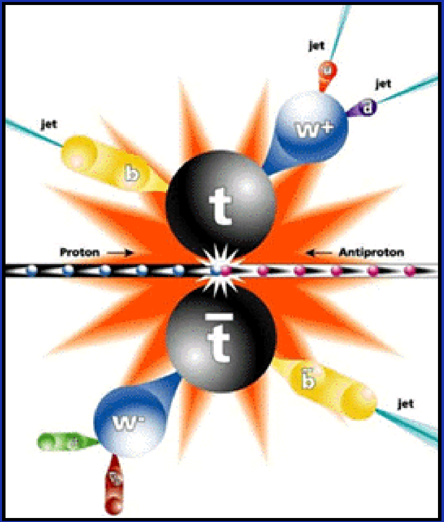
Measurement of the $t\bar{t}$ Production Cross Section at DØ using b-tagging



Gustavo Otero y Garzón, University of Illinois at Chicago
for the DØ experiment

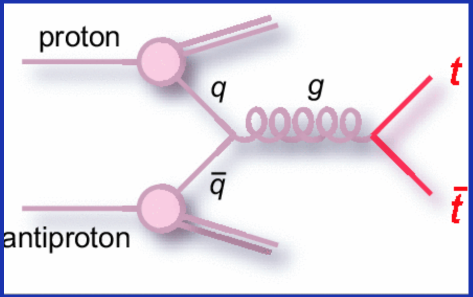
Joint Meeting of Pacific Region Particle Physics Communities
October 29 – November 03, 2006; Honolulu, Hawaii

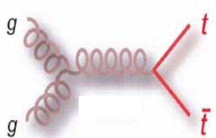
$\sigma_{t\bar{t}}$!

- The top quark was discovered 11 years ago and so far it has been only observed at Fermilab
  - RunI measured σ_{ttbar} to a 25% precision with $L\sim100pb^{-1}$ and $\sqrt{s}=1.8$ TeV
  - At present, 30% higher production rate at $\sqrt{s}=1.96$ TeV and higher luminosity
- The theoretical prediction of σ_{ttbar} has a 9-12% accuracy
- Top pair events are an important background source for other physics processes
  - Single Top
  - Higgs search
- Measuring the top pair production cross section is the first step toward any Top property analysis

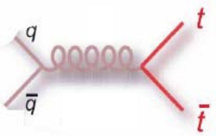
Top Quark Pair Production and Decay

- Top quarks are mainly produced in pairs (strong interactions) at Tevatron energies





15%

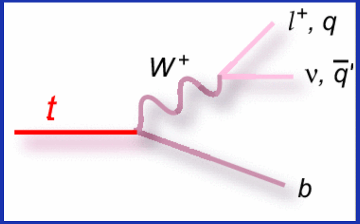


85%

$\sigma_{inel} / \sigma_{ttbar} \sim 10^{10}$

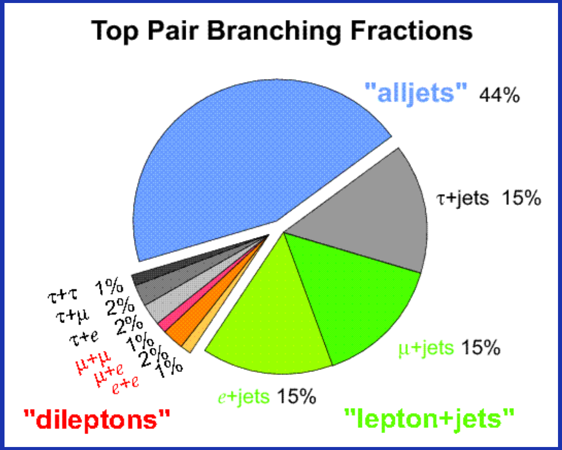
- High luminosity
- High efficiency

- No hadronic bound state due to short lifetime
- Electroweak decay



$|V_{tb}|$~1

- Final state determined by the decay of the W boson

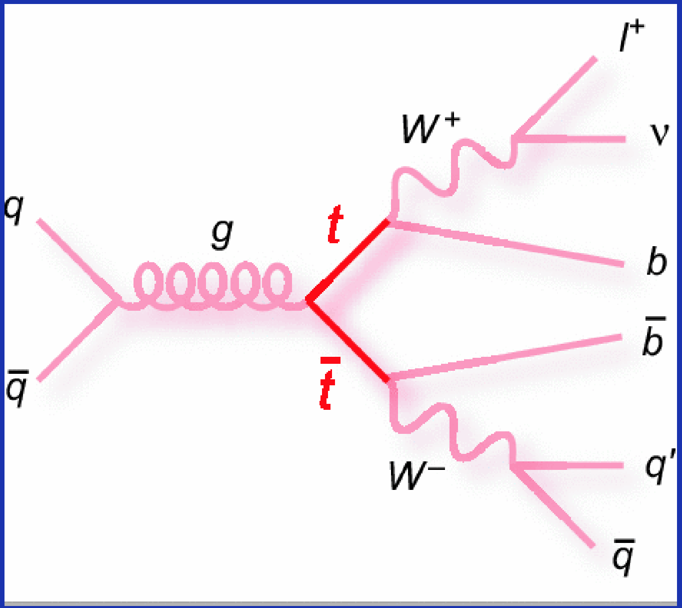


- dilepton channel (low bkg)
- lepton + jets channel (moderate bkg)
- all hadronic channel (huge bkg)

Lepton≡ e, μ from W or from τ from W

The Lepton + Jets Channel

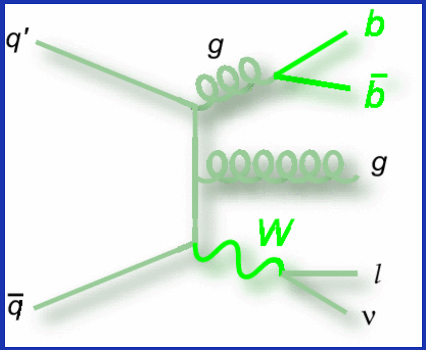
signal



- 1 isolated high p_T lepton (μ, e)
- 1 ν (reconstructed as missing transverse energy (MET))
- ≥ 3 high p_T central jets

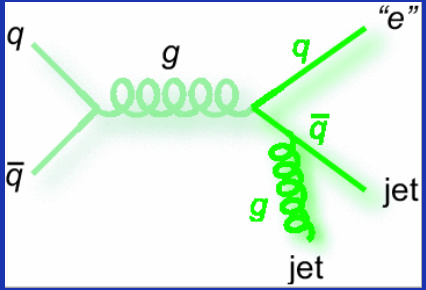
Background

$W(\rightarrow l\,\nu) + \geq 3$ jets



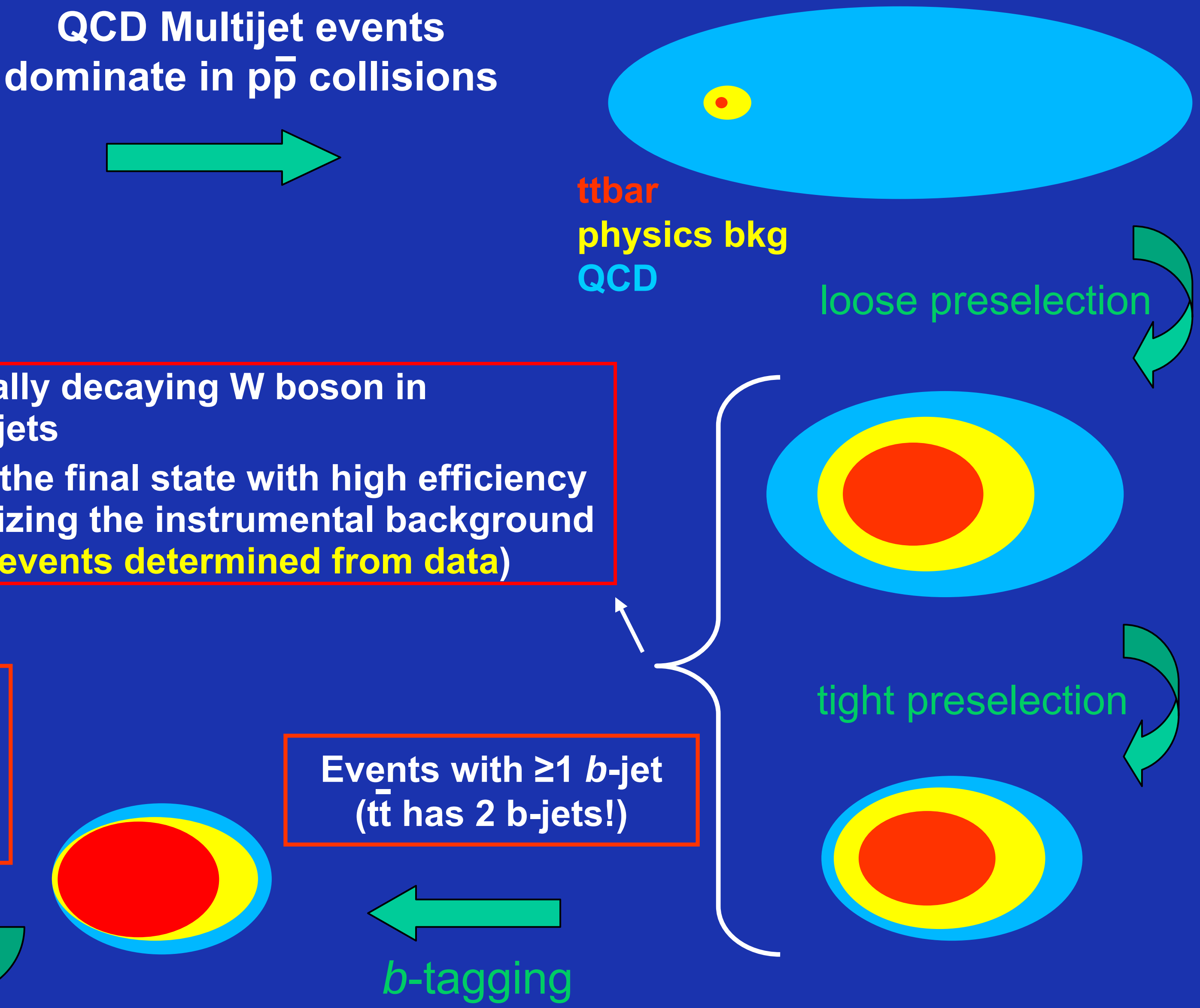
QCD Multijet

- fake isolated lepton
- misreconstructed MET



Method Overview

QCD Multijet events dominate in $p\bar{p}$ collisions



- **Select a leptonically decaying W boson in association with jets**
- **Select objects in the final state with high efficiency and purity minimizing the instrumental background (QCD and W-like events determined from data)**

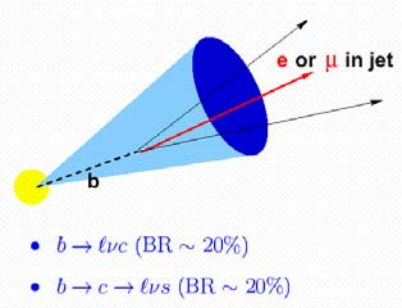
Events with ≥1 *b*-jet ($t\bar{t}$ has 2 b-jets!)

Extract $\sigma_{t\bar{t}}$ from the excess over the predicted background

b-tagging

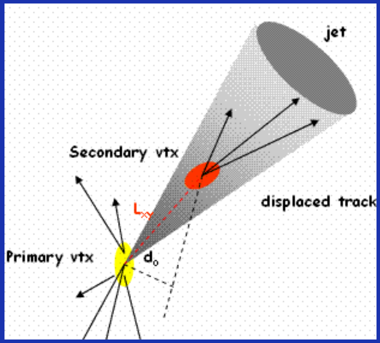
- *b*-quarks hadronize into long lived (ct ~ 450μm) *B* hadrons which travel a few millimeters before decaying

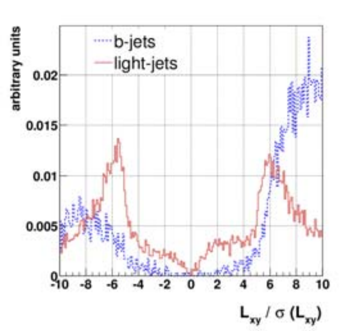
- b-jets can be identified!
  - Soft Lepton Tagging: lepton within a jet from a semileptonic B decay



- $b \to \ell \nu c$ (BR ~ 20%)
- $b \to c \to \ell \nu s$ (BR ~ 20%)

  - Secondary Vertex Tagging: reconstruct SV from tracks significantly displaced from the PV originating from lifetime effects of B hadrons

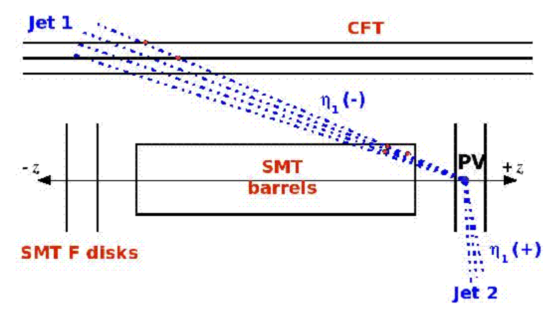


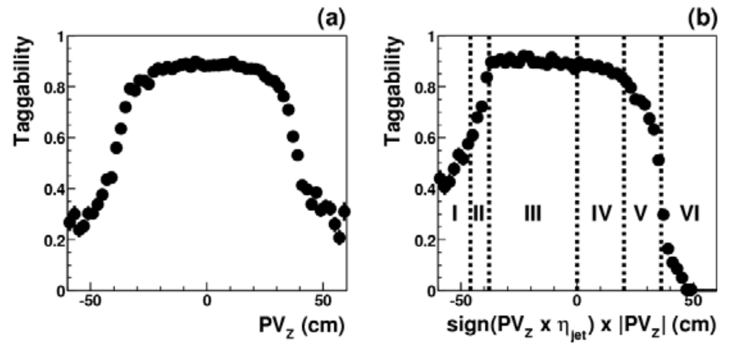


  - To decouple tagging efficiency from tracking inefficiencies and calorimeter noise problems the SVT tagging probability is split into:
    - Probability for a jet to be taggable
    - Probability for a jet to be tagged

