Flavour@High-p_T Interplay

Tobias Hurth

SuperB Physics Workshop, Frascati, 30.11.-4.12.2009

Flavour@High-p_T Interplay

Correlations of high-p_T and flavour physics

How can flavour data help to interprete high-p_T physics ?

What can ATLAS/CMS tell us about flavour ?

Can ATLAS/CMS exclude MFV ?

Can we ignore flavour when analysing possible

new physics at the electroweak scale?

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$\Rightarrow$ CERN workshop on the interplay of flavour and collider physics
Fleischer,Hurth,Mangano see http://mlm.home.cern.ch/mlm/FlavLHC.html

Flavour in the era of the LHC

a Workshop on the interplay of flavour and collider physics

First meeting:

CERN, November 7-10 2005

http://mlm.home.cern.ch/mlm/FlavLHC.html

- BSM signatures in B/K/D physics, and their complementarity with the high-pT LHC discovery potential
- Flavour phenomena in the decays of SUSY particles
- Squark/slepton spectroscopy and family structure
- Flavour aspects of non-SUSY BSM physics
- Flavour physics in the lepton sector
- g-2 and EDMs as BSM probes
- Flavour experiments for the next decade

Local Organizing Committee

International Advisory Committee

5 meetings between 11/2005 and 3/2007

arXiv:0801.1800 [hep-ph] “Collider aspects of flavour physics at high Q”

arXiv:0801.1833 [hep-ph] “B, D and K decays”

arXiv:0801.1826 [hep-ph] “Flavour physics of leptons and dipole moments”

published in EPJC 57 (2008) 1-492

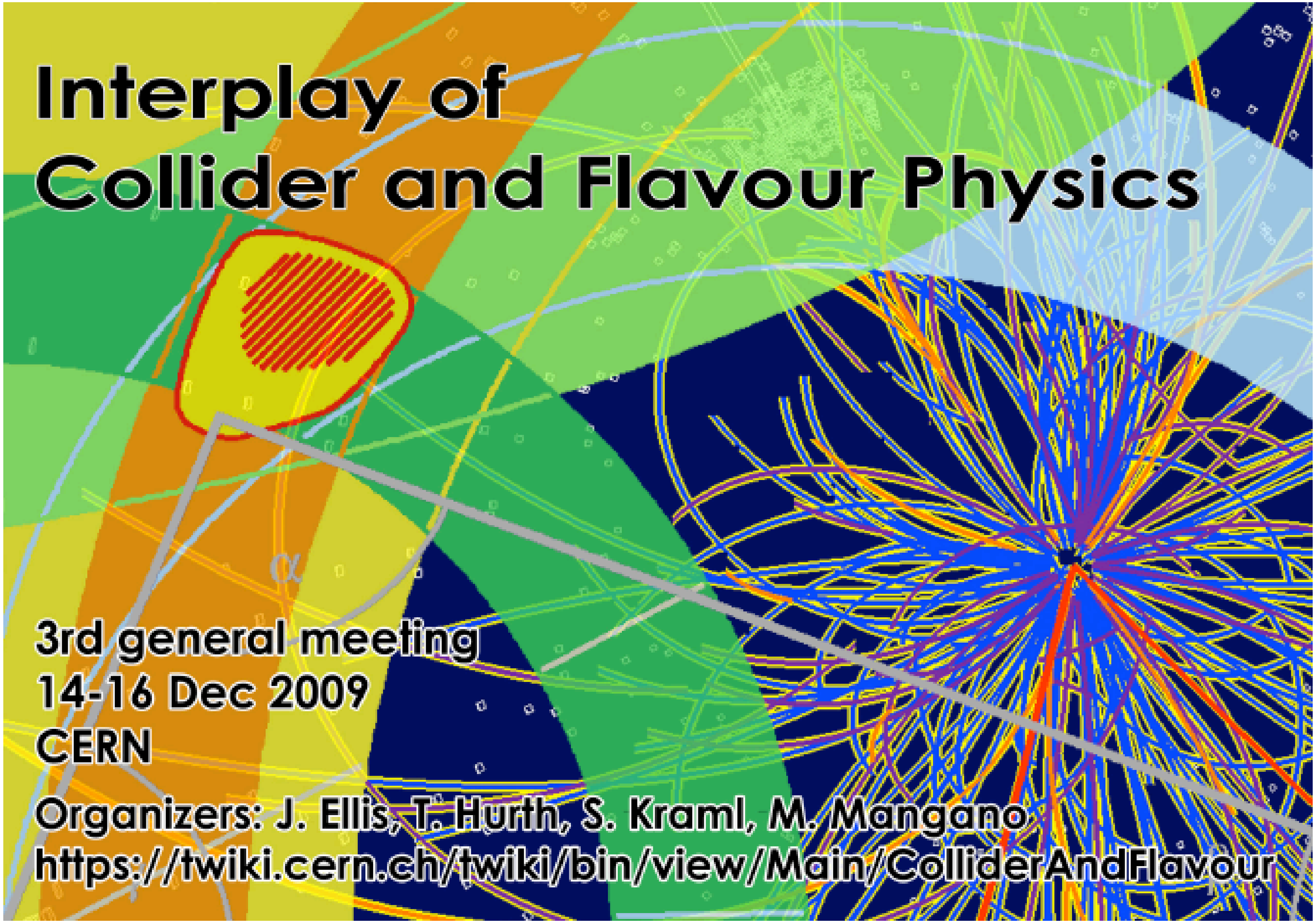
and in Advances in the Physics of Particles and Nuclei, Vol 29, 480p, 2009

Reference book for flavour in the LHC era

Follow-up workshop

Recent meeting 16.-18. of March 2009 at CERN

Next meeting 14.-16. of December 2009 at CERN



Interplay of
Collider and Flavour Physics

3rd general meeting
14-16 Dec 2009
CERN

Organizers: J. Ellis, T. Hurth, S. Kraml, M. Mangano
https://twiki.cern.ch/twiki/bin/view/Main/ColliderAndFlavour

Ambiguity of new physics scale from flavour data

$$\mathcal{L} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \sum_i \frac{c_i^{New}}{\Lambda_{\mathrm{NP}}} \mathcal{O}_i^{(5)} + \ldots$$

- SM as effective theory valid up to cut-off scale Λ_{NP}

- Typical example: $K^0 - \bar{K}^0$-mixing $\mathcal{O}^6 = (\bar{s}\,d)^2$:

$$c^{SM}/M_W^2 \times (\bar{s}\,d)^2 + c^{New}/\Lambda_{\mathrm{NP}}^2 \times (\bar{s}\,d)^2 \qquad \Rightarrow \quad \Lambda_{\mathrm{NP}} > 10^4\,\mathrm{TeV}$$

(tree-level, generic new physics)

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(tree-level, generic new physics)

- Natural stabilisation of Higgs boson mass (hierarchy problem)

(i.e. supersymmetry, little Higgs, extra dimensions) $\Rightarrow \quad \Lambda_{\mathrm{NP}} \leq 1\mathrm{TeV}$

- EW precision data ↔ little hierarchy problem $\Rightarrow \Lambda_{\mathrm{NP}} \sim 3 - 10\mathrm{TeV}$

Possible New Physics at the TeV scale has to have a very non-generic flavour structure

Parameter bounds from flavour physics are model-dependent

Status of the inclusive mode $\bar{B} \to X_s\gamma$

HFAG: $\mathcal{B}(B \to X_s\gamma) = (3.57 \pm 0.24) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

vs

SM: $\mathcal{B}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

NNLO calculation by M.Misiak
PRL98,022003(2007)

