Search for the Standard Model Higgs Boson in the *WH->lνbb* Channel at CDF

Yoshikazu Nagai

(Univ. of Tsukuba)

Contents

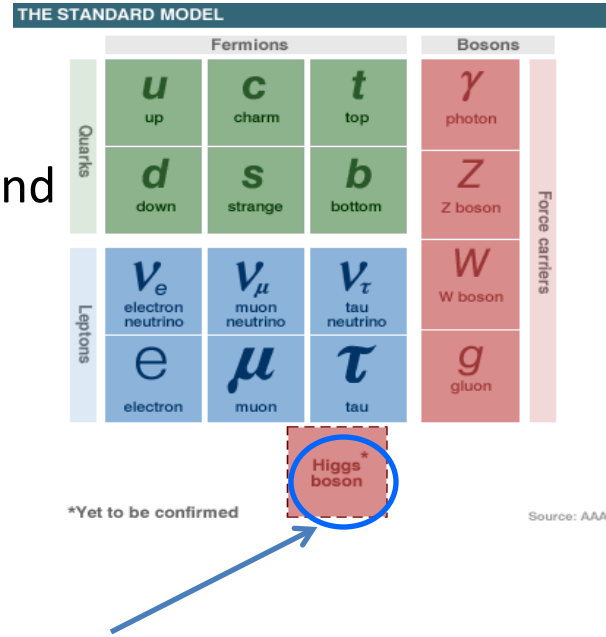
- Introduction & Motivation
- Experimental Apparatus
- Event Selection
- Background Estimation
- Analysis Optimization
- Systematic Uncertainties
- Result
- Summary

Introduction & Motivation

The Standard Model

- **Describe matter and interaction**
  - 6 kinds of quarks and leptons (fermions)
  - 4 kinds of gauge boson mediating Electroweak and strong force

The most successful model of the particle physics so far !!



Motivation

- **The Higgs boson is the only undiscovered "elementary" particle in the Standard Model**
- **Its discovery will help answer the questions:**
  - **How do fermions/weak bosons acquire the mass?**
  - **How EW symmetry is broken?**
- **The SM can not predict the Higgs boson mass**
  - **Need to be determined by experiment !!**

Status of SM Higgs boson search

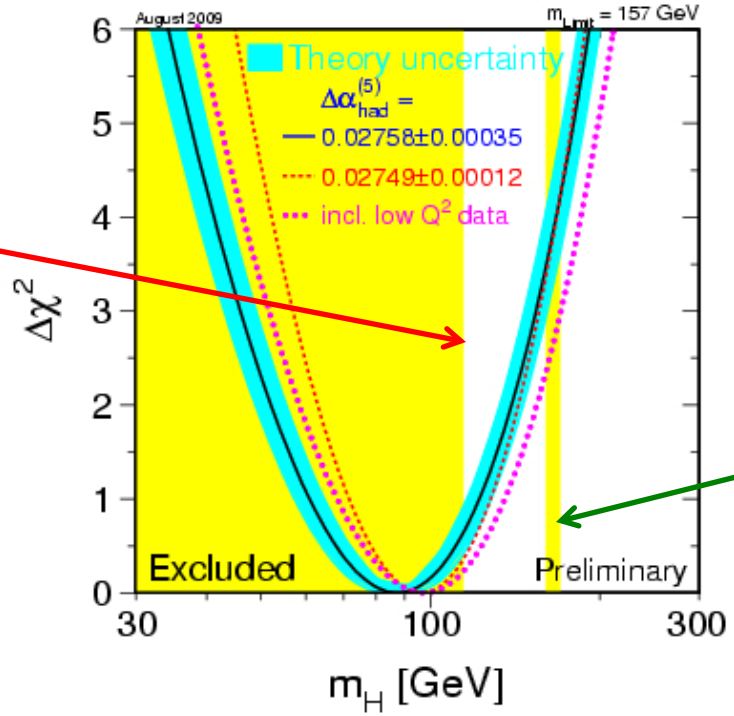
Current constraint on the SM Higgs boson

- **LEP II searches exclude:** $M_H < 114.4\,GeV/c^2$
- **Tevatron searches exclude:** $162 < M_H < 166\,GeV/c^2$
- **A fit to precision electroweak data:**

$$M_H = 87^{+35}_{-26}\,GeV/c^2 \quad M_H < 157\,GeV/c^2$$

SM prefers light SM Higgs boson !!

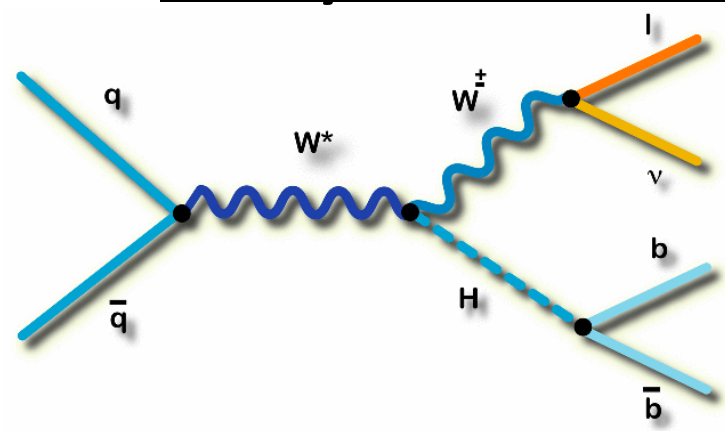
LEP II exclusion



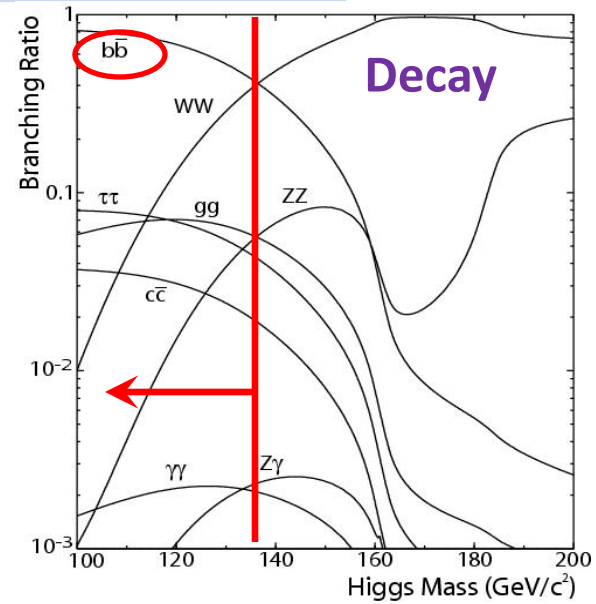
Tevatron exclusion

We focus on the low mass Higgs search with: $WH \rightarrow l\nu b\bar{b}$

Why the $WH \rightarrow l\nu b\bar{b}$ channel?



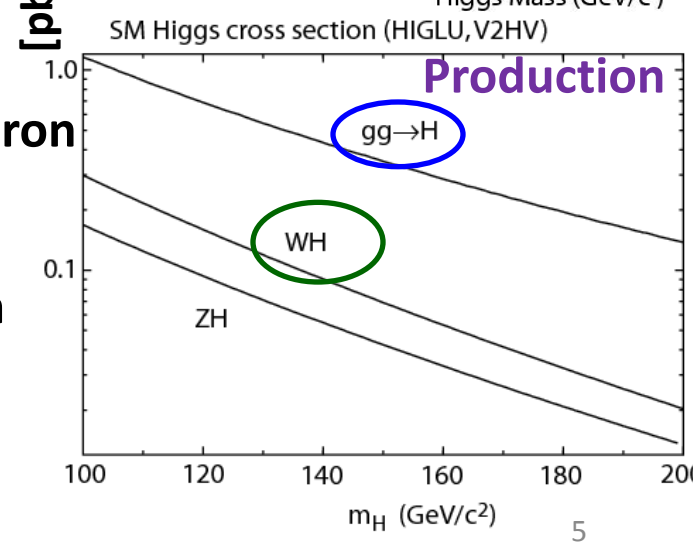
Low mass region



Focus on Low mass Higgs boson Search

$$M_H < 135\,GeV/c^2$$

Dominant decay for this region is: $H \rightarrow b\bar{b}$



- $gg \rightarrow H \rightarrow b\bar{b}$: **Highest cross section @ Tevatron**
  But, huge QCD background with $p\bar{p} \rightarrow b\bar{b}$
- $q\bar{q} \rightarrow WH \rightarrow l\nu b\bar{b}$: **2nd highest cross section**
  $W \rightarrow l\nu$ **requirement: Cleaner signature**

Previous WH->lvbb studies

1fb^{-1} analysis (published in Phys. Rev. Lett, Phys. Rev. D)

- Use central electron and muon
- Use Secondary Vertex b-tagging algorithm
- Analysis sensitivity @ m_H = 115 GeV: 17 x σ(SM)

Improvement

1.9fb^{-1} analysis (published in Phys. Rev. D)

- Add forward electron
- Employ Jet Probability b-tagging as 2nd algorithm
- Employ an artificial neural network discriminator
- Analysis sensitivity @ m_H = 115 GeV: 8.7 x σ(SM)

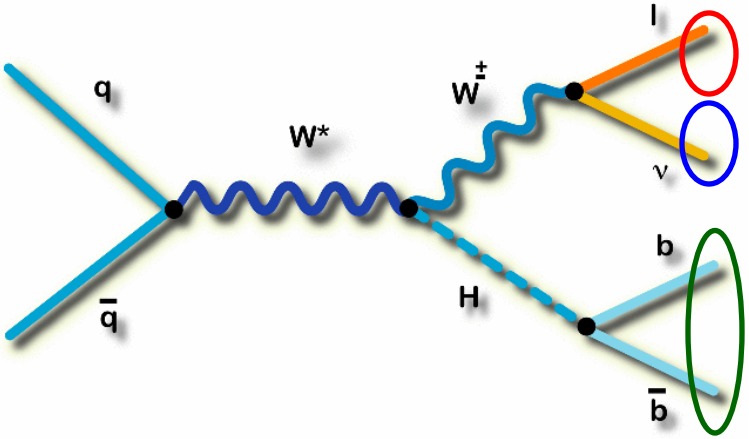
49%

2.7fb^{-1} analysis (published in Phys. Rev. Lett)

- Add Isolated track
- Analysis sensitivity @ m_H = 115 GeV: 5.8 x σ(SM)

33%

Event Signature



One high-p_T lepton

Large Missing Energy from neutrino (MET)

Two jets derived from *b*-quark

Analysis Strategy

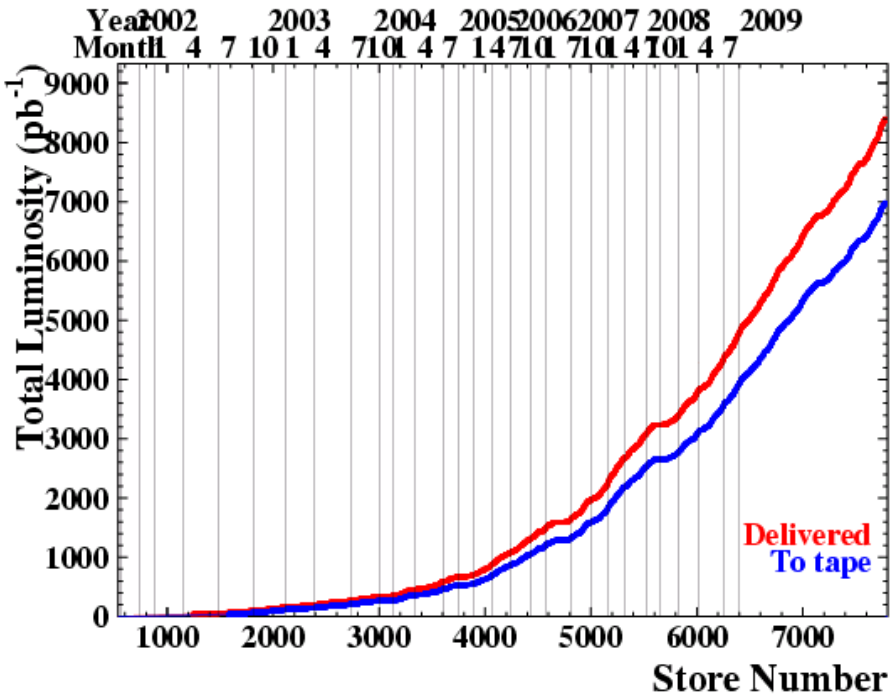
- Trigger event with high-p_T lepton trigger or MET based trigger
- Select lepton + 2-jets signature
- Use 3 *b*-tagging algorithms (SECVTX, JETPROB, NN)
- Apply neural network b-jet energy correction
- Use Bayesian neural network discriminant
- Use approximately 4.3fb^{-1} of data

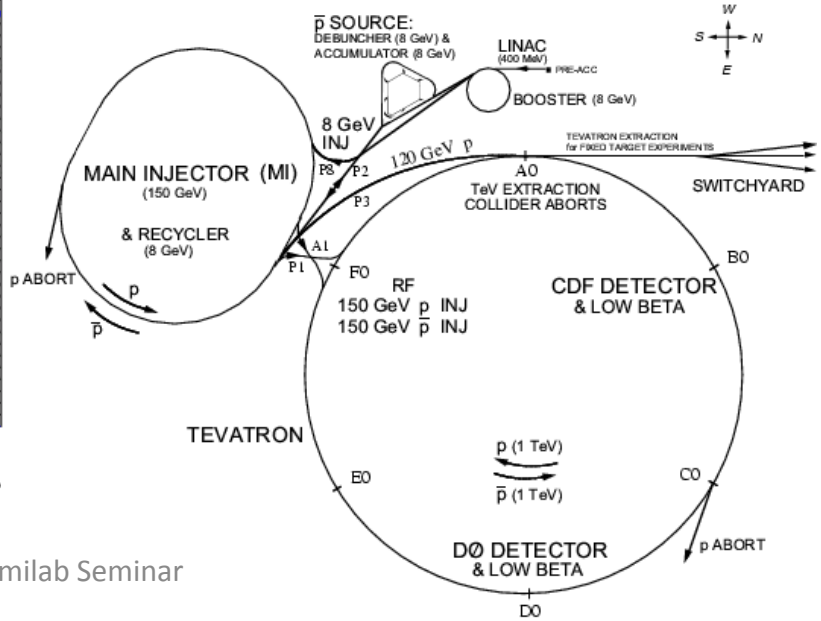
Experimental Apparatus

- Tevatron collider
- CDF detector

Tevatron Collider

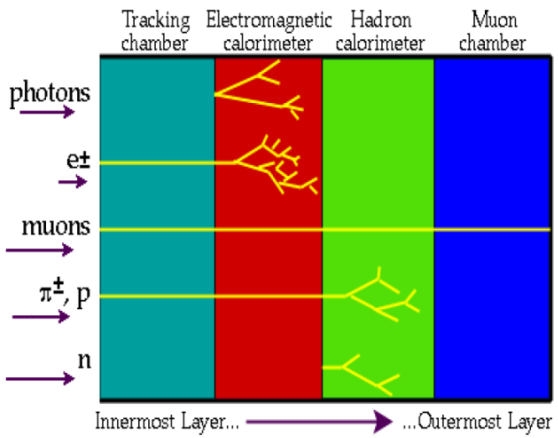
- Proton-antiproton collision at $\sqrt{S} = 1.96\text{TeV}$
- Currently **> 8.0 fb^{-1}** of data is delivered, and **> 7.0 fb^{-1}** of data is recorded.
- This analysis uses **4.3fb^{-1}** of data

