Tevatron Searches for the Standard Model Higgs in $ZH \rightarrow l^+l^-b\bar{b}$

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[On Behalf of the CDF and D0 Collaborations]

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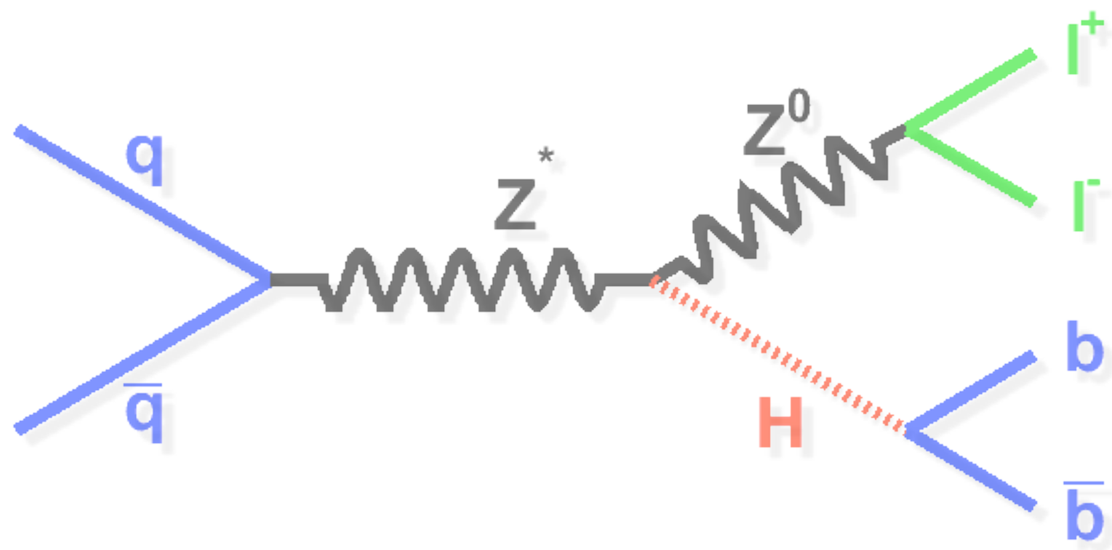
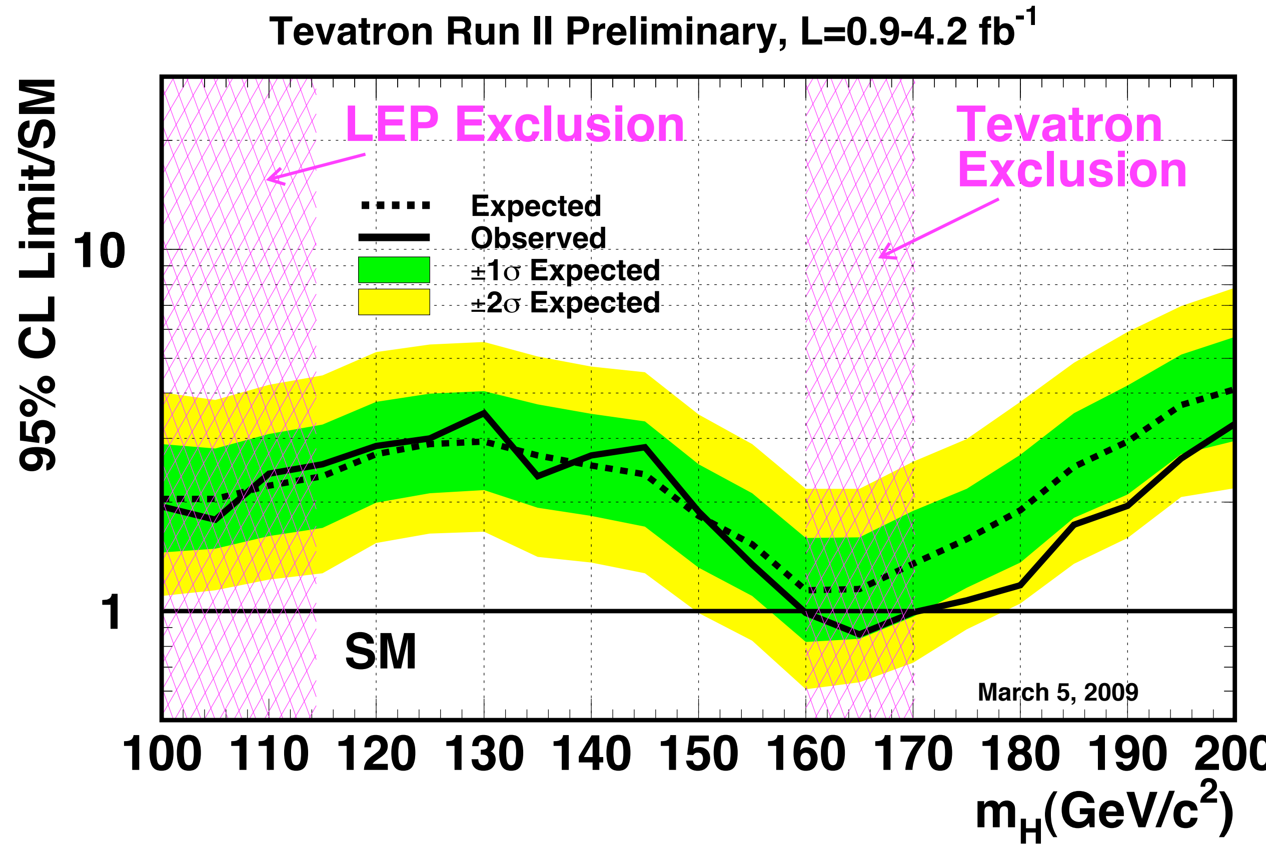


Introduction

- The Higgs Boson plays a crucial role in the standard model ...
- Since M_H is not specified by theory, rely on experimental constraints to narrow the search region



* Direct Searches at LEP/Tevatron :

M_H >114 and not between 160 and 170 GeV/c^2 @ 95% CL

* Indirect constraint from precision EW measurements (M_t , M_W) :

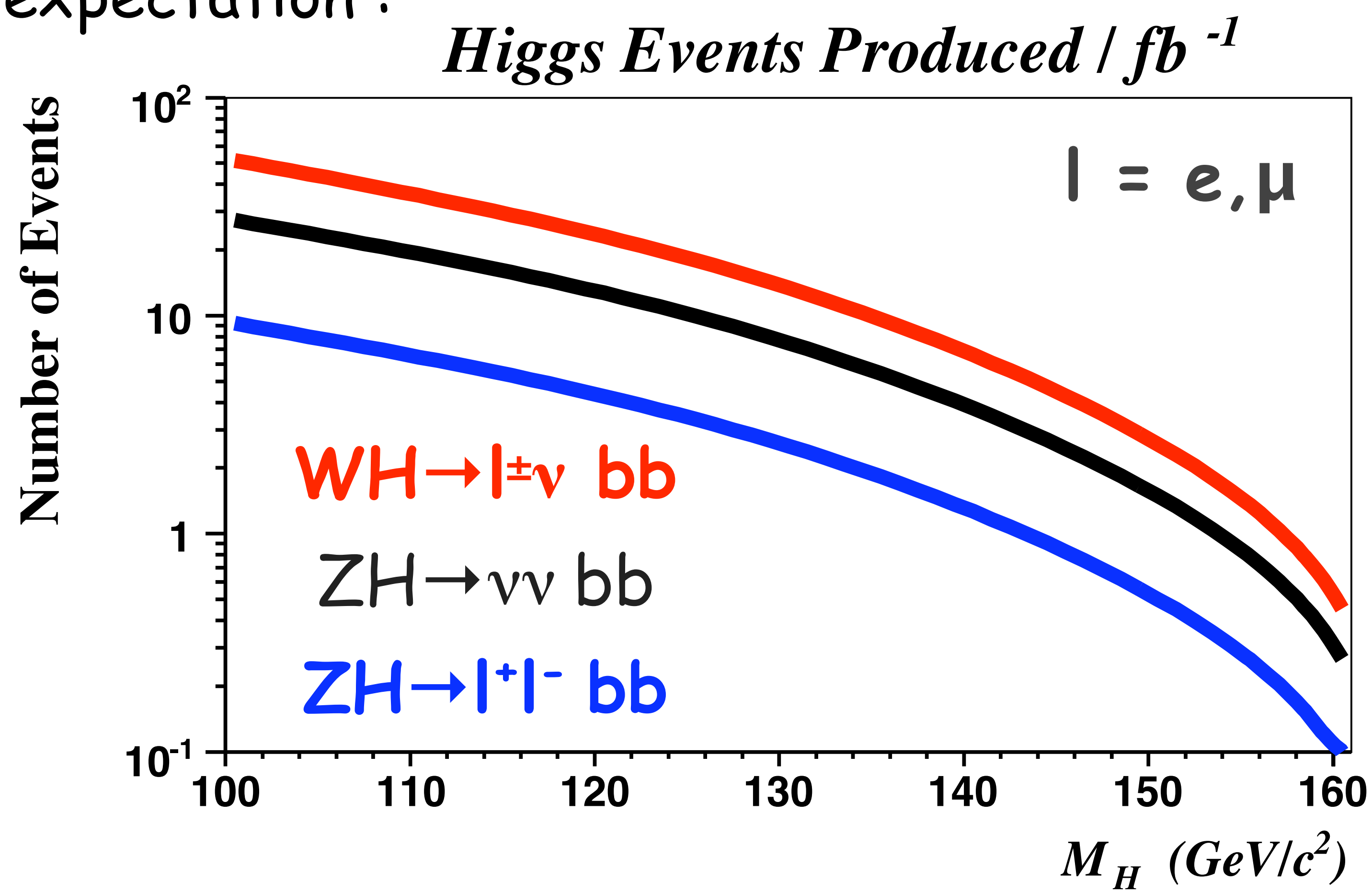
Lower masses are favored !

