Physics background at Tevatron

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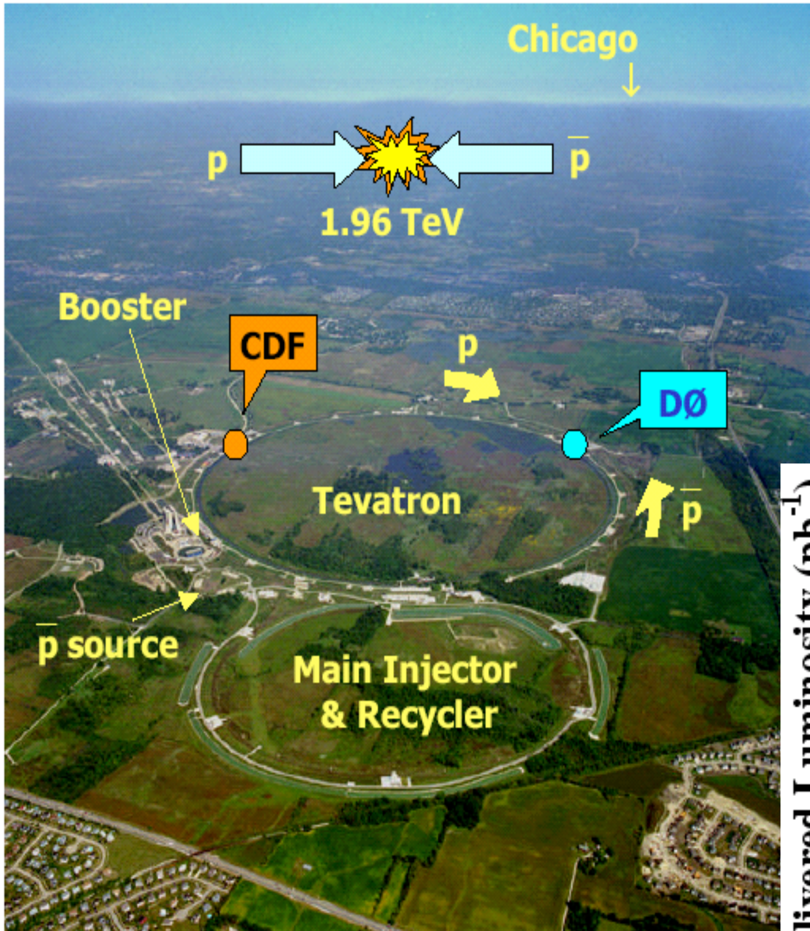
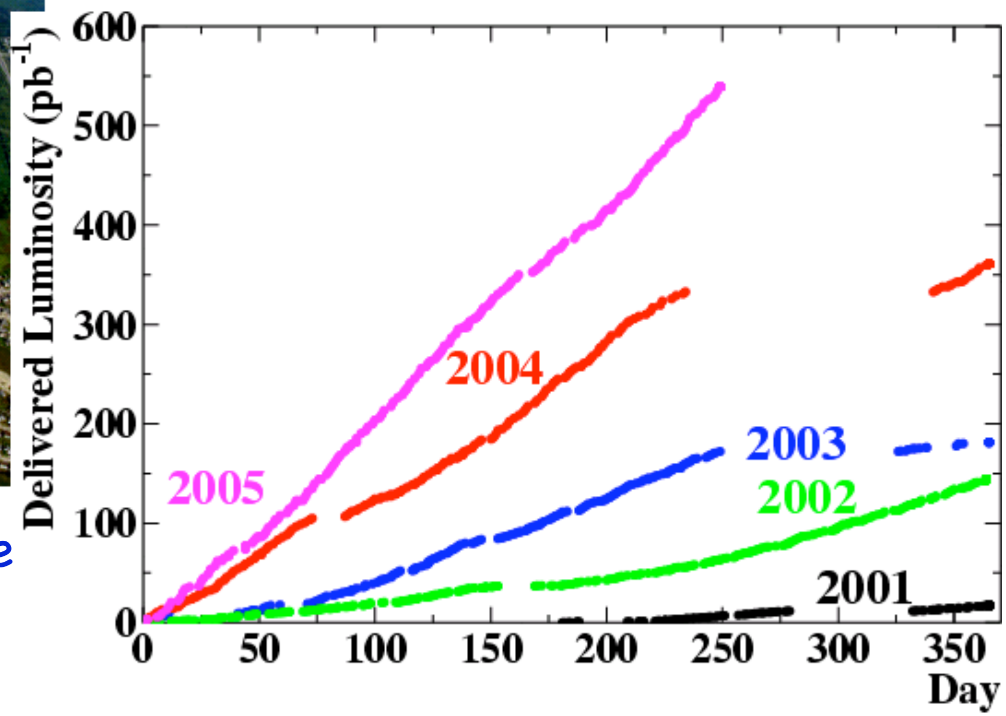
Tevatron

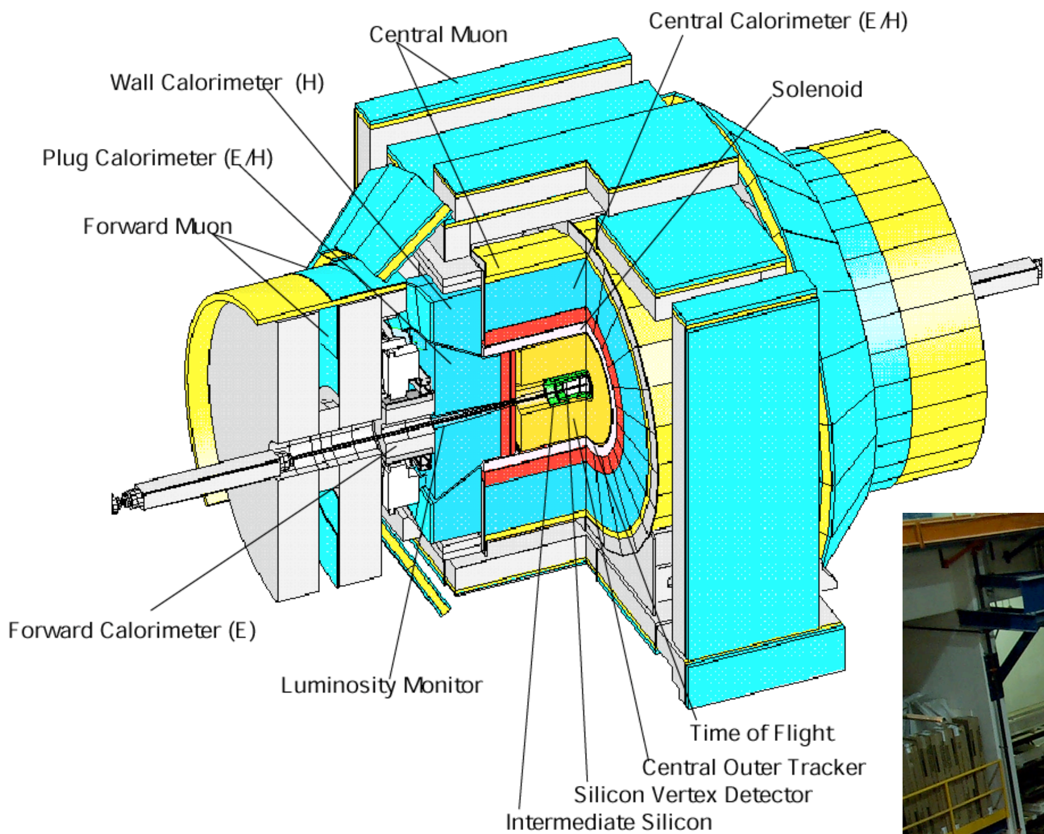


- Proton-Antiproton collisions
- sqrt(s) = 1.96 TeV
- 36 bunches: 396 ns crossing time
- Peak luminosity 1.4 x $10^{32}cm^{-2}s^{-1}$



- $1fb^{-1}$ per experiment on tape
- 1.3 fb^{-1} delivered luminosity

CDF II

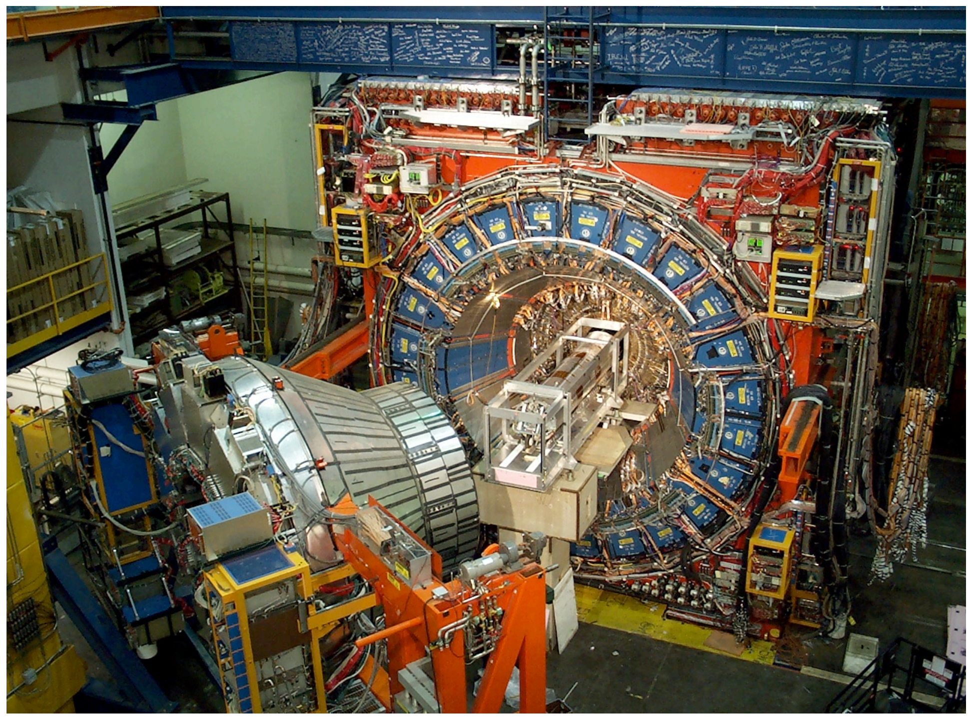


Run II upgrades

- New silicon tracking
- New drift chamber
- Upgraded muon chambers
- New plug calorimeters
- New TOF

Data taking efficiency 85 %

About 1 fb^{-1} on tape



Introduction

Larger data sample than ever

Measurements start being dominated by systematic errors

For high p_T physics is crucial to have under control the backgrounds and the MonteCarlo tools for signal & backgrounds modeling

Introduction

EWK Physics:

- large cross sections (nb)
- small B/S (1-5%)
- limited by detector syst.

→ right place to develop, understand and test the algorithm for the background identification and subtraction to: e, μ and Met signals

QCD Physics:

- large cross sections (nb)
- deeply falling with jet p_T
- limited by jet correction

→ understand jet energy scale, MI, UE. Now is crucial to tune MC on data to have a good description of UE & soft physic

Top & Higgs:

- small cross sections (pb)
- small S/B (O(1))
- limited by jet correction & physics bkgd modeling

→

- model Boson + jets bkgd
- measure HF fraction (W/Z+jet)
- understand non W background

Electroweak Physics: W

W -> $e\nu$

	Frac.	Meth.	Syst.
W->$\tau\nu$	1.9%	MC	5%
QCD	1.6%	Data	50%
Z->ee	0.8%	MC	5%
Tot.	4.4%		20%

QCD bkgd to the W signal is the dominant bkgd to a number of analyses, need to be characterized where the is a good understanding of the other components.

W -> $\mu\nu$

	Frac.	Meth.	Syst.
W->$\tau\nu$	3.1%	MC	5%
QCD	0.7%	Data	50%
Z->$\mu\mu$	5.4%	MC	5%
Tot.	9.4%		5%

Background dominated by μ that escaping the detector mimic a Met signal.

