Top differential Cross Section Measurements at the Tevatron

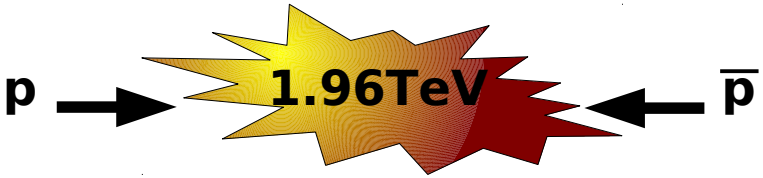
- Introduction
- Differential cross section
- Conclusions & Outlook

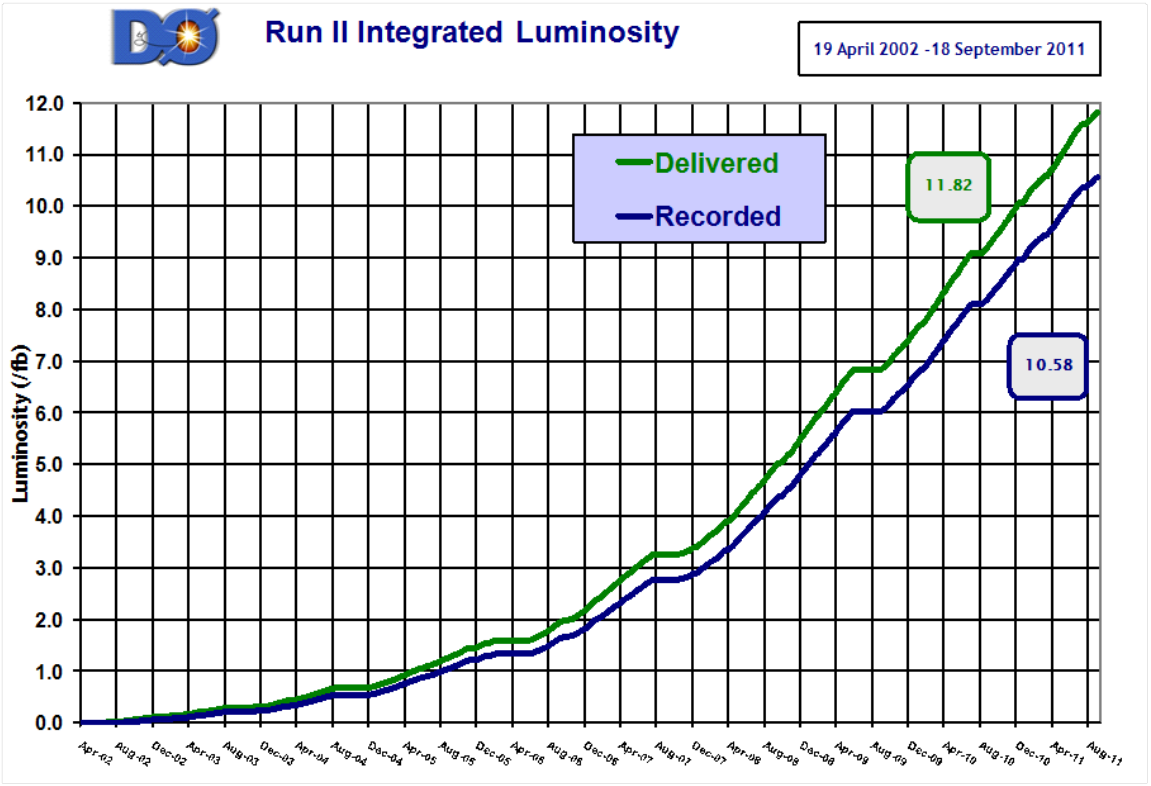
Andreas Jung (Fermilab) for the CDF & DØ collaboration

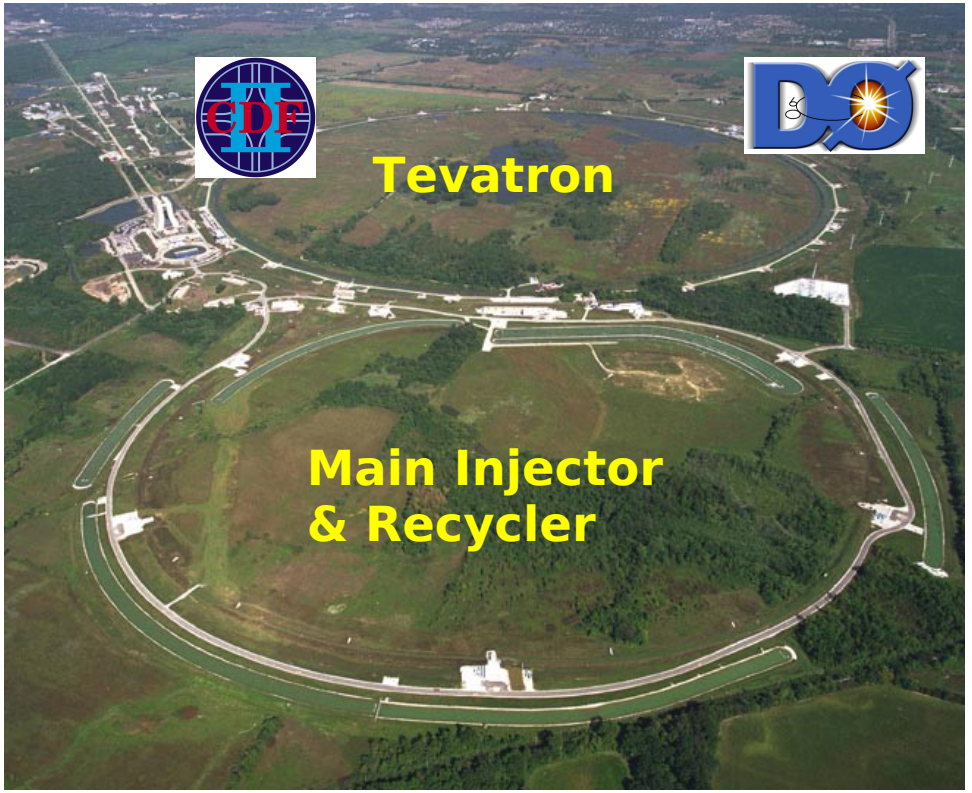
IV International Workshop on Top Quark Physics
September 25-30, 2011, Sant Feliu de Guixols, Spain

The Tevatron

- As an example:





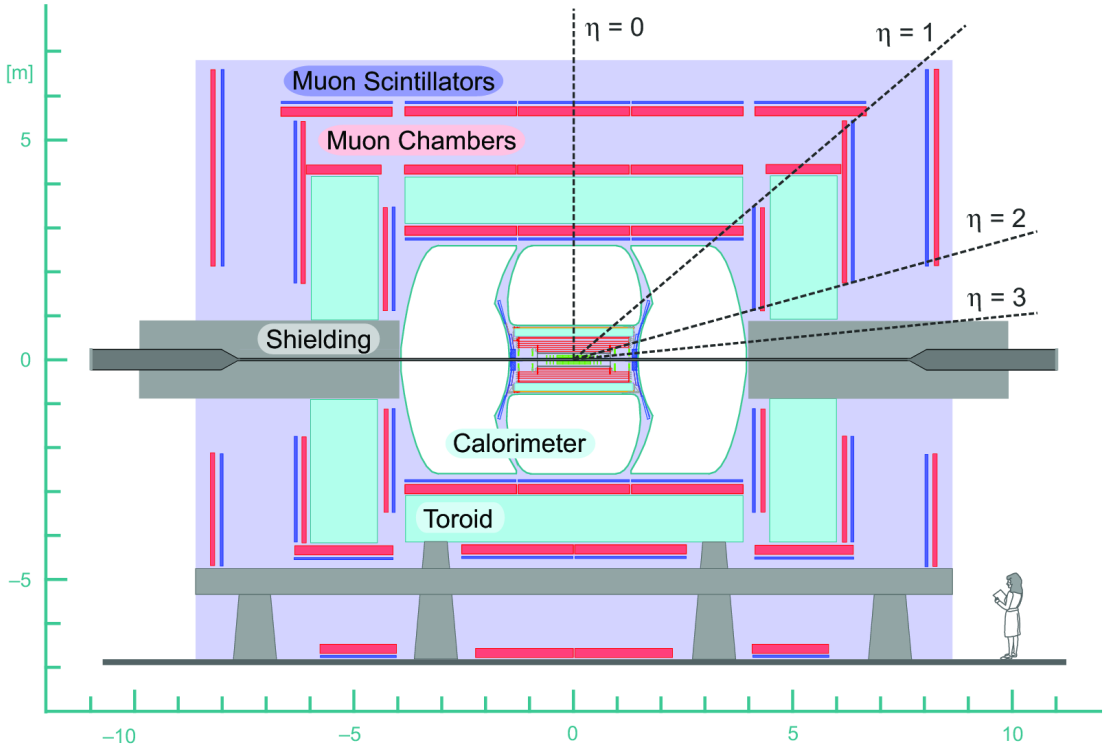


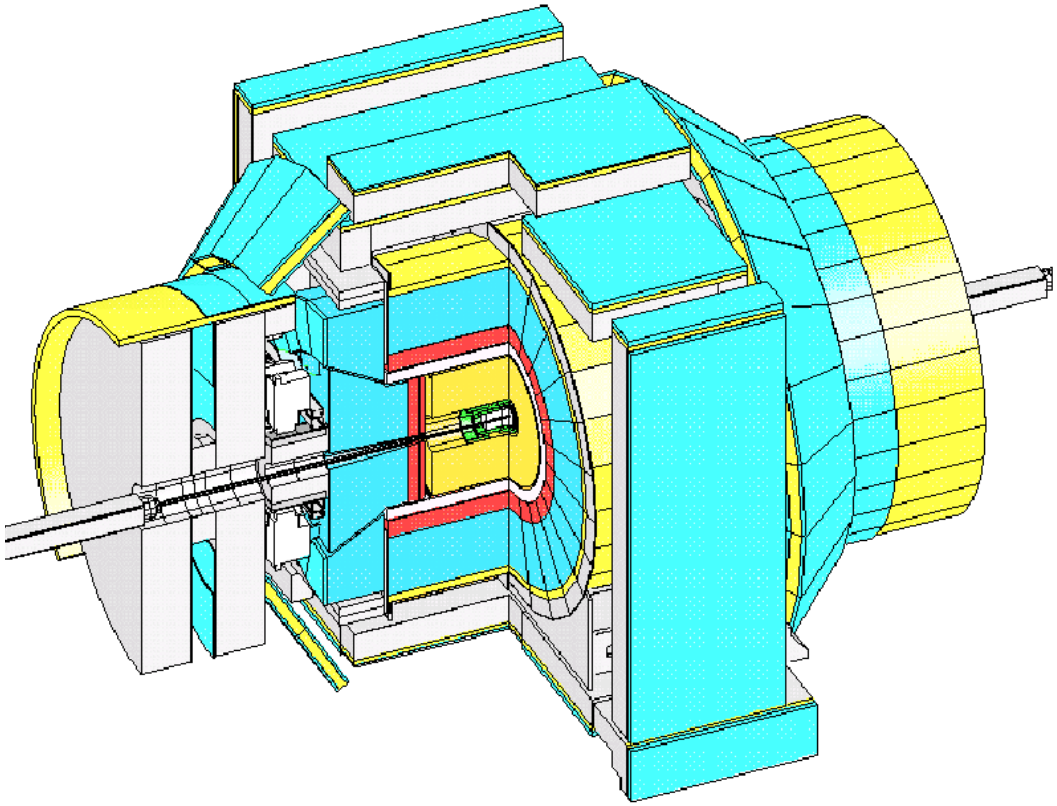
- Initial luminosities: 3 – 4 x 10^{32} $cm^{-2}s^{-1}$
- Data taking will end 30th September 2011

Thanks to the Accelerator Division and to dedicated DØ shifters & experts !

The Experiments: CDF & DØ

- 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



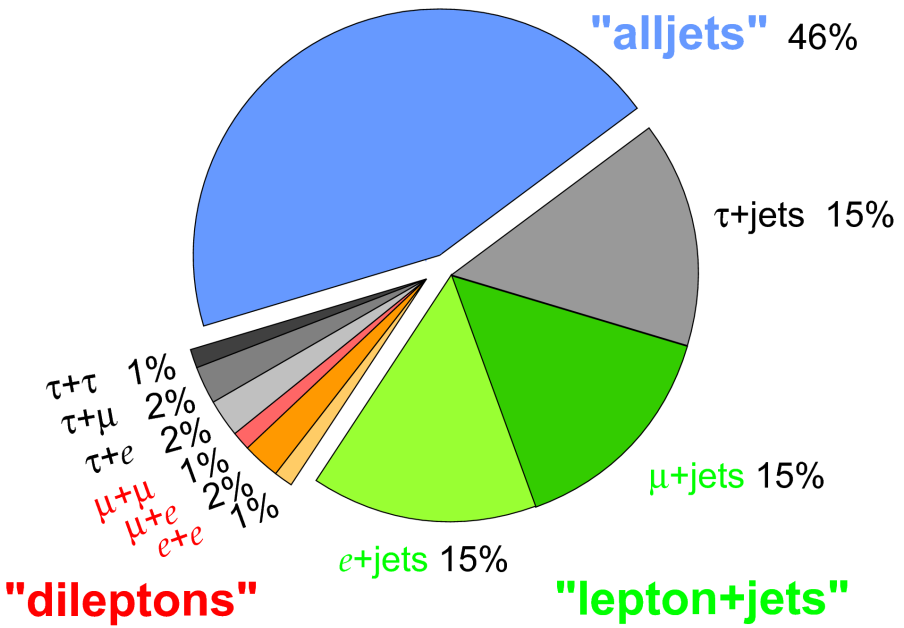


Introduction – Recap

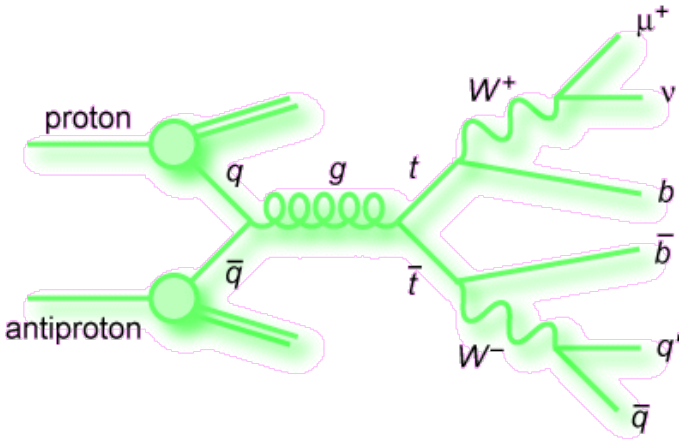
- Top is the heaviest fundamental particle discovered so far: $\underline{m_t = 173.3 \pm 1.1 \text{GeV}}$
- Lifetime: $\tau \approx 5 \times 10^{-25}$ s, bare quark
- Charge: +2/3e
- SM top quark, ~100% decay into Wb
- Tevatron has access to quantities that are harder to measure at the LHC, because of the initial state: gg vs. $q\bar{q}$

