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

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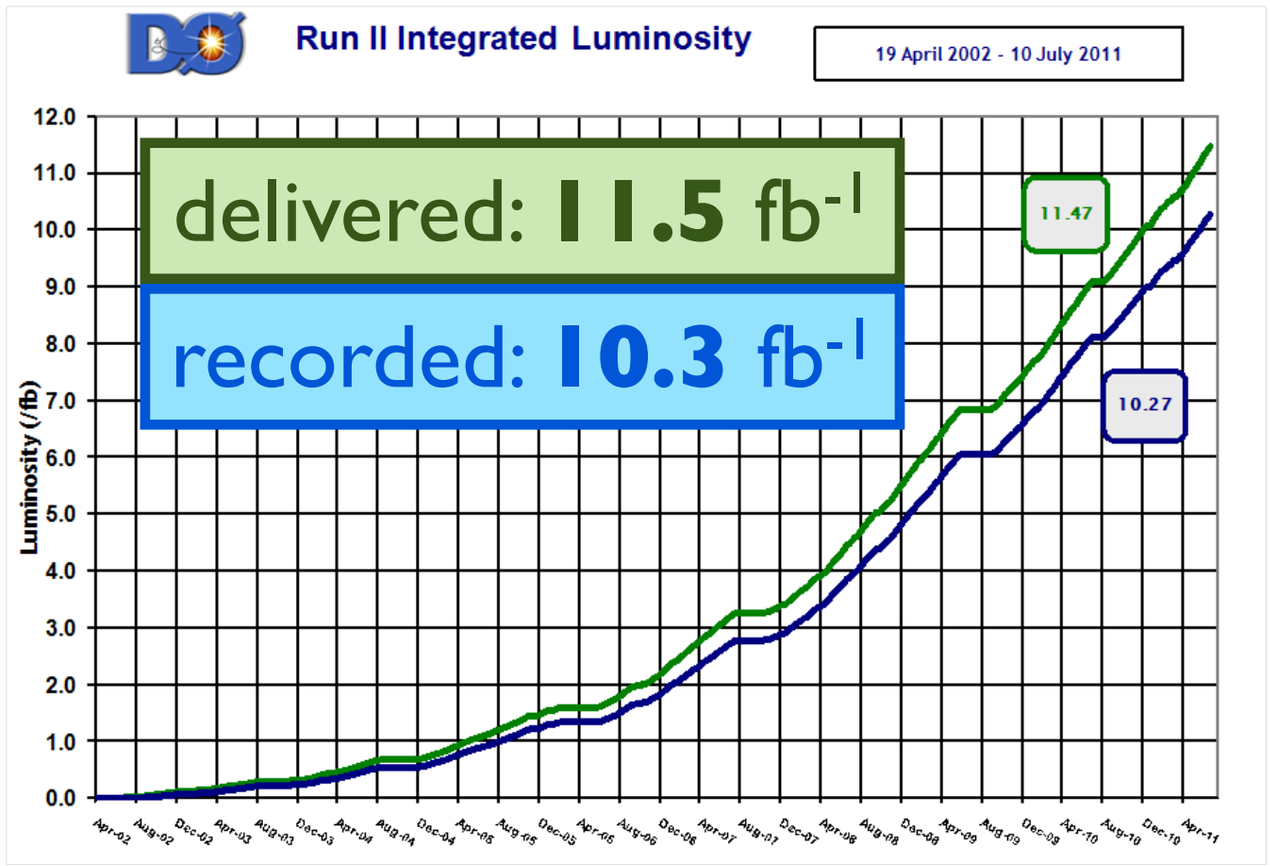
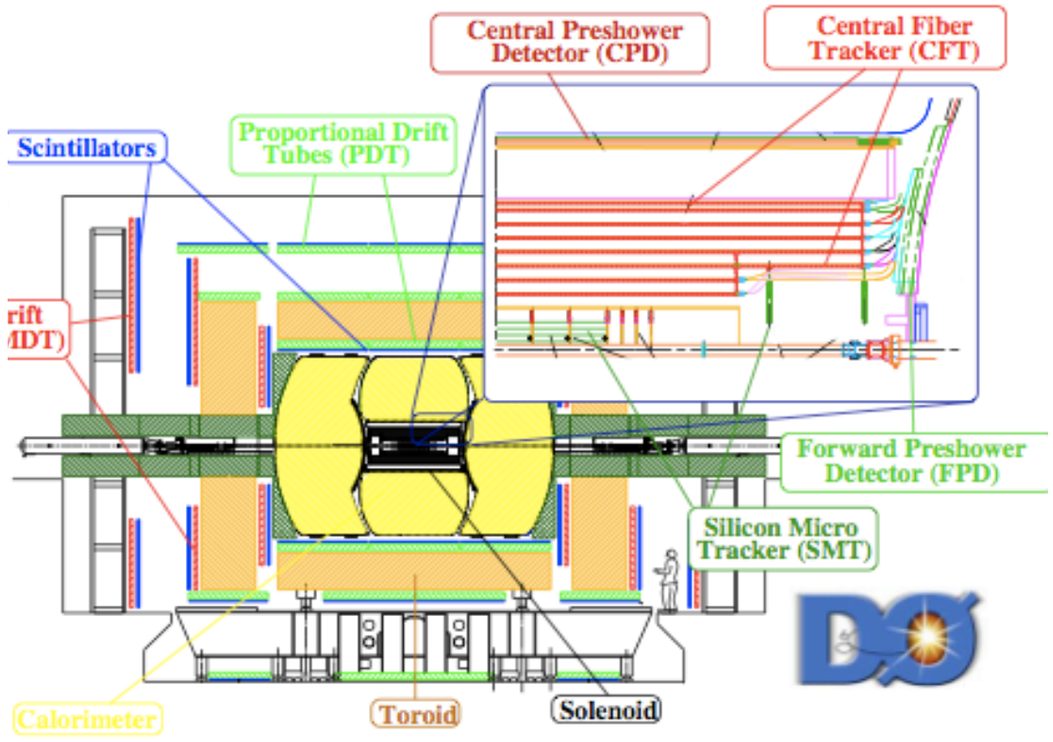
EPS-HEP

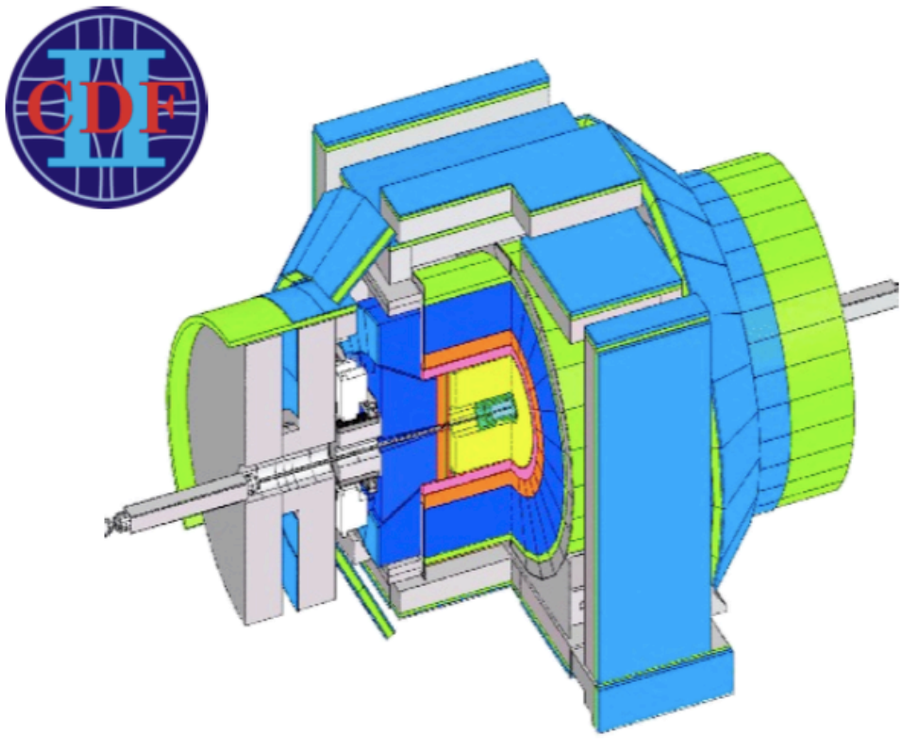
Grenoble, France

Outline

- ✓ Introduction
- ✓ MSSM Higgs searches
  - ✦ inclusive $h \to \tau\tau$ search
  - ✦ associated hb production
    - bbb final state
    - $\tau\tau$b final state
- ✓ H^{++} search
- ✓ Conclusions







Higgs sector in the MSSM

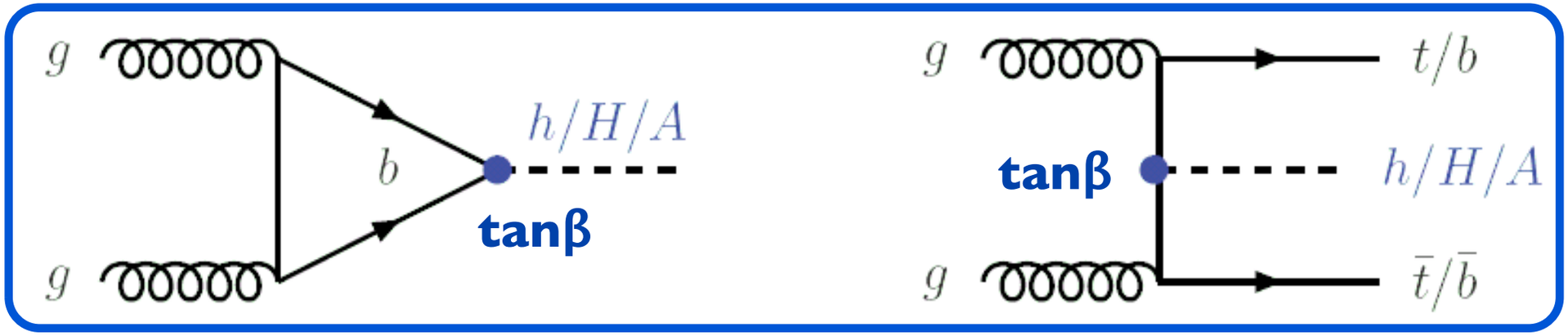
- MSSM: exactly 2 Higgs doublets coupling to down-type quarks (vev v_d), and up-type quarks (vev v_u). $\tan\beta = v_u/v_d$

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

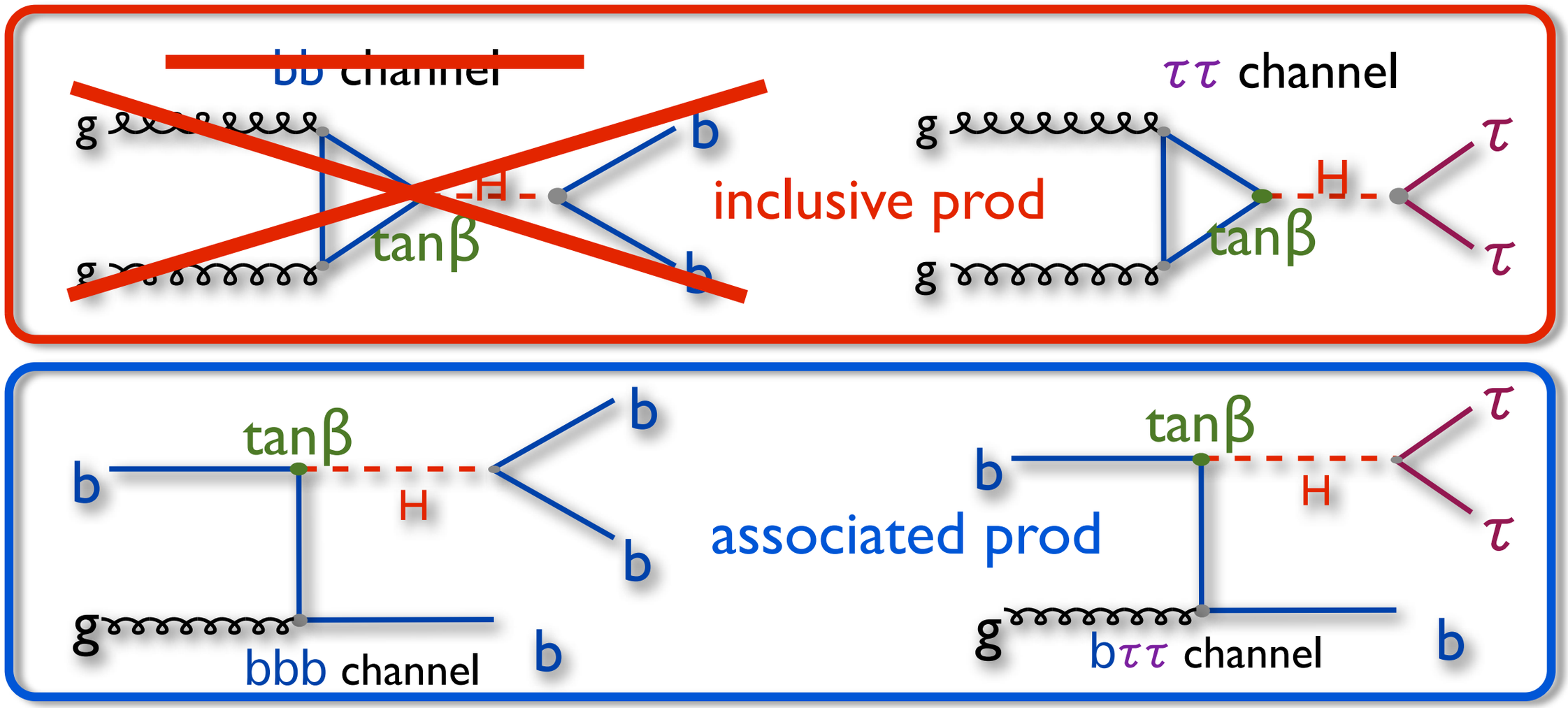
- After EW breaking: 5 physical states
  - 3 neutral Higgs bosons: h/H (CP-even) and A (CP-odd)

    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 $\quad \sigma_{prod}$ x 2!
  - coupling to b quarks enhanced by $\tan\beta$
  - neutral Higgs: $\mathcal{B}(\phi \to b\bar{b}) \approx 90\ \%$ and $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10\ \%$

Susy Higgs production



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

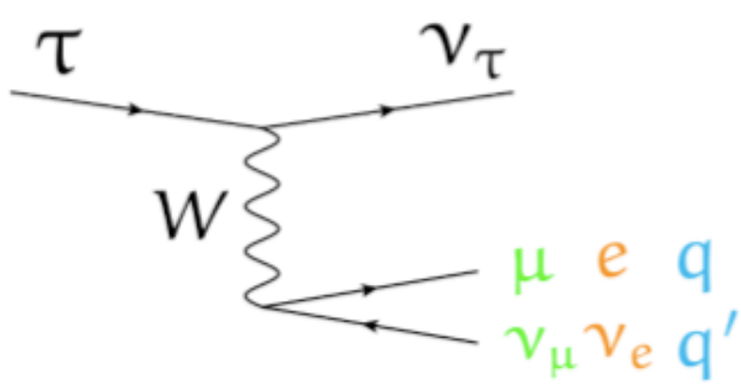


$\tau\tau$ modes are much less sensitive to radiative corrections!

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)

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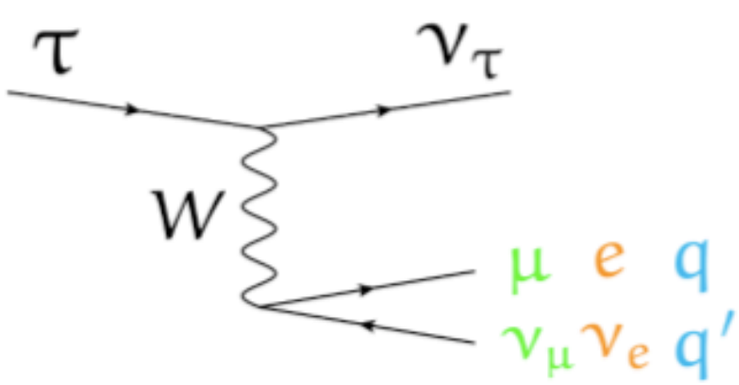

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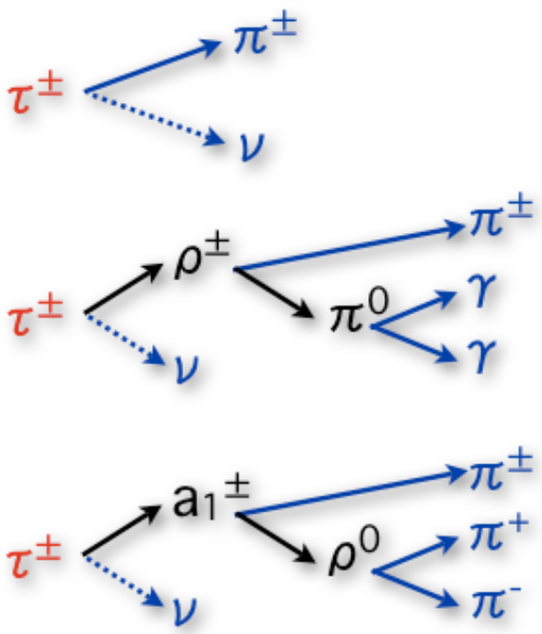
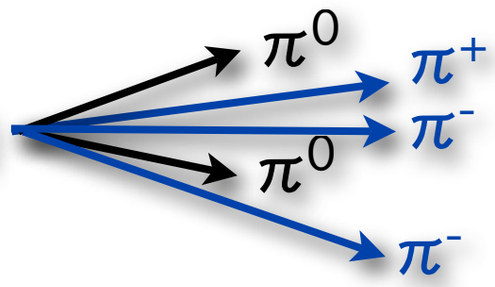


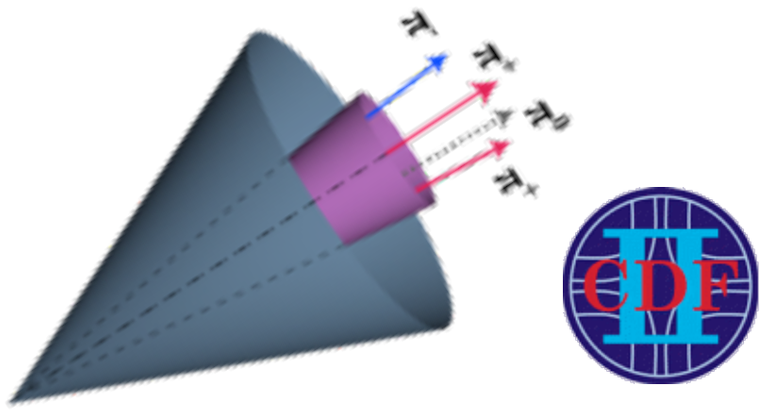
type 1:
trk + cal
(no EM cluster)

type 2:
trk + cal
(with EM cluster)

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

large jet background



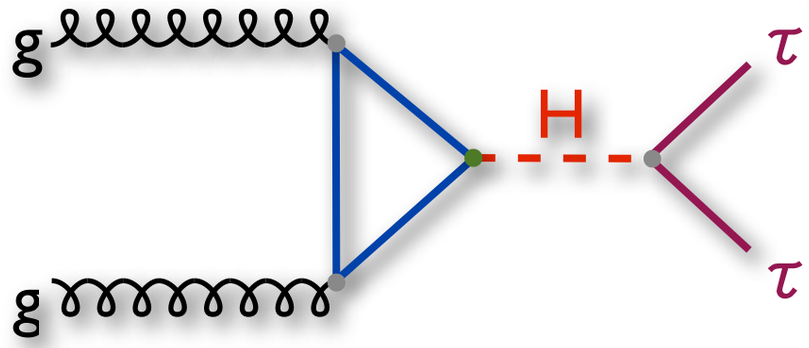


\+ NN_τ based on isolation, shower shape, trk-cal consistency variables

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

Inclusive $h \to \tau\ \tau$

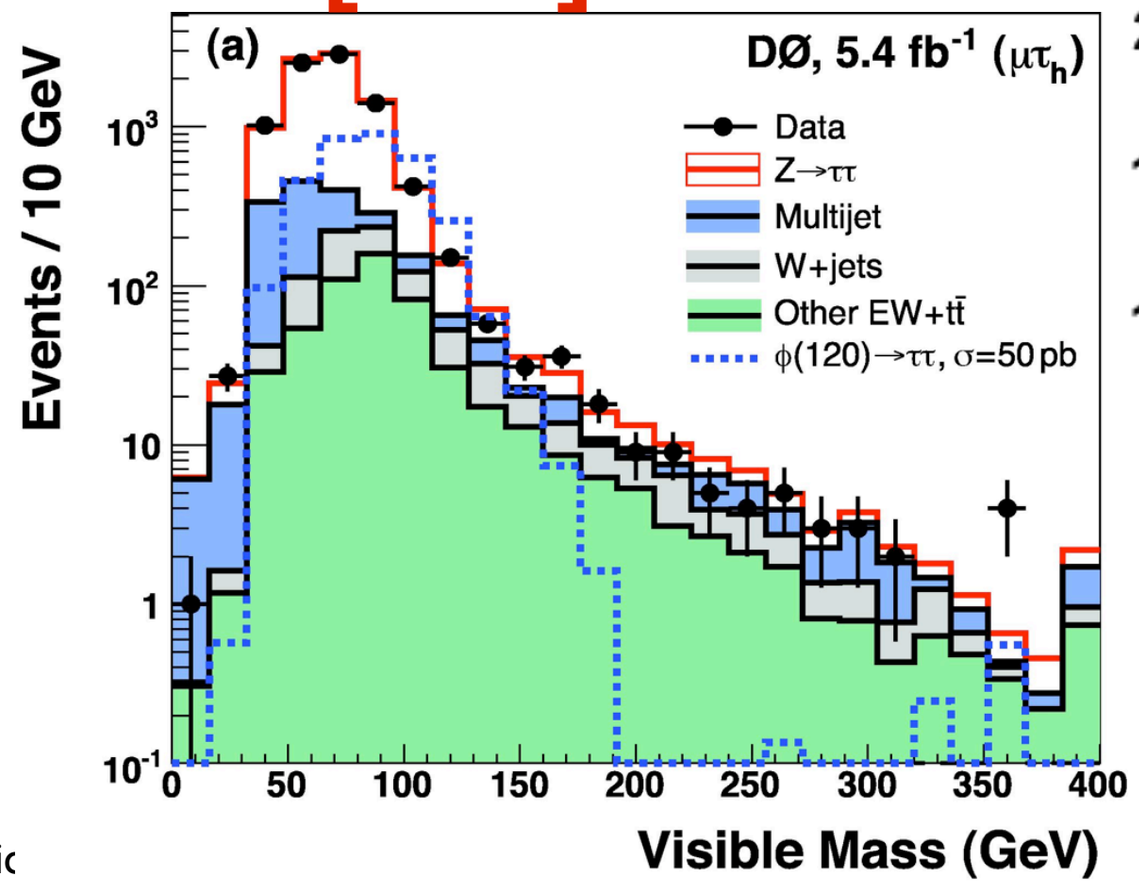
- DØ: $\tau_\mu\tau_h$, $\tau_\mu\tau_e$ (5.4 fb^{-1})
  1.0 fb^{-1} result: Phys. Rev. Lett. **101**, 071804 (2008)
- CDF: $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_\mu\tau_e$ (1.8 fb^{-1})



