Tevatron searches for BSM Brout-Englert-Higgs (BEH) Bosons

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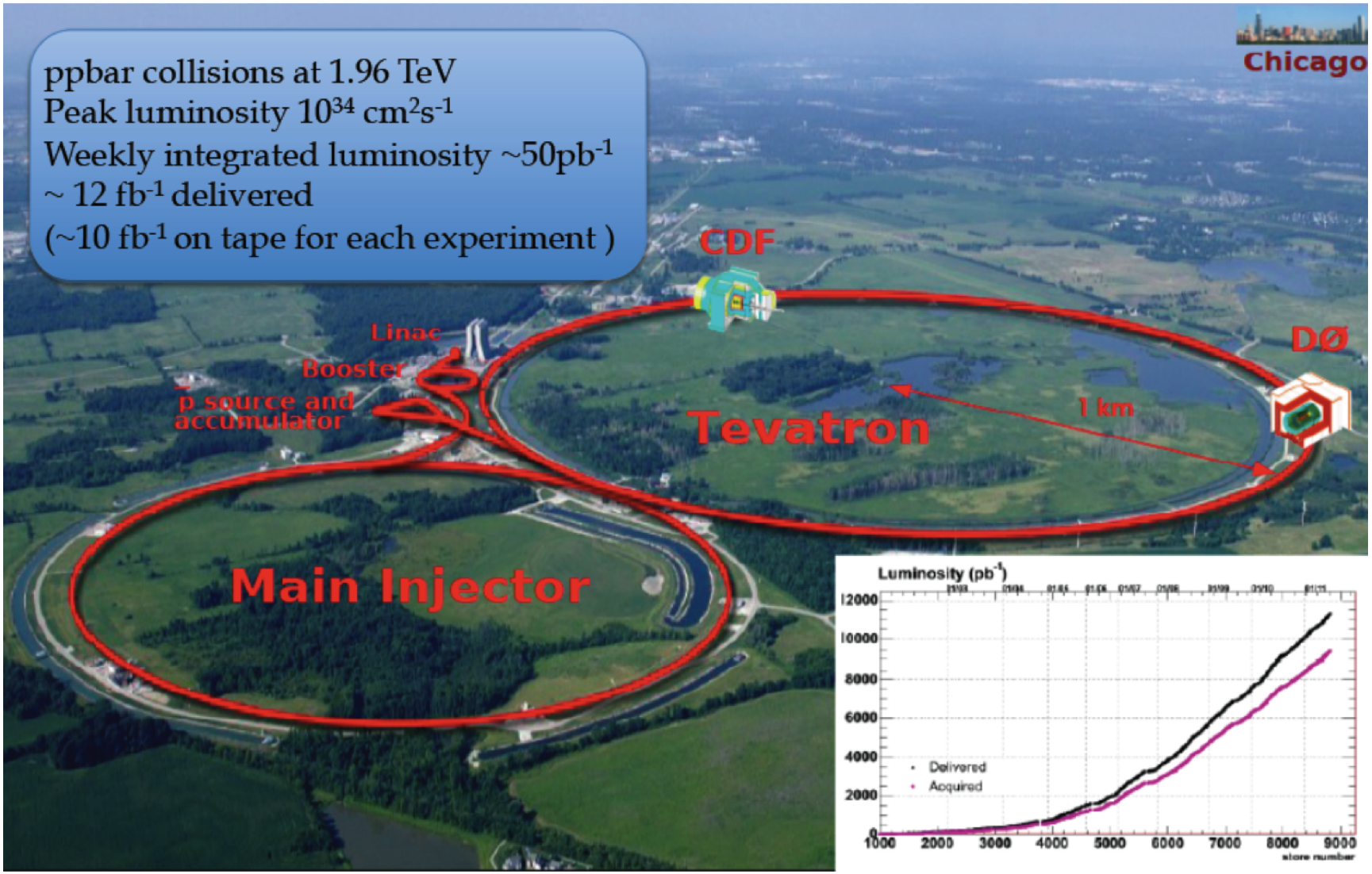
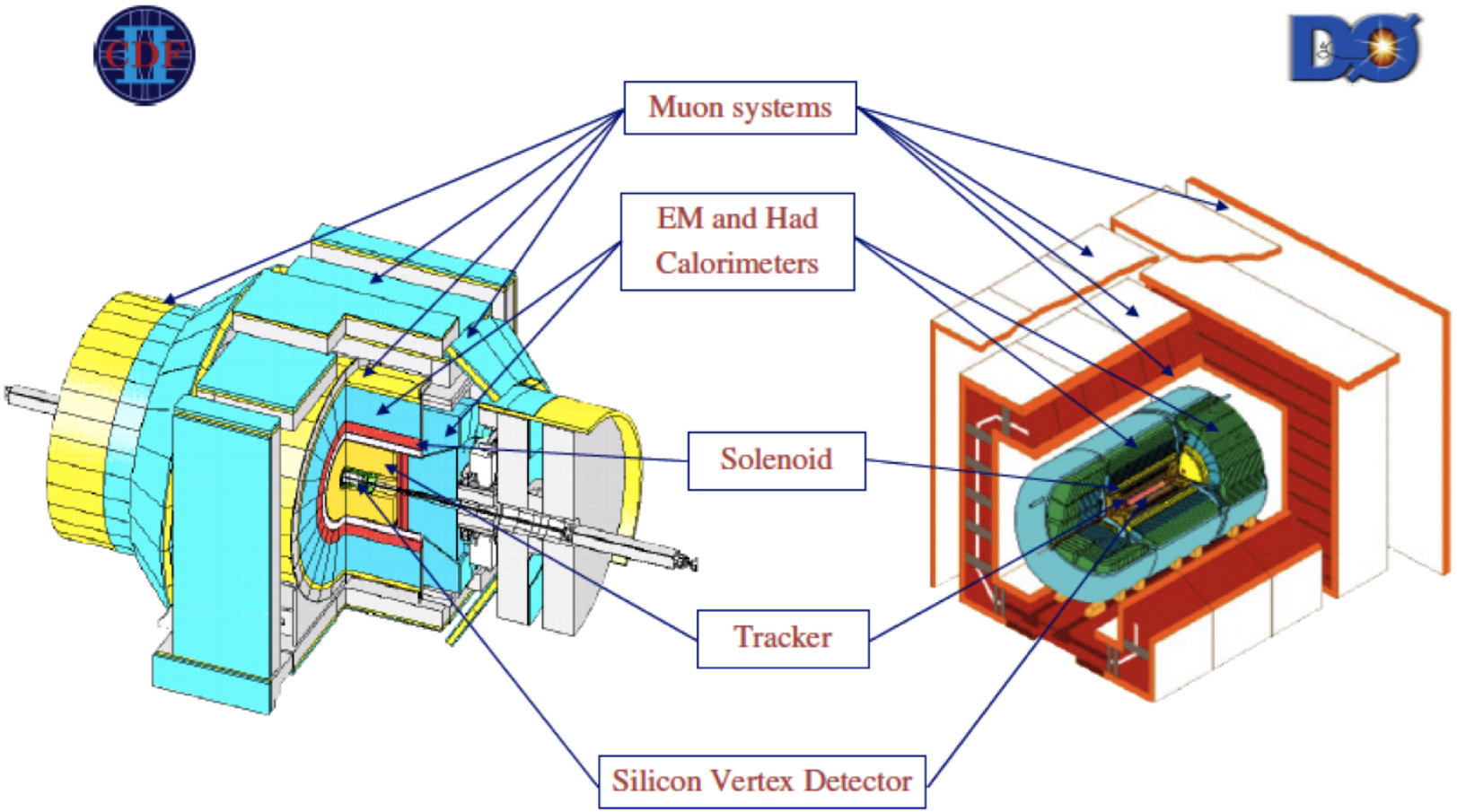
Introduction

