Tevatron Non-SM Higgs Searches

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SUSY 2011 – Fermilab
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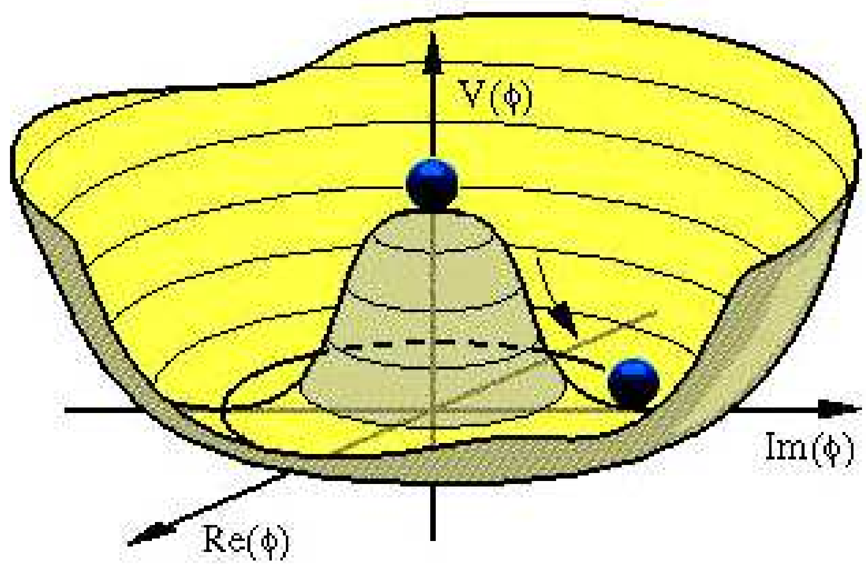
On behalf of the CDF and D0 Collaborations

Why Do We Expect a Higgs?



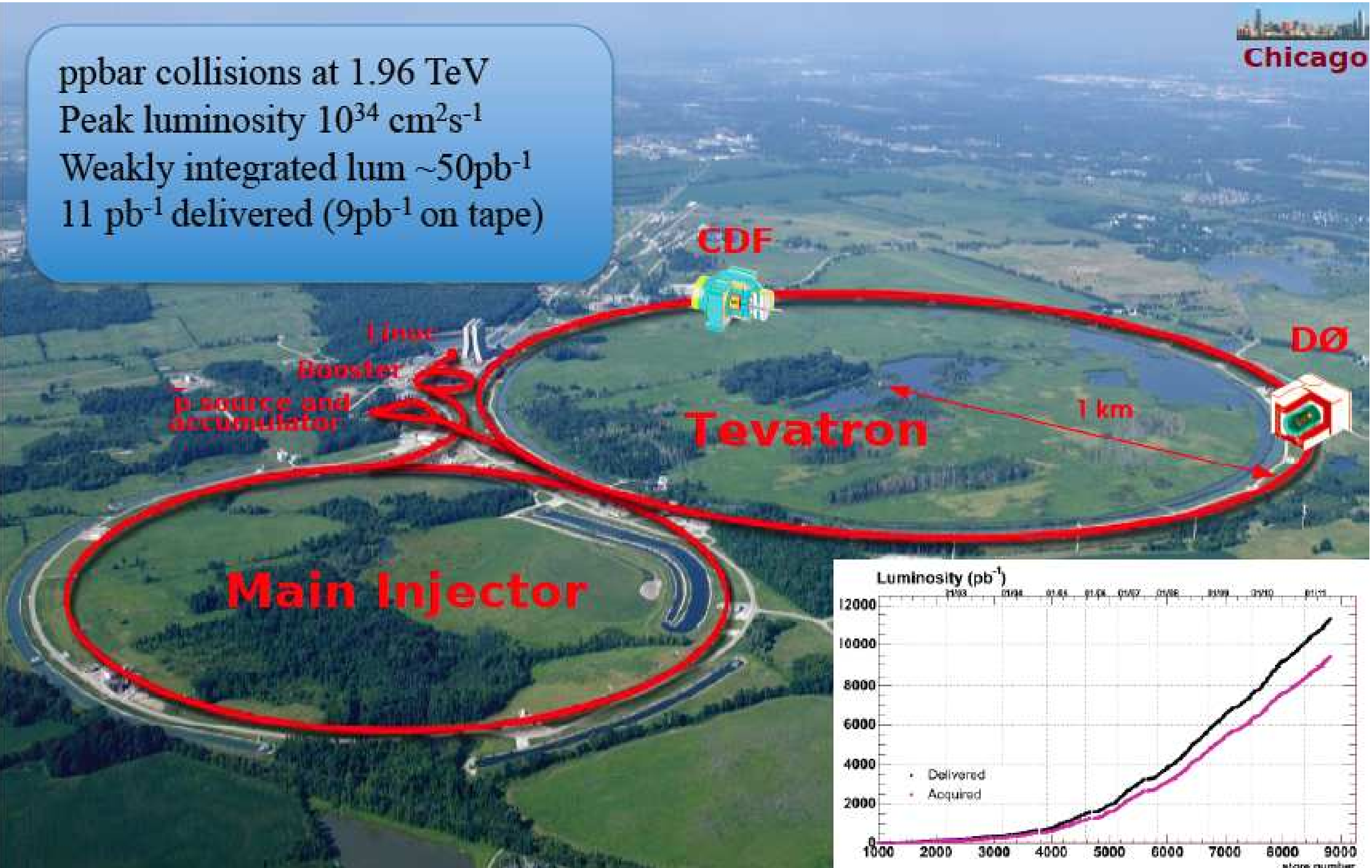
- Standard Model fermion/boson interactions specified by $SU(2)_L$ x $U(1)_Y$ symmetry
- But, fermion and boson mass terms are forbidden by same symmetry!

- Introduce pair of complex scalar fields with a particular shape, and interactions with fermions/bosons
- All compatible with $SU(2)_L$ x $U(1)_Y$
- Then break the symmetry

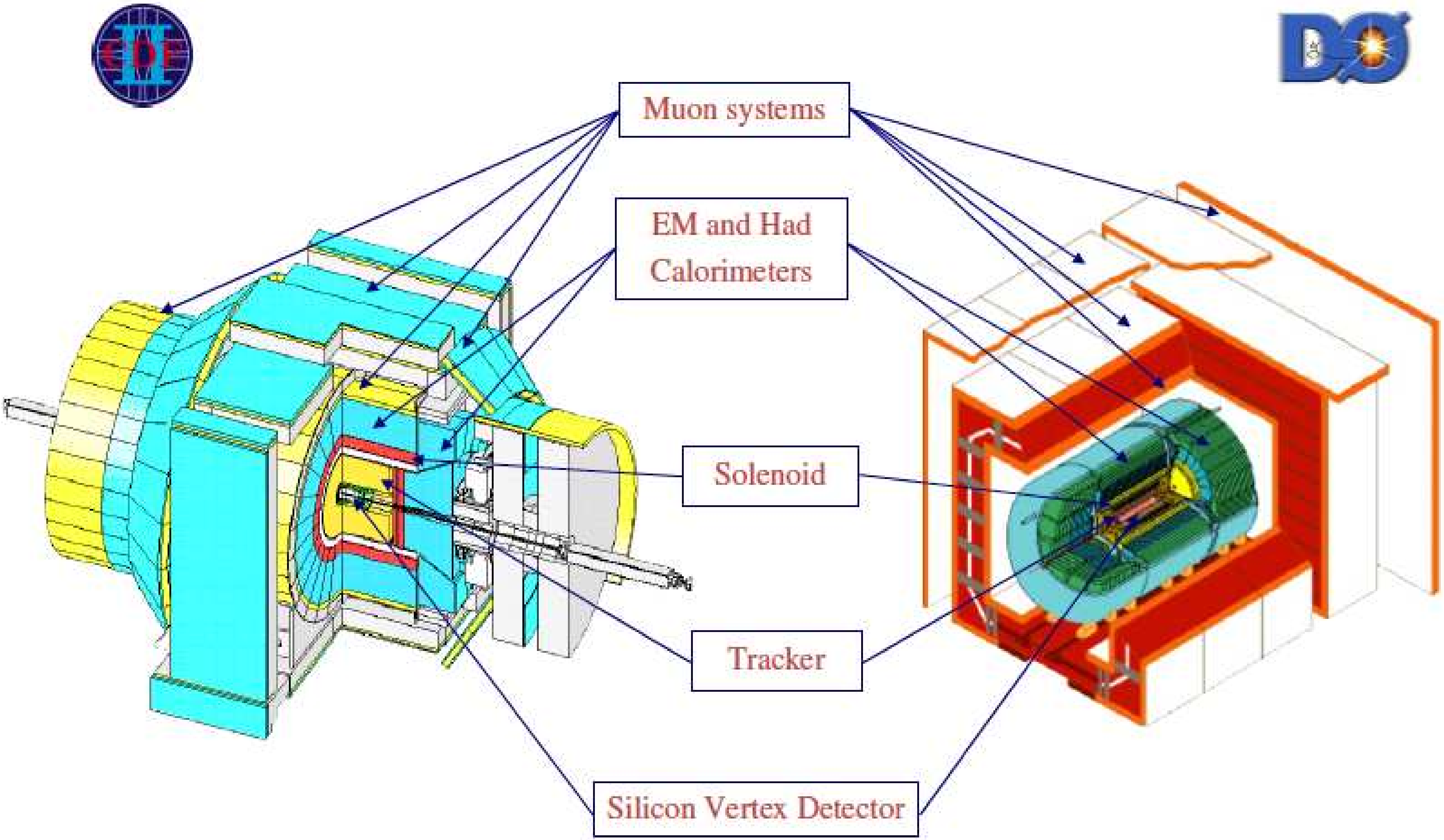
- Excitations away from mimimum
  - Physical Higgs scalar
- Original interactions split
  - VEV terms – masses!
  - Interactions with physical Higgs strength proportional to mass

The Tevatron

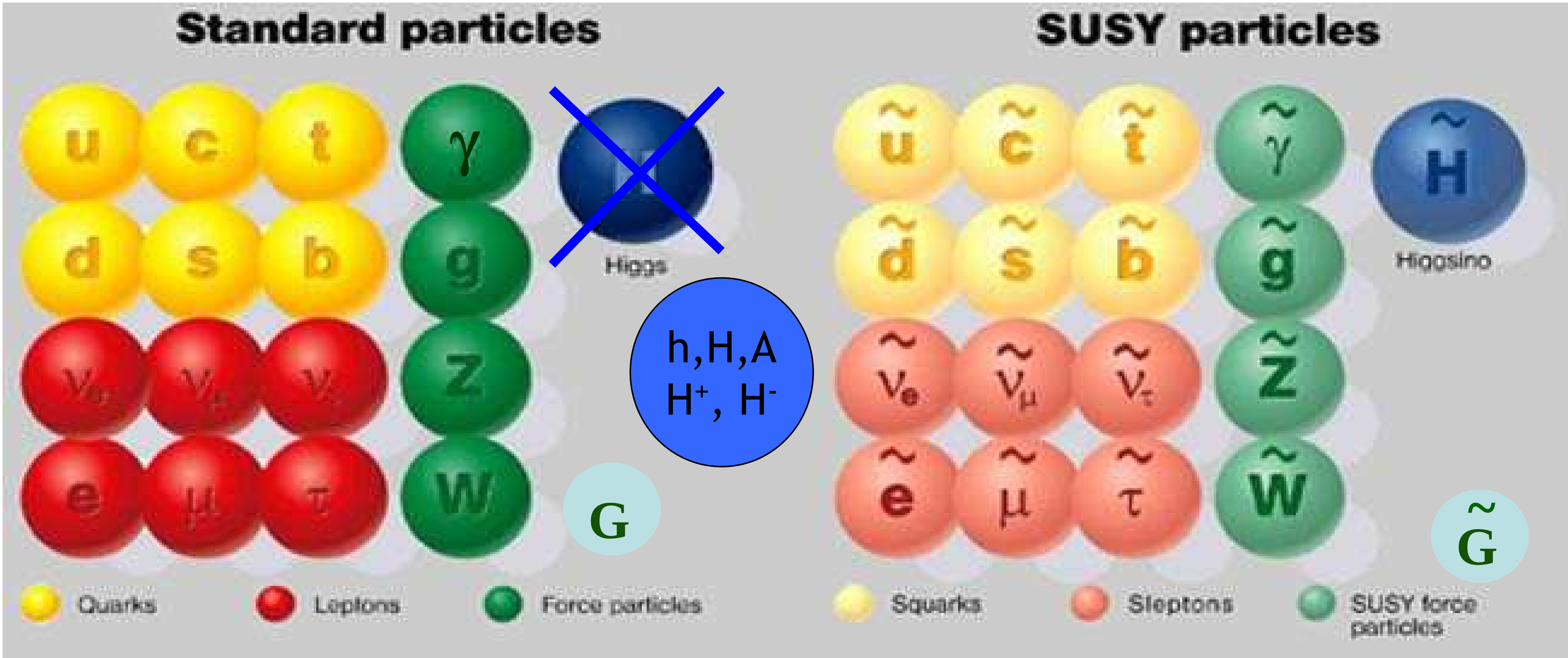
ppbar collisions at 1.96 TeV
Peak luminosity 10^{34} cm^2s^{-1}
Weakly integrated lum ~50pb^{-1}
11 pb^{-1} delivered (9pb^{-1} on tape)



The CDF and D0 detectors



Supersymmetry



- SM particles have supersymmetric partners: differ by 1/2 unit in spin
- SUSY has many attractive properties
  - Cancellation of Higgs mass divergence, coupling unification, etc
  - Lightest neutralino is a dark matter candidate
- Requires larger Higgs sector than the single scalar of the SM
  - Simplest case: Minimal Supersymmetric Standard Model (MSSM)