- At lower masses ($M_H \lesssim 135$ GeV/c^2) the dominant Higgs process ($gg \rightarrow H \rightarrow bb$) is overwhelmed by multi-jet background events, so we rely on WH/ZH modes.

low mass channels
$WH \rightarrow l^{\pm}\nu\ bb$
$ZH \rightarrow \nu\nu bb$
$ZH \rightarrow l^+l^- bb$

ZH→l^+l^-bb @ the Tevatron

- Of the main low mass search channels, ZHllbb has the smallest signal expectation :



Expect < 6 events per fb^{-1} for M_H = 115 GeV/c^2

- Basic event selection :
  - 2 high Pt muons/electrons
  - 2 energetic jets
  - at least 1 jet "b-tagged"
- Major backgrounds :
  - Z + jets / mult-jet ~ 88%
  - tt ~ 8%
  - WW,WZ,ZZ ~ 4%

- However, Z+H resonances and fully constrained final state (no neutrinos) result in relatively lower backgrounds

channel	~ Size of Background
WH→l±ν bb	9 X ZH→llbb Background
ZH→ννbb	5 X ZH→llbb Background

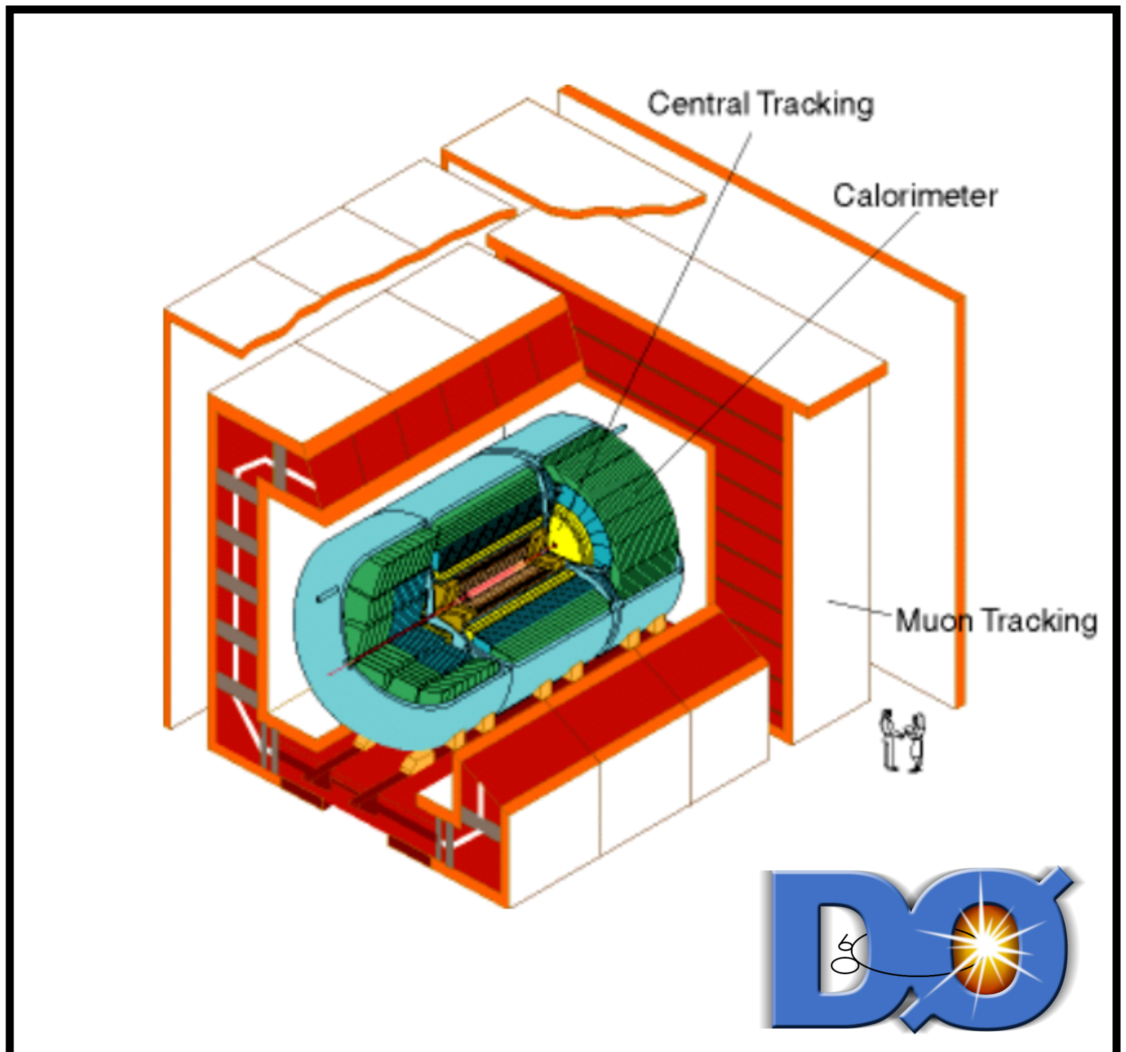
Tevatron, D0, and CDF

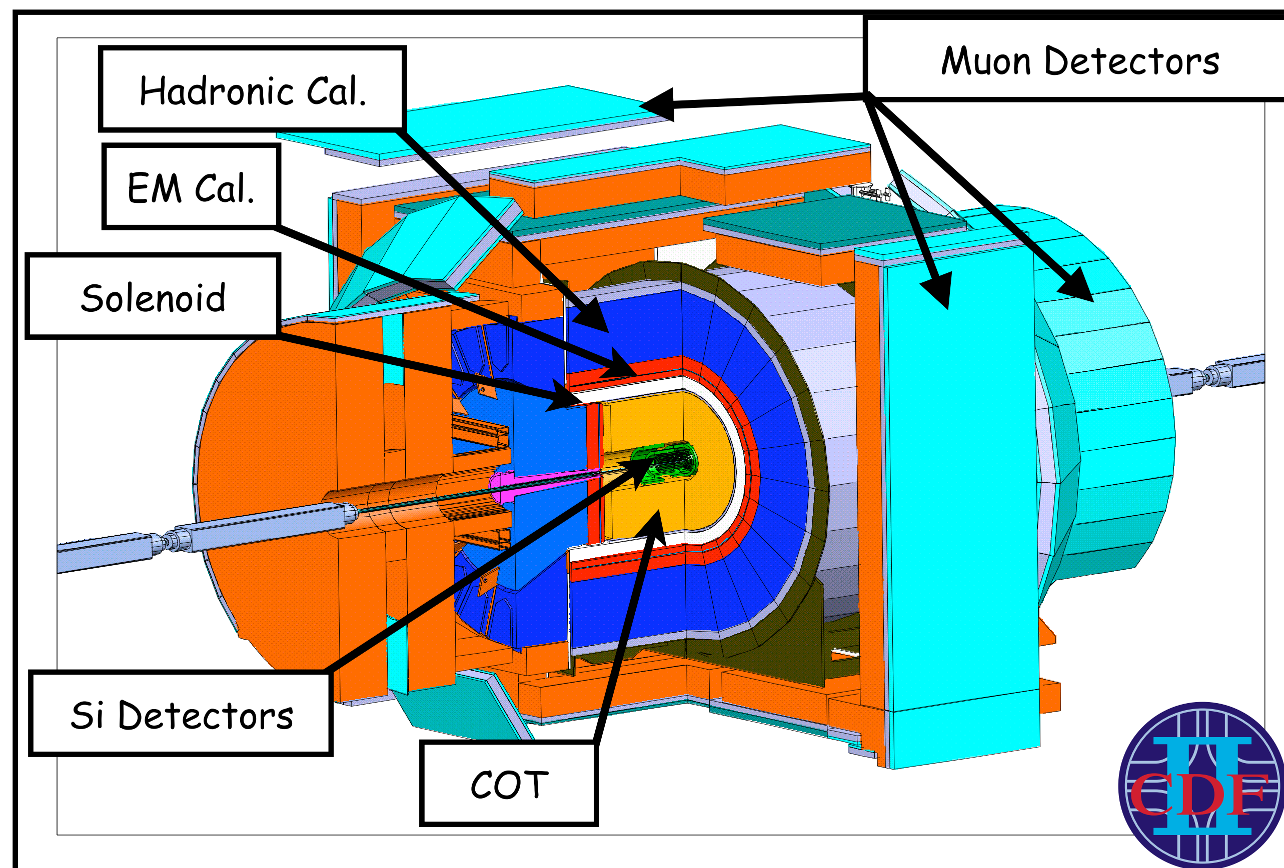
The Tevatron :

- p anti-proton Collider at Fermilab
- Center of Mass Energy = 1.96 TeV
- ~ 6fb^{-1} recorded per experiment
- Current ZHllbb analyses use up to 4.2 fb^{-1}

D0 and CDF II :

- Multi-purpose Detectors
  - Silicon Detectors critical for b-jet ID
  - Tracking : CDF Drift Chamber (COT)
    D0 Fiber Tracker
  - Calorimeters and Muon Detectors



