Real life combination

World average top quark mass

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FSP 101 ATLAS

PHYSICS AT THE TERA SCALE Helmholtz-Alliance

Top quark mass

Tevatron combination

The method

The measurements

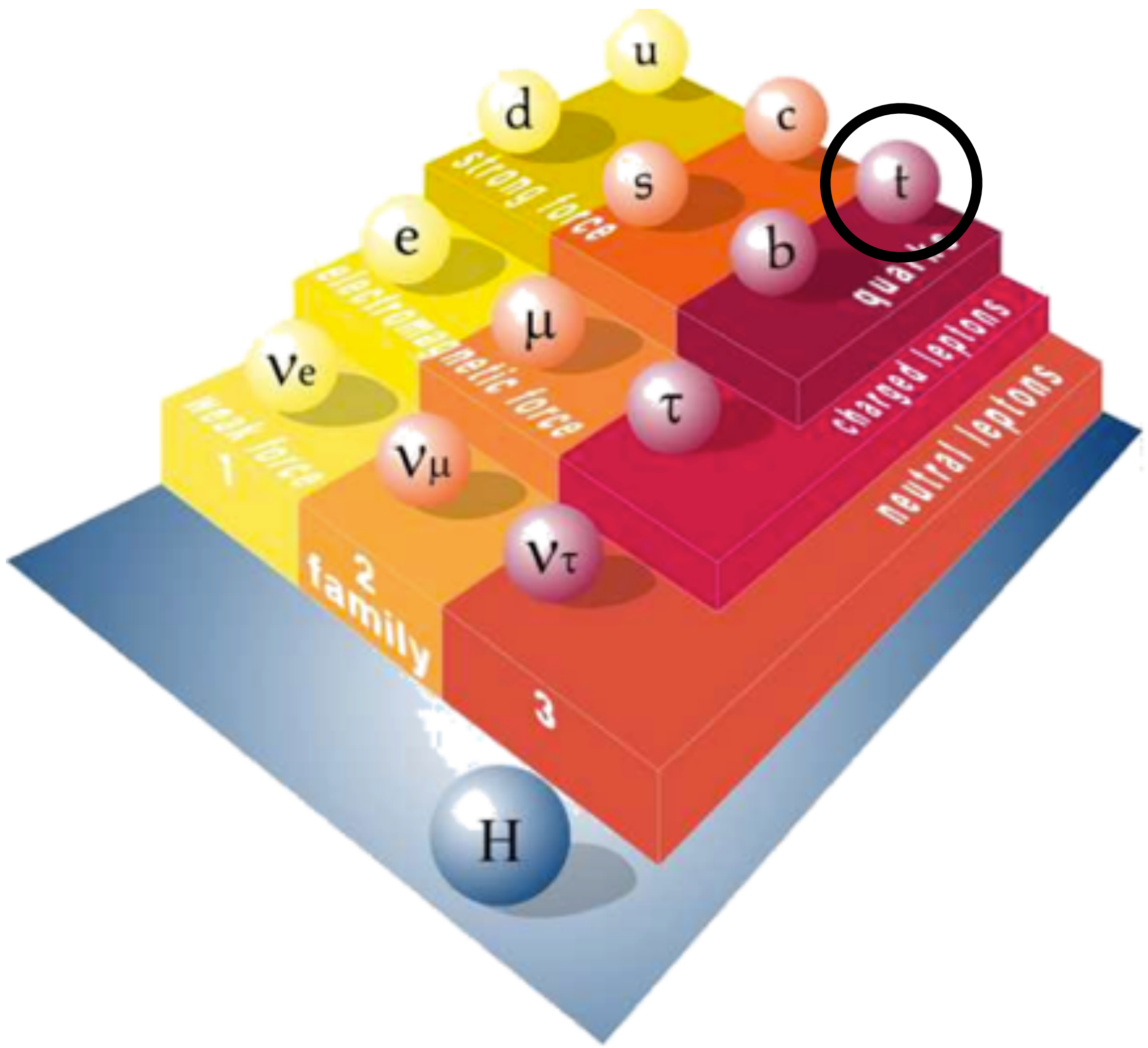
Uncertainties

Correlations

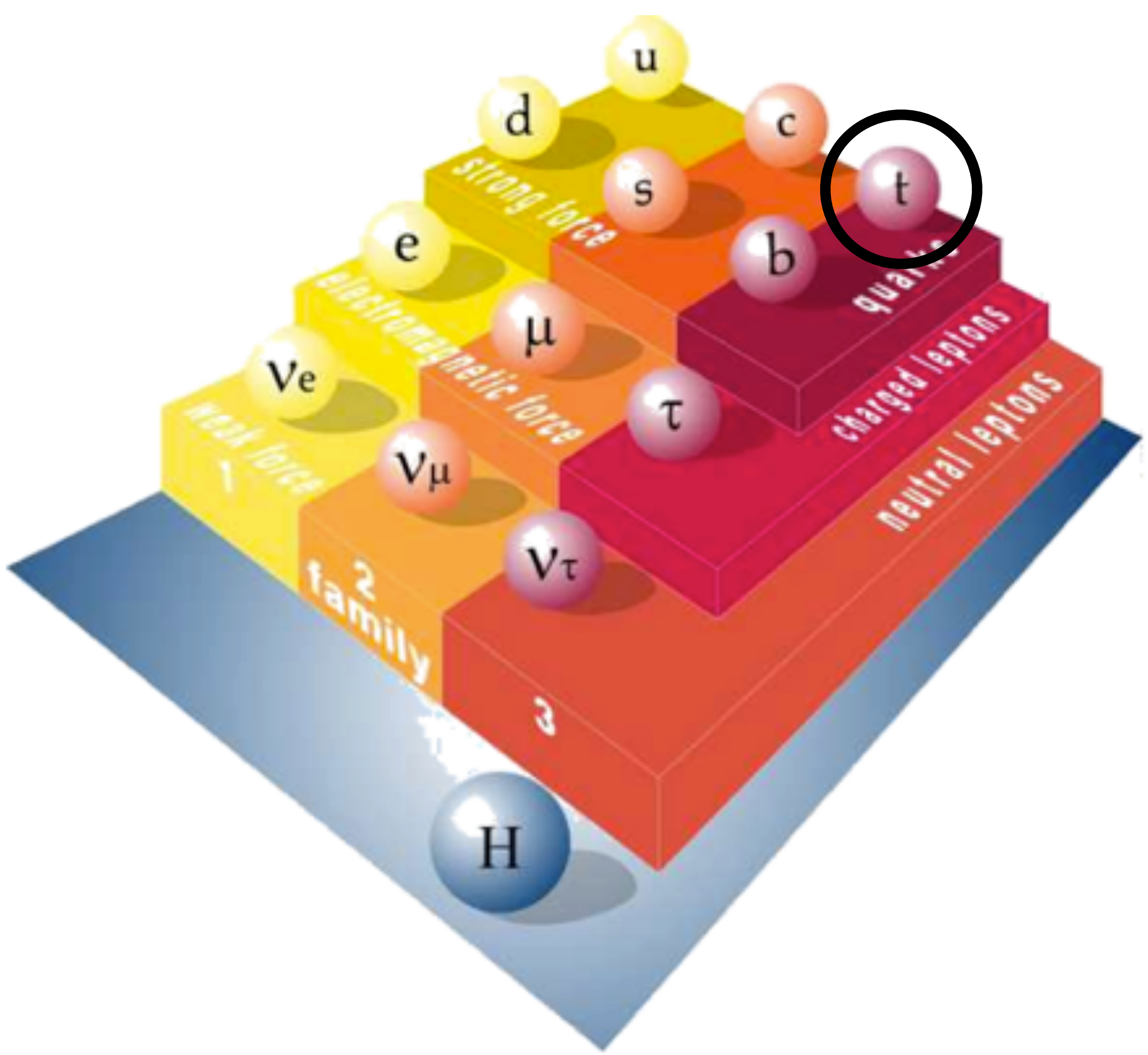
Results

Exercises

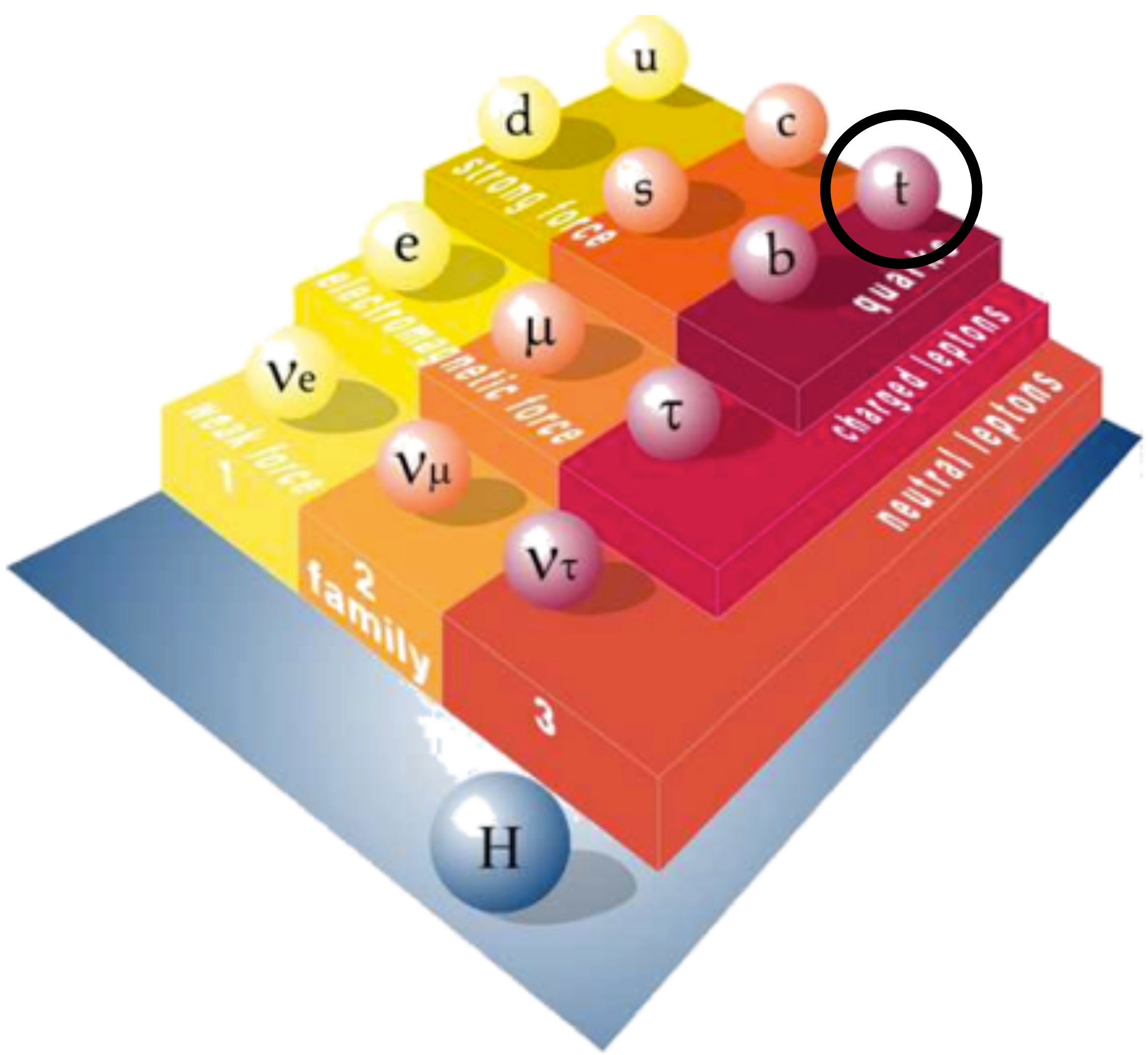
Top quark mass

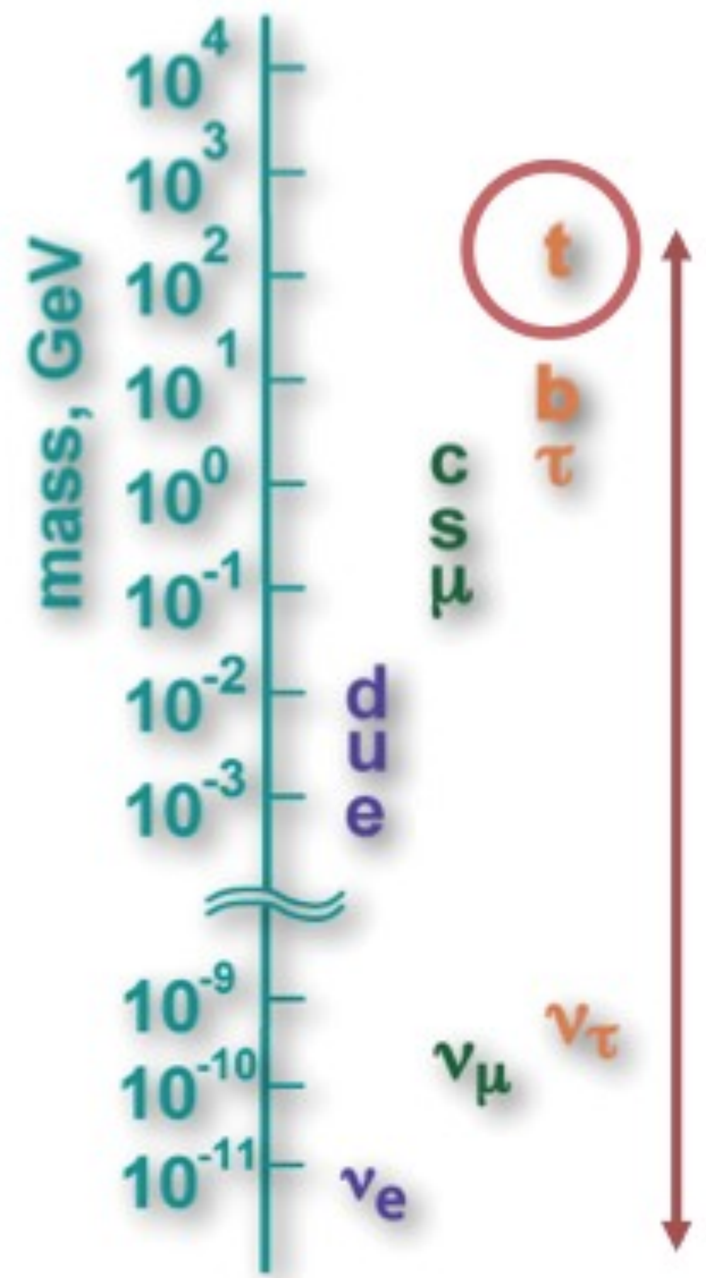

u
d
c
s
t
b
e
μ
τ
νe
νμ
ντ
H
strong force
electromagnetic force
weak force
charged leptons
neutral leptons
1
2
family
3