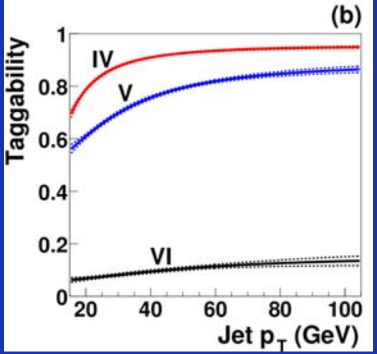
Taggability

- A jet is taggable if it has a matched track-jet
- Tracks in a track-jet must have hits in the SMT
  - Strong dependence on the SMT geometry

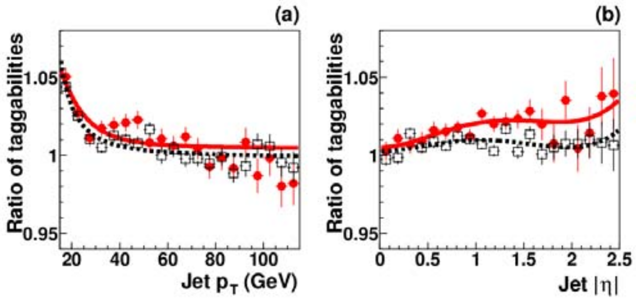




- Parameterized vs. η^{jet} and $p_T{}^{jet}$ in 6 bins of sign(PV_Z * η^{jet})*$|PV_Z|$
- Measured in *l*+jets data

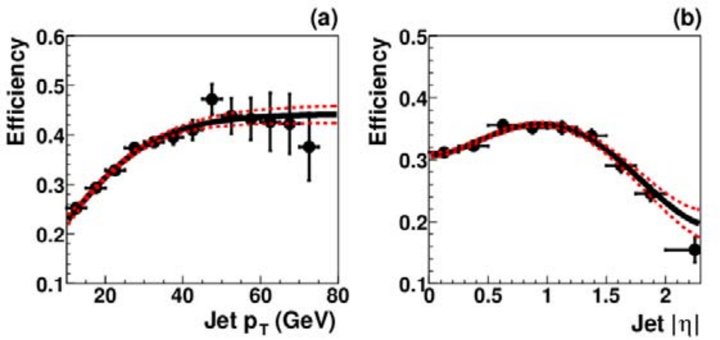


- Taggability is jet flavor dependent
- Corrected with ratios of *b*(*c*) / light taggabilities measured in MC



b-Tagging Efficiency

- **Semileptonic *b*-tagging rate measured purely from 2 μ-in-jet data samples (subset enriched in heavy flavor)**
- **Parameterized in terms of p_T^{jet} and η^{jet}**

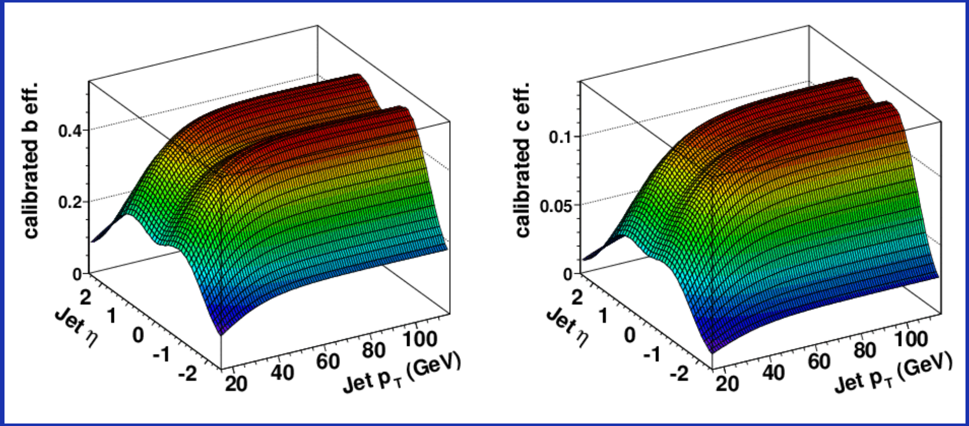


- **Calibrated by data-to-MC scale factor given by the ratio of semileptonic b-tagging efficiencies measured in data and $b\bar{b}$ MC**

- **Inclusive *b* (*c*) tagging rates measured in $t\bar{t}$ MC and corrected with $SF_{\text{data-MC}}$**

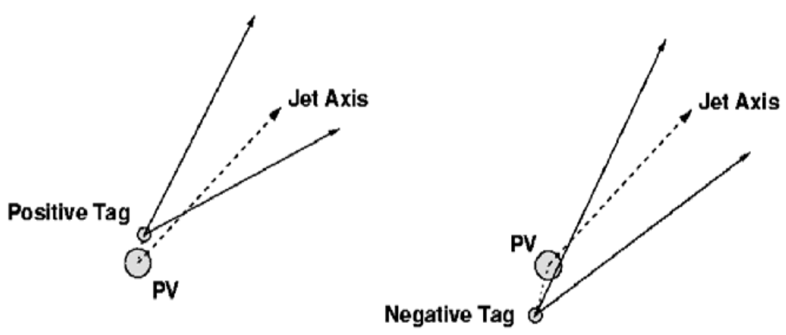
$$SF_{\text{data-to-MC}}(p_T,\eta) = \frac{\epsilon^{\text{data}}_{b\to\mu}(p_T,\eta)}{\epsilon^{\text{MC}}_{b\to\mu}(p_T,\eta)}$$

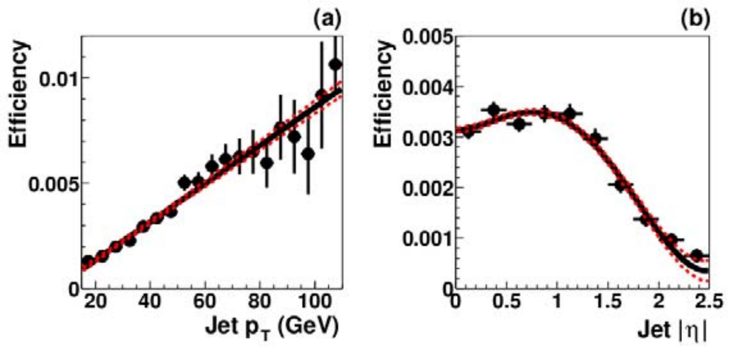
➡



Mistag Rate

- A light (*u,d,s,g*) jet identified as heavy flavor is a mistag (fake tag)
- Originated from misreconstruction and resolution effects
- Determined from the negative tagging rate
  - Measured in QCD data, dominated by light jets (ε_-^{data})





- MC based corrections to ε_-^{data} for:
  - Heavy flavor contamination in QCD data (~0.5)
  - Long lived particles (K^0_S, Λ^0) not present in ε_- (~1.6)

Event Tagging Probability

Jet $^{\text{Taggability}}{}_{\text{flavor } \alpha}$

Jet $^{\text{Tagging Probabililty}}{}_{\text{flavor } \alpha}$

$\alpha = b, c, light$

→ **Per Jet Probability (Weight all jets)**

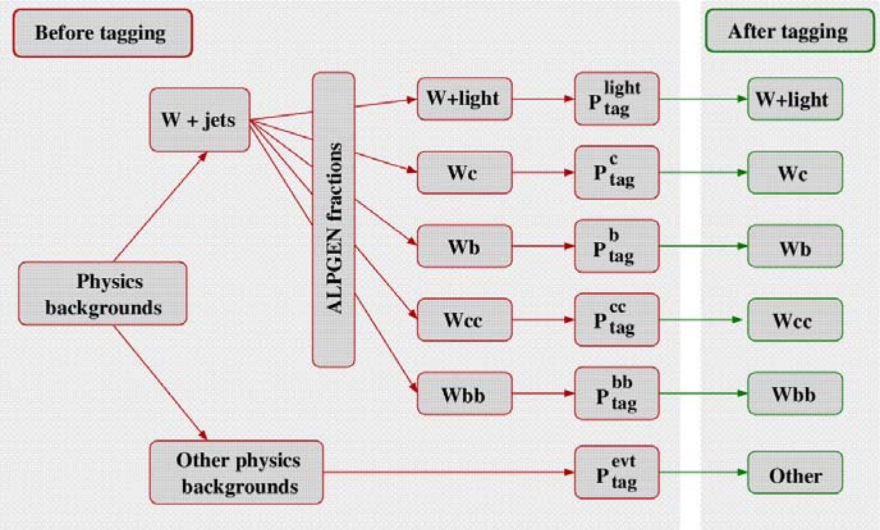
Trigger weight

→ **Event Tagging Probability**

$$\boxed{P^{\,t\bar{t}\;4\geq\text{jets}}_{=1\text{ tag}} = 0.45}$$

$$\boxed{P^{\,t\bar{t}\;4\geq\text{jets}}_{\geq 2\text{ tag}} = 0.14}$$

- **W+jets tagging probabilities:**
  - **Add probabilities for different flavor configurations**
  - **Weight each configuration with the corresponding flavor fraction**
  - **Fractions determined as cross section ratios of hadron-matched-jets ALPGEN MC samples**



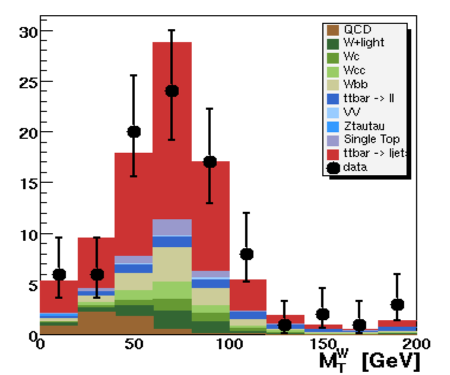
Background Estimate

- QCD-multijet production in the tagged sample:
  - Apply the Matrix Method to the tagged data sample

- Additional low rate electroweak background processes

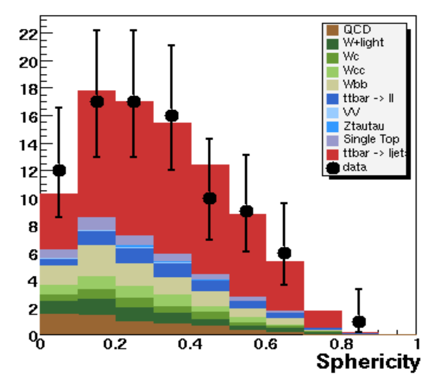
$N^{presel}_{i} = \sigma^{theory}_{i} \times \varepsilon^{presel}_{i} \times BR \times L$ i = single top, diboson and $Z \rightarrow \tau\tau$

$N^{tag}_{bkg\ i} = N^{presel}_{i} \times P^{tag}_{i}$



- W+jets (dominant background)
  - Overall normalization from data

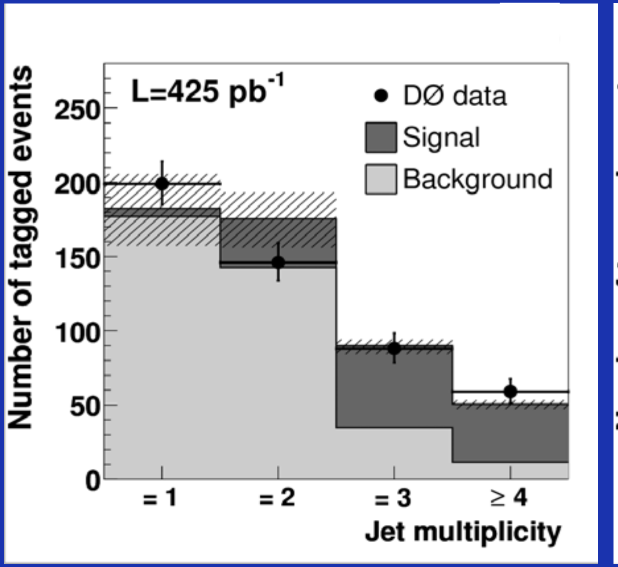
$N^{Presel}_{W+jets} = N^{sig} - N^{Presel}_{tt} - \sum_{i} N^{presel}_{i}$



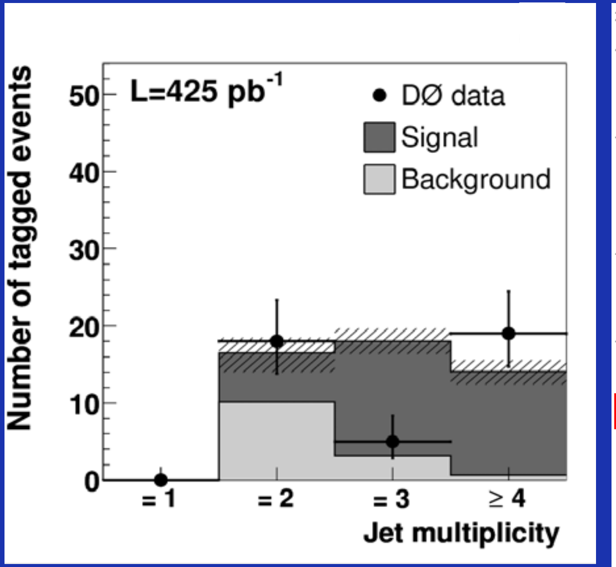
  - Apply different tagging probabilities based on the jets' flavor configurations