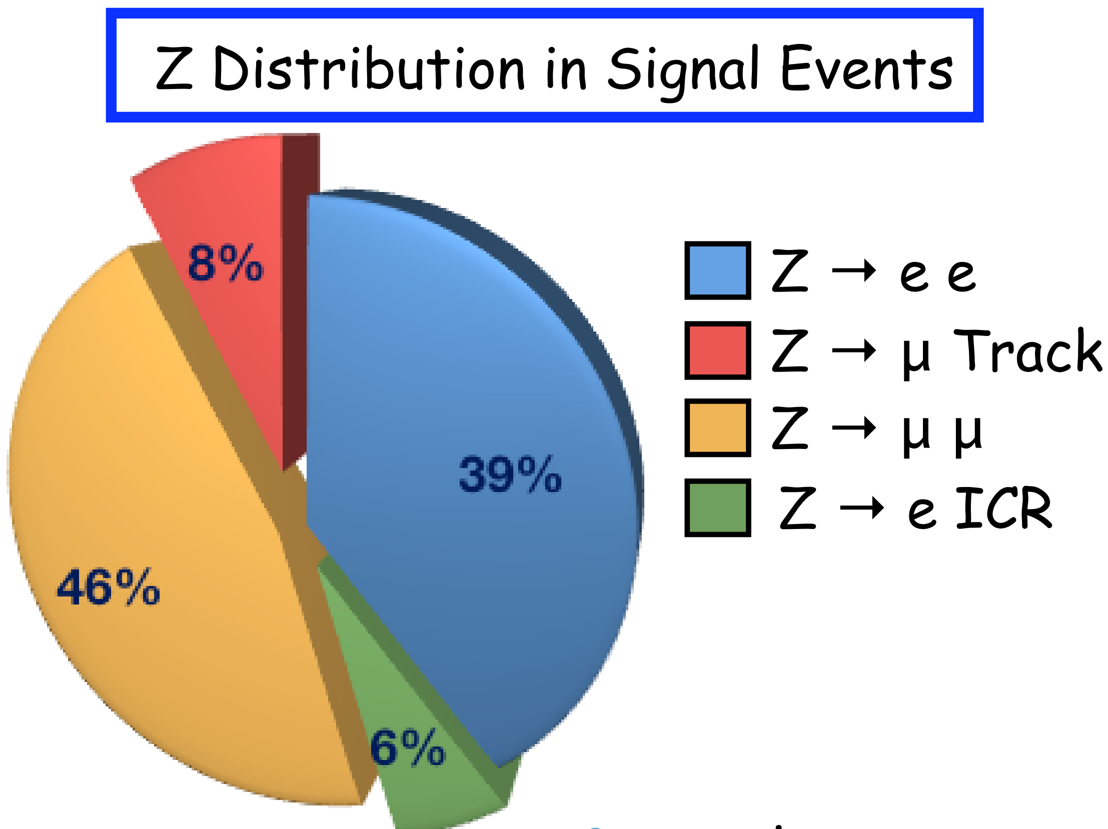


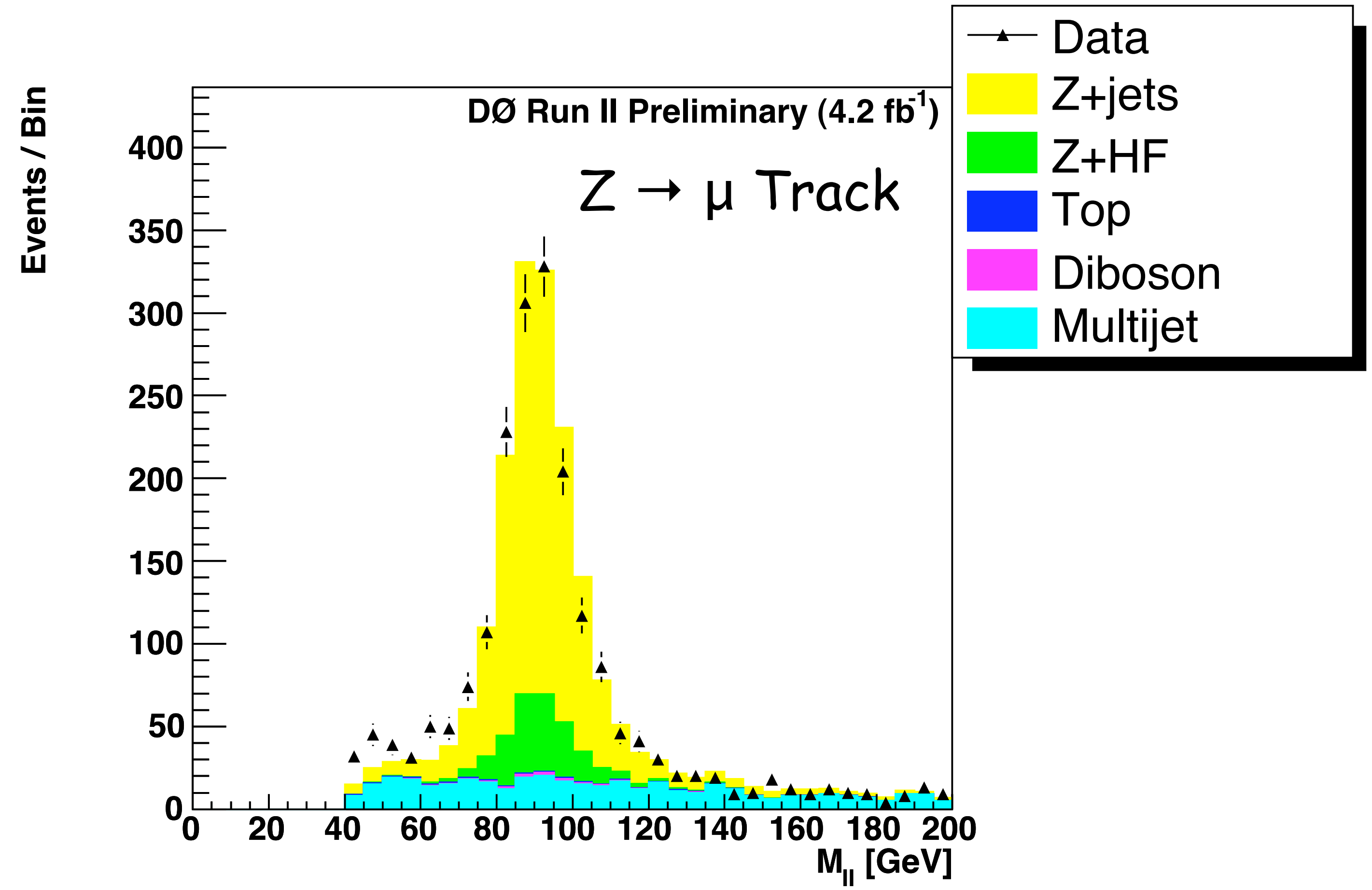
General ZH→l^+l^-bb Search Strategy

- Step 1 Compensate for low signal expectation with increased Z acceptance
- Step 2 Validate data model
- Step 3 Identify b-jets using various algorithms
- Step 4 Exploit the constrained final state
- Step 5 Combine multiple kinematic distributions using multivariate techniques to enhance Signal/Background separation

Step 1 : Maximizing Z Acceptance @ D0

- Define four Z classes depending on lepton types and locations in the detector





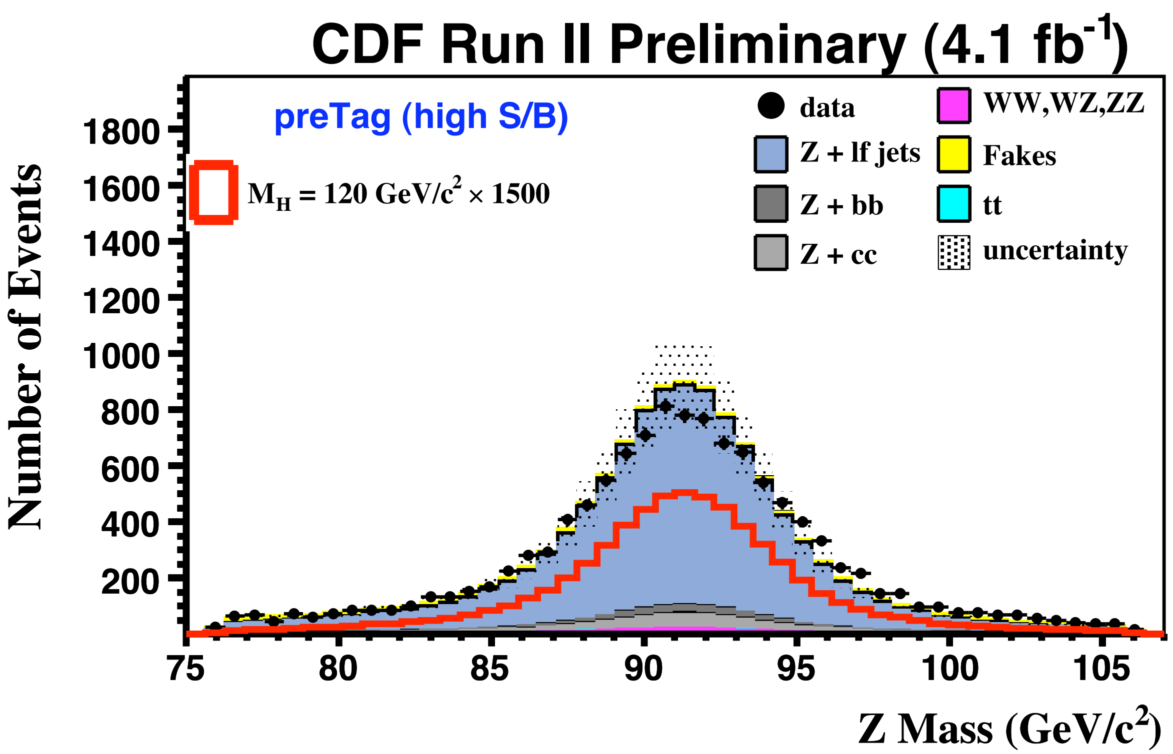
- e = electron candidate passing calorimeter cuts
- ICR = loose electron reconstructed from Track + Jet using a NN
- μ = muon candidate passing muon/track cuts
- Track = loose muon candidate reconstructed from track

- Expand Z mass cut from [70,110] to [70,130] GeV/c^2
- Net gain of ~15% more signal Z's by using Track and ICR loose lepton types

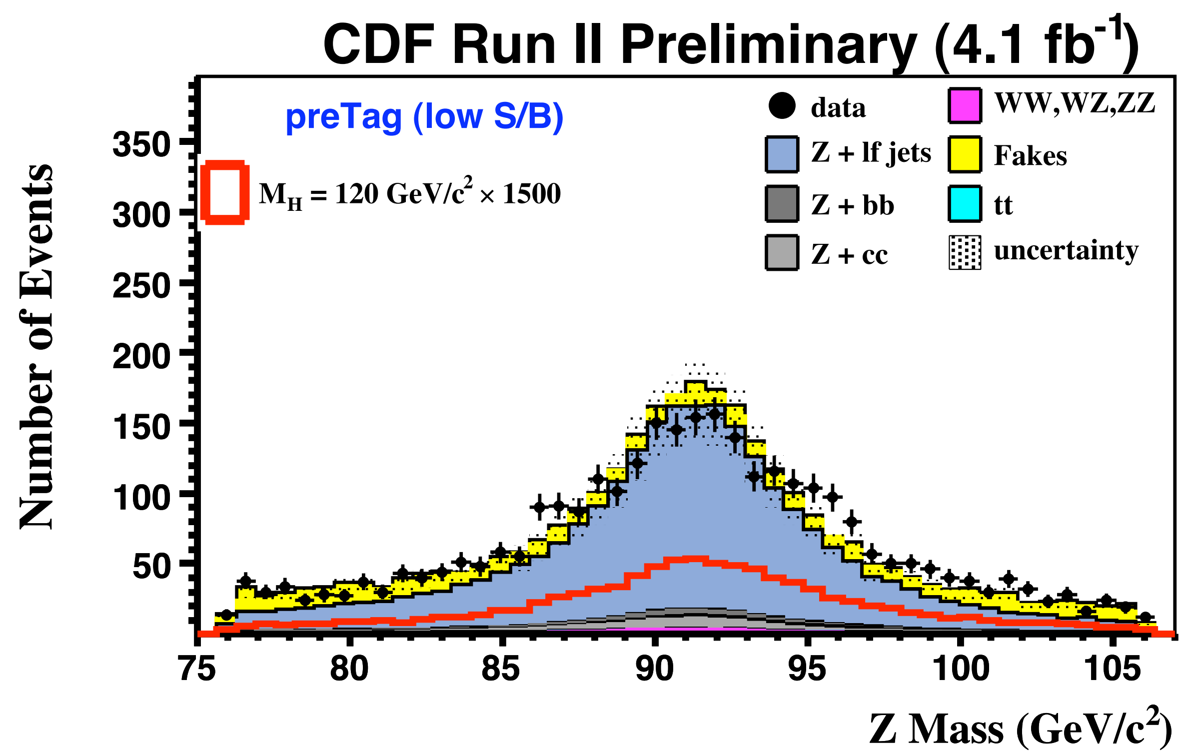
Step 1 : Maximizing Z Acceptance @ CDF

- In addition to the standard central lepton triggers, Use additional **Trigger** which accepts events with >= 2 calorimeter deposits (Et>18 GeV) without a track requirement
- Extra Trigger allows for **loose selection cuts** on **both** leptons
- Additional Z acceptance ➜ ~10% improvement in expected limits

