CDF TOP ISSUES

This talk is about present efforts in CDF to understand a recent version of the Monte Carlo generator (PYTHIA V6.4), which includes the latest and fanciest parton shower model and color reconnection. All CDF top measurements have been done using PYTHIA V6.2.

How much are the measurements affected by the new version? This version is used by ATLAS top analyses and it is important to see if it fits the Tevatron data.

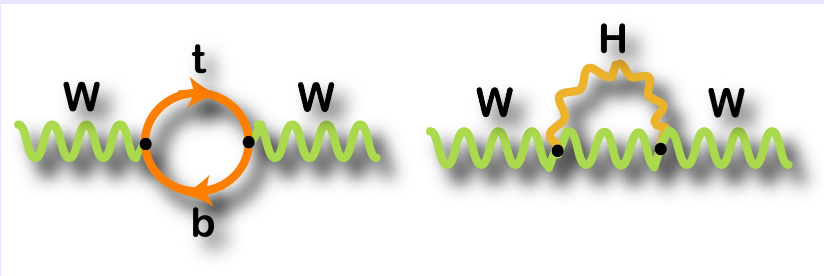
Outtline:

- Motivation
- How different is the new shower model?
- How different are the jets?
- What is the effect on the top mass measurement?
- Status of the validation

Motivation: Top Mass

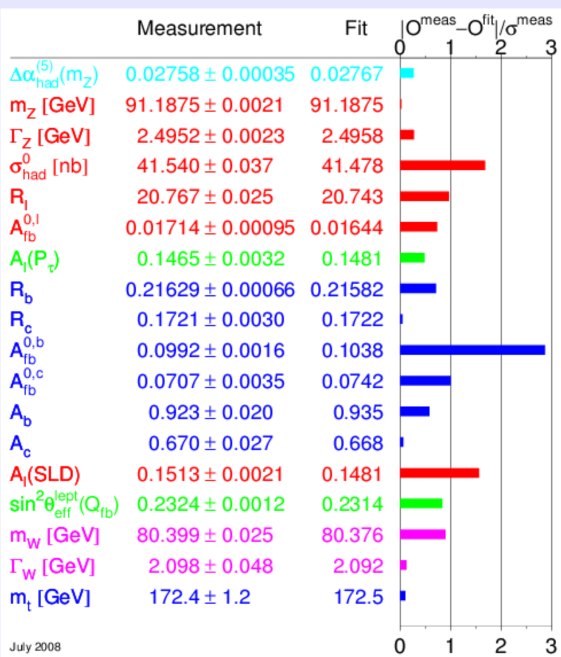
CDF is studying top quark production and decay properties. The LBL group is working on a precision measurement of the top quark mass .

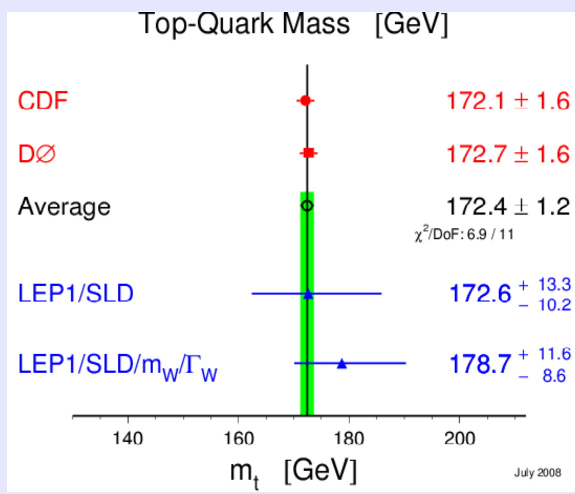
- Quantum loop corrections to many EWK observables are sensitive to the top mass
- Top Mass is highly correlated to M_W and M_H in Standard Model EWK theory

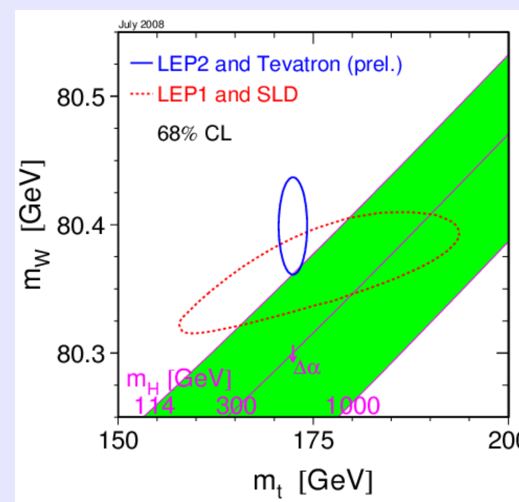


$\sim M_t^2$ $\sim \log(M_H)$

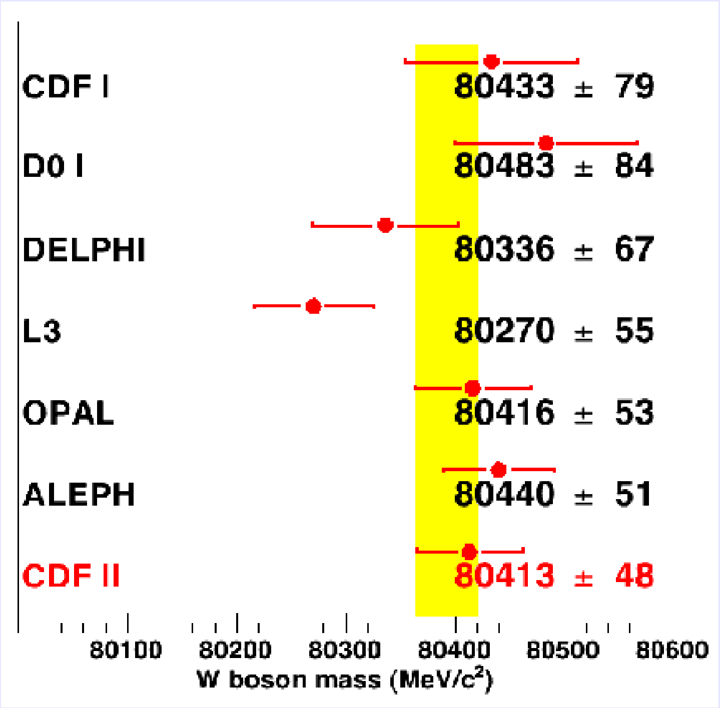
EWK fits using 15 SM precision measurements give very large error on M_T and M_H. Direct M_{top} measurement reduces uncertainty.



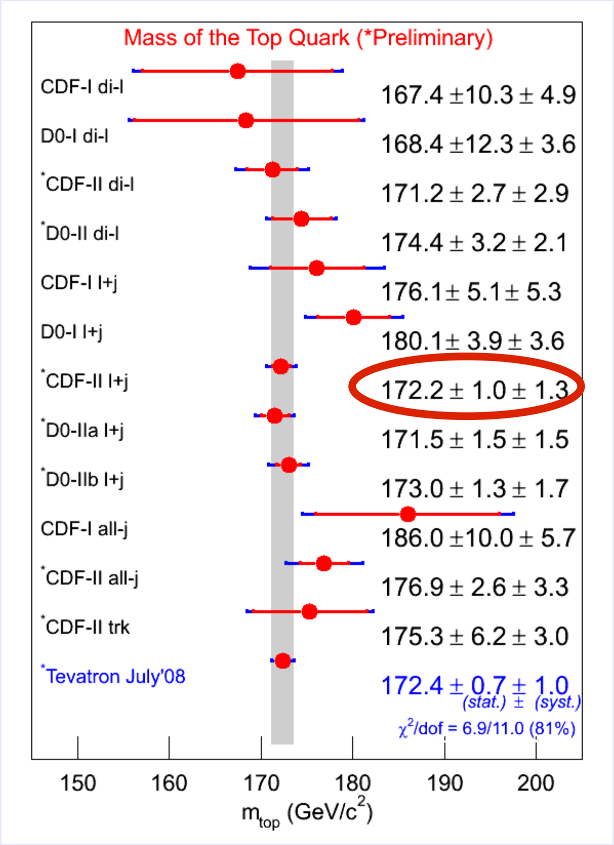




M_W and M_{top} measurements



M_W= 80399 ± 25 MeV

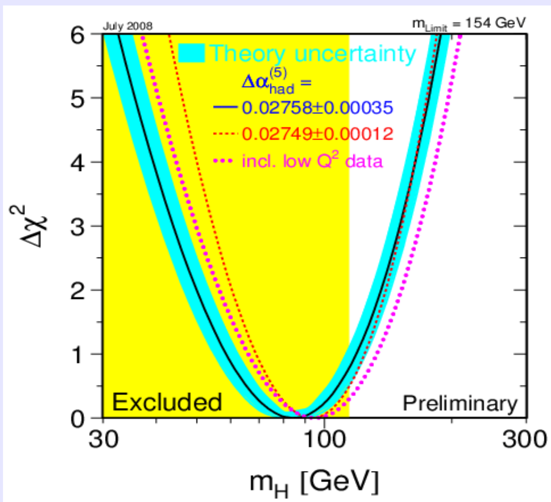


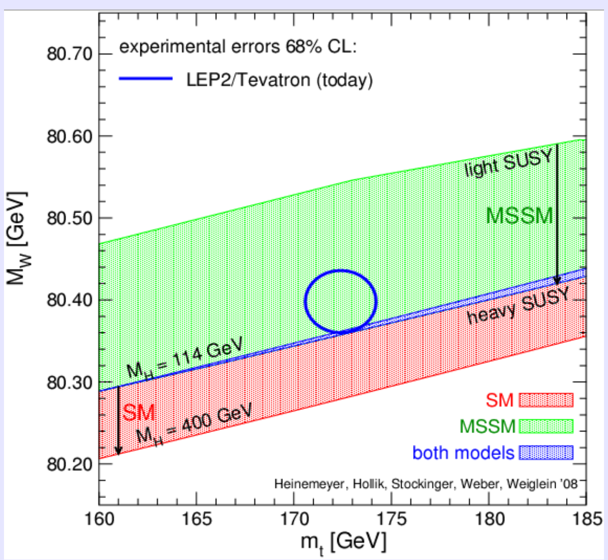
M_{top} = 172.2± 0.9 (stat.)±1.3 (syst) GeV/c^2 = 172.2 ± 1.6 GeV/c^2

LBL's is the best Tevatron mass measurement (uses 2.7 fb^{-1}).
It contributes 46.1% towards the mass average.
(Paul Lujan, Jeremy Lys, Igor Volobouev, Jason Nielsen + LG)

EWK Fit: Winter 2008

Summer Conferences EWK Fit, gives $M_H < 185$ GeV/c^2





Summer 2008 best Fit

$M_H = 84^{+34}_{-26}$ GeV/c^2

and

$M_H < 154$ GeV/c^2 at 95% CL

Direct limit:

$M_H > 114$ GeV at 95% CL

adding the direct limit

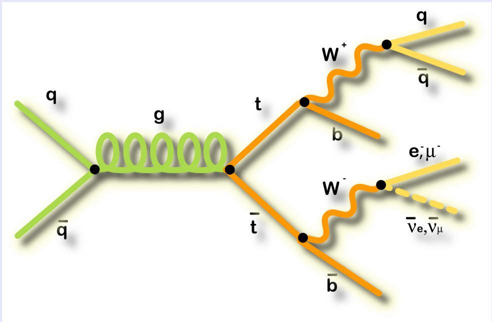
$M_H < 185$ GeV/c^2 at 95% CL

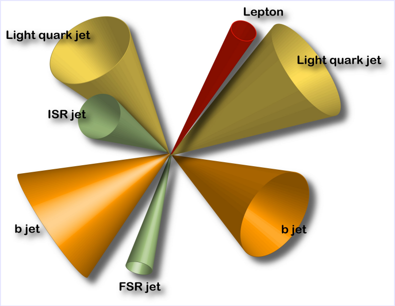
Need to reduce the uncertainties.

For δM_t = +1.2(-1.2) GeV δM_H =+9 (-8)GeV

For δM_W= +25(-25) MeV δM_H= -13(+17)GeV

Top Mass measurement





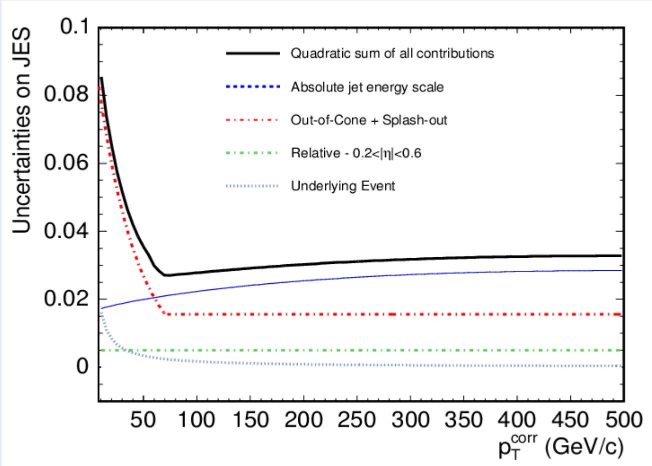
$$\tilde{t}\ t \rightarrow W^{+}\ b\ \ W^{-}\ \tilde{b}$$
$$\rightarrow j_1\ j_2\ b\ \ l\ \nu\ \ b$$

What ingredients in the measurement depend on the MC used?
Can we include the effects from the new MC in the systematics?

- Jet energy corrections and systematics
- Parton shower uncertainties (pQCD)
- ISR and FSR uncertainties (pQCD)
- Hadronization uncertainties (non-perturbative)

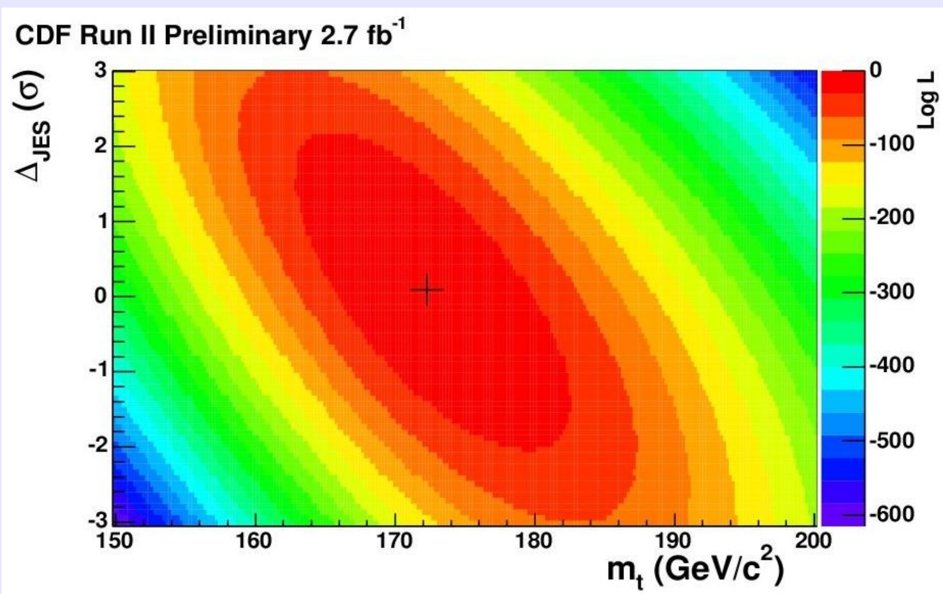
Jet energy scale uncertainties are the major contributors to the top mass systematics. To study this we use for jets the variable

Δ_{JES} = number of s.d. away from the central value

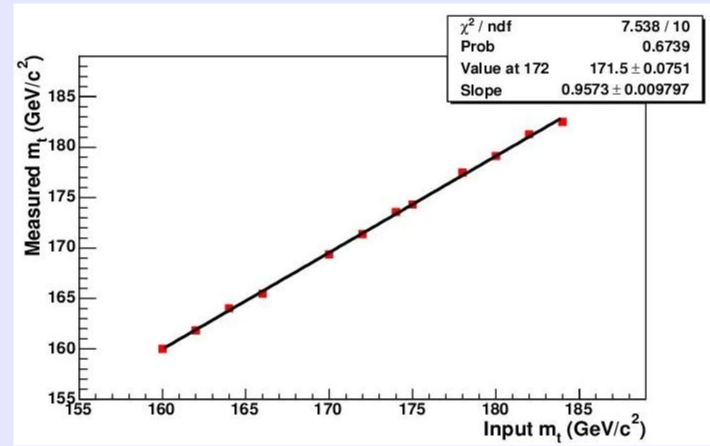


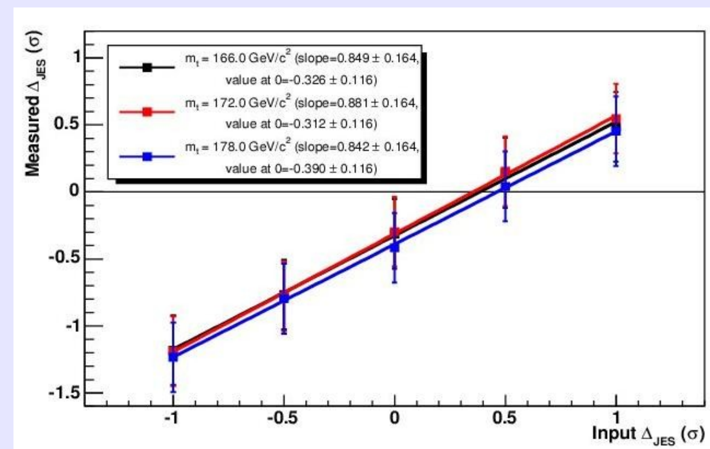
M_{top} Measurement (schematic)

To evaluate Δ_{JES} we use a 2D likelihood with M_t and Δ_{JES}.
We "constrain" the W mass to the measured value, using the 422 selected events (85± 34 backg), thus obtaining the Δ_{JES} from data.



Mass and Δ_{JES} Calibrations





M_{top} = 172.2 ± 1.0 (stat.) ± 0.9 (JES) ± 1.0 (sys) GeV/c^2 = 172.2 ± 1.7 GeV/c^2

Also find Δ_{JES} = (0.09 ± 0.29)σ (statistics limited)

Top Mass systematics

Tevatron has delivered 5.8 fb^{-1}
CDF has recorded on tape 4.8 fb^{-1}
Statistical error will get smaller, both (stat) and (JES) uncertainties.

Measurement soon will be dominated by systematic uncertainties.

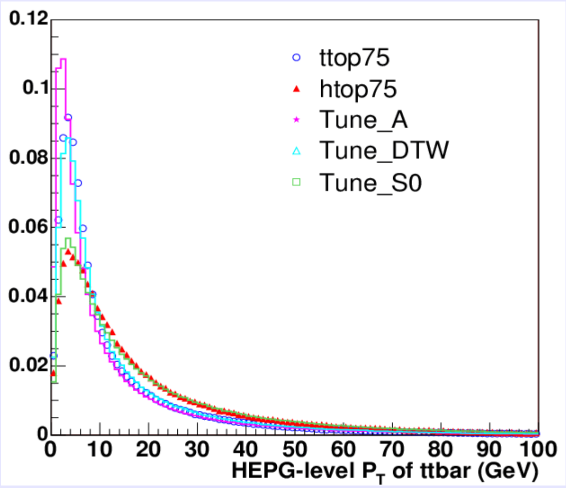
MC dependent systematics are in red

Systematic source	Δm_t (GeV/c^2)
Calibration	0.14
MC generator	0.51
ISR and FSR	0.29
Residual JES	0.52
b-JES	0.38
Lepton P_T	0.18
Permutation weights	0.01
Pileup	0.09
PDFs	0.17
Background: fraction	0.36
Backg: composition	0.18
Backg: average shape	0.03
Backg: Q^2	0.08
Backgrounf:MC statistics	0.05
Total (MC Dependent)	1.01 (0.88)

Meetings with MC experts to understand overlapping sys (when I was at CERN in April, I organized a couple of meetings there).
Meeting with D0, so that we do similar things to help with the mass combination.

P. Skands (PYTHIA), D. Wicke have been evaluating the Color Reconnection contribution (not included in our analysis) and written papers saying that it is an additional 1 GeV to be added to the 0.88 GeV (systematics coming from MC).

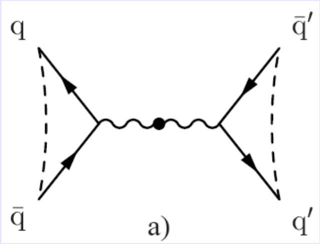
Monte Carlo Issues: P_T(ttbar)



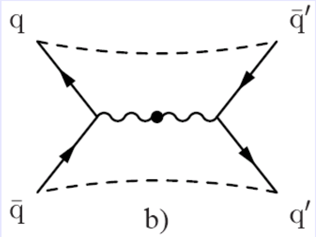
Discussions with the PYTHIA authors were motivated by the disagreement of the p_T(ttbar) distribution between PYTHIA and HERWIG

Solution: PYTHIA V6.4, tune S0, gives a correct p_T(ttbar) distribution. However, V6.4 includes color reconnection (CR) effects, not present in V6.2.

CR effects at LEP, W mass



CR effects on the MW measurement at LEP contribute to systematics

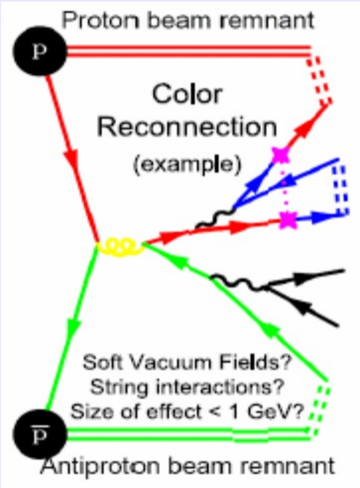


CR(sys) = 8 MeV

out of 22 MeV (total sys)

(LEPEWWG hep-ex/061203)

CR at the Tevatron



Systematics on top mass can be as large as 1 GeV

PYTHIA V6.4 versus V6.2

Our top mass measurements have been done using V6.2 (2003)
Color reconnection effects are included in PYTHIA V6.4.

Changes in V6.4

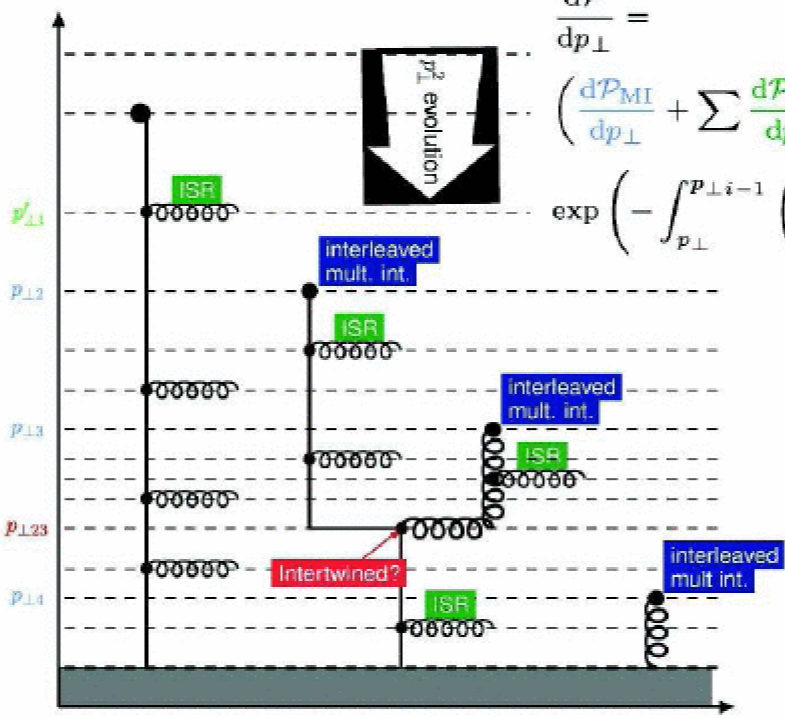
- Parton shower uses p_T ordering rather then Q^2 ordering
- ISR and FSR also uses a p_T ordering algorithm
- Multiparton (MPI) interactions are now part of the parton shower
- Model interleaves MPI process with ISR evolution off the hard process
- New model for beam renmants, including baryon junctions
- Color reconnection added with an “annealing model” by M. Sandhoff and P. Skands

P. Skands and D. Wicke hep-ph/0703081v1 (March 2007)
D. Wicke and P. Skands hep-ph/0807.3248 v1 (July 2008)
D. Wicke and P. Skands TOP08

New PYTHIA model (P. Skands etc.)

Pythias Underlying Event Models

- Old: UE generated after the ISR is done, i.e. uncorrelated.
- New: Parton showers interleaved with UE. (Requires p_T ordered shower).



$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}p_\perp} = \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{JI}}}{\mathrm{d}p_\perp}\right) \times \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p'_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p'_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{JI}}}{\mathrm{d}p'_\perp}\right) \mathrm{d}p'_\perp\right)$$

⇨ successive "finegraining" of all perturbative activity

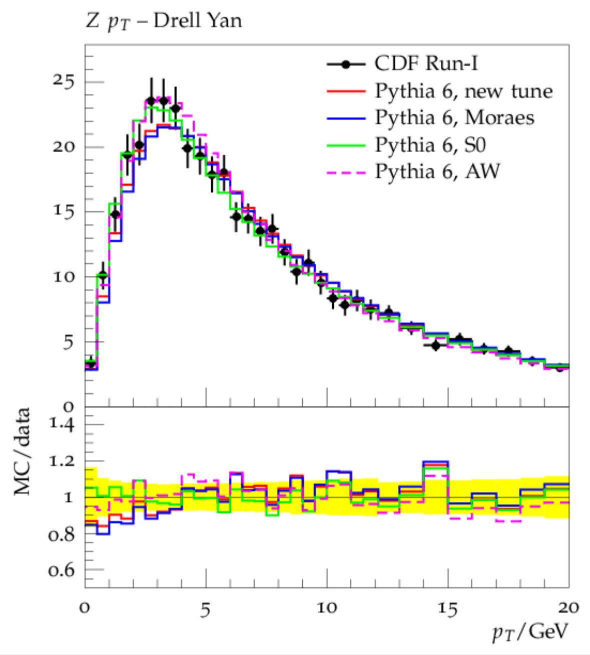
+ correlated multiparton pdfs (with flavour/momentum cons)
+ Impact parameter dependence
+ String fragmentation developed for baryonic colour topologies ⇨ improved description of beam remn.

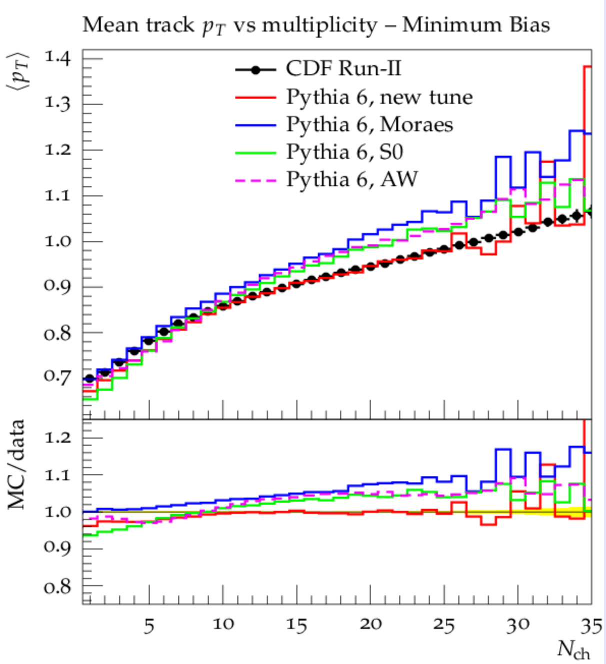
Daniel Wicke, Non-perturbative QCD and Top Mass, Modelling   Top2008, La Biodola, Elba, 18–24 May 2008   5

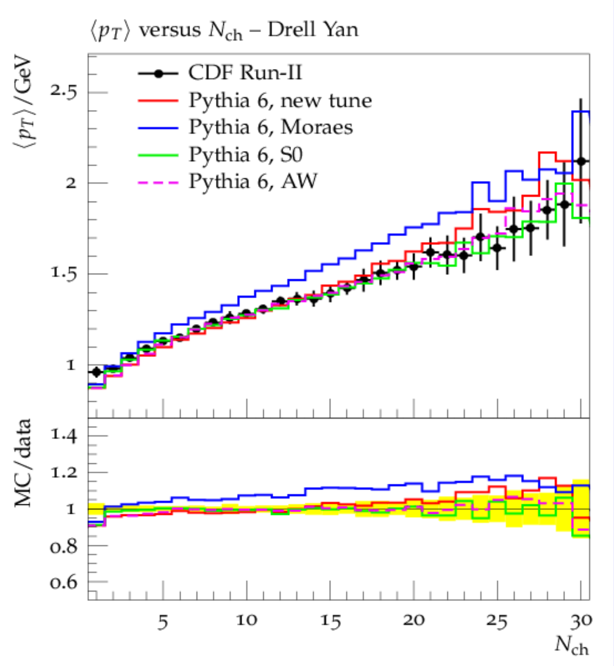
Some Tevatron plots with new tunes

From Hendrix Hoeth talk (Perugia 2008). New tunes (called professor from tools used) use LEP data: event shapes, fragmentation functions and flavor spectra. The flavor and hadronization parameters are tuned for the new P_T ordered shower. New UE and MPI model not tuned. (Done for old Q^2 ordered parton shower).

Some comparison with Tevatron data has been shown at Perugia Tune S0 (used by CDF), Tune Moraies (used by ATLAS).

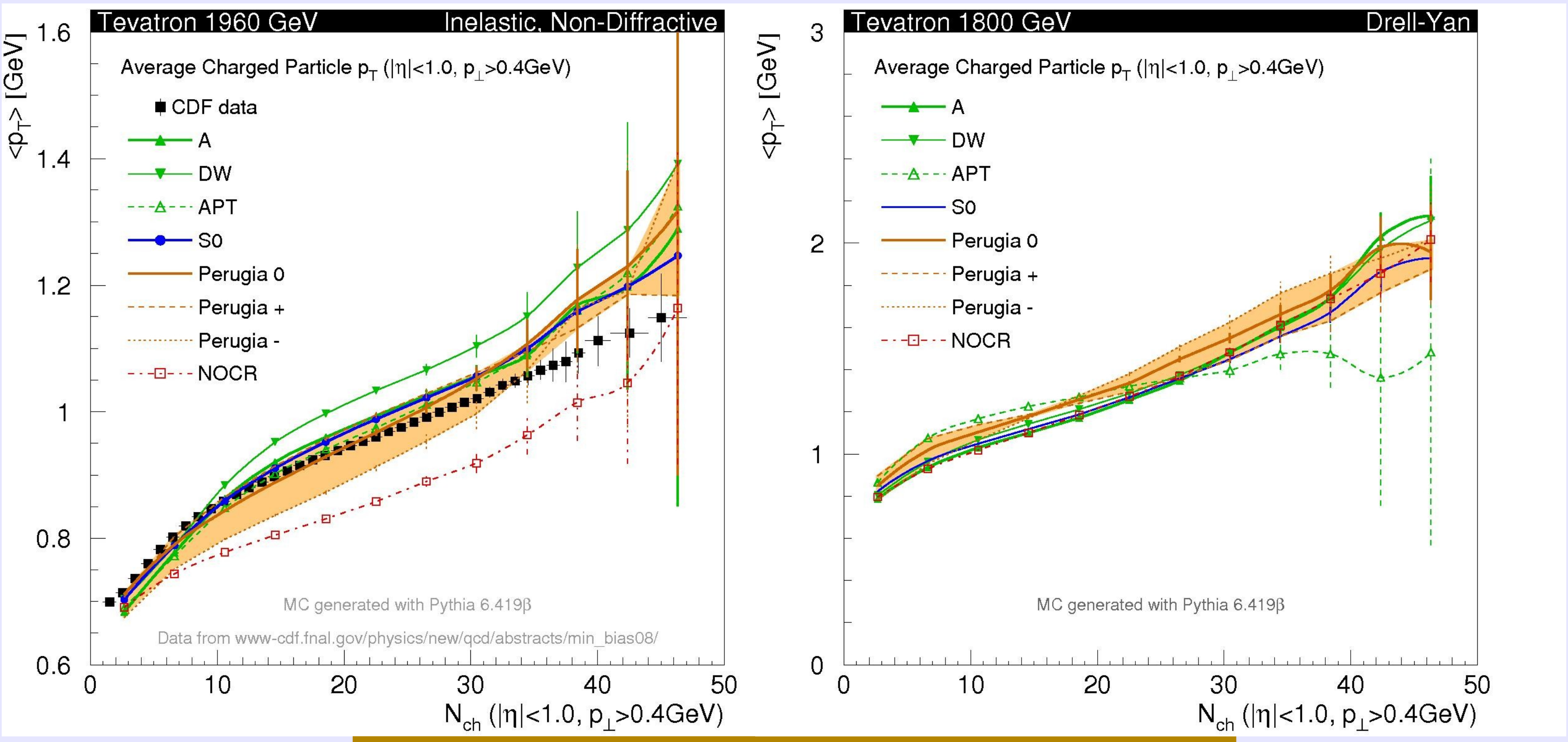






Perugia Tunes

- Perugia tunes of new model, using Tevatron 630/1800/1960 GeV data
  - Average track pT as a function of multiplicity: sensitive probe of CR?
  - Used to fix CR strength parameter in tunes



Data from CDF, N. Moggi et al., 2008

From Peter Skands talk at Perugia

CDF Studies of CR Effects

There is a lot of activity from the PYTHIA team to tune the new generator (V6.4) with existing data. (see Perugia, Oct. 2008). Tuning of UE and MPI parameters not yet redone after the inclusion of LEP data.

P. Skands is helping us generate events with the new tunes. We have already tried previous versions, also run the new tunes done for Perugia. More work on their part is expected.

More comparison with Tevatron data is needed.

We are looking at other samples to see if the new model fits the data: dijet, gam+jet . Compare jet shapes with data.

In the mean time, we are pursuing studies relevant to the top mass measurement.

Procedures

Use the l+jets sample: events with 1 lepton + 4 jets (Et>20 GeV)

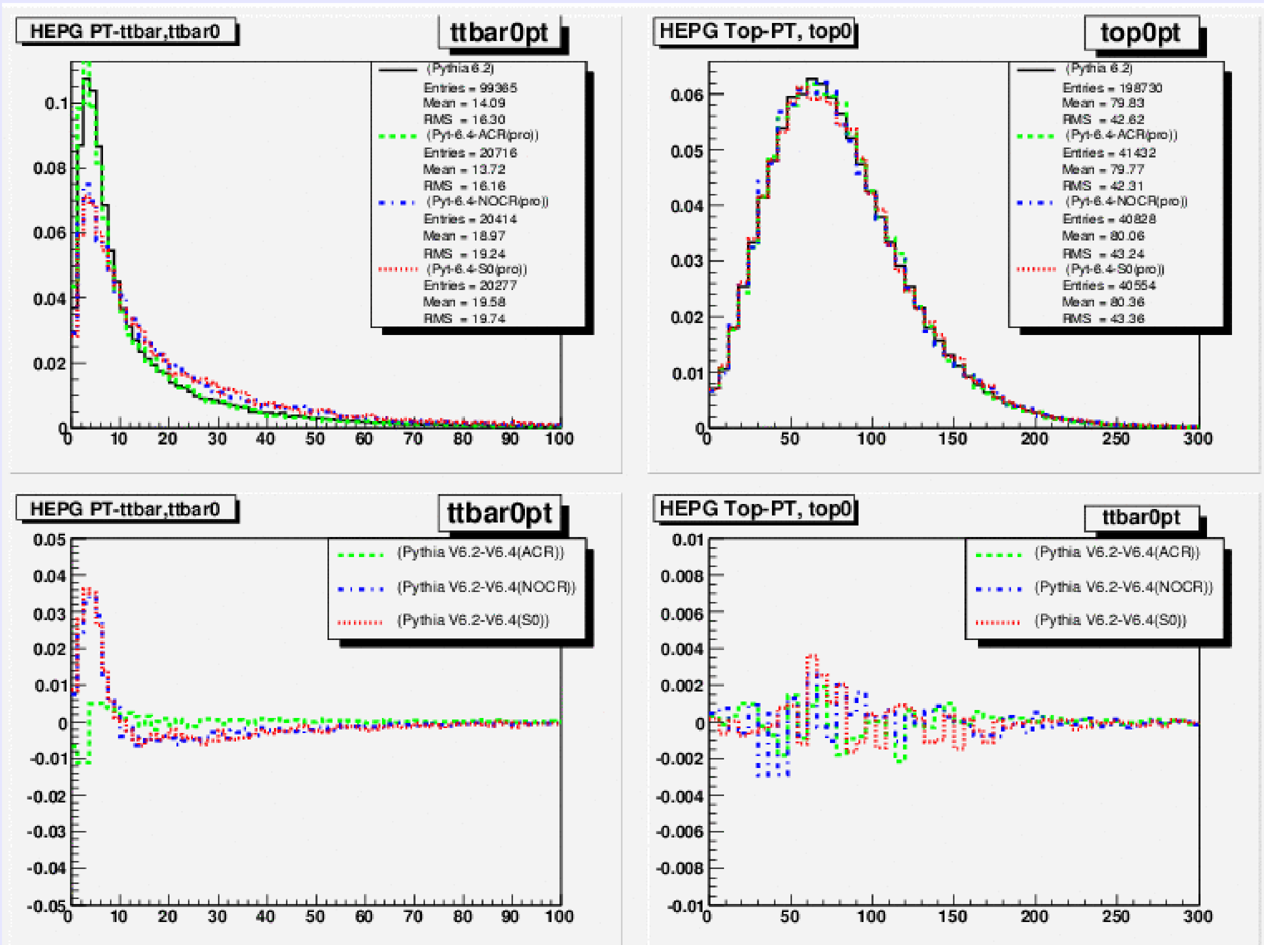
A. Given a MC sample, for each event we match the partons from top decays to the observed jets (Ntight = 4)
We then know which jet is light quark jet and which ones are b-jets.
We correct the jets at L5 (no out of cone correction)
To check the changes between the 2 MC's we do the following:

- Compare Pt5/Pt(parton) and dE in cone of R=0.4
- We calculate M(W) and M(top) using the matched jets

B. We apply to each sample the top mass measurement analysis to obtain a mass and an uncertainty.

- For methods A and B, we compare results obtained for
  V6.2(tune A) old MC (used for CDF measurements)
  V6.4 (tune ACR) only CR added to old shower
  V6.4 (tune NOCR, S0) new shower, wo/w CR

P_T(ttbar) and P_T(top) at parton level



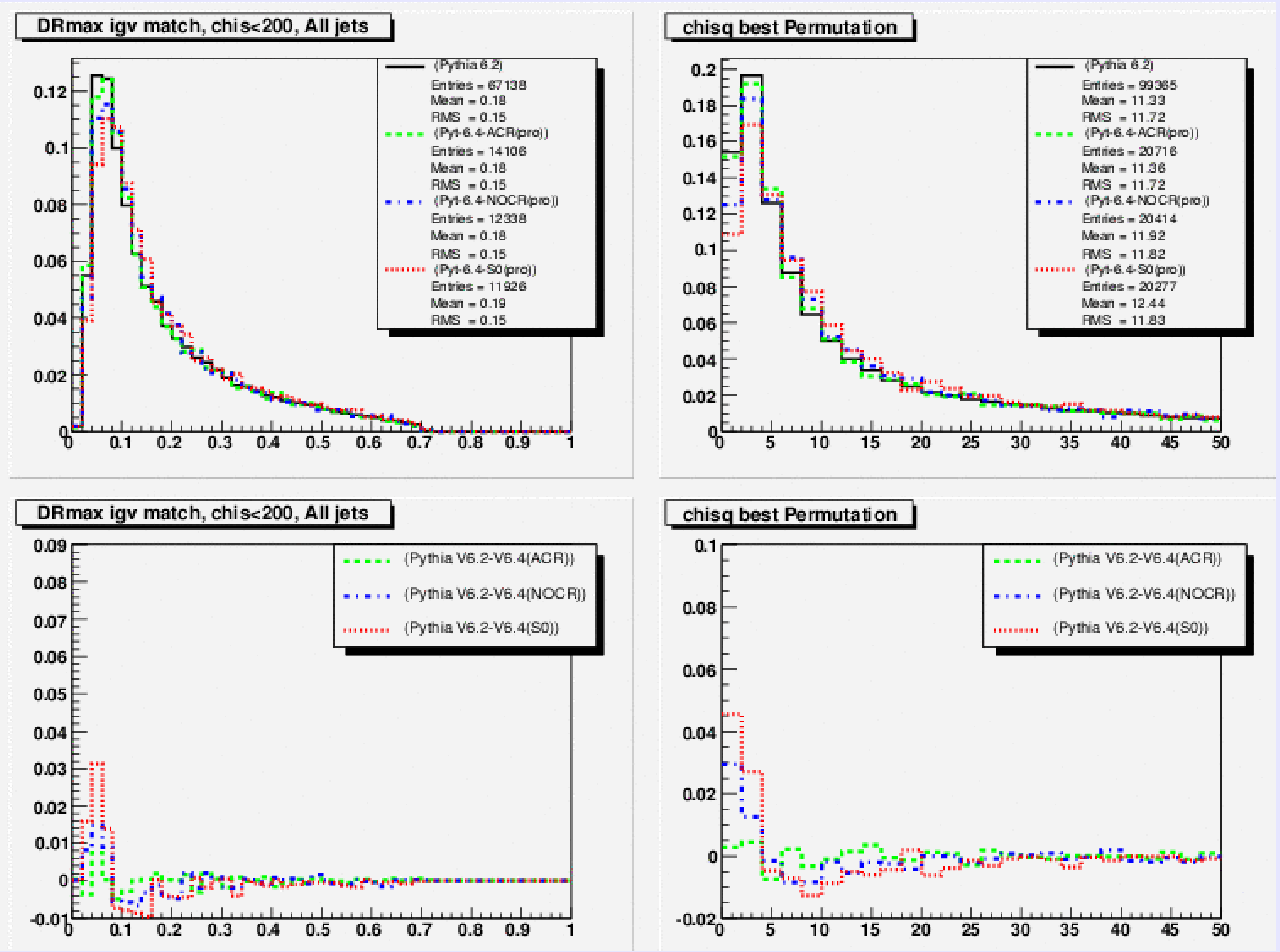
M=175 GeV
V6.2 (tune A)
V6.4 ACR
V6.4 NOCR
V6.4 S0

P_T (ttbar) for the new shower tunes is wider as advertised, ACR needs work

P_T(top) is not affected much by the new modeling

Comparison of matching

The whole event is matched using ΔR for each parton-jet pair. An overall χ^2 is calculated, best $\chi^2 < 200$ are accepted as matched



M=175 GeV

V6.2 (tune A)	68%
V6.4 ACR	68%
V6.4 NOCR	60%
V6.4 S0	59%

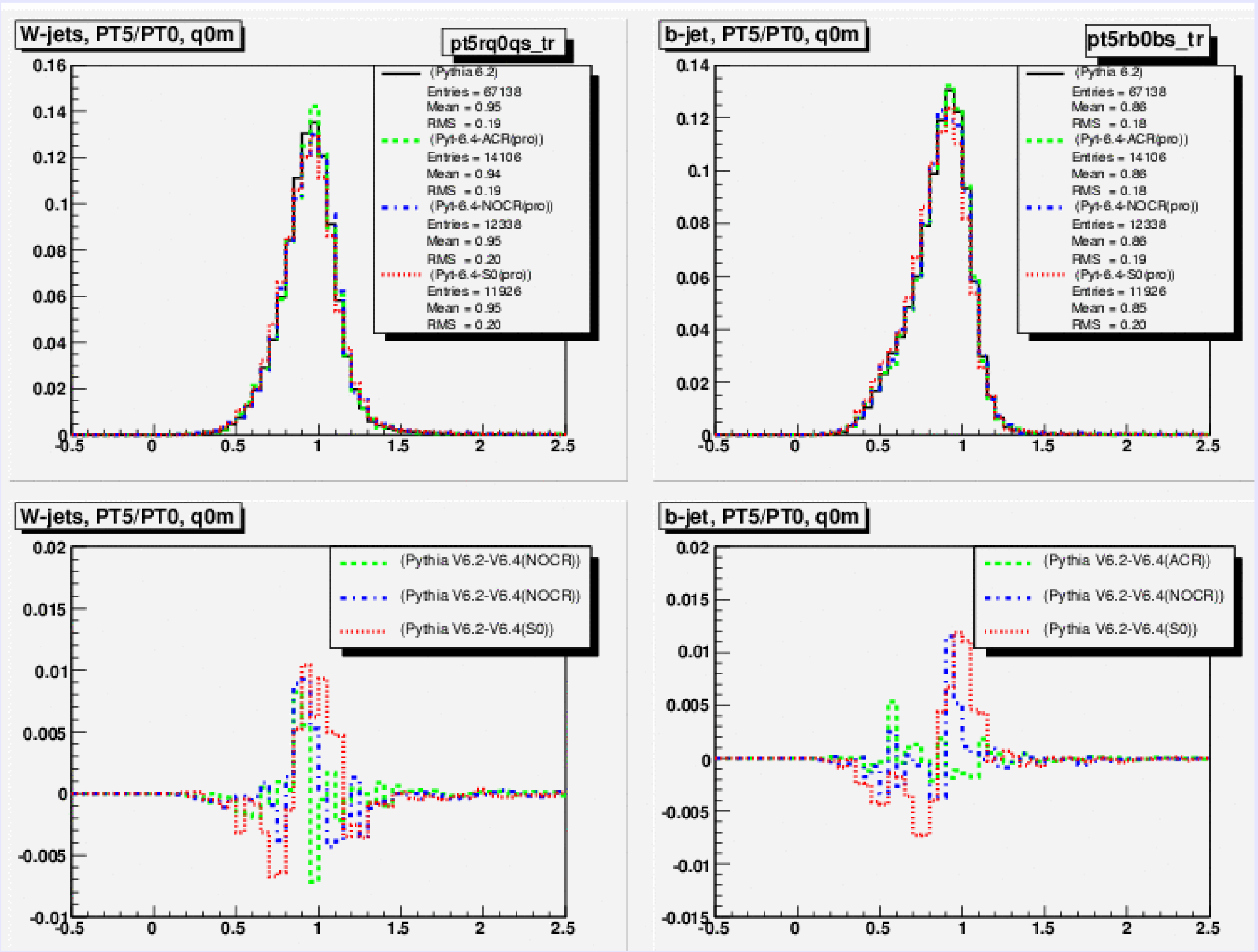
Samples with new parton shower have:

wider χ^2 distributions

wider ΔR "

Jets with new parton shower are more displaced from the partons.

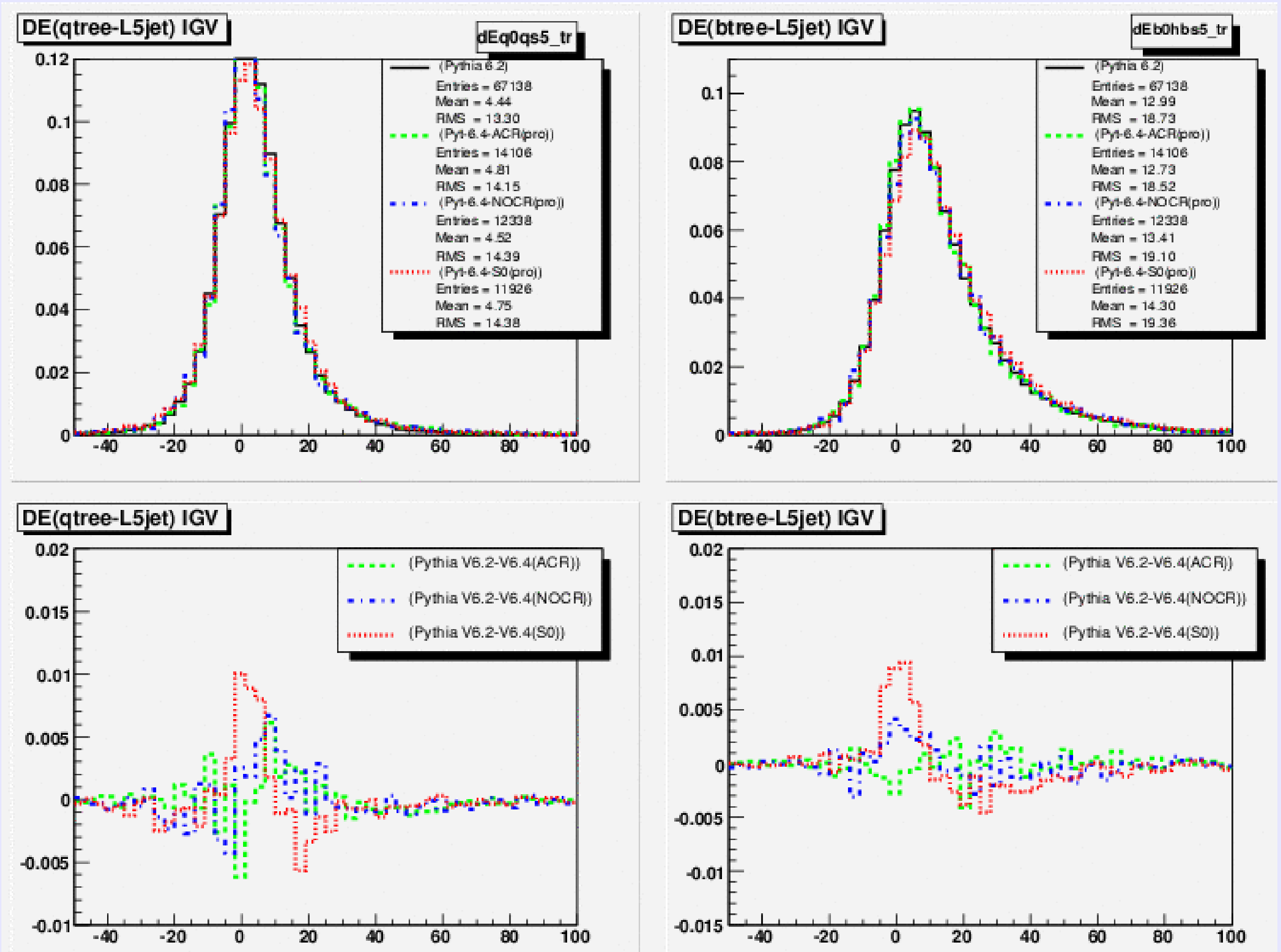
P_T(jet)/P_T(parton) for jets in top events



M=175 GeV
V6.2 (tune A)
V6.4 ACR
V6.4 NOCR
V6.4 S0

Distributions for V6.4 tune S0 look a bit wider (PT(jet)/PT(parton) smaller) and shifted for the b-jets

E(parton)-E(jet) in cone ΔR=0.4



M=175 GeV
V6.2 (tune A)
V6.4 ACR
V6.4 NOCR
V6.4 S0

For the S0 tune, there is less energy in the cone with R = 0.4

What did we learn about jets?

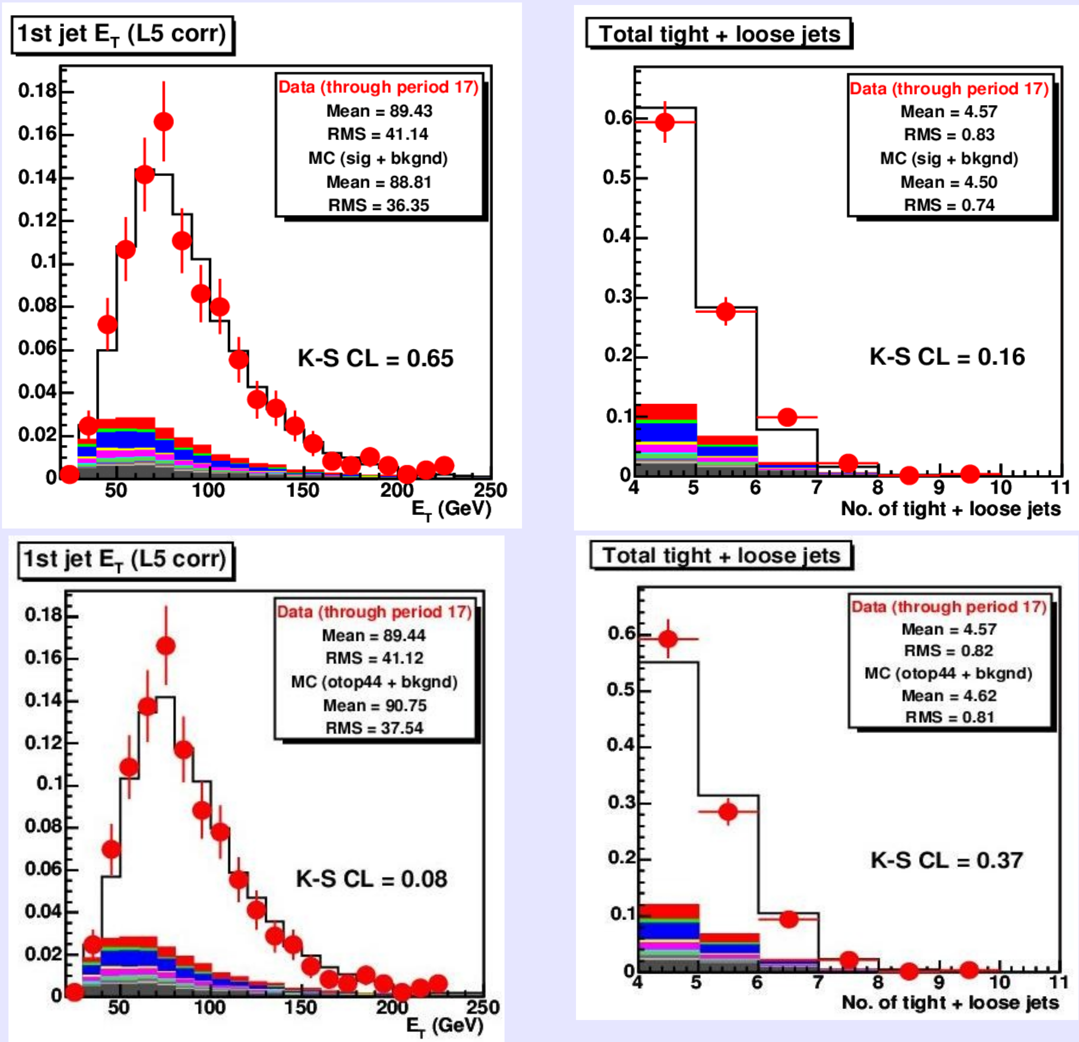
	MC samples at $M = 175$ GeV/c^2					
Sample	Jets from W			b Jets		
	PT	dE(part-jet)	Δ(dE)	PT	dE(part-jet)	Δ(dE)
	GeV/c	GeV	GeV	GeV/c	GeV	GeV
V6.2 (nominal) (ttkt75)	56.0	4.44±0.05	–	71.6	13.0±0.07	–
V6.4 ACR (otop46)	56.0	4.81±0.12	0.37±0.13	71.4	12.7±0.16	-0.26±0.17
V6.4 NOCR (otop47)	56.3	4.52±0.13	0.08±0.14	72.2	13.4±0.16	+0.58±0.18
V6.4 S0 (otop44)	56.2	4.65±0.13	0.31±0.14	72.1	14.3±0.18	1.31±0.19

- The jets are wider in S0, i.e. less energy in a cone of 0.4 radius. The b-jets are shifted by 1.3 GeV.
- The ACR case has smaller effects than S0
- The NOCR shows less visible effects than S0 (0.58 GeV b-jet shift)

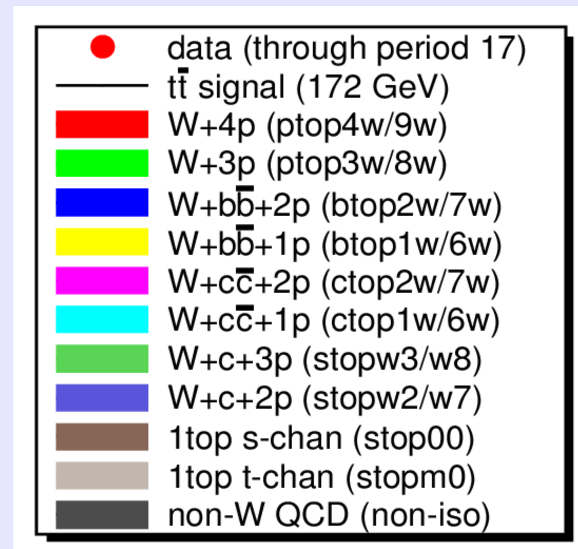
New parton shower gives jet with less energy in cone of R=0.4

Data-MC comparison V6.2 and 6.4

CDF Data (494 events in 2.7 fb-1), not enough to distinguish!



PYTHIA V6.2

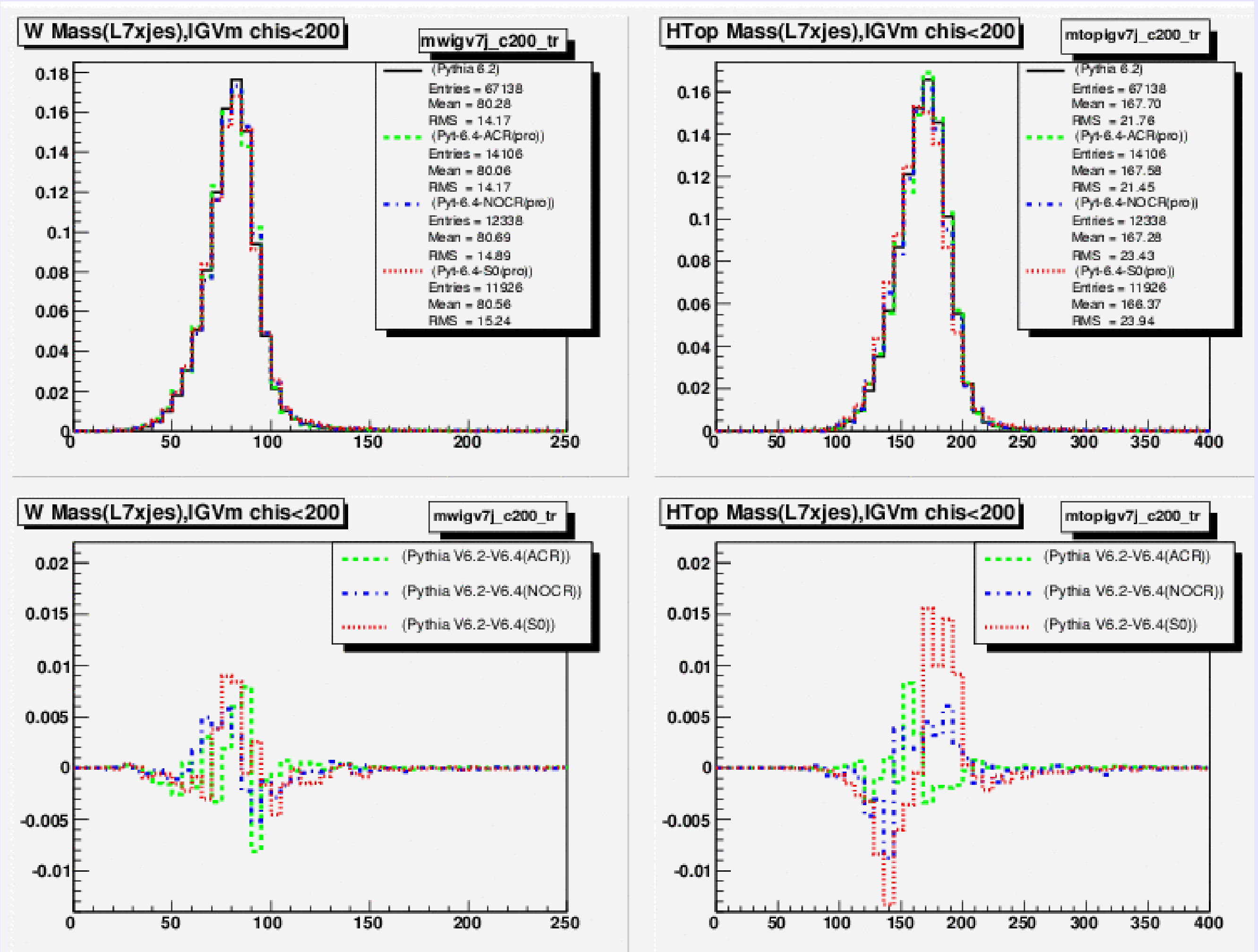


PYTHIA V6.4 (S0)

Highest E_T jet: there is a 2 GeV difference between the two MC samples

Reconstructed W and top masses

Using event matching we find:



M=175 GeV
V6.2 (tune A)
V6.4 ACR
V6.4 NOCR
V6.4 S0

M_W is somewhat shifted . M_{top} shifted for both the NOCR and the S0 samples

Summary of studies on M_{top}

Comparison of V6.2 (nominal) to V6.4 (the “pro” tune)
Using both methods, i.e., reconstructing top mass with our ME method.

	MC event matching		MTM3 Pseudo-Exp		
Sample	Δm_W (GeV/c^2)	Δm_t (GeV/c^2)	m_t (GeV/c^2)	Δm_t (GeV/c^2)	Δ_{JES} (σ)
	MC samples at $M = 175$ GeV/c^2				
V6.2 (nominal) (ttkt75)	–	–	175.27±0.21	-	0.01±0.05
V6.4 tune A (otop45)	-0.13±0.13	-0.12±0.20	175.21±0.22	+0.18±0.27	0.03±0.05
V6.4 ACR (otop46)	-0.22±0.14	-0.12±0.21	174.70±0.22	-0.33±0.27	0.07±0.05
V6.4 NOCR (otop47)	+0.41±0.14	-0.42±0.22	173.75±0.23	-1.28±0.28	0.21±0.05
V6.4 S0 (otop44)	+0.28±0.15	-1.33±0.23	173.30±0.25	-1.73±0.30	0.11±0.05

- ACR (old shower+CR) shows very little effect from CR =-0.33 ±0. 27 GeV
- NOCR: Event matching finds large ΔM_W, ME fit compensated for this with a large value of Δ_{JES}, resulting in ΔM_{top} = -1.28 GeV
- S0 : ΔM_{top} = -1.7 GeV, expected because of -1.3 GeV b-jet shift.

comparing NOCR and S0, we find CR (sys)= -0.45 ± 0.41 GeV

Summary

- We find the following CR values from the "pro" tune files:
  -0.33 $\pm$ 0.27 GeV from ACR
  -0.45 $\pm$ 0.41 from S0-NOCR, both consistent with zero, <0.45 GeV

- The S0-pro tune gives ΔM_{top} = -1.7 GeV
  this is directly related to different jet shapes, i.e., different p-shower

- Tune S0-pro includes systematics that we are already taking into account ,i.e.
  generator: $\Delta(m_t)$ = 0.51 +- 0.37 GeV
  ISR/FSR: $\Delta(m_t)$ = 0.29 +- 0.26 GeV
  OOC : $\Delta(m_t)$ = 0.52 GeV
  b-jets : $\Delta(m_t)$ = 0.38 GeV
  that is 0.87 GeV, most of the MC related systematics.

- More comparison of the S0 tune with Tevatron data need to be done before we use it. We also need to disentangle the various sys contributions

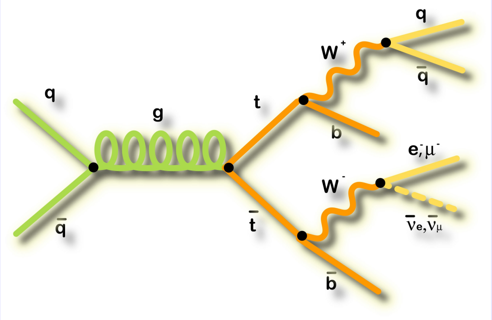
Top Mass Measurement and CR

Backup slides

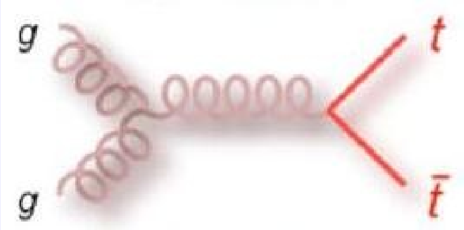
L+jets:Sample Composition

- Event Selection
  - Isolated lepton, P_T > 20 GeV
  - MET > 20 GeV (neutrino)
  - N (jets): only 4 jets with E_T >20 GeV
  - ≥1 b-tag by the SVX algorithm
- Background :
  - Mistag in W+light quarks
  - non-W QCD
  - Physics background: Wbb, Wcc
  - Single top, WW, WZ etc.

~85%



~15%



Background	1 b-tag	$\geq$ 2 b-tags
non-W QCD	13.8 $\pm$ 11.5	0.5 $\pm$ 1.5
W+q(mistag)+WW,WZ,ZZ	21.8 $\pm$ 3.6	0.8 $\pm$ 0.1
$W + b\bar{b}$, $c\bar{c}$, c	26.1 $\pm$ 10.2	3.4 $\pm$ 1.4
Single top	3.0 $\pm$ 0.2	0.9 $\pm$ 0.1
Total background	64.7 $\pm$ 16.3	5.5 $\pm$ 2.6
Predicted $t\bar{t}$ signal	182.6 $\pm$ 24.6	69.4 $\pm$ 11.2
Events observed	284	87

In 1.9 fb-1 find 371 events

Estimated background:

70 ± 17 events

But: are these events only top+SM background?

Top Mass Measurement ME(1)

- For each event we evaluate a likelihood as a function of the top mass and Δ_{JES} (related to the jets momenta measurements)
- All possible jet permutations are included with weights = wi.

$$L(\vec{y} \mid m_t, \Delta_{\mathrm{JES}}) = \frac{1}{N(m_t)} \frac{1}{A(m_t, \Delta_{\mathrm{JES}})} \sum_{i=1}^{24} w_i L_i(\vec{y} \mid m_t, \Delta_{\mathrm{JES}})$$

measured quantities **normalization** **acceptance** **24 Permutations**

$$L_i(\vec{y} \mid m_t, \Delta_{\mathrm{JES}}) = \int \frac{f(z_1) f(z_2)}{FF} \mathrm{TF}(\vec{y} \mid \vec{x}, \Delta_{\mathrm{JES}}) \, |M(m_t, \vec{x})|^2 \, d\Phi(\vec{x})$$

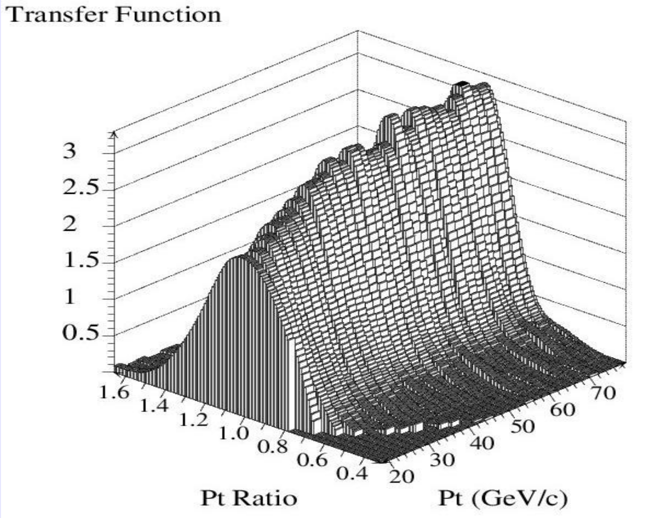
Incoming partons **Transfer functions** **parton level quantities**

- We integrate over phase space (d Φ) and Matrix Element (M) for t t production and decay.

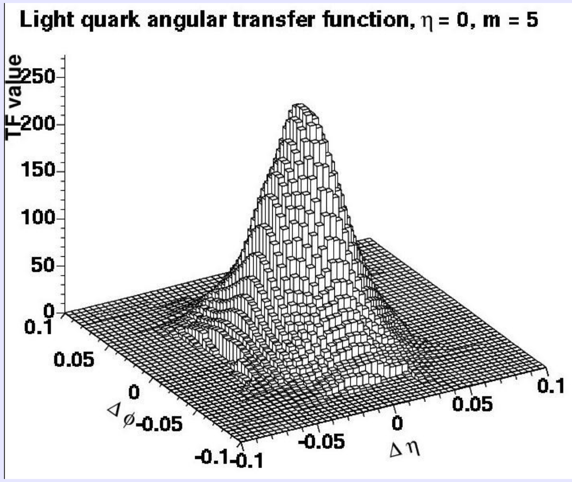
Top Mass: Transfer Functions (2)

- The transfer functions for a given parton x, give the probability that we observe y. Detector effects, resolutions etc. are included
- Both angular and P_T transfer functions are used
- Multiplied by efficiency for proper normalization
- Transfer functions depend on jet mass as well as on P_T (in η bins). Also they are evaluated for 25 values of Δ_{JES}.

P_T ratio= P_T(jet)/P_T(q)



P_T(q)=40 GeV, m_{jet}=30 GeV



Top Mass : integration (3)

- From 32 parameters in

  $z_1 + z_2 = q\, q'\, b_1 + \text{lep}\, \nu\, b_2$,

  assumptions on incoming partons, lepton masses, charged lepton P and energy-momentum conservation leave a 19-dimensional integration, performed by Quasi-Monte Carlo method.
- Integration variables:

  M_1^2 and M_2^2 , the hadronic and leptonic top mass squared

  m_1^2 and m_2^2 , the hadronic and leptonic W mass squared

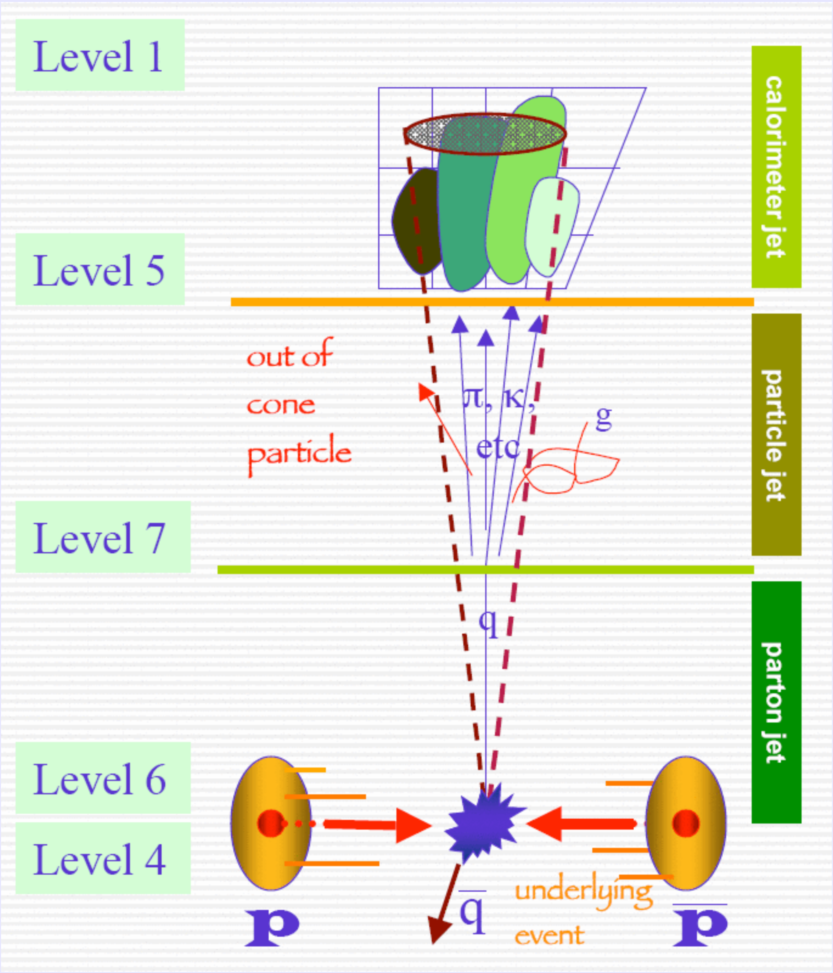
  $\beta = \log(\rho_q/\rho_{q'})$, log of ratio of momenta of the two q from W

  $P_T(t\, t)$, priors from MC

  $\Delta\eta$ (parton-jet) , $\Delta\Phi$ (parton-jet) for each jet.

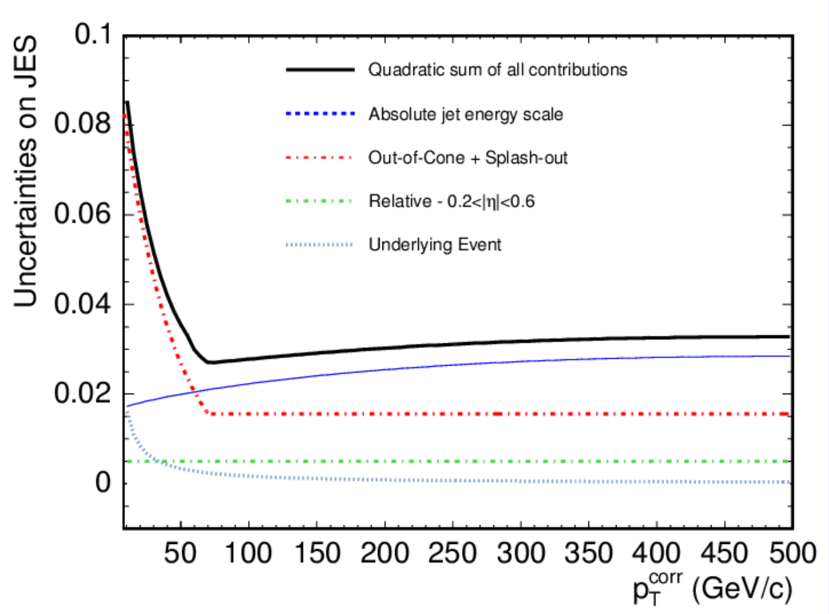
  Mass of each p-jet. All jet priors from MC

Tools: Jet Reconstruction (4)



Use cone algorithm

- Use calorimeter information only
- Jet calibration done in many steps
- 3% systematics at high p_T



Source of the largest uncertainty on the top mass measurement

In Situ JES calibration (5)

- Likelihood parameters are m_t and Δ_{JES}
- We shift each jet by the factor

$$JES = 1 + \Delta_{JES} \times \sigma_{JES}(p_T,\eta)$$

where $\sigma_{JES}(p_T,\eta)$ is the systematic uncertainty on the jet p_T

- Δ_{JES} is determined using the decay

$$W \rightarrow j_1 j_2$$

and using the measured value for the W mass

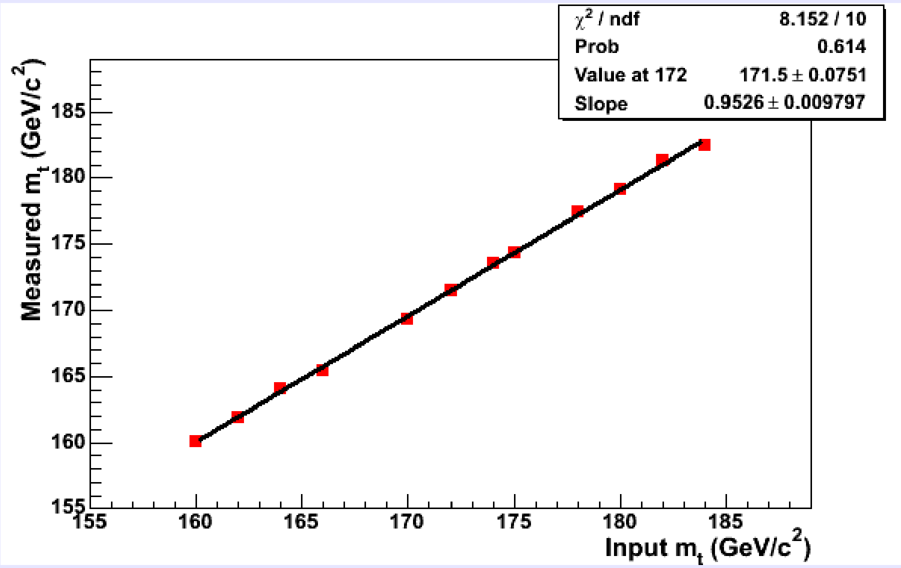
- Precision on Δ_{JES} is determined by the statistics we have, thus a systematics uncertainty is now a statistical one

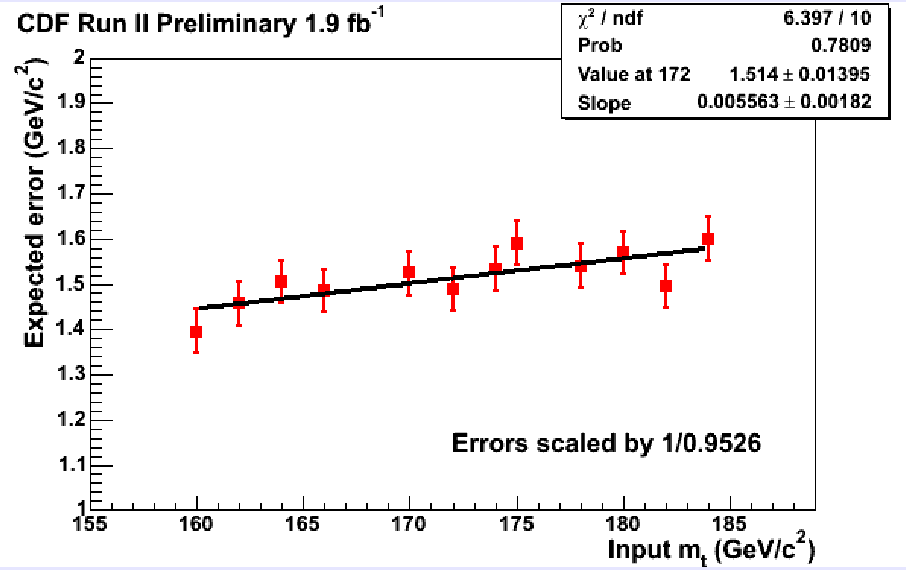
Top Mass: MC Calibration(6)

We use 12 mass point between 160 and 185 GeV/c^2 to calibrate the method

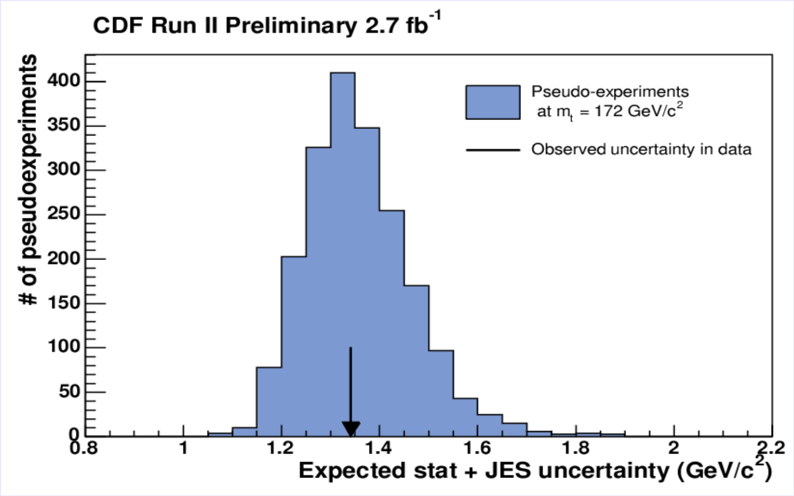
M_{meas} =(0.953± 0.009) □m_{input}

$\delta m(172)=1.5$ GeV/c^2

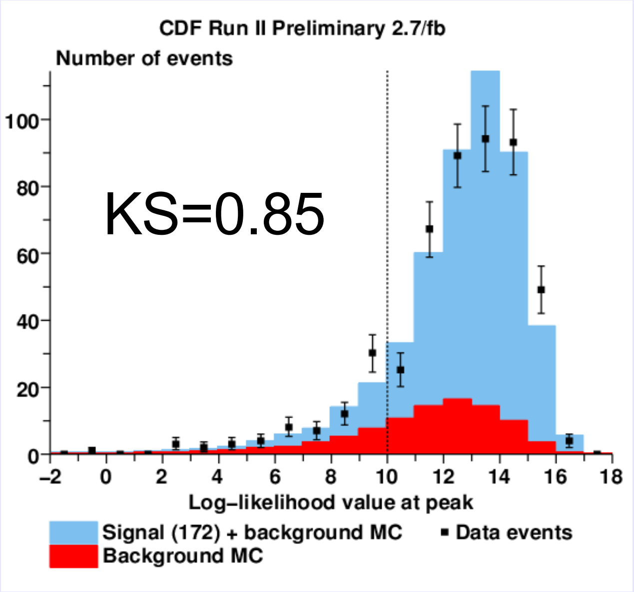




Top Mass Results (7)



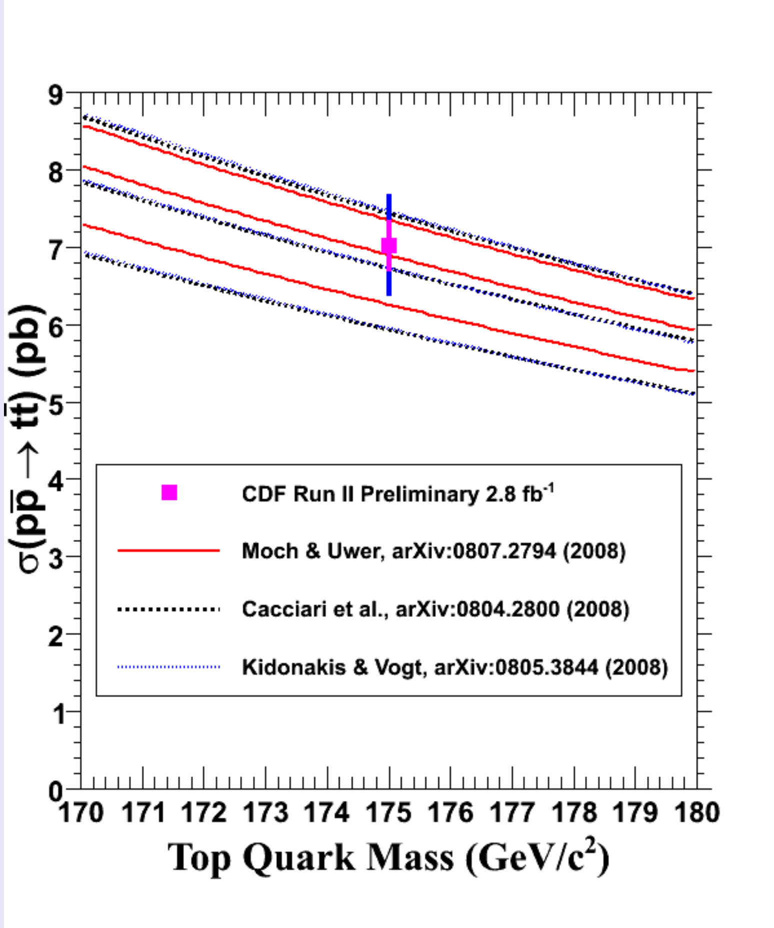
Expected uncertainty distribution from MC. The arrow shows the uncertainty for the data sample (422 events). 49% of the pseudoexperimets are below the arrow.



The peak of the likelihood for each MC events compared with the distribution for the 494 events. We cut the likelihood at a value of 10 to reduce background and badly reconstructed events

Cross section for ttbar production

Any other measurements are affected?



Background to many searches: Higgs 30%,
SUSY trilepton xx%
It is important to reduce systematics.

Contribution from the l+jets+SVX b-tag topology is 44%.

~0.2 of the syst error comes from MC related uncertainties,

CDF average summer '08

7.0 ± 0.3 (stat.) ± 0.4 (syst)

MPI Models in Pythia 6.4

► **Old Model: Pythia 6.2 and Pythia 6.4**

- "Hard Interaction" + **virtuality-ordered** ISR + FSR
- p_T-ordered MPI: **no ISR/FSR**
- Momentum and color explicitly conserve
- Color connections: **PARP(85:86) → 1** in Rick Field's Tunes
- No explicit color **re**connections

MPI create kinks on existing strings, rather than new strings

► **New Model: Pythia 6.4 and Pythia 8**

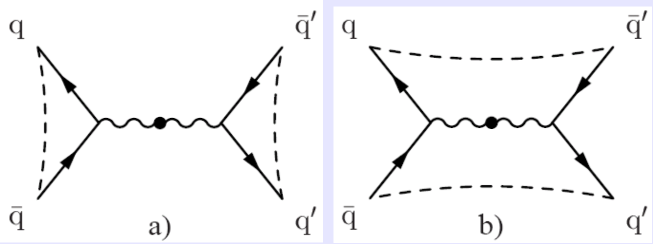
- "Hard Interaction" + **p_T-ordered** ISR + FSR
- p_T-ordered MPI + **p_T-ordered** ISR + FSR
  - ISR and FSR have **dipole kinemati**
  - **"Interleaved"** with evolution of hard one common sequence
- Momentum, color, and **flavor** explicitly conserverd
- Color connections: random or ordered
- Toy Model of Color reconnections: **"color annealing"**

Hard System + MPI allowed to undergo color reconnections

Color Reconnection

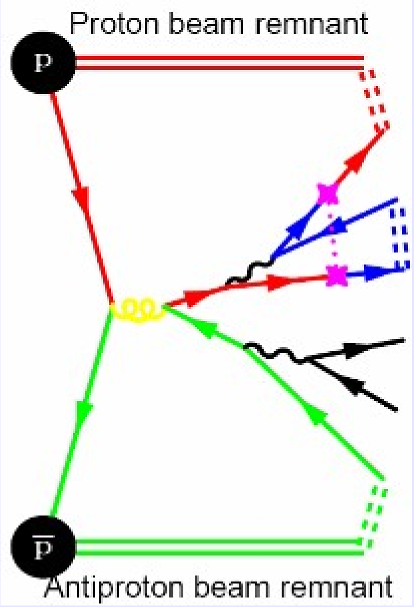
Sjöstrand, Khoze, Phys Rev Lett 72(1994)28 & Z. Phys C62(1994)281 + more

OPAL, Phys Lett B453(1999)153 & **OPAL**, hep-ex0508062



- **Searched for at LEP**
  - Major source of W mass uncertainty
  - Most aggressive scenarios excluded
  - But effect still largely uncertain $P_{reconnect} \sim 10\%$

- Prompted by CDF data and Rick Field's studies to reconsider.
  What do we know?
  - Non-trivial initial QCD vacuum
  - A lot more colour flowing around, not least in the UE
  - String-string interactions? String coalescence?
  - Collective hadronization effects?
  - More prominent in hadron-hadron collisions?
  - What (else) is RHIC, Tevatron telling us?
  - *Implications for precision measurements:Top mass? LHC?*



Existing models only for WW → a new toy model for all final states: **colour annealing**

Attempts to minimize total area of strings in space-time (similar to Uppsala GAL)

• Improves description of minimum-bias collisions

PS, Wicke EPJC52(2007)133 ;

Preliminary finding Delta(mtop) ~ 0.5 GeV

Slide from P. Skands' talk, Perugia MC workshop, October 2008

Color reconnection in PYTHIA V6.4

New CR Models: Colour Annealing

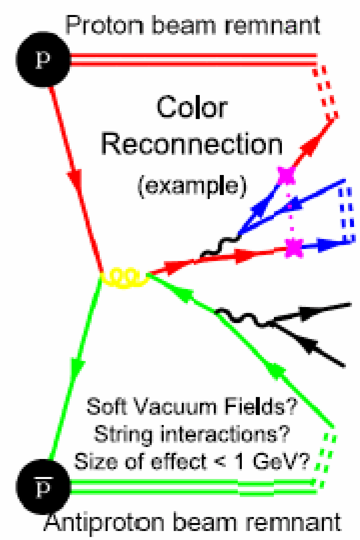
Allow CR also within the hard interaction.

- At hadronisation strings pieces may reconnect

$$P_{\text{reconnect}} = 1 - (1 - \chi)^n$$

χ — strength parameter
n — number of interactions
(counts number of possible interactions)

- New connection chosen to minimise string length, i.e. minimise potential energy in strings
- Model variations: $S0$, $S1$, $S2$ differ in suppression of gluon only string loops



These models of colour reconnection are applicable to any final state.

Daniel Wicke, Non-perturbative QCD and Top Mass, Modelling   Top2008, La Biodola, Elba, 18–24 May 2008   8