DØ Top Quark Results

& their Dependence on Successful Grid Computing

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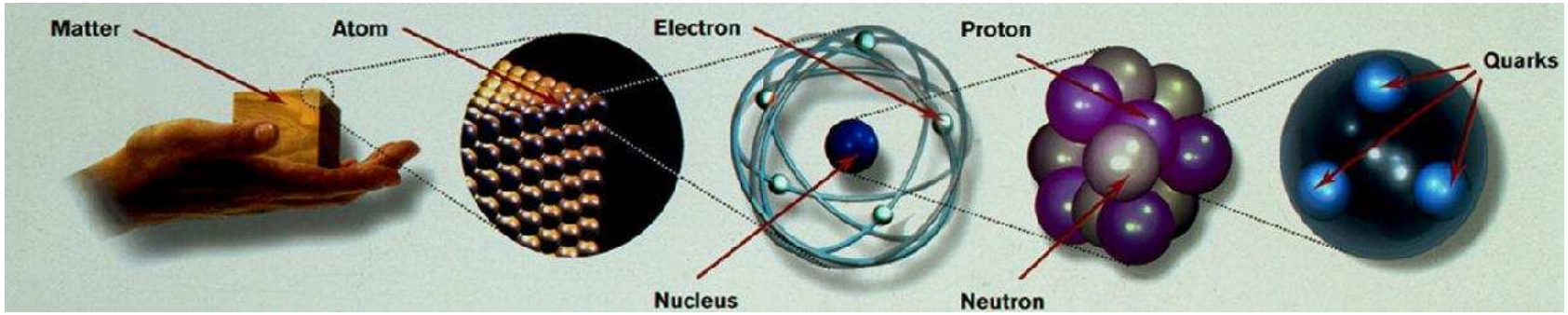
(Fermilab)

Outline

- Introduction
- Tevatron and the DØ detector
- Grid activities
- Data analysis and results
- Summary

Introduction



The Standard Model of Elemetary Particle Physics

Matter

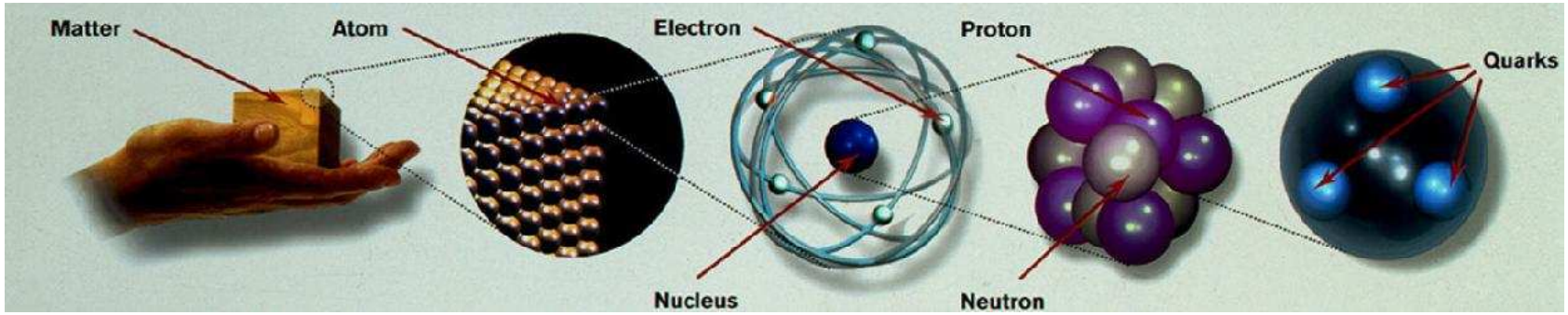
e electron
ν_e electron neutrino

u up-quark
d down-quark

Forces

Electromagnetism: Photon γ, Weak force: $Z, W^{\pm}$, Strong force: Gluon g

Introduction



The Standard Model of Elemetary Particle Physics

Three families of matter

e	electron	μ	muon	τ	tauon
ν_e	electron neutrino	ν_μ	muon neutrino	ν_τ	tau neutrino
u	up-quark	c	charm-quark	t	top-quark
d	down-quark	s	strange-quark	b	bottom-quark

Forces

Electromagnetism: Photon γ, Weak force: $Z, W^{\pm}$, Strong force: Gluon g

Is the Top Quark special?

Yes, it is! It is ...

- more than 30 time heavier than the second heaviest elementary Fermion. Its mass is surprisingly close to electro-weak scale.
- the only bare quark (i.e. decays before it hadronises)
- the last of the predicted quarks.

No, it isn't! It has ...