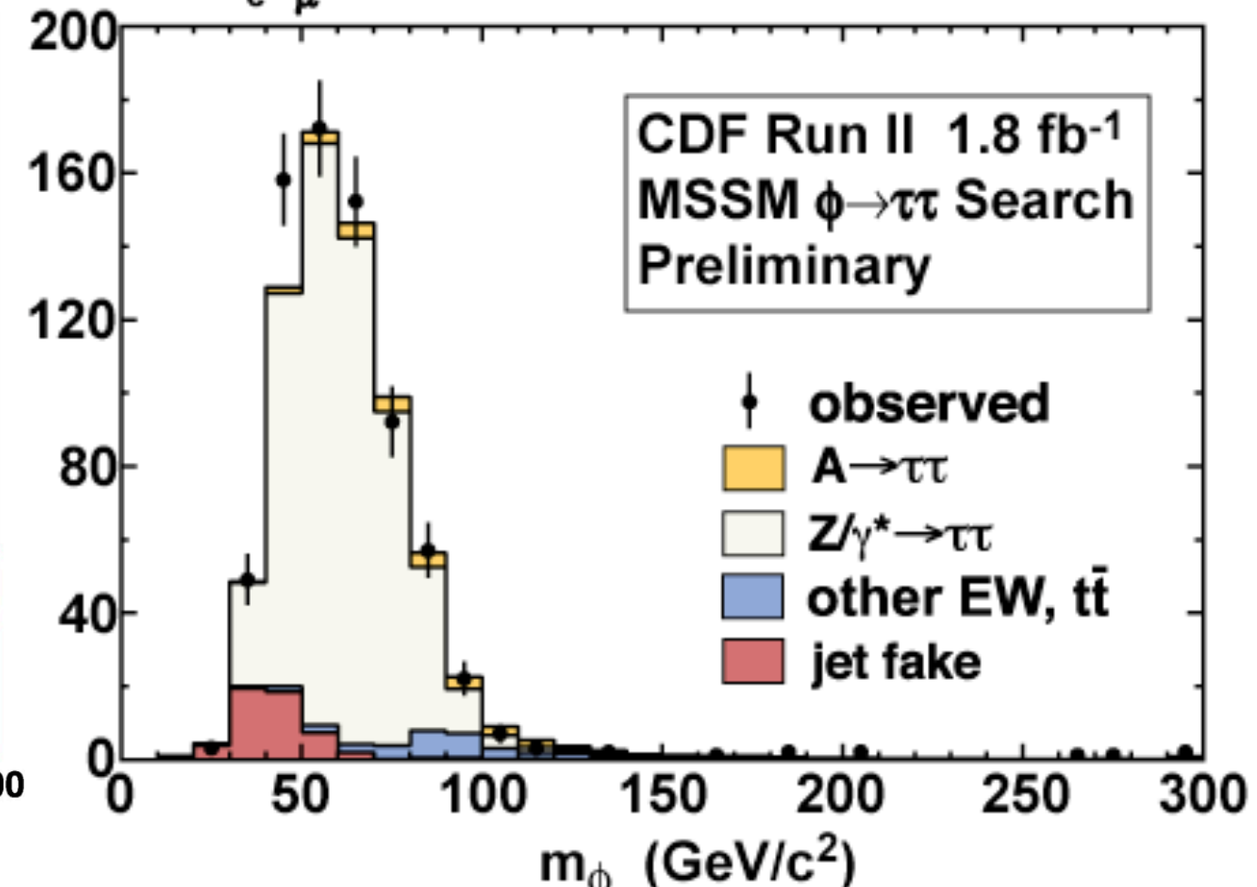
- Search for 2 high p_T isolated leptons, opposite sign
- Escaping neutrinos info is partially recovered by using $\not\!\!E_T$
- Look for a bump in:

$$M_{vis} = \sqrt{\left(p_{\tau_h} + p_\mu + \not\!\!E_T\right)^2}$$

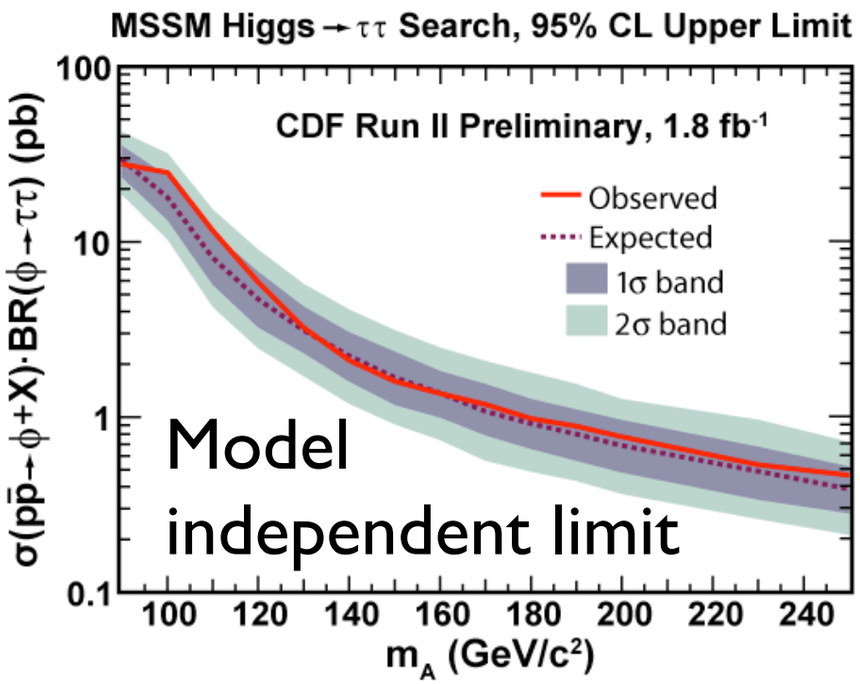
[New] ττ: 5.4 fb^{-1}



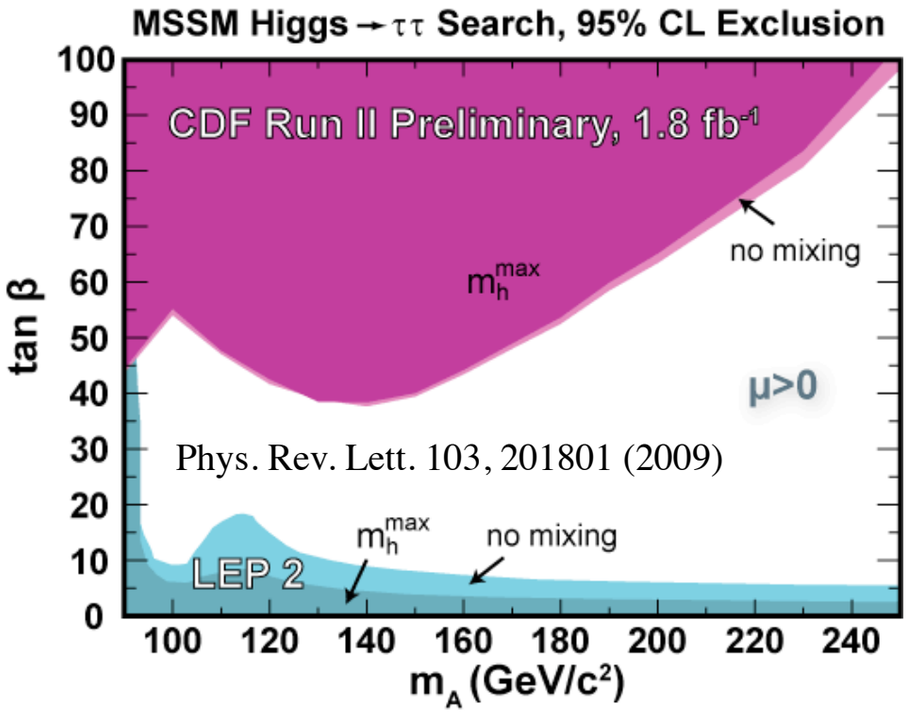
$\tau_e\tau_\mu$ channel Phys. Rev. Lett. 103, 201801 (2009)



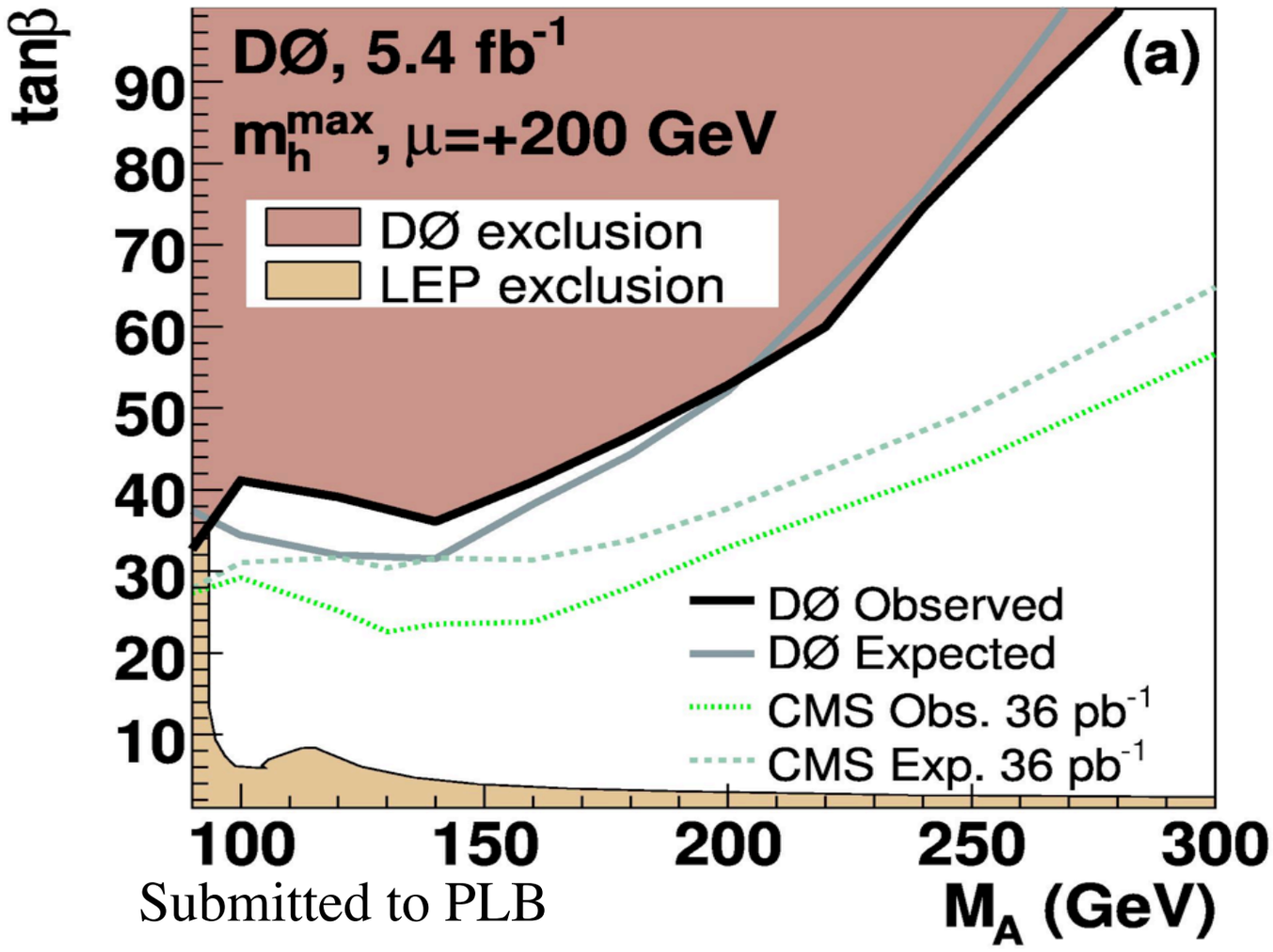
$h \to \tau\ \tau$ Results



Data compatible with bkg



translation in MSSM parameter space



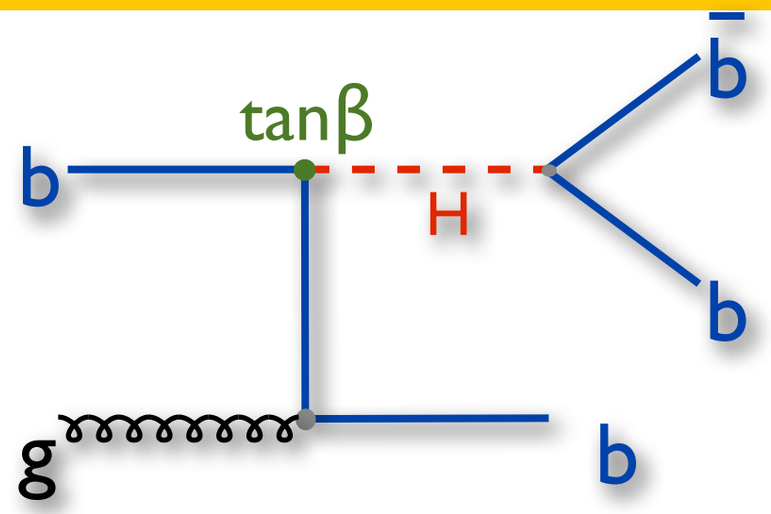
Submitted to PLB

Reaching the interesting region of $\tan\beta \approx 30\text{-}40$ for $M_A < 200$ GeV

Also DØ (2.2 fb^{-1})+CDF combo

$bh \rightarrow bbb$ search

- $b\Phi \rightarrow bbb$ selection:
  - 3 to 5 high p_T jets
  - at least 3 b-tagged jets



- Large multijets background:
  - Triggering
  - Powerful b-tagger
  - Challenging background model

DØ : 5.2 fb^{-1} Phys. Lett. B **698**, 97 (2011)
CDF: 2.6 fb^{-1} Submitted to PRD

$bh \rightarrow bbb$ search

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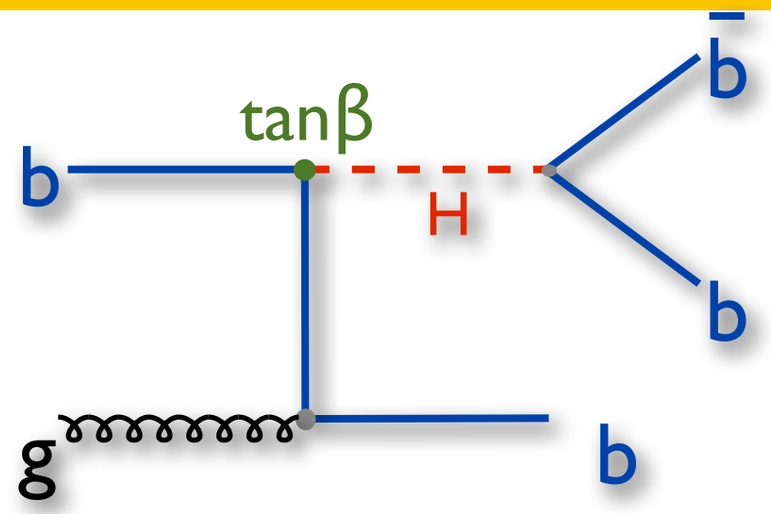

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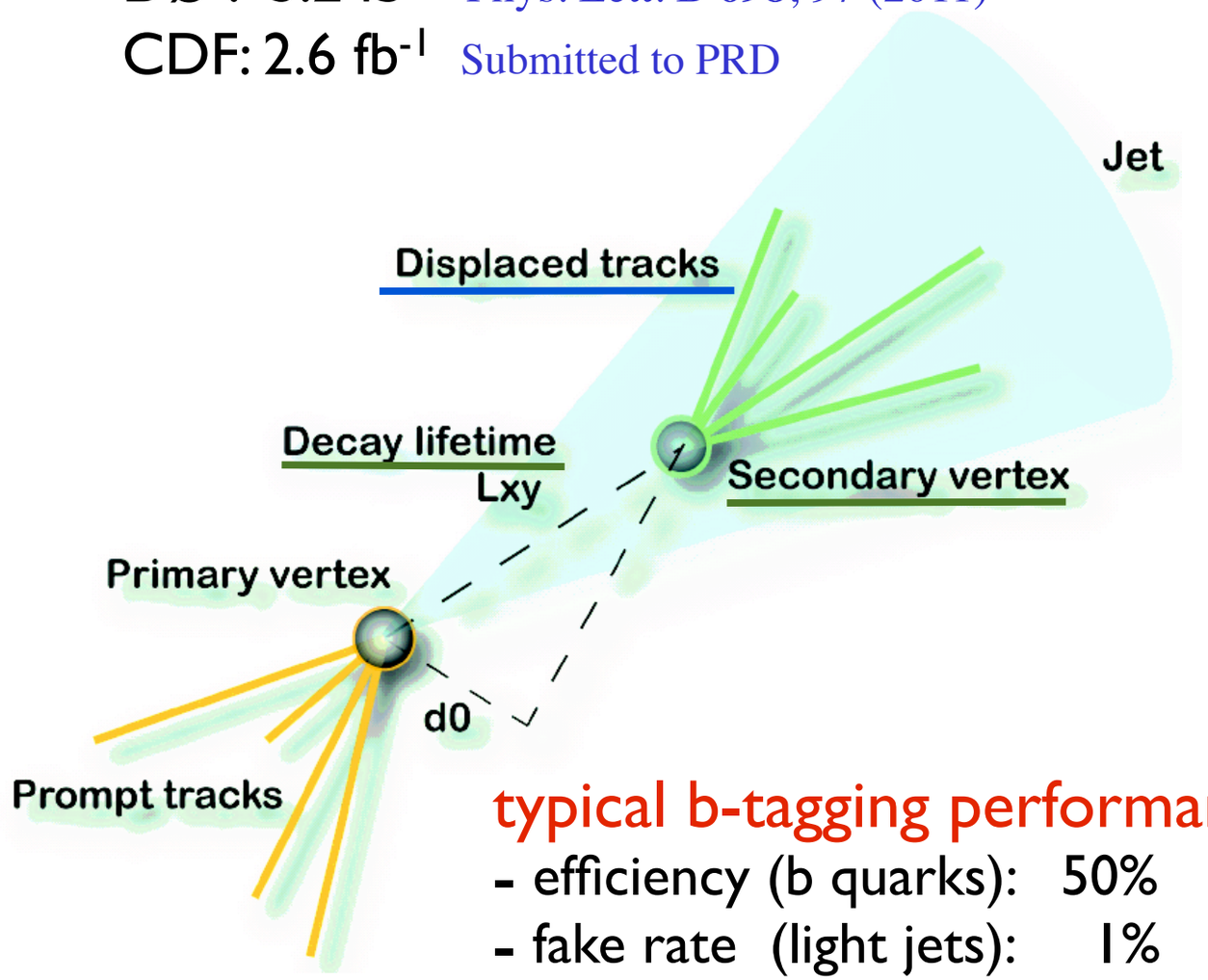
DØ : 5.2 fb^{-1} Phys. Lett. B **698**, 97 (2011)
CDF: 2.6 fb^{-1} Submitted to PRD

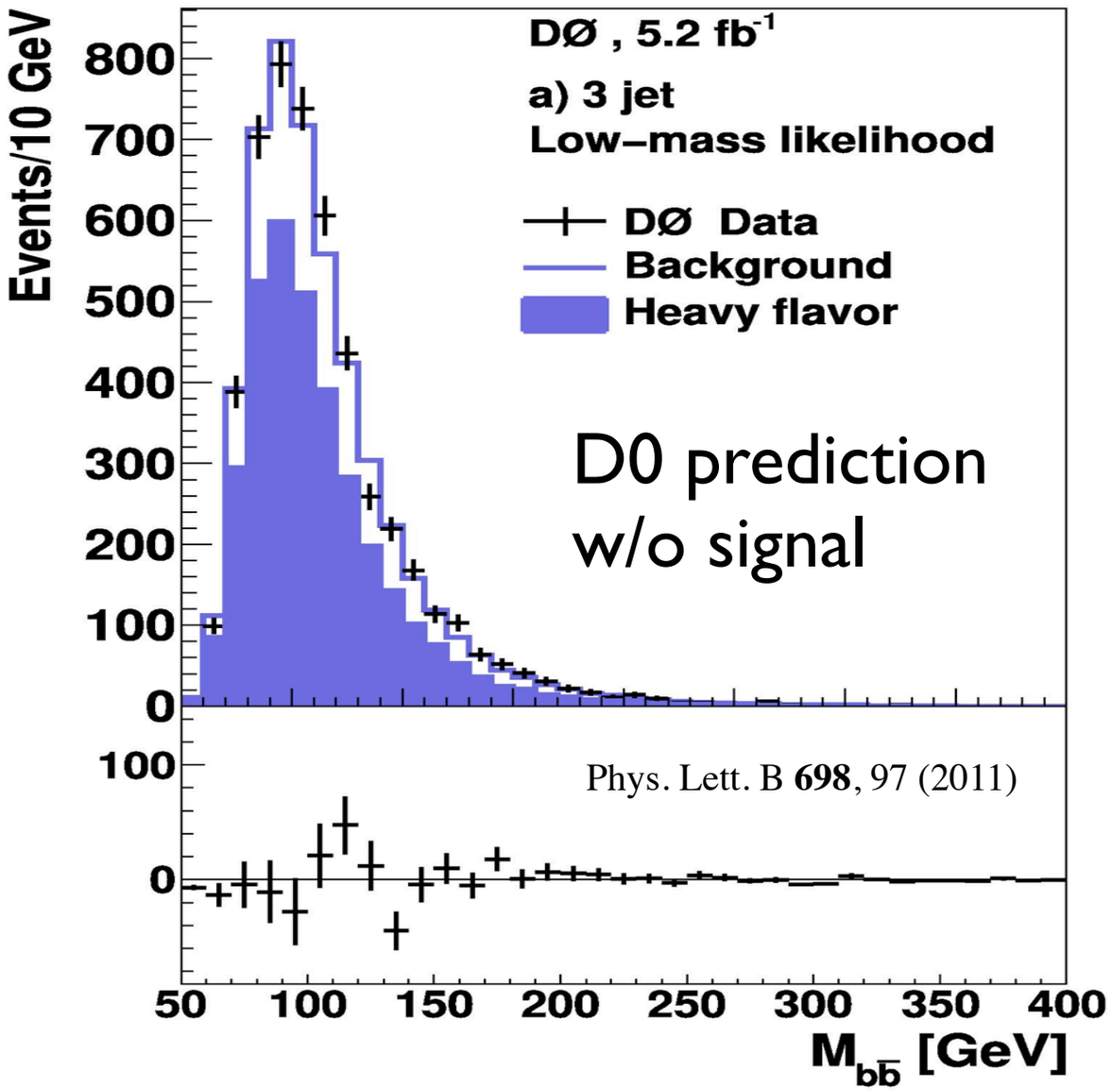
b-tagging @ DØ: combine var. in a multivariate discriminant
b-tagging @ CDF: displaced vertices
+ L_{xy}/σ cut
+ vertex mass separation



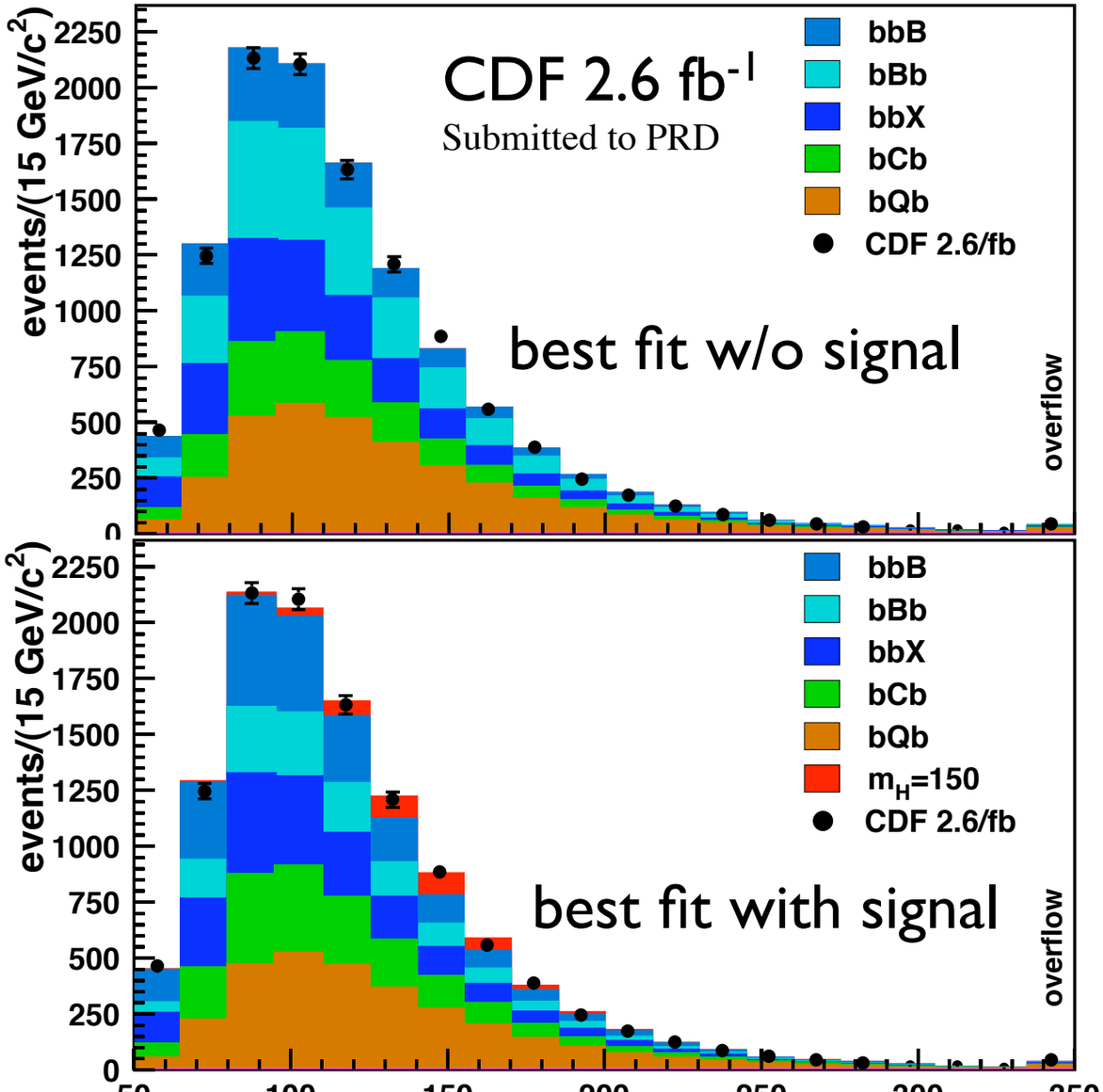
typical b-tagging performance
- efficiency (b quarks): 50%
- fake rate (light jets): 1%

bbb search: dijet mass

- CDF & DØ employ similar strategy:
  - ✓ predict background shapes and composition data control sample
  - ✓ Limits obtained from a fit to data with & without signal



