MSSM Higgs bosons searches in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV

Fabrice Couderc
For the DØ & CDF collaborations

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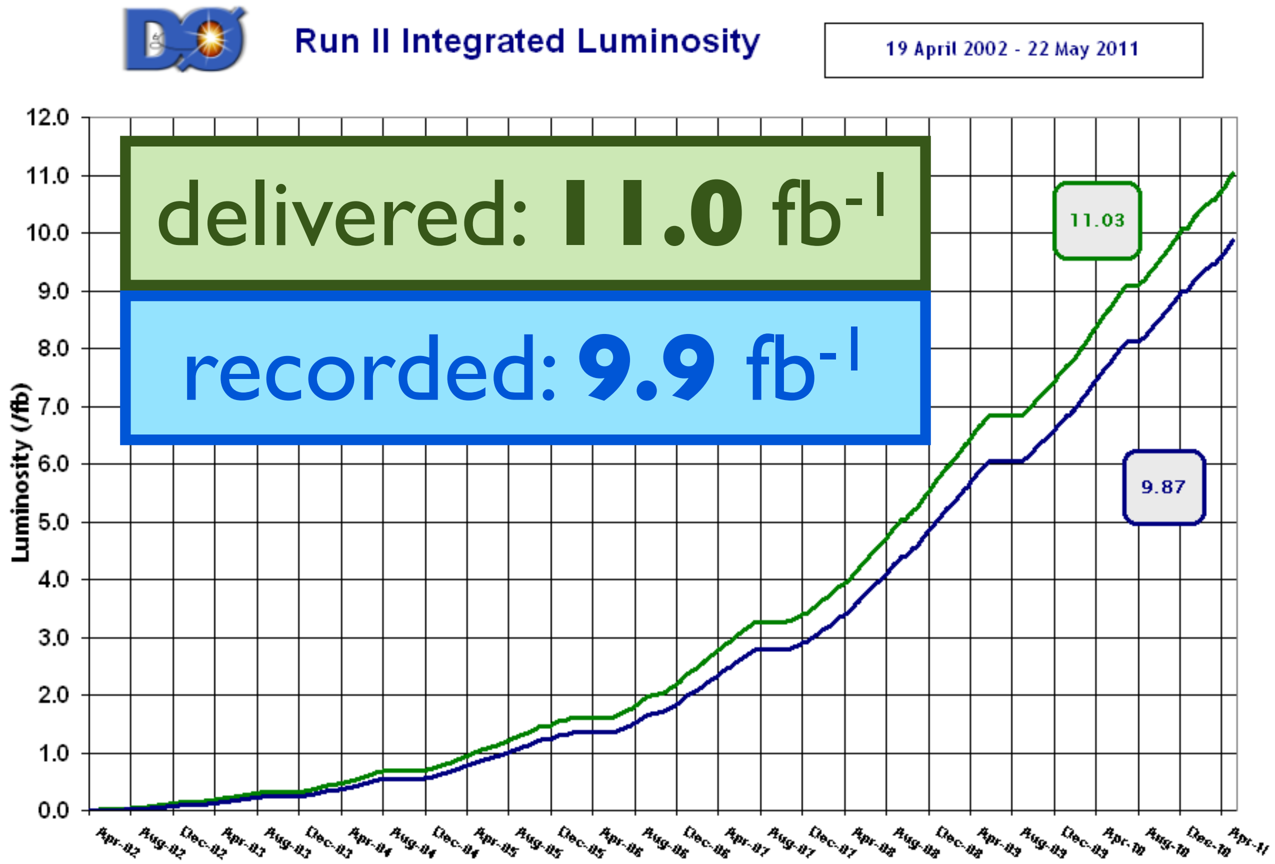
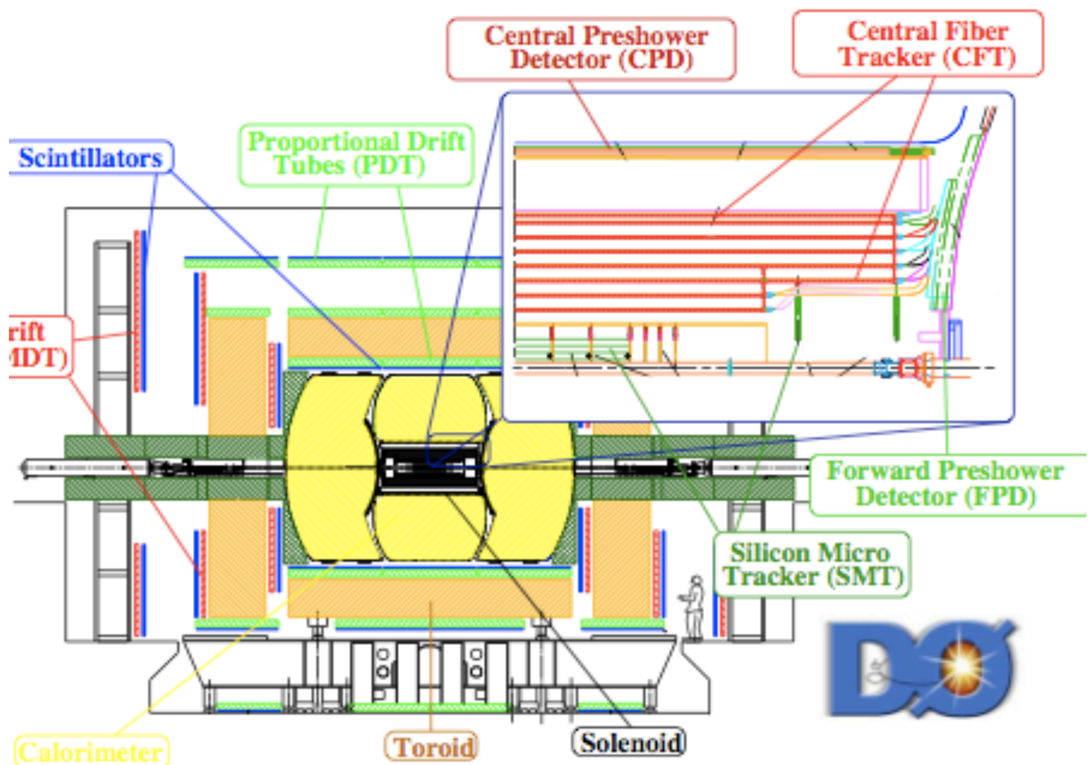
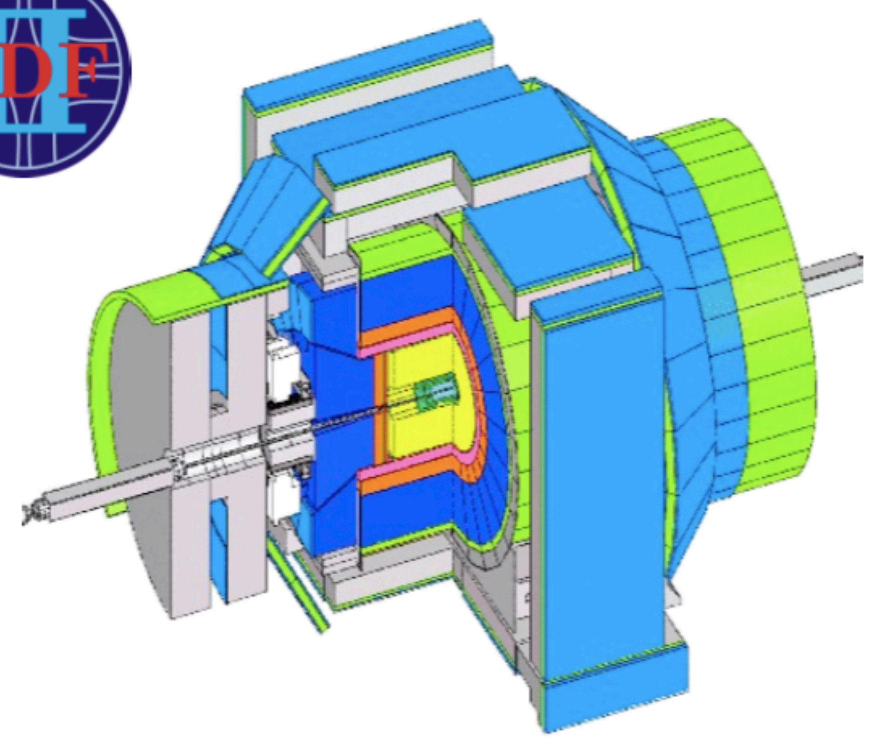
Les Rencontres de Blois
Blois, France

Outline

- ✓ Introduction
- ✓ MSSM Higgs searches
  - ✦ inclusive $h \to \tau\tau$ search
  - ✦ associated hb production
    - bbb final state
    - $\tau\tau$b final state
- ✓ Conclusions & Prospects







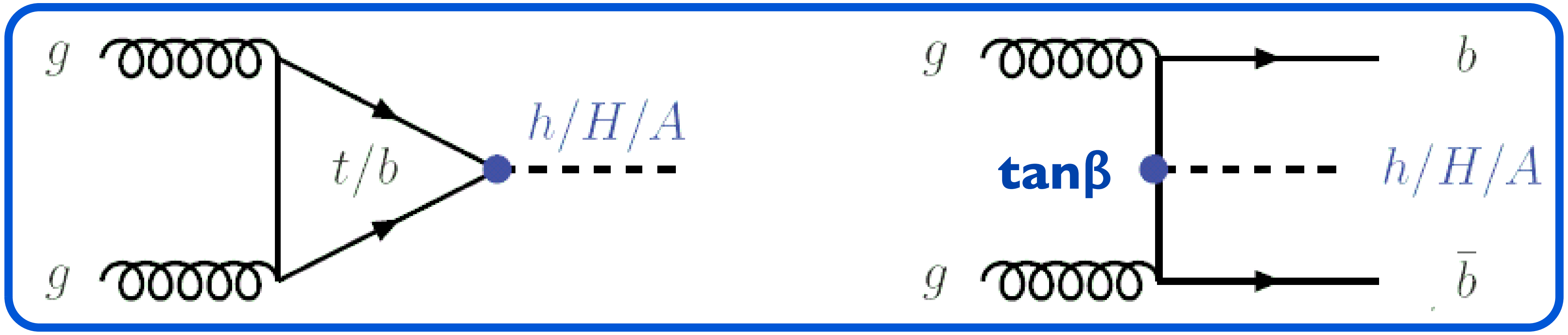
Higgs sector in the MSSM

- MSSM: exactly 2 Higgs doublets coupling to down-type quarks (vev v_d), and up-type quarks (vev v_u). $\tan\beta = v_u/v_d$

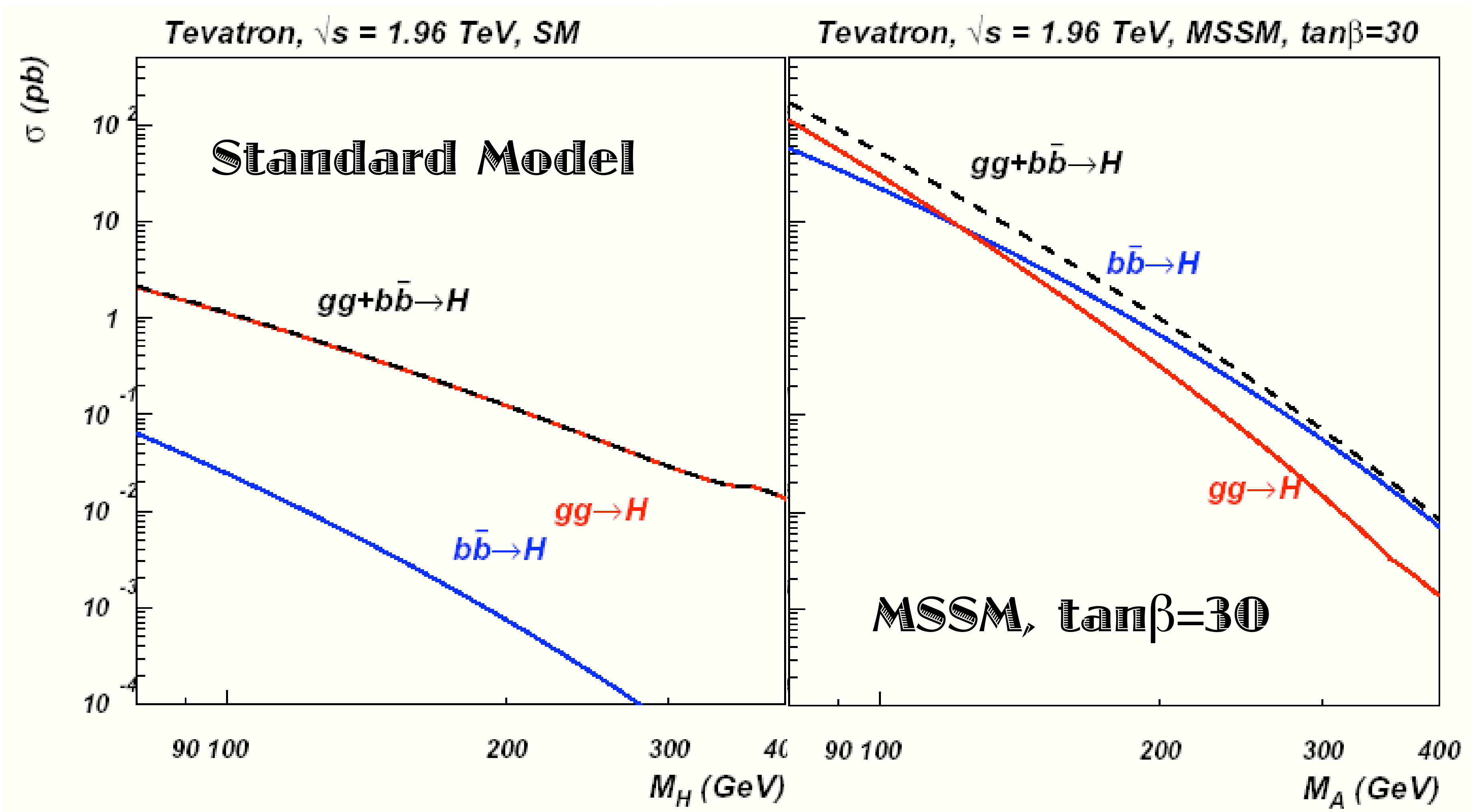
  NB: $\tan\beta \sim 35 = m_t/m_b$ is appealing (large $\tan\beta$)

- After EW breaking: 5 physical states
  - 3 neutral Higgs bosons: h/H (CP-even) and A (CP-odd)

    convention: $m_h < m_H$, h/H/A generically denoted Φ
  - 2 charged Higgs bosons: $H^{\pm}$
- At tree level: EW breaking controlled by M_A and $\tan\beta$. Radiative corrections make it more model dependent
- High $\tan\beta$ regime:
  - h/A or H/A are degenerate in mass $\sigma_{prod} \times 2!$
  - coupling to b quarks enhanced by $\tan\beta$
  - neutral Higgs: $\mathcal{B}(\phi \to b\bar{b}) \approx 90\ \%$ and $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10\ \%$



enhanced by $\tan^2\beta$ compared to SM



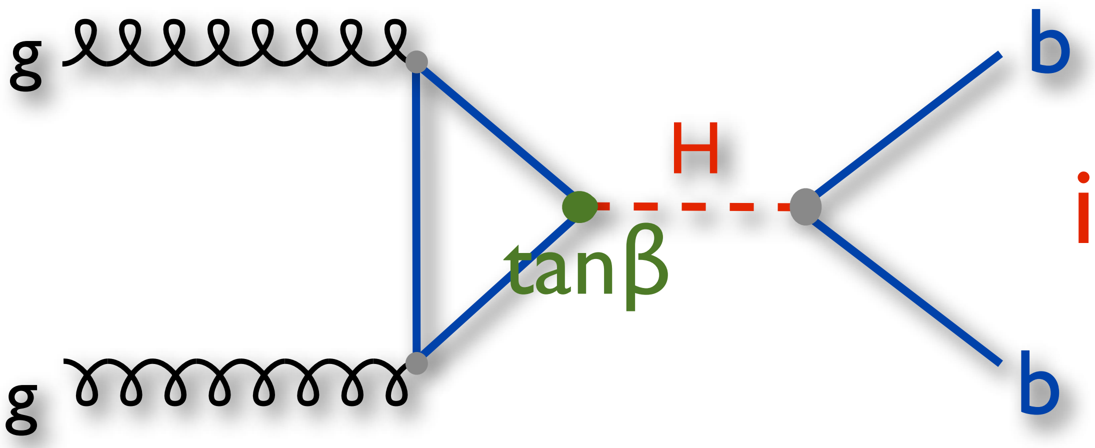
Enhancement at high tanβ: appreciable production rate at the Tevatron

@ LO $\sigma(bb \to \phi)_{\mathrm{MSSM}} = 2 \times \tan^2\beta \times \sigma(bb \to \phi)_{\mathrm{SM}}$

