Top Quark Mass in Lepton+Jets Decays at the Tevatron

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on behalf of

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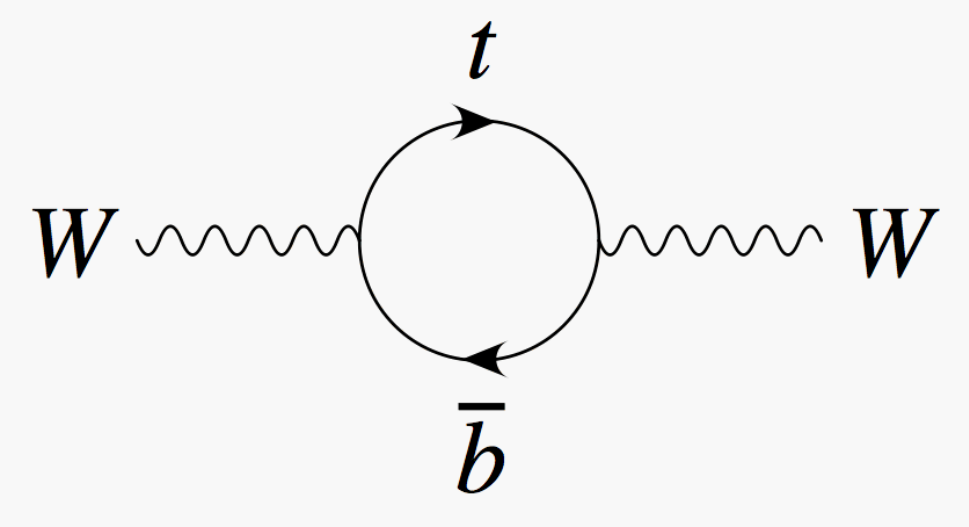
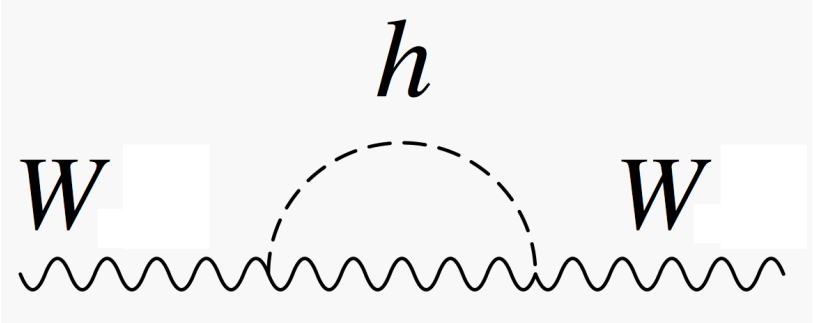
The Top Quark Mass

- free parameter in the Standard Model

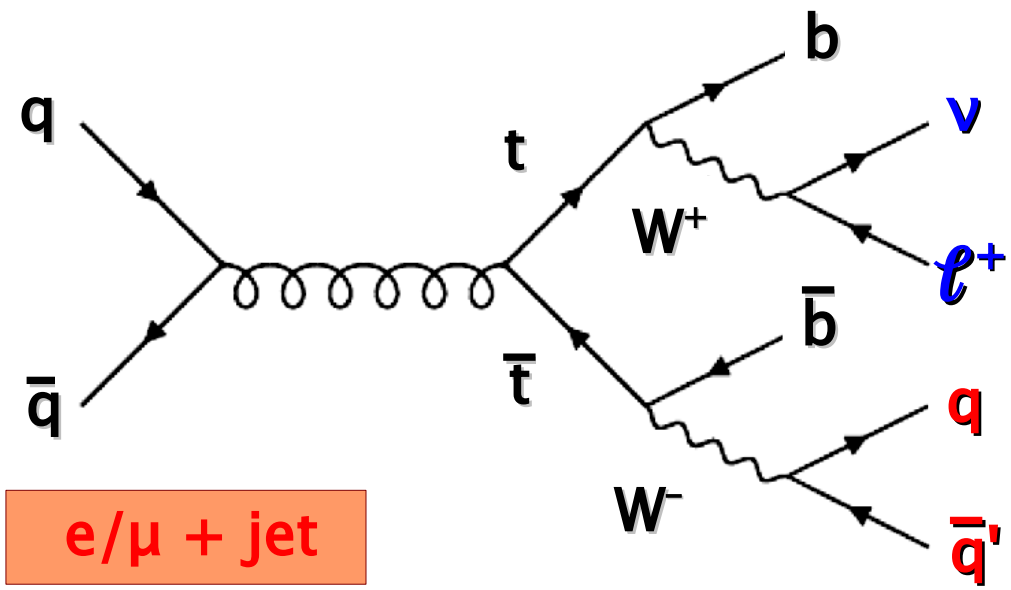
- check the self-consistency of the Standard Model in combination with W mass measurement



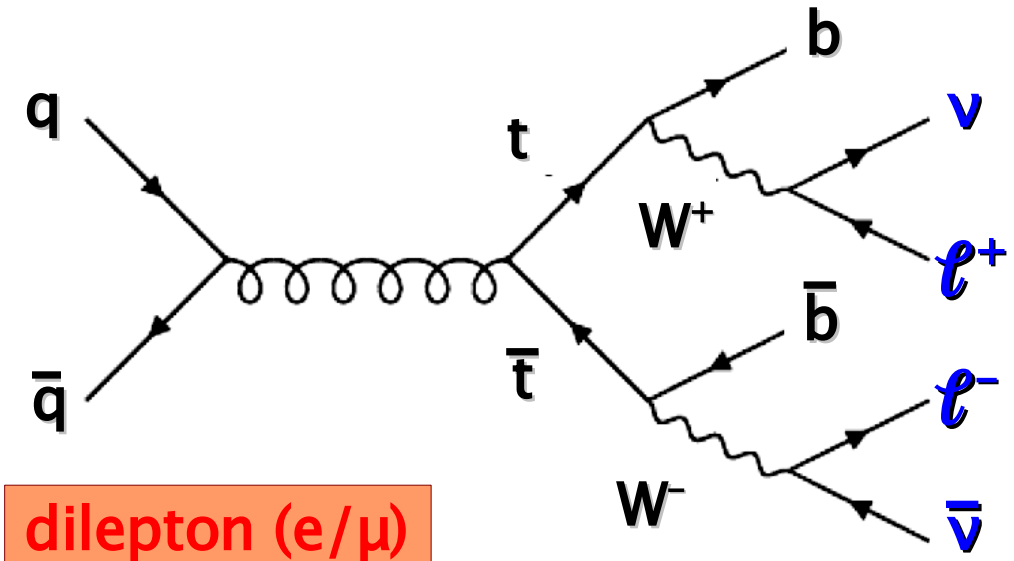


Top anti-top signatures

signal



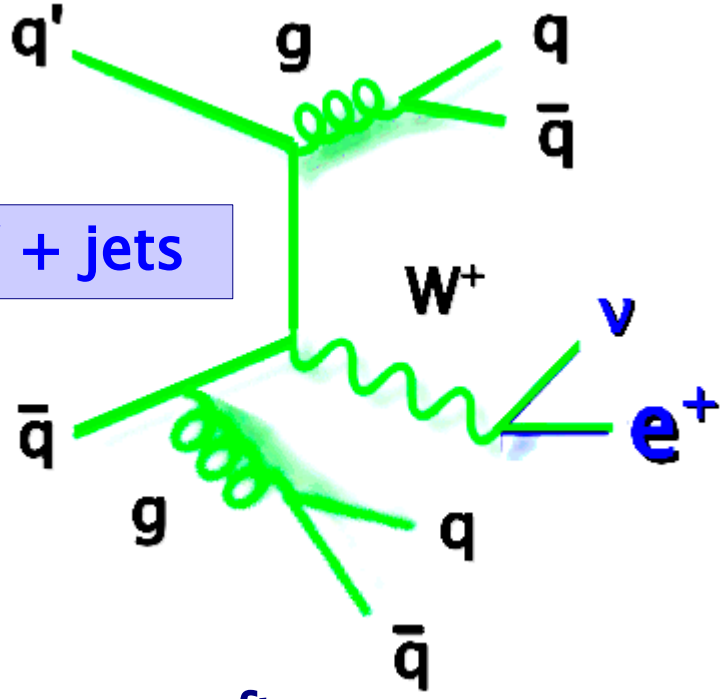
e/μ + jet



dilepton (e/μ)

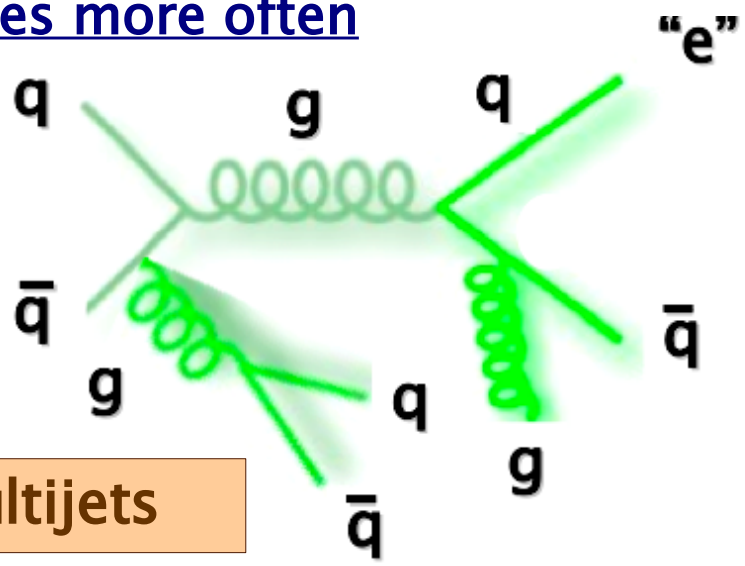
background

3000 times more often



W + jets

10^{10} times more often



multijets

Outline

Templates

Matrix Elements

Cross Section

Summary

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Matrix Elements

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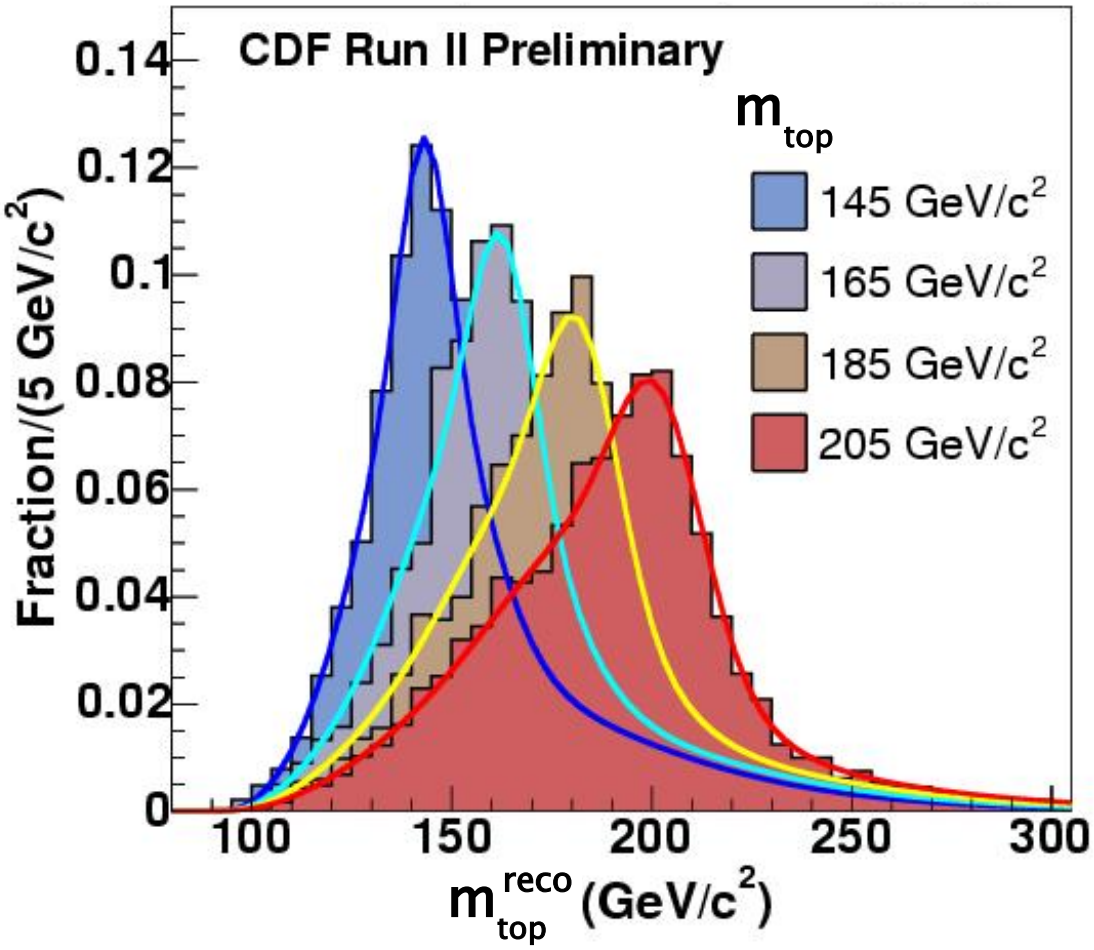
Summary

Extraction techniques: template method

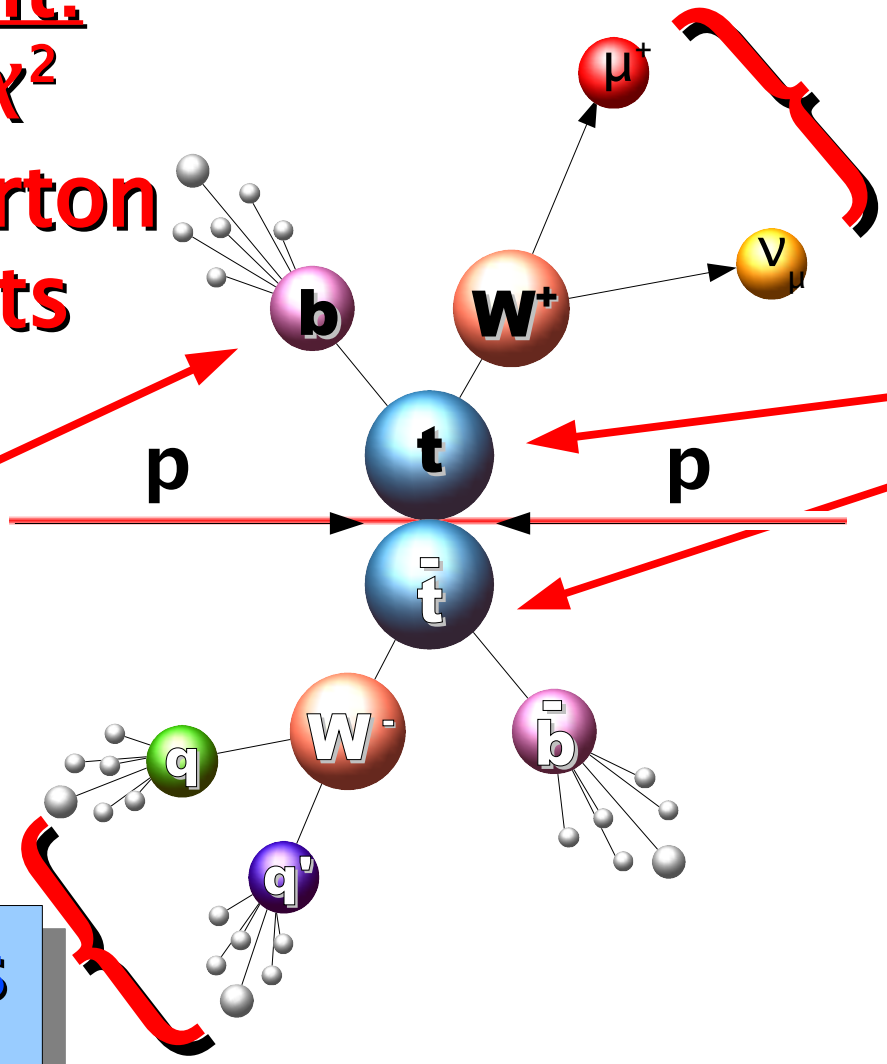
- use variables strongly correlated with m_{top}
- compare data to MC with different m_{top} hypotheses

l+jets



Top mass reconstruction

constrained kinematic fit:
minimize χ^2 for all jet–parton assignments



invariant mass m_W (2 ν solutions)

