Search for Technicolor particles in W + 2 jet with b-tag channel

Workshop on Physics at the First Muon Collider and at Front End of a Muon Collider
Strong Dynamics Working Group 11/08/97

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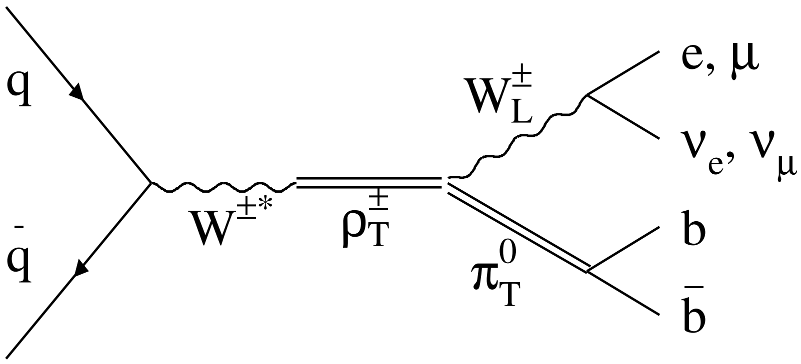
(Representing CDF Collaboration)

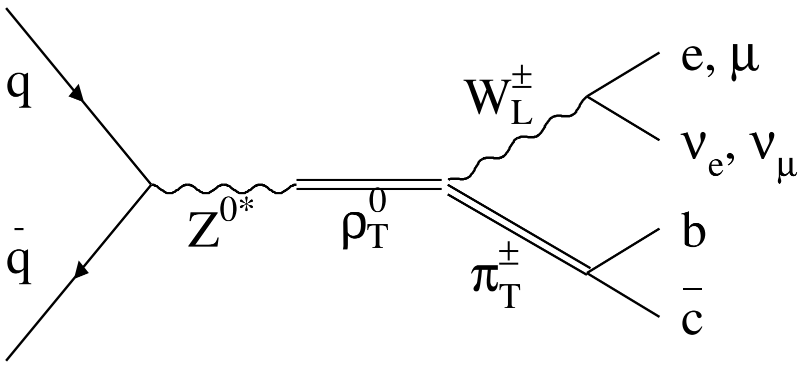
Outline

1. Production Cross Section
2. W+2jet with SECVTX b-tag Selection
3. TC Signal Acceptance
4. Background
5. 2jet Topology Cuts $\Delta\phi_{jj}$ and $p_{T_{jj}}$
6. π_T, ρ_T Mass Window Cuts
7. Systematic Uncertainties
8. Number of Events and Cross Section Limits
9. Summary Plots