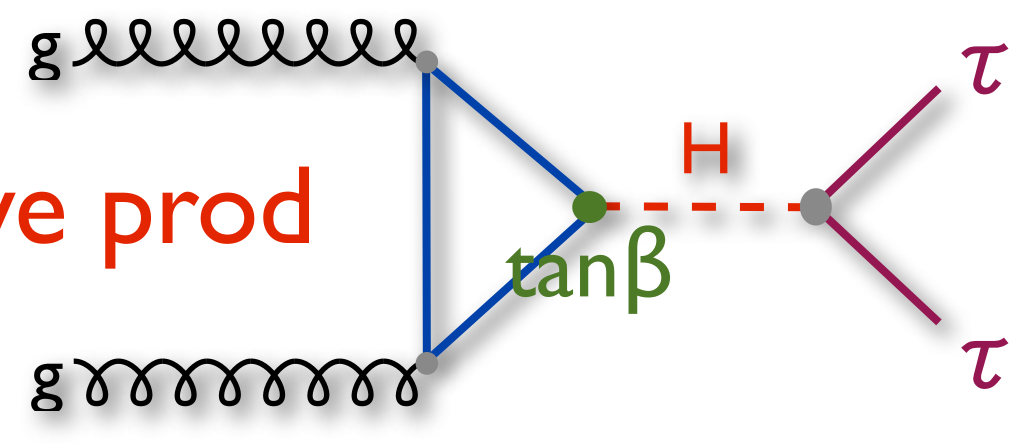
Golden modes

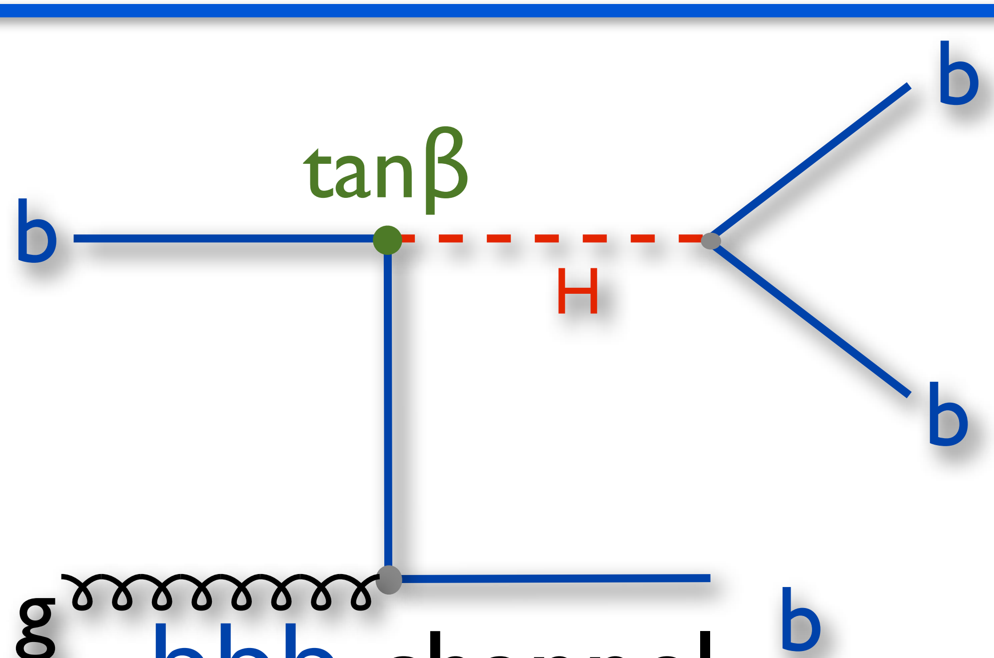
bb channel

$\tau\tau$ channel

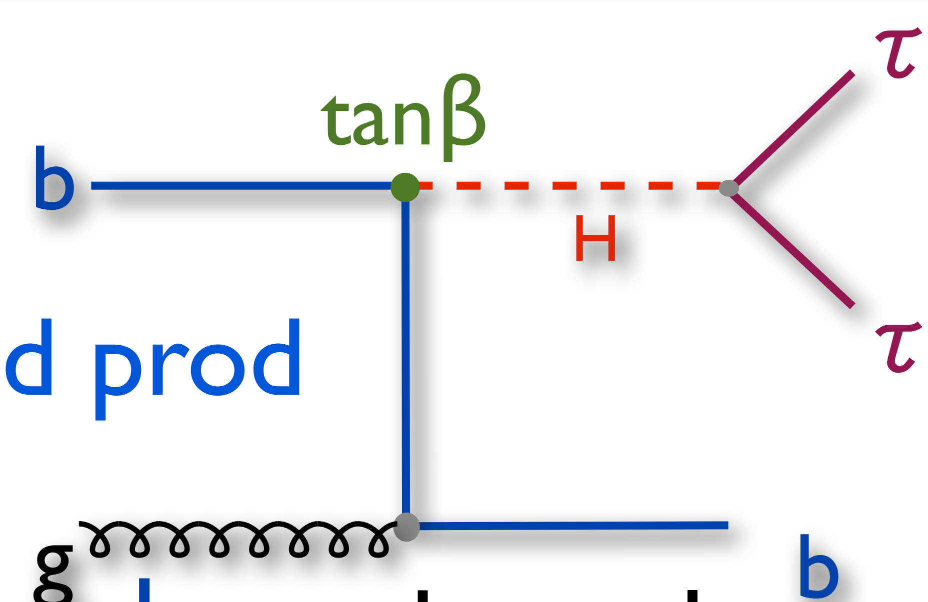


inclusive prod





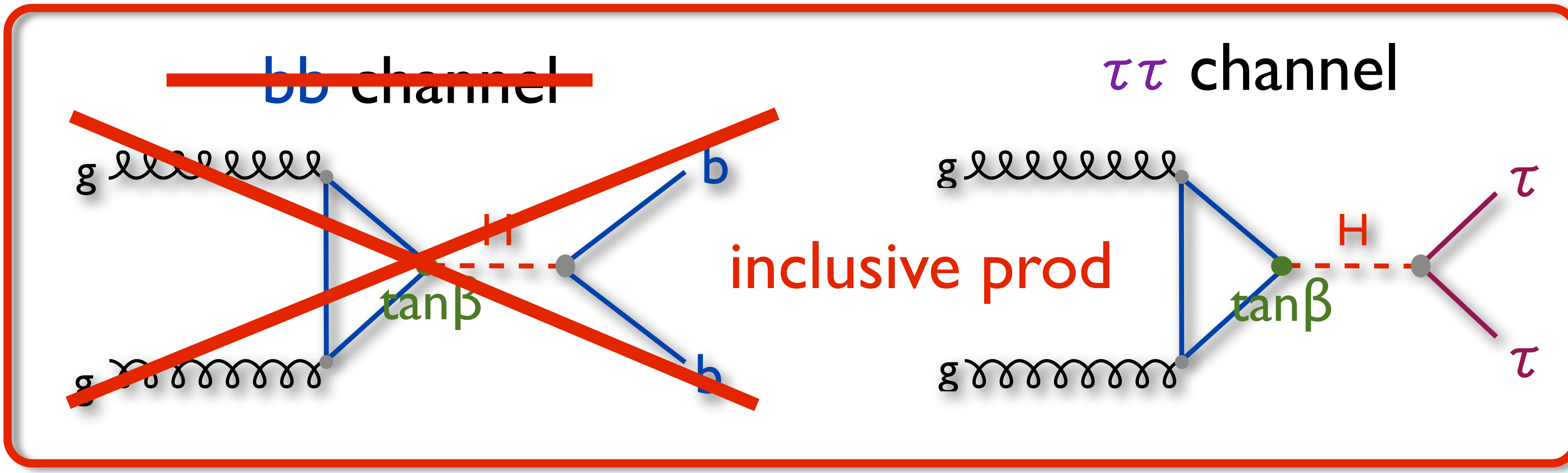
associated prod

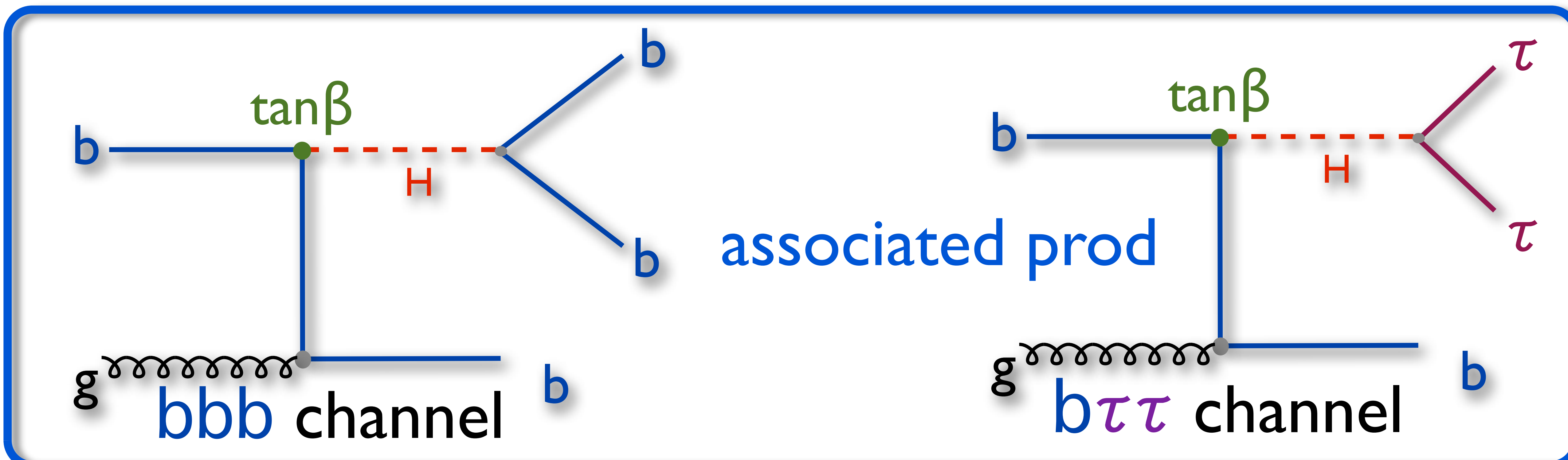


bbb channel

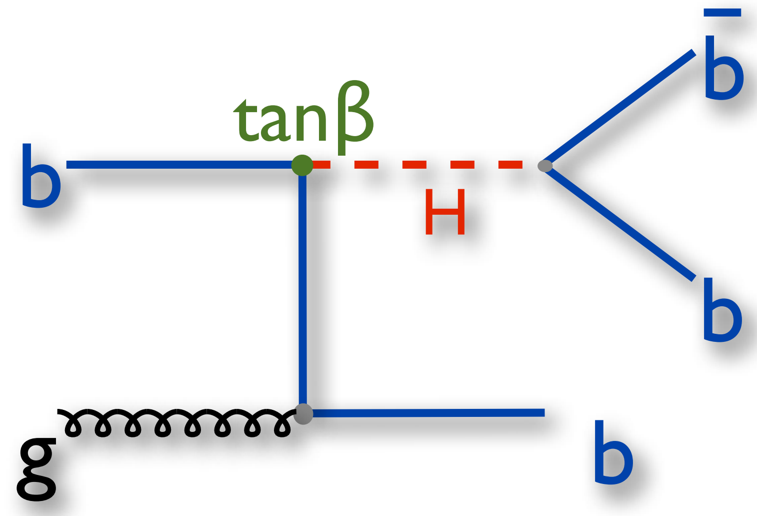
$b\tau\tau$ channel

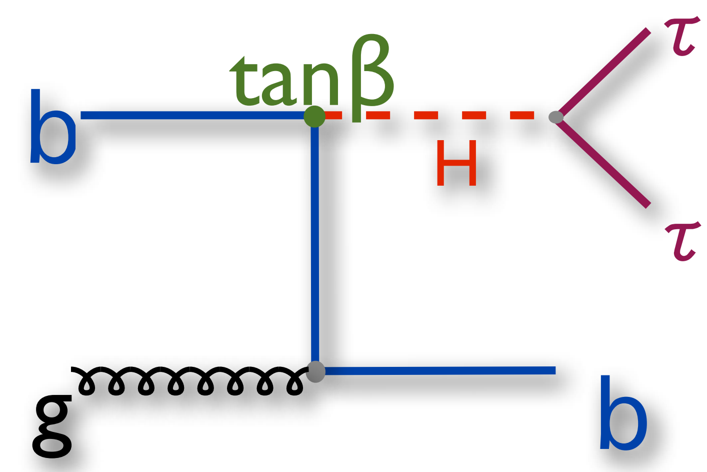
Golden modes

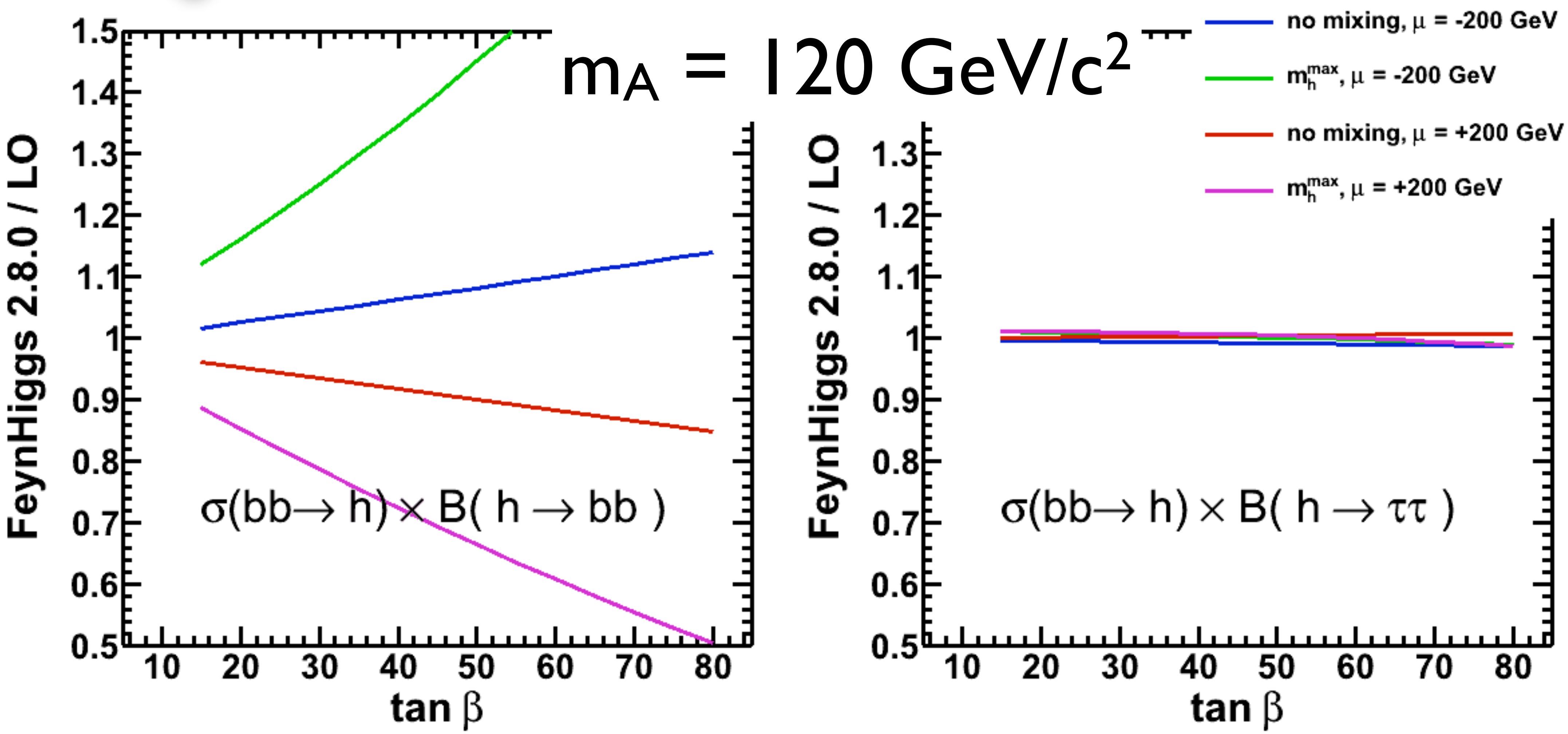




Golden modes





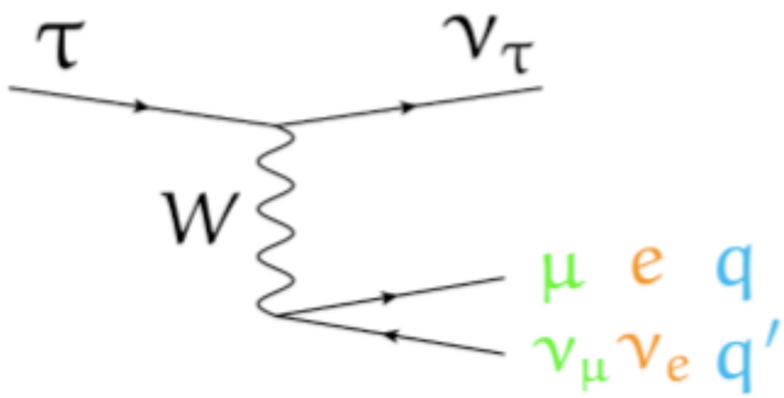


Beyond tree level, h→ττ modes are less sensitive to the MSSM parameters than h→bb

di-tau mode challenges

τ-lepton channels peculiarities:

- several channels to combine
- relatively "soft" decay products
  (multijet background, triggering...)



Need to reconstruct τ hadronic decay (τ_h)

di-tau mode challenges

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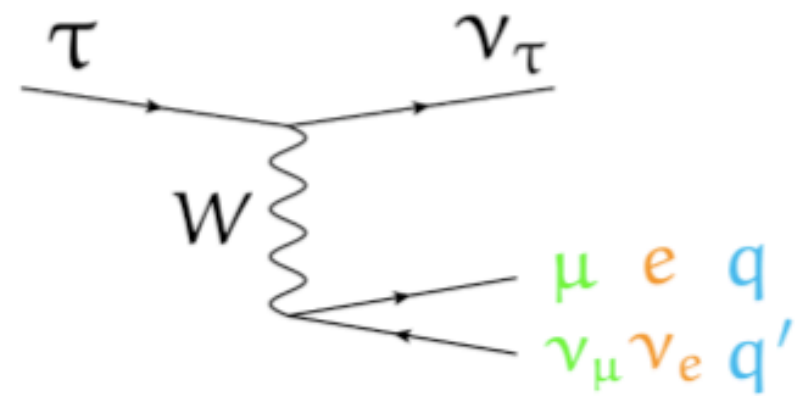

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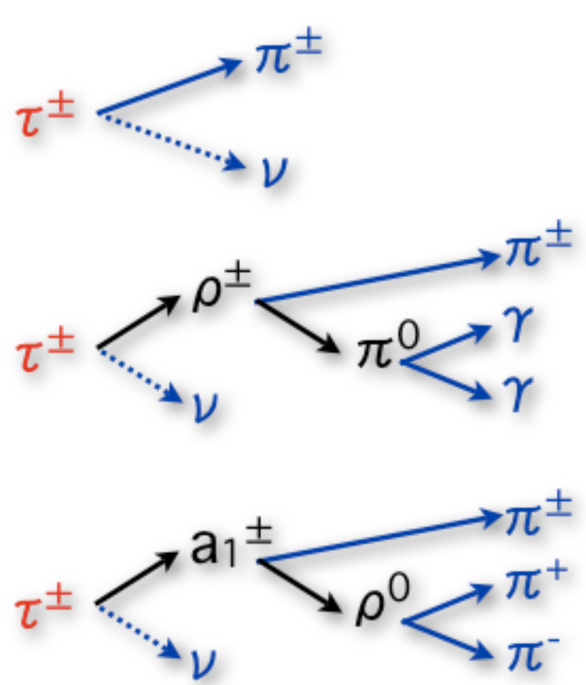
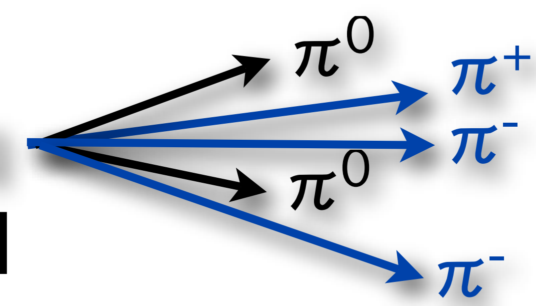


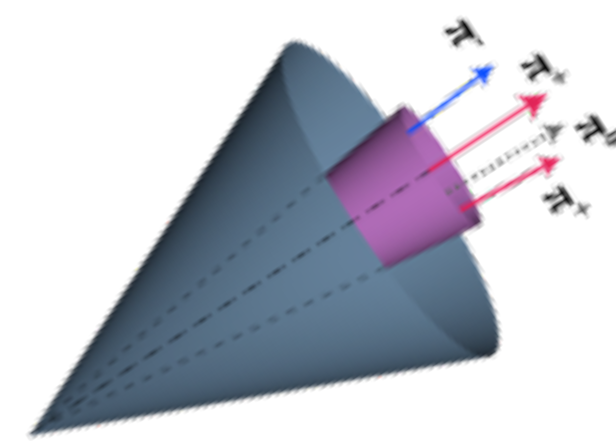
type 1:
trk + cal
(no EM cluster)

type 2:
trk + cal
(with EM cluster)

type 3:
> 1 trk**s** + cal

large jet background





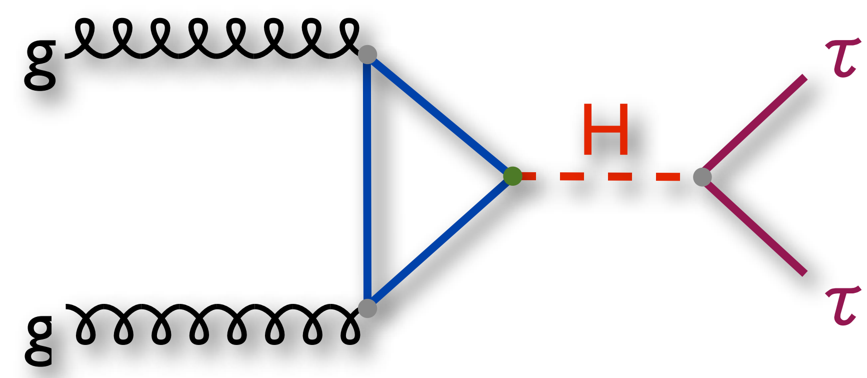
+ *NN_τ* based on isolation, shower shape, trk-cal consistency variables

τID performance

- DØ: eff=65% vs fake rate = 2.5%
- CDF: eff=50% vs fake rate < 1%

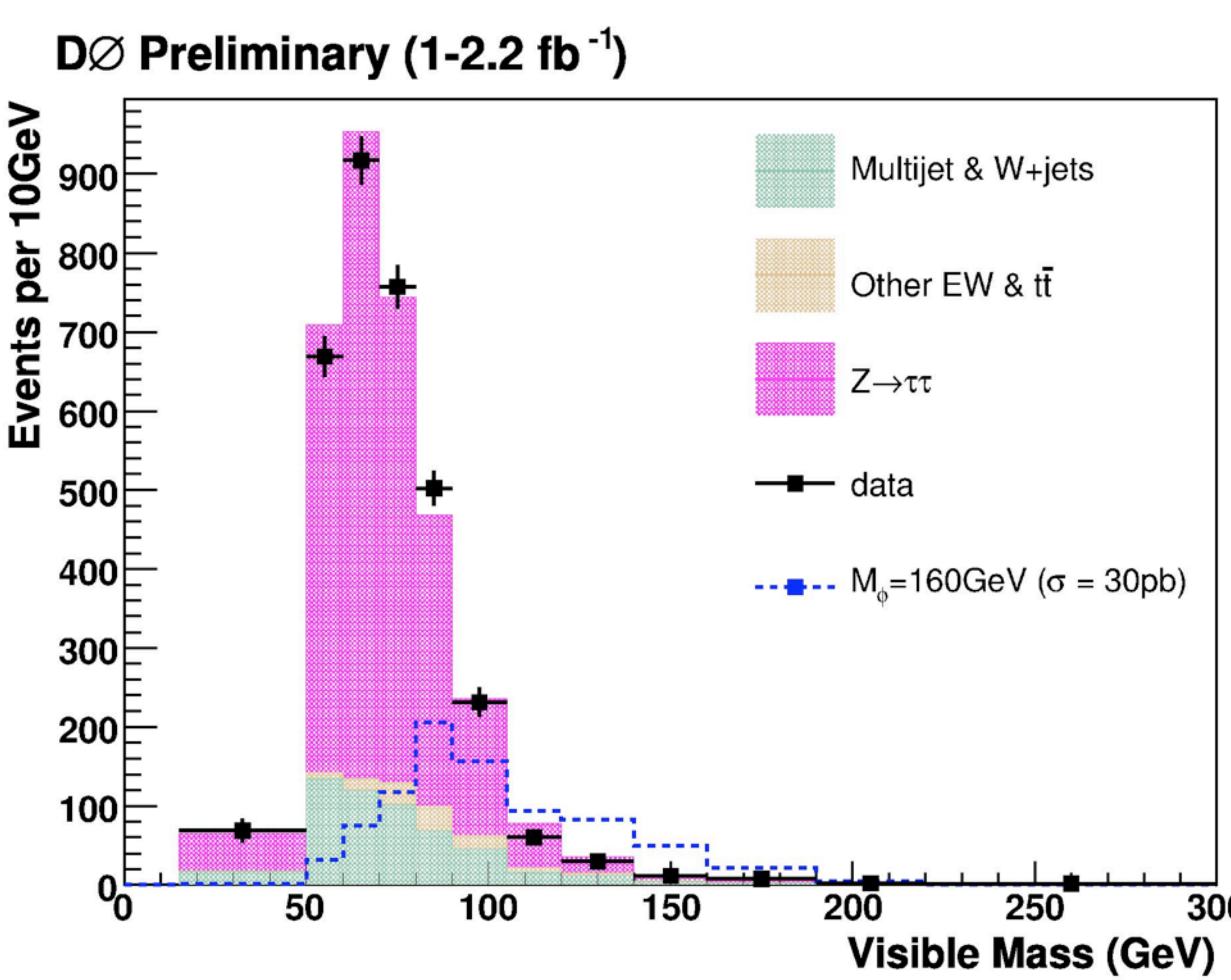
inclusive $h \to \tau\ \tau$

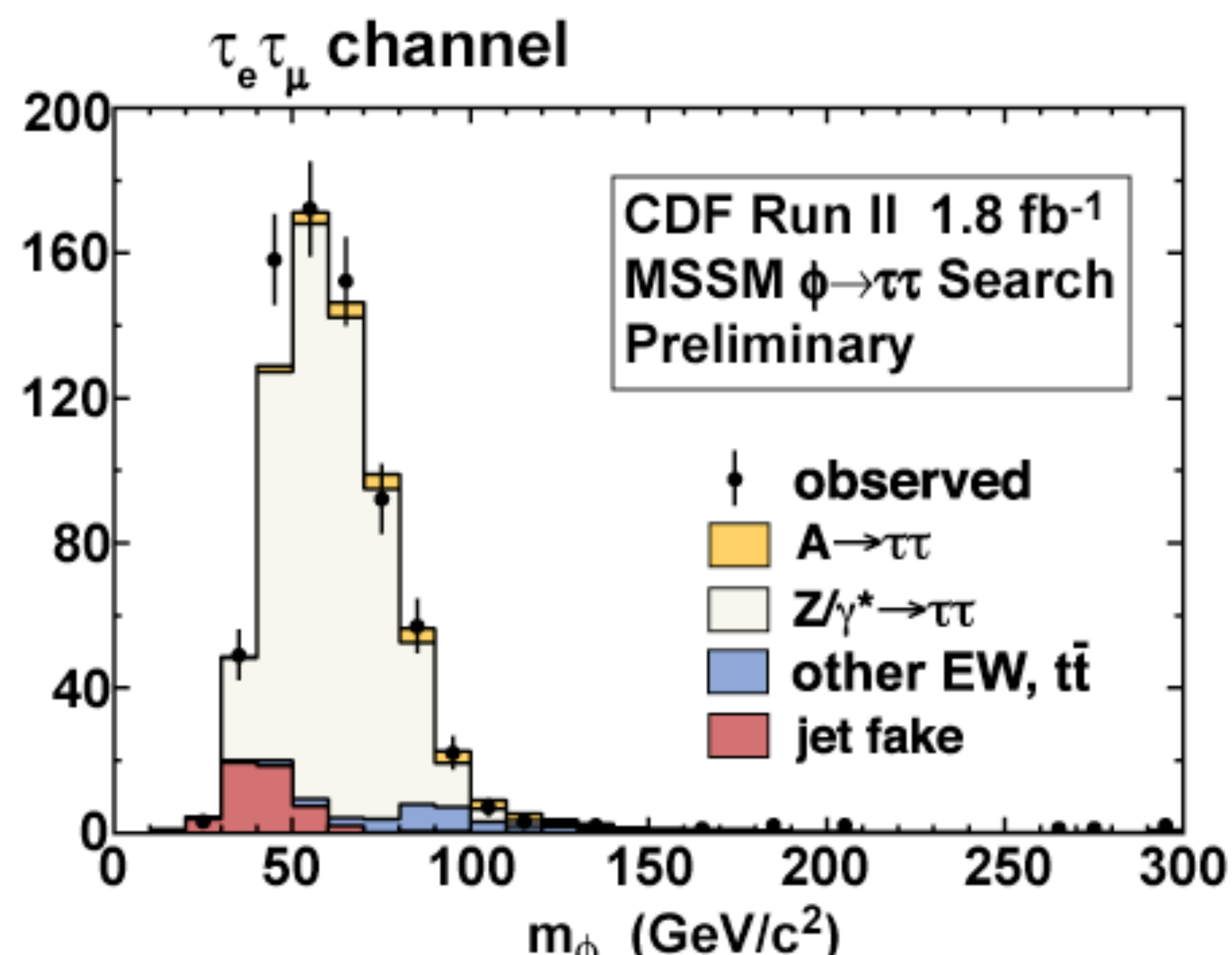
- DØ: $\tau_\mu \tau_h$ (2.2 fb^{-1}), $\tau_e \tau_h$ (1.0 fb^{-1}), $\tau_\mu \tau_e$ (1.0 fb^{-1})
  1fb^{-1} result: Phys. Rev. Lett. **101**, 071804 (2008)
- CDF: $\tau_\mu \tau_h$, $\tau_e \tau_h$, $\tau_\mu \tau_e$ (1.8 fb^{-1})



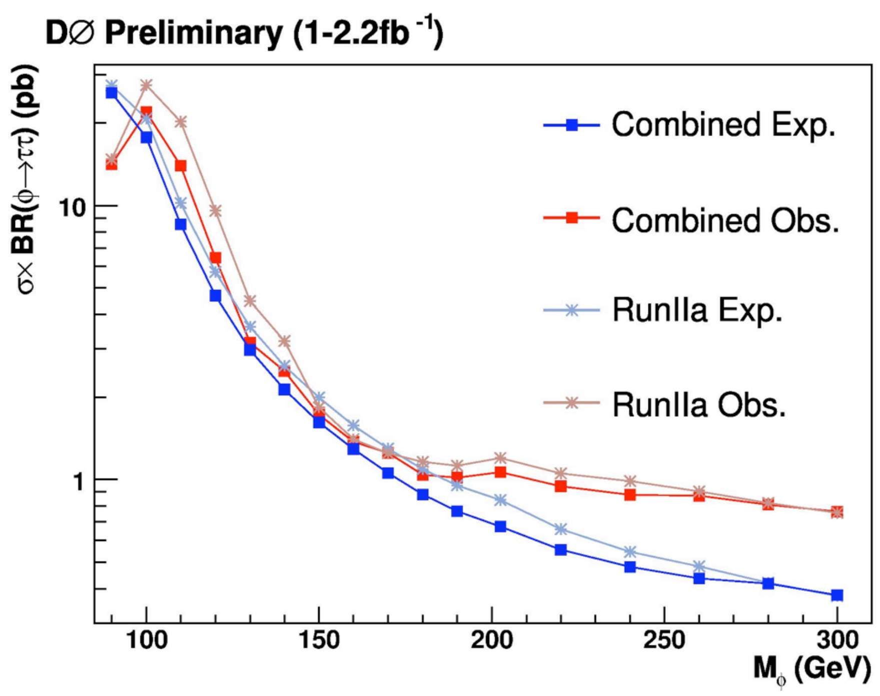
- Search for 2 high p_T isolated leptons, opposite sign
- Escaping neutrinos info is partially recovered by using $\not{E}_T$
- Look for a bump in:

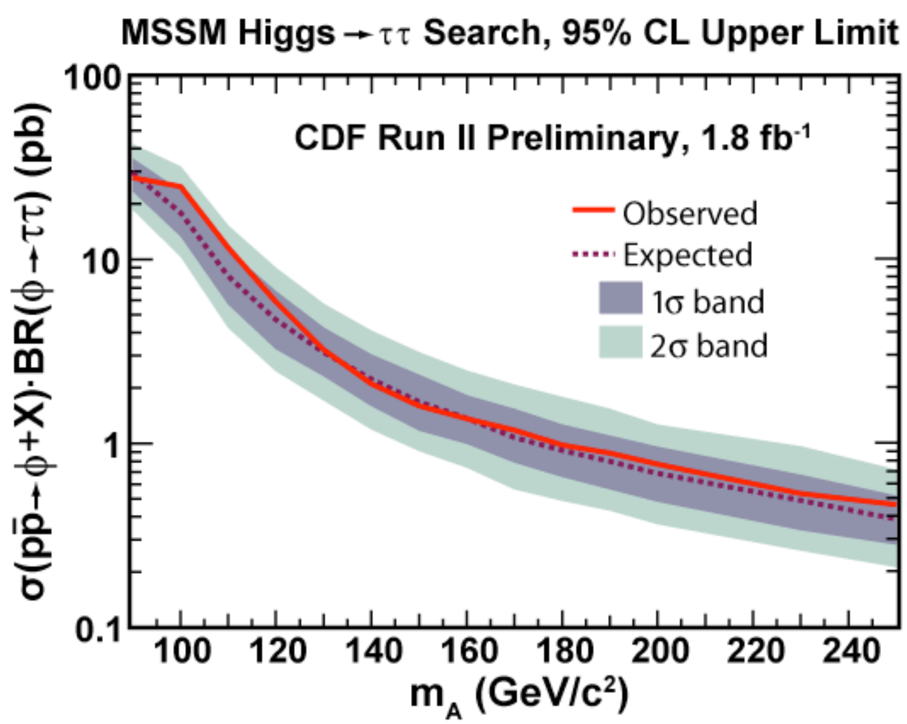
$$M_{vis} = \sqrt{(p_{\tau_h} + p_\mu + \not{E}_T)^2}$$



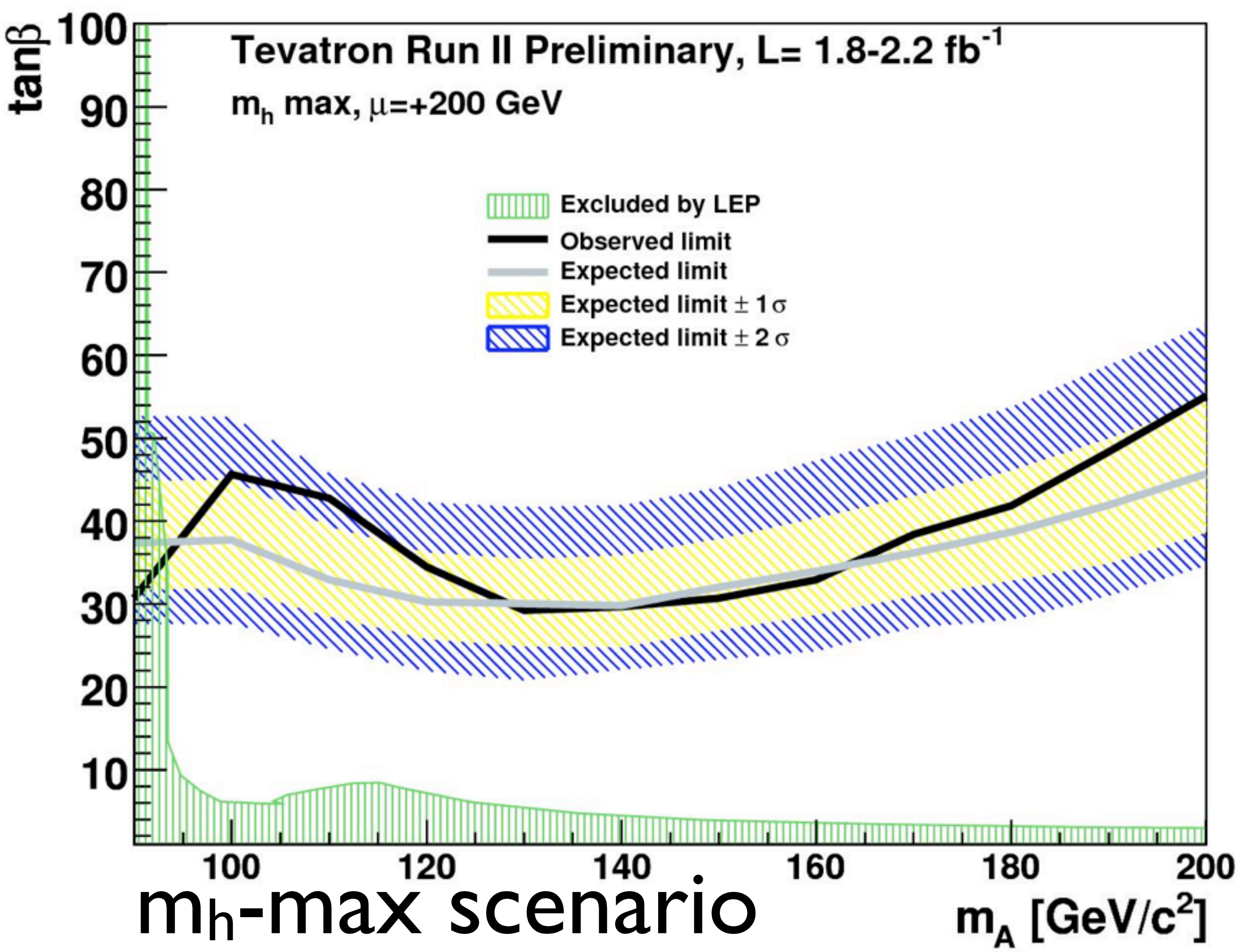


$h \to \tau\ \tau$ Results





Model independent limit



m_h-max scenario

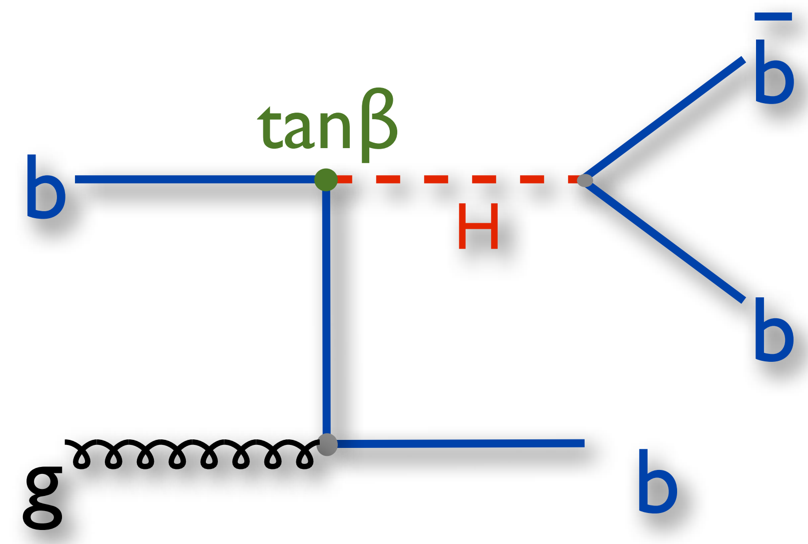
Data compatible with background

- DØ+CDF combination
- translation in MSSM parameter space

Reaching the interesting region of $\tan\beta \approx 30\text{-}40$

$bh \to bbb$ search

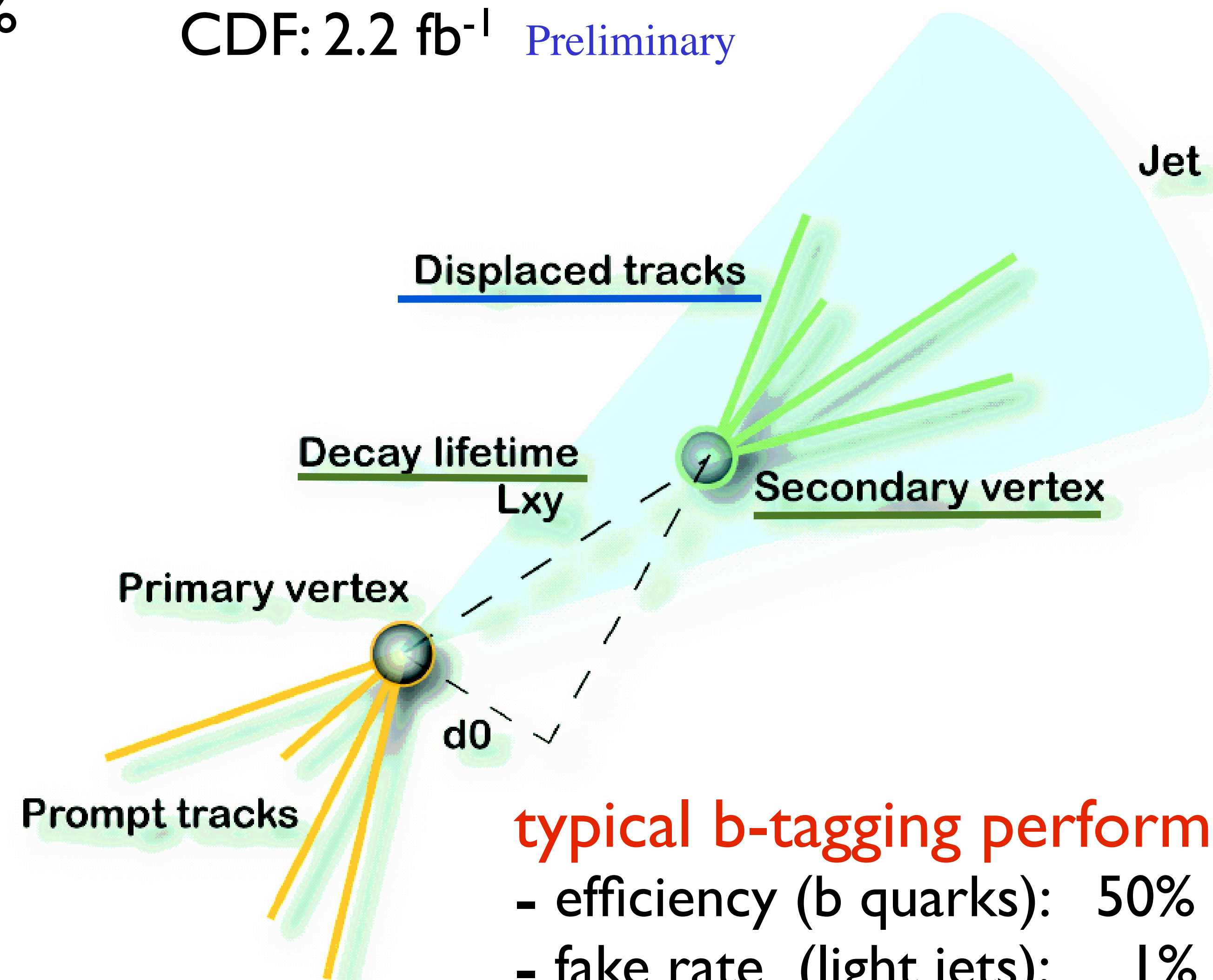
- $b\Phi \to bbb$ selection:
  - 3 to 5 high p_T jets
  - at least 3 b-tagged jets
- Large multijets background:
  - trigger on multijets events + impact parameter b-tag (60-70% efficient)
  - Need a powerful b-tagger to reject the abundant multijet background
  - Challenging background model!



