Search for neutral supersymmetric Higgs bosons in di-tau and bbb(b) final states in ppbar collisions at $\sqrt{s}$ = 1.96 TeV

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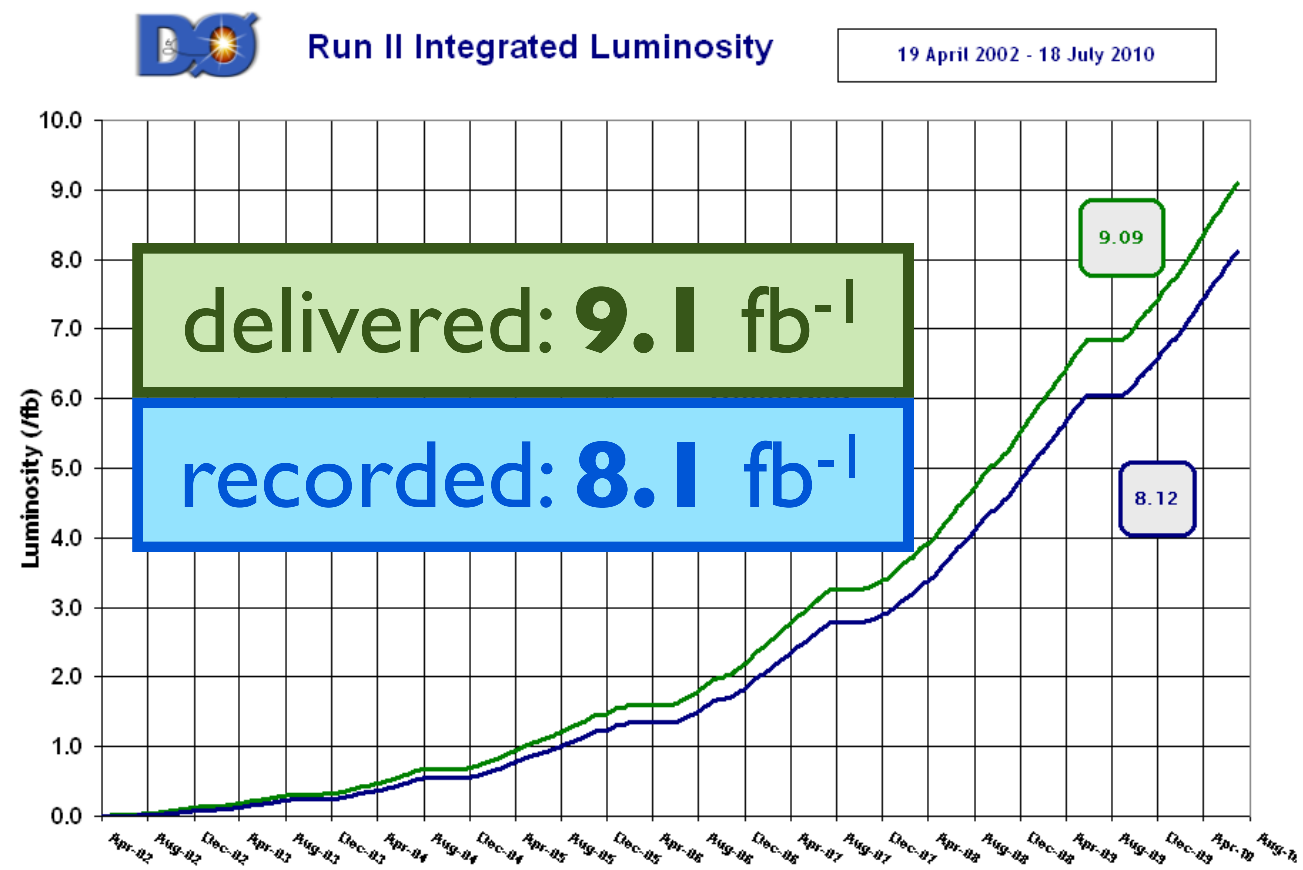
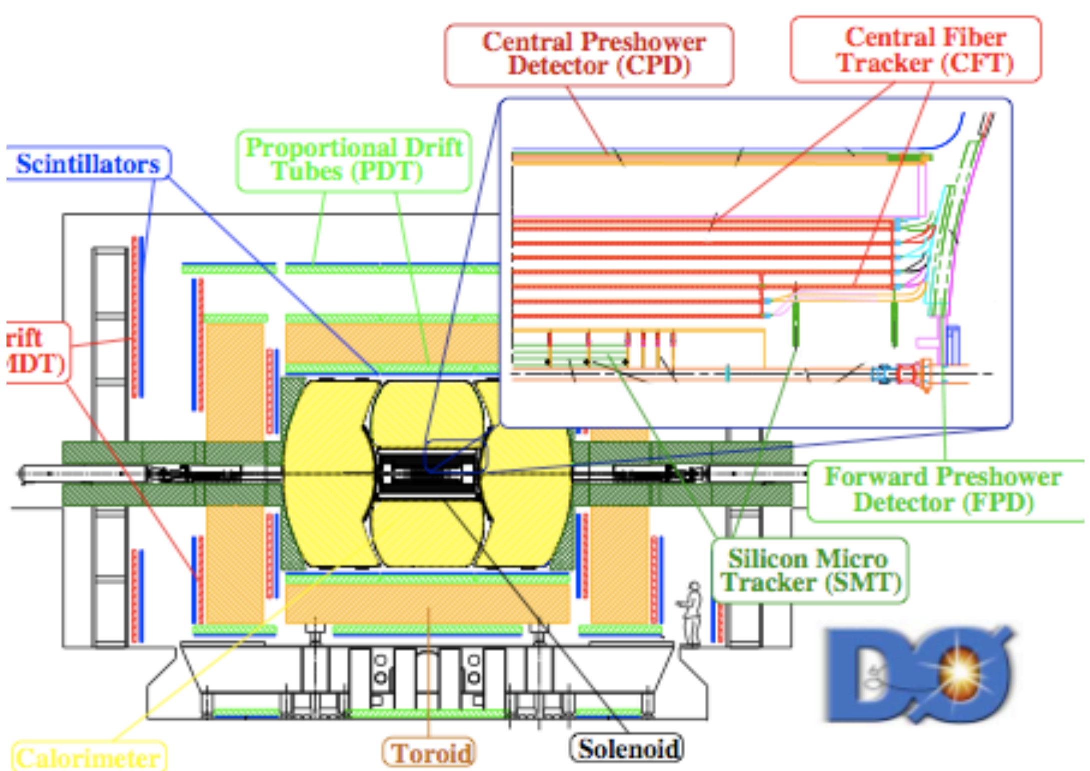
For the DØ Collaboration

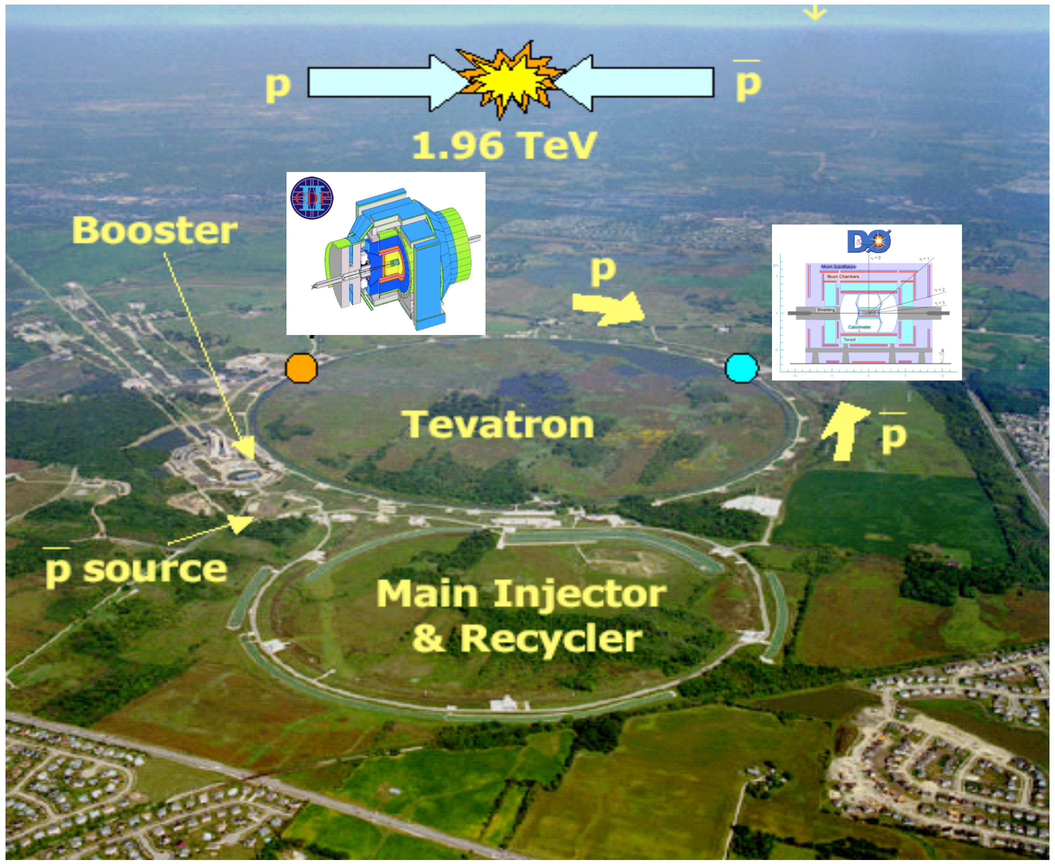
23rd of August 2010

SUSY 2010
Bonn, Deutschland

- ✓ Introduction
- ✓ MSSM Higgs searches
  - ✦ inclusive $h \rightarrow \tau\tau$ search
  - ✦ associated hb production
    - bbb final state
    - ττb final state
  - ✦ DØ combination
- ✓ Conclusions & Prospects







Higgs sector in the MSSM

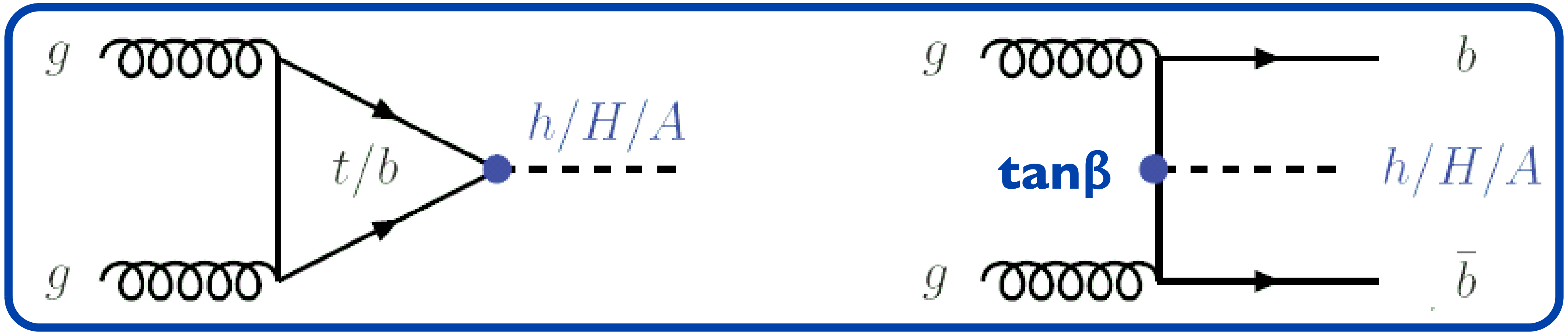
- MSSM: exactly 2 Higgs doublets coupling to down quarks (vev v_d), and up quarks (vev v_u). $\tan\beta = v_u/v_d$

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

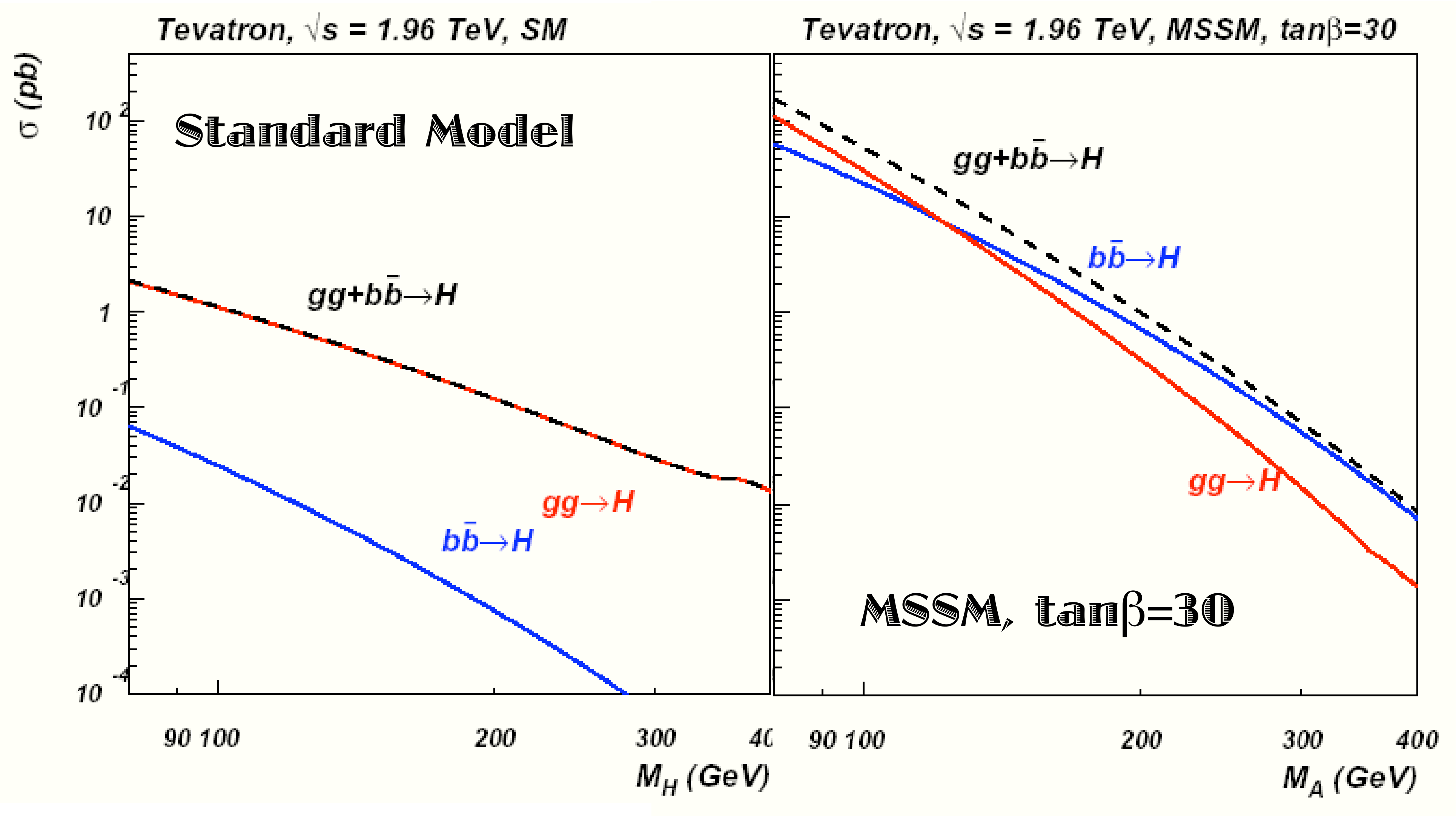
- After EW breaking: 5 physical states
  - 3 neutral Higgs bosons: h/H (CP-even) and A (CP-odd)

    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 $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10~\%$

Susy Higgs production



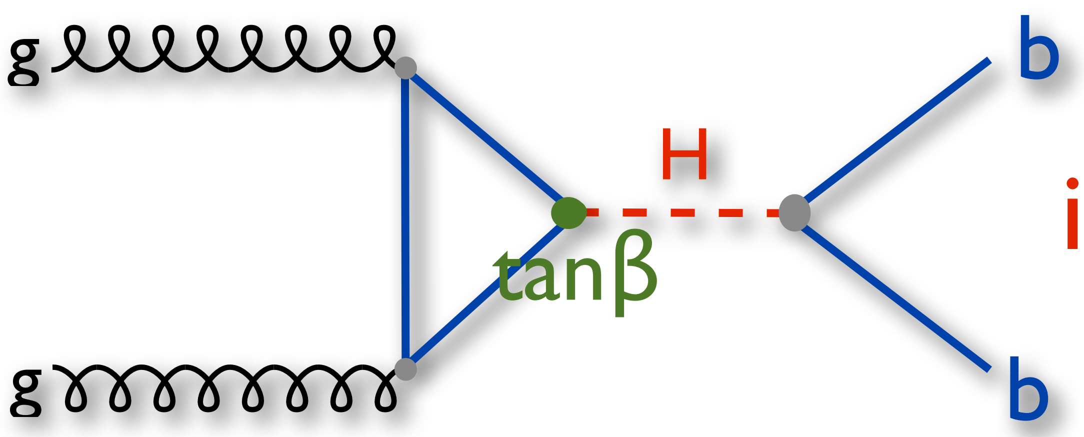
enhanced by $\tan^2\beta$
compared to SM



Look for
high tanβ!

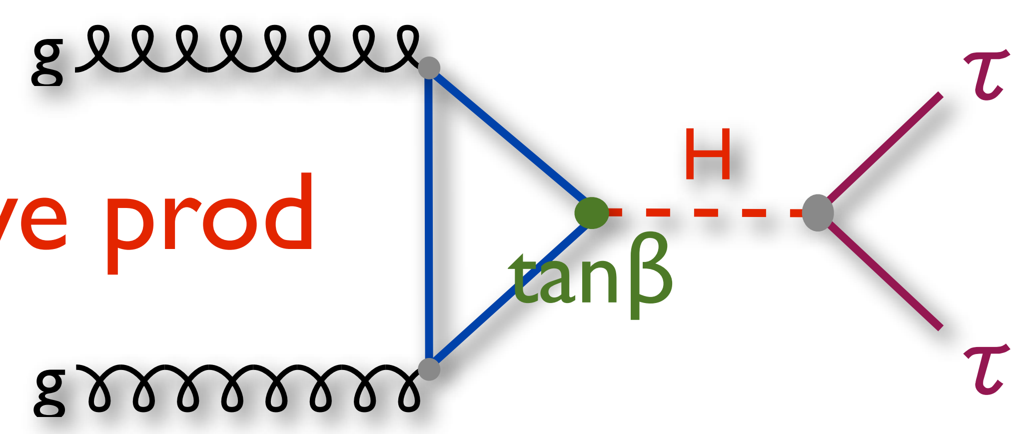
Golden modes

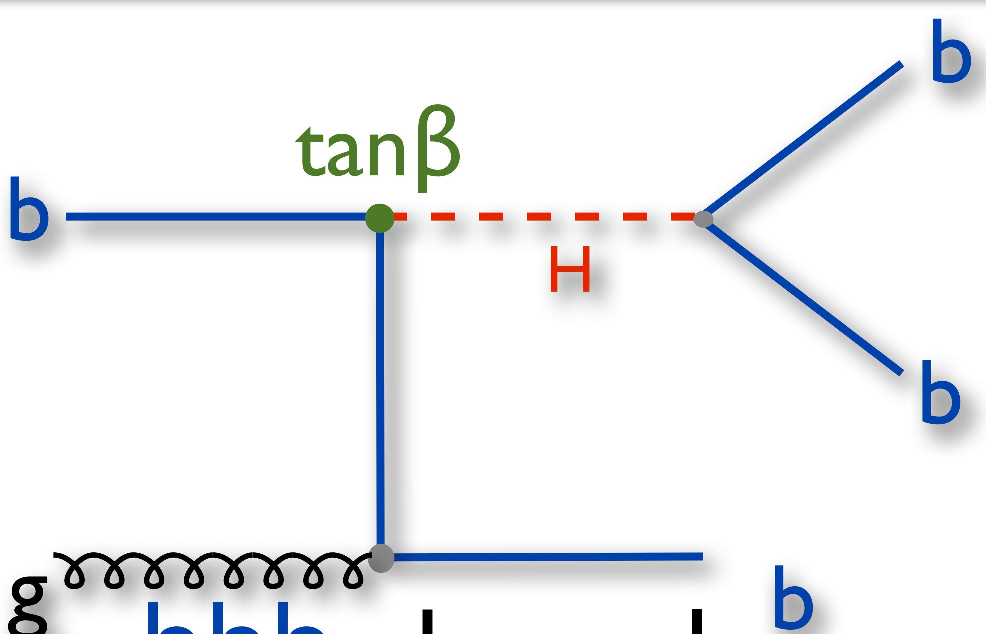
bb channel



inclusive prod

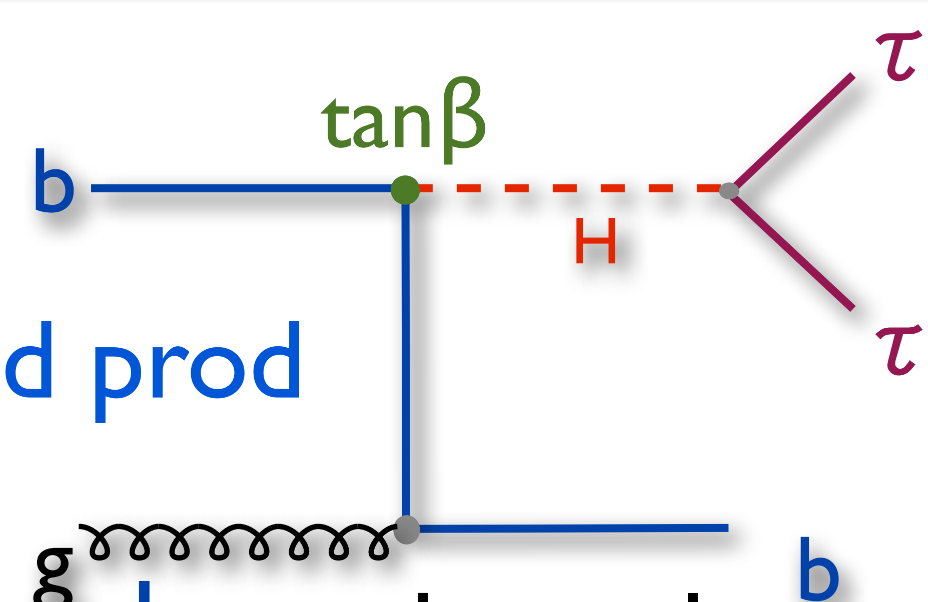
ττ channel





bbb channel

associated prod

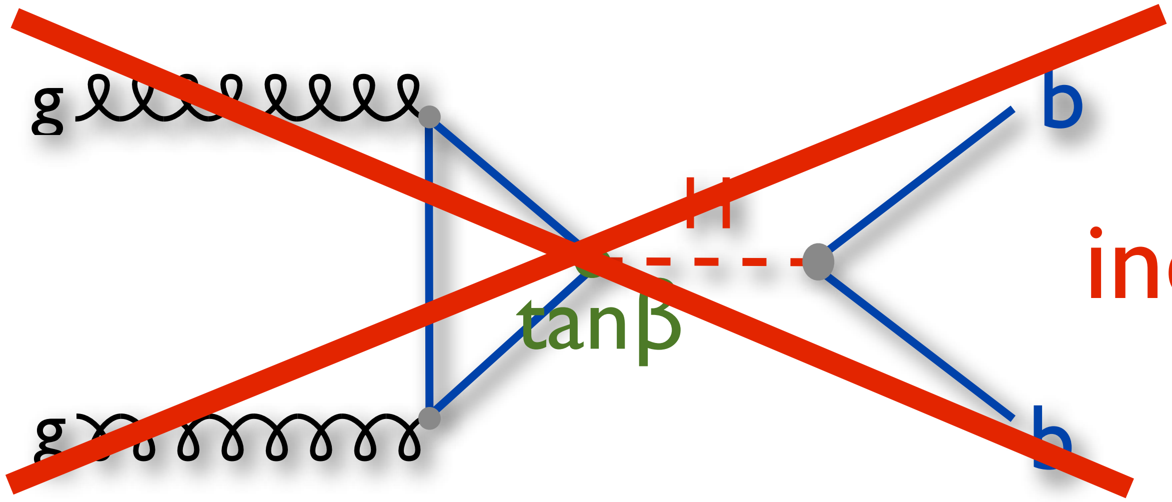


bττ channel

h→ττ modes are much less sensitive to radiative corrections (i.e. less model dependent) than h→bb

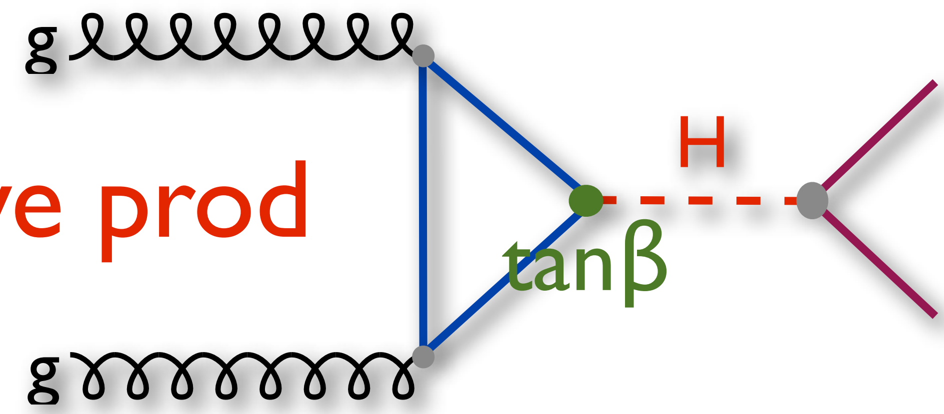
Golden modes

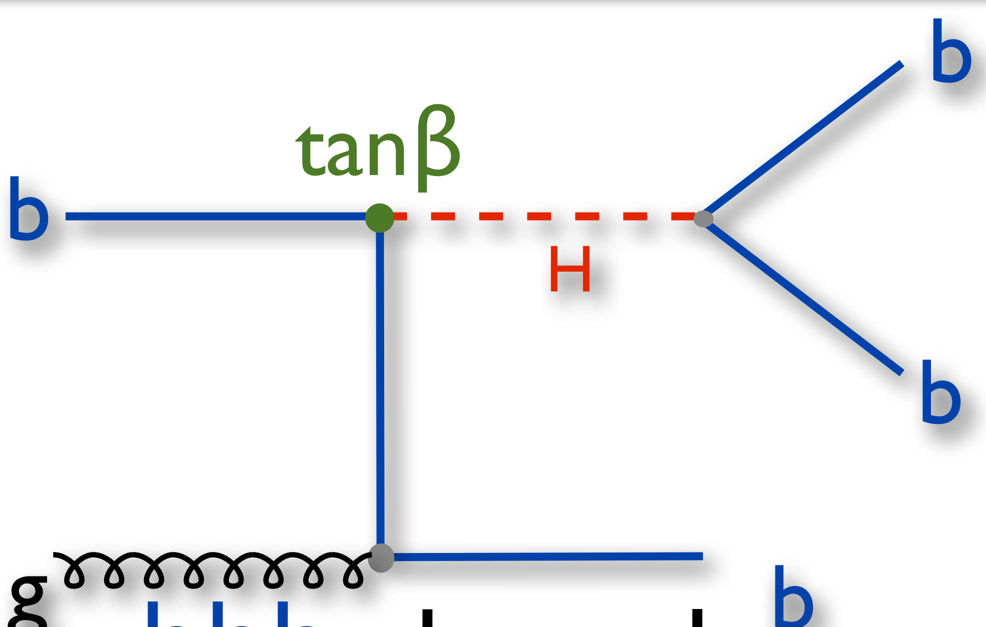
~~bb channel~~



inclusive prod

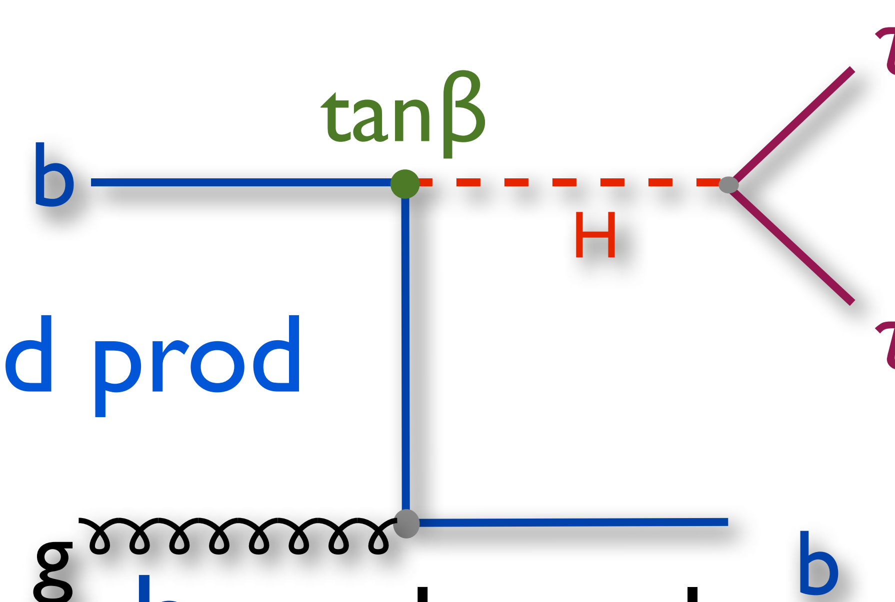
$\tau\tau$ channel





bbb channel

associated prod



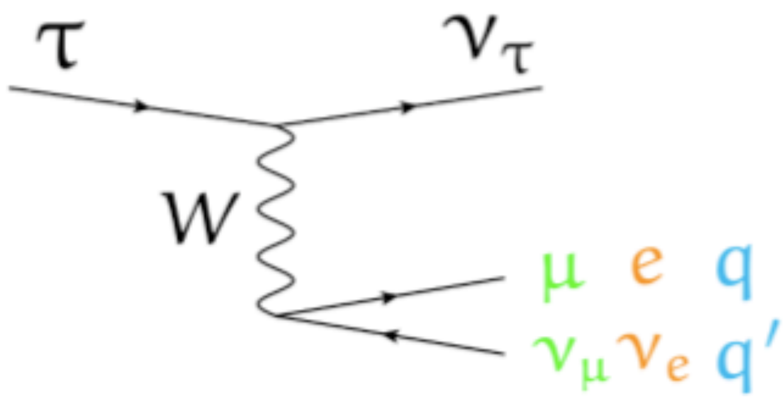
b$\tau\tau$ channel

h→$\tau\tau$ modes are much less sensitive to radiative corrections (i.e. less model dependent) than h→bb

di-tau mode challenges

τ-lepton channels peculiarities:

