Collider aspects of flavour physics at high Q

Summary

Werner Porod (IFIC-CSIC)

on behalf of T. Lari and L. Pape

- The tasks of WG1

- Identified subjects

- Outlook & future plans

The tasks

- Explore/document the potential of ATLAS/CMS for BSM flavour studies

- Identification of observables which allow different models to be distinguished
  - between different model classes, e.g. SUSY and UED
  - between different different realization of a particular model class, e.g. MSSM with MFV or additional flavour structures

Subjects

- Flavour phenomena in top decays
  - FCNC, anomalous couplings
  - constraints form EW precision tests & B decays versus direct measurements

Experimental talks by N. Castro (ATLAS) and L. Benucci (CMS), theoretical talks by J. Guasch, S. Heinemeyer and C. Verzegnassi

Physics motivation

- Top is the least studied quark in the SM
- The LHC will be a top factory

  $\sigma(pp \rightarrow t\bar{t}) = 833$ pb

  ($L = 10$ fb$^{-1} \longrightarrow \sim 8$ million of $t\bar{t}$ pairs per year)
- Top decays can be a window to physics beyond the SM:
  - new physics in $t \rightarrow bW$ decay
  - top quark FCNC decays: $t \rightarrow qZ$, $t \rightarrow q\gamma$, $t \rightarrow qg$

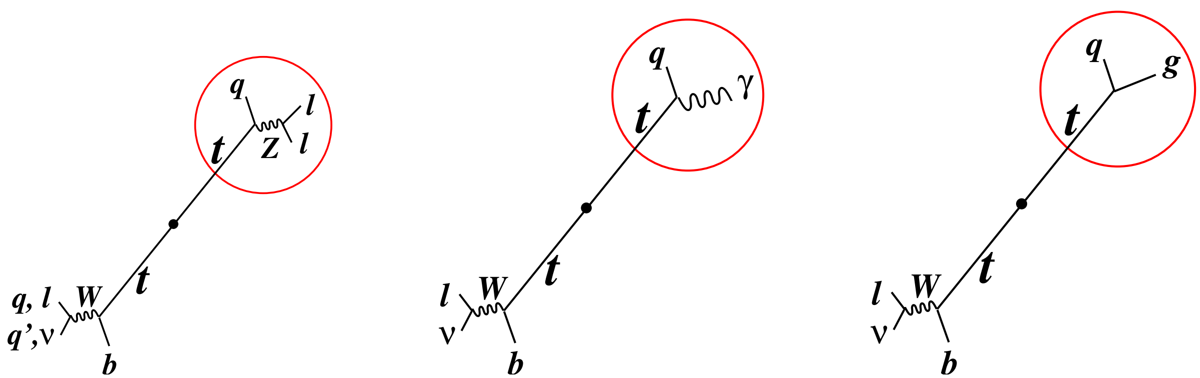
Top quark FCNC decays

	BR in SM	2-Higgs	SUSY	exotic quarks
$t \to qZ$	$\sim 10^{-13}$	$\sim 10^{-6}$	$\sim 10^{-4}$	$\sim 10^{-2}$
$t \to q\gamma$	$\sim 10^{-13}$	$\sim 10^{-7}$	$\sim 10^{-5}$	$\sim 10^{-5}$
$t \to qg$	$\sim 10^{-11}$	$\sim 10^{-5}$	$\sim 10^{-3}$	$\sim 10^{-4}$

- GIM suppressed in the SM
- higher BR in some SM extensions

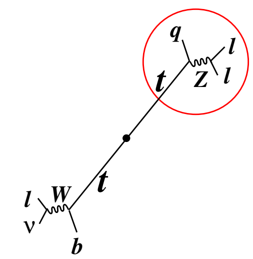
  (2-Higgs doublet, SUSY, exotic fermions, . . .)
- 3 top decay channels studied:

$t \to qZ$ $\qquad$ $t \to q\gamma$ $\qquad$ $t \to qg$



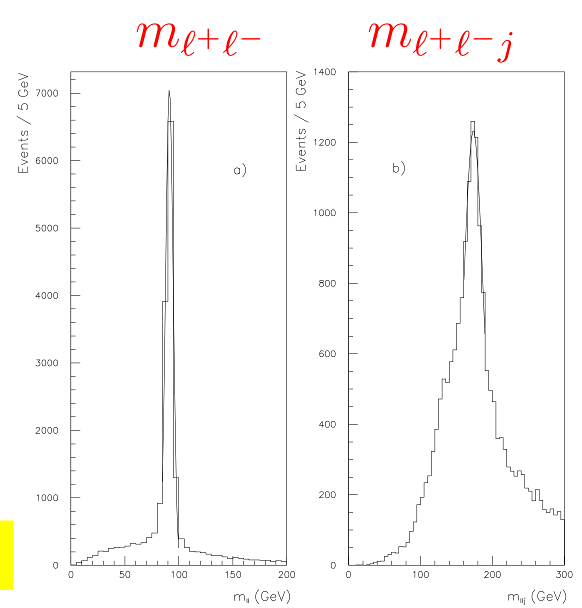
Top quark FCNC decays

$t \to qZ$



Sequential analysis: $Z \to ll, W \to l\nu$

- ≥ 2 jets with $p_T > 50$ GeV$/c$ and $|\eta| < 2.5$
- only 1 b-tagged jet
- ≥ 3 leptons:
  - $p_T > 20$ GeV$/c$ and $|\eta| < 2.5$
  - 2 leptons with same flavour and opposite charges ($\ell^+\ell^- = e^+e^-, \mu^+\mu^-$)
  - $|M(\ell^+\ell^-) - M_Z| < 6$ GeV$/c^2$
- $p_T^{missing} > 30$ GeV$/c$



$|M(\ell^+\ell^- j) - M_t| < 24$ GeV$/c^2$:

0.6 back. events (mainly $t\bar{t}$)

$\varepsilon \times BR$ = 0.08%

L=10 fb^{-1}

Top quark FCNC decays

- **expected 95% CL limits on BR (absence of signal)**
  - **Sequential analysis** [$|M(\ell^+\ell^- j) - M_t| < 24$ GeV$/c^2$ cut]:

	$t \to qZ$ ($Z \to ll, W \to l\nu$)	$t \to qZ$ ($Z \to ll, W \to qq'$)
$L = 100$ fb^{-1}	6.3×10^{-5}	2.8×10^{-4}

  - **Discriminant analysis:**
    * Modified frequentist likelihood method [A.L. Read, CERN report 2000-005 (2000) 81]
    * No cuts on the discriminant variable used

	$t \to qZ$	$t \to q\gamma$	$t \to qg$
$L = 10$ fb^{-1}	3.4×10^{-4}	6.6×10^{-5}	1.4×10^{-3}
$L = 100$ fb^{-1}	6.5×10^{-5}	1.8×10^{-5}	4.3×10^{-4}

    * Dominant systematics: M_t and $\varepsilon_{btag} < 20\%$

Estimated Br_{FCNC} sensitivity

An evidence for a $t \to Zq$ can be claimed at 5σ (99% CL) if:

$S/\sqrt{(S+B)} > 5$

An FCNC signal with branching ratio $Br_{UPPER}(FCNC)$ is given by:

$$S = \sigma(t\bar{t}) \; Br(W \to \nu l) \; Br(Z \to ll) * 2 * \int \mathcal{L}dt * \varepsilon * Br_{UPPER}(FCNC)$$

with $\int \mathcal{L}dt$ integrated luminosity and ε selection efficiency

Expected signal efficiency: 3-5%	10 fb^{-1}	100 fb^{-1}
Expected $t\bar{t}$ events	22÷31	220÷310
Expected S	39÷43	88÷101
Expected $Br_{UPPER}(FCNC)$	$(5.3 \div 11.4)\ 10^{-4}$	$(2.0 \div 4.1)\ 10^{-4}$

significant improvement to existent limit – close to exotic models predictions

Leonardo Benucci, ***Top FCNC: preliminary studies in CMS***
FLAVOUR IN THE ERA OF THE LHC – Cern Workshop, 7th-10th November 2005