DØ : 5.2 fb^{-1} Phys. Lett. B **698**, 97 (2011)
CDF: 2.2 fb^{-1} Preliminary

b-tagging @ DØ: combine var. in a multivariate discriminant

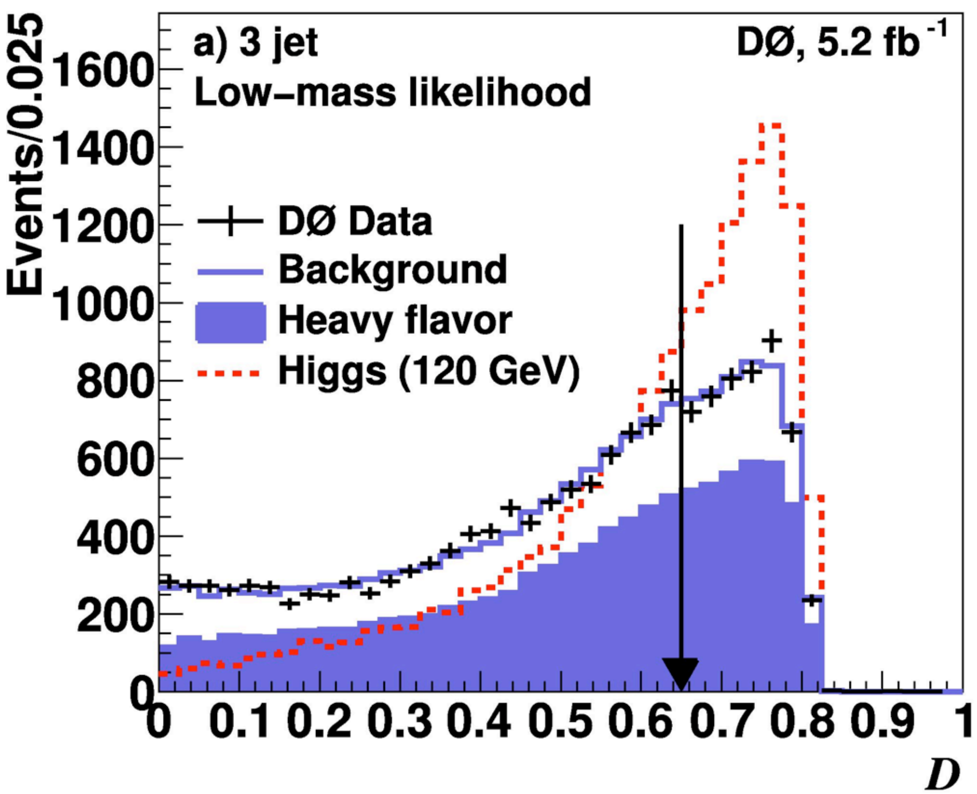
b-tagging @ CDF: displaced vertices
+ L_{xy}/σ cut
+ vertex mass separation

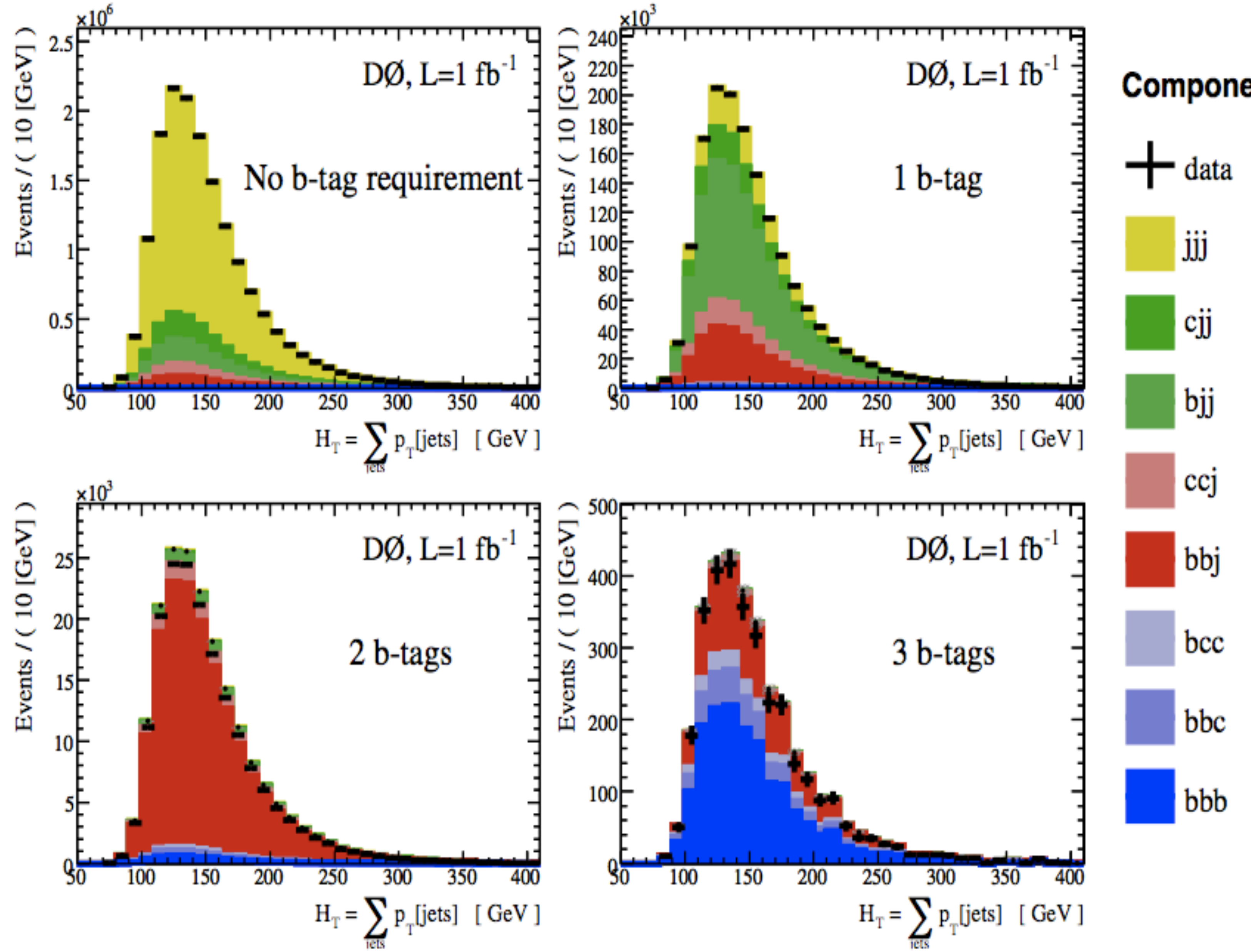


typical b-tagging performance
- efficiency (b quarks): 50%
- fake rate (light jets): 1%

bbb strategy example @ DØ

- ✓ signal to bkg discri. only relies on dijet mass
- ✓ Likelihood discri to enhance S:B ratio



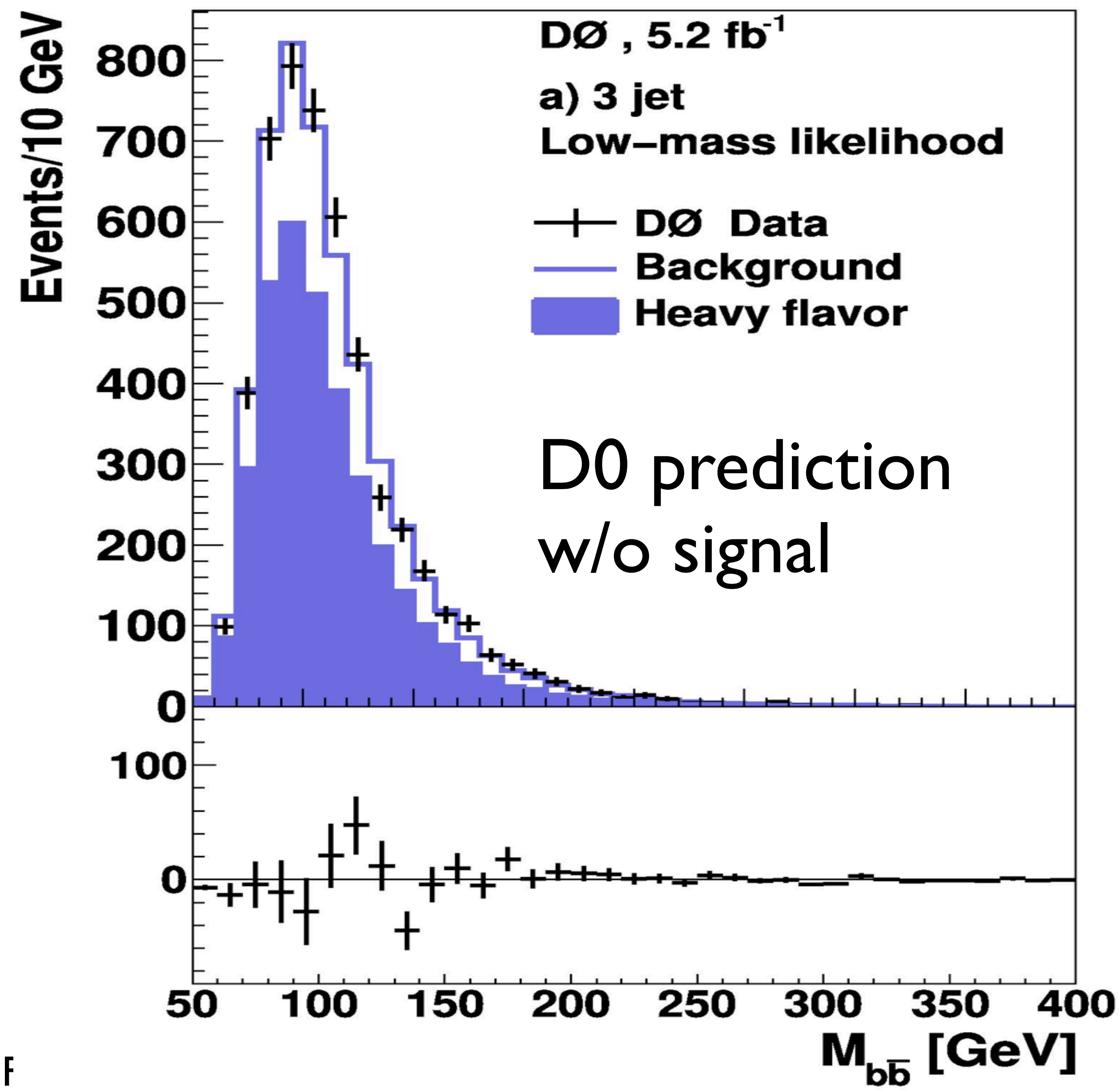


- ✓ bkg composition from global fit to: 0/1/2/3 b-tag samples
- ✓ bkg shape from data using the 2 b-tag sample (signal free) via:

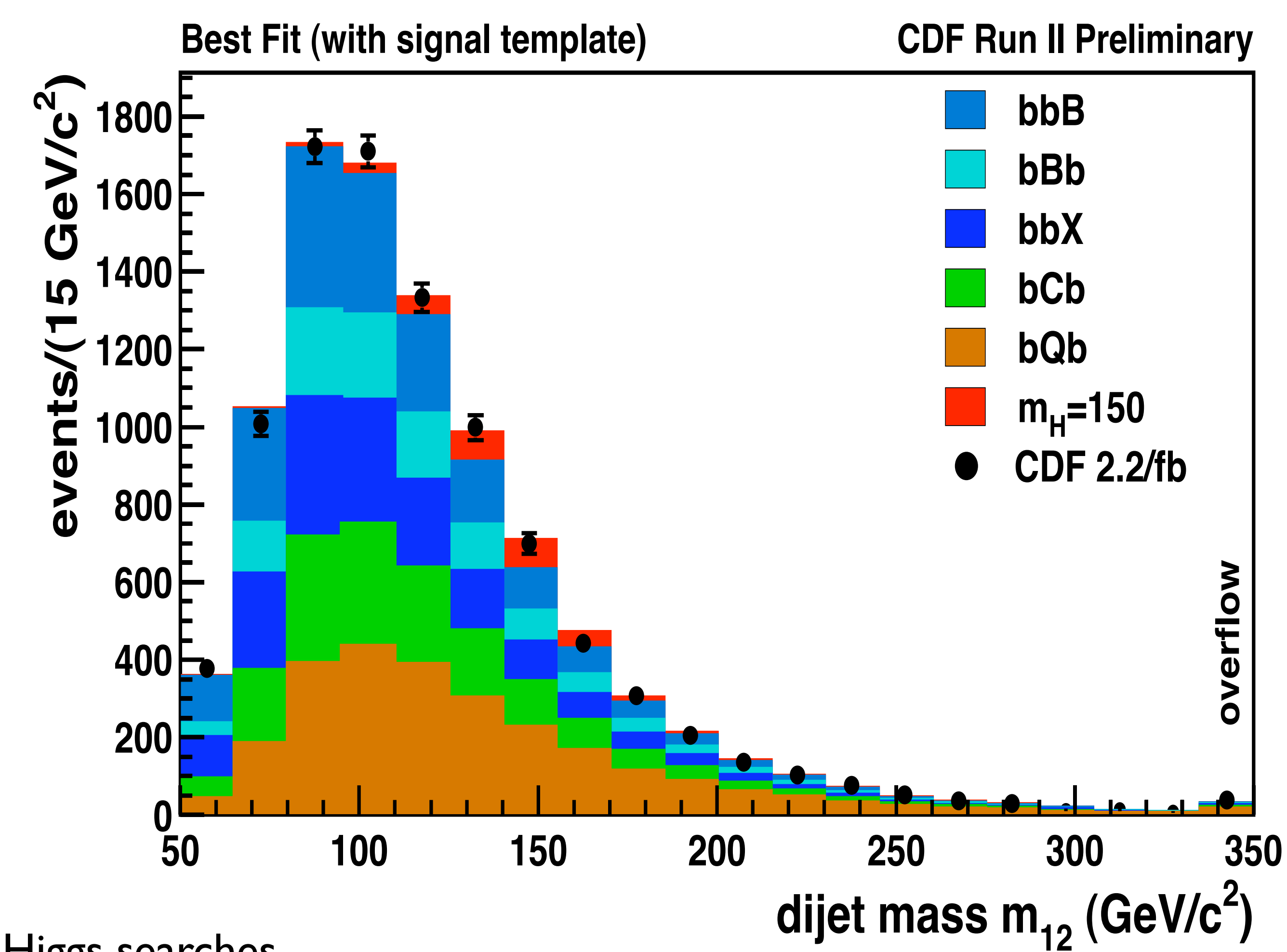
$$S^{exp}_{3tag}(M_{bb},\mathcal{D}) = \frac{S^{MC}_{3tag}(M_{bb},\mathcal{D})}{S^{MC}_{2tag}(M_{bb},\mathcal{D})} \times S^{DATA}_{2tag}(M_{bb},\mathcal{D})$$

bbb search: dijet mass

- CDF employs a similar strategy:
  - ✓ predict background shapes from 2 b-tag sample (with b-tagging probability applied on 3rd jet).
  - ✓ 2D fit to data (dijet mass vs flavor separator for bkg composition). Fit is done w & w/o signal



CDF best fit including signal

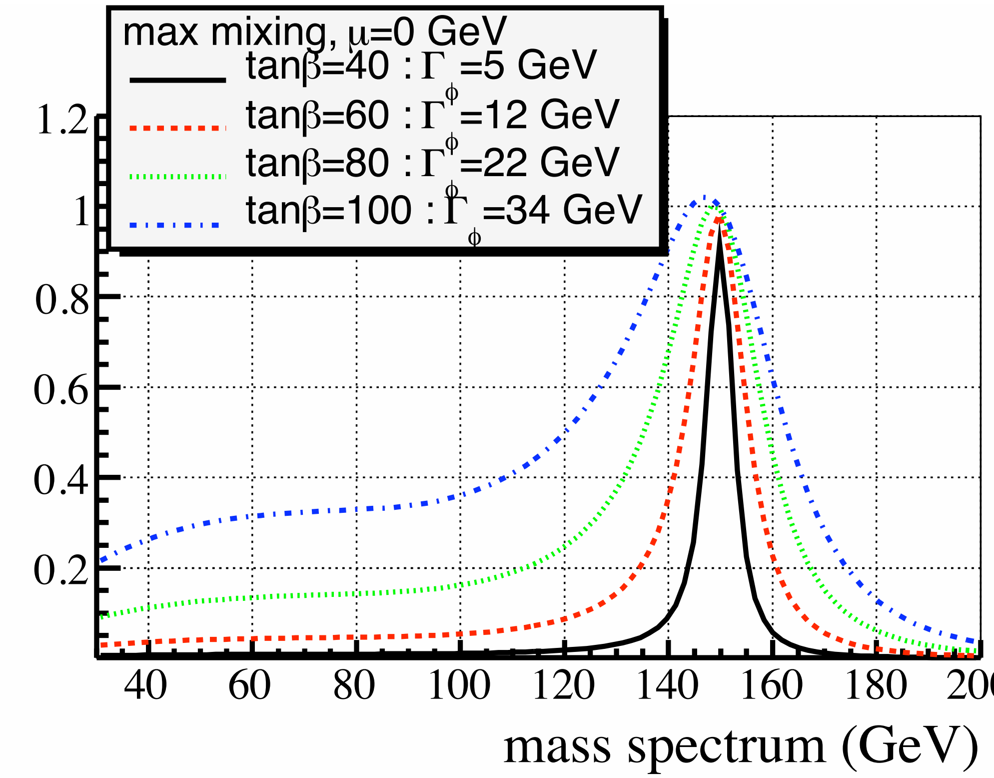


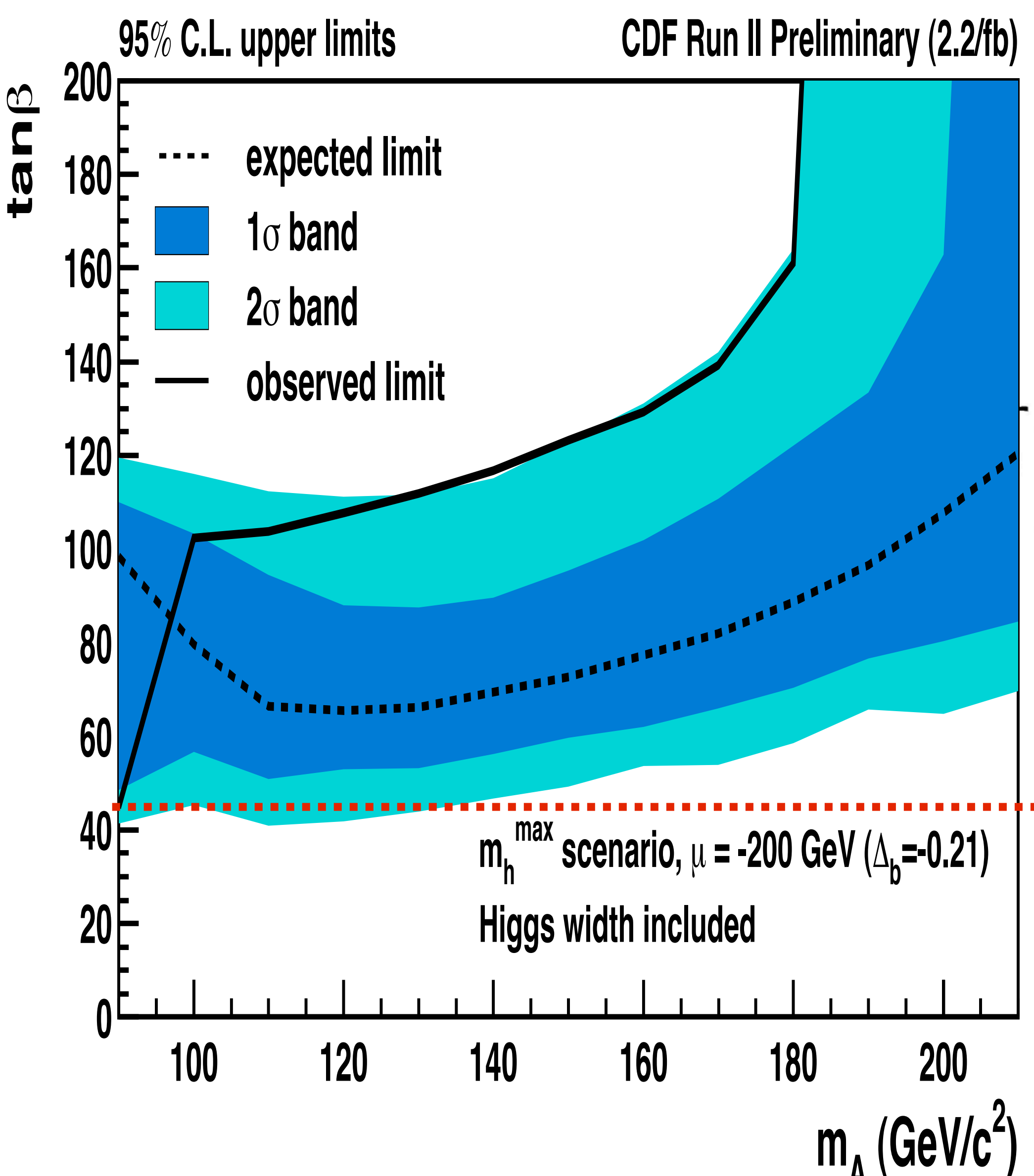
Very sensitive to radiative corrections

High tanβ: signal width effect not negligible

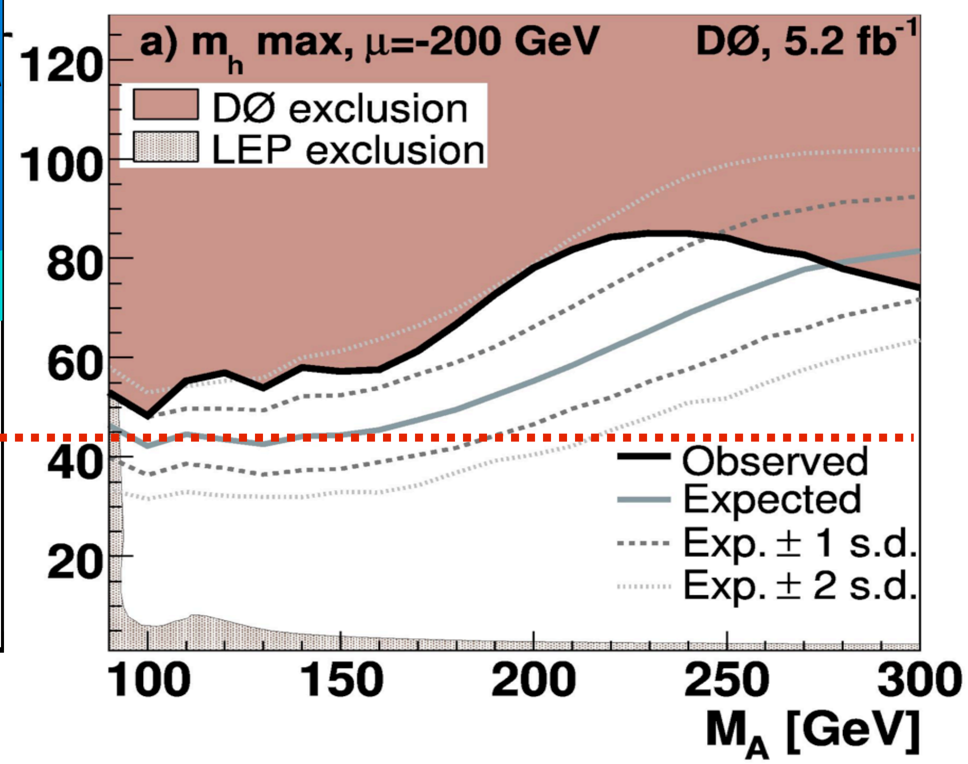
(compared to the experimental mass resolution).

$$\frac{d\sigma}{dm} = \sigma(m, \tan\beta, \Gamma = 0) \times BW(m, m_\phi, \tan\beta)$$





Exp. sensitivity down to tanβ=40

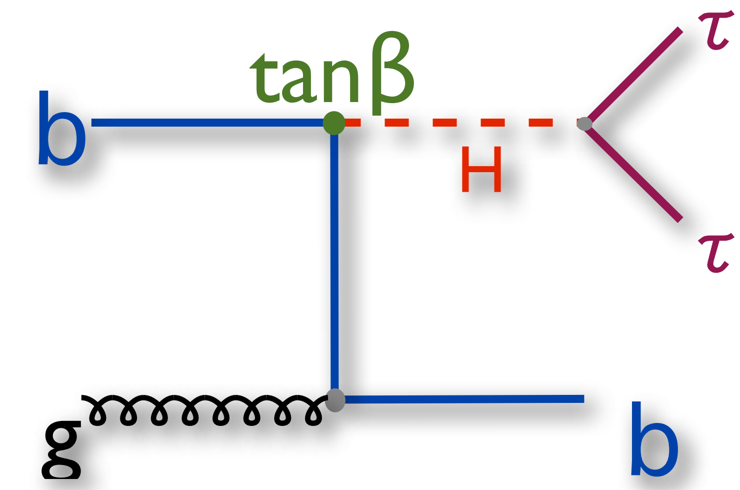


Data compatible with bkg but both collab. see a broad excess at the 1-2σ level.

