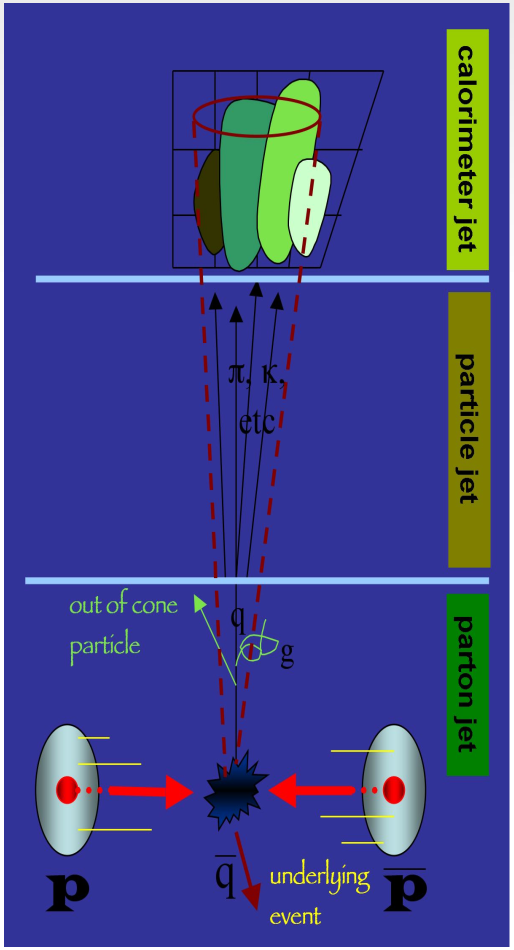
Search for Higgs and new Physics at CDF

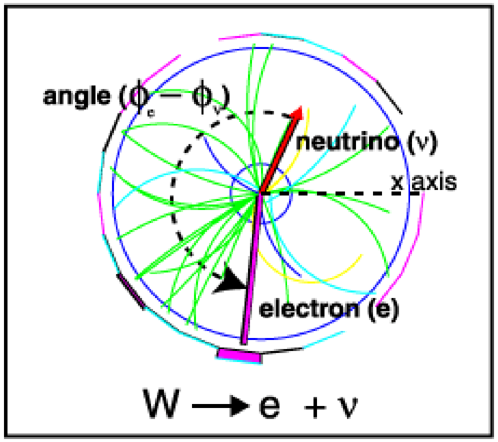
Outline:

- Search for Standard Model Higgs
  - ✔ Introduction
  - ✔ Analysis methods for low mass Higgs
  - ✔ Strategies for high mass Higgs
- Search for new Physics
  - ✔ Signature based
  - ✔ Model driven

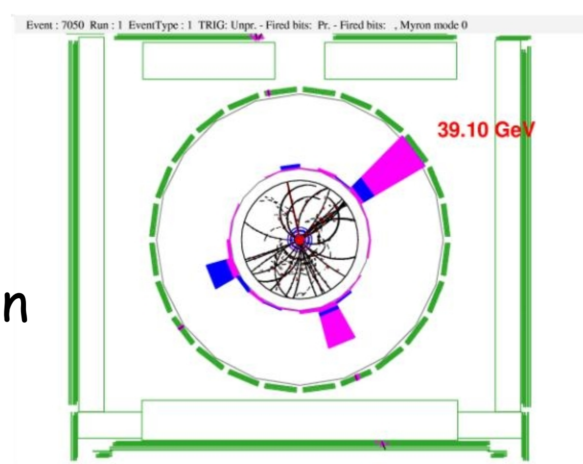
Jet identification



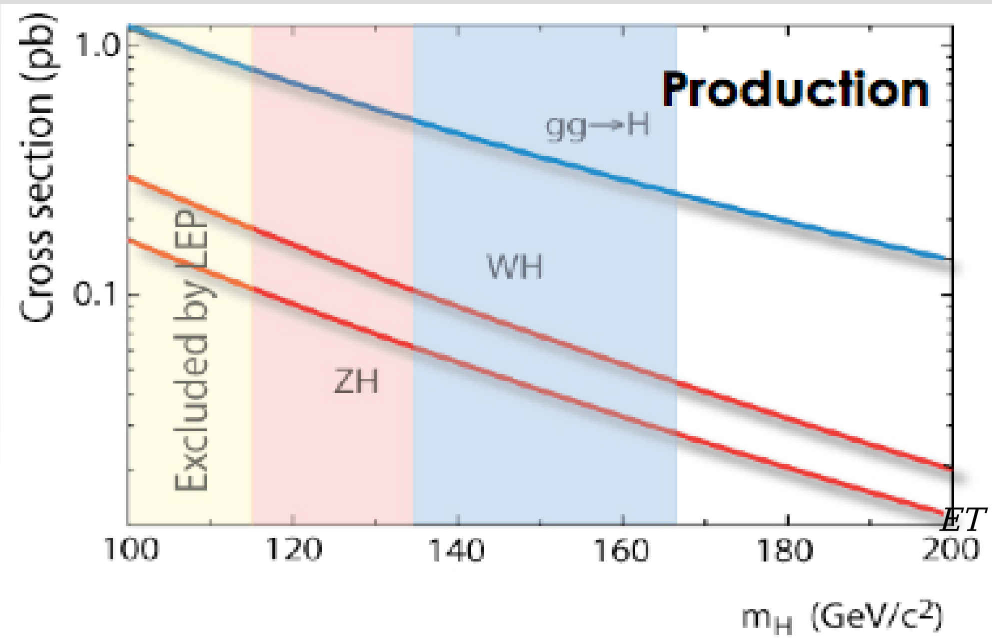
Electron identification

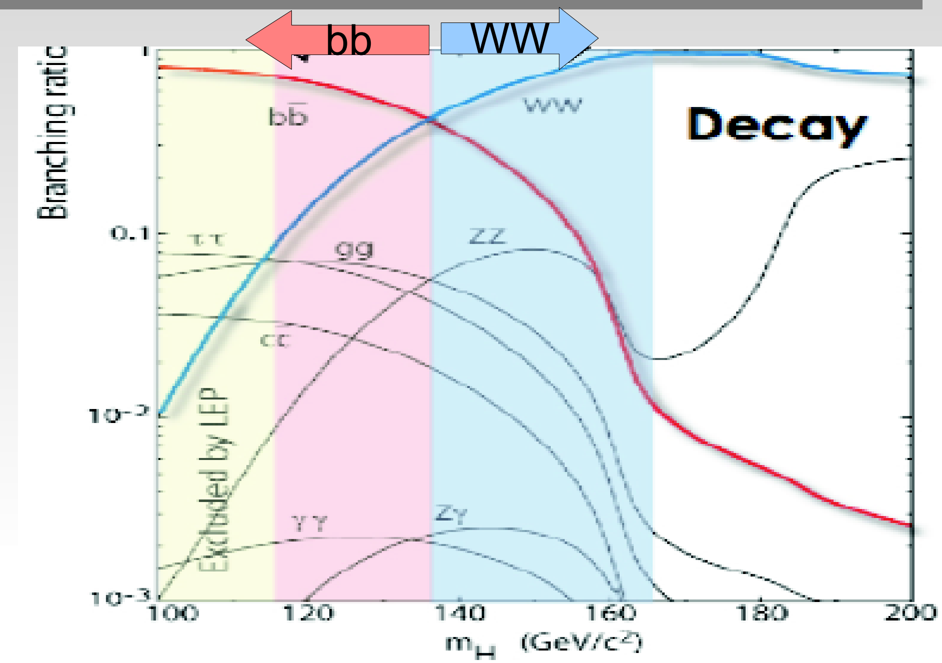


Muon identification



Higgs Production and Decay





Low Mass Higgs Final States

$WH \to l\nu b\bar{b}$ → 1 high Pt Lepton + MET + b jets

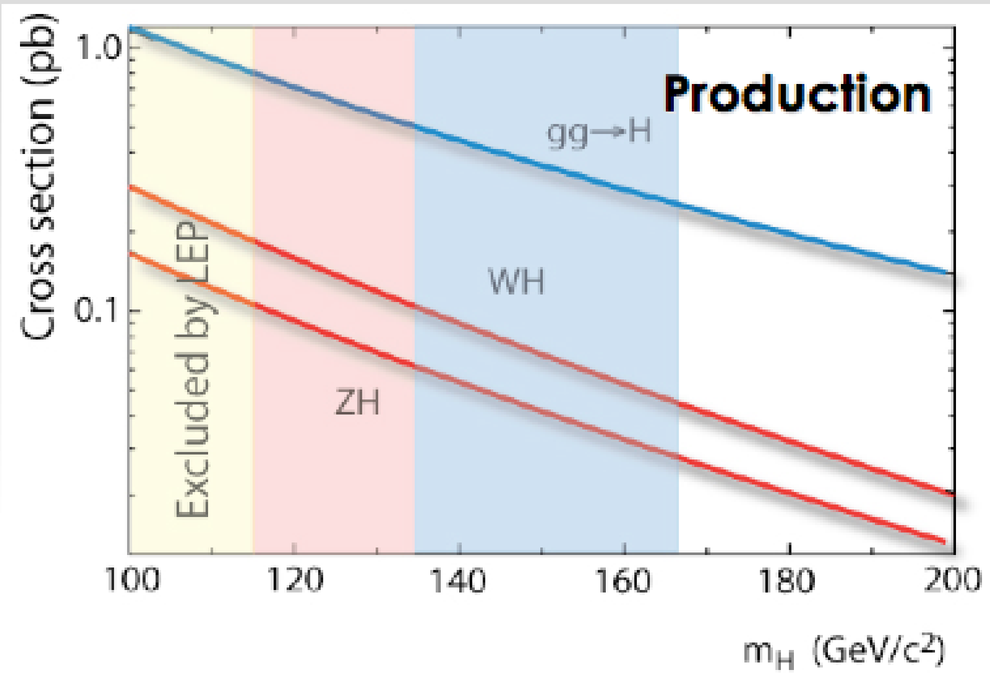
$ZH \to ll b\bar{b}$ → 2 high Pt Lepton + b jets

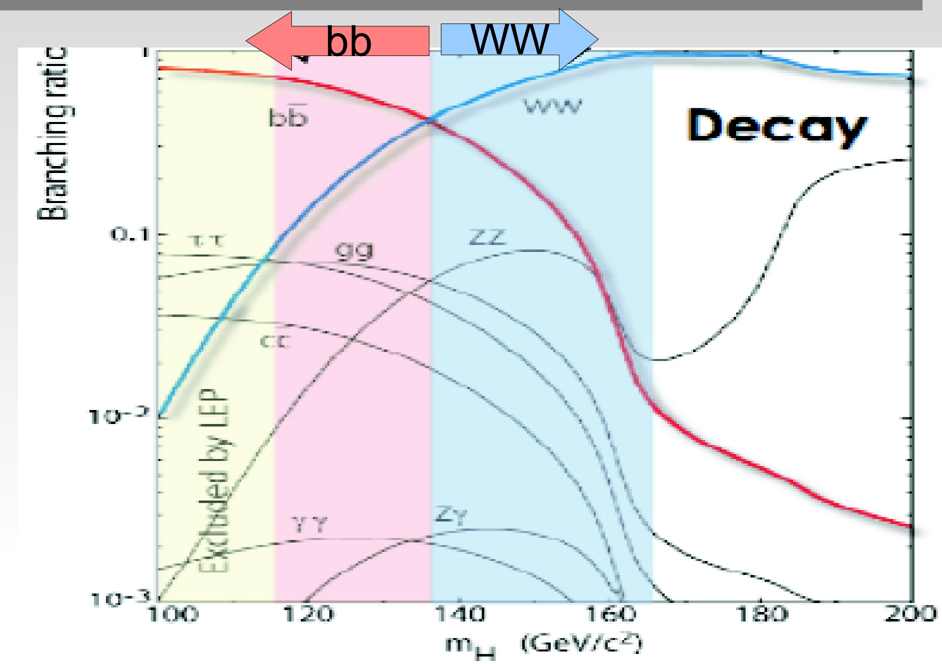
$WH \to l\nu b\bar{b}$
$ZH \to \nu\nu b\bar{b}$ → 0 high Pt Lepton + MET + b jets