Discovered at Fermilab in 1995



Discovered at Fermilab in 1995

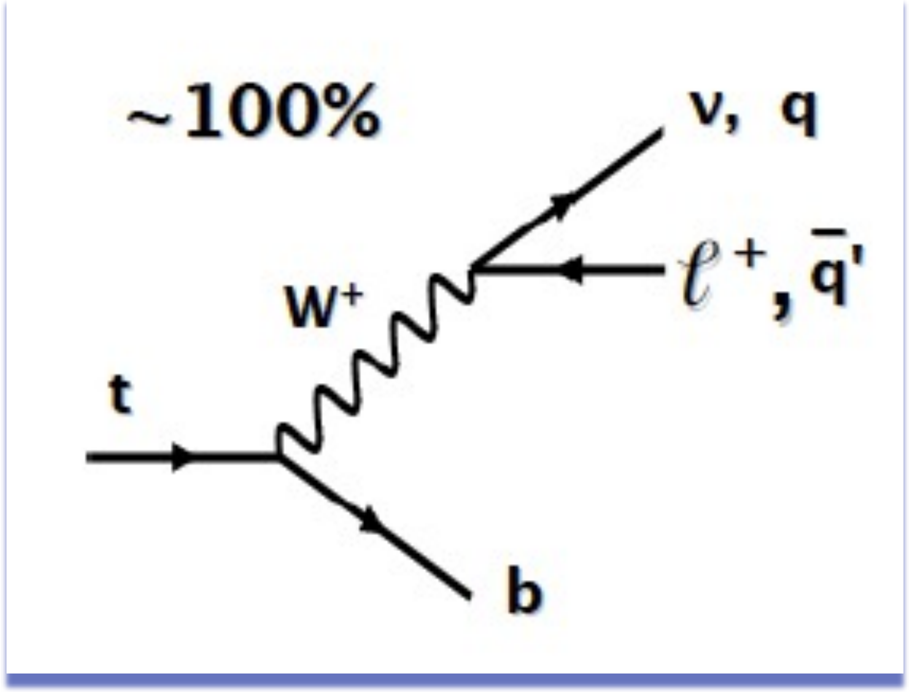


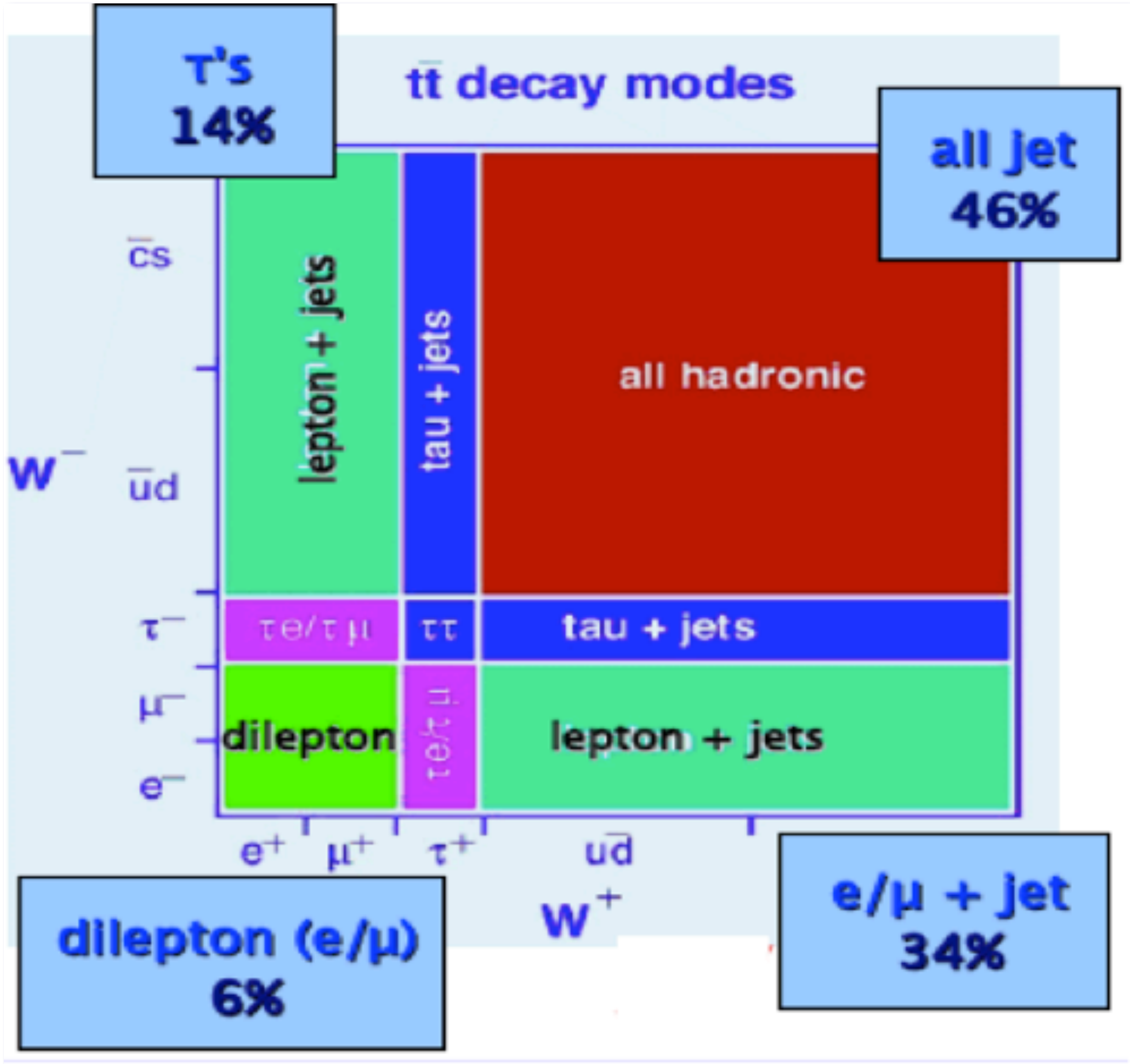


As heavy as the atom of gold

Top quark decay

In Standard Model

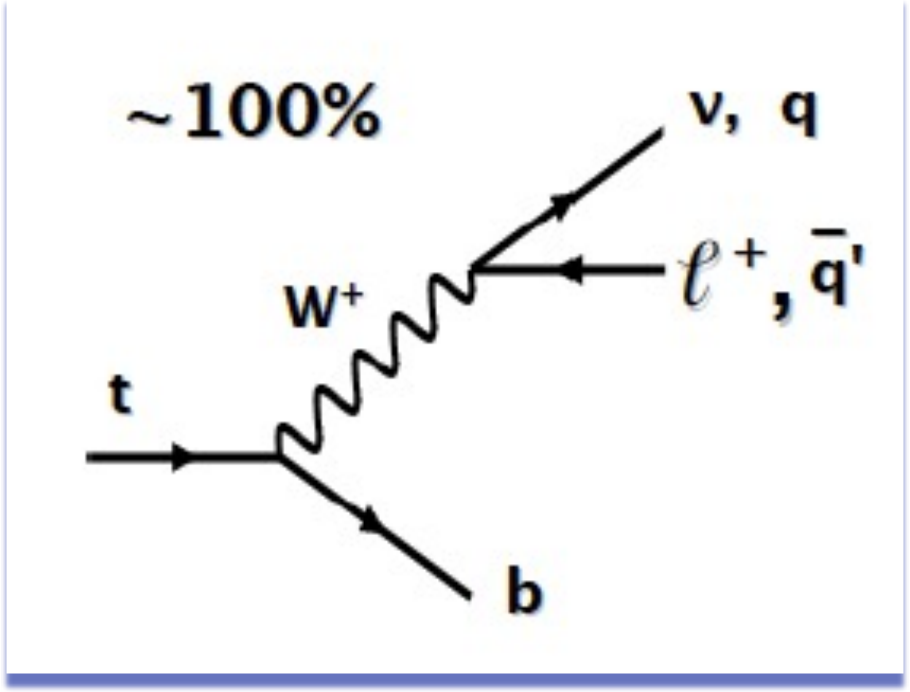




W decay mode defines top pair final state

Top quark decay

In Standard Model



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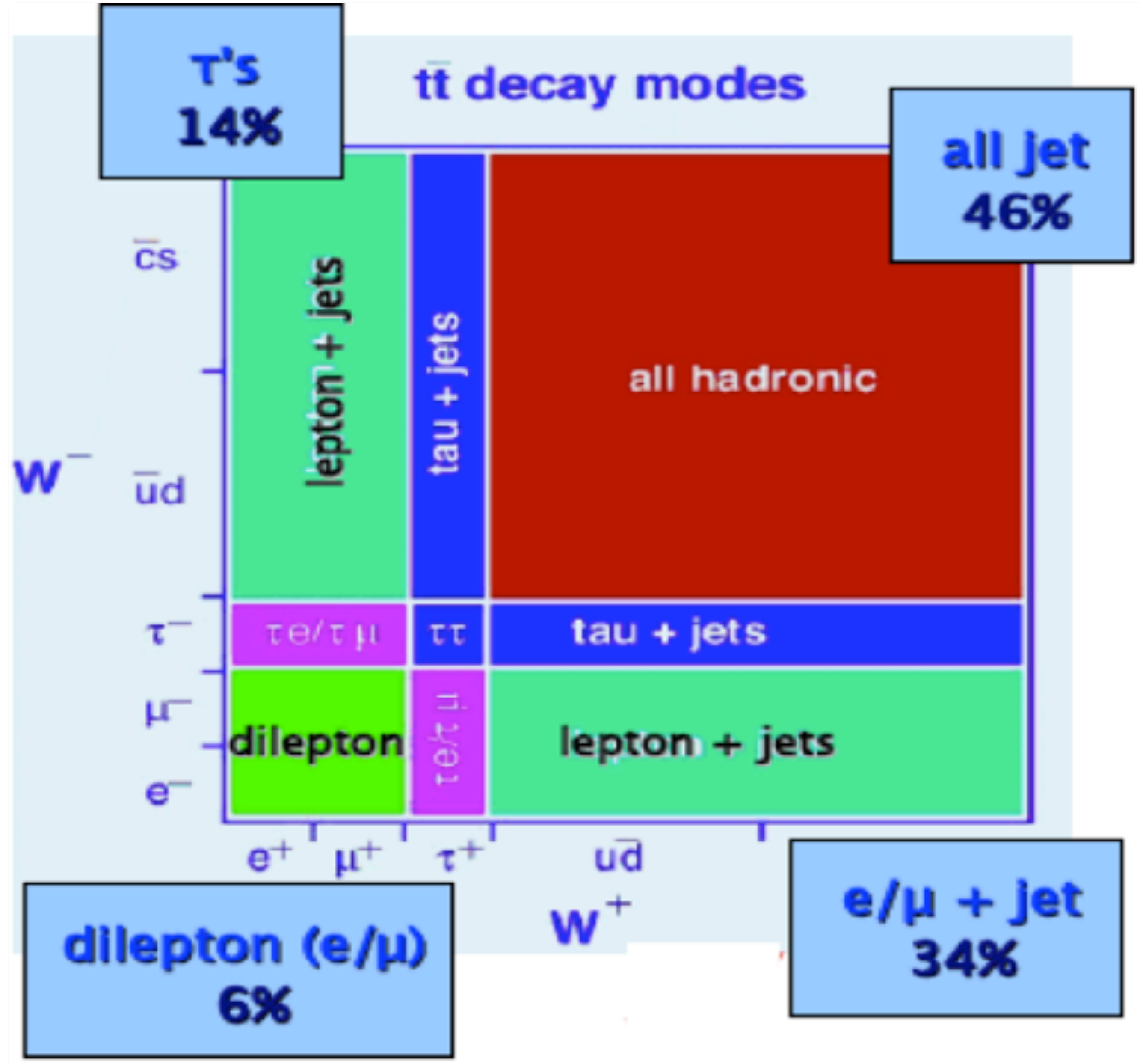
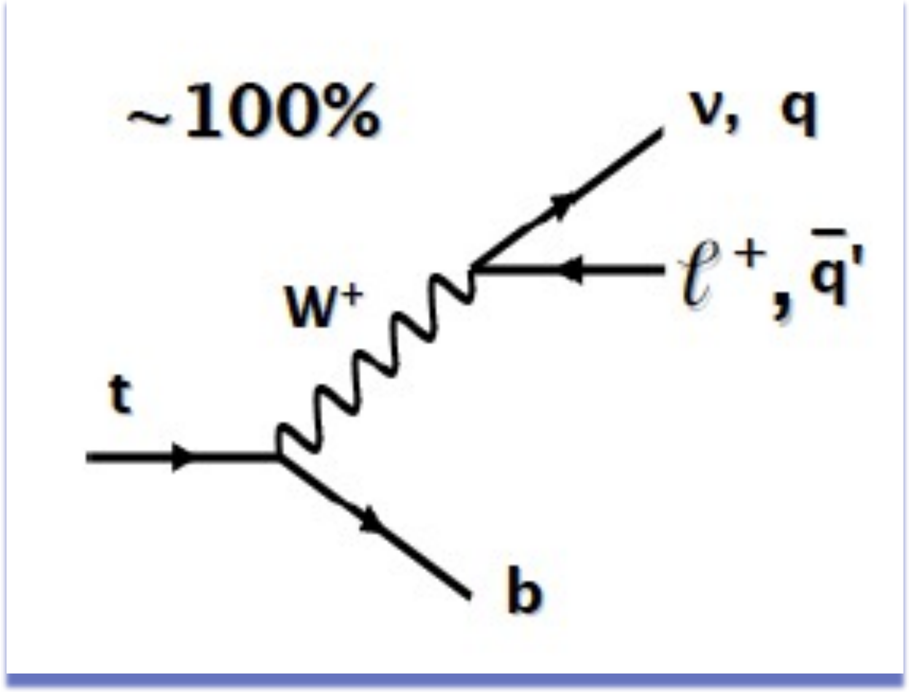


