WH→lνbb using DLM and Discriminant Analysis at CDF

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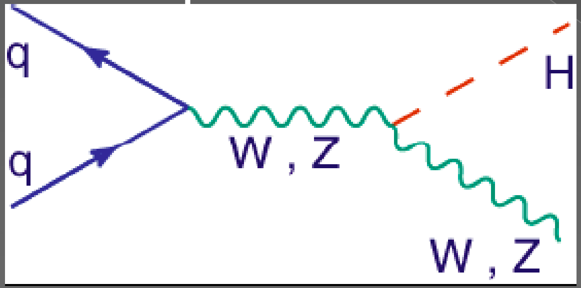
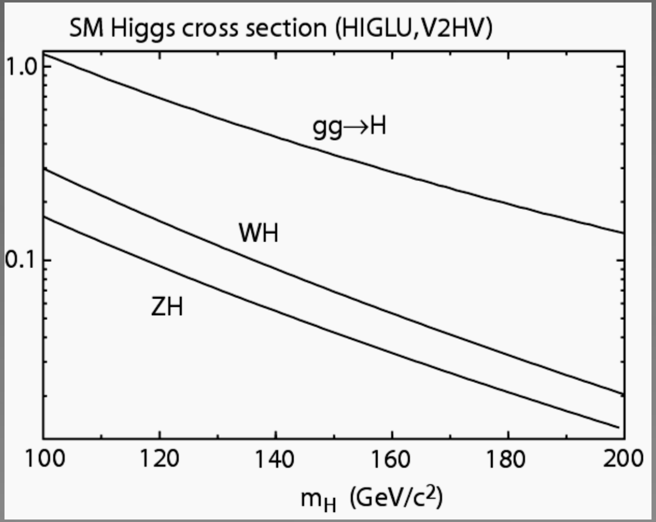
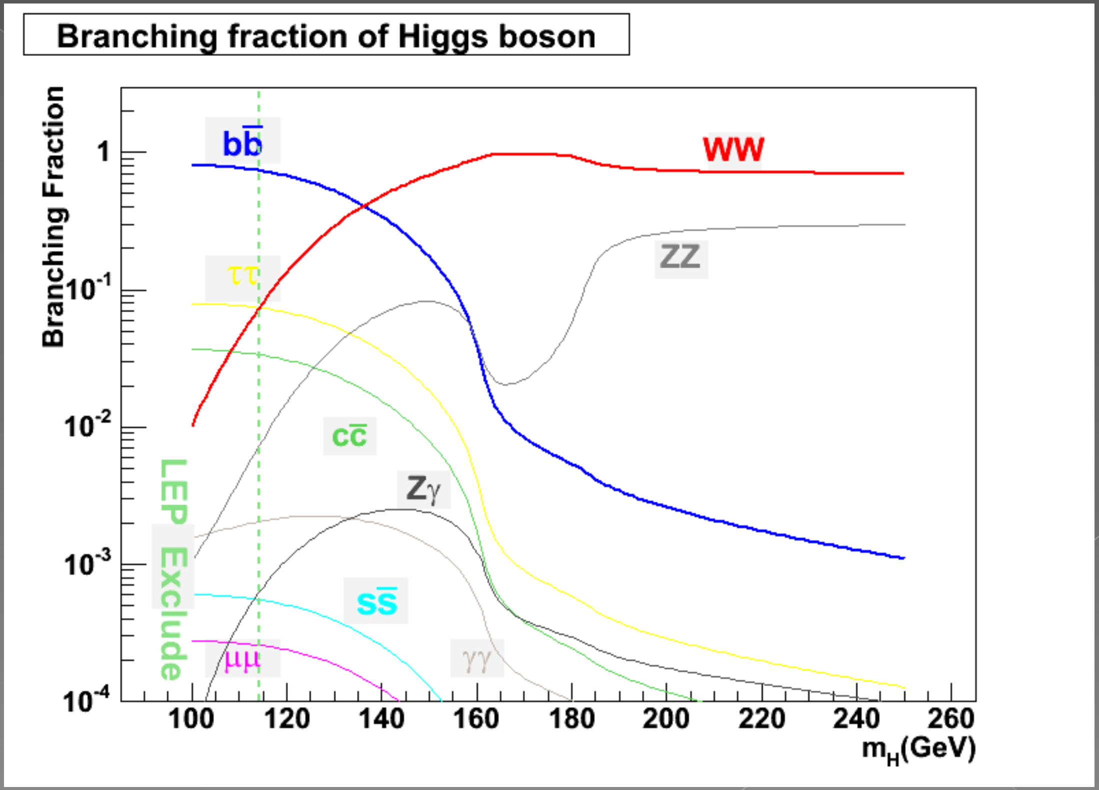
Introduction

- Higgs associate W→WH→lνbb process is a strong channel at Tevatron
  - It is a golden channel for low mass(m_H<135GeV) because Higgs dominantly decays into b quark pair(b-tagging is >50% efficient)
  - By requiring one lepton, large QCD background can be suppressed
  - The process is distinct from other backgrounds



Higgs associated





WH analysis and DLM

- At CDF, previous techniques used to search for WH process:
  - Neural Network
  - Matrix Element
- Main challenge: develop a technique to separate signal from backgrounds
  - We developed a new technique for extracting signal information
  - Establish Dynamical Likelihood Method(DLM)
  - We calculate a discriminant based on DLM to evaluate upper limit on cross section for WH
- DLM was used for top analysis so far
  - Top mass measurement
  - ttbar resonance search

Event selection and data

- Event selection is based on the standard criteria of WH analysis at CDF
  - Use the events with central lepton or plug electron
    good quality Isolated track
  - Selection cuts: **2jets + 1 lepton + large MET**
    - Jet: 2jets with Et>20GeV and $|\eta_{det}|<2.0$
    - Lepton: Et>20 GeV and require tight lepton selection
      or Isolated track Selection
    - Missing Et>20GeV (for central, Isolated Track), 25 GeV (for plug)
  - b-tag to reject large background events
    - 3 b-tag categories: Double tag(2 categories) and Single tag
- Data and Monte Carlo
  - Data: evaluate expected sensitivity for 7.5 fb^{-1}
  - MC: Pythia or MadGraph+Pythia (for EWK)
    Alpgen+Pythia (for W+jets)

