Charged-Higgs collider signals with or without flavor

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Can a non-minimal flavor sector affect $H^\pm$-production at the LHC and can we learn something from $H^\pm$-production about flavor ?

based on S.Dittmaier, GH, T.Plehn and M.Spannowsky hep-ph/0708.0940.

Flavor in the Standard Model

flavor and CP in SM: $-\mathcal{L}_Y = \bar{Q} Y_U h^C U + \bar{Q} Y_D h D + \bar{L} Y_E h E + h.c.$

flavor symmetry: $U(3)^5 \xrightarrow{Y} U(1)_B \times U(1)_L \times U(1)_Y$

non-abelian quark part: $G_F \equiv SU(3)_Q \times SU(3)_D \times SU(3)_U$

Yukawas are spurions of G_F: $Y_D(3, \bar{3}, 1)$, $Y_U(3, 1, \bar{3})$

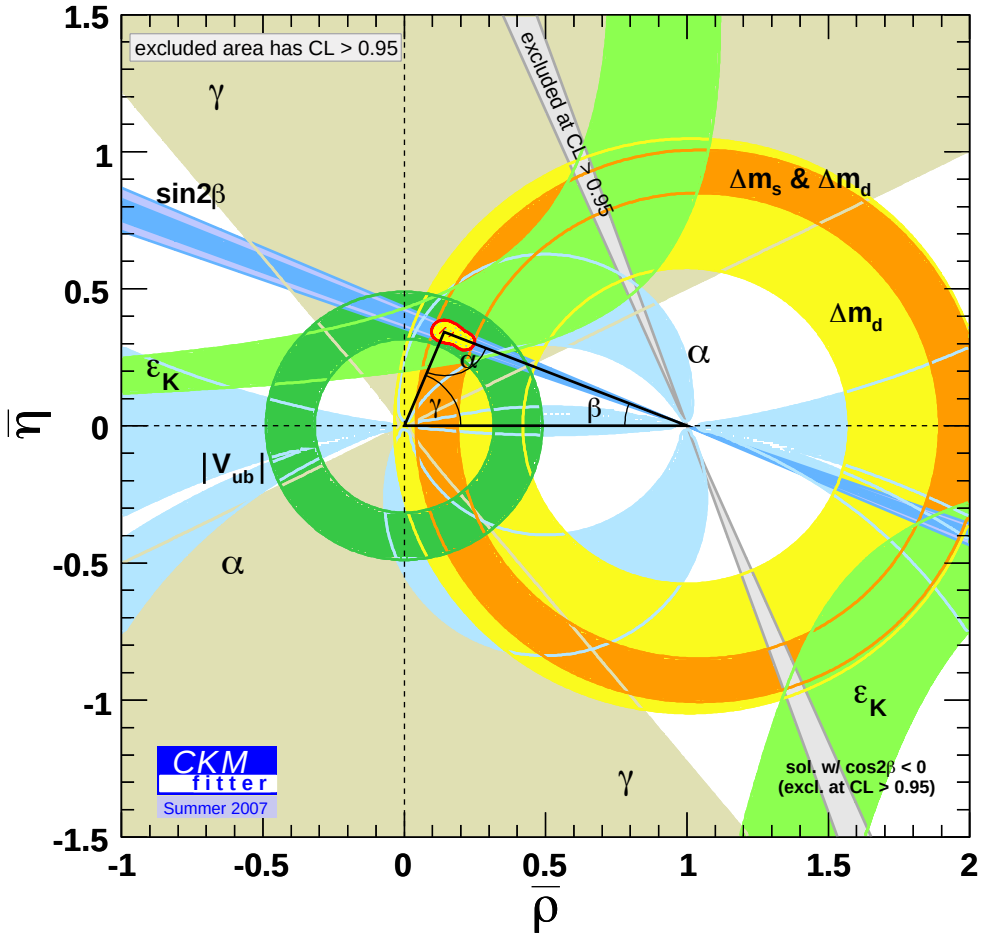
Minimal Flavor Violation (MFV)= Y_D, Y_U are the only spurions of flavor G_F breaking Chivukula, Georgi '87; d'Ambrosio et al '02

