Measurement of $\sigma_{t\bar{t}}$ in the lepton + jets channel at D0

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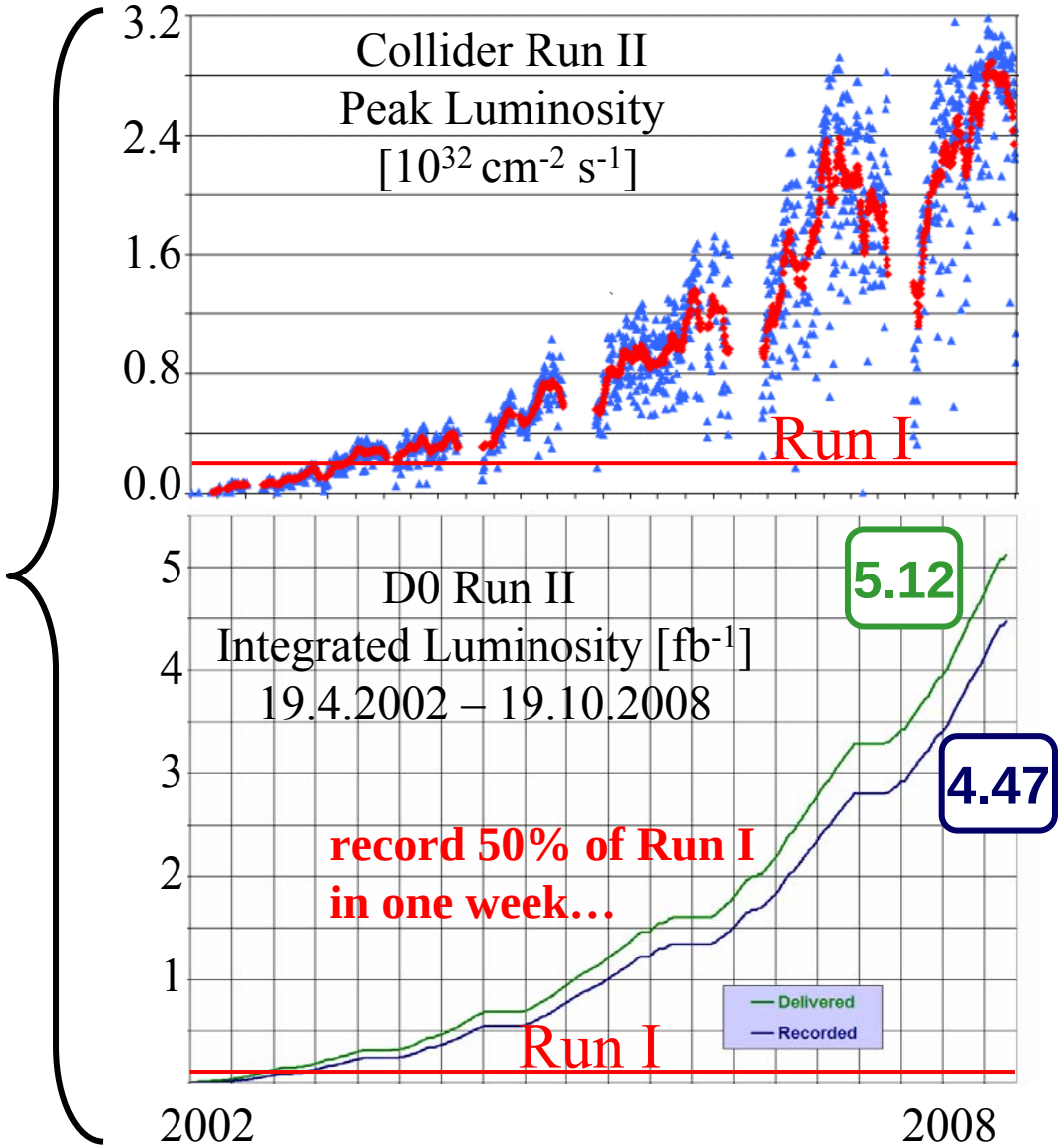
Introduction
Measurement Techniques
Systematic Uncertainties
Result

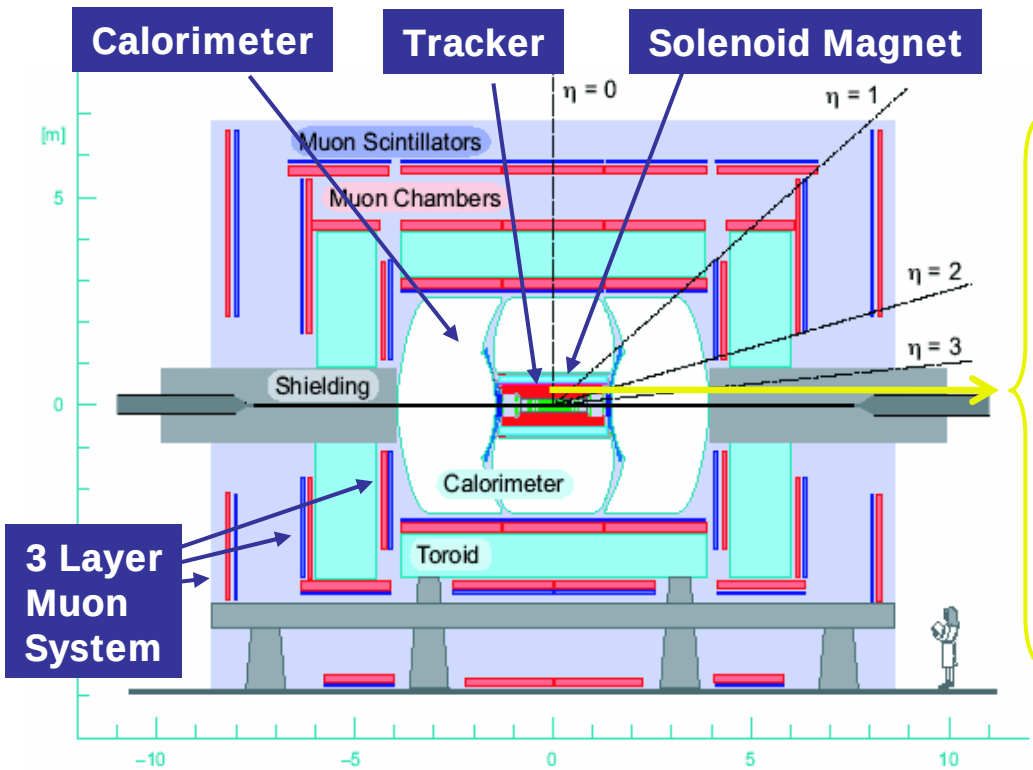
3rd Top Workshop @ Grenoble : from the TeVatron to ATLAS, 24.10.2008