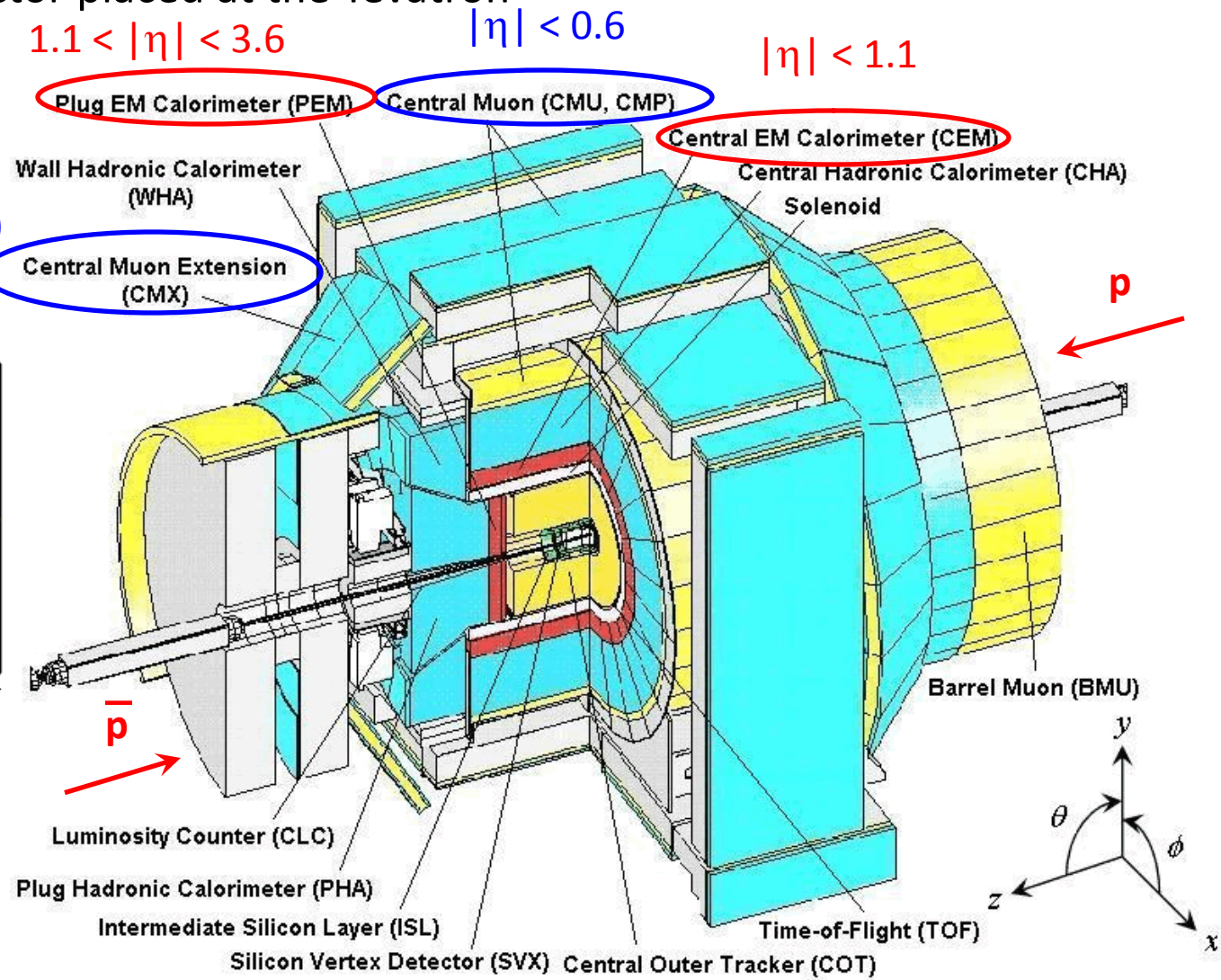




The Collider Detector at Fermilab (CDF)

- General purpose detector placed at the Tevatron





$$\eta = -\ln\tan\left(\frac{\theta}{2}\right)$$

- Data acquisition system consists of three level triggers
  - **Reduce the data rate while keep physically interesting events** **1.7MHz -> 100 Hz**

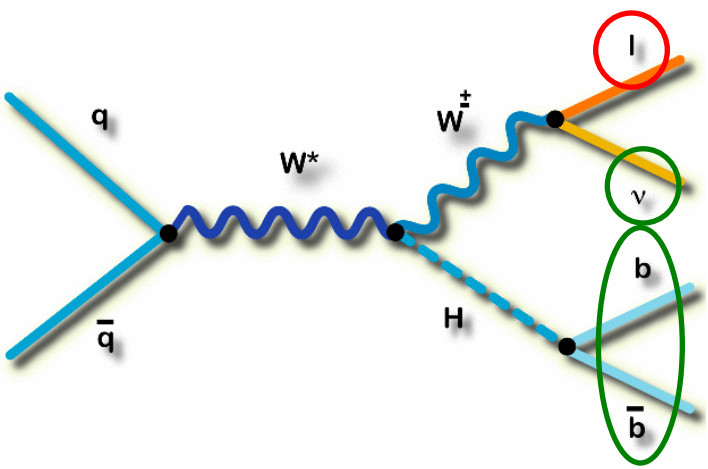
Event Selection

Event Triggers

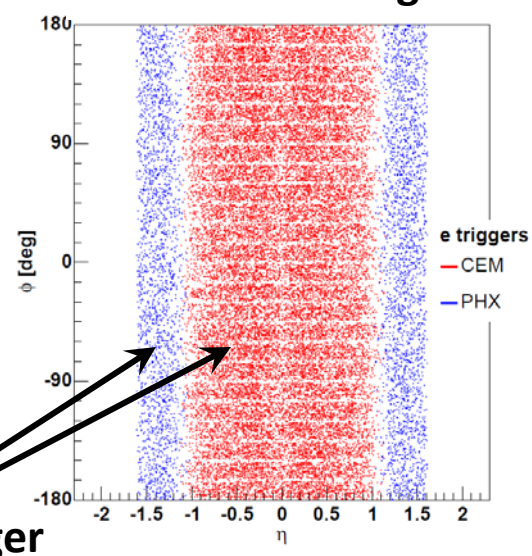
Use high p_T lepton trigger and missing transverse energy trigger

- **High p_T central electron and muon triggers**
  Central lepton candidate
- **High p_T forward electron trigger**
  Forward electron candidate
- **MET + jets or MET trigger**
  Lepton is reconstructed as the isolated track

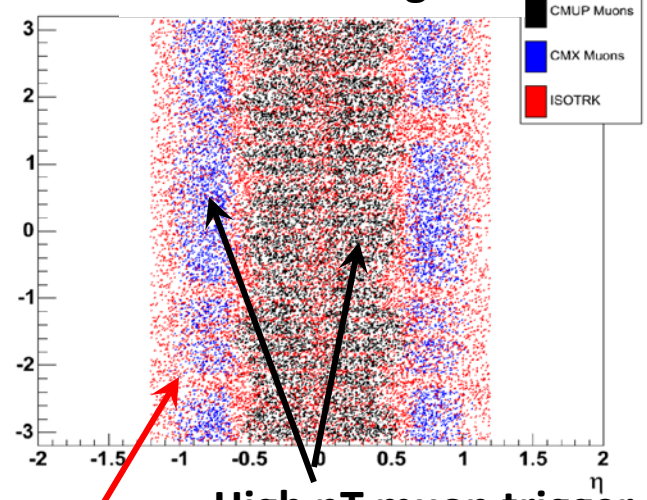
3 lepton categories



Electron Coverage



Muon Coverage



High pT electron trigger

High pT muon trigger

Isolated tracks on different triggers

Event selection

- **High p_T lepton (e/μ) or isolated track**

  P_T > 20GeV

- **Large missing transverse energy**

  MET > 20 GeV

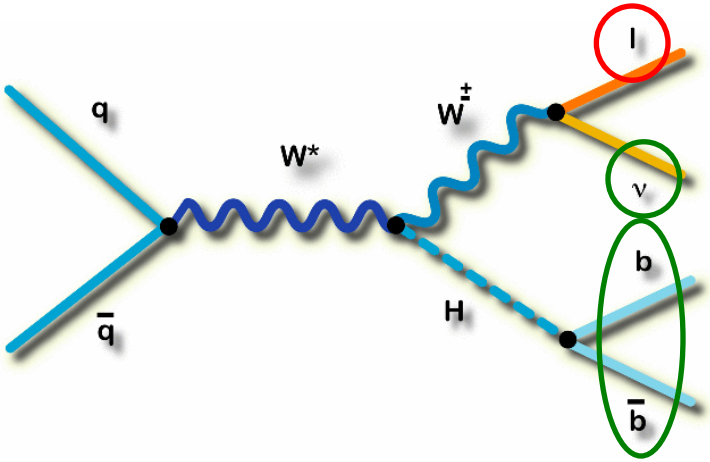
- **Two central high energy jets**

  E_T > 20 GeV, $|\eta|$ < 2.0

- **At least one *b*-tagged jet**

W boson selection

W + 2 b-jets selection

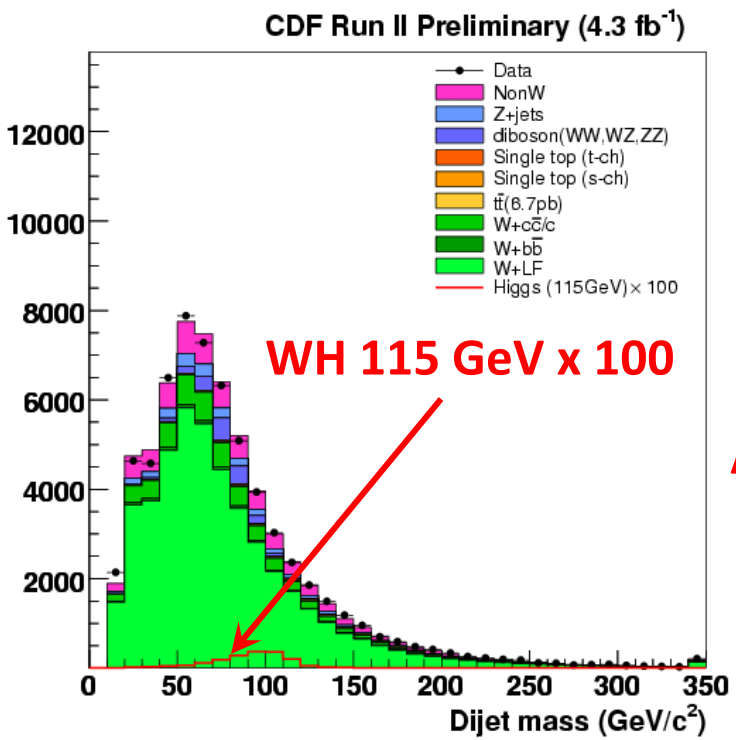


Why b-tagging?

b-tagging is very important to improve S/B

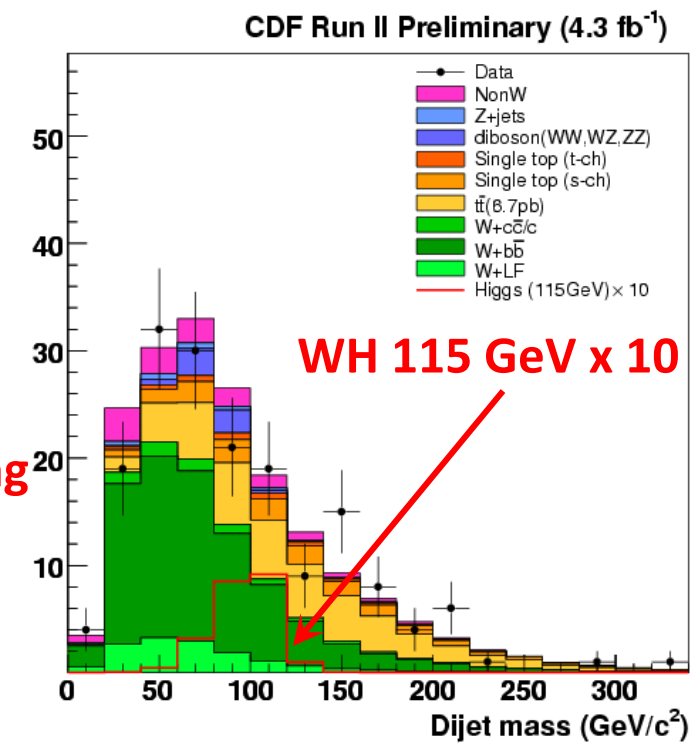
S/B ~1/5000 (no b-tag requirement)

S/B ~1/100 (2 b-tagged jet)



Dominant Background: W+LF

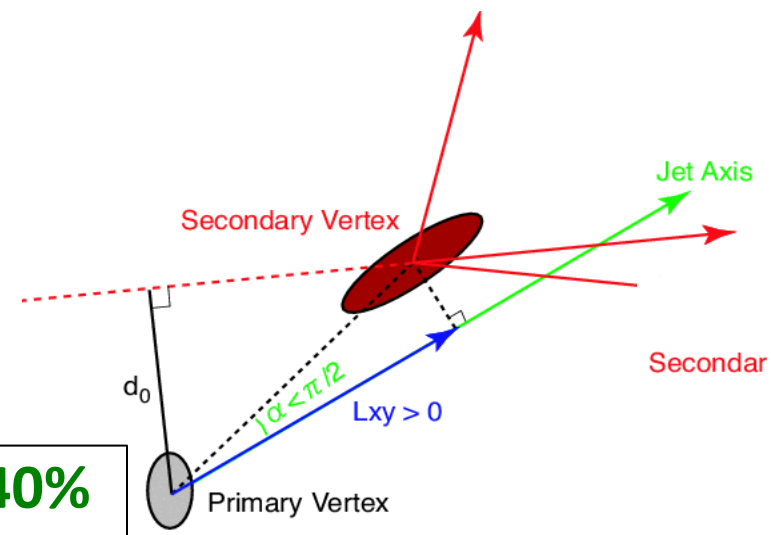
Apply b-tagging



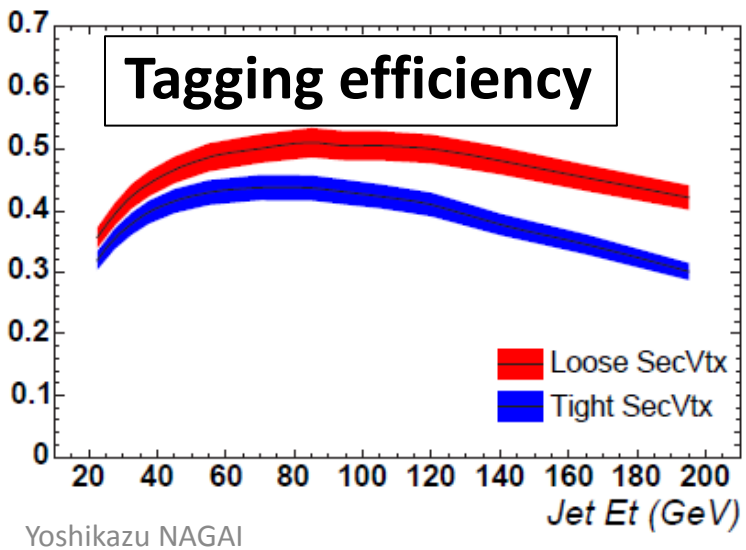
Dominant Background: W+bb and tt

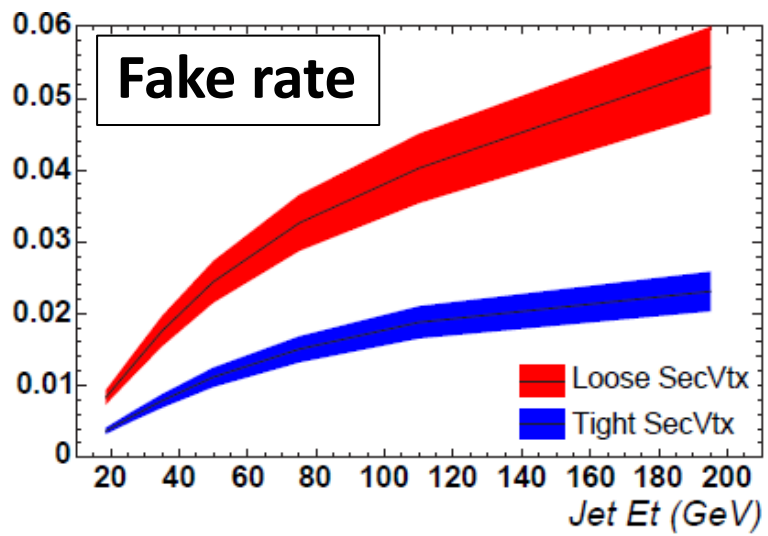
b-jet tagging algorithm

- **Secondary Vertex (SECVTX)**
  - ➢ B-hadron have a long life time: typically travel a few mm
  - ➢ Reconstruct secondary vertex displaced from primary vertex
  - ➢ Employ as the tightest b-tagging algorithm in this analysis



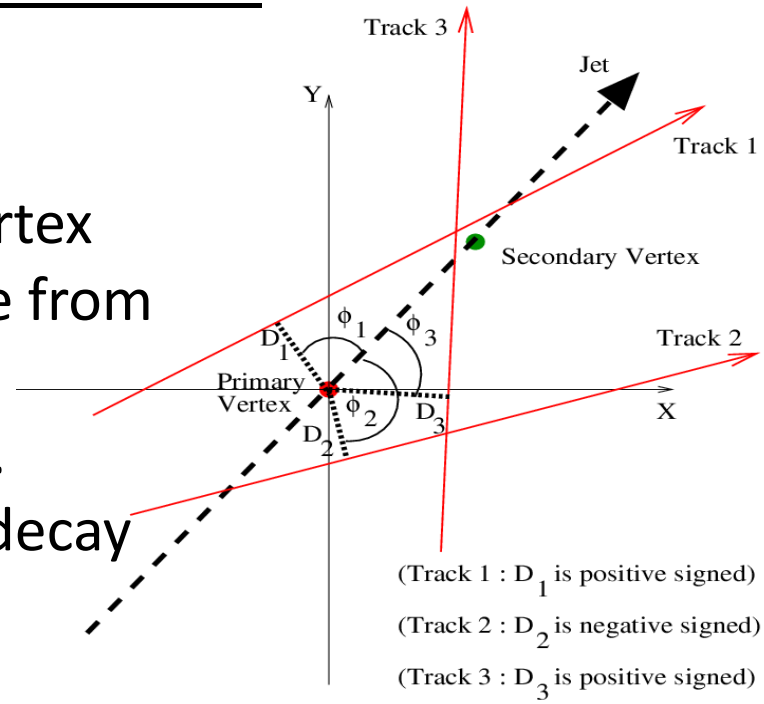
Efficiency ~40%
Fake rate ~1%



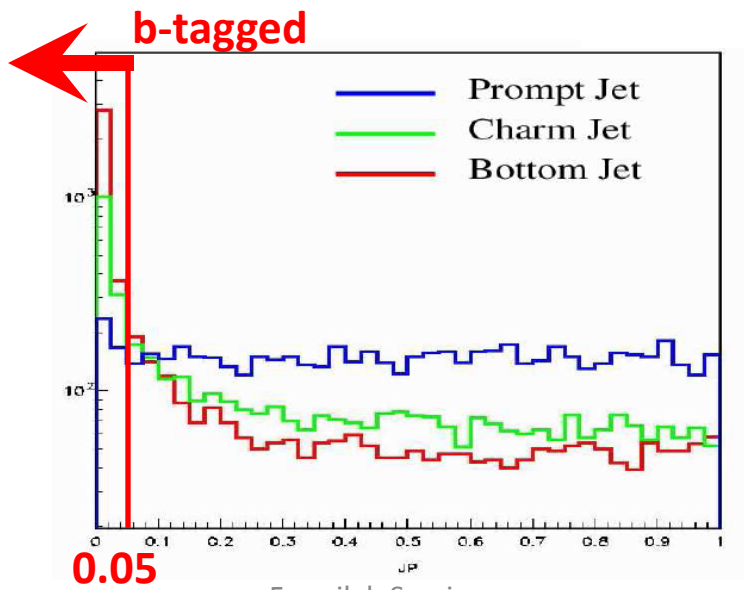


b-jet tagging algorithm

- **Jet Probability (JETPROB)**
  - B-hadron have a long life time: displaced tracks from the primary vertex
  - Calculate probability for a jet to come from the primary vertex
  - Uniform for a light flavor or gluon jet. Peak at 0 for a jet from heavy flavor decay
  - Employ as the 2nd tightest b-tagging algorithm

