$t\bar{t}$ production cross section in $t\bar{t} \to \ell(\equiv e, \mu) + Jets$ mode

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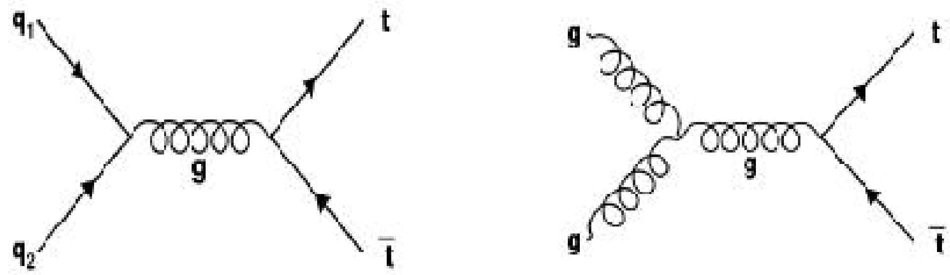
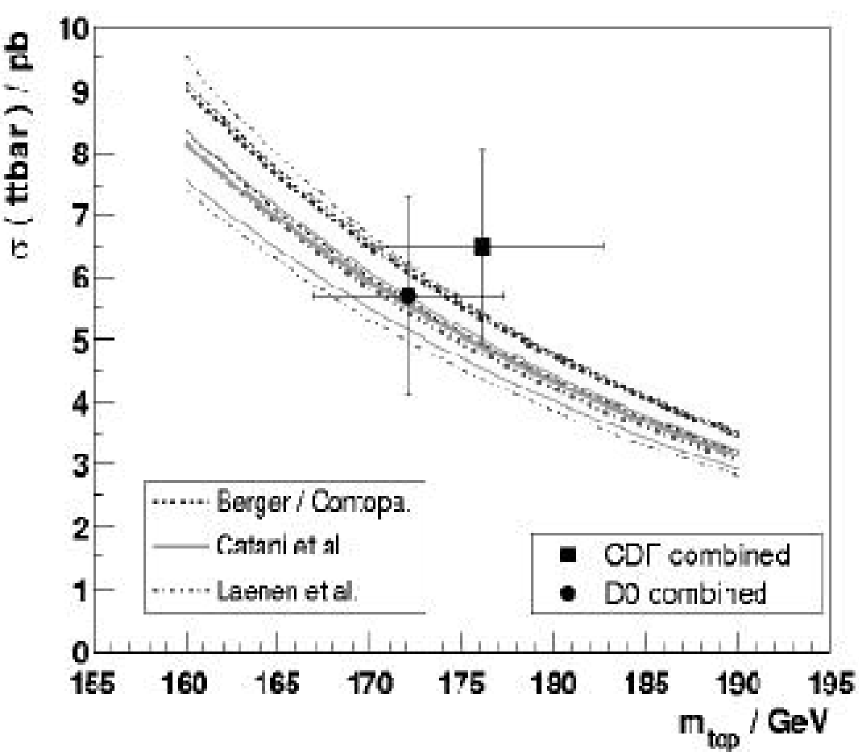
Introduction, 1

- Pair production of top quarks via strong interaction



- In Run2 ($\sqrt{s} = 1.96$ TeV) we expect $\sim 30\%$ higher production cross section than Run1 ($\sqrt{s} = 1.8$ TeV).

Run1 (CDF, all channels): $\sigma(p\bar{p} \to t\bar{t}X) = 6.5^{+1.7}_{-1.4}$ pb

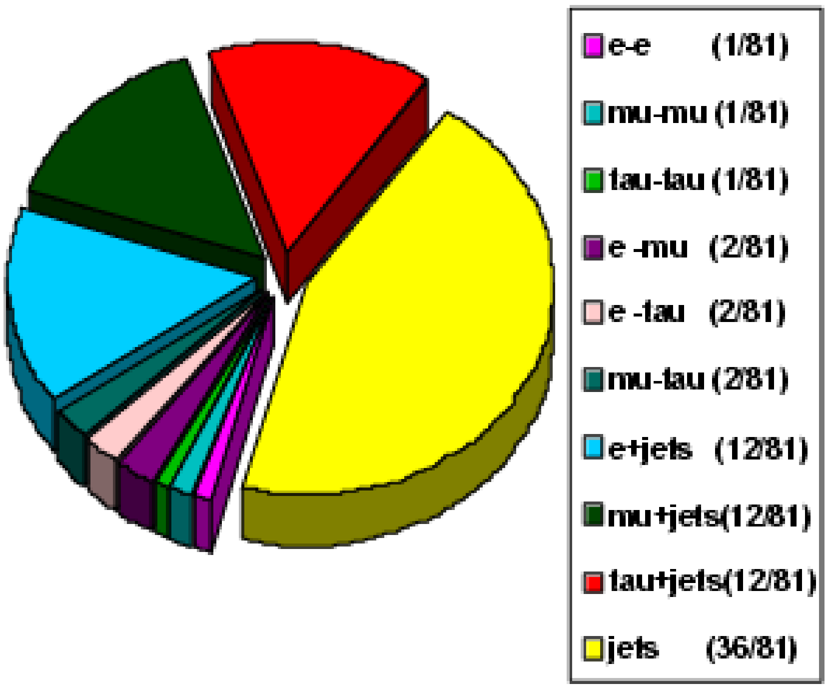


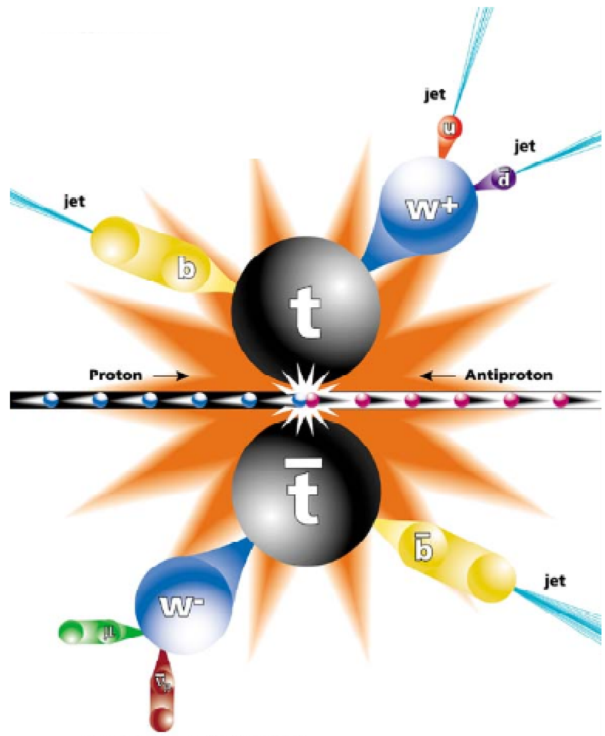
Introduction, 2

- Assume 100% $t \rightarrow W^{+}b$, and $\bar{t} \rightarrow W^{-}\bar{b}$.

Decay possibilities of W determine $t\bar{t}$ decay mode.

Almost 30% of the time we get $t\bar{t} \rightarrow \ell(\equiv e, \mu) + Jets$.