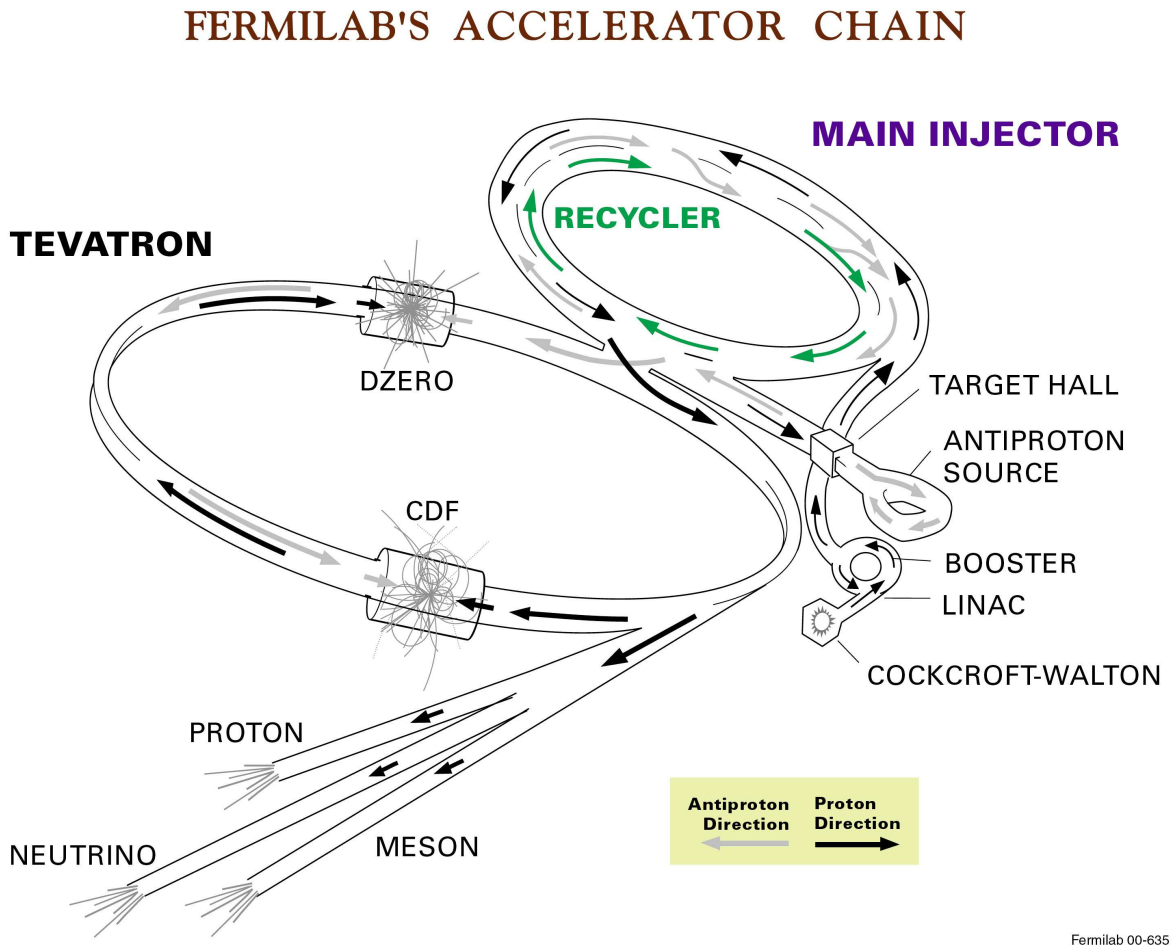
- the same electrical charge as u and c-quarks.
- the same weak couplings as the other quarks.
- the same colour charge as the other quarks. *Really??*

Maybe ...

- it has different couplings ($\Rightarrow$ new physics)
- it isn't last quark ($\Rightarrow$ new physics) *very interesting!*

The $p\bar{p}$ Accelerator Tevatron

- Circumfence 7 km.
- $p\bar{p}$ collisions
- Run I (1987-1995)
- Run II (since 2001)
  Collision energy 2 TeV
- 2 experiments,
  CDF and DØ,
  record events.



The Tevatron

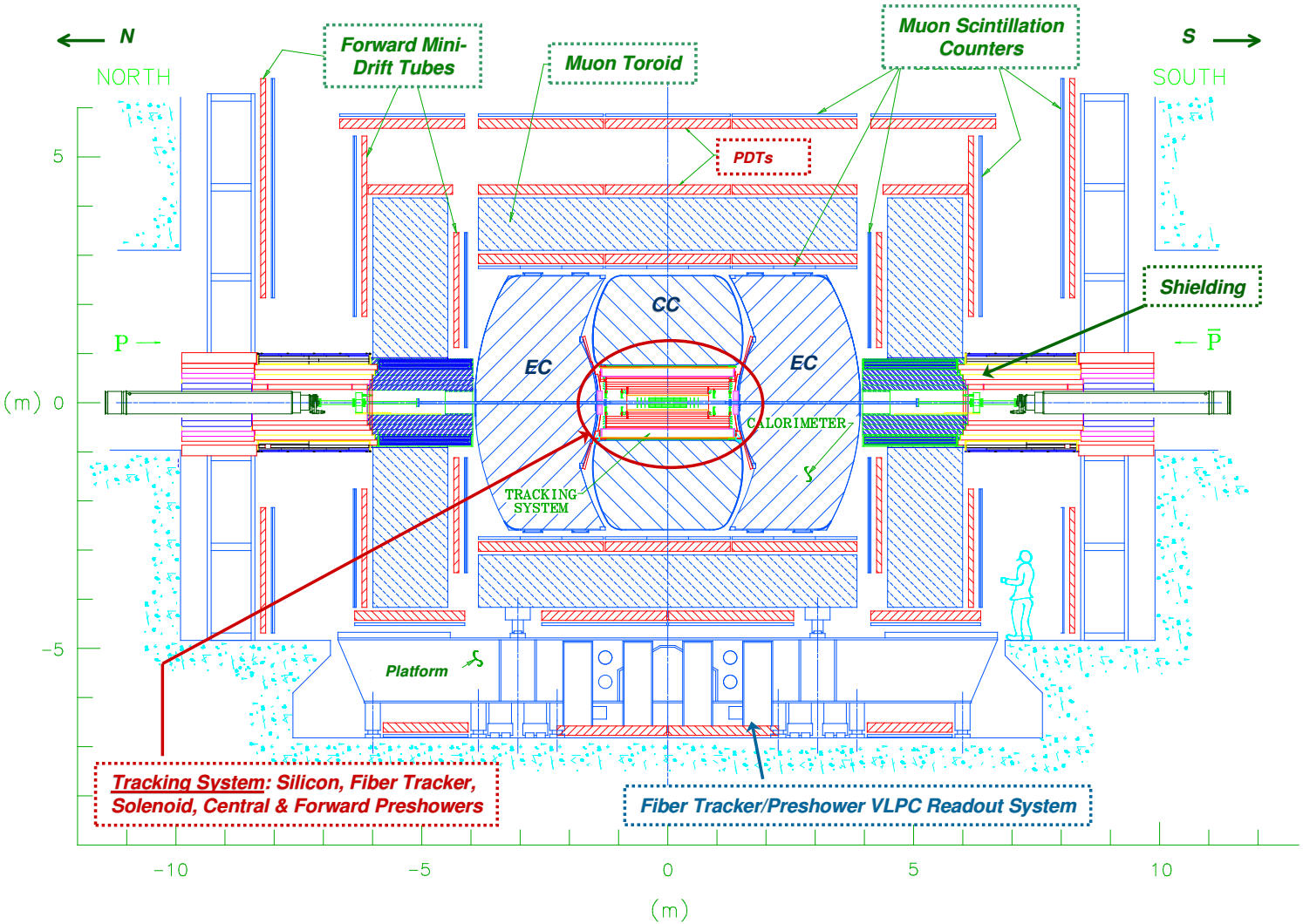
DØ

- International collaboration
- 86 institutes, 670 physicists
- 19 countries from 4 continents

