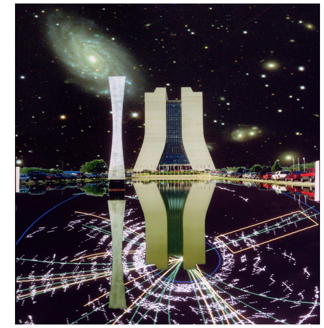
Jet Production with Vector Bosons and Heavy Flavor at the Tevatron



Sebastian Grinstein

ICREA/IFAE-Barcelona

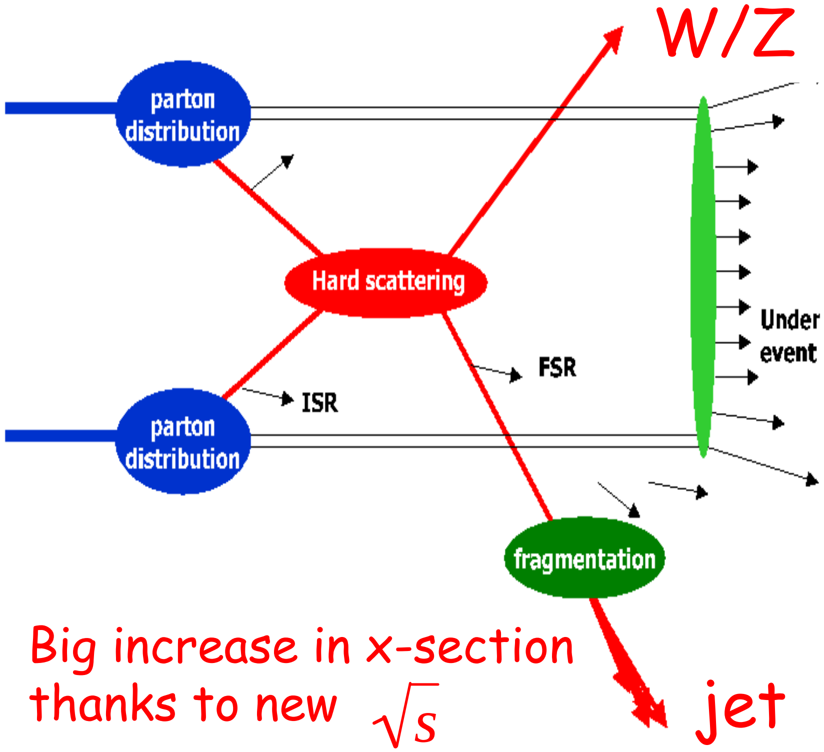
Results from CDF & D0 Collaborations

APS April Meeting 2009
Denver, CO
http://flickr.com/photos/72926532@N00

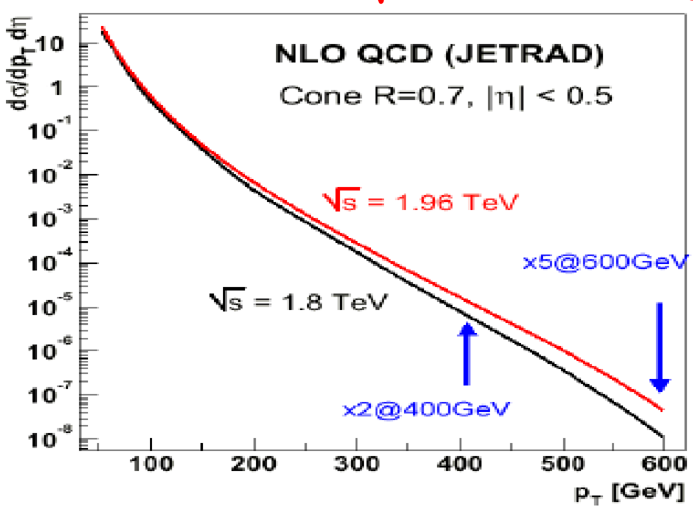
Outline

- Underlying Event Studies
- Z/W+jets Production
- Experimental Techniques
  - b-Jet Identification
- $b\bar{b}$ Production
- Z+b Production
- W+b/W+c Production
- Final Remarks

High pT QCD Physics at 2 TeV



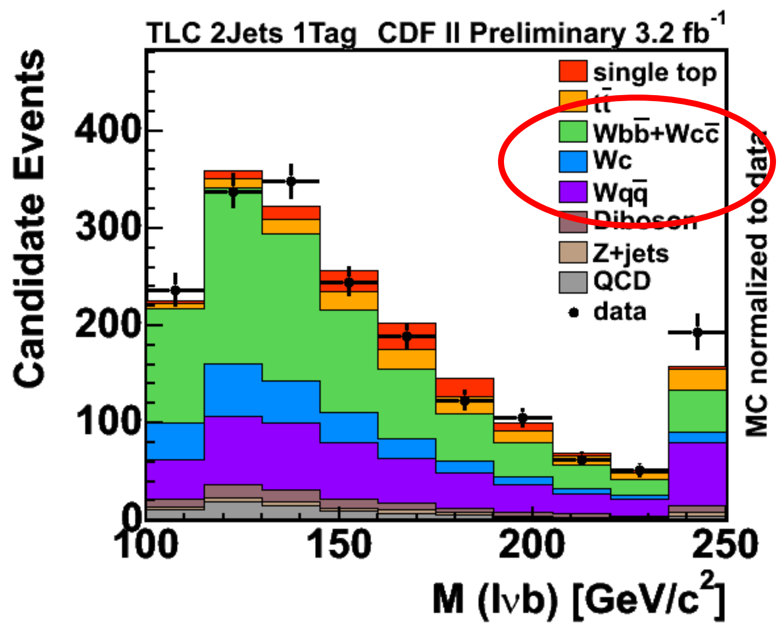
Big increase in x-section thanks to new $\sqrt{s}$



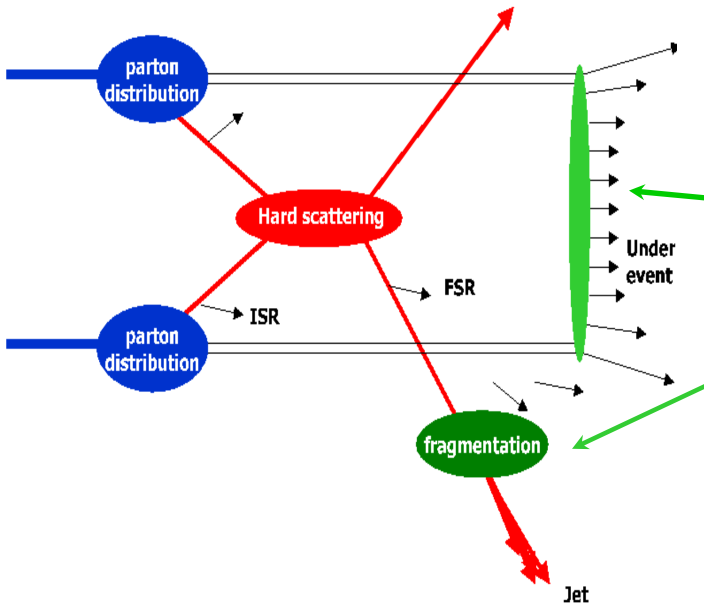
Big step forward in Run II

- Larger statistics
- Increased pT range
- Measurements in wide rapidity region
- Improvements in jet algorithms
- Inclusion of non-pQCD contributions

W/Z + Jets major background to many measurements and searches



Non-pQCD Contributions

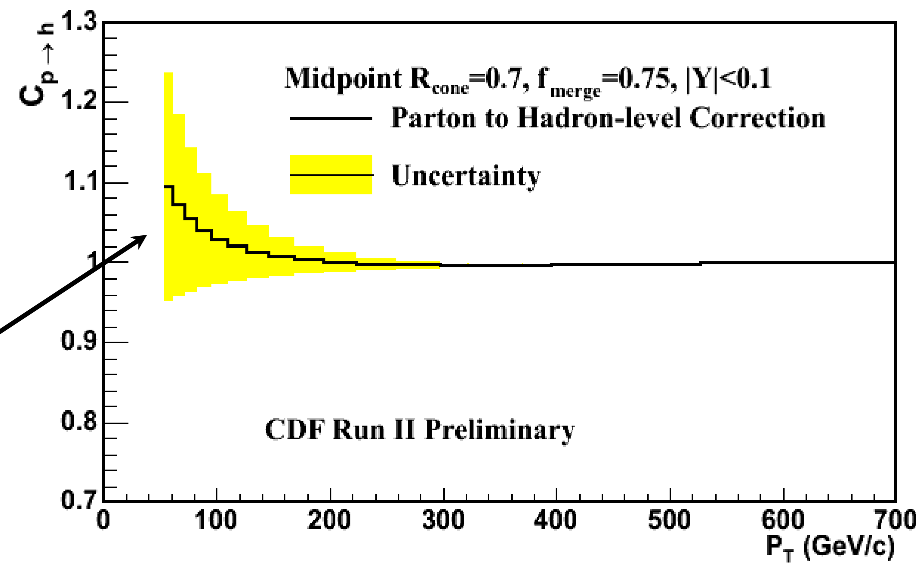


- Non-pQCD contributions
- Underlying Event (remnant-remnant interactions)
- Fragmentation into hadrons

Underlying Event and Fragmentation contributions must be considered before comparing to NLO QCD predictions
(only way to perform a fair comparison)

Precise measurements at low Pt require good modeling of the non-pQCD terms

Dedicated measurements are needed to validate the Monte Carlo modeling

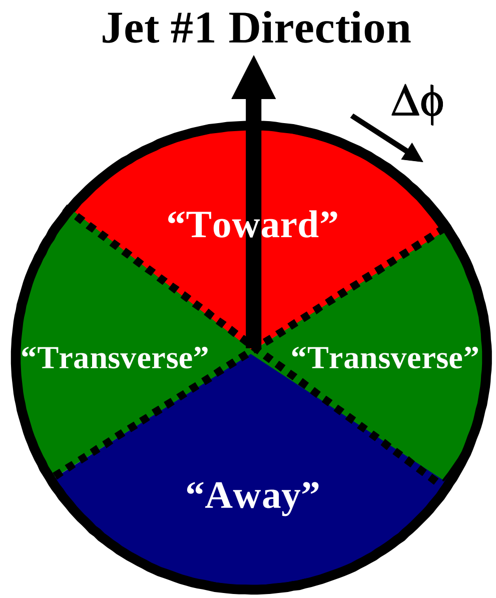


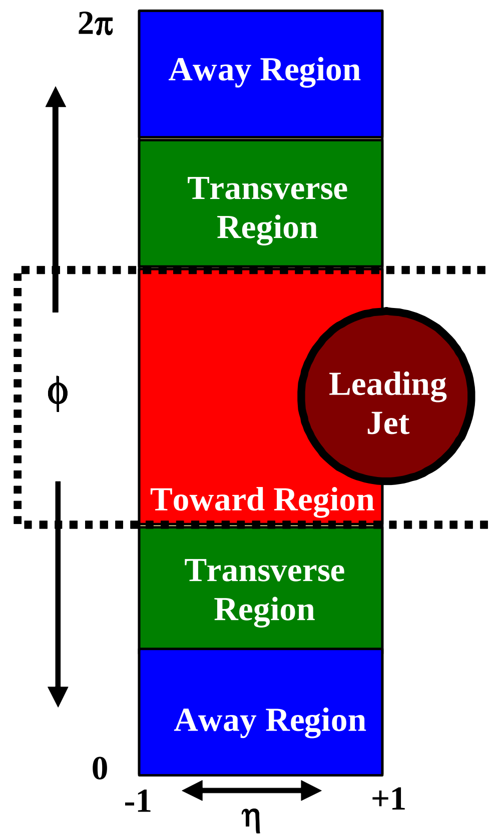
Underlying Event Studies

Goal: improve understanding and modeling of high energy collider events

Define 3 regions in an event, based on the leading jet

- "toward"
- "away"
- "transverse"