Higgs in the MSSM

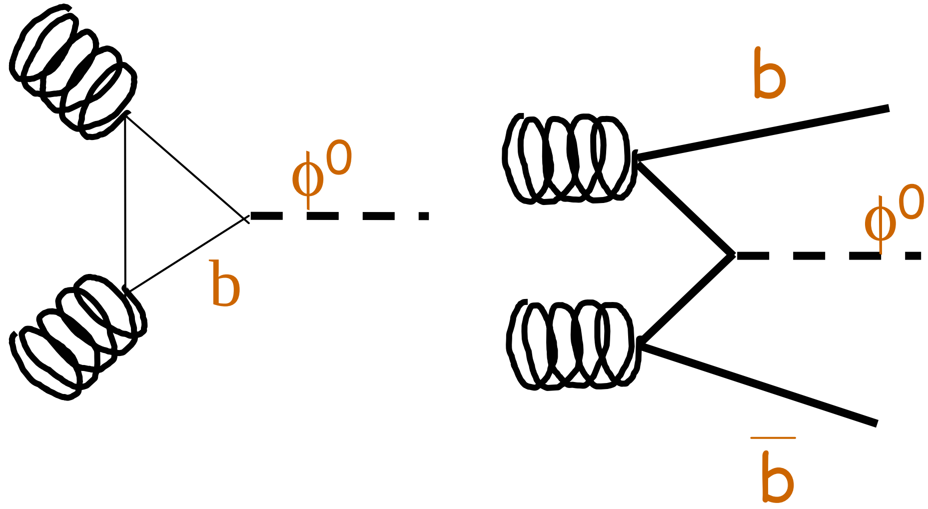
- Instead of one scalar, get five:
  - Three neutral: h, H, A : (generically "ϕ")
  - Two charged: H^+, H^-
- Separate couplings for up-type and down-type fermions
- Properties of the Higgs sector largely determined by two parameters:
  - m_A : mass of pseudoscalar
  - $\tan\beta$: ratio of down-type to up-type couplings
- Typically, $m_h < m_A < m_H$, and $m_{H\pm} \sim m_A$
- For $\tan\beta$ near 1, h is SM-like and light - LEP-II limits apply
- Larger $\tan\beta$ shows more interesting behavior
  - A becomes degenerate with h or H (mass, couplings, etc)
  - Other decouples, SM-like, mass around 120 GeV
  - A + h/H production controlled by $\tan\beta$
- In the Standard Model, Higgs cross section is fixed – no free parameters
- In MSSM, production of A/h/H depends on $\tan\beta$ – range of possibility
  - For the right value of $\tan\beta$, could already have discovery potential

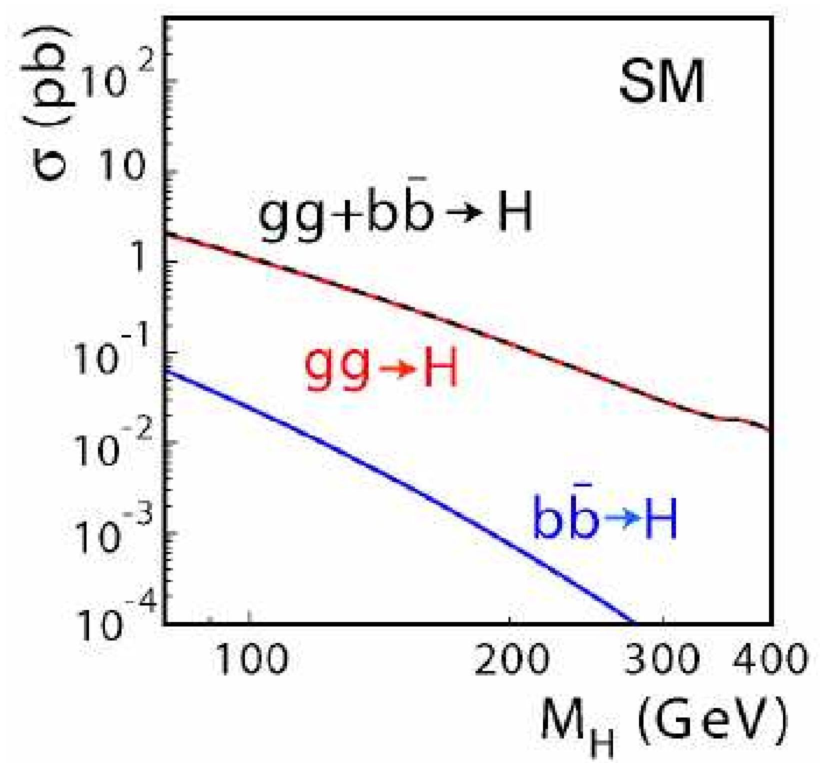
Higgs at High tanβ

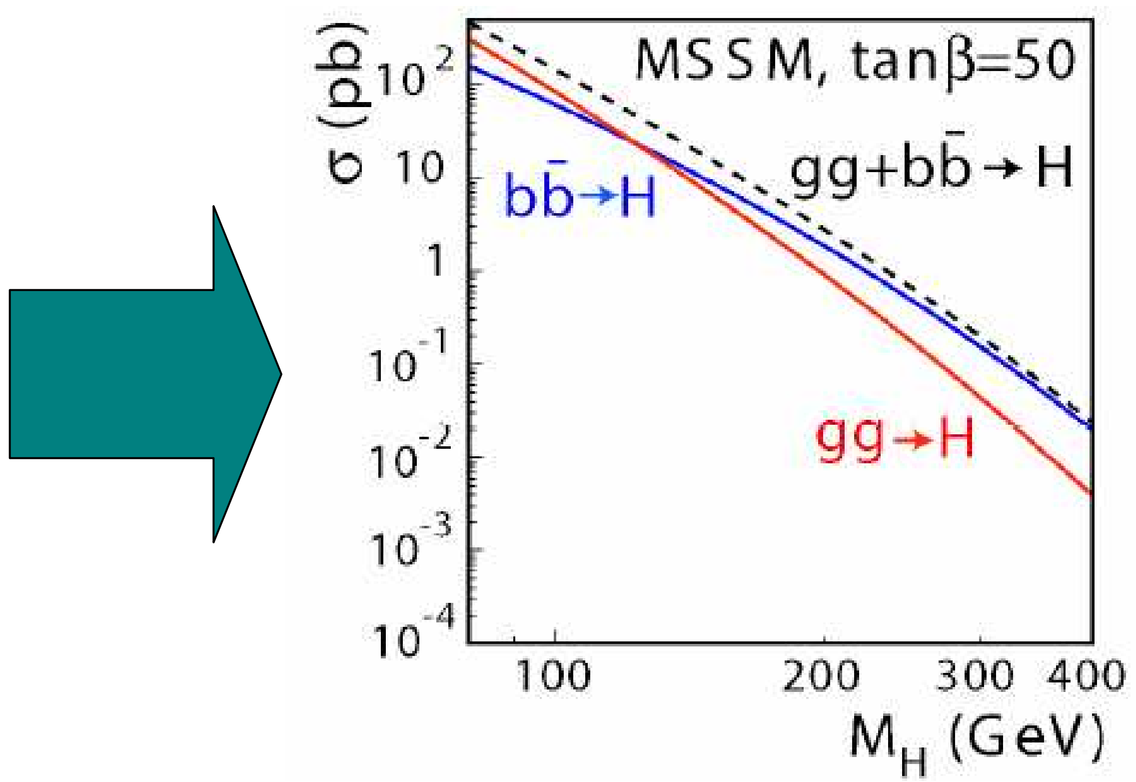
Processes involving bottom quarks (down-type) enhanced by $\tan^2\beta$

Boost from femtobarns to picobarns

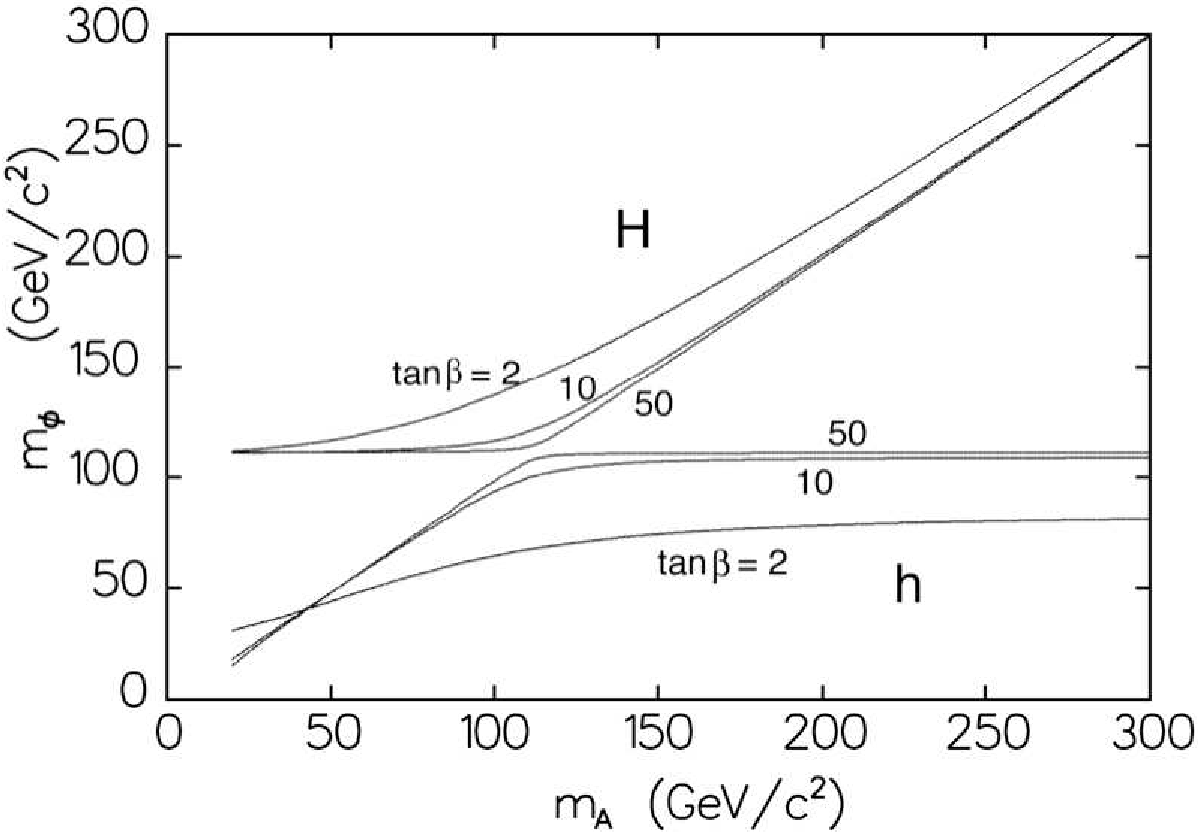
Could be observable at Tevatron!







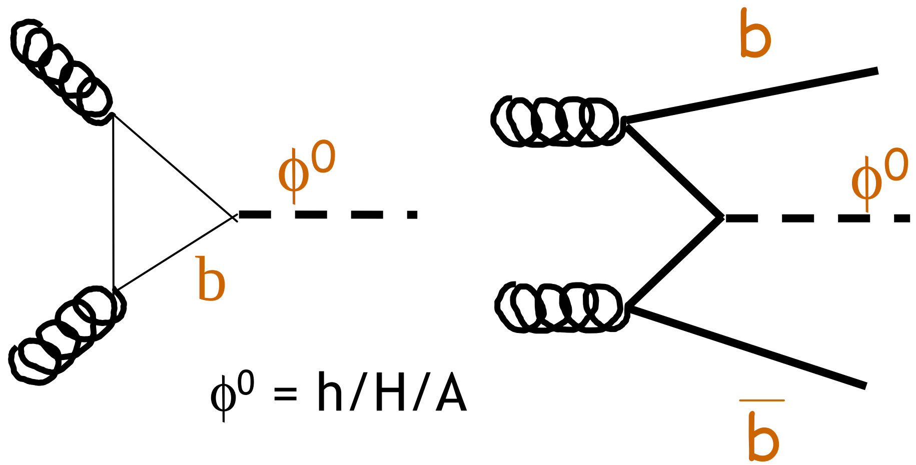
Higgs at High tanβ



- Neutral sector simplifies at high tanβ
- A and h/H become degenerate
- Other scalar SM-like, low cross section
- Only need to search for a single mass peak (ϕ)

- For the A and its twin h/H, at high tanβ decays into b$\underline{b}$ (90%) and ττ (10%) dominate

MSSM Higgs Search Channels



- Inclusive production
  - Only $\tau\tau$ decays (bb backgrounds too large)

- Associated production
  - Additional b-quarks suppress QCD backgrounds
  - Searches in $\tau\tau$ and bb decays