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



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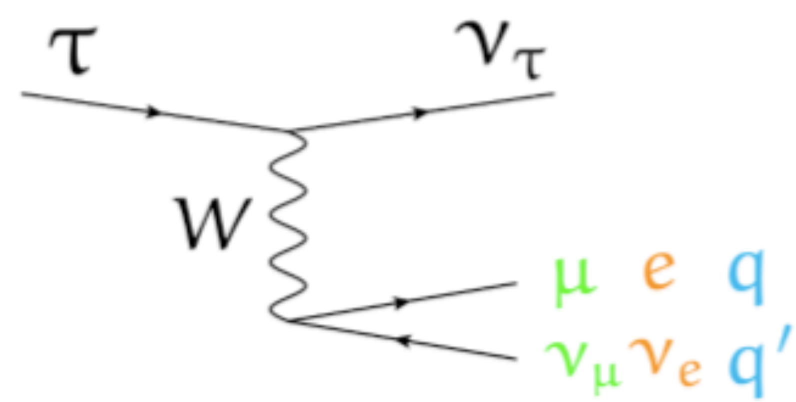

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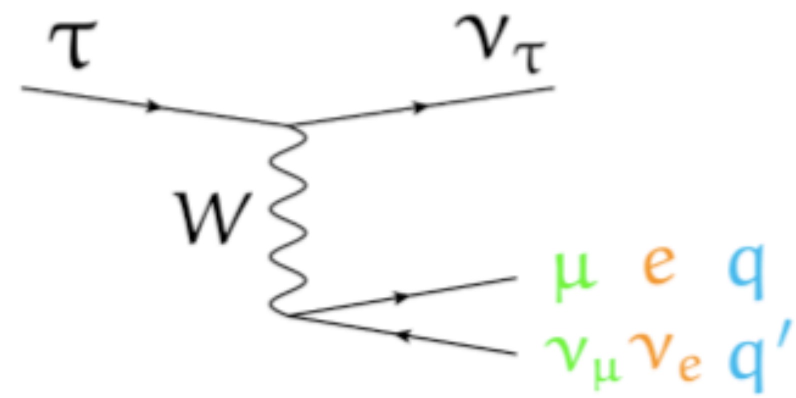
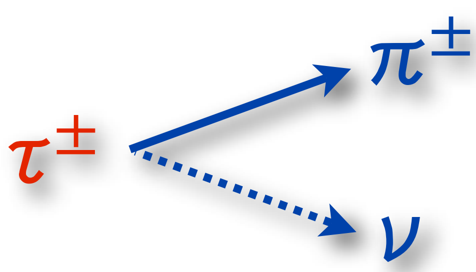
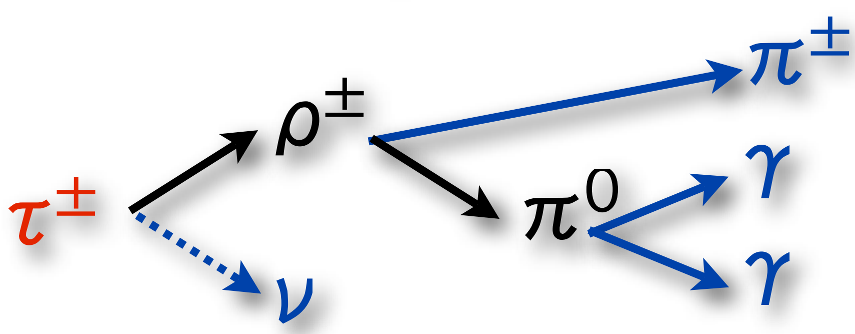


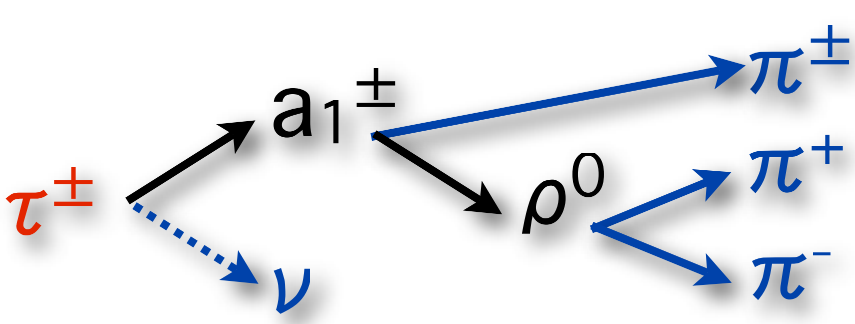
Need to reconstruct τ hadronic decay (τ_h)



type 1:
trk + cal
(no EM cluster)

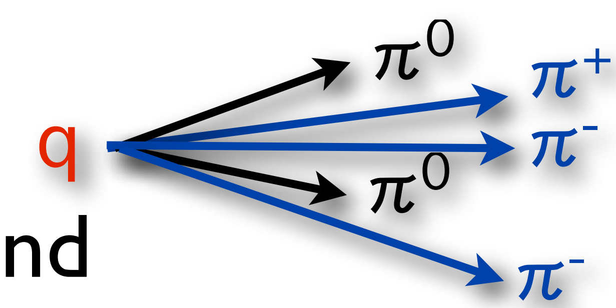


type 2:
trk + cal
(with EM cluster)



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

large jet background



di-tau mode challenges

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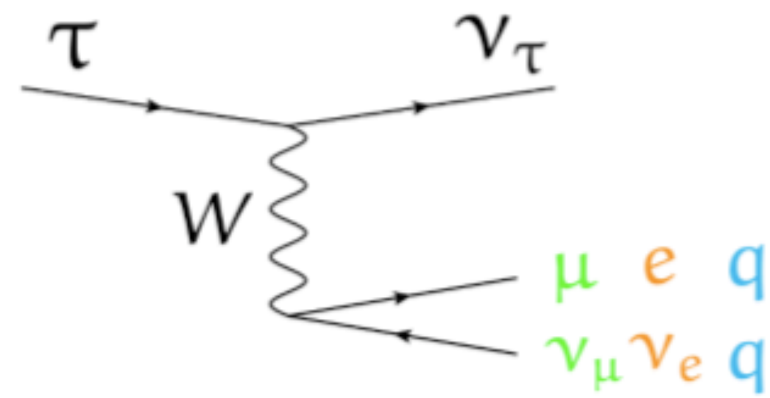

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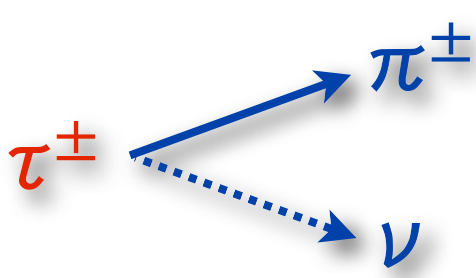

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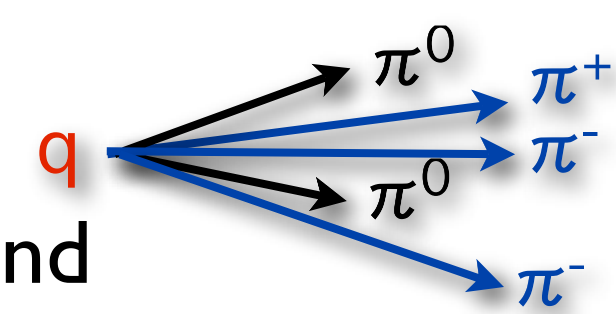
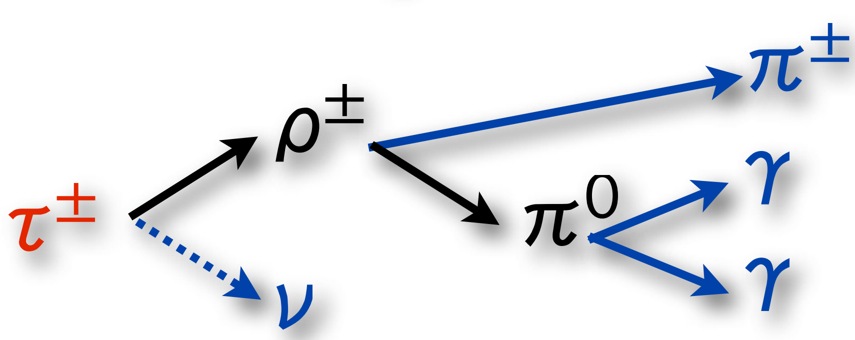
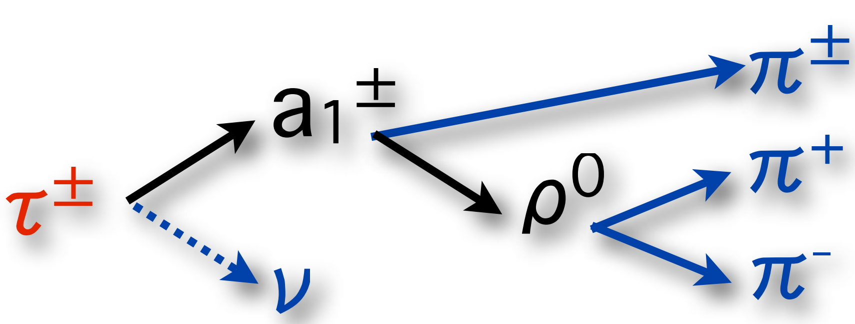




type 2:
trk + cal
(with EM cluster)

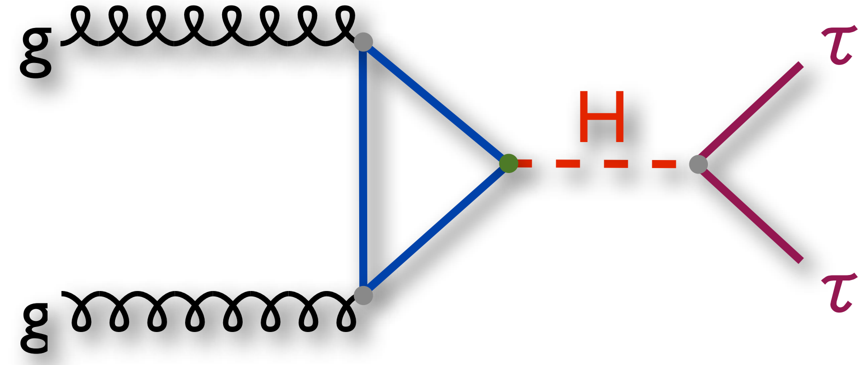
NN$_\tau$ based on isolation, shower shape, trk-cal consistency variables



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

NN$_\tau$ performances (not including τ-reco efficiency) @ DØ

- efficiency (τ leptons): 60/75/65 %
- fake rate (light jets): 3.0/2.5/2.5 %



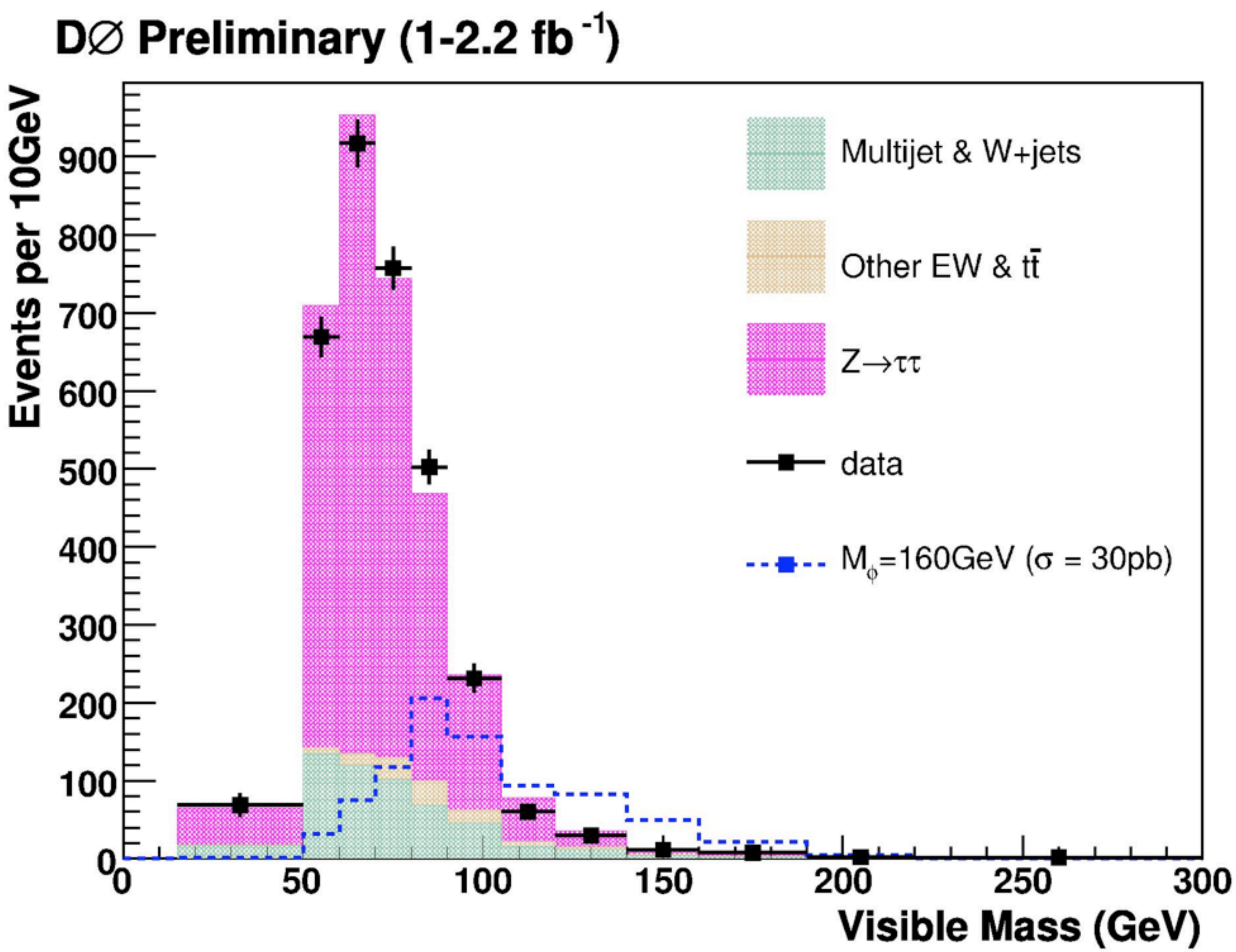
- Combine the following channels: $\tau_\mu\tau_h$ (2.2 fb^{-1}), $\tau_e\tau_h$ (1.0 fb^{-1}), $\tau_\mu\tau_e$ (1.0 fb^{-1})

  run2a (1fb^{-1}) result: Phys. Rev. Lett. **101**, 071804 (2008)

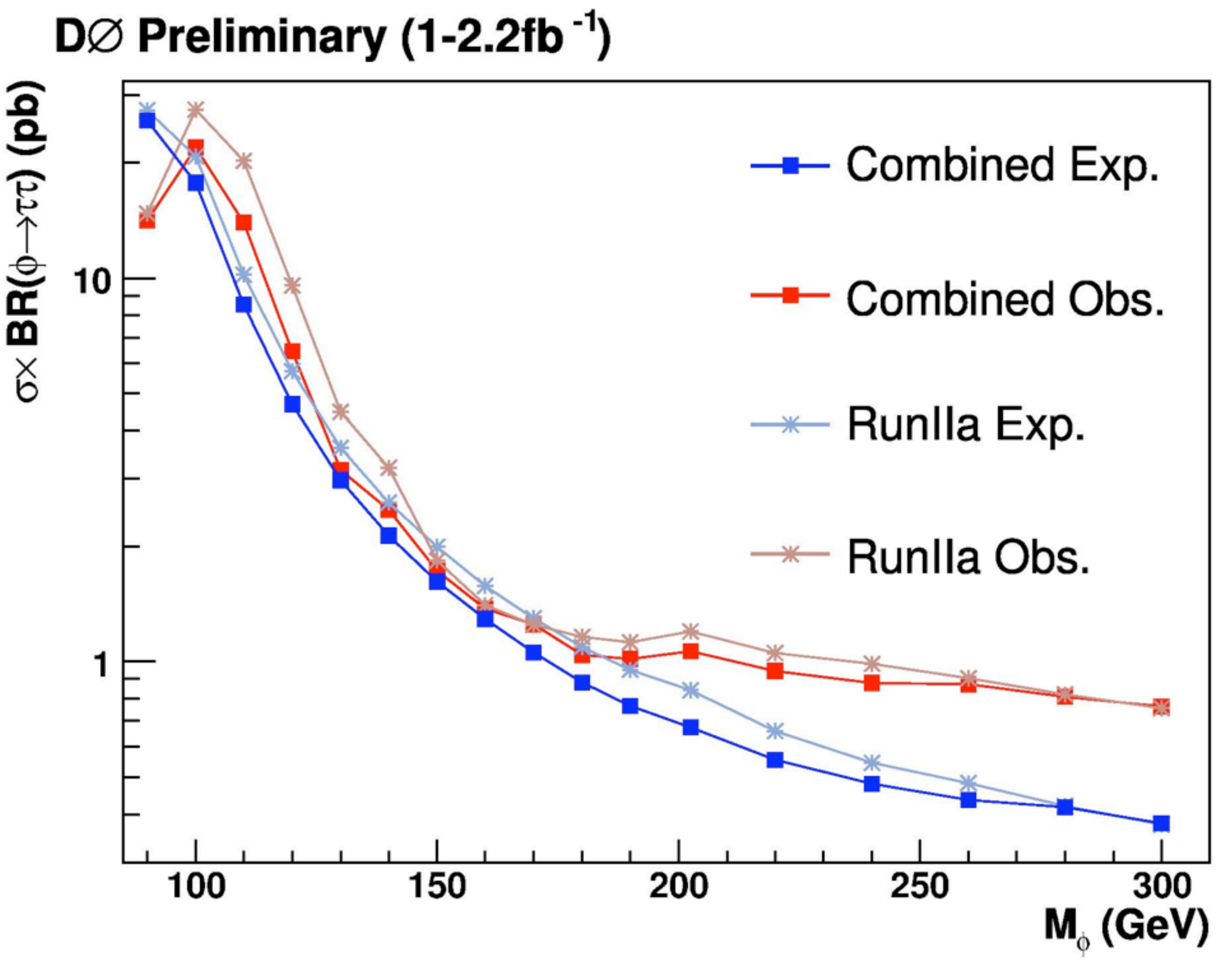
- $\tau_h\tau_h$: not considered, difficult to trigger on and overwhelmed by multijets background

- 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:

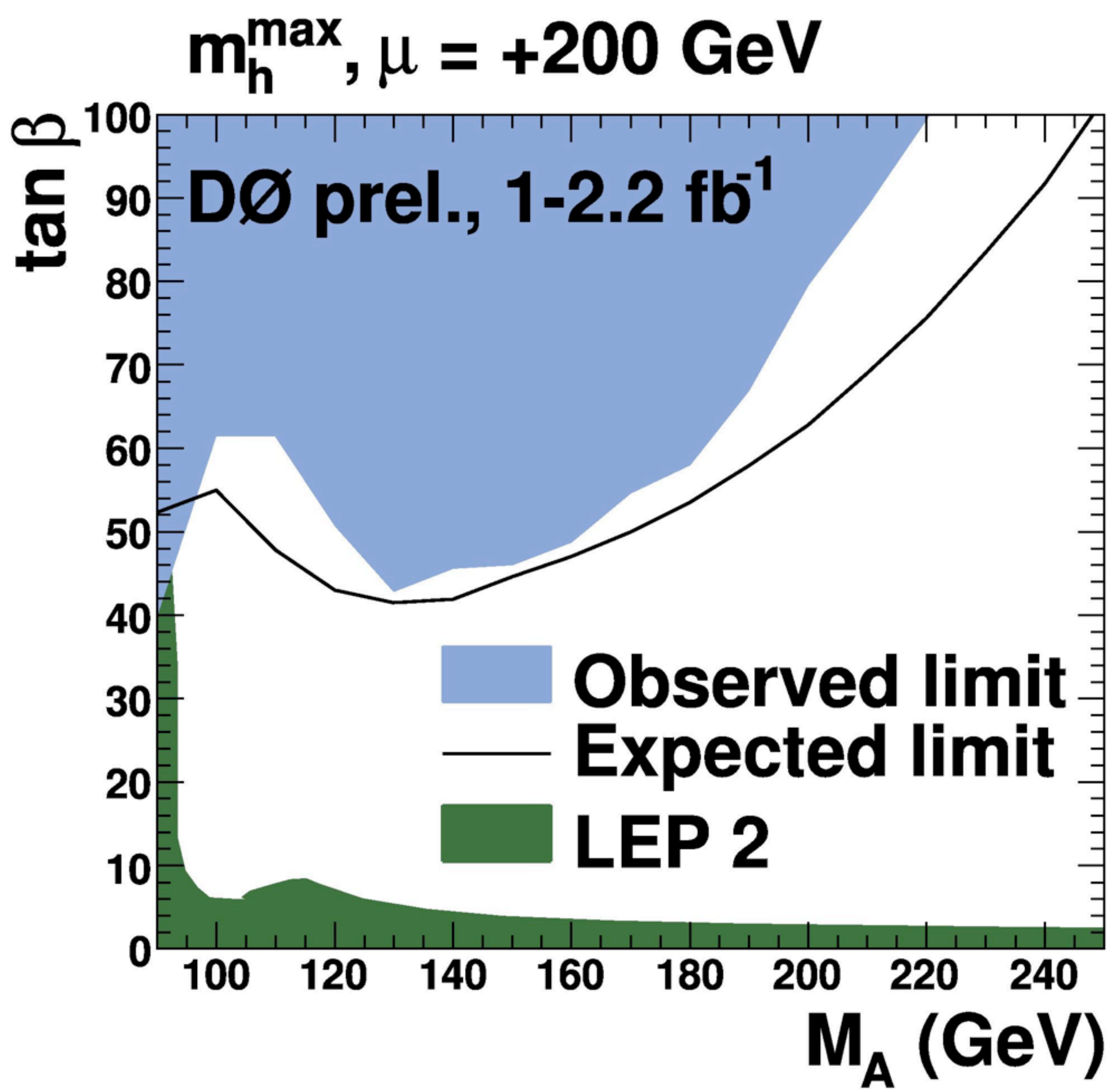
$$M_{vis} = \sqrt{p_{\tau_h} + p_\mu + \not{E}_T}$$



- Data are compatible with background
- Set limits: higgs width effect negligible