$VH\ H \to \tau\tau$ + 2Jets → 1 high Pt Lepton + Trk + b jets

$gg \to H \to b\bar{b}$ → 2 b jets

Higgs Production and Decay



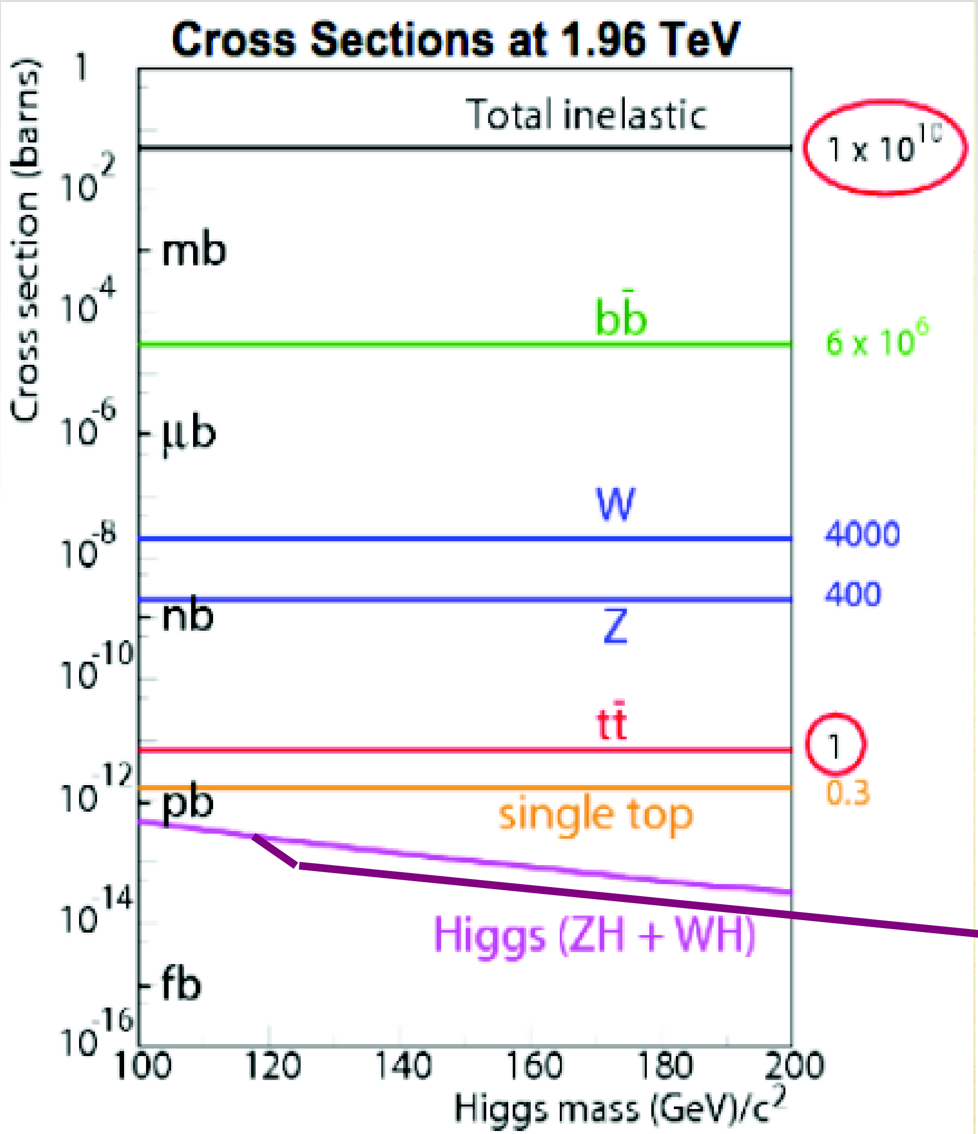


High Mass Higgs Final States

$H \rightarrow W^{+}W^{-(*)} \rightarrow l^{+}\nu l^{-}\nu$ ➡ 2 high Pt Lepton + MET

$W^{\pm}H \rightarrow W^{\pm}W^{+}W^{-(*)} \rightarrow l^{\pm}\nu l^{+}\nu l^{-}\nu$ ➡ 2 high Pt Leptons same sign+MET

Signal and background



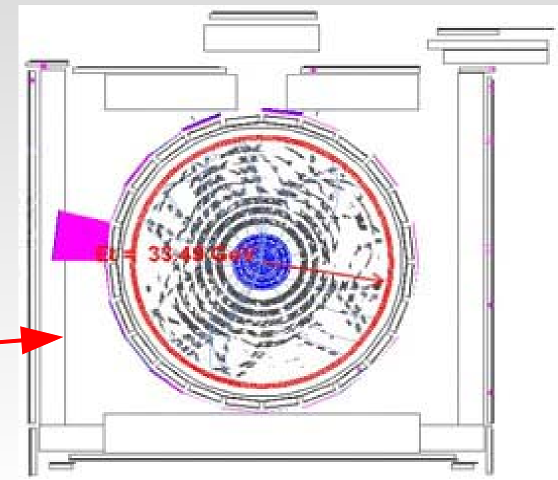
- Higgs Production is a low rate process at the Tevatron
- Backgrounds are many orders of magnitude larger
- Challange is separate Signal from Background:

  S:B ~ 1:10^{11} before any selection

Preliminary selections

Select events with:

- leptons, e, μ and τ of high P_T
- neutrinos via missing energy



$$MET = -\sum \vec{E} = \sum_{towers} (E_i \sin\theta_i)\hat{n}_i$$

S:B ~ 1:50 $H \to W^+W^{-(*)} \to l^+\nu l^-\nu$

- jets from b-quarks (low M_H): b-tagging

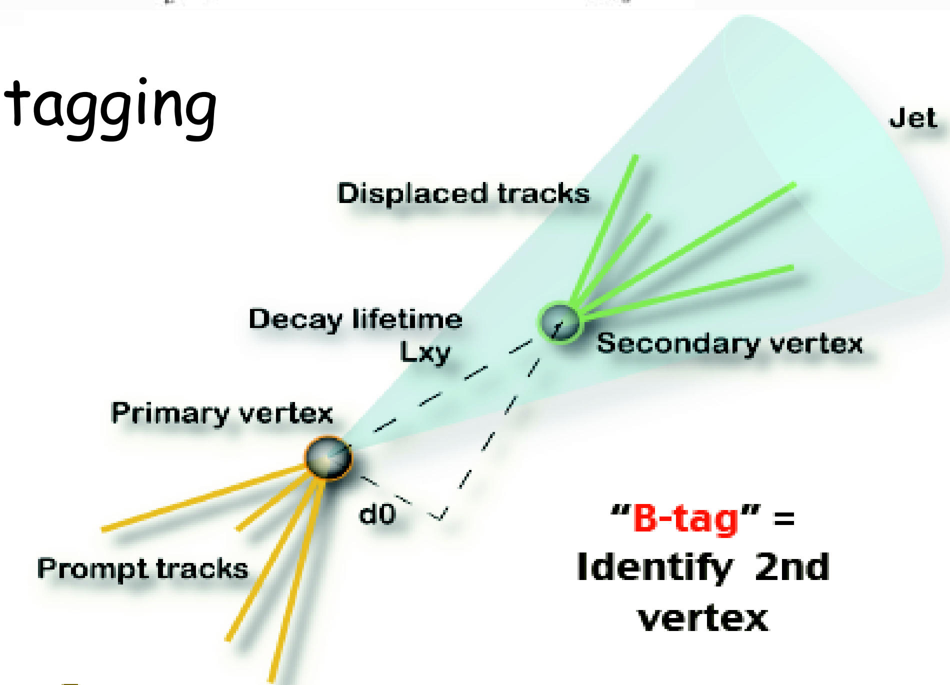
b-tagging is 50%-70% efficiencient

it has a depnendence on jet E_T and η

$VH \to l\nu b\bar{b}$

$S:B_{1\text{-}tag}$ ~ 1:400

$S:B_{2\text{-}tag}$ ~ 1:50/100



S:B Optimization

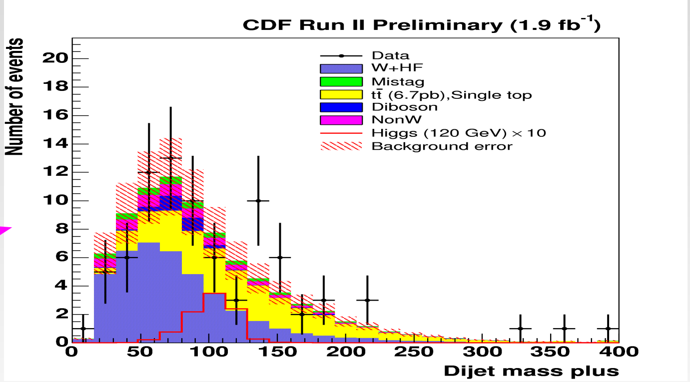
- Trigger: change configurations to collect all decay process
- Preliminary selections:
  - identify as many high Pt leptons as possible.
  - increase B-tag efficiency and purity
- Reject backgroud
- Improuve Jet energy resolution and MET
  - Critical for M_{JJ}

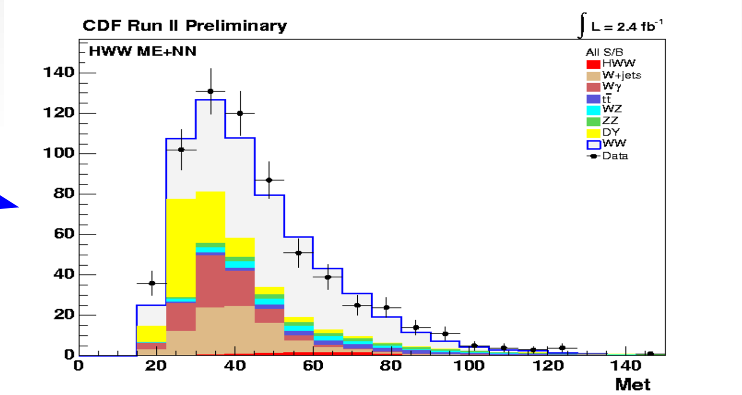
Then the Analysis

Separate Signal from Backgroud:

Use several variables:

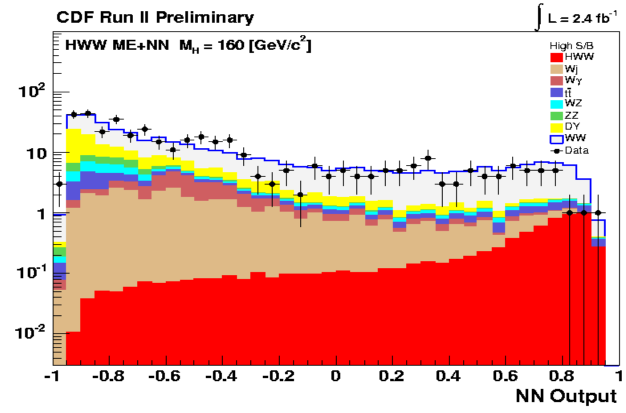
- Di-jets invariant mass M_{JJ} most discriminating at low mass
- MET important for high mass





Then use

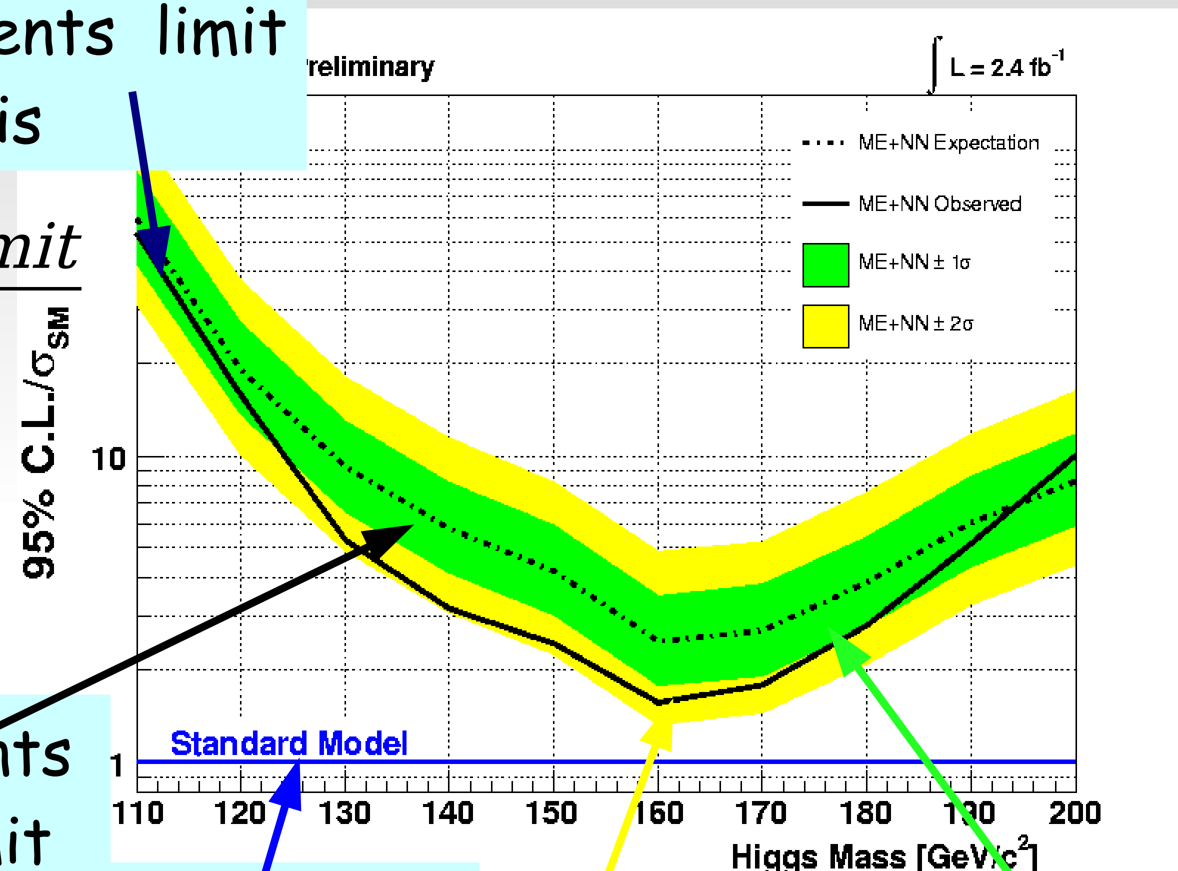
- Artificial Neural Network
- Matrix Element
- Other discriminant