- Cross section measurement: $\sigma(t\bar{t}) = \frac{N_{obs} - N_{bkg}}{\epsilon_{t\bar{t}} \cdot \int Ldt}$

N_{obs} observed events with signal characteristics

N_{bkg} background events with signal characteristics

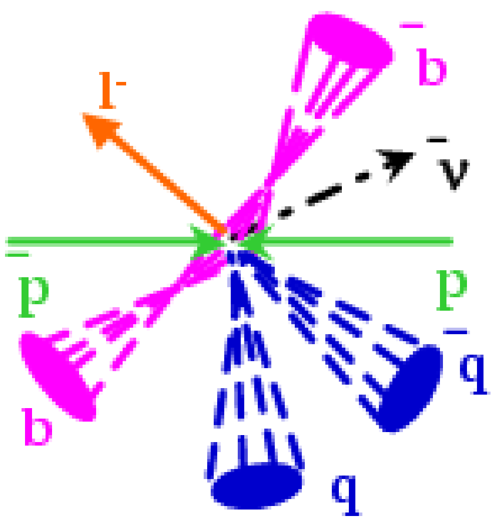
$\epsilon_{t\bar{t}}$ efficiency for detecting signal events

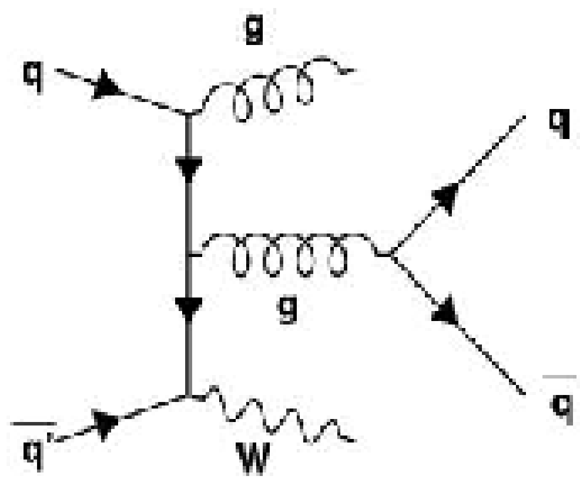
$\int Ldt$ integrated luminosity of dataset used.

Experimental signature and backgrounds: $\ell + Jets$

$t\bar{t} \rightarrow \ell(\equiv e, \mu) + Jets$

- One energetic and isolated lepton: $p_T > 20$ GeV/c
  $Iso \equiv$ extra energy in $R \leq 0.4$ of lepton / $p_T(\ell) < 0.1$
- Missing energy from neutrino ($E_T^{miss} > 20$ GeV)
- (Ideally 4) "tight" jets ($E_T > 15$ GeV at $|\eta| < 2$)
- At least one jet "tagged" as b-jet



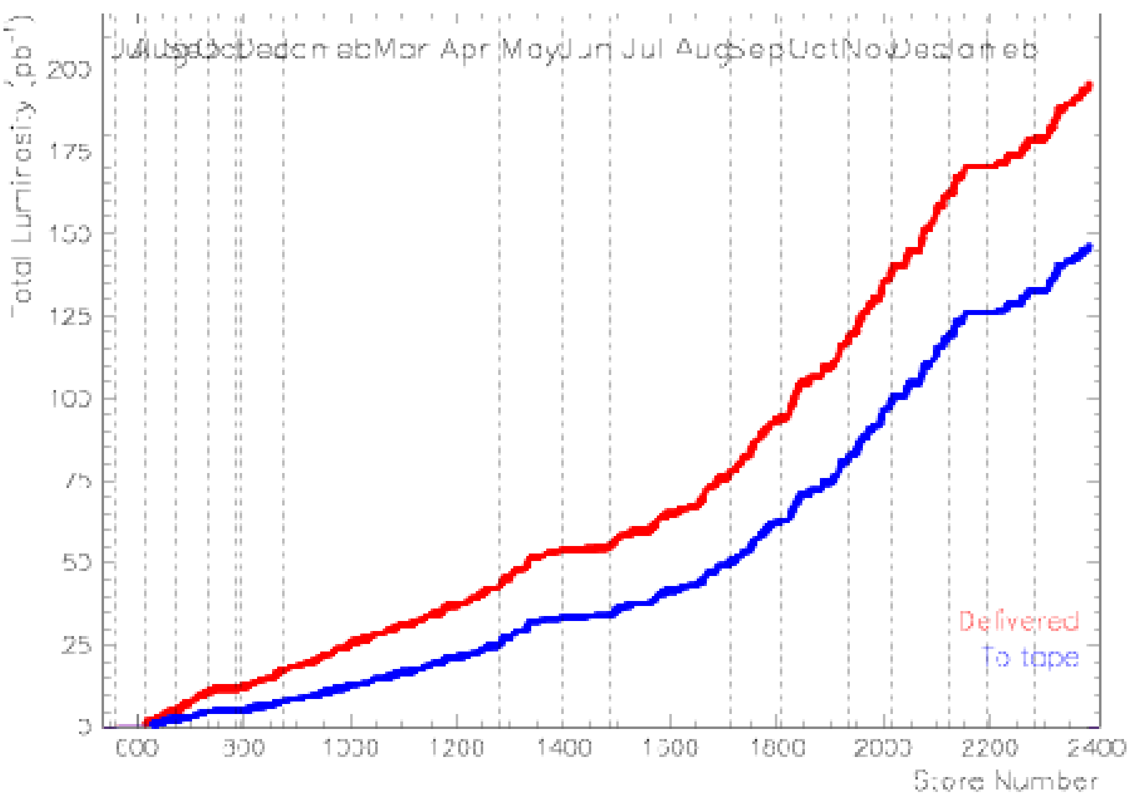


Backgrounds

- W/Z + heavy flavour (e.g., $g \rightarrow b\bar{b}$ or $c\bar{c}$)
- Heavy flavour jets + a fake lepton ("non-W")
- Mistags from light quark jets or gluon jets
- Di-boson, Drell-Yan, single top production

Data sample

- Collected between 23-Mar-2002 and 12-Jan-2003 (runs 141544 – 156847): First run the electron L3 was functioning properly, till January 2003 shutdown
  - 57.5 ± 3.4 pb^{-1} good for CEM $e^{\pm}$ and CMUP $\mu^{\pm}$ (require COT and SVX tracking, calorimeters and central muon sustems)
  - 47.3 ± 2.8 pb^{-1} good for CMX $\mu^{\pm}$ ($0.6 < |\eta| < 1.0$). Runs 150145 – 156847



Pre-tagging signal efficieny measurement: $e + Jets$

- 200K simulated $t\bar{t}$ events: `HERWIG`, $m_t = 175$ GeV/c^2

$$\epsilon_{t\bar{t}} = \epsilon_{t\bar{t}-pretag} \cdot \epsilon_{tag\,event}$$

$$\epsilon_{t\bar{t}-pretag} = \epsilon^{MC}_{t\bar{t}-pretag} \cdot \epsilon^{data}_{z0} \cdot \epsilon^{data}_{trig} \cdot \frac{\epsilon^{data}_{lepID}}{\epsilon^{MC}_{lepID}}$$

- CEM electrons:

Cut	$e\nu q\bar{q}b\bar{b}$	$\mu\nu q\bar{q}b\bar{b}$	$\tau\nu q\bar{q}b\bar{b}$	$e\nu e\nu b\bar{b}$	$\mu\nu\mu\nu b\bar{b}$	$\tau\nu\tau\nu b\bar{b}$	$e\nu\mu\nu b\bar{b}$	$e\nu\tau\nu b\bar{b}$	$\mu\nu\tau\nu b\bar{b}$	$q\bar{q}q\bar{q}b\bar{b}$	Total
N_{init}	29644	29340	29748	2528	2435	2479	4937	4878	4952	89059	200000
N_{obsv}	28728	28356	28825	2451	2357	2395	4780	4723	4779	85995	193389
N_{geom}	19184	9475	11482	2017	478	828	2956	3050	1380	37907	88757
N_{lepID}	11638	86	1067	1615	9	154	2022	2010	171	353	19125
N_{iso}	10525	9	880	1536	0	132	1896	1878	146	51	17053
N_{met}	9392	8	766	1407	0	117	1742	1722	130	26	15310
N_{jet}	8457	5	693	514	0	55	356	761	22	25	10888
N_{diLVet}	8442	3	693	401	0	51	181	737	14	25	10547
N_{Zveto}	8217	3	679	304	0	47	162	669	12	24	10117
$N_{convVet}$	8202	2	668	304	0	47	162	669	12	17	10083
$\epsilon^{MC}_{t\bar{t}-pretag}$	0.0521 ± 0.0005										

$\epsilon_{z0} = 0.951$ (z of primary vertex ≤ 60 cm)

$\epsilon_{trig} = 0.968$, $\frac{\epsilon^{data}_{lepID}}{\epsilon^{MC}_{lepID}} = 0.990$

$$\Rightarrow \epsilon^{CEM}_{t\bar{t}-pretag} = (4.7 \pm 0.04 \pm 0.5)\%$$

Pre-tagging signal efficieny measurement: $\mu + Jets$

- CMUP muons:

Cut	$e\nu q\bar{q}b\bar{b}$	$\mu\nu q\bar{q}b\bar{b}$	$\tau\nu q\bar{q}b\bar{b}$	$e\nu e\nu b\bar{b}$	$\mu\nu\mu\nu b\bar{b}$	$\tau\nu\tau\nu b\bar{b}$	$e\nu\mu\nu b\bar{b}$	$e\nu\tau\nu b\bar{b}$	$\mu\nu\tau\nu b\bar{b}$	$q\bar{q}q\bar{q}b\bar{b}$	Total
N_{init}	29644	29340	29748	2528	2435	2479	4937	4878	4952	89059	200000
N_{obsv}	28728	28356	28825	2451	2357	2395	4780	4723	4779	85995	193389
N_{geom}	577	8211	1201	37	1123	125	1378	164	1489	1942	16247
N_{lepID}	44	7210	596	3	1055	83	1216	85	1335	125	11752
N_{iso}	1	6448	484	0	988	73	1126	78	1215	4	10417
N_{met}	0	5742	416	0	906	68	1021	70	1103	2	9328
N_{jet}	0	5178	377	0	185	30	352	18	496	2	6638
N_{diLVet}	0	5169	376	0	93	30	244	10	467	2	6391
N_{Zveto}	0	5093	372	0	83	28	215	10	433	2	6236
$\epsilon^{MC}_{t\bar{t}-pretag}$	0.0323 ± 0.0004										

$$\epsilon_{cosmVet} = 1, \quad \epsilon_{trig} = 0.904, \quad \frac{\epsilon^{data}_{rec*lepID}}{\epsilon^{MC}_{rec*lepID}} = 0.962 \times 0.937,$$

$$\Rightarrow \boxed{\epsilon^{CMUP}_{t\bar{t}-pretag} = (2.5 \pm 0.03 \pm 0.3)\%}$$

- CMX muons:

Cut	$e\nu q\bar{q}b\bar{b}$	$\mu\nu q\bar{q}b\bar{b}$	$\tau\nu q\bar{q}b\bar{b}$	$e\nu e\nu b\bar{b}$	$\mu\nu\mu\nu b\bar{b}$	$\tau\nu\tau\nu b\bar{b}$	$e\nu\mu\nu b\bar{b}$	$e\nu\tau\nu b\bar{b}$	$\mu\nu\tau\nu b\bar{b}$	$q\bar{q}q\bar{q}b\bar{b}$	Total
N_{init}	29644	29340	29748	2528	2435	2479	4937	4878	4952	89059	200000
N_{obsv}	28728	28356	28825	2451	2357	2395	4780	4723	4779	85995	193389
N_{geom}	233	3798	526	19	535	60	614	60	620	26	7291
N_{lepID}	21	3281	274	3	472	37	551	36	548	96	5319
N_{iso}	0	2940	219	0	441	33	510	33	521	1	4698
N_{met}	0	2621	185	0	405	29	476	30	474	1	4221
N_{jet}	0	2340	169	0	81	11	181	12	191	1	2986
N_{diLVet}	0	2331	169	0	44	10	124	10	181	1	2870
N_{Zveto}	0	2294	168	0	35	9	107	6	166	1	2786
$\epsilon^{MC}_{t\bar{t}-pretag}$	$0.0144 \pm 0.0.003$										

$$\epsilon_{cosmVet} = 1, \quad \epsilon_{trig} = 0.901, \quad \frac{\epsilon^{data}_{rec*lepID}}{\epsilon^{MC}_{rec*lepID}} = 0.978 \times 1.005,$$

$$\Rightarrow \boxed{\epsilon^{CMX}_{t\bar{t}-pretag} = (1.2 \pm 0.02 \pm 0.1)\%}$$

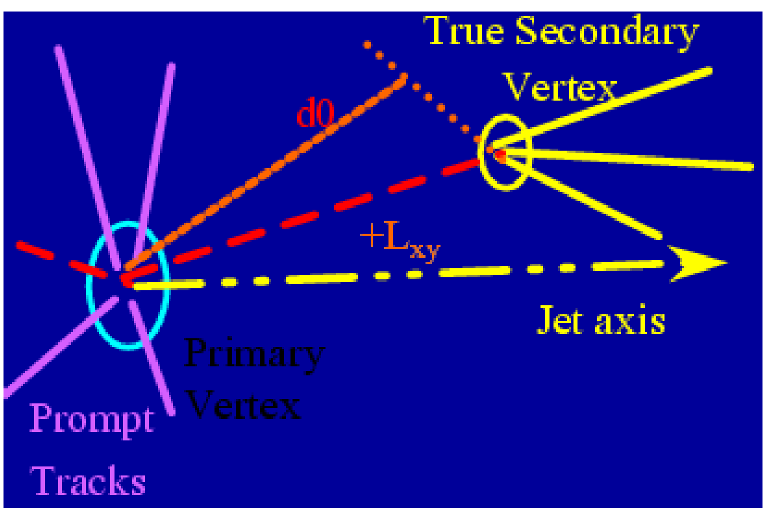
Tagging b-jets

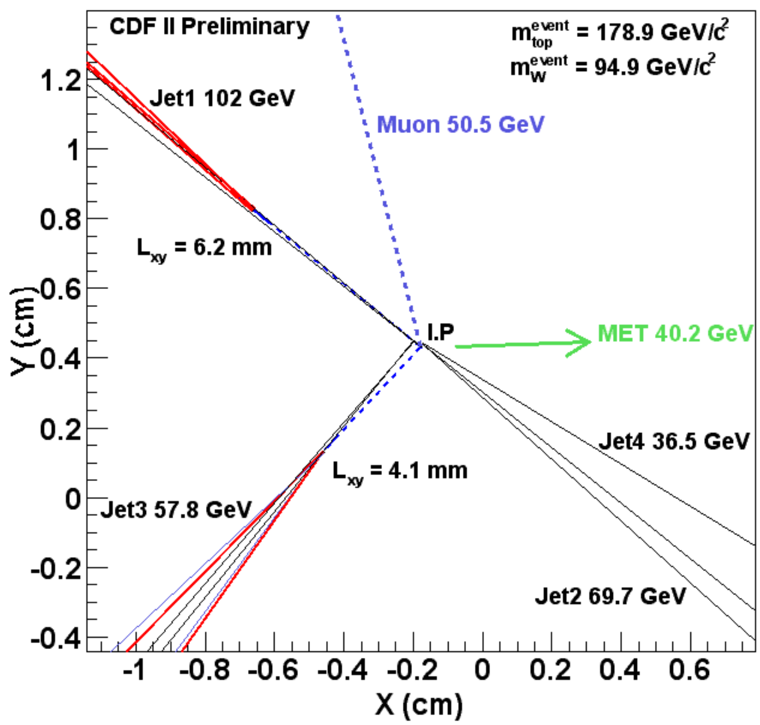
- Exploit the long lifetime ($c\tau \sim 450\ \mu$m) of b-hadrons