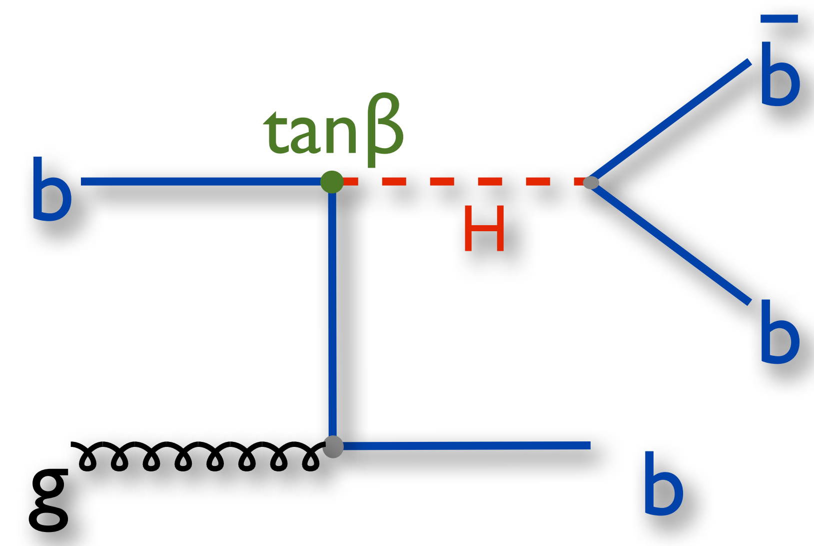


Model independent limit

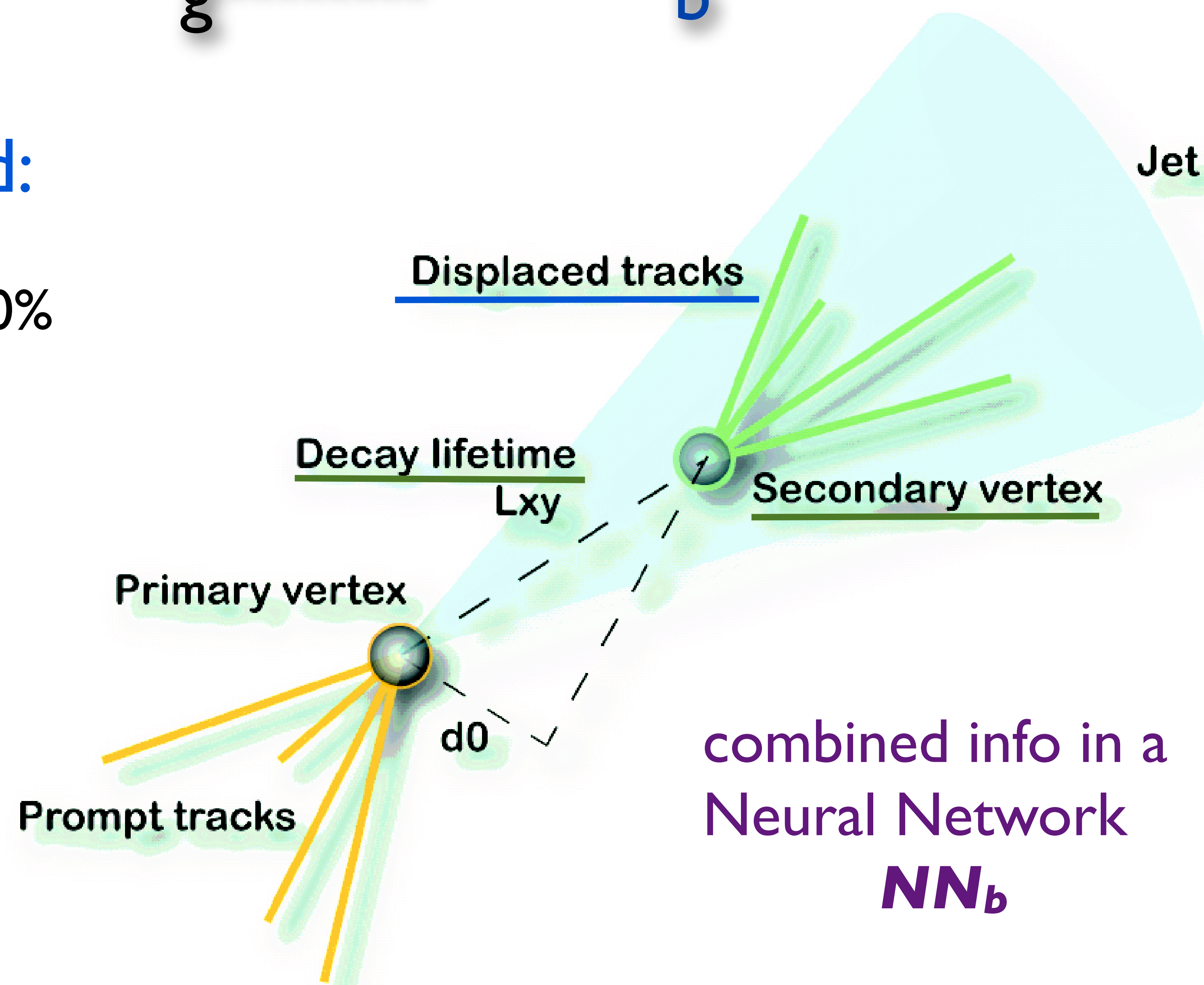


$bh \rightarrow bbb$ search

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

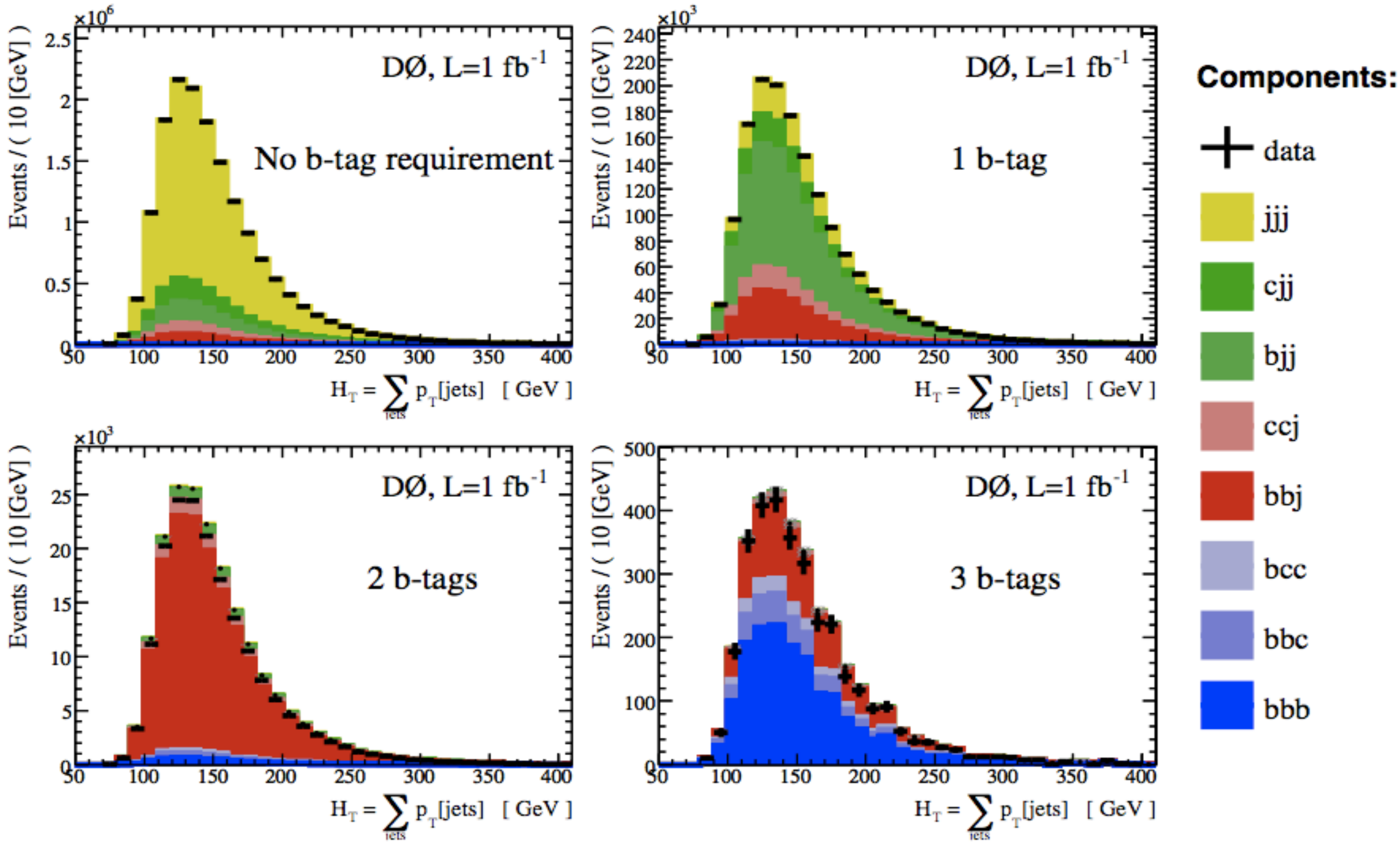


- Large multijets background:
  - trigger on multijets events + impact parameter b-tag (60-70% efficient)
  - Need a powerful b-tagger to reject the abundant multijet background



b-tagging performances @ DØ
- efficiency (b quarks): 50% / 70%
- fake rate (light jets): 0.5% / 4.5%

combined info in a Neural Network
NN_b

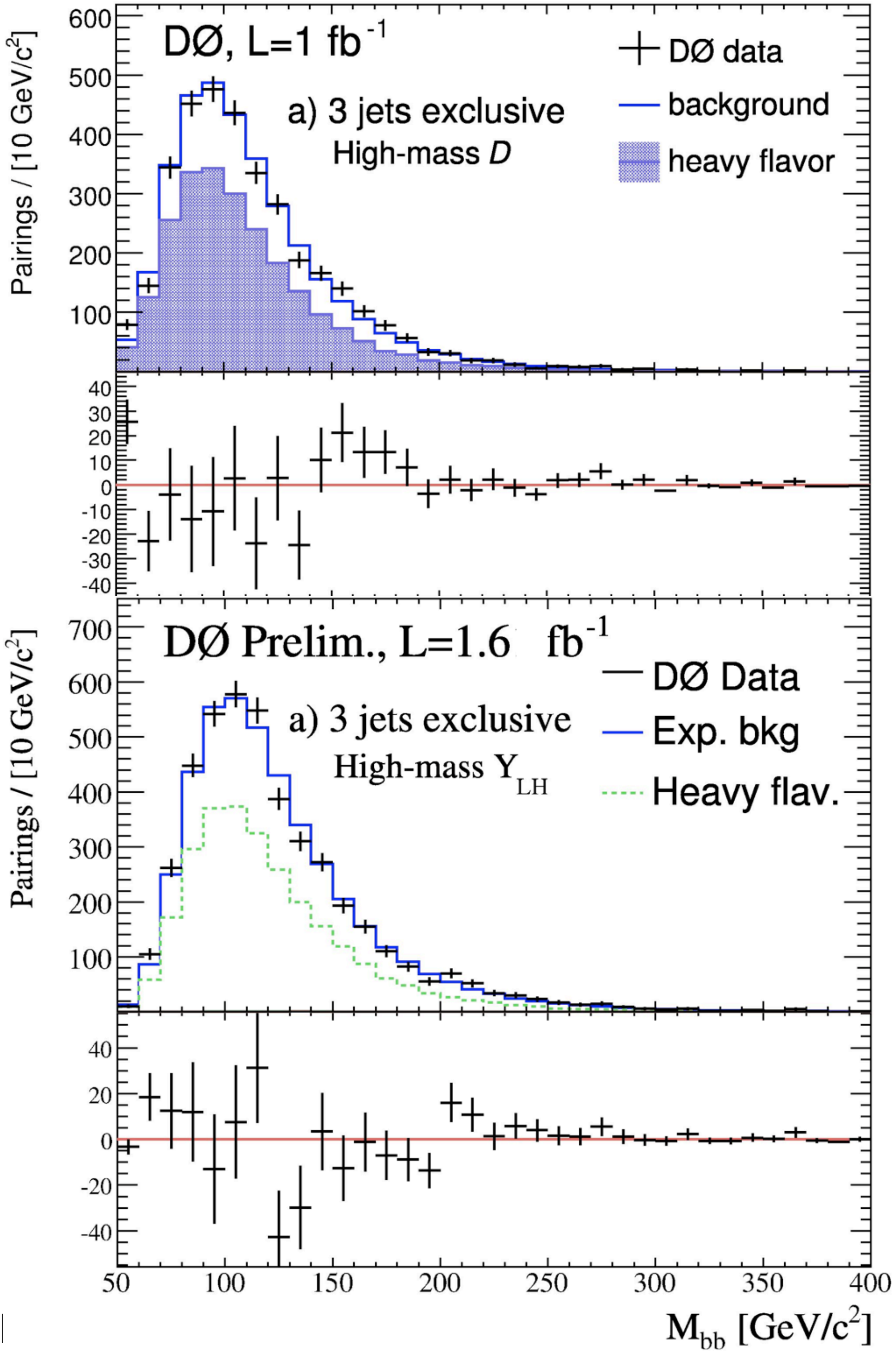


- ✓ total normalisation unknown, signal to background discrimination relies only on dijet mass shape.
- ✓ background shape obtained from data using the 2 b-tagged sample (no signal contamination) via:

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

Data samples:

- Run 2a: 1 fb^{-1} PRL101, 221802 (2008)
- Run 2b: 1.6 fb^{-1}

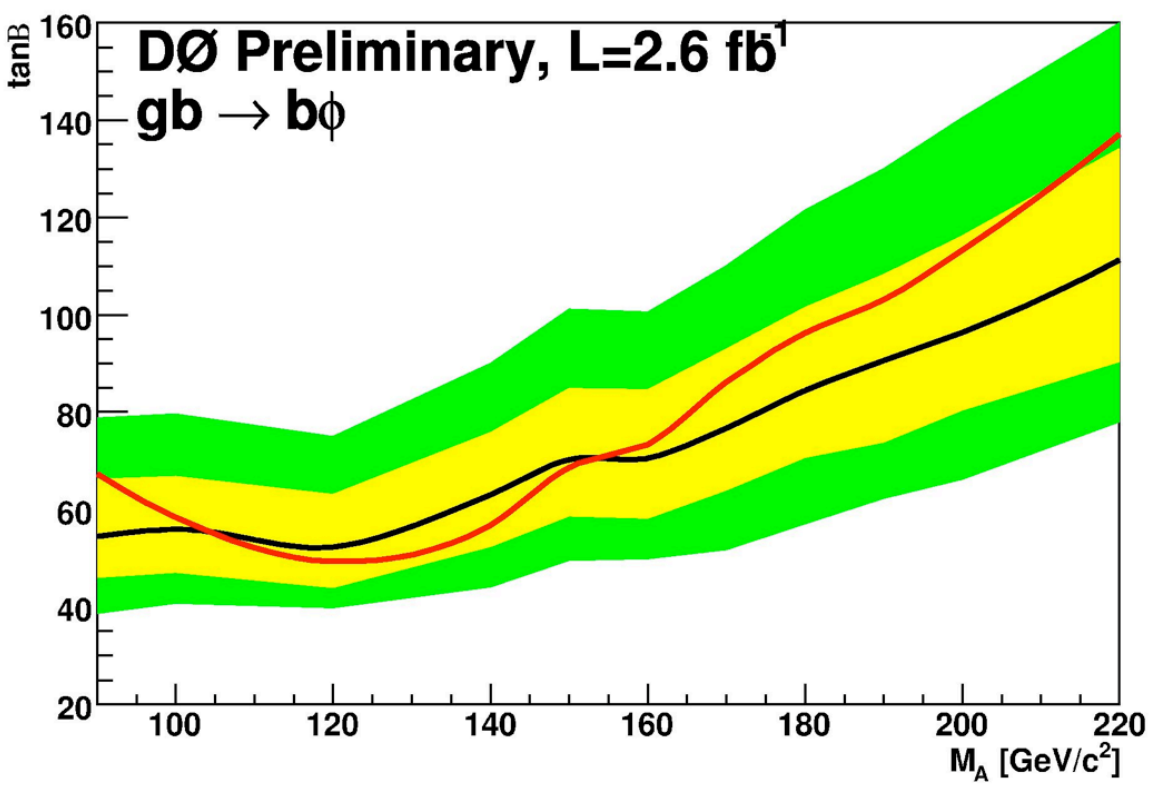


- likelihood-discriminant cut to improve sensitivity.
- use dijet mass distribution as final variable

Data compatible with background. Place limits:

narrow width approximation + tree level enhancement (model independent limit):

$$\frac{\sigma_{MSSM}}{\sigma_{SM}} = 2 \times tan^2\beta$$

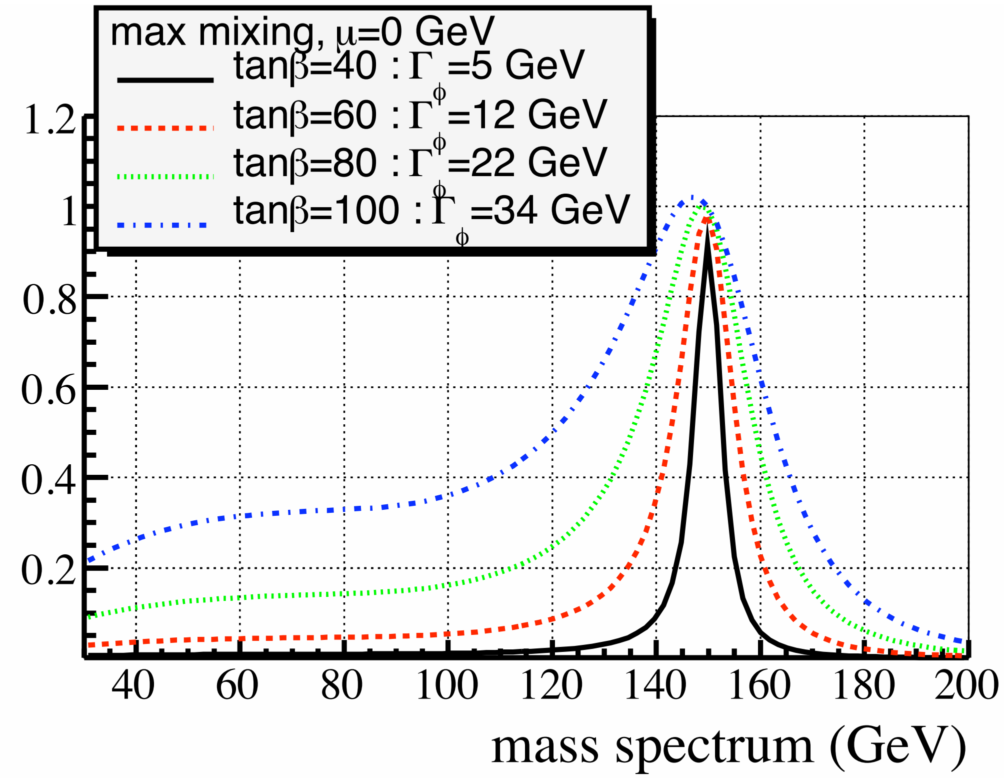


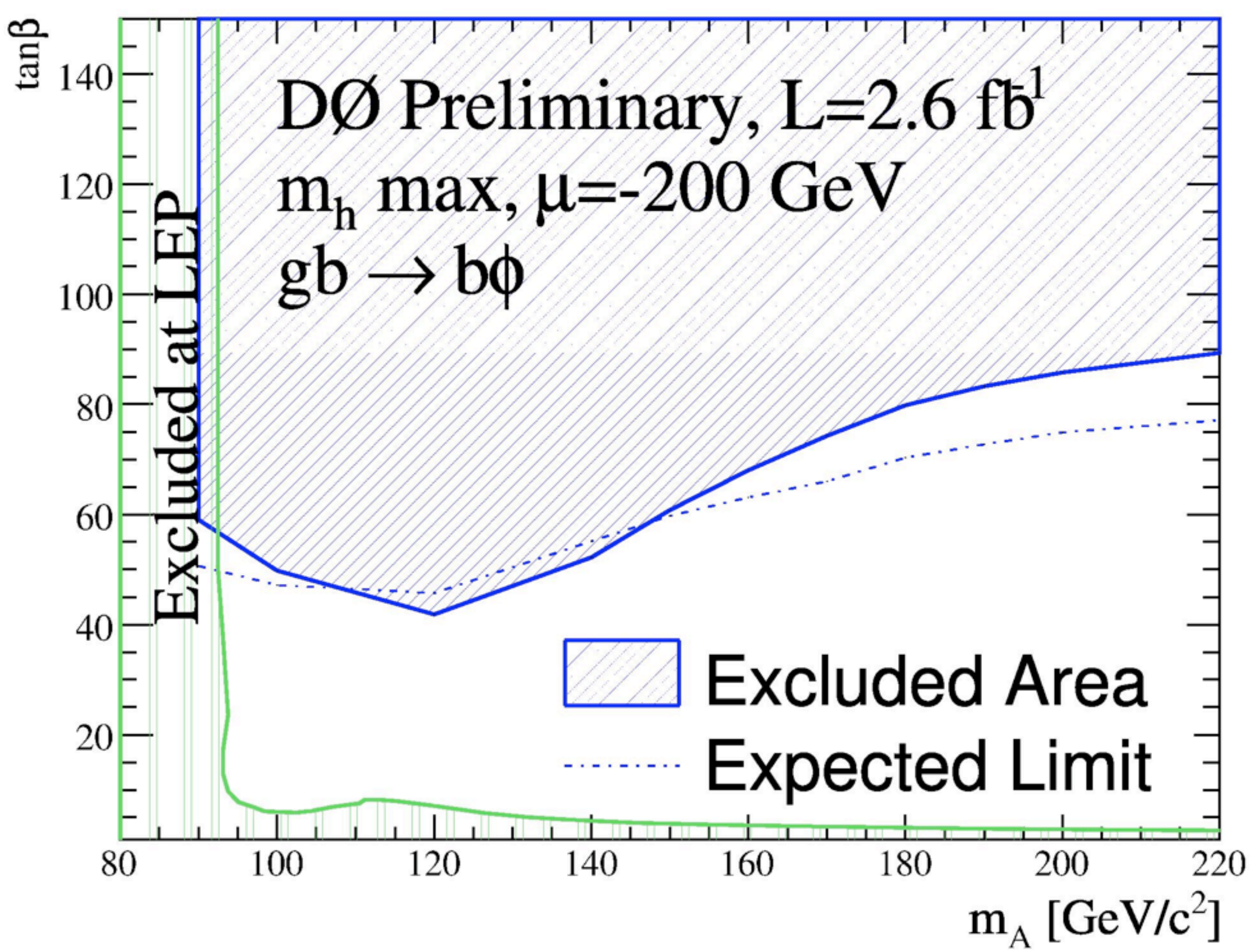
Very sensitive to radiative correction

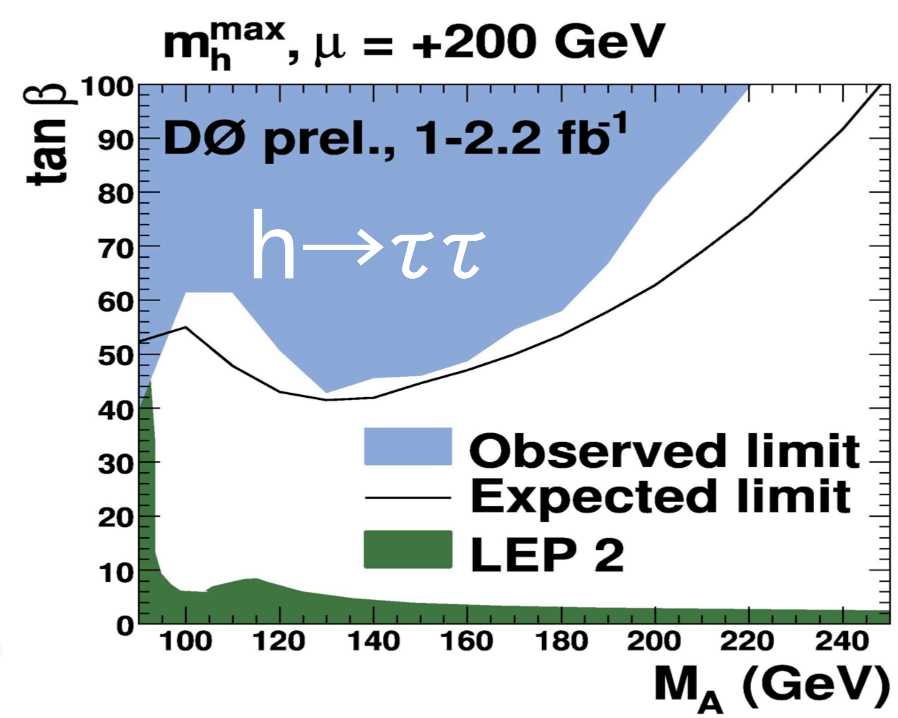
High tanβ: signal width effect not negligible

(compared to the experimental mass resolution).

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





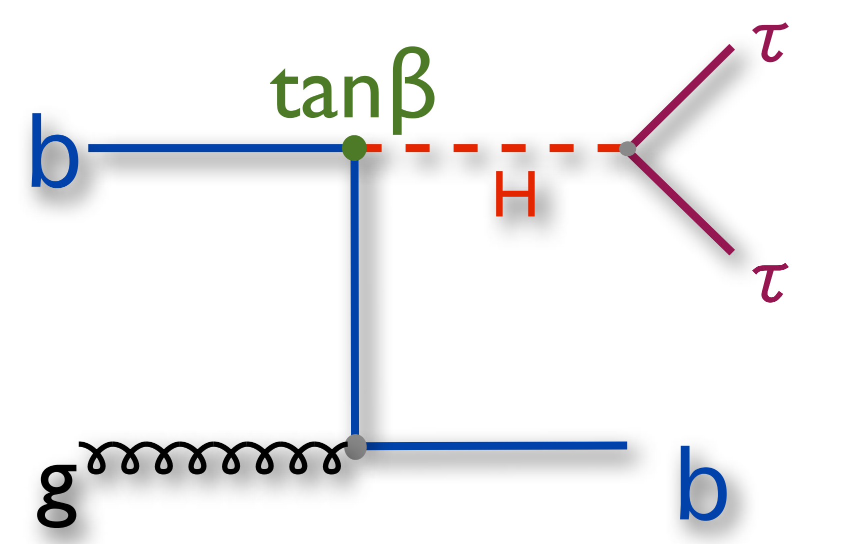


In some scenarios bbb competitive with h→ττ

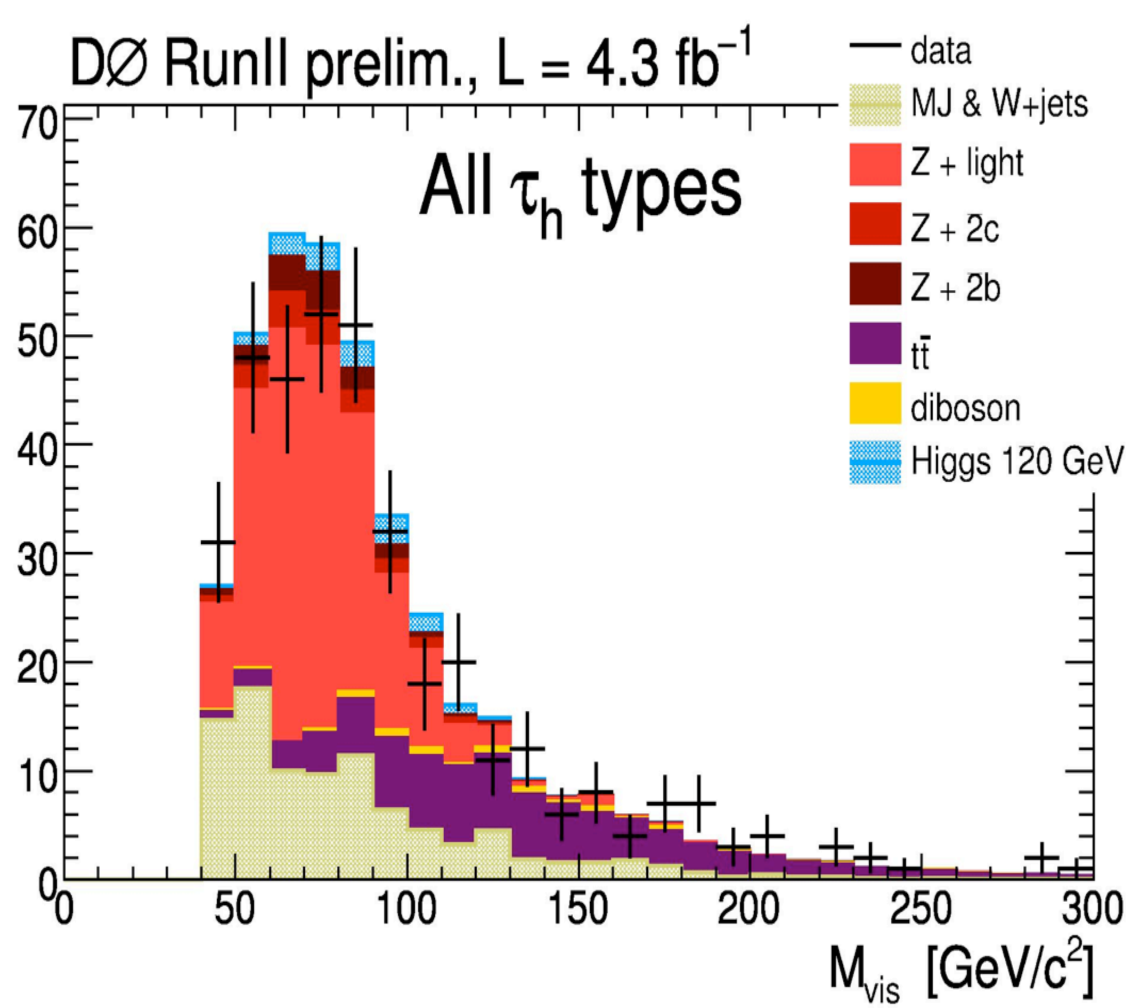
$b\Phi \rightarrow b\tau\tau$ *search*

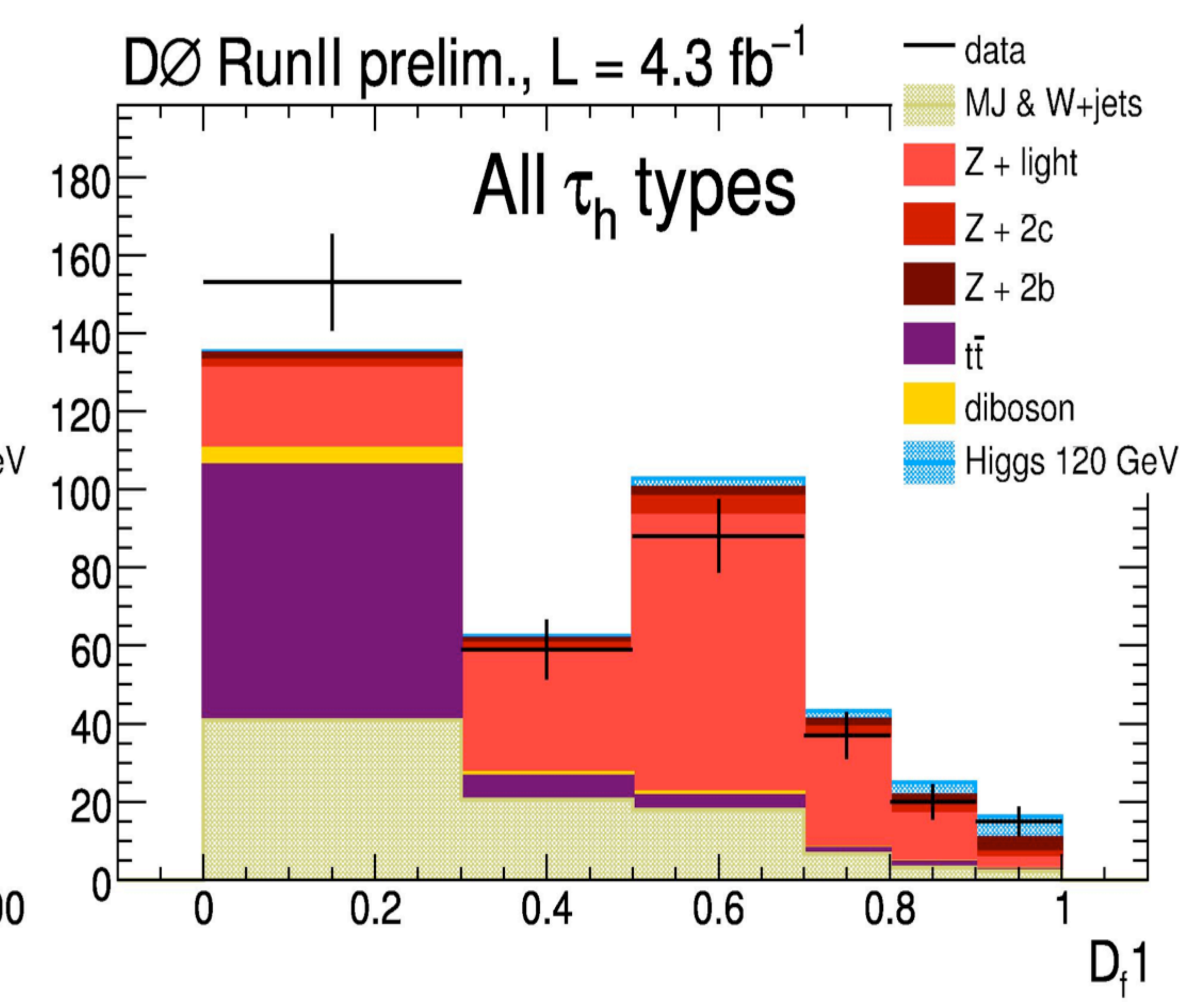
[update]: $b\tau_\mu\tau_h$: 4.3 fb^{-1}