small rate, small background
main background: Drell-Yan

Top quark decay

In Standard Model



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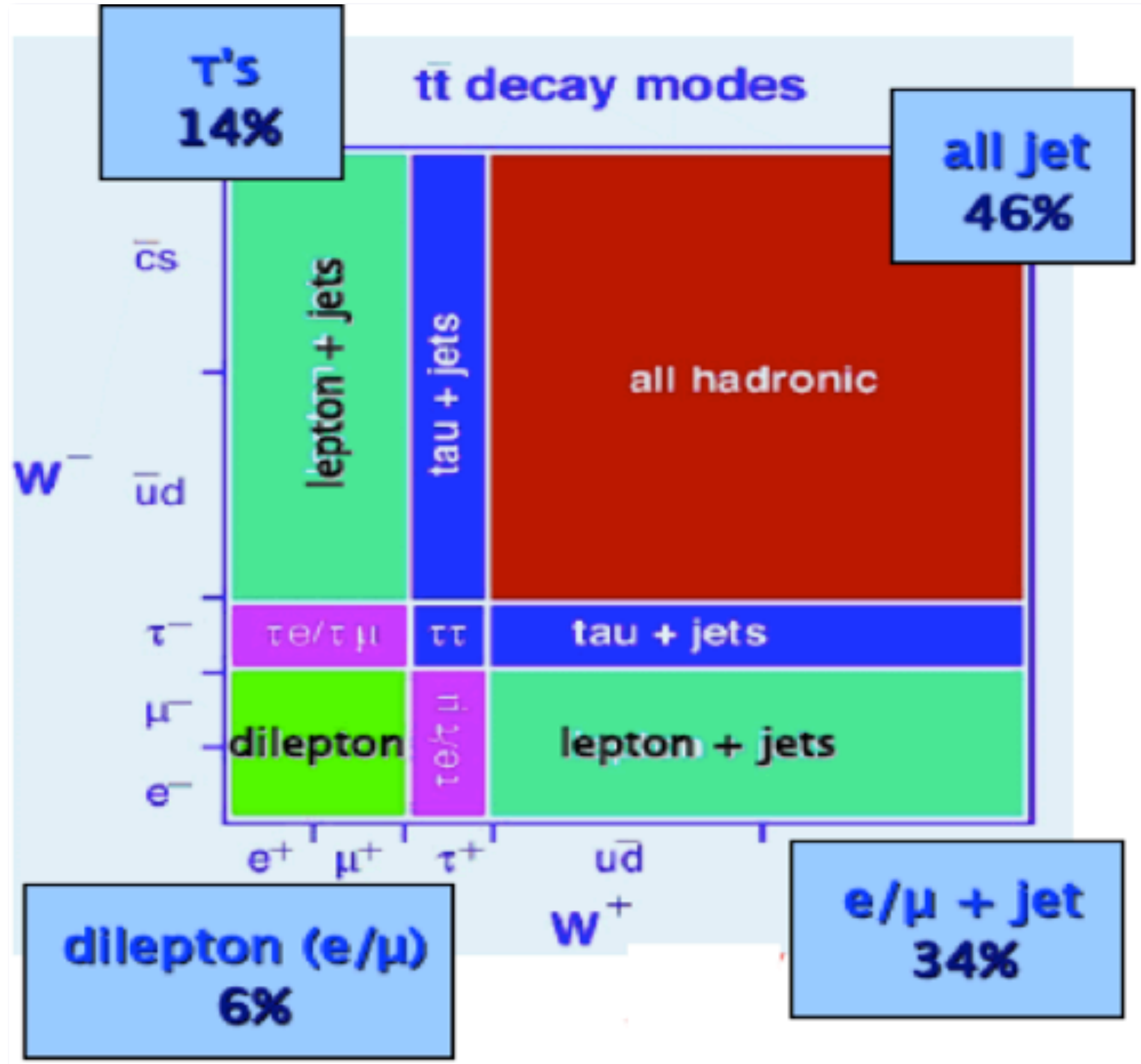


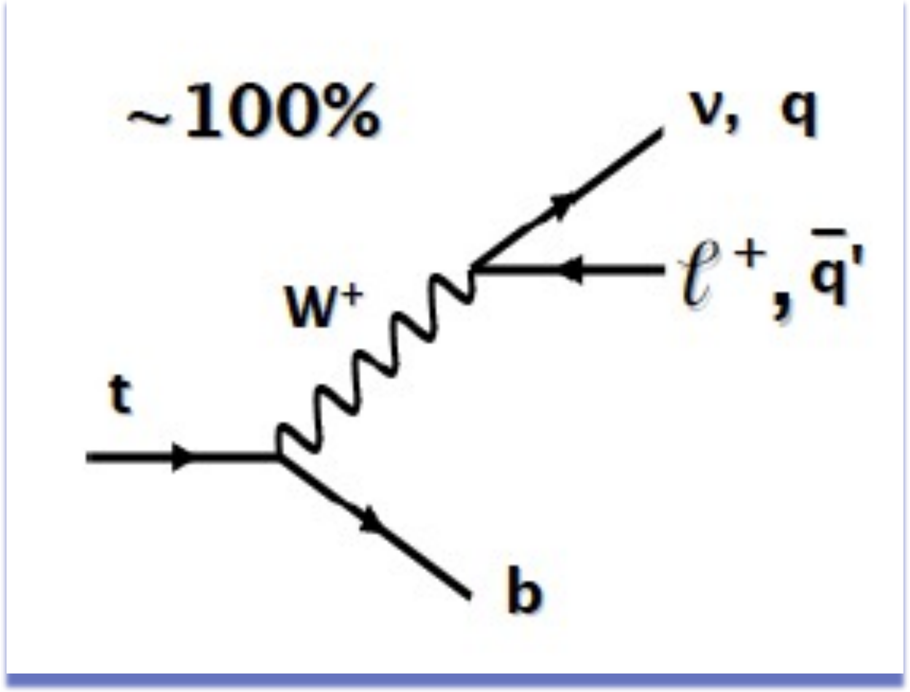
small rate, small background
main background: Drell-Yan

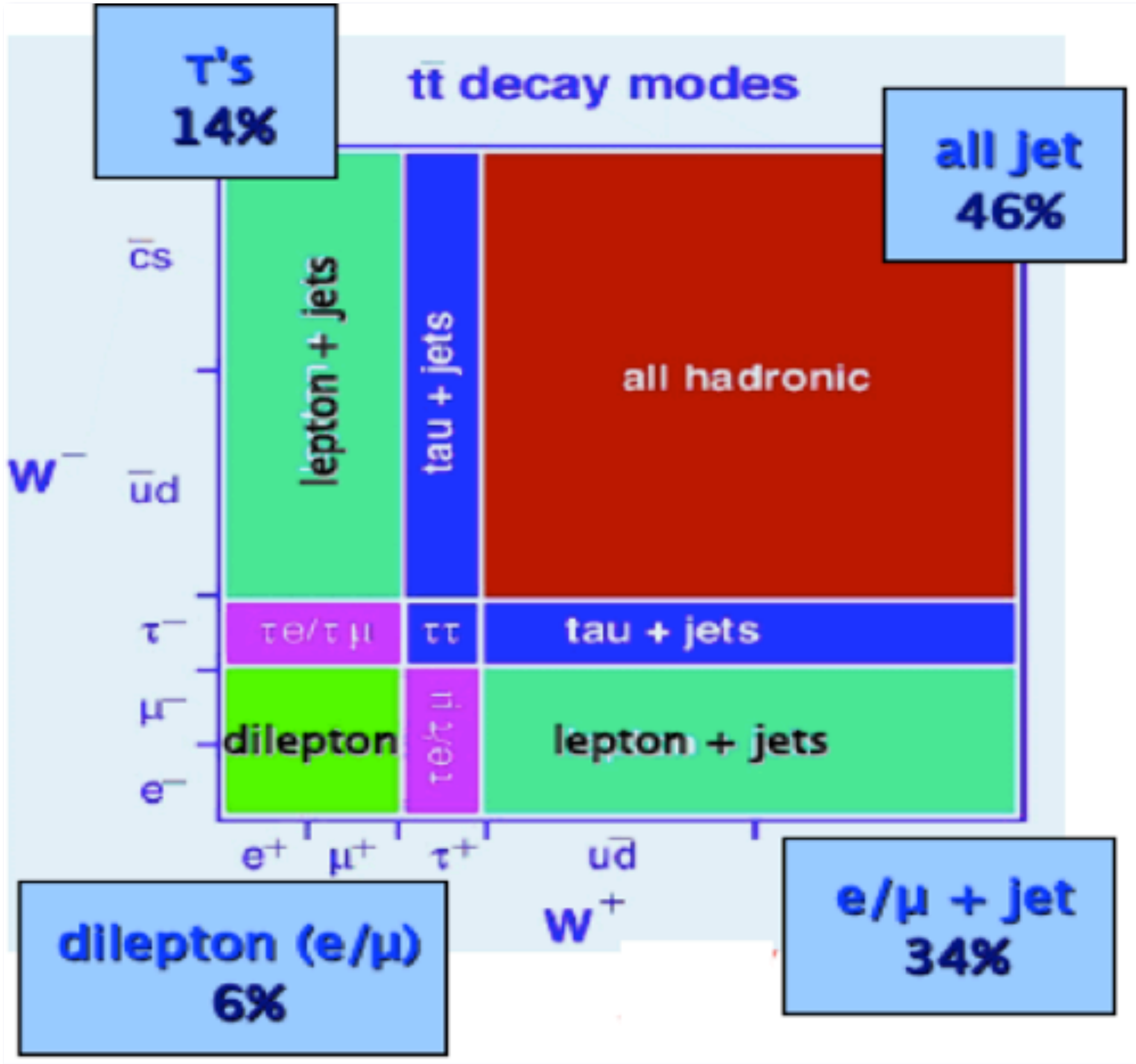
good rate, manageable background
main background: W+jets