MFV is a property of the SM. MFV might hold at higher energies by means of flavor symmetry G_F. pre-symmetry based definitions: Ciuchini et al '98; Buras et al '00

MFV is potential organizing principle for BSM

Indirect tests of Minimal Flavor Violation

the unitarity triangle $V_{ub}V_{ud}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$

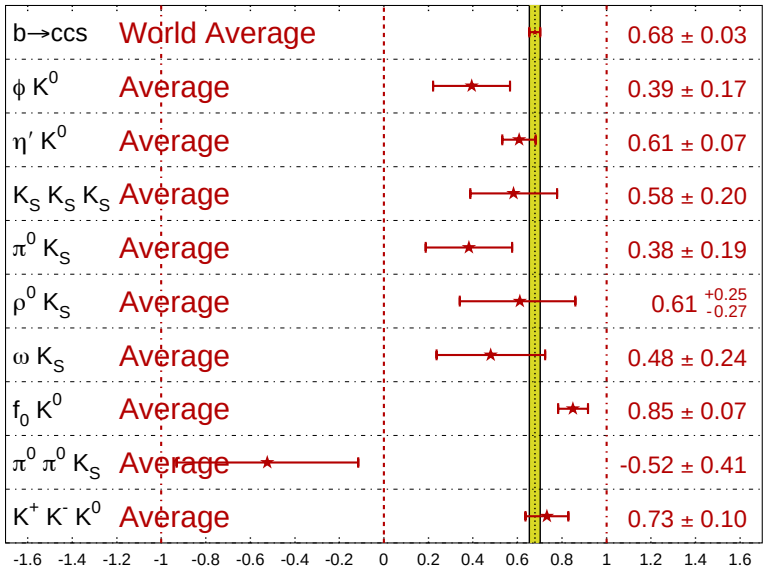


MFV appears to hold for the set of considered observables

Challenges to Minimal Flavor Violation

$$\sin(2\beta^{\rm eff}) \equiv \sin(2\phi_1^{\rm eff})$$

HFAG
LP 2007
PRELIMINARY



$$\pm \sin 2\beta(\underbrace{(\bar{s}s)K_S}_{FCNC}) = \sin 2\beta(\underbrace{(\bar{c}c)K_S}_{tree}) + |\underbrace{\frac{V_{ub}V_{us}^*}{V_{tb}V_{ts}^*}}_{0.02}| \cdot \#(hadronic)$$

non-CKM CP-phases, right-handed currents, CKM-links broken,

e.g., $\mathcal{B}(B_d \to \mu\mu)/\mathcal{B}(B_s \to \mu\mu) \neq |f_{Bd}V_{td}|^2/|f_{Bs}V_{ts}|^2$, ...

MFV is ...

- in agreement with current experiments (mostly indirect).
- MFV is useful due to hierarchies in Yukawas – in SM & BSM for amplitude guesstimates and background control, e.g., $\mathcal{B}(b \to d\gamma)/\mathcal{B}(b \to s\gamma) = |V_{td}/V_{ts}|^2 =$ few $\%$.

  "bookkeeping device" Feldmann, Mannel '06

- a high energy concept: MFV doesn't tell us why the Yukawas look the way they look like; If confirmed, we learn about flavor that flavor has nothing to do with the TeV-scale.

Can we test MFV at colliders ?

Can we access flavor at high p_T ?