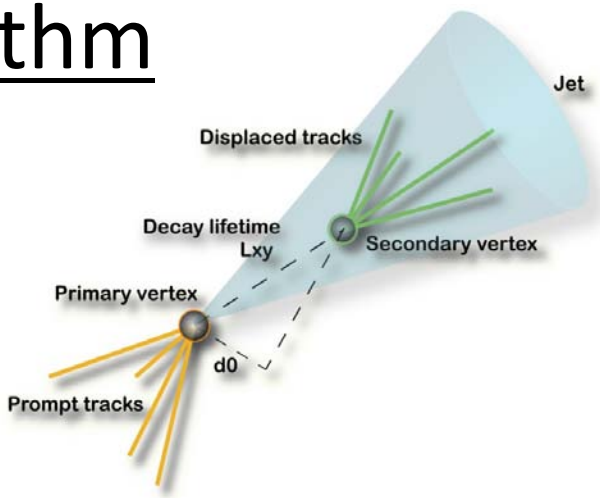


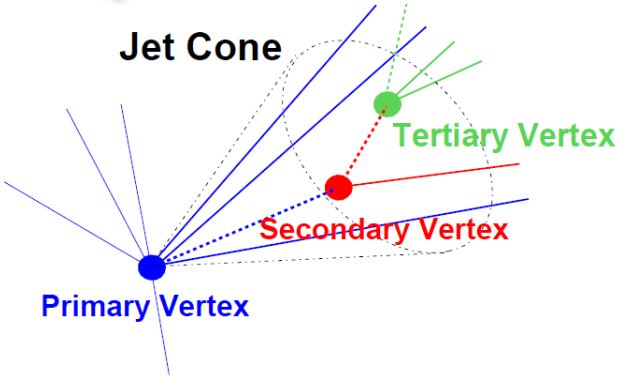
Efficiency ~50%
Fake rate ~5%



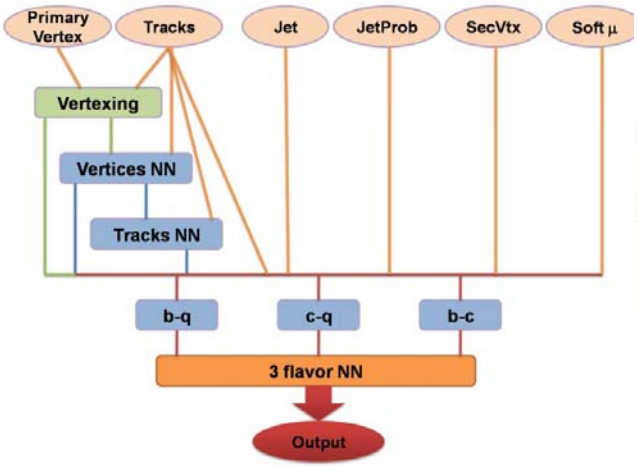
b-jet tagging algorithm

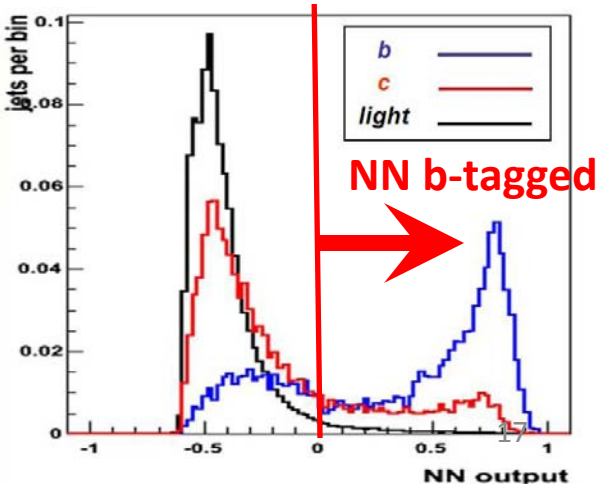
- **Neural Network (NN)**
  - ➢ Combine parameters of vertices, tracks, SECVTX, JETPROB, and a muon in jets using an artificial neural network
  - ➢ Optimize to separate b-quark jets from c-quark jets and light flavor jets
  - ➢ Employ as the loosest b-tagging algorithm in this analysis





Efficiency
~ 40% (non-muon jet)
~ 75% (muon jet)
Fake rate 5-10%





b-tagging categories

Use three standard b-tagging algorithms in CDF

- Secondary Vertex b-tagging algorithm (ST)
- Jet Probability b-tagging algorithm (JP)
- Neural Network b-tagging (NN)

tight

loose

Define 4 independent b-tagging categories

- Two ST-tagged jets (ST+ST)
- One ST-tagged jet + One JP-tagged jet (ST+JP)
- One ST-tagged jet + One NN-tagged jet (ST+NN)
- One ST-tagged jet (1-ST)

good S/B

worse S/B

This optimization is done to maximize the search sensitivity!!

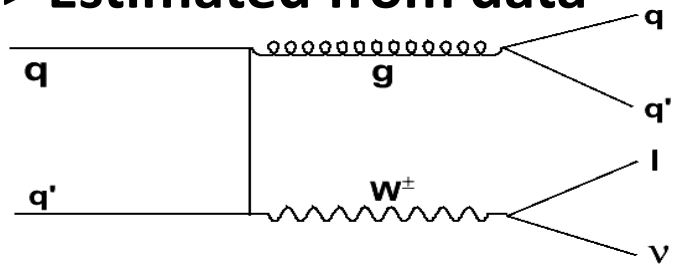
3 lepton categories x 4 b-tagging categories = 12 exclusive categories !

Background Estimation

Background Estimation

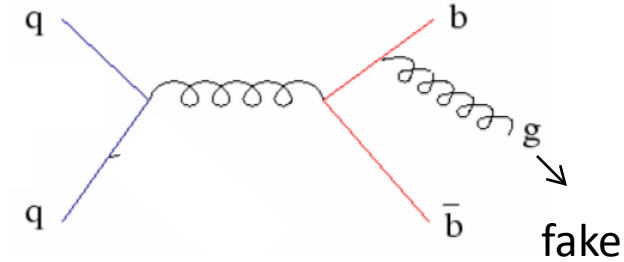
Mistag: falsely b-tagged W+LF jets

-> Estimated from data

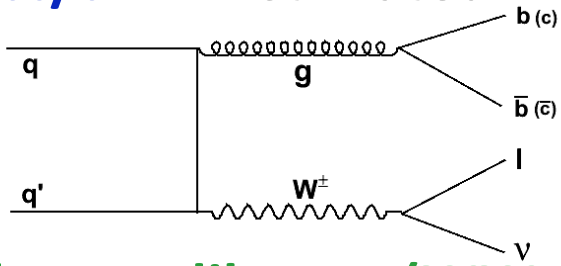


Non-W: QCD multi-jet fake

-> Estimated from data

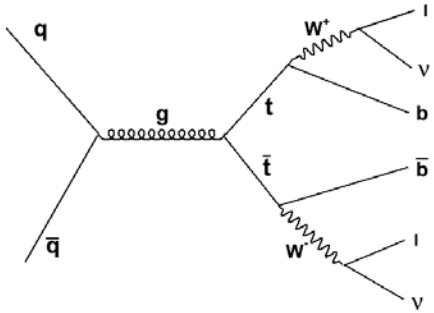


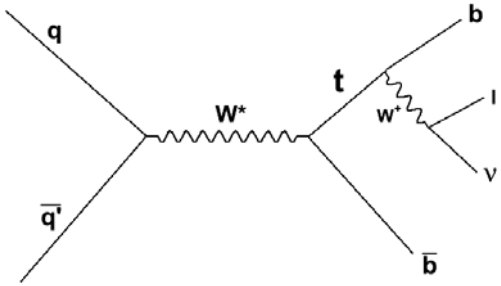
W+HF: W+bb, W+cc/c **-> Estimated from data and MC**

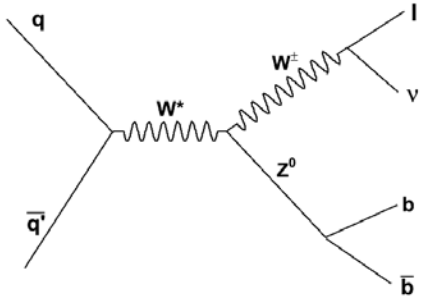


MC: top pair, single top, diboson (WW, WZ, ZZ), Z+jets

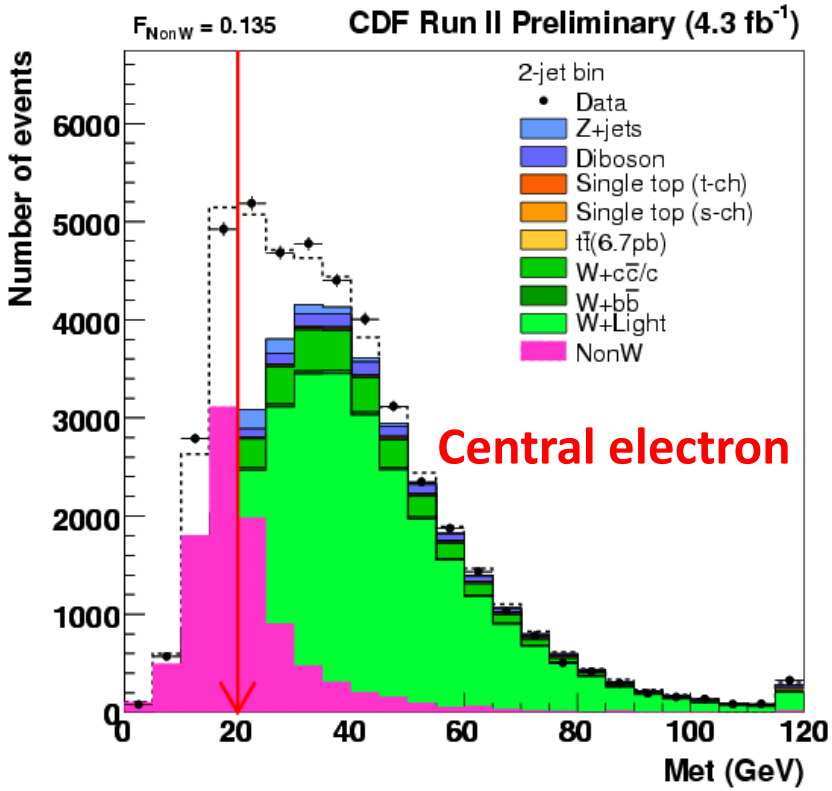
-> Estimated from MC using theoretical cross section







Background modeling



W+jets: ALPGEN + PYTHIA

MC (tt and diboson): PYTHIA

MC (single top): MADEVENT+ PYTHIA

MC (Z+jets): ALPGEN + PYTHIA

Non-W: side band data

(loose lepton selection)

The normalization of the Non-W and W+jets background is determined from the Missing transverse Energy distribution of the Pre b-tagged sample.

Data/MC agreement is quite well !!

Background Estimation

- Mistag: falsely b-tagged W+LF jets
- Non-W: QCD multi-jet fake
- W+HF: W+bb, W+cc/c
- MC Total: top pair, single top, diboson (WW, WZ, ZZ), Z+jets

Event Yield at 4.3fb^{-1}

	ST+ST	ST+JP	ST+NN	1-ST
Mistag	20.5 +/- 8.9	53.1 +/- 23.1	77.4 +/- 33.5	834.7 +/- 361.8
W+HF	116.8 +/- 32.6	115.9 +/- 29.6	61.1 +/- 23.2	1435.7 +/- 399.8
MC Total	98.1 +/- 14.4	95.1 +/- 13.9	45.4 +/- 7.7	509.3 +/- 66.0
Non-W QCD	19.2 +/- 8.5	21.8 +/- 7.9	17.7 +/- 6.8	464.9 +/- 82.4
Total background	254.6 +/- 44.7	285.8 +/- 55.1	201.6 +/- 57.6	3244.6 +/- 768.9
Observed Events	258	261	204	3160
WH 115 GeV	3.21	2.62	1.22	6.62

Tighter b-tag requirement
Good S/B or sensitivity

Looser b-tag requirement
Worse S/B or sensitivity

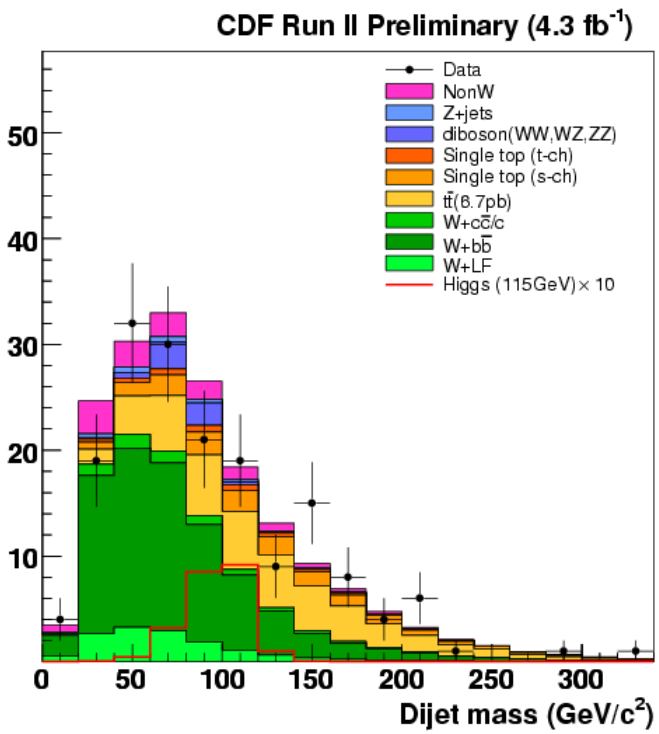
Analysis Optimization

- **Counting experiment is hopeless due to the large backgrounds**
- **We employ sophisticated techniques to further improve analysis sensitivity**
  - Neural network b-jet energy correction
  - Bayesian neural network discriminant

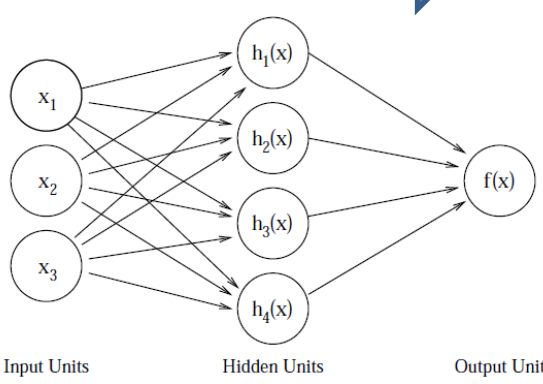
b-jet energy correction

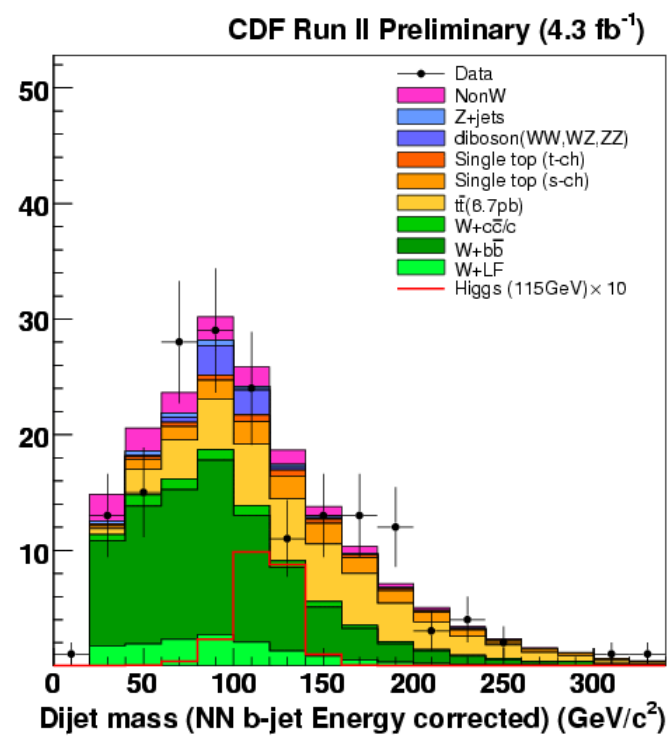
- Di-jet invariant mass is the most sensitive variable in WH->lνbb
- We develop Neural Network b-jet energy correction method