Top quark decay

high rate, high background
main background: multijet

In Standard Model





W decay mode defines top pair final state

small rate, small background
main background: Drell-Yan

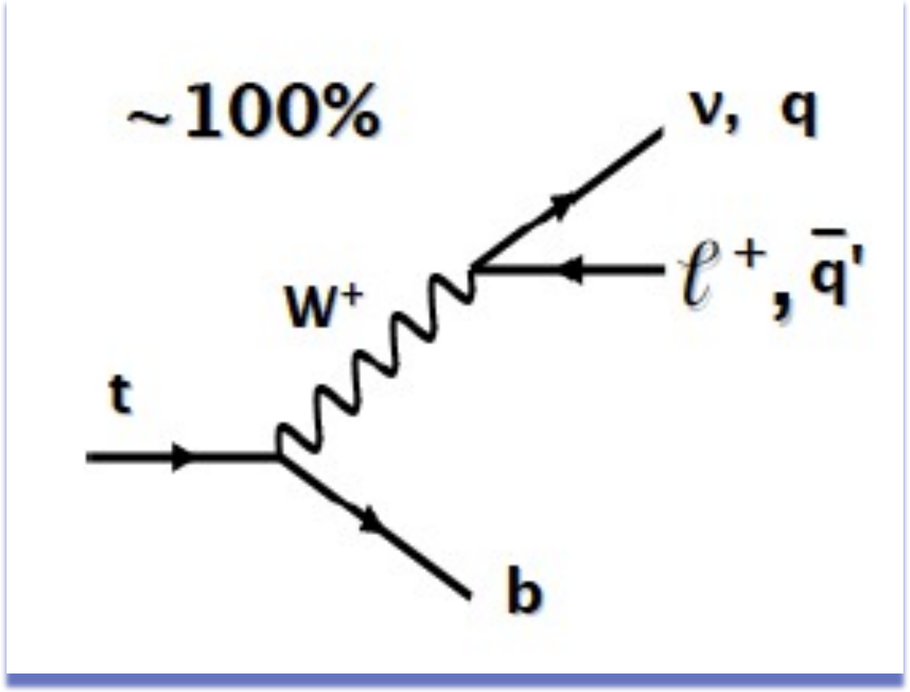
good rate, manageable background
main background: W+jets

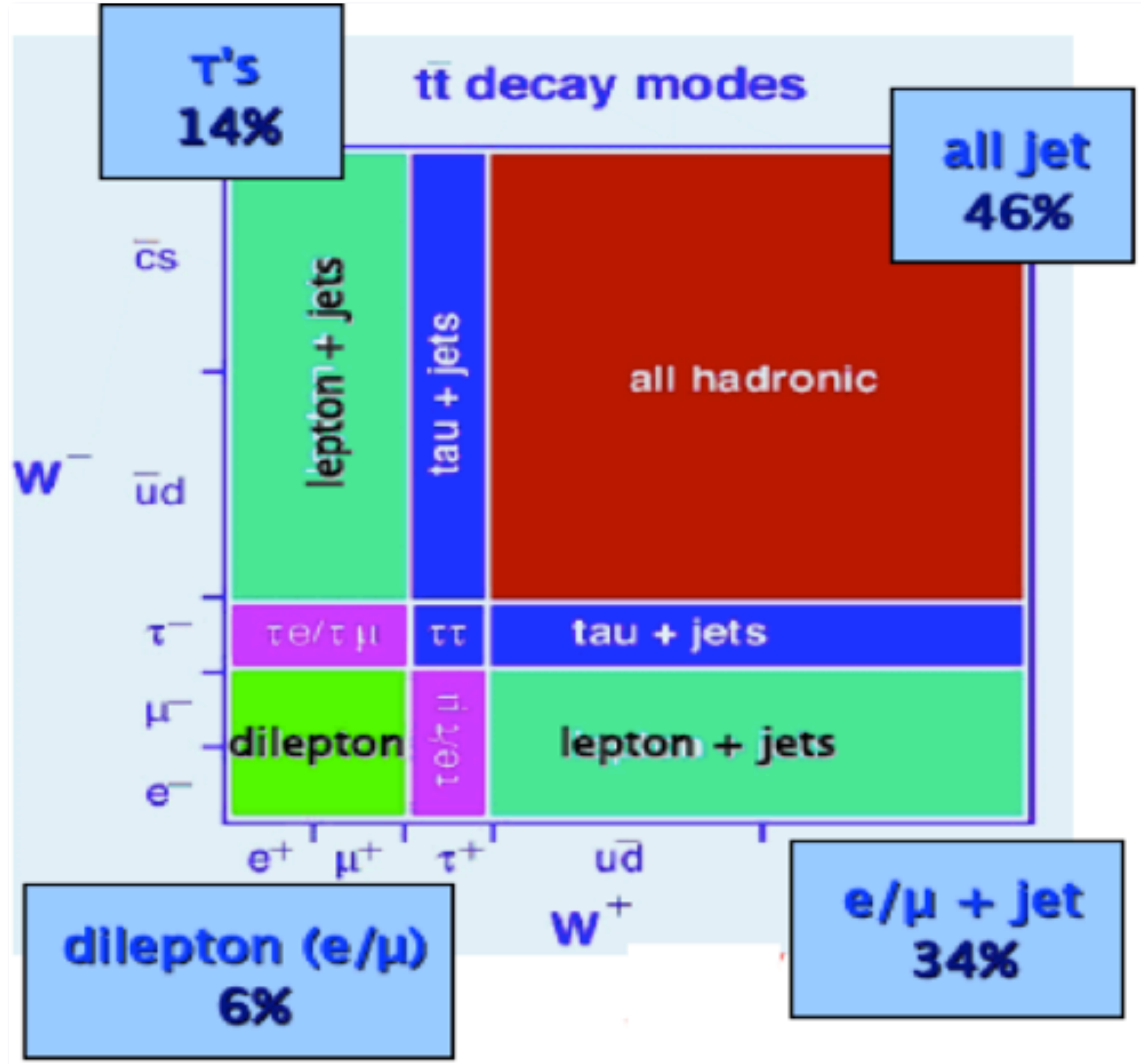
Top quark decay

small rate, high background
backgrounds: multijet, W+jets

high rate, high background
main background: multijet

In Standard Model





W decay mode defines top pair final state

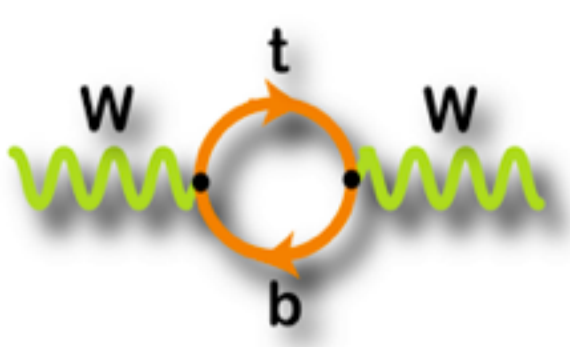
small rate, small background
main background: Drell-Yan

good rate, manageable background
main background: W+jets

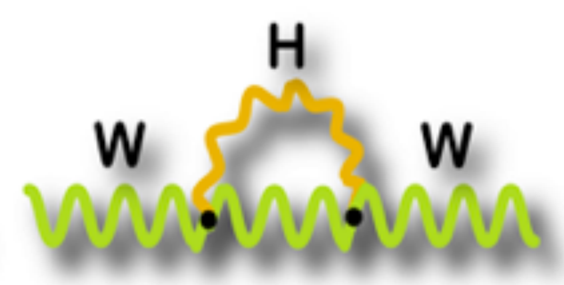
Top quark mass

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}} \frac{1}{\sin\theta_W \sqrt{1 - \Delta r}}$$

$$\cos\theta_W = \frac{M_W}{M_Z}$$



$\Delta r_t \sim m_t^2$



$\Delta r_{Higgs} \sim \ln(m_H^2)$

- Free parameter of the SM
- Together with W mass constrains SM Higgs mass
- Provides guideline for SM Higgs searches
- Constraint on Higgs mass can point to physics beyond the SM

Top quark mass

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

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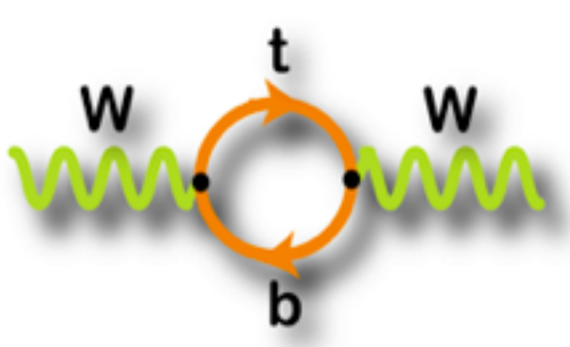
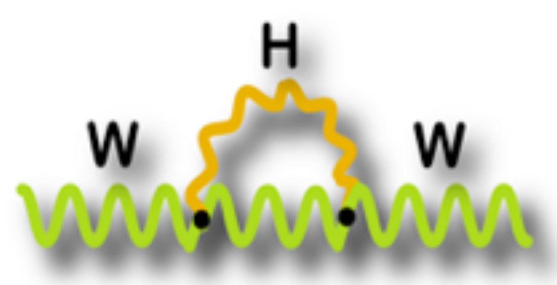


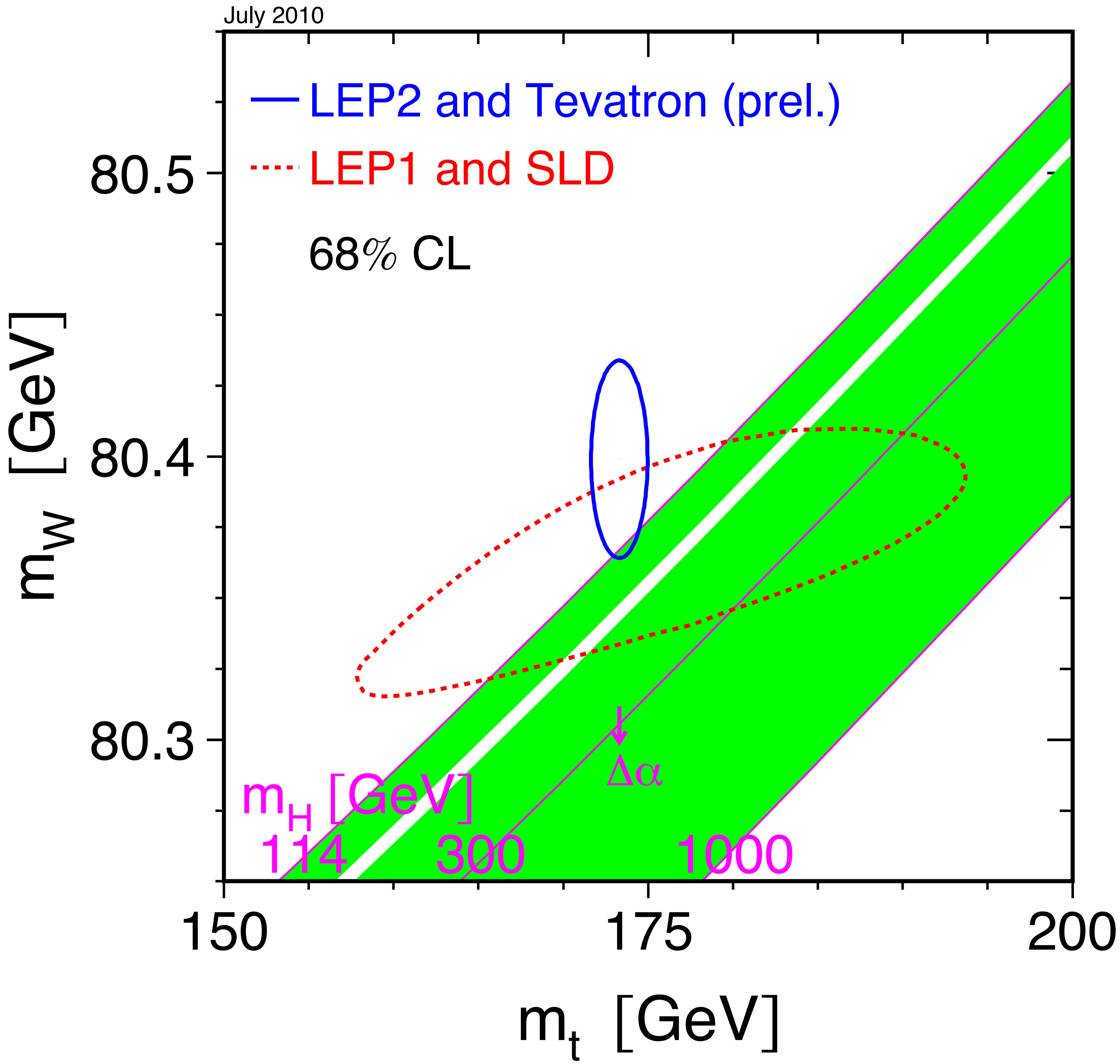
$\Delta r_t \sim m_t^2$



$\Delta r_{Higgs} \sim \ln(m_H^2)$

The most precisely known top quark property

EW fit constraints



Updated inputs: m_{top}, W width

M_H<158 GeV

ignoring direct limit

M_H<185 GeV

including 114 GeV LEP limit

$M_H = 89^{+35}_{-26}$ GeV

EW fits alone without theory uncertainties

Tevatron combination

The method

Tevatron combination

- CDF and D0 have been combining their top quark mass measurements for over 10 years
  - first: FERMILAB-TM-2084 (1999)
  - last: arXiv:1007.3178v1 (July 2010)
  - updated once a year when both experiments have major improvements
- Method unchanged
  - BLUE (Best Linear Unbiased Estimator)
- Details and challenges

The method: BLUE

- Well established methodology widely used throughout HEP

  L.Lyons, D.Gibaut, P.Clifford, NIM A270 (1988), A.Valassi, NIM A500 (2003)

  - Allows combination of correlated measurements of one or more parameters
  - Yields unbiased estimate of parameter with the smallest variance
  - Produces a fit χ^2 to evaluate consistency of inputs
  - Provides clean way to breakdown uncertainties
  - Measurement correlations are required as input
  - Assumes all uncertainties Gaussian distributed