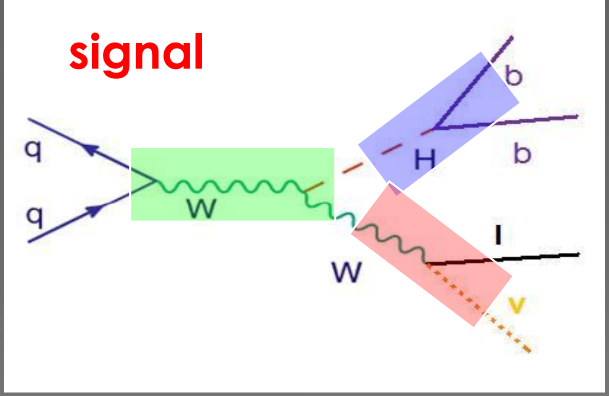
Dynamical Likelihood Method

- We use DLM method to separate signal and Backgrounds
- DLM is a method to extract signal events from data by evaluating matrix elements as likelihood function.
  - DLM is applicable to processes for which matrix elements can be calculated theoretically : WH, Single top, Wbb
- Formulation:

Likelihood function of DLM:

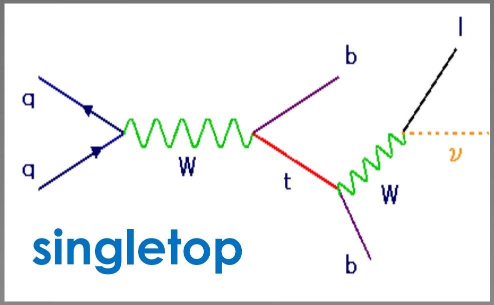
$$L_{path}(\alpha, x \mid y) = N \frac{d\sigma}{d\Phi} w(x \mid y)$$

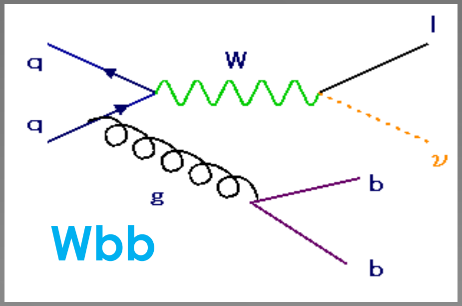
$$\bar{L} = \frac{1}{n_{path}} \sum_{k}^{n_{path}} L_{path}^{(k)}(\alpha, x \mid y)$$



w(x|y): transfer function
⇒ a probability density function for x (parton momenta) when y (observed quantities) is given.