Data accessibility

Video conferencing

The DØ Detector

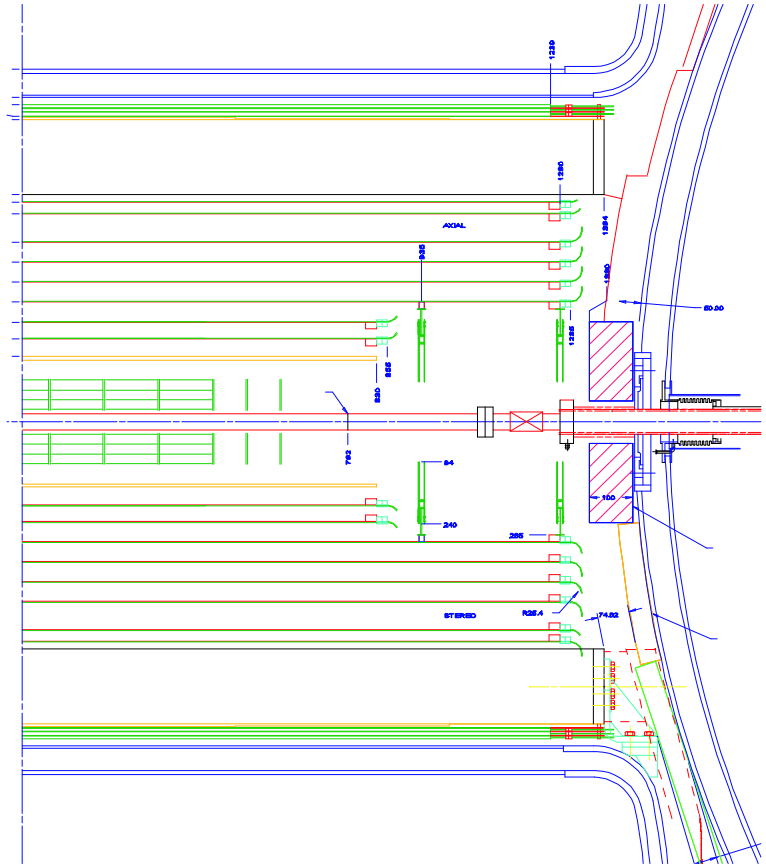


- Dimensions: $12 \times 12 \times 20\mathrm{m}^3$

Tracking

- Super conducting solenoid of 2T
- Fiber tracker (77 000 channels)
- Silicon tracker (840 000 chann.)

Data taking rate: $50\mathrm{Hz} \times 250\mathrm{kB} = 1.3\mathrm{MB/s}$
Raw data on tape: $\sim 400\mathrm{TB}$



Data reconstruction

- Hits combine to tracks
- Calorimeter combine to jets
- Global properties computed
  Trans. momentum misbalance ($\not{E}_T$).

... and many more. A very CPU intense task.

Grid activities in DØ

SAM — Sequential Access through Metadata

DØ's data handling system

- Request datasets not file lists.
- Datasets defined by metadata.
- The system optimises the order minimises tape/copy operations.
- Metadata describe datafiles
  - derived from which inputs
  - with which application/version
- complete production book-keeping

Data can be accessed coherently from all over the globe

JIM — Job Information Monitoring

- Job submission to distributed sites (based on Globus and Condor)
- Provides monitoring for fast error recovery.

SAM + JIM == SamGrid

Production of simulated events

Simulated events with full detector response and reconstruction generated at various remote sites **since 2001**. 80M events produced in last year.

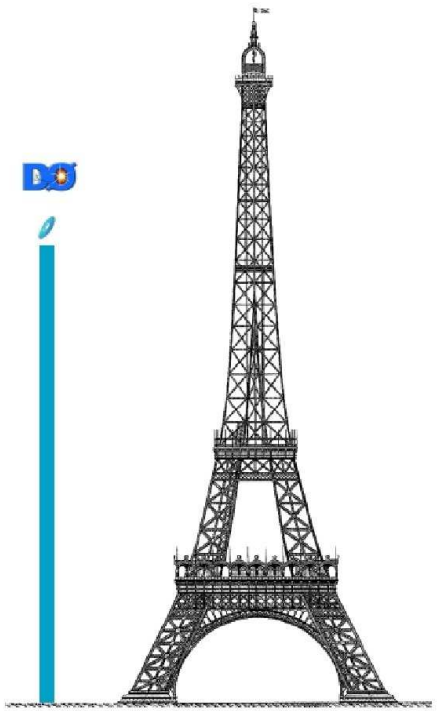
Relies heavily on SAM data handling.

(Re)reconstruction of raw detector data

Investigation of detector performance lead to improved understanding thus better algorithms.

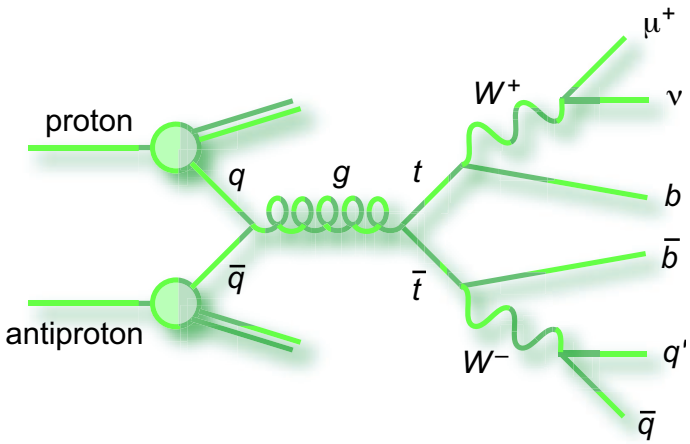
2003 Rereconstruction 300M events (45TB);
30% at remote sites. *Relied on SAM data handling.*
Doubled dataset available for this years publications

2005 Rereconstruction 1G events from raw (250TB);
total 1600CPU years provided by 10 centres.
Relies on SamGrid, i.e. JIM for job handling;
SAM for book-keeping and data handling
Doubles dataset for next years publications