$b\Phi \rightarrow b\tau_e\tau_h$ search

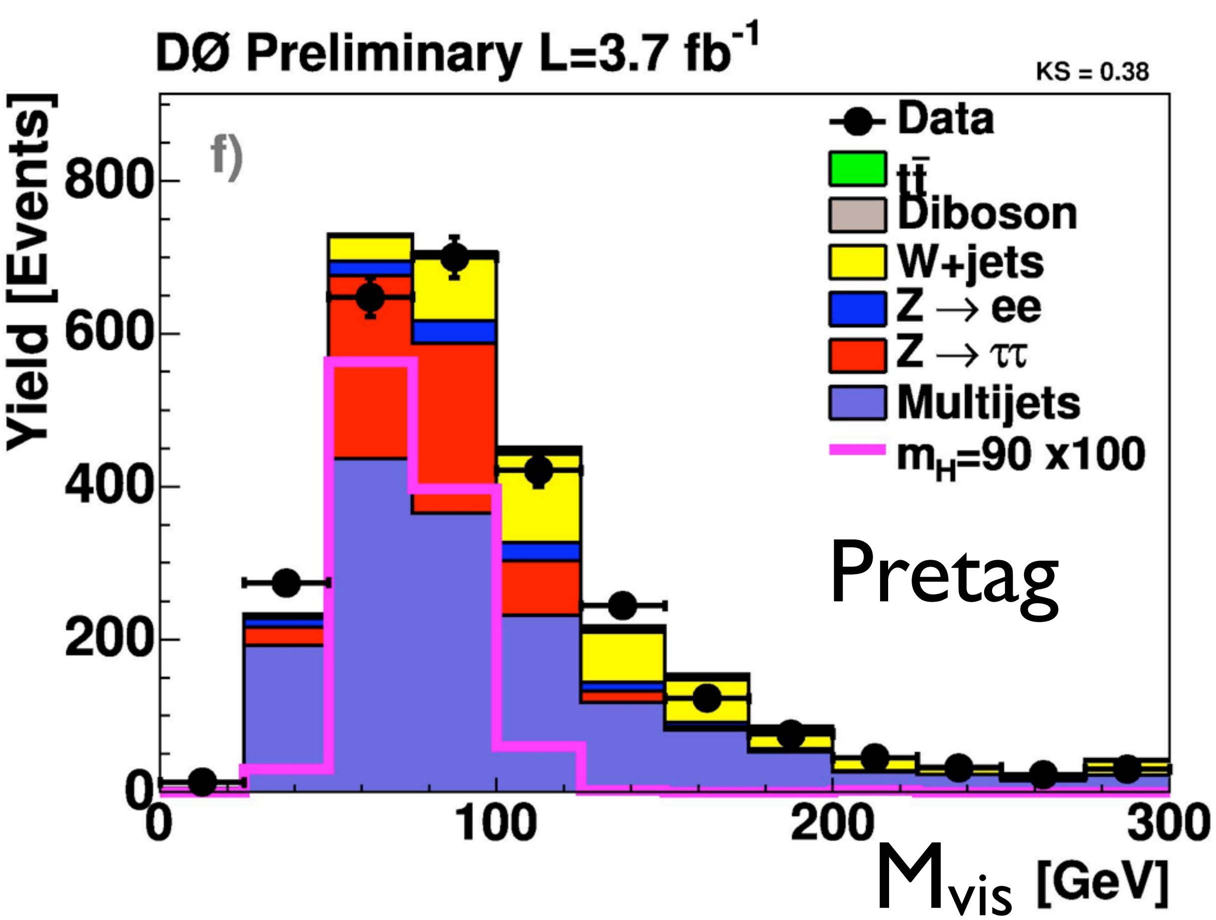
- Channel complementary to
  - $b\Phi \rightarrow bbb$: lower $\mathcal{B}r$ but much lower bkg, less sensitive to radiative corrections
  - $\Phi \rightarrow \tau\tau$: more sensitive near the Z peak

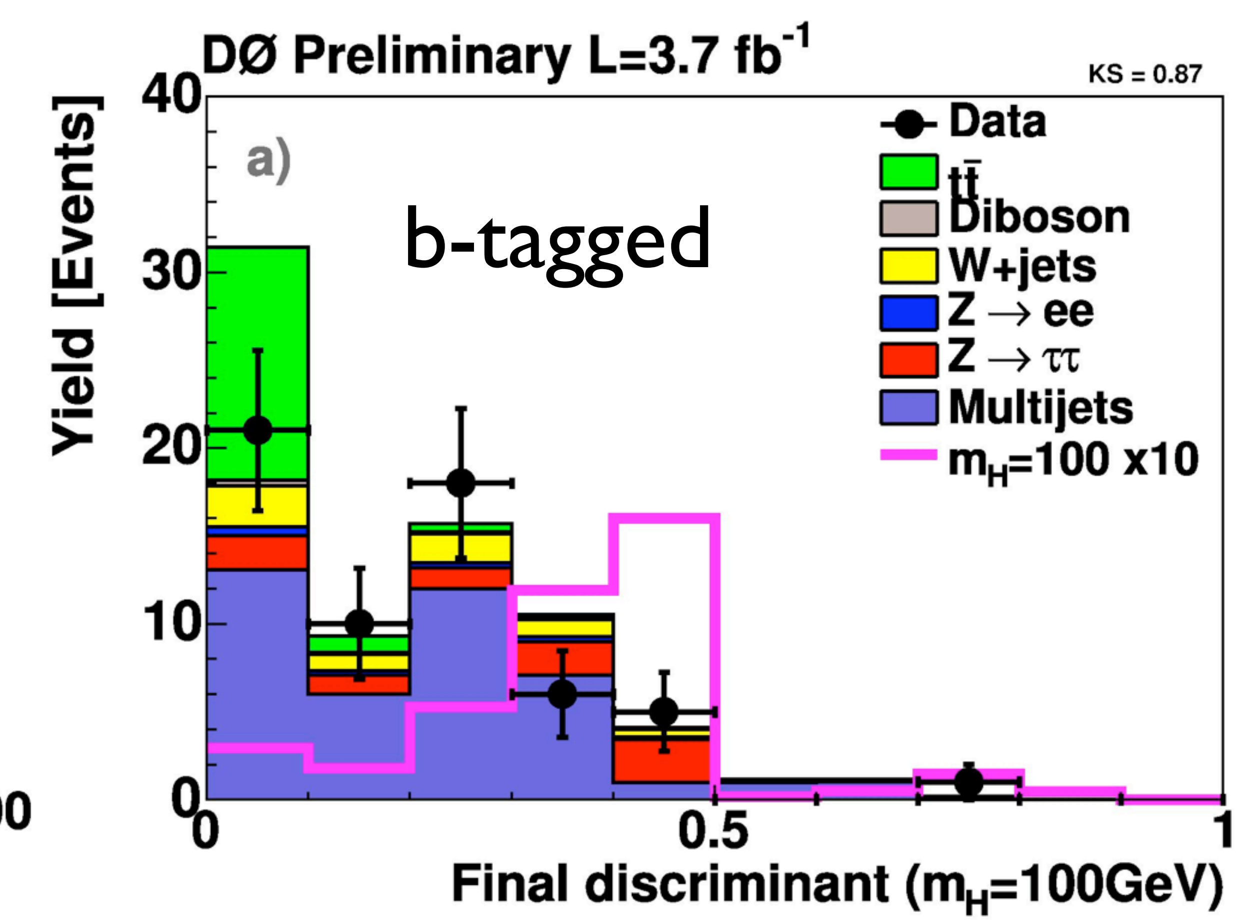
[NEW] $b\tau_e\tau_h$: 3.7 fb^{-1}



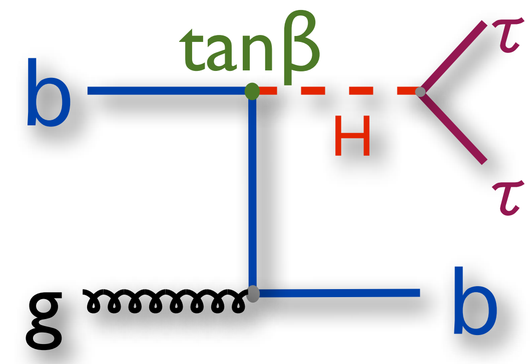
- $Z \rightarrow \tau\tau$: require one b-tag jet
- Specific discri against main backgrounds: multijets (D_{MJ}) and $t\bar{t}$ (D_{tt}).
- Final discri: $(D_{MJ}+10) \times D_{tt} / 20$

$$\frac{\sigma(\phi\, b_{tag})}{\sigma(\phi incl)} = 0.16 \qquad \frac{\sigma(Z\, b_{tag})}{\sigma(Z incl)} < 0.005$$

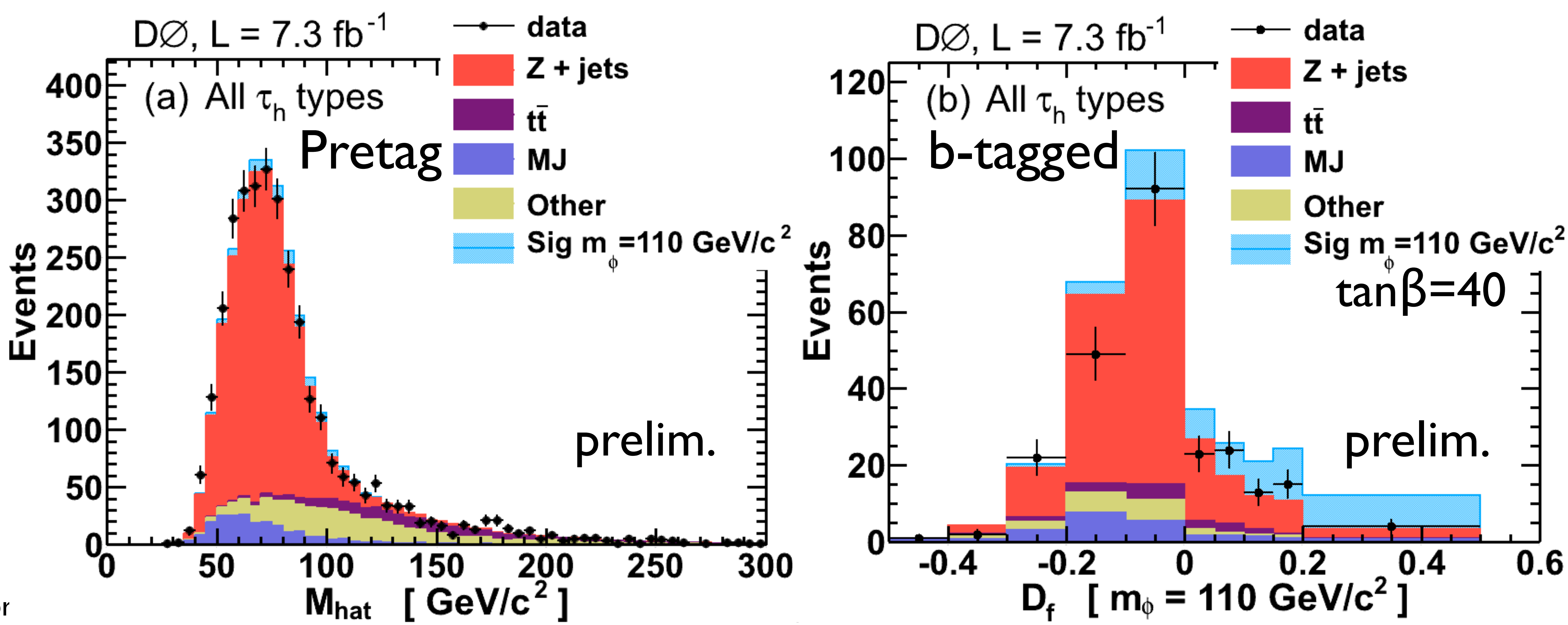




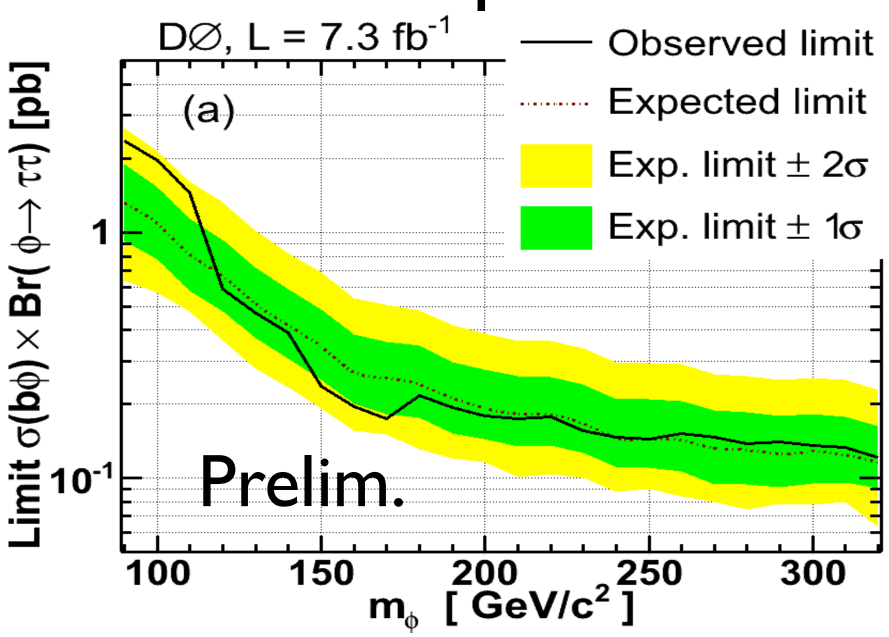
[Brand New for Blois] $b\tau_\mu\tau_h$: 7.3 fb^{-1}



- Specific discriminants against main backgrounds:
  $t\bar{t}$ (D_{tt}), multijets (D_{MJ}) and $Z\rightarrow\tau\tau$ (NN_b)
- Final discri: D_f likelihood formed with D_{tt}, D_{MJ}, NN_b, M_{hat}
- Inclusive trigger approach
- Main background ($Z\rightarrow\tau\tau$) constrained from data using $Z\rightarrow\mu\mu$. Greatly reduces the loss of sensitivity due to syst. uncertainties.



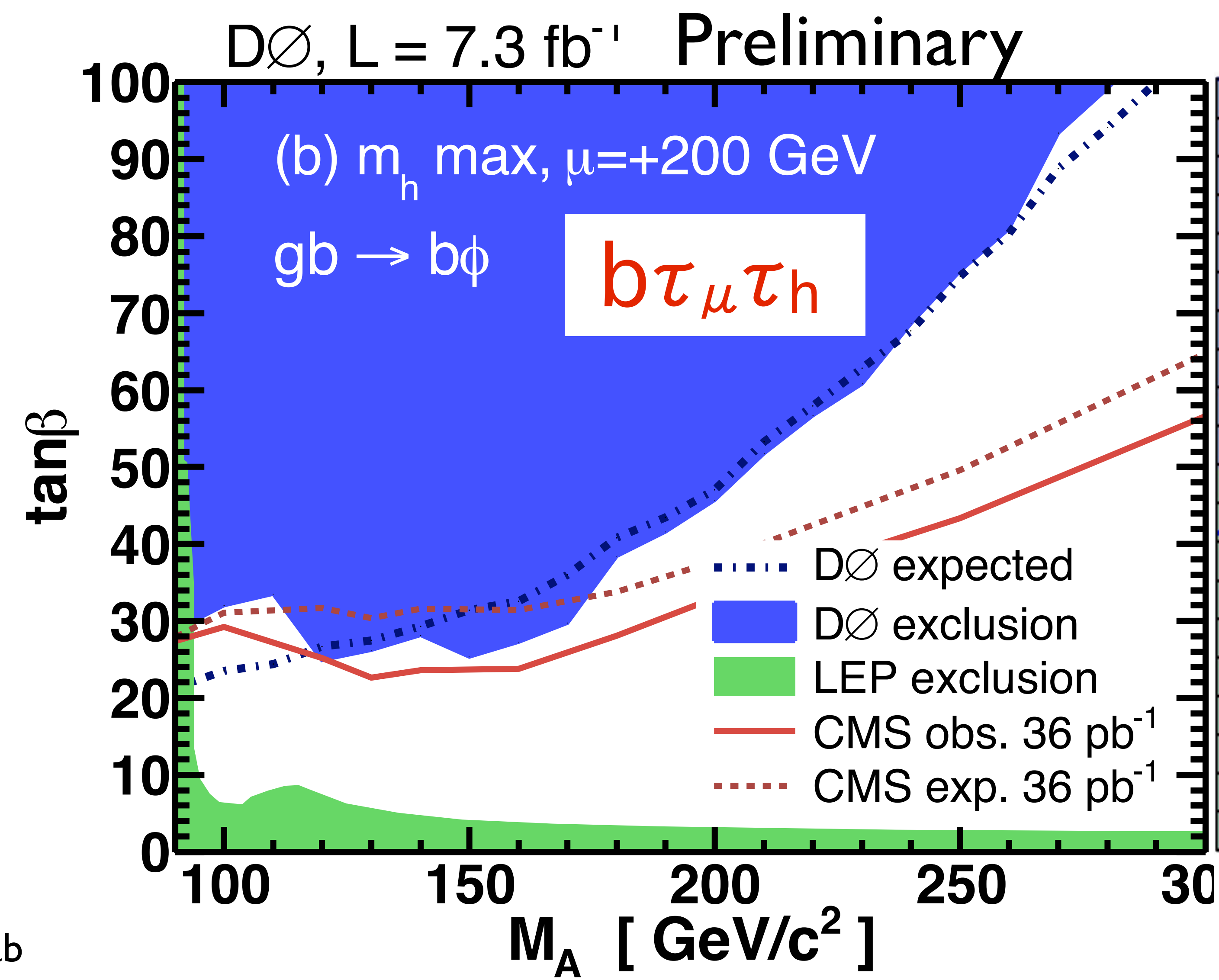
model independent limit

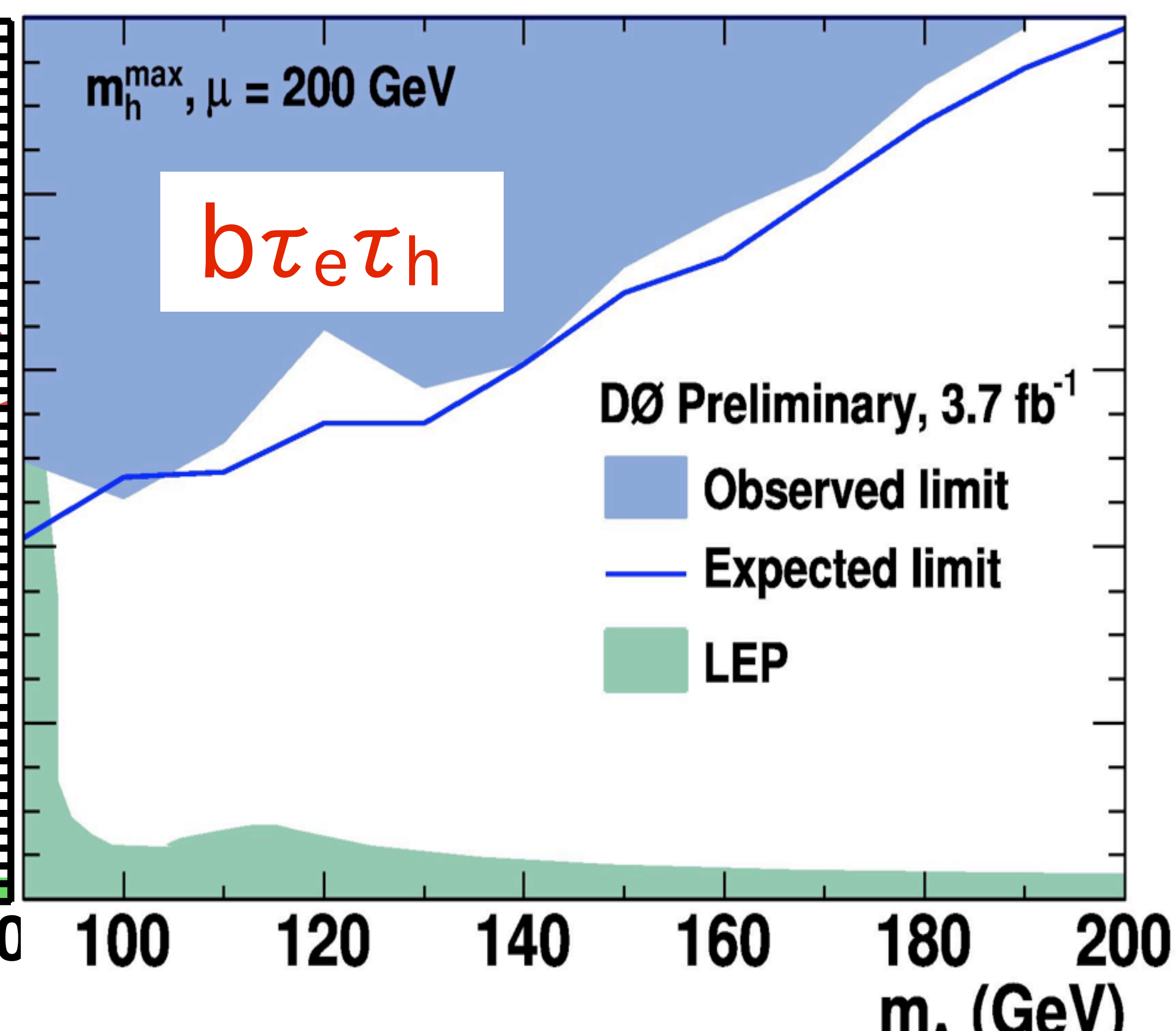


Data compatible with background

At low mass:
most stringent limits to date obtained in a direct search at Tevatron

($b\tau_\mu\tau_h$ result to be submitted to PRL)

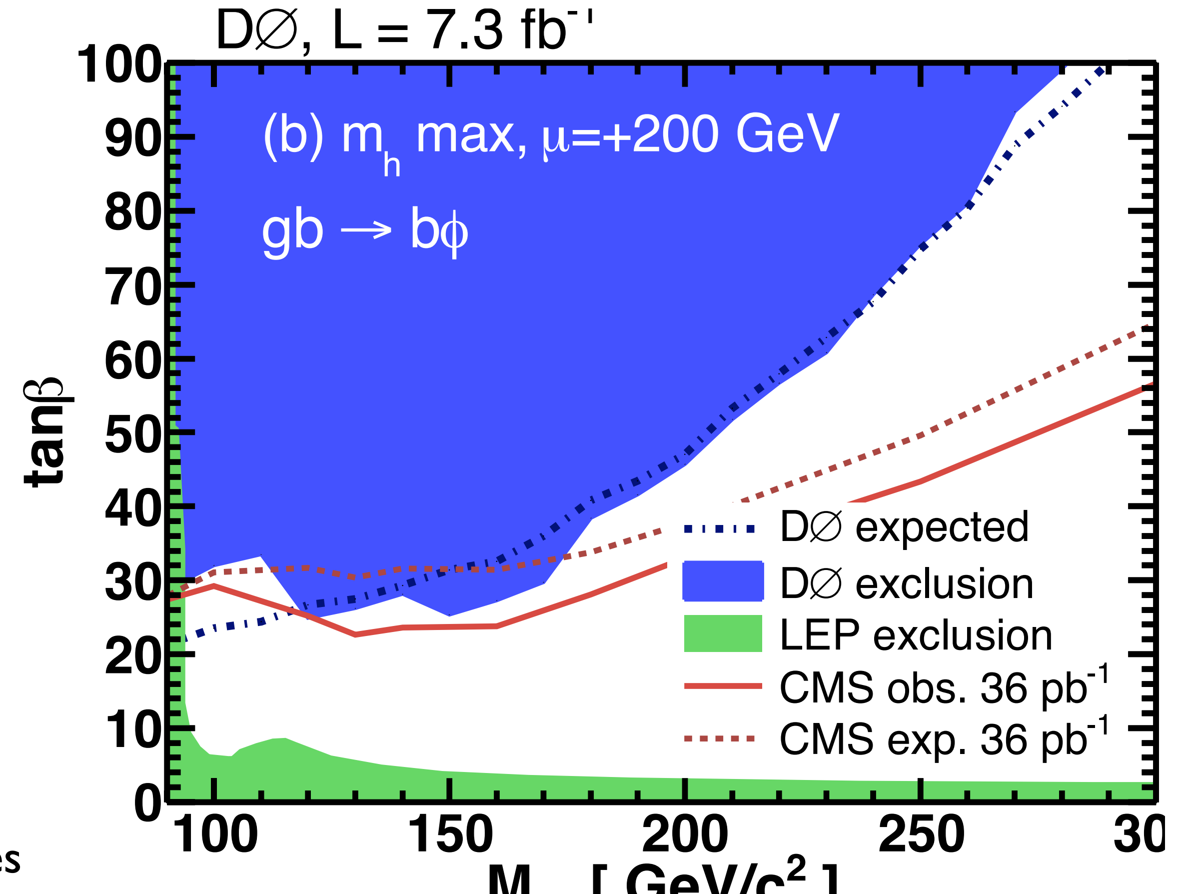




Conclusions & prospects

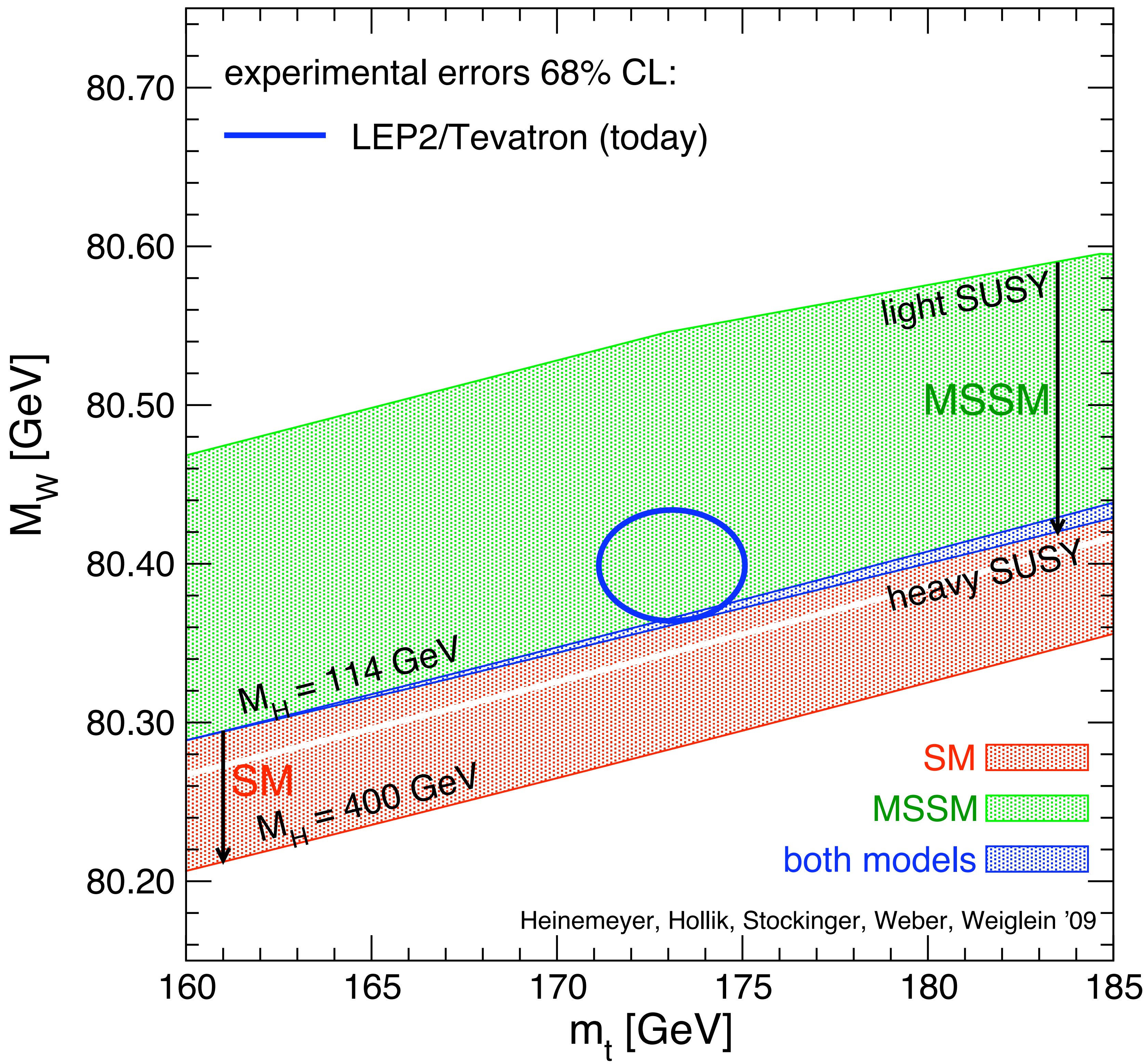
- Results with up to 7.3 fb^{-1} reported here
- Also H^+ searches not covered in this talk
- Reaching the interesting region of $\tan\beta \approx 30\text{-}40$ (even below).
- $b\tau_\mu\tau_h$ is (still) competitive with LHC inclusive $\tau\tau$ searches and even achieve a better sensitivity at low M_A. This is also a different and complementary channel (involving b-tagging)...
- Some excesses both for D0 and CDF in the bbb channel, worth to keep an eye on.
- Several modes with similar sensitivity (combine!)
- Expected (very) soon:
  - hb → bbb search update
  - inclusive $h \to \tau\tau$ update
  - combinations update
  - ...

Several updates planned for summer'11, stay tuned!

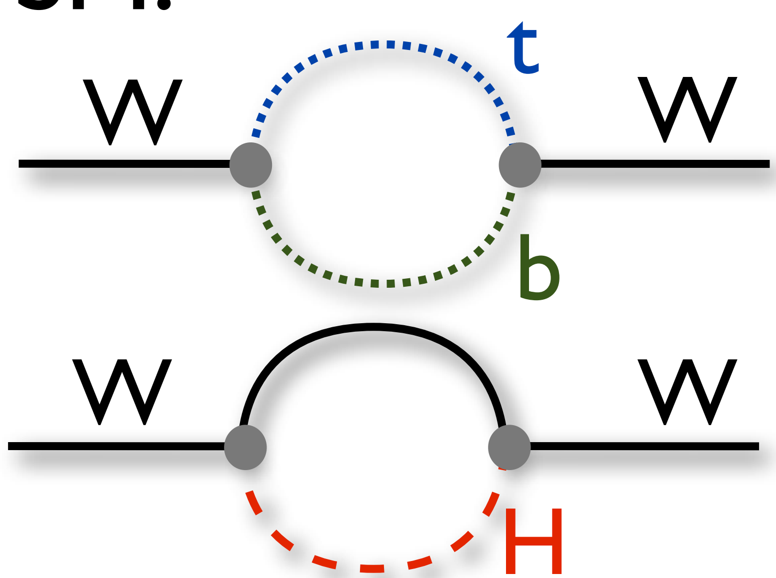


Backup

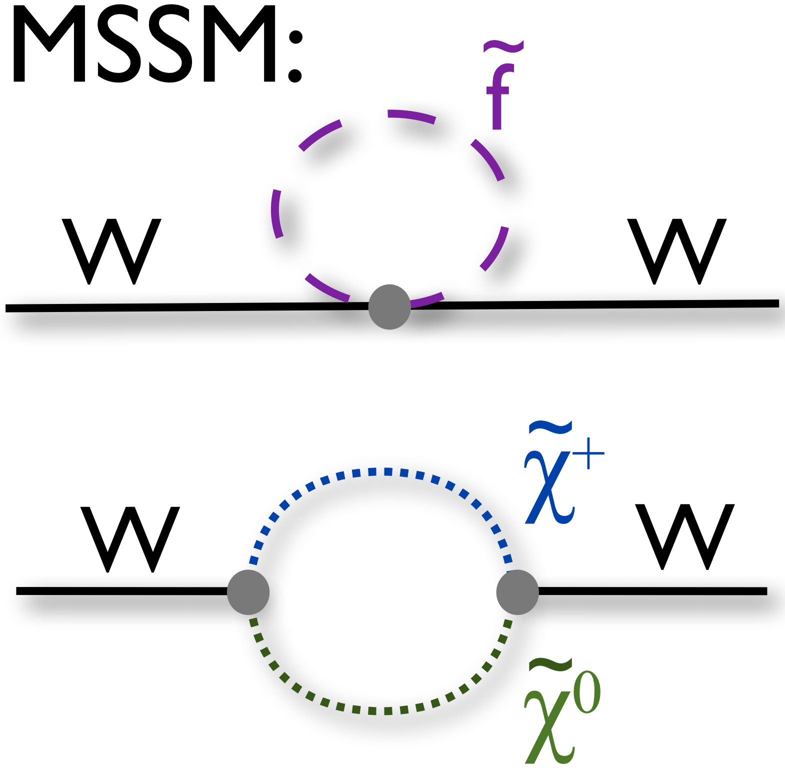
Why looking to the MSSM?