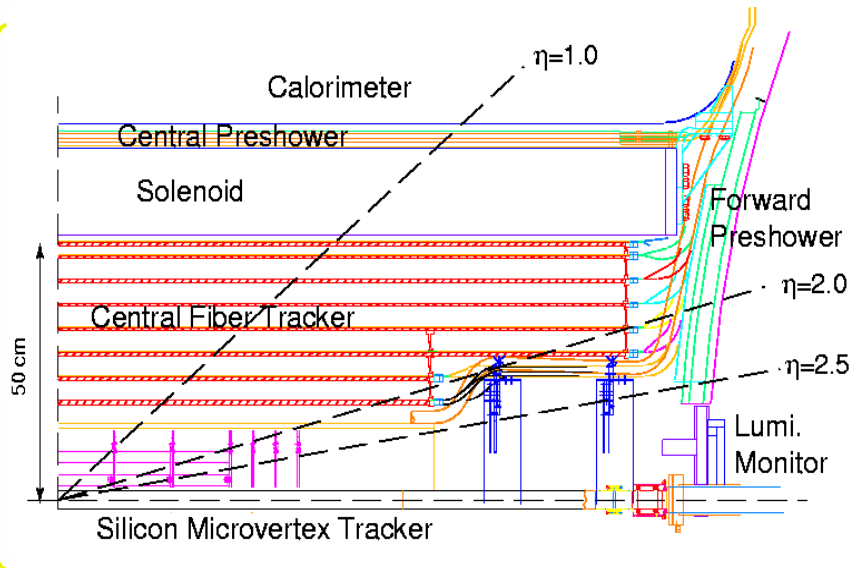
The Tevatron @ Fermilab

- $p\bar{p}$ collisions at $\sqrt{s}$ =1.96 TeV
- 36 bunches (396 ns spacing)
- 1 km ring radius
- World record lumi: $3.2 \cdot 10^{32}/cm^2 s$
- >5 fb^{-1} delivered per experiment
- expect +2 fb^{-1} per year of running



The DZero Detector





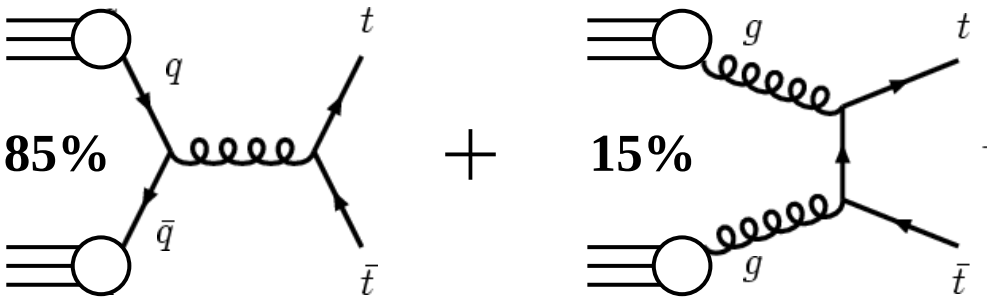
- Excellent calorimetry

$$\frac{\sigma_E}{E} = \frac{15\%}{\sqrt{E}} \oplus 0.3\%\,(\text{elm}), \quad \frac{\sigma_E}{E} = \frac{45\%}{\sqrt{E}} \oplus 4\%\,(\text{had})$$

- Large muon acceptance
- Central tracking inside 2 T solenoid
  - –Silicon vertex detector (=>b-jet ID)
  - –Scintillating fiber tracker

Top Quark Production & Decay

- Main **production** of Top Quarks – via strong interaction in *pairs*:

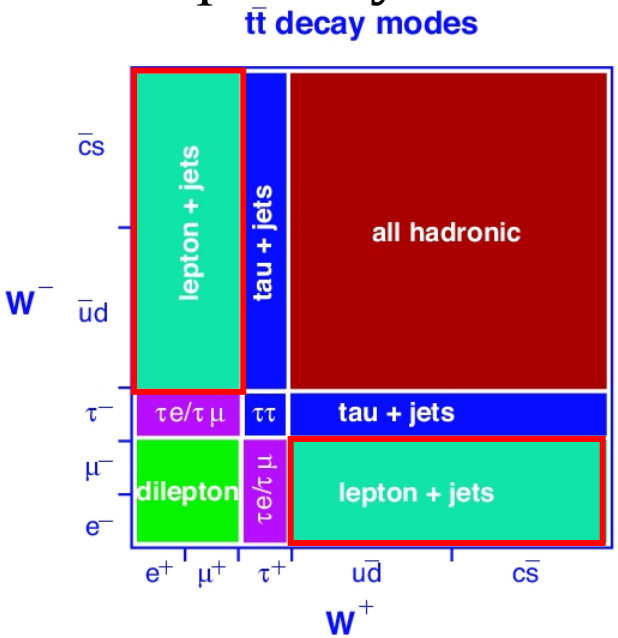


Theoretical expectation:

$$\sigma_{t\bar{t}} = (6.6^{+0.7}_{-0.8})\ \text{pb}$$

Cacciari et al., JHEP0809,127, m_t=175 GeV

- SM Top **decay** ≈100% Wb ⇒ Final states determined by W decay mode
  - ⇒ 2 b-jets
  - ⇒ Up to two charged leptons/neutrinos
  - ⇒ Up to four additional jets