See talks by: P.Bartos, C. Gerber, K. Potamianos

Top Pair Branching Fractions



- Sample classified according to W-decay: dilepton ($\ell\ell$), lepton+jets (ℓ+jets), all jets



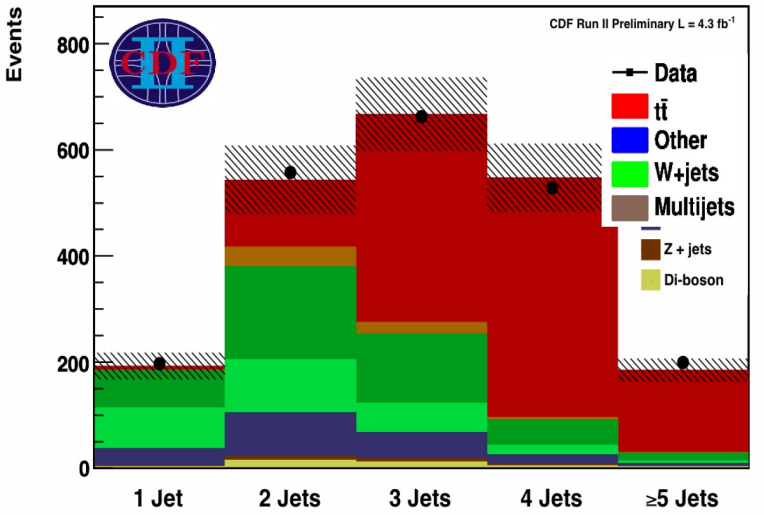
ttbar cross section

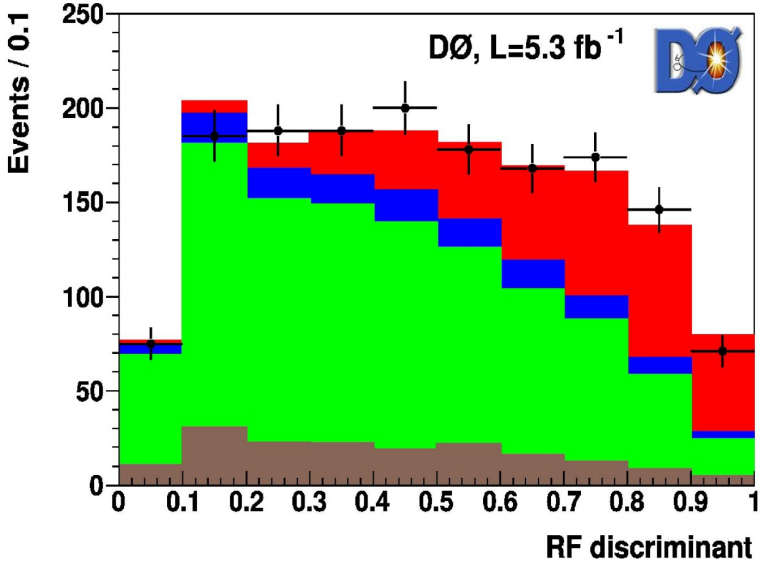
See talk by: P.Bartos

- tt pair production tests QCD while the decaying system properties can be used as an electro-weak laboratory to search for new physics.

A recipe:

- ℓ+1,2 jets as control, 3 and ≥ 4 jet bins for measurement.
- Require at least one jet as a b-jet using a NN-based tagger.
- Require an isolated lepton and large missing transverse energy.
- Largest physics background: W/Z+jets; include di-boson, single-top.
- Include NLO/LO scale factors.
- Multi-jet background from data





Why differentially ?

Why measuring differential cross sections:

- Theoretical predictions and Models need to be tuned and tested with measurements
- Differential cross sections provide detailed information about the underlying process
- This is an iterative process !
- Always ambiguous (simplified): Is it a detector effect or new physics ?

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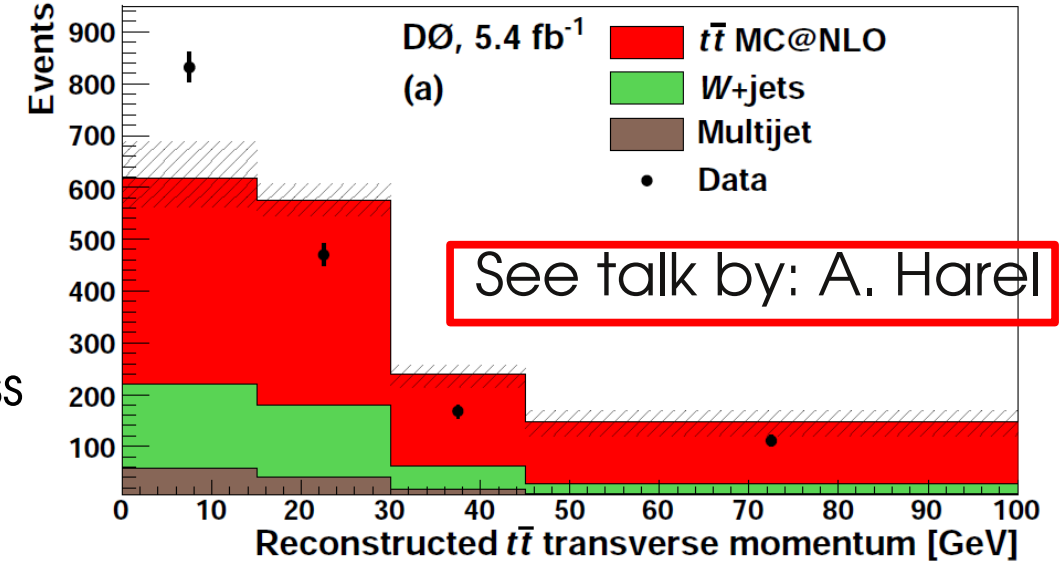

See talk by: A. Harel

Example: Forward-backward asymmetry

- ℓ+jets decay channel
- MC@NLO fails to describe the $p_T(t\bar{t})$ spectrum
- Need to understand if its a detector effect ?

