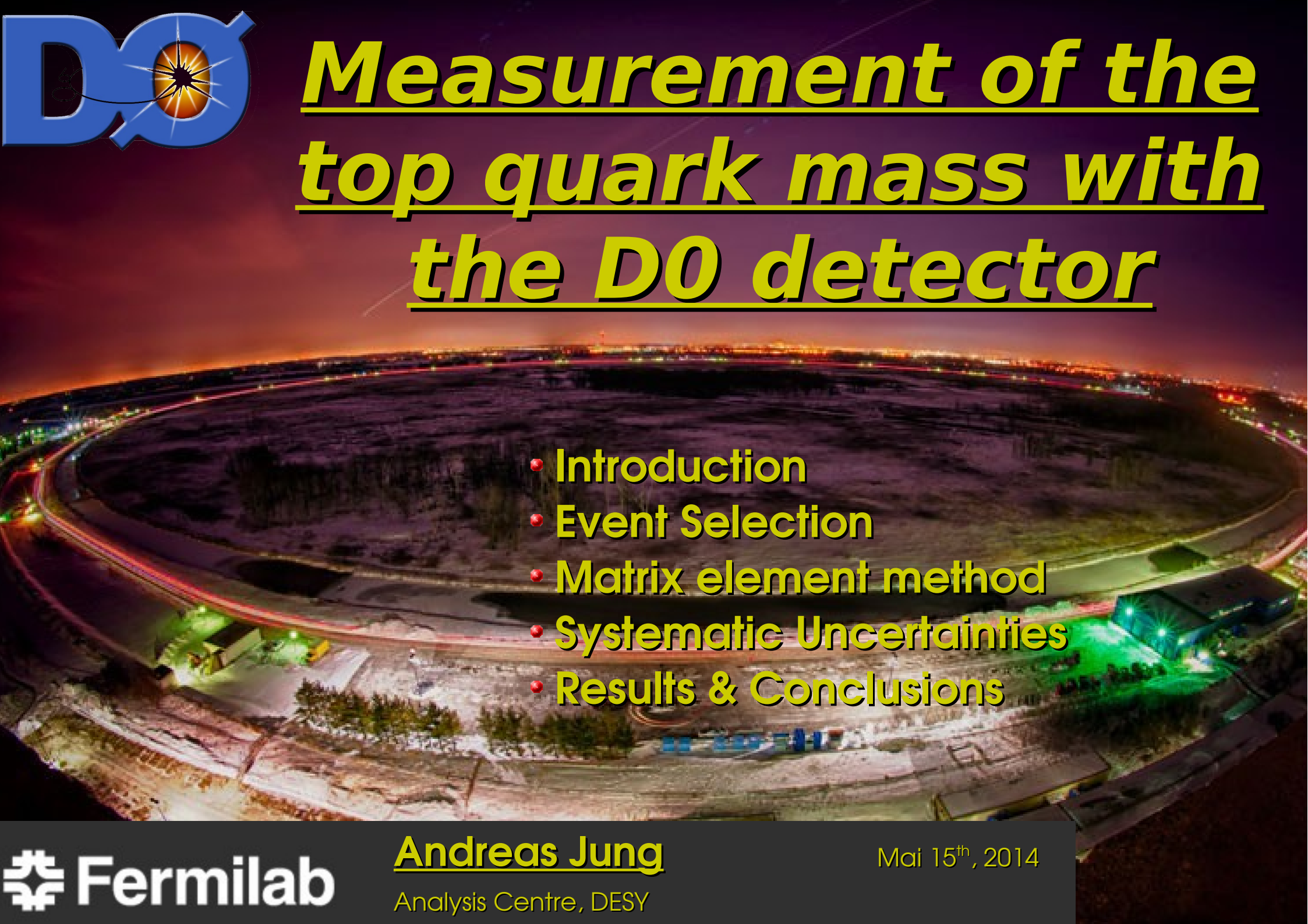


Measurement of the top quark mass with the D0 detector

- Introduction
- Event Selection
- Matrix element method
- Systematic Uncertainties
- Results & Conclusions

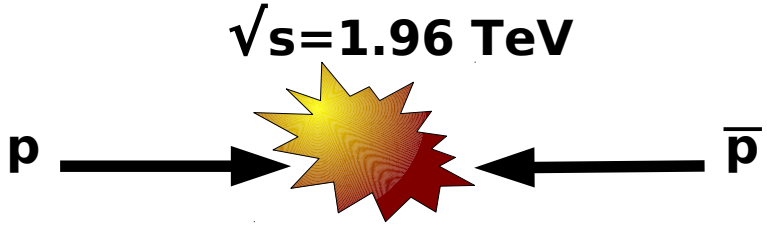
Fermilab

Andreas Jung

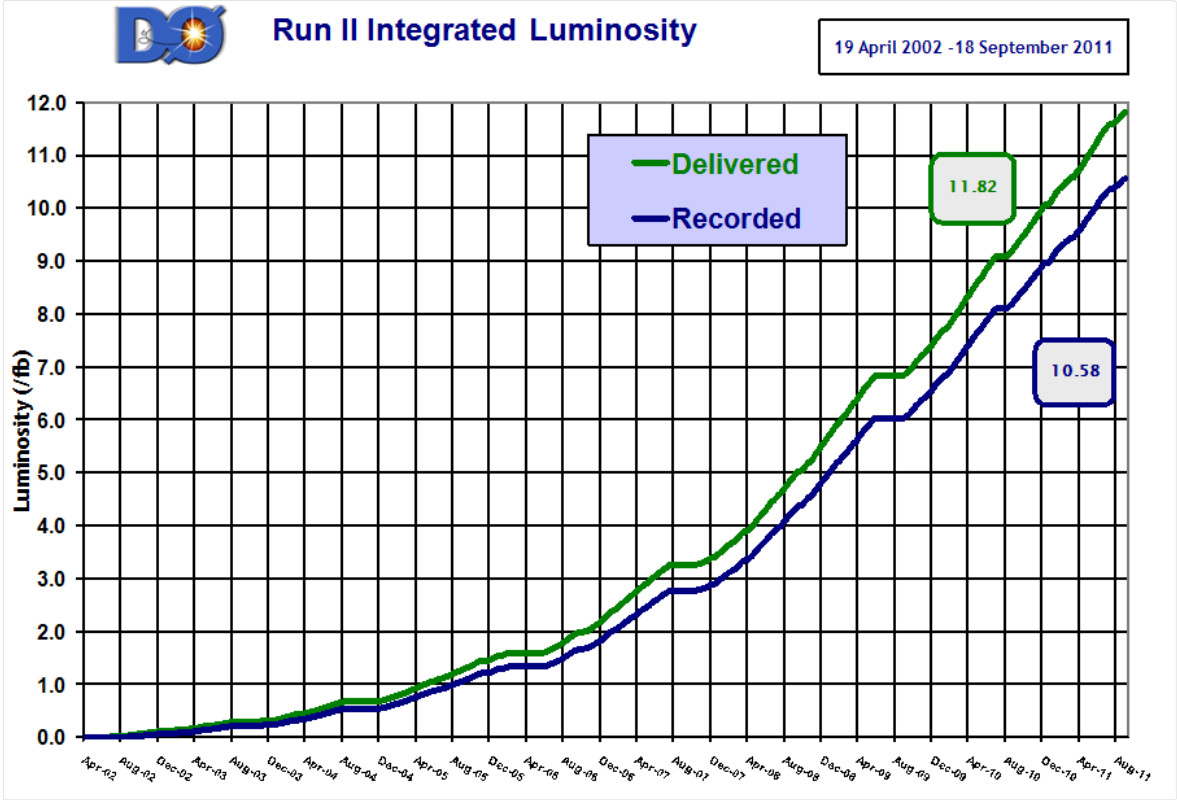
Analysis Centre, DESY

Mai 15th, 2014

Tevatron – Introduction

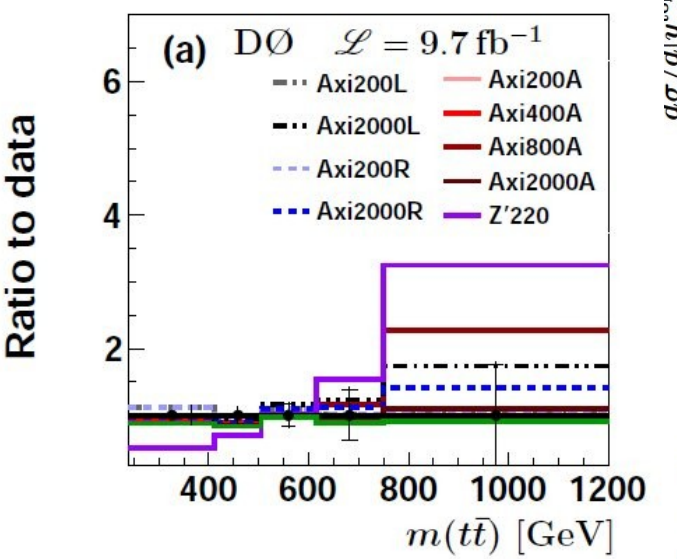


- Peak luminosities: 3 – 4 x 10^{32} $cm^{-2}s^{-1}$
- ~10 fb^{-1}/experiment recorded

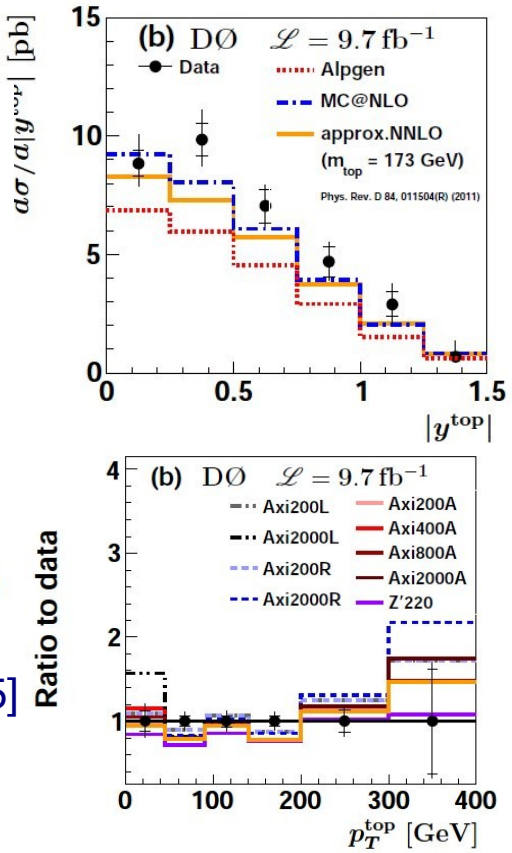


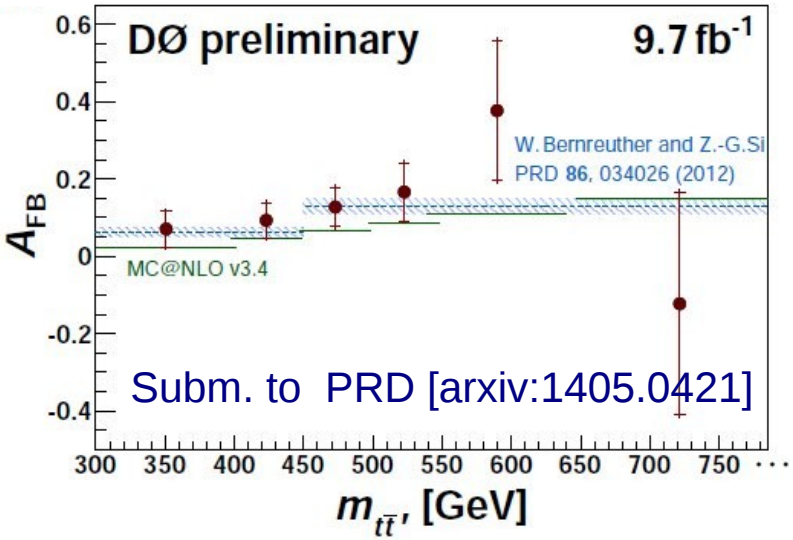
Tevatron – Introduction

- Worlds largest $p\bar{p}$ data set for a long time
- Well understood detectors
- Initial state allows for unique measurements
- Less pile-up effects



Subm. to PRD [arxiv:1401.5785]





Subm. to PRD [arxiv:1405.0421]

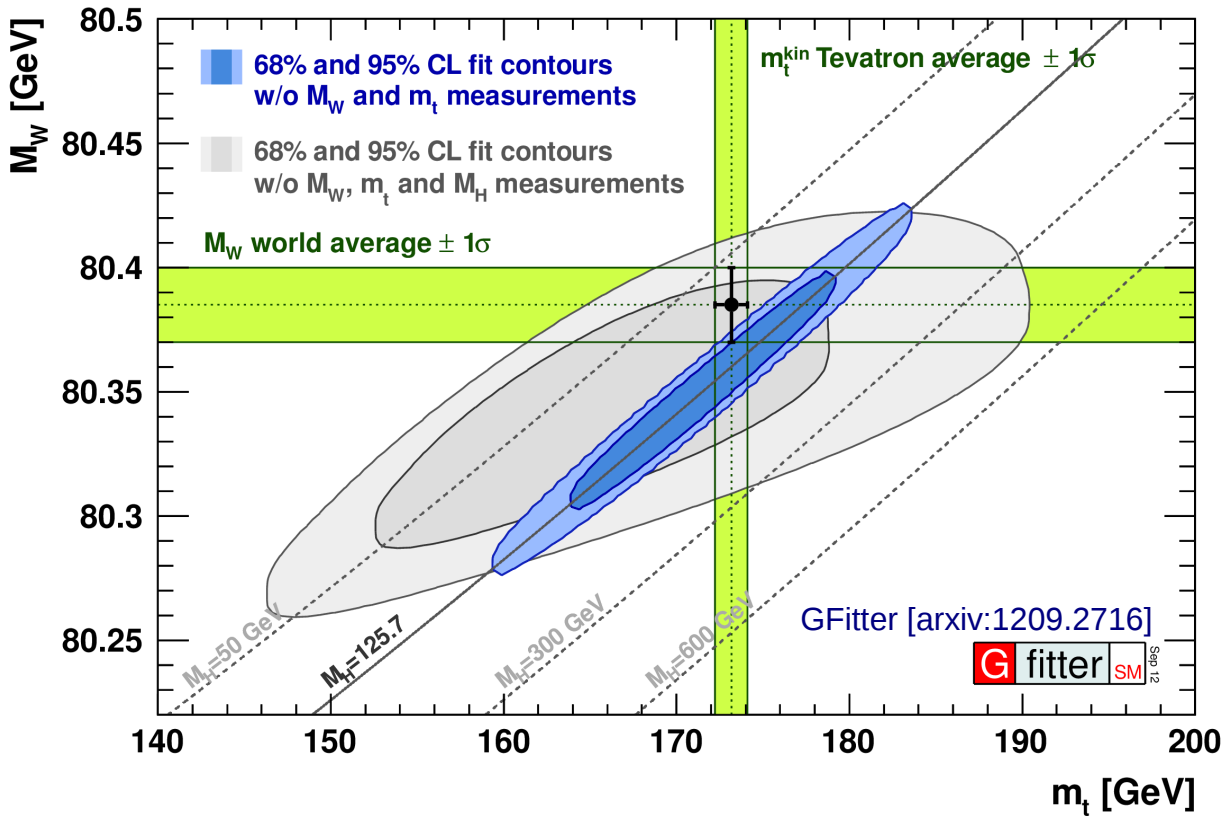
Recent new top quark results:

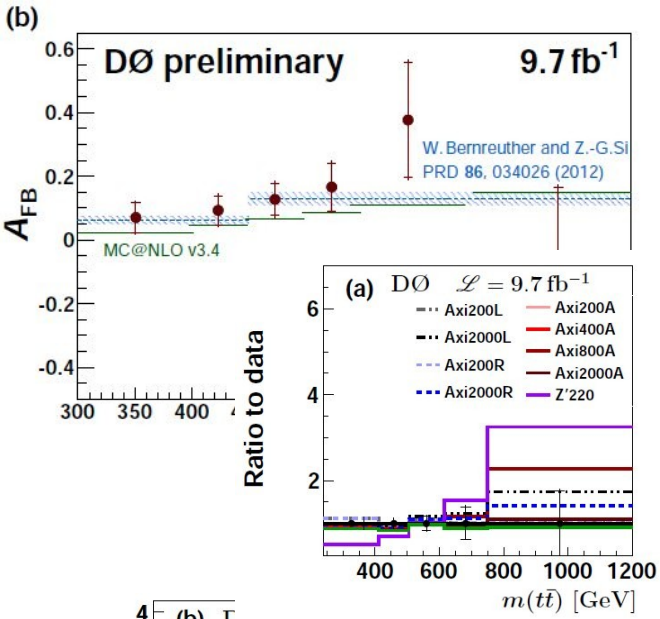
- Differential cross sections
- Charge/Forward-Backward Asymmetry (top based)

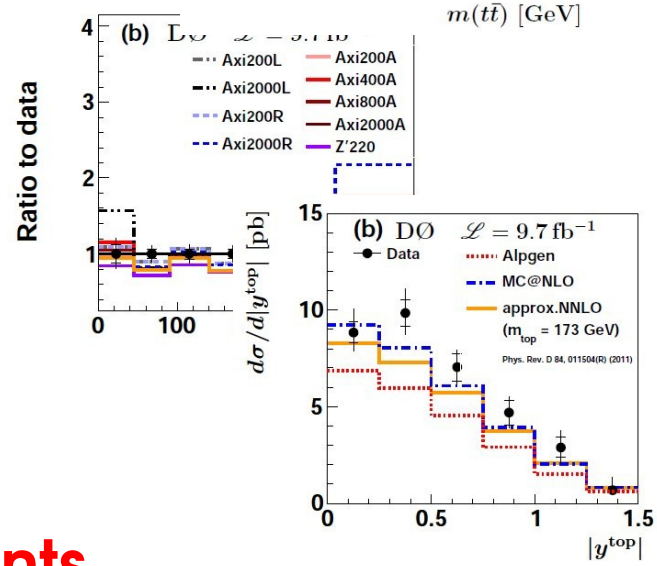
→ D0 Top quark physics results

Tevatron – Introduction

- Worlds largest $p\bar{p}$ data set for a long time
- Well understood detectors
- Initial state allows for unique measurements
- Less pile-up effects





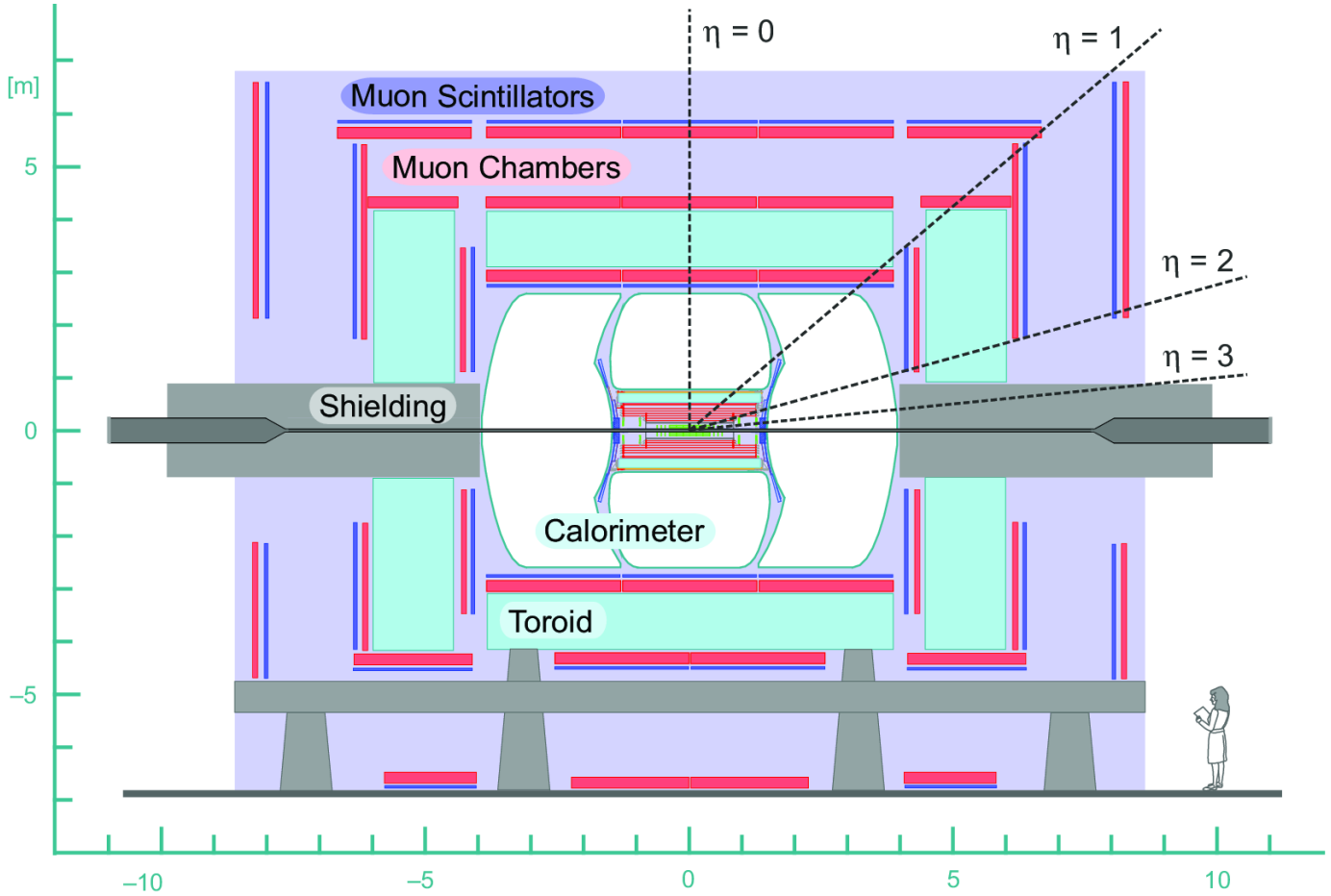


Tevatron: → **High precision m_W and m_t measurements**

The D0 Detector

- General purpose 4π detectors:

Tracker: Detection and momentum measurement for charged particles
Calorimeter: Identification and energy measurement of jets and electrons
Muon system: Identification and momentum measurement of muons

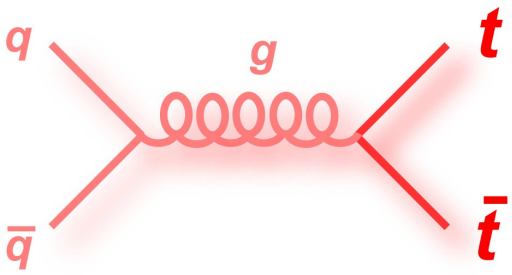


- Upgrade activities, aging, etc → D0 defines **four run periods**

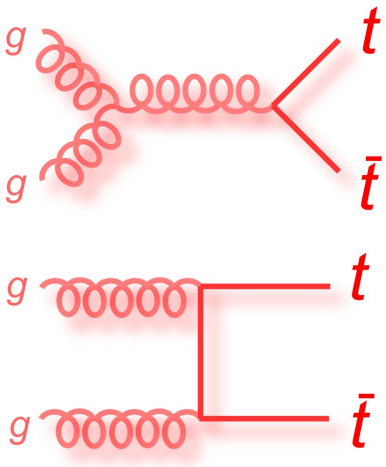
Top quark introduction

- Top is the heaviest fundamental particle discovered so far:
  → m_t = 173.2 ± 0.9 GeV [arxiv:1305.3929]
- Top plays special role in EWSB ?
  → λ_t = 0.995 ± 0.005
- Lifetime: $\tau \approx 5 \times 10^{-25}$ s << Γ_{QCD}
  → **Observe bare quark**

- Strong interaction: Top pairs



$q\bar{q}$ annihilation



gg fusion

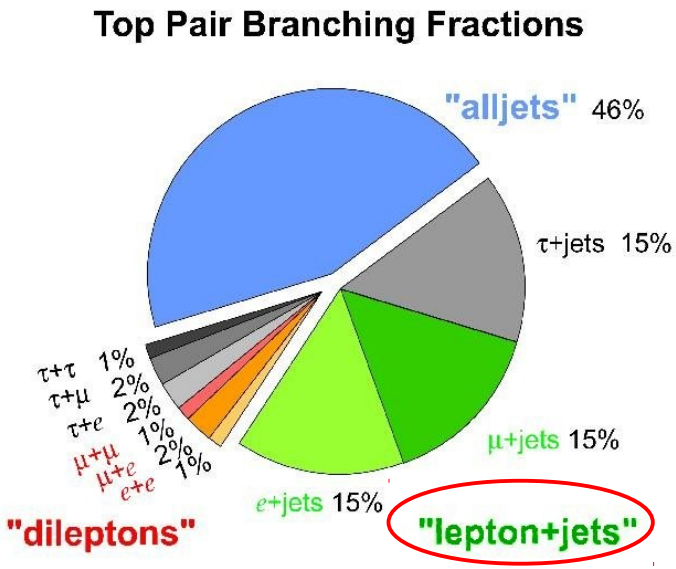
Tevatron vs. LHC:
(1.96 TeV 7/8 TeV)

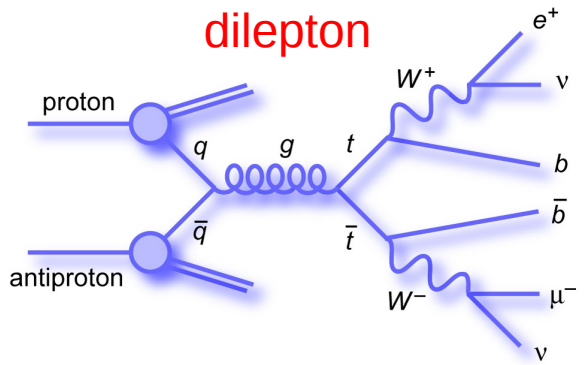
$q\bar{q}$: ~85% ~15/13% (~10%, 14 TeV)

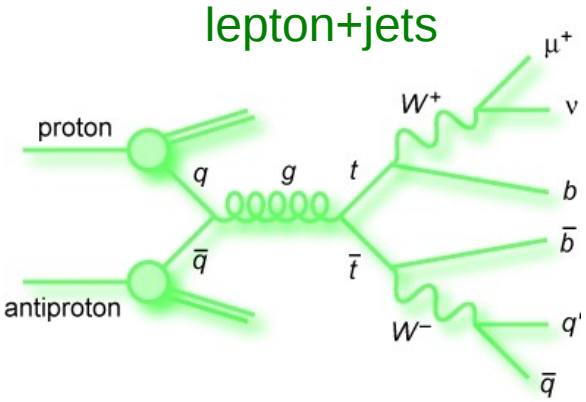
gg: ~15% ~85/87% (~90%, 14 TeV)

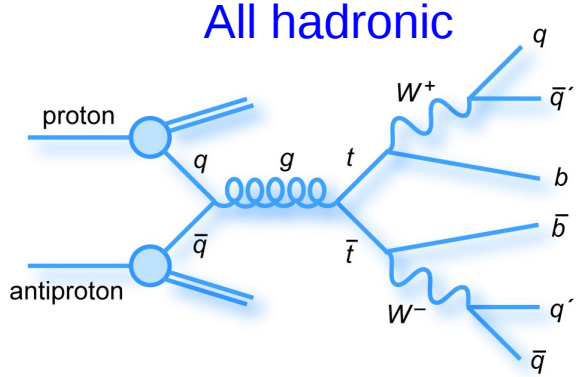
Top quark introduction

- Top is the heaviest fundamental particle discovered so far:
  → m_t = 173.2 ± 0.9 GeV [arxiv:1305.3929]
- Top plays special role in EWSB ?
  → λ_t = 0.995 ± 0.005
- Lifetime: $\tau \approx 5\times10^{-25}$ s << Γ_{QCD}
  → **Observe bare quark**
- Different decay channels:
  → **~100% to *Wb***