Cross Section Extraction

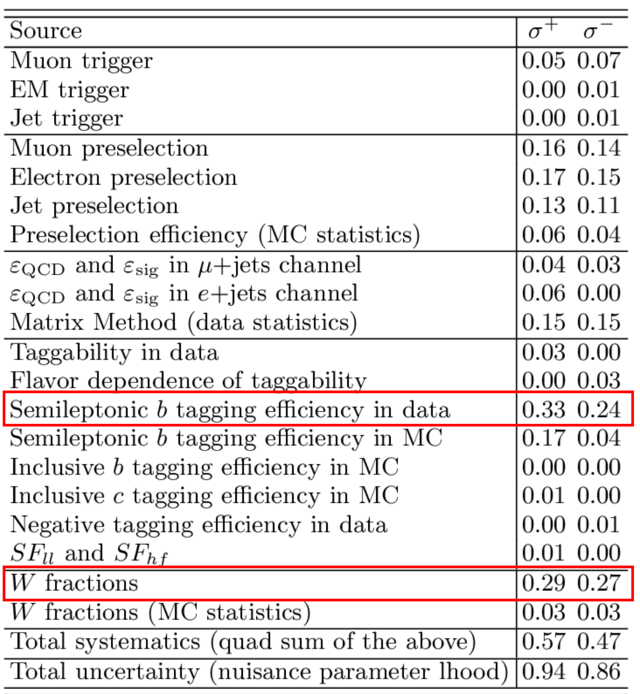
- The ttbar cross-section is calculated combining 8 channels
  - *e* + jets and μ + jets
  - single tags and double tags
  - = 3 jets and ≥ 4 jets



Single tags



Double tags



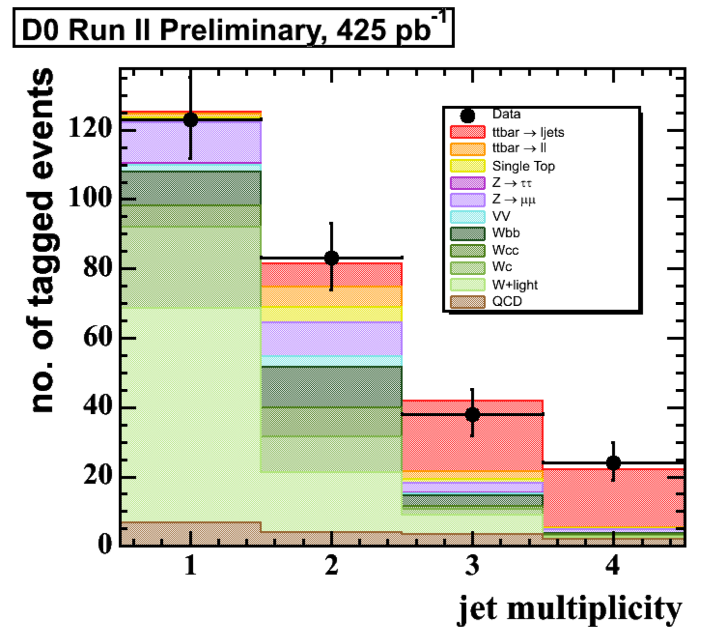
Source	σ^+	σ^-
Muon trigger	0.05	0.07
EM trigger	0.00	0.01
Jet trigger	0.00	0.01
Muon preselection	0.16	0.14
Electron preselection	0.17	0.15
Jet preselection	0.13	0.11
Preselection efficiency (MC statistics)	0.06	0.04
$\varepsilon_{\mathrm{QCD}}$ and $\varepsilon_{\mathrm{sig}}$ in μ+jets channel	0.04	0.03
$\varepsilon_{\mathrm{QCD}}$ and $\varepsilon_{\mathrm{sig}}$ in e+jets channel	0.06	0.00
Matrix Method (data statistics)	0.15	0.15
Taggability in data	0.03	0.00
Flavor dependence of taggability	0.00	0.03
Semileptonic b tagging efficiency in data	0.33	0.24
Semileptonic b tagging efficiency in MC	0.17	0.04
Inclusive b tagging efficiency in MC	0.00	0.00
Inclusive c tagging efficiency in MC	0.01	0.00
Negative tagging efficiency in data	0.00	0.01
SF_{ll} and SF_{hf}	0.01	0.00
W fractions	0.29	0.27
W fractions (MC statistics)	0.03	0.03
Total systematics (quad sum of the above)	0.57	0.47
Total uncertainty (nuisance parameter lhood)	0.94	0.86

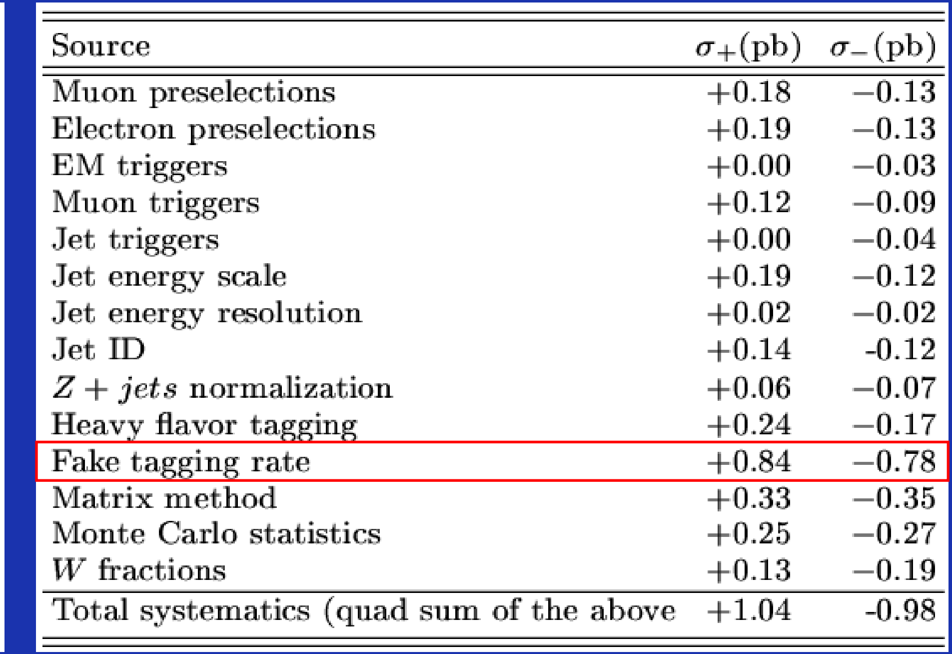
Systematic Uncertainties

The Soft Lepton Tag Analysis

- SLT tagging depends on the physics process
  - Tagging rates measured in MC for each process (in agreement with tagging rates measured in data!)

- Same philosophy as the SVT analysis
  - Same preselected data set
  - Same backgrounds + $Z \rightarrow \mu^+\mu^-$ (determined from MC, normalized to data)
  - Similar cross section extraction procedure (single and double together)





Source	σ_+(pb)	σ_-(pb)
Muon preselections	+0.18	−0.13
Electron preselections	+0.19	−0.13
EM triggers	+0.00	−0.03
Muon triggers	+0.12	−0.09
Jet triggers	+0.00	−0.04
Jet energy scale	+0.19	−0.12
Jet energy resolution	+0.02	−0.02
Jet ID	+0.14	-0.12
$Z + jets$ normalization	+0.06	−0.07
Heavy flavor tagging	+0.24	−0.17
Fake tagging rate	+0.84	−0.78
Matrix method	+0.33	−0.35
Monte Carlo statistics	+0.25	−0.27
W fractions	+0.13	−0.19
Total systematics (quad sum of the above	+1.04	-0.98

Results

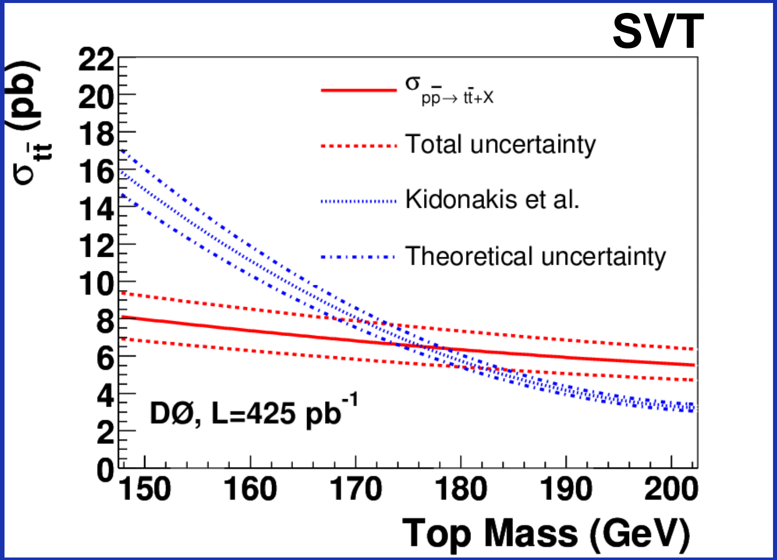
$$\sigma = \frac{N^{tag}_{observed} - N^{tag}_{background}}{Br \cdot \mathcal{L} \cdot \varepsilon_{presel} \cdot P^{tag}}$$

Perform a maximum likelihood fit to the observed number of events incorporating all systematic uncertainties in the fit using a nuisance parameter likelihood method

***l* + jets :** $\sigma_{ttbar} = 6.6 \pm 0.9(stat+syst) \pm 0.4(lum)$ **pb** **SVT**

***l* + jets :** $\sigma_{ttbar} = 7.3^{+2.0}_{-1.8}(stat+syst) \pm 0.4(lum)$ **pb** **SLT**

Based on 425 pb^{-1} of DØ data



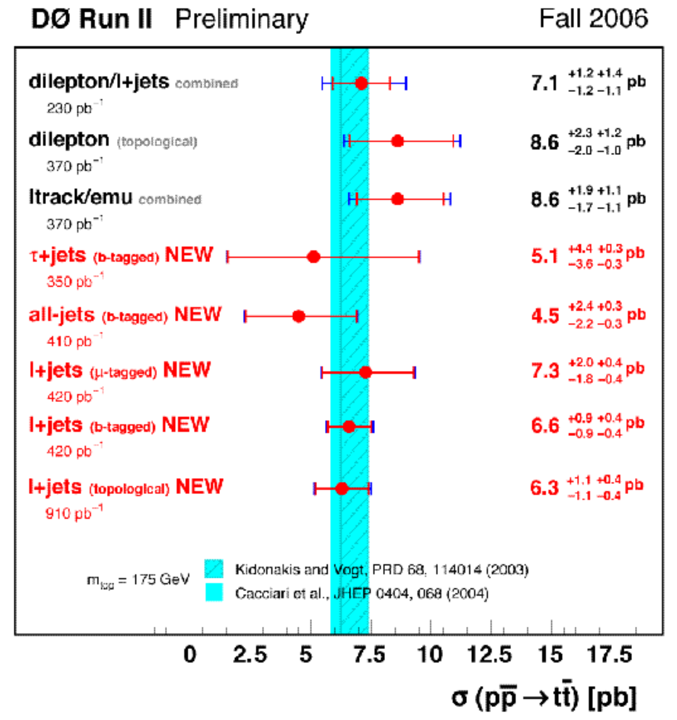
$\sigma_{ttbar}^{NLO} = 6.8 \pm 0.6$ **pb**

N. Kidonakis and R. Vogt, Phys. Rev. D **68** (2003)

Summary

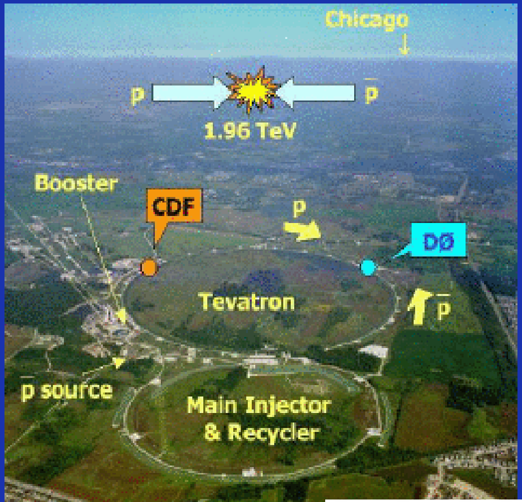
- Entering the top quark precision measurement era at the Tevatron
- Results in agreement with the Standard Model prediction at NLO
- First preliminary DØ RunII result with SLT
- SVT analysis currently DØ's most precise top cross section measurement (down to 15% uncertainty)
  - Better understanding of systematic uncertainties (12% stat ⊕ 8% syst)
  - At the DØ gate on its way to PRD (FERMILAB-PUB-06-386-E)

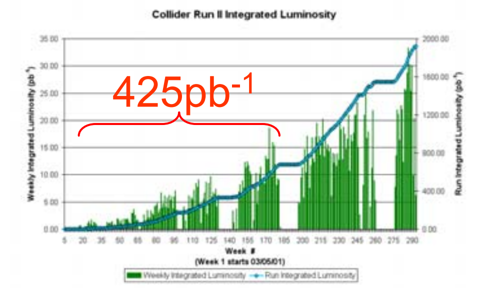
… expect fb^{-1} results soon!