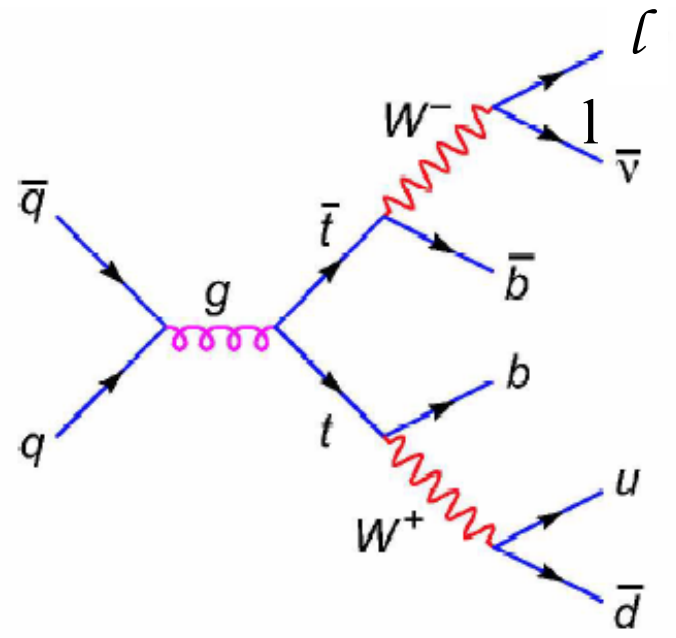


Need to reconstruct/identify:

- **Electrons, muons,** taus
- **Missing transverse energy,**
- **Jets/b-jets**

l+jets decay signature & preselection

- Lepton + jets triggered dataset with good data quality
- Primary vertex: ≥ 3 tracks, $|z| \leq 60$ cm, Δz (primary vertex, ℓ) < 1 cm



Electron in $|\eta| < 1.1$, rec. track
Muon in $|\eta| < 2$, rec. track
} $p_T > 20$ GeV

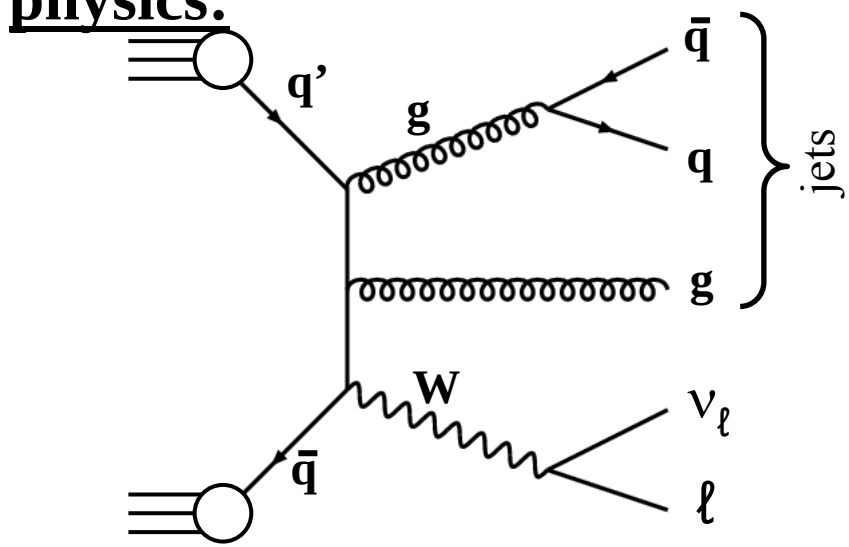
$\not{E}_T > 20$ (e) resp. 25 (μ) GeV, $\Delta\Phi(\ell, \not{E}_T)$ cuts

≥3 Jets with $|\eta| < 2.5$, $p_T > 20$ GeV
leading jet $p_T > 40$ GeV

- Orthogonality w.r.t. other analyses: Veto isolated μ/e, second same flavour lepton

Main backgrounds

physics:

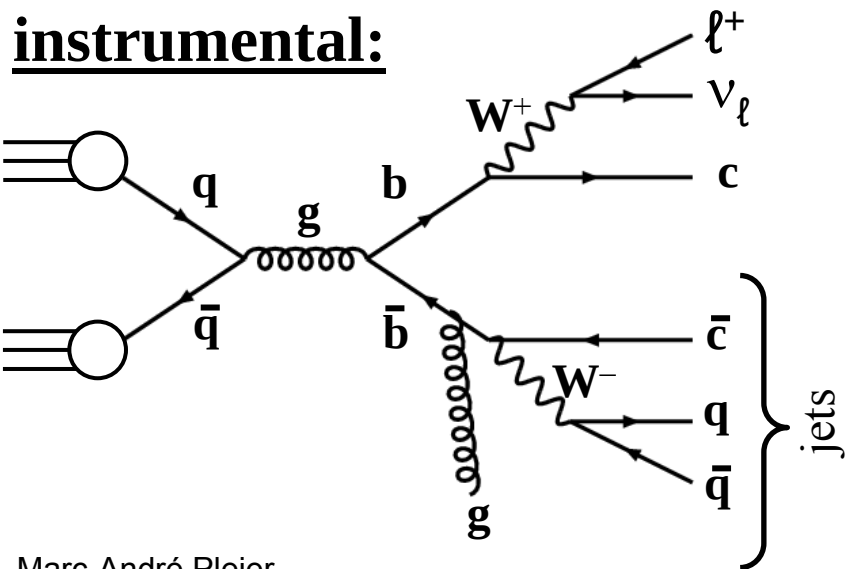


Electroweak W production:

- $W \rightarrow \ell + \nu_\ell$
- additional ≥ 3 jets from gluon radiation

→ **use Monte Carlo simulation**

instrumental:



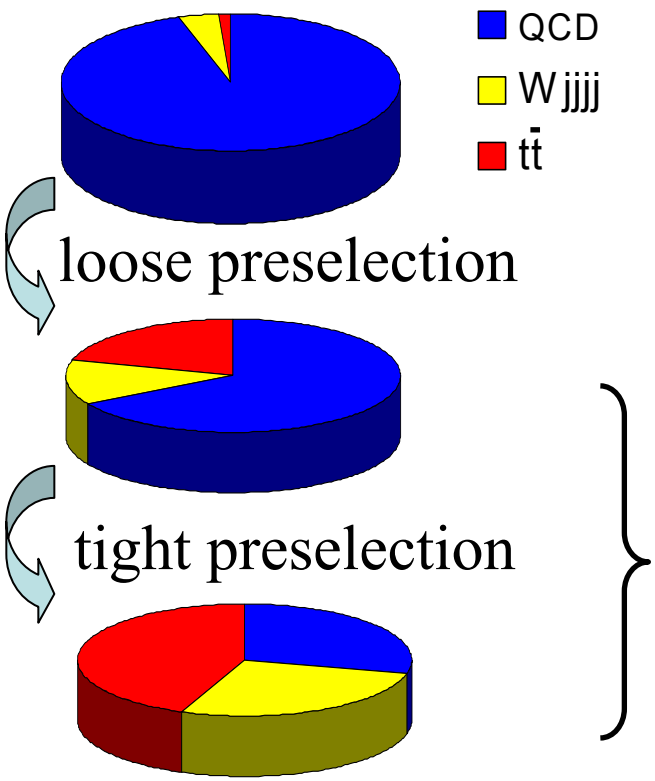
Multijet production with fake lepton, MET:

- Electrons faked by (electromagnetic) jets
- Muon-fakes: real muons, fakely isolated (eg. from semileptonic b-decays, with non-reconstructed b-jet)
- misreconstructed MET

→ **use data to model properly**

Determination of QCD background

Data (e): ≈ 35 M events, 913 pb^{-1}



320 events with ≥ 4 Jets

Derive QCD background *based on data*: solve linear system of equations for $N^{W+t\bar{t}}$, N^{QCD} ("Matrix Method")

Tight preselection
=
loose preselection + tighter lepton quality

$$N_l = N^{W+t\bar{t}} + N^{QCD}$$

$$N_t = \varepsilon_{sig} N^{W+t\bar{t}} + \varepsilon_{QCD} N^{QCD}$$

N_l, N_t = events remaining in final data sample,
need loose/tight efficiencies ε_{sig}, ε_{QCD} (derived from data)

Sample composition after preselection

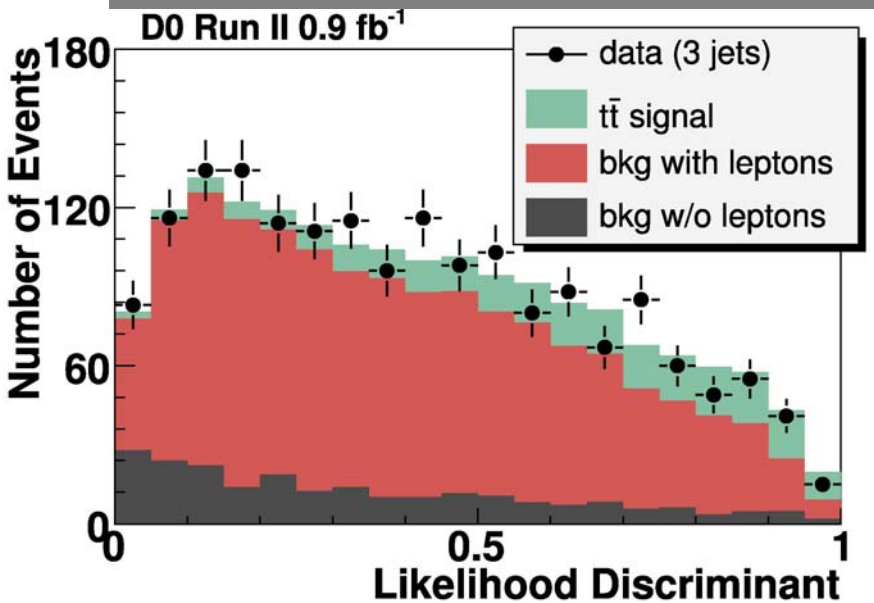
TABLE I. Event counts in the inclusive lepton + jets sample.

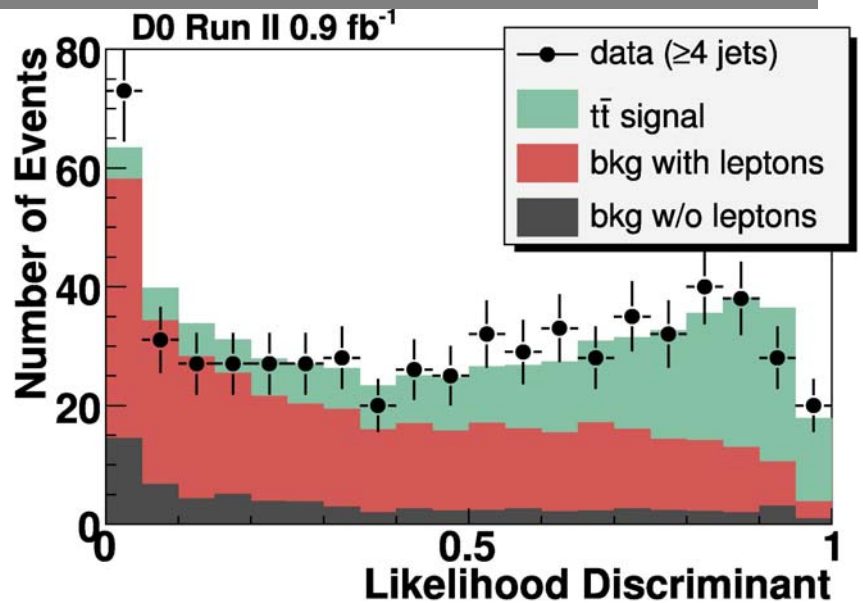
	e + 3 jets	$e+ \geq 4$ jets	μ + 3 jets	$\mu+ \geq 4$ jets
N_{data}	1300	320	1120	306
N_{loose}	2592	618	1389	388
ϵ_s (%)	84.8 ± 0.3	84.0 ± 1.8	87.3 ± 0.5	84.5 ± 2.2
ϵ_b (%)	19.5 ± 1.7	19.5 ± 1.7	27.2 ± 5.4	27.2 ± 5.4
$N_{t\bar{t}}$	182 ± 20	156 ± 17	137 ± 15	129 ± 14
$N_{W\text{jets}}$	718 ± 42	69 ± 20	802 ± 26	131 ± 16
N_{other}	132 ± 15	35 ± 4	139 ± 15	36 ± 4
N_{jj}	268 ± 34	60 ± 10	42 ± 14	10 ± 6

- N_{other}: single top, Z+jets, diboson production – from MC with NLO cross section
- top signal: ~20% of the sample, normalisation from b-tagging measurement

Topological Analysis Approach

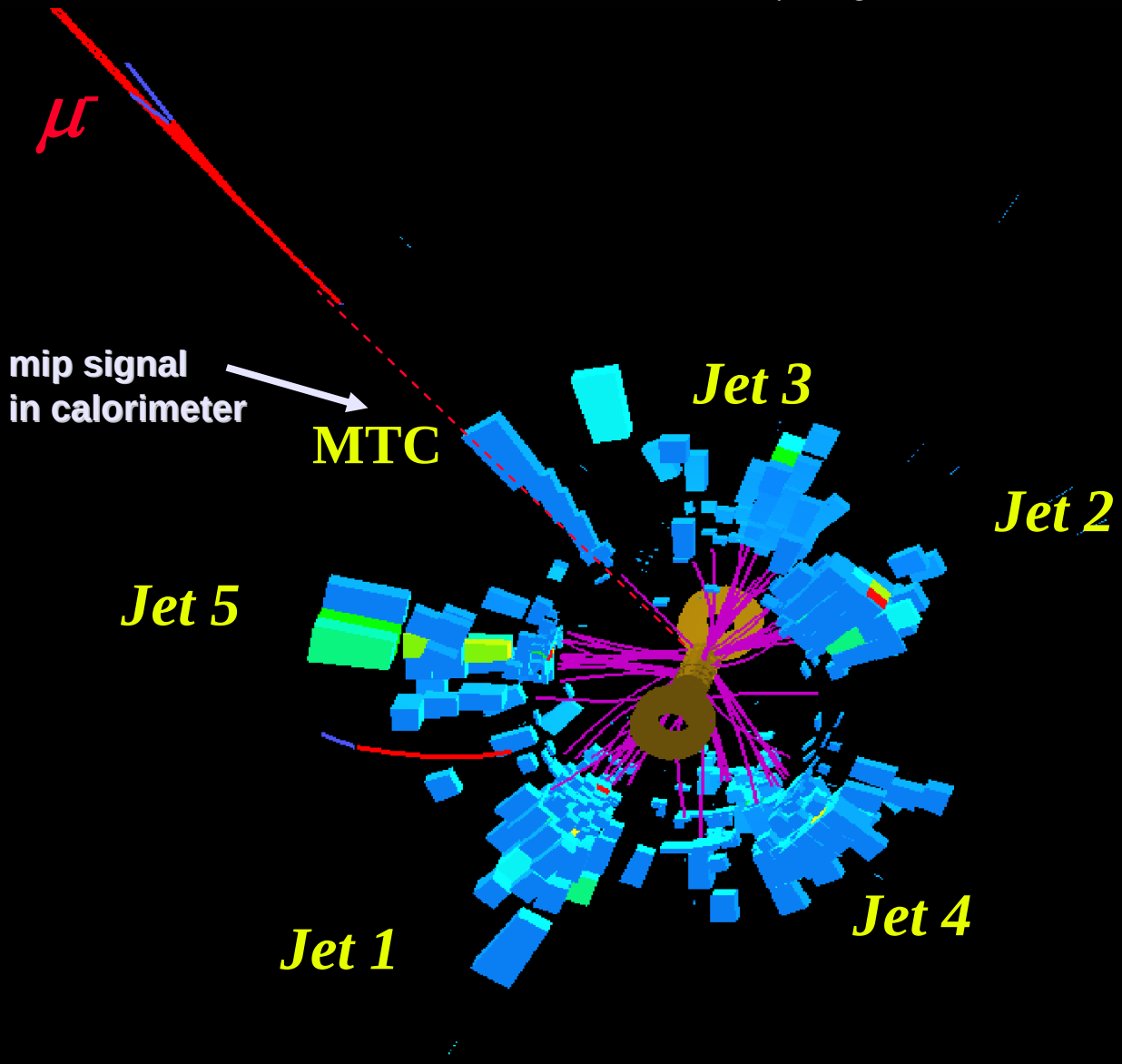
- Apply preselection **without** b-jet identification → high background levels!
- For events with 3 jets additional cut: sum jet p_Ts > 120 GeV
- Verify background model in signal-depleted samples
- Use multivariate discriminant (event kinematics based) to extract signal
- Consider 4 channels: lepton flavour e,μ and jet multiplicity =3, ≥4
- Signal contribution: simultaneous fit of linear combination of templates





m_t=175 GeV: $\sigma_{t\bar{t}} = 6.62 \pm 0.78\,(\text{stat}) \pm 0.36\,(\text{syst}) \pm 0.40\,(\text{lumi})\,\text{pb}$

