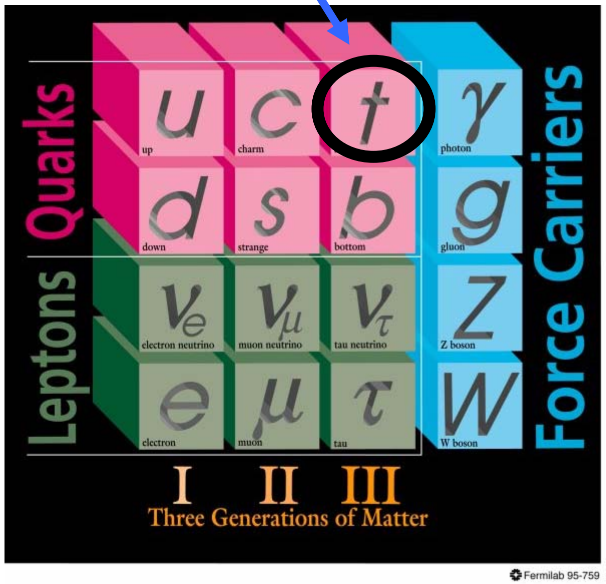
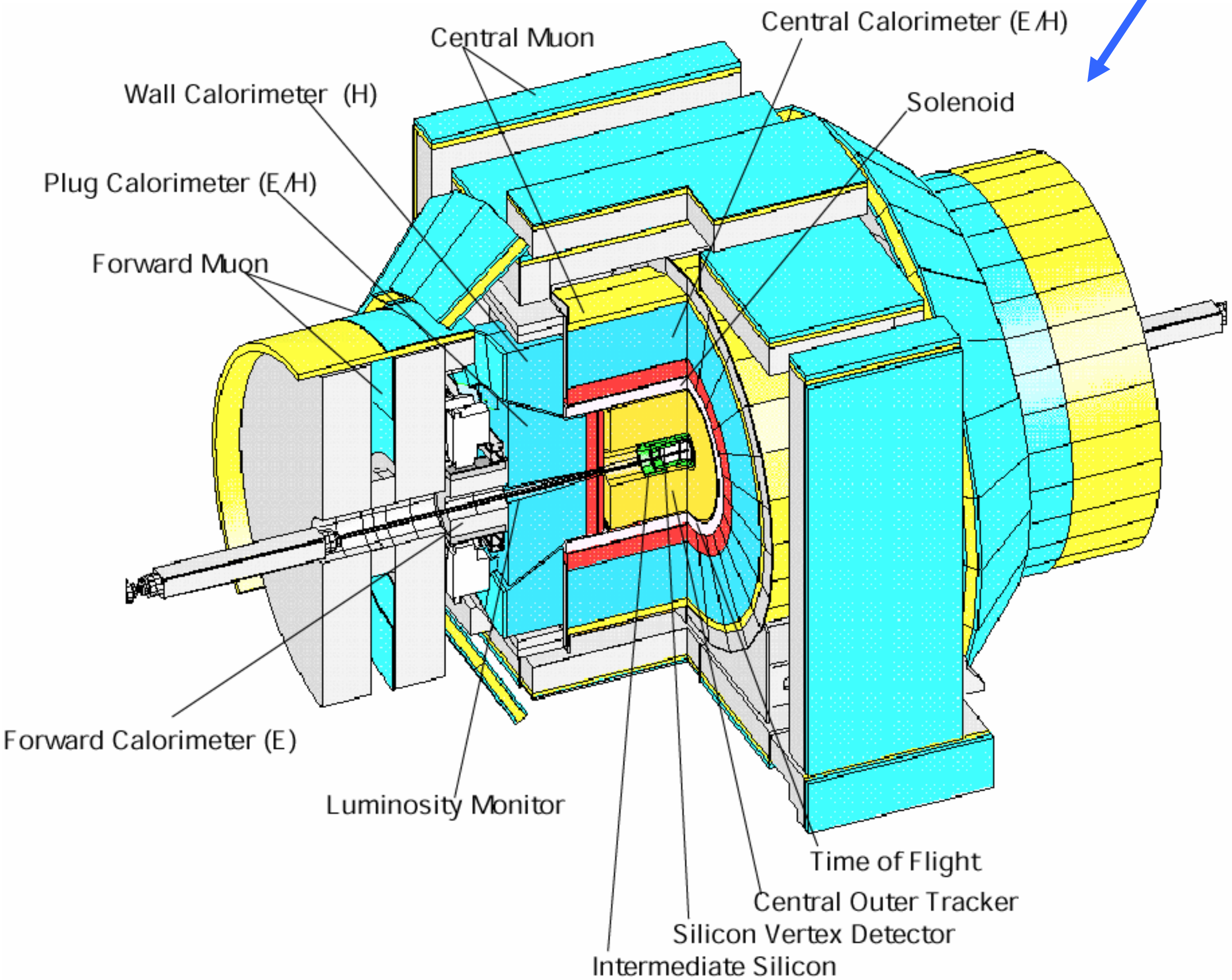
Top Mass Measurement at CDF



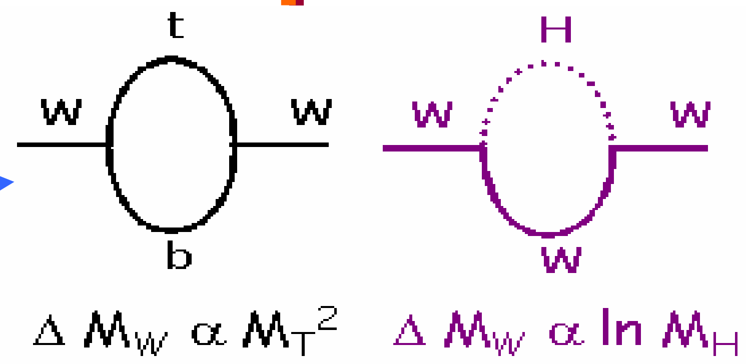


Kostas KORDAS
INFN – Frascati

Frontier Science 2005
Milano, 12-17 Sept. 2005

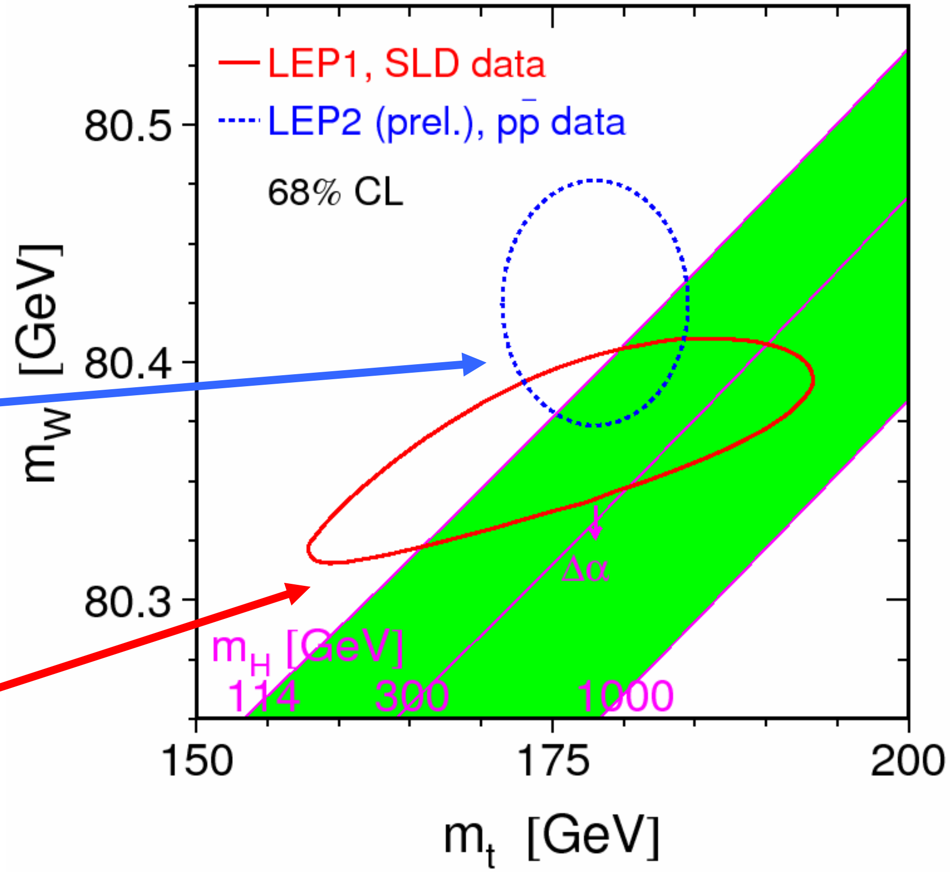
Why measuring the top mass?

- **Top mass** unpredicted in Standard Model (SM), but **related to *W, Higgs*** (and other observables).



(Higgs is mass giver to all)

- When all *W, t, H* measured:
  test SM
  (and to test you have to measure well…)