Input variables: Jet E_T, Jet M_T (= (P_T/P) x M), Jet Raw E_T, L_{XY}, $\sigma(L_{XY})$, SecVtxP_T, Track Sum P_T (P_T sum of tracks inside the jet), Track Max P_T



Apply NN correction





- Di-jet invariant mass resolution is improved **~4%**

Bayesian Neural Network (BNN)

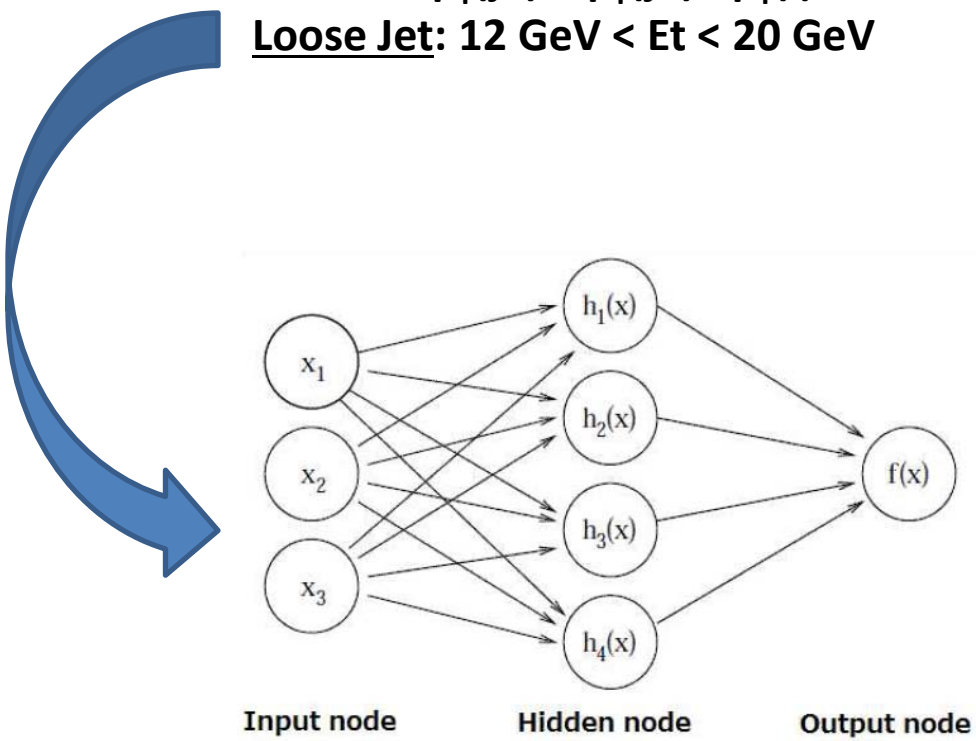
Separate signal and background using Bayesian Neural Network

BNN inputs M_{jj}, PtImbal, $M_{l\nu j}$, $Q_{lep} x \eta_{lep}$, Σ(LooseJetEt), $p_T(W)$, H_T

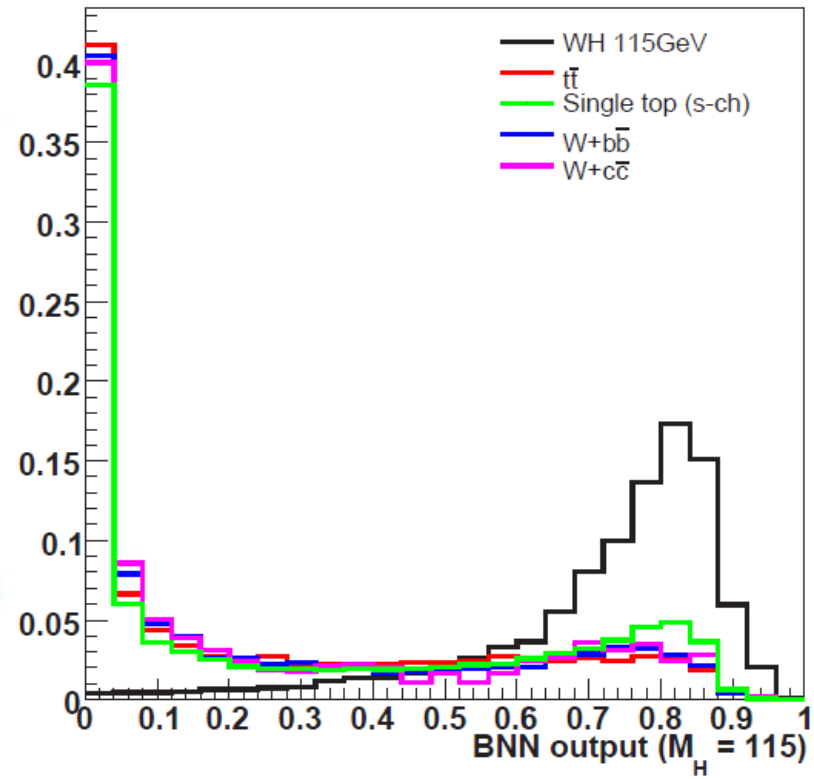
7 input

PtImbal: $p_T(j1) + p_T(j2) + p_T(l) - MET$ **Ht**: $p_T(j1) + p_T(j2) + p_T(l) + MET$

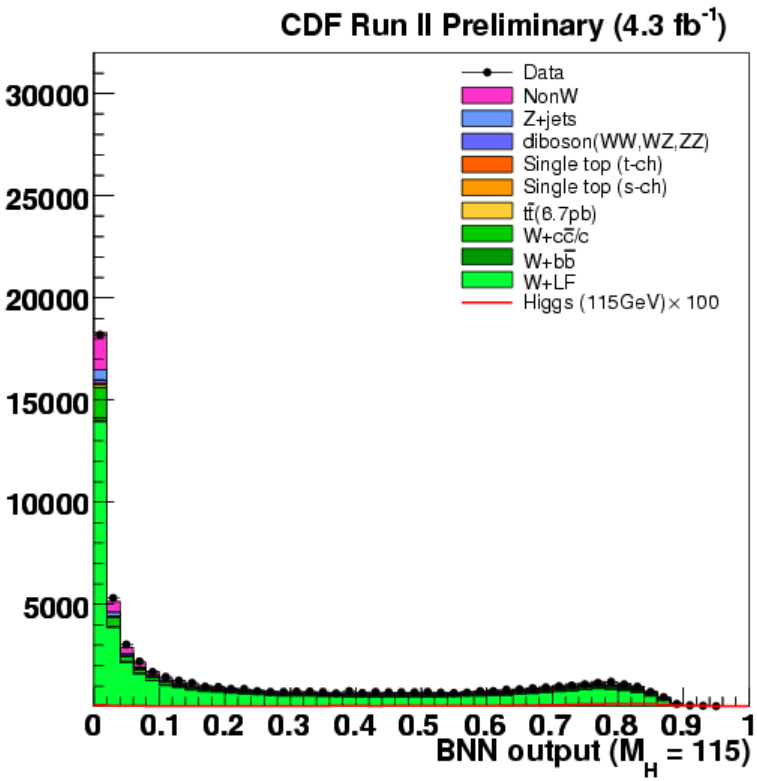
Loose Jet: 12 GeV < Et < 20 GeV

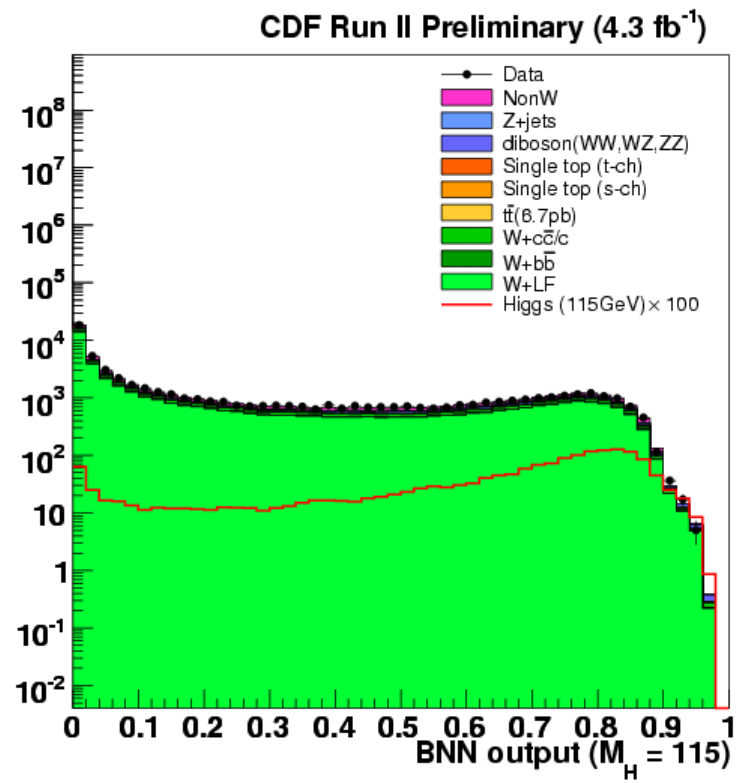


BNN output



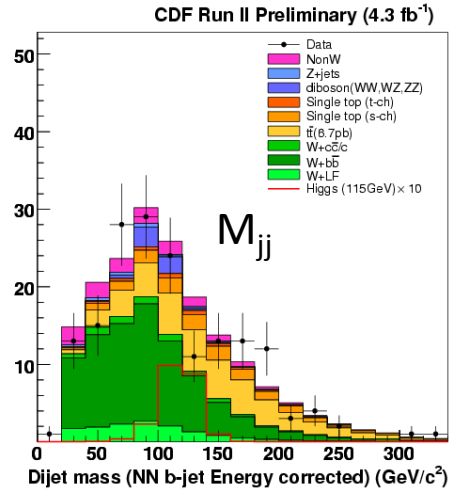
Pretag BNN outputs (Control region)

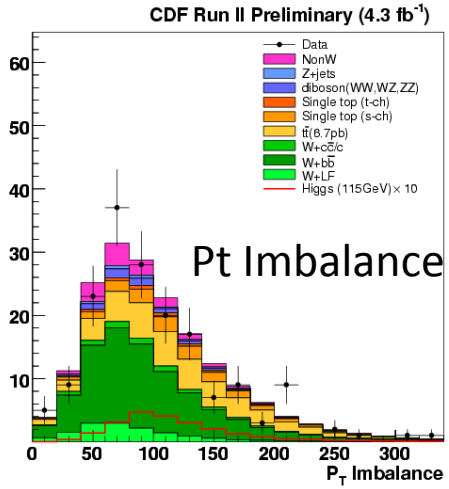


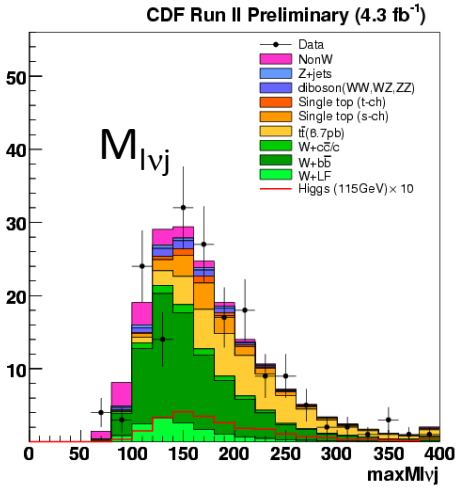


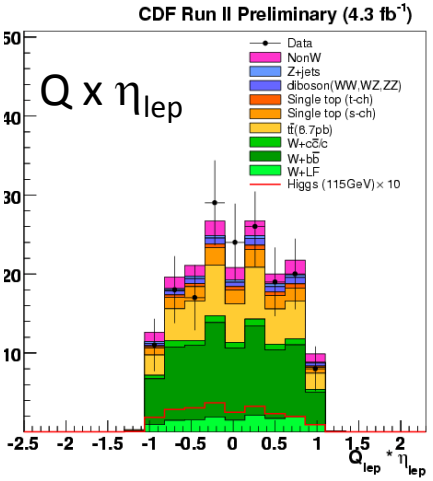
Data/MC agreement is quite well !!

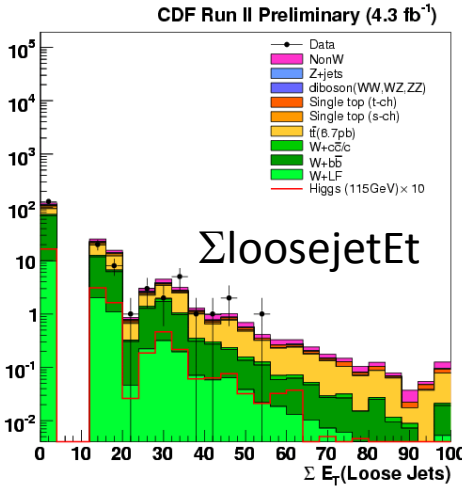
BNN input variables (Signal region)

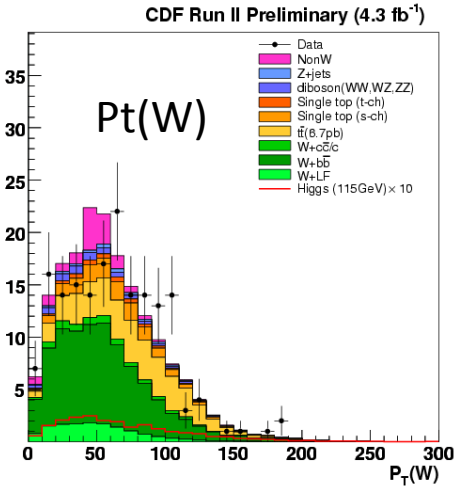


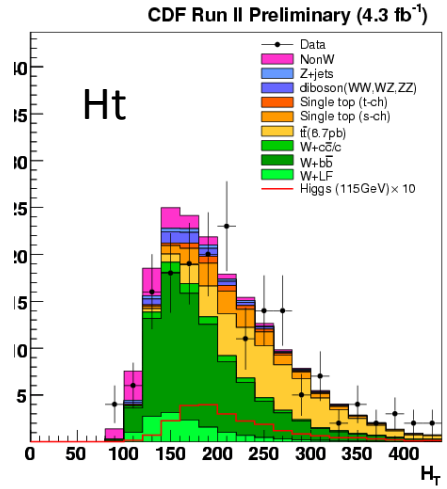






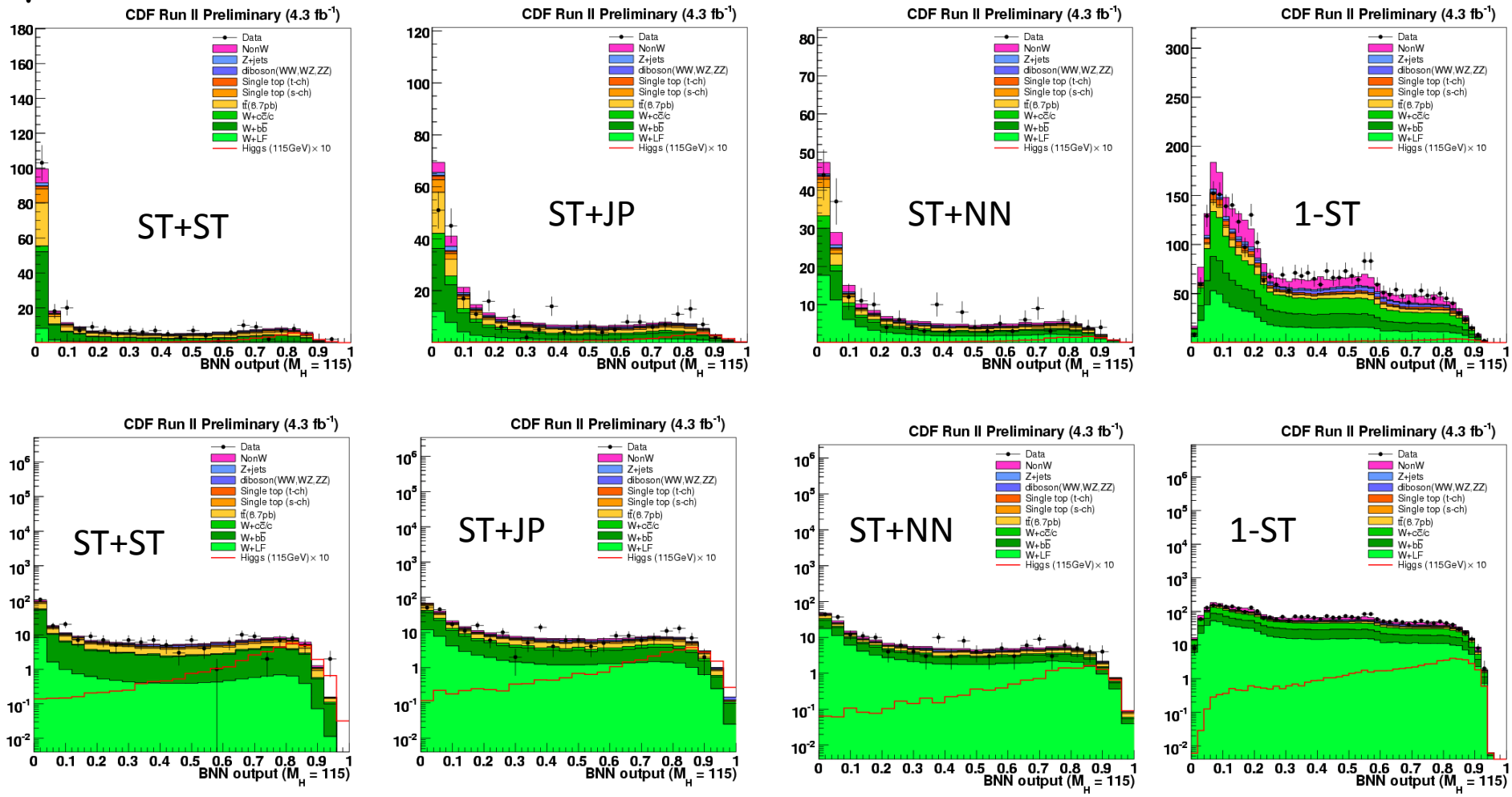






All lepton combined BNN output (signal region)

Open the box !



