



Beyond Standard Model Charged Higgs boson and tau leptons at the Tevatron

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10 -25 years of DØ-France –October 14th, 2008

- Search for singly charged Higgs boson (H^\pm)
in the single top mode and in the top pair production
- Search for doubly charged Higgs boson ($H^{\pm\pm}$)
- Tau identification in DØ
- Prospects

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Charged Higgs

Extensions of Standard Model Higgs sector leads to many physical Higgs bosons

Singly charged Higgs (H^\pm):

- Arise in models with two Higgs doublets (2HDM) such as SUSY and GUT
- Different 2HDM depending on strategy used to avoid FCNC (Type-I, Type-II, Type-III)
- Models typically depend on M_{H^\pm} and $\tan\beta = v_1/v_2$

direct production: $p \bar{p} \rightarrow H^\pm \rightarrow t \bar{b} \rightarrow W^\pm b \bar{b} \rightarrow l^\pm \nu b \bar{b}$

top quark decays: $p \bar{p} \rightarrow t \bar{t} \rightarrow (H^\pm b)(W^\mp b) \rightarrow ((c \bar{s}/\bar{\tau} \nu) b)(l \bar{\nu} \bar{b})$

Doubly charged Higgs ($H^{\pm\pm}$):

- For example, arise in Left/Right symmetric models, Higgs triplet, Little Higgs.
- Model depends on $M_{H^{\pm\pm}}$ and left/right Higgs couplings

direct production: $p \bar{p} \rightarrow H^{++} H^{-} X \rightarrow \mu^+ \mu^+ \mu^- \mu^- X$

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Search for high mass charged Higgs bosons

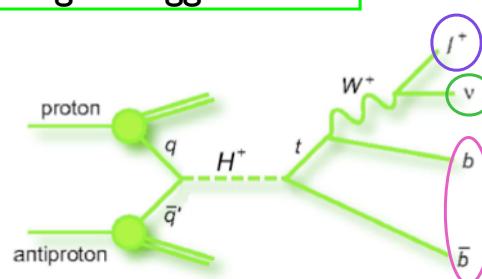
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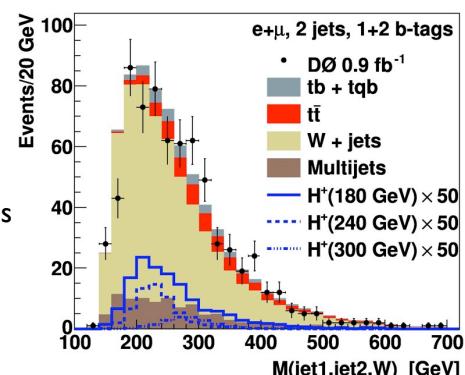
Direct Production of charged Higgs boson

$L=0.9 \text{ fb}^{-1}$



- Assume $M_{H^+} > M_{\text{top}}$
 $180 < M_{H^+} < 300 \text{ GeV}$
- In most models, the decay $H^\pm \rightarrow tb$ dominates for large regions of parameters space
- Use the same event selection as for SM single top quark search
 - W boson decaying to leptons
 - exactly one isolated lepton
 electron $E_T > 15 \text{ GeV}$ $|\eta| < 1.1$
 muon $E_T > 18 \text{ GeV}$ $|\eta| < 2.0$
 - $15 \text{ GeV} < \text{MET} < 200 \text{ GeV}$
 - but 2 jets only, at least 1 identified as b-jet.
- Discriminating variable: reconstructed invariant mass

See F. Déliot's talk
E. Busato, M. AGelou, B. Clément

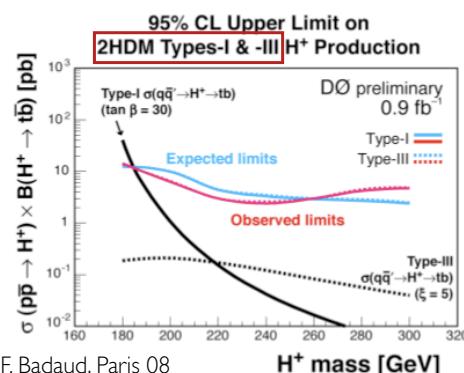
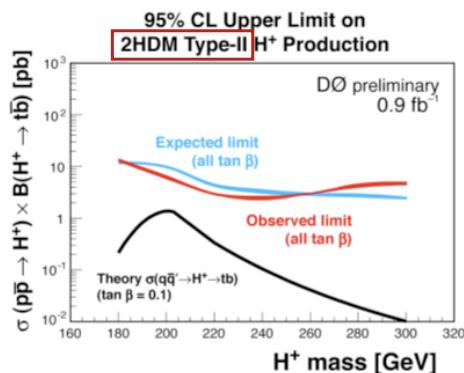