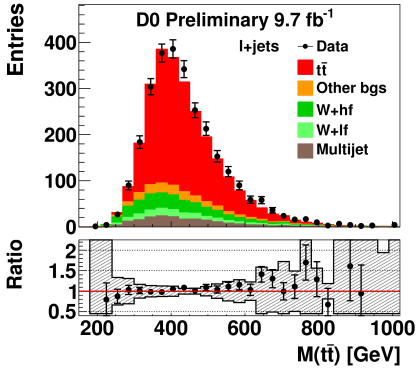


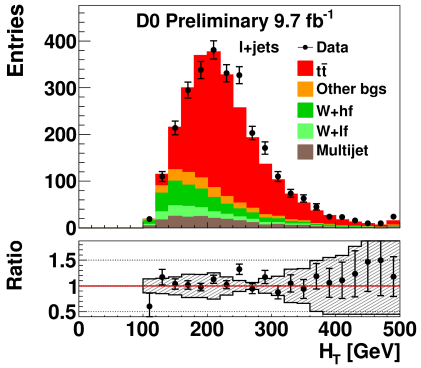
BR, bg decrease

BR, bg increase

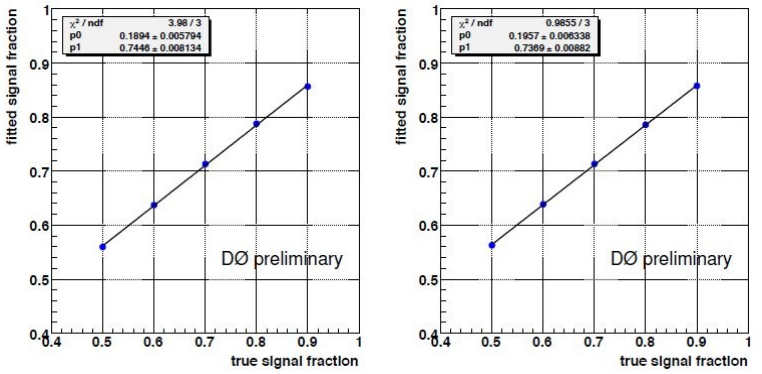
Measurement strategy

I. Event selection & Sample Composition

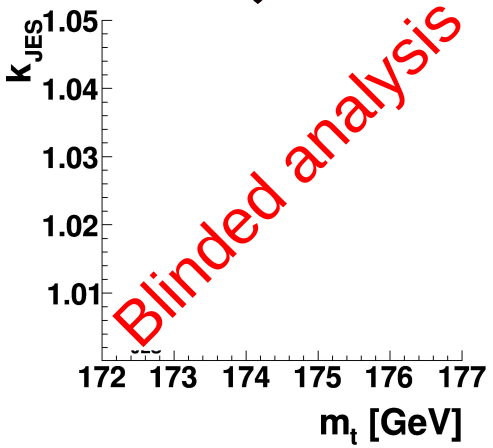




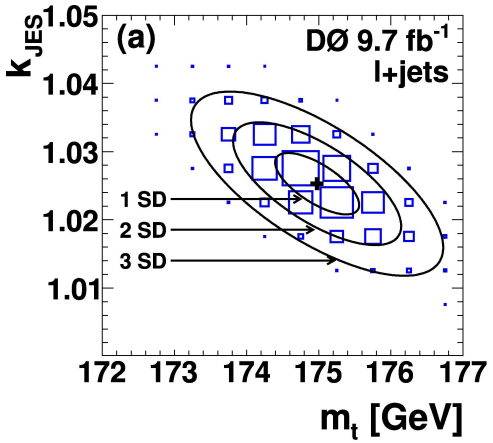
II. Matrix element method & calibration of the method



III. Check consistency, estimate systematic uncertainties (!)

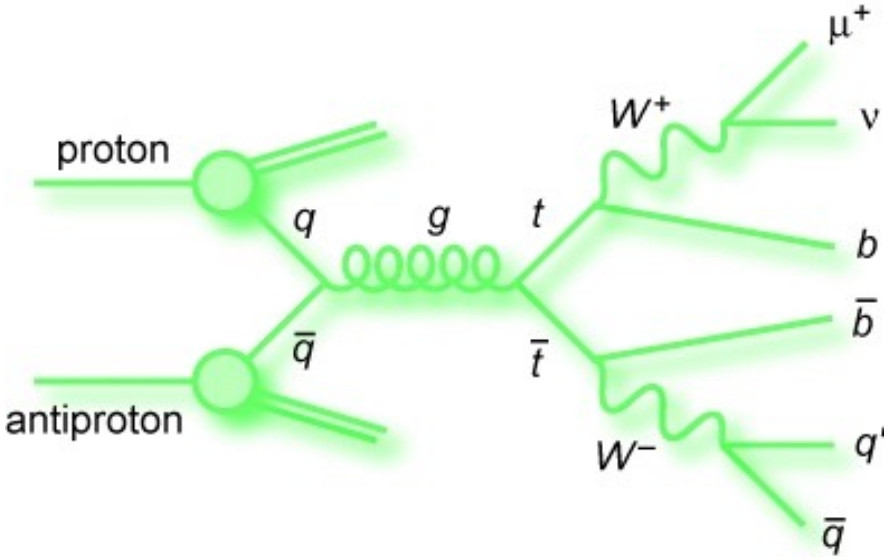


IV. Unblinding & Final results



Event selection

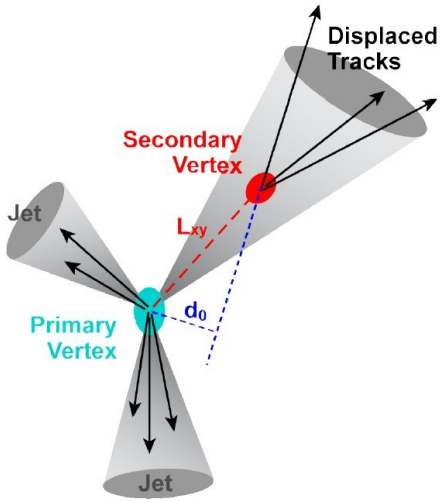
- Lepton+jets decay channel: **Full Run II data recorded by D0**



variable	kinematic range
lepton $\eta(\ell)$	$\lvert\eta(e)\rvert < 1.1$ and $\lvert\eta(\mu)\rvert < 2.0$
lepton $p_T(\ell)$	$p_T(\ell) > 20$ GeV
$\not\!\!E_T$	$\not\!\!E_T > 20$ GeV
jet $\eta(jet)$	$\lvert\eta(jet)\rvert < 2.5$
jet $p_T(jet)$	$p_T(jet) > 20$ GeV

→ Exactly four jets with at least 1 *b*-tag

- One of the most important experimental techniques "b-tagging":

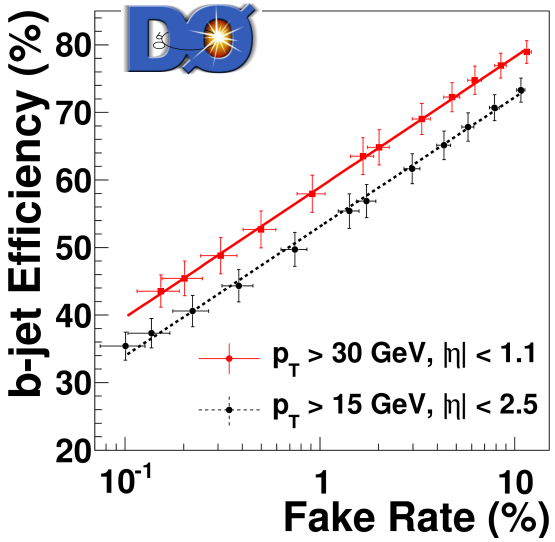


b-quarks hadronize before decaying into a *c*-quark:

→ Long-lived *B* hadrons decay some mm away

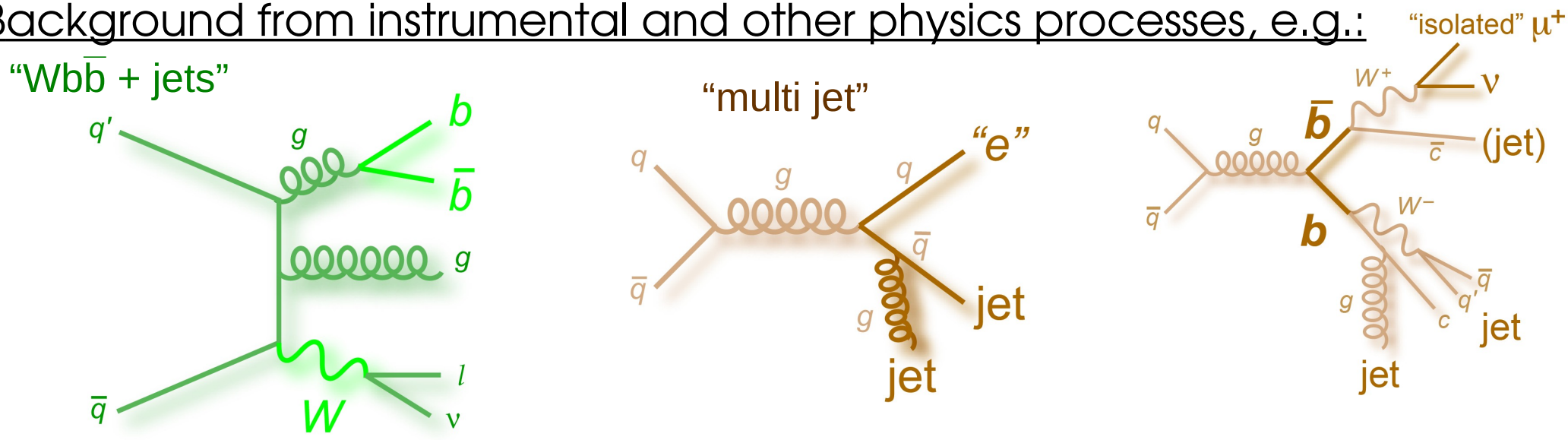
→ Multi-Variate Analysis technique

Subm. to NIM [arxive:1312.7623]



MC & backgrounds

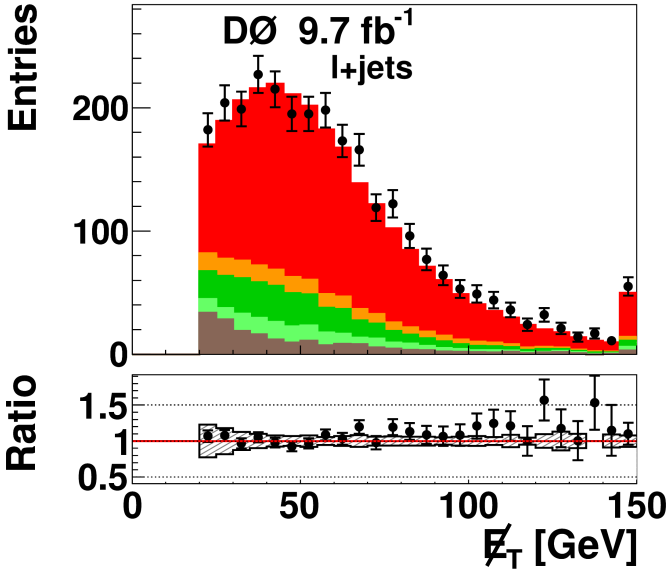
- Background from instrumental and other physics processes, e.g.:

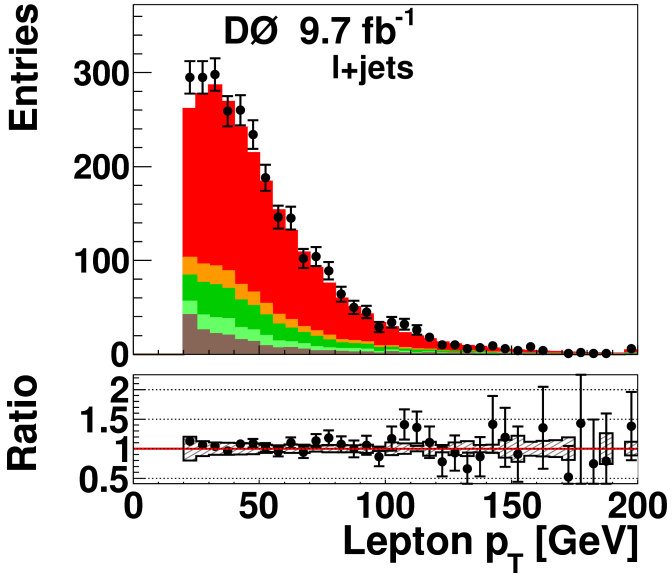


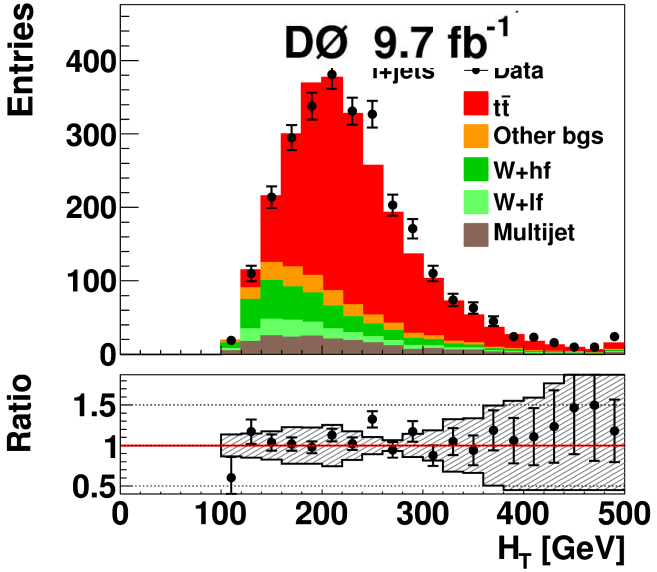
- Multi jet and W + heavy flavor + jets contribution derived from data

- Samples for signal and backgrounds:
  - $t\bar{t}$: Alpgen+Pythia (0,1, ≥2lp)
    systematic uncertainties: Alpgen+Herwig, MC@NLO+Herwig
  - W+jets: Alpgen+Pythia (0,1,2,3,4, ≥5lp)
    Whf+jets: Alpgen+Pythia (0,1,2,≥3lp)
  - Multijet shape is taken from inverted loose lepton-ID selection

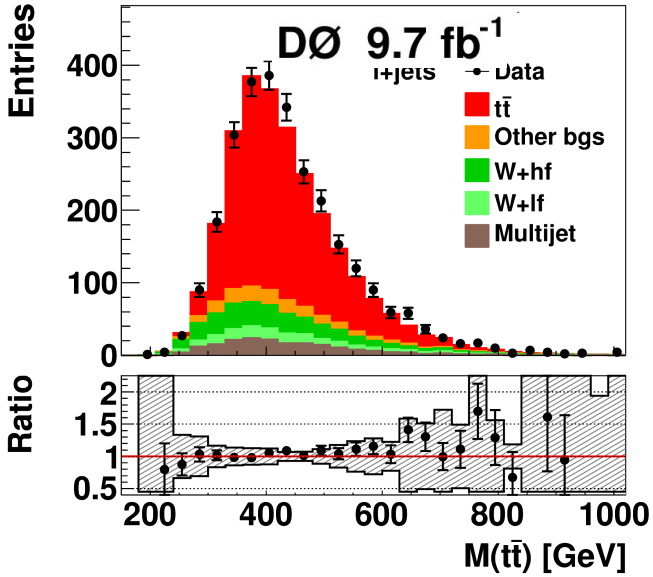
Control distributions







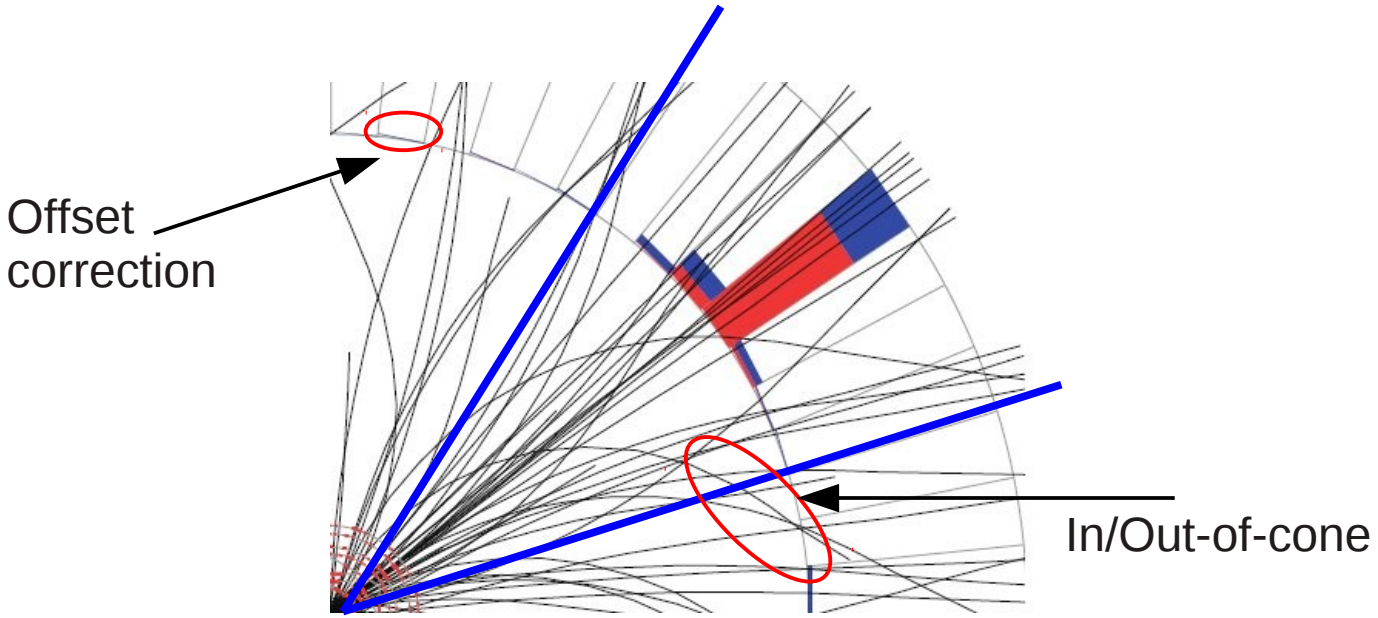
Contribution	$e+$jets			$\mu+$jets		
Data	1502.00	±	38.76	1286.00	±	35.86
$t\bar{t}$	918.11	±	3.63	824.88	±	3.48
$W+$jets	77.85	±	2.13	101.03	±	2.93
$W+$HF	125.98	±	2.12	162.21	±	2.81
Multijet	144.41	±	24.19	48.17	±	16.11
Other backgrounds	97.75	±	0.51	79.24	±	0.94
Expected	1364.10	±	24.65	1215.53	±	17.00



→ Good description/modeling of the data
(Assuming measured cross section)

Jet Energy Scale (JES)

- Its not just a "jet" from a quark...in reality much more complex:
  - Initial state & final state radiation, underlying events, multiple parton interaction, the parton shower
  - Need a correction to take these effects into account



- JES corrects reconstructed energy back to particle level (D0 case)

$$E^{\mathrm{ptcl}} = \frac{E^{\mathrm{meas}} - E_{\mathrm{O}}}{R \cdot S}$$

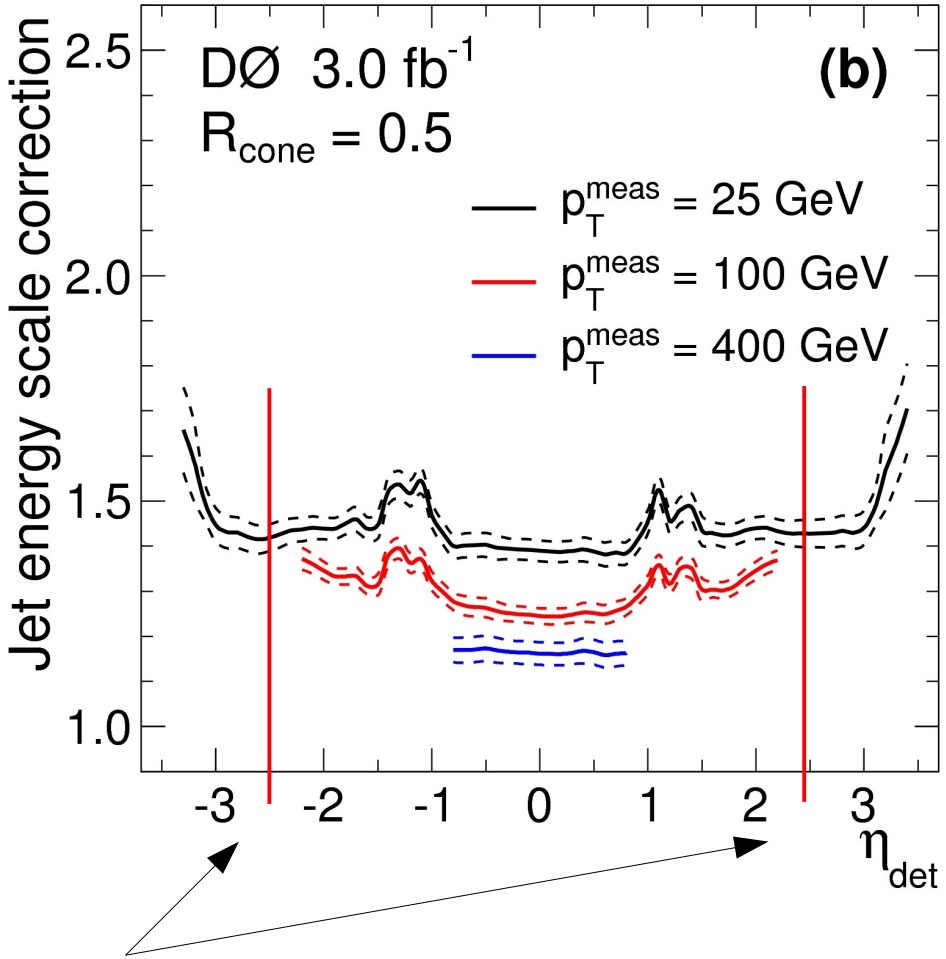
E_o – offset correction
R – response correction (jet composition, etc.)
S – Showering corrections, In/Out of cone

  - To be exact: D0 JES only valid for Pythia Tune A

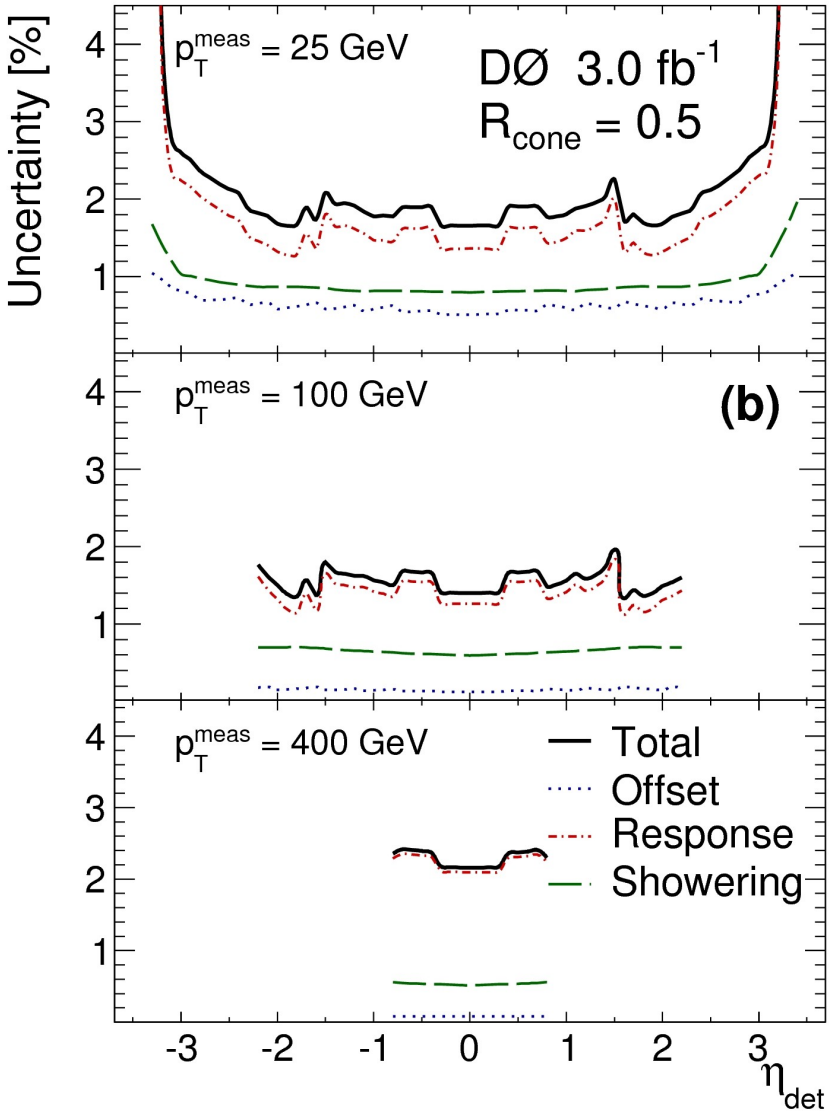
Jet Energy Scale (JES)

- Latest JES calibration applied
- Correction depends on jet energy, uncertainties of 1-2%

Accepted by NIM



Jet cuts required in top quark measurements



Single Particle Response

- JES does not distinguish quark and gluon jets
- Employ γ+jets events to calibrate response in MC to data
- Derive a correction factor F_{corr} for MC:

$$F_{\mathrm{corr}} = \frac{1}{\langle F \rangle_{\gamma+\mathrm{jet}}} \cdot \frac{\sum_i E_i \cdot R_i^{\mathrm{data}}}{\sum_i E_i \cdot R_i^{\mathrm{MC}}}$$

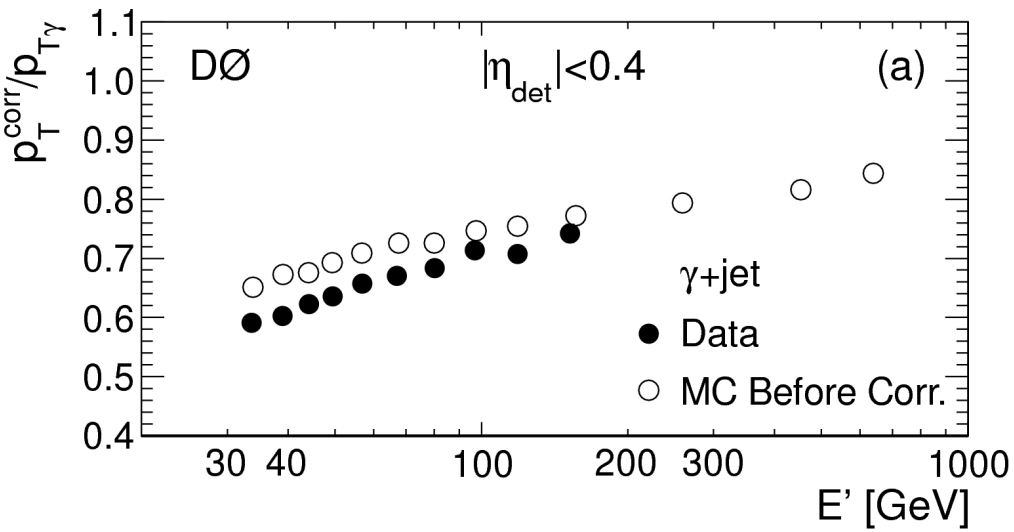
- Response in calorimeter for data or MC for particle *i* inside particle jet
- Matching with $dR < 0.25$

