Charged Higgs search in the leptonic-τ channel

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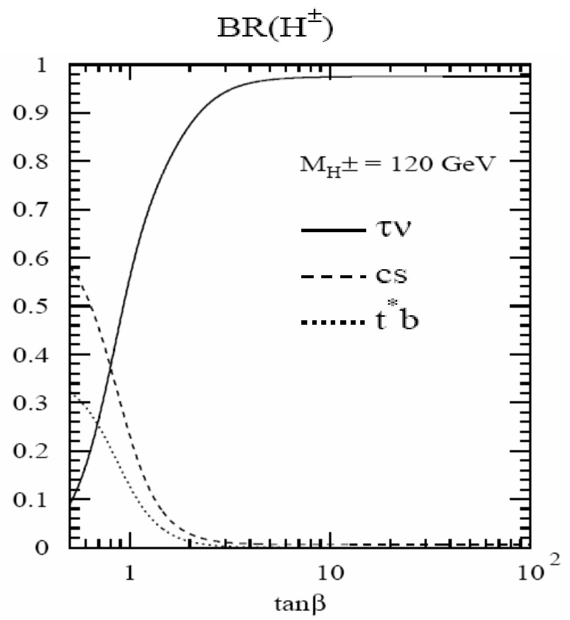
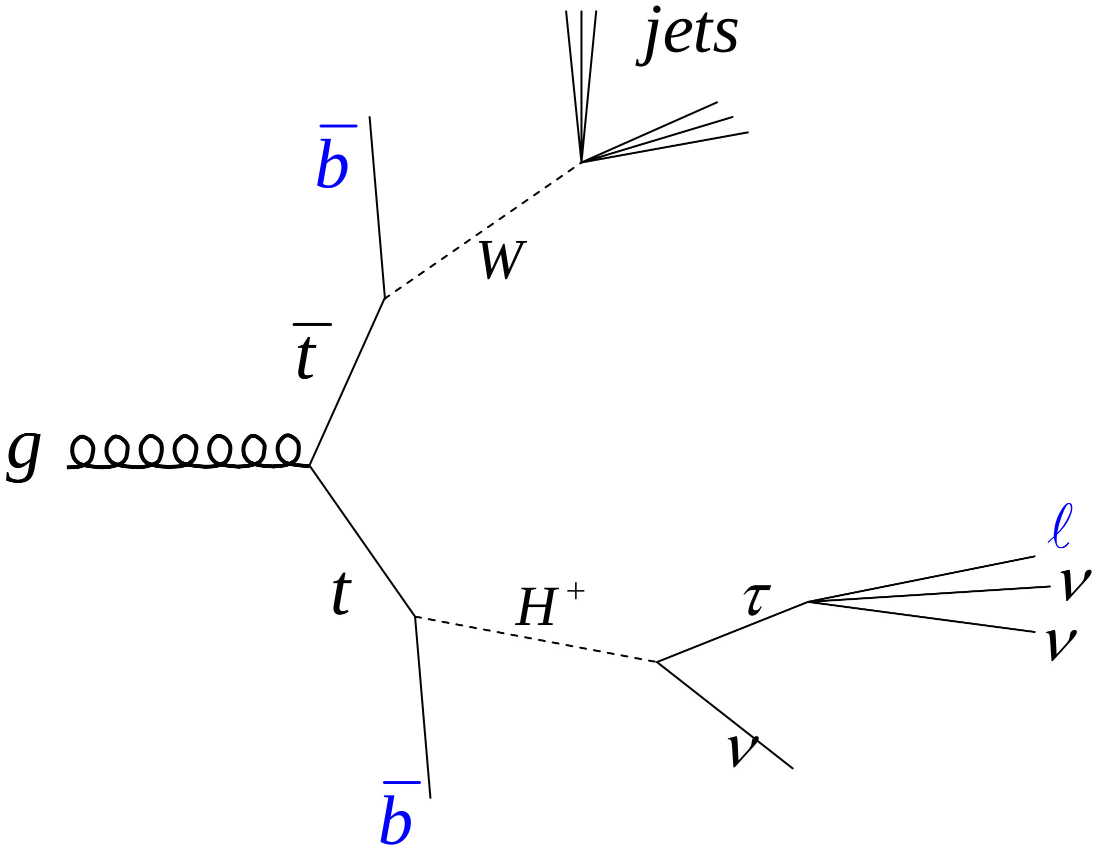
Introduction

- A light charged Higgs is expected to decay via $H^+ \to \tau\nu$ at almost 100%.
- The 'standard' method of observing H^+ is based on identification of hadronic τ's.
- About 35% of τ decay is to leptons (e/μ): a potentially significant channel, independent of hadronic τ-identification.
- We investigate kinematical observables that can provide sensitivity to a charged Higgs in this channel.