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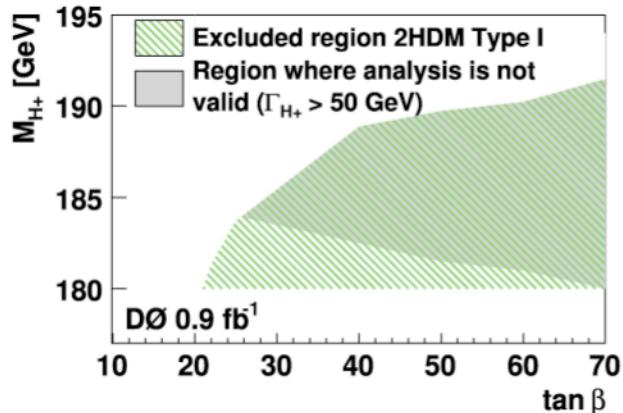


Direct Production of charged Higgs boson : limits



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- binned likelihood method
- set limits at 95 % C.L. on $\sigma(p\bar{p} \rightarrow H^+) \times \text{Br}(H^+ \rightarrow t\bar{b})$
 - ♦ limits for type II and III above expected cross sections
 - ♦ only type I model has an exclusion region



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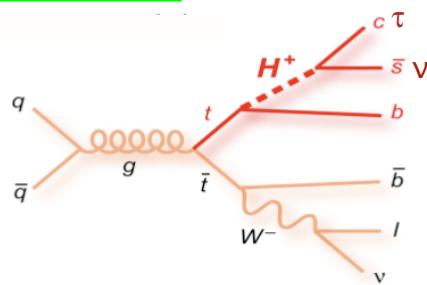
Search for low mass charged Higgs bosons

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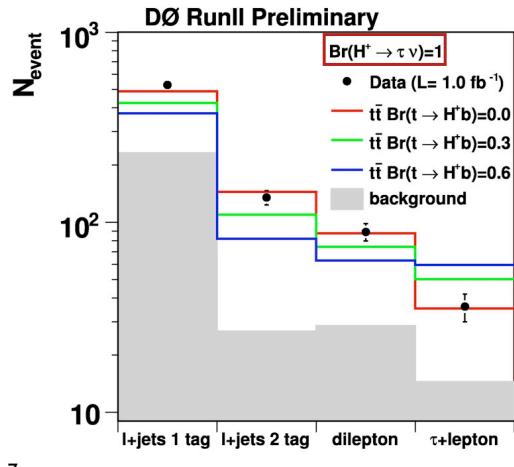
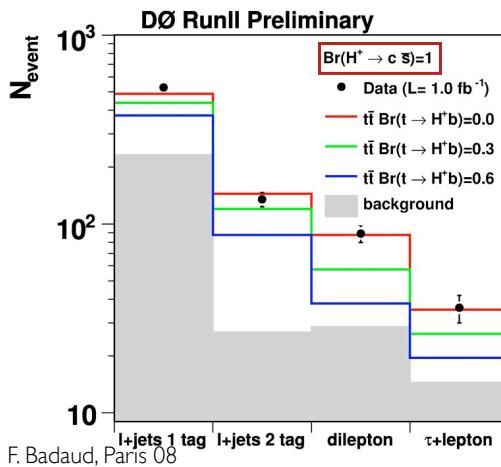


Charged Higgs in top decays : $t \rightarrow H^\pm b$

$L=1.0 \text{ fb}^{-1}$



- Decays $t \rightarrow W^\pm b$ and $t \rightarrow H^\pm b$ can compete. deviations from the SM $\sigma_{tt} \times \text{BR}$ for individual decays channels of tt events.
- Consider H^\pm decays :
 - purely tauonic decay : $H^\pm \rightarrow \tau \bar{\nu}$
 - leptophobic decay : $H^\pm \rightarrow c \bar{s}$