QCD bkgd

Background from data: QCD

Missidentified leptons + large unbalanced E_T

Main technique: correlation between lept.Iso & Met

QCD uncorrelated on IsoMet plane

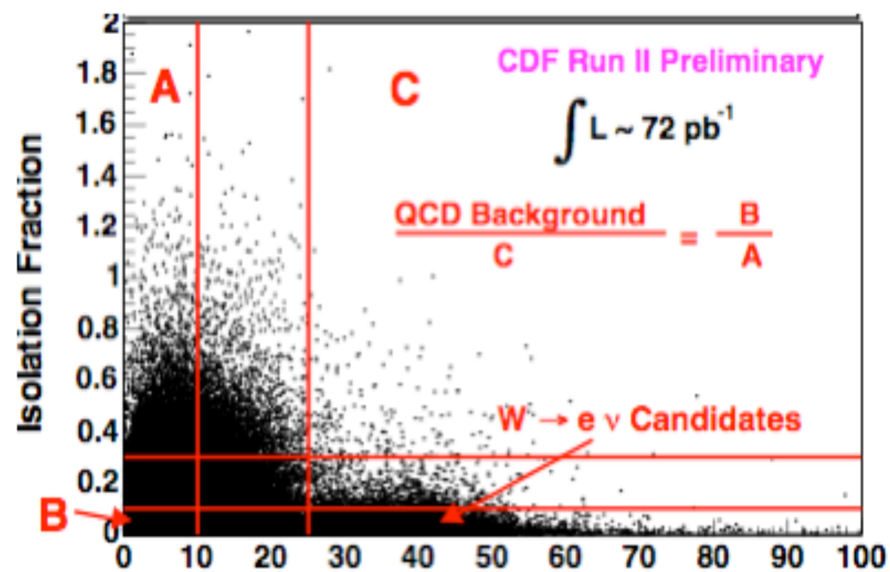
Extrapolate bkgd from low Met region

Correct for other boson bkgd:

Z->ee (peaks reg B)

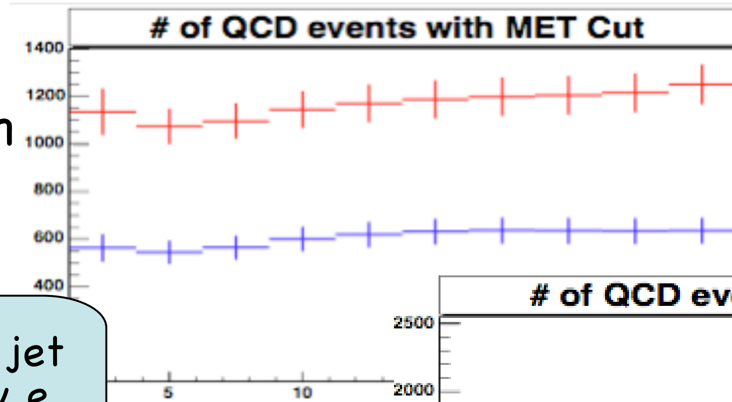
W->tn (peaks reg C)

Signal contamination (reg B&C)

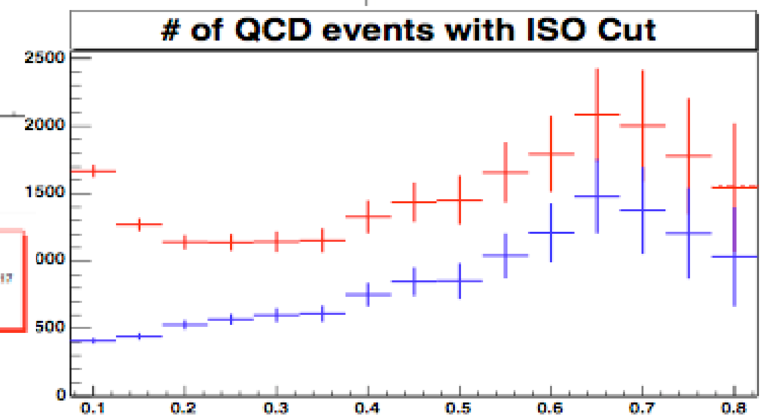


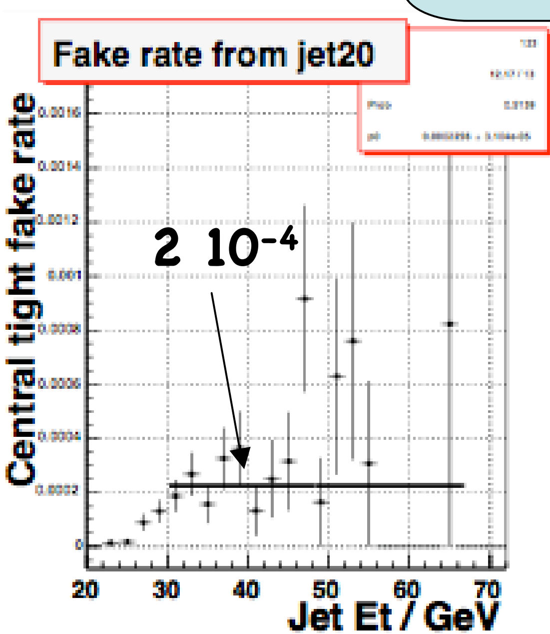
Systematic & alternatives

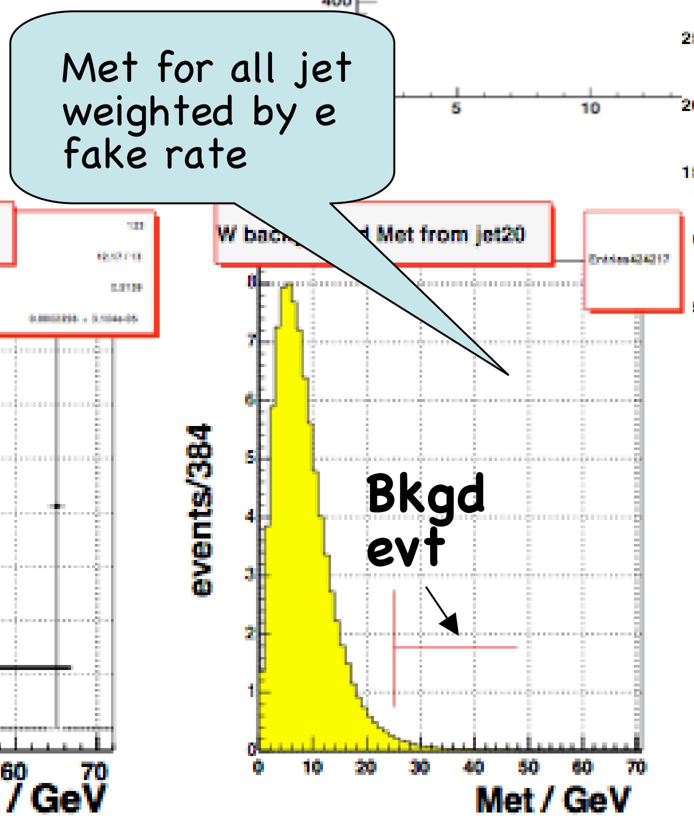
Systematic:
Vary the region definition



EWK corrected
Raw method







Fake method:
Di-jet events E_T >15 GeV
Met< 15GeV -> negligible
EWK contamination.

QCD background composition

Electron identification

- ✓ Conv. removal (trident allowed)
- ✓ E/p < 2 if p<50 GeV
- ✓ Isol(0.4)< 0.1 (energy based)
- ✓ Had/EM < 0.055 + c(E)
- ✓ Good track
- ✓ Matching track EM cluster
- ✓ Lateral EM cluster shape

Source	%
Conv.	60
Had. (ch.ex, overlap)	20
Heavy flavor	20

Jets Physics

A jet is a composite object:

Complex detector properties

- non-linear detector properties
- non-instrumented regions

Correct to particle level

- pile up
- detector efficiency/resolution

Complex underlying physics

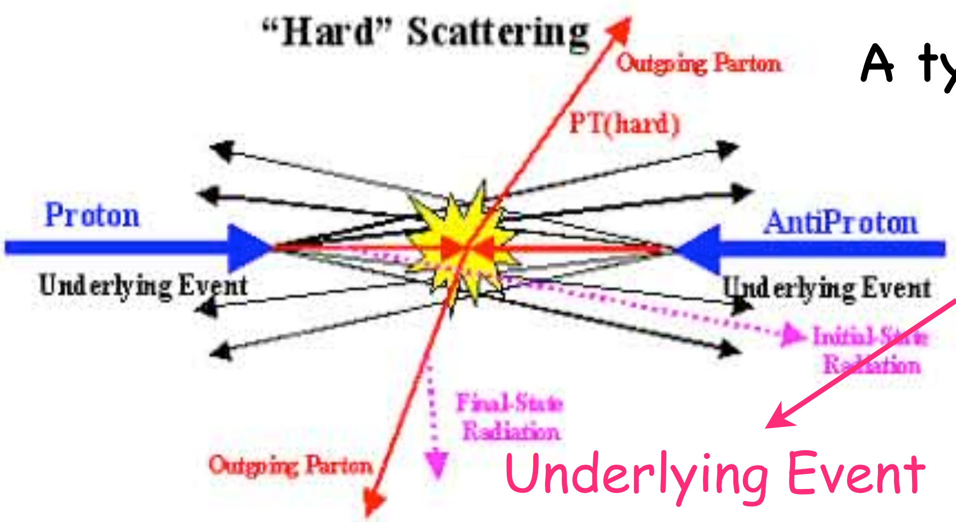
- events contain spectator interaction
- processes connected via color
- hadron fragmentation
- different type of jets: q, g, b/c

Model dep. correction

- underlying event
- parent parton energy

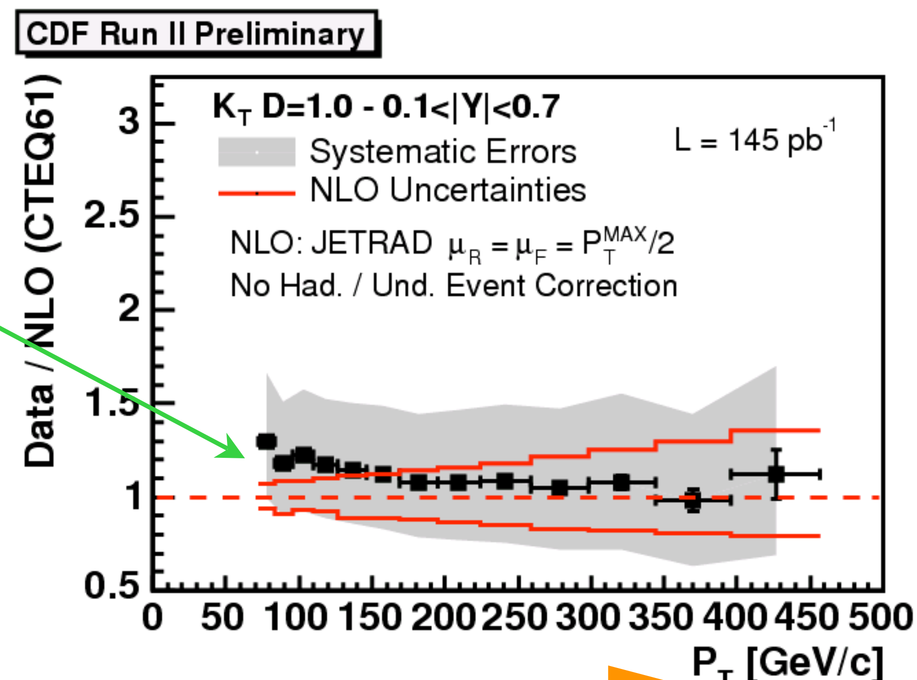
Data + Unfolding ⟷ Jet Algorithms ⟷ pQCD + Soft contribution

The Underlying Event



A typical Tevatron event consists of:

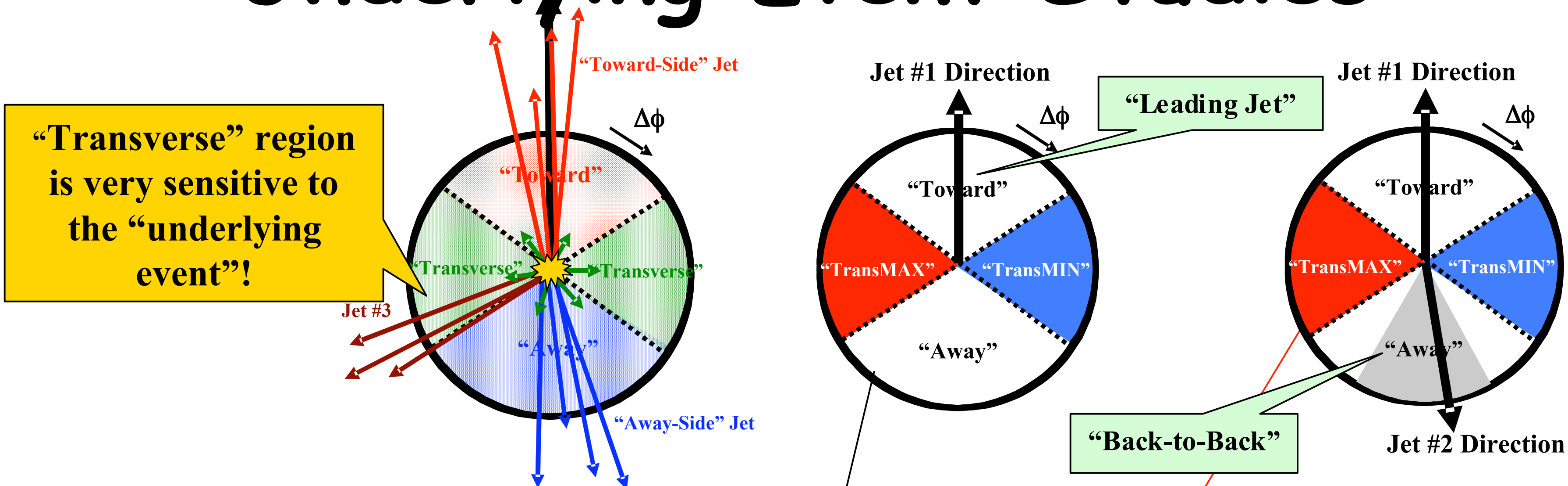
- hard interaction
- initial/final radiation
- interaction between remnants
- multiple parton interactions



Precise measurements at low Pt require good modeling of the underlying event

Tune MonteCarlo to reproduce data in as many as possible variables sensitive to underlying physics.

