Search for Technicolor Particles in association with $W^{\pm}$ boson at CDF

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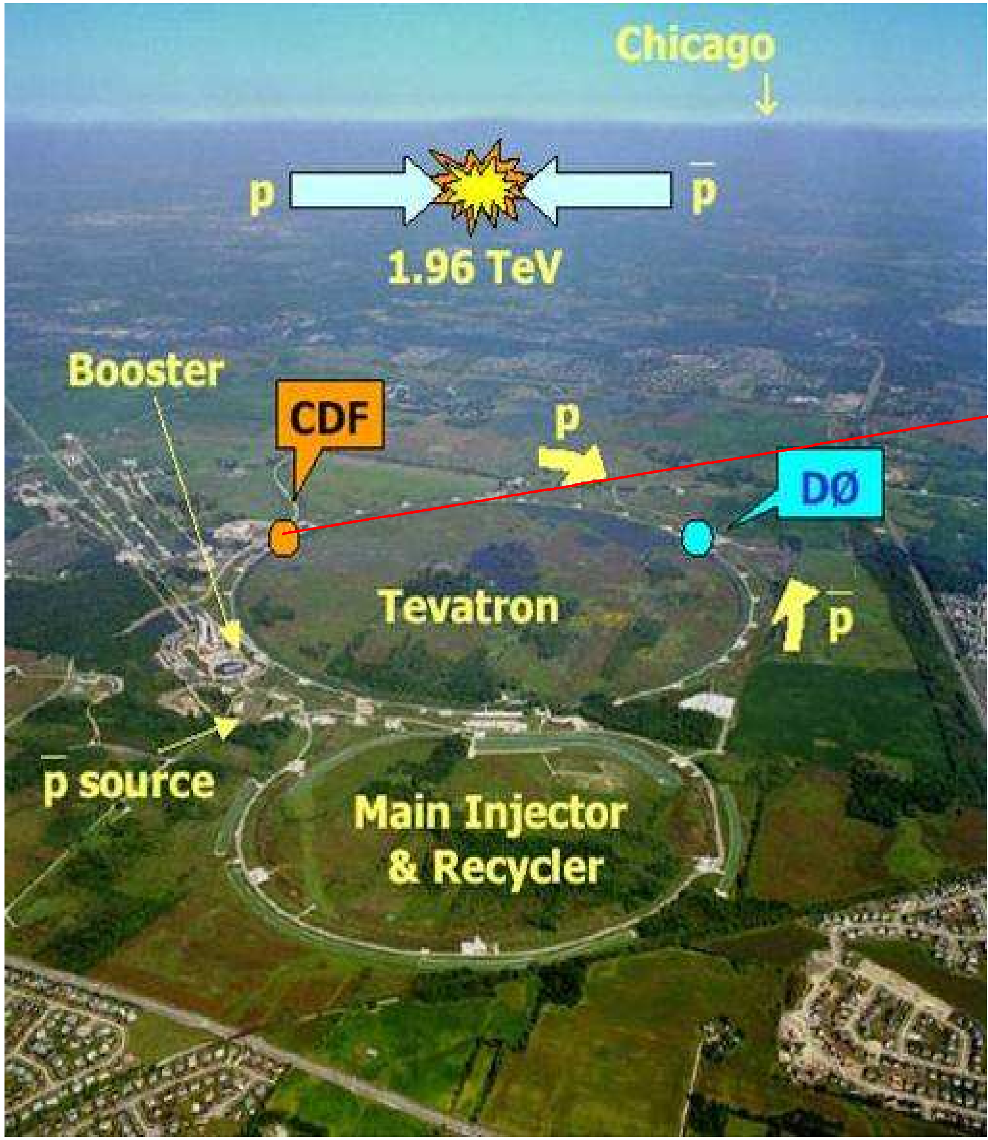
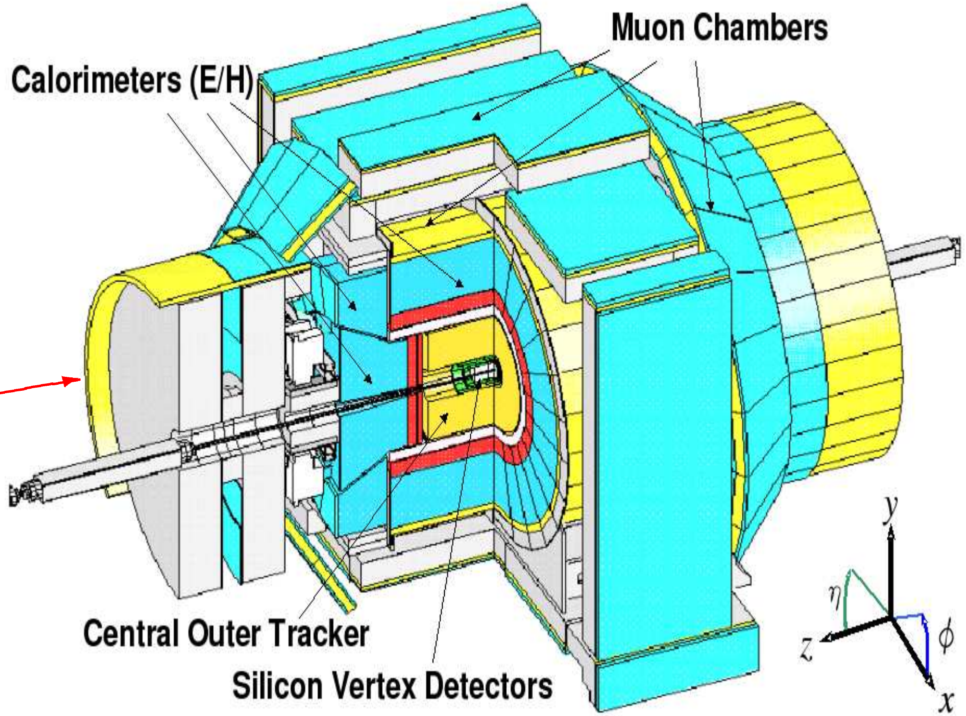
Outline

- Introduction
- Event Selection
- Background Estimation
- Technicolor Acceptance
- Results of Technicolor search
- Conclusion and Plan

Introduction(Tevatron and CDF detector)



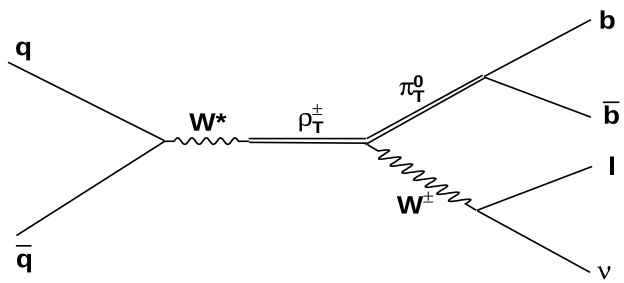


- Currently $\sim$ 2 fb^{-1} delivered, $\sim$ 1.6 fb^{-1} recorded to tape
- Expect to collect $\sim$ 9 fb^{-1} by 2009
- This analysis use $\sim$ 1 fb^{-1} data collected up to February 2006

Introduction and Motivation(Technicolor)

Theoretical motivation

- **Technicolor theory provides electroweak symmetry breaking by predicting a new strong gauge theory and new fermions (techniquarks)**
  $\Rightarrow$ Technipion (fermion-pair) plays a role in Higgs boson.
  - **e.g. Technicolor-Straw Man model for low-scale Technicolor (hep-ph/0605119)**
- **The most likely processes and search modes**
  - $\rho_T^{\pm} \rightarrow W^{\pm}\pi_T^0 \rightarrow l^{\pm}\nu + b\bar{b}$, $\quad \rho_T^0 \rightarrow W^{\pm}\pi_T^{\pm} \rightarrow l^{\pm}\nu + b\bar{c}, b\bar{u}$
  - $\omega_T^0, \rho_T^0 \rightarrow \gamma\pi_T^0, \gamma\pi_T^{0\prime} \rightarrow \gamma b\bar{b}$, $\quad \omega_T^0, \rho_T^0 \rightarrow e^+e^-, \mu^+\mu^-$



Technicolor Cross section

- **Search region : $\rho_T^{\pm}$ 180-210 GeV, π_T^0 95-125 GeV**
- $\sigma(\rho_T^{\pm} \rightarrow W\pi_T^0) \times BR(\pi_T^0 \rightarrow b\bar{b})$ **: about 1~3 pb**

Previous analysis at CDF

- **First RunII results uses 160 pb^{-1} $\rightarrow$ Set the cross section limit**
- **Use about six times data!!**

Event Selection

- **Event Selection**
  - High p_T central isolated electron or muon($p_T > 20$ GeV)
  - Large missing E_T ($\not\!\!E_T >$ 25(20) GeV for one b-tag events(two b-tag events))
  - Exact two high E_T jets ($E_T >$ 15 GeV with $|\eta| < 2.0$)
  - At least one jet to be identified as b-jet using silicon detector (b-tag)
  - Additionally apply b-tagging with Neural Network (NN tag) for exact one b-tagged events. (See Yoshiaki's talk at Higgs Session on Oct 31)
- **Analysis Strategy**
  - Estimate both exact one b-tag (w/ NN tag) events and two b-tag events separately
  - Finally, one tag and two tag events are combined in calculating limit

Background Estimation

- **Background Components**
  - **W+Light Flavors (mis-tagged event)**
  - **QCD fake events (Non-W events)**

  $\Leftarrow$ **Data based background**

  - **W+Heavy Flavors ($Wb\bar{b}, Wc\bar{c}, Wc$)**
  - **Z+Heavy Flavors ($Zb\bar{b}, Zc\bar{c}, Zc$)**

