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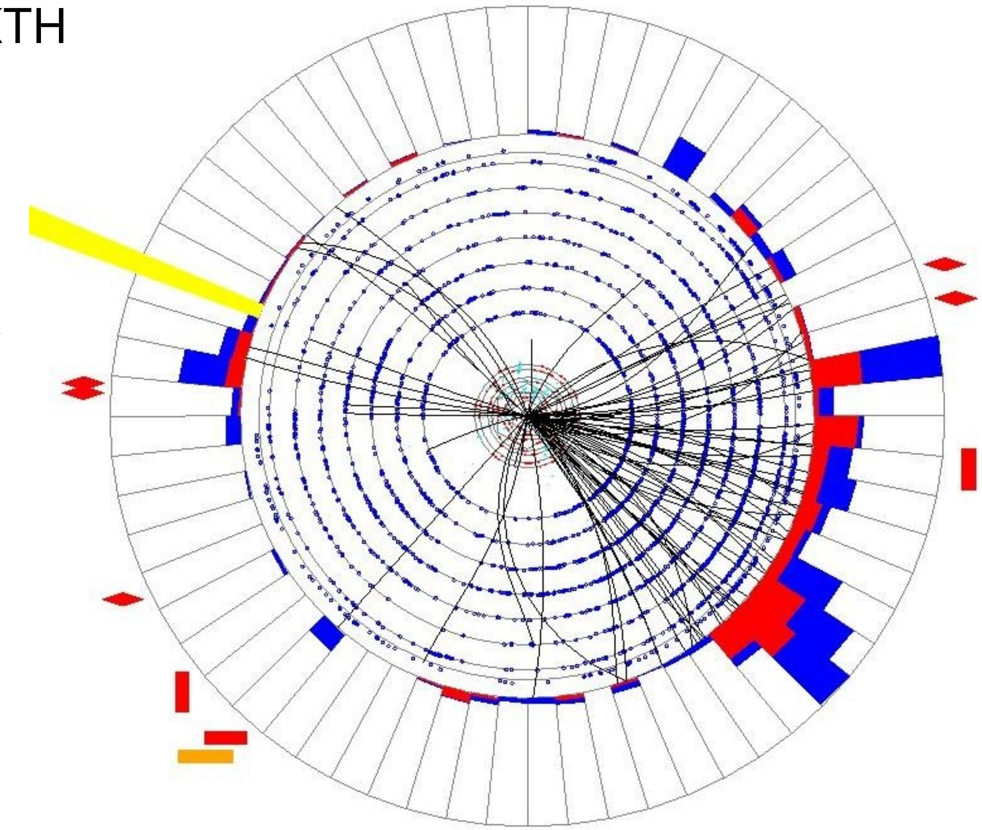


Measurement of the top quark Electric Charge and Branching Fractions at D0

on behalf of the

D0 Collaboration

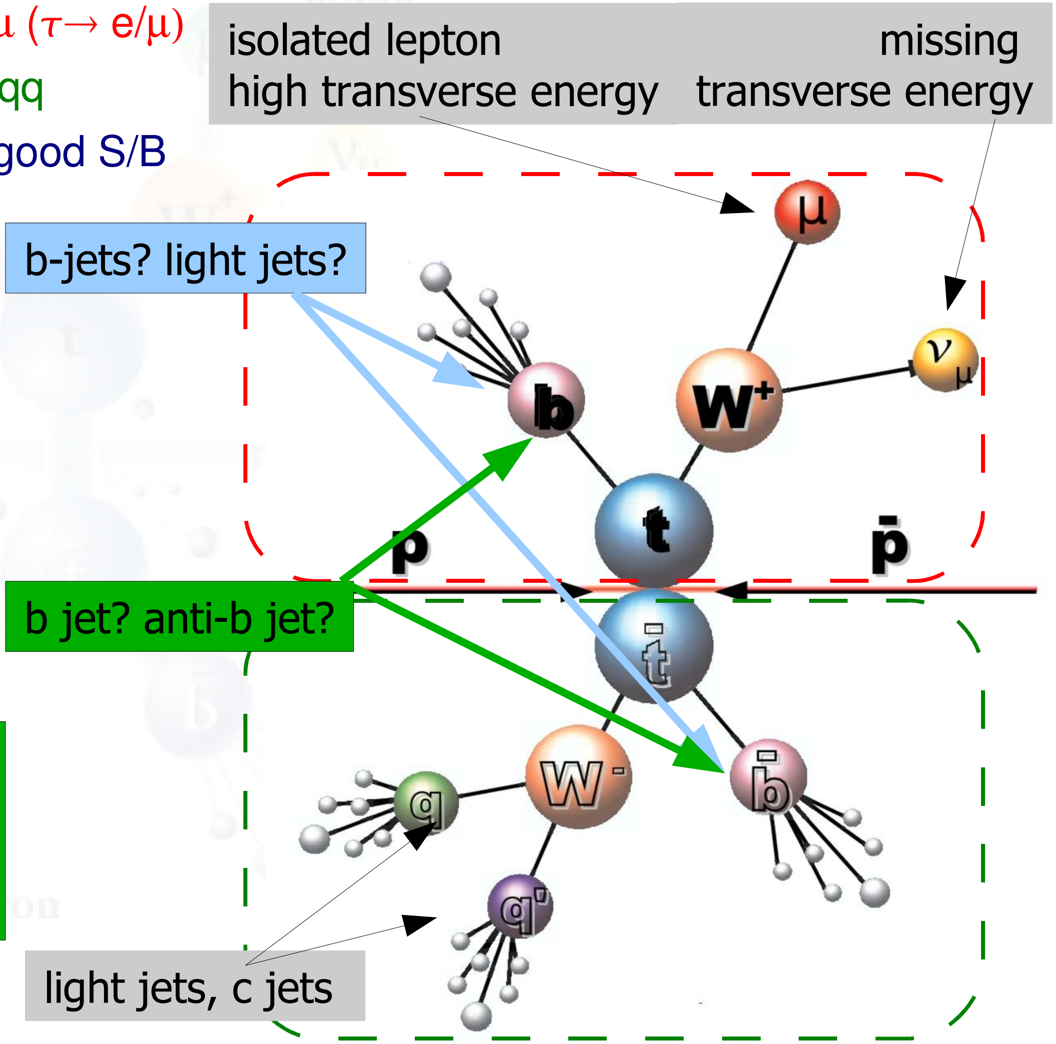
APS April Meeting 2007

Session K14, Top II

Charge and Br(t→Wb) Analyses

- Select a top pair – enriched sample
  - One W decays leptonically: W → e/μ (τ→ e/μ)
  - Other W decays hadronically: W → qq
  - Large statistics Br(tt→l+jets)~34%, good S/B

lepton+jets channel



<u>Key issues in these analysis</u>

- Top quark branching ratio
  - Discriminate between t→Wb and t→Wq_{light} (q_{light}= s,d)
  - Background estimation