"transverse" region

→ very sensitive to underlying event

Study (in all regions)

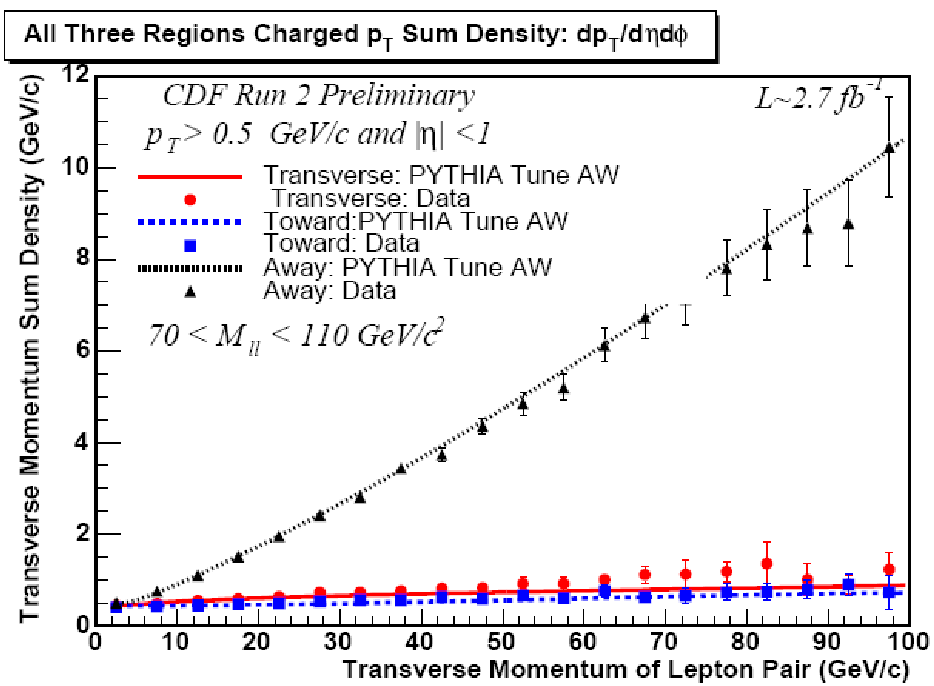
- charged particle density
- pTsum density
- Etsum density

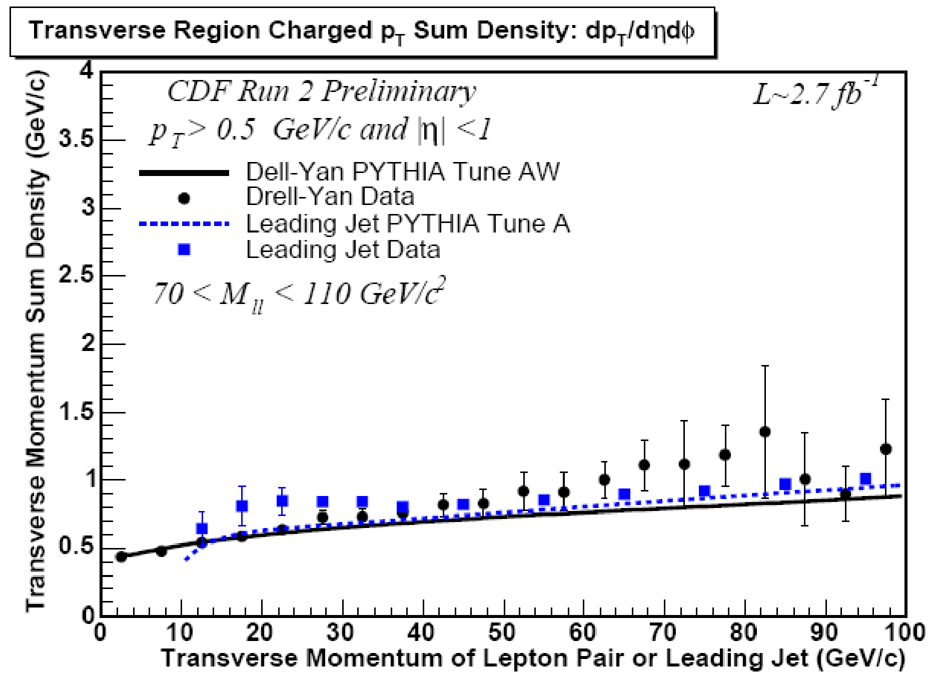
Underlying Event in Drell-Yan and Jet Production

→ charged pT sum density

Comparison of the **three regions** in DY:

- "away" region: pT density increases with lepton pair pT
- "transverse", "toward" regions: pT density flat with lepton pair pT

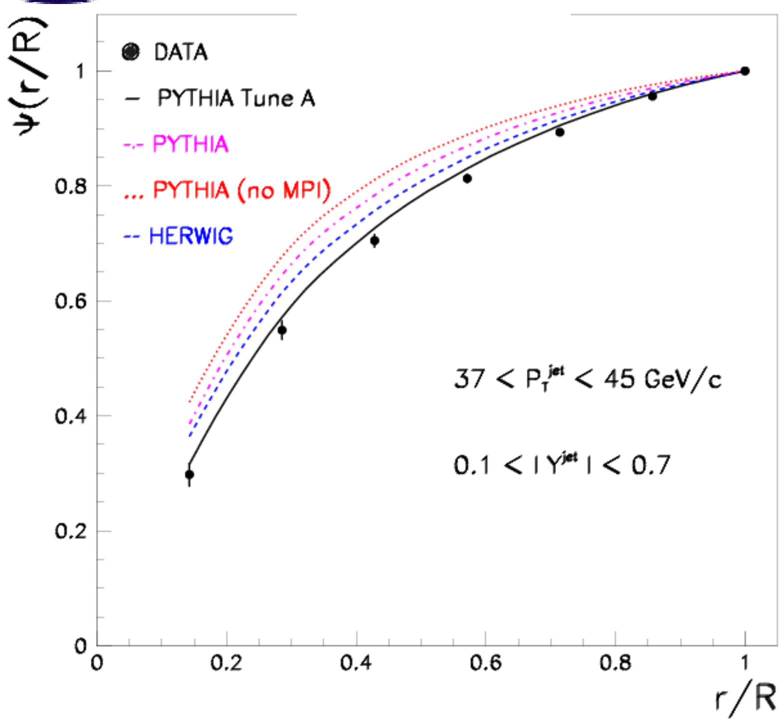


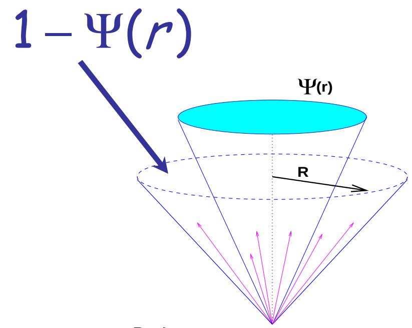


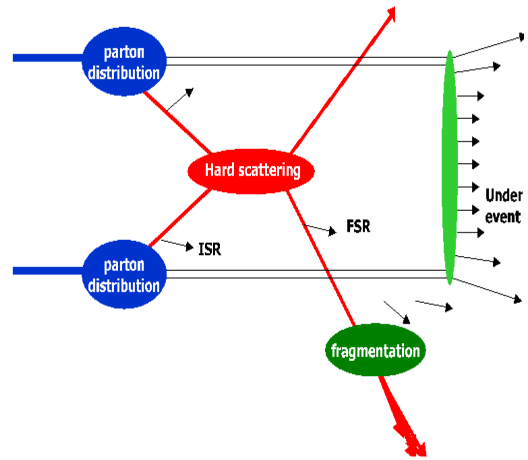
Comparison of "transverse" region between **jets and DY**

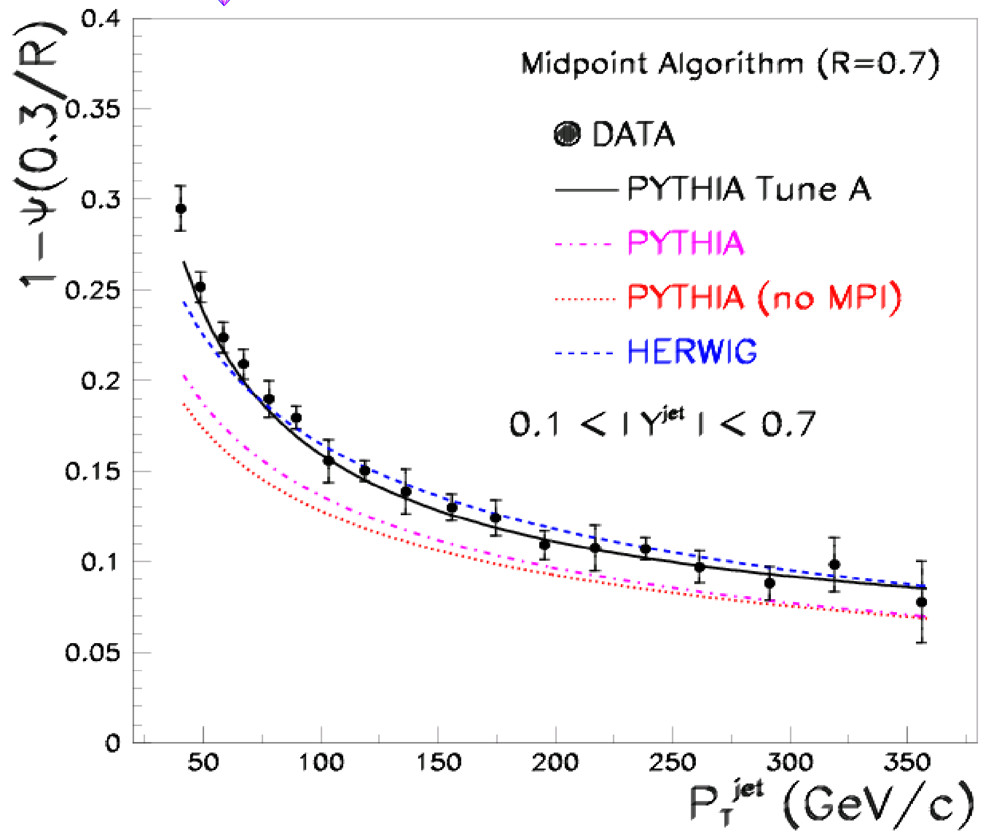
- Similar trend in both
- Tuned PYTHIA describes data

