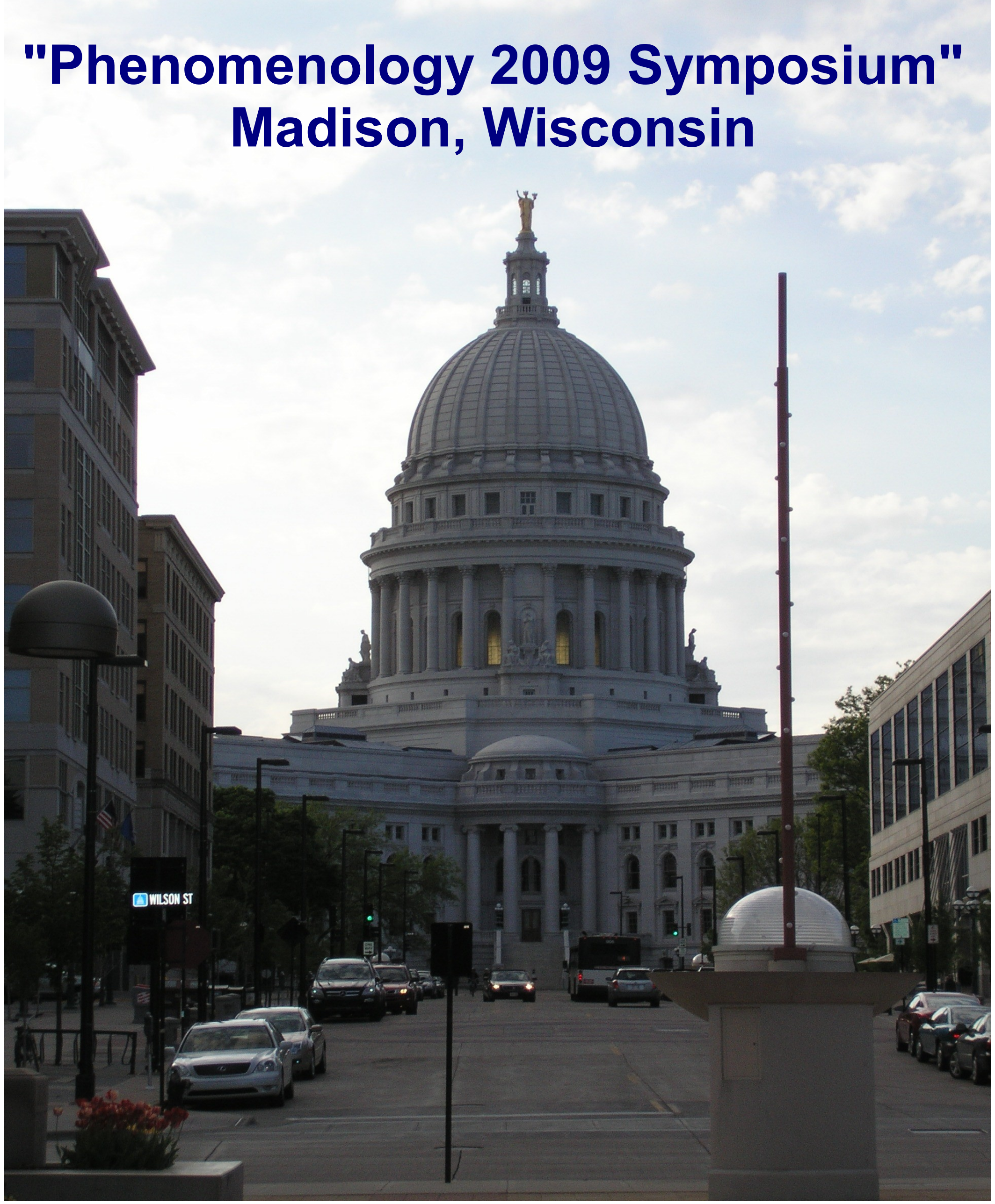
Search for SM Higgs Boson associated with a W Boson using ME technique

Bárbara Álvarez
on behalf of the CDF collaboration

Universidad de Oviedo

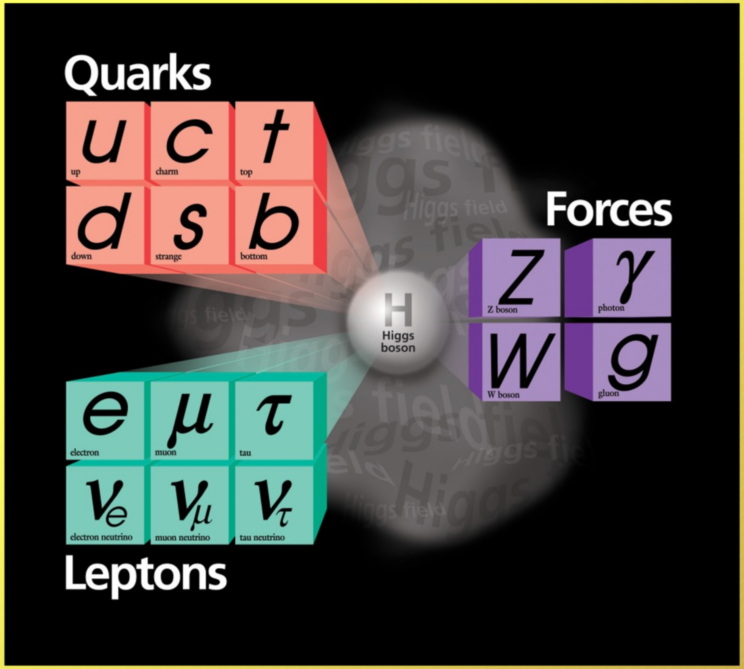
OUTLINE:

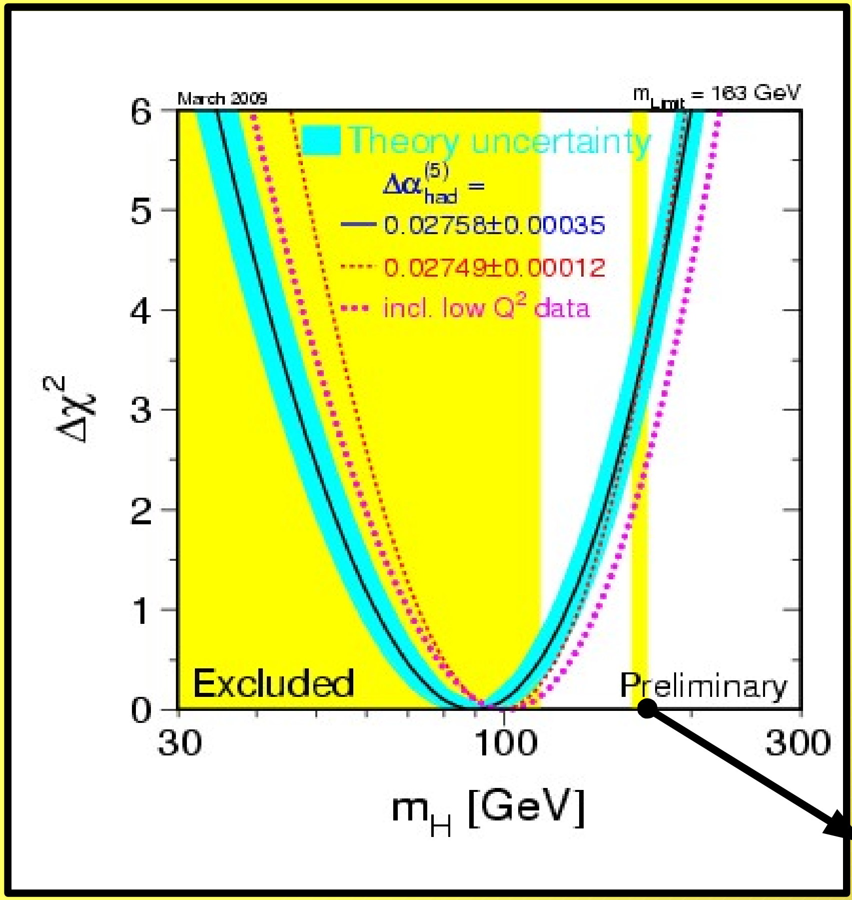
- Introduction and Motivation
- Fermilab and the CDF detector
- Event Selection
- Background Estimation
- ME and BDT Technique
- ME+BDT Result
- Combined Result
- Conclusions



MOTIVATION

- The ***Higgs boson*** is the only Standard Model (SM) particle that has not yet been observed.
- The ***Higgs boson*** would explain the difference between the massless photon, and the massive W and Z bosons.





The SM does not predict the mass of the Higgs boson need to be determined from experiement.