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



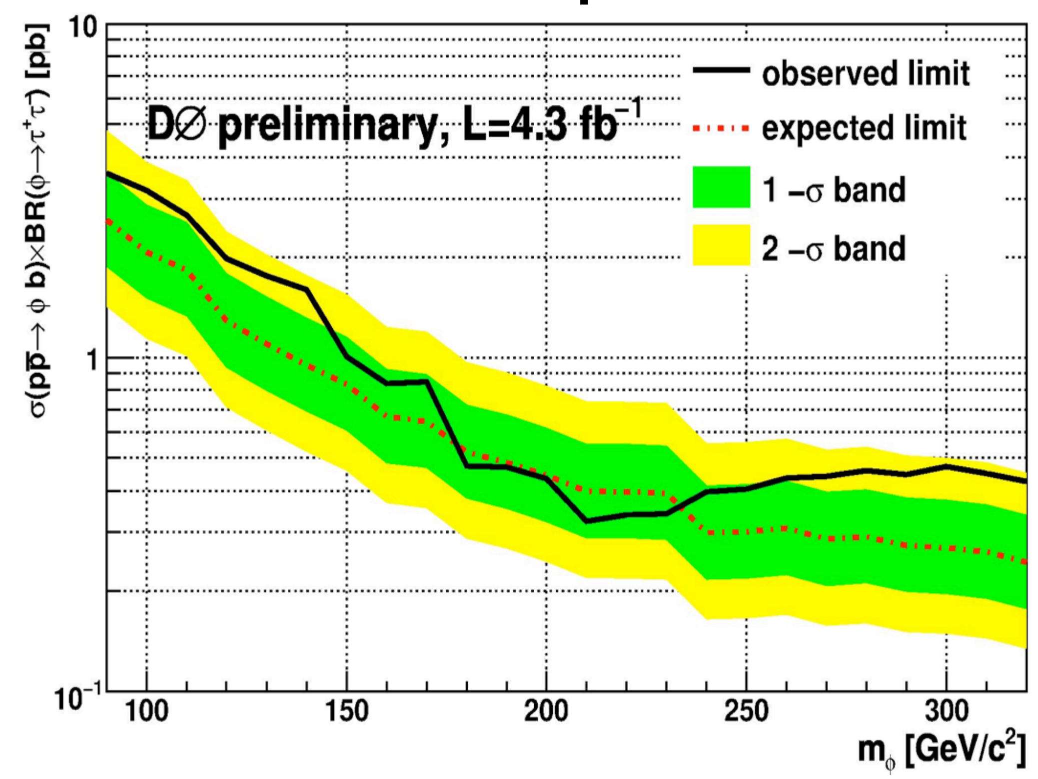
- Specific discriminant against main backgrounds: $t\bar{t}$ (D_{tt}), multijets (D_{MJ}) and $Z \rightarrow \tau\tau$ (NN_b)
- Final variable: $D_f = (NN_b \times D_{tt} \times D_{MJ})^{1/3}$





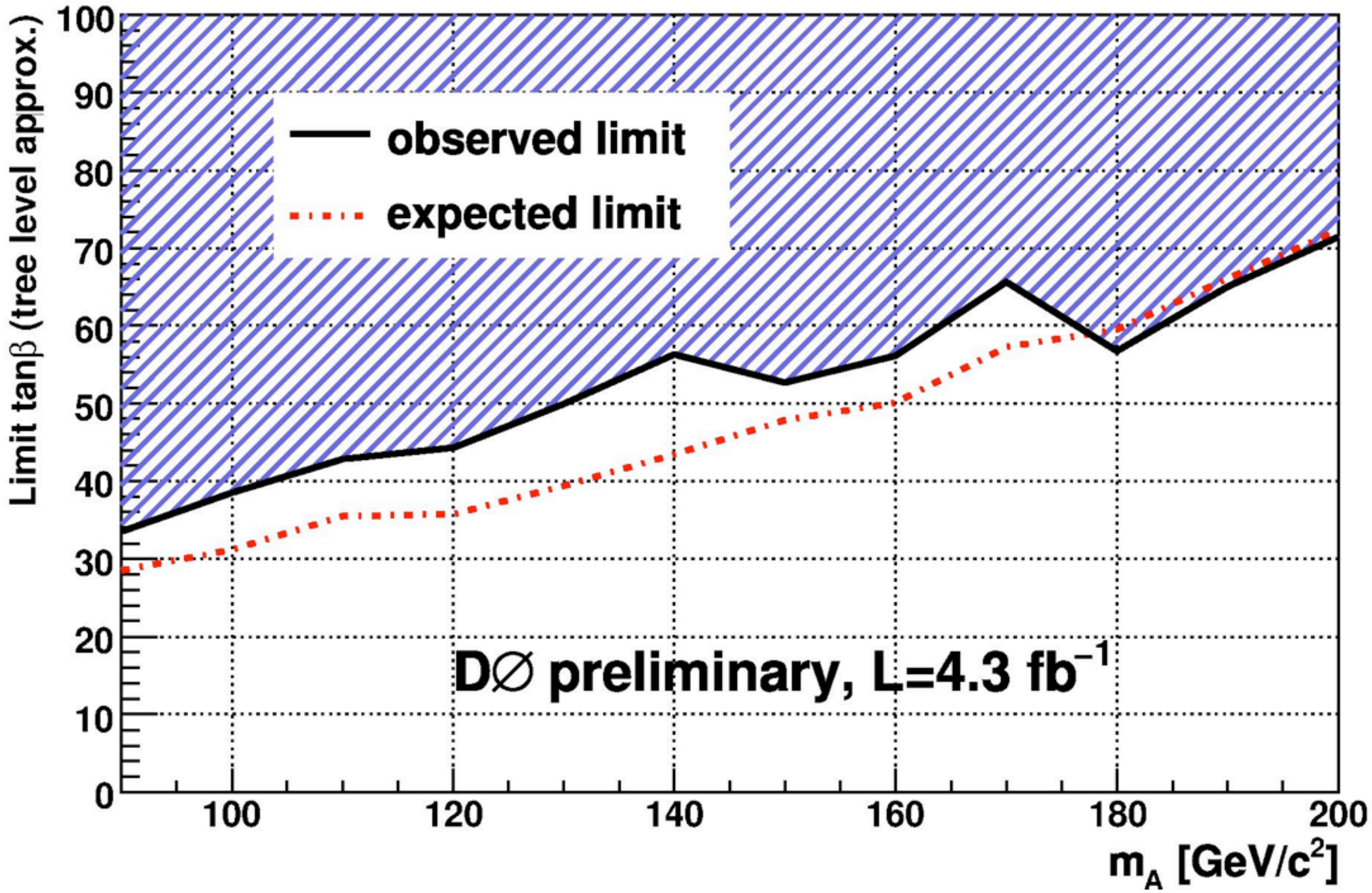
bΦ→bττ results

model independent limit



Data compatible with background

Narrow width approximation + Tree level enhancement (remember ττ channels are little sensitive to radiative corrections)

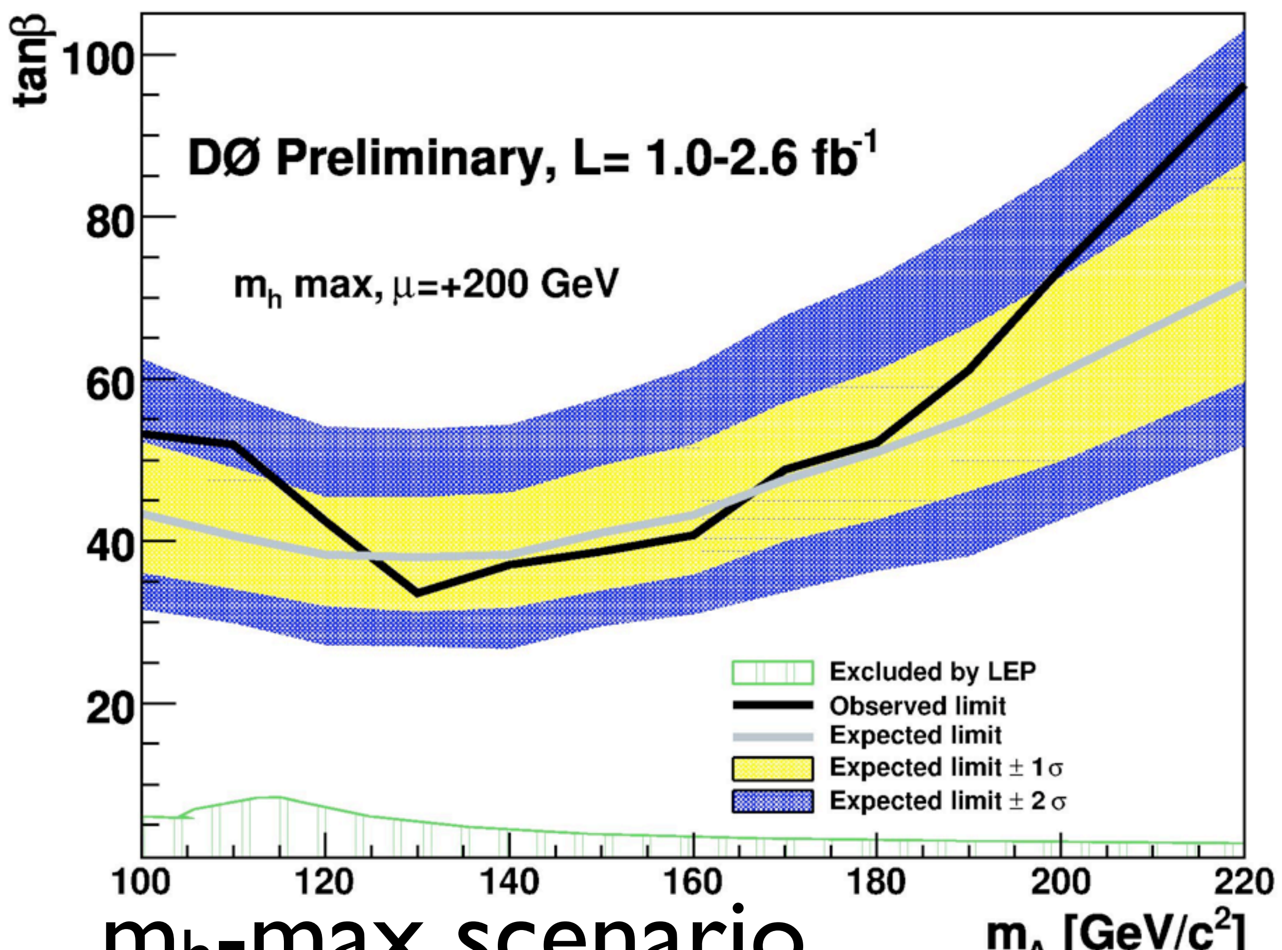


At low mass: most stringent limits to date obtained in a direct search

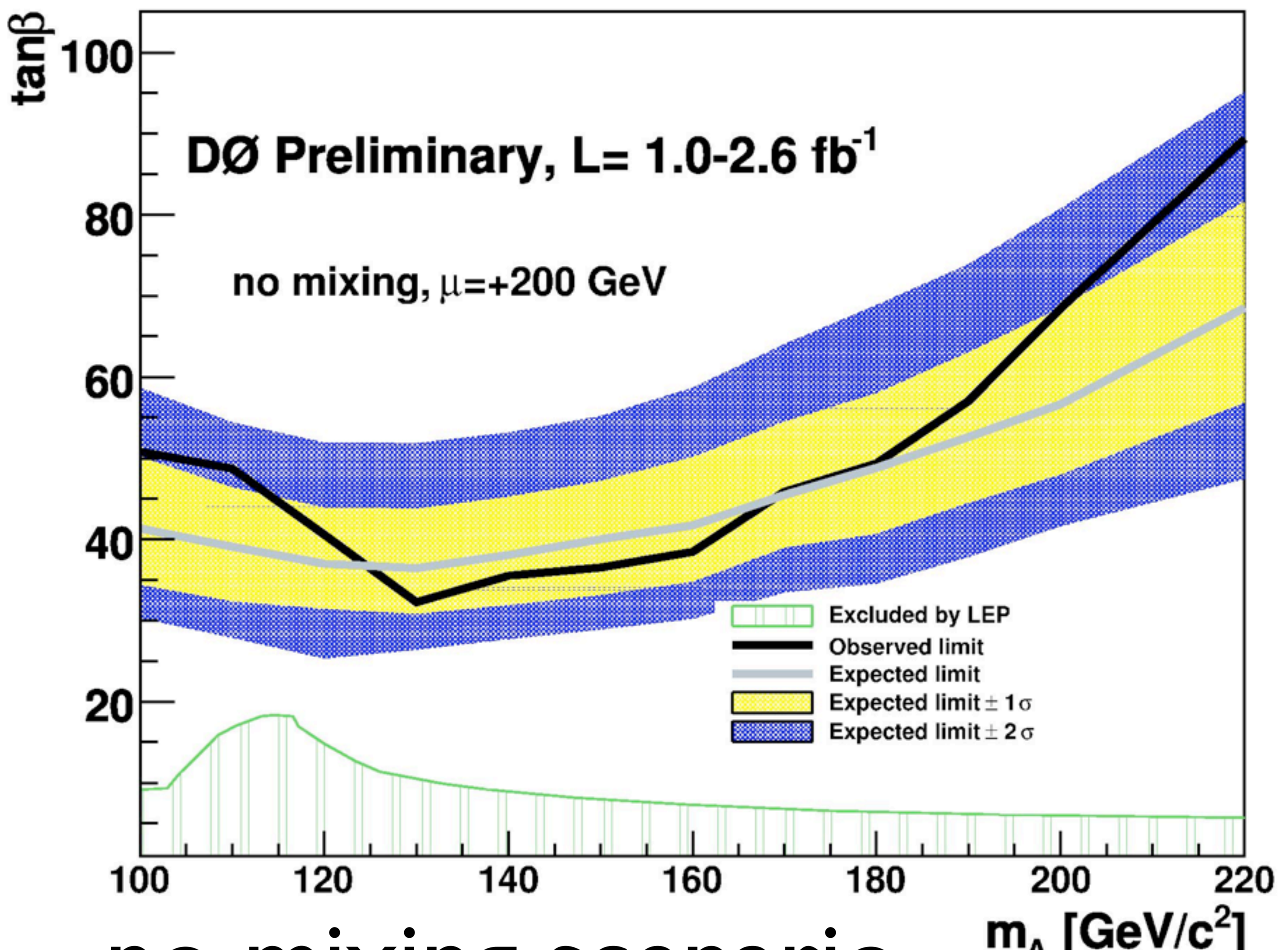
published result
PRL 2.7 fb^{-1}: 104, 151801 (2010)

Channel	Integrated Luminosity / fb^{-1} Run IIa	Run IIb	Final Variable
$h \to \tau_e \tau_{\rm had}$	1.0	-	visible mass
$h \to \tau_\mu \tau_{\rm had}$	1.0	1.2	visible mass
$h \to \tau_e \tau_\mu$	1.0	-	visible mass
$bh \to b\tau_\mu \tau_{\rm had}$	-	1.2	1D-discriminant
$bh \to bb\bar{b}$	1.0	1.6	M_{bb}

Reaching the interesting region of tanβ≈40



m_h-max scenario

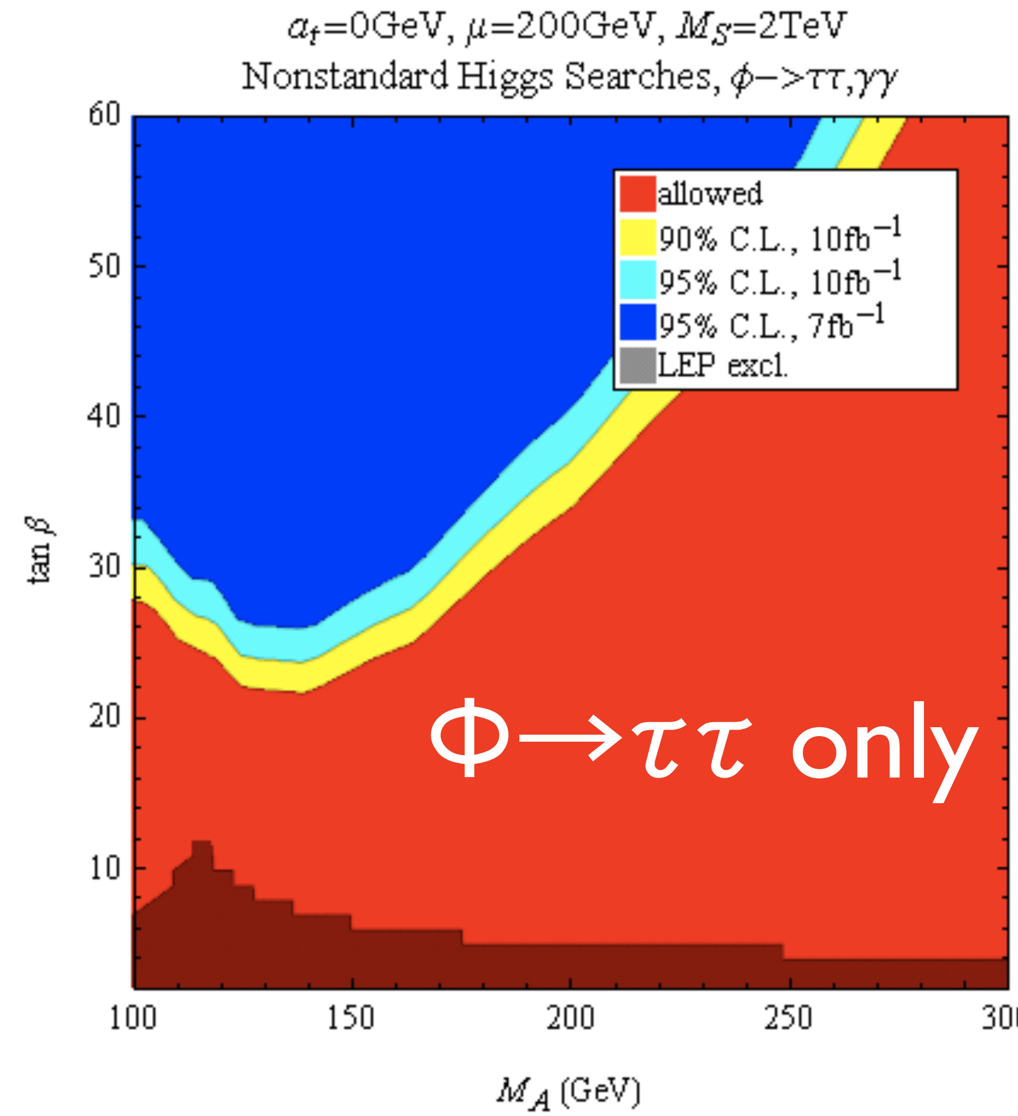


no mixing scenario

Conclusions & prospects

- Results with up to 4.3 fb^{-1} reported here
- DØ reaching the interesting region of tanβ ≈ 40, down to tanβ ≈ 30 at low M_A.
- Expected soon:
  - hb → bbb search update
  - inclusive h→ττ update
  - combination update
  - improved technique (new b-tagger with better performances...)

- SM searches can also be used to constrain SM-like Higgs in MSSM:
  - See P. Draper et al. arXiv:0905.4721v2
  - Potential to probe a significant region of the MSSM phase space



Much more statistics to come (10 fb^{-1} by end of 2011), stay tuned!

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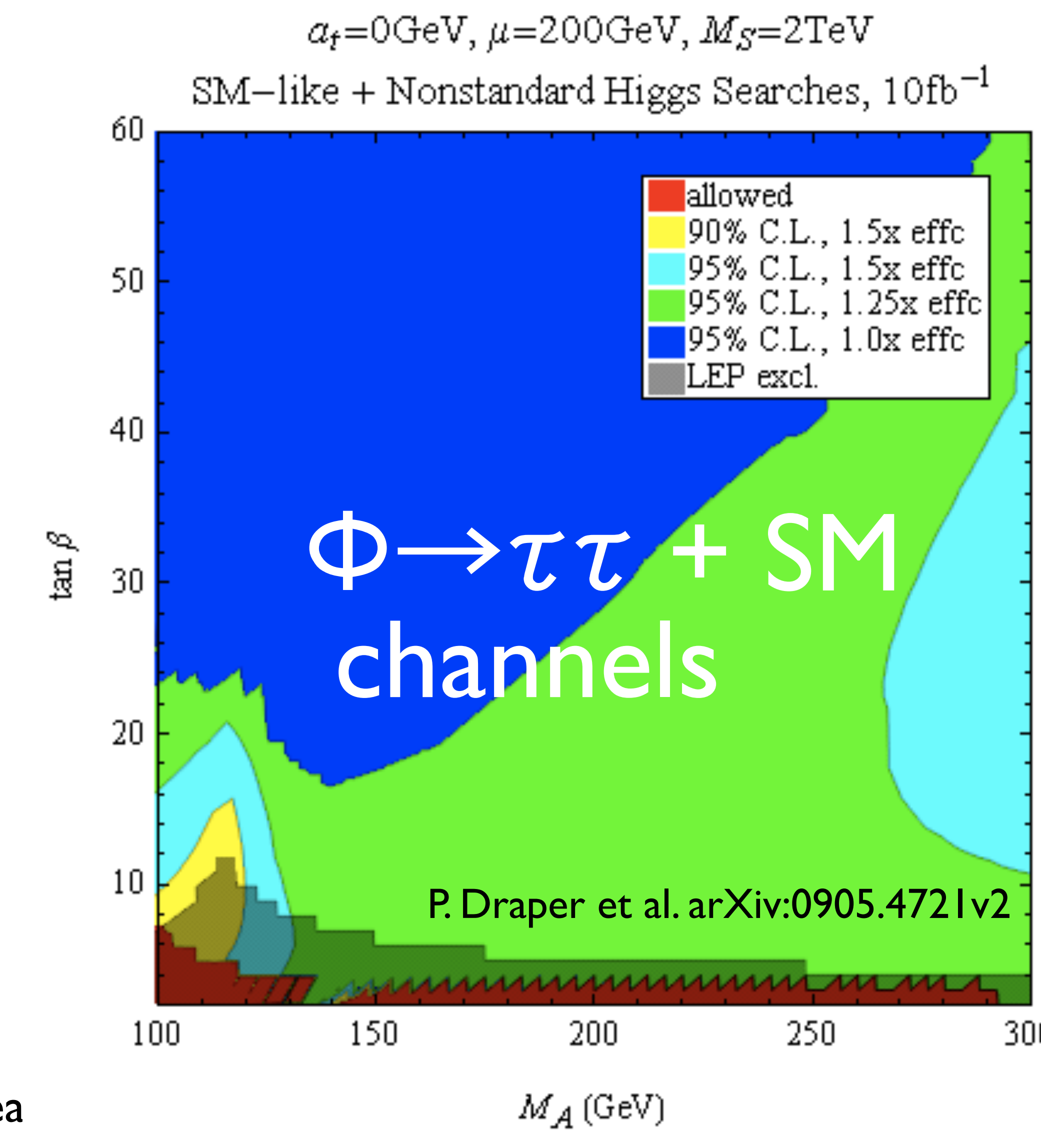

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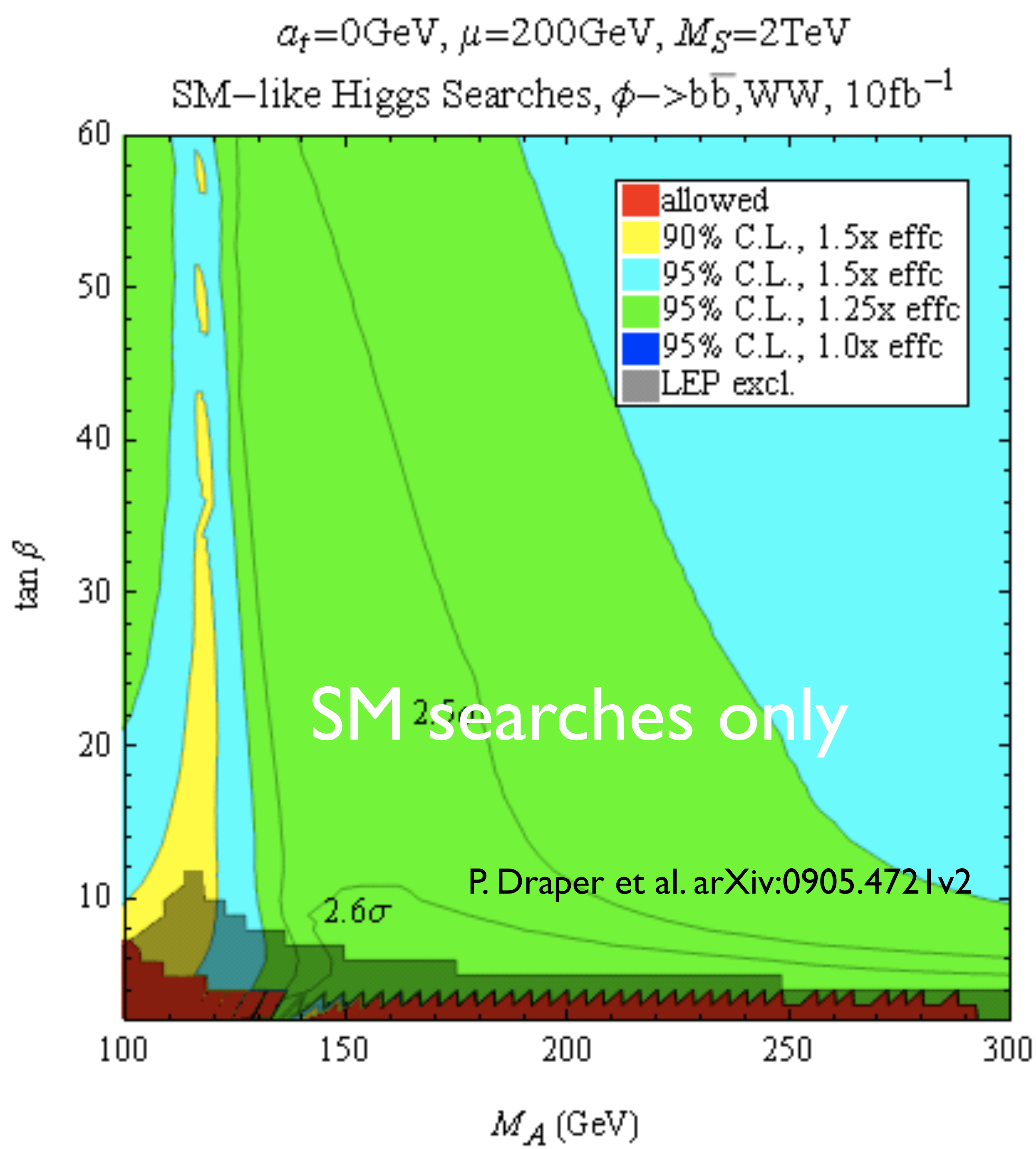
Backup