- Top quark electric charge
  - Discriminate b/w b- and anti-b jets
  - b-quark and W boson association

Br(t→Wb): motivation

- Expressible in terms of CKM elements $$R=\frac{Br(t\to Wb)}{Br(t\to Wq)}=\frac{|V_{tb}|^2}{|V_{tb}|^2+|V_{ts}|^2+|V_{td}|^2}$$
- Unitarity & CKM experimental constraints: 0.9980< R <0.9985
  - Assumed to be ≈1 in top mass and cross section analyzes, but might deviate:

i)Additional quark families, ii) non-SM production/decay, iii) exotic 'pollution' in top quark sample

CKM matrix:

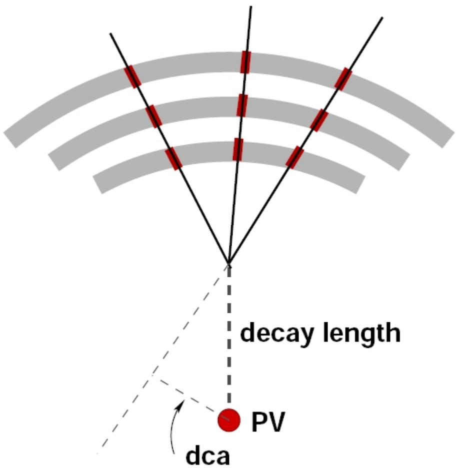
~~3×3 unitary constraint~~

$$\begin{pmatrix} 0.9730 \text{ to } 0.9746 & 0.2174 \text{ to } 0.2241 & 0.0030 \text{ to } 0.0044 \dots \\ 0.213 \text{ to } 0.226 & 0.968 \text{ to } 0.975 & 0.039 \text{ to } 0.044 \dots \\ 0 \text{ to } 0.08 & 0 \text{ to } 0.11 & 0.07 \text{ to } 0.9993 \dots \\ \vdots & \vdots & \vdots \end{pmatrix}$$

← $|V_{tb}|$

Experimentally

- # ttbar events with 0, 1 or 2 b-jets
  - Br(t→Wb)
  - (b-)Jet identification efficiency



b-jet identification

- Exploit long lifetime of B-hadrons ~ 2mm decay length
- Identify tracks from displaced vertex

Derived from data:

- b-tagging efficiency: ~35%
- mis-tag rate ~ 0.025%

Br(t→Wb): method

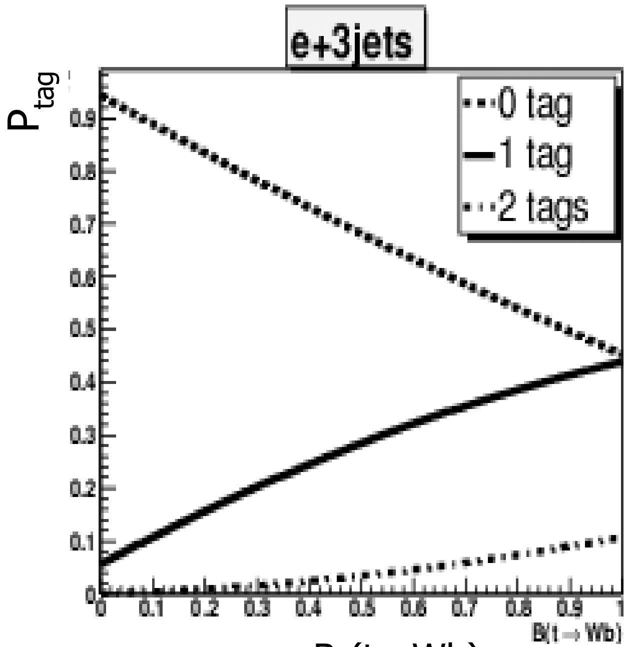
- Probability to observe n-tags in a ttbar event ($P_{tt}^{n\text{-tags}}$)
  - Three scenarios

$$R = \frac{Br(t \to Wb)}{Br(t \to Wq)}$$

$$P_{t\bar{t}}^{n-tags} = P^{n-tags}(t\bar{t} \to bb) \times R^2 + P^{n-tags}(t\bar{t} \to qb) \times 2R(1-R) + P^{n-tags}(t\bar{t} \to qq) \times (1-R)^2$$

n-tags = 0, 1 or 2

- Event tagging probability
  - Derived separately for each scenario



Br(t→Wb)

Number of ttbar events with n-tags, depends on R

Br(t→Wb): result

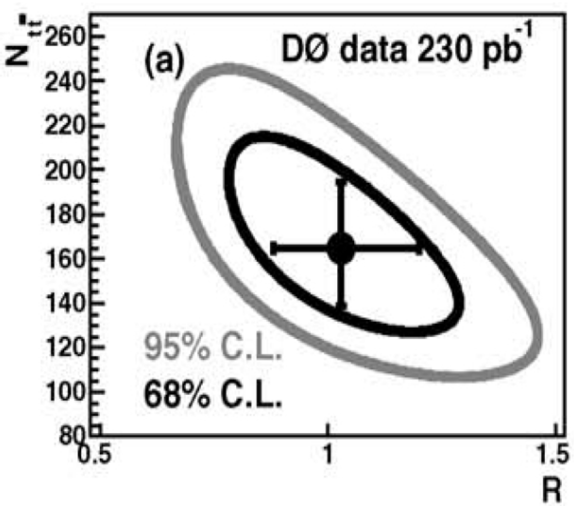
PLB 639, 616 (2006)

- Count events with n-tags (bkg estimation technique same as in cross section analysis)

$$N^{n-tags} = P_{t\bar{t}}^{n-tags}(\boldsymbol{Br}(\boldsymbol{t} \to \boldsymbol{Wb}))\, N_{t\bar{t}} + P_{bkg}^{n-tags} \times N_{bkg}$$

→ **Fit N_{tt} and R simultaneously to $N^{n\text{-tags}}$ using 2D nuisance likelihood fit**

  - Constraints on R from relative number of events with 0, 1 or 2-tags
  - 0-tag sample ⇨ include in the fit shape of topological variables



$$\text{Br}(t\to Wb) = 1.03^{+0.19}_{-0.17}$$

- Assuming 3 generations (SM):

$$|V_{tb}| = \sqrt{\boldsymbol{Br}(\boldsymbol{t} \to \boldsymbol{Wb})}$$

95% C.L. : R>0.61, $|V_{tb}|$>0.78

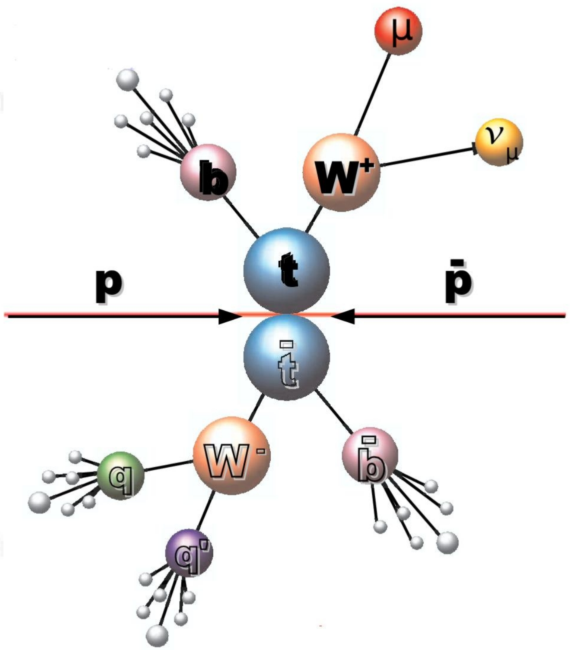
Top Charge: motivation

- Lepton + jets channel
  - Require ≥ 4 jets & ≥ 2 b-tagged jets

The assignment of lepton and b-jet is unknown

$t \rightarrow W^{+} b$ ⟺ $t \rightarrow W^{-} b$?