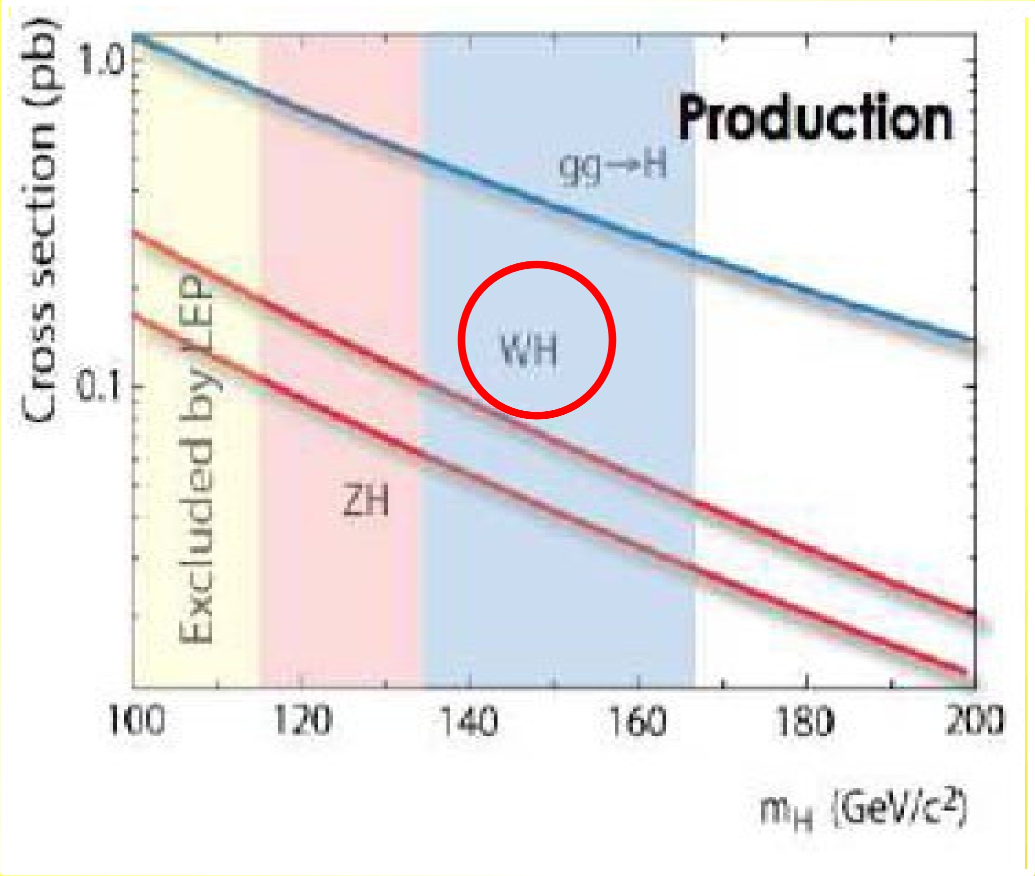
- Direct searches at LEP:
  m_H **> 114.4 GeV/c²** at 95% at C.L.

- Indirect EWK constrains:
  m_H **< 163 GeV/c²**

The most recent combined result excluding the mass range of 160 GeV/c^2 to 170 GeV/c^2 at 95%CL.

