It's all about tau's

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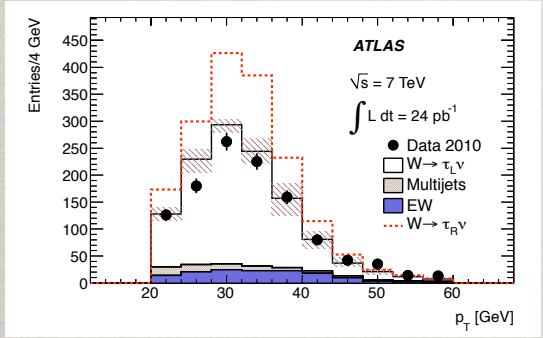
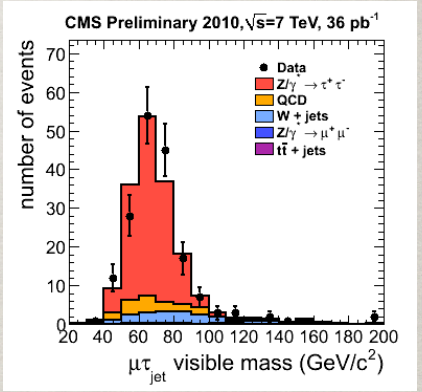
Congrats to LHC!
Thanks to ATLAS & CMS!

tau's have been identified in W/Z decays:



[ATLAS arXive:1204.6720.]



[CMS, TAU-11-001.]

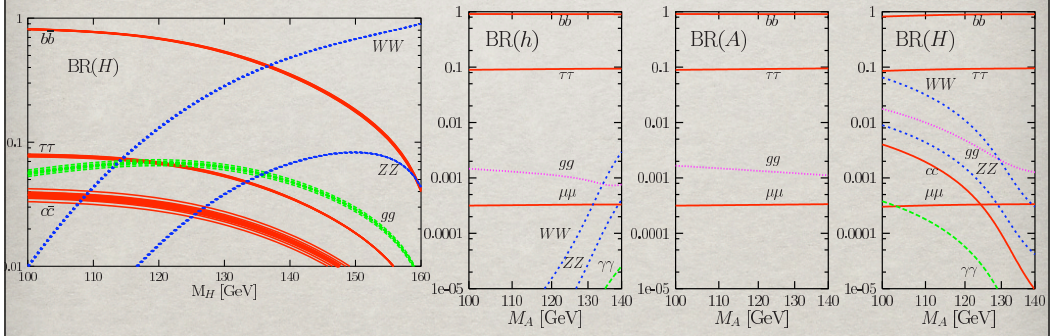
See next talks by Sridhara, Zofia.

Why tau's

A. The heaviest Lepton, strongest couplings to Higgs

Example I: Great Signal for $h^0/H^0/A^0$:

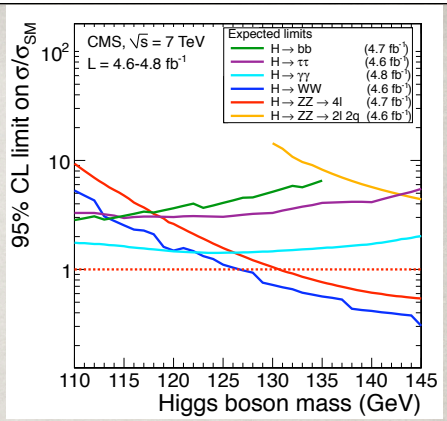
SM : $= i\frac{m_\tau}{v}$, MSSM $(H,\ A)$: $\approx i\frac{m_\tau \tan\beta}{v}(1,\gamma^5)$



tau's are important:

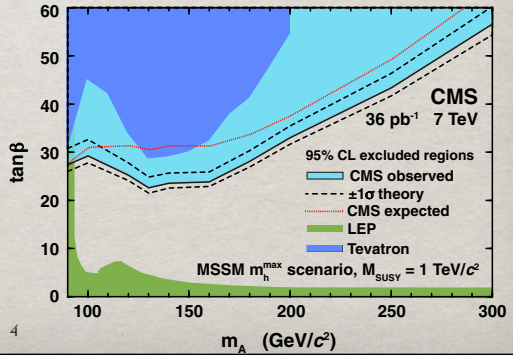
SM-like h^0 at CMS:

CMS-PAS-HIG-11-023



SUSY H^0/A^0 at CMS:

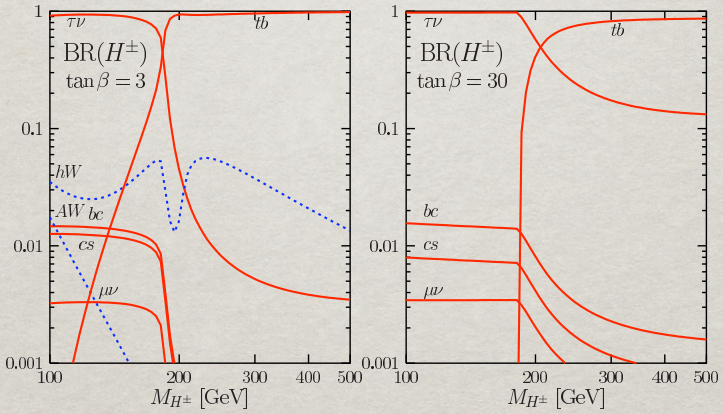
CMS-PAS-HIG-11-009



Why tau's

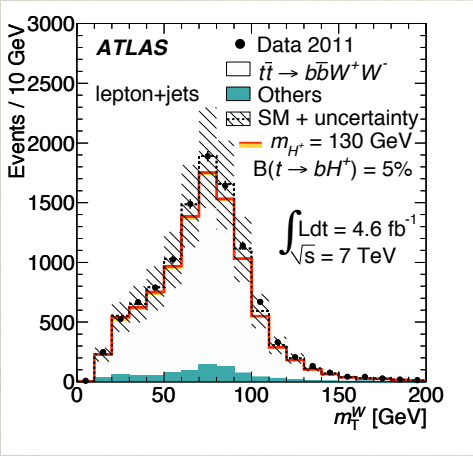
Example 2: Leading Signal for $H^{\pm}$:

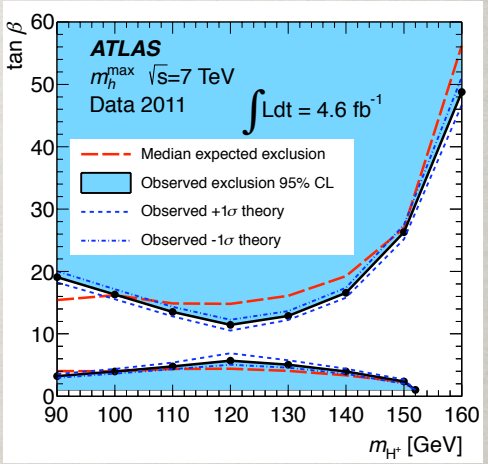
$$\text{MSSM } H^+ \bar{\nu} \tau^- : \quad i\frac{m_\tau \tan\beta}{\sqrt{2}v}\left(\frac{1+\gamma^5}{2}\right)$$



e.g., ATLAS search for $H^{\pm}$:

$$t \to bH^{\pm}, \text{ with BR}(H^{\pm} \to \tau^{\pm}\nu) = 100\%.$$





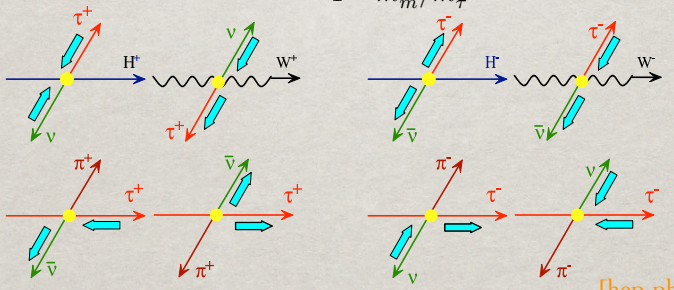
[ATLAS arXive:1204.2760.]