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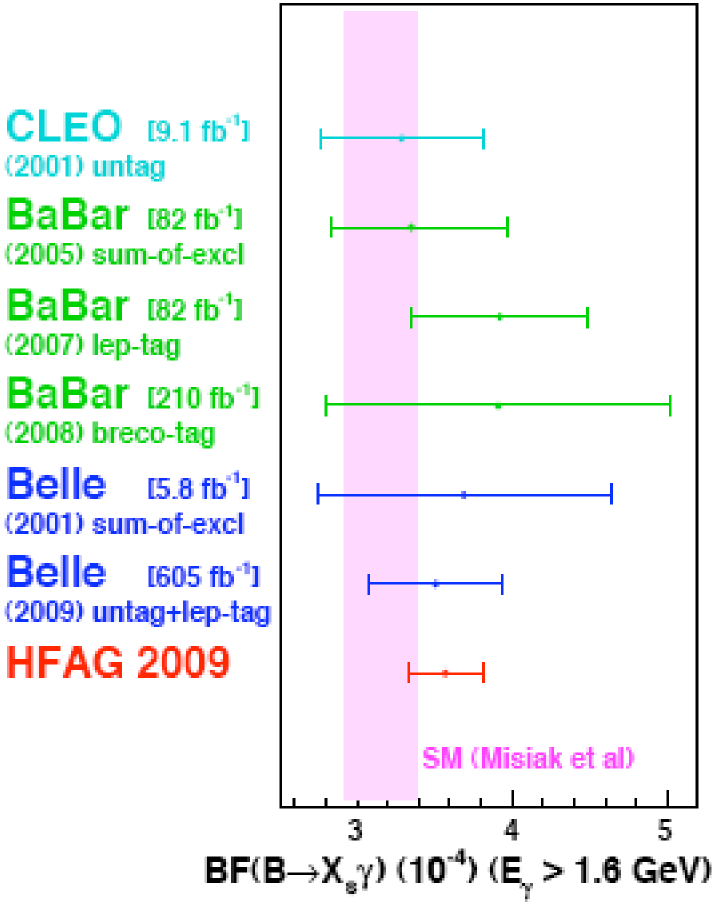

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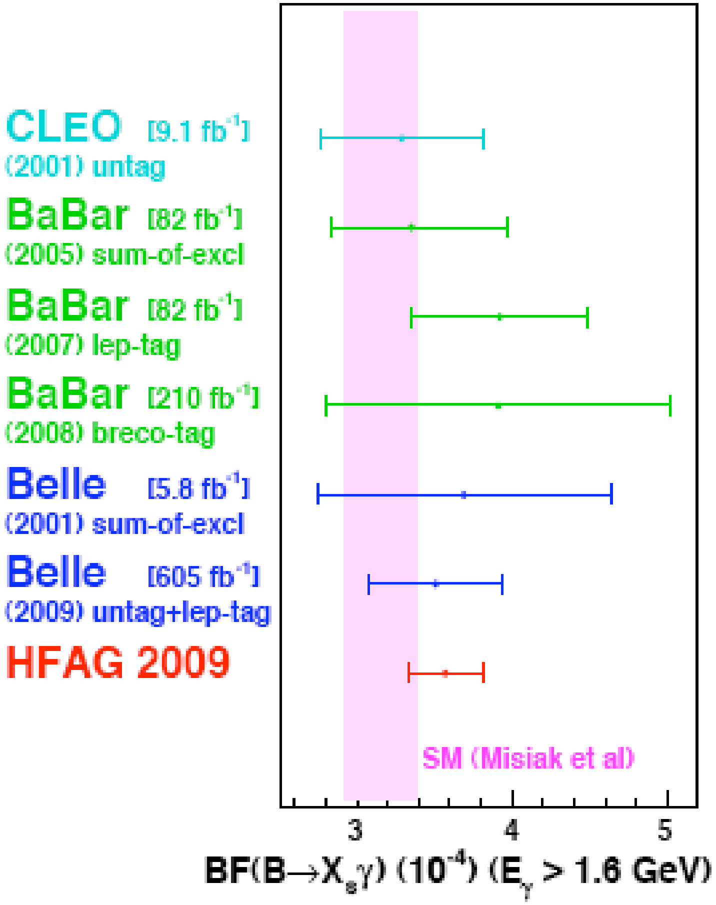
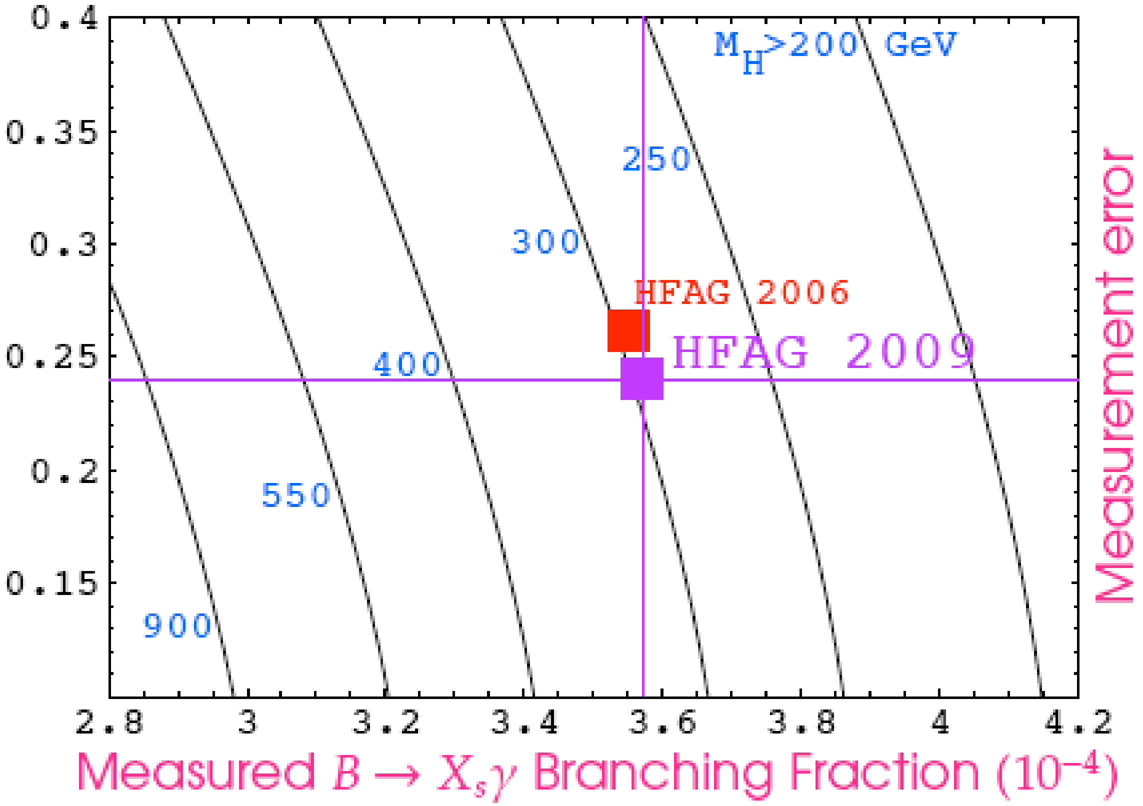
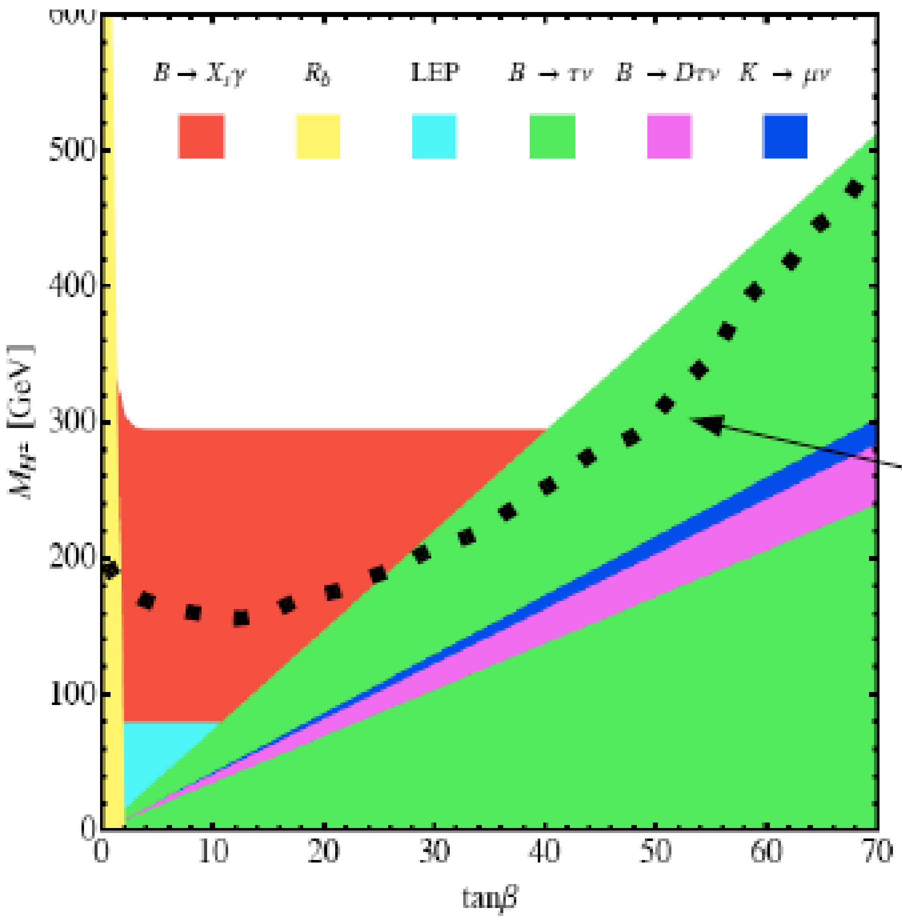