Understanding The Limit Plot 101

Solid line represents limit from data analysis

$$y = \frac{\sigma * B\, 95\ CL\ upper\ limit}{SM\, \sigma * B}$$

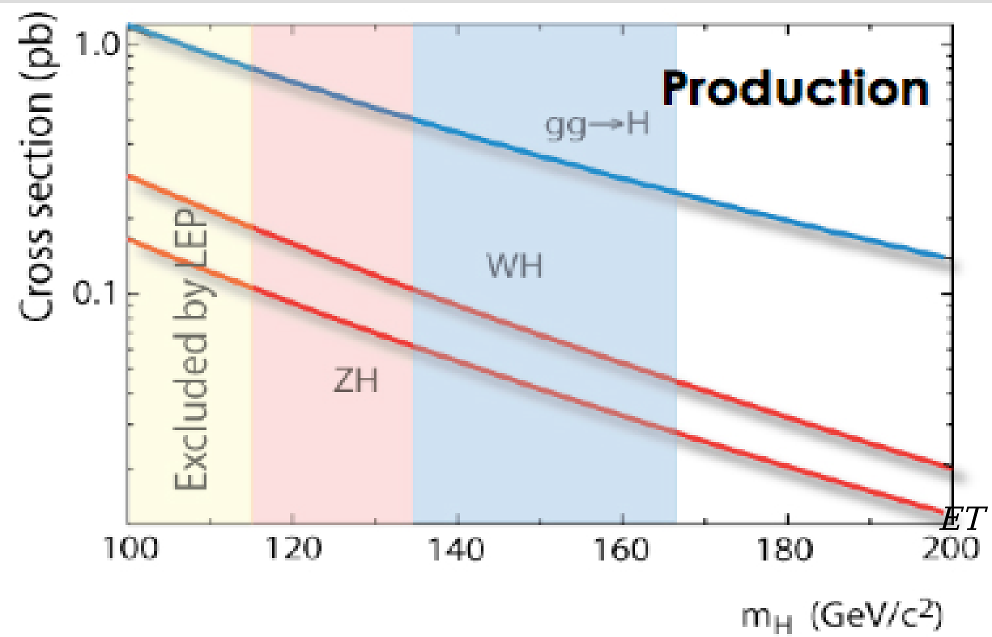


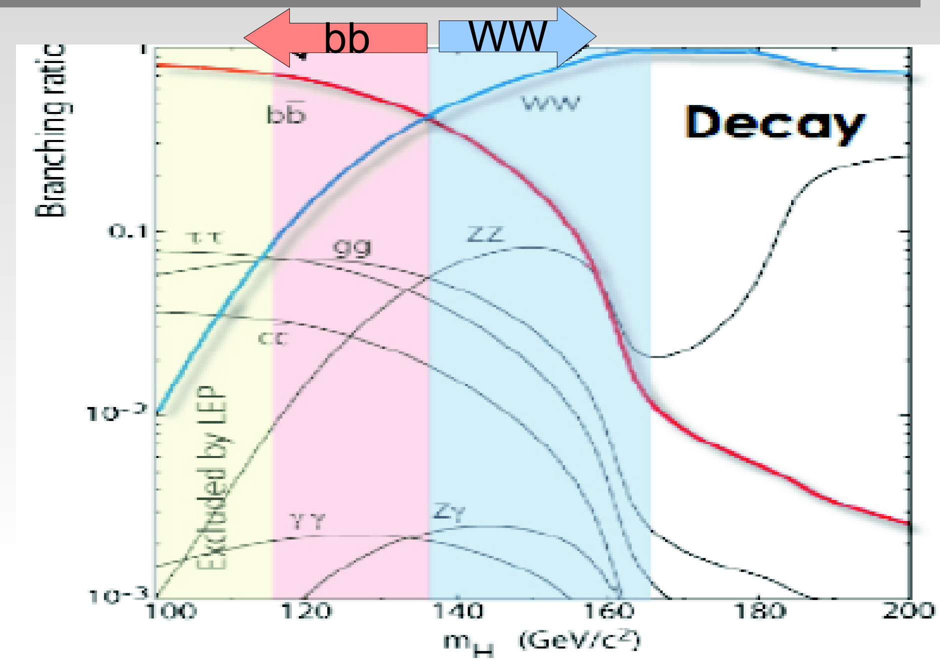
Dashed line represents median predicted limit from MC

SM σ·B at 1

Bands represents 1σ and 2σ range of predicted limit

Low Mass Higgs searches





Low Mass Higgs Final States

$WH \rightarrow l\nu b\bar{b}$ ➡ 1 high Pt Lepton + MET + b jets

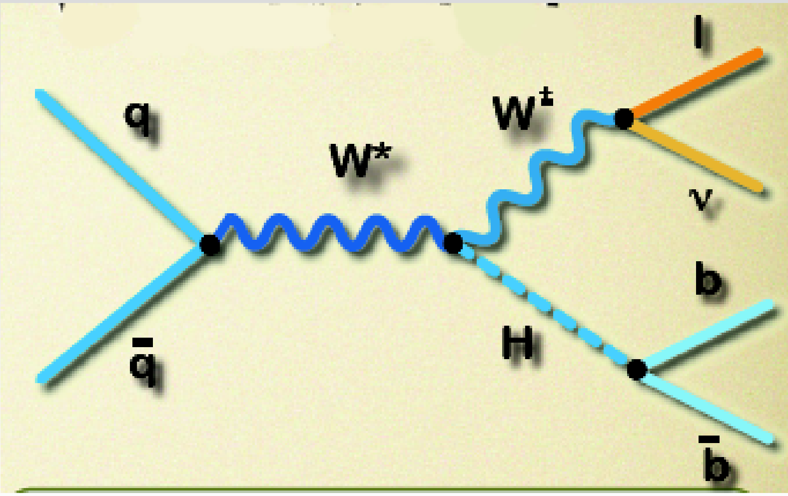
$ZH \rightarrow ll b\bar{b}$ ➡ 2 high Pt Lepton + b jets

$WH \rightarrow l\nu b\bar{b}$
$ZH \rightarrow \nu\nu b\bar{b}$ ➡ 0 high Pt Lepton + MET + b jets

$VH\ H \rightarrow \tau$ + 2Jets ➡ 1 high Pt Lepton + Trk + b jets

$gg \rightarrow H \rightarrow b\bar{b}$ ➡ 2 b jets

$WH \to l\nu b\bar{b}$: Selections



Event characterization

- High P_T lepton (e,μ)
- MET
- Two b-Jets: 2 b-tags

Primary Backgrounds

$Wb\bar{b}$, $Wc\bar{c}$, Wqq'

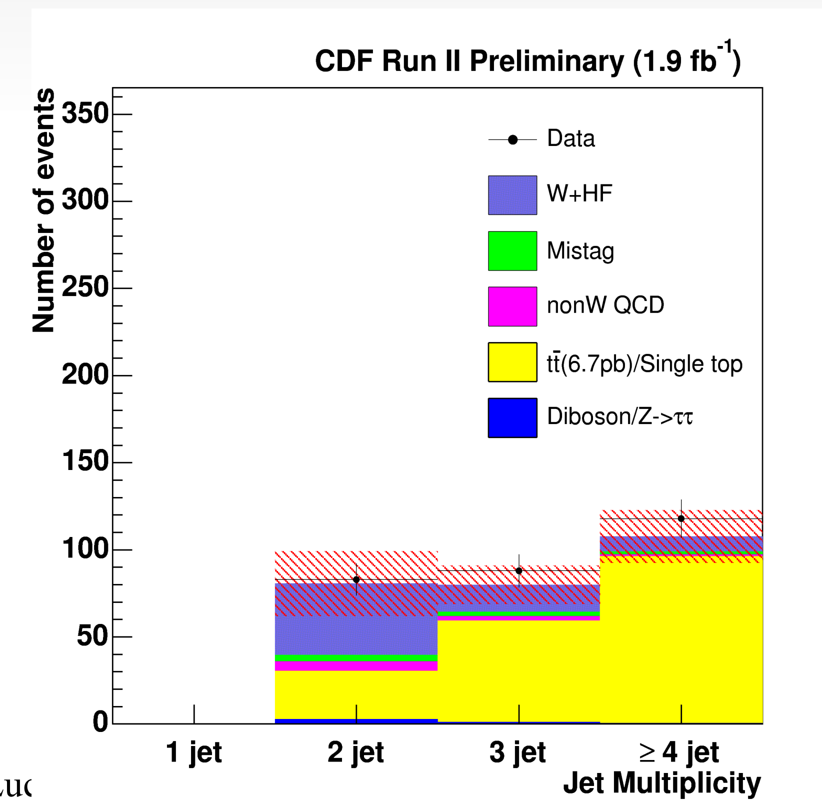
$t\bar{t}$

Single top

non − W QCD

WZ, WW

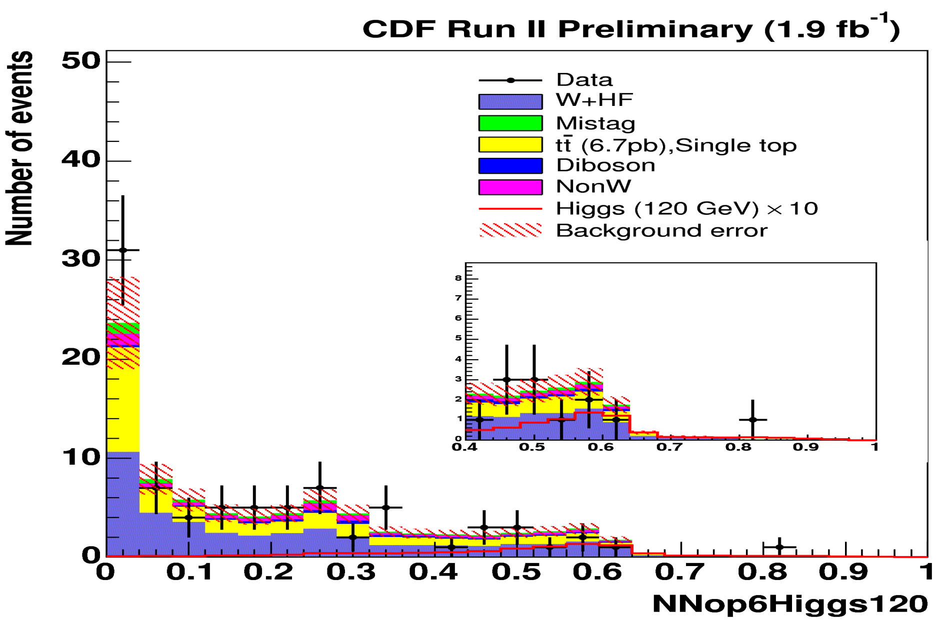
$Z \to \tau\tau$

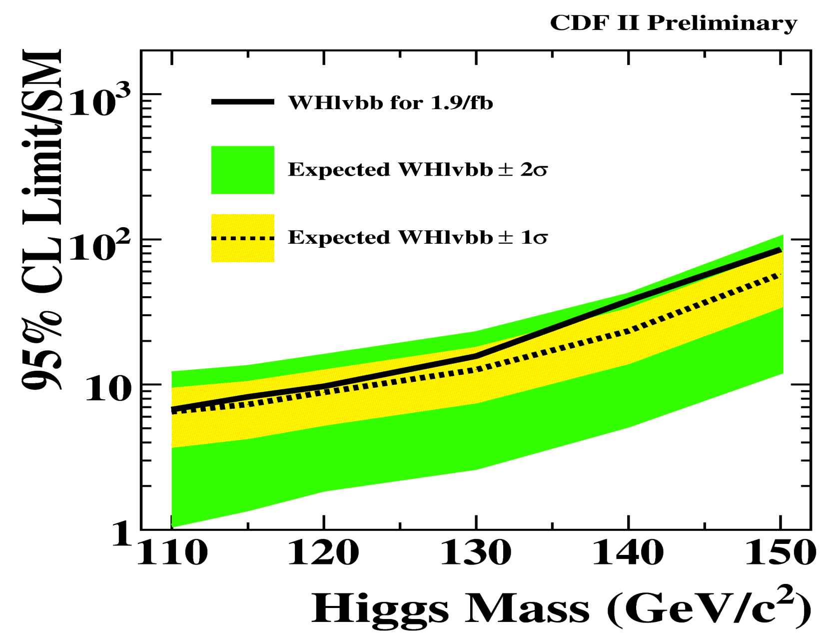


$WH \rightarrow l\nu b\bar{b}$:ANN and Result

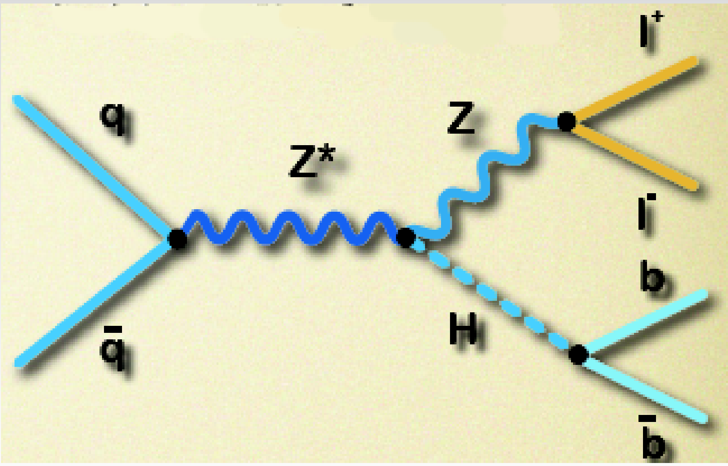
Quantities used in the ANN:

- Di-jets mass: M_{JJ} two b-jets + an extra loose jet ΔR(b-jet,jet-loose)<0.9
- Pt imbalance : Pt(jet1)+Pt(jet2)+Pt(lepton) - MET
- System Pt : Pt of the lepton, MET and jets system
- Min Invariant mass :invariant mass of lepton, MET and jet (those min. M)
- ΔR(lepton-neutrino) : η-φ distance, neutrino pz is from W mass constr.
- Scalar sum of loose jet Et





ZH →llb$\bar{b}$



Event characterization

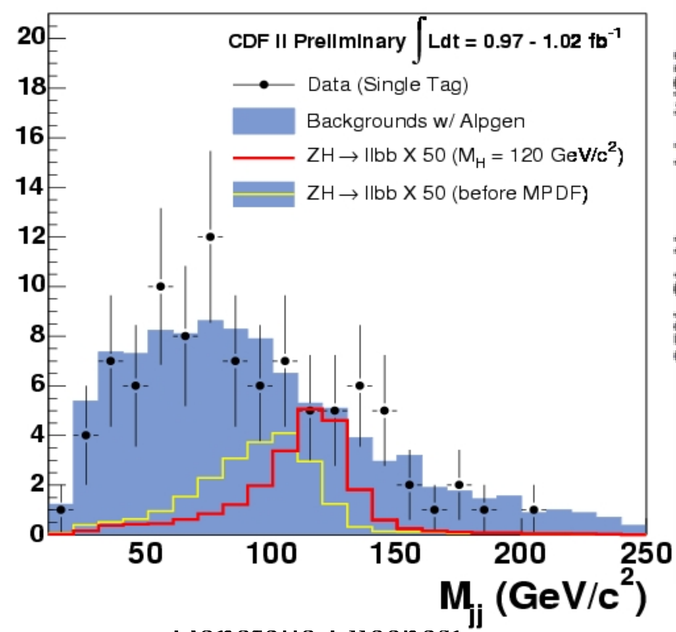
- Two High P_T leptons
- $M_{ll} \sim M_Z$ (76-106)
- NO MET
- Two b-Jets: 2 b-tags

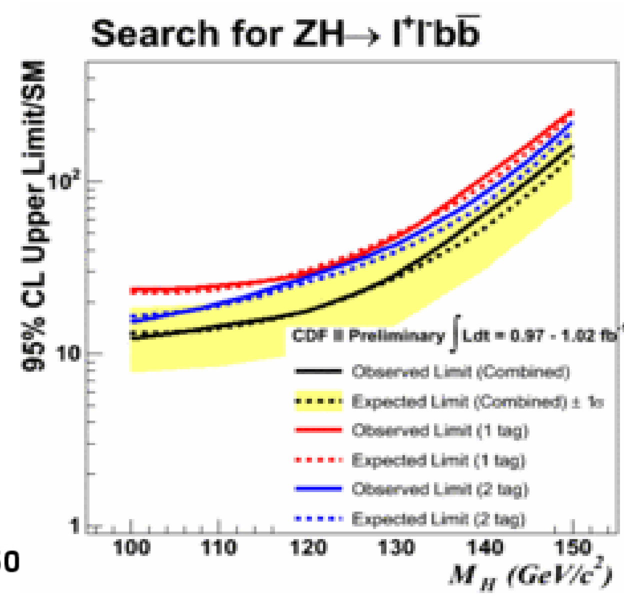
<u>Main Backgrounds</u>

Z+$b\bar{b}$/$c\bar{c}$,
$t\bar{t}$, WW+Jets,
WZ,ZZ

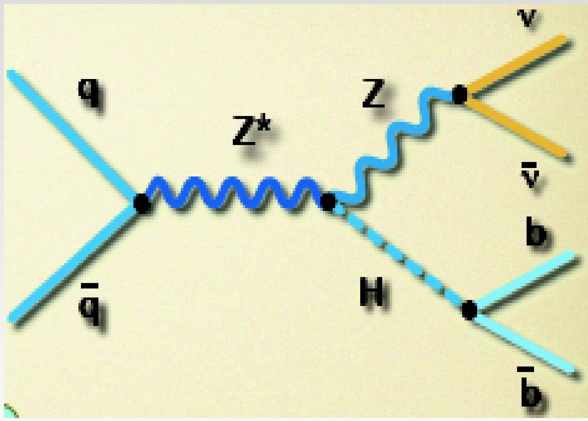
<u>ANN input variables:</u>

MET, M_{JJ},
ΔR(Z-Jet1,2)
ΔR(Jet1-Jet2),
Sphericity,
ηjets, ΣEt





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



Event characterization

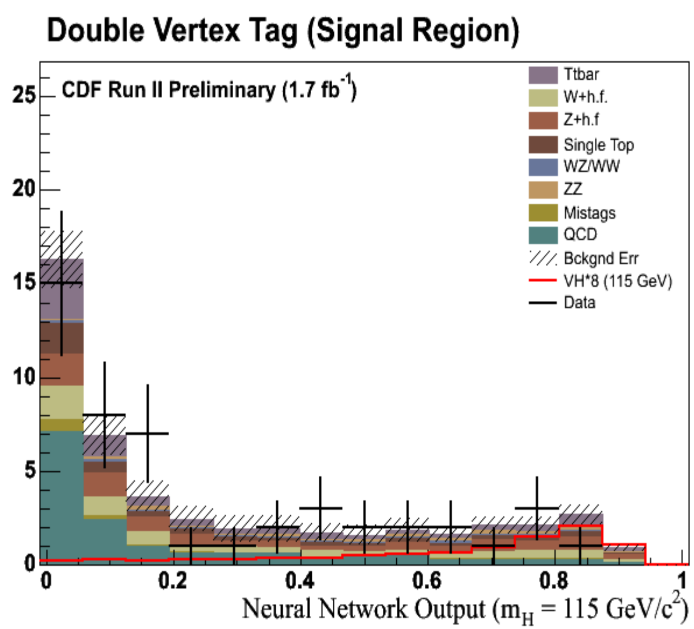
- No leptons
- Two b-Jets: 2 b-tags
- Large MET recoiling against 2 Jets

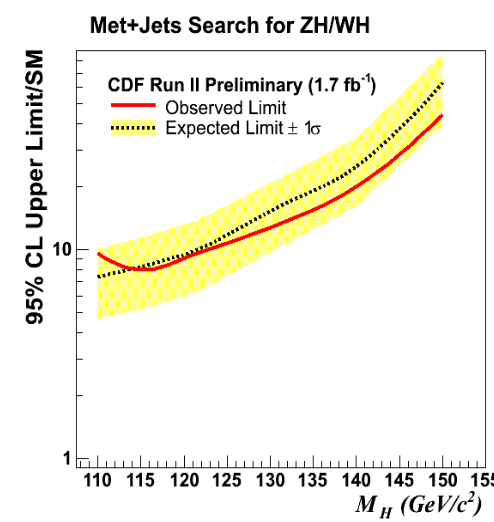
Main Backgrounds

QCD: MET+ $b\bar{b}$
W/Z+$b\bar{b}$/$c\bar{c}$,
$t\bar{t}$, single top,
WW,WZ,ZZ

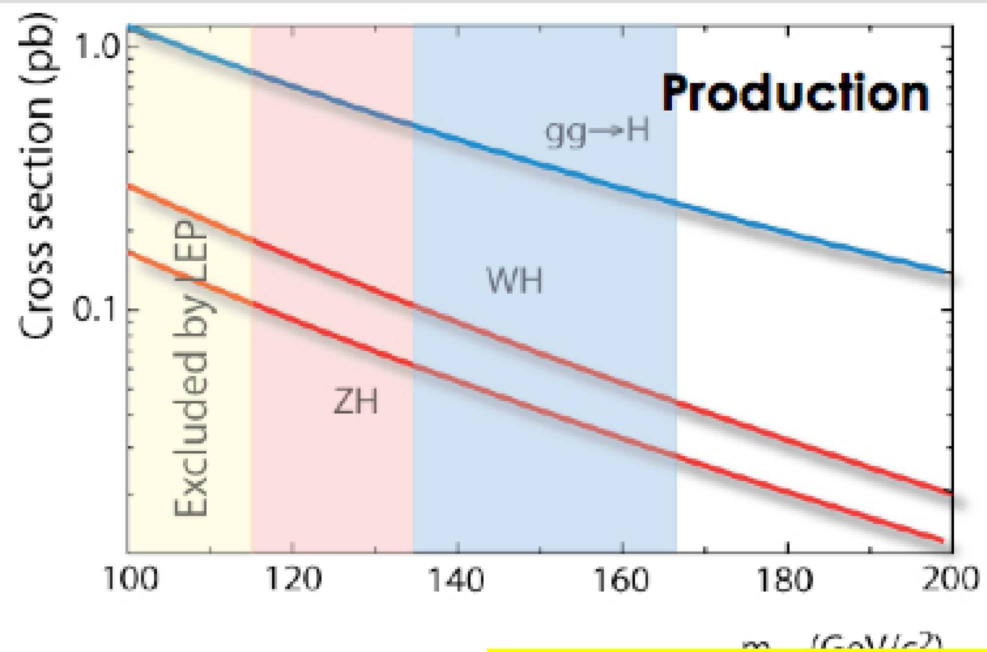
ANN input variables:

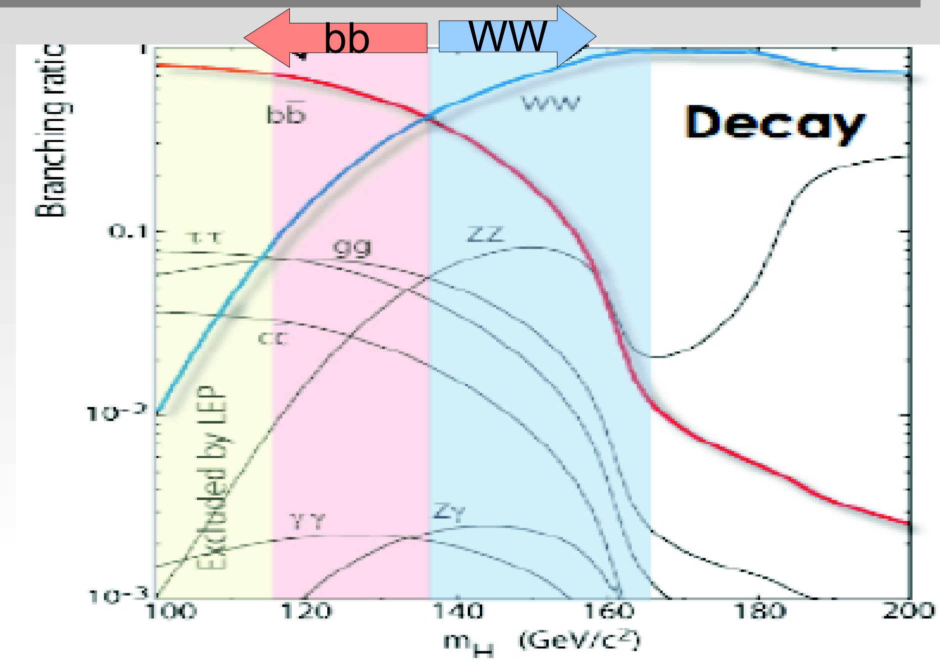
MET, MJJ,
ΔR(Jet1-Jet2),
Proj. MET against 2jets





Higgs Production and Decay



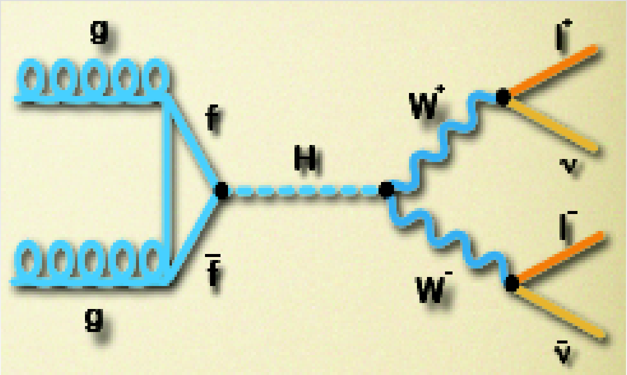


High Mass Higgs Final States

$H \rightarrow W^+W^{-(*)} \rightarrow l^+\nu l^-\nu$ ➡ 2 high Pt Lepton + MET

$W^{\pm}H \rightarrow W^{\pm}W^+W^{-(*)} \rightarrow l^{\pm}\nu l^+\nu l^-\nu$ ➡ 2 high Pt Leptons same sign+MET