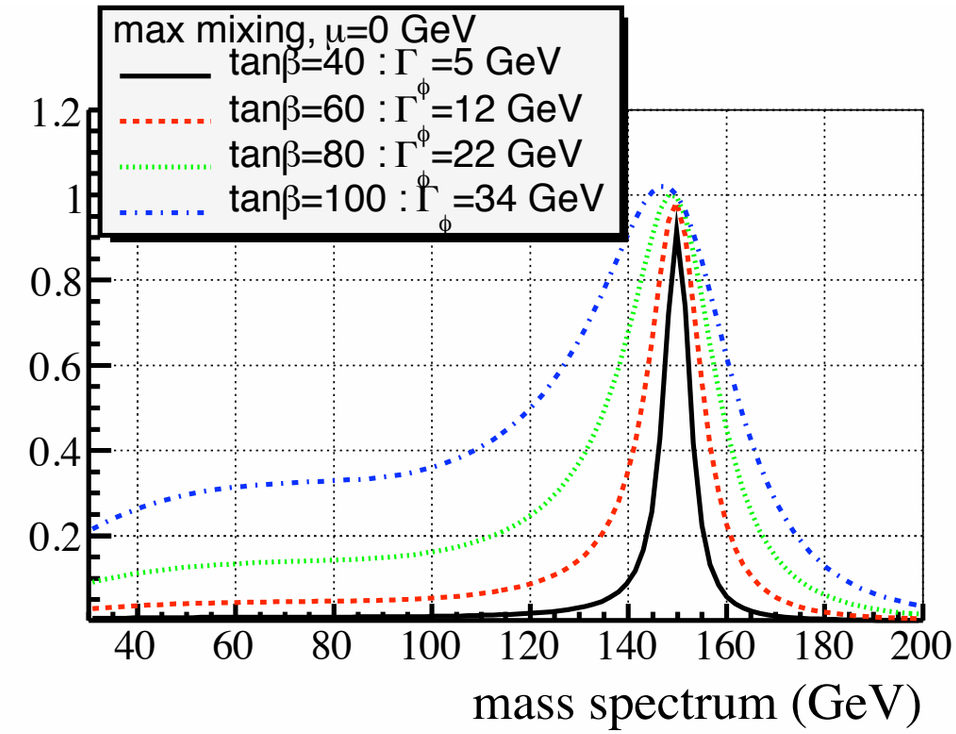
[New] bbb: 2.6 fb^{-1}

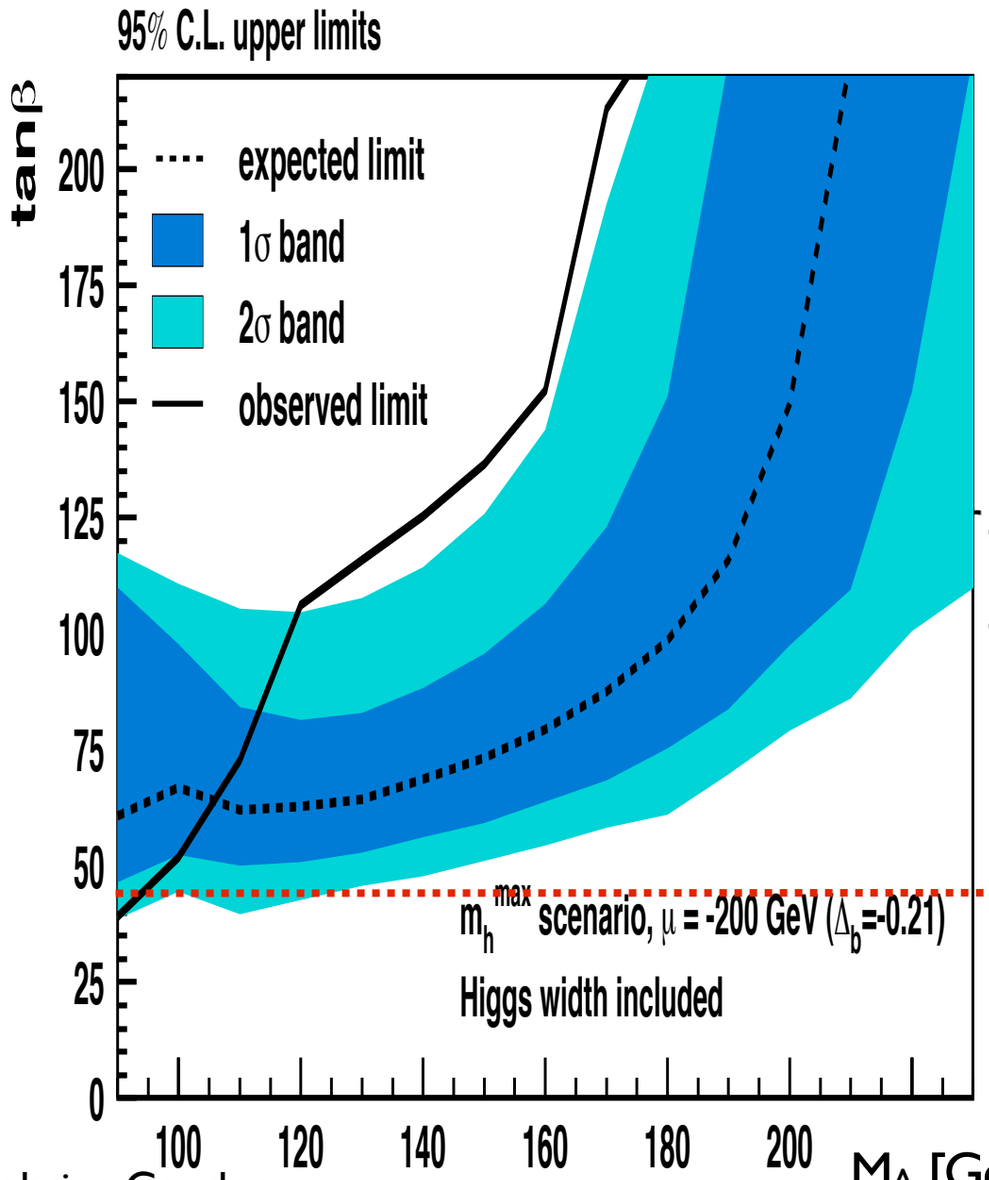


MSSM interpretation

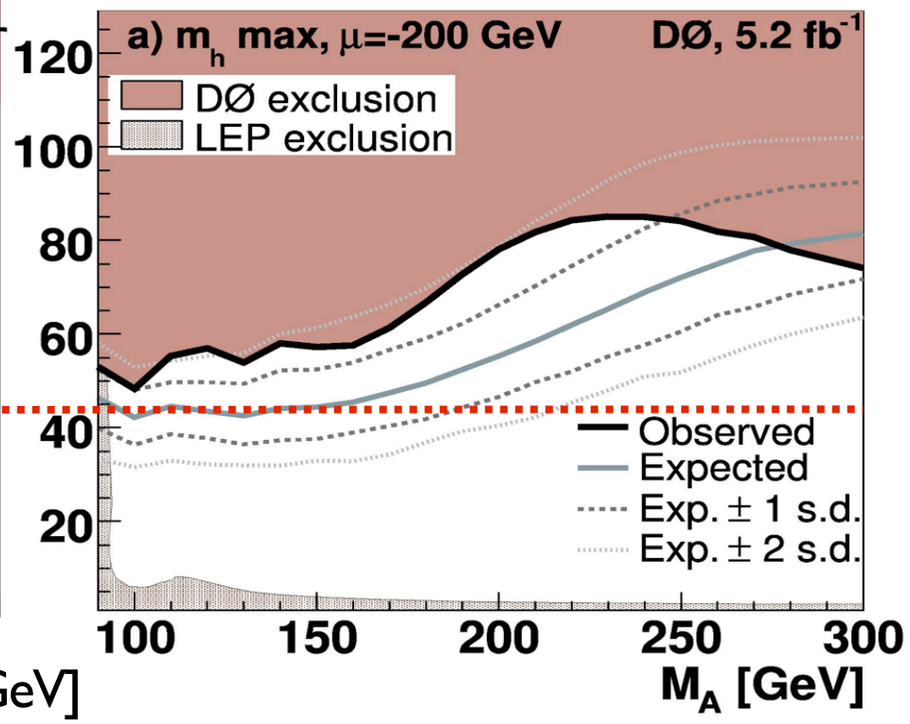
Very sensitive to radiative corrections
High tanβ: signal width effect not negligible
(compared to the experimental mass resolution).

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





Exp. sensitivity down to tanβ=45



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

bΦ→b$\tau_e\tau_h$ search

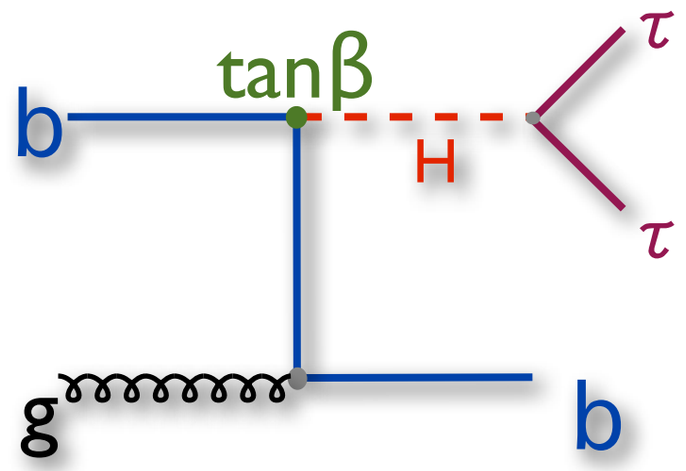
- Channel complementary to
  - bΦ→bbb: lower $\mathcal{B}r$ but much lower bkg, less sensitive to radiative corrections
  - Φ→ττ: more sensitive near the Z peak

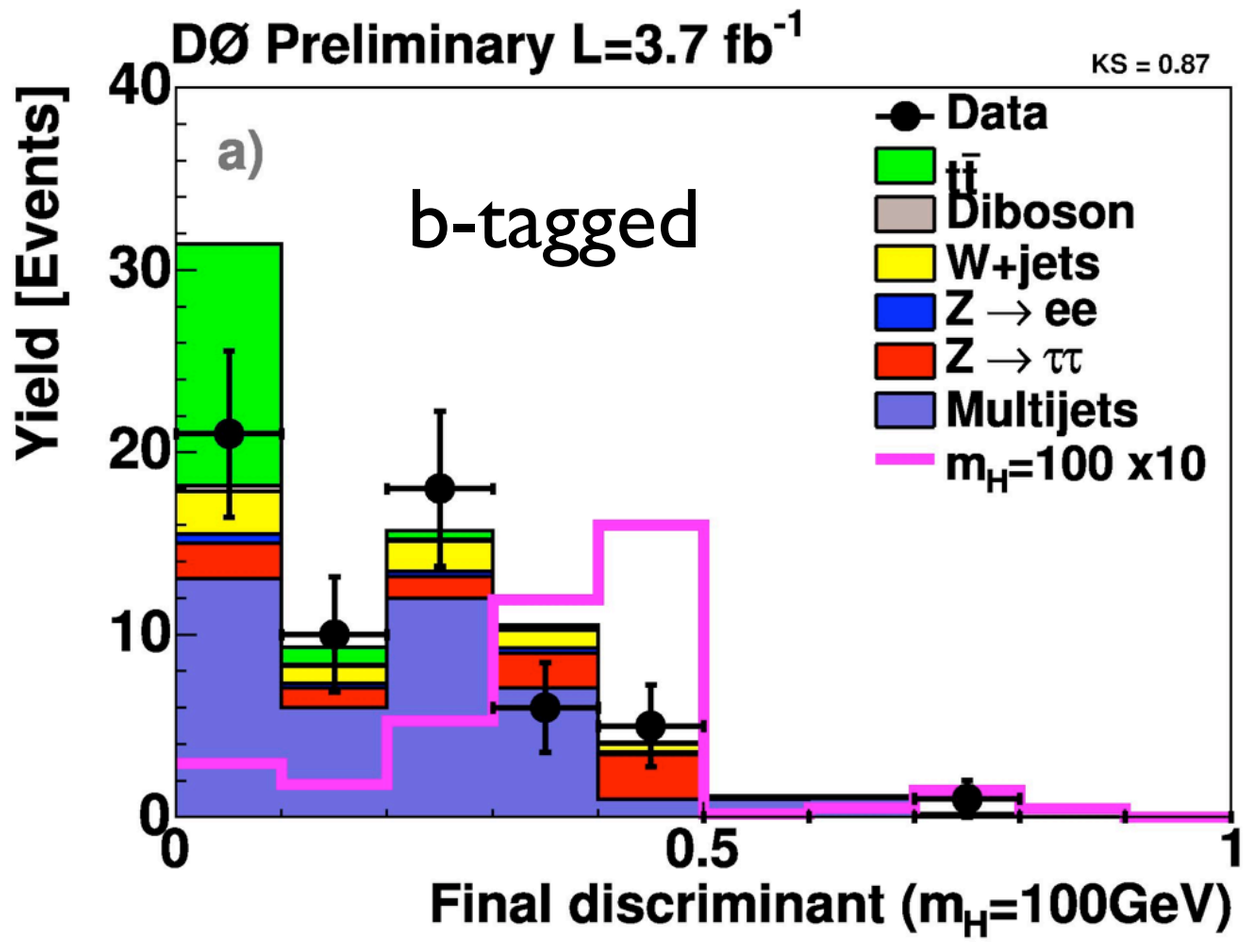
$$\frac{\sigma(Z\,b_{tag})}{\sigma(Zincl)} < 0.005$$

$$\frac{\sigma(\phi\,b_{tag})}{\sigma(\phi incl)} = 0.16$$

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

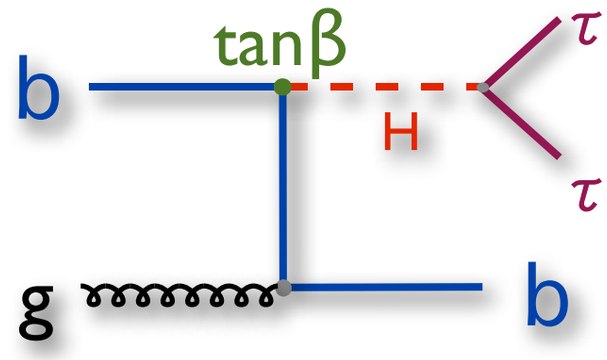
$b\tau_e\tau_h$: 3.7 fb^{-1}



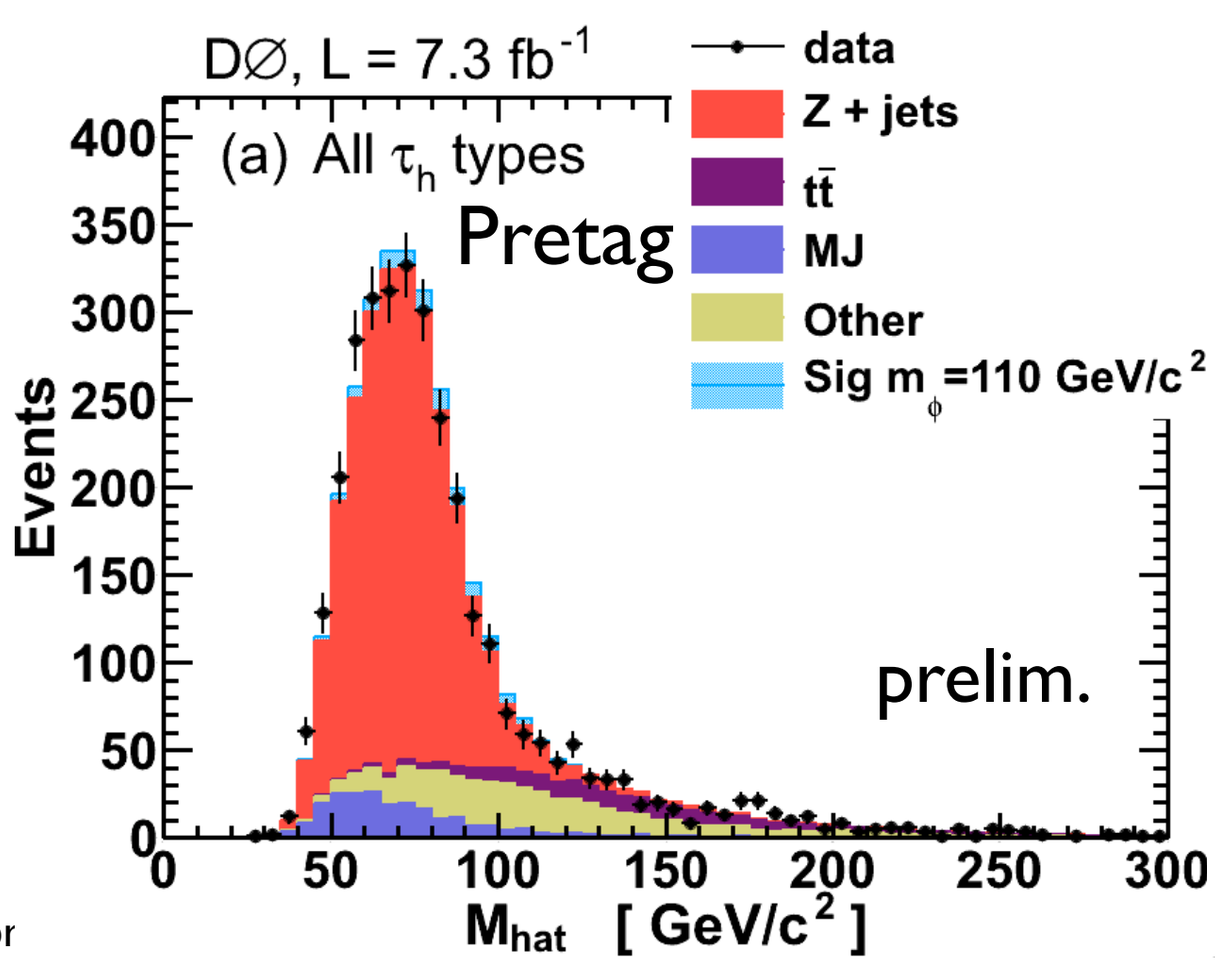


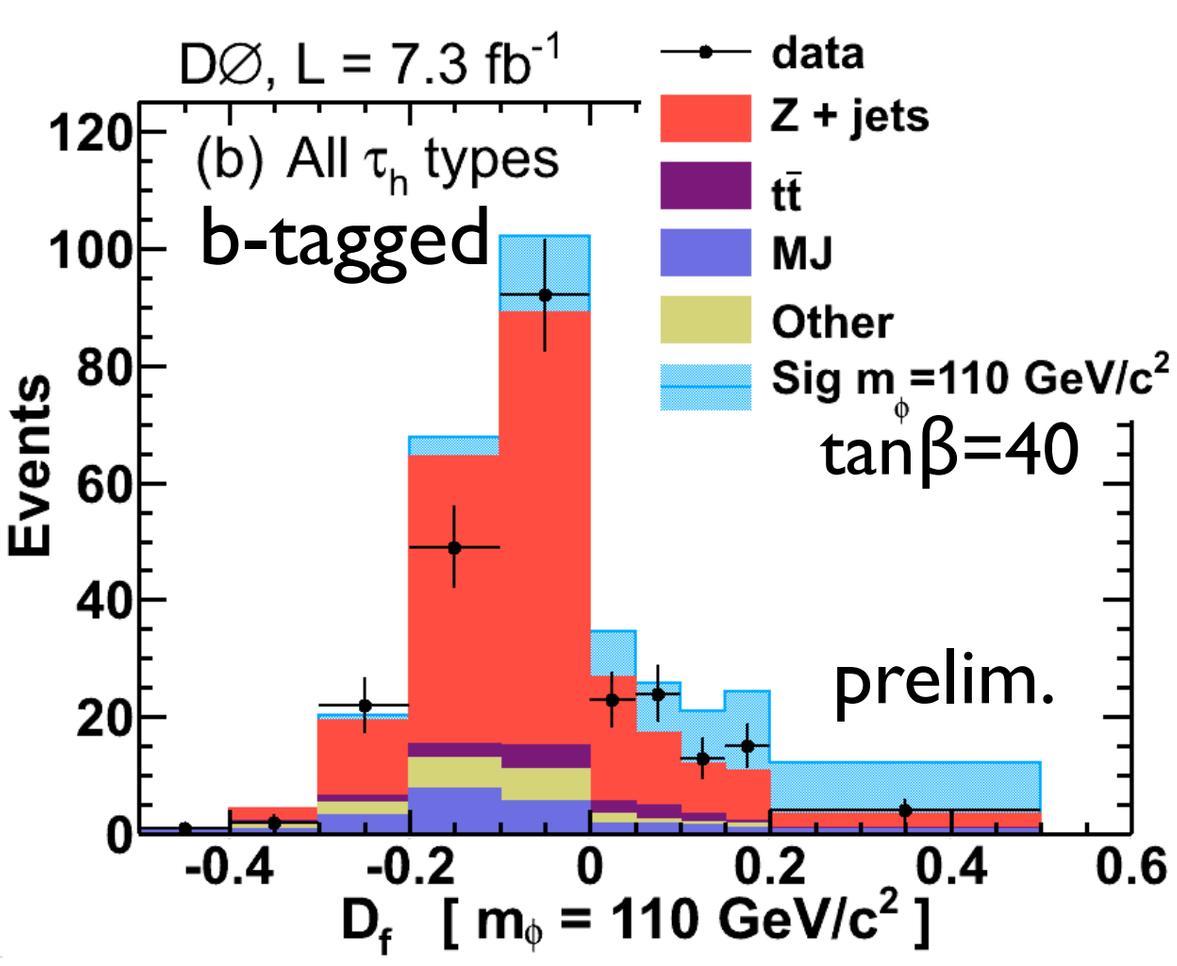
$b\Phi \to b\tau_\mu \tau_h$ search

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



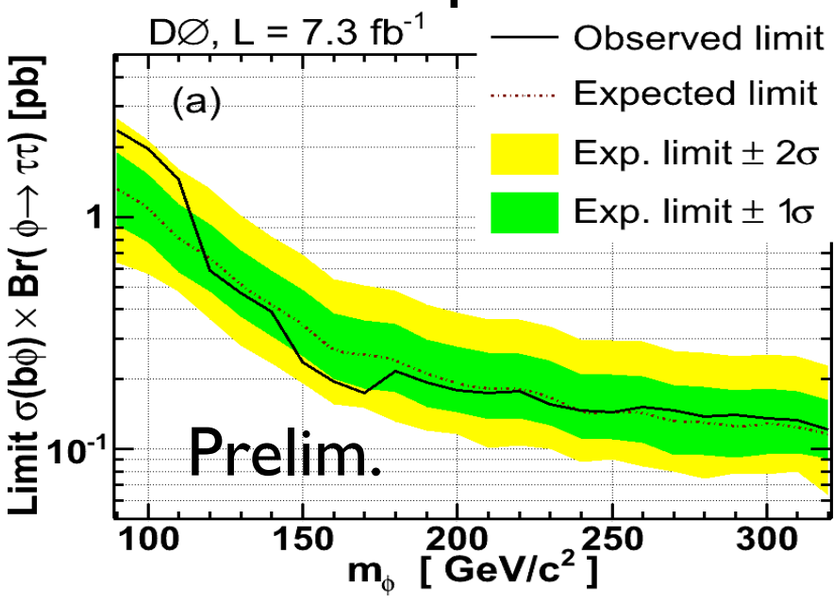
- Specific discriminants against main backgrounds:
  $t\bar{t}$ (D_{tt}), multijets (D_{MJ}) and $Z \to \tau\tau$ (NN_b)
- Final discri: D_f likelihood formed with D_{tt}, D_{MJ}, NN_b, M_{hat}
- Main background ($Z \to \tau\tau$) constrained from data using $Z \to \mu\mu$.
  Greatly reduces the loss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





bΦ→bττ results

model independent limit

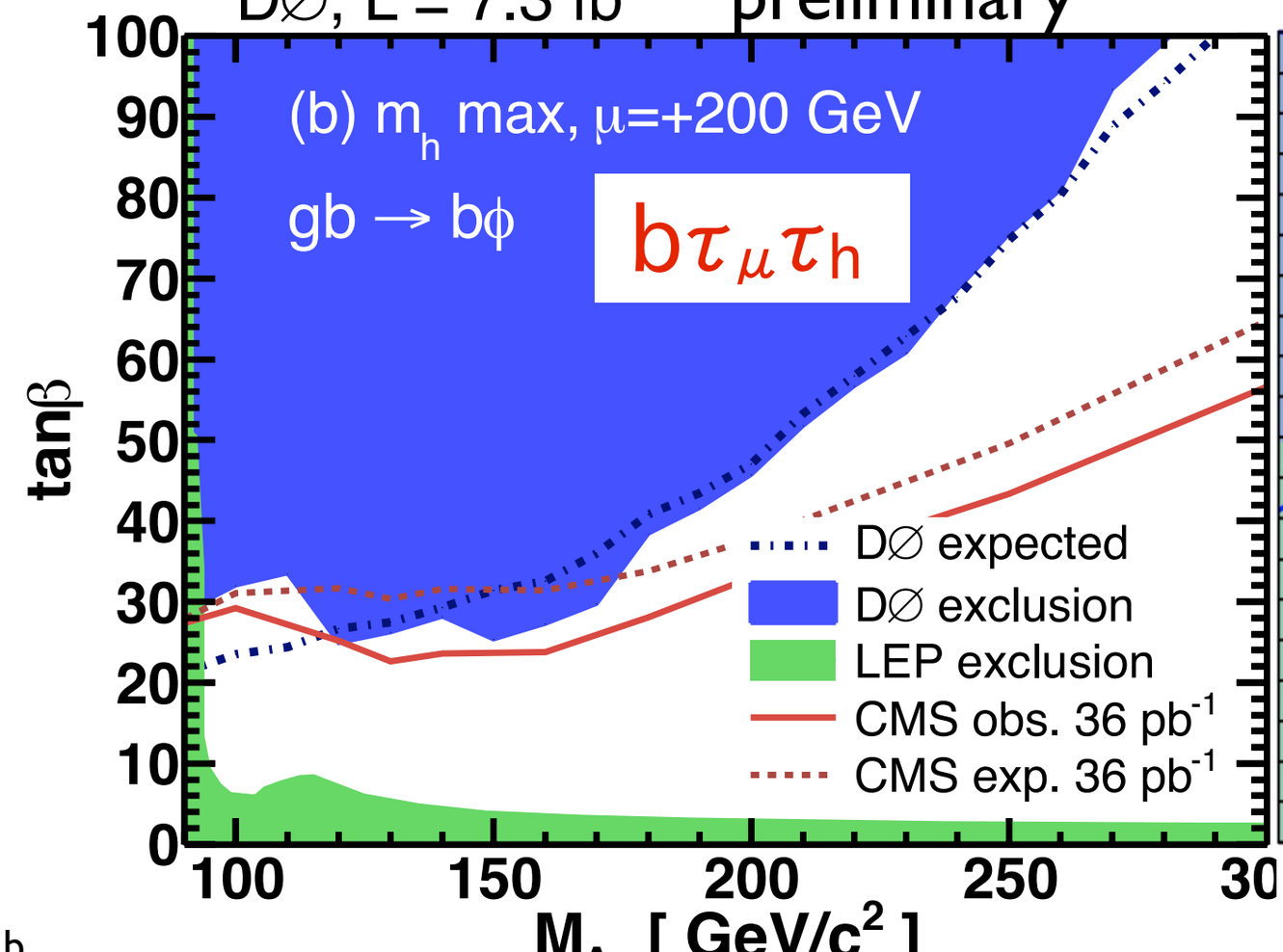


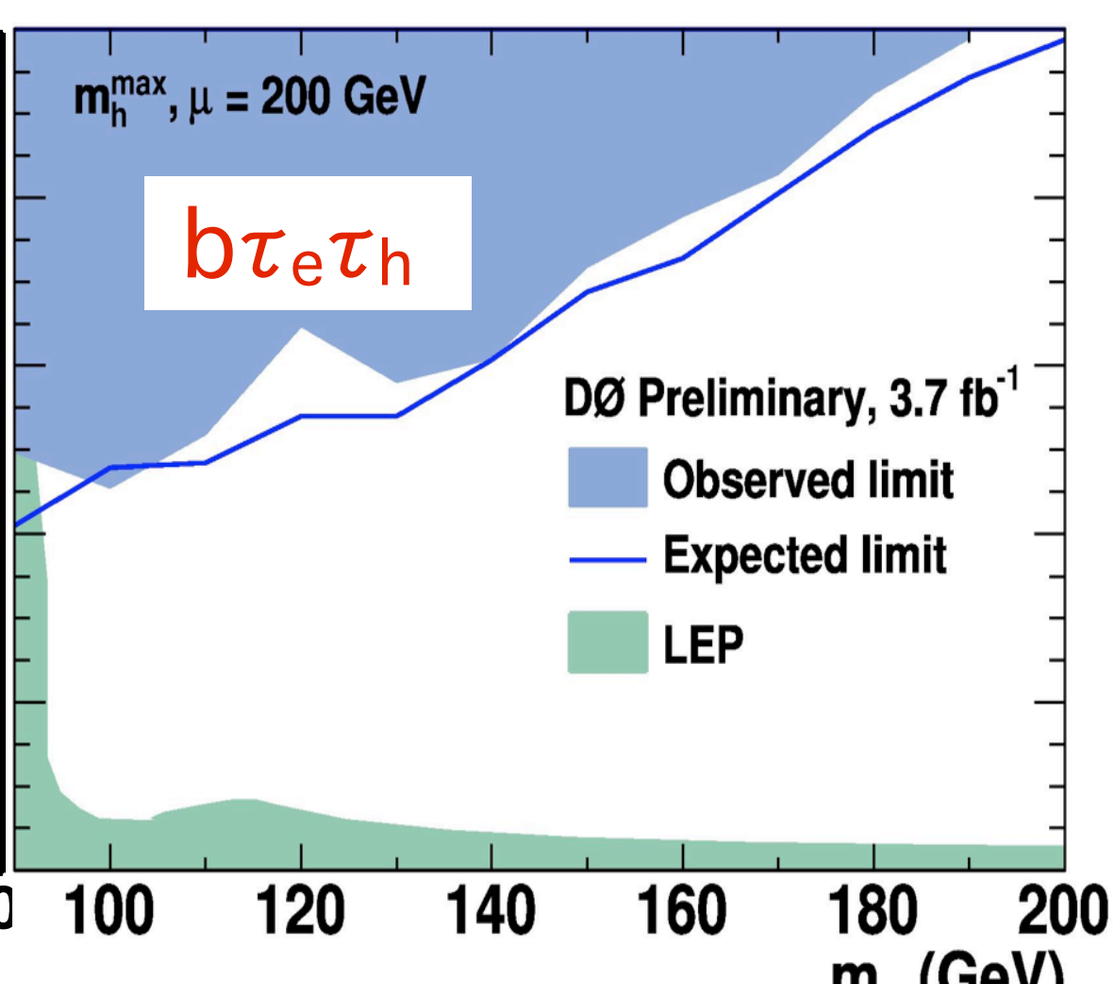
Data compatible with background

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

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

DØ, L = 7.3 fb-1 preliminary





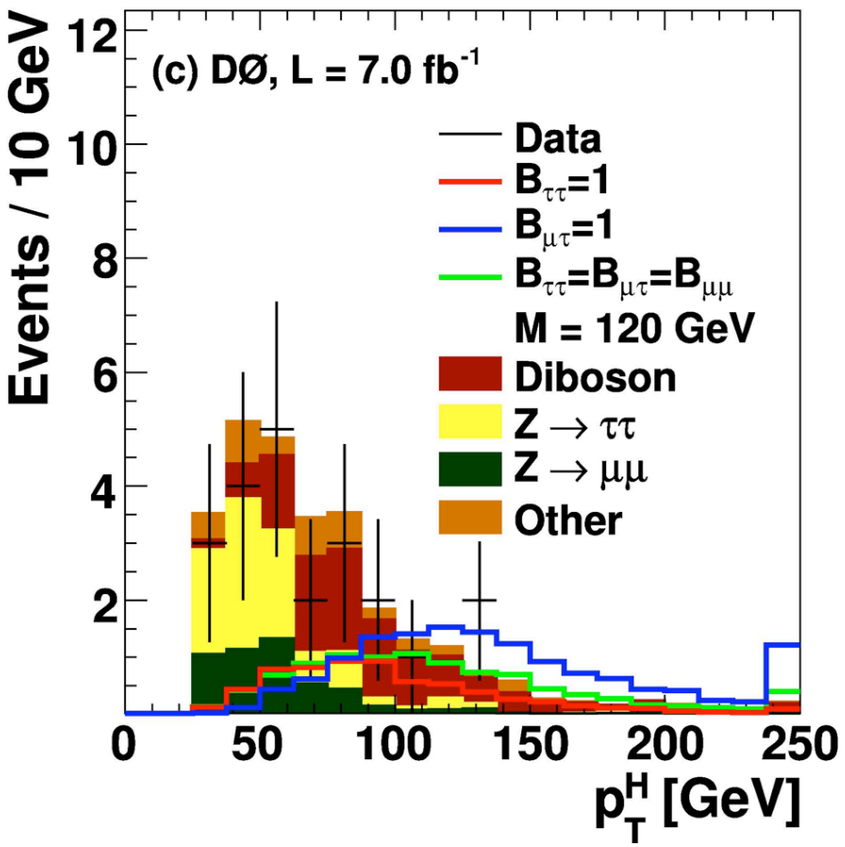
Doubly charged Higgs H^{++}

- Arise in Little Higgs, Left-Right symmetry, $SU(3)_L \times U(1)_Y$ gauge symmetry models (and can be supersymmetrized).
- Search for $H^{++} \to \mu\mu/\mu\tau/\tau\tau$: $\tau\tau$ search premiere at a hadron collider and most stringent limits in these channels