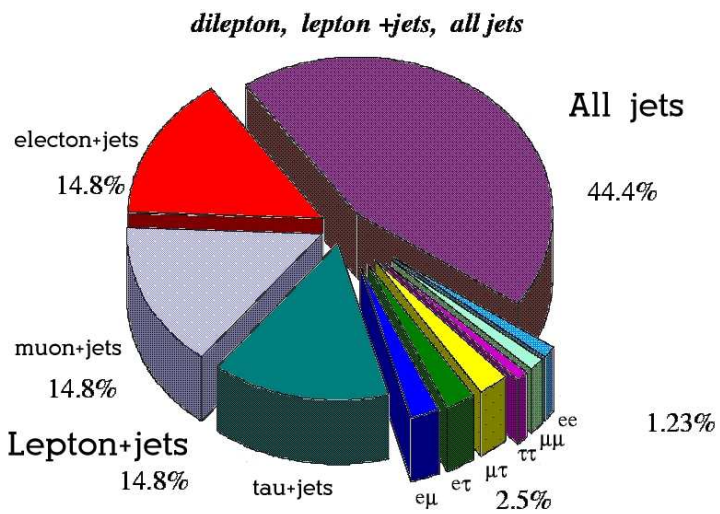
Pair Production Cross-Section

The strong production mechanism



Signal Signatures

- Only one parton of each colliding (anti-)proton participates in the reaction
- The top quark decays to bW ($\sim 100\%$)
- Decay modes are defined by W-decays:
  - Dilepton $(2b + 2l + 2\nu)$
  - Lepton+jets $(2b + 2q + l\nu)$
  - Alljets $(2b + 4q)$



The cross-section formula

$$\sigma_{t\bar{t}} = \frac{N - B}{\varepsilon \mathcal{L} \cdot \mathrm{BR}}$$

Backgrounds

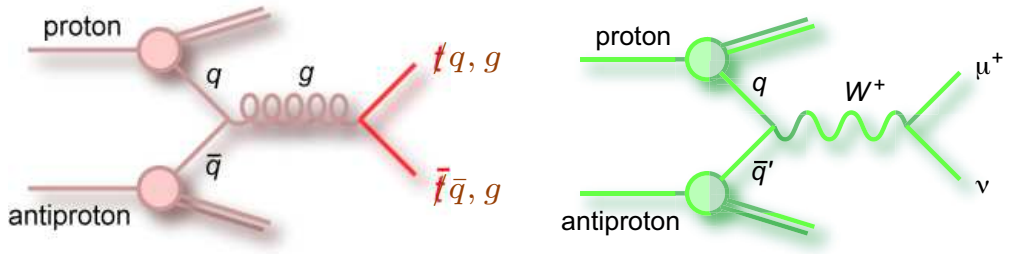
Physics background

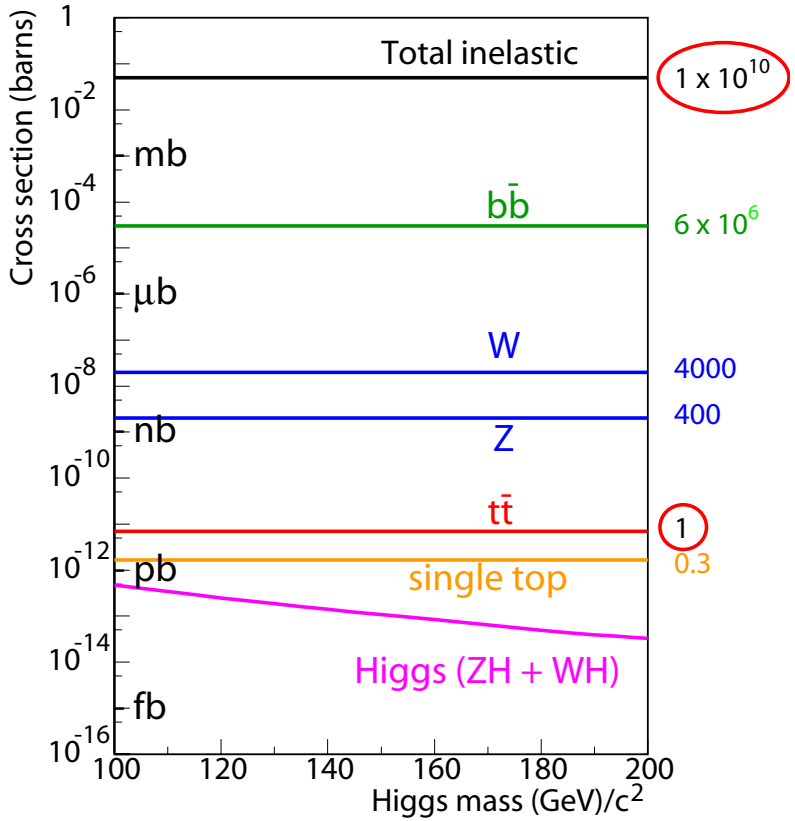
- Multijet events
  ($q\bar{q}$ or gg + gluon radiation)
- W+jets
- Z+jets

Instrumental background

- Physics object misidentification
- Mismeasurement of energies
  thus overestimated $\not\!\!E_T$

Not big in themselves,
but amplified by cross-section.





Analysis (lepton+jets)

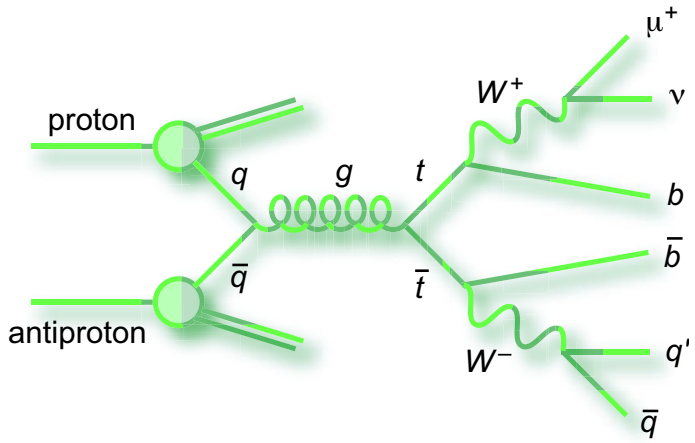
Signal selection

Require

- at least 4 jets
- isolated lepton (not collinear)
- and missing transverse momentum