Relationship between parton level and detector measurement

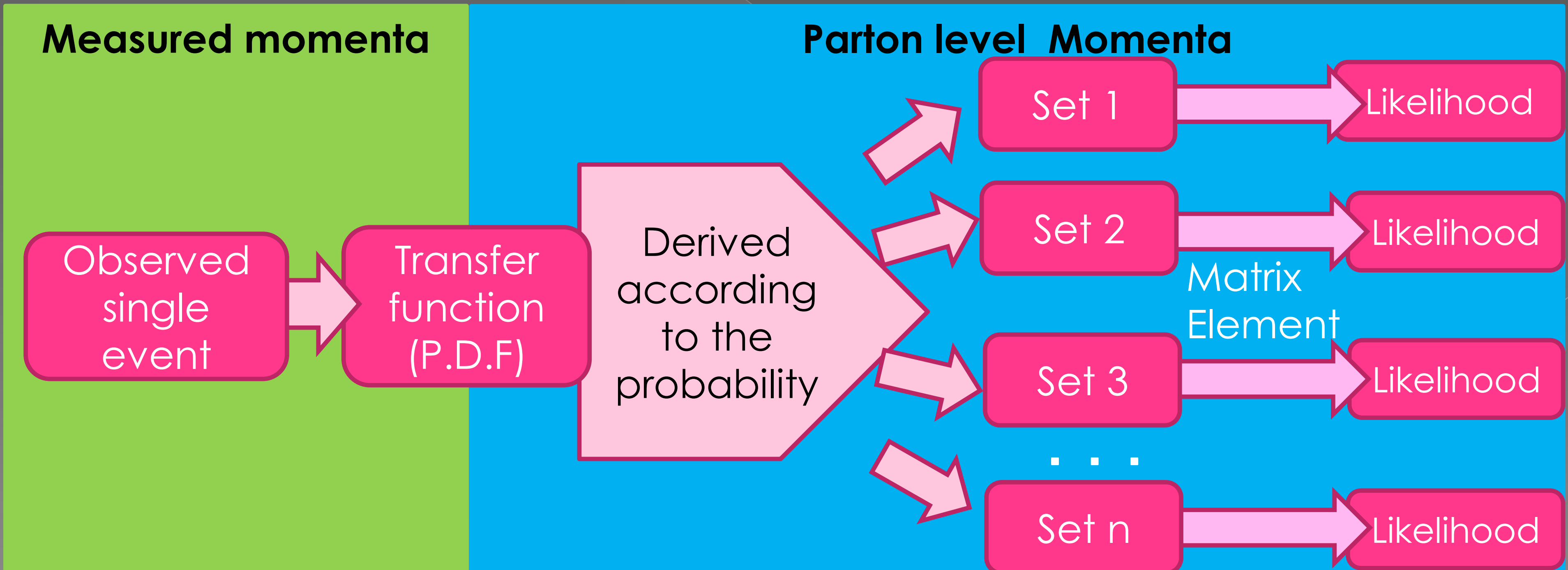




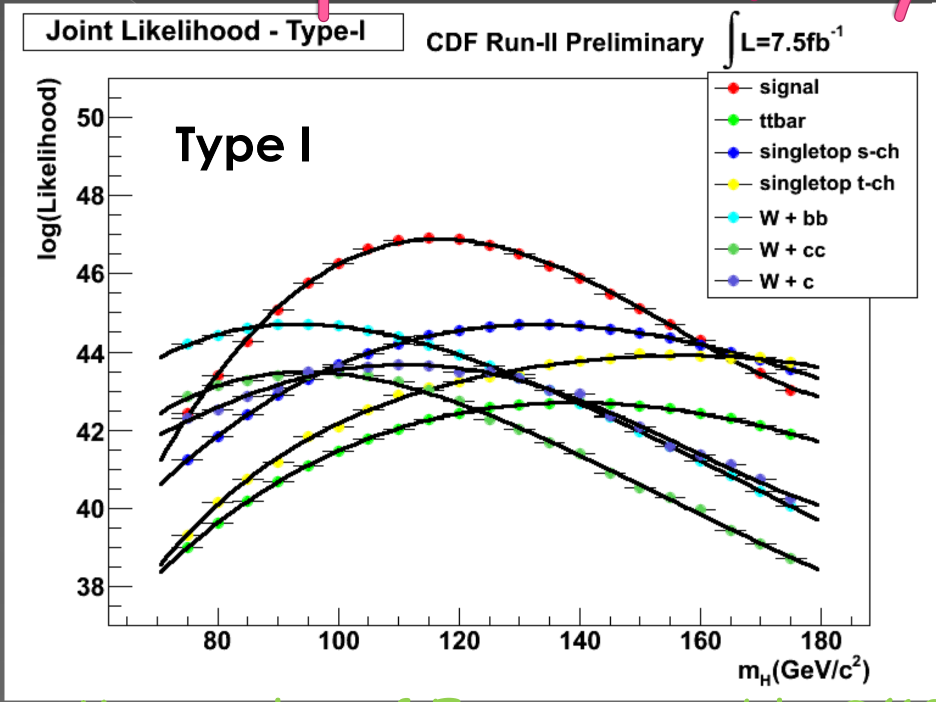
Summary of DLM

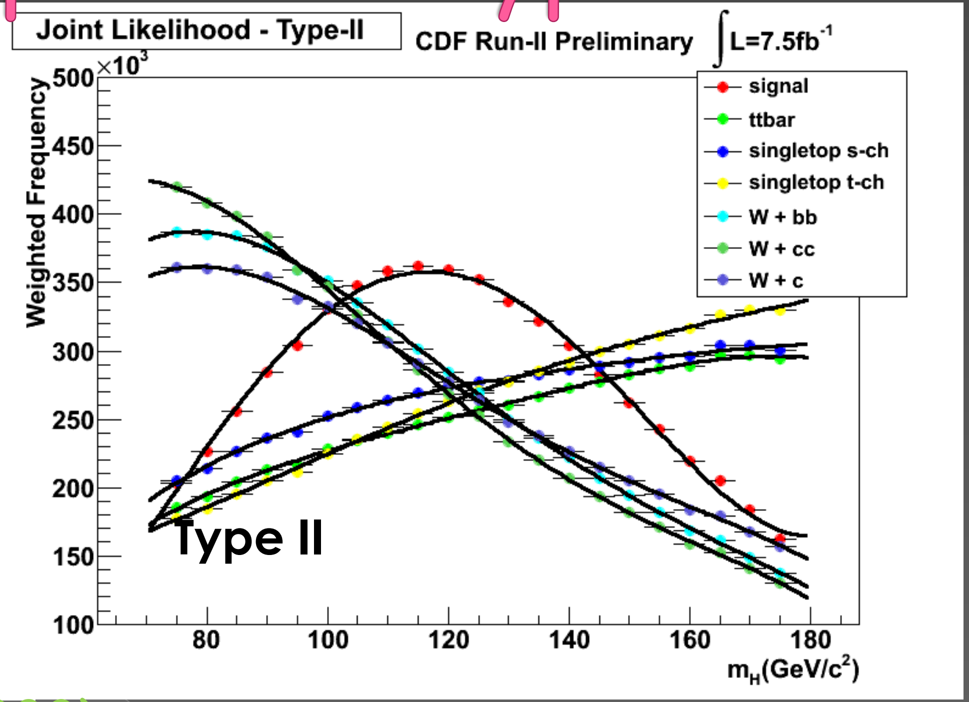
Basic idea of DLM

- Given the single event, Parton level Momenta set can be obtained randomly according to the probability of Transfer Functions(P.D.F)
- We can calculate Matrix Element using parton level momenta set.
- We can treat statistically by accumulating the results of many parton level momenta sets
- Likelihood of each momenta set is given by $L_{path}(\alpha, x \mid y) = N \frac{d\sigma}{d\Phi} w(x \mid y)$



Comparison of Type I and Type II





Mean value of Event ensemble O(1000)

$$L_{joint} = \frac{1}{n_{event}} \sum_{i}^{n_{event}} \overline{L_{eve}} \quad @each\ Higgs\ mass$$

For the better discrimination of signal and backgrounds,

- Shape information should be obtained from Type II
  - Because the signal shape is quite different from backgrounds
- Absolute value information should be obtained from Type I
  - Basically, signal likelihood is higher than backgrounds at whole Higgs mass range

seem good

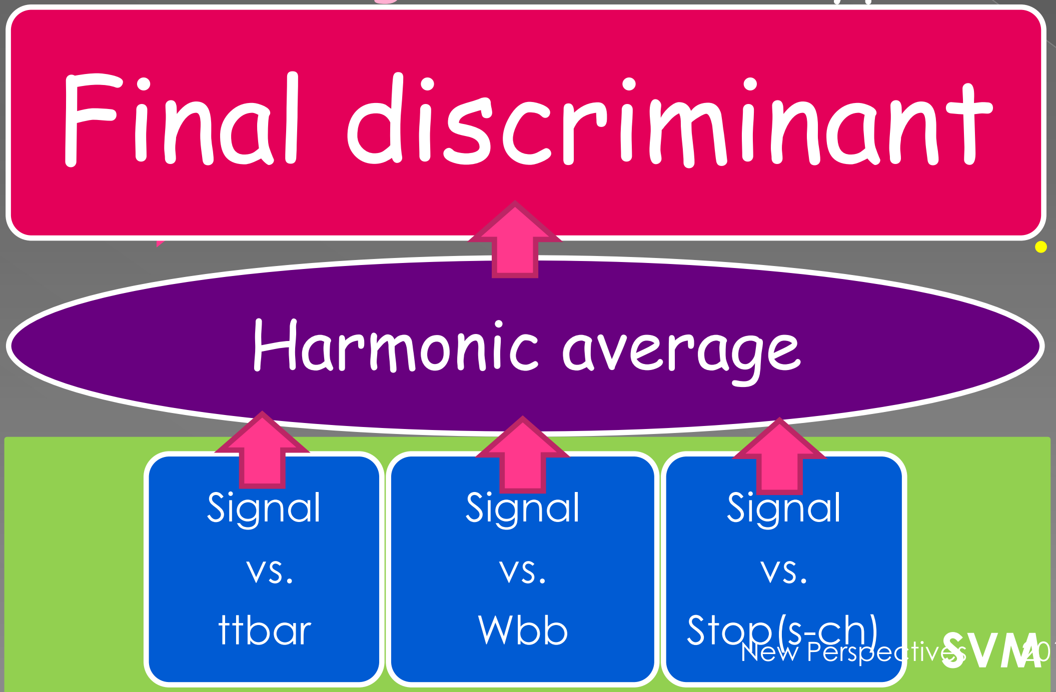
Input variable candidates for MVA

- Extract the signal feature with 2 points
  - Higgs mass dependence shape
    - Evaluate Localized Moment – use up to 6th order