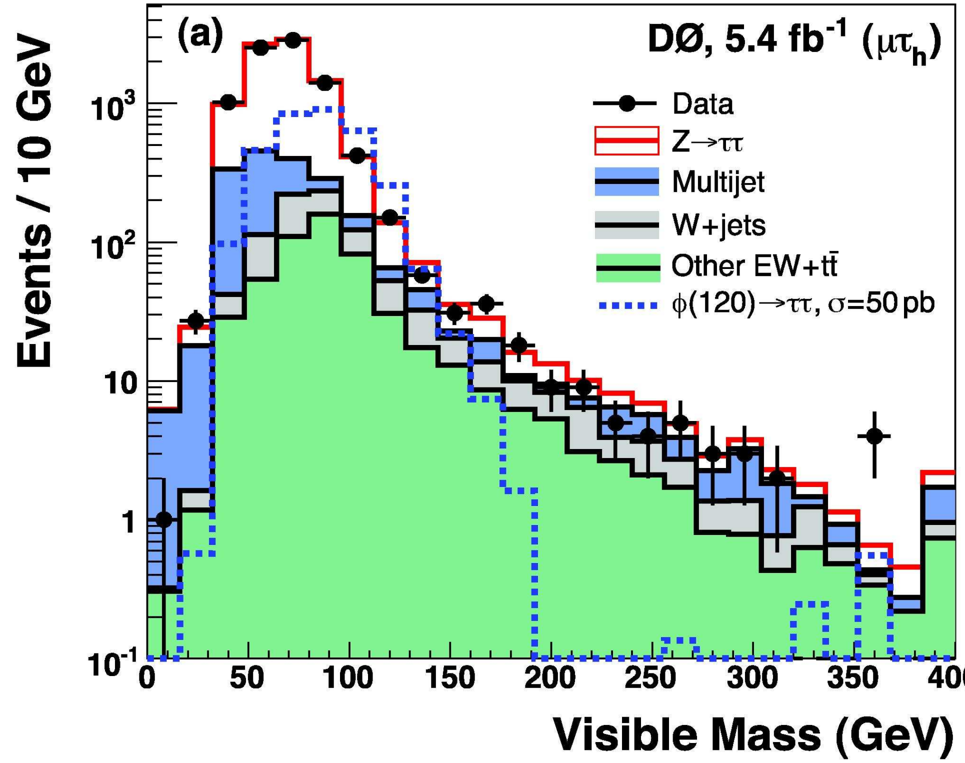
Inclusive H → ττ

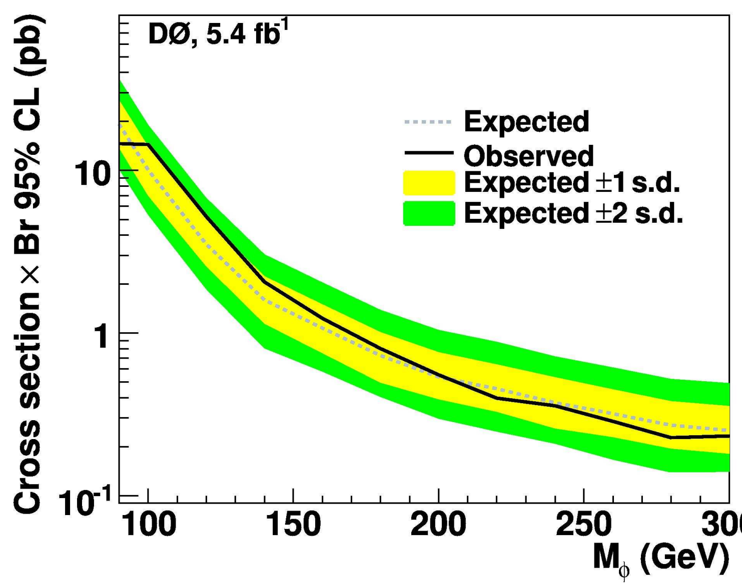
- Require at least one tau to decay leptonically (here μ, also e)
- Second tau can decay leptonically or hadronically
  - Only eμ, not ee or μμ

- Impossible to fully reconstruct Higgs mass due to multiple neutrinos
- Use 'visible mass' treating MET as massless

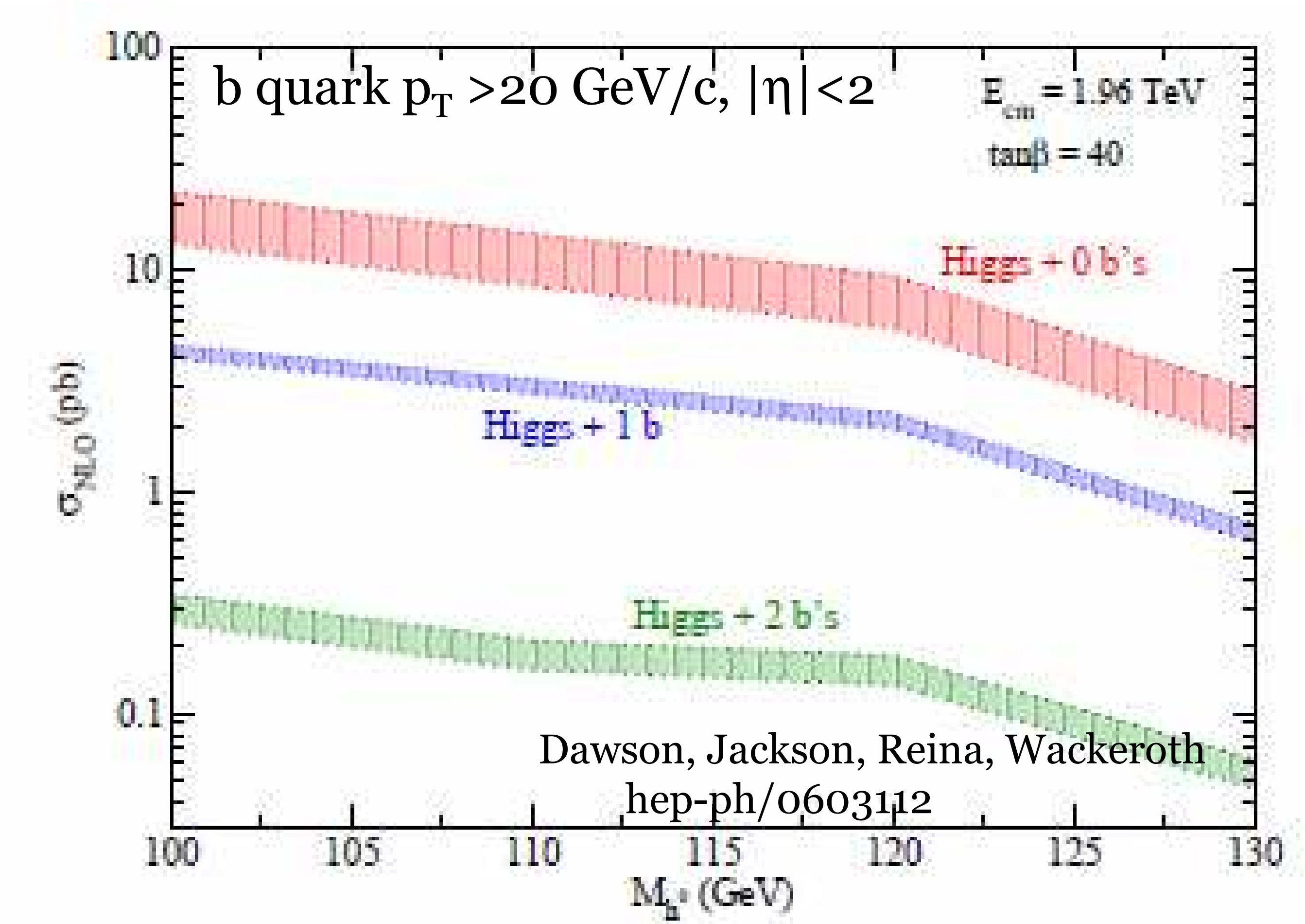
- No significant excess observed up to 300 GeV/c²

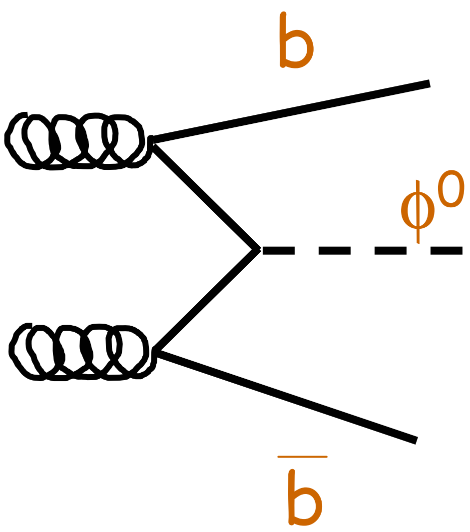
- arXiv:1106.4555 (submitted to PLB)





Associated Production

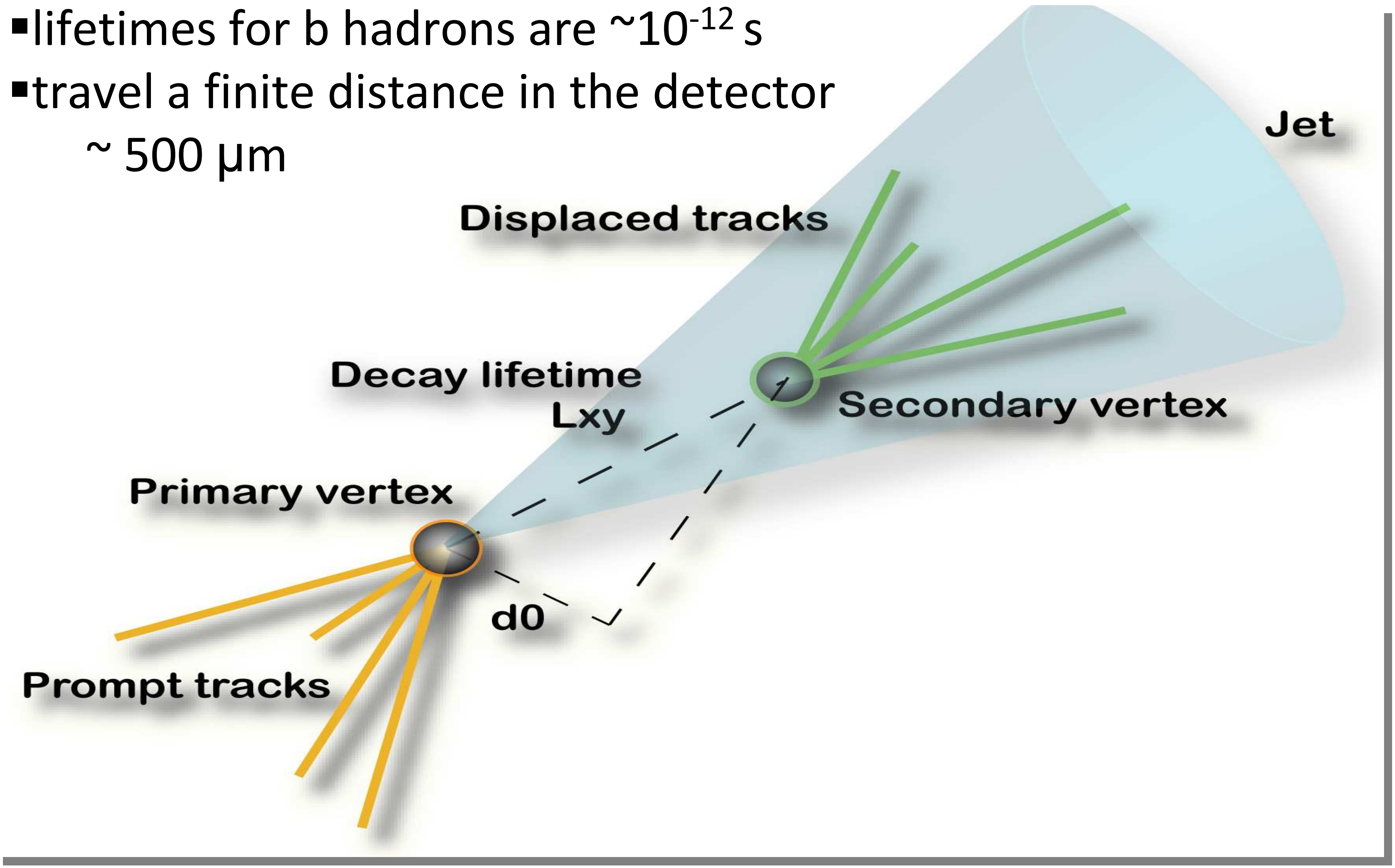




- Search for the bbϕ process
- Less cross section when requiring both b's to be high-p_T
- Look for the Higgs + 1b case