Charged Higgs bound (2HDM)
$m_{H^+} > 300$ GeV



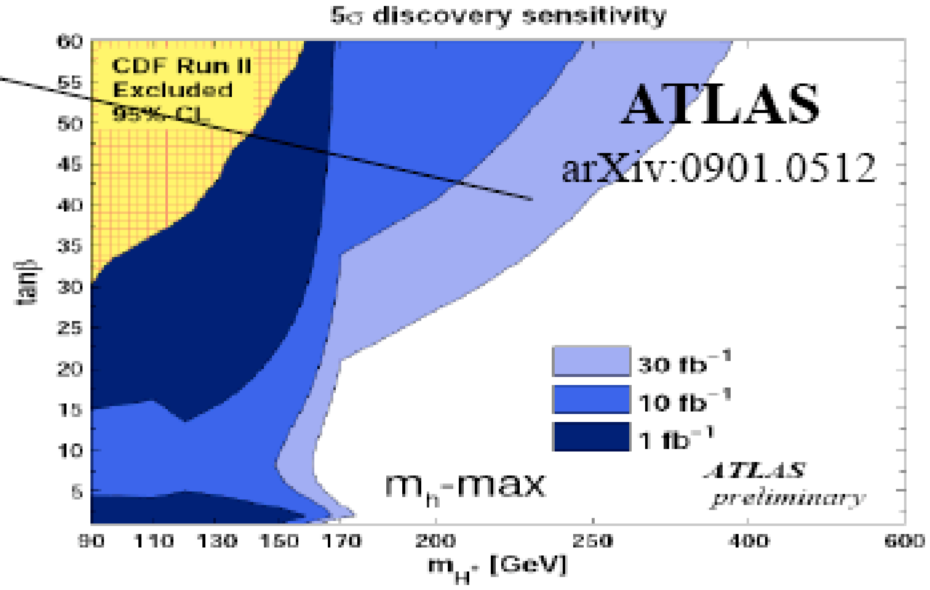
Courtesy of Mikihiko Nakao

LHC versus Flavour constraints



U. Haisch arXiv:0805.2141 [hep-ph]
(presented at FPCP 2008)

Current flavour constraints are already very competitive with LHC expected direct search sensitivity for charged Higgs



Courtesy of Steven Robertson

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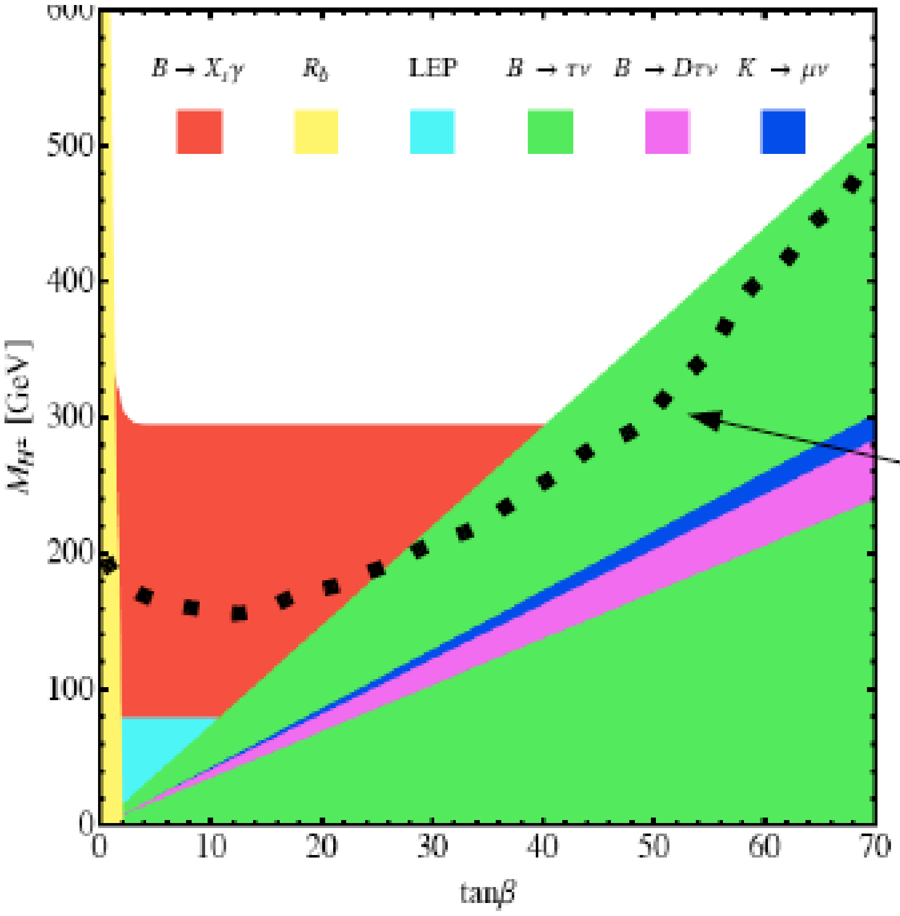

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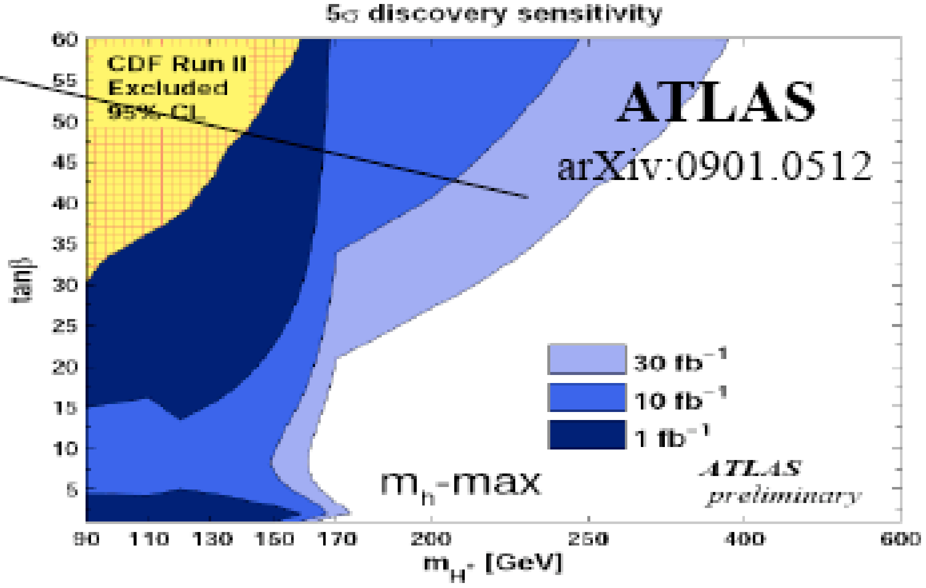