$\Rightarrow$ Within a jet, find tracks from displaced vertex

- Taggable jet: ≥ 2 tracks within $R < 0.4$ of jet axis
- Tagged jet: at least one cobination of ≥ 2 tracks with $|L_{xy}/\sigma_{xy}| > 3$

$\Rightarrow$ True b-tag: $L_{xy} > 0$



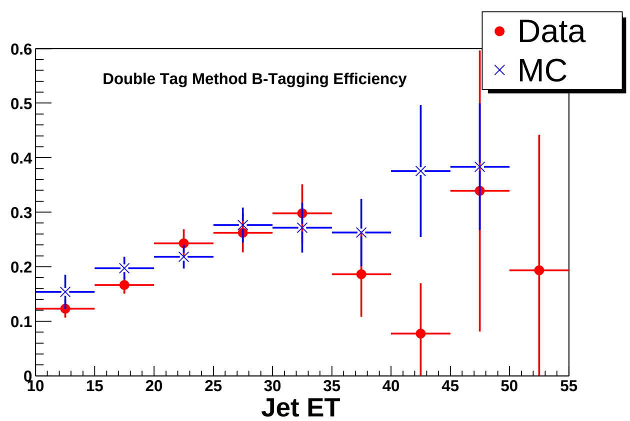


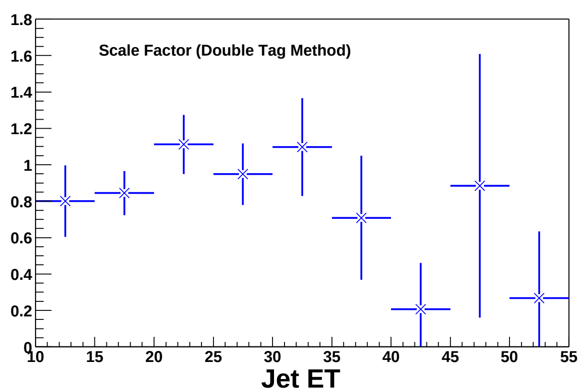
E.g., Run/Event 153693/799494: μ+4$Jets$ (2 b-tags)

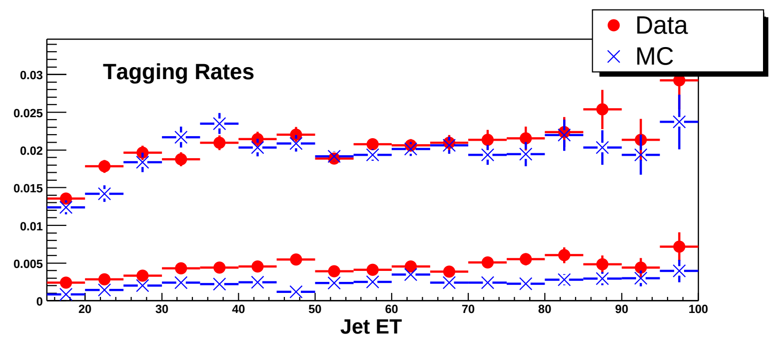
b-tagging: scale between data b-jet and MC b-jet

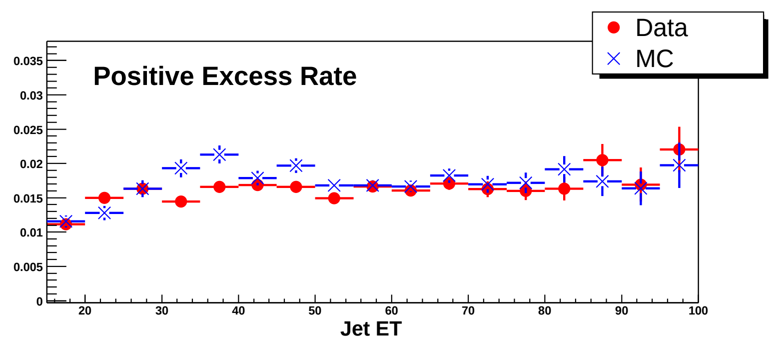
- Do we expect correct efficiency from MC?

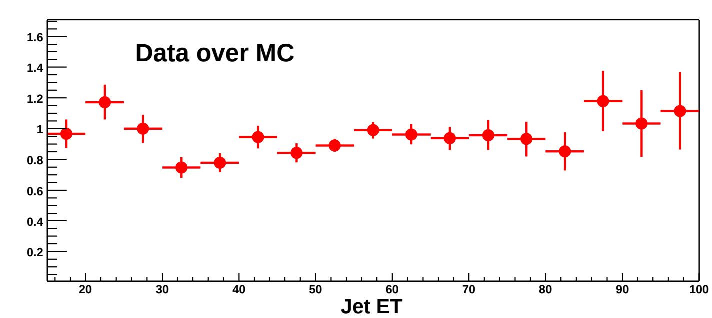
$\Rightarrow$ Using inclusive $e^{\pm}$ sample find that jets in data are tagged 89% as often as MC jets ($S.F = 0.89 \pm 0.09$).











Left: Scale factor in b-enriched sample

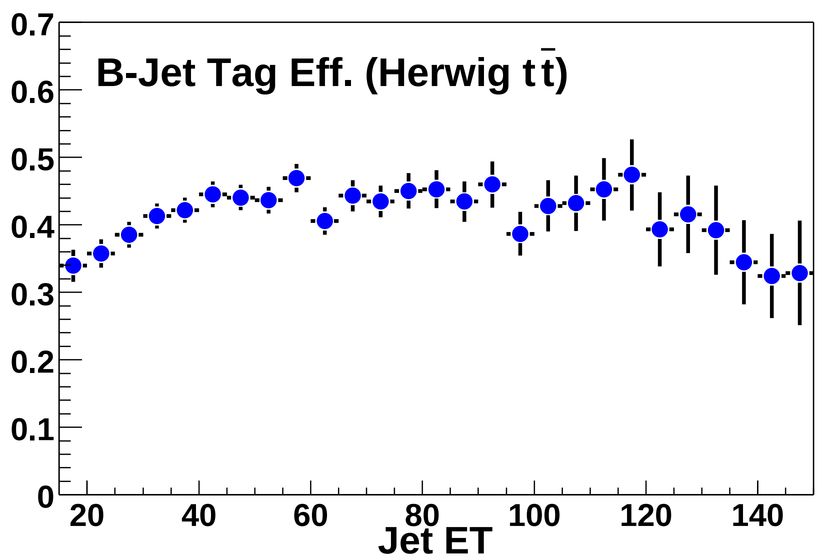
Right: Scale factor E_T dependance in Jet data.

b-tagging efficiency

- Use the same simulated $t\bar{t}$ events (HERWIG) and randomly reject 11% of tagged jets.