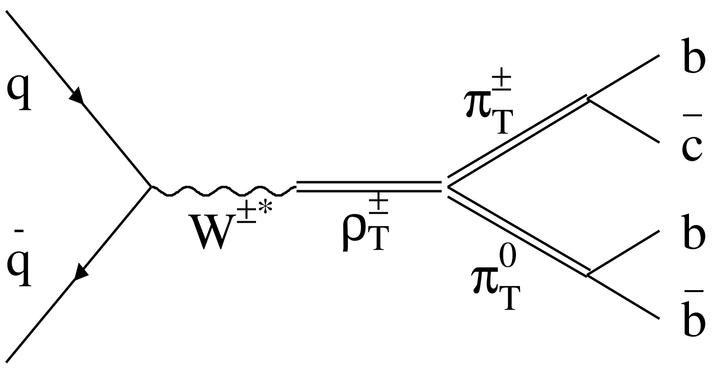
Technicolor Signatures

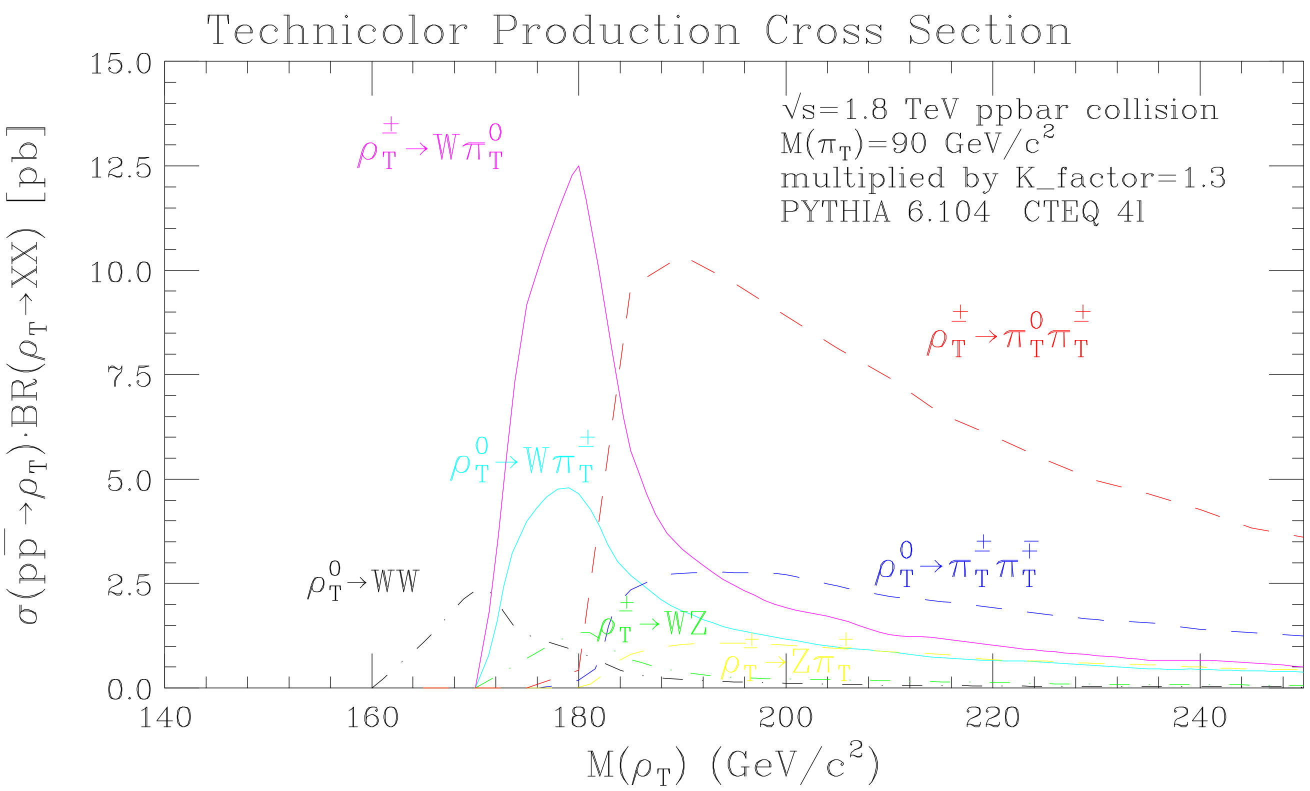
This analysis : W + 2 jet with b-tag



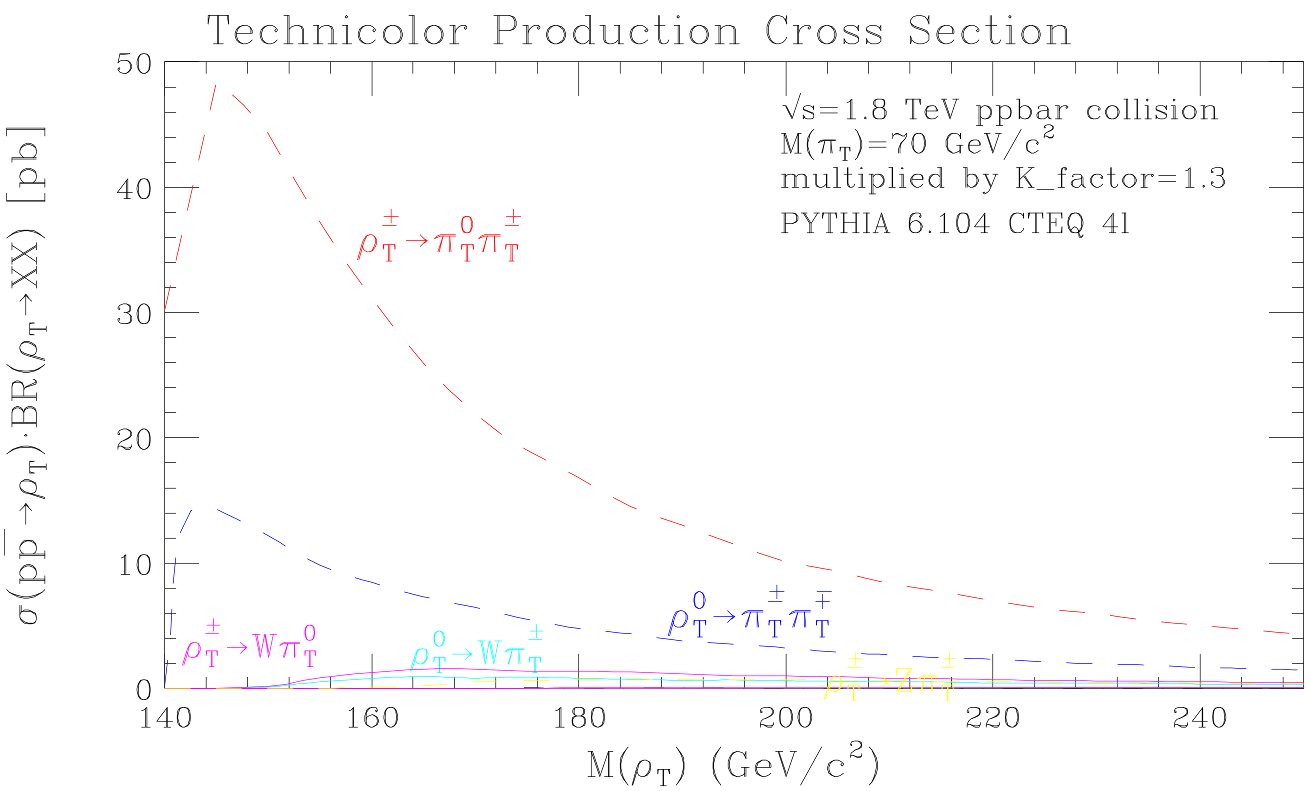


Another analysis : Multijet with Double b-tag

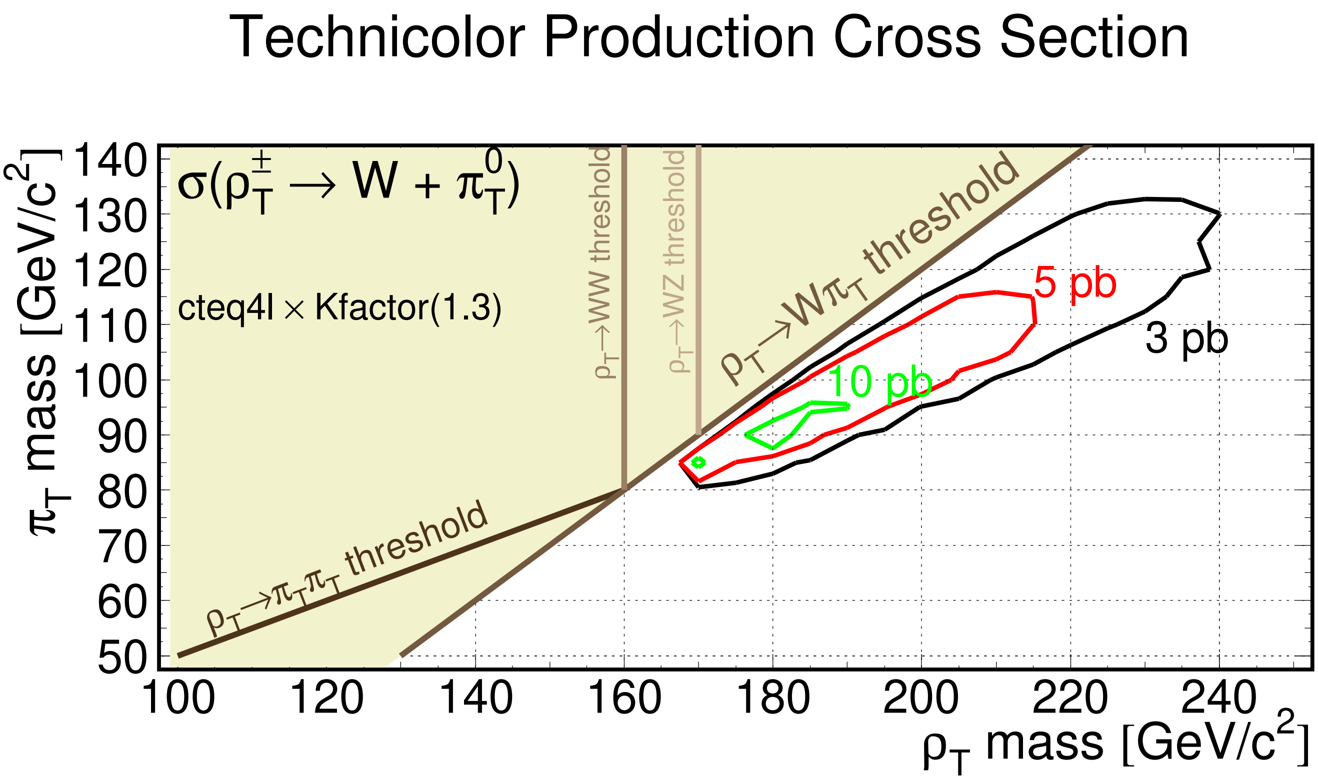




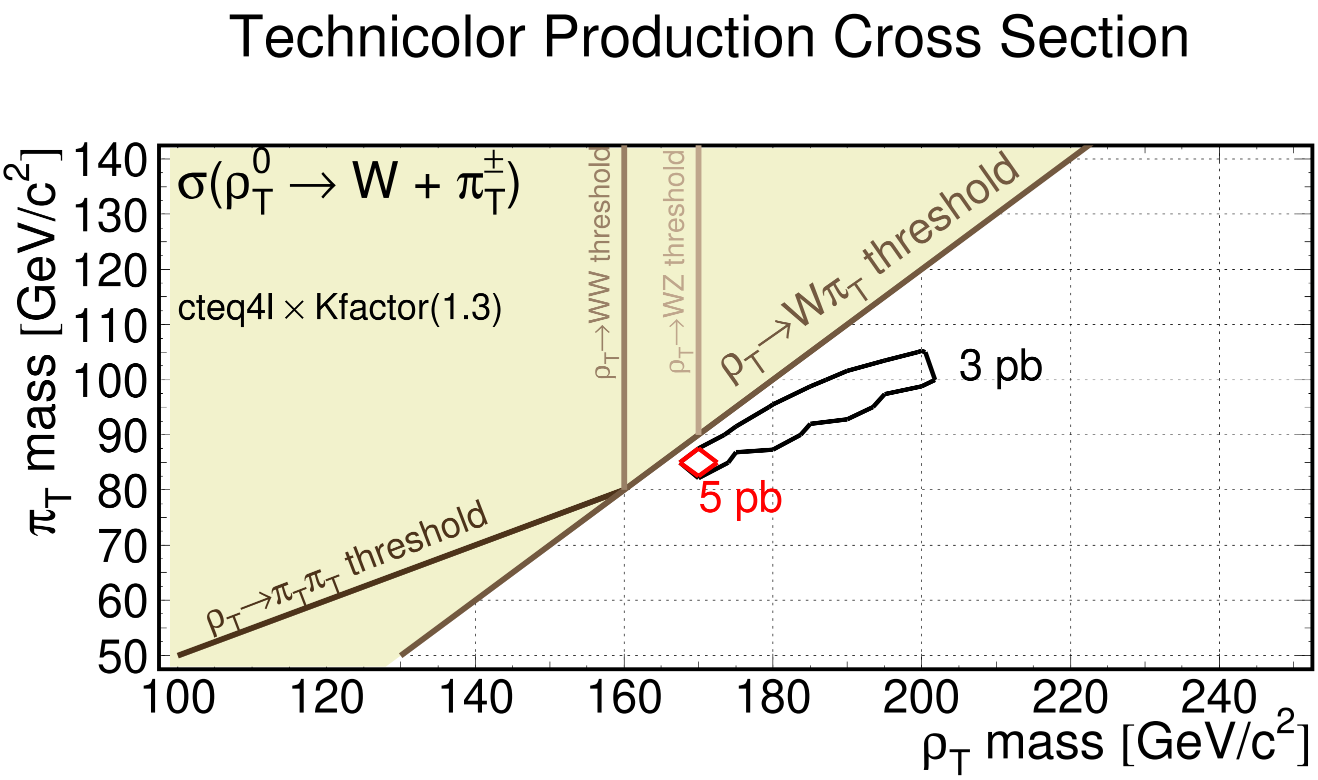
Technicolor Production Cross Section
√s=1.8 TeV ppbar collision
M(π_T)=90 GeV/c^2
multiplied by K_factor=1.3
PYTHIA 6.104 CTEQ 4l
$\sigma(p\bar{p}\to\rho_T)\cdot BR(\rho_T\to XX)$ [pb]
$M(\rho_T)$ (GeV/c^2)
$\rho_T^\pm\to W\pi_T^0$
$\rho_T^\pm\to\pi_T^0\pi_T^\pm$
$\rho_T^0\to W\pi_T^\pm$
$\rho_T^0\to\pi_T^\pm\pi_T^\mp$
$\rho_T^0\to WW$
$\rho_T^\pm\to WZ$
$\rho_T^\pm\to Z\pi_T^\pm$



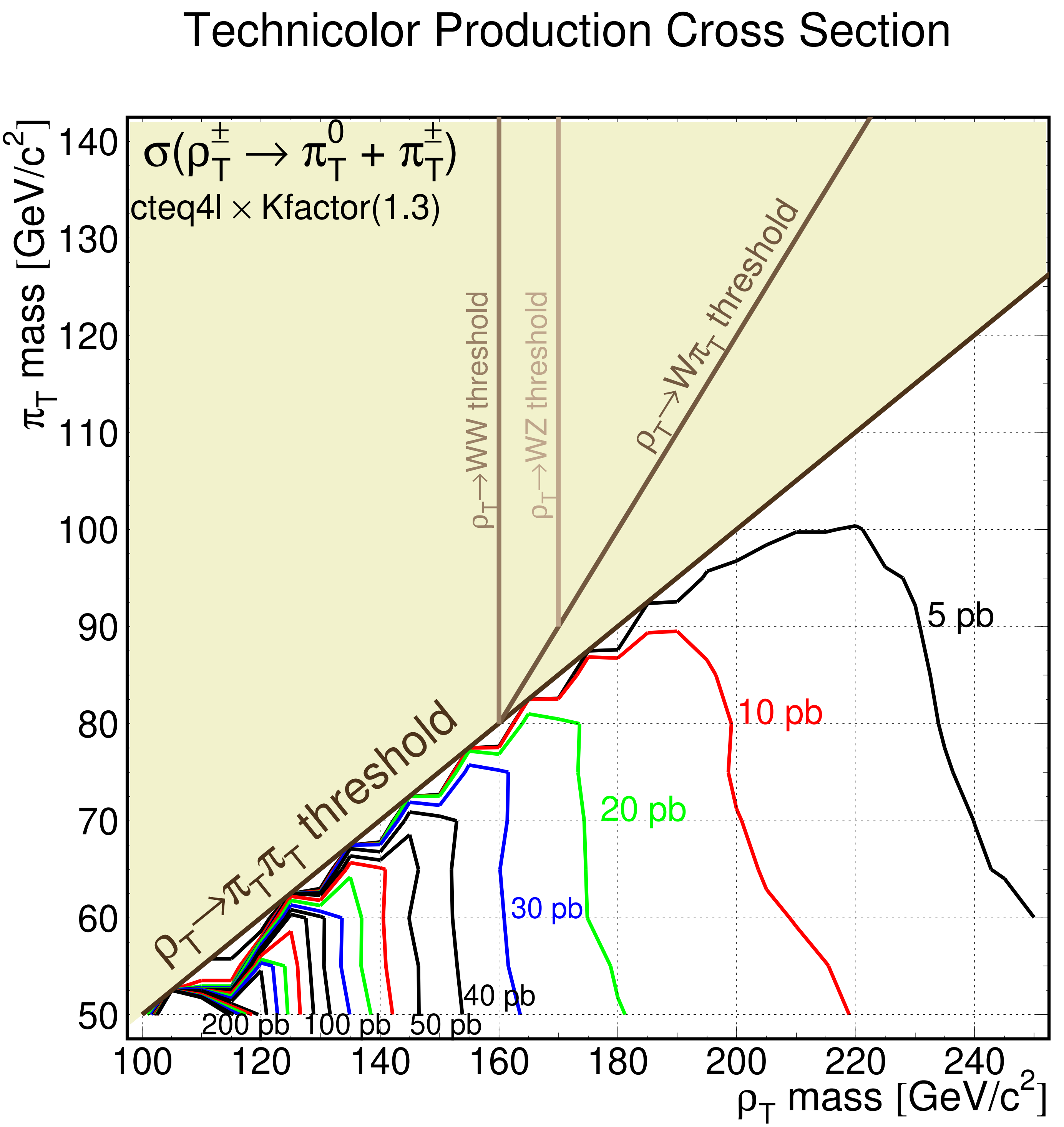
Technicolor Production Cross Section
√s=1.8 TeV ppbar collision
M(π_T)=70 GeV/c^2
multiplied by K_factor=1.3
PYTHIA 6.104 CTEQ 4l
$\sigma(p\bar{p}\to\rho_T)\cdot BR(\rho_T\to XX)$ [pb]
$M(\rho_T)$ (GeV/c^2)
$\rho_T^\pm\to\pi_T^0\pi_T^\pm$
$\rho_T^0\to\pi_T^\pm\pi_T^\mp$
$\rho_T^\pm\to W\pi_T^0$
$\rho_T^0\to W\pi_T^\pm$
$\rho_T^\pm\to Z\pi_T^\pm$