$|Q| = \frac{2e}{3}$ ⟺ $|Q| = \frac{4e}{3}$?



Choudhury, Tait, Wagner, Phys. Rev. D65,053002
Chang, Chang , Ma,et al., Phys. Rev. D59, 091503 ; D61, 037301;

Analysis Recipe

1. Charge of the high p_T lepton
2. Discriminate between b and anti-b jets
3. Associate lepton with correct b-jet

$$Q_1 = \left| q_l + q_{b-jet}^{leptonic} \right|$$

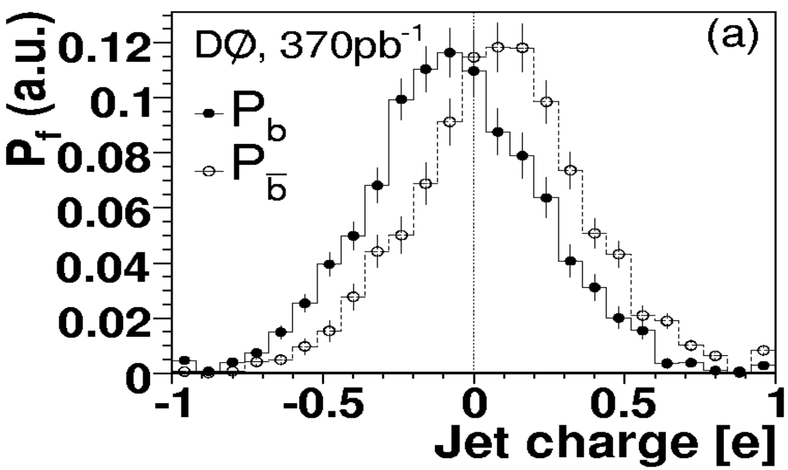
$$Q_2 = \left| -q_l + q_{b-jet}^{hadronic} \right|$$

Top Charge: jet charge

- Discriminate between b and anti-b jets
  - Sum charges q_i of tracks in the jet weighted by p_T
  - Apply only to jets identified as b-jets by displaced vertex

$$q_{jet} = \frac{\sum_i q_i \, p_{T_i}^{0.6}}{\sum_i p_{T_i}^{0.6}}$$

- Extract performance from data



<u>Jet charge calibration</u>

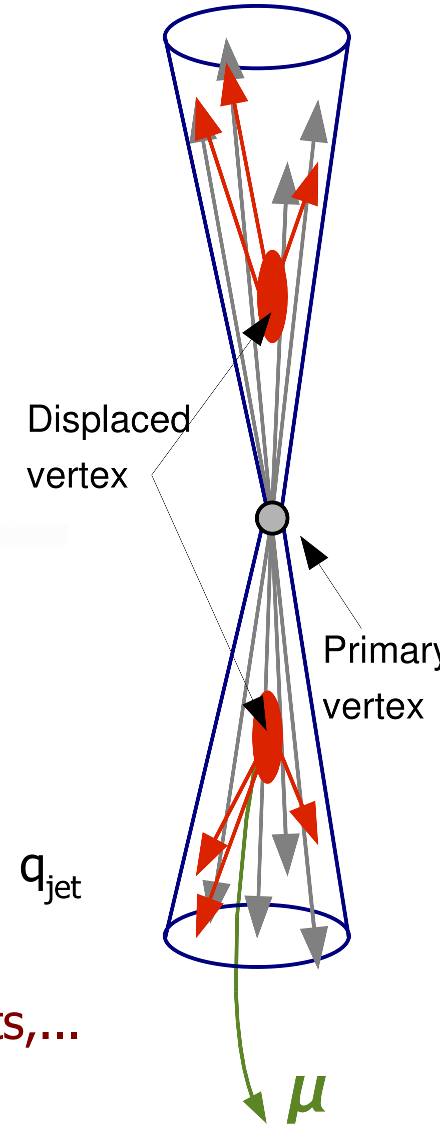
i) Select bbbar dijet events

ii) Muon gives true charge

iii) Opposite side jet charge: q_{jet}

<u>Take into account</u>

B-mixing,charge mis-id,c-jets,...
differences in jet kinematics

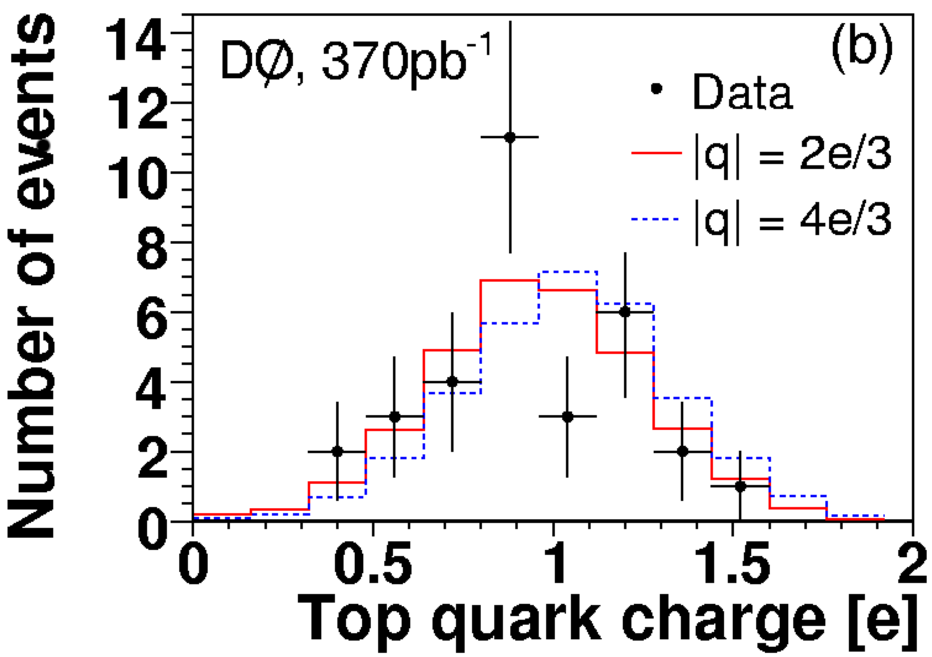


Top Charge: templates

- Constrained kinematic fit to top production hypothesis
  - 85% pairing purity: b-quark ⇔ W boson