      $\int (m_H - m_{H0})^n \cdot f_{event}(m_H) dm_H$ nth-order moment
      - As m_{H0}, expected mass of signal from DLM is used
  - Absolute value of likelihood
    - Several kinds of likelihood can be obtained from DLM result with signal Matrix Element
      - Maximum likelihood on Higgs mass dependence
      - Likelihood@ DLM expected Higgs mass
      - Higgs part likelihood @ maximum likelihood of overall Matrix Element
      - W part liielihood @ maximum likelihood of overall Matrix element
    - Likelihoods as a result of DLM with Wbb & singletop(s-ch) Matrix Element
      - All the parameters(mass, width, etc) in the Matrix Element are set

Forming discriminant

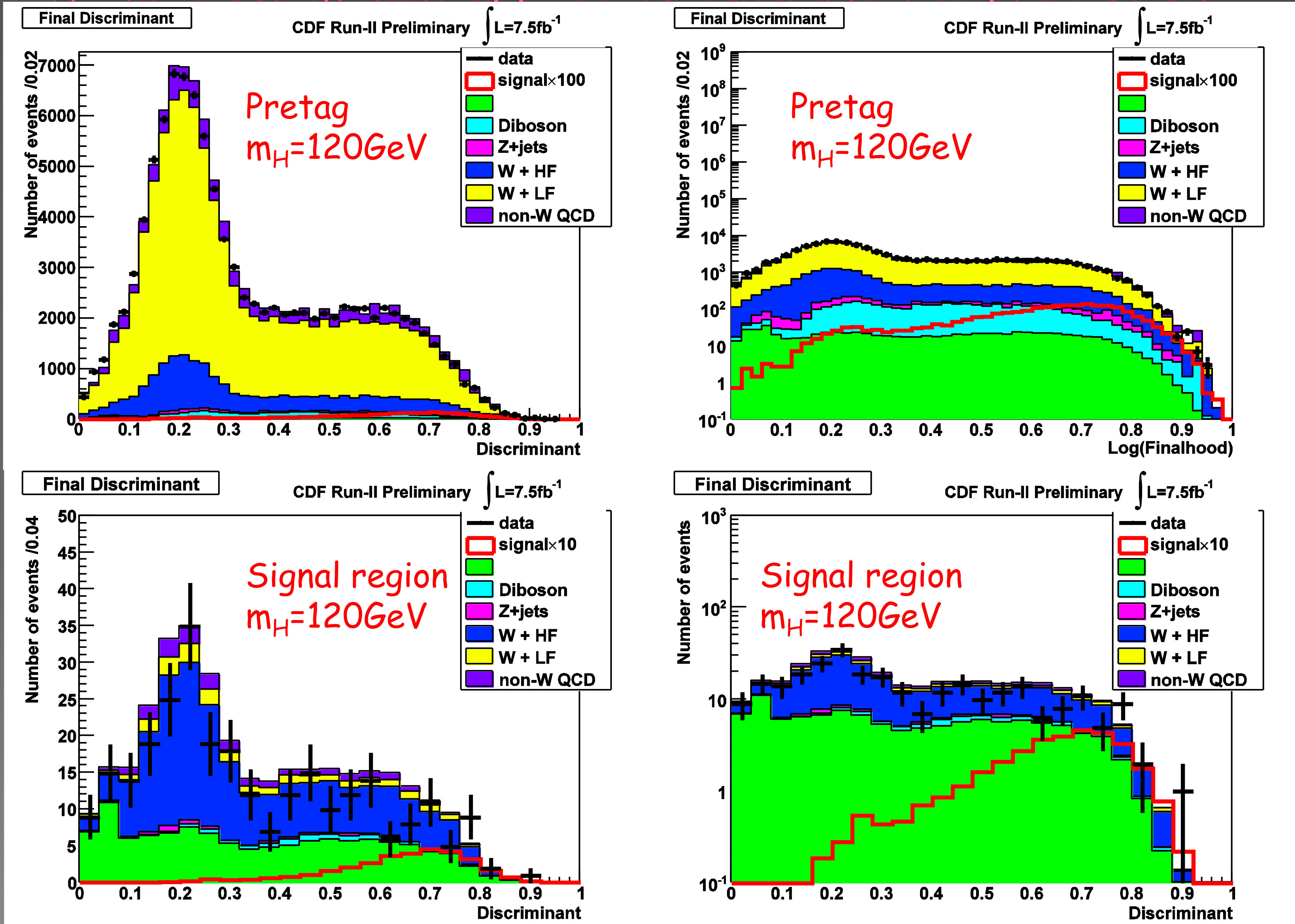
- **Using Support Vector Machine to separate signal from background**
  - 3-type discriminants are made using SVM
    - Signal vs. ttbar (d_{ttbar})
    - Signal vs. Wbb (d_{Wbb})
    - Signal vs. singletop(s-ch) (d_{stop})
  - Final discriminant is obtained by calculating harmonic average of those 3-type discriminants:



$$d_{final} = \frac{3}{\frac{1}{d_{ttbar}} + \frac{1}{d_{Wbb}} + \frac{1}{d_{stop}}}$$

- Signal event requires high scores of these 3-type discriminant
  - Harmonic average can impose strict condition
  - Harmonic average obtains maximum S/N

Final discriminant applied to data and the prediction



Systematics summary on signal

Source	Error (%)		
	STST	STJP	ST
JES	2.4	2.2	2.9
ISR/FSR	6.0	4.0	3.1
PDF	1.5	1.4	1.1
b-tagging	8.6	8.1	4.3
Luminosity	6	6	6
Lepton ID SF	2	2	2
Trigger	~ 1	~ 1	~ 1