$m_{top} = m_{anti\text{-}top}$

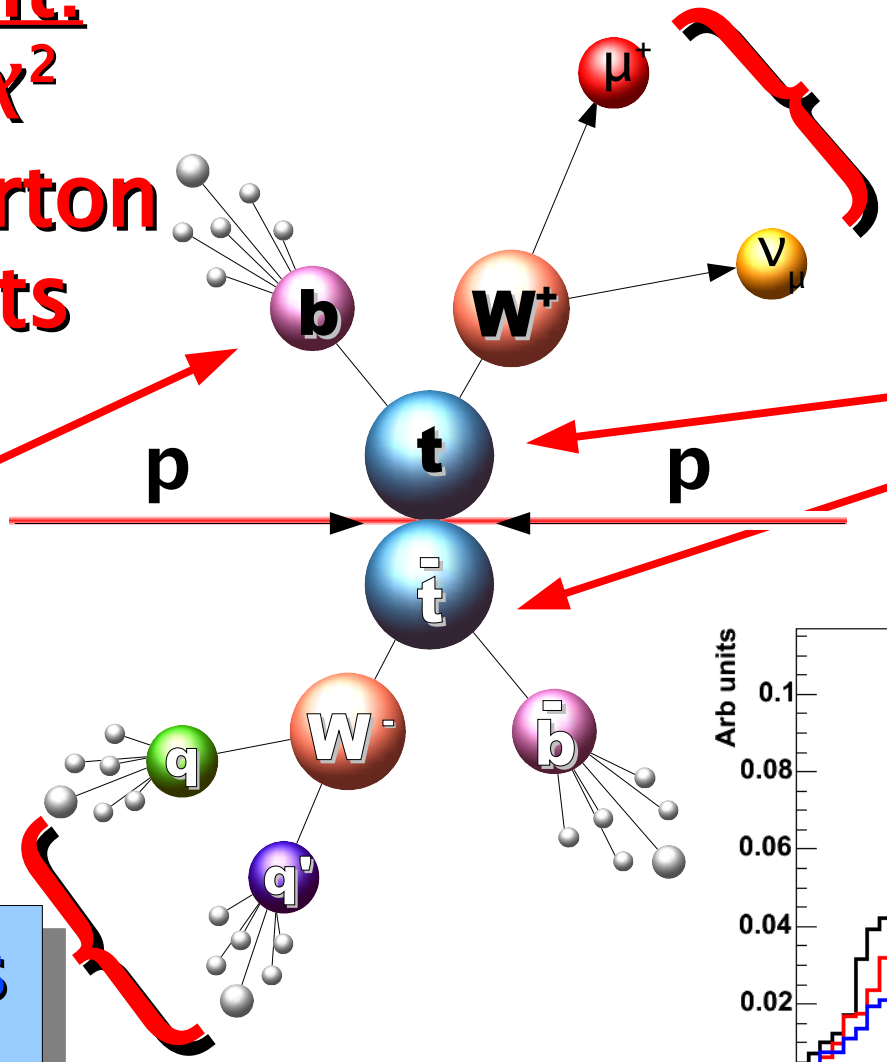
b–tag

invariant mass m_W

Top mass reconstruction

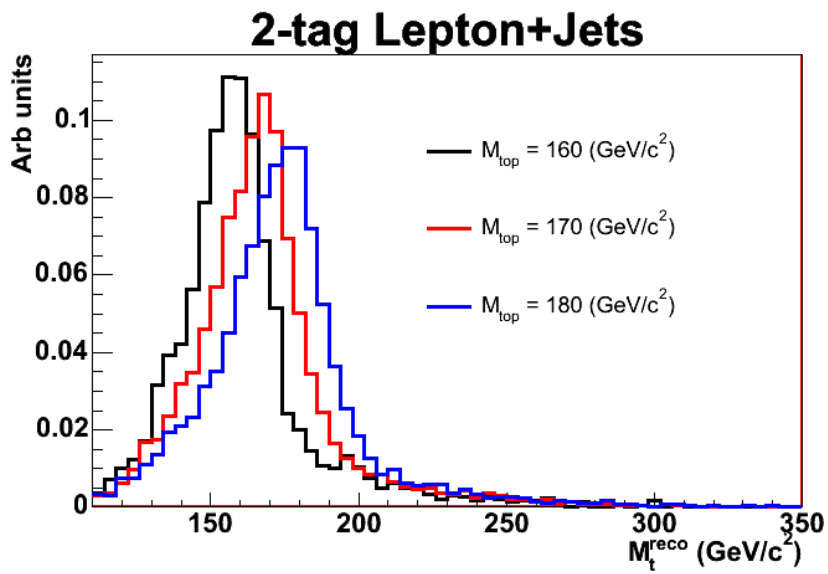
constrained kinematic fit: minimize χ^2 for all jet–parton assignments

invariant mass m_W (2 ν solutions)



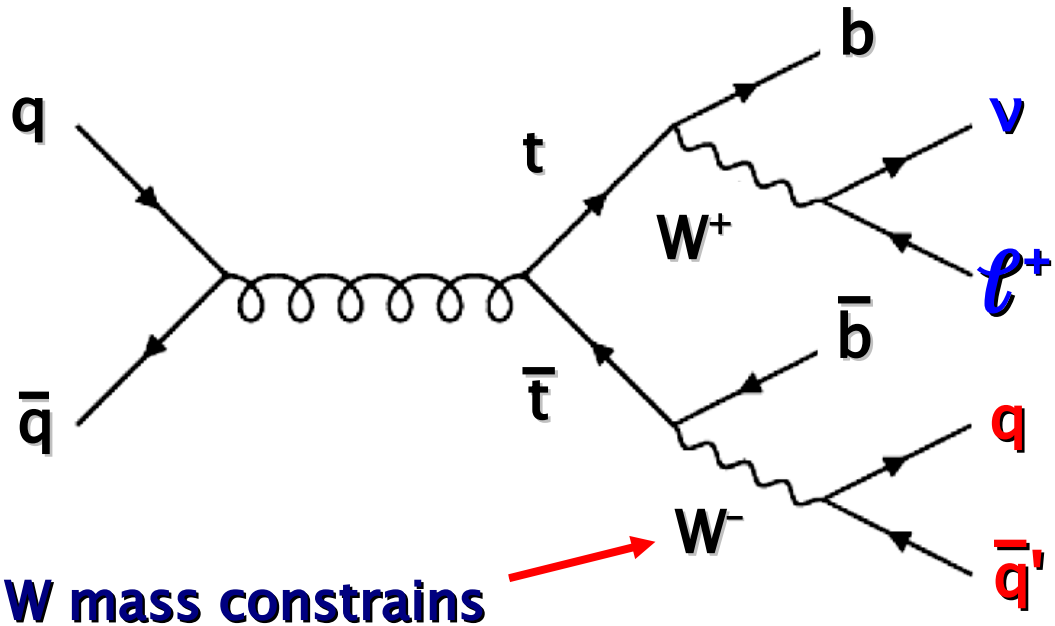
b–tag

$m_{top} = m_{anti\text{-}top}$



invariant mass m_W

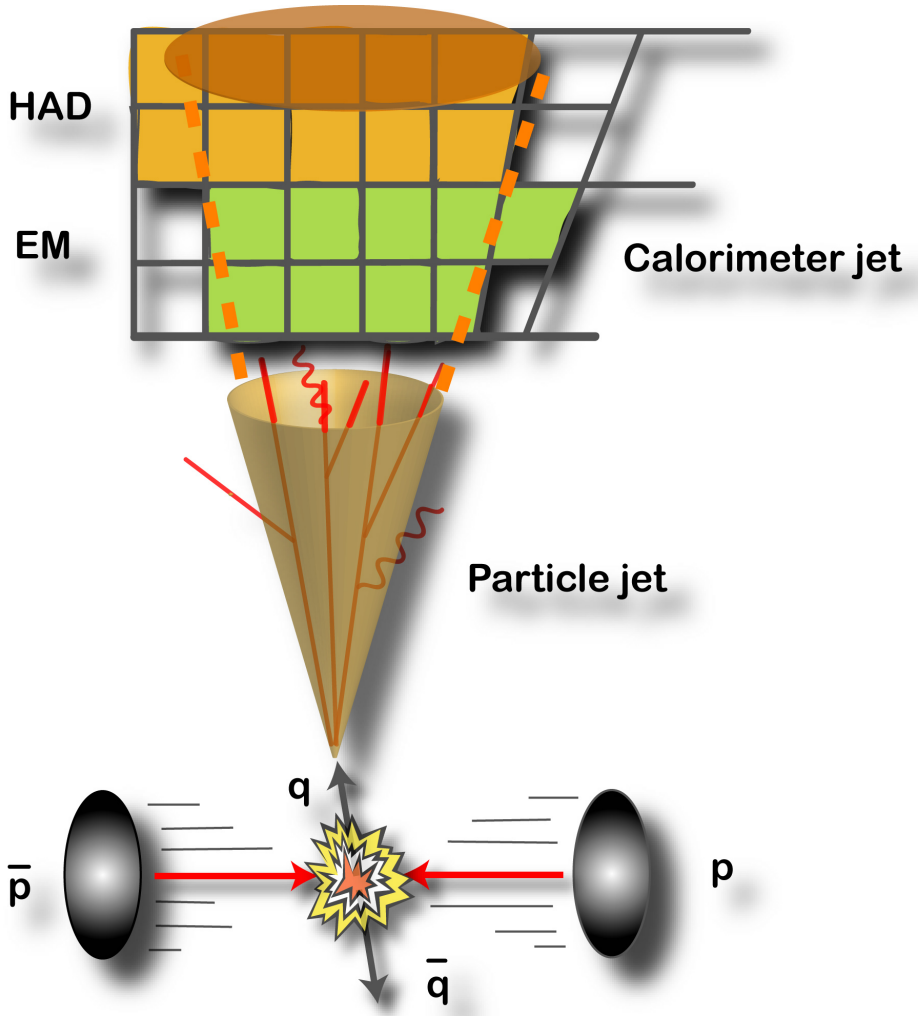
Main systematics: jet energy scale



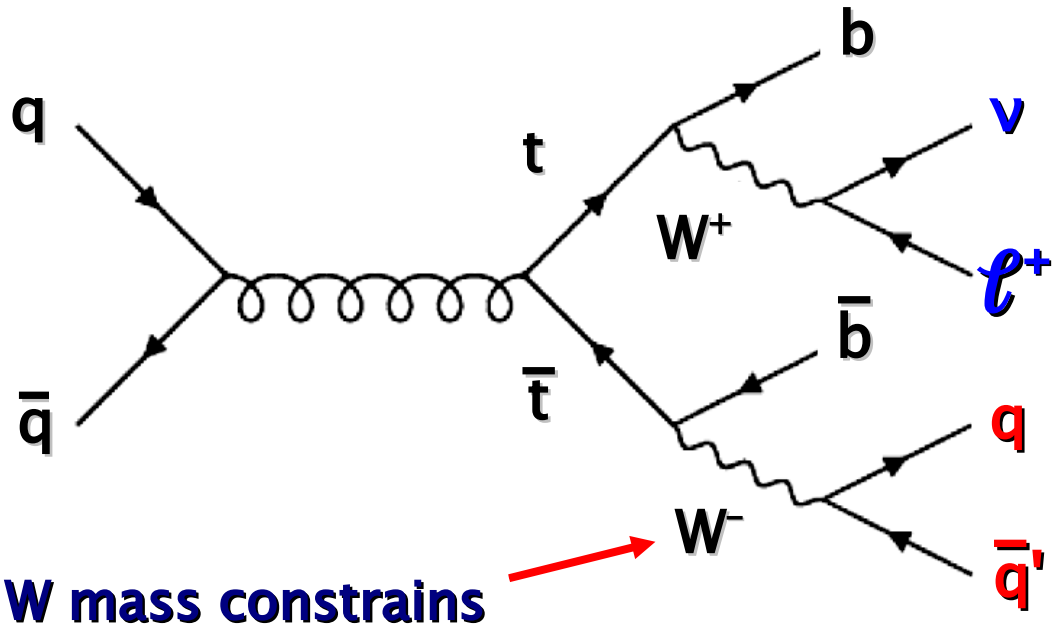
W mass constrains jet energy scale

jet energy scale:

translate jet into parton energy

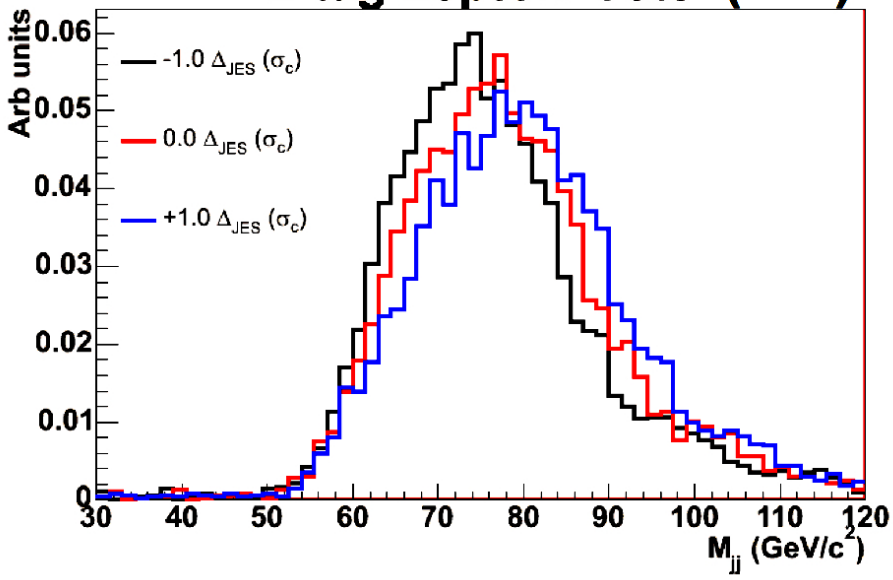


Main systematics: jet energy scale



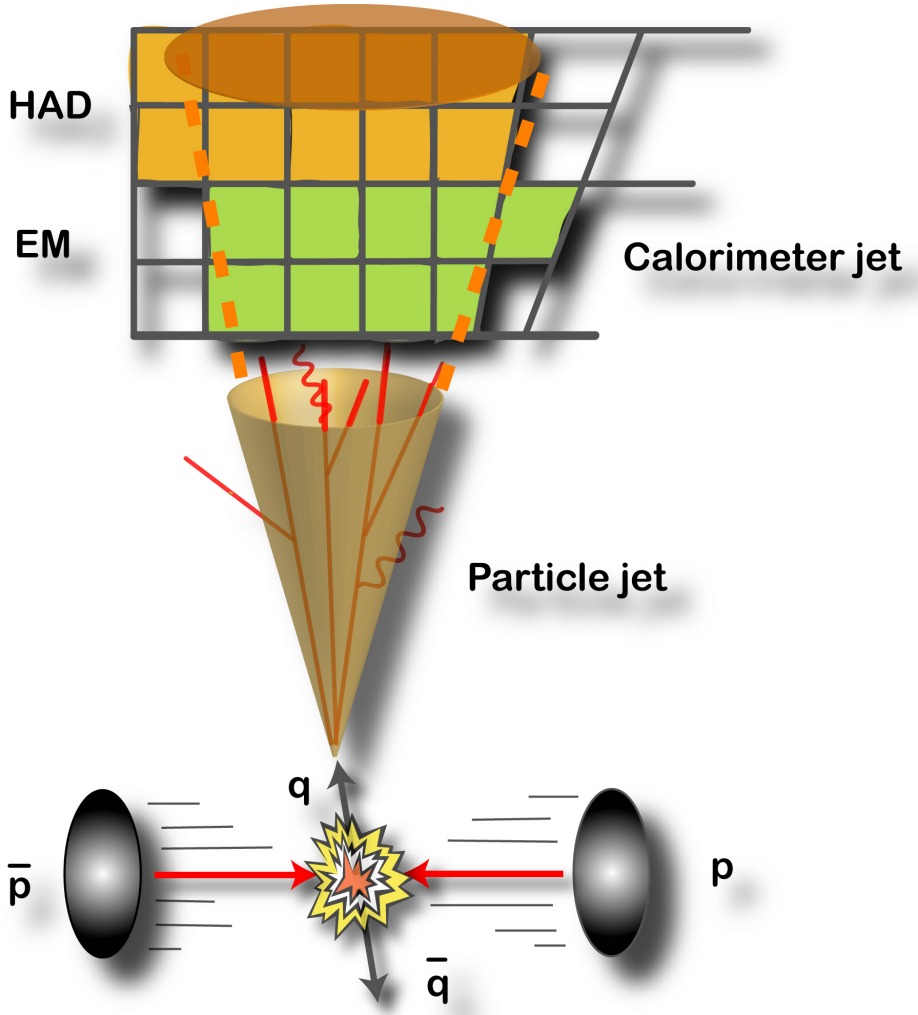
W mass constrains jet energy scale

2-tag Lepton+Jets (MC)