  $\Leftarrow$ **Data and MC based background**

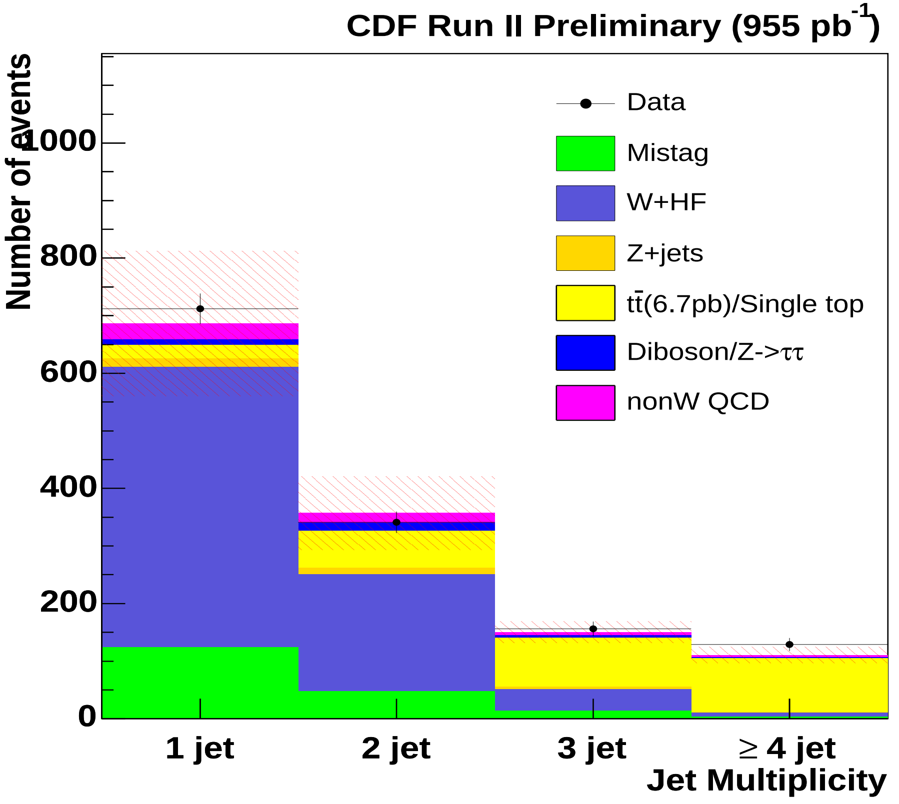
  - **Top events ($t\bar{t}$ and single top)**
  - **Diboson ($W^+W^-, W^\pm Z^0, Z^0Z^0$) and $Z^0 \rightarrow \tau\tau$**

  $\Leftarrow$ **MC based background**

Background Summary

- Exact one b-tagged events on W+2jet

Njet	2 jet
Before b-tagging Events	13246
Mistag	47.7± 9.6
$Wb\bar{b}$	132.3± 44.8
$Wc\bar{c}$	39.3± 13.5
Wc	31.4± 8.3
Z+jets	10.8 ± 4.3
$t\bar{t}$ (6.7pb)	40.2 ± 6.2
Single top	24.2± 2.1
Diboson/Z→ $\tau\tau$	14.4± 2.4
nonW QCD	16.8± 3.1
Total Bkg	357.0 ± 63.6
Observed events	341

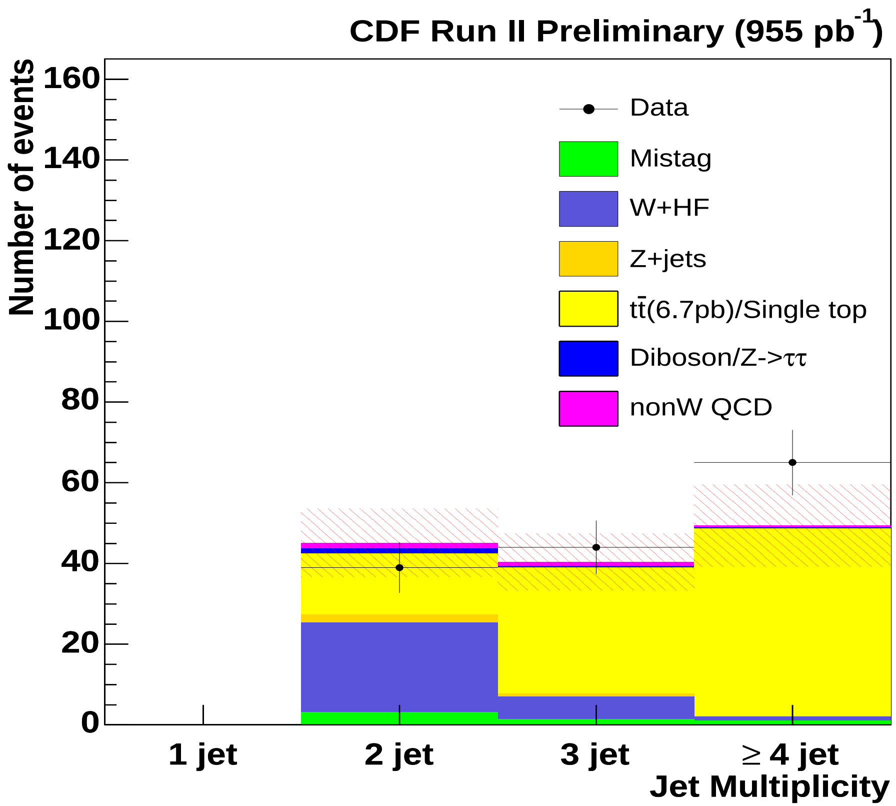


- Observed data is consistent with estimated background for each jet bin

Background Summary

- Double b-tagged events on W+2jet

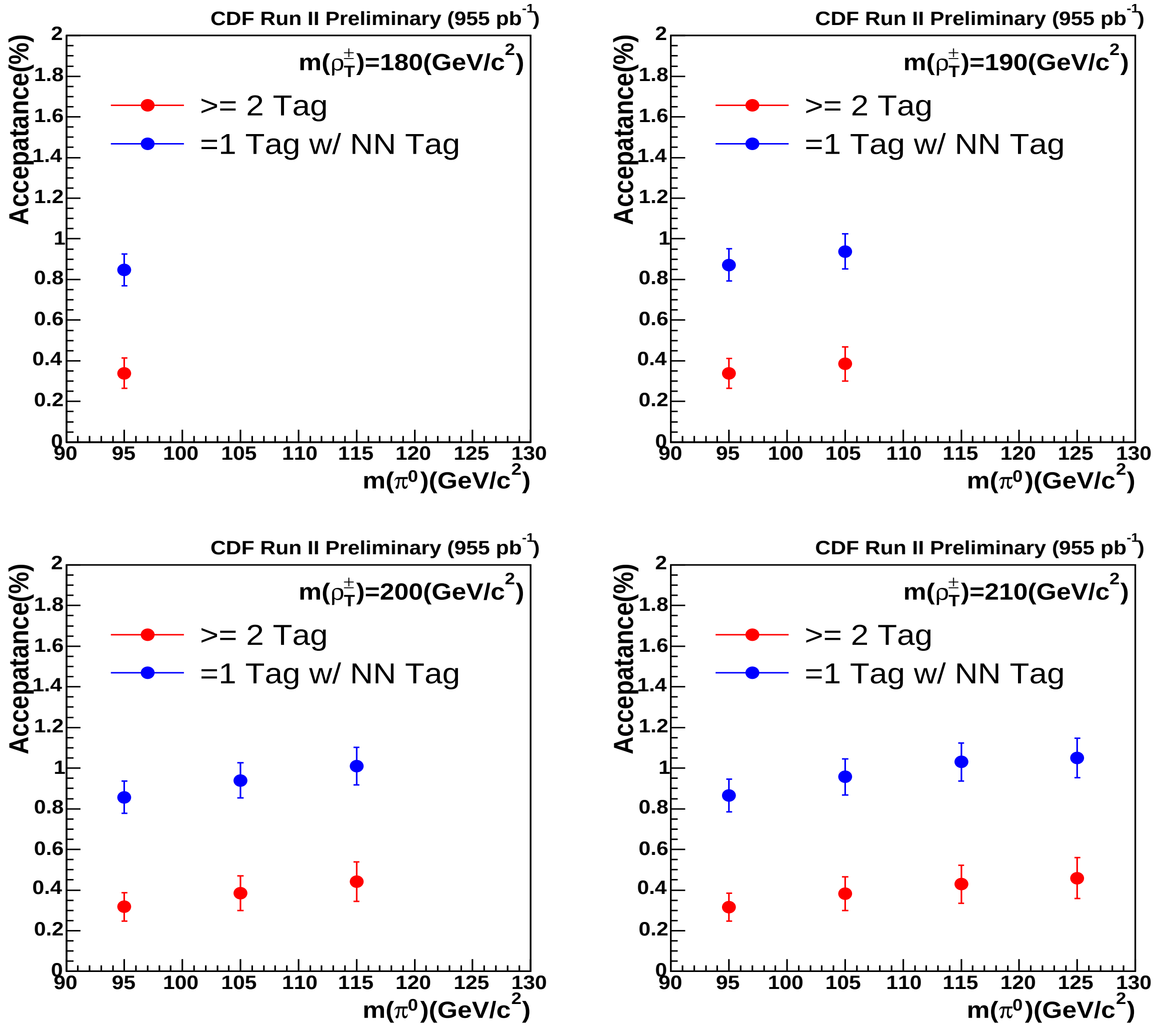
Njet	2 jet
Before b-tagging Events	14604
Mistag	3.2± 0.5
$Wb\bar{b}$	19.2± 6.5
$Wc\bar{c}$	3.0± 1.1
Z+jets	1.9 ± 0.8
$t\bar{t}$ (6.7pb)	10.5 ± 2.3
Single top	4.7± 0.8
Diboson/$Z\to\tau\tau$	1.2± 0.2
nonW QCD	1.5± 0.3
Total Bkg	45.2 ± 8.4
Observed events	39