SM:



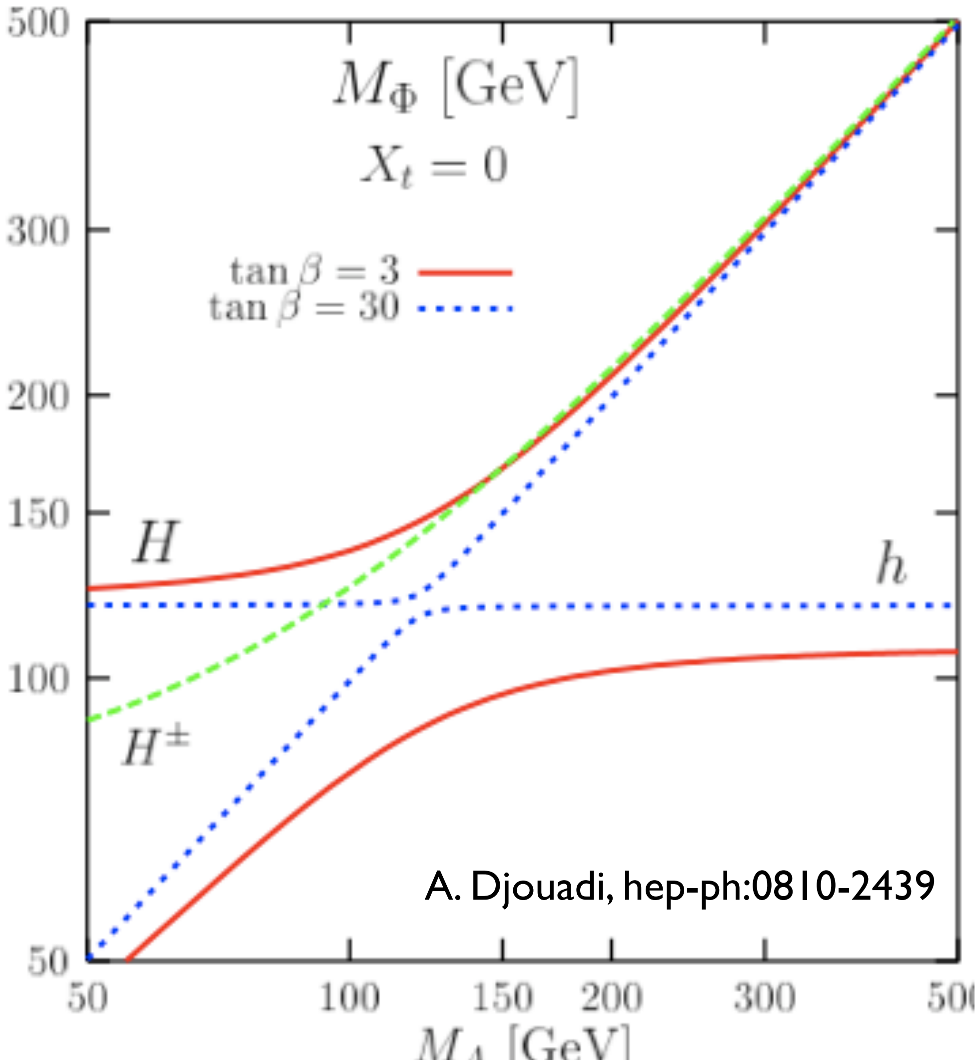
MSSM:



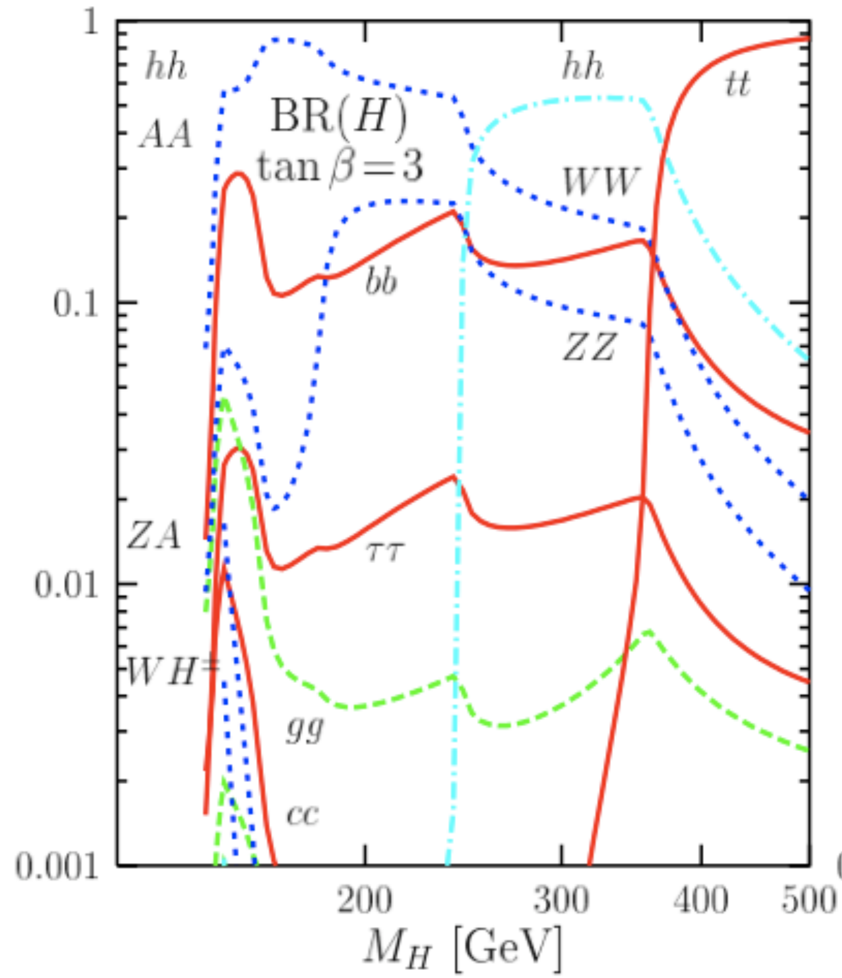
.....

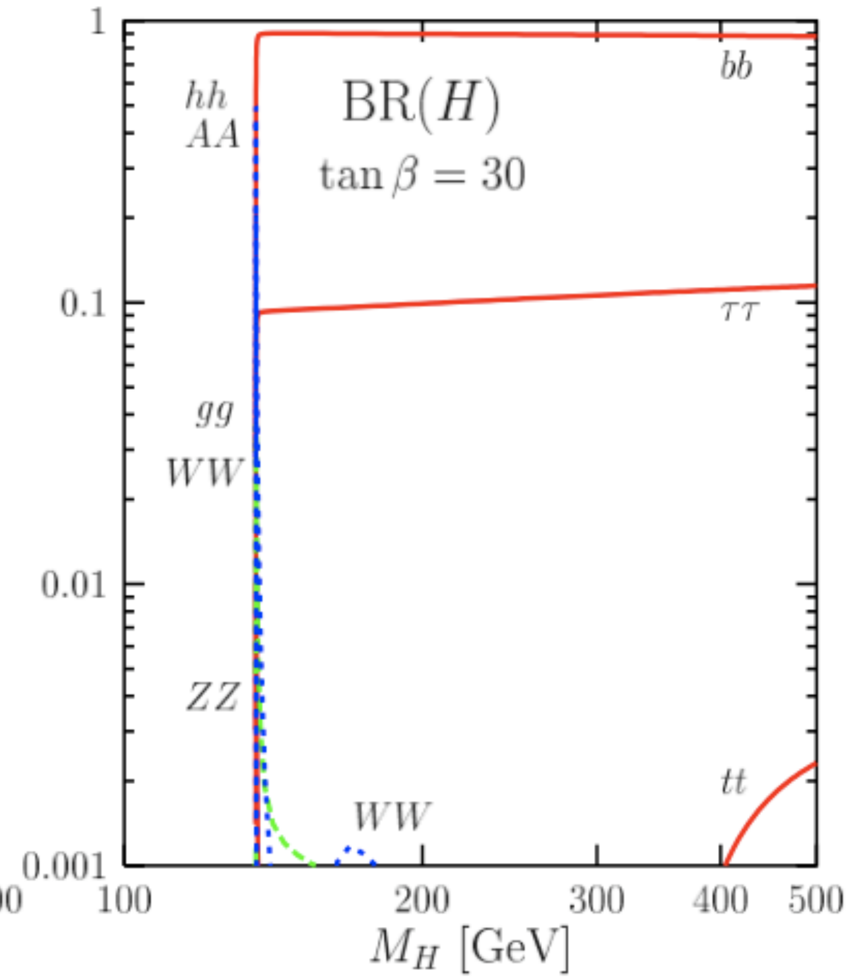
MSSM dedicated Higgs searches at the TeVatron usually takes place in the high tanβ regime:

- h/A or H/A are degenerate in mass $\sigma_{prod} \times 2$!
- coupling to b quarks enhanced by tanβ
- neutral Higgs: $\mathcal{B}(\phi \to b\bar{b}) \approx 90\ \%$ and $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10\ \%$
- charged Higgs: if $m_{H+} < m_{top}$: $\mathcal{B}(H^+ \to \tau^+\nu_\tau) \approx 1$



A. Djouadi, hep-ph:0810-2439





A. Djouadi, hep-ph0810-2439

Strategy for limit settings

If data are compatible with background:

1. place limits in a model independent way
2. place limits into 4 different scenarii

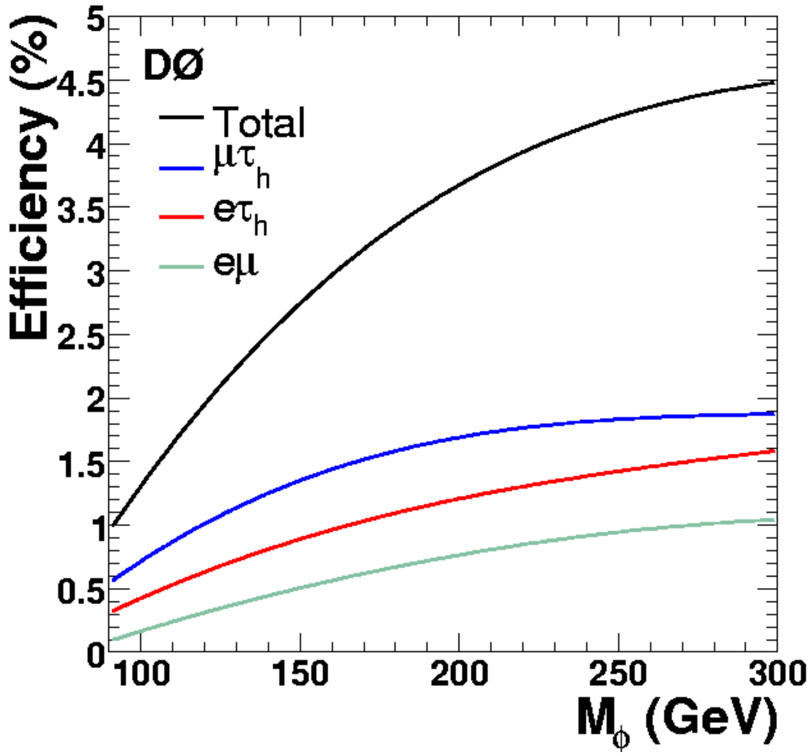
   use *FeynHiggs* or *CPSuperH* to get the MSSM cross sections

- m_h^{max} **scenario:**
  - $* \; X_t = 2$ TeV;
  - $* \; \mu = \pm 0.2$ TeV;
  - $* \; M_2 = 0.2$ TeV;
  - $* \; m_{\tilde{g}} = 0.8$ TeV
  - $* \; M_{SUSY} = 1$ TeV

- **No-mixing scenario:**
  - $* \; X_t = 0$ TeV;
  - $* \; \mu = \pm 0.2$ TeV;
  - $* \; M_2 = 0.2$ TeV;
  - $* \; m_{\tilde{g}} = 1.6$ TeV;
  - $* \; M_{SUSY} = 2$ TeV

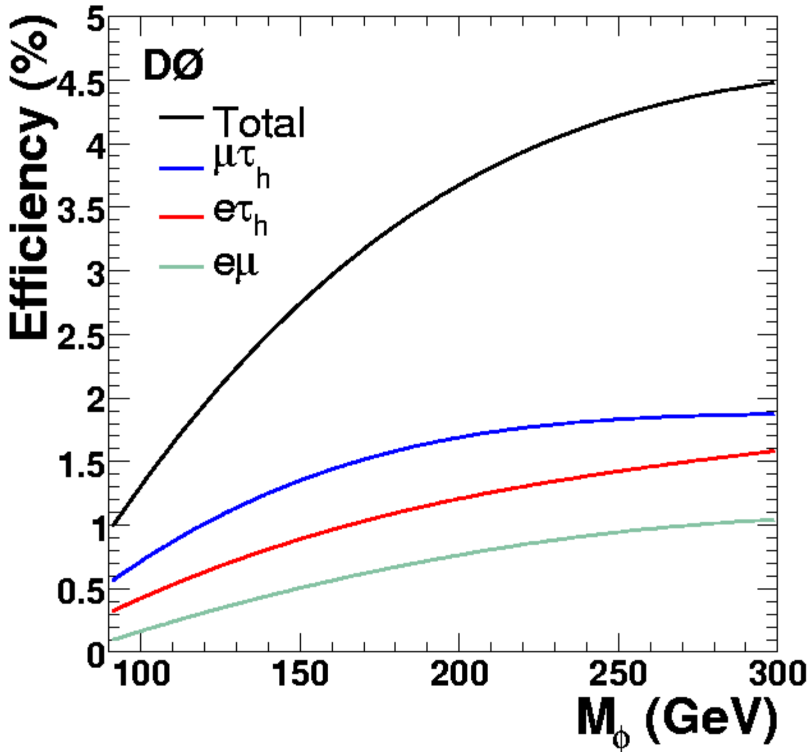
M. S. Carena, S. Heinemeyer, C. E. M. Wagner, and G. Weiglein, Eur. Phys. J. C 26, 601 (2003).

Best channel: $\tau_\mu\tau_h$

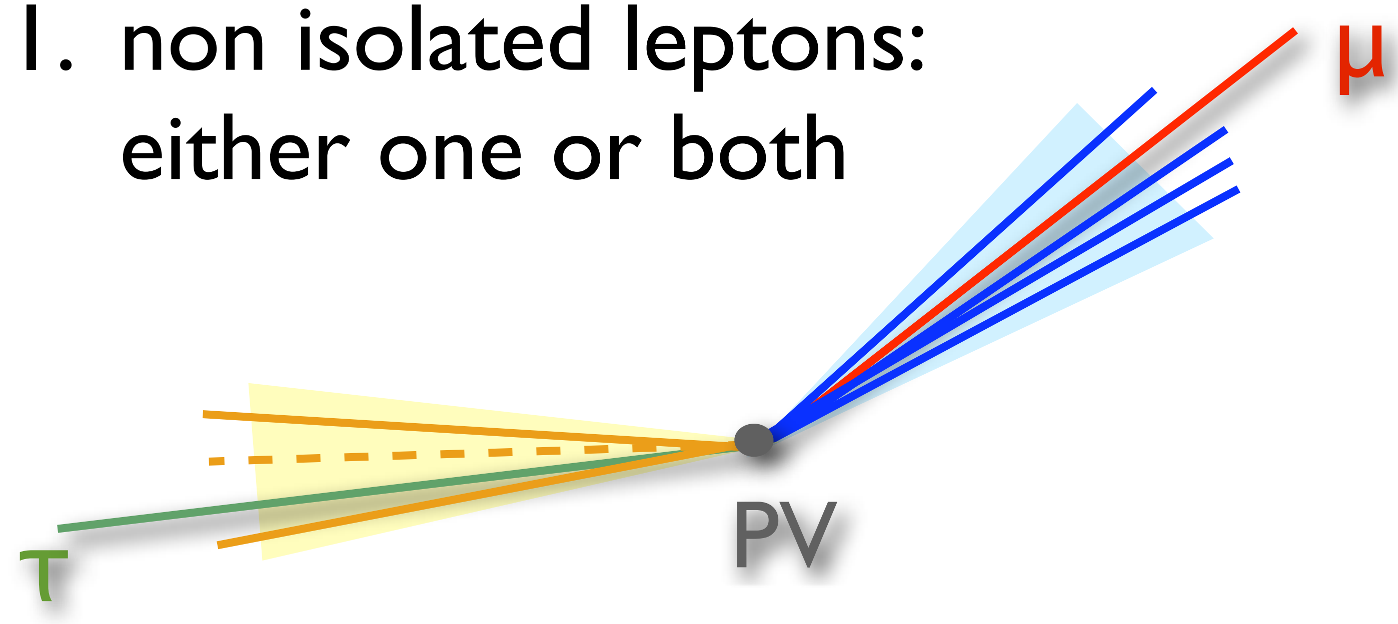


- Multijets estimated from 2 samples:

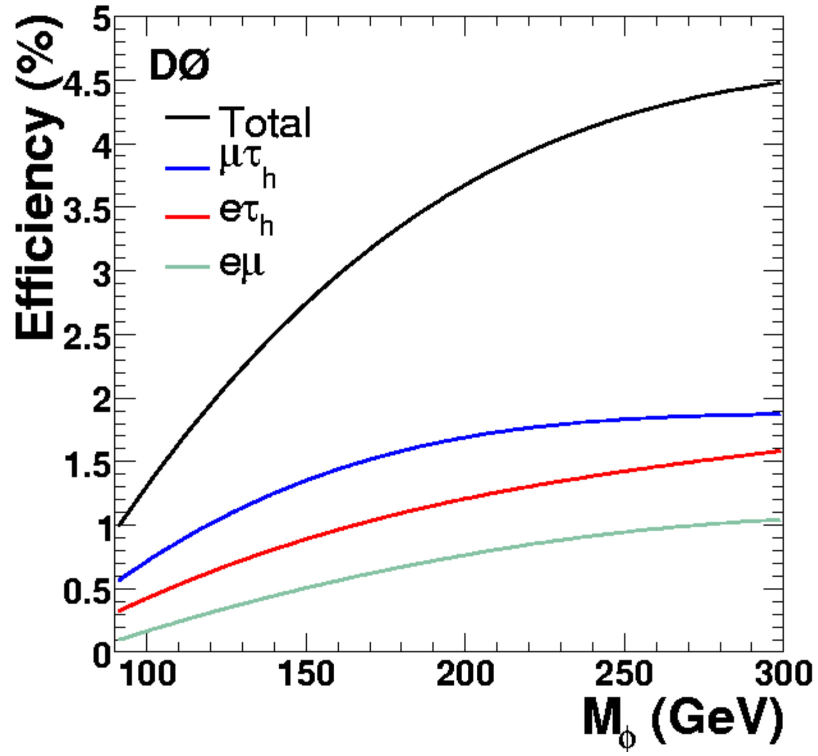
Best channel: $\tau_\mu \tau_h$



- Multijets estimated from 2 samples:
  1. non isolated leptons: either one or both



Best channel: $\tau_\mu \tau_h$



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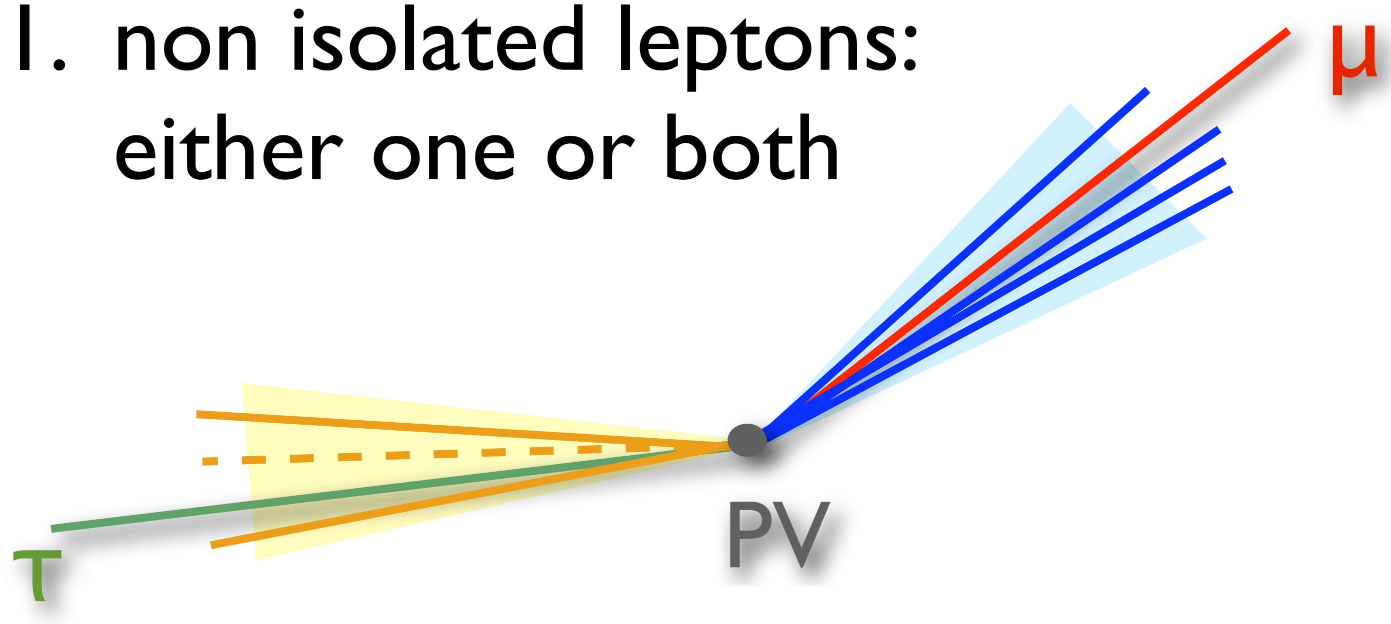
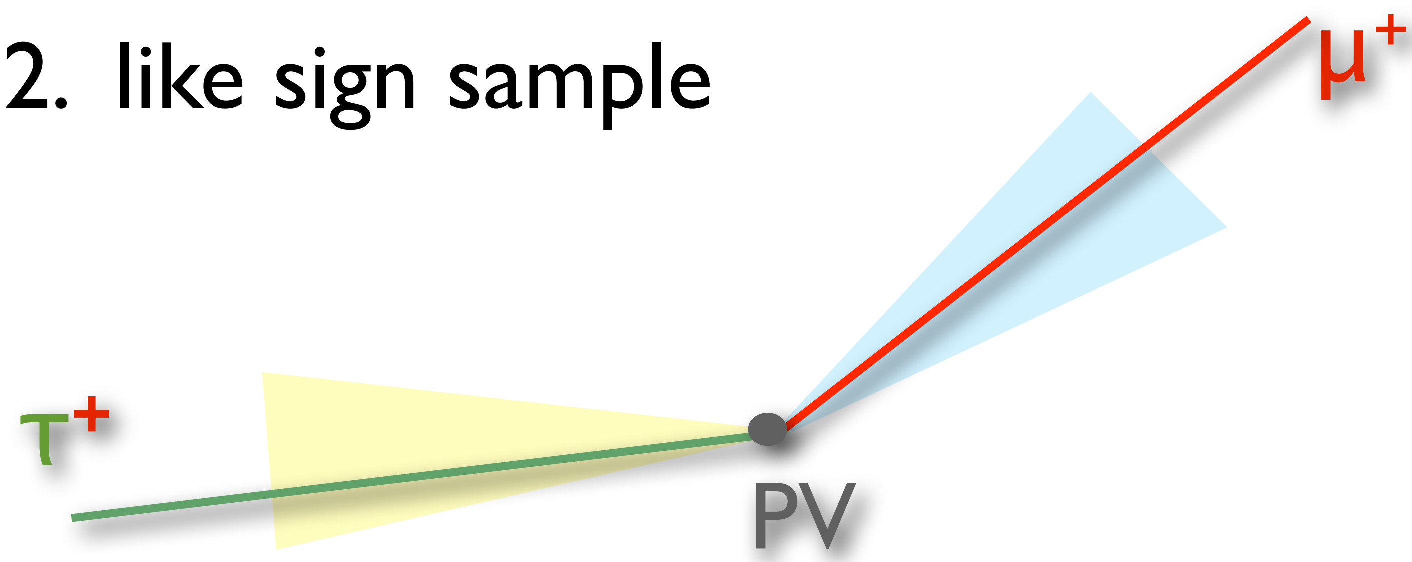
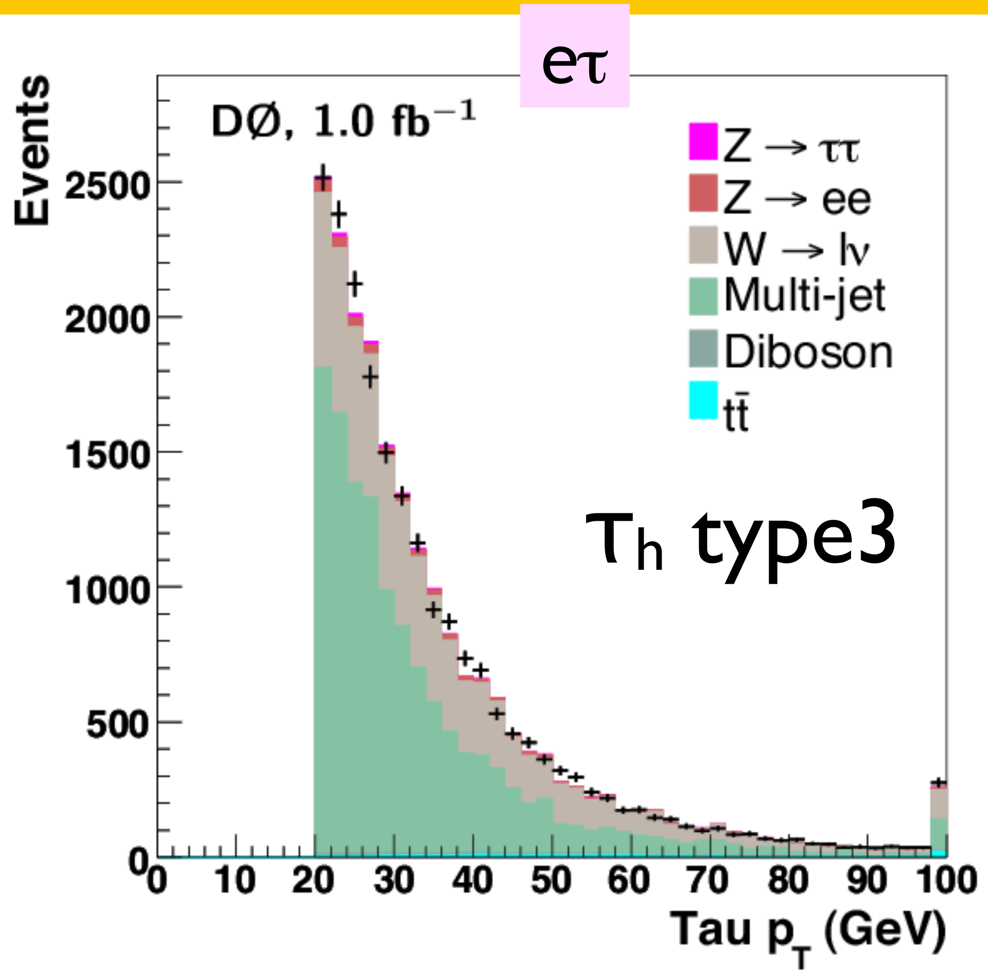