First observation of the top quark electric charge

- Only events with 2 b-tags: low statistics (21 events) but large S/B ~ 11



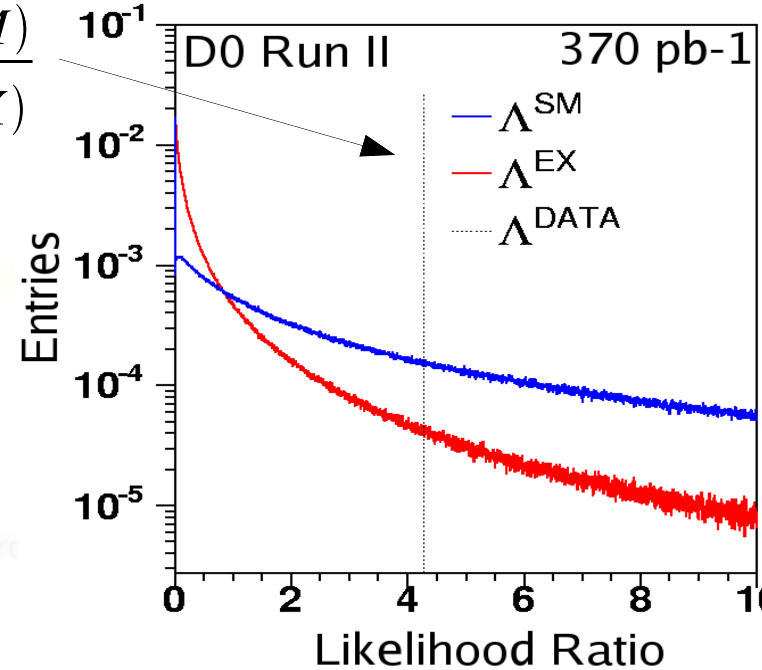
- Expected charge templates
  - MC simulation + jet charge from data
- Data prefers Standard Model
  - Statistically limited
  - Careful control of systematic uncertainties

Top Charge: result

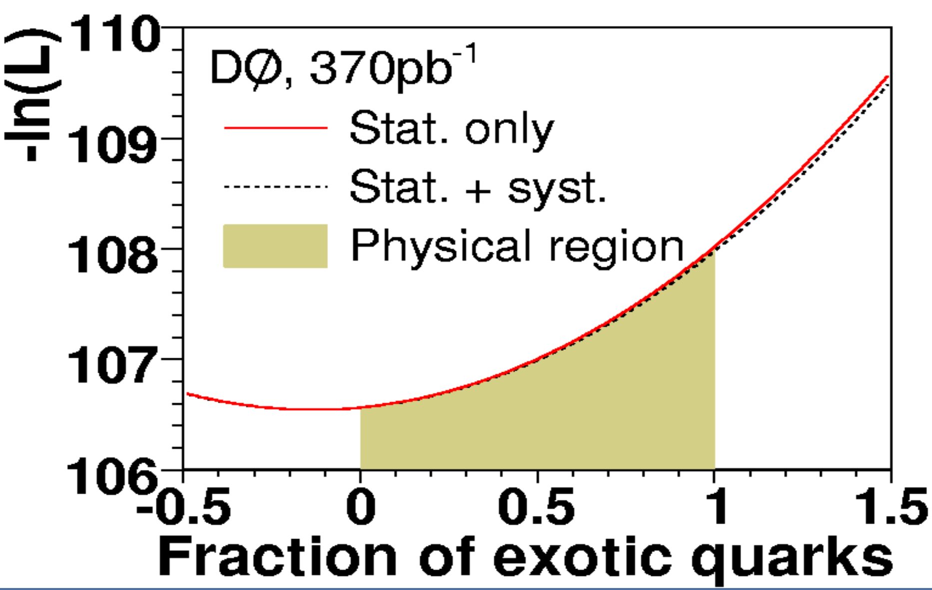
PRL 98, 041801 (2007)

- Likelihood ratio test
  - Nuisance param. to incl. systematics
  - Observed 'Bayes factor': 4.3 (positive)
  - p-value = 0.078

$$\Lambda^{DATA} = \frac{p(SM)}{p(EX)}$$



Exclude 100% exotic quark scenario up to Max. 92% Confidence Level



- Mixture of charges not excluded
  - Perform maximum likelihood fit

$$-0.13 \pm 0.66(stat) \pm 0.11(syst)$$

Fraction exotic quarks ρ

$\rho < 0.80$ @ 90% C.L.

The End

muon
Jet 1(b)
neutrino
antiproton beam
proton beam
neutrino
electron
Jet 2 (b̄)