Jet shapes





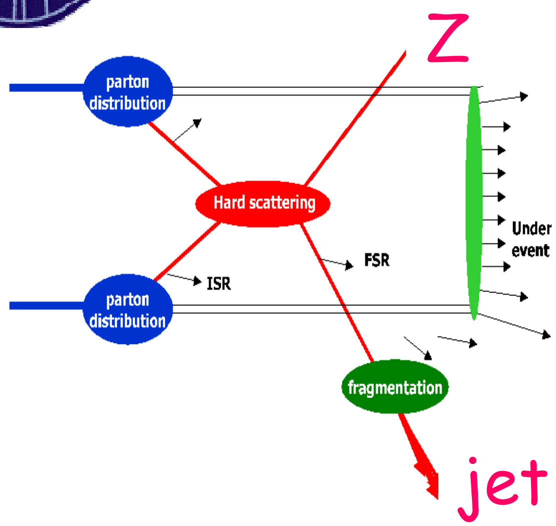


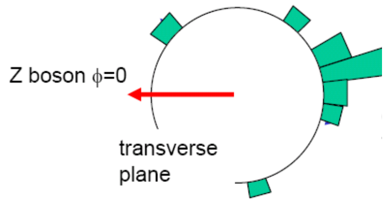


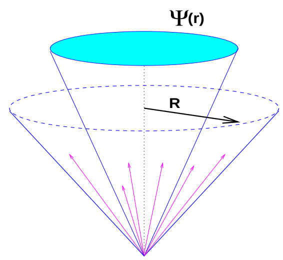
- PYTHIA Tune A describes the data (enhanced ISR + MPI tuning)
- PYTHIA default too narrow
- MPI are important at low Pt
- HERWIG too narrow at low Pt

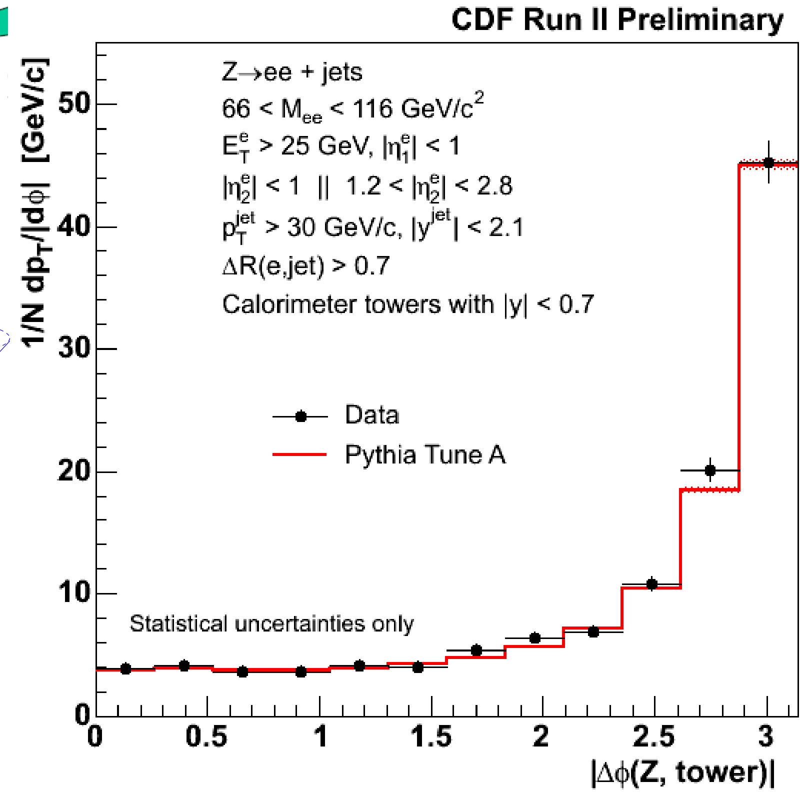
We know how to model the UE at 2 TeV for QCD jet processes

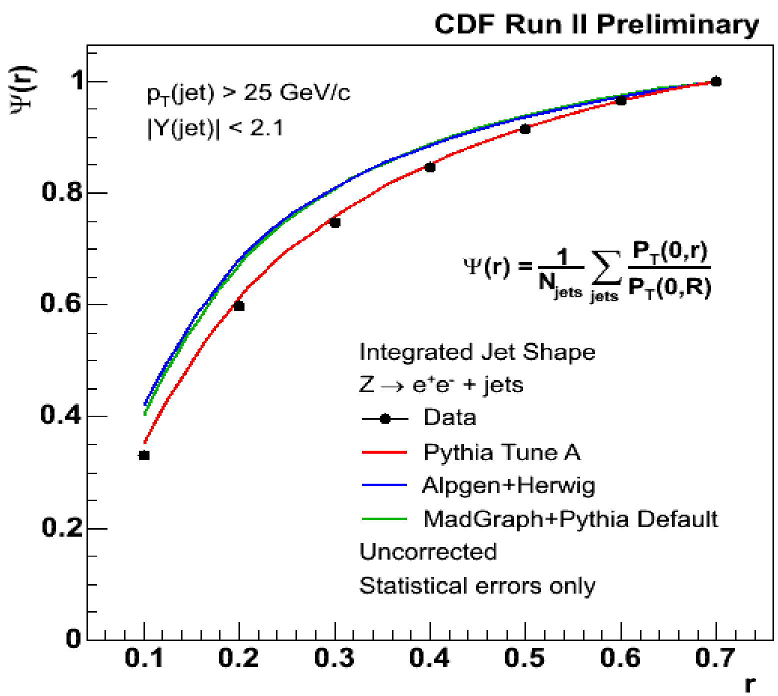
Soft radiation in Z+jet(s)







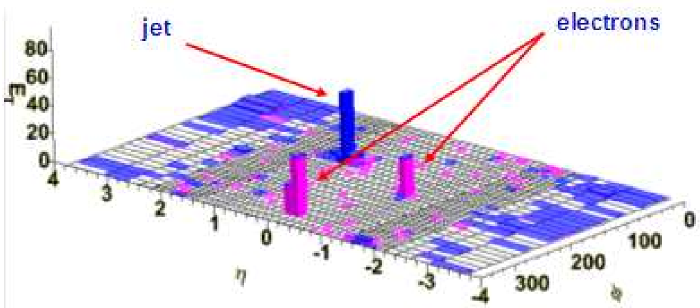


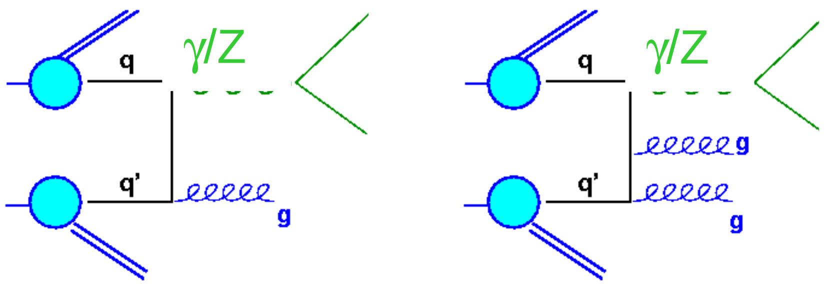


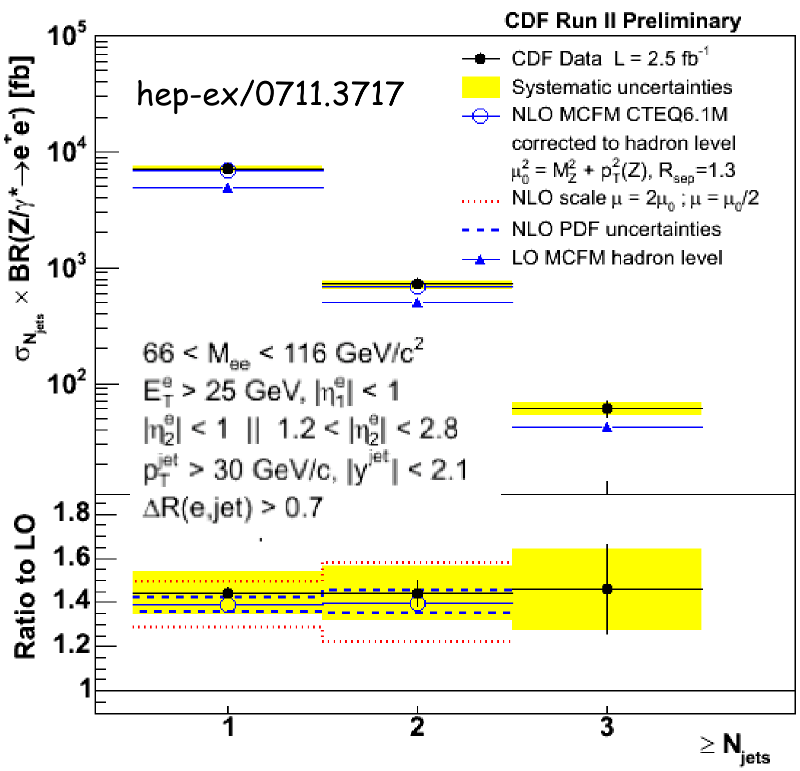
- Implementation of proper modeling of UE still needed in new W/Z+Jet(s) Monte Carlos....very important
- Pythia tune A: good agreement

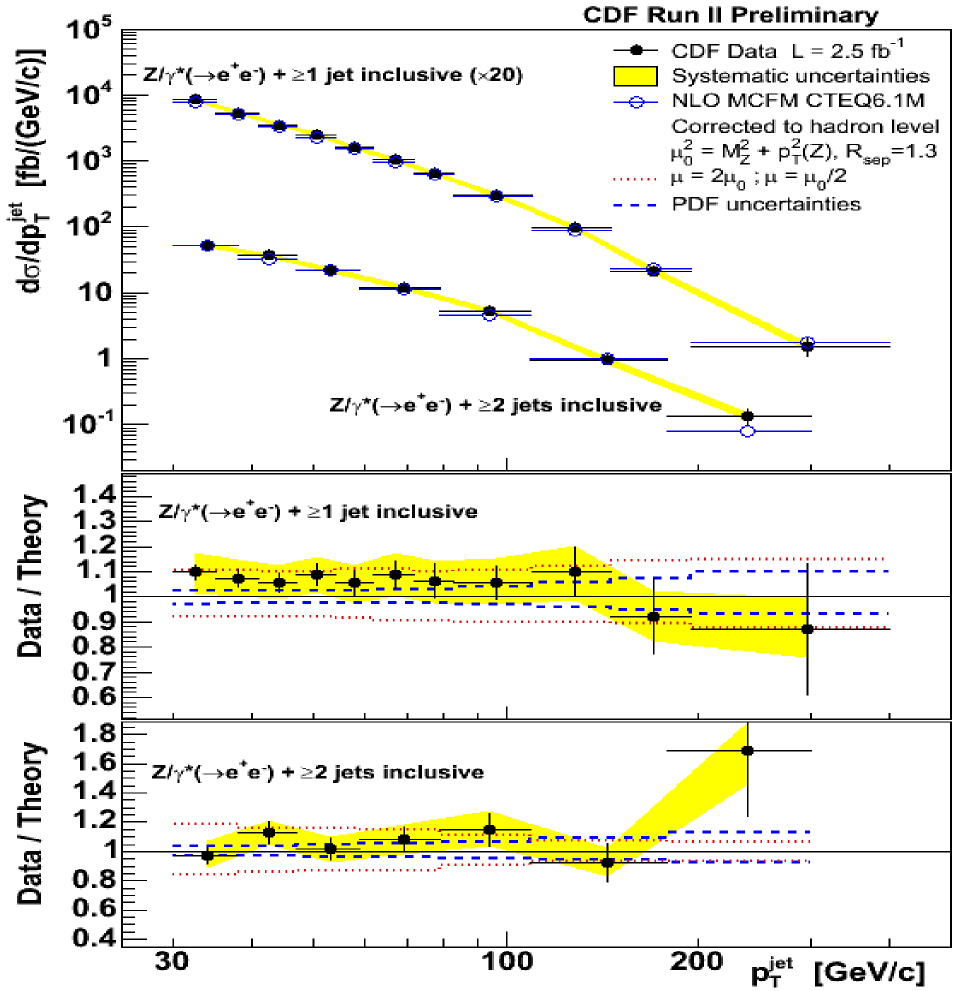
$Z/\gamma^*(\to ee)$ +jet(s)

Clean and allows to validate $Z\to\nu\nu$+jets bkgs.