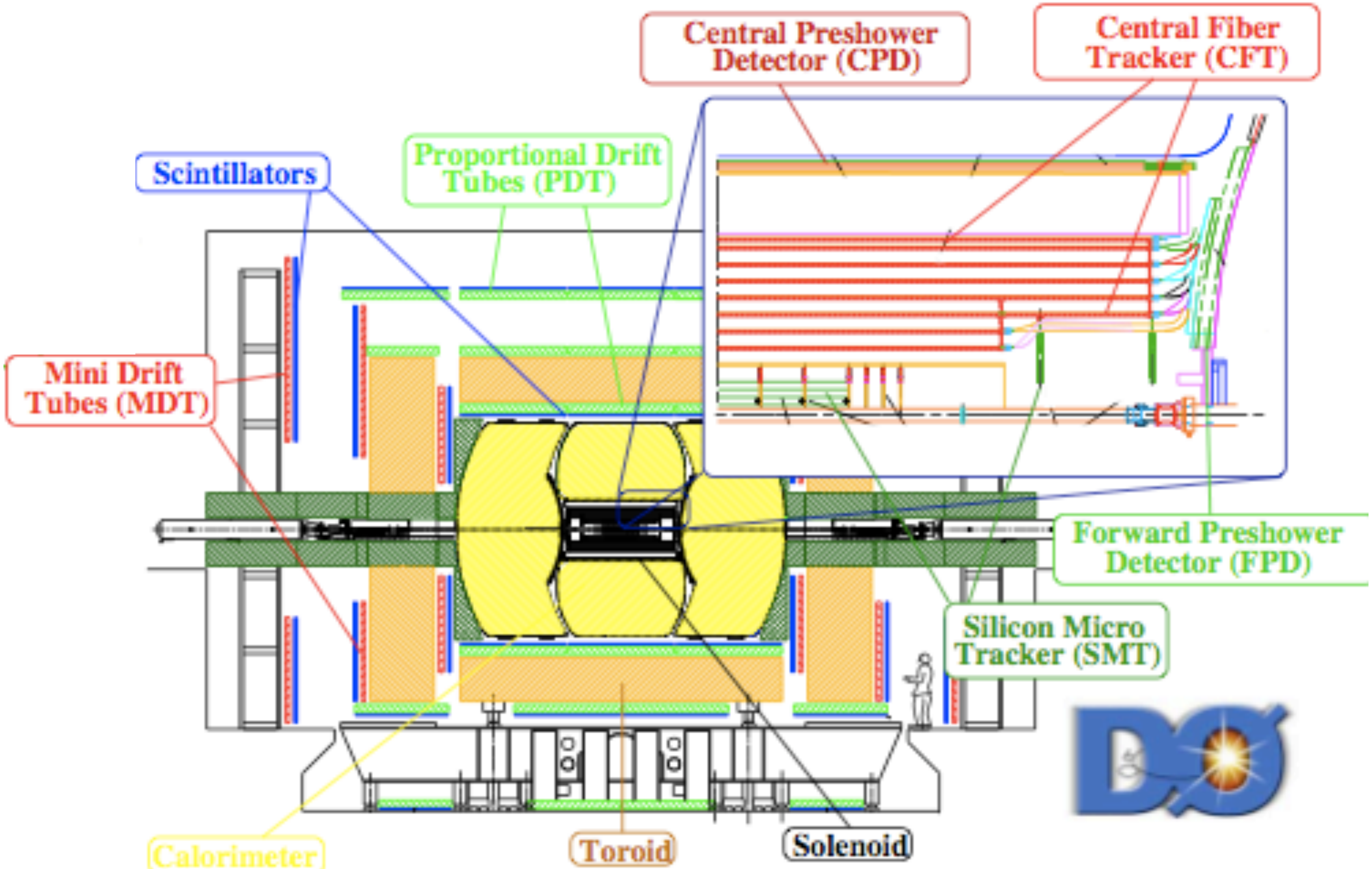
SM searches

- SM searches can be used as well:
  - h has SM like couplings on a large portion of the MSSM phase space
  - H becomes increasingly SM-like when M_A decreases.
  - based on the work by P. Draper et al. arXiv:0905.4721v2:
    - they consider SM Higgs exclusion and translate it into MSSM constraints for 4 MSSM scenarii
    - furthermore they combined with $\Phi \rightarrow \tau\tau$ searches
    - use 10 fb^{-1} + improvements in SM anlysis (25%)


a_t=0GeV, μ=200GeV, M_S=2TeV
SM–like Higgs Searches, ϕ–>b$\bar{b}$,WW, 10fb^{-1}
allowed
90% C.L., 1.5x effc
95% C.L., 1.5x effc
95% C.L., 1.25x effc
95% C.L., 1.0x effc
LEP excl.
tan β
M_A (GeV)
2.6σ
SM searches only
P. Draper et al. arXiv:0905.4721v2

Multi purpose detector:

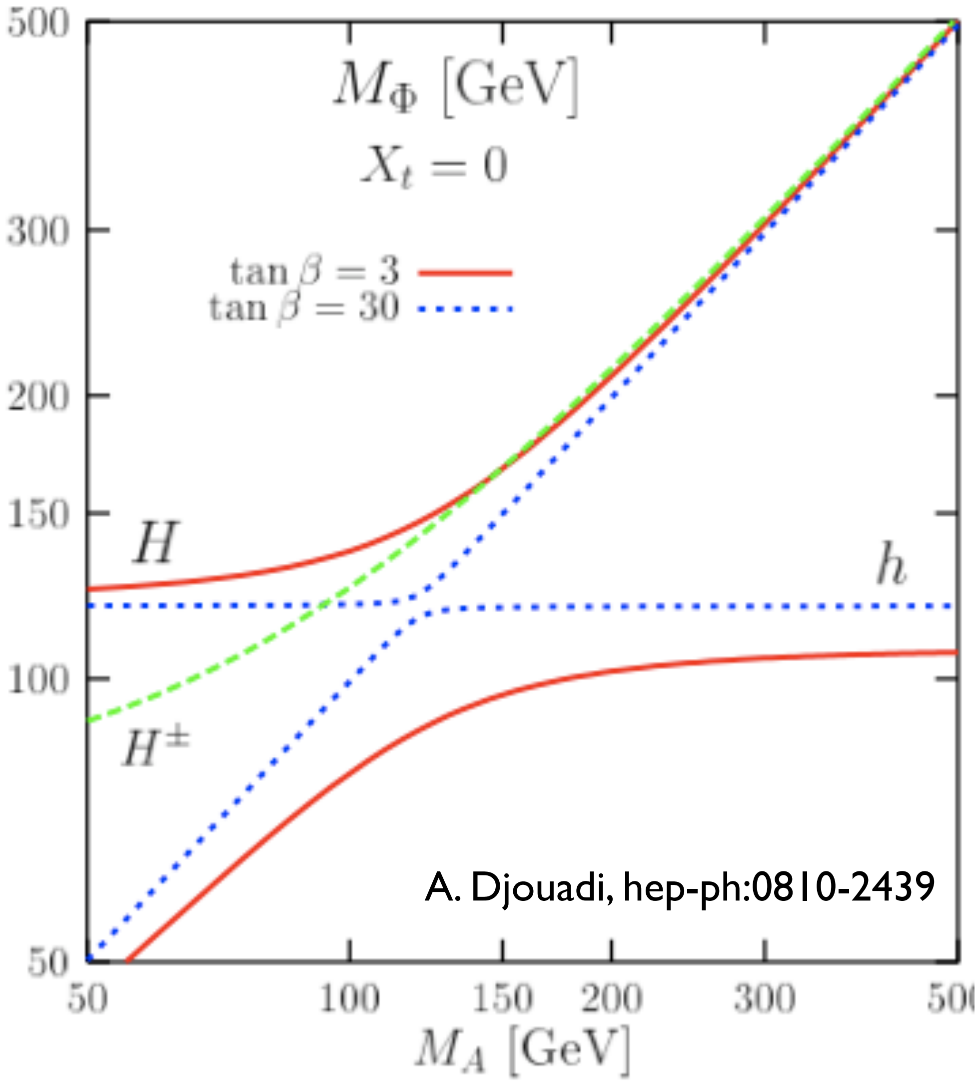
μ id, EM id, jets, taus, $\not{E}_T$, b-jets tagging



High tan β 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 $\sigma_{prod} \times 2!$
- coupling to b quarks enhanced by tanβ



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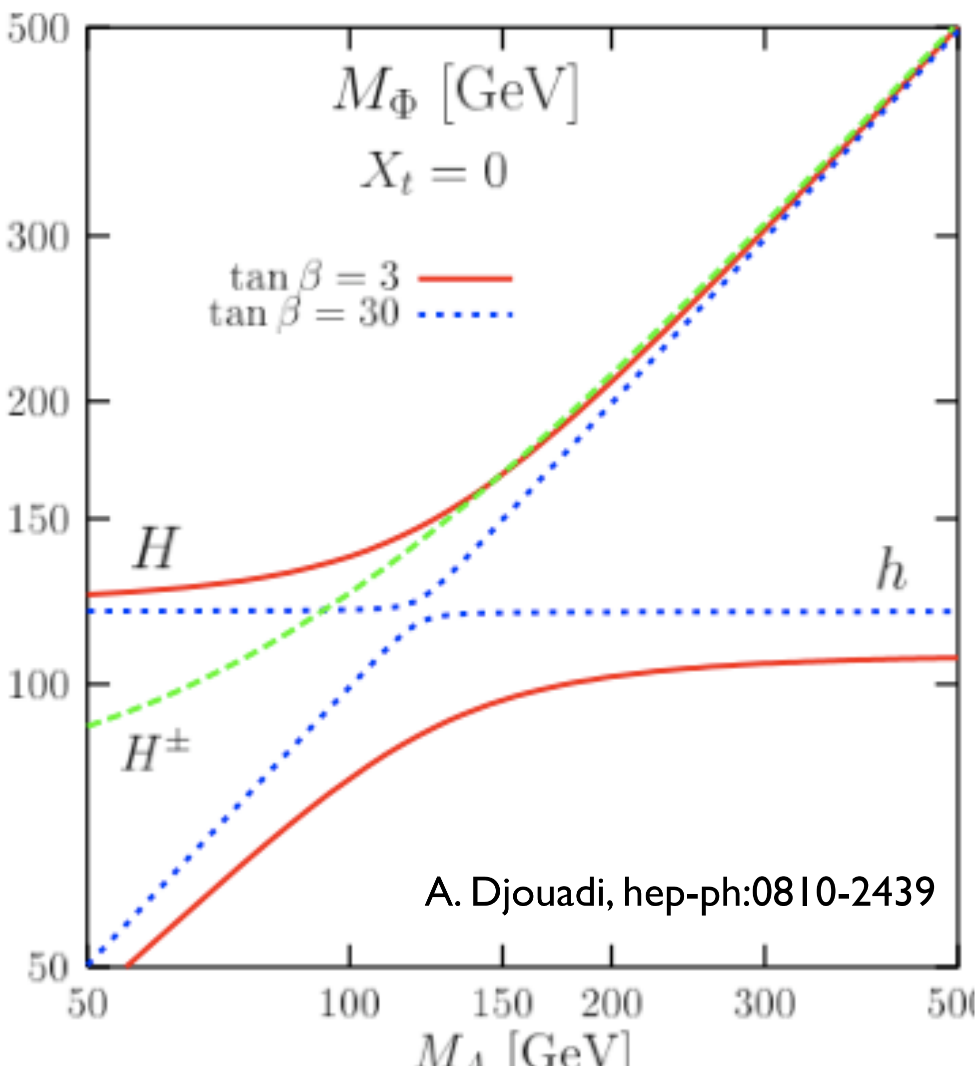
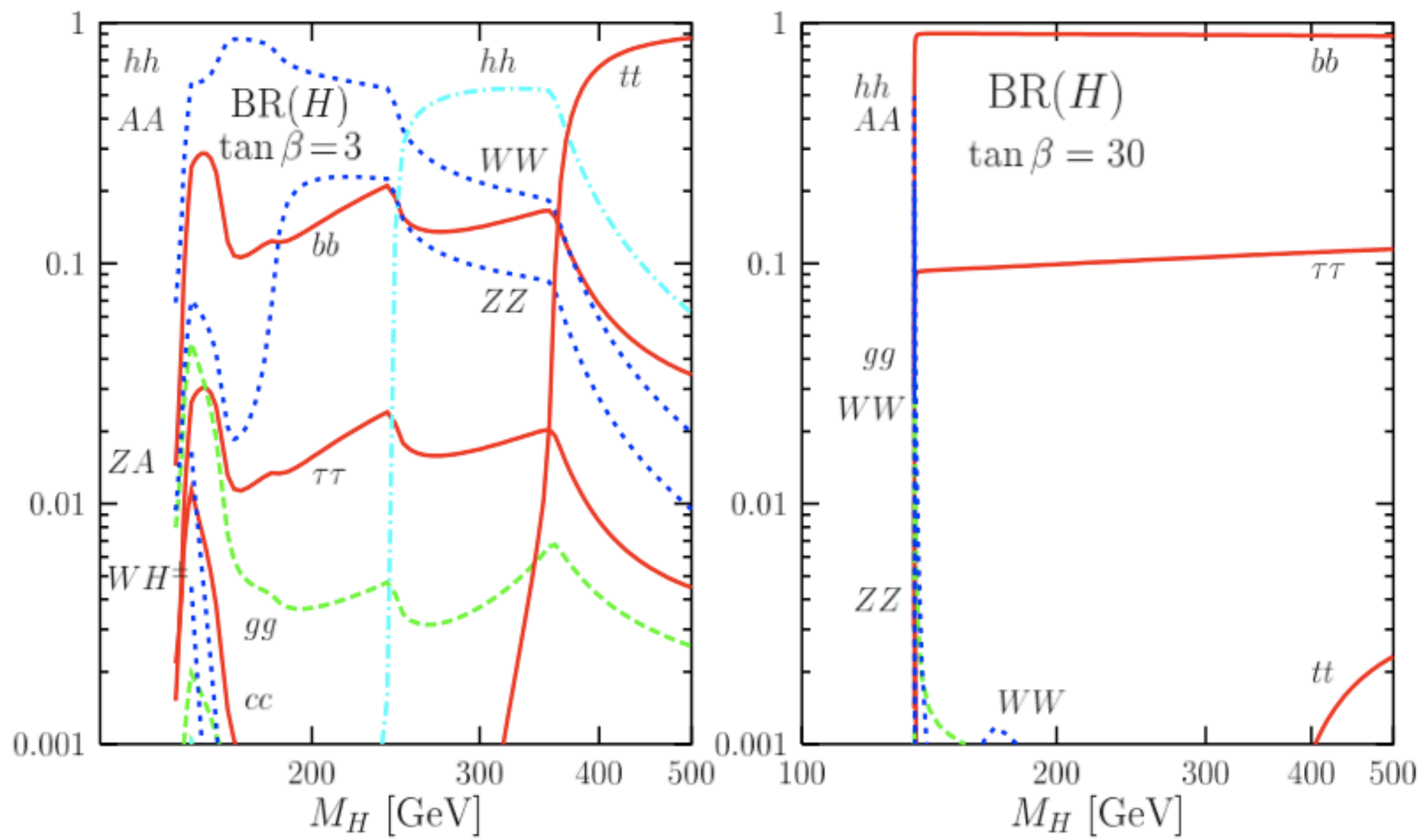
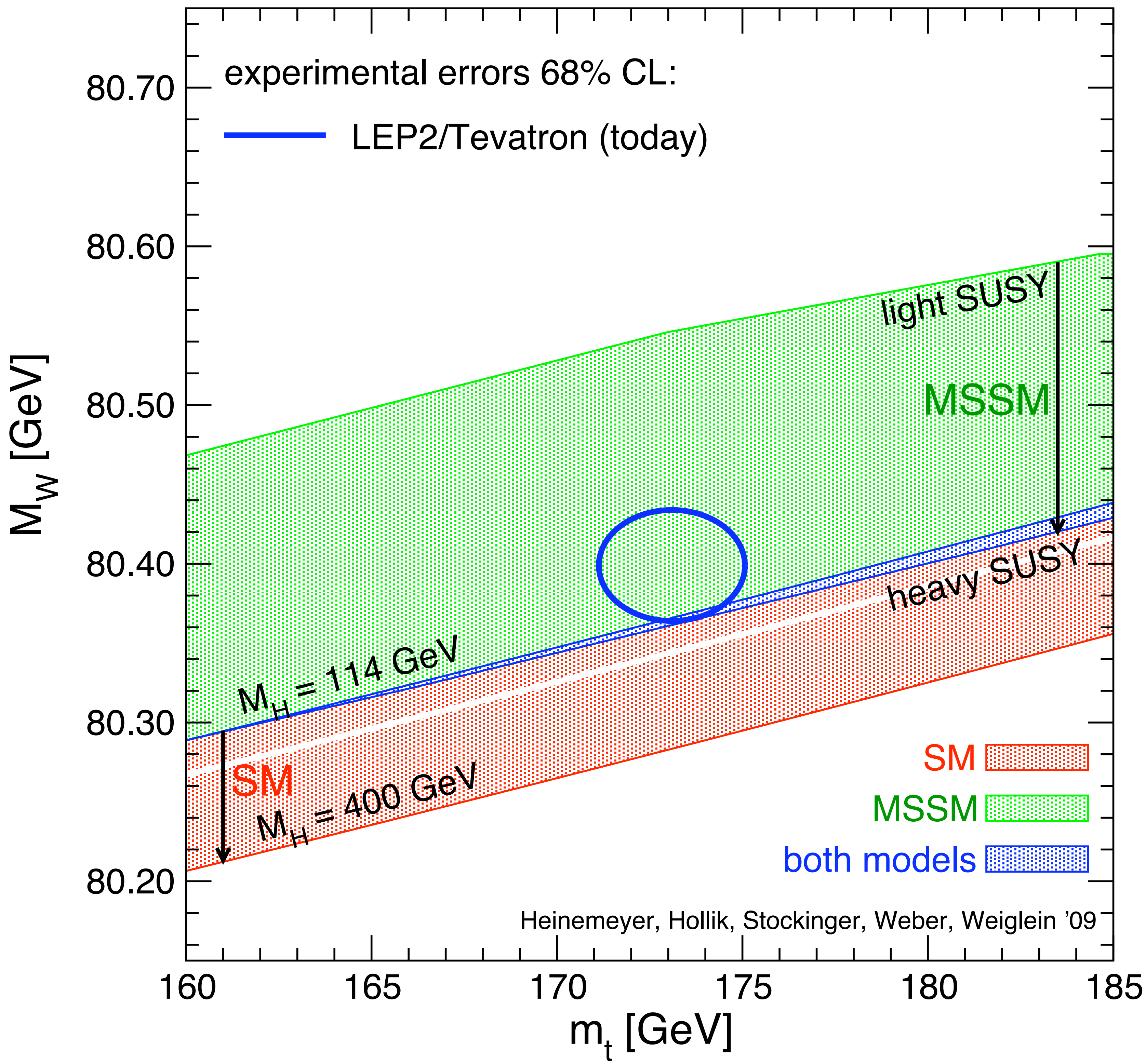
- neutral Higgs: $\mathcal{B}(\phi \to b\bar{b}) \approx 90~\%$ and $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10~\%$
- charged Higgs: if $m_{H+} < m_{top}$: $\mathcal{B}(H^+ \to \tau^+\nu_\tau) \approx 1$



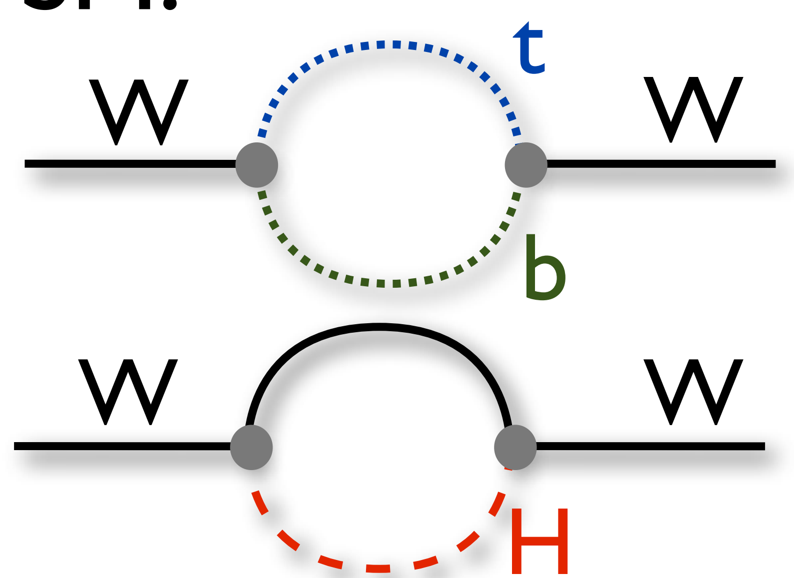


A. Djouadi, hep-ph0810-2439

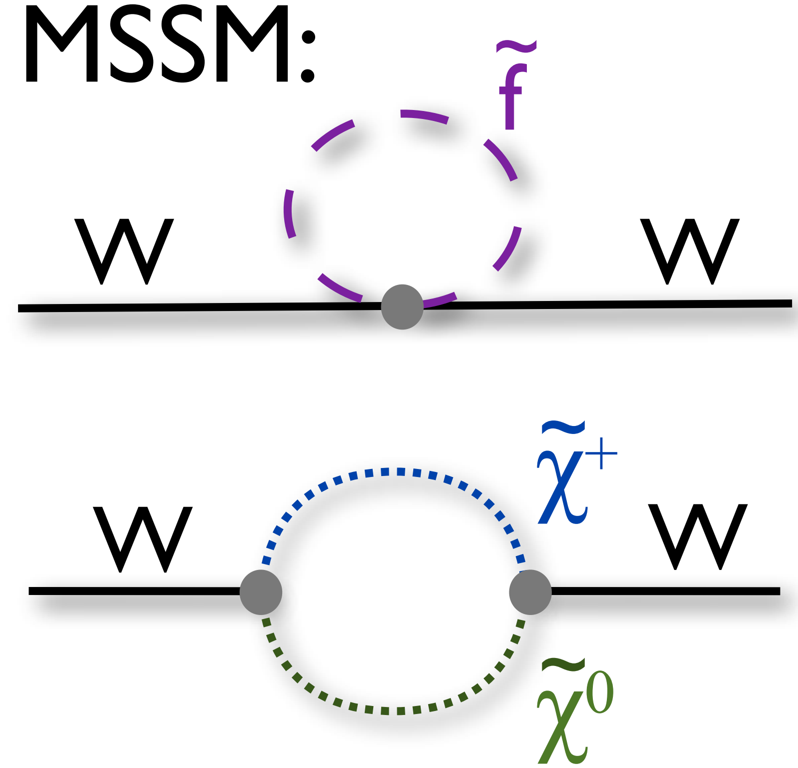
Why looking to the MSSM?



SM:

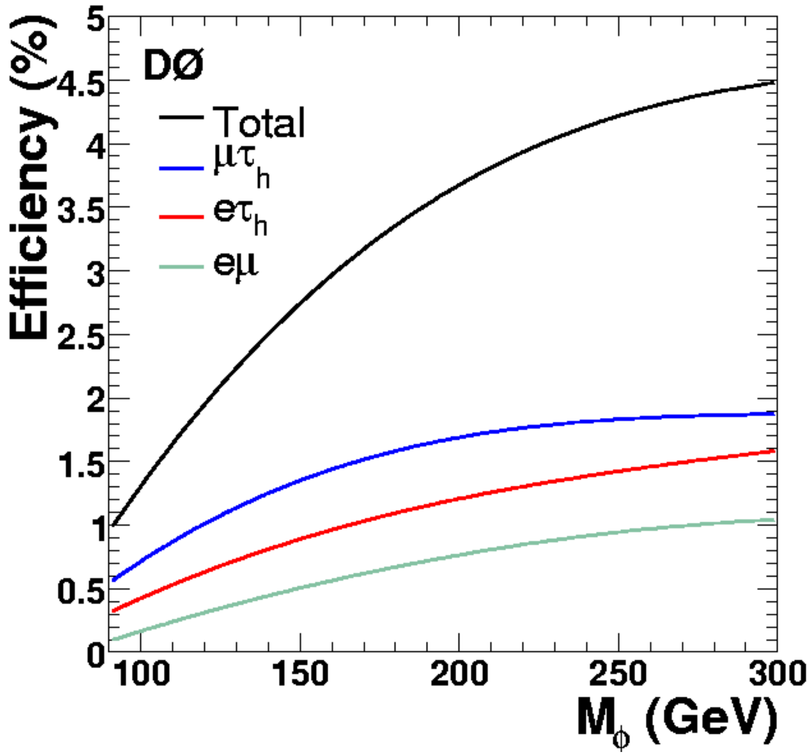


MSSM:



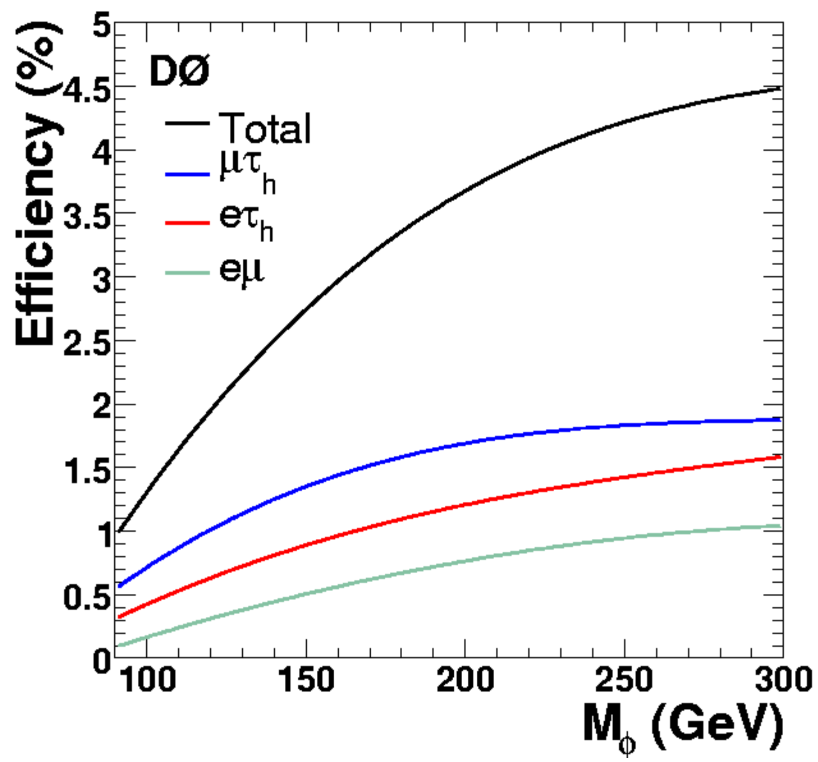
.....