- Observed data is consistent with estimated background for each jet bin
- Not apply Neural net b-tagging

Signal Acceptance and Systematics

- **Signal Acceptance**



0.8-1.0% (one tag w/ NNtag), 0.3-0.4% (double tag)

- **Expected Signal Event**

  ($m(\rho_T)$ 200 GeV, $m(\pi_T)$ 115 GeV) :

  12.1 event (1 tag w/ NNtag)

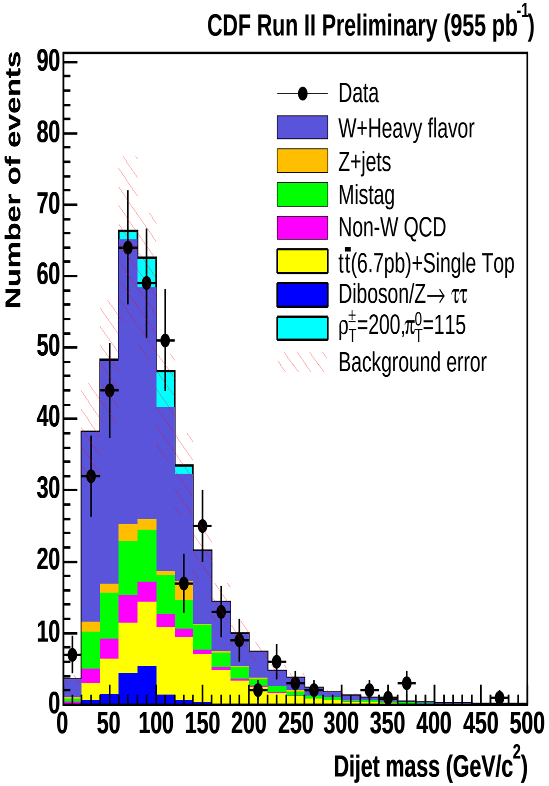
  4.7 event (double tag)

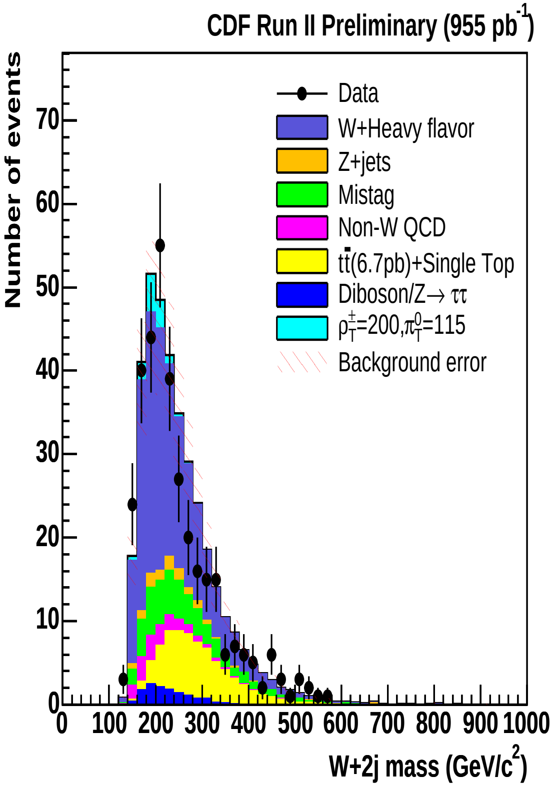
- **Systematics**

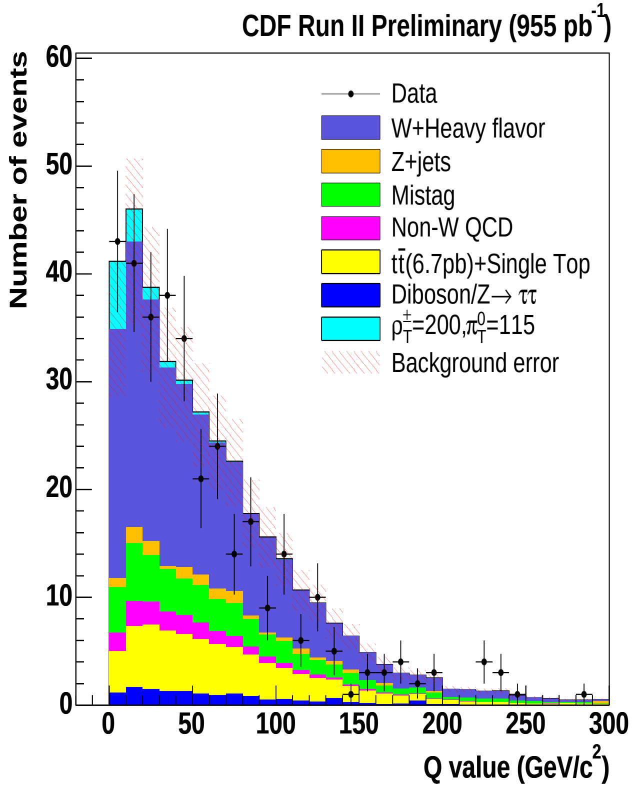
	1tag w/ NNtag	double tag
Lepton ID	~ 2%	~ 2%
Trigger	< 1%	< 1%
ISR/FSR	6.7%	14%
PDF	1.7%	2.6%
JES	2.8%	3.9%
b-tagging	5.3%	16%
Total	9%	22%

Reconstructed Mass

- Reconstructed mass on 1tag w/ NNtag



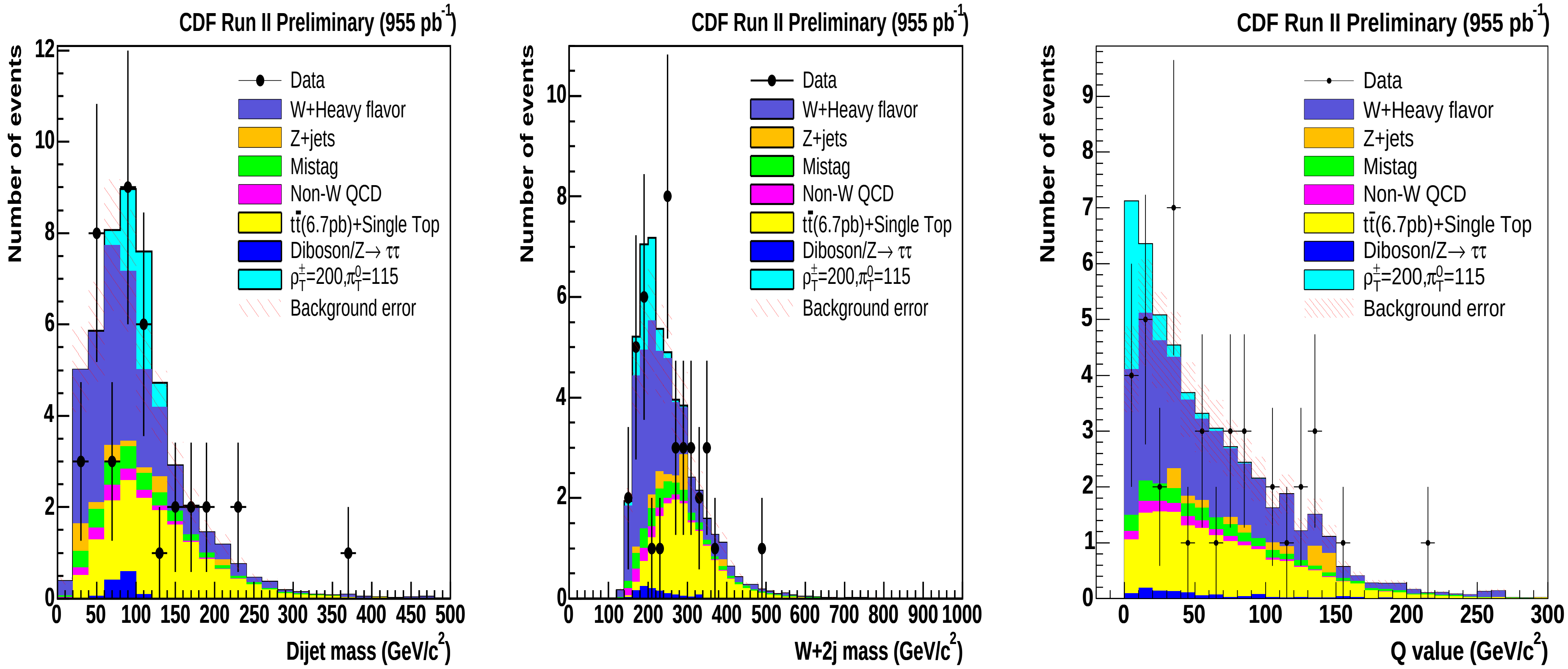




- Q value is defined by Q=m(W+2jet)-m(dijet)-m(W)
- Observed data is consistent with total background estimate

