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Search for Standard Model and Beyond Standard Model Higgs bosons in tau final states at DØ

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International Workshop on Tau Lepton Physics

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(for the DØ Collaboration)

The University of Manchester

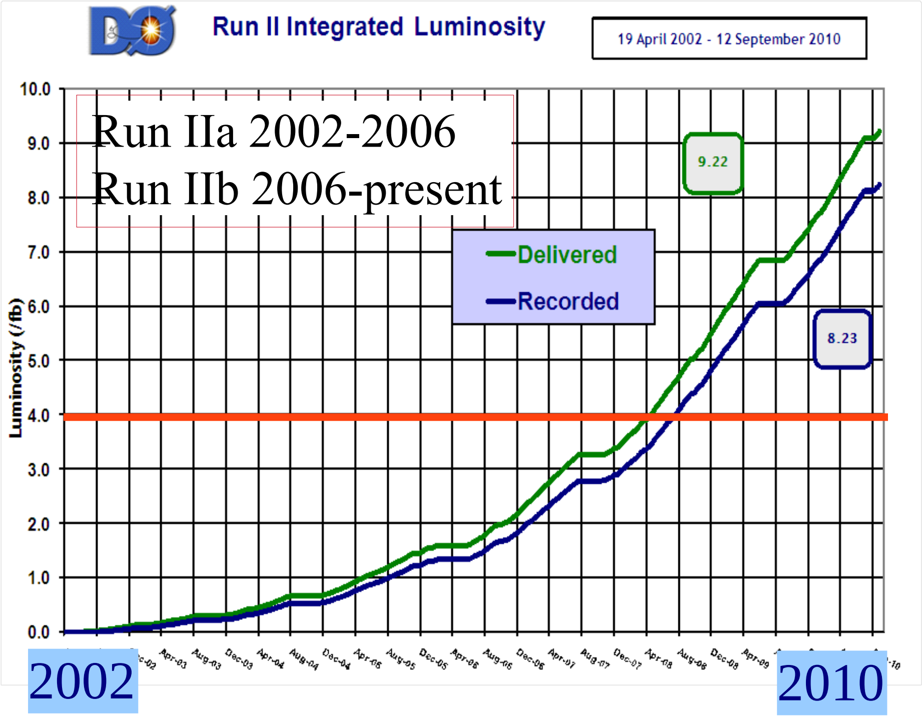
Outline

- **Identification of hadronic tau decays in DØ:**
  * Very narrow and low multiplicity jets. Challenging at hadron colliders like Tevatron. → R. Madar

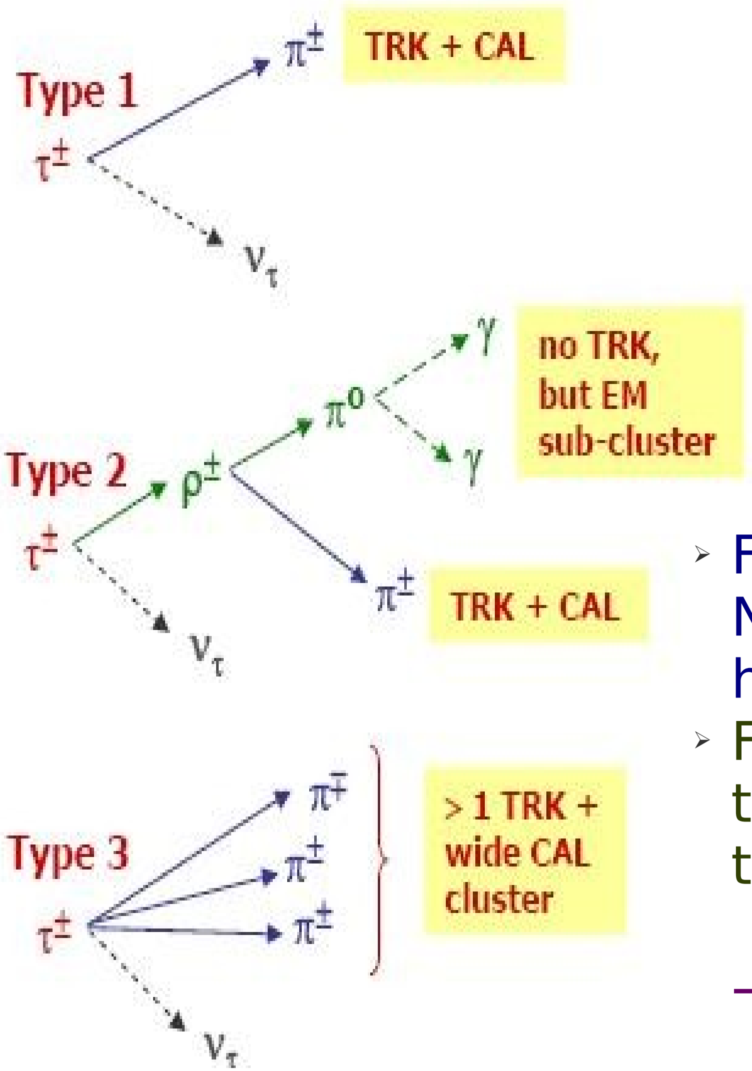
- **SM Higgs searches**
  * $WH \rightarrow \tau\nu b\bar{b}$
  * $HV \rightarrow \tau^+\tau^- q\bar{q}$, V=W,Z

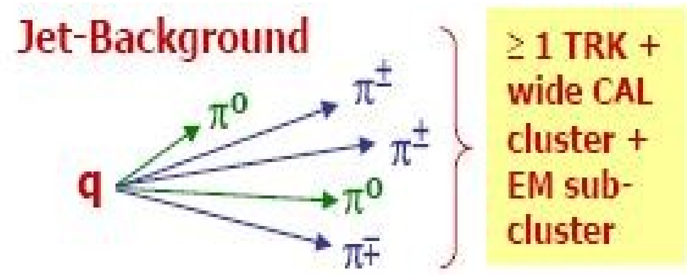
- **MSSM Neutral Higgs**
  * $\phi \rightarrow \tau\tau$, ϕ = A, h, H
  * $b\phi \rightarrow b\tau\tau$
  * MSSM combination