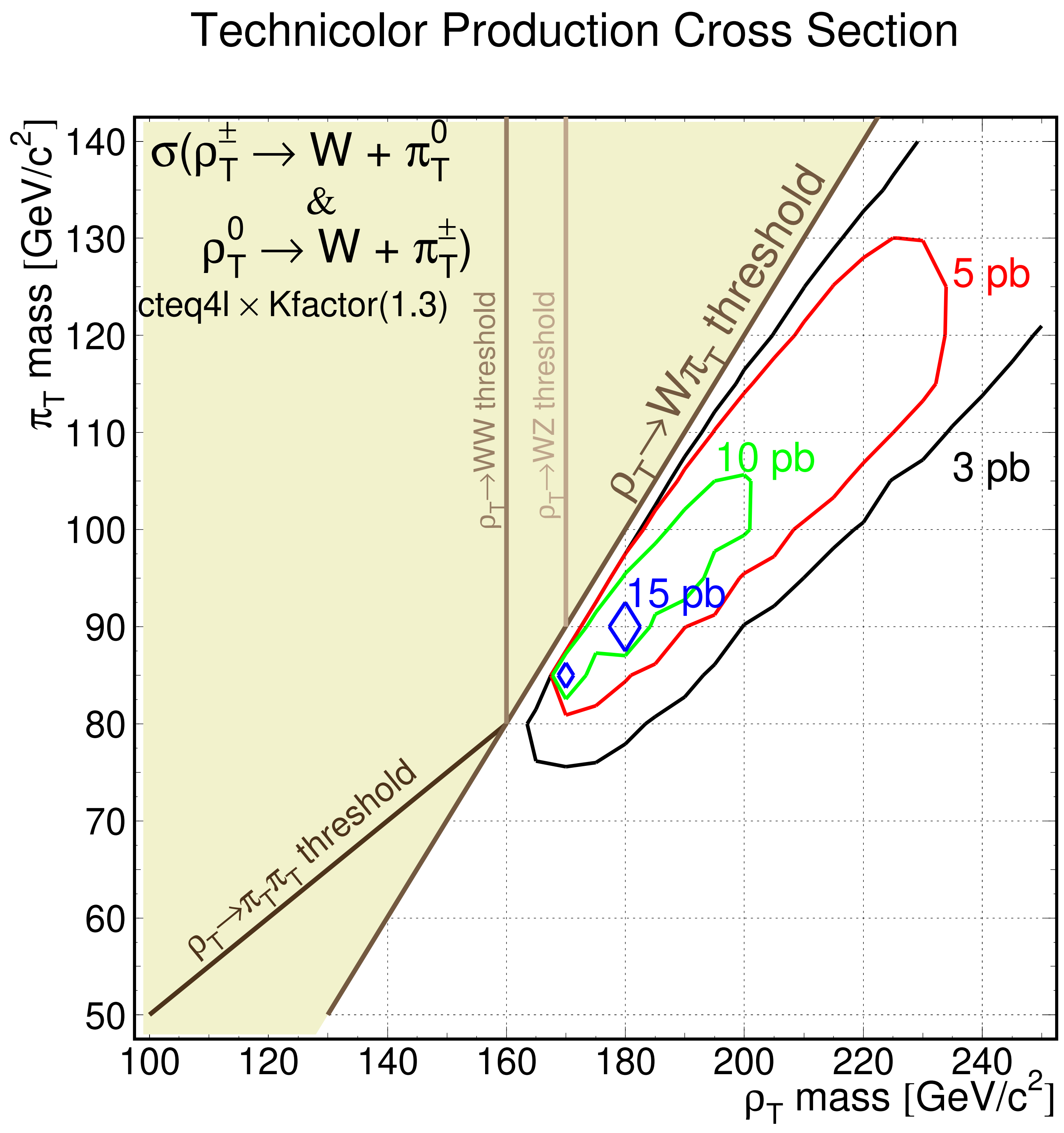


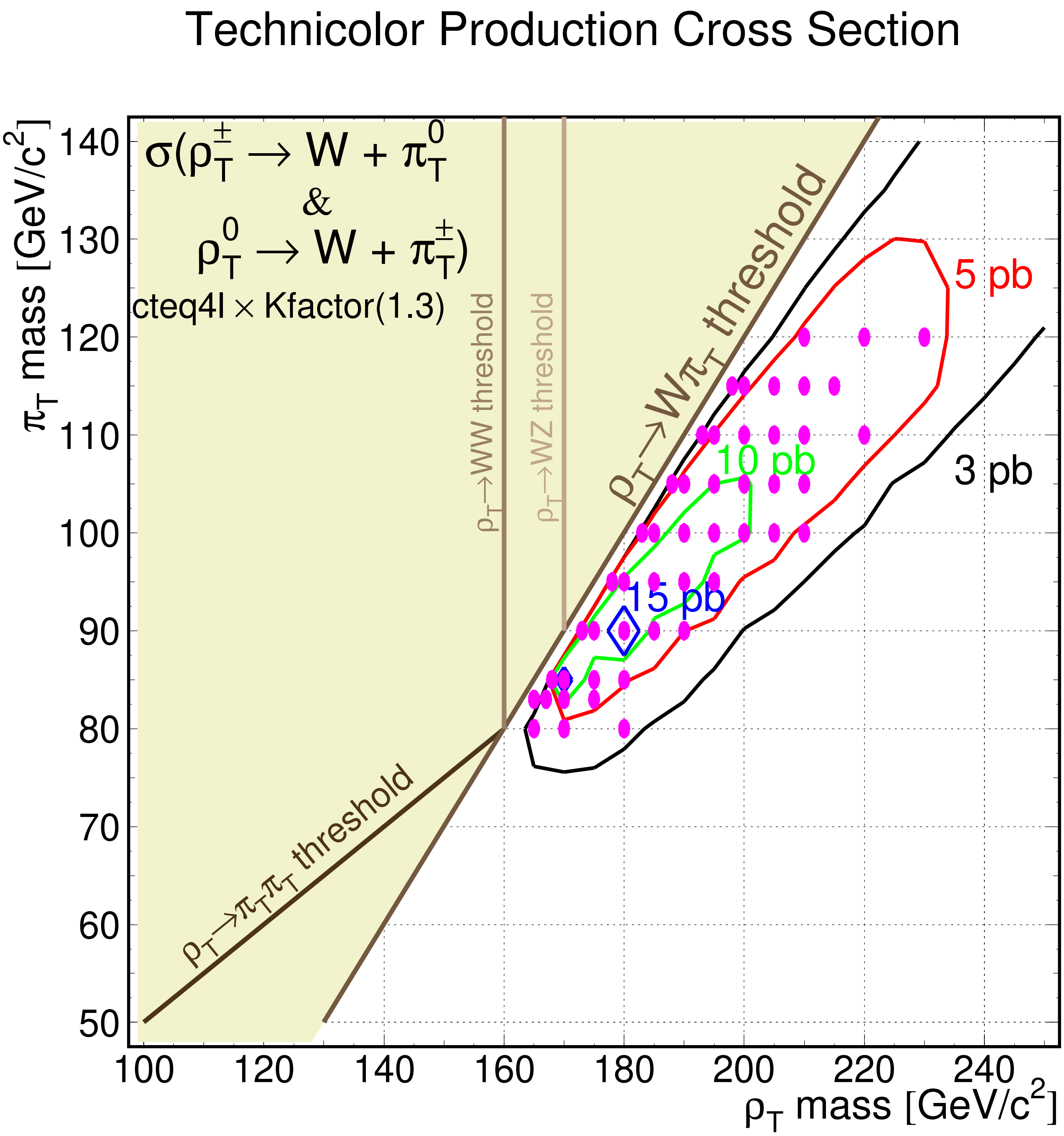
Technicolor Production Cross Section
$\sigma(\rho_T^{\pm} \rightarrow W + \pi_T^0)$
cteq4l × Kfactor(1.3)
$\rho_T \rightarrow WW$ threshold
$\rho_T \rightarrow WZ$ threshold
$\rho_T \rightarrow W\pi_T$ threshold
$\rho_T \rightarrow \pi_T\pi_T$ threshold
5 pb
3 pb
10 pb
π_T mass [GeV/c^2]
ρ_T mass [GeV/c^2]



Technicolor Production Cross Section
$\sigma(\rho_T^{0} \rightarrow W + \pi_T^{\pm})$
cteq4l × Kfactor(1.3)
$\rho_T \rightarrow WW$ threshold
$\rho_T \rightarrow WZ$ threshold
$\rho_T \rightarrow W\pi_T$ threshold
$\rho_T \rightarrow \pi_T\pi_T$ threshold
3 pb
5 pb
π_T mass [GeV/c^2]
ρ_T mass [GeV/c^2]


Technicolor Production Cross Section
σ(ρT± → πT0 + πT±)
cteq4l × Kfactor(1.3)
ρT→WW threshold
ρT→WZ threshold
ρT→WπT threshold
ρT→πTπT threshold
5 pb
10 pb
20 pb
30 pb
40 pb
200 pb
100 pb
50 pb
πT mass [GeV/c2]
ρT mass [GeV/c2]


Technicolor Production Cross Section
σ(ρT± → W + πT0
&
ρT0 → W + πT±)
cteq4l × Kfactor(1.3)
ρT→WW threshold
ρT→WZ threshold
ρT→WπT threshold
ρT→πTπT threshold
5 pb
10 pb
15 pb
3 pb
πT mass [GeV/c2]
ρT mass [GeV/c2]
50
60
70
80
90
100
110
120
130
140
100
120
140
160
180
200
220
240


Technicolor Production Cross Section
$\sigma(\rho_T^\pm \to W + \pi_T^0$
&
$\rho_T^0 \to W + \pi_T^\pm)$
cteq4l × Kfactor(1.3)
$\rho_T \to WW$ threshold
$\rho_T \to WZ$ threshold
$\rho_T \to W\pi_T$ threshold
$\rho_T \to \pi_T\pi_T$ threshold
5 pb
10 pb
15 pb
3 pb
π_T mass [GeV/c^2]
ρ_T mass [GeV/c^2]

W + 2 jet with SECVTX b-tag Event Selection

- W Selection
  - $*$ High P_T Electron or Muon $P_T > 20$ GeV/c
  - $*$ $\not{E}_T > 20$ GeV
- Dilepton Removal
  - $*$ Remove 75 GeV/c^2 < $M_{l_i l_i}$ < 105 GeV/c^2
  - $*$ Remove $t\bar{t}$ dilepton candidate
  - $*$ Remove oppositely charged tracks(>15 GeV/c)
- 2 jet Selection
  - $*$ $|\eta| < 2.0$
  - $*$ $E_T > 15$ GeV (use lepton vertex, uncorrected)
- b quark tagging
  - $*$ Require at least 1 jet is SECVTX b-tagged
- Jet Energy Correction
  - $*$ Apply JTC96S('EY' option) for Mass Reconstruction.

CDF Preliminary

Selection	Number of events (electron/muon)
W	113710 (68874/44836)
W + 2 jet	1611 (904/707)
SECVTX b-tag	42 (24/18)

Signal Monte Carlo

⋆ Pythia 6.1 with pdflib cteq4l + QFL'

⋆ Calculate Efficiency for

$$\rho_T^{\pm} \to W^{\pm}\pi_T^0 \to l\nu b\bar{b}$$
$$\rho_T^0 \to W^{\pm}\pi_T^{\pm} \to l\nu b\bar{c}$$

Generate 10,000 events at each Mass Combination

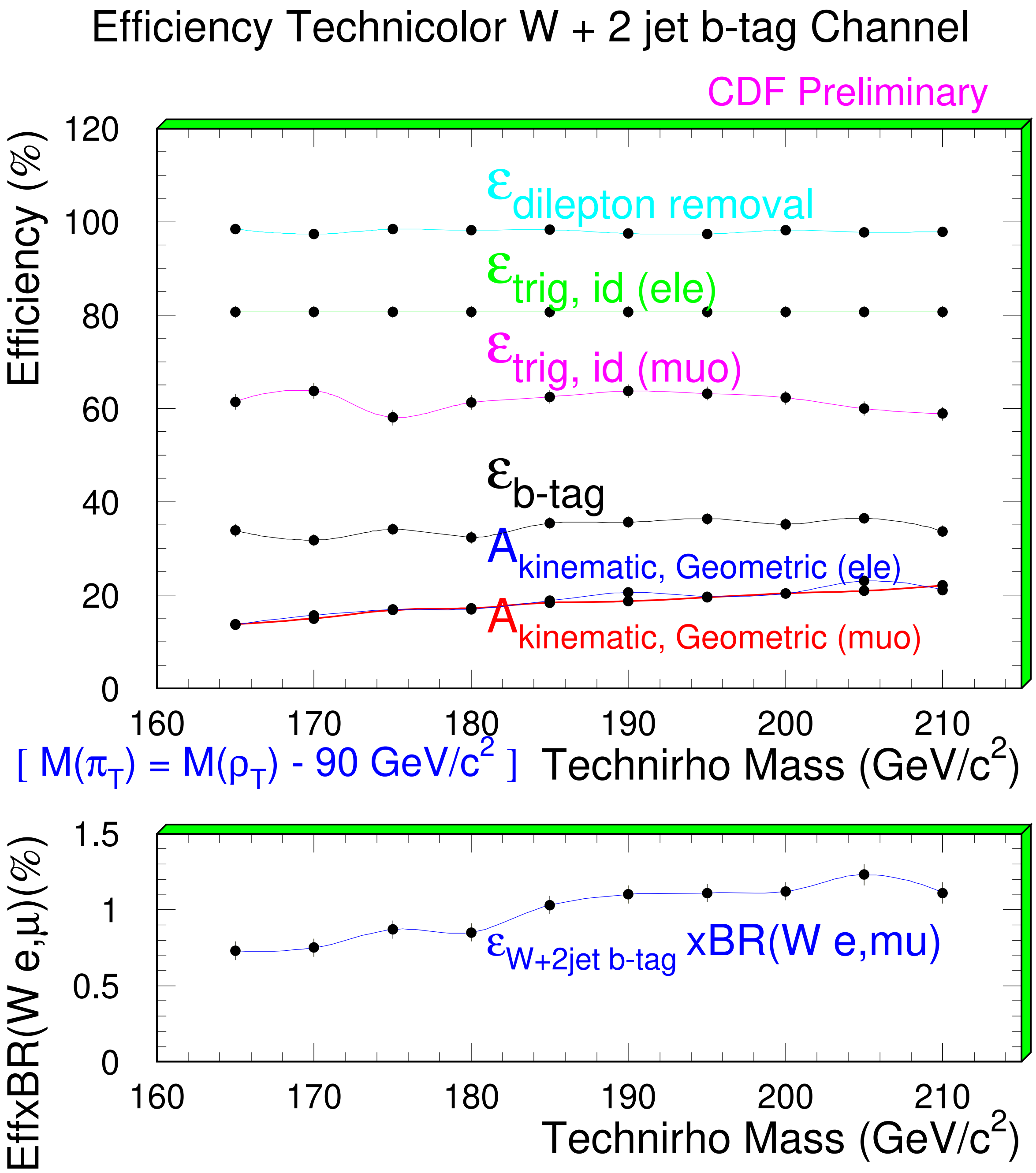
(force W$\to e\nu, \mu\nu$)