Reconstructed Mass

- **Reconstructed mass on double tag**

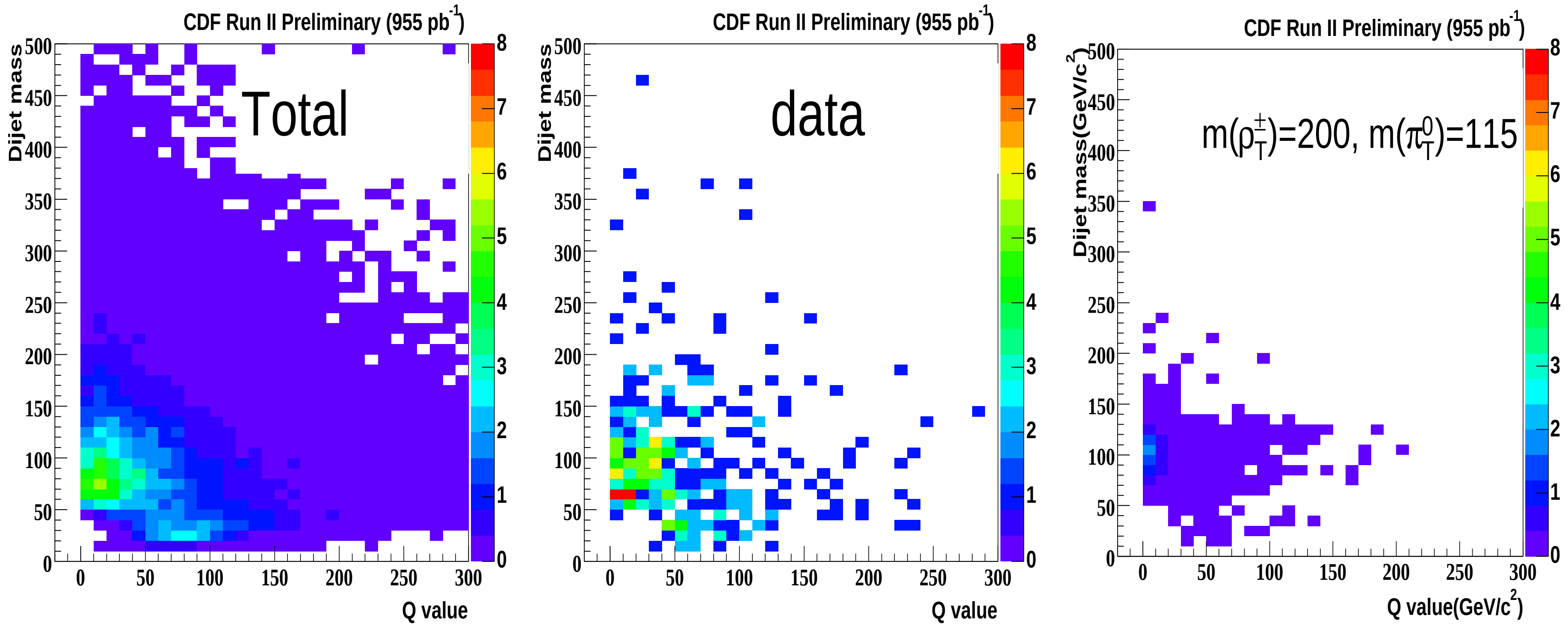


- Observed data is consistent with total background estimate

Reconstructed Mass(2D plots)

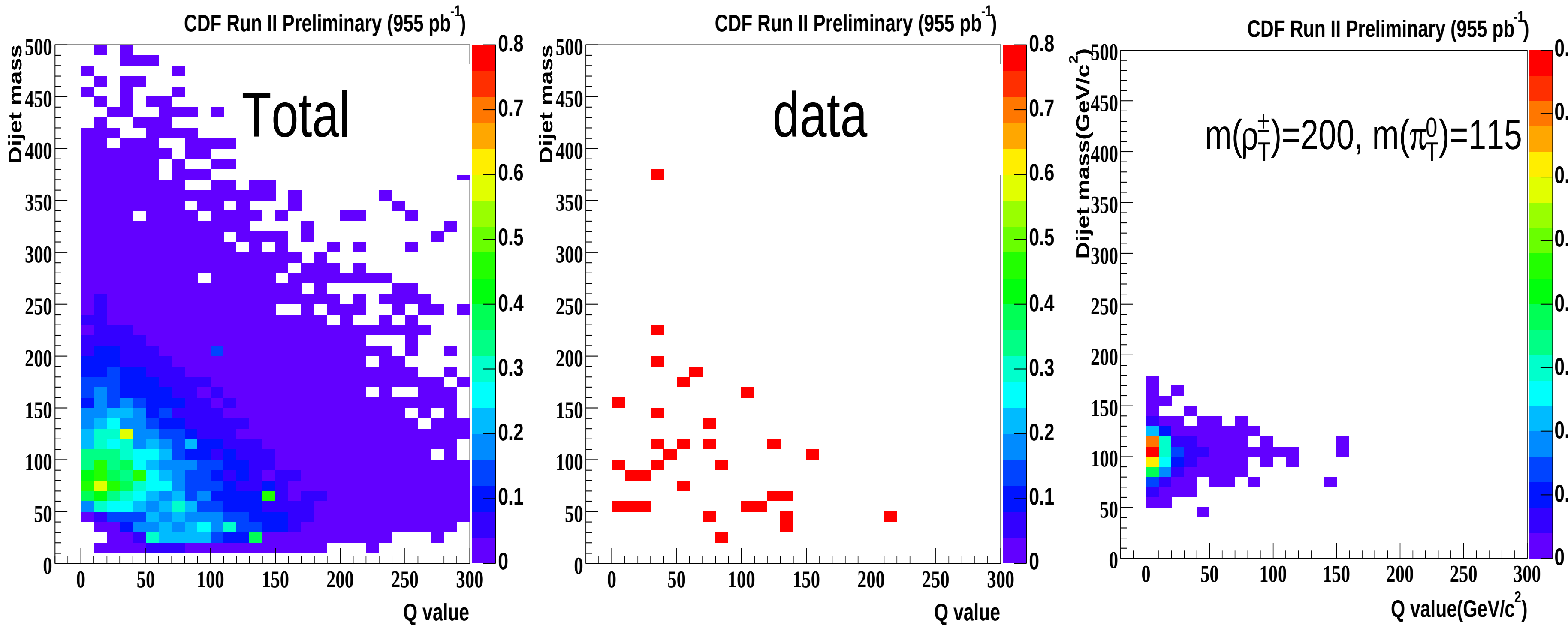
- **Set an upper limit on Technicolor production cross section by fitting dijet mass and Q value with 2D binned likelihood technique**

- **2D plots on 1tag w/ NNtag for total background, data and one signal sample**



Reconstructed Mass(2D plots)

- 2D plots on double tag for total background, data and one signal sample



Set Upper limit

2D Binned Likelihood Technique

- **Event count in each bin is supposed to be ruled by Poisson statistics**
- **Utilize the maximum information in each bin by defining a likelihood as**

$$L(\sigma \times Br) = \iiint \prod_{i=1}^{N_{xbin}} \prod_{j=1}^{N_{ybin}} \frac{\mu_{ij}^{n_{ij}} e^{-\mu_{ij}}}{n_{ij}!} G(N_{QCD}, \sigma_{N_{QCD}}) G(N_{Top}, \sigma_{N_{Top}}) G(N_{sig}, \sigma_{N_{sig}}) dN_{QCD} dN_{Top} dN_{sig}$$

$$\mu_{ij} = f_{ij}^{(QCD)} \cdot N^{(QCD)} + f_{ij}^{(Top)} \cdot N^{(Top)} + f_{ij}^{T} (\epsilon \cdot \mathcal{L} \cdot \sigma(p\bar{p} \to \rho_T^{\pm} \to \pi_T^0 W) \cdot BR(\pi_T^0 \to b\bar{b}))$$