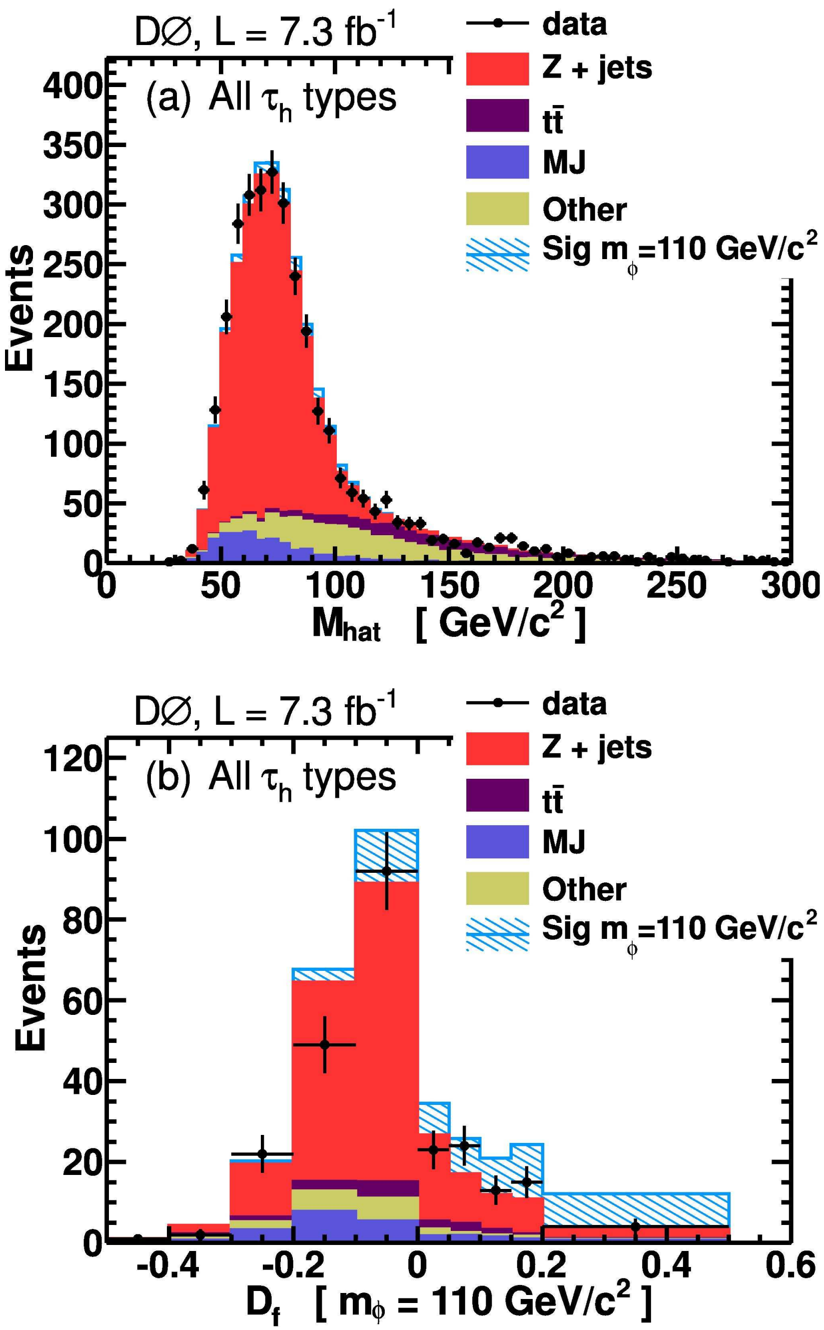
Identifying b jets

- lifetimes for b hadrons are ~10^{-12} s
- travel a finite distance in the detector
  ~ 500 μm



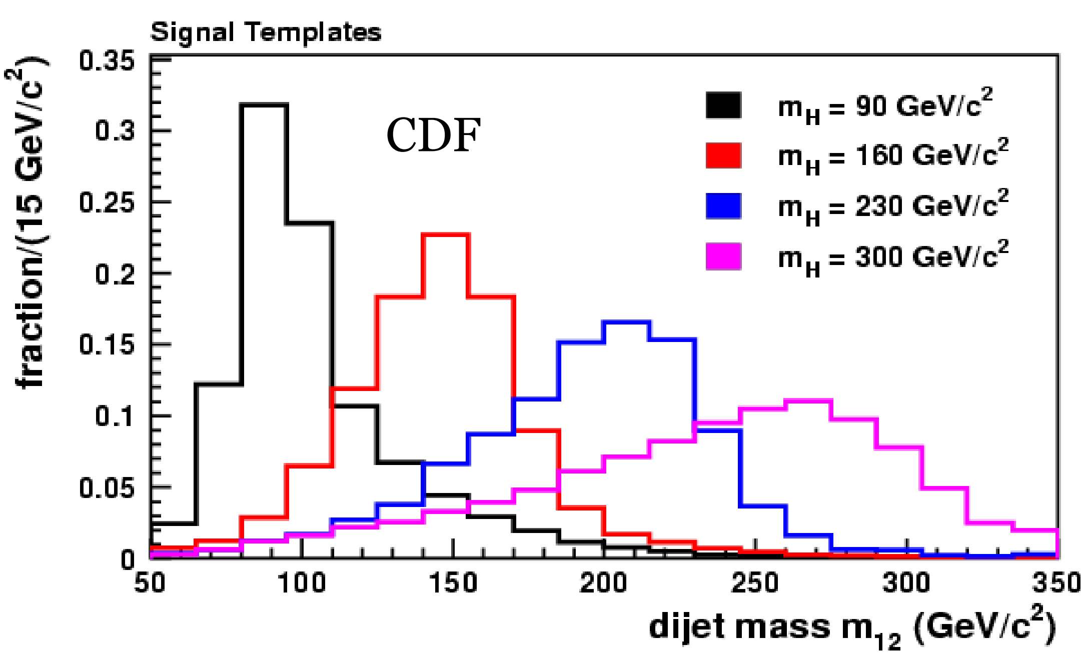
MSSM Higgs in $b\phi \rightarrow b\tau\tau$

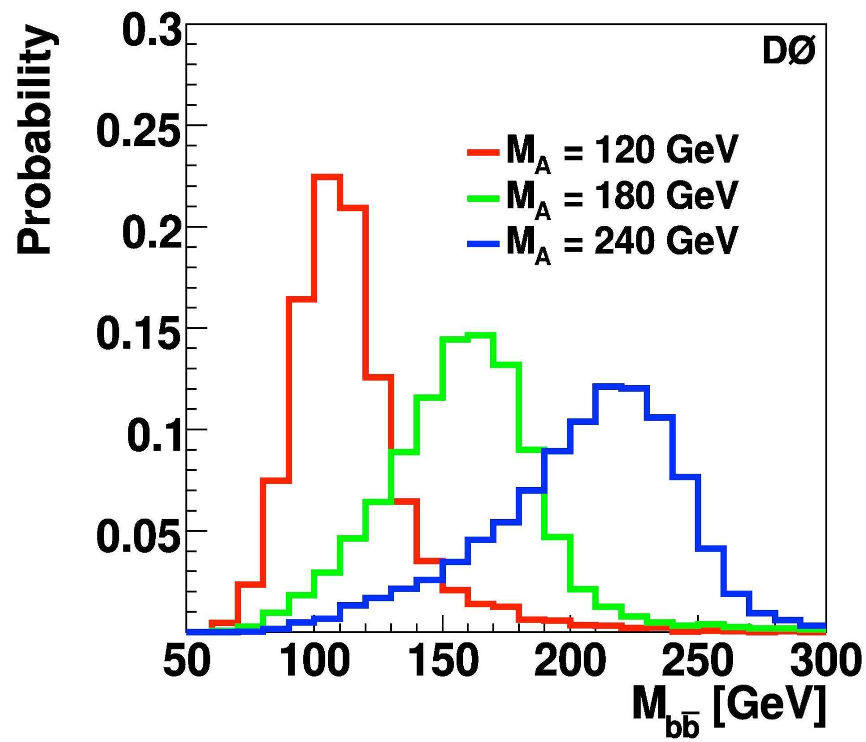
- Combines the high purity of the $\tau\tau$ decay mode with the background suppression of associated production
- Require one τ to decay into a muon and the other hadronically
- At least one b-tagged jet
- Similar mass reconstruction techniques as inclusive ditau search
- Recoil against b-jet allows projection along τ axes, better signal discrimination – here reflected in a multivariate discriminant
- arXiv: 1106.4885 (submitted to PRL)



MSSM Higgs in bϕ → bbb

- For b-bbar Higgs decays, signal is three b-tagged jets
- Search for a resonance in two of them
  - CDF – two leading, DO – jet pair chosen event-by-event

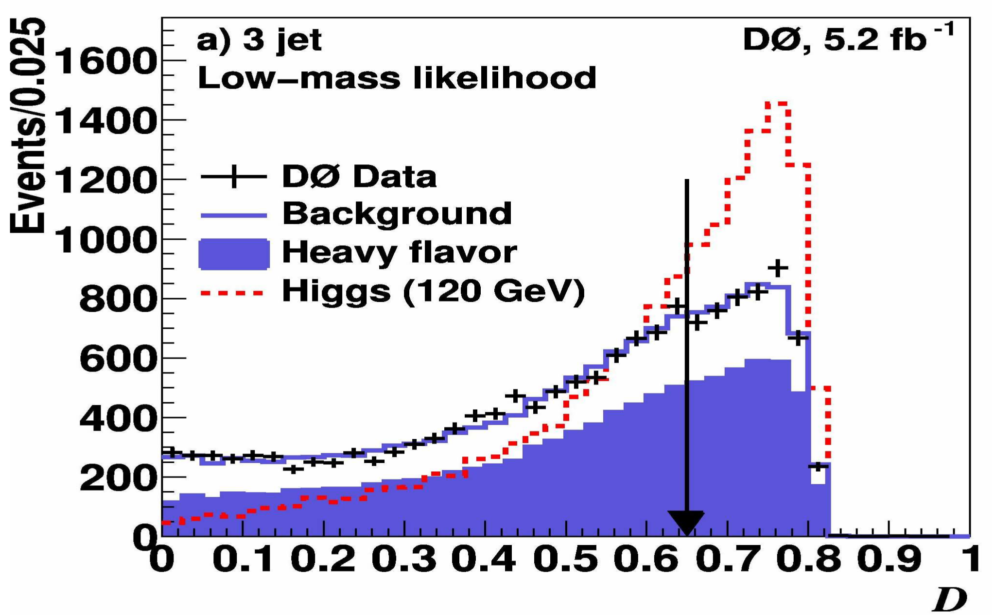


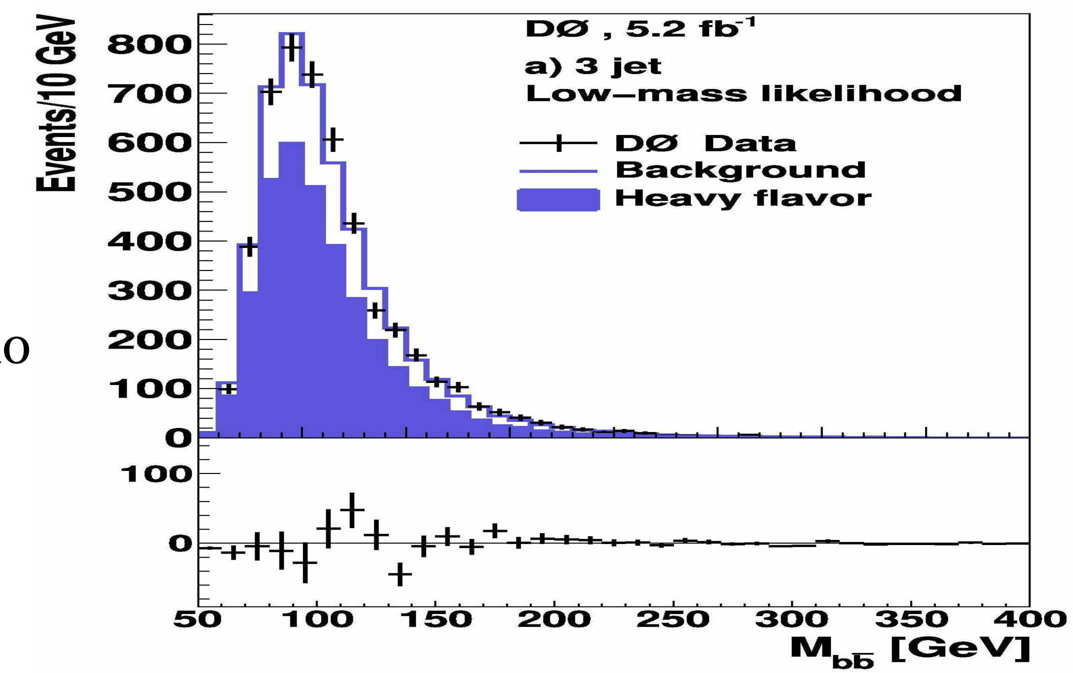


Combined detector acceptance and ID efficiency is about 1 % for both experiments.

MSSM Higgs in bϕ → bbb

- Require three or more jets, at least three b-tagged
- Kinematic likelihood to separate signal/background and also to choose which jet pair is the most likely Higgs candidate
- Search in the mass of the most likely jet pair
- Backgrounds are derived from double-tagged data
  - Fake tags (i.e. bb + light jet)
  - True HF (bbb, bbc, bcc, etc)
- Correct using triple/double-tag ratio from ALPGEN HF samples
- Phys.Lett.B698:97-104, 2011