Table 1: Summary of systematic uncertainties on the acceptance in central lepton events

Source	Error (%)		
	STST	STJP	ST
JES	2.7	3.6	2.5
ISR/FSR	4.4	5.9	5.5
PDF	2.7	1.7	4.1
b-tagging	8.6	8.1	4.3
Luminosity	6	6	6
Lepton ID SF	2	2	2
Trigger	~ 1	~ 1	~ 1

Table 2: Summary of systematic uncertainties on the acceptance in forward-backward electron events

	STST	STJP	ST
JES	2.2	3.6	2.5
ISR/FSR	4.0	5.9	5.2
PDF	2.8	1.2	1.2
b-tagging	8.6	8.1	4.3
Luminosity	6	6	6
Track Reco.	8.85	8.85	8.85
Trigger	2	2	2

Table 3: Summary of systematic uncertainties on the acceptance in Isolated Track events

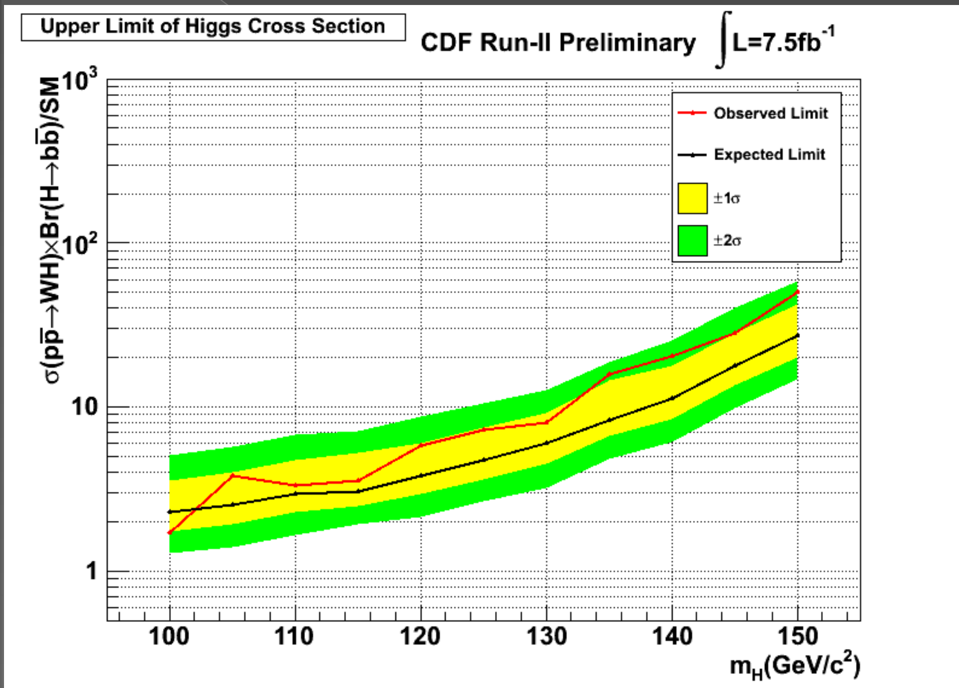
Systematics summary on backgrounds

Typical value

Source	Error (%)							
	$t\bar{t}$	singletop	$W+b\bar{b}$	$W+c\bar{c}$	Mistag	Diboson	Z+jets	nonW
JES	7	2	10	10		2	8	
ISR/FSR	5	3						
PDF	5	1				3	5	
HF fraction			38	38				
Mistag rate					20			
Z+jets cross section						7		
Fit								40
Luminosity	6	6				6	6	
Trigger(central & plug)	1	1				1	1	
Trigger(Isolated Track)	2	2				2	2	
Lepton ID (central & plug)	2	2				2	2	
Reconstruction (Isolated Track)	8.9	8.9				8.9	8.9	
b-tag(STST)	8.6	8.6	8.6	8.6		8.6	8.6	
b-tag(STJP)	8.1	8.1	8.1	8.1		8.1	8.1	
b-tag(ST)	4.3	4.3	4.3	4,3		4.3	4.3	

Table 4: Summary of systematic uncertainties on the backgrounds

The preliminary result of upper limit



@m_H=125GeV
Exp. 4.74 × SM Obs. 7.32 × SM

m_H(GeV)	Obs.	-2σ	-1σ	median	$+1\sigma$	$+2\sigma$
100	1.72	1.29	1.76	2.29	3.56	5.14
115	3.85	1.41	1.94	2.54	4.02	5.73
110	3.32	1.67	2.31	2.94	4.79	6.77
115	3.60	1.93	2.49	3.07	5.30	7.19
120	5.88	2.16	2.94	3.82	6.08	8.78
125	7.32	2.67	3.63	4.74	7.53	10.64
130	8.10	3.21	4.50	6.04	9.21	12.67
135	15.83	4.81	6.69	8.33	14.48	18.76
140	20.41	6.10	8.54	11.30	17.95	25.54
145	28.05	9.88	13.59	17.84	28.18	40.22
150	57.95	14.88	20.13	27.42	42.70	58.69

Table 1: The numbers of the upper limit of Higgs production cross section

Summary

- DLM is being established to analyze WH→lvbb process
  - Signal information can be extracted effectively
  - Performance check is OK for Higgs analysis
- Expected upper limit is calculated using Discriminant
  - Discriminant is obtained by Support Vector Machine and integrate into the final discriminant