Tight Z Selection

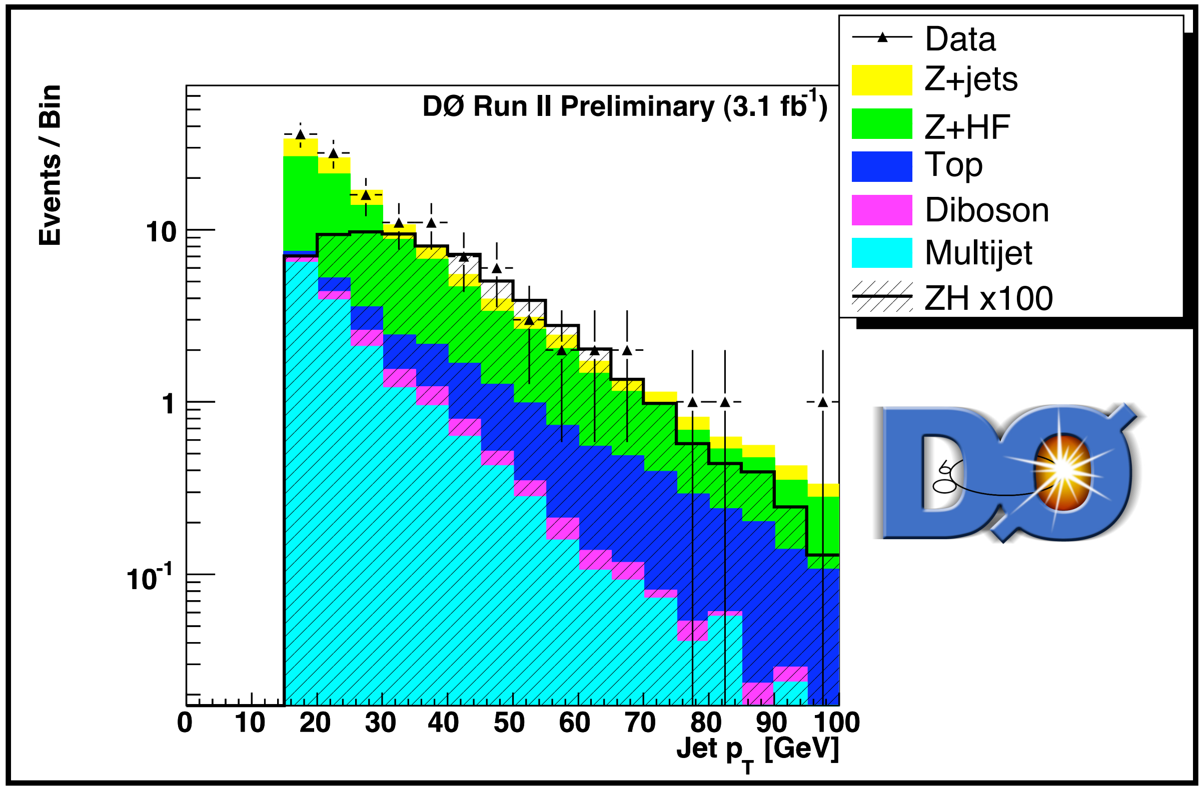


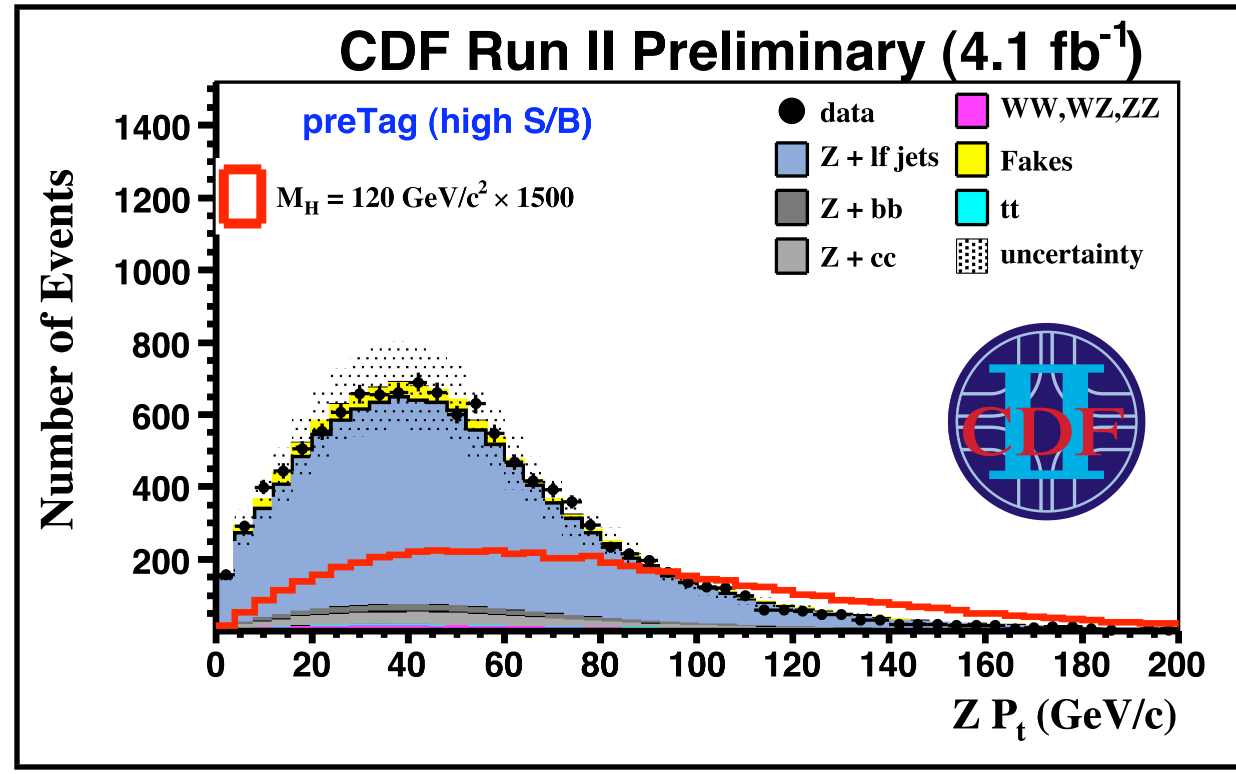
Loose Z Selection



Step 2 : Validate Data Model

- Check multiple kinematic distributions to ensure data is well understood



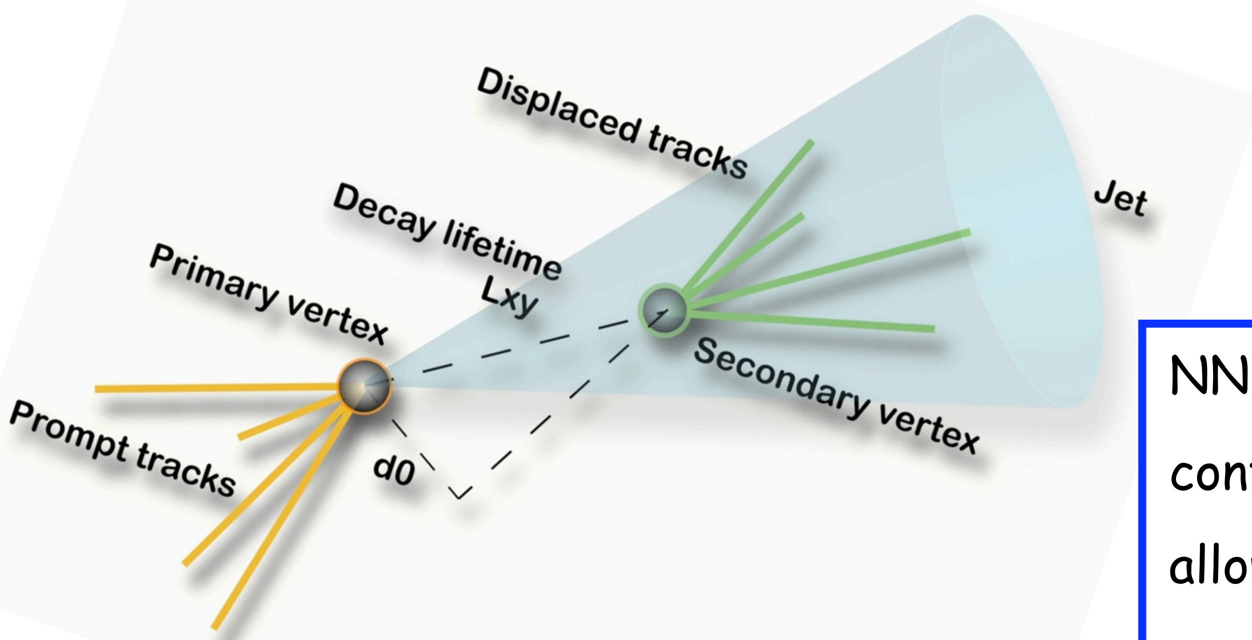


Data Model

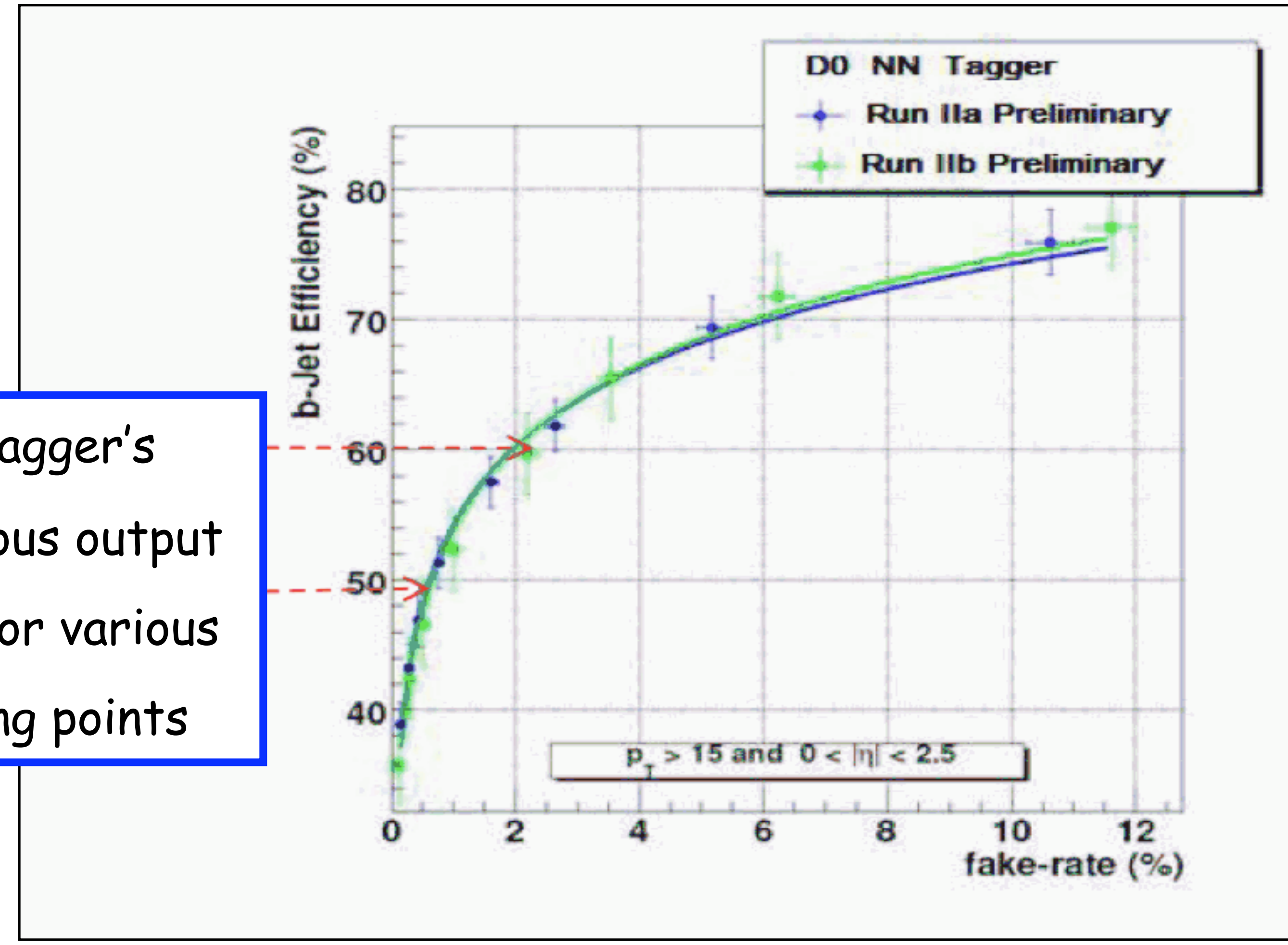
- Signal, Diboson, top, Z+bb, Z+cc modeled with MC
- Use data-derived estimates for fakes lepton and incorrectly tagged jet contributions

Step 3 : Identifying b-jets @ D0

- Employ a b-tagging artificial Neural Network



NN b-Tagger's continuous output allows for various operating points



- Distinguishes b-jets from c/light jets
- Exploits long lifetime of b
- Various operating points

Tight : 50% eff. with 0.5% fake rate

Loose : 72% eff. with 4% fake rate

b-tagging rejects about 95% of Z+jets background !