Underlying Event Studies

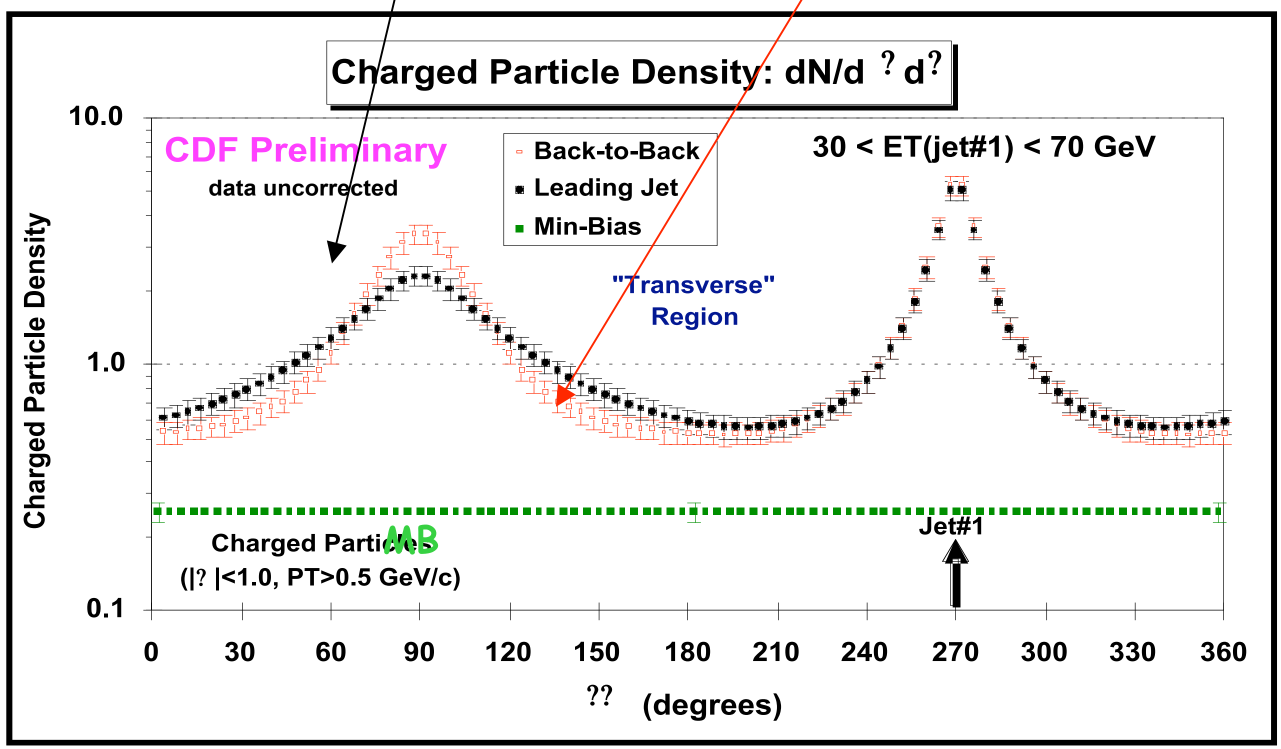


Important to model:

- Soft particle multiplicity
- Particle average energy

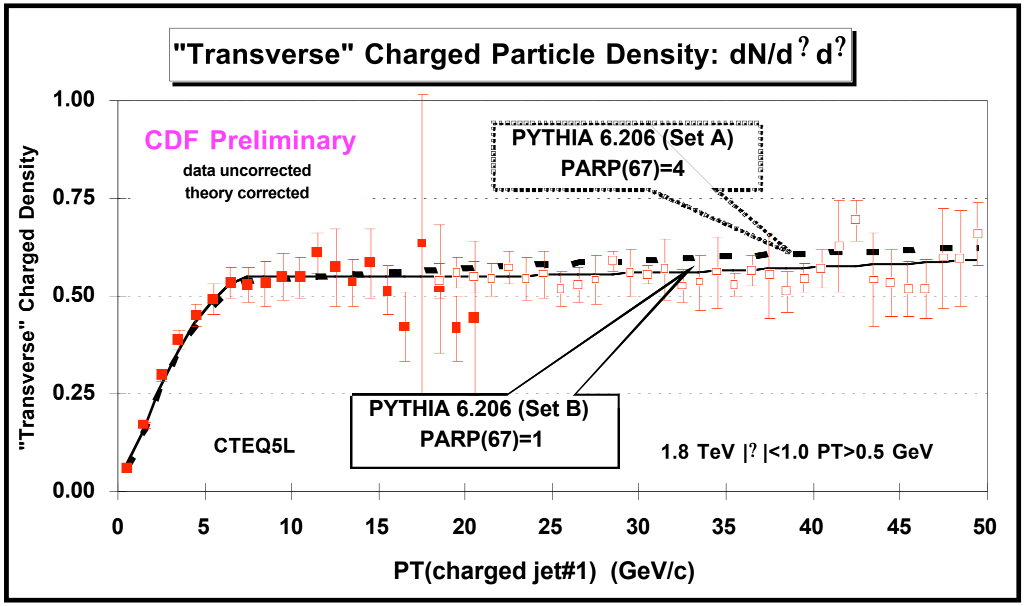
Study:

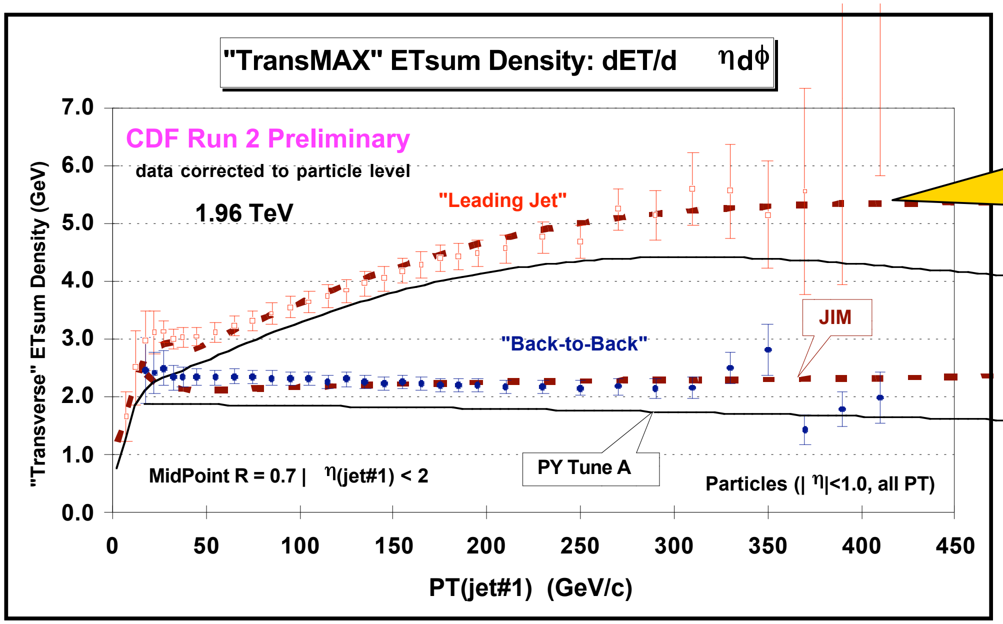
E_T, p_T, charged particle density



Tune MonteCarlo on data

Plot shows the "Transverse" charged particle density versus P_T(jet) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1, less ISR) and Set A (PARP(67)=4), more ISR).





JIMMY was tuned to fit the energy density in the "transverse" region for "leading jet" events!

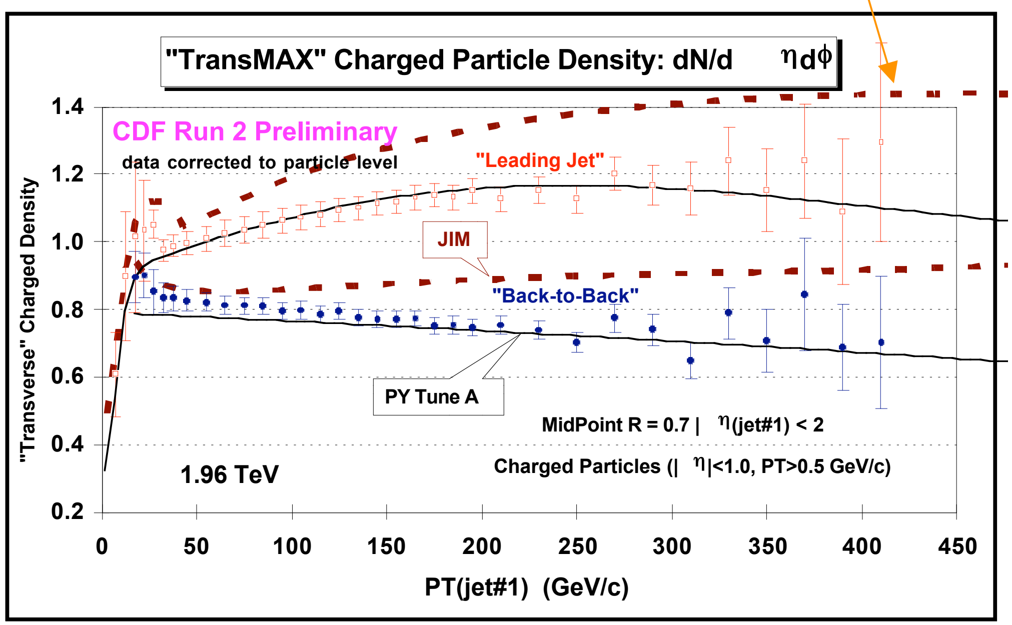
Shows the Etsum density in the "transMAX" and "transMIN" region versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events.

Underlying event

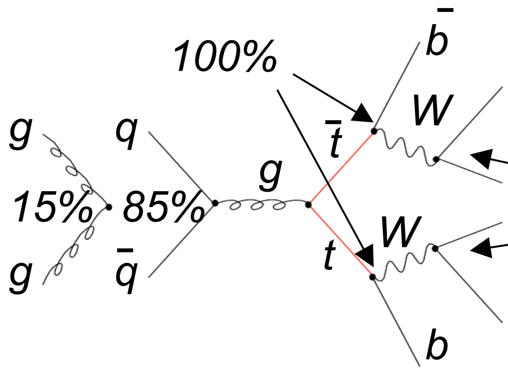
We are making good progress in understanding and modeling the "underlying event". We have PYTHIA Tune A and JIMMY tune A, however, we do not yet have a perfect fit to all the features of the "underlying event". We are working on new improved Run 2 tunes!

Work in progress:

Look at the UE in other physics process Z, DY,...