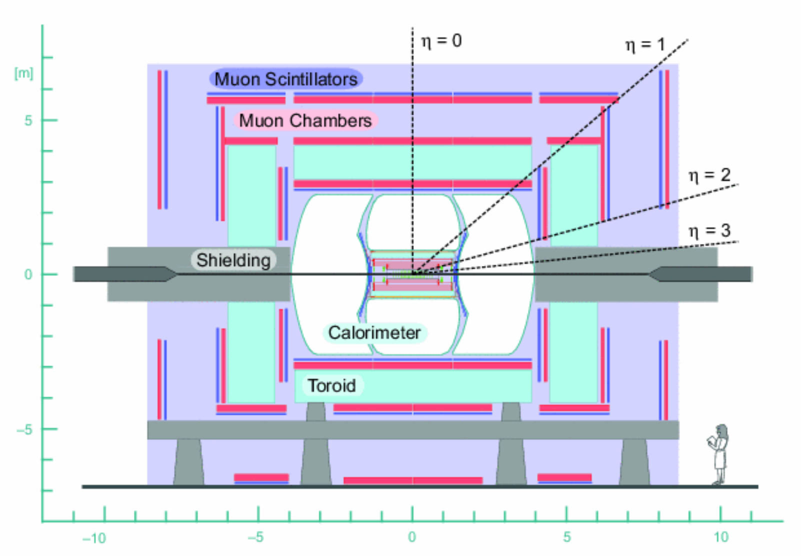


Back Up Slides

The Tevatron and DØ





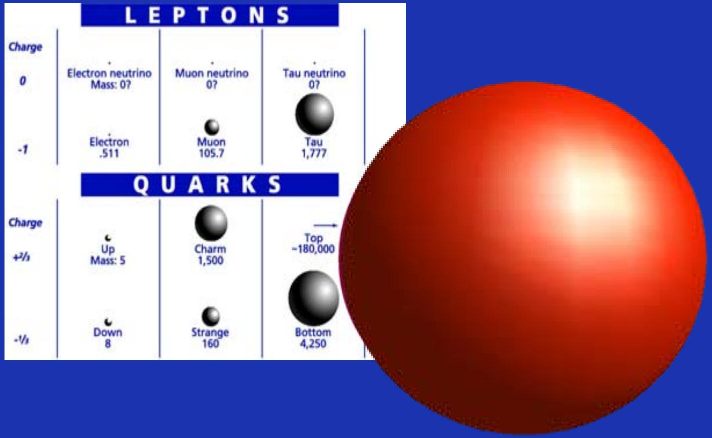


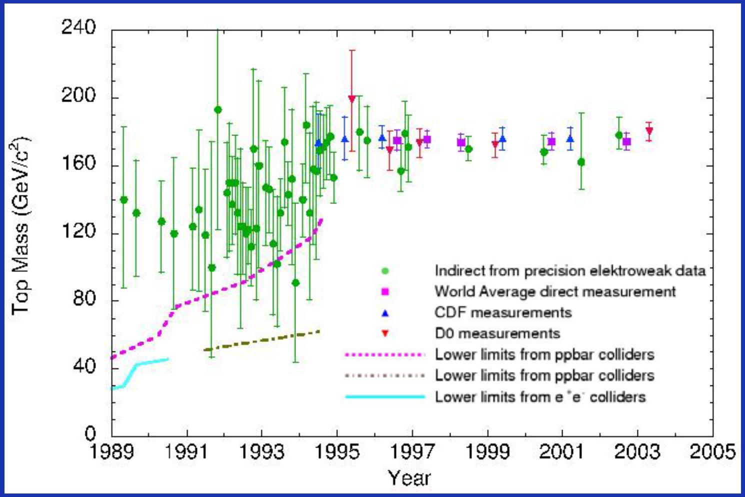
- **Tevatron**
  - **Proton anti-proton collider**
  - **$\sqrt{s}$ = 1.96 TeV**
  - **~1.8 fb^{-1} delivered**
  - **Expected x40-80 Run I data set!**

- **DØ**
  - **A truly international collaboration**
  - **Multipurpose detector**
    - **central tracking embedded in a solenoidal field**
    - **preshowers**
    - **EM and hadronic calorimeters**
    - **muon system**

Why study the Top Quark?

- Predicted in the'70s by the SM and discovered in 1995
  - Least well studied component of the SM (only produced at the Tevatron so far)
- Only known fermion with a mass at the natural Electroweak scale
- Lifetime (5x10^{-25} s) shorter than the hadronization time (no top hadronic bound states)
- The top quark is relevant for many Electroweak analyses
- Strongest coupling to the Higgs (Yukawa coupling $\lambda_t \propto m_t \sim 1$)

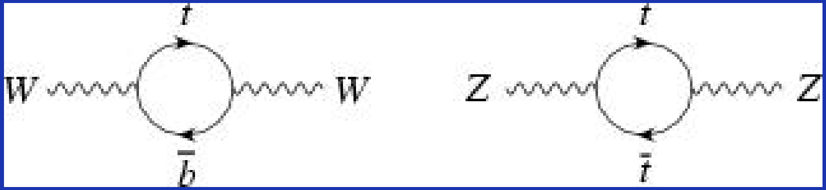




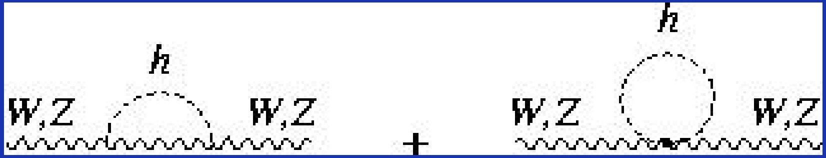
The Top Quark and the SM Higgs

Corrections to W and Z boson masses from top quark and Higgs boson loops constrain the Higgs boson mass

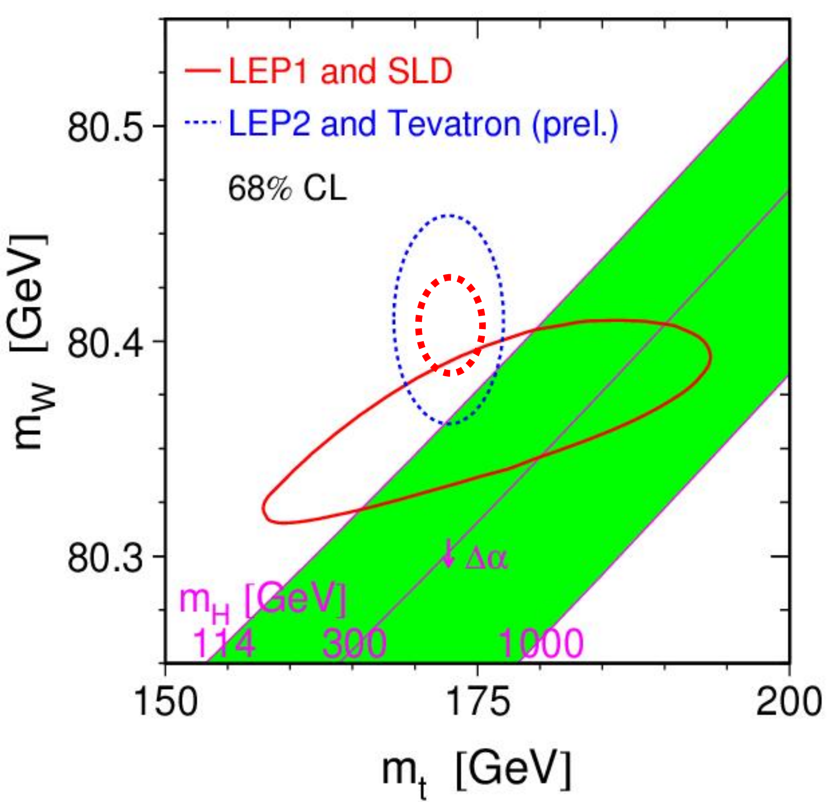
$$M_W^2 = M_W^{(0)} \times (1 - \Delta)$$



$$\Delta_t^{-1} \sim M_t^2$$



$$\Delta_H \sim \ln(M_H^2)$$



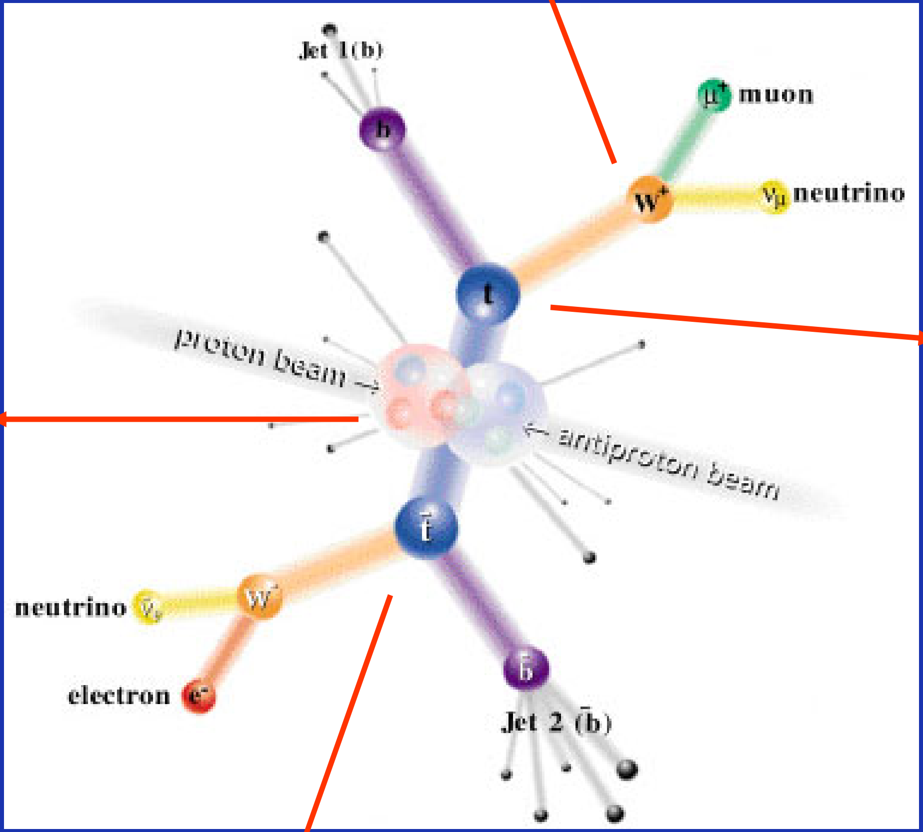
Goal for Tevatron in Run II:

ΔM_t = 3 GeV

ΔM_W = 20 MeV

Top Quark Physics

W Helicity



Production Cross Section

Production Kinematics

Top Spin Polarization

Resonance Production

Top Charge

Branching Ratios

$|V_{tb}|$

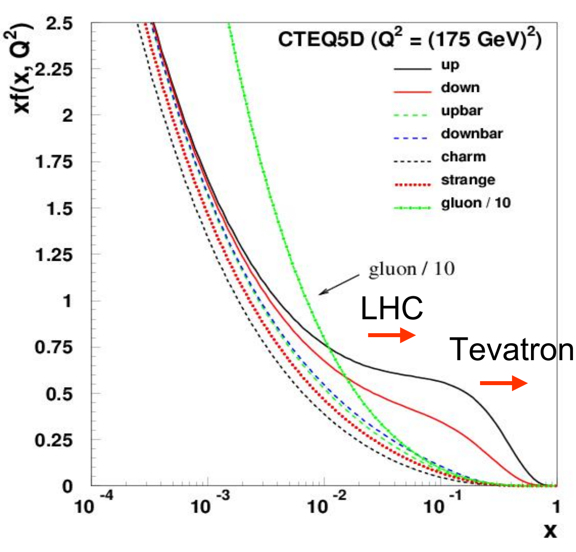
Spin Correlation

Non-SM decays

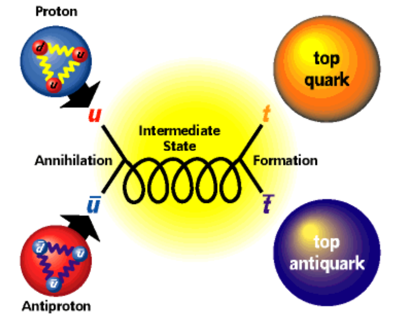
Top Mass

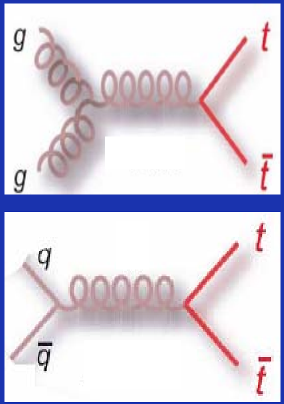
Top Quark Pair Production

Top quarks are mainly produced in pairs (through strong interactions) at Tevatron energies (electroweak production to be observed soon!)



$$x = \frac{2 \times m_t}{\sqrt{s}}$$





	$\sigma_{t\bar{t}}^{NLO}$ (pb)	$q\bar{q} \to t\bar{t}$	$gg \to t\bar{t}$
Run I (1.8 TeV)	4.87±10%	90%	10%
Run II (2.0 TeV)	6.70±10%	85%	15%
LHC (14 TeV)	803±15%	10%	90%

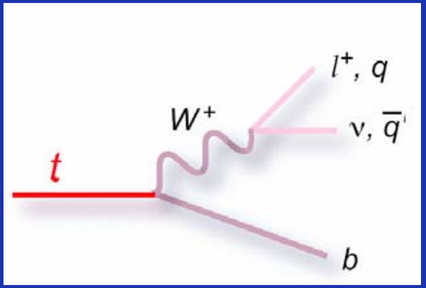
$\sigma_{inel} / \sigma_{ttbar} \sim 10^{10}$