- **Conclusion**



Hadronic Tau(τ_{had}) Identification at DØ



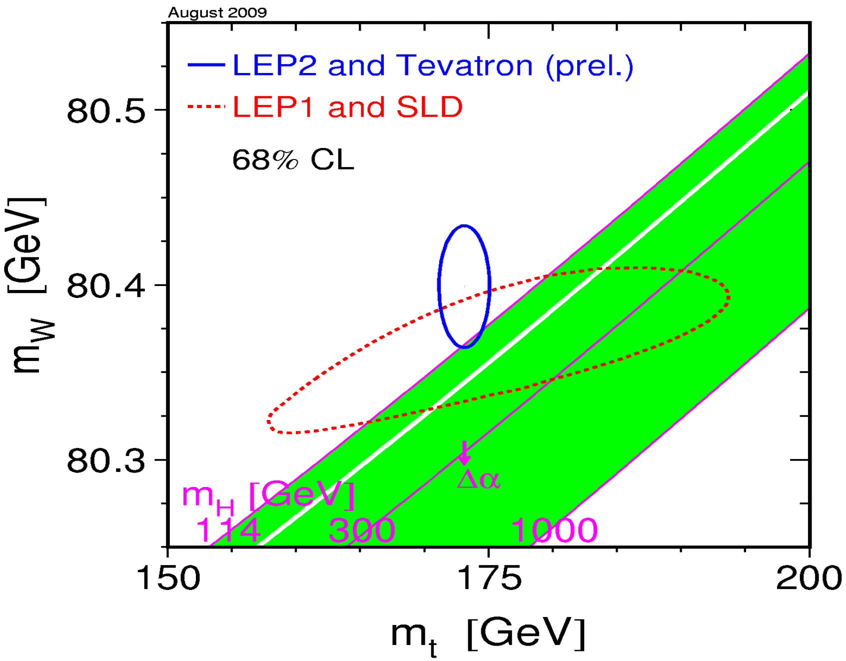


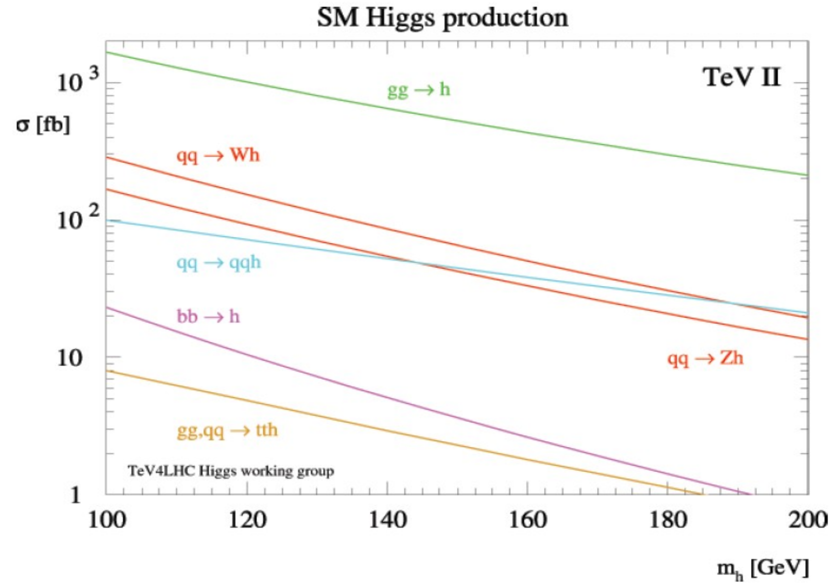
- For each tau type, a separate Neural Network is trained to separate hadronic taus from jets.
- For type 2 taus, an additional NN is trained (NNe) to further discriminate type 2 taus and electrons.

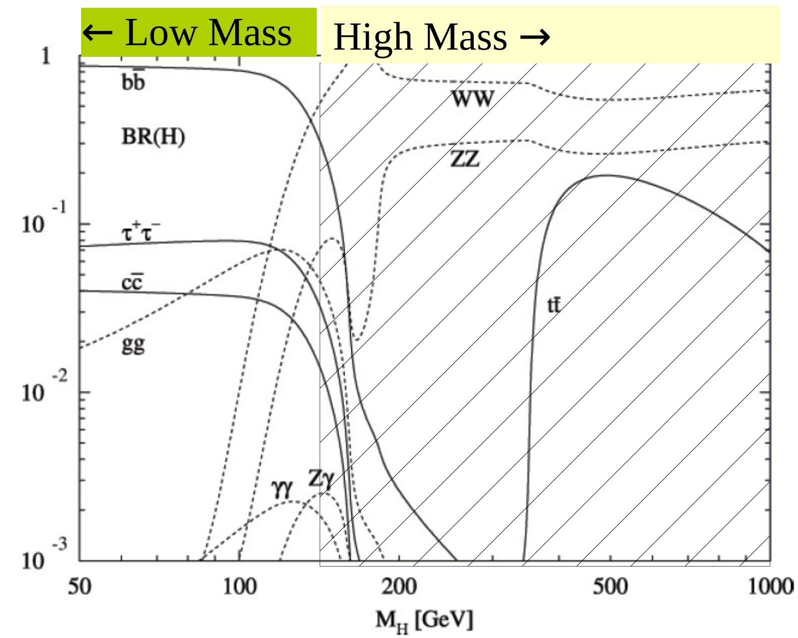
→ See talk by R. Madar

SM Higgs boson searches (1)

Precise electroweak measurements prefer low mass Higgs boson.



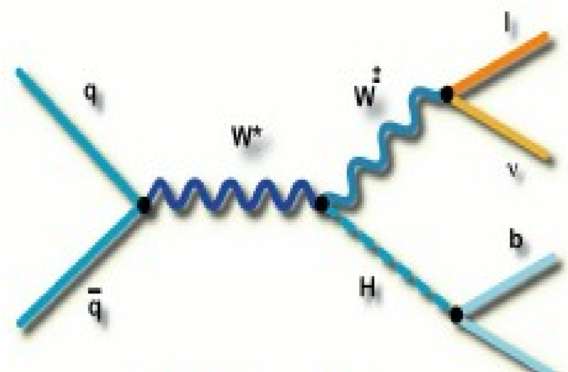




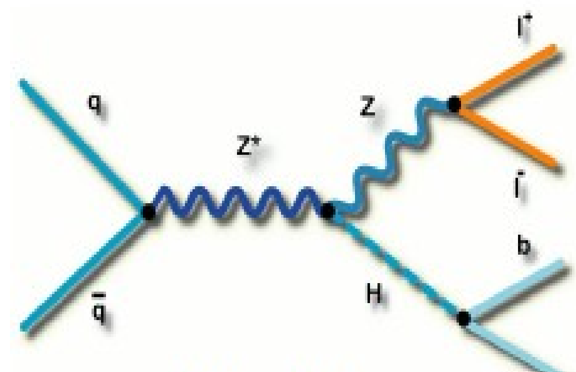
- Gluon fusion is the dominant channel, but is overwhelmed by multijet process at the Tevatron.
- Next is associated production of W/Z+ Higgs.
- W→e/μ provide clean final states, but tau final states also contribute.
- Also, large coupling of SM Higgs to leptons is via taus.

SM Higgs boson searches (2)

$WH \rightarrow \tau \nu b\bar{b}$



$WH \rightarrow \tau \upsilon b\bar{b}$

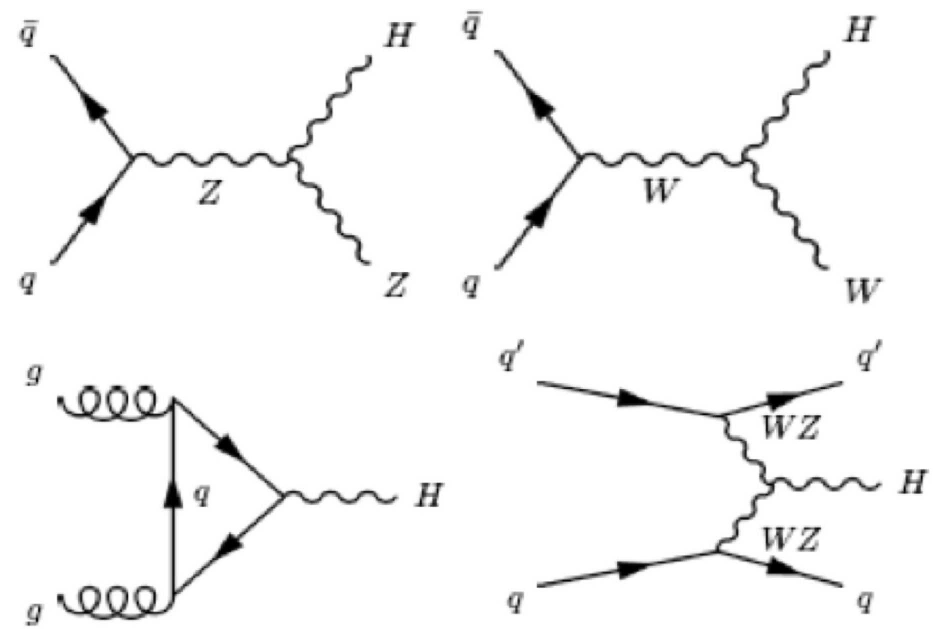


$ZH \rightarrow \tau\tau b\bar{b}$

$HV \rightarrow \tau^{+}\tau^{-} q\bar{q}$

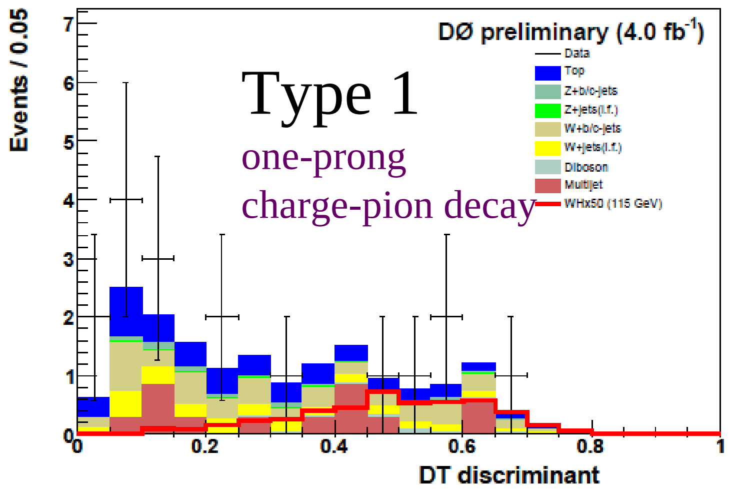
If one of the taus is not identified.