Best channel: $\tau_\mu \tau_h$

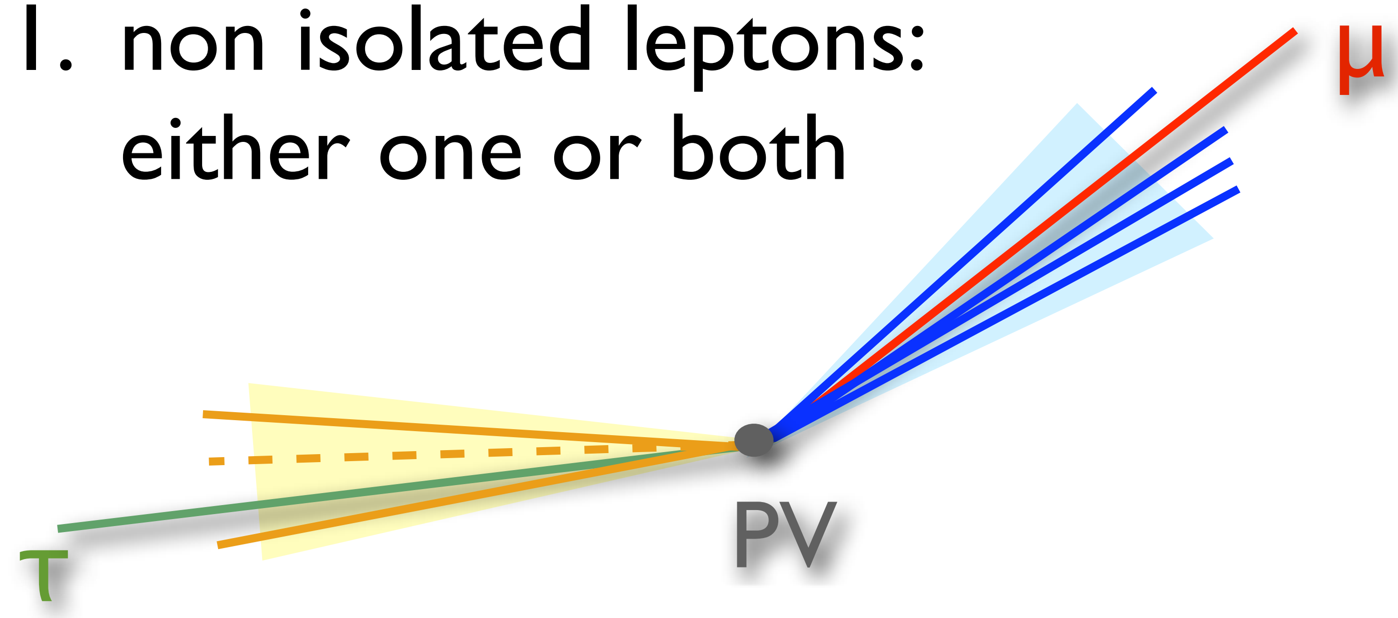


- Multijets estimated from 2 samples:

Best channel: $\tau_\mu \tau_h$



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



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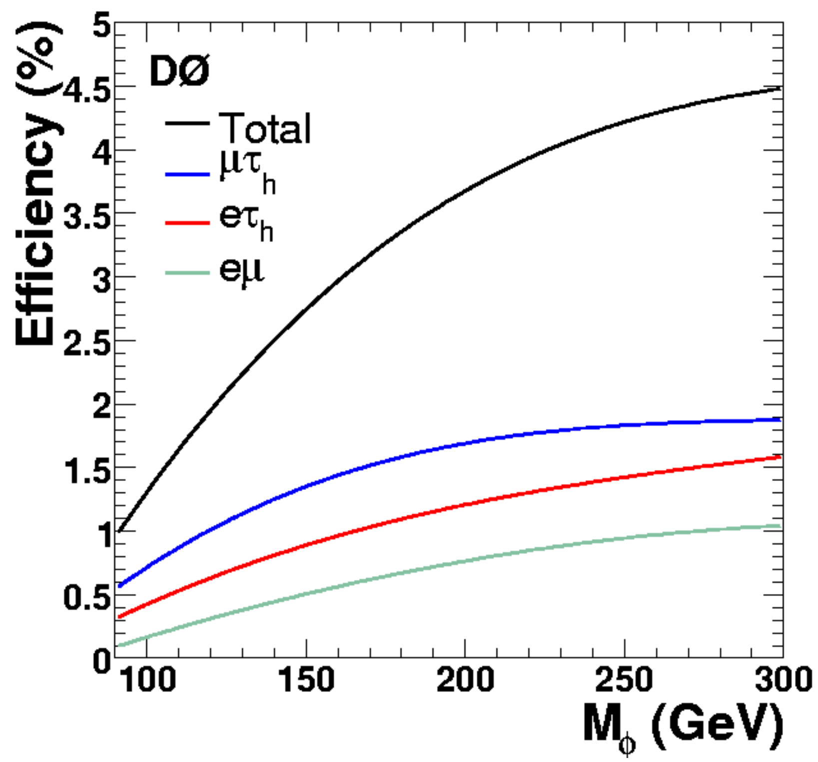

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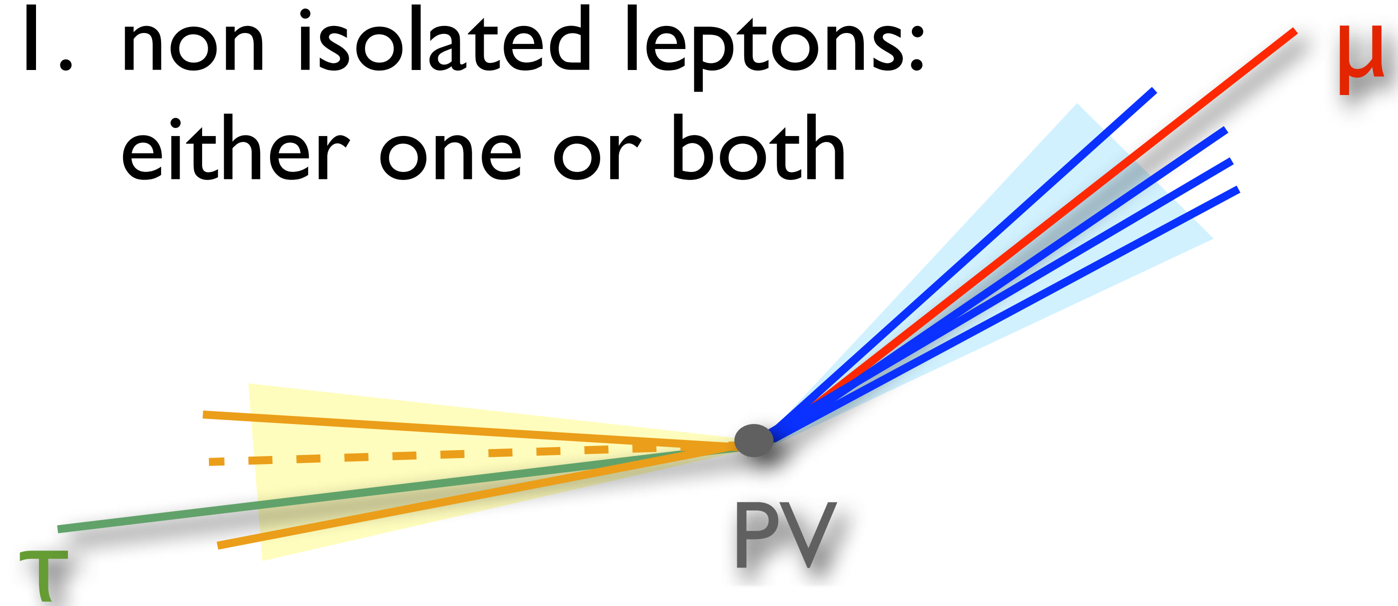
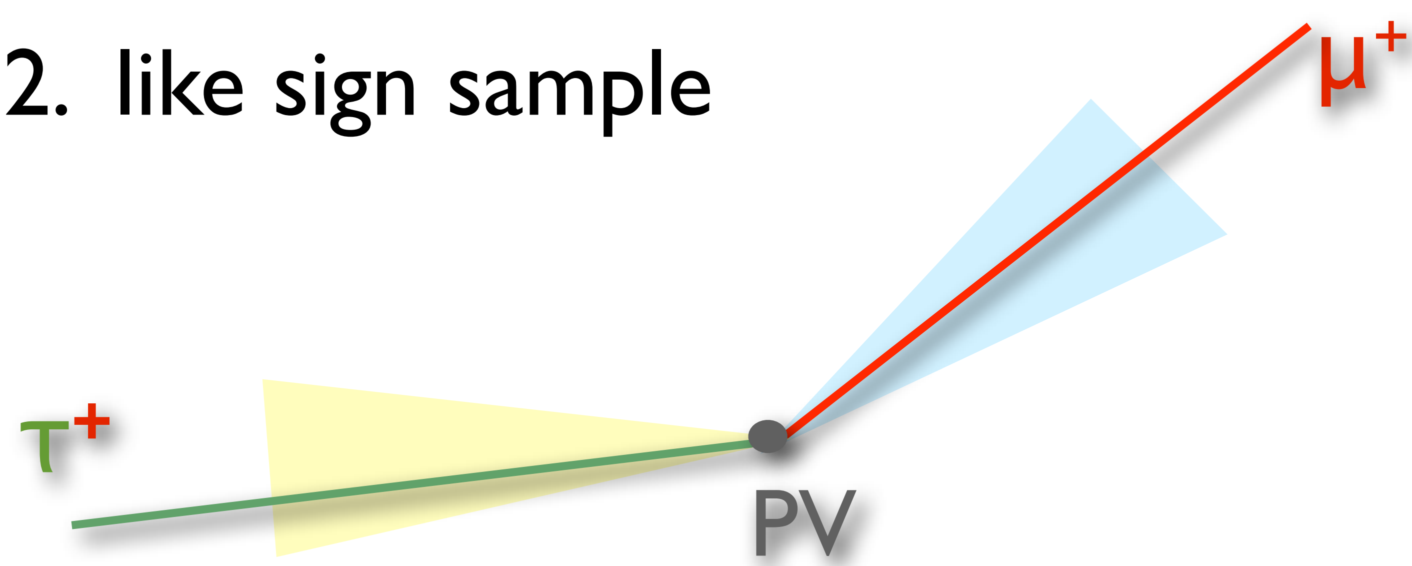
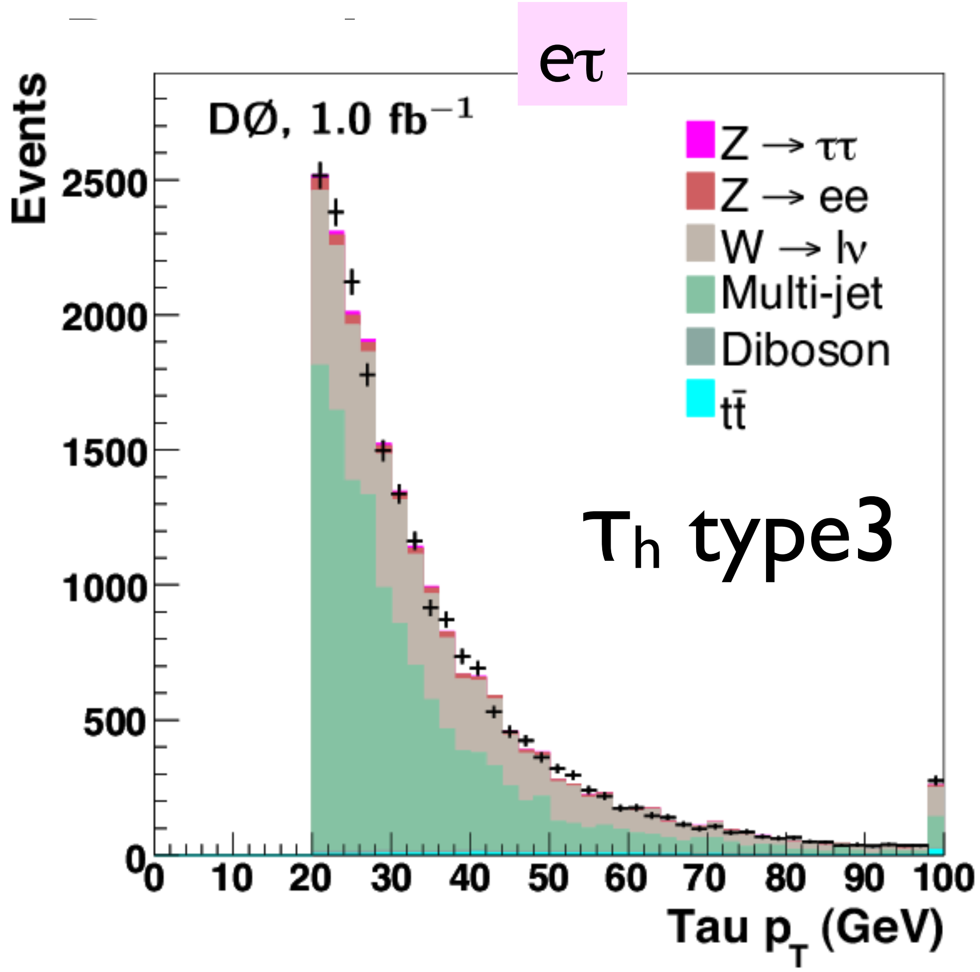


  2. like sign sample





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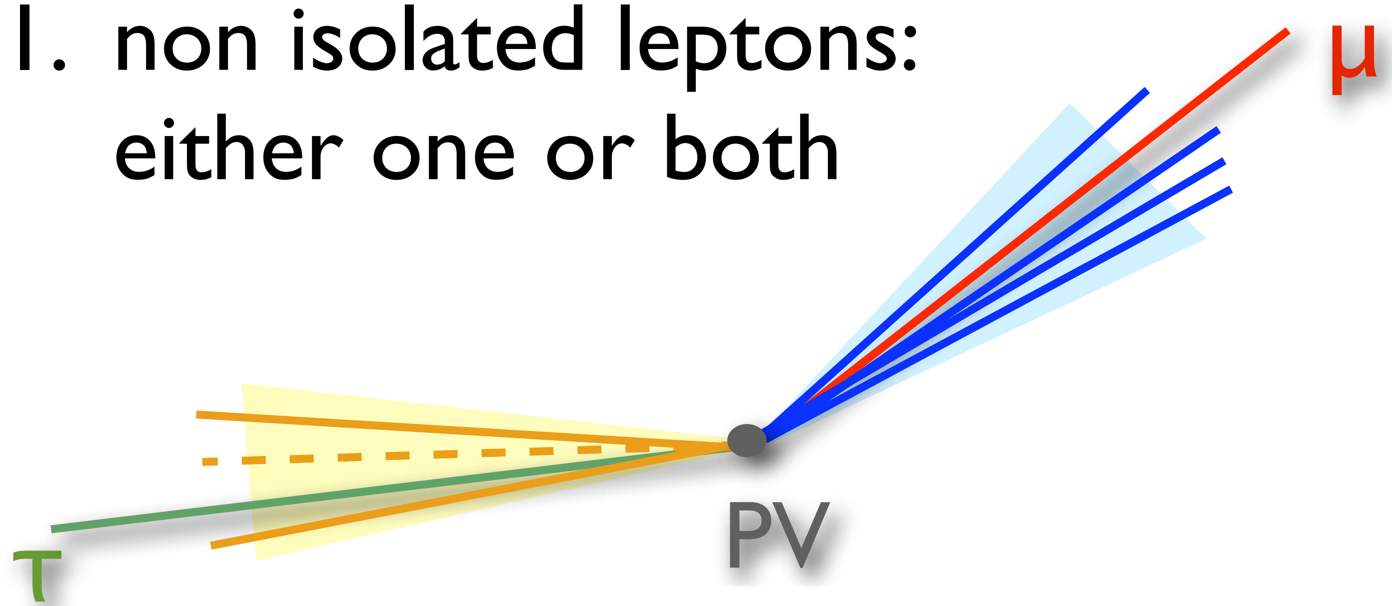

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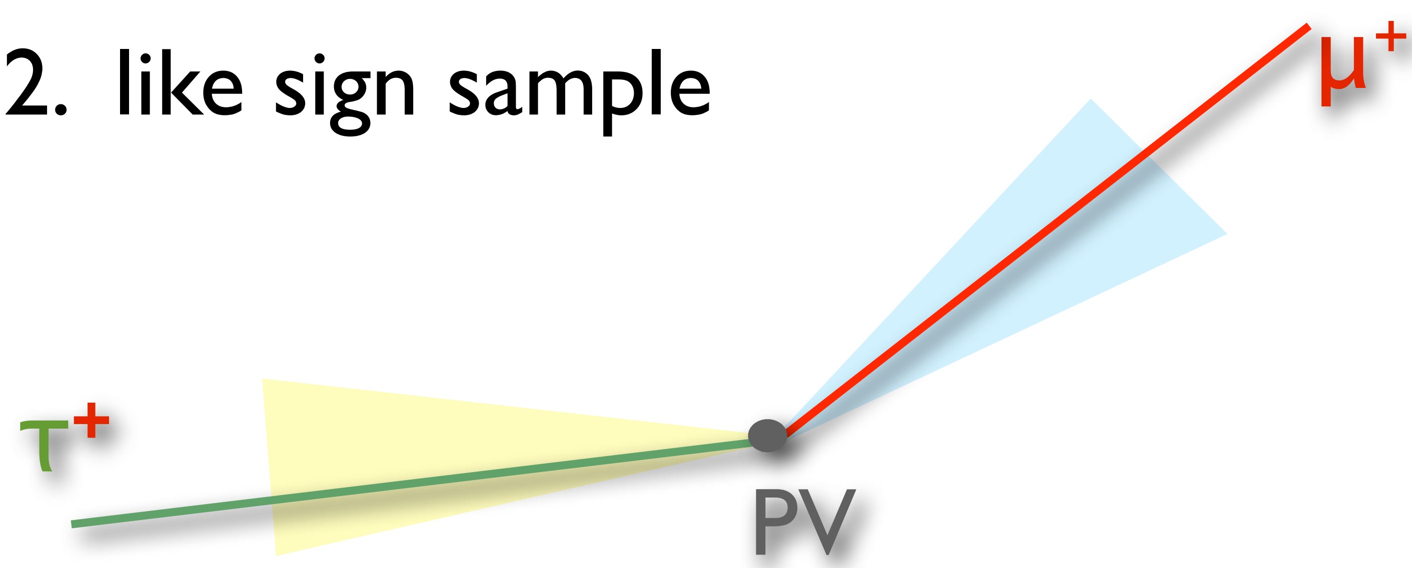


- In W MC, τ_h fake is also corrected for

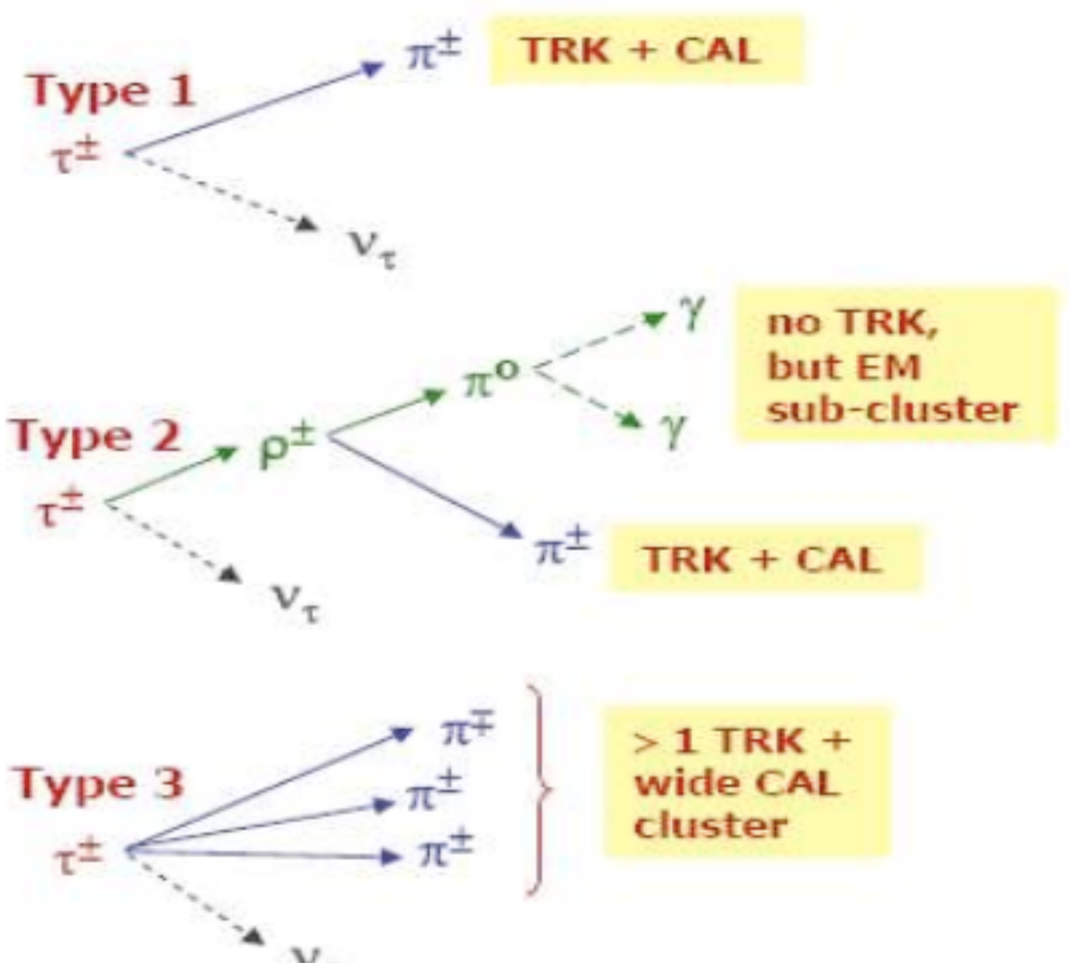
$h \rightarrow \tau\tau$ selections:

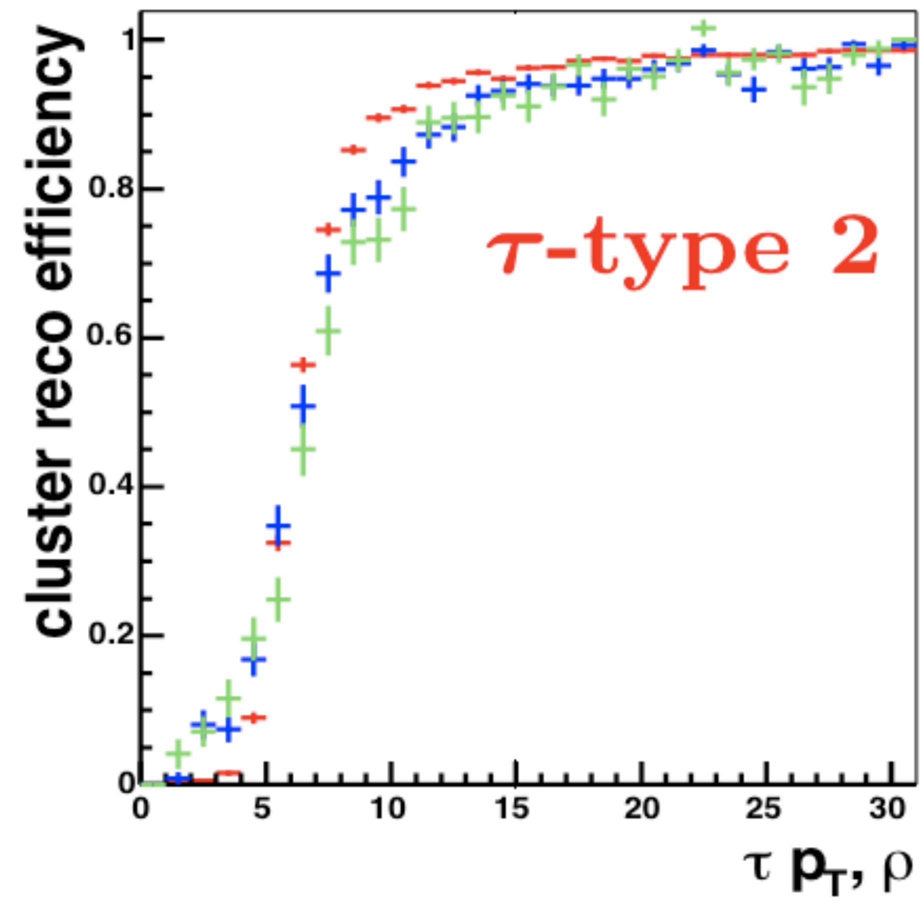
1. $\tau_\mu\tau_h$ and $\tau_e\tau_h$:
   - opposite charged leptons
   - $p_T[h] > 15$ GeV/c & $|\eta_h| < 2$
   - NN_τ cuts applied
   - $p_T[\mu/e] > 16.5$ GeV/c & $|\eta_\mu| < 2$; $|\eta_e| < 2.5$
   - μ/e isolated
   - $M_T[W] < 40$ GeV/c^2
   - \+ additional kinematic cuts to remove W
   - \+ additional cuts to remove $Z \rightarrow ee$
   - \+ muon veto to kill $Z \rightarrow \mu\mu$

2. $\tau_\mu\tau_e$:
   - opposite charged leptons
   - $p_T[e] > 12$ GeV/c & $|\eta_\mu| < 1.6$
   - $p_T[\mu] > 10$ GeV/c & $|\eta_e| < 2.0$
   - μ/e isolated
   - $M_T[W]$min < 10 GeV/c^2
   - $p_T[e] + p_T[\mu] + mE_T > 65$ GeV/c
   - $\Delta\varphi$min$[e/\mu\ ; mE_T] < 0.3$
   - $H_T < 70$ GeV/c

Final state	BR (%)	decay type	notation in this talk	detector properties
$e\,\upsilon\,\upsilon$	17.8 %	leptonic	τ_e	EM id
$\mu\,\upsilon\,\upsilon$	17.4 %	leptonic	τ_μ	muon id
$\pi/K\,\upsilon$	11.6 %	1-prong	τ_h	1 track + calo
$\pi/K\,\upsilon + \geq 1\pi^0$	37.1 %	1-prong	τ_h	1 track + calo
$\pi\pi\pi\,\upsilon + \geq 0\,\pi^0$	15.2 %	3-prong	τ_h	3 tracks + calo

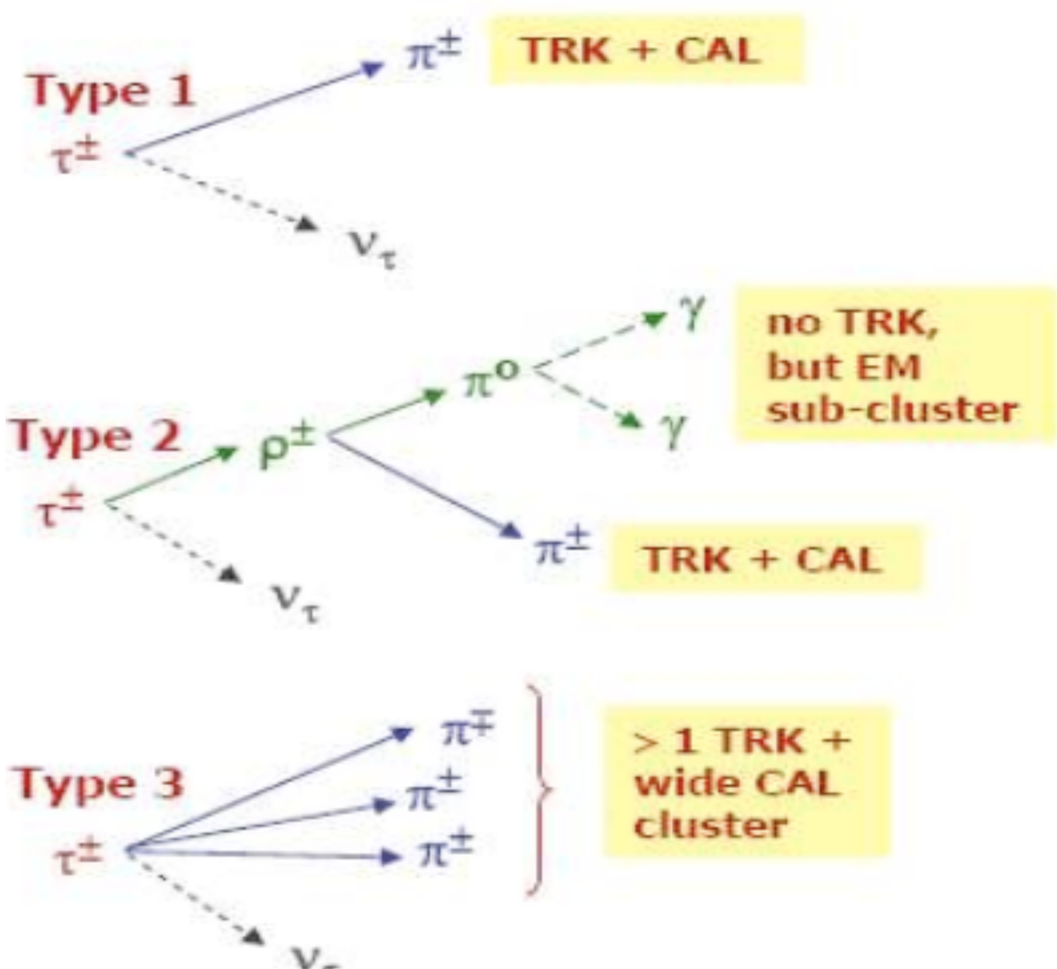
τ signal:
distinguish 3 tau types





NB: electrons are τ_h type2

τ signal:
distinguish 3 tau types



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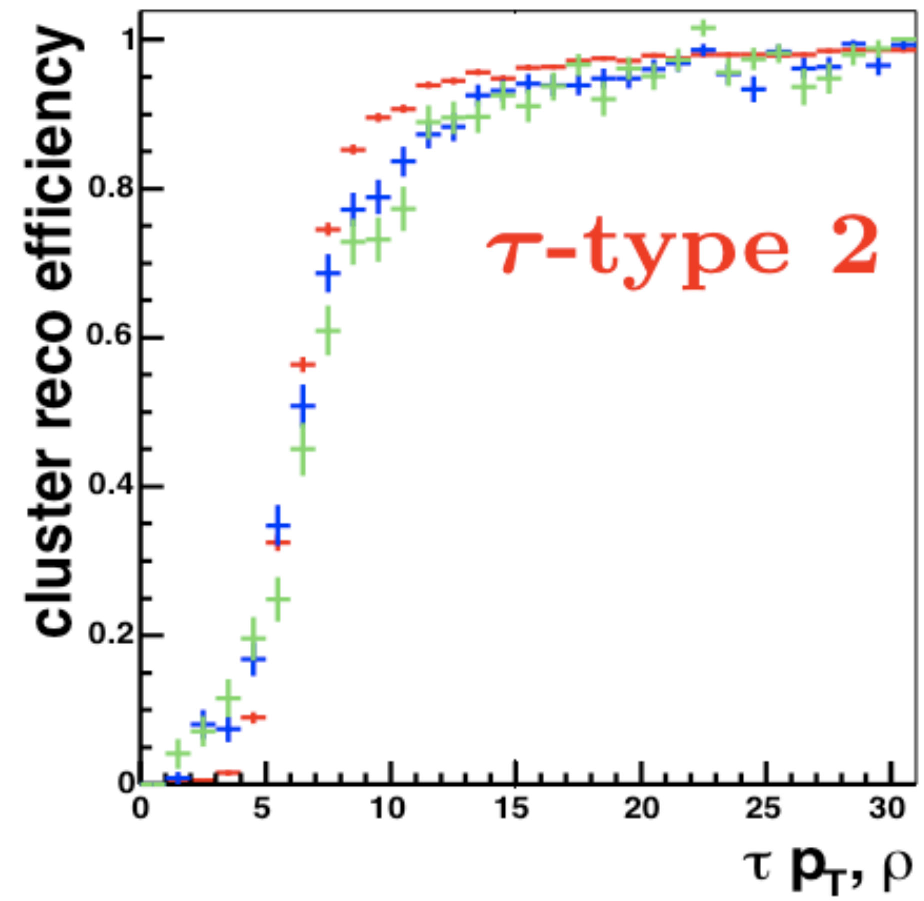
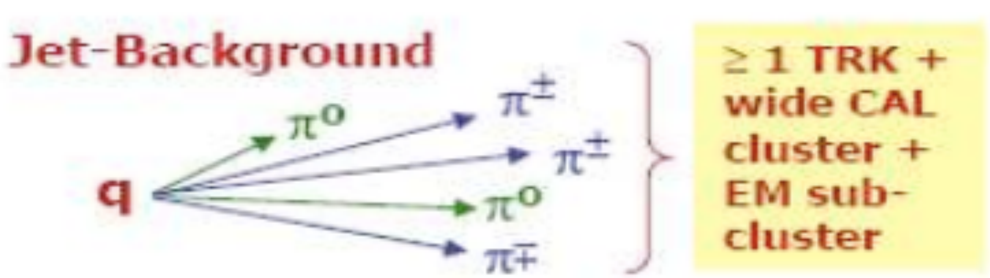


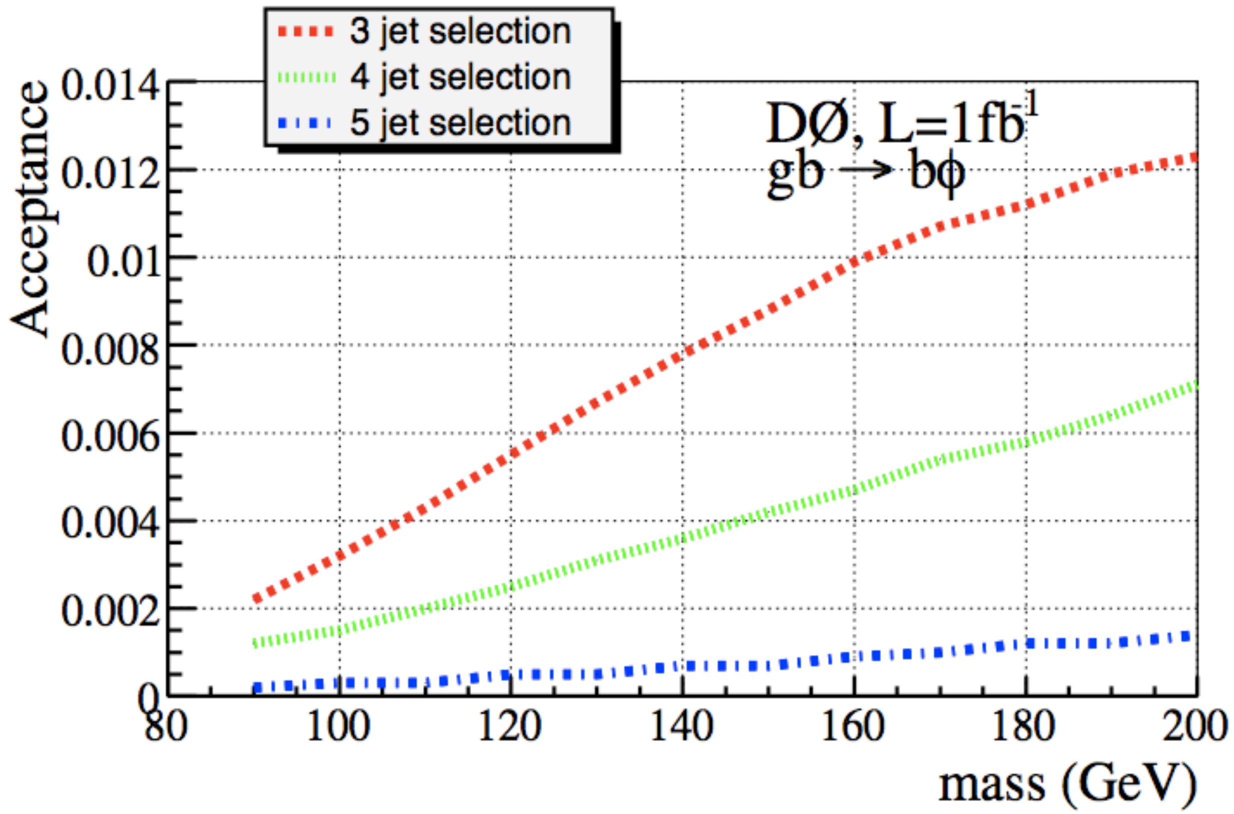
build a NN based on shower shape and isolation variables.