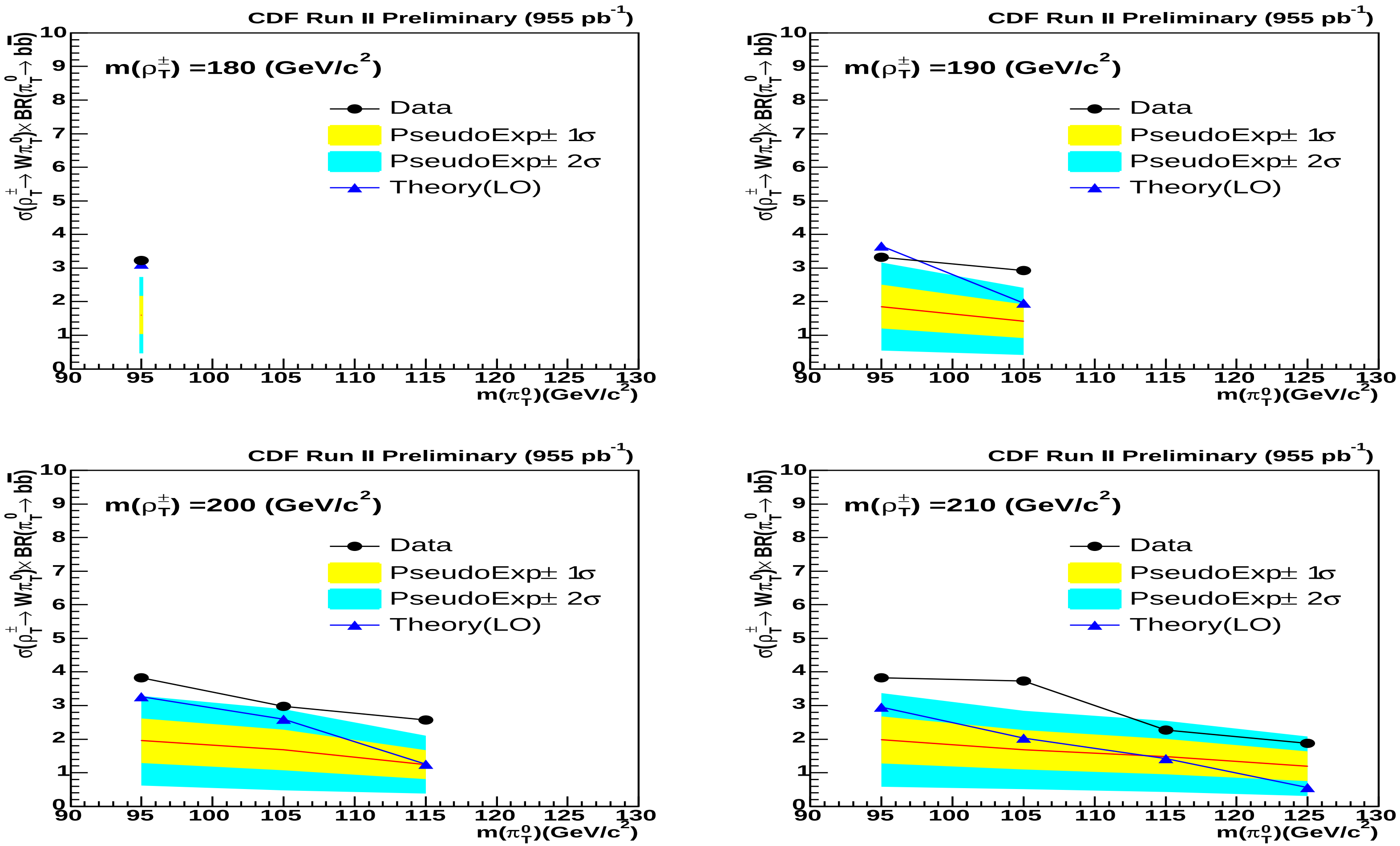
Combined Likelihood

$$L_{com}(\sigma \times Br) = L_{1tag}(\sigma \times Br) \times L_{2tag}(\sigma \times Br)$$

$$\beta = \frac{\int_0^{\alpha} L(\alpha) d\alpha}{\int_0^{\infty} L(\alpha) d\alpha} \to \text{set } \beta = 0.95$$

Results

- **Upper limit using** $L_{com}(\sigma \times Br)$

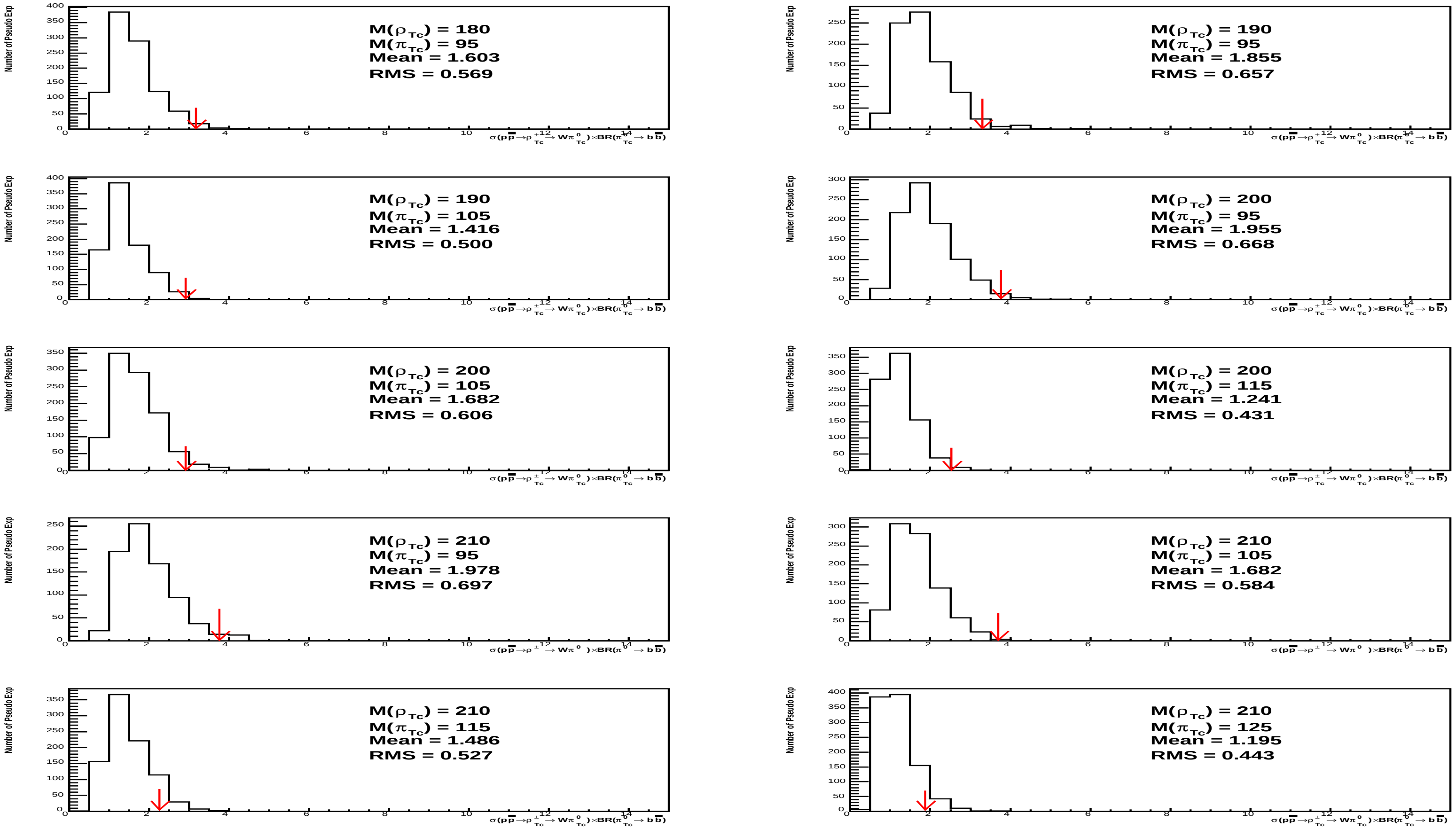


♦ **Exclude small region : 95<** π_T **<98GeV for** ρ_T**=190 GeV**

Results (cont.)

- Pseudo Experiment results

CDF RunII Preliminary (955 pb-1)



Observed limit is 2 σ level higher than expected

Conclusion and Plan

- We set an upper limit on Technicolor production cross section using $\sim$ 1fb^{-1}.
- We exclude region :

95 GeV $< m(\pi_T) <$ 98 GeV for $m(\rho_T)$ = 190 GeV

- The observed limit is worse than the expected. But the statistical significance of such excess is 2.6% even if Technicolor wasn't there.
  $\Rightarrow$ We need more DATA!!

Future plan

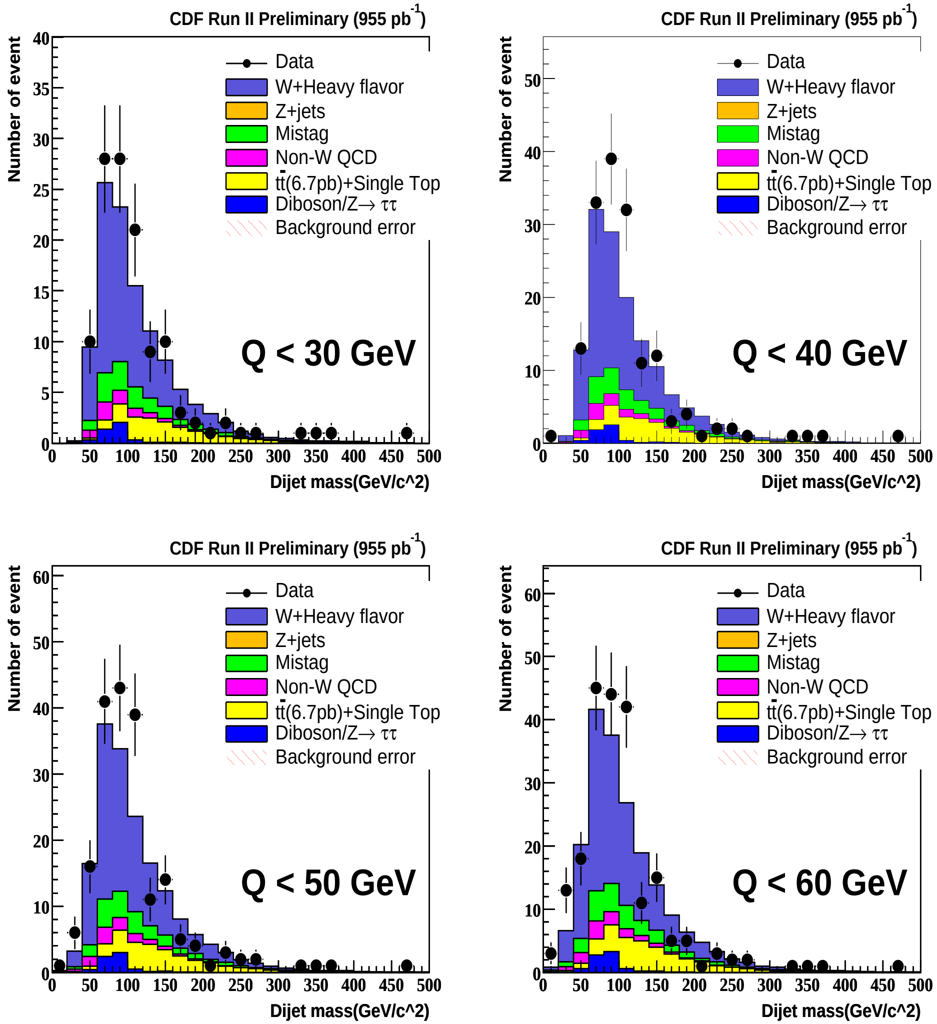
- 1.2 fb^{-1} data is available by Winter Conference
- Try to optimize event selection