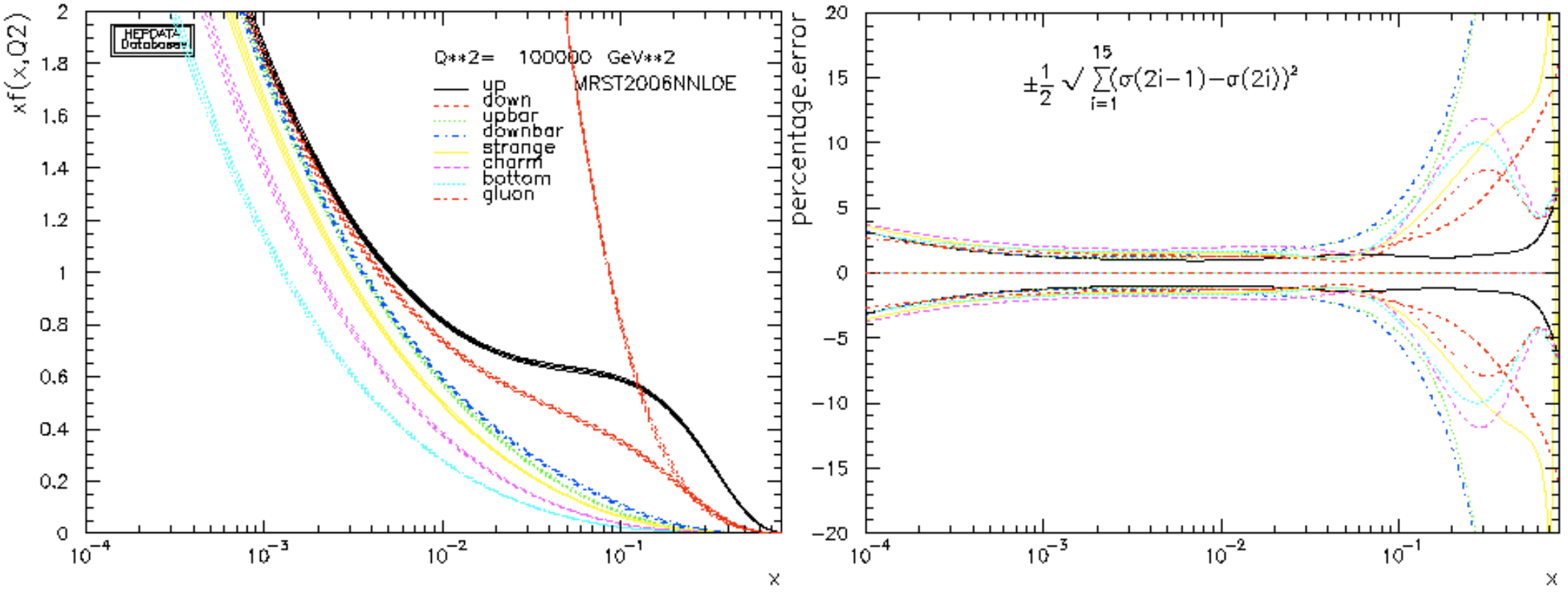
Are we getting the whole story if we ignore flavor in the exploration of the electroweak scale ?

(YES,YES,NO)

LHC: $\sqrt{s} = 14$ TeV:

- proton $= u, d, s, c, b, \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}, g \rightarrow$ plot; p has flavor @ LHC.
- production of particles with flavor $t, \tilde{t}, ..$
- particles decay into flavor $Z \rightarrow \bar{b}b$, $Z \rightarrow \bar{b}s$
- no particle ID; t, b and all the others

Proton pdfs at high Q^2



MFV/Flavor @ Colliders studies

SUSY FCNC rates can be sizeable $\mathcal{O}(10\%)$ Hurth, Porod '03

$\mathcal{B}(\tilde{t}_{1,2} \to \tilde{\chi}^+ b) \sim 50\%$ and $\mathcal{B}(\tilde{u} \to \tilde{\chi}^+ b) \sim 13\%$

Problem for squark mass determination from edges in cascades (implicitly assumed MFV, i.e., $\tilde{m}_1^2 = \tilde{m}_2^2 \neq \tilde{m}_3^2$ and FCNC$= 0$).

Flavored di-squark-production $pp \to \tilde{q}\tilde{q}' X$ Klasen et al '05, '07; Rainwater '05

MSSM $h^0 \to \bar{b}s, b\bar{s}$ decays Hahn, Hollik, Illana, Penaranda '05

NON-SUSY: Study with 2 down-quark singlets show that there is discriminating power between MFV or not Grossmann, Nir, Thaler, Volansky, Zupan '07

Charged-Higgs-production with or without flavor $pp \to H^+ X$,

$pp \to H^+ + jet + X$ Diaz-Cruz,He,Yuan '02; Dittmaier,GH,Plehn,Spannowsky '07

superpotential (unbroken R-parity):

$$W_{MSSM} = Q Y_u H_u U + Q Y_d H_d D + L Y_e H_d E + \mu H_d H_u$$ MFV !