$p\bar{p} \rightarrow H \rightarrow WW^*$



Event characterization

- Two high P_T leptons
- Large MET
- No Jets activity

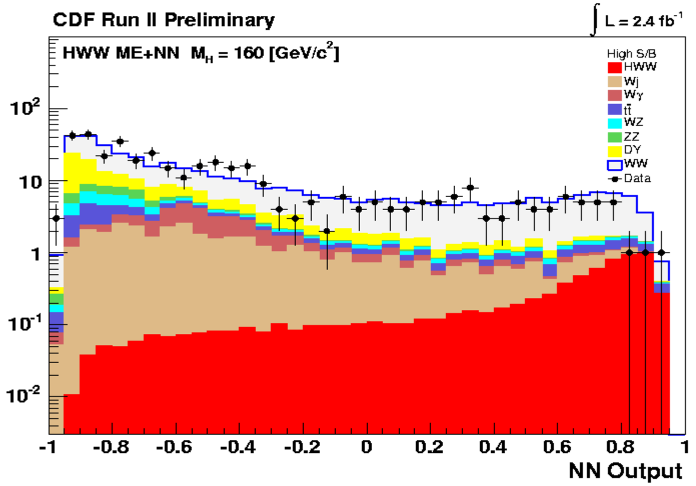
Main Backgrounds

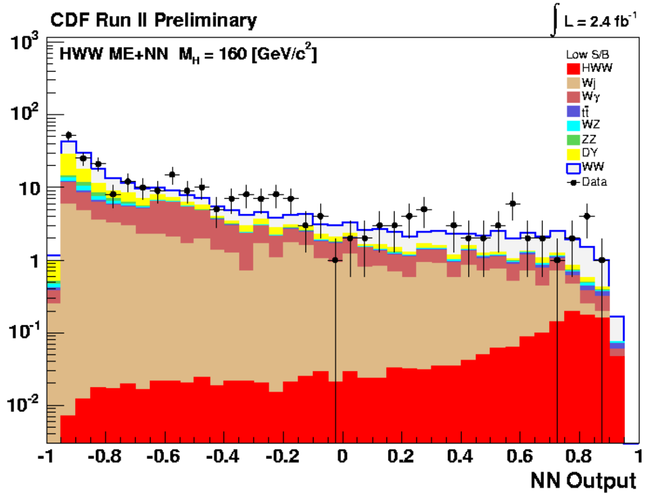
WW, WZ,ZZ

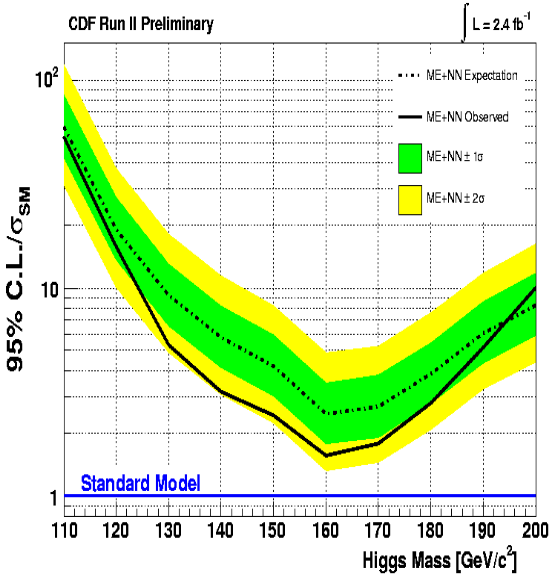
W+Jets, $t\bar{t}$

ANN for two class of events:

high S/B, low S/B







Decay Channels Combination

No single decay channel has sufficient power to reach Standard Model prediction.

Bayesian Posterior Probability

$$p(R|\vec{n}) = \frac{\int\int d\vec{s}d\vec{b}L(R,\vec{s},\vec{b}|\vec{n})\pi(R,\vec{s},\vec{b})}{\int\int\int dRd\vec{s}d\vec{b}L(R,\vec{s},\vec{b}|\vec{n})\pi(R,\vec{s},\vec{b})} \Rightarrow \int_0^{R_{0.95}} p(R|\vec{n})dR = 0.95$$

$R = (\sigma \times BR)/(\sigma_{SM} \times BR_{SM})$, $R_{0.95}$: 95% Credible Level Upper Limit

$\vec{s},\vec{b},\vec{n} = s_{ij}, b_{ij}, n_{ij}$(# of signal, background and observed events in j-th bin for i-th channel)

π : Bayes' prior density

Combined Binned Poisson Likelihood

$$L(R,\vec{s},\vec{b}|\vec{n}) = \prod_{i=1}^{N_{\text{channel}}} \prod_{j=1}^{N_{\text{bin}}} \frac{\mu_{ij}^{n_{ij}} e^{-\mu_{ij}}}{n_{ij}!}$$

$\mu_{ij} = R \cdot s_{ij} + b_{ij}$

Principle of ignorance

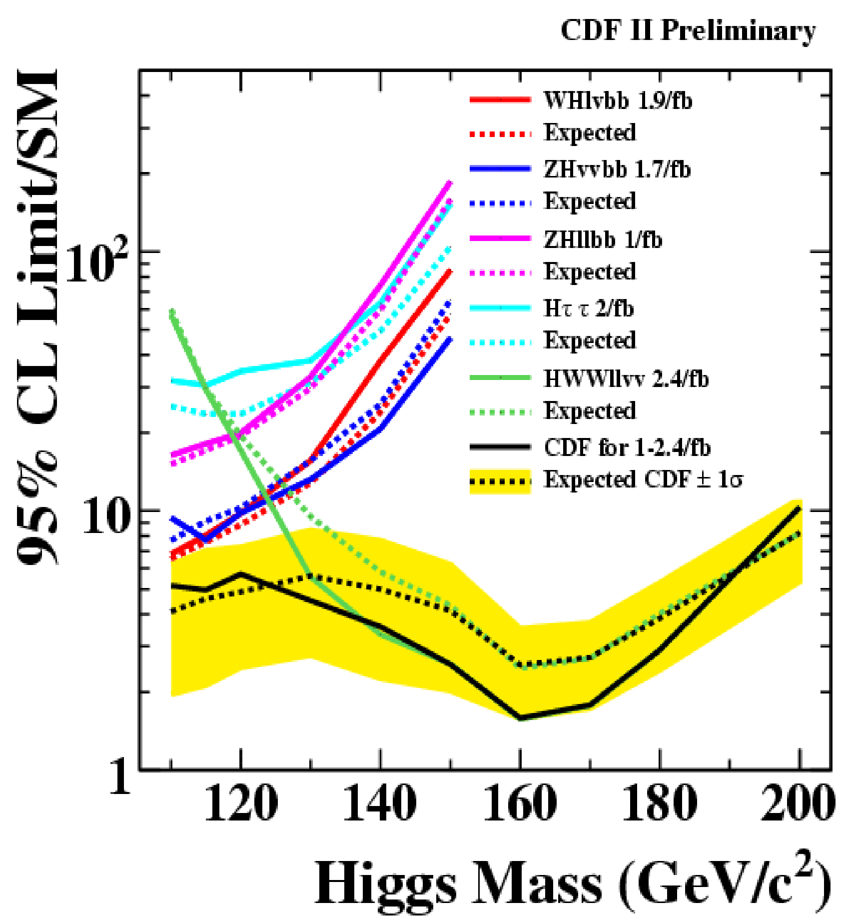
- for the number of higgs events (instead of higgs Xsec)

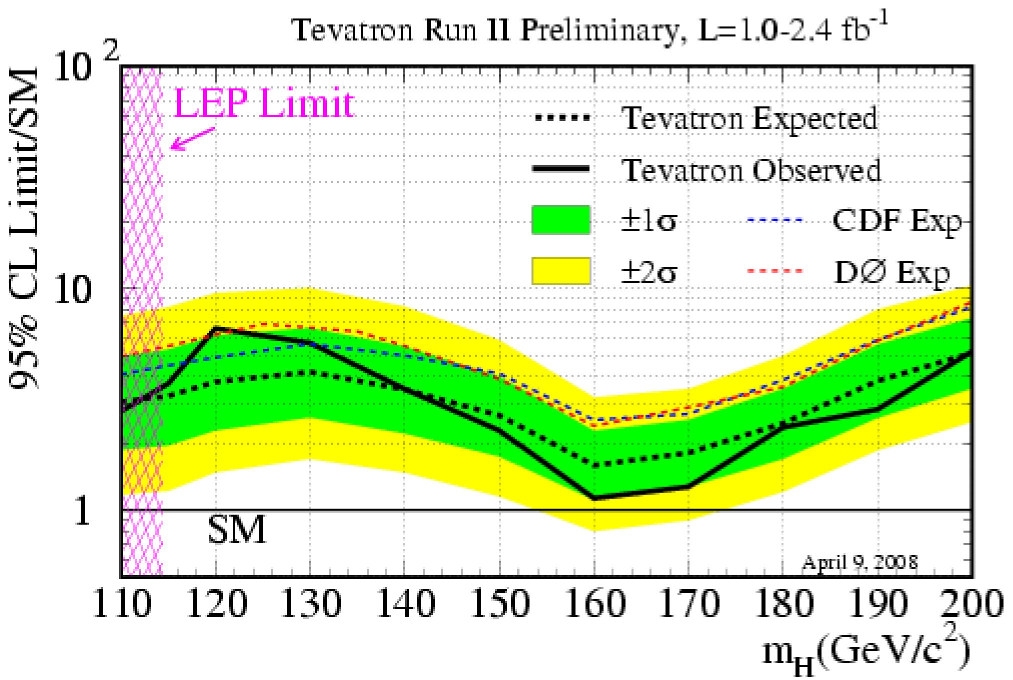
$$\pi(R,\vec{s},\vec{b}) = \pi(R)\pi(\vec{s})\pi(\vec{b}) = s_{tot}\theta(Rs_{tot})\pi(\vec{s})\pi(\vec{b})$$

$s_{tot} = \Sigma_{i,j} s_{ij}$: Total number of signal prediction

$\pi(x) = G(x|\hat{x},\sigma_x)$ $(x = s,b)$ $\hat{x}$: expected mean, σ_x: total uncertainty

Results Decay Channels Combination





Search for New Physics

Search for new Physics process organizing them by their signature

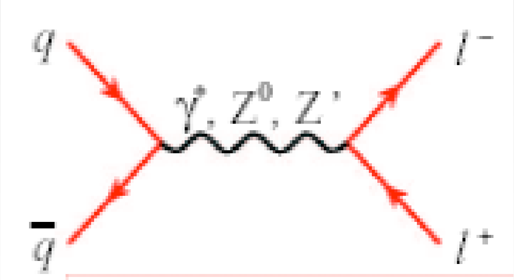
- Lepton-only final states
  - e/μ identification well understood
  - τ id more complex
- ...+ MET and Photons
  - wealth of models and exotic process
  - detector effect are important
- ...+ Jets and Heavy Flavor
  - more complex signatures

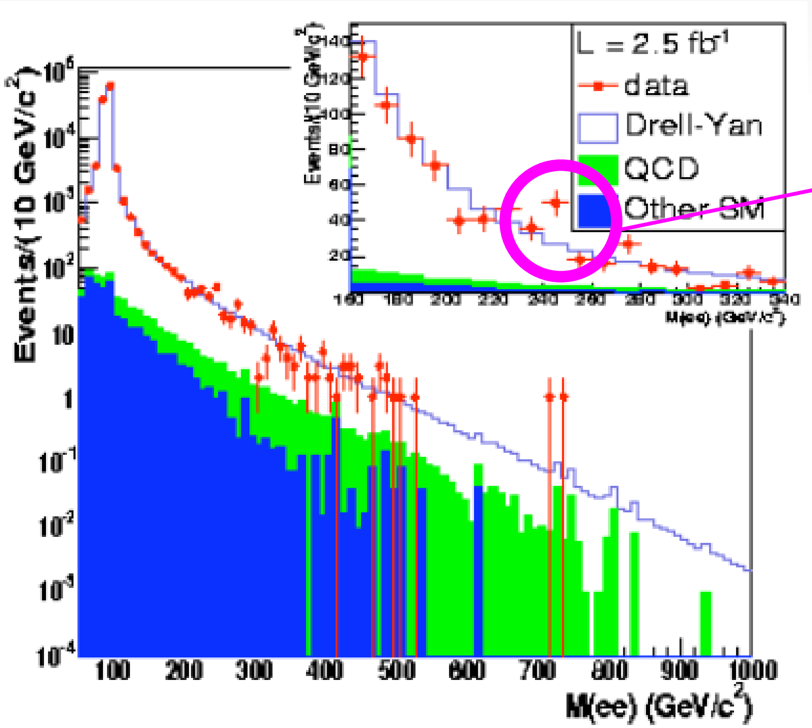
Two approaches:
signature based, final results interpreted in term of specific models
example: di-leptons searches
model driven, results are presented as testing a specific model, there is check in the control region defined in term of process signature (blind analysis)

Di-leptons searches:Staring Point

Search for resonances in ee/μμ above 150 GeV

- lepton id well under control
- Z peak used as reference
- clean events





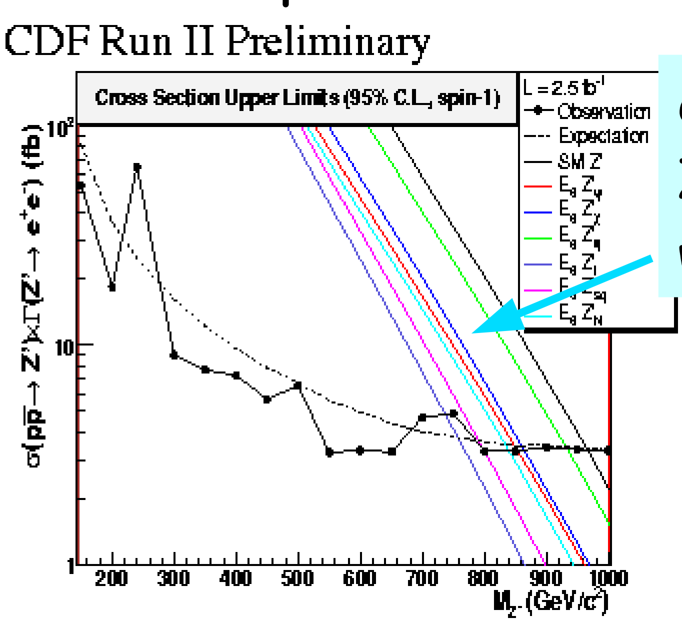
Excess? 3.8 standard deviations over SM. Keep monitoring

The probability of observing a background fluctuation with significance equal to or greater than 3.8 anywhere in the mass range of 150-1,000 GeV/c^2 is about 0.6%, corresponding to a 2.5 σ significance.