- Radiative corrections affect observables

  ↓

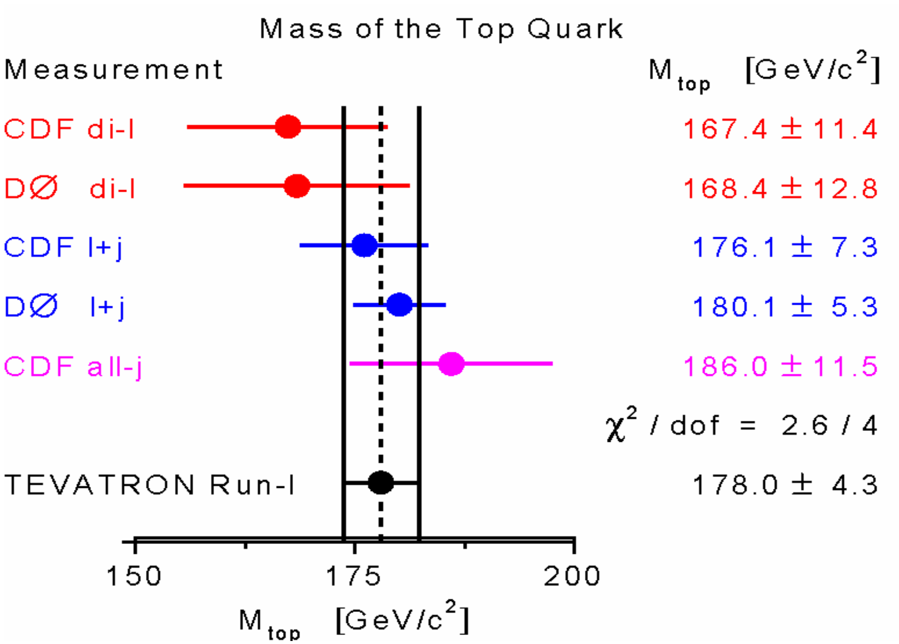
  Game of ElectroWeak fits

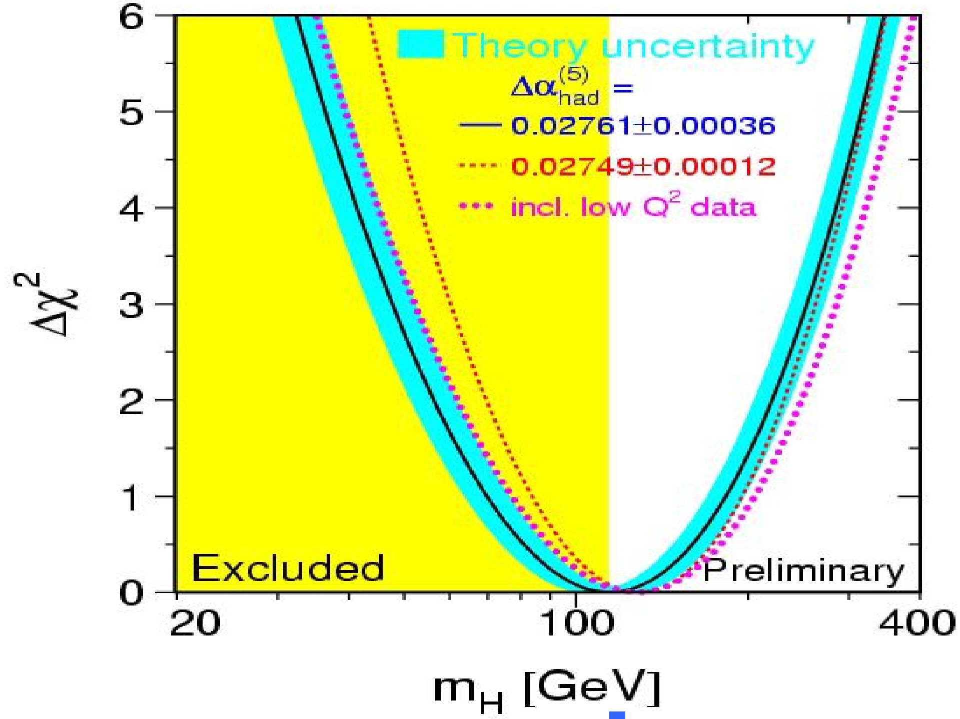
History of M_{top} measurements

- Top first observed at CDF & D0 in 1995. Tevatron's Run I: ~110pb^{-1} per exp.

- Run I Average:

$$M_{top} = 178.0 \pm 4.3 GeV / c^2$$

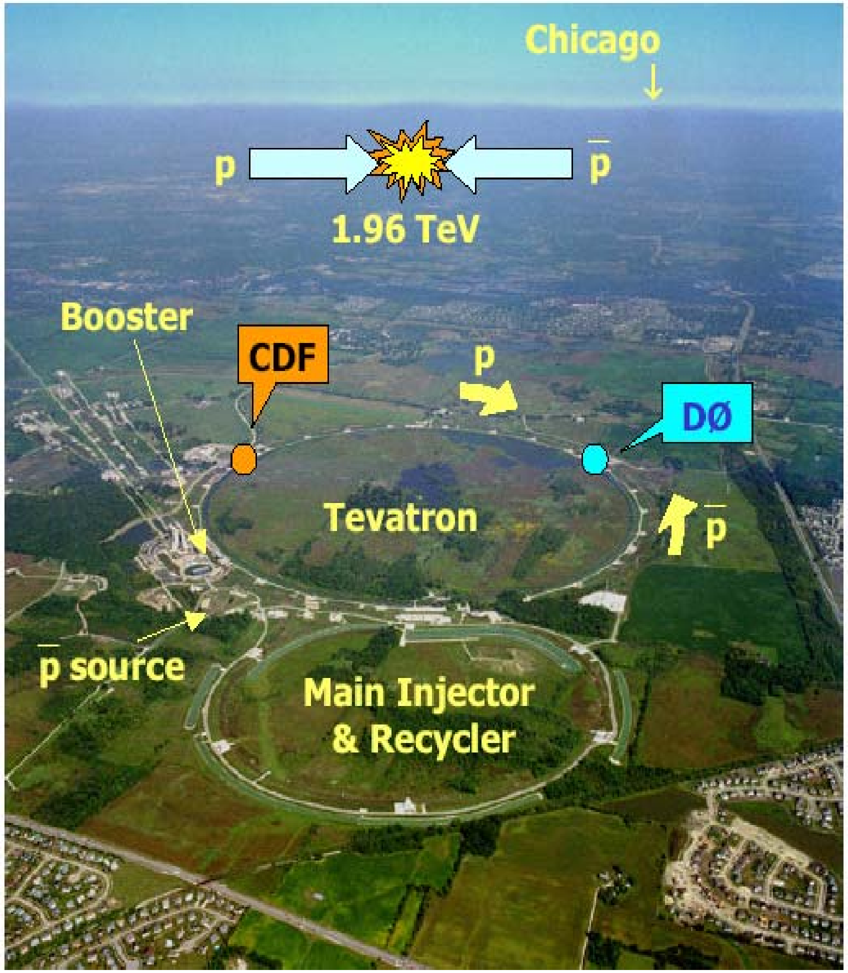




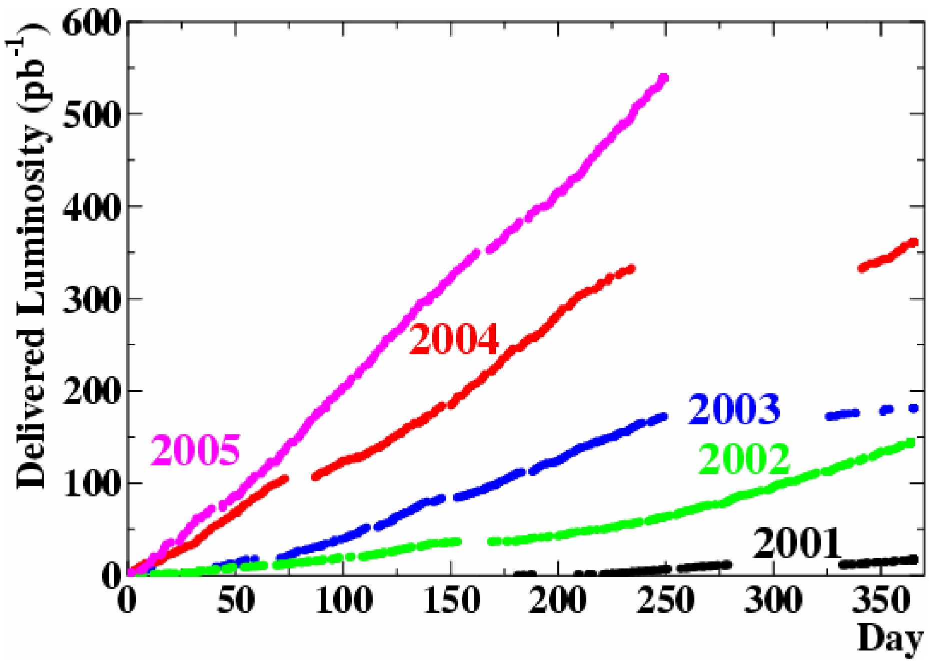
$$M_H = 126^{+73}_{-48} GeV / c^2$$

$$M_H < 280 GeV / c^2 \ @95\% C.L.$$

Where do we get top quarks?



- $1 fb^{-1}$ per experiment on tape
- $\sim 1.3\ fb^{-1}$ delivered luminosity
- Peak luminosity $1.4 \times 10^{32} cm^{-2} s^{-1}$
- Presented here: $320 - 360\ pb^{-1}$



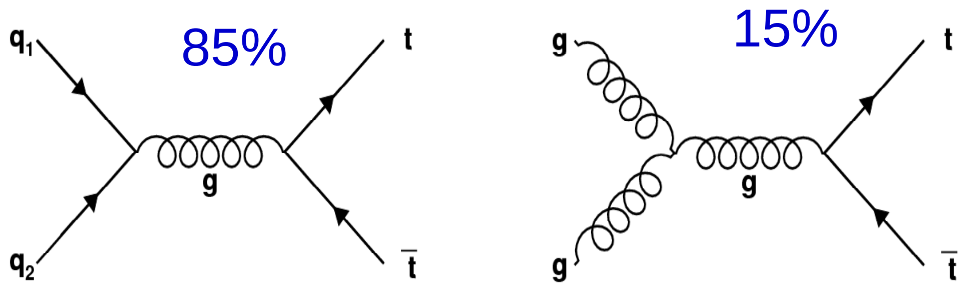
Goal of Run II per experiment:

$$\int Ldt \approx 4-8\ fb^{-1} \rightarrow \sigma_{M_{top}} \approx 2GeV/c^2$$

($1\ fb^{-1} \sim 6 \times 10^{13}$ collisions, $\sim 6.5 \times 10^3$ top pairs)

Top production and decay

- Production: mainly $t\bar{t}$

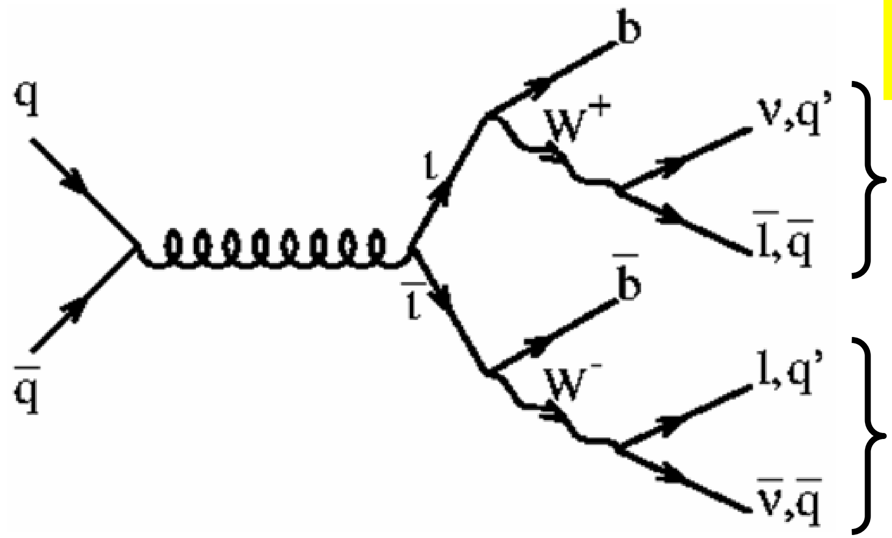


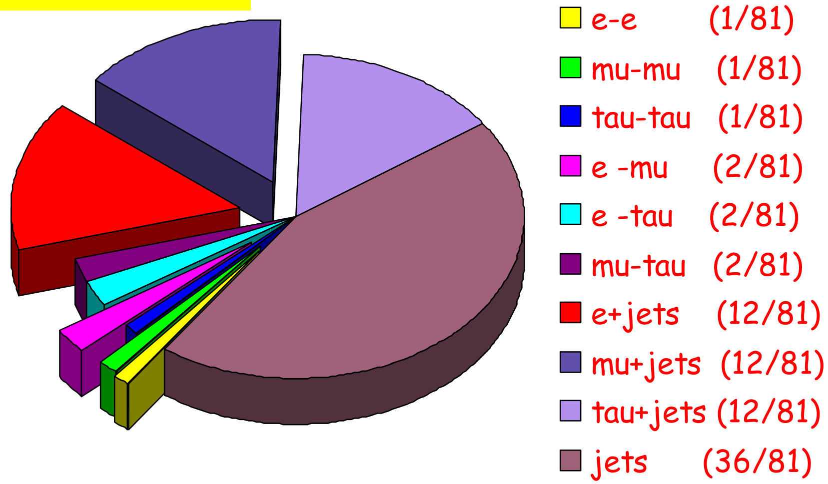
$$\sigma(\bar{p}p \to t\bar{t} @ m_t = 175\,\text{GeV}) \approx 6.7\ \text{pb}$$
$$\sigma(\bar{p}p \to t\bar{t} @ m_t = 178\,\text{GeV}) \approx 6.1\ \text{pb}$$
$$\sigma(\bar{p}p \to t\bar{t} @ m_t = 180\,\text{GeV}) \approx 5.7\ \text{pb}$$