- High luminosity
- High efficiency

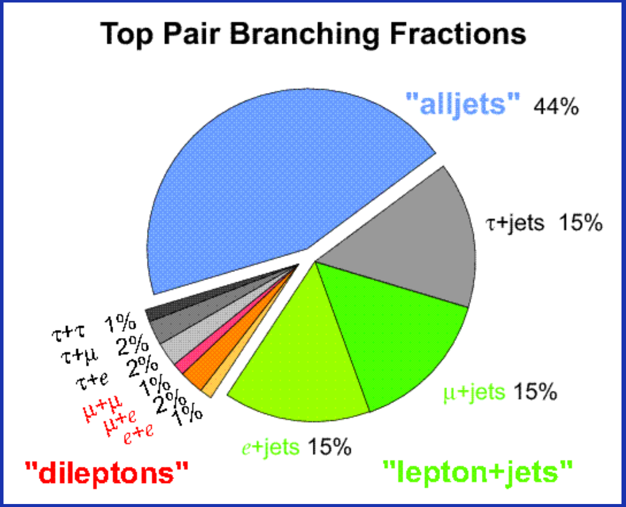
Top Quark Decay

- $\Gamma_t^{SM} \approx 1.5$ GeV ($m_t = 175$ GeV) $\Rightarrow \tau \sim 10^{-25}$ s $\Rightarrow$ no hadronic bound states
- Top quark decays via the Weak interaction exclusively as t → W b
  - $|V_{tb}| > 0.999$

$$R = \frac{BR(t \to Wb)}{BR(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$



  - R = 1.03 ± 0.19 (hep-ex/0503002)
  - Negligible rates for FCNC (t → q γ,Z,g)
- Final state determined by the decay of the W boson:



- dilepton channel (low bkg)
- lepton + jets channel (moderate bkg)
- all hadronic channel (huge bkg)

Lepton≡ e, μ from W or τ from W

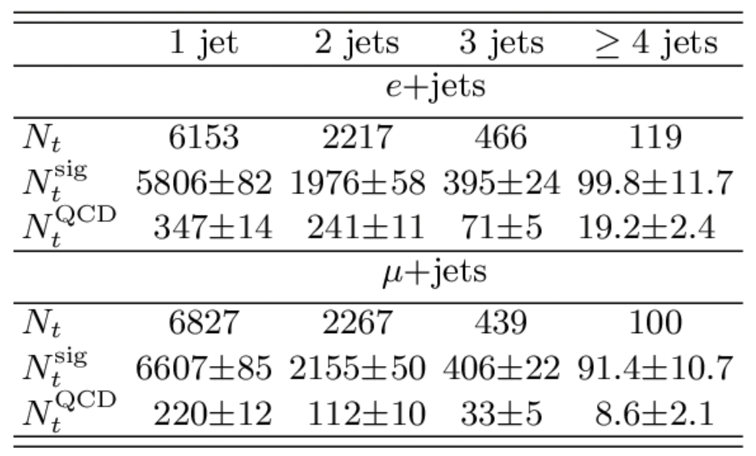
Preselected Sample

- Require:
  - All events pass the signal trigger
  - A tight isolated lepton
  - Large MET (neutrino)
  - At least one jet
  - MET separated from the lepton in the transverse plane
  - Second lepton veto (orthogonal to dilepton analyses)

- Composition of the preselected sample determined by defining two samples (Matrix Method)
  - Tight sample : the preselected sample (N_t)
  - Loose sample : events passing the preselection but with a loose lepton requirement

$$\begin{tikzcd}
N_l \arrow[r, phantom, "="] & N^{sig} \arrow[d, "\varepsilon_{sig}"'] \arrow[r, phantom, "+"] & N^{QCD} \arrow[d, "\varepsilon_{QCD}"'] \\
N_t \arrow[r, phantom, "="] & \varepsilon_{sig} . N^{sig} \arrow[r, phantom, "+"] & \varepsilon_{QCD} . N^{QCD}
\end{tikzcd}$$

ε_{sig} ~85%	→	efficiency for a loose lepton from a W decay to pass the tight criteria
ε_{QCD} ~15%	→	rate for a loose lepton in QCD to appear to be tight



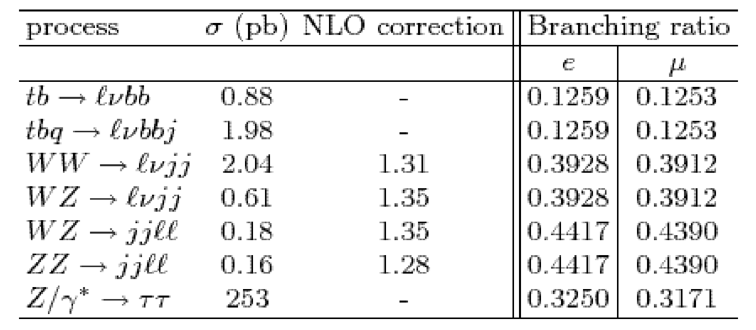
	1 jet	2 jets	3 jets	≥ 4 jets
		e+jets		
N_t	6153	2217	466	119
N_t^{sig}	5806±82	1976±58	395±24	99.8±11.7
N_t^{QCD}	347±14	241±11	71±5	19.2±2.4
		μ+jets		
N_t	6827	2267	439	100
N_t^{sig}	6607±85	2155±50	406±22	91.4±10.7
N_t^{QCD}	220±12	112±10	33±5	8.6±2.1

- Top events populate 3rd and 4th jet multiplicity bins
- Events with 1 and 2 jets used as control of background estimate

Event Simulation

- ttbar and W+jets are generated using ALPGEN 1.3 followed by PYTHIA 6.2 to simulate the underlying event and the hadronization

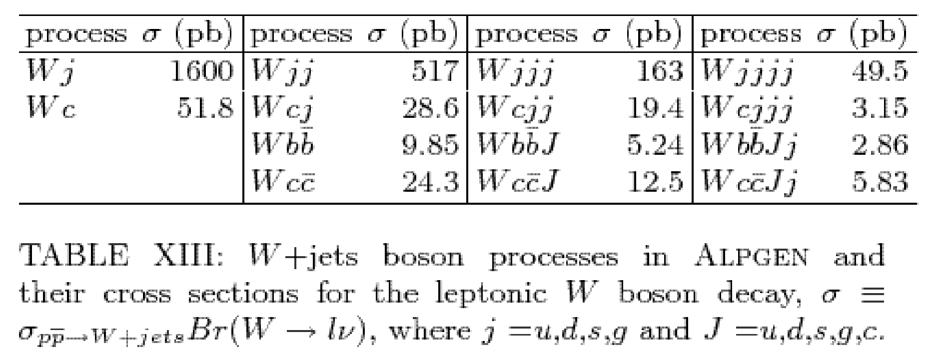
- Other small backgrounds
  - Single top (CompHEP/PYTHIA)
  - Diboson (ALPGEN/PYTHIA) + NLO K-factor
  - Z/gamma* (PYHIA) @ NNLO



process	σ (pb)	NLO correction	Branching ratio	
			e	μ
$tb \to \ell\nu bb$	0.88	-	0.1259	0.1253
$tbq \to \ell\nu bbj$	1.98	-	0.1259	0.1253
$WW \to \ell\nu jj$	2.04	1.31	0.3928	0.3912
$WZ \to \ell\nu jj$	0.61	1.35	0.3928	0.3912
$WZ \to jj\ell\ell$	0.18	1.35	0.4417	0.4390
$ZZ \to jj\ell\ell$	0.16	1.28	0.4417	0.4390
$Z/\gamma^* \to \tau\tau$	253	-	0.3250	0.3171

- TAUOLA simulates τ decays

- W+jets samples are generated separately for processes with 1,2,3, and 4 or more partons in the final state using ALPGEN

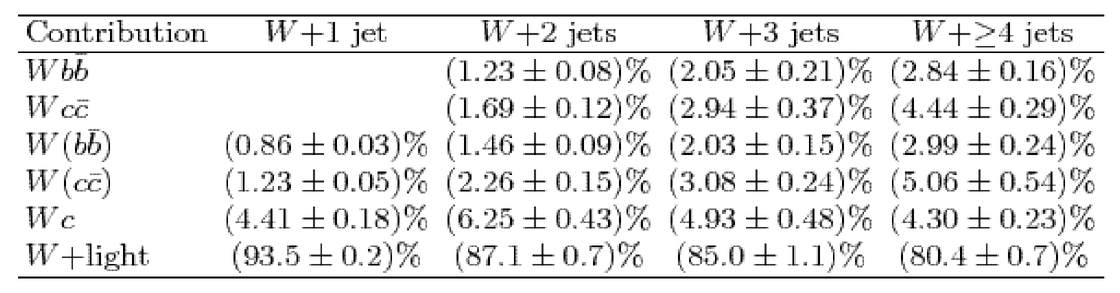


process	σ (pb)	process	σ (pb)	process	σ (pb)	process	σ (pb)
Wj	1600	Wjj	517	$Wjjj$	163	$Wjjjj$	49.5
Wc	51.8	Wcj	28.6	$Wcjj$	19.4	$Wcjjj$	3.15
		$Wb\bar{b}$	9.85	$Wb\bar{b}J$	5.24	$Wb\bar{b}Jj$	2.86
		$Wc\bar{c}$	24.3	$Wc\bar{c}J$	12.5	$Wc\bar{c}Jj$	5.83

TABLE XIII: W+jets boson processes in ALPGEN and their cross sections for the leptonic W boson decay, $\sigma \equiv \sigma_{p\bar{p}\to W+jets} Br(W \to l\nu)$, where j =u,d,s,g and J =u,d,s,g,c.

W+jets event generation

- LO parton level calculations from ALPGEN need to be combined with the partonic evolution from PYTHIA to avoid double counting of configurations leading to the same final state
- Ad-hoc MLM matching is used: matrix element partons are matched to reconstructed jets within a 0.5 cone and classified according to the number of HF jets in the final state
  - Keep events only if the number of reconstructed jets equals the number of matrix element partons in the 1,2,3 jets bin.
  - Keep all events with >=4 reconstructed jets in the n>=4 jets bin, independently of the additional number of non-matched light jets.
- NLO K-factor applied to the Wbbar, Wccbar, W(bbbar) and W(ccbar)



Contribution	W+1 jet	W+2 jets	W+3 jets	W+≥4 jets
$Wb\bar{b}$		$(1.23 \pm 0.08)\%$	$(2.05 \pm 0.21)\%$	$(2.84 \pm 0.16)\%$
$Wc\bar{c}$		$(1.69 \pm 0.12)\%$	$(2.94 \pm 0.37)\%$	$(4.44 \pm 0.29)\%$
$W(b\bar{b})$	$(0.86 \pm 0.03)\%$	$(1.46 \pm 0.09)\%$	$(2.03 \pm 0.15)\%$	$(2.99 \pm 0.24)\%$
$W(c\bar{c})$	$(1.23 \pm 0.05)\%$	$(2.26 \pm 0.15)\%$	$(3.08 \pm 0.24)\%$	$(5.06 \pm 0.54)\%$
Wc	$(4.41 \pm 0.18)\%$	$(6.25 \pm 0.43)\%$	$(4.93 \pm 0.48)\%$	$(4.30 \pm 0.23)\%$
W+light	$(93.5 \pm 0.2)\%$	$(87.1 \pm 0.7)\%$	$(85.0 \pm 1.1)\%$	$(80.4 \pm 0.7)\%$

Systematic error on the fractions comes from difference between matching schemes, choice of matching cone size, PDF and renormalization and factorization scales

Jet Flavor Identification in MC

- For all MC samples, the jet flavor (b, c, or light) is determined by matching the direction of the reconstructed jet to the hadron flavor within a cone of R=0.5
- If more than one hadron is found within the cone, the jet is considered a:
  - b-jet, if the cone contains at least one B hadron
  - c-jet, if the cone contains at least one C, and no B hadron
  - light, if the cone contains no B or C hadron.

W+jets Background

- The dominant background by far
- Overall normalization before tagging obtained directly from Data

$$N^{presel}_{(W\to l\nu)+nj} = N^{sig}_{t} - N^{presel}_{t\bar{t}\to l+jets} - N^{presel}_{t\bar{t}\to ll} - \sum_{bkg\ i} N^{presel}_{bkg\ i}$$

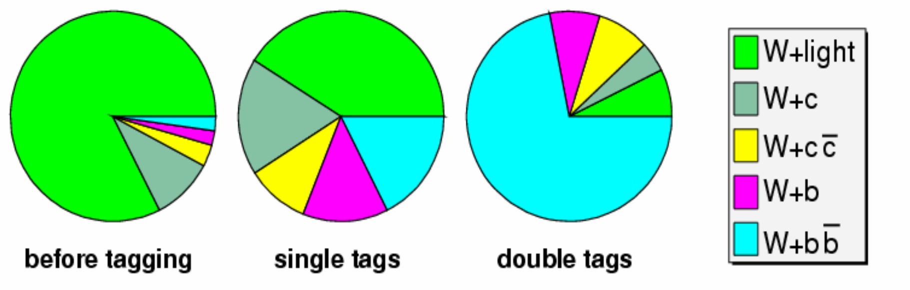
- Number of W+jets events in the tagged sample determined by

$$N^{tag}_{(W\to l)+nj} = N^{presel}_{(W\to l)+nj}\, P^{tag}_{(W\to l)+nj}$$

- The event tagging probability results from adding the tagging probabilities for the different flavor configurations weighted with their fractions

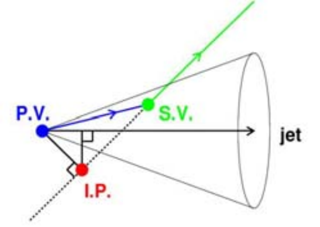
$$P^{tag}_{(W\to l)+nj} = \sum_{\Phi_n} F_{\Phi_n} P^{tag}_{\Phi_n}$$

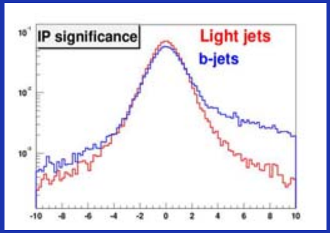
$$F_{\Phi,n} = \frac{\sigma^{\mathrm{eff}}_{\Phi,n}}{\sum_{\Phi} \sigma^{\mathrm{eff}}_{\Phi,n}}$$



