MANCHESTER 1824

The University of Manchester

Top Mass Measurements, JES, and Systematic at CDF

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The University of Manchester

Workshop on Top Physics, LPSC, Oct 18-20, 2007

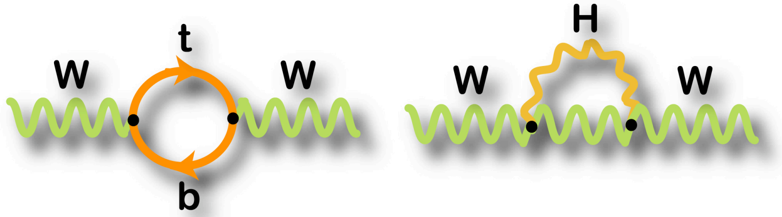
Outline

- Why Precise Mt?
- Challenges?
- CDF Program (Template in Lepton+Jet)
- Jet Energy Scale and Uncertainty
  - generic jet, light quark jet, and b-jet -
- ISR/FSR and NLO

Why Precise Top Mass?

- Top mass is a fundamental SM parameter

  - ❑ Important in loop corrections

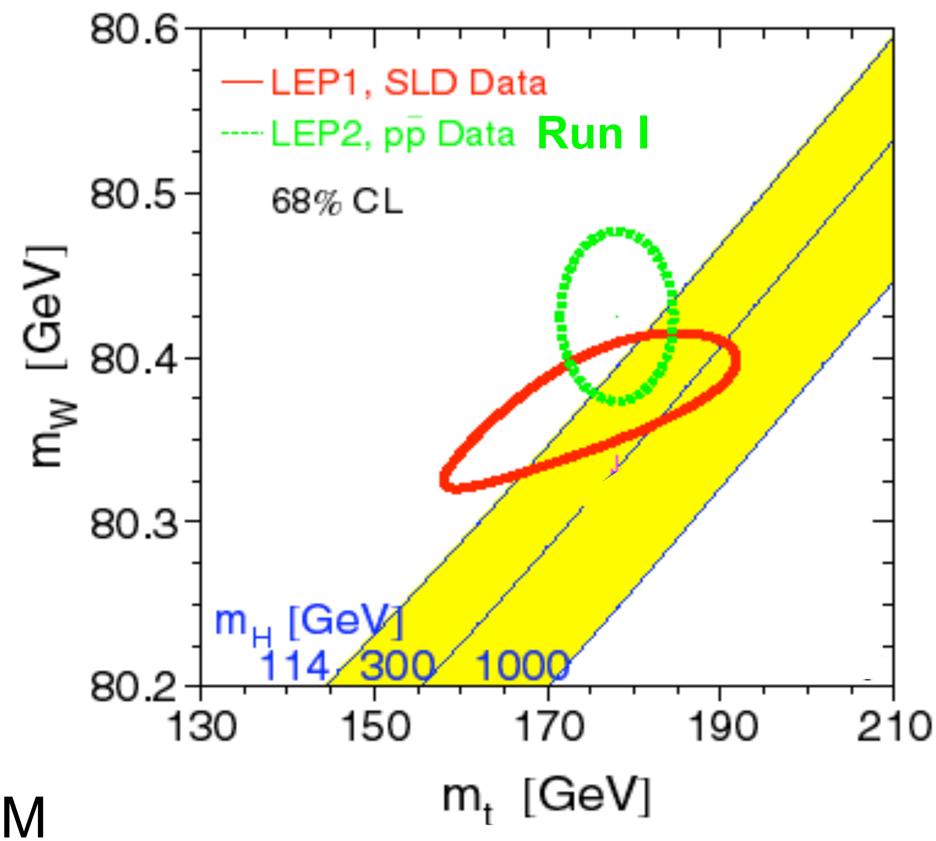


$\propto m_t^2$ $\propto ln(m_H)$

  - ❑ Precise Top & W masses

    - Constraint on SM Higgs
      - It can point to physics BSM

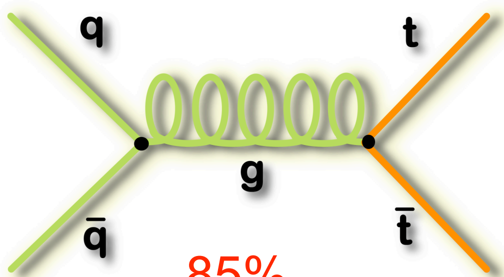
    - Constrain new physics (SUSY) with M_{Higgs}



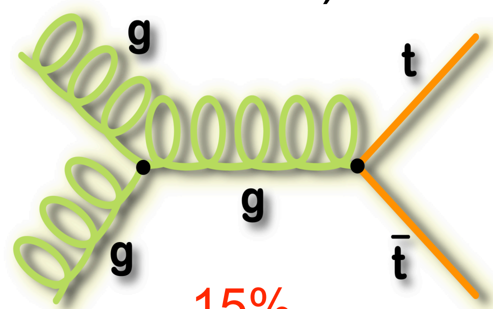
- Is it a SM top?

Top Production and Decay

- At the Tevatron, mainly primarily produced in pairs via strong interaction (σ~7pb: 1 for every 10^{10} collisions)



85%

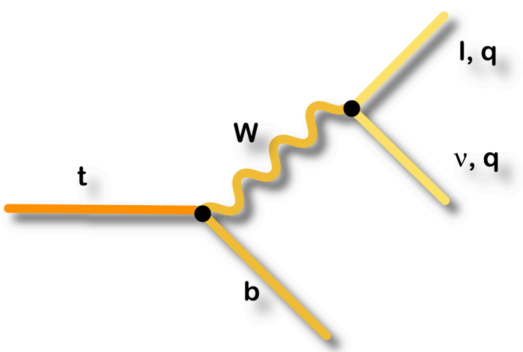


15%

LHC (90%)

~100σ

- Top decays as free quark due to large mass (τ_{top} ~ 4 x 10^{-25} s)



- Dilepton (5%, small bkgds)

  2 leptons(e/μ), 2 b jets, missing E_T (2νs)

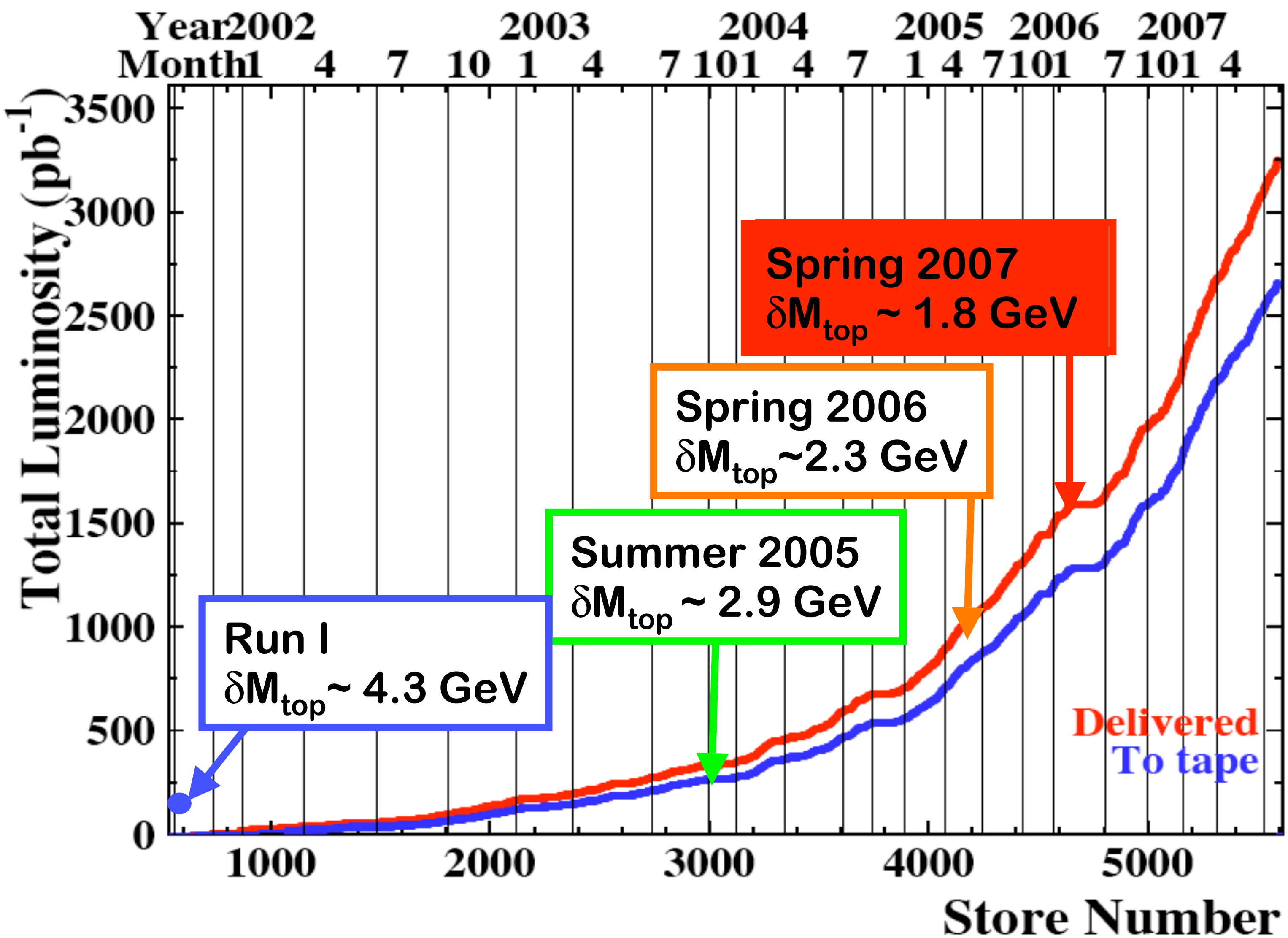
- Lepton+Jet (30%, manageable bkgds)

  1 lepton(e/μ), 4 jets (2 b jets), missing E_T (1ν)

- All-hadronic (44%, large bkgds)

  6 jets (2 b jets)

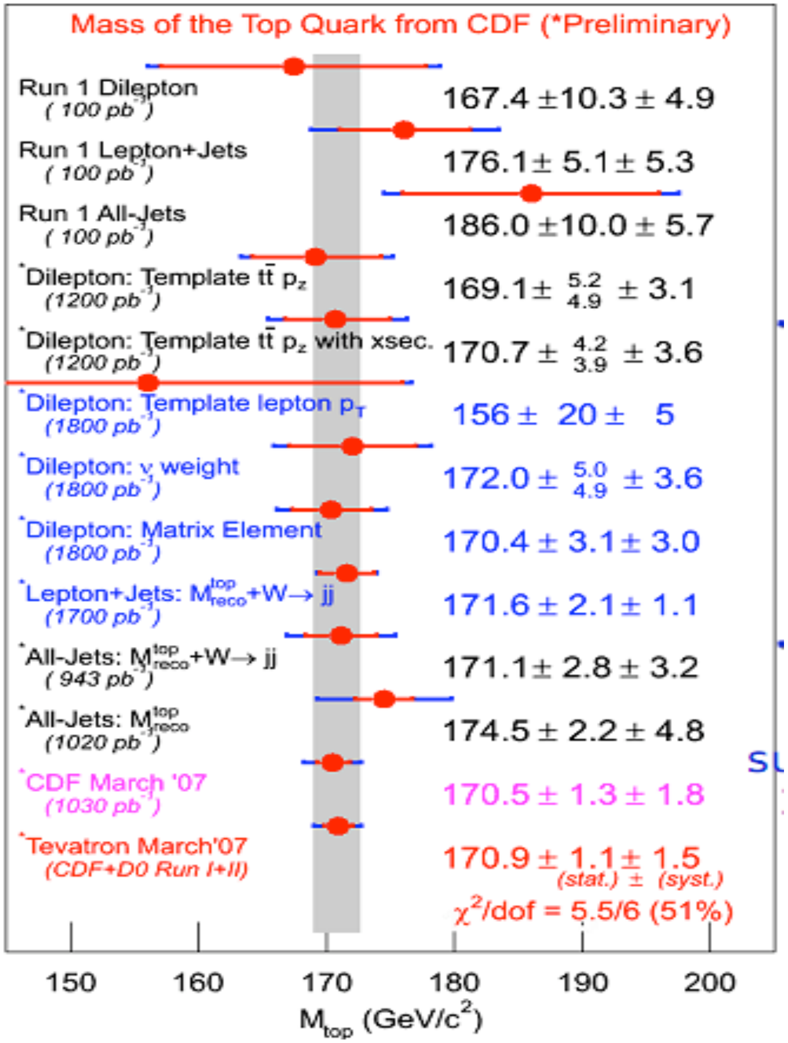
Great Performance

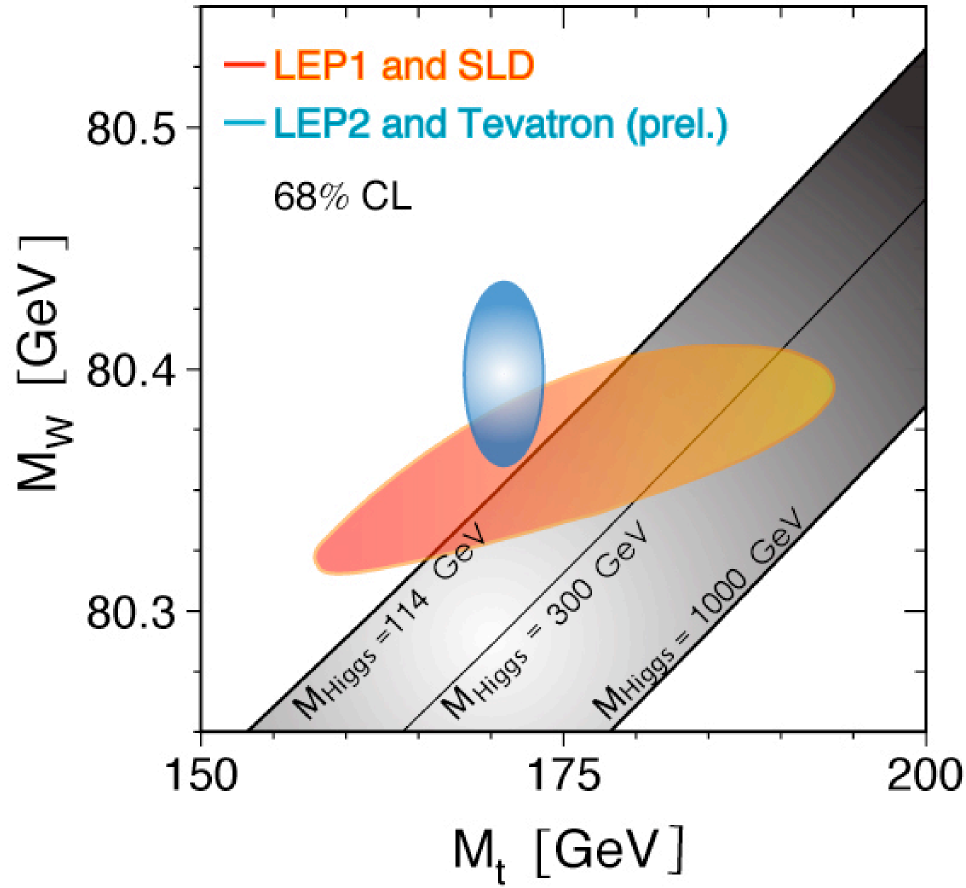


5 more

In summer 07

Precision Measurements and Impact





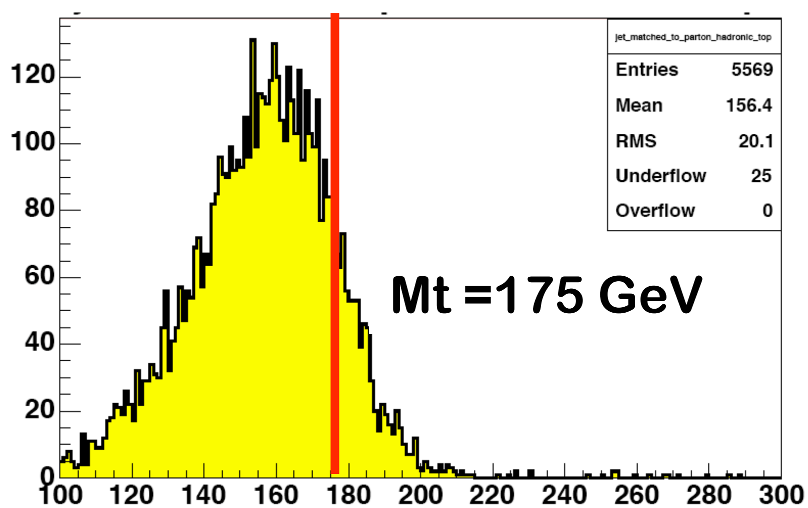
Different channels
with different methods!!!
New best single: 1.25%

$$M_H = 76^{+33}_{-24}\,\mathrm{GeV/c^2}$$

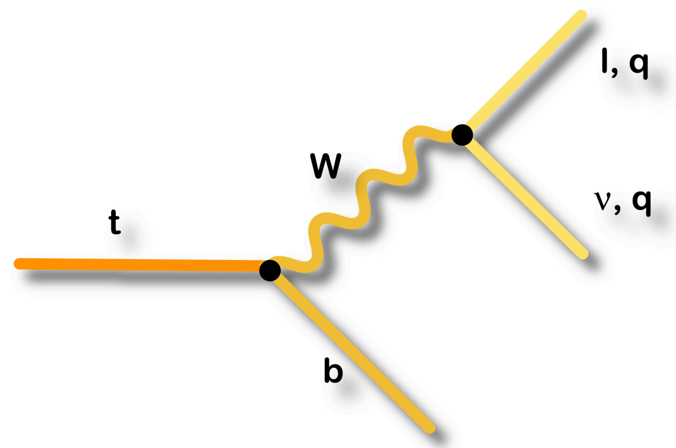
$$M_H < 144\ \mathrm{GeV/c^2}\ @95\%C.L$$

M_{top} Measurement : Challenge 1

- Not a simple calculation of the invariant mass of W(jj) and b



Why $M(bjj) \neq 175$ GeV?



M_{top} Measurement : Challenge 1

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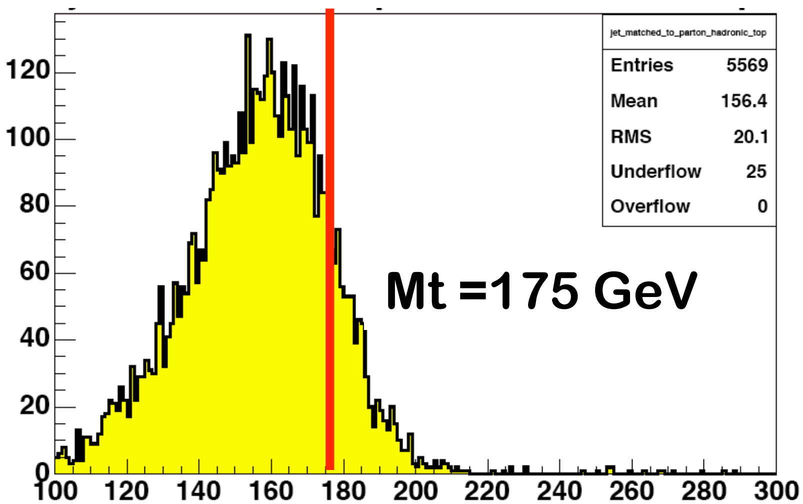
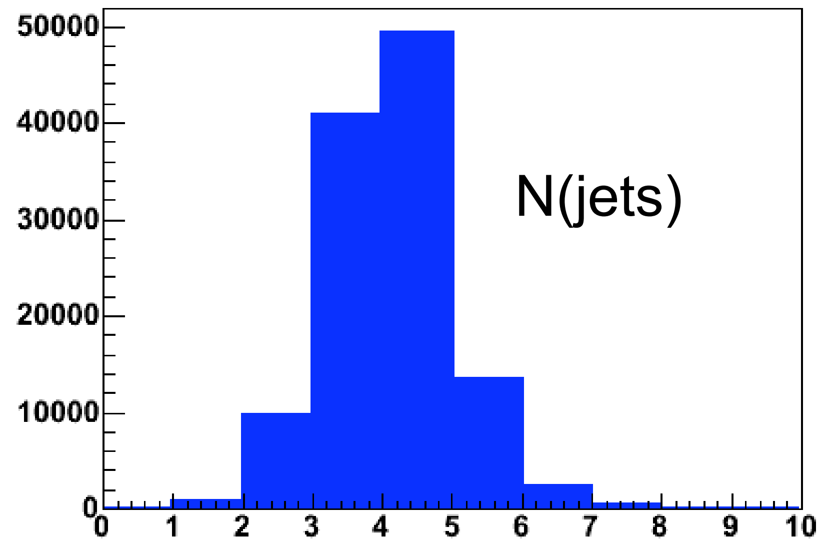


Why M(bjj) ≠ 175 GeV?



- Measured jet energy

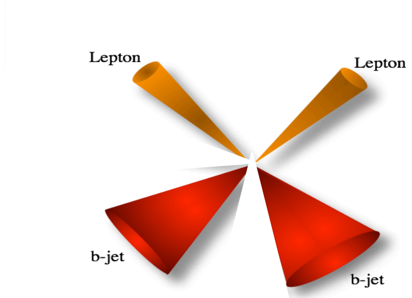
  ≠ quark energy from top decay

  - ❑ Quarks: showering, hadronization, jet clustering
  - ❑ Extra radiated jets

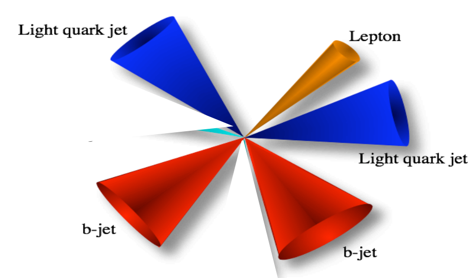
- Require excellent jet energy correction and good modeling of extra gluon radiations (40%)

Challenge 2

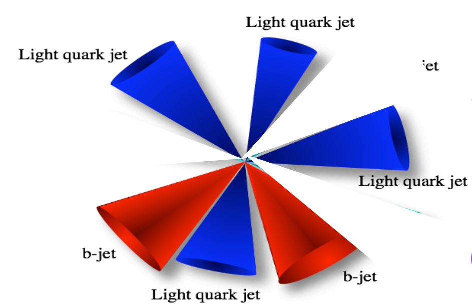
- Too many combination to reconstruct two top quarks



2(2)



12 (6)

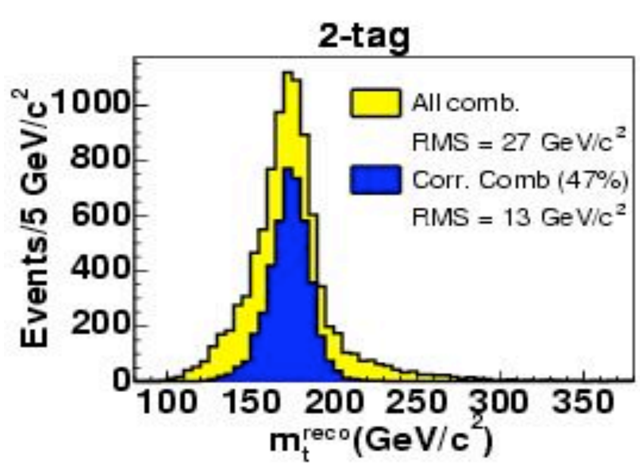


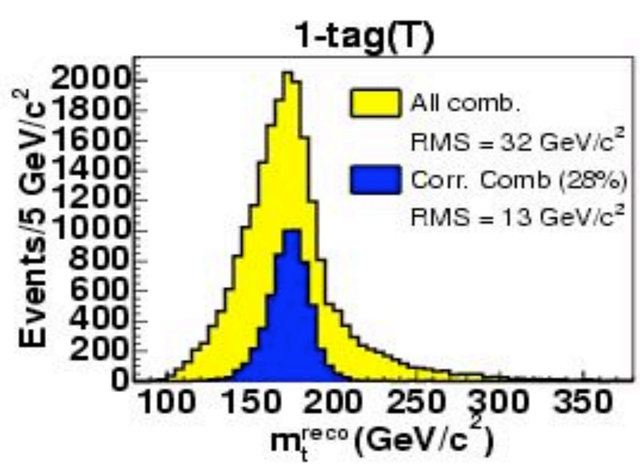
360(90)

3 constraints:
two M(w)=80.4
one M(t)=M(tbar)

2 ν:unconstrained	1 ν:over-constrained	No ν:over-constrained

- B-tagging helps!: reduces wrong comb. and improves resolution





Top Mass Measurements

Template

- Reconstruct a per-event observable, M_t(reco), Lxy etc: sensitive to M_t
- Create "templates" using fully simulated events for different top mass values, and bkgds
- Maximum Likelihood fit using signal+backgrounds templates

Matrix Element

- Calculate probability dist. as M_t for all combinations in each event by Matrix Element calculation
  - maximize dynamic information
- Build Likelihood directly from the probabilities
- Calibrate measured mass and it's error using fully simulated events

Strategy

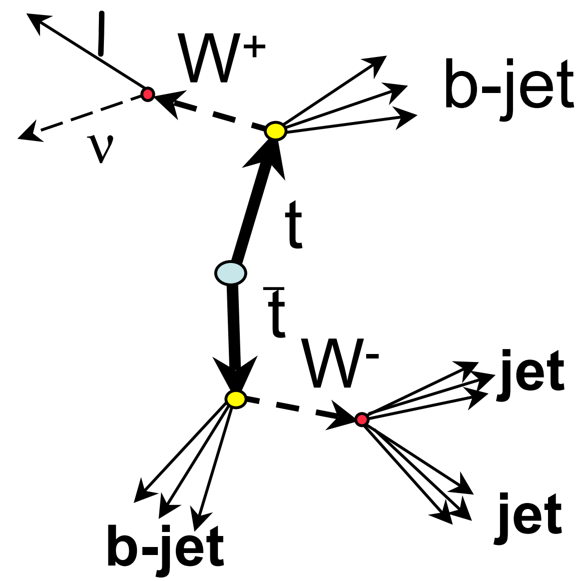
- Precision & consistency
  - Different channels
  - Different methods (using different information)
- New Physics (bias)

	Method	Njets		B-tag		JES			Rec. variables
		Exact	+extra	Yes	No	Wjj+std	Wjj	No	
LJ	TMP	4	>4						mt, m_{jj}, Lxy,Pt(e/μ)
	ME	4							P(Mt,JES)
DIL	TMP	2	>2						mt, Pt(e/μ)
	ME	2							P(Mt)
All-J	TMP+ME	6	>6						mt, m_{jj}

Completed(~15 analyses groups)

Template Method in Lepton+Jets

- Event selection
  - High-pt central leptons (e,μ): Pt>20 GeV
  - 4 jets: Et>20 GeV, |η|<2.0
  - Large missing Et > 20 GeV



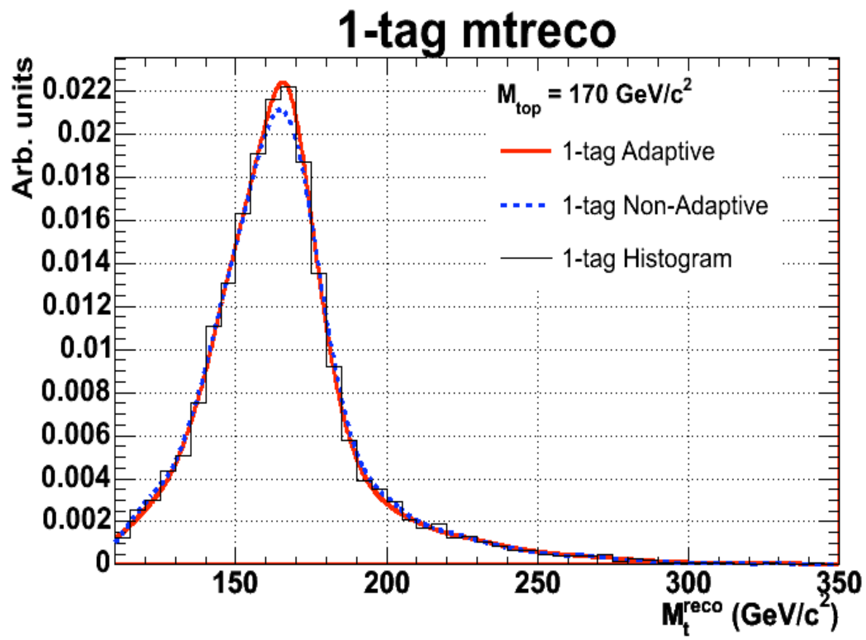
- χ^2 kinematic fitter: fully reco. ttbar system

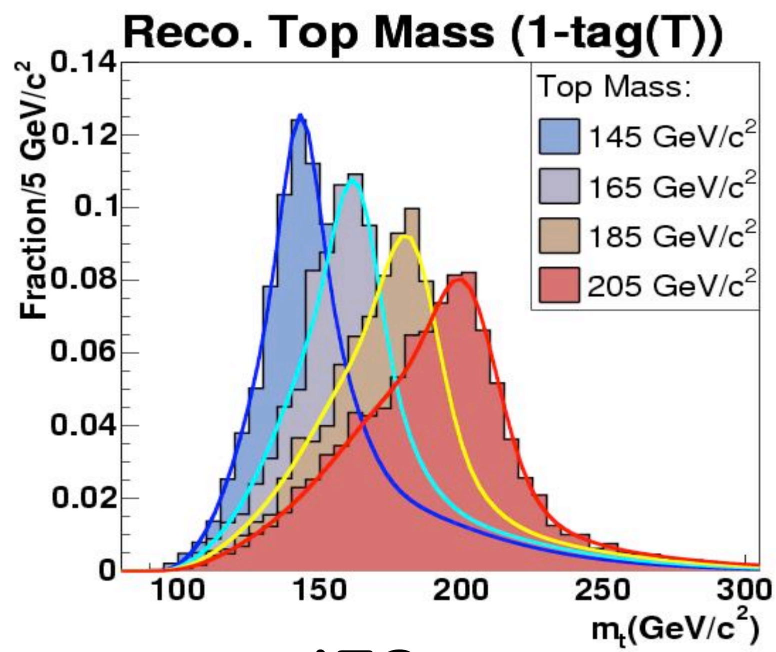
$$\chi^2 = \sum_{i=l,4\,jets} \frac{(\hat{p}_T^i - p_T^i)^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(\hat{p}_T^{UE} - p_T^{UE})^2}{\sigma_j^2}$$

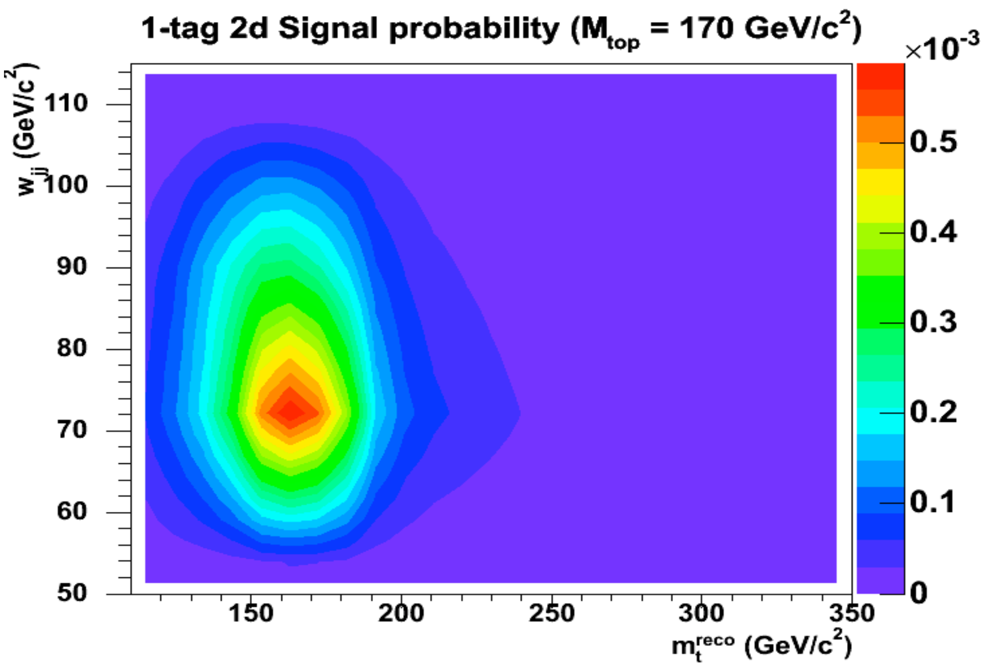
$$+ \frac{(m_{jj} - m_W)^2}{\Gamma_W^2} + \frac{(m_{l\nu} - m_W)^2}{\Gamma_W^2} + \frac{(m_{bjj} - m_t)^2}{\Gamma_t^2} + \frac{(m_{bl\nu} - m_t)^2}{\Gamma_t^2}$$

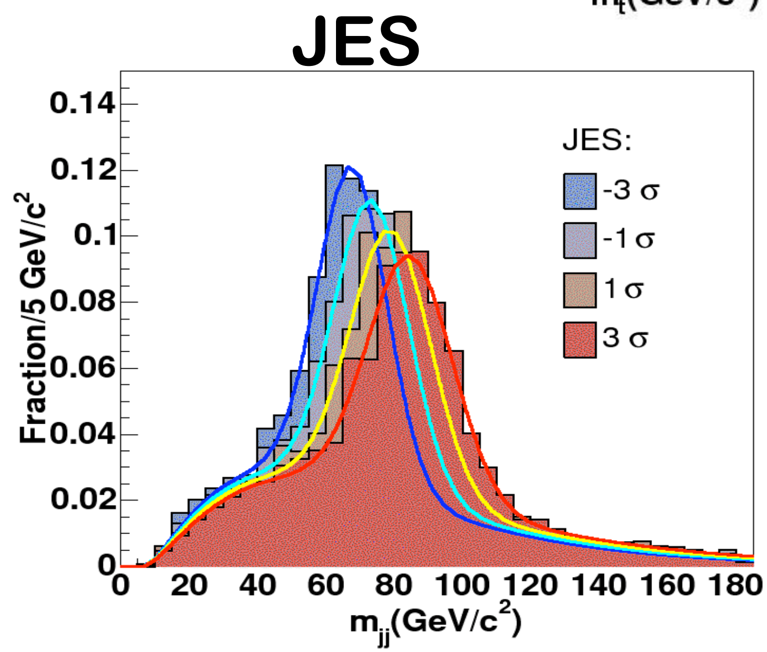
- ❑ Find m_t that fits event best over all combinations (m_W=80.4 GeV, $m_t = m_{\bar{t}}$)
- ❑ Reject badly reconstructed event

Signal Templates (m_t, JES)



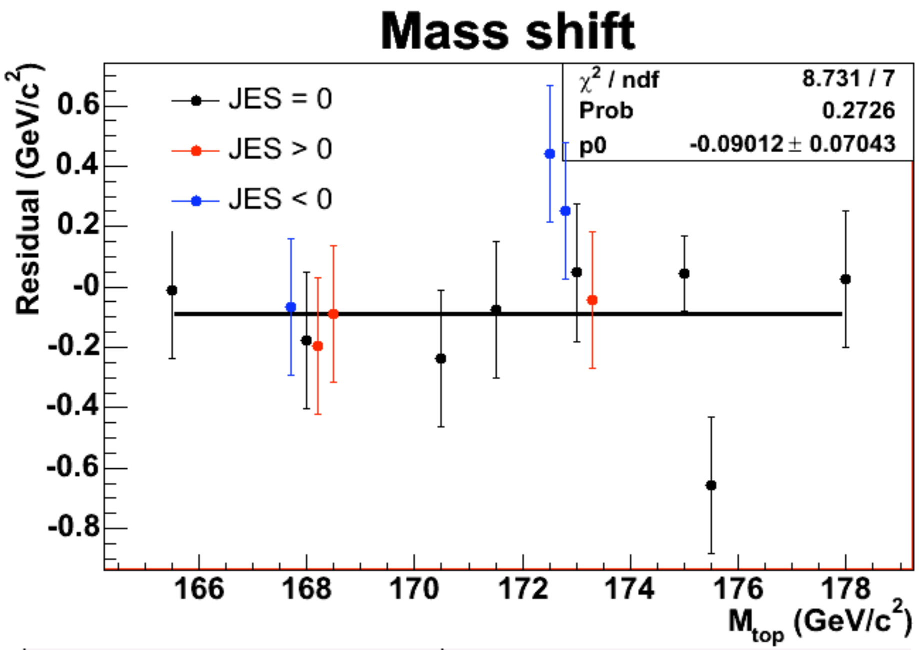


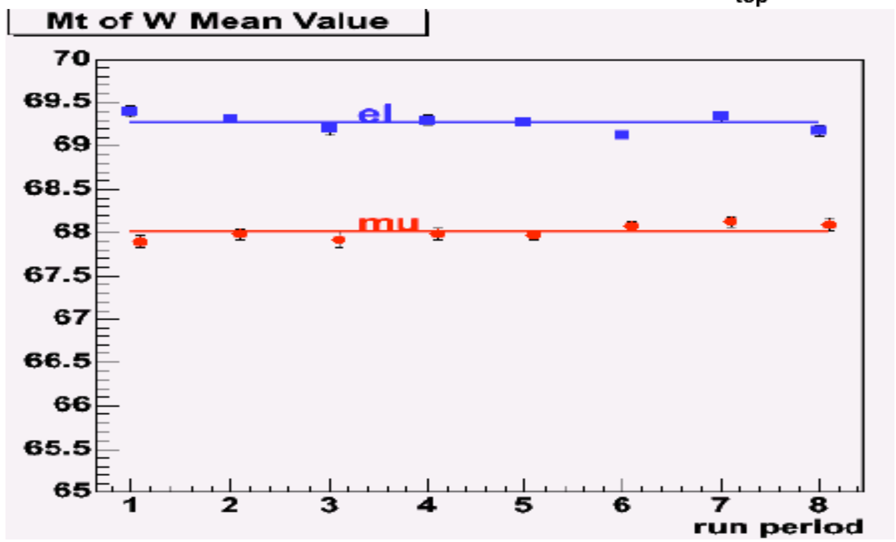




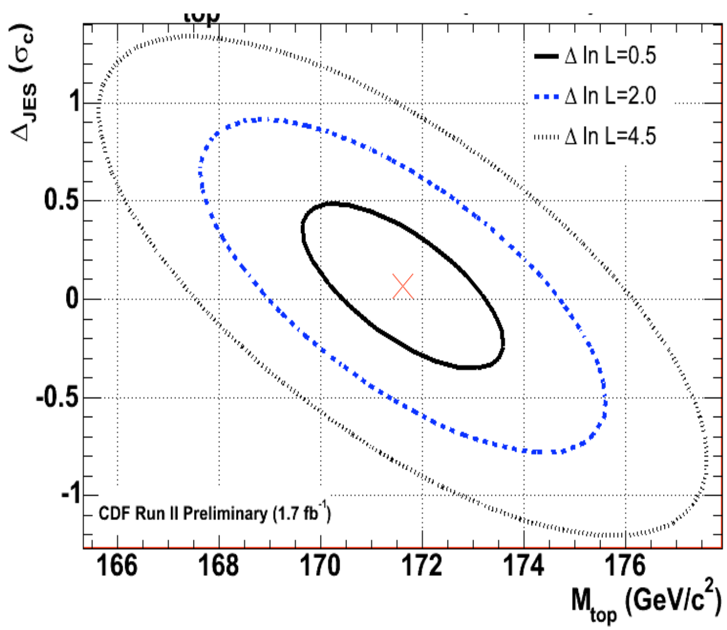
Check Check Check Before the Fit

- Pseudo-experiments
  - Bias in central value
  - Bias in error estimation
  - Test using blind Mt and JES MC sample
- Challenges
  - Acceptance
  - Shapes (mean, RMS for Mt sensitive variables)

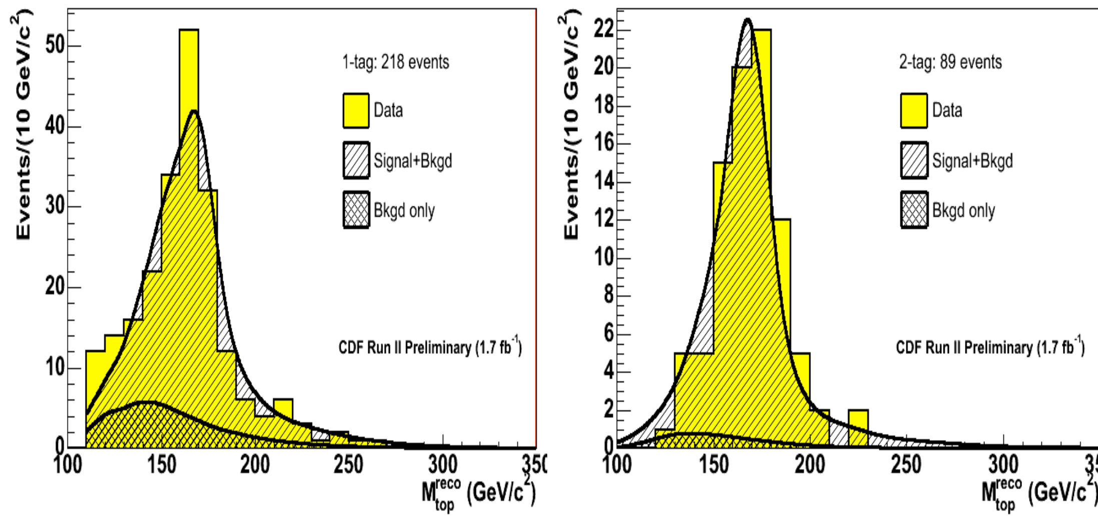




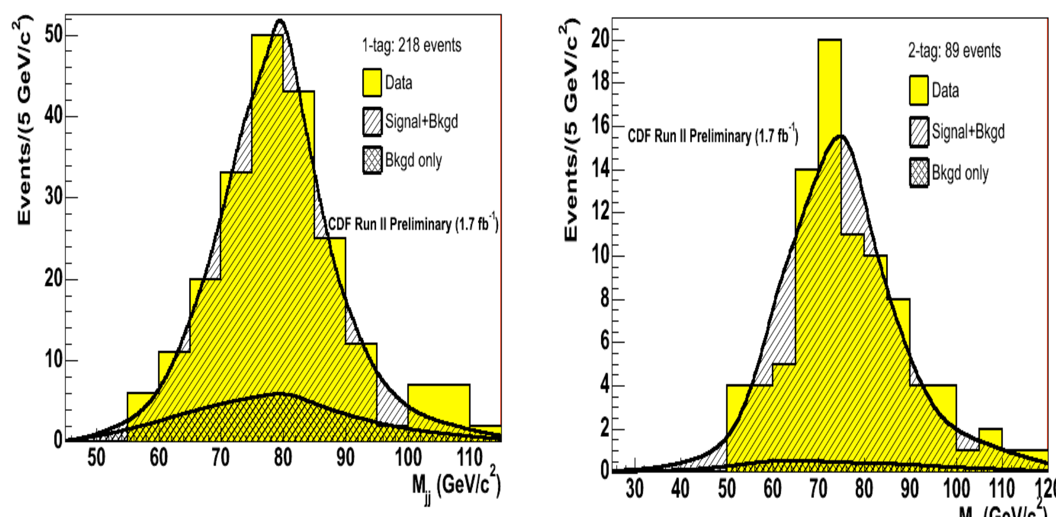
Template Results in Lepton+Jets



mt (1-tag, 2-tag)



mjj (1-tag, 2-tag)



$$M_t = 171.6 \pm 2.1(\text{stat.} + \text{JES})$$
$$\pm 1.1(\text{syst.})\ \text{GeV}/c^2$$

$$\text{JES} = -0.07 \pm 0.42\sigma$$

- **more than a factor of two improvement on JES with 1.7 fb^{-1}**

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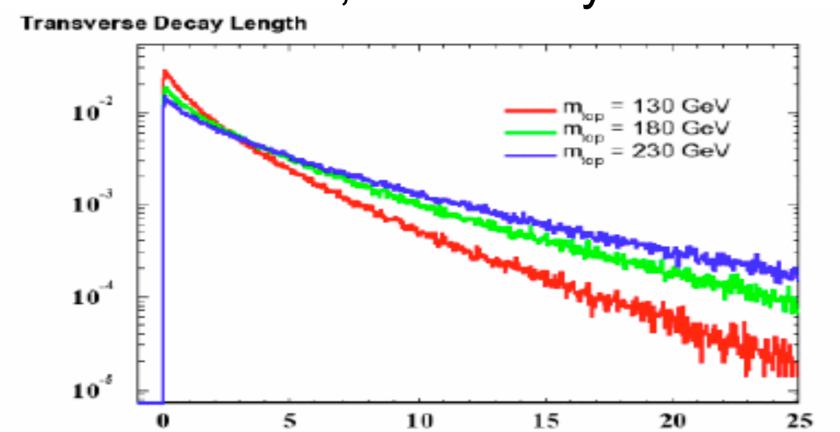
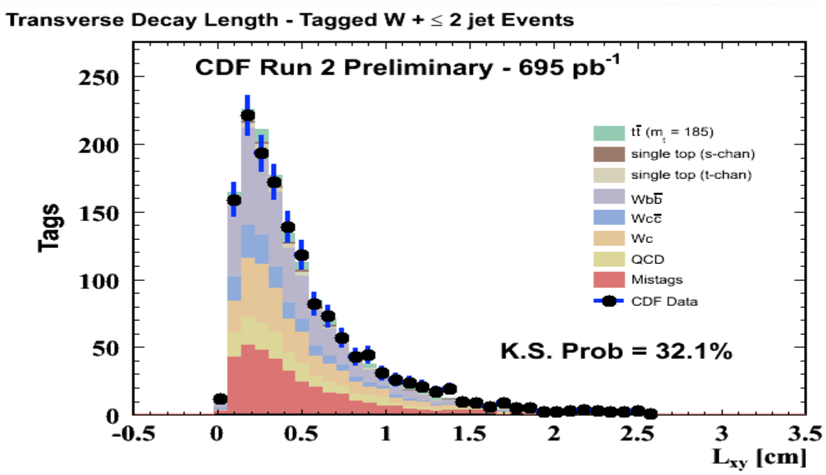
Template using Decay Length (Lxy)

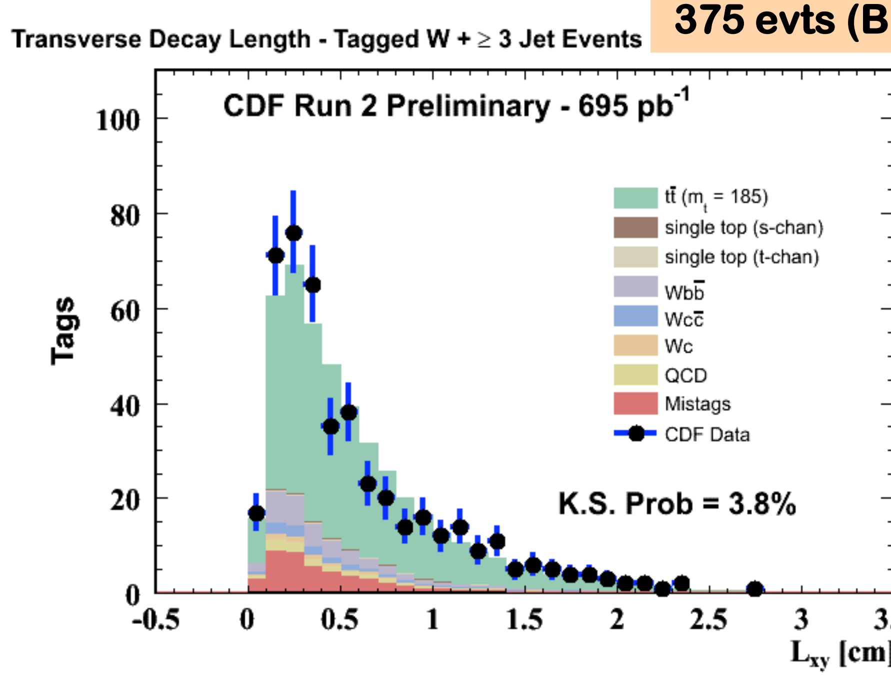
- Uses the average transverse decay length, Lxy of the b-hadrons
- B hadron decay length $\propto$ b-jet boost $\propto$ M_{top} (>=3jets)

PRD 71, 054029 by C. Hill *et al.*





375 evts (B:111)



$$M_{top} = 183.9^{+15.7}_{-13.9}\,(\text{stat}) \pm 0.3\,(JES) \pm 5.6\,(\text{syst})\ \text{GeV}/c^2$$

Insensitive to JES,
but need Lxy simulation

Statistics limited, but it can make big contributions at LHC

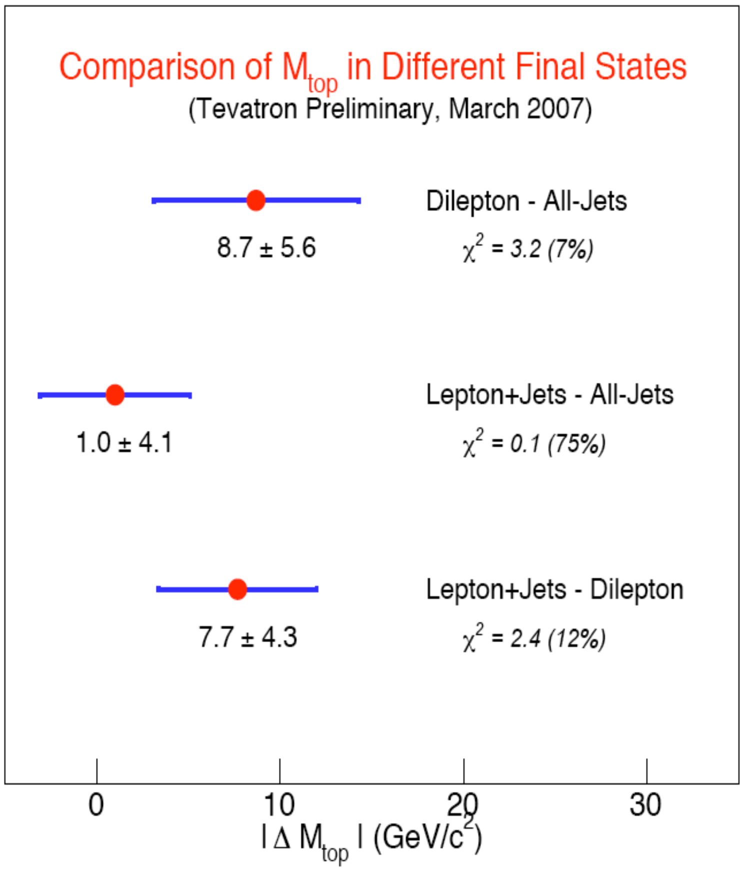
Comparisons in Lepton+Jets (1.7fb^{-1})

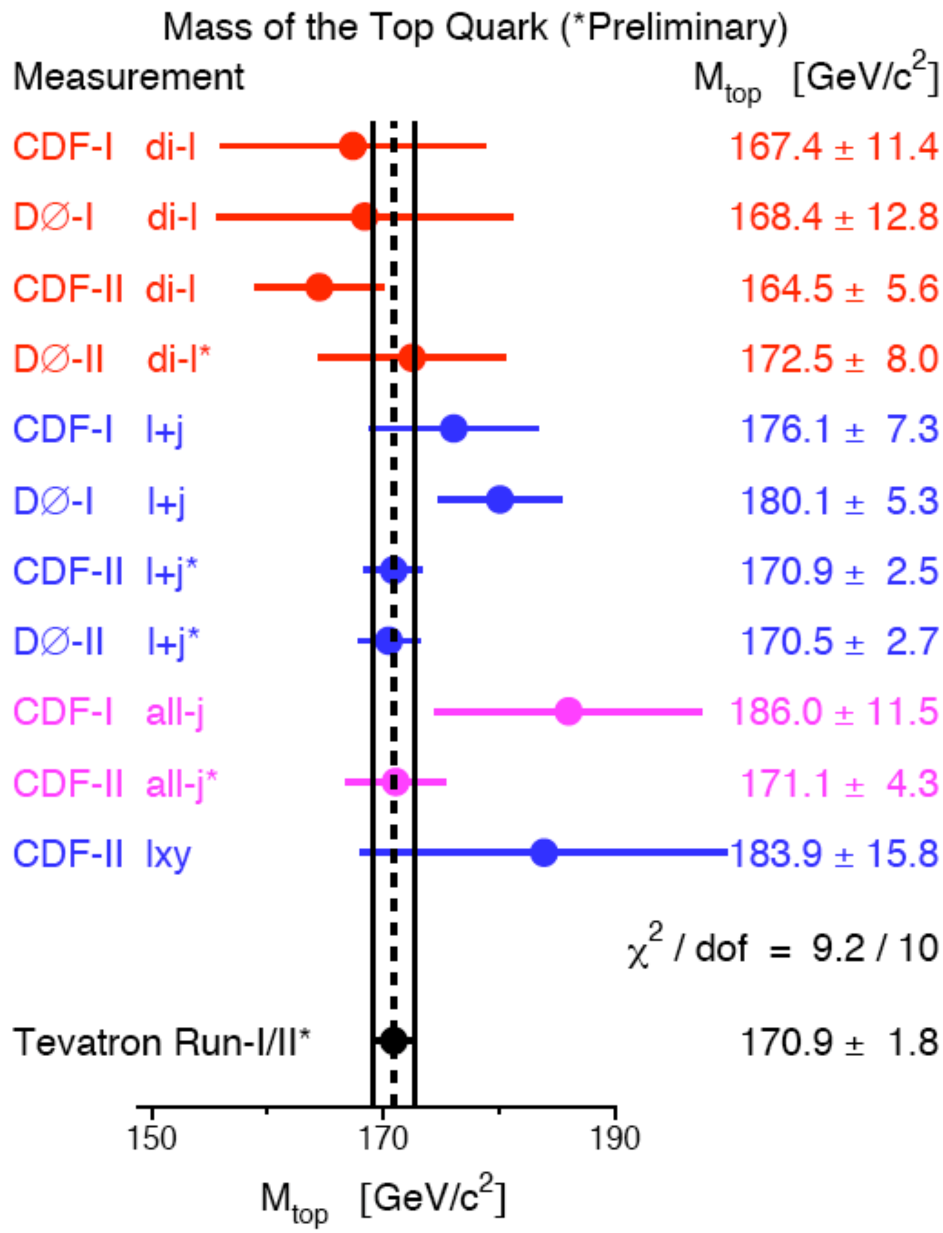
Measurement	Template	ME	Lxy (0.7fb^{-1})
JES	(1.5)	(1.2)	0.3
Residual	0.7	0.5	
B-jet JES	0.6	0.4	
ISR/FSR	0.4 0.5	0.5	1.3
Bkgd shapes/ normalization	0.3 0.5	0.6	3.3
Generators	0.3	0.4	0.7
PDFs	0.2 0.3	0.3	Data/MC <Lxy> SF 4.2
Methods	0.1 0.3	0.1	
Total	1.1 1.3	1.2	5.6

Red: 0.7fb^{-1} including no b-tag
Paramterization <- KDE

Combining M_{top} Results

- Are all channels consistent ?

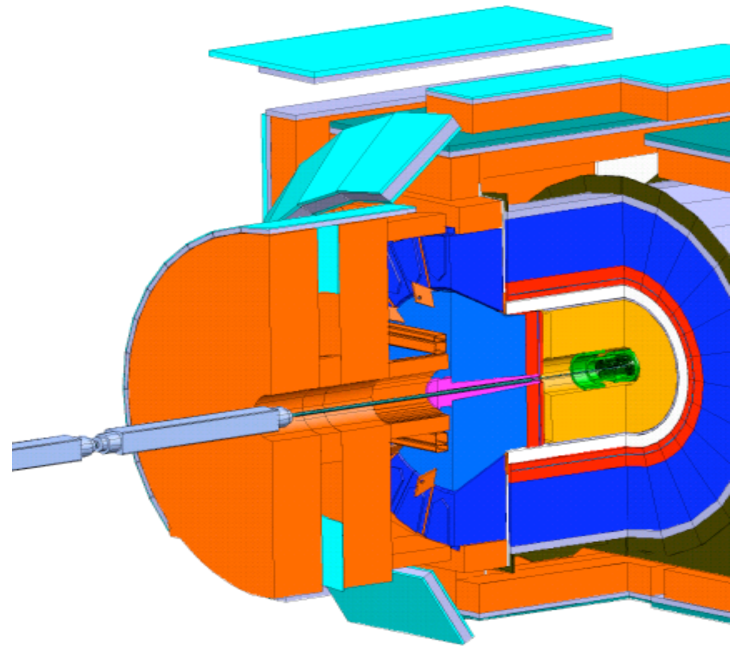




$$M_{top} = 170.9 \pm 1.8 \text{ GeV}/c^2 \ (1.1\%)$$

Jet Energy Scale at CDF

- Top: cone algorithm (0.4),
  QCD: Midpoint and Kt algorithms
- Standard calibration (~3%)
  - Use dijet samples & tuned MC
  - Systematic: difference between MC and data, uncertainty from the method
- Wjj in-situ calibration (~1.3%@1.7fb^{-1})
  - Light quark JES: consistent with Std calibration
  - Apply to b-JES
  - Rely on MC about JES & b-JES difference
- Z(bbbar) (~2% @0.6fb^{-1})
  - Special SVT trigger sample
  - Consistent with Std calibration
  - Had not applied to top mass yet.



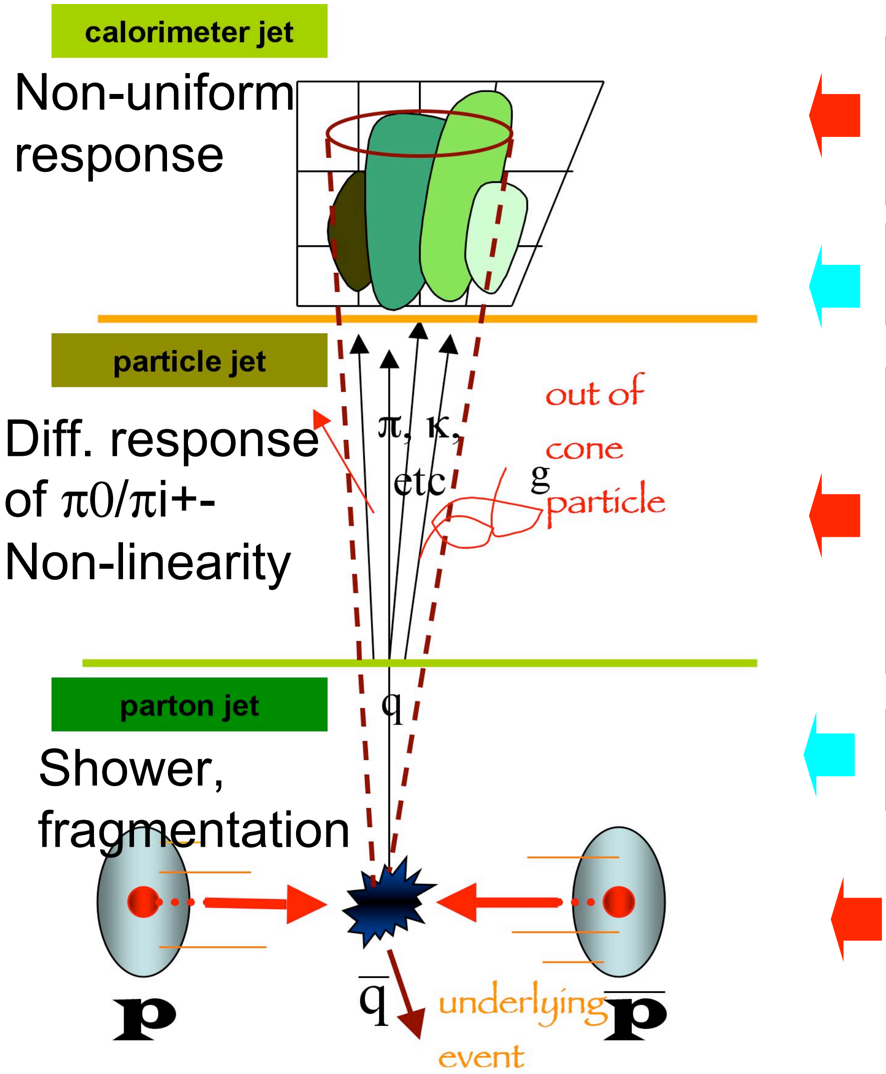
Scintillating tile non-compensating calorimeter with lead/iron absorbers

Electrons: $\sigma_E / E = 13.5\% / \sqrt{E}$ **(central)**

$\sigma_E / E = 16\% / \sqrt{E}$ **(plug)**

Jets: $\sigma_E / E \sim 80\% / \sqrt{E}$

Jet Energy Correction



Relative using dijet balance: to make response uniform in η

Multiple ppbar interactions: pileup

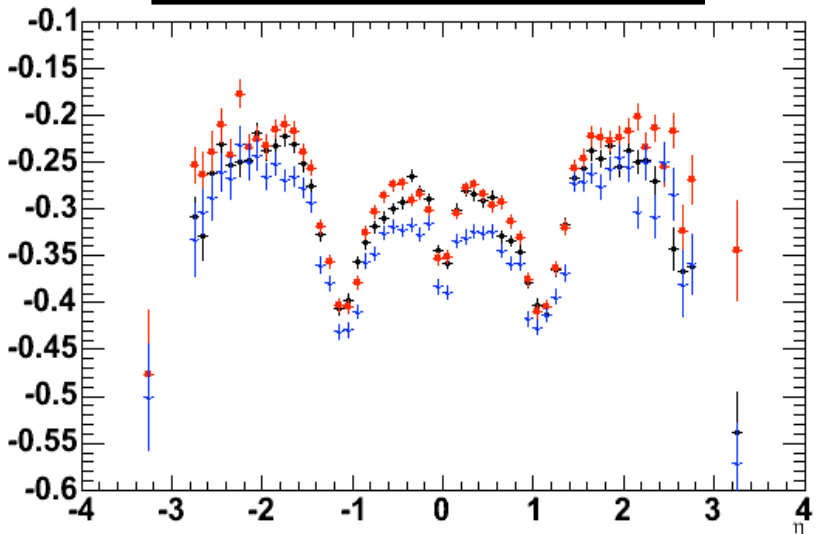
Absolute correction using dijet MC tuned for single particle E/P, material, and fragmentations: due to non-linear and non-compensating calorimeter

Underlying events due to spectators

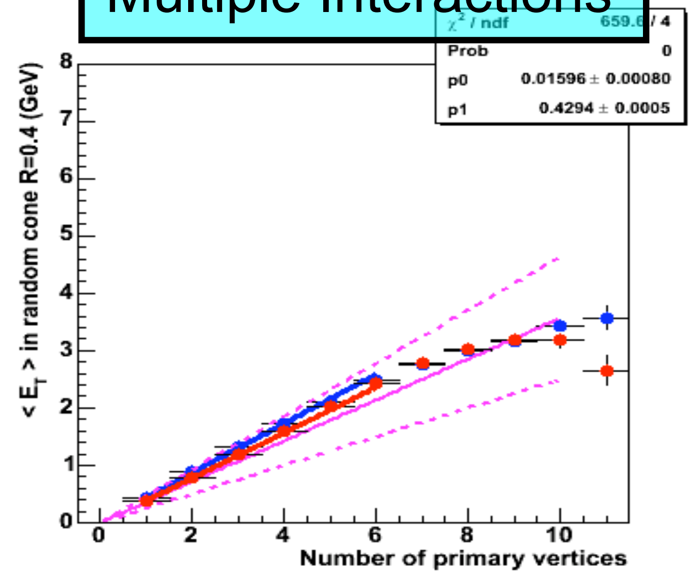
Out-of-Cone : due to energy outside cone

Jet Corrections

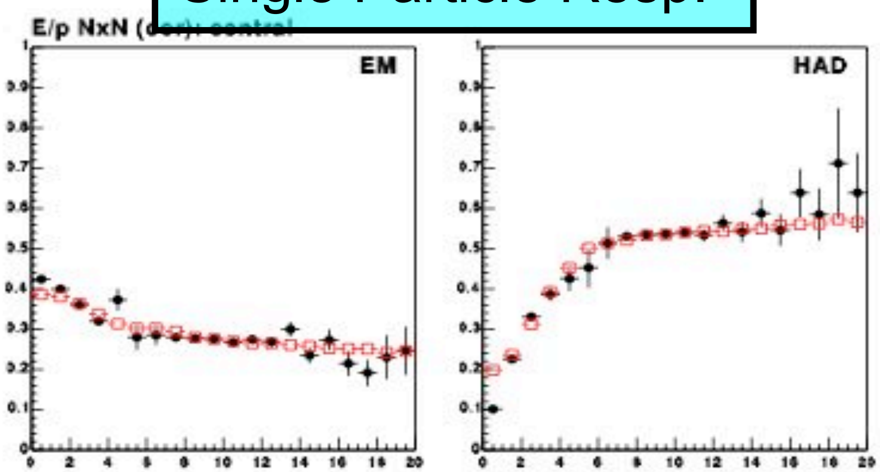
Relative Correction



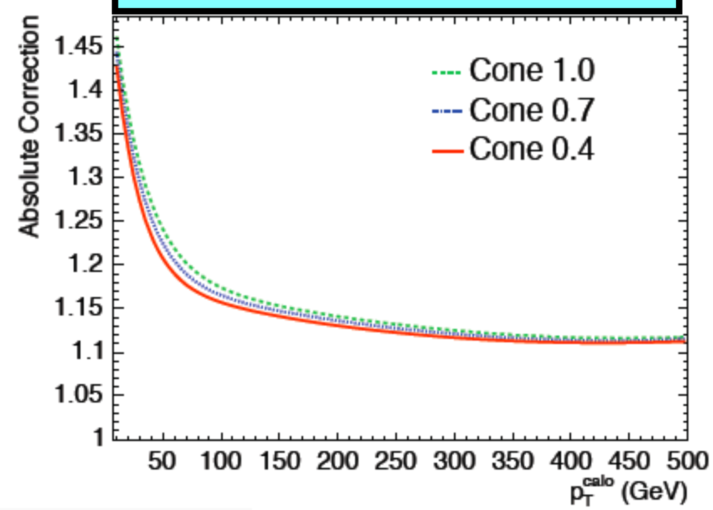
Multiple Interactions



Single Particle Resp.

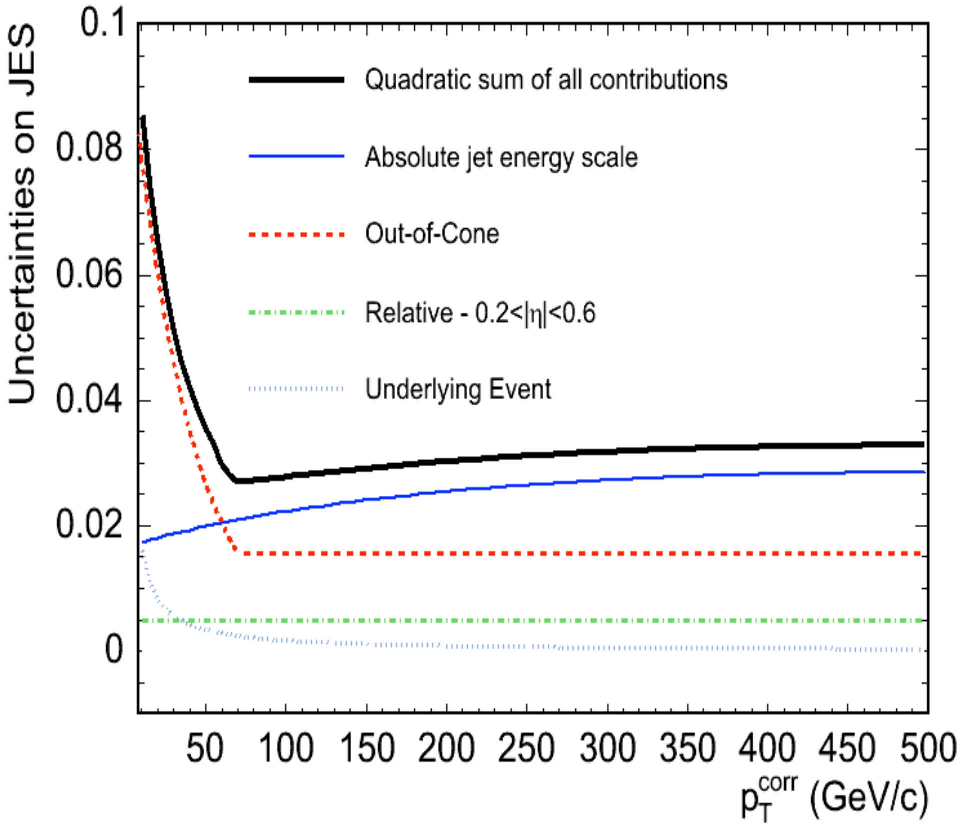


Absolute Correction



JES Uncertainty

Standard calib.



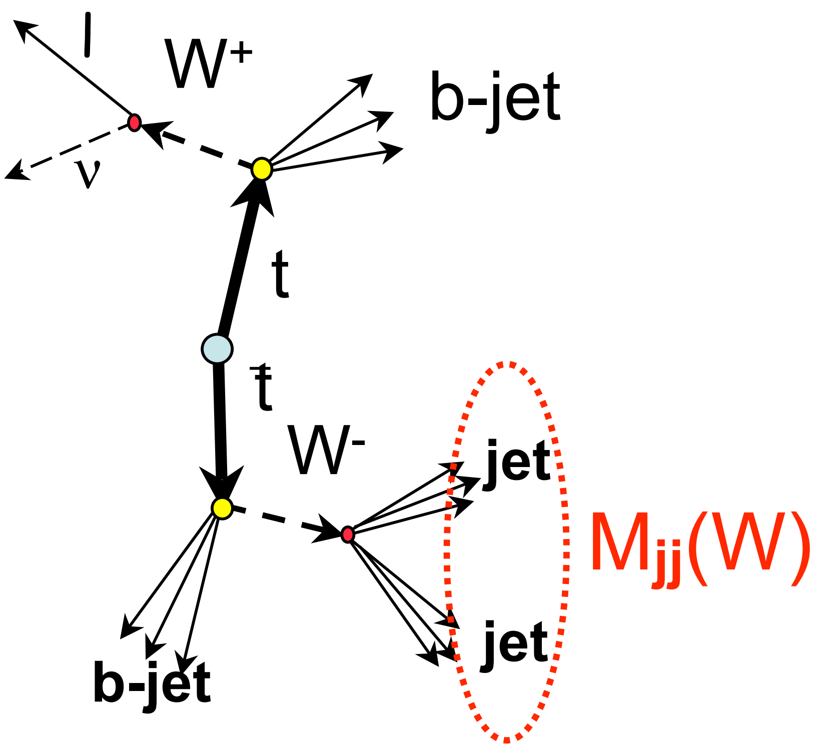
About 3 GeV of M_{top}

Systematic Checks

- γ-Jet:
  - highest statistics ☺
  - systematically limited (kt-kick, BG contributions: π^0) ☹
  - Not available for E_T<25 GeV (trigger) ☹
- Z-Jet:
  - Usable at lower E_T values than γ-Jet ☺
  - lower statistics than γ-Jet at high E_T ☹

In-Situ Wjj JES Calibration

In-situ calibration: W->jj resonance



- But 70% of δJES in top mass comes from b-jet. How can you apply JES to b-jet?

JES	ΔM_{top}
Relative	0.6
Absolute	2.2
OOC	2.1
Total	3.1

B-JES	ΔM_{top}
B frag.	0.4
Color flow	0.3
Br(b->$l\nu$X)	0.4
Total	0.6

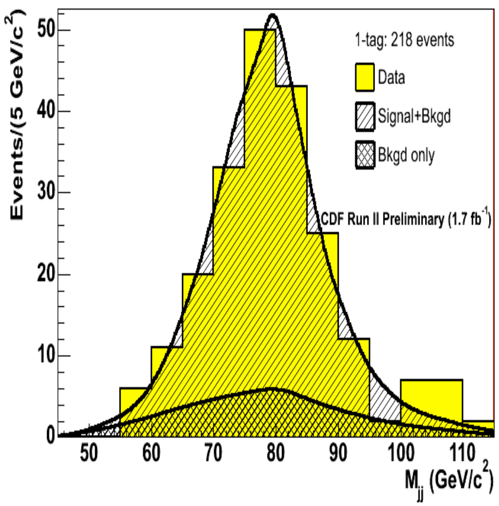
JES uncertainty:
mostly statistical,
scaled with lum

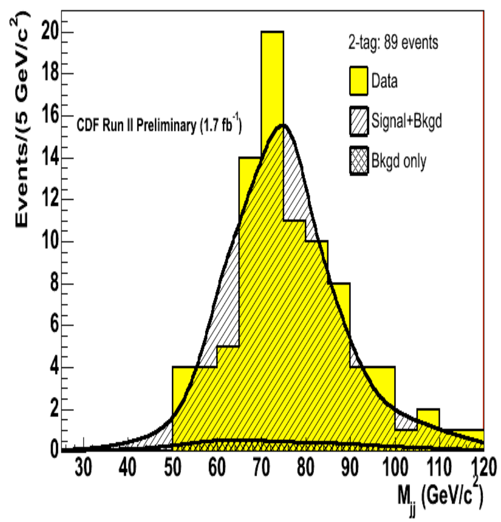
Ans) b-jet specific uncertainty
is small

B-JES

- 2-D simultaneous fit to Mt and JES

$$JES = -0.07 \pm 0.42\sigma$$

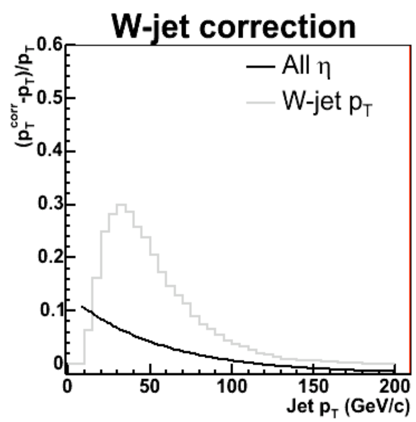


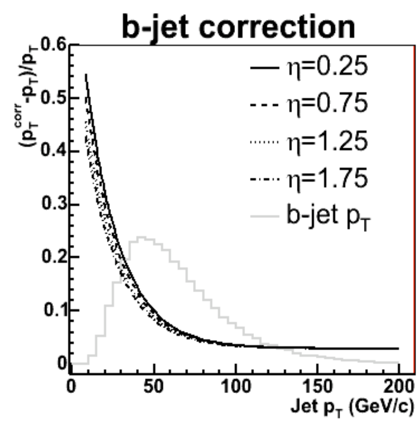


mjj (1-tag, 2-tag): 1.7fb^{-1} ~300 evts
~1.3% precision on JES

- Additional correction to correct b-jet back to b-quark level

- Additional B-jet specific uncertainty based on the constraints from other experiments using MC





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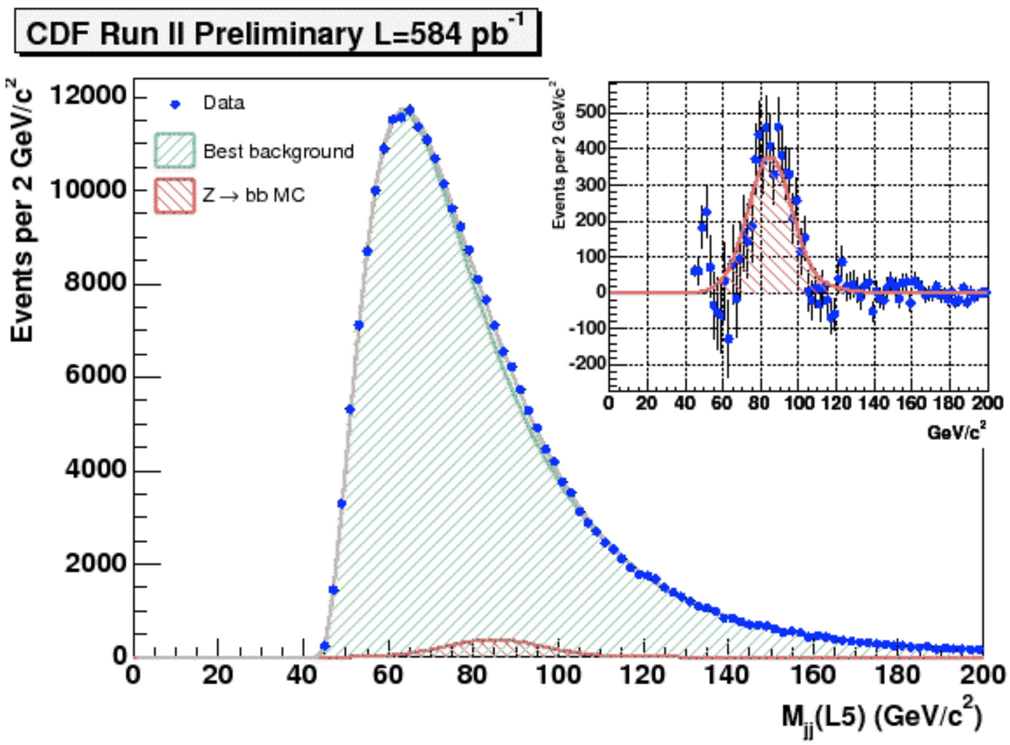
b-JES using Z(bb)

- Di b-jets with Et>22 GeV, $\Delta\Phi$>3.0,$E_t^{(3rd)}$<15 GeV using SVT impact parameter trigger at L2
- To measure data/MC b-JES

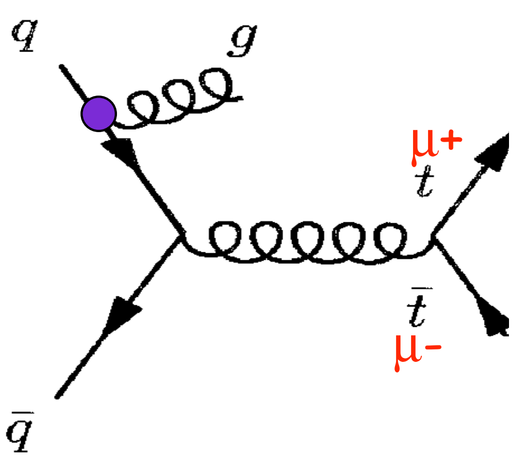


- Has not applied to b-JES in top mass
  - different cone size
  - different pt spectrum

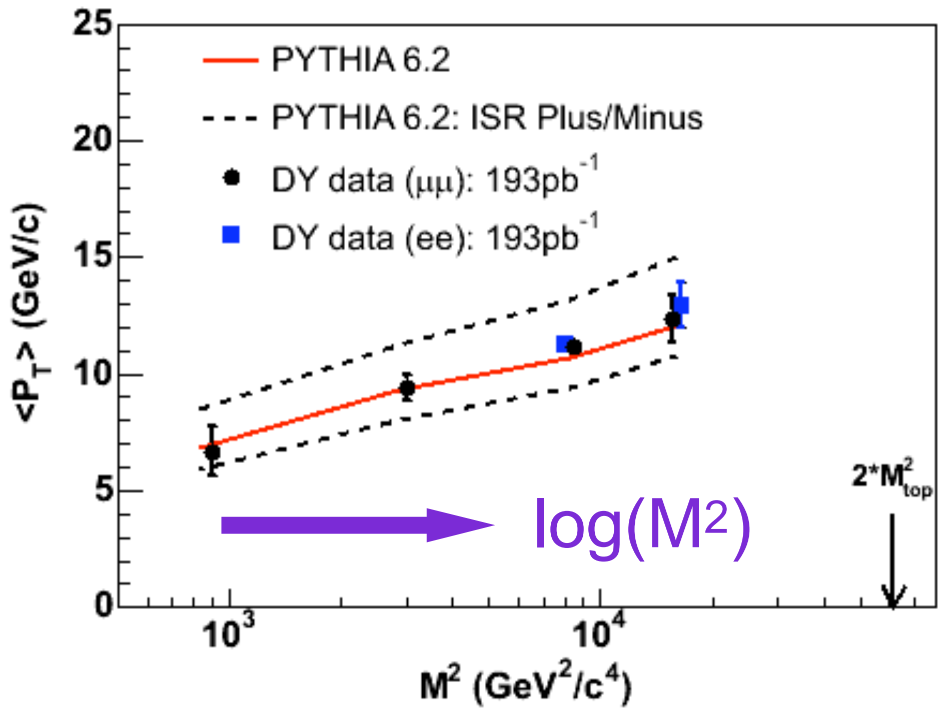
$$\text{b-JES} = 0.974 \pm 0.011(stat) +^{+0.017}_{-0.014}(syst)$$

ISR/FSR in $t\bar{t}$ system?

- ISR is governed by DGLAP eq.: Q^2, Λ_{QCD}, splitting functions, PDFs
- Use DY data for ISR (no FSR): study Pt of the dilepton as $M^2(ll)$



$q\bar{q} \rightarrow t\bar{t}$(85%)



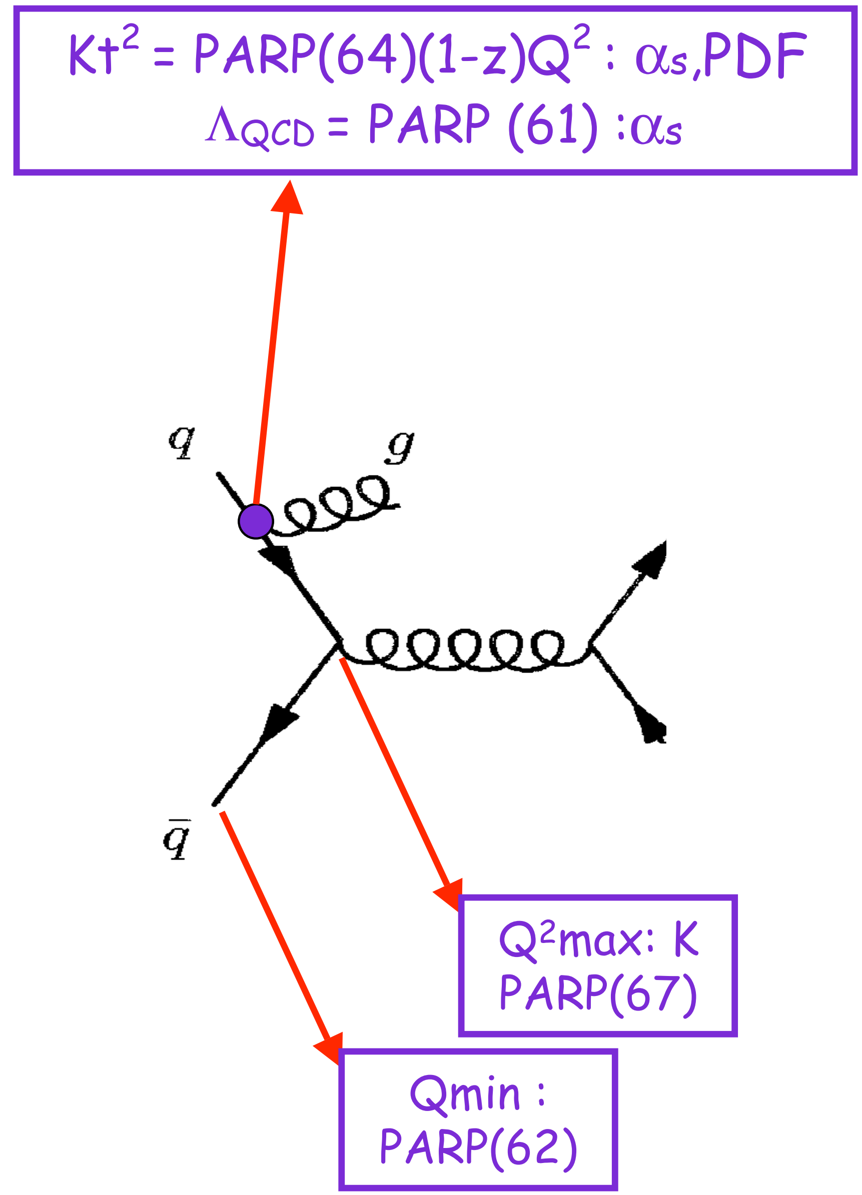
A good logarithmic Q^2 ($\sim M^2$) dependence was observed

ISR/FSR Syst.

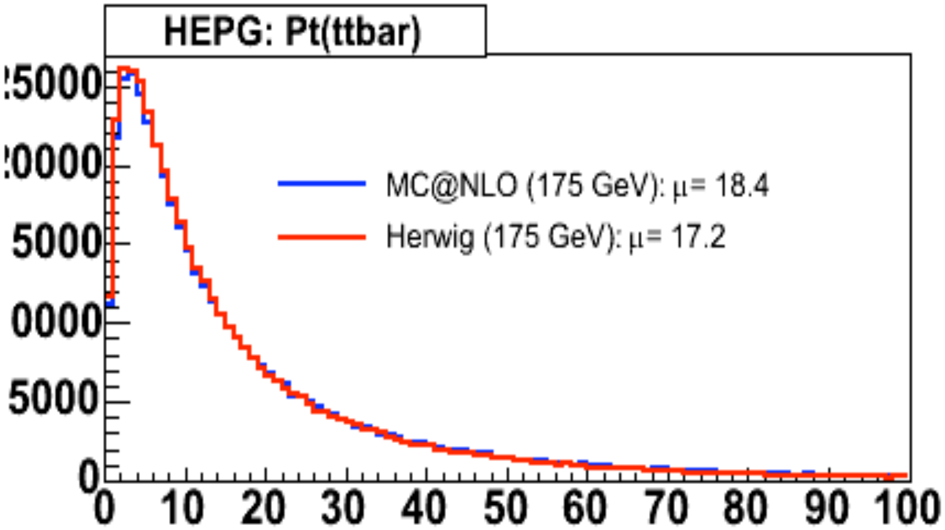
Pythia 6.2	ISR more	ISR less
PARP(61) (D=0.146)	0.292 (5 flavor)	0.073
PARP(64) (D=1.0)	0.25	4.0

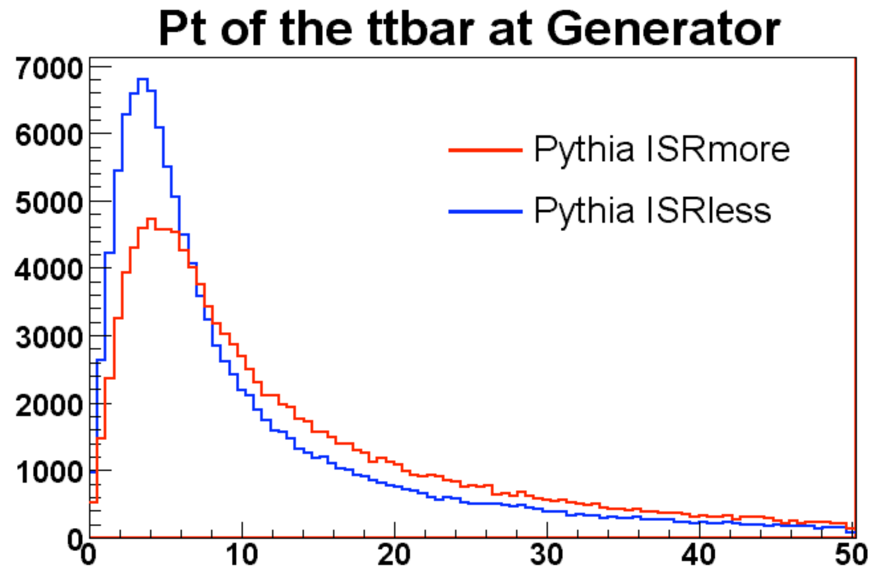
Pythia	FSR more	FSR less
PARP(72)	0.292	0.073
PARP(71) (D=4)	8.0	2.0

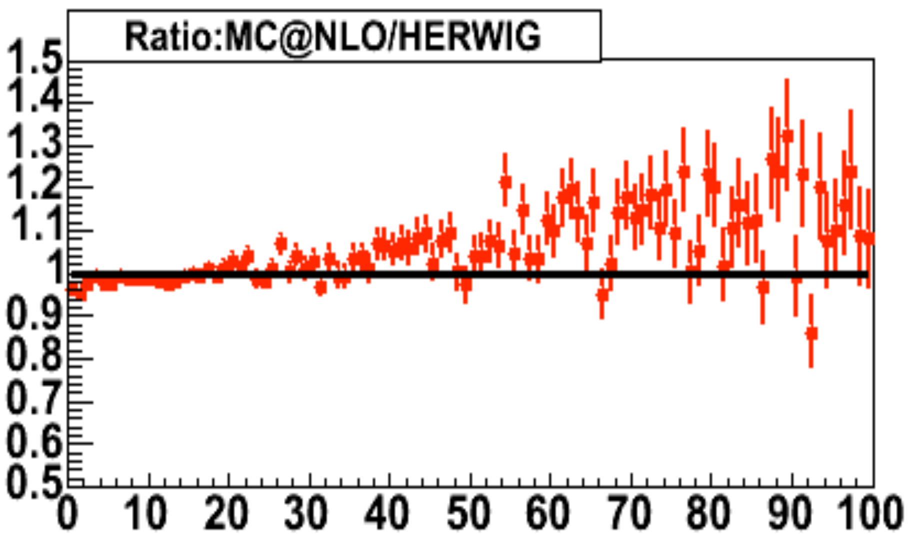
Physics process independent

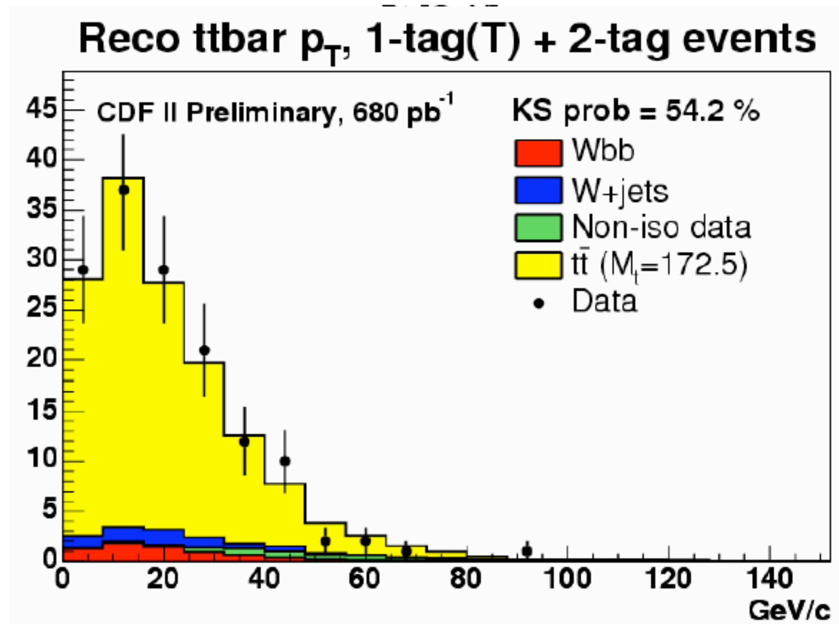


Pt of $t\bar{t}$: ISR syst. vs NLO

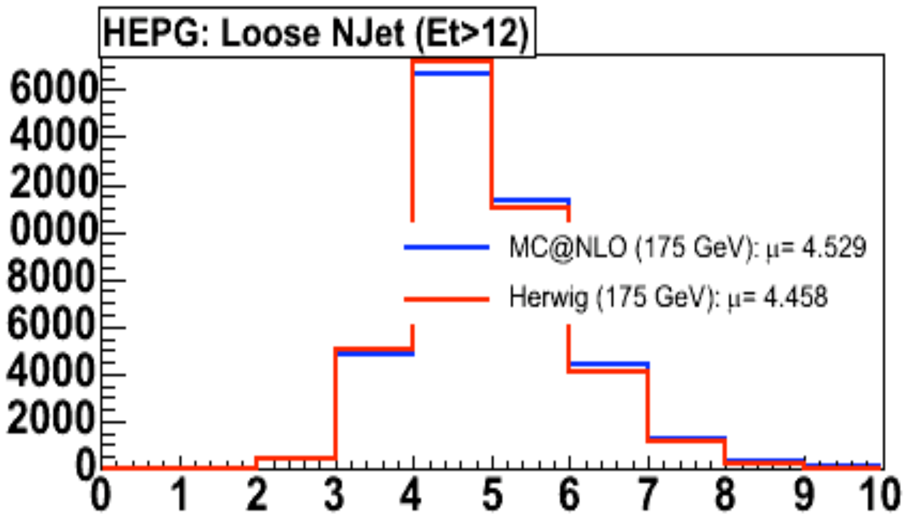


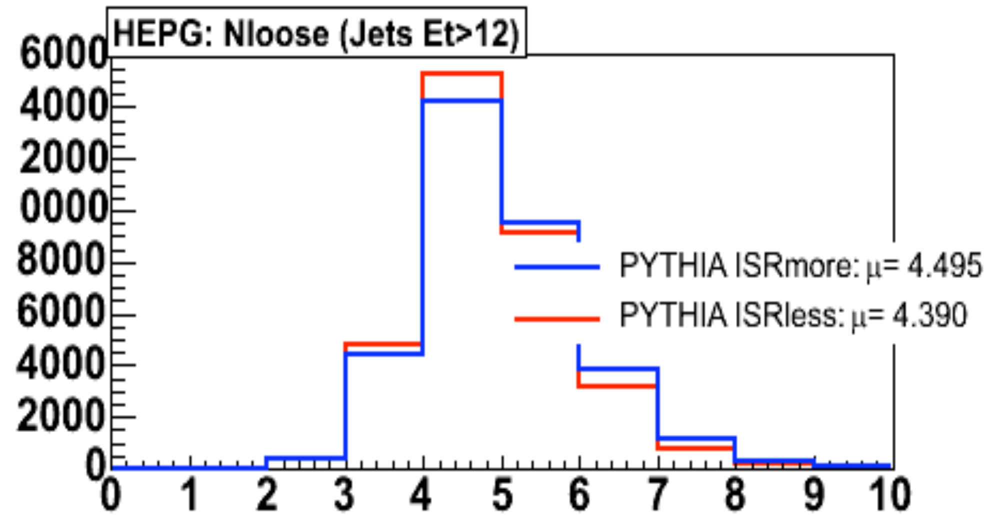


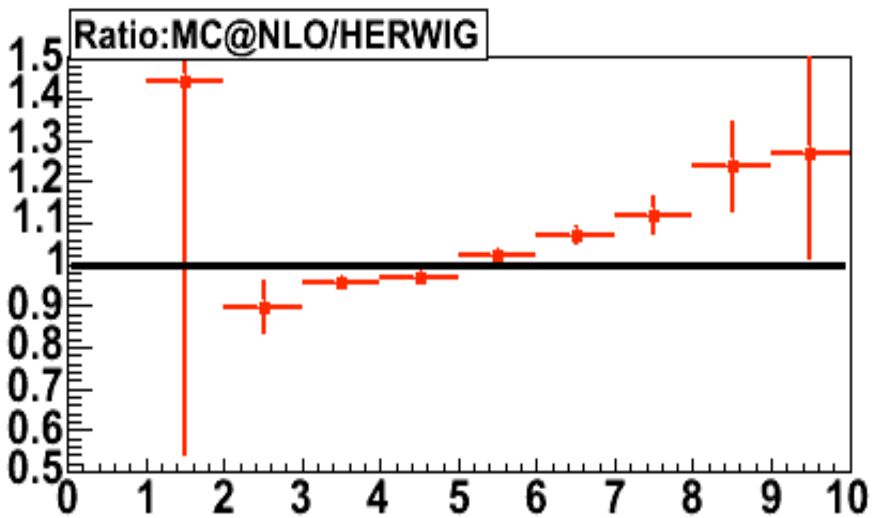


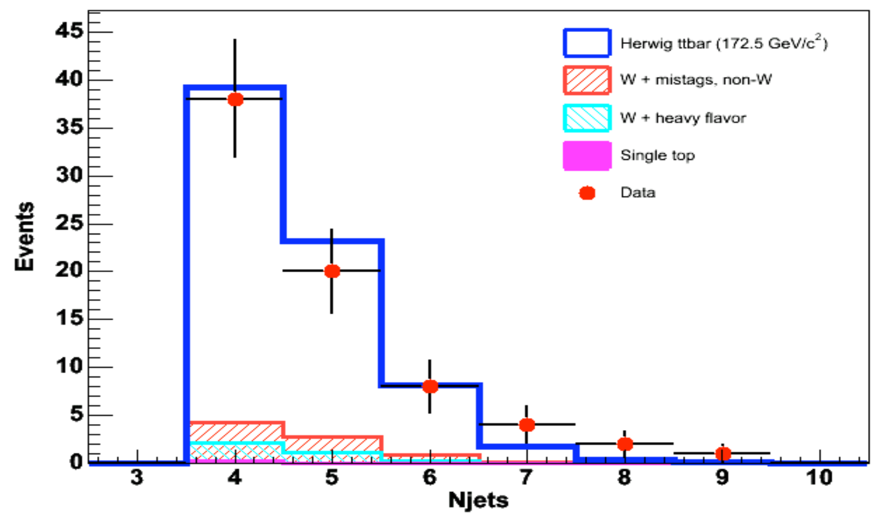


Njets : ISR syst. vs NLO







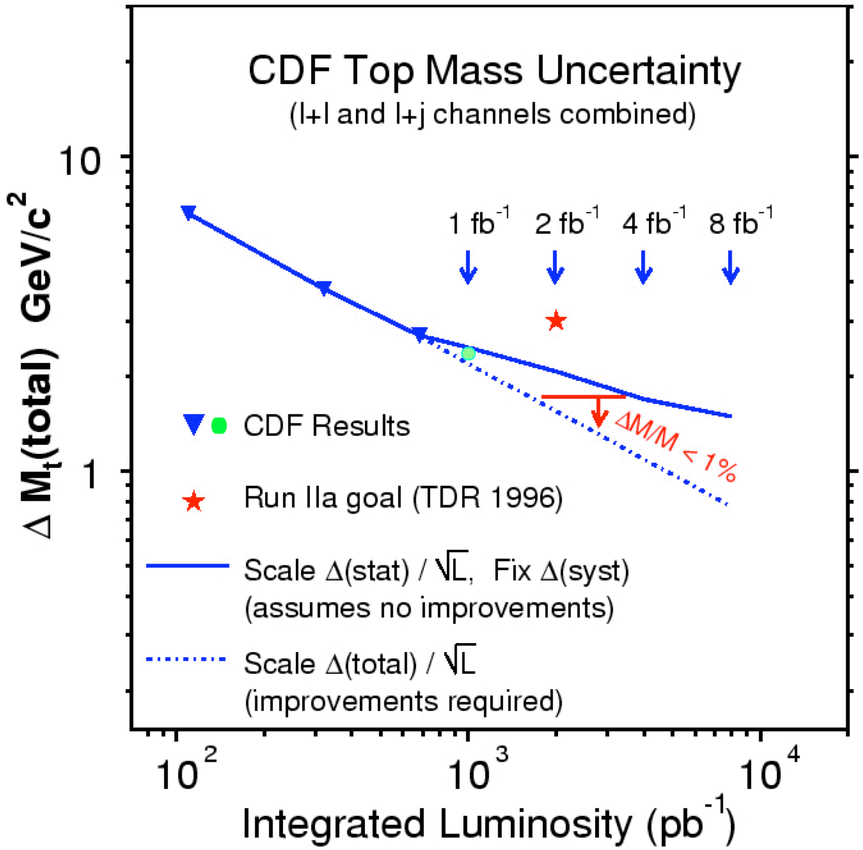


➢ISR less/more absorbs a NLO effect

Njets for 1-tag+2-tag:
Et>8 GeV

Summary and Lessons

- 1.1% precision and no bias due to new physics appeared yet
- Reasons we surpassed Run-IIa goal:
  - *In-situ* Wjj calibration
  - Dedicated people working coherently
- But *In-situ* calibration will be soon limited by b-jet specific uncertainty
- Small effects at Tevatron (<400 MeV)
  - ❑ NLO using MC@NLO
  - ❑ qq vs gg events (2 GeV diff.)
  - ❑ Spin correlation
  - ❑ Multiple interactions(pileup)
  - ❑ Color interference?



- What Mt have we measured? Joyful debate @ $\delta M_t < 1 GeV/c^2$

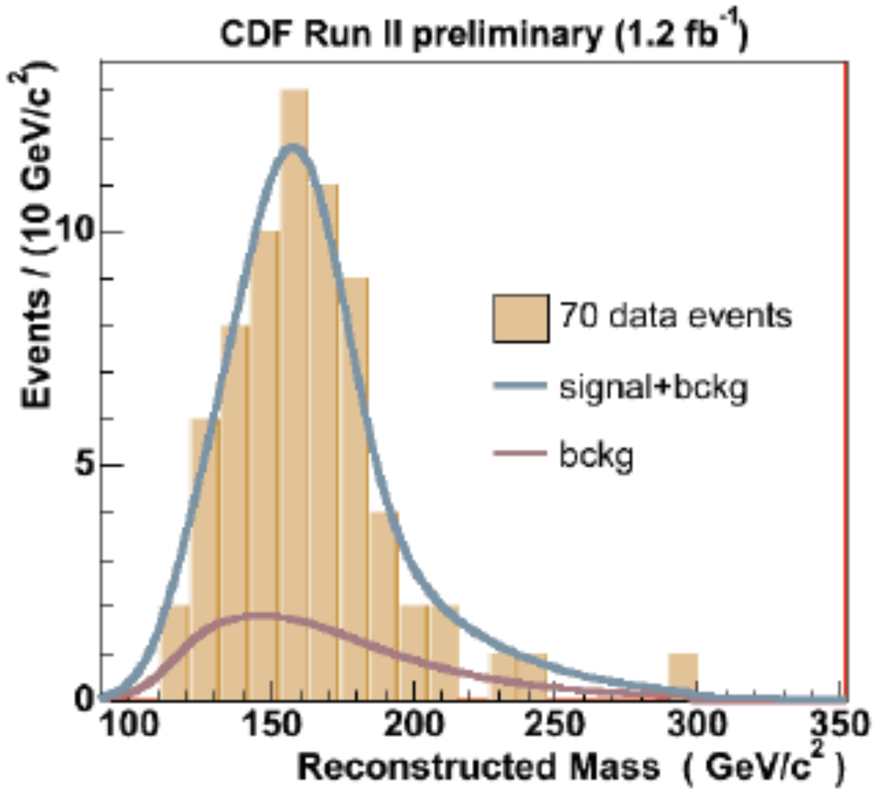
Backup: Methods in dilepton

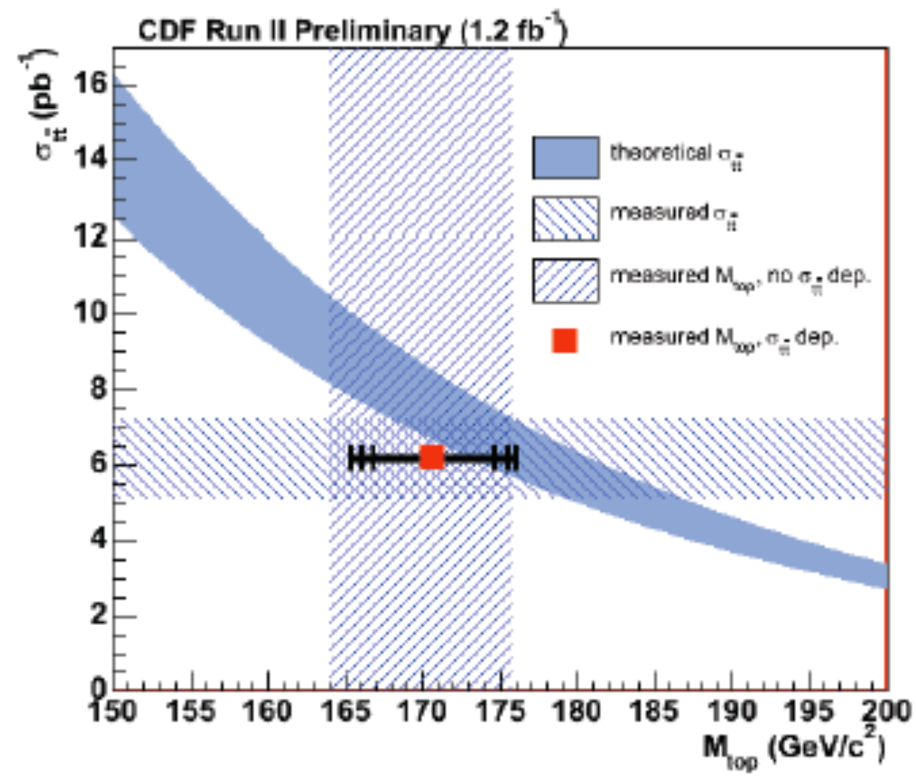
- Unconstrained system;
  2 neutrinos, but 1 missing E_T observable

- Template:
  - Assume $\eta(\nu)$ (or $\phi(\nu)$, $P_Z(tt)$)
  - Sum over all kinematic solutions, and (l,b) pairs, select the most probable value as a reco. M_t

- Matrix Element:
  - Integrated over unknown variables using the LO Matrix Element assuming jet angles, lepton are perfect, and all jets are b's
  - Obtain P(Mtop) for signal and backgrounds
  - Calibrate off-set in pull and pull width using fully simulated MC

Backup: Results in dilepton





$M_{top} = 169.7^{+5.2}_{-4.9}(\text{stat.}) \pm 3.1\,(\text{syst.})\ \text{GeV}/c^2$

$M_{top} = 170.7^{+4.2}_{-3.9}(\text{stat.}) \pm 2.6\,(\text{syst.}) \pm 2.4\,(\text{the.})\ \text{GeV}/c^2$

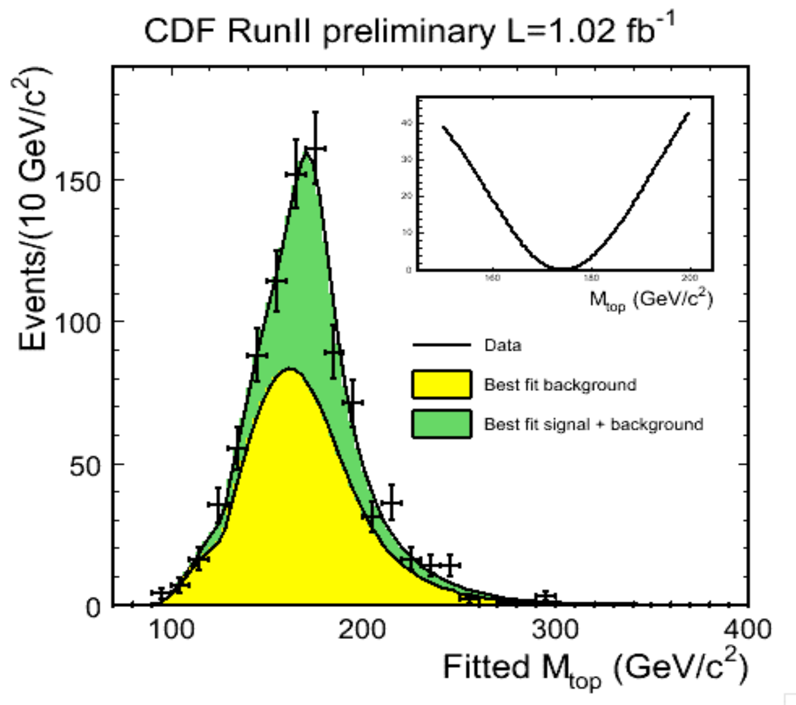
- Event selections: 2 leptons (Pt>20), 2jets (Et>15), MET> 25 GeV
- Syst. error is comparable to the stat. error
- Toward 2nd publications with 1fb^{-1}

Backup:Template in all-jets

- Template method with fitted M_{top} as observable
- Choose among all possible comb ination of 6 jets

  using a kinematic fitter
- Event seletion:
  - $E_T / \sqrt{(\Sigma E_T)} < 3\ (GeV)^{1/2}$
  - $\Sigma E_T \geq 280$ GeV
  - $n_{b\text{-}tag} \geq 1$ (b-tag)
  - $6 \leq N_{jet} \leq 8$
  - Neural Network selection

    to improve S/B = 1/2 (vs 1/8)
- And data-driven background template



$$M_{top} = 174.0 \pm 2.2(stat.) \pm 4.5(JES) \pm 1.7(syst.)\ GeV/c^2$$

$$\text{New } M_{top} = 171.1 \pm 3.7(\text{stat.} + \text{JES}) \pm 2.1(\text{syst.})\ \text{GeV}/c^2$$