Two Final Tag Categories :

1 Jet passing Tight NN b-tag requirement

2 Jets passing Loose NN b-tag requirement

Step 3 : Identifying b-jets @ CDF

- Use a combination of b-tagging Algorithms for a 15% increase in signal efficiency:

➡ Secondary Vertex Taggers :

- Use displacement of the jet vertex from the primary event vertex to identify b-jets (larger displacement = more likely a b -jet)

➡ JetProbability Tagger :

- Uses track impact parameters to calculate P(jet vertex = primary vertex)

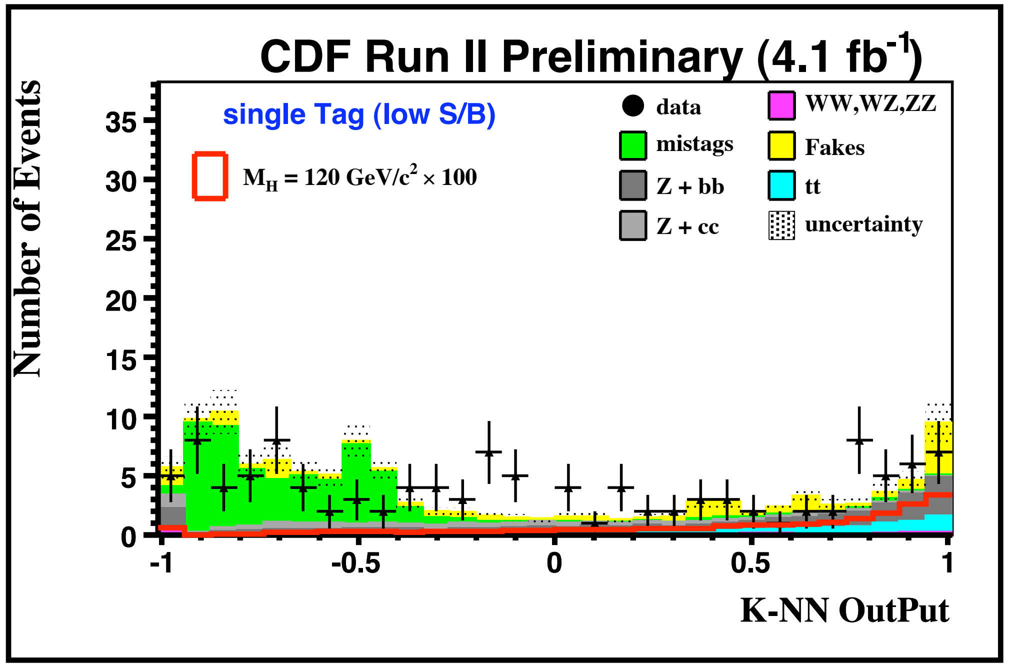
Three Final Tag Categories :

2 Tight SecVtx Tagged Jets

1 Loose SecVtx Tagged Jet + one JetProb Tagged Jet

1 Tight SecVtx Tagged Jet

- Enhance the ability of our final discriminant to reject incorrectly tagged lf jets (mistags) with a flavor separator NN (used as an input to final discriminant)

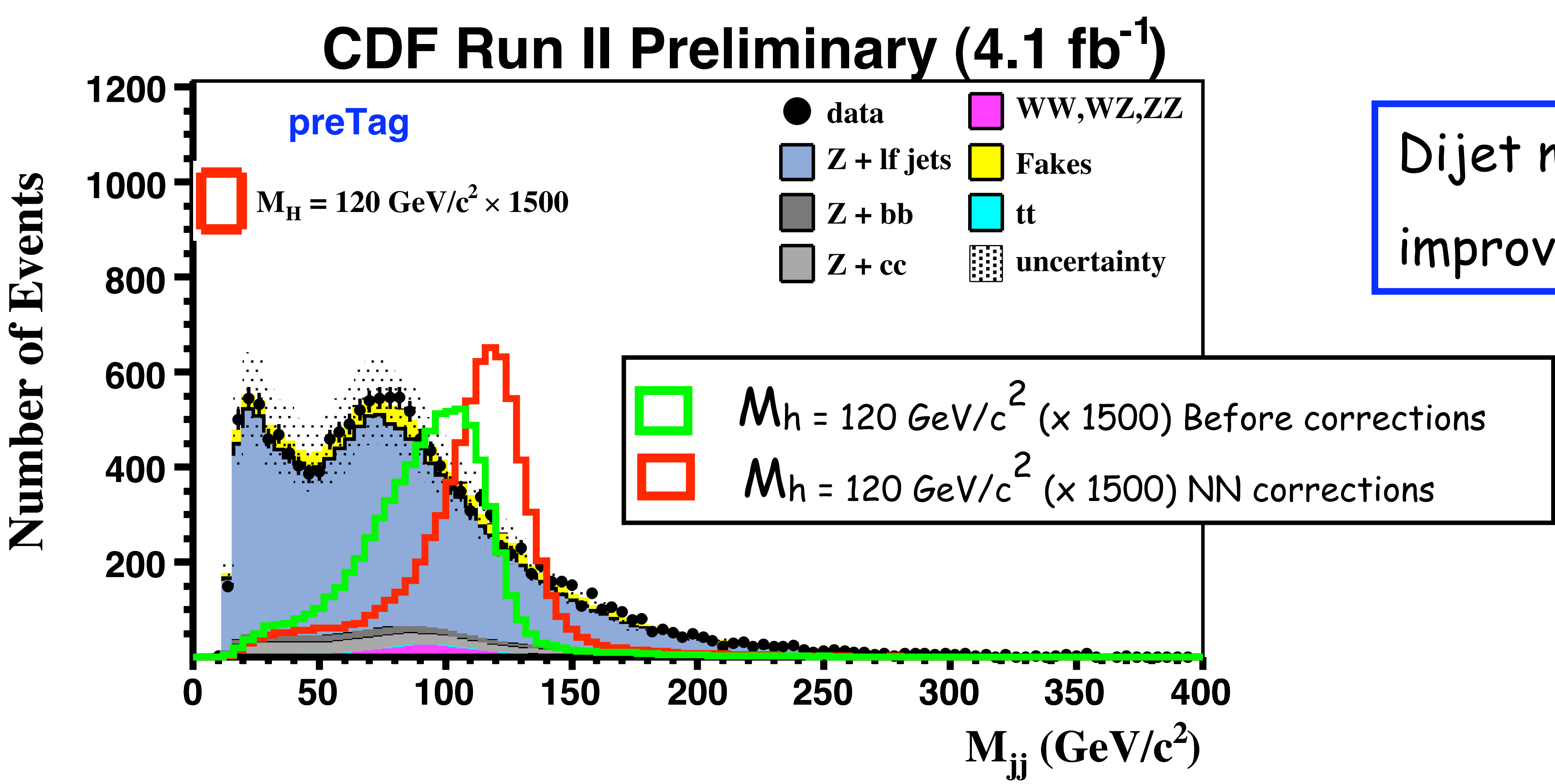


Step 4 : Exploiting the Final State @ CDF

- No Neutrinos in signal final state ➜ Missing Energy is mostly due to mis-measured jet Energies
- Improved jet energy resolution enhances the discriminating power of jet based kinematic distributions

The CDF Approach :

- CDF Employs a **NN derived function** to correct jet energies for missing E_t
- The NN returns correction factors for the jets depending on the orientation and magnitude of missing E_t and jets

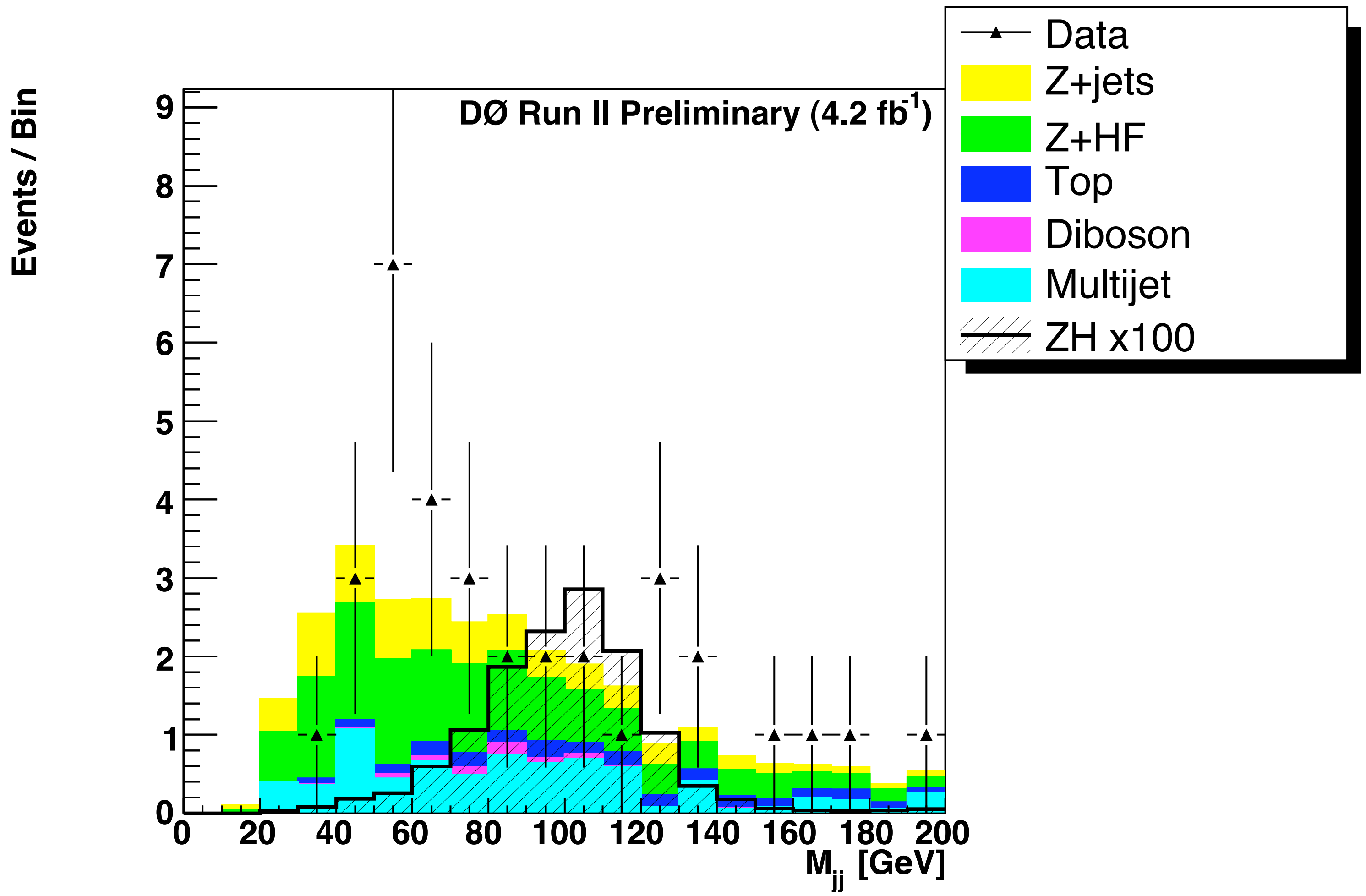


Dijet mass resolution improves from 18 to 12%

Step 4 : Exploiting the Final State @ D0

The D0 Approach :