	CEM	CMUP	CMX
N_{obsv}	193389	193389	193389
$N_{pre-tag}$	10083	6236	2786
$\epsilon^{MC}_{t\bar{t}-pretag}$ (%)	5.21 ± 0.05	3.22 ± 0.04	1.44 ± 0.03
$\epsilon_{t\bar{t}-pretag}$ (%)	$4.7 \pm 0.05 \pm 0.5$	$2.5 \pm 0.03 \pm 0.3$	$1.2 \pm 0.02 \pm 0.1$
N_{b-tag}	4600	2757	1242
$\epsilon^{MC}_{tag\,event}$ (%)	45.6 ± 1.0	44.2 ± 1.0	44.6 ± 1.0
$< \epsilon_{tag\,event} >$ (%)	$45 \pm 1 \pm 5$		
$\epsilon_{t\bar{t}}$ (%)	$2.1 \pm 0.03 \pm 0.3$	$1.1 \pm 0.02 \pm 0.2$	$0.54 \pm 0.01 \pm 0.08$
$\int Ldt$ (pb^{-1})	57.5 ± 3.4	57.5 ± 3.4	47.3 ± 2.8
$\epsilon_{t\bar{t}} \cdot \int Ldt$ (pb^{-1})	$1.2 \pm 0.02 \pm 0.2$	$0.65 \pm 0.01 \pm 0.1$	$0.26 \pm 0.006 \pm 0.04$
Total $\epsilon_{t\bar{t}} \cdot \int Ldt$	$2.1 \pm 0.02 \pm 0.3$ pb^{-1}		

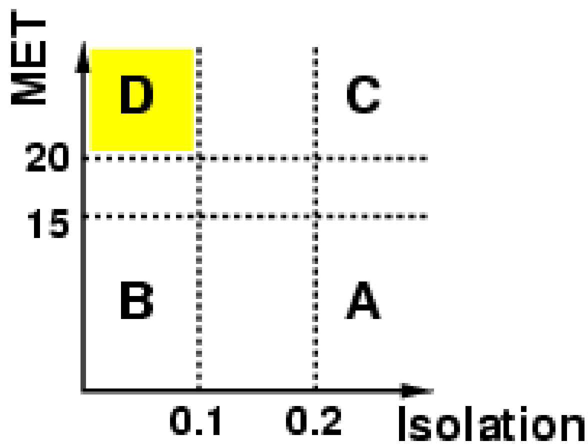
- Tagging a $t\bar{t}$ event with $\ell+ \geq 3Jets$ (incl. S.F) $\epsilon_{tag\,event} = (45 \pm 1 \pm 5)\%$



- $\epsilon_{tag\,taggable\,jet}$

Backgrounds: non-W (1)

- Assume E_T^{miss} and lepton isolation are uncorrelated.
- Use pre-tagged sample to calculate non-W event fraction in signal region (D) from the other regions:



$$N_{non-W}^{pre-tag} = \frac{N_B \cdot N_C}{N_A}$$

- Calculate tag rate from region B:

$$N_{non-W}^{tag} = \frac{N_B \cdot N_C}{N_A} \, EventTagRate_B$$

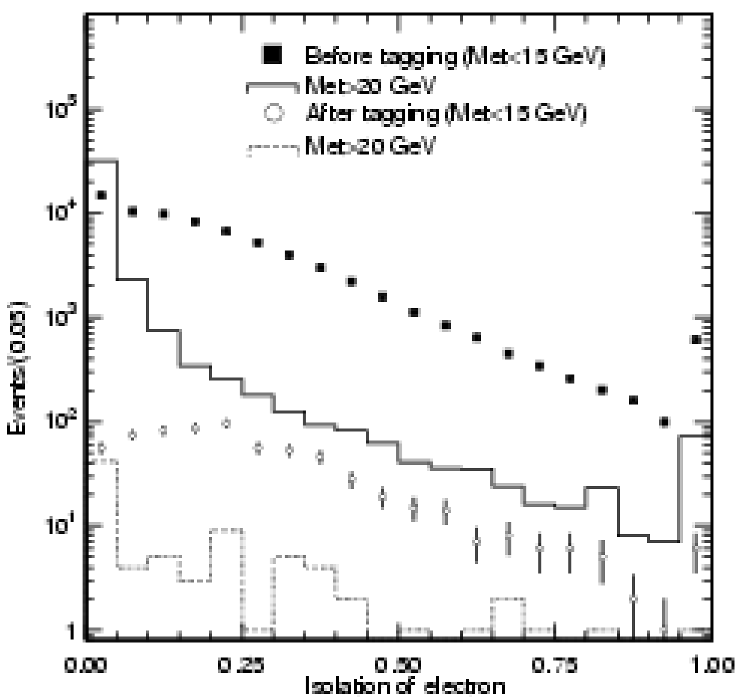
$$EventTagRate_B = \frac{\text{\# tagged events, i.e.,having jets with } L_x > 0}{\text{\# events}}$$

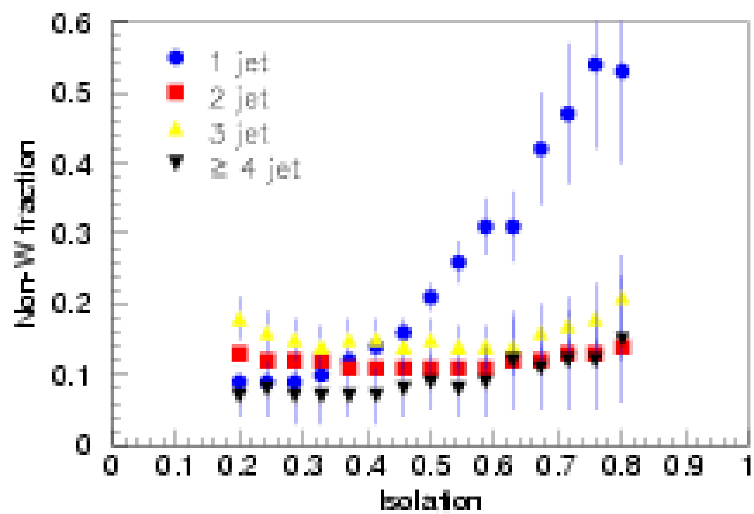
CEM

Jet multiplicity	1 jet	2 jets	3 jets	$\geq$ 4jets
F_{non-W}	0.09 ± 0.045	0.12 ± 0.06	0.15 ± 0.08	
region B evt tag rate	0.010 ± 0.001	0.032 ± 0.006		
# events in D	2871	449	63	16
N_{non-W}^{tag}	2.6 ± 1.3	1.7 ± 0.9	0.3 ± 0.17	0.08 ± 0.05
region B tag rate/taggable	0.019 ± 0.002	0.028 ± 0.005		
# taggable jets in D	1654	504	120	42
N_{non-W}^{tag}	2.8 ± 1.4	1.7 ± 0.8	0.6 ± 0.3	0.1 ± 0.1

Backgrounds: non-W (2)

- Alternatively, use only tagged events and compare shape of isolation distribution in low and high E_T^{mis} regions:



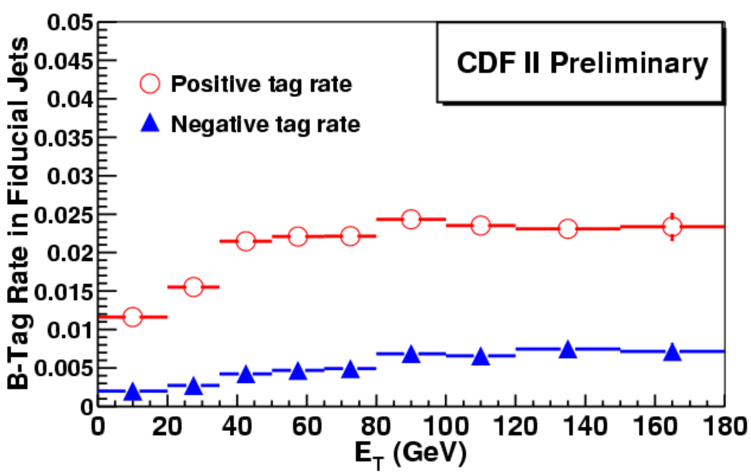


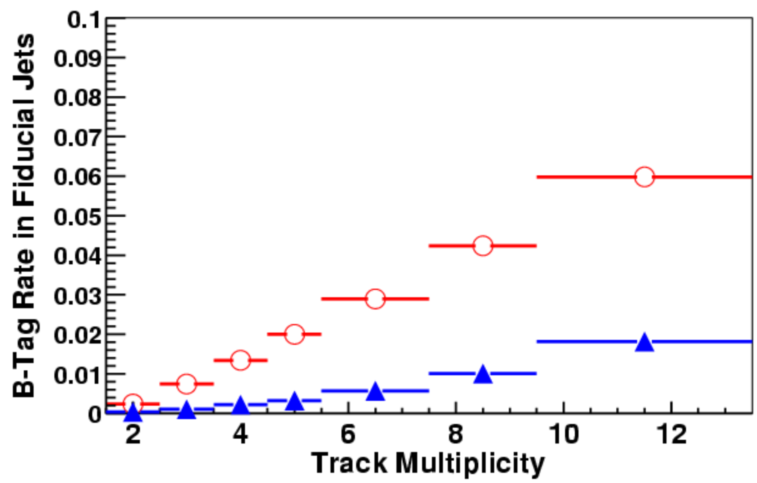
Jet multiplicity	1 jet	2 jets	3 jets	$\geq$ 4 jets
N_{non-W}^{tag} electrons	4.2$\pm$ 1.1	2.0$\pm$ 0.6	0.65$\pm$ 0.26	0.15$\pm$ 0.07
N_{non-W}^{tag} muons	0.9$\pm$ 0.3	0.4$\pm$ 0.15	0.17$\pm$ 0.08	0.06$\pm$ 0.02

Backgrounds: $Wb\bar{b}, Wc\bar{c}$ and mistags. Method I

- Measure jet tag rate in Jet data in binds of E_T, N_{tacks}, $\sum E_T$ (tag matrix)
- Apply this rate to taggable jets in $W + Jets$ sample

  assumes same heavy flavour contnet for $W + Jets$ as jet events.





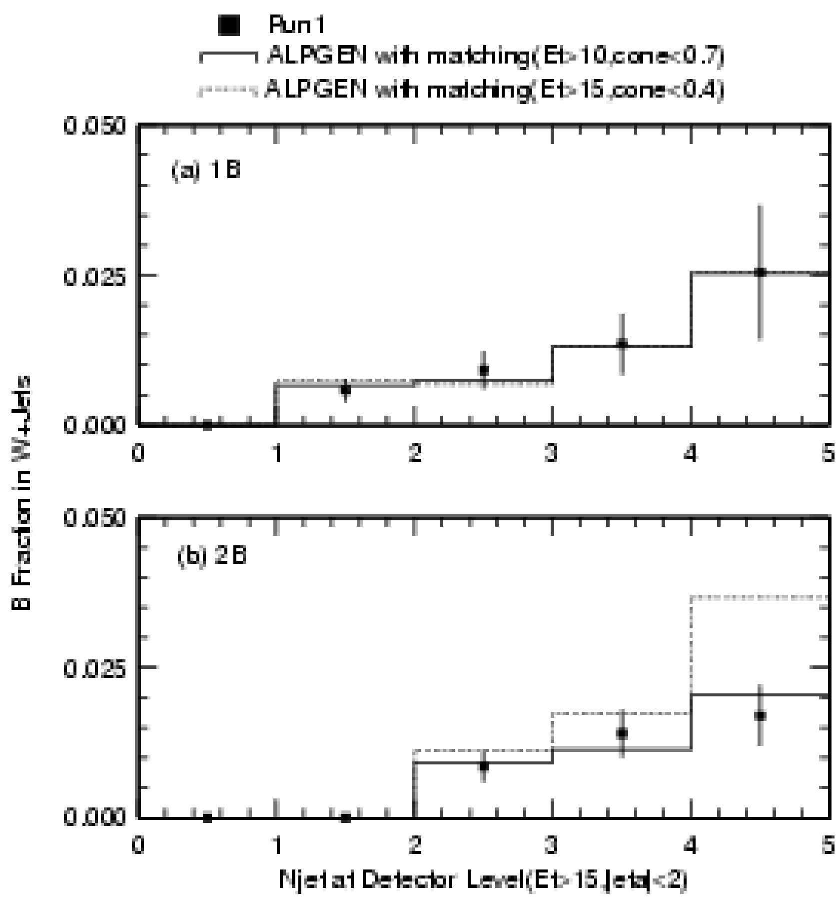
$$N_{tag} = \sum_{ijk} N^{ijk}_{taggable} \cdot \epsilon_{ijk}$$

Jet multiplicity	1 jet	2 jets	3 jets	$\geq$ 4jets
electrons	20.1 $\pm$ 2.7	7.1 $\pm$ 1.1	1.9 $\pm$ 0.4	0.6 $\pm$ 0.2
muons	15.0 $\pm$ 1.8	5.3 $\pm$ 0.7	1.0 $\pm$ 0.2	0.3 $\pm$ 0.1
TOTAL	35.1 $\pm$ 3.6	12.4 $\pm$ 1.4	2.9 $\pm$ 0.4	1.0 $\pm$ 0.2

Backgrounds: $Wb\bar{b}, Wc\bar{c}$ and mistags. Method II

- Get mistag rate from jets tagged with $L_{xy} < 0$
- Heavy flavour fraction in W events from MC (gluon-splitting, flavour excitation), normalised to $W + Jets$ data and corrected for b-taging efficiency.