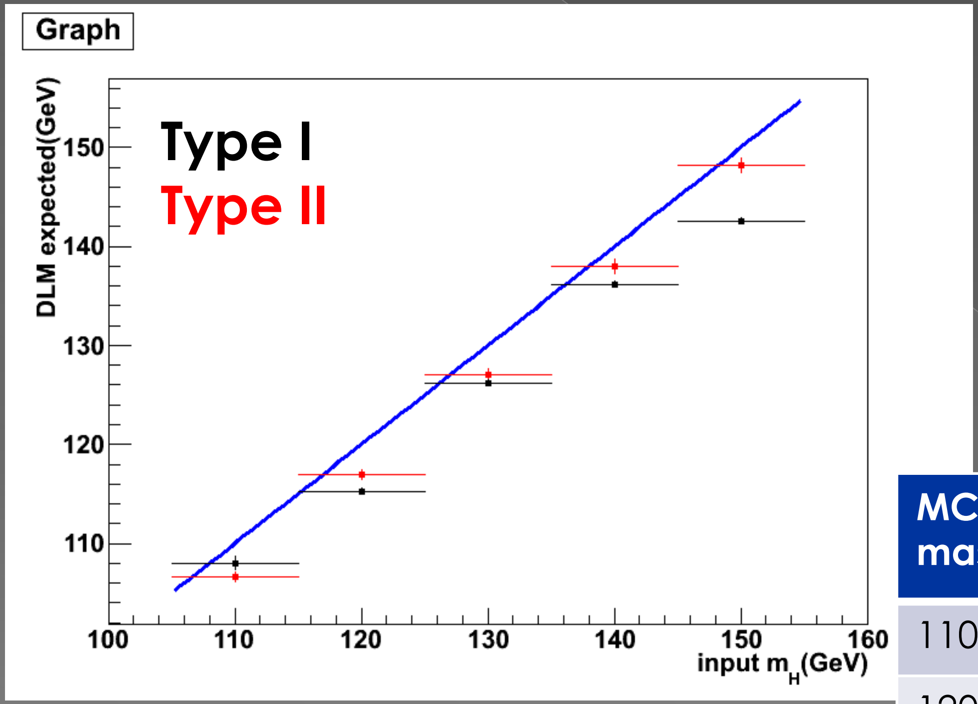
To do:

- Increase the acceptance
  - Use Full data set of CDF
  - Use additional lepton events – looser selected lepton events
  - Incorporate same b-tagging as standard analysis
    - Introducing new b-tagger
- Finally, validate background modeling, and calculate observed limit with systematics

Backups

Linearity check

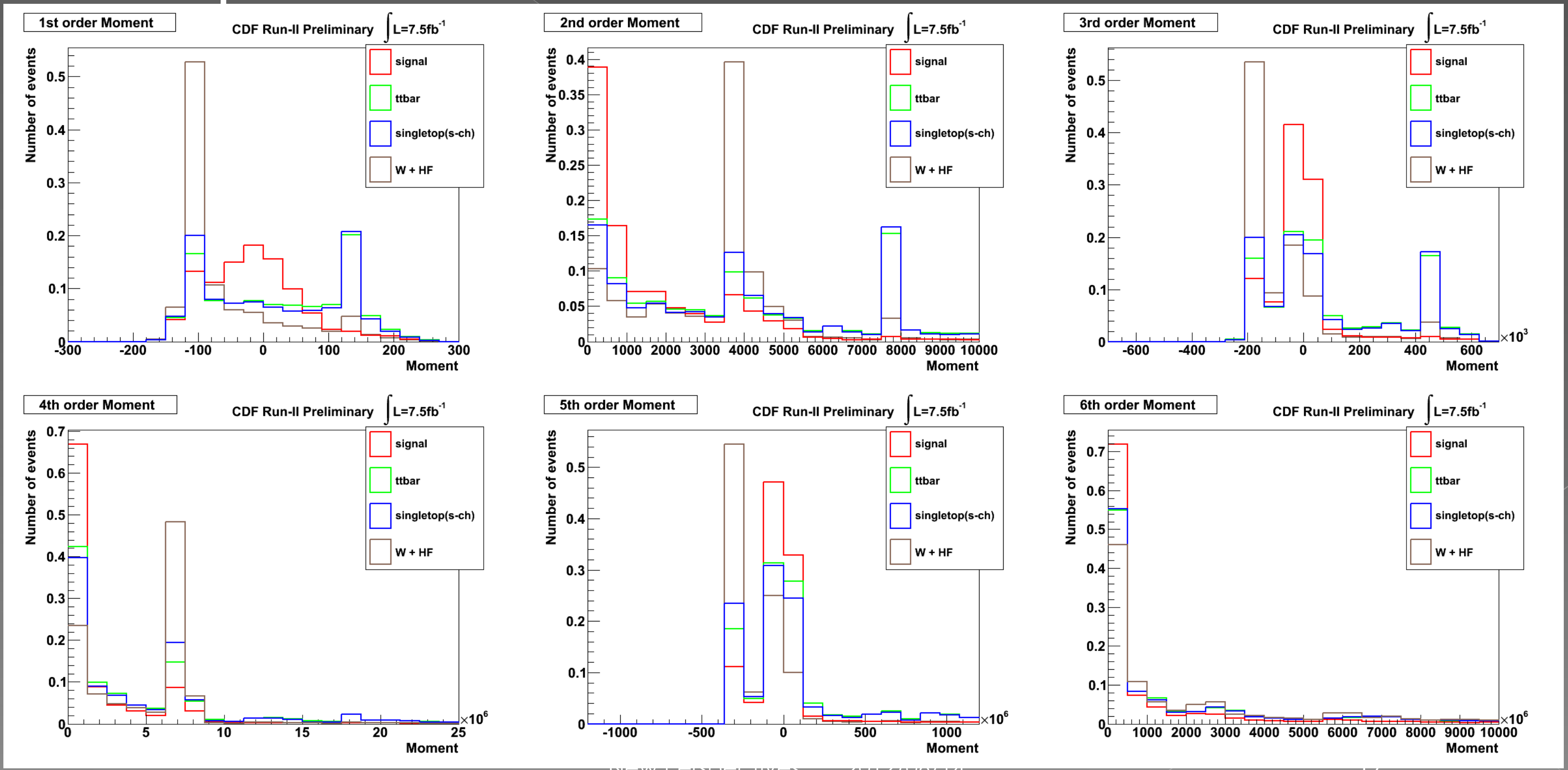
- DLM expected Higgs mass is defined as the maximum likelihood point of the mean of event ensemble
- Linearity is well reserved when using Type II



MC Higgs mass(GeV/c^2)	DLM expected Type I(GeV/c^2)	DLM expected Type II(GeV/c^2)
110	108.0±0.7	106.6±0.5
120	116.2±0.3	117.0±0.5
130	125.2±0.2	127.0±0.6
140	136.2±0.2	138.0±0.7
150	142.6±0.2	148.2±0.7