Good agreement with NLO pQCD predictions including non-pQCD corrections

Z/γ*(-> ee) +jet(s)

- Test pQCD predictions and event generators
- Jets: $p_T > 20$ GeV, $|y|<2.5$, R=0.5
- Electrons: $E_T > 25$ GeV, 65 < Mee < 115 GeV

hep-ex/0903.1748

- NLO pQCD large improvement over LO

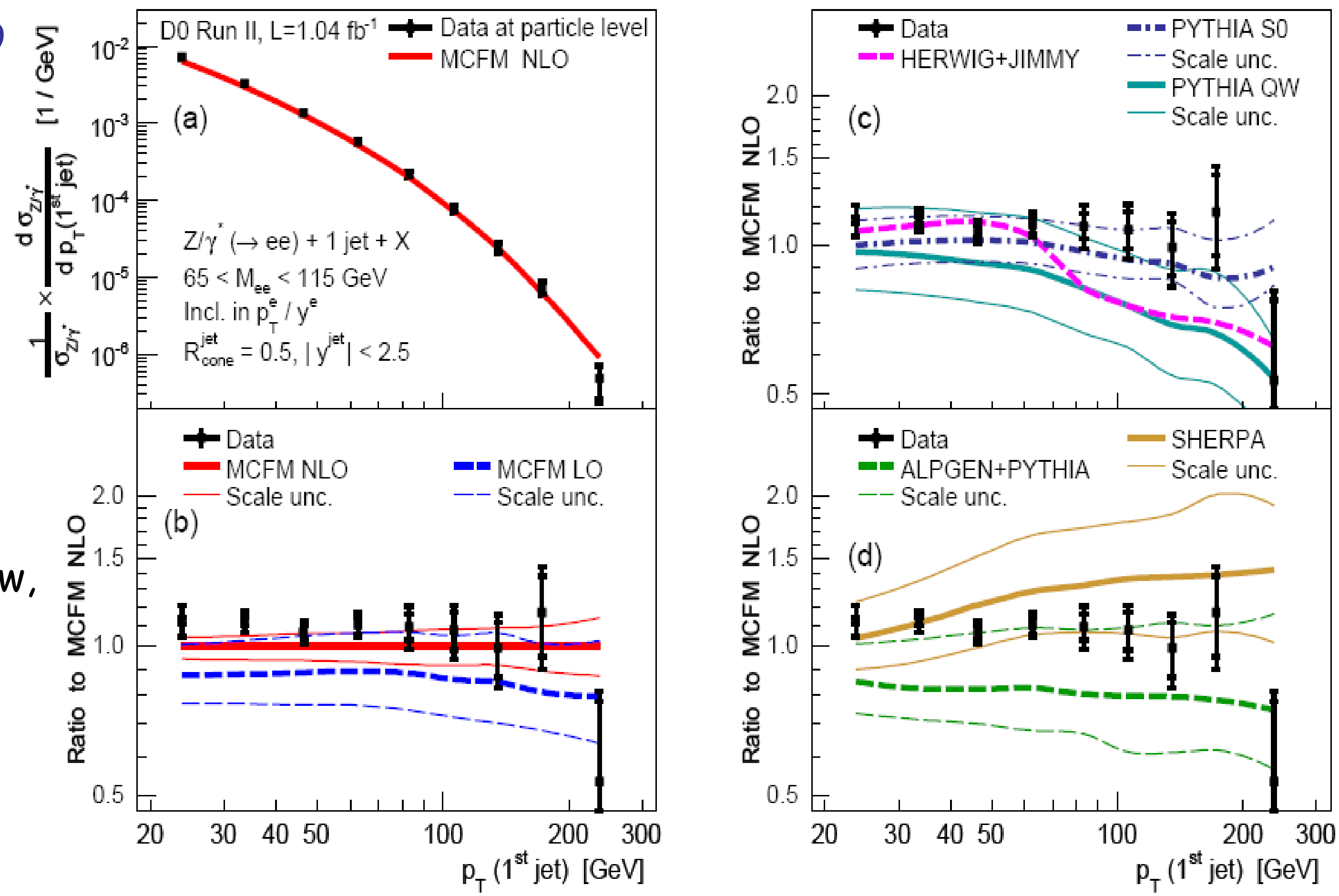
- Event Generators:

  Pythia "pT ordered" better description

  Sherpa: harder than data

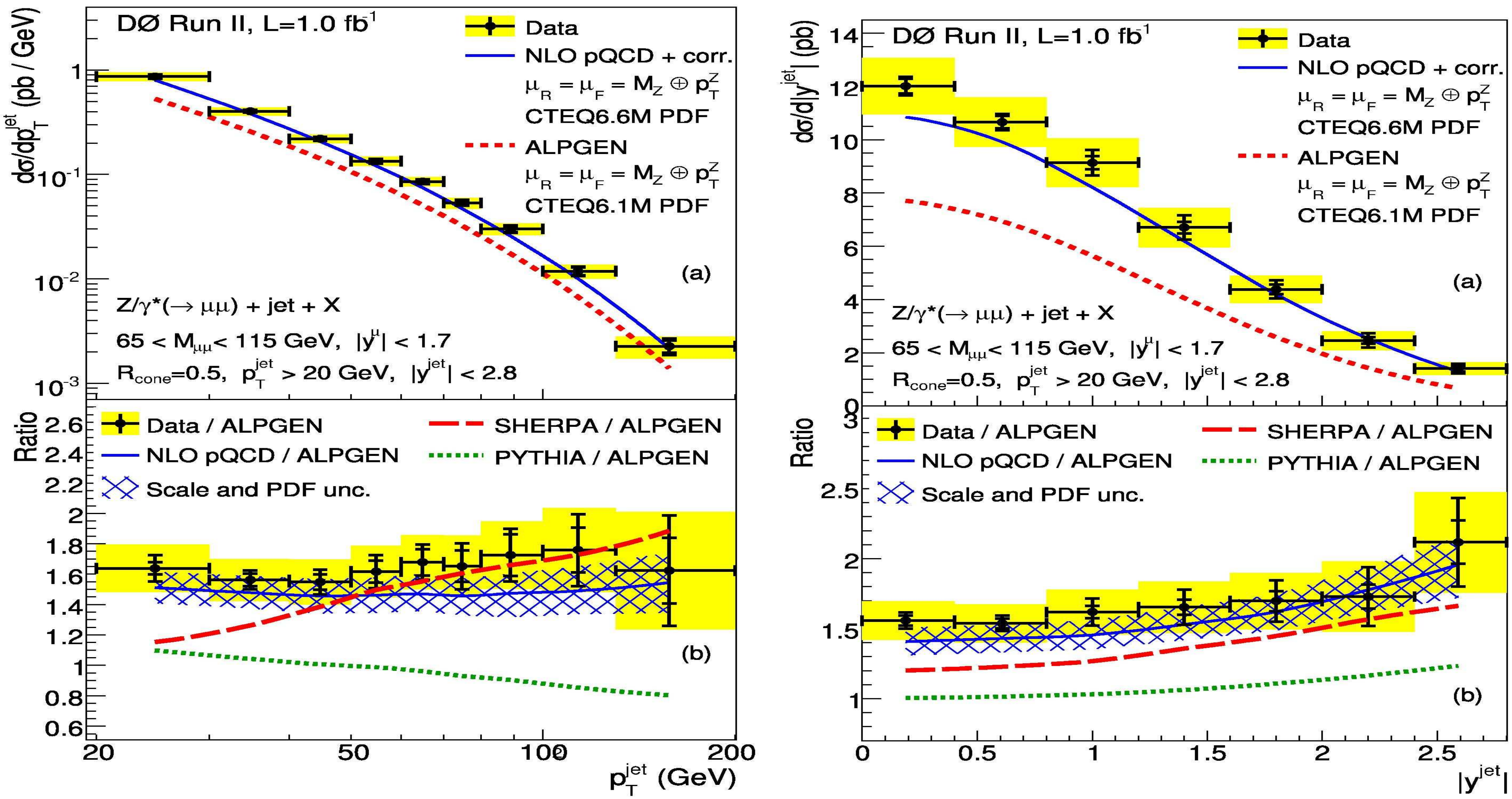
  Alpgen+Pythia: too low, but right shape

P_T (1st Jet), Normalized with $\sigma(Z)^{-1}$



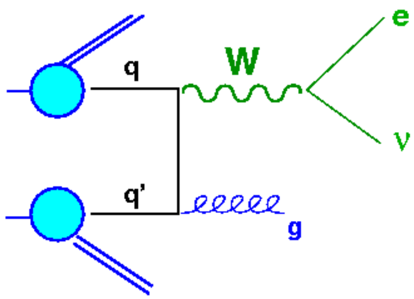
Z/γ*(-> μμ) +jet(s)

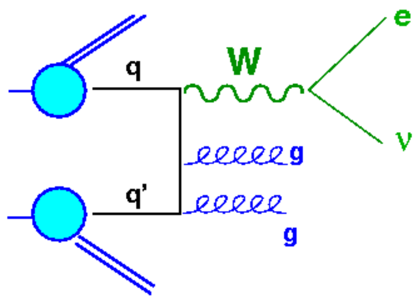
hep-ex/0808.1296



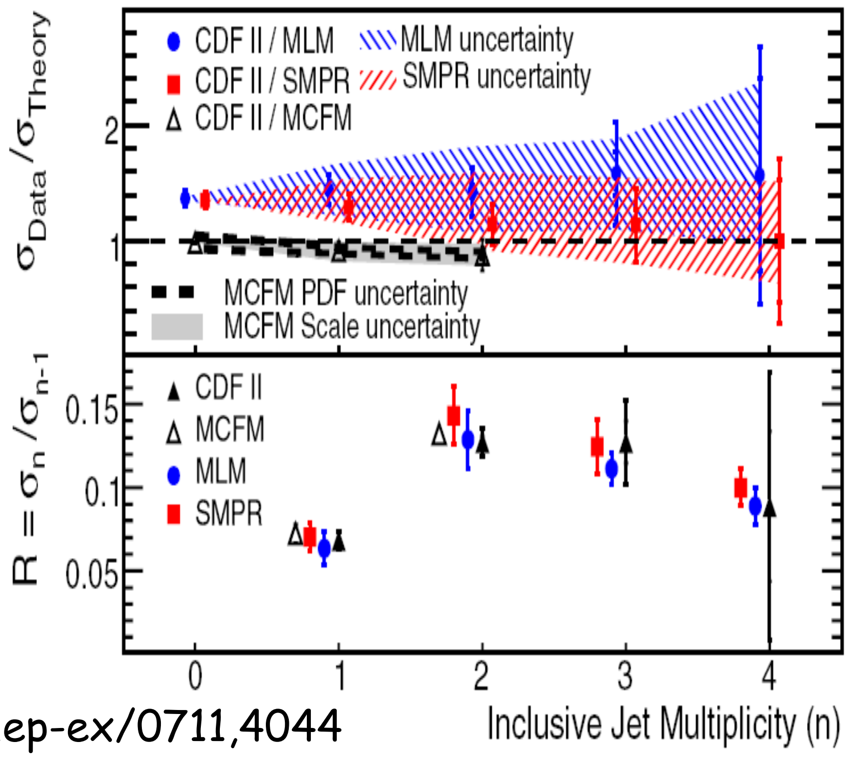
- Data described by NLO pQCD
- PYTHIA and ALPGEN below the data (consistent with LO prediction)
- SHERPA in between LO and NLO predictions (better at large Pt)

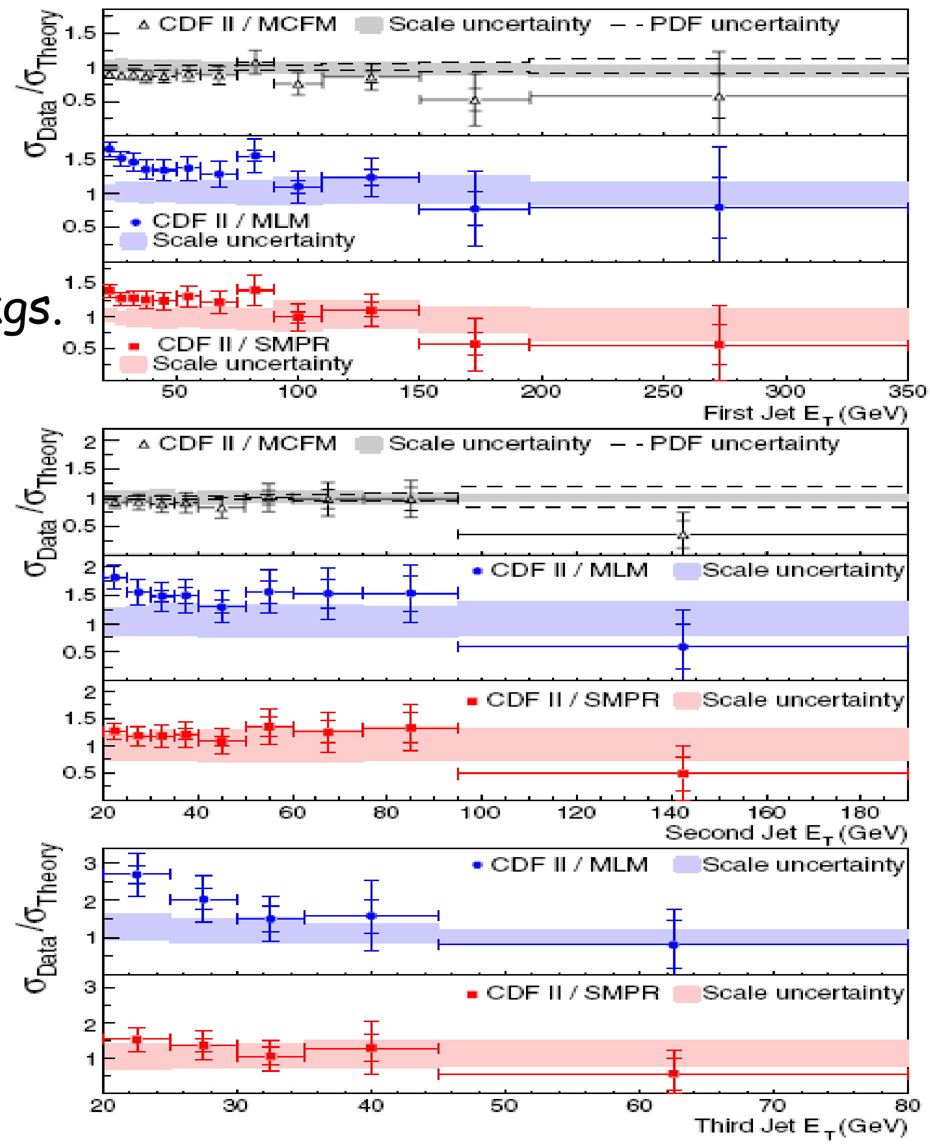
W+jet(s) Production





x 10 more cross section than Z+jets
But requires to control QCD and Top bkgs.

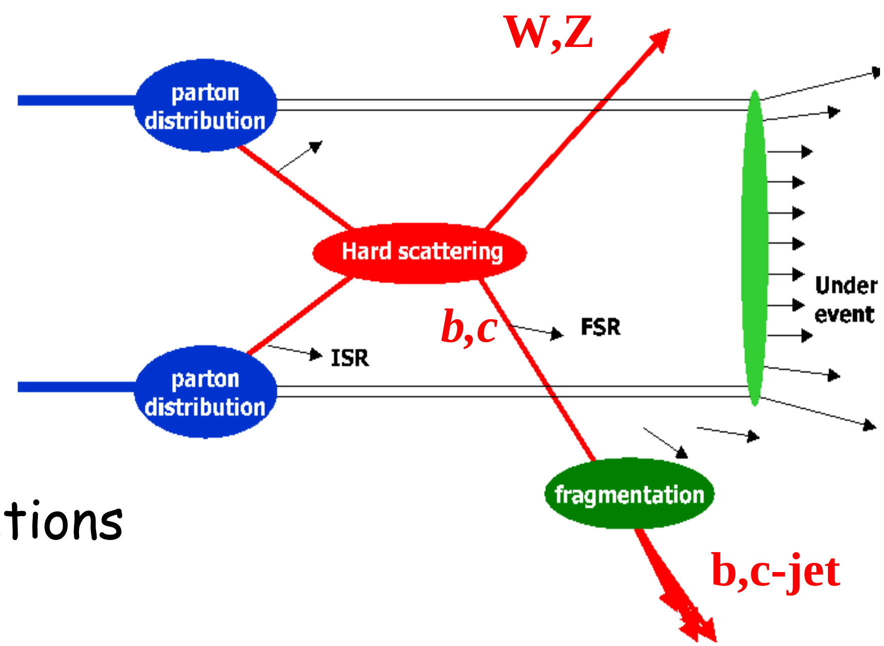




hep-ex/0711,4044

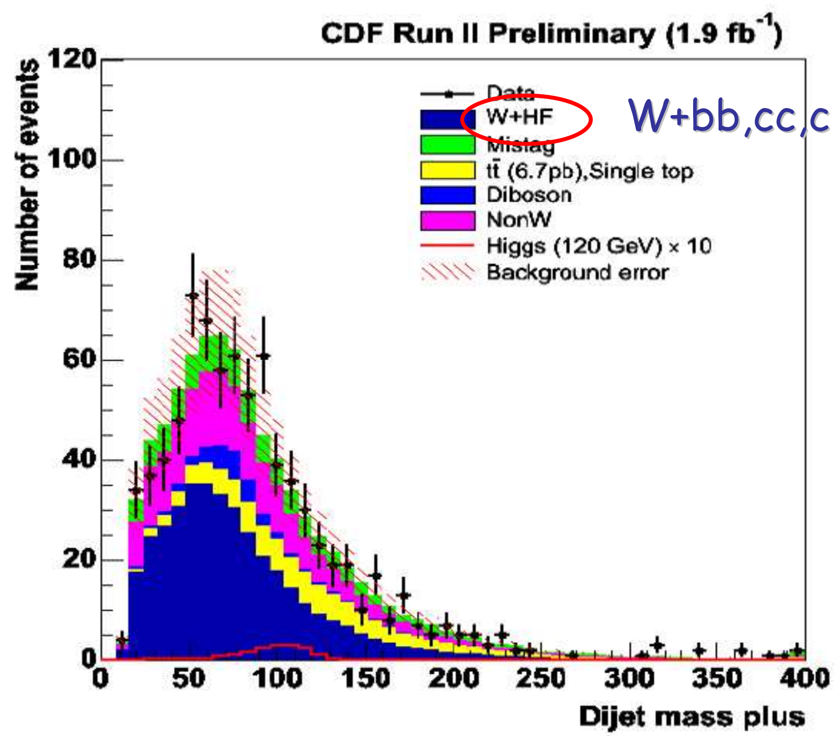
Good agreement with pQCD NLO calculation (includes non-pQCD effects)
At low P_T Monte Carlo needs a better modeling of UE (ALPGEN+PYTHIA)

Vector Boson + HF Jets



Important for physics program at Tevatron

- For QCD
  - Test perturbative QCD predictions
  - W/Z(γ) direct probe of hard scattering dynamics
  - Sensitive to PDFs HF content
- Understand Background
  - W/Z+HF production is bkgd for: ttbar, single top, and searches like Higgs, SUSY…
  - Challenging to accurately simulate need to validate data



b-Jet Identification

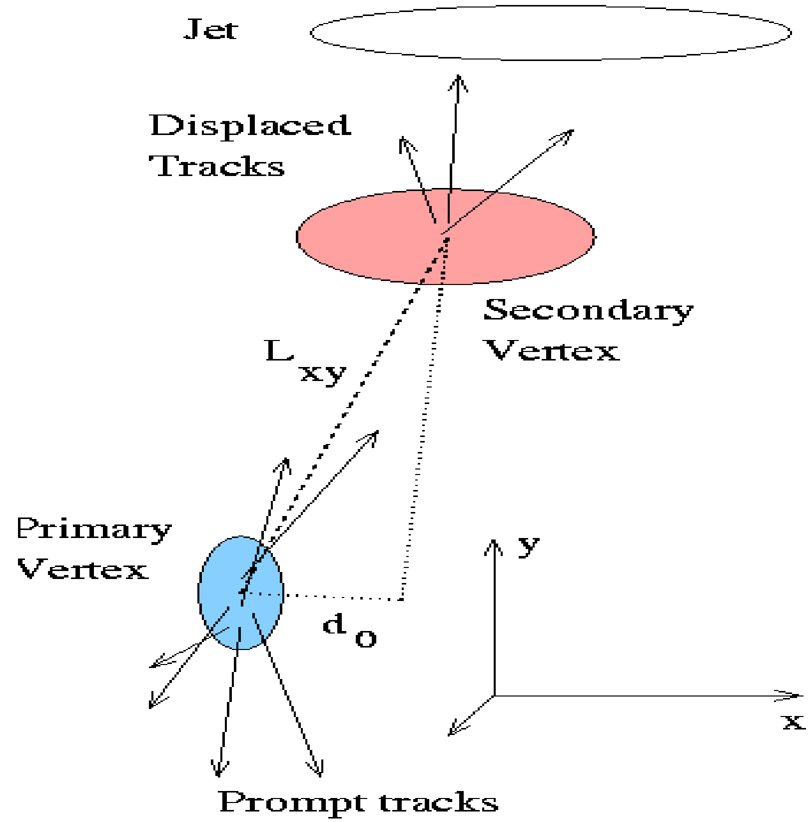
Lifetime taggers:

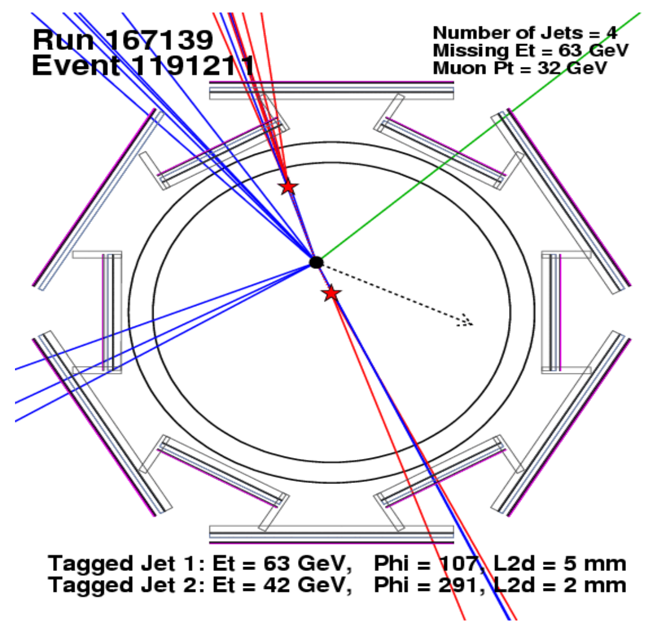
- Most common b-tagging technique exploits long lifetime of b-hadrons
- Secondary vertex:
  - → Select tracks in jet
  - → Identify displaced tracks (not from primary vertex)
  - → Make secondary vertex with displaced tracks
  - → If large transverse displacement (Lxy) jet is b-tagged

Soft Lepton Taggers:

- Identify soft leptons inside jets (~20% semi-leptonic branching fraction)

Need to characterize tagger: efficiency and mistag rate (light flavor tags)

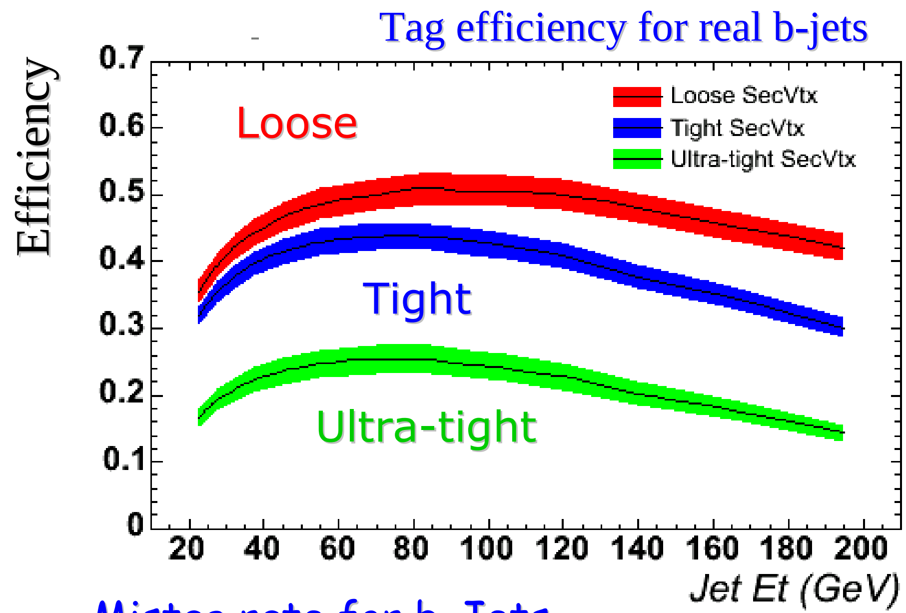


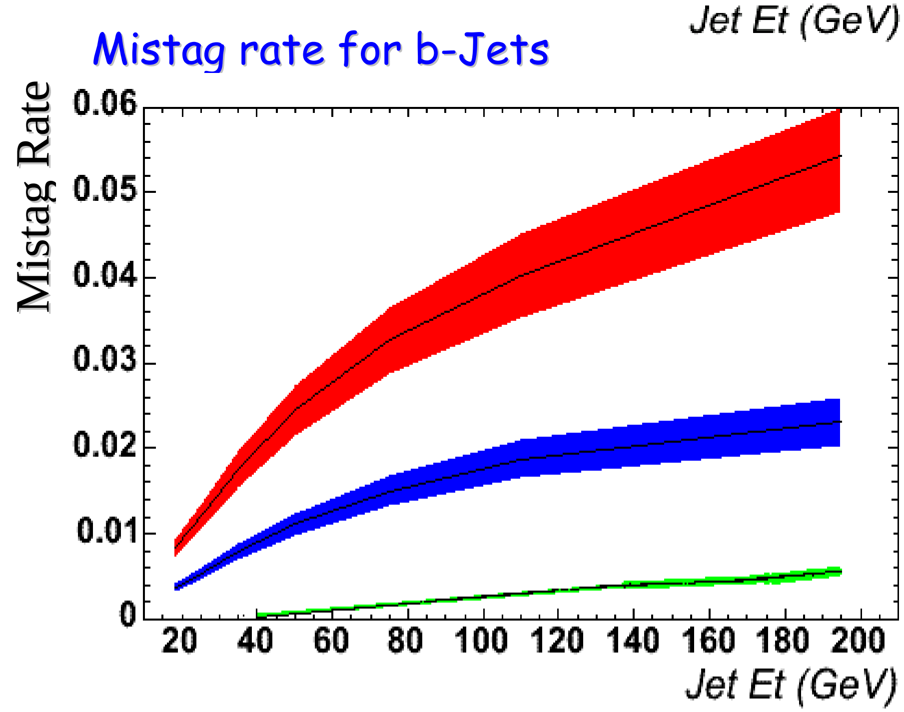


b-Jet Identification (cont'd)

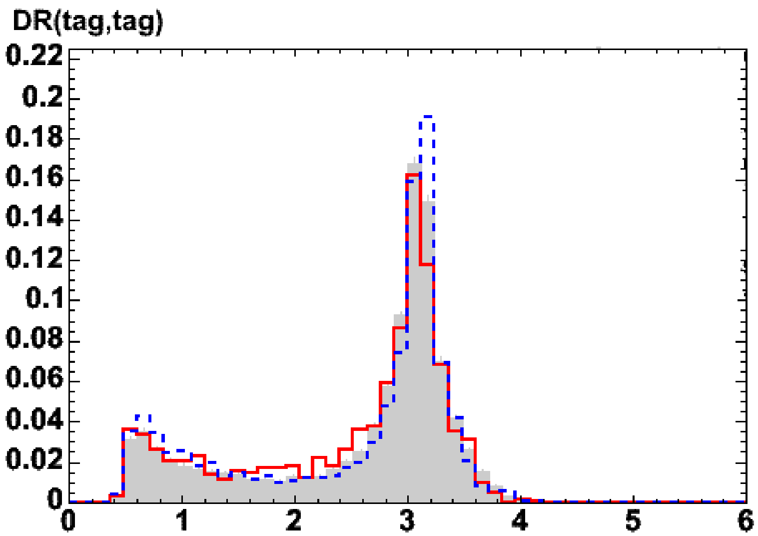
Lifetime tagger, different operating points:

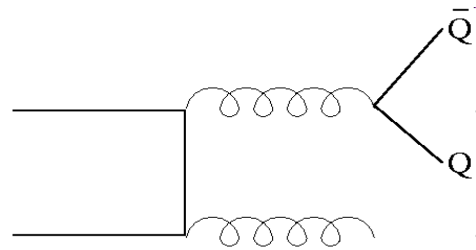
- Loose: optimized for efficiency (e.g. double tagged analyses)
- Tight: optimized for purity (e.g. top cross section)
- Ultra-tight: very high purity (reduce mistags)





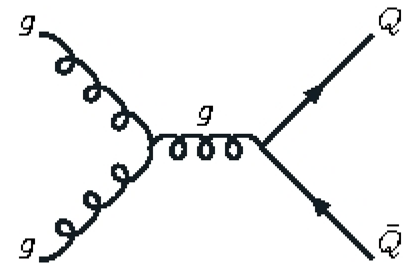
Dijet Production ($b\bar{b}$)





Gluon Splitting

Small DR

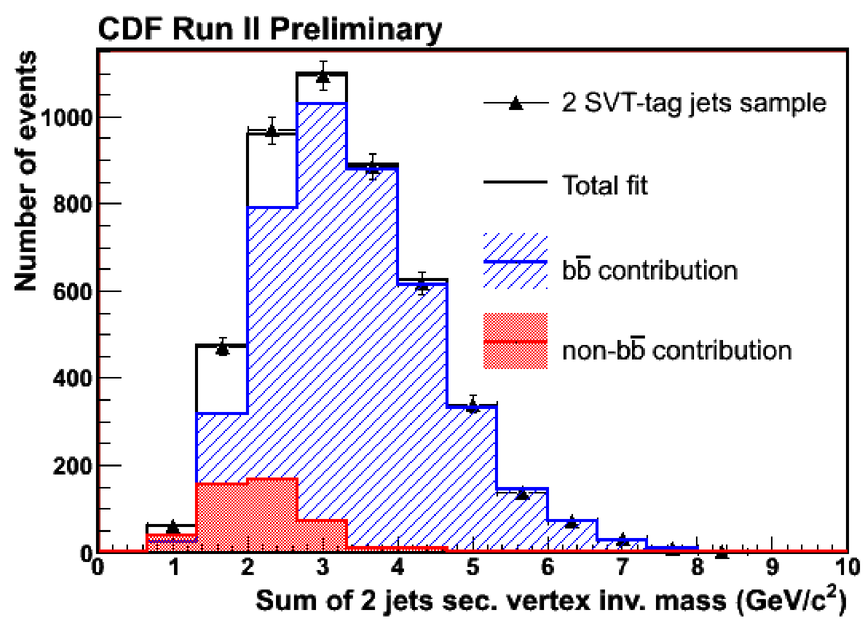


Direct Production

Large DR

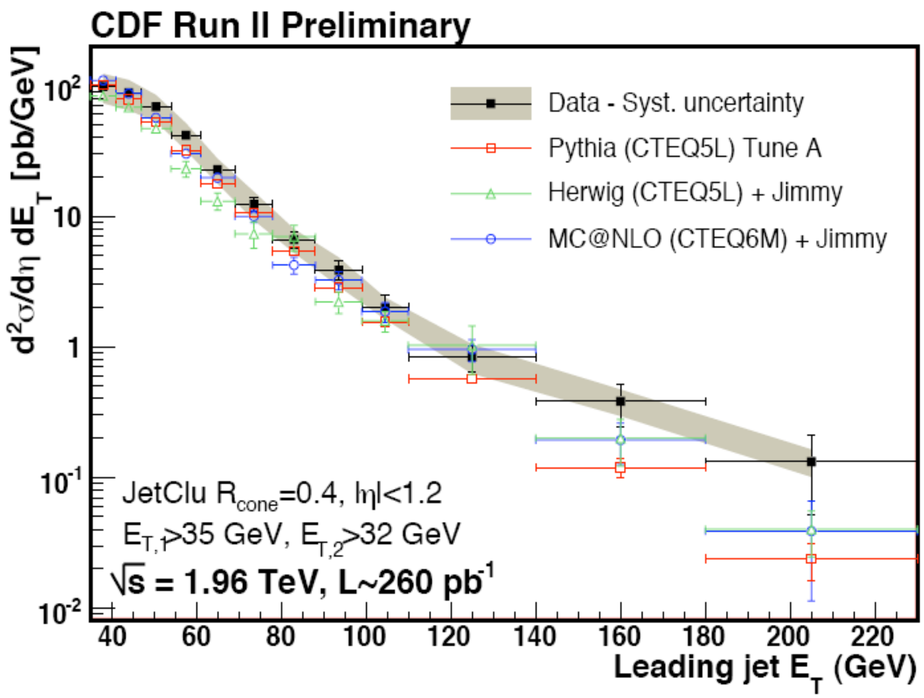
Measure phi correlation to get insight on contribution of LO and NLO terms.

