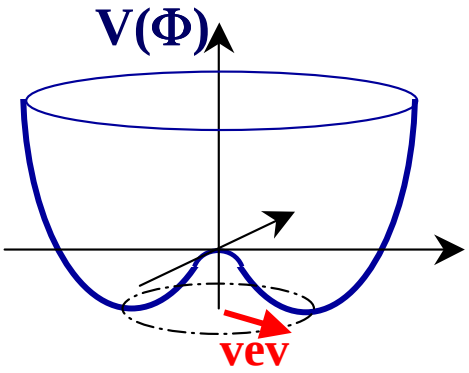
Search for non-SM Higgs at DØ

Alex Melnitchouk
(Brown University)
for the DØ collaboration



PHENO 2004
April 27
Madison, WI

BROWN UNIVERSITY

DØ

OUTLINE

- Higgs beyond the Standard Model
  - ü **Light Higgs with enhanced $\gamma\gamma$ decays**
  - ü **Neutral Higgses in high tanβ SUSY** ($b\bar{b}\phi(\rightarrow b\bar{b})$)
  - ü **Double-charged Higgs**

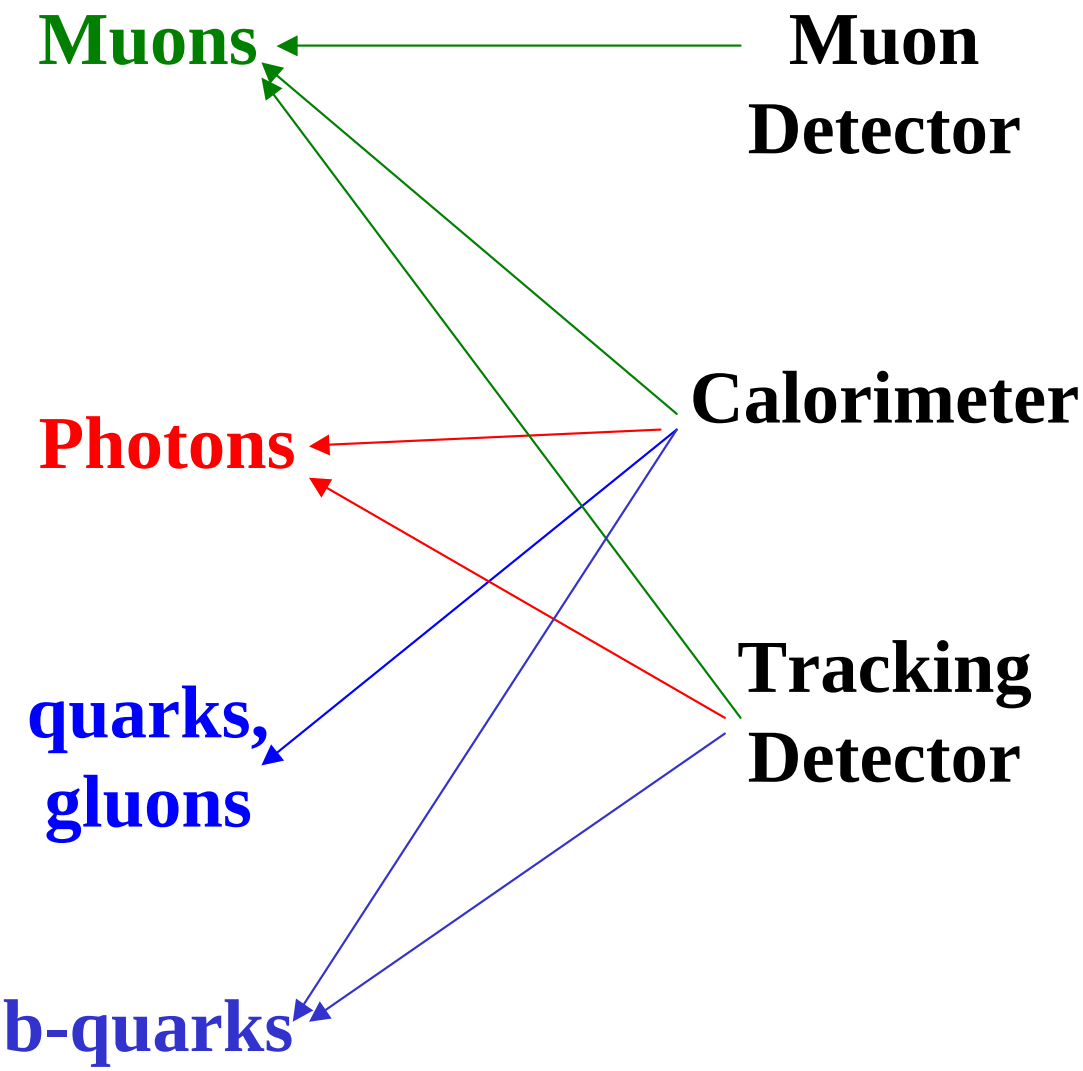
    ($p\bar{p} \rightarrow H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$)
- Search Strategies
- Results
- Summary

Final states contain muons, photons, and b-jets

What Detectors Do We Need for Mentioned Non-SM Higgs Searches ?

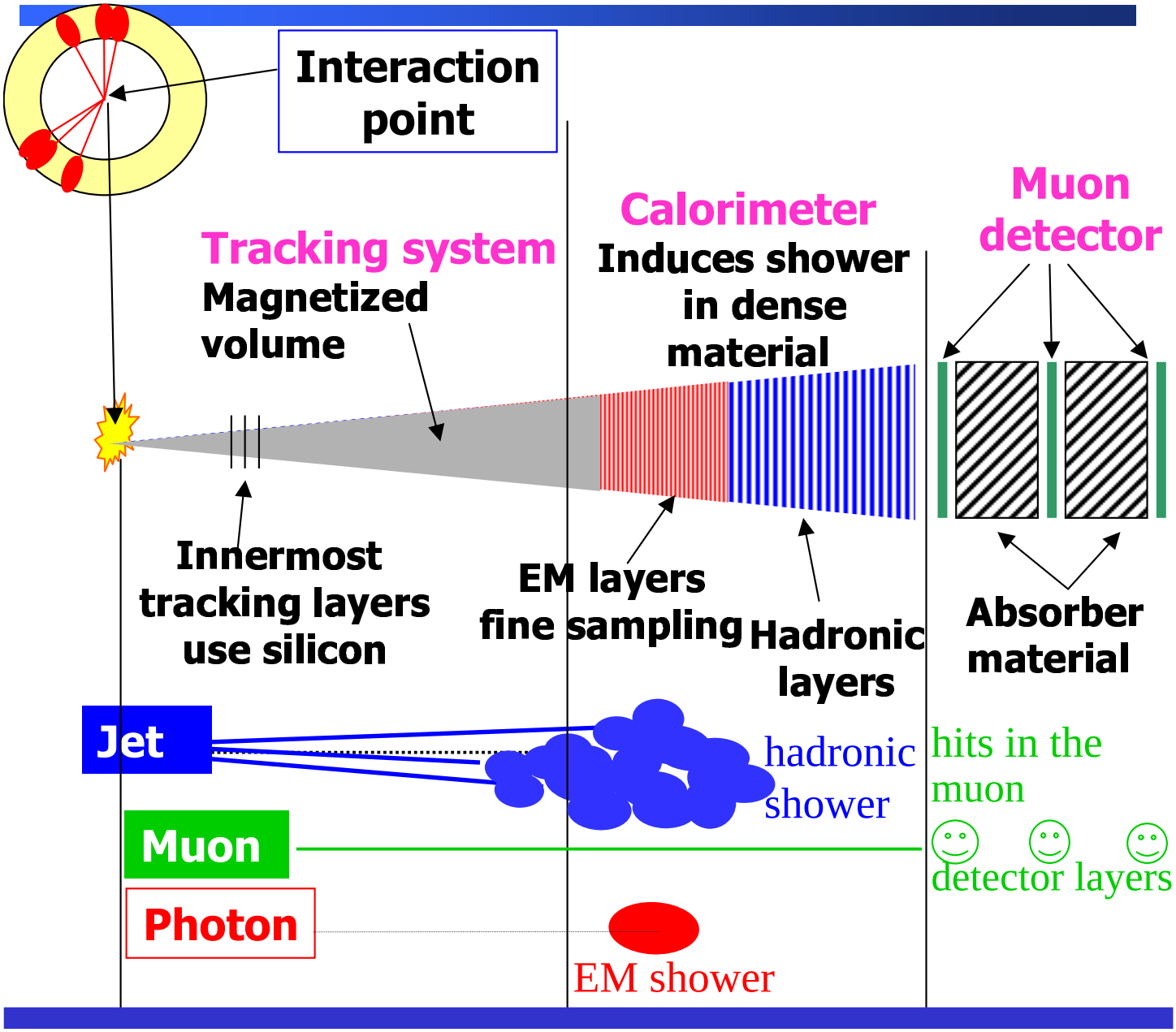
The final states of interest contain:

