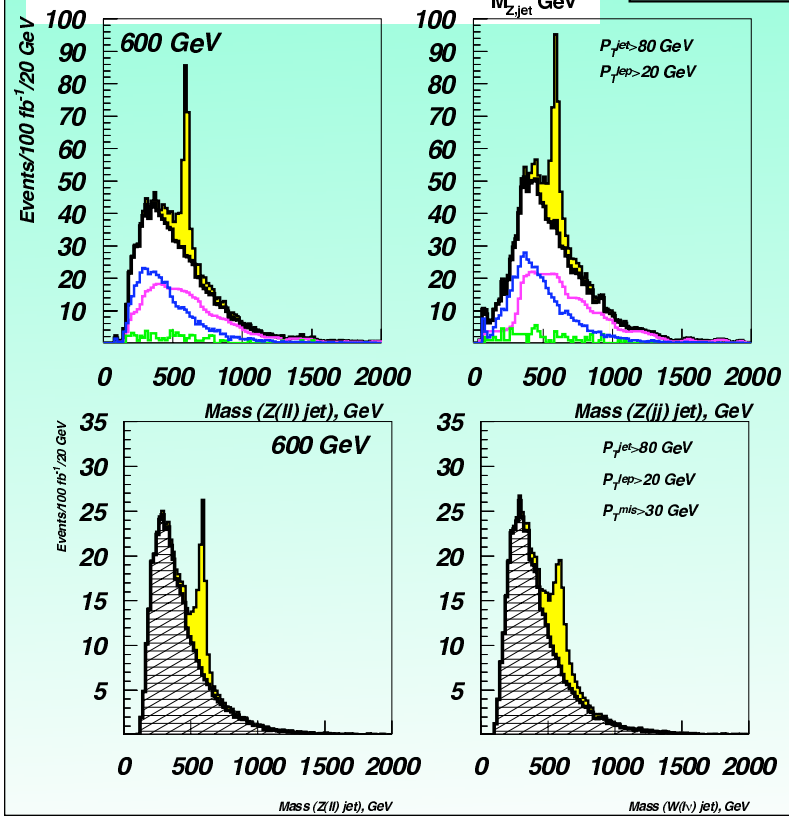
ATLAS prospects for E6 quarks

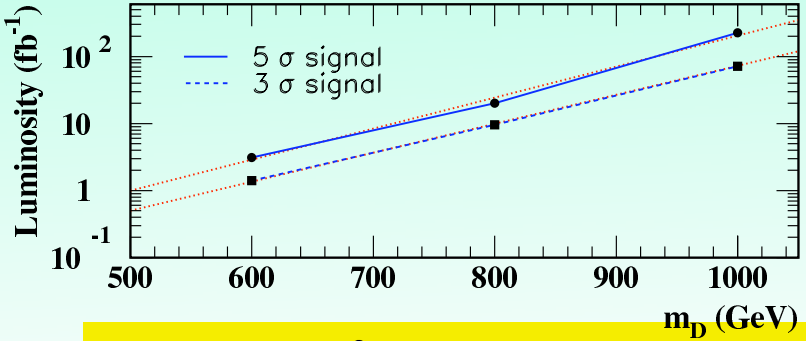
$D\bar{D} \rightarrow$	Final State	Expected Signal	Decay B.R.	Total B.R.
$Z\,Z\,d\,\bar{d}$	$Z \rightarrow l\bar{l}\;\; Z \rightarrow l\bar{l}$	$4\,l\,+2\,jet$	0.07×0.07	0.0005
0.33×0.33	$Z \rightarrow l\bar{l}\;\; Z \rightarrow \nu\nu$	$2\,l\,+2\,jet+P_T$	$2 \times 0.07 \times 0.2$	0.0030
	$Z \rightarrow l\bar{l}\;\; Z \rightarrow q\bar{q}$	$2\,l\,+4\,jet$	$2 \times 0.07 \times 0.7$	0.0107
$Z\,W\,d\,u$	$Z \rightarrow l\bar{l}\;\; W \rightarrow l\bar{\nu}$	$3\,l\,+2\,jet+P_T$	0.07×0.21	0.0065
$2 \times 0.33 \times 0.67$	$Z \rightarrow l\bar{l}\;\; W \rightarrow q\bar{q}$	$2\,l\,+4\,jet$	0.07×0.68	0.0211