  2. like sign sample





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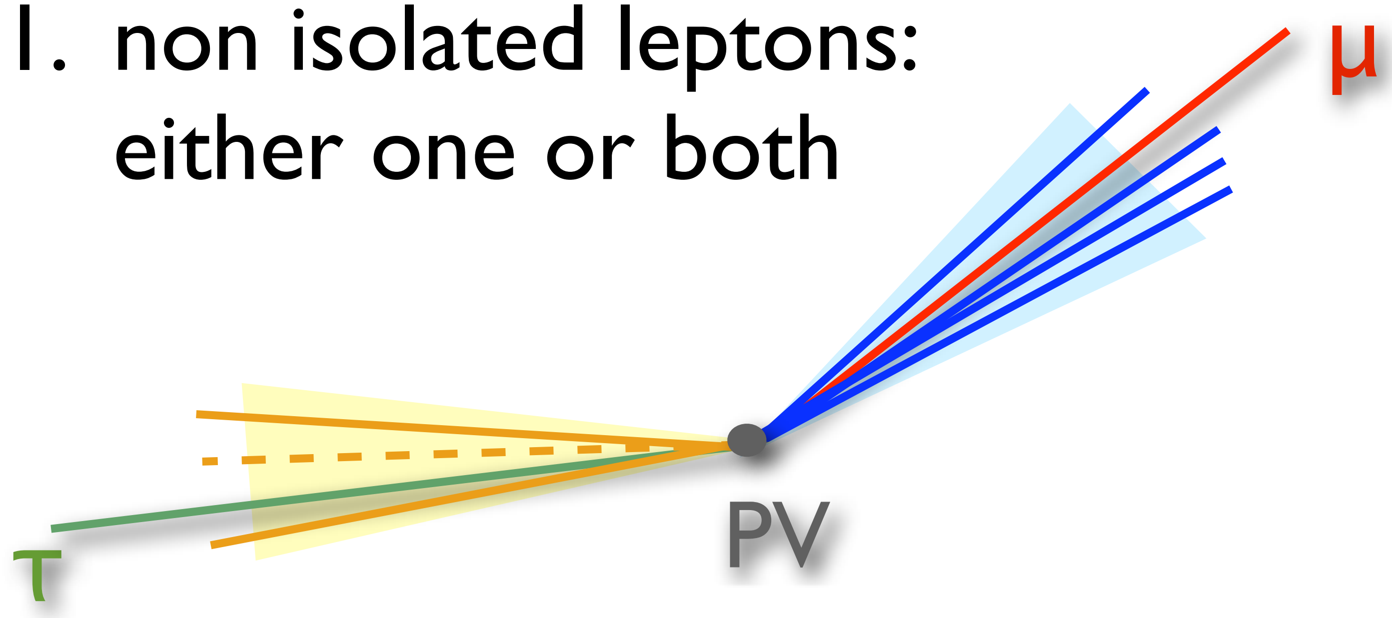
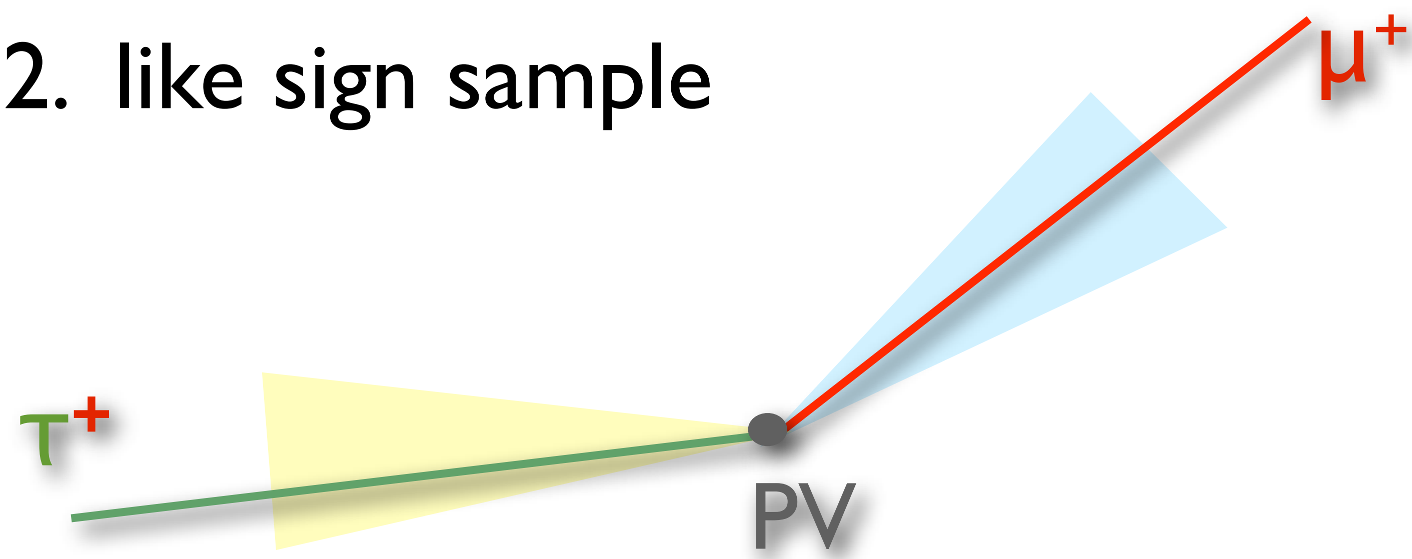
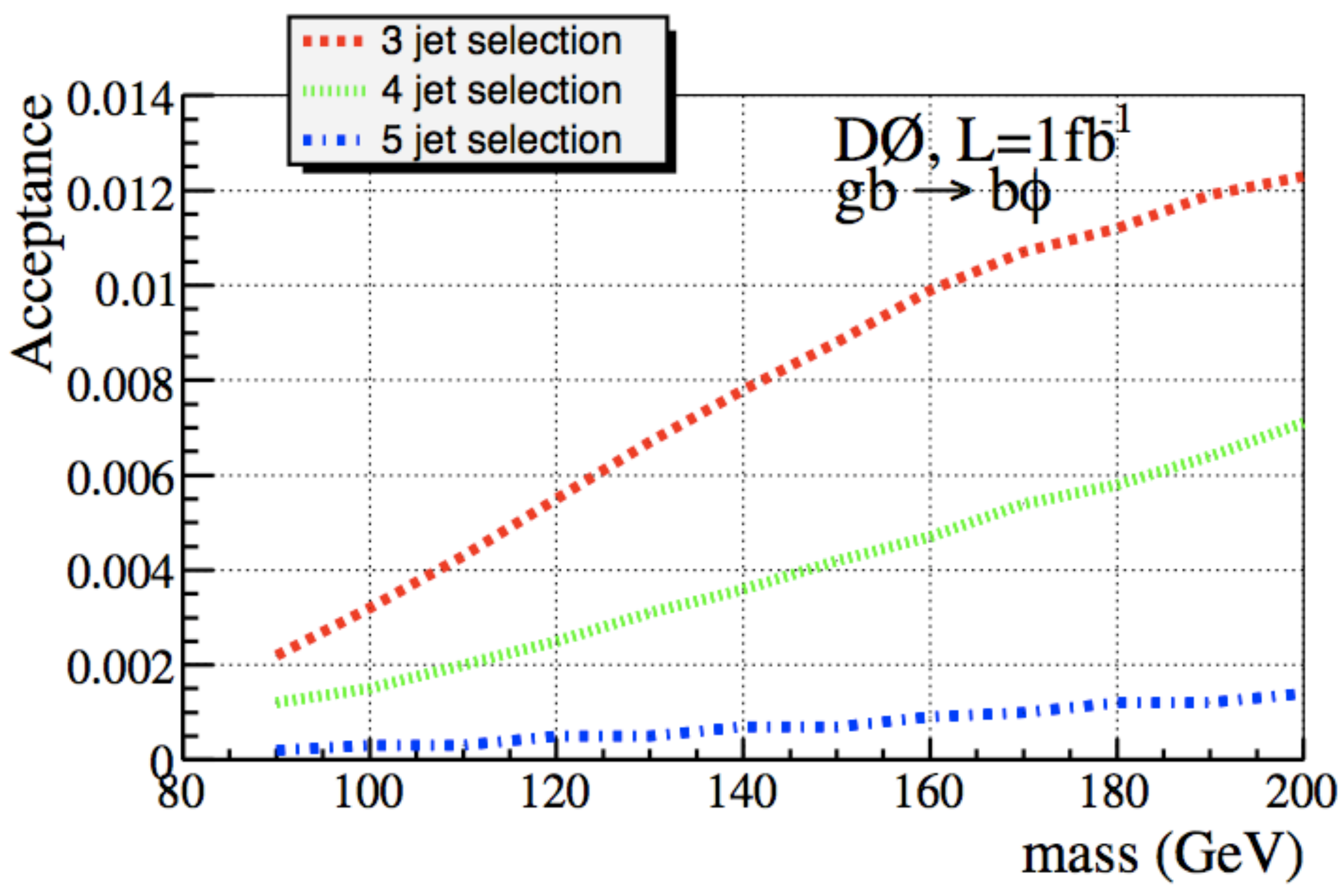


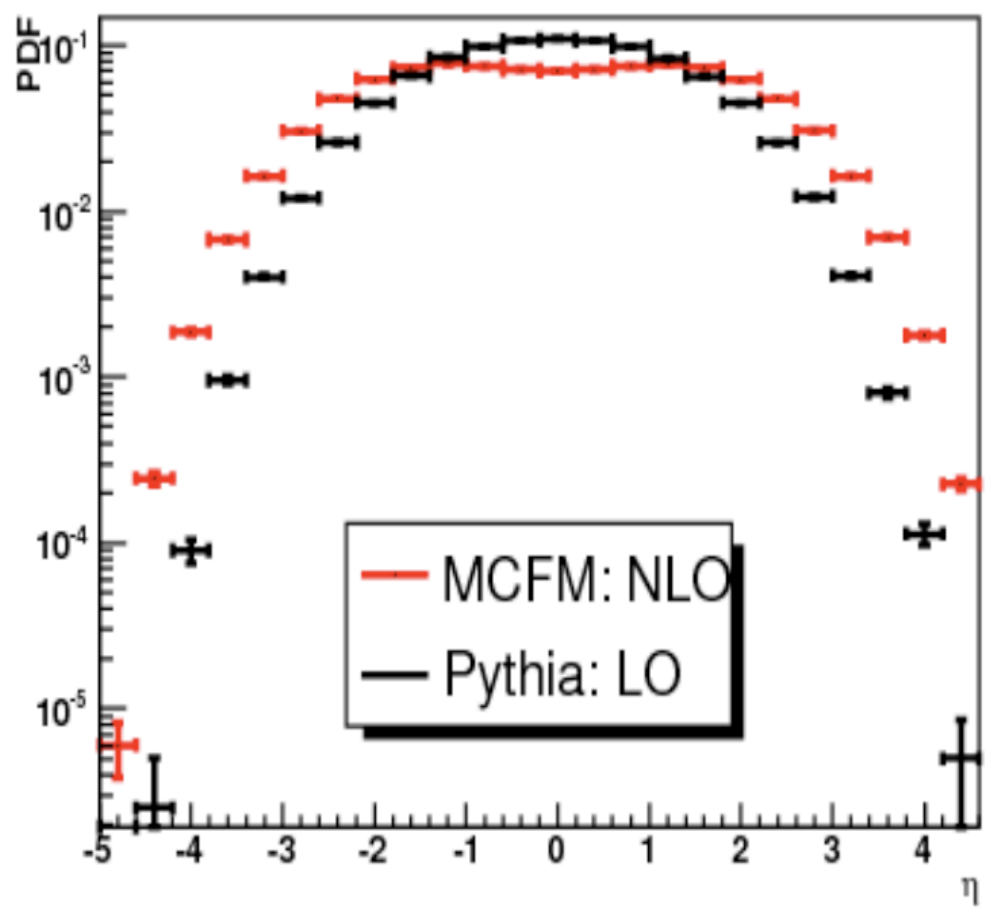
- In W MC, τ_h fake is also corrected for

2. like sign sample

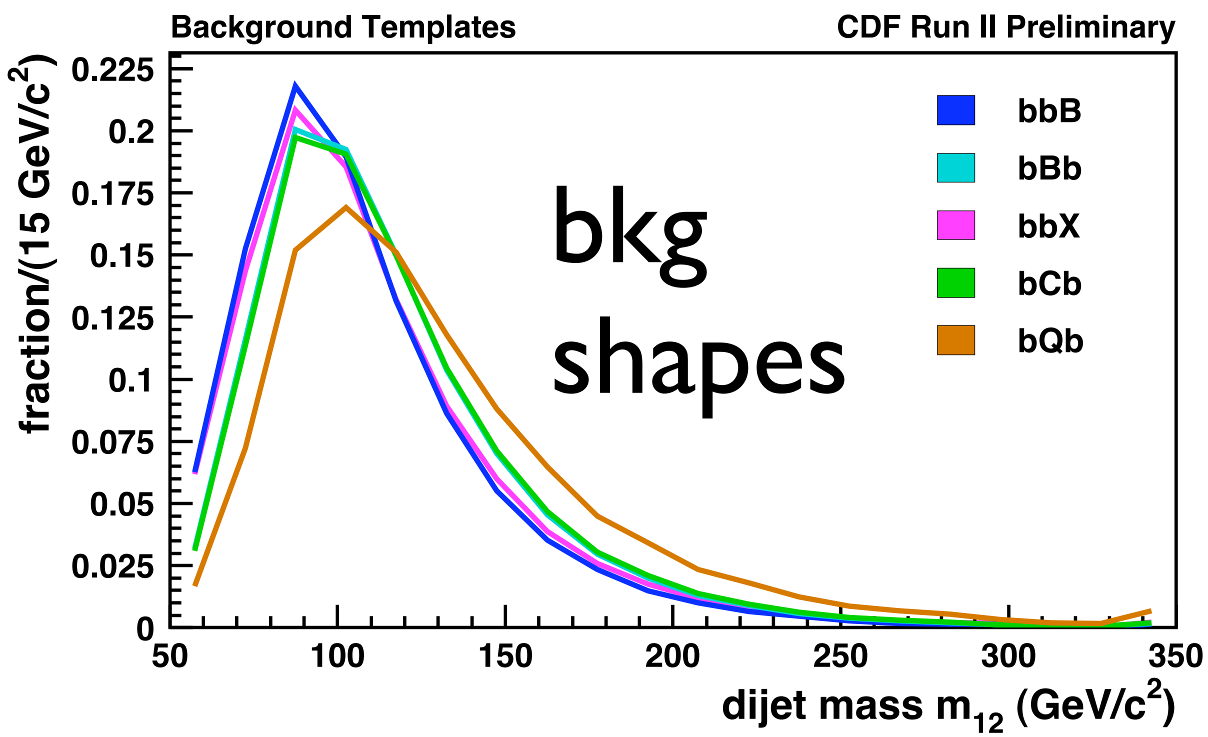


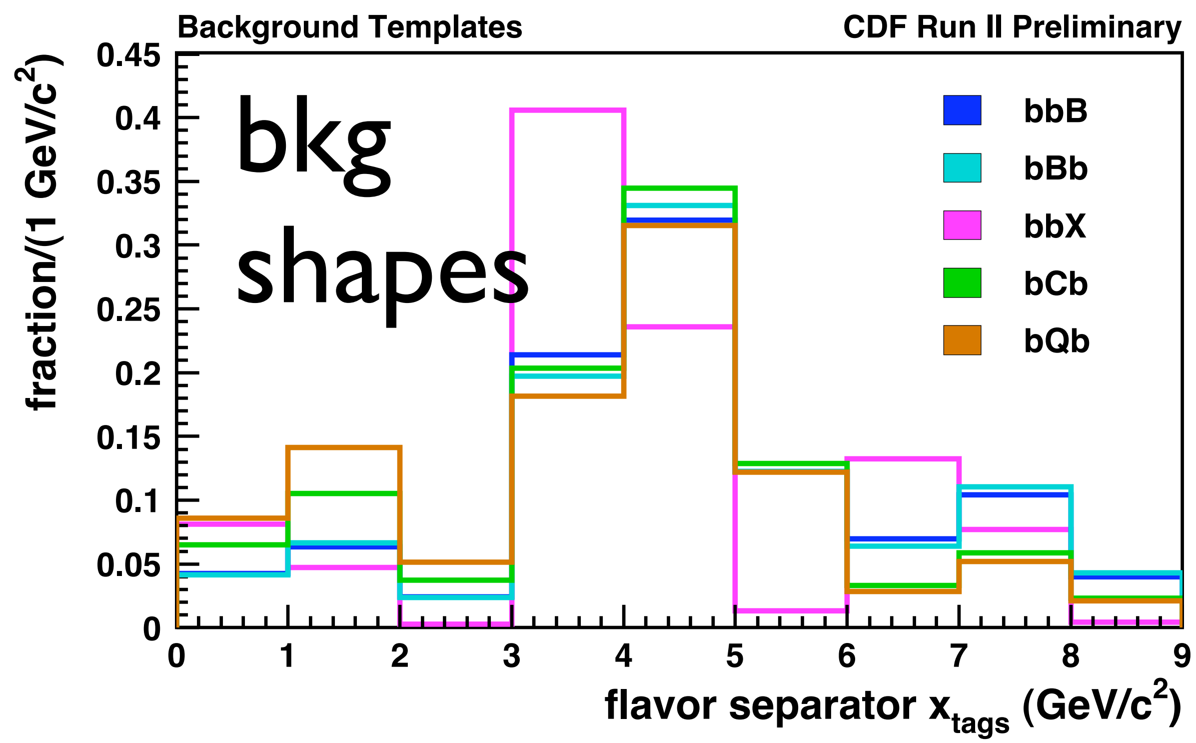
- Signal simulation: pythia bg → bH but spectator b quark kinematics reweighted to NLO (MCFM)