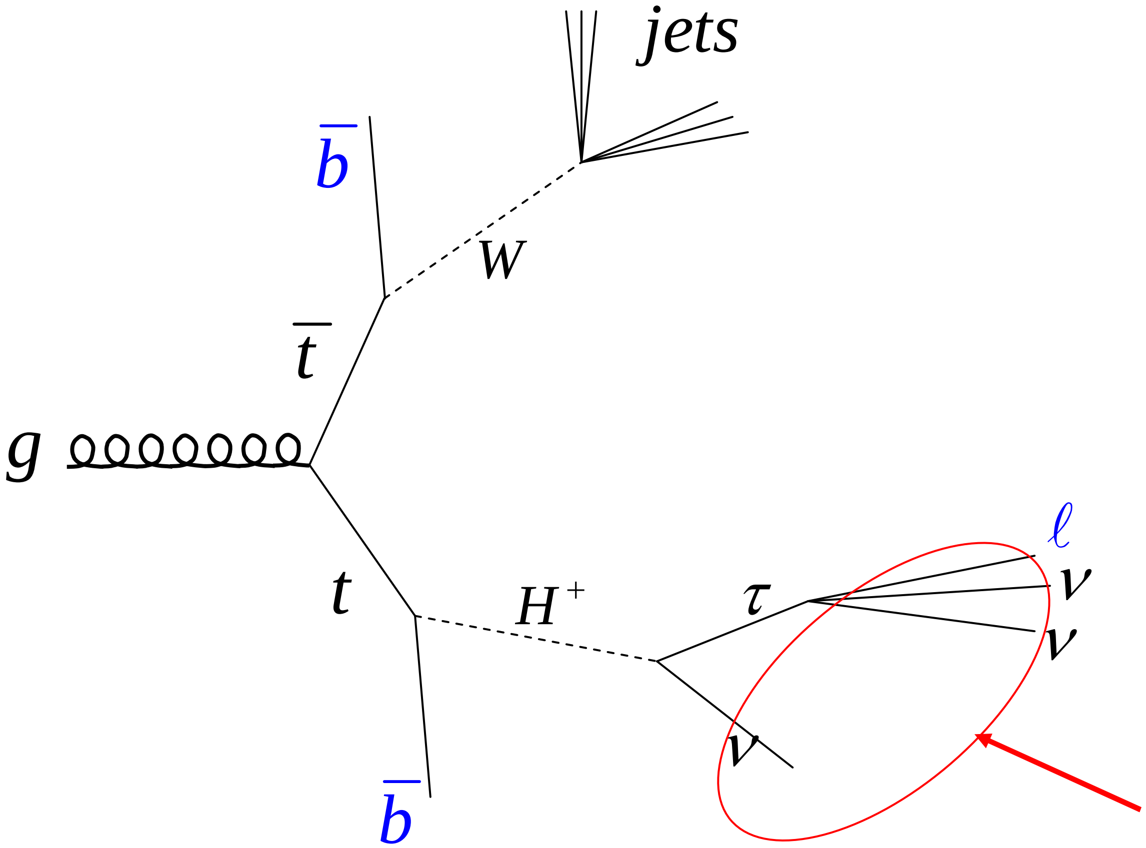


M. Carena, *et al.* [hep-ph/0010338]

Event topology



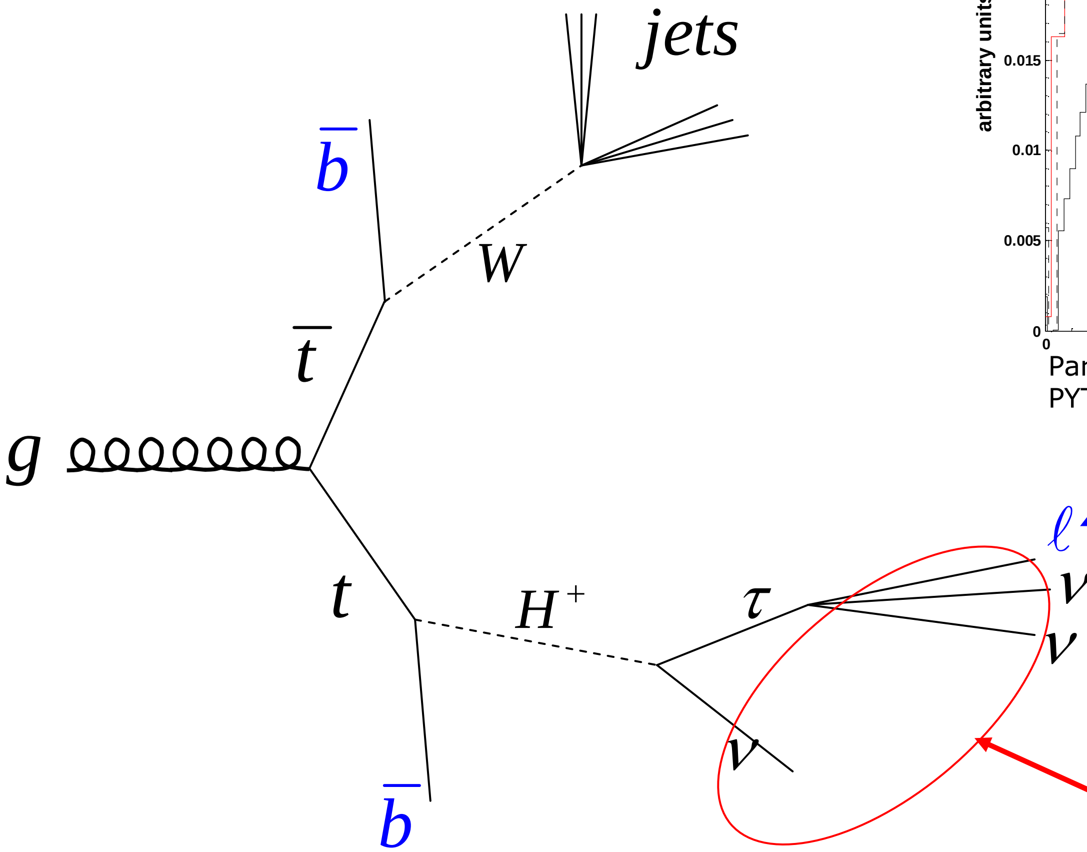
Event topology

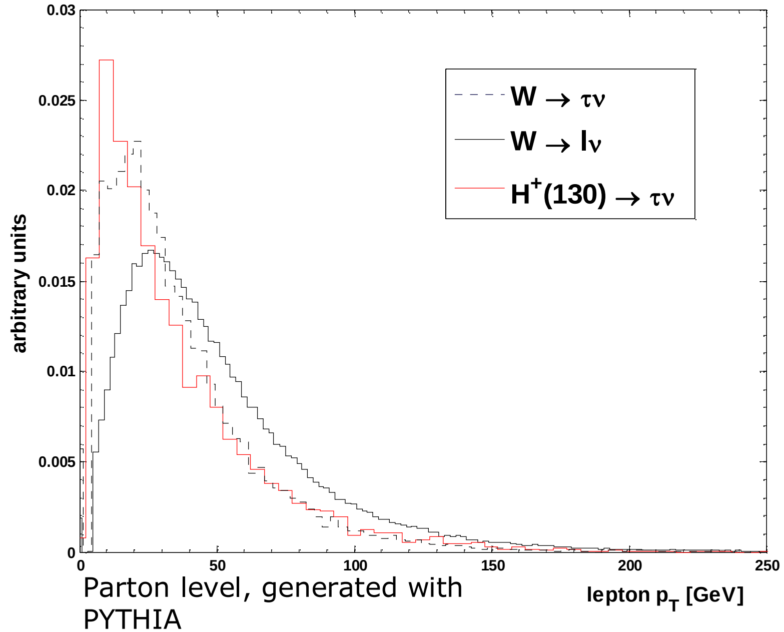


Missing energy from 3 neutrinos:

Full reconstruction of m_{H+} not possible

Event topology





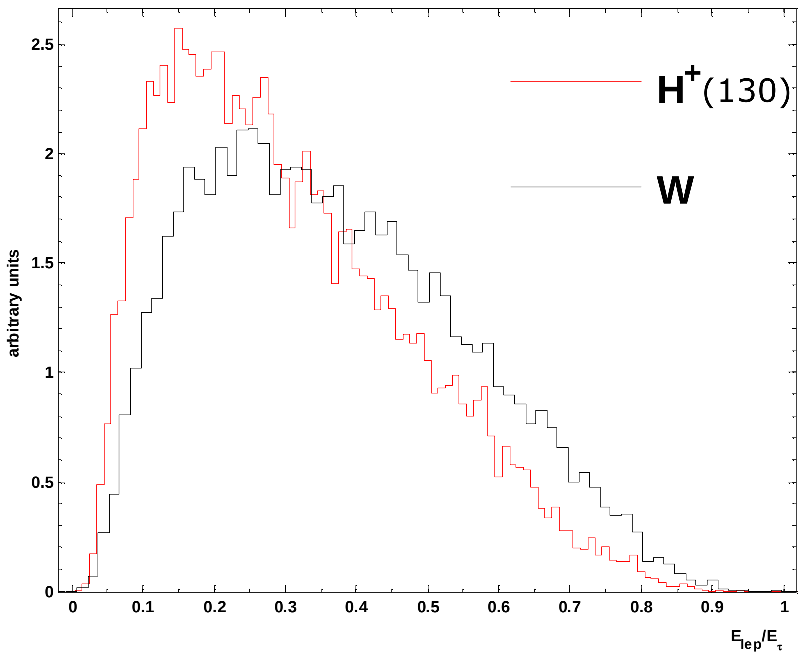