jet energy scale:

translate jet into parton energy

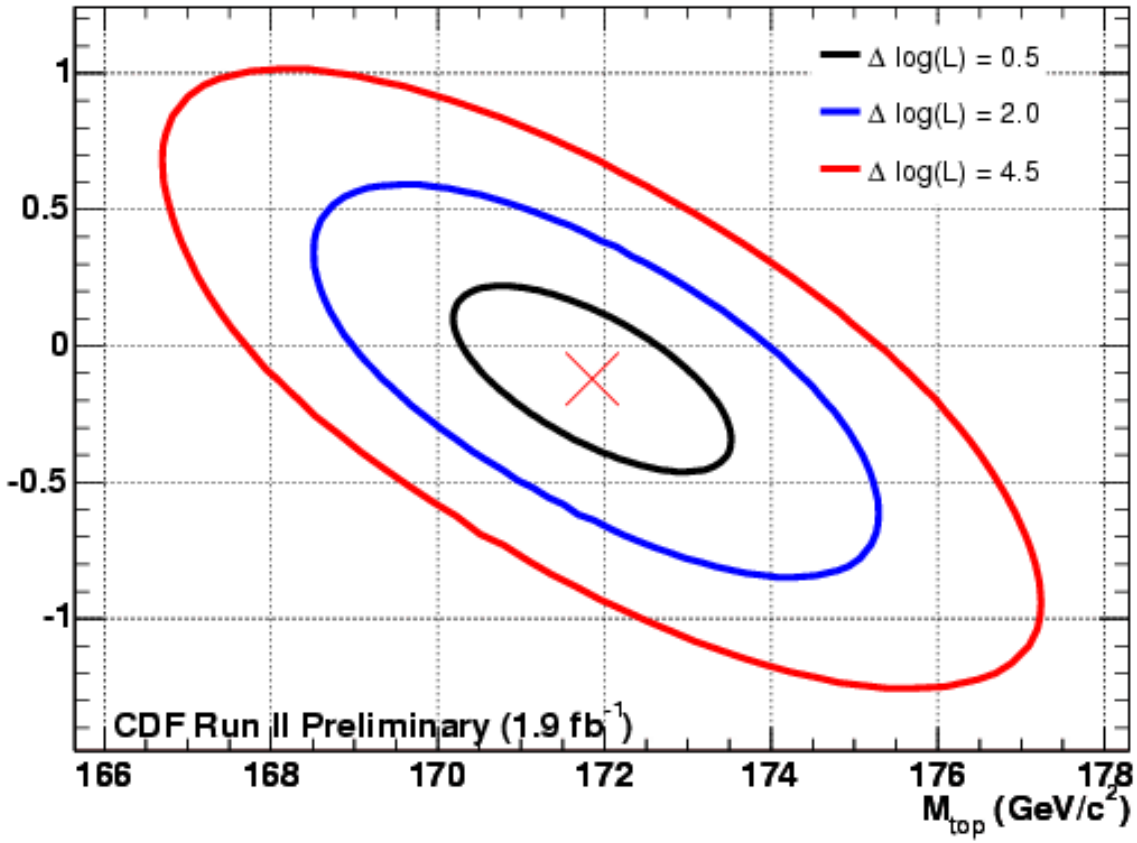


Results

1.9 fb^{-1}

- Probability density functions with Kernel Density Estimates
- maximum Likelihood fit using signal and background pdfs

Δ jet energy scale



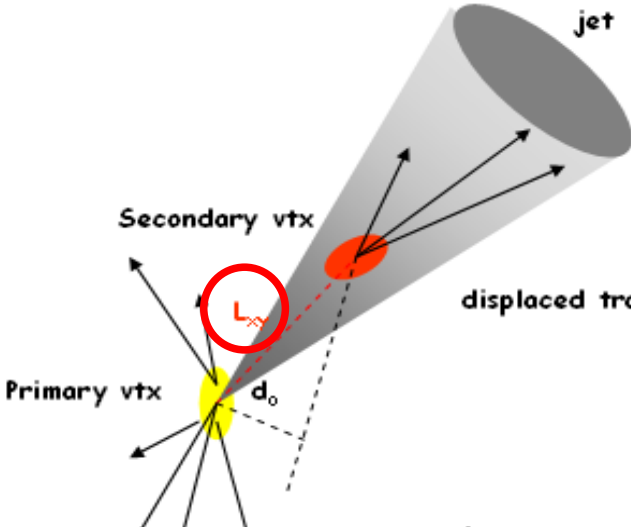
- l+jets/dilepton combined

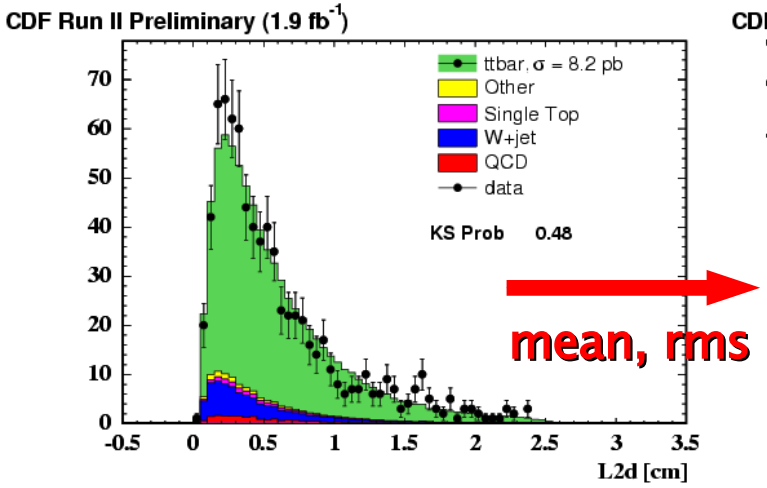
m_{top} = 171.9 ± 1.7 (stat+JES) ± 1.0 (syst) GeV

±1.1%

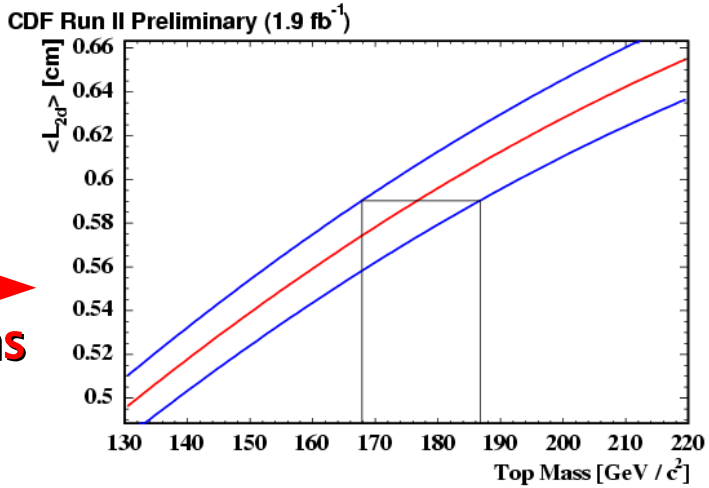
Alternative template method

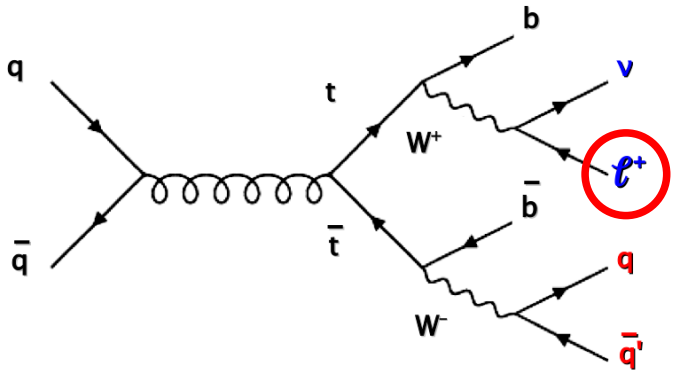
- Quantities with minimal dependence on jet energy scale