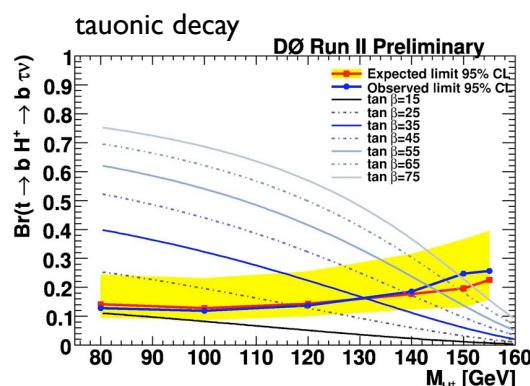
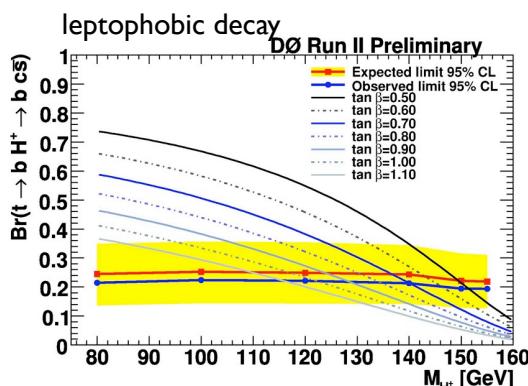
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Charged Higgs in top decays : $\text{BR}(t \rightarrow H^\pm b)$

$M_{H^+} < M_{\text{top}}$

- Combination $t\bar{t}$ cross-section analyses in different final states : di-leptons, $I+jets$, $\tau+lepton$
See F. Déliot's talk : [B. Martin, F. Beaudette, S. Greder, J.R. Vlimant, F. Chevalier, F. Lacroix](#)
- Use Feldman and Cousins likelihood ordering principle
- Simultaneous fit to cross section σ_{tt} and $\text{BR}(t \rightarrow H^\pm b)$



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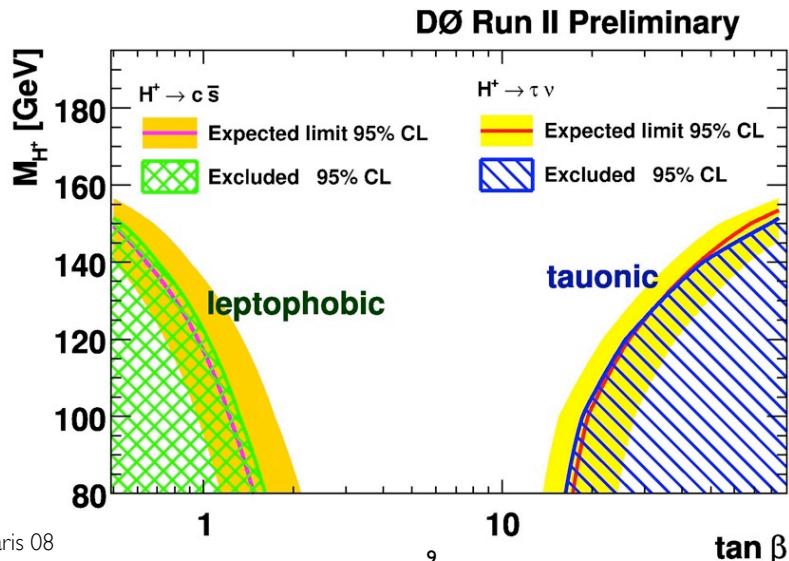
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Charged Higgs in top decays : exclusion

$M_{H^+} < M_{top}$

- Set exclusion limits, results interpreted in terms of MSSM assuming leptophobic/tauonic decay dominates in small/large $\tan\beta$ regions.