Localized moment around signal

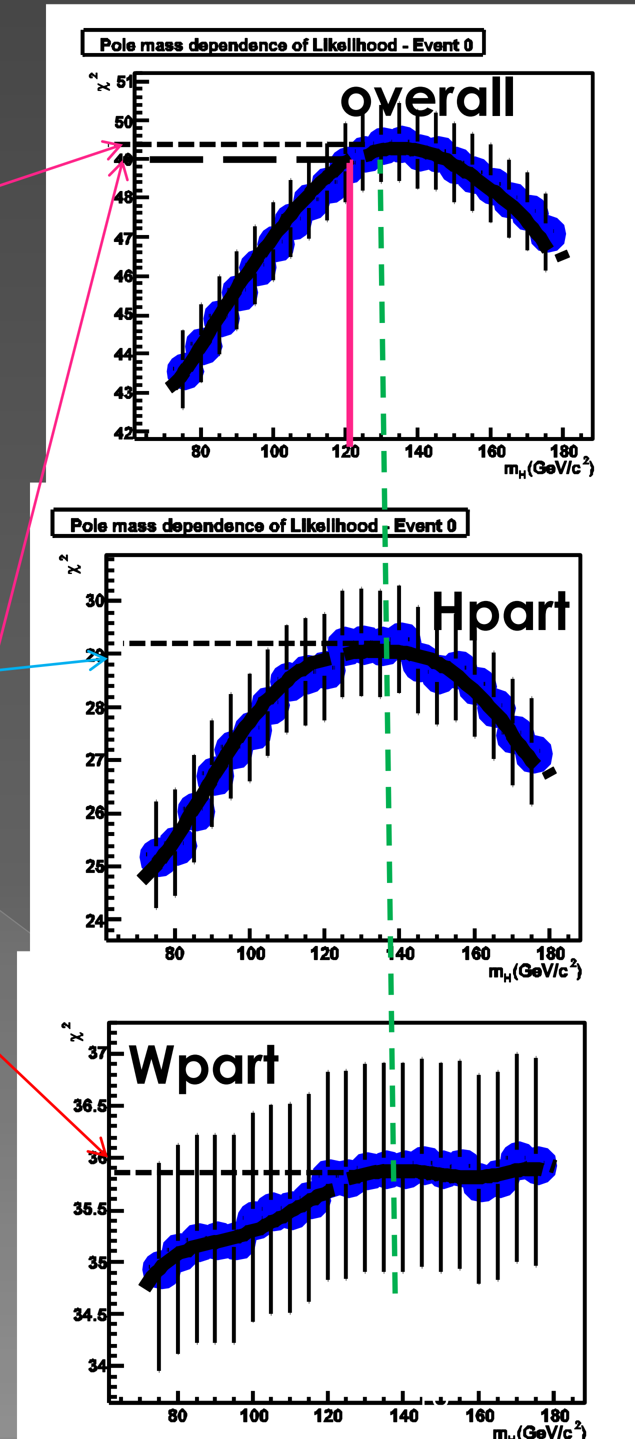
- Localized moment around signal expected mass for each process
  - $\int (m_H - m_{H0})^n \cdot f_{event}(m_H) dm_H$ nth-order moment
  - Up to 6th order



Likelihood used

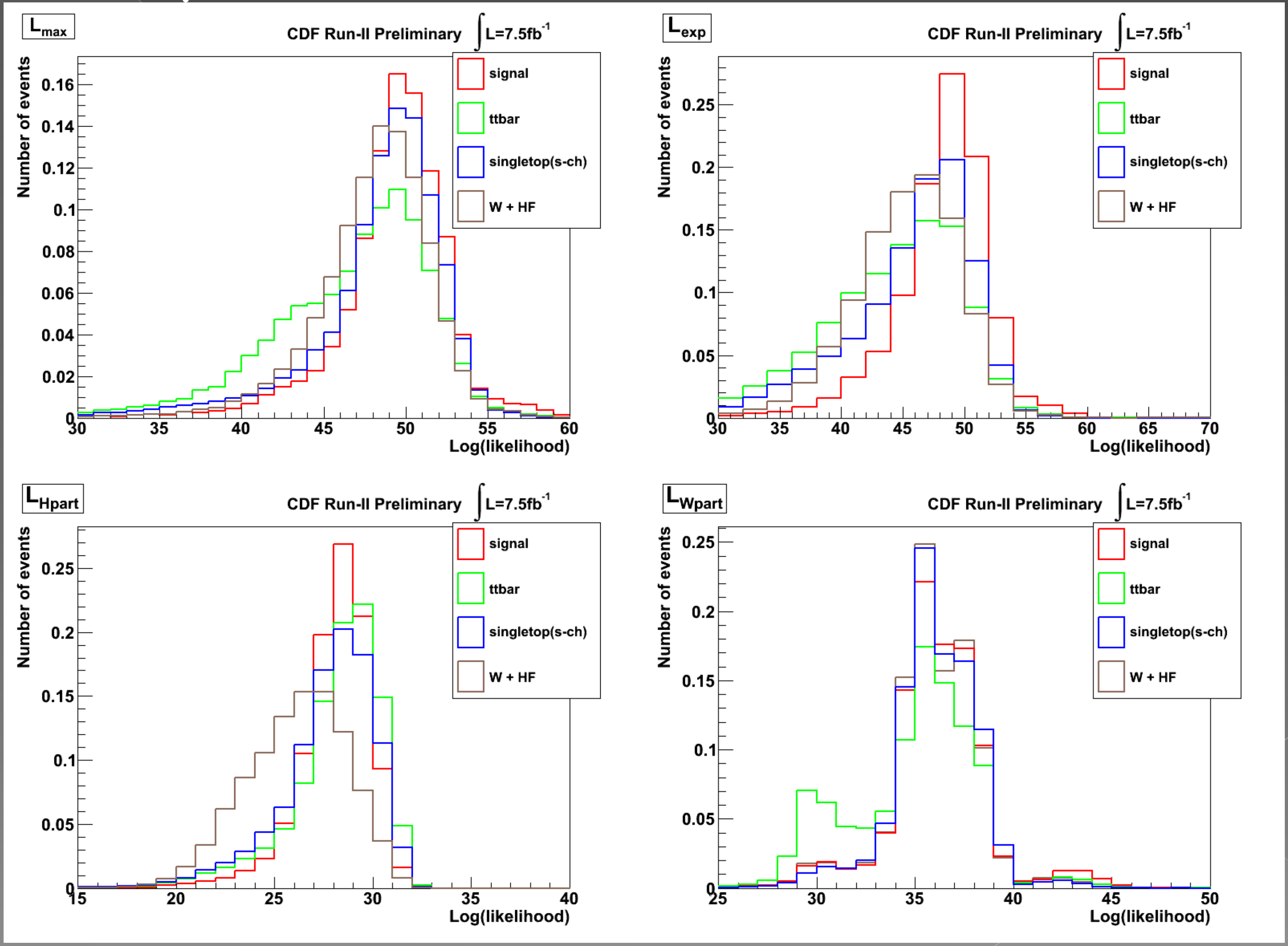
- Maximum likelihood: L_{max}
  - Use them event-by-event
- Expectation value of likelihood
  - Wbb : L_{Wbb}
  - singletop(s-ch): L_{stop}
- Higgs part likelihood : L_{Hpart} @maximum likelihood in overall
  - vertex of Higgs decay & T.F.
- W part likelihood: L_{Wpart} @maximum likelihood in overall
  - vertex of W decay & T.F.
- Likelihood @ DLM expected mass: L_{exp}
  - Expected mass means the result of event ensemble