To indentify these particles we need:



A Slice of the DØ Detector.

Experimental Signatures of μ, γ, b



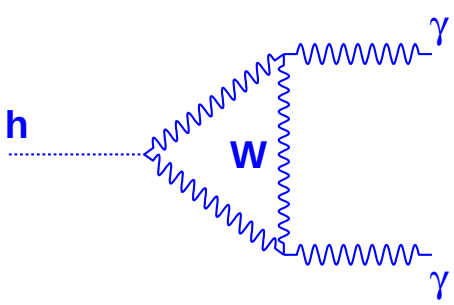
Muon – hits in the layers of muon system + track

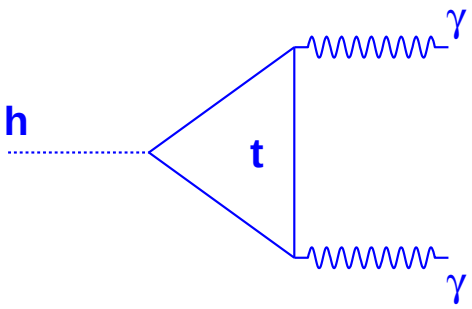
Photon – EM-like shower + NO track

b-quark – hadronic shower that points to a secondary vertex and/or contains electron/muon

h→γγ decay mode in the SM and beyond. Why γγ ?

- no tree-level Hγγ coupling (Higgs is neutral)
- diphoton decays happen via W or top-quark loop:

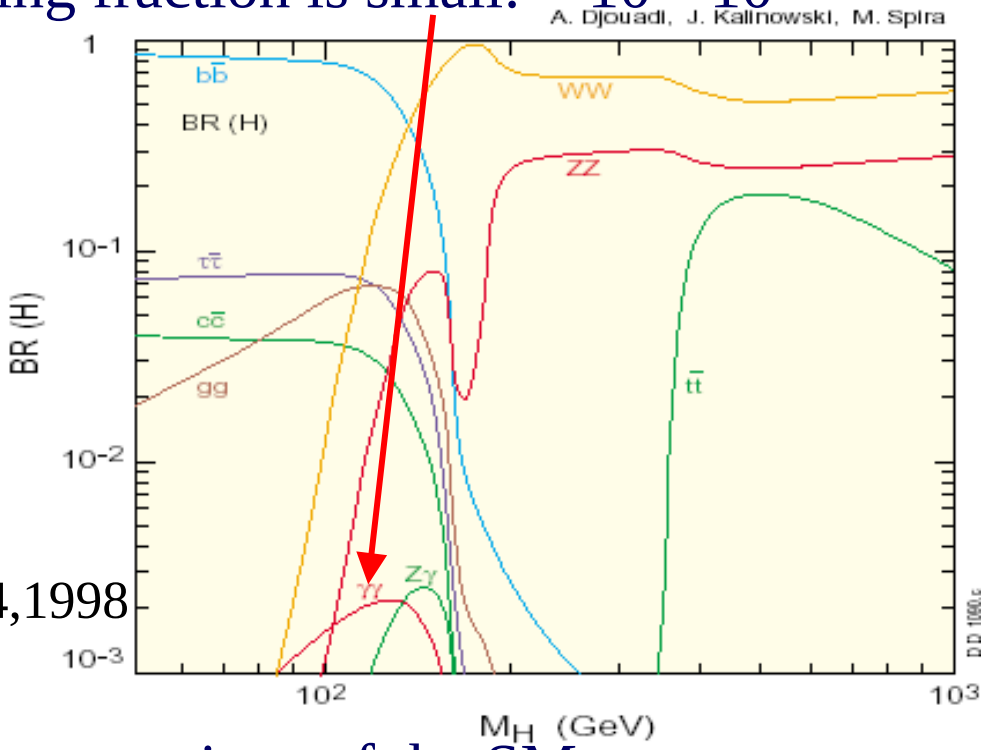




⇒

- H→γγ branching fraction is small: ~ 10^{-3}-10^{-4}

Higgs decays mostly to b-quark and W pairs



Comput.Phys. Commun. 108:56-74,1998

- however many extensions of the SM predict enhanced γγ decay rate of the Higgs

$h \rightarrow \gamma\gamma$ decays can be enhanced

- due to **suppressed couplings** to

- – all fermions *(Fermiophobic Higgs)*
  H.E.Haber et al, Nucl. Phys. ***B161****, 493 (1979)*
- – all fermions but top quark *(Topcolor Higgs)*
  B.Dobrescu, Phys. Rev. ***D63,*** *015004 (2001)*
- – top and bottom quark
  J.D. Wells, Phys. Rev. ***D56****, 1504 (1997)*
- – down-type fermions,
  H. Baer, J.D. Wells, Phys. Rev. ***D57****, 446 (1998)*

- Enhanced $\gamma\gamma$ rate is also predicted by some models that employ **Large Extra Dimensions**
  L. Hall, C.Kolda, Phys. Lett. ***B459****, 213 (1999)*

- In addition, $\gamma\gamma$ decay loop can be enhanced by a contribution from a **heavy charged particle** coming from new physics

Look for a bump in $\gamma\gamma$ invariant mass spectrum !

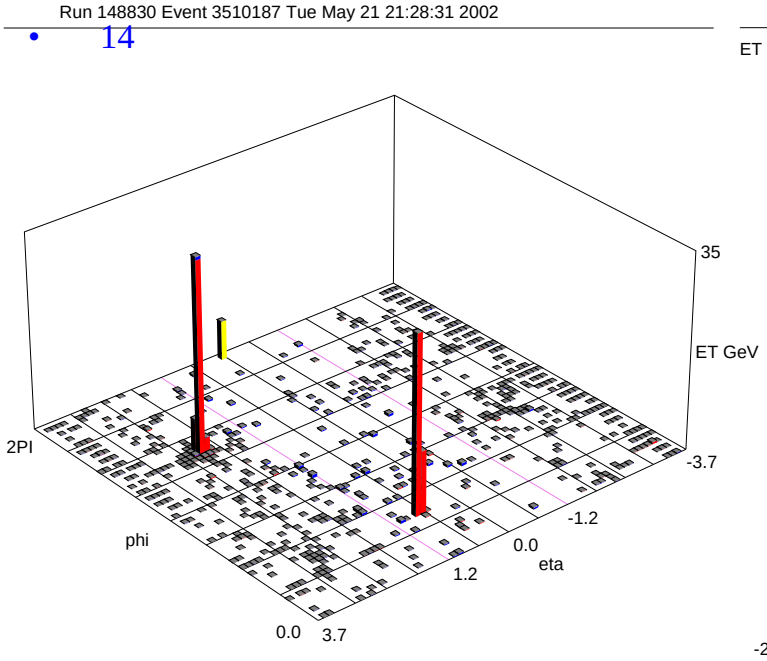
Selection of $\gamma\gamma$ Candidate Events