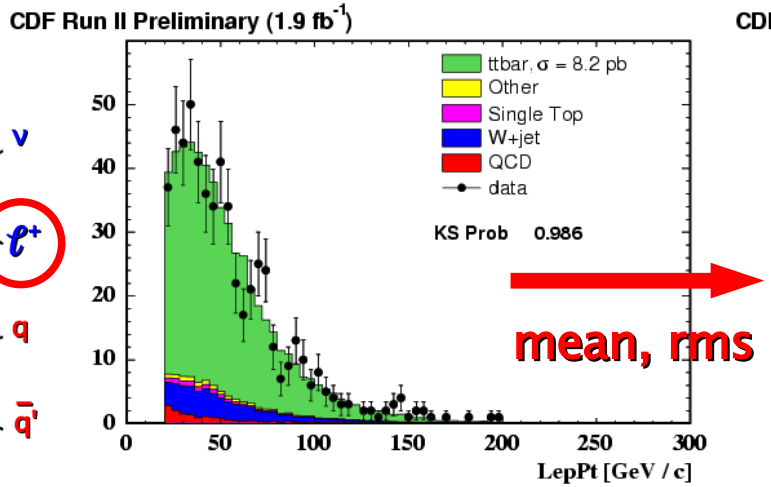




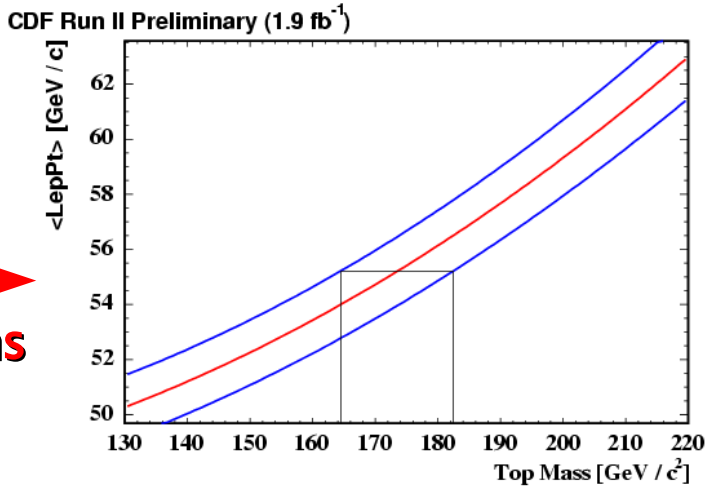
mean, rms







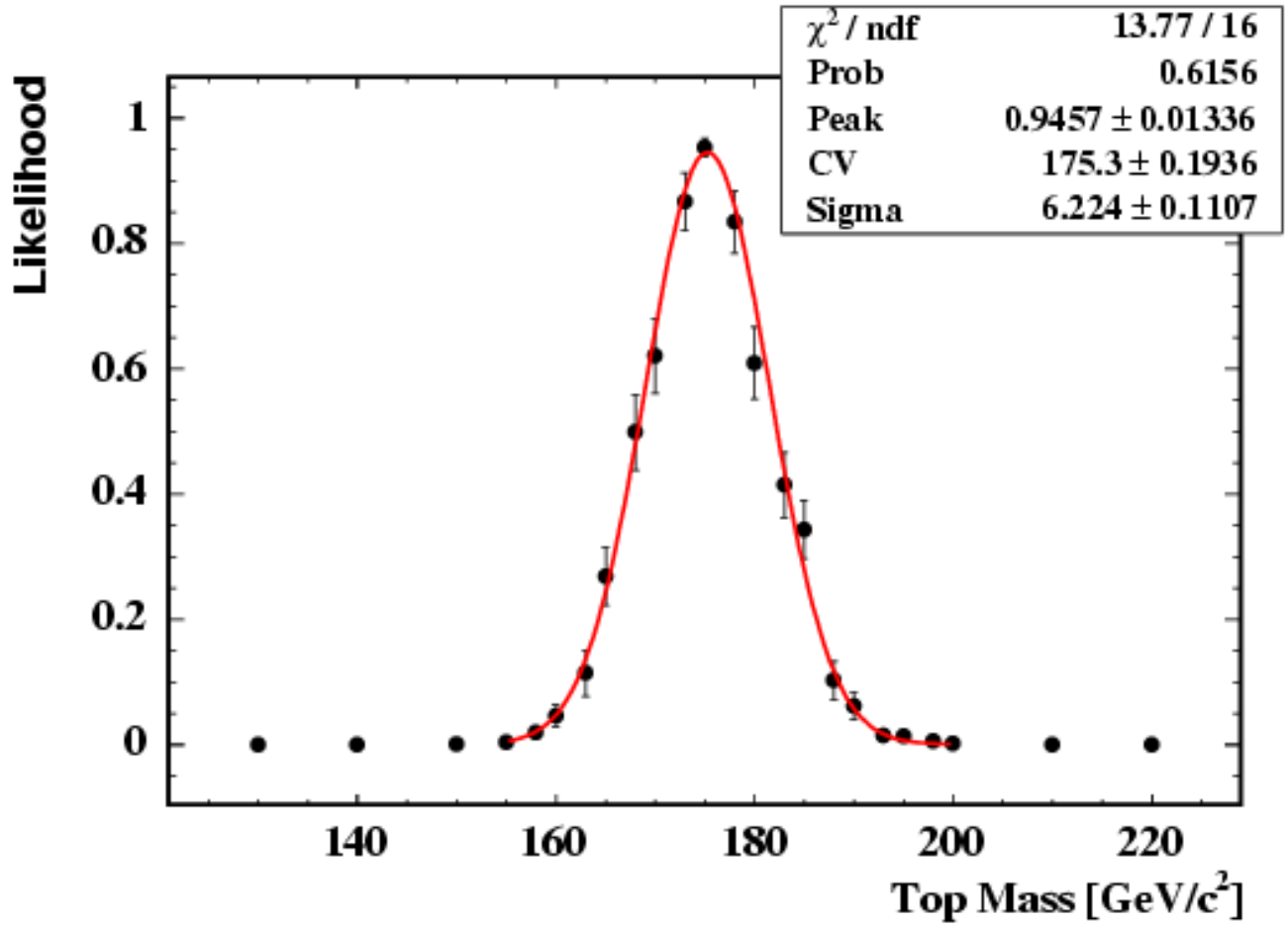
mean, rms



Results

1.9 fb^{-1}

- Likelihood fit for data using mean values of both variables



m_{top} = 176.7 ± 6.2 (stat) ± 3.0 (syst) GeV

±3.9%

Outline

Templates

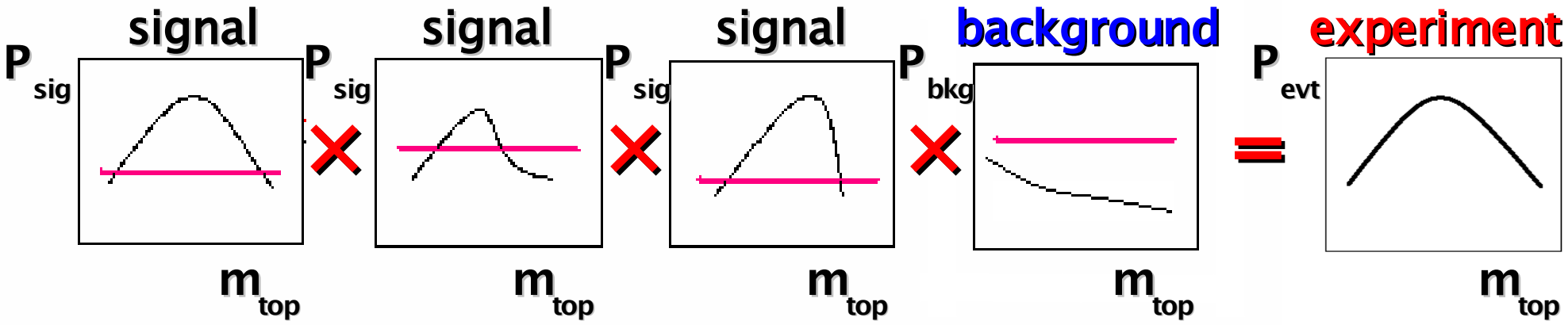
Matrix Elements

Cross Section

Summary

Extraction techniques: matrix element

- **probability densities for every event as function of m_{top}**



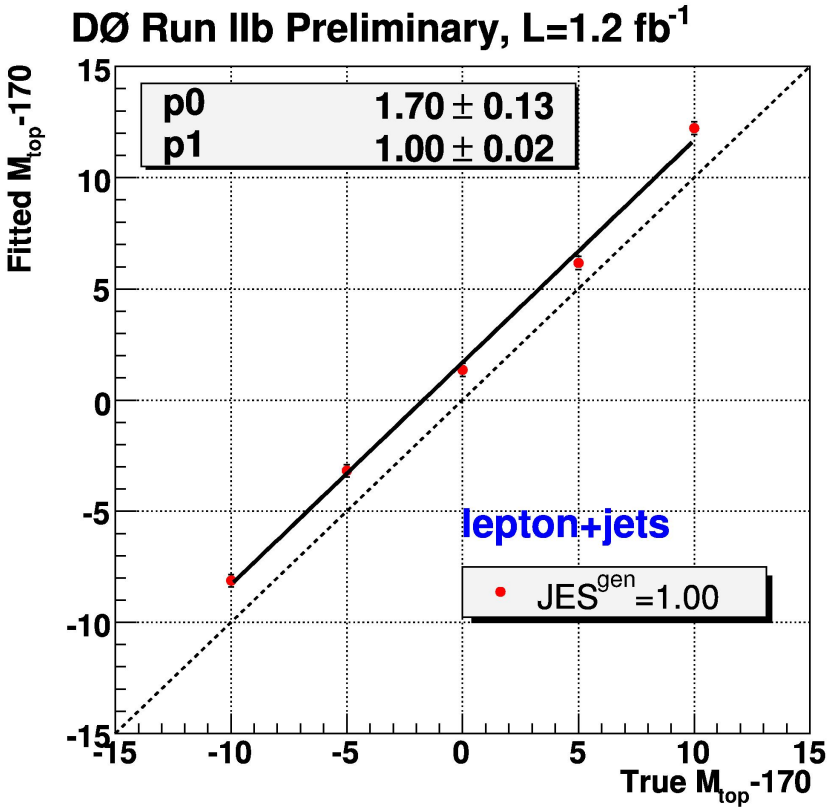
$$P_{sig}(x; m_{top}, JES) = \underbrace{Acc(x)}_{\text{Acceptance (selection, trigger,...)}} \times \frac{1}{\sigma} \int d^n \underbrace{\sigma(y; m_{top})}_{\text{LO-Matrix element x phase space}} \underbrace{dq_1\, dq_2\, f(q_1)\, f(q_2)}_{\text{PDF's}} \underbrace{W(x, y; JES)}_{\text{Transfer Functions (Probability to measure x when y was produced)}}$$

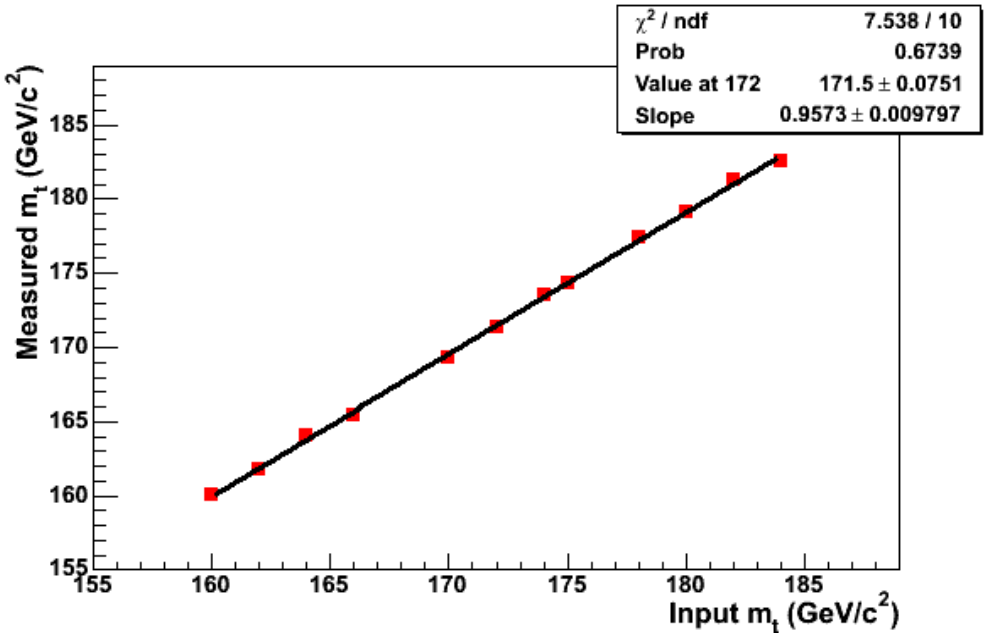
- **maximum Likelihood fit:**

$$L(x_1, .., x_n; m_{\text{top}}, JES, f_{\text{top}}) = \prod_{i=1}^{n} P_{\text{evt}}(x_i; m_{\text{top}}, JES, f_{\text{top}})$$

Calibration: ensemble tests

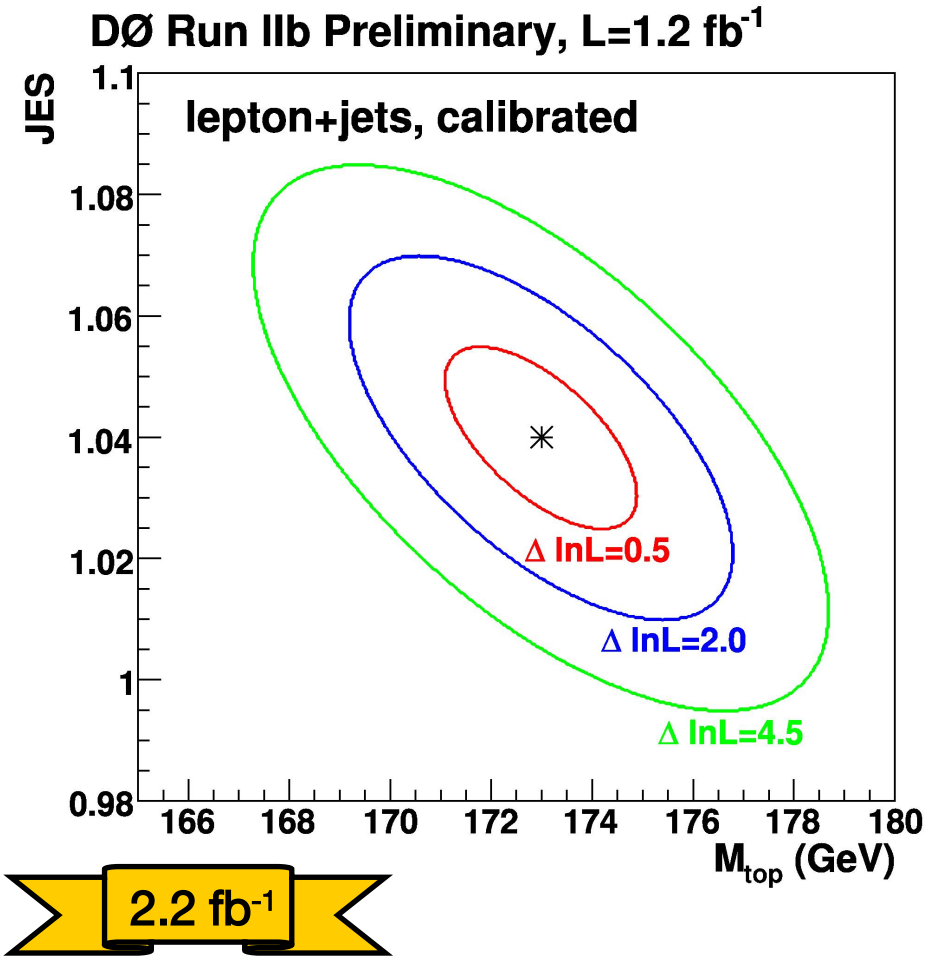
- pseudo experiments: compare measured mass with generated
- correct for differences: calibration curve





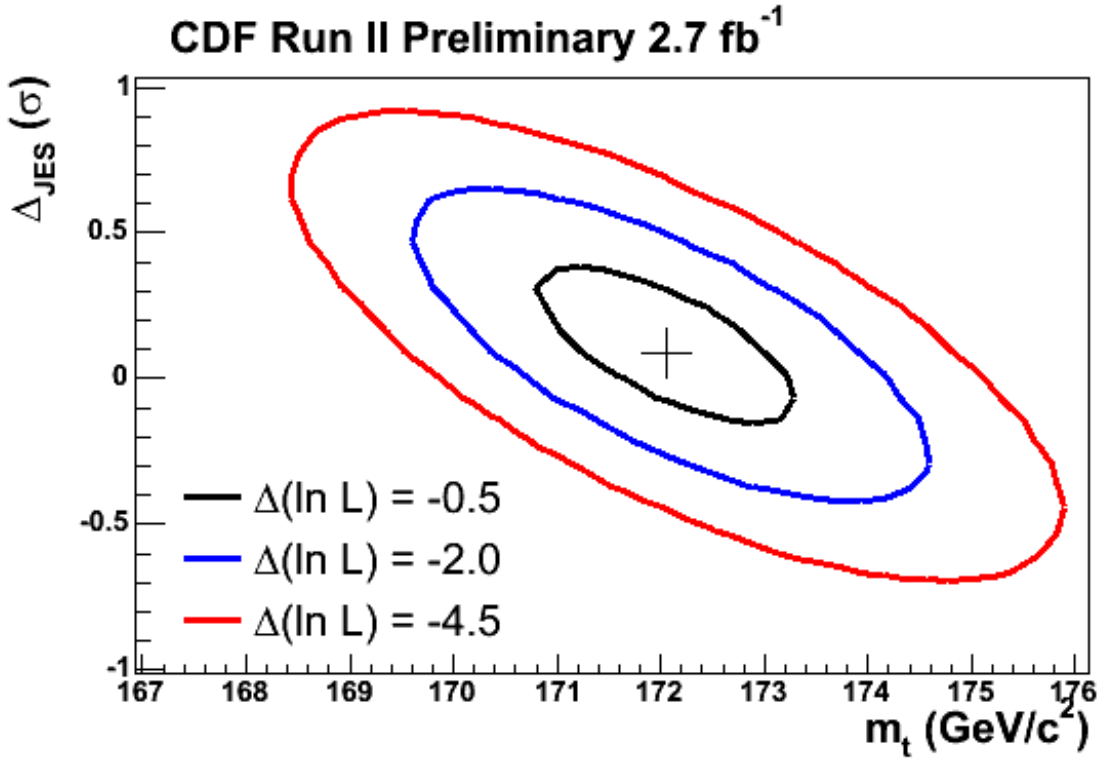
- rely on MC simulations (ALPGEN, PYTHIA) in detail...

Results



2.2 fb^{-1}

2.7 fb^{-1}



m_{top} = 172.2 ± 1.0 (stat) ± 1.4 (syst) GeV

±1.0%

m_{top} = 172.2 ± 1.0 (stat) ± 1.3 (syst) GeV

±1.0%

Systematics apart from simultaneous JES

Source	Uncertainty on top mass (GeV/c^2)
Signal modeling	±0.40
Background modeling	±0.08
W heavy flavor factor	±0.07
b fragmentation function	±0.10
PDF uncertainty	±0.24
Residual JES uncertainty	±0.03
Relative b/light Jet Energy Scale	±0.82
b-tagging efficiency	±0.16
Trigger efficiency	±0.09
Jet energy resolution	±0.30
Multijet background	±0.20
MC calibration	±0.14
Total	±1.0

Systematic source	Systematic uncertainty (GeV/c^2)
Calibration	0.1
MC generator	0.5
ISR and FSR	0.3
Residual JES	0.5
b-JES	0.4
Lepton P_T	0.2
Pileup	0.1
PDFs	0.2
Background	0.4
Total	1.0