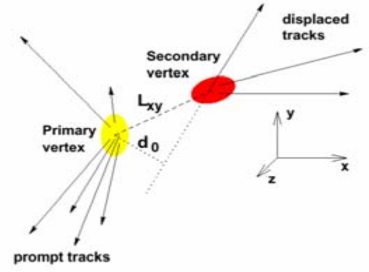
Secondary Vertex Tagger Algorithm

The Secondary Vertex Tagger (SVT) is a lifetime tagger that explicitly reconstructs vertices which are displaced from the Primary Vertex

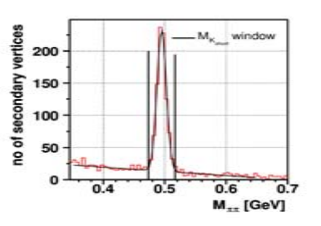


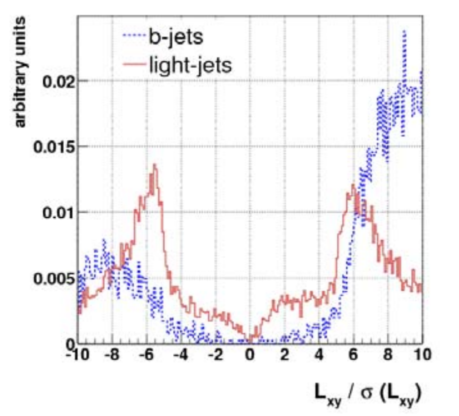


- **Use of tracks with significant impact parameter with respect to the Primary Vertex**



- **Build-up method fitting pairs of selected tracks within track-jets**



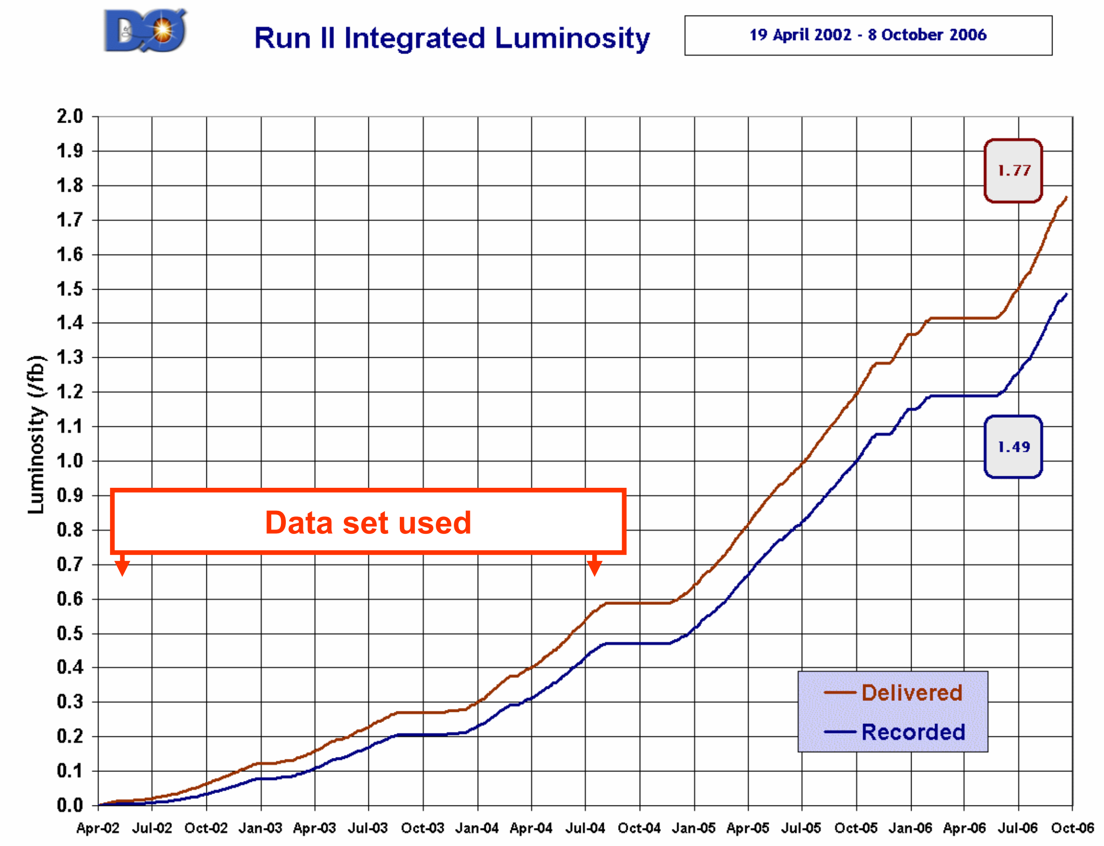


- **Removes track pairs in the mass windows corresponding to K^0_S, Λ^0 and photon conversions ($\gamma \rightarrow e^+e^-$)**
- **A jet is identified as a b-jet (tagged) if it contains a reconstructed secondary vertex within a jet**

Top events have two *b*-jets while events from other processes very seldom have heavy flavor!

Data Sample

- Run Quality, Luminosity Block and Event Quality Selections applied
- A lepton and a jet are required at trigger level
- Trigger efficiencies are estimated by folding into the MC the per-object individual trigger conditions measured in Data



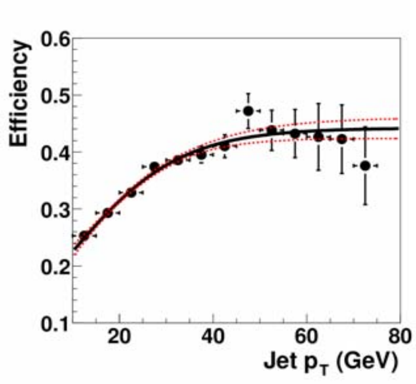
Analysis Method

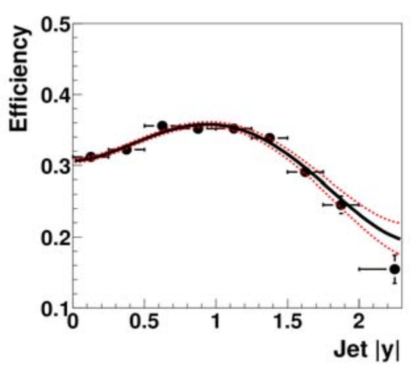
- Determine the number of selected events for each background
- Parameterize the tagging efficiencies determined in data
- Determine event tagging probabilities for all the backgrounds
- Use the Monte Carlo simulation event kinematics and fold in the tagging efficiencies from data to estimate the number of tagged events
- Estimate the ttbar cross section from the excess in the actual number of tagged events with 3 and ≥ 4 jets over the background prediction

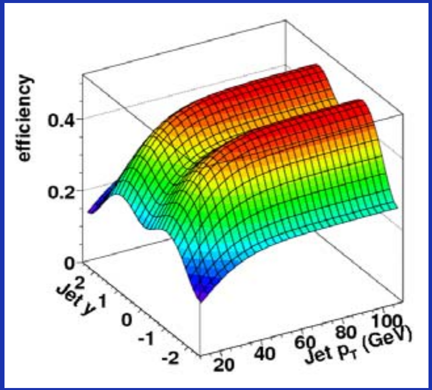
$$\boxed{\sigma = \frac{N^{tag}_{observed} - N^{tag}_{background}}{BR \cdot L \cdot \varepsilon_{presel} \cdot \bar{P}^{tag}}}$$

Semileptonic *b*-Tagging Efficiency

- *b*-tagging rate is measured purely from data applying SVT and Soft Lepton Tagger to two samples:
  - muon-in-jet
  - muon-in-jet away jet tagged (enriched in heavy flavor)
- Use system8
  - Samples with different fractions of signal and background
  - SVT and SLT have different efficiencies for signal and background
  - SVT and SLT decorrelated
  - 8 equations with 8 unknowns
- Parameterize in terms of p_T^{jet} and y^{jet}





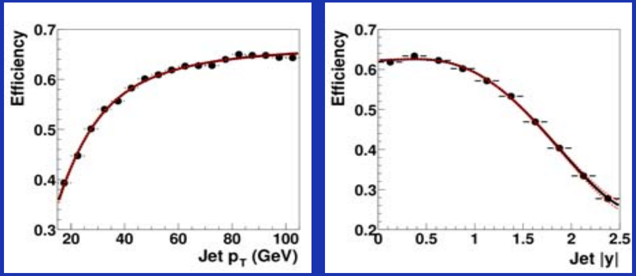


Systematic uncertainties arise from the variation of the correlation parameters in System8

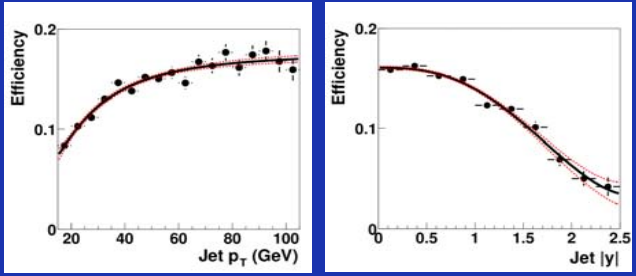
Inclusive Tagging Efficiencies

- **Inclusive *b(c)*-tagging efficiency in MC**
  - **Measured in ttbar**

b-inclusive (ttbar MC)



c-inclusive (ttbar MC)



- **Calibrated by data-to-MC scale factor given by the ratio of semileptonic b-tagging efficiencies measured in data and bbbar MC**

$$SF_{b\to\mu}(p_T,\eta) = \frac{\epsilon^{data}_{b\to\mu}(p_T,\eta)}{\epsilon^{MC}_{b\to\mu}(p_T,\eta)}$$

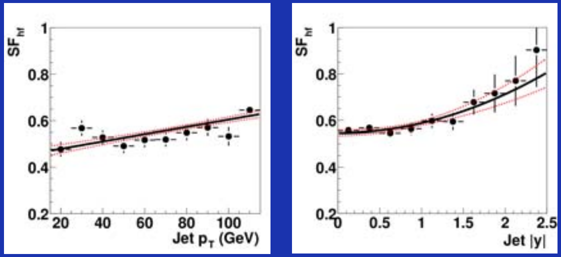
Systematic uncertainties on the inclusive efficiencies coming from the difference between parameterizations obtained in ttbar MC with two choices of b-fragmentation models. Systematic uncertainty on semileptonic b efficiency in MC takes as the difference in efficiency between bbbar and ttbar.

Mistag Rate

The Negative Tagging Rate is corrected for:

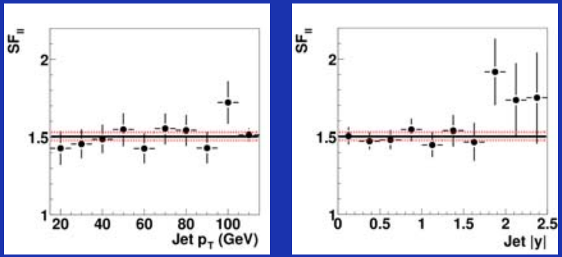
- **Heavy flavor contamination in QCD data (estimated in QCD MC)**

$$SF_{hf}(p_T,y) = \frac{\varepsilon_-^{light}(p_T,y)}{\varepsilon_-^{inclusive}(p_T,y)}$$



- **Remaining long lived particles (K^0_s, Λ^0) not present in the negative tagging rate (estimated in *QCD* MC)**

$$SF_{ll}(p_T,y) = \frac{\varepsilon_+^{light}(p_T,y)}{\varepsilon_-^{light}(p_T,y)}.$$



- **The mistag rate is then** $\varepsilon_+^{light}(p_T,y) = \varepsilon_-^{data}(p_T,y) SF_{hf}(p_T,y) SF_{ll}(p_T,y)$

Systematic uncertainties determined by varying by 20% the b and c fractions in PYTHIA QCD MC used for the SFs

Composition of the Preselected Sample

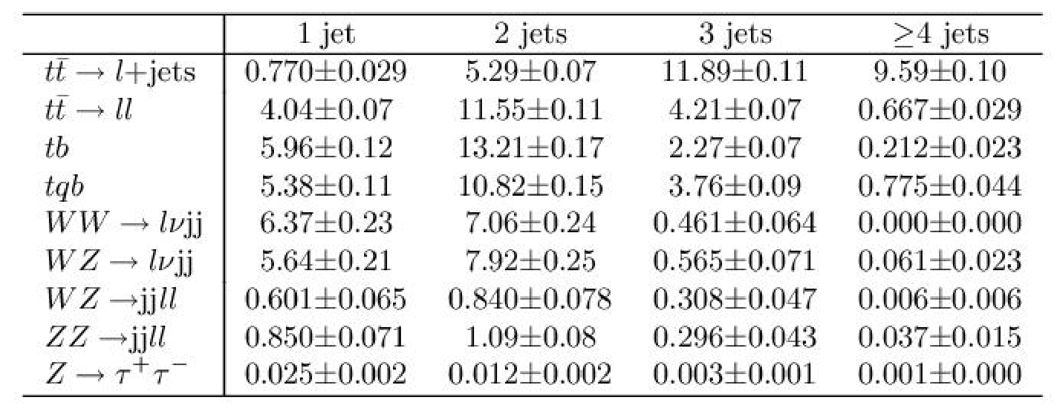
- The Matrix Method separates QCD from Physics Backgrounds
- Expected number of signal events:

$$N^{presel}_{ttbar} = \sigma^{theory}_{ttbar} \times \varepsilon^{presel}_{ttbar} \times BR \times L$$