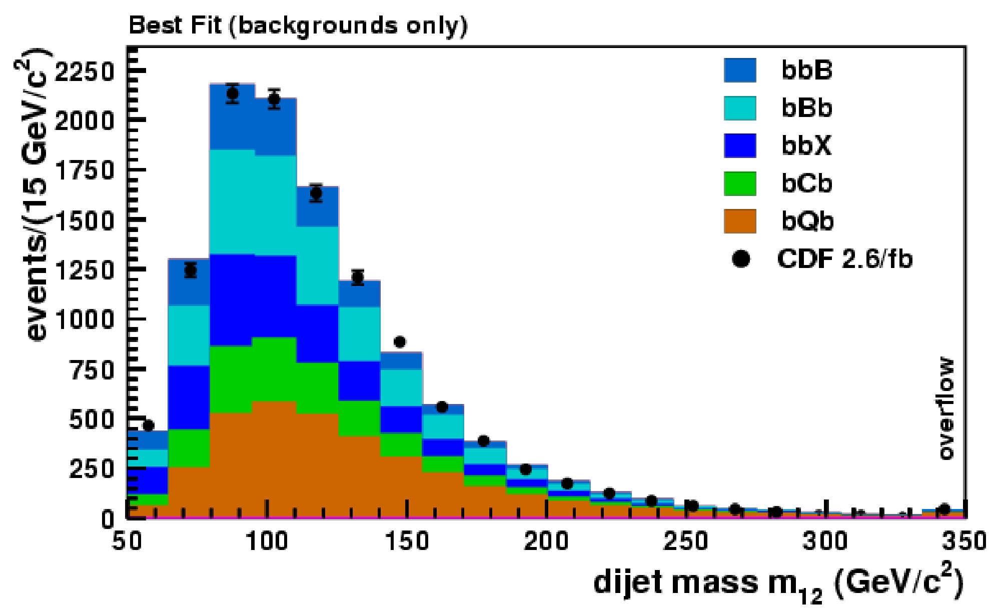


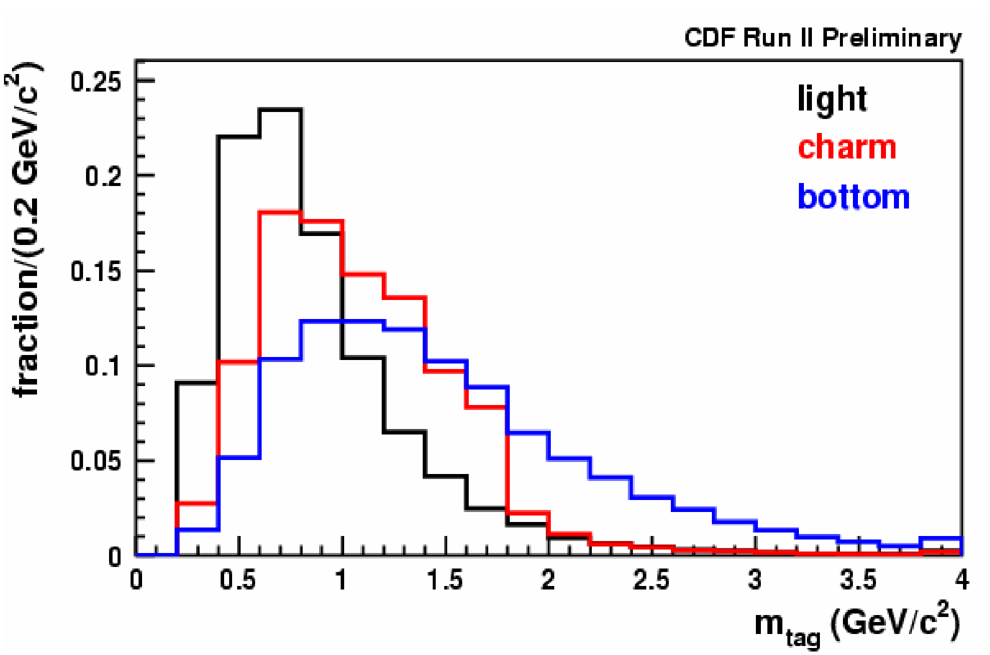


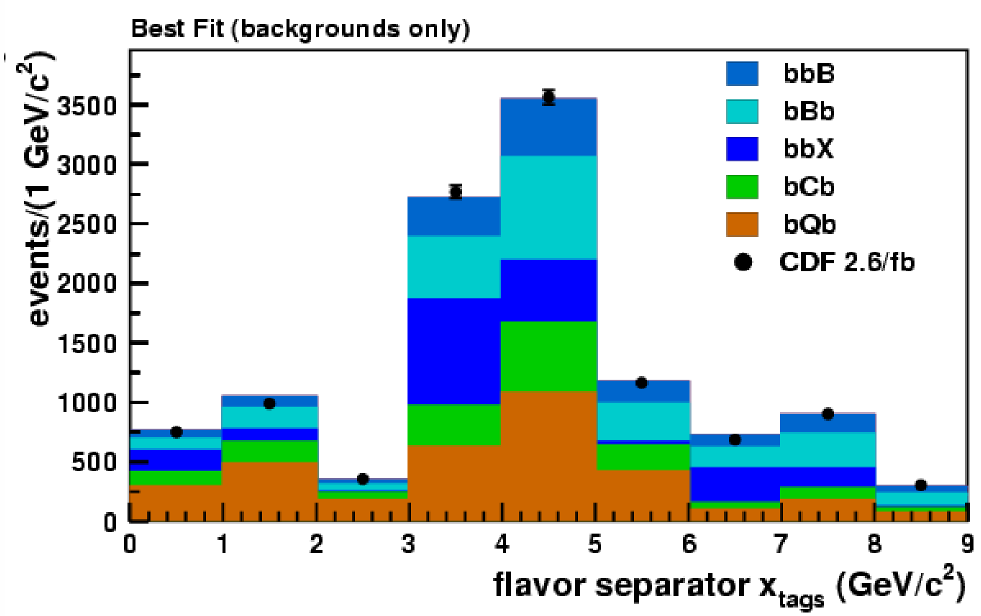
MSSM Higgs in bϕ → bbb

- CDF uses double-tagged events with simulated third tag under various flavor hypotheses
- Use properties of b-tags to fit background normalizations
- Compare fits without/with Higgs signal templates

- arXiv: 1106.4782 (submitted to PRD)

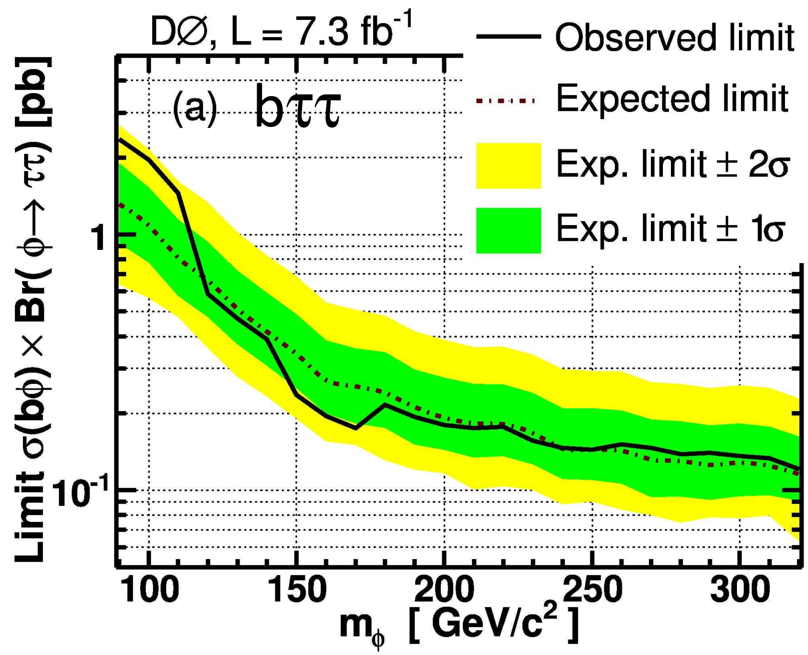


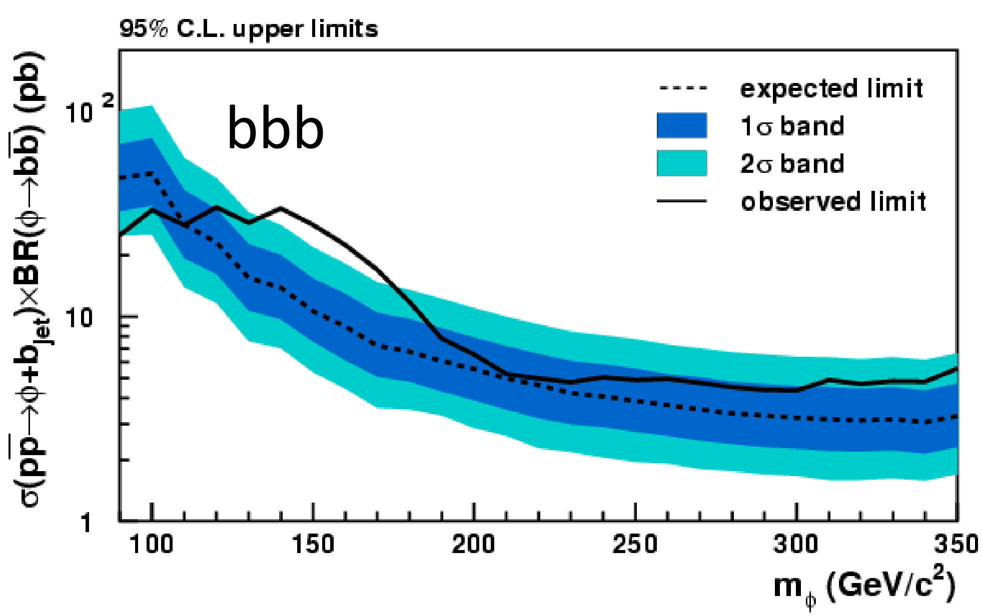


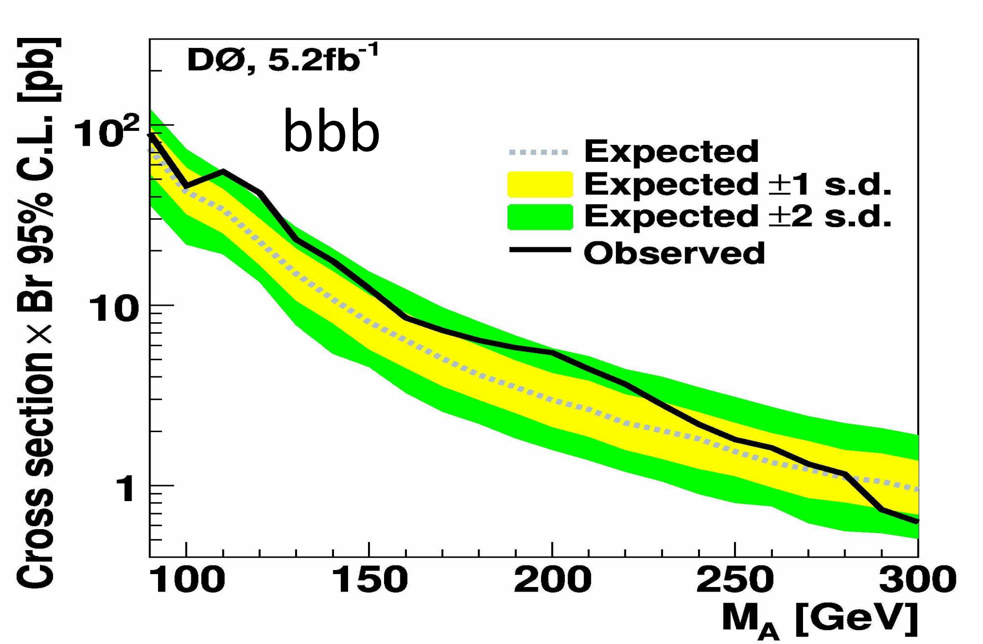


MSSM Higgs Search Results

- No significant excess observed in the bϕ channels
- Each experiment sees a <2σ excess in the bbb channel at 120-150 GeV (including trials factors)





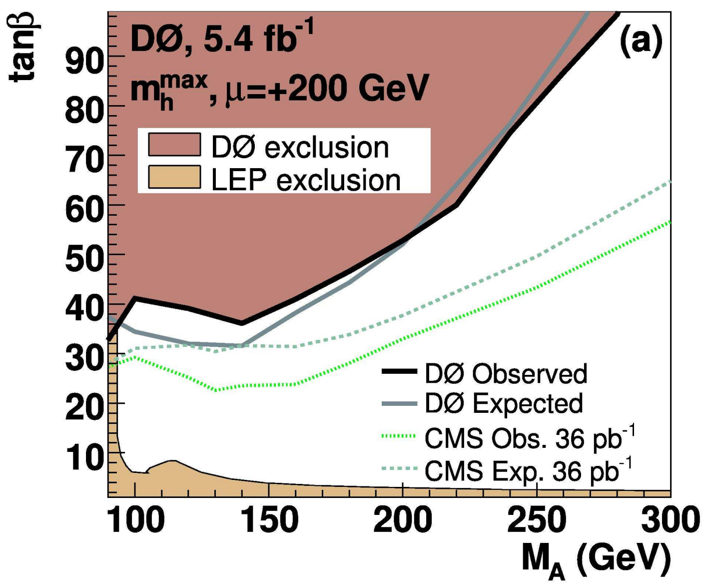


MSSM Interpretation

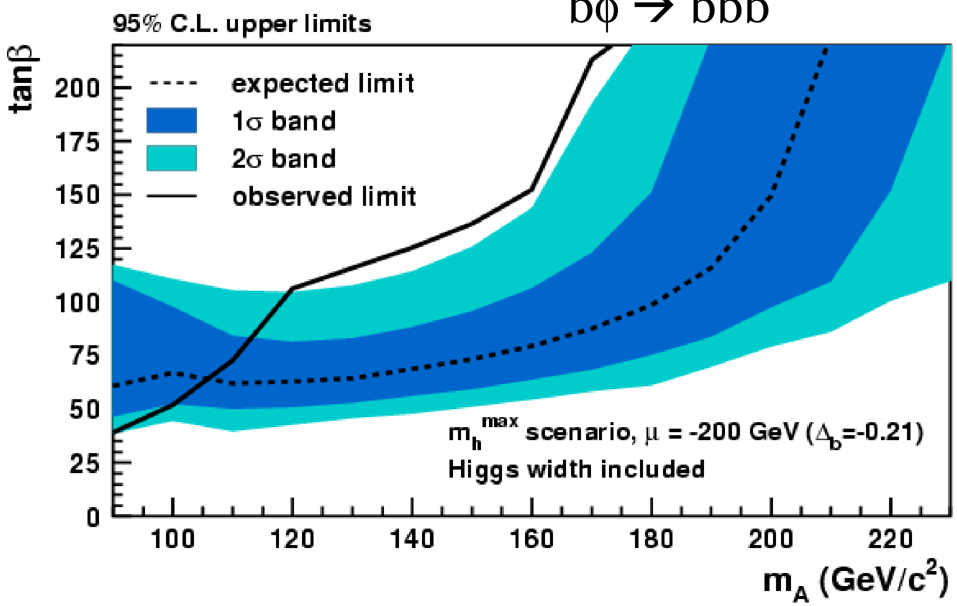
- Previous limits apply only for resonances much narrower than the experimental resolution
  - SM Higgs, new scalars, etc
- MSSM Higgs in high-tanβ scenarios are not generally narrow
- At tree level, $\sigma \times BR = 2\sigma_{SM}\tan^2\beta \times 90\%$ (10% for ττ)
- To extract limits on tanβ uncertainties on cross section and Higgs width should be taken into account.
- Higgs properties are largely, but not completely, determined by m_A and tanβ
- Loop corrections introduce dependence on other SUSY parameters
  - M. Carena *et al*., Eur.Phys.J. C45 (2006) 797-814 (hep-ph/0511023)
- Important to specify which benchmark scenario is being used