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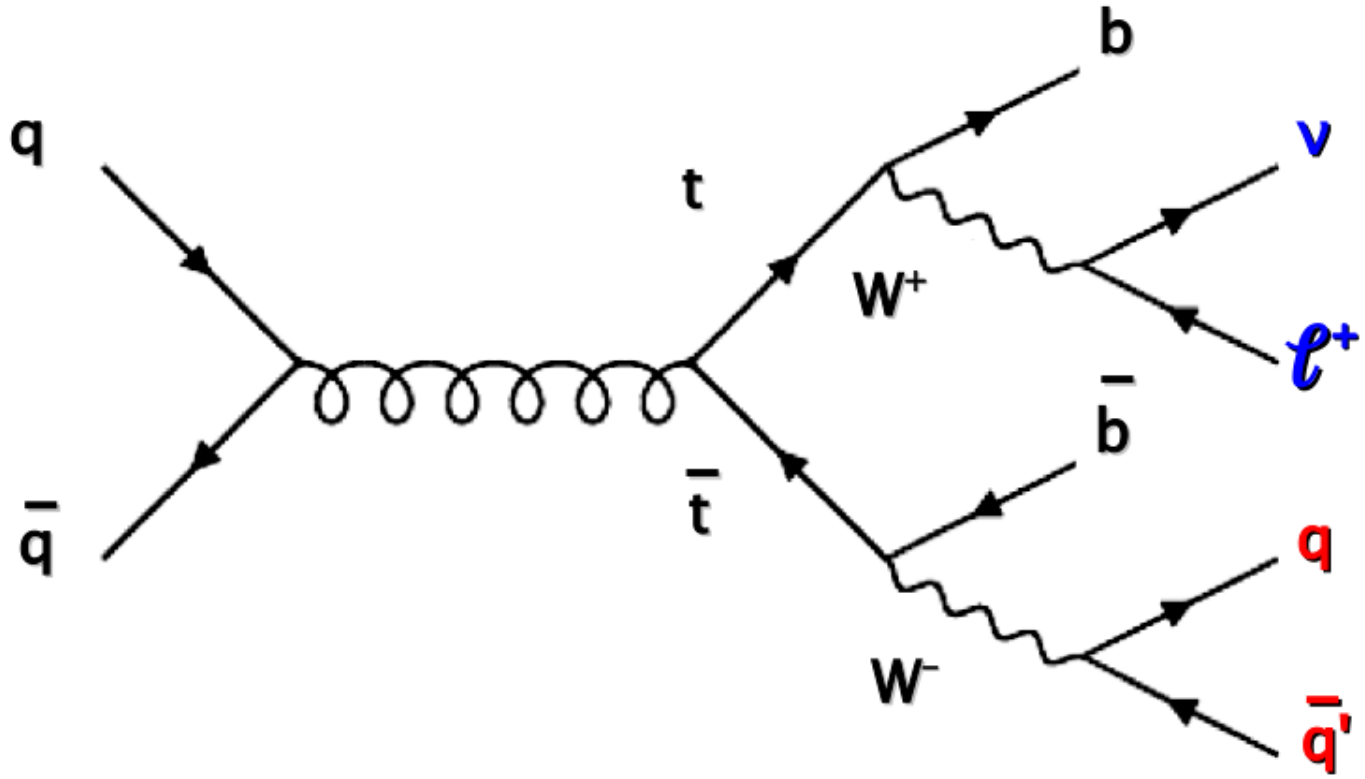
- work together to get uniform treatment where possible

Top mass interpretation

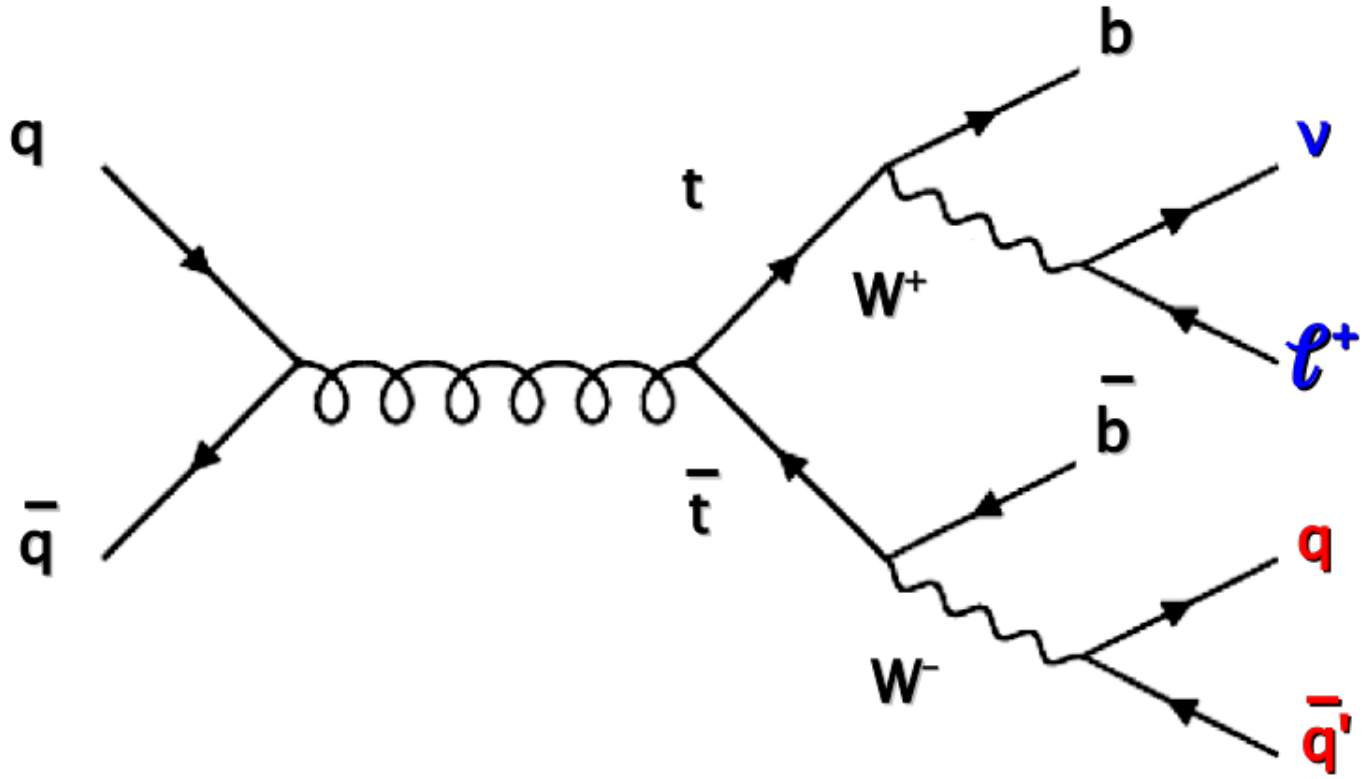
the concept of quark mass is convention-dependent!



Top mass interpretation

the concept of quark mass is convention-dependent!

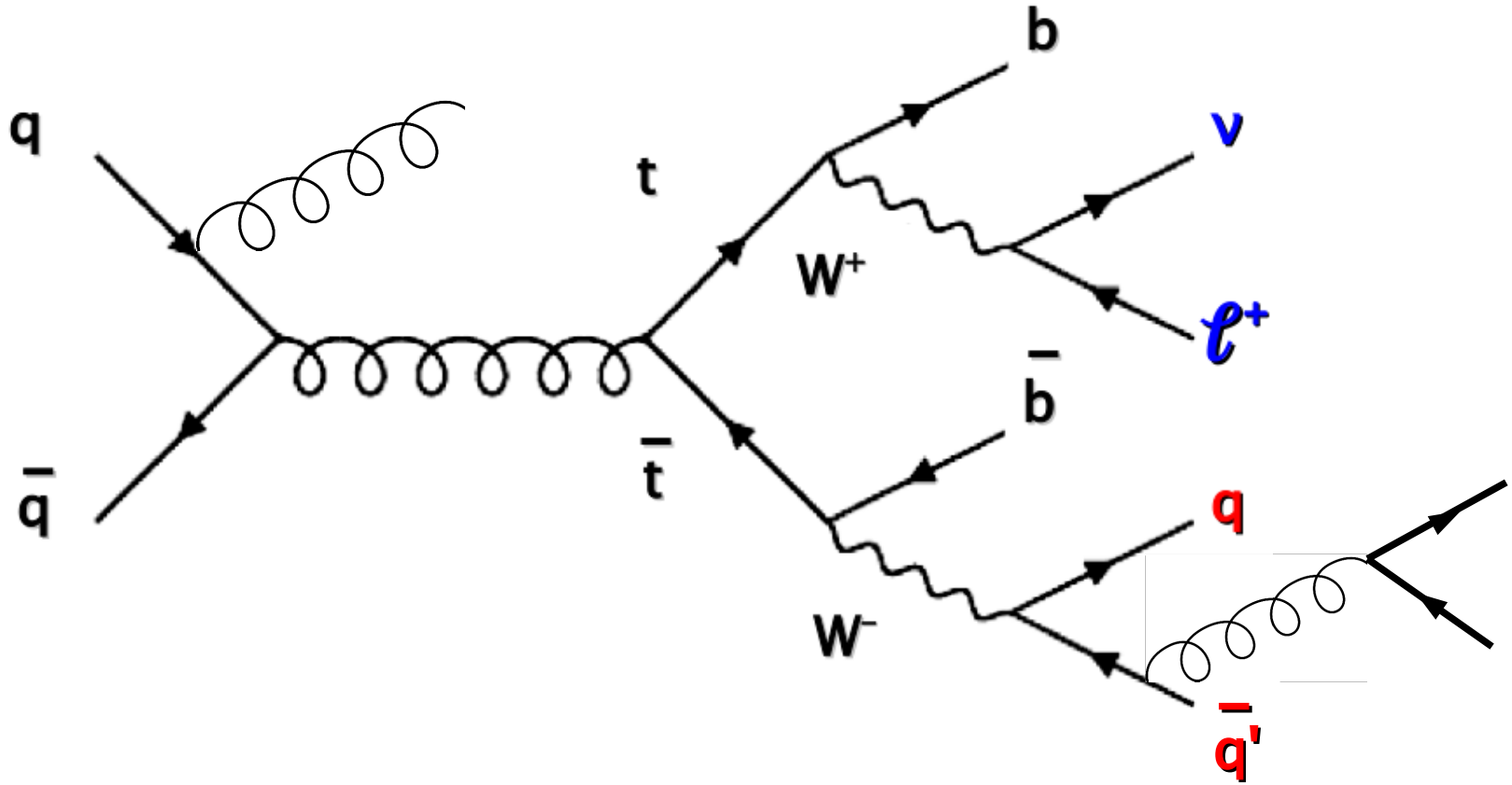
- **matrix element in LO QCD**



Top mass interpretation

the concept of quark mass is convention-dependent!

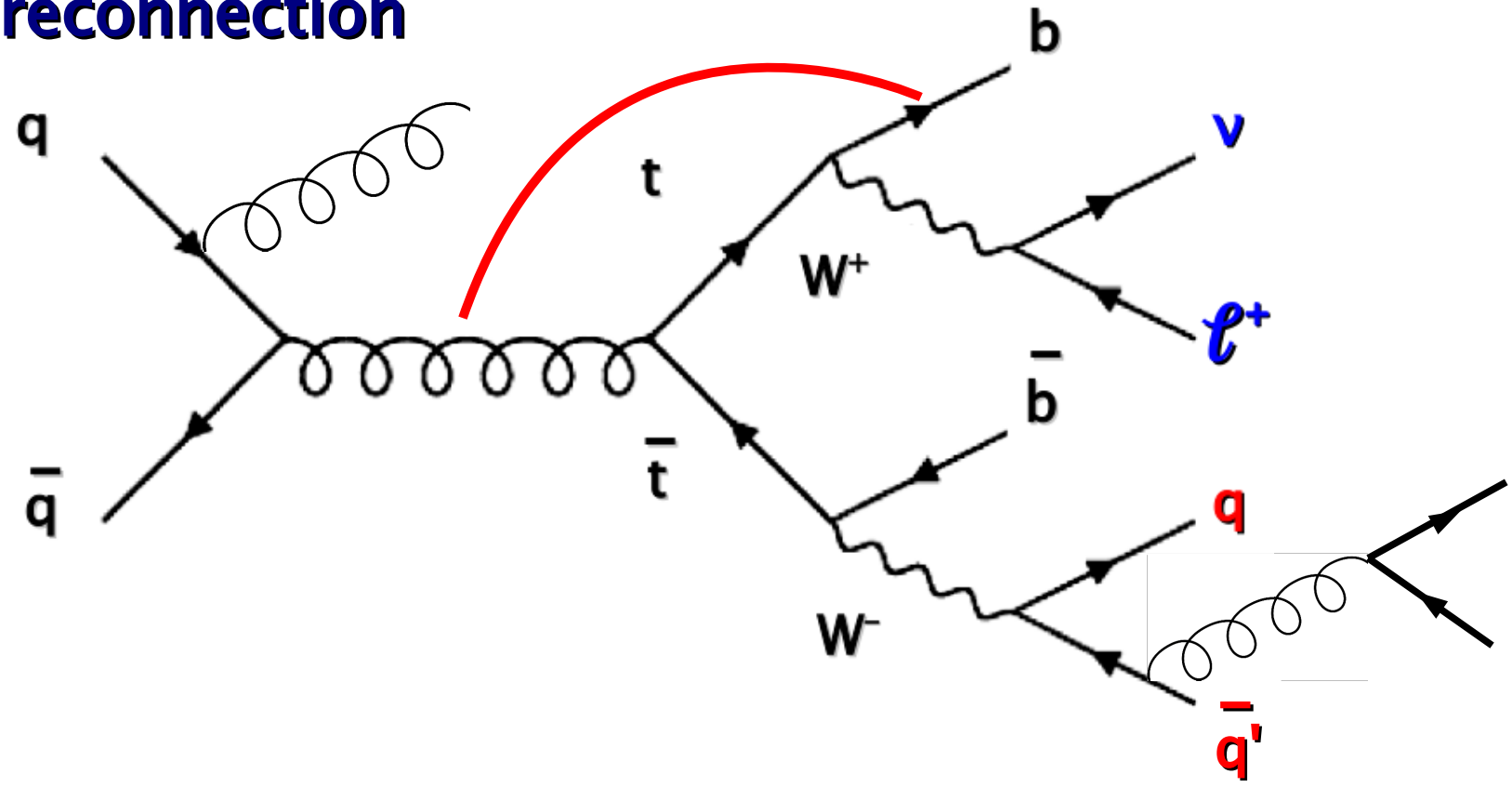
- matrix element in LO QCD
- parton showers



Top mass interpretation

the concept of quark mass is convention-dependent!

- matrix element in LO QCD
- parton showers
- color reconnection



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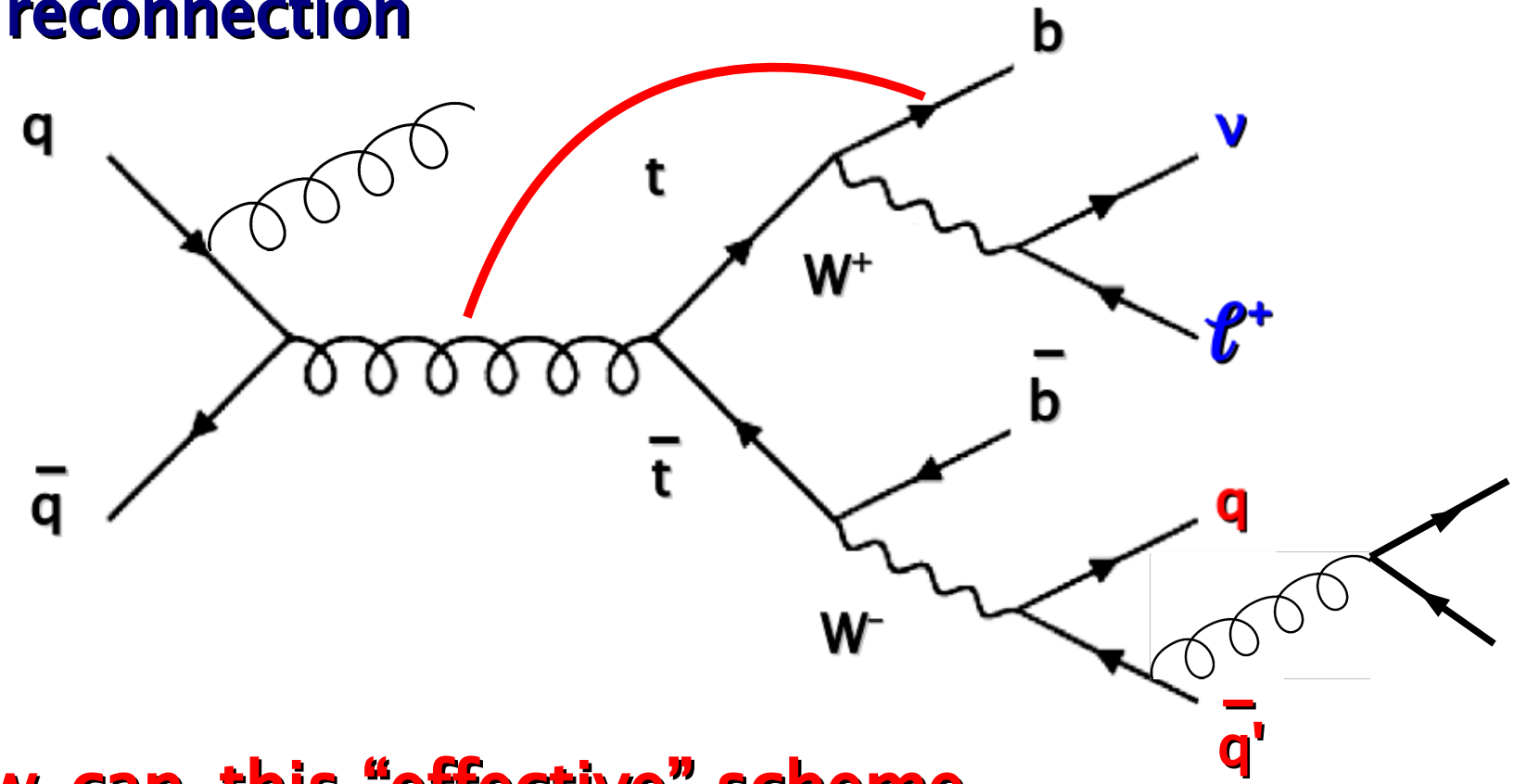


⇒ how can this "effective" scheme translated to a renormalisation scheme?