(e.g. 117.01GeV@mH=120GeV)

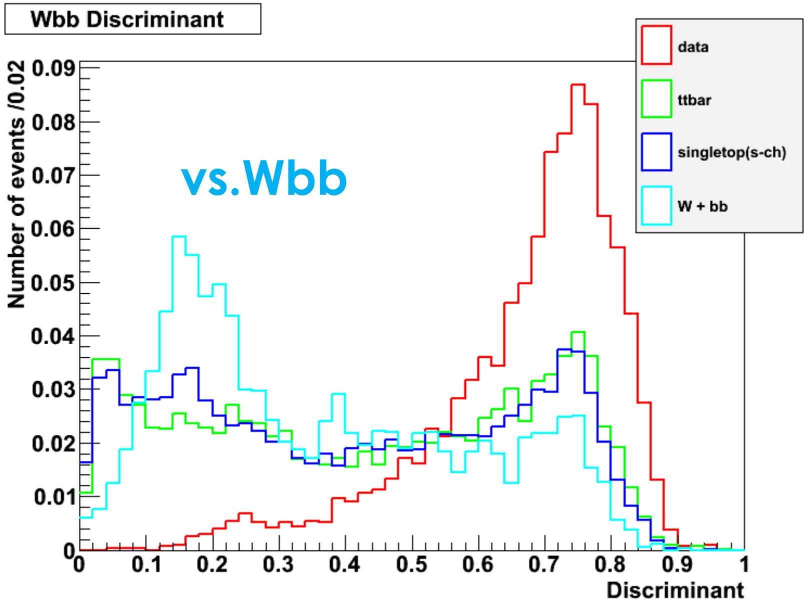


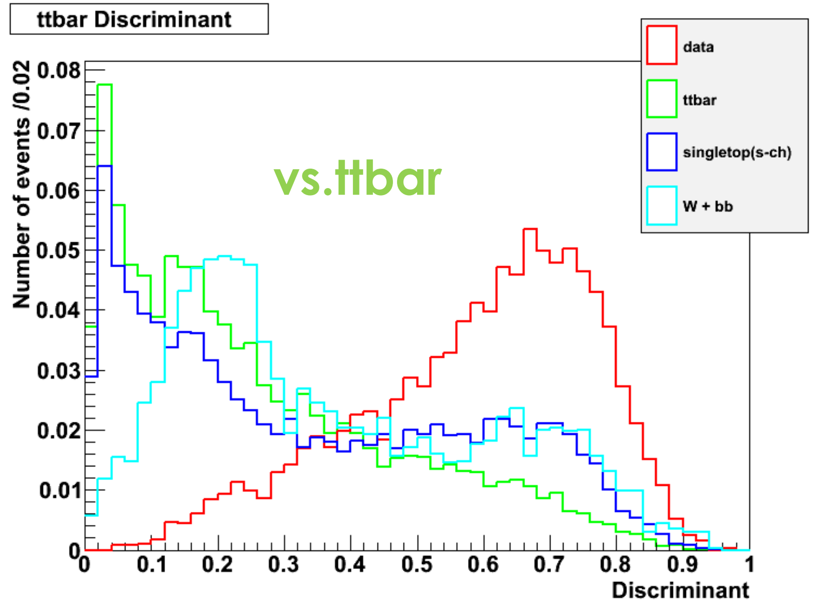
Likelihood – from signal M.E

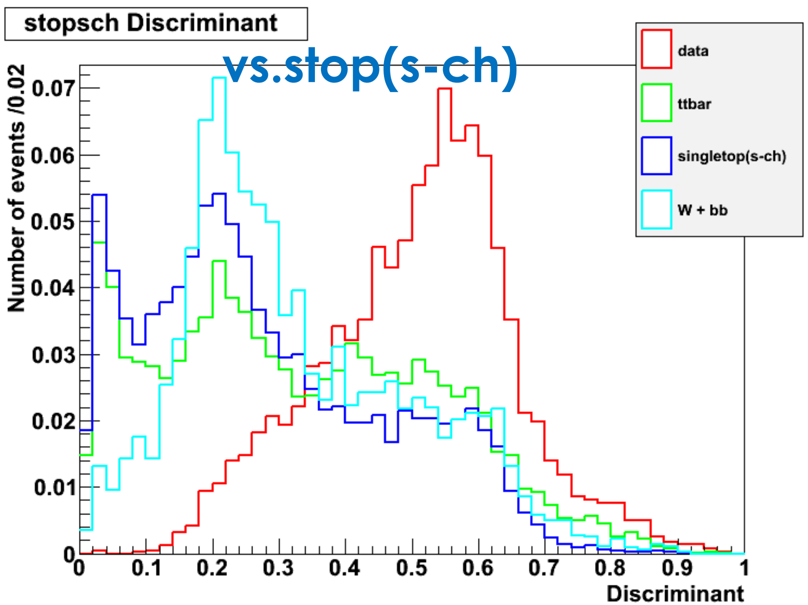
- Comparison of the distribution



SVM output example







Output result after training
2secvtx tag case

Signal
ttbar
Stop(s-ch)
Wbb

Final discriminant

- Final discriminant after calculating harmonic average
  - $d_{final} = \frac{3}{\frac{1}{d_{ttbar}} + \frac{1}{d_{Wbb}} + \frac{1}{d_{stop}}}$
  - m_H=120GeV
  - 2secvtx tag