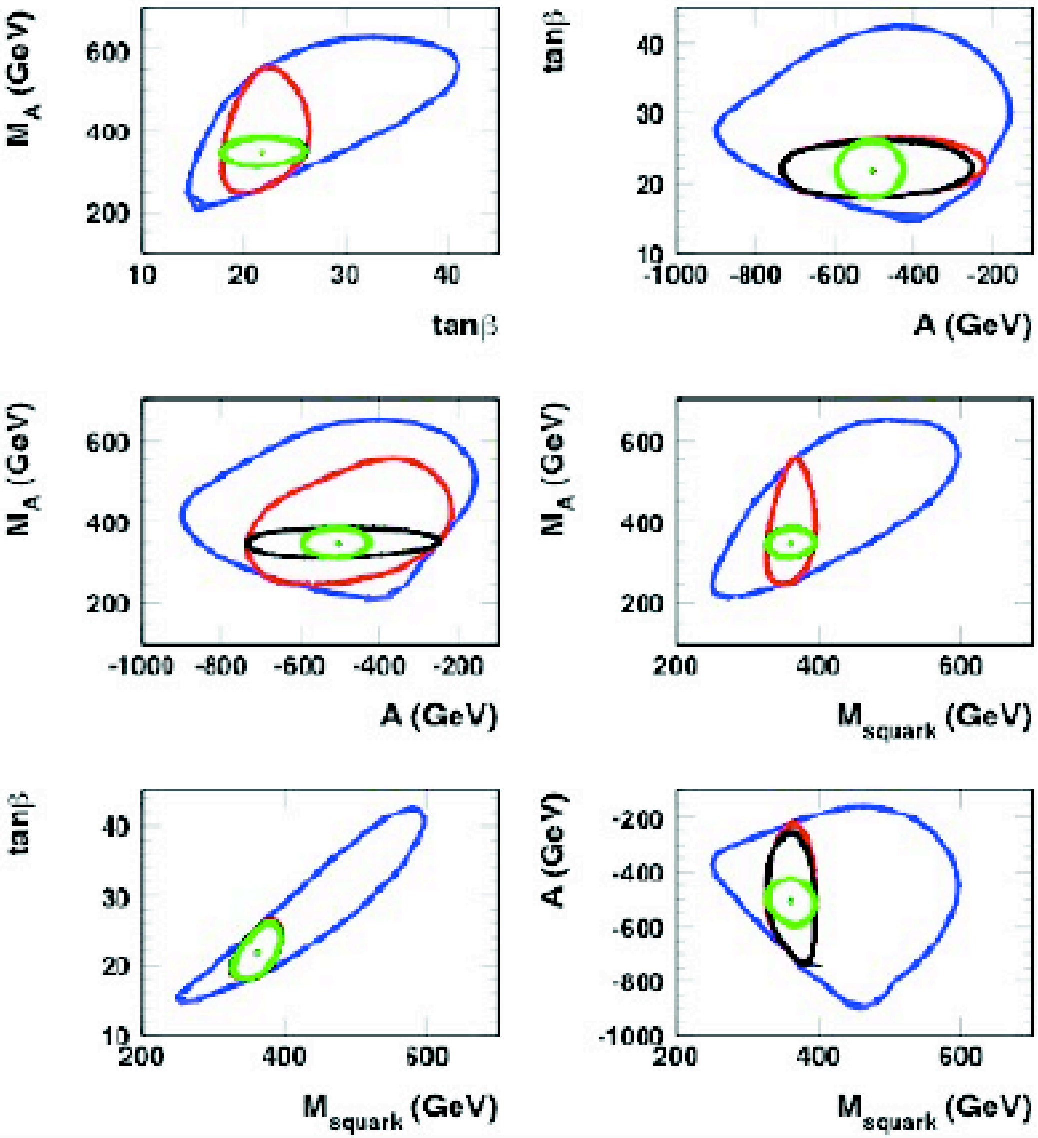
Courtesy of Steven Robertson

2HDM

Extension to the MSSM will be shown by Oscar Stal on Tuesday afternoon

Flavour constraints in the cMSSM

Ronga et al., arXiv:0801.1833



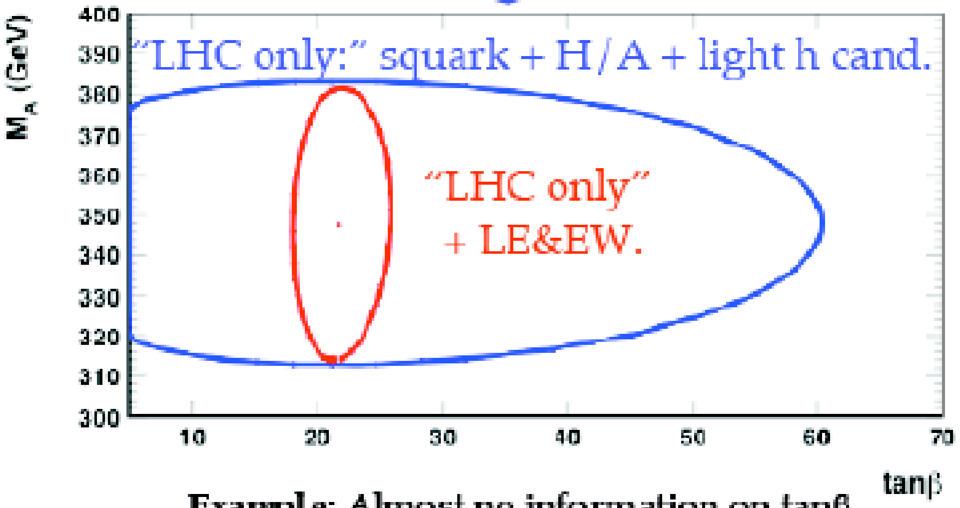
🟦 LE&EW: low-energy (LE) and EW constraints

🟥 LE&EW + squark candidate

⬛ LE&EW + squark cand. + H/A cand.

🟩 LE&EW + squark + H/A + light h cand.

Including LW&EW constraints facilitates the determination of fundamental MSSM parameters



Example: Almost no information on tanβ without external constraints. Note that a direct measurement of tanβ is very difficult at the LHC