- Expected number of non-*W* background events:

$$N^{presel}_{i} = \sigma^{theory}_{i} \times \varepsilon^{presel}_{i} \times BR \times L$$

i = single top, diboson (*WW, WZ, ZZ*) and $Z \rightarrow \tau\tau$



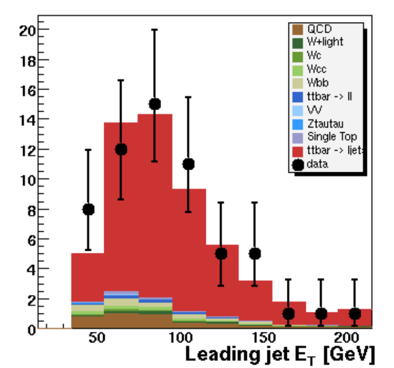
	1 jet	2 jets	3 jets	≥4 jets
$t\bar{t} \rightarrow l$+jets	0.770±0.029	5.29±0.07	11.89±0.11	9.59±0.10
$t\bar{t} \rightarrow ll$	4.04±0.07	11.55±0.11	4.21±0.07	0.667±0.029
tb	5.96±0.12	13.21±0.17	2.27±0.07	0.212±0.023
tqb	5.38±0.11	10.82±0.15	3.76±0.09	0.775±0.044
$WW \rightarrow l\nu$jj	6.37±0.23	7.06±0.24	0.461±0.064	0.000±0.000
$WZ \rightarrow l\nu$jj	5.64±0.21	7.92±0.25	0.565±0.071	0.061±0.023
$WZ \rightarrow$jjll	0.601±0.065	0.840±0.078	0.308±0.047	0.006±0.006
$ZZ \rightarrow$jjll	0.850±0.071	1.09±0.08	0.296±0.043	0.037±0.015
$Z \rightarrow \tau^+\tau^-$	0.025±0.002	0.012±0.002	0.003±0.001	0.001±0.000

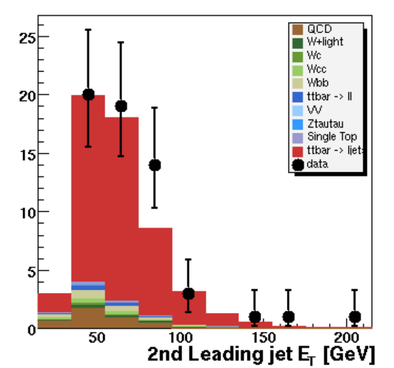
Preselection Efficiencies in the *e*+jets channel

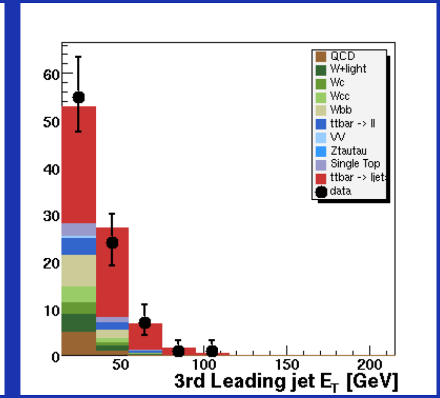
- Expected number of *W* background events:

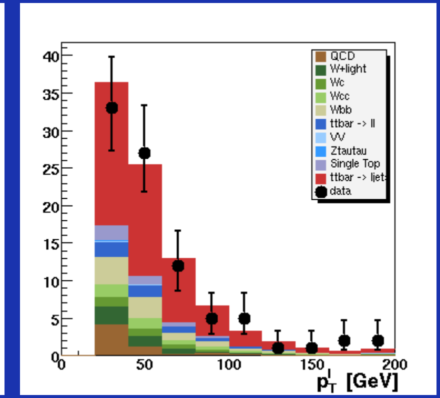
$$N^{presel}_{W} = N^{sig}_{t} - N^{presel}_{ttbar} - \Sigma\, N^{presel}_{i}$$

