Search for Large Extra Dimensions Using Missing Energy
PRE-BLESSING

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Exotics Meeting
October 3, 2002

- Introduction
- Description of Signal
- Normalization of Background Monte Carlos
- Optimization of Cuts
- Signal Systematics
- Extraction of Limit

Theoretical Motivation

New solution to the hierarchy problem

Model of Arkani-Hamed, Dimopoulos, and Dvali (ADD)

- n toroidal extra dimensions compactified at radius R
- Standard Model constrained to 4 dim. wall
- Gravity exists in 4+n dim. "bulk"
- Planck scale, M_{Planck}, related to new effective Planck scale, M_D

$$M_{Planck}^2 \sim R^n M_D^{2+n}$$

Collider Signatures of Extra Dimensions

- Real Graviton Emission, Virtual Graviton Exchange
- For graviton emission: 3 processes

$$q\overline{q} \to gG$$
$$qg \to qG$$
$$gg \to gG$$

- Graviton "escapes" into extra dimensions $\Rightarrow$ Missing Energy

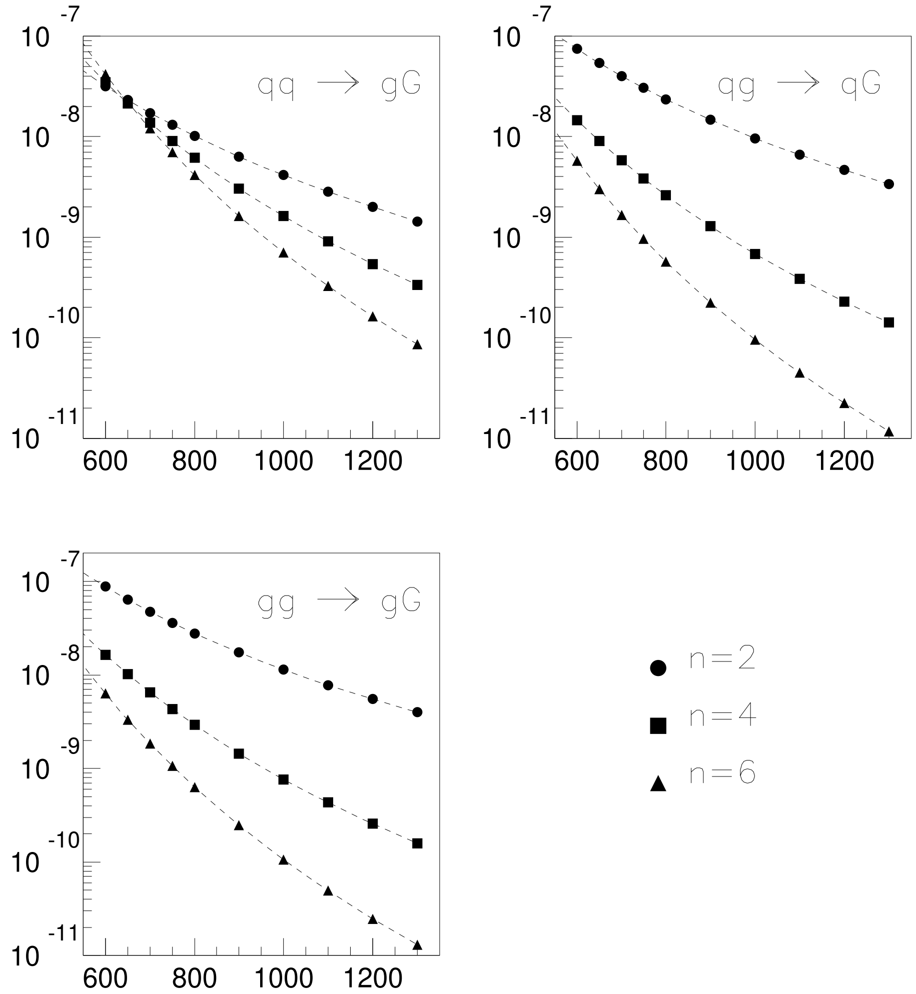
Graviton Emission in Monte Carlo

Implemented in Pythia 6.1

- Collaboration with J. Lykken(FNAL) and K. Matcheev (Florida)
- Uses model of Arkani-Hamed, Dimopoulos, and Dvali
- Calculations of Giudice, Ratazzi, and Wells
- 3 processes handled separately
- Choose # extra dimensions,M_D