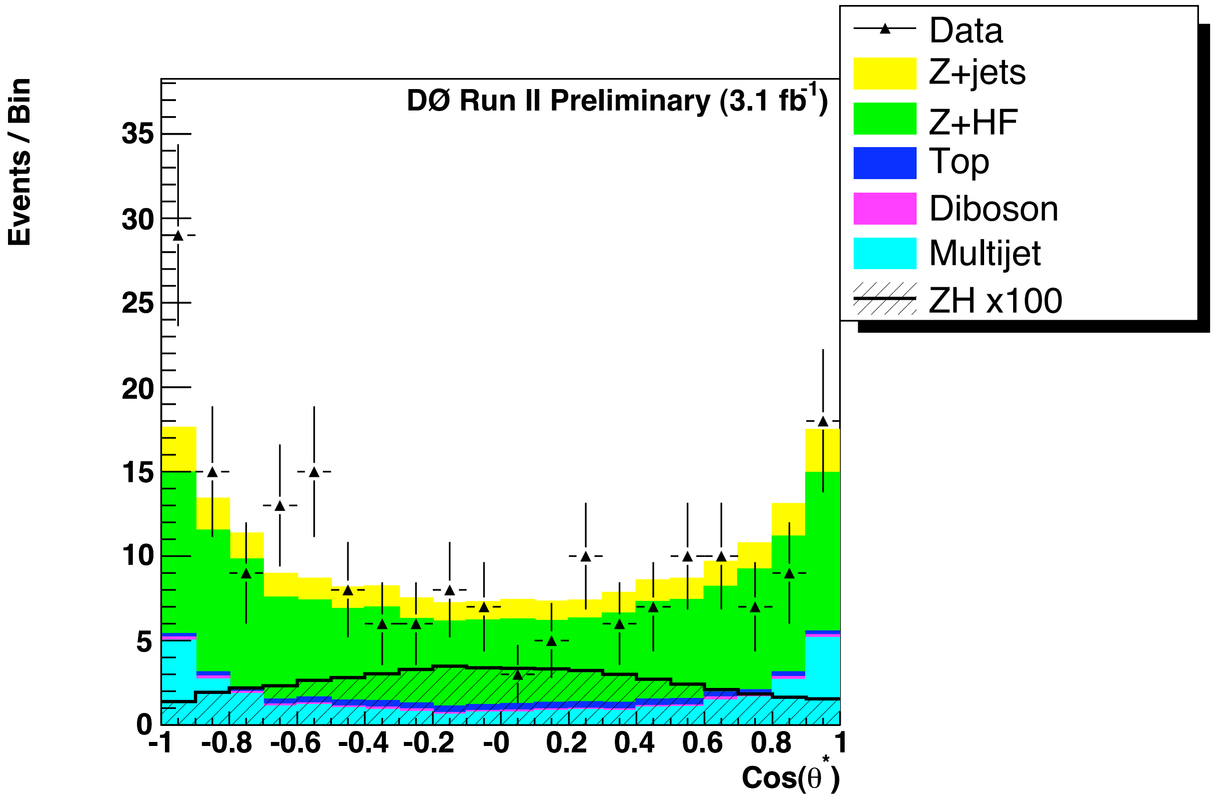
- D0 performs a **Kinematic χ^2 fit** to improve signal discrimination
- lepton/jet energies and angles are allowed to float within detector resolution, to minimize χ^2 under the constraints
  - dilepton mass = Z mass +/- Z width
  - P_t of dilepton + dijet system is constrained to zero +/- 7 GeV

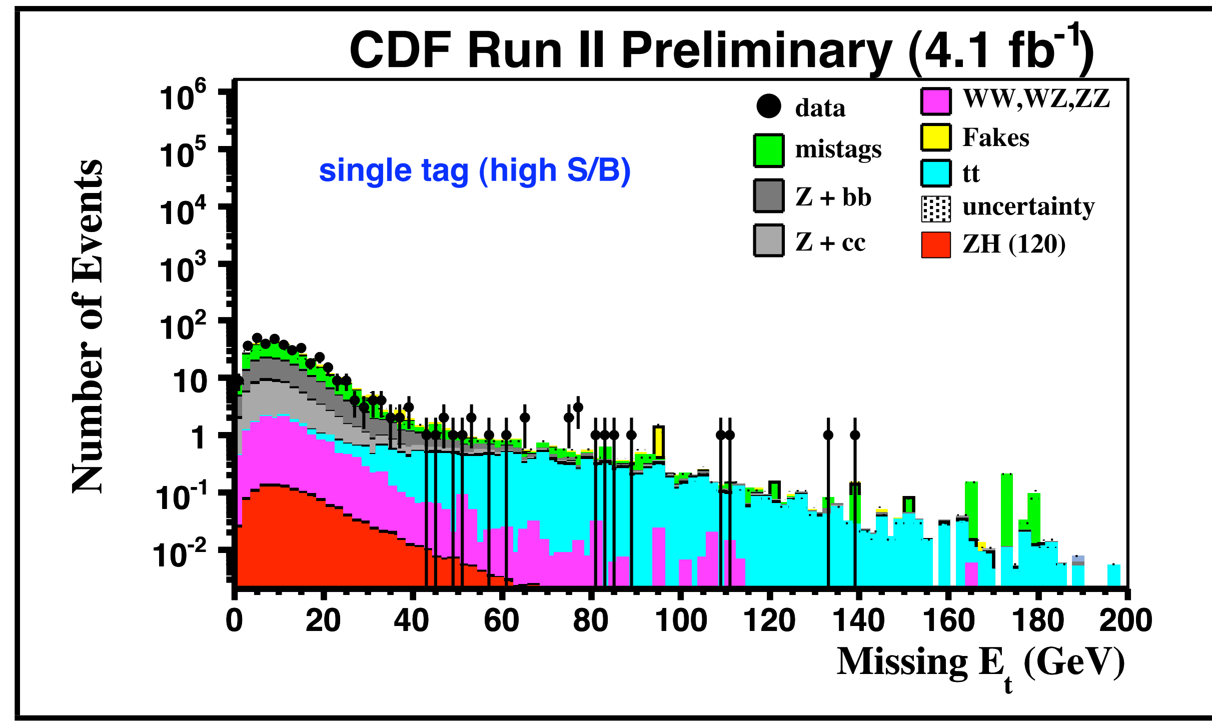


Dijet mass resolution similar to that of CDF

Step 5 : Multivariate S/B Discrimination

- Several distributions contain S/B discriminating power
- For example M_{jj}, MET, jet P_t's, angular variables :