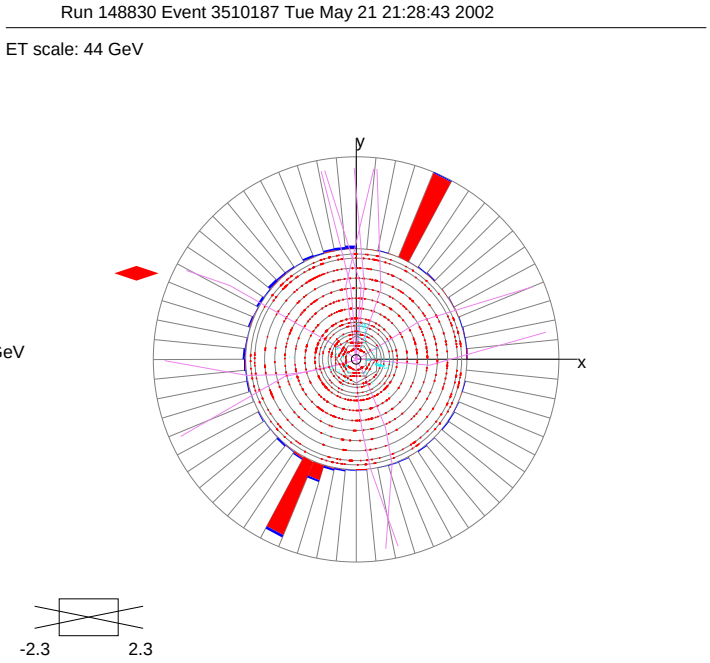
- ***Trigger:***
  di-EM* high p_T trigger

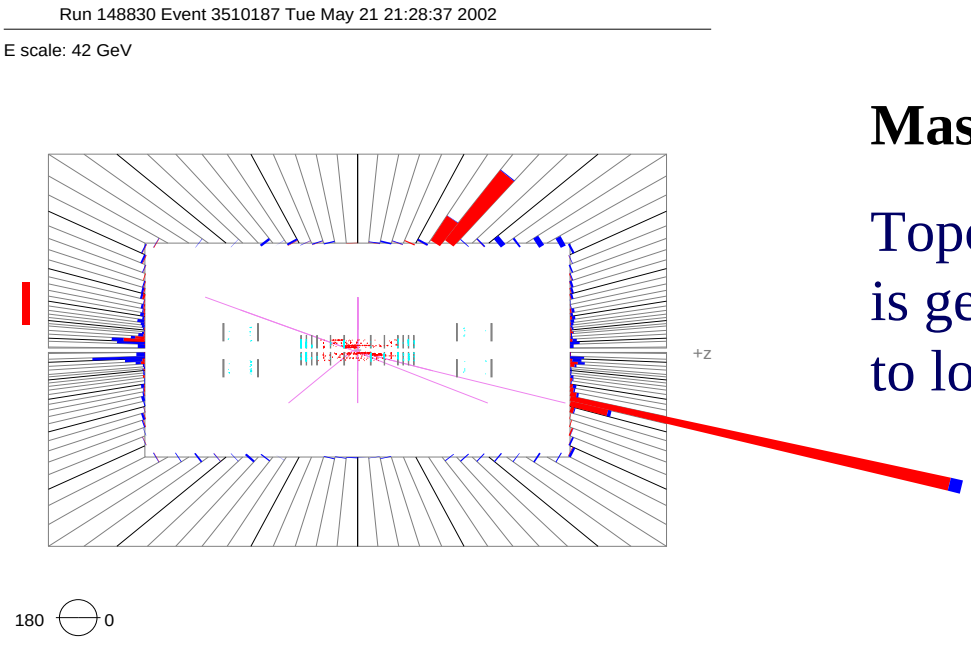
- ***Offline:*** *(on both objects)*
- **Kinematic cuts:** $p_T > 25$GeV
- **Acceptance cuts:** Central or End Cap Calorimeter up to $|\eta|=2.4$
- **Photon ID:** -- shower shape consistent with EM shape (EMfraction, Isolation, shower shape cut)
  -- sum of p_T of all tracks in a hollow cone of $0.05<R<0.4$ around photon candidate must be < 2.0 GeV
  -- track veto

- **EM = Electromagnetic Object (Photon or Electron)*

Event Displays of γγ Candidate







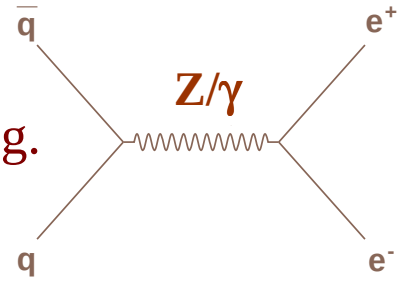
Mass = 125.8 GeV

Topcolor $h \rightarrow \gamma\gamma$ event is generally expected to look like this one

Major Backgrounds :
Drell-Yan and QCD

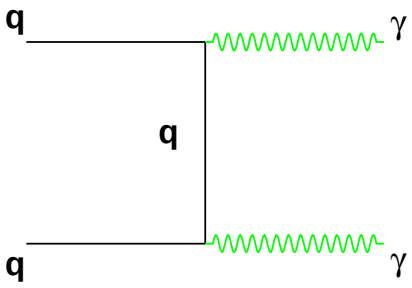
- **$Z/\gamma \rightarrow e^+e^-$** with e^+e^- misidentified as photons (lost tracks)

e.g.



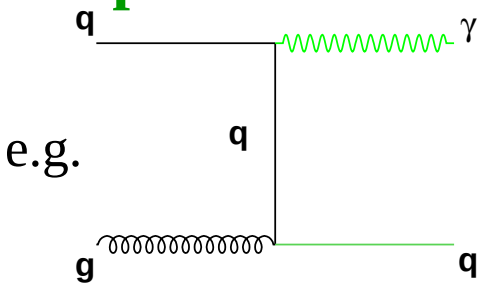
- **QCD processes that in the final state contain :**

1. two photons



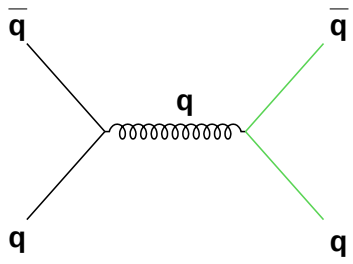
2. a photon and **a hadronic jet misidentified as photon**

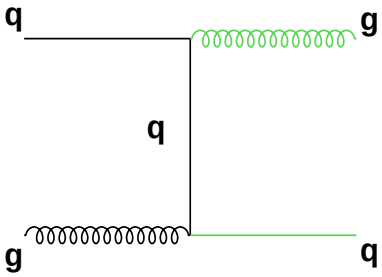
e.g.