An important feature:

$$H^- \to \tau_R^- \bar{\nu}_R; \qquad H^+ \to \tau_L^+ \nu_L.$$
$$W^- \to \tau_L^- \bar{\nu}_R; \qquad W^+ \to \tau_R^+ \nu_L.$$

- **Polarization in hadronic decays:**

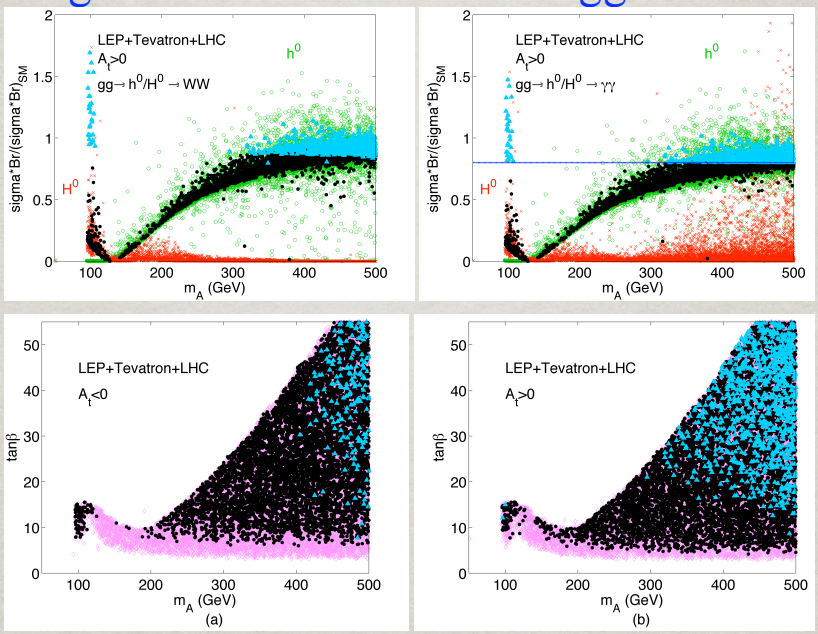
$$\frac{1}{\Gamma}\frac{d\Gamma(\tau^\pm \to \pi^\pm \nu)}{d\cos\theta} = BR_\pi \ \frac{1}{2}(1 \mp P_\tau \cos\theta)$$
$$\frac{1}{\Gamma}\frac{d\Gamma(\tau^- \to v^- \nu)}{d\cos\theta} = BR_v \ \frac{1}{2}\left(1 + \frac{m_\tau^2 - 2m_v^2}{m_\tau^2 + 2m_v^2} P_\tau \cos\theta\right)$$
$$\cos\theta = \frac{2E_m/E_\tau}{1 - m_m^2/m_\tau^2} - 1$$



[hep-ph/0311083, Q.H.Cao, Kanemura, C.-P. Yuan]

τ^+ is left-handedly polarized in $H^+ \to \tau^+\nu$, and right-handedly polarized in $W^+ \to \tau^+\nu$.