$t\bar{t} \rightarrow \mu$+jets candidate event



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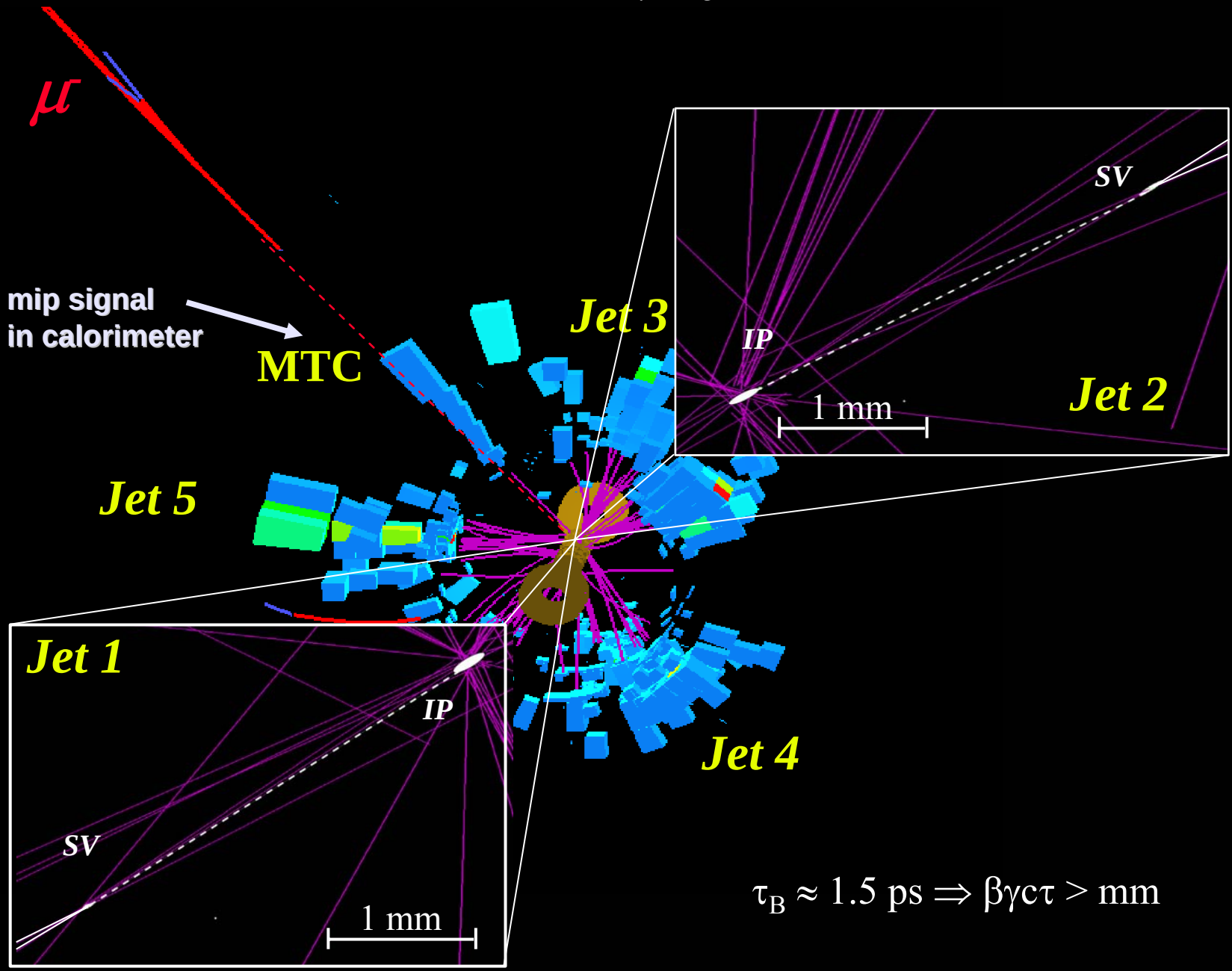
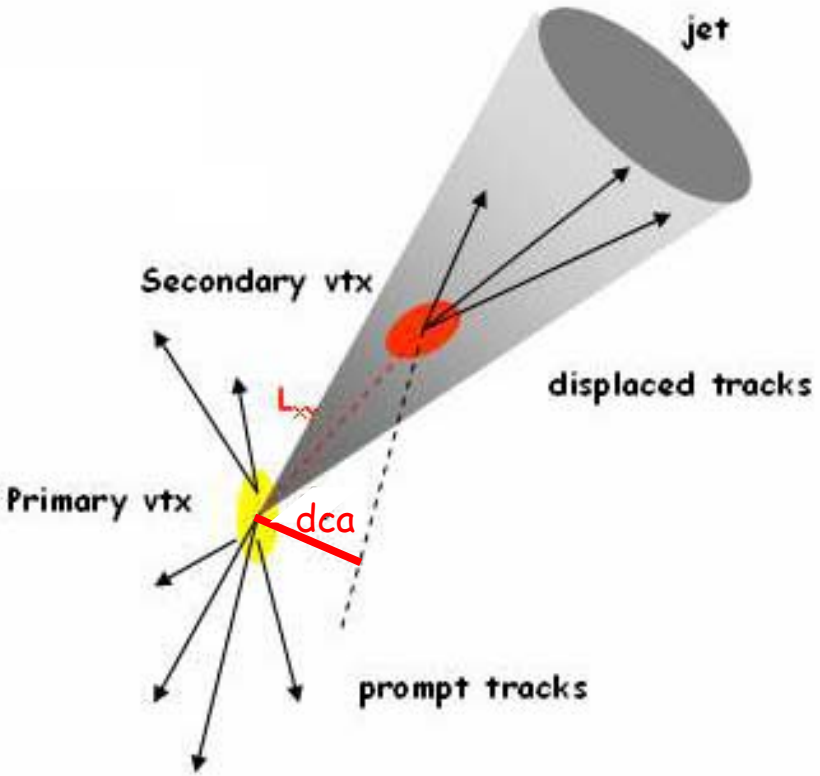