SUSY-breaking can contain non-minimal flavor:

$$\tilde{Q}^\dagger m_Q^2 \tilde{Q} + \tilde{U}^\dagger m_U^2 \tilde{U} + \tilde{D}^\dagger m_D^2 \tilde{D} + (A_u \tilde{Q} H_u \tilde{U}^* + A_d \tilde{Q} H_d \tilde{D}^* + h.c.)$$

$$\frac{m_U^2}{m_0^2} = \begin{pmatrix} 1 & \delta^u_{12RR} & \delta^u_{13RR} \\ h.c & 1 & \delta^u_{23RR} \\ h.c & h.c & 1-\Delta \end{pmatrix}, \quad \frac{A_u}{A_0} = \begin{pmatrix} \frac{M}{v_u}\delta^u_{11LR} & \frac{M}{v_u}\delta^u_{12LR} & \frac{M}{v_u}\delta^u_{13LR} \\ \frac{M}{v_u}\delta^u_{21LR} & \frac{M}{v_u}\delta^u_{22LR} & \frac{M}{v_u}\delta^u_{23LR} \\ \frac{M}{v_u}\delta^u_{31LR} & \frac{M}{v_u}\delta^u_{32LR} & \frac{m_t}{v_u} + \frac{M}{v_u}\delta^u_{33LR} \end{pmatrix}$$

with MFV, flavor blind SUSY breaking: $m^2_{Q,D,U} \propto 1$ and $A_{u,d} \propto Y_{u,d}$
up to powers of Yukawas, eg., $(YY^\dagger)^n$ GH, Schmaltz'02, D'Ambrosio et al '02

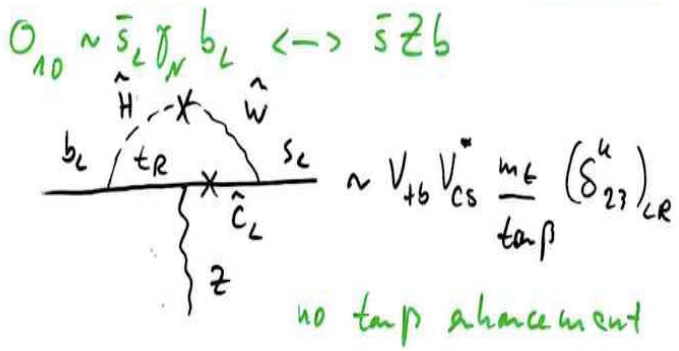
MFV: $\delta^{u,d}_{i\neq j\, RR,LL,LR} \to 0$

Constraints on the flavor δ's

Strong constraints on mixing between first and second generation $\delta^{u,d}_{ij}$, $i,j=1,2$. (from K-physics, $D^0-\bar{D}^0$ mixing)

Strong constraints from gluino loop-induced K,B-FCNCs on δ^d.

Strong constraints from $b\to s\gamma, b\to s\ell^+\ell^-$ and Δm_s on $\delta^u_{23\,LL}, \delta^u_{23\,LR}$.



Similar from $B\to\rho\gamma, B\to\pi\ell^+\ell^-$ and Δm_d on $\delta^u_{13\,LL}, \delta^u_{13\,LR}$.

Constraints from K,B-physics on mixing with light $SU(2)$ singlets $\delta^u_{3i\,LR}, \delta^u_{3i\,RR}$ very loose due to mass suppression.