Outline

Templates

Matrix Elements

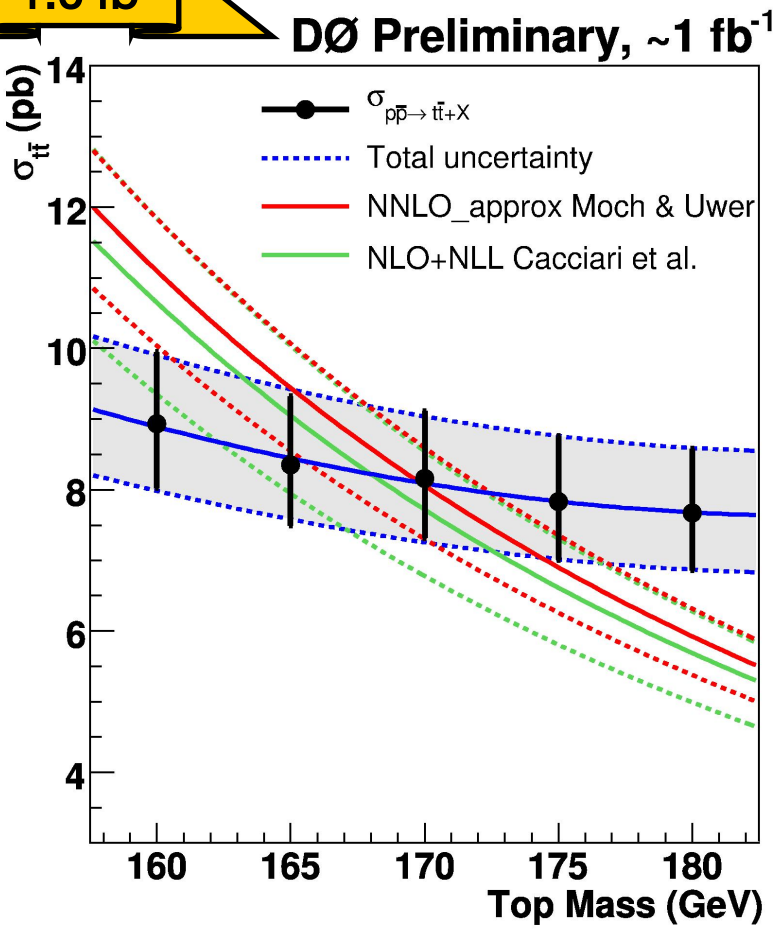
Cross Section

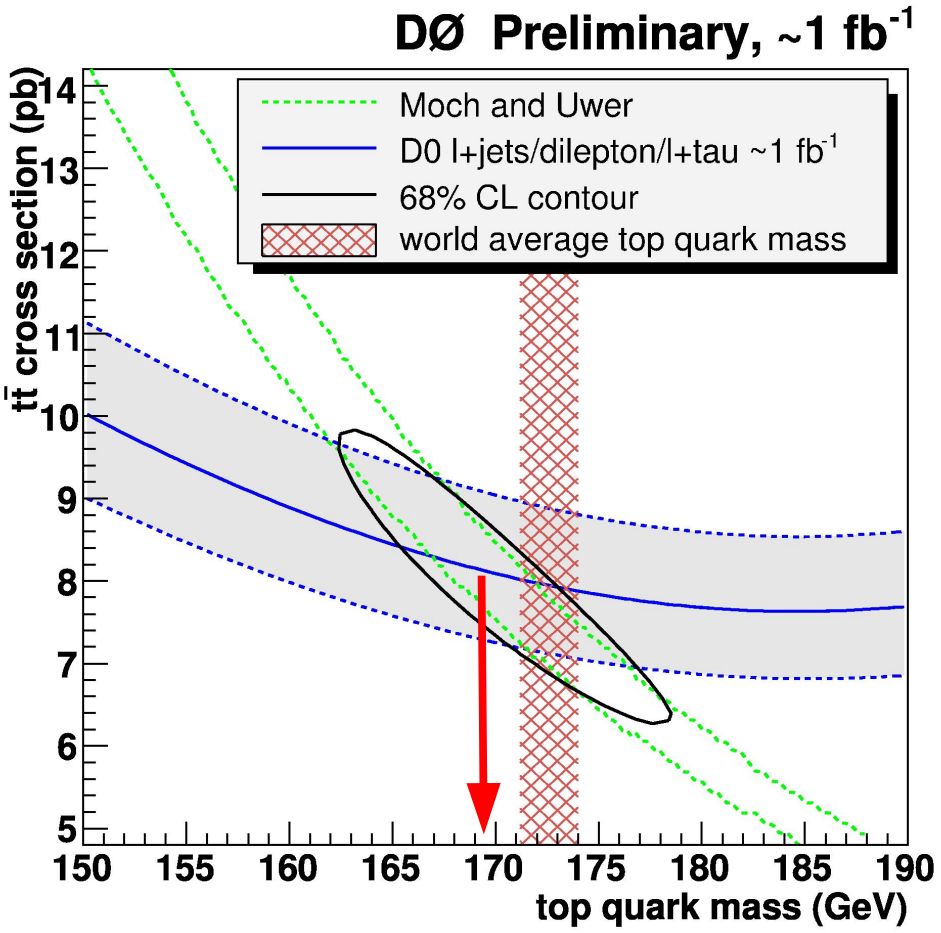
Summary

Top mass from cross section measurement

- **lepton+jets/dilepton/lepton+tau combination**

1.0 fb^{-1}





pole mass $M_{top} = 169.6 \pm 5.5$ GeV with $NNLO_{approx}$ **±3.2%**

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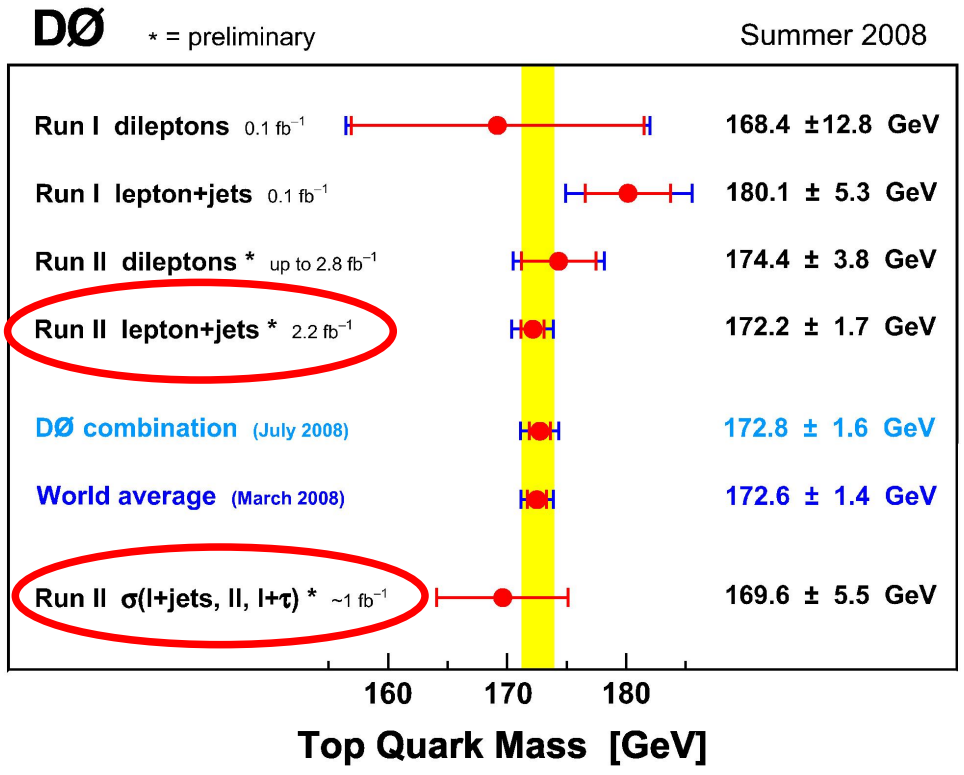
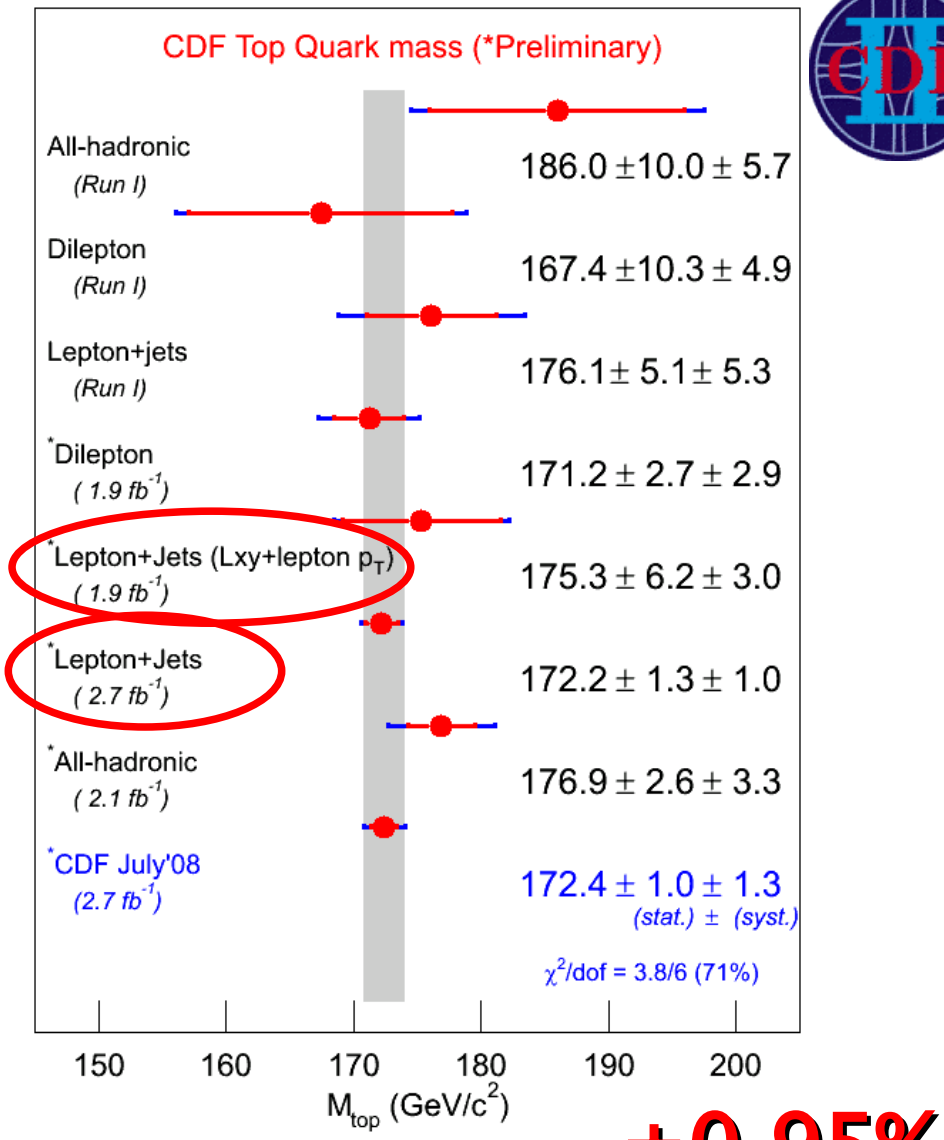