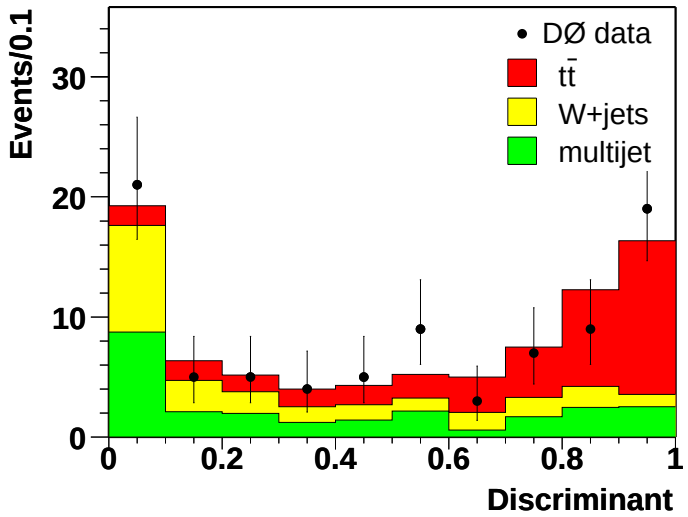
all with $p_T > 20\,\text{GeV}$

Leads to 87 (80) e+jets (μ+jets) events



Background description

- Construct discriminant to distiguish bkg. from signal on statistical basis
- Instrumental bkg. from data
- Fit signal to phys. background ratio



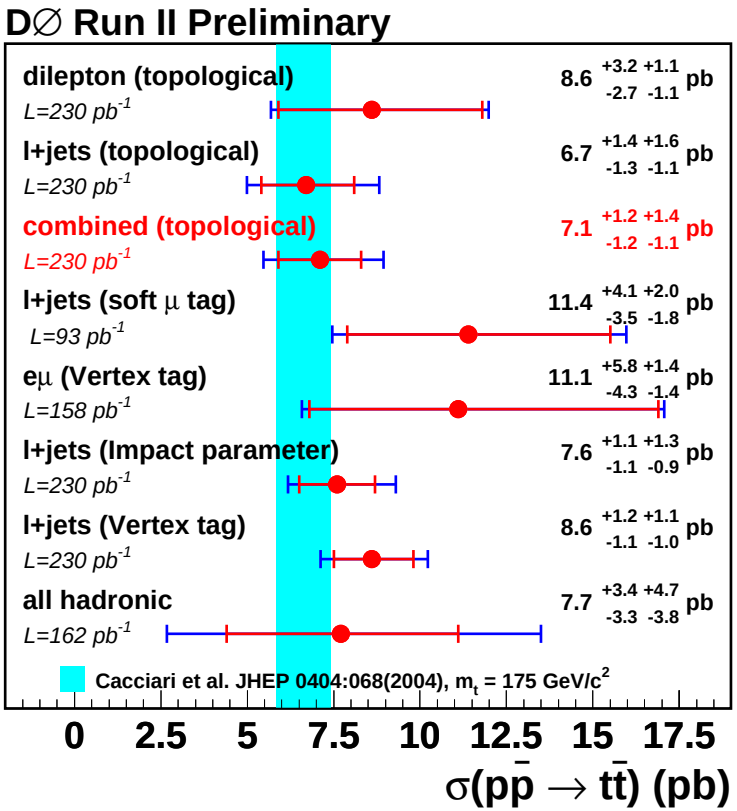
$$\mathcal{D} = S/(S+B)$$

Results on top pair production

- Using $230\,\mathrm{pb}^{-1}$ l+jets channel yields:

$$\sigma_{t\bar{t}} = 6.7^{+1.4}_{-1.3\mathrm{stat}}{}^{+1.6}_{-1.1\mathrm{syst}} \pm 0.4_{\mathrm{lumi}}\,\mathrm{pb}$$

- Various channels & methods explored
- Good consistency and agreement with SM (prediction $\sigma_{t\bar{t}} = 6.77 \pm 0.42\mathrm{pb}$)



Dependence on Grid Computing

Monte Carlo production for signal and background description.
2003/4 data reprocessing for improved $\not\!\!E_T$ and b-tagging in complete dataset.

Single Top Production

The electroweak production meachanism

Signal signatures

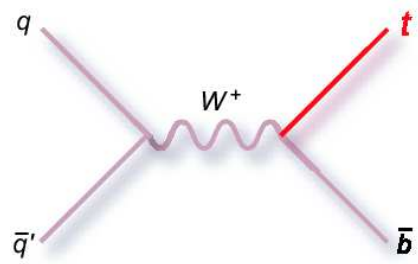
(Consider only $t \to bW \to b + l\nu$.)

s-channel

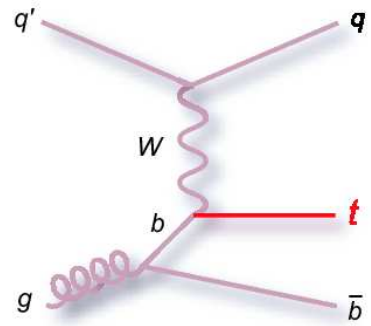
- 2 b-quarks $\to$ 2 b-tagged jets.
- 1 lepton $\to$ electron or muon.
- 1 neutrino $\to$ missing transverse energy

t-channel

- 1 b-quark and 1 light quark $\to$ 2 jets (1 b-tagged).
- 1 lepton $\to$ electron or muon.
- 1 neutrino $\to$ missing transverse energy



s-channel



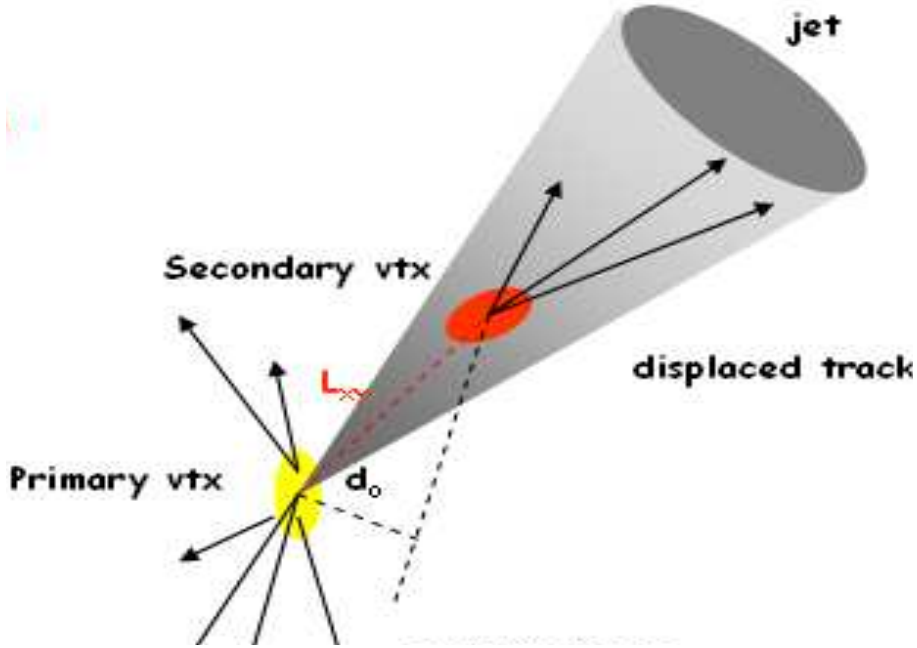
t-channel

B-tagging

B Hadrons can travel several mm before they decay.