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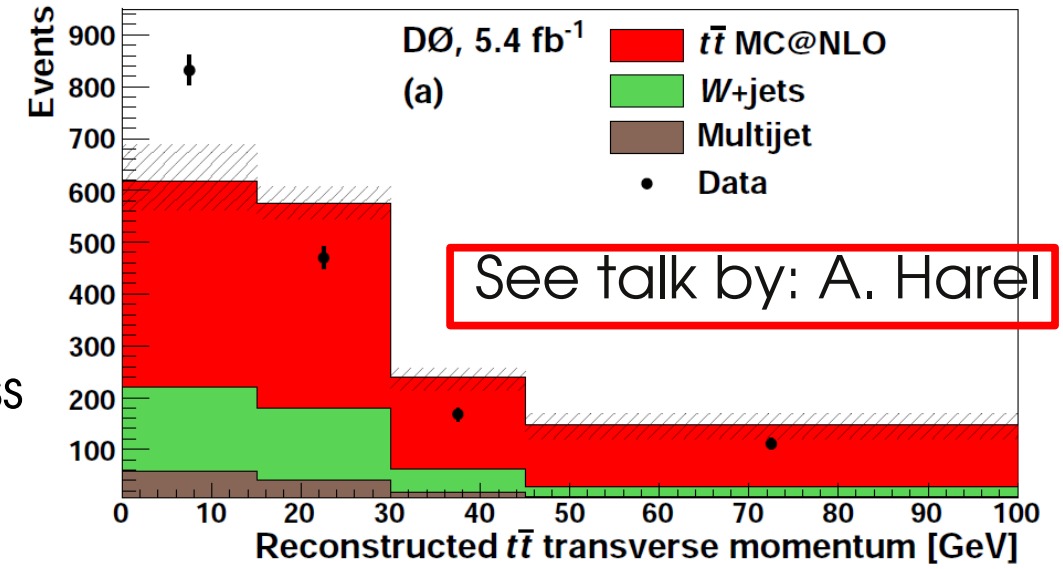

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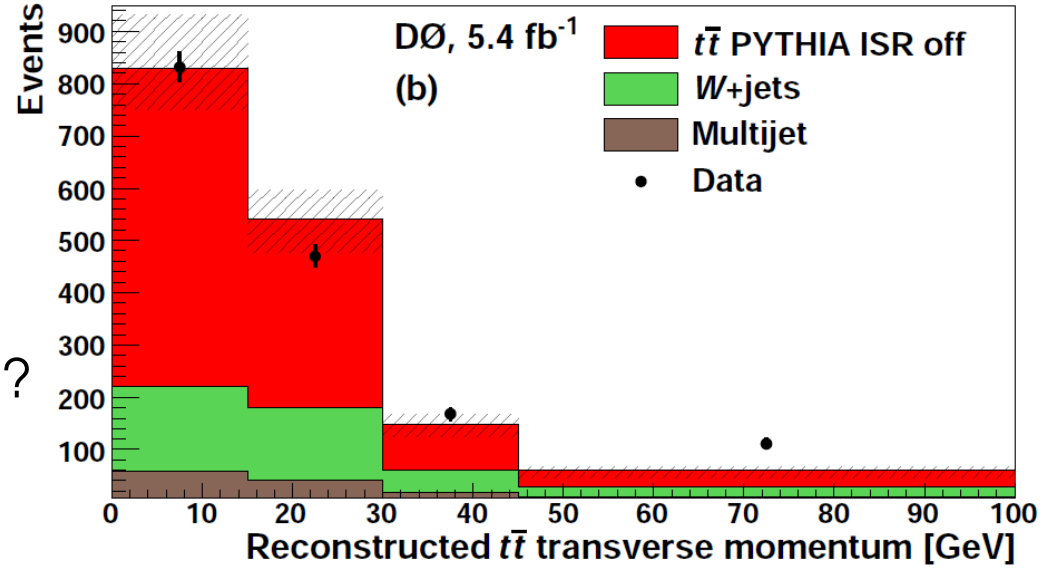


How ? Unfolding!

- Bin-by-bin correction method common in HEP:
  - Possibly strong model dependencies
  - Errors in general too optimistic
- Unfolding introduces:
  - No bias with respect to a particular model of the physical process and MC simulation
  - No or small bias, with respect to general requirements of the solution (smoothness, ...)

"Correction factors – a disaster. ...The data will tend to follow the MC that gave you the correction factors..."
(R. Barlow, SLUO lecture 9 (2000) SLAC)

	Bin-by-Bin method	regularized Unfolding, m > n
Measurement errors taken into account	no	yes
small bin-to-bin correlations	no	yes
unbiased w.r.t. Model	no	yes
simple	yes	no

- For a discrete measurement with n bins:

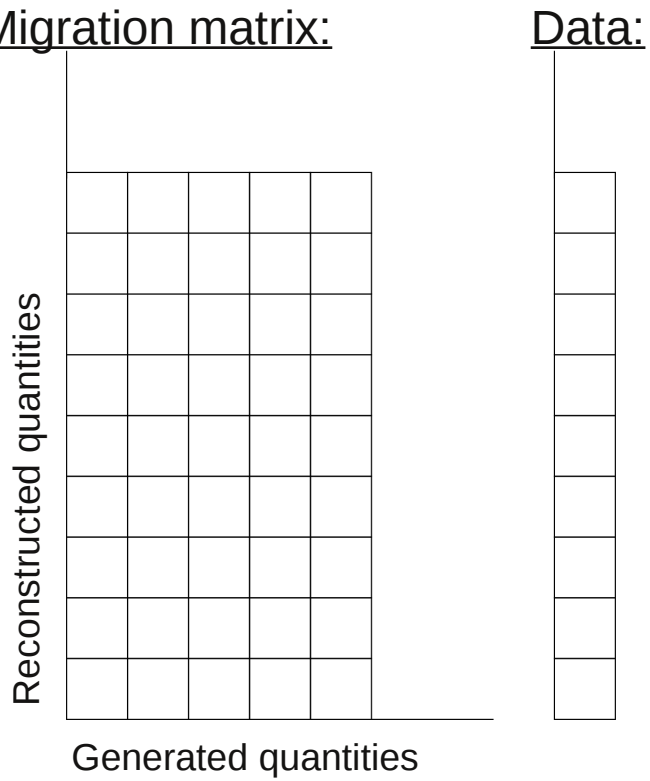
$$\boldsymbol{Ax = y \;\rightarrow\; x = A^{-1}y} \qquad \boldsymbol{V_x = A^{-1}V_y(A^{-1})^T}$$

x = n-histogram of true variable x
y = m-histogram of measured variable y
A = m × n response matrix

$\boldsymbol{V_x}$ = error propagation for true variable x
$\boldsymbol{V_y}$ = error of measured variable y

How ? Unfolding!

- Fill a migration matrix that correlates generated & reconstructed quantities
- Most difficult part is to have the appropriate matrix structure for the given problem