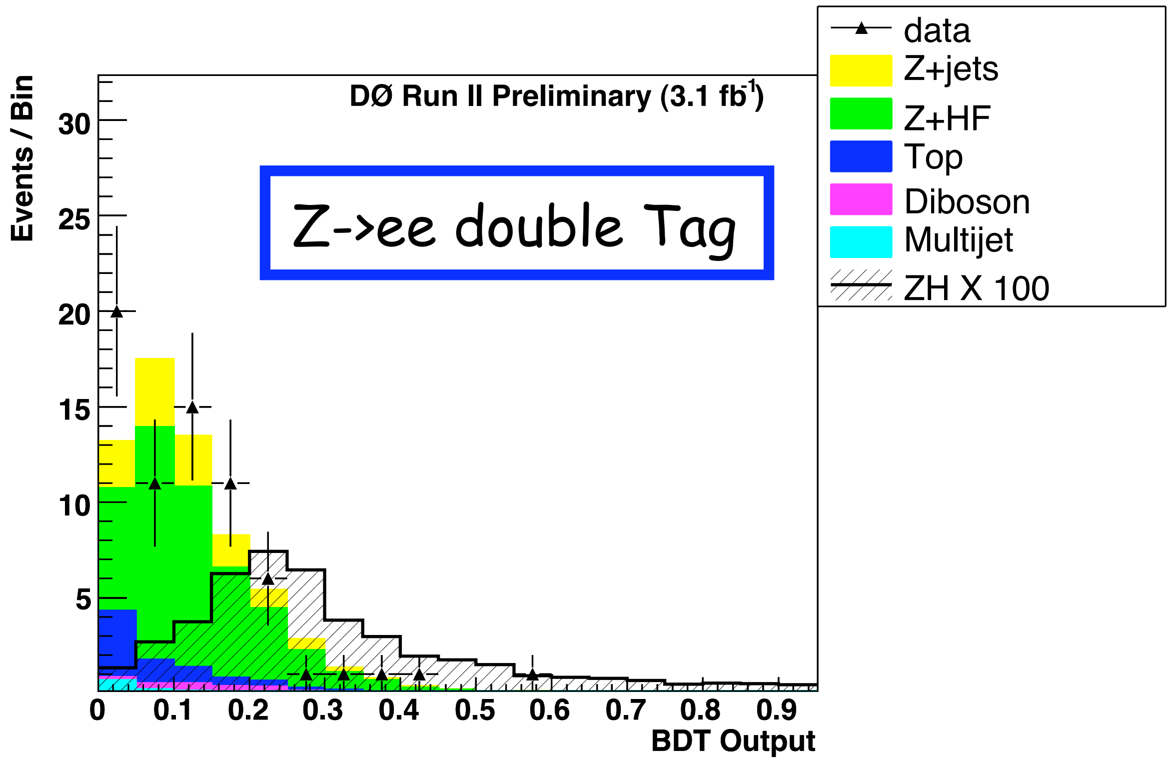


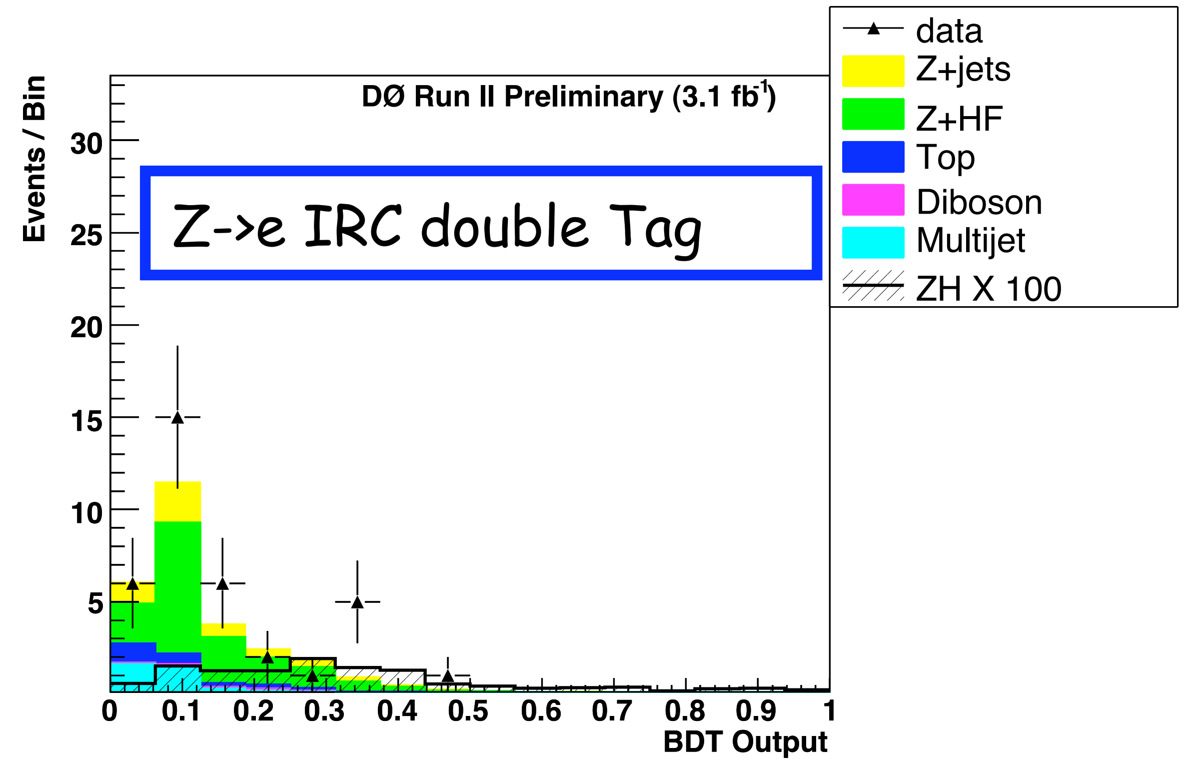
- Multivariate techniques are used to combine the discriminating power of several variables
- Also exploit the correlations between variables

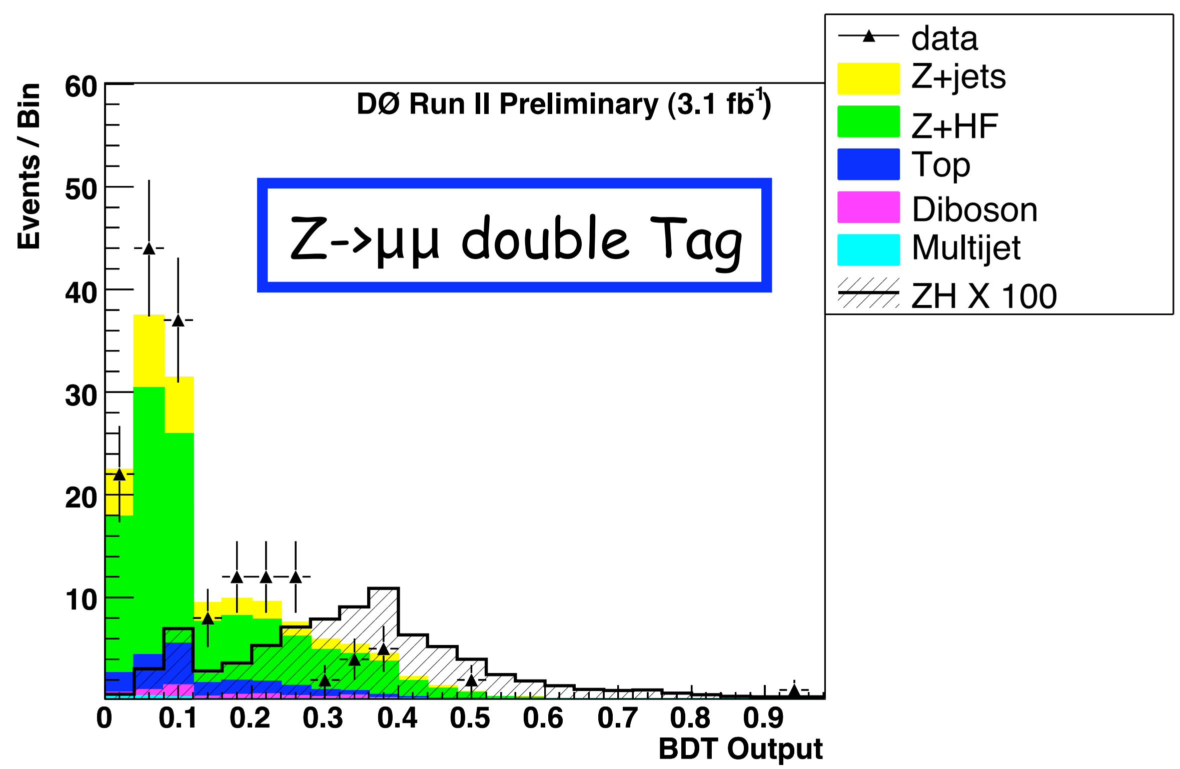
➡ CDF : Matrix Elements + NNs
➡ D0 : Boosted Decision Trees

Step 5 : Multivariate S/B Discrimination @ D0

- Optimize a Boosted Decision Tree for each Tag/Z type combination
- Trained to separate ZH from major backgrounds

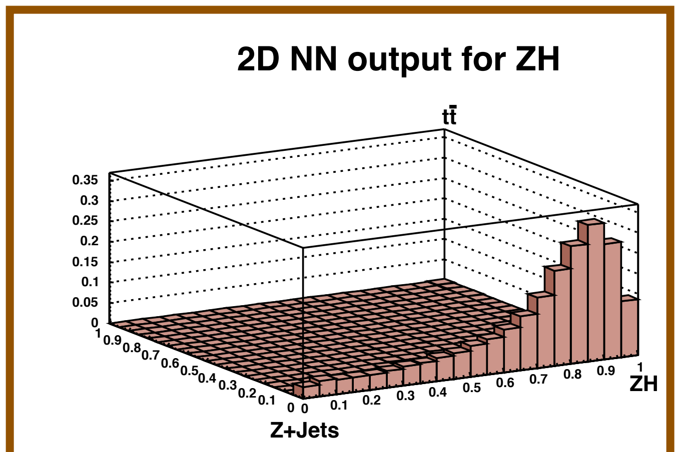


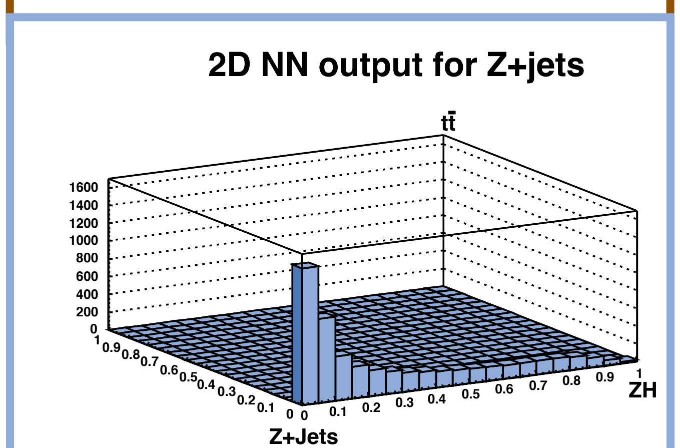


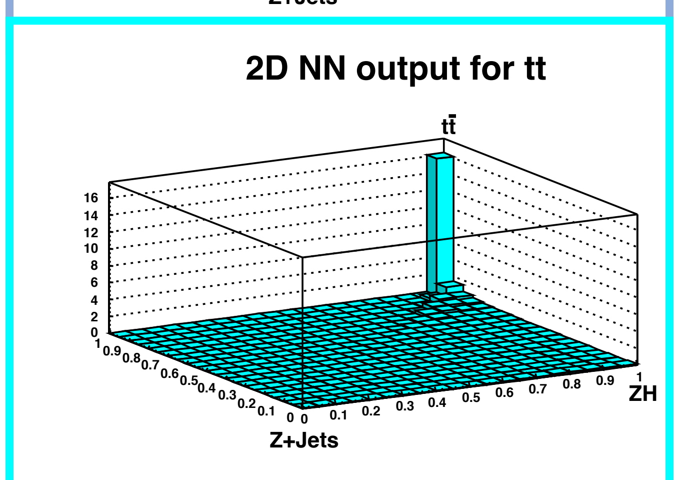


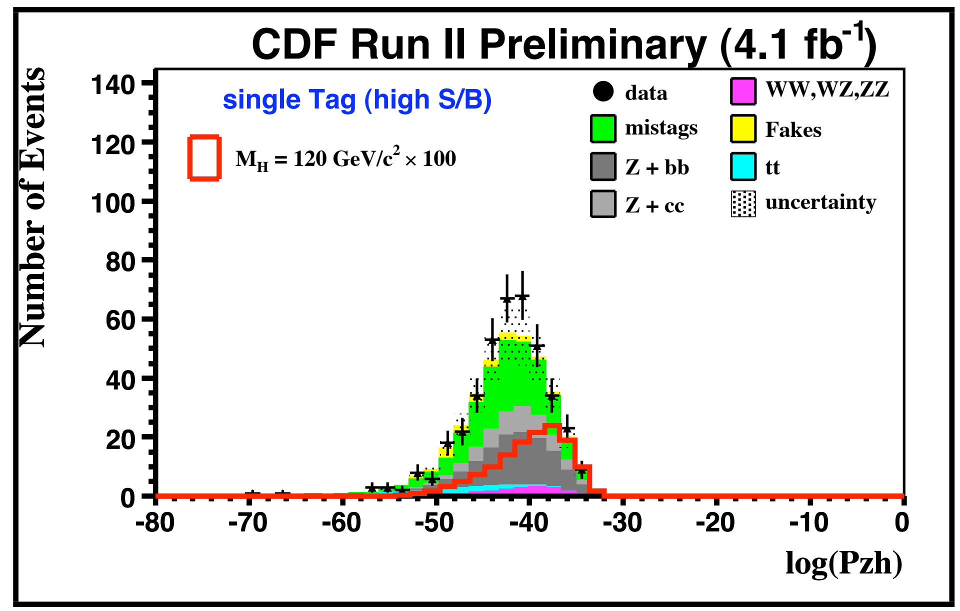
Step 5 : Multivariate S/B Discrimination @ CDF