Di-leptons searches:New Phyiscs searches

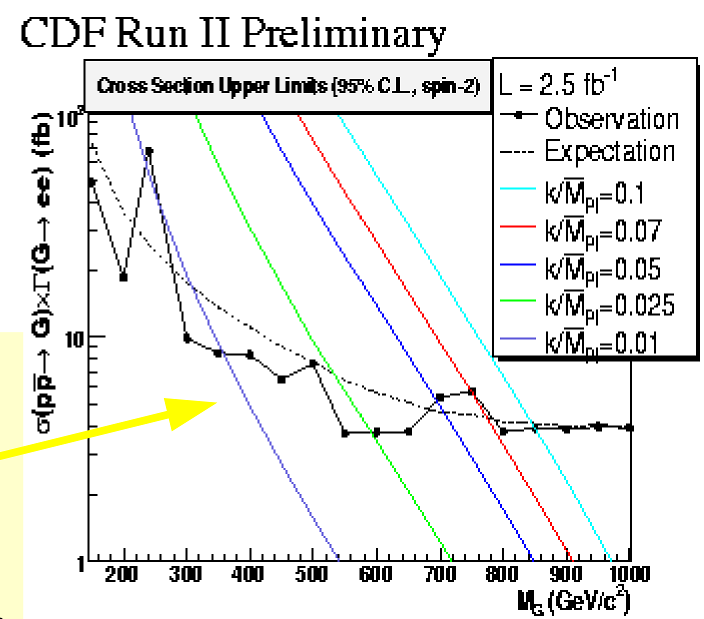
New Physics limits

- understand very well data spectrum in term of SM process
- calculate new signal acceptances and trigger efficiencies
- derive number of new physics events are expected
- if no events found in data calculate 95% CL cross section limit and set particle mass limit

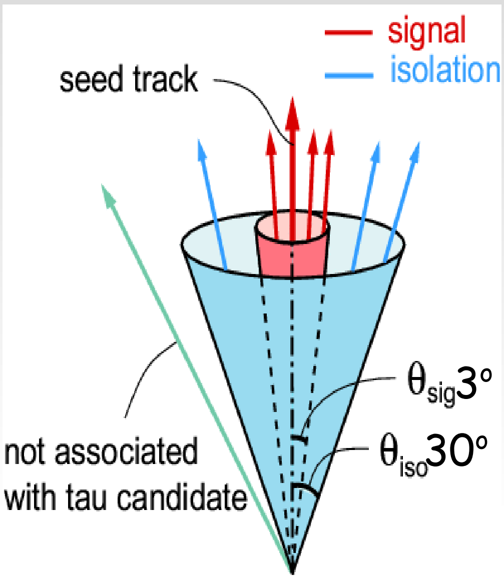


exclude 95%CL
Z' with SM coupling
with mass <966 GeV

Randall-Sundrum
graviton with
mass< 850 GeV
excluded at 95%CL



Tau final states searches

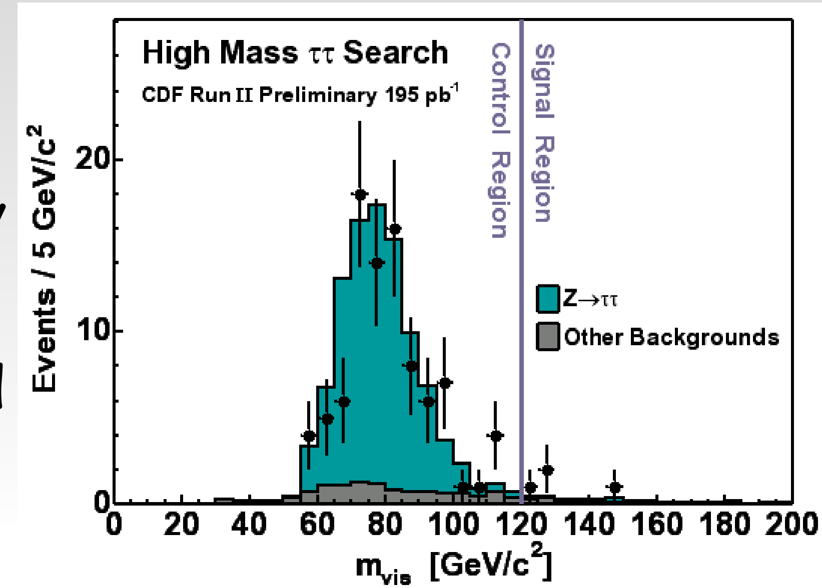


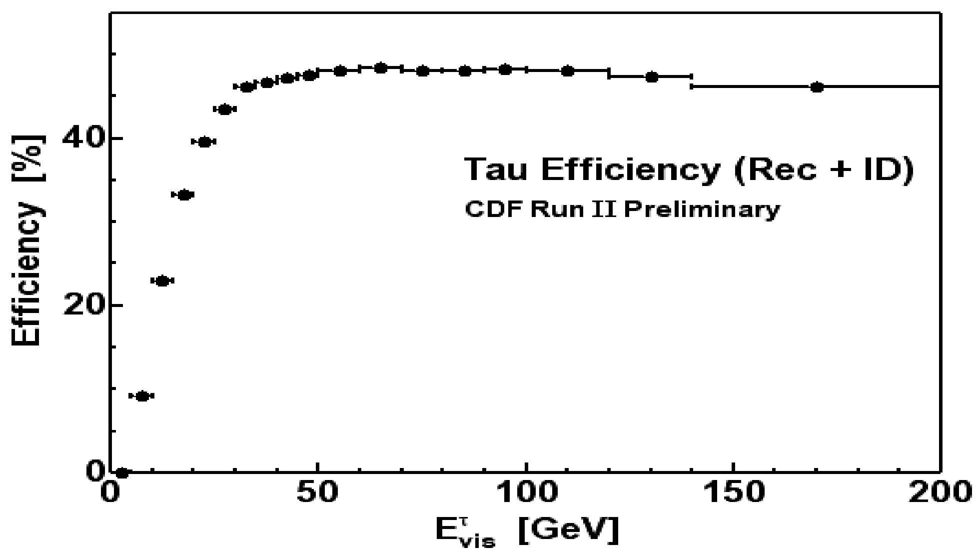
Di-taus:

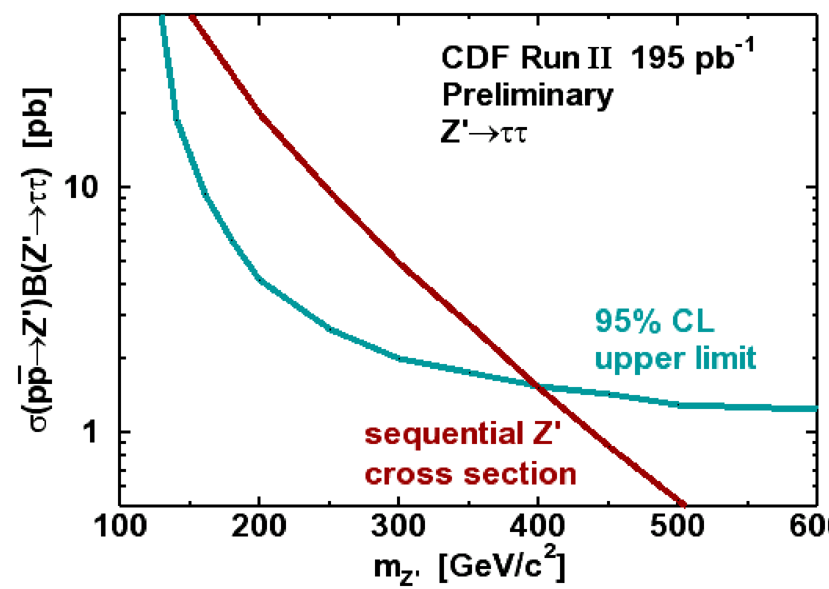
one τ decays leptonically

one τ decays hadronically:

1 or 3 tracks in an isolated cone



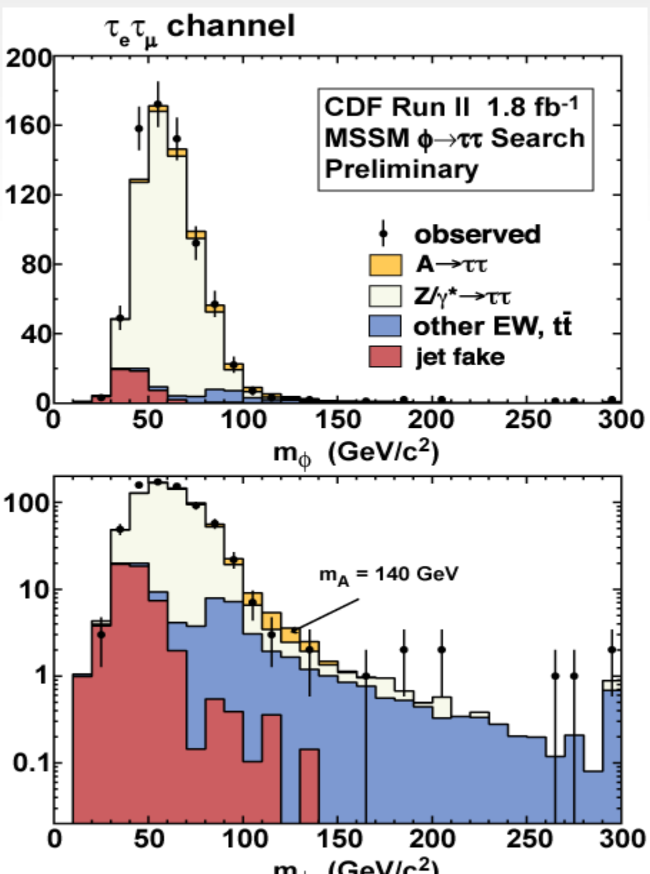


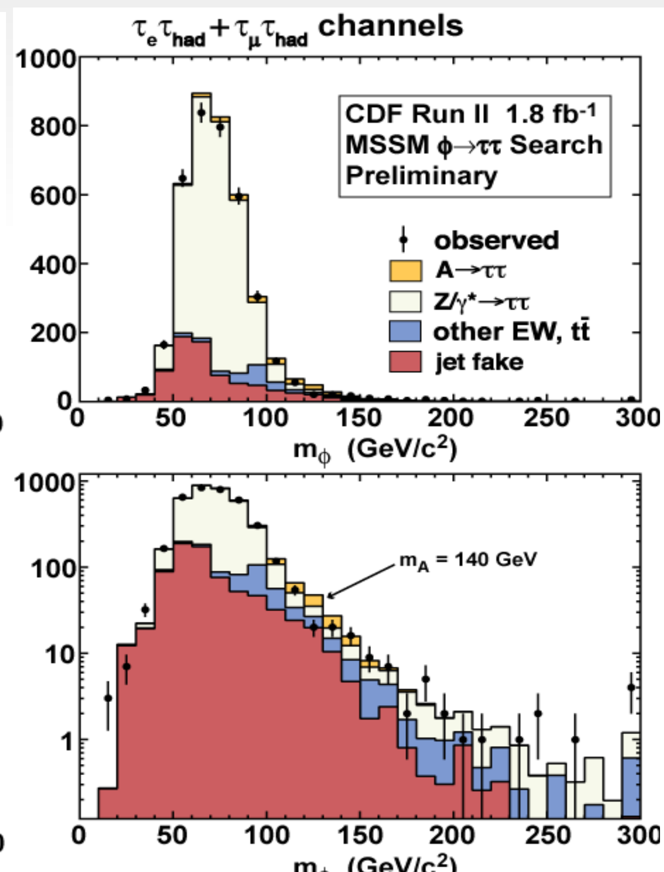


$\Phi \rightarrow \tau$ searches

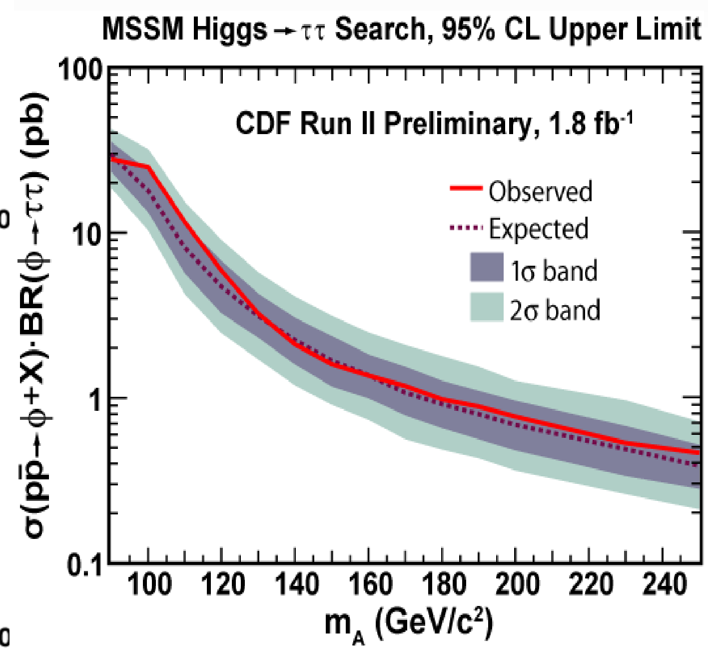
In the Minimal Supersymmetric Standard Model at high tan(β) higgs neutral sector simplifies: A and h/H become degenerate = Φ