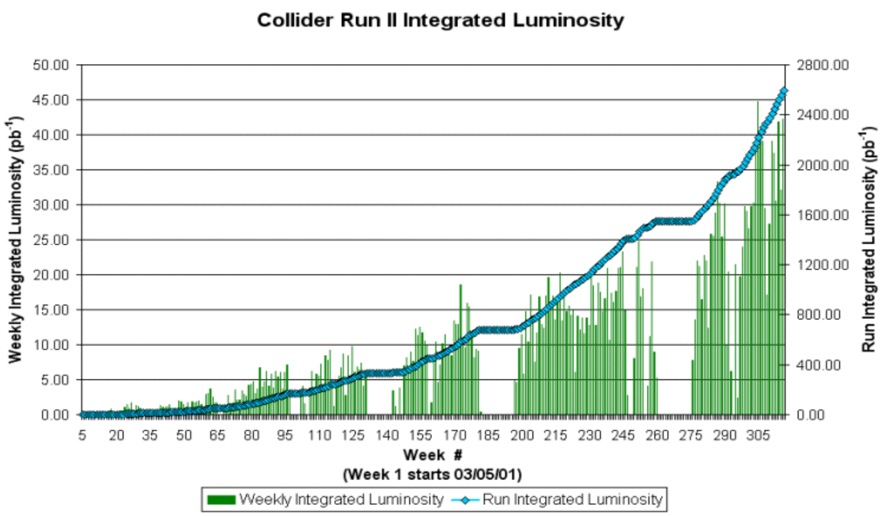
Backup slides

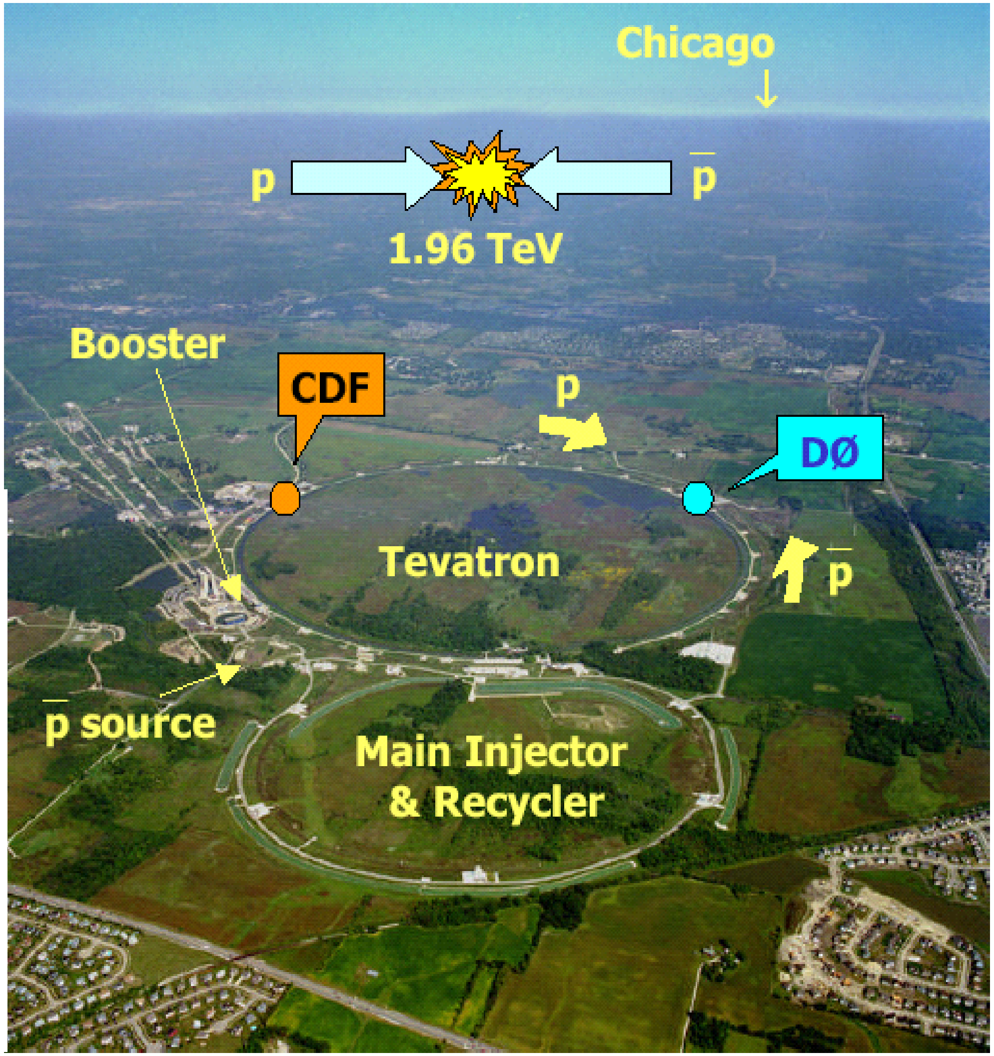
Top Charge: statistics

- Discussions ongoing between D0 and CDF regarding statistical treatment
  - Experts debating on the definition on the C.L. (probably continues.....)
- Clarification from D0 about the 92% C.L. in the paper (no errata)
  - D0 provides a public web page for deeper clarification (within a few days)
- The “cream”
  - Had we a priori chosen a rejection region at α=5% (α=10%) we would (not) exclude the exotic hypothesis at the 95% (90%) confidence level based on our observation
  - ⇨ The Maximum confidence level we could exclude the exotic hypothesis based on our observation is the 92% C.L. stated in the paper
- Comparison to other measurements
  - Later measurements are recommended to use e.g. the Bayes factor (4.3) or the p-value

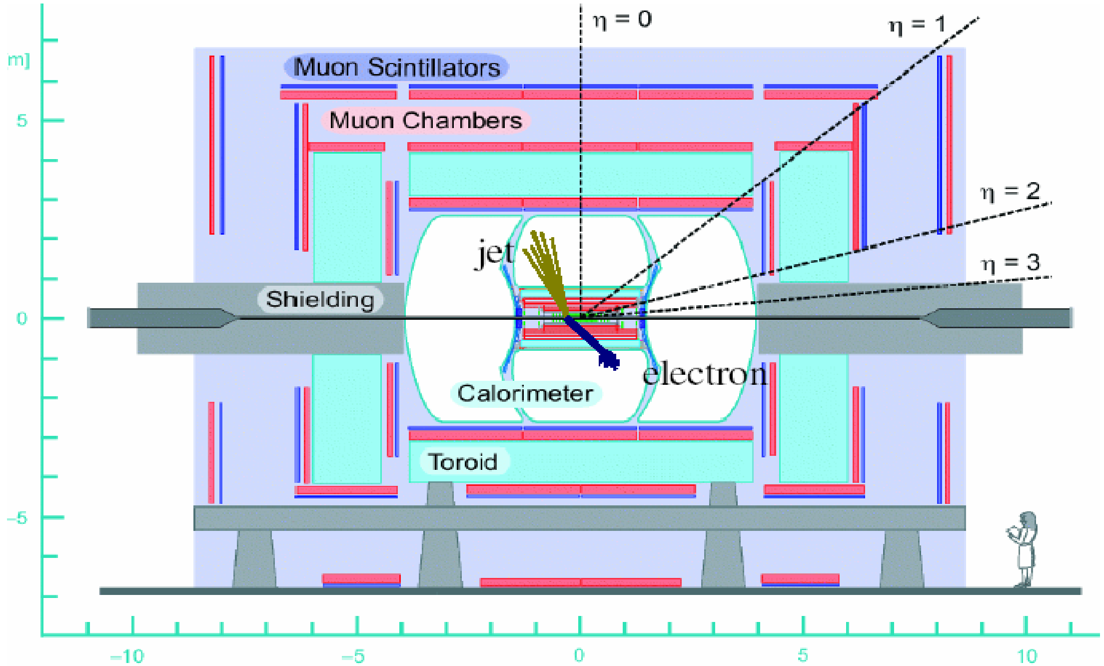
The Fermilab Tevatron

- Highest energy accelerator currently in operation
- Experiments at D0 and CDF
- Data delivered: >2fb^{-1}
  - Goal of RunII is 4-9fb^{-1}

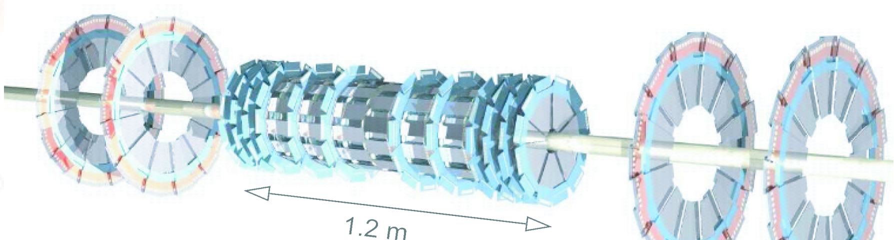




The D0 Experiment



- Tracking
  - Silicon + fiber tracker
  - 2T magnetic field solenoid
  - Pre-shower detectors
- Calorimeter
  - Liquid argon (EM+HAD)
- Muon system
  - Wire chambers
  - 1.8 T iron toroid