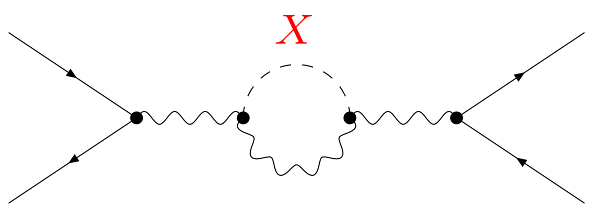
Precision Observables (POs):

Comparison of electro-weak precision observables with theory:

EW Precision data:		Theory:
M_W, $\sin^2\theta_{\text{eff}}$, m_h	$\leftrightarrow$	SM, MSSM, extensions

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections

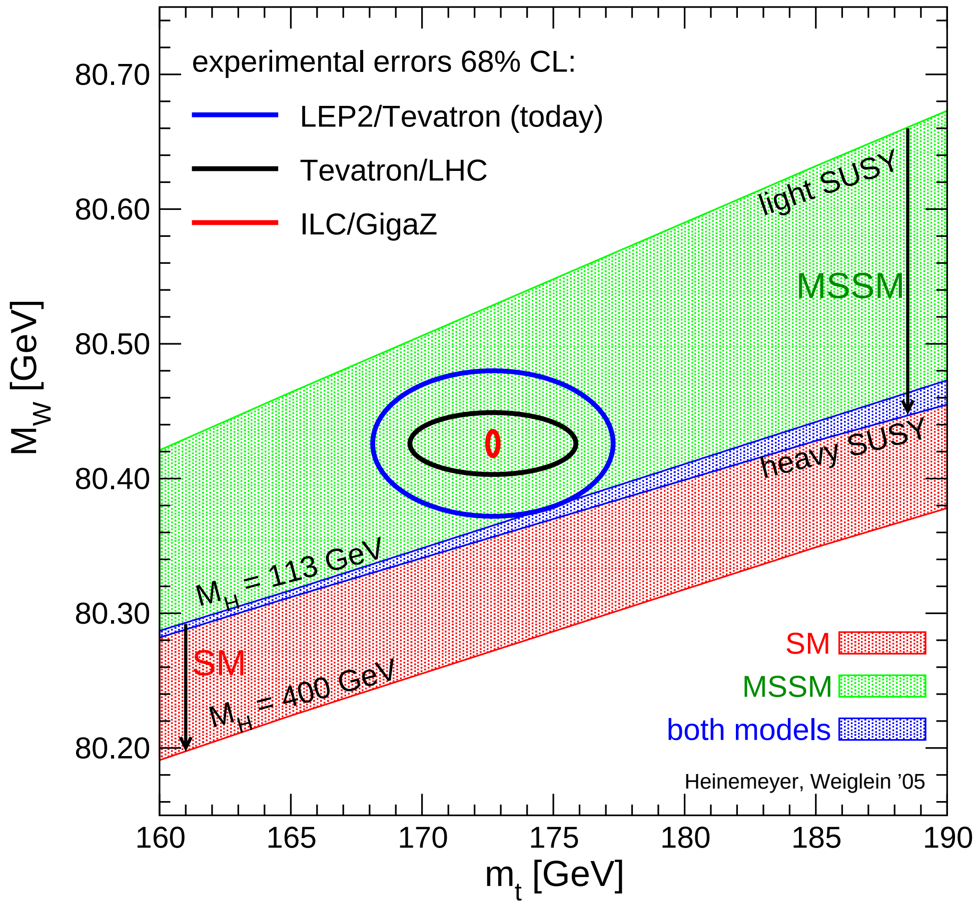


$\Downarrow$

Very high accuracy of measurements and theoretical predictions needed

- Which model fits better?
- Does the prediction of a model contradict the experimental data?

MSSM Example: Prediction for M_W in the SM and the MSSM :



MSSM uncertainty:
unknown masses
of SUSY particles

SM uncertainty:
unknown Higgs mass

Sven Heinemeyer, Flavour in the Era of the LHC, 08.11.2005 *6*

$\Rightarrow$ Evaluate electroweak precision observables including NMFV effects:

Mixing of stop/scharme and of sbottom/sstrange:

$$(\tilde{t}_L, \tilde{t}_R, \tilde{c}_L, \tilde{c}_R) \begin{pmatrix} \tilde{T} & \neq 0 \\ \neq 0 & \tilde{C} \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \\ \tilde{c}_L \\ \tilde{c}_R \end{pmatrix} \qquad (\tilde{b}_L, \tilde{b}_R, \tilde{s}_L, \tilde{s}_R) \begin{pmatrix} \tilde{B} & \neq 0 \\ \neq 0 & \tilde{S} \end{pmatrix} \begin{pmatrix} \tilde{b}_L \\ \tilde{b}_R \\ \tilde{s}_L \\ \tilde{s}_R \end{pmatrix}$$

Analytical result:
evaluation with arbitrary NMFV couplings

Numerical result: LL mixing most relevant for EWPO:

$$\tilde{t}/\tilde{c}: \begin{pmatrix} \lambda\sqrt{\tilde{T}_{LL}\tilde{C}_{LL}} & 0 \\ 0 & 0 \end{pmatrix} \qquad \tilde{b}/\tilde{s}: \begin{pmatrix} \lambda\sqrt{\tilde{B}_{LL}\tilde{S}_{LL}} & 0 \\ 0 & 0 \end{pmatrix}$$

$SU(2)$: $\tilde{T}_{LL} \approx \tilde{B}_{LL}$, $\tilde{C}_{LL} \approx \tilde{S}_{LL}$

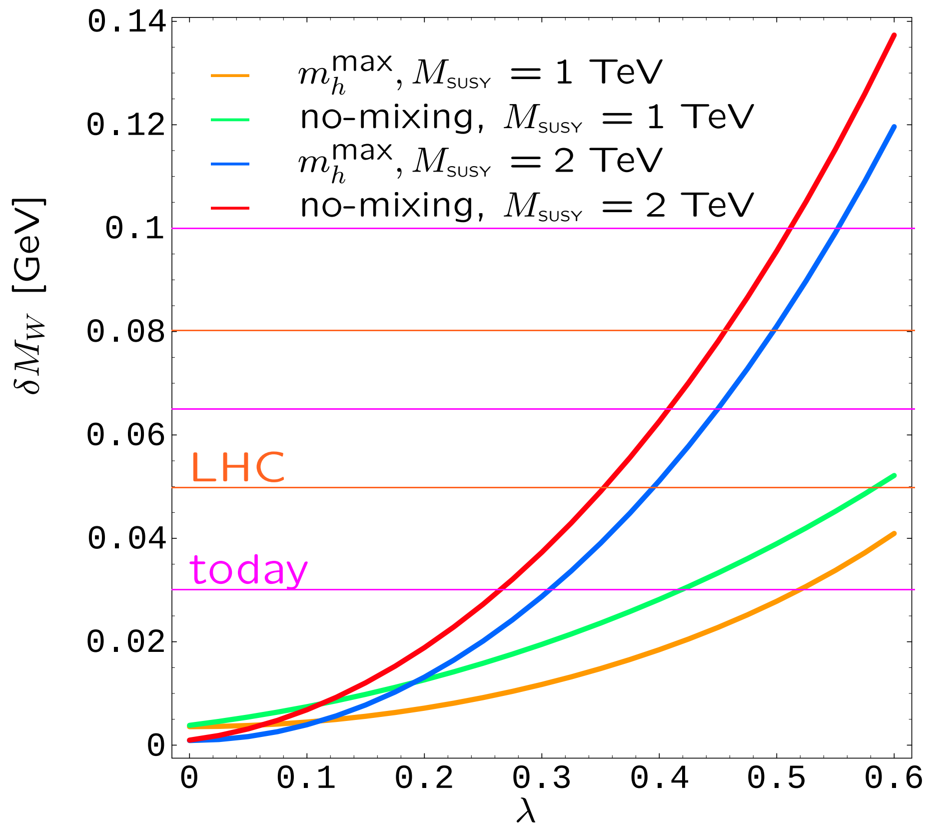
$\to$ suggested by RGE analysis: $LL > LR, RL > RR$

$\to$ no relevant experimental bounds on λ

Sven Heinemeyer, Flavour in the Era of the LHC, 08.11.2005 *8*

δM_W as a function of λ:

[S.H., W. Hollik, F. Merz, S. Peñaranda '04]



increasing λ
$\Rightarrow$ increasing mixing
$\Rightarrow$ increasing M_W

increasing M_{SUSY}
$\Rightarrow$ increasing mixing
$\Rightarrow$ increasing M_W

$\delta M_W^{\text{exp,today}} = 34$ MeV

$\delta M_W^{\text{exp,LHC}} = 15$ MeV

$\Rightarrow$ extreme parameter regions already ruled out

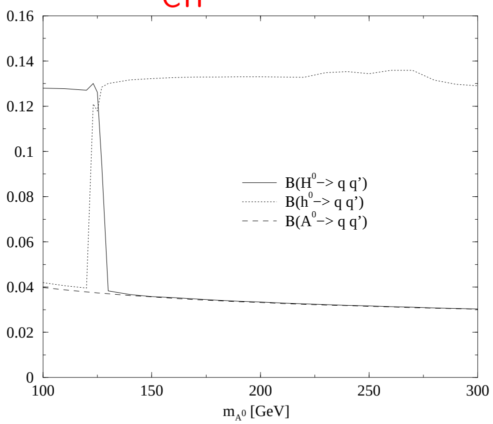
Sven Heinemeyer, Flavour in the Era of the LHC, 08.11.2005 11

Numerical results $BR(h \to bs)$

- Find the maximum $BR(h \to bs)$: MSSM parameter space scan

fine-tuning

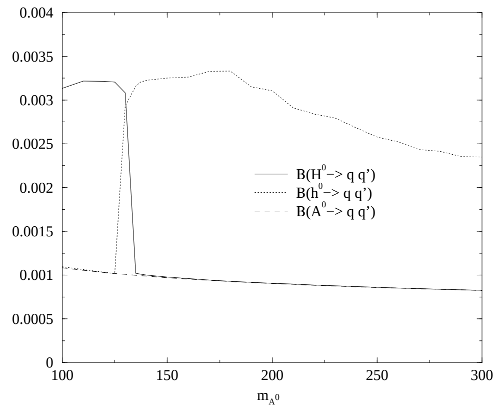
small α_{eff}



$BR^{max}(h^0) \sim 13\%$

no fine-tuning

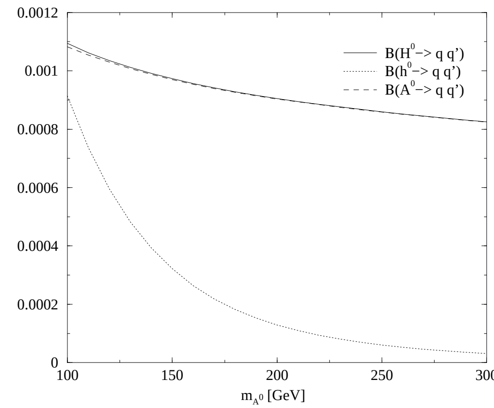
small α_{eff}



$BR^{max}(h^0) \sim 3.1 \times 10^{-3}$

no fine-tuning

no small α_{eff}



$BR(h^0) \sim 1.3 \times 10^{-4}$
$(M_{A^0} = 200\text{ GeV})$

- We will avoid the fine-tuning region from now on
- The maximum $BR(h^0 \to bs)$ is obtained in the small α_{eff} scenario

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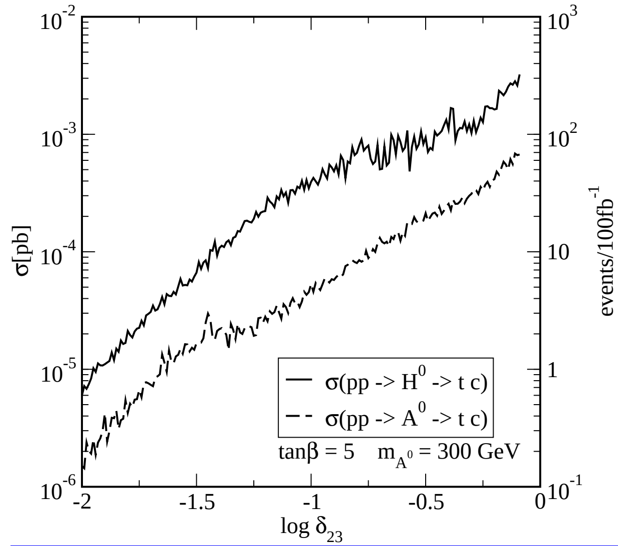
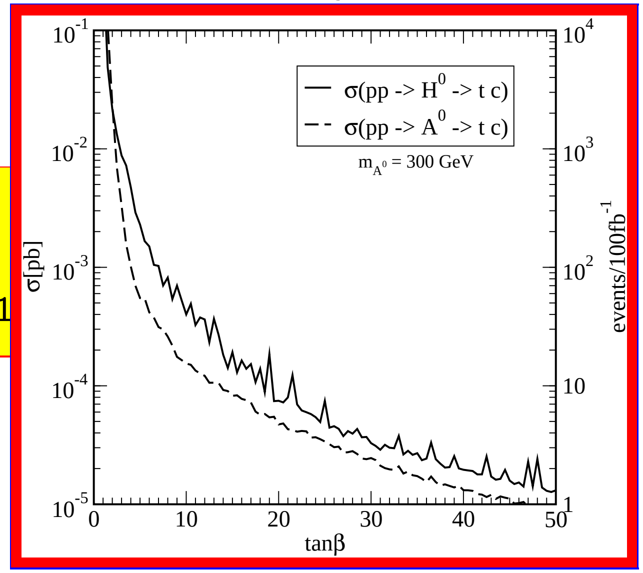
- Maximum at maximal δ_{23}
- Maximum at maximal M_{SUSY}
- One physical squark is always light

$M_{A^0} = 300\,\text{GeV}, \tan\beta = 5$

h	H^0	A^0
$\sigma(pp \to h \to t\,c)$	2.4×10^{-3} pb	5.8×10^{-4} pb
events/100 fb^{-1}	240	58
$B(h \to tc)$	1.9×10^{-3}	5.7×10^{-4}
$\Gamma(h \to X)$	0.41 GeV	0.39 GeV
δ_{23}	$10^{-0.10}$	$10^{-0.13}$
$m_{\tilde{q}}$	880 GeV	850 GeV
A_t	−2590 GeV	2410 GeV
μ	−700 GeV	−930 GeV
$B(b \to s\gamma)$	4.13×10^{-4}	4.47×10^{-4}

- $\tan\beta = 4 \Longrightarrow \sim 500$ events/100 fb^{-1}
- $\tan\beta = 3 \Longrightarrow \sim 900$ events/100 fb^{-1}
- $\tan\beta = 2 \Longrightarrow \sim 2000$ events/100 fb^{-1}





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- J. Guasch, S. Heinemeyer, S. Peñaranda, . . . : top FCNC versus electroweak precision measurements in SUSY inclduing LR and RR mixing

- we need people for other models

- Explore complementarity of searches/discoveries BSM @ LHC and the potential of low energy flavour physics
  how can the information be used to get a coherent picture of the flavour sector

- Supersymmetry
  - slepton spectroscopy: separation of $\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$, mixing angles, $\tilde{\nu}_i$
  - CP & flavour violation in the slepton sector
  - $\tilde{t}$, $\tilde{b}$ versus other $\tilde{q}$: separation and identification
  - electroweak baryogenesis and light stop models
  - flavour violation in $\tilde{g}$, $\tilde{\chi}^0_i$, $\tilde{\chi}^\pm_j$

Experimental talks by T. Lari (ATLAS) and I. Borjanovic (ATLAS), theoretical talks by W.P and T. Hurth

SPS1a (bulk region)
m_0= 100 GeV,
$m_{1/2}$= 250 GeV,
A_0= -100 GeV,
tan(β)=10 , μ>0