Mehdiyev, Siodmok, Sultansoy, Ünel
SN-ATLAS-2007-067 EPJC54,2008

$m_D(GeV)$		600	800	1000
$4\ell+2j$	Signal	16	3.7	0.74
	background	3.0	1.3	0.4
	-ln p	21.47	4.78	1.44
$2\ell+2j+\not{E}_T$	Signal	53	19	4
	background	12	13	5
	-ln p	120	15.81	3.32
$3\ell+2j+\not{E}_T$	signal	97	18.3	1.8
	background	24.9	9.0	1.05
	-ln p	191.4	20.66	1.69
$2\ell+4j$	signal	133	18	2.5
	background	9	3	2.8
	-ln p	983	25.3	2.44
$-\Sigma\ln p$		1315.9	66.5	8.9
Combined Significance (σ)		51.3	11.3	3.8





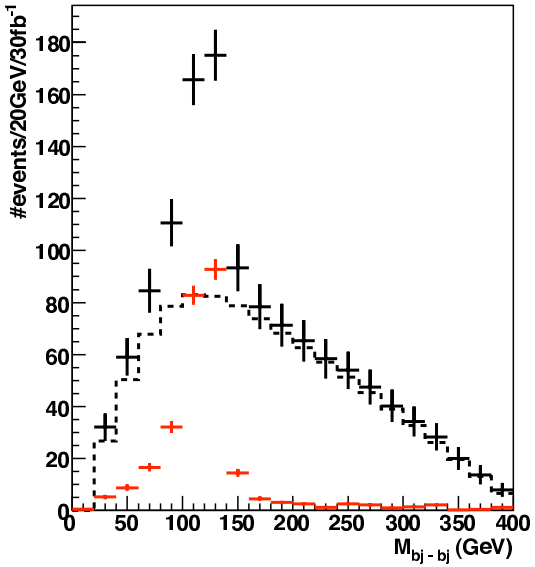
Combination of channels allows discovery in early data taking. 100 fb^{-1} is enough to scan up to 1TeV

E6 and the Higgs

DD->hj Wj channel studied for a light Higgs + m_D scan

- other channels:
- h->bb possible

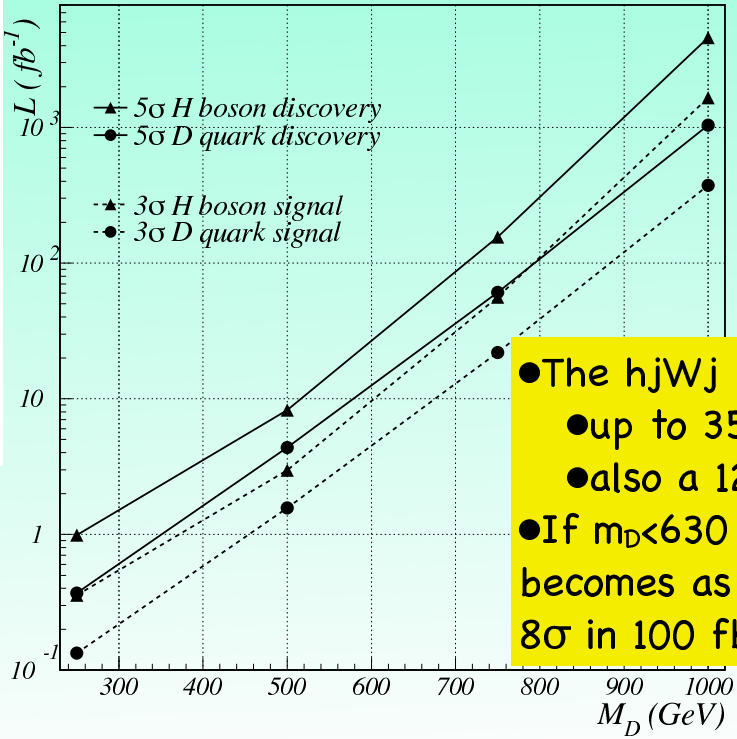
D_1	D_2	BR	#expected Higgs/100fb^{-1}	expected final state
$D \to h\,j$	$D \to h\,j$	0.029 (0.053)	0.58×10^6 (2.65×10^4)	$2j\,4j_b$
$D \to h\,j$	$D \to Z\,j$	0.092 (0.120)	0.92×10^6 (3.01×10^4)	$2j\,2j_b\,2l$
$D \to h\,j$	$D \to W\,j$	0.190 (0.235)	1.9×10^6 (6.04×10^4)	$2j\,2j_b\,l\,E_{T,miss}$



Both h and D reconstruction possible

Sultansoy, Unel, SN-ATLAS-2007-066, PLB, 669, 1,2008.