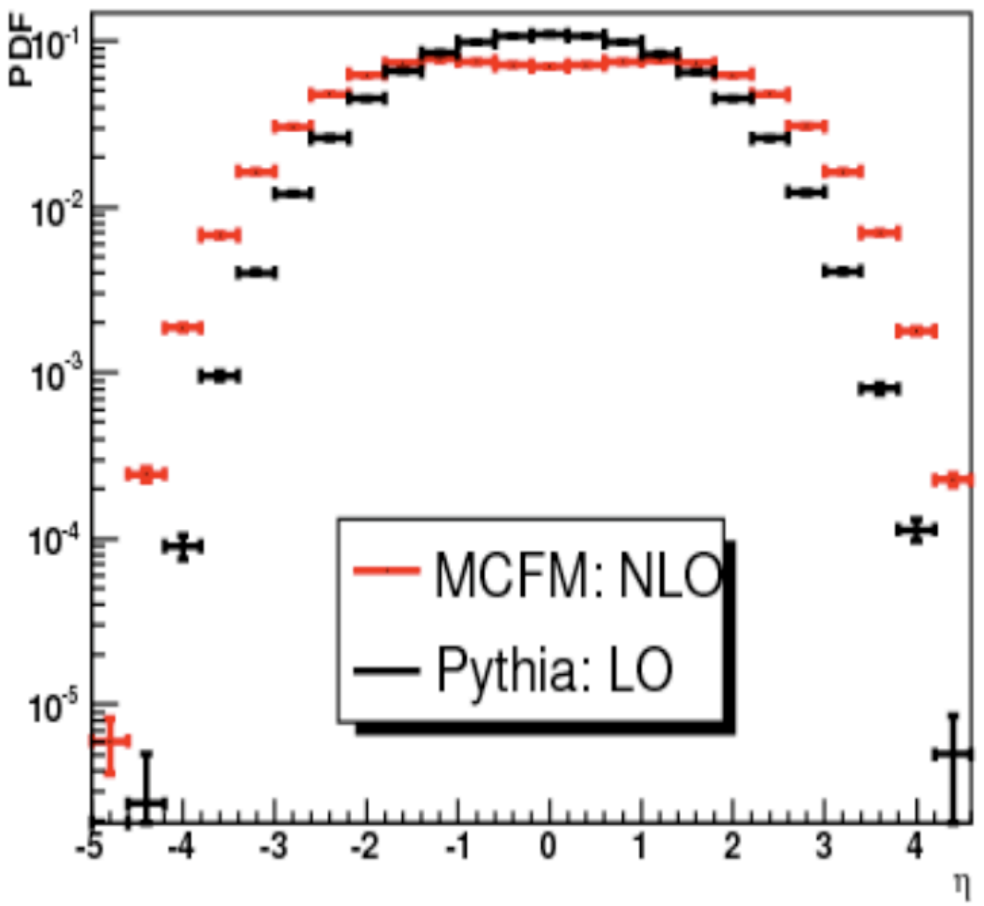
NN cut effi	τ_h 1	τ_h 2	τ_h 3
jets	3 %	2.5 %	2.5 %
τ	60 %	75 %	65 %

jets mimic τs



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





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

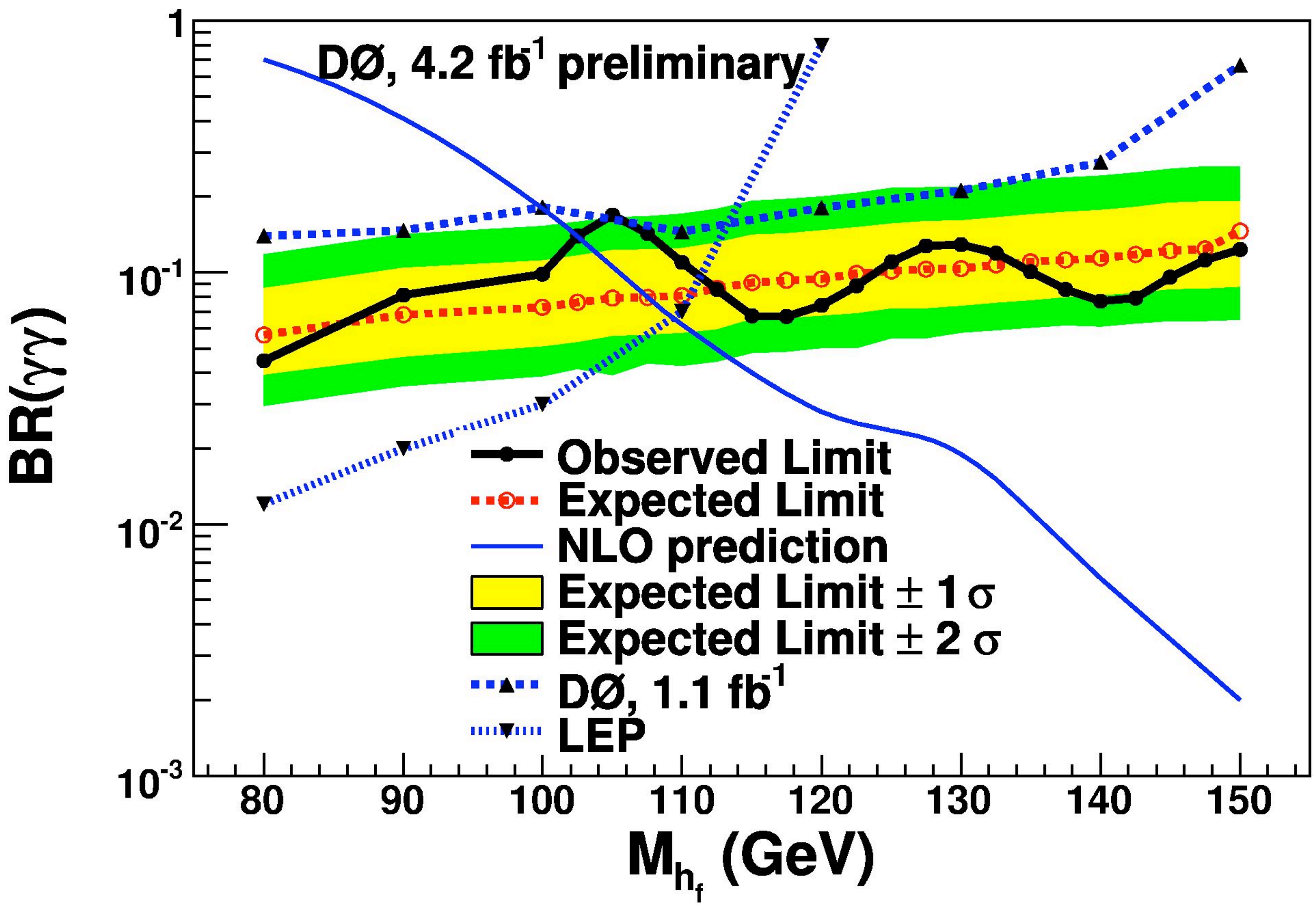
- **m_h^{max} scenario:**
  - $X_t = 2$ TeV;
  - $\mu = \pm 0.2$ TeV;
  - $M_2 = 0.2$ TeV;
  - $m_{\tilde{g}} = 0.8$ TeV
  - $M_{SUSY} = 1$ TeV

- **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

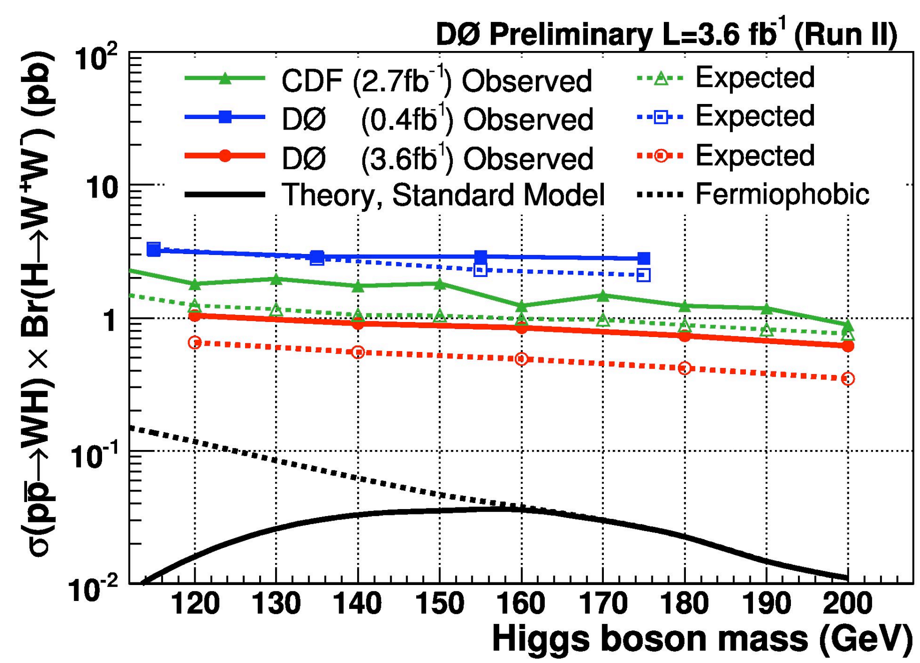
M. S. Carena, S. Heinemeyer, C. E. M. Wagner, and G. Weiglein, Eur. Phys. J. C 26, 601 (2003).

Fermiophobic Higgs

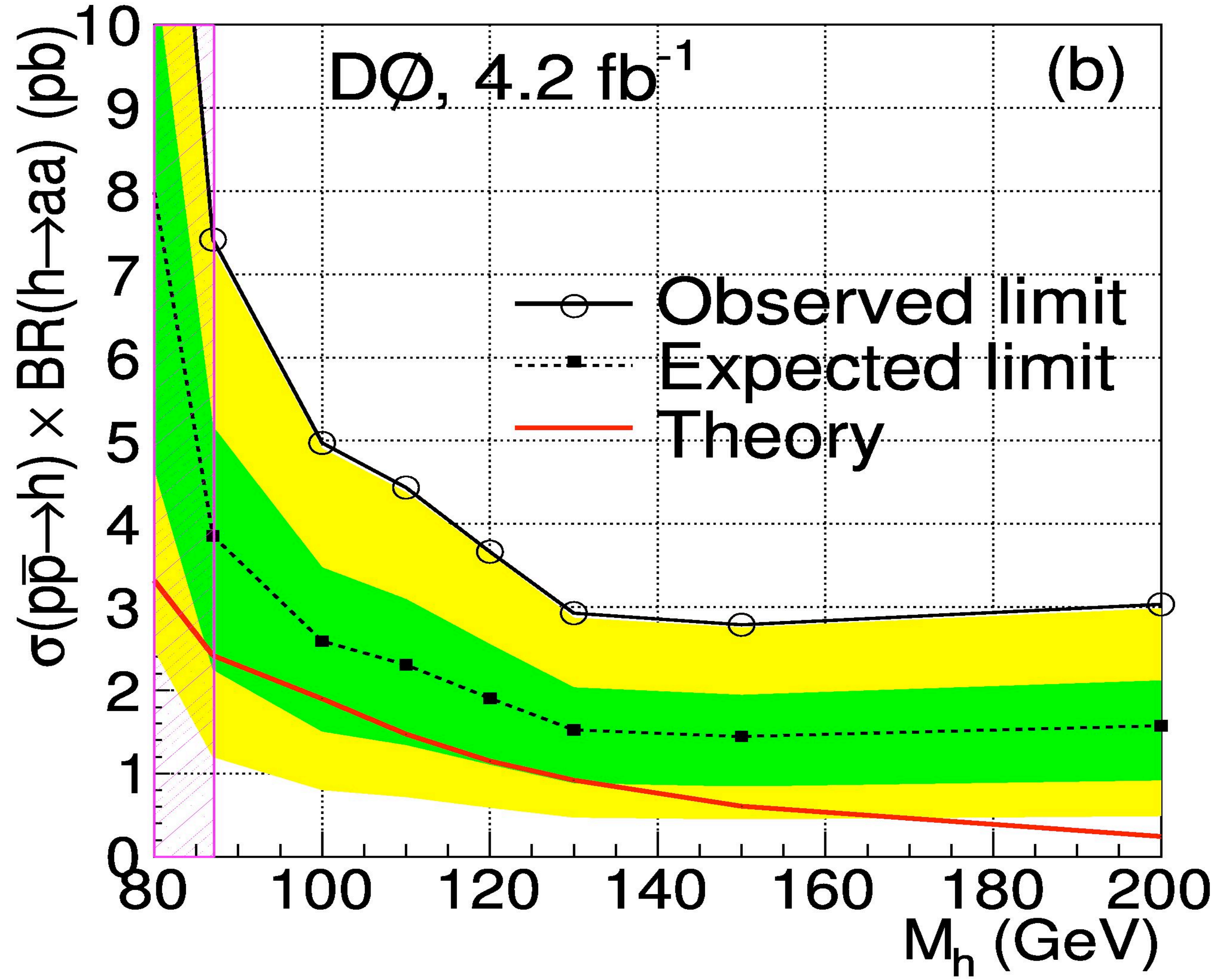
- Fermiophobic Higgs
  - Search channels:
    - WH → WWW or H → γγ



Limits ~105GeV

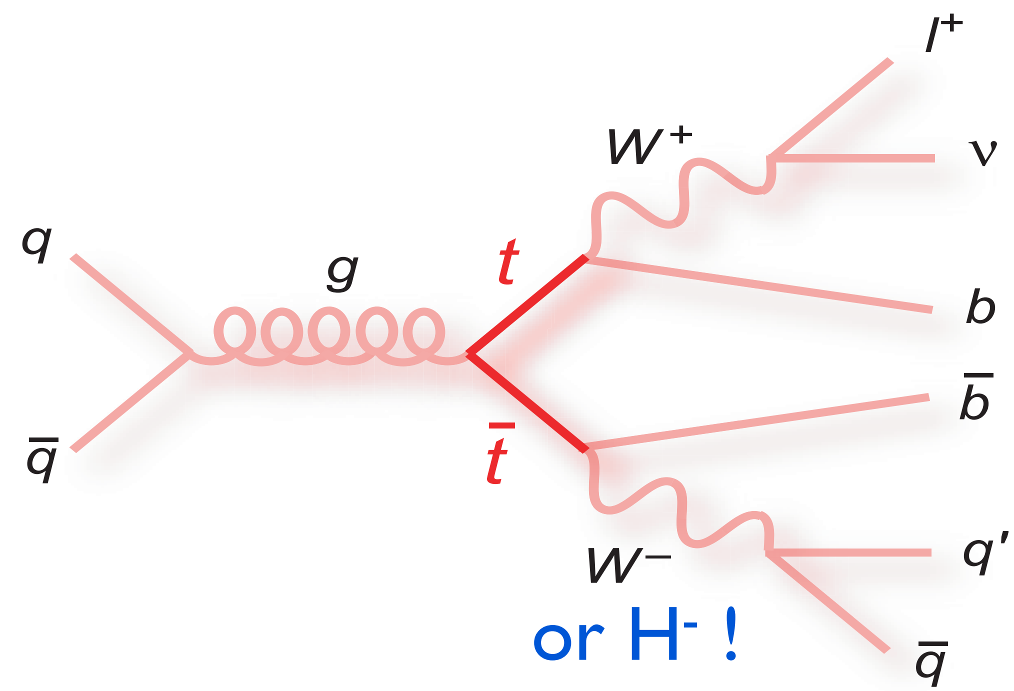


- NMSSM: $gg \rightarrow h \rightarrow aa$, $a \rightarrow \mu\mu$ or $\tau\tau$
  - If $m_a < 2m_\tau$: $h \rightarrow aa \rightarrow \mu\mu\mu\mu$
    - Two pairs of collinear muons
  - If $m_a > 2m_\tau$: $h \rightarrow aa \rightarrow \mu\mu\tau\tau$
    - Back-to-back μ and τ pairs



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

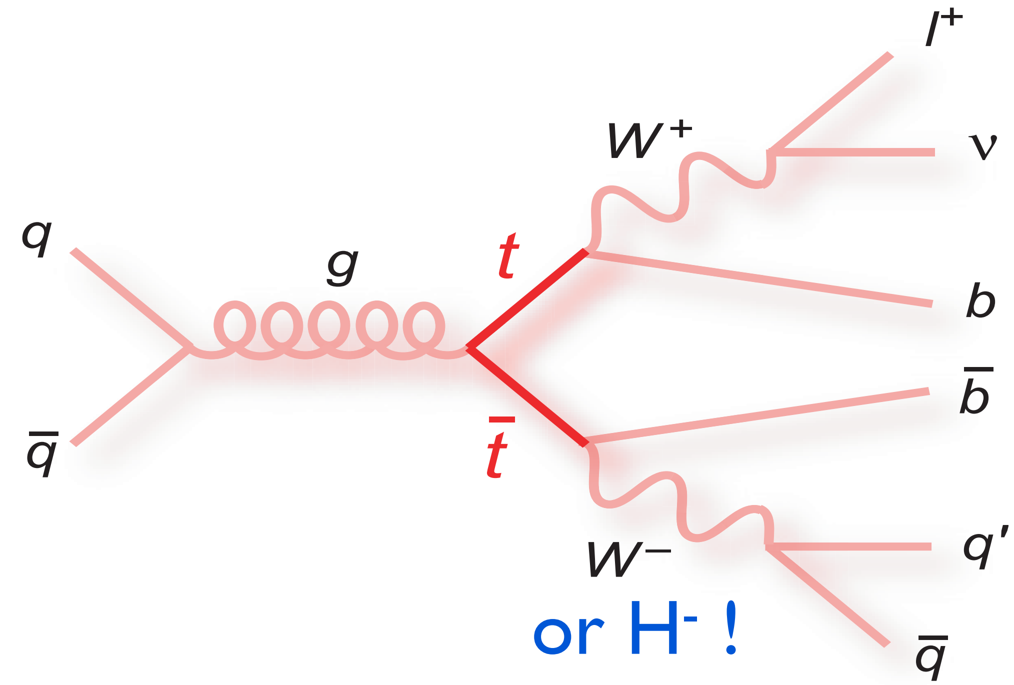
  $t \rightarrow H^+ b$ opens



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

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

  $t \rightarrow H^{+} b$ opens



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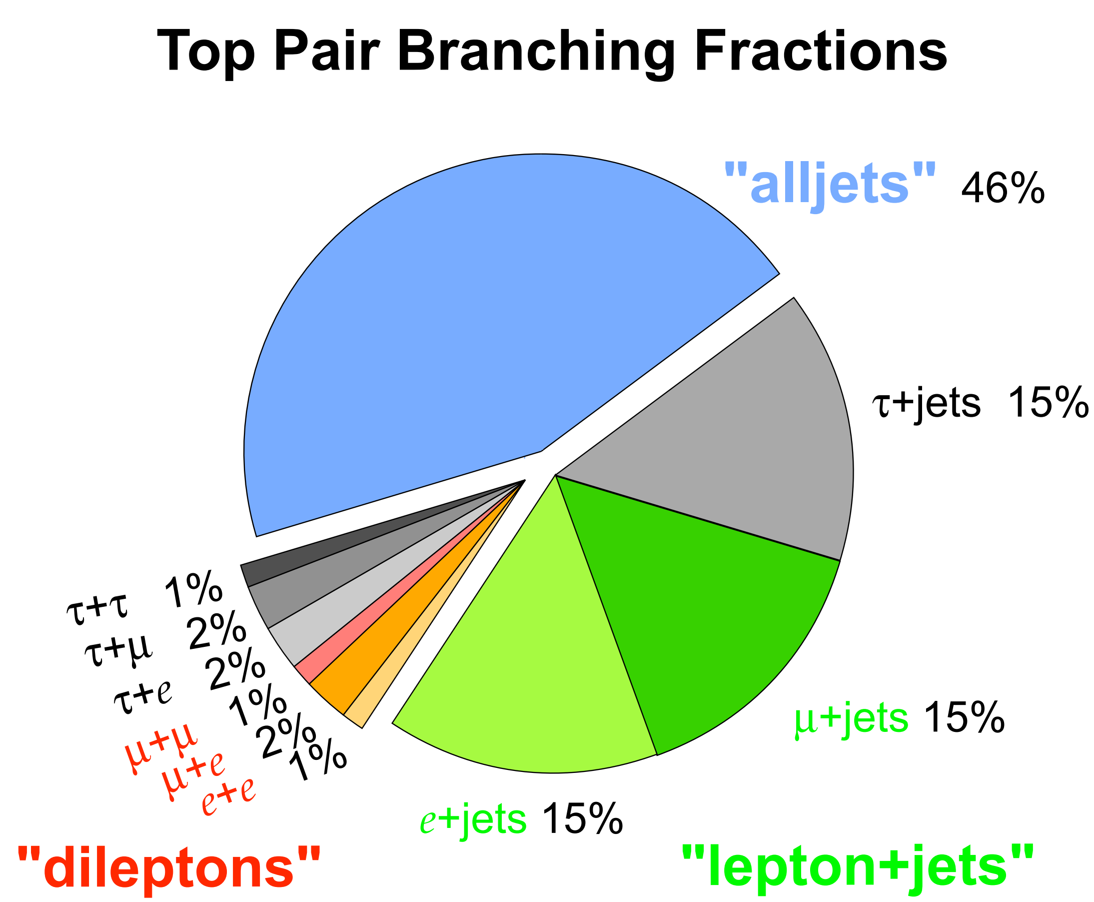
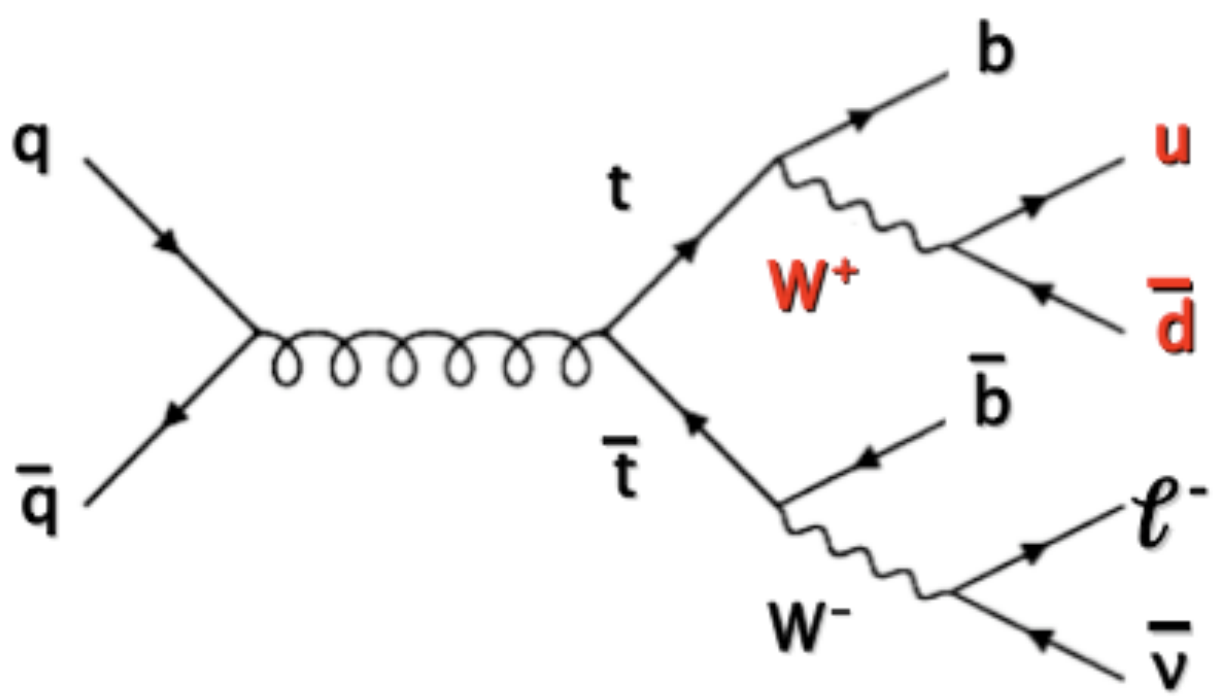
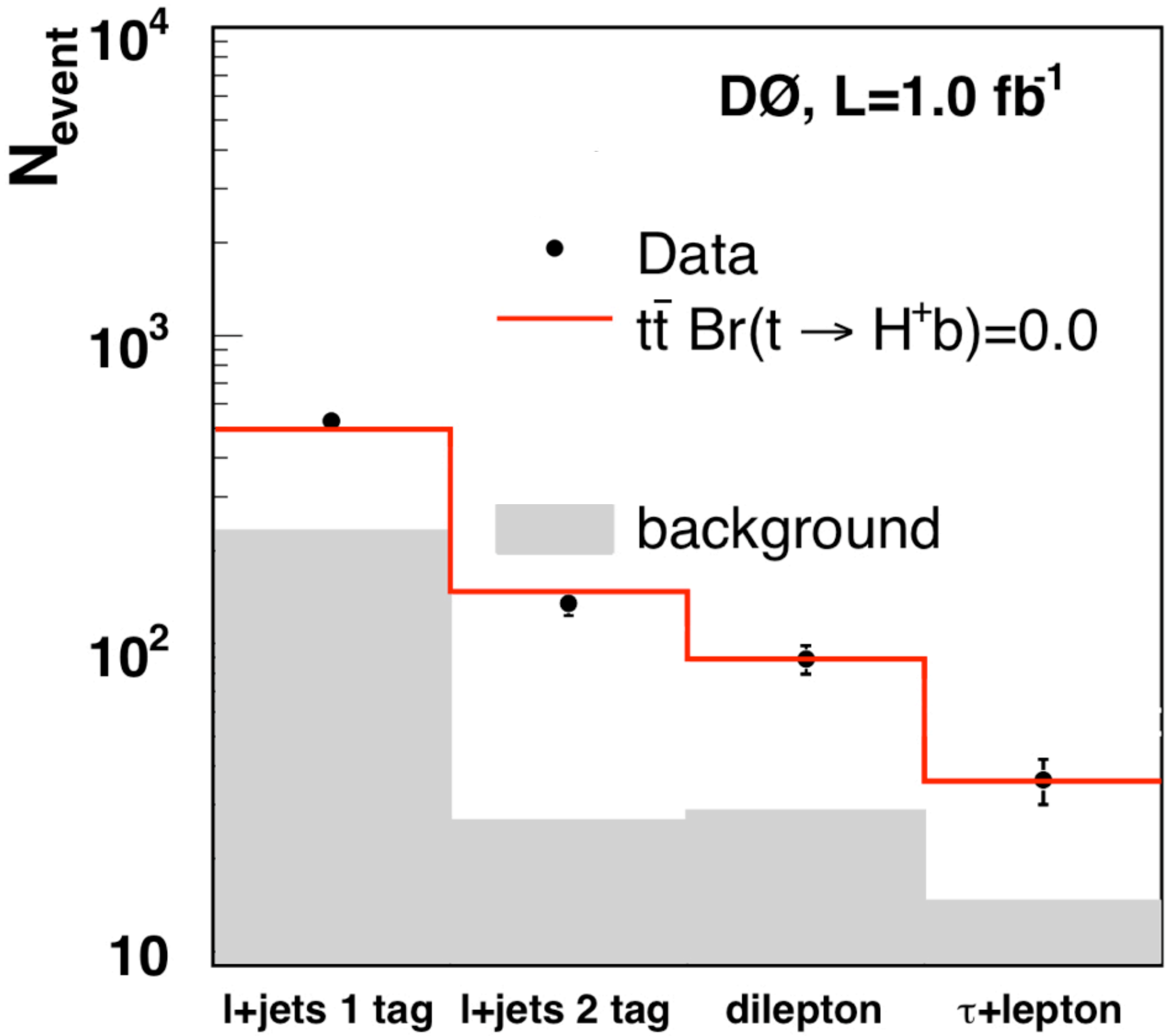
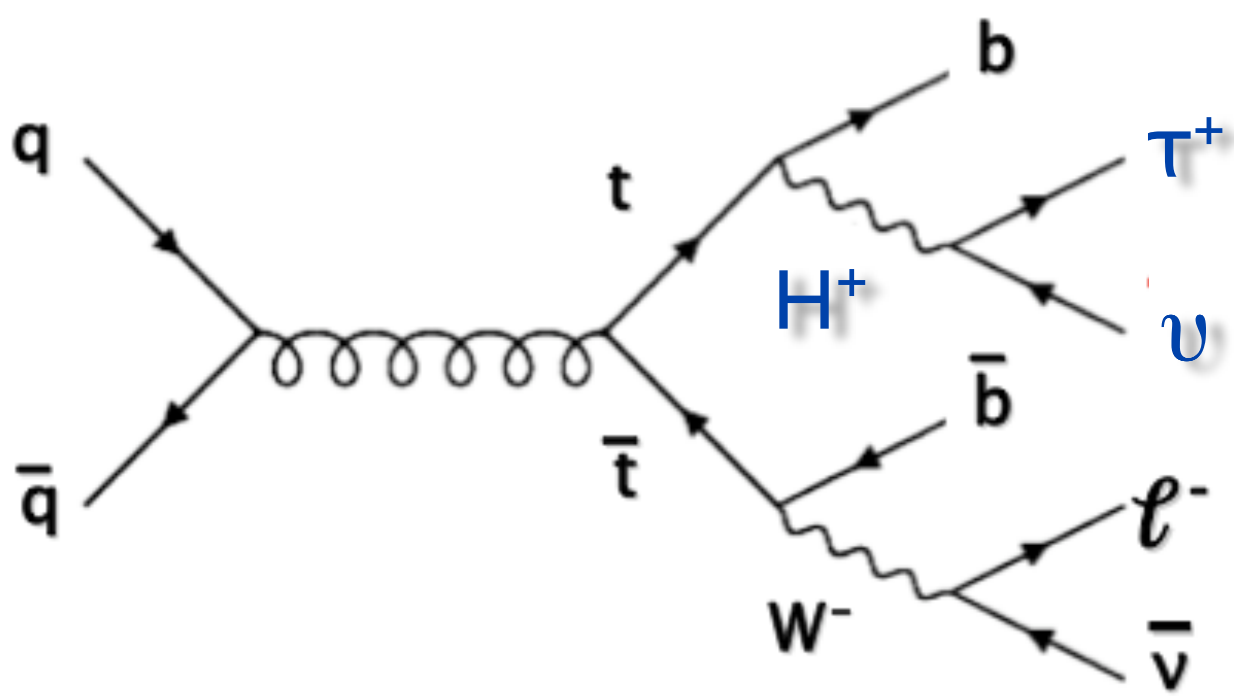