MSSM Results

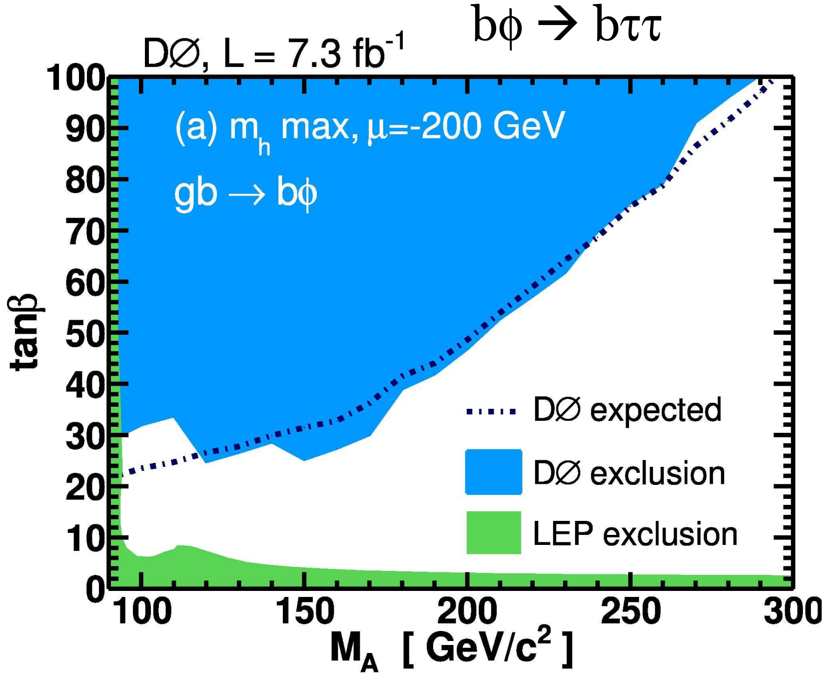
Inclusive ττ



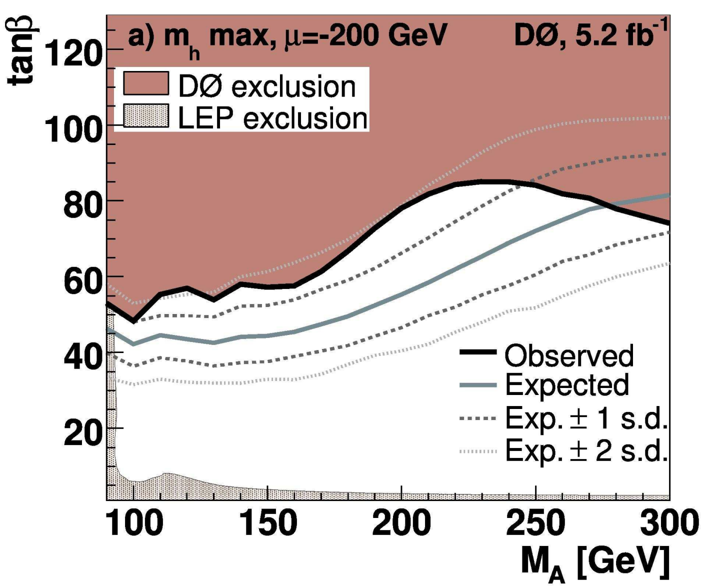
bϕ → bbb



bϕ → bττ



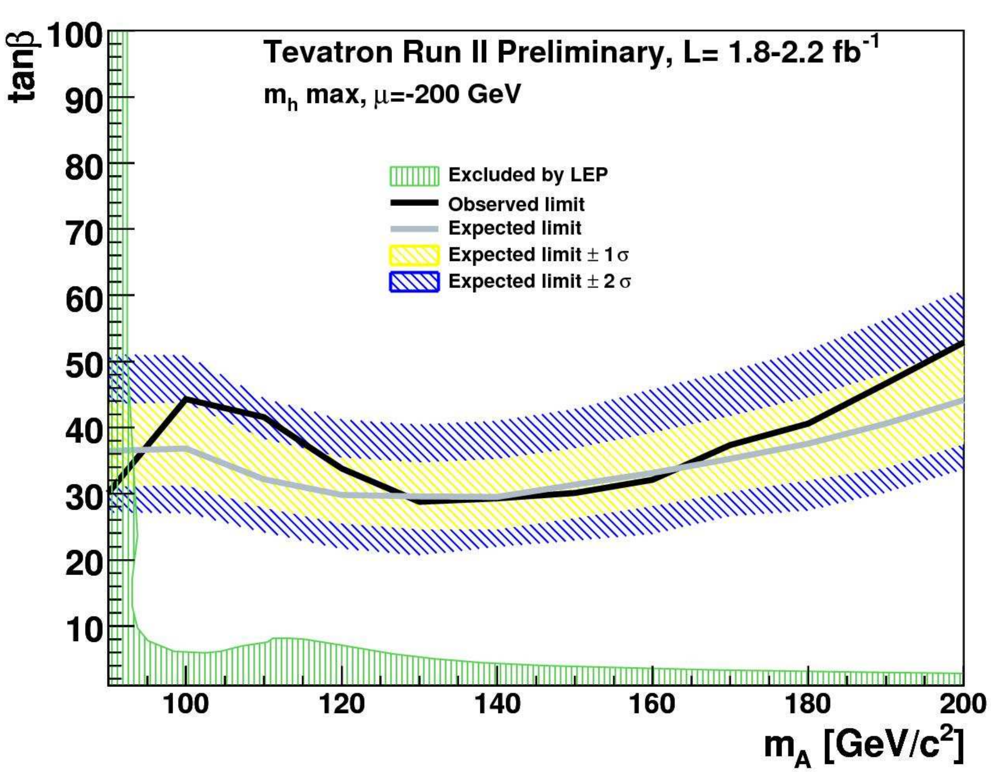
bϕ → bbb

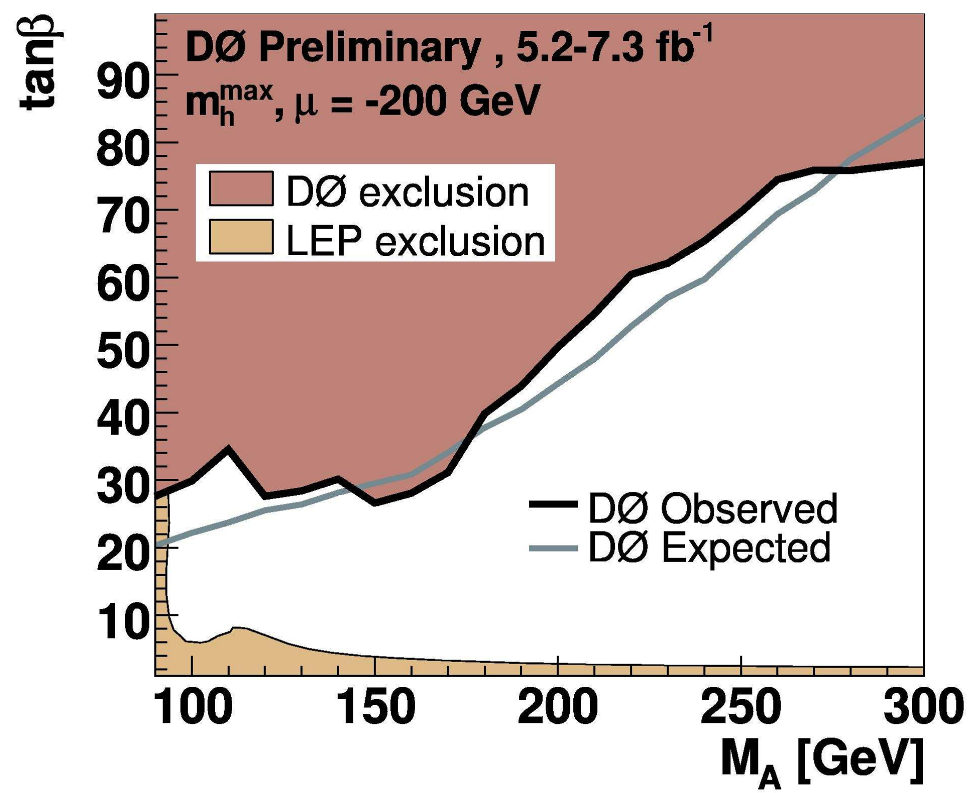


MSSM Combinations

- Left – Tevatron combination of CDF and D0 inclusive ditau results (only up to 2.2 fb-1)
- Right – D0 combination of bττ and bbb channels

- Combination of CDF and D0 bbb results is in progress





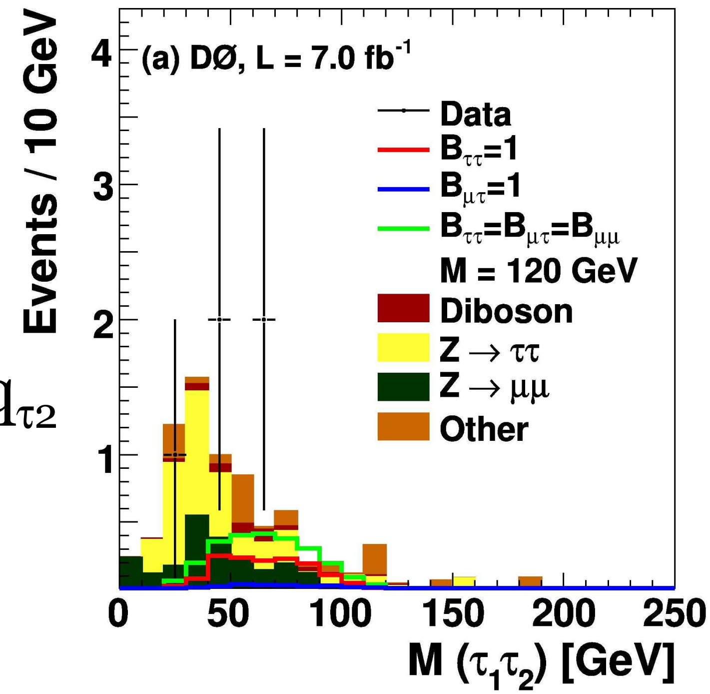
Doubly-Charged Higgs

- Possible in models like Little Higgs and L-R symmetry
- Pair-produced $H^{++}H^{--}$
- Some models favor ττ decays, others have ~equal BR's into μμ, μτ, ττ
- First search for the ττ decay mode

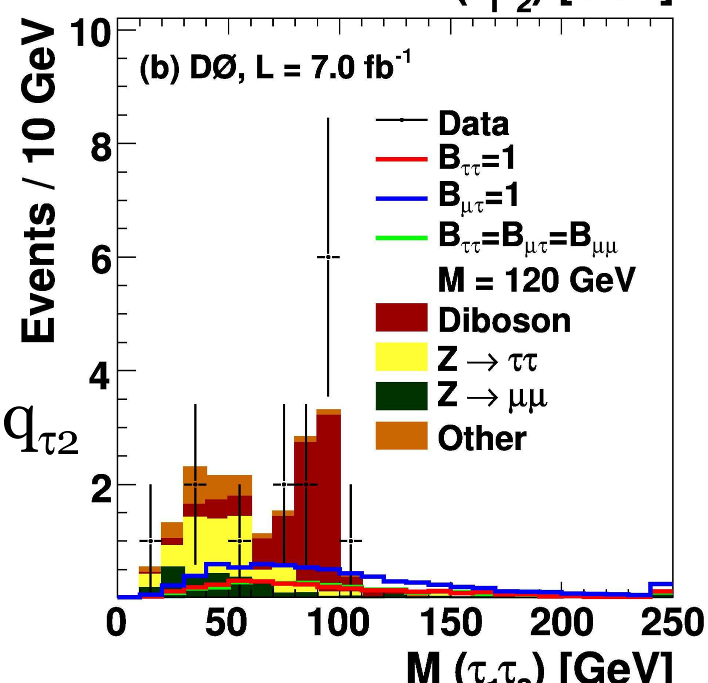
- Base event selection: at least one muon and two hadronic τ candidates