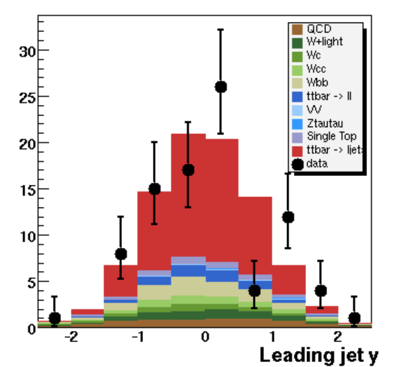
Lepton+Jets Single Tag 3rd Jet Bin

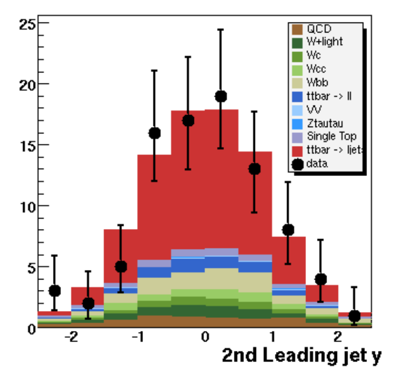


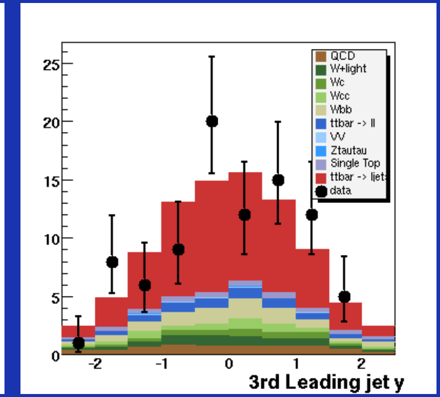


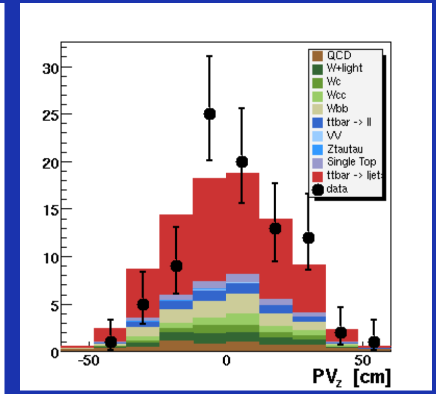




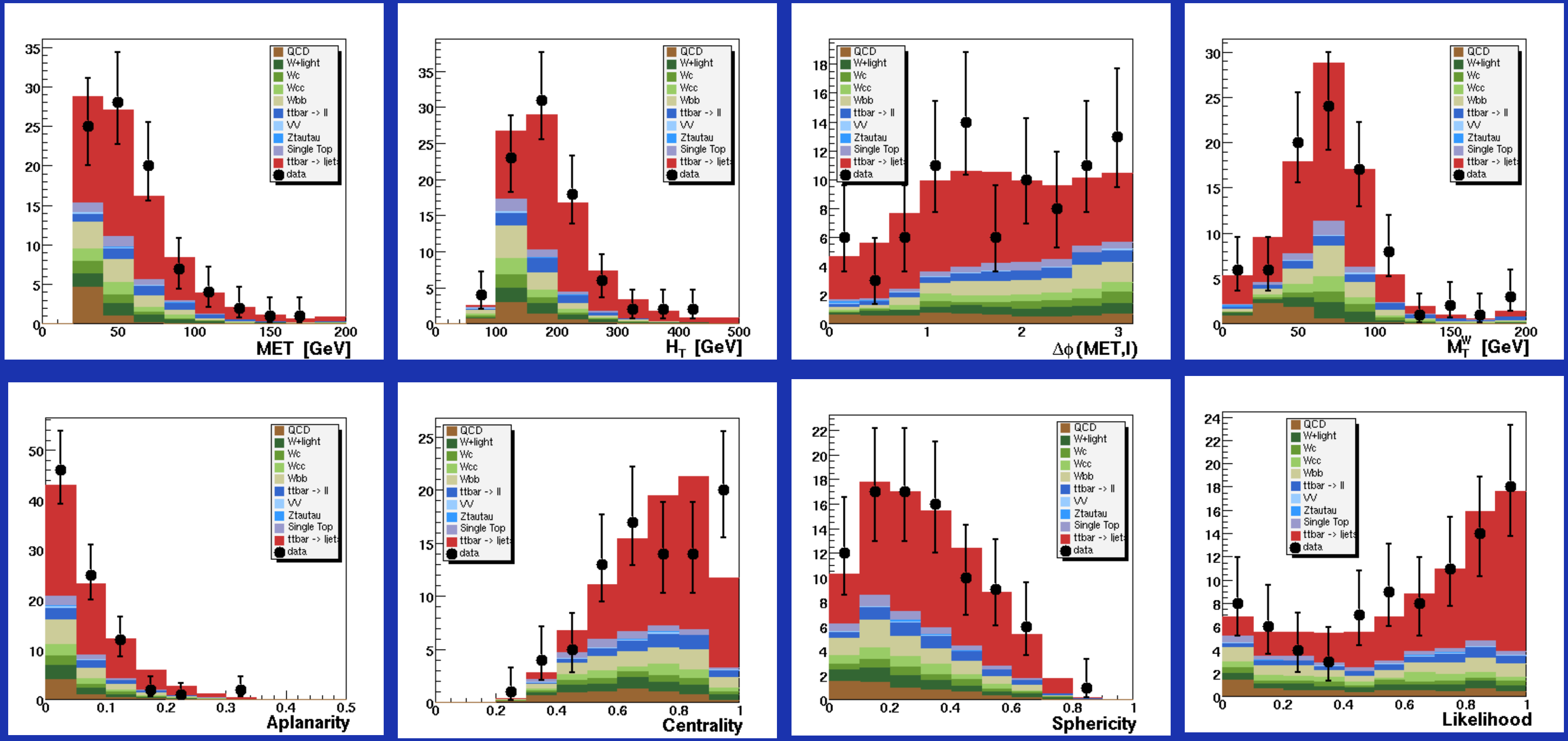




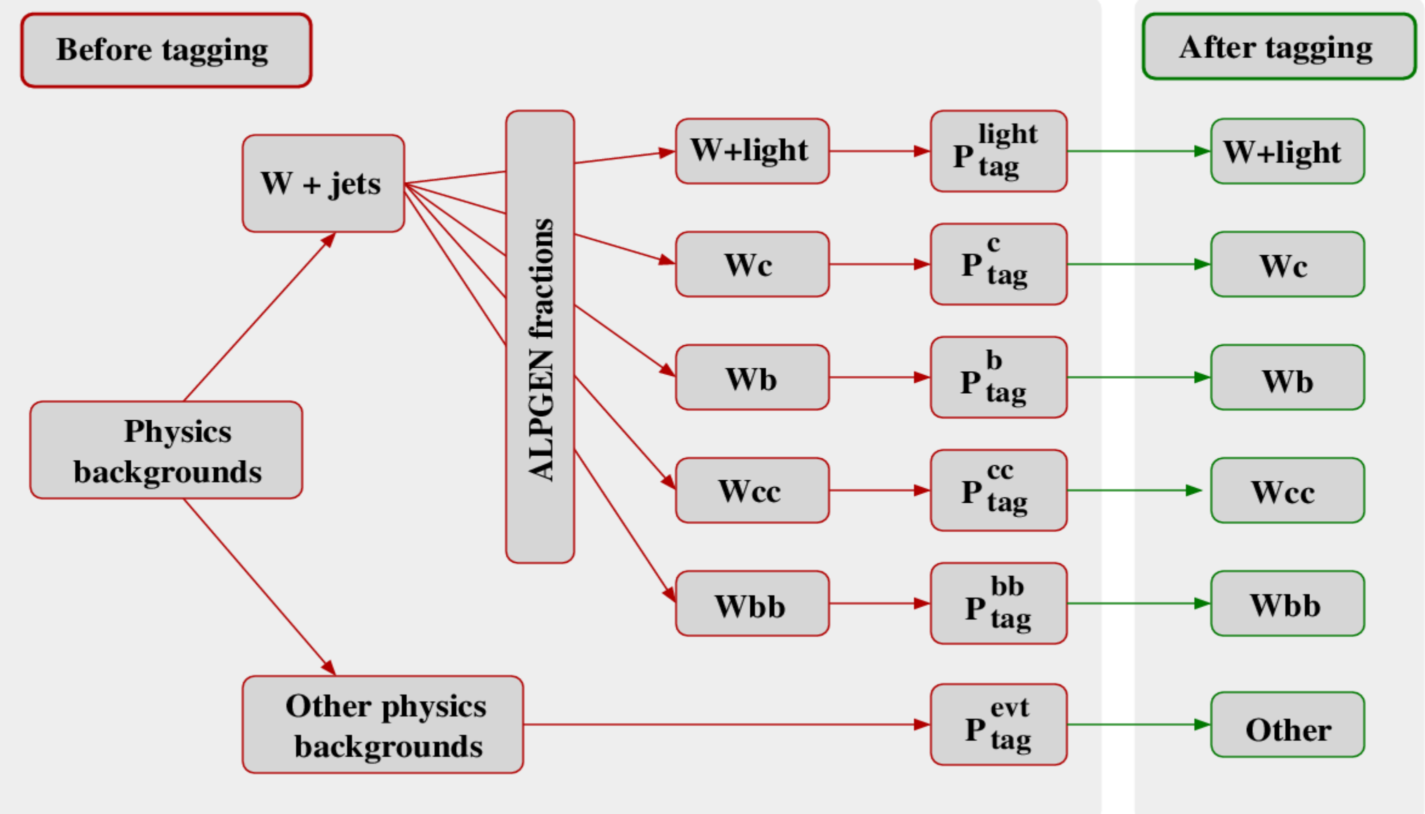




Lepton+Jets Single Tag 3rd Jet Bin



b-Tagging Sumary



Before tagging

Physics backgrounds

W + jets

Other physics backgrounds

ALPGEN fractions

W+light

Wc

Wb

Wcc

Wbb

P^{light}_{tag}

P^{c}_{tag}

P^{b}_{tag}

P^{cc}_{tag}

P^{bb}_{tag}

P^{evt}_{tag}

After tagging

W+light

Wc

Wb

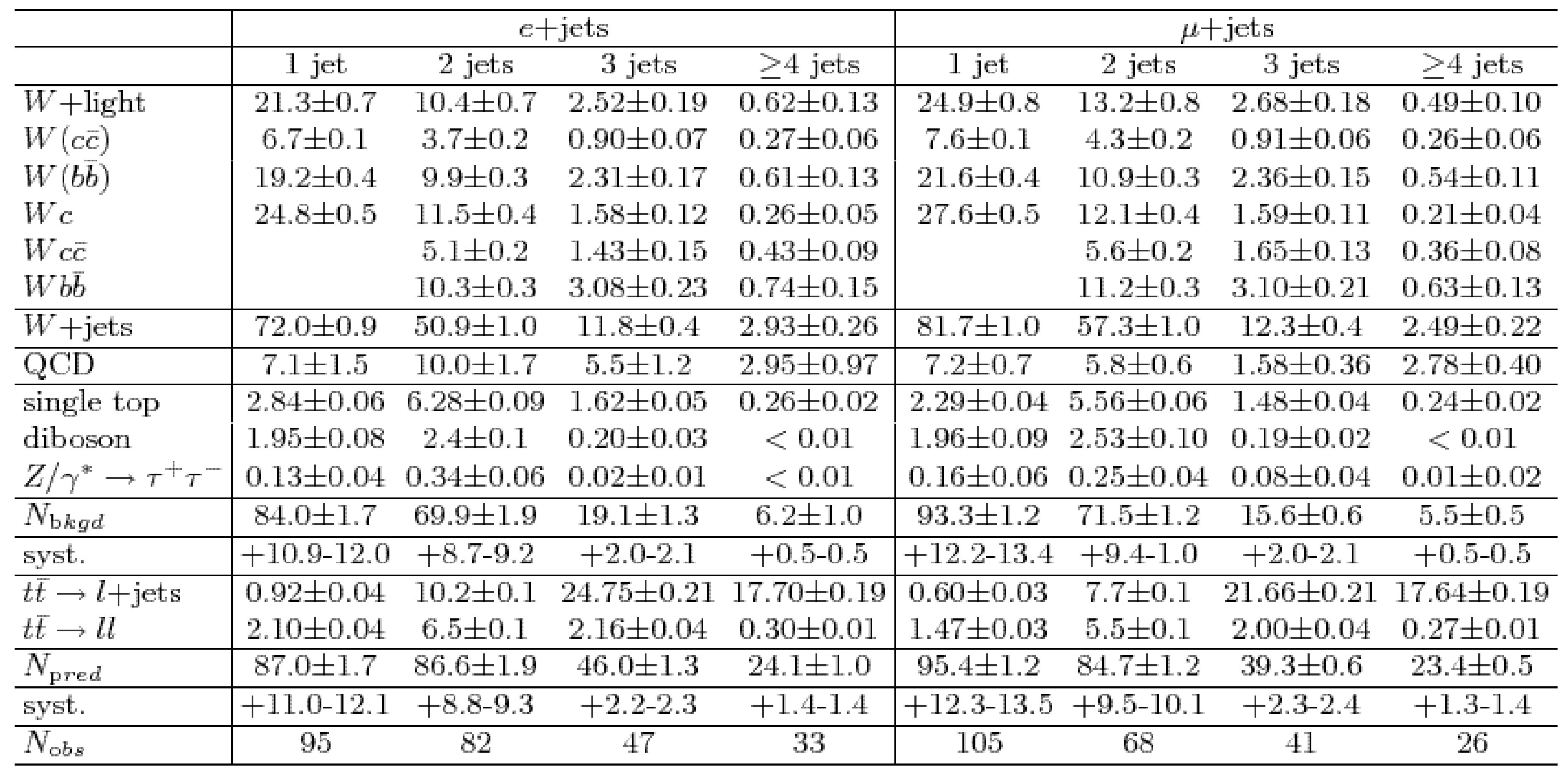
Wcc

Wbb

Other

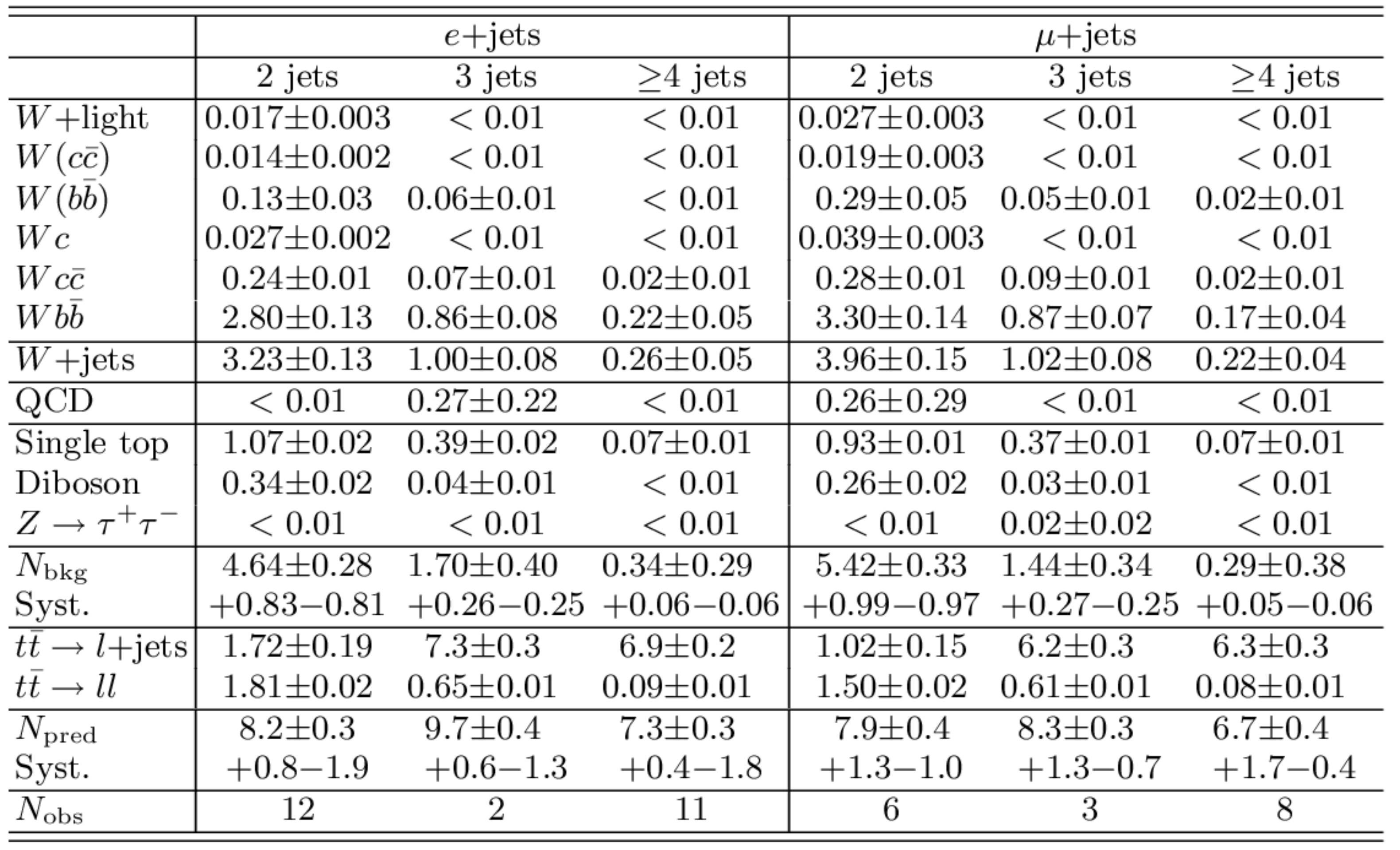
- Estimate the ttbar cross-section from observed excess in the number of tagged events with respect to the background prediction
- Optimum use of the statistical information (single and double tags)

Observed vs. Predicted single tags



	e+jets				μ+jets			
	1 jet	2 jets	3 jets	≥4 jets	1 jet	2 jets	3 jets	≥4 jets
W+light	21.3±0.7	10.4±0.7	2.52±0.19	0.62±0.13	24.9±0.8	13.2±0.8	2.68±0.18	0.49±0.10
$W(c\bar{c})$	6.7±0.1	3.7±0.2	0.90±0.07	0.27±0.06	7.6±0.1	4.3±0.2	0.91±0.06	0.26±0.06
$W(b\bar{b})$	19.2±0.4	9.9±0.3	2.31±0.17	0.61±0.13	21.6±0.4	10.9±0.3	2.36±0.15	0.54±0.11
$W c$	24.8±0.5	11.5±0.4	1.58±0.12	0.26±0.05	27.6±0.5	12.1±0.4	1.59±0.11	0.21±0.04
$W c\bar{c}$		5.1±0.2	1.43±0.15	0.43±0.09		5.6±0.2	1.65±0.13	0.36±0.08
$W b\bar{b}$		10.3±0.3	3.08±0.23	0.74±0.15		11.2±0.3	3.10±0.21	0.63±0.13
W+jets	72.0±0.9	50.9±1.0	11.8±0.4	2.93±0.26	81.7±1.0	57.3±1.0	12.3±0.4	2.49±0.22
QCD	7.1±1.5	10.0±1.7	5.5±1.2	2.95±0.97	7.2±0.7	5.8±0.6	1.58±0.36	2.78±0.40
single top	2.84±0.06	6.28±0.09	1.62±0.05	0.26±0.02	2.29±0.04	5.56±0.06	1.48±0.04	0.24±0.02
diboson	1.95±0.08	2.4±0.1	0.20±0.03	< 0.01	1.96±0.09	2.53±0.10	0.19±0.02	< 0.01
$Z/\gamma^* \to \tau^+\tau^-$	0.13±0.04	0.34±0.06	0.02±0.01	< 0.01	0.16±0.06	0.25±0.04	0.08±0.04	0.01±0.02
N_{bkgd}	84.0±1.7	69.9±1.9	19.1±1.3	6.2±1.0	93.3±1.2	71.5±1.2	15.6±0.6	5.5±0.5
syst.	+10.9-12.0	+8.7-9.2	+2.0-2.1	+0.5-0.5	+12.2-13.4	+9.4-1.0	+2.0-2.1	+0.5-0.5
$t\bar{t} \to l$+jets	0.92±0.04	10.2±0.1	24.75±0.21	17.70±0.19	0.60±0.03	7.7±0.1	21.66±0.21	17.64±0.19
$t\bar{t} \to ll$	2.10±0.04	6.5±0.1	2.16±0.04	0.30±0.01	1.47±0.03	5.5±0.1	2.00±0.04	0.27±0.01
N_{pred}	87.0±1.7	86.6±1.9	46.0±1.3	24.1±1.0	95.4±1.2	84.7±1.2	39.3±0.6	23.4±0.5
syst.	+11.0-12.1	+8.8-9.3	+2.2-2.3	+1.4-1.4	+12.3-13.5	+9.5-10.1	+2.3-2.4	+1.3-1.4
N_{obs}	95	82	47	33	105	68	41	26

Observed vs. Predicted double tags



	e+jets			μ+jets		
	2 jets	3 jets	≥4 jets	2 jets	3 jets	≥4 jets
W+light	0.017±0.003	< 0.01	< 0.01	0.027±0.003	< 0.01	< 0.01
$W(c\bar{c})$	0.014±0.002	< 0.01	< 0.01	0.019±0.003	< 0.01	< 0.01
$W(b\bar{b})$	0.13±0.03	0.06±0.01	< 0.01	0.29±0.05	0.05±0.01	0.02±0.01
Wc	0.027±0.002	< 0.01	< 0.01	0.039±0.003	< 0.01	< 0.01
$Wc\bar{c}$	0.24±0.01	0.07±0.01	0.02±0.01	0.28±0.01	0.09±0.01	0.02±0.01
$Wb\bar{b}$	2.80±0.13	0.86±0.08	0.22±0.05	3.30±0.14	0.87±0.07	0.17±0.04
W+jets	3.23±0.13	1.00±0.08	0.26±0.05	3.96±0.15	1.02±0.08	0.22±0.04
QCD	< 0.01	0.27±0.22	< 0.01	0.26±0.29	< 0.01	< 0.01
Single top	1.07±0.02	0.39±0.02	0.07±0.01	0.93±0.01	0.37±0.01	0.07±0.01
Diboson	0.34±0.02	0.04±0.01	< 0.01	0.26±0.02	0.03±0.01	< 0.01
$Z \rightarrow \tau^+\tau^-$	< 0.01	< 0.01	< 0.01	< 0.01	0.02±0.02	< 0.01
$N_{\rm bkg}$	4.64±0.28	1.70±0.40	0.34±0.29	5.42±0.33	1.44±0.34	0.29±0.38
Syst.	+0.83−0.81	+0.26−0.25	+0.06−0.06	+0.99−0.97	+0.27−0.25	+0.05−0.06
$t\bar{t} \rightarrow l$+jets	1.72±0.19	7.3±0.3	6.9±0.2	1.02±0.15	6.2±0.3	6.3±0.3
$t\bar{t} \rightarrow ll$	1.81±0.02	0.65±0.01	0.09±0.01	1.50±0.02	0.61±0.01	0.08±0.01
$N_{\rm pred}$	8.2±0.3	9.7±0.4	7.3±0.3	7.9±0.4	8.3±0.3	6.7±0.4
Syst.	+0.8−1.9	+0.6−1.3	+0.4−1.8	+1.3−1.0	+1.3−0.7	+1.7−0.4
$N_{\rm obs}$	12	2	11	6	3	8