Backup Slide

The Source of Higher Observed Limit

- **Higher observed limit come from 1tag events (We don't see it due to statistical limit in double tag events)**
- **This results seem stable (Already check shapes after changing event selection more tight or loose)**
- **Other many kinematic shapes have good agreements between data and expected background.**

- **Dijet mass distribution for each Q value region (one tag event)**



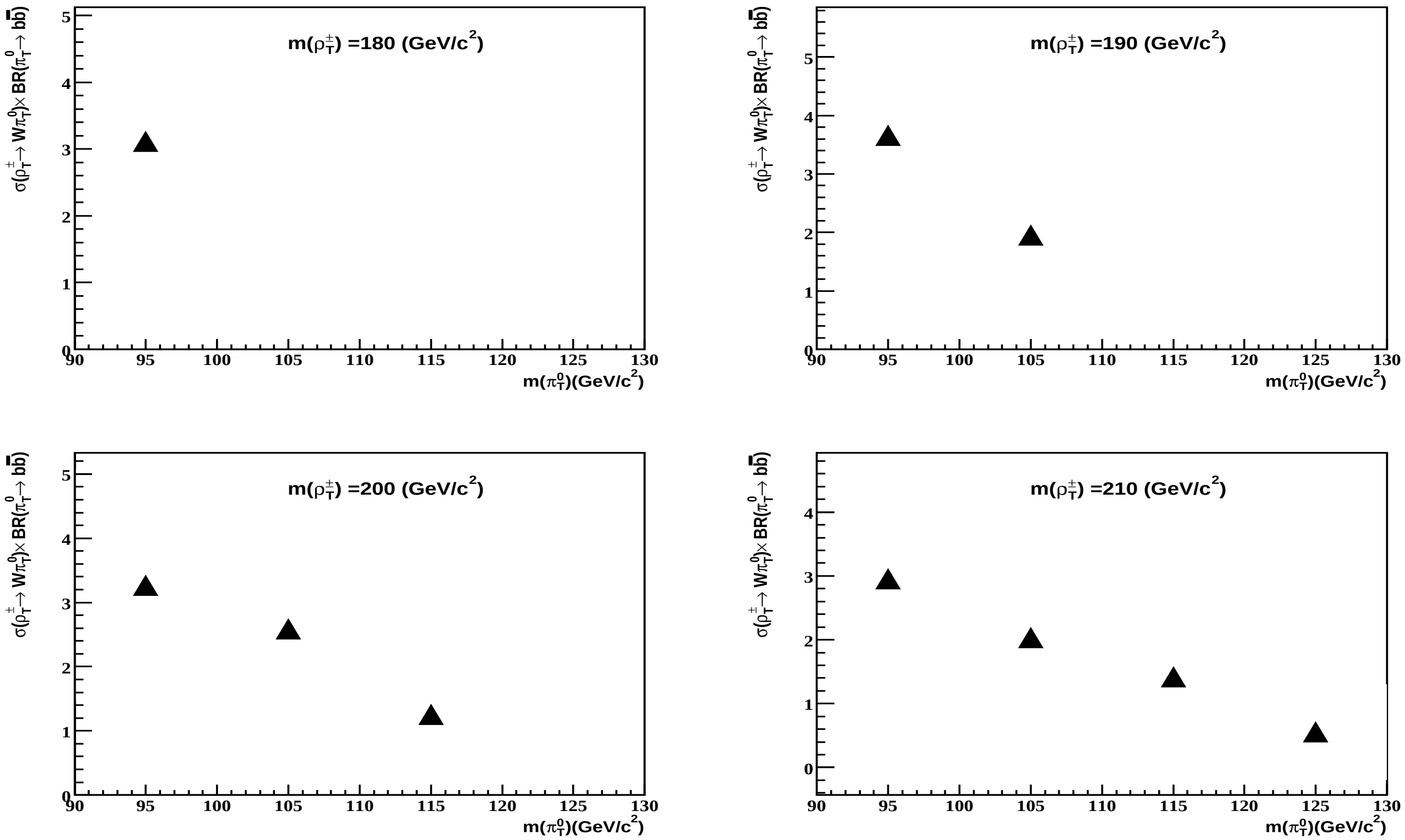
The parameter of Technicolor

- **Main parameter of Technicolor in this analysis**
  - N_{TC} = 4
  - M_V = M_A = 200 GeV
  - Q_U = $\frac{4}{3}$
  - Q_D = $Q_U - 1$ = $\frac{1}{3}$
- **Generated mass**

$m(\rho_T) \backslash m(\pi_T)$	95 GeV	105 GeV	115 GeV	125 GeV
180 GeV	√			
190 GeV	√	√		
200 GeV	√	√	√	
210 GeV	√	√	√	√

Technicolor Cross Section

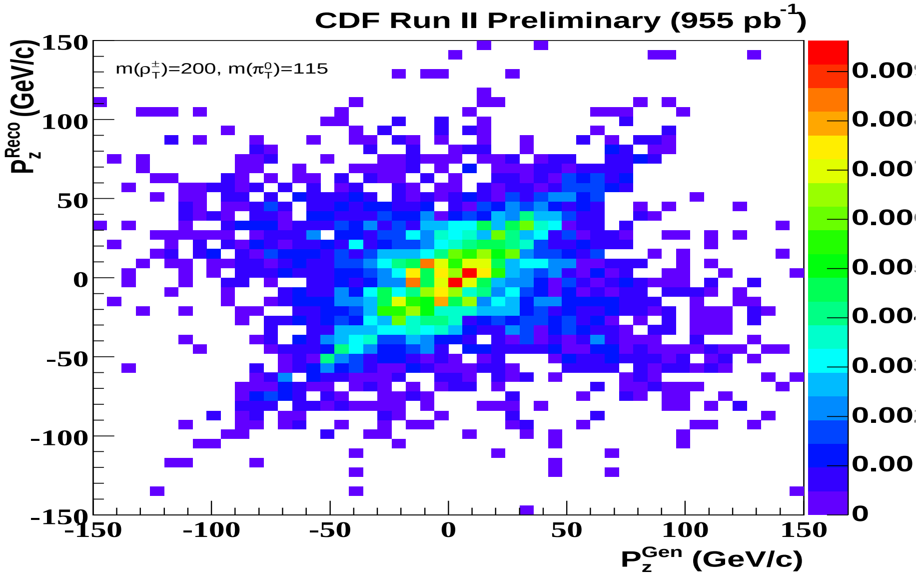
- **Search region :** $\rho_T^{\pm}$ **180-210 GeV,** π_T^0 **95-125 GeV** $\Leftarrow$ **Generate using PYTHIA MC**
- **Signal cross section(LO) is calculated from MC**

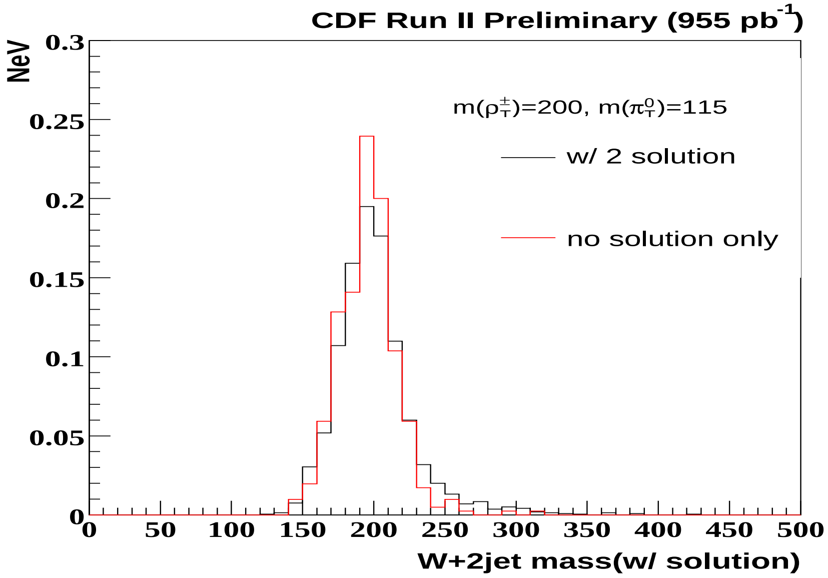


$\dagger$ $\sigma(\rho_T^{\pm} \rightarrow W\pi_T^0) \times BR(\pi_T^0 \rightarrow b\bar{b})$ **is about 1** $\sim$ **3 pb**

Neutrino Solution

- Need to solve Pz of neutrino to reconstruct W + 2 jet mass
- Procedure
  - Use the W boson mass constraint in a lepton-neutrino system and solve the quadratic equation
    1) Take smaller pz from the two solutions $\sim 70\%$
    2) If there is no solution for pz, we take real part as pz of neutrino $\sim 30\%$