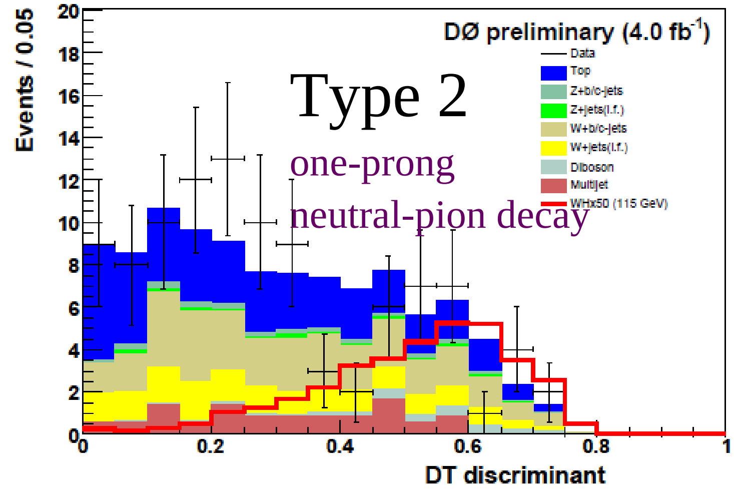
* $p\bar{p} \rightarrow ZH$; $Z \rightarrow \tau\tau$; $H \rightarrow q\bar{q}$
* $p\bar{p} \rightarrow HZ$; $H \rightarrow \tau\tau$; $Z \rightarrow q\bar{q}$
* $p\bar{p} \rightarrow HW$; $H \rightarrow \tau\tau$; $W \rightarrow q\bar{q}'$
* $gg \rightarrow H$; $H \rightarrow \tau\tau$ + 2 additional jets
* vector boson fusion with $H \rightarrow \tau\tau$



SM Higgs boson searches (3)

$WH \to \tau\nu b\bar{b}$ 4.0 fb^{-1} : Background modelling

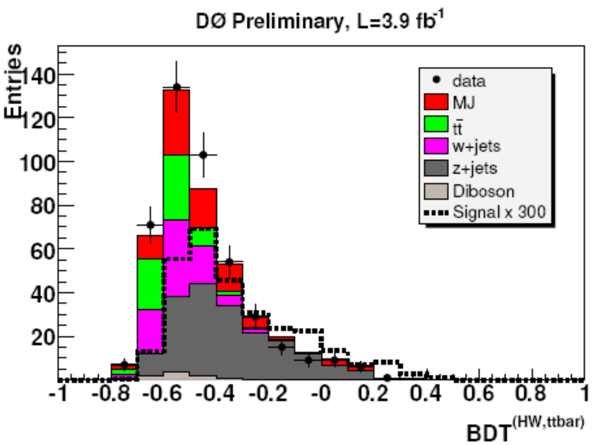


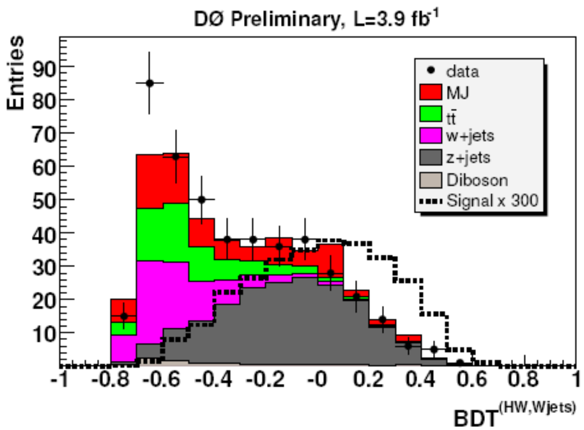


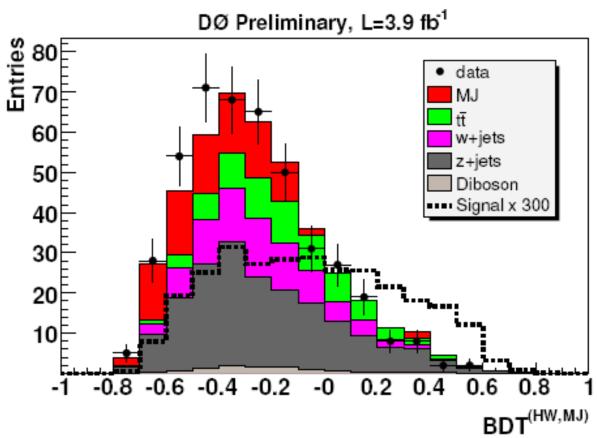
- Main background sources:
  * (W/Z)+(light jets) due to flavour misidentification
  * multijet events with fake missing transverse energy (MET)
  * ttbar and di-boson
- Multijet background is estimated from events with $0.3 \leq NN_\tau \leq 0.7$
- Final state signature: two tagged b-jets, MET $\geq$ 15 GeV, with only type 1 & 2 hadronic tau candidates.
- Use Boosted Decision Tree (BDT) to distinguish Higgs signal events from background.

SM Higgs boson searches (4)

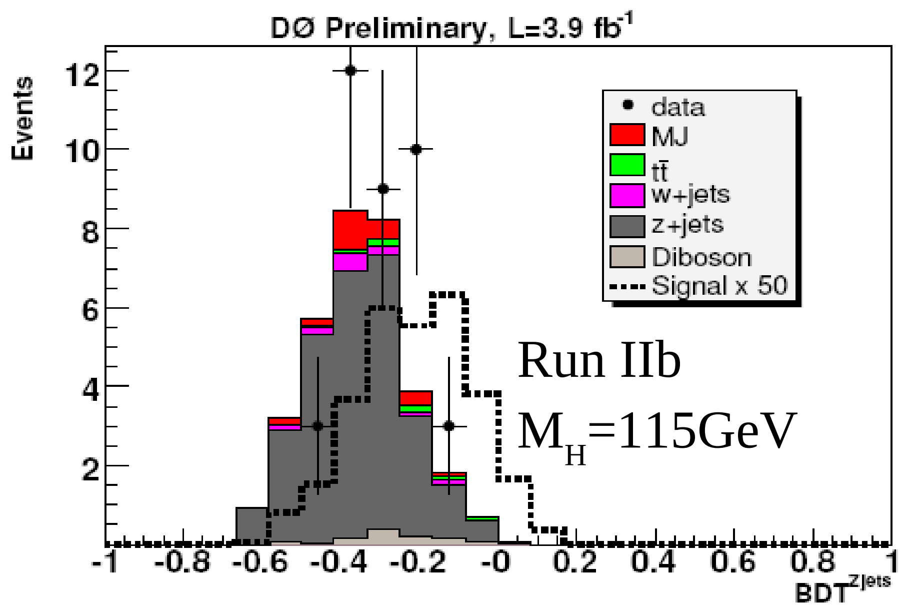
HV→$\tau^+\tau^- q\bar{q}$: Background modelling







- BDT trained separately for different sig. and bkg. processes.
  * ttbar, W+jets, and multijets
    used as one selection cut
  * Z+jets (more signal like)
    used as final discriminant

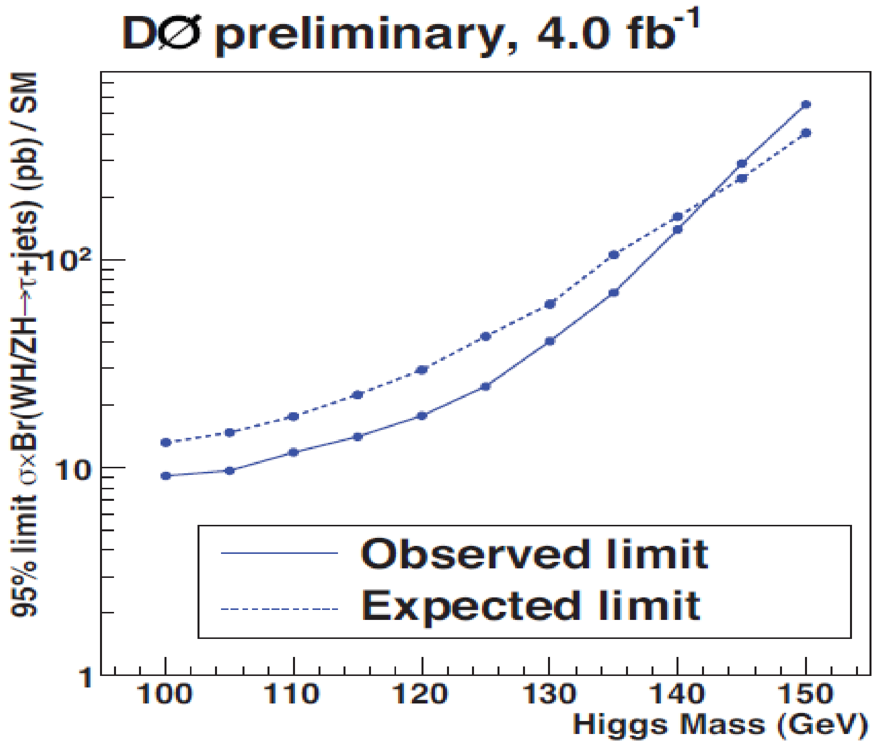


SM Higgs boson searches (5)

- No excess is observed, σ X BR Limits are set at 95% C.L.