Top physics



- Dilepton 5% : clean but small signal, 2ν
- Lepton+jet 30%: 1ν, menageble background
- Hadronic 44%: large background
- τ + X 21%: τ ID is challenging

Top properties:

✓ Measure cross section
  - ✓ Test QCD/SM

✓ Properties:
  - ✓ different decay modes
  - ✓ spin/W elicity

⇓

Larger sample

Understand W + jet sample

Top Mass:

Fundamental parameter SM

Mtop ≈ EWSB scale

M_{top} & MW constrain M_{higgs}

⇓

Understand background(QCD/W+jet)

Understand jet energy scale

Xsec b-tagging (lepton+jet)

Background

Wbb,Wcc,Wc

- HF frac from MC
- Normalized to W+jets data

W+light (mistags)

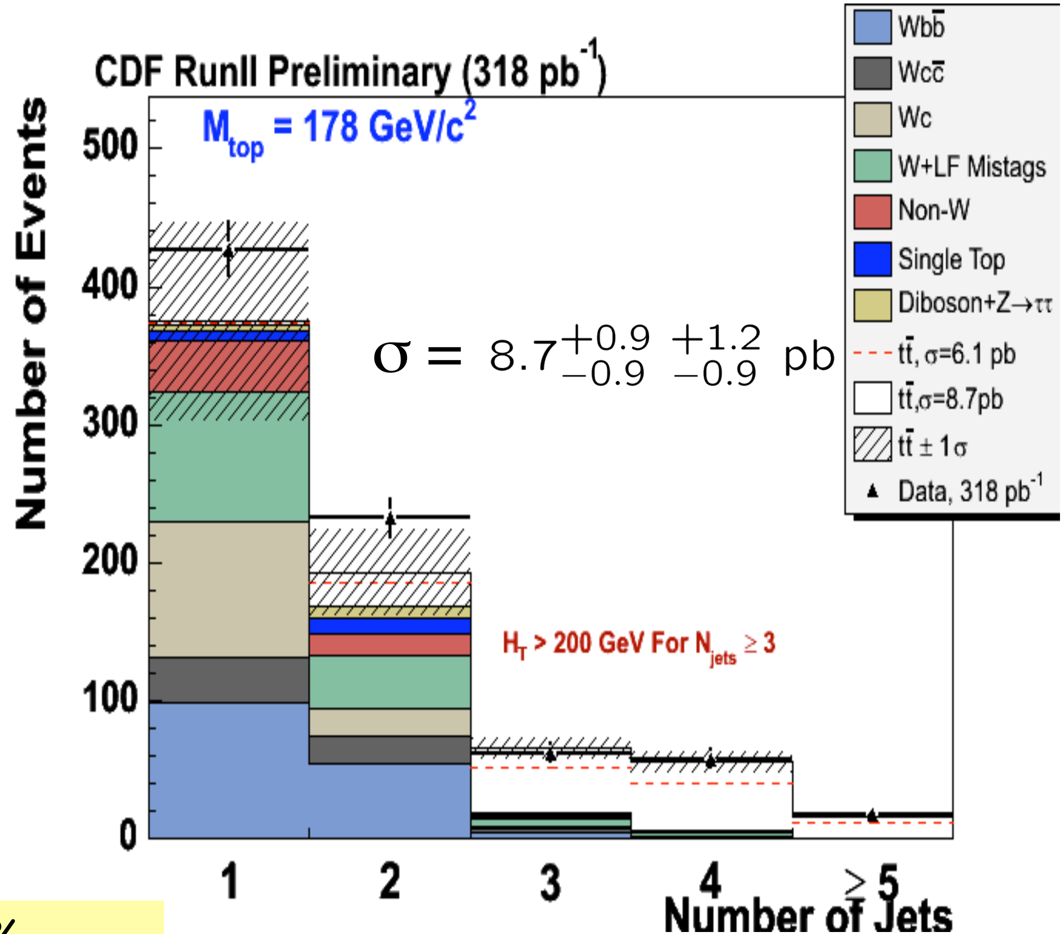
- Mistag from jet sample
- Applied to W+jets data

Non-W

- From data

Electroweak (WW, WZ, Z-> $\tau\ \tau$)

- From MC Small contribution



Systematics

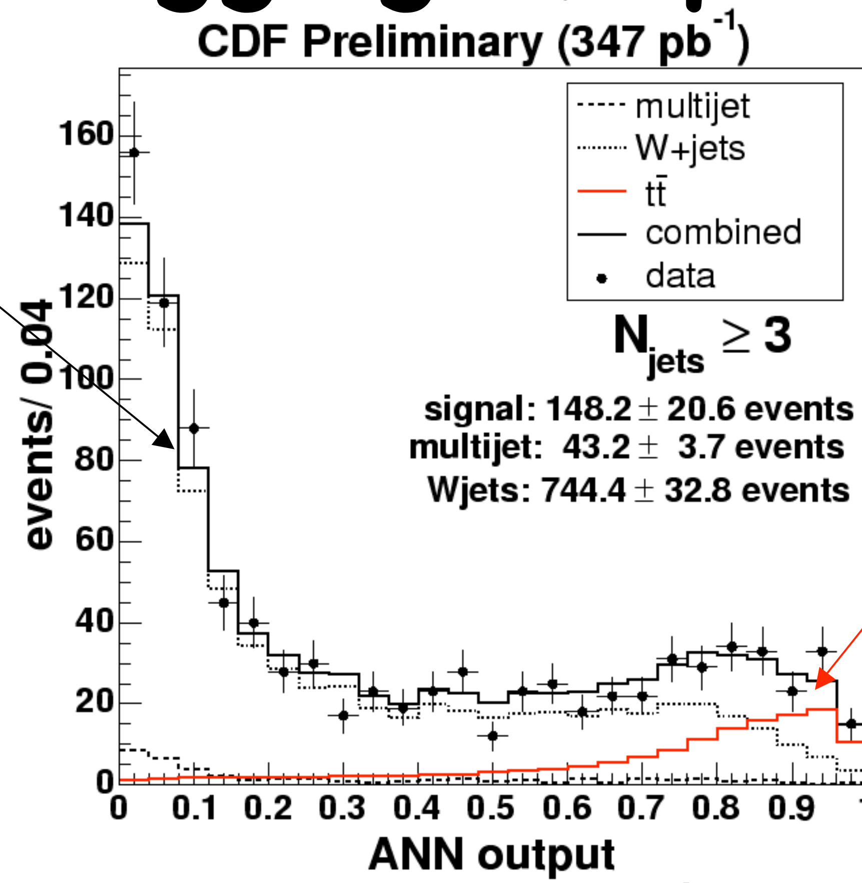
B-Tagging: 5.2%
Lepton Isolation: 5%
W+Heavy Flavor: 4.4%
Luminosity: 5.9%
Total: 11%

Xsec no b tagging (lepton+jet)

Background:
ALPGEN+HERWIG $W + 3p$
and $W + 4p$ MC

tt and W-background float
QCD fixed to 4.6%

Seven input variables
- H_T
- Aplanarity
- Maximum jet η
- ΣE_T (Jets 3, 4, and 5)
- $\Sigma p_Z / \Sigma E_T$
- Minimum dijet invariant mass
- Minimum dijet separation (ΔR)



PYTHIA *tt* MC

Sample	Events	Fitted *tt*	σ(*tt*)
$W + \geq 3$ jets	936	148.2 ± 20.6	6.0 ± 0.8 ± 1.0 pb
$W + \geq 4$ jets	210	80.9 ± 15.0	6.1 ± 1.1 ± 1.4 pb

Systematics	Total
Jet Et Scale	8.3%
W+jets Q^2 Scale	10.2%
ttbar PDF	4.4%
Total	16.4%

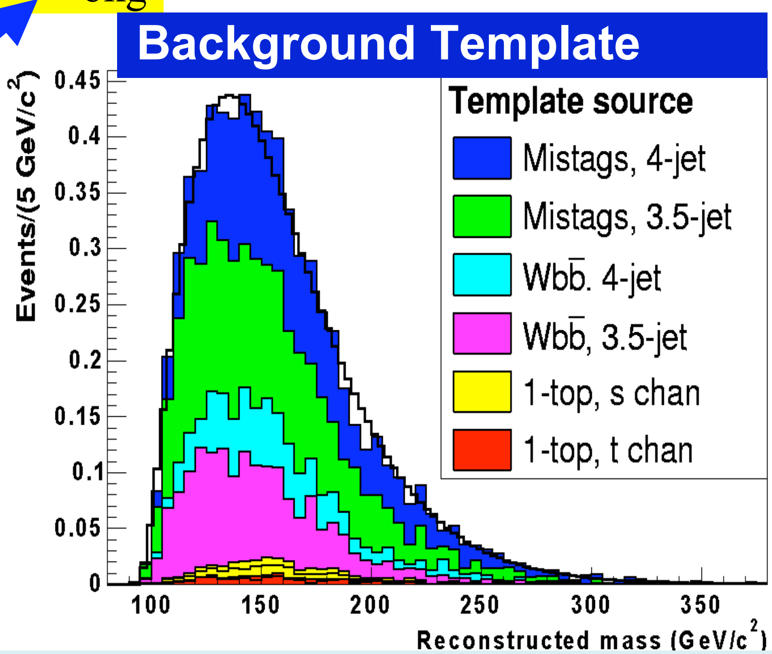
M_{top} lepton+jet: 1D templates

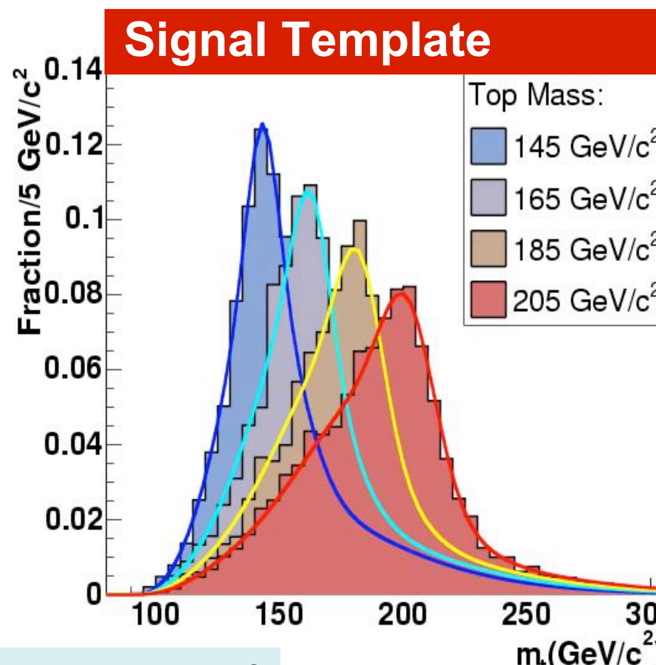
Exclusive samples in # b-tags

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	N/A	N/A	40

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

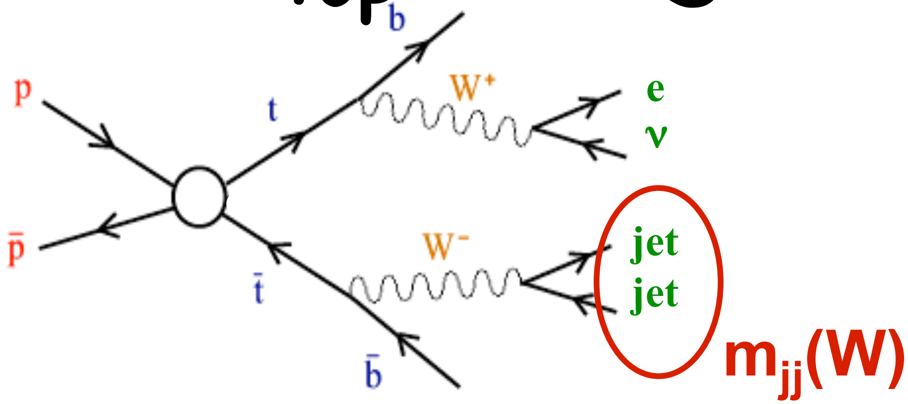
background constrained to prediction (except for 0-tag)