[New] H^{++}: 7.0 fb^{-1}

Selection:

at least $1\mu + 2\tau_h$



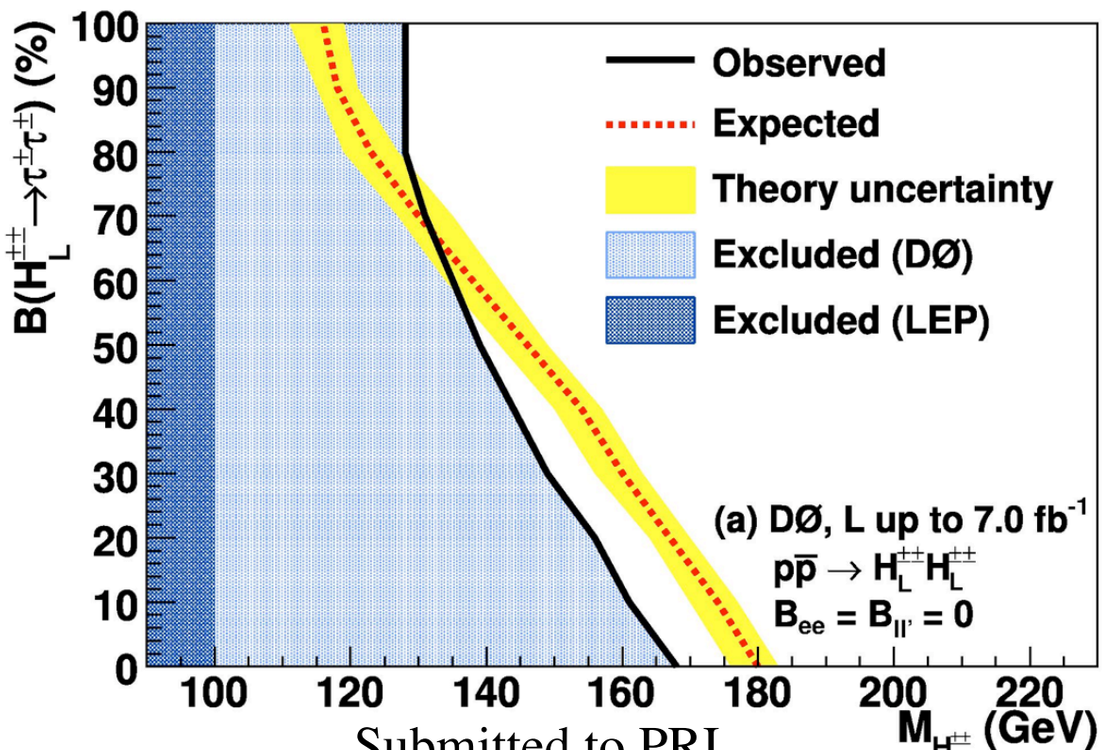
obs. (exp.) limits

$\mathcal{B}(H^{++} \to \tau\tau) = 1 : m(H_L^{++}) > 128\ (116)$ GeV

$\mathcal{B}(H^{++} \to \mu\tau) = 1 : m(H_L^{++}) > 144\ (149)$ GeV

$\mathcal{B}(H^{++} \to \mu\tau) = \mathcal{B}(H^{++} \to \tau\tau) = \mathcal{B}(H^{++} \to \mu\mu) = 1/3 : m(H_L^{++}) > 138\ (130)$ GeV

$\mathcal{B}(H^{++} \to \tau\tau) + \mathcal{B}(H^{++} \to \mu\mu) = 1$, scan:

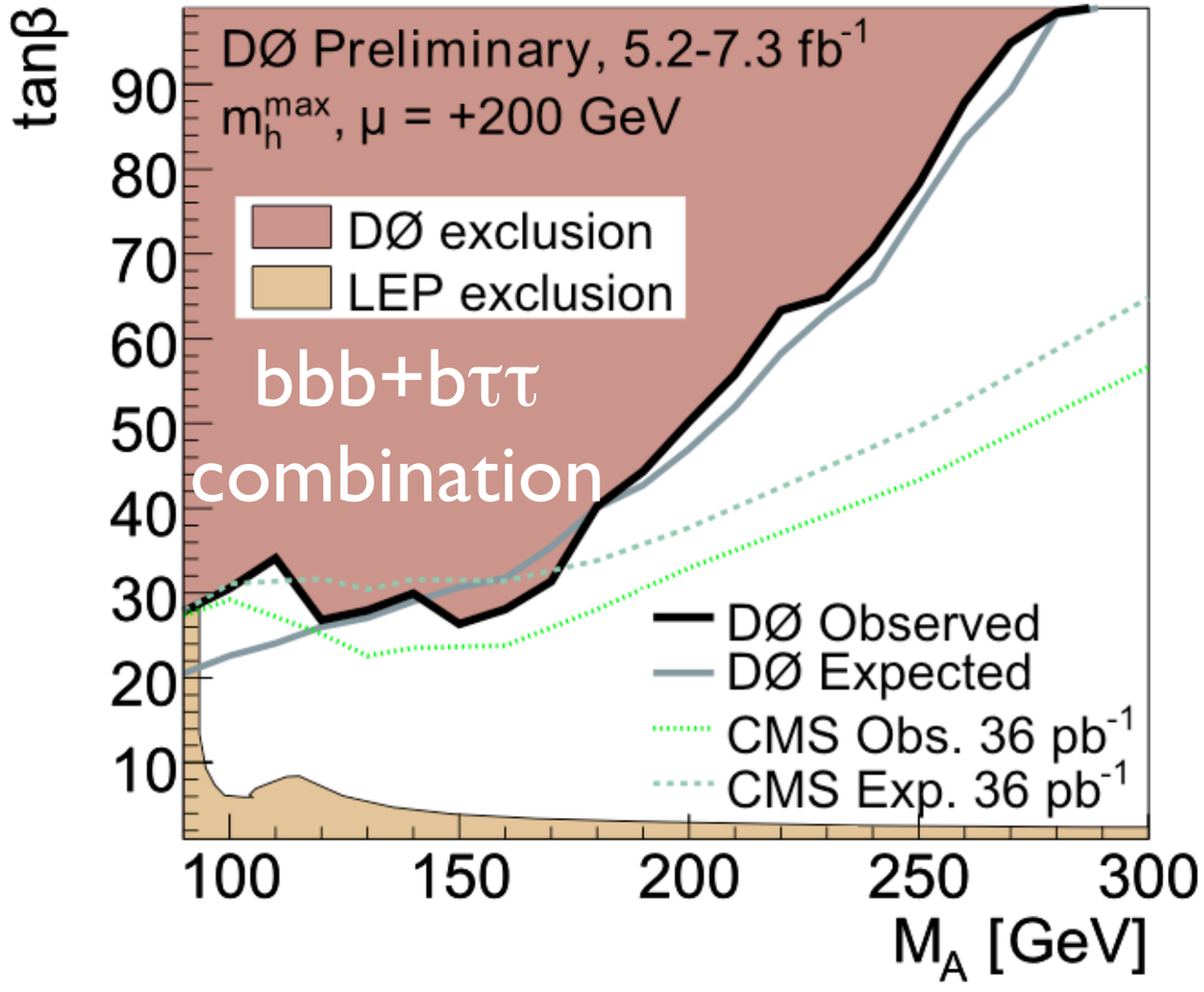


Submitted to PRL

Conclusions & prospects

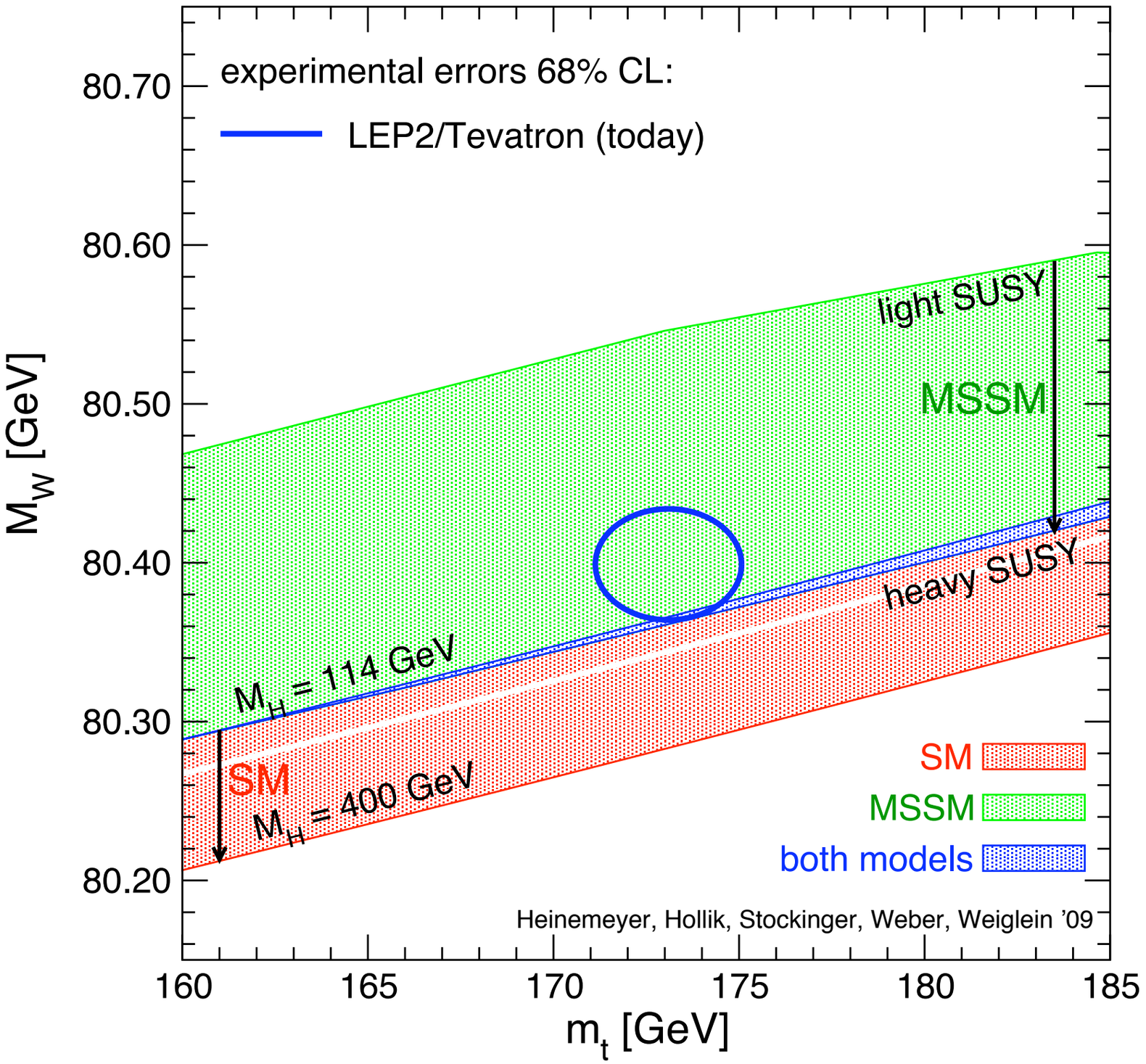
- Report results with up to 7.3 fb^{-1}
- Also H^+ searches and NMSSM searches not covered here
- Reaching the interesting region of $\tan\beta \approx 20\text{-}30$
- $b\tau_\mu\tau_h$ is (still) competitive with LHC inclusive $\tau\tau$ searches. This is also a different and complementary channel (involving b-tagging)...
- Several modes with similar sensitivity (combine!)
- Some excesses both for D0 and CDF in the bbb channel, worth to keep an eye on.
- Expected (very) soon:
  - hb → bbb search update
  - combinations update
  - ...

Hot off the press:
DØ bbb + bτ combination

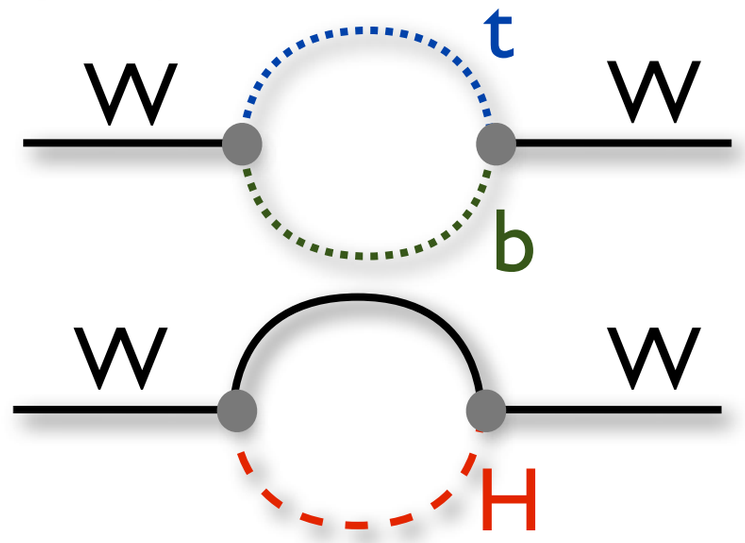


Backup

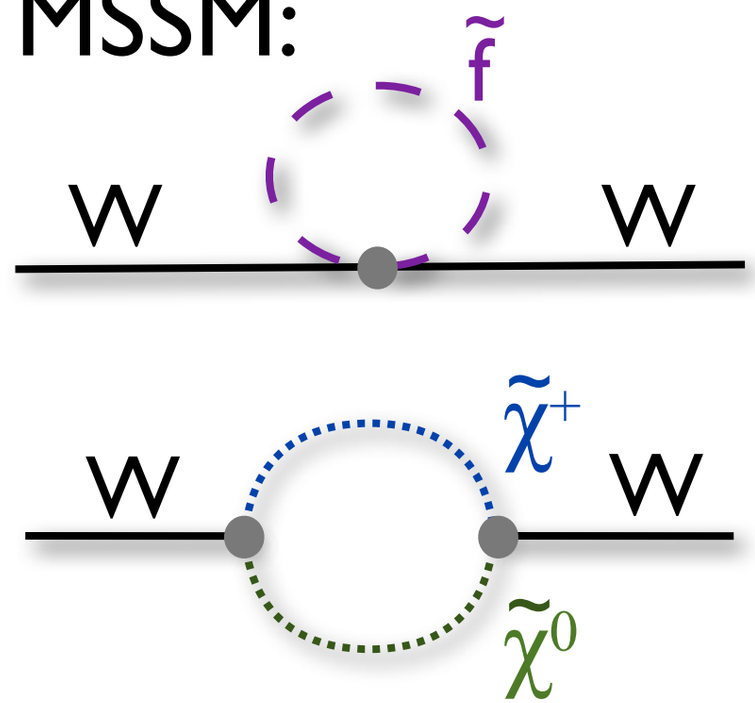
Why looking to the MSSM?



SM:



MSSM:

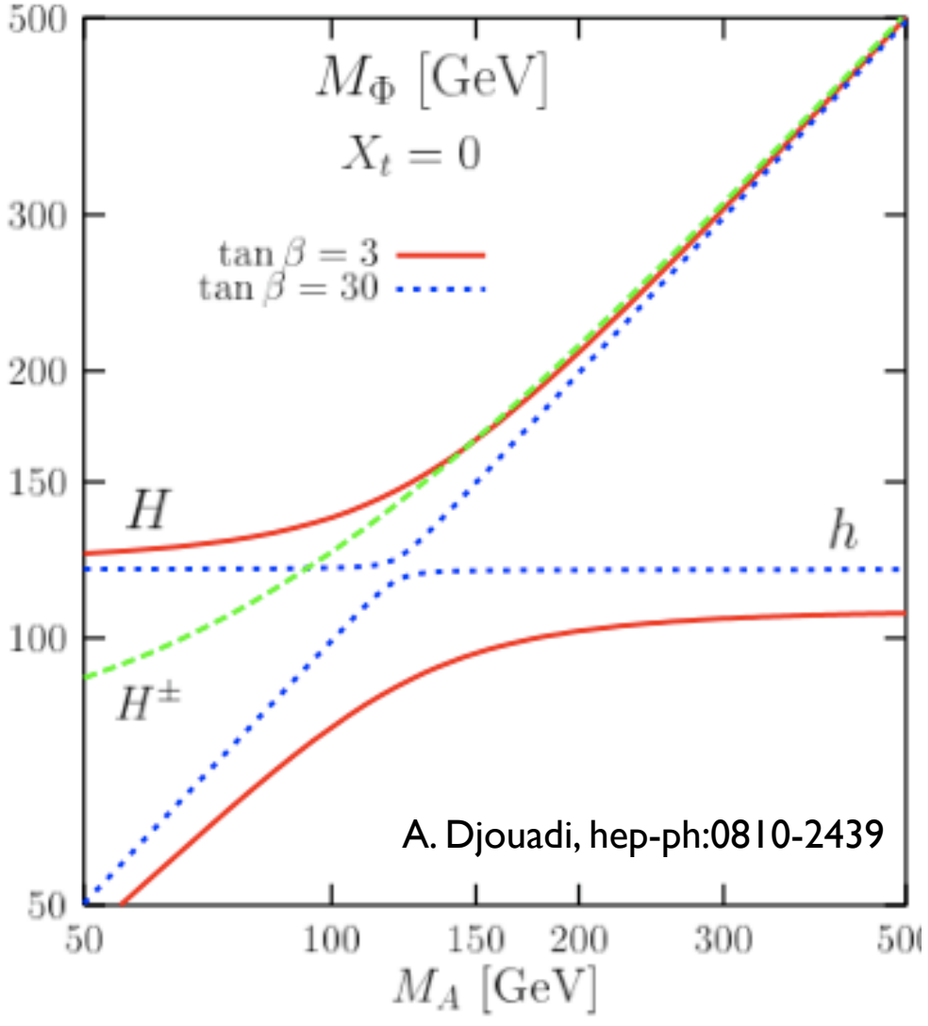


.....

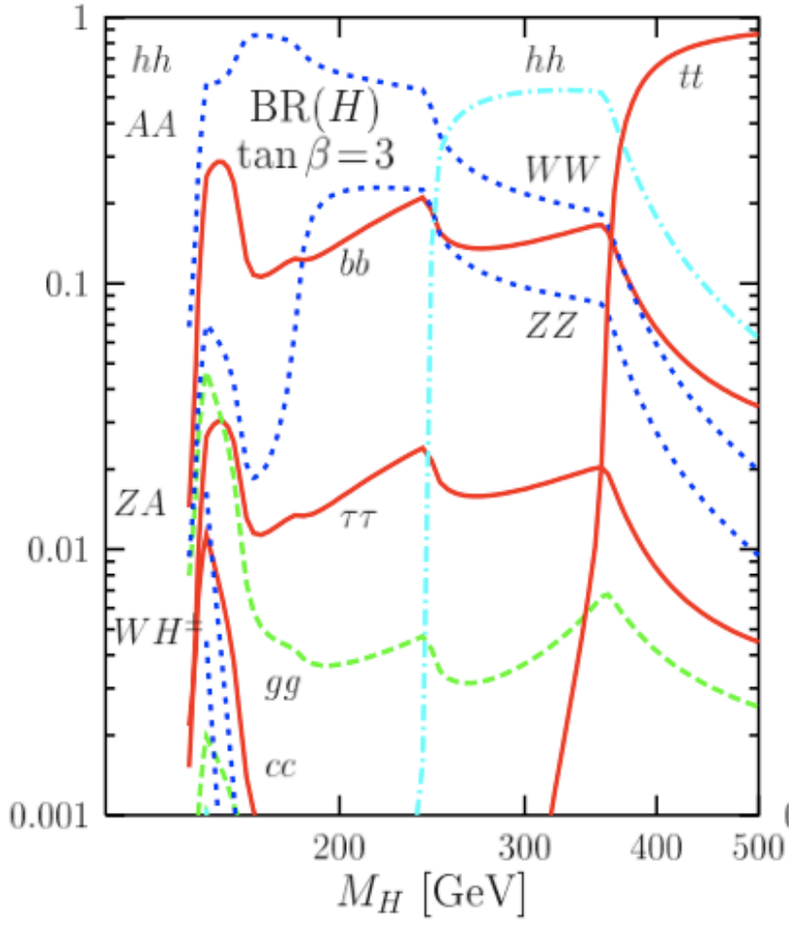
High tanβ regime

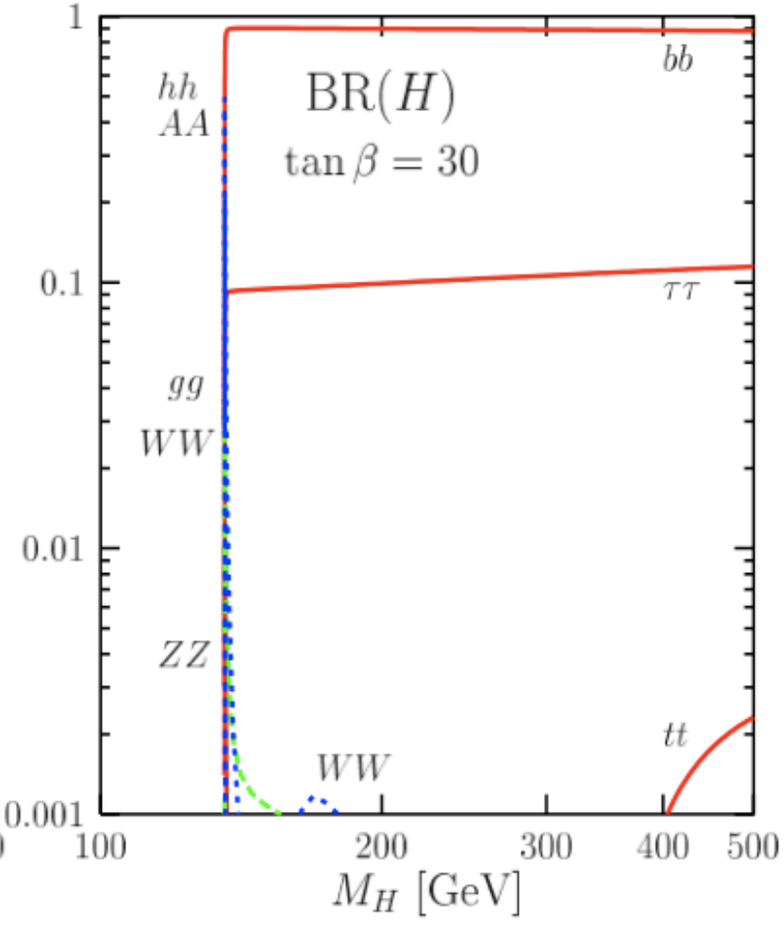
MSSM dedicated Higgs searches at the TeVatron usually takes place in the high tanβ regime:

- h/A or H/A are degenerate in mass σ_{prod} x 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 $m_{H+} < m_{top}$: $\mathcal{B}(H^+ \to \tau^+\nu_\tau) \approx 1$