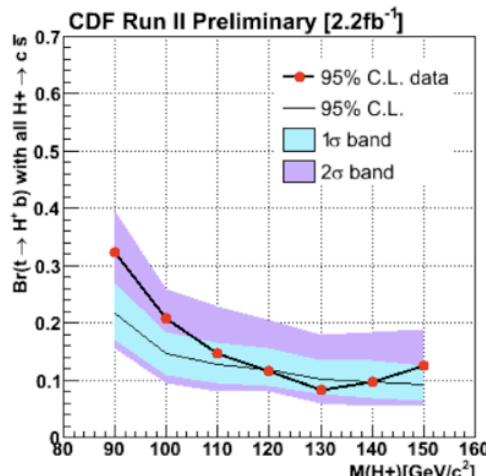
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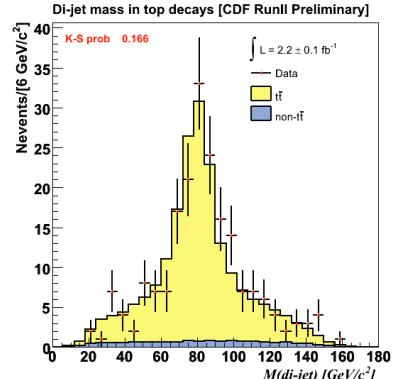
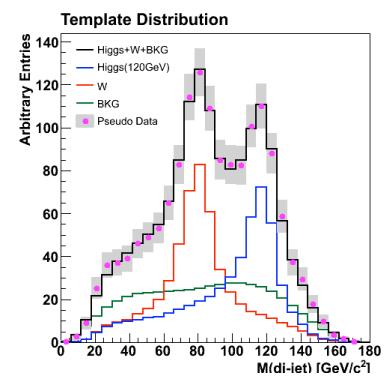
Charged Higgs in top decays : $t \rightarrow H^\pm b$

$L=2.2 \text{ fb}^{-1}$

- Search for $H^+ \rightarrow cs$ (Assume 100% Br) [dominant decay for small $\tan\beta$ region in MSSM]
- Perform template fit of reconstructed di-jet invariant mass in 1+jets events using binned maximum likelihood



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Search for doubly charged Higgs

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II

Search for doubly charged Higgs boson



$L=0.35 \text{ fb}^{-1}$

$q\bar{q} \rightarrow Z/\gamma^* \rightarrow H^{++} H^{--} \rightarrow l^+ \tau^+ l^- \tau^-$

Search for lepton flavor violating decay modes

$p\bar{p} \rightarrow H^{++} H^{--} \rightarrow l^+ \tau^+ l^- \tau^-$

- 3 or 4 leptons events
- remove $Z \rightarrow ll$ background
- further reduce background using HT cut

signal efficiency
~ 8% at $M_{H^{++}} = 85 \text{ GeV}$
~ 14% for $M_{H^{++}} = 135 \text{ GeV}$

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$L=1.1 \text{ fb}^{-1}$

$q\bar{q} \rightarrow Z/\gamma^* \rightarrow H^{++} H^{--} \rightarrow \mu^+ \mu^- \mu^+ \mu^-$

Search for muon final states

$p\bar{p} \rightarrow H^{++} H^{--} X \rightarrow \mu^+ \mu^+ \mu^- \mu^- X$

- 2 like-sign muons
- third muon
- $\Delta\phi$ requirement to reduce $Z \rightarrow \mu\mu$ bkg

Total signal efficiency nearly independent of mass ~ 32-34%

Search for doubly charged Higgs : limits

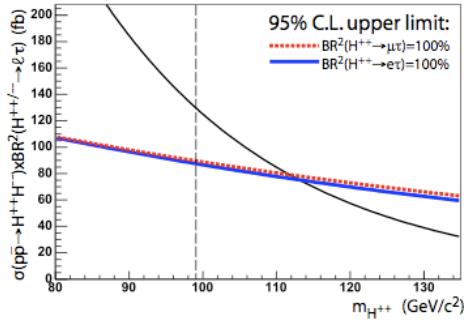


- Use Bayesian method
- Assume exclusive e+tau or mu+tau decays

$$M(H_L^{++}) > 113.6 \text{ GeV}/c^2 (e+\tau)$$

$$M(H_L^{++}) > 112.1 \text{ GeV}/c^2 (\mu+\tau)$$

CDF Run II Preliminary ($\mathcal{L}=350 \text{ pb}^{-1}$)



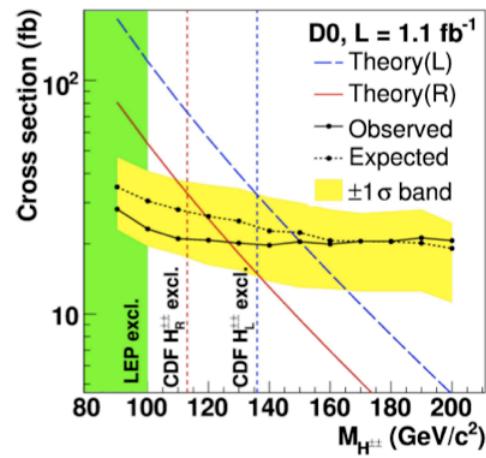
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Assume 100% BR to muons
when setting limits