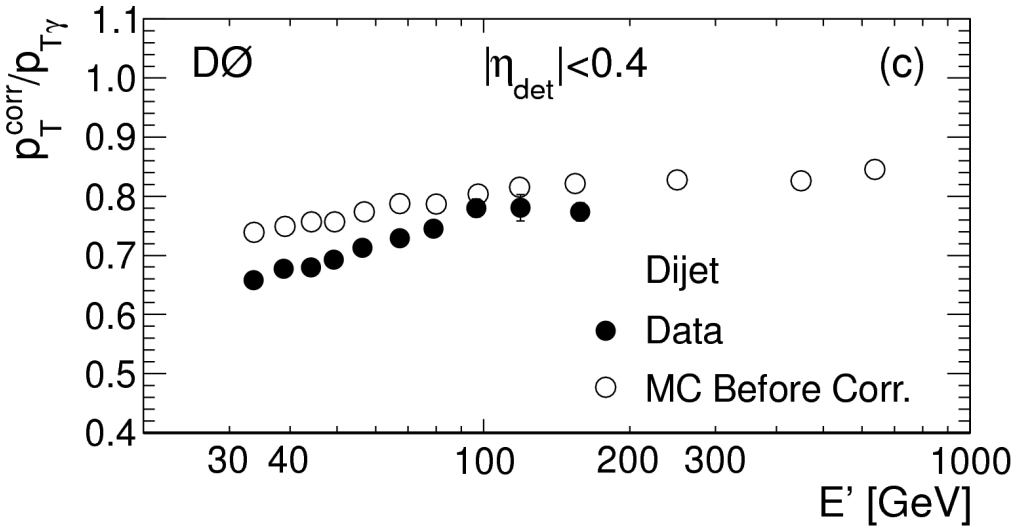
- Preserves standard JES calibration
- <u>Calibration by using:</u>
  - Reconstructed jet p_T with offset correction: p_T^{corr}
  - p_T of EM cluster with tight photon ID: p_T^{γ}
  - Calibrate ratio $p_T^{corr} / p_T^{\gamma}$

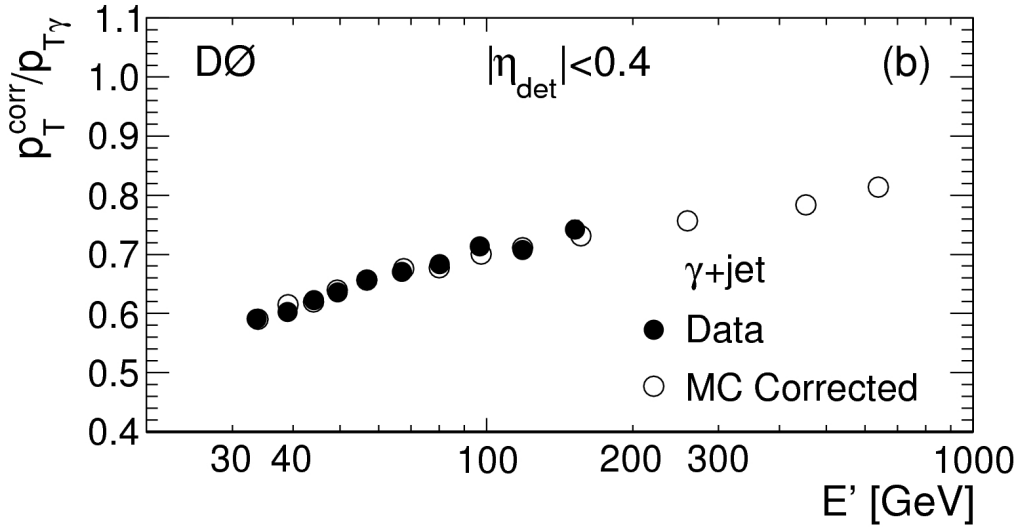
Assuming the single particle composition as in MC

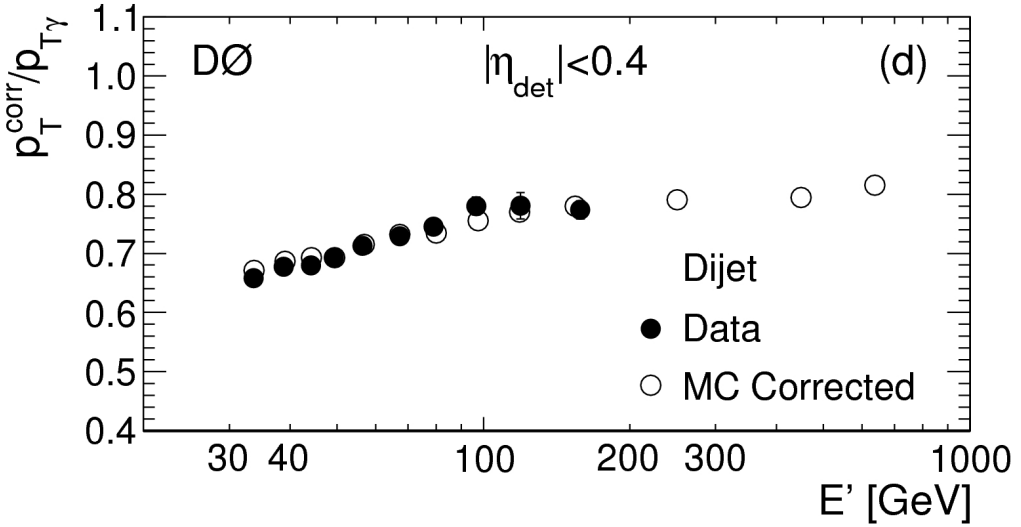
Single Particle Response

- Does not correct the response of gluon and quark jets to be the same
  → the response of jets in MC and data to be the same



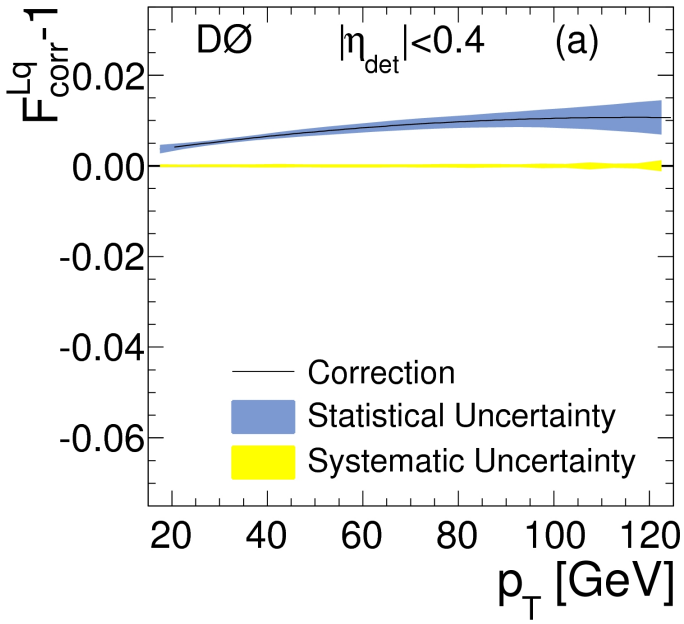


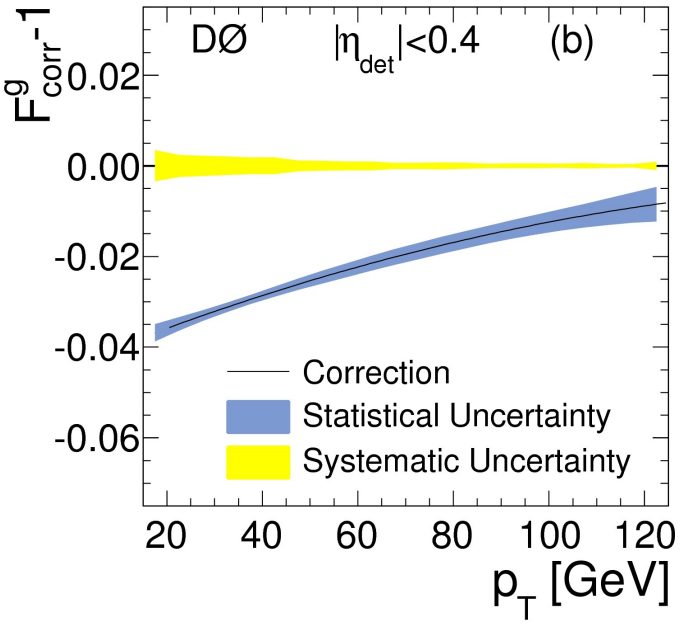


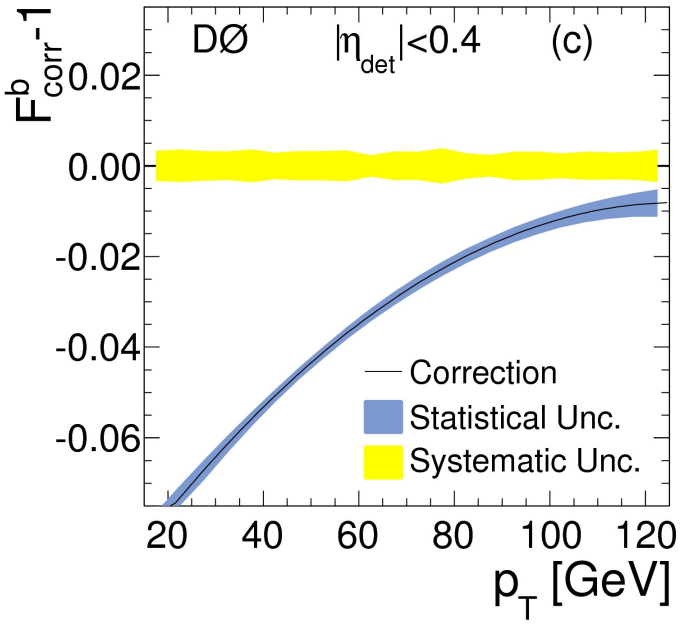


Single Particle Response

- Improves MC description of jets and reduces sample-dependency
- Resulting F_{corr} for different jet flavors and their uncertainties



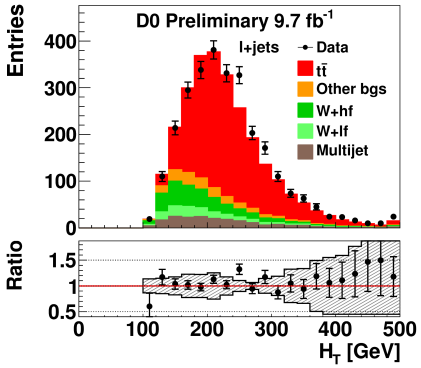


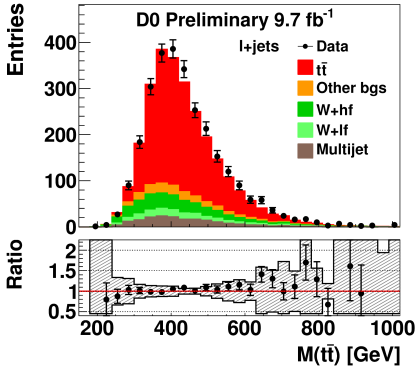


- Small correction to light quarks (*u,d,s,c*), several % for *g* and *b* quarks
- Without that correction, the measurement (see 1\fb result) suffers an uncertainty for the b/light response ratio of 0.83 GeV, by far dominant source Phys. Rev. Lett. 101, 182001 (2008)

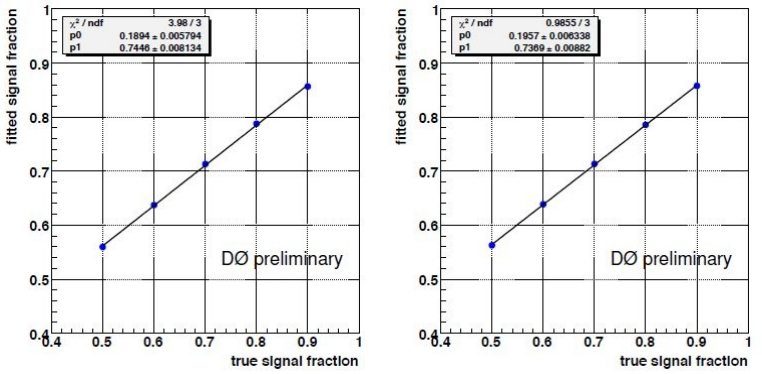
Measurement strategy

I. Event selection & Sample Composition





II. Matrix element method
& calibration of the method



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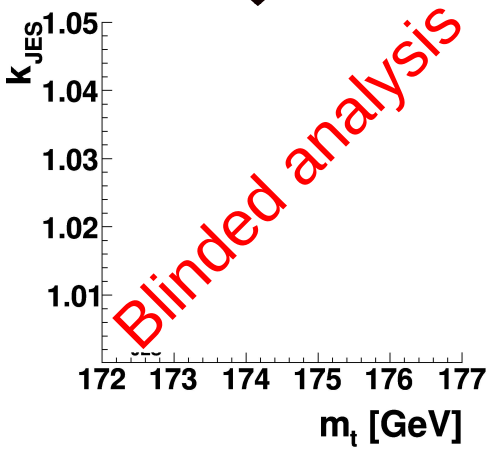

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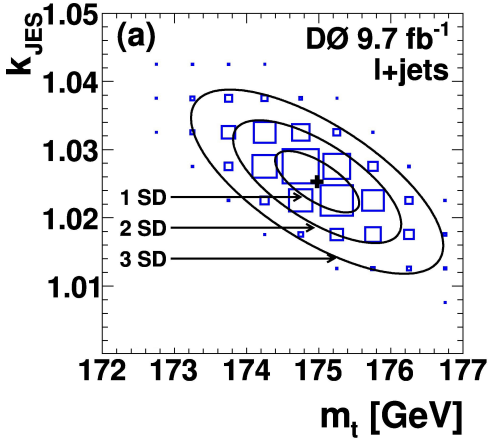


Matrix element method

- Matrix Element method (ME) calculates event probability densities (PD) from differential cross sections and detector resolutions:
  - Maximizes statistical power due to maximal use of kinematical and topological information

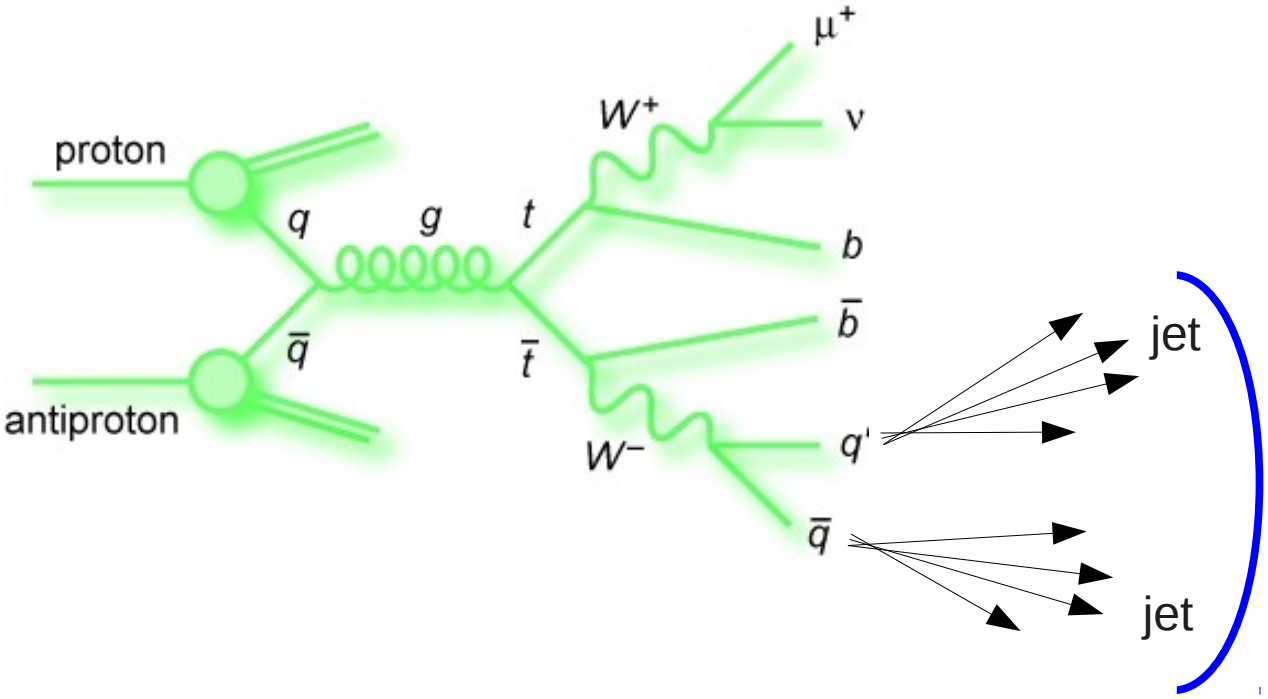
$$P(x, m_t) = \frac{1}{\sigma(m_t)} \int \sum \underbrace{d\sigma(y, m_t)}_{\text{LO ME}}\, dq_1 dq_2\, \underbrace{f(q_1) f(q_2)}_{\text{PDFs}}\, \underbrace{W(y, x, k_{\text{JES}})}_{\text{Transfer function}}$$

$$f P_{\text{sig}}(\vec{x}; m_t, k_{\text{JES}}) + \ (1 - f) P_{\text{bkg}}(\vec{x}; k_{\text{JES}})$$

- The Transfer functions relate the PD of measured set *x* of kinematic quantities to partonic set *y*
- 10 dim phase space integral, with sum of incoming parton flavors and neutrino p_z solutions

Matrix element method

- k_{JES} is a global factor for the Jet Energy Scale
  - **In-situ calibration** by using the hadronic W decay (does not account for b-JES)



- **Simultaneous extraction of m_t and global JES scale factor k_{JES}**
  - Method robust against changes in kinematics in different phase space regions

Matrix element method

Updates compared to last publication/measurement:

- More data 3.6/fb → 9.7/fb (full Run II)
- Improved object IDs (e, μ, b)
- Faster method:
  - Random number generation
  - Modify treatment of kJES
    → Verified that method gets same result as with "old" method, but factor of
    ~ 100 faster
  - Allowed **dramatic increase** in MC statistics

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Higher-order effects	±0.25
ISR/FSR	±0.26
Hadronization and UE	±0.58
Color reconnection	±0.28
Multiple $p\bar{p}$ interactions	±0.07
Modeling of background	±0.16
W+jets heavy-flavor scale factor	±0.07
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Residual jet energy scale	±0.21
Data-MC jet response difference	±0.28
b-tagging efficiency	±0.08
Trigger efficiency	±0.01
Lepton momentum scale	±0.17
Jet energy resolution	±0.32
Jet ID efficiency	±0.26

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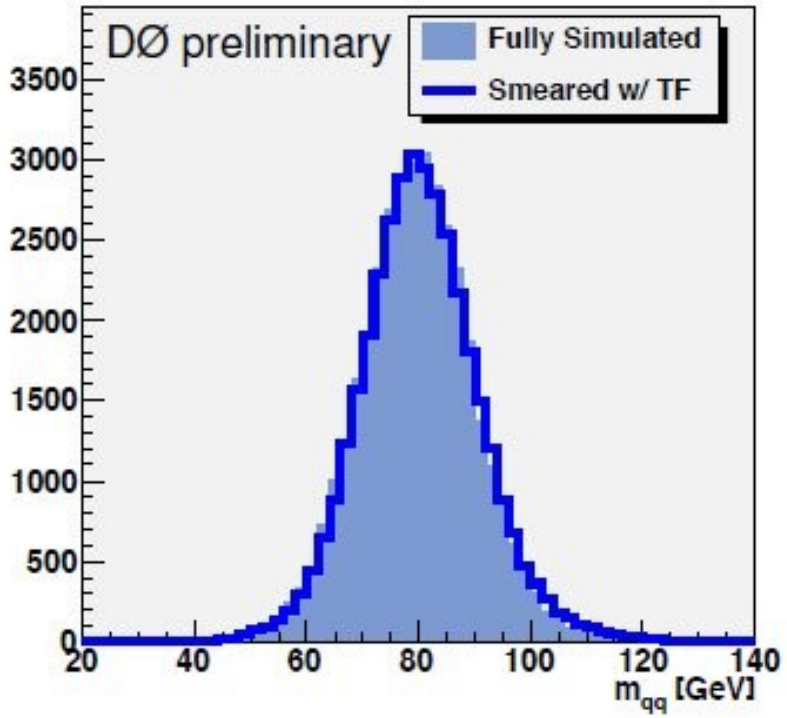
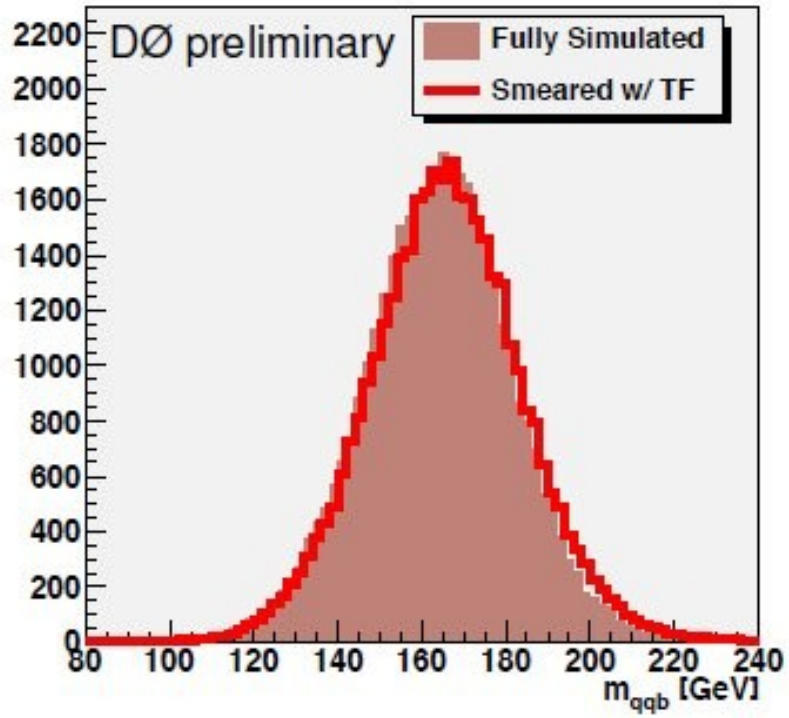
→ Typical statistical uncertainty:
~0.25 GeV → ~ 0.01 – 0.05 GeV

Transfer functions

- ME method **needs parton momenta**, derive transfer functions
  - Sum of two gaussian fcts, separately for light, b-tagged jets with soft muons and b-tagged jets in 4 regions in $|\eta|$
  - Directions of lepton and jets are measured with high precision
    - No need for transfer functions, employ δ-functions
  - *m*(di-jet), *m*(tri-jet) matched to W boson, top quark mass:

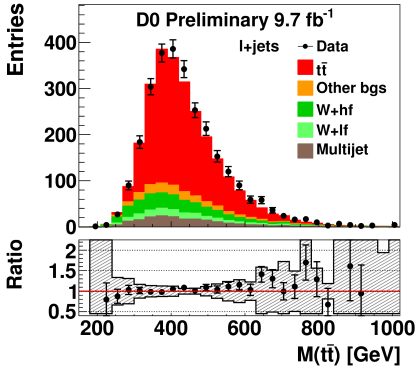


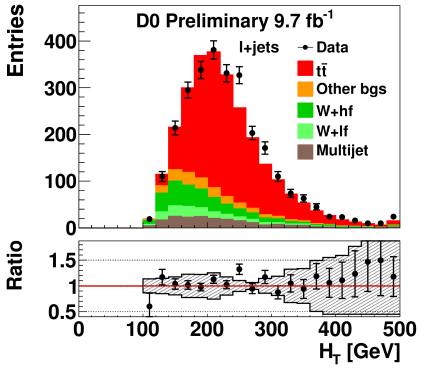


- Very good modeling of the detector response

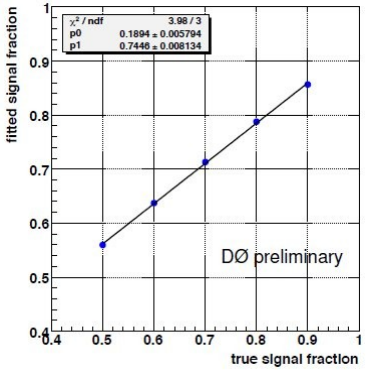
Measurement strategy

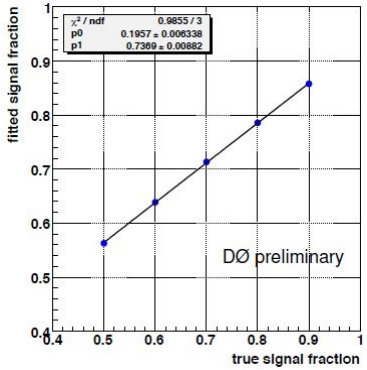
I. Event selection & Sample Composition



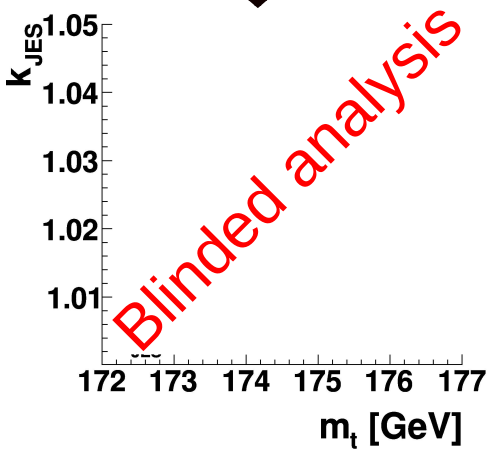


II. Matrix element method **& calibration of the method**

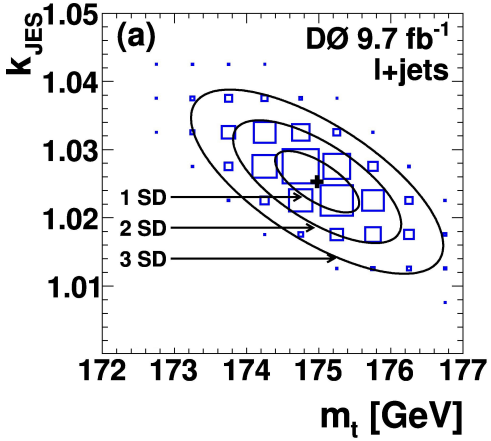




IV. Unblinding & Final results



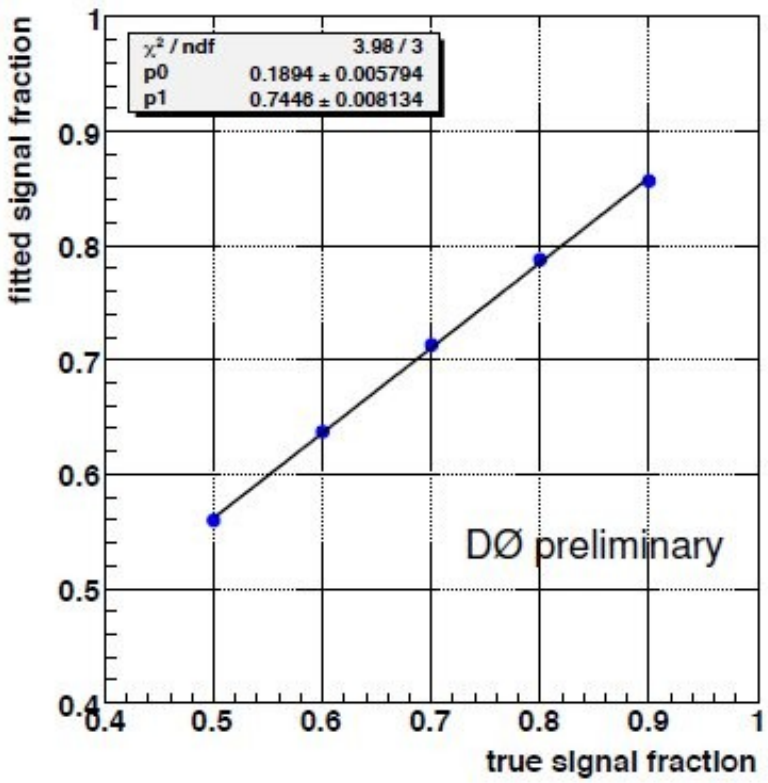
III. Check consistency, estimate systematic uncertainties (!)