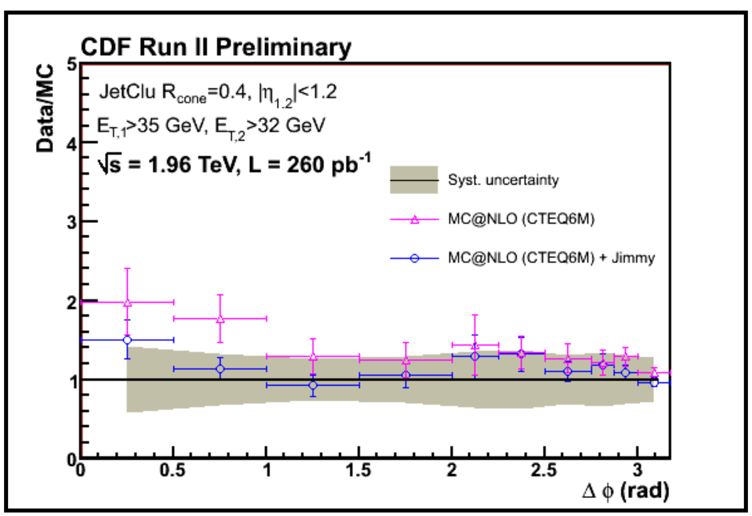
Secondary vertex mass used to separate bottom from (uds + c) contributions



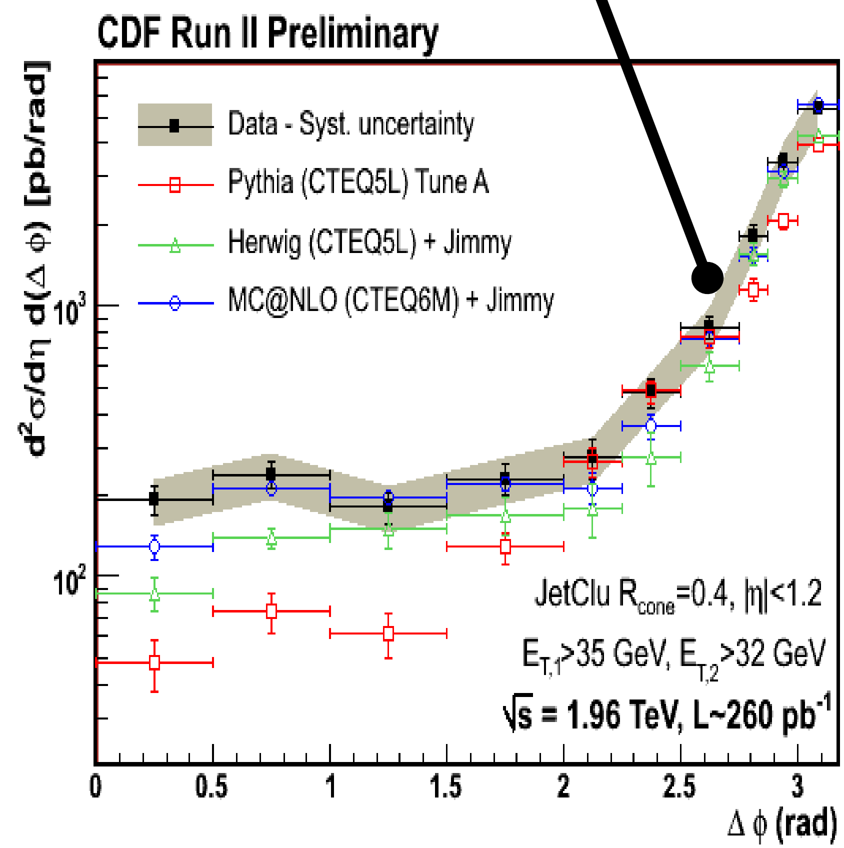
Dijet Production ($b\bar{b}$)

2 jets with ET > 35 (32) GeV
and |y| < 1.2



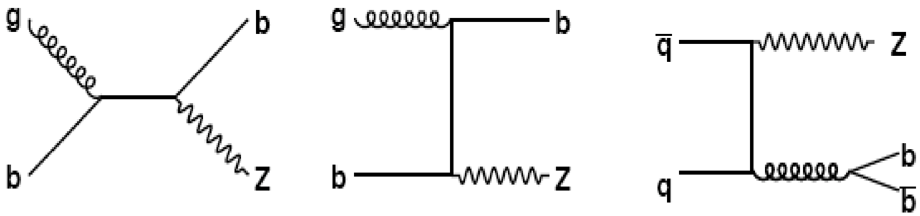


Direct Production



NLO prediction closest to the data

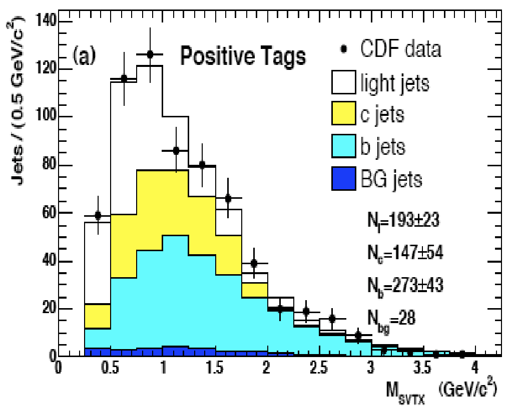
Inclusive Z+b



Test of background for Higgs / SUSY

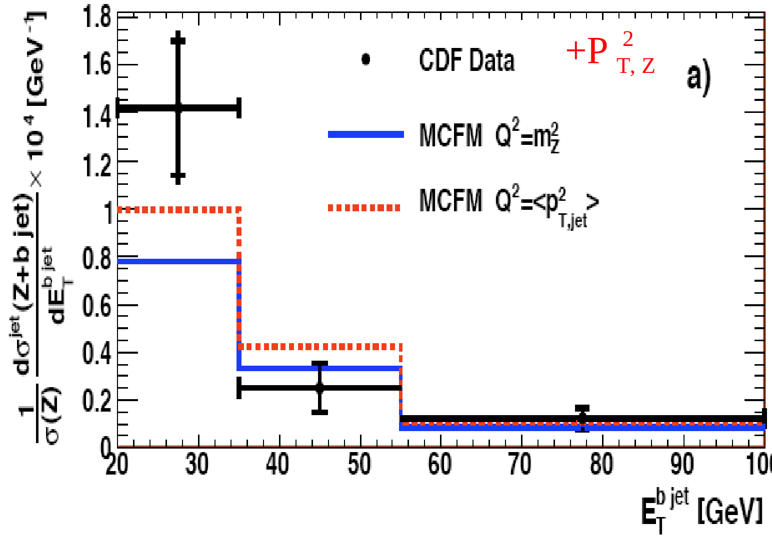
Considering both electron and muon channels and jets with Et > 20 GeV and |η| < 1.5

hep-ex/0812.4458



$$\frac{\sigma(Z+b)}{\sigma(Z+jets)} = 2.08 \pm 0.33 \pm 0.34 (\%)$$

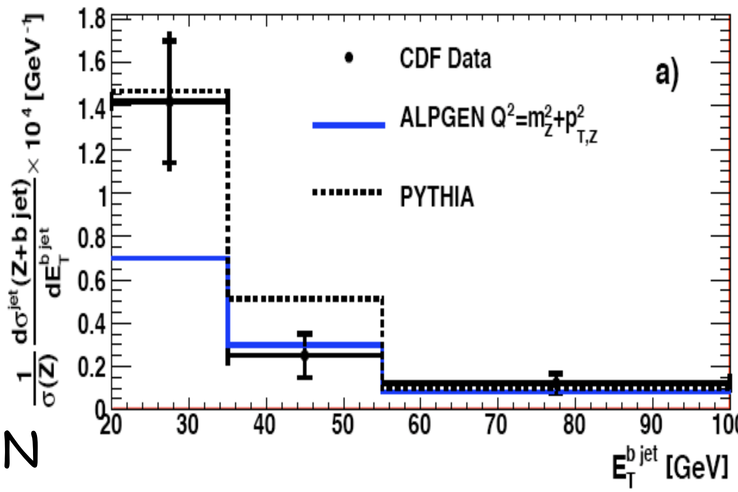
$$MCFM: 1.8\%\ (Q^2 = M_Z^2 + P_{T,Z}^2)\ ;\ 2.2\%\ (Q^2 = \ < P_{T,Jet}^2 >)$$



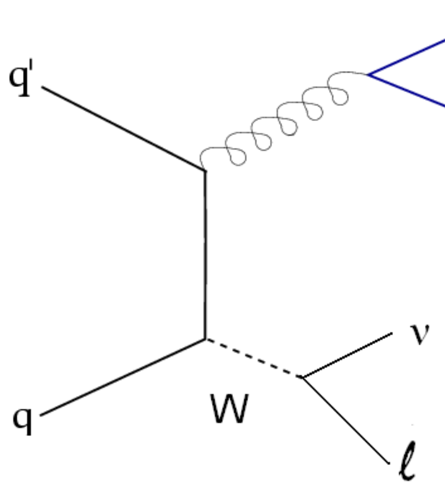
Measurements in agreement with predictions (large uncertainties in both data and theory)

→No complete NLO prediction in the Z+bb̄ case translates into a large scale dependence

Also large variations between PYTHIA and ALPGEN

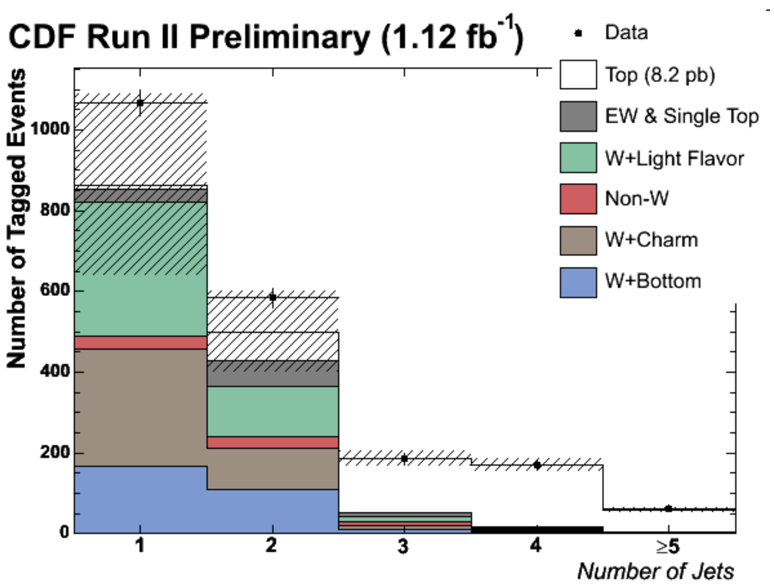


W+*b*-jets production



Large background for many analyses

- SM Higgs (WH) production
- Single top quark production
- $t\bar{t}$ production



- **$W \rightarrow l\,\nu$ (l=e,μ) selection:**
  - e: E_T > 20 GeV, |η| < 1.1
  - μ: p_T > 20 GeV/c, |η| < 1.0
  - ν: Missing E_T, MET > 25 GeV
- **1 or 2 jets in final state**
- **b-Jet selection:**
  - Cone algorithm, R= 0.4
  - E_T > 20 GeV, |η| < 2.0
  - b-identification: "ultratight"