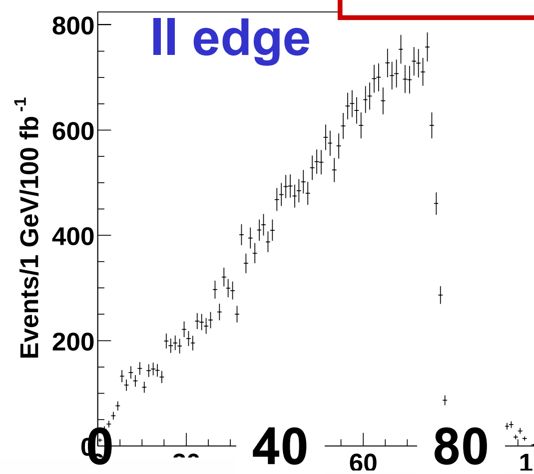
Left squark cascade decay

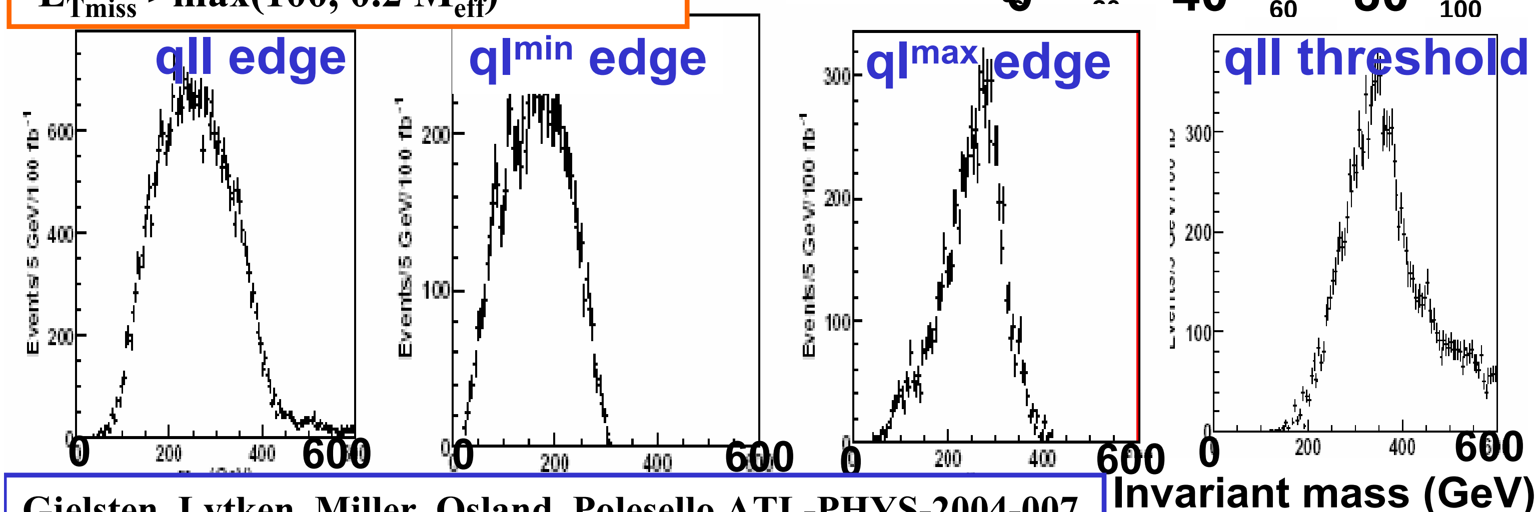
fast sim.

L=**100 fb^{-1}**

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0\, q \rightarrow \tilde{l}_R\, l\, q \rightarrow llq\, \tilde{\chi}_1^0$$

2 SFOS lep., p_T>20, 10 GeV
≥ 4 jets, p_T>150,100,50,50 GeV
M_{eff} > 600 GeV
E_{Tmiss} >max(100, 0.2 M_{eff})





Gjelsten, Lytken, Miller, Osland, Polesello,ATL-PHYS-2004-007

L=**100 fb^{-1}**

Fit results

Edge	Nominal Value	Fit Value	Syst. Error Energy Scale	Statistical Error
$m(ll)^{\text{edge}}$	77.077	77.024	0.08	0.05
$m(qll)^{\text{edge}}$	431.1	431.3	4.3	2.4
$m(ql)^{\text{edge}}_{\text{min}}$	302.1	300.8	3.0	1.5
$m(ql)^{\text{edge}}_{\text{max}}$	380.3	379.4	3.8	1.8
$m(qll)^{\text{thres}}$	203.0	204.6	2.0	2.8

Mass reconstruction

5 endpoints measurements, 4 unknown masses

$$\chi^2 = \sum \chi_j^2 = \sum \left[\frac{E_j^{\text{theory}}(\vec{m}) - E_j^{\text{exp}}}{\sigma_j^{\text{exp}}} \right]^2$$

$$E_j^i = E_j^{\text{nom}} + a_j^i \sigma_j^{\text{fit}} + b^i \sigma_j^{Escale}$$

$m(\chi_1^0)$ = 96 GeV
$m(l_R)$ = 143 GeV
$m(\chi_2^0)$ = 177 GeV
$m(q_L)$ = 540 GeV

$\Delta m(\chi_1^0)$= 4.8 GeV, $\Delta m(\chi_2^0)$= 4.7 GeV,
$\Delta m(l_R)$ = 4.8 GeV, $\Delta m(q_L)$= 8.7 GeV

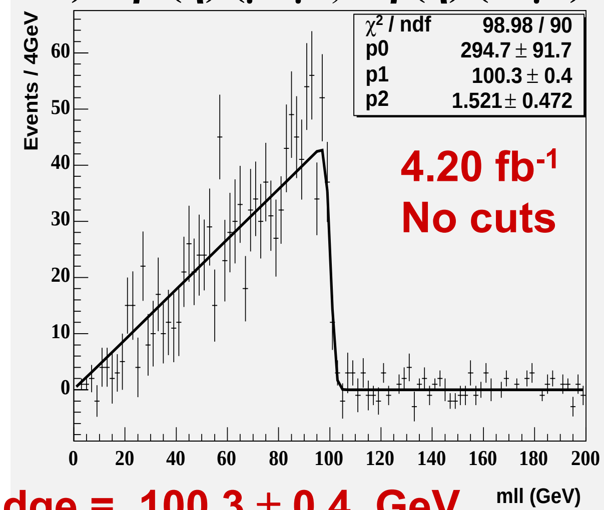
Gjelsten, Lytken, Miller, Osland, Polesello, ATL-PHYS-2004-007

SU3 dileptons

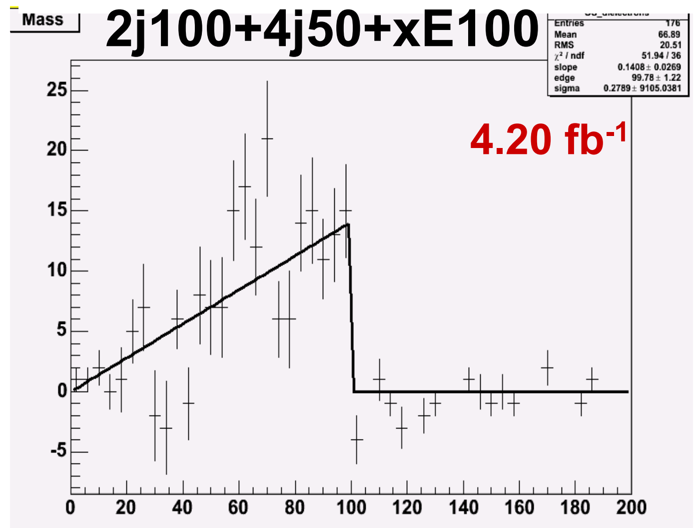
ATLAS preliminary

Selected events with two OS leptons.