Bárbara Álvarez - U. Oviedo

STANDARD MODEL HIGGS

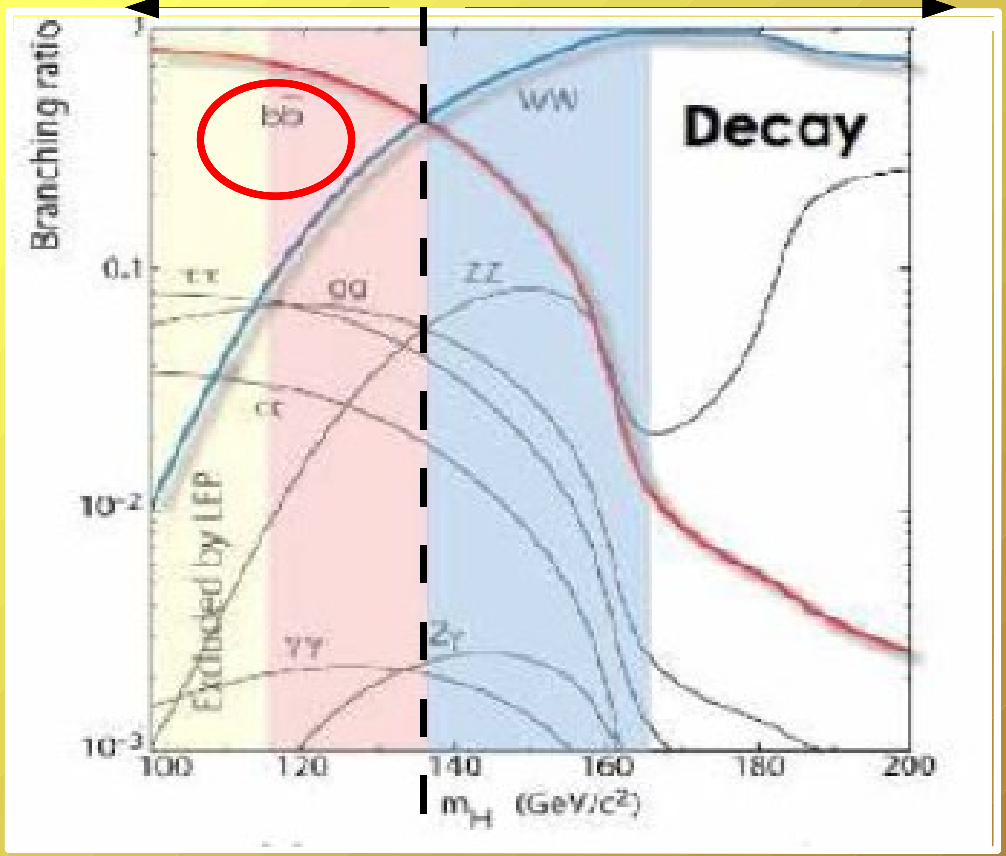


Low Mass Region

High Mass Region

m_H < 135 GeV/c²

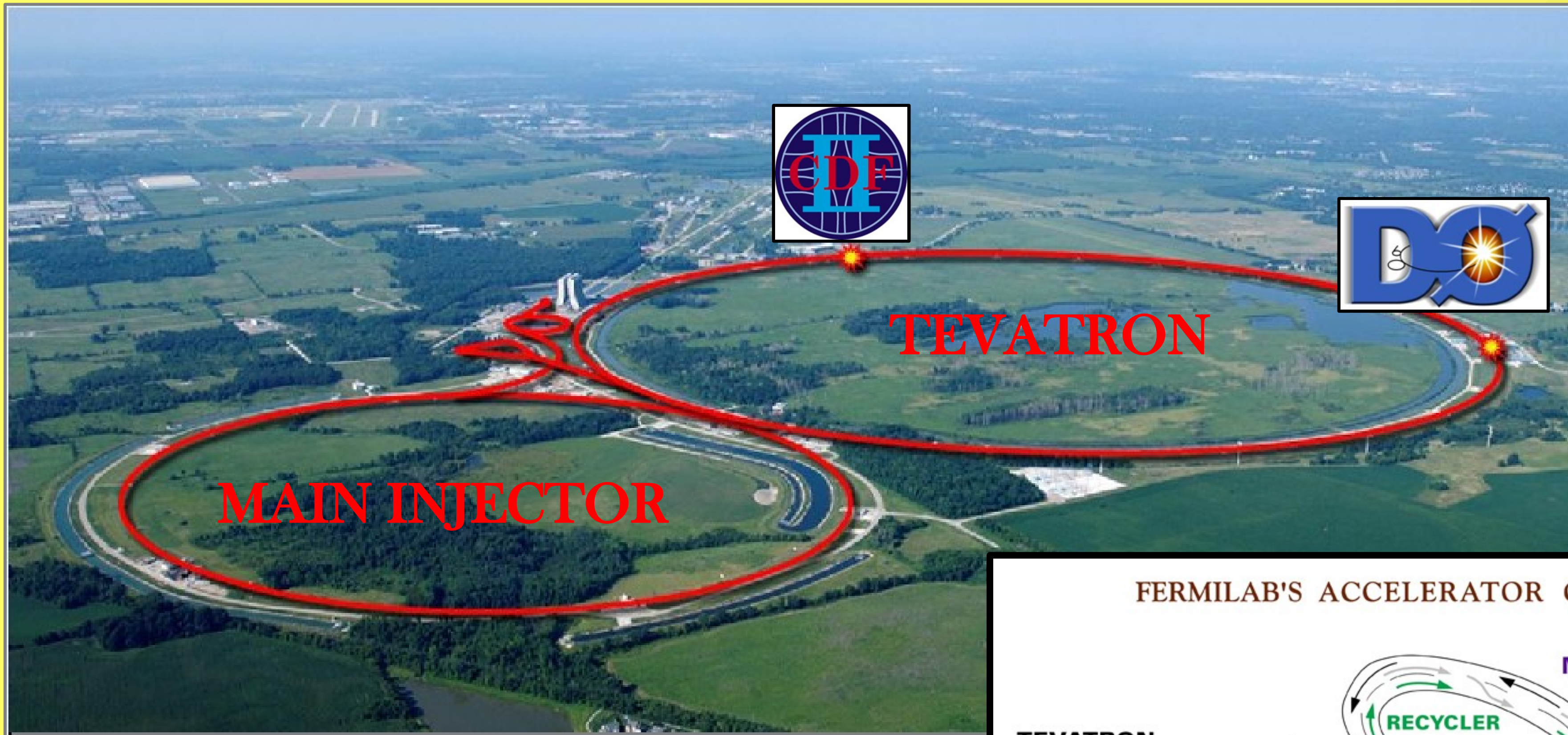
m_H > 135 GeV/c²

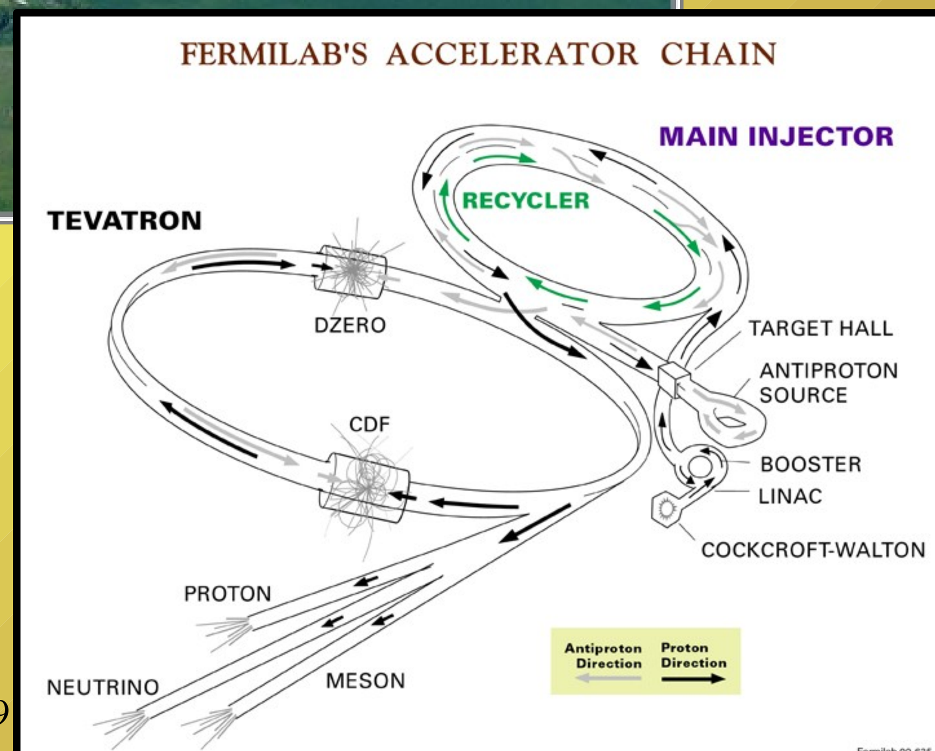


- The most relevant production mechanism at the Tevatron is the one associated with a vector boson (W or Z).

- The largest branching ratio decay channel is H → bb.

From Madison to Fermilab!!!

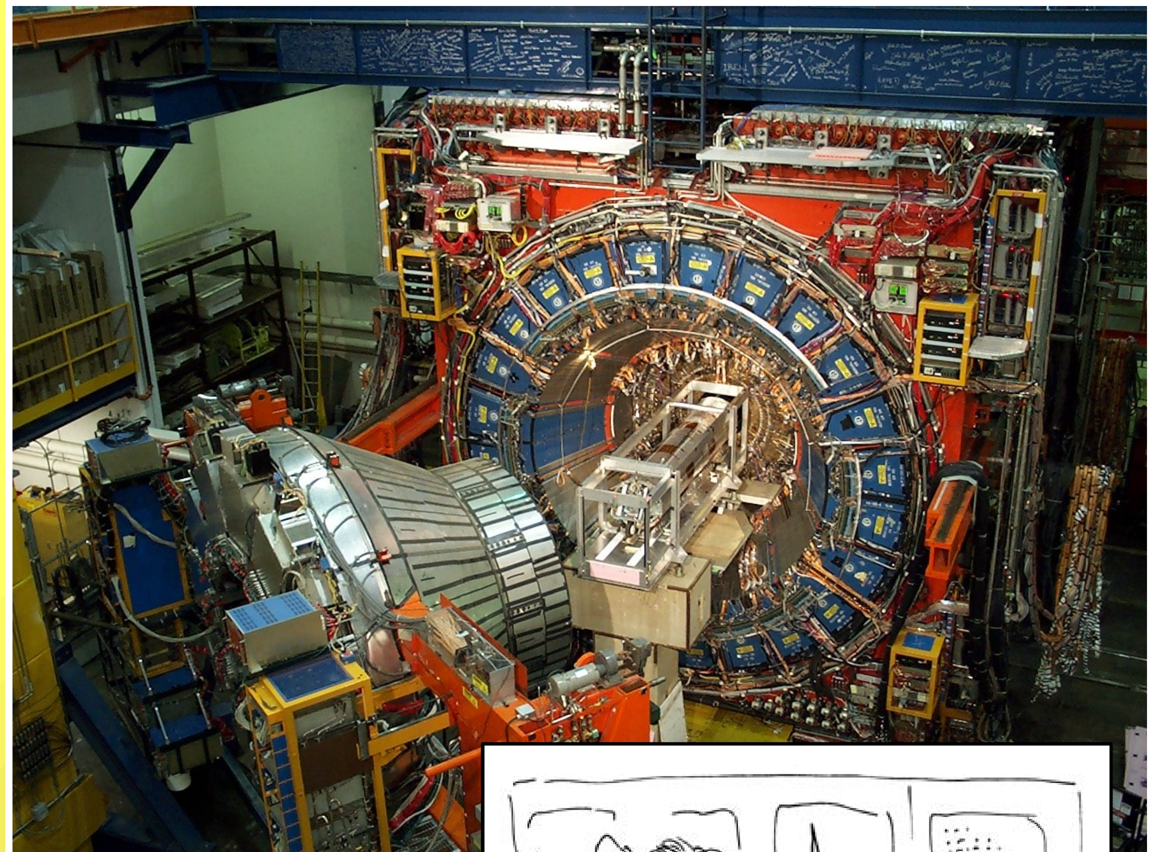




- Fermilab is home of the Tevatron.
- Proton and antiproton collisions at $\sqrt{s} = 1.96$ GeV.
- Two collision points: **CDF** and **D0**.

COLLIDER DETECTOR AT FERMILAB (CDF)

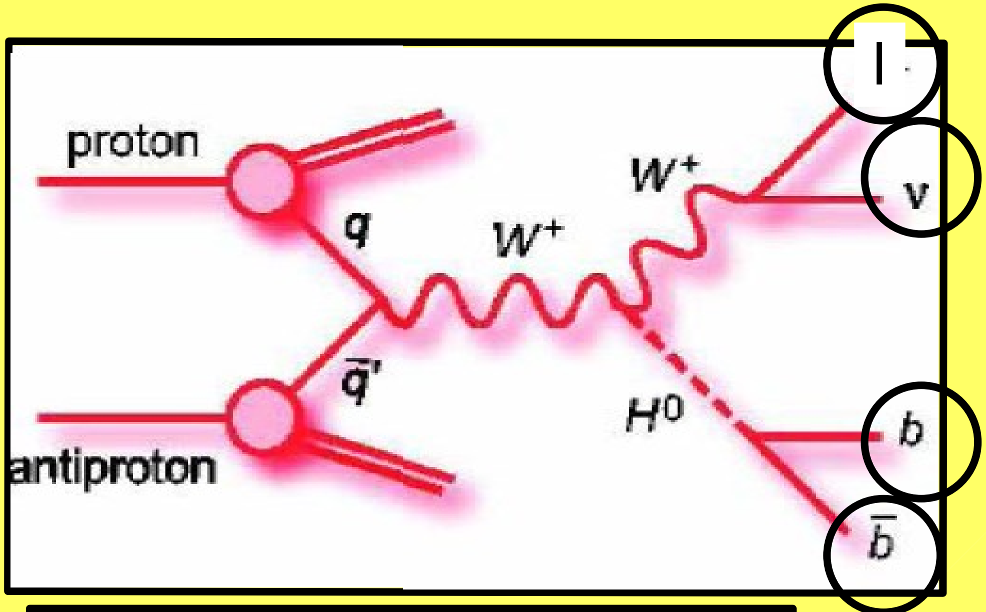
General purpose particle detector with cylindrical symmetry



- **Tracking** (inside a 1.4 T solenoidal magnetic field).
- **Calorimetry**: Electromagnetic and hadronic calorimeter.
- **Muon systems**.

For Higgs physics the *full detector* is needed!!