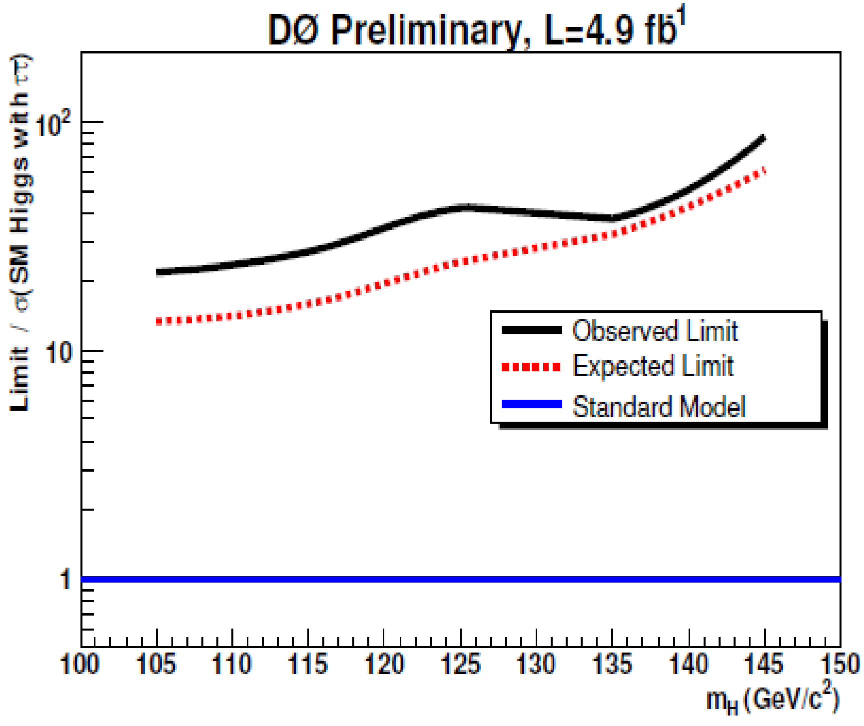
$WH \to \tau\nu b\bar{b}$ (4.0 fb^{-1})

M_H=115 GeV: $14\sigma_{SM}$

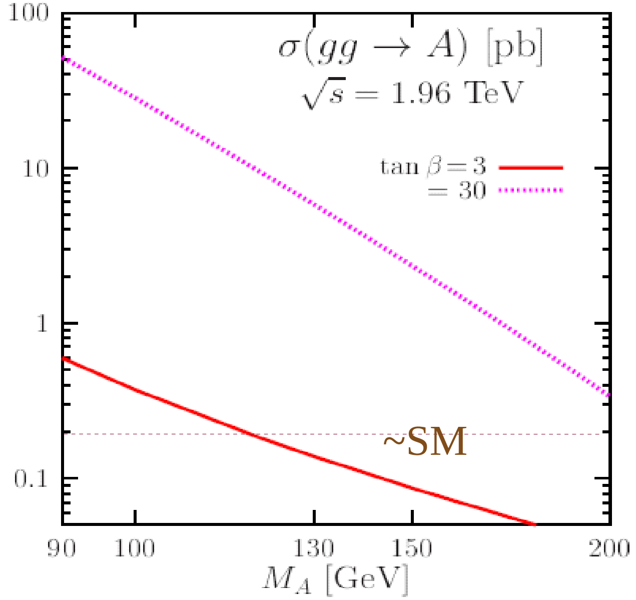


$HV \to \tau^+\tau^- q\bar{q}$ (4.9 fb^{-1})

M_H=115 GeV: $27\sigma_{SM}$
M_H=145 GeV: $86\sigma_{SM}$

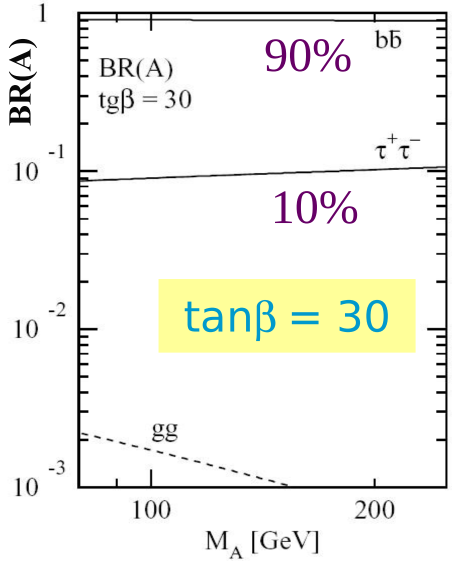


MSSM Neutral Higgs Searches

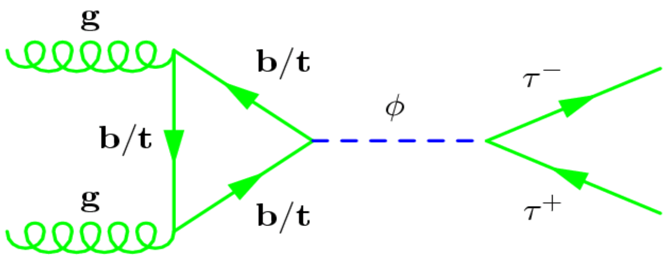


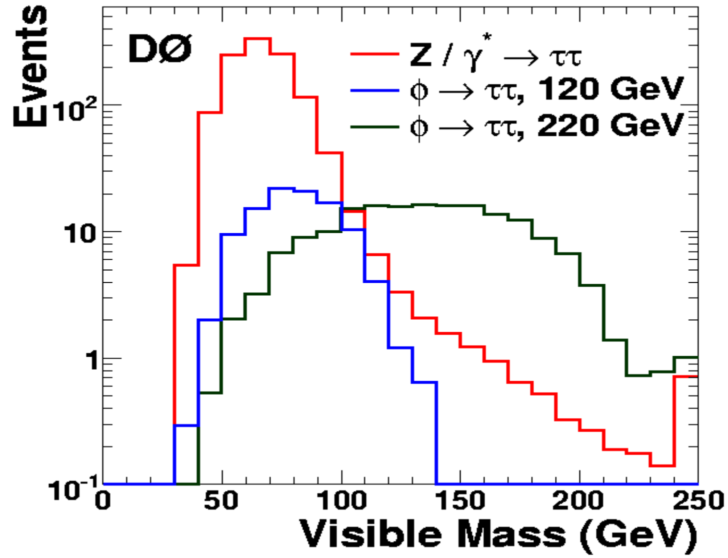
- **MSSM Higgs Search**
  - * 3 physical neutral Higgs bosons after EWSB
    - - two CP-even : h,H
    - - one CP-odd: A
    - (h/H/A are denoted as ϕ)
  - * tanβ: ratio of two v.e.v
  - * Production cross section is enhanced ~ $\tan^2\beta$

- $\phi \to b\bar{b}$ (BR ~ 90%)
  overwhelmed by large multijet background in hadron colliders.
- $\phi \to \tau\tau$ (BR ~ 10%)
  smaller BR, but cleaner signature



$\phi \to \tau\tau$ (1-2.2 fb^{-1})