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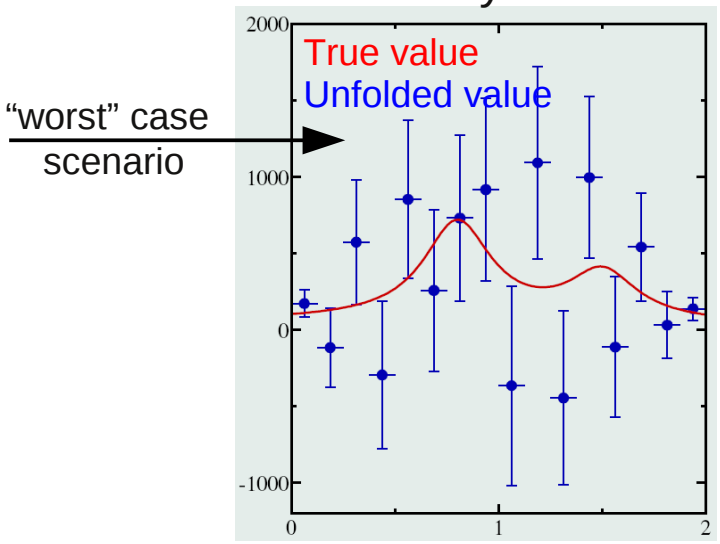
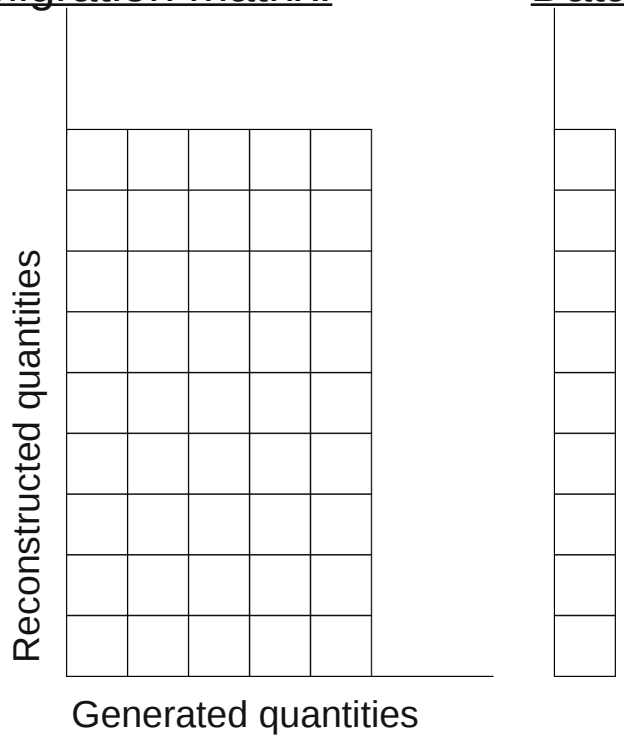
Taken from a talk by V.Blobel:



Migration matrix:



Data:

- Next step: Unfold
  - Need regularization to avoid large oscillations by insignificant solutions

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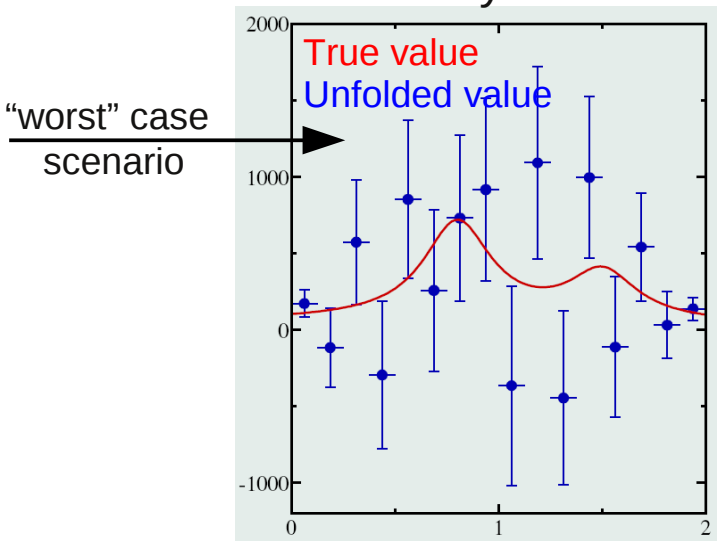

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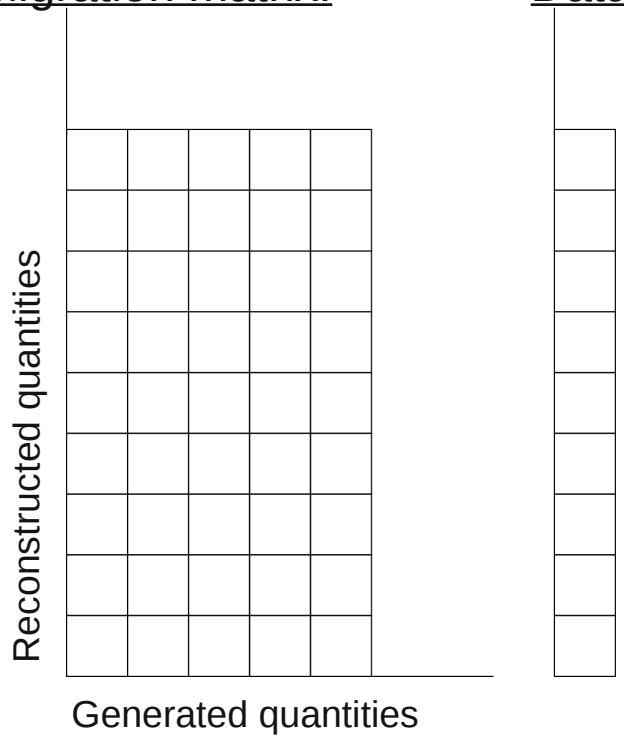


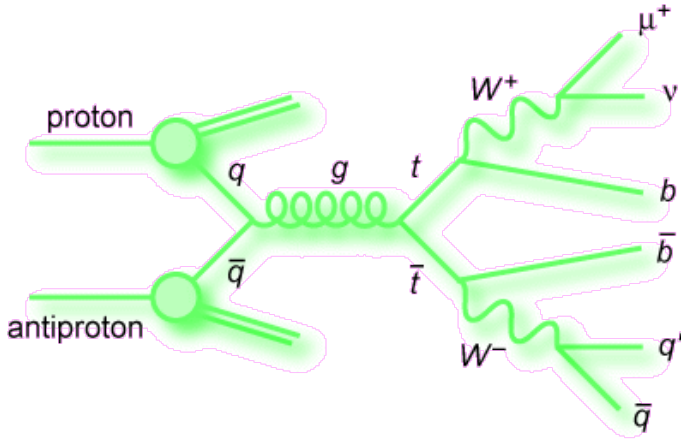
Data:

- Next step: Unfold
  - Need regularization to avoid large oscillations by insignificant solutions
  - Many options, have to carefully check for bias
  - Very personal comment: Its not a 1-day thing...

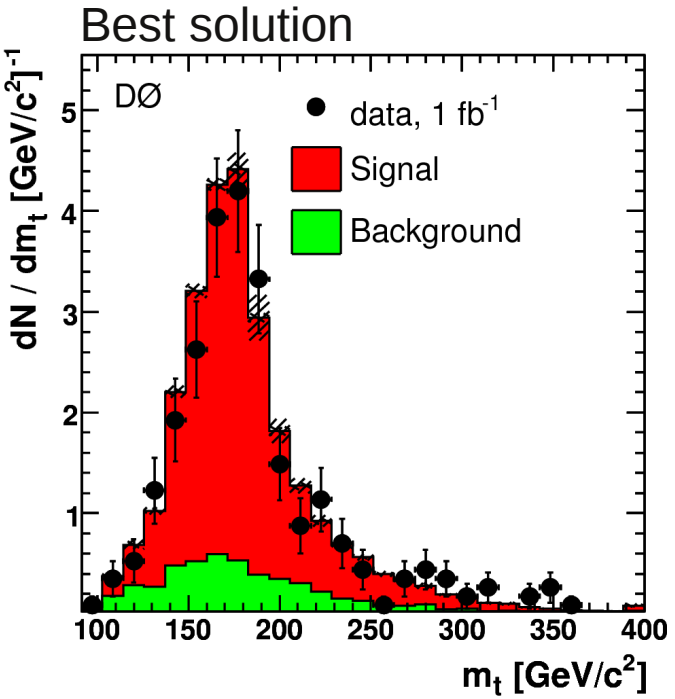
→ Use the best correction method with minimized bias: **Matrix Unfolding**