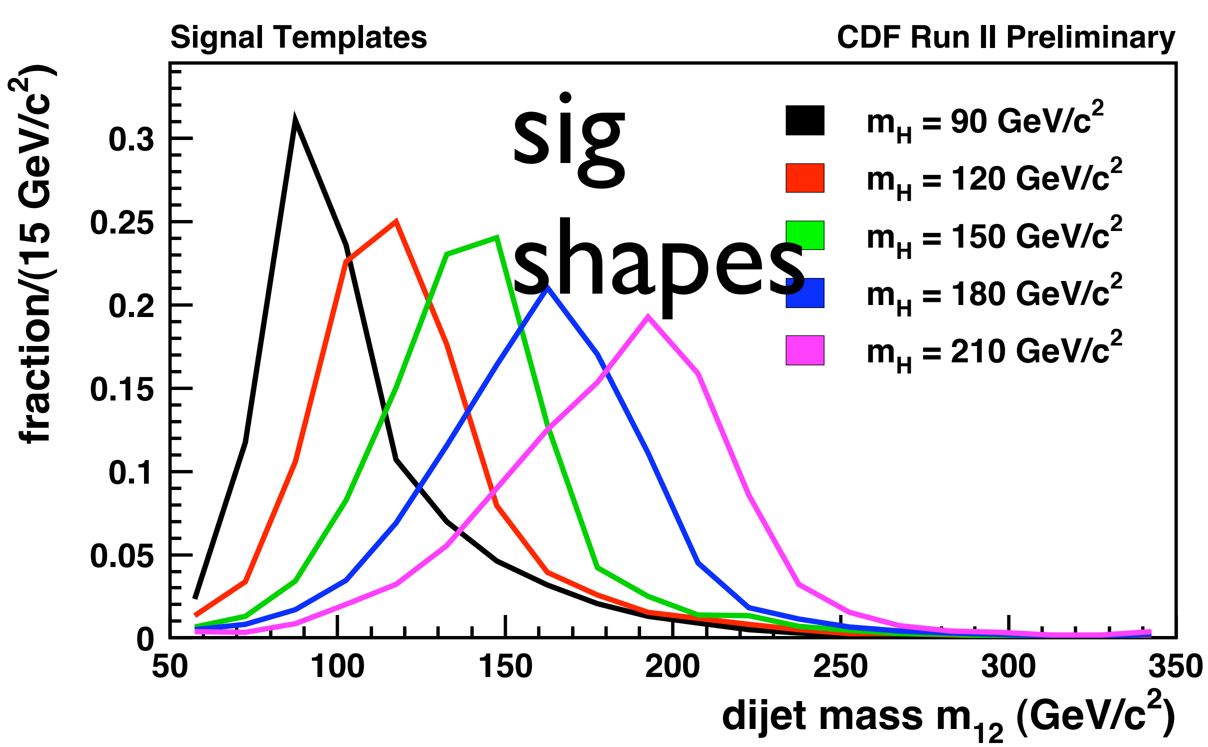


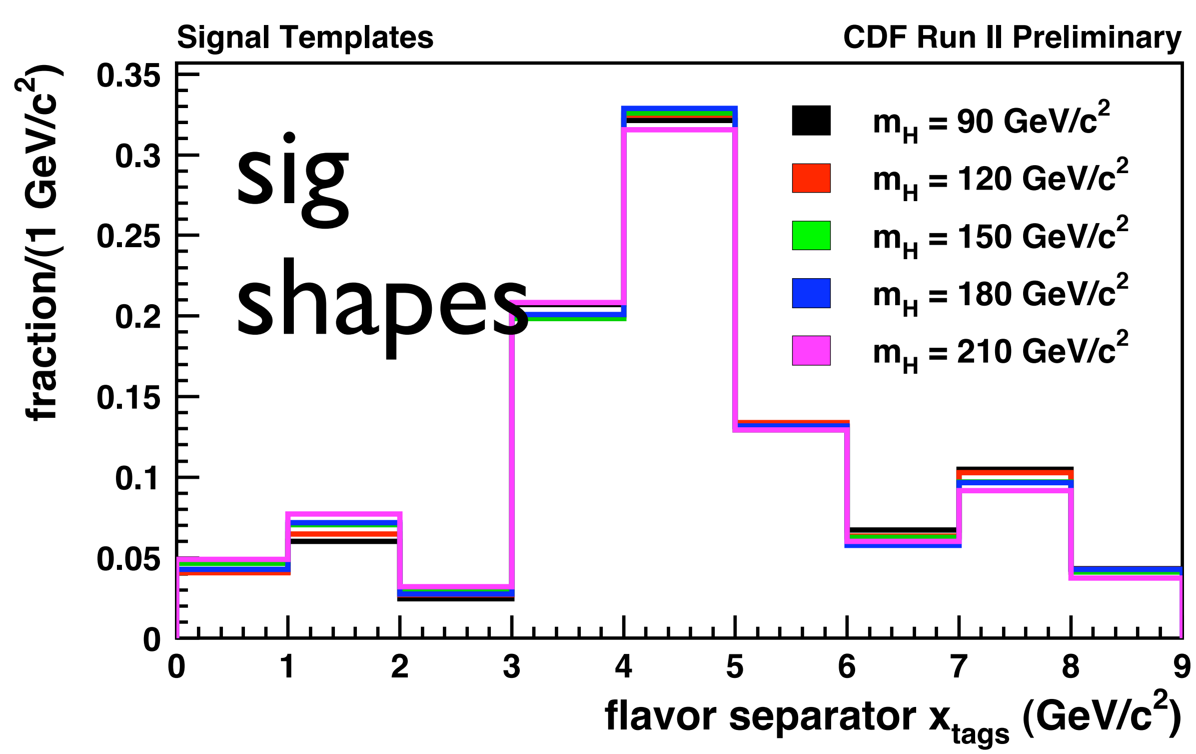


bbb background modeling

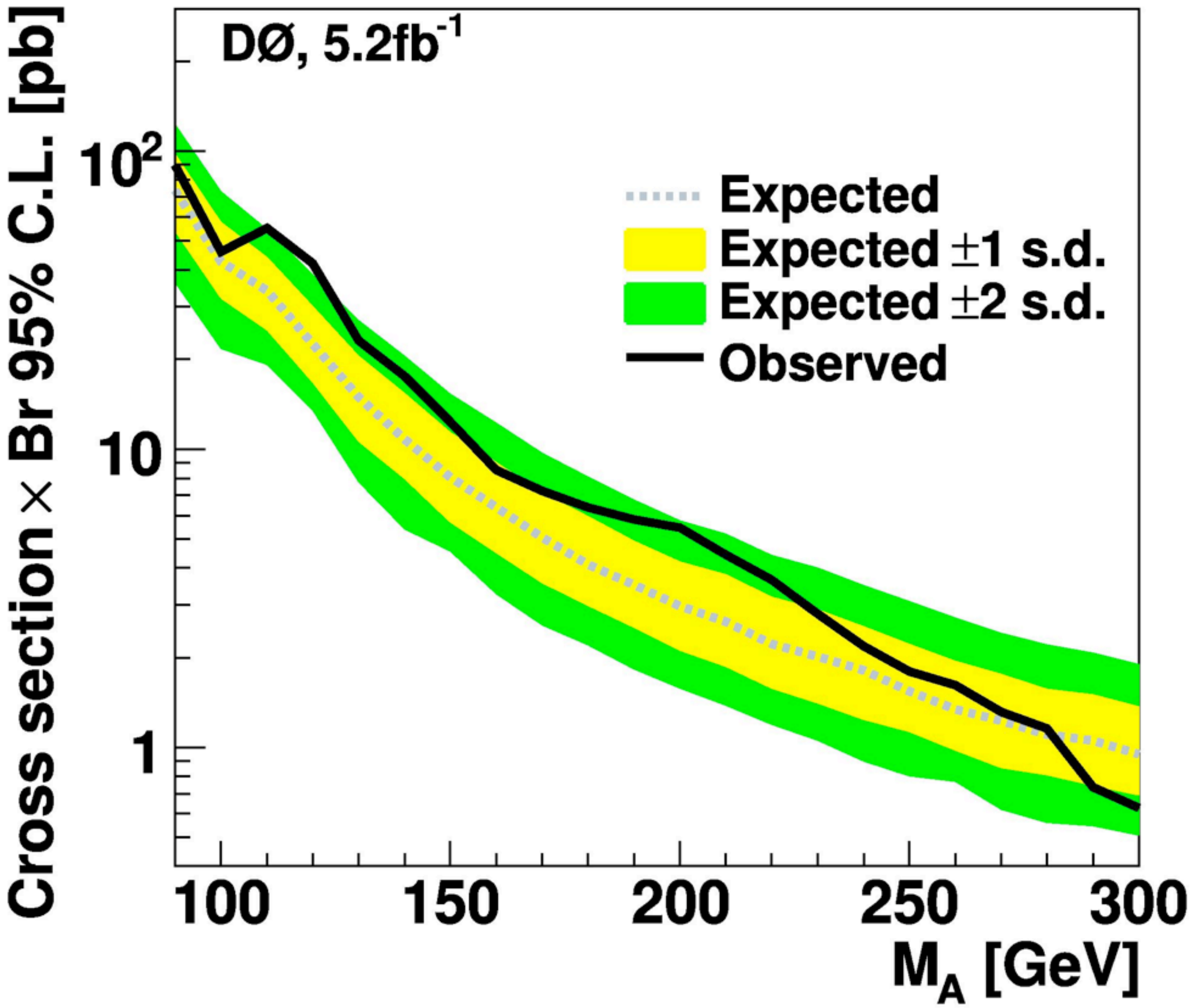


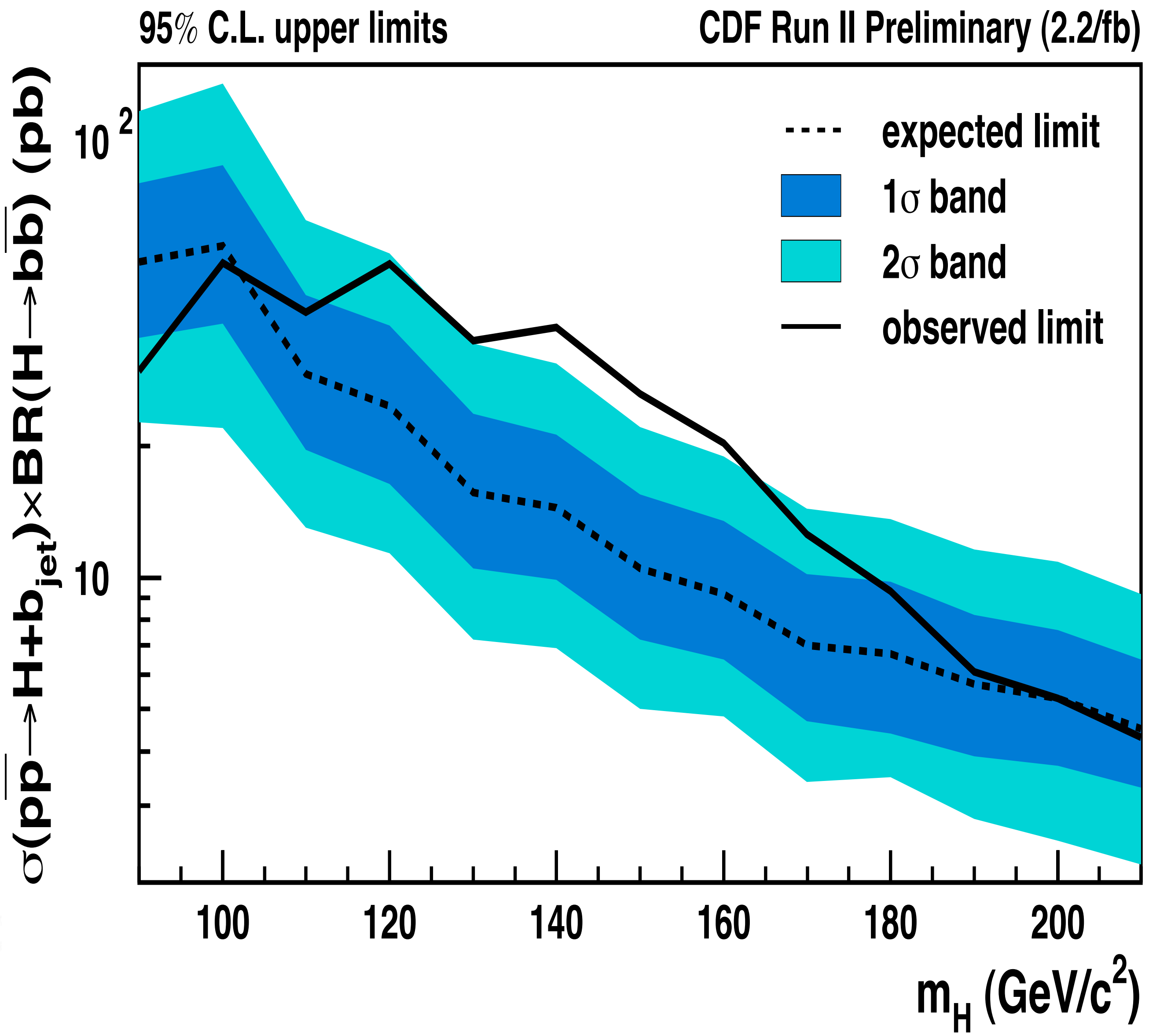






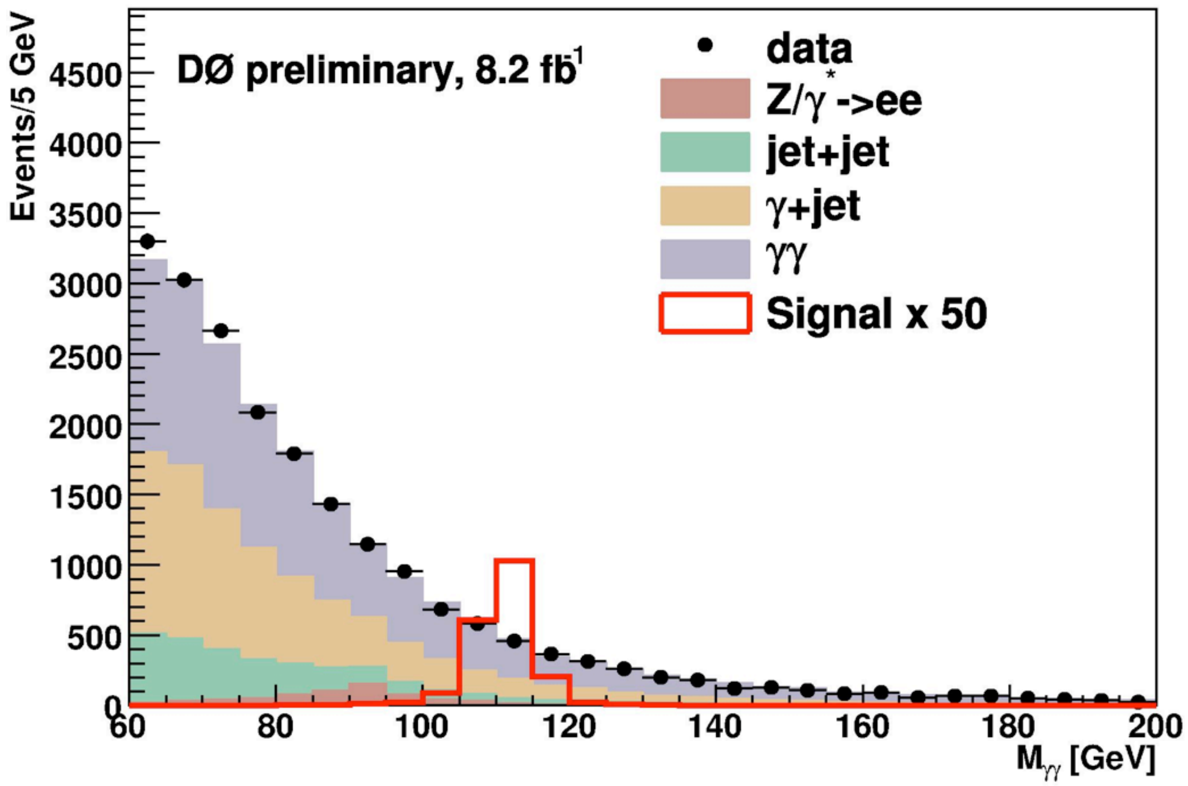
bbb results





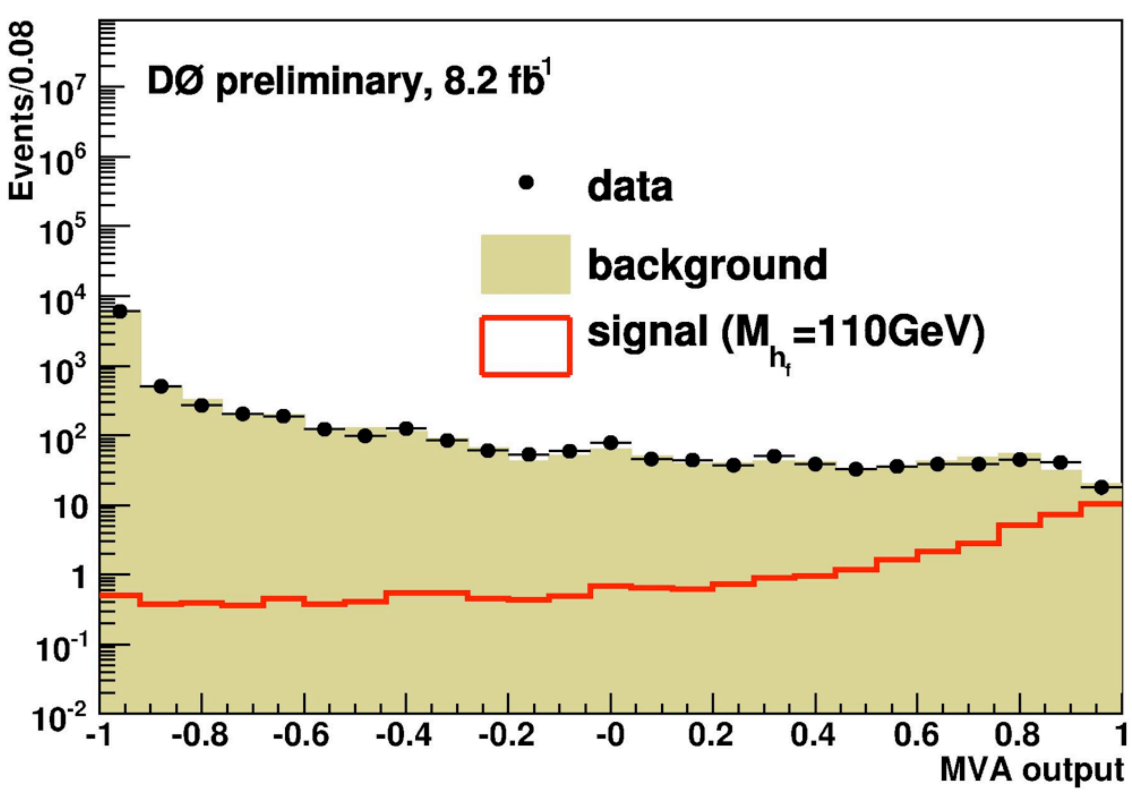
Model independent limit, neglecting the width

Fermiophobic Higgs

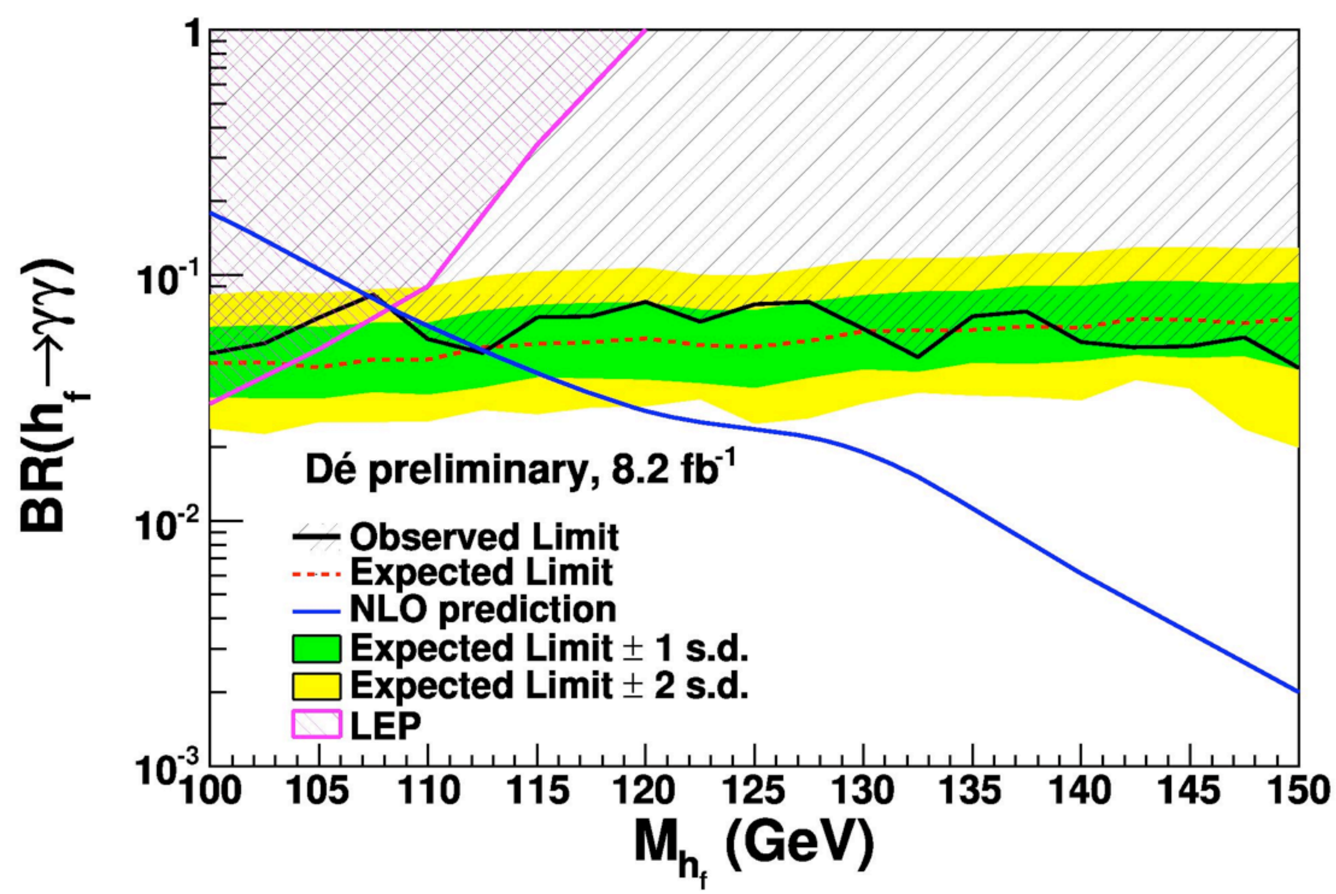


Fermiophobic Higgs:

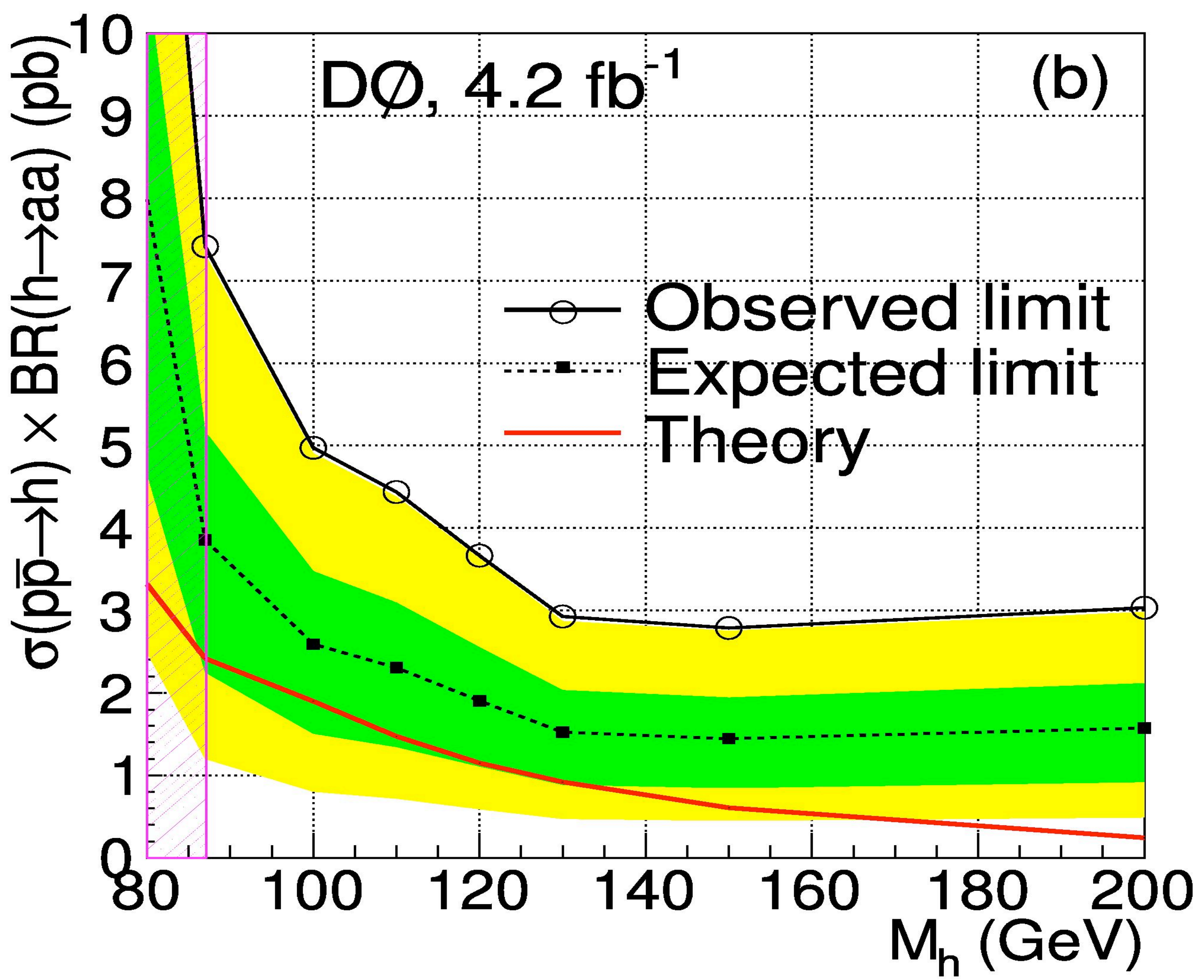
- No coupling to fermions
- same W/Z couplings as in SM
- production via WH / ZH



Excludes $m_{Hf} < 112\ \mathrm{GeV/c^2}$



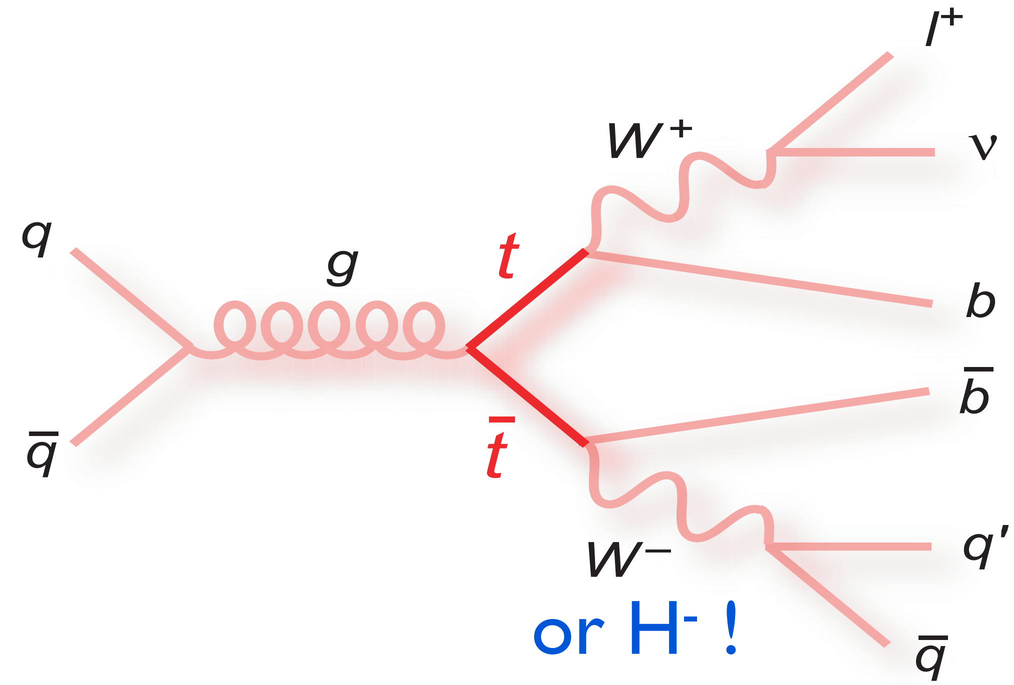
- NMSSM: gg → h → aa, a → μμ or ττ
  - If $m_a < 2m_\tau$: h → aa → μμμμ
    - Two pairs of collinear muons
  - If $m_a > 2m_\tau$: h → aa → μμττ
    - Back-to-back μ and τ pairs



- If $m_{H+} < m_{top}$:

  $t \rightarrow H^+ b$ opens

- H^+ decays are very different from W^+ decays:
  - ✓ high tanβ: $B(H^+ \rightarrow \tau\, \upsilon) = 1$
  - ✓ leptophobic: $B(H^+ \rightarrow c\, \bar{s}\,) = 1$



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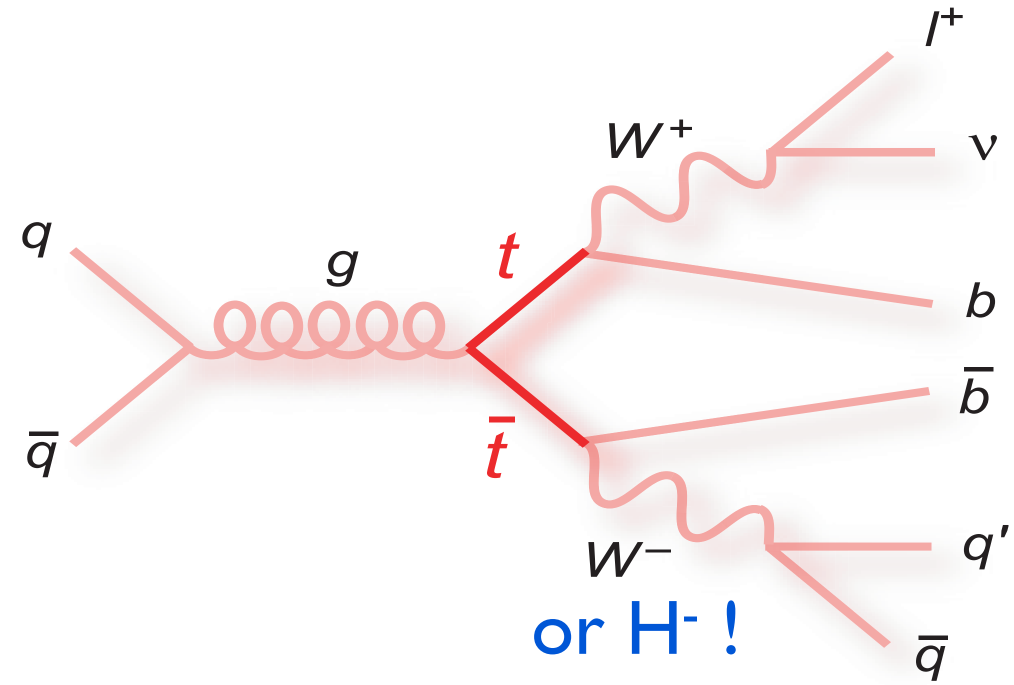

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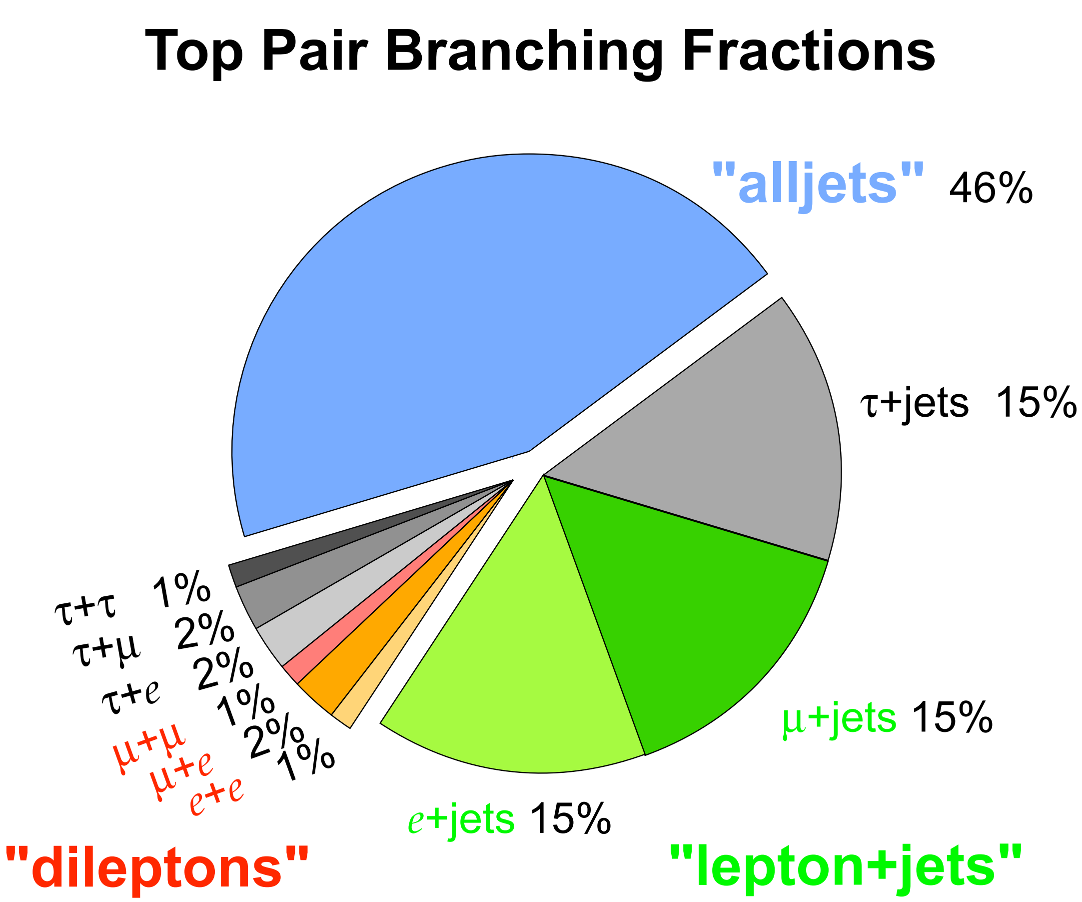
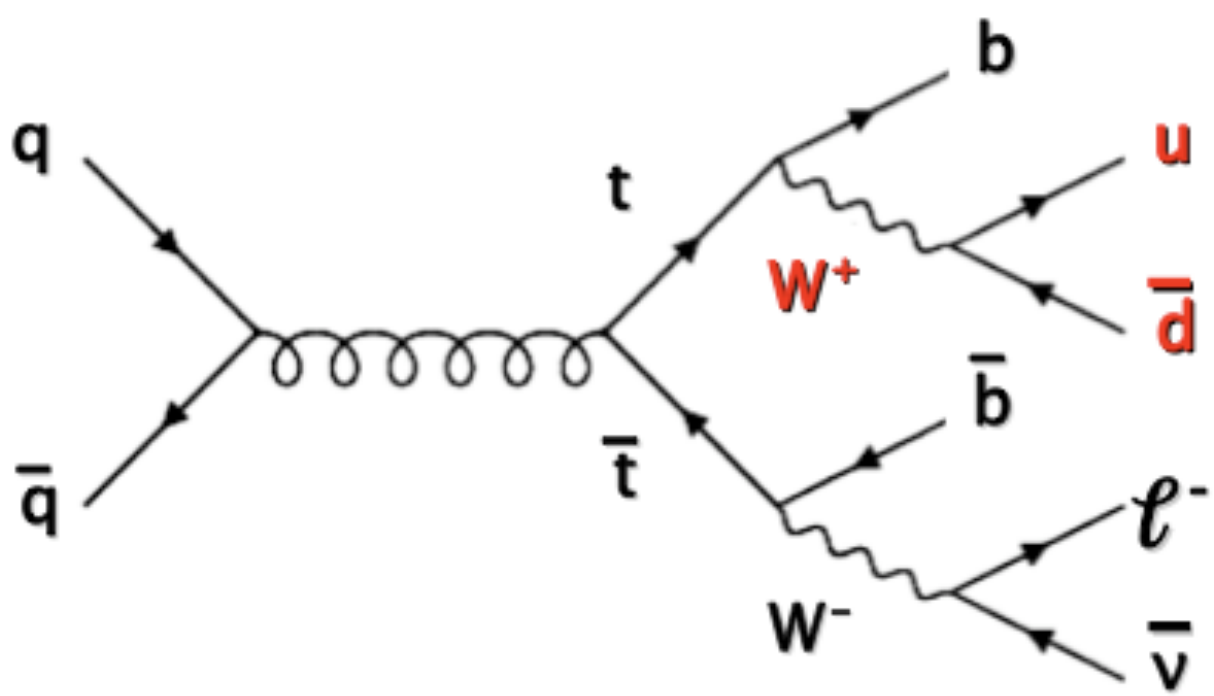
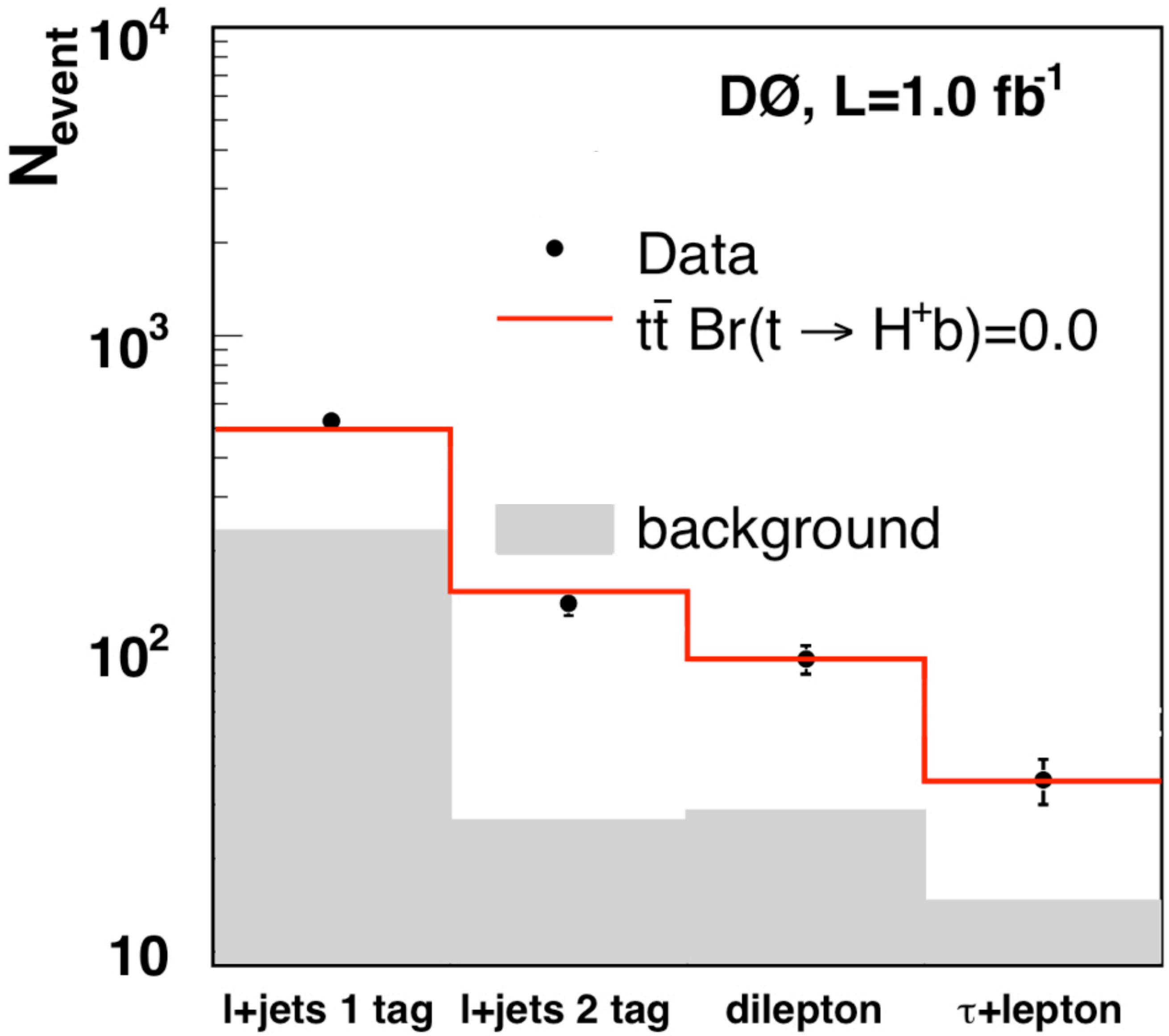
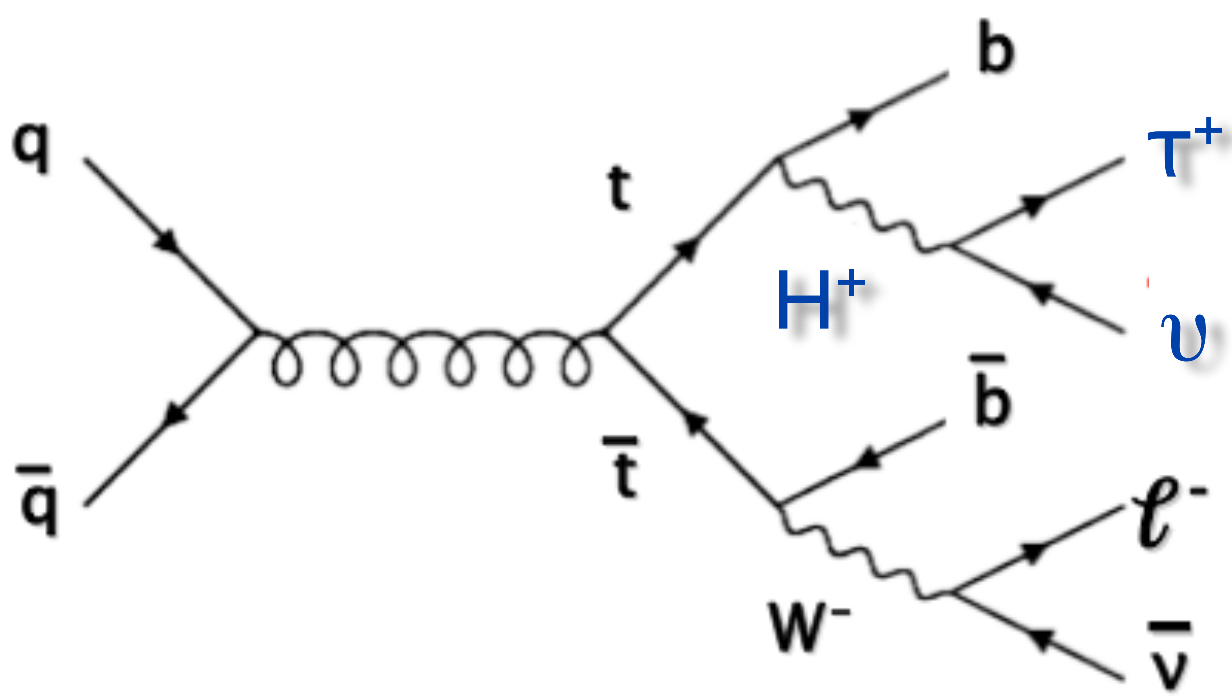