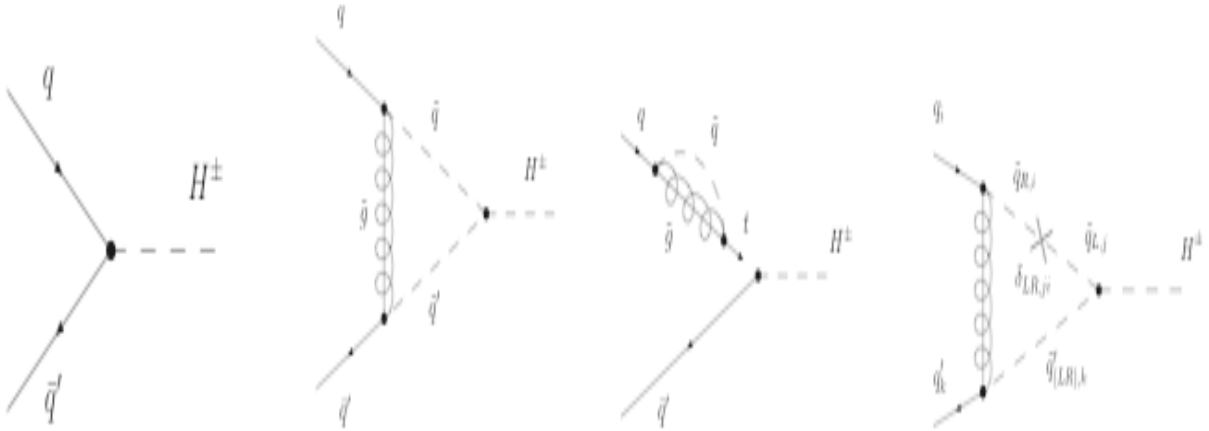
Charged-Higgs Production in pp with Flavor

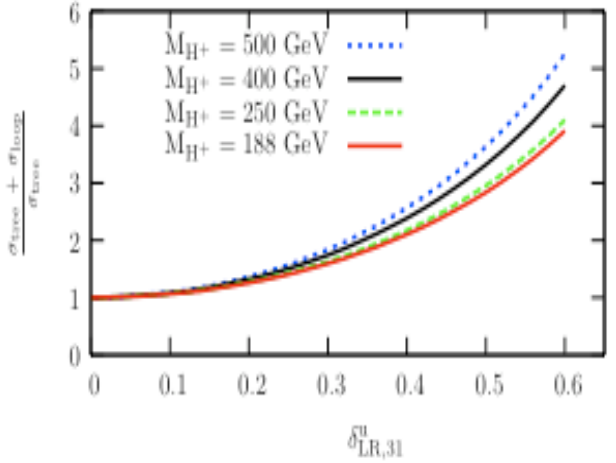
H^+ in 2HDM: no tree level H^+W^-V coupling.

H^+-production with fermions: $\bar{Q}H_uU, \bar{Q}H_dD$ (Yukawas) and $\bar{Q}H_u^C D, \bar{Q}H_d^c U$ ("wrong Higgs") vanish in chiral limit.

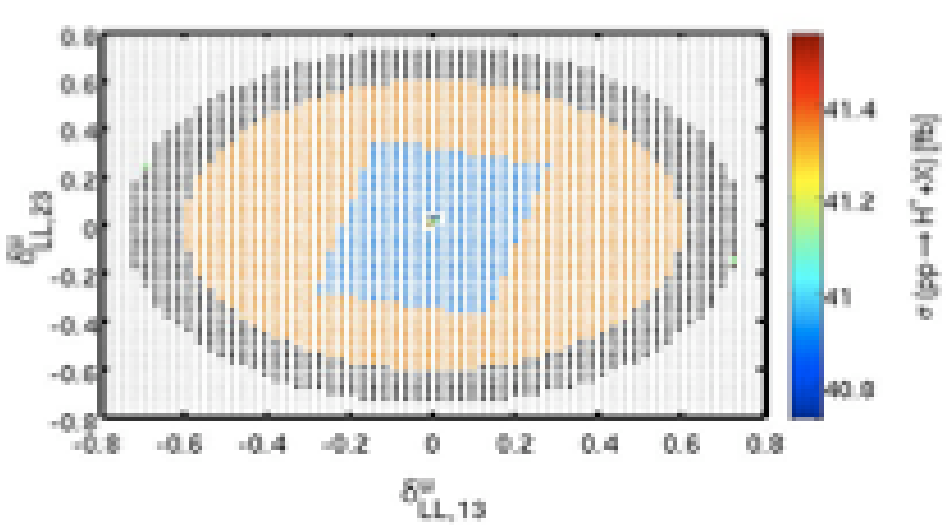
Enhancement from SUSY loops beyond MFV:

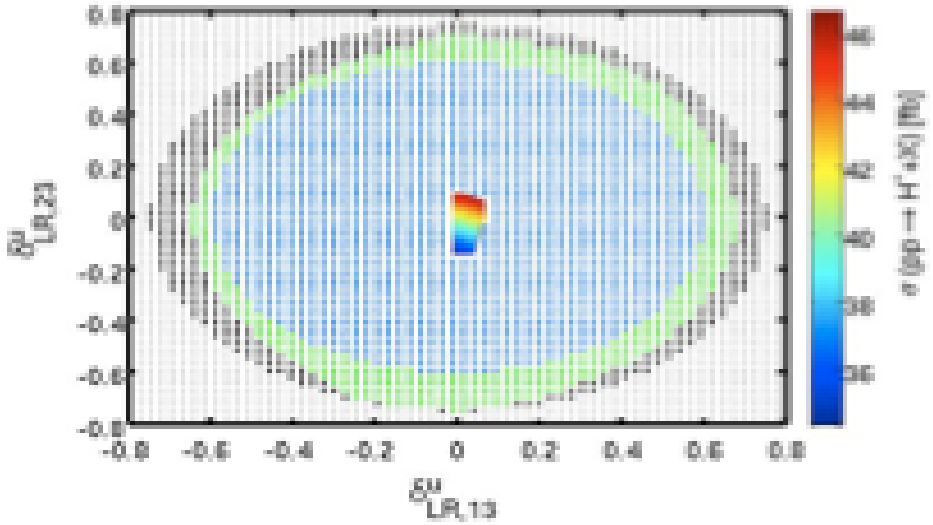
$A_{beyondMFV}/A_{tree} \sim \frac{\alpha_s}{4\pi} \frac{m_{\tilde{g}}}{V_{cb} m b \tan\beta^2} \delta^u_{3i\,LR}$.