Event selection

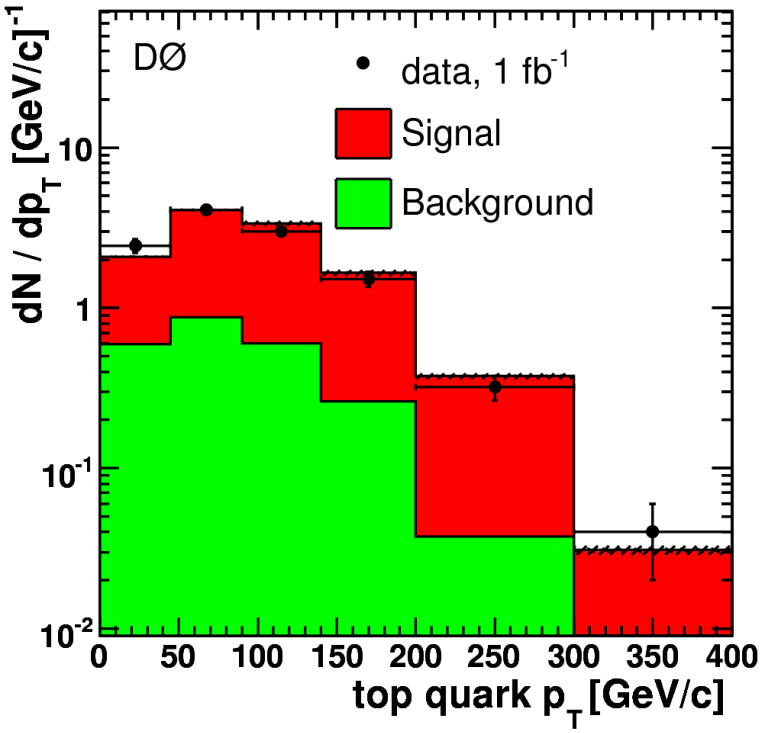
- Lepton+jets decay channel:
  - Isolated lepton p_T > 20 GeV/c
  - $\not\!\!E_T$(e) > 20 GeV, $\not\!\!E_T$(μ) > 25 GeV
  - 4 jets p_T > 20 GeV/c, $p_T^{lead.jet}$ > 40 GeV/c
  - $|\eta(jet)|$ <2.5 and at least 1 *b*-tag

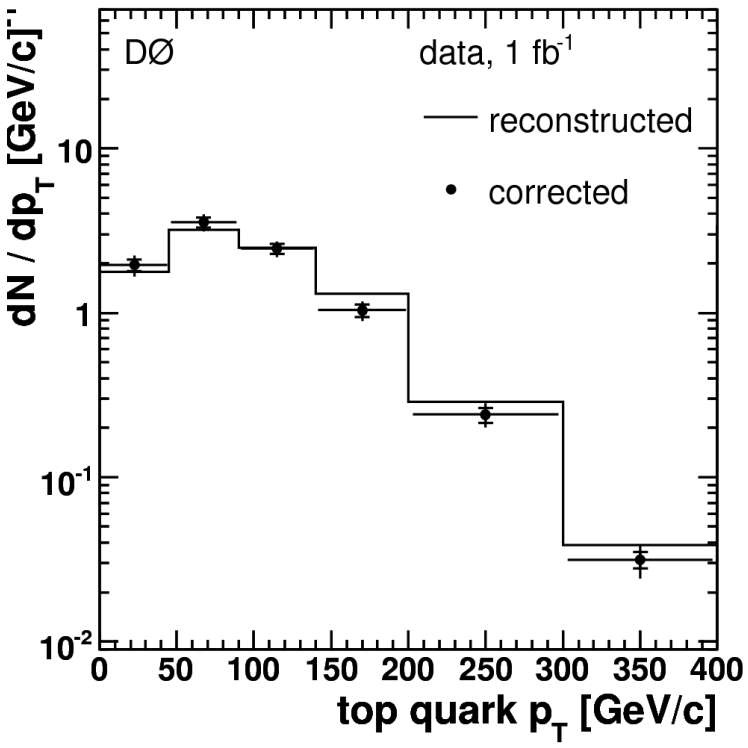


- Signal fraction 0.79
- Associate leptons and jets with individual top quarks by constrained kinematic fit:
  - Takes unreconstructed ν into account
  - W boson mass is 80.4 GeV/c^2