Mass Combination [M(π_T),M(ρ_T)]

[80,165] [80,170] [80,180]
[83,165] [83,167] [83,170] [83,175]
[84,165] [84,168] [84,175]
[85,168] [85,170] [85,175] [85,180]
[90,173] [90,175] [90,180] [90,185] [90,190]
[95,178] [95,180] [95,185] [95,190] [95,195]
[100,183] [100,185] [100,190] [100,195] [100,200] [100,205] [100,210]
[105,188] [105,190] [105,195] [105,200] [105,205] [105,210]
[110,193] [110,195] [110,200] [110,205] [110,210] [110,220]
[115,198] [115,200] [115,205] [115,210] [115,215]
[120,210] [120,220] [120,230]

$$\varepsilon_{W+2\,jet\ b\text{-}tag} = A_{kin,geom} \cdot \varepsilon_{trig} \cdot \varepsilon_{l_{id}} \cdot \varepsilon_{dil,Zremoval} \cdot \varepsilon_{b-tag} \cdot SF_{id} \cdot SF_{b-tag}$$
$$A_{kin,geom} = A_{l\_fid} \cdot A_{E_{T_l}} \cdot A_{l\_iso} \cdot A_{\not{E}_T} \cdot A_{2\,jet} \cdot A_{zvtx}$$

$$SF_{id} = \frac{\varepsilon_{trig}^{DATA} \cdot \varepsilon_{l_id}^{DATA}}{\varepsilon_{trig}^{MC} \cdot \varepsilon_{l_id}^{MC}} \qquad SF_{b-tag} = \frac{\varepsilon_{b-tag}^{MCDegrade}}{\varepsilon_{b-tag}^{MC}}$$



Efficiency Technicolor W + 2 jet b-tag Channel
CDF Preliminary
Efficiency (%)
ε dilepton removal
ε trig, id (ele)
ε trig, id (muo)
ε b-tag
A kinematic, Geometric (ele)
A kinematic, Geometric (muo)
[M(π_T) = M(ρ_T) - 90 GeV/c^2]
Technirho Mass (GeV/c^2)
EffxBR(W e,μ)(%)
ε W+2jet b-tag xBR(W e,mu)
Technirho Mass (GeV/c^2)

Signal Efficiency and Expected Number of events

W + 2 jet with SVX b-tag.

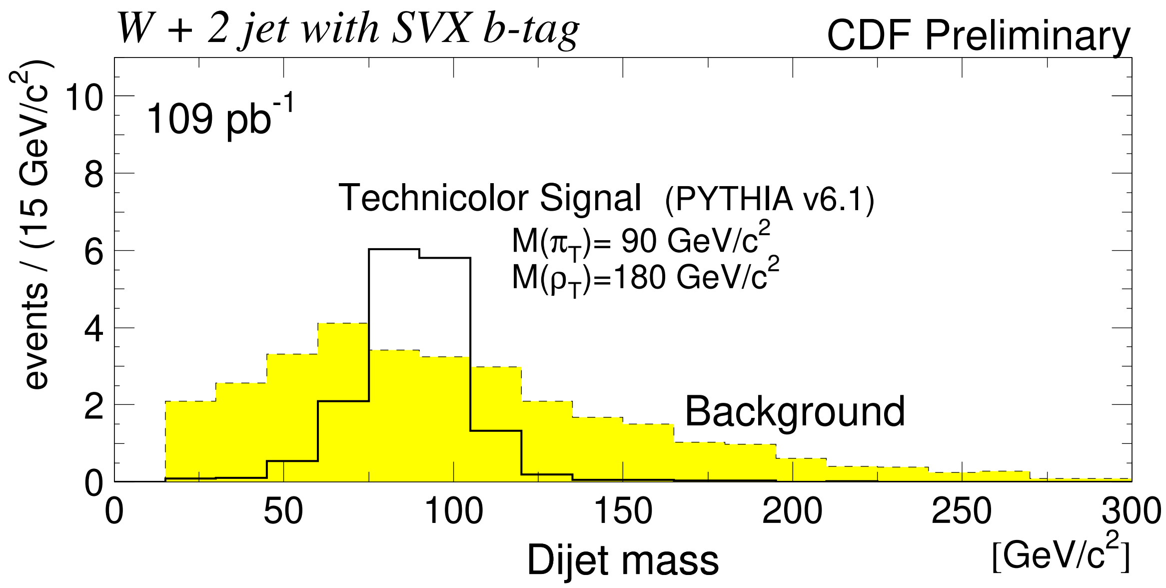
CDF Preliminary

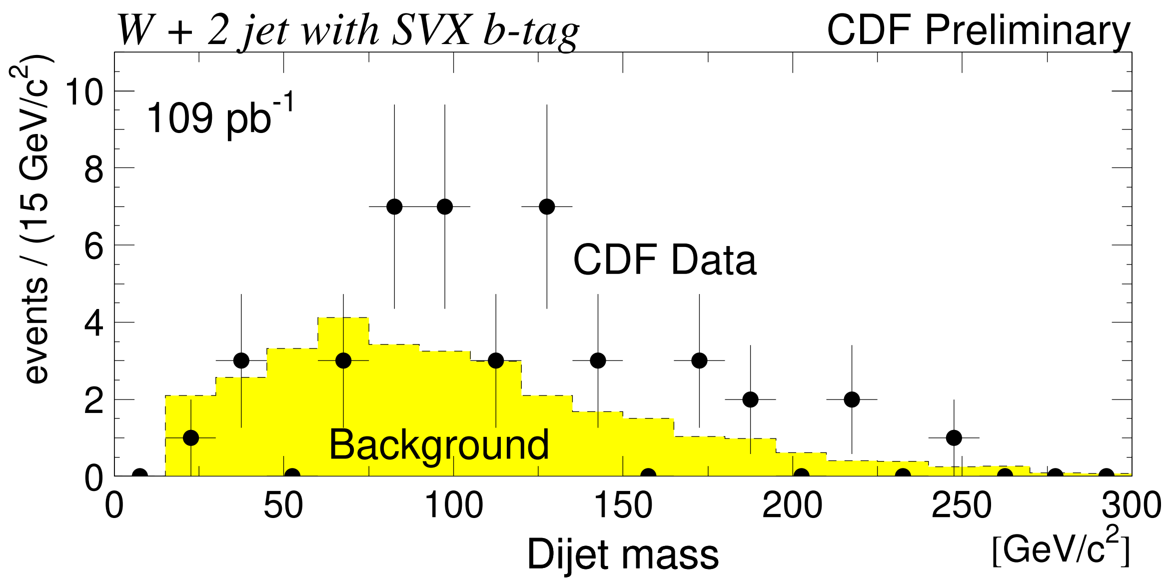
M_{π_T}, M_{ρ_T} $[GeV/c^2]$	σ	$\varepsilon \cdot BR(W \to e, \mu)$	N_{expect}(109 pb^{-1})
80,165	4.2 pb	0.73 %	3.3 events
80,170	4.1 pb	0.78 %	3.5 events
80,180	3.1 pb	0.74 %	2.5 events
85,170	15.4 pb	0.87 %	14.6 events
85,175	7.5 pb	0.75 %	6.1 events
85,180	5.1 pb	0.80 %	4.4 events
90,175	12.9 pb	0.93 %	13.1 events
90,180	17.6 pb	0.85 %	16.4 events
90,185	8.4 pb	0.89 %	8.1 events
95,180	10.7 pb	1.06 %	12.4 events
95,185	14.2 pb	1.03 %	15.9 events
95,190	13.8 pb	0.93 %	13.9 events
100,190	12.0 pb	1.11 %	14.5 events
100,195	12.0 pb	0.99 %	12.9 events
100,200	10.9 pb	0.95 %	11.3 events
105,195	10.1 pb	1.11 %	12.2 events
105,200	10.4 pb	1.10 %	12.5 events
105,205	9.3 pb	0.99 %	10.0 events
110,200	8.4 pb	1.12 %	10.2 events
110,205	8.9 pb	1.14 %	11.0 events
110,210	8.1 pb	1.07 %	9.5 events
115,205	7.2 pb	1.23 %	9.7 events
115,210	7.7 pb	1.17 %	9.8 events
115,215	7.2 pb	1.11 %	8.7 events

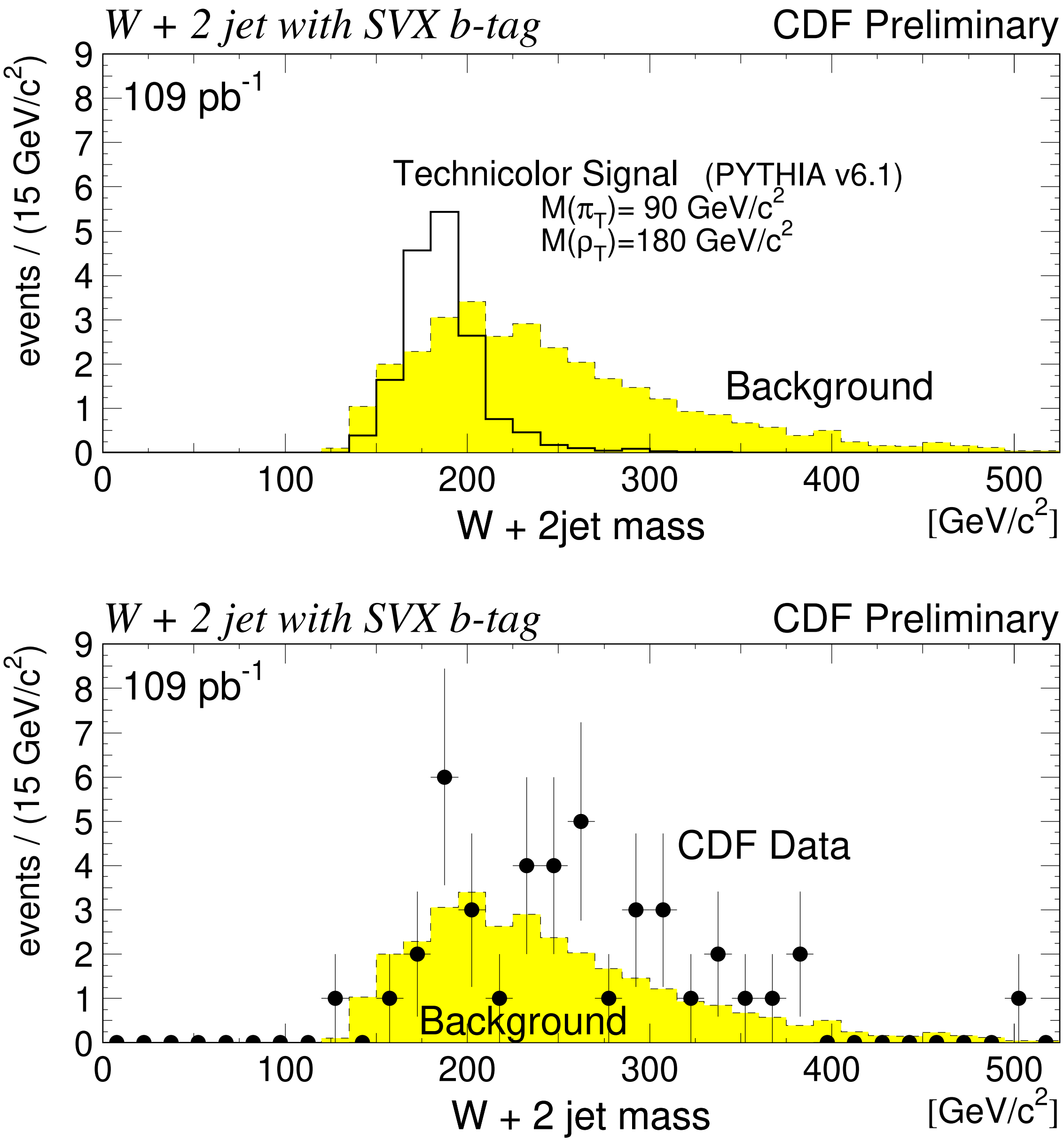
W + 2 jet at least 1 b-tag Background

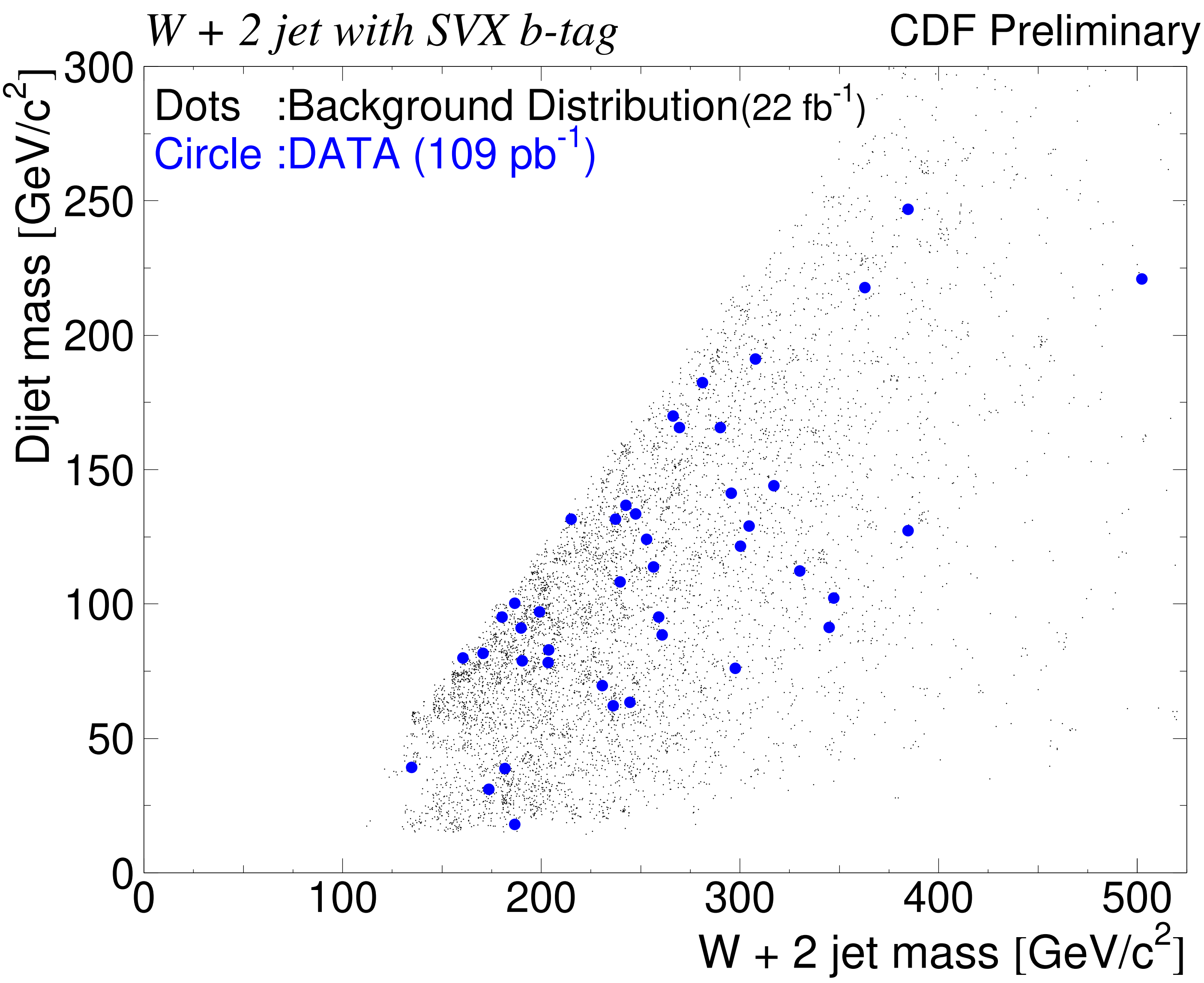
CDF Preliminary

Source	Distribution	N_{event} (109 pb^{-1})
Mistag	DATA (W + 2 jet)	5.1±2.0
Wbb Wcc	Herwig	9.4±2.5
Z+h.f.	VECBOS	1.4±0.5
Wc	Herwig	4.6±1.5
WW,WZ,Z$\tau\tau$	PYTHIA	1.5±0.5
non-W	DATA($\not{E}_T$,Iso method)	2.1±1.3
$t\bar{t}$	Herwig(σ=7.5 pb)	5.1±1.9
single top	Herwig(W* and Wg)	2.4±0.8
TOTAL		31.6±4.3


W + 2 jet with SVX b-tag
CDF Preliminary
109 pb-1
Technicolor Signal (PYTHIA v6.1)
M(πT)= 90 GeV/c2
M(ρT)=180 GeV/c2
Background
events / (15 GeV/c2)
Dijet mass
[GeV/c2]


W + 2 jet with SVX b-tag
CDF Preliminary
109 pb-1
CDF Data
Background
events / (15 GeV/c2)
Dijet mass
[GeV/c2]


W + 2 jet with SVX b-tag
CDF Preliminary
109 pb^{-1}
events / (15 GeV/c^2)
Technicolor Signal (PYTHIA v6.1)
M(π_T)= 90 GeV/c^2
M(ρ_T)=180 GeV/c^2
Background
W + 2jet mass
[GeV/c^2]
W + 2 jet with SVX b-tag
CDF Preliminary
109 pb^{-1}
events / (15 GeV/c^2)
CDF Data
Background
W + 2 jet mass
[GeV/c^2]


W + 2 jet with SVX b-tag
CDF Preliminary
Dots :Background Distribution(22 fb^{-1})
Circle :DATA (109 pb^{-1})
Dijet mass [GeV/c^2]
W + 2 jet mass [GeV/c^2]
0
50
100
150
200
250
300
0
100
200
300
400
500

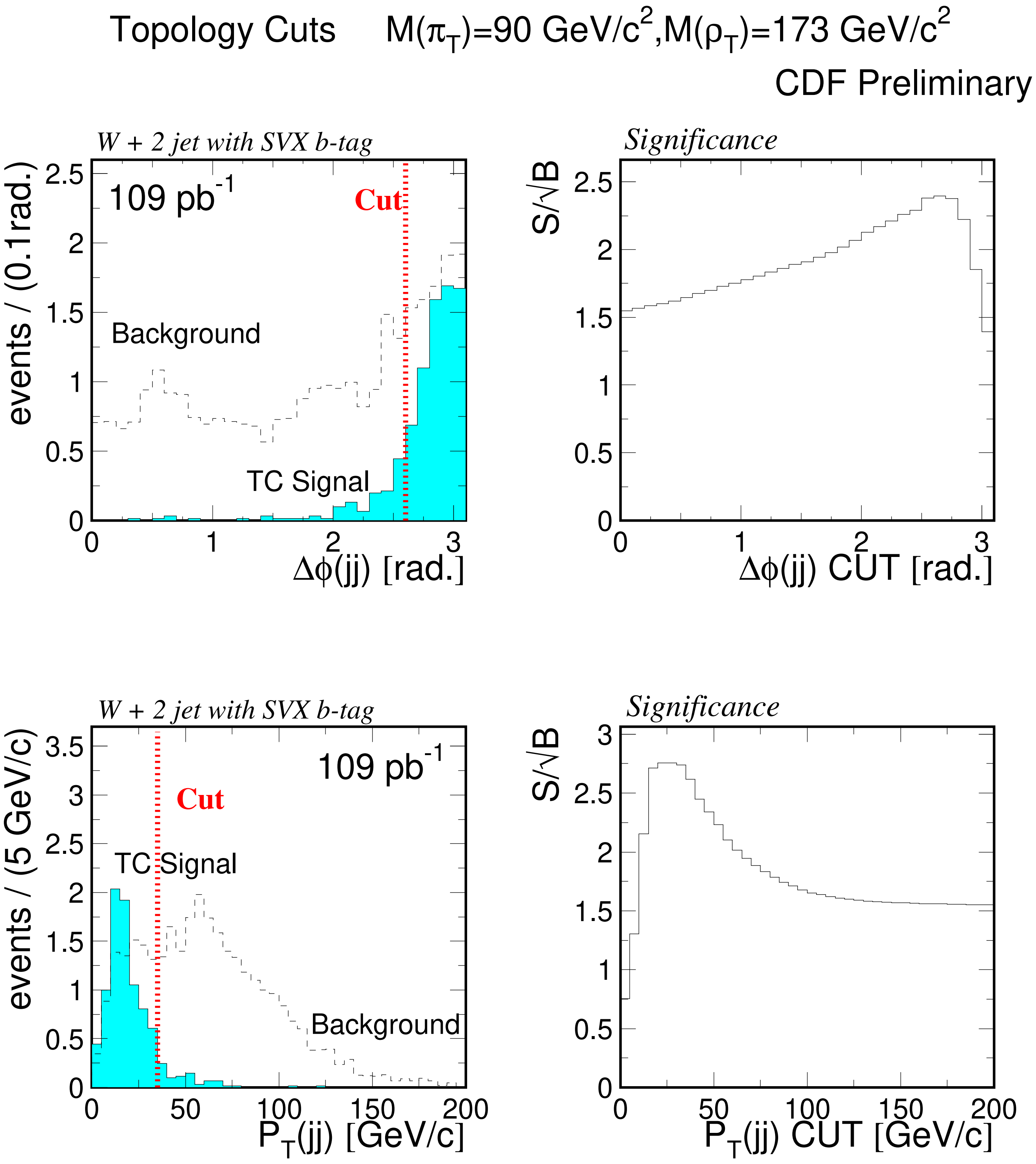
Topology Cuts

Reference : *'Finding Low Scale Technicolor at Hadron Colliders'*
by Estia Eichten, Kenneth Lane, and John Womersley,
Phys.Lett.B405:305-311,1997