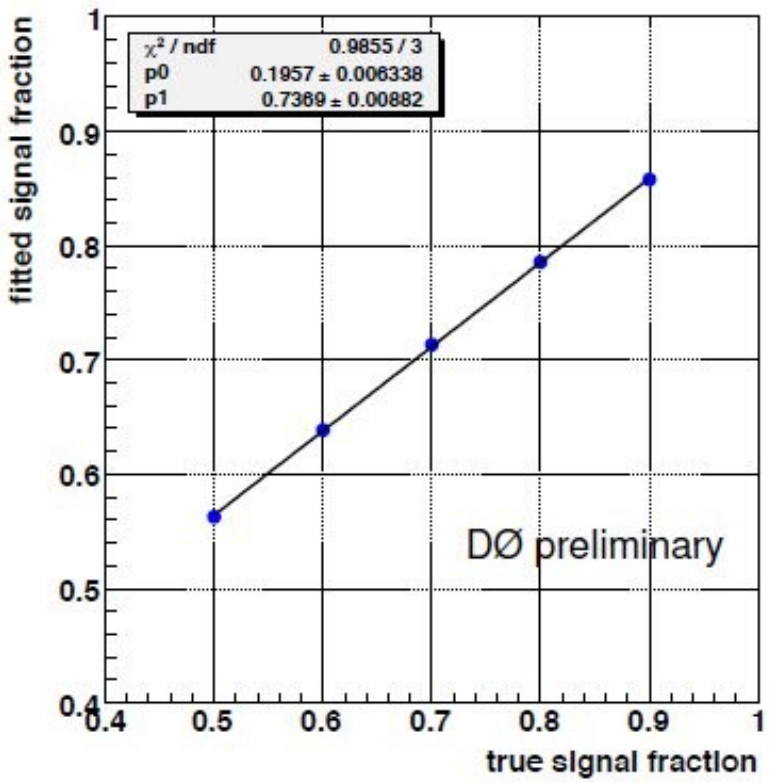


Calibration signal fraction

- Employ pseudo-experiment to calibrate the method
  - Calibration for each run period and lepton type → **8 channels**
  - Pseudo-experiments with:
    - N(data)
    - W+jets and Multi-jet background (others are few %)
    - *n*=1000 at each calibration point

- Signal fraction:
  → Integrate over m_t and k_{JES}





Calibration signal fraction

- Signal fractions measured per run period:

Epoch	Channel	Signal fraction	$\sigma_{t\bar{t}}$ (pb)
Run IIa	e+jets	0.72	8.9
	μ+jets	0.65	7.8
Run IIb1	e+jets	0.77	7.6
	μ+jets	0.66	6.8
Run IIb2	e+jets	0.68	7.8
	μ+jets	0.66	7.5
Run II3+4	e+jets	0.56	7.6
	μ+jets	0.75	8.0
→ Run II	e+jets	0.63	7.8
	μ+jets	0.70	7.6

- In good agreement with latest Tevatron $\sigma_{t\bar{t}}$ combination (≤ 8.8/fb):

→ $\sigma_{t\bar{t}}$ = 7.62 ±0.42 pb (m_t = 172.5 GeV) PRD 89, 072001 (2014)

Calibration

- Employ pseudo-experiments to calibrate the method in m_t and k_{JES}
  - Calibrate m_t by using m_t = 165, 170, 172.5, 175, 180 (k_{JES} =1) and in k_{JES} = 0.95, 1.00, 1.05
  - Apply measured signal fractions per run period
  - Calibrated quantities defined as:

$$m_t' = \frac{(m_t - 172.5\ \text{GeV}) - p_0^{m_t}}{p_1^{m_t}} + 172.5\ \text{GeV}$$

$$k_{\text{JES}}' = \frac{(k_{\text{JES}} - 1) - p_0^{k_{\text{JES}}}}{p_1^{k_{\text{JES}}}} + 1$$

- Statistical uncertainties corrected by using the pull: $pull = \frac{\langle x \rangle - \bar{x}}{\sigma}$

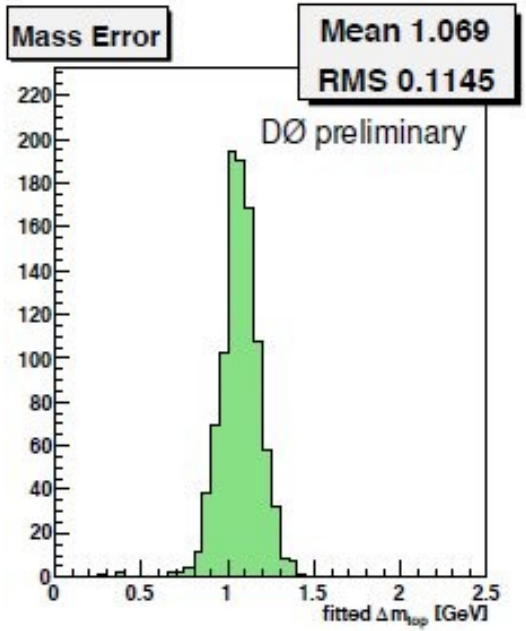
$$\sigma'(m_t') = \sigma(m_t') \times w_{\text{pull}}(m_t)$$

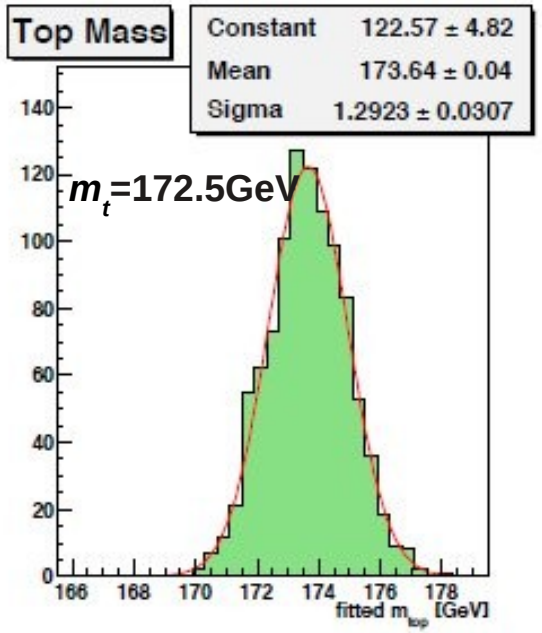
$$\sigma'(k_{\text{JES}}') = \sigma(k_{\text{JES}}') \times w_{\text{pull}}(k_{\text{JES}})$$

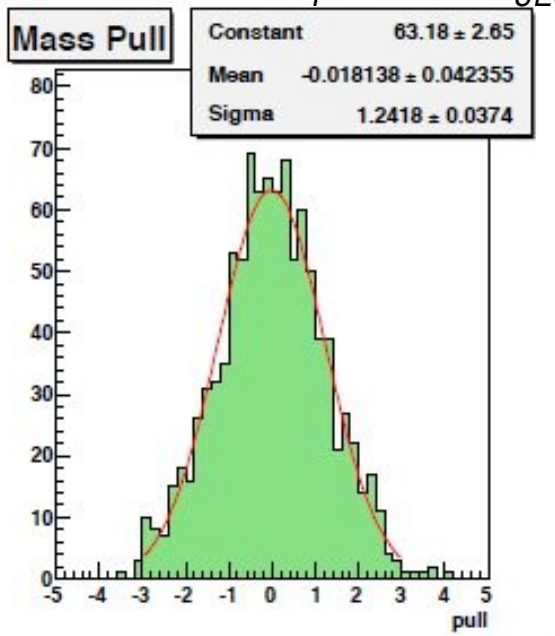
Width of the pull distribution

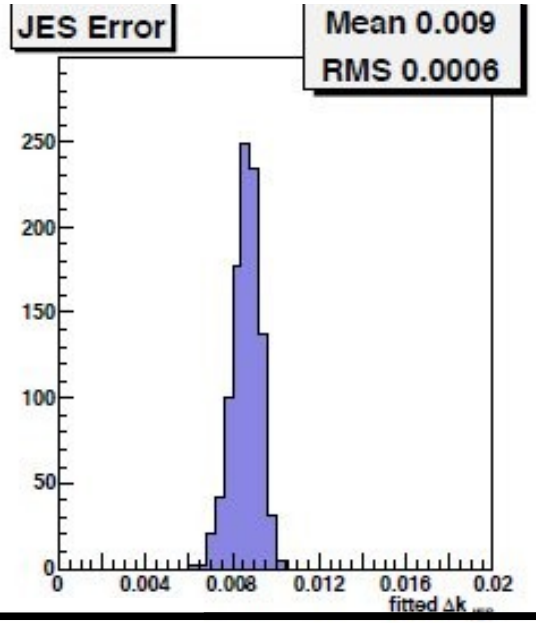
Calibration

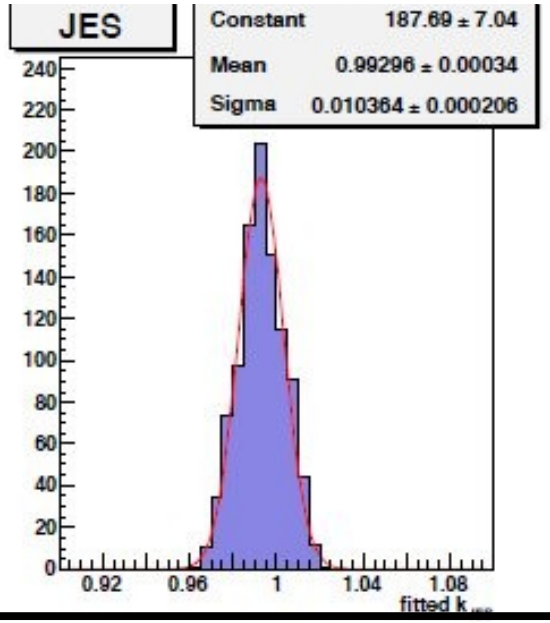
- Use pseudo-experiments to calibrate the method in m_t and k_{JES}

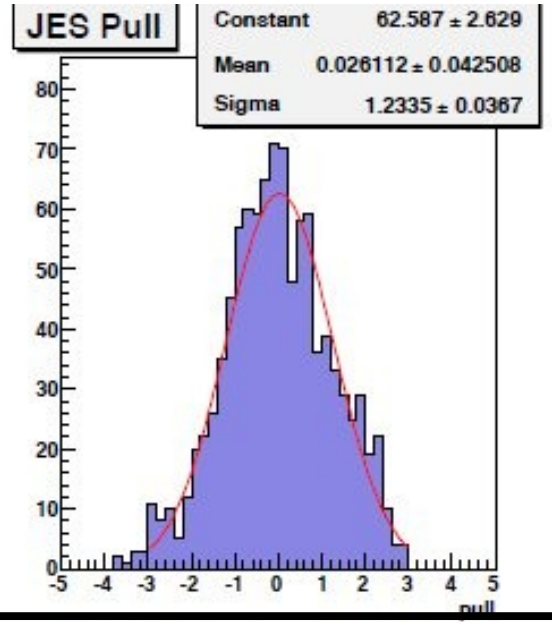












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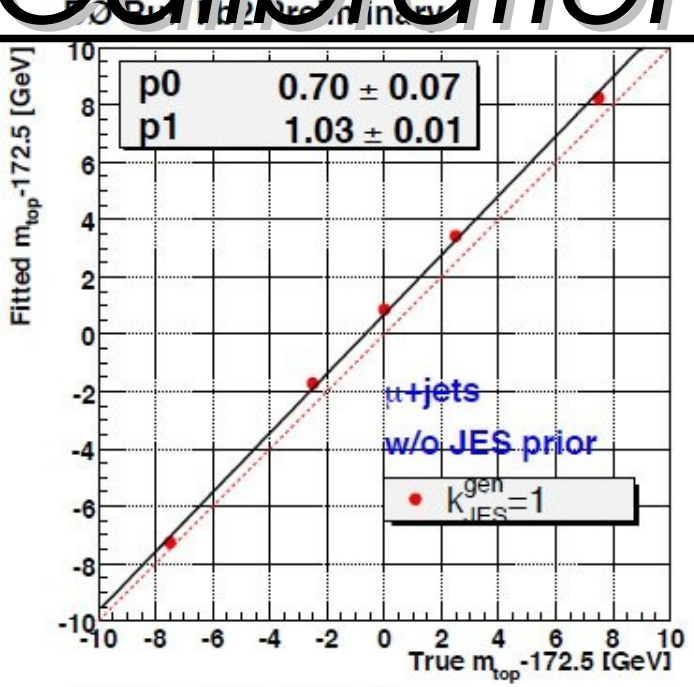

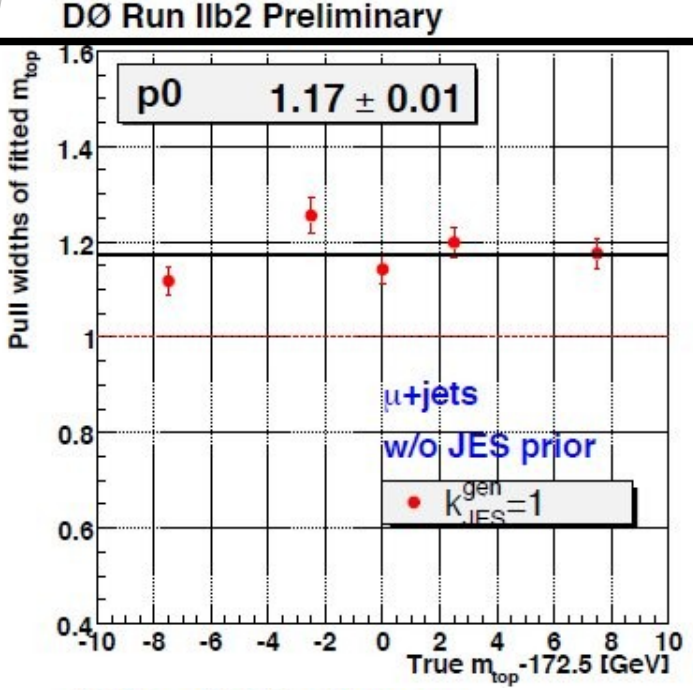

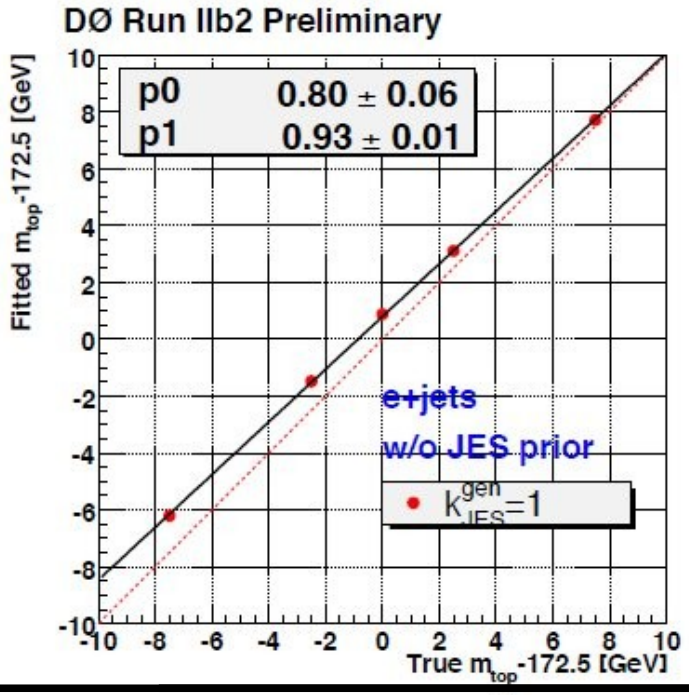

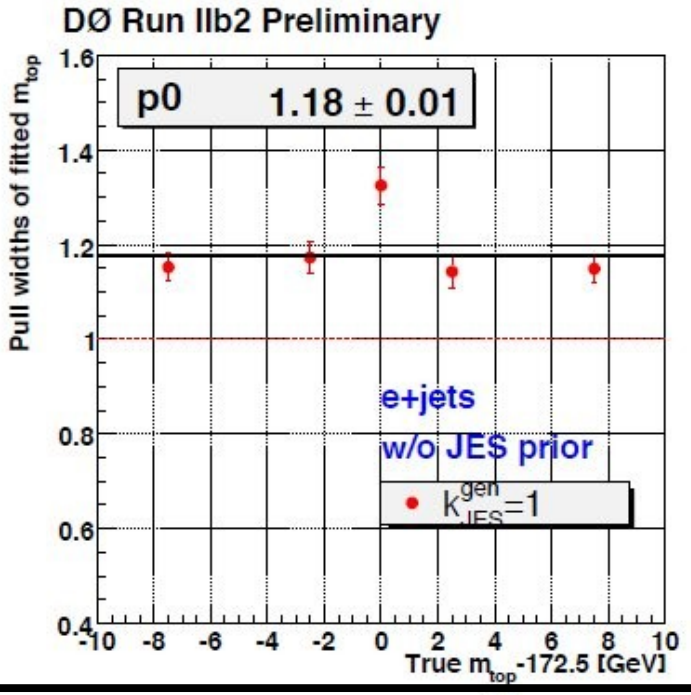

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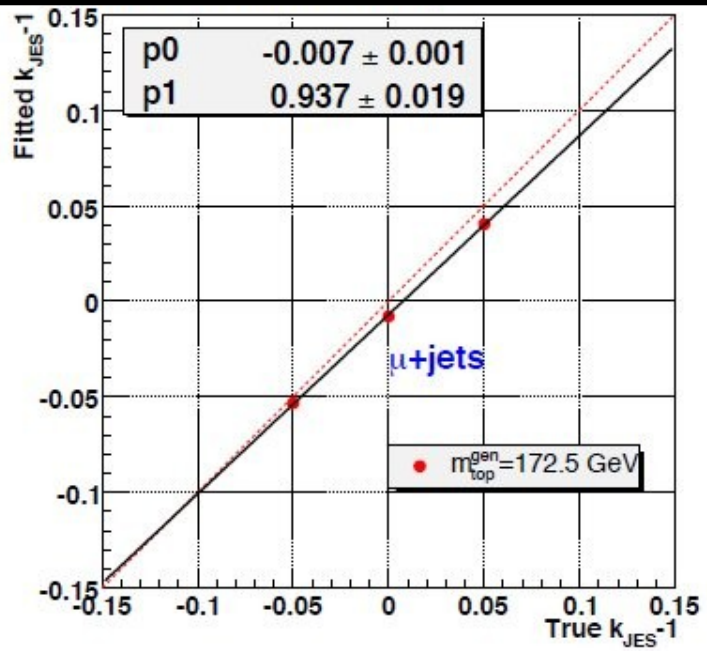

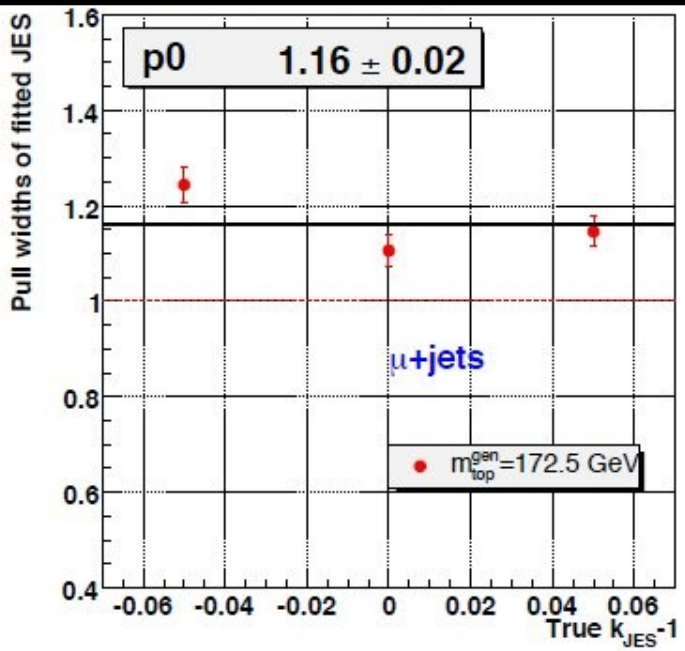

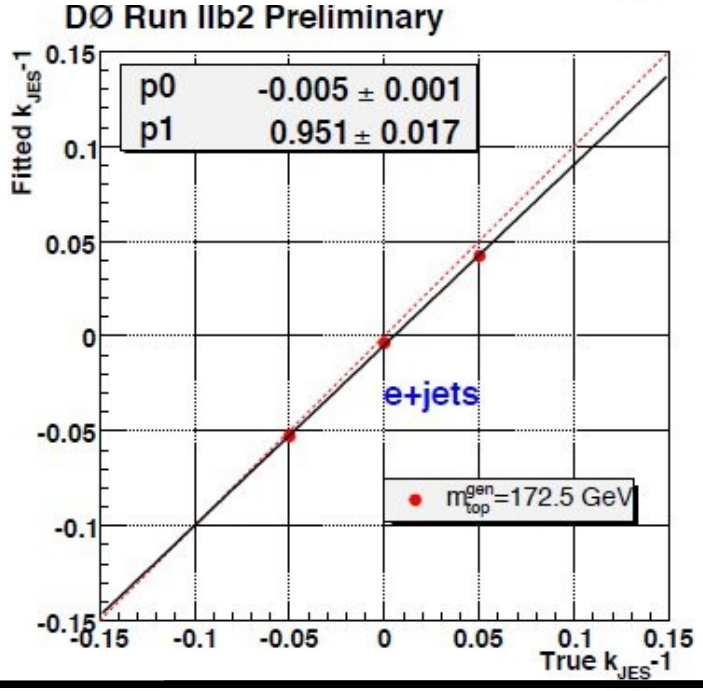

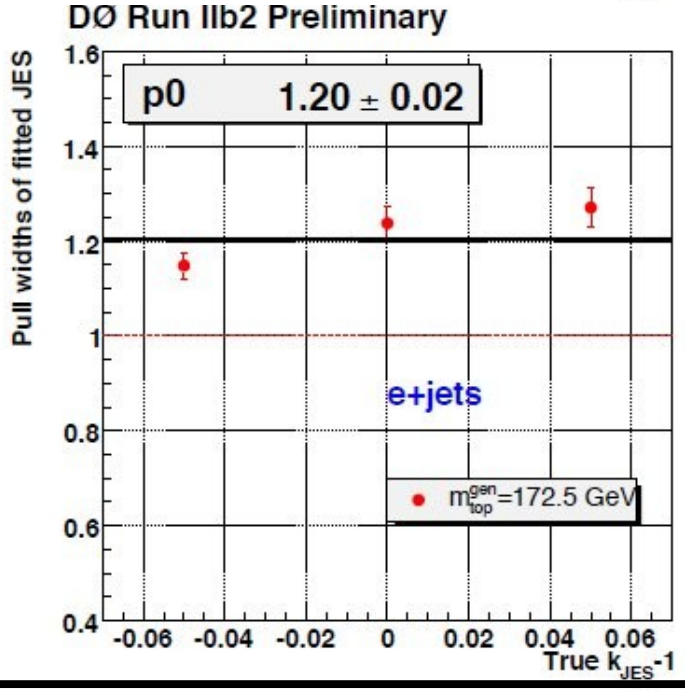

Measurement strategy

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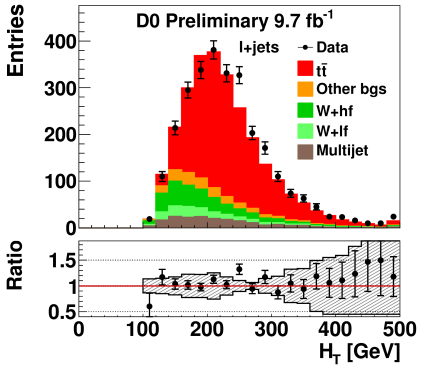

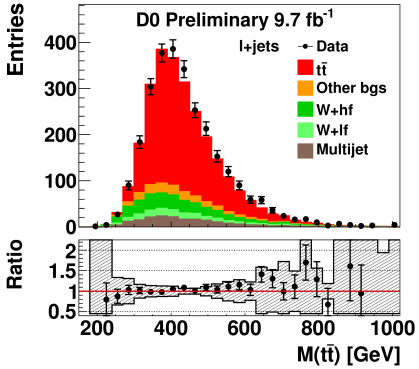

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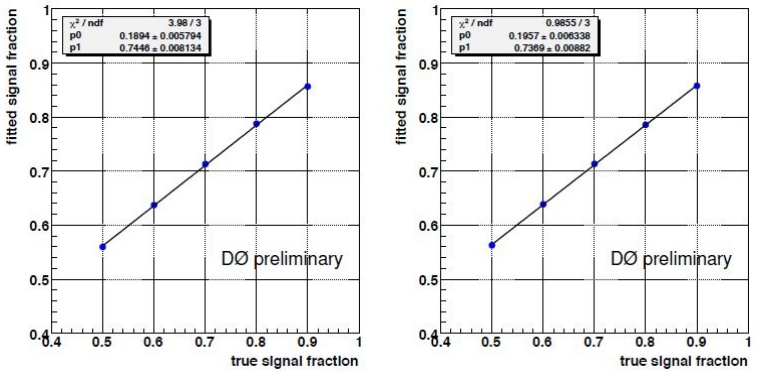
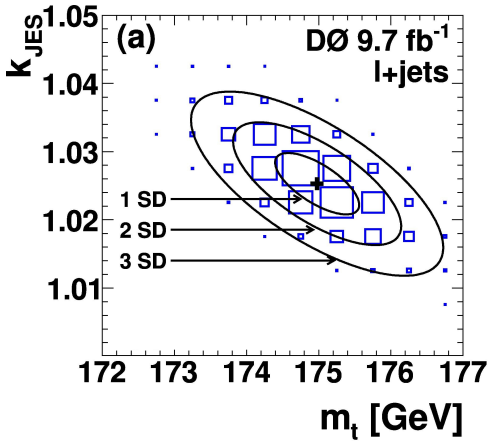
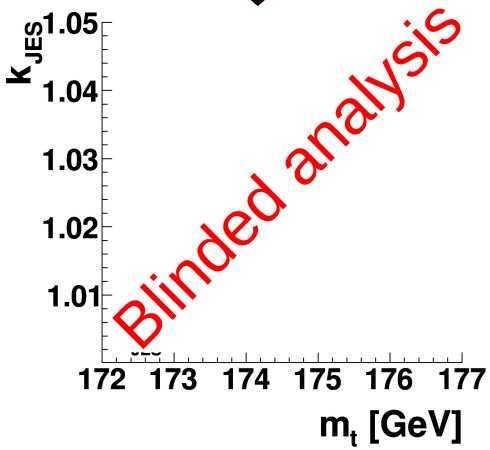


III. Check consistency, estimate systematic uncertainties (!)

IV. Unblinding & Final results





Systematic Uncertainties

- Construct PEs identically to default calibration, including W+jets and multi-jet background (not in 3.6/fb)

- Signal model uncertainties are dominant
  - Alternative models processed through ME method and compared to reference

- All others re-derive calibration

  - As a reminder stat. unc. of systematic uncertainties:
    - ~ 0.25 GeV previously
      → assign stat. unc. if systematic uncertainty smaller

e.g.

Source	Uncertainty (GeV)
Modeling of production:	
Modeling of signal:	
Higher-order effects	±0.25
ISR/FSR	±0.26
Hadronization and UE	±0.58
Color reconnection	±0.28
Multiple $p\bar{p}$ interactions	±0.07
Modeling of background	±0.16
W+jets heavy-flavor scale factor	±0.07
Modeling of b jets	±0.09
Choice of PDF	±0.24
Modeling of detector:	
Residual jet energy scale	±0.21
Data-MC jet response difference	±0.28
b-tagging efficiency	±0.08
Trigger efficiency	±0.01
Lepton momentum scale	±0.17
Jet energy resolution	±0.32
Jet ID efficiency	±0.26
Method:	
Multijet contamination	±0.14
Signal fraction	±0.10
MC calibration	±0.20
Total	±1.02

Phys. Rev. D 84, 032004 (2011)

Systematic Uncertainties

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- Signal model uncertainties are dominant
  - Alternative models processed through ME method and compared to reference

- All others re-derive calibration

  - As a reminder stat. unc. of systematic uncertainties:
    - ~ 0.25 GeV previously
    - **~ 0.05 GeV** for 1st case
    - **~ 0.01 GeV** for 2nd case

e.g.