(e+e-) + $\beta^2(\eta)$ (μ+μ-) – $\beta(\eta)$ (e+μ-)



Edge = 100.3 ± 0.4 GeV

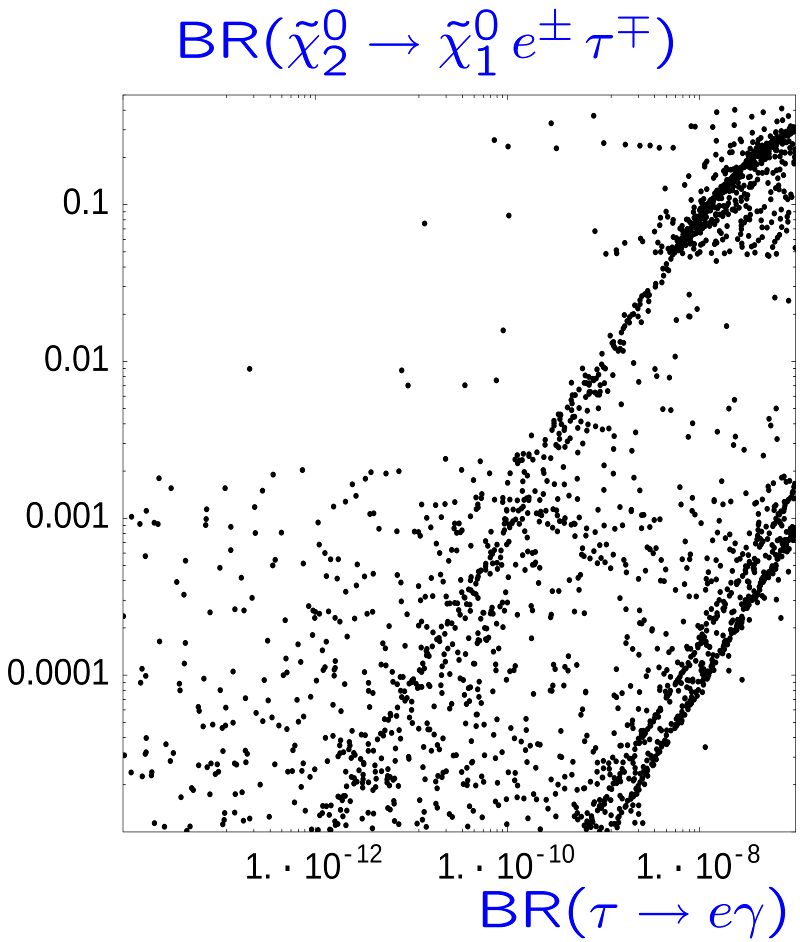


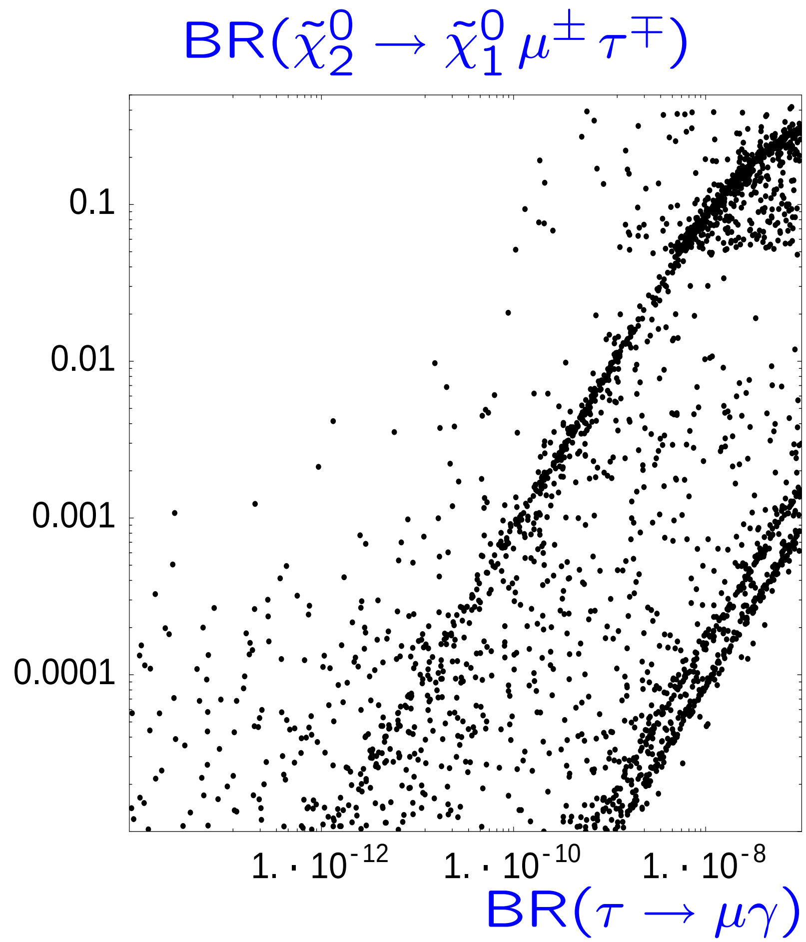
Edge after cuts: 99.8 ± 1.2 GeV

Fit with a triangular distribution with gaussian smearing.
Edge in good agreement with true value 100.31 GeV

SM Background expected to be <u>negligible</u> after cuts. However, SUSY statistic also reduced. Study of SM background and optimization of cuts generally still under way

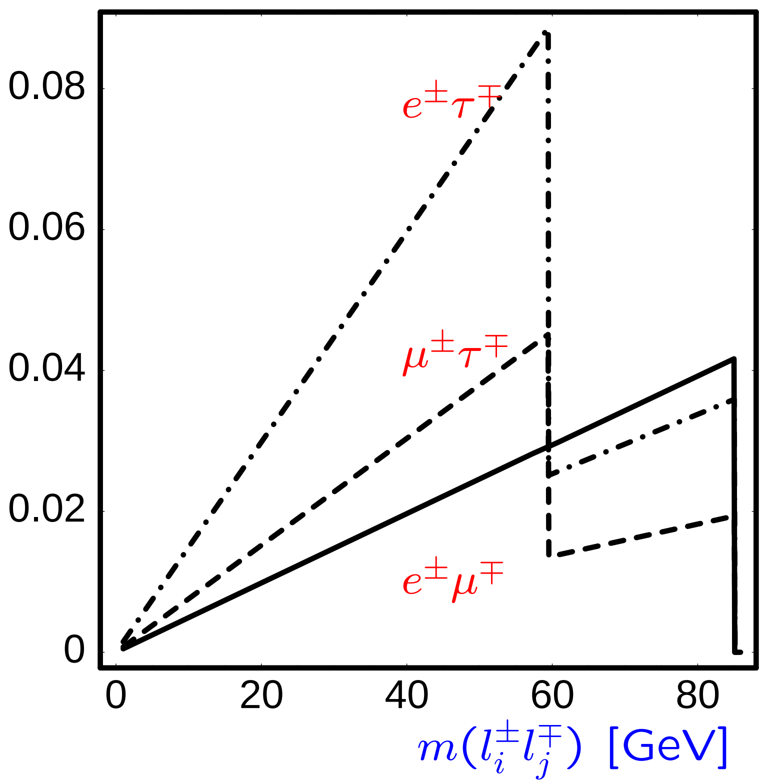
$$\tilde{\chi}^0_2 \to \tilde{l}_i l_j \to l_k l_j \tilde{\chi}^0_1$$



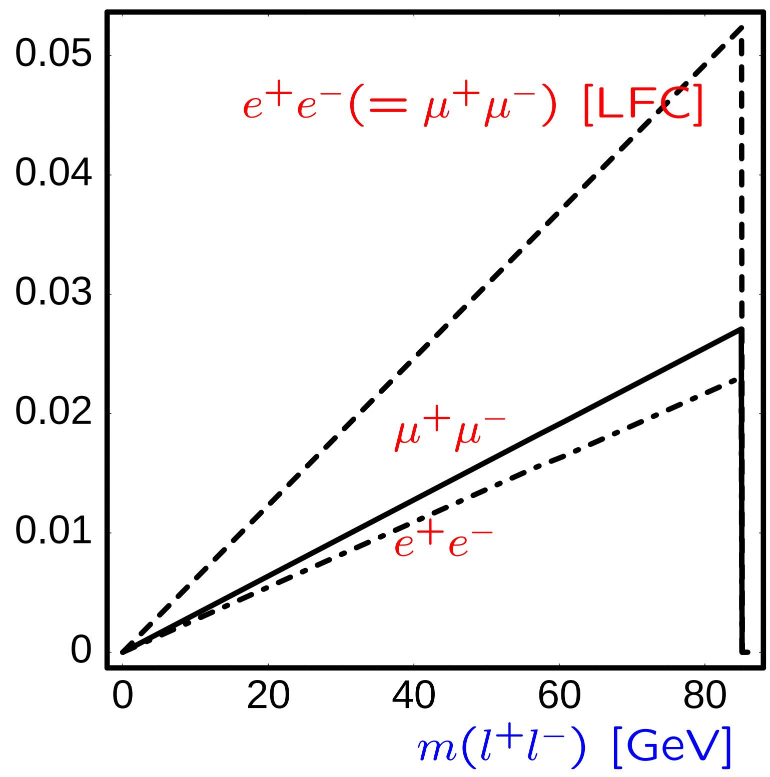


Variations around SPS1a

$100/\Gamma_{tot} d\Gamma(\tilde{\chi}^0_2 \to l_i^\pm l_j^\mp \tilde{\chi}^0_1)/d\, m(l_i^\pm l_j^\mp)$