	All	$N_\mu = 1$, $N_\tau = 2$, $q_{\tau_1} = q_{\tau_2}$	$N_\mu = 1$, $N_\tau = 2$, $q_{\tau_1} = -q_{\tau_2}$	$N_\mu = 1$, $N_\tau = 3$	$N_\mu = 2$, $N_\tau = 2$
Signal					
$\tau^\pm\tau^\pm$	6.6 ± 0.9	1.4 ± 0.2	3.1 ± 0.4	1.6 ± 0.2	0.4 ± 0.1
$\mu^\pm\tau^\pm$	13.9 ± 1.9	0.3 ± 0.1	6.8 ± 0.9	0.4 ± 0.1	6.3 ± 0.9
Equal $\mathcal{B}$	9.5 ± 1.3	2.5 ± 0.3	3.1 ± 1.0	1.2 ± 0.2	2.6 ± 0.4
Background					
$Z \to \tau^+\tau^-$	8.2 ± 1.1	3.4 ± 0.5	4.8 ± 0.7	< 0.1	< 0.1
$Z \to \mu^+\mu^-$	5.1 ± 0.7	2.2 ± 0.3	2.5 ± 0.4	0.1 ± 0.1	0.2 ± 0.1
$Z \to e^+e^-$	0.3 ± 0.1	< 0.1	0.3 ± 0.1	< 0.1	< 0.1
W + jets	2.9 ± 0.4	1.1 ± 0.2	1.8 ± 0.3	< 0.1	< 0.1
$t\bar{t}$	0.6 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	< 0.1
Diboson	10.5 ± 1.7	0.5 ± 0.1	8.5 ± 1.4	0.4 ± 0.1	1.1 ± 0.2
Multijet	< 0.8	< 0.2	< 0.5	< 0.1	< 0.1
Background Sum	27.6 ± 4.9	7.5 ± 1.2	18.2 ± 3.3	0.6 ± 0.1	1.3 ± 0.2
Data	22	5	15	0	2

$q_{\tau 1} = q_{\tau 2}$

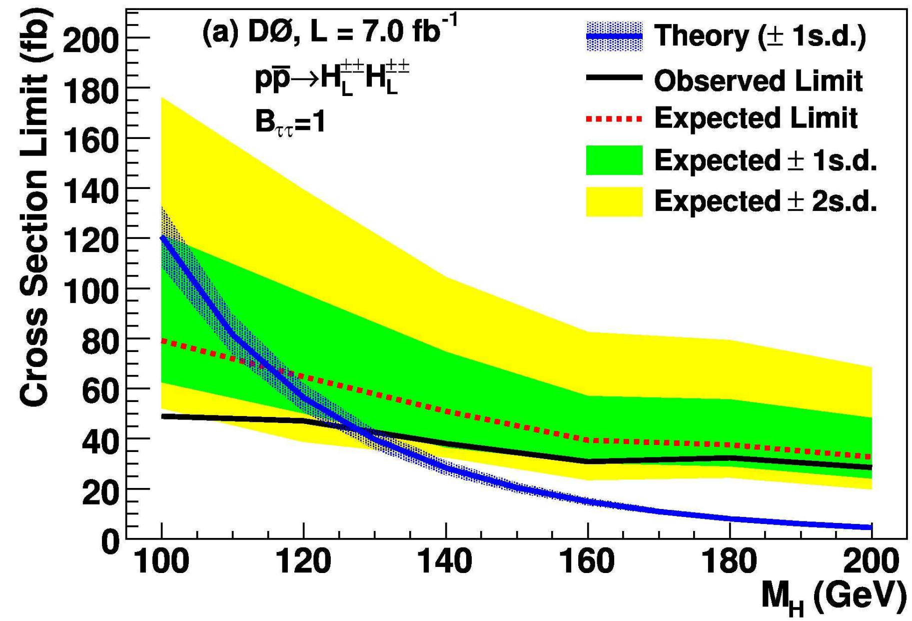


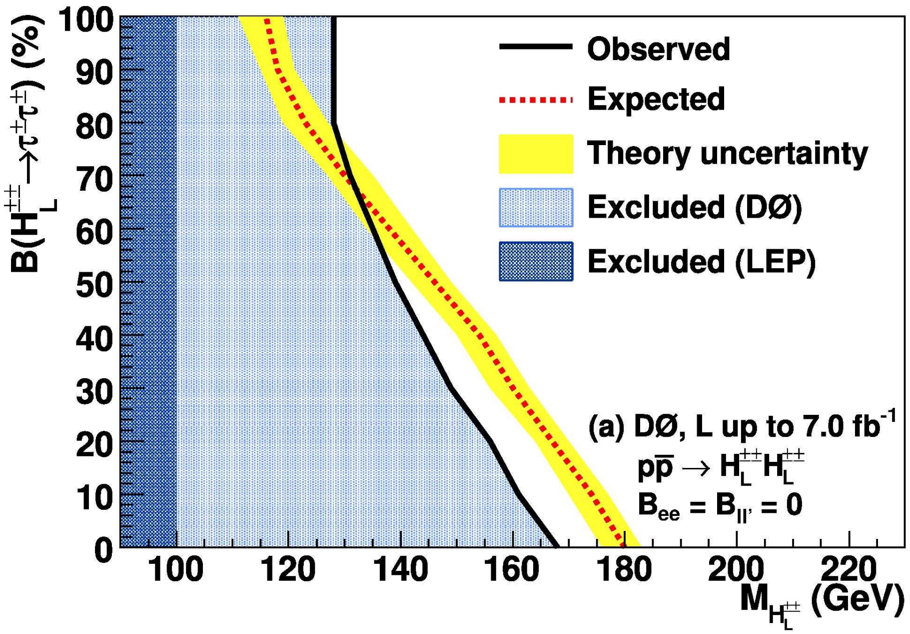
$q_{\tau 1} = -q_{\tau 2}$

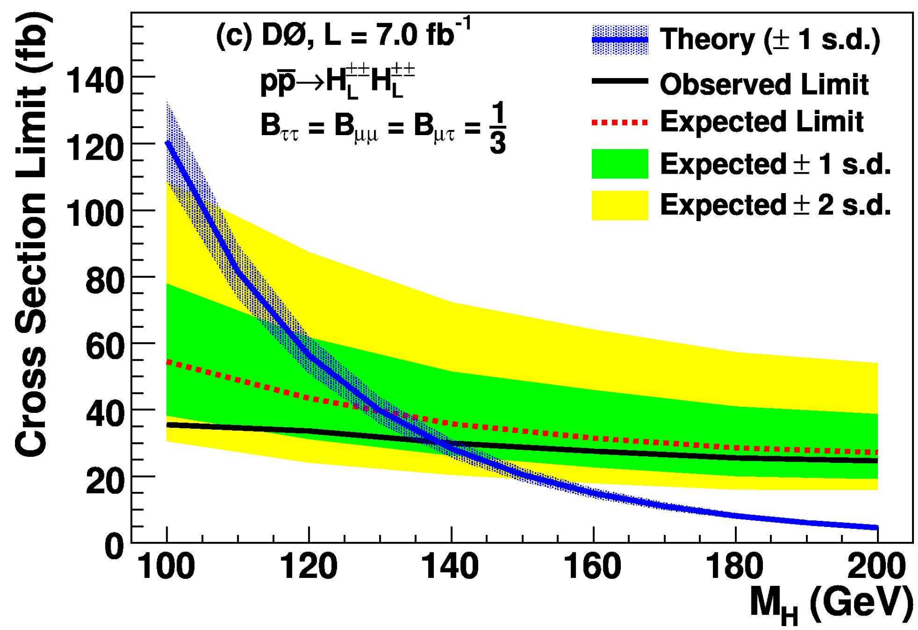


Doubly-Charged Higgs

- Cross section limits for various BR hypotheses
- Exclude $M(H_L^{\pm\pm}) > 128$ (100% $\tau\tau$), 144 (100% $\mu\tau$), 130 (equal $\mu\mu$,$\mu\tau$,$\tau\tau$) GeV
- Exclusion region in $B(H\rightarrow\tau\tau)$ vs $M(H_{L,R})$ for a model with only $\mu\mu$ and $\tau\tau$ decays
- arXiv:1106.4250 (submitted to PRL)







Fermiophobic Higgs

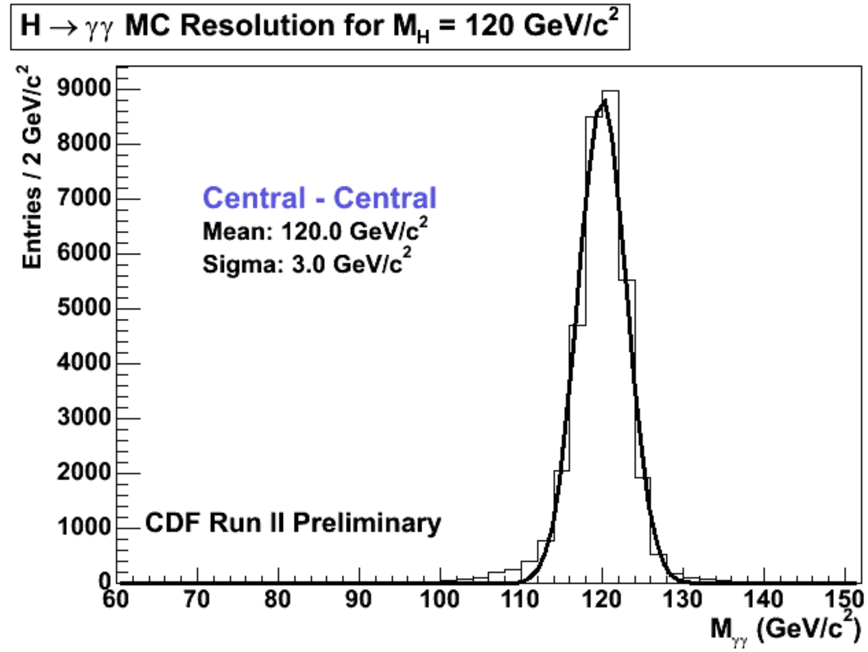
- Low-mass Higgs in these models wouldn't appear in b-bbar searches
- Search instead in diphoton decays

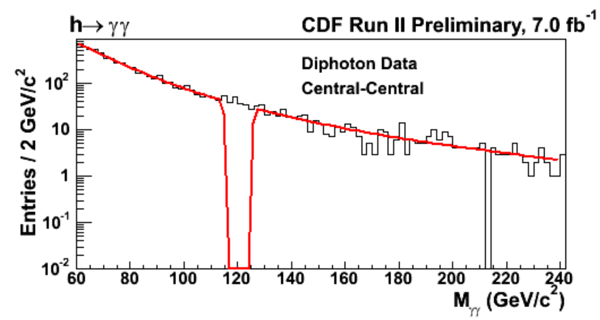
- Production is W/ZH and VBF
  - No inclusive gg->H because no coupling to quark loop

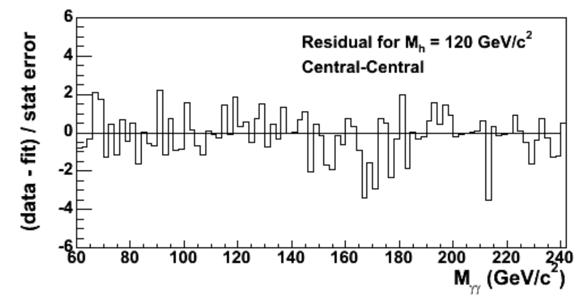
- Signal is narrow (~3% resolution)

- Model the background using a sideband fit

- Split sample by diphoton system p_T to enhance sensitivity
  - Higgs signal is recoiling