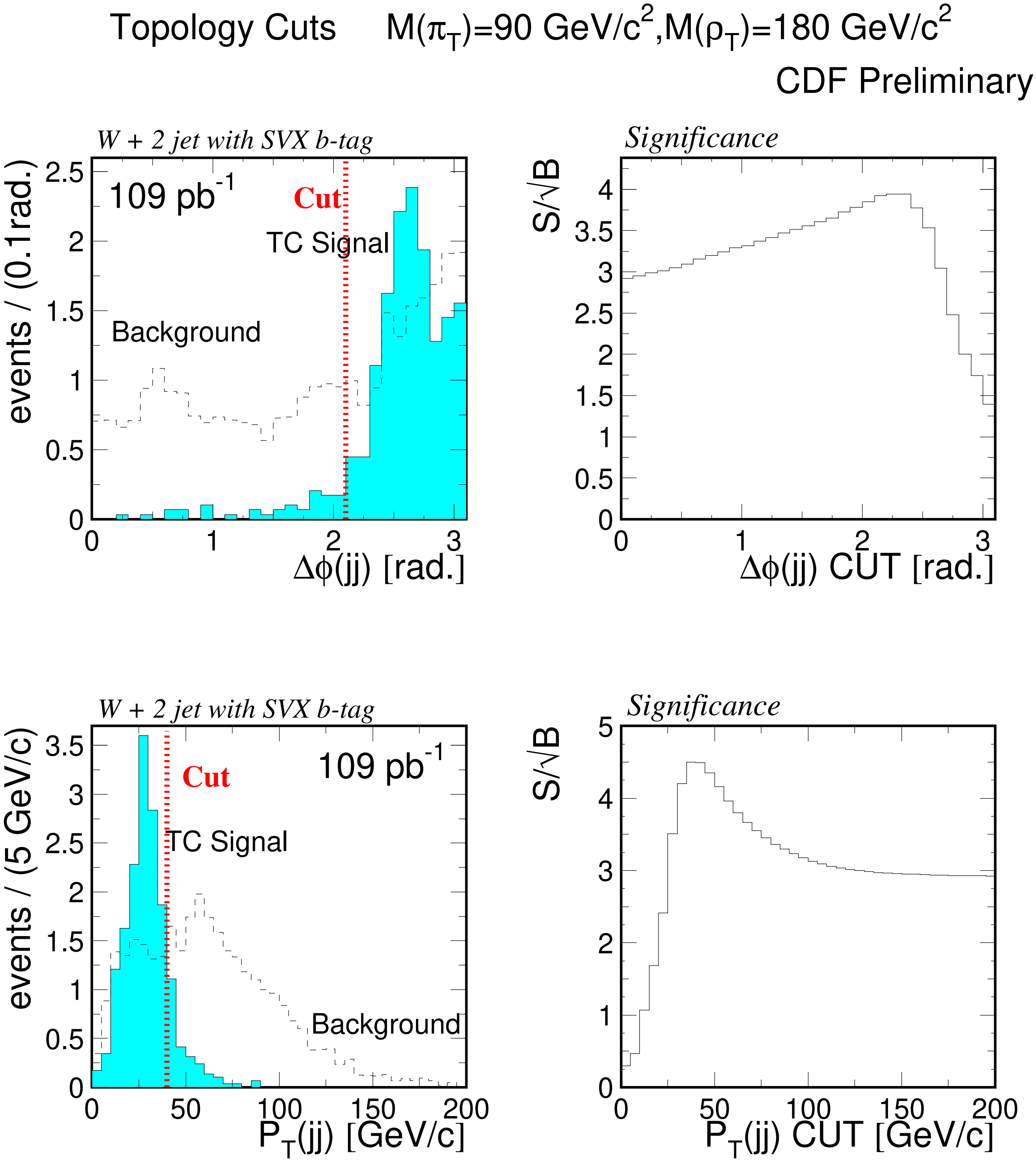
Apply these cuts in addition to W + 2 jet with SVX b-tag

1. $\Delta\phi$ between two jets : $\Delta\phi(jj)$
2. P_T of two jet system : $P_T(jj) \sim (P_T(\pi_T))$

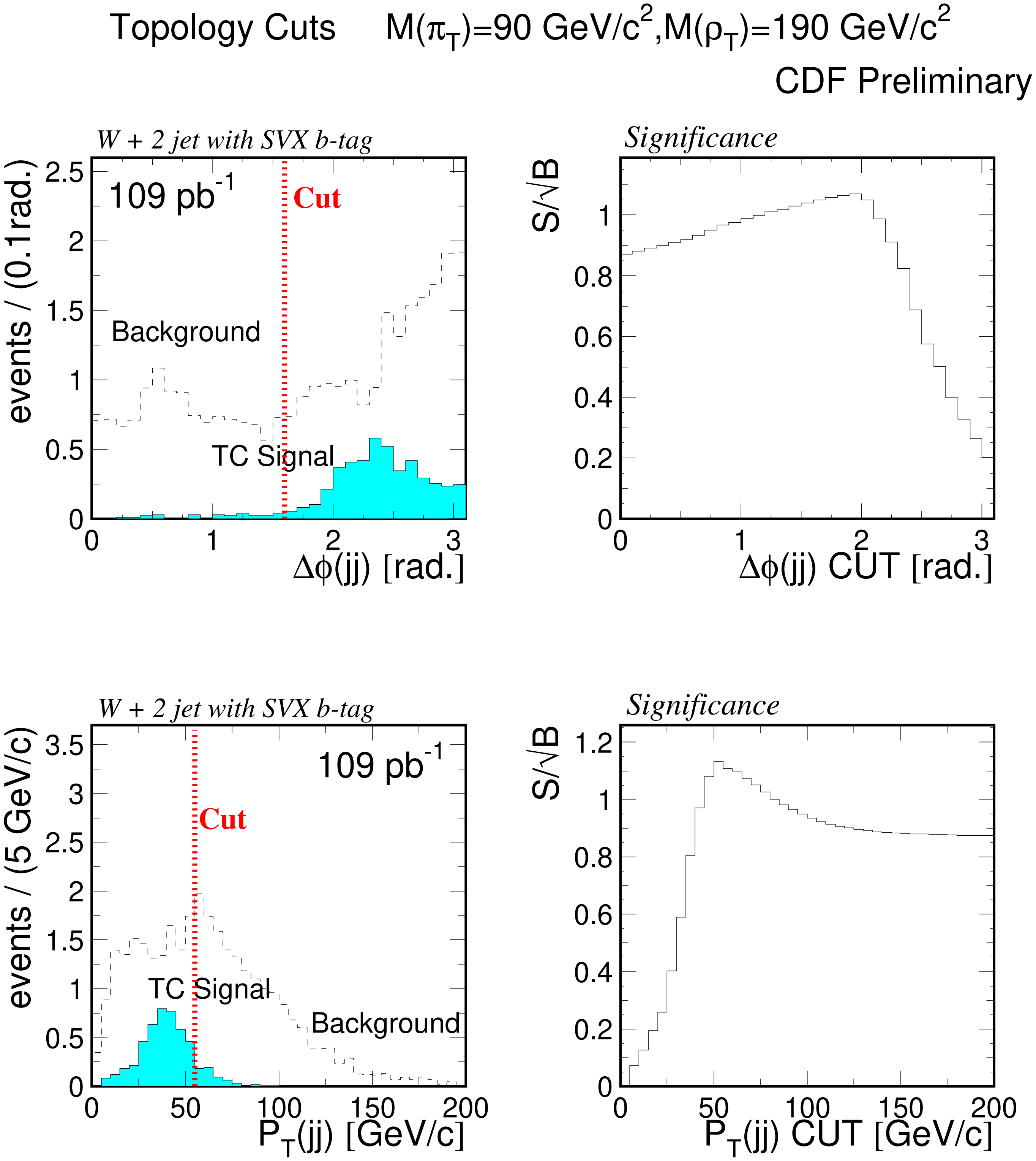
——> Optimized $S/\sqrt{B}$



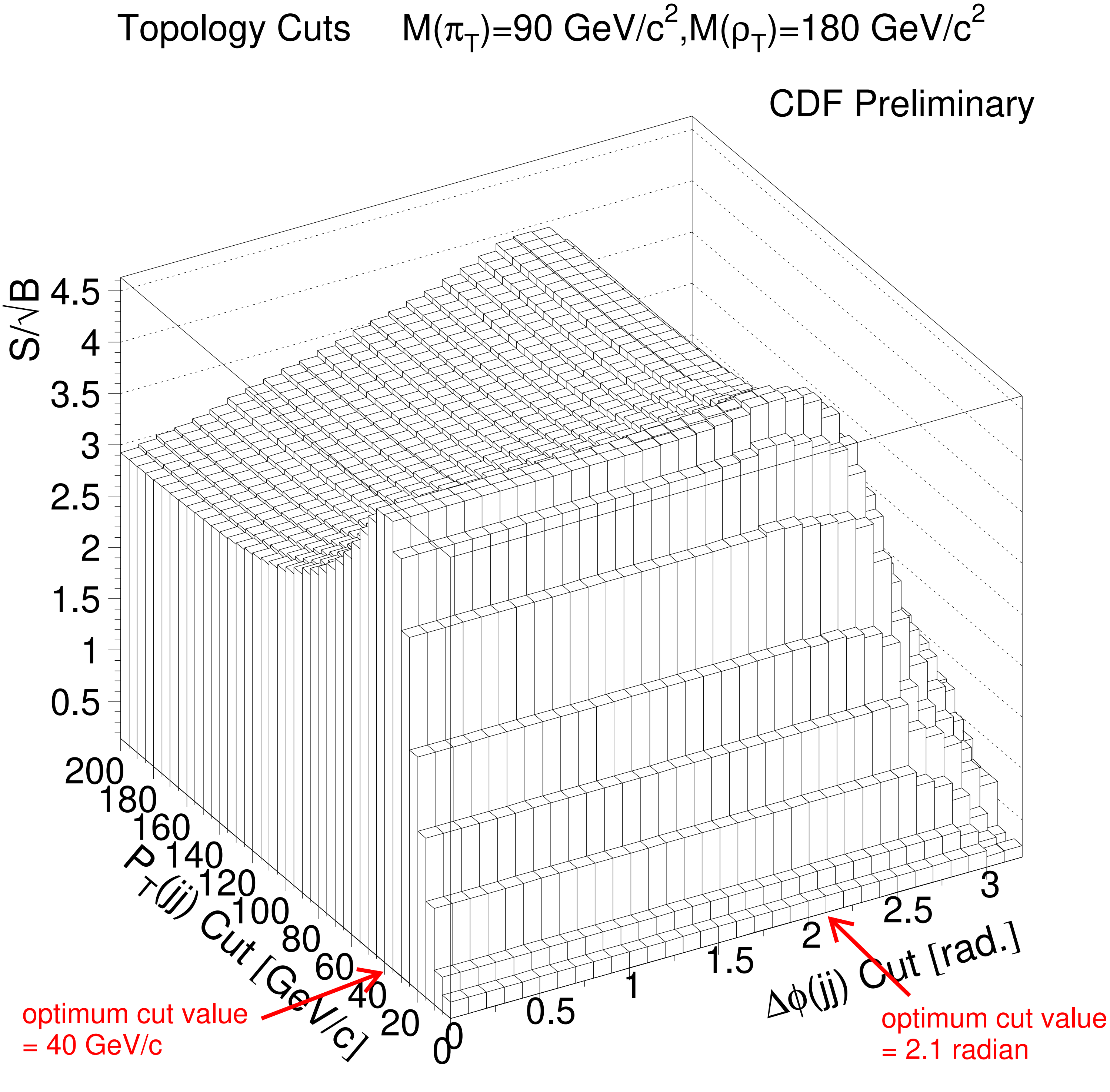
Topology Cuts
M(π_T)=90 GeV/c^2,M(ρ_T)=173 GeV/c^2
CDF Preliminary
W + 2 jet with SVX b-tag
109 pb^-1
Cut
Background
TC Signal
events / (0.1rad.)
Δφ(jj) [rad.]
Significance
S/√B
Δφ(jj) CUT [rad.]
W + 2 jet with SVX b-tag
109 pb^-1
Cut
TC Signal
Background
events / (5 GeV/c)
P_T(jj) [GeV/c]
Significance
S/√B
P_T(jj) CUT [GeV/c]