$100/\Gamma_{tot} d\Gamma(\tilde{\chi}^0_2 \to l^+ l^- \tilde{\chi}^0_1)/d\, m(l^+ l^-)$

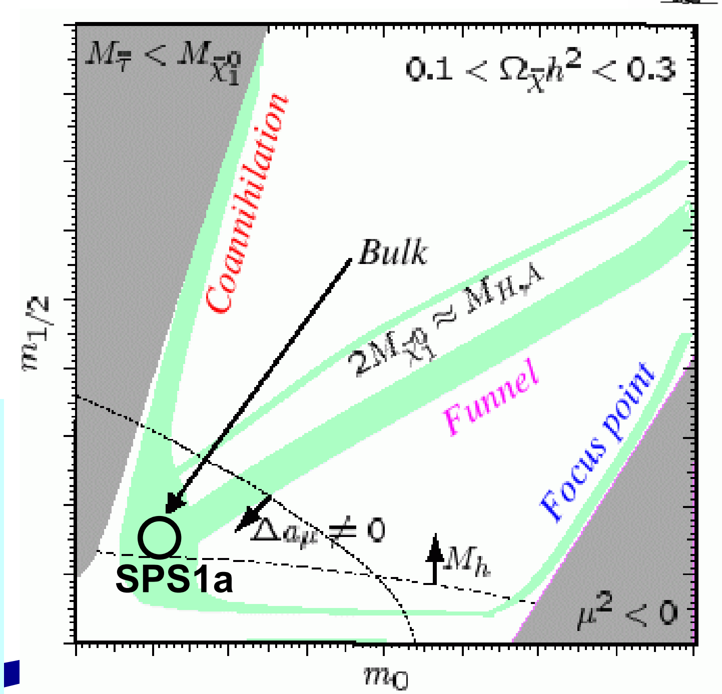


SPS1a

A detailed study for SPS1a (**bulk** region of parameter space) was done in fast simulation

Gjelsten, Lytken, Miller, Osland, Polesello, ATL-PHYS-2004-007

- $\tilde{q}_L$ mass from
  $\tilde{q}_L \to q\chi^0_2 \to q\, l\, \tilde{l} \to q\, l\, l\, \chi^0_1$
- $\tilde{q}_R$ mass from
  $\tilde{q}_R \to q\, \chi^0_1$
- $\tilde{b}$, $\tilde{g}$ mass from
  $\tilde{g} \to b\tilde{b} \to bb\, \chi^0_2 \to bb\, l\tilde{l} \to bb\, ll\, \chi^0_1$



Flavour Workshop
CERN ...11/2005
squark flavour studies with ATLAS

Going up the decay chain

- Once the mass of the χ^0_1 is known, it is possible to get the momentum of the χ^0_2 using the approximate relation

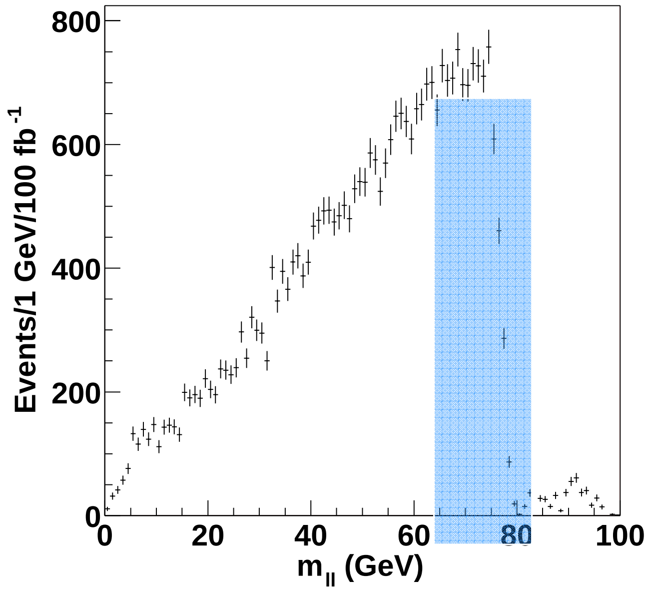
  $$p(\chi^0_2) = (1-m(\chi^0_1)/m(ll))\ p_{ll}$$

  valid for lepton pairs with invariant mass near the edge.
- The χ^0_2 can be combined with b-jets to reconstruct the **gluino and sbottom mass peaks**:

  $$\tilde g \to b\tilde b \to bb\chi^0_2$$

b-tagging used to separate light and bottom squark decay chains

ATLAS fast sim.
ATL-PHYS-2004-007

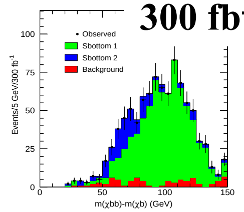


Dilepton invariant mass

squark flavour studies with ATLAS

sbottom mass

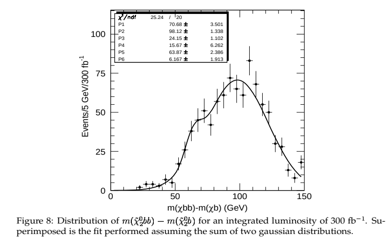
ATLAS fast simulation
ATL-PHYS-2004-007
300 fb^{-1}



$\tilde{b}_2$

$\tilde{b}_1$

ATLAS fast simulation
ATL-PHYS-2004-007
300 fb^{-1}



m(χbb)-m(χb) (GeV)

m(χbb)-m(χb) (GeV)

With 300 fb^{-1} it should be possible to separate the $\tilde{b}_1$ and $\tilde{b}_2$ peaks

$m(\tilde{g})-m(\tilde{b}_1) = (103.3 \pm 1.8)$ GeV **$m(\tilde{g})-m(\tilde{b}_2) = (70.6 \pm 2.6)$ GeV**

With lower statistics only measure the average

squark flavour studies with ATLAS

- Low energy constraints
  - K-physics: ϵ'/ϵ, K^0-$\bar{K}^0$ mixing, ...
    significantly constrain $1-2$ and $1-3$ mixing
  - B-physics: $b \to s\gamma$, ΔM_{B_s}, ...
    most important beyond SM contributions: H^+, $\tilde{\chi}_i^+$, $\tilde{g}$

- Correlations to Collider Physics
  - Squark decays:

$$\begin{aligned} \tilde{u}_i &\to u_j \tilde{\chi}_k^0, d_j \tilde{\chi}_l^+ \\ \tilde{d}_i &\to d_j \tilde{\chi}_k^0, u_j \tilde{\chi}_l^- \end{aligned}$$

  - These decays are governed by the same mixing matrices as the contributions to flavour violating low-energy observables and no GIM or Super-GIM is active.

    Squark can have large flavourviolating decay modes, compatible with present data from flavour physics

Branching ratios (in %) of u-type squarks

	$\tilde{\chi}^0_1 c$	$\tilde{\chi}^0_1 t$	$\tilde{\chi}^0_2 c$	$\tilde{\chi}^0_2 t$	$\tilde{\chi}^0_3 c$	$\tilde{\chi}^0_3 t$	$\tilde{\chi}^0_4 c$	$\tilde{\chi}^0_4 t$	$\tilde{\chi}^+_1 s$	$\tilde{\chi}^+_1 b$	$\tilde{\chi}^+_2 s$	$\tilde{\chi}^+_2 b$
$\tilde{u}_1$	4.7	18	5.2	9.6	$6\ 10^{-3}$	0	0.02	0	11.3	46.4	$2\ 10^{-3}$	4.7
$\tilde{u}_2$	19.6	1.1	0.4	17.5	$2\ 10^{-2}$	0	$6\ 10^{-2}$	0	0.5	57.5	$3\ 10^{-3}$	2.9
$\tilde{u}_3$	7.3	3.7	20	1.4	$6\ 10^{-2}$	0	0.6	0	40.3	3.1	1	18.5
$\tilde{u}_6$	5.7	0.4	11.1	5.3	$4\ 10^{-2}$	5.7	0.6	13.2	22.9	13.1	0.6	8.0