EVENT SELECTION

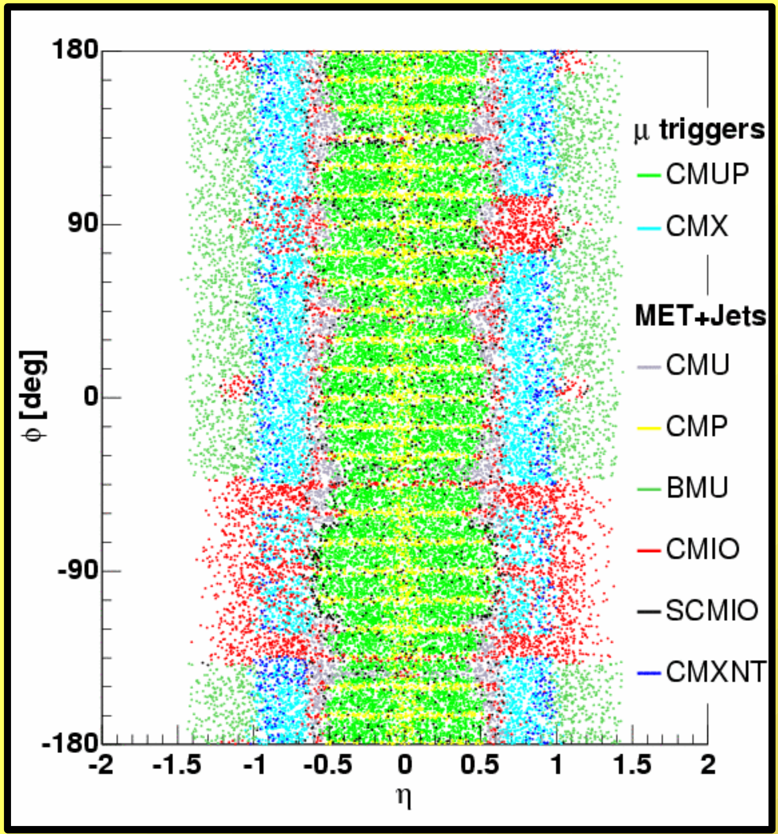


- **High p_T isolated lepton** (e / μ):
  $p_T > 20$ GeV
  Adding new muon types increase the acceptance ~25%.

- **High missing transverse energy**:
  MET > 20 GeV.

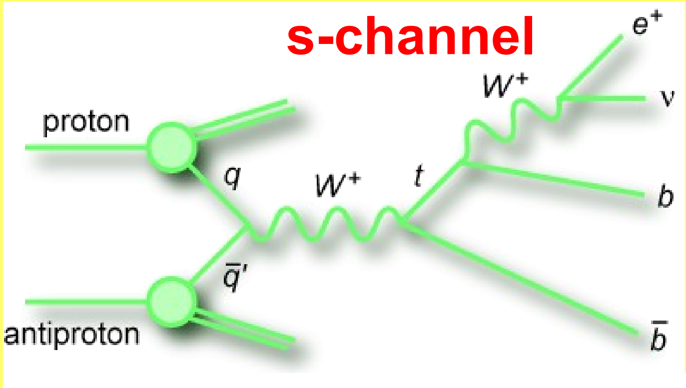
- **Two central energetic jets**:
  Transverse energy: $E_T > 20$ GeV.
  Pseudorapidity: $|\eta| < 2.0$

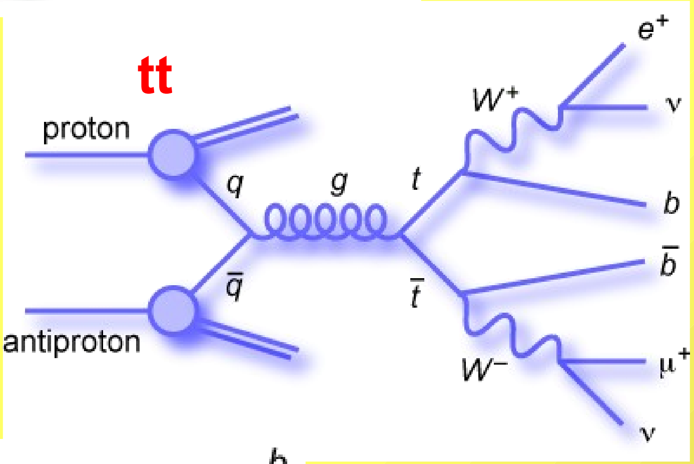
- At least one jet identified as **b-jet.**

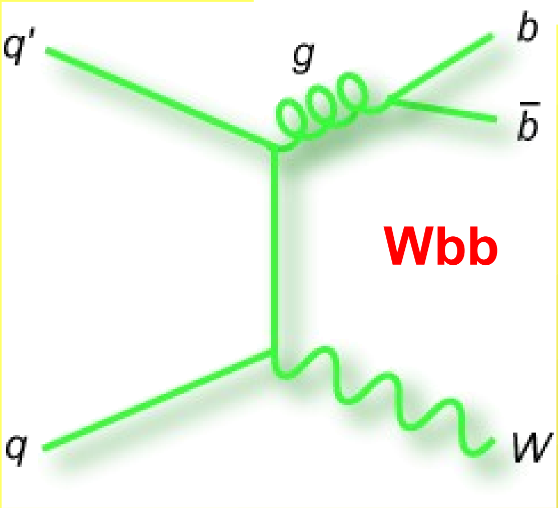


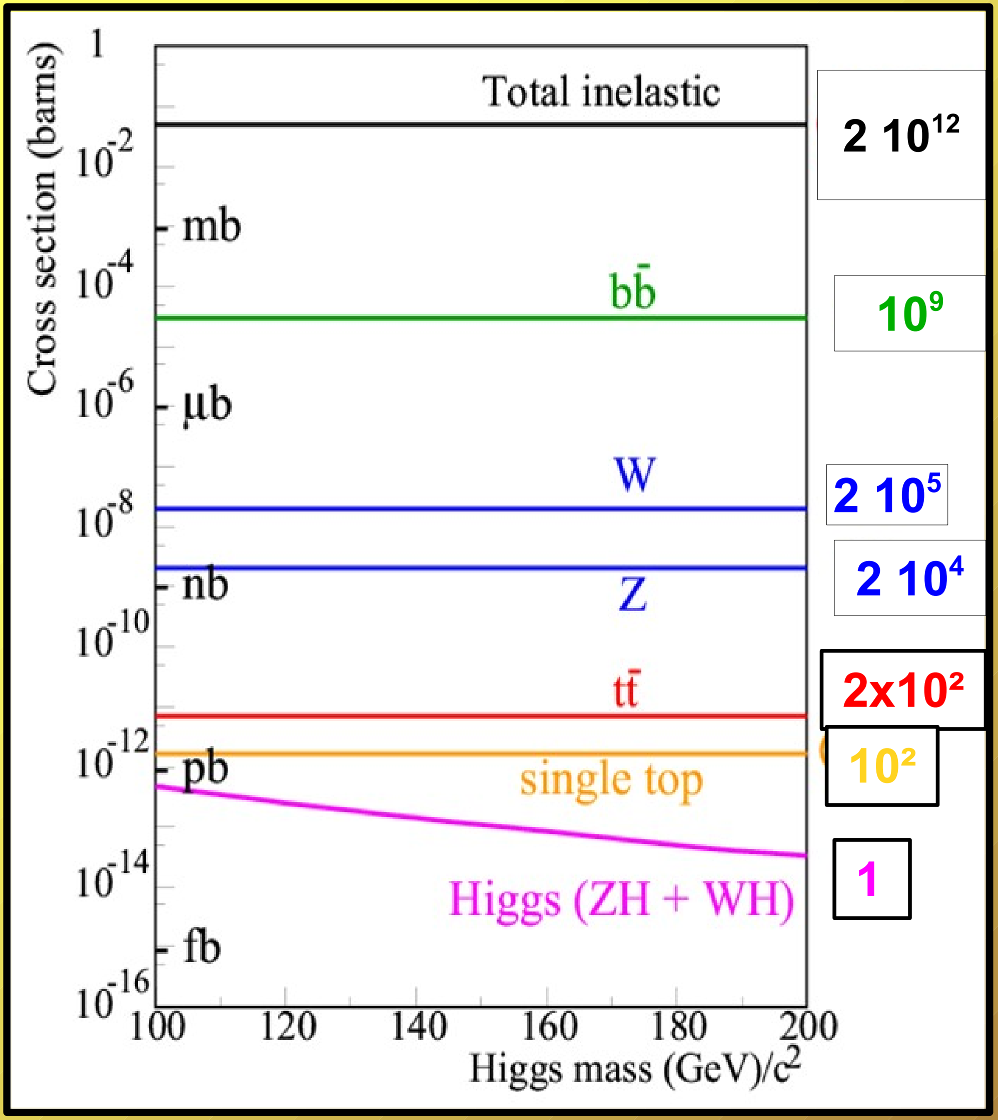
BACKGROUNDS

Main backgrounds: Wbb, top pair, single top...