- In the SM, the spontaneously symmetry breaking mechanism requires a single doublet of a complex scalar field.
- But does nature follow this minimal version or does it require a multi-Higgs sector ?
  - Thus, extended Higgs sectors with doublets fields
- The Minimal Supersymmetric Standard Model (MSSM) predicts the existence of five physical BEH bosons after symmetry breaking.
  - Provides a natural solution to the hierarchy problem
- It is possible that the symmetry breaking mechanism responsible for giving masses to gauge bosons is separate from that which generates the fermion masses.
  - Fermiophobic models

Tevatron


ppbar collisions at 1.96 TeV
Peak luminosity 10^{34} cm^2s^{-1}
Weekly integrated luminosity ~50pb^{-1}
~ 12 fb^{-1} delivered
(~10 fb^{-1} on tape for each experiment)
Chicago
CDF
DØ
Linac
Booster
p source and accumulator
Tevatron
1 km
Main Injector
Luminosity (pb^{-1})
12000
10000
8000
6000
4000
2000
0
Delivered
Acquired
1000
2000
3000
4000
5000
6000
7000
8000
9000
store number

The CDF and the D0 Detectors

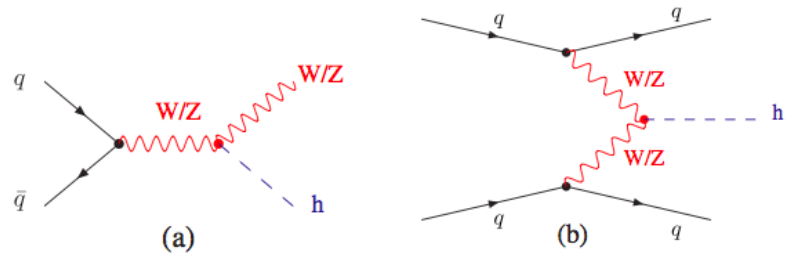


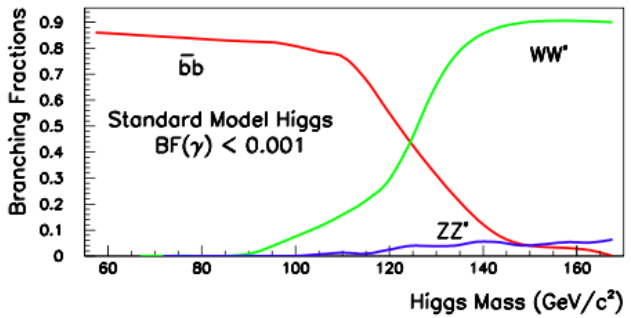
2 Higgs Doublet Models (Fermiophobic)

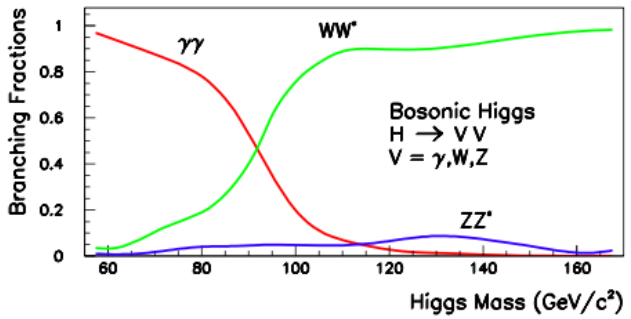
- Two Higgs Doublet Model (2HDM)
  $\phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix}$, $\phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}$
- The vacuum expectation values
  $< \phi_1 >= \begin{pmatrix} 0 \\ v_1 \end{pmatrix}$, $< \phi_2 >= \begin{pmatrix} 0 \\ v_2 \end{pmatrix}$
- 5 Physical BEH bosons
  h, H, A, H^+, and H^-
- 2HDM type-I
  - ϕ_1 does not couple with fermions, but ϕ_2 does
  - α, mixing angle in neutral Higgs sector, h and H
  - If $\cos\alpha \to 0$,
    - $hf\bar{f} \to 0$, Thus " fermiophobia"
    - $h \to h_f$ (fermiphobic Higgs or Bosonic Higgs)