Background: SM $W^{\pm}bbjj$ = 520 pb

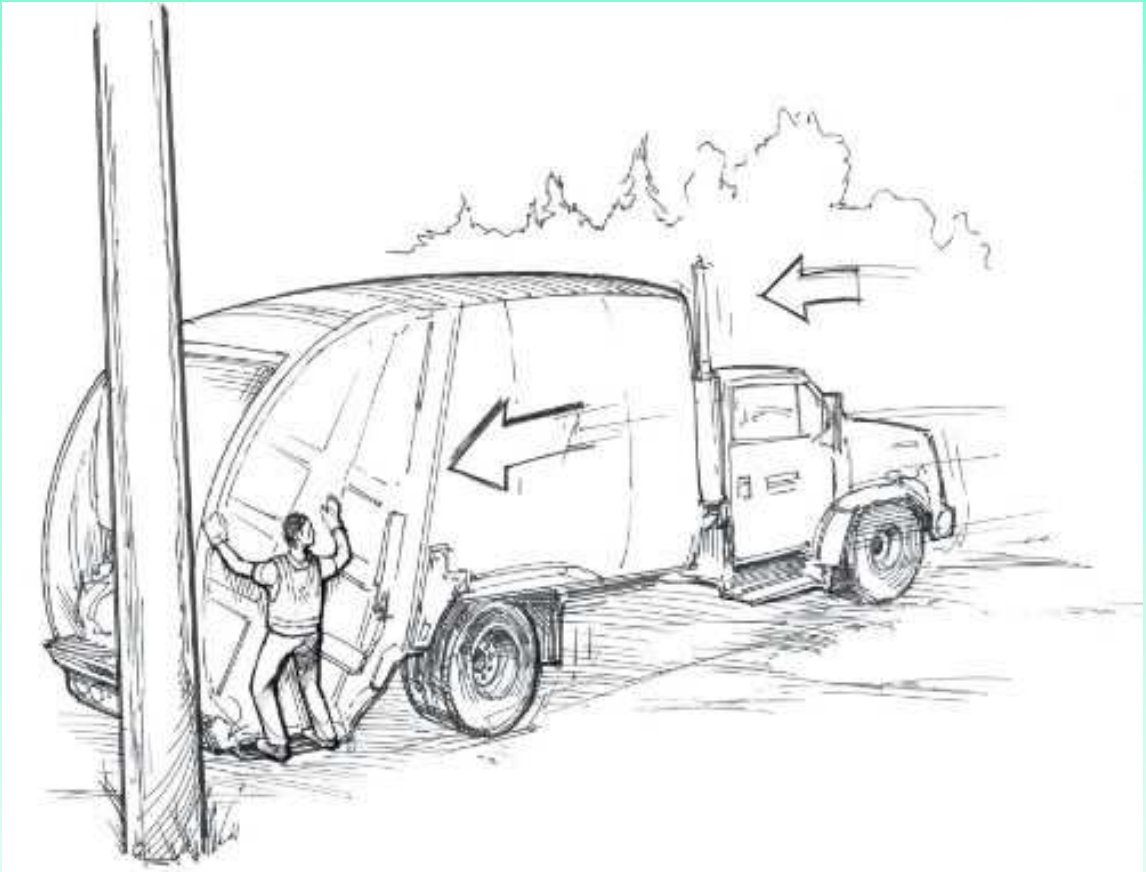


- The hjWj mode only allows 5σ
  - up to 350GeV D quark with 1fb^{-1}
  - also a 120GeV Higgs with 2fb^{-1}
- If m_D<630 GeV, hjWj channel becomes as promising as H→γγ . (i.e. 8σ in 100 fb^{-1})

Conclusions

- There are several BSM candidates predicting additional quarks.
- We saw the ATLAS discovery prospects for FF and E6 models:
  - FF model
    - quarks up to 450 GeV with 100 pb^{-1} if 1^{st} or 2^{nd} & 4^{th} generations mix
    - neutrinos up to 160 GeV with $1fb^{-1}$ if Higgs is ≥300 GeV
  - E6 model
    - If m_D <500GeV, ATLAS could discover with $1fb^{-1}$ by combining different channels.
    - With 100 fb^{-1}, the observation reach increases to m_D=1000 GeV.
- we saw the potential boost to Higgs searches:
  - FF model
    - $\sigma 4th(gg->h) \simeq 9\ \sigma SM(gg->h)$ => golden mode reachable w/ $1fb^{-1}$ for all h masses.
    - $300<m_h<500$GeV w/ $1fb^{-1}$ from ν_4 (Dirac & Majorana identification possible)
  - E6 model
    - if $mh\simeq120$ GeV & $m_D<630$ GeV, hjWj channel becomes as promising as $h\rightarrow\gamma\gamma$
- Watch the "ATLAS" channel, interesting things are about to happen.