$\tau_B \approx 1.5$ ps $\Rightarrow \beta\gamma c\tau >$ mm

Lifetime b-tagging at DØ



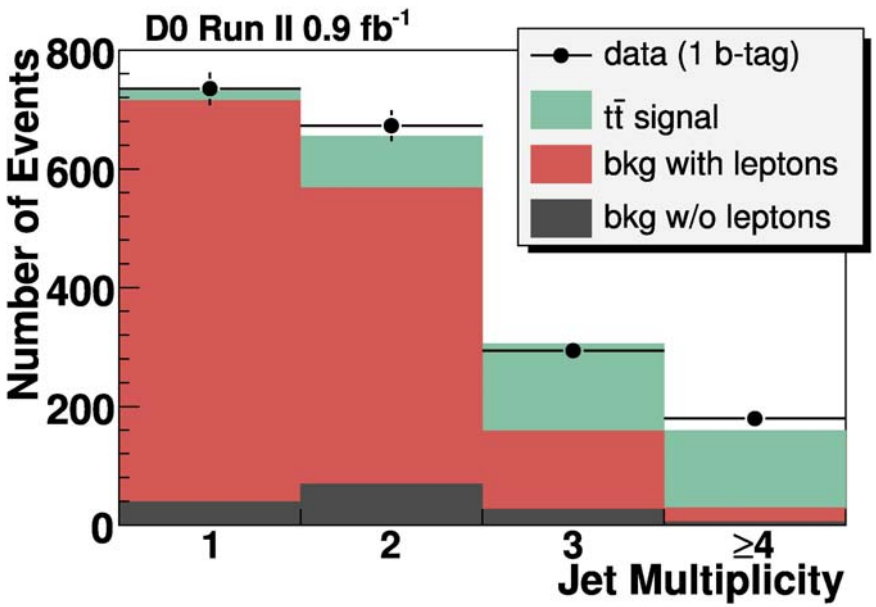
(dca = distance of closest approach)

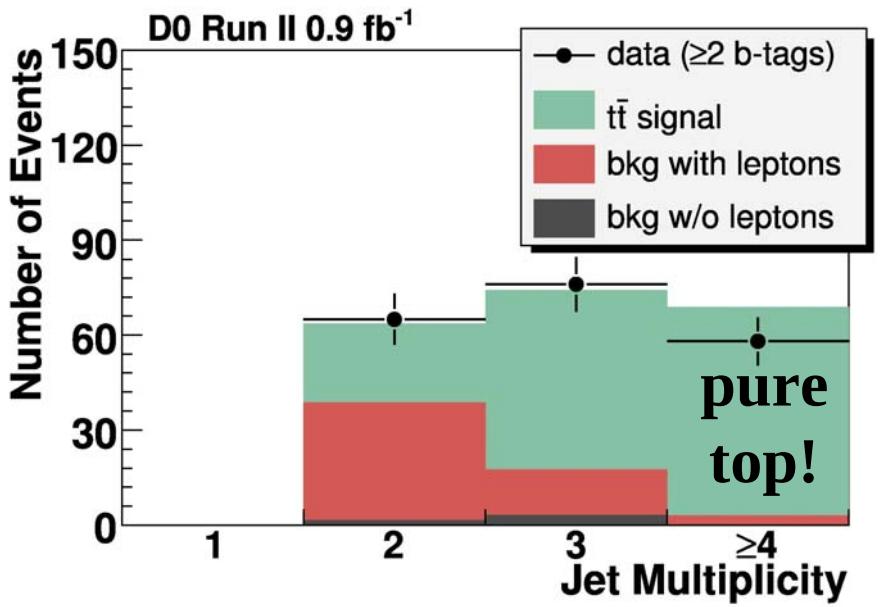
- Separate *b*-jets from light-quark and gluon jets ⇒ reject most multijet & *W*+jets background processes
- $\tau_B \approx 1.5$ ps ⇒ $\beta\gamma c\tau >$ mm
- Neural network based on impact parameter and reconstructed vertex information
- "Tagging" efficiencies:
  - *b*-jet ≈ 50%
  - *c*-jet ≈ 10%
  - light-jet ≈ 0.5%

See talk by Sebastien Greder!

b-tagging Analysis Approach

- **Require b-tagged jets** in the event to further suppress background
- Analyse eight channels separately: e/μ, 1/≥2 tags, 3/≥4 jets
- Perform maximum likelihood fit to observed number of events in the different channels





m_t=175 GeV: $\sigma_{t\bar{t}} = 8.05 \pm 0.54\,(\text{stat}) \pm 0.70\,(\text{syst}) \pm 0.49\,(\text{lumi})\,\text{pb}$

Systematic uncertainties

TABLE III. Breakdown of systematic uncertainties.

Source	b-tag	Likelihood	Combined
Selection efficiency	0.26 pb	0.25 pb	0.25 pb
Jet energy calibration	0.30 pb	0.11 pb	0.20 pb
b tagging	0.48 pb	-	0.24 pb
MC model	0.29 pb	0.11 pb	0.19 pb
N_{jj}	0.06 pb	0.10 pb	0.07 pb
Likelihood fit	-	0.15 pb	0.08 pb

- Selection efficiency includes acceptance and efficiency for leptons and jets
- Jet energy calibration includes jet energy scale and resolution
- b tagging includes efficiencies for b, c, q, g jets
- MC model includes ALPGEN vs. PYTHIA signal sample differences, scale variations for W+jets samples, PDF uncertainties
- N_{jj}: uncertainty on QCD constraints
- Likelihood fit: uncertainty from statistical fluctuations in template shapes

Combined Result

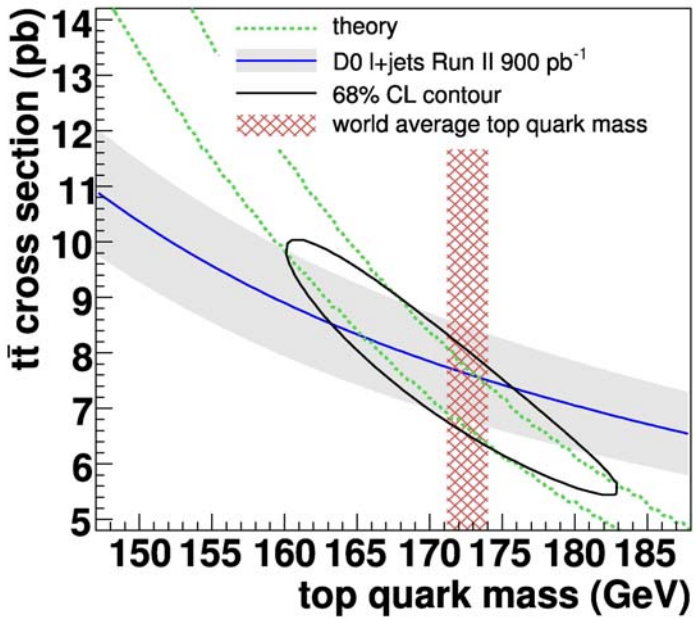
Use Best Linear Unbiased Estimate method to combine results:

$$\sigma_{t\bar{t}} = 7.42 \pm 0.53\ (\text{stat}) \pm 0.46\ (\text{syst}) \pm 0.45\ (\text{lumi})\ \text{pb}$$