Parton level, generated with PYTHIA

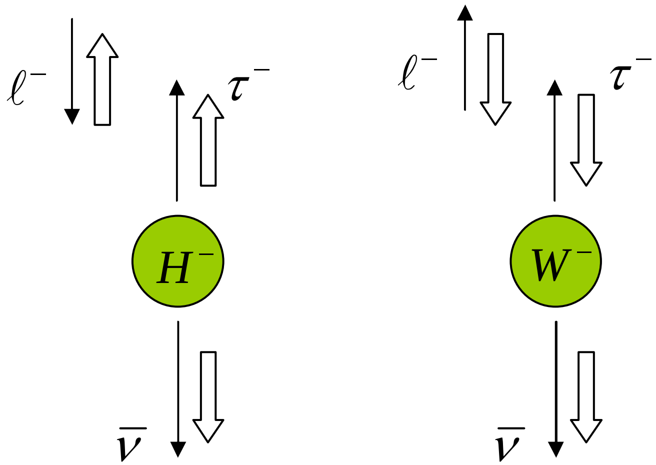
Lower p_T lepton (effect of opposite τ helicity)

Missing energy from 3 neutrinos

τ polarization effect

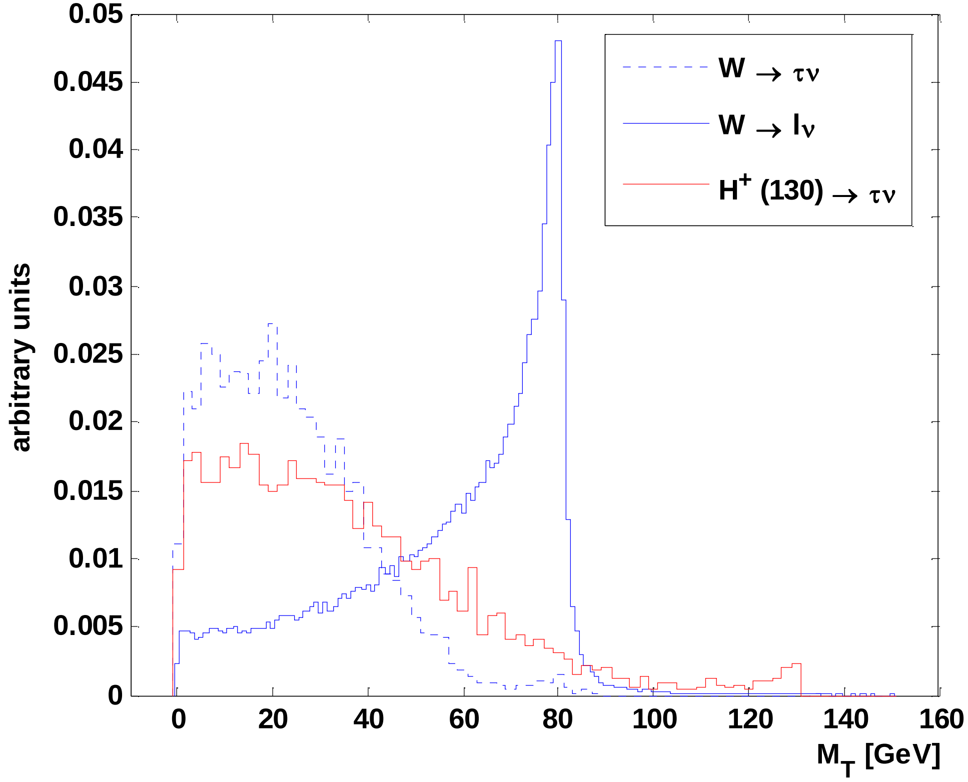
- τ's from H^+ decay are almost purely right-handed, leading to a decrease in daughter lepton energy