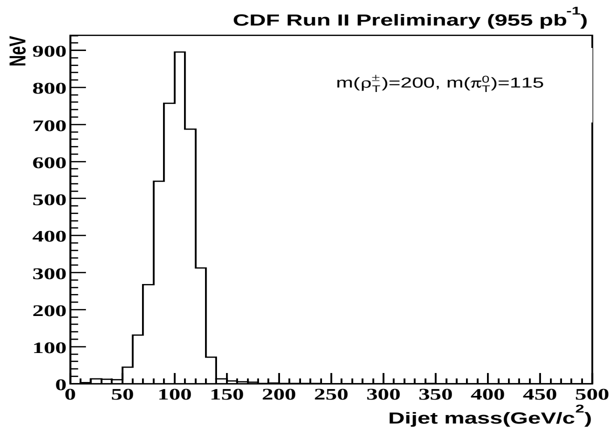


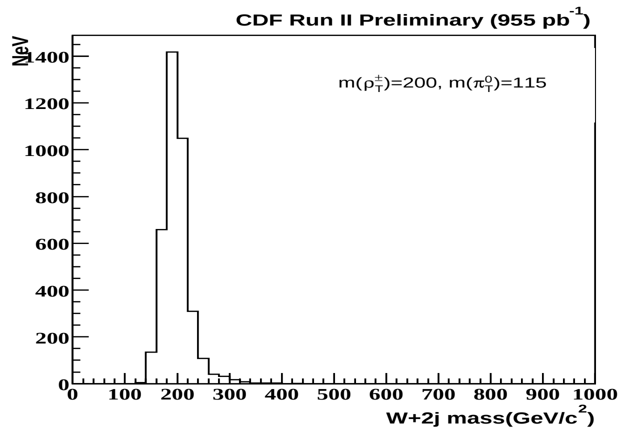
Reconstructed Pz vs. generator Pz

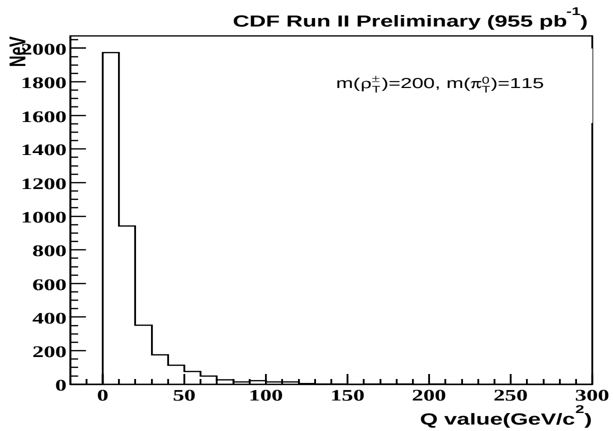
the difference of shape for each solution case.

Mass Distribution of Signal

- **Dijet mass and W + 2 jet mass of signal sample ($\rho_T^{\pm}$=200 GeV, π_T^0=115 GeV)**







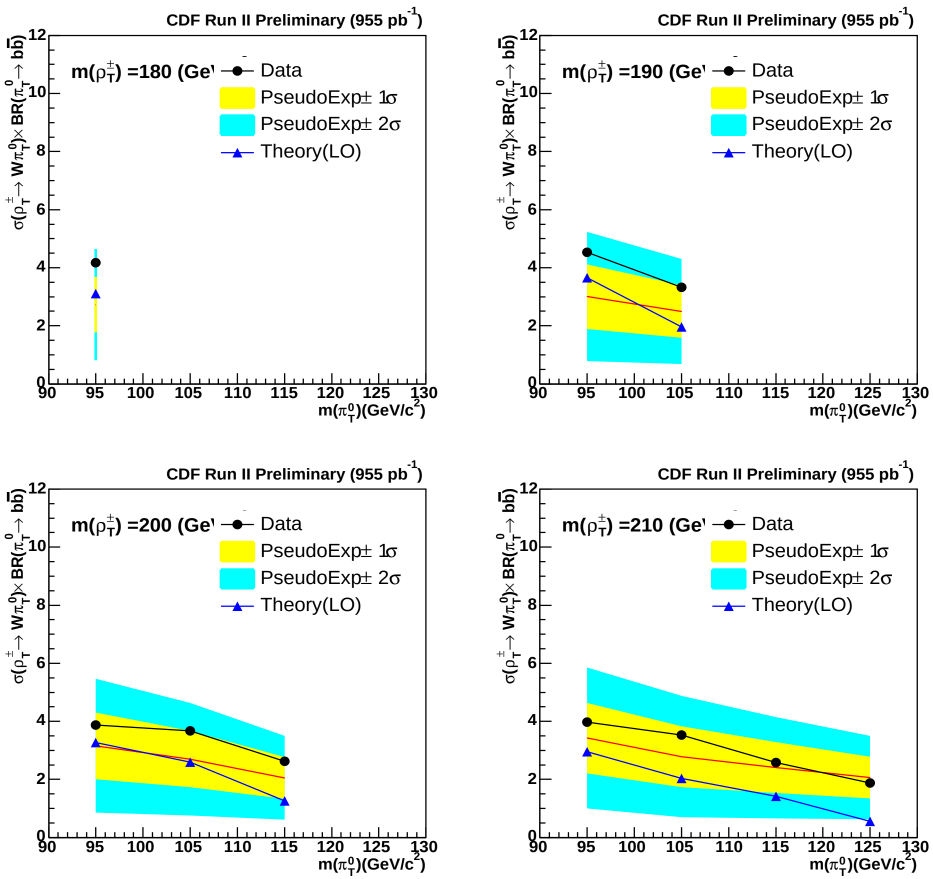
m($\rho_T^{\pm}$)=200, m(π_T^0)=115

Q = m(Wjj) - m(jj) - m(W)

*** Q value is uncorrelated to dijet mass → apply Q value and dijet mass in fitting.**

Check Observed Limit

- **Double tag observed limit and Pseudo experiments results**



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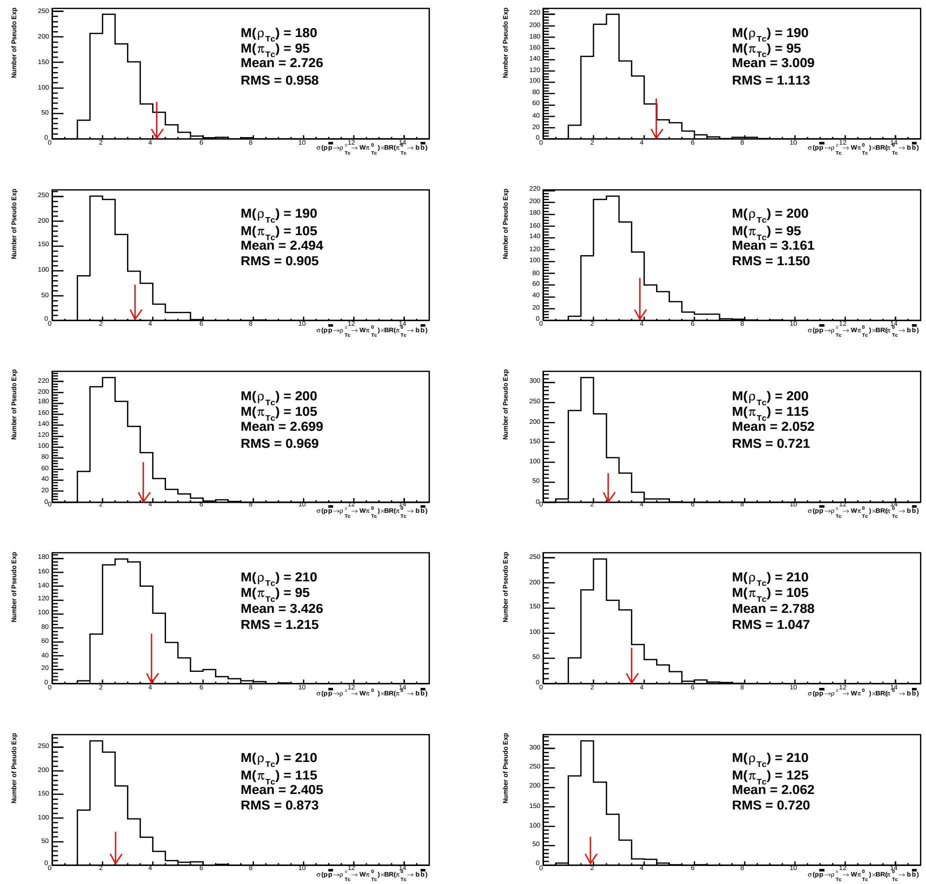
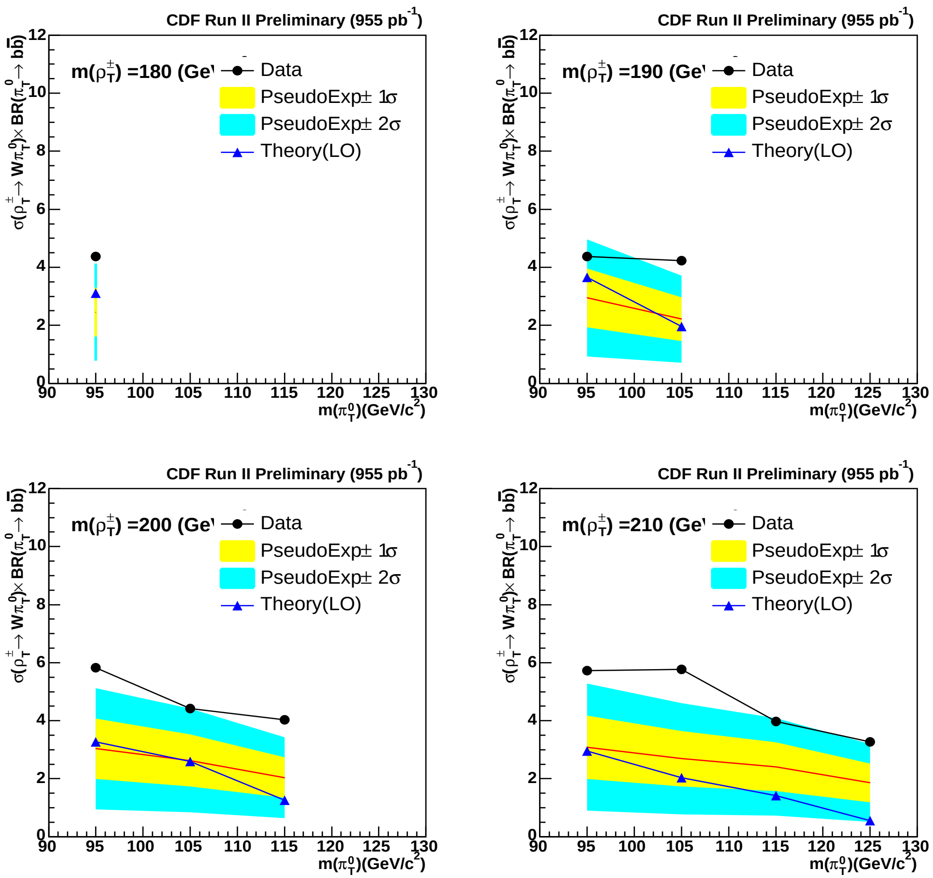