(m_t=175 GeV, PRL **100**, 192004, 2008)

Can obtain top quark mass measurement from observed mass dependence of result and theoretical prediction:

m_t = 170 ± 7 GeV



$$\sigma_{t\bar{t}} / \text{pb} = 7.42 - 7.9\times10^{-2}\Delta m + 9.7\times10^{-4}(\Delta m)^2 - 1.7\times10^{-5}(\Delta m)^3$$

($\Delta m = m_t - 175$)

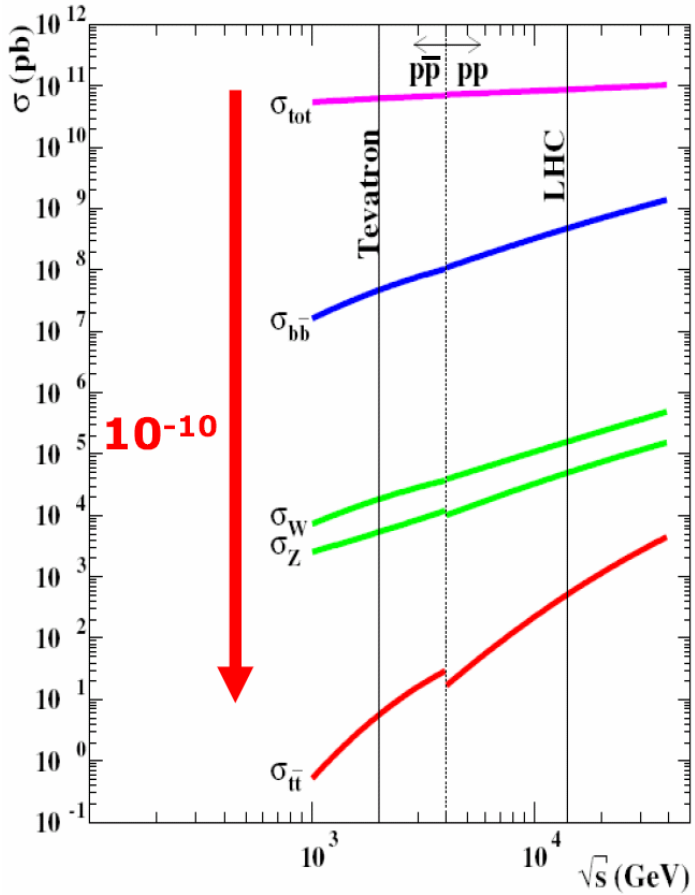
backup slides

Top Quark Production @ Tevatron: The precision era

Top Discovery: Tevatron "Run I" ('92-'96): ~125pb^{-1}, $\sqrt{s}$ = 1.8 TeV.

Now "RunII":

- Increased luminosity
- Increased $\sqrt{s}$: 1.96 TeV $\Rightarrow$ +30% σ_{Top}



Topological Analysis Approach

TABLE IV. Variables used for the likelihood discriminant. $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ and i indexes the list of N_j jets with $p_T > 15$ GeV, ordered in decreasing p_T.

Variable	Channel
$\sum_{i=3}^{N_j} p_T(i)$	All
$\sum_{i=1}^{N_j} p_T(i) / \sum_{i=1}^{N_j} p_z(i)$	e + 3 jets, $e+ \geq 4$ jets
$\sum_{i=1}^{N_j} p_T(i) + p_T(e) + \not{p}_T$	e + 3 jets, $e+ \geq 4$ jets
ΔR between lepton and jet 1	All
ΔR between jets 1 and 2	$e+ \geq 4$ jets, $\mu+ \geq 4$ jets
$\Delta\phi$ between lepton and $\not{p}_T$	μ + 3 jets, $\mu+ \geq 4$ jets
$\Delta\phi$ between jet 1 and $\not{p}_T$	e + 3 jets, μ + 3 jets
Sphericity	All but μ + 3 jets
Aplanarity	All but μ + 3 jets

Topological Analysis Approach

TABLE V. Sample composition from the likelihood fit. $N_{t\bar{t}}$ is based on the cross section measured by the likelihood analysis.

	3 jets	≥ 4 jets
N_{data}	1760	626
$N_{t\bar{t}}$	245 ± 20	233 ± 19
$N_{W\text{jets}} + N_{\text{other}}$	1294 ± 48	321 ± 30
N_{jj}	227 ± 28	70 ± 12

b-tagging Analysis Approach

TABLE II. Numbers of events in the b-tagged analysis. $N_{t\bar{t}}$ is based on the cross section measured by the b-tag analysis.

	3 jets, 1 tag	3 jets, $\geq$ 2 tags	$\geq$ 4 jets, 1 tag	$\geq$ 4 jets, $\geq$ 2 tags
$N_{t\bar{t}}$	147 ± 12	57 ± 6	130 ± 10	66 ± 7
$N_{W\text{jets}}$	105 ± 5	10 ± 1	16 ± 2	2 ± 1
N_{other}	27 ± 2	5 ± 1	8 ± 1	2 ± 1
N_{jj}	27 ± 6	3 ± 2	6 ± 3	0 ± 2
Total	306 ± 14	74 ± 6	159 ± 11	69 ± 7
N_{data}	294	76	179	58