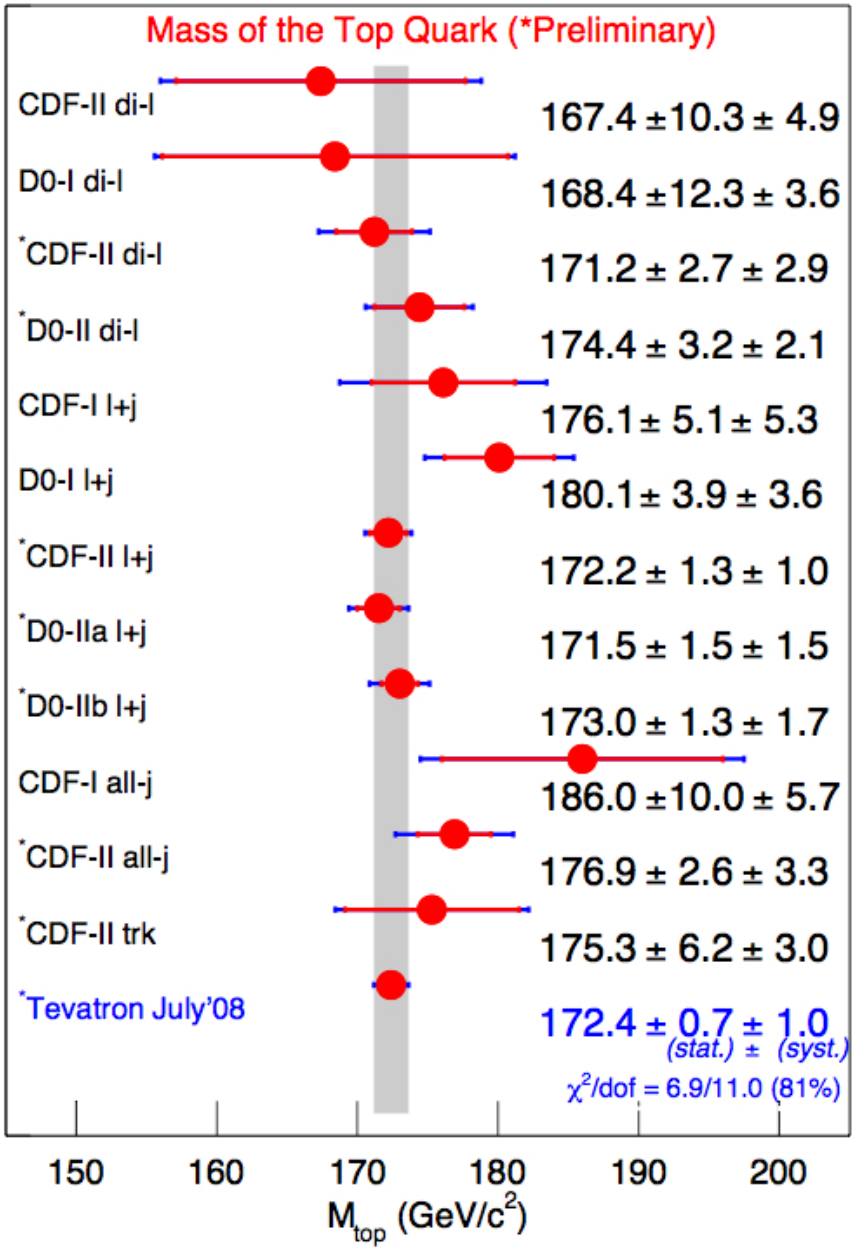
±0.92%



±0.95%

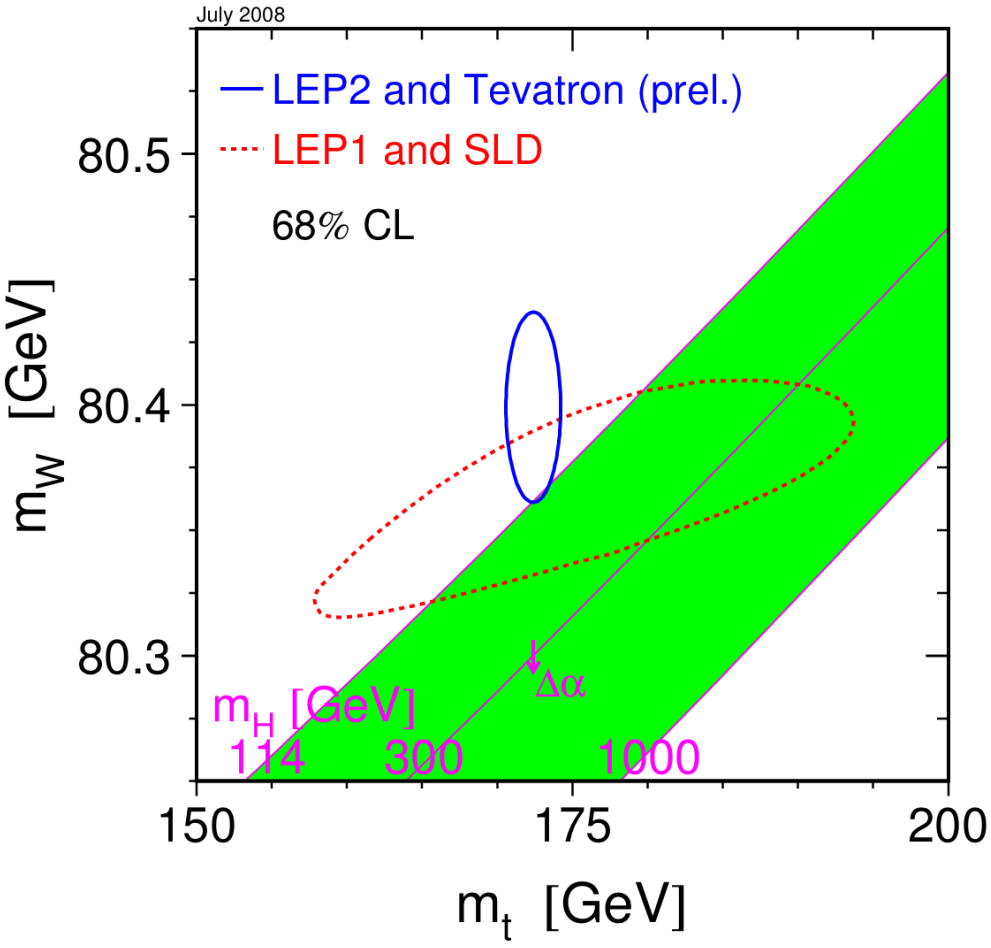
- **ideogram method**
- **template**
- **dynamical likelihood**

Tevatron Combination: July 2008



- up to 2.8 fb^{-1}

$M_{top} = 172.4 \pm 1.2$ GeV ±0.7%



Conclusions

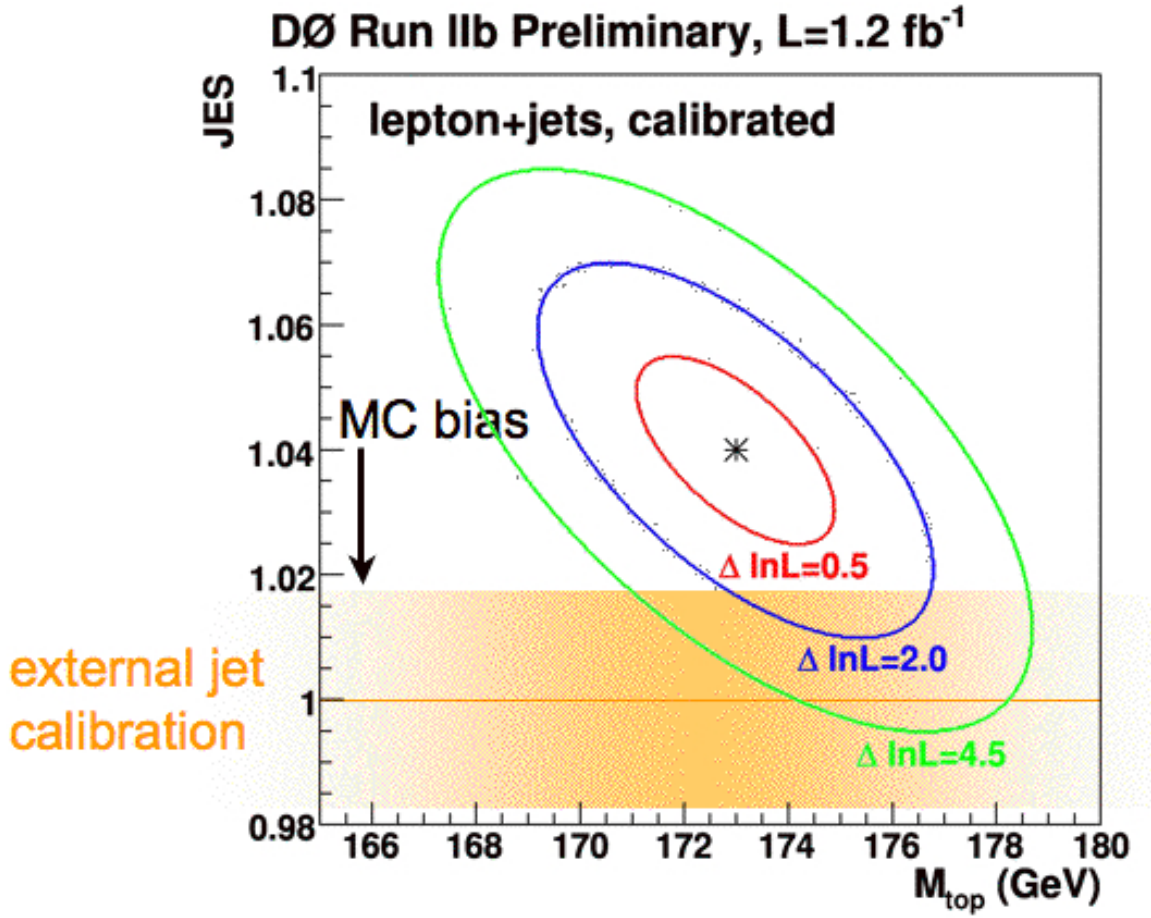
main challenges for the future:

- CDF & DØ:
  better understanding of systematics

- Theory & experiment:
  better understanding on theoretical uncertainties and interpretation of top quark mass

Backup

Results

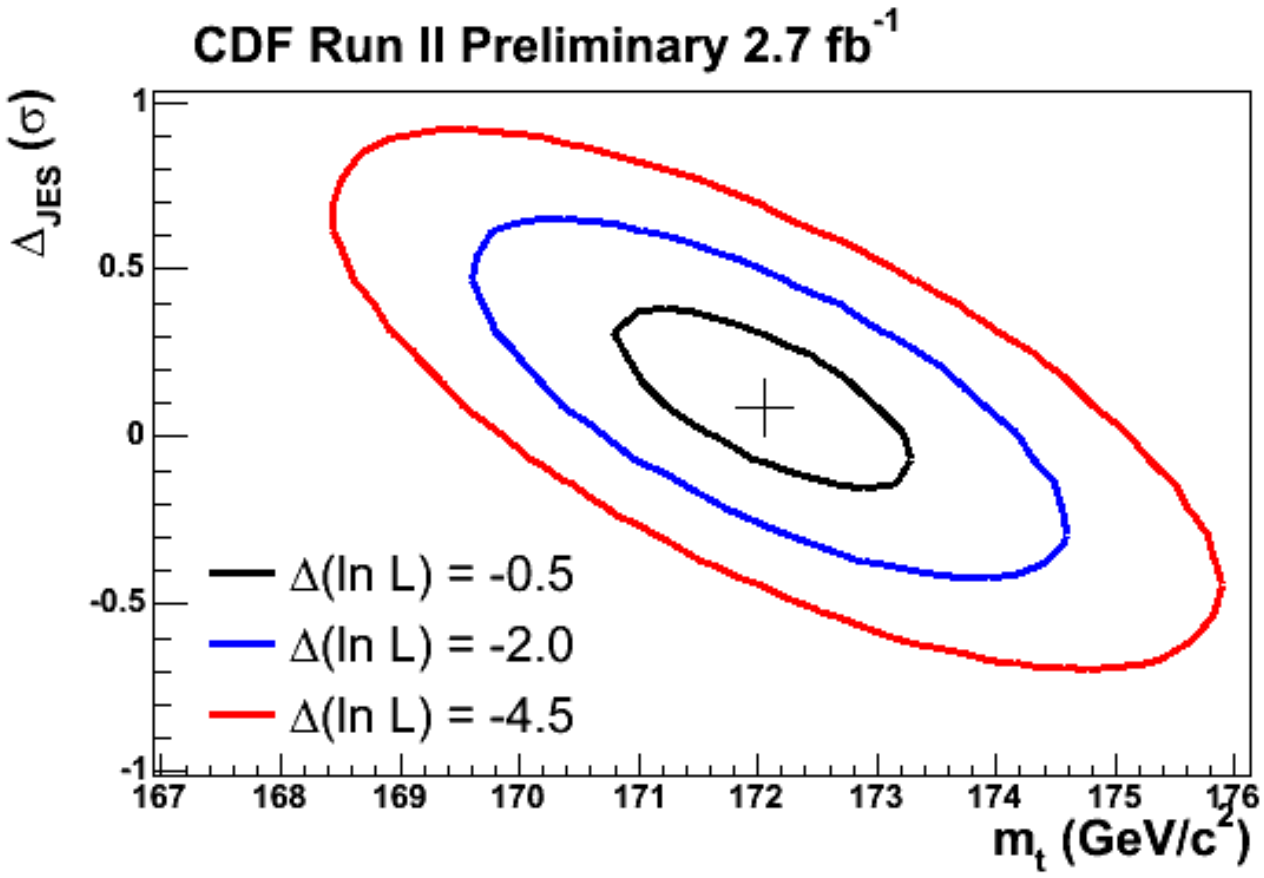


±1.0%

m_{top} = 172.2 ± 1.0 (stat) ± 1.4 (syst) GeV

2.2 fb^{-1}

Results

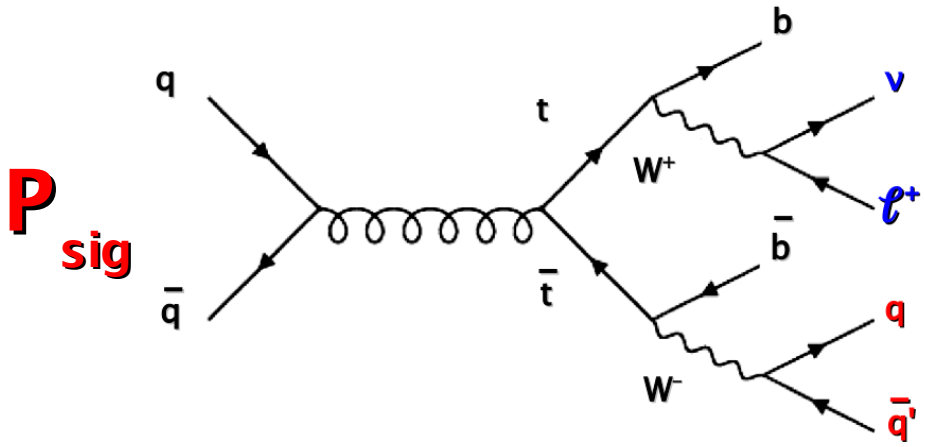


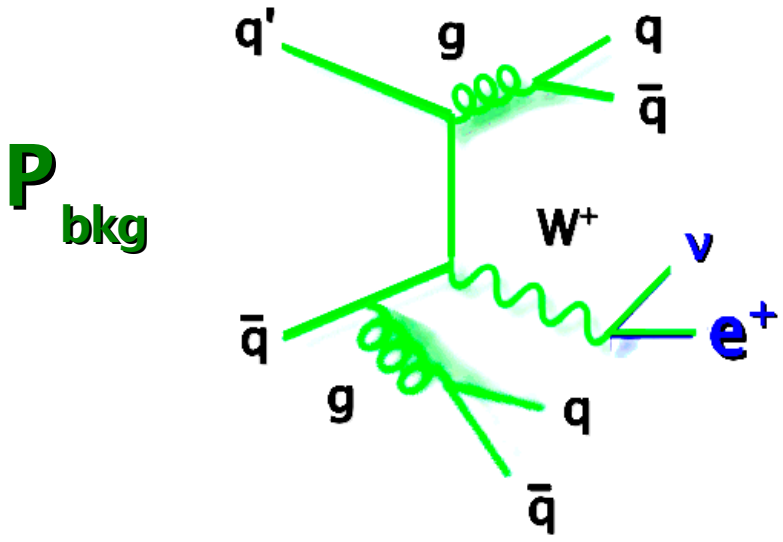
±1.0%

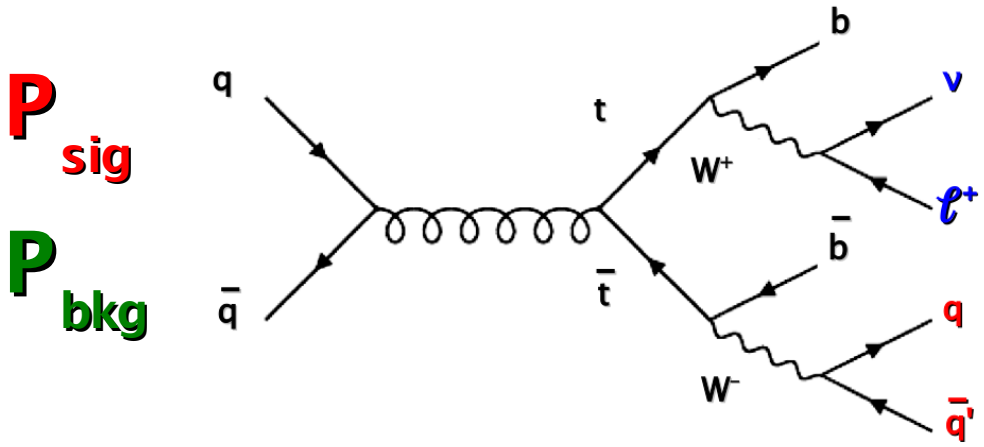
m_{top} = 172.2 ± 1.0 (stat) ± 1.3 (syst) GeV