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

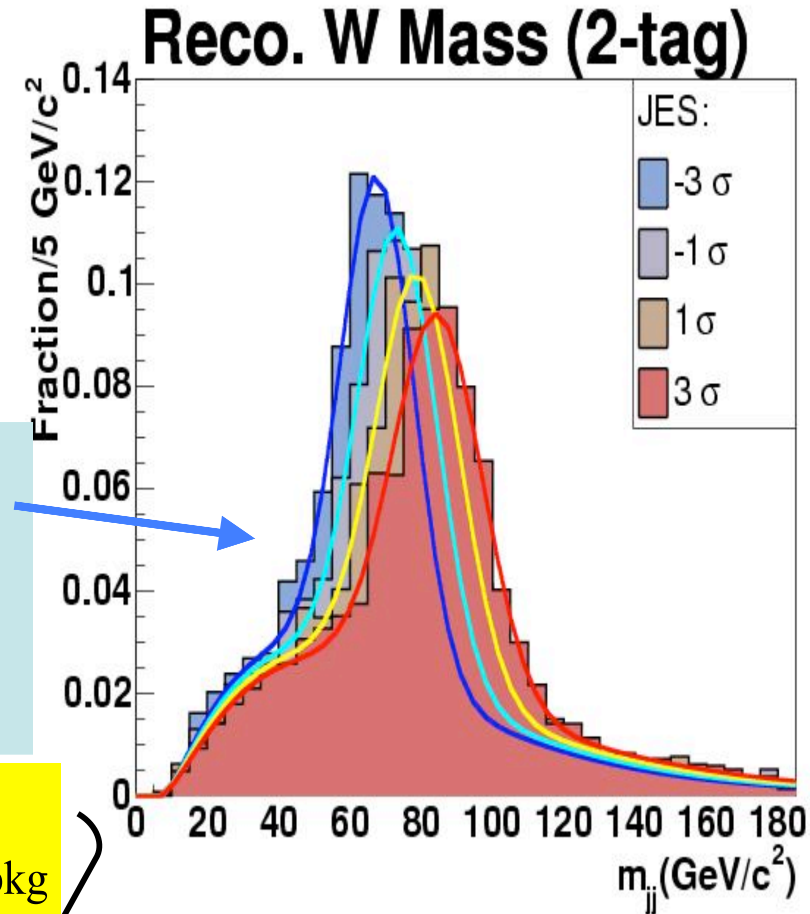
M_{top} using W→*jj* template



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

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

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



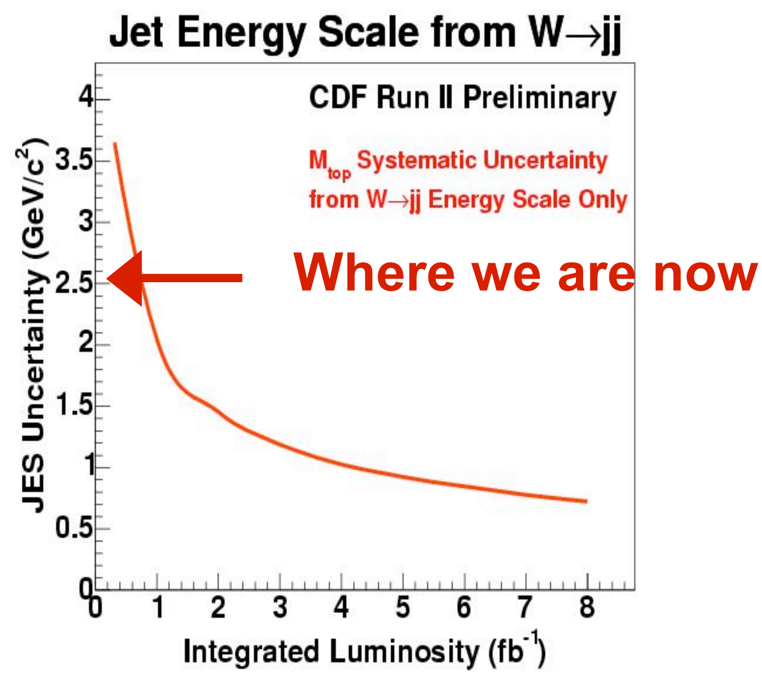
$$L = L_{JES} \times \Pi_i L_{sample(i)}$$

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

M_{top} systematics

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 with stat.



Soon the background systematic will dominate

The systematic on the top cross section and mass measurement receive a substantial contribution from the background knowledge

How do we plan to improve the W + jets background Knowledge.

boson+jets Cross Section

W/Z/photon + jets cross sections are important measurements:

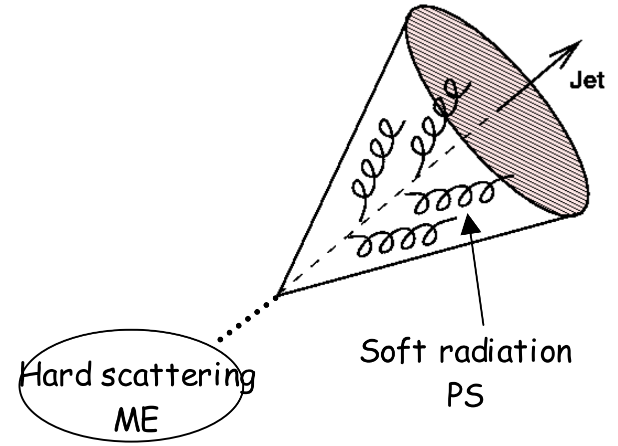
Bkgd for a number of high p_T analyses:

- ✓ top cross section & top mass
  - o W+jet/W+HF main background ~ 40%
- ✓ higgs searches
  - o Z+b bbar
  - o W+b bbar

QCD-Wise:

- ➢ high q^2 interactions (~M(boson))
- ➢ smaller subset of diagrams compare to jet production
- ➢ specific color flaw paths
- ➢ proton PDF (W/Z + HF)

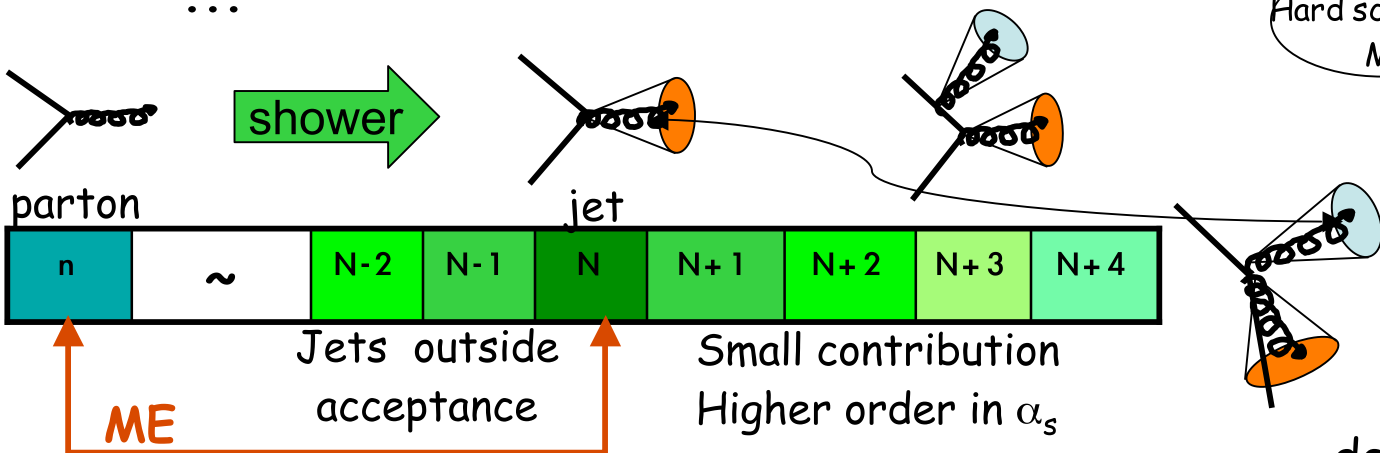
MC issues



Naïve: W+n p (ME)+(PS) ~ W + ≥ N jet

W+(n+1) p (ME)+(PS) ~ W + ≥ N+1 jet

...



2 topologies ~ O(α)

Same jet multiplicity

⇩

double counting

dep. on parton-level cuts

Problems:

how to generate the whole n jet spectrum avoiding double counting ?

how be sure that the selected jet is coming from the ME and not PS ?

Goal:

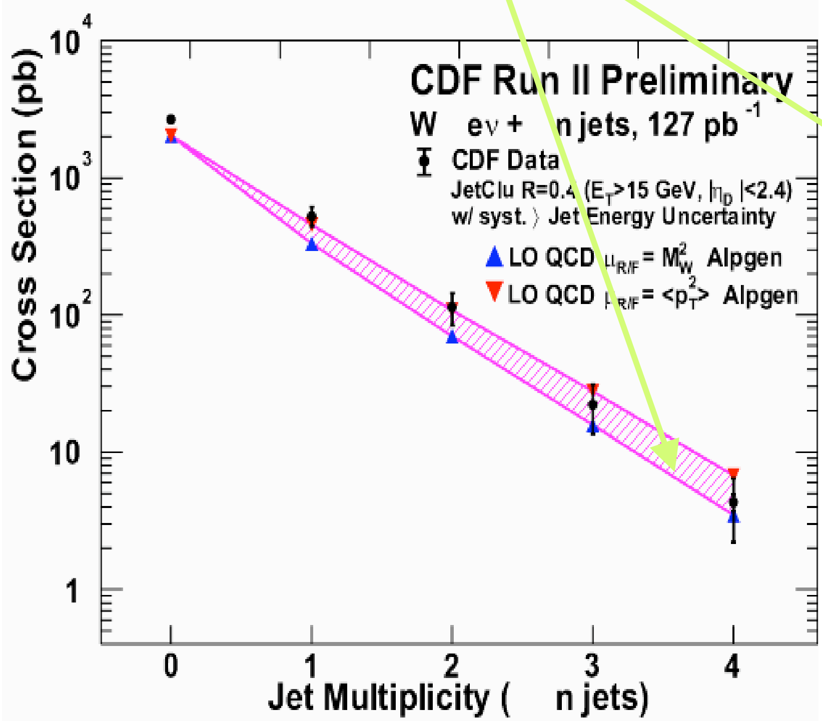
have a prescription to safely merge different MC multiplicity samples

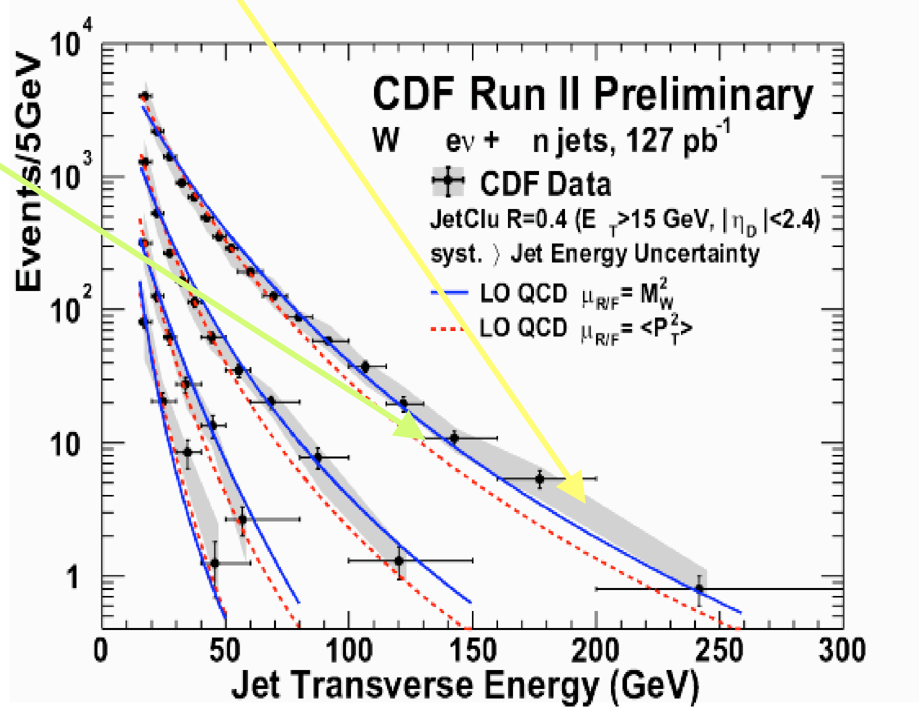
reduce the dependence on parton lavel phase-space

W+jet

MC sensitive to parton level cuts & Q² scale.

Data affected by large jet energy correction systematic.





Next step: tune the new tools on data by making measurement model independent (out of cone correction) and easily usable to test new models.