Production Mechanisms and Final States

- Diphoton channel
  - Clean signature
  - Narrow resonance
- Other channel
  - We combine WW and ZZ with diphoton channel to gain some sensitivity, especially at high masses

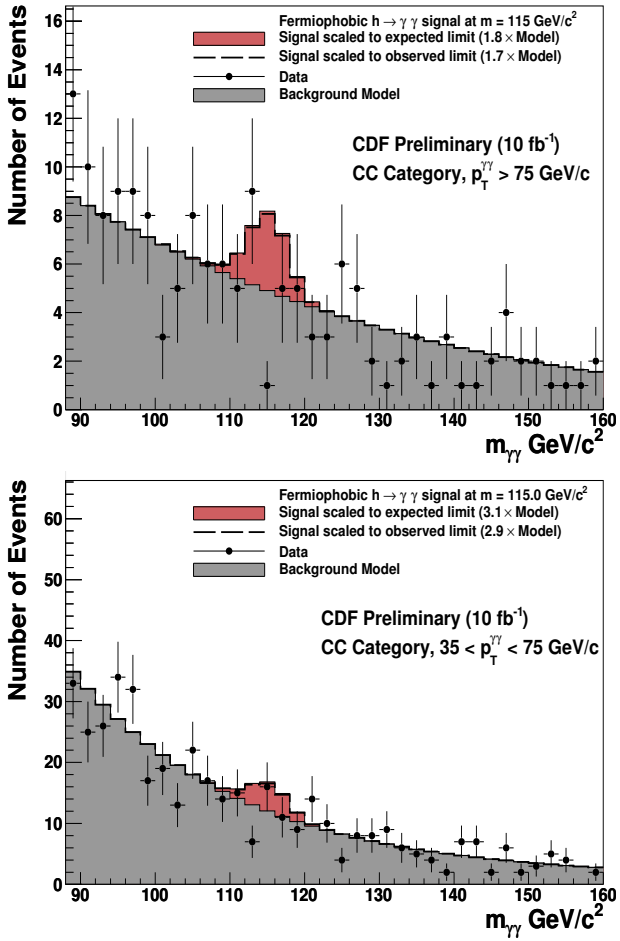






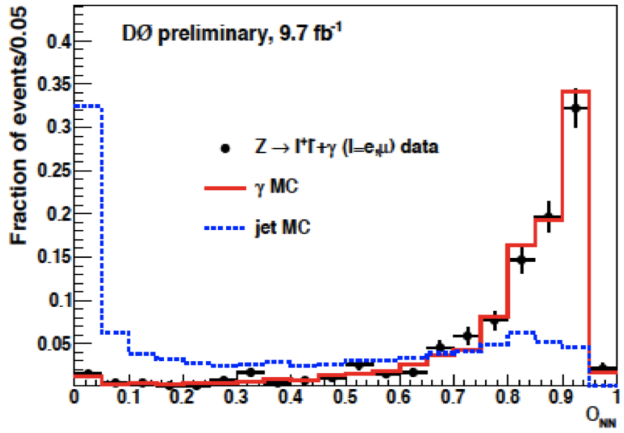
Fermiophobic Searches CDF

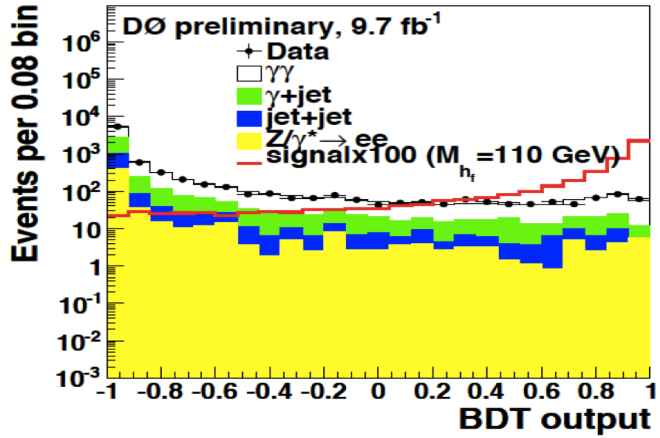
- Event selection
  - NN for Central region
  - Converted photon are recovered
  - h_f is produced with a W or Z boson, so $p_T^{\gamma\gamma}$ is higher relative to diphoton BG.
  - Three subsamples from $p_T^{\gamma\gamma}$ cut.
  - Another 4 subsamples for detector location of di-photon
- Assume a null hypothesis
- Fit made to sideband regions of $M_{\gamma\gamma}$ distribution
- Fit interpolated into the 12 GeV signal region per BEH boson mass point studied



Fermiophobic Searches D0

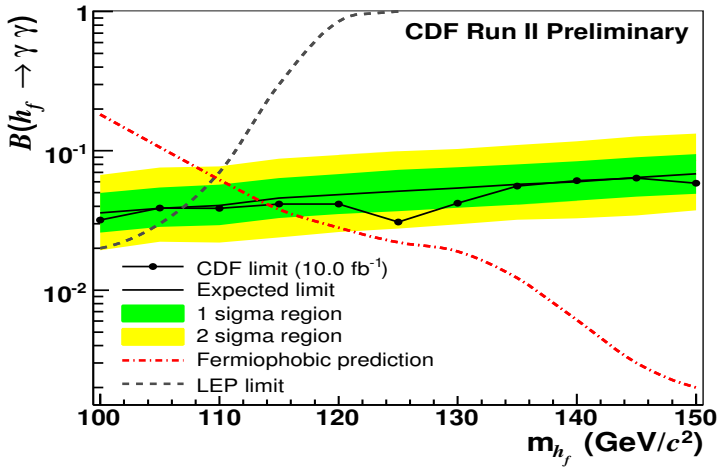
- Use a Neural Network for ID
- Trained on Jet vs. Photon MC
- Validated with $Z \rightarrow ll + \gamma$ data
- Reject candidates with low NN output
- Separate candidates between NN in midrange and high
  - Categorise events into 4 categories
  - Pass, Fail $\times 2$ candidates
  - Using 4×4 efficiency matrix, derive the number of events from $\gamma\gamma$, γj, $j\gamma$, and jj
- Use BDTs to separate signal from BG