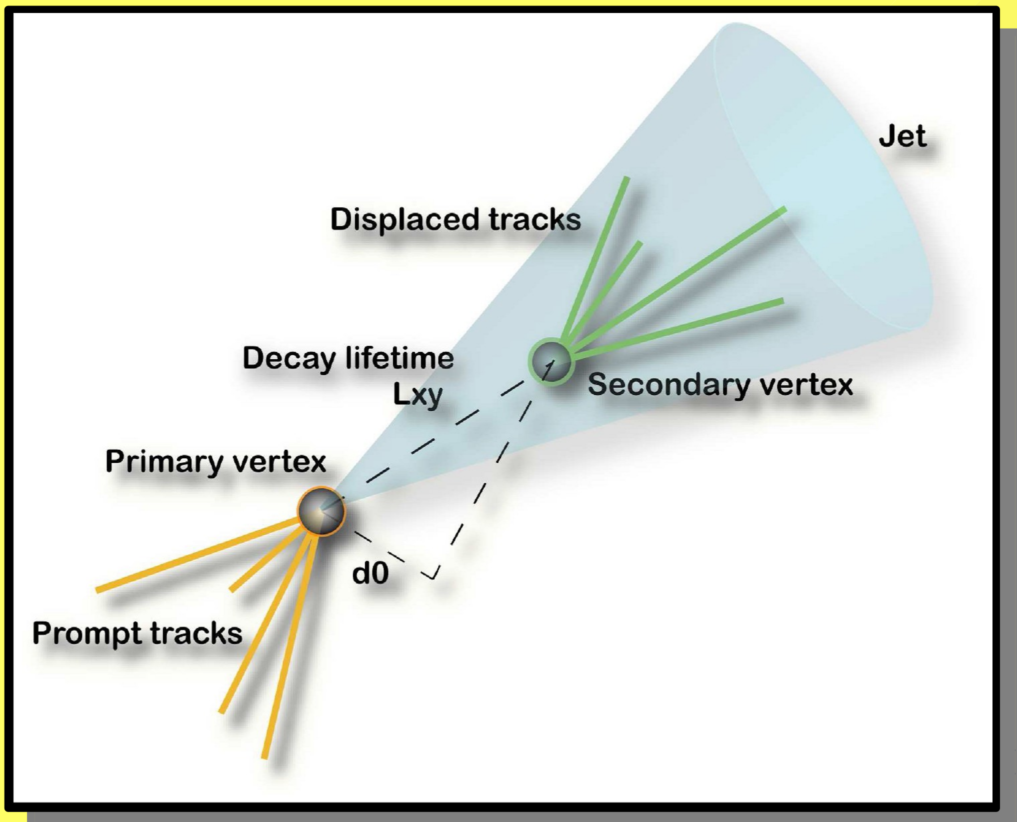


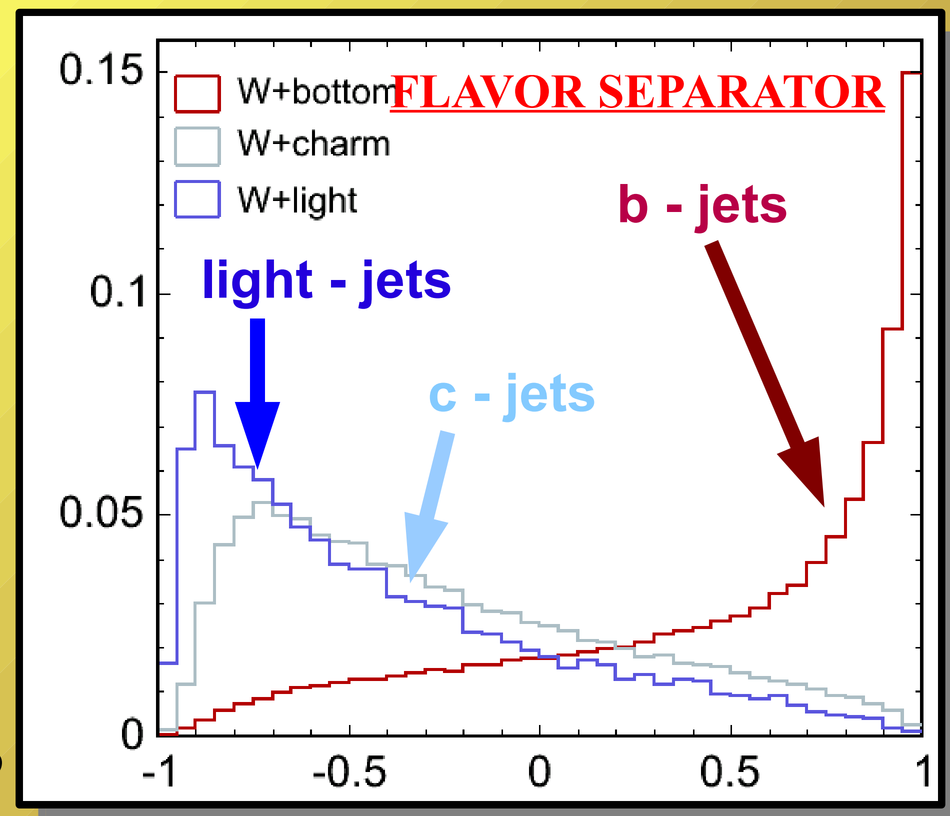


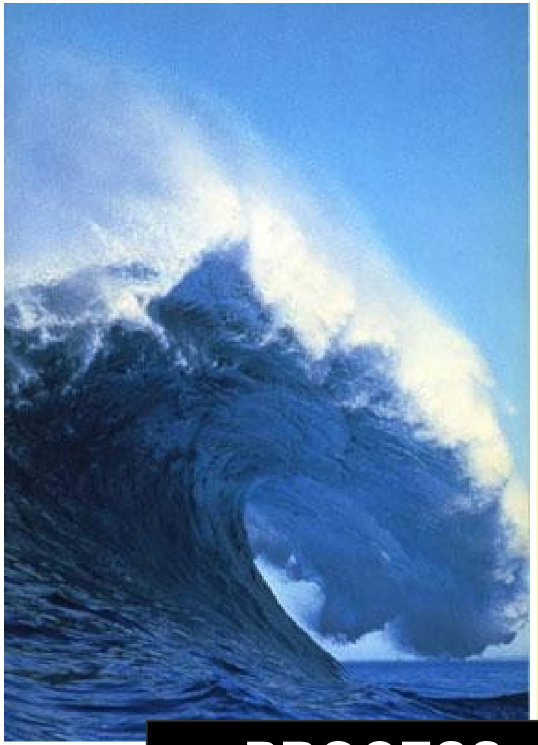
B-TAGGING CATEGORIES AND FLAVOR SEPARATOR

- Using the two Standard b-tagging algorithms in CDF (**Secondary Vertex and JetProbability**) we define 3 independent regions, events with:
  - Two **SecVtx** tagged jets (STST).
  - One **SecVtx** and one **JetProb** tagged jet (STJP).
  - One single SecVtx tagged jet (ST).

- Even after b-tagging half of the background events still have HF jets.
- We use a Neural Net b-tagger to distinguish b-quark jets from charm or light quark flavor jets.







BACKGROUND ESTIMATION

Overwhelming backgrounds!!

- **Total MC:** Diboson, top, single top, Z+jets.
- **Data driven:** Mistags, QCD.
- **Total HF:** W+bb, W+cc, W+c.

EVENT YIELD, L = 2.7 fb^{-1}

PROCESS	STST	STJP	ST
Total MC	77.21 ± 24.70	86.75 ± 28.99	938.59 ± 284.96
Total HF	59.79 ± 7.52	50.71 ± 8.74	342.54 ± 29.05
Mistags	2.14 ± 0.57	10.72 ± 3.55	447.21 ± 54.89
Non-W	8.90 ± 3.56	14.63 ± 5.85	126.86 ± 50.74
Total Prediction	**148.03 ± 26.07**	**162.81 ± 31.05**	**1855.20 ± 296.03**
WH 115GeV	**2.00 ± 0.23**	**1.44 ± 0.22**	**4.91 ± 0.40**
Observed	**157.00**	**159.00**	**1851.00**