- b-tag eff. $\simeq$ 25% higher in Run2. c-tag same



Njet	1	2	3	≥ 4
$-L_{xy}$	7.4 ± 0.77	2.9 ± 0.33	0.7 ± 0.1	0.25 ± 0.046
$Wb\bar{b}$	6.3 ± 2.3	3.9 ± 1.3	0.8 ± 0.3	0.30 ± 0.11
$Wc\bar{c}$	2.3 ± 1.0	1.5 ± 0.7	0.2 ± 0.1	0.07 ± 0.03
Total	16.0 ± 3.4	8.4 ± 2.0	1.7 ± 0.4	0.6 ± 0.2

Backgrounds: Wc

- Wc fraction and tagging efficiency from MC
- Scale MC tagging eff. to data $S.F = 0.89 \pm 0.09$
- Subtract the non-W fraction to be left with real W's
- Normalize to pre-tag $W + Jets$ sample

$$N_{Wc} = N_{W+Jets} \times (1 - F_{non-W}) \times F_{Wc} \times \epsilon_{tag} \times S.F$$

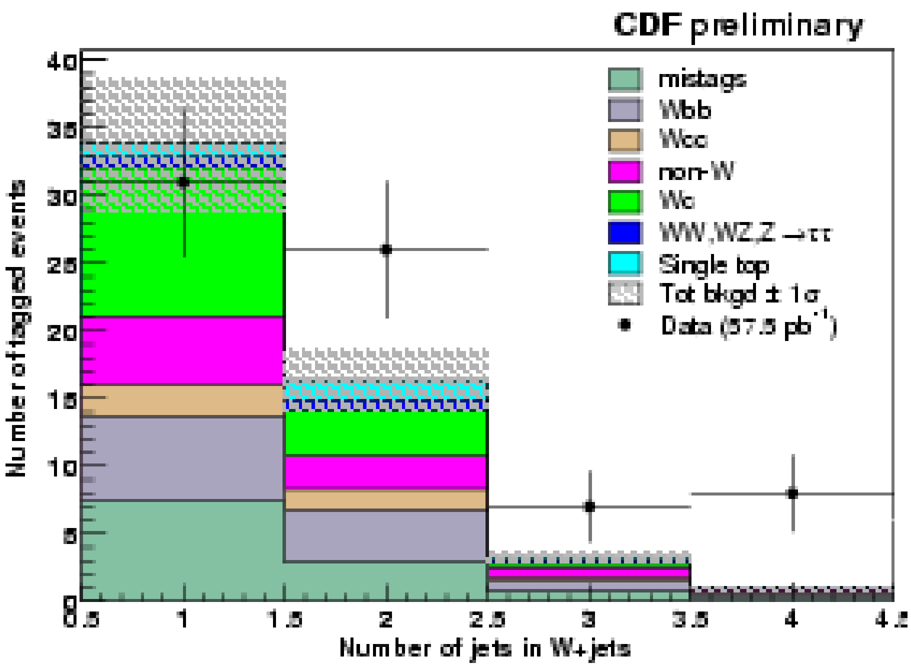
Jet multiplicity	1 jet	2 jets	3 jets	$\geq$ 4jets
F_{Wc}^{RunI} (%)	5.9 ± 1.5	8.3 ± 1.7	8.9 ± 1.7	8.9 ± 1.7
ϵ_{tag}^{RunII} (%)	4.6 ± 0.2	6.4 ± 0.6	4.2 ± 1.1	4.2 ± 1.1
$N_{W\ \mathrm{electrons}}$	2871	449	63	16
$N_{W\ \mathrm{muons}}$	2042	319	36	10
$N_{Wc\ \mathrm{electrons}}$	6.3 ± 1.8	1.9 ± 0.5	0.18 ± 0.06	0.05 ± 0.02
$N_{Wc\ \mathrm{muons}}$	4.7 ± 1.3	1.5 ± 0.4	0.11 ± 0.04	0.03 ± 0.01
$N_{Wc\ \mathrm{TOTAL}}$	11.0 ± 3.1	3.4 ± 0.9	0.3 ± 0.1	0.08 ± 0.03

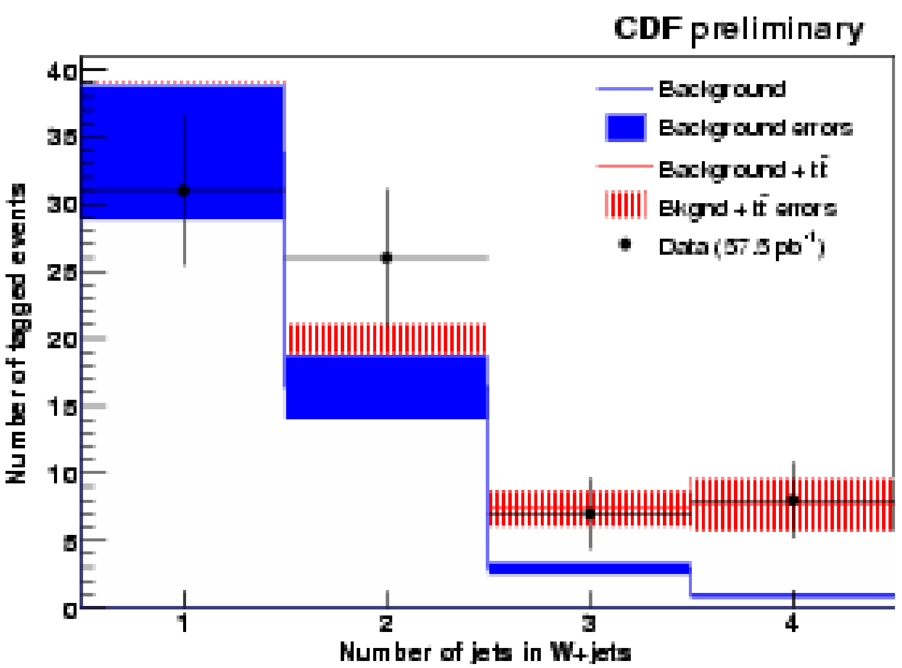
Backgrounds: all

Background	W + 1 jet	W + 2 jets	W + 3 jets	W + $\geq$ 4jets
$Wb\bar{b}$, $Wc\bar{c}$, mistags (Method I)	35.1 $\pm$ 3.6	12.4 $\pm$ 1.4	2.9 $\pm$ 0.4	1.0 $\pm$ 0.2
$Wb\bar{b}$, $Wc\bar{c}$, mistags (Method II)	16.0 $\pm$ 3.4	8.4 $\pm$ 2.0	1.7 $\pm$ 0.4	0.6 $\pm$ 0.2
Wc	11.0 $\pm$ 3.1	3.4 $\pm$ 0.9	0.3 $\pm$ 0.1	0.08 $\pm$ 0.03
WW/WZ, $Z \to \tau\tau$	0.8 $\pm$ 0.2	0.8 $\pm$ 0.2	0.16 $\pm$ 0.05	0.04 $\pm$ 0.01
non-W	5.1 $\pm$ 1.1	2.4 $\pm$ 0.6	0.8 $\pm$ 0.3	0.2 $\pm$ 0.07
single top	0.9 $\pm$ 0.1	1.5 $\pm$ 0.2	0.4 $\pm$ 0.1	0.06 $\pm$ 0.01
extra $Z + b\bar{b}$ correction	0.2 ± 0.1	0.08 ± 0.03	0.02 ± 0.01	0
Total (method I)	53.1 $\pm$ 4.9	20.6 $\pm$ 1.8	4.6 $\pm$ 0.5	1.4 $\pm$ 0.2
Total (method II)	33.8 $\pm$ 5.0	16.4 $\pm$ 2.4	3.3 $\pm$ 0.5	1.0 $\pm$ 0.2
Corrected Total (method I)	53.1 $\pm$ 4.9	20.6 $\pm$ 1.8	5.2 $\pm$ 0.5	
Corrected Total (method II)	33.8 $\pm$ 5.0	16.4 $\pm$ 2.4	3.8 $\pm$ 0.5	
Observed positive tags	31	26	7	8