Lepton energy fraction E_{lep}/E_{tau}

Signature of a leptonic τ : the W transverse mass



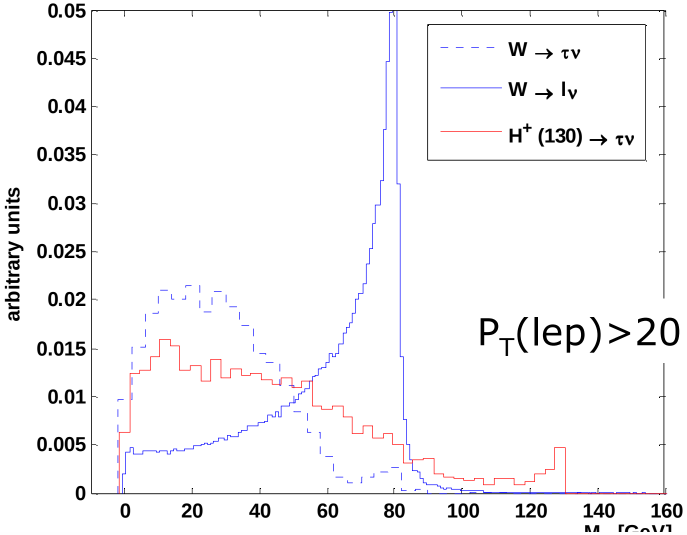
$$m_T = \left| p_T^{\ell} \right| \left| p_T^{miss} \right| (1 - \cos \phi_{\ell, miss})$$

Events with direct leptons

Contribute mainly to the Jacobian peak region of the transverse mass distribution

An excess of tau-events could be observed, but with little discrimination between H^+ and W→ $\tau\nu$

Signature of a leptonic τ : the W transverse mass

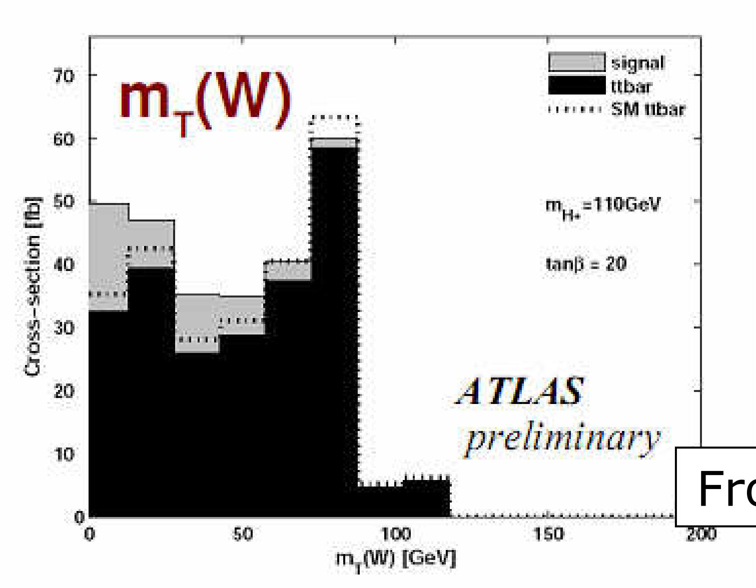


P_T(lep)>20 GeV

$$m_T = \left| p_T^{\ell} \right| \left| p_T^{miss} \right| (1 - \cos \phi_{\ell,miss})$$

Events with direct leptons

Contribute mainly to the Jacobian peak region of the transverse mass distribution



An excess of tau-events could be observed, but with little discrimination between H^+ and W→ $\tau\nu$

From Martin’s talk

Transverse mass as an extremal point

- The W transverse mass could be defined as:

$$m_T^2 = \min_{\substack{p_z^{miss}, E^{miss} \\ (p^{miss})^2 = 0}} [(p^{lep} + p^{miss})^2]$$

$$\left(\begin{array}{l} p^{miss} = \text{missing 4-momentum} \\ = (E^{miss}, p_z^{miss}, \vec{p}_T^{miss}) \end{array} \right)$$

- Similarly, we define a 'charged Higgs transverse mass' as :

$$(m_T^{H+})^2 = \max_{\substack{p_z^{miss}, E^{miss} \\ (p^{miss} + p^b + p^{lep})^2 = m_{top}^2}} [(p^{lep} + p^{miss})^2]$$