- **W+b-jets cross section:**

$$\sigma_{W+bjets} \cdot Br = \frac{N_{b-tags} \cdot f^{bjets} - N_{bkg}^{bjets}}{L \times A \times \varepsilon}$$

N_{b-tags} : number of b – tags

f^{bjets} : b – jet purity in b - tag sample

N_{bkg}^{bjets} : number of tagged b – jets not from $W + b\bar{b}$

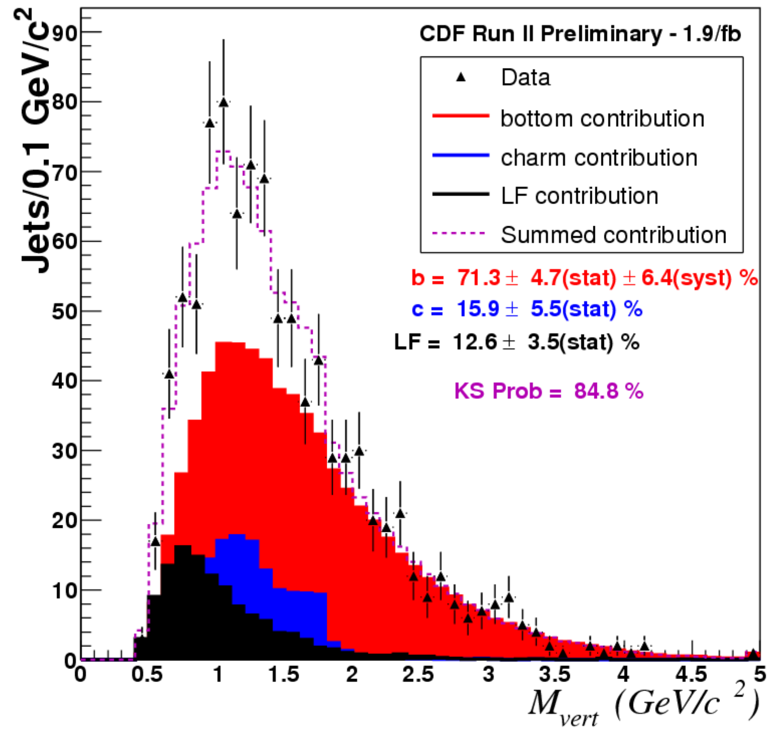
W+*b*-jets production

$$\sigma_{W+bjets} \cdot Br = \frac{N_{b-tags} \cdot f^{bjets} - N_{bkg}^{bjets}}{L \times A \times \varepsilon}$$

- **Major b-jets bkgd. (S/B ~ 3/1):**
  - ttbar (40% of total bkgd)
  - single top (30%)
  - Fake *W* (15%)
  - *WZ* (5%)

- **Measurement:**
  $\sigma \cdot BR$ =2.74 ± 0.27(stat) ± 0.42(syst) pb
  ($p_T^{e\mu}$>20 GeV/c, $|\eta^{e\mu}|$<1.1, p_T^{ν}>25 GeV,
  E_T^{bjet}>20 GeV, $|\eta^{bjet}|$<2.0)

- **Alpgen (LO) prediction:**
  $\sigma \cdot BR$ = 0.78 pb



The measurement x3.5 larger than the Alpgen prediction. Waiting for other theoretical predictions (MCFM NLO etc.)

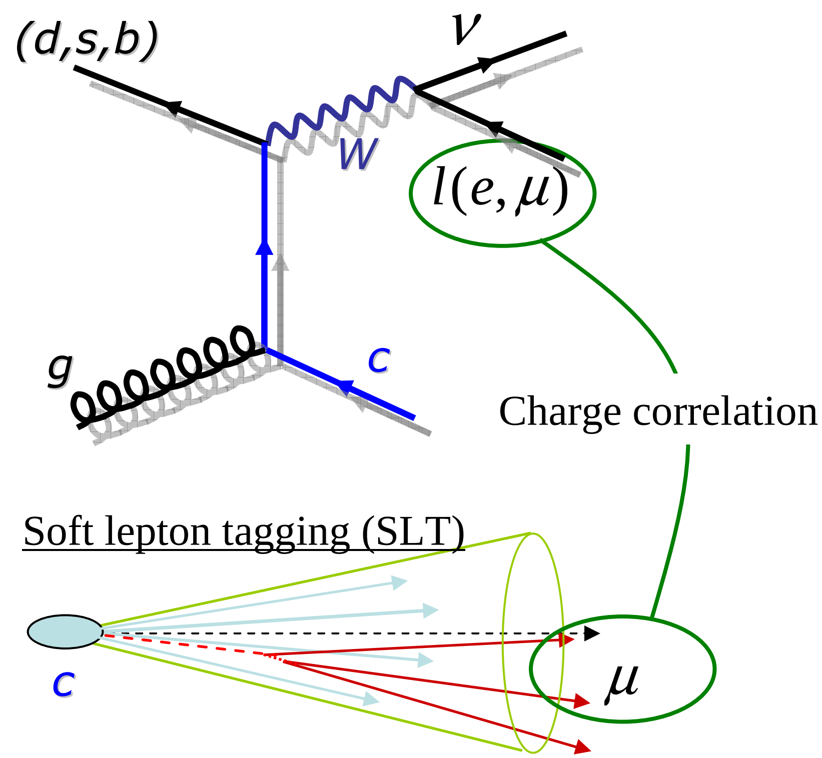
W + Single c Production

Motivation:

- Probe s-content of proton at high Q^2
  - $g+s \sim 0.9$, $g+d \sim 0.1$.
- Important BG for top quark studies, searches for Higgs, stop…

Strategy:

- $W \rightarrow l+\nu$ selected by high p_T e,μ + MET
- Charm-jet identified by the soft lepton tagging (SLT) algorithm.
- Utilize charge correlation between W lepton and SLT lepton.
  - W+c production: opposite sign (OS)
  - In W+bb(cc), same sign (SS) ~ OS.

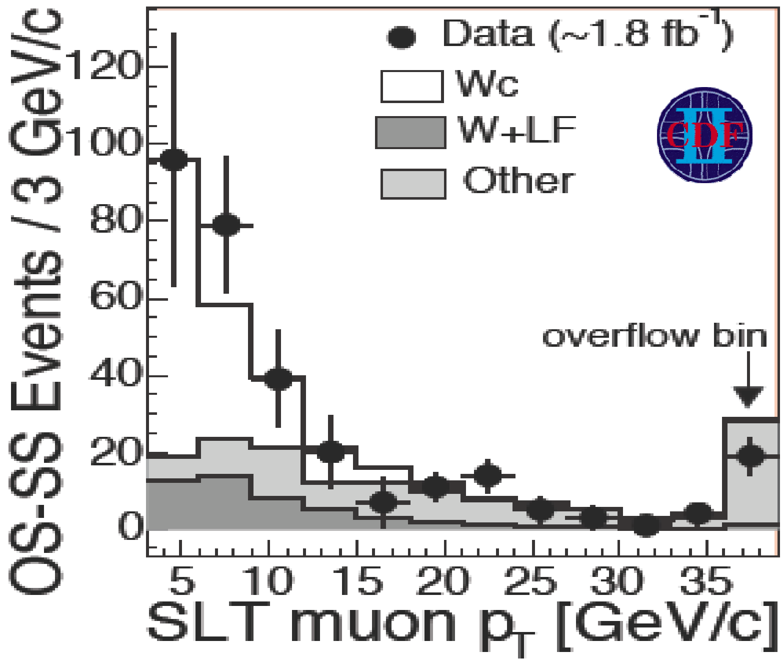


$$\sigma_{W+c} \times Br(W \rightarrow l\nu) = \frac{N^{OS-SS}_{measured} - N^{OS-SS}_{bkg}}{L \times A \times \varepsilon}$$

- Main OS-SS backgrounds
  - Fake W
  - W+light jets
  - Drell-Yan

W+ Single c Production

- D0 uses both e and muon soft leptons For jets with Pt > 20 GeV, |η|<2.5
- Measure the ratio σW+c/σW+jets. Many systematic uncertainties cancel.



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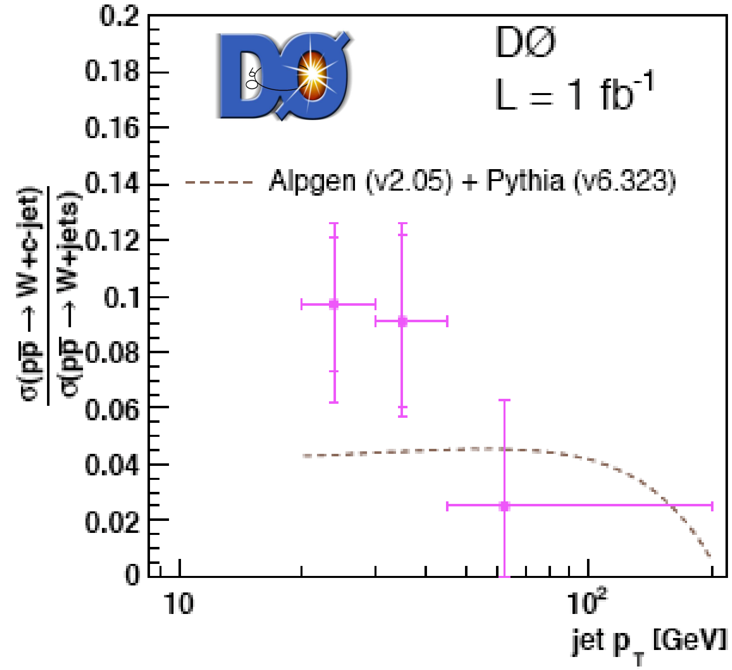

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$$\sigma_{Wc} x Br(W \to l\nu) = 9.8(stat.) \pm 2.8^{+1.4}_{-1.6}(syst.) pb$$

$$NLO: 11.0^{+1.4}_{-3.0}\, pb\, (p_{Tc} > 20\, GeV/c,\ |\eta_c| < 1.5)$$

$$\frac{\sigma_{W+c}}{\sigma_{W+jets}} = 0.074 \pm 0.019(stat.)^{+0.012}_{-0.014}(syst.)$$

LO (**Alpgen+Pythia**): 0.044 ± 0.003

In good agreement

In reasonable agreement

Final Notes

- Proper Modeling of the Underlying Event

- Z/W+jet(s) : good agreement with predictions, results test background estimations in searches for new physics

- Good understanding of Vector Boson and HF jets production critical for Tevatron and LHC
  - First Z/W+HF measurements start challenging large theoretical uncertainties
  - W+charm well described by recent NLO predictions
  - W+bottom does not agree well with predictions

- **Tevatron promises ~8 fb^{-1} by End 2009** (further improvements likely)

- **First LHC physics data by End 2009 ….**

"Just checking."