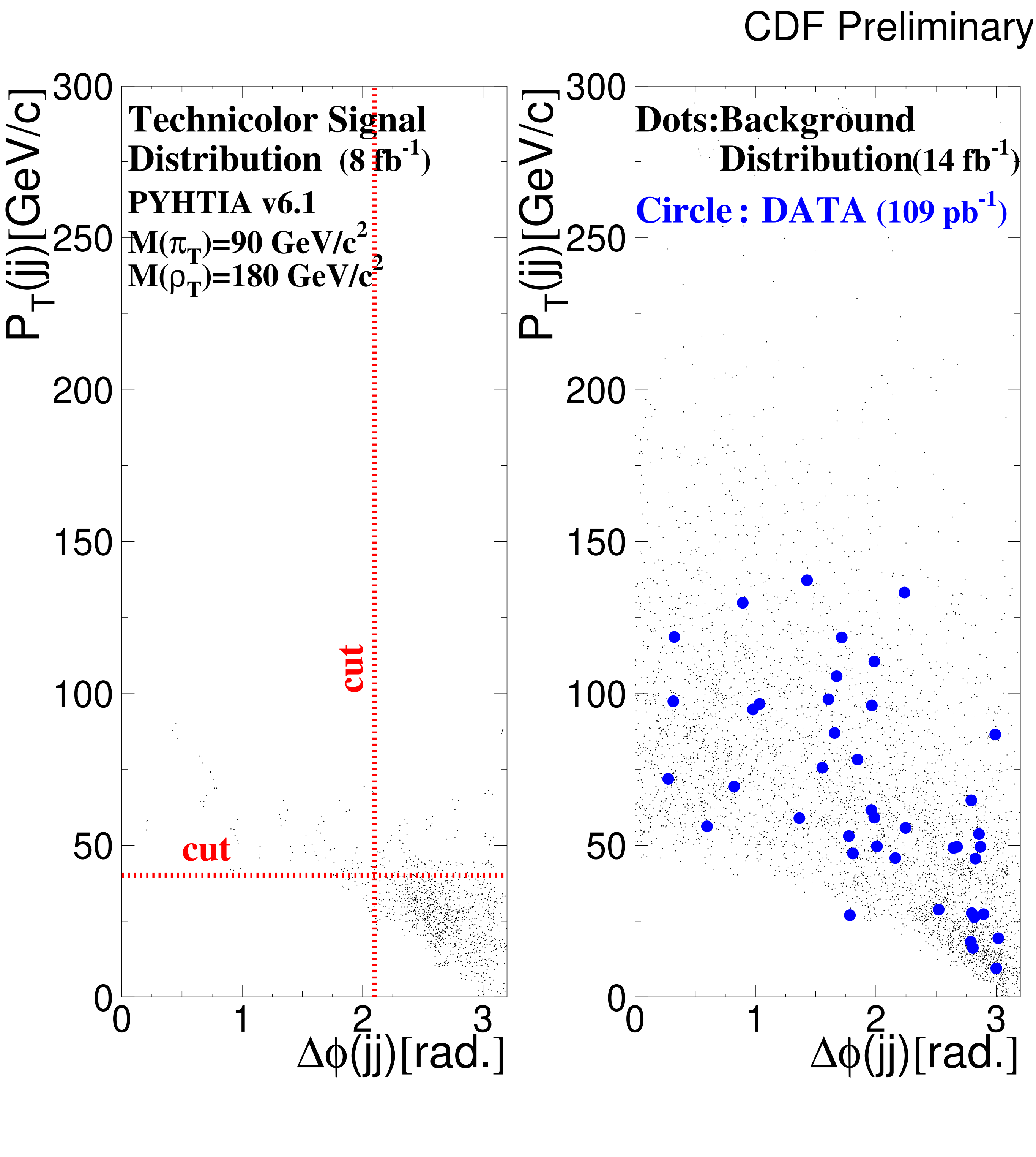
Topology Cuts M(π_T)=90 GeV/c^2,M(ρ_T)=180 GeV/c^2
CDF Preliminary
W + 2 jet with SVX b-tag
109 pb^-1
Cut
TC Signal
Background
events / (0.1rad.)
Δφ(jj) [rad.]
Significance
S/√B
Δφ(jj) CUT [rad.]
W + 2 jet with SVX b-tag
109 pb^-1
Cut
TC Signal
Background
events / (5 GeV/c)
P_T(jj) [GeV/c]
Significance
S/√B
P_T(jj) CUT [GeV/c]



Topology Cuts
$M(\pi_T)=90$ GeV/c^2, $M(\rho_T)=190$ GeV/c^2
CDF Preliminary
W + 2 jet with SVX b-tag
109 pb^{-1}
Cut
Background
TC Signal
events / (0.1rad.)
$\Delta\phi$(jj) [rad.]
Significance
$S/\sqrt{B}$
$\Delta\phi$(jj) CUT [rad.]
W + 2 jet with SVX b-tag
109 pb^{-1}
Cut
TC Signal
Background
events / (5 GeV/c)
P_T(jj) [GeV/c]
Significance
$S/\sqrt{B}$
P_T(jj) CUT [GeV/c]



Topology Cuts M(πT)=90 GeV/c2,M(ρT)=180 GeV/c2
CDF Preliminary
S/√B
4.5
4
3.5
3
2.5
2
1.5
1
0.5
200
180
160
140
120
100
80
60
40
20
0
PT(jj) Cut [GeV/c]
0
0.5
1
1.5
2
2.5
3
Δφ(jj) Cut [rad.]
optimum cut value
= 40 GeV/c
optimum cut value
= 2.1 radian



CDF Preliminary
Technicolor Signal Distribution (8 fb-1)
PYHTIA v6.1
M(πT)=90 GeV/c2
M(ρT)=180 GeV/c2
cut
cut
PT(jj)[GeV/c]
Δφ(jj)[rad.]
Dots:Background Distribution(14 fb-1)
Circle : DATA (109 pb-1)
PT(jj)[GeV/c]
Δφ(jj)[rad.]

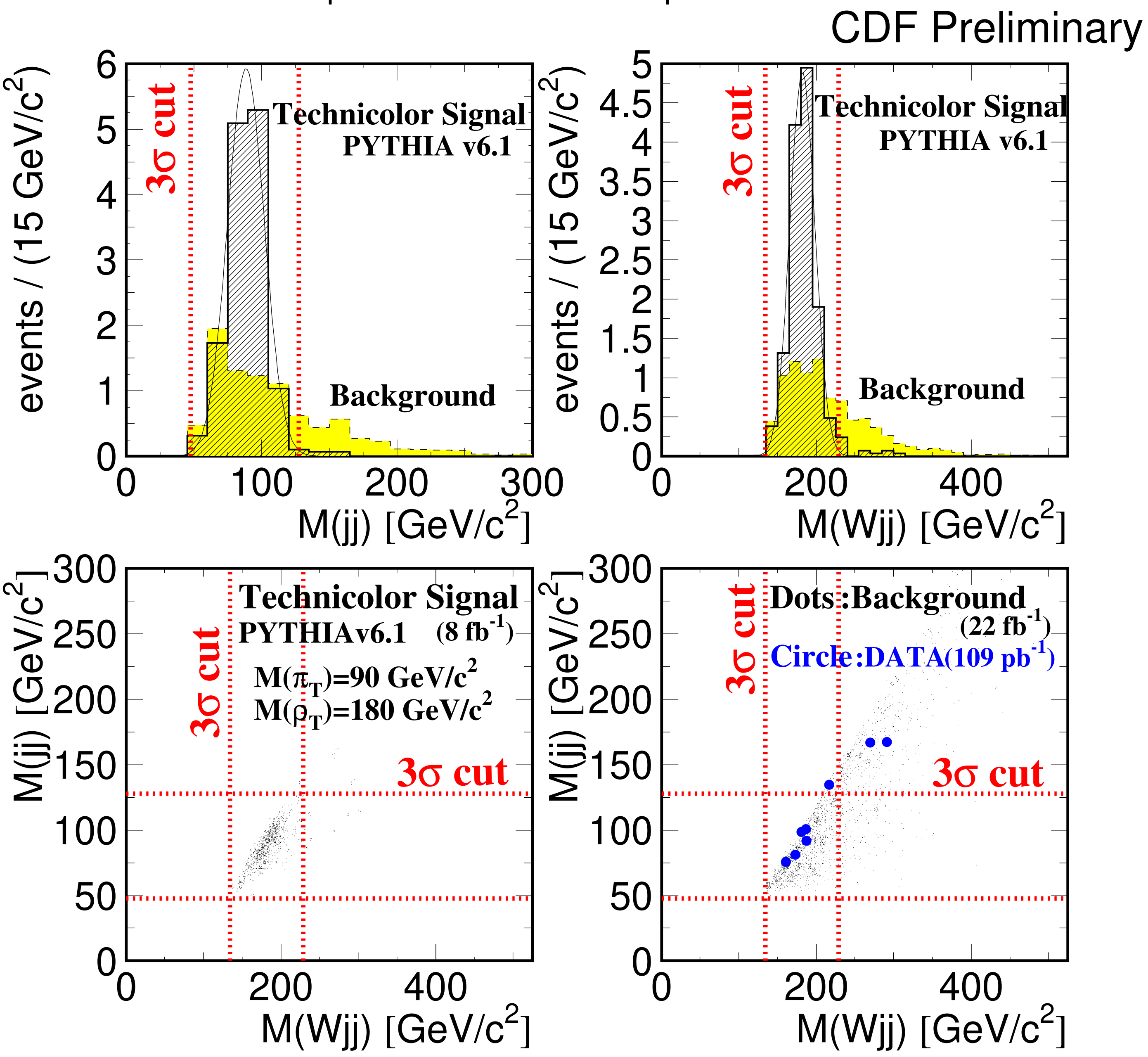
⋆ Topology Cuts

CDF Preliminary

M_{π_T}, M_{ρ_T}	Cut Value $\delta\phi$[rad],p_T[GeV/c]	Eff/B.G.Retain	$S/\sqrt{B}$ before Cuts		$S/\sqrt{B}$ after Cuts
80,165	2.2, 30	84.0 % / 21.3 %	0.6	→	1.1
80,170	2.0, 40	85.4 % / 28.2 %	0.6	→	1.0
80,175	1.5, 55	86.2 % / 41.9 %	0.4	→	0.6
85,170	2.5, 30	84.6 % / 18.8 %	2.6	→	4.7
85,175	2.1, 40	78.8 % / 27.7 %	1.1	→	1.7
85,180	1.9, 50	83.0 % / 35.9 %	0.8	→	1.2
90,175	2.5, 35	80.3 % / 21.2 %	2.3	→	4.1
90,180	2.1, 40	83.5 % / 27.7 %	2.9	→	4.6
90,185	2.0, 55	87.4 % / 37.3 %	1.4	→	2.1
95,180	2.3, 40	89.3 % / 26.4 %	2.2	→	3.8
95,185	2.0, 45	88.6 % / 32.1 %	2.8	→	4.4
95,190	1.9, 50	90.1 % / 35.9 %	2.5	→	3.7
100,190	2.0, 40	85.3 % / 28.2 %	2.6	→	4.1
100,195	2.1, 55	87.9 % / 36.0 %	2.3	→	3.4
100,200	1.8, 65	91.5 % / 45.7 %	2.0	→	2.7
105,195	2.2, 45	87.9 % / 30.7 %	2.2	→	3.4
105,200	2.1, 55	87.7 % / 36.0 %	2.2	→	3.3
105,205	1.9, 60	90.1 % / 41.6 %	1.8	→	2.5
110,200	2.1, 50	91.2 % / 33.7 %	1.8	→	2.9
110,205	2.0, 55	89.1 % / 37.3 %	2.0	→	2.9
110,210	1.9, 65	92.0 % / 43.8 %	1.7	→	2.3
115,205	2.2, 55	93.5 % / 34.8 %	1.7	→	2.7
115,210	2.0, 55	89.1 % / 37.3 %	1.7	→	2.5
115,215	2.1, 65	89.3 % / 40.1 %	1.5	→	2.2

Mass Window Cuts after Topology Cuts

$M(\pi_T)$=90 GeV/c^2,$M(\rho_T)$=180 GeV/c^2



$\star$ Mass Window cuts(3σ) after Topology Cuts

CDF Preliminary

M_{π_T}, M_{ρ_T}	Efficiency	B.G. retain
80,165	96.7 %	60.9 %
80,170	96.1 %	60.6 %
80,175	96.1 %	57.4 %
85,170	95.3 %	64.0 %
85,175	96.5 %	62.8 %
85,180	95.4 %	57.3 %
90,175	97.7 %	62.7 %
90,180	97.0 %	65.1 %
90,185	97.1 %	61.1 %
95,180	97.8 %	67.0 %
95,185	97.6 %	64.1 %
95,190	96.4 %	65.0 %
100,190	97.5 %	70.5 %
100,195	97.0 %	66.2 %
100,200	97.4 %	67.8 %
105,195	97.4 %	68.0 %
105,200	97.4 %	65.0 %
105,205	97.4 %	66.9 %
110,200	98.0 %	70.4 %
110,205	98.7 %	69.6 %
110,210	97.5 %	70.8 %
115,205	98.0 %	74.6 %
115,210	98.7 %	71.3 %
115,215	97.5 %	71.0 %