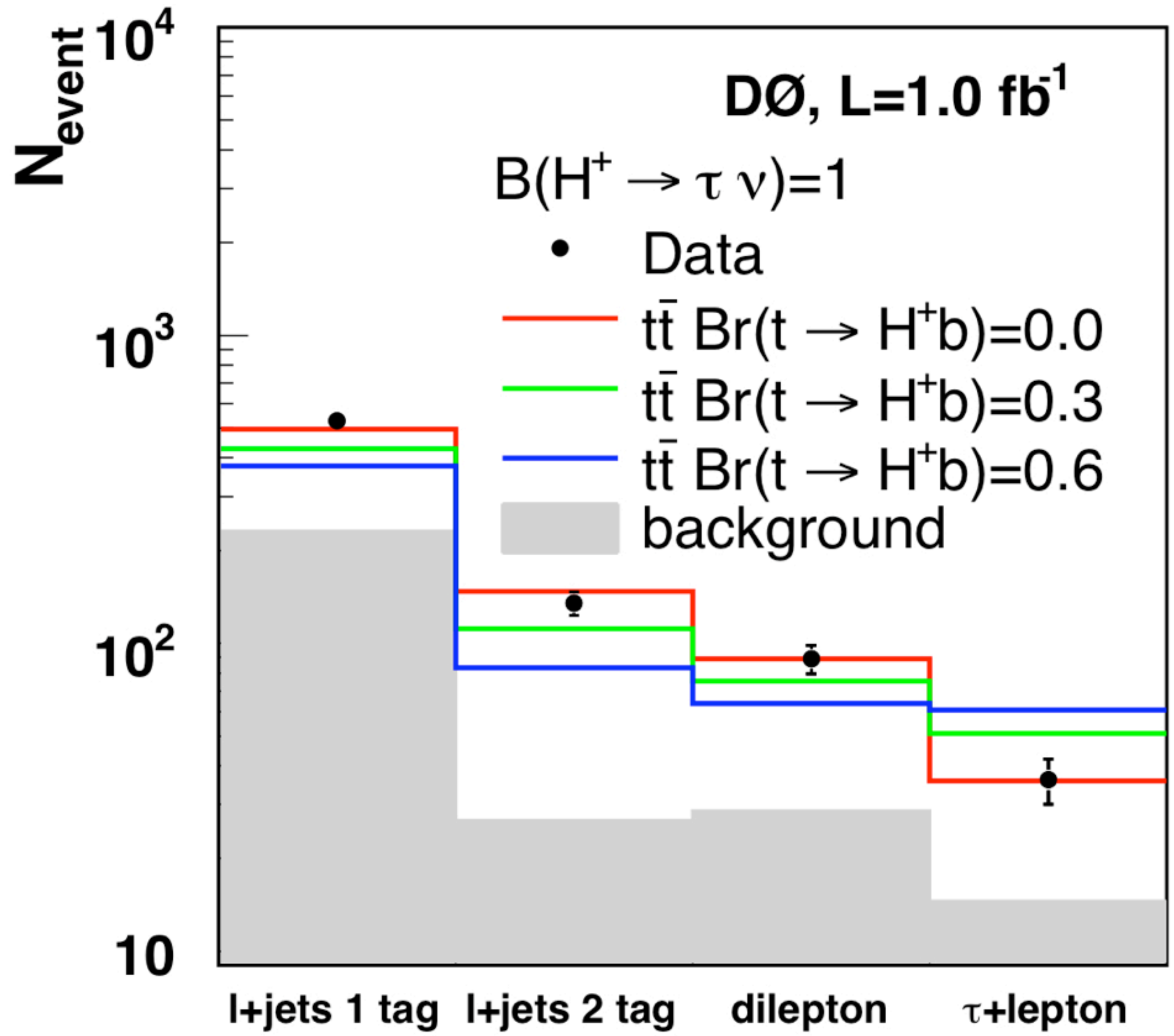
- Changes the different channels contributions: compare all the measured cross sections

Charged Higgs

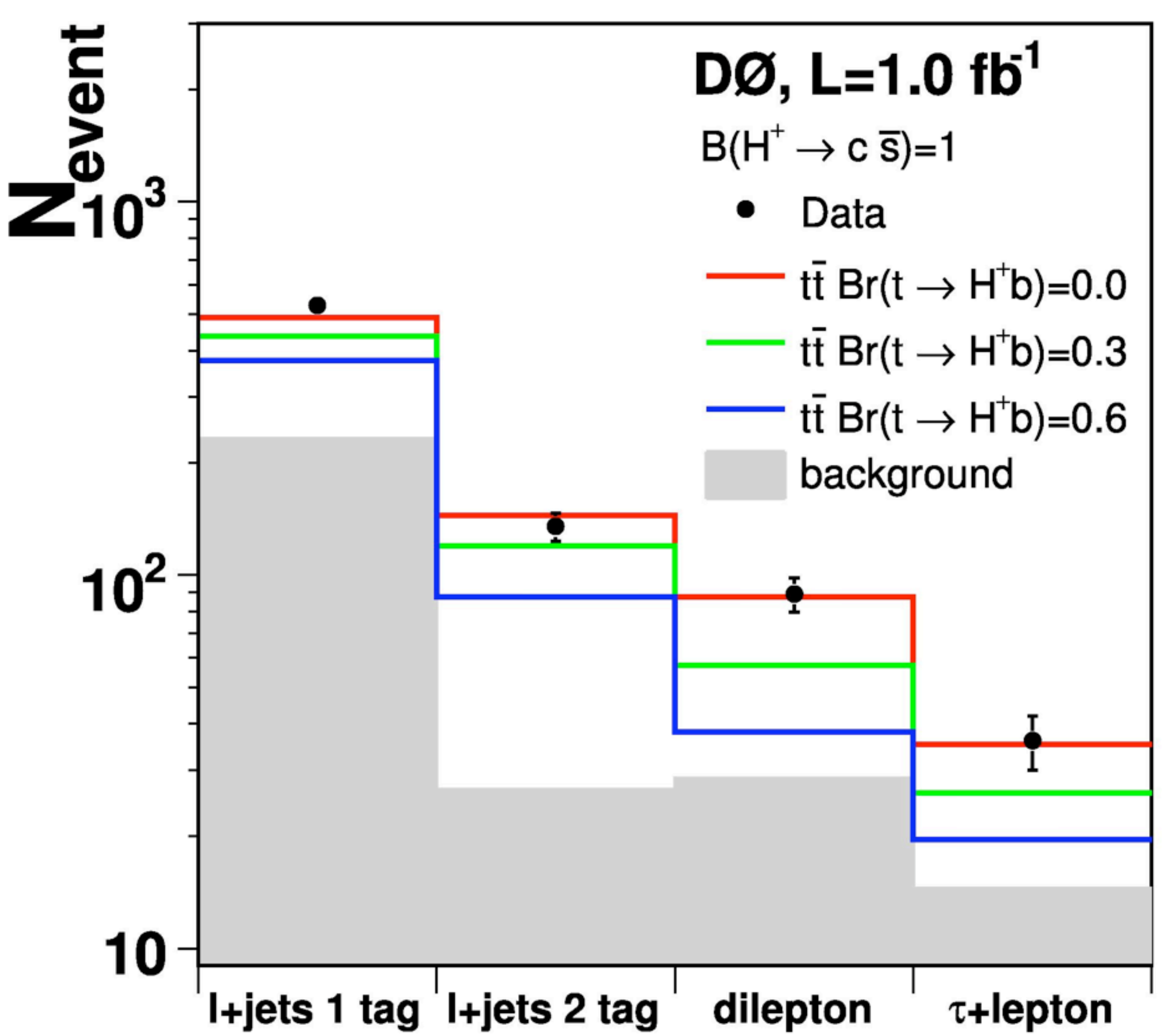




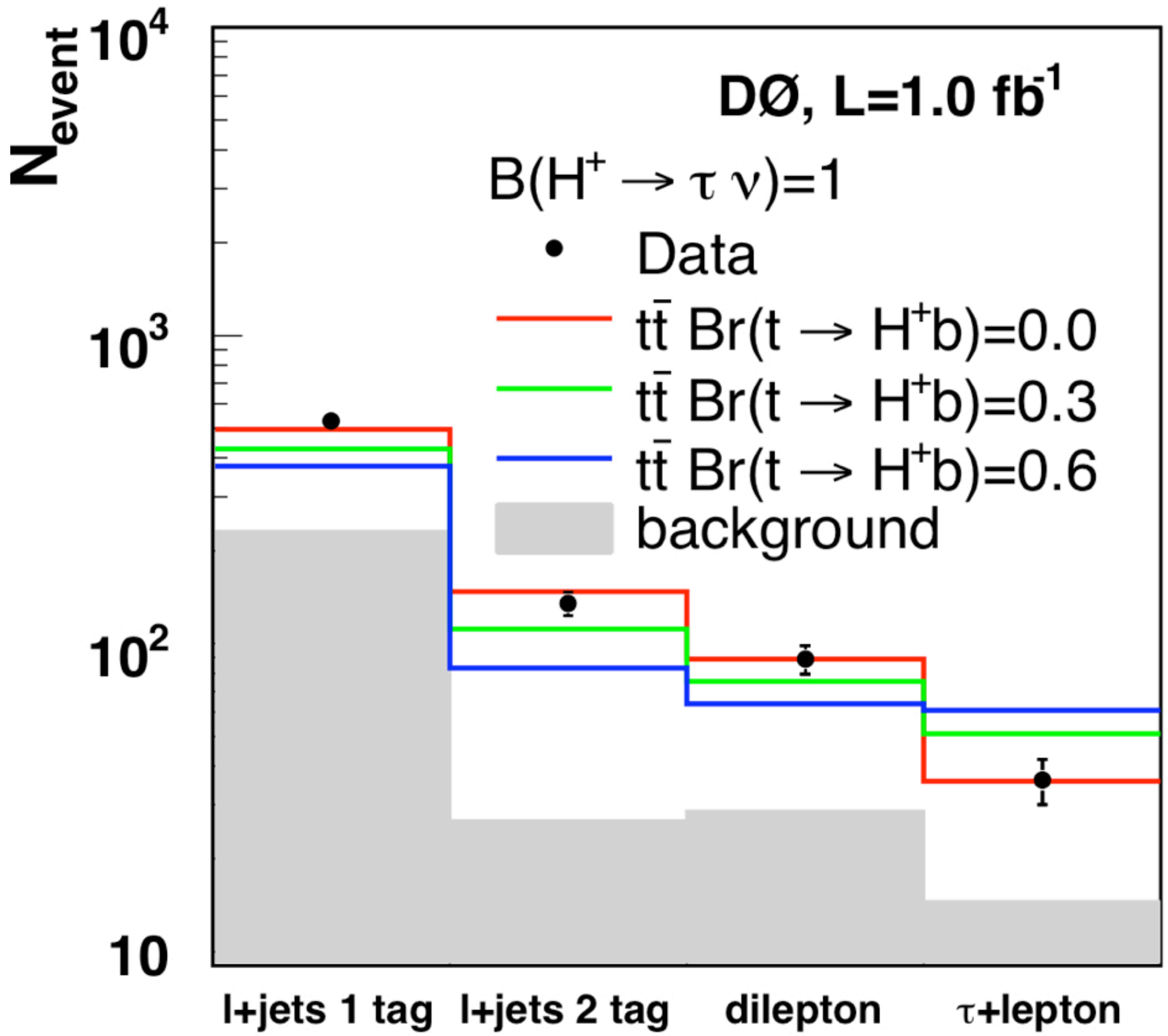

q
$\bar{q}$
t
$\bar{t}$
b
$\bar{b}$
H^+
τ^+
υ
W^-
ℓ^-
$\bar{\nu}$

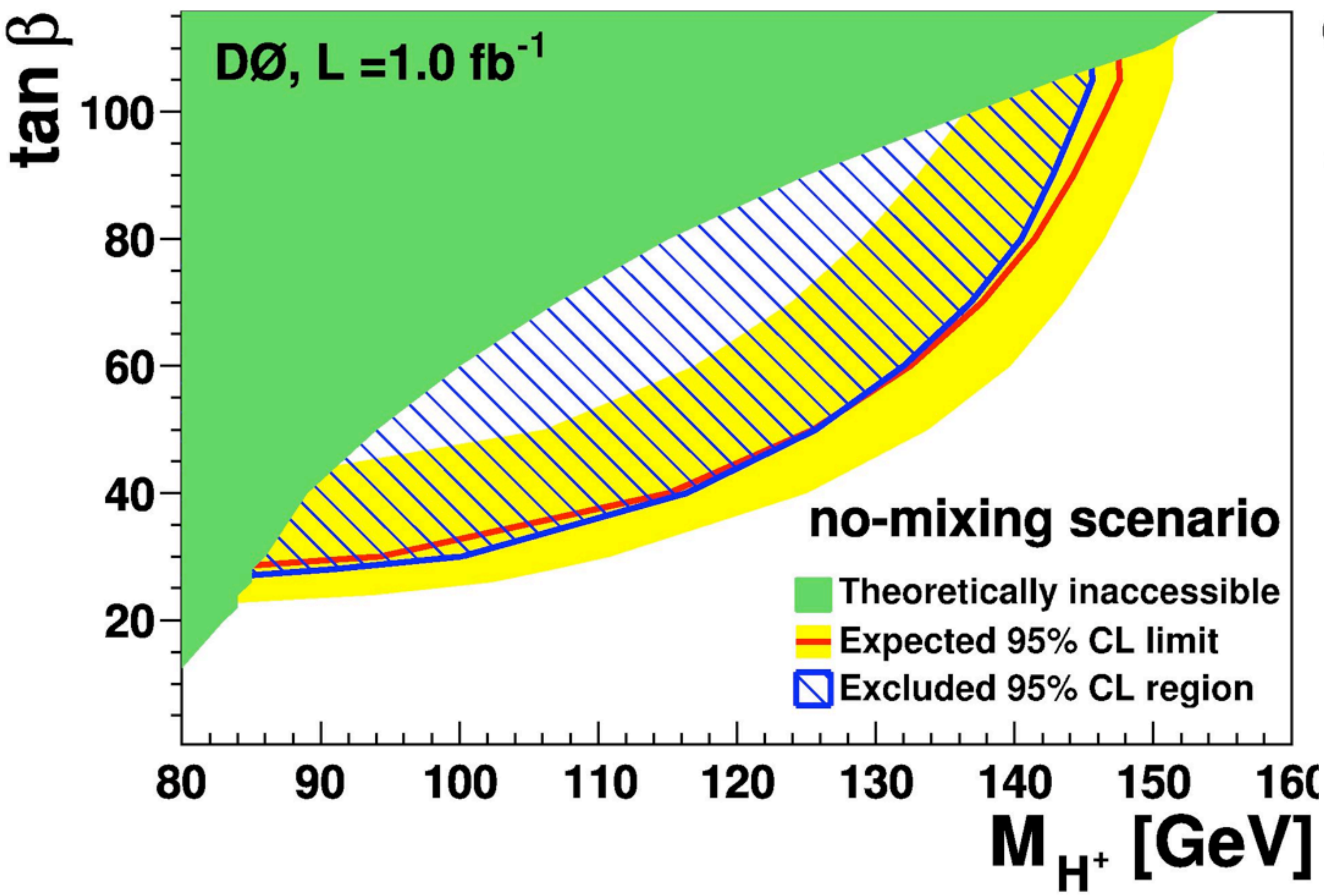

N_{event}
10^4
10^3
10^2
10
DØ, L=1.0 fb^{-1}
$B(H^+ \to \tau\nu)=1$
Data
$t\bar{t}$ Br(t → H^+b)=0.0
$t\bar{t}$ Br(t → H^+b)=0.3
$t\bar{t}$ Br(t → H^+b)=0.6
background
l+jets 1 tag
l+jets 2 tag
dilepton
τ+lepton

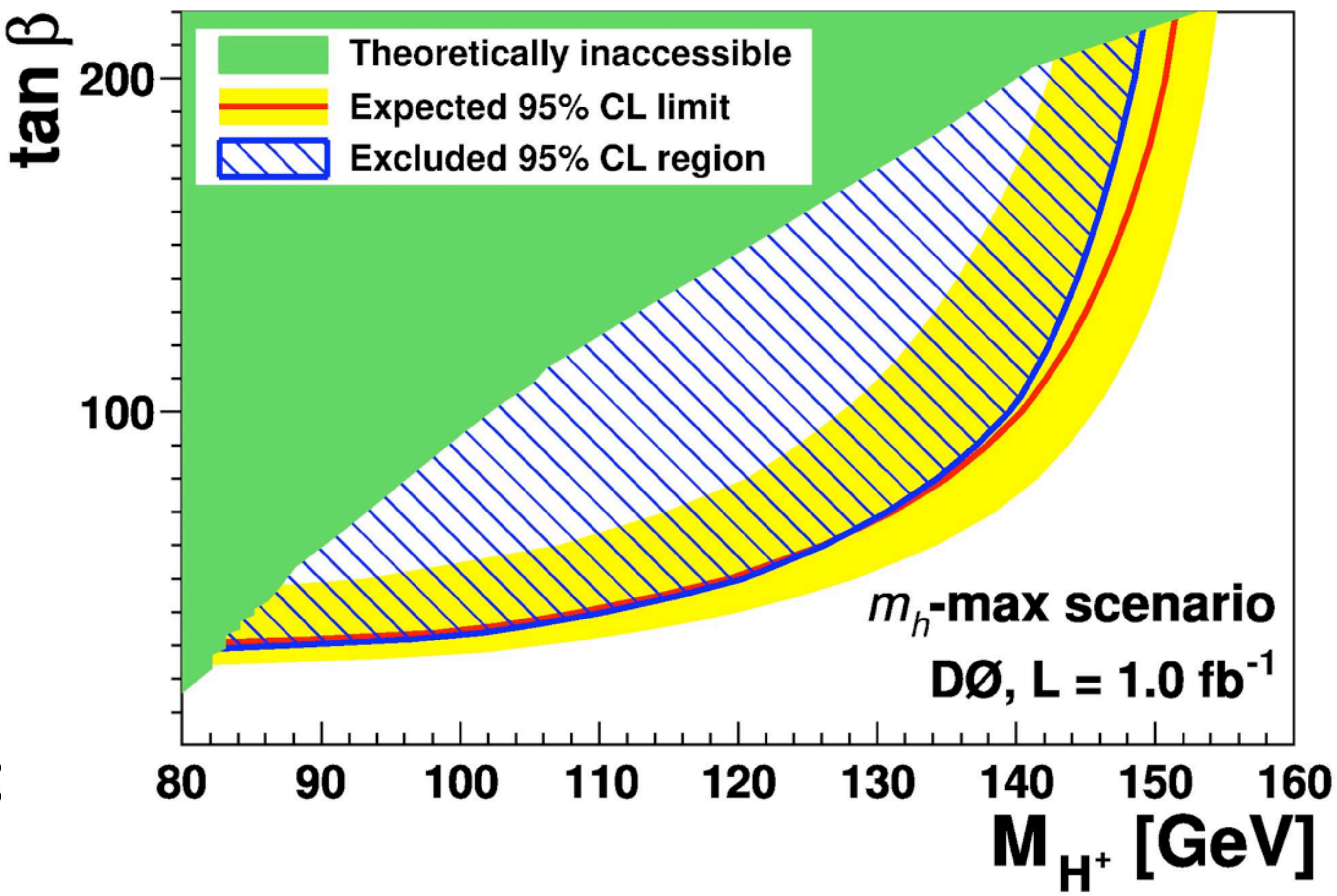
leptophobic Higgs



tauonic Higgs





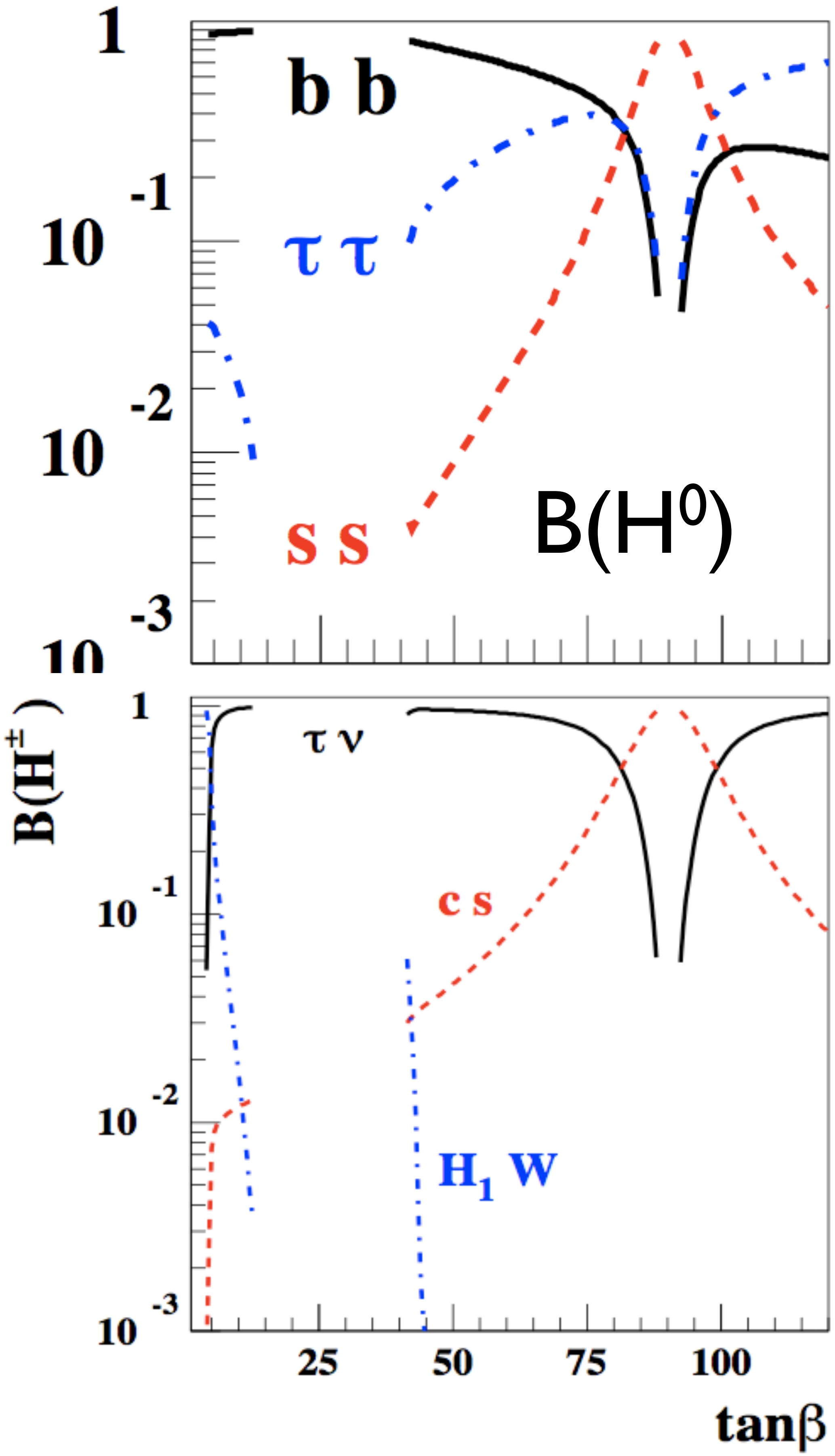


arXiv:0908.1811, submitted to PLB

method based only on cross section ratios:
arXiv:0903.5525, submitted to PLB

Another strategy:
The topological method
PRL 102, 191802 (2009)

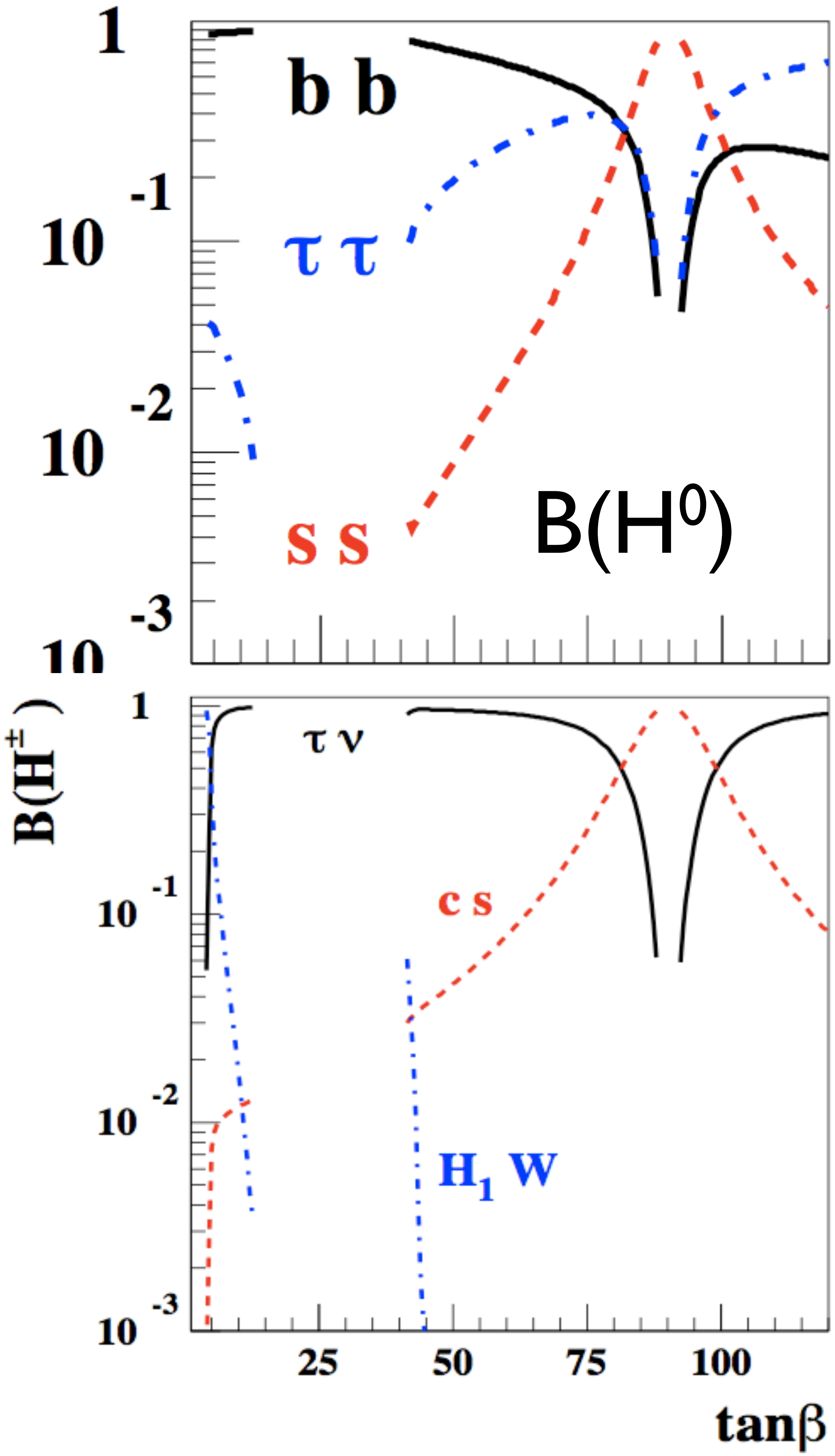
CPX scenario



CPX benchmark scenario:

- coupling to s-quark dramatically enhanced compare to b
- strangephilic Higgs bosons
- $B(H^+ \rightarrow cs) \approx 1$

Lee, Peters, Pilaftsis,and C. Schwanenberger, arXiv:0909.1749



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