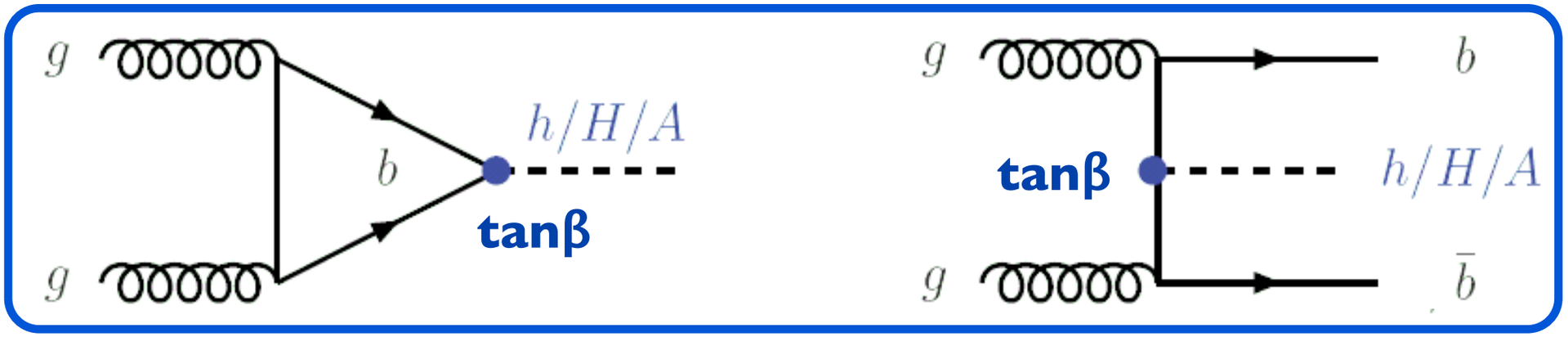
A. Djouadi, hep-ph:0810-2439



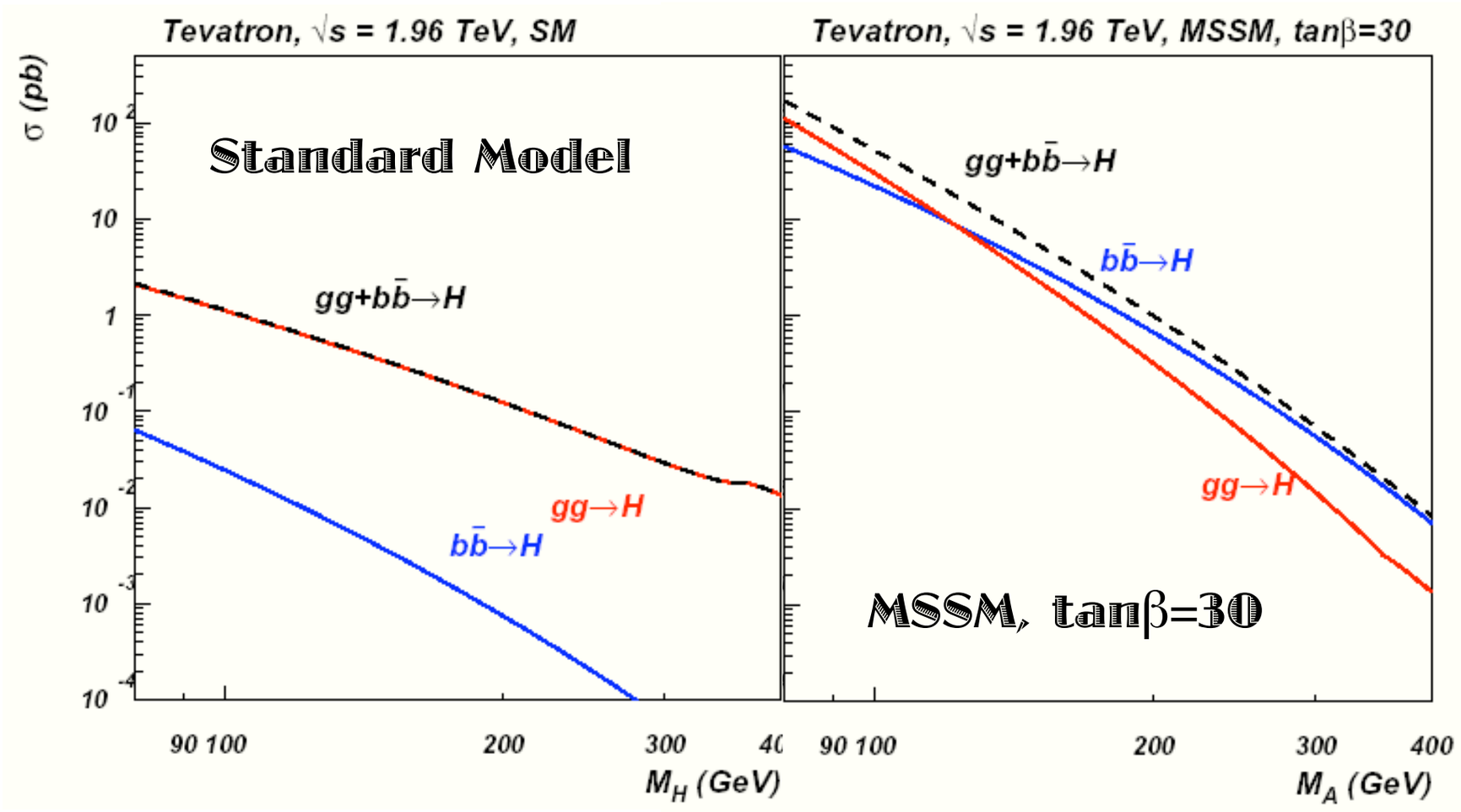


A. Djouadi, hep-ph0810-2439

Susy Higgs production



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



Enhancement at high tanβ: appreciable production rate at the Tevatron

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

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

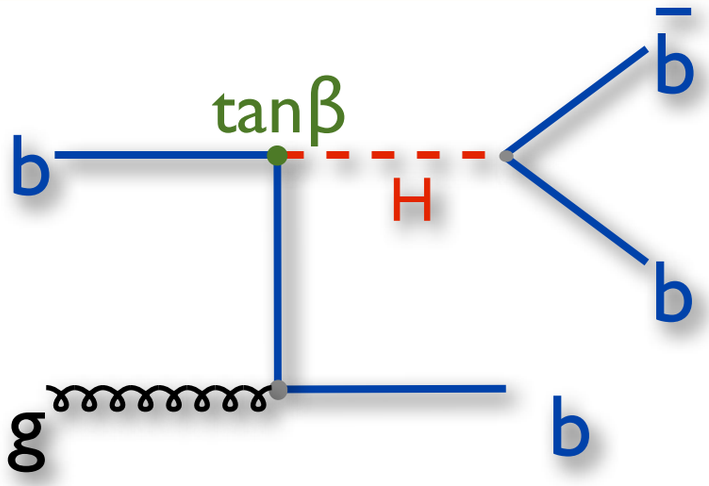
   use *FeynHiggs* or *CPSuperH* to get the MSSM cross sections

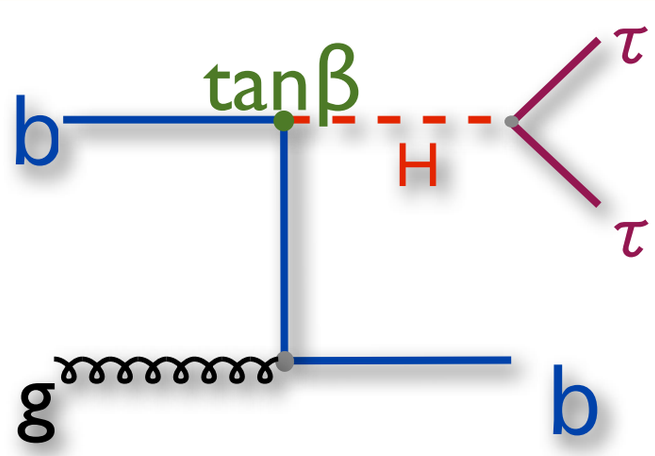
- m_h^{max} **scenario:**
  - $X_t = 2$ TeV;
  - $\mu = \pm 0.2$ TeV;
  - $M_2 = 0.2$ TeV;
  - $m_{\tilde{g}} = 0.8$ TeV
  - $M_{SUSY} = 1$ TeV

- **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

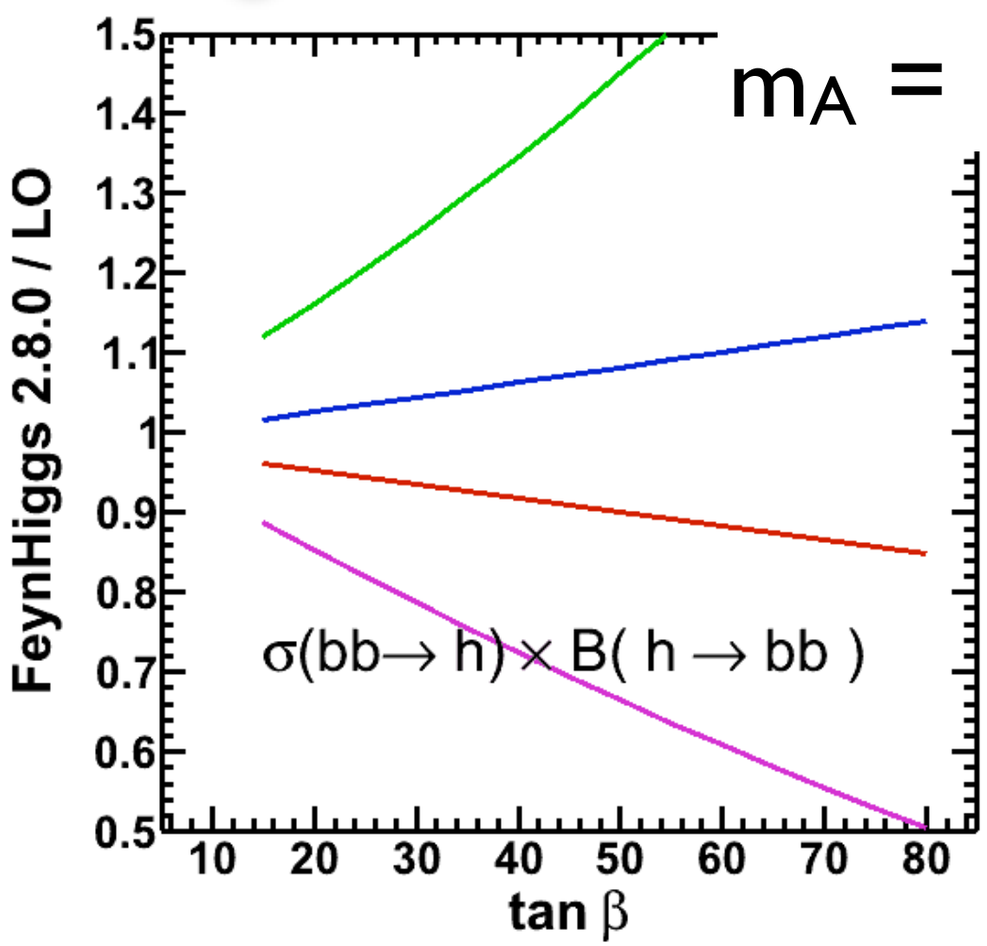
M. S. Carena, S. Heinemeyer, C. E. M. Wagner, and G. Weiglein, Eur. Phys. J. C 26, 601 (2003).

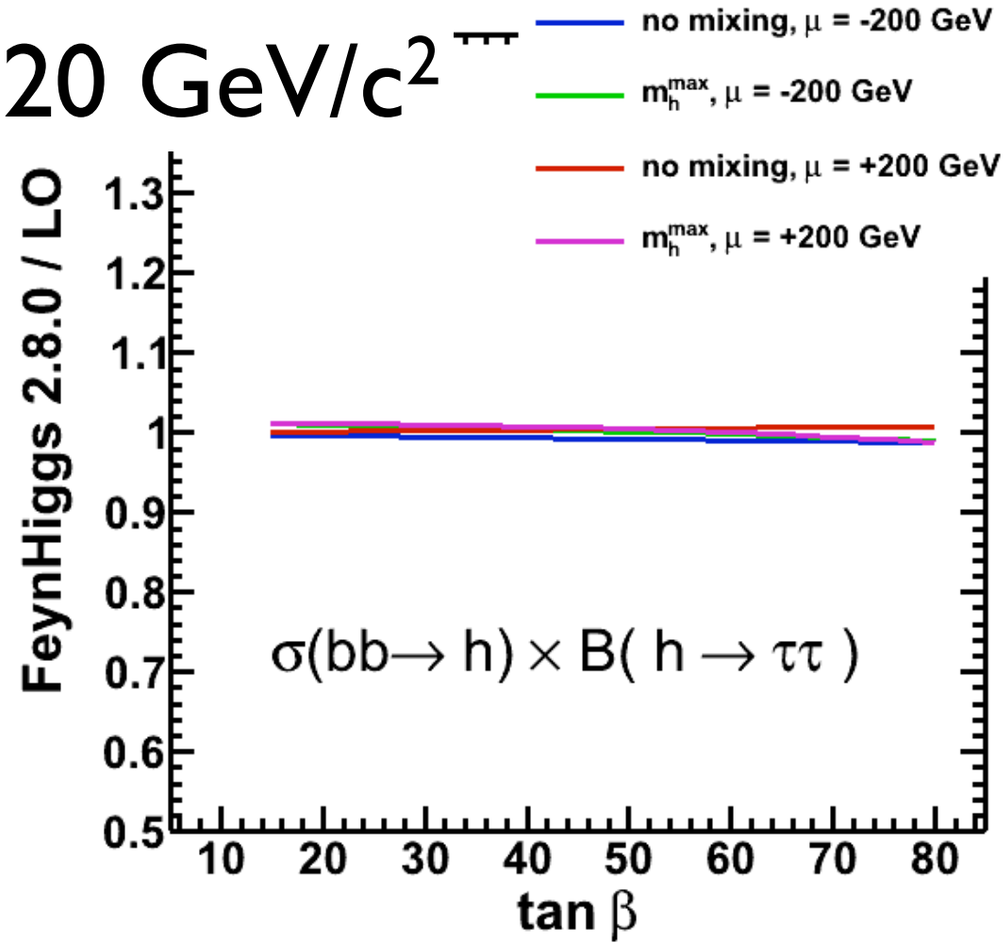
Golden modes





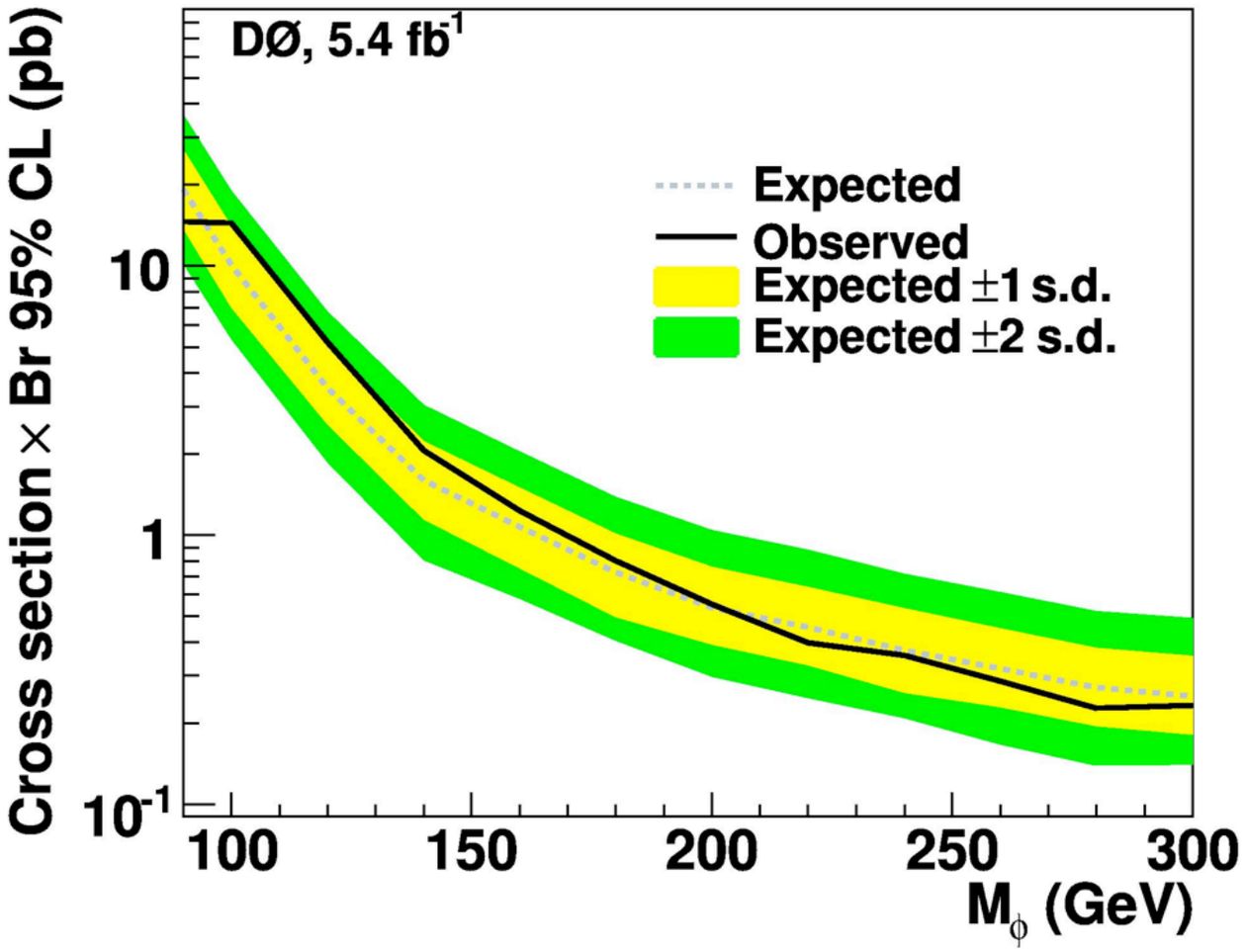
m_A = 120 GeV/c^2





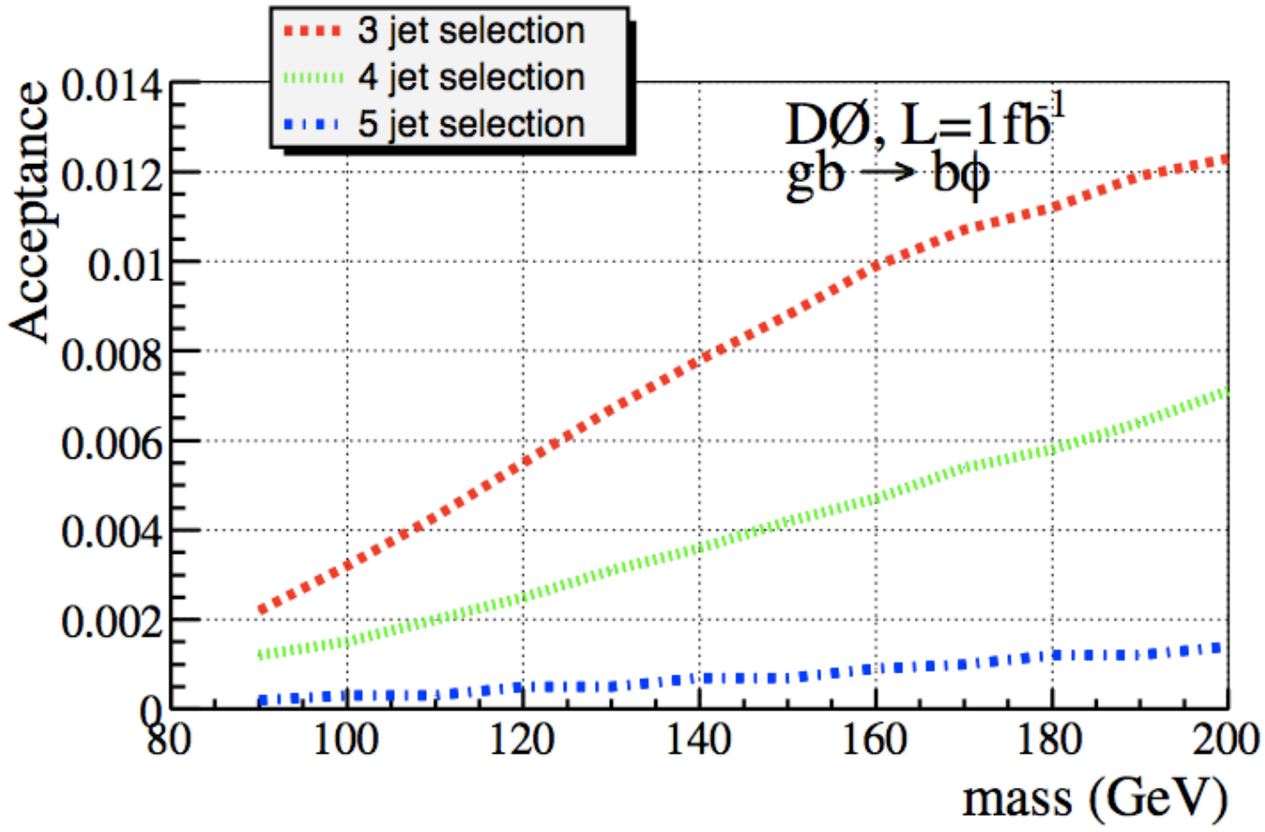
Beyond tree level, h→$\tau\tau$ modes are less sensitive to the MSSM parameters than h→bb

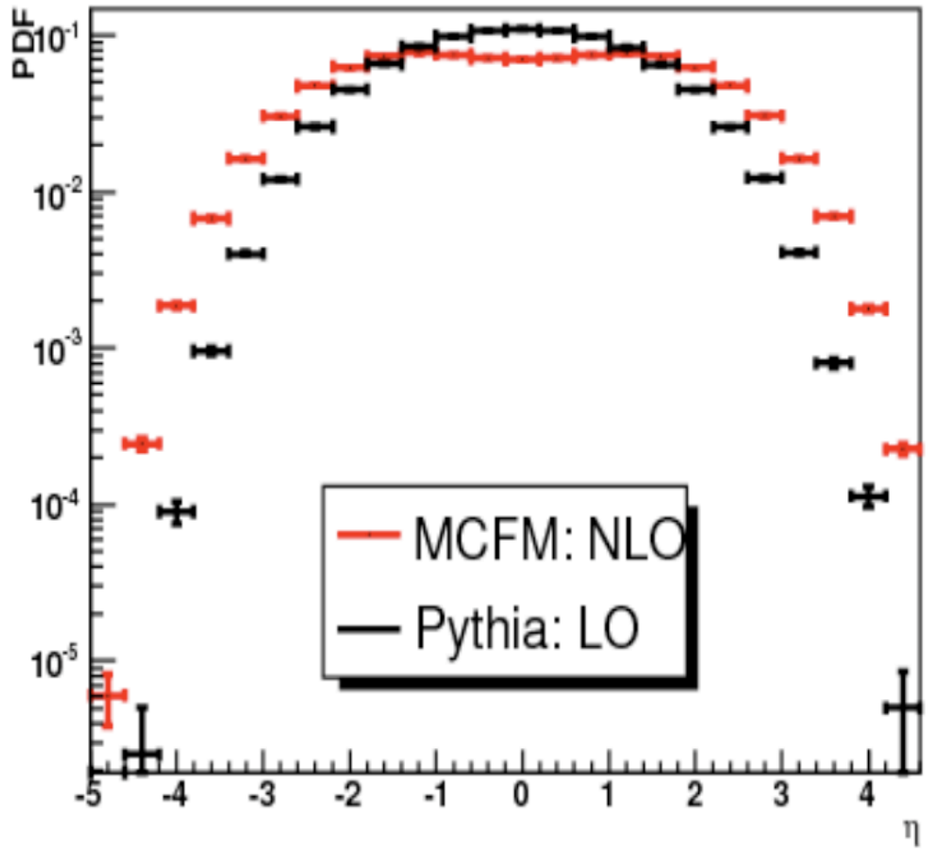
$h \to \tau\ \tau$


DØ, 5.4 fb-1
Expected
Observed
Expected ±1 s.d.
Expected ±2 s.d.
Cross section × Br 95% CL (pb)
10
1
10-1
100
150
200
250
300
Mϕ (GeV)

hb signal modelling

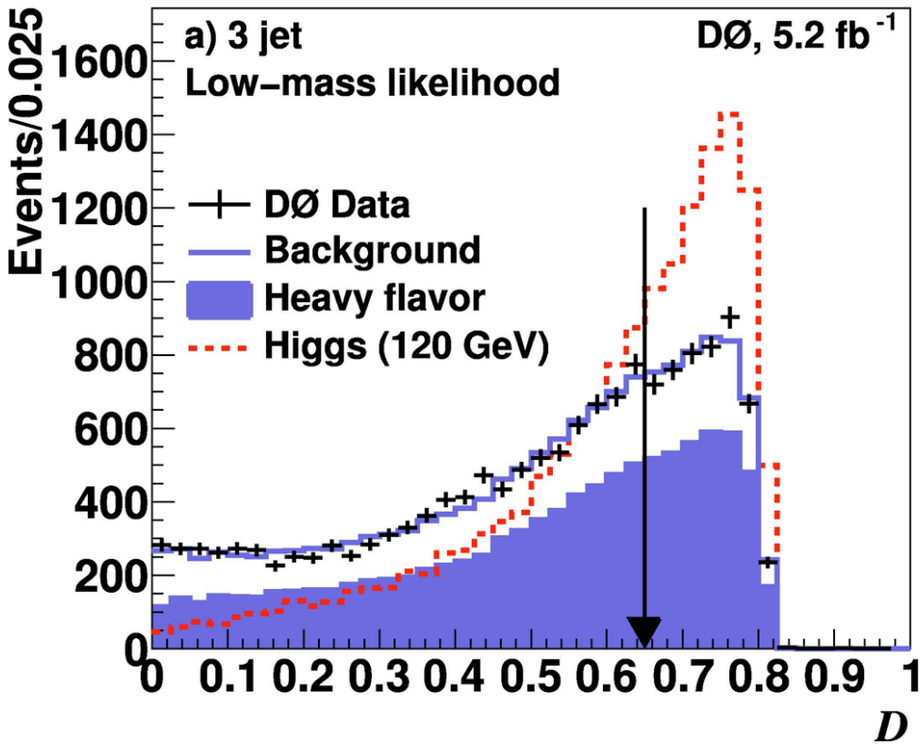
- Signal simulation: pythia bg → bH but spectator b quark kinematics reweighted to NLO (MCFM)