Branching ratios (in %) of d-type squarks

	$\tilde{\chi}^0_1 s$	$\tilde{\chi}^0_1 b$	$\tilde{\chi}^0_2 s$	$\tilde{\chi}^0_2 b$	$\tilde{\chi}^0_3 s$	$\tilde{\chi}^0_3 b$	$\tilde{\chi}^0_4 s$	$\tilde{\chi}^0_4 b$	$\tilde{\chi}^-_1 c$	$\tilde{\chi}^-_1 t$	$\tilde{\chi}^-_2 c$	$\tilde{\chi}^-_2 t$	$\tilde{u}$[illegible]
$\tilde{d}_1$	1.2	5.7	8.4	10.6	2×10^{-2}	1.5	0.2	0.9	16.6	34.1	0.6	0	
$\tilde{d}_2$	17.4	5.8	5.1	15.7	7×10^{-2}	7.4	0.3	09.2	9.7	19.7	0.7	0	[illegible]
$\tilde{d}_4$	14.7	21.7	11.3	2.2	5×10^{-2}	10.6	0.5	8.4	22.1	3.6	1.2	0	[illegible]
$\tilde{d}_6$	1.7	0.5	20.5	6.9	0.1	0.9	1.2	1.3	40.3	10.2	3.4	11.1	[illegible]

- non-SUSY BSM
  - isosinglet quarks (as e.g. in E_6) and flavour physics
  - extra dimensions

Experimental talk by G. Ünel (ATLAS) and theoretical talks by G. Burdman and J.A. Aguilar-Saavedra

Objective of this study

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- SuperStrings & GUT models predict E_6 as the effective group for underlying symmetry.
- Assume that SM comes from breaking down of E_6:

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

- 3 quark families with additions as predicted by E_6:

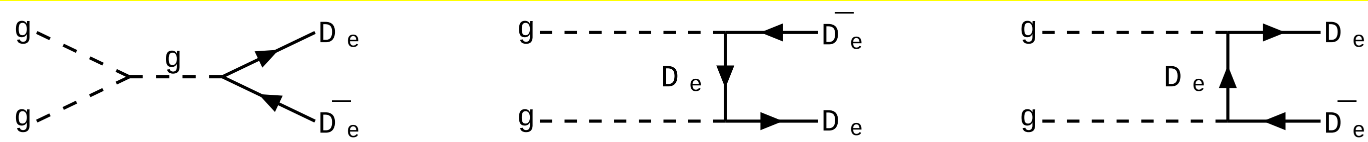
$$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, u_R, d_R, D_L, D_R \quad \begin{pmatrix} c_L \\ s_L \end{pmatrix}, c_R, s_R, S_L, S_R \quad \begin{pmatrix} t_L \\ b_L \end{pmatrix}, t_R, b_R, B_L, B_R$$

New iso-singlet quarks

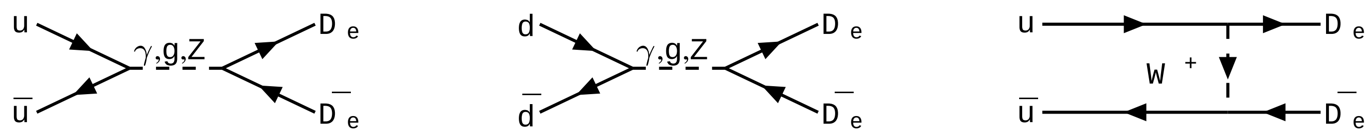
Can ATLAS discover these & validate E_6 GUT models ?

Pair Production at LHC

4



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

- σ_D pair $>$ σ_D single , hence we study pair production
- both DD and $D\bar{D}$ are considered

Signal channels

$D\bar{D} \to$	Final State	Expected Signal	Decay B.R.	Total B.R.	
$Z\,Z\,d\,\bar{d}$	$Z \to l\bar{l}\ Z \to l\bar{l}$	$4\,l\ + 2\,jet$	0.07×0.07	0.0005	NC-1
0.33×0.33	$Z \to l\bar{l}\ Z \to vv$	$2\,l\ + 2\,jet + P_T$	$2 \times 0.07 \times 0.2$	0.0030	NC-2
	$Z \to l\bar{l}\ Z \to q\bar{q}$	$2\,l\ + 4\,jet$	$2 \times 0.07 \times 0.7$	0.0107	
$Z\,W\,d\,u$	$Z \to l\bar{l}\ W \to l\bar{v}$	$3\,l\ + 2\,jet + P_T$	0.07×0.21	0.0065	CC-1
$2 \times 0.33 \times 0.67$	$Z \to l\bar{l}\ W \to q\bar{q}$	$2\,l\ + 4\,jet$	0.07×0.68	0.0211	

We initially study: NC-1, NC-2, CC-1 (NC-1 details: **ATL-COM-PHYS-2005-041***)*

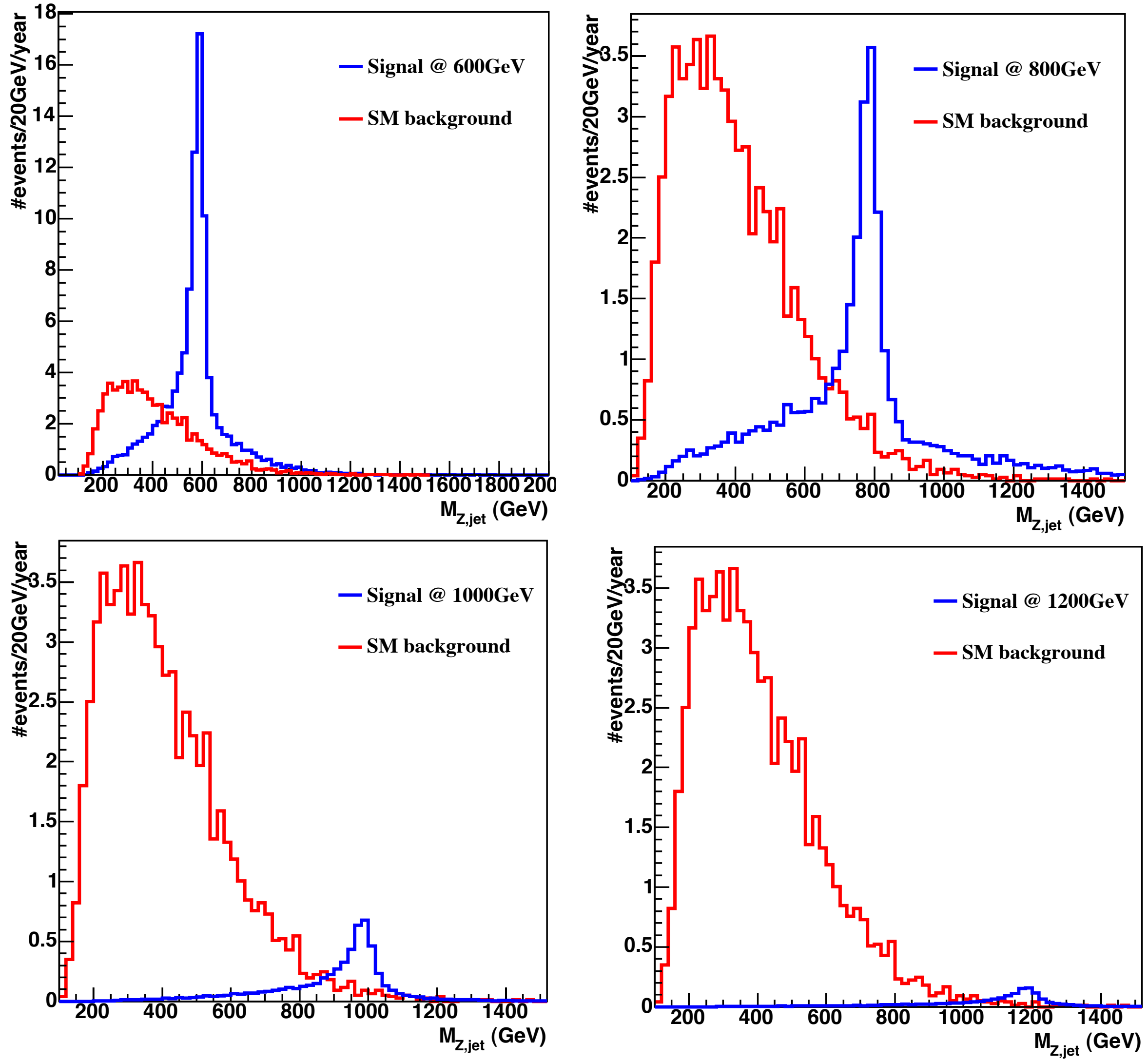
- All SM processes giving similar final state are studied as background. (2jet & 2Z, 2jet & WZ)
  - misidentifications not considered: e/gamma
- We studied 4e, 4μ & 2e/2μ cases for Z decays.
  - Events generated in CompHEP & MadGraph
  - Used ATLAS software framework (Athena-9.0.3) for a fast simulation (ATLFast) based study, analysis done in ROOT

NC-1: DD→ZZjj

$Z_1, Z_2 \to ll$ ($l=e,\mu$)

D mass from ZZjj

- D quark mass reach is up to ~1TeV for NC-1.