Requires pairing the correct b-jet to the lepton

Transverse mass as an extremal point

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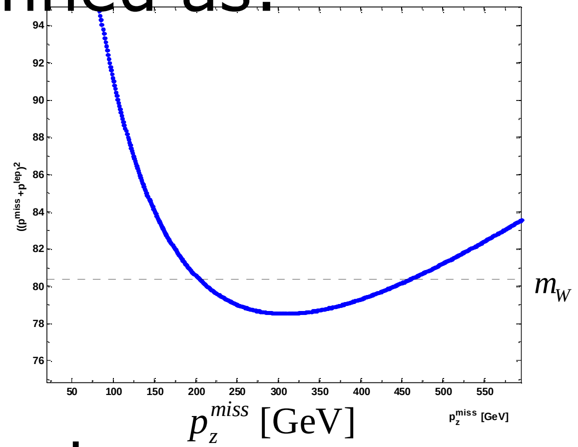
$$m_T^2 = \min_{\left\{ \substack{p_z^{miss}, E^{miss} \\ (p^{miss})^2 = 0} \right\}} [(p^{lep} + p^{miss})^2]$$

$$\Rightarrow m_T \le m_W$$



- Similarly, we define a 'charged Higgs transverse mass' as :

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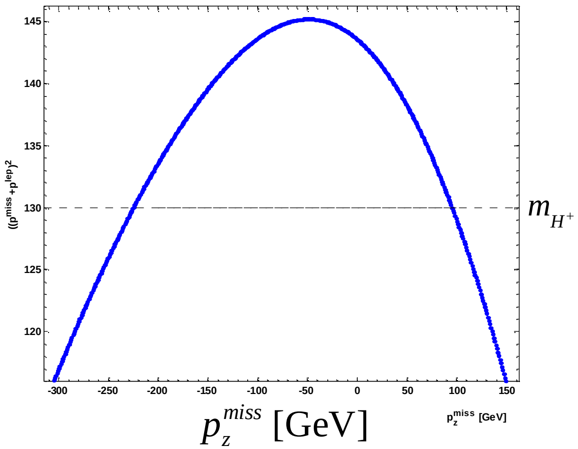
$$\Rightarrow m_{top} \ge m_T^{H+} \ge m_{H+}$$



Derivation of m_T^{H+}

$$m_{H+}^2 = (p_{\|}{}^{\ell} + p_{\|}{}^{miss})^2 - (\vec{p}_T{}^{\ell} + \vec{p}_T{}^{miss})^2$$

$$m_{top}^2 = (p_{\|}{}^{\ell} + p_{\|}{}^{miss} + p_{\|}{}^{b})^2 - (\vec{p}_T{}^{\ell} + \vec{p}_T{}^{miss} + \vec{p}_T{}^{b})^2$$

Event kinematics

$$p_{\|} = (E, p_z)$$

$$p_{\|}{}^2 = E^2 - p_z^2$$

$$\frac{\partial}{\partial p_{\|}{}^{miss}}((p_{\|}{}^{\ell} + p_{\|}{}^{miss})^2 - \lambda(p_{\|}{}^{\ell} + p_{\|}{}^{miss} + p_{\|}{}^{b})^2) = 0$$

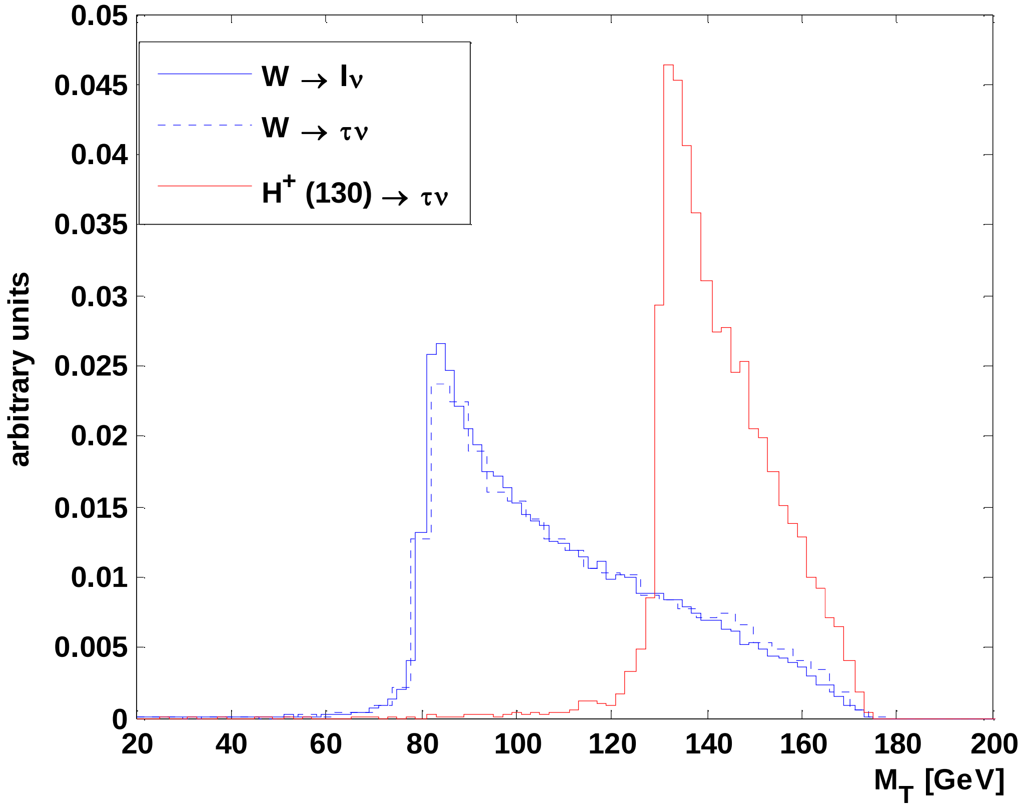
Maximize w.r.t $p_{\|}{}^{miss}$

$$\longrightarrow \quad p_{\|}{}^{miss} = \frac{\lambda}{1-\lambda} p_{\|}{}^{b} - p_{\|}{}^{\ell} \qquad 1 - \lambda = \frac{p_T^b}{\sqrt{m_{top}^2 + (\vec{p}_T{}^{\ell} + \vec{p}_T{}^{miss} + \vec{p}_T{}^{b})^2}}$$

$$(m_{H+}^T)^2 = \left(\sqrt{m_{top}^2 + (\vec{p}_T^{\ell} + \vec{p}_T^{b} + \vec{p}_T^{miss})^2} - p_T^b\right)^2 - \left(\vec{p}_T^{miss} + \vec{p}_T^{\ell}\right)^2$$