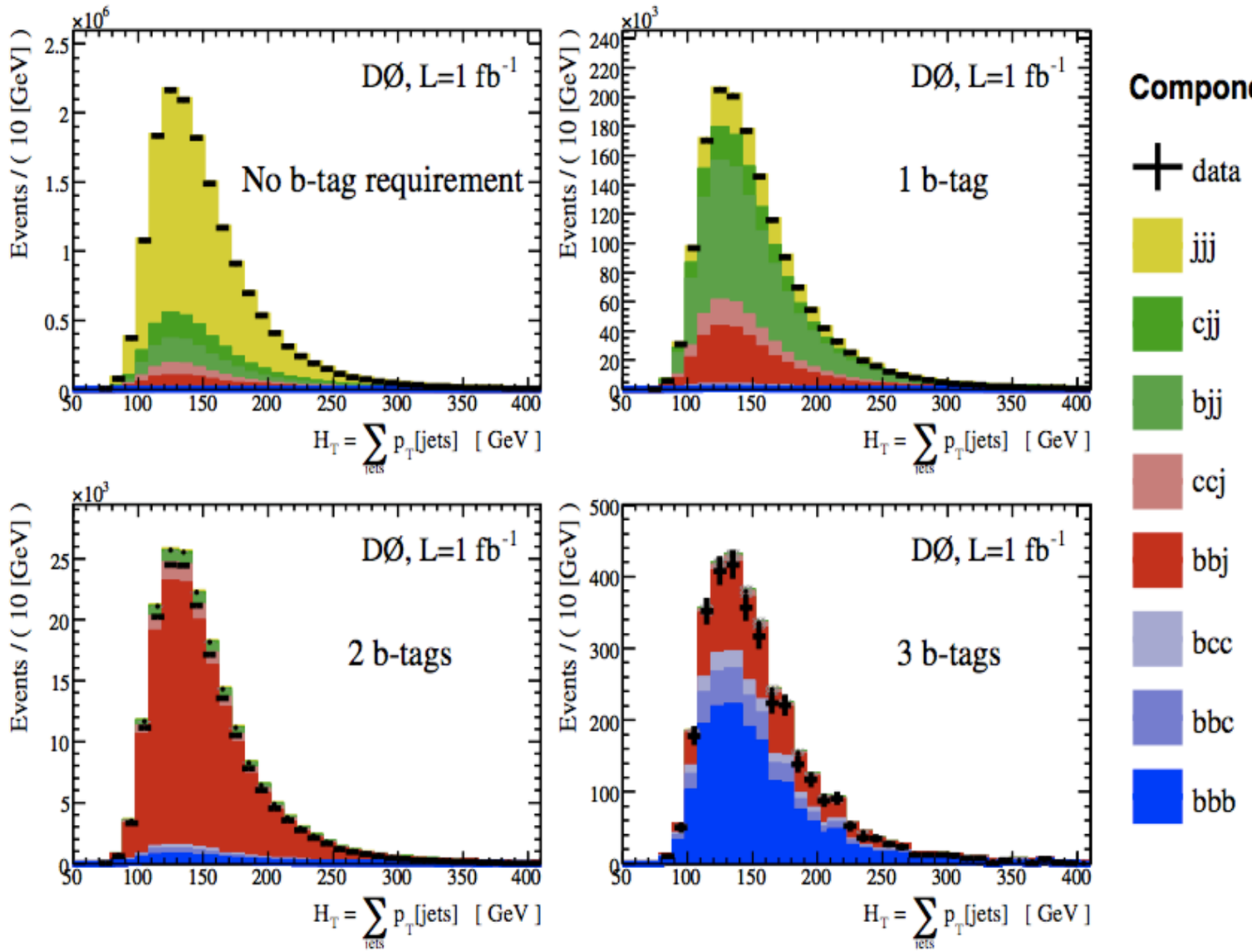




bbb strategy example @ DØ

✓ Likelihood discri to enhance S:B ratio





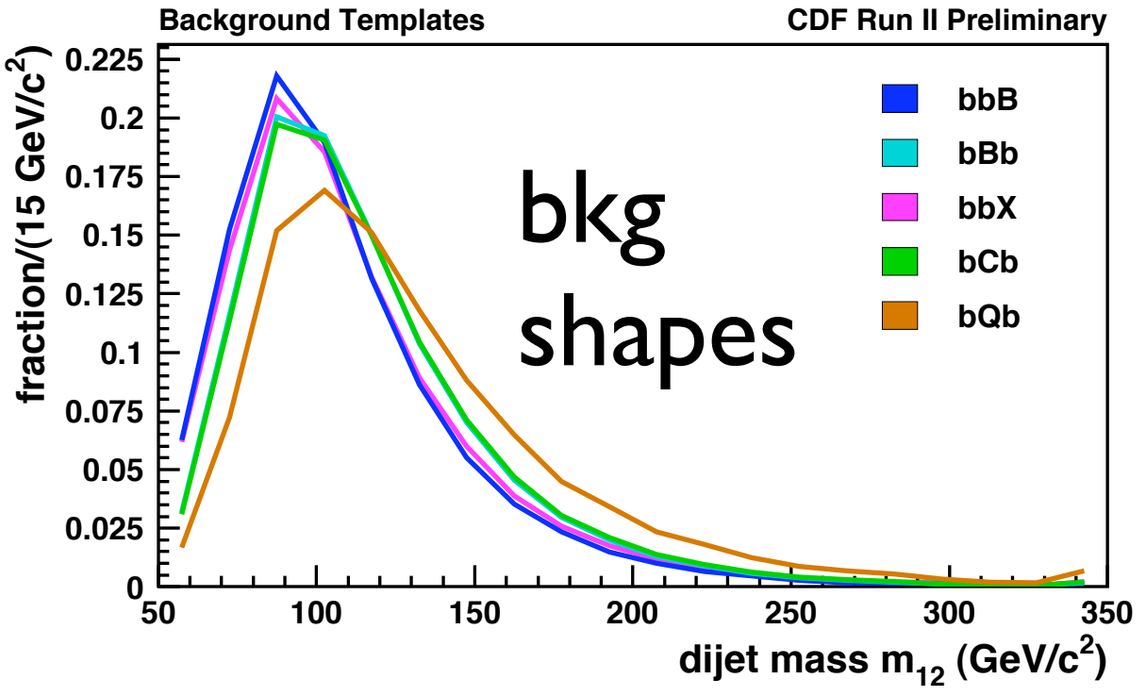
✓ signal to bkg discri. only relies on dijet mass shape

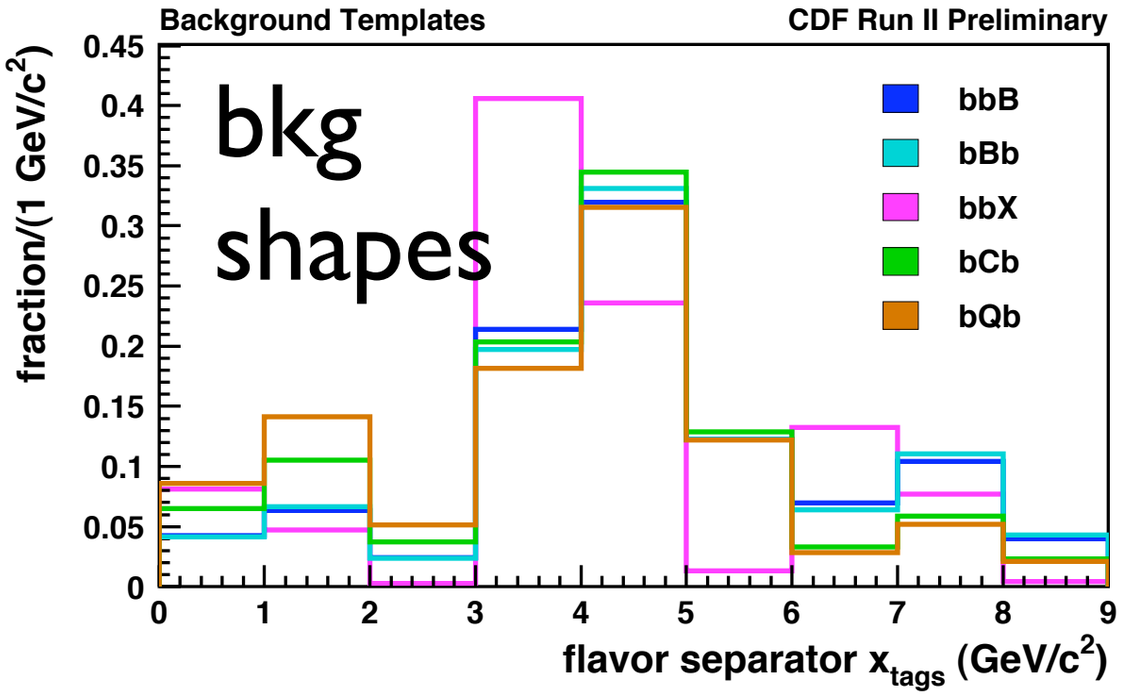
✓ bkg composition from global fit to: 0/1/2/3 b-tag samples

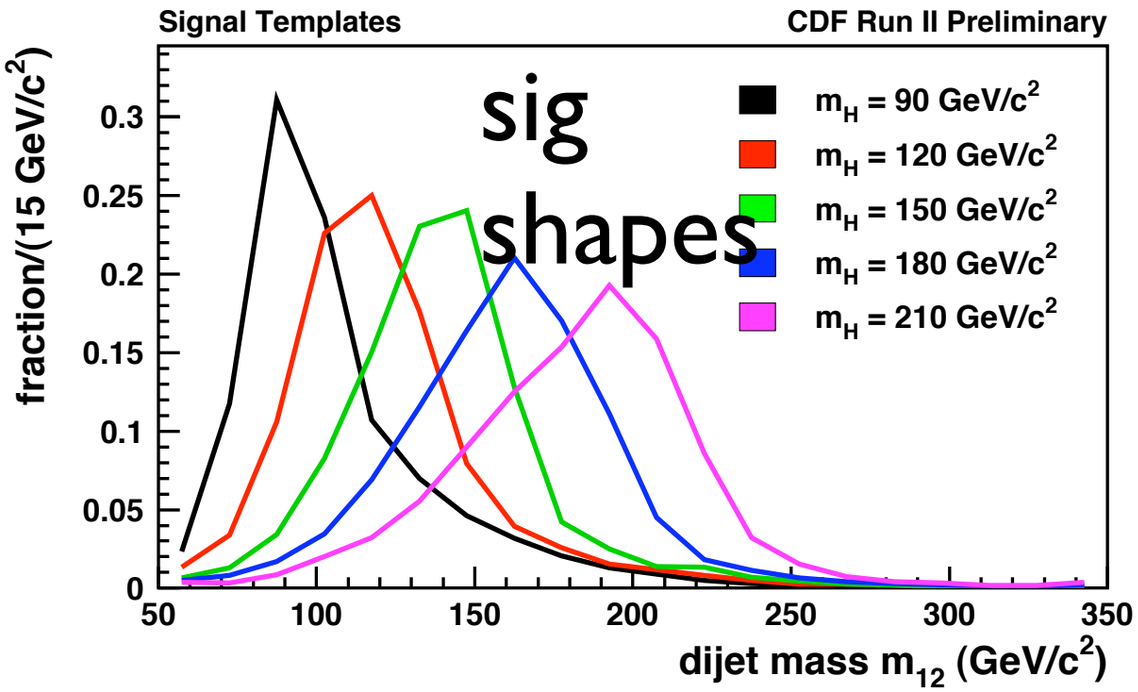
✓ bkg shape from data using the 2 b-tag sample (signal free) via:

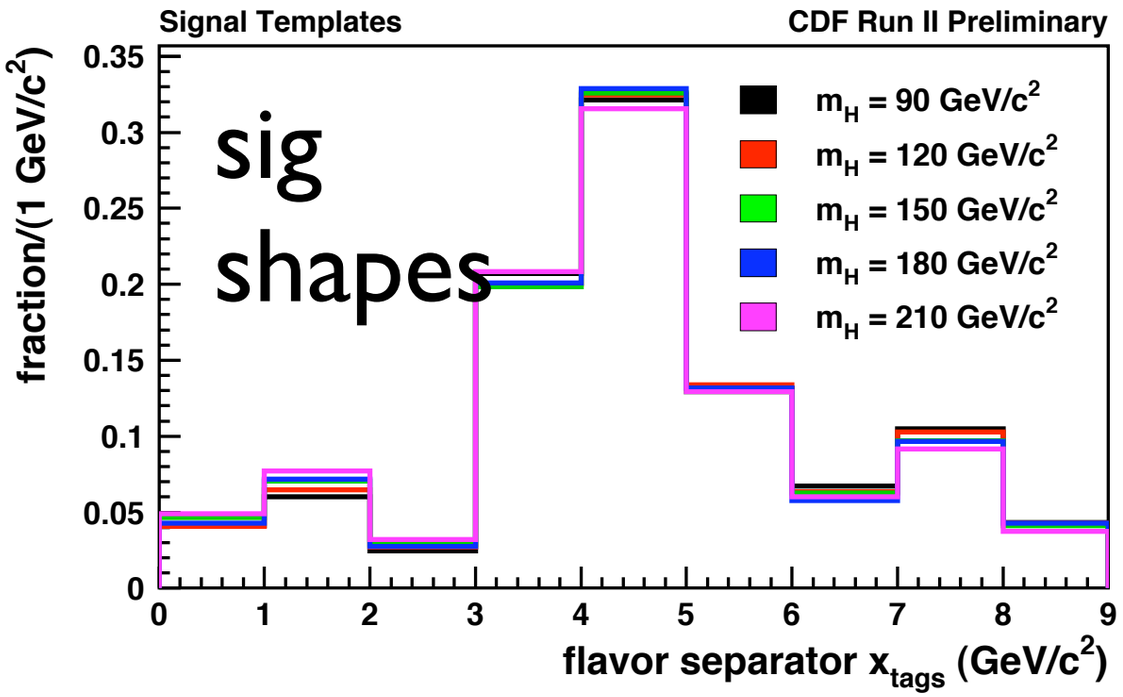
$$S^{exp}_{3tag}(M_{bb},\mathcal{D}) = \frac{S^{MC}_{3tag}(M_{bb},\mathcal{D})}{S^{MC}_{2tag}(M_{bb},\mathcal{D})} \times S^{DATA}_{2tag}(M_{bb},\mathcal{D})$$

bbb background modeling

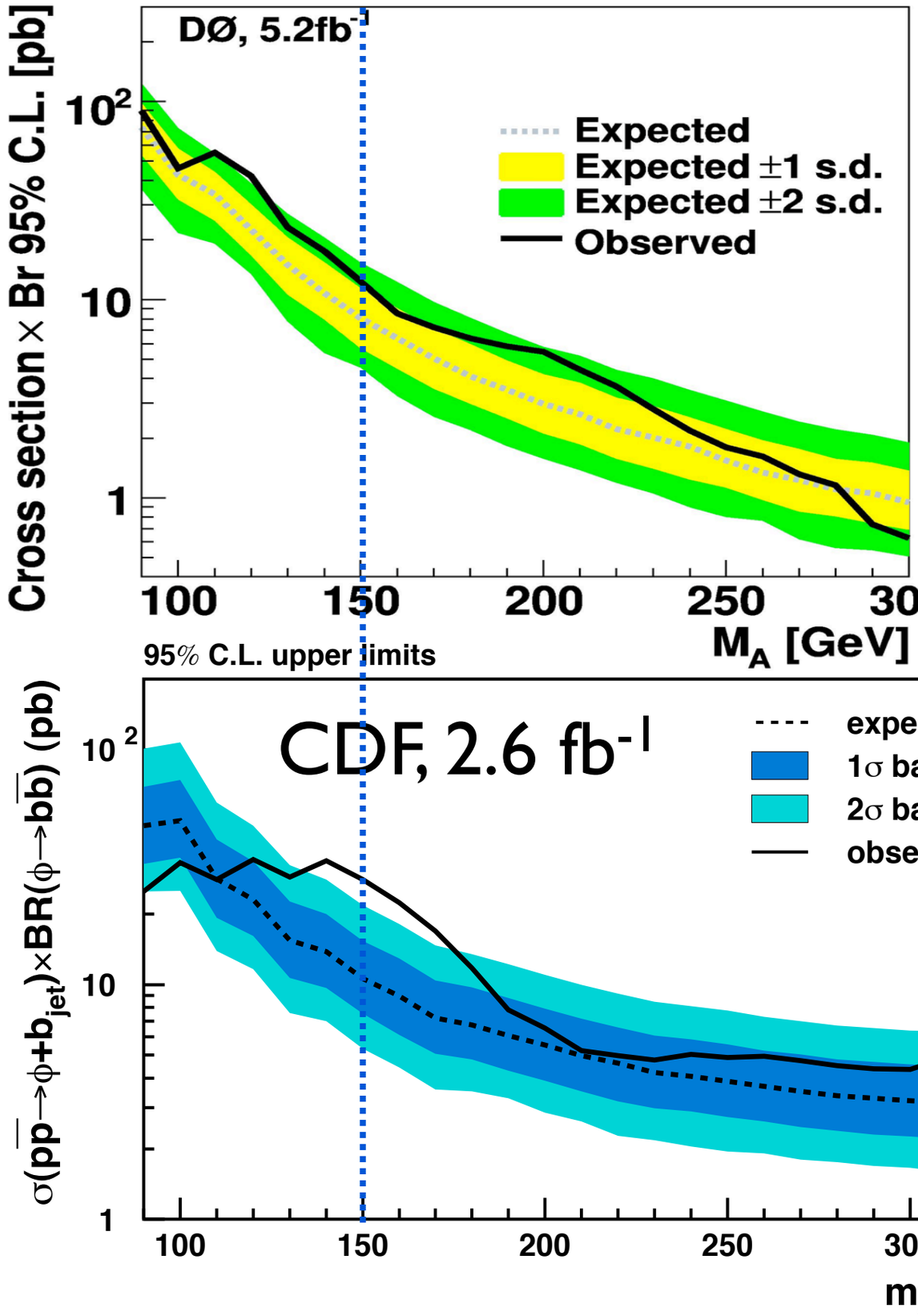








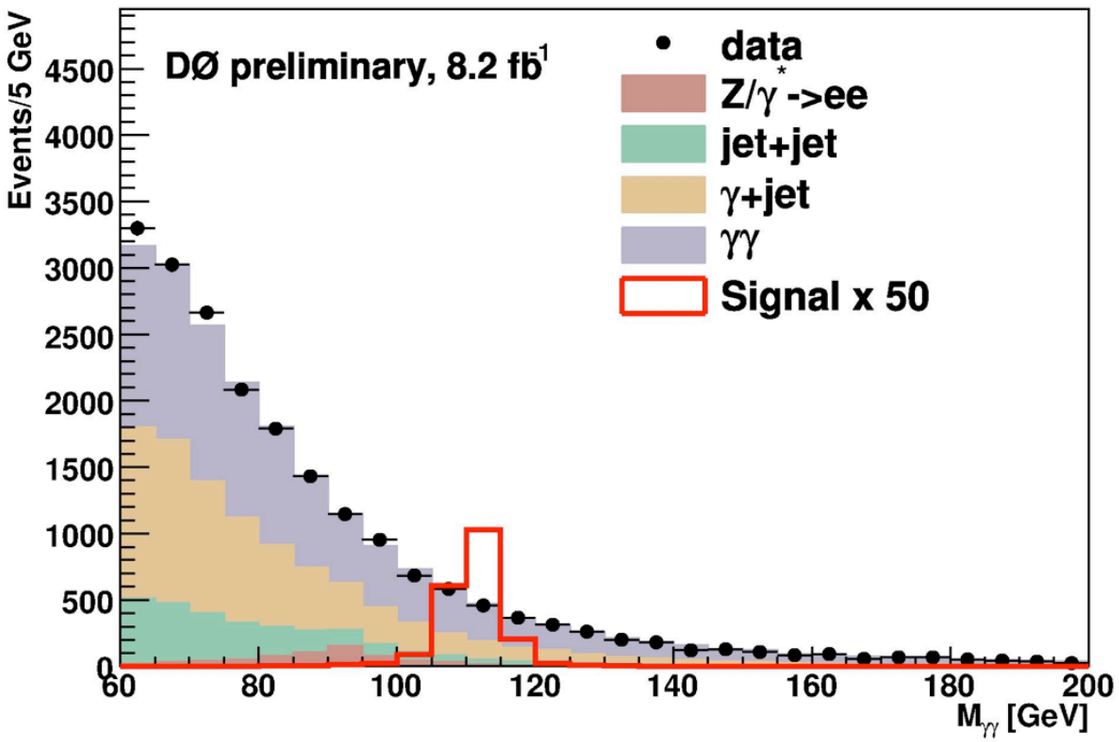
bbb results



Model independent limit, neglecting the width

In the narrow width approx. CDF result gives:
p-value: 0.23% (3σ)
and 2.5% including trial factor (2.2σ)

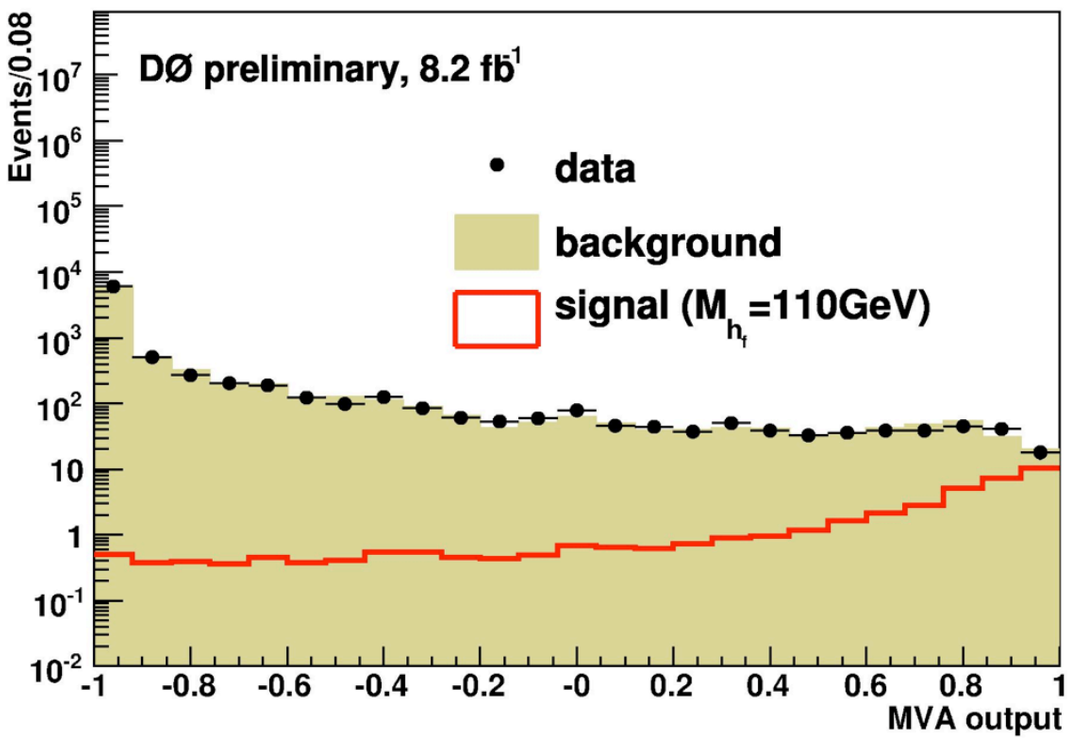
Fermiophobic Higgs

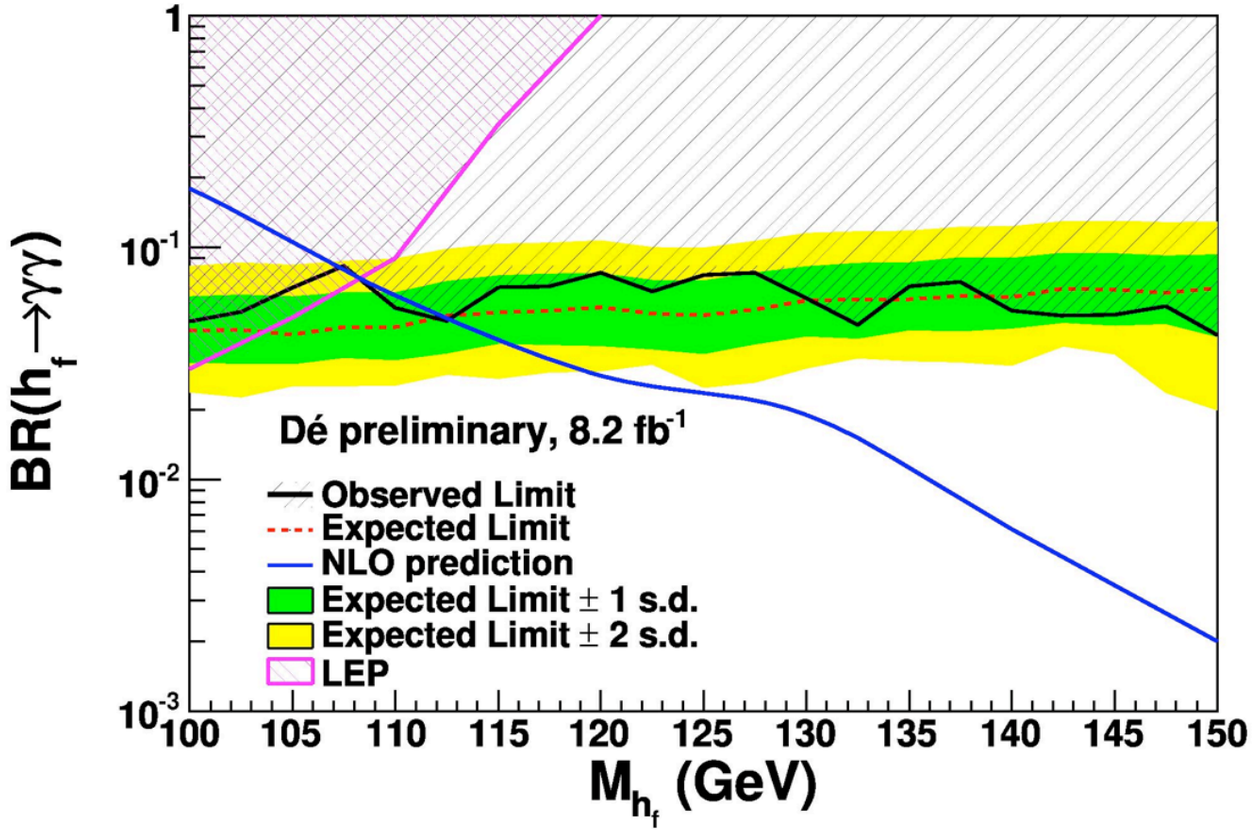


Fermiophobic Higgs:

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

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

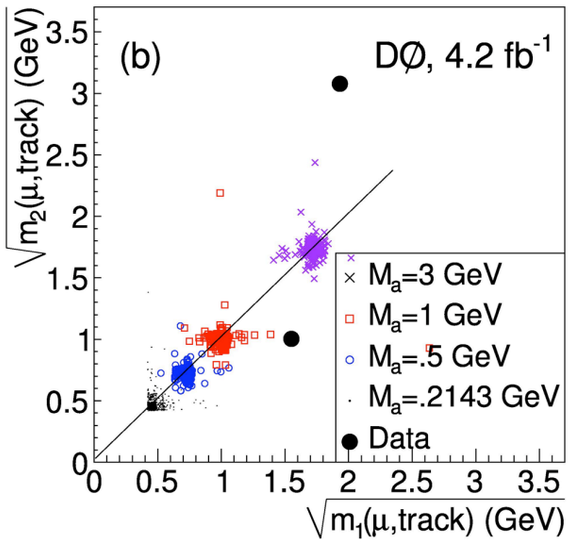




NMSSM $h \to aa$

Phys. Rev. Lett. 103 , 061801 (2009)