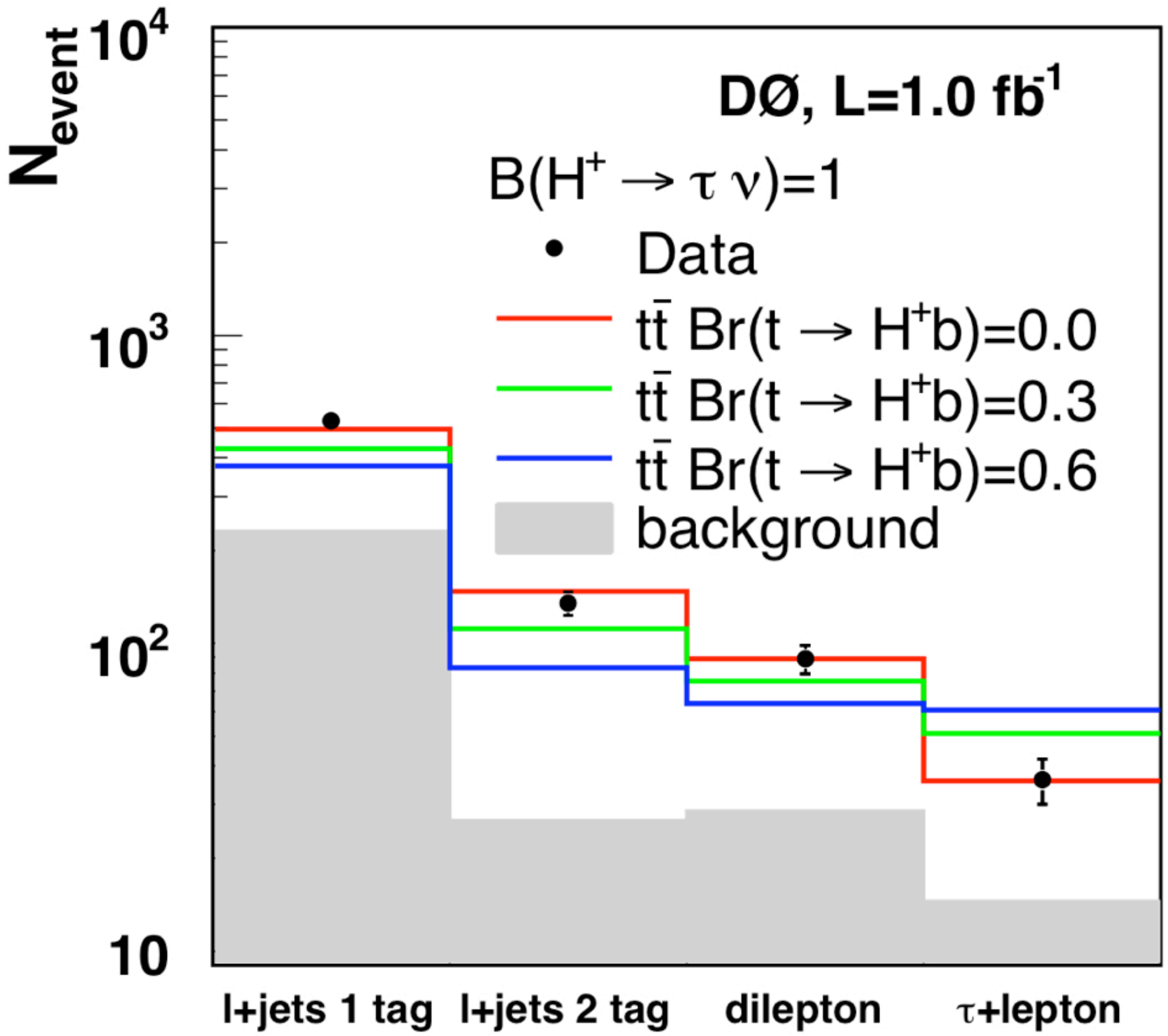
- Changes the different channels contributions: compare all the measured cross sections

Charged Higgs

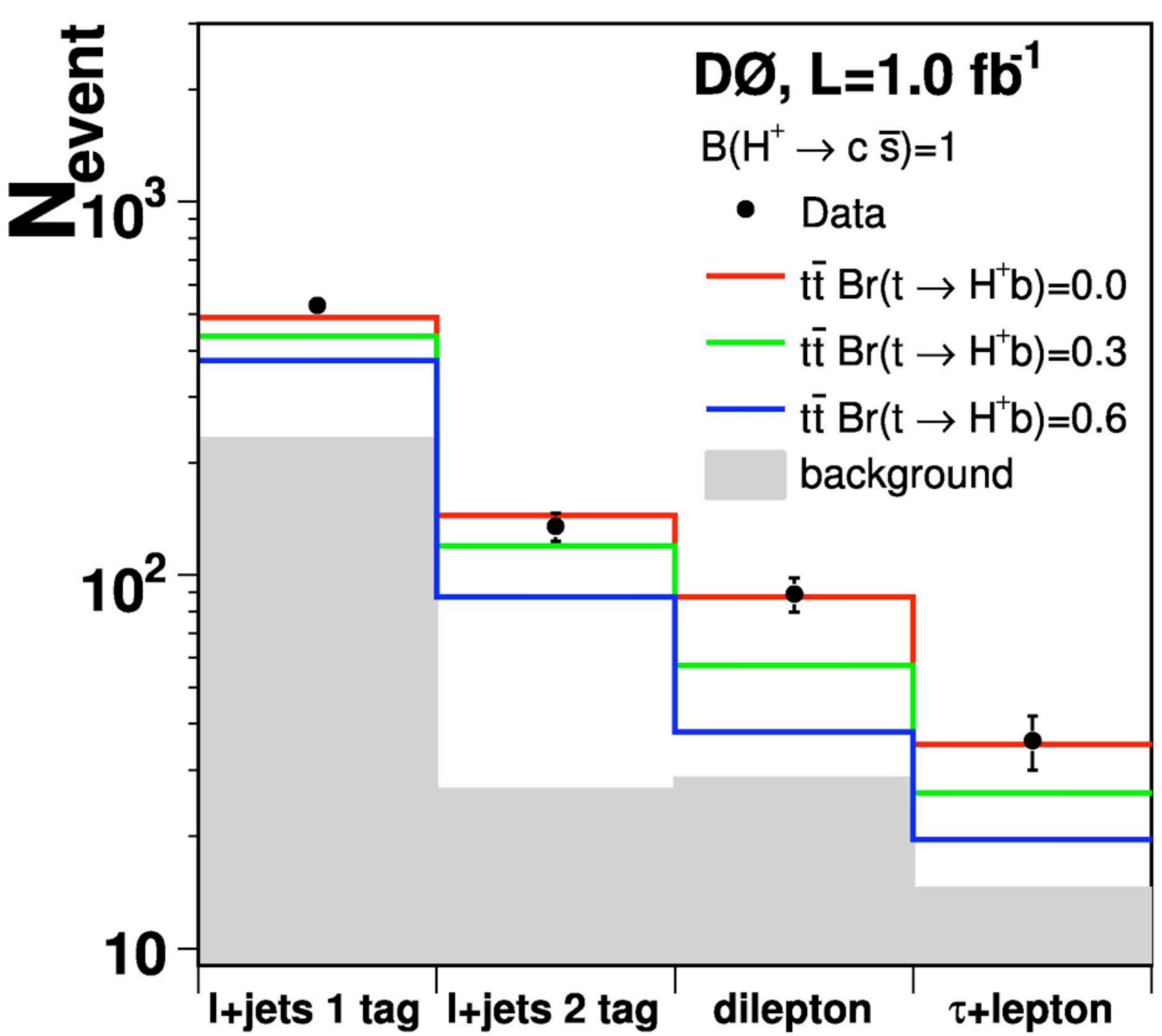




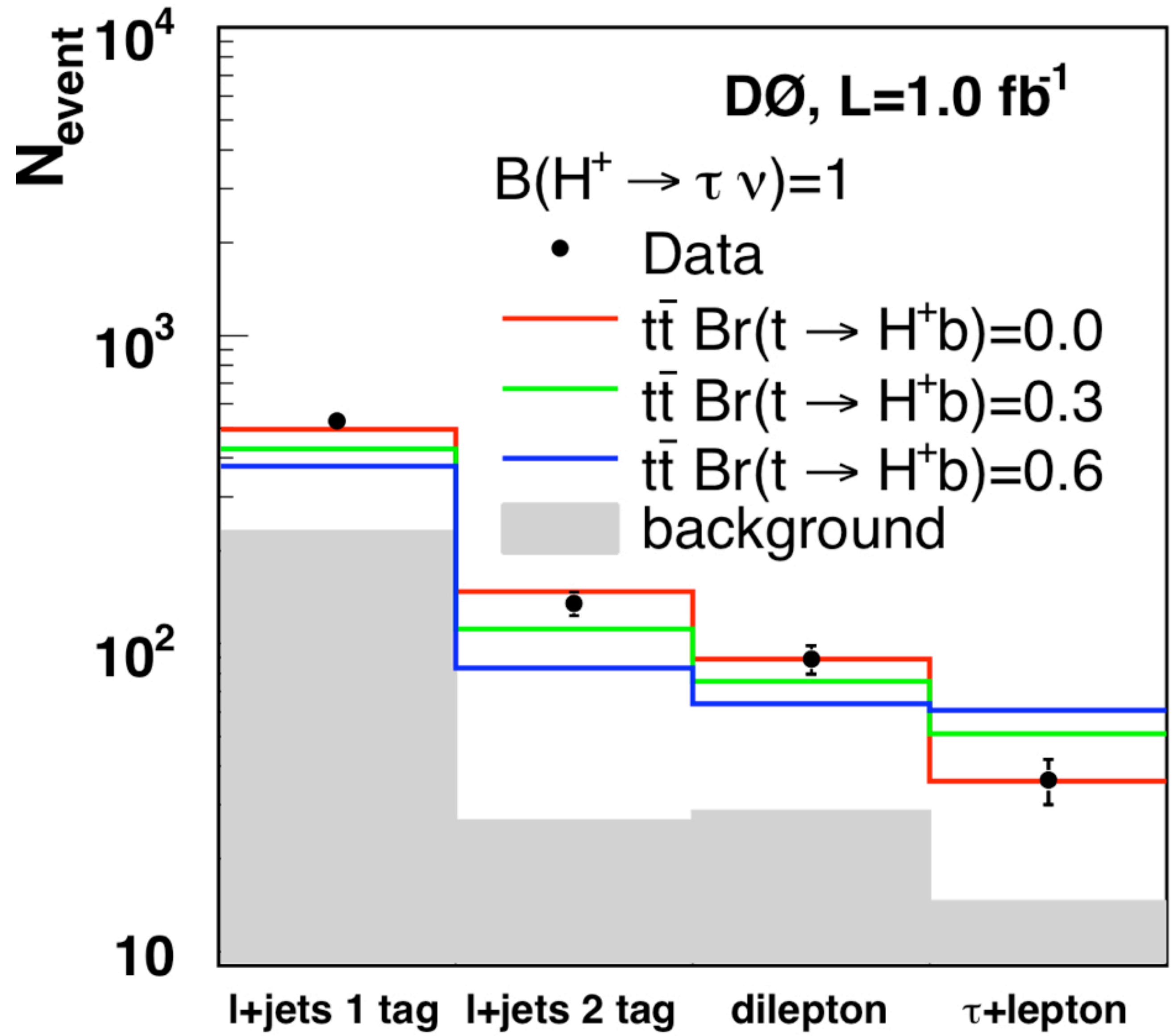

q
q̄
t
t̄
b
b̄
H+
W-
τ+
υ
ℓ-
ν̄

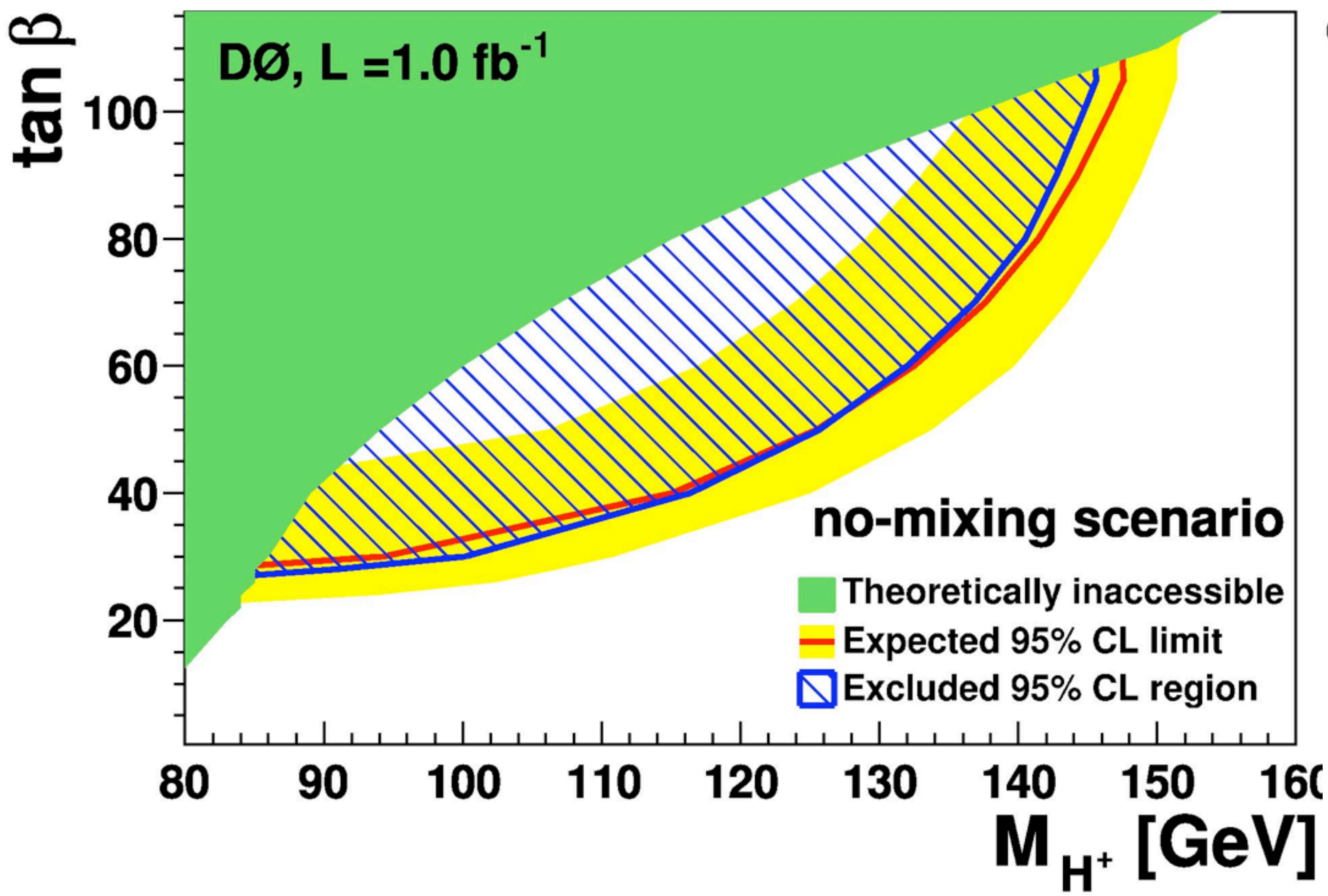

DØ, L=1.0 fb-1
B(H+ → τ ν)=1
Data
tt̄ Br(t → H+b)=0.0
tt̄ Br(t → H+b)=0.3
tt̄ Br(t → H+b)=0.6
background
N_event
10
10^2
10^3
10^4
l+jets 1 tag
l+jets 2 tag
dilepton
τ+lepton

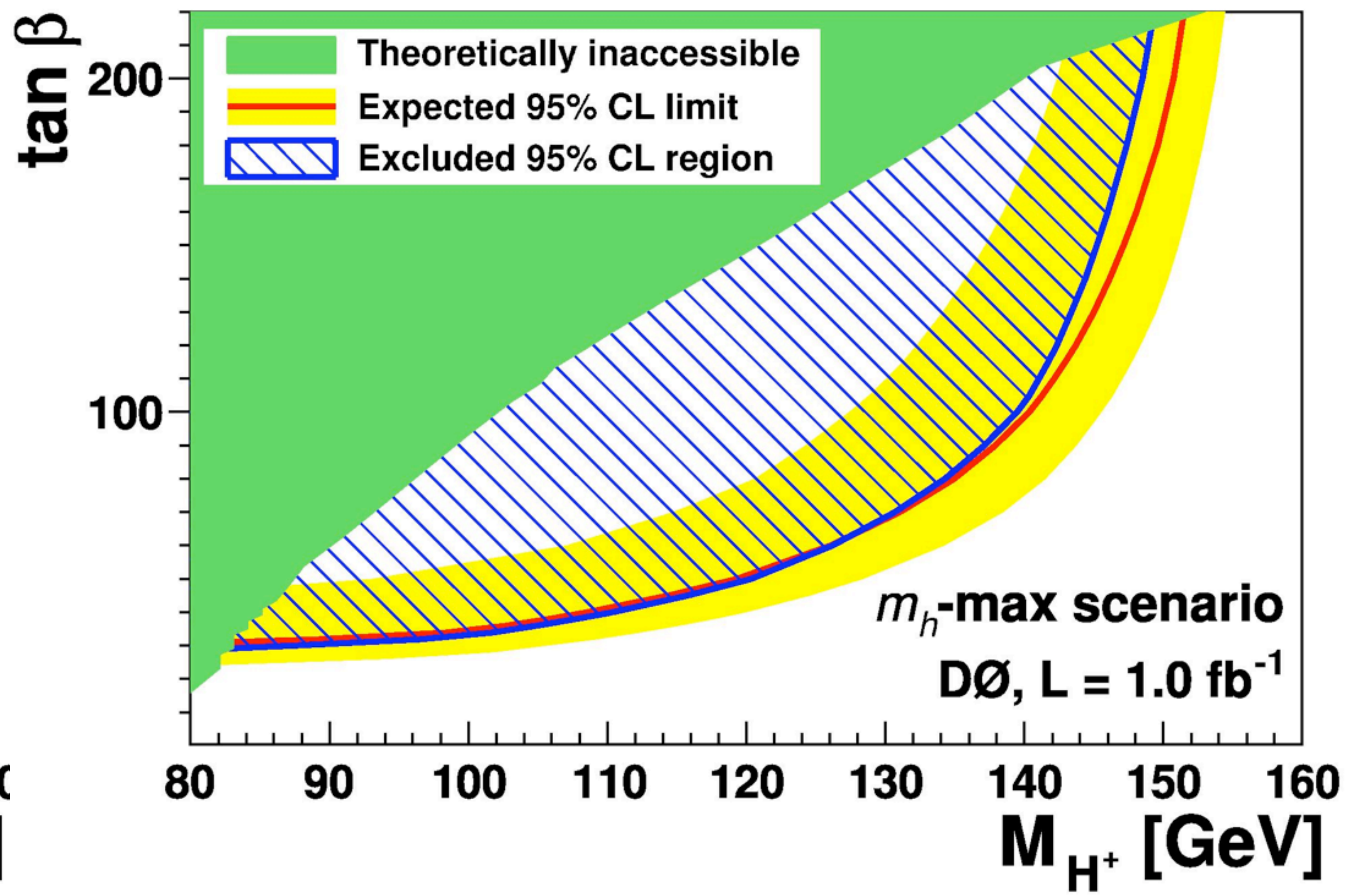
leptophobic Higgs



tauonic Higgs





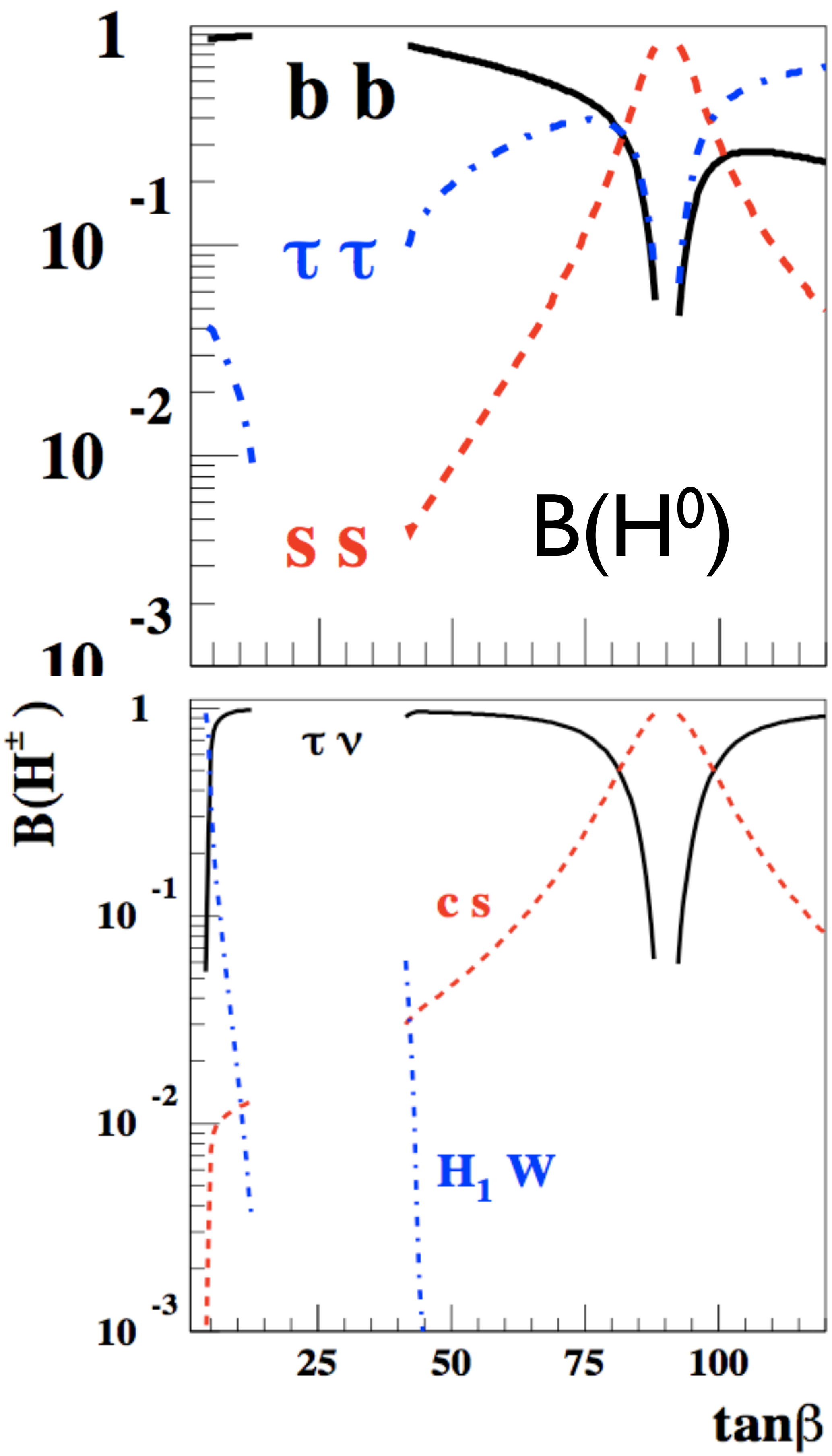


arXiv:0908.1811, submitted to PLB

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
- $B(H^+ \to cs) \approx 1$

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

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