In light of the current SM Higgs searches:

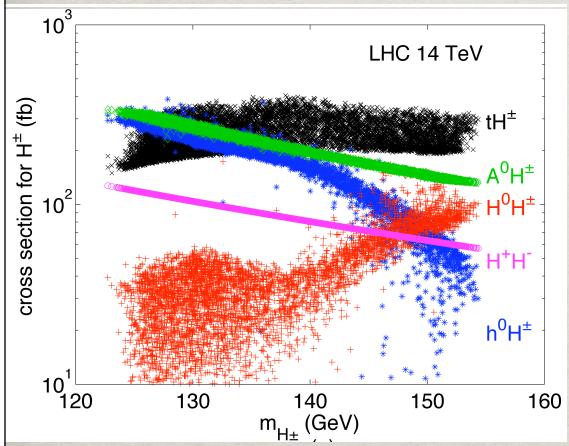


[arXive:1006.2904, Christensen, Han, Su]

Example 3: Higgs pair production :

Non-decoupling region: $m_{h^0} \sim m_A \sim m_Z, \quad m_{H^0} \sim m_{H^\pm} \sim 125\,\mathrm{GeV}$

pair production important!



$pp \to W^\pm \to A^0 H^\pm \to \tau\nu + b\bar{b}$

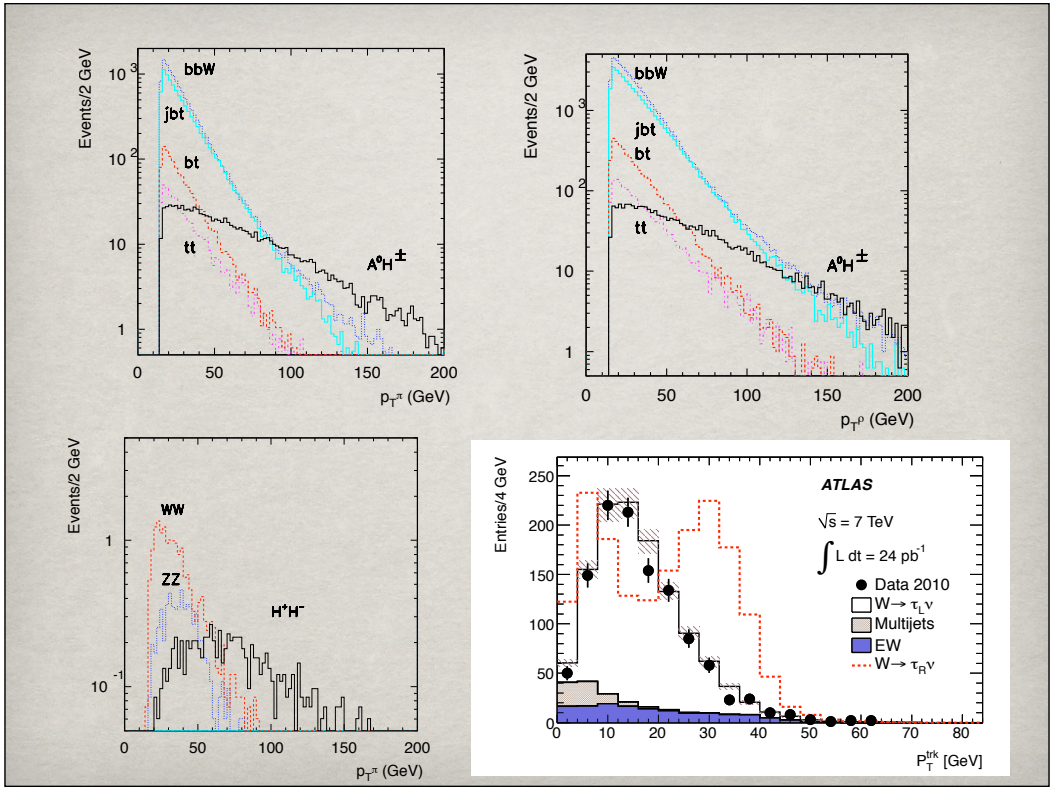
$pp \to \gamma/Z^* \to H^+ H^- \to \tau\nu + \tau\nu$