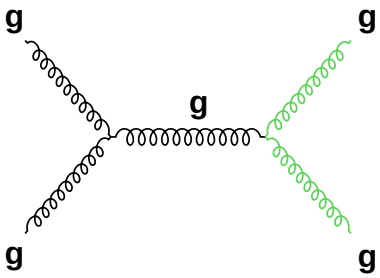


3. two hadronic jets misidentified as photons

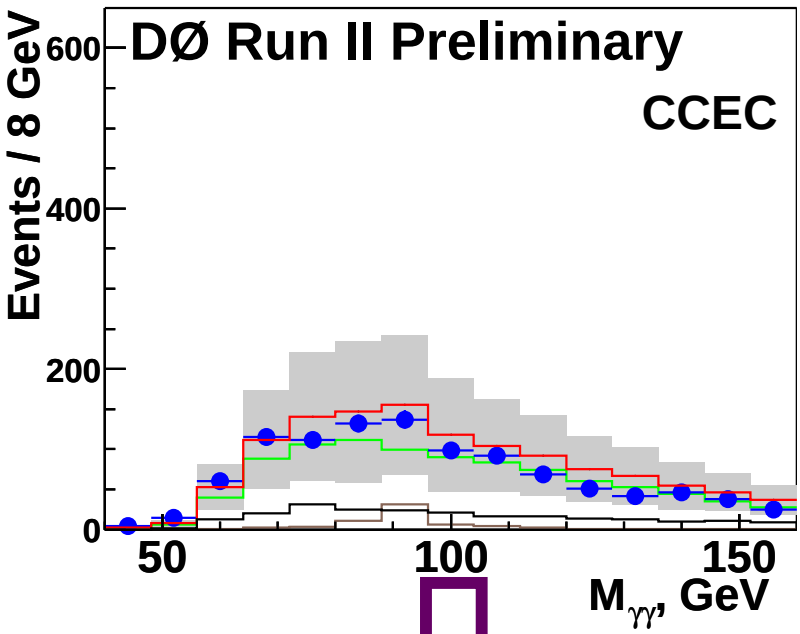
e.g.







$\gamma\gamma$ ($\int Ldt \approx 190\text{pb}^{-1}$) **Results**



data = 1037.0

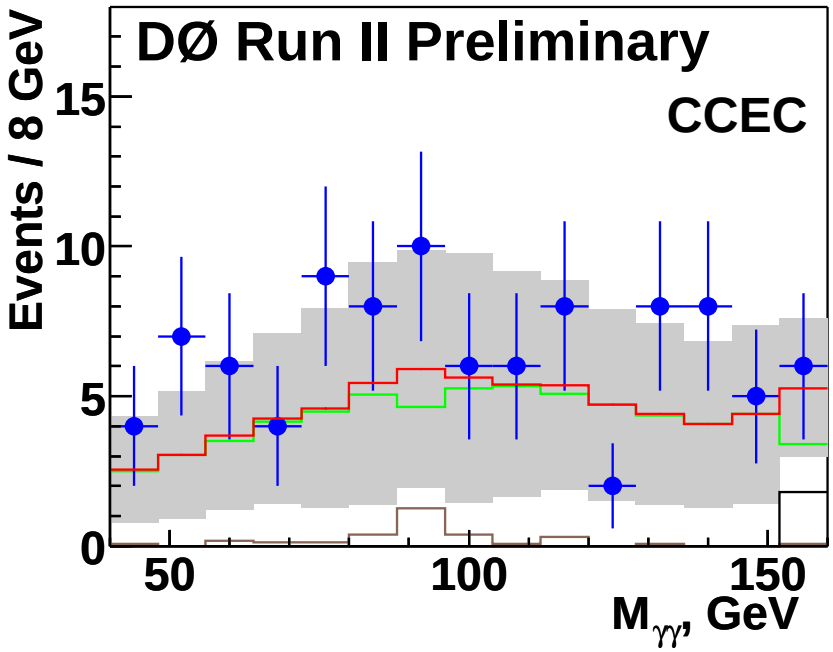
bkgd = 1211.5 +- 671.0

QCD = 922.1 +- 667.2

DY = 64.8 +- 69.4

$\gamma\gamma$ = 224.5 +- 16.6

Diphoton p_T (35 GeV) cut



data = 97.0

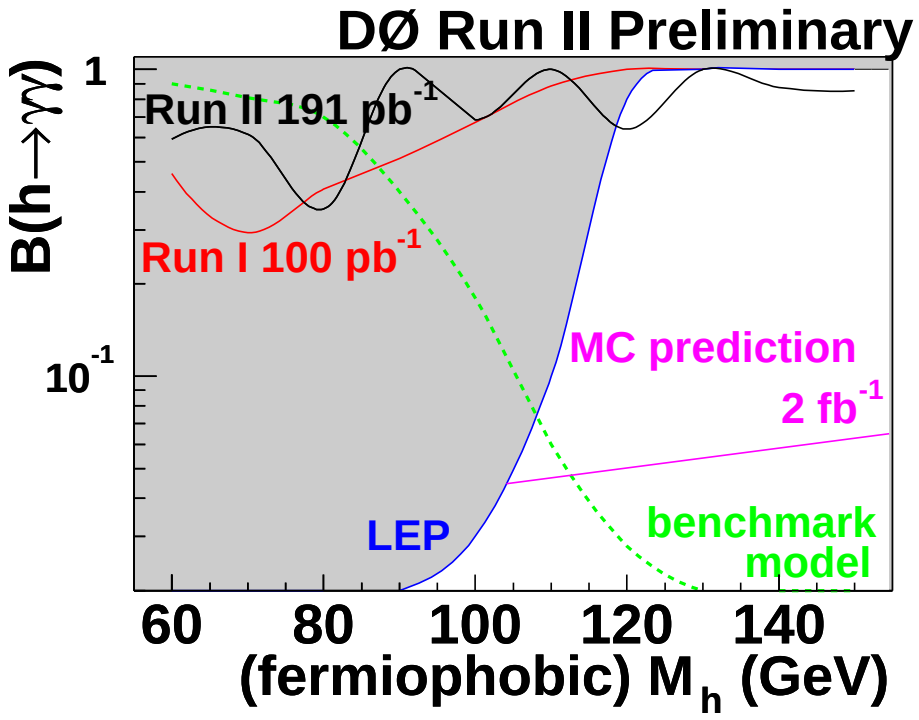
bkgd = 68.8 +- 45.8

QCD = 64.0 +- 45.7

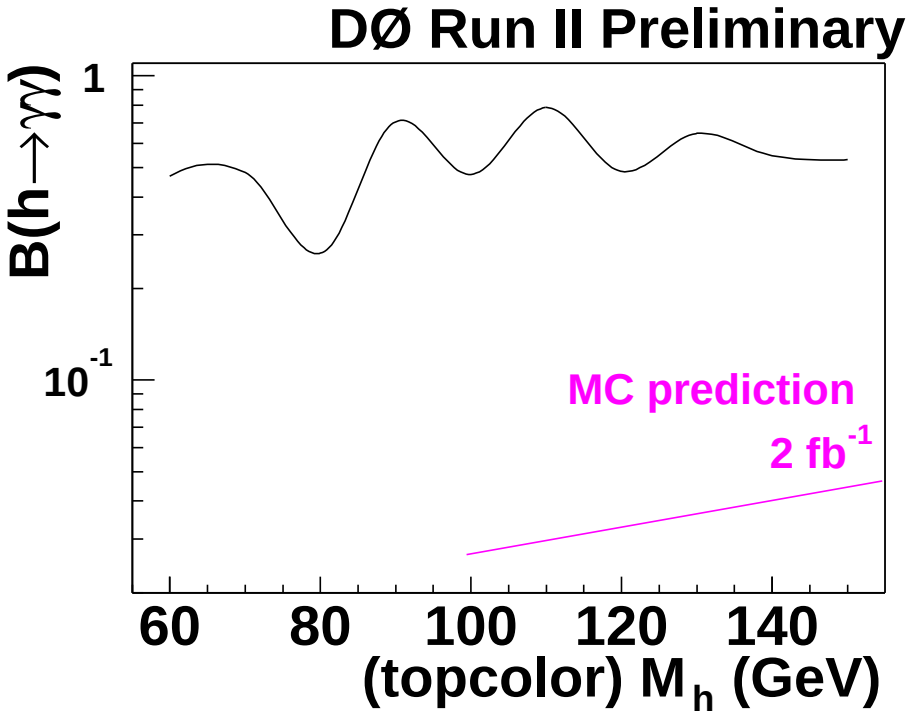
DY = 3.0 +- 3.0

$\gamma\gamma$ = 1.8 +- 0.1

($\int Ldt \approx 190 pb^{-1}$) B(h→γγ) Limits



G.Landsberg, K.Matchev, PRD 62, 035004 (2000)