One method of b-tagging is through reconstruction of secondary vertices:

- Find track-jets
- Find secondary vertices within jets.
- Determine distance between secondary and primary vertex.

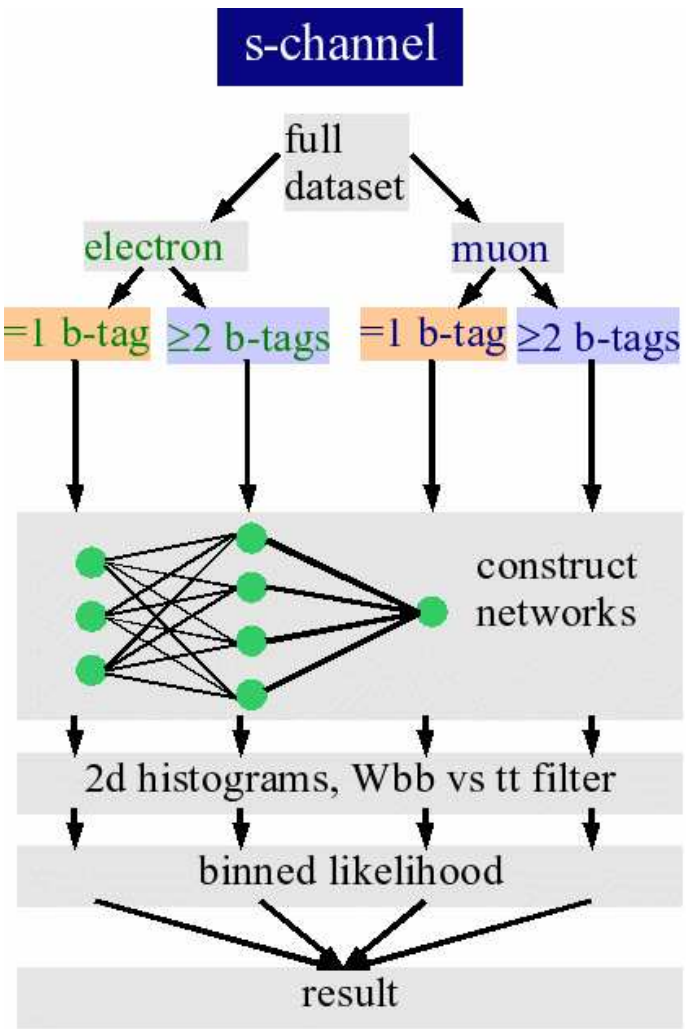


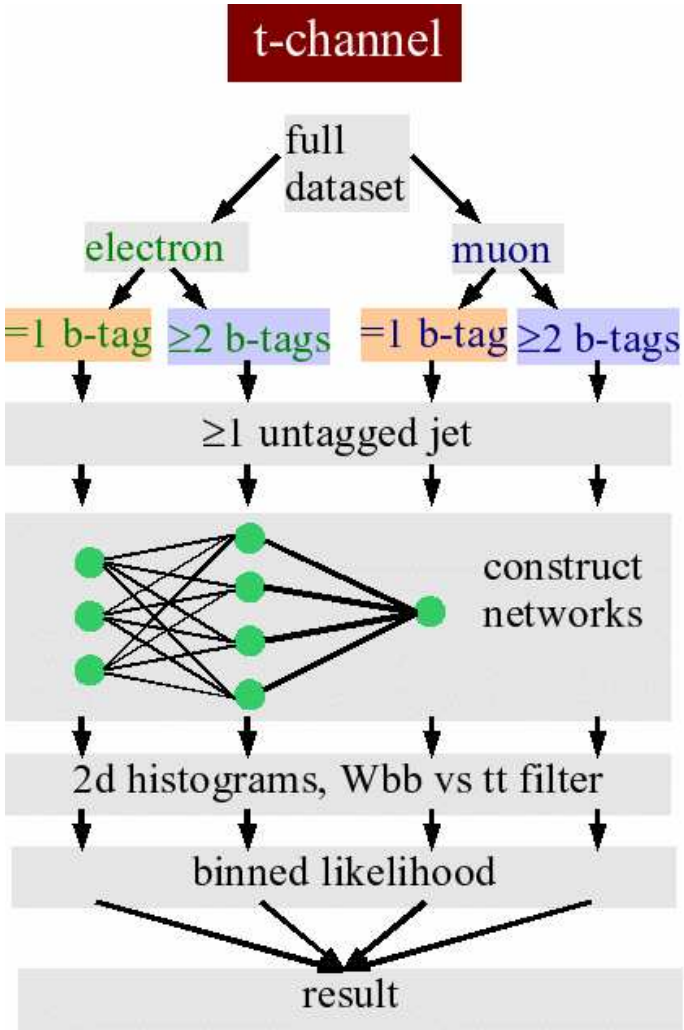
Check the significance of the displacement of the sec. vertex

Tagging efficiencies and purities directly enter into signal efficiencies and purities.

Requires precise reconstruction of tracks as obtained by first reprocessing.