No significant excess observed

Systematic Uncertainties

Systematic Uncertainties on Signal Acceptance

- **Lepton identification**: The difference of ID efficiency between data and MC
- **Trigger efficiency**: The uncertainties of trigger efficiency
- **Initial/Final state radiation (ISR/FSR)**: The difference between higher and lower ISR/FSR MC samples
- **Jet Energy Scale (JES)**: Estimated by JES $\pm$ 1σ shift from default value
- **Parton distribution function (PDF)**: The difference among various PDFs (Estimated from MC)
- **b-tagging**: The difference of b-tagging efficiency between data and MC

- **Systematic uncertainties**

b-tagging category	Lepton ID	Trigger	ISR/FSR/PDF	JES	b-tagging	Total
1-ST	2%	$< 1\%$	3.0%	2.3%	4.3%	6.1%
ST+ST	2%	$< 1\%$	4.9%	2.0%	8.6%	10.3%
ST+JP	2%	$< 1\%$	4.9%	2.8%	8.1%	10.1%
ST+NN	2%	$< 1\%$	7.7%	2.2%	13.6%	15.9%

- **Luminosity uncertainty 6%**

Results

Limit Calculation

- We do not observe any significant excess
- Set 95% C.L. limit using binned likelihood technique
- It is applied to BNN distributions.

Binned Likelihood technique

$$L(\sigma/\sigma_{\rm SM}) = \int \cdots \int \prod_{i \in \text{ bins}} \frac{\mu_i^{N_i} \cdot e^{-\mu_i}}{N_i!} \prod_{k=1}^{Bkg} G(N_k, \sigma_{N_k}) \times G(N_{WH}, \sigma_{N_{WH}}) dN_k dN_{WH}. \quad \mu_i = \sum_{k=1}^{\text{Bkg}} f_i^k \cdot N^k + f_i^{WH \to l\nu b\bar{b}} \cdot (\varepsilon \cdot \mathcal{L} \cdot \sigma_{WH \to l\nu b\bar{b}})$$

where, N_i is the number of observed data in each bin

N_k, Number of background for each process,

f is fraction for each bin, $\mathcal{L}$ is integrated luminosity, ε is signal acceptance

Likelihood for 12 exclusive categories
(3 lepton categories and 4 b-tagging categories)

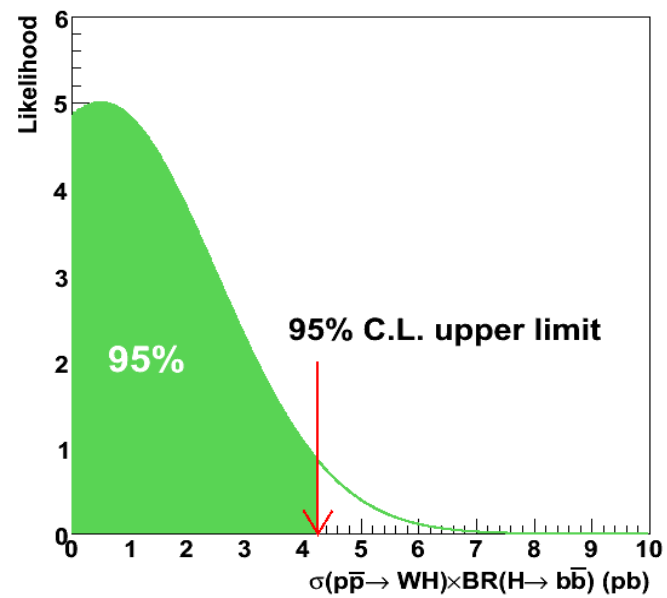
Limit Calculation

- Combined likelihood

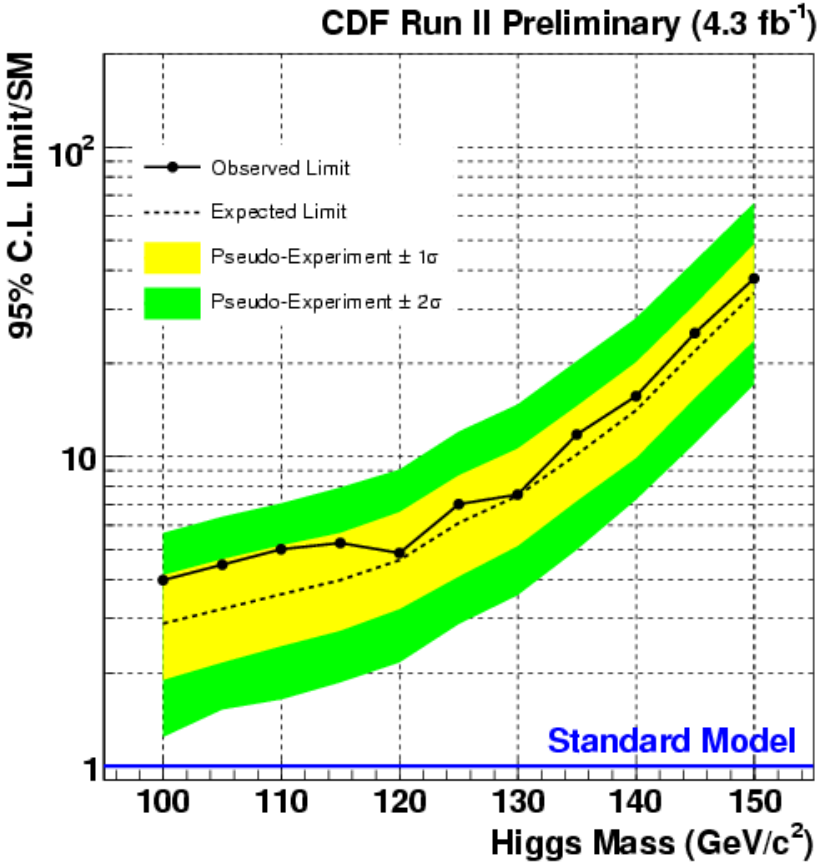
$$L(\sigma/\sigma_{\rm SM}) = \prod_{i\in \text{ leptons}} L(\sigma/\sigma_{\rm SM}|\text{ST+ST})_i \times L(\sigma/\sigma_{\rm SM}|\text{ST+JP})_i \times L(\sigma/\sigma_{\rm SM}|\text{ST+NN})_i \times L(\sigma/\sigma_{\rm SM}|1-\text{ST})_i$$

- 95% confidence level upper limit

$$0.95 = \frac{\int_0^x L(\alpha)d\alpha}{\int_0^\infty L(\alpha)d\alpha} \Rightarrow Set \quad x$$



Final Result



- 4 b-tagging categories
- Bayesian Neural Network
- 4.3fb^{-1} of data

Expected upper limit

4.0 x σ(SM) (m_H = 115 GeV)

Observed upper limit

5.3 x σ(SM) (m_H = 115 GeV)

	100	105	110	115	120	125	130	135	140	145	150
Expected	2.8	3.1	3.5	4.0	4.6	6.0	7.4	10.0	14.1	21.8	33.7
Observed	4.0	4.5	5.0	5.3	4.9	7.0	7.5	11.8	15.7	25.0	37.6

Final result

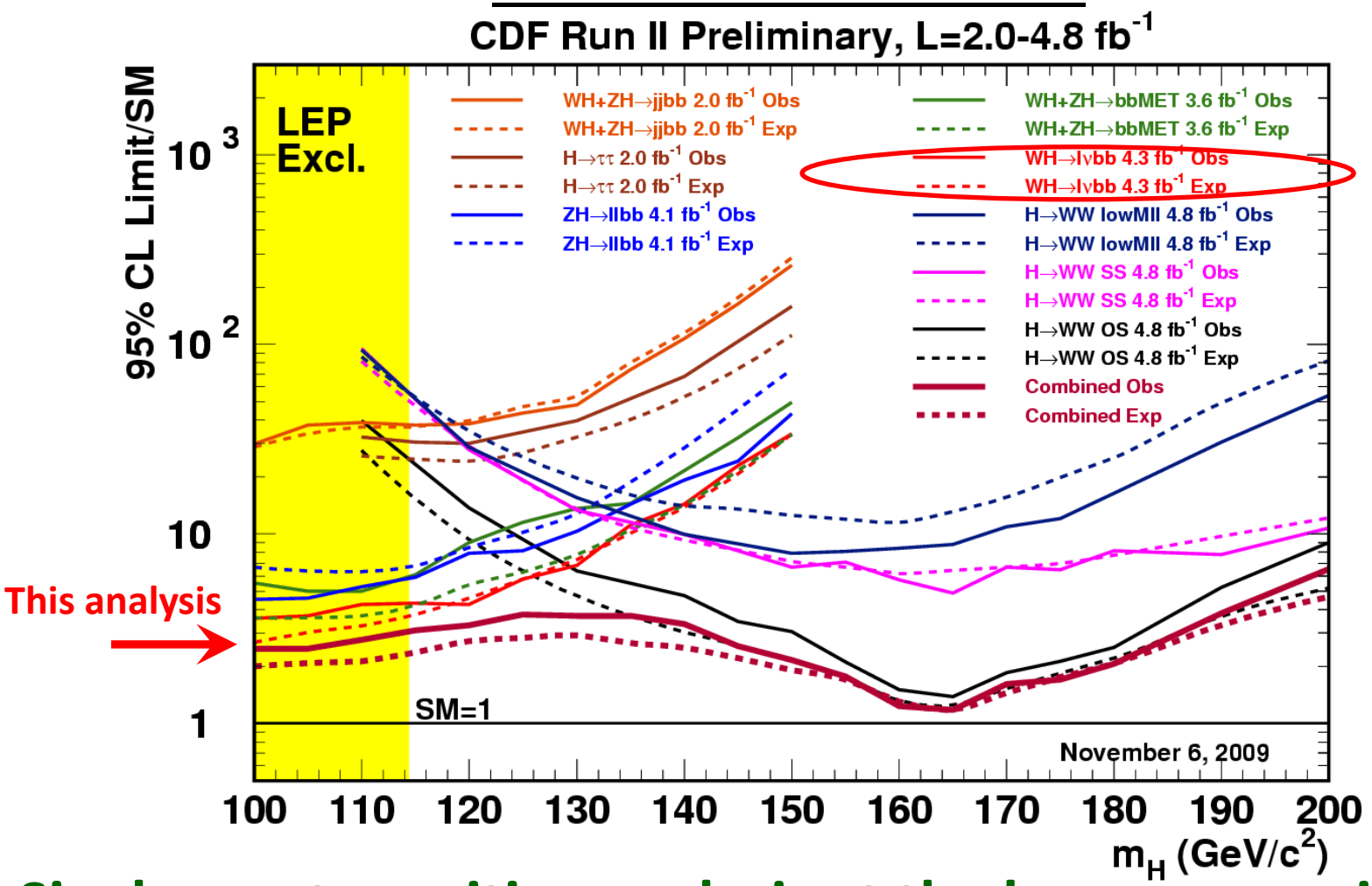
- **2.7fb^{-1} analysis (published in Phys. Rev. Lett)**
  - **Add Isolated track**
  - **Analysis sensitivity @ m_H = 115 GeV: 5.8 x σ(SM)**
- **4.3fb^{-1} analysis (This result)**
  - **Employ Neural Network b-tagging algorithm**
  - **Develop Neural Network b-jet energy correction**
  - **Implement unused trigger data**
  - **Improve Bayesian Neural Network discriminator**
  - **Analysis sensitivity @ m_H = 115 GeV: 4.0 x σ(SM)**

Improvement

31%

Significant improvement from 2.7fb^{-1} !!

CDF Combination



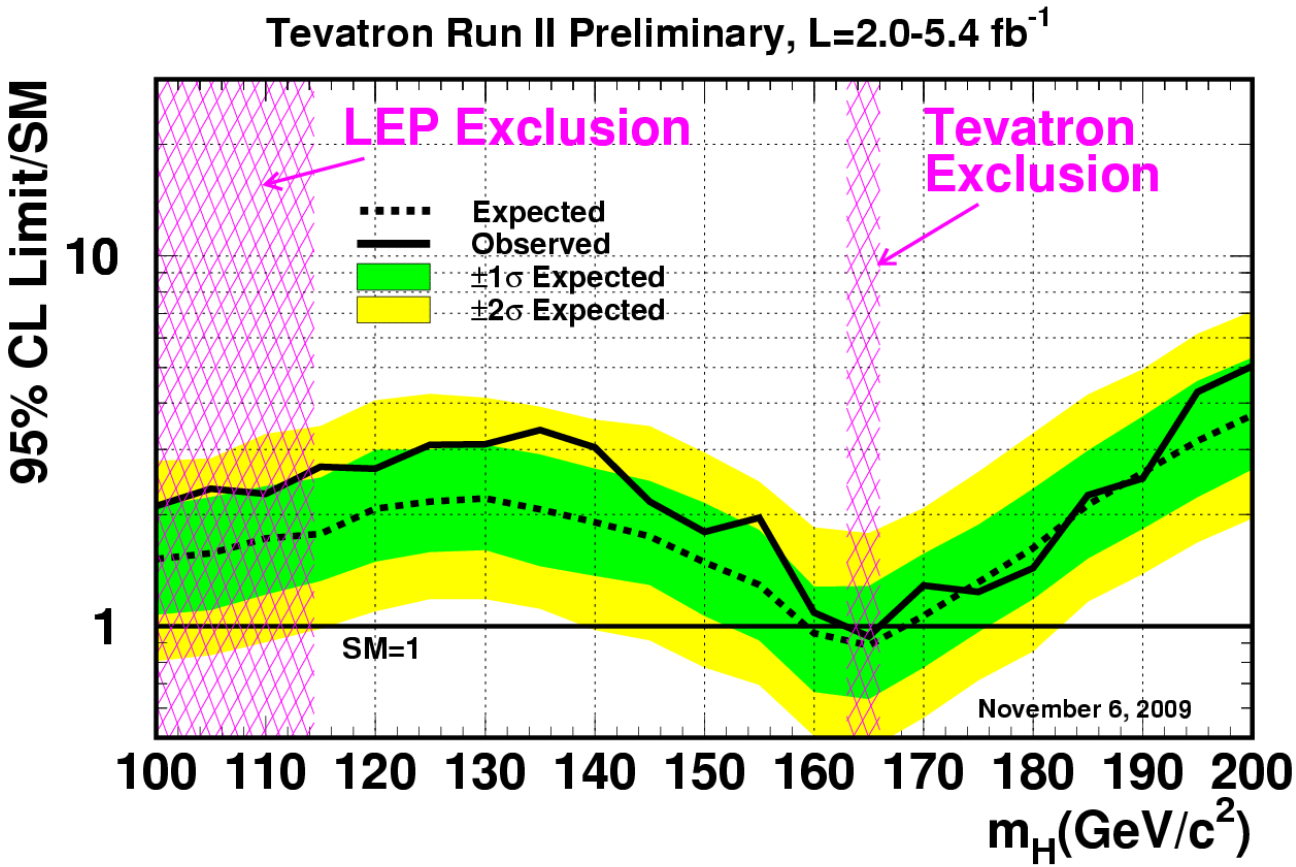
This analysis

Single most sensitive analysis at the low mass region !