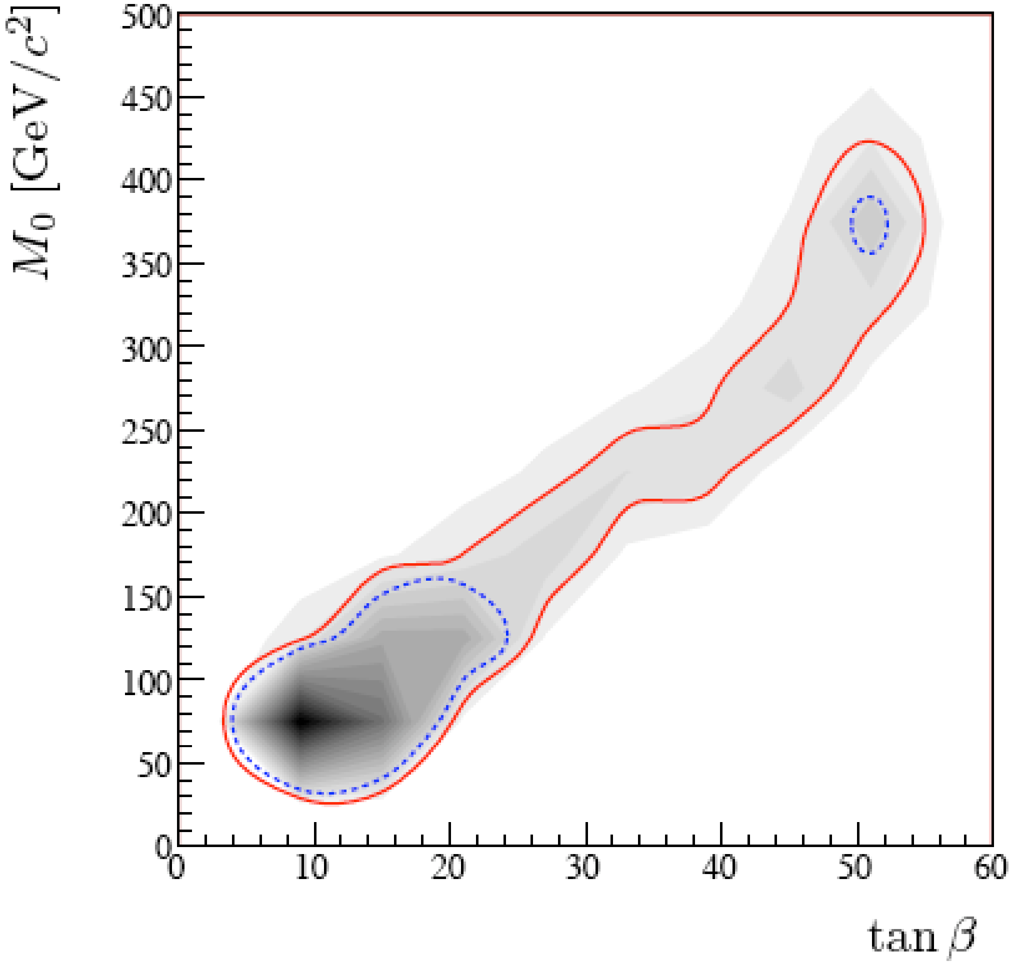
Illustrative Example

More flavour constraints in the cMSSM

Weiglein et al,arXiv:0707.3447

Update Weiglein et al.,arXiv:0907.5568

Multi-parameter χ^2 fit for all CMSSM parameters, $M_0, M_{1/2}, A_0, \tan\beta$



68% (dotted) and

95% (solid) CL

$(g-2)_\mu$, $b \to s\gamma$, Ω_{CDM}

Constraints on the lightest Higgs boson mass

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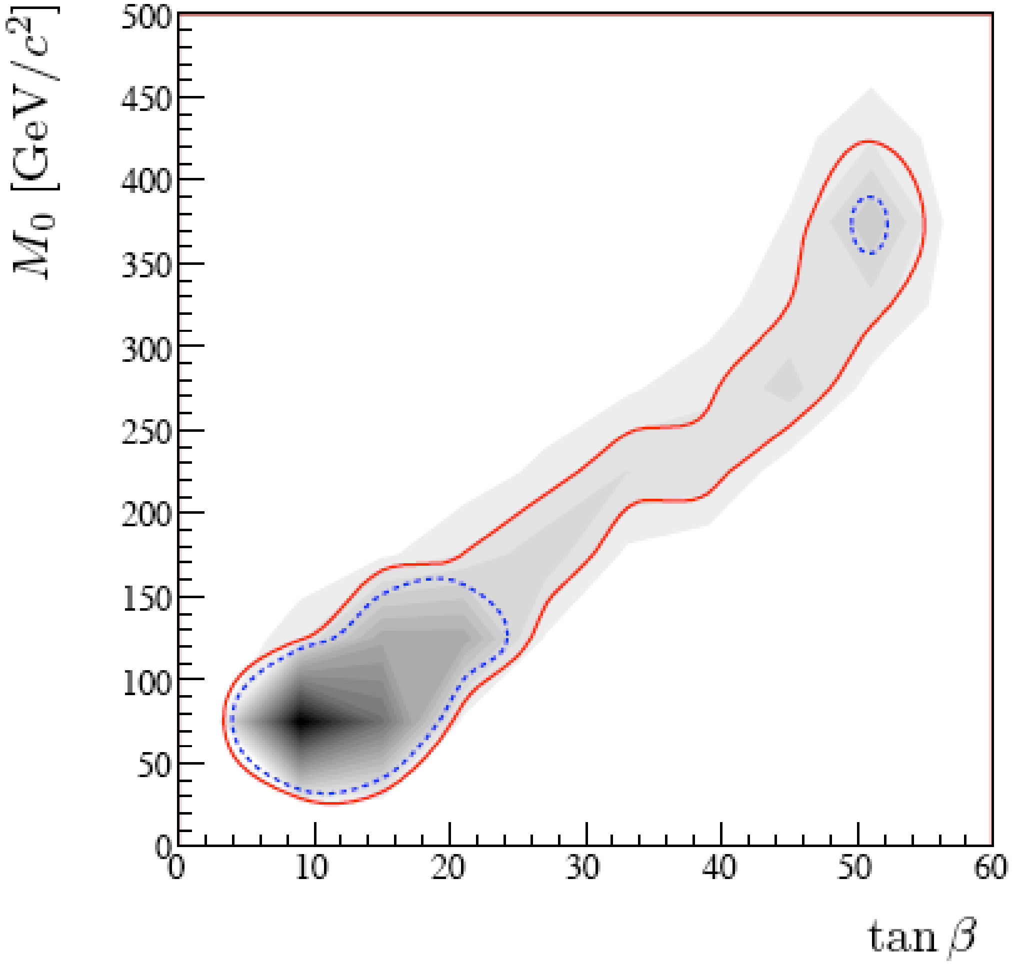

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Constraints on the lightest Higgs boson mass

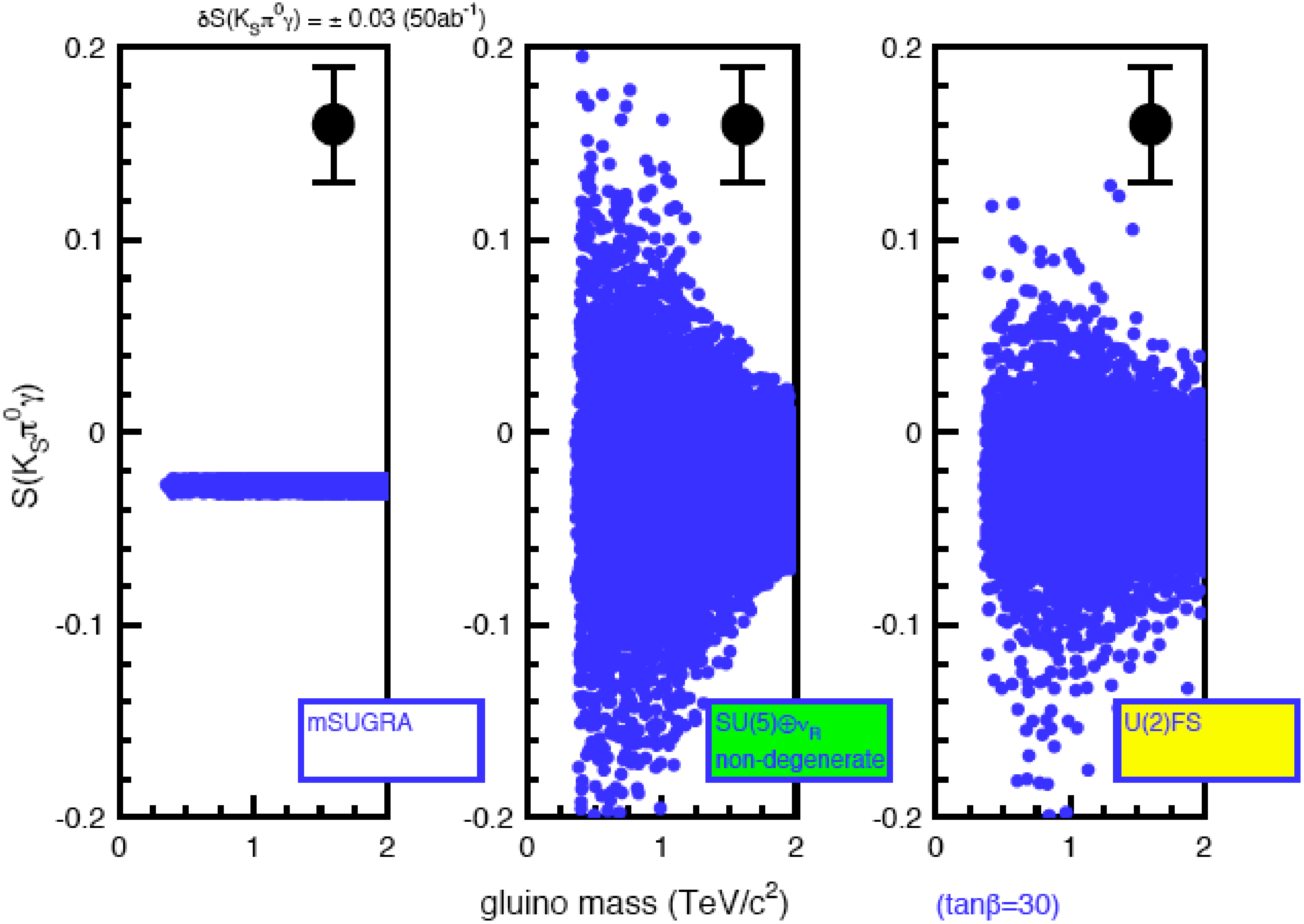
$$m_{\rm h}^{\rm CMSSM} = 110^{+8}_{-10}\ ({\rm exp.}) \pm 3\ ({\rm theo.})\ {\rm GeV}/c^2$$

no restriction on m_h
imposed in the fit

Dynamics of flavour ⇔ mechanism of SUSY breaking

($BR(b \to s\gamma) = 0$ in exact supersymmetry)

