Top Mass and Jet Corrections: Smarter, Better, and Moving Towards Publication

Adam Gibson
For the Top Mass and Jet Corrections Groups

April 30, 2004

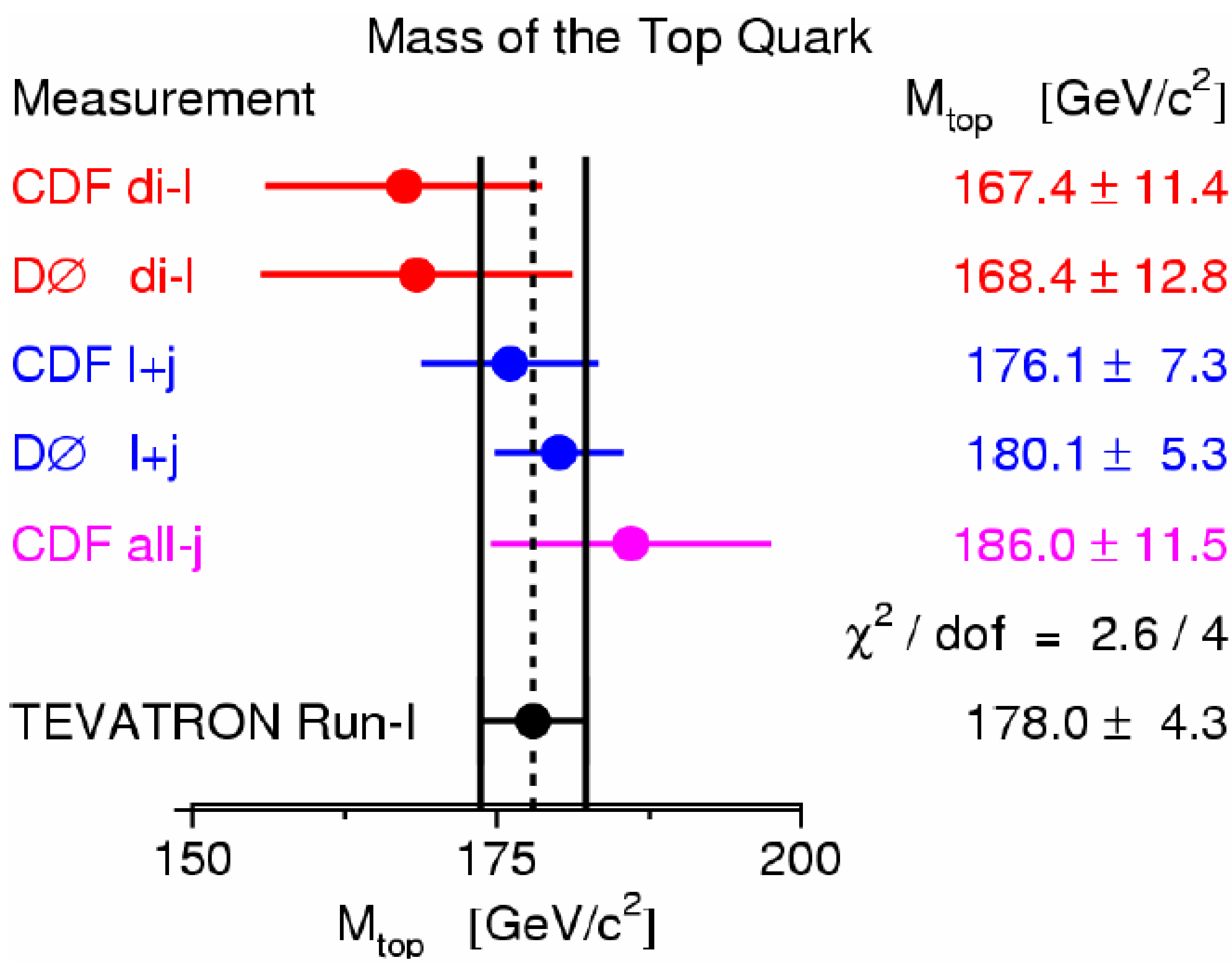
CDF Collaboration Meeting

Everything in this talk is the result of the work of many dedicated individuals – apologies to everyone I don't mention by name!

Outline

- Overview
- Broad Perspective of Ongoing Analyses
- Systematics from the 4.11.2 era
  - Lepton + Jets Template Method as Example
- Improvements in Jet Corrections
  - Relative Jet Corrections
  - Central Calorimeter Energy Scale
  - Much work left to do!
  - Expected Systematics in 5.3.1
- Better Understanding of Other Systematics
  - PDF's
  - ISR/FSR
- Details of Selected Analyses (and Publication Plans)
- Conclusions

New Run I Combination From TeV EW/Top-Working Group

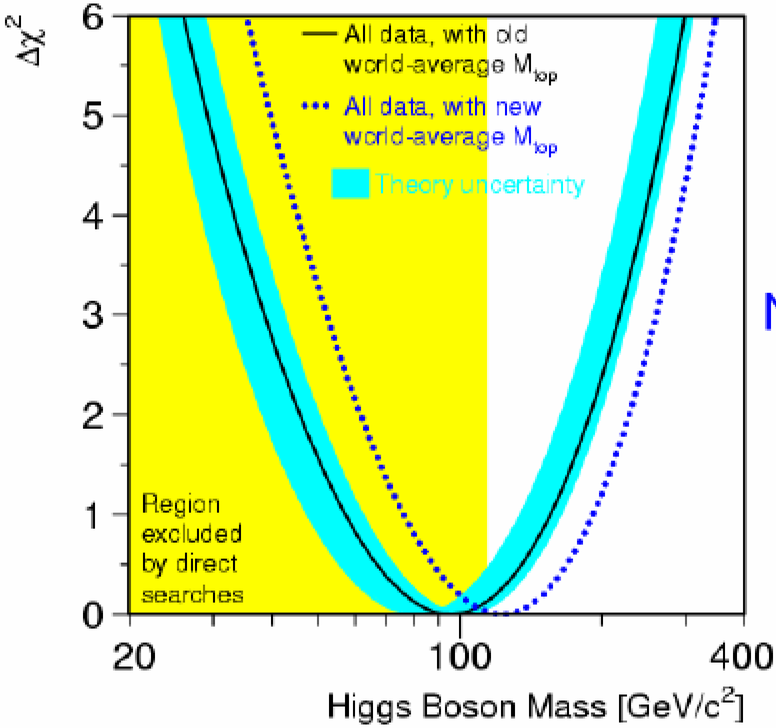


~1 year old D0 matrix element analysis

Consequences for Standard-Model Higgs

Precision electroweak data:

Constrain M_H in the MSM



Old:

$$M_{top} = 174.3 \pm 5.1 \text{ GeV}$$
$$\log M_H = 1.98^{+0.21}_{-0.22}$$
$$M_H = 96^{+60}_{-38} \text{ GeV}$$
$$\text{or} < 219 \text{ GeV (95\% CL)}$$

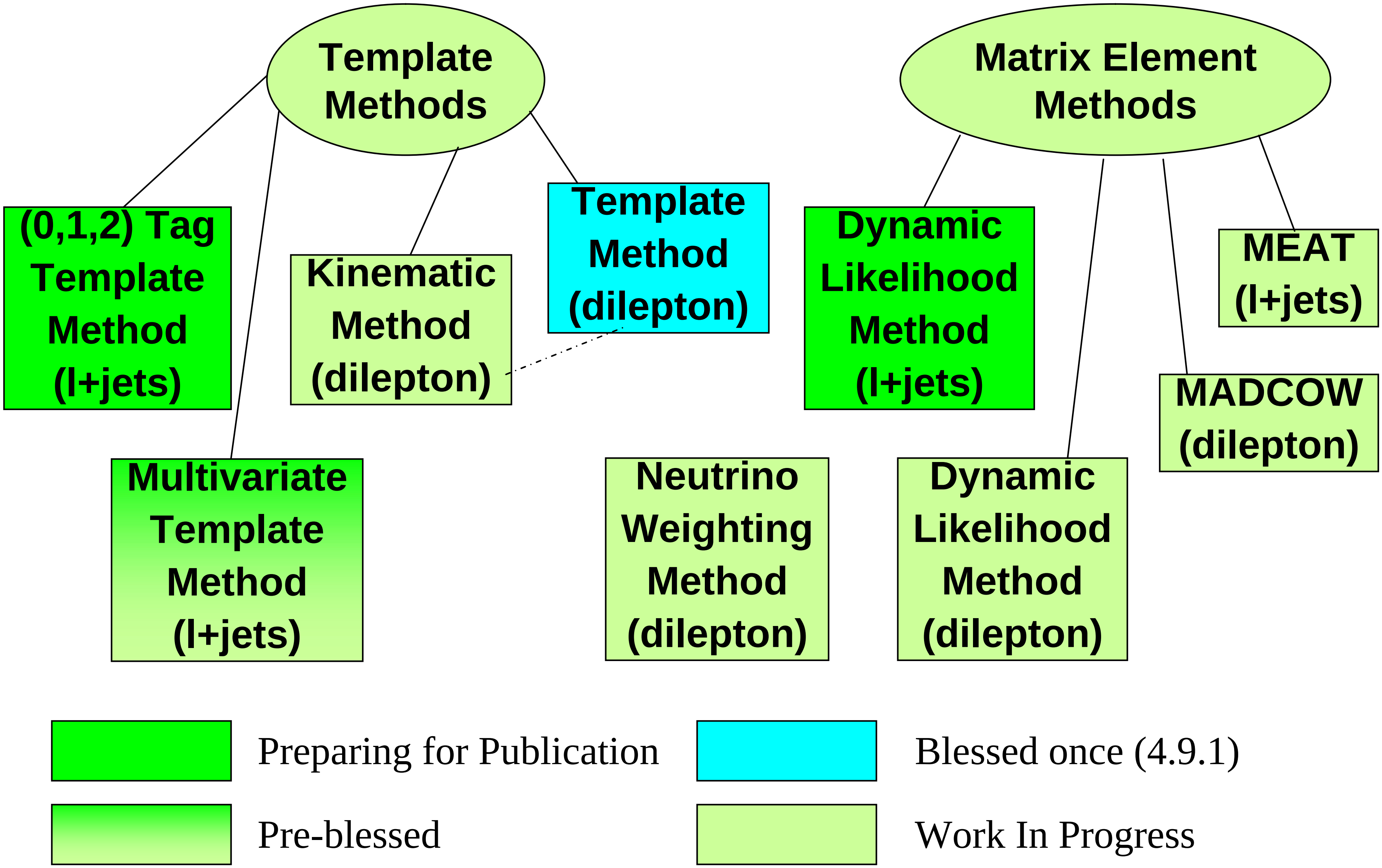
New:

$$M_{top} = 178.0 \pm 4.3 \text{ GeV}$$
$$\log M_H = 2.07^{+0.20}_{-0.21}$$
$$M_H = 117^{+67}_{-45} \text{ GeV}$$
$$\text{or} < 251 \text{ GeV (95\% CL)}$$

(Procedure as in hep-ex/0312023!)

From A. Quadt, CDF Top Mass Meeting March 26, 2004

Ongoing Run II Top Mass Analyses



	Lepton + Jets			Dilepton
	Template Method	Multivariate Template Method	Dynamic Likelihood Method	Kinematic Method
Event Selection	≥3.5 (≥4) jets, 0, 1, or 2 b tags	≥3.5 (≥ 4) jets, b tag	==4 jets, b tag	dilepton
Jet Corrections	Level 5/7, Top Specific (JF)	Level 7, Top Specific (LBL)	Level 5, Transfer Functions	Level 7
Mass Reconstruction	Minuit χ^2	Kinematic fit	None	Scan Params
Mass Fitting	2-comp. fit	KDE, template weighting	Mat. Elmt. $\otimes$ TF	Bkgd-subtracted 1-comp. fit
Background Treatment	Fitted with constraint	Fitted without constraint	Mapping function	Systematic Error

Errors From Selected Analyses

[All values in GeV/c^2]	Lepton + Jets				Dilepton
	Pretag Template Method (~194 pb^{-1})	Tagged Template Method (~162 pb^{-1})	Dynamic Likelihood Method (~162 pb^{-1})	Multivariate Template Method (~162 pb^{-1})	Kinematic Template Method (~126 pb^{-1})
Mean Expected Statistical Error	**8.8**	**6.9**	**5.2**	**7.8**	**16.9**
Measured Statistical Error	+ 14.9 - 9.3	+ 7.1 - 7.7	+ 4.5 - 5.0	+ 6.4 - 6.3	+ 17.4 - 16.9
Jet Systematic Error	8.9	6.3	5.7	6.7	7.1
ISR/FSR Syst. Error	0.8	1.0*	0.7	0.6	2.7
PDF Syst. Error	2.5	0.2*	2.0	1.2	3.1
Total Syst. Error	9.6	6.5	6.2	6.8	8.4
Total Measured Uncertainty	+ 17.7 - 13.4	+ 9.6 - 10.1	+ 7.7 - 8.0	+ 9.3 - 9.3	+ 19.3 - 18.9

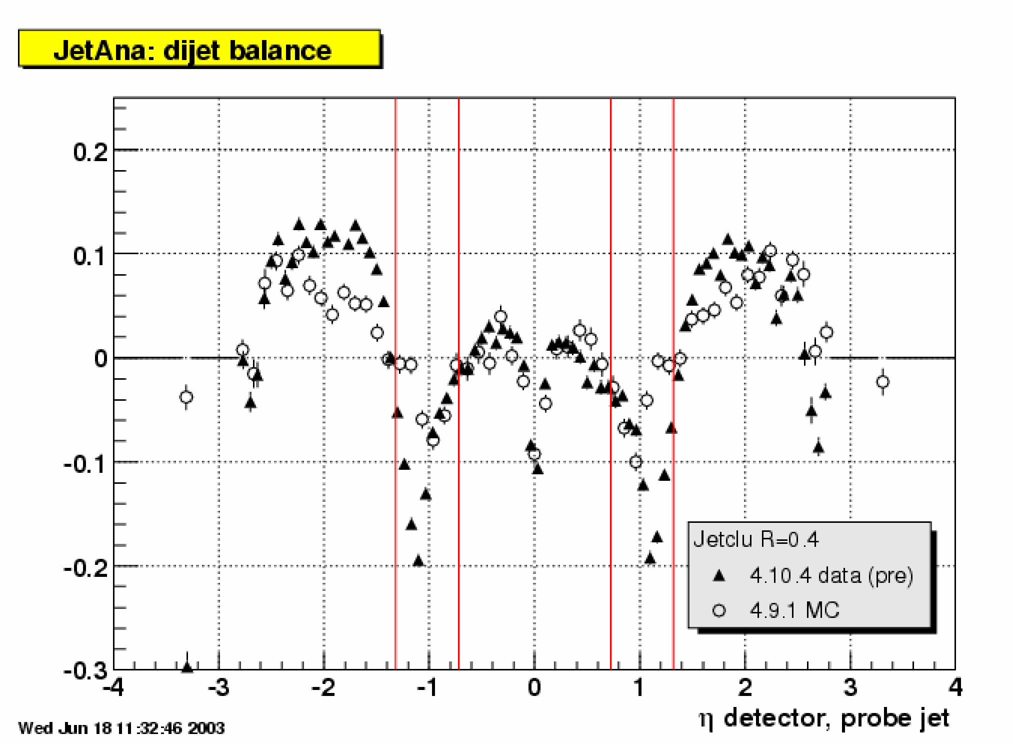
Methods Preparing for Publication

Jet Corrections Systematics

- Jet energy systematics are the dominant systematic uncertainty for the top mass measurement
- Improvements have been made:
  - Calorimeter simulation – η-dependent systematics will be reduced
  - Run I – Run II difference – central raw scale systematic will be further reduced (for data)
- Lots of work remains, for example:
  - Run II absolute corrections
  - Pythia-Herwig difference in gamma-jet balancing

Source of Corrections		ΔM_{top} (GeV/c^2)	
Level	Description	v4.9.1hpt1	v4.11.1
		≥ 3.5 jets	≥ 3.5 jets
1 (sim)	η-Dependent Calibration **	3.77 ± 0.24	2.40 ± 0.11
1 (data)	η-Dependent Calibration **	0.91 ± 0.24	1.74 ± 0.11
2 (data)	Calorimeter Stability	0.99 ± 0.24	0.88 ± 0.11
3 (sim)	Raw Scale (central) **	4.45 ± 0.24	3.57 ± 0.11
3 (data)	Raw Scale (central) **	4.87 ± 0.24	2.72 ± 0.11
5	Absolute Scale	2.17 ± 0.24	2.20 ± 0.11
7	Out-of-cone: up to cone 1.0	1.21 ± 0.24	1.72 ± 0.11
	Out-of-cone: outside cone 1.0	1.15 ± 0.24	1.47 ± 0.12
Total		7.9 ± 0.7	6.3 ± 0.3

Errors on Relative Corrections, 4.11.2

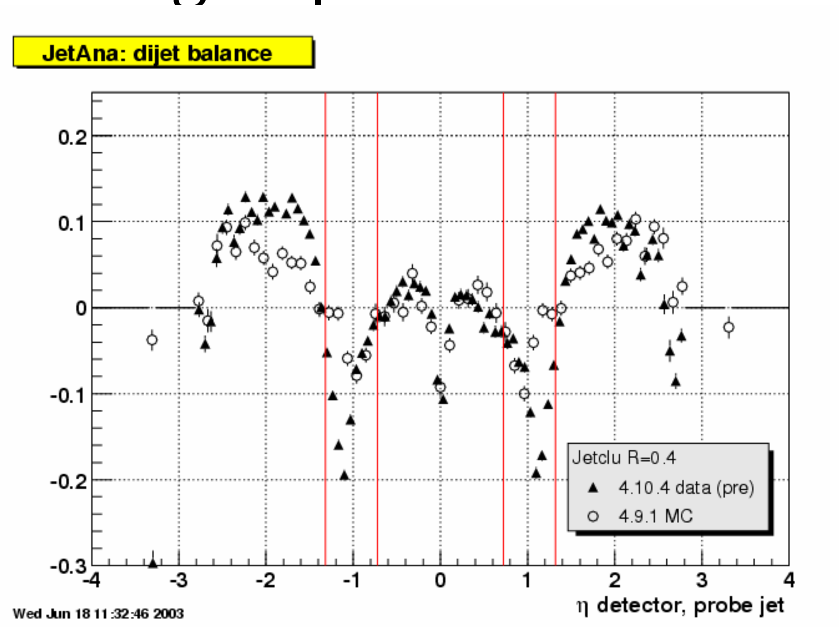


eta	data	MC
<0.2	3%	1%
0.2-0.6	0.5%	1%
0.6-1.0	2%	1%
1.0-1.4	4%	7%
1.4-2.0	2%	6%
>2.0	7%	7%

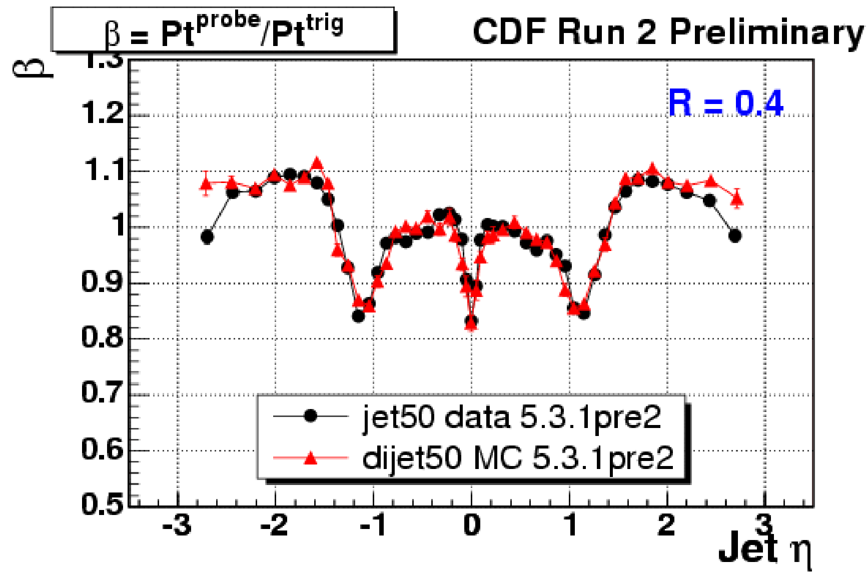
-MC error is half the difference between data and MC

- Inflated data errors in crack and plug

Big Improvement in MC Modeling of Dijet Balancing



4.9.1 MC, 4.10.4 data



5.3.1pre2 MC, data

Thanks to the Jet Task Force!

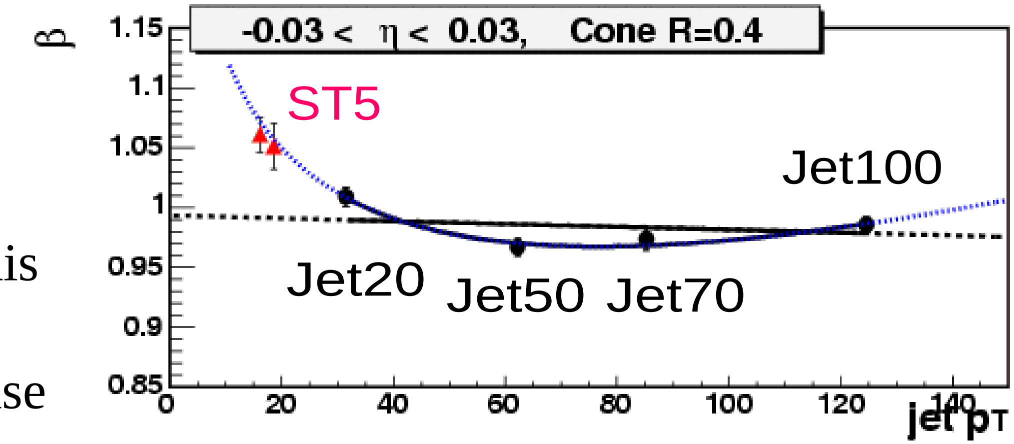
Doug Hoffman and Young-Kee Kim (Chicago), Charles Currat and Lina Galtieri (LBNL), Beate Heinemann (Liverpool), Irina Shreyber (Moscow ITEP), Giuseppe Latino (New Mexico), Yeon Sei Chung and Bo Young Han (Rochester), Anwar Bhatti and Ken Hatakeyama (Rockefeller), Dan Ryan (Tufts), Koji Ebina and Kohei Yorita (Waseda), Lee Pondrom and Yeongdae Shon (Wisconsin), and any others.

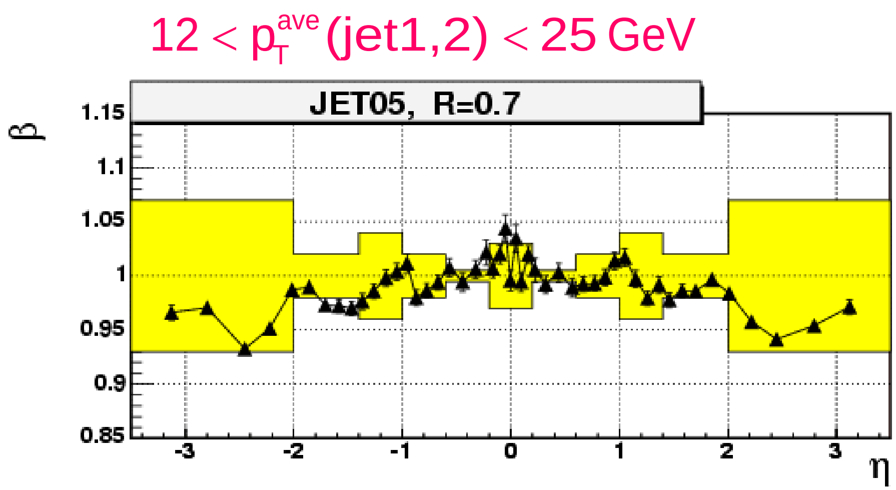
Led by Dave Ambrose (Penn) and Soon Yun (Carnegie Mellon).

Yeon Sei Chung (Rochester) is filling Soon's leadership role.

Relative Corrections At Low Energies

- Had been (4.11.2) using relative corrections linear in jet P_T
- Looked at single tower 5 data and improved the parameterization
- Linear fit had left residual biases, this is helped by new fit
- But, still, error in cracks may increase

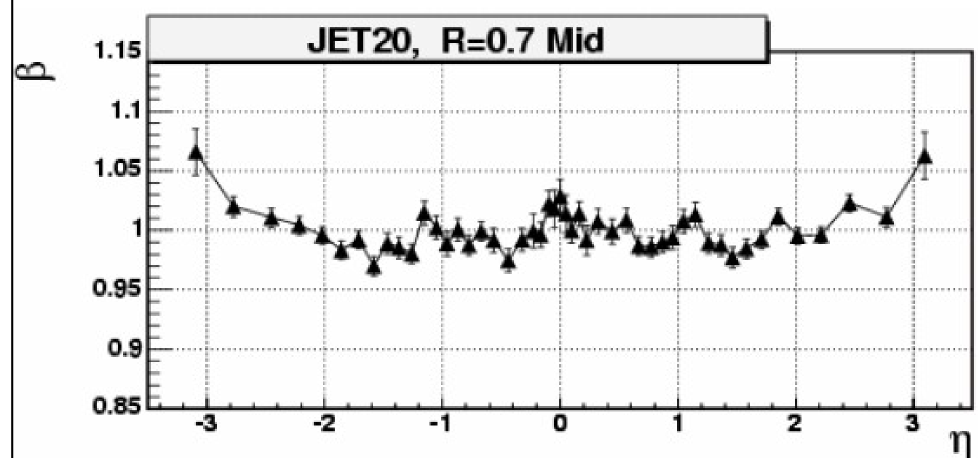




Residual η-dependence with new fit

Kenichi Hatakeyama and Anwar Bhatti (Rockefeller)

Default (JetClu derived) relative corrections work pretty well in MidPoint, and similarly for cone 0.4 out to η 1.0 or so



Preliminary Error Estimate on Relative Corrections for 5.3.1

4.11.2

eta	data	MC
<0.2	3%	1%
0.2-0.6	0.5%	1%
0.6-1.0	2%	1%
1.0-1.4	4%	7%
1.4-2.0	2%	6%
>2.0	7%	7%

	optimistic	pessimistic	optimistic	pessimistic
eta	data	data	MC	MC
<0.2	0.5%	2%	3%	5%
0.2-0.6	0.5%	0.5%	0.5%	0.5%
0.6-1.0	0.5%	1.5%	1%	2%
1.0-1.4	0.5%	1.5%	1%	2%
1.4-2.4	0.5%	1.5%	1%	2%
>2.4	5%	7%	5%	7%

Beate Heinemann

- -MC much better descriptor of data after tuning
- -Residual errors will come from stat. and possible Et dependence
- -Need to check 5.3.1 MC's when available

Raw Central Scale: Level 3 Data, Run I – Run II Difference

- Setting the Raw Scale:
  - **Currently (4.11.2) 3% error** due to Run I – Run II difference in γ-Jet
- CHA recalibration by Frascati group (CDF 6891 in preparation)
- Other Known Effects
  - Extra material (1%)
  - Shorter gate (0.6%)
  - CEM scale redefinition (Blessed!)

CDF 6891: M.Cordelli, S.Dell'Agnello, F.Happacher, N.Luthzesky,S.Miscetti,F.Ptohos, A.Sansoni

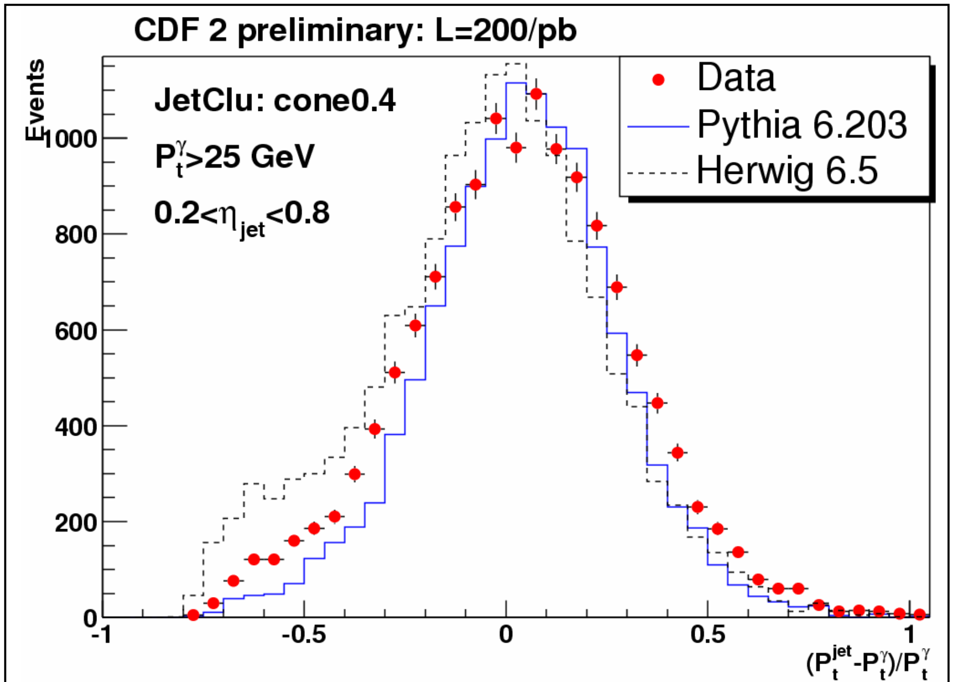
CDF note 6930: Anwar Bhatti (Rockefeller), Adam Gibson (LBNL), Beate Heinemann (Liverpool), Giuseppe Latino (New Mexico)

- Current Run I – Run II γ-Jet Difference (cone 0.7) -2.8 ± 0.4 (stat) $^{+0.9}_{-0.6}$ (syst) %
- Expected Difference (cone 0.7) $-1.6\,^{+1.1}_{-1.1}$%
- Run I – Run II difference understood within errors
- **Reduce error to 1.5% (optimistic) or 2.5% (pessimistic)**
- Long term: this error may never go away…but possibly can be reduced to about 1% or so
- Efforts are also beginning to study high energy single tracks
  - Perhaps we can calibrate *in situ* and move away from test beam, the Run I – Run II comparison, and the 1% error

Raw Central Scale: Level 3 MC Uncertainty

- Compare γ-Jet Balancing after full corrections and background subtraction
- Difference between data and Pythia (4.11.2):
  - 5% cone 0.4, 3% cone 0.7, 1% cone 1.0
- Data has uncertainty of 3%: don't double count
- Systematic error on MC in 4.11.2 was 4% (subtracting 3 from 5 in quadrature)
- Still have large discrepancy Pythia-Herwig-Data (order 5%)
- With work, for 5.3.1 maybe can quote 2% (optimistic) or keep 4% (pessimistic)
- Long term: this error can go to 0 when MC tuning (response and fragmentation) is final

γ-Jet Balancing



4.11.2 data compared to 5.1.0pre7 simulation, full jet corrections. Similar discrepancy in 5.3.1

A. Gibson, B. Heinemann, G. Latino have worked on this and related issues

F. Canelli, M. Lancaster, A. Wyatt, Troy Vine, and A. Malkus (Chicago) are looking into them.

Estimated 5.3.1 Uncertainties on Top Mass

- Preliminary estimates from Beate et. al. (previous pages) for 5.3.1 jet corrections uncertainties
- Take the lepton+jets (>=1 SecVtX tag) template analysis as an example and make some estimates
- Current jet systematic error on top mass (4.11.2) 6.3 GeV
- Estimated jet systematic error on top mass based on estimated 5.3.1 jet corrections systematics
  - 4.7-5.0 GeV optimistic
  - 6.5-6.6 GeV pessimistic

J.F. Arguin and A. Gibson

Time Table for 5.3.1 Jet Corrections and Systematics

- Waiting for MC – total request:
  - 30M jet events (Pythia and Herwig, various energies)
  - 8M gamma-jet (Pythia and Herwig, various energies)
- Should be ready in a month or so
  - Thanks to Reda Tafirout et al. at Toronto!
- Time scale depends on workers!
  - To repeat that status quo in 5.3.1: 4-6 weeks assuming MC comes soon
- Improvements will take longer
  - Run II derived absolute (Level 5) corrections require tuning the fragmentation, final tuning of CDFSim, etc.

Ongoing and Future Work in Jet Corrections

With additional work (and workers) the systematic errors **will** go down. **More help is needed.**

- Well Covered
- Partially Covered
- Insufficiently Covered
- Not Covered

Anwar Bhatti and Beate Heinemann

Short Term Studies

L1: Plug vs Central	Dijet balance: Data and MC	Gamma-Jet as Cross-check		
L2: Time Dep.	Single Particle E/p (e and pi) versus time: C and P	Gamma-Jet and Dijet versus time: C and P		
L3: Raw Scale	Gamma-jet Run 1 vs 2	Gamma-jet Data vs MC	Gamma-jet: Herwig vs Pythia	Z-jet: Data vs MC
L4: Multiple Interactions	Et(cone) vs Nvtx: Min Bias data, cross check with W's, jets	Revise Procedure: So far central only. Plug extra?		
L5: Measured to Particle	Measure/Tune Fragmentation in Dijet, W/Z, gamma-jet data vs Et	Tune Response In cdfSim	Understand pi0 scale (raw Zmass)	
	Use MC to derive measured/true from flat Et spectrum: use tuned Herwig/Pythia	Use γ–jet for Et<100 GeV? Better syst. error?		
L6: Underlying Event	Evaluate benefit from Rick Field's studies: use Pythia to model UE instead of MinBias data?	Does UE depend on eta?		
L7:Out Of Cone	Measure Et in annuli around jets in data and MC (dijet, W/Z.γ-jet): Develop correction/tune MC/derive syst. err			

Long Term Studies

L1: Plug vs Central

Derive absolute correction for Plug and the remove this level:
Can all be done at Level 5 then

Resolution

Jet Energy Correction versus EMF, SumPT, Ntrack, etc.

Tower Energy correction based on particle type (Kuhlmann et al.)

Tower Energy correction in WHA crack? Also good for Met.
Study using E/p in single particles, test on gamma-jet resolution

Syst. err

Z-> bbbar

W->jj mass in top

Test ARIADNE PS model in Pythia

Other

Understand Everything for MidPoint and Kt algorithms

Use actual given Et spectrum of each process
Rather than flat Et spectrum: may improve resolution

Other Systematics: PDF's

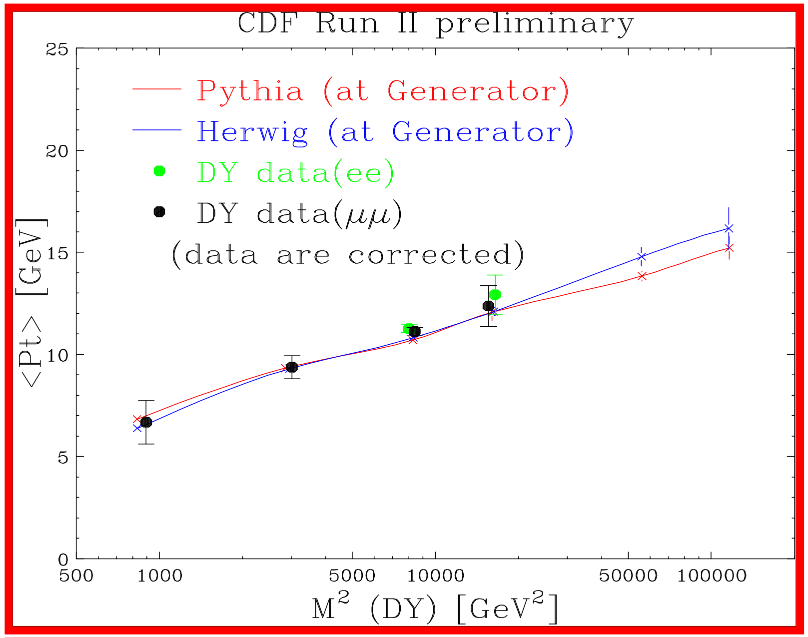
- New recommended procedure (as discussed by Tony yesterday)
  - CTEQ 6M error PDF's
  - MRST comparisons for alpha-s variation
  - Check MRST vs. CTEQ
- Using Stephen Miller's reweighting technique the lepton+jets template mass reduced their overall estimated PDF systematic from

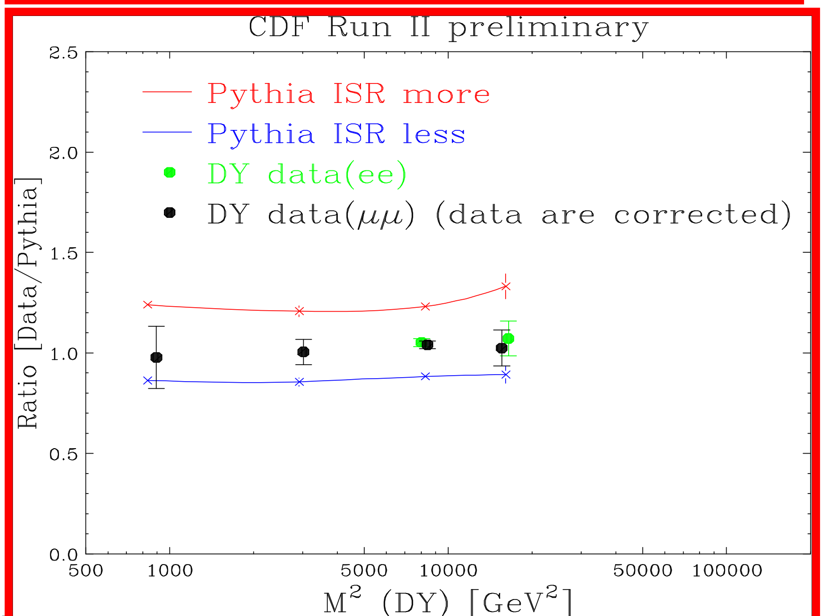
  1.5 GeV (dominated by MC statistics) $\rightarrow$ 0.2 GeV
- DLM has estimated PDF systematics based on parton level events, and studies connecting parton level events to fully simulated and reconstructed events for the DLM mass analysis

  1.0 ± 1.0 GeV $\rightarrow 1.4 \pm 0.4$ GeV for CTEQ 6M eigenvector errors

Other Systematics: ISR/FSR

- Studies of Drell-Yan data suggest a reasonable range of uncertainty for ISR
- Had been comparing default MC to MC with ISR off! (obvious overestimate)
- New FSR samples chosen by analogy with ISR samples
- Comments from Torbjorn Sjorstrand (Pythia author) are consistent, but suggest further samples for comparison (perhaps at HEPG level)
- ISR/FSR systematic for l+jets template has gone from 2.6 GeV → 1.0 GeV

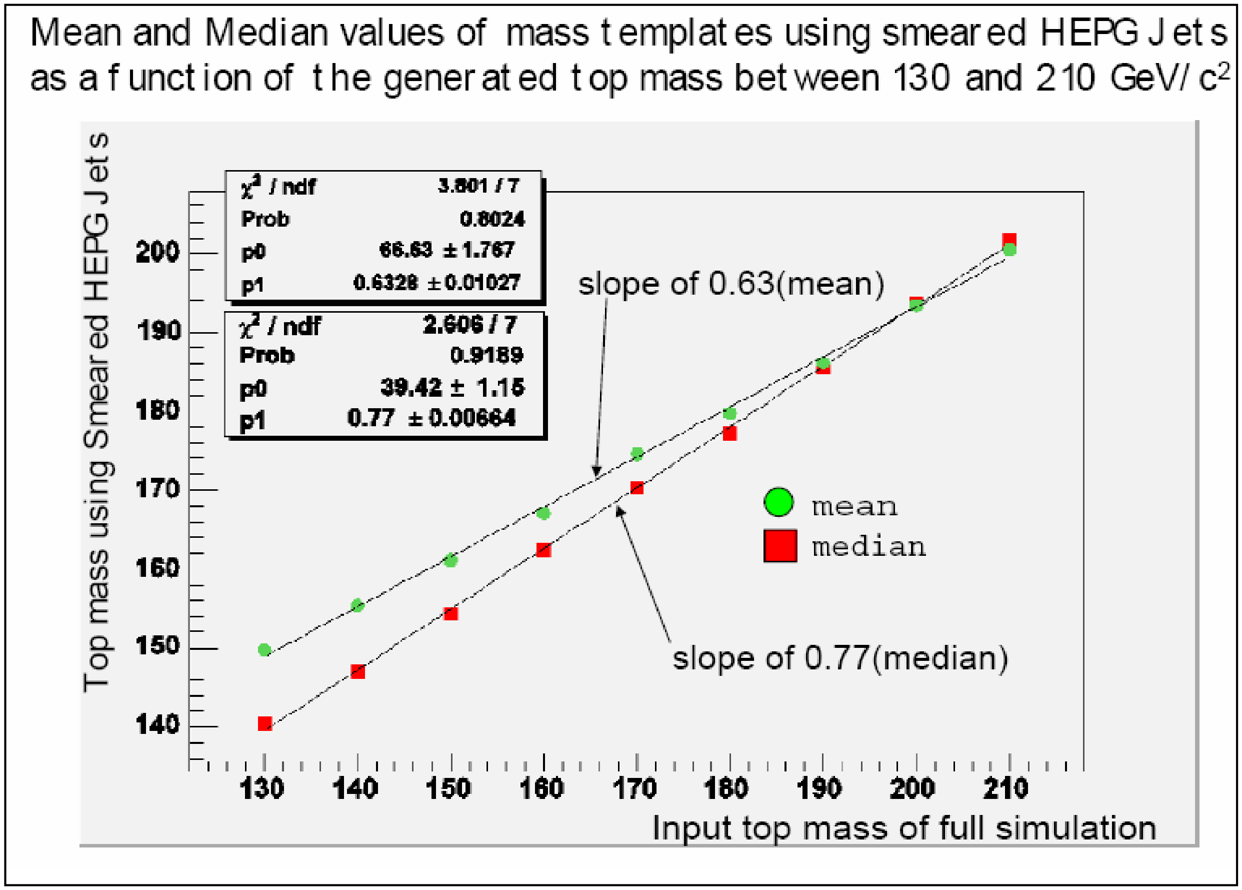




Un-Ki Yang and Young-Kee Kim (Chicago)

Comparing Smeared HEPG Jets to Full Simulation

- Using parton-level events or HEPG Jets to estimate systematics can make it possible to generate large samples more quickly
- Slopes compare favorably to results from full simulation where the mean has slope 0.65, and the median has slope 0.772
- Studies on this page using lepton+jets template mass machinery



Eun-Ju Jeon (Seoul), Young-Kee Kim and Un-Ki Yang (Chicago)

Details of Selected Analyses

- Lepton + Jets Template Analysis (1 or 2 SECVTX tags, Blessed!)
- Dynamical Likelihood Method (Lepton + Jets) (Blessed!)
- Top Mass With Multivariate Templates (Lepton + Jets) (Pre-Blessed)

Lepton+Jets Template Analysis Overview

Datasets

Data

Wbb MC

tt MC

Mass fitter

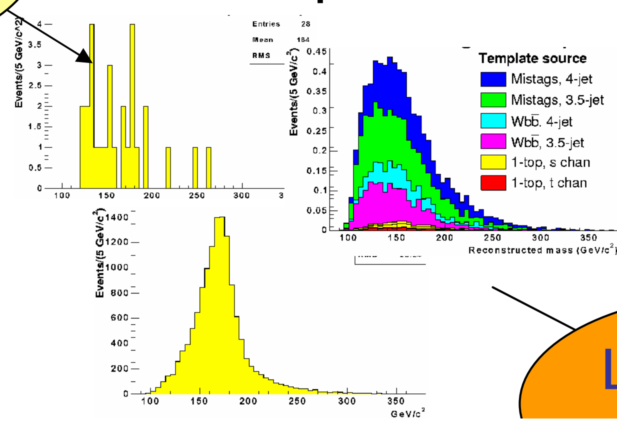
χ^2 mass fitter:

Finds top mass that fits event best

One number per event

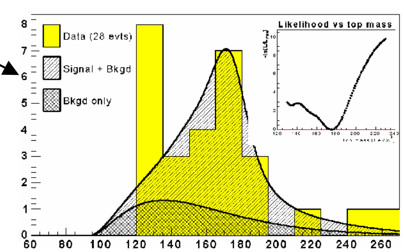
Additional selection cut on resulting χ^2

Templates



Likelihood fit

Result



Likelihood fit:

Best signal + bkgd templates to fit data

Compare to paramiz'n, not directly

Constraint on background normalization

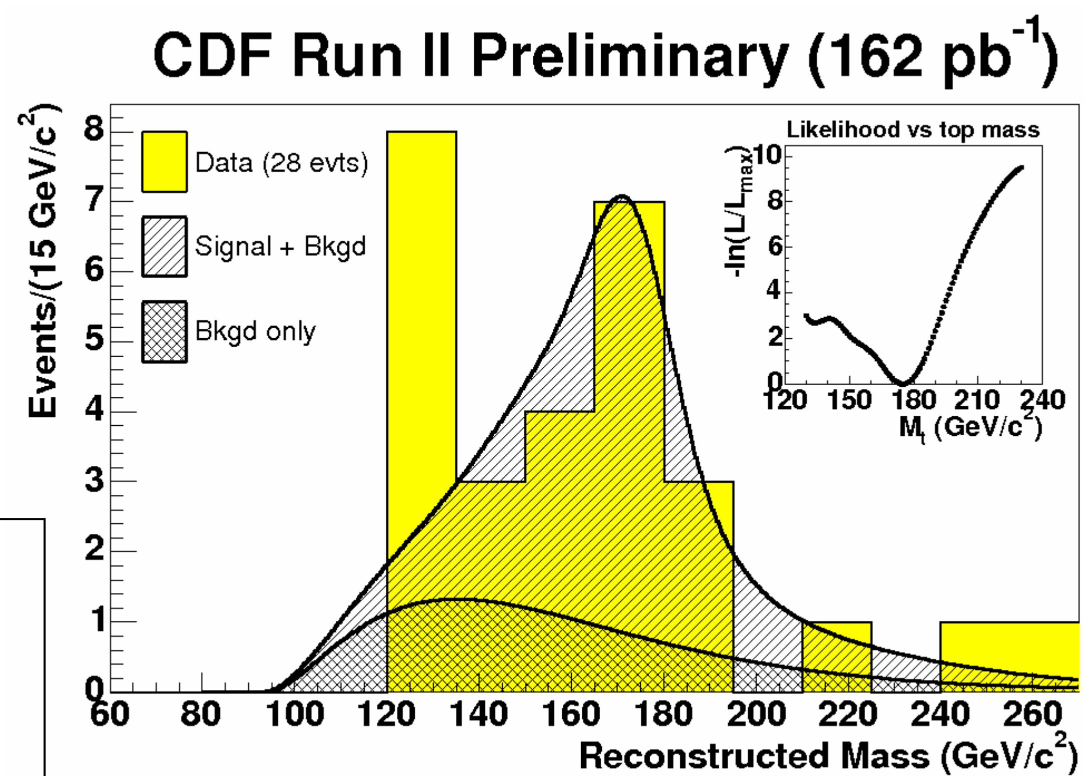
Recent Improvements in l+jets Template Analysis

•Top-specific corrections now defined from L5 and using MPV instead of median

•More MC statistics and mass steps

•Better parameterization of signal templates

•Understanding Systematics



Erik Brubaker, Adam Gibson (LBNL)
Jahred Adelman, Young-Kee Kim,
Mel Shochet, Un-Ki Yang (Chicago)
Jean-Francois Arguin, Pekka Sinervo
(Toronto)

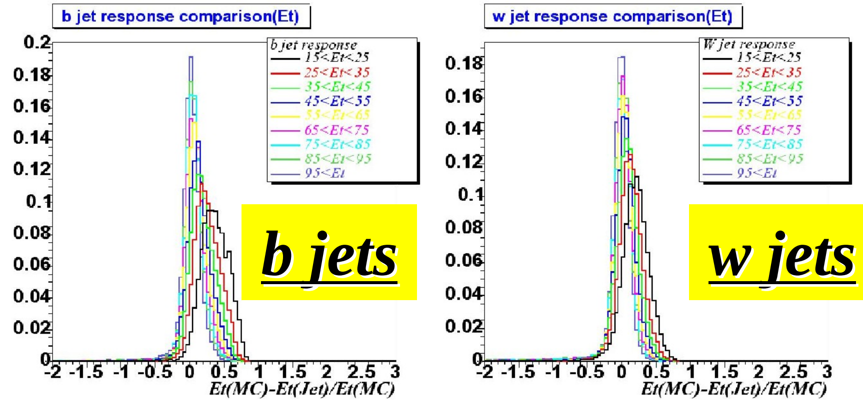
Mtop = 174.9 +7.1 -7.7 (stat.) ± 6.5(syst.) GeV/c2

Dynamical Likelihood Method

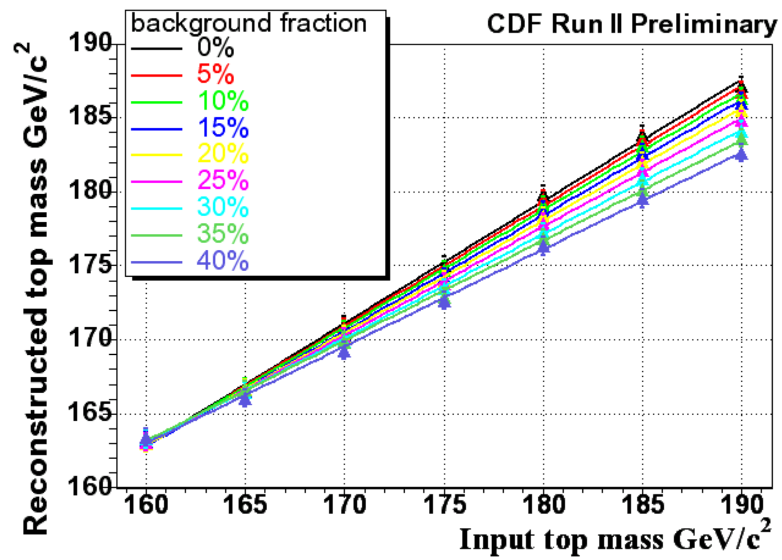
- Use the leading order ttbar matrix element, convoluted with transfer functions, to make an event by event likelihood distribution as a function of top mass
  - Combines all combinations and events according to their power to distinguish the top mass

$$L^i(M_{top}) = \int \sum_{comb} \sum_{nsol} \frac{2\pi^4}{Flux} |M|^2 F(z_1, z_2) f(p_t) w(\mathbf{x}, \mathbf{y}_t; \alpha) d\mathbf{x}$$

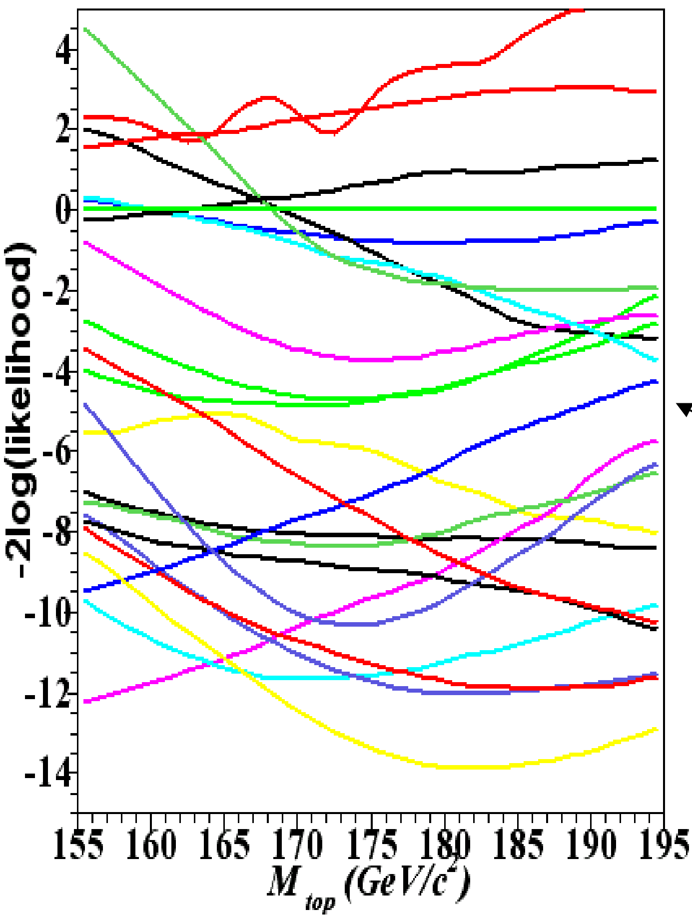
- Transfer functions that, given a jet, return the probability that it came from partons of various energies
  - Models the shape of the response curve, not just the mean
- Mapping function to account for background and for the dependence of the transfer functions on top mass
- Similar to the recent l+jets analysis from D0, but a CDF original measurement
  - Proposed in 1988 by K. Kondo (J. Phys. Soc. 56, 4126)
- We now have a top mass measurement that's systematics dominated!



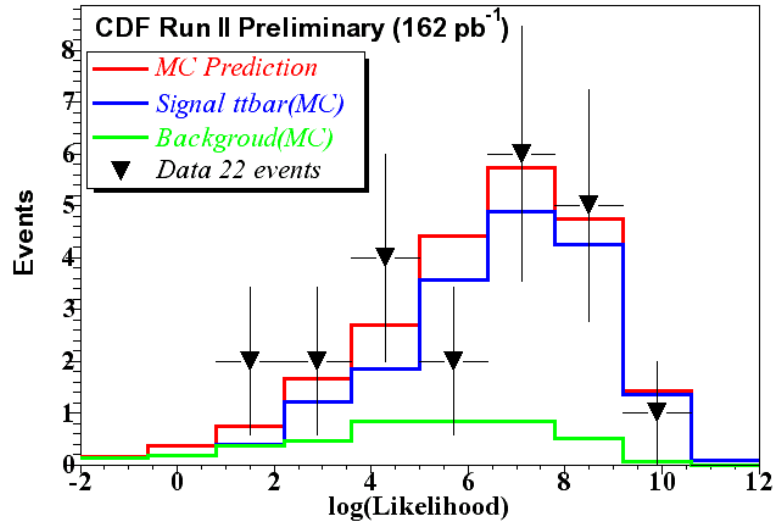
Transfer functions for various E_T bins

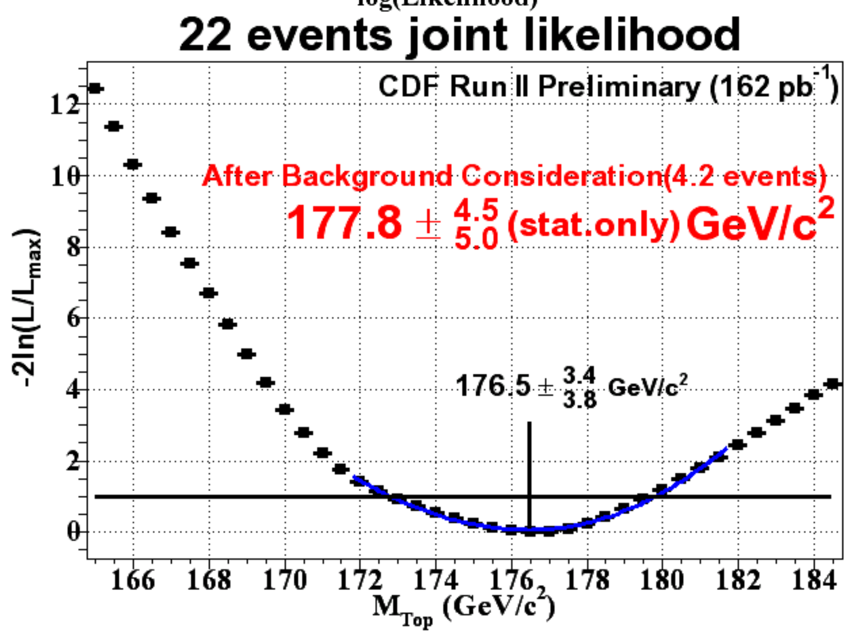


Dynamical Likelihood Method Results



Likelihood curves for the 22 events in data.



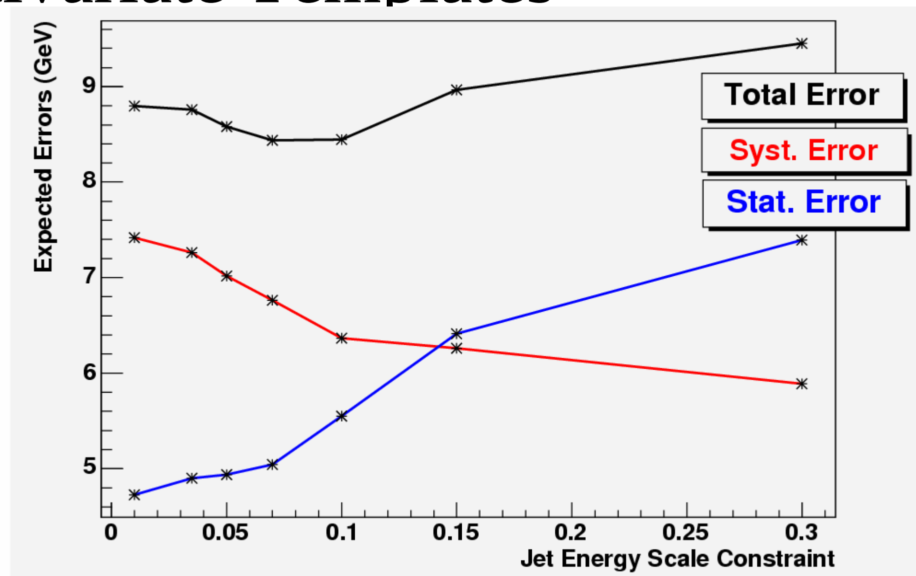


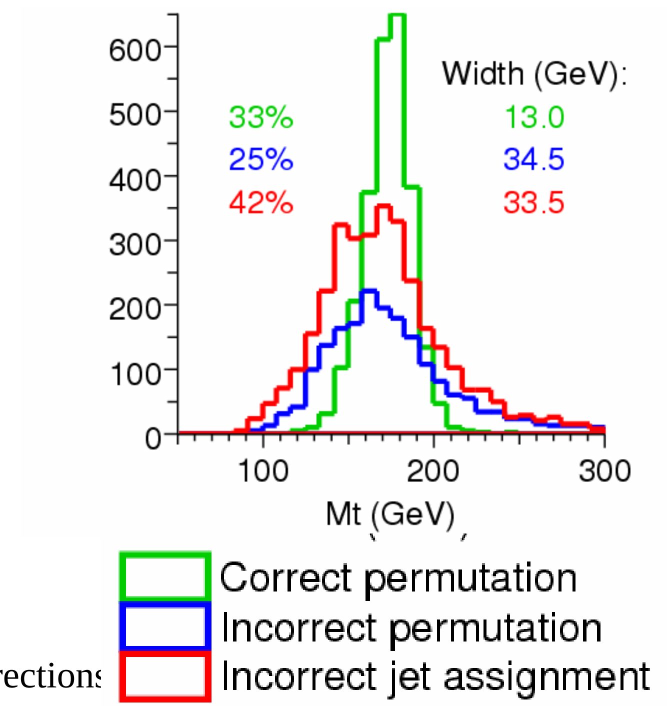
Kohei Yorita, Kunitaka Kondo, Koji Ebina (Waseda)

Mtop = 177.8 +4.5 -5.0 (stat.) ± 6.2(syst.) GeV/c2

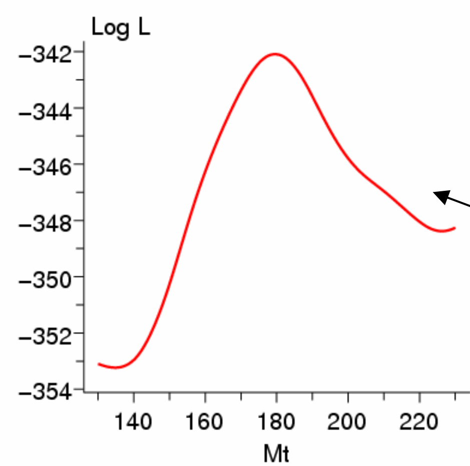
Top Mass With Multivariate Templates

- Reduce jet systematics (while increasing stat. error) by calibrating jet energy scale event by event with W mass
- Improve signal/background separation by using other kinematic variables (sum of four leading jet P_T's) in addition to reconstructed top mass
- Estimate the probability to pick correct combination event-by-event and reweight events.
- Use nonparametric techniques (kernel density estimation) to make multivariate templates
- Fit background fraction in data

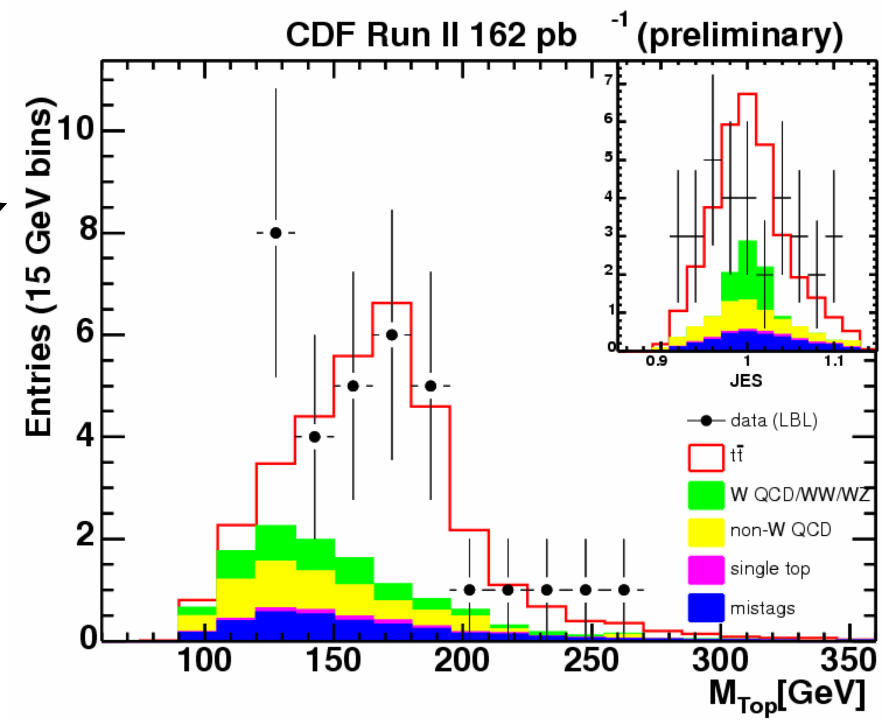




Multivariate Templates – Preliminary (Pre-Blessed) Results



≥3.5 jets



Fitted background fraction 34 ± 14%

Mtop = 179.6 +6.4 -6.3 (stat.) ± 6.8(syst.) GeV/c2

I. Volobouev (Chicago / LBNL), P. Fernandez, J. Freeman, A. Galtieri, J. Lys (LBNL)

Dilepton

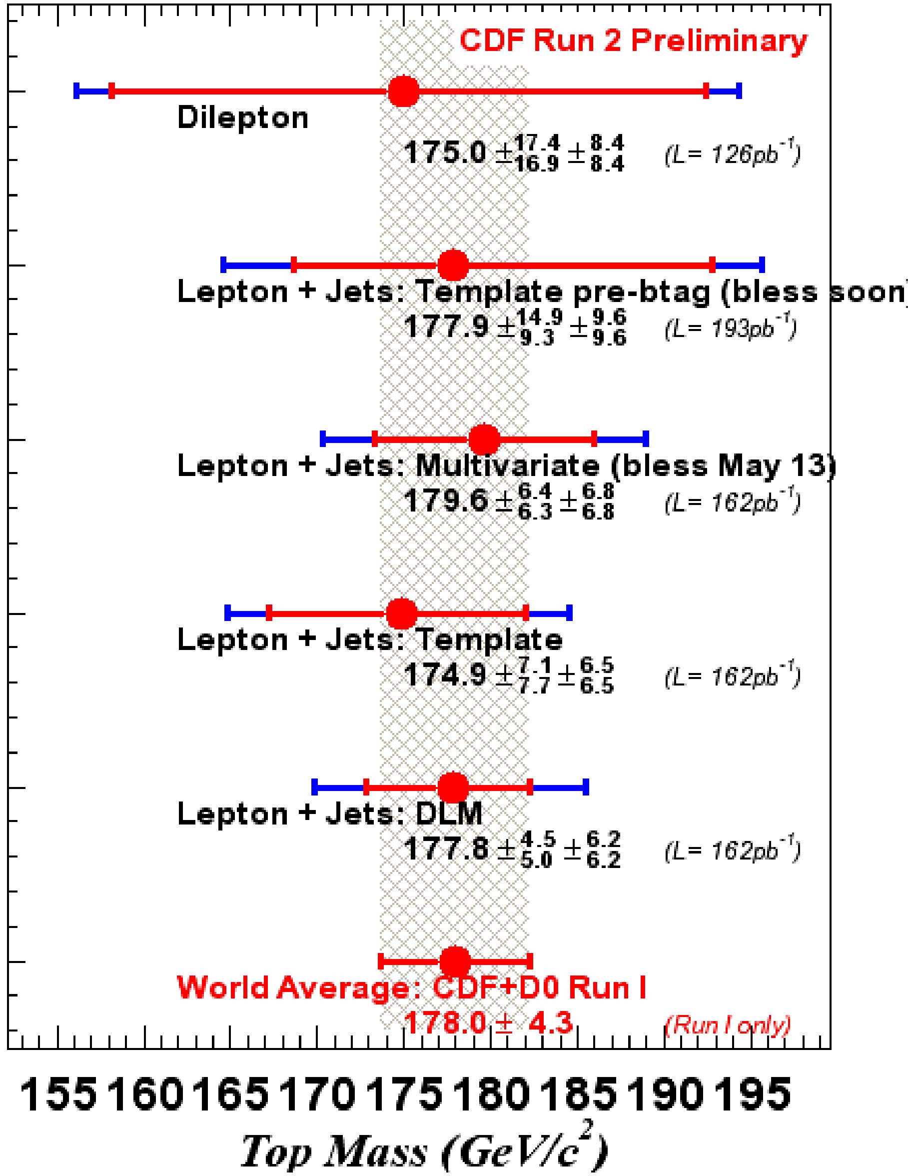
- Kinematic analysis was first on the scene
  - J. Antos, A. Beretvas, Y.C. Chen, R. Lysak, M. Siket, G.P. Yeh (CDF 6465)
- Many new analyses, including matrix element methods are being developed
  - Template
  - ν-weighting
  - MADCOW
  - DLM
- All methods studying event selection seriously
  - Tight lepton + track (gain tau acceptance, but different kinematics)
  - Tight lepton + loose lepton (less acceptance, but better understood)
- Next few months will be very active!

All-Hadronic

- Cross section blessed recently, same group planning on working on the mass next
  - P.Azzi, A.Castro, T.Dorigo, G.Cortiana, A.Gresele, J.Konigsberg, G.Lungu, A.Sukhanov
  - CDF 6914

Publication Plans

- Godparents assigned for lepton + jets template method
  - Ashutosh Kotwal, Larry Nodulman (chair), Weiming Yao
- and DLM
  - Florencia Canelli, Joel Heinrich, Mel Shochet (chair)
- Combination efforts planned and underway
  - 0+1+2 tags in lepton + jets template
- Finalizing analysis details for publication
- Prepare PRD's now with 4.11.2, godparent review
- Update them (plug in the numbers) when full 5.3.1 MC samples and tools are available
  - Publish PRD and PRL
- Many new analyses under development!



From
Evelyn Thomson

CDF Run I (l+jets) : Mtop = 176.1 ± 5.1 (stat.) ± 5.3(syst.) GeV/c2

Conclusions

- Much energy invested into advanced analysis techniques
  - We now have mass measurements that are systematics dominated
- A lot of energy has been put into understanding a number of the systematics
  - MC Simulation / Relative Jet Corrections (big improvement)
  - Central Energy Scale (Run I – Run II difference) (continued improvement)
  - PDF's (big improvement overcoming limited MC statistics)
  - ISR/FSR
- Other Jet Systematics Need Work
  - See long list on page 19-20! Can reduce systematics with workers and effort
- The first top mass publication(s) will come together this summer.
- Measurements will improve rapidly as we
  - Take more data
  - Continue to develop sophisticated analytical techniques
  - Better understand our detector, simulation, and Monte Carlo

DLM (l+jets) : Mtop = 177.8 +4.5 -5.0 (stat.) ± 6.2(syst.) GeV/c2
Template (l+jets) : Mtop = 174.9 +7.1 -7.7 (stat.) ± 6.5(syst.) GeV/c2