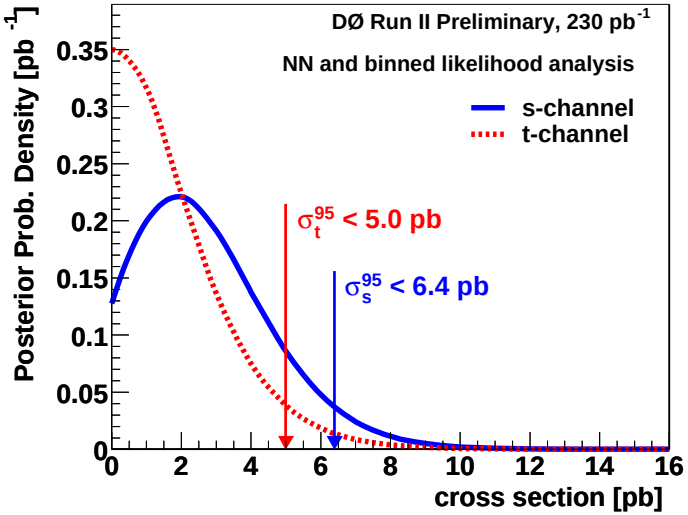
Analysis

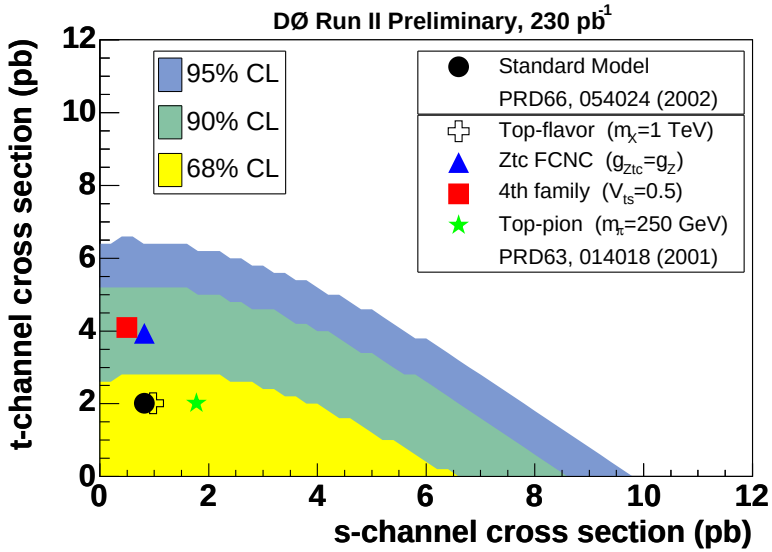

s-channel
full dataset
electron
muon
=1 b-tag
≥2 b-tags
=1 b-tag
≥2 b-tags
construct networks
2d histograms, Wbb vs tt filter
binned likelihood
result


t-channel
full dataset
electron
muon
=1 b-tag
≥2 b-tags
=1 b-tag
≥2 b-tags
≥1 untagged jet
construct networks
2d histograms, Wbb vs tt filter
binned likelihood
result

Results on single top quark production

Using $230\,\mathrm{pb}^{-1}$ DØ set upper limits





s-channel: $\sigma < 6.4\mathrm{pb}$ 95%CL
t-channel: $\sigma < 5.0\mathrm{pb}$ 95%CL

Current worlds best limit

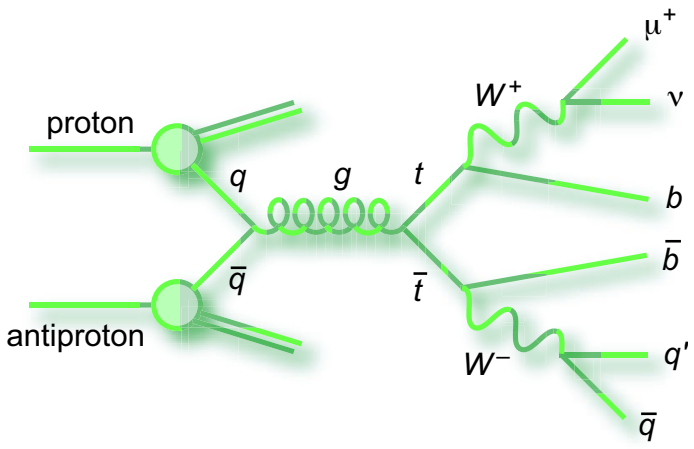
Dependence on Grid Computing

Monte Carlo production for signal and background description
2003/4 data reprocessing for improved b-tagging in complete coherent dataset.

Top Mass

Signal Sample

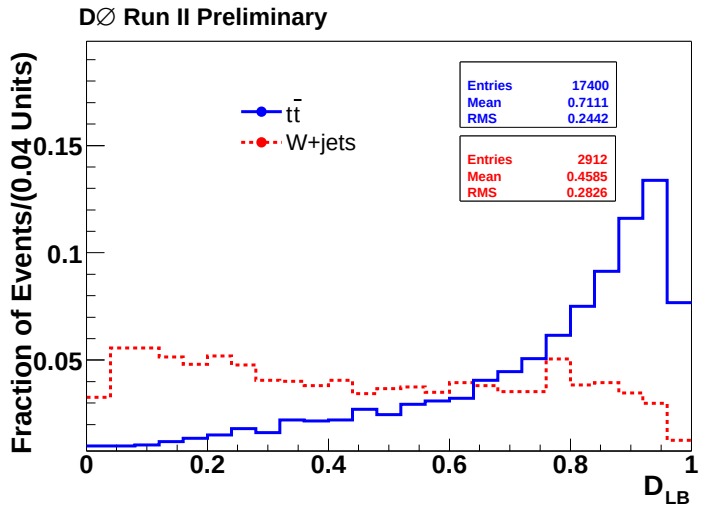
- Semileptonic decay mode (lepton+jets)
- Selection as for cross-section measurement
- Purify sample by cutting on discriminant



Determination of m_t

Find 4-momenta of t-quarks event by event

- Recover ν momentum
- Assign (correctly) $l\nu$ and 4 jets to 2 tops
- Sum measured 4-momenta for particles assigned to each top; $m^2 = E^2 - \vec{p}^2$