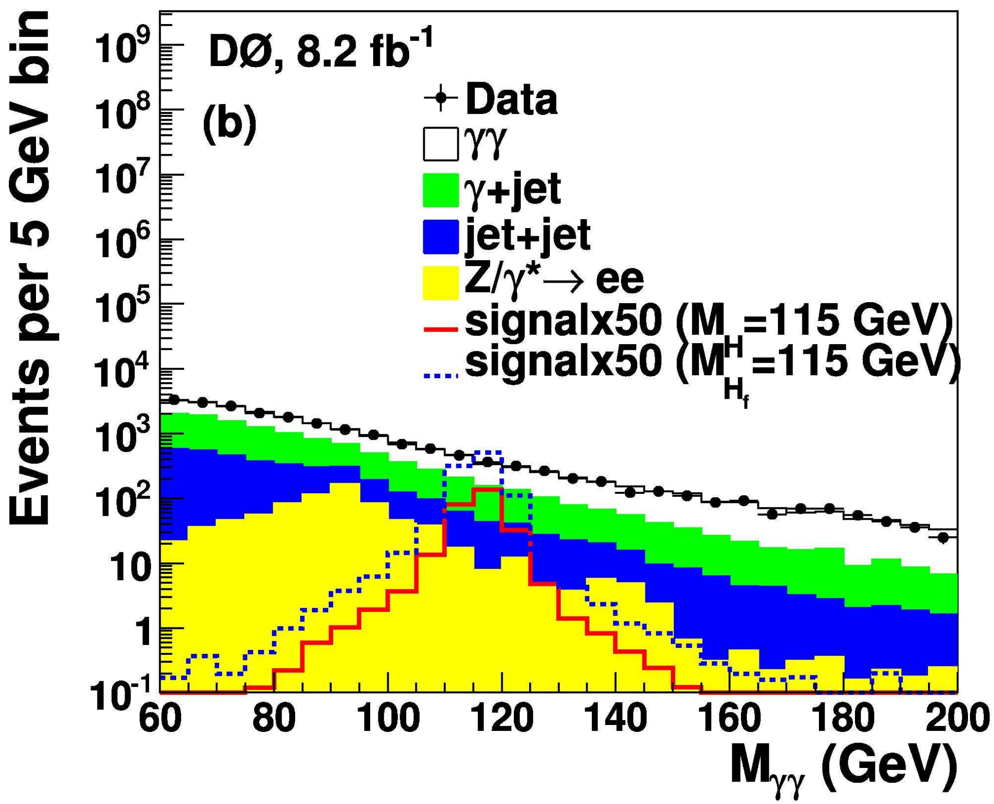
Fermiophobic Higgs

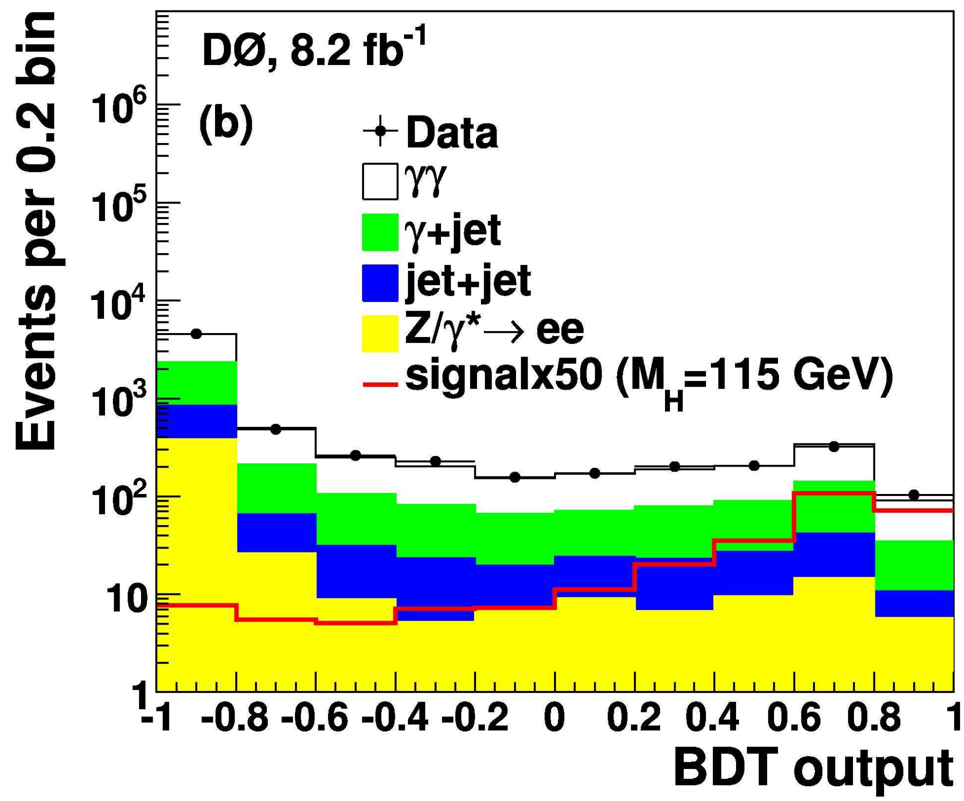
- DO combines the diphoton mass and p_T and a few other variables ($\delta\phi$, p_{T1}, p_{T2}) in a BDT discriminant

- Fake photon backgrounds derived from data

- Direct diphoton background modeled by SHERPA, with floating normalization in the BDT fit

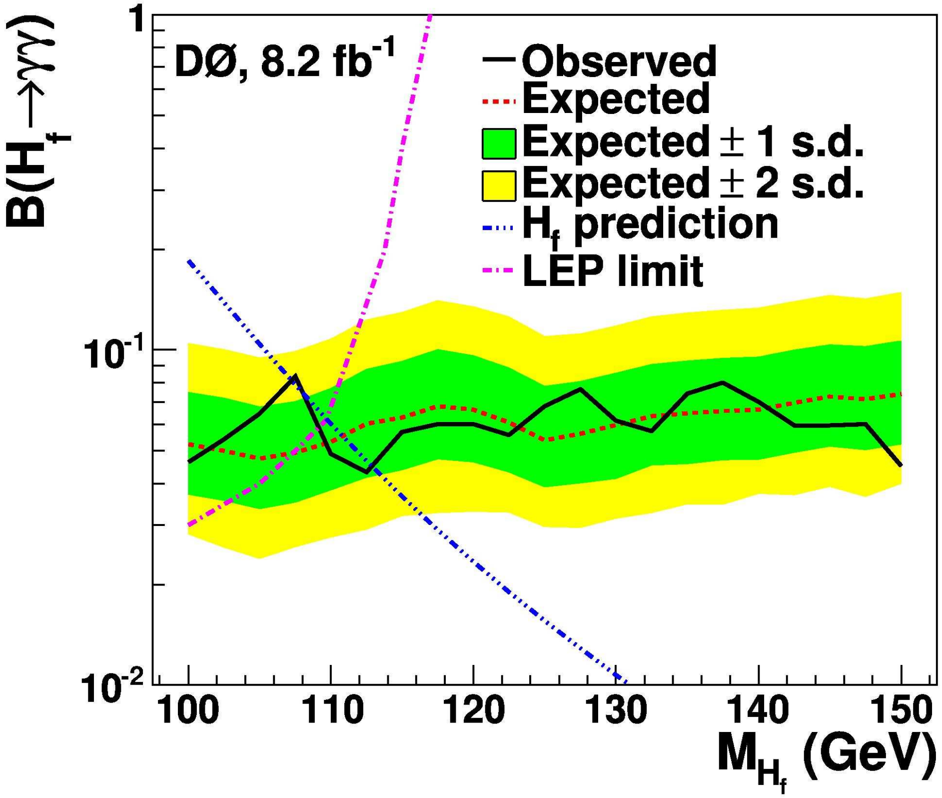
arXiv:1107.4587 (submitted to PRL)

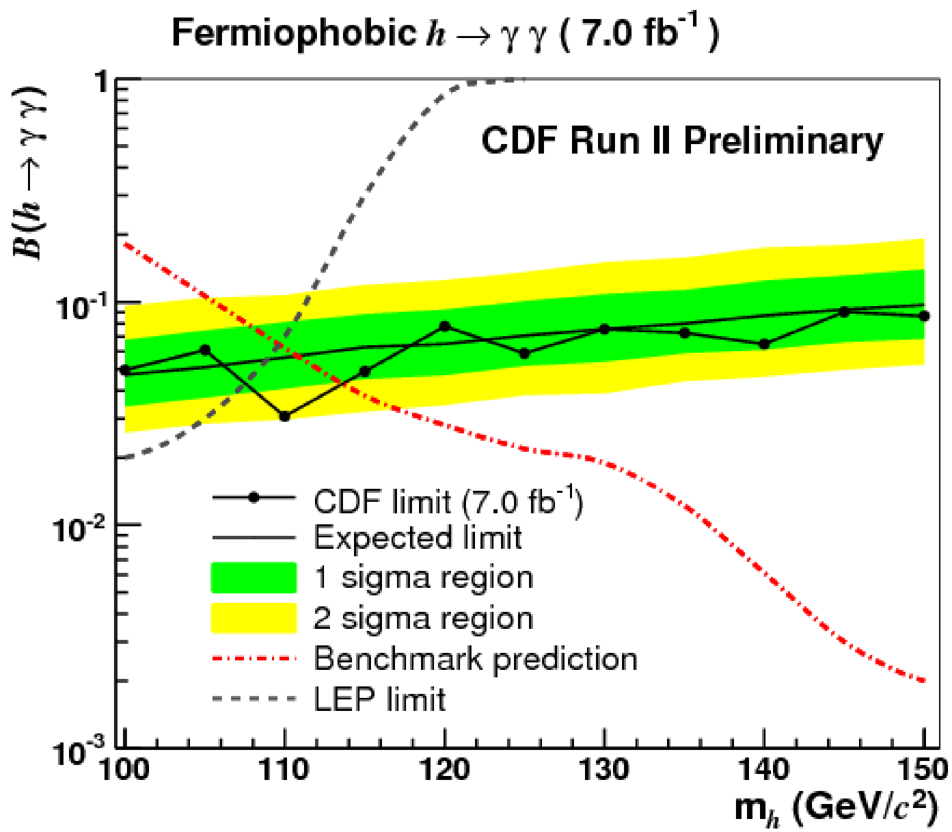




Fermiophobic Higgs Limits

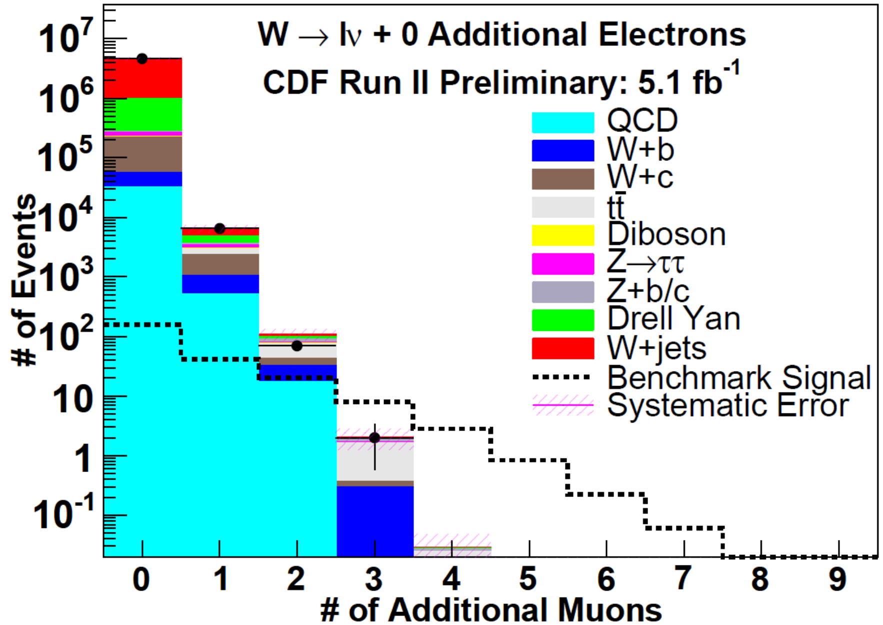
- No significant excess observed by either experiment
- Exclude fermiophobic Higgs masses up to 113-114 GeV/c²
- Combination of CDF/D0 in progress

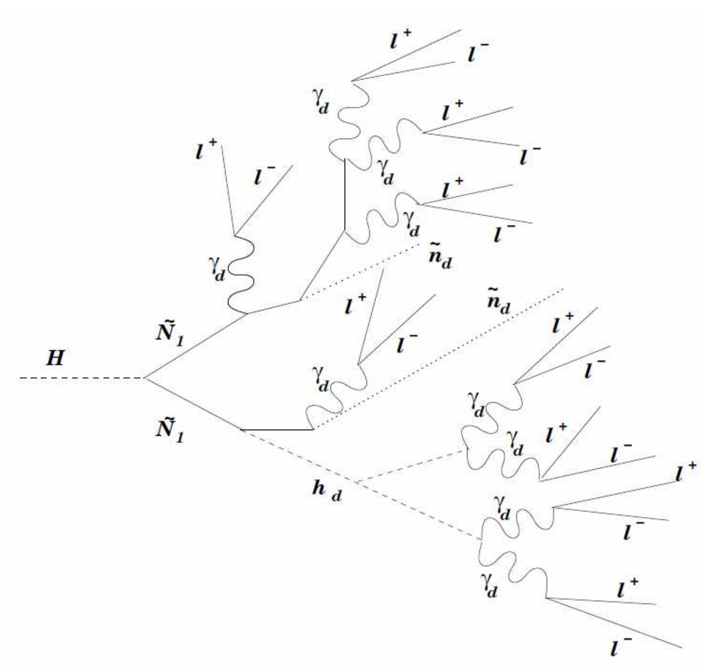


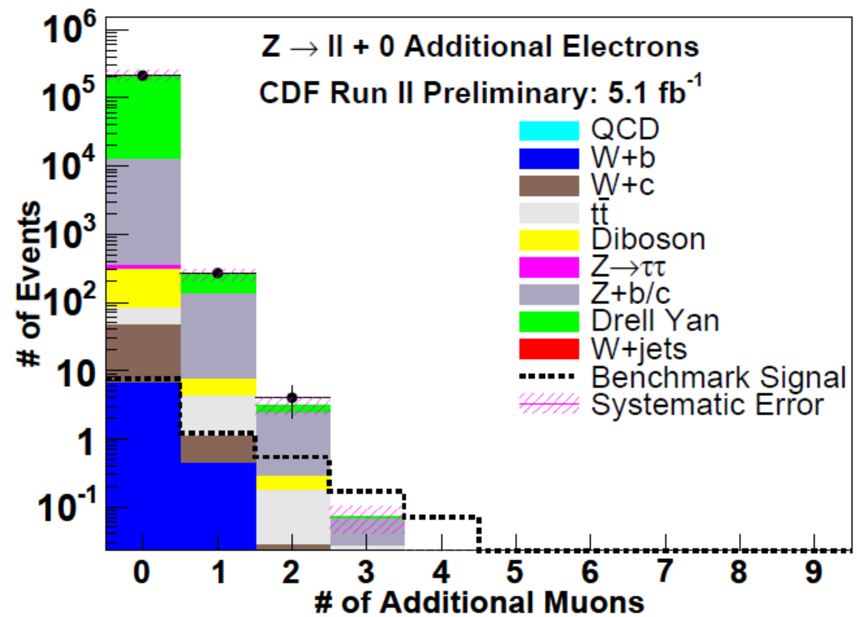


Dark Sector Decays

- One of several ways to hide a light Higgs from the LEP limits
  - Decays through neutralinos and dark sector “photons”
  - Falkowski *et al* arXiv:1002.2952
- Search for W/Z+H production, final state containing many soft leptons
- Exclude this particular benchmark scenario at 99.7% CL







Summary

- Tevatron experiments are pursuing a wide-ranging search program for non-SM Higgs
  - MSSM and other “exotic” models
- Results continue to update with new data
- No evidence yet but still more data to analyze

- For more, see these parallel session talks
  - Parallel session 4 (Mon PM)
    - Tevatron searches for charged and doubly-charged Higgs - Z. Hubacek
    - Tevatron combination of fermiophobic Higgs searches - G. Chen
  - Parallel session 8 (Thurs AM)
    - SUSY Higgs in bbb final state – TW
    - SUSY H--> tau tau and b tau tau and combination of D0 SUSY Higgs – J. Haley