$$M(H_L^{++}) > 150 \text{ GeV}/c^2$$

$$M(H_R^{++}) > 127 \text{ GeV}/c^2$$



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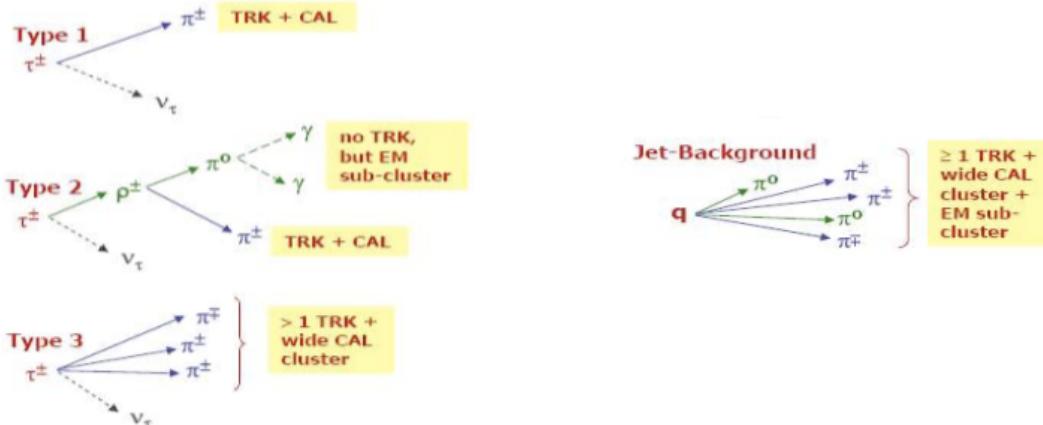
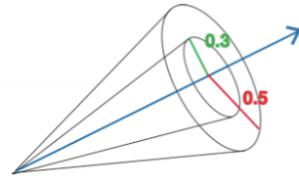
Tau identification



Hadronic tau candidate

Anne-Catherine le Bihan

- **CALorimeter cluster** : found using Simple Cone Algorithm in $\Delta R < 0.5$ cone
a core cone of size $R=0.3$ is used for the calculation of isolation variables.
- **EM sub-cluster** : seeded in EM3 calorimeter layer (double granularity) and reconstructed using Nearest Neighbour Algorithm.
EM3 transverse energy deposit of a subcluster > 800 MeV
- **TRK** : at least 1 associated track found within $\Delta R < 0.5$ cone
invariant mass cut, highest track $p_T > 1.5$ GeV



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Neural Networks for tau id

- 3 separate anti-jets NNs, one for each type
- discriminating input variables based on shower shape, isolation, core, energy fractions, sub-clusters in the EM layers of the calorimeter, additionnal tracks found in an 0.5 cone not attached to the τ
 → exploit the fact that τ are narrow, isolated jets with lower multiplicity than QCD jets.
- most of input variables are ratios of energy to minimize the dependence in E_T
- training samples :
 - signal : single taus from MC
 - background: QCD jets in events with a non-isolated μ (data)
- Electrons make nice type 2 τ 's.
 → another Neural Network trained on data electrons as a background.



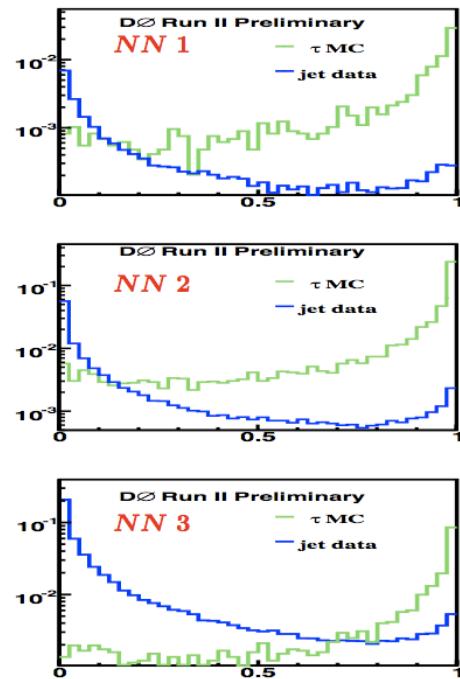
Jet-tau discrimination

Efficiencies (%)