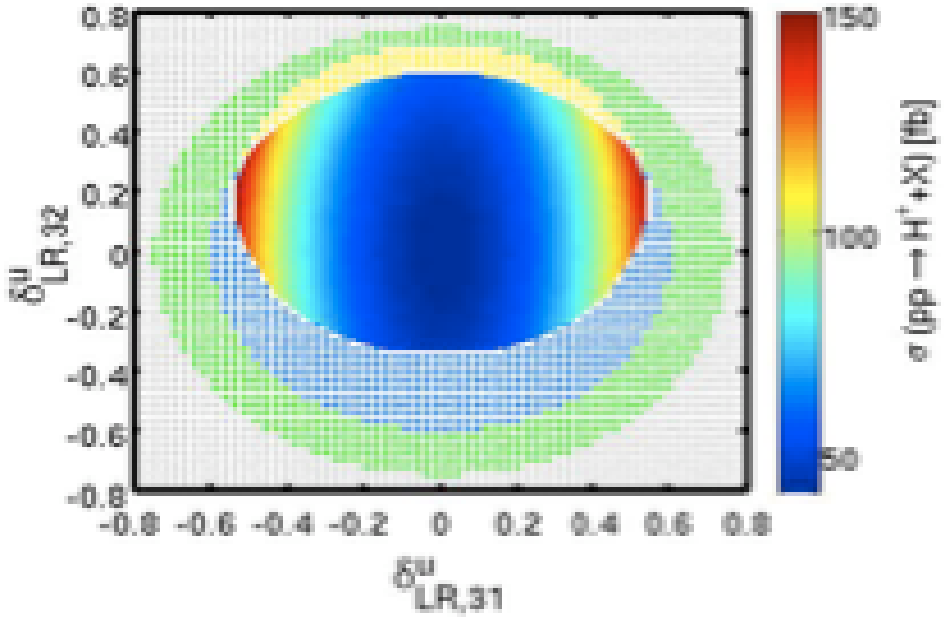


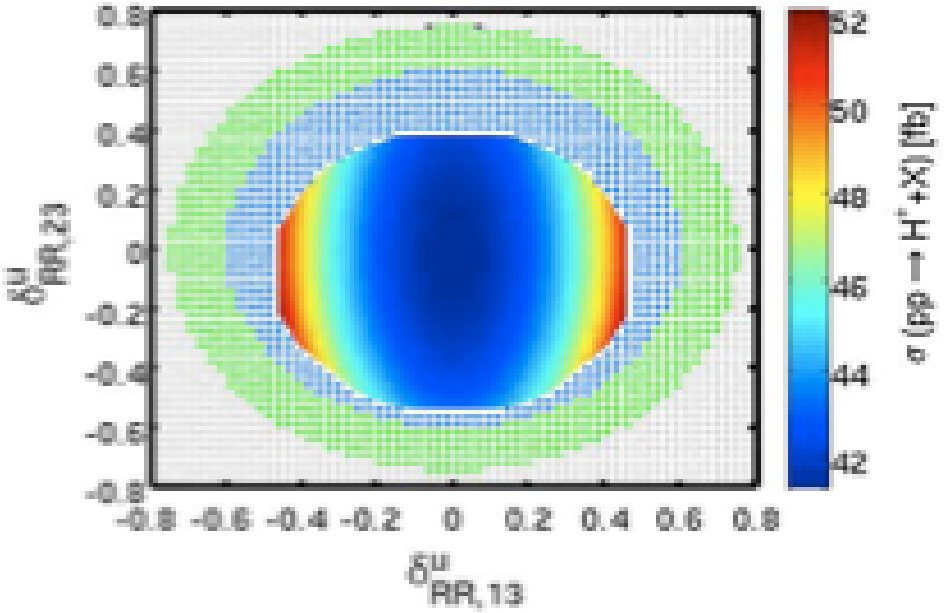


Charged-Higgs Production in pp with Flavor





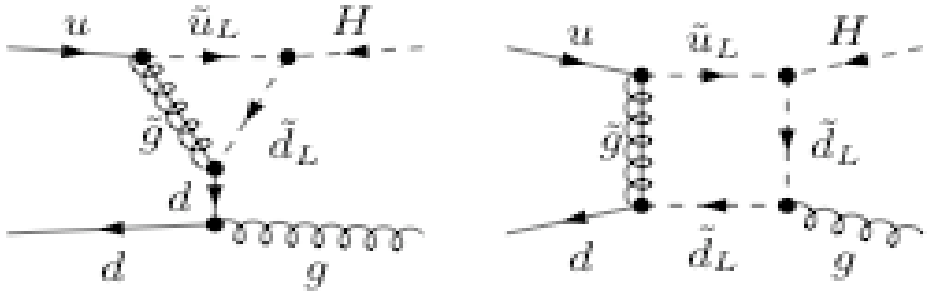




Charged-Higgs plus Jet $qg \to q' H^+$

Idea: avoid chiral suppression by extra gauge boson, e.g., $\bar{Q}\gamma_\mu Q H_u D^\mu H_u^C$.

D-term contribution from $H^+\tilde{q}\tilde{q}'$ finite in chiral limit and MFV.