- All-hadronic: 44%
- **Lepton + jets: 30%**
- Dilepton: 5%

- Decay: BR(t → W b) ~ 100%

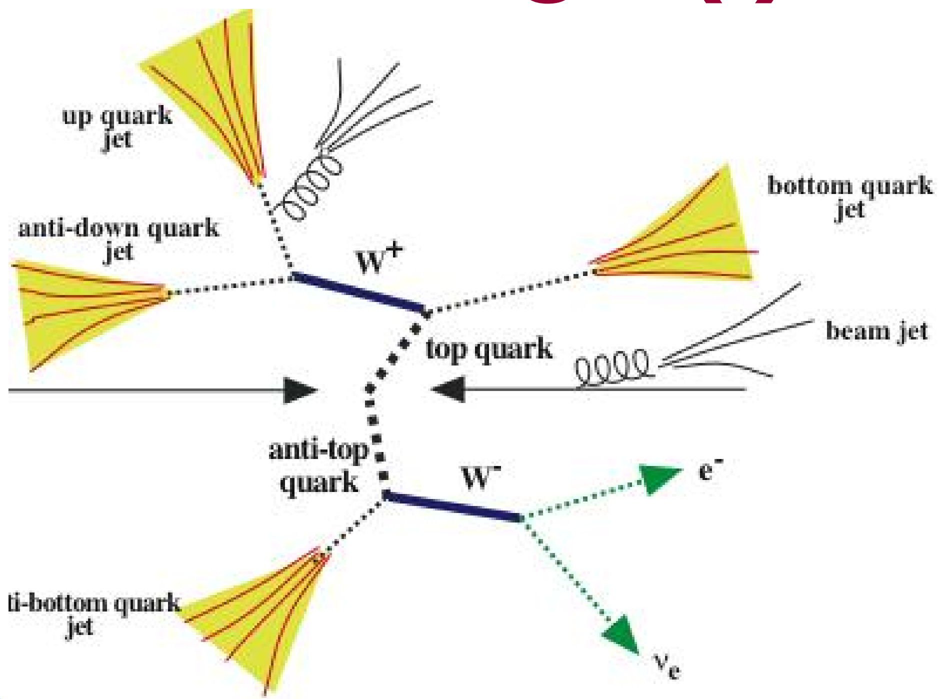
W decay defines $t\bar{t}$ decay mode





M_{top} measurement challenge (I)

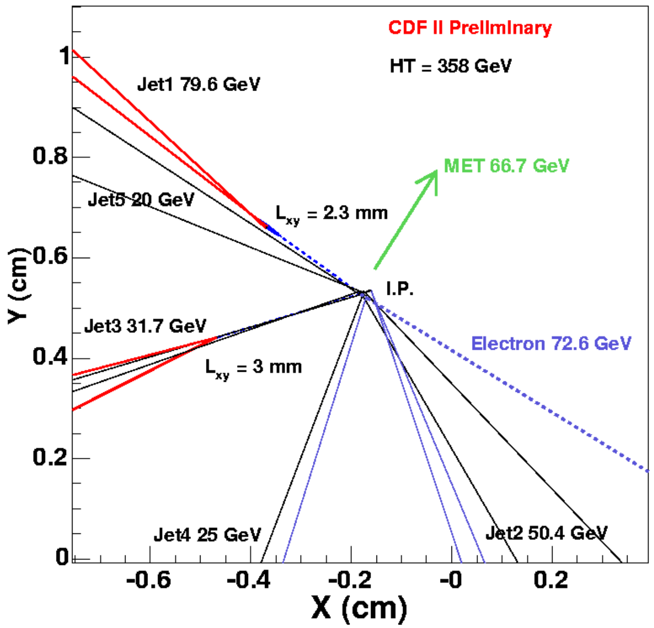
Measure: e, μ, jets, tracks, $\not{E}_T$



1. Association to top daughters?
2. Background events?

→ **Dileptons**: extra lepton, only 2 jets (but 2 ν's →1 $\not{E}_T$, low stat)

→ **B-tagging helps a lot!**



Lepton + jets event:

B-tags	Jet assignments
None	24
1	6
2	2

Best case!

M_{top} measurement challenge (II)

- **Accuracy of measurements**

  Dominant uncertainty:

  Jet Energy Scale (JES)

  ➔ jet→quark energy mapping

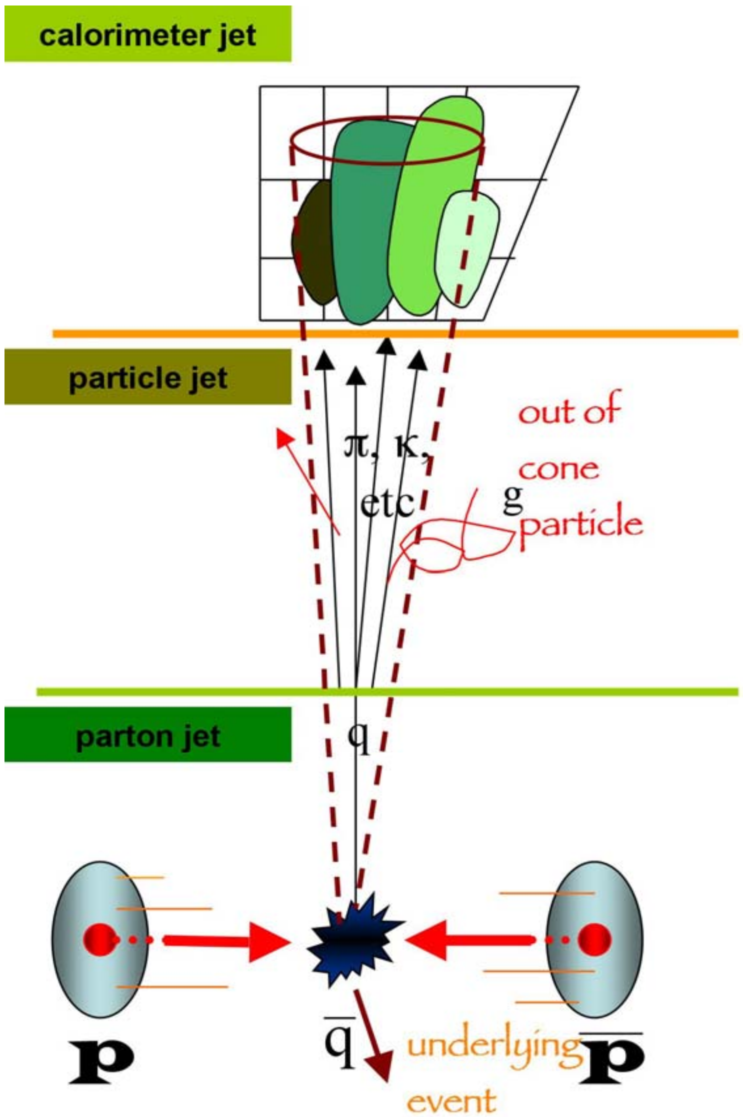
- Run I world average uncertainty (±4.3 GeV/c²):

  → 2.6 GeV/c² from JES

  → 2.7 GeV/c² from stat.

- Scale from "1st principles": σ/E_T **~3%**
- What about standard candles?

  W → *jet jet* (use *W* in top events)



M_{top} lepton+jets (1D template method)

Datasets

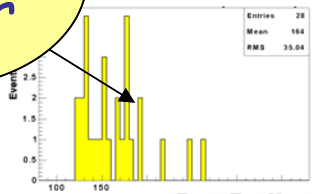
Data

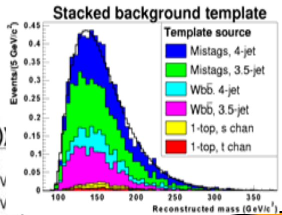
bkg MC

tt MC

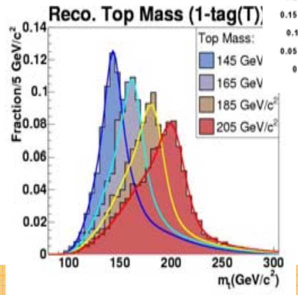
Mass fitter

χ^2 mass fitter:
Impose mass constraints, find best top mass & jet-parton assignment ➔ One M_{top} per event
Additional selection cut on resulting χ^2



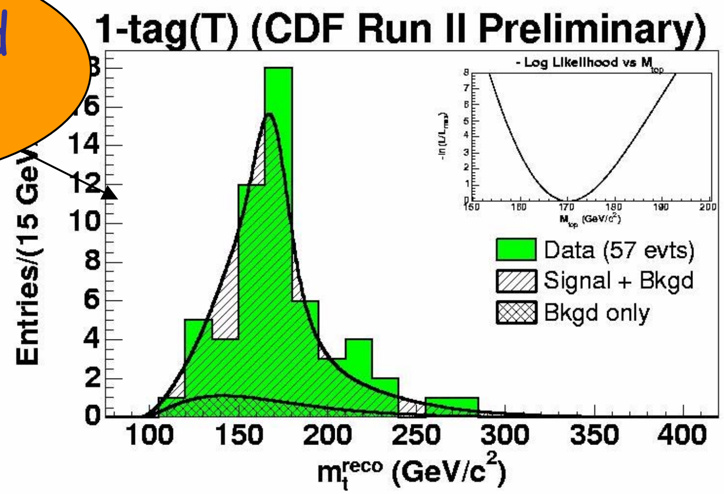


Templates



Likelihood fit

Result



Likelihood fit:
Best signal + bkg templates to fit data
Compare to parameterization, not directly
Constraint on background normalization

M_{top} lelpton+jets: 1D templates

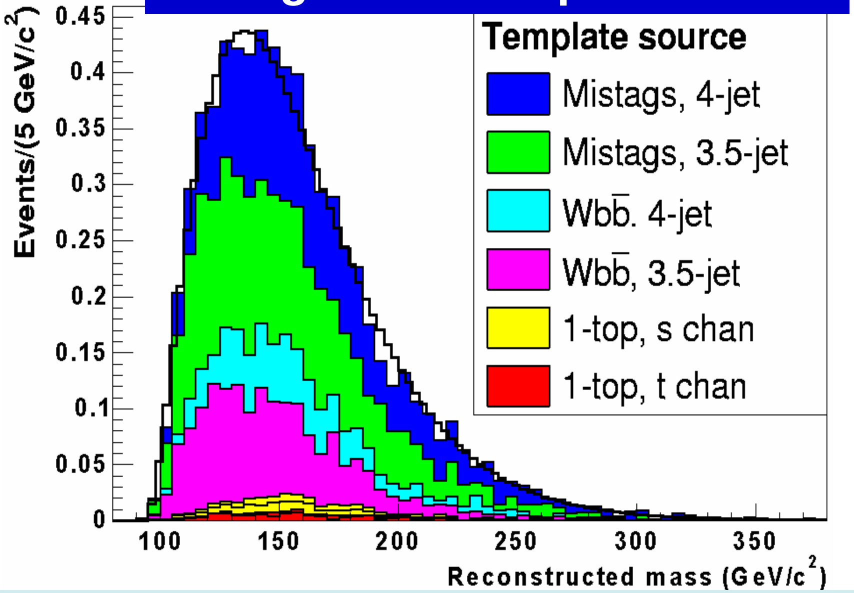
- Exclusive samples in # b-tags

Sample	Jet E_T cut [GeV]	S/B	<bkg>	Events
2 b-tags	3 jets $E_T > 15$, 4th jet $E_T > 15$	18:1	0.7 ± 0.2	**16**
1 b-tag	(T) 4 jets $E_T > 15$	4:1	7.6 ± 1.2	**57**
1 b-tag	(L) 3 jets $E_T > 15$, 4th jet $8 < E_T < 15$	1:1	10.2 ± 1.7	**25**
0 b-tags	4 jets $E_T > 21$	1:1	N/A	**40**

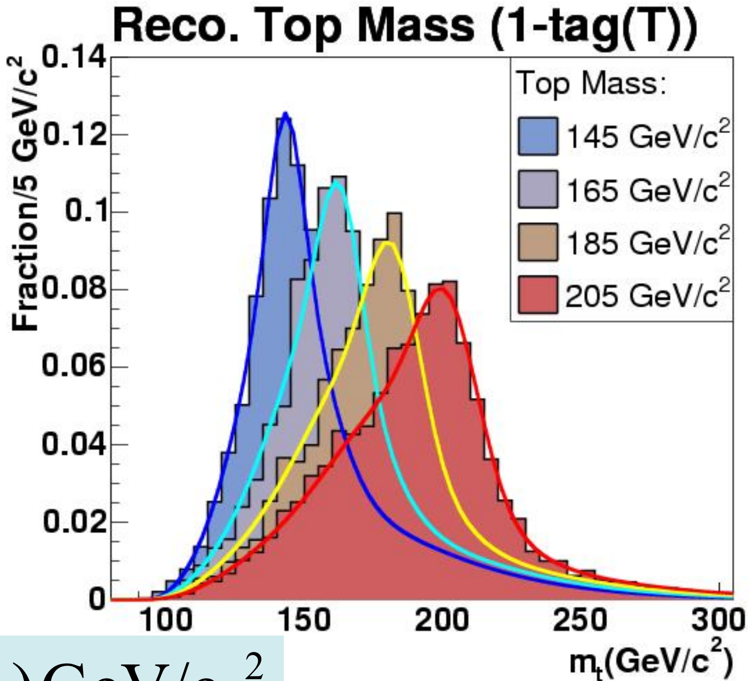
$$L_{sample} = L_{shape} \times L_{bkg}$$

background constrained to prediction (except for 0-tag)

Background Template

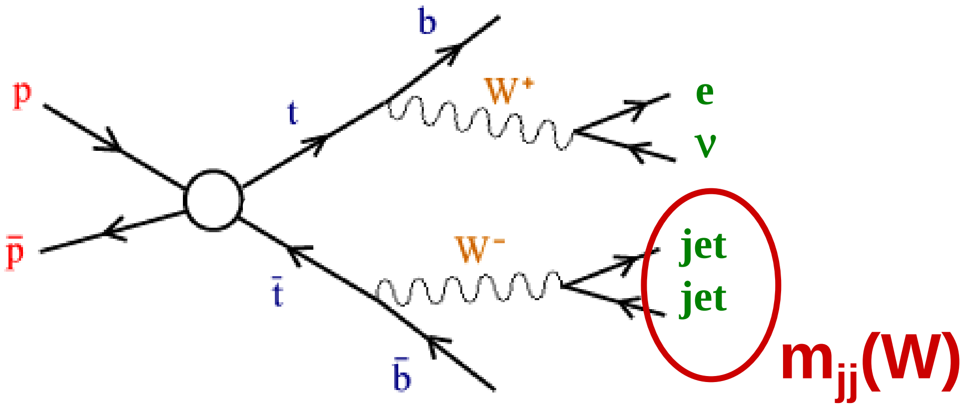


Signal Template

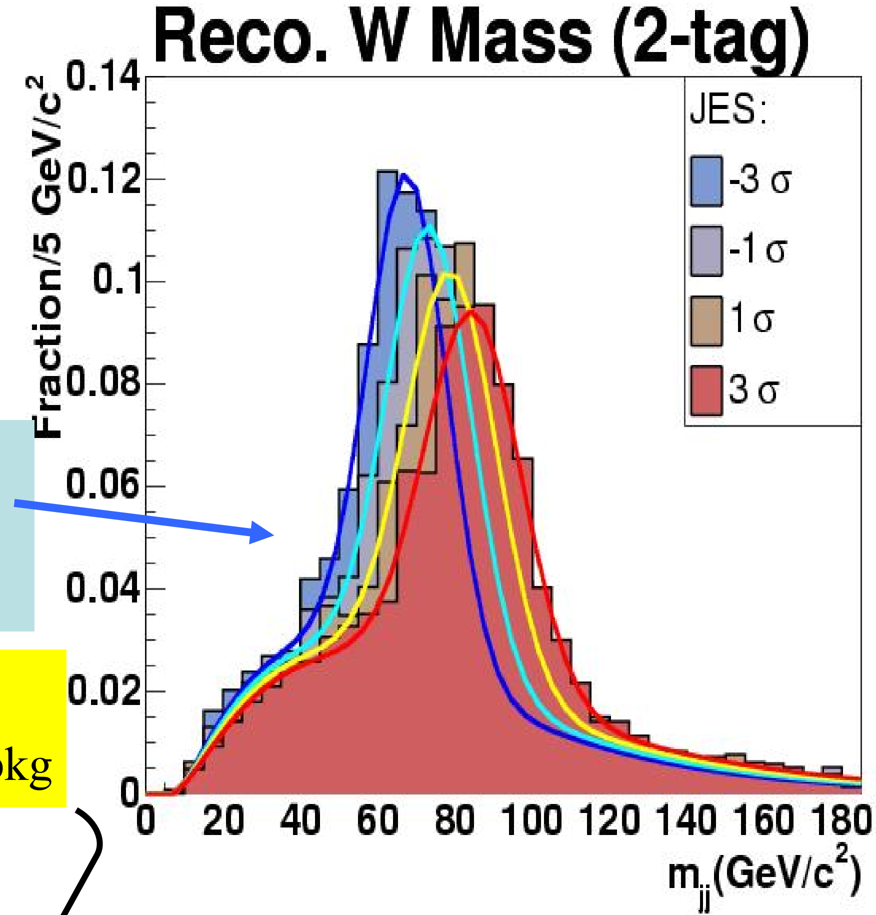


$$M_{top} = 173.2^{+2.9}_{-2.8}(\text{stat.}) \pm 3.1(\text{JES}) \pm 1.5(\text{syst.})\, \text{GeV}/c^2$$

M_{top} using *W→jet jet*: 2D templates



- Sensitive to Jet Energy Scale (JES)
- minimal sensitivity to M_{top}



$$L_{sample} = L_{shape}^{M_{top}} \times L_{shape}^{m_{jj}} \times L_{bkg}$$

$$L_{JES} = \exp\left(-\frac{(JES - JES_{STD})^2}{2\sigma^2_{JES_{STD}}}\right)$$

Constrain to a-priori JES estimate

$$L = L_{JES} \times \prod_i L_{sample(i)}$$

Find best (M_{top}, JES) to fit data

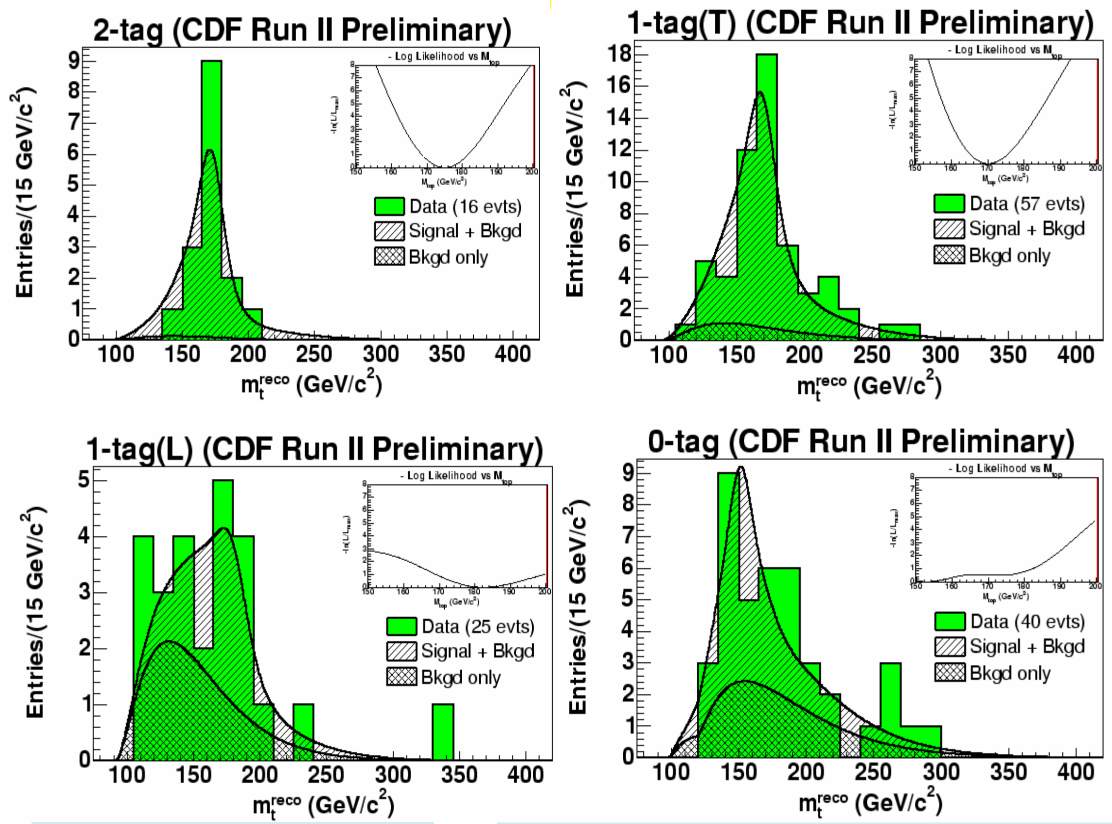
M_{top} lepton+jets (2D): result

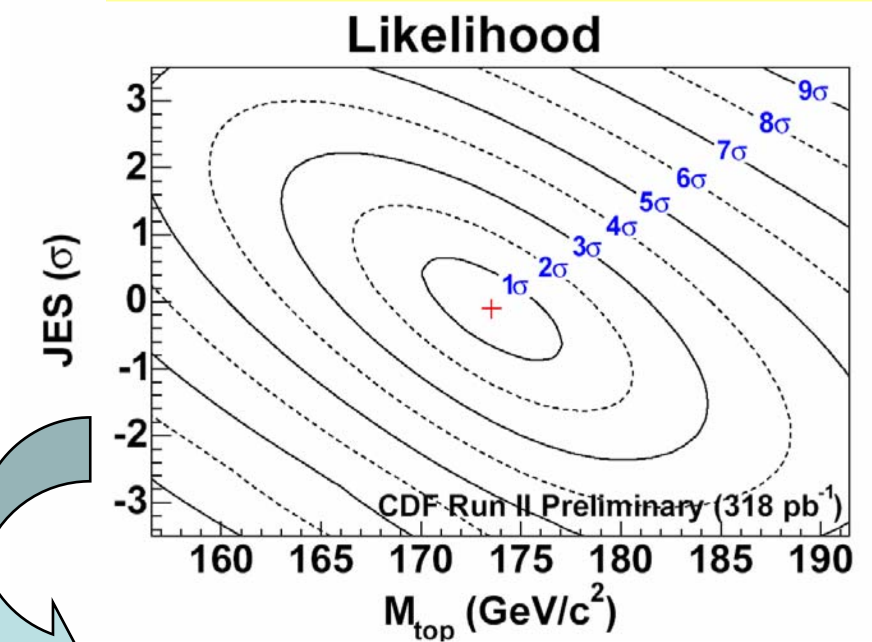
- **2D template method (using W→ jet jet):**

best single measurement (318 pb^{-1}) better than Run I average

$$M_{top} = 173.5^{+2.7}_{-2.6}(\text{stat.}) \pm 2.5(\text{JES}) \pm 1.7(\text{syst.})\,\text{GeV/c}^2$$

$$M_{top} = 173.5^{+4.1}_{-4.0}\,\text{GeV/c}^2$$





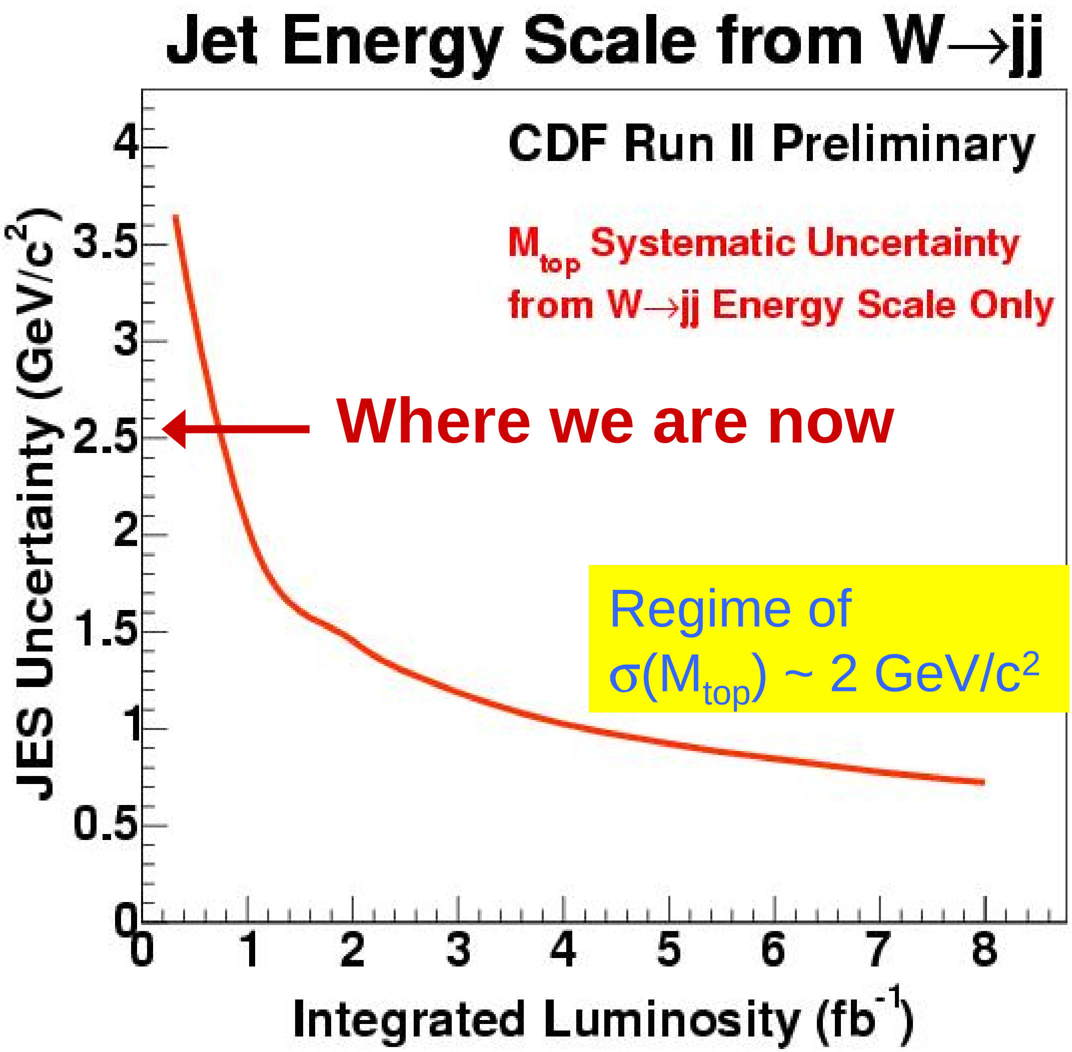
$$\text{JES} = -0.1^{+0.78}_{-0.80}\,\sigma_{\text{JES STD}}$$

1D template: $M_{top} = 173.2^{+2.9}_{-2.8}(\text{stat.}) \pm 3.1(\text{JES}) \pm 1.5(\text{syst.})\,\text{GeV/c}^2$

M_{top} *lepton+jets systematics (2D)*

Systematic Source	**2-D fit** ΔM_{top} (GeV)	**1-D fit** ΔM_{top} (GeV)
JES	2.5	3.1
b-jet modeling	0.6	0.6
ISR	0.4	0.4
FSR	0.6	0.4
PDFs	0.3	0.4
Generators	0.2	0.3
Bkg shape	1.1	1.0
b-tagging	0.1	0.2
MC statistics	0.3	0.4
Method	0.5	-
TOTAL	**3.0 = 2.5⊕1.7**	**3.4 = 3.1⊕1.5**

- Jet Energy Scale dominates
- In-situ calibration improves w/ statistics



M_{top} *lepton+jets*: Dynamical Likelihood

- Implement knowledge transparently

K. Kondo J. Phys. Soc. 57 4126 (1988)

$d^n\sigma$: cross section (LO Matrix element)

W(y,x): probability parton variables ***y*** measured as variables ***x***

$$L(x;M_{top}) = \frac{1}{N}\sum \int d^n\sigma(y;M_{top})dq_1 dq_2 f(q_1) f(q_2) W(x,y)$$

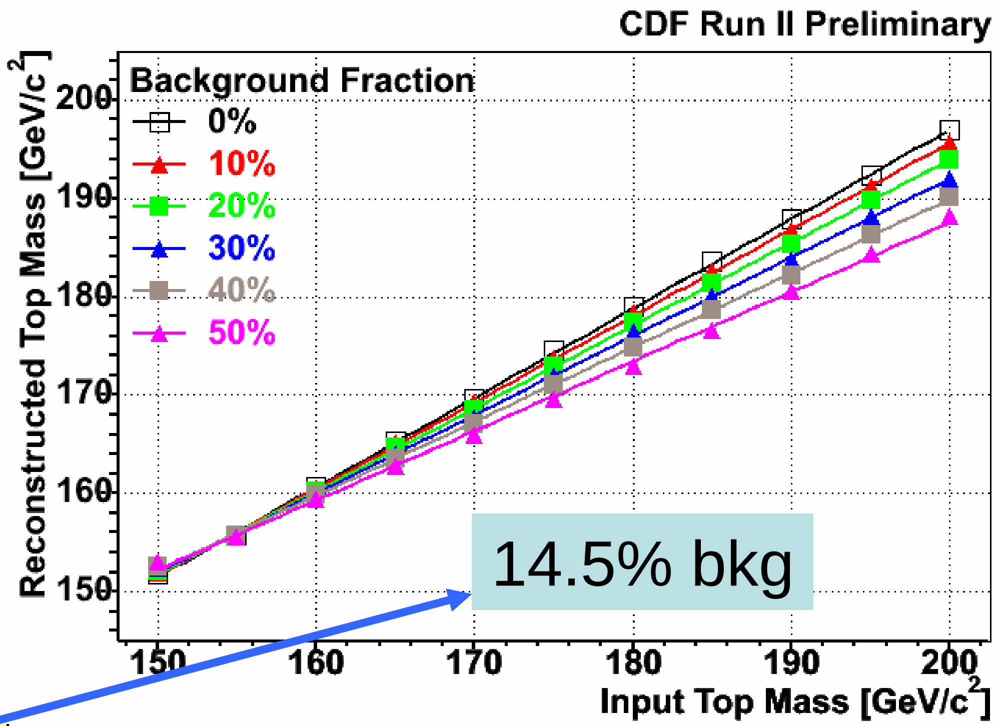
f(q) : probability distribution that parton has momentum ***q***

Σ over jet assignments & ν solutions

- **Sample $\mathcal{L} = \Pi_i L^i (x;M_{top})$**

No background probability term

Map effect on reconstructed M_{top}

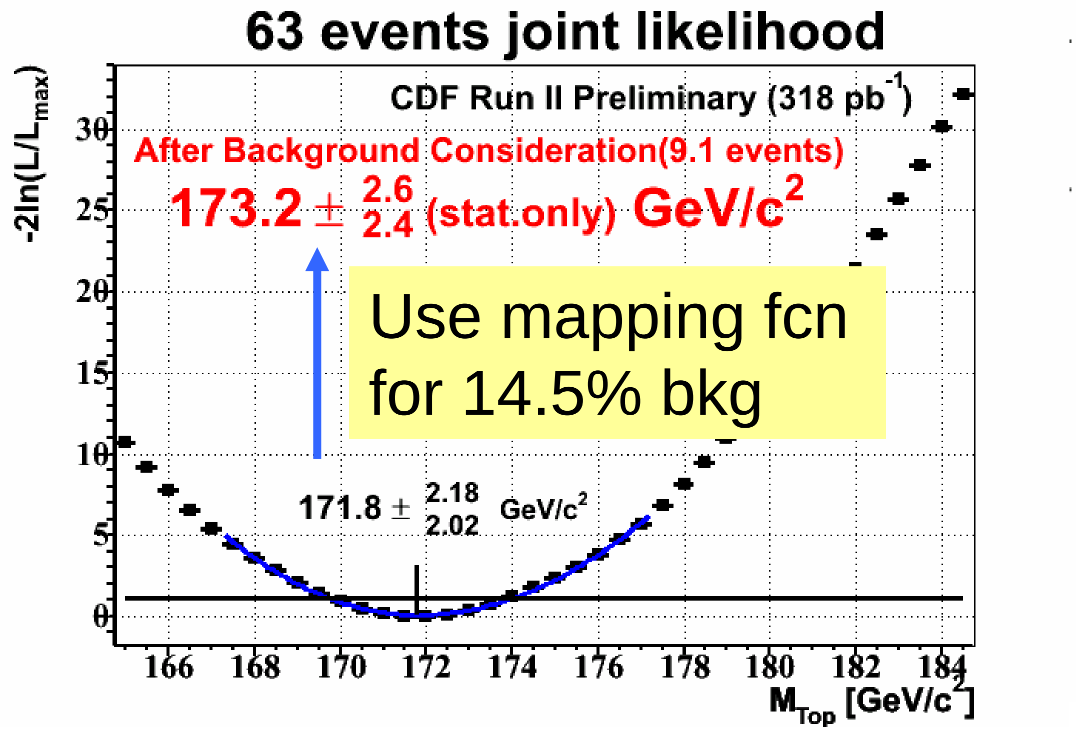


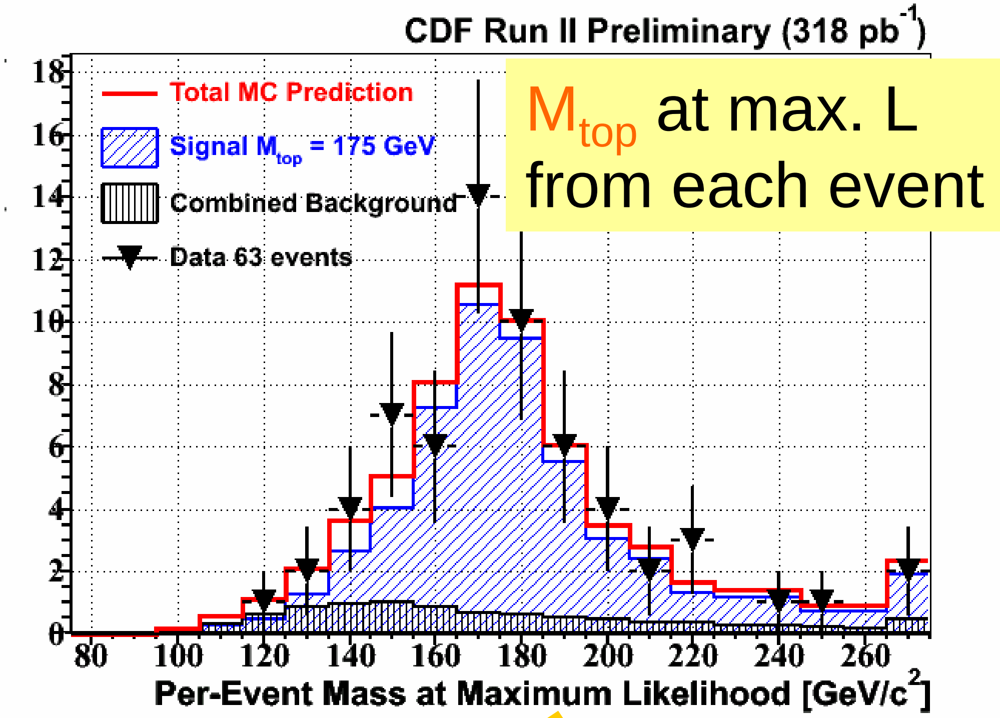
- **Data:**

4 jets $E_T > 15$ GeV , min.1 b-tagged

➔ 63 events, 9.2 ± 1.8 expected bkg

M_{top} *lepton+jets*: Dynamical Likelihood





$$M_{top} = 173.2^{+2.6}_{-2.4}(\text{stat.}) \pm 3.2(\text{syst.})\,\text{GeV/c}^2$$

$$M_{top} = 173.2^{+4.1}_{-4.0}\,\text{GeV/c}^2$$

(318 pb-1)

from Jet Energy Scale : 3 GeV/c^2

Same uncert. as 2D template method

M_{top} *dileptons*: Neutrino Weighting

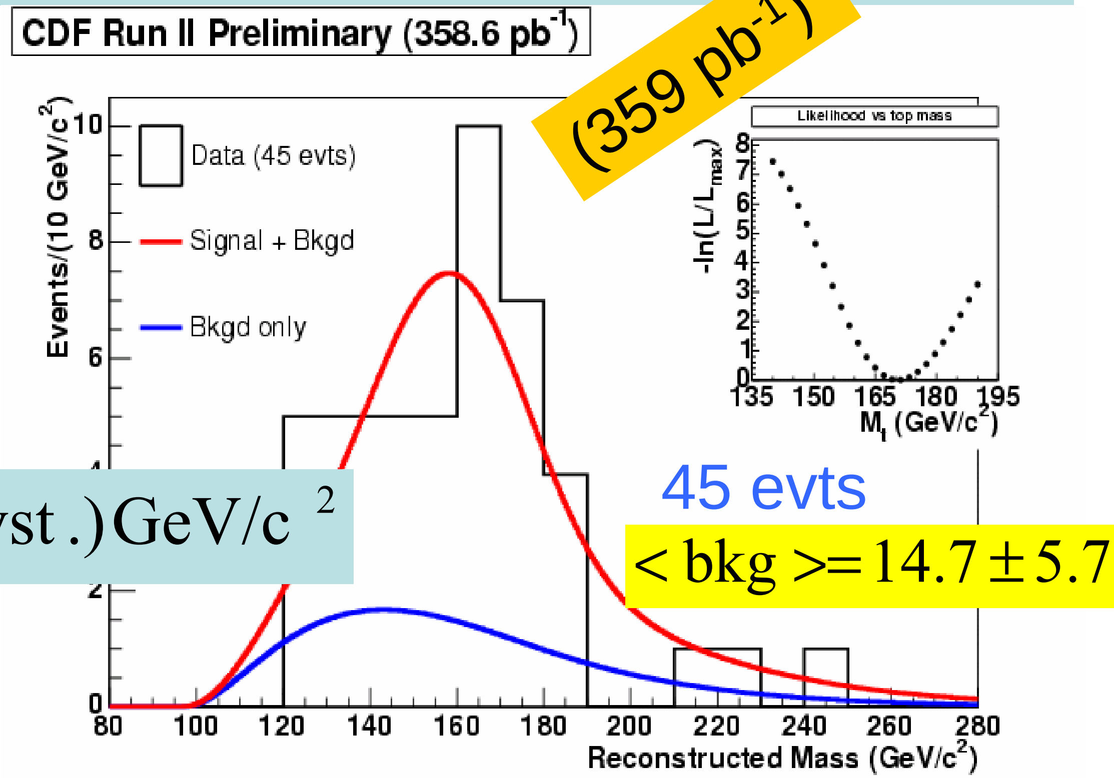
A) Under-constrained: 2 ν's → 1 $\not{E}_T$ measurement

1. Assume: M_{top} , M_W , η of ν's ➔ Prob. to match measured $\not{E}_T$
2. Integrate jet-parton assignments & η of ν's ➔ **Prob vs. M_{top}**
3. Get most Prob. M_{top} ➔ rest is 1D **template method**

B) Boost statistics:

e or μ + isolated track

catch more τ's



$$M_{top} = 170.6^{+7.1}_{-6.6}(\text{stat.}) \pm 4.4(\text{syst.})\,\text{GeV/c}^2$$

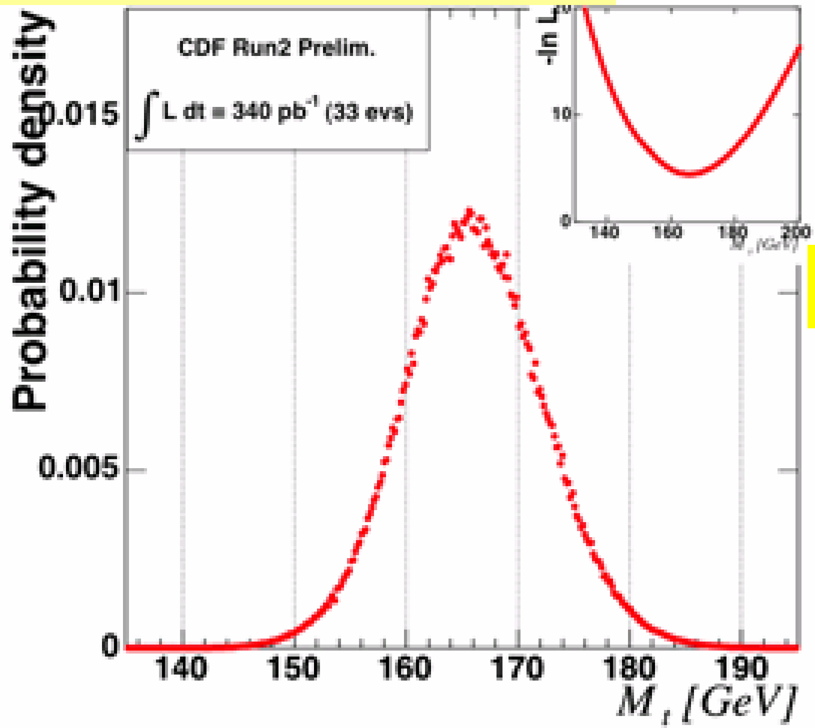
$$< \text{bkg} >= 14.7 \pm 5.7$$

2.6 from JES uncertainty

M_{top} *dileptons*: Matrix element

A) Like Dynamical Likelihood,
w/ explicit bkg likelihood terms

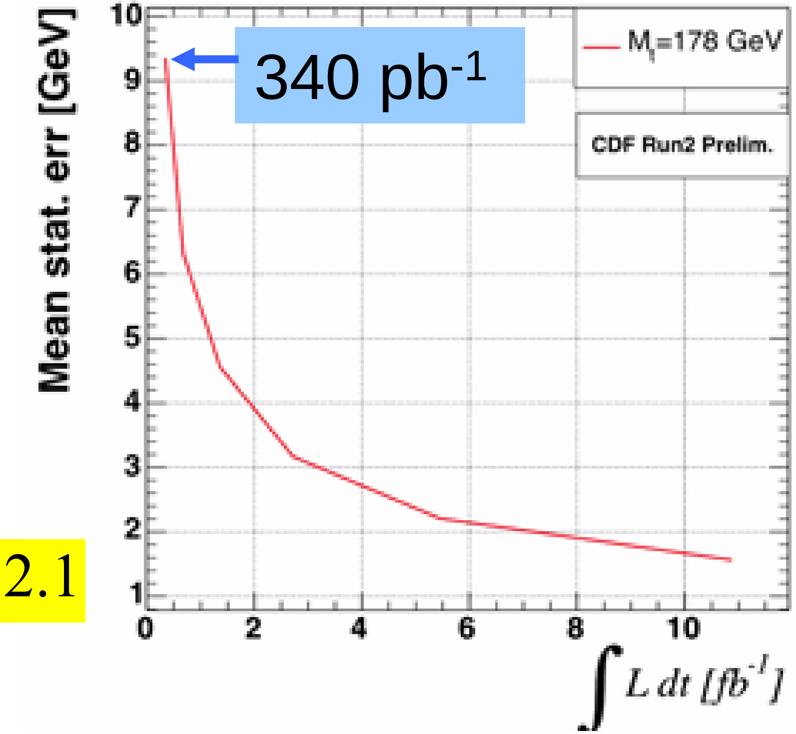
B) 2 identified e or μ



(340 pb⁻¹)

33 evts

$< bkg >= 11.6 \pm 2.1$



Most powerful dilepton method a-priori & in practice

	Weight	*Pull*
Matrix El.	36%	-0.60
ν Weight	27%	0.42
Kinematic	13%	0.33
ν Phi	10%	0.20
Run1	14%	-0.07

$$M_{top} = 165.3 \pm 6.3(\text{stat}) \pm 3.6(\text{syst.})\ \text{GeV/c}^2$$

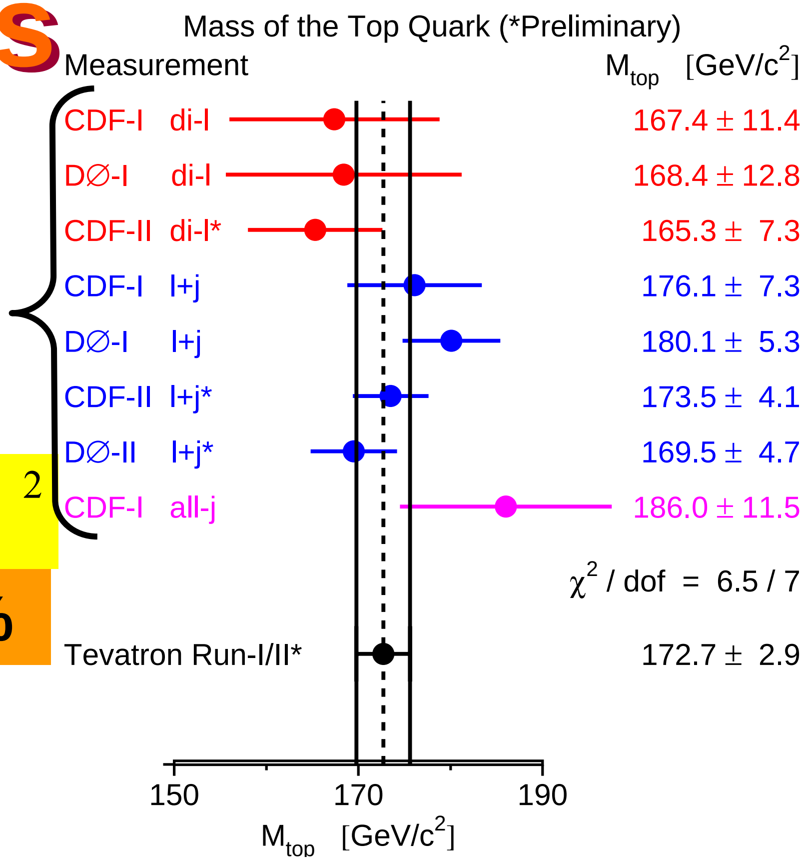
(2.6 from JES)

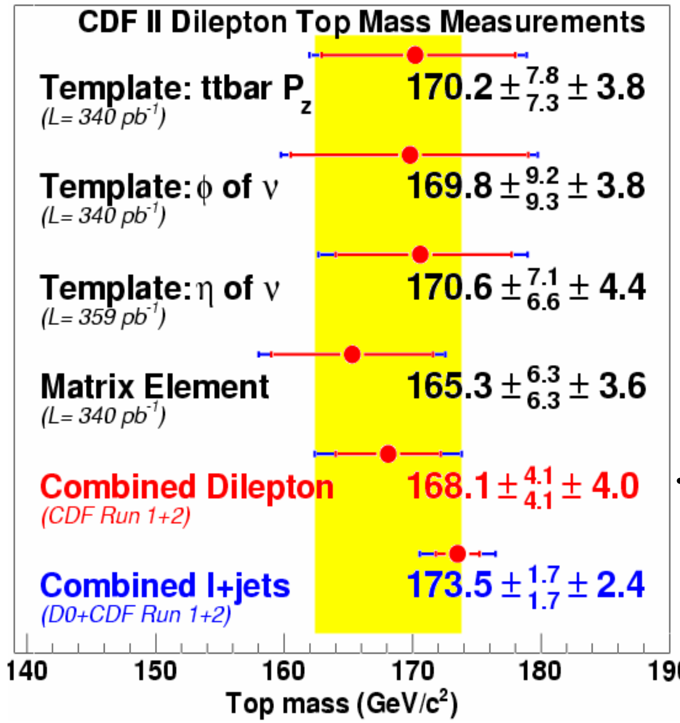
M_{top} : combined results

- Use exclusive datasets (Runs, experiments, channels)
- Combine best measurement from each channel

$$M_{top} = 172.7 \pm 1.7(\text{stat}) \pm 2.4(\text{syst.})\ \text{GeV/c}^2$$

Precision = 1.7%





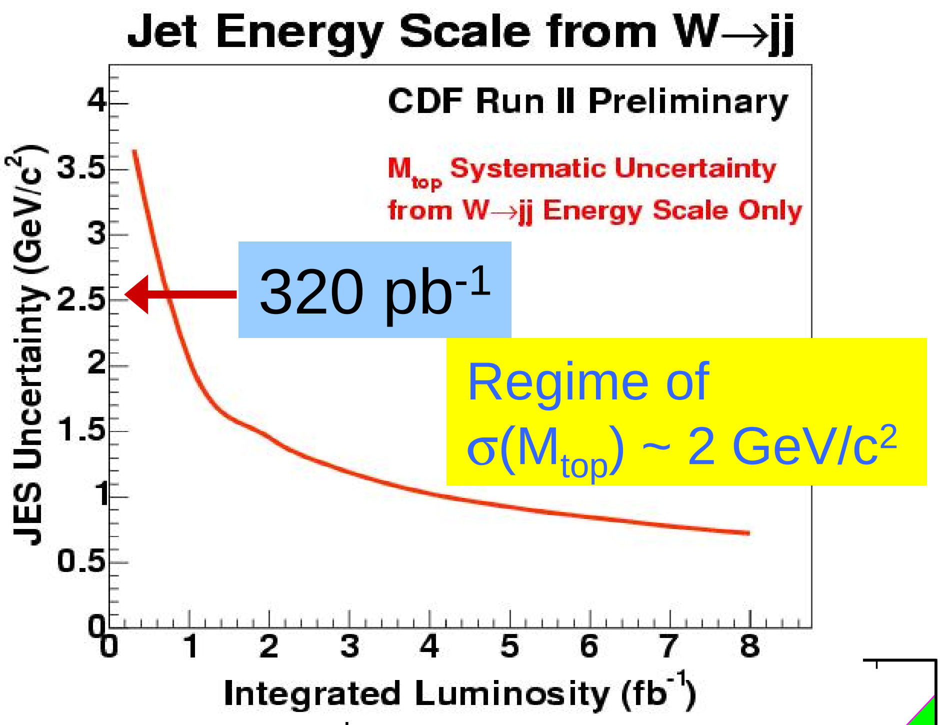
- NEW! Combining dilepton M_{top} at CDF

- Dileptons are relevant:
  - Important (8%) weight to M_{top}
  - Different physics "contamination" of top samples

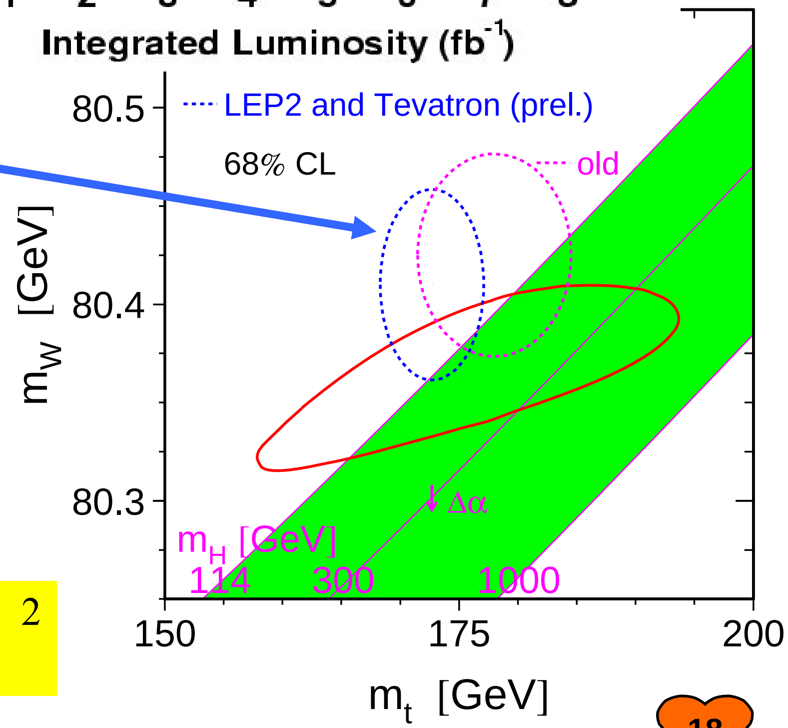
Summary

- 1fb^{-1} per experiment on tape & Tevatron performing well!
- New techniques applied for M_{top} ← also, never underestimate "simplicity" (e.g., templates with in situ W's to calibrate jet energies)
- Precision limited by systematics
- M_{top} measurement averages in progress:

$$M_{top} = 172.7 \pm 1.7(\text{stat}) \pm 2.4(\text{syst.}) \text{ GeV/c}^2$$

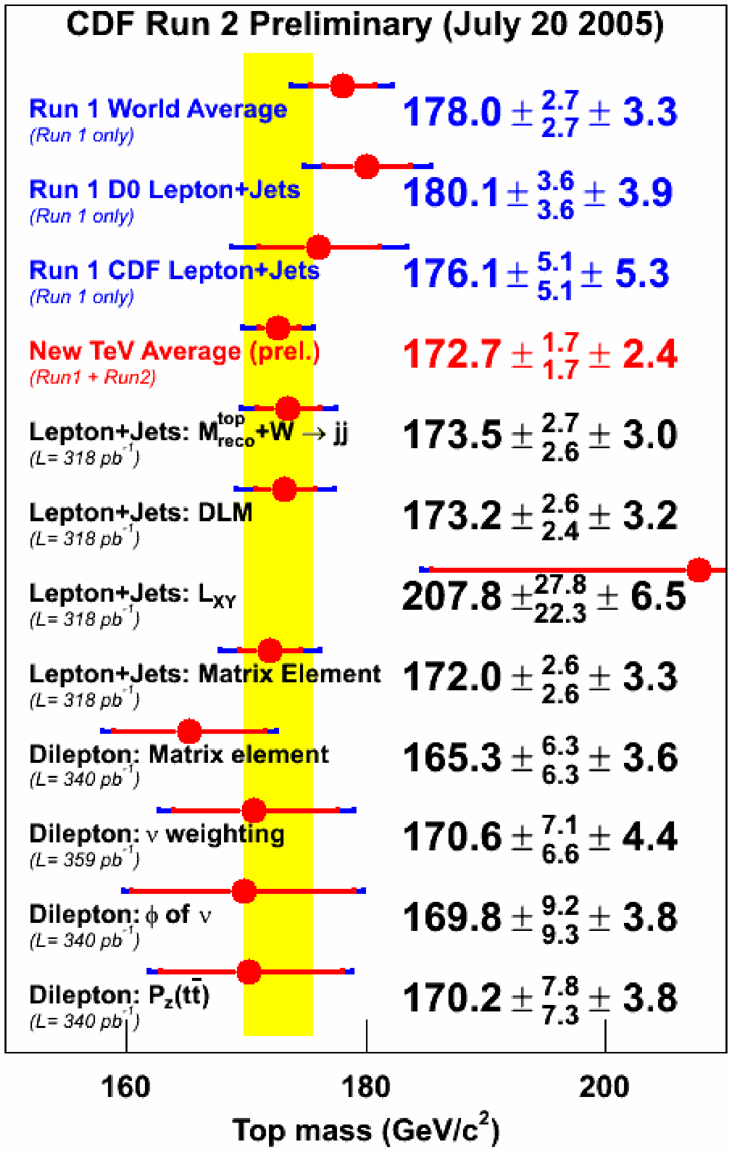


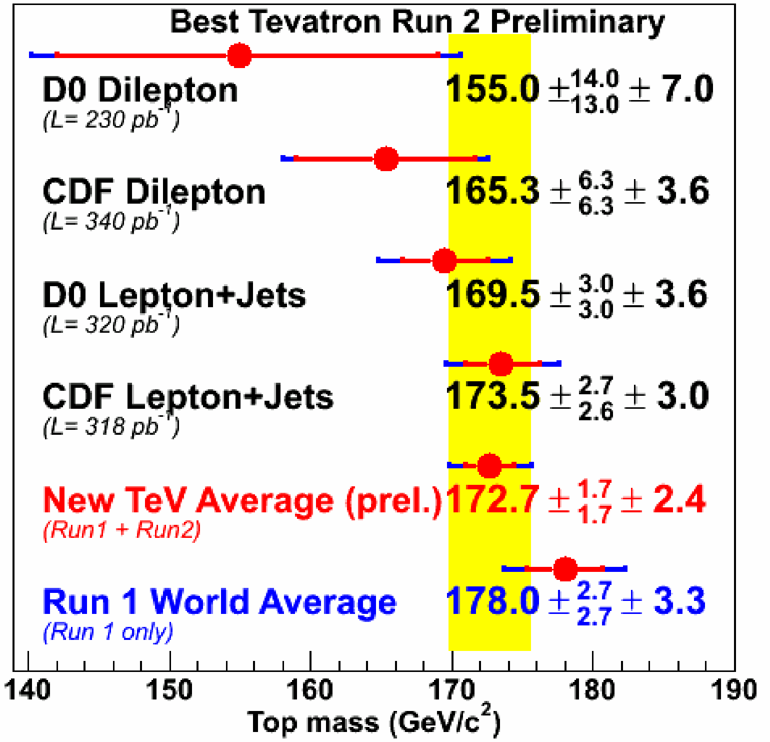
As I said, to test you better measure well! Need also $m_W \pm \sigma(m_W)$

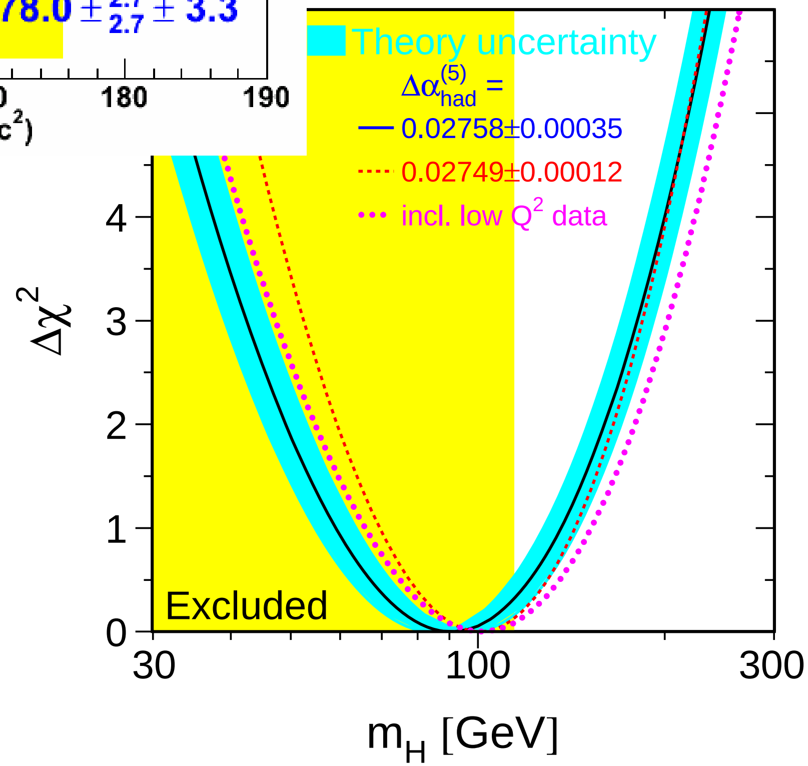


THE END
(for now…)

M_{top} : results

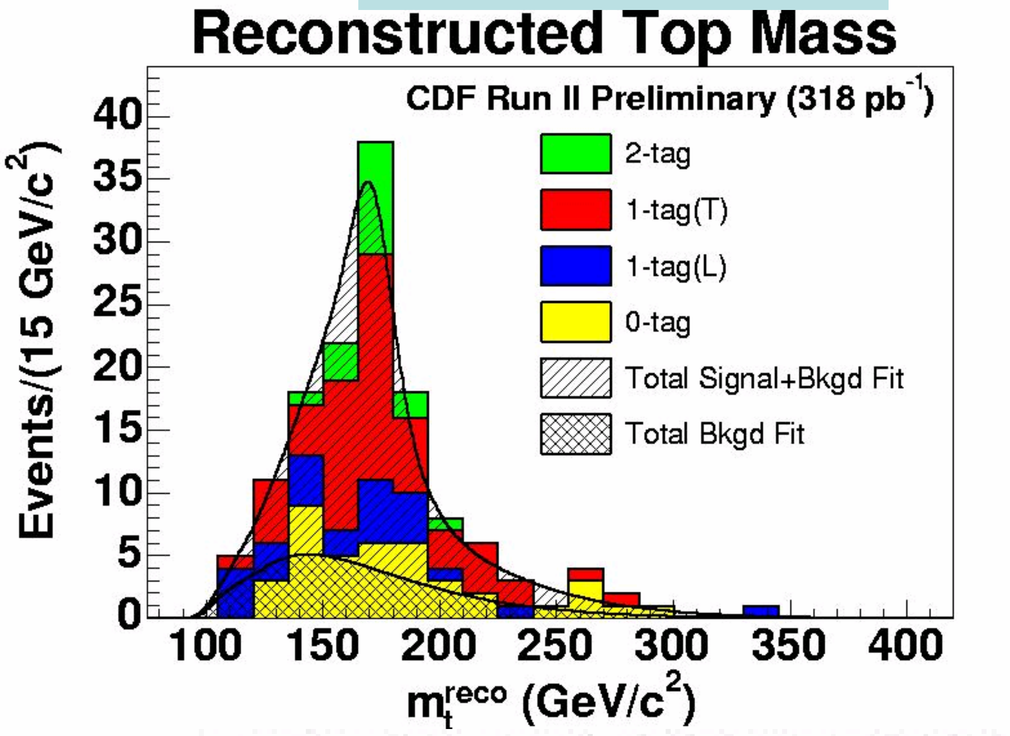




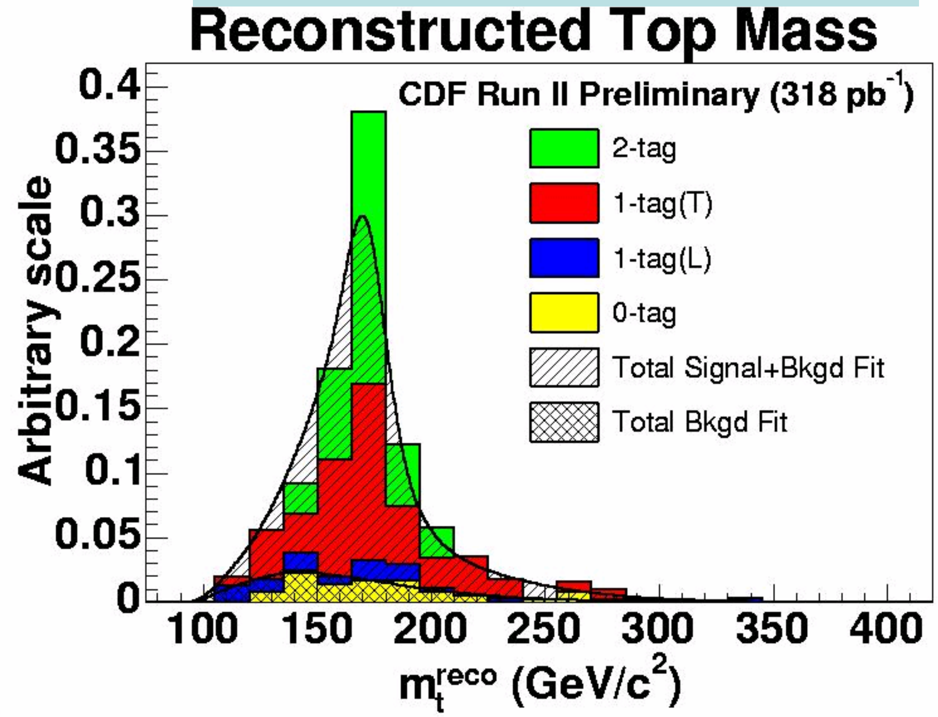


M_{top} *lepton+jets* (2D): samples

Plain event count



Weighted with likelihood



CDF Run II Preliminary (318 pb^{-1})

Subsample	M_{top} (GeV/c^2)	JES (σ)
2-tag	$175.0^{+4.6}_{-4.6}$	$-0.47^{+0.86}_{-0.84}$
1-tag(T)	$170.1^{+4.4}_{-4.2}$	$0.47^{+0.87}_{-0.88}$
1-tag(L)	$182.3^{+10.8}_{-9.0}$	$0.05^{+0.96}_{-0.96}$
0-tag	$153.0^{+10.1}_{-6.6}$	$0.29^{+0.98}_{-0.99}$

All samples useful, especially for JES calibration!

1) lepton+jets 1D Template: the likelihood

Interesting Parameter!

$$L = L_{\text{shape}} \times L_{\text{bg}}$$

$$L_{\text{shape}} = e^{-(n_s+n_b)}(n_s+n_b)^N \prod_{i=1}^{N} \frac{n_s P_{sig}(m_i; M_{\text{top}}) + n_b P_{bg}(m_i)}{n_s+n_b}$$

$$L_{\text{bg}} = e^{-\frac{(n_b^{fit}-n_b^{\exp})^2}{2\sigma_{n_b}^2}}$$

bkgd (mean) constraint

2) Matrix element techinques:

Prob(event x | M_{top}) = Prob(partons | M_{top}) x Prob (event x | partons)