…new merging tools

Separate multijet phase-space

- Matrix element domain
- Parton shower domain

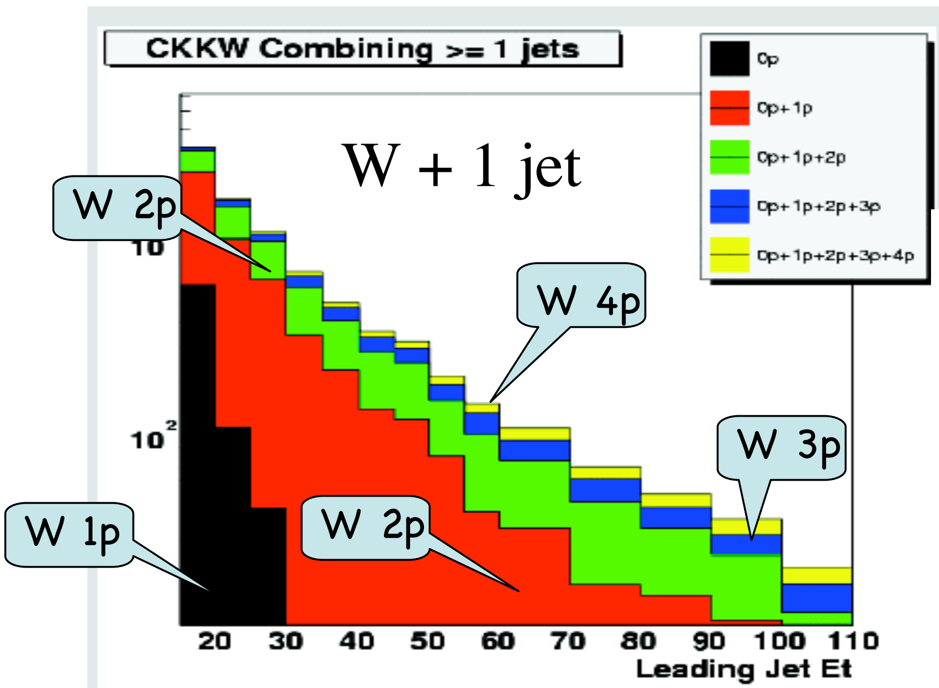
LO ME calculation interfaced with parton shower MonteCarlo

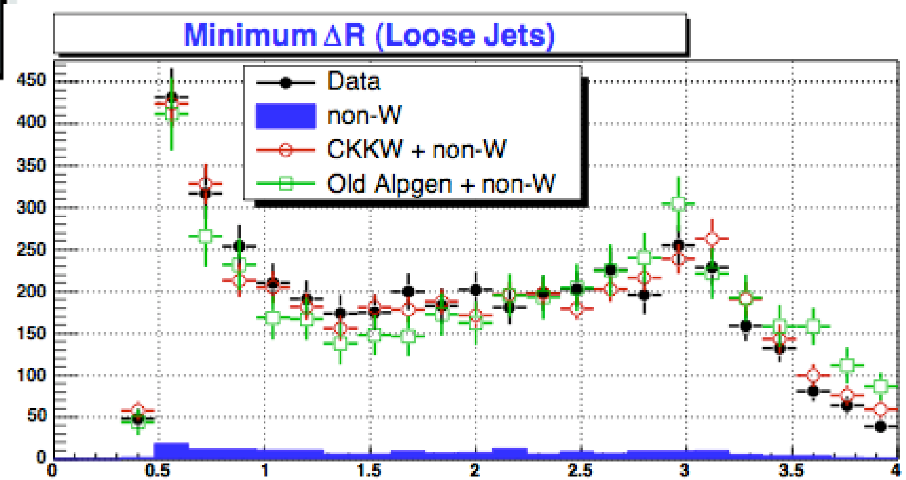
MLM's matching

Michelangelo Mangano

CKKW prescription

Catani, Krauss, Kuhn, Webber





Have to be validated & tuned on data

MC validation on data

- Measure cross sections for boson + jets (k-factors)
- Differential cross sections wrt (hard scale merging parameter)
  - Jet-E_T spectrum
  - Angular correlation jet-jet
  - Di-jet invariant mass
  - Boson p_T spectrum

Be as less as possible model depentend.
Provide clear results to be compared with theory

$\sigma(W|E^{ele}_T>20GeV, Met>30GeV)$
Is well defined both
theoretically & experimentally

$$\frac{\delta\sigma\left[\begin{array}{l} P_T^e > 20, M_T > 20 \\ P_T^{\upsilon} > 30, \eta^e < 1.1 \end{array}\right]}{\delta E_T^j}$$

Restrict the W cross-section to the measurable decay phase space

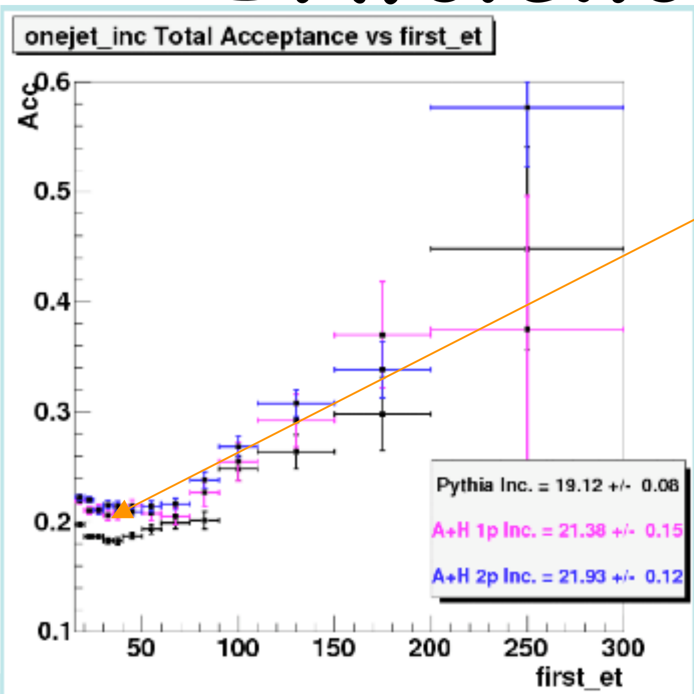
Jets corrected hadron level

JETCLU 0.4 (Midpoint)

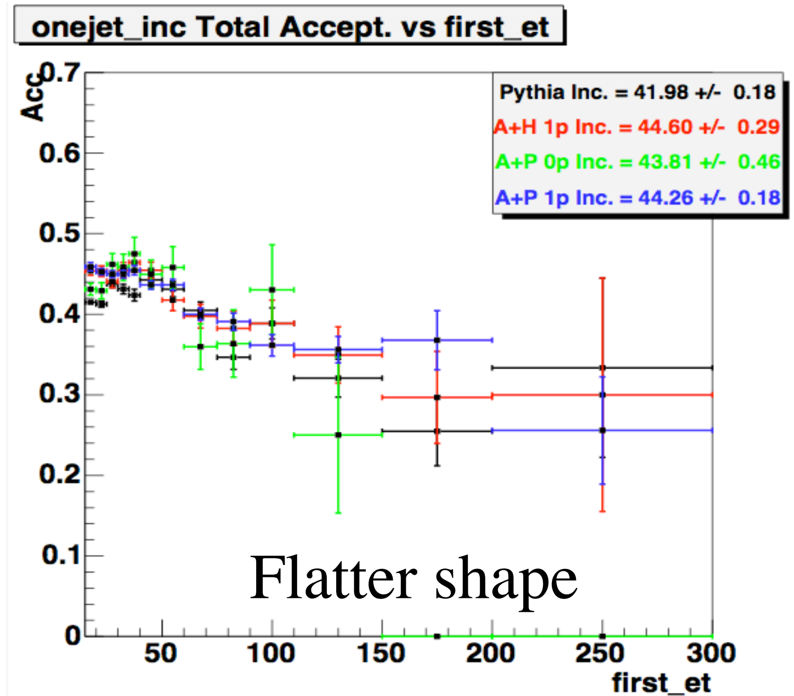
$E_T^{corr} \geq 15$ GeV; $\eta \leq 2.4$

Best prescription for theoretical comparisons

Efficiency/Acceptance



Difference in the leptons kinematic model enhanced by correcting back to the whole W phase space



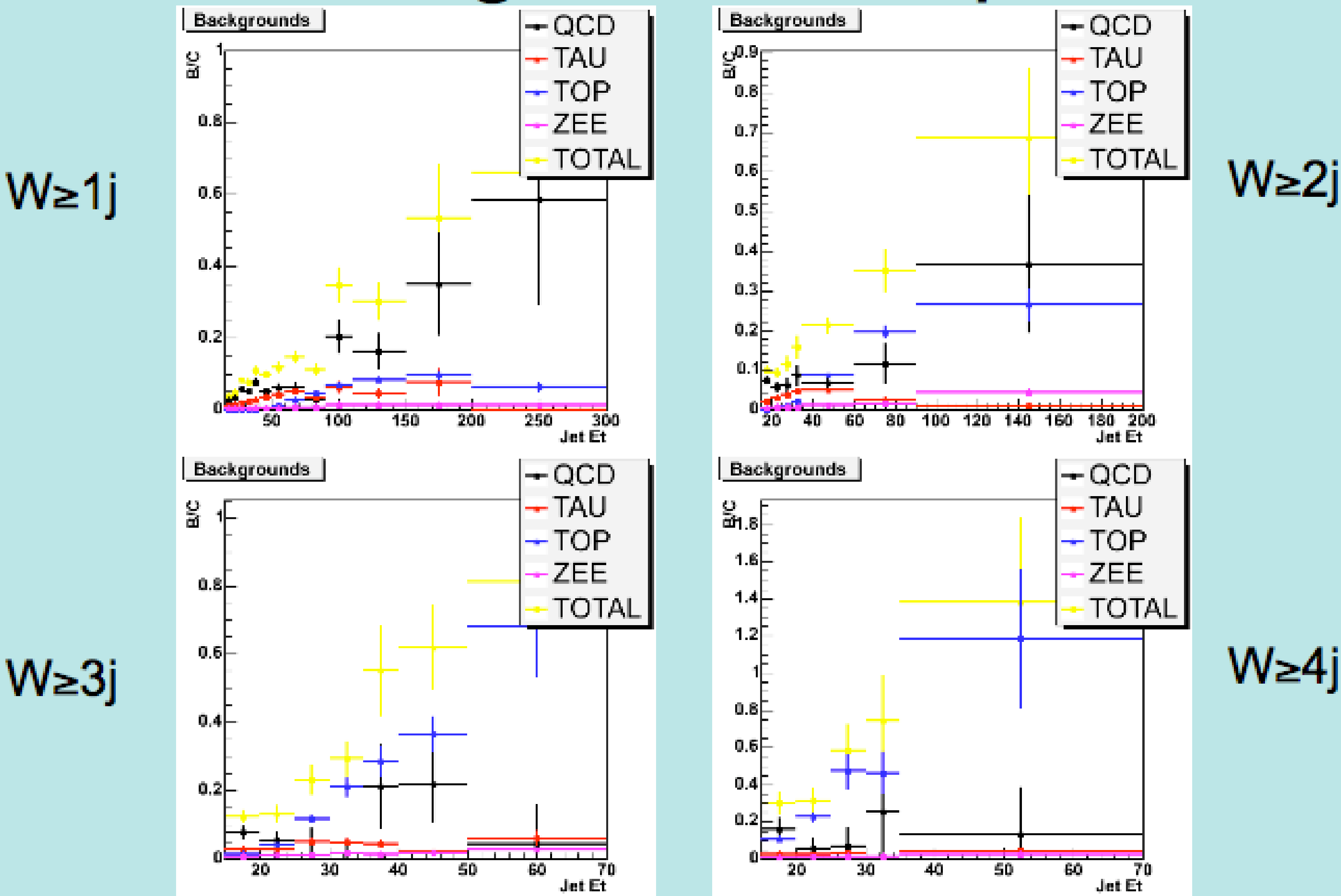
- Defining cross-section phase space as W detector cut acceptance:
  - Acceptance will correct only for detector resolution effects - independent of theoretical model?
- Use W+np MC for acceptance and ID efficiency
  - Systematic on ID efficiency comparing Z MC and data
  - Systematic on acceptance from different MC models

Reconstructed level cuts in numerator

$$A^{j^n_{E_T}} = \frac{N^{j^n_{E_T}}(E_T; P_T; \not{E}_T; WM_T; \eta^D; fid)_{Reco}}{N^{j^n_{E_T}}(E_T; \not{E}_T; WM_T; \eta)_{Gen}}$$

Generator level cuts in denominator

B/C Background Composition



QCD background - part II

For differential measurement a sample of QCD bkgd events is needed with a reliable shape.