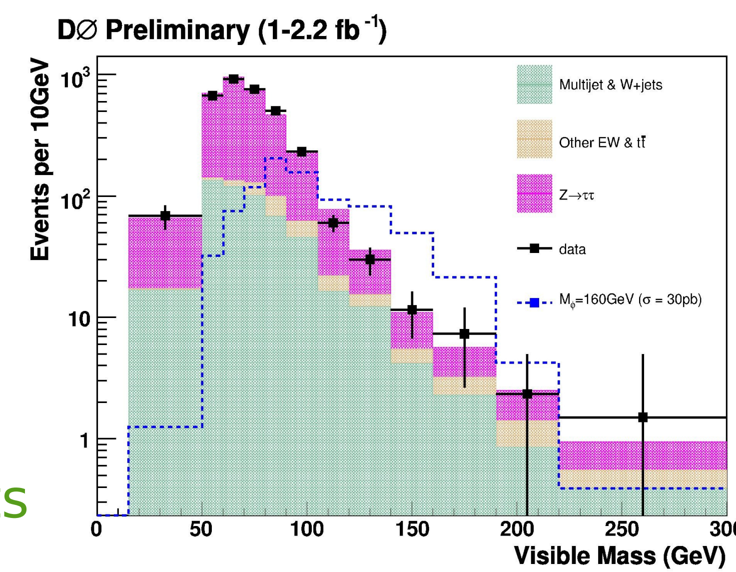


Search in three decay channels:

$\phi \to \tau^+\tau^- \to \mu\tau_h$ (2.2 fb^{-1})

$e\tau_h$ (1.0 fb^{-1})

$e\mu$ (1.0 fb^{-1})

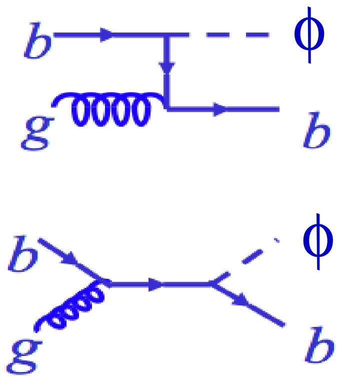


- **Distinguish signal from $Z \to \tau\tau$ background mainly by mass.**
- **Presence of neutrinos, not possible to reconstruct full mass.**

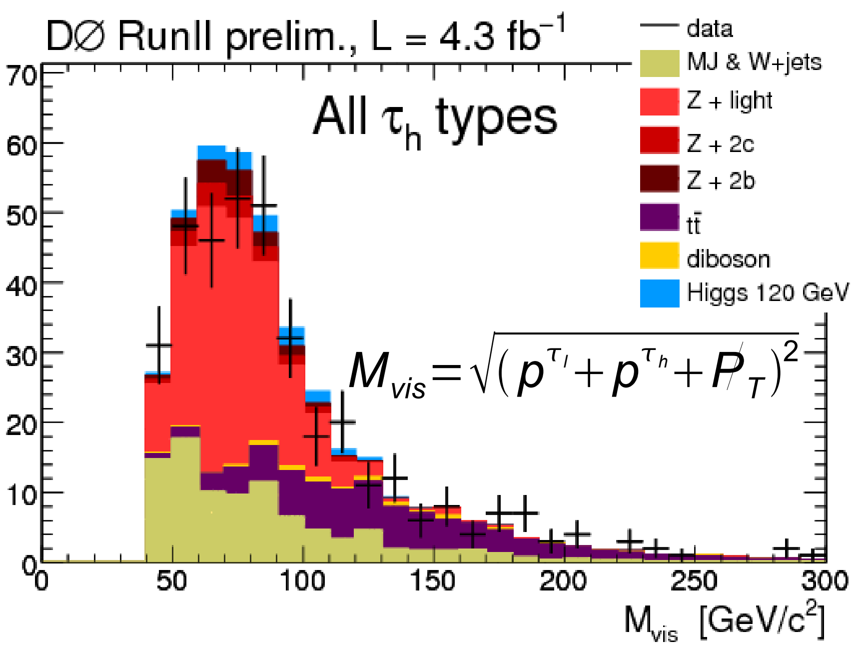
$$M_{vis} = \sqrt{(p^{\tau_l} + p^{\tau_h} + \not{P}_T)^2}$$

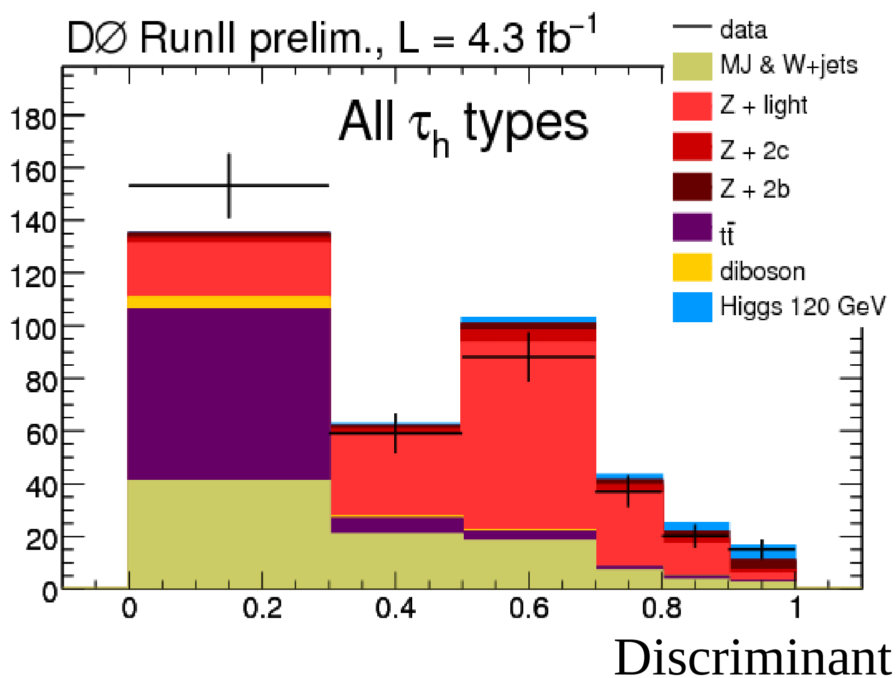
P is the 4-vector of tau decay products and missing transverse momentum

bϕ→bττ (4.3 fb^{-1})



- Select b-tagged jets to suppress large contribution from Z→ττ.
- post b-tag: dominant background consists of ttbar and multijet events.
- Build final discriminant based on b-tagging, multijet, and ttbar MVA discriminants

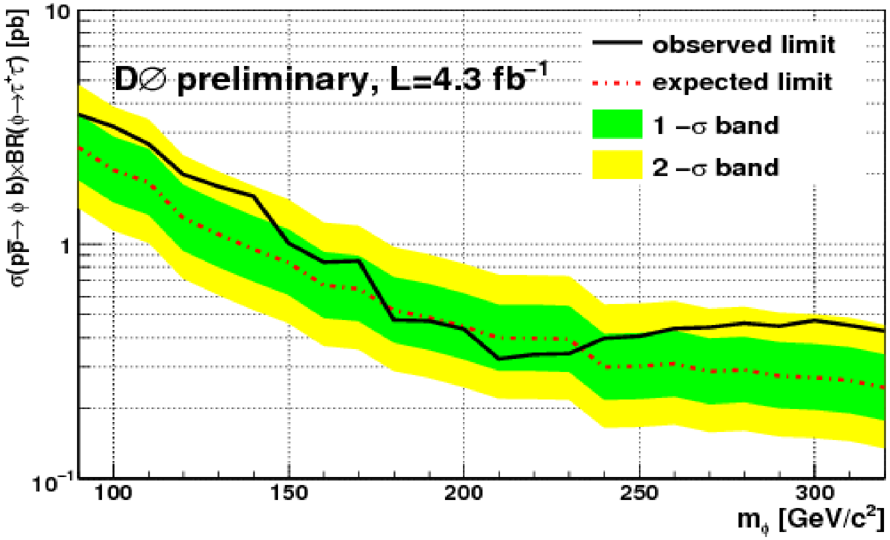




Limits

95% C.L. mass-dependent limits calculated for σ X BR

Example on bφ→bττ



Translate into MSSM exclusions in tanβ-M_A space:

* **M_h^{max} (max-mixing):** Maximises M_h for given tanβ, M_A

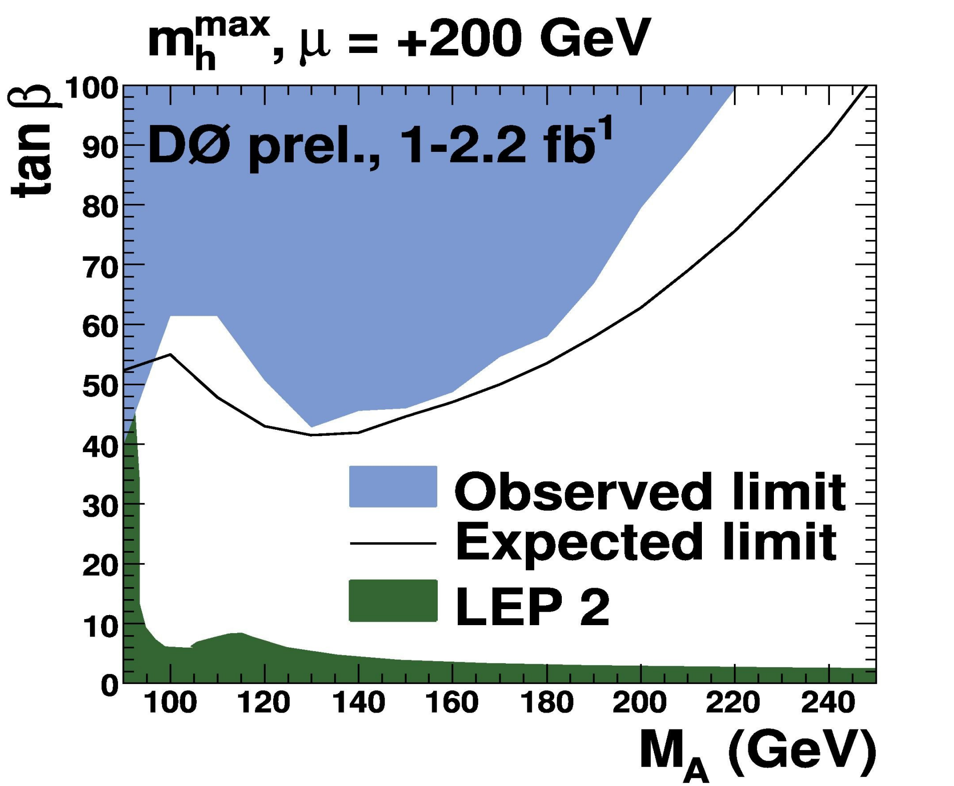
* **No-mixing:** Small M_h.

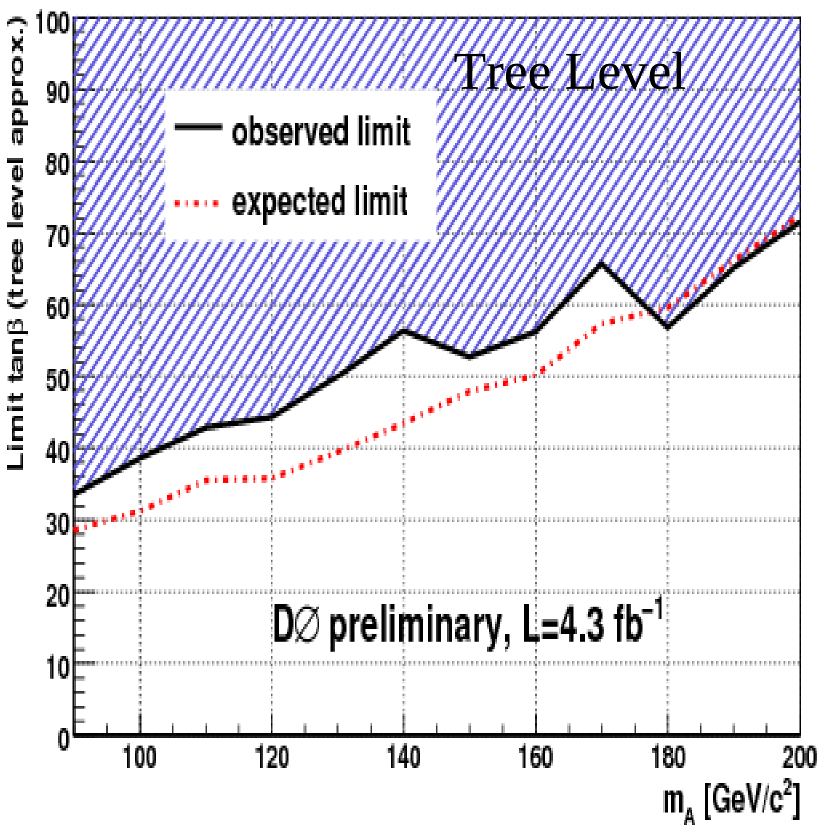
* Both with two given value of Higgs mass parameter μ.

Limits (cont.)

$\phi \rightarrow \tau\tau$

Larger statistics and not sensitive to the sign of μ. Provides a good probe at higher masses



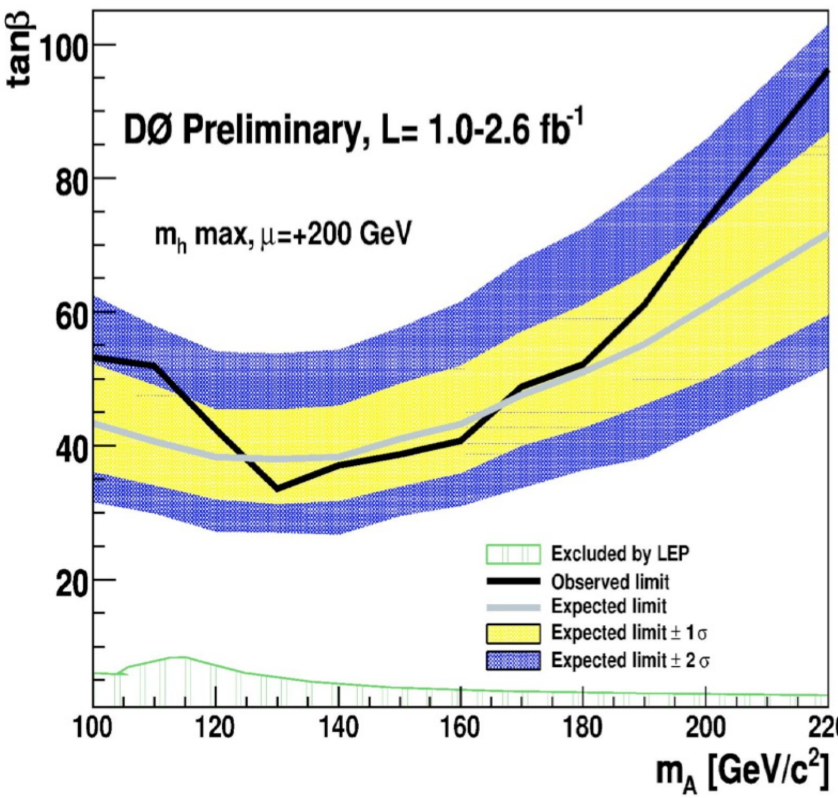


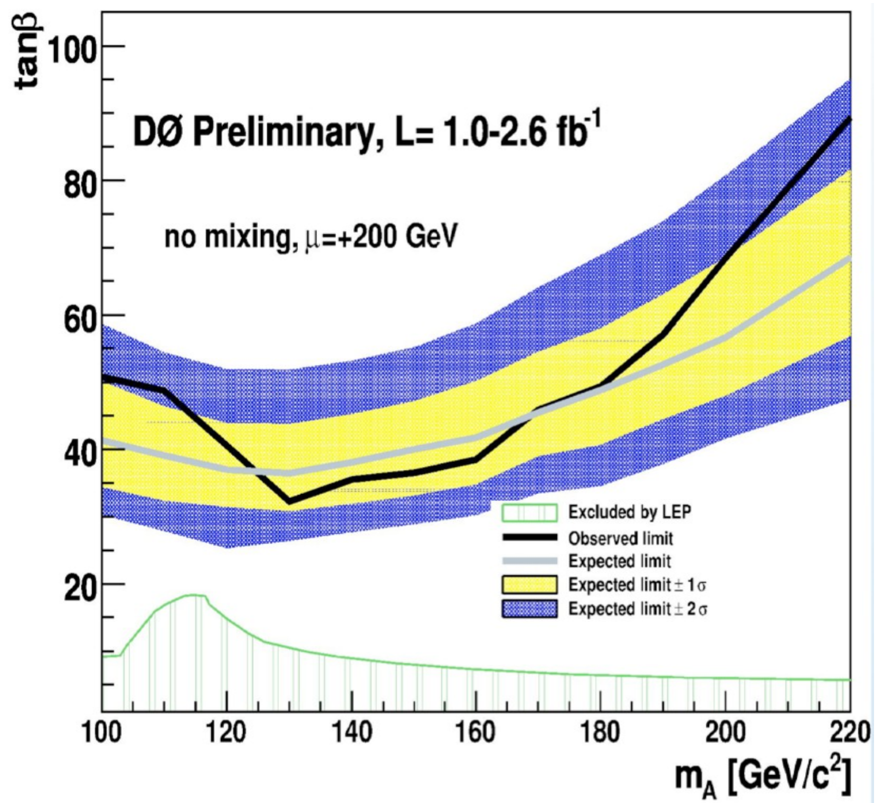
$b\phi \rightarrow b\tau\tau$

Most stringent results to date from a single channel for direct MSSM Higgs search and reaches tanβ~35 at low m_A (~90 GeV).