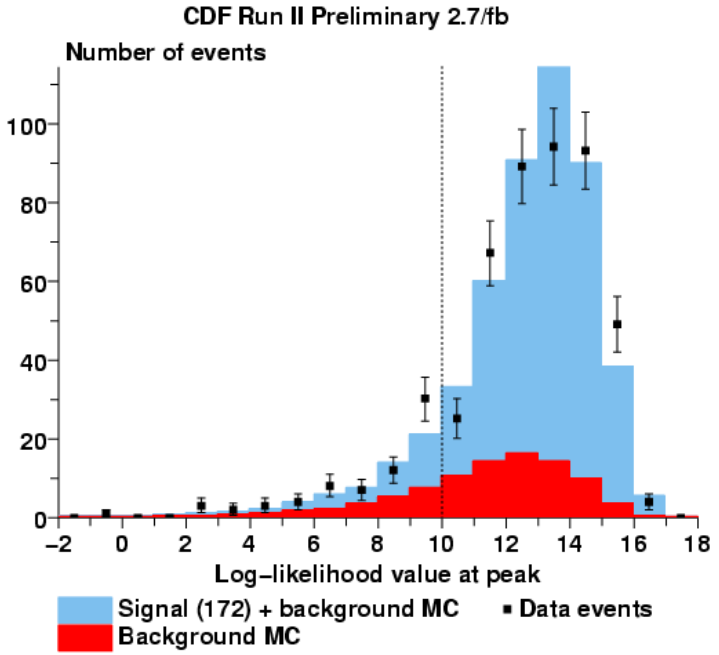
2.7 fb^{-1}

Matrix element method comparisons









Differences in top mass definitions

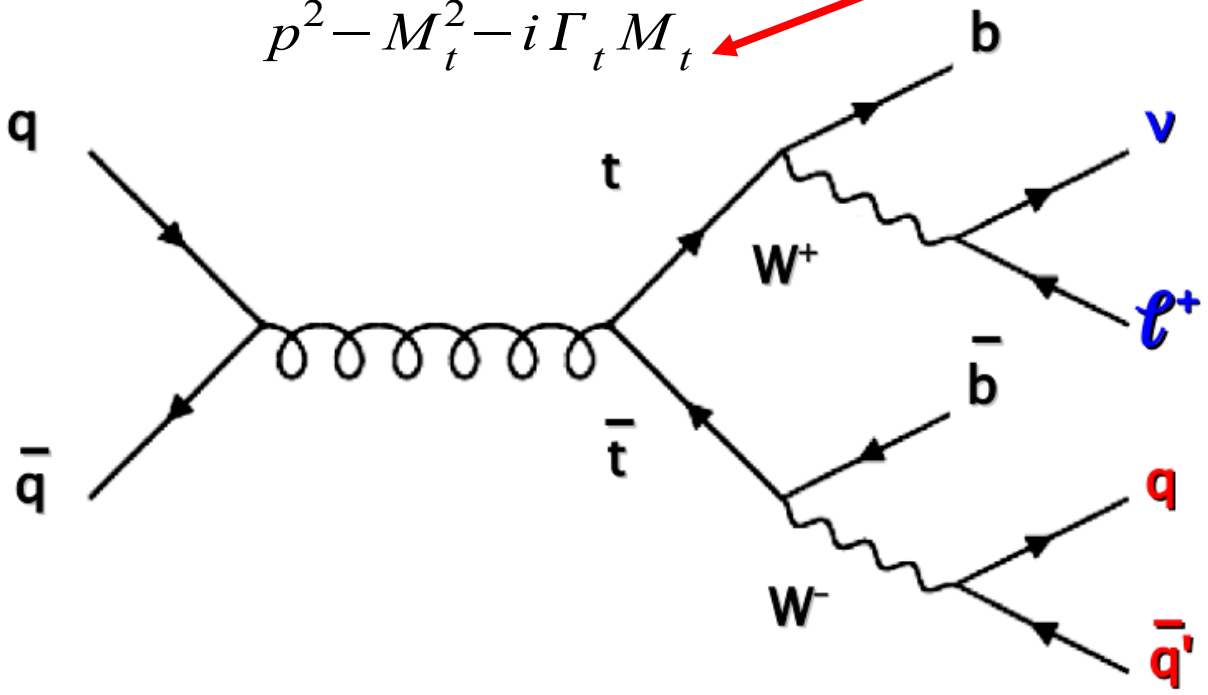
hep-ph/0001002

$$\overline{m}_t \equiv m_t^{\overline{\rm MS}}(m_t) = \frac{M_t}{1+\frac{4}{3\pi}\alpha_s(M_t)}$$

$\overline{\rm MS}$ scheme

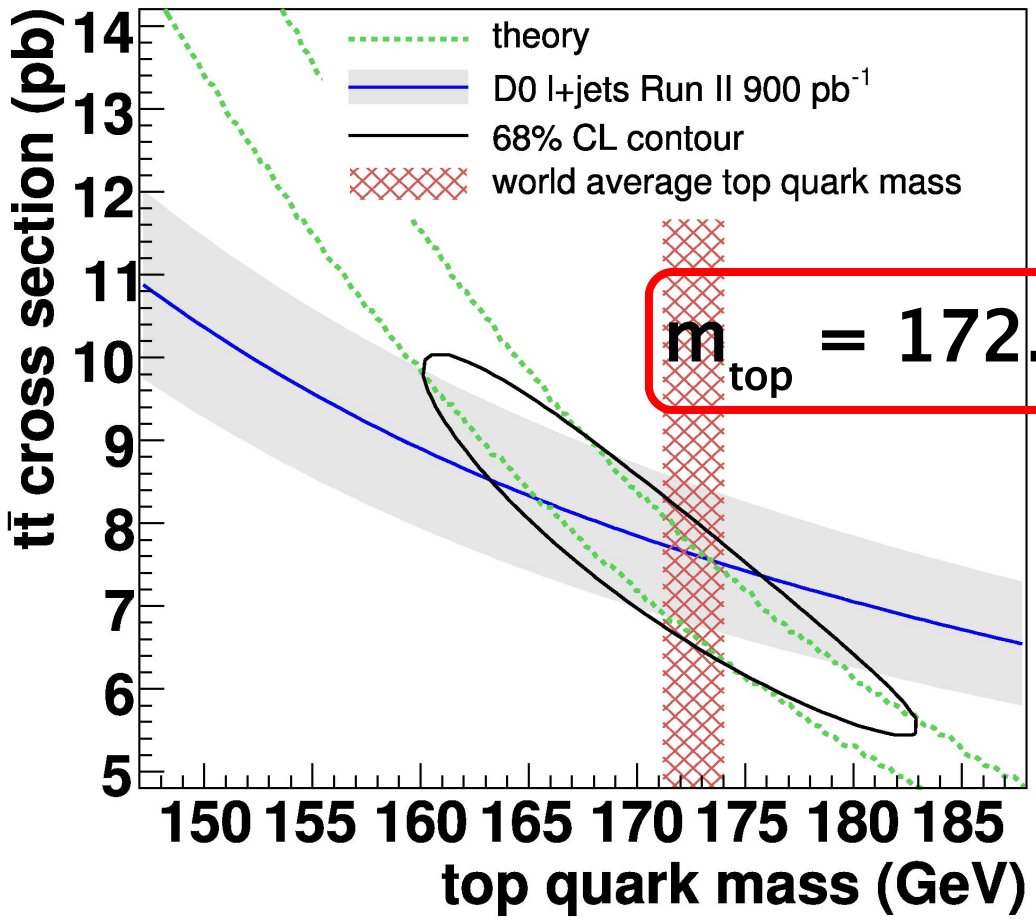
pole mass

$$\frac{1}{p^2 - M_t^2 - i\,\Gamma_t M_t}$$



⇒ difference between $\overline{\rm MS}$ and pole mass is ≈7 GeV...

Top mass from cross section measurement



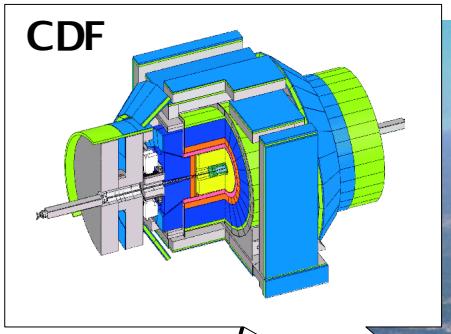
$m_{top} = 172.6 \pm 1.4$ GeV

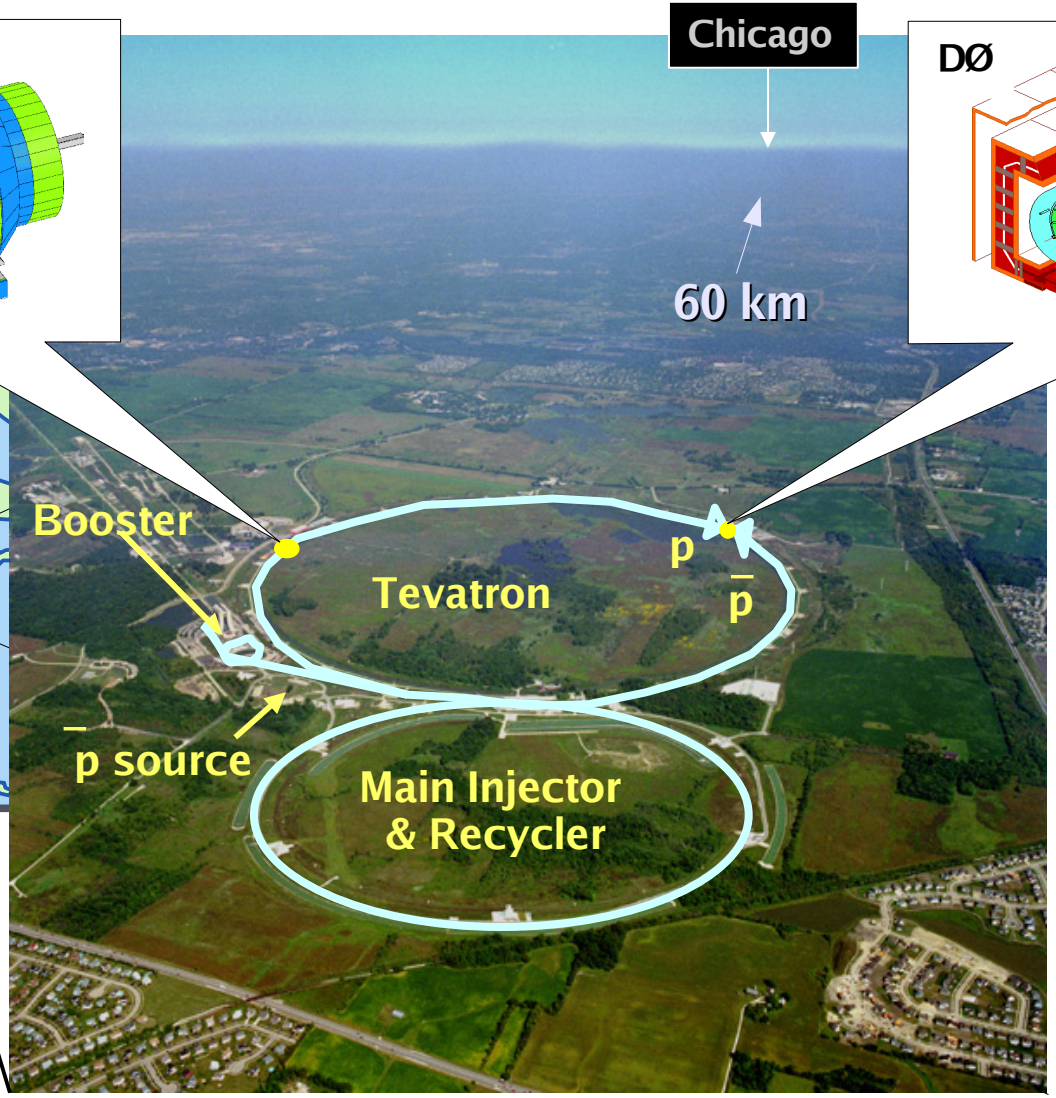
"LO Pythia mass"

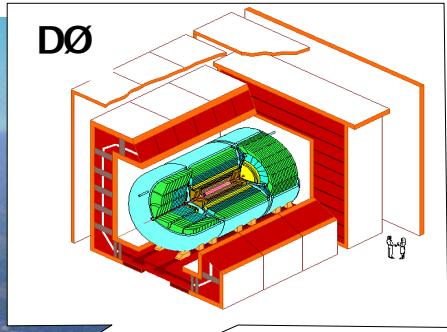
$M_{top} = 170 \pm 7$ GeV

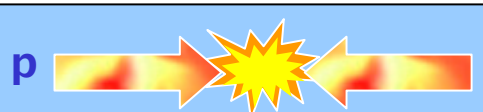
pole mass

The Tevatron at FERMILAB: $p\bar{p}$ Collisions









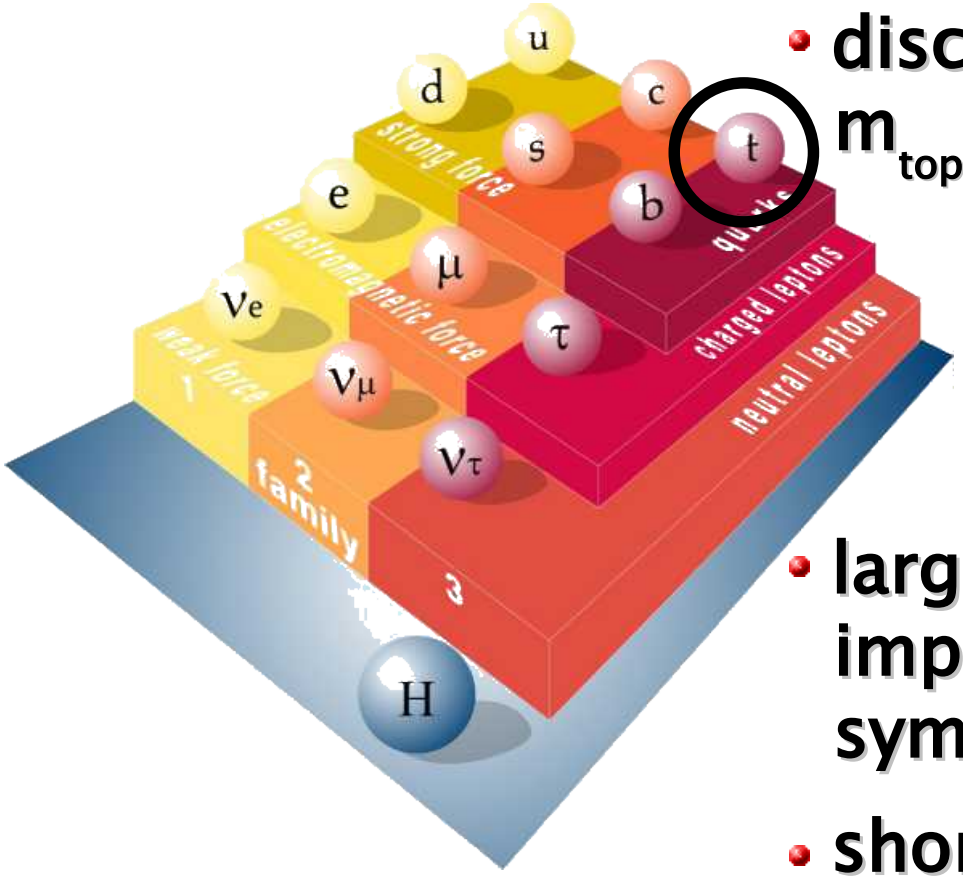
$\sqrt{s}$ =1.96 TeV
Δt = 396 ns

Run I 1987 (92)–95
Run II 2001–09: 40x larger dataset
at increased energy

top quark discovery

measure properties with high precisions:
is it really the particle expected in the SM?

The Top Quark



- needed as isospin partner of bottom quark
- discovered in 1995 by CDF and DØ: m_{top} ~ gold atom
- large coupling to Higgs boson ~ 1: important role in electroweak symmetry breaking?
- short lifetime: $\tau \sim 5 \cdot 10^{-25}\text{s} \ll \Lambda^{-1}_{QCD}$: decays before fragmenting → observe "naked" quark