Source	Uncertainty (GeV)
Modeling of production:	
Modeling of signal:	
Higher-order effects	±0.25
ISR/FSR	±0.26
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Total	±1.02

Phys. Rev. D 84, 032004 (2011)

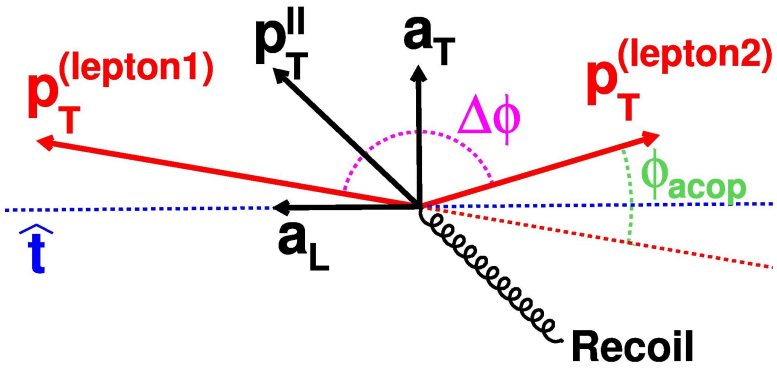
Systematic Uncertainties

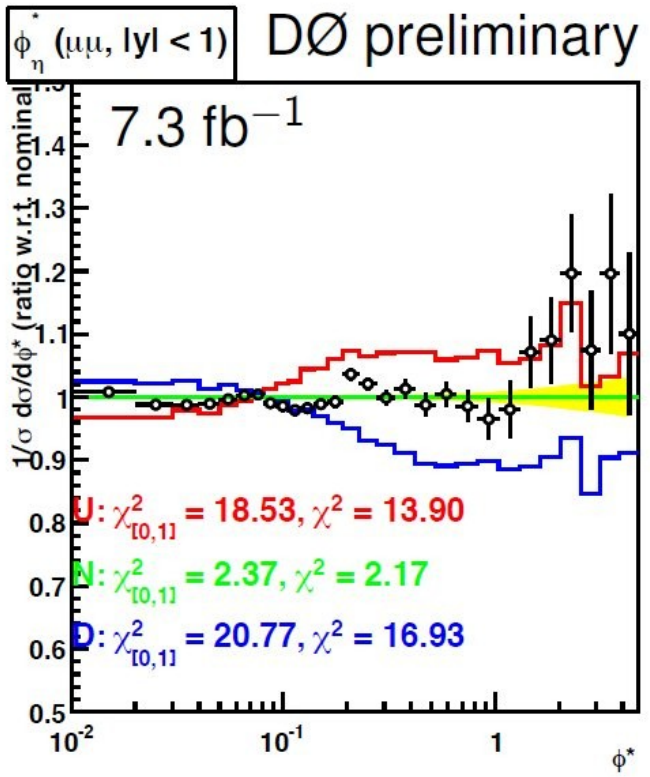
- Complete list for 9.7/fb, see right
- Will discuss a bit more about the ← ones
- Couple of systematic uncertainties benefit from new calibrations and improved methods →

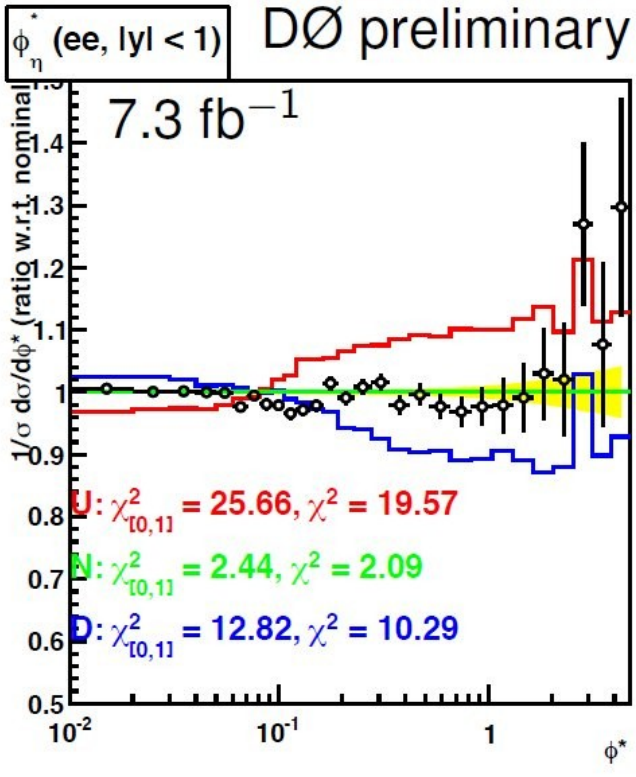
Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	+0.15
Initial/final state radiation	±0.09 ←
Hadronization and UE	+0.26 ←
Color reconnection	+0.10
Multiple $p\bar{p}$ interactions	−0.06
Heavy flavor scale factor	±0.06
b-jet modeling	+0.09
PDF uncertainty	±0.11
Detector modeling:	
Residual jet energy scale	±0.21
→ Flavor-dependent response to jets	±0.16 ←
→ b tagging	±0.10
Trigger	±0.01
→ Lepton momentum scale	±0.01
→ Jet energy resolution	±0.07
→ Jet ID efficiency	−0.01
Method:	
Modeling of multijet events	+0.04
Signal fraction	±0.08
MC calibration	±0.07

Initial/Final state radiation

- Vary renormalization scale in Alpgen
  - Constrain variation by employing D0 φ^* measurement, ($|y| < 1$; $1 < |y| < 2$; $|y| < 2$)
  - Variation by factor 1.5 covers spread of differences between data and MC







- Measurement only depends on directions of two leptons
  → measured precisely

Phys. Rev. Lett. 106, 122001 (2011)

Initial/Final state radiation

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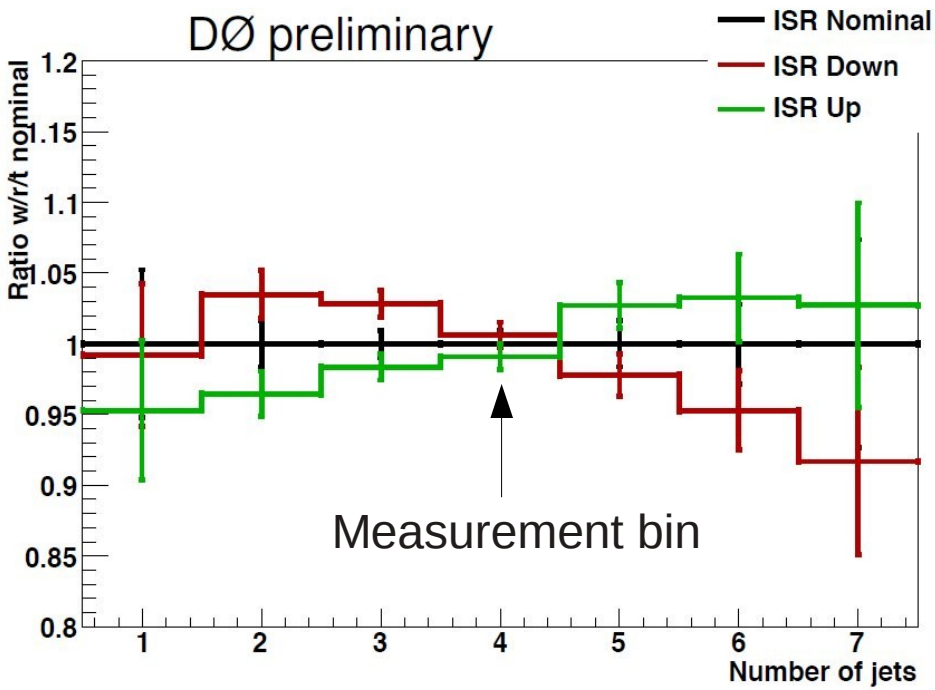
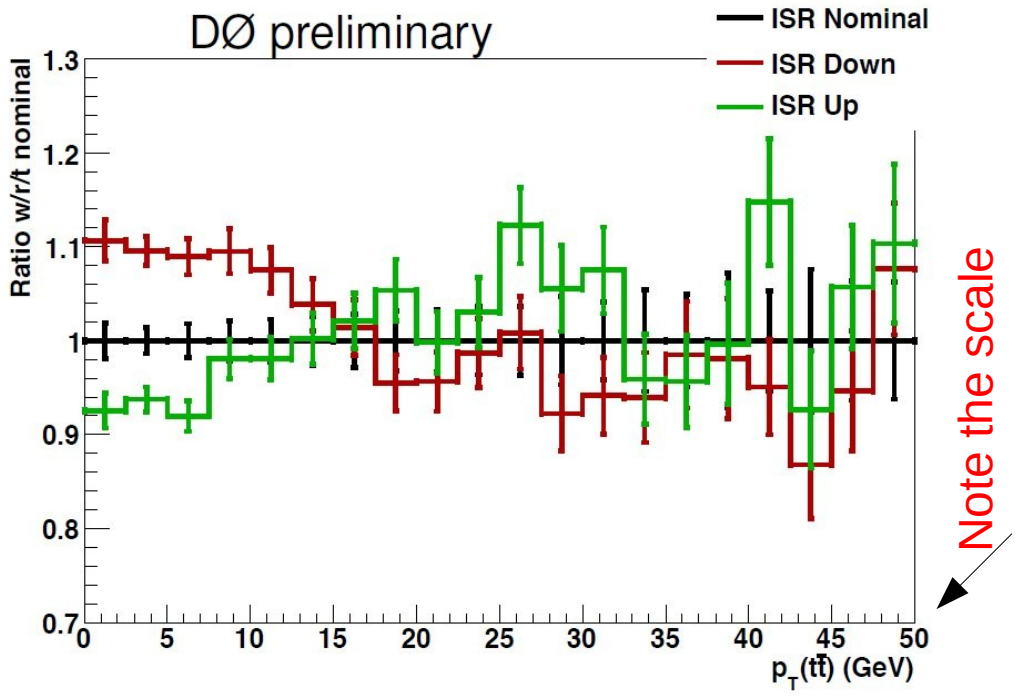
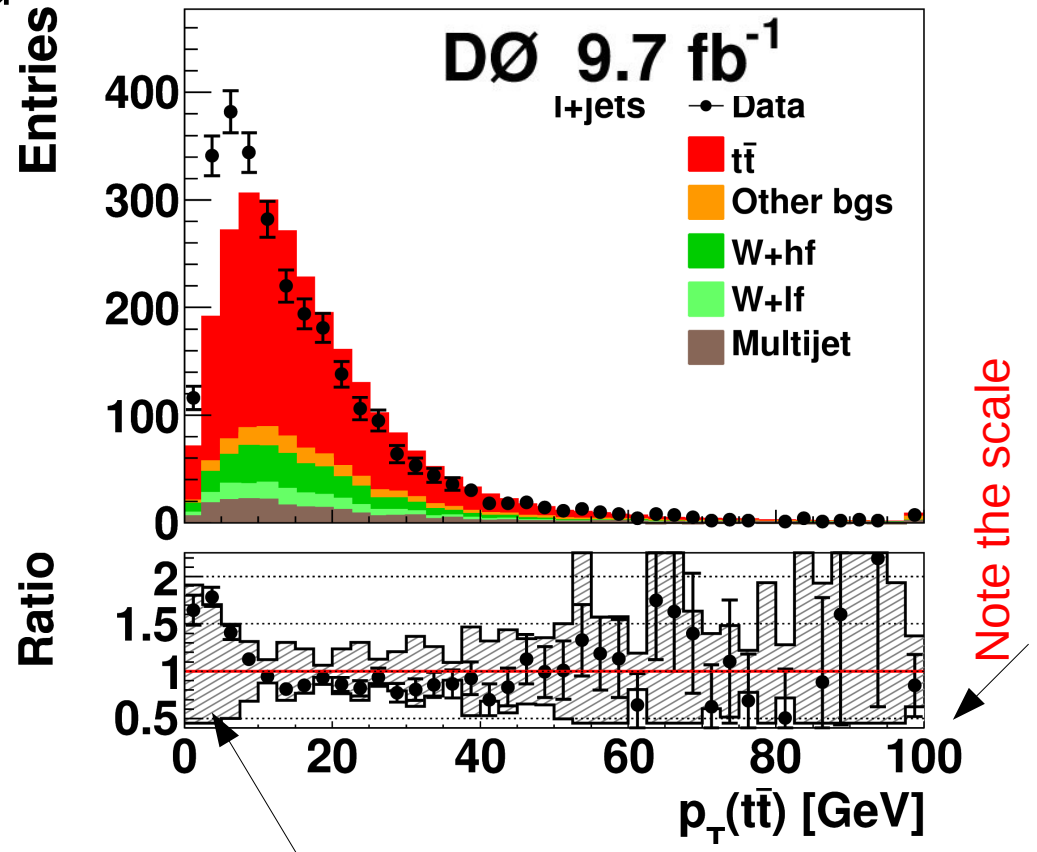




- Results in an uncertainty of: 0.06 GeV

Initial/Final state radiation

- The $p_T(t\bar{t})$ distribution is not modeled by MC:
  - Known issue...$p_T(t\bar{t})$ is closely tied to Initial/Final state radiation (see previous slide)
  - Assign a systematic uncertainty based on data-MC difference in $p_T(t\bar{t})$ → 0.07 GeV



- Add in quadrature the effects from scale variations constrained by φ^* measurement and $p_T(t\bar{t})$ reweighting:

→ Initial/Final state radiation uncertainty:
0.09 GeV (previously 0.26 GeV)

Hadronization/UE

- Compare **Alpgen+Pythia versus Alpgen+Herwig**, drawbacks:
  - D0 JES not applicable to Herwig, by "default" results in difference
  - A residual JES uncertainty in p_T, η is already applied

    → double-counting

- <u>To avoid double-counting refined strategy:</u>
  - Factorize effects in this comparison by using particle level jets

    → no effects from JES
  - Match particle level with detector level jets: $\Delta R \leq 0.25$
  - $p_T(t\bar{t})$ differs in Alpgen+Pythia versus Alpgen+Herwig, a larger effect already included via ISR/FSR

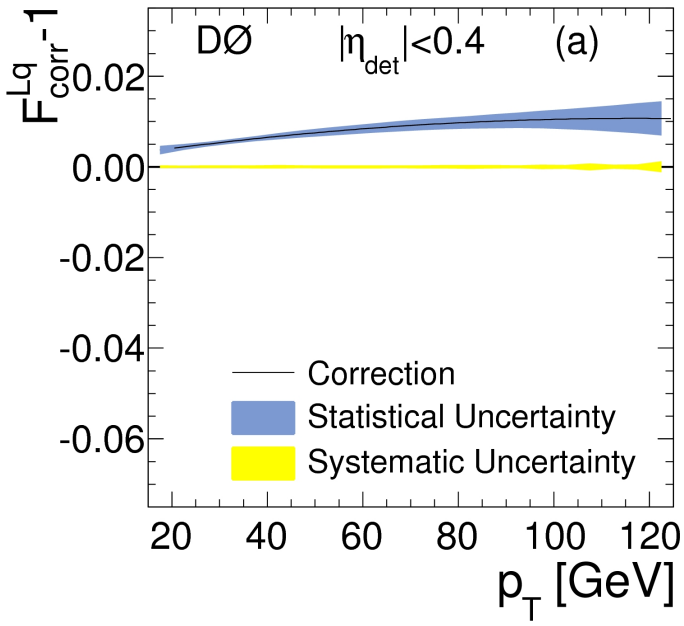
    → reweight $p_T(t\bar{t})$ in Herwig to default (Pythia)

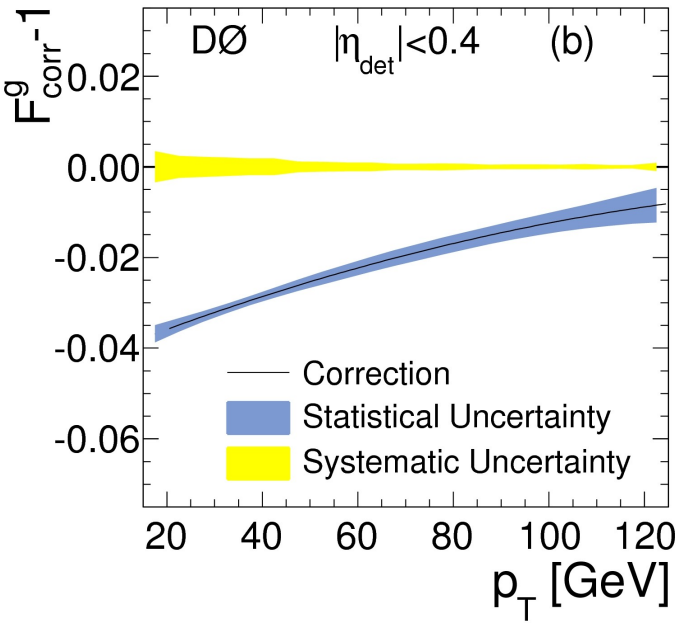
→ <u>Hadronization/UE uncertainty:</u>

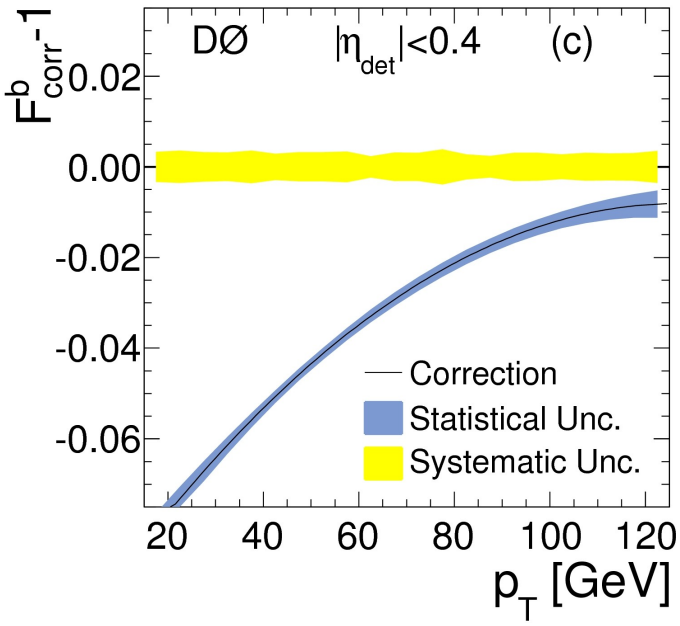
0.26 GeV (previously 0.58 GeV)

Single Particle Response

- Improves MC description of jets and reduces sample-dependency
- Resulting F_{corr} for different jet flavors and their uncertainties







- Small correction to light quarks (*u,d,s,c*), several % for *g* and *b* quarks

→ Flavor dependent response on jets:
0.16 GeV (previously 0.28 GeV)

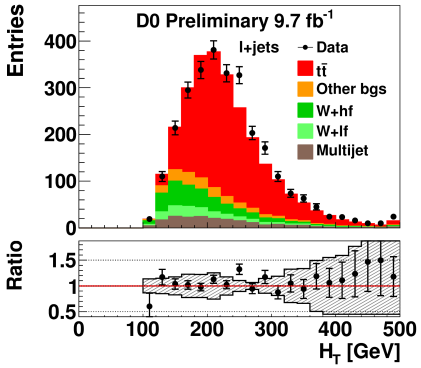
Systematic Uncertainties

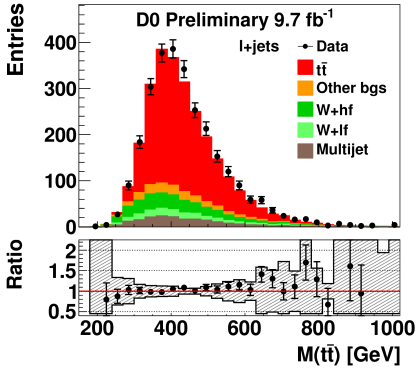
Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	$+0.15$
Initial/final state radiation	± 0.09
Hadronization and UE	$+0.26$
Color reconnection	$+0.10$
Multiple $p\bar{p}$ interactions	-0.06
Heavy flavor scale factor	± 0.06
b-jet modeling	$+0.09$
PDF uncertainty	± 0.11
Detector modeling:	
Residual jet energy scale	± 0.21
Flavor-dependent response to jets	± 0.16
b tagging	± 0.10
Trigger	± 0.01
Lepton momentum scale	± 0.01
Jet energy resolution	± 0.07
Jet ID efficiency	-0.01
Method:	
Modeling of multijet events	$+0.04$
Signal fraction	± 0.08
MC calibration	± 0.07
Total systematic uncertainty	± 0.49

→ Total systematic uncertainty: **± 0.49 GeV**

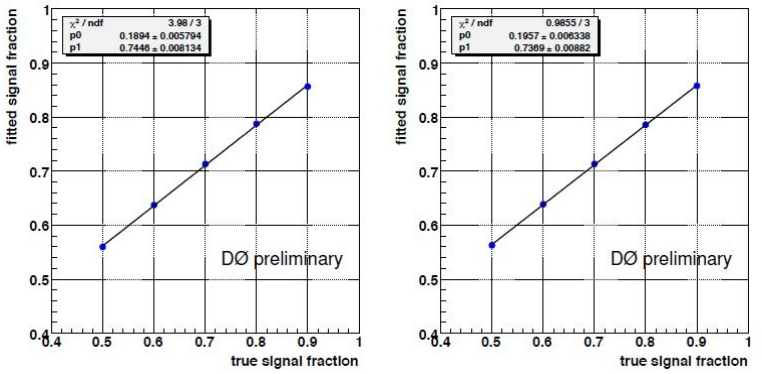
Measurement strategy

I. Event selection & Sample Composition

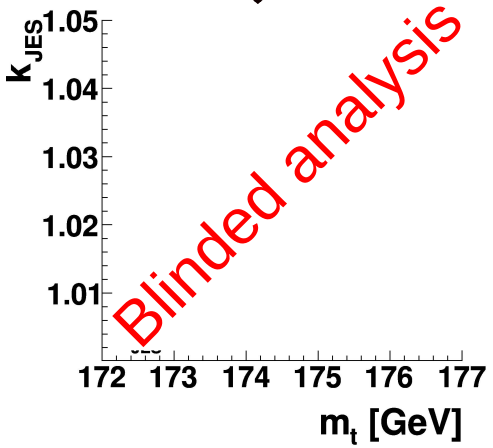




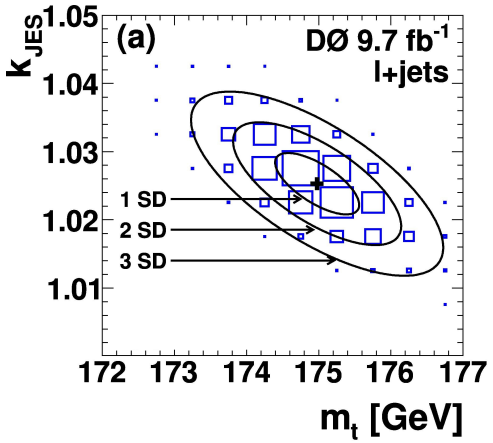
II. Matrix element method & calibration of the method



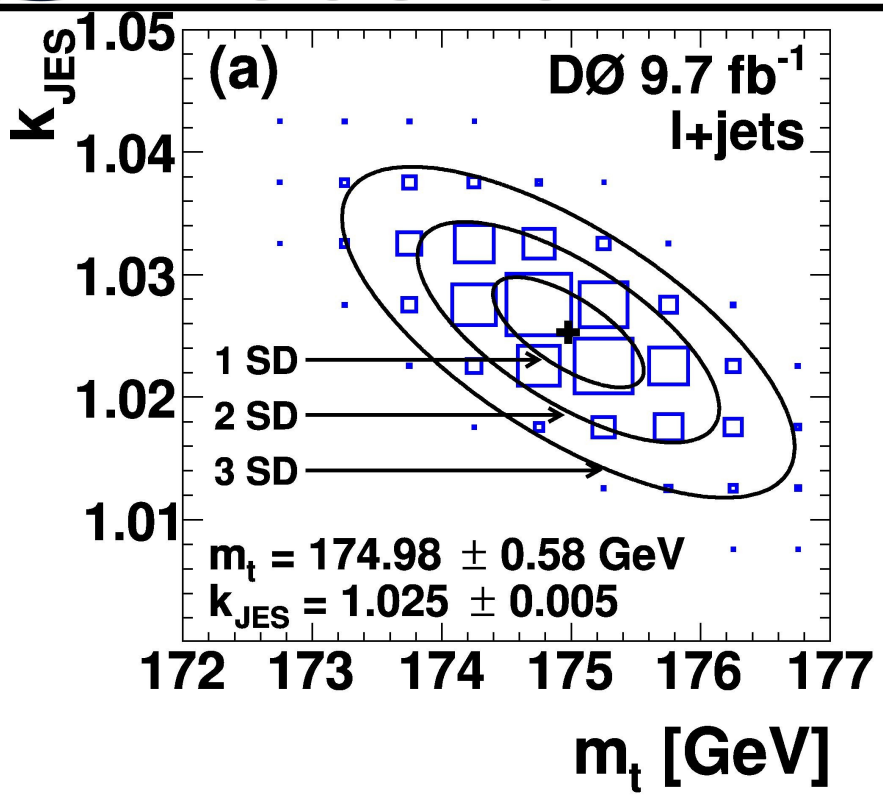
III. Check consistency, estimate systematic uncertainties (!)