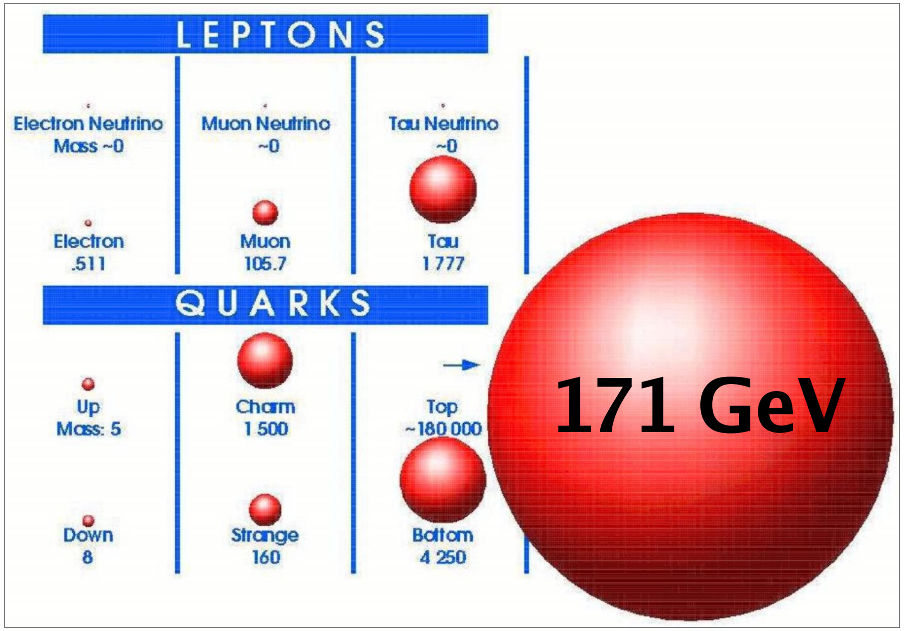


Silicon Tracker

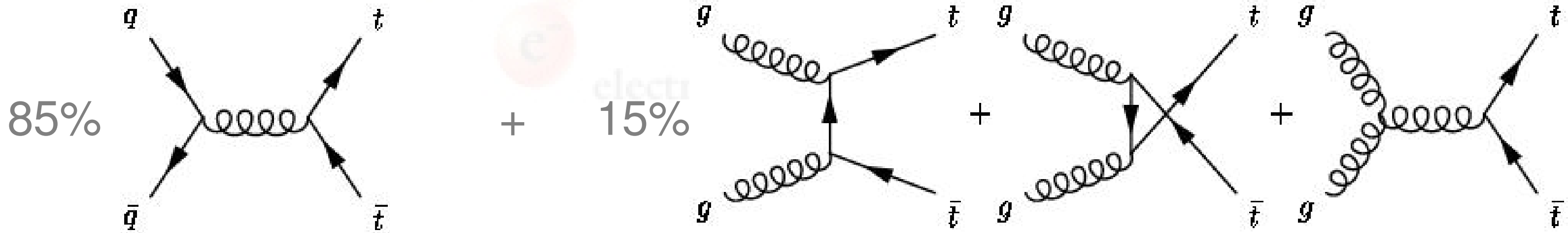
The SM Top Quark

- Predicted after discovery of the τ lepton (1973) and b-quark (1977)
  - Discovered in 1995 by D0 and CDF
  - Much heavier than any other known elementary particle
- ~10 years after discovery: only a few hundred top events observed
  - Many properties not/poorly known
  - In particular:

    the electric charge was not determined!

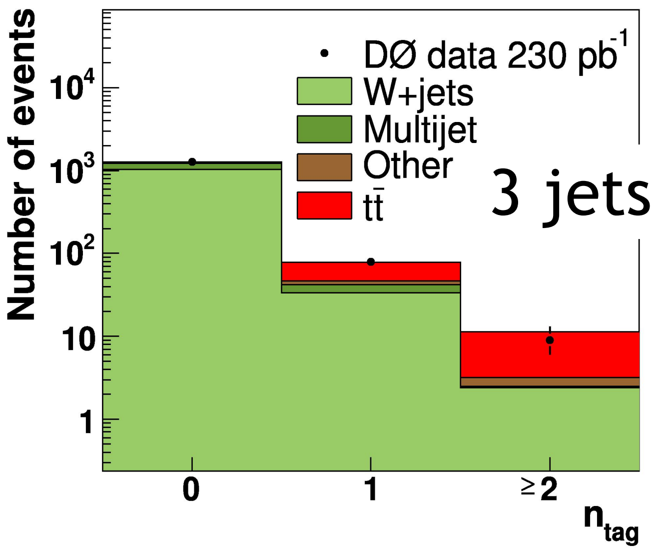


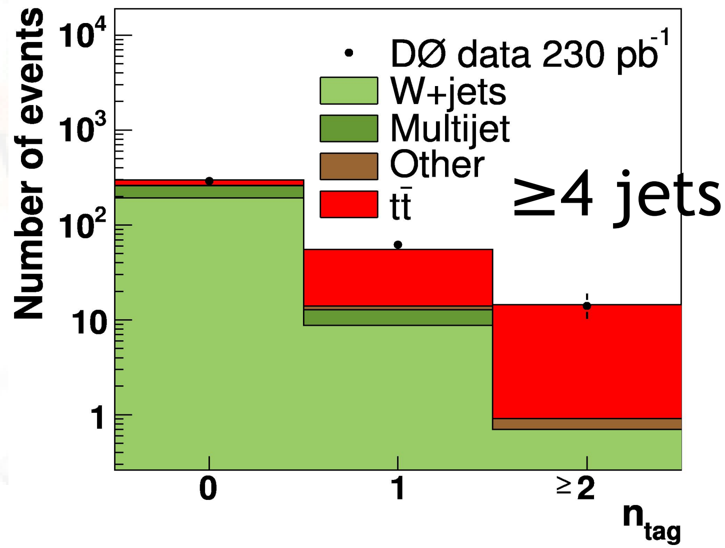
- Pair production in pairs via quark and gluon fusion
  - Evidence for single top production this year! (Session X13, 10:45)