⋆ Systematic Uncertainties

CDF Preliminary

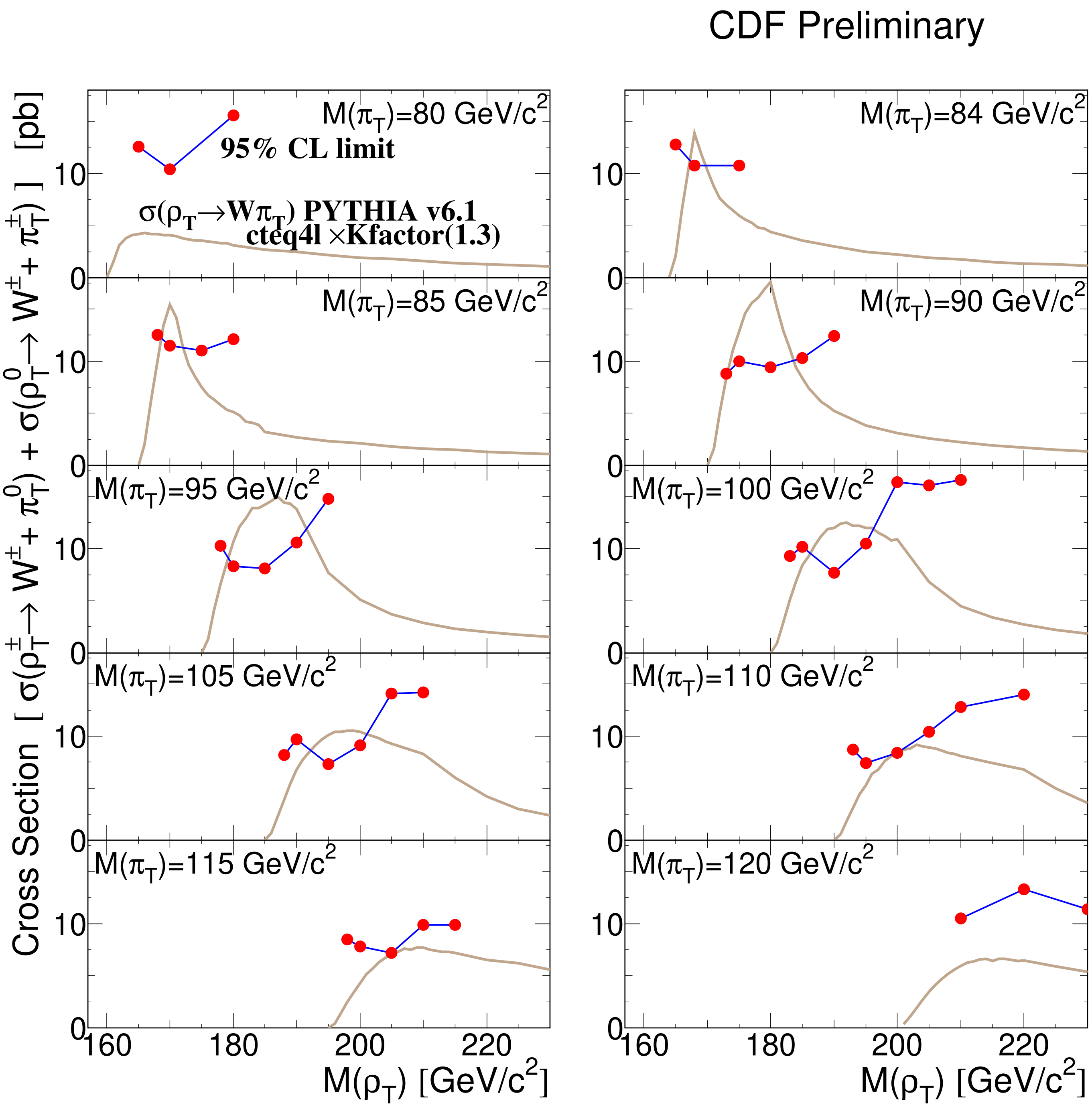
Source	M_{π_T}, M_{ρ_T} 85,170	M_{π_T}, M_{ρ_T} 90,180	M_{π_T}, M_{ρ_T} 100,200	M_{π_T}, M_{ρ_T} 110,200
Initial State Radiation	9 %	10 %	11 %	11 %
Final state Radiation	15 %	19 %	17 %	15 %
pdflib	8 %	6 %	4 %	4 %
Jet Energy Scale	5 %	4 %	1 %	2 %
Lepton ID	5 %	5 %	5 %	5 %
b-tag	9 %	9 %	9 %	9 %
Luminosity	7 %	7 %	7 %	7 %
MC Statistics	5 %	4 %	4 %	4 %
TOTAL	24 %	26 %	24 %	23 %

Apply 26 % systematic uncertainty for all the mass combinations

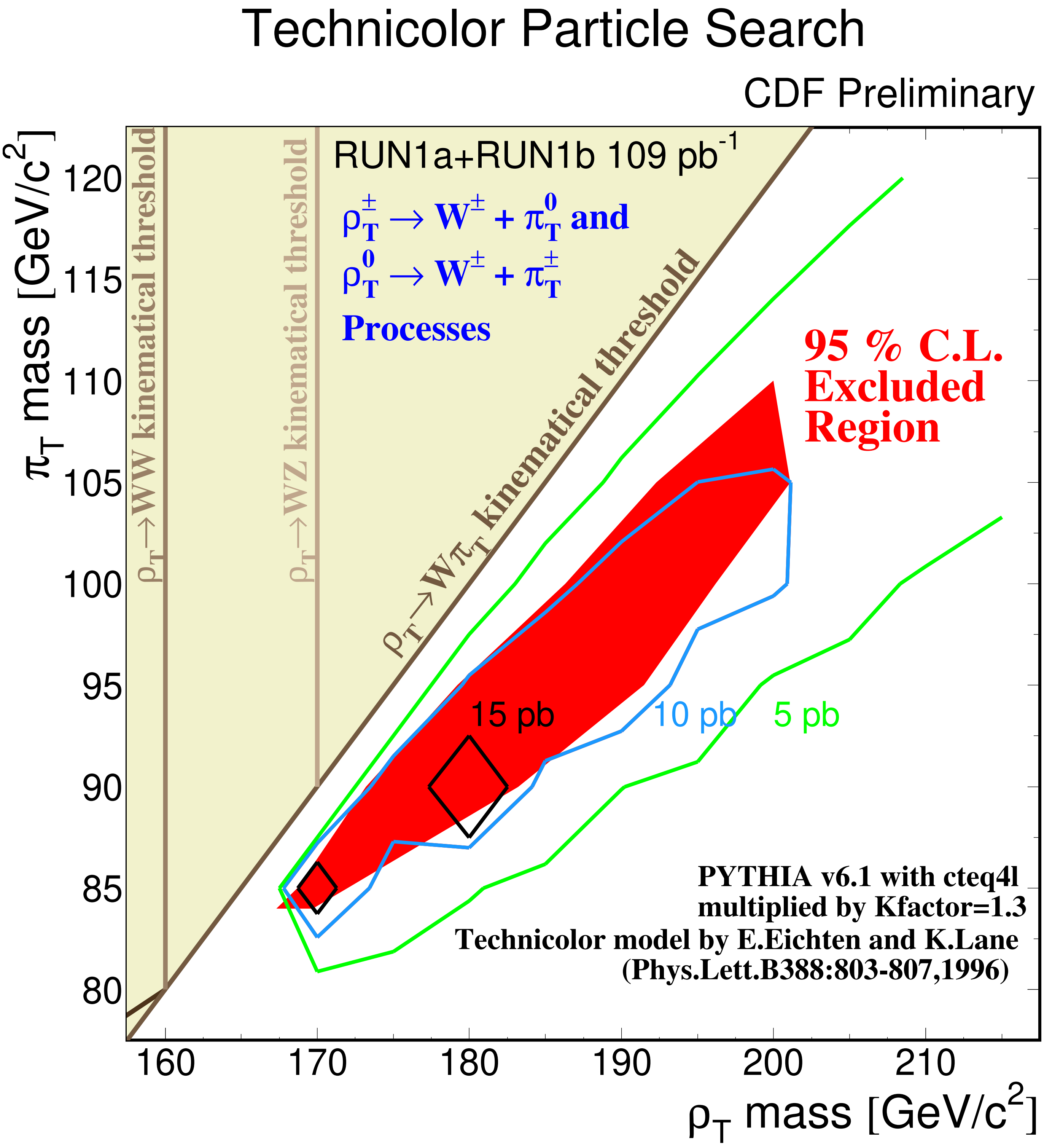
⋆ Number of events & Cross Section Limits

CDF Preliminary

M_{π_T}, M_{ρ_T}	σ	$N^{allcuts}_{Signal}$ (109 pb^{-1})	$N^{allcuts}_{B.K.}$ (109 pb^{-1})	DATA	95 % C.L. limits $N_{95\,\%limit}$	$\sigma_{95\,\%limit}$
80,165	4.2 pb	2.7	4.1±0.6	5	8.1	12.6 pb
80,170	4.1 pb	2.9	5.4±0.7	5	7.2	10.4 pb
80,175	3.1 pb	2.1	7.6±1.0	9	10.4	15.6 pb
85,170	15.4 pb	11.1	3.8±0.5	5	8.3	11.5 pb
85,175	7.5 pb	4.9	5.5±0.8	5	7.2	11.0 pb
85,180	5.1 pb	3.7	6.5±0.9	7	8.8	12.1 pb
90,175	12.9 pb	10.3	4.2±0.6	5	8.0	10.0 pb
90,180	17.6 pb	13.3	5.7±0.8	5	7.1	9.4pb
90,185	8.4 pb	6.9	7.2±1.0	7	8.4	10.3 pb
95,180	10.7 pb	10.8	5.6±0.8	6	8.3	8.3 pb
95,185	14.2 pb	13.7	6.4±0.9	6	7.8	8.1 pb
95,190	13.8 pb	12.1	7.5±1.0	8	9.3	10.6 pb
100,190	12.0 pb	12.1	6.5±0.9	6	7.7	7.7 pb
100,195	12.0 pb	10.9	7.1±1.0	8	9.6	10.5 pb
100,200	10.9 pb	10.0	9.7±1.3	14	15.1	16.4 pb
105,195	10.1 pb	10.4	6.6±0.9	6	7.6	7.3 pb
105,200	10.4 pb	10.7	7.4±1.0	8	9.3	9.1 pb
105,205	9.3 pb	8.8	8.8±1.2	12	13.3	14.1 pb
110,200	8.4 pb	9.1	7.5±1.0	8	9.2	8.4 pb
110,205	8.9 pb	9.5	8.2±1.1	10	11.2	10.4 pb
110,210	8.1 pb	8.6	9.8±1.3	13	13.6	12.8 pb
115,205	7.2 pb	8.9	8.2±1.1	8	8.8	7.2 pb
115,210	7.7 pb	8.5	8.4±1.2	10	11.0	9.9 pb
115,215	7.2 pb	7.6	9.0±1.2	10	10.5	9.9 pb



CDF Preliminary
Cross Section [$\sigma(\rho_T^{\pm} \to W^{\pm} + \pi_T^0) + \sigma(\rho_T^0 \to W^{\pm} + \pi_T^{\pm})$] [pb]
95% CL limit
$\sigma(\rho_T \to W\pi_T)$ PYTHIA v6.1
cteq4l ×Kfactor(1.3)
$M(\pi_T)$=80 GeV/c^2
$M(\pi_T)$=84 GeV/c^2
$M(\pi_T)$=85 GeV/c^2
$M(\pi_T)$=90 GeV/c^2
$M(\pi_T)$=95 GeV/c^2
$M(\pi_T)$=100 GeV/c^2
$M(\pi_T)$=105 GeV/c^2
$M(\pi_T)$=110 GeV/c^2
$M(\pi_T)$=115 GeV/c^2
$M(\pi_T)$=120 GeV/c^2
$M(\rho_T)$ [GeV/c^2]


Technicolor Particle Search
CDF Preliminary
RUN1a+RUN1b 109 pb^{-1}
$\rho_T^{\pm} \to W^{\pm} + \pi_T^0$ and
$\rho_T^0 \to W^{\pm} + \pi_T^{\pm}$
Processes
95 % C.L.
Excluded
Region
$\rho_T \to WW$ kinematical threshold
$\rho_T \to WZ$ kinematical threshold
$\rho_T \to W\pi_T$ kinematical threshold
15 pb
10 pb
5 pb
PYTHIA v6.1 with cteq4l
multiplied by Kfactor=1.3
Technicolor model by E.Eichten and K.Lane
(Phys.Lett.B388:803-807,1996)
π_T mass [GeV/c^2]
ρ_T mass [GeV/c^2]

Summary

- Using 1A + 1B sample of $109\,\mathrm{pb}^{-1}$, we exclude some π_T and ρ_T masses of the Walking Technicolor model in W + 2 jet decay mode.
- We plan to continue this search in multijet mode and combine results with leptonic W + 2 jet mode.