Combined channels

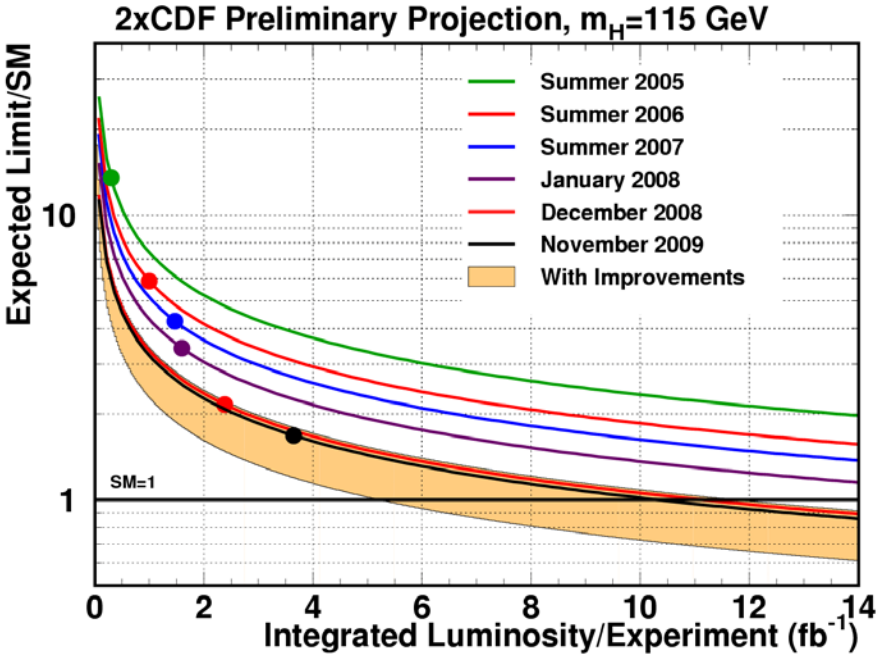
WH->lνbb, VH->MET+bb, ZH->llbb, H->WW->lνlν VH->jjbb, H->ττ + 2jets

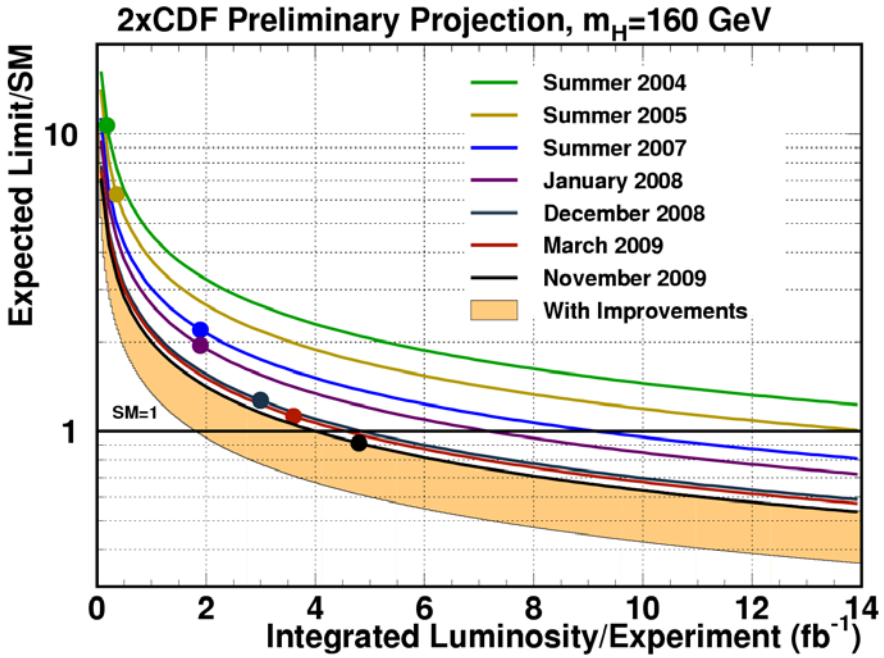
Tevatron Combination



- M_H = 162 – 166 GeV/c^2 is excluded at the 95% C.L.
- Observed (expected) upper limit @ 115 GeV/c^2: 2.7 (1.8) x σ(SM)
- Observed (expected) upper limit @ 165 GeV/c^2: 0.9 (0.9) x σ(SM)

Future Expectation





- Tevatron plan to run through 2011 -> expected > 10fb^{-1} of data
- We can reach to the SM sensitivity even at the M_H = 115 GeV/c^2
- With improvements, we can achieve earlier Higgs discovery!

What we can do next?

General

- Analyze large data set, Tevatron is performing really well !
  - -> For this summer, I plan to analyze ~6.0fb^{-1} of data
- Analyze new channel not included for the combination so far
  - -> ggH -> WW -> lνjj, VH -> VWW -> lνjjjj, etc …

WH-> lνbb

- Add 3-jet bin channel to gain the signal acceptance
  - -> Estimated signal acceptance increase is > 15 %
- Loosen lepton and b-tagging requirement
  - -> Expect some acceptance gain
- Re-optimize the analysis techniques
  - -> To further improve analysis sensitivity

Summary

- We have performed search for the SM Higgs boson using the $p\bar{p} \rightarrow W^{\pm}H \rightarrow l\nu b\bar{b}$ channel with **4.8fb^{-1}** of CDF data
- We employ sophisticated multivariate technique:
  Bayesian Neural Network
- We get the significant improvement from previous analysis
- We do not observed significant excesses
- We observed the 95% C.L. upper limit @ m_H = 115 GeV:
  5.3 x σ(SM) (observed) 4.0 x σ(SM) (expected)

- Tevatron can reach the Standard Model sensitivity with > 10fb^{-1} of data, even at the low mass region.

Backup

Higgs Mechanism

- **Introduce Higgs potential to give mass to W/Z boson with keeping gauge invariance in Electroweak theory via Spontaneous symmetry breaking**

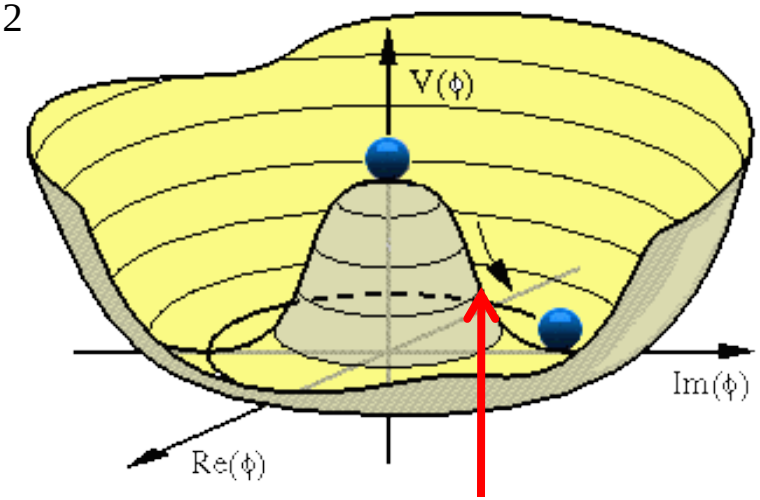
$$\mu^2 < 0, \ \lambda > 0$$

- **Higgs potential :** $V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$

$$\varphi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi^1 + i\phi^2 \\ \phi^3 + i\phi^4 \end{pmatrix}$$

SSB

$$\phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$$



Spontaneous symmetry breaking (SSB)

weak boson mass

$$m_W = \frac{1}{2} v g = 80.4 \text{ GeV}$$

$$m_Z = \frac{1}{2} v \sqrt{g^2 + g'^2} = 91.2 \text{ GeV}$$

g, g' **are coupling constant**

v ~ 246 GeV

Higgs mass

$$m_H = \sqrt{2\lambda} v = ??$$

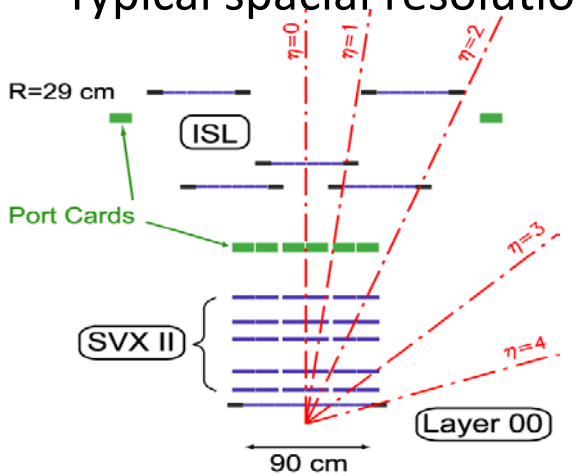
Higgs boson mass is not predicted by SM

➔ It needs to determine by experiments

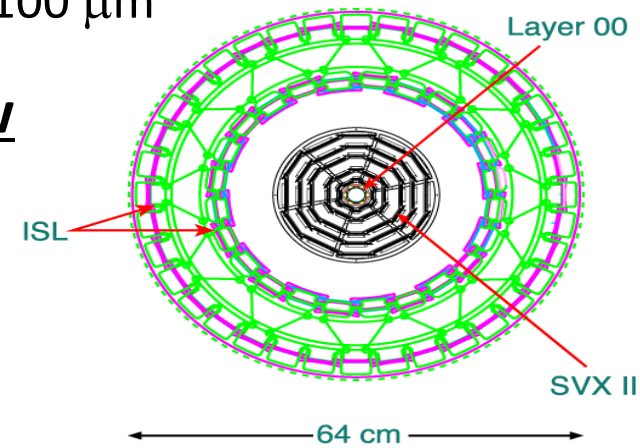
Tracking system

Reconstruct trajectory of charged particles and measure their momenta

- Silicon vertex detector (L00, SVX II, ISL) (|η| < 2.0)
  - Typical spacial resolution in x-y plane is: 25 – 100 μm

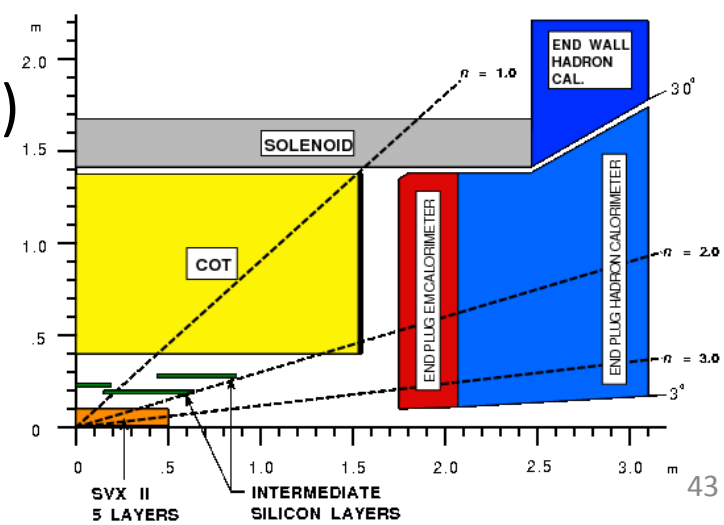


r-z view **x-y view**



- Central Outer Tracker (COT) (|η| < 1.0)
  - Cylindrical drift chamber
  - Position resolution is ~140 μm

CDF Tracking Volume



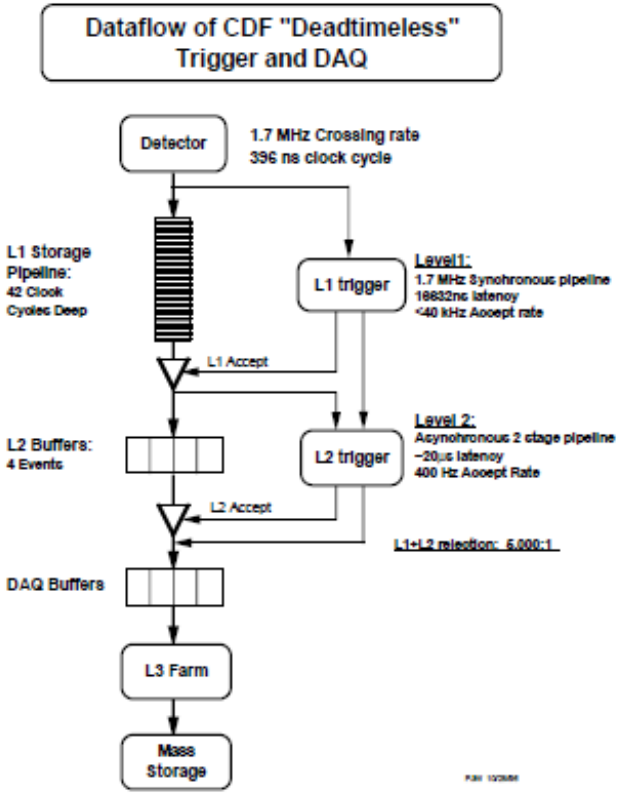
Trigger

- Collision occurs every 396 ns (actual collision rate is ~1.7MHz)

  -> Too high rate to record every events in disk

  -> Need to discard the most events while keep interesting events

- Three level trigger system:
  - L1: 1.7MHz -> 40kHz
  - L2: 40kHz -> 400Hz
  - L3: 400Hz -> 100Hz



- Our analysis uses High-p_T lepton trigger and Missing E_T trigger

Central lepton

- CEM (4.31/fb)
- CMUP (4.31/fb)
- CMX (4.26/fb)

Plug electron

- MET_PEM (4.31/fb)

Isolated track

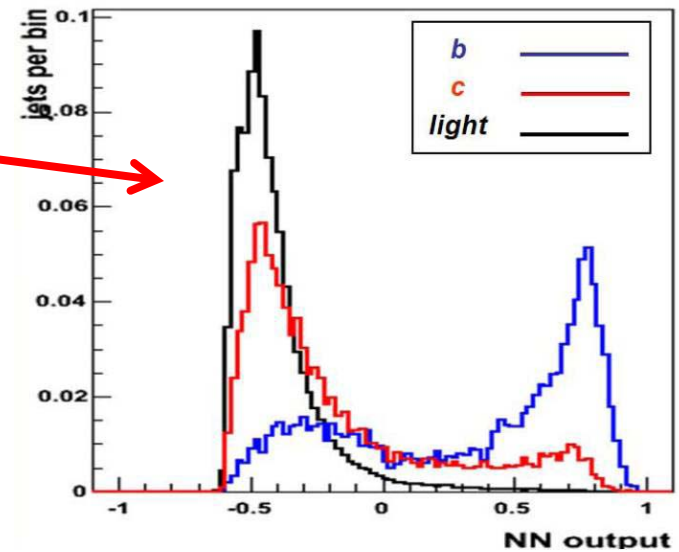
- MET2J (3.95/fb)
- MET45 (4.17/fb)

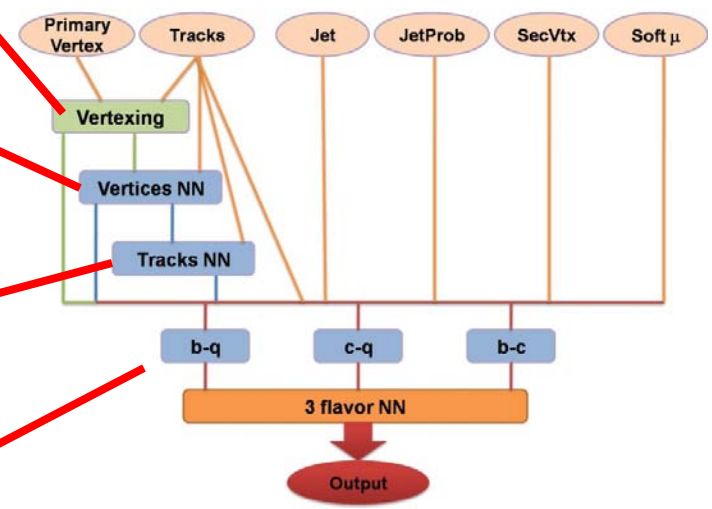
b-jet tagging algorithm (NN)

- Distinguish b-jet from light or charm flavor jet
- Consist of vertexing algorithm and three neural networks

Algorithm

- Reconstruct vertices inside the Jet using primary vertex and track information
- Distinguish reconstructed vertices from: primary vertex, true displaced vertex originating from a long-lived particle, or fake displaced vertex.
- Recover tracks which are not associated with a vertex but from real B-hadron decay
- Combine every information and separate b-jets from c-jets or light-jets
- Define output > 0.0 as b-tagged jet





Efficiency ~40%
Mistag rate 5-10%

Event Selection (Isolated track)

- We use MET2J, MET45 trigger parallel

If given event require jet1, jet2 E_T> 25GeV, $|\eta_{j1}$ or $\eta_{j2}| < 0.9$, $\Delta R(j1\text{-}j2) > 1.0$

→ We consider this as MET2J region event

If given event fail jet1, jet2 E_T> 25GeV, $|\eta_{j1}$ or $\eta_{j2}| < 0.9$, $\Delta R(j1\text{-}j2) > 1.0$

→ We consider this as MET45 region event

WH (115GeV) signal yield at 4.3/fb

m_H	STST	STJP	STNN	1-ST
MET2J only	0.59	0.42	0.22	0.94
MET2J + MET45	0.70	0.52	0.27	1.31
Signal gain	18.6%	19.2%	18.5%	39.4%

We largely improve signal acceptance for Isolated track events!!