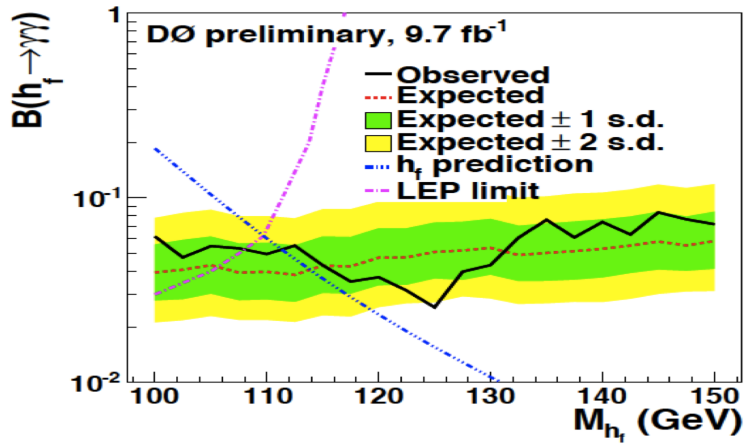




Fermiophobic Searches Results

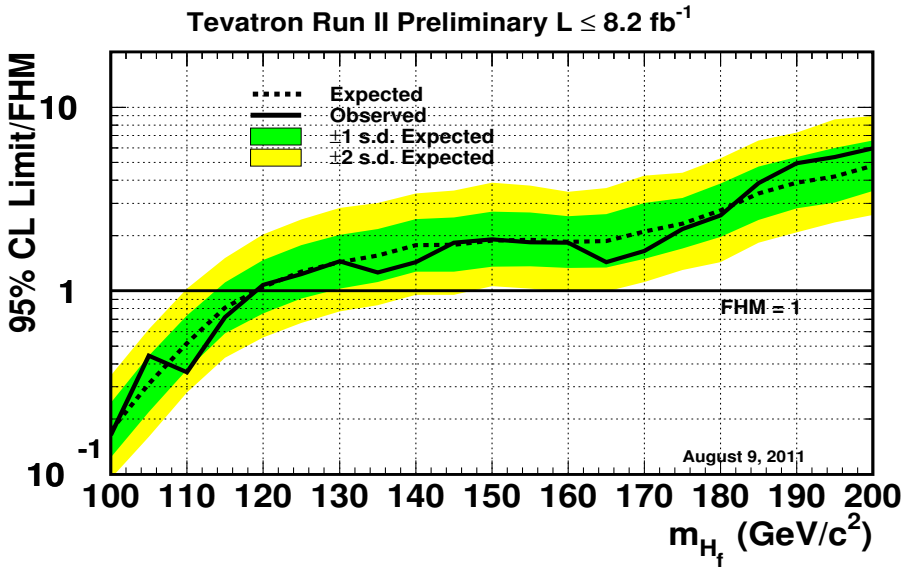
- CDF (10 fb^{-1})
  - Observed (expected) 95% C.L. limits on $\sigma \times B(h_f \to \gamma\gamma)$exclude a Fermiophobic BEH boson with a mass < 114 GeV (113 GeV)
- D0 (9.7 fb^{-1})
  - Expected limit 114 GeV
  - Observed limit 111.4 GeV





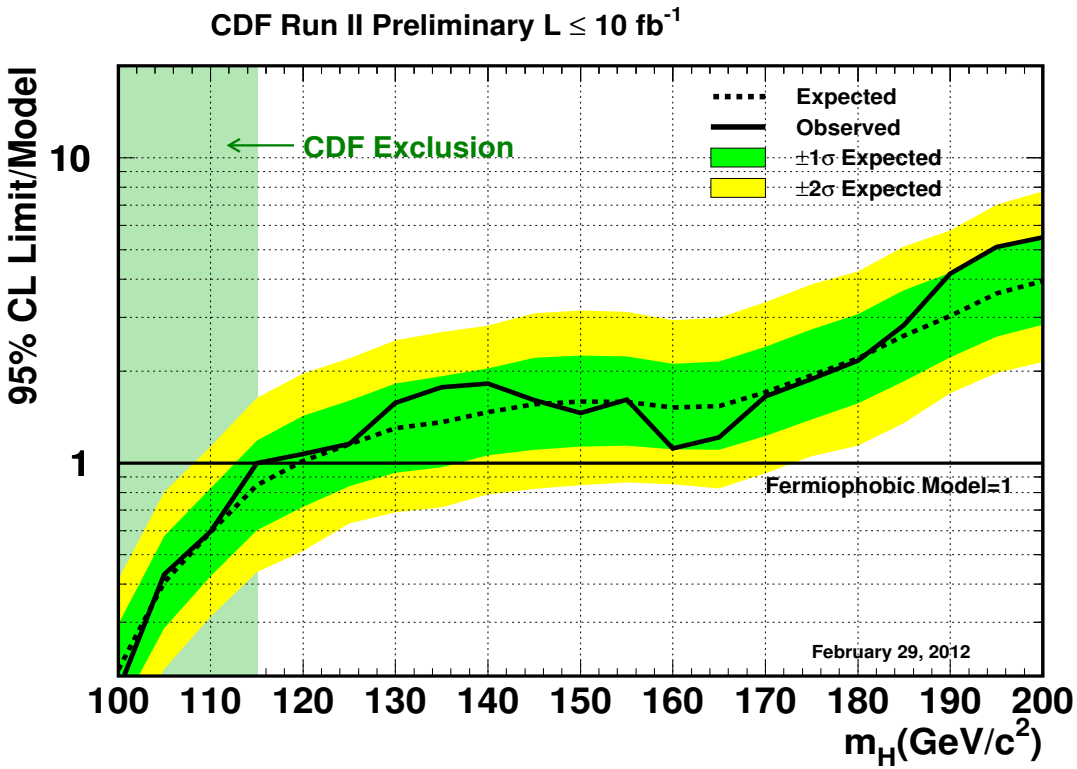
Fermiophobic Tevatron Combination, Summer 2011

$L_{CDF} = 7\text{fb}^{-1}$ and $L_{D0} = 8.2\text{fb}^{-1}$



- Exclude a BEH boson of mass $m_{H_f} < 119 GeV/c^2$
- Combination includes $H_f \to \gamma\gamma$ and $H_f \to WW$
- A new Tevatron Combination is coming soon

Fermiophobic CDF Combination, Full Data Set



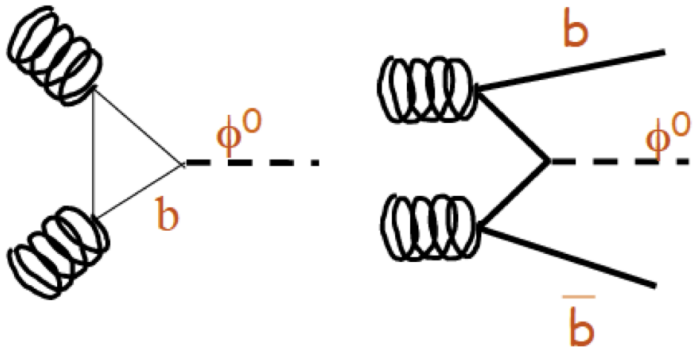
- Exclude, at the 95% CL, a BEH boson of mass $m_{H_f} < 115 GeV/c^2$.
- Combination includes $H_f \to \gamma\gamma$,$H_f \to WW$, and $H_f \to ZZ$

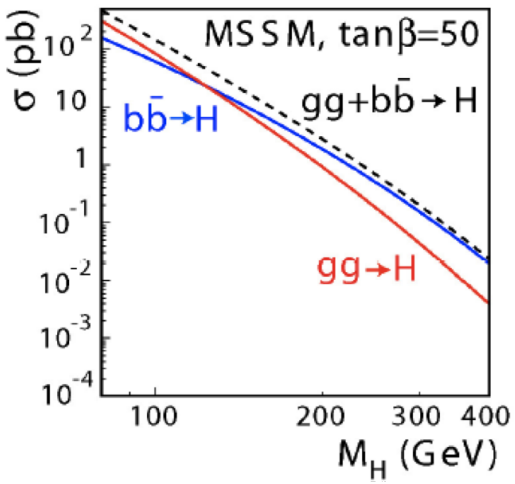
The MSSM Model

- Five BEH bosons
  - Three neutral: h, H, A
  - Two charged: H^+, H^-
  - Separate couplings for up-type and down-type fermions
- Properties
  - m_A : mass of pseudoscalar
  - tan(β) : ratio of down-type to up-type couplings
  - Typically, $m_h < m_A < m_H$, and $m_{H^\pm} \sim m_A$
  - For tan(β) near 1, h is SM-like and light - LEP-II limits apply
- At large tan(β)
  - Two of the three neutral bosons have approximately the same mass and couplings $\rightarrow$ degenerate.
  - Adds a factor of two enhancement in σ.
  - Overall enhancement at LO scales approximately as $2tan^2(\beta)$.

Production Mechanisms and Final States

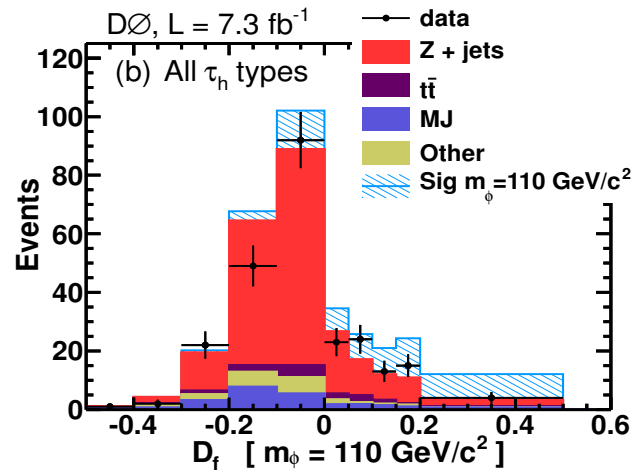
- Will not show the $\phi \to \tau\tau$
  - LHC has a lead in that channel
- Will Search in $bb\phi$ mode
  - $\phi \to \tau\tau$
  - $\phi \to bb$

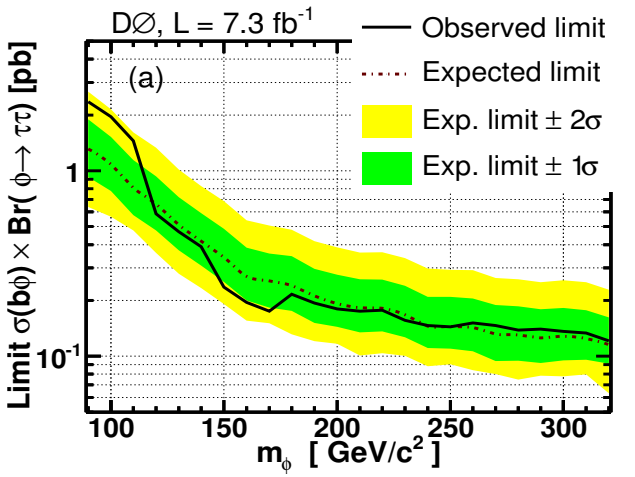




MSSM Searches: $bh \rightarrow b\tau_\mu\tau_{had}$ (7.3fb^{-1})