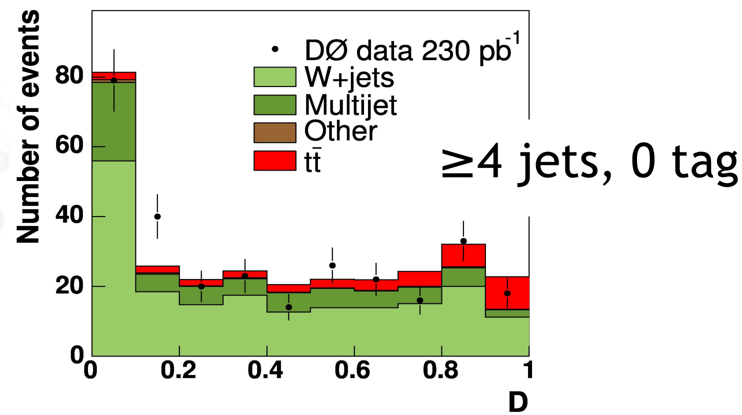
Br(t→Wb): result

- Observed and fitted number of events





- Number of ttbar events with 0-tags
  - Constrained by template likelihood fit
  - 4 kinematic variables discriminating between signal and background



Br(t→Wb): result

- Observed and fitted number of events

Observed number of events, predicted backgrounds and fitted $N_{t\bar{t}}$

$\ell + 3$ jets	0-tag	1-tag	$\geqslant$ 2-tag
W + jets	1032 ± 38	34 ± 5	2.4 ± 0.4
Multi-jet	192 ± 23	8.3 ± 1.5	$0.1^{+0.3}_{-0.1}$
Other bkg	18.4 ± 1.3	4.3 ± 0.3	0.7 ± 0.1
Fitted $t\bar{t}$	32.4 ± 1.6	32.3 ± 1.6	8.2 ± 0.5
Total	1275 ± 44	79 ± 5	11.4 ± 0.8
Observed	1277	79	9

$\ell + \geqslant 4$ jets	0-tag	1-tag	$\geqslant$ 2-tag
W + jets	193 ± 17	8.8 ± 1.2	0.7 ± 0.1
Multi-jet	65 ± 9	4.1 ± 1.1	0.0 ± 0.4
Other bkg	2.9 ± 0.4	1.2 ± 0.2	0.2 ± 0.1
Fitted $t\bar{t}$	35.6 ± 2.8	41.5 ± 3.3	13.5 ± 1.4
Total	297 ± 19	56 ± 4	14.4 ± 1.4
Observed	291	62	14

Br(t→Wb): uncertainties

- Summary of uncertainties on R

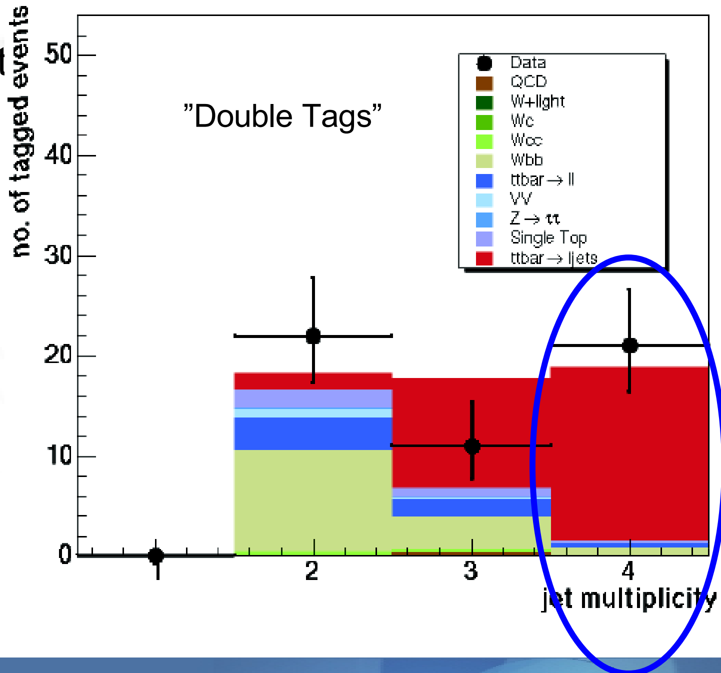
Summary of statistical and systematic uncertainties on R

Uncertainties on R			
Statistical	$+0.17$		-0.15
b-tagging efficiency	$+0.06$		-0.05
Background modeling	$+0.05$		-0.04
Jet identification and energy calibration	$+0.04$		-0.03
Multijet background		± 0.02	
Total error	$+0.19$		-0.17

- Largest contribution
  - Statistical
  - b-jet identification efficiency

Top quark pair selection

- Some preselection to select real W boson events
  - Signal triggers
  - Tight isolated 20 GeV muon (or electron) with $|\eta|<2.0$ ($|\eta|<1.1$) for muon (electron)
  - At least 1(4) jet(s) with $p_T > 15$GeV
  - Large Missing E_T, at least 20GeV
  - Good primary vertex
- Apply b-tagging to extract the ttbar events
  - Split sample into electron/muon + 1,2,3, 4 or more jet
  - 1,2 jet bins used to cross-check backgrounds
- Top charge analysis uses only events with
  - 4 or more jets
  - 2 or more tagged using lifetime tagging



Br(t→Wb): sample composition

- ttbar
- W+jets
- Z+jets
- WW,ZZ,WZ
- Single top
- Multijet

"Other": Z+jets, WW,ZZ,WZ, Single top

ttbar, W+jets, Z+jets, WW,ZZ,WZ, Single top: true isolated lepton

Multijet: fake isolated lepton

Define two samples ("loose" and "tight"):
- Based on lepton ID (tight $\subset$ loose)
- N_{fake}, N_{true} from: Prob. event (loose → tight)

N_{other} from MC simulation

$N_{W+jets} = N_{true} - N_{other} - N_{fake} - N_{tt}$

- Same procedure as top pair cross-section
- Dominated by W+jet processes

$\ell + \geq 4$ jets	0-tag	1-tag	$\geq$ 2-tag
W+jets	203±17	9.2±1.2	0.7±0.1
Multijet	65±9	4.1±1.1	0.0±0.4
Other bkg	2.9±0.4	1.2±0.2	0.2±0.1
$t\bar{t}$	32.5±3.0	36.3±3.3	11.4±1.4
Total expected	304±20	51±4	12.3±1.4
Observed	291	62	14

σ(tt) =7pb

Event tagging probability derived for each background
- Sample composition after b-tagging
- Large S/B for tagged events

Top Charge: sample comp.

	l+jets		
	2jets	3jets	≥4jets
W+light	0.043±0.004	0.028±0.003	0.010±0.001
$W(c\bar{c})$	0.05±0.01	0.029±0.002	0.016±0.003
$W(b\bar{b})$	0.59±0.06	0.22±0.01	0.07±0.01
Wc	0.081±0.003	0.031±0.002	< 0.01
$Wc\bar{c}$	0.72±0.02	0.27±0.02	0.10±0.01
$Wb\bar{b}$	9.5±0.2	3.03±0.13	0.97±0.08
W+jets	10.9±0.2	3.60±0.14	1.18±0.08
QCD	< 0.01	0.32±0.36	< 0.01
tb	1.82±0.02	1.00±0.02	0.31±0.01
$t\bar{t} \to ll$	3.27±0.03	1.75±0.02	0.38±0.01
VV	0.93±0.03	0.13±0.01	0.014±0.004
$Z \to \tau^+\tau^-$	0.03±0.03	0.02±0.02	< 0.01
background	16.6±0.3	6.8±0.4	1.53±0.38
syst.	+2.81-2.79	+1.00-0.99	+0.31-0.31
$tt \to l$+jets	1.70±0.04	10.9±0.1	17.4±0.1
total	18.3±0.3	17.7±0.4	18.9±0.4
syst.	+2.94-2.86	+1.74-1.73	+2.51-2.83
tags	22	11	21