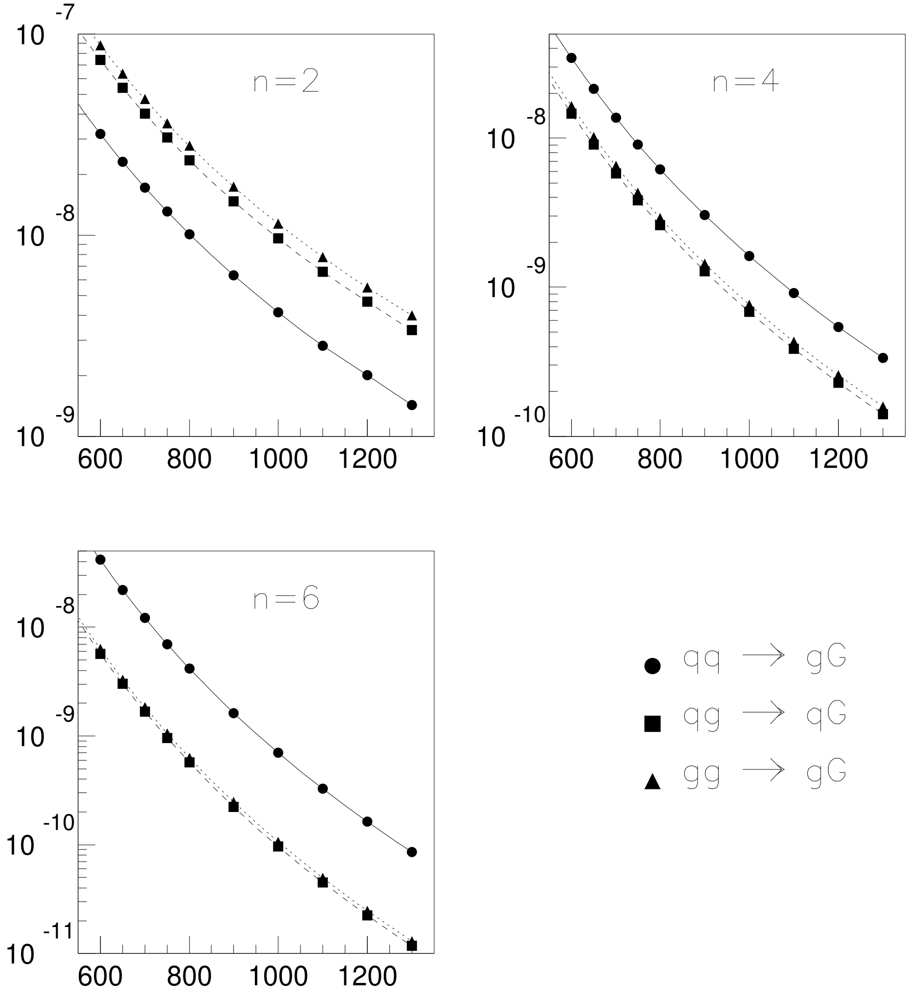
Studies of Signal Monte Carlo

Recall: $\sigma \sim 1/M_D^{n+2}$



Studies of Signal Monte Carlo

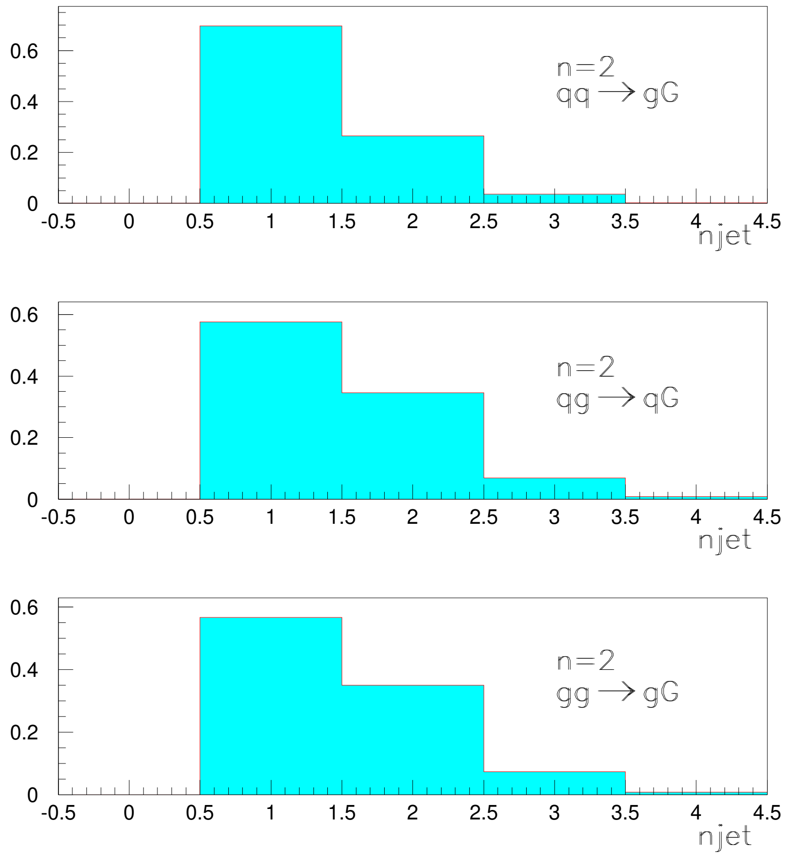
Recall: $\sigma \sim 1/M_D^{n+2}$

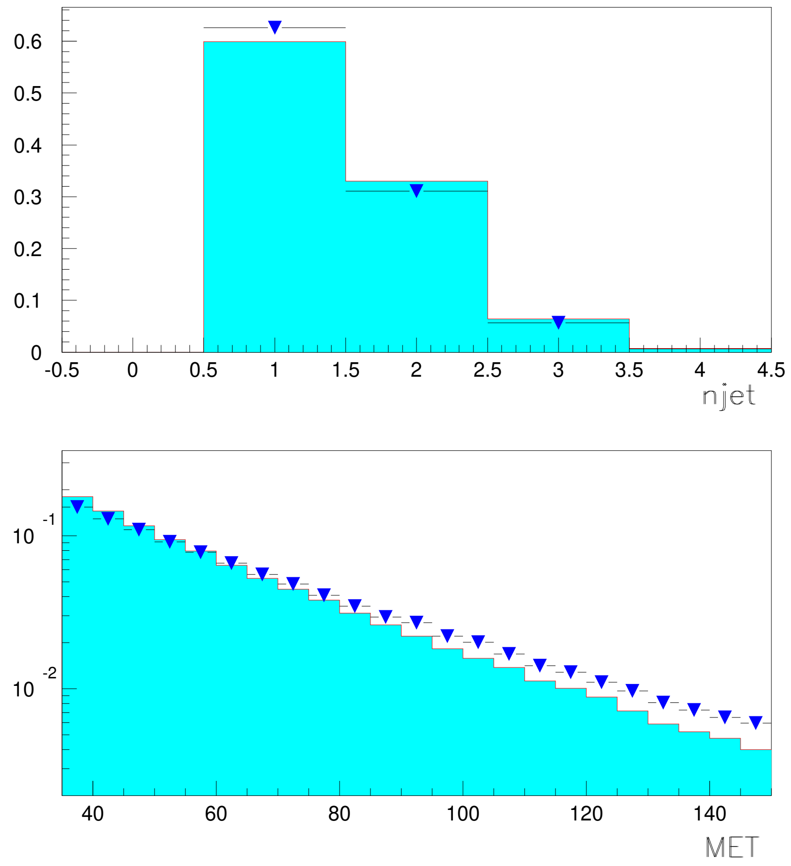


Studies of Signal MC

Signal has MET plus 1 or 2 jets

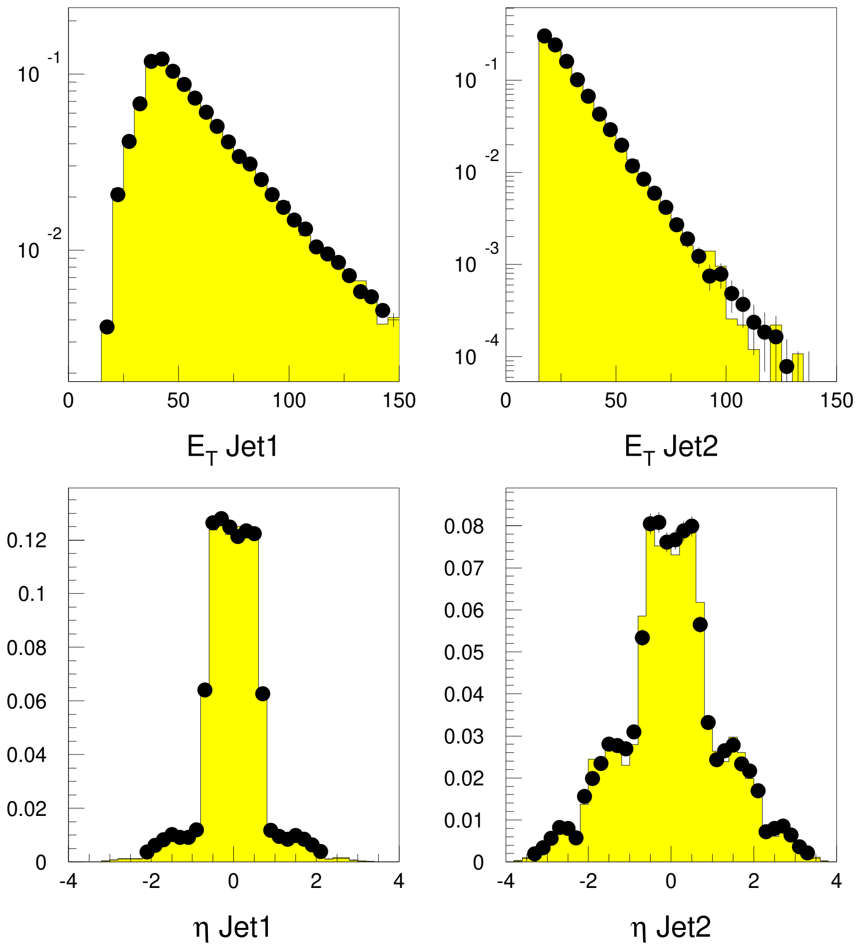
- Kinematics vary slightly with n
- histogram:n=2, points:n=6





Studies of Signal Monte Carlo

- For a given n kinematics do not depend on M_D
- Histogram: $M_D = 700$ GeV, Points: $M_D = 1$ TeV



List of Backgrounds

- $Z \to \nu\overline{\nu}$ + jets (Looks just like the signal)
- $W \to \tau\nu$ + jets
- $W \to \mu\nu$ + jets
- $W \to e\nu$ + jets
- QCD di-jets
- Dibosons
- $t\bar{t}$, single top

General Strategy for Backgrounds

- Generate background processes in Monte Carlo
- Normalize MC to data using other signals

Z and W Backgrounds

- Generate PYTHIA Z + jets, W + jets
- 2$\rightarrow$2 processes, not 2$\rightarrow$1
- For Z + jets, turn off γ/Z interference

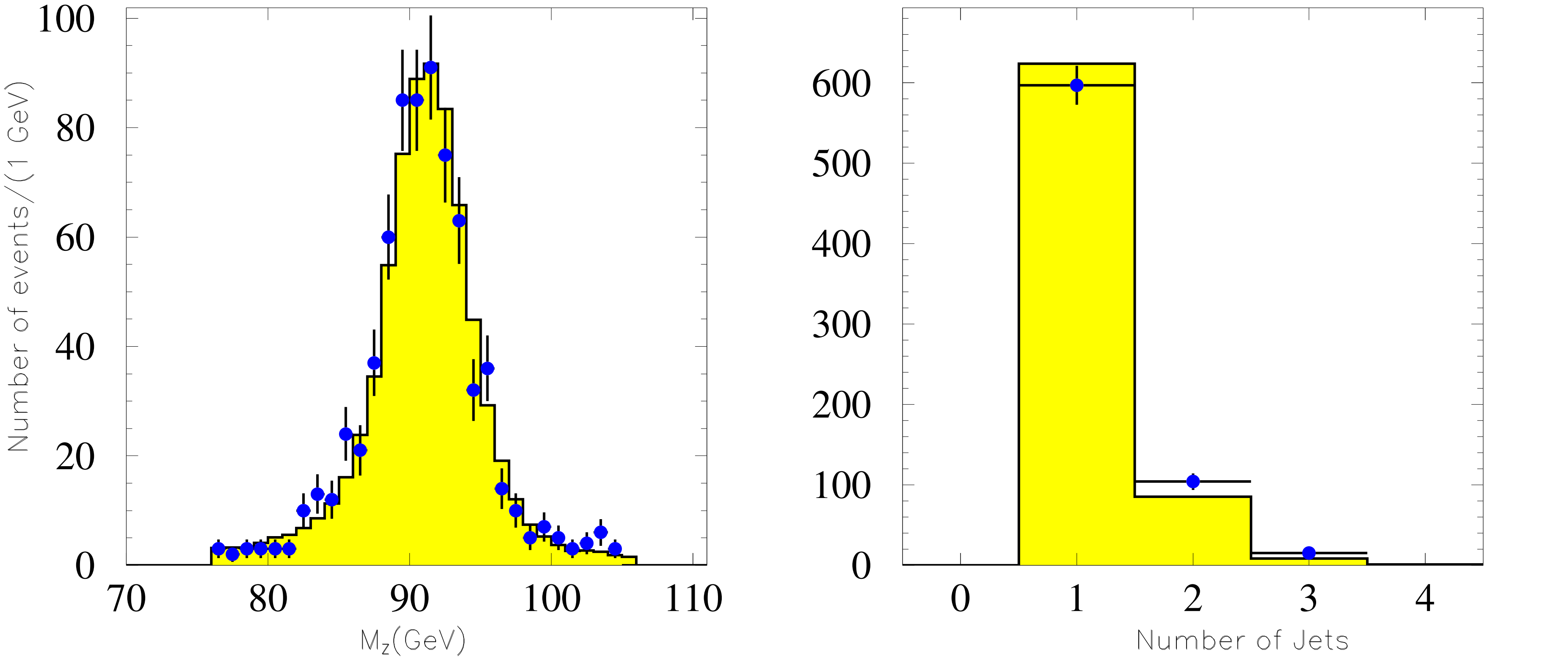
Validation of Monte Carlo

- Generate $Z \rightarrow ee + jets$, $W \rightarrow e\nu + jets$
- Select Z and W using Duke cuts
- Compare to $Z \rightarrow ee + jets$, $W \rightarrow e\nu + jets$ data