Met.vs.Iso inadequate with jets:

- ✓ limited statistic for high jet multiplicity
- ✓ difficult to generalize for jet kinematic
- ✓ some correlation between anti-isolated ele & jet (for example in 1jet event)
- ✓ Met is sensitive to the event jet multiplicity

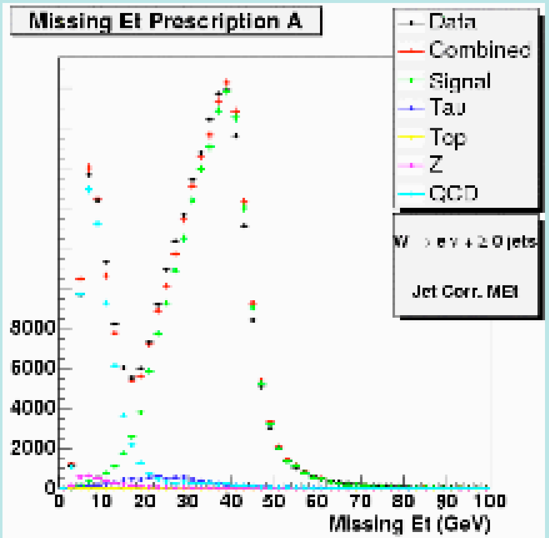
QCD background - part II

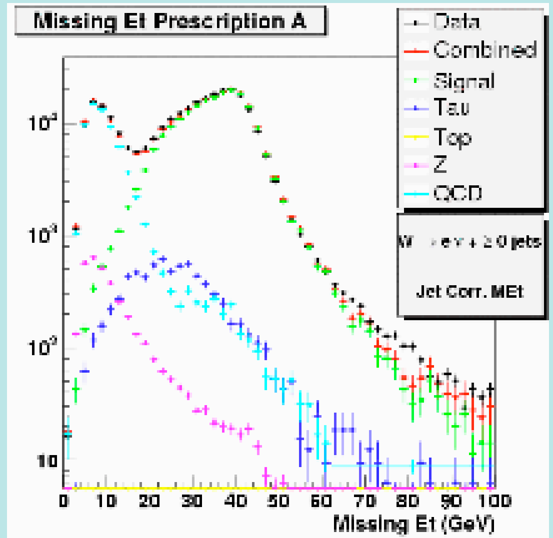
- ✓ form a fake electron sample by requiring passes "kinematic" cuts but fails at least 2"ID"variables
  - ✓ kinematic ET, PT, h, E/P, isolation
  - ✓ pure ID Had/Em, chi2 track, matching track-cal
- ✓ ID variables will not introduce kinematic bias: the fake ele sample will be kinematically identical to fakes in data

- ✓ Correct the Met for jets by looking to the Z events
- ✓ Make the Met correction a function of the Z recoil energy than the jet multiplicity

- ✓ Bkgd rate by fitting the Met shape of antielectron & W-like bkgd to data
- ✓ Antielectron sample does contain EWK contamination 5%

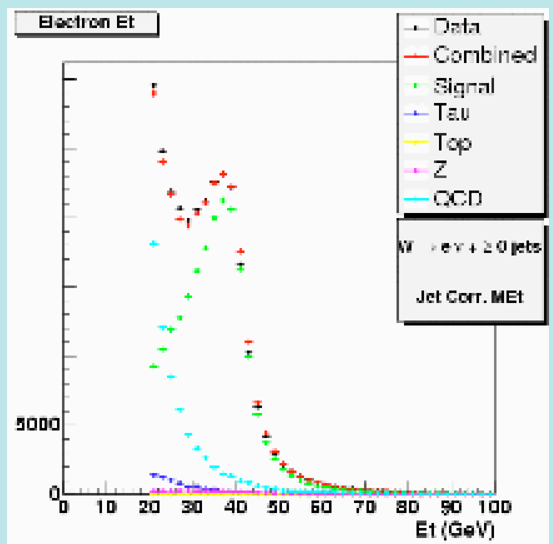
Background Method

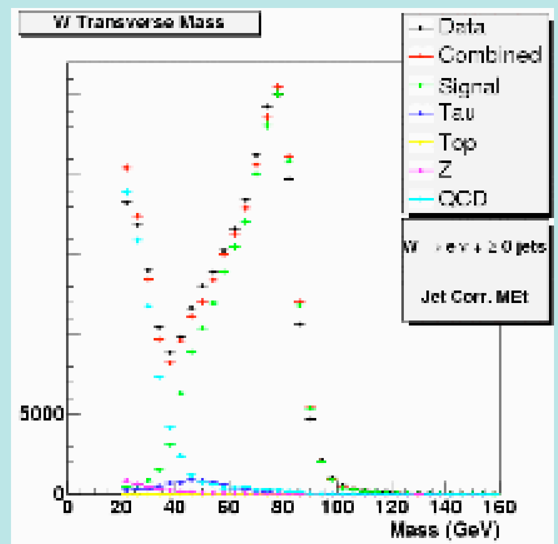




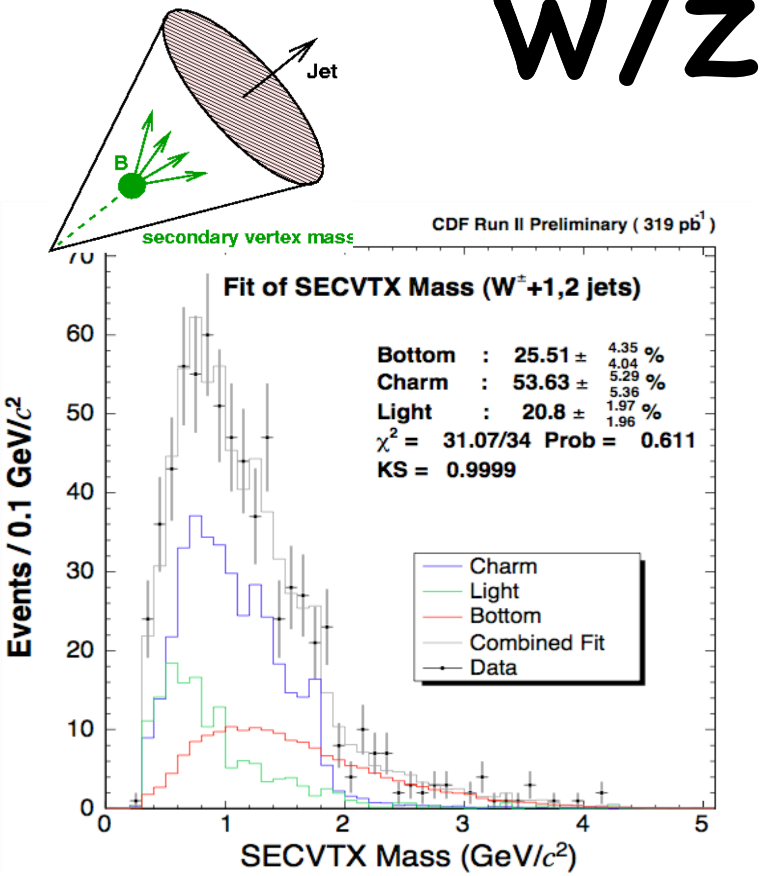
Max. likelihood fit of antielectron and MC model shapes to data - integrals above 30GeV give inclusive bkgds

QCD and MC models give excellent agreement with data in WM_T and electron E_T kinematics

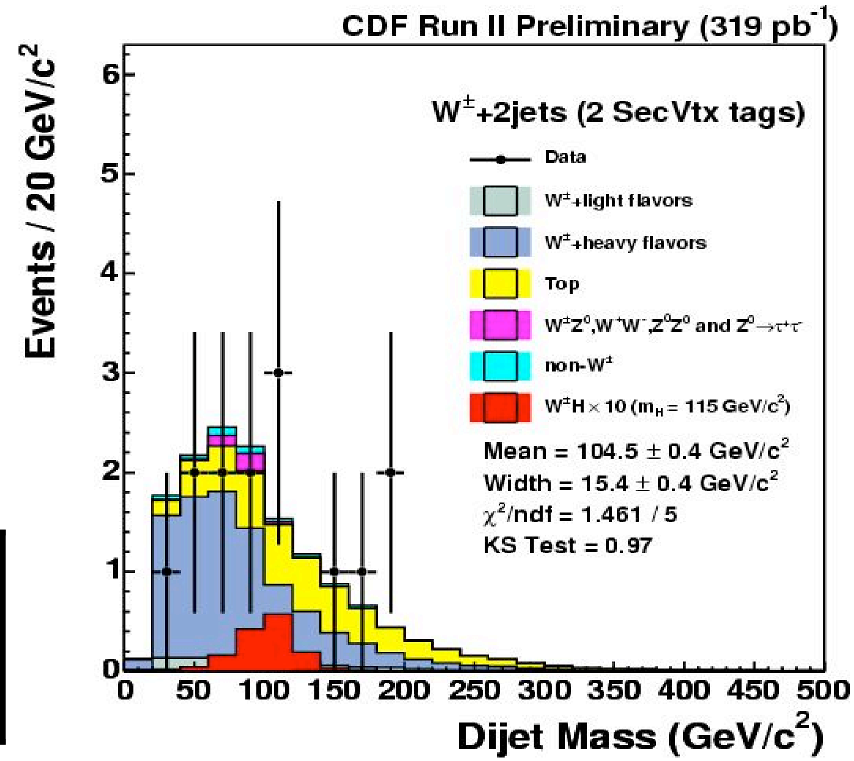




W/Z + HF jets



Use the secondary vertex invariant mass to discriminate between b, c, light quark



W+ b jet

	σ(W + b) / σ(W + jet)
1 jet	0.0169 ±0.0101
2 jet	0.0169 ±0.0101

Z+ b jet

E^{jet}_T > 20GeV, $|\eta^{jet}|$ < 1.5	CDF Prelim. Data	PYTHIA
σ(Z + b jet)	0.96±0.32 ±0.14pb	0.83pb
σ(Z + b jet)/σ(Z + jet)	0.0237 ±0.0078 ±0.033	0.0207

Conclusions

- To make precise measurement and to set stringent limits a good knowledge of the backgrounds is needed.
  - QCD, boson + jets and soft underlying physics are some of the high p_T relevant backgrounds

- We are making progress in the MonteCarlo tuning to have a reliable description of relevant backgrounds

Backup slides

...new merging tools

CKKW prescription
Catani, Krauss, Kuhn, Webber

MLM's matching
Michelangelo Mangano

Separate multijet phase-space

- Matrix element domain
- Parton shower domain

1. Reweight the ME parton level inclusive N-jet rate to reproduce the probability of N-jet exclusive final state
2. Veto the showers with hard emission

1. Generate parton: $p_T > p_{TMin}$; $\Delta R_{jj} > R_{Min}$
2. Perform parton showering
3. Reconstruct event with a cone algorithm (E_{Tmin}; R_{jet}), before had.
4. Match partons with jets in R
5. If all partons are matched keep the event, else discard it
6. Define exclusive N-jet samples by requiring $N_{jet} = N_{part}$

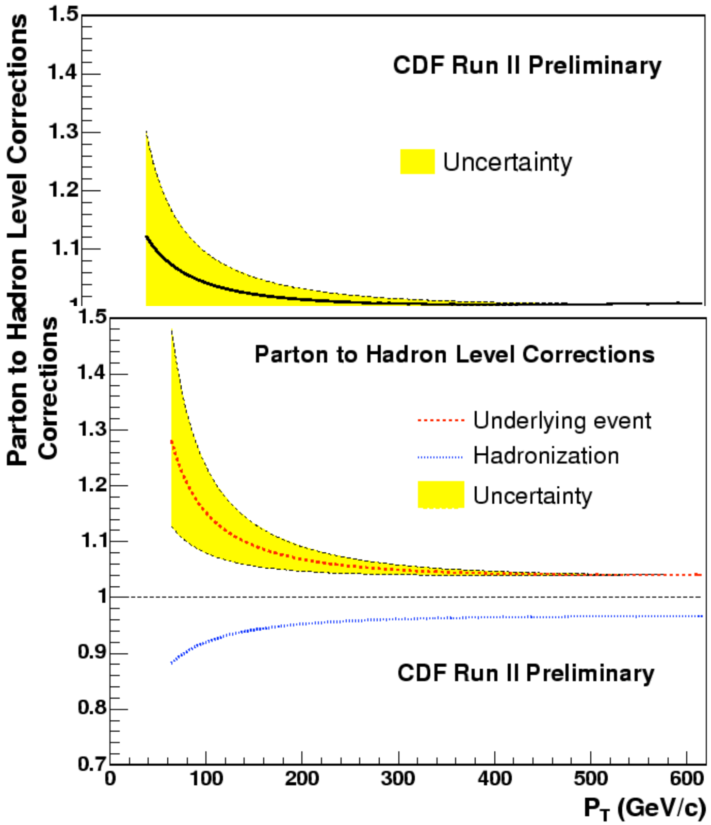
Correct to parton level

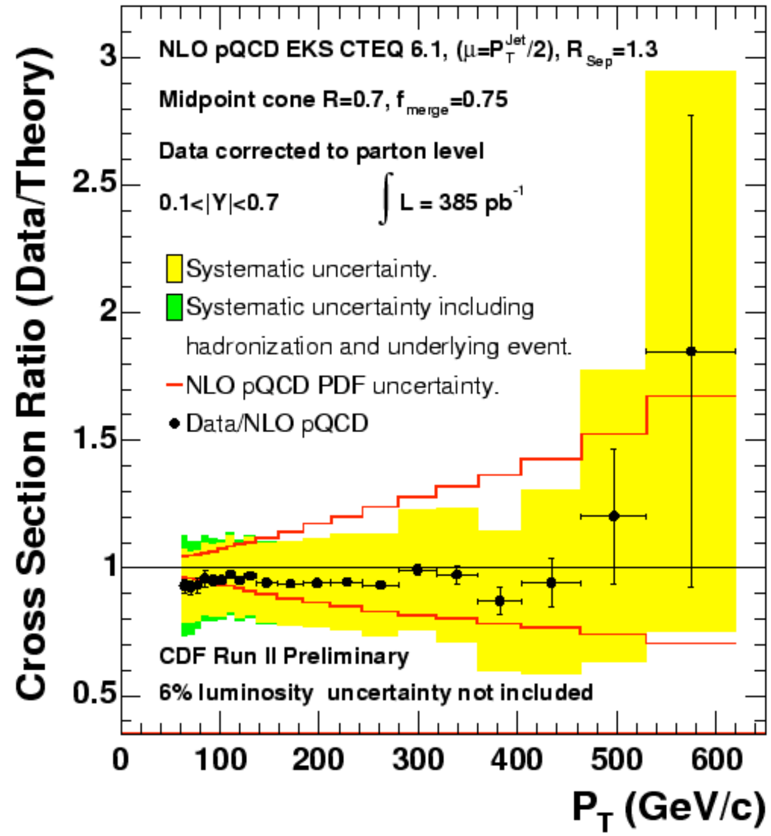
MidPoint Cone Algorithm (R = 0.7, f_{merge} = 0.75)