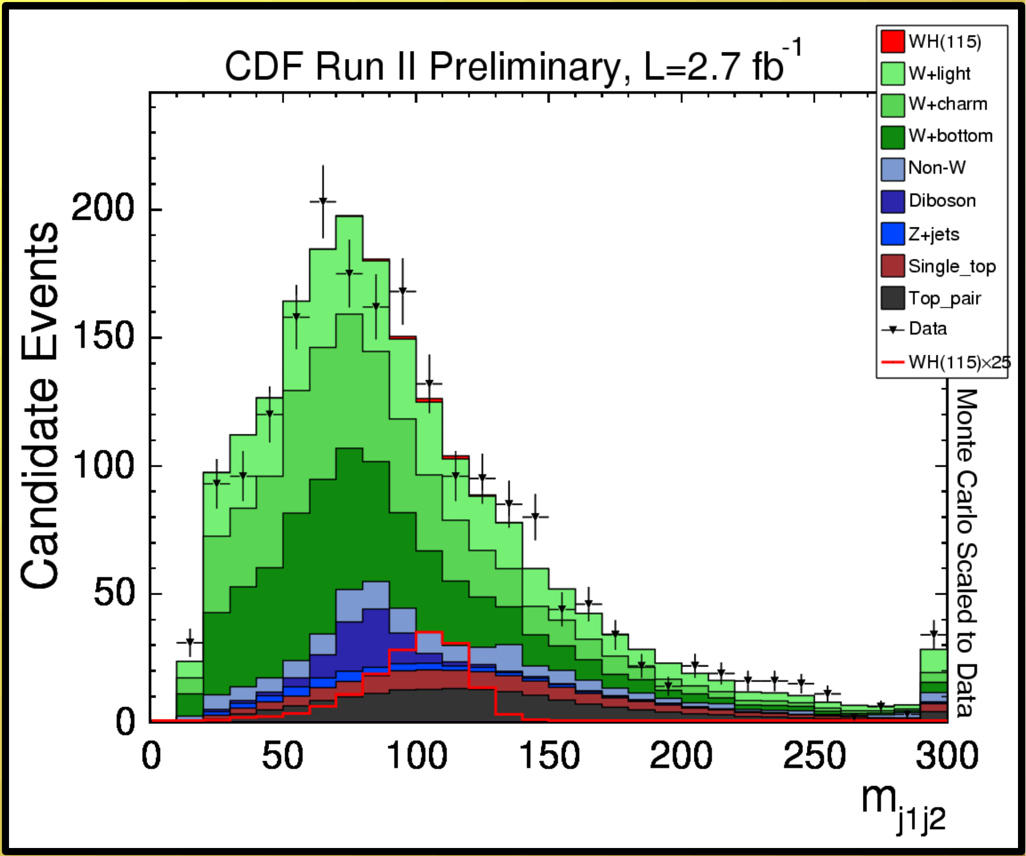
THE CHALLENGE

- Signal is much smaller than background uncertainties.
- Counting experiment is not possible.
- Need sophisticated tools to isolate events with high signal purity.

✔ **We use a Matrix Element (ME) Technique to calculate event probabilities for the signal and the background (bkg) hypothesis.**

✔ **A BDT trained with ME info, kinematic variables and the flavor separator is used as final discriminant.**

The flavor separator gives us ~15% of gain in sensitivity!



MATRIX ELEMENT METHOD

Calculate the probability density of an event resulting from a giving process:

$$P(p_l, p_{j1}, p_{j2}) = \frac{1}{\sigma}\int d\rho_{j1}\, d\rho_{j2}\, dp_\nu \sum \phi_4 \left|M(p_i)\right|^2 \frac{f(q_1)\, f(q_2)}{|q_1||q_2|} W_{jet}(E_{parton}, E_{jet})$$

Inputs: lepton and jet 4-vectors; no other information needed

Phase Space Factor

Matrix Element

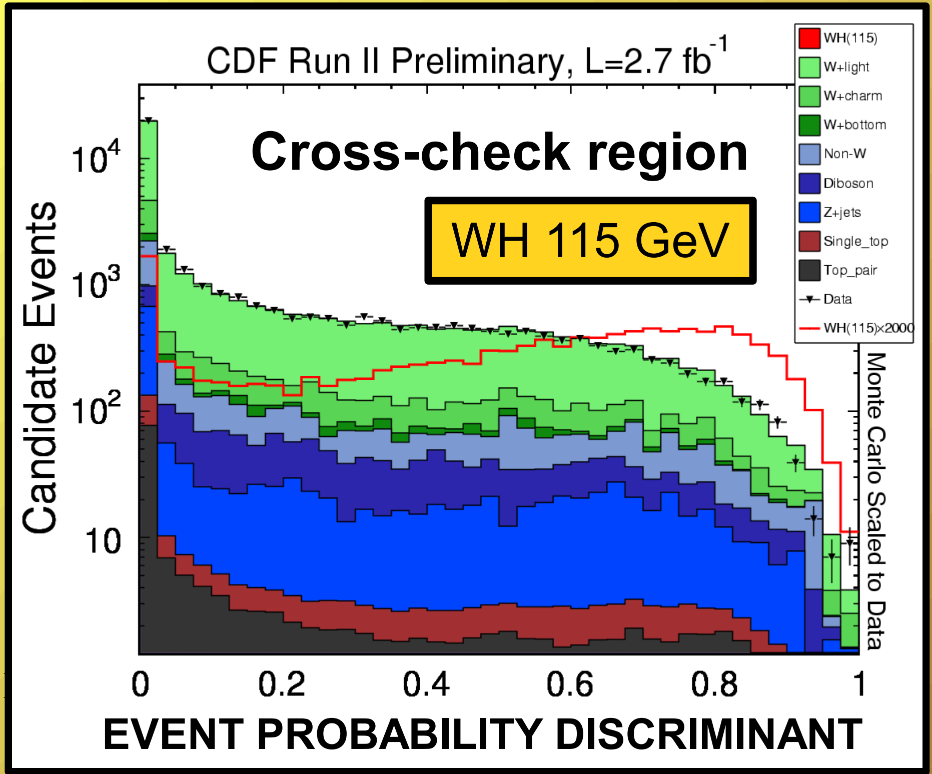
Parton Distribution Function

Transfer Function

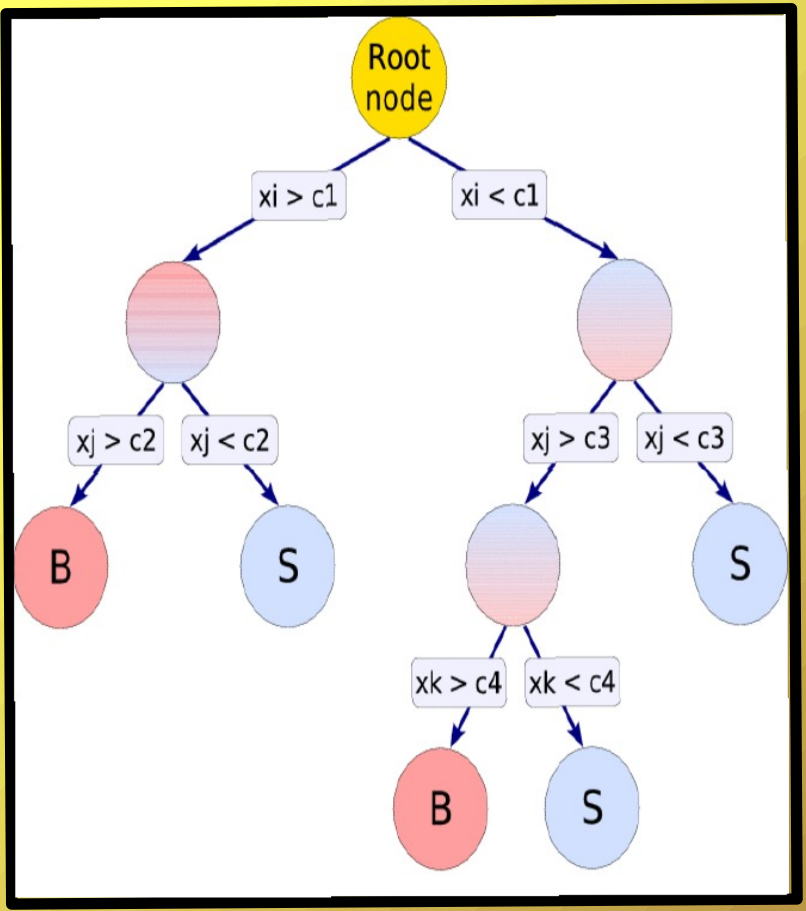
We define the **Event Probability Discriminant (EPD)** as follows:

$$EPD = \frac{P_{signal}}{P_{signal} + \sum P_{backgrounds}}$$

Backgrounds peak to zero and signal peaks higher.



BOOSTED DECISION TREES METHOD



- **DT:** Sequence of binary splits using the discriminating variable which gives best signal-background separation.