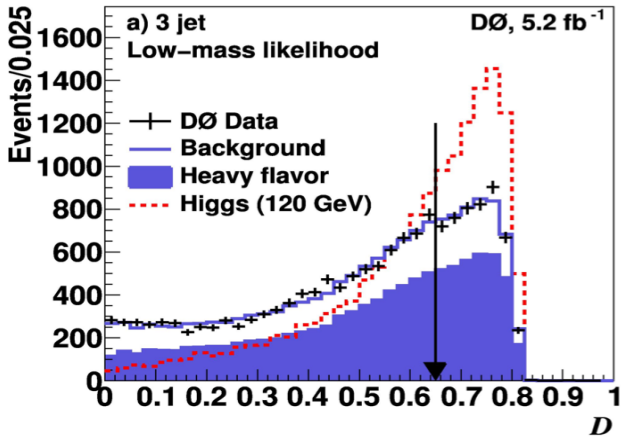
- τ_h decays are split into 3 categories: τ-types 1, 2 (3) are 1-prong (3-prong) candidates
- NN_τ is trained for each type to separate τ_h decays from jets
- b-jets are identified by a (NN_{btag}) algorithm
- Additional rejection of multi-jet and $t\bar{t}$ production BGs is achieved using an MVA, DMJ, and a NN Dtt
- The distribution of a likelihood discriminant, D_f is constructed from the various MVA discriminants, DMJ, Dtt, and NNbtag

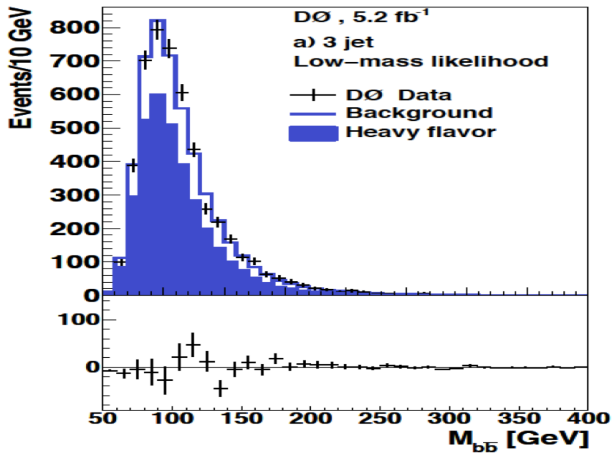




MSSM Searches: *bbb* Final States (D0)

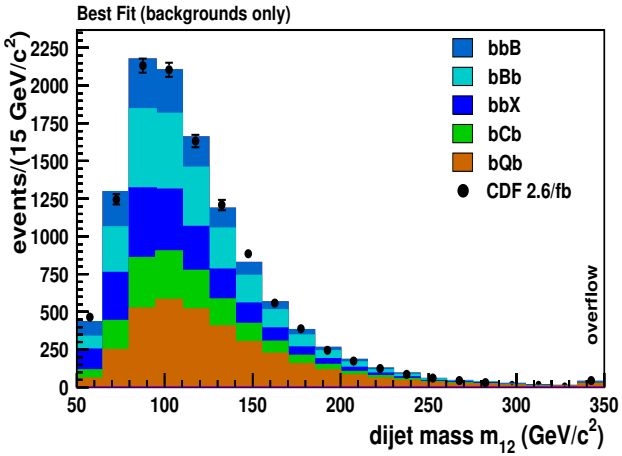
- Trigger
  - Multi-jet trigger with b-tagging.
- Background
  - Background shape modeled from a combination of data and Alpgen.
    - Rate obtained from fits to data
- Discriminant
  - Construct likelihood discriminant based on several angular and kinematic variables.
  - Cut on to improve S/B and highest likelihood value used to select jet pair for m_{jj}
  - Use low likelihood region as control region
  - Look for BEH boson in m_{jj}

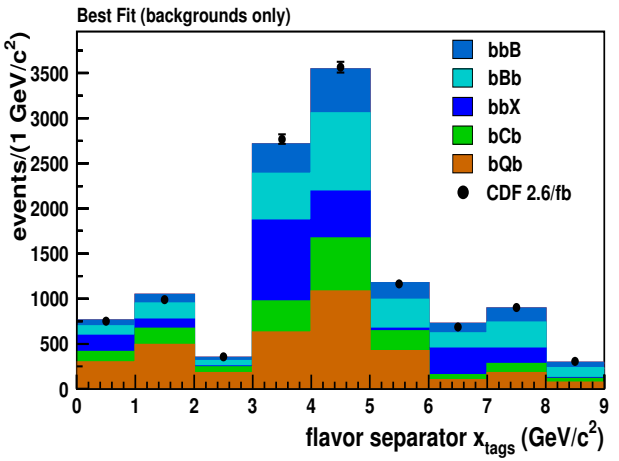




MSSM Searches: *bbb* Final States (CDF)

- Trigger
  - Based on two jets and two displaced tracks
- Background
  - Derive estimates for each flavor combination from the data
    - Use Pythia to check for bias
- Discriminant
  - Look for an excess in the mass of the two leading jets m_{12}
  - Use tag mass (m_{tag}) information to understand flavor composition
  - 2D fit to the data using these estimates
  - Tag mass information determines background composition
  - Look for BEH boson in m_{12} distribution