⇒ Discrimination between various SUSY-breaking mechanism



Expected Super-B sensitivity ($50ab^{-1}$)

Goto,Okada,Shindou,Tanaka,arXiv:0711.2935

Study lepton flavour at the LHC

Feng,Lester,Nir,Shadmi,arXiv:0712.0674

Consider degeneracy and alignment beyond MFV

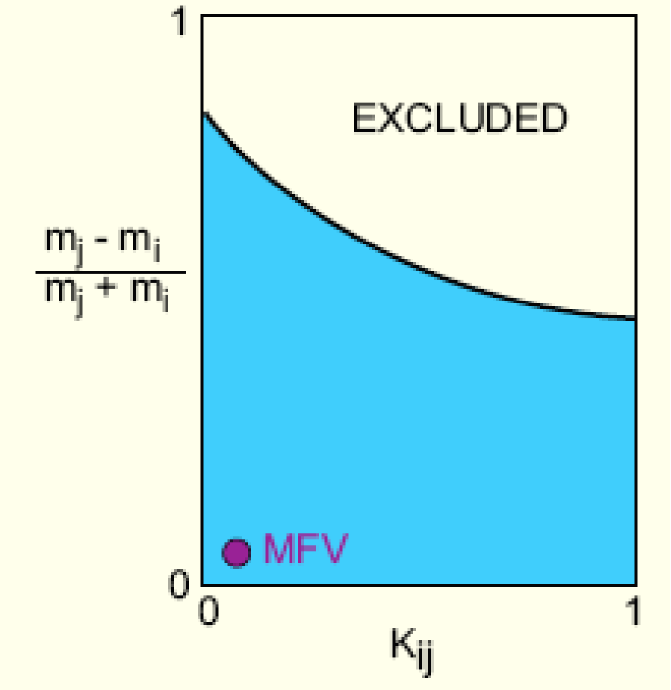
Natural Susy models span a large allowed area in the $(\Delta m^2_{ij}, K_{ij})$ plane.

(mass-squared splitting of slepton generations versus their mixing)

FCNC lead to upper bounds for $\Delta m^2_{ij} \times K_{ij}$ only,

$BR(\mu \to e\gamma) \leq 1.2 \times 10^{-11}$, $BR(\tau \to e\gamma) \leq 1.1 \times 10^{-7}$, $BR(\tau \to \mu\gamma) \leq 6.8 \times 10^{-8}$,

while ATLAS/CMS can constrain either or both of the factors.



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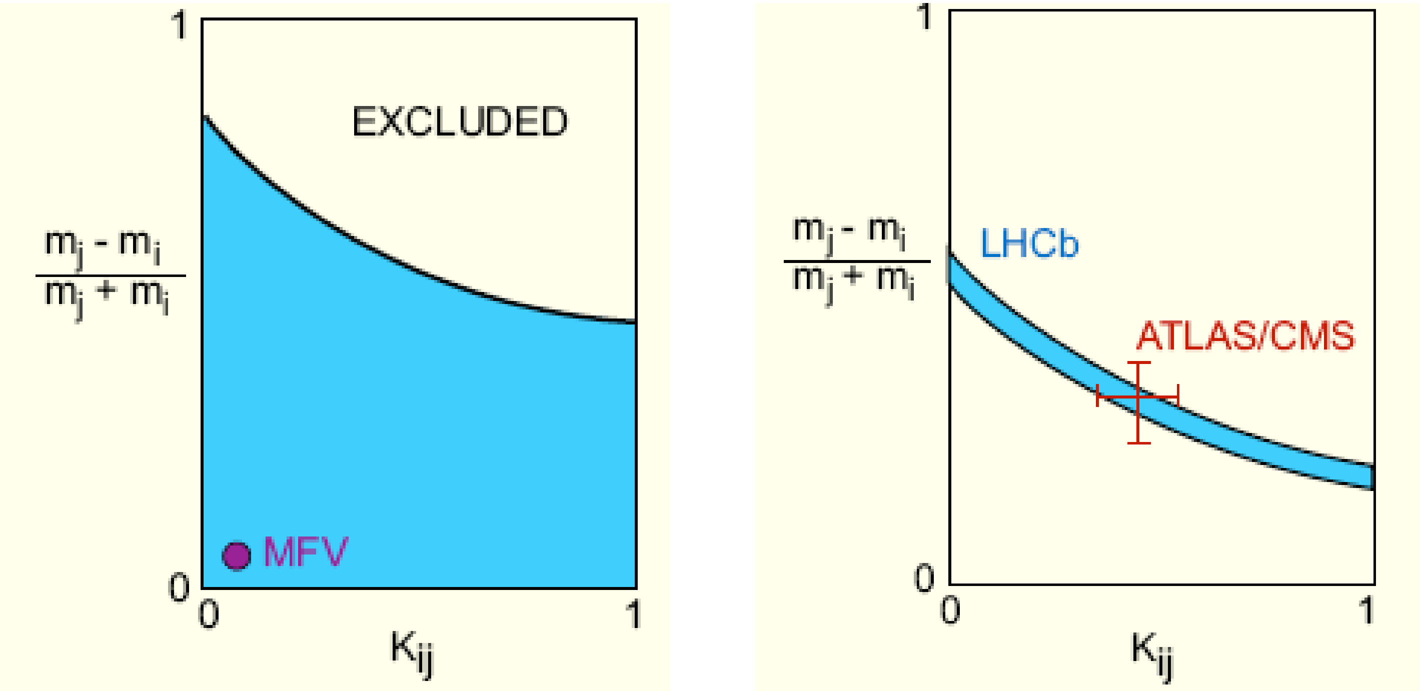

Measuring slepton masses and mixings at the LHC Feng et al., arXiv:0910.1618

Concrete model: Susy hybrid model (gauge/gravity mediation), determination of slepton masses and their mixing possible

Quark flavour at ATLAS/CMS

- **Probing Minimal Flavour Violation at the LHC**

Grossman,Nir,Thaler,Volansky,Zupan,arXiv:0706.1845

To an accuracy of $\mathcal{O}(0.05)$

$$V_{\text{LHC}}^{\text{CKM}} = \begin{pmatrix} 1 & 0.23 & 0 \\ -0.23 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

New particles (i.e. heavy vector-like quarks) that couple to the SM quarks decay to either 3rd generation quark, or to non-3rd generation quark, but not to both.

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If ATLAS/CMS measures $BR(q_3) \sim BR(q_{1,2})$ then this excludes MFV.

MFV prediction for events with B' pair production:

$$\frac{\Gamma(B'\overline{B'} \to X q_{1,2} q_3\,)}{\Gamma(B'\overline{B'} \to X q_{1,2} q_{1,2}\,) + \Gamma(B'\overline{B'} \to X q_3 q_3\,)} \lesssim 10^{-3}$$

Flavour tagging efficiencies are crucial.