SUSY Higgs

- **Supersymmetry** (SUSY)
  is a symmetry between spin degrees of freedom
  ≈ any ordinary particle has
  a (much heavier) supersymmetric partner particle
  (to be discovered yet)

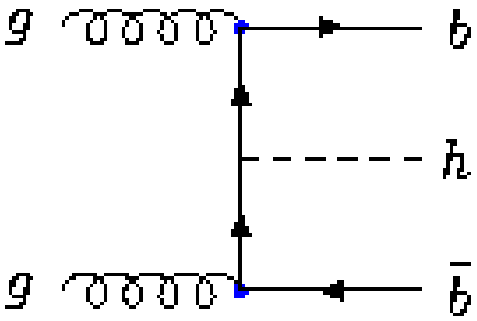
- SUSY Higgs sector consists of
  more than one Higgs particle

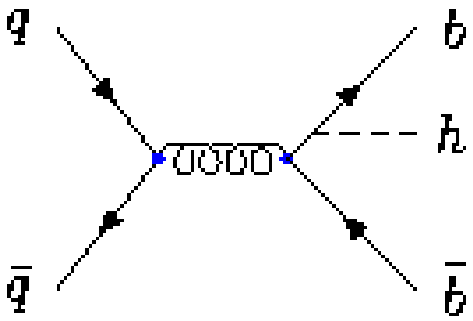
- e.g. Minimal Supersymmetric Model (MSSM) :
  - ü two complex scalar Higgs doublets
  - ü two Vacuum Expectation Values v1 and v2
    ($\tan\beta = v1/v2$)
  - ü 5 Higgs particles : h^0, H^0, A^0, H^+, H^-

Current focus: Neutral Higgses !

Search for Neutral SUSY Higgs Bosons (h,A,H)

- Look for the $b\bar{b}$ decays of a neutral Higgs produced in association with two b-quarks:





- Production cross section ~ $(\tan\beta)^2$
- High $\tan\beta$ (>~30) models are motivated by Grand Unification

  Neutral Higgs Production can be enhanced

- look for a signal in the invariant mass spectrum of the two highest E_T jets in the triple b-tagged multi-jet events

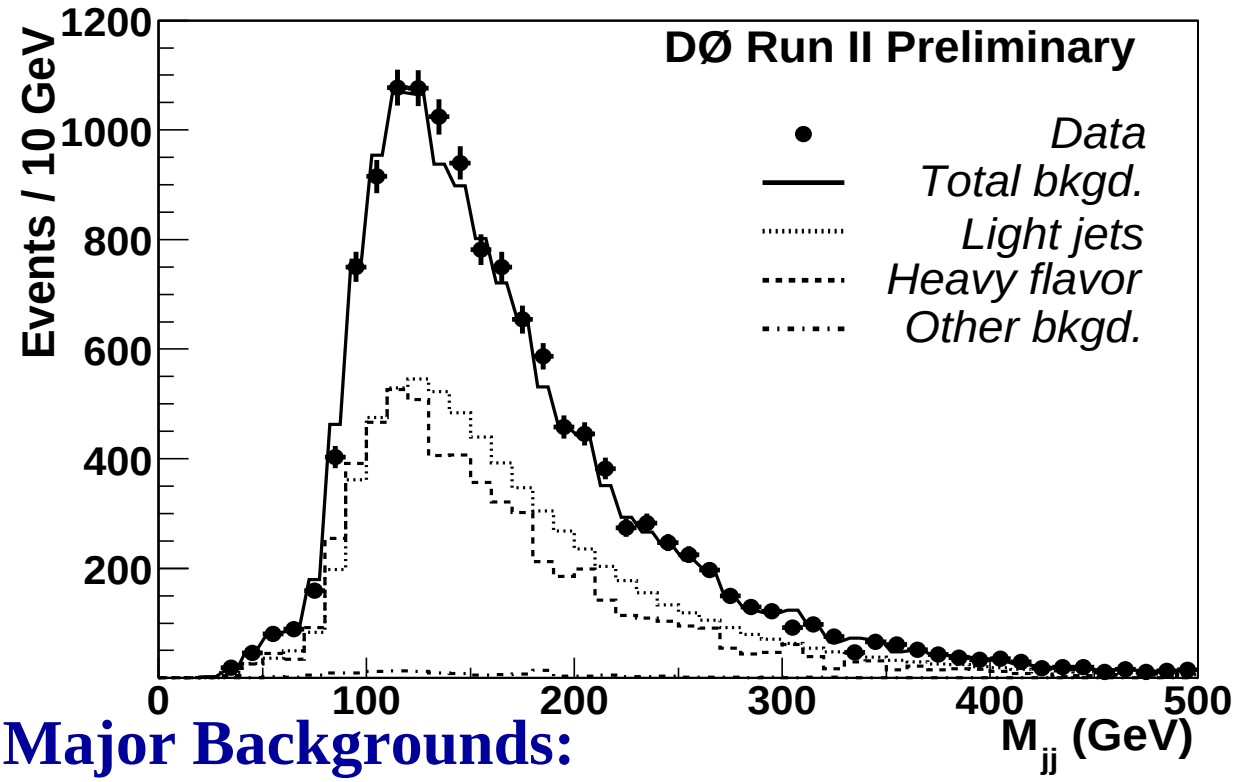
Initial Selection of bbh(→bb) Candidate Events

Trigger: at least three jets
with E_T>15 within $|\eta|$<2.4
at the highest trigger level

Offline: - at least three jets with
E_T >15,15, and 20 GeV
- apply jet energy scale corrections(30%)
- optimize E_T thresholds separately for each Higgs mass point (e.g. for m_h=120 GeV: E_T =45,35, and 15 GeV)

Di-jet Mass Spectrum in Double b-tagged Events

- Look at events with >=4 jets
- Require that at least two jets are b-tagged with Secondary Vertex tagging algorithm