BLUE

- Inputs

$$\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{pmatrix} \qquad M = \begin{pmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \rho_{13}\sigma_1\sigma_3 & \cdots & \rho_{1N}\sigma_1\sigma_N \\ \rho_{12}\sigma_1\sigma_2 & \sigma_2^2 & \rho_{23}\sigma_2\sigma_3 & & \\ \rho_{13}\sigma_1\sigma_3 & \rho_{23}\sigma_2\sigma_3 & \sigma_3^2 & & \\ \vdots & & & \ddots & \\ \rho_{1N}\sigma_1\sigma_N & & & & \sigma_N^2 \end{pmatrix}$$

- Output

$$\hat{x} = \sum_{i=1}^{N} w_i x_i \qquad \sigma_{\hat{x}}^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} M_{ij} w_i w_j$$

- where

$$w = M^{-1}U / (U_T M^{-1} U) \qquad \chi^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} (\hat{x} - x_i)(\hat{x} - x_j) M_{ij}^{-1}$$

In practice

- Decompose total uncertainty into a set of contributions (e.g. stat, signal model, bckg model etc)

$$M = \begin{pmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \cdots \\ \rho_{12}\sigma_1\sigma_2 & \sigma_2^2 & \\ \vdots & & \ddots \end{pmatrix}_{Stat} + \begin{pmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \cdots \\ \rho_{12}\sigma_1\sigma_2 & \sigma_2^2 & \\ \vdots & & \ddots \end{pmatrix}_{Signal} + \begin{pmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \cdots \\ \rho_{12}\sigma_1\sigma_2 & \sigma_2^2 & \\ \vdots & & \ddots \end{pmatrix}_{Bgnd} + \ldots$$

- Evaluate statistical correlations using MC pseudo-experiments
- Systematic correlations
  - often hard, assign $|\rho_{ij}|=0$ or 1

Tevatron combination

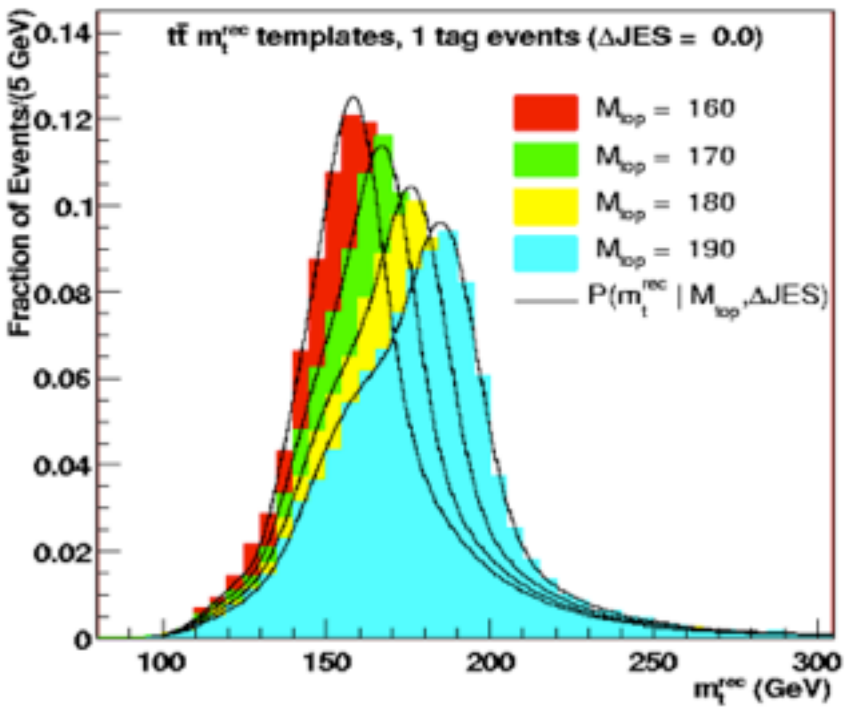
The measurements

The latest combination

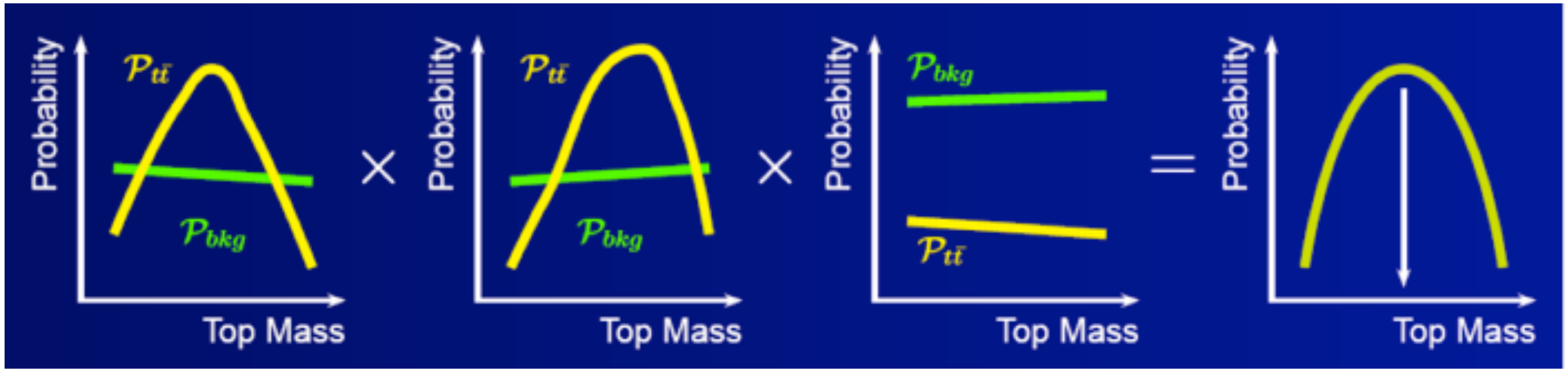
- Uses 11 input measurements
  - 5 published Run I results
    - CDF: l+jt (lepton+jets channel), di-l (dilepton channel), allh (all hadronic channel)
    - D0: l+jt, di-l
  - 4 CDF Run II results
    - latest and greatest lj+t, di-l, allh
    - published Lxy (l+jets channel but uses b decay length)
  - 2 D0 Run II results
    - latest and greatest l+jt, dil
- and 15 separate uncertainty categories

Mass extraction methods

- Template method
  - Choose variable strongly correlated with the top mass
  - Compare data to MC with different mass hypothesis



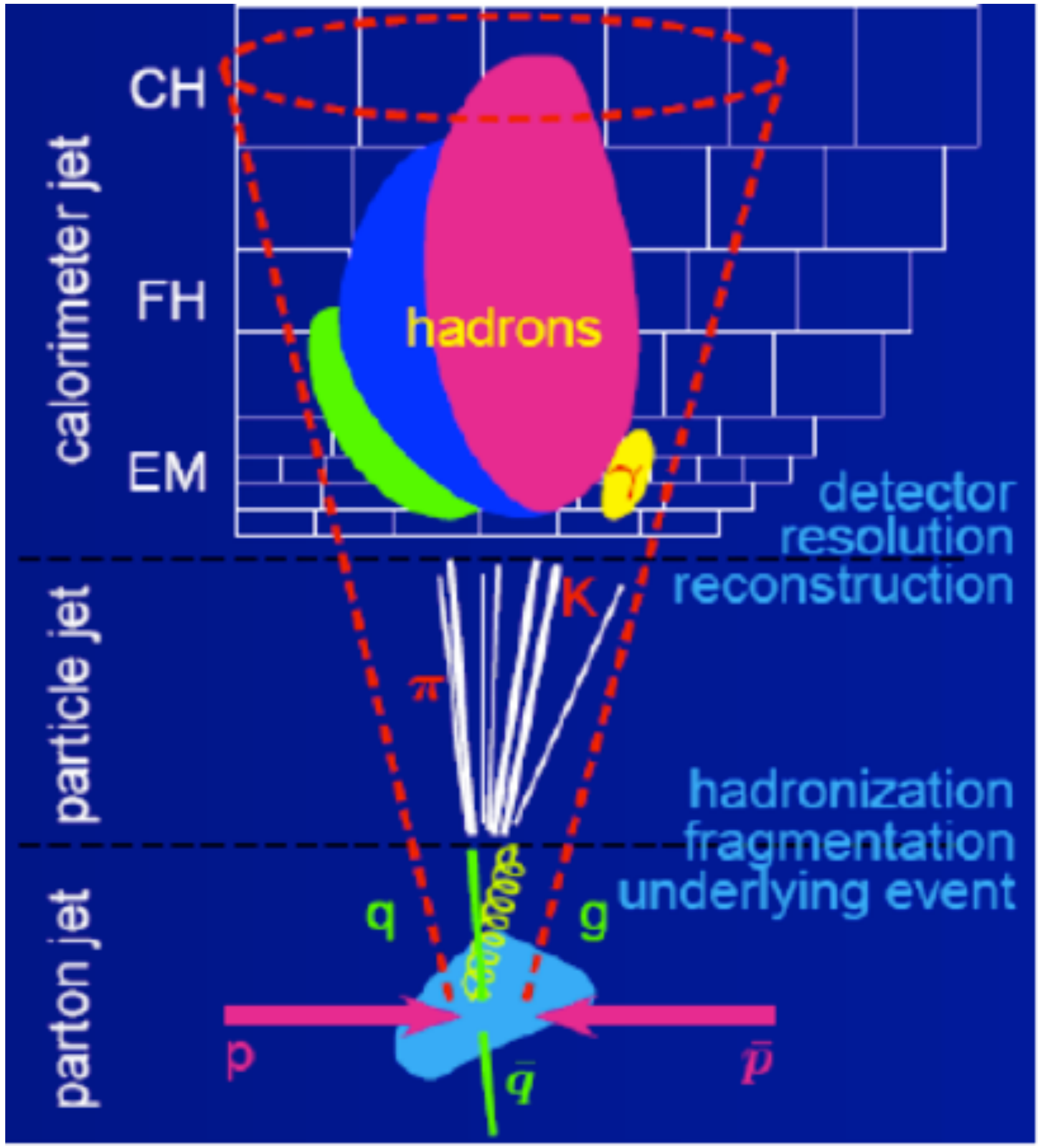
- Matrix element method
  - Calculate probability for event to be signal or background as a function of top mass
  - Multiply event probabilities to extract the most likely mass

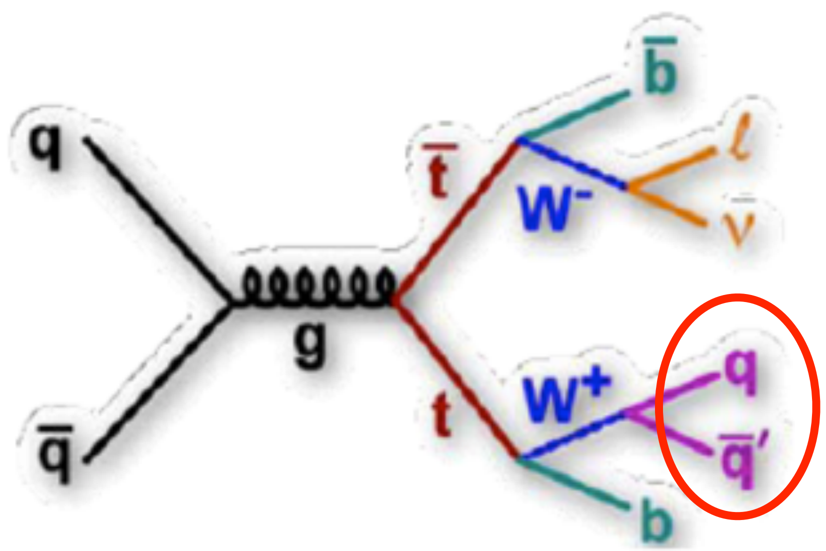


Maximizes statistical power by using full event information

Experimental challenges

- only jets can be measured
- clean mapping between reconstructed objects and partons
- jet energy scale calibration to particle level
  - dominating uncertainty
- in-situ calibration using hadronic W mass