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



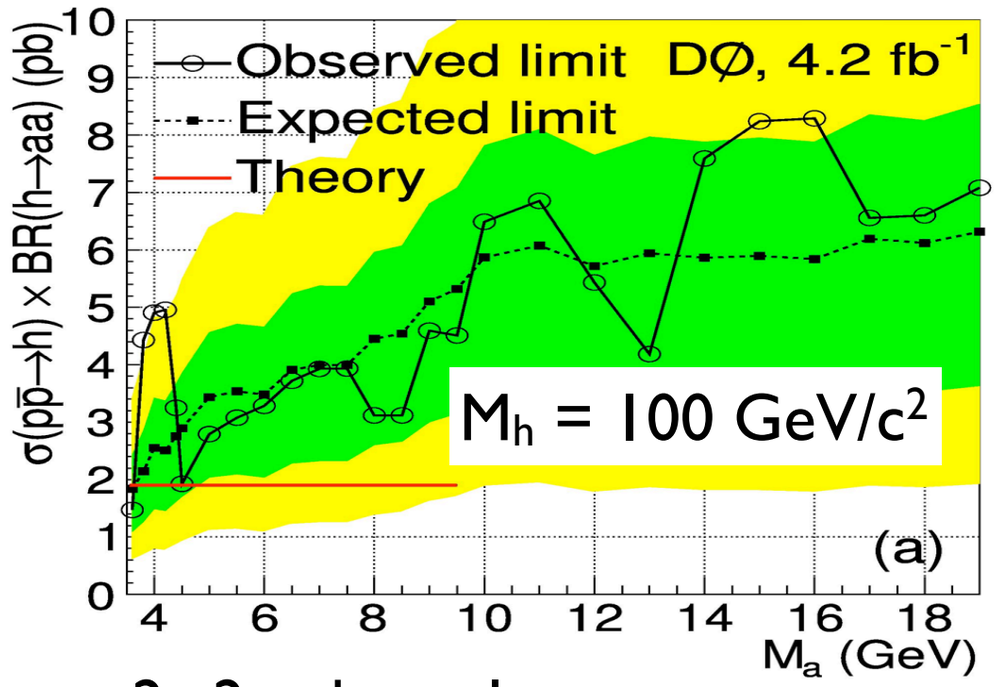
4μ channel, limit:

$\mathcal{B}(a \to \mu\mu) < 7\%$

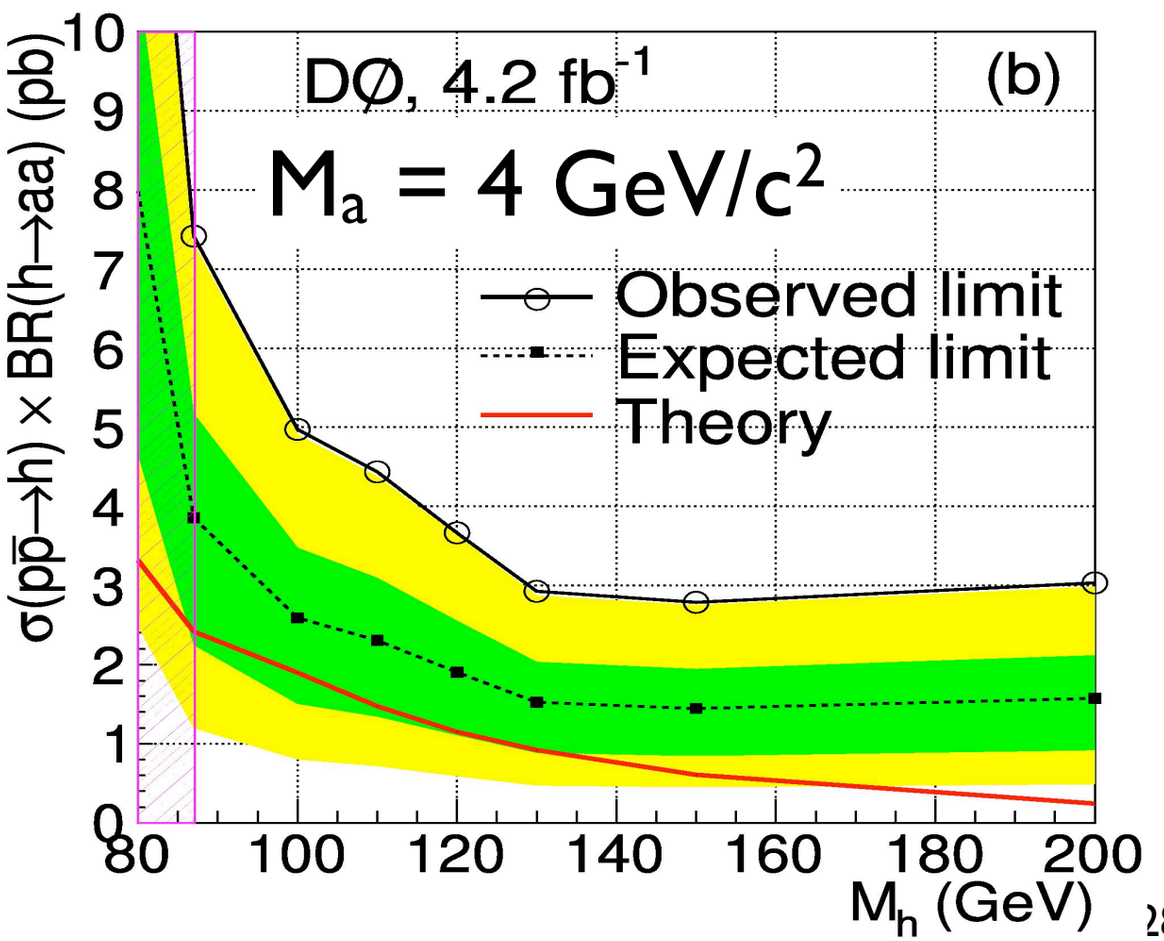
while theo ($M_a < 2m_c$):

$\mathcal{B}(a \to \mu\mu) \sim 10\%$

M_a (GeV)	Window (MeV)	Eff.	N_{bckg}	N_{obs}	$\sigma \times$BR [exp] obs (fb)
0.2143	±15	17%	0.001±0.001	0	[10.0] 10.0
0.3	±50	16%	0.006±0.002	0	[9.5] 9.5
0.5	±70	12%	0.012±0.004	0	[7.3] 7.3
1	±100	13%	0.022±0.005	0	[6.1] 6.1
3	±230	14%	0.005±0.002	0	[5.6] 5.6



$2\mu 2\tau$ channel



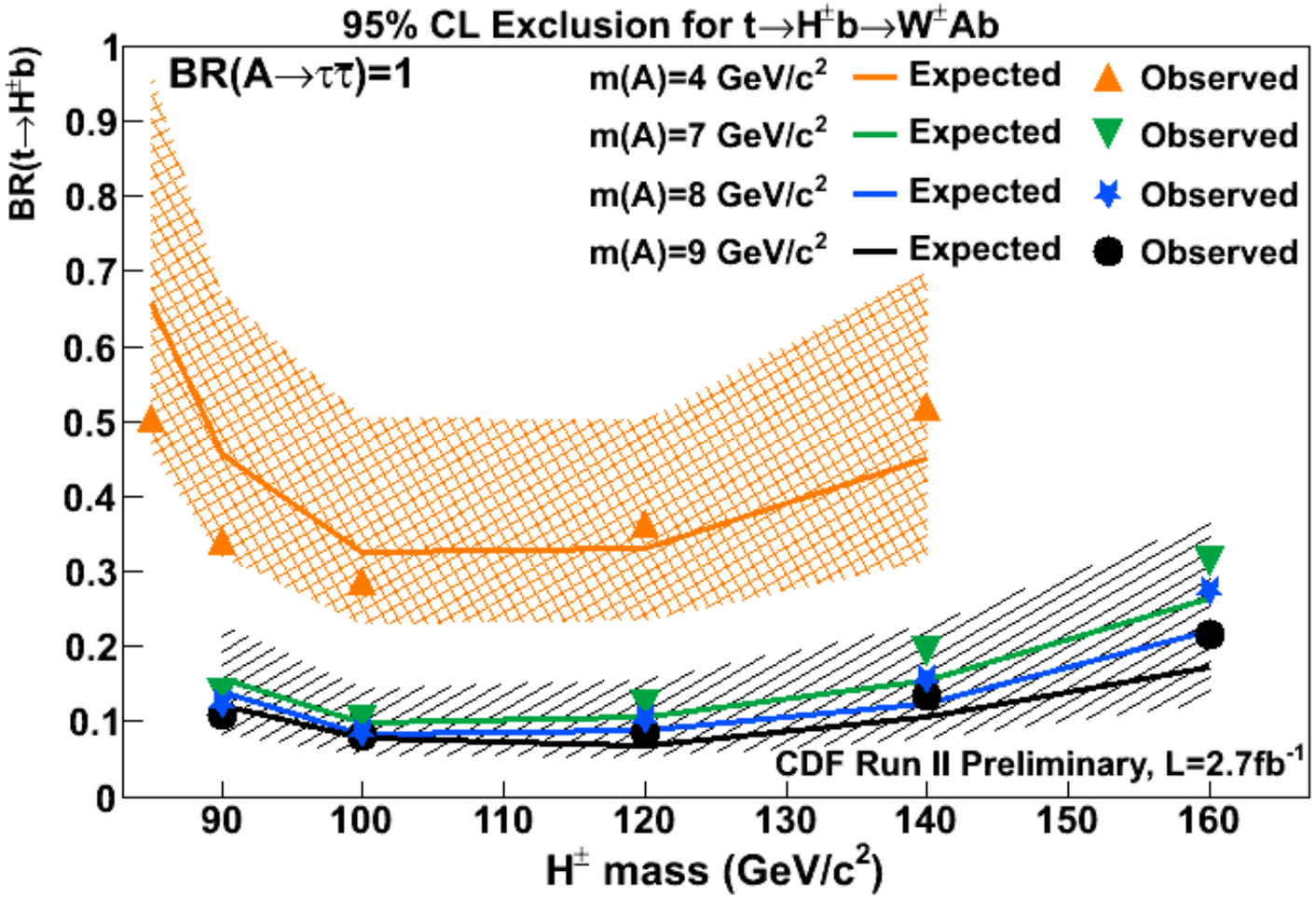
NMSSM $\mathcal{H}^+ \to W^+ a_1$

$$t \to H^{\pm} b \to W^{\pm} A b \to W^{\pm} b \tau \bar{\tau}$$

If a charged higgs of around ~100 GeV exists, then the branching ratio of top to charged higgs may be as high as 10 to 40%

This search assumes the mass of the light psuedo-scalar higgs boson is less than twice the b-quark mass, a region not experimentally excluded

This is the first limits on this decay mode



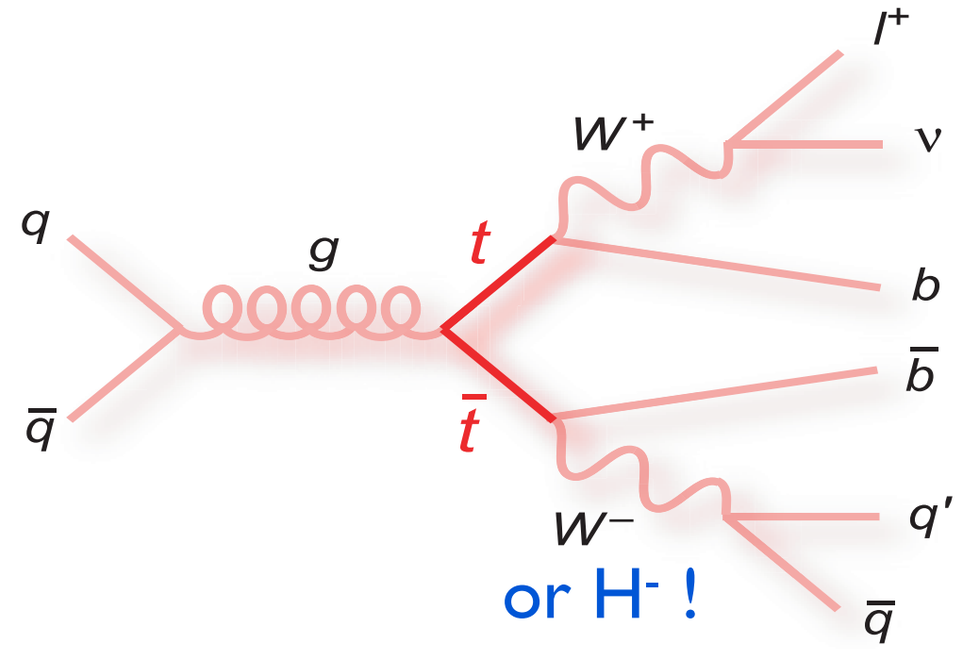
Expect for $M_a < 2m_b$:
$\mathcal{B}(H^+ \to W^+ a_1) \sim 50\%$

CDF preliminary

Charged Higgs

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

  $t \rightarrow H^+ b$ opens



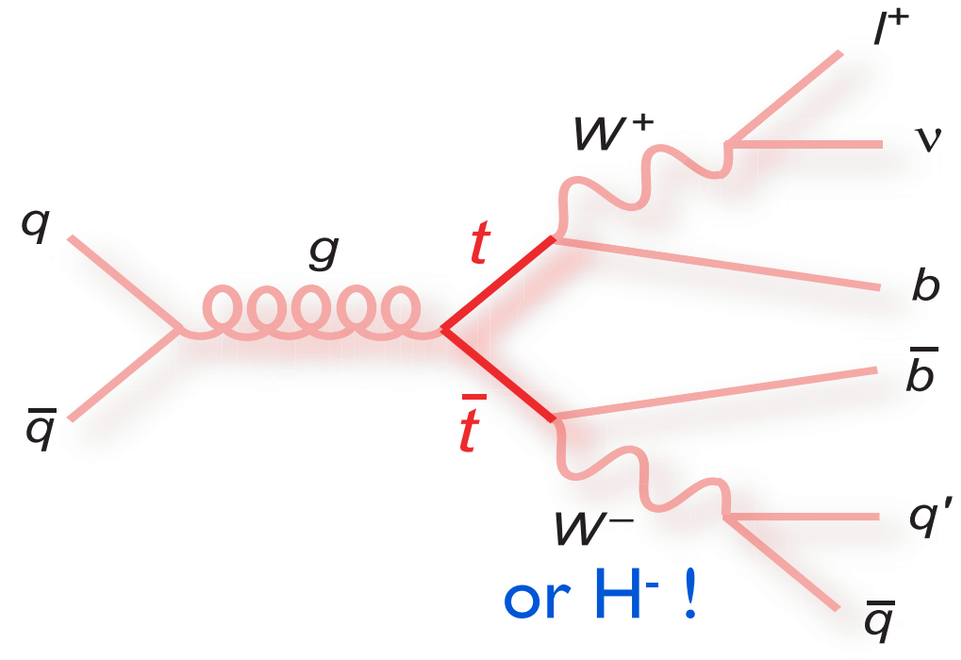
- H^+ decays are very different from W^+ decays:

  ✓ high tanβ: $B(H^+ \rightarrow \tau\, \upsilon) = 1$

  ✓ leptophobic: $B(H^+ \rightarrow c\, \bar{s}) = 1$

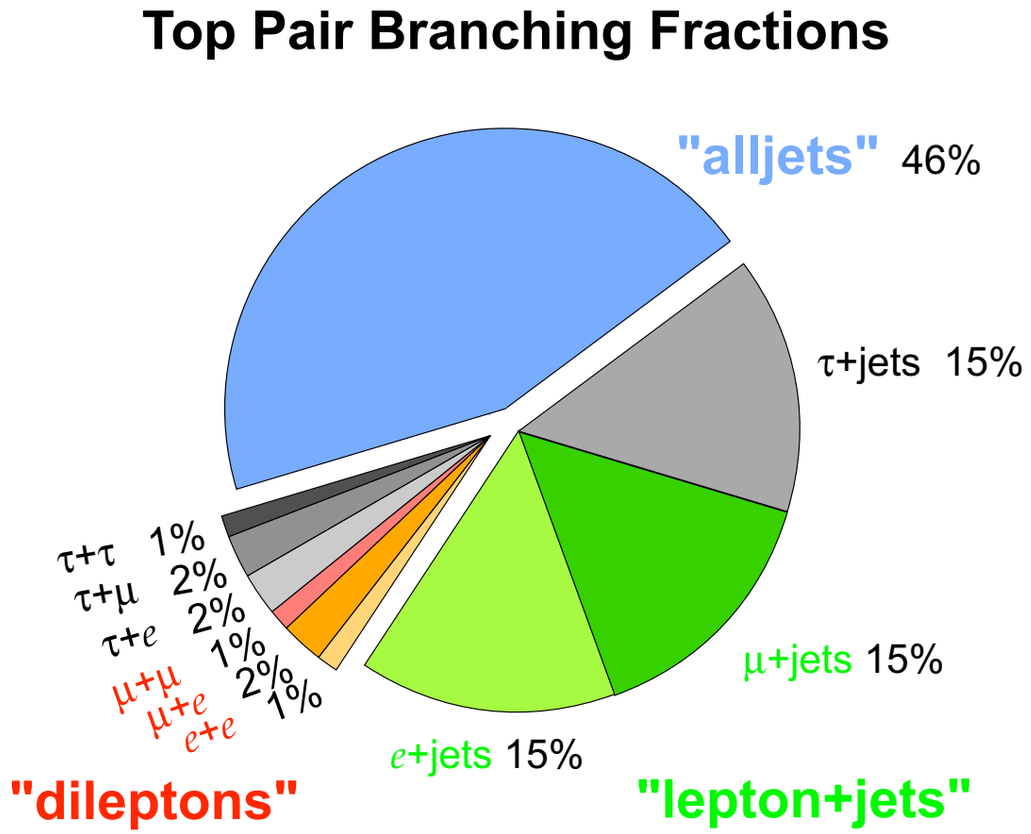
- If $m_{H+} < m_{top}$:

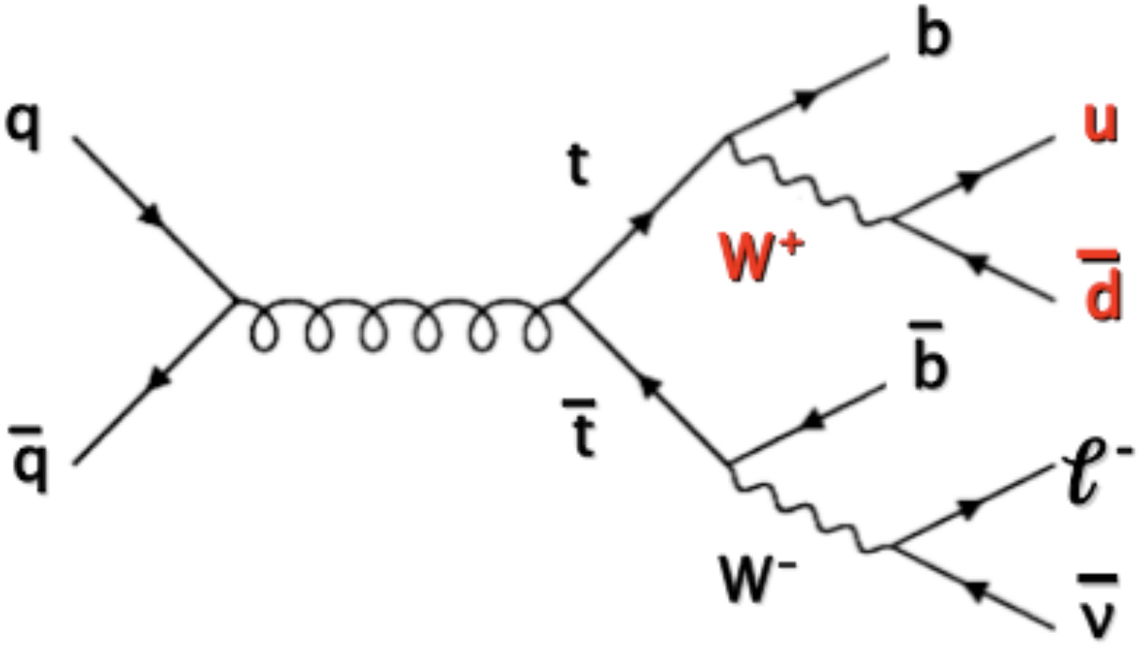
  $t \rightarrow H^+ b$ opens

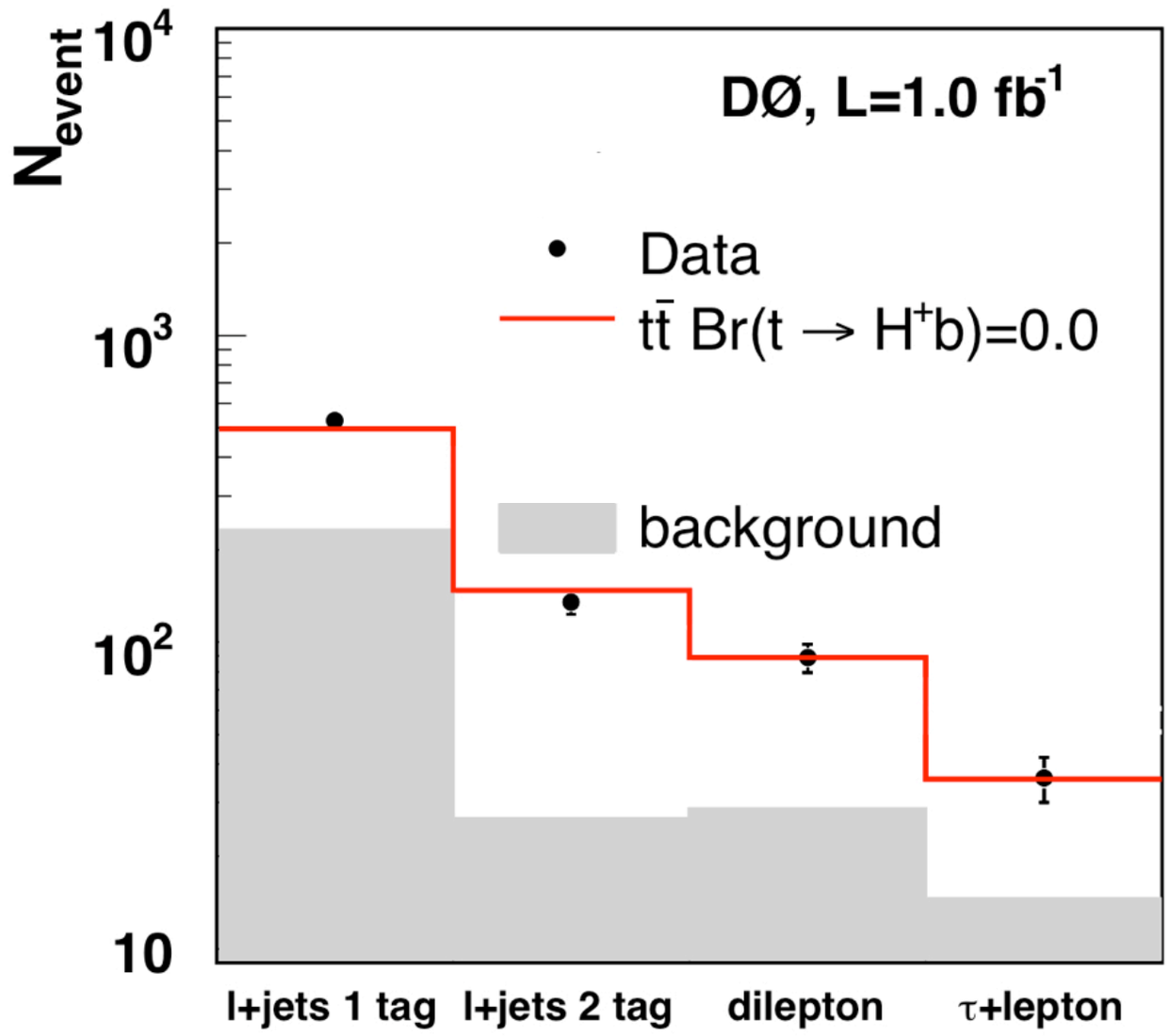


- H^+ decays are very different from W^+ decays:
  - ✓ high tanβ: $B(H^+ \rightarrow \tau\, \upsilon) = 1$
  - ✓ leptophobic: $B(H^+ \rightarrow c\, \bar{s}) = 1$

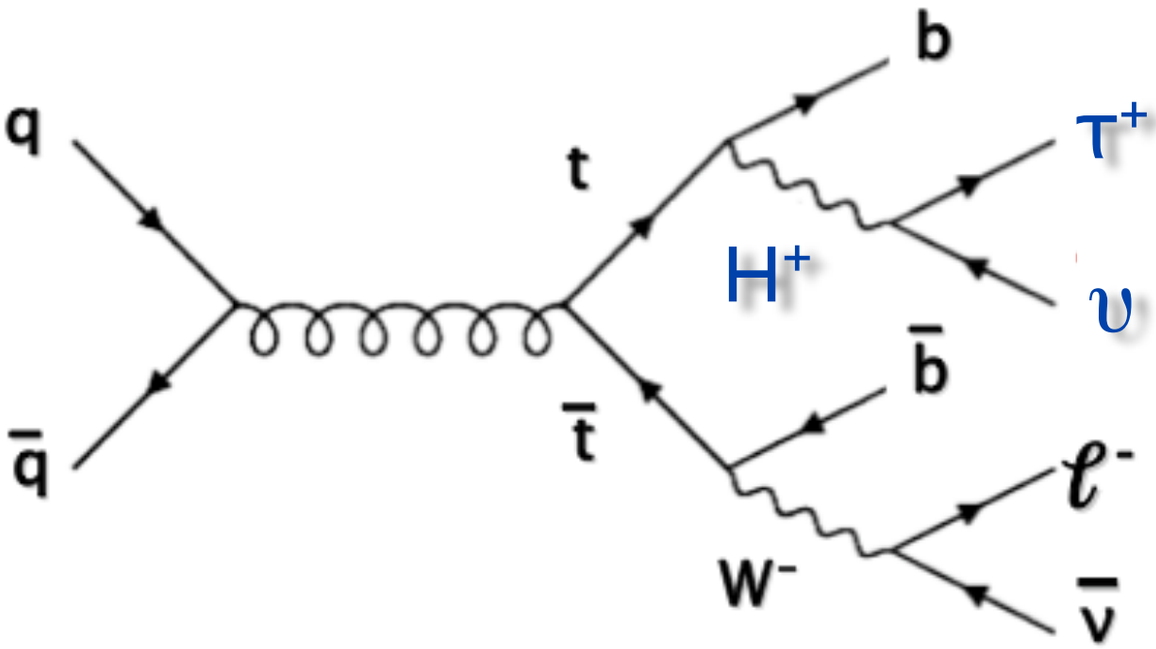
- Changes the different channels contributions: compare all the measured cross sections