Quark flavour at ATLAS/CMS II

- Flavour-violating squark and gluino decays

Hurth,Porod,hep-ph/0311075
arXiv:0904.4574 [hep-ph],
to appear in JHEP

- Squark decays:

$$\tilde{u}_i \rightarrow u_j \tilde{\chi}^0_k \,,\, d_j \tilde{\chi}^+_l \qquad \tilde{d}_i \rightarrow d_j \tilde{\chi}^0_k \,,\, u_j \tilde{\chi}^-_l$$

  with $i = 1,..,6$, $j = 1,2,3$, $k = 1,..,4$ and $l = 1,2$.

- These tree decays are governed by the same mixing matrices as the contributions to flavour violating low-energy observables

- In the unconstrained MSSM new contributions to flavour violation
  - CKM-induced contributions from H^+, χ^+ exchanges
  - flavour mixing in the sfermion mass matrix

- Possible disalignement of quarks and squarks

Strategy:

- Take susy benchmark points: SPS1a',γ, and I''
- Vary flavour nondiagonal parameters

  (off-diagonal squark mass entries)
- Use all experimental and theoretical bounds

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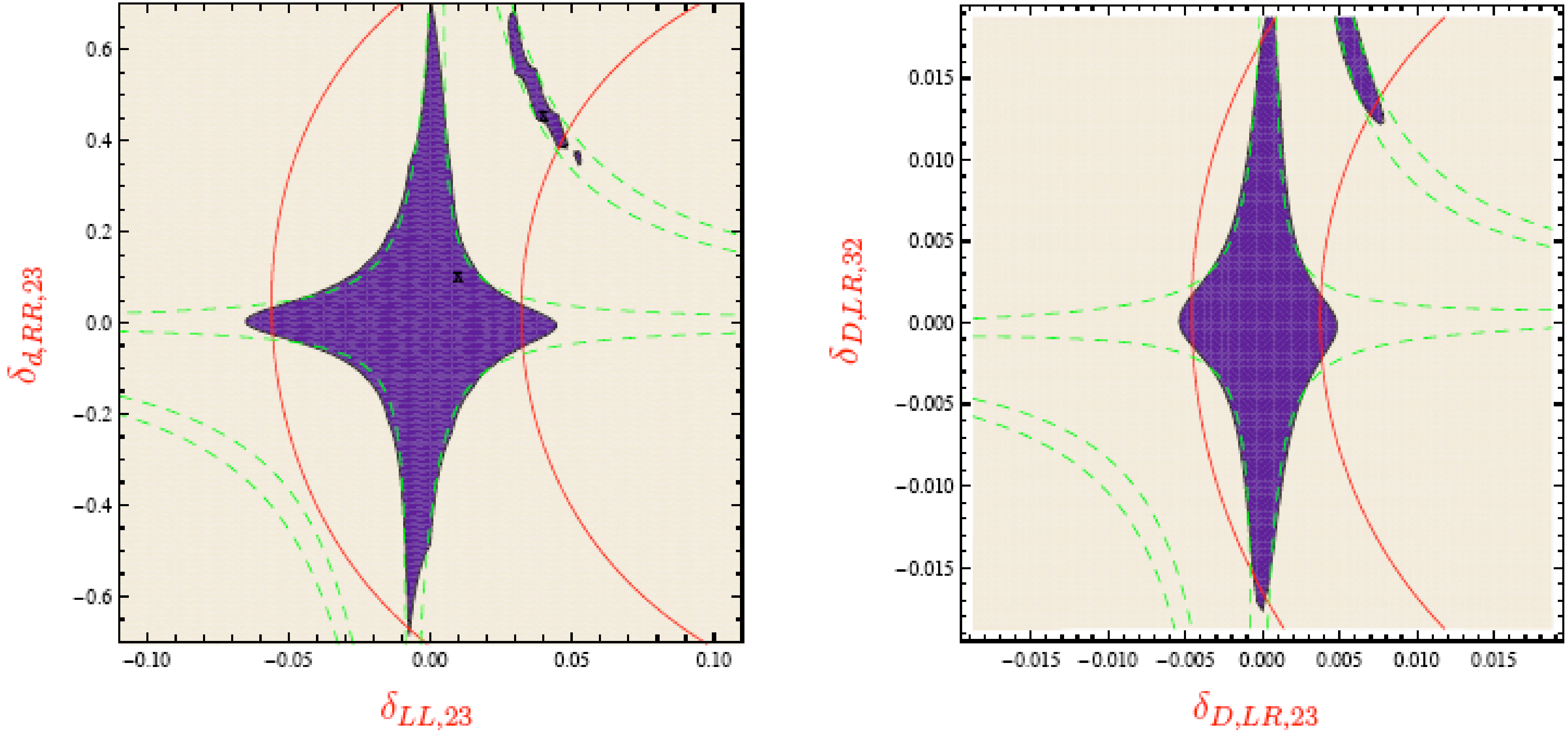
$\Rightarrow$ Bounds on δ parameters



($b \to s\gamma$ red lines, ΔM_{B_s} magenta)

Strategy:

- Take susy benchmark points: SPS1a',γ, and I''
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  (off-diagonal squark mass entries)
- Use all experimental and theoretical bounds

$\Rightarrow$ Information on flavour-violating tree decays

- Flavour-violating squark and gluino decays can be typically of order of 10%,

  - consistent with the present flavour data.

  - common feature for a couple of SUSY benchmark points like SPS1a',γ, and I''