Data corrected to the parton level

$0.1 < |y_{jet}| < 0.7$

Compared with NLO QCD (JetRad, R_{sep} = 1.3)



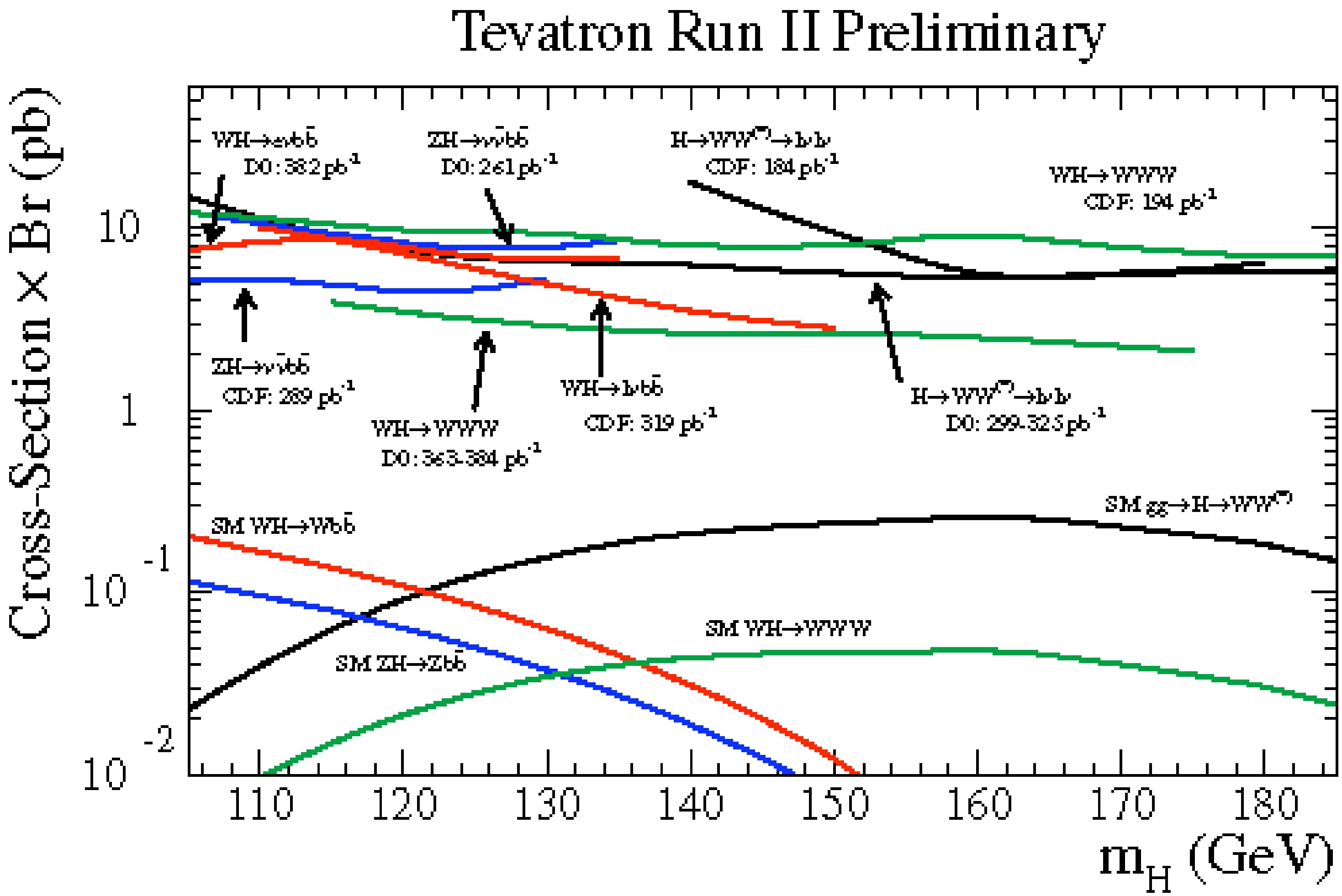


Contributions resulting from the underlying event and hadronization effects to the overall hadron to parton correction.
The corrections are derived using PYTHIA. The uncertainty of the correction was estimated by taking the difference between HERWIG and PYTHIA and is shown as the band in the plot.

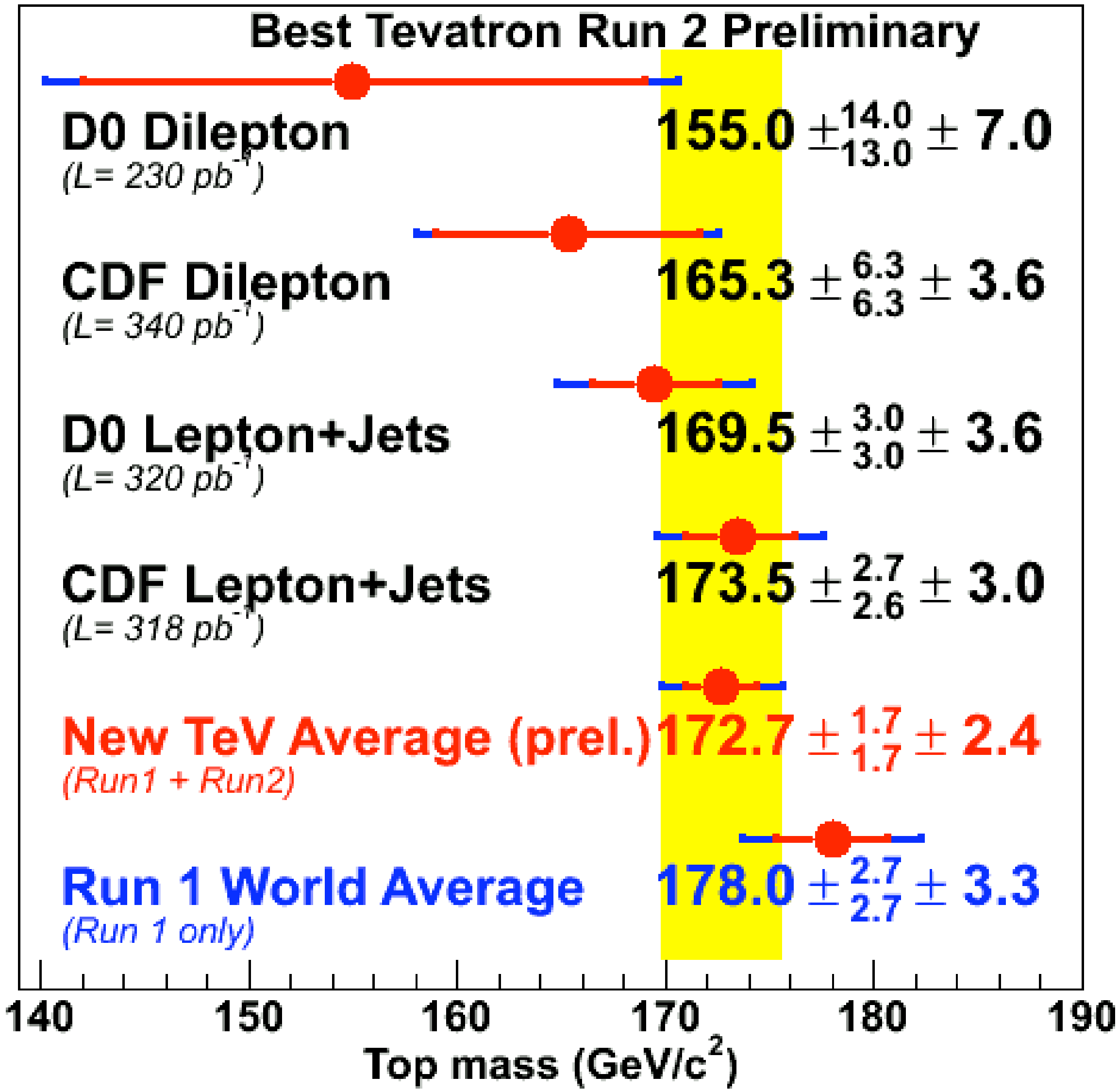
W mass systematic

Systematic [MeV]	Electrons (Run 1b)	Muons (Run 1b)	Common (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)	25
Recoil Scale and Resolution	50 (37)	50 (35)	50
Backgrounds	20 (5)	20 (25)	
Production and Decay Model	30 (30)	30 (30)	25 (16)
Statistics	45 (65)	50 (100)	
Total	105 (110)	85 (140)	60 (16)

Higgs limits

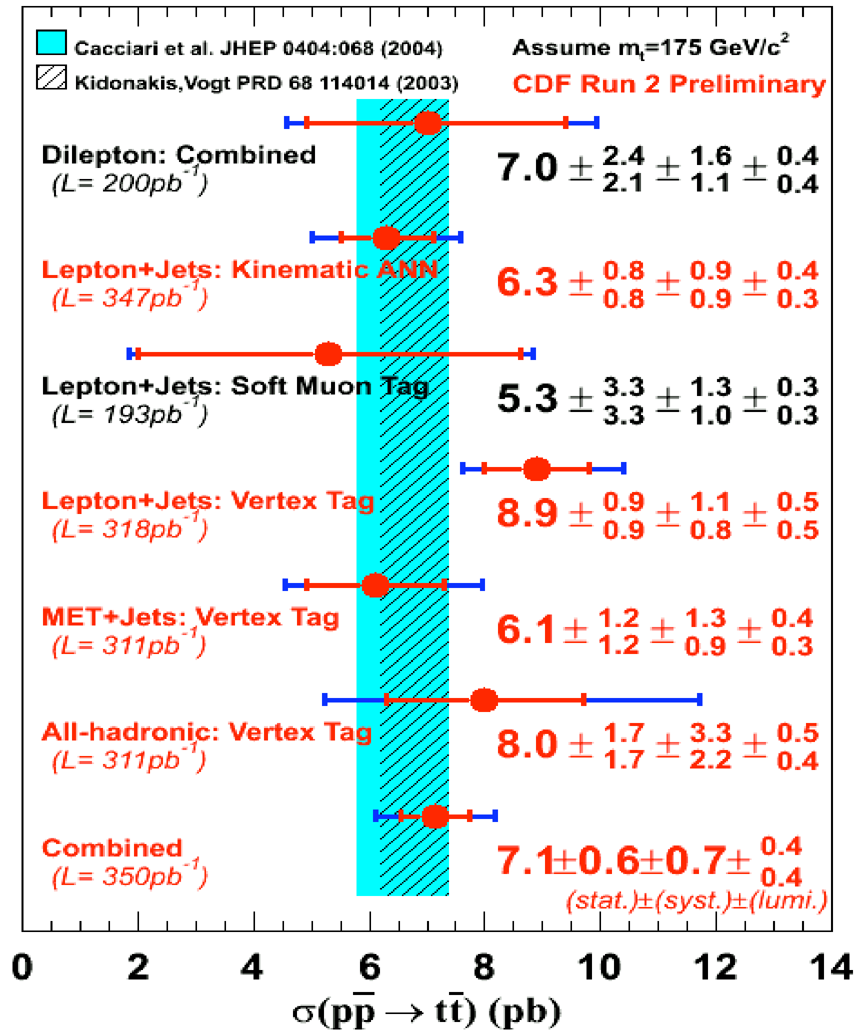


Top Mass



Best Tevatron Run 2 Preliminary
D0 Dilepton
(L= 230 pb^-1)
155.0 ± 14.0/13.0 ± 7.0
CDF Dilepton
(L= 340 pb^-1)
165.3 ± 6.3/6.3 ± 3.6
D0 Lepton+Jets
(L= 320 pb^-1)
169.5 ± 3.0/3.0 ± 3.6
CDF Lepton+Jets
(L= 318 pb^-1)
173.5 ± 2.7/2.6 ± 3.0
New TeV Average (prel.)
172.7 ± 1.7/1.7 ± 2.4
(Run1 + Run2)
Run 1 World Average
178.0 ± 2.7/2.7 ± 3.3
(Run 1 only)
140
150
160
170
180
190
Top mass (GeV/c^2)

Top Cross Section



b-tagging

Displaced tracks⇒sec.vtx

Tag ε *per* jet from physics MC (Pythia top)

Scale factor from di-jet Data/MC