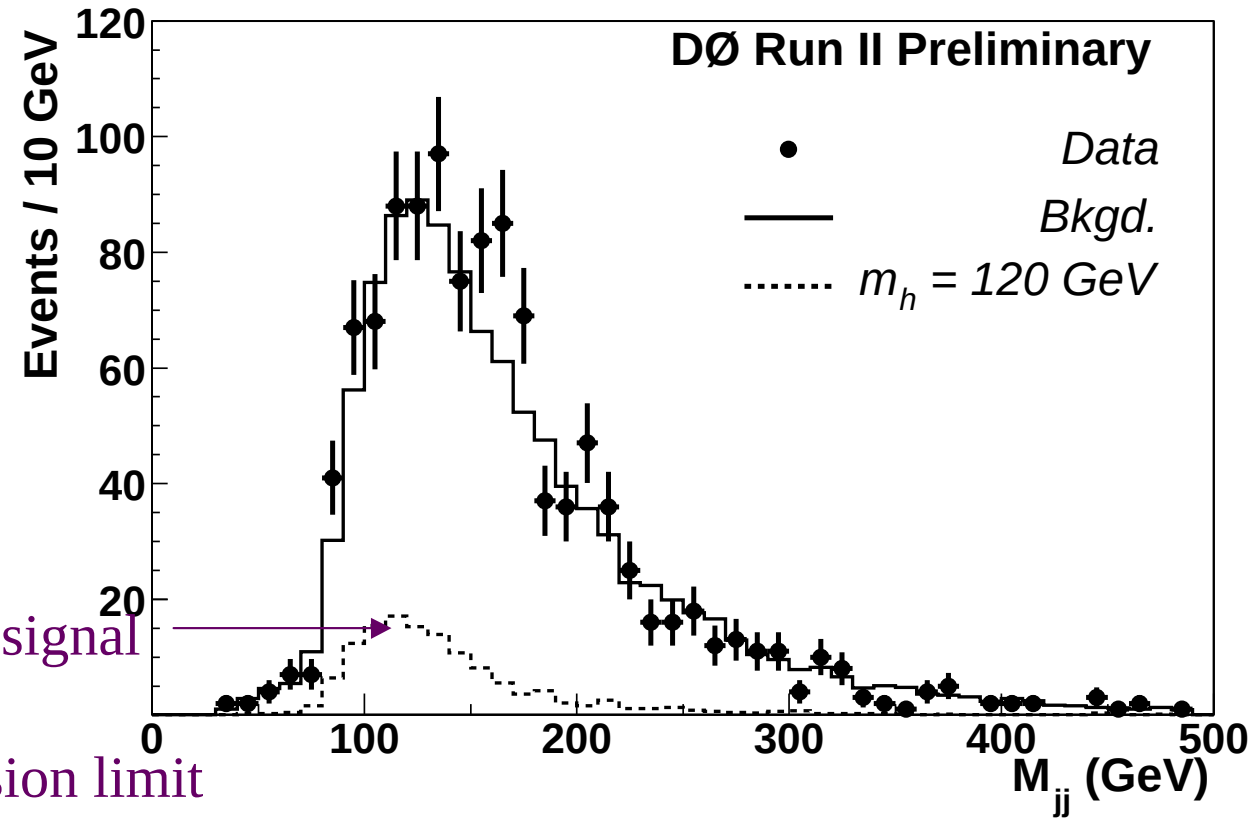
Major Backgrounds:

- "Light jets" = Multi(u/d/s/g)-jet events in which at least two jets were misidentified for b-jets
- "Heavy flavor" = bbj, bbjj events in which both b-quark jets were tagged.

Secondary Vertex tagging does not distinguish between b and c. Need to rely on MC (MADGRAPH) to evaluate relative composition of b and c.

Di-jet Mass Spectrum in Triple b-tagged Events

- From the double b-tagged spectrum(previous slide) derive the shape of the triple b-tagged background
- Normalize to data using the region where negligible amount of signal is expected (outside 1σ window)

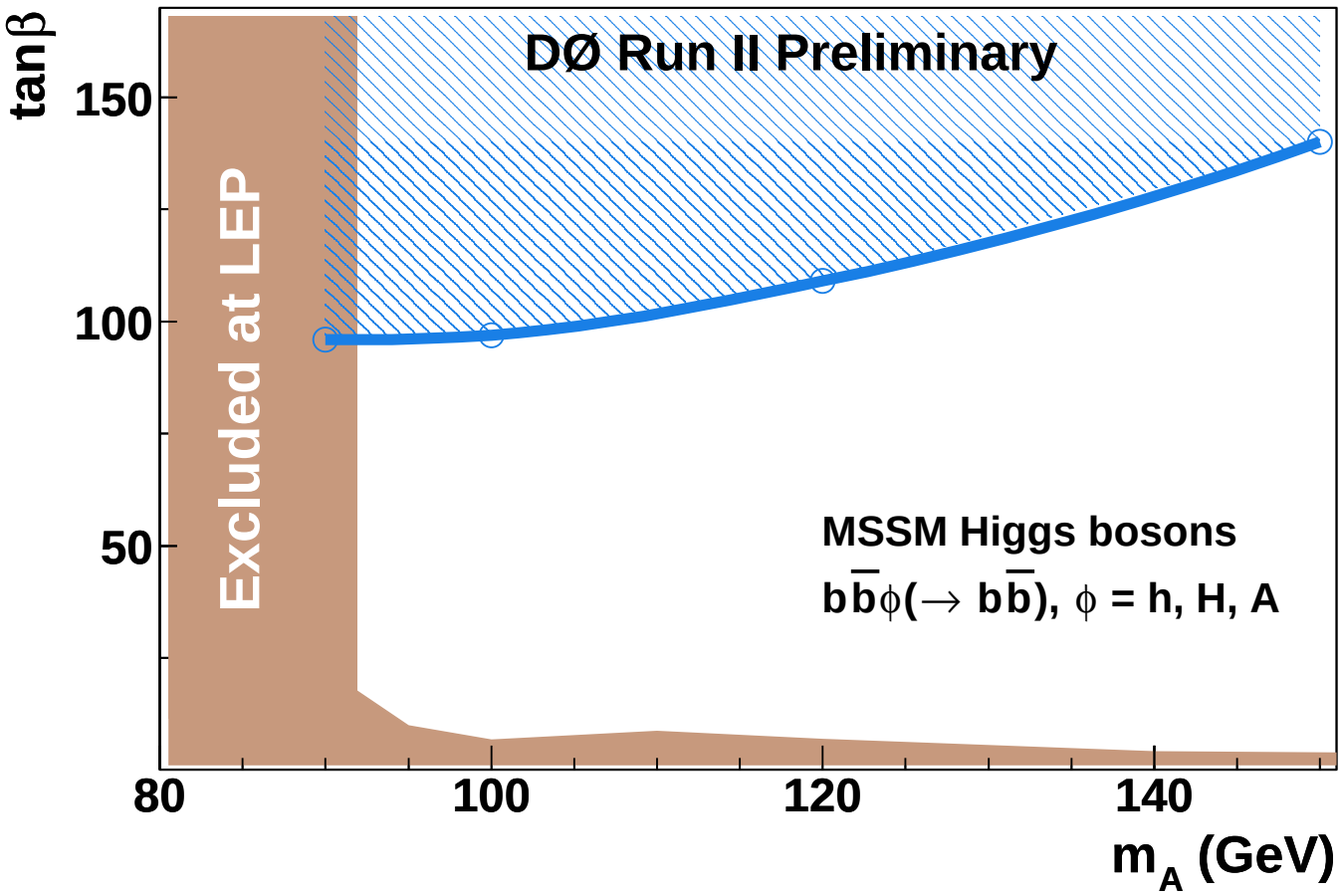


Higgs signal at the exclusion limit

Invariant mass spectrum for >=3 jets (three b-tagged)

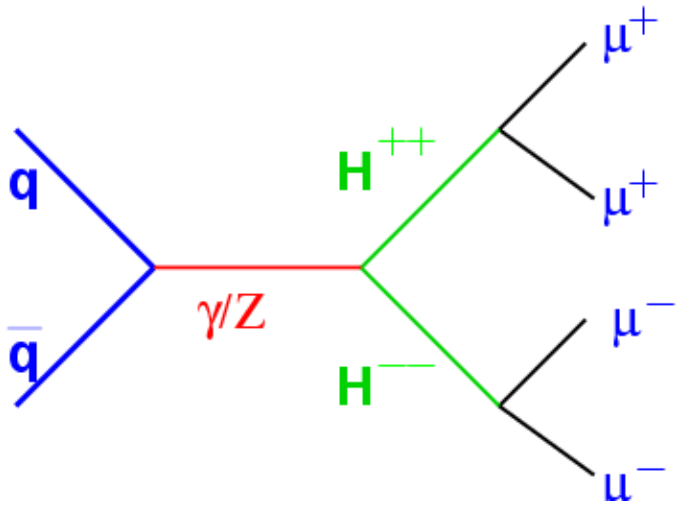
Neutral SUSY Higgs Limits

$\int Ldt \approx 130\ \text{pb}^{-1}$ (**tan β vs. m_A**)