Jacobian peak: $\frac{d\sigma}{dm_{H+}^T} = \frac{d\sigma}{dE_{miss}}\left(\frac{dm_{H+}^T}{dE_{miss}}\right)^{-1}$ $\qquad \frac{dm_{H+}^T}{dE_{miss}}\Big|_{m_{H+}^T = m_{H+}} = 0.$

Charged Higgs transverse mass



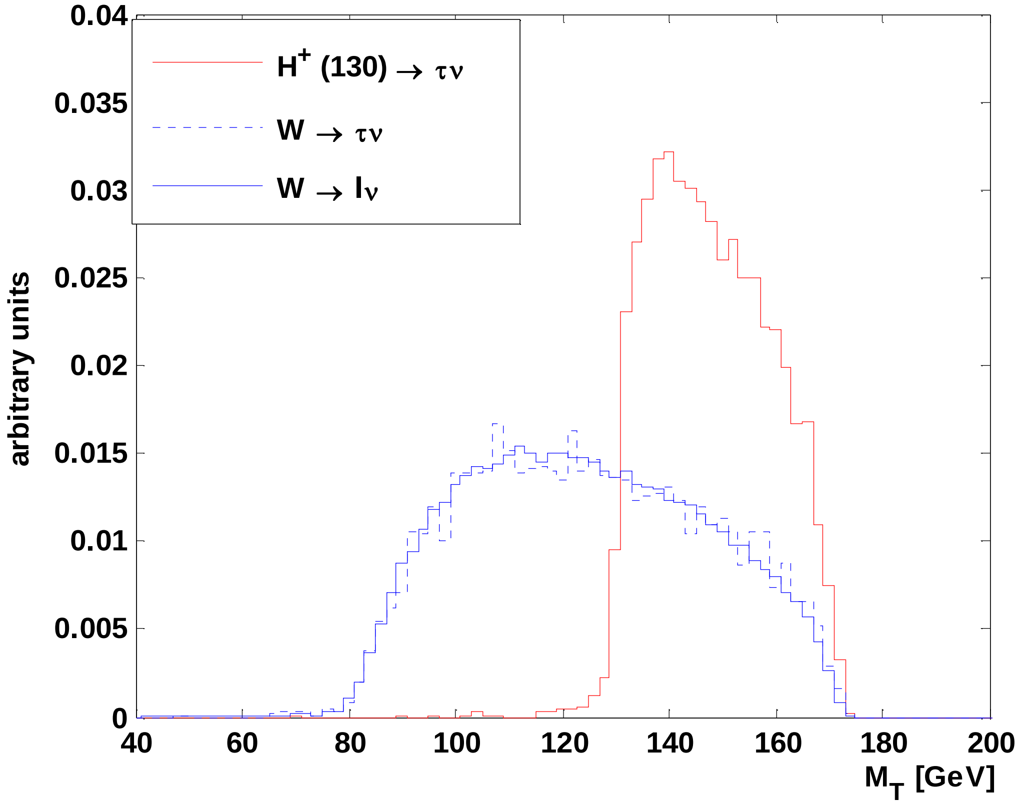
Not including gluon radiation from top quark decay

The distribution is not sensitive to the decay mode of the W, since

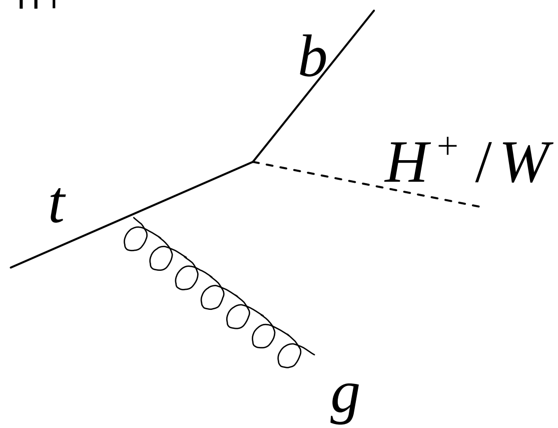
It depends only on

$$\vec{p}_T^{\,miss} + \vec{p}_T^{\,\ell}$$

Charged Higgs transverse mass



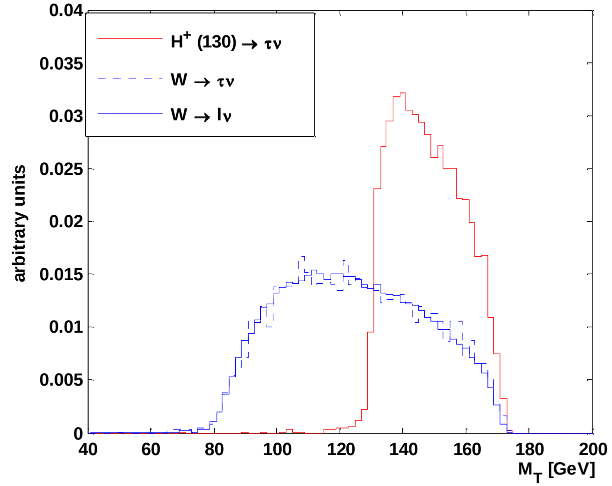
Gluon radiation from top decay smears the Jacobian peak, but there is still an edge at m_{H+} .