MSSM Combination

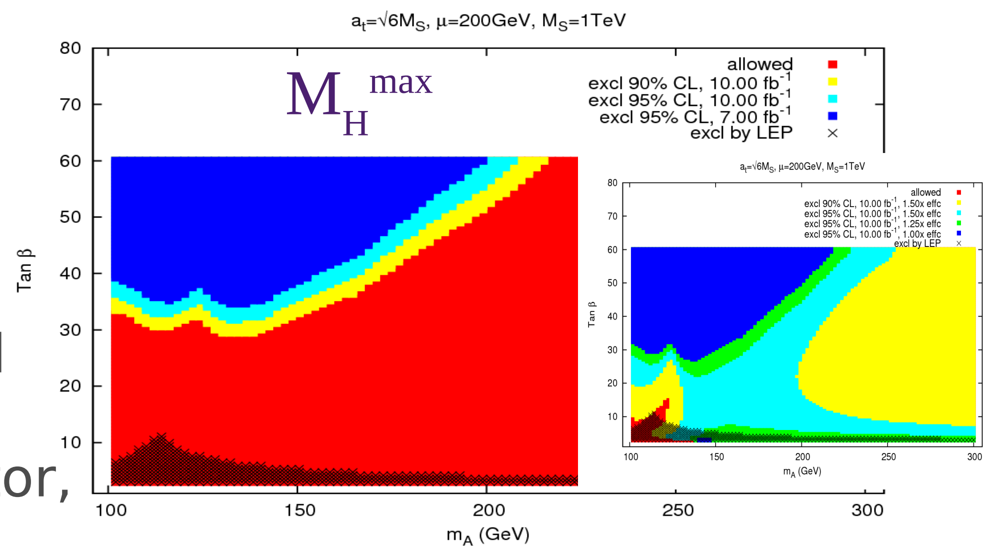
- Combine:
  $\phi\rightarrow\tau\tau$ (1.0-2.2 fb^{-1}), $b\phi\rightarrow b\tau\tau$ (1.2 fb^{-1}), and $b\phi\rightarrow bbb$ (2.6 fb^{-1})
- Latest $b\phi\rightarrow b\tau\tau$ (4.3 fb^{-1}) is not yet included,
- Similar sensitivity as Tevatron combination on MSSM Higgs searches in τ final states.





Conclusion and Outlook

- Tau channels are important for both SM and MSSM Higgs boson searches.
- No signal observed in data over expected background.
- For SM searches, dominant channels at DØ are e/μ final states, but tau channels also contribute to $\sigma \times BR$ limits.
- At high mass, $H \to WW \to \mu\nu + \tau\upsilon$ channel is expected to be included in future SM combinations.
- For MSSM searches, tau channels are very promising.
- Cross-section limits are set at 95% C.L., and subsequently translated into exclusions in MSSM parameter space.
- More than 8 fb^{-1} integrated luminosity has been recorded by the DØ detector, and more is coming!



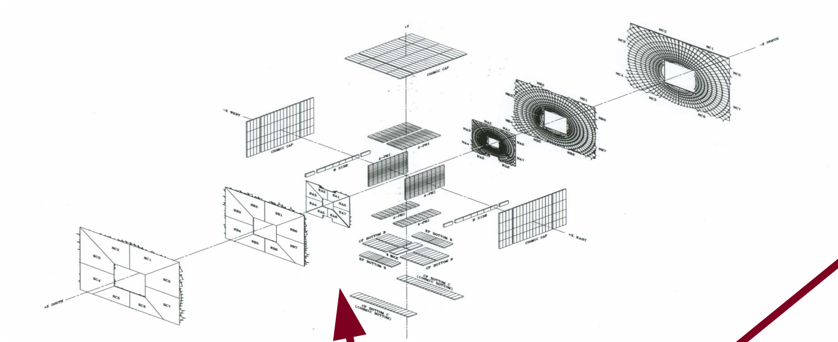
ArXiv 0905.4721 P. Draper et. al.

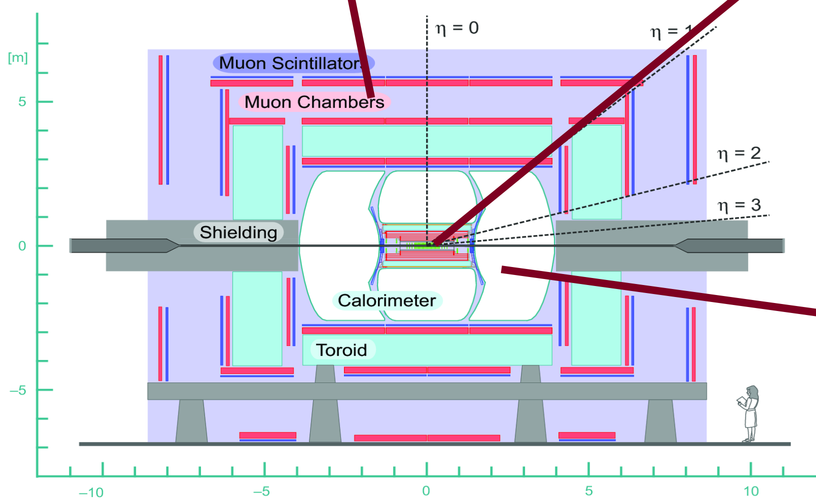
Reference Slides

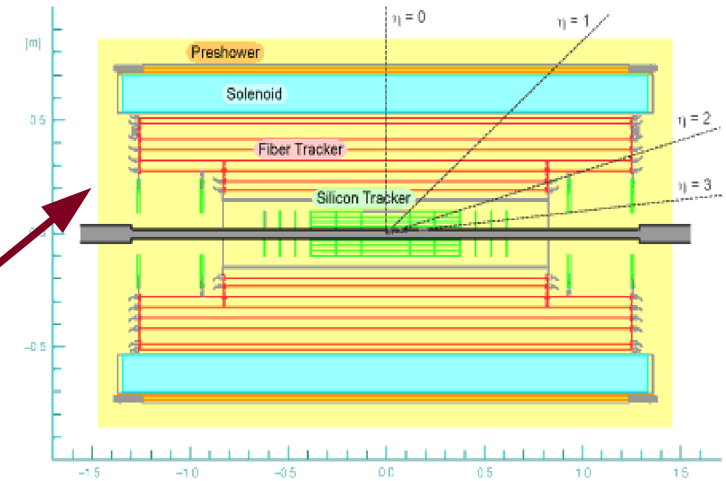
DØ Detector

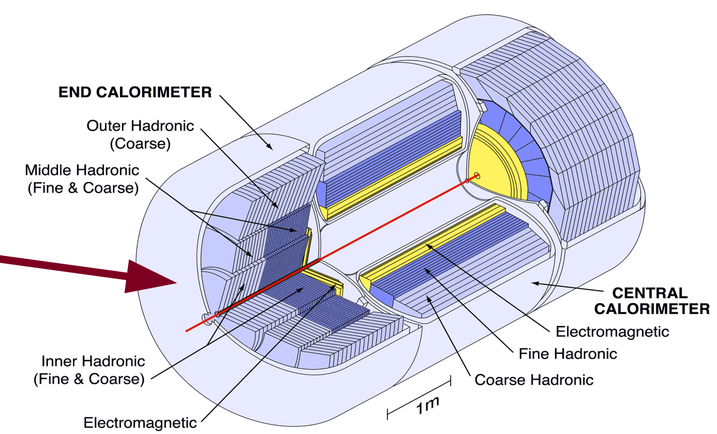
Main Features:

- Silicon tracker and scintillating fiber tracker in 2.0T field.
- Liquid argon/uranium calorimeters.
- Muon system covers up to |η|=2.0.