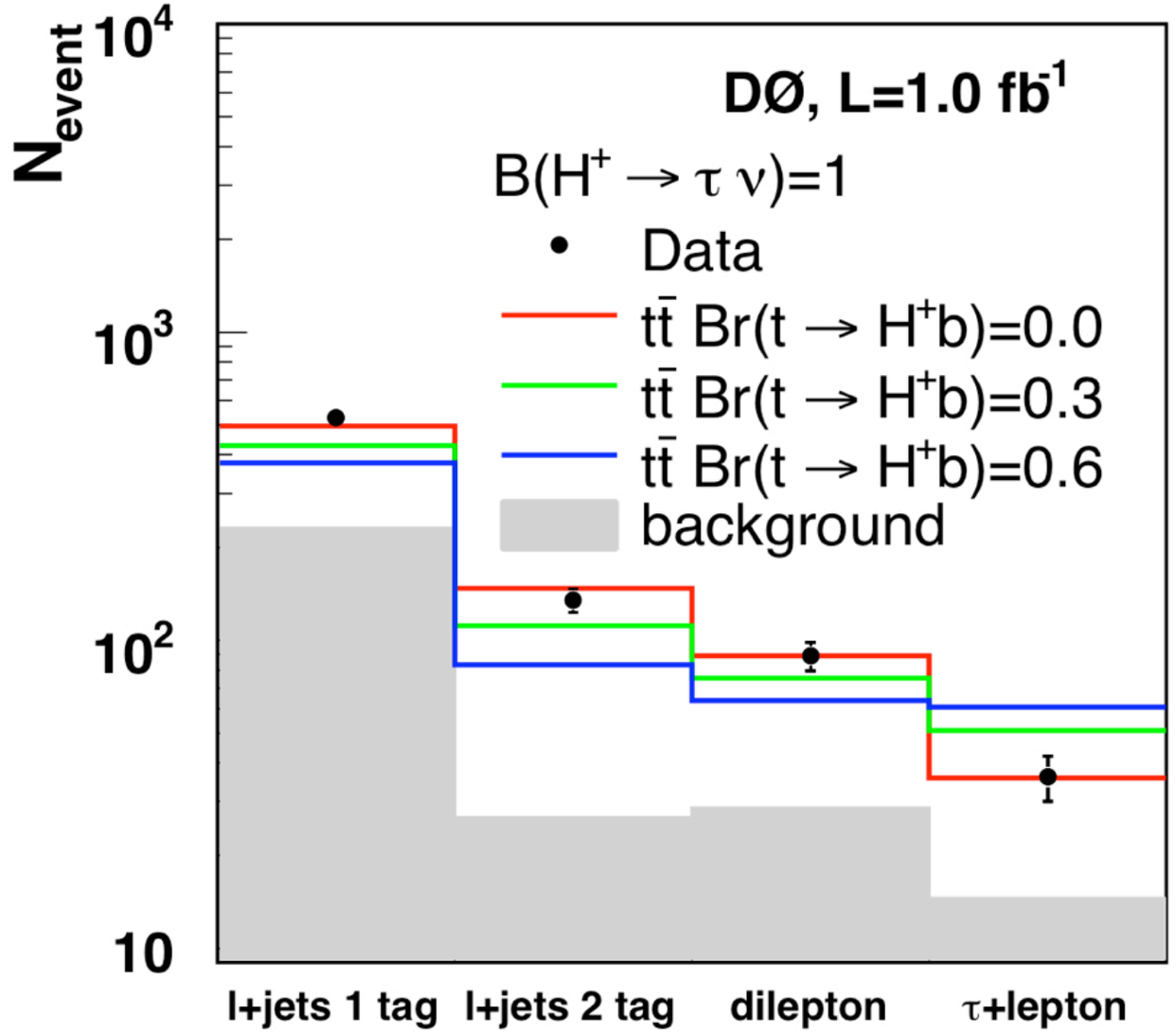



q
$\bar{q}$
t
$\bar{t}$
b
W+
u
$\bar{d}$
$\bar{b}$
W-
ℓ^-
$\bar{\nu}$

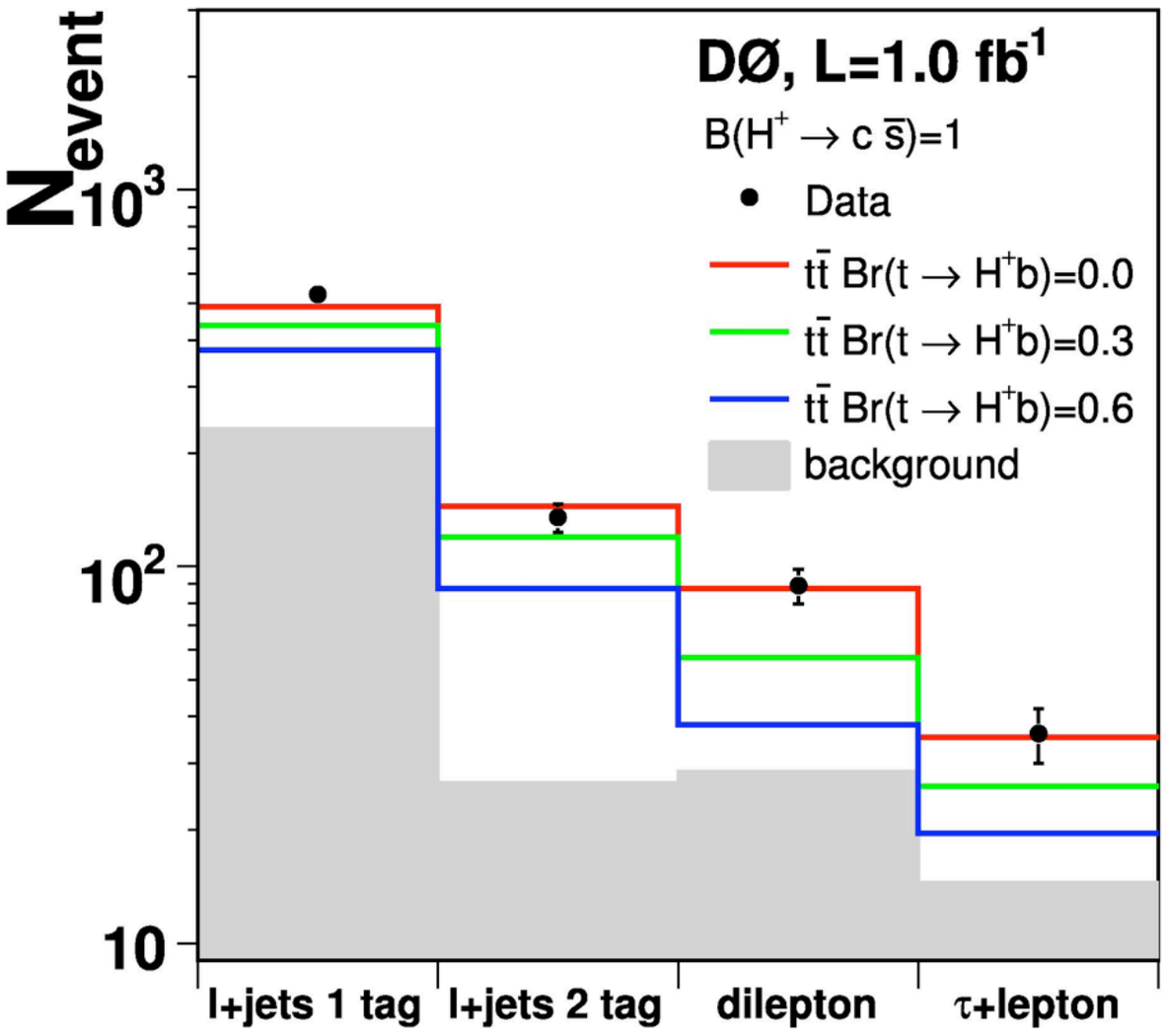

N_{event}
10^4
10^3
10^2
10
DØ, L=1.0 fb^{-1}
Data
$t\bar{t}$ Br(t → H$^+$b)=0.0
background
l+jets 1 tag
l+jets 2 tag
dilepton
τ+lepton

Charged Higgs

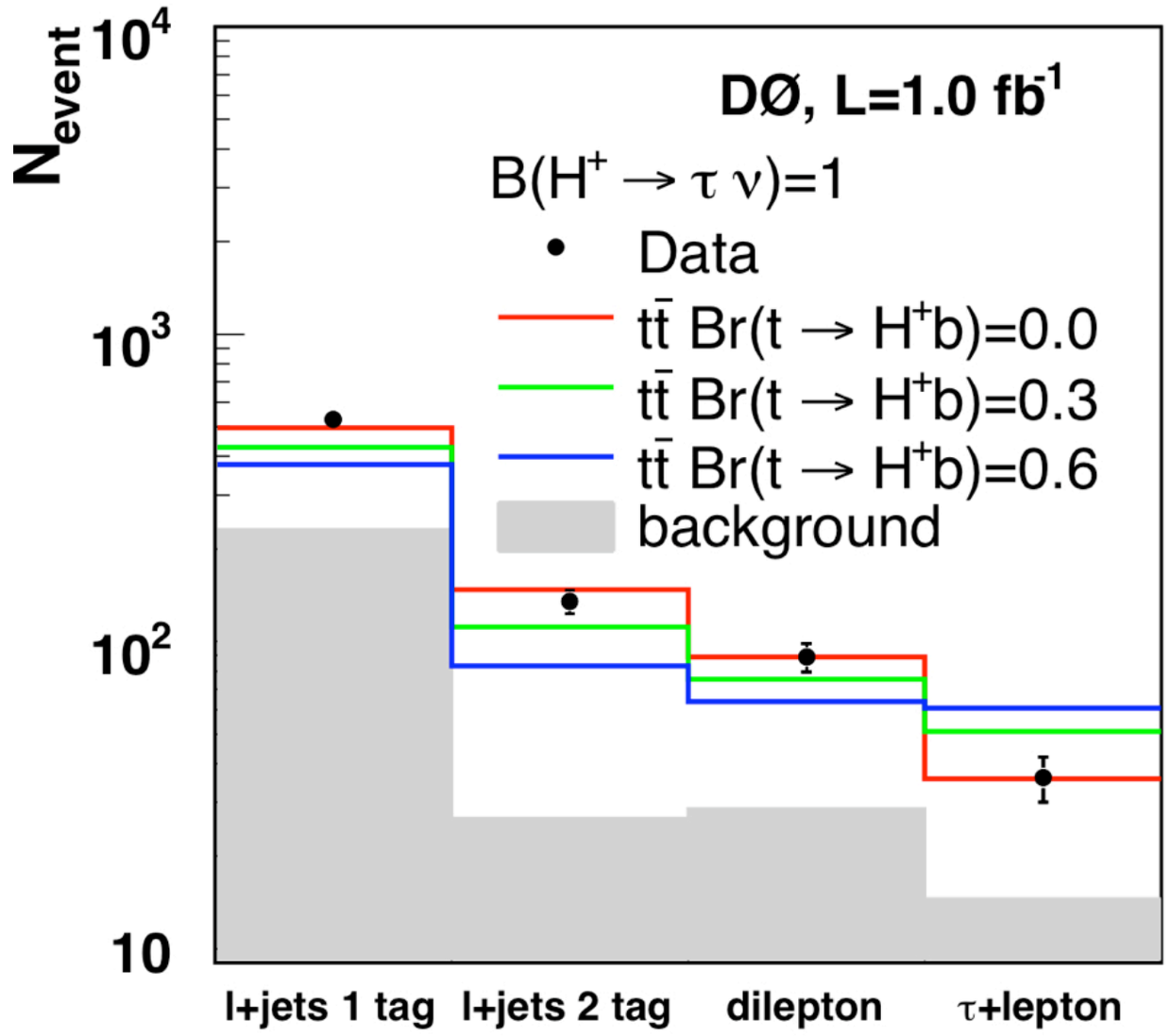




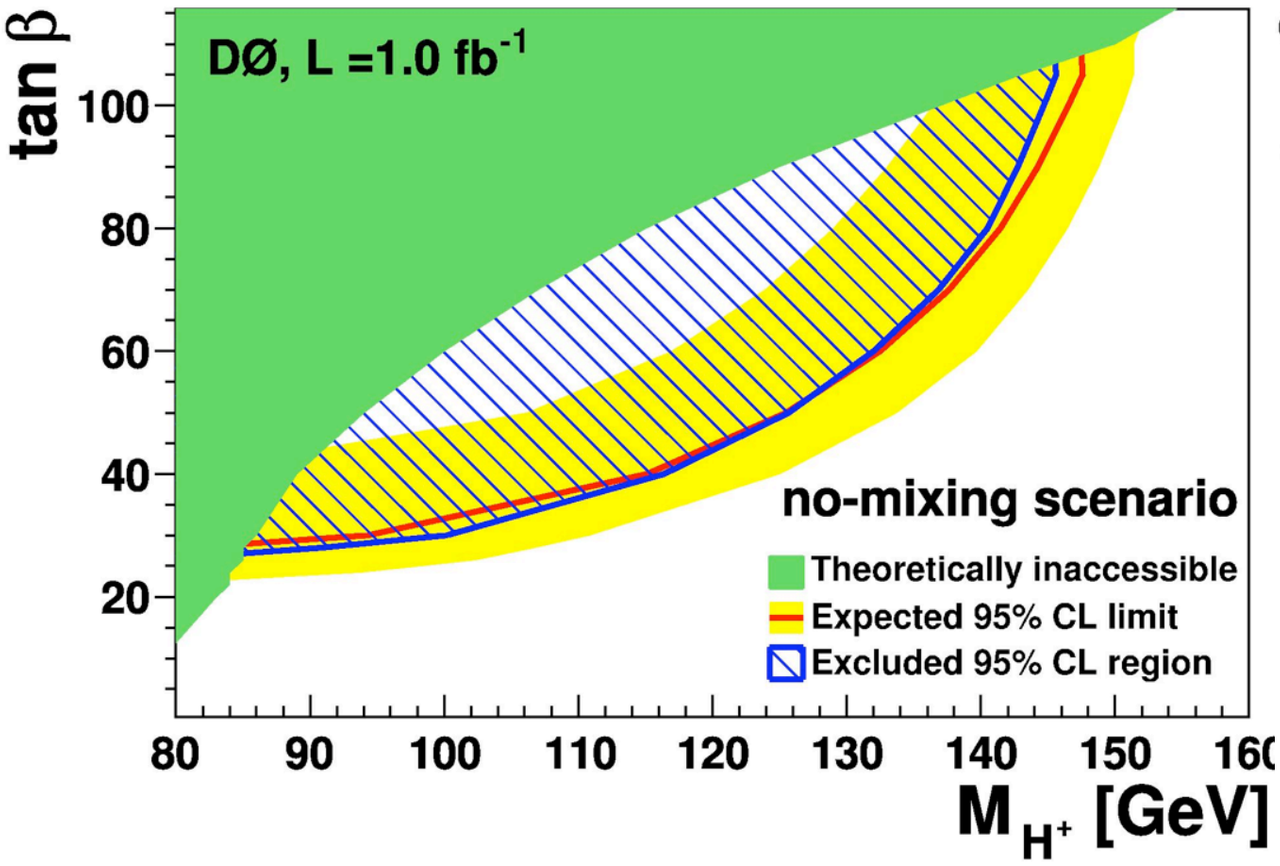
leptophobic Higgs

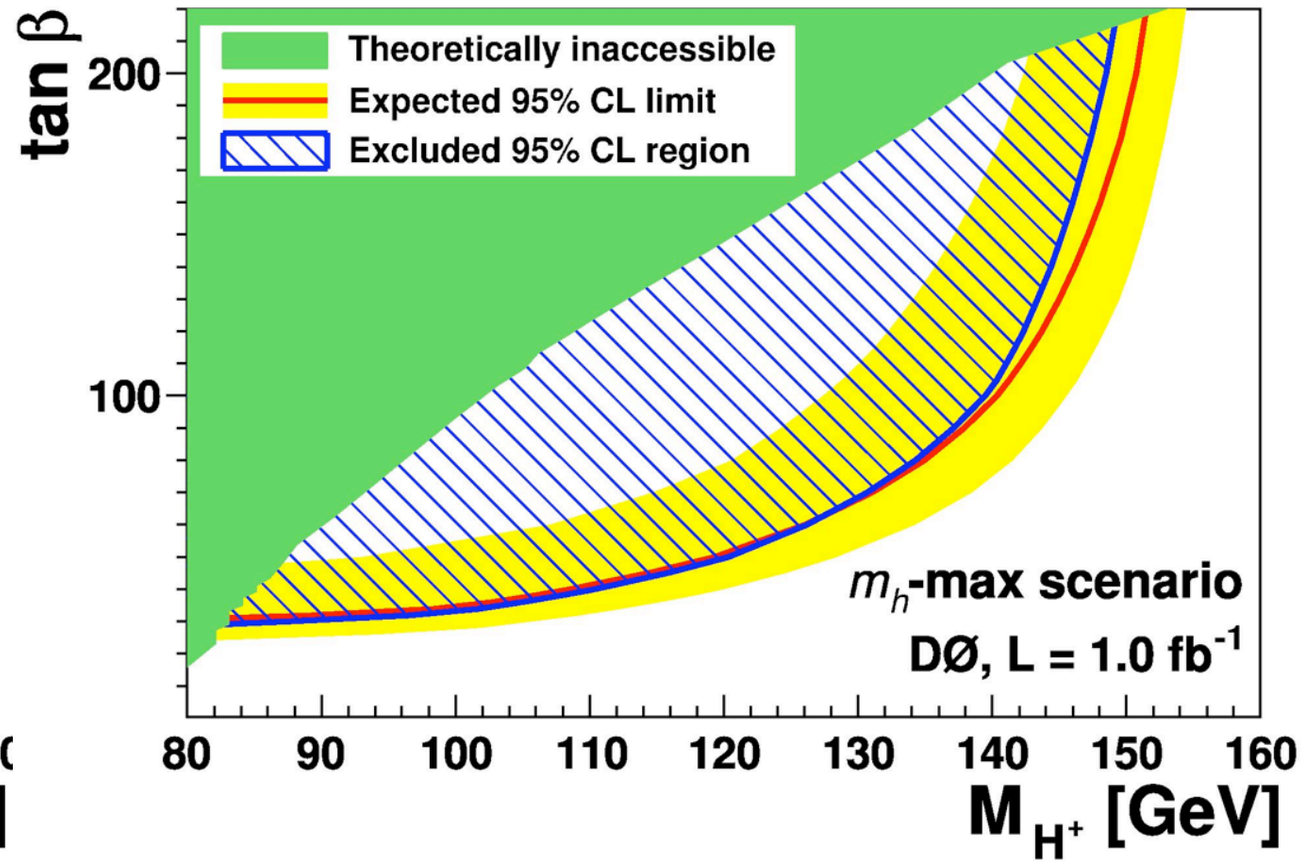


tauonic Higgs



MSSM interpretation



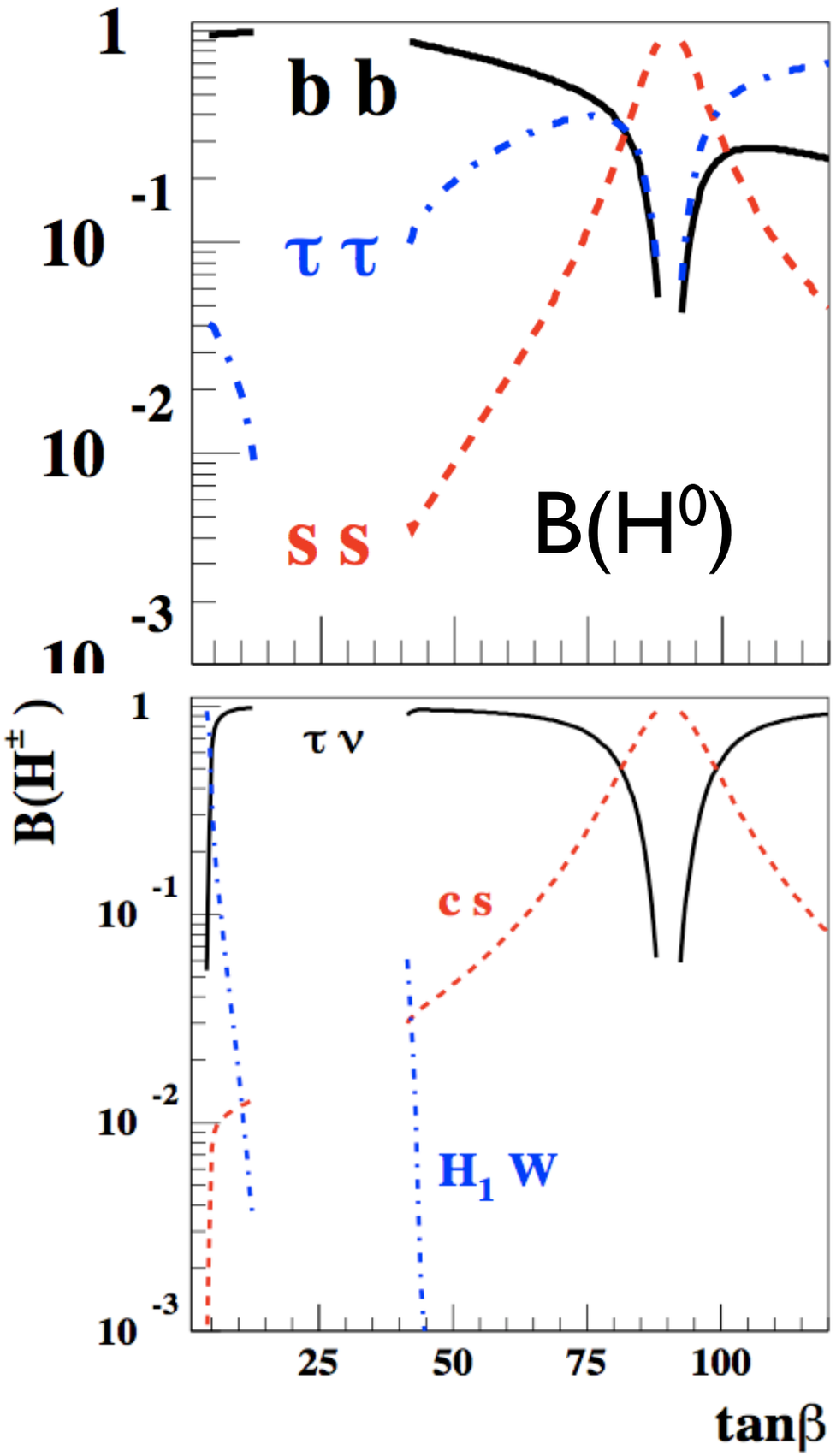


arXiv:0908.1811, submitted to PLB

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

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

CPX scenario

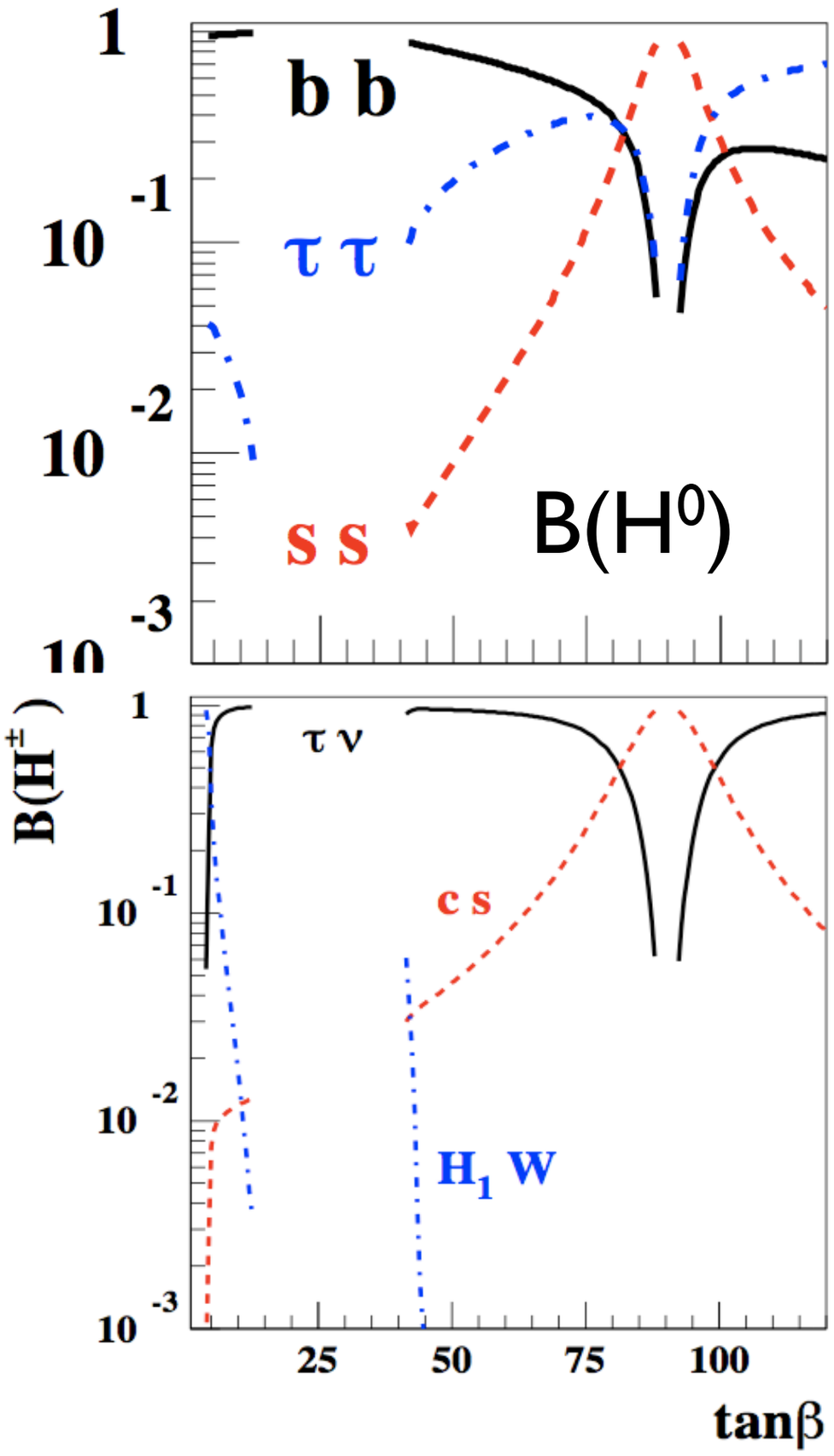


CPX benchmark scenario:

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

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

CPX scenario



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