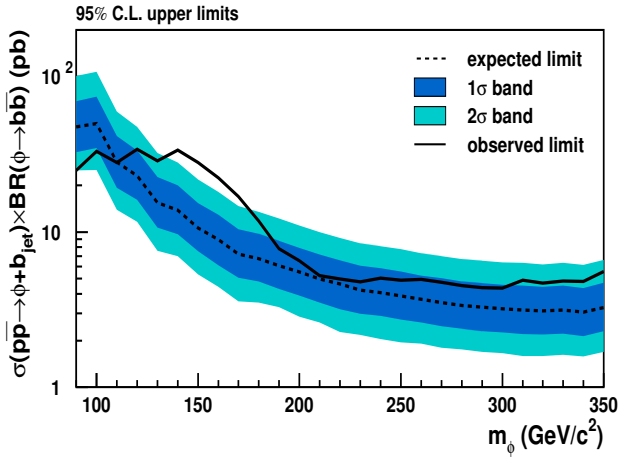


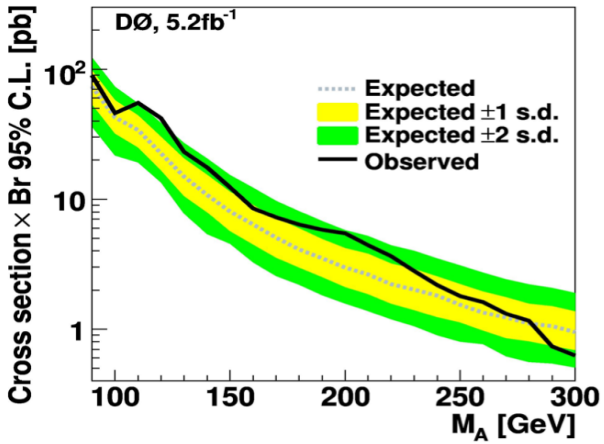


MSSM Searches: *bbb* Final States Results

With the assumption of a narrow width

- CDF
  - Max deviation from expected at 150 GeV
  - Including the trials factor, (1.9σ)
  - Corresponds to $\sigma \times BR \sim$15 pb
- D0
  - Max deviation from expected at 120 GeV
  - Including the trials factor about 2.0σ

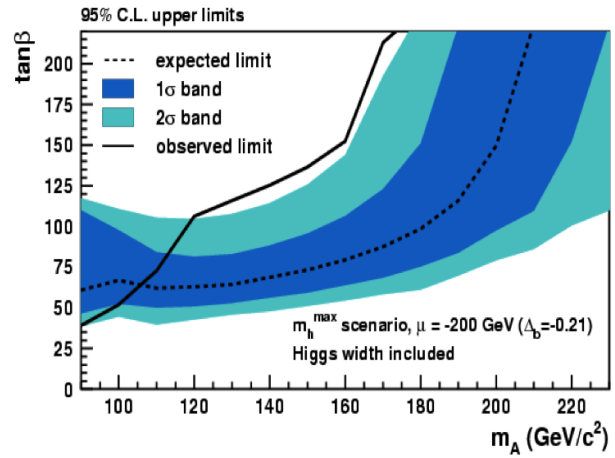


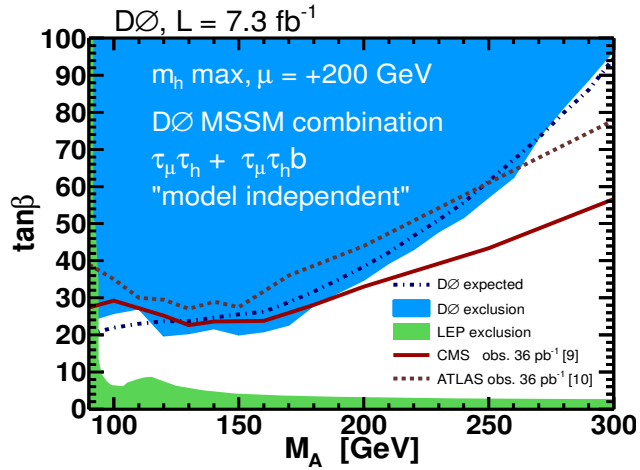


MSSM Constraints

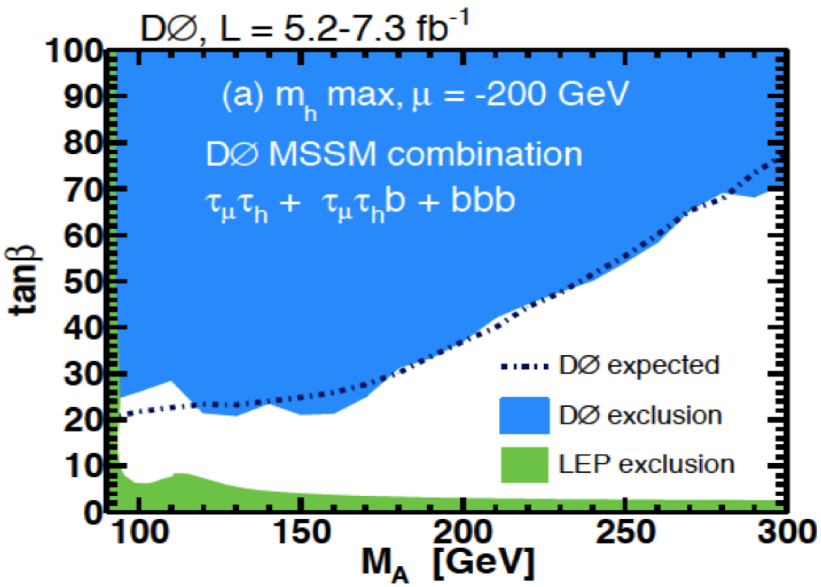
Interpretation

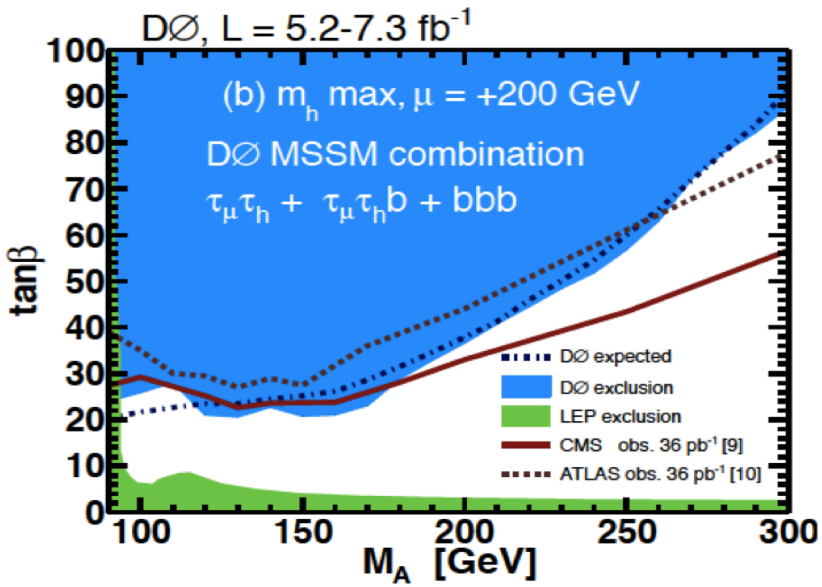
- MSSM BEH boson in high-tan(β) scenarios not generally narrow
- To extract limits on tan(β) uncertainties on σ and Γ_{BEH} should be taken into account.
- BEH boson properties are largely, but not completely, determined by m_A and tan(β)
- Loop corrections introduce dependence on other SUSY parameters