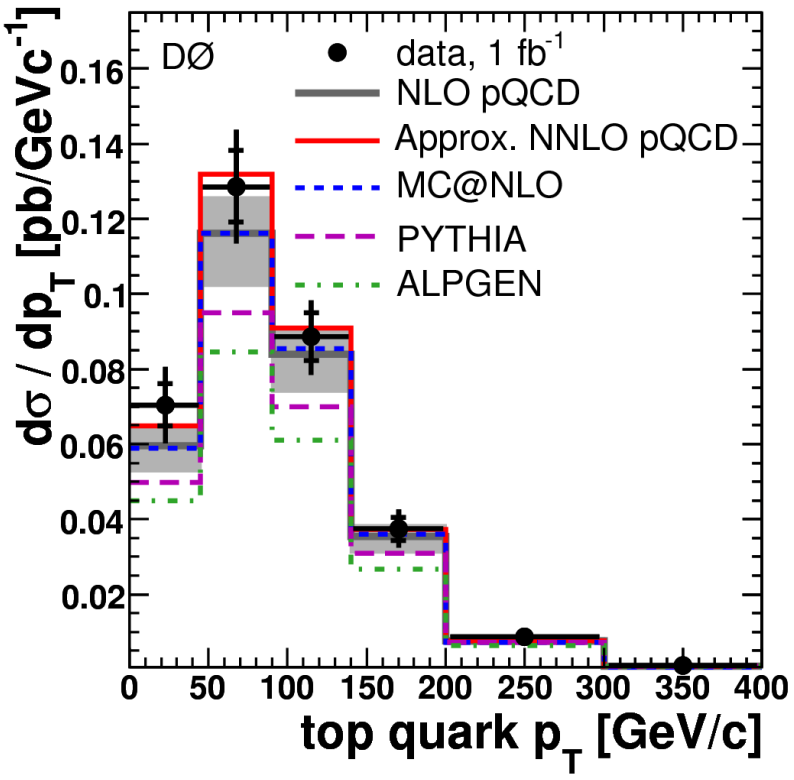
Differential cross section

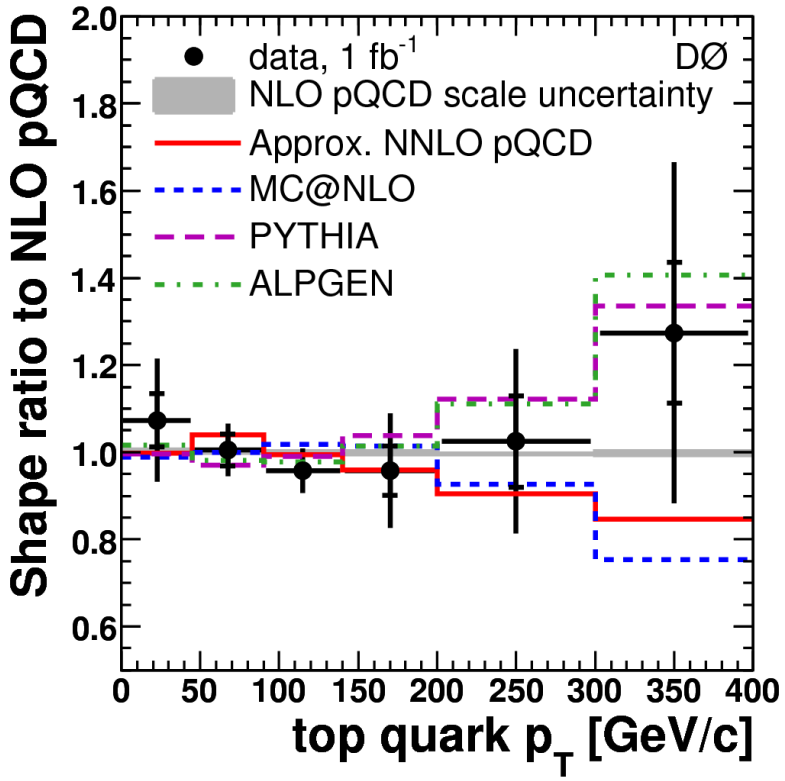




- CTEQ6L1 with $\mu_{r/f} = m_t + \Sigma p_T^{jets}$, $m_t = 170$ GeV/c^2
- Combines leptonic & hadronic decay of the W boson
- Background subtracted data (–) gets unfolded and thus corrected for finite detector resolution by means of a regularized unfolding

Differential cross section



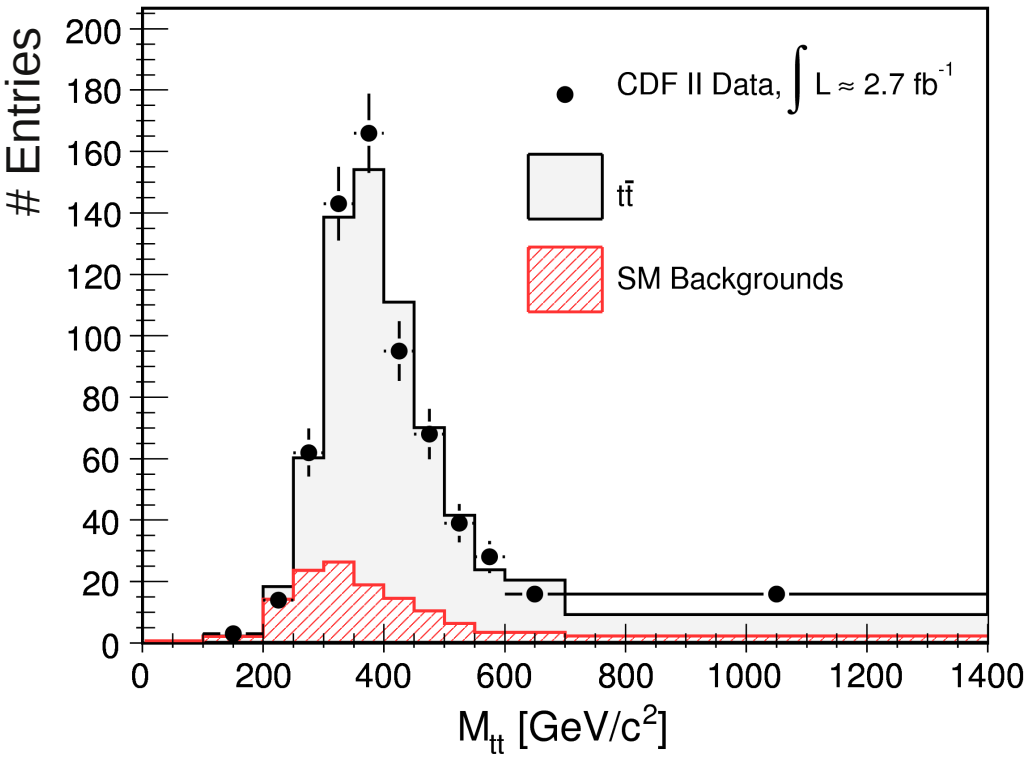


Phys. Lett. B 693, 515 (2010), arXiv.org:1001.1900

- Largest shape uncertainty: Jet energy scale (1.5-5%)
- All use: CTEQ61 with $\mu_{r/f} = m_t$, except approx. NNLO pQCD uses MSTW08
- Integrated cross section: $\sigma = 8.31 \pm 1.28$ (stat.) pb

→ Normalization nicely described by pQCD (N)NLO, however offset for PYTHIA, ALPGEN. Shape is reasonable decribed by all predictions

Differential cross section



PRL 102 222003 (2009)

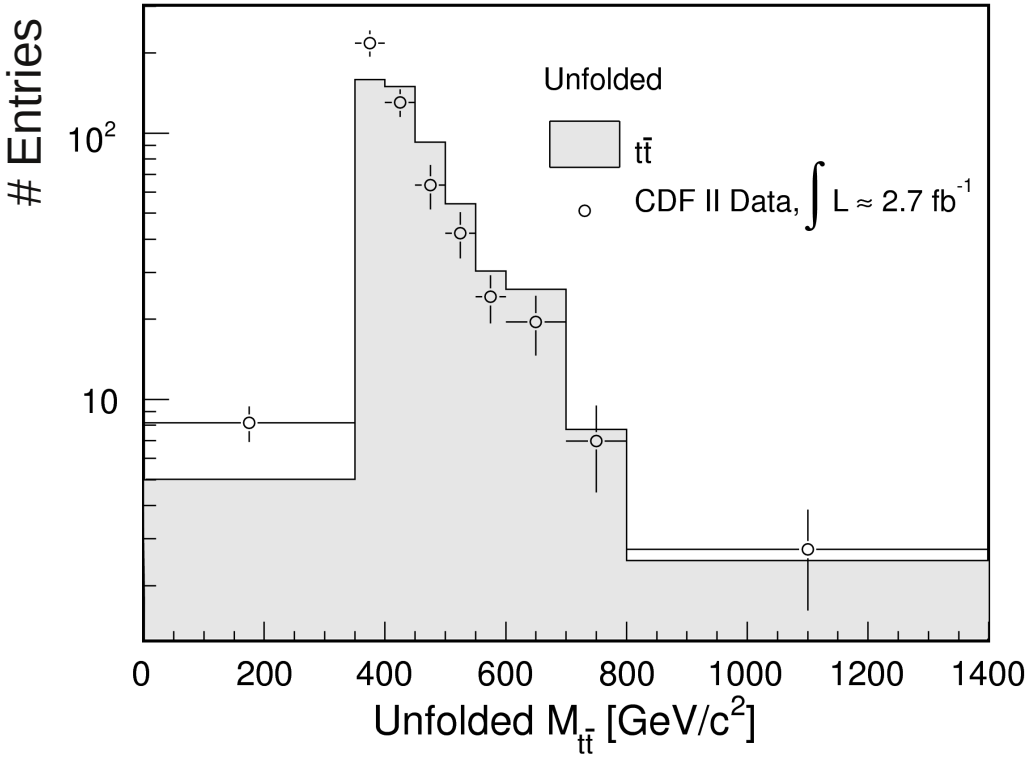
- Selection:
  - Isolated lepton p_T > 20GeV/c
  - $\not\!\!E_T$ > 20 GeV
  - 4 jets p_T > 20 GeV/c
  - $|\eta(\text{jet})|$ <2.0 and at least 1 *b*-tag
- MC uses CTEQ5L, m_t = 175 GeV/c^2