Normalize MC based on # of $Z \rightarrow ee + jets$ in data

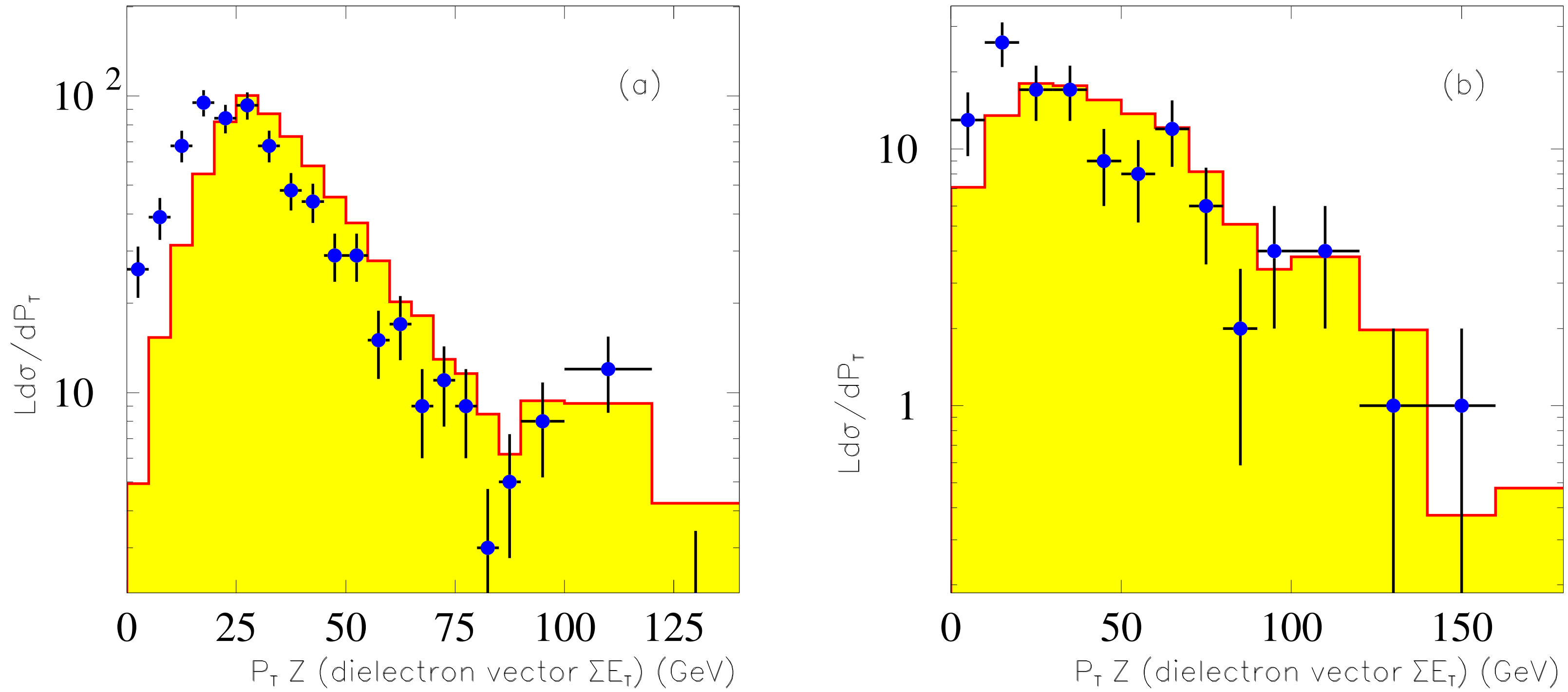
Z+jets Background

- **Points: Data, Histogram: Pythia MC**
- **(a):** $m(Z)$, **(b):** N_{jet}



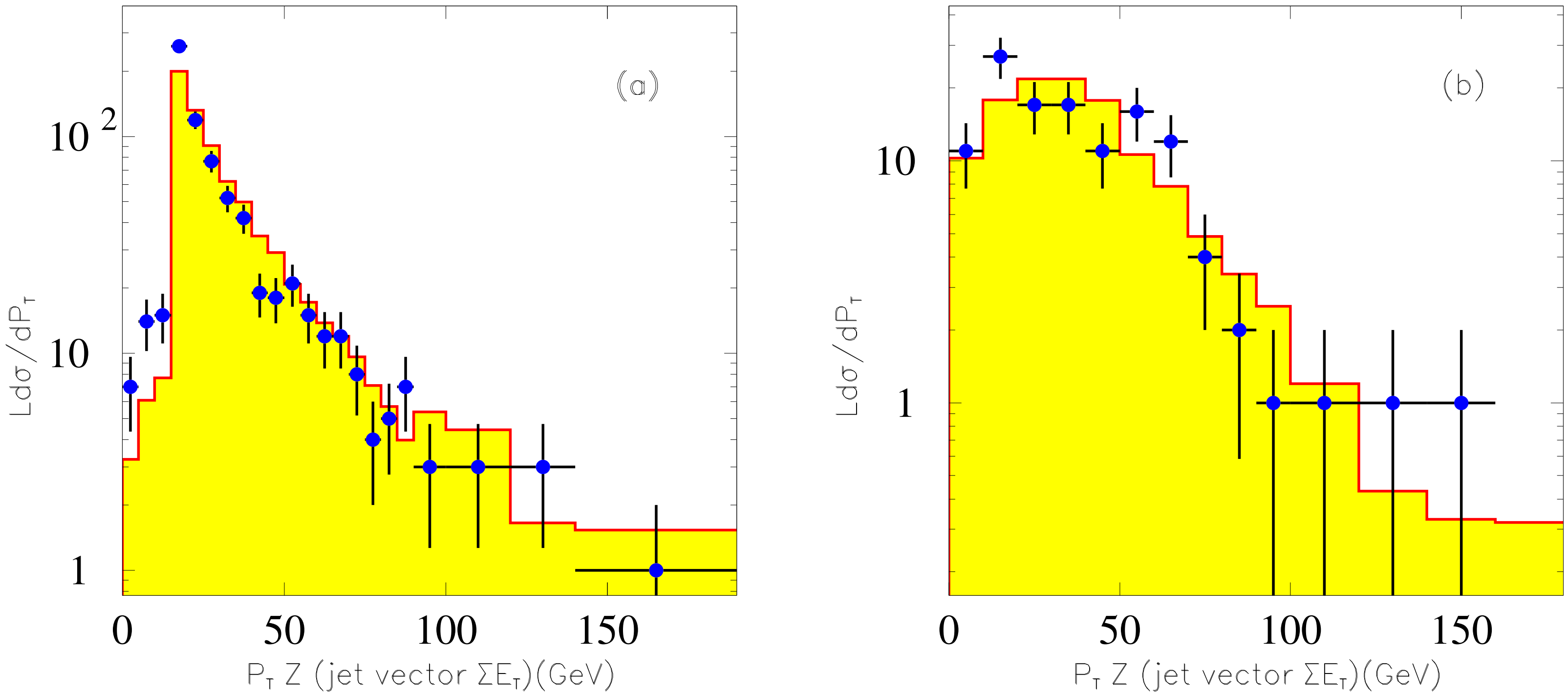
Check Kinematics of W,Z Pythia Monte Carlo

- $P_T(Z)$ using electrons
- (a) $Z \rightarrow ee+ \geq 1j$: Hist = Pythia MC, Points = Data
- (b) $Z \rightarrow ee+ \geq 2j$: Hist = Pythia MC, Points = Data



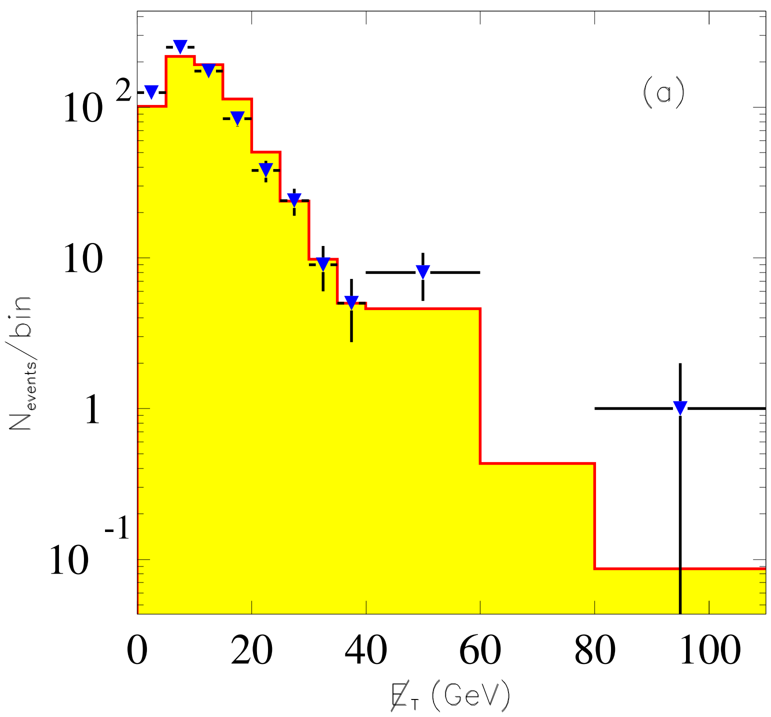
Check Kinematics of W,Z Pythia Monte Carlo

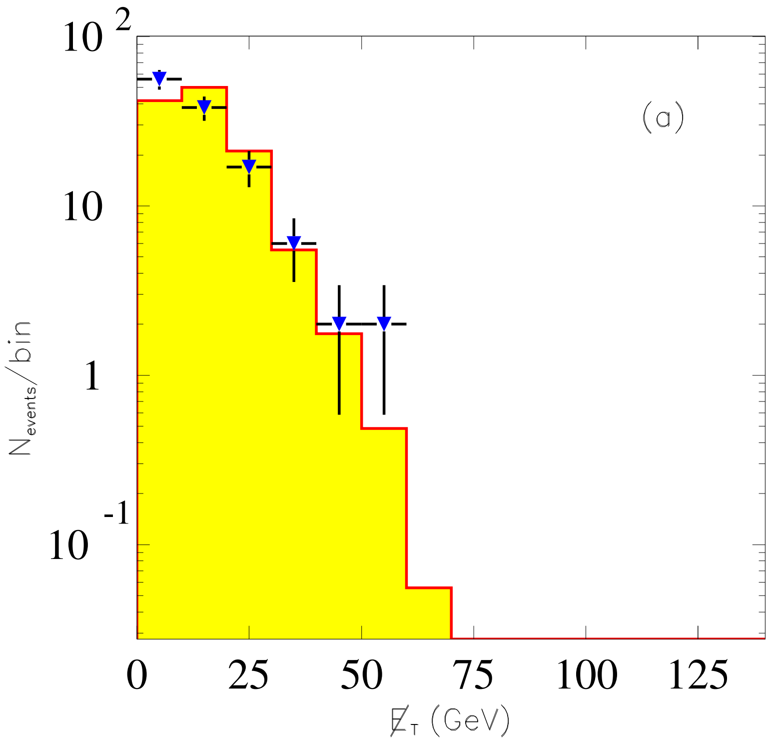
- $P_T(Z)$ using jets
- (a) $Z \to ee + \geq 1j$: Hist = Pythia MC, Points = Data
- (b) $Z \to ee + \geq 2j$: Hist = Pythia MC, Points = Data