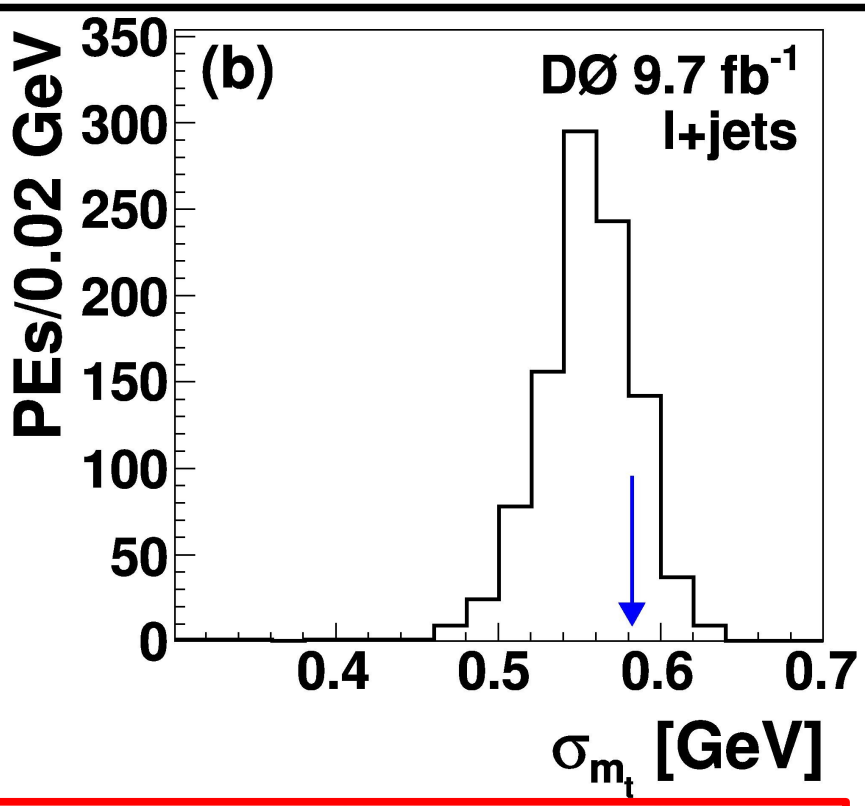


IV. Unblinding & Final results



Results

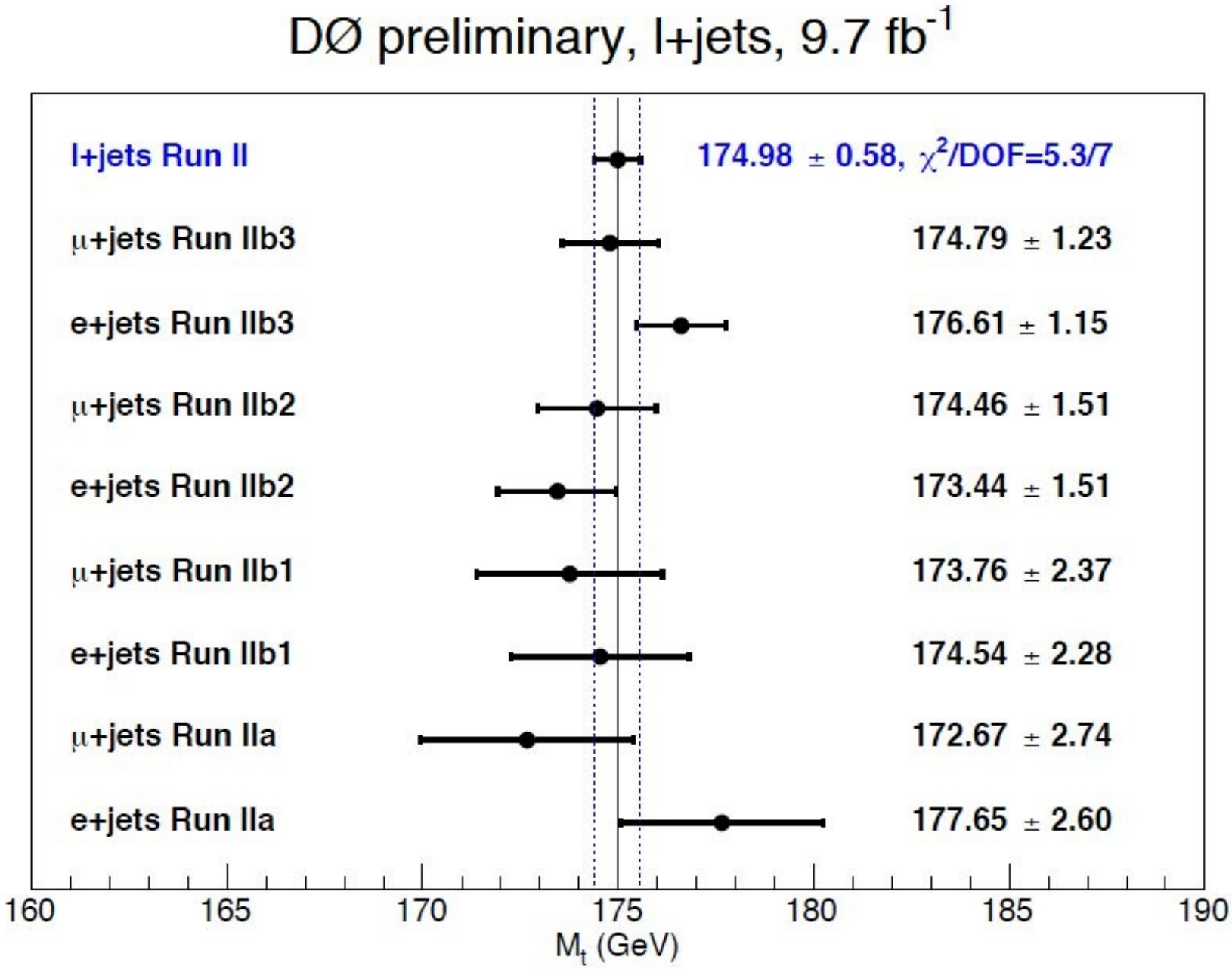




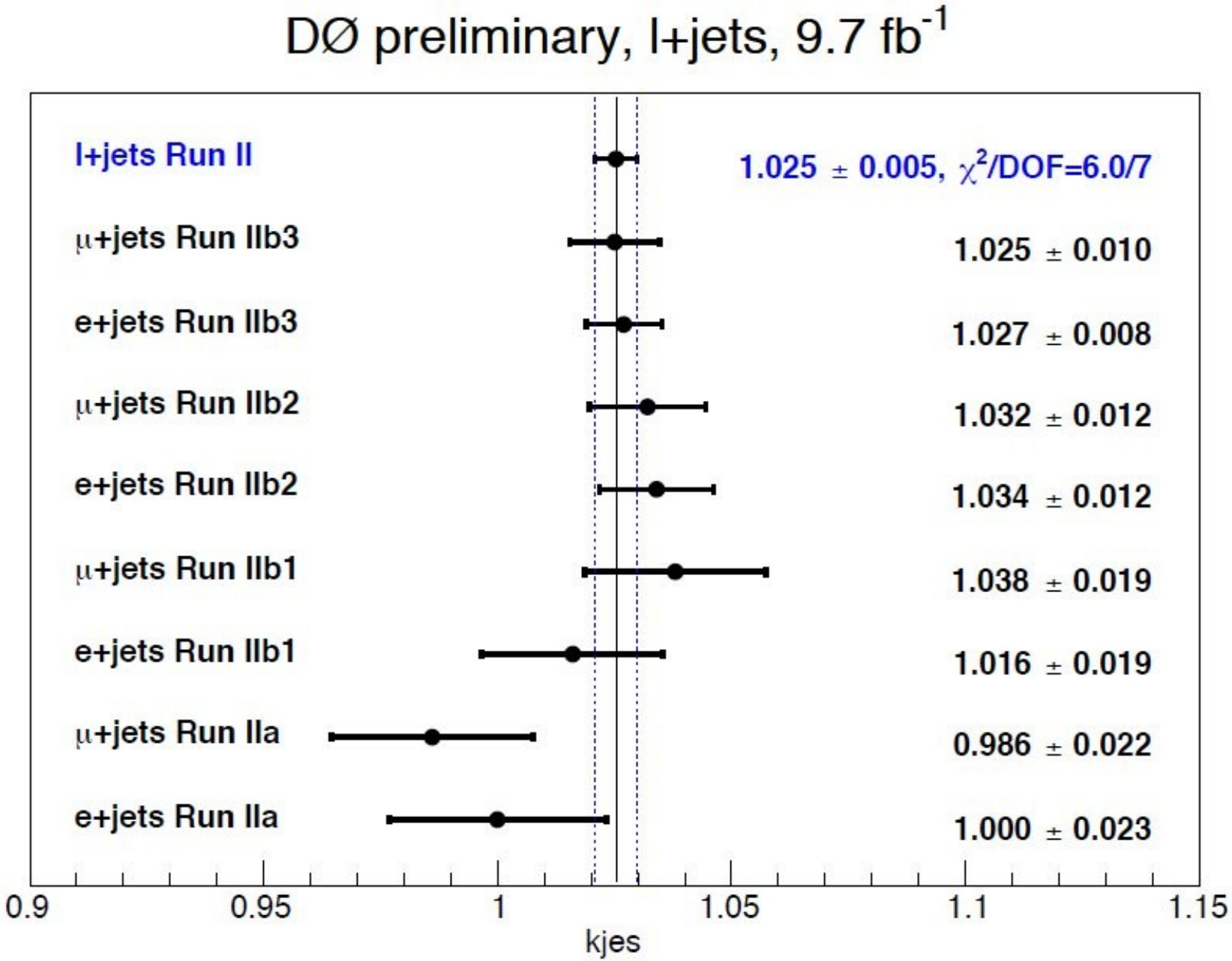
→

ℓ + jets, final	:	m_t	=	174.98 ± 0.58 (stat+JES) GeV
		k_{JES}	=	1.025 ± 0.005 (stat)
e + jets, final	:	m_t	=	175.55 ± 0.81 (stat+JES) GeV
		k_{JES}	=	1.026 ± 0.006 (stat)
μ + jets, final	:	m_t	=	174.36 ± 0.84 (stat+JES) GeV
		k_{JES}	=	1.025 ± 0.007 (stat)

Results per channel

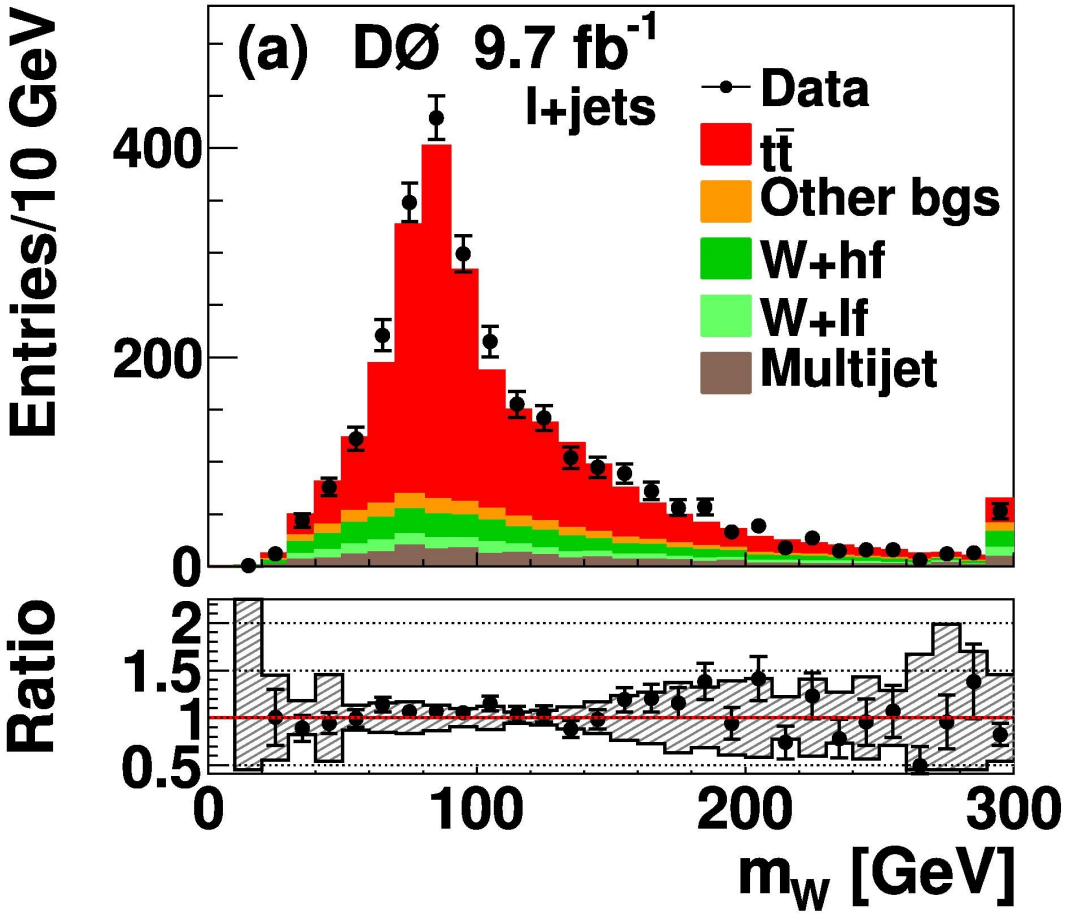


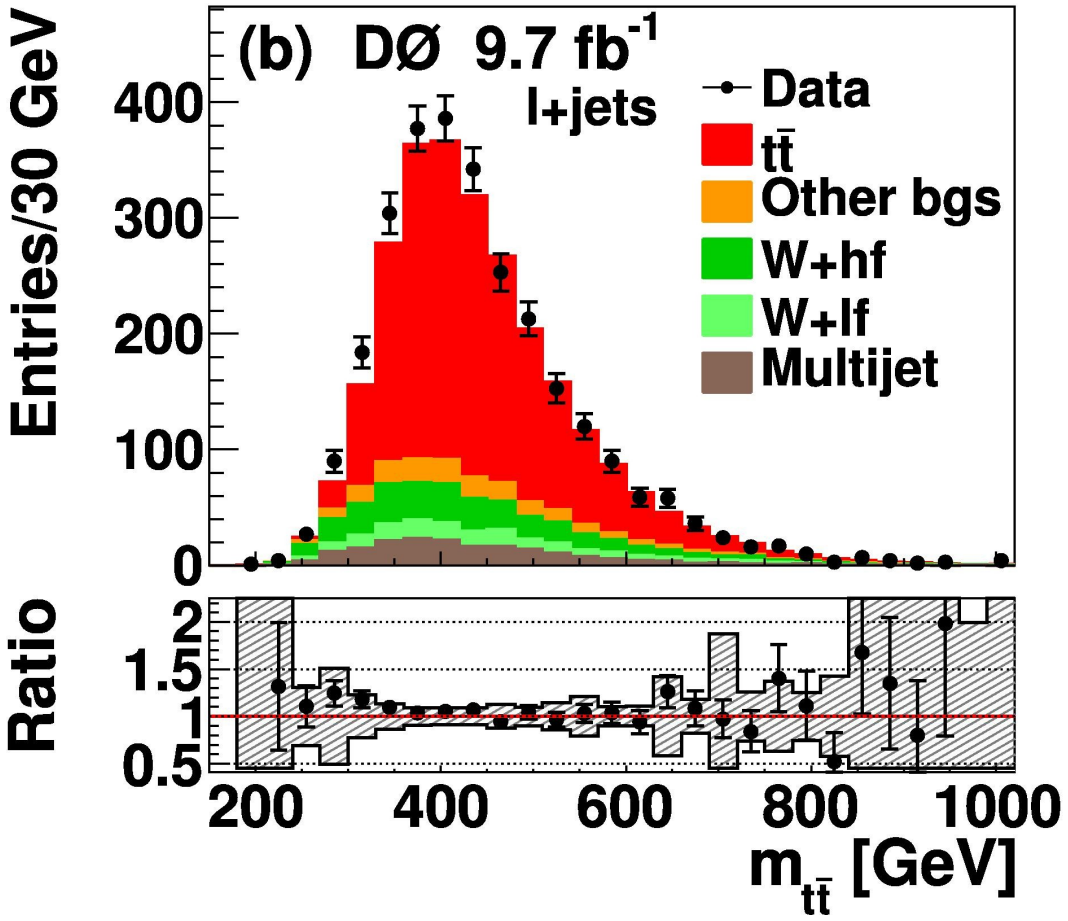
Results per channel



Control distributions

- Apply ME results to control distributions in m_W and $m_{t\bar{t}}$
  - MC (Alpgen+Pythia) with m_t=175 GeV and k_{JES} = 0.025
  - $\sigma_{t\bar{t}}$ as measured by ME method





- Nicely modeled by MC, improved description compared to pre-ME

Summary

- Measurement in **lepton+jets channel** ("golden channel") with **full Run II data** set, applying latest Jet energy scale corrections
  - **Accelerated matrix element method** allowing for integration of **large statistics sample**, "not" limited by MC sample size
  - Improved strategy for estimation of systematic uncertainties

- Result using 9.7/fb of D0 data:

Subm. to PRL [arxiv:1405:1756]

→ m_t = 174.98 ± 0.58 (stat. + JES) ± 0.49 (syst) GeV

m_t = 174.98 ± 0.76 (total) GeV

0.43% relative uncertainty

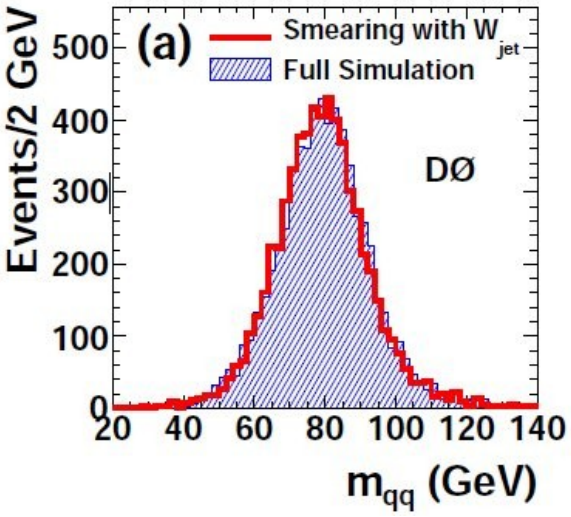
- WA: m_t = 173.34 ± 0.76 (total) GeV (→ 1.7 SD, D0 only stat. unc.)

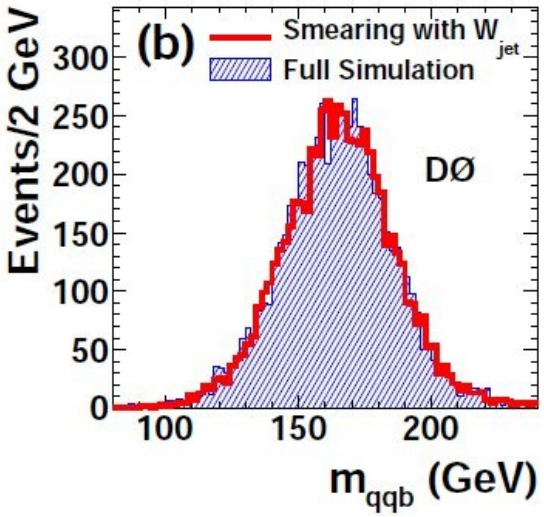
Outlook:

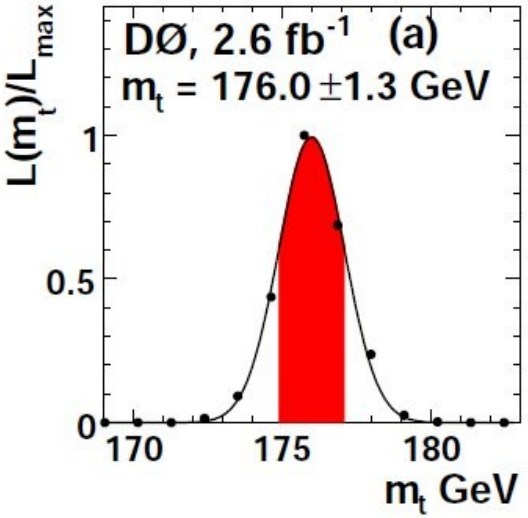
- **Expect more results in the near future** (all-jets and dilepton channel)

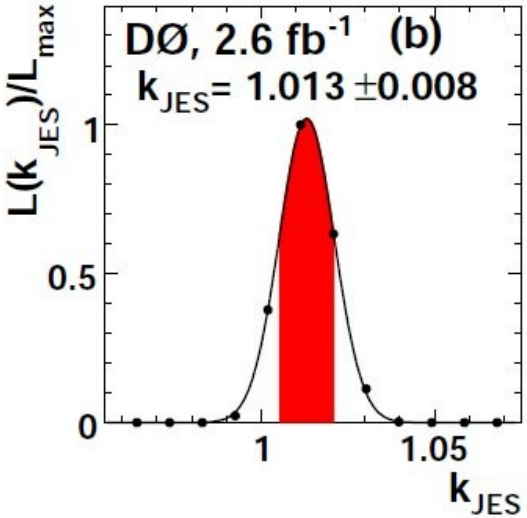
Backup

3.6/fb measurement









Source	Uncertainty (GeV)
Modeling of production:	
Modeling of signal:	
Higher-order effects	±0.25
ISR/FSR	±0.26
Hadronization and UE	±0.58
Color reconnection	±0.28
Multiple $p\bar{p}$ interactions	±0.07
Modeling of background	±0.16
W+jets heavy-flavor scale factor	±0.07
Modeling of b jets	±0.09
Choice of PDF	±0.24
Modeling of detector:	
Residual jet energy scale	±0.21
Data-MC jet response difference	±0.28
b-tagging efficiency	±0.08
Trigger efficiency	±0.01
Lepton momentum scale	±0.17
Jet energy resolution	±0.32
Jet ID efficiency	±0.26
Method:	
Multijet contamination	±0.14
Signal fraction	±0.10
MC calibration	±0.20
Total	±1.02

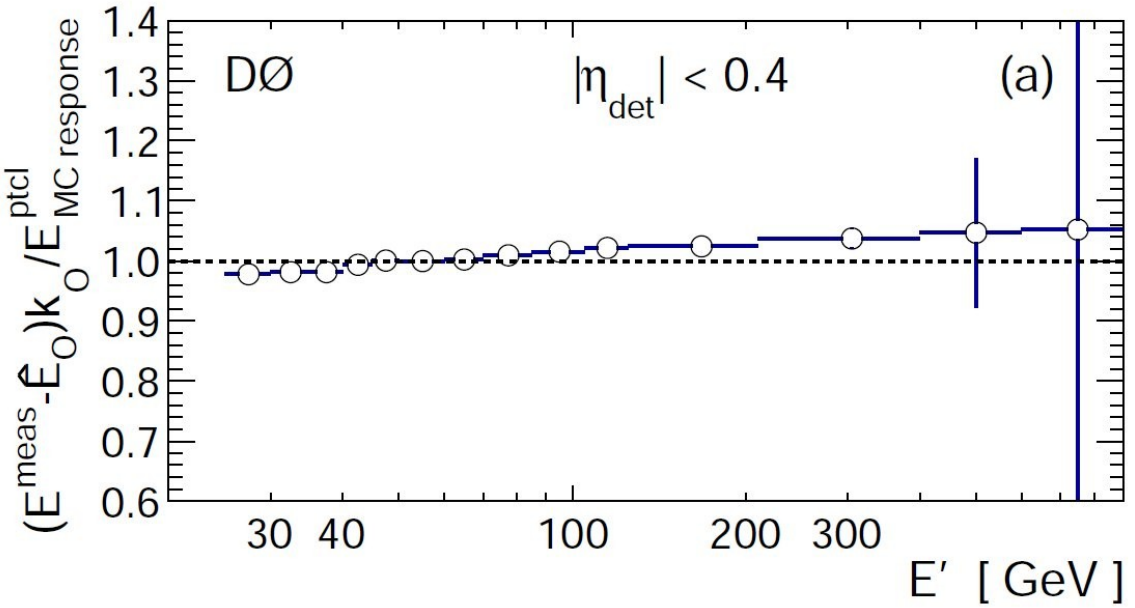
Single Particle Response

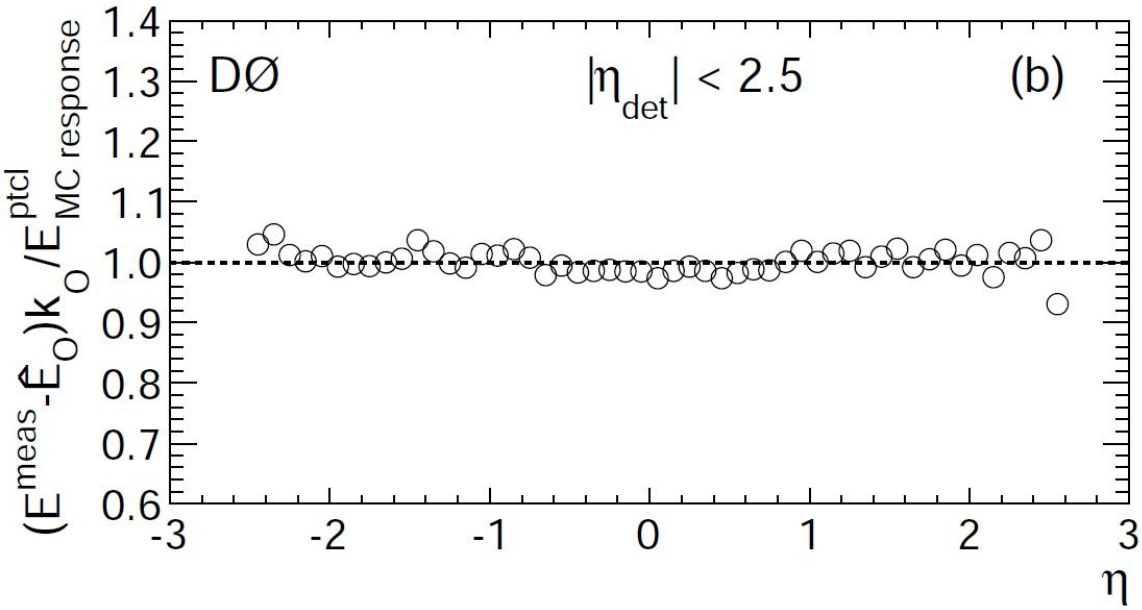
- Responses parametrized as a function of energy and pseudo-rapidities
- Construct ratio:

Offset contribution and bias corrected calorimeter energy

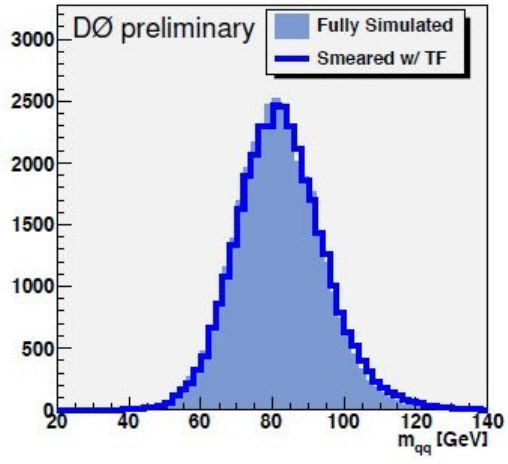
$$\frac{k_{\mathrm{O}}(E^{\mathrm{meas}} - \hat{E}_{\mathrm{O}})}{\sum_i E_i \cdot R_i^{\mathrm{MC}}}$$

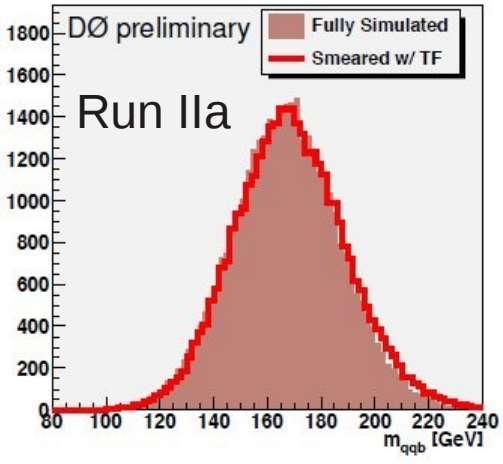
- Ratio is within 2% across E' or pseudo-rapidities
  → assigned as systematic uncertainty