$$\sqrt{(p^{\ell} + p^{b} + p^{miss})^2} = m^*_{top} < m_{top}$$

$$m_T^{H+}(m_{top}) > m_T^{H+}(m^*_{top}) \geq m_{H+}$$

Charged Higgs transverse mass



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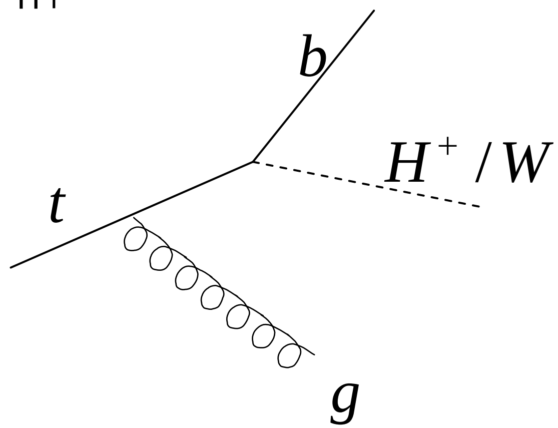
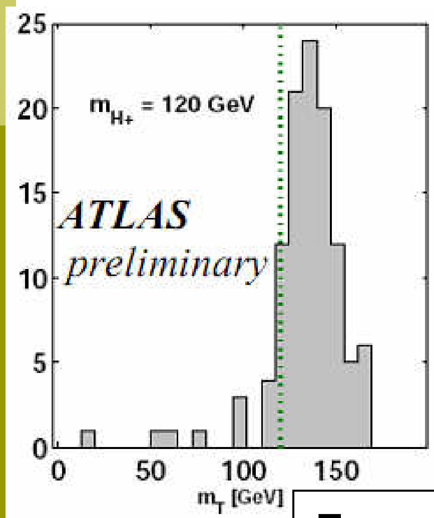
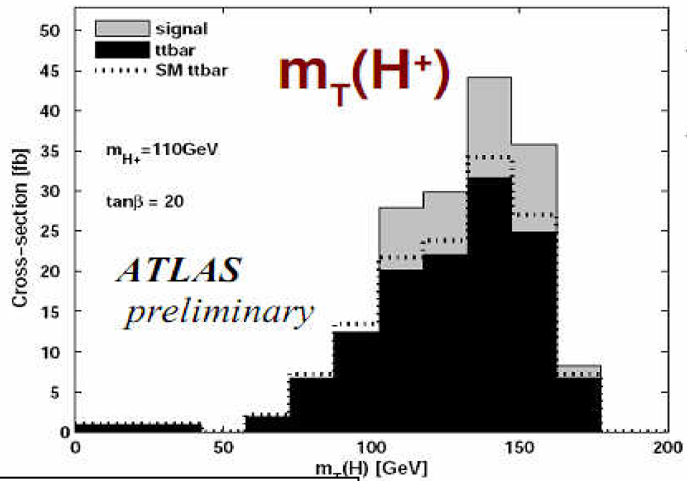






From Martin's talk

$$\sqrt{(p^{\ell} + p^{b} + p^{miss})^2} = m^*_{top} < m_{top}$$

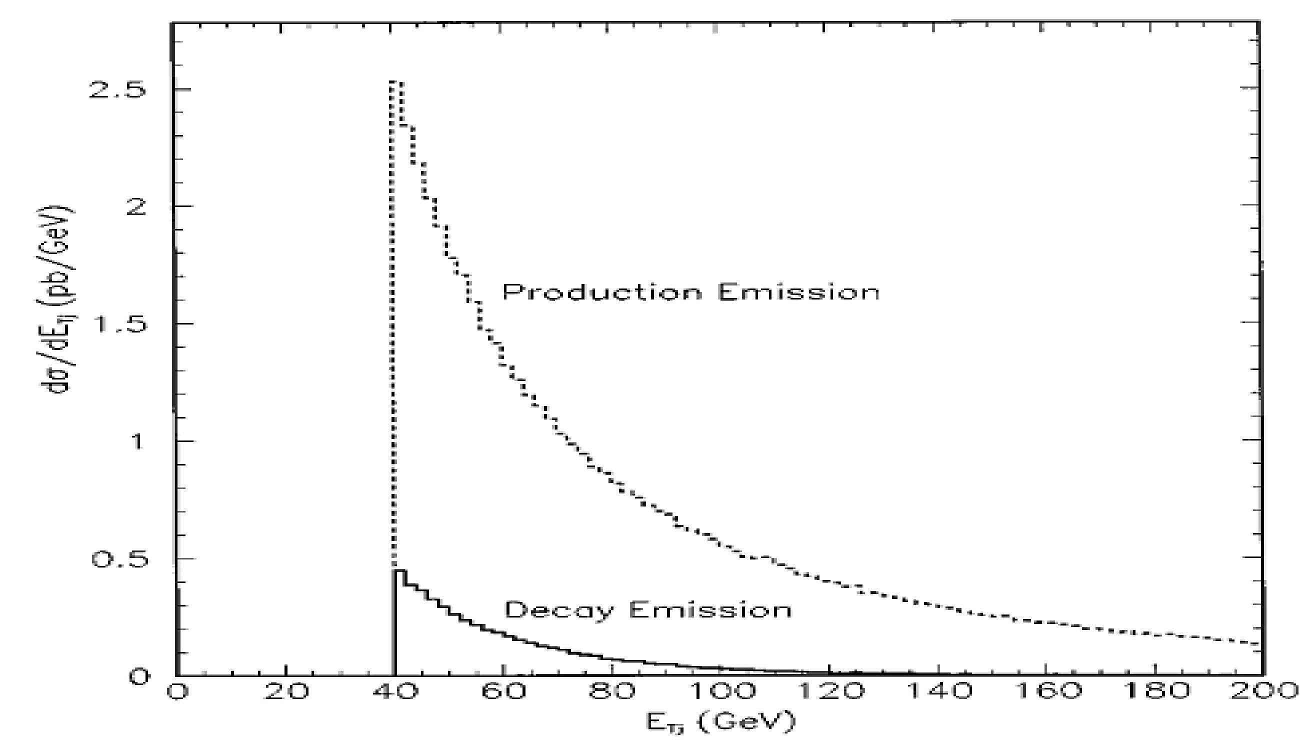
$$m_T^{H+}(m_{top}) > m_T^{H+}(m^*_{top}) \geq m_{H+}$$