Background Estimation Overview

- Start from the W+jets data before b-tagging (pretag)
- Estimate MC-based backgrounds

$$N_{MC} = \left(\sum_i \sigma_i \varepsilon_i \right) \int \mathcal{L} dt$$

- Estimate pretag W+jet yield and non-W QCD

$$\begin{cases} N_{NonW} = f_{nonW} N_{Data}^{Pretag} \\ N_W = N_{Data}^{Pretag} - N_{nonW} - N_{MC} \end{cases}$$

- Multiply by heavy flavor fraction and b-tagging efficiency to get W+HF

$$N_{W_{HF}}^{btag} = N_W F_{HF} K \varepsilon_{btag}$$

- Subtract W+HF from pretag and estimate mistag (W+LF)

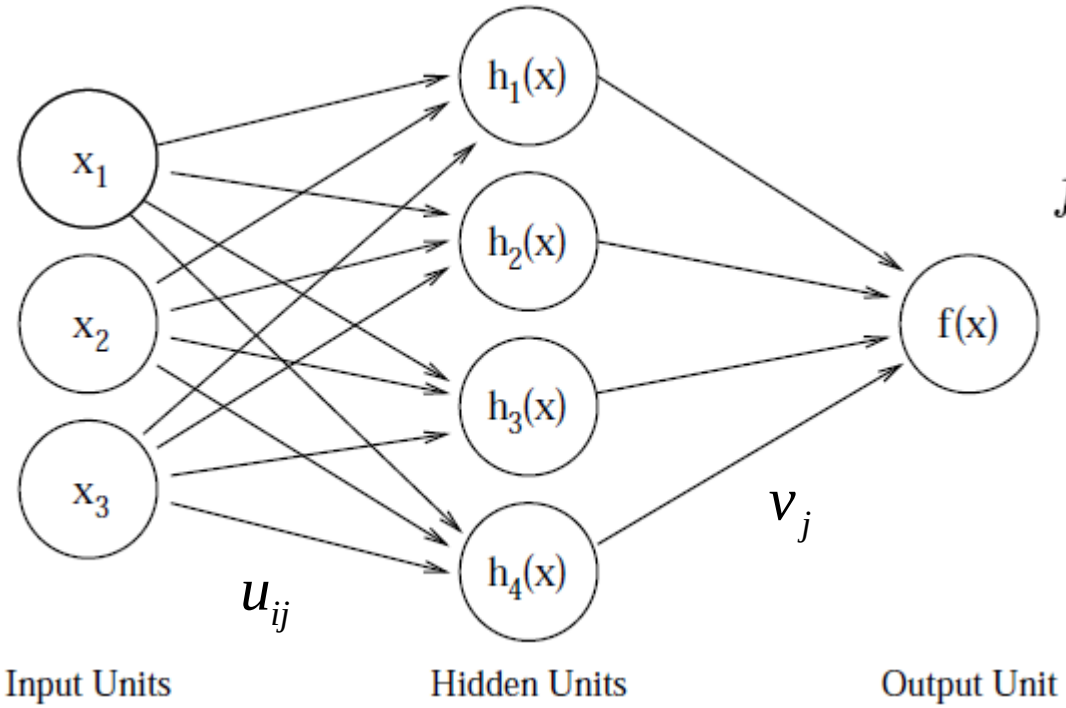
$$N_{W_{LF}}^{btag} = N_{Data}^{Negative\ Tag} \left(\frac{N_W - N_{W_{HF}}}{N_{Data}^{Pretag}} \right)$$

- Estimate b-tagged backgrounds from MC-based and non-W backgrounds

$$\begin{cases} N_{MC}^{btag} = \left(\sum_i \sigma_i \varepsilon_i \varepsilon_{btag} \right) \int \mathcal{L} dt \\ N_{NonW}^{btag} = f_{nonW} N_{Data}^{btag} \end{cases}$$

Neural Network

- Neural Network architecture (3 layer)



Output node:
Linear combination
of hidden nodes

$$f(x) = b + \sum_{j=1}^{H} v_j h_j(x)$$

weight determined by training

Training is performed to minimize error function

$$E = \frac{1}{2}(f(x) - t)^2$$

target value:
1 -> signal, 0->background

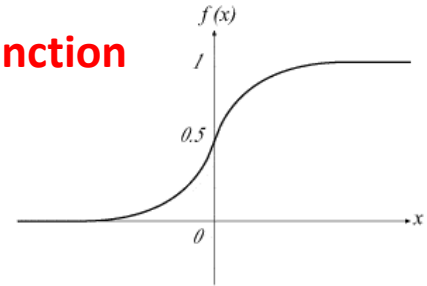
Hidden nodes: Each is a sigmoid dependent on the input variables

$$h_j(x) = \frac{1}{1 + \exp(-\sum_{i=1}^{I} u_{ij} x_i)}$$

weight determined by training

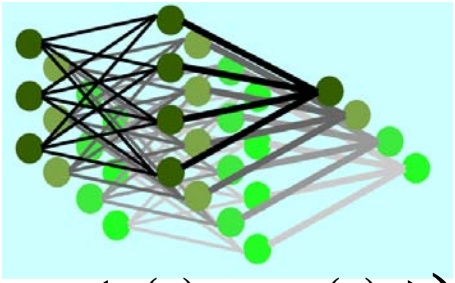
sigmoid function

$$f(x) = \frac{1}{1 + \exp(-x)}$$



Bayesian Neural Network

- Bayesian idea:
  - ➢ Rather than finding one value for each weight, determine the posterior probability for each weight
- Form many networks by sampling from the posterior



$$P\left(f(x^{(n+1)})\,|\,x^{(n+1)},(x^{(1)},w^{(1)}),\ldots,(x^{(n)},w^{(n)})\right)$$
$$=\int dw P\left(f(x^{(n+1)})\,|\,x^{(n+1)},w\right)\times P\left(w\,|\,x^{(n+1)},(x^{(1)},f(x^{(1)})),\ldots,(x^{(n)},f(x^{(n)}))\right)$$

if training is ideal:

signal (t=1) -> f(x) = 1, background (t=0) -> (1-f(x))

$$P\left(t\,|\,(x^{(1)},w^{(1)}),\ldots,(x^{(n)},w^{(n)})\right)=\prod_{i=1}^{N} f(x^{(i)})^{t_i}\left(1-f(x^{(i)})\right)^{1-t_i}$$

Final estimation is given by the weighted average:

$$\overline{f\left(x'\,|\,(t_1,x_1),\ldots,(t_n,x_n)\right)}=\int f(x',w)\,p\left(w\,|\,(t_1,x_1),\ldots,(t_n,x_n)\right)$$
$$\approx\frac{1}{K}\sum_{k=1}^{K} f(x',w_k)$$

Higgs signal acceptance

- Expected number of signal is calculated as follows:

$$N_{WH\to l\nu b\bar{b}} = \epsilon_{WH\to l\nu b\bar{b}} \cdot \mathcal{L} \cdot \sigma(p\bar{p} \to WH) \cdot \mathrm{Br}(H \to b\bar{b})$$

$$\epsilon_{WH\to l\nu b\bar{b}} = \epsilon_{Z0} \cdot \epsilon_{\mathrm{trig}} \cdot \epsilon_{\mathrm{leptonid}} \cdot \epsilon^{\mathrm{MC}}_{WH\to \ell\nu b\bar{b}} \cdot \left(\sum_{l=e,\mu,\tau} \mathrm{Br}(W \to l\nu) \right)$$

- Each category is exclusive

m_H = 115 GeV/c^2

1-ST Tag		
CEM	2.68	6.62
PHX	0.53	
CMUP	1.39	
CMX	0.69	
IsoTrk(MET2J)	0.95	
IsoTrk(MET45)	0.38	

ST+JP Tag		
CEM	1.07	2.62
PHX	0.20	
CMUP	0.56	
CMX	0.26	
IsoTrk(MET2J)	0.43	
IsoTrk(MET45)	0.11	

ST+ST Tag		
CEM	1.25	3.21
PHX	0.26	
CMUP	0.66	
CMX	0.33	
IsoTrk(MET2J)	0.60	
IsoTrk(MET45)	0.11	

ST+NN Tag		
CEM	0.48	1.22
PHX	0.10	
CMUP	0.26	
CMX	0.12	
IsoTrk(MET2J)	0.21	
IsoTrk(MET45)	0.05	

Total expected number of signal: 13.7 event

Systematic Uncertainties

Central

b-tagging category	Lepton ID	Trigger	ISR/FSR/PDF	JES	b-tagging	Total
1-ST	2%	$< 1\%$	3.0%	2.3%	4.3%	6.1%
ST+ST	2%	$< 1\%$	4.9%	2.0%	8.6%	10.3%
ST+JP	2%	$< 1\%$	4.9%	2.8%	8.1%	10.1%
ST+NN	2%	$< 1\%$	7.7%	2.2%	13.6%	15.9%

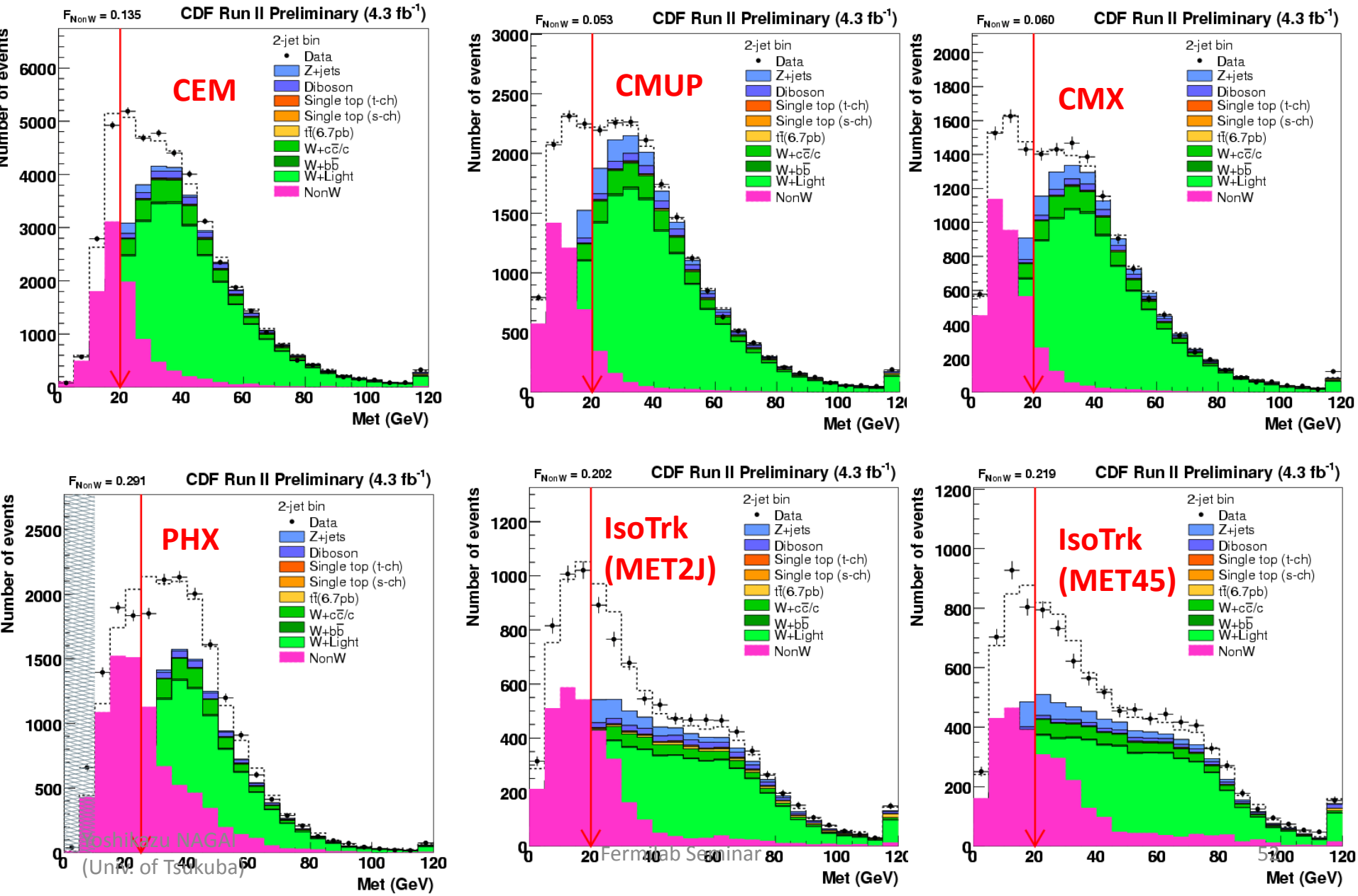
PHX

b-tagging category	Lepton ID	Trigger	ISR/FSR/PDF	JES	b-tagging	Total
1-ST	2%	$< 1\%$	5.7%	2.9%	4.3%	8.0%
ST+ST	2%	$< 1\%$	7.7%	2.4%	8.6%	12.0%
ST+JP	2%	$< 1\%$	4.5%	3.9%	8.1%	10.3%
ST+NN	2%	$< 1\%$	12.9%	6.7%	13.6%	20.0%

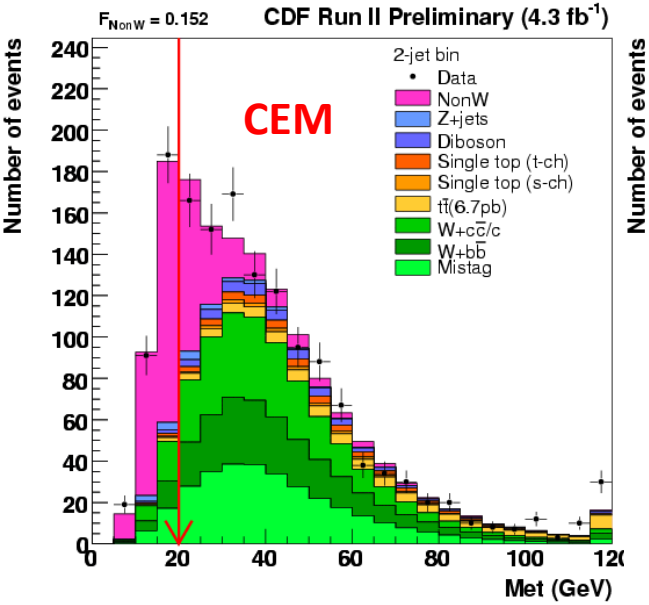
IsoTrk

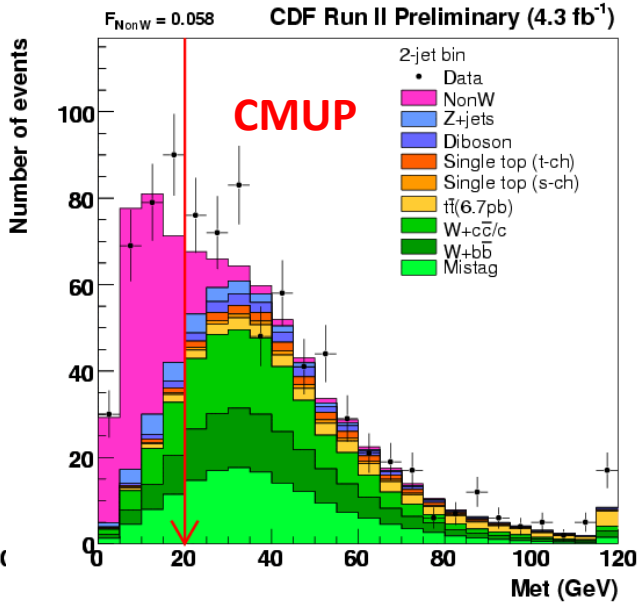
b-tagging category	IsoTrk Reco	Trigger	ISR/FSR/PDF	JES	b-tagging	Total
1-ST	8.85%	2%	8.4%	4.7%	4.3%	13.9%
ST+ST	8.85%	2%	7.1%	1.7%	8.6%	14.5%
ST+JP	8.85%	2%	6.4%	2.4%	8.1%	14.0%
ST+NN	8.85%	2%	19.5%	1.9%	13.6%	25.5%