MSSM D0 Combination

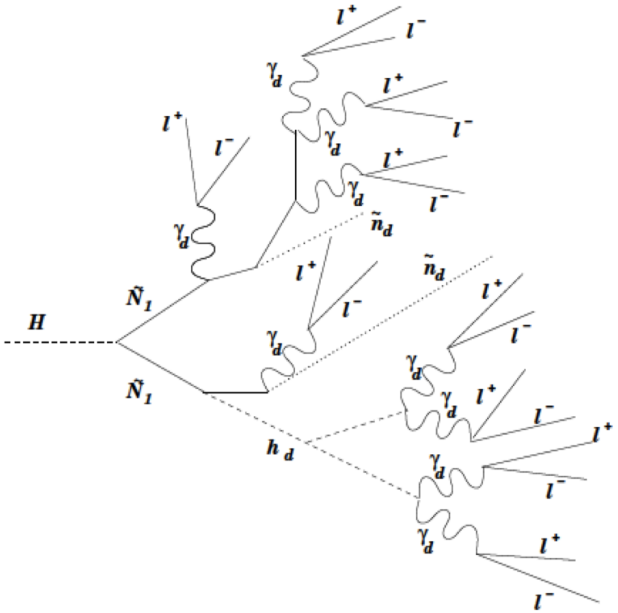


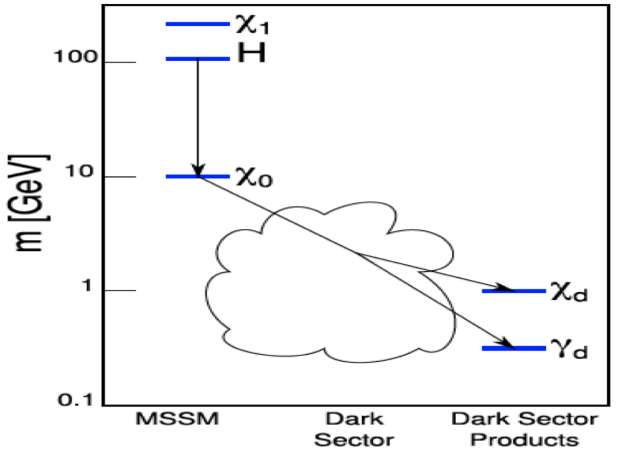


Exclude a substantial region of the MSSM parameter space, especially for $M_A < 180\ GeV$ and $\tan(\beta) > 20 - 30$

Dark Sector Hidden Scalar Boson

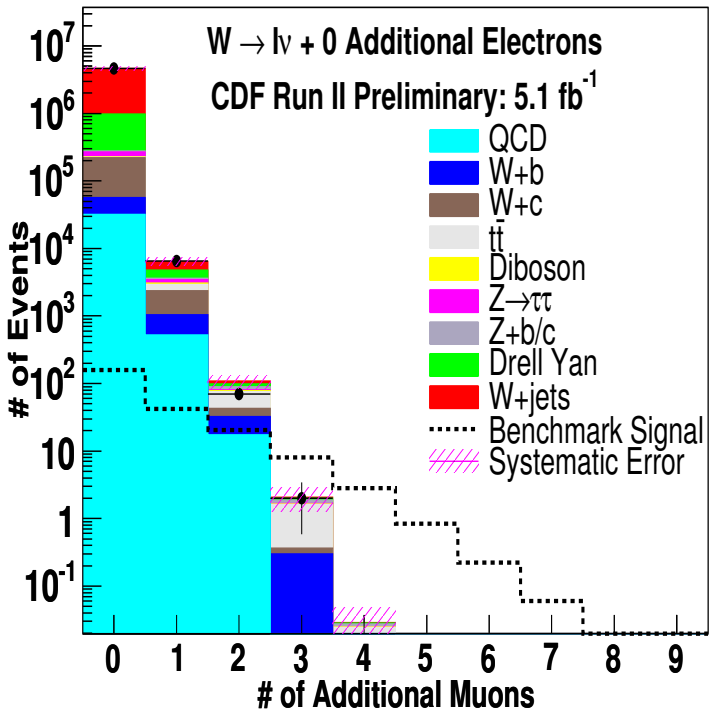
- Multiple leptons is a common signature in many BSM models
  - NMSSM, little Higgs models, and R parity violating MSSM models
- Leptons spatially close to each other (Lepton Jets)
- Could have evaded previous searches (low momentum, non-isolated)
- Lepton Jet searches have been done, but have often focused on specific topology requirements
- This analysis is a very general signature-based search, sensitive to a wide range of multiple-lepton scenarios





Dark Sector Hidden Scalar Boson

- Broad search for additional electrons and muons with p_T above a low threshold (3 GeV for μ and 1 GeV for e) in W and Z events.
- Most sensitive in muons, due to photon conversion background
- The Neutralino model has a cross-section of 389 fb to produce a leptonic W or Z plus a Higgs. We set a limit of 112 fb, at 95% C.L.
- Rule out the model at the standard cross section at a confidence level of 99.7%



Conclusion

- We presented Tevatron searches for BSM BEH bosons optimizing for several models
  - We presented results for a search for fermiophobic models in diphton channel using 10.0 fb^{-1} of CDF and D0. We exclude Fermiophobic BEH bosons with mass < 119 GeV
  - High values of tan(β) have been excluded
  - The 3b channel is unique at Tevatron, searches with full dataset should yield insights on current excess at low M_A
  - Dark Sector Hidden Scalar Boson
- Tevatron is still searching for BSM BEH bosons with full data sets
- Tevatron Combination in progress