Check Kinematics of W,Z Pythia Monte Carlo

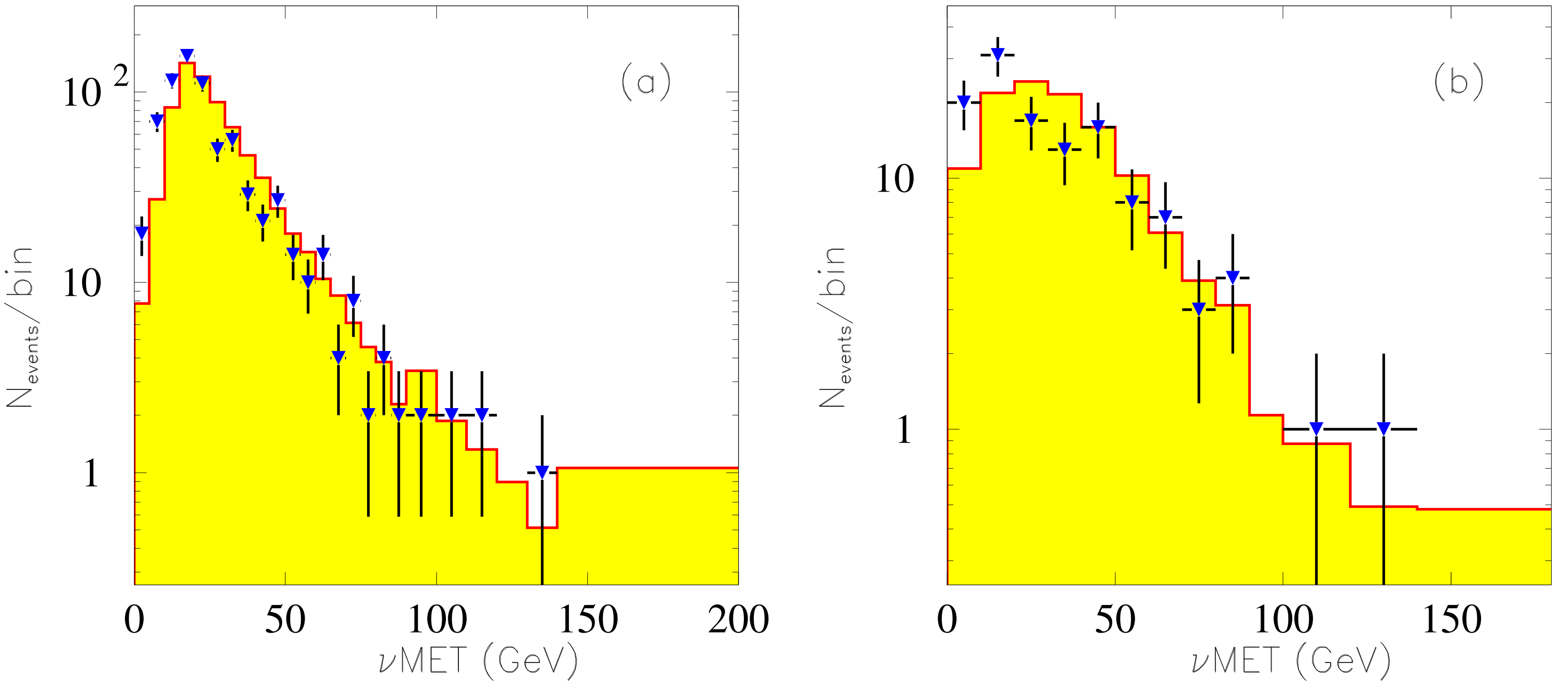
- Missing E_T
- (a) $Z \rightarrow ee+ \geq 1j$: Hist = Pythia MC, Points = Data
- (b) $Z \rightarrow ee+ \geq 2j$: Hist = Pythia MC, Points = Data





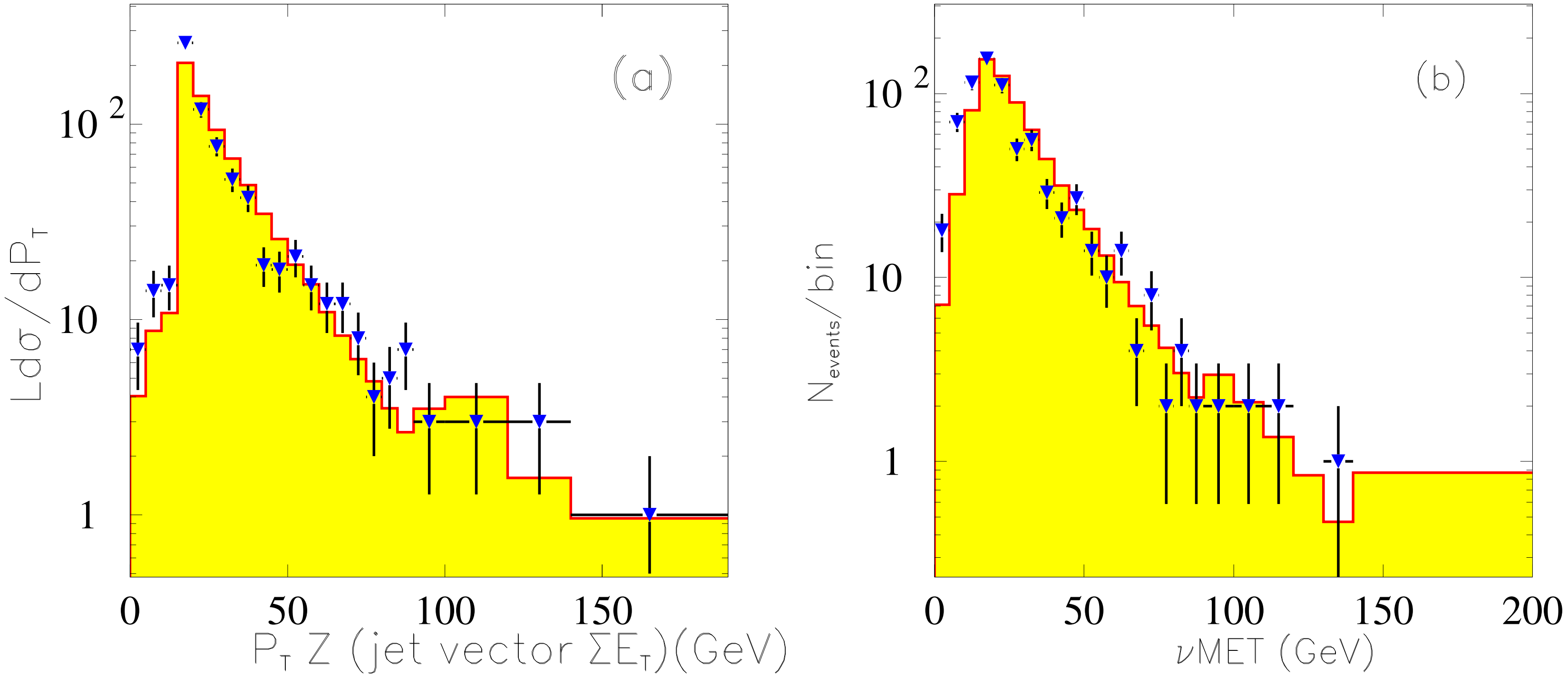
Check Kinematics of W,Z Pythia Monte Carlo

- $\nu MET = \not{E}_T + \Sigma\ E_T(e)$
- (a) $Z \rightarrow ee+ \geq 1j$: Hist = Pythia MC, Points = Data
- (b) $Z \rightarrow ee+ \geq 2j$: Hist = Pythia MC, Points = Data



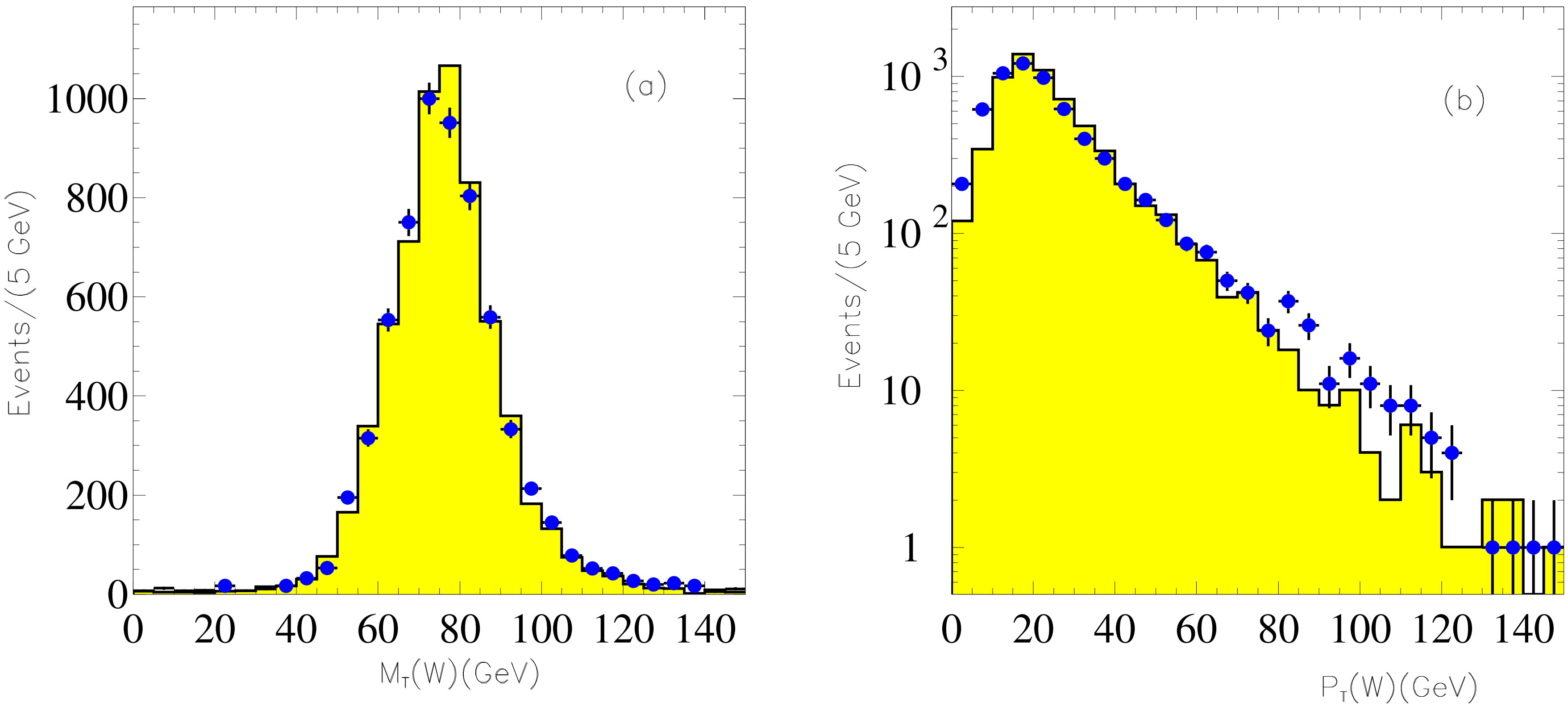
Check Kinematics of W,Z Pythia Monte Carlo

- (a)$P_T(Z)$: Hist = Pythia $Z \to \nu\nu + \geq 1j$, Points = $Z \to ee + \geq 1j$ Data
- (b)$\not{E}_T$: Hist = Pythia $Z \to \nu\nu + \geq 1j$, Points = $Z \to ee + \geq 1j$ Data



W+jets Background

- **Points:Data, Histogram: Pythia MC**
- **(a):** $m_T(W)$, **(b):** $P_T(W)$



Normalization of Z and W Backgrounds

Normalize $Z \to ee + jets$ MC to data

- Select $Z \to ee$+jets in data and MC
- MC sample luminosity from ratio of MC/data
- MC $\sigma(Z \to ee)$ using luminosity
- $\sigma(Z \to \nu\overline{\nu}) \ = \ 6 \times \sigma(Z \to ee)$
- Use $\sigma(Z \to \nu\overline{\nu})$ in normalizing $Z \to \nu\overline{\nu}$ MC

Normalize $W \to e\nu + jets$ MC with W/Z ratio

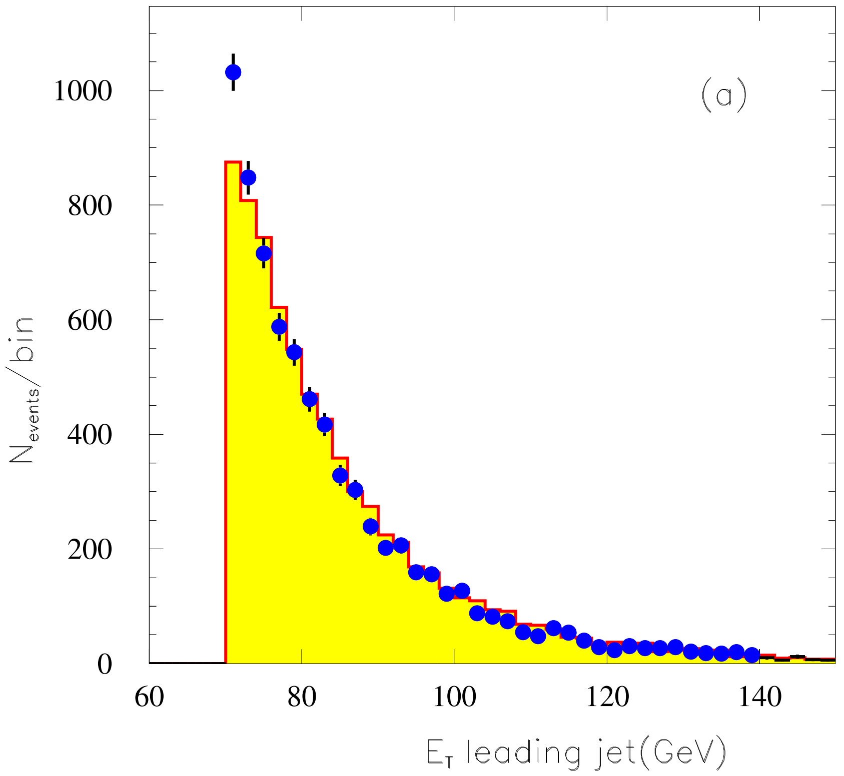
- Normalize $W \to e\nu + jets$ and $Z \to ee + jets$ MC samples to same luminosity using Pythia cross-sections
- Obtain ratio of found W/Z in MC
- Multiply with data-normalized $\sigma(Z \to ee)$ to obtain $\sigma(W \to e\nu)$
- Use ratio before trigger efficiency to avoid double-counting efficiency
- Cross check with normalization to $W \to e\nu$ data
  - Agrees to within 3%

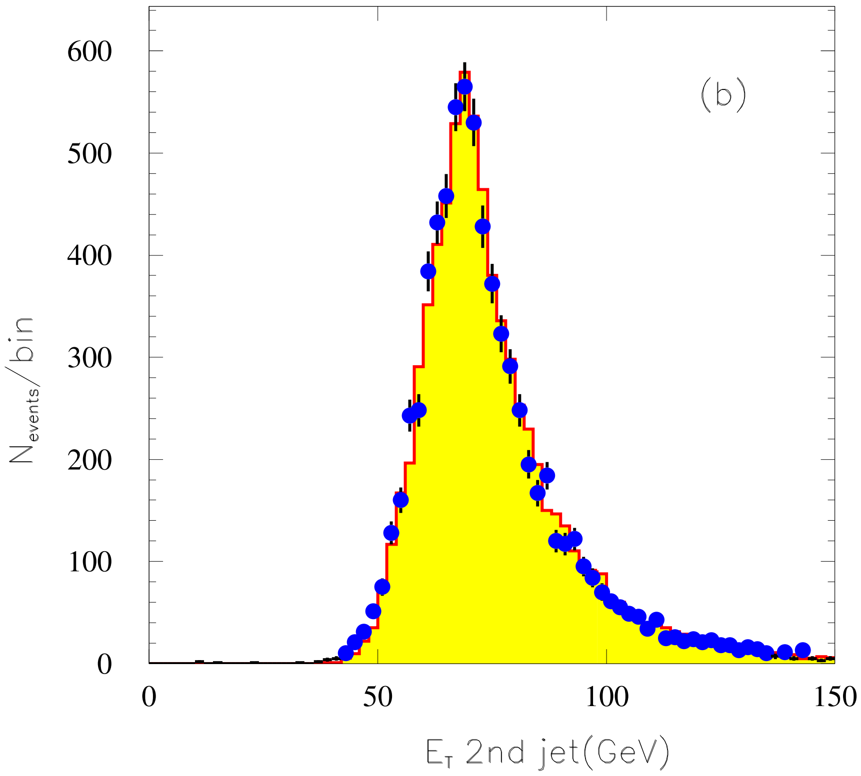
QCD Background

- Generate Herwig Jet50 Monte Carlo
- Actually two samples:
  - Default has Jet $E_T > 50$ GeV
  - Second sample requires $\not{E}_T > 40$ GeV to fill out $\not{E}_T$ tails
- For normalization and validation of MC, select dijets:
  - Exactly 2 jets
  - $E_T > 80$ GeV
  - $\not{E}_T < 20$ GeV
  - $\Delta\phi(jet - jet) > 2.7$
- Normalize # of dijets in MC to # in Jet50 Data
- Check normalization by reversing $\not{E}_T$ cut and seeing that it still holds.

Normalization of QCD MC with Dijets

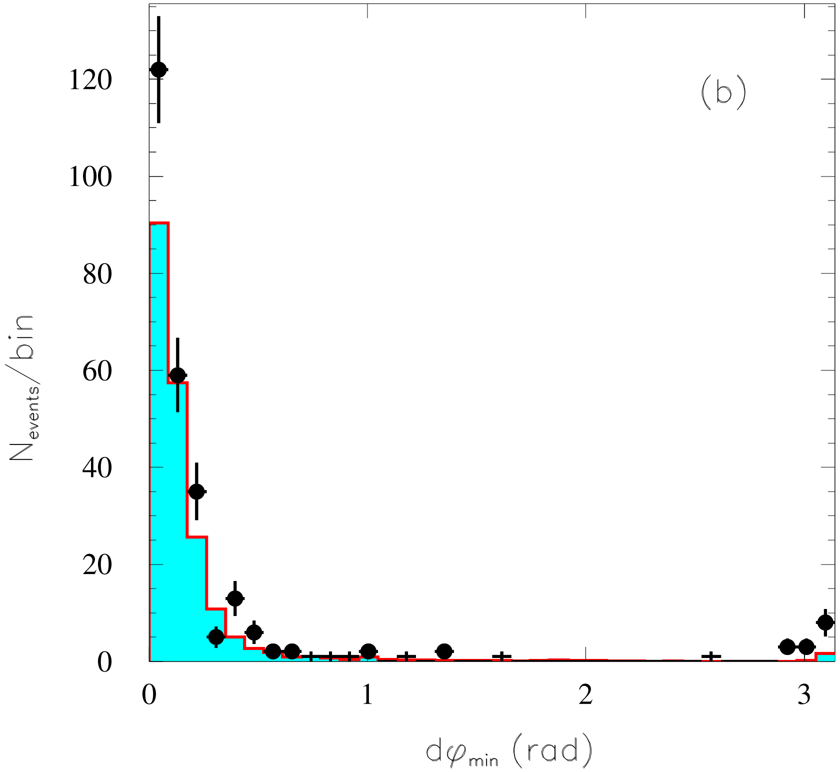
- **Points: Jet50 Data, Histogram: Herwig**
- **(a):** $E_T(1)$, **(b):** $E_T(2)$

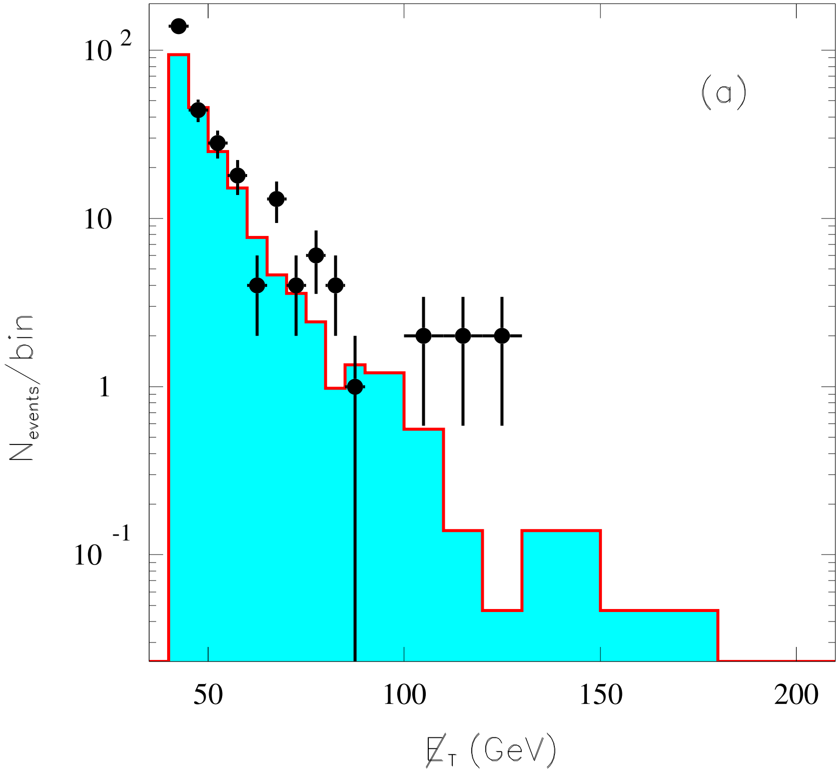




QCD Background

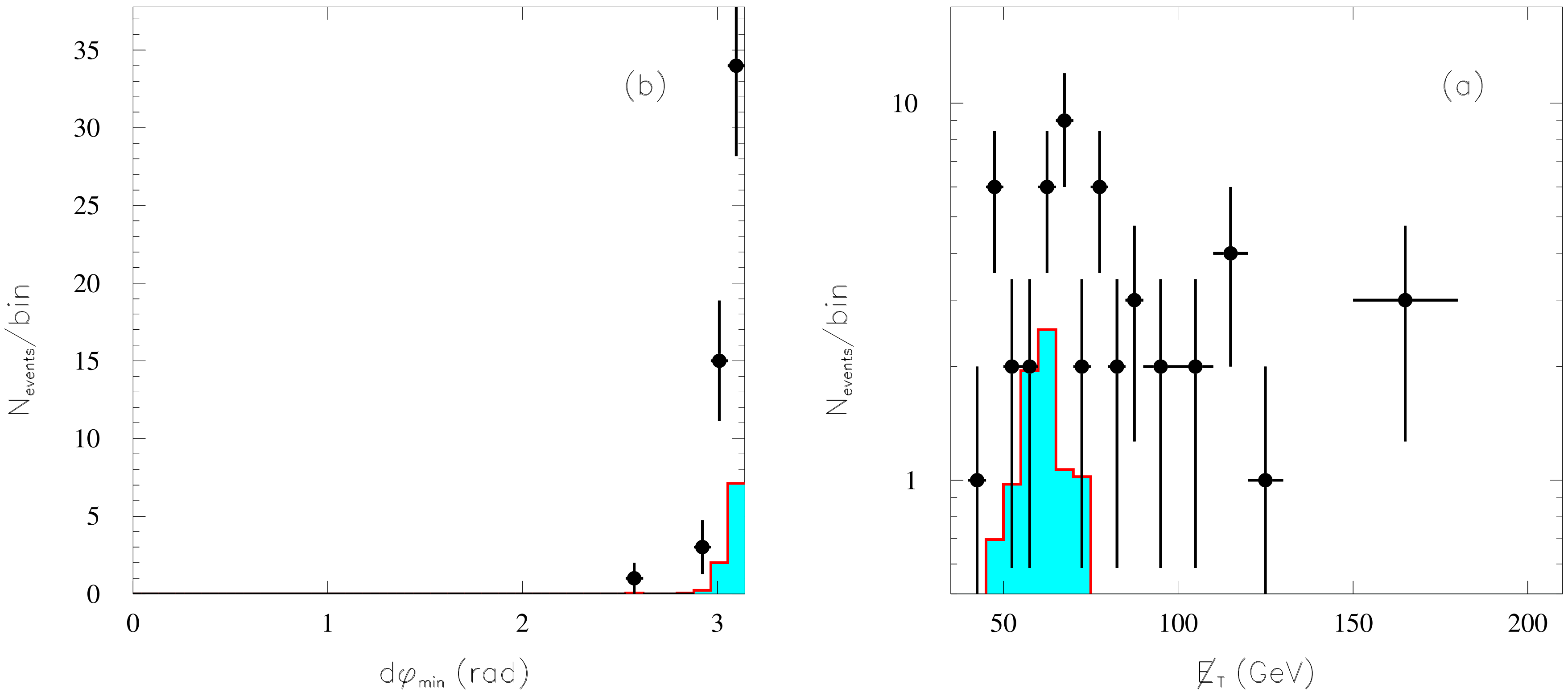
Release Dijet cuts to check normalization





QCD Background

Normalization breaks down if only 1-jet events are used



Data Selection

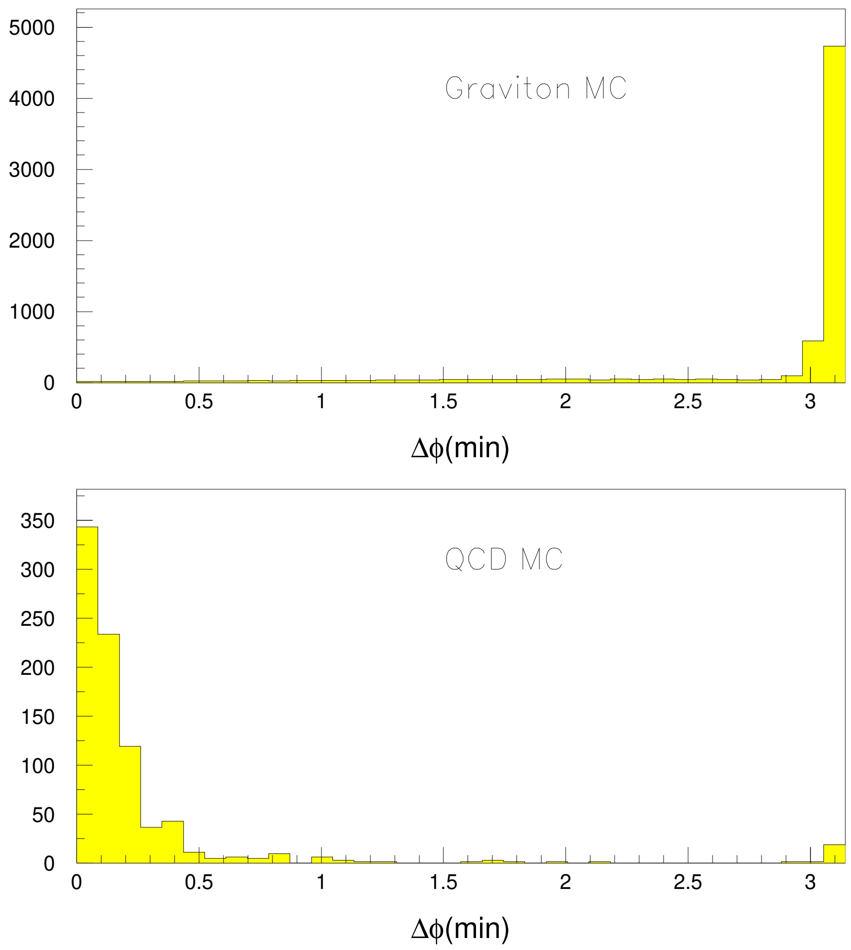
Initial Cuts

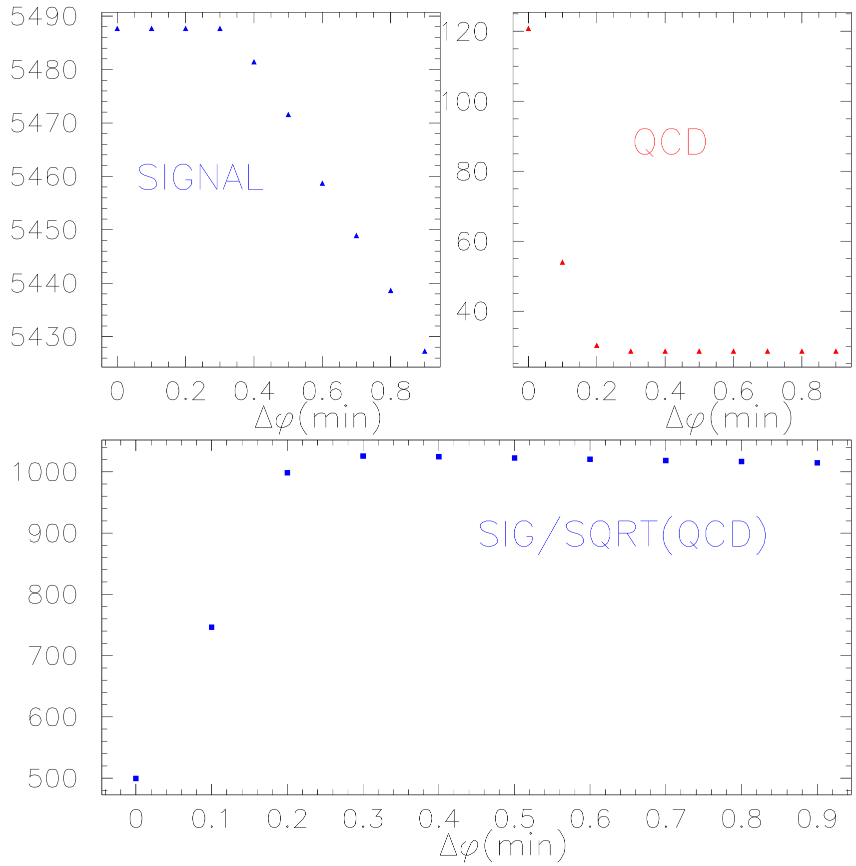
- SEL1 selection
  - $\not\!\!E_T \geq 35$
  - $EOT \leq 10$
  - $NOT \leq 5$
- SEL2 selection
  - $\geq 1\ jet,\ |\eta_d| < 0.7$
  - $ECHF \geq 0.1775$
  - $EEMF \geq 0.1$
- Remove bad runs, jets near cracks

Graviton Selection

- Keep 1 jet events and 2 jet events with high P_T 2nd jet
  - $n_{jets} \leq 2$
  - $E_T(j1) > 80$ GeV
  - If 2 jets, $E_T(j2) > 30$ GeV
- No isolated stiff tracks
- $\not\!\!E_T > 80$ GeV
- $\Delta\phi_{min}(Jet - \not\!\!E_T) > 0.3$
- $\not\!\!E_T$ and $\Delta\phi_{min}$ cuts optimized with $S/\sqrt{B}$

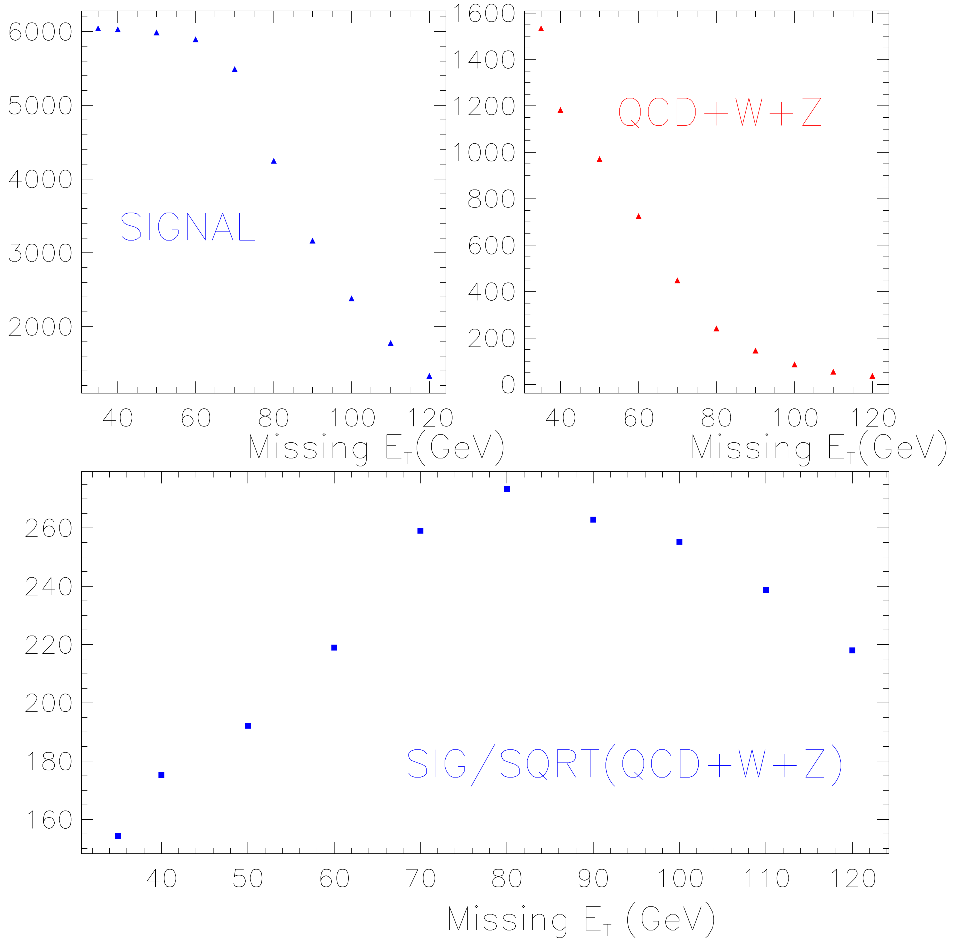
Optimization of $\Delta\phi_{min}$ Cut





Optimization of $\not\!\!E_T$ Cut

To optimize $\not\!\!E_T$ cut, combine QCD, W, and Z, with relative normalizations

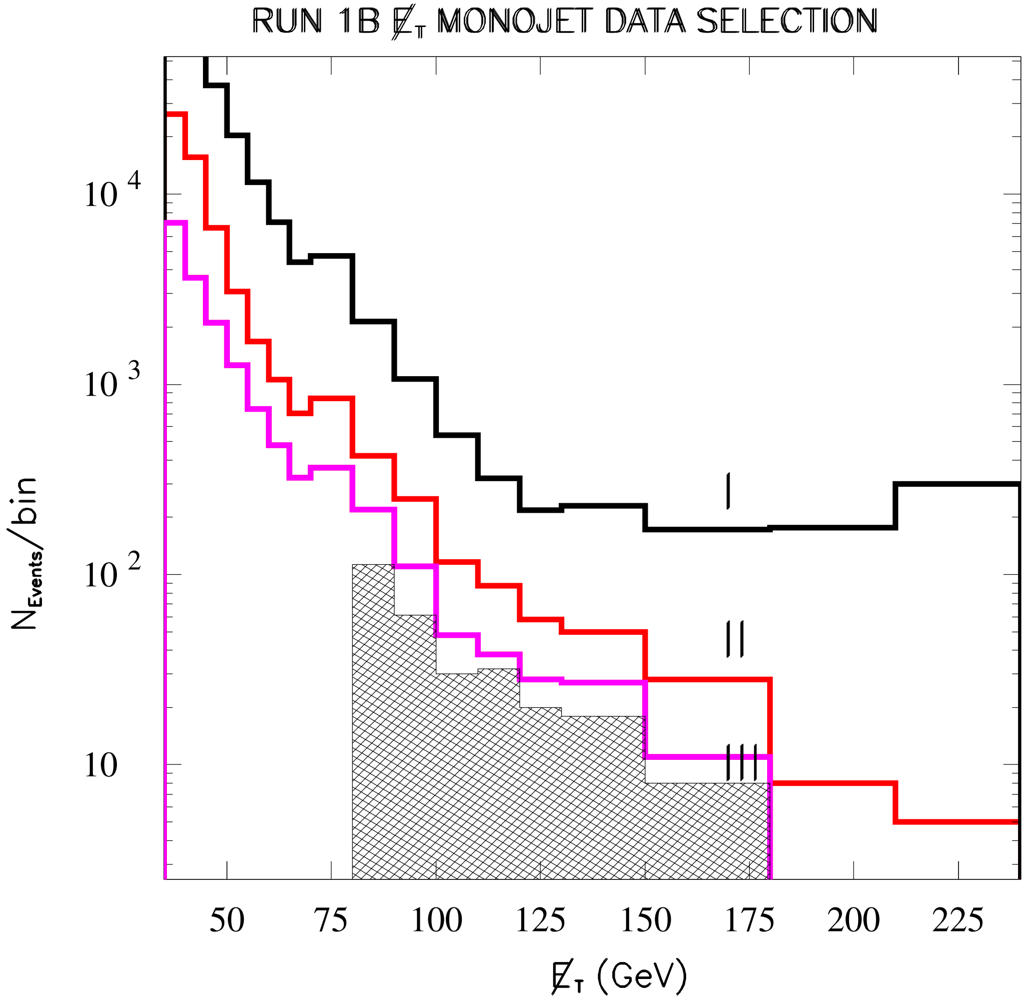


Summary of Backgrounds

- $Z \to \nu\nu$, $W \to \ell\nu$,QCD, $t\bar{t}$,single top, dibosons
- Normalized either to data or with theoretical cross section
- Uncertainties are statistical plus systematic
- If normalized to data, uncertainy includes 4% uncertainty on luminosity
- Additional 13.5% uncertainty on QCD due to jet resolution.

Background	
$Z \to \nu_i\bar{\nu}_i$	160.3 $\pm$ 11.5
$W \to \tau\nu_\tau$	48.6 $\pm$ 5.7
$W \to \mu\nu_\mu$	24.5 $\pm$ 5.1
$W \to e\nu_e$	18.6 $\pm$ 4.4
top, dibosons	3.9 $\pm$ 0.2
Total EWK	256 $\pm$ 14.5
QCD	22 $\pm$ 6.7
Total predicted	278 $\pm$ 16

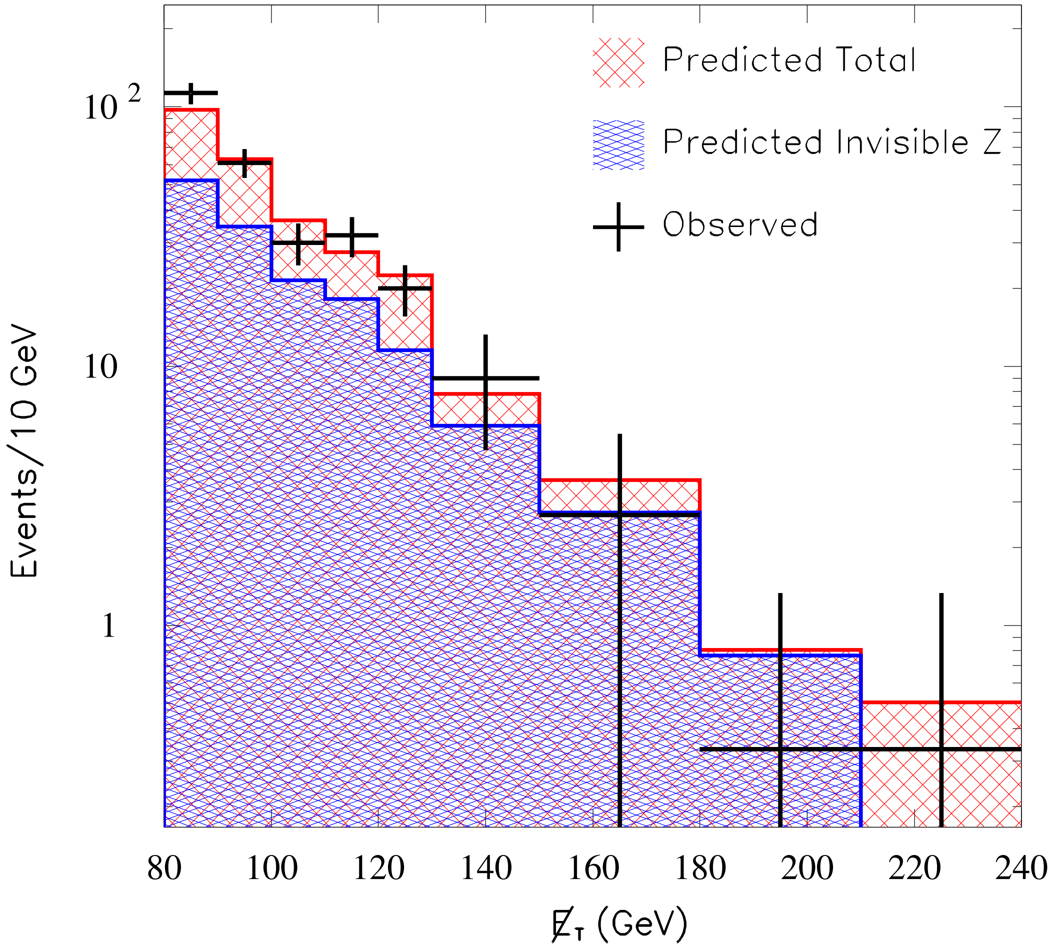
Data After Final Selection



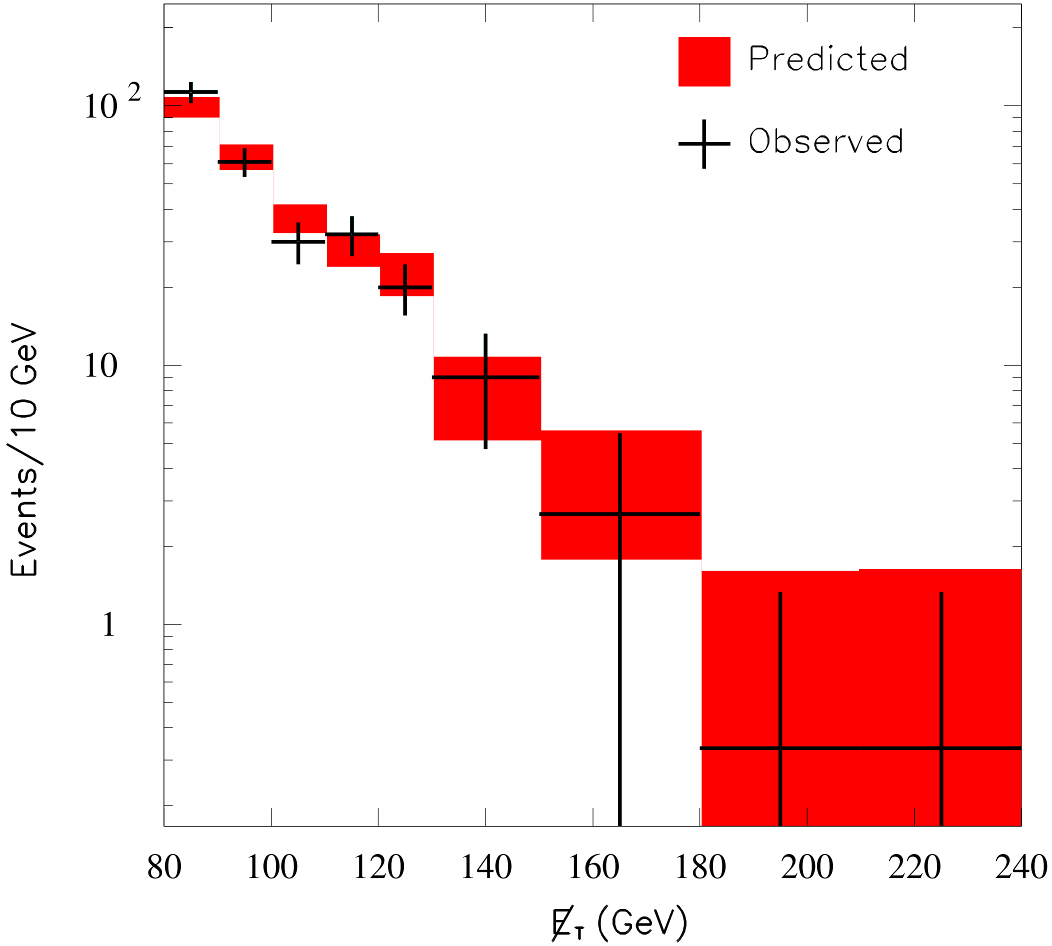
Data vs. Predicted Backgrounds

Background	
$Z \to \nu_i \bar{\nu}_i$	160.3 ± 11.5
$W \to \tau \nu_\tau$	48.6 ± 5.7
$W \to \mu \nu_\mu$	24.5 ± 5.1
$W \to e \nu_e$	18.6 ± 4.4
top, dibosons	3.9 ± 0.2
QCD	22 ± 6.7
Total Predicted	278 ± 16
Data Observed	284

Data vs. Predicted Backgrounds



Data vs. Predicted Backgrounds

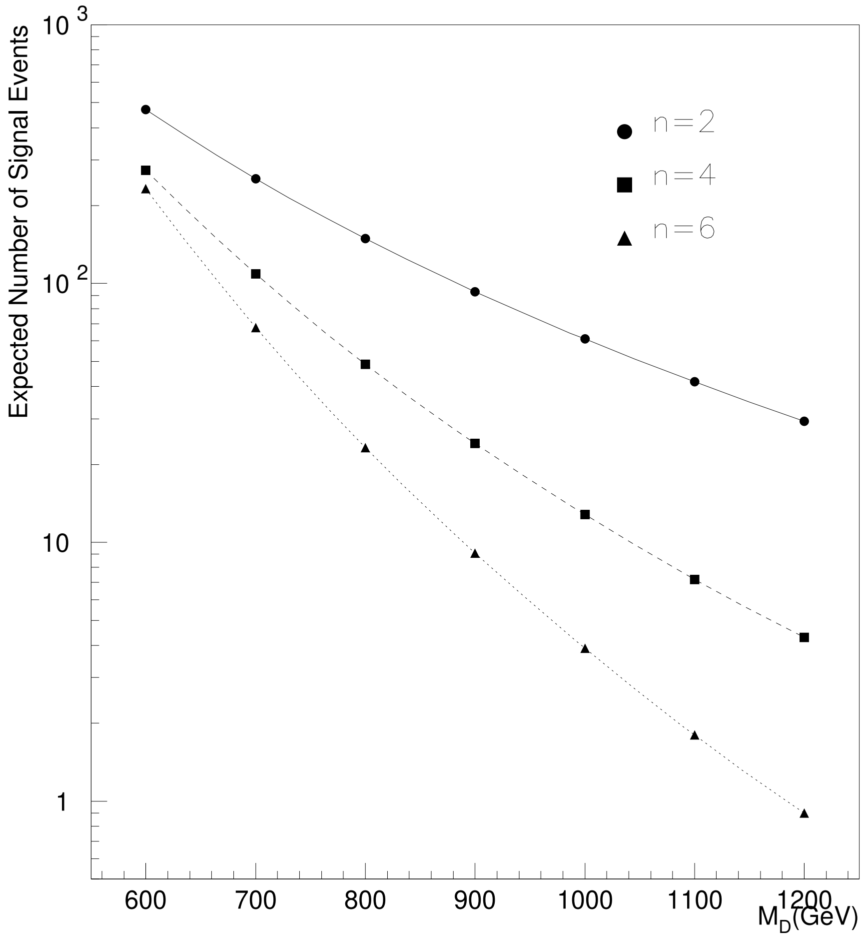


Signal Acceptance After Final Selection

Requirement	Signal Acceptance(%)
Preselection, $\not\!\!E_T > 35$ GeV 1≥N$_{jet}$ ≤2 (cone .7,E_T≥ 15 GeV) $\|\eta_d\|(1\ or\ 2) < 1.1$ fiducial 2nd jet	30
EMF(1),EMF(2)≤ 0.9,N^{iso}_{trk}=0	28
$\|vertex\| \leq\ 60\ cm$,$\delta\phi_{min} \geq 0.3$	28
E_T(1)≥80GeV If two jets E_T(2)≥30GeV	6
$\not\!\!E_T$ ≥80	5

Expected Signal After Final Selection

Signal events vs M_D for n = 2, 4, 6



M_D(GeV)	n=2	n=4	n=6
600	471	274	232
700	254	109	68
800	149	49	23
900	93	24	9
1000	61	13	4
1100	42	7	2
1200	29	4	1

Signal Systematics

- Jet Energy Scale
  - Vary jet energies by $\pm$ 5%
  - Systematic: 11%
- Q^2 Scale
  - Default is $Q_0 = \frac{1}{2}m_{KK}^2 + P_T^2$
  - Vary to $2 * Q_0$ and $\frac{1}{2} * Q_0$
  - Systematic: 8%
- ISR/FSR
  - Default is ISR ON / FSR ON
  - Compare with OFF/OFF, OFF/ON, and ON/OFF
  - Systematic: 21%
- PDF's
  - Default MRSD-, Check with CTEQ2M
  - Systematic: 2%
- Trigger Efficiency
  - Systematic: 2%
- Total = 25%

Setting a Limit

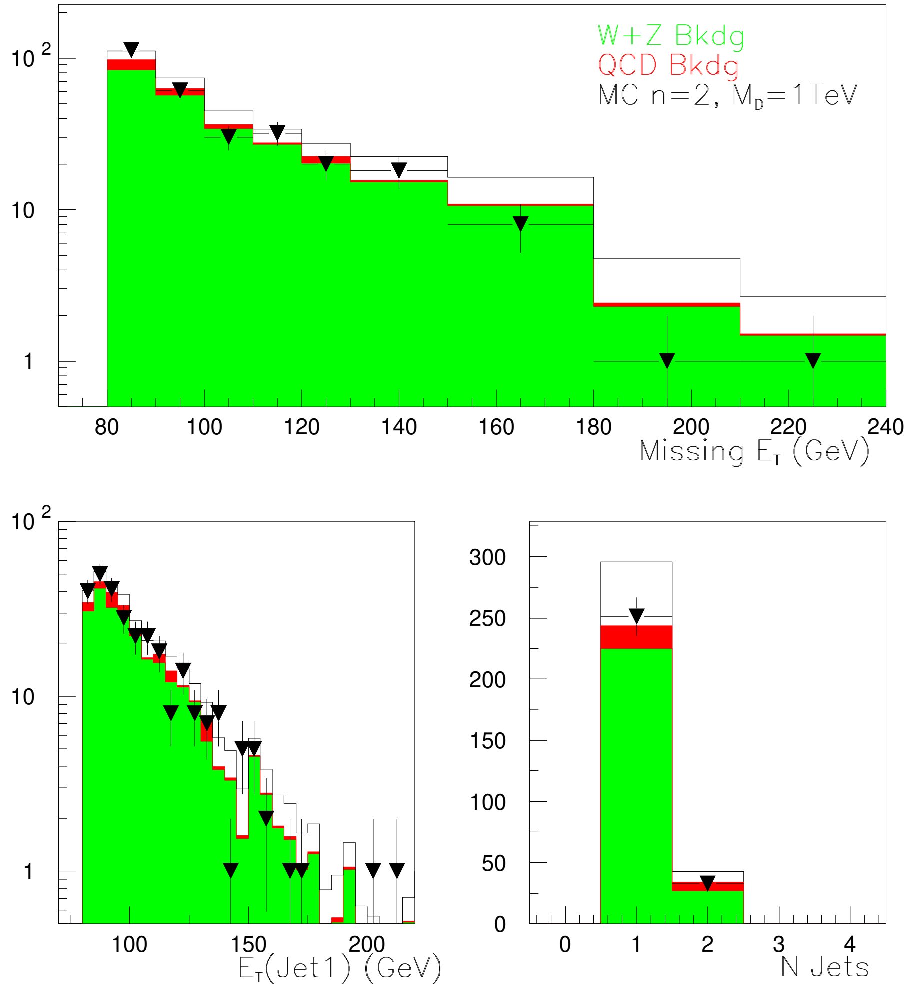
- Events Predicted:278 $\pm$ 16
- Observed in Data:284
- Uncertainty on Signal Acceptance: 25%
- Use POILIM to extract limit

Upper Limit (95%CL): 58.9 events

Convert to Limit on M_D

- n=2 $M_D \geq$ 1007 GeV (D0: 886 GeV, 987 GeV(K=1.34))
- n=4 $M_D \geq$ 774 GeV (D0: 663 GeV, 728 GeV(K=1.34))
- n=6 $M_D \geq$ 711 GeV (D0: 626 GeV, 646 GeV(K=1.34))

If there were LED for n=2, M_D= 1 TeV...



Conclusions

- **Predicted SM backgrounds match data well**
- **Limits set on Extra Dimensions in ADD model**
  - **n=2:** $M_D \geq$ **1007 GeV**
  - **n=4:** $M_D \geq$ **774 GeV**
  - **n=6:** $M_D \geq$ **711 GeV**
- **Want to add limit for Lykken-Randall model**
  - **Same as n=6 limit** $\times$ **constant factor**