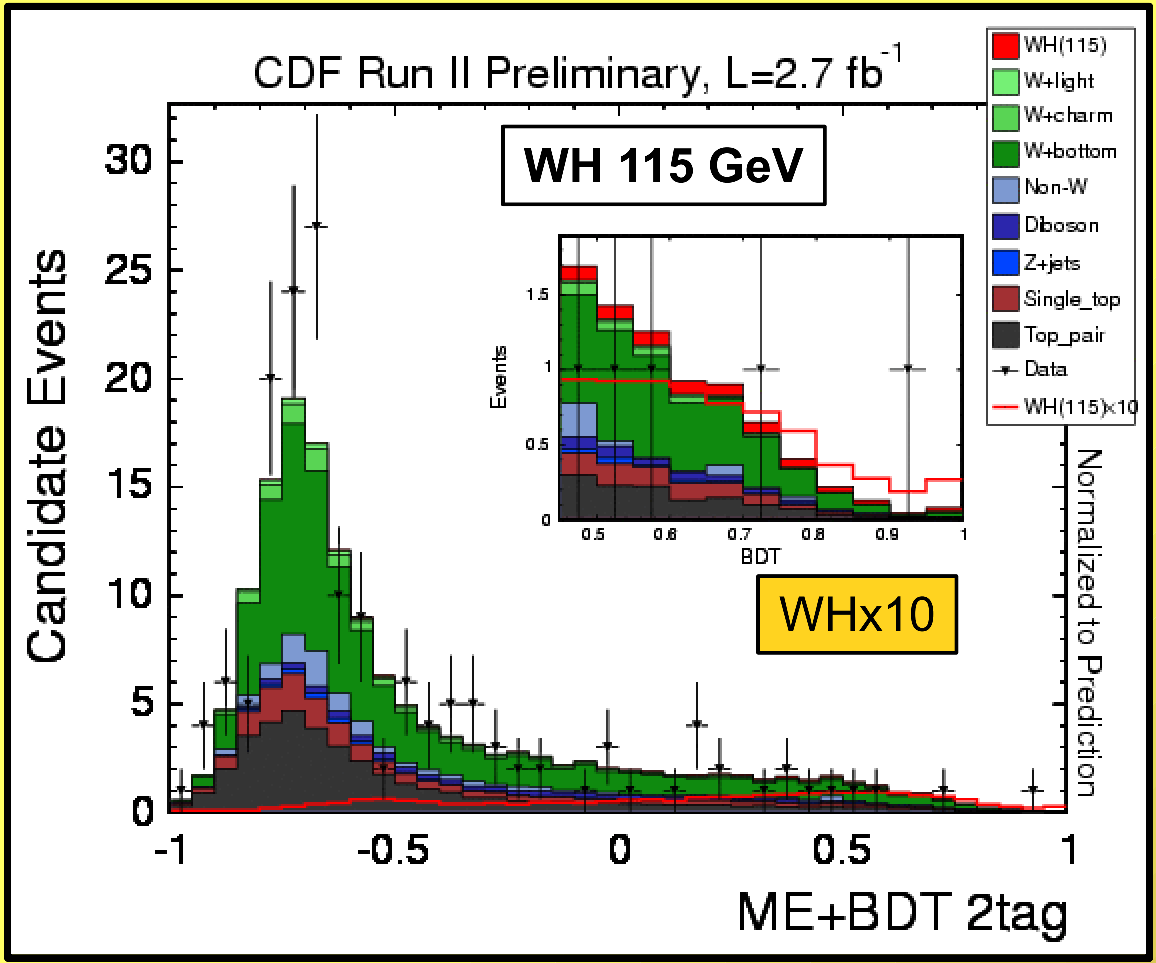
- Leaf nodes are classied as signal-like or background-like depending on majority of events ending up in the respective leaf.

- A **forest of DTs** trained using a boosting procedure performs better than a single DT:
  - Misclassified events in a DT training are given a higher weight for the next DT training.

- **17 variables** used for the training including ME discriminant (EPD), best ranked variable. **Our most powerful variable!!**

FINAL DISCRIMINANT

Our final discriminant is a ME+BDT output:



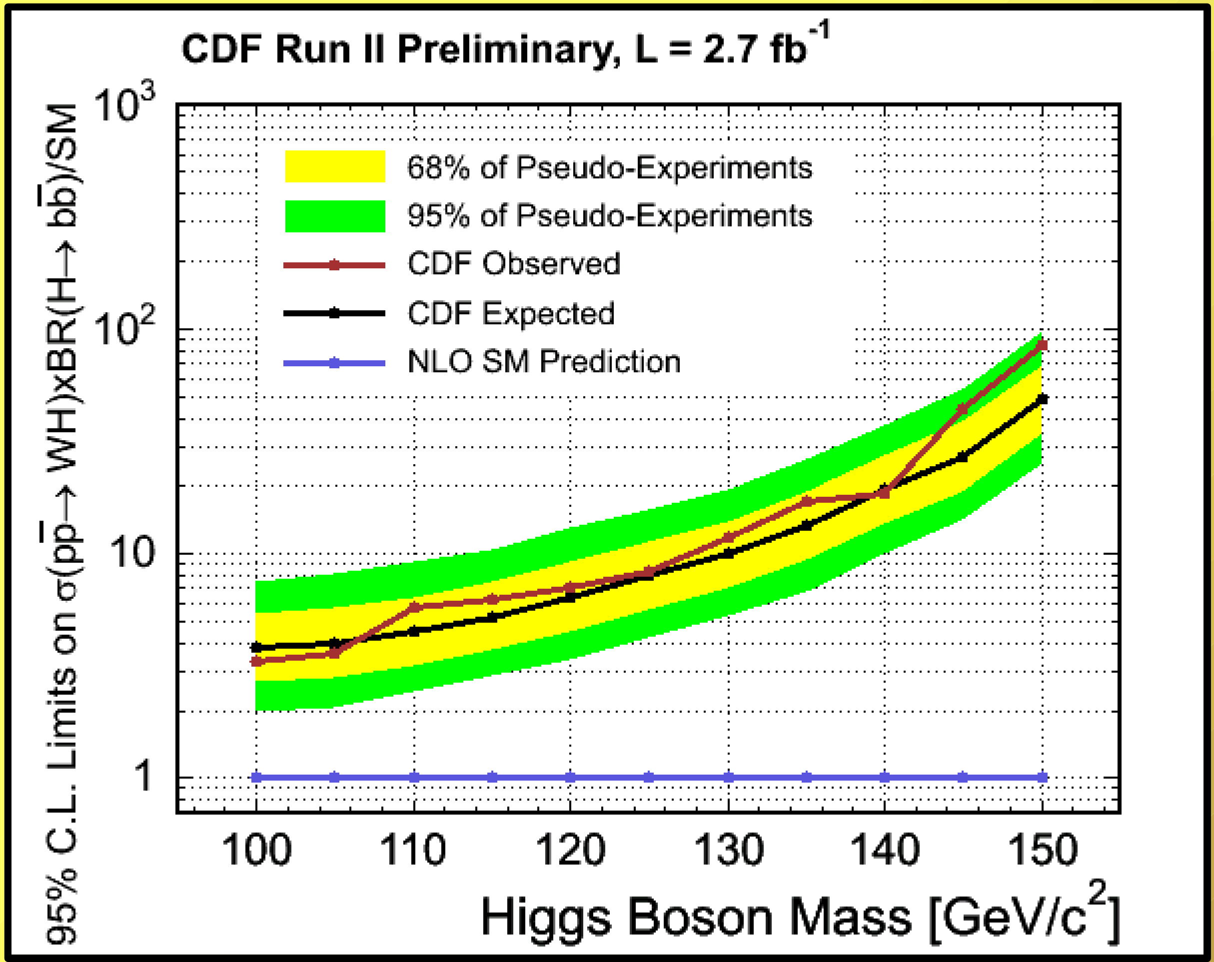
Systematic Uncertainties

SOURCE	ST+ST	ST+JP	ST
Trigger Lepton ID	2 %	2 %	2 %
Lepton Trigger	< 1 %	< 1 %	< 1 %
ISR/FSR	5.2 %	4.0 %	2.9 %
PDF	2.1 %	1.5 %	2.3 %
JES	2.5 %	2.8 %	1.2 %
B-tagging	8.4 %	9.1 %	3.5 %
TOTAL	**10.6 %**	**10.5 %**	**5.6 %**

✗ **No significant excess observed!!**

ME+BDT RESULT

✔ The 95% C.L. expected upper limit for a Higgs mass of 115 GeV/c^2 is 5.24 x SM, and 6.23 x SM for the observed limit.

