

# Decorrelation of Dijets at Low $x$ and $Q^2$

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HaQ Meeting, March 21 2007

## Outline

⇒ Motivation & Selection

⇒ Reminder:  $d^2\sigma/dx_{bj}d\Delta\phi^*$ ,  $d^2\sigma/dQ^2d\Delta\phi^*$

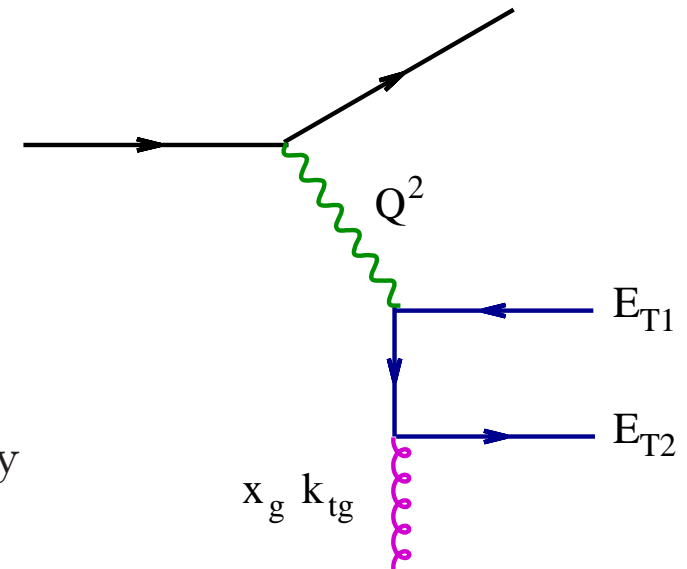
⇒  $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ : P, S, C, cross sections

⇒  $d^2\sigma/dx_gd\Delta\phi^*$ :  $x_g$  reconstruction, P, S, C, cross sections

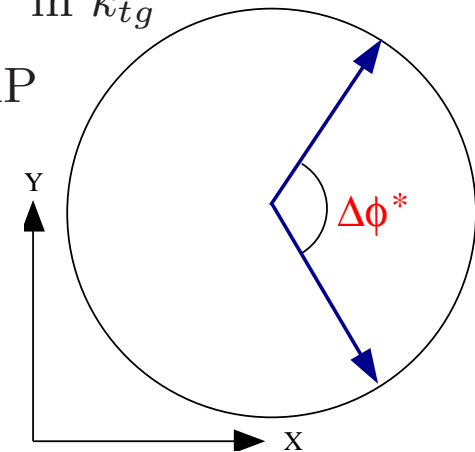
⇒ Summary

# Motivation

**DGLAP:** Gluon collