CDF Run II W + Jets Analysis

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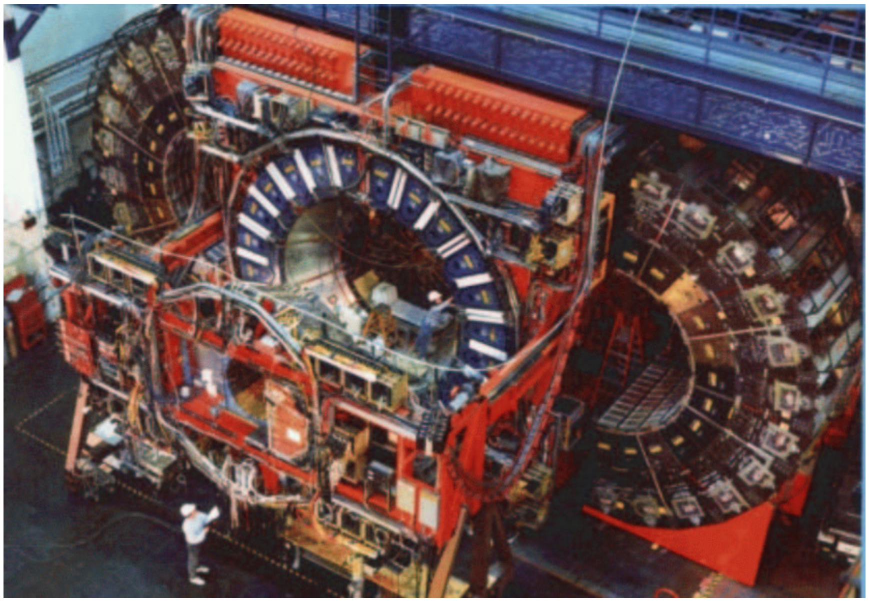
The Tevatron Collider

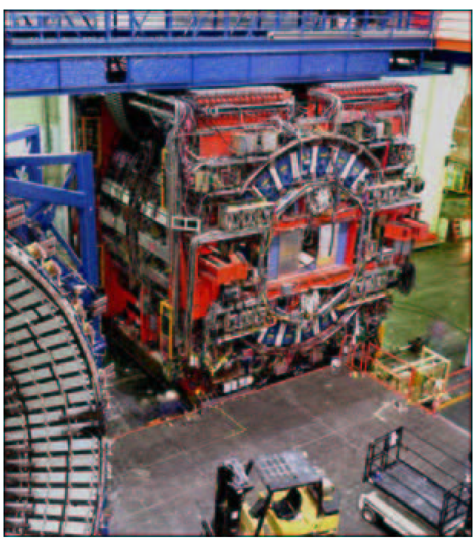
- $p\bar{p}$ collider, operating at $\sqrt{s} = 1.96$ TeV.
- Bunch crossing rate = 7.6 MHz.
- Average luminosity of $2.3 \times 10^{31} cm^{-2} s^{-1}$ since Run II began in March 2001.
- Thus far delivered an integrated luminosity of $194 pb^{-1}$ in Run II. 50% more than entire Run I.

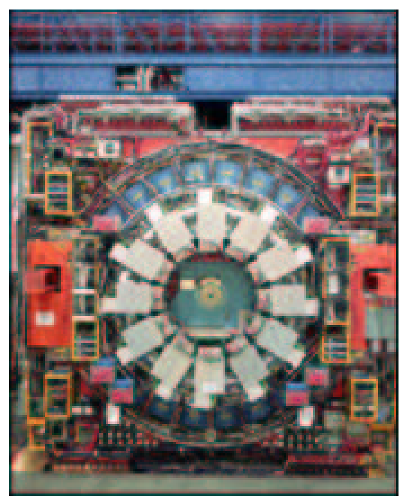
The Collider Detector at Fermilab (i)

- One of two multipurpose detectors at the Tevatron.
- Tracking: Silicon vertex detector, open cell drift chamber.
- Calorimetry: Separate electromagnetic and hadronic scintillator-based sampling calorimeters.
- Muon Detection: Four systems of scintillators and proportional chambers.
- Hermetic in ϕ.
- Good rapidity coverage:
  - Tracking: Drift Chamber $|\eta| \leq 1.0$, Silicon $|\eta| \leq 2.0$.
  - Calorimetry: Central $|\eta| \leq 1.1$, Plug $|\eta| \leq 3.64$.
  - Muon Chambers: $|\eta| \leq 2.0$.

The Collider Detector at Fermilab (ii)

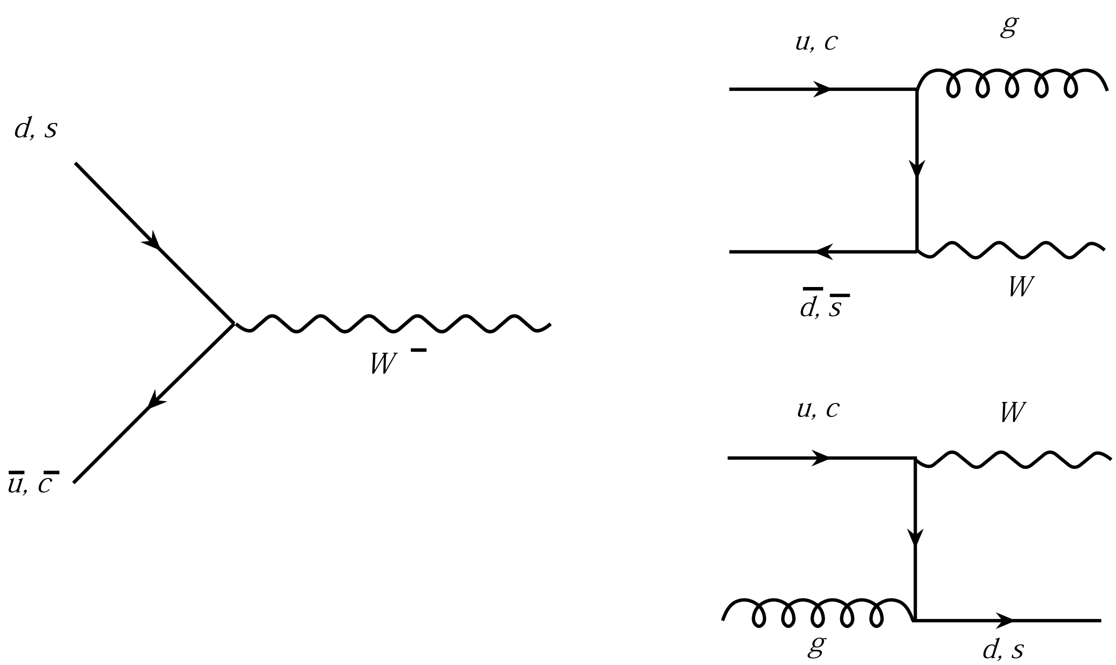






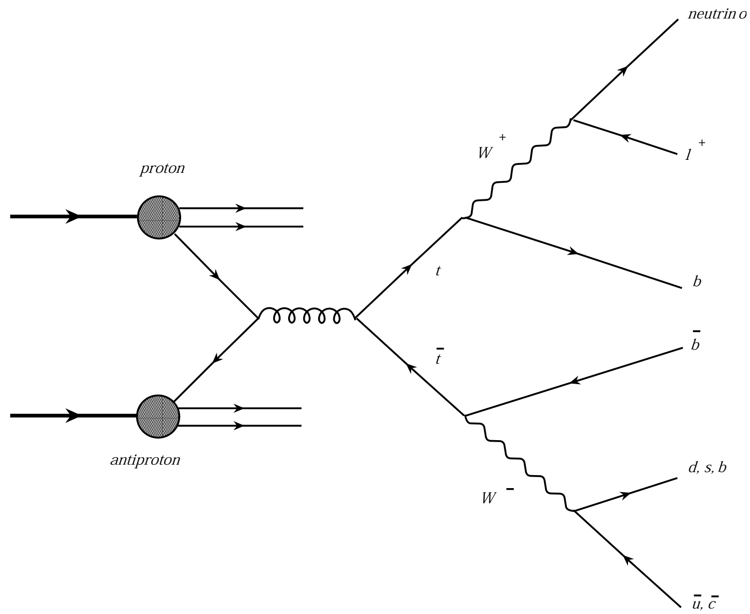
The W + Jets Process at CDF Run II

- Inclusive $q\bar{q} \to W$ cross-section = 29.77nb according to recent NNLO calculation
- Thus expect 4.6 million direct W events produced with $2fb^{-1}$ data, or 502000 direct $W(\to e\upsilon)$ events.
- Large enough sample to study $q\bar{q} \to W(\to e\upsilon)$ + n Jets up to large n.

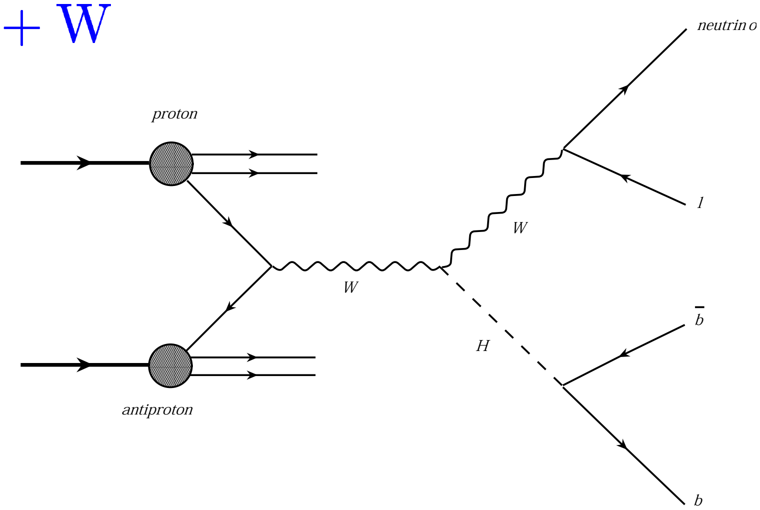


Motivation for W + Jets Study (i)

$p\bar{p} \to t\bar{t}$



$p\bar{p} \to H + W$

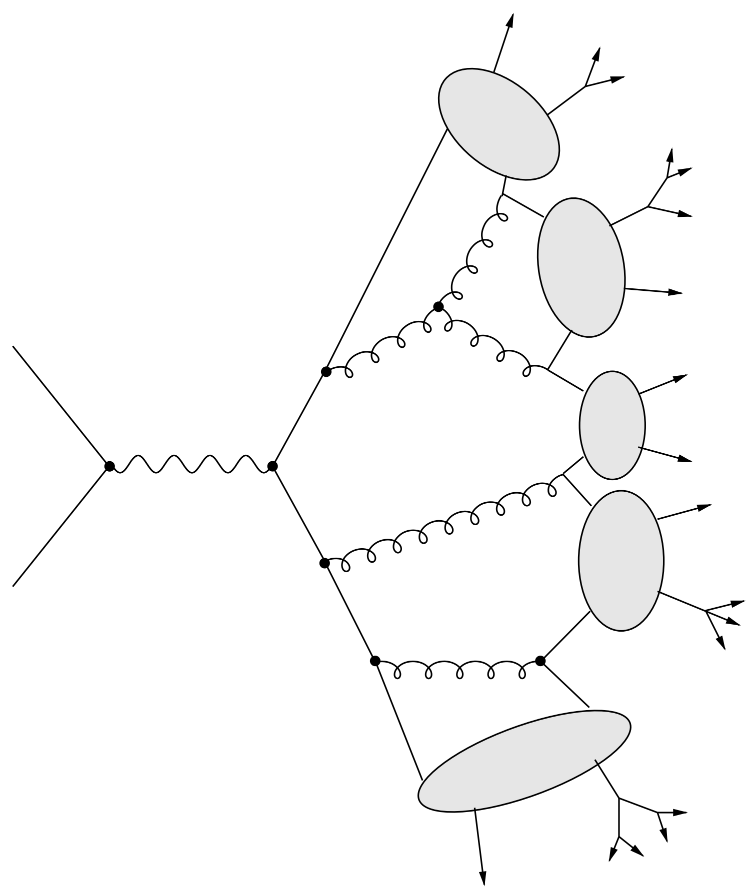


Motivation for W + Jets Study (ii)

- The process is a major background to two of the most important processes in CDF Run II: **TOP** quark production and light **HIGGS** production in association with a W boson.
- Accurate background prediction via the latest Monte Carlo tools is crucial to both studies.
- To have confidence in these background predictions one must compare them in detail to real data: σ and kinematics.
- Such comparisons are important in their own right as they test the very latest QCD predictions and hence our current understanding of this aspect of the standard model.

Run II W + Jets Monte Carlo Status(i)

- Enhanced Leading Order (ELO) approach is adopted : Leading order (LO) W + n parton generator combined with a parton-showering programme to provide some higher order corrections and hadronisation.



Run II W + Jets Monte Carlo Status(ii)

- In Run I ELO VECBOS was the LO generator used, with HERWIG providing the p/s and hadronisation.
- In Run II ELO ALPGEN has replaced VECBOS.
- Problems with ELO:
  - Higher order corrections provided by HERWIG, although well-motivated by theory, do not involve explicit matrix element calculations.
  - "Double Counting": Overlap of phase space between ELO W + 1 parton and leading order W + 2 parton. Data has to be compared inclusively e.g. W + $\geq$ 1 jets data compared to ELO W + 1 parton generated events.

Overview of Preliminary Run II W + Jets Study

- Used $89.9pb^{-1}$ of data collected using high $\mathrm{P_T}$ ($\geq$ 18 GeV) electron trigger.
- Comparison of event numbers and jet kinematic distributions between Run I and Run II made.
- Agreement between Run II data and ALPGEN + HERWIG Monte Carlo ELO predictions also tested.
- Important to note that background corrections have not yet been made.

Selection of W + Jets Sample

"Exactly" the same selection procedure as Run I.

Electron Cut	**Requirement**
P_T	≥ 13 GeV
$\mid \eta \mid$	≤ 1.1
E/P	≥ 0.5 and ≤ 2
Had/Em	$\leq 0.055 + .0045*E$
Frac. Isolation	≤ 0.1

Electron $E_T \geq$ 20 GeV
Missing $E_T \geq$ 30 GeV

Jets defined using a seeded cone algorithm ($R_{cone} = 0.4$) with the following cuts:

Jet $E_T \geq$ 15 GeV
$|\eta| \leq$ 2.4.

Comparison of Event Numbers Run I → Run II

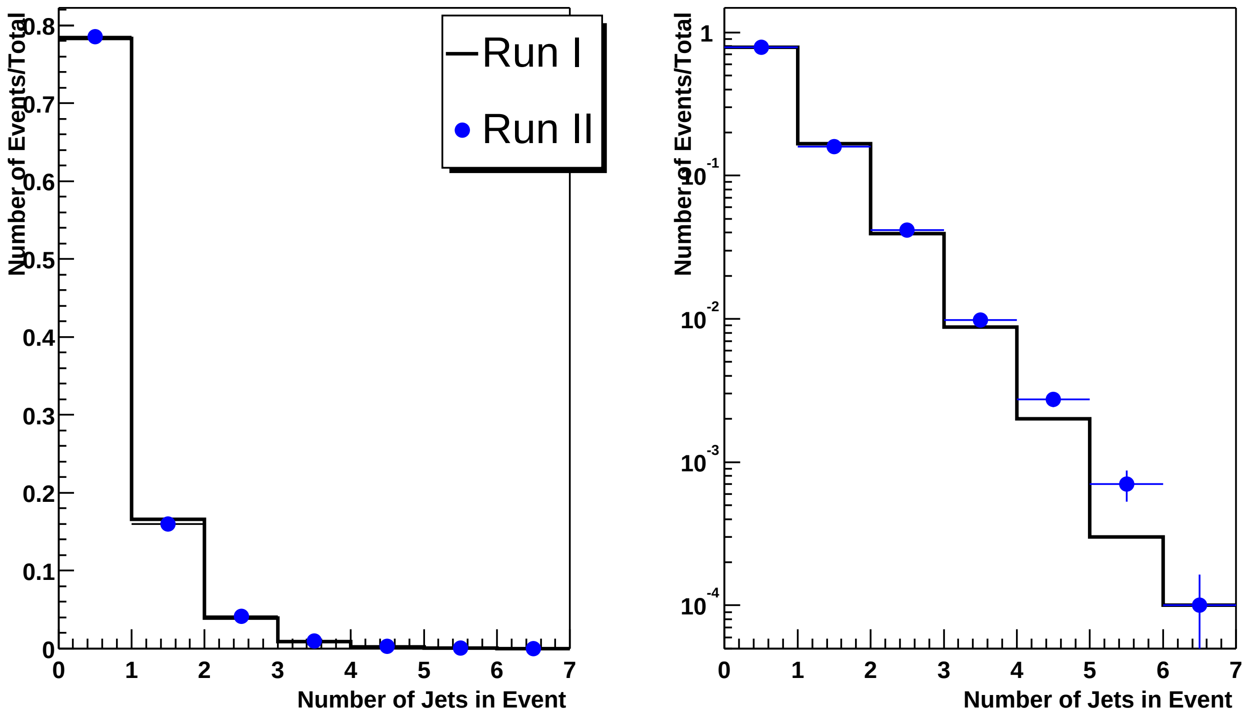
- Scale Run I event numbers by luminosity ratio ($L_{RII}/L_{RI} = 0.83$) and the increased cross-section of Run II to give a predicted number of events in Run II.
- Errors shown are statistical only.
- Neither Run I or Run II event numbers are corrected for background.

No. Jets	Scaled Run I	Observed Run II	**% Diff.**
≥ 0	47092	44836	-5 ±0.5
1	8112	7153	-12 ±1
2	1980	1873	-5 ±2
3	468	441	-6 ±4
4	104	123	+15 ±11

Comparison of Event Numbers Run I $\rightarrow$ Run II

- Comparison of scaled Run I with Run II event numbers reveals deficit in Run II?
- However, doesn't account for large systematic errors:
  - Error on Run II luminosity measurement of 6% - will effect all bins
  - Error on Run II jet energy scale of 5% - will effect only events containing a jet.
- The recent Run II inclusive $W(\rightarrow e\upsilon)$ cross-section measurement is 2% lower than Run I (this is background corrected).
- More work is required to understand this.

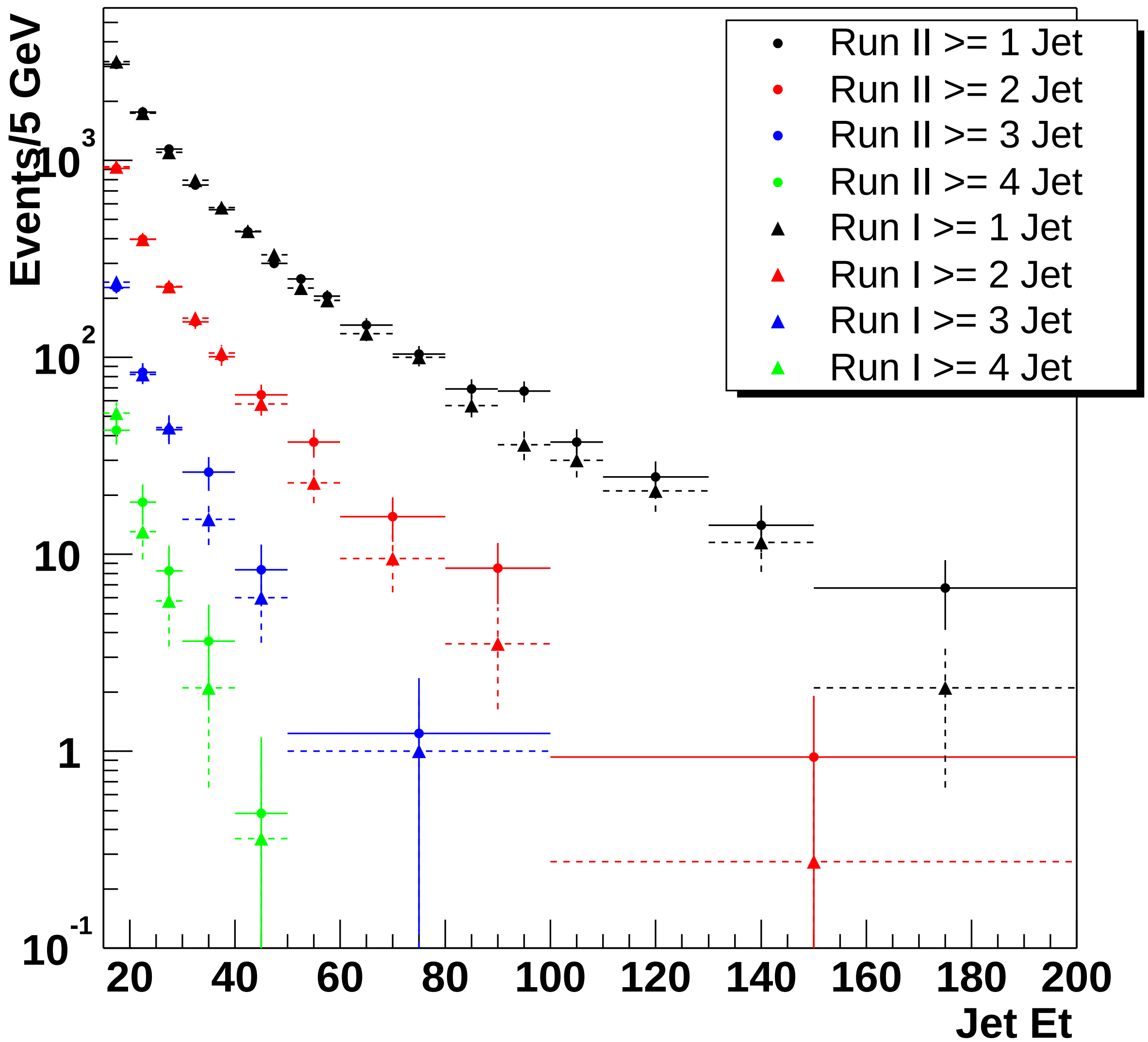
Jet Multiplicity Distribution $R_I \rightarrow R_{II}$



- Run I Errors $\simeq$ Run II Errors (statistical only).
- Lower multiplicity bins agree well.
- Run II displays a larger fraction of high multiplicity events?

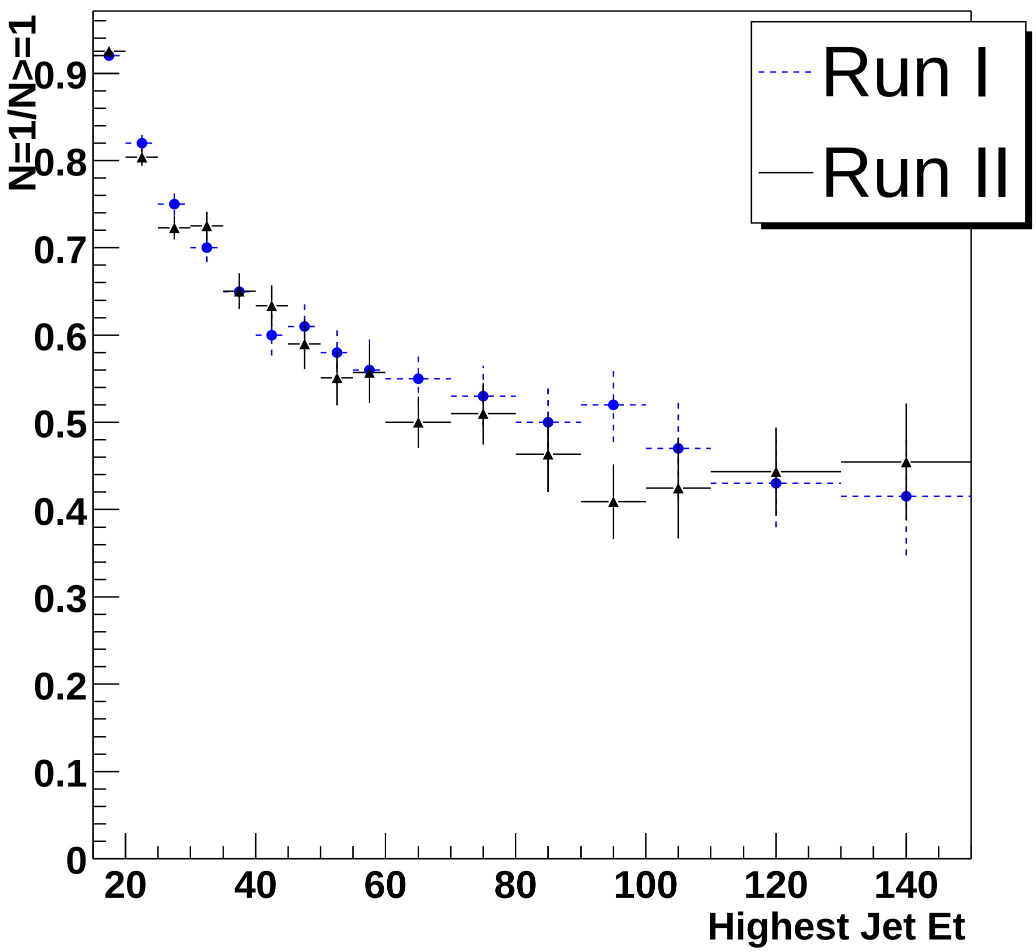
Jet E_T Distribution $R_I \rightarrow R_{II}$

- Shown is the leading jet in W + $\geq$ 1 jet events, the second jet in W + $\geq$ 2 jet events etc.



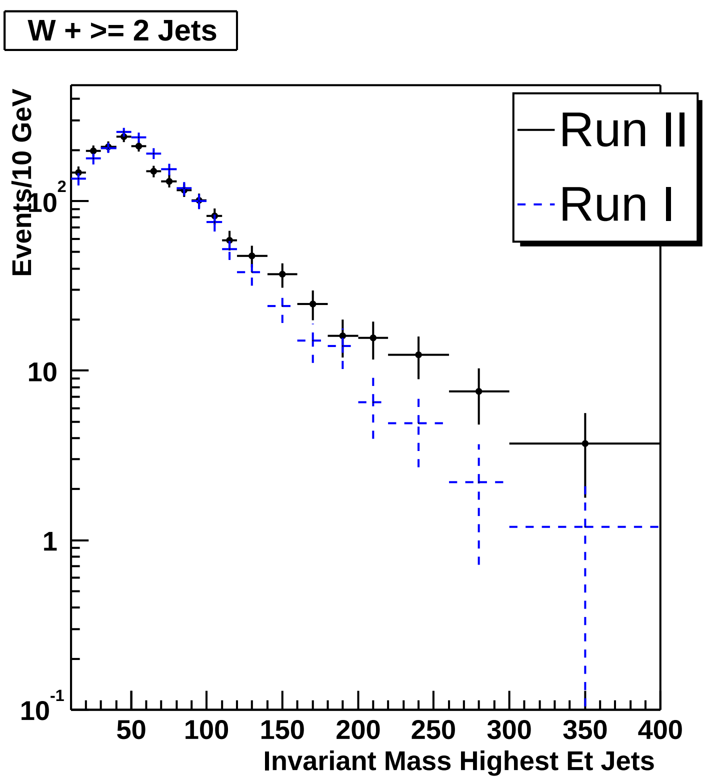
One Jet Fraction Vs First Jet E_T $R_I \rightarrow R_{II}$

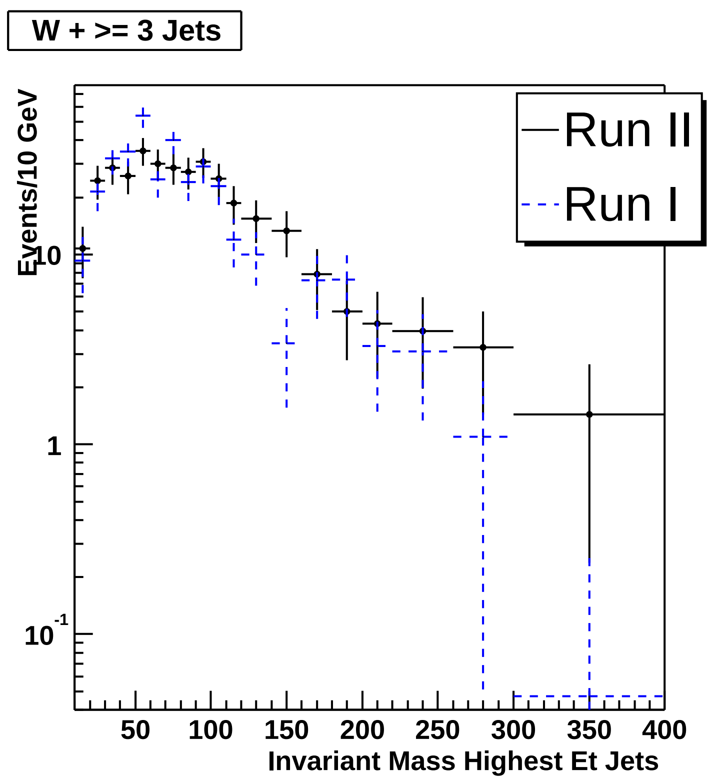
- Highlights the relationship between the jet energy and jet multiplicity of an event.
- Run I and Run II agree reasonably well - Expected?



Dijet M_{jj} Distributions $R_I \rightarrow R_{II}$

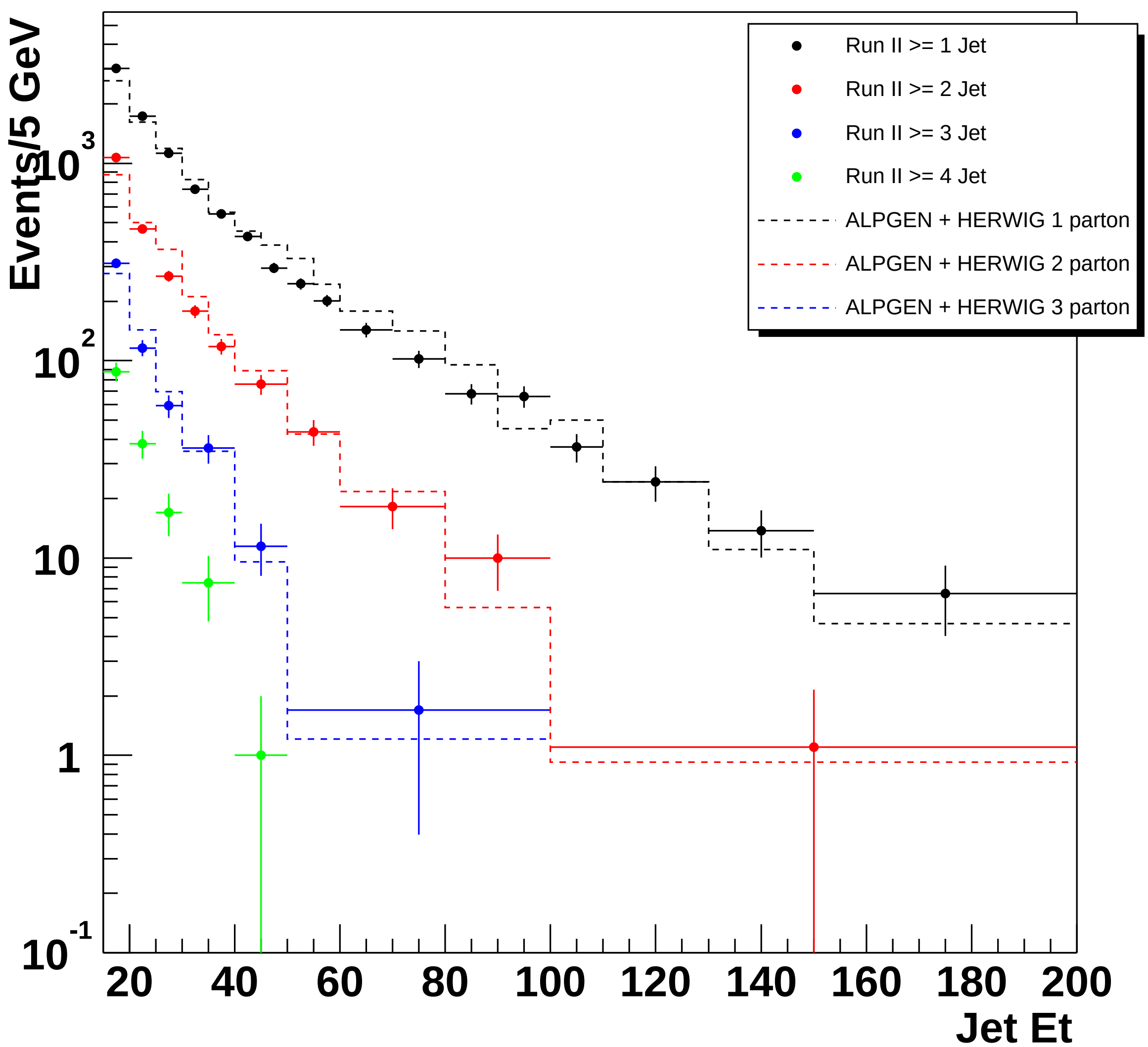
- Shown is the invariant mass of the two leading jets (M_{jj}) for W + $\geq$ 2 Jets and W + $\geq$ 3 Jets events.
- Discrepancy at high M_{jj}:
  - Related to harder jet E_T spectrum in Run II?
  - Systematic uncertainty in jet energy scale.





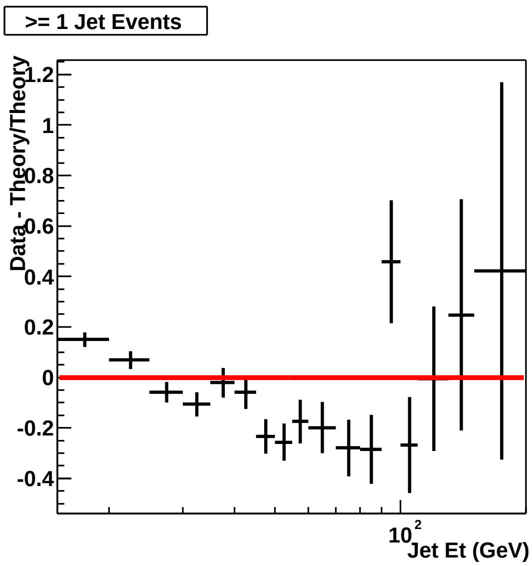
Jet E_T Distribution ELO $\rightarrow$ R_{II} (i)

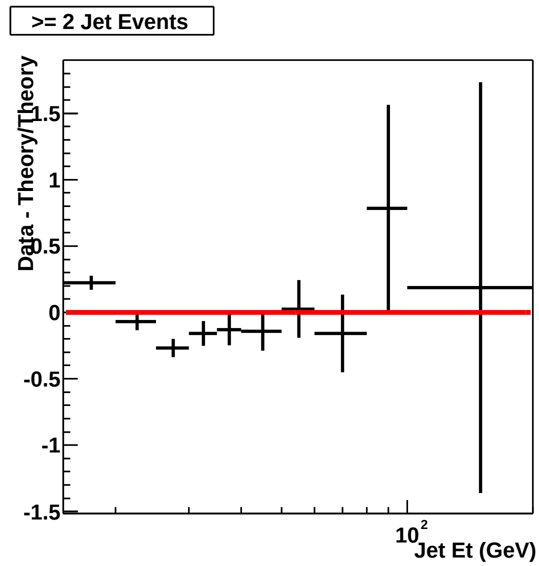
- Run II W + $\geq$ 1 Jet compared to ALPGEN + HERWIG (A+H) 1 parton, Run II W + $\geq$ 2 Jets compared to A+H 2 parton etc.

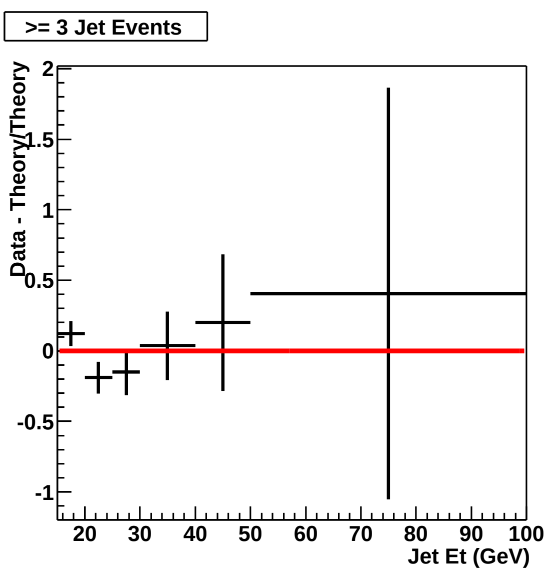


Jet E_T Distribution ELO $\rightarrow R_{II}$ (ii)

- Theoretical predictions show a deficit in the high and low E_T regions - exactly as was observed in Run I.

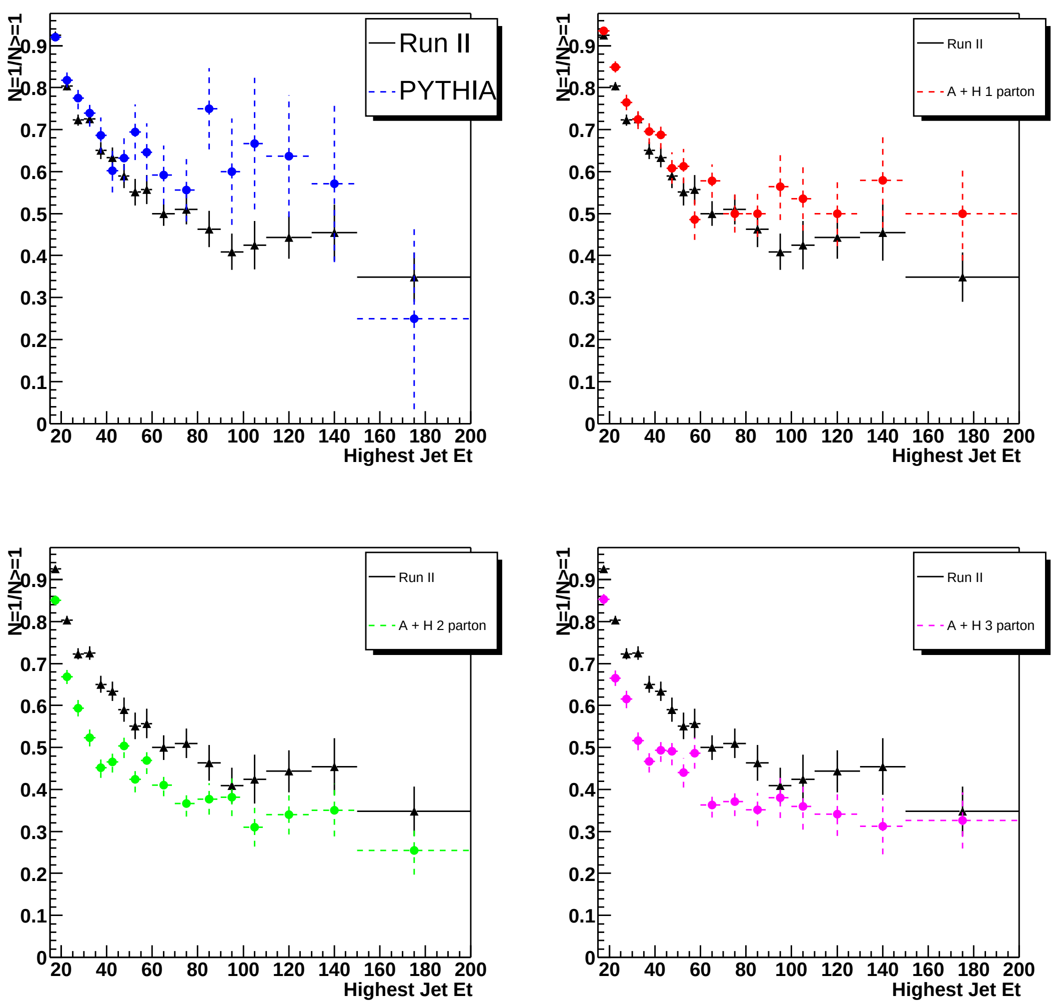




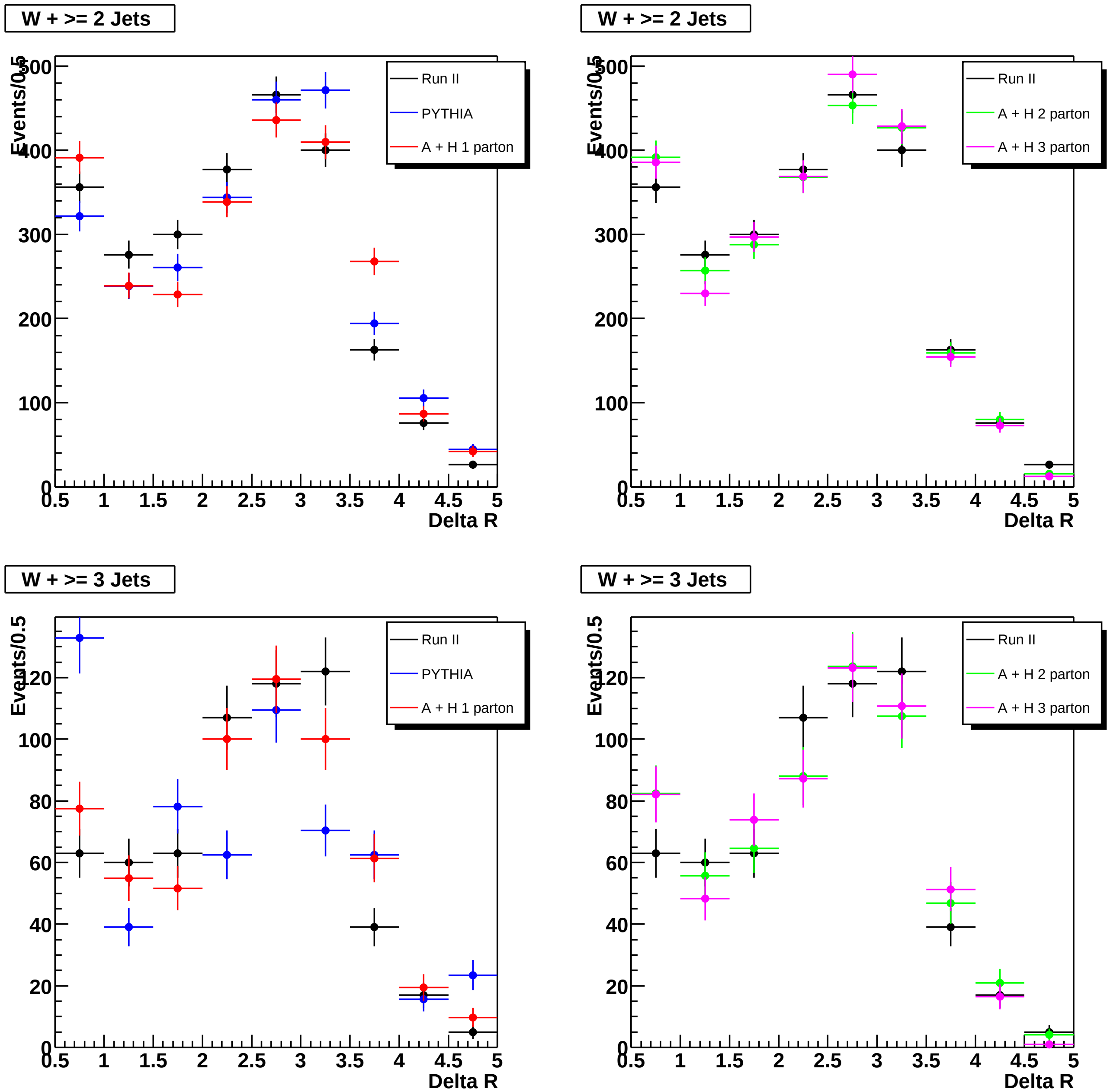


One Jet Fraction Vs First Jet E_T ELO $\rightarrow R_{II}$

- $\frac{N=1}{N\geq 1}$ One Jet Fraction vs First Jet E_T.
- Run II compared to various ELO Monte Carlo samples.



Jet ΔR Distributions ELO $\rightarrow R_{II}$



Conclusions

- Possible deficiency in the number of events observed in Run II cf Run I.
- Run II Jet E_T distribution harder than in Run I; possibly due to the increased $\sqrt{s}$. More data needed.
- Harder Jet E_T spectrum results in greater fraction of high jet multiplicity events cf Run I?
- Limitations of ELO QCD predictions are evident in certain distributions as was the case in Run I.
- ELO Limitations not so evident in the ΔR_{jj}; not so sensitive to higher order corrections?

Short Term Plan

- Explain the discrepancy between Run I and Run II event numbers.
- Investigate the possibility that a harder Run II jet energy spectrum is due to an increase in centre-of-mass energy via examination of Monte Carlo samples of varying $\sqrt{s}$.
- Fully correct the sample to account for contamination from background processes.
- Estimate and incorporate systematic errors.

Long Term Plan

- Compare data to NLO QCD predictions using Monte Carlo generators such as MCFM. Will these reduce the sensitivity to higher order corrections?
- Investigate in detail the effect of varying renormalisation/factorisation and fragmentation scales within these Monte Carlos.
- Examine other event shapes which could also display the limitations of ELO and the need for higher order corrections, such as thrust.
- Move to a more theoretically sound jet algorithm such as the K_T clustering or Midpoint algorithms. These could make a considerable difference to NLO comparisons.
- Do the full inclusive cross-section measurement for the W + Jets process using the increased statistics of Run II.