$20 < E_T^\tau < 40 \text{ GeV}, |\eta^\tau| < 2.5$

τ -type	1	2	3	all
jets	2	12	38	52
τ	11	60	24	95
$NN > 0.9$				
jets	0.06	0.24	0.80	1.1
τ	7	44	16	67

Note: $NN \rightarrow 1$ for signal
 $NN \rightarrow 0$ for bkg



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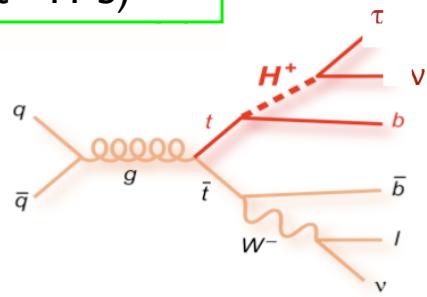
Prospects

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Charged Higgs boson : $B(t \rightarrow H^\pm b)$

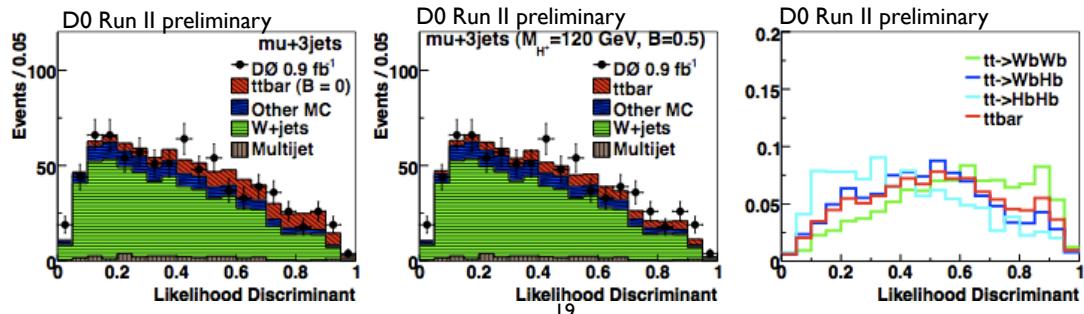
$L=0.9 \text{ fb}^{-1}$



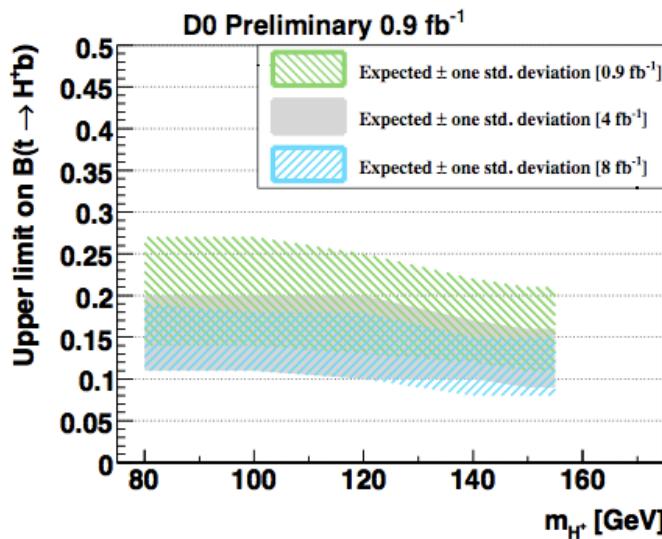
- aim : measure $B(t \rightarrow W^\pm b)$ under the constraint $B(t \rightarrow W^\pm b) + B(t \rightarrow H^\pm b) = 1$
- assuming $BR(H^\pm \rightarrow \tau\nu) \approx 1$
- Use the same event selection 1+jets as for SM $t\bar{t}$

- exactly one isolated lepton : electron $E_T > 20 \text{ GeV}$ $|\eta| < 1.1$, $\mu E_T > 20 \text{ GeV}$ $|\eta| < 2.0$
- 20 (25) $\text{GeV} < \text{MET}$
- 3 jets or ≥ 4 jets without τ id.

- Likelihood Discriminant to differentiate $t\bar{t}$ from non $t\bar{t}$ events



Charged Higgs boson : $B(t \rightarrow H^\pm b)$ prospectives



- The projected sensitivities at integrated luminosities of 4 and 8 fb^{-1} are also shown.
→ Adding a tau identification should help
- Dedicated analysis τ +leptons [J.Jammes](#)