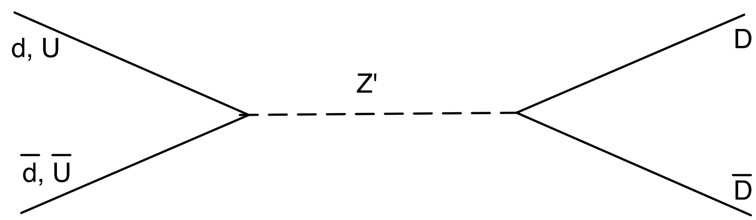
reconstructed m_D for different masses

Details of this study can also be found in ATLAS public note:
ATLAS-PHYS PUB-2005-021

Next steps

- Merge results of all channels (NC1 +NC2 +CC) to improve the discovery reach.

- Additional neutral gauge bosons (Z') predicted by E_6 could enhance the signal cross section,
  - Implemented in CompHEP, preparing a draft note.



- study an example D quark mass and background with full (Geant) simulation to verify the fast simulation results.

Signals at LHC

- Production of the new quark T

  QCD pair production $pp \to T\overline{T}$ [Aguila et al., NPB '90]

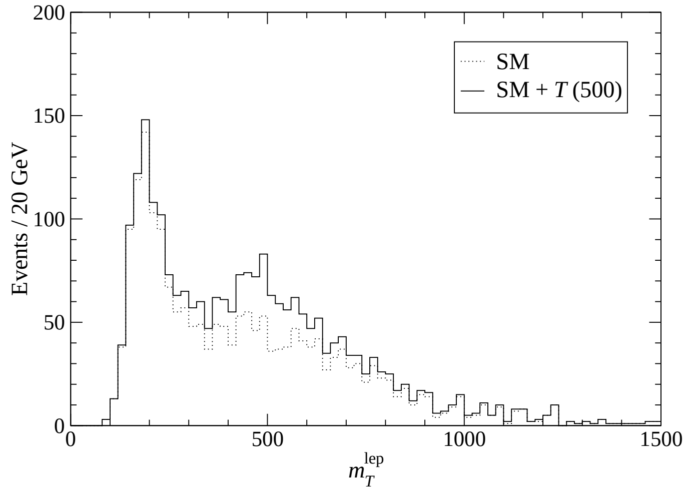
  EW single production $pp \to Tj$ [Han et al., PRD '03]

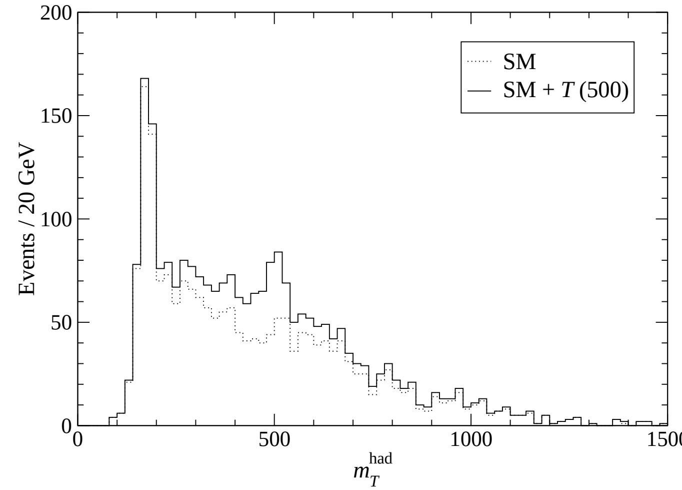
- FCN processes involving the top quark [JAAS, APPB '04]

  Rare top decays $t \to Zq$, $t \to Hq$ $(q = u, c)$

  Single top production $gq \to Zt$, $gq \to Ht$

$m_T = 500$ GeV, 10 fb^{-1} $\longrightarrow$ 10.9 σ evidence (300 – 660 GeV)





$$\text{`SM'} = t\bar{t}\,,\ Wb\bar{b}jj\,,\ Zb\bar{b}jj\,,\ t\bar{b}j$$

$$\begin{aligned} \text{`}T\text{'} &= T\overline{T} \to W^+b\,W^-\bar{b} \to \ell^\pm \nu b\bar{b}jj \\ &+ T\overline{T} \to W^+b\,H\bar{t}\,,\ Ht\,W^-\bar{b} \to W^+b\,W^-\bar{b}\,H \quad (H \to b\bar{b}, c\bar{c}) \\ &+ T\overline{T} \to W^+b\,Z\bar{t}\,,\ Zt\,W^-\bar{b} \to W^+b\,W^-\bar{b}\,Z \quad (Z \to jj, b\bar{b}, \nu\bar{\nu}) \end{aligned}$$

See details

Conclusions

$Q = 2/3$ singlets with a mass up to ~ 1 TeV can be observed at LHC

If they exist, they may give new effects in low energy physics

- CP asymmetries in B decays
- δm_{B_s}, δm_D
- Rare kaon decays

as well as in top physics

- top FCN decays $t \to qZ$
- $e^+e^- \to t\bar{t}$ (ILC)

Flavor Physics in UED

- If we consider the SM in the bulk in d extra dimensions

$$\mathcal{L} = \mathcal{L}_F + (D_M \Phi(x,y))^\dagger D^M \Phi(x,y) + \frac{1}{\Lambda^{d/2}} \bar{\Psi}(x,y) Y \Phi(x,y) \Psi(x,y)$$

  and Y is the only source of flavor violation $\Rightarrow$ MFV. Here Λ is the UV cutoff, and $\Lambda R \gg 1$.
- In this scenario, only flavor physics effects are generated by loops of KK modes in flavor observables: B, D K rare decays and mixing. (Buras, Spranger, Poschenrieder, Weiler ’03)
- There is no high p_T signal for flavor

WED Flavor Signals

Two type of flavor effects:

- FCNC couplings of the Z:
  - Interesting low energy flavor signals. E.g. $b \to s\ell^+\ell^-$ (Burdman, Nomura '03, Agashe, Perez, Soni '04)
  - Deviations in $\bar{t_L} t_L Z$ and $\bar{t_L} b_L W$ are $\mathcal{O}(\text{few}\%)$.
  - Deviations in $\bar{t_R} t_R Z$ could be $\mathcal{O}(1)$.
- FCNC couplings of KK gauge bosons (e.g. KK gluons):
  - E.g. FCNC coupling of the 1st KK gluon $G^{(1)} t\bar{c}$.
  - Effects in non-leptonic B decays and CP Asymmetries (Burdman '03)
  - $\Rightarrow$ Potentially large effect in single-top production at the LHC
  - Kinematics is very different than the SM single-top.
  - Also anomaly in the angular distribution in $b\bar{b}$.

Outlook & future plans

- additional top studies concerning FCNC and precision data initiated

- Experimentalists should check their strategies concerning theory motivated assumptions in the flavour sector

- experimental studies are needed to get hand on flavour information at LHC

- Which BSM processes at LHC are interesting from the experimental / theoretical side $\Rightarrow$ we need some more talking

- c identification

- Flavour benchmark points
  - SUSY: W.P., . . .
  - extra dimensions: G. Burdman, . . .
  - other non-SUSY BSM: are they needed, who is willing to start
  - need of program set/interfaces to combine collider programs with low energy data [SLHA2 for SUSY case]
  - webpage will be created with complete information and links to programs