Top Charge: uncertainties

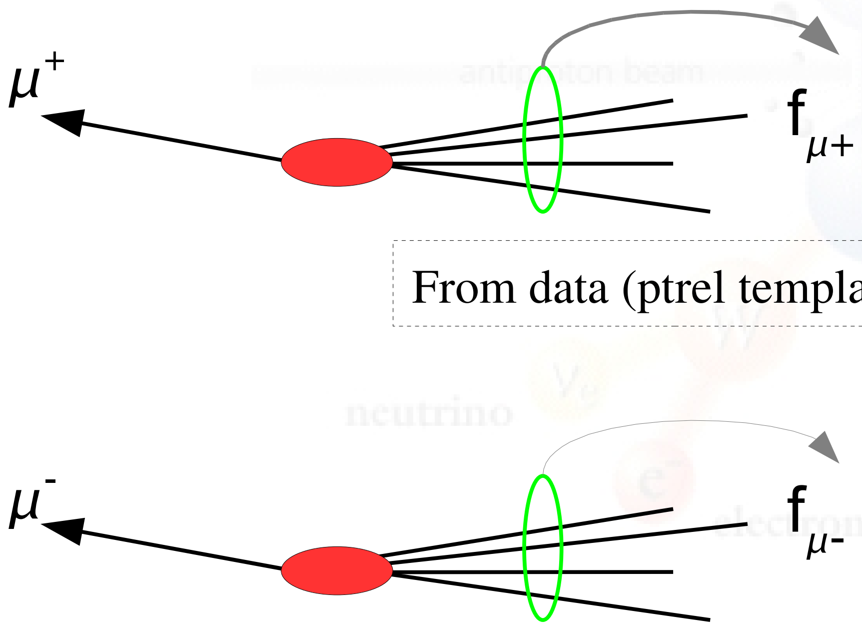
- None very large systematic uncertainty
- Dominant sources
  - Statistical uncertainty on the kinematic correction
  - Uncertainty of the dijet data production mechanism
  - Statistical uncertainty on the b-jet charge templates

Systematic	Observed	Expected
Statistical uncertainty only	95.8	95.3
+ Fraction of $c\bar{c}$ events	95.8	95.2
+ Charge-flipping processes	95.7	95.2
+ Weighting with respect to p_T and y spectra	94.4	94.1
+ Fraction of flavor creation	93.7	93.4
+ Statistical error on P_f	93.3	93.1
+ Jet energy calibration[a]	92.4	91.8
+ Top quark mass	92.2	91.2

Data calibration

- Parametrize the jet charge distribution on the probe jet side in the triple tag selection by:
  - fraction of ccbar events → x_c
  - fraction of events with "flipped" tag muon charge (B-mixing, cascade, etc,...) → x_{flip}
  - the real jet charge distributions for b- and c-jets

$$\left(f_b, f_{\bar{b}}, f_c, f_{\bar{c}}\right)$$



$$f_{\mu^{+1}} = (1-x_c)(x_{flip} \times f_{\bar{b}} + x_{noflip} \times f_b) + x_c \times f_{\bar{c}}$$

From data (ptrel templates)

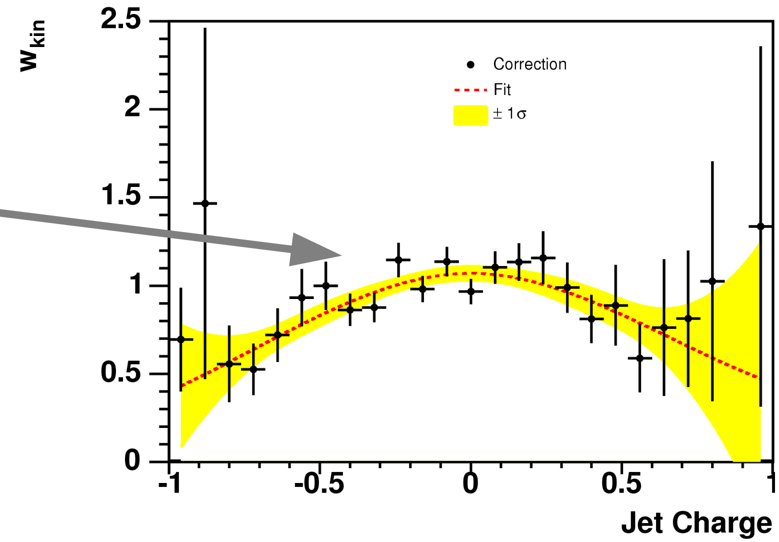
From simulation

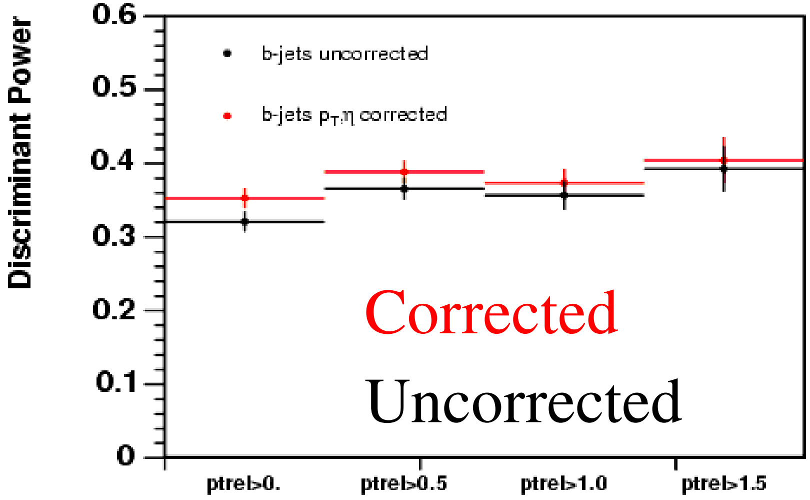
$$f_{\mu^{-1}} = (1-x_c)(x_{flip} \times f_b + x_{noflip} \times f_{\bar{b}}) + x_c \times f_c$$

Data calibration

- The correction function is defined as the ratio of the weighted and unweighted jet charge distribution (distributions denoted as f)

$$f_b^{w}(Q) = f_b^{b\bar{b}}(Q) \times \frac{f_b^{t\bar{t}+w}(Q)}{f_b^{t\bar{t}}(Q)}$$





- The correction improve discrimination
  - As expected from the study on p_T dependence