Conclusions

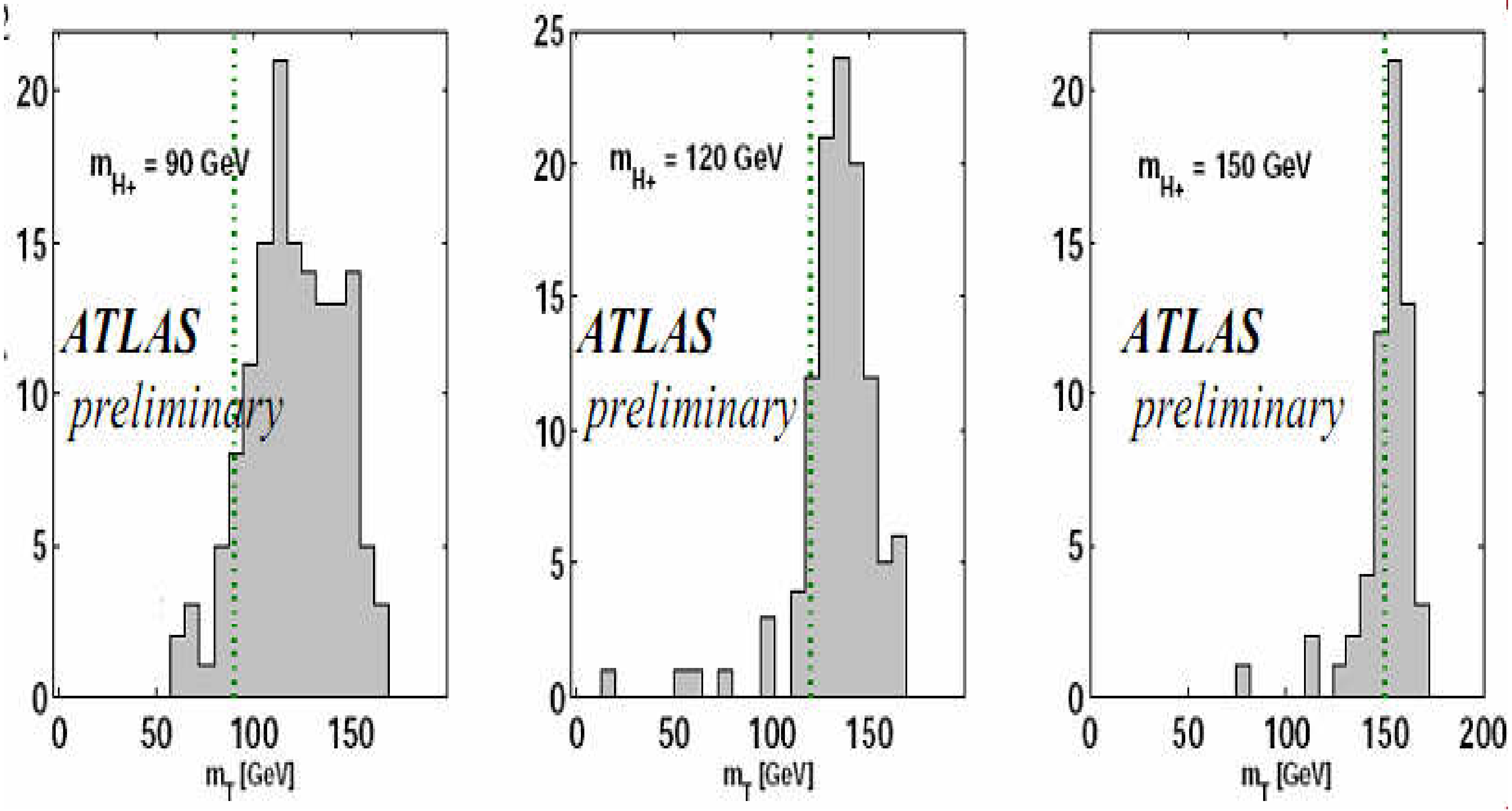
- The leptonic τ decay channel can be used to increase the sensitivity to a light charge Higgs.
- We introduced a new transverse mass for this channel, which has a lower edge at the true charged Higgs mass.
- This transverse mass provides discrimination between a charged Higgs and W decay, which is the major background source.

Backup Slides

Gluon radiation in top quark decay



[L.H.Orr,T.Stelzer,W.J.Striling, *Phys. Rev. D* ***56*** *1* (1997)]



m_H+ = 90 GeV
ATLAS
preliminary
m_T [GeV]
m_H+ = 120 GeV
ATLAS
preliminary
m_T [GeV]
m_H+ = 150 GeV
ATLAS
preliminary
m_T [GeV]