  - even 40% possible for large new physics contributions

Typical results for squark and gluino decays

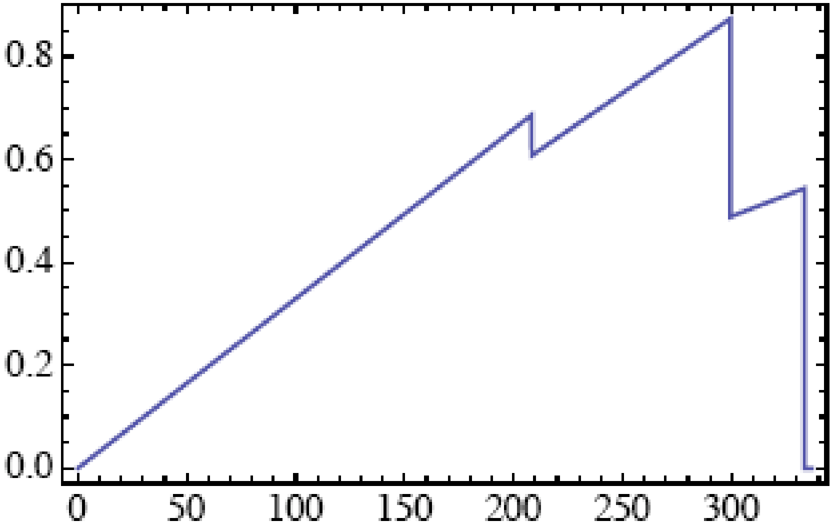
decaying particle	final states and corresponding branching ratios in % for.					
	I. $\delta_{LL,23} = 0.01, \delta_{D,RR23} = 0.1$			II. $\delta_{LL,23} = 0.04, \delta_{D,RR23} = 0.45$		
$\tilde{d}_1 \to$ I: $\tilde{b}_L(\tilde{b}_R)$	$\tilde{\chi}^0_1 b$, 4.4 $\tilde{u}_1 W^-$, 27.7	$\tilde{\chi}^0_2 b$, 29.8	$\tilde{\chi}^-_1 t$, 37.0	$\tilde{\chi}^0_1 s$, 36.8 $\tilde{\chi}^-_1 t$, 9.6	$\tilde{\chi}^0_1 b$, 42.2	$\tilde{\chi}^0_2 b$, 10.9
$\tilde{d}_2 \to$ I: $\tilde{b}_R(\tilde{b}_L, \tilde{s}_R)$	$\tilde{\chi}^0_1 s$, 8.0 $\tilde{\chi}^0_3 b$, 1.1 $\tilde{u}_1 W^-$, 38.9	$\tilde{\chi}^0_1 b$, 6.4 $\tilde{\chi}^0_4 b$, 1.8	$\tilde{\chi}^0_2 b$, 19.0 $\tilde{\chi}^-_1 t$, 24.6	$\tilde{\chi}^0_1 b$, 2.1 $\tilde{u}_1 W^-$, 33.2	$\tilde{\chi}^0_2 b$, 27.3	$\tilde{\chi}^-_1 t$, 34.6
$\tilde{d}_4 \to$ I: $\tilde{s}_R(\tilde{s}_L, \tilde{b}_R)$	$\tilde{\chi}^0_1 s$, 9.1 $\tilde{\chi}^-_1 u$, 2.1	$\tilde{\chi}^0_1 b$, 6.3 $\tilde{\chi}^-_1 c$, 47.3	$\tilde{\chi}^0_2 s$, 25.3 $\tilde{u}_1 W^-$, 4.8	$\tilde{\chi}^0_1 d$, 2.3 $\tilde{\chi}^-_1 c$, 3.0	$\tilde{\chi}^0_2 d$, 31.7 $\tilde{\chi}^-_2 u$, 2.3	$\tilde{\chi}^-_1 u$, 59.7
$\tilde{d}_5 \to$ I: $\tilde{d}_L$	$\tilde{\chi}^0_1 d$, 2.3 $\tilde{\chi}^-_1 c$, 2.8	$\tilde{\chi}^0_2 d$, 31.7 $\tilde{\chi}^-_2 u$, 2.3	$\tilde{\chi}^-_1 u$, 59.9	$\tilde{\chi}^0_1 s$, 2.2 $\tilde{\chi}^-_1 c$, 58.5	$\tilde{\chi}^0_2 s$, 30.7 $\tilde{\chi}^-_2 c$, 2.3	$\tilde{\chi}^-_1 u$, 2.9
$\tilde{d}_6 \to$ I: $\tilde{s}_L(\tilde{s}_R)$	$\tilde{\chi}^0_1 s$, 3.1 $\tilde{\chi}^-_1 c$, 58.1	$\tilde{\chi}^0_2 s$, 30.6 $\tilde{\chi}^-_2 c$, 2.4	$\tilde{\chi}^-_1 u$, 2.7	$\tilde{\chi}^0_1 s$, 19.7 $\tilde{\chi}^0_4 b$, 2.9 $\tilde{g} b$, 39.8	$\tilde{\chi}^0_1 b$, 18.8 $\tilde{\chi}^-_2 t$, 5.8 $\tilde{u}_1 W^-$, 5.5	$\tilde{\chi}^0_3 b$, 2.9 $\tilde{g} s$, 2.2
$\tilde{g} \to$	$\tilde{u}_1 t$, 19.2 $\tilde{u}_4 u$, 4.2 $\tilde{d}_1 s$, 1.4 $\tilde{d}_2 s$, 6.3 $\tilde{d}_4 s$, 2.3	$\tilde{u}_2 c$, 8.2 $\tilde{u}_5 c$, 4.2 $\tilde{d}_1 b$, 20.6 $\tilde{d}_2 b$, 9.0 $\tilde{d}_4 b$, 1.3	$\tilde{u}_3 u$, 8.3 $\tilde{d}_3 d$, 8.3 $\tilde{d}_6 s$, 2.8	$\tilde{u}_1 t$, 13.5 $\tilde{u}_4 c$, 2.6 $\tilde{d}_1 s$, 21.1 $\tilde{d}_2 b$, 14.0 $\tilde{d}_4 d$, 2.3	$\tilde{u}_2 c$, 5.8 $\tilde{u}_5 u$, 2.6 $\tilde{d}_1 b$, 22.7 $\tilde{d}_5 d$, 3.3	$\tilde{u}_3 u$, 5.8 $\tilde{d}_3 d$, 5.9

II: $\tilde{d}_1 \simeq \tilde{b}_R, \tilde{s}_R(\tilde{b}_L)$, $\tilde{d}_6 \simeq \tilde{s}_R, \tilde{b}_R(\tilde{b}_L)$, $\tilde{d}_2 \simeq \tilde{b}_L$, $\tilde{d}_3 \simeq \tilde{d}_R$, $\tilde{d}_4 \simeq \tilde{d}_L$ and $\tilde{d}_5 \simeq \tilde{s}_L$

Impact on LHC

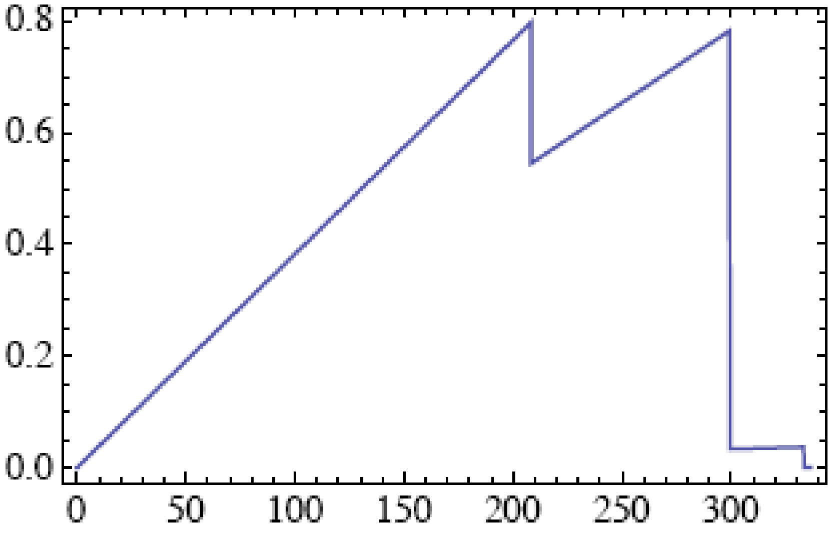
This can complicate determination of sparticle masses: $\tilde{g} \longrightarrow b\tilde{b}_j \longrightarrow b\bar{b}\tilde{\chi}^0_k$

$10^4\ d(\mathrm{BR}(\tilde{g} \rightarrow b\bar{b}\tilde{\chi}^0_1)/dm_{bb}$



$m_{bb} = \sqrt{(p_b + p_{\bar{b}})^2}$

$10^4\ d(\mathrm{BR}(\tilde{g} \rightarrow bs\tilde{\chi}^0_1)/dm_{bs}$



m_{bs}

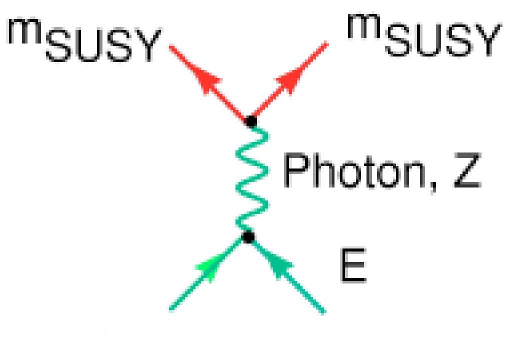
Again: flavour-tagging at LHC important, but difficult

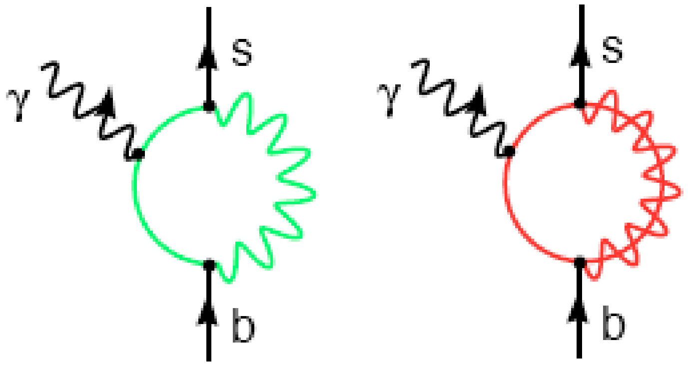
Additional information from ILC or from Superflavour factory needed !

Flavour@high-p_T

Immense potential for synergy and complementarity between high-p_T and flavour physics within the search for new physics

Why?





The indirect information will be most valuable when the general nature of new physics will be identified in the direct search, especially when the mass scale of the new physics will be fixed.

$$(\, C^i_{\mathsf{SM}}/M_W + C^i_{\mathsf{NP}}\,/\Lambda_{\mathsf{NP}}\ ) \times \mathcal{O}_i$$