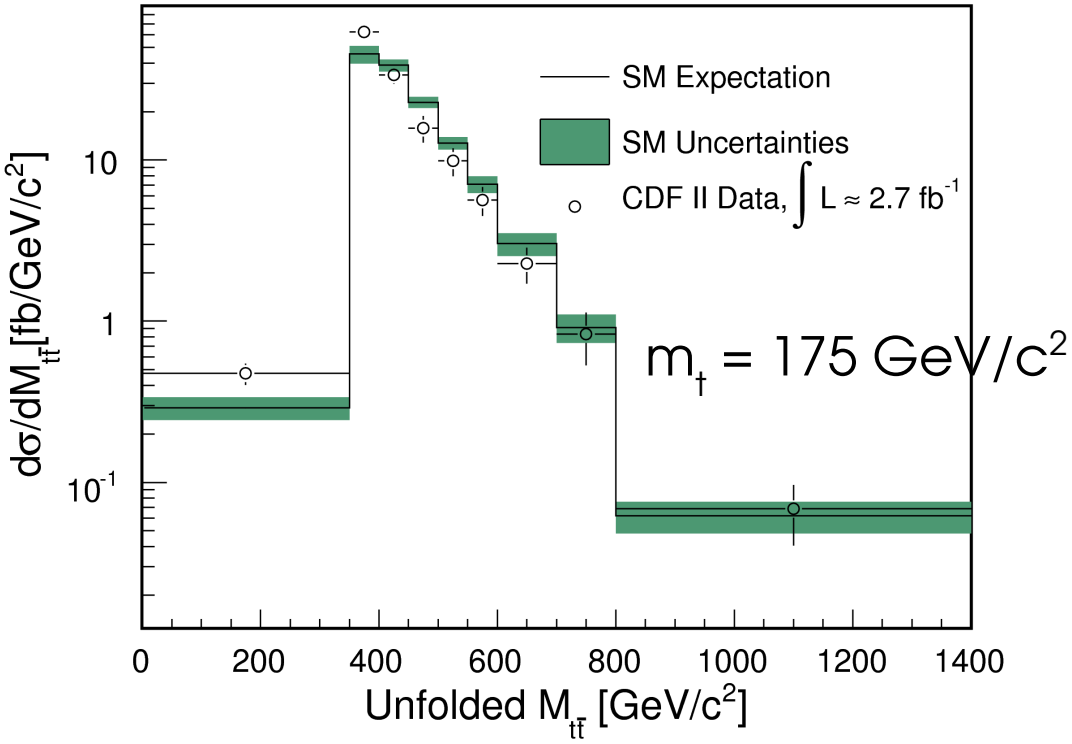
- W → q'q to constrain Jet Energy Scale (JES)
- Reconstruct invariant mass of tt̄ system: M(tt̄)

→ Tail of M(tt̄) is sensitive to broad enhancements as well as to narrow resonances

Differential cross section

- Correct for detector effects & finite resolution by regularized unfolding





- Dominant systematics: JES 2-8% and at high M($t\bar{t}$) PDF up to 18%
- Integrated cross section: σ = 6.9 ± 1.0 (stat.+JES) pb

→ Invariant mass distribution of the $t\bar{t}$ system is described by SM
28% of pseudo-experiments show larger deviation

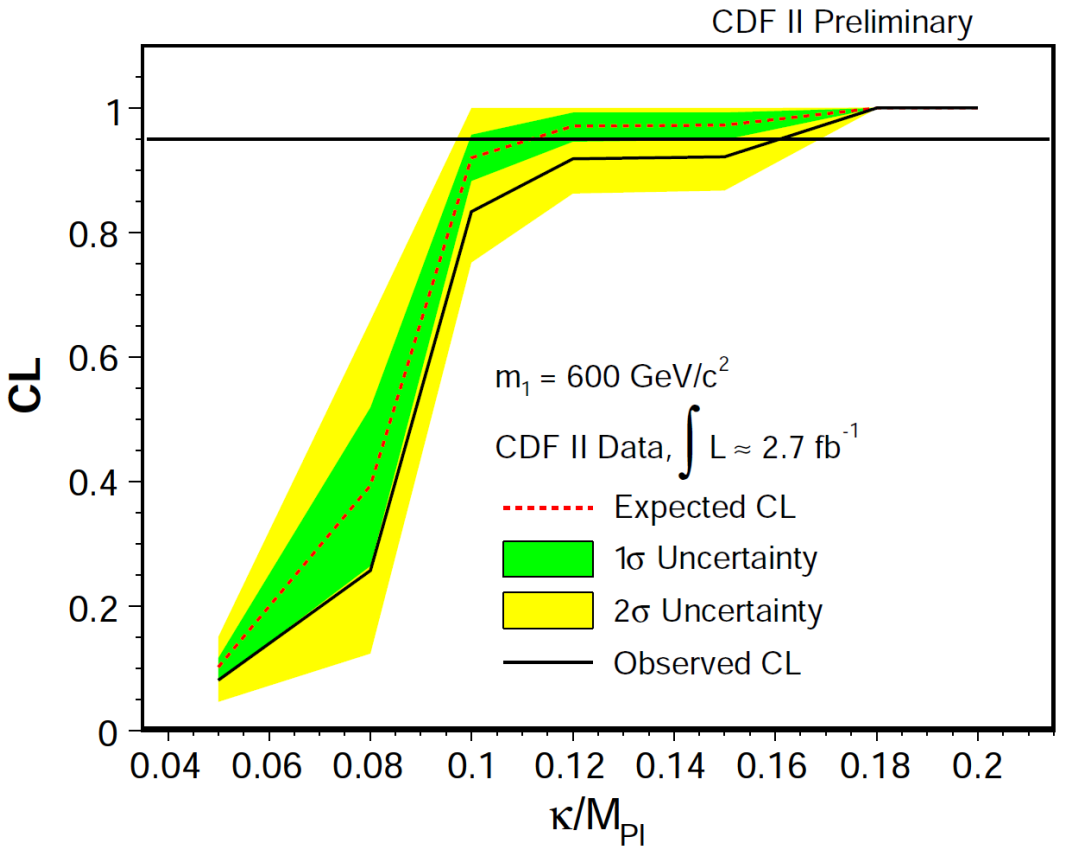
Differential cross section

- Evaluate agreement between data and SM expectation
- Most sensitive region: Tail of distribution M(tt̄) > 450 GeV/c^2
- BSM results:

$$\kappa/M_{\mathrm{Pl}} > 0.16 \text{ at } 95\%\text{C.L.}$$
$$(m_1 = 600\,\mathrm{GeV})$$

- More on BSM at the Tevatron:

See talk by: D. Wicke



Summary

- Presented top differential cross section measurements at the Tevatron – good agreement with various predictions
- Differential distributions add valuable information

Outlook:

- Final samples will have 3-10x the statistics
- More precise results in near future
- Tevatron is an exciting place to do Physics
- Tevatron is building up its legacy

To the theoreticians:

- Which distributions are of interest ?

Backup

Unfolding

- Why only 1fb^{-1} for DØ?

Unfolding

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