Jet scale used to be severely limiting factor for top quark mass measurement

lepton+jets channel

Top mass and JES extracted simultaneously from maximum likelihood fit to data

D0 — 3.6 fb^{-1}

m_{top}=173.7±0.8(stat)±1.6(syst) GeV

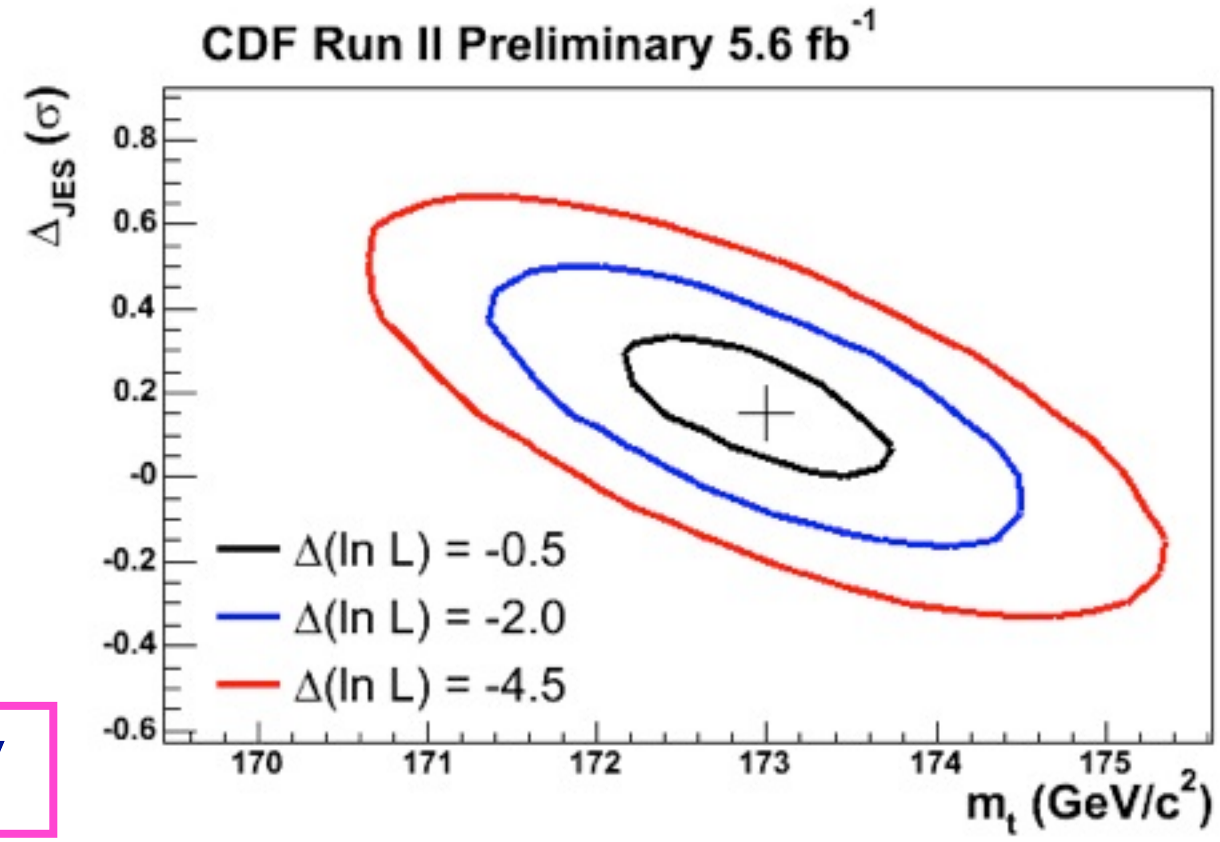
±1%

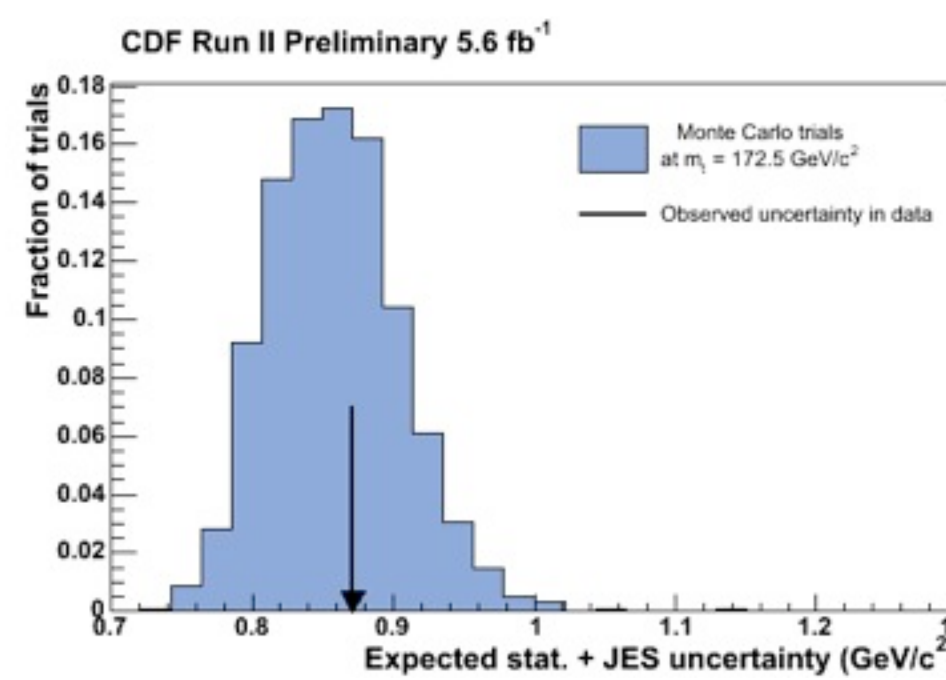
CDF — 5.6 fb^{-1}

$\Delta_{JES} = 0.15 \pm 0.18\ \sigma$

m_{top}=173.0±0.7(stat)±1.1(syst) GeV
±1.2(total) GeV

the most precise single measurement: ±0.7%





~1,000 top events with ≥1 b-tag

Ready to combine?

Figure 6: Calibrated results of the 2D analysis on Run IIb data.

Source	Uncertainty on top mass in Run IIb (GeV)	Uncertainty on top mass in Run IIa (GeV)
Higher Order Effects	±0.25	±0.25
ISR/FSR	±0.26	±0.40
Hadronization and UE	±0.58	±0.58
Color Reconnection	±0.40	±0.40
Multiple Hadron Interactions	±0.07	±0.01
Background Modeling	±0.03	±0.04
W HF factor	±0.07	±0.09
b-Modeling	±0.09	±0.03
PDF Uncertainty	±0.24	±0.14
Residual JES Uncertainty	±0.21	±0.10
Relative b/Light Response	±0.81	±0.83
Sample-Dependent JES	±0.56	±0.56
b-Tagging Efficiency	±0.08	±0.15
Trigger Efficiency	±0.01	±0.19
Lepton Momentum Scale	±0.17	±0.17
Jet Identification Efficiency	±0.26	±0.26
Jet Energy Resolution	±0.32	±0.03
QCD Background	±0.14	±0.14
Signal Fraction	±0.10	±0.09
Muon Resolution	-	±0.10
Signal Contamination	-	±0.13
MC Calibration	±0.20	±0.26
Total	±1.41	±1.43

Ready to combine?

CDF Run II Preliminary, 5.6 fb^{-1}

Systematic source	Systematic uncertainty (GeV/c^2)
Calibration	0.10
MC generator	0.37
ISR and FSR	0.15
Residual JES	0.49
b-JES	0.26
Lepton P_T	0.14
Multiple hadron interactions	0.10
PDFs	0.14
Background modeling	0.34
Color reconnection	0.37
Total	0.88

m_{top}=173.0±0.7(stat)±0.6(JES)±0.9(syst) GeV

Tevatron combination

Uncertainties

Common categories

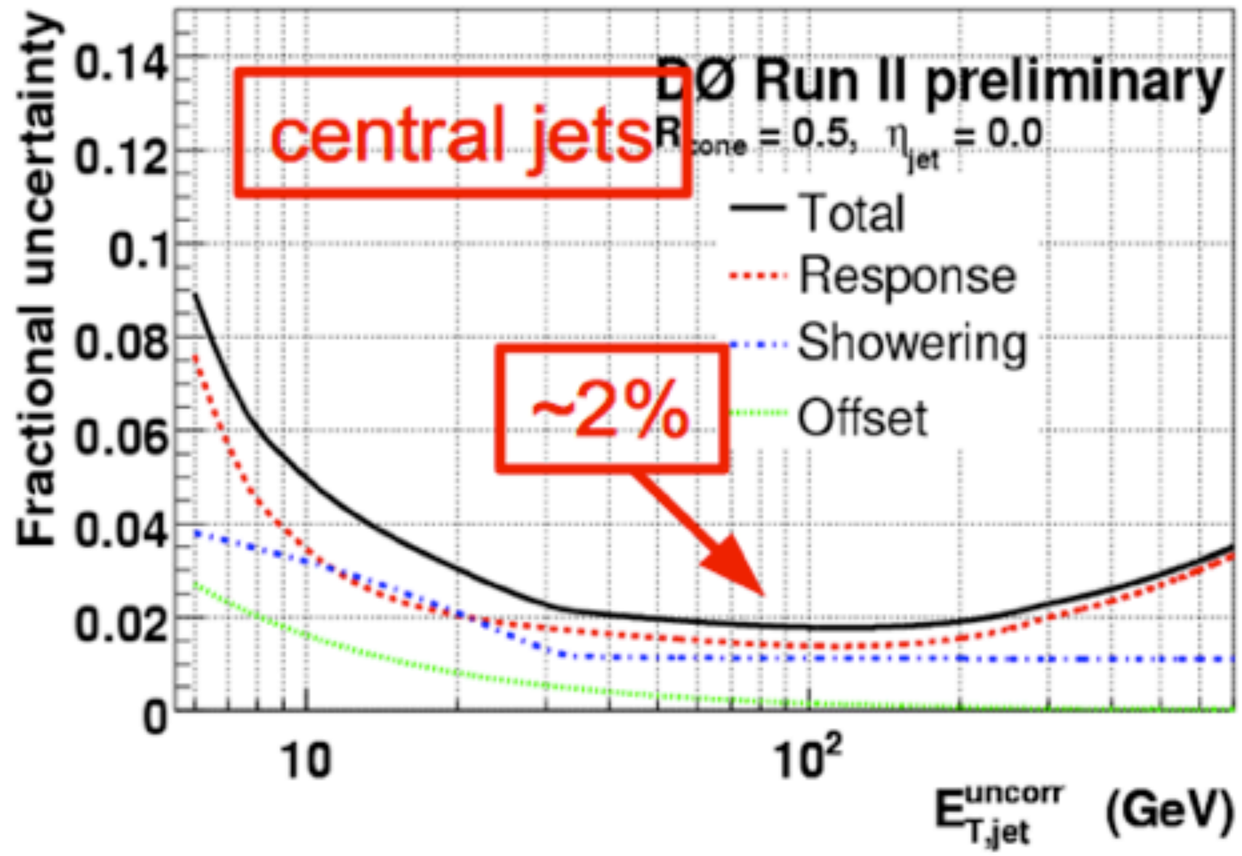
- Statistical: limited data statistics
- Monte Carlo
  - Pythia vs Herwig
- Signal modeling
  - ISR/FSR, PDF, higher order corrections (MC@NLO vs Alpgen)
- Color reconnection
  - phenomenological description of CR between final state particles
- Background modeling
  - normalization, shape
- Lepton transverse momentum scale
- Fit
  - fit method, b-tagging, limited MC statistics
- MHI:
  - multiple interaction per BC modeling
- UN/MI:
  - D0 uranium noise and multiple interactions
- JES - complicated!

JES: D0

- Corrects to particle level

$$E_{corr} = \frac{E_{meas} - O}{R \times S}$$

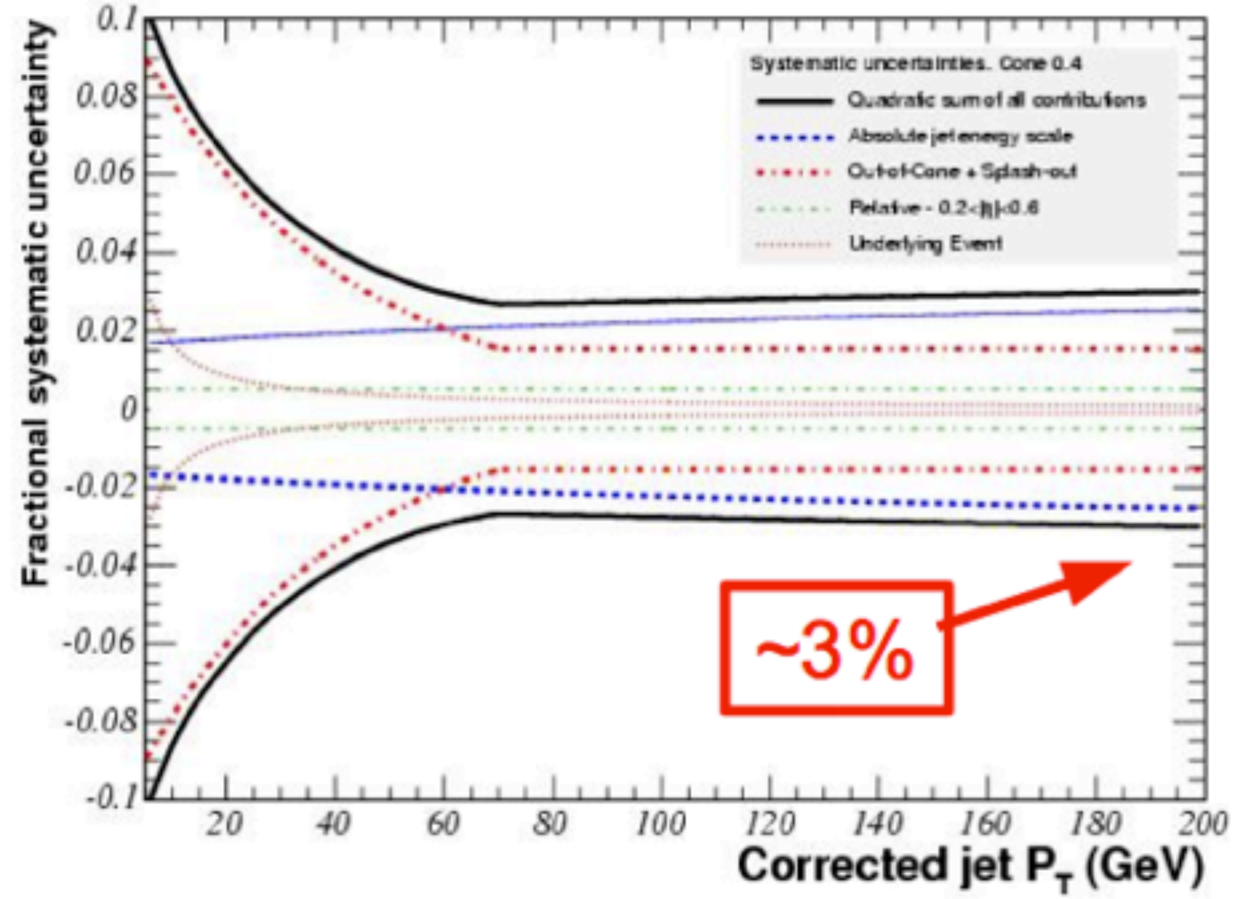
- Offset – energy not associated with hard scatter: noise, pile-up, multiple interactions
- Response – fraction of particle jet energy deposited in calorimeter by particles; R (F) – absolute (relative) correction
- Showering – energy flow in/out of calorimeter jet due to detector effects (finite calorimeter tower and hadron shower size, magnetic field)