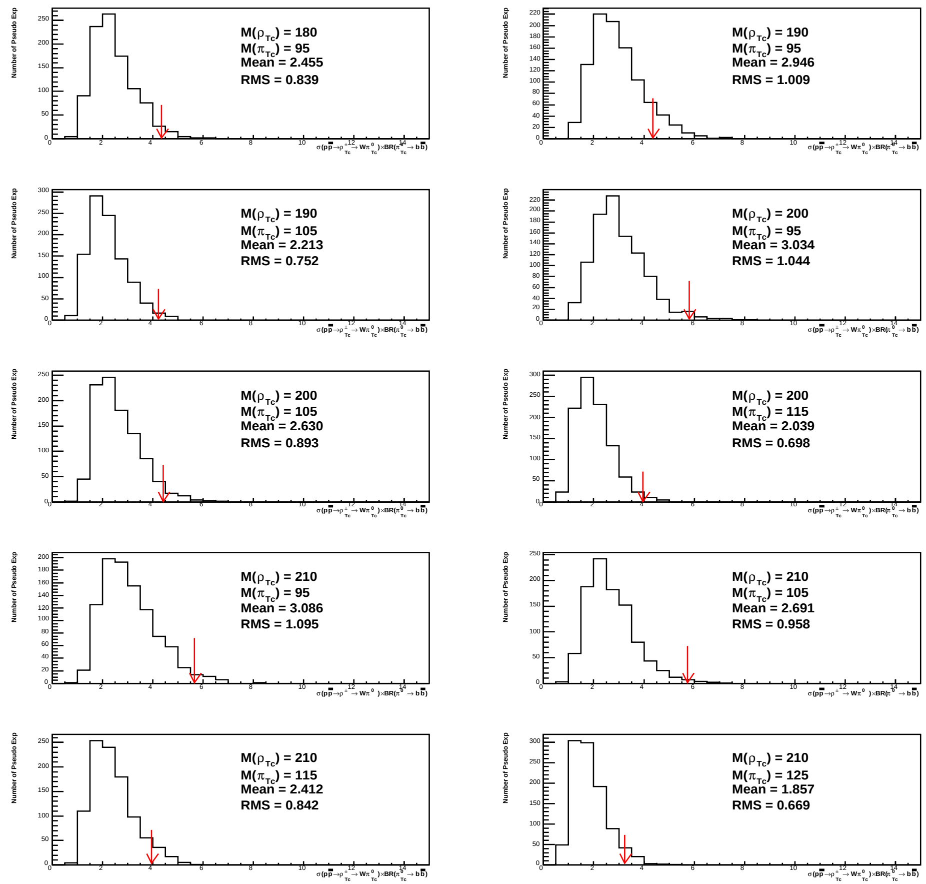
† **Observed limits are reasonable**

Check Observed Limit

- **1tag w/ NN tag and Pseudo experiments results**

CDF RunII Preliminary (955 pb-1)

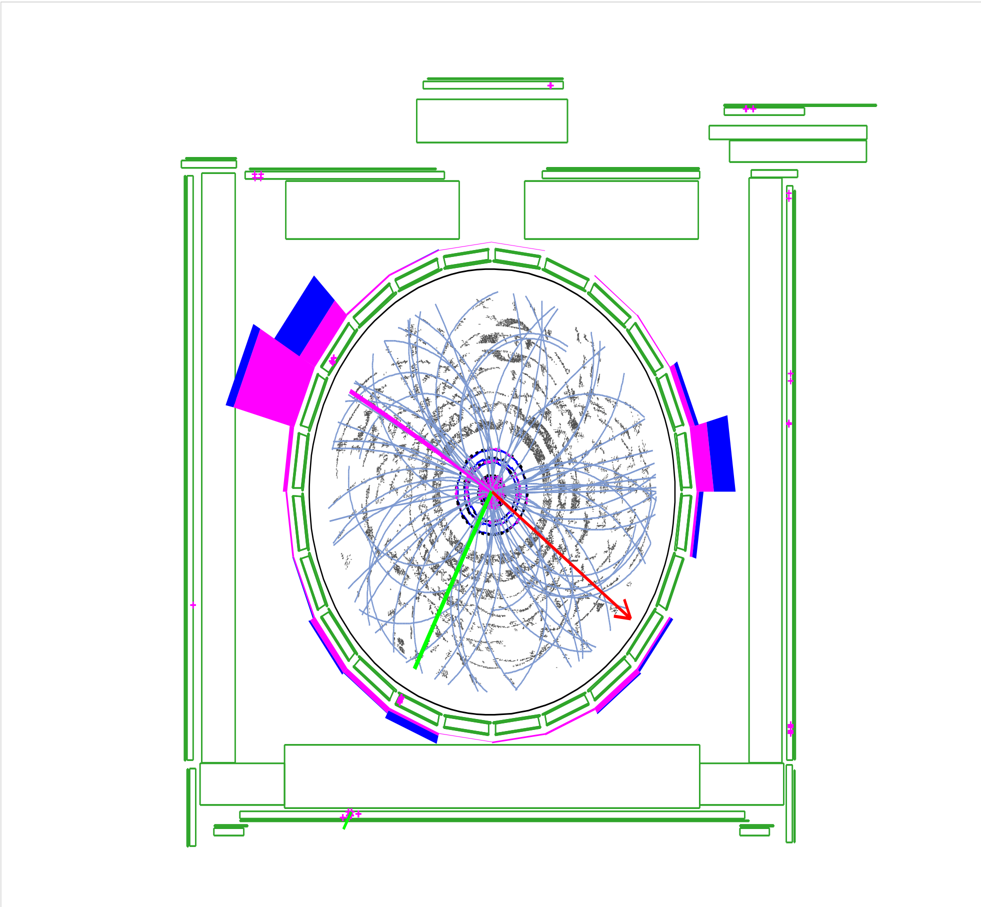


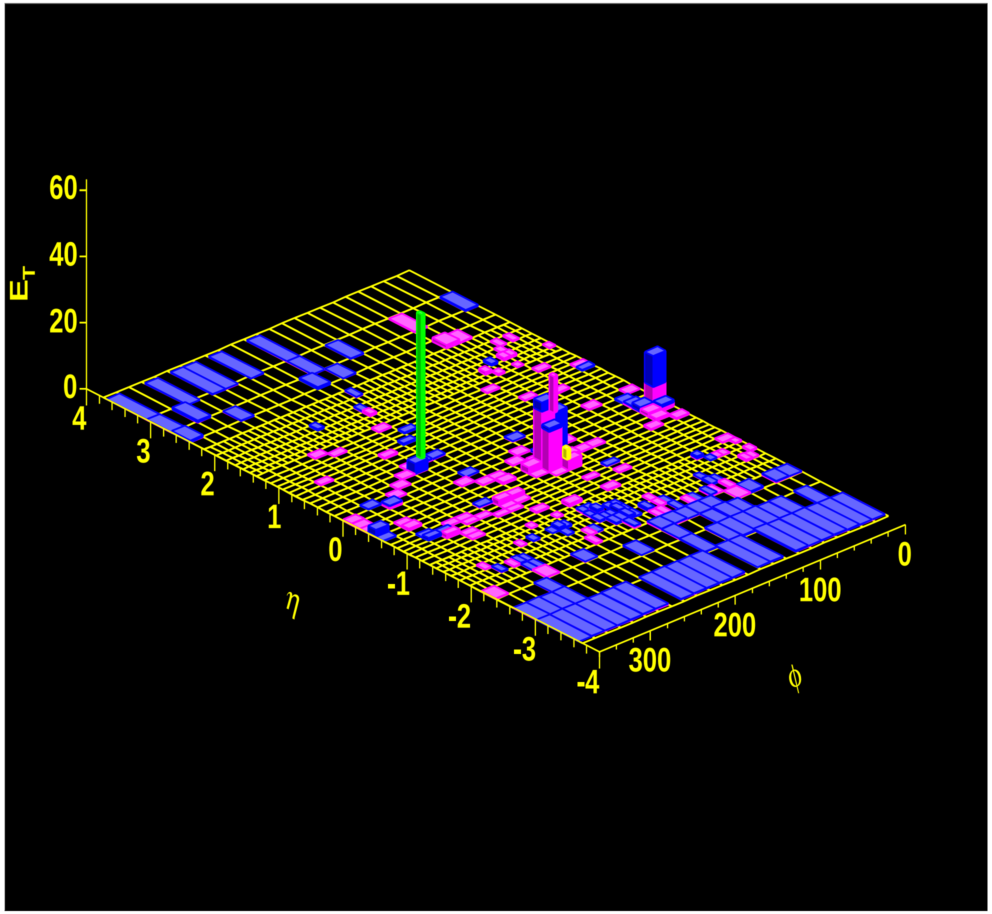


† **Observed limits are much higher than pseudo experiments unluckily**

Event Display in Signal Region

- **Central Muon event : #Run : 184377, #Event : 13093573**





† Reconstructed dijet mass : 96.3 GeV, W+2jet mass : 222.1 GeV