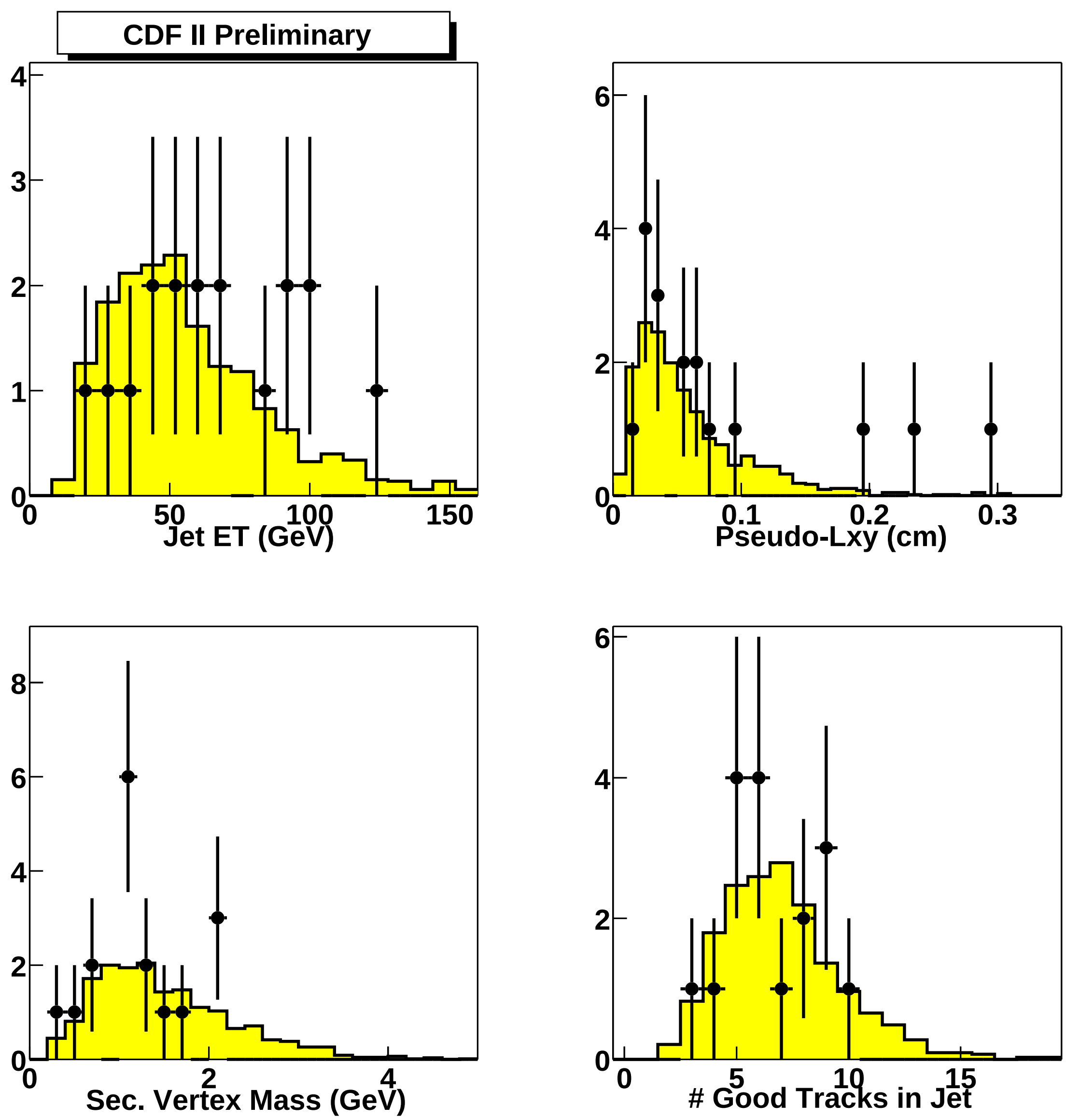
Observed events: N_{jets} distribution

- 15 events with ≥ 3 jets tagged (2 w/ double tags).





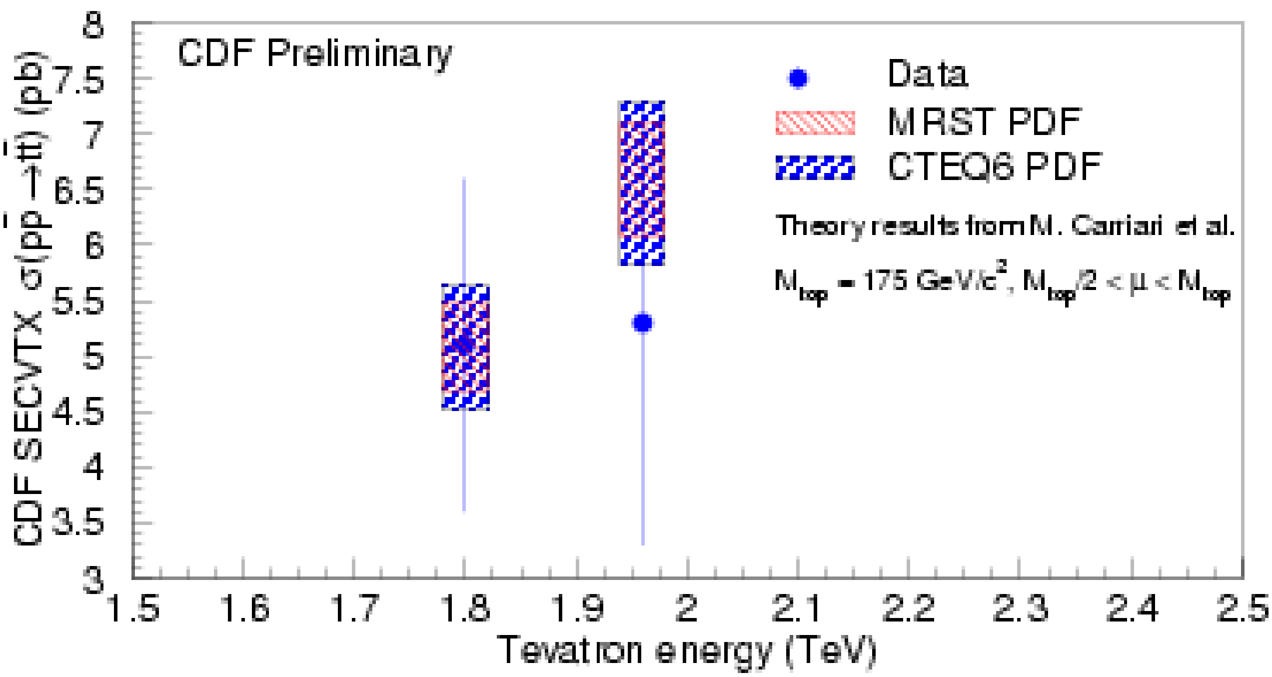
Observed events: the tagged jets



$p\bar{p} \to t\bar{t}X$ cross section

- $\sigma(t\bar{t}) = \frac{N_{obs} - N_{bkg}}{\epsilon_{t\bar{t}} \cdot \int L dt}$
- $\epsilon_{t\bar{t}} \cdot \int L dt = 2.1 \pm 0.02 \pm 0.3$ pb^{-1}
- $N_{obs} = 15$
- $N_{bkg} = 3.8$

$$\Rightarrow \sigma(t\bar{t}) = 5.3 \pm 1.9(stat) \pm 0.8(syst) \text{ pb}$$



Summary and Outlook

- The top is here and tagging is working.

- Need improvements to get to $\sim 60\%$ goal (e.g., 3-D tracking)

- Will employ more taggers to look for b-jets. Jet-Probability starting be used. Soft-Leptons later.

- Understad the N_{jets} distribution and the events it's made up from.

- After all, the signle top is at $W + 2Jets$, as well is Higgs.