model independent EW processes

$pp \to W^\pm \to h^0 H^\pm,\ H^0 H^\pm \to \tau\nu,\ b\bar{b}$

model dependent, complementary

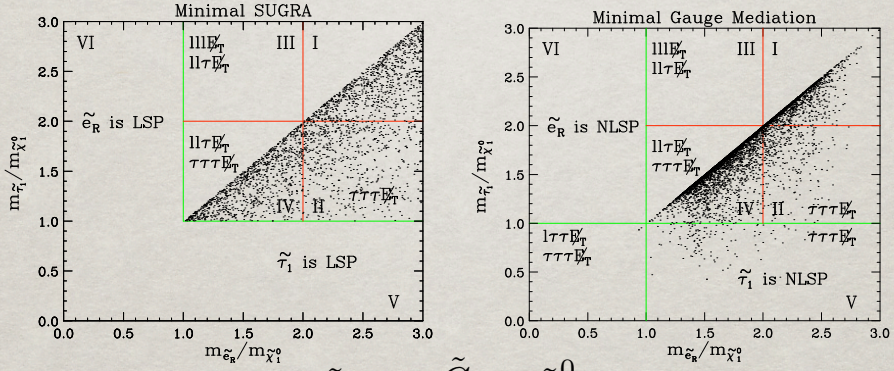
[arXive:1006.2904, Christensen, Han, Su]


Events/2 GeV
bbW
jbt
bt
tt
A°H±
p_T^{π} (GeV)
Events/2 GeV
bbW
jbt
bt
tt
A°H±
p_T^{ρ} (GeV)
Events/2 GeV
WW
ZZ
H⁺H⁻
p_T^{π} (GeV)
Entries/4 GeV
ATLAS
√s = 7 TeV
∫ L dt = 24 pb⁻¹
Data 2010
W→ τ_L ν
Multijets
EW
W→ τ_R ν
P_T^{trk} [GeV]

Why tau's

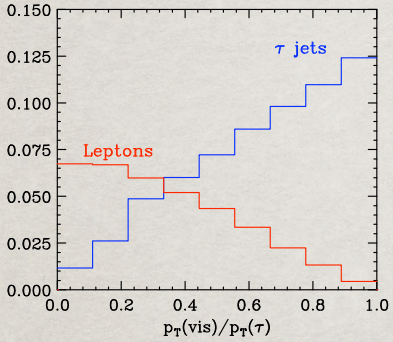
B. Lightest S-lepton $\tilde{\tau}$

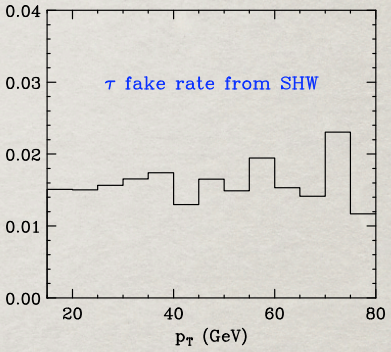
RGE running: The large Yukawa drags its mass lower



$$\tilde{\tau} \to \tau\, \tilde{G},\ \tau\, \tilde{\chi}^0$$

[arXive:1006.2904, Lykken, Matchev.]





tau's: vehicle for further studies:

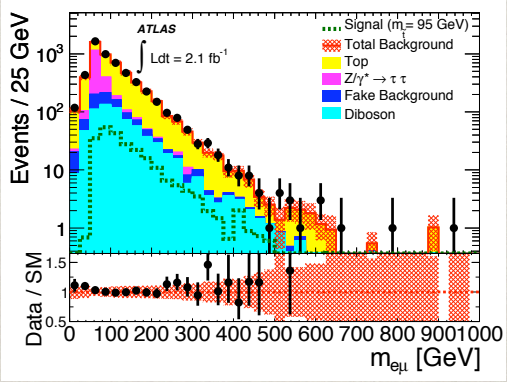
Probing coupling [arXive:1006.2904, Kitano et cl.]

$$\tilde{\chi}^0 \to \tau\ \tilde{\tau}$$

Why tau's

C. Lepton Flavor Mixings:

Recent ATLAS report $e^- \mu^+$ [arXive:1205.0725]



tau's more interesting:

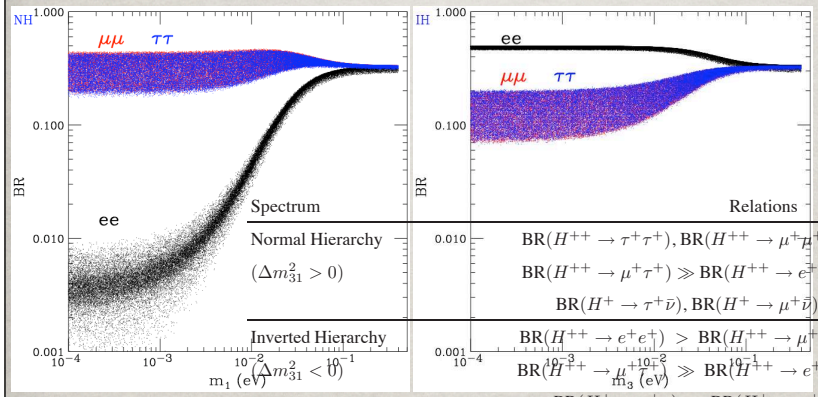
less constrants;

stronger coupling;

neutrino connection θ_{23}

e.g., Type 2 Seesaw: Doubly charged Higgs

$$H^{++} \to \tau^+\tau^+,\ \mu^+\mu^+,\ e^+e^+$$



Spectrum	Relations
Normal Hierarchy	$\mathrm{BR}(H^{++} \to \tau^+\tau^+), \mathrm{BR}(H^{++} \to \mu^+\mu^+) \gg \mathrm{BR}(H^{++} \to e^+e^+)$
$(\Delta m^2_{31} > 0)$	$\mathrm{BR}(H^{++} \to \mu^+\tau^+) \gg \mathrm{BR}(H^{++} \to e^+\mu^+), \mathrm{BR}(H^{++} \to e^+\tau^+)$
	$\mathrm{BR}(H^+ \to \tau^+\bar{\nu}), \mathrm{BR}(H^+ \to \mu^+\bar{\nu}) \gg \mathrm{BR}(H^+ \to e^+\bar{\nu})$
Inverted Hierarchy	$\mathrm{BR}(H^{++} \to e^+e^+) > \mathrm{BR}(H^{++} \to \mu^+\mu^+), \mathrm{BR}(H^{++} \to \tau^+\tau^+)$
$(\Delta m^2_{31} < 0)$	$\mathrm{BR}(H^{++} \to \mu^+\tau^+) \gg \mathrm{BR}(H^{++} \to e^+\tau^+), \mathrm{BR}(H^{++} \to e^+\mu^+)$
	$\mathrm{BR}(H^+ \to e^+\bar{\nu}) > \mathrm{BR}(H^+ \to \mu^+\bar{\nu}), \mathrm{BR}(H^+ \to \tau^+\bar{\nu})$
Quasi-Degenerate	$\mathrm{BR}(H^{++} \to e^+e^+) \sim \mathrm{BR}(H^{++} \to \mu^+\mu^+) \sim \mathrm{BR}(H^{++} \to \tau^+\tau^+) \approx 30\%$
$(m_1, m_2, m_3 > \lvert\Delta m_{31}\rvert)$	$\mathrm{BR}(H^+ \to e^+\bar{\nu}) \sim \mathrm{BR}(H^+ \to \mu^+\bar{\nu}) \sim \mathrm{BR}(H^+ \to \tau^+\bar{\nu}) \approx 30\%$

Why tau's

D. Unique Properties for observation:

- Displaced Vertex:

  $\ell_\tau \approx 87\ \mu m$

  Signal identification, background separation

- Decay products collimated:

  when $E_\tau \gg m_\tau$

  Simple collinear kinematics

tau's for new physics:
Theoretically: hopeful
Experimentally: playful

Why tau's

(a street banner in Brugge)