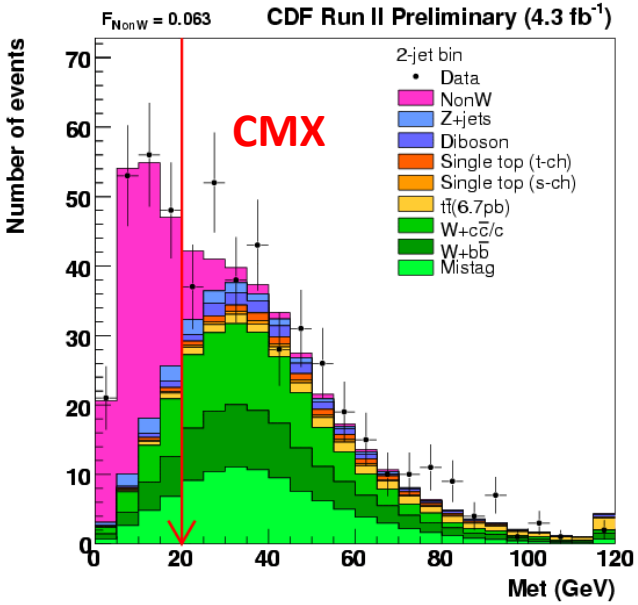
Pretag non-W and W+jets Estimation

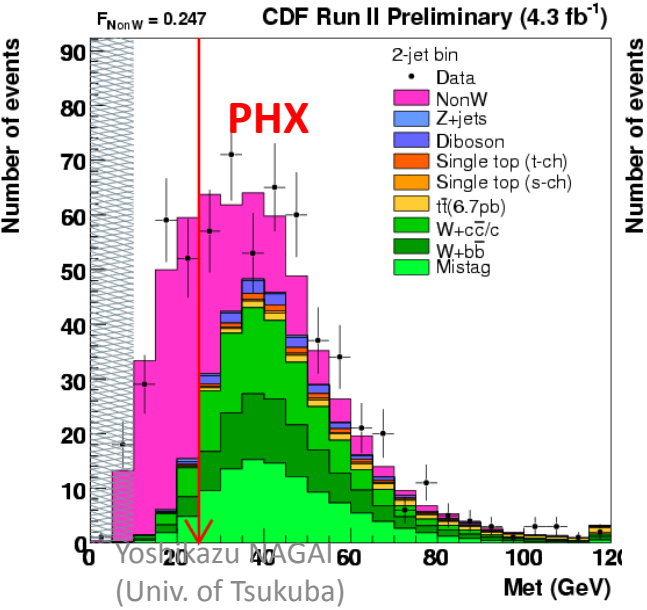


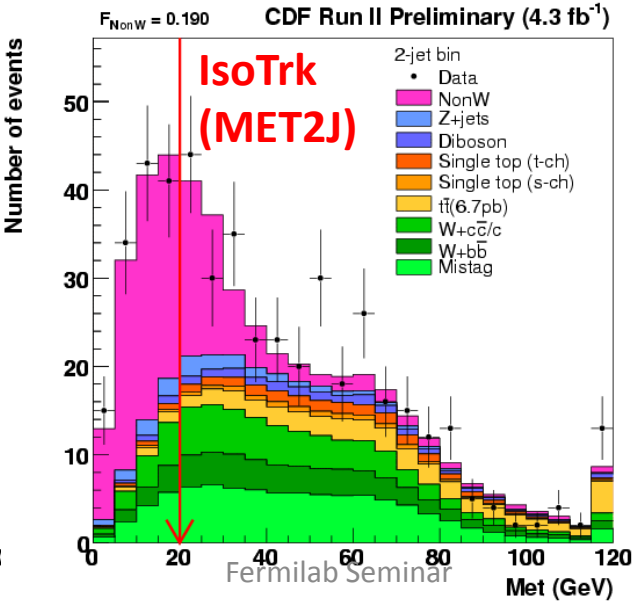
Non-W fit (1-ST)

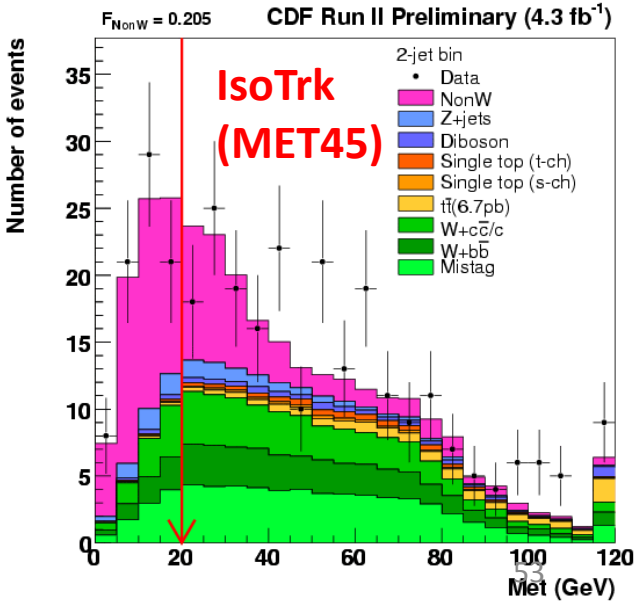

F_{NonW} = 0.152
CDF Run II Preliminary (4.3 fb^{-1})
CEM
2-jet bin
Data
NonW
Z+jets
Diboson
Single top (t-ch)
Single top (s-ch)
$t\bar{t}$(6.7pb)
W+$c\bar{c}$/c
W+$b\bar{b}$
Mistag
Number of events
Met (GeV)


F_{NonW} = 0.058
CDF Run II Preliminary (4.3 fb^{-1})
CMUP
2-jet bin
Data
NonW
Z+jets
Diboson
Single top (t-ch)
Single top (s-ch)
$t\bar{t}$(6.7pb)
W+$c\bar{c}$/c
W+$b\bar{b}$
Mistag
Number of events
Met (GeV)

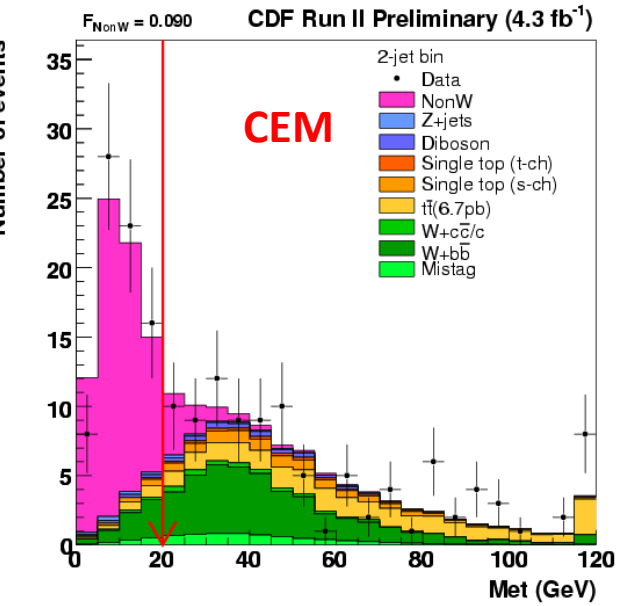

F_{NonW} = 0.063
CDF Run II Preliminary (4.3 fb^{-1})
CMX
2-jet bin
Data
NonW
Z+jets
Diboson
Single top (t-ch)
Single top (s-ch)
$t\bar{t}$(6.7pb)
W+$c\bar{c}$/c
W+$b\bar{b}$
Mistag
Number of events
Met (GeV)

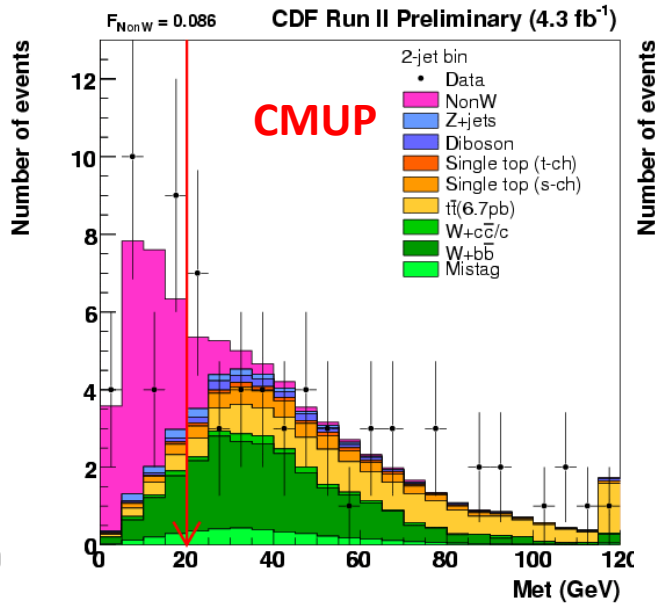

F_{NonW} = 0.247
CDF Run II Preliminary (4.3 fb^{-1})
PHX
2-jet bin
Data
NonW
Z+jets
Diboson
Single top (t-ch)
Single top (s-ch)
$t\bar{t}$(6.7pb)
W+$c\bar{c}$/c
W+$b\bar{b}$
Mistag
Number of events
Met (GeV)

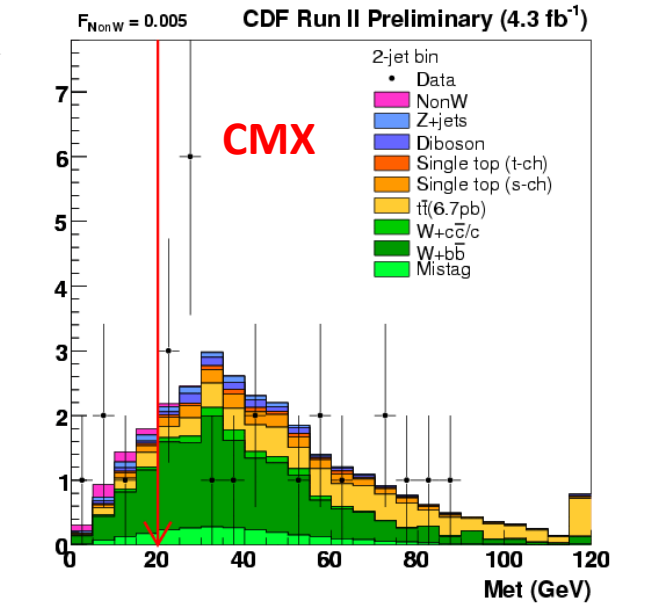

F_{NonW} = 0.190
CDF Run II Preliminary (4.3 fb^{-1})
IsoTrk
(MET2J)
2-jet bin
Data
NonW
Z+jets
Diboson
Single top (t-ch)
Single top (s-ch)
$t\bar{t}$(6.7pb)
W+$c\bar{c}$/c
W+$b\bar{b}$
Mistag
Number of events
Met (GeV)

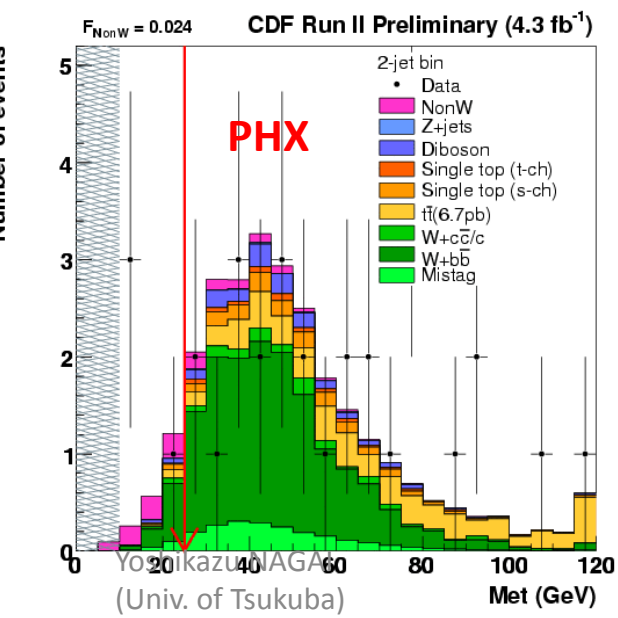

F_{NonW} = 0.205
CDF Run II Preliminary (4.3 fb^{-1})
IsoTrk
(MET45)
2-jet bin
Data
NonW
Z+jets
Diboson
Single top (t-ch)
Single top (s-ch)
$t\bar{t}$(6.7pb)
W+$c\bar{c}$/c
W+$b\bar{b}$
Mistag
Number of events
Met (GeV)

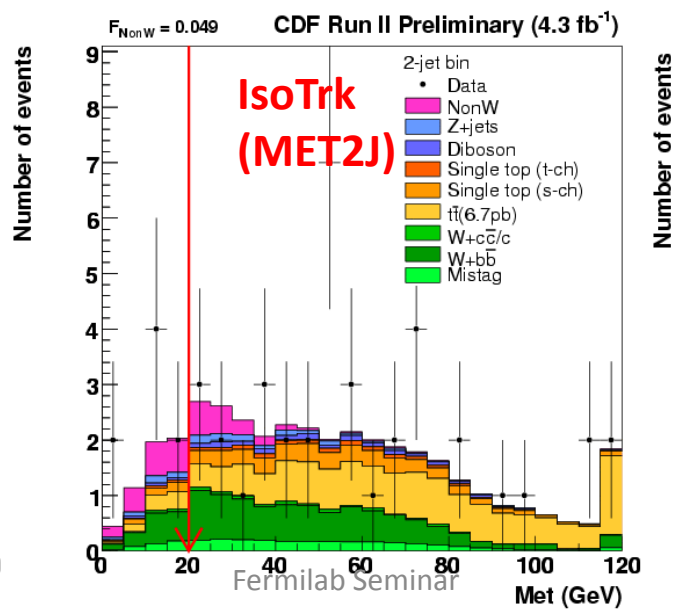
Non-W fit (STST)

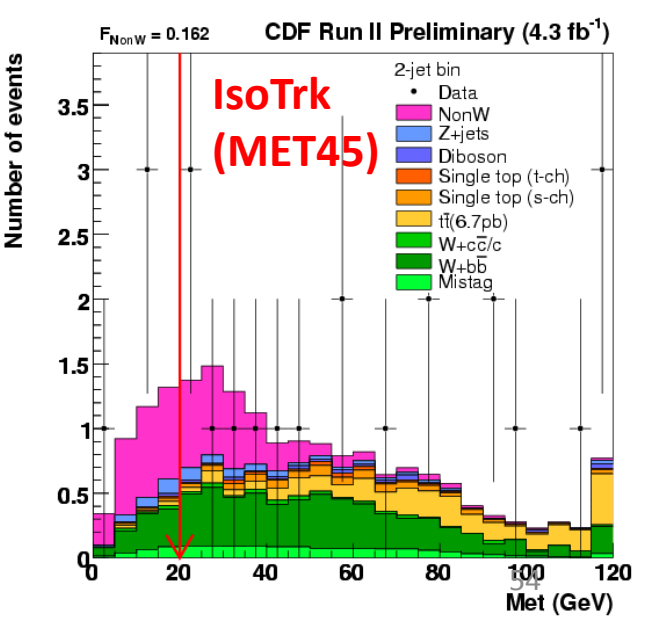


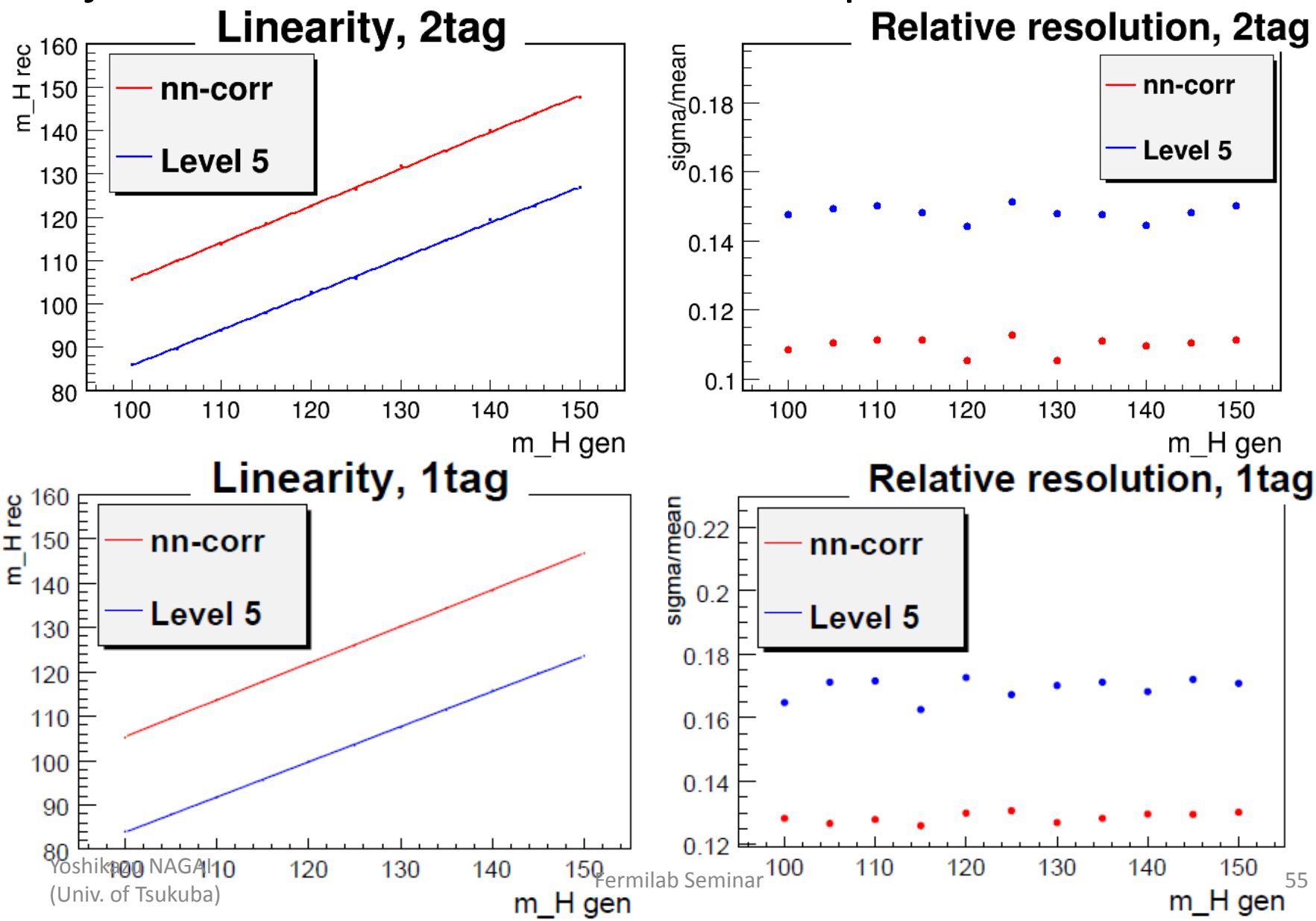










b-jet energy correction

- Di-jet invariant mass resolution is improved **~4%**