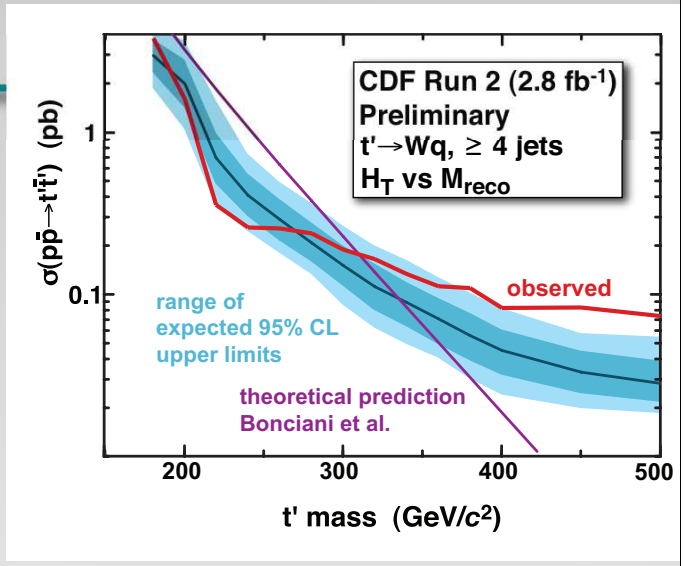
thank you..