- Two separate JES: for data, MC
- Derived mainly from γ + jets data and MC events, verified with multijet and Z+ jets
- Largest uncertainty – absolute response correction

JES: CDF

- Corrects to parton level
- Divided into different levels to accommodate different effects
  - response of the calorimeter
  - non-linearity of response
  - non-instrumented regions
  - spectator interactions
  - energy radiated outside the jet clustering algorithm cone
- Single particle response tuned to
  - Collision data at pT<20 GeV
  - Test beam data for pT>20 GeV
- Depending on the physics analyses, a subset of these corrections can be applied
- Smaller uncertainties due to better tuning of MC to data (factor of ~5)



- Main contributions:
  - Out-of -cone at low pT
  - Absolute JES at high pT

Common categories: JES

- aJES: Run-II b-jet/light jet detector response (D0)
- bJES: issues specific to b-jets modeling (b-fragmentation, semileptonic BR)
- cJES: fragmentation and out-of-cone showering
- dJES: relative (e.g. pseudo-rapidity, pT dependent) JES corrections, calorimeter response to light jets (D0)
- iJES: statistical component of JES from in-situ calibration from $W \rightarrow jj$
- rJES: remaining JES dominated by calorimeter response to light jets (CDF)

Tevatron combination

Correlations

Correlations

Run I
l+jets
dilepton

Run II
l+jets
dilepton

Run I
l+jets
dilepton
all had

Run II
l+jets
dilepton
all had

Correlations

DØ	CDF
Run I l+jets dilepton	**Run I** l+jets dilepton all had
Run II l+jets dilepton	**Run II** l+jets dilepton all had

correlated among all measurements modeling related uncertainties (signal, bJES, cJES, MC, color reconnection)

Correlations

DØ

Run I	Run I
l+jets	l+jets
dilepton	dilepton
	all had
Run II	Run II
l+jets	l+jets
dilepton	dilepton
	all had

CDF

correlated among all measurements of the same experiment (rJES, UN)

Correlations

Run I l+jets dilepton	Run I l+jets dilepton all had
Run II l+jets dilepton	Run II l+jets dilepton all had

correlated in the same run and the same experiment (aJES, dJES, lepton PT, MHI)

Correlations

correlated between all measurements in the same channel (background)

DØ	CDF
Run I	Run I
l+jets	l+jets
dilepton	dilepton
	all had
Run II	Run II
l+jets	l+jets
dilepton	dilepton
	all had

Correlation taken to be 100%

– no negative correlations

– variations are part of cross-checks

– only pragmatic options (and also probably right)

Correlations

Run I
l+jets
dilepton

Run II
l+jets
dilepton

Run I
l+jets
dilepton
all had

Run II
l+jets
dilepton
all had

uncorrelated
(statistical, iJES, fit)

Inputs

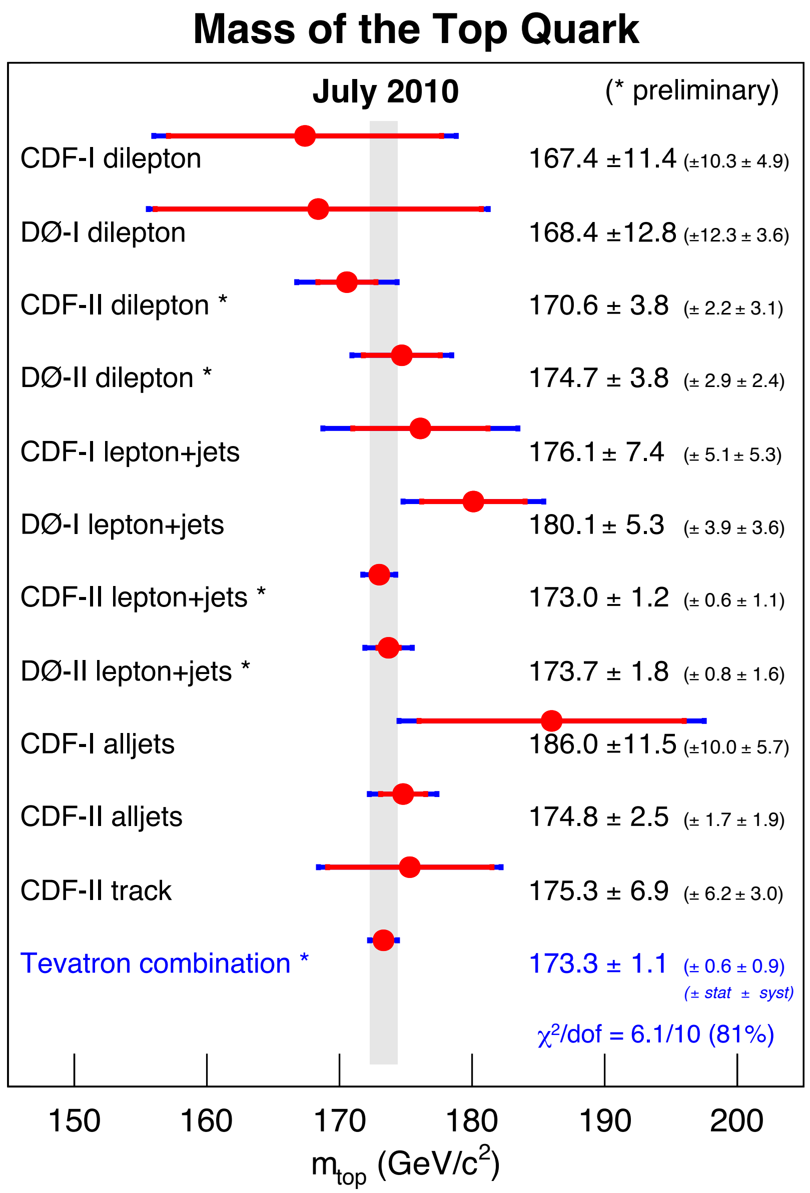
	Run I published					Run II published		Run II preliminary			
	CDF			DØ		CDF		DØ		CDF	
	all-j	l+j	di-l	l+j	di-l	all-j	trk	l+j	di-l	l+j	di-l
$\int \mathcal{L}\, dt$	0.1	0.1	0.1	0.1	0.1	2.9	1.9	3.6	3.6	5.6	4.8
Result	186.0	176.1	167.4	180.1	168.4	174.80	175.30	173.75	174.66	173.00	170.56
iJES	-	-	-	-	-	1.64	-	0.47	-	0.58	-
aJES	-	-	-	-	-	-	-	0.91	1.32	-	-
bJES	0.6	0.6	0.8	0.7	0.7	0.21	0.0	0.07	0.26	0.26	0.35
cJES	3.0	2.7	2.6	2.0	2.0	0.49	0.60	0.0	0.0	0.27	2.01
dJES	0.3	0.7	0.6	0.0	0.0	0.08	0.0	0.84	1.46	0.01	0.64
rJES	4.0	3.4	2.7	2.5	1.1	0.21	0.10	0.0	0.0	0.41	1.98
LepPt	0.0	0.0	0.0	0.0	0.0	-	1.10	0.18	0.32	0.14	0.31
Signal	1.8	2.6	2.8	1.1	1.8	0.23	1.60	0.45	0.65	0.21	0.36
Backgd	1.7	1.3	0.3	1.0	1.1	0.35	1.60	0.08	0.08	0.34	0.27
Fit	0.6	0.0	0.7	0.6	1.1	0.67	1.40	0.21	0.51	0.10	0.05
MC	0.8	0.1	0.6	0.0	0.0	0.31	0.60	0.58	1.00	0.37	0.57
UN/MI	-	-	-	1.3	1.3	-	-	-	-	-	-
CR	-	-	-	-	-	0.41	0.40	0.41	0.41	0.37	0.61
MHI	-	-	-	-	-	0.17	0.70	0.05	0.00	0.10	0.27
Syst	5.7	5.3	4.9	3.9	3.6	1.99	3.10	1.60	2.43	1.06	3.09
Stat	10.0	5.1	10.3	3.6	12.3	1.70	6.20	0.83	2.92	0.65	2.19
Total	11.5	7.3	11.4	5.3	12.8	2.61	6.94	1.80	3.80	1.24	3.79

Tevatron combination

Results

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Tevatron mass combination



new

0.6% relative uncertainty

m_{top}=173.3±1.1(total) GeV

m_{top}=173.32±0.56(stat)±0.89(syst) GeV

Systematic source		δm_{top} (GeV)
statistical component of JES	iJES	0.46
b-jet response	aJES	0.21
b-jet energy scale	bJES	0.20
modeling uncertainties	cJES	0.13
residual JES	dJES	0.19
detector response	rJES	0.15
	Lepton p_T	0.10
ISR/FSR, PDF, NLO	Signal model	0.19
	Background	0.23
	Fit	0.11
showering model	MC generator	0.40
	Color reconnection	0.39
	Multiple interactions	0.08
	Statistical	0.56
	Total	**1.06**

Monday, October 18, 2010

Correlation matrix

	Run I published					Run II published		Run II preliminary			
	CDF			DØ		CDF		DØ		CDF	
	l+j	di-l	all-j	l+j	di-l	all-j	trk	l+j	di-l	l+j	di-l
CDF-l+j	1.00	-	-	-	-	-	-	-	-	-	-
CDF-I di-l	0.29	1.00	-	-	-	-	-	-	-	-	-
CDF-I all-j	0.32	0.19	1.00	-	-	-	-	-	-	-	-
DØ-I l+j	0.26	0.15	0.14	1.00	-	-	-	-	-	-	-
DØ-I di-l	0.11	0.08	0.07	0.16	1.00	-	-	-	-	-	-
CDF-II all-j	0.15	0.10	0.12	0.10	0.05	1.00	-	-	-	-	-
CDF-II trk	0.16	0.08	0.07	0.12	0.05	0.06	1.00	-	-	-	-
DØ-II l+j	0.10	0.08	0.06	0.07	0.04	0.10	0.11	1.00	-	-	-
DØ-II di-l	0.07	0.06	0.05	0.04	0.03	0.07	0.07	0.52	1.00	-	-
CDF-II l+j	0.36	0.19	0.23	0.20	0.07	0.19	0.19	0.22	0.15	1.00	-
CDF-II di-l	0.48	0.28	0.35	0.23	0.11	0.21	0.12	0.11	0.08	0.43	1.00

Pulls and weights

	Run I published					Run II published		Run II preliminary			
	CDF			DØ		CDF		DØ		CDF	
	l+j	di-l	all-j	l+j	di-l	all-j	trk	l+j	di-l	l+j	di-l
Pull	+0.38	−0.52	+1.11	+1.30	−0.39	+0.62	+0.29	+0.29	+0.37	−0.50	−0.76
Weight [%]	−2.5	−0.5	−0.7	+1.3	+0.2	+10.5	−0.5	+26.2	−2.1	+70.0	−1.8

$$\text{Pull} = \frac{|m_i - <m>|}{\sigma_i}$$

Exercises

Tutorial

- http://physik2.uni-goettingen.de/~elis/tutorial.tar.gz
- or lxplus.cern.ch:/afs/cern.ch/user/e/elis/public/

- tar -zxf tutorial.tar.gz
- cd tutorial
- executable combine.exe, no compilation needed
- to run:

  ./tevatron_Summer_2010

  output is the latest world average top quark mass

Input

Measurements with uncertainties

```
./combine.exe<<!
'D0 Run II Combination Summer 2010 - ICHEP'
-1 -1 0     internal & minuit debug level, dependency flag
1 11 15       # of observables, measurements, error classes
'Mtop'      name of observable
                          'Stat' 'iJES' 'aJES' 'bJES' 'cJES' 'dJES' 'rJES' 'Lept' 'Signal' 'GEN' 'UN/MI' 'BG'
'C-1 l+jt' 'Mtop' 176.1    5.1    0.0    0.0    0.6    2.7    0.7    3.35   0.0    2.60    0.10  0.0   1.30   0.
'C-1 di-l' 'Mtop' 167.4    10.3   0.0    0.0    0.8    2.6    0.6    2.65   0.0    2.80    0.60  0.0   0.30   0.
'C-1 allh' 'Mtop' 186.0    10.0   0.0    0.0    0.6    3.0    0.3    4.00   0.0    1.80    0.80  0.0   1.70   0.
'D-1 l+jt' 'Mtop' 180.1   3.6     0.0    0.0    0.71   2.0    0.0    2.53   0.0    1.105   0.00  1.3   1.00   0.
'D-1 di-l' 'Mtop' 168.4   12.3    0.0    0.0    0.71   2.0    0.0    1.12   0.0    1.80    0.00  1.3   1.10   1.
'C-2 l+jt' 'Mtop' 173.00   0.65   0.58   0.000  0.264  0.27   0.01   0.41   0.14   0.207   0.37  0.00  0.34   0.
'C-2 di-l' 'Mtop' 170.56   2.19   0.00   0.00   0.35   2.01   0.64   1.98   0.31   0.36    0.57  0.00  0.27   0.
'C-2 allh' 'Mtop' 174.800 1.700 1.640  0.000  0.210  0.490  0.080  0.210  0.000  0.230   0.310 0.000 0.350  0.
'C-2 Lxy ' 'Mtop' 175.30   6.20   0.00   0.00   0.00   0.60   0.00   0.10   1.10   1.600   0.600 0.00  1.60   1.
'D-2 l+jt' 'Mtop' 173.747   0.8294 0.4701 0.9092 0.0715 0.0000 0.8397 0.0000 0.1783 0.4512 0.580 0.00  0.0834 0.
'D-2 di-l' 'Mtop' 174.656   2.9203 0.0000 1.3231 0.2571 0.0000 1.4596 0.0000 0.3220 0.6523 1.000 0.00  0.0791 0.
1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 Stat
0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0

1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 iJES
0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0
```

Correlation matrices

Example I

- Examine the weights of individual measurements
- Exclude the measurements with negative weights from combination
- Report the effect on the top mass uncertainty
- Is it consistent with expected based on L.Lyons, D.Gibaut, P.Clifford, NIM A270 (1988)

Example 2

- Remove all inputs except for Run II l+jets D0, CDF ("D2 l+jt", "C2 l+jt")
- Run combination with these two results only
- Compare resulting uncertainties with the full Tevatron combination
- Scale all uncertainties of statistical origin assuming integrated luminosity of 10 fb^{-1}.
- Run combination. What will be the limiting factor for m_{top} precision?

Example 3

- Remove all inputs except for Run II l+jets D0, CDF ("D2 l+jt", "C2 l+jt")
- Remove all systematic uncertainties, leave only statistical
- Reproduce case (1) from p112 of Lyons et al
- Change correlations to reproduce case (2)
- Change correlations to obtain negative weights

Examples 4-6

Starting from initial inputs obtain:

- D0 combination, CDF combination using two options:
  - (a) fitting two variables at once (b) creating separate combination code for D0 and CDF
  - is there a difference between (a) and (b)
  - compare your result with D0 note D0combination.pdf and CDF note CDFsum10MtCombo.pdf
- Run I D0+CDF, Run II D0+CDF
  - use same two options as above and compare
  - compare Run I and Run II uncertainties
- combined m_{top} separately for dilepton, lepton+jets and all hadronic channel compare the results with the Tevatron combination note
  - use same two options as above and compare
- are all measurements consistent with each other?

Backup

Tevatron categories

Systematic source	correlation
iJES	uncorrelated
aJES	correlated among Run (I or II) for the same experiment
bJES	correlated among all measurements
cJES	correlated among all measurements
dJES	correlated among Run (I or II) for the same experiment
rJES	correlated among all measurements of the same experiment
Lepton p_T	correlated among Run (I or II) for the same experiment
Signal model	correlated among all measurements
Background	correlated among all measurements of the same experiment and chanel
Fit	uncorrelated
MC generator	correlated among all measurements
Color reconnection	correlated among all measurements
Multiple interactions	correlated among all measurements
Total	1.06

Uncertainty symmetrization

2 types of uncertainties:

1) result from the +/- 1 sigma variation of a certain quantity

3 types of treatment: M_{nom} = central value, σ_M = quoted uncertainty

1.a) +/- shift leads to M_+/M_- where $M_+<M_{nom}<M_-$ or $M_-<M_{nom}<M_+$

$\sigma_M = | M_- - M_+|/2$

1.b) +/- shift when M_+-M_{nom} and $M_- - M_{nom}$ have the same sign

$\sigma_M = \max(|M_+-M_{nom}|/2, |M_- - M_{nom}|/2)$

JES, residual JES, b-JES, PDF, ISR/FSR, detector modeling, method , bkg

1.c) only one sided variation allowed:

quote full difference as one sided systematic (asymmetric)

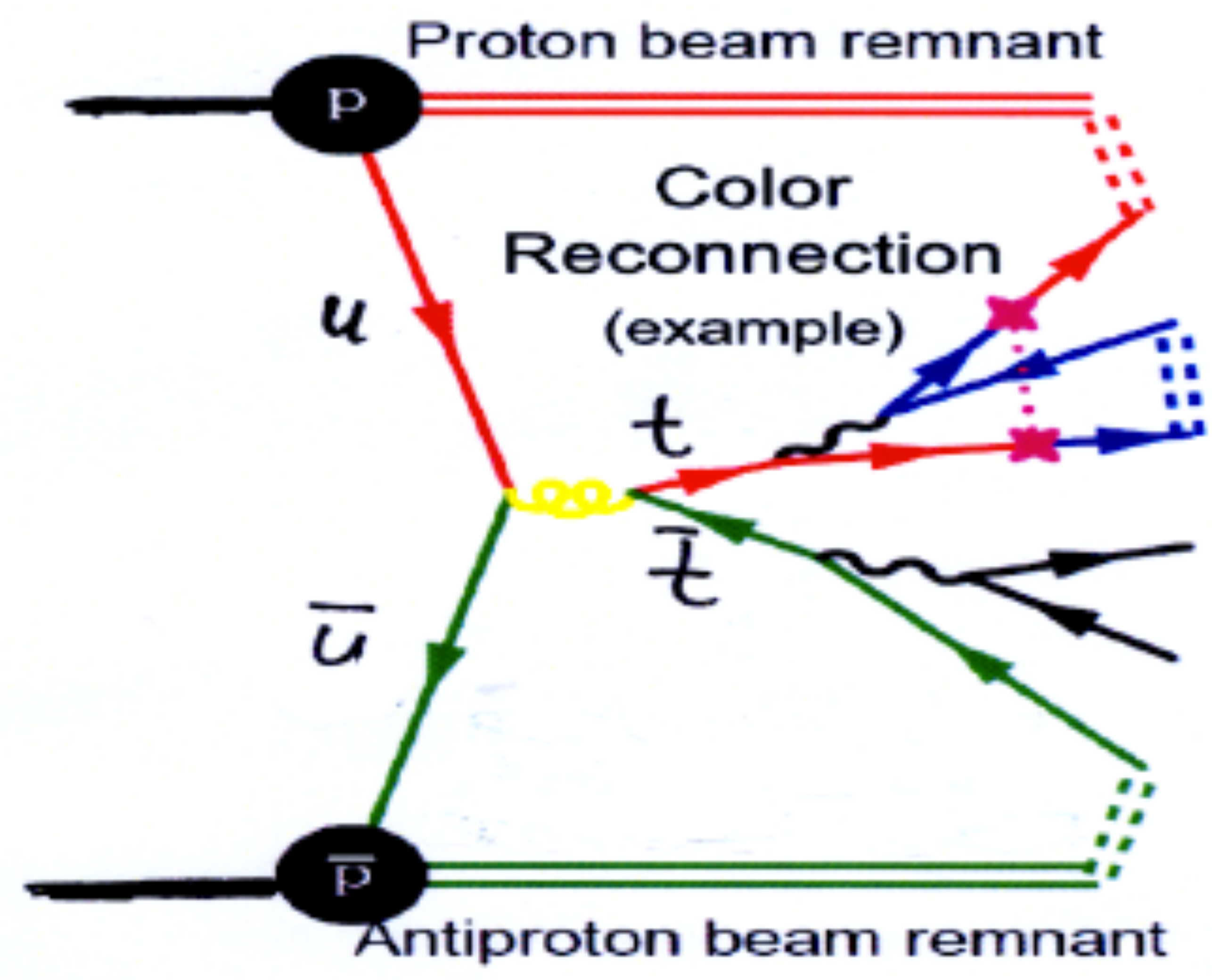
sample dependence JES, sometimes trigger, lepton momentum scale

2) difference between 2 (more) models

full maximal difference as σ_M (symmetrized)

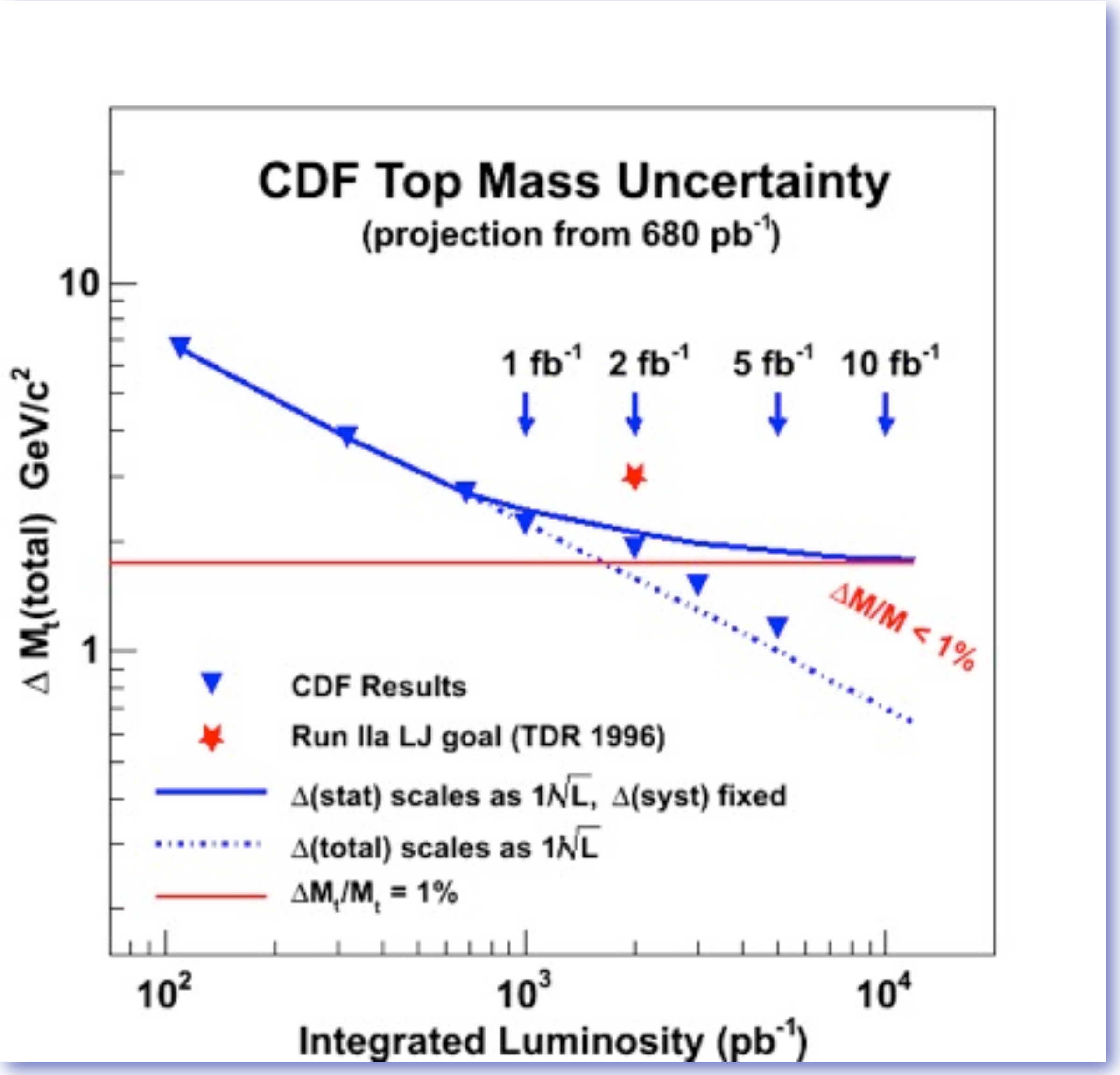
b-fragmentation, hadronization modeling, higher order effects, UE and CR

Color reconnection



Future precision

CDF example



Systematic source	δm_{top} (GeV)
calibration	0.10
MC generator	0.37
Radiation	0.15
Residual jet energy scale	0.49
b-jet energy scale	0.26
Lepton p_T	0.14
Multiple hadron interactions	0.10
PDFs	0.14
Background	0.34
Gluon fraction	0.03
Color reconnection	0.37
Total	**0.88**

Approaching 1 GeV uncertainty on a single measurement