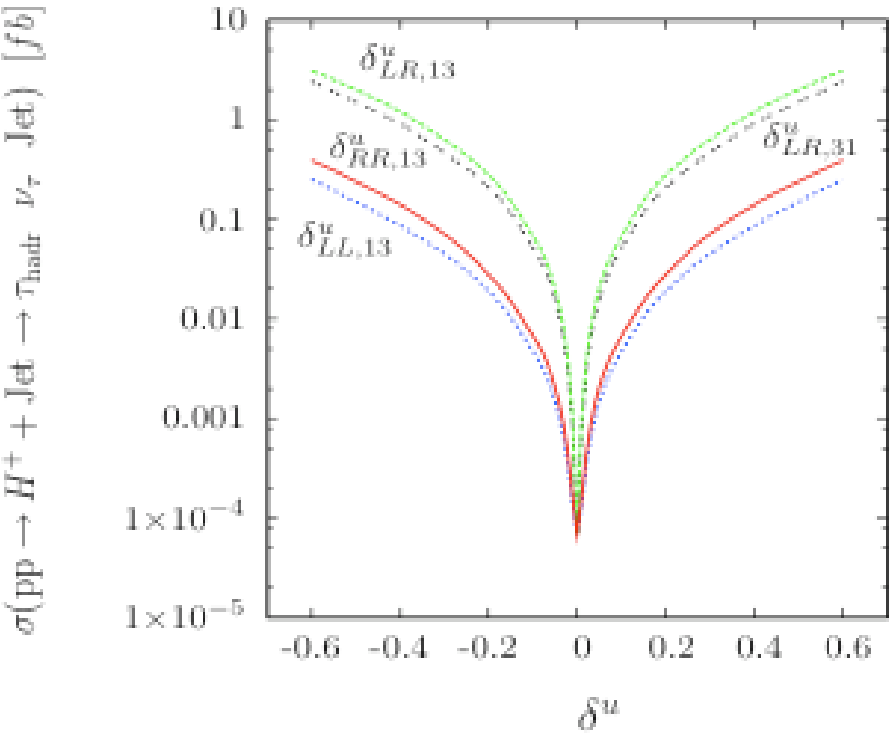


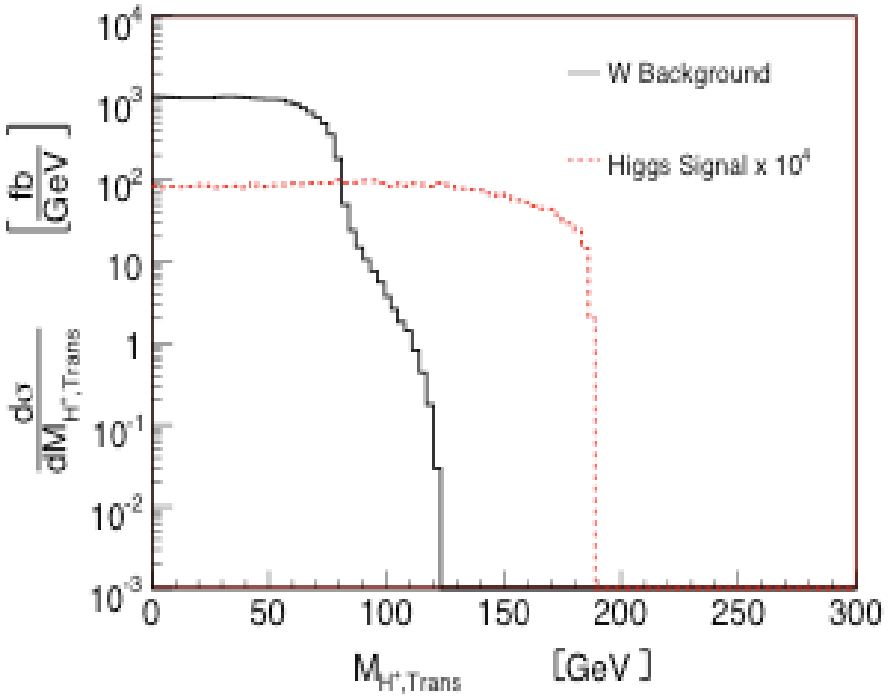
$\sigma_{pp->H^+j}$	2HDM	MFV D-term only	MFV with $m_q \neq 0$	beyond MFV
$\tan\beta = 3$	$2.5 \cdot 10^{-1} fb$	$6.7 \cdot 10^{-4} fb$	$\simeq \sigma_{2HDM}$	$14.3 fb$

D-term decouples faster than chirally suppressed terms.

With flavor O(30) enhancement over MFV (small/moderate $\tan\beta$).

Charged-Higgs plus Jet $qg \to q' H^+$





works for small $\tan\beta$; substantial W-BGD Dittmaier,GH,Plehn,Spannowsky '07

Discovery of charged-Higgs prod. would signal breakdown of SM and non-standard flavor/Higgssector, including breakdown of MFV.

Summary

- Charged-Higgs production shows that:

  i collider signals dramatically change through flavor, and
  ii complementary information on flavor can be obtained from collider physics w.r.t. indirect searches.

- In SUSY $\delta^u_{3i\,LR}, \delta^u_{3i\,RR}$ are unconstrained by K,D,B-physics, big effects in Higgs and top sector.

  Tests flavor models

  $\delta^q_{LR\,ij} \sim \frac{m_{q_i} m_{q_j}}{\tilde{m}^2}$ (alignment)

  $\delta^u_{LR\,3j} \sim \frac{V^*_{jb} m_{u_j}}{\tilde{m}}, \delta^u_{LR\,i3} \sim \frac{V^*_{ti} m_t}{\tilde{m}}$ (abelian flavor) Nir, Seiberg'93

  and Minimal Flavor Violation (=SM flavor violation).