Doubly-Charged Higgs

- Double charged Higgs appears in left-right symmetric models, Higgs triplet models, Little Higgs models.
- Search for pair production of doubly-charged Higgs in $p\bar{p} \rightarrow H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$



- Can also look for Higgs decays to electrons and taus (as well as mixed lepton flavor decays)
- **Currently focus on $\mu^+\mu^+\mu^-\mu^-$ final state assuming B(μμ)=100%**

$H^{++} \rightarrow \mu^+\mu^+\mu^-\mu^-$ Event Selection. Backgrounds

- **Initial selection: at least two muons, p_T >15 GeV**
- **Next event selection steps:**

Muons have to be isolated (based both on tracking and calorimeter information) → reduce → **Backgrounds : $b\bar{b}$**

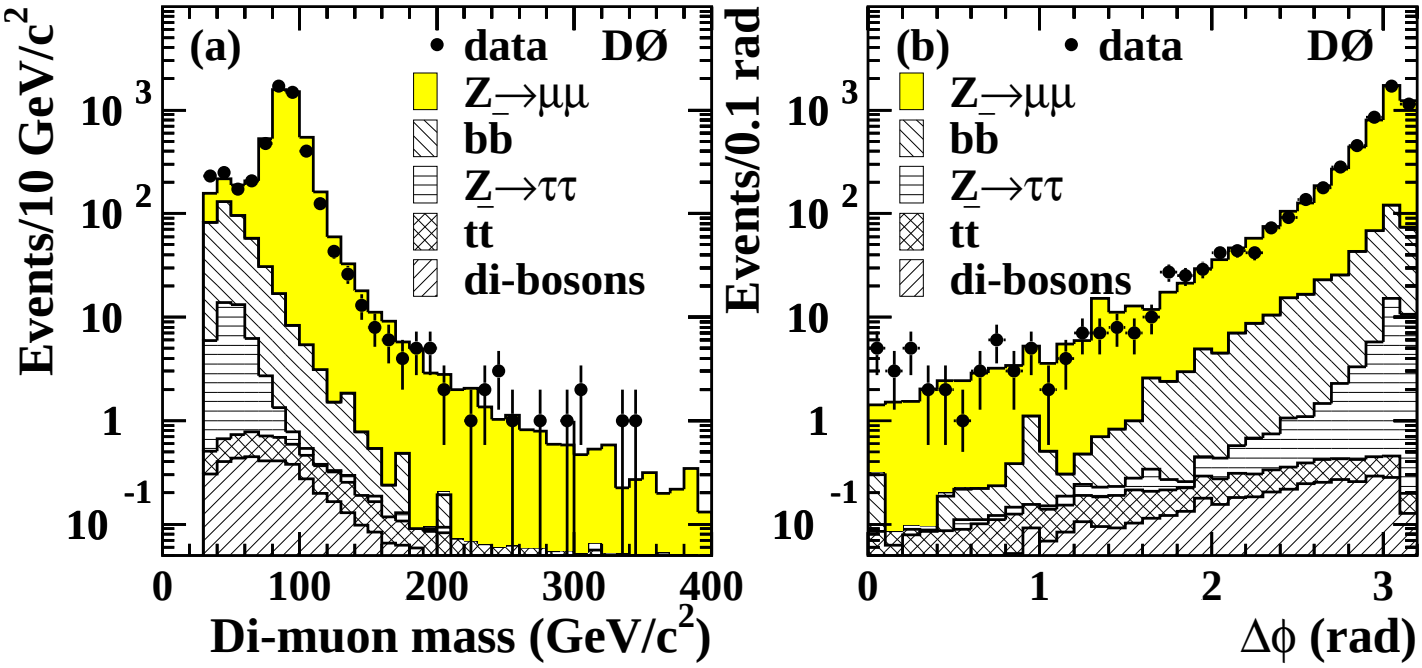
Events with exactly two muons: difference in azimuthal angle $\Delta\phi<0.8\pi$ → **$Z \rightarrow \mu^+\mu^-$**, **$Z \rightarrow \tau^+\tau^-$**

Like Sign Charge (reduce all bkgds)

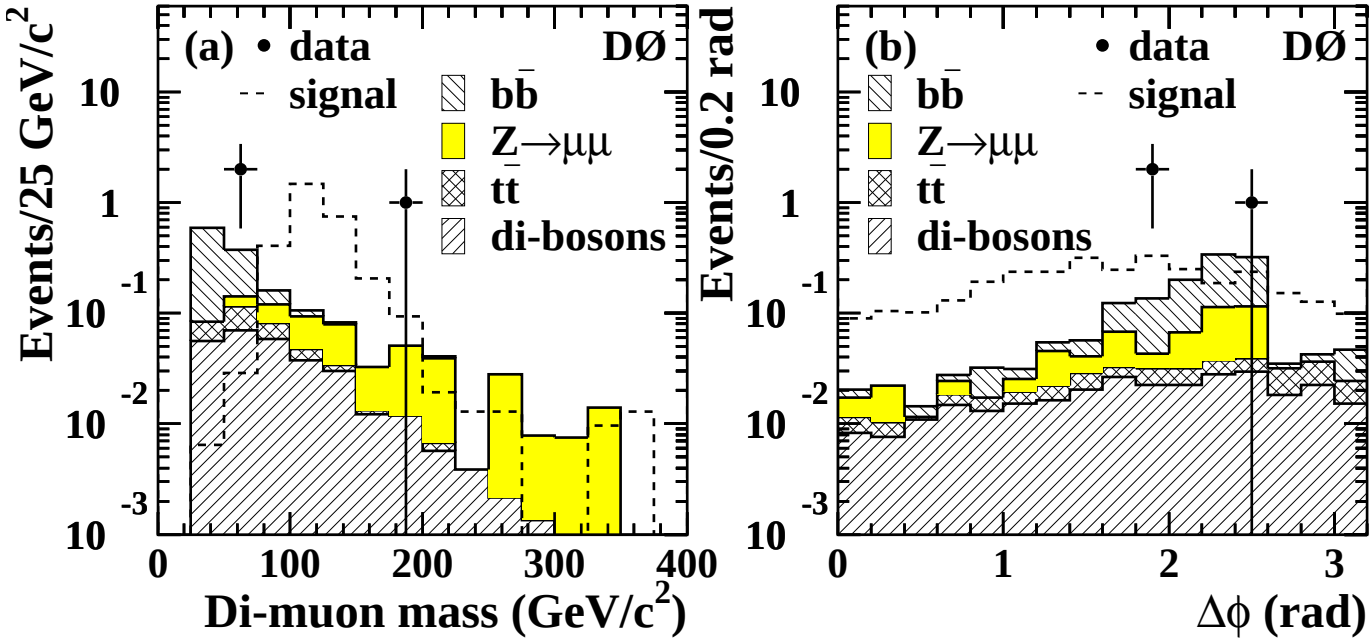
Other ($t\bar{t}$, ZZ, WW,WZ)