Correct assignment and precise momenta crucial

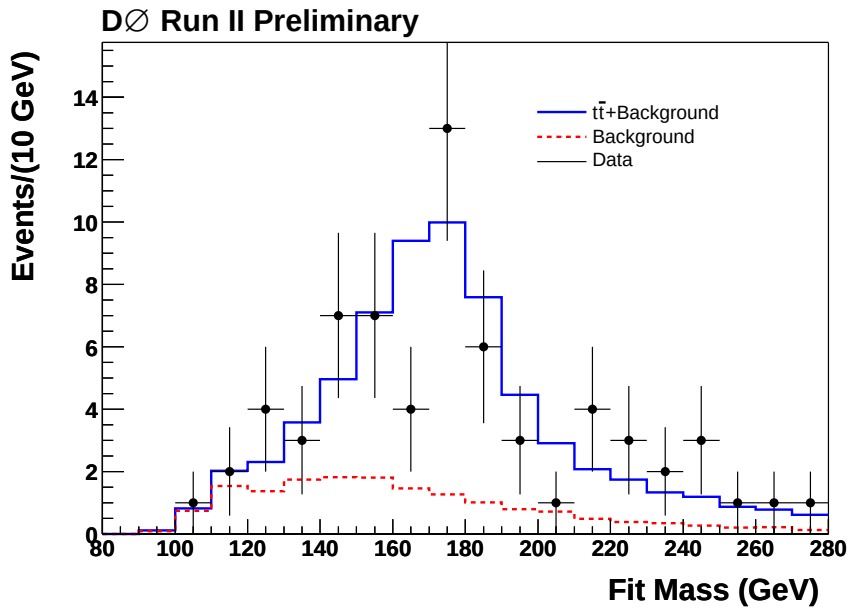
Determination of m_t (2)

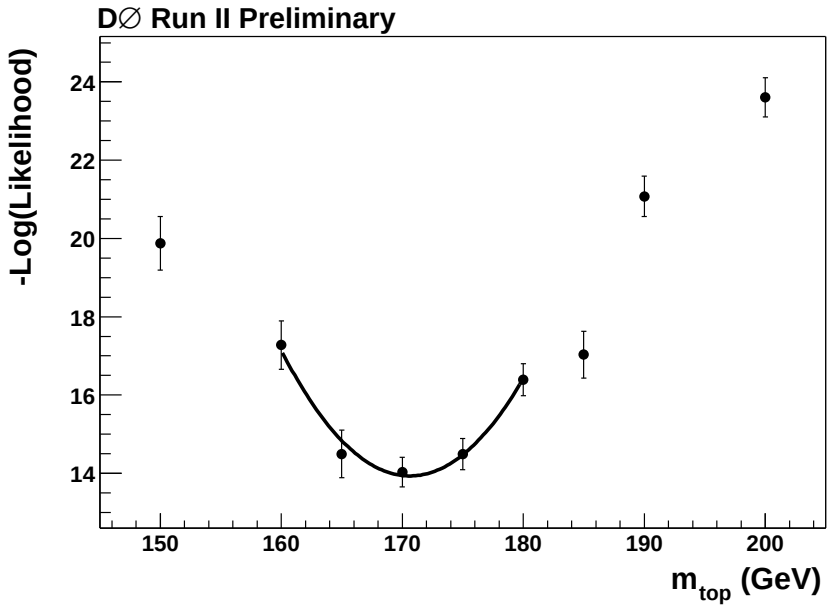
- Build histogramms of observed masses
- Compare data to simulation
  - made for various values of m_t
  - including the expected amount of background
- Use max. likelihood method to extract final result.

Results are obtained separately for

- pure topological selection (all data)
- b-tagged events (less background)

plots for b-tagged sample ⟶





Results on top mass

Template method

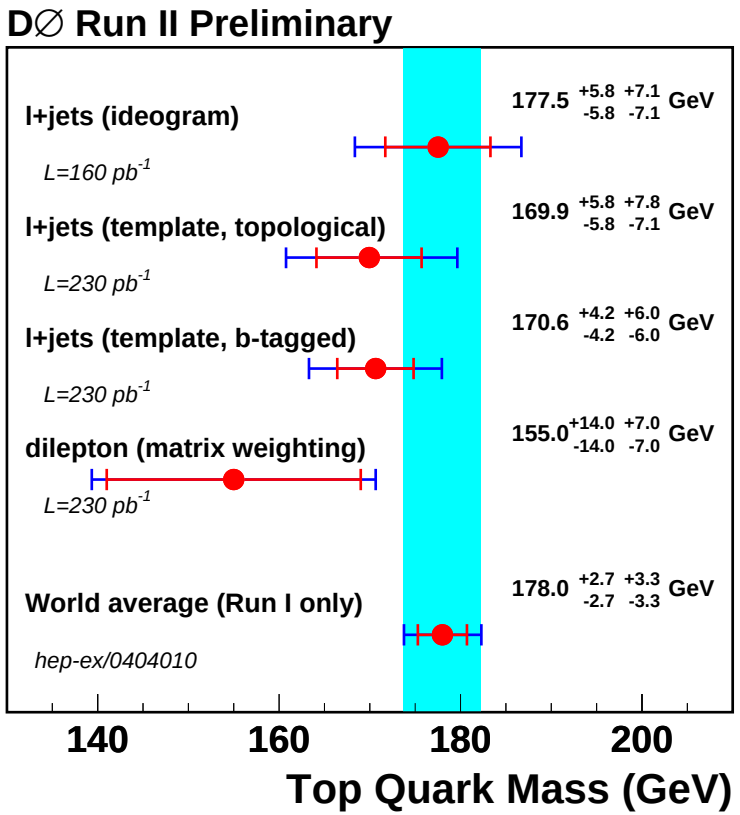
Based on $230\,\mathrm{pb}^{-1}$ of data

$m_t = 169.0 \pm 5.8_{\mathrm{stat}}{}^{+7.8}_{-7.1}{}_{\mathrm{syst}}$ GeV (topo.)

$m_t = 170.6 \pm 4.2_{\mathrm{stat}} \pm 6.0_{\mathrm{syst}}$ GeV (b-tag)

Systematic uncertainties

Dominated by absolute jet energy scale.



Dependence on Grid Computing

Monte Carlo production for signal and background description
2003/4 data reprocessing for improved b-tagging in complete (doubled) dataset.
2005 data reprocessing for improved jet energy scale.

Summary

- DØ's top quark program is producing world class results
  - production cross-sections ($t\bar{t}$ and single top) sent for publication
  - studies on couplings, top charge, branching ratios, ... are underway
- Besides the top quark DØ has a wide program of measurements including all aspects of the standard model as well as direct searches for new physics
- DØ makes heavy use of Grid technologies through SamGrid
  - SAM provides data access for physicists around the globe.
  - JIM allows to utilise (opportunistic) computing resources at many sites.

  These capabilities allow distributed production of simulated events and distributed data reconstruction.

Grid computing enables physics.