Φ->$b\bar{b}$ (90%), Φ->$\tau^+\tau^-$ (10%). Φ->$\tau^+\tau^-$ searched looking at visible mass:

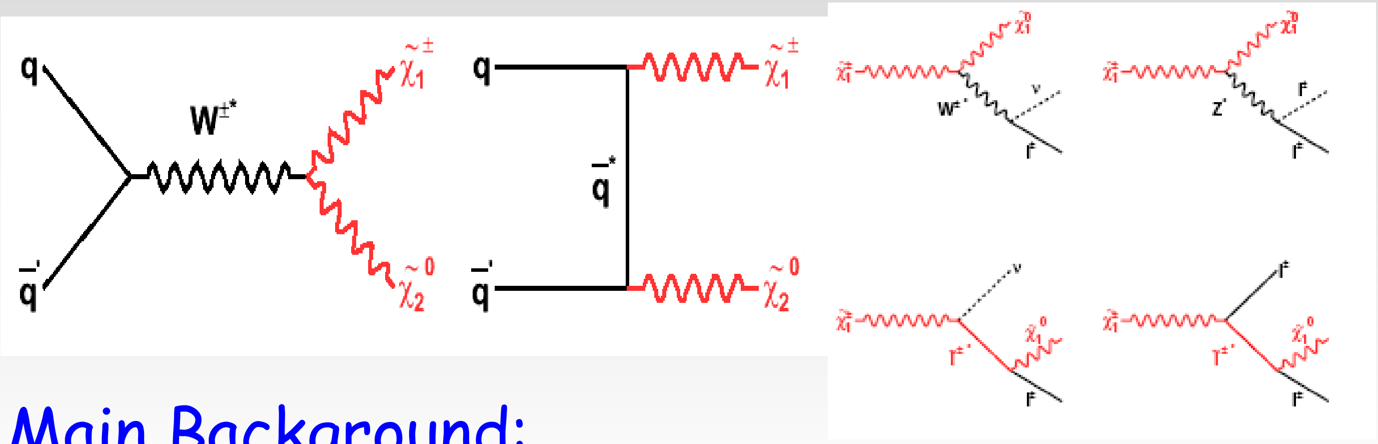




combined limit



Multileptons Final States:SUSY 3leptons



Select events with

3 leptons

MET

no jets

Z veto

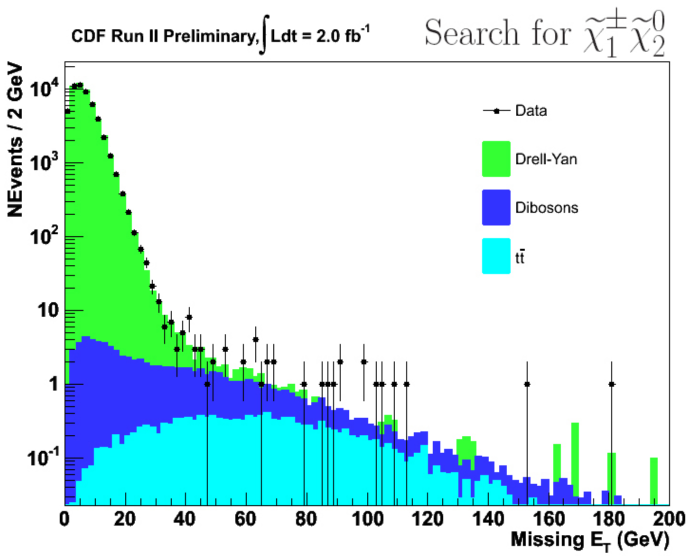
Main Background:

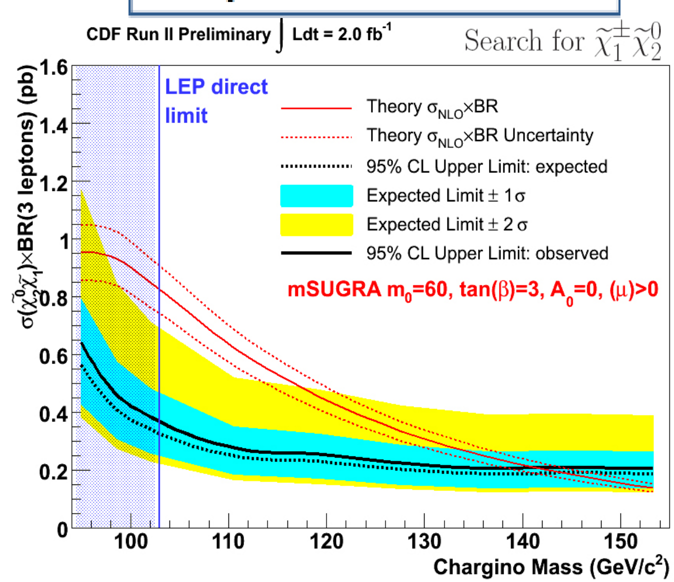
Z+γ, DY, di-bosons

$M(\chi_1^{\pm})$ > 140 GeV/c² at 95% CL

Background validation done in the control region

$76<M_{ll}<106$





Photon + MET

Photon+MET rare in Standard Model ➡ sensitive to new high-energy invisible particles. Photons can be radiated by incoming parton or be produced in the decay chains of new particles.

One model: Large Extra Dimensions.

Large Extra Dimensions (LED) by Arkani-Hamed, Dimopoulos, and Dvali (ADD): $q\bar{q}\to\gamma G$, $q\bar{q}\to gG$, $qg\to qG$, $gg\to qG$

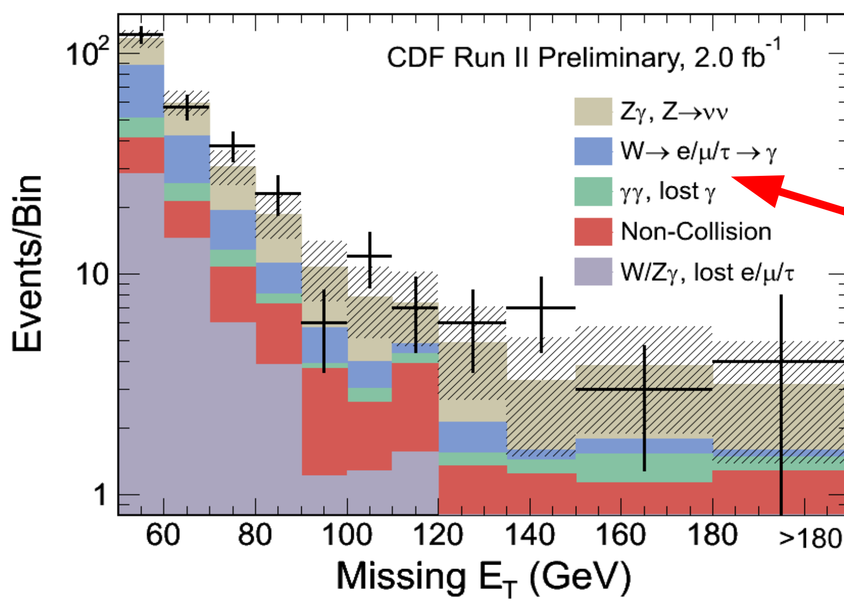
Data Selection:

Central Photon E_t>50 GeV

Missing Et >50 GeV

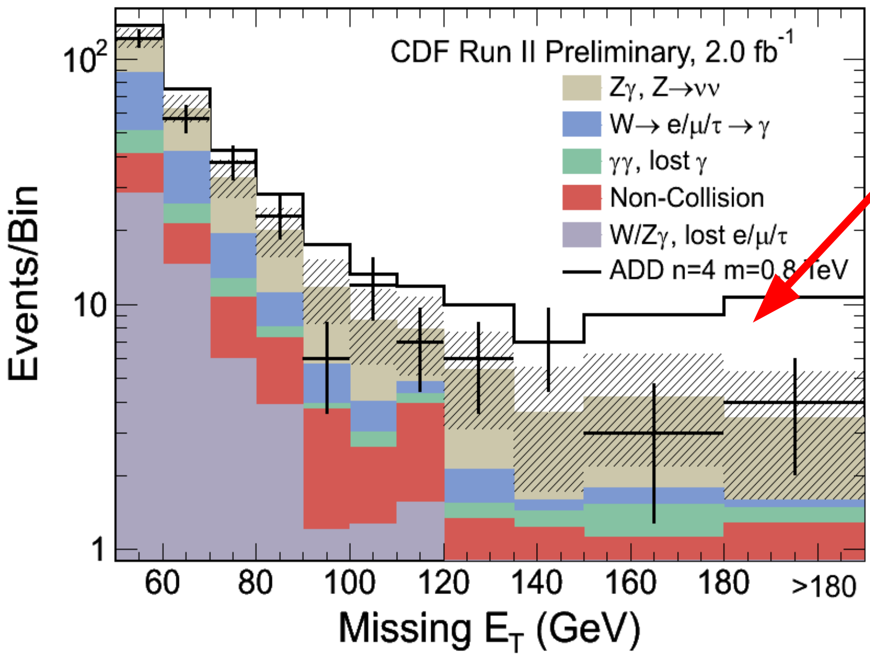
No jets with Et > 15 GeV

No tracks

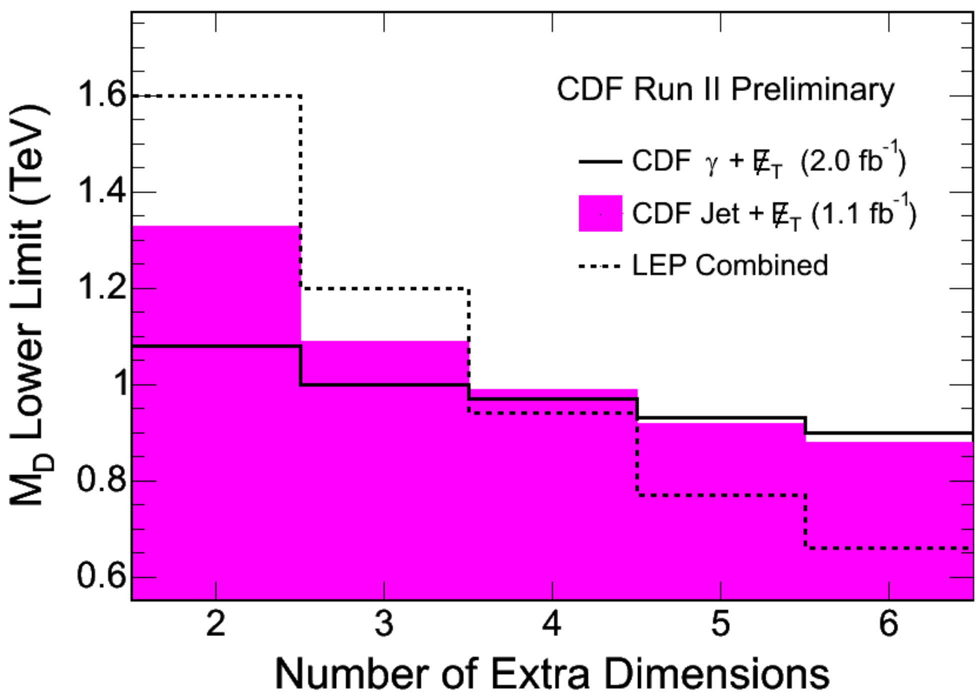


Main backgrounds

Photon + MET:Results



MET distribution including extradimensions, n=4

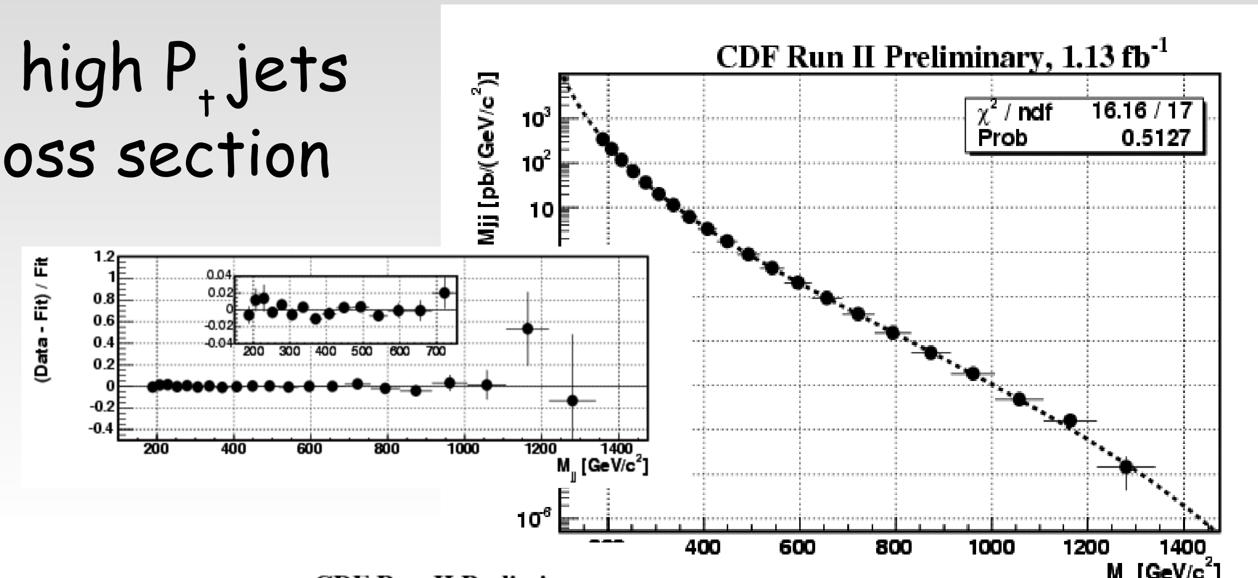


M_D=4+n dimensional Planck scale

n=N of extra dimensions

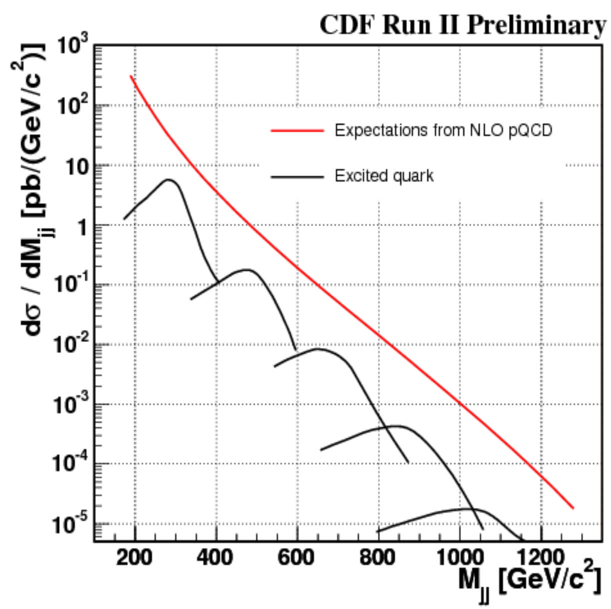
Di-jets Final States:mass bumps

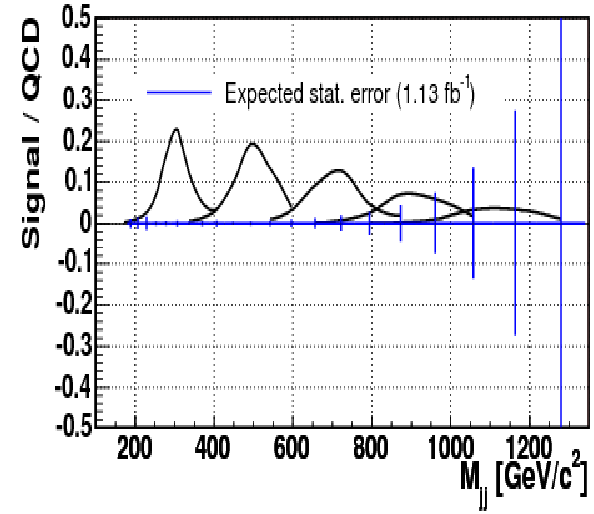
Selects events with two high P_t jets
Look for bumps in M_{jj} cross section



Excited quarks

Dijet mass spectrum from QCD and excited quark production.
Excited quark mass=300, 500, 700, 900, 1100 GeV/c^2.
Excited quark decaying to a quark-gluon pair simulated with Pythia





Di-jets Final States:mass bumps cont'd

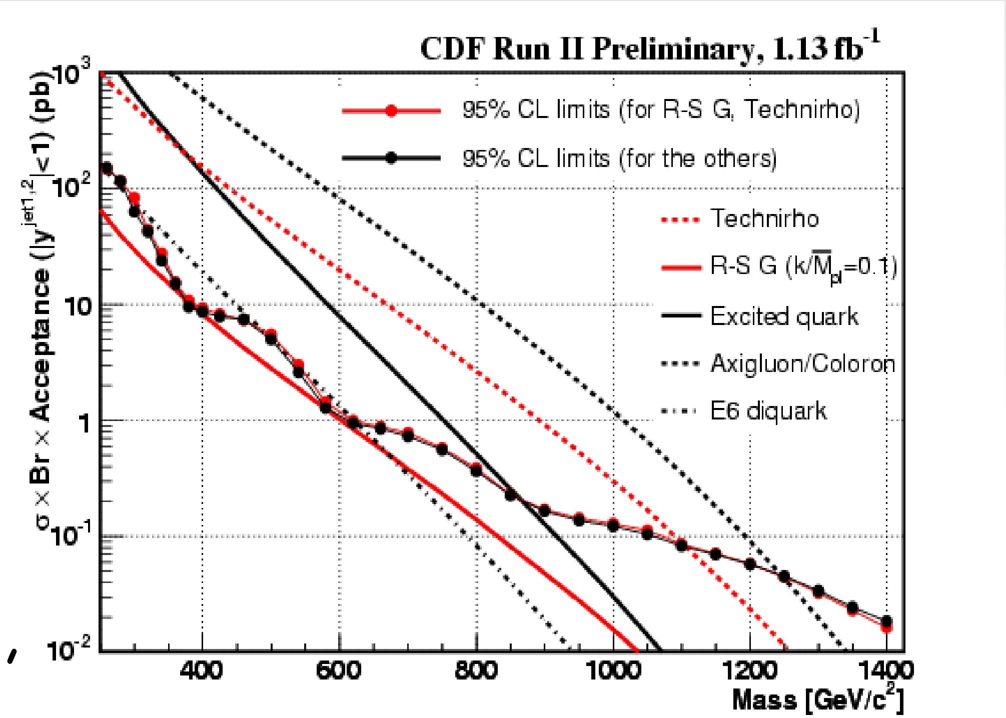
New particles

Red:

limits on the Randall-Sundrum graviton and color-octet technirho

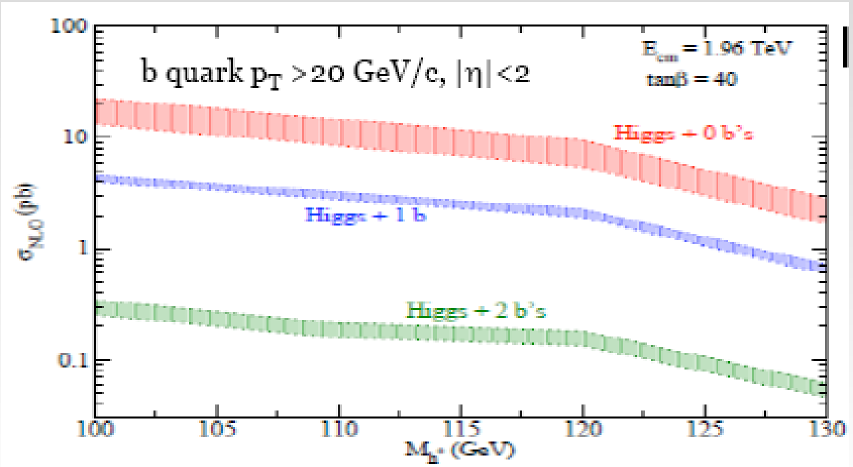
Black

limits on the excited quark, axigluon, flavor-universal coloron, and E6 diquark

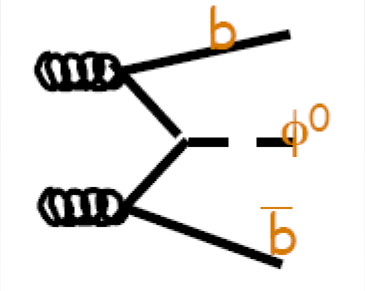


These limits are compared with theoretical predictions for these particle production.

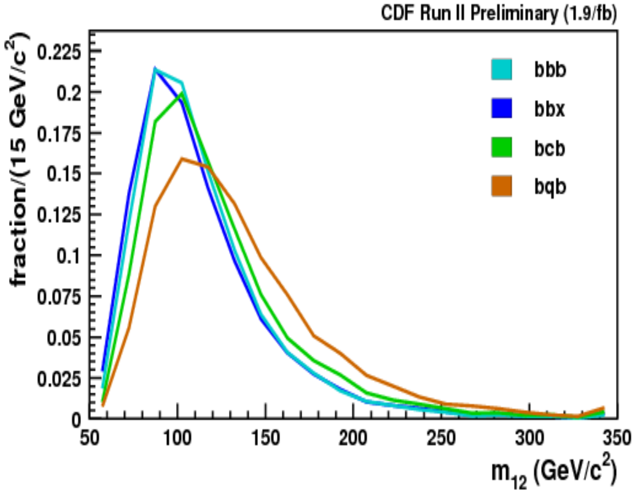
Di-jets Final States: $b\bar{b}$

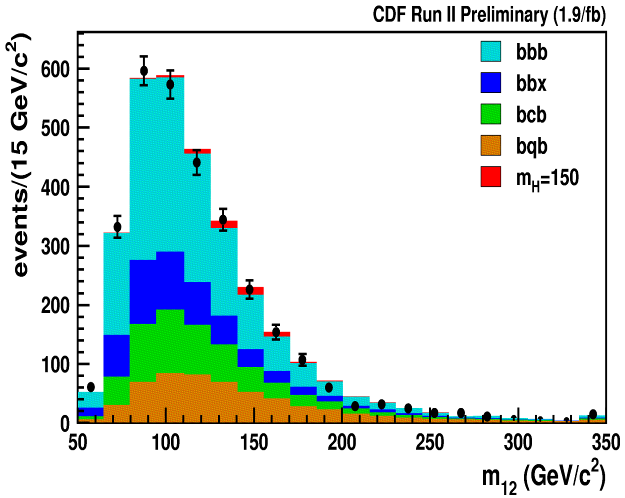


- Inclusive bb is hard due to QCD background
- Require a 3[d] b-jets
- Good compromise between signal and background rate

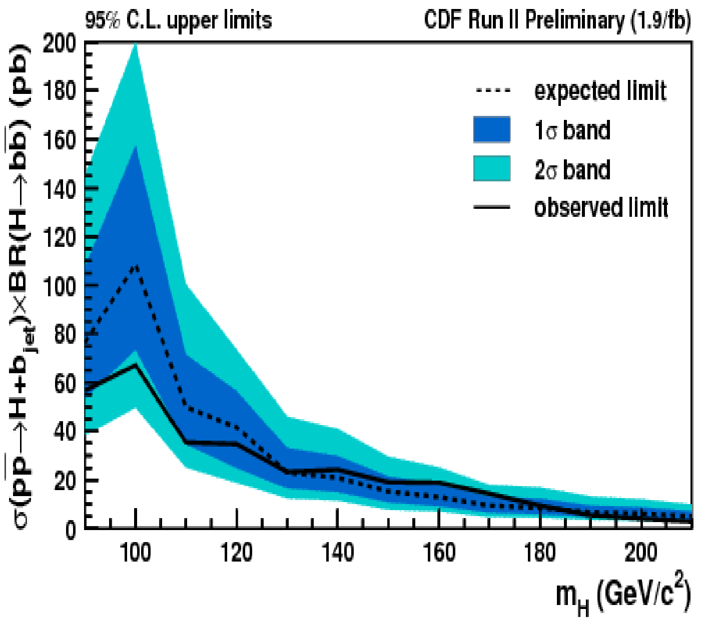


M_{12}, inv. mass of 2 leading jets used to separate signal from background





Result:



Summary

Search for Higgs following Standard Model predictions is well established: missing parameter Higgs mass.

Several other process studied and measured to sure we understand detector and trigger:

WW, ZZ, WZ, $t\bar{t}$, $b\bar{b}$

Search for new Phenomena more complex.

Compare a given theory to what we see in the data and extract limit. Cross section and mass are unknown.

Detector effect can mimic a small signal