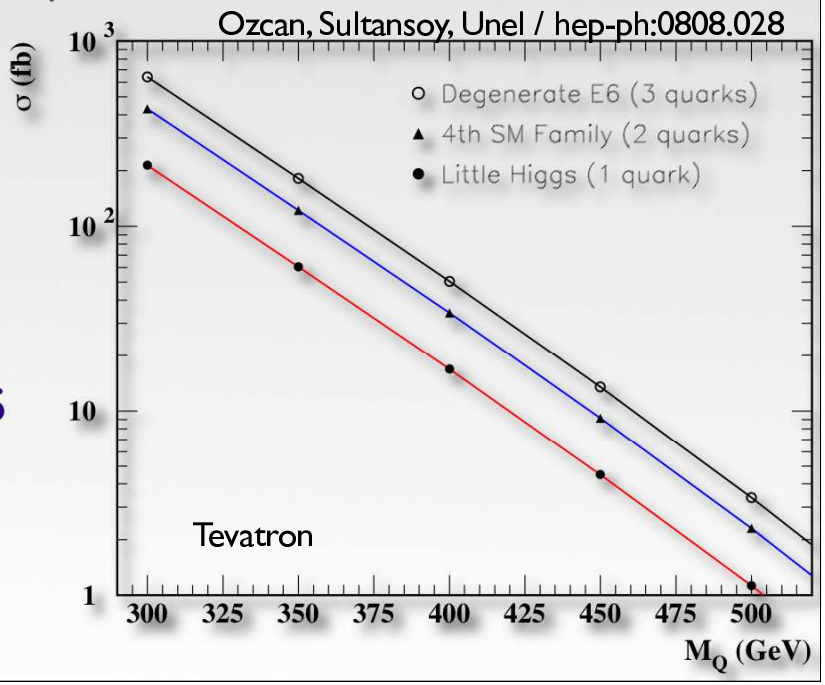


backup

About CDF hint

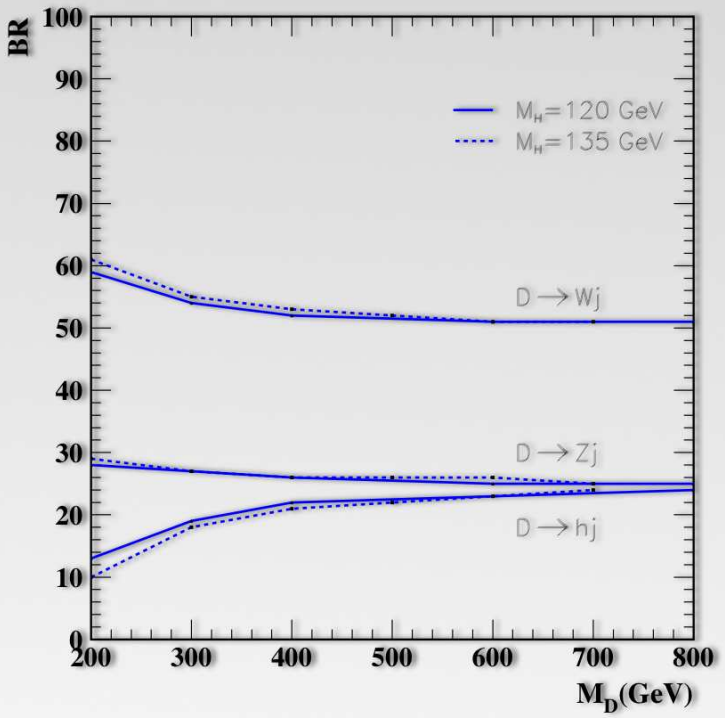
- Too many events, how could this be?
  - Little Higgs model predicts 1 T quark, heavy iso-singlet up type
    - similar to the model given in CDF paper
    - not enough cross section
  - E6-GUT predicts 3 down type, heavy iso-singlet quarks (D, S, B)
  - Fourth Family model: u_4, d_4 quarks
    - $\Delta m(u_4,d_4) \leq m_W/2$
  - A susy model with more quarks?
- Only multiple degenerate quarks or anomalous production could explain the number of "signal" events.



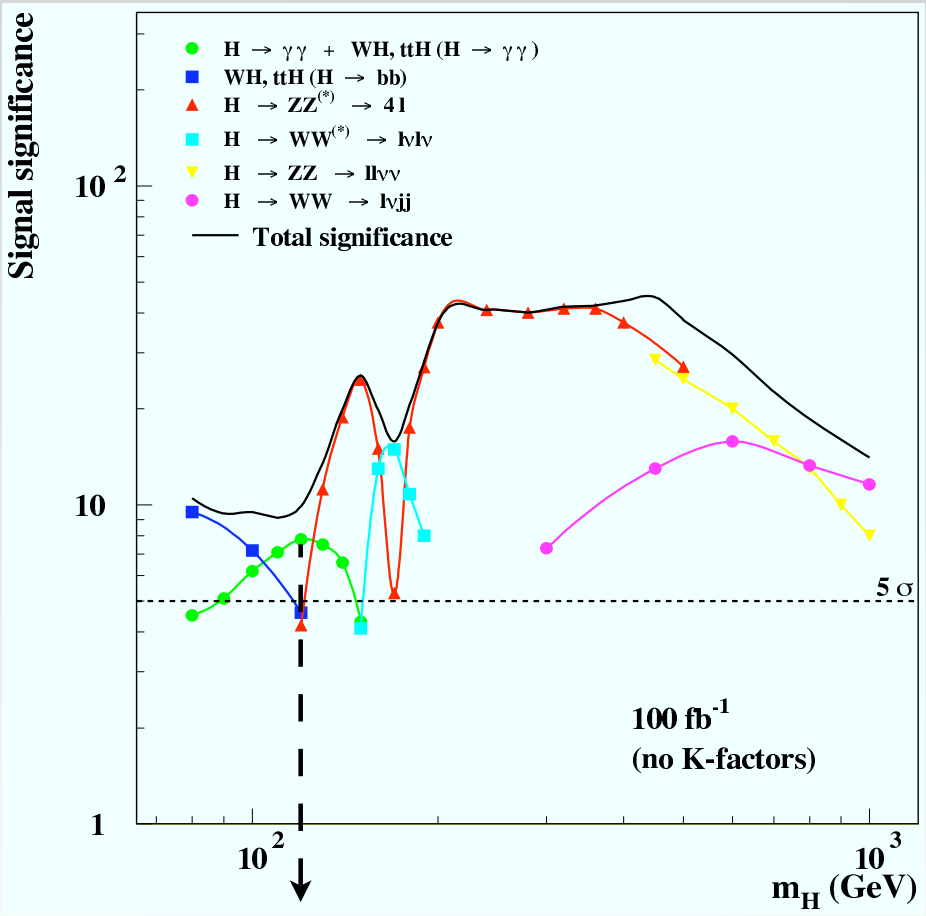


Light Higgs & E6

m_h=120 .. 135 GeV



- if sinϕ becomes 10 times smaller, total cross section increases by few percent.



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