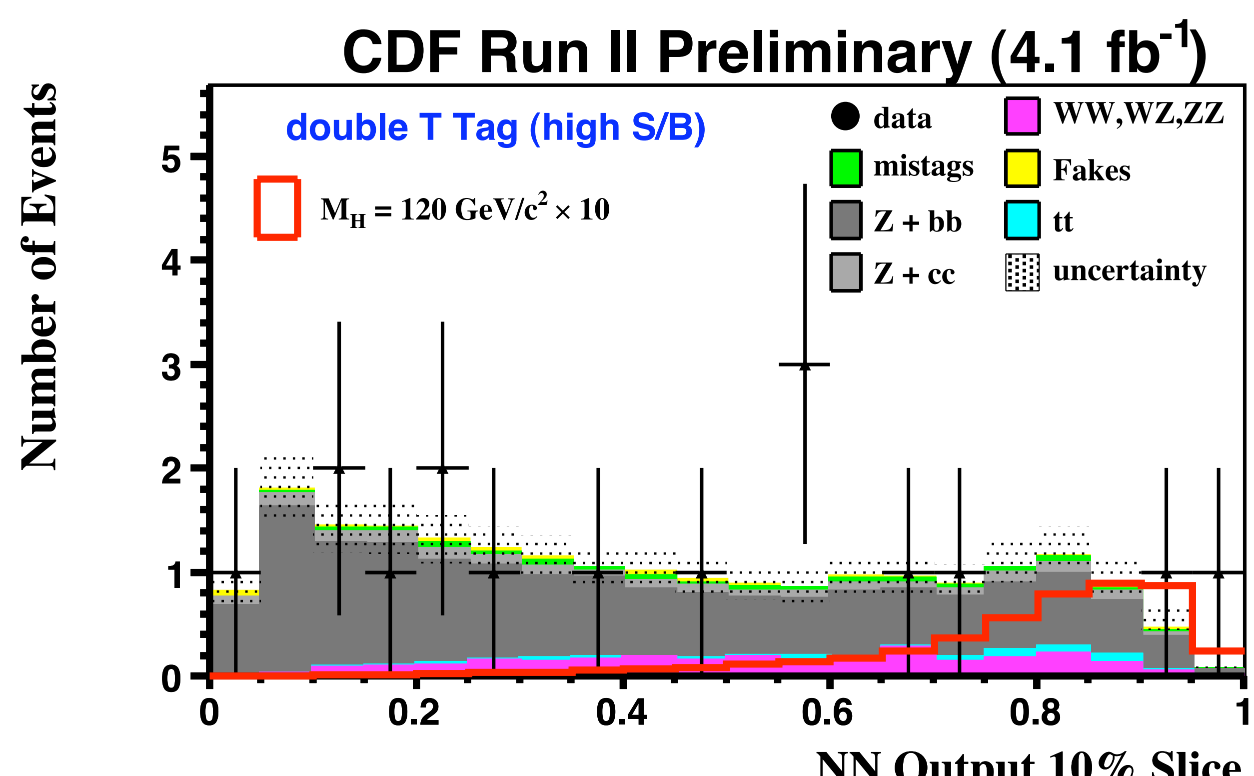
- Optimize a 2D-NN for each Tag/Z type combination
- Trained to separate ZH, tt, and Z+jets in two dimensions
- Matrix Elements + Kinematic distributions as inputs :











Systematics

- Both D0 and CDF consider a long list of systematic uncertainties :

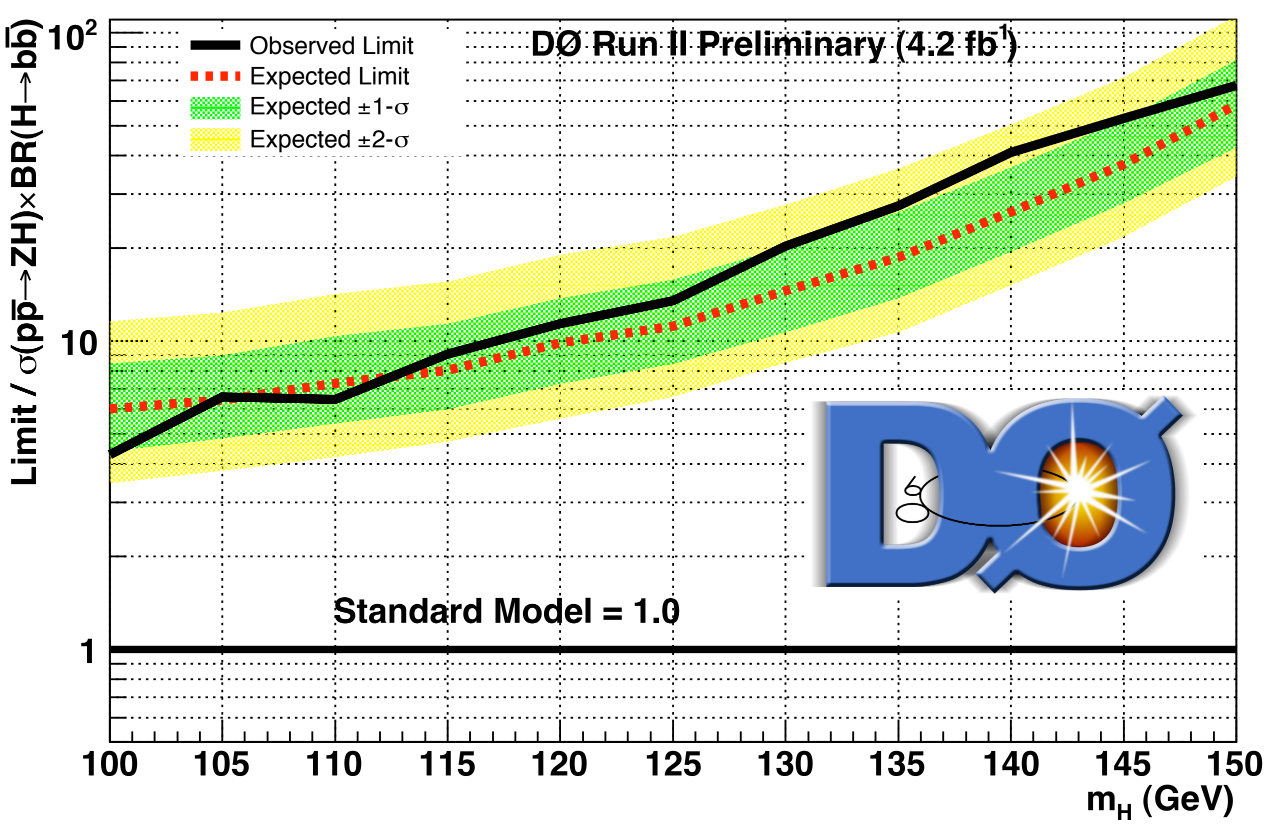
Systematic Uncertainties	
Luminosity	b-tag rates
Z + hf cross-section	fake rates
tt cross-section	Jet Energy Scale
DiBoson cross-sections	ISR/FSR
Mistag Rate Uncertainties	

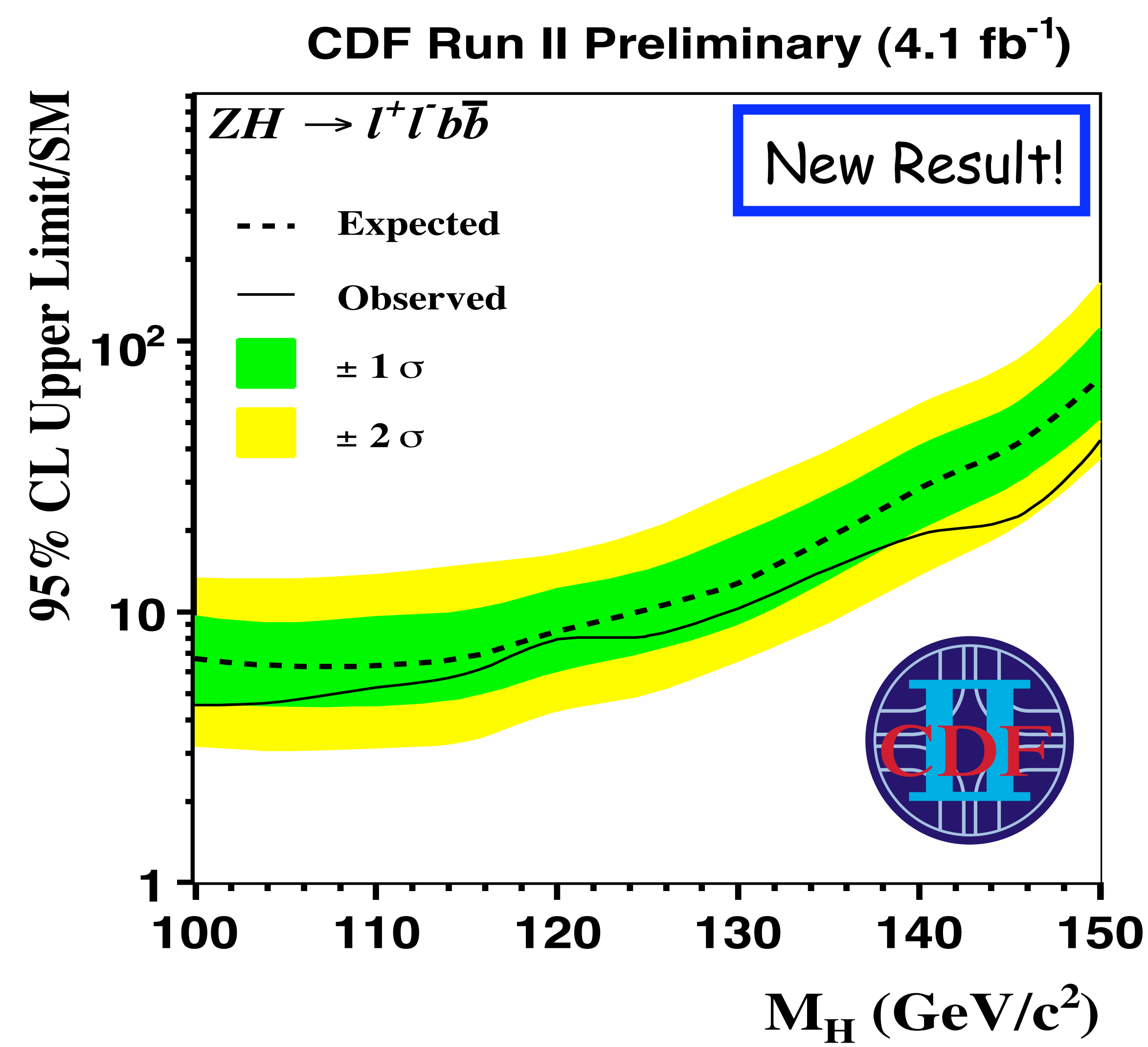
Results :

- For both CDF and D0, the observed data is consistent with expected background
- Both experiments set 95% CL upper limits on ZHllbb for masses between 100 and 150 GeV/c^2

D0 Limits for Mh = 115 GeV/c^2
4.2 fb-1
Obs. → 9.1 X SM Prediction
Exp. → 8.0 X SM Prediction

CDF Limits for Mh = 115 GeV/c^2
4.1 fb-1
Obs. → 5.9 X SM Prediction
Exp. → 6.8 X SM Prediction





Conclusions :

- CDF and D0 each have updated searches with improved $ZH \rightarrow llbb$ sensitivity since the March 2009 Tevatron SM Higgs Combination
- Steady improvements to analysis technique have allowed for sensitivity to improve faster than the expectation from additional data