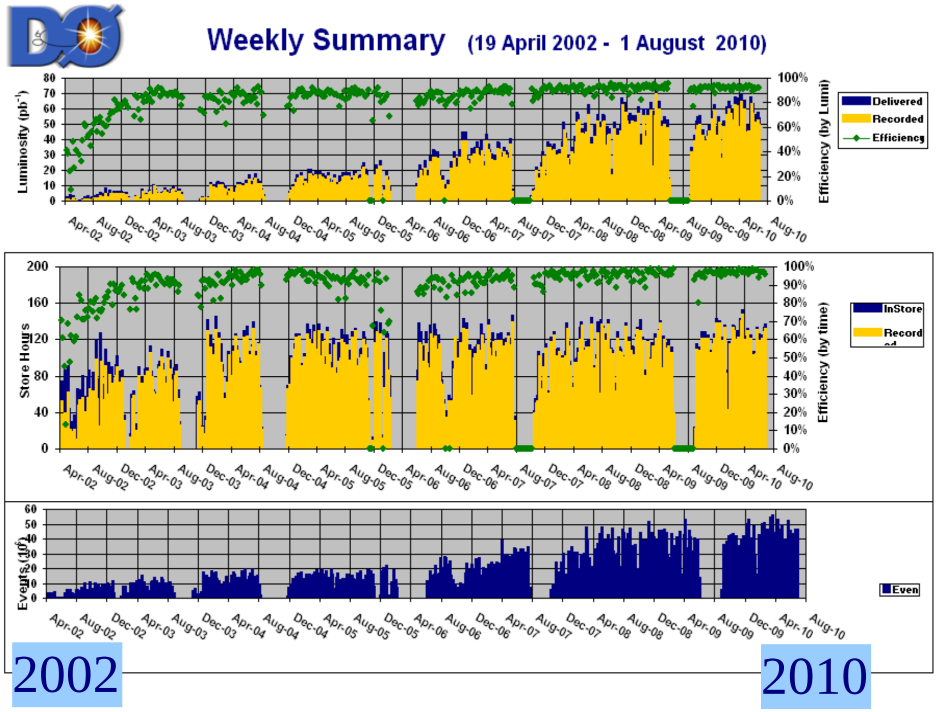




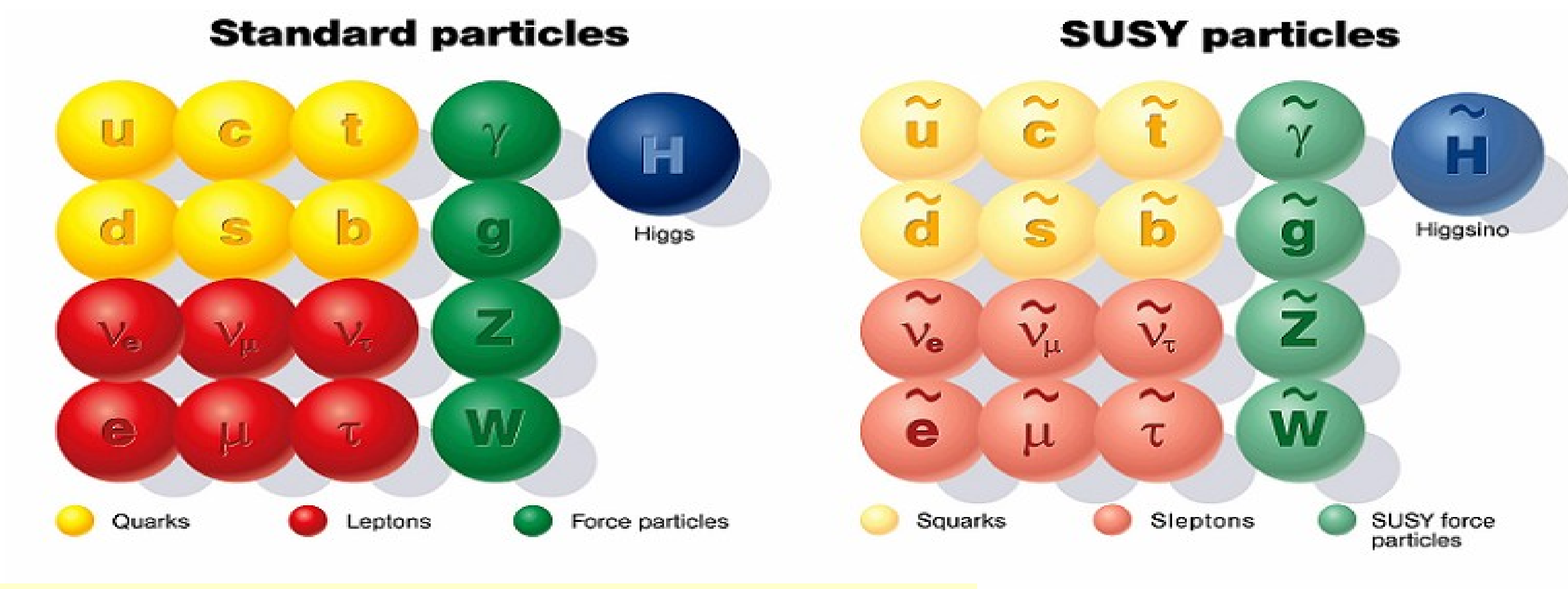


DØ Data Collection

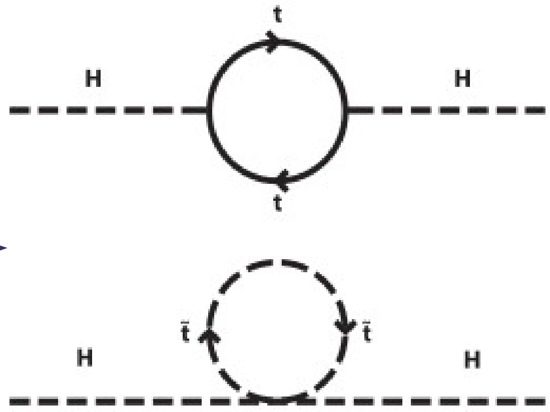
- D∅ also performs very well and records high quality physics data smoothly.
- The average data taken efficiency ~ 90%.
- Typically, over 55 pb^{-1} recorded in a week, ~8.1 recorded in RunII.
- Analysis at D0 use up to 6.3fb^{-1} data.



Supersymmetry



- One of the most popular solutions for those open questions in the SM is the Supersymmetry (SUSY).
- In SUSY, every elementary particle has a super-partner differs by ½ spin.
- This provides a natural solution for the Hierarchy problem of the SM.
- The minimal extension of the SM is called Minimal Supersymmetric Standard Model (MSSM)



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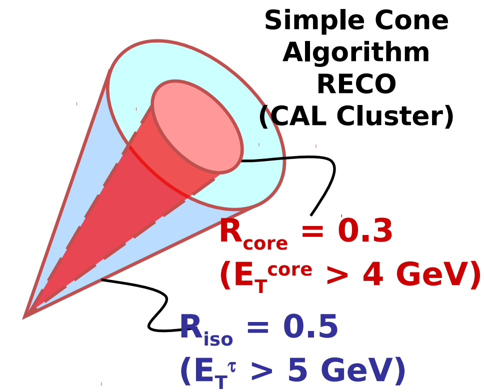

- τ lepton properties:
  - Mass: 1.78 GeV ; Short lifetime: O(10^{-13}s)
  - Decay prior to reaching any detector component.
- Main decay channels:

Decay products	BR (%)	Decay Type	
$e + \upsilon_e + \upsilon_\tau$	17.8	Leptonic (35.2%)	e
$\mu + \upsilon_\mu + \upsilon_\tau$	17.4		μ
$\pi^{\pm}$(/K)$+\upsilon_\tau$	11.8	1-prong (48.7%)	τ_h
$\pi^{\pm}$(/K)$+\geq 1\pi^0+\upsilon_\tau$	36.9		
$\pi^{\pm}\pi^{\pm}\pi^{\pm}+\geq 0\pi^0+\upsilon_\tau$	13.9	3-prong	

Detect using standard e/μ ID algorithms

Need dedicated tau ID to measure narrow , low multiplicity jet object

- τ identification at DØ begins with calorimeter cluster using single cone algorithm.
- Search for the associate EM sub-cluster.

Interpretation within MSSM

- At tree level, Higgs sector is described by tanβ and M_A.
- Higher order corrections introduce dependency on additional SUSY parameters.
- Cross-sections taken from FeynHiggs v.2.6.4

Five additional, relevant parameters:

M_{SUSY} Common Scalar mass
X_t Mixing Parameter
M_2 SU(2) gaugino mass term
μ Higgs mass parameter
m_g gluino mass

Two common benchmarks:

M_h^{max} (max-mixing):
Higgs boson mass, m_h, close to maximum possible value for a given tanβ.

No-mixing:
vanishing mixing in stop sector, small Higgs boson mass, m_h