Di-Muon Invariant Mass and Azimuthal Separation

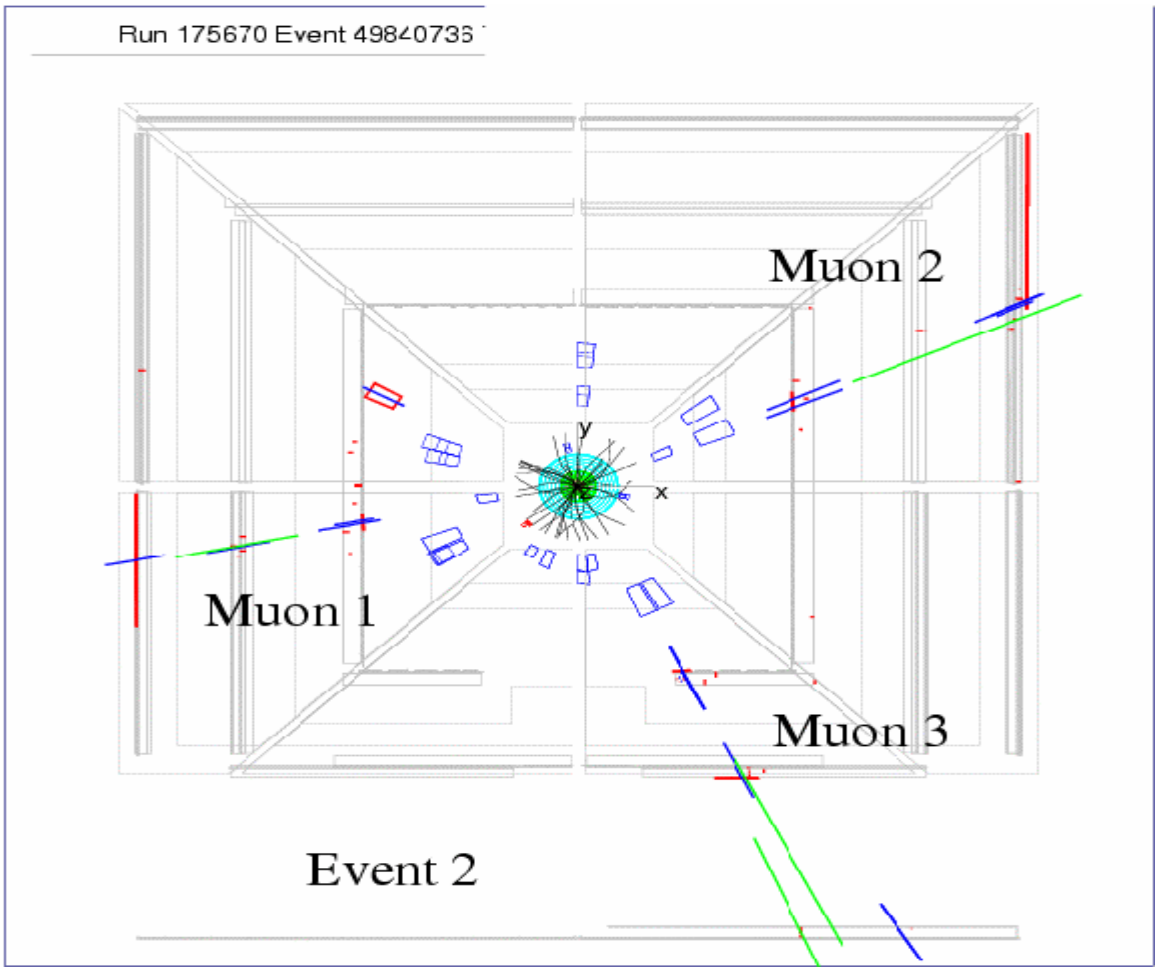
After Initial Selection:



After all Selection Requirements: observe 3 events



Event Display of an observed event

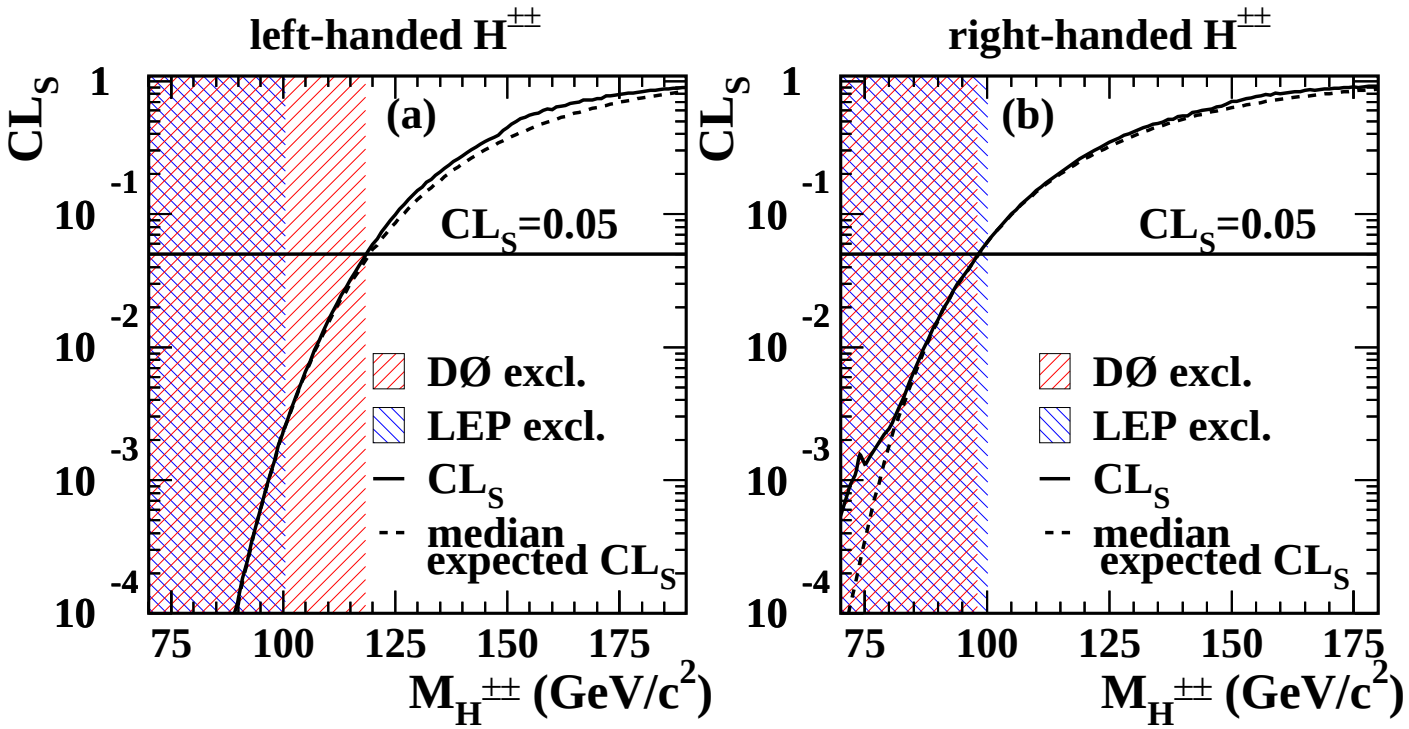


- Invariant Mass($\mu(1)^- \mu(2)^+$) = 91 GeV
- This event contains also a fourth (0.7 GeV) muon matched with the central track
- No significant Missing ET

$\Rightarrow$ Consistent with $\mathbf{Z(\rightarrow \mu^+\mu^-)Z(\rightarrow \mu^+\mu^-)}$

Doubly-Charged Higgs Limits
($\int Ldt \approx 113$ pb^{-1})

- In the absence of a signal we set 95% CL limits of **118.4 GeV** and **98.2** GeV for left-handed and right-handed doubly-charged Higgs boson assuming B($H^{++}/H^{--} \rightarrow \mu\mu$)=100%



Summary

- We have reported on several non-SM Higgs searches at DØ
  - ü In case of bbh and doubly-charged Higgs we already extended LEP reach
  - ü Doubly-charged Higgs analysis just submitted to PRL (hep-ex/0404015)
- We are looking forward to getting more data and updating these analyses
- Stay tuned !