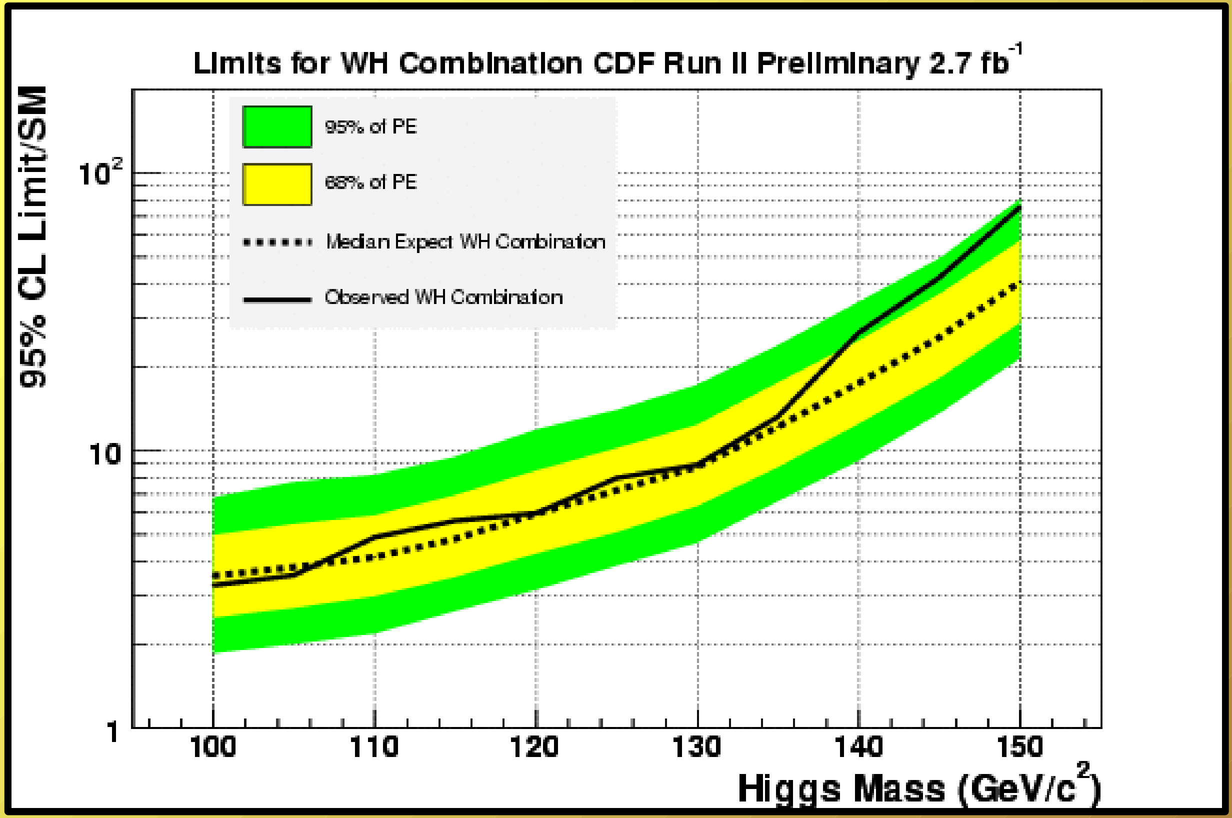


COMBINED RESULTS

- Combining the ME+BDT result with a WH NN analysis based on kinematic information we get an improvement of ~8% over each individual result:
  - The ME+BDT and the NN bases analyses have the same event selection.
  - They differ in terms of multivariate discriminants, designed to separate signal from bkg.

These two analyses are combined into a single analysis by using them as inputs to another neural network to produce a super-discriminant

mH (GeV/c^2)	Exp. Limit (σ/σ_{SM})	Obs. Limit (σ/σ_{SM})
115	4.8	5.6



Public web page:

http://www-cdf.fnal.gov/physics/new/hdg/results/whlnubb_081107/homepage.html

CONCLUSIONS

- SM Higgs search with **ME+BDT** technique has been performed with **2.7 fb^{-1} of CDF data**.

- Boosted decision trees use the ME information as input with some other kinematic variables.

- The 95% C. L. observed upper limit is **6.23 x SM** for a Higgs mass of 115 GeV/c^2.

- We combine this result with a similar analysis that uses NN and we get ~8% improvement over each individual result, **5.6 x SM** for a Higgs mass of 115 GeV/c^2.

- Combining CDF and D0 all channels we got a 2.5 x SM for a Higgs mass of 115 GeV/c^2.

- We expect to increase the sensitivity including new data (a total of ~ 4 fb^{-1}) and improving the analysis techniques.


THANK
YOU

BACKUP SLIDES

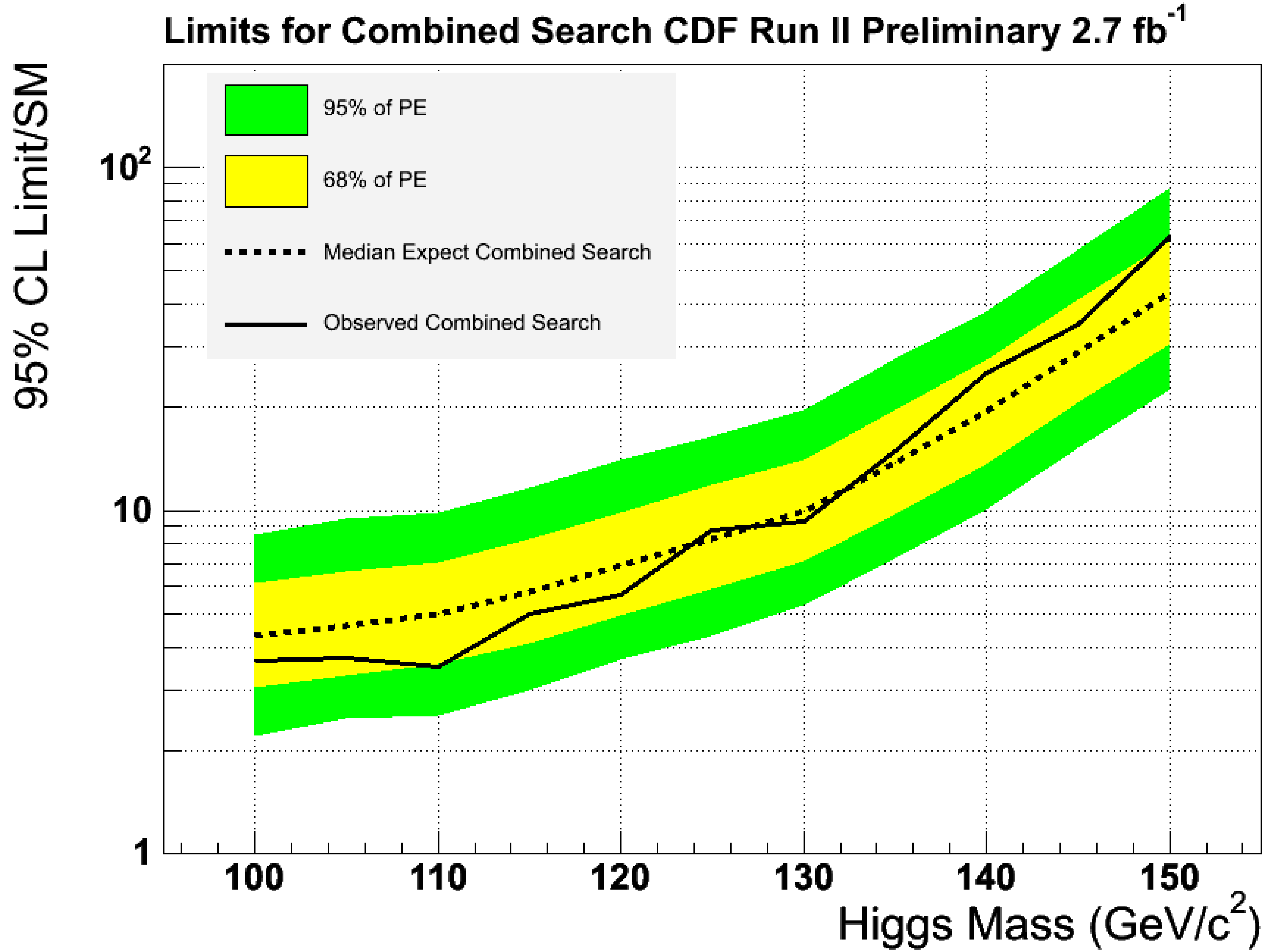
Theoretical Cross Sections for the Background Estimation

PROCESS	THEORETICAL CROSS SECTION
s-channel	0.884 ± 0.11
t-channel	1.980 ± 0.25
WW	12.4 ± 0.25
WZ	3.96 ± 0.06
ZZ	1.58 ± 0.05
tt	6.7 ± 0.8
Z+jets	787.4 ± 85.0

Higgs Cross sections and Branching Ratios

m_H	BR($H \rightarrow bb$)	σ (pb)	BR x σ (pb)
100	0.812	0.286	0.232
105	0.796	0.253	0.201
110	0.770	0.219	0.169
115	0.732	0.186	0.136
120	0.679	0.153	0.104
125	0.610	0.136	0.083
130	0.527	0.120	0.063
135	0.436	0.103	0.045
140	0.344	0.086	0.030
145	0.256	0.078	0.020
150	0.176	0.070	0.012

WH NN RESULT



Limits for Combined Search CDF Run II Preliminary 2.7 fb^{-1}
95% of PE
68% of PE
Median Expect Combined Search
Observed Combined Search
95% CL Limit/SM
10^2
10
1
100
110
120
130
140
150
Higgs Mass (GeV/c^2)