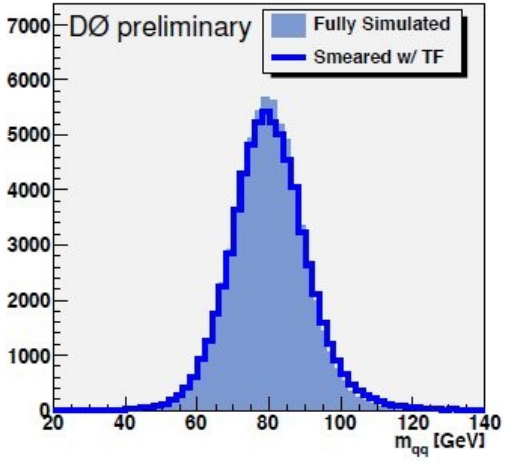


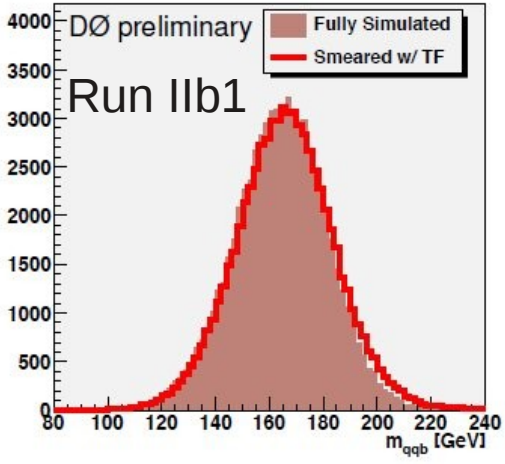


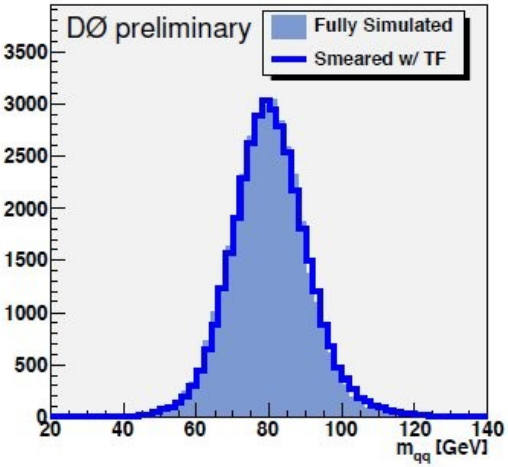
Transfer functions

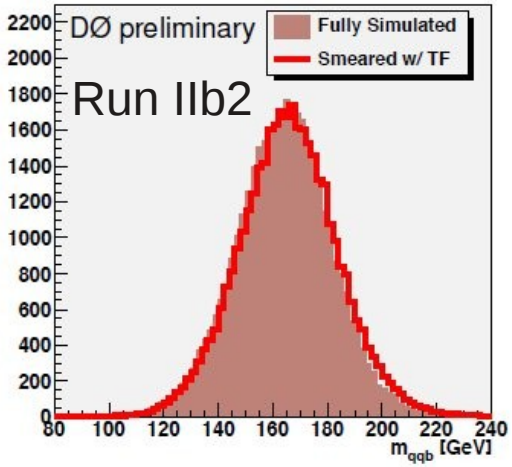


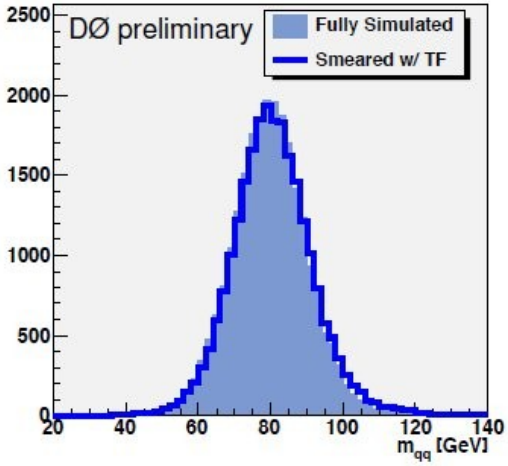


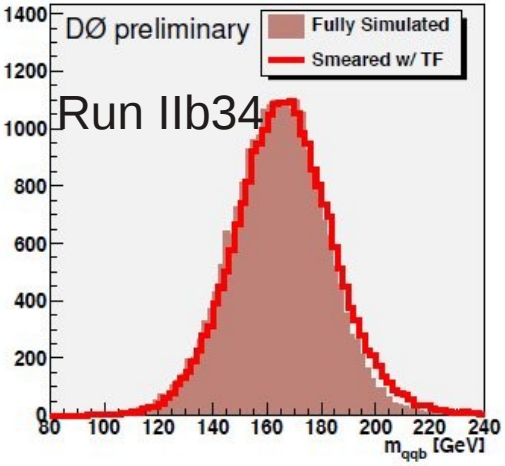




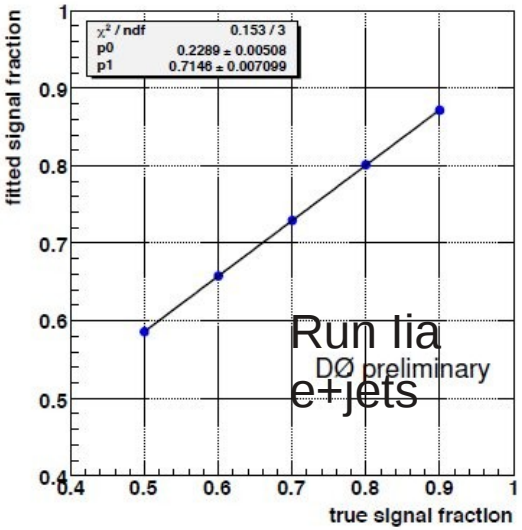


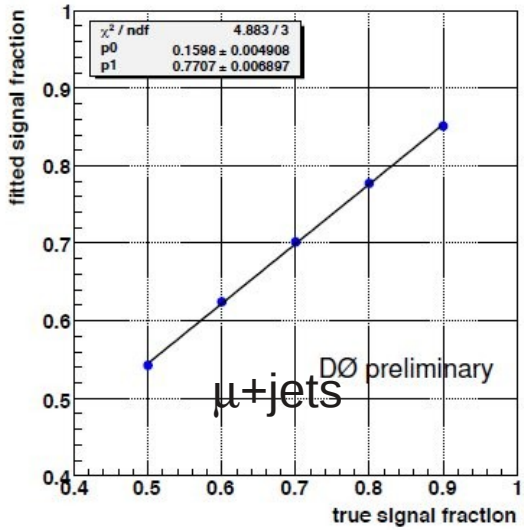


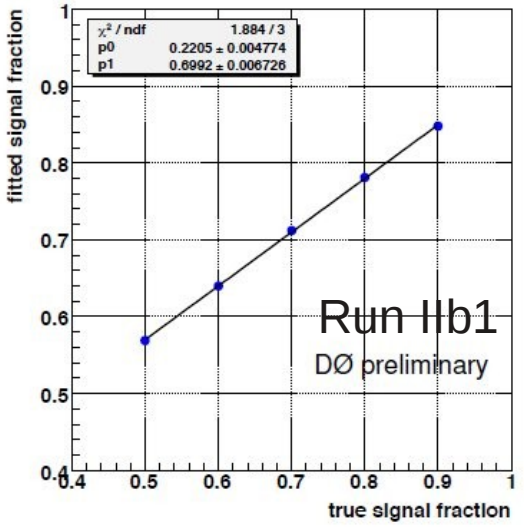


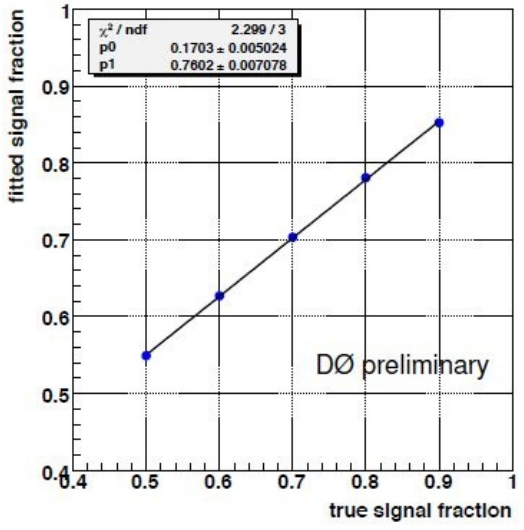


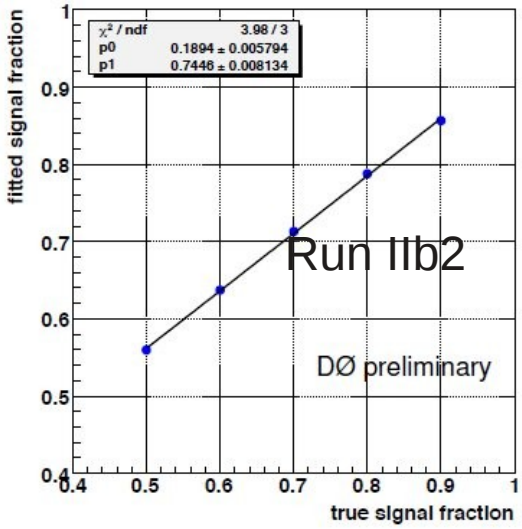
Calibration

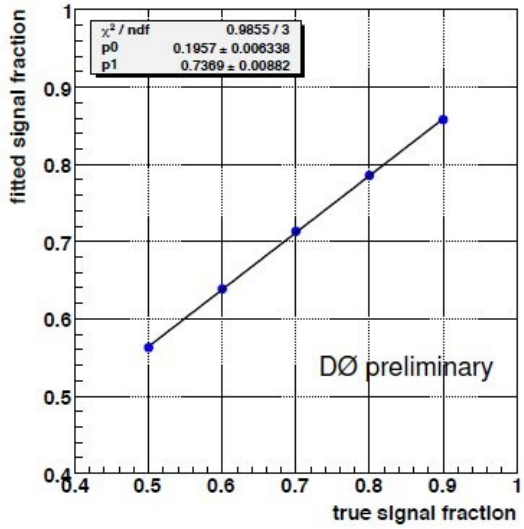


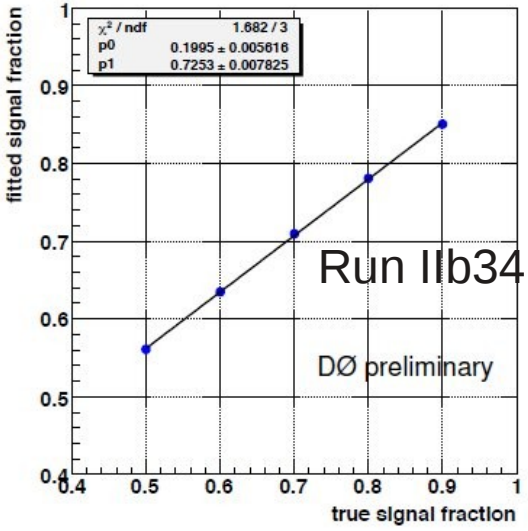


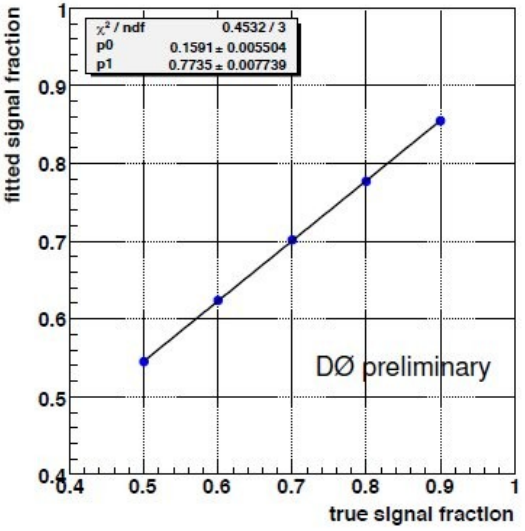












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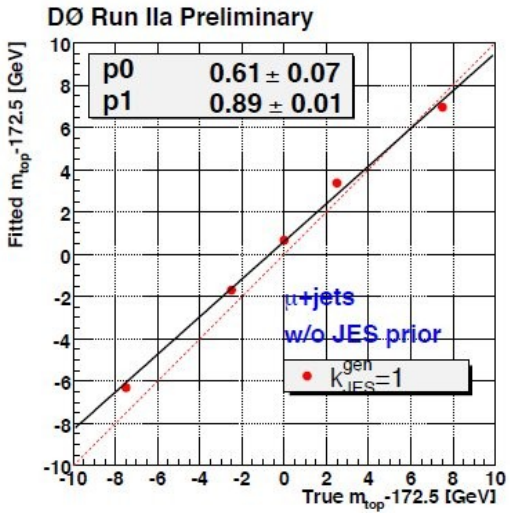
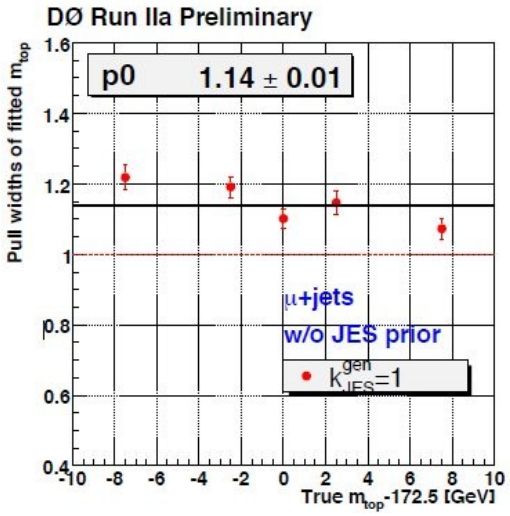
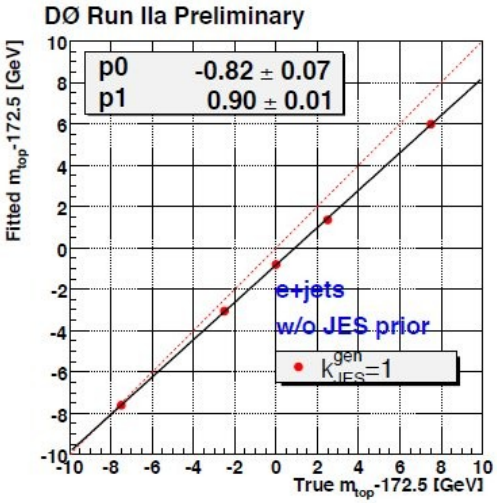
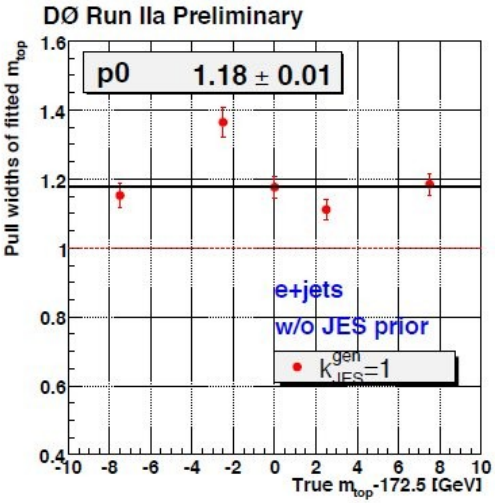
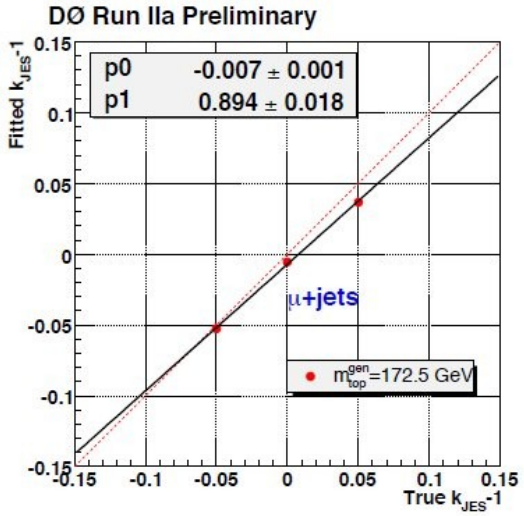
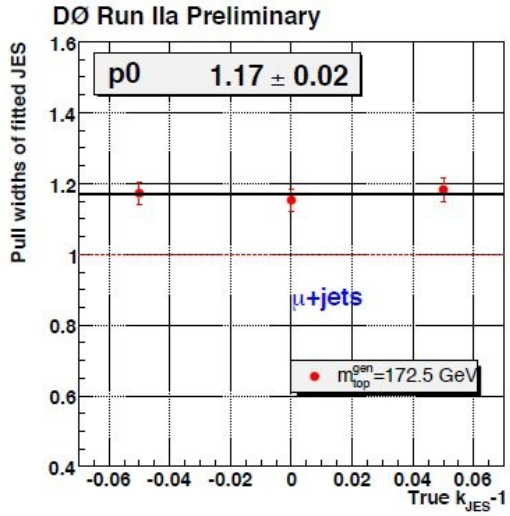


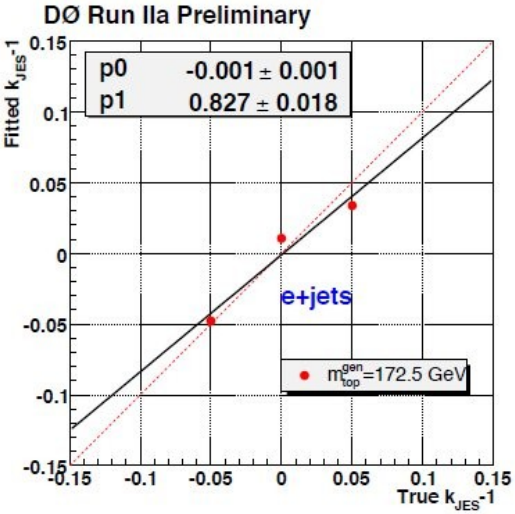


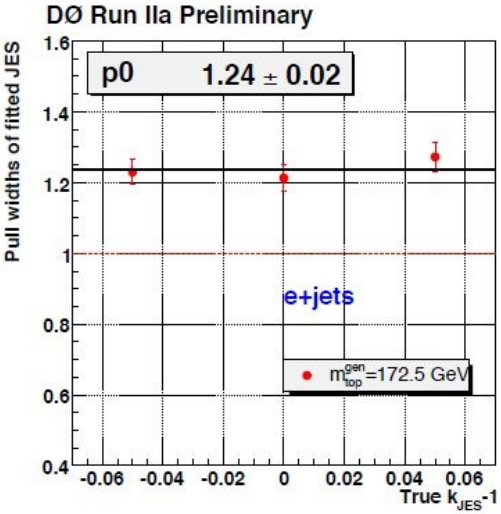




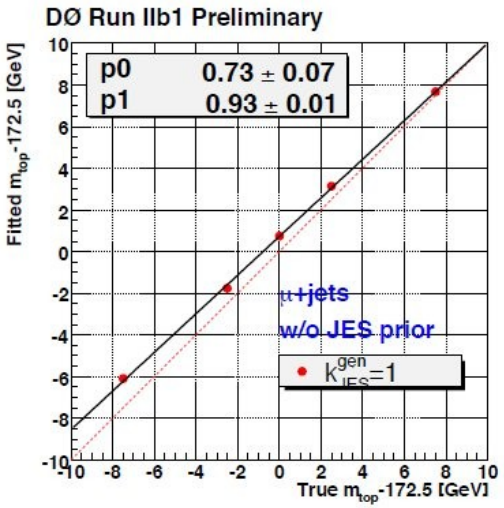


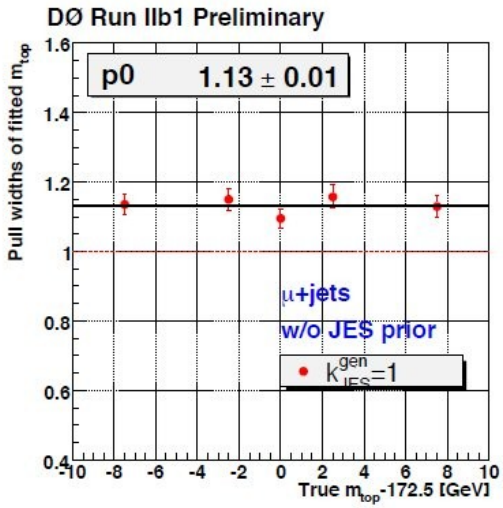


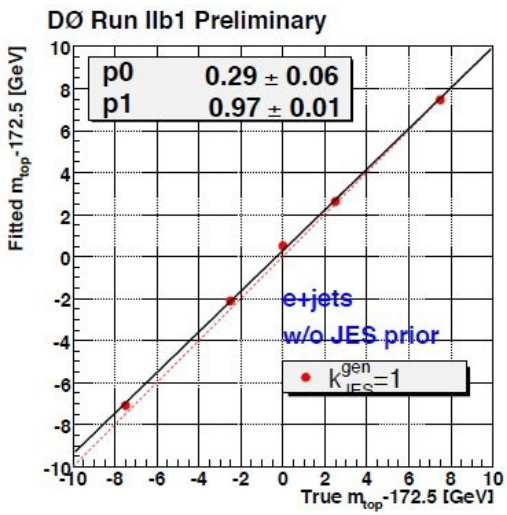


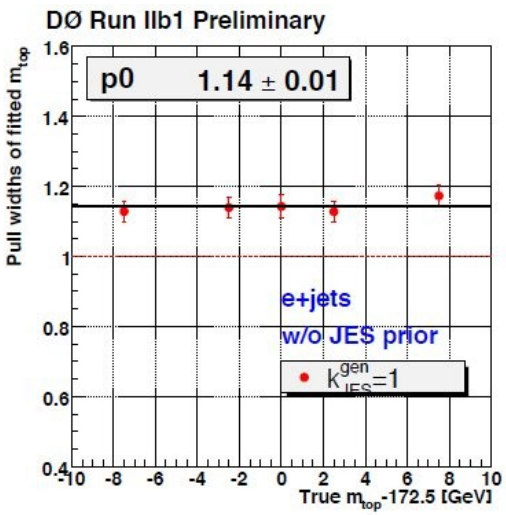


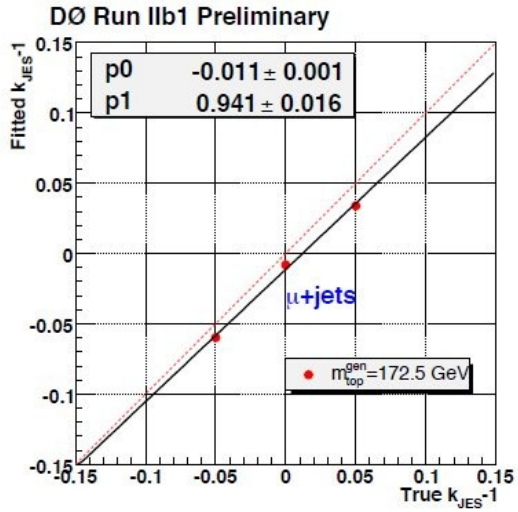
Calibration

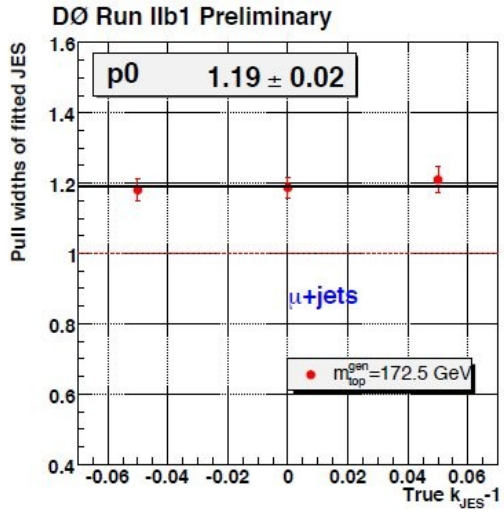


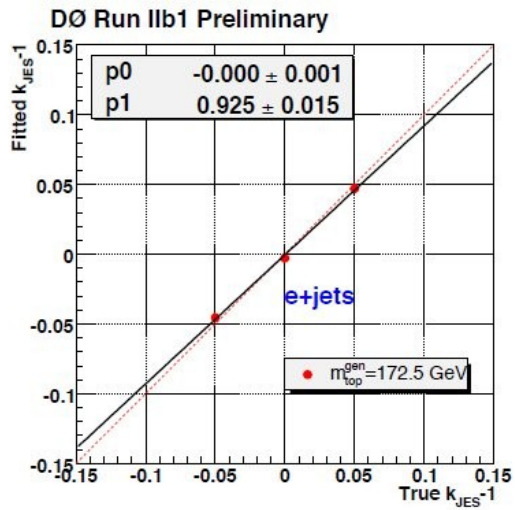


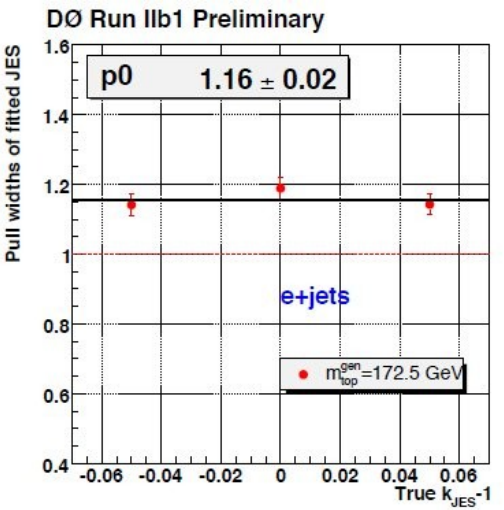




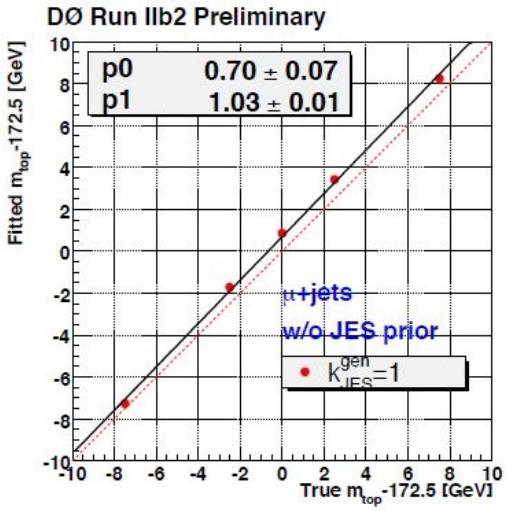


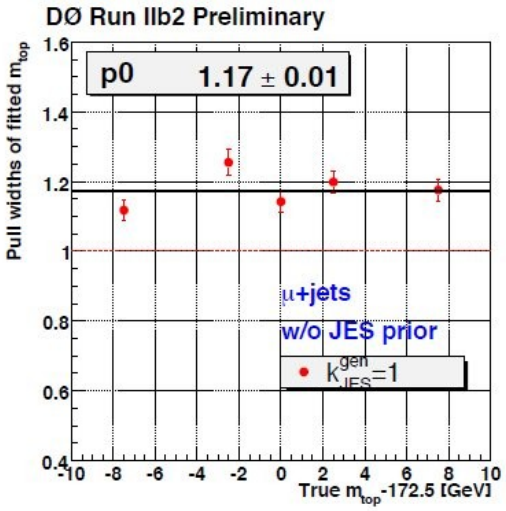


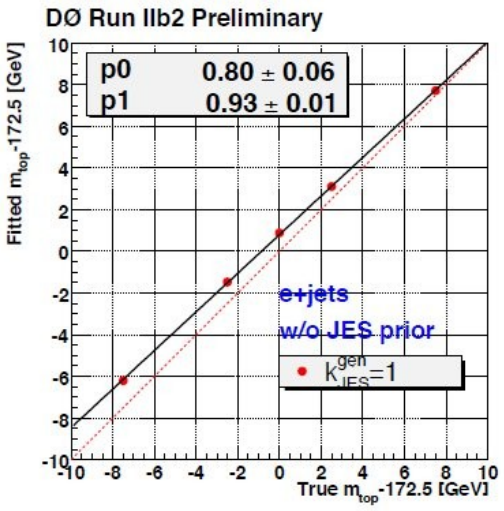


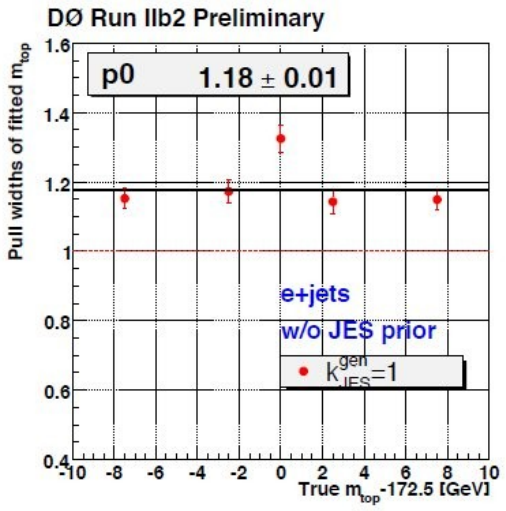


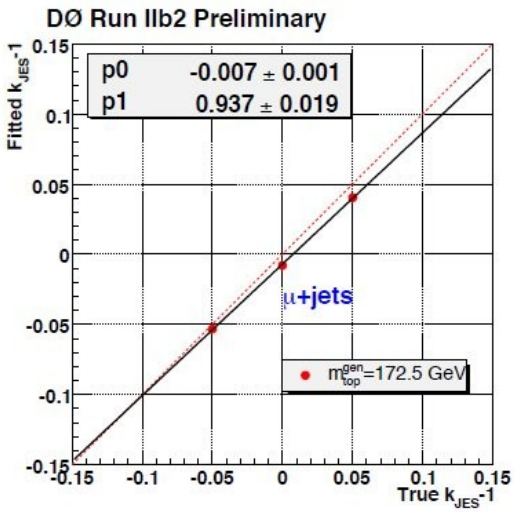
Calibration

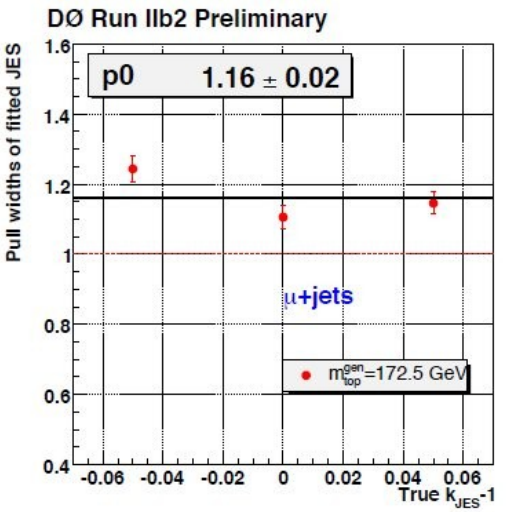


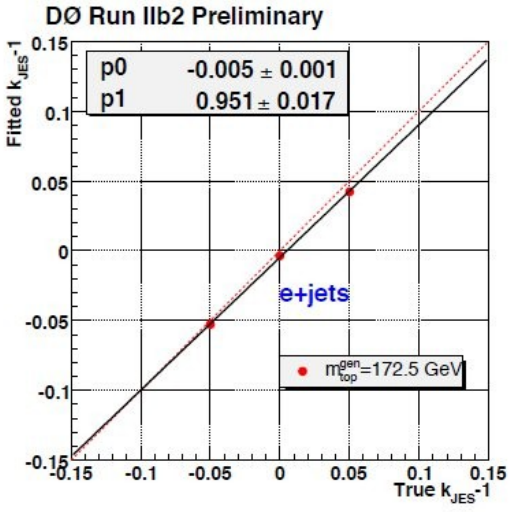


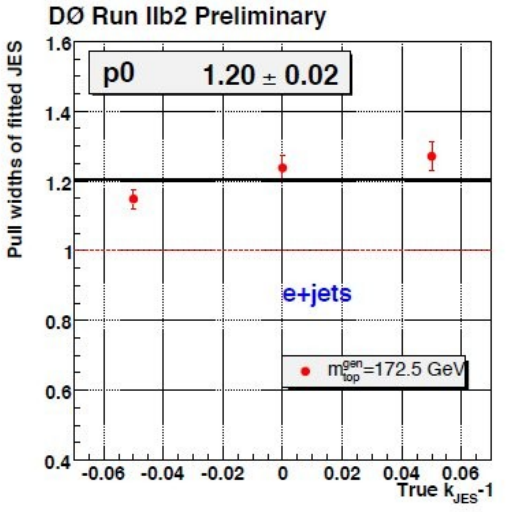




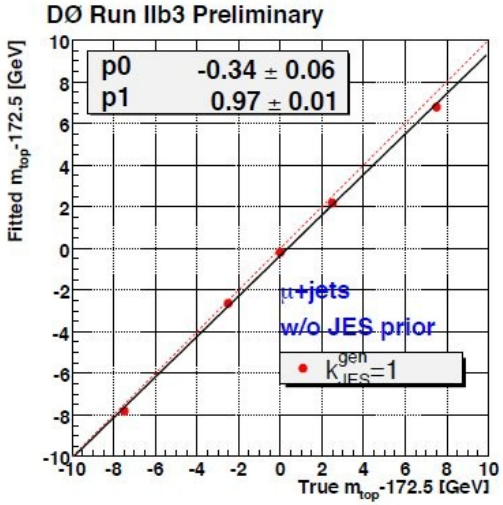


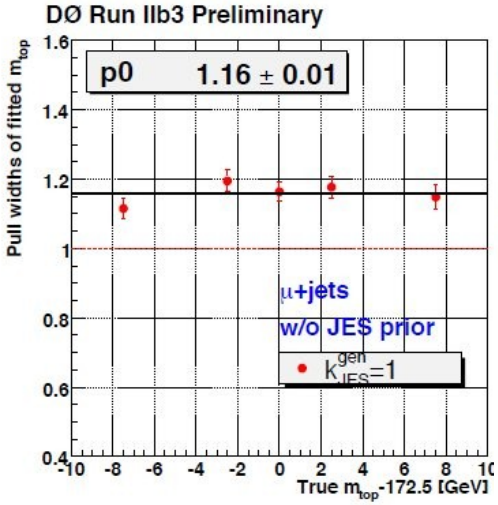


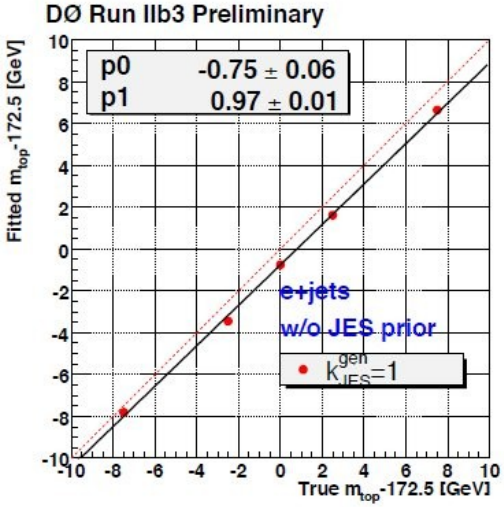


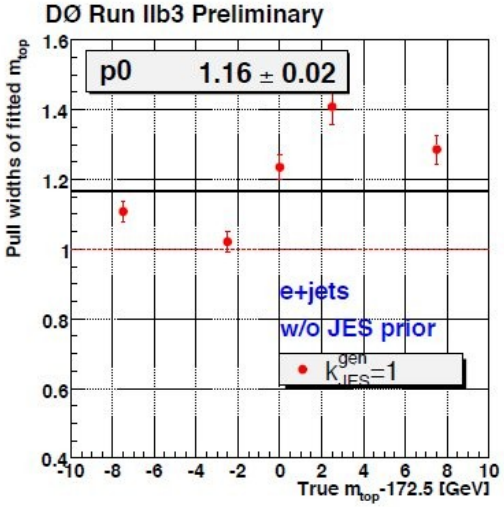


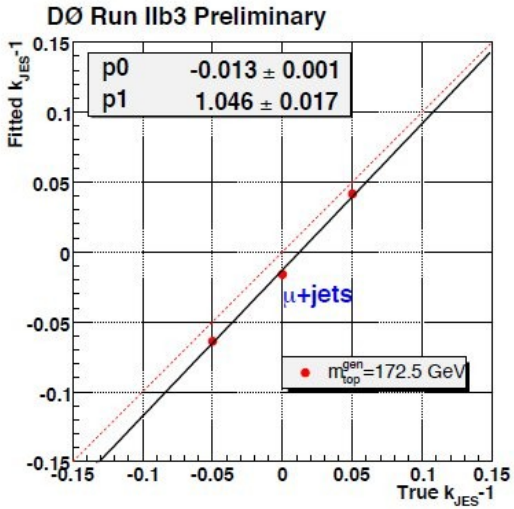
Calibration

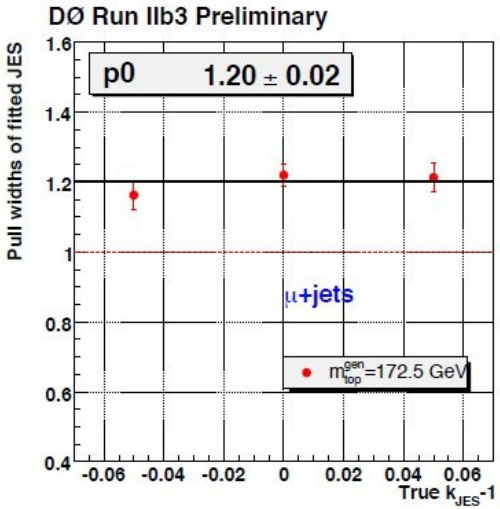


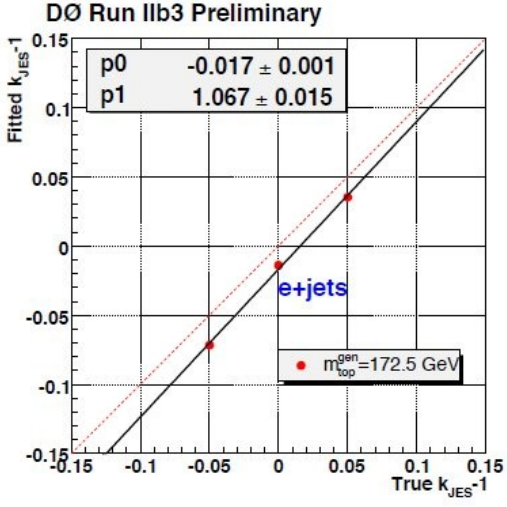


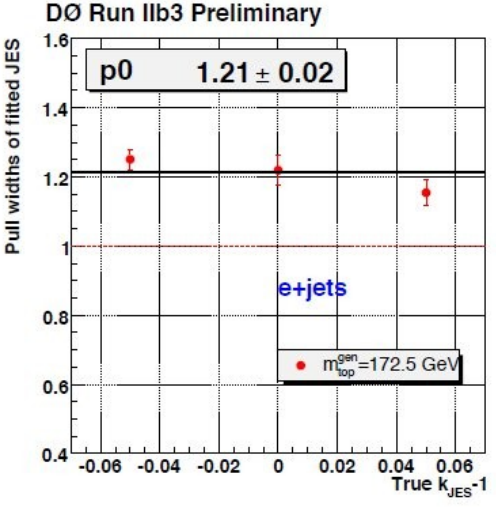


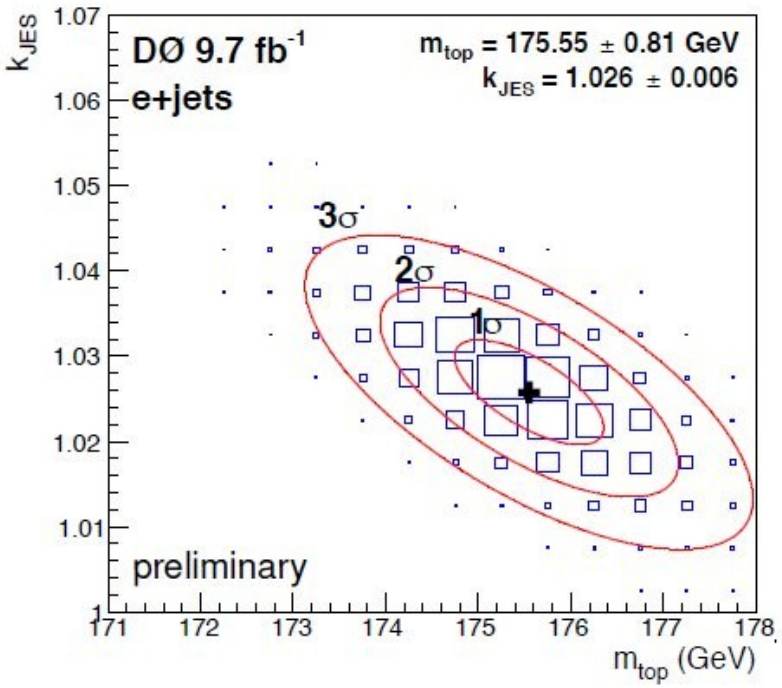


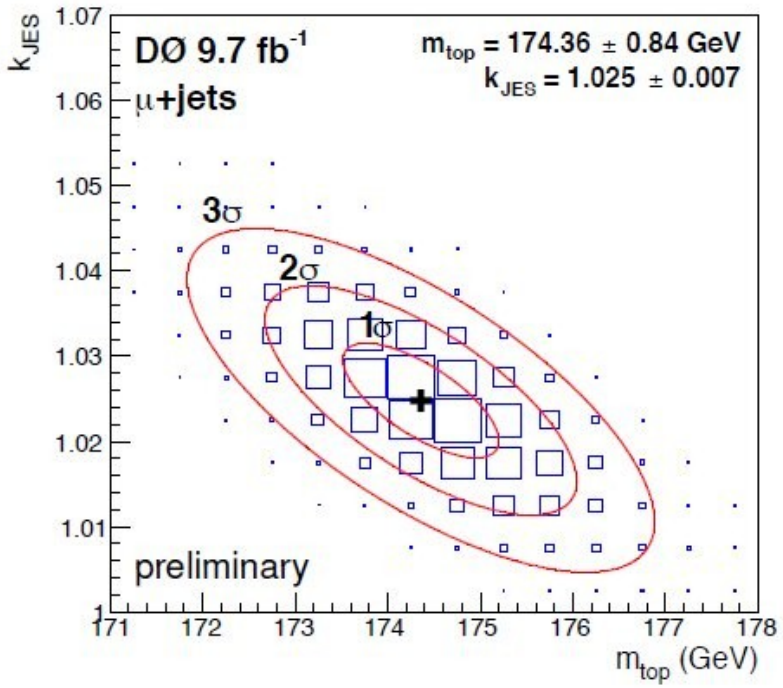






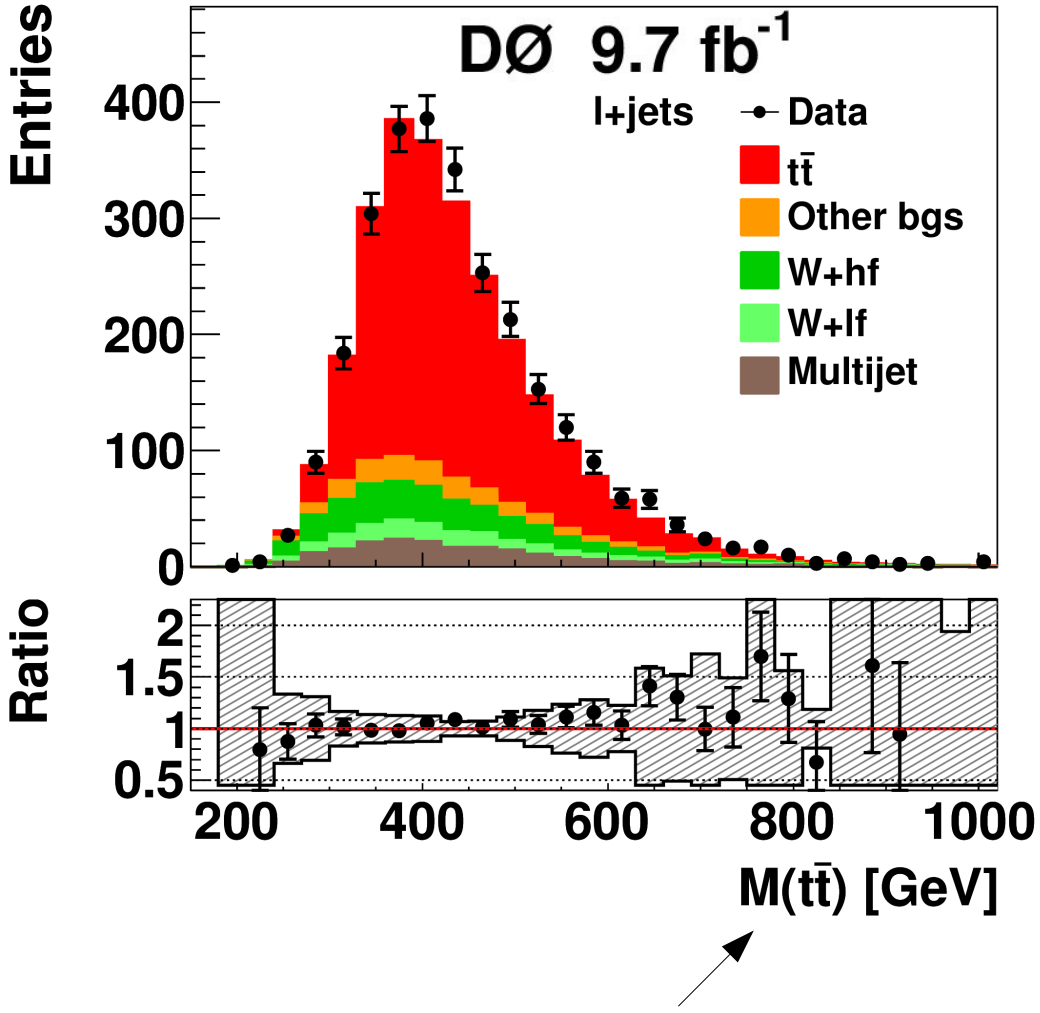




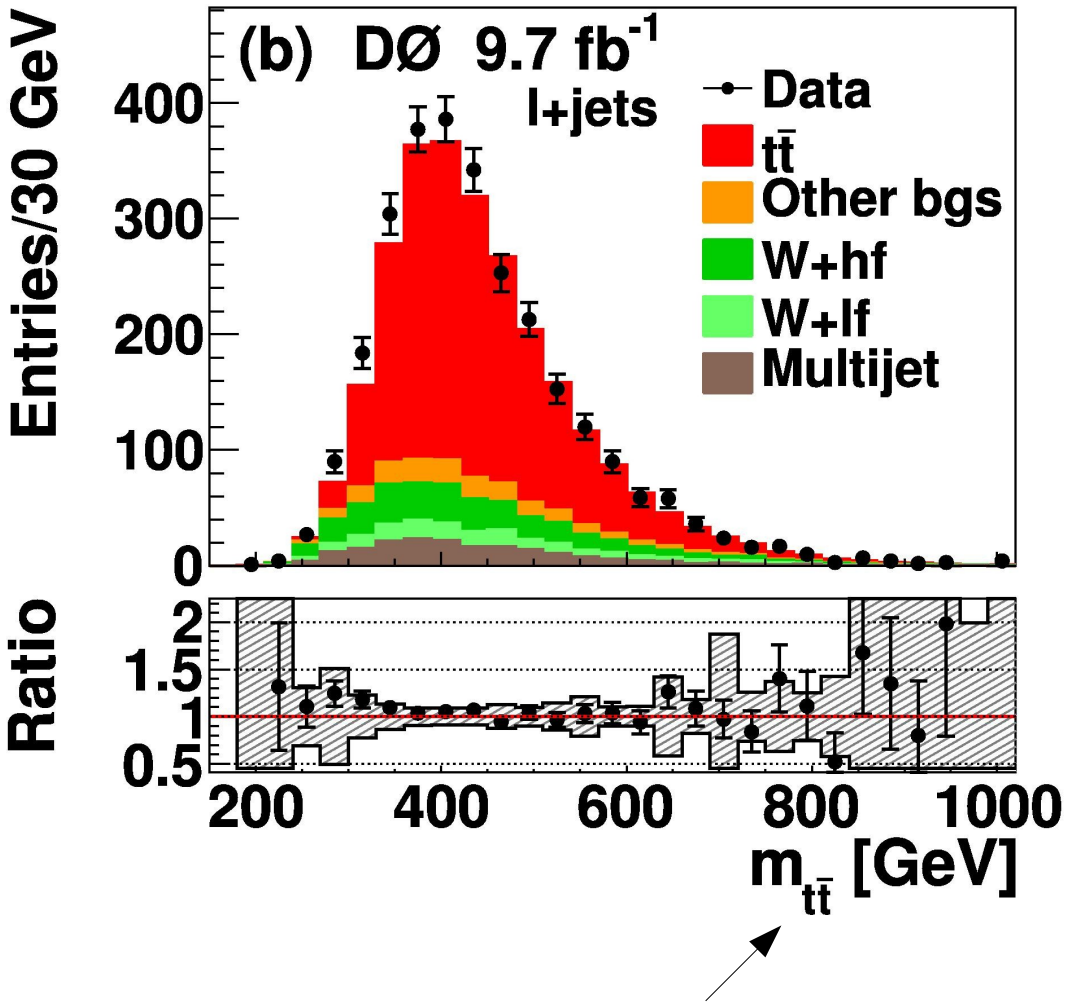


CMS: m_t = 172.22 ± 0.73 (total) GeV (→ 2.9 SD, D0 only stat. unc.)

Control distributions



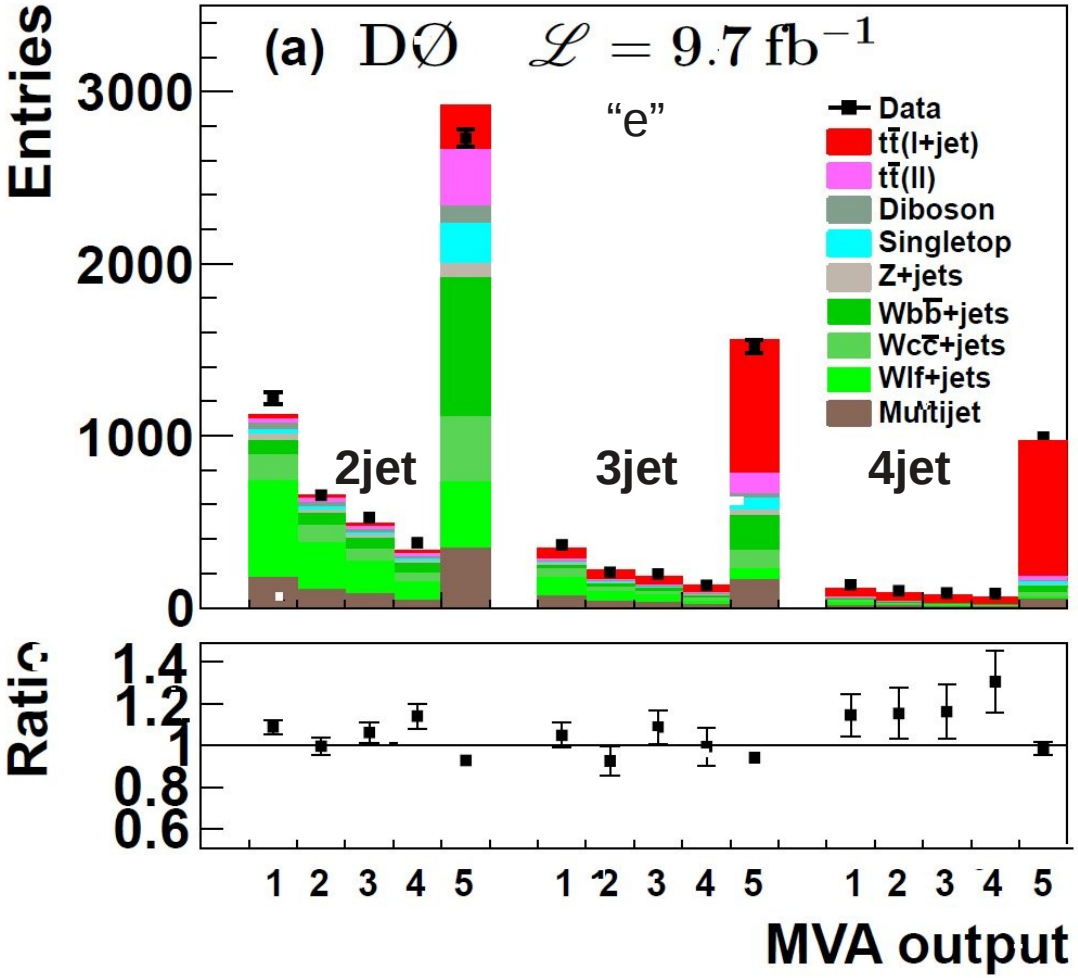
Not shifted by JES factor

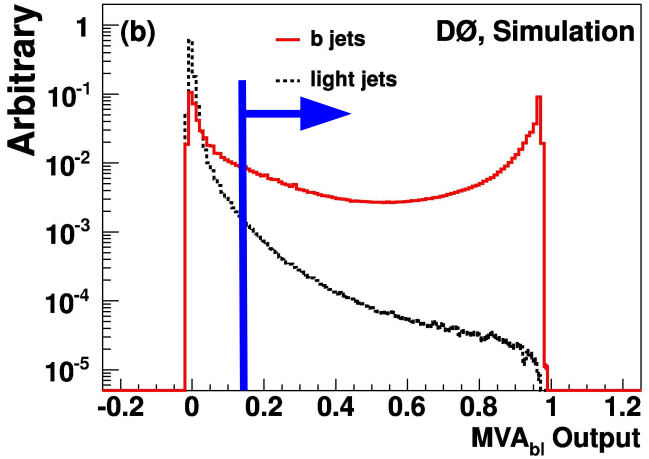


Shifted by JES factor

Sample composition

- W + heavy flavor + jets (***W*+hf+jets**) contributions constrained by using the 2, 3, and ≥ 4 jet-bin output distributions of the multi-variate *b*-ID technique
- Apply 0.15 ("medium") cut on output values
- Simultaneous fit of ***W*+hf+jets** & ***tt̄*** contribution:





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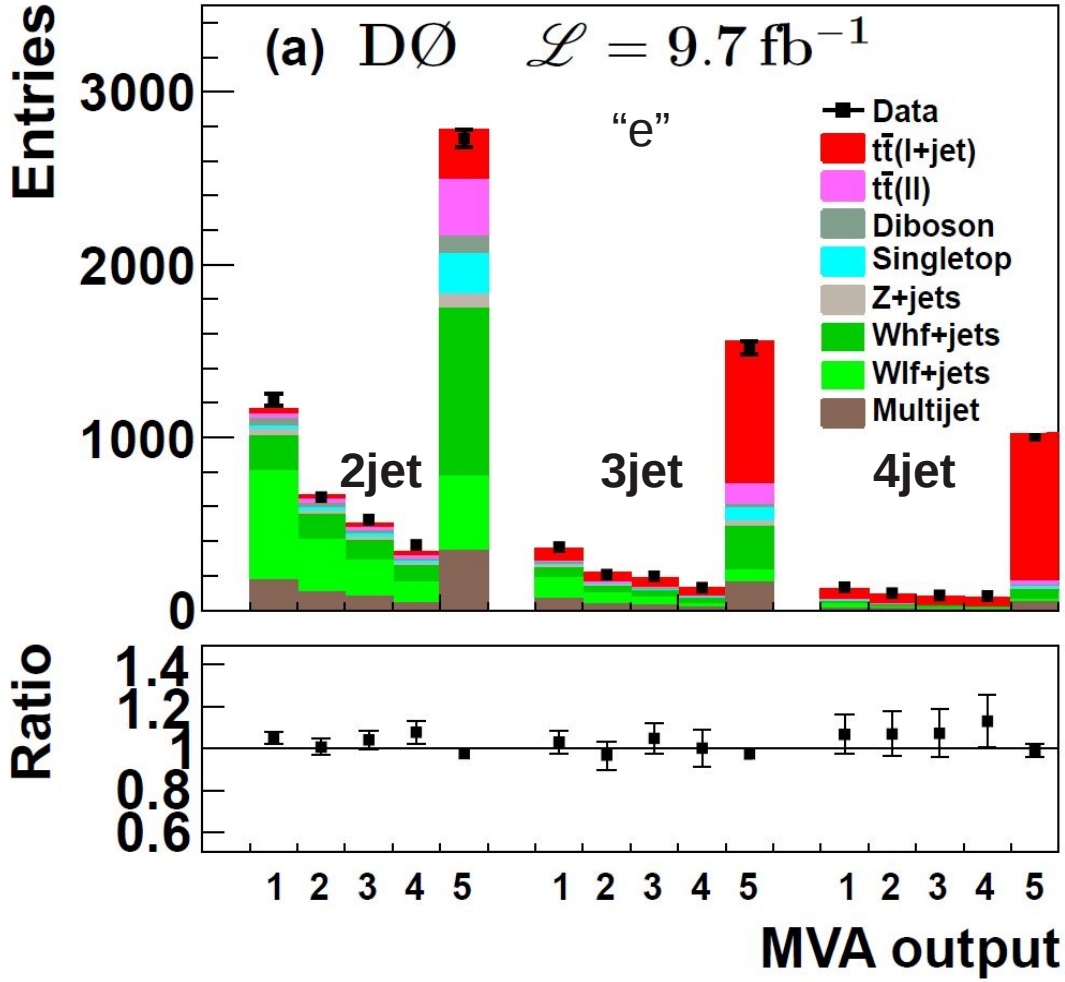

Result: ***k*(*W*+hf+jets) = 0.89 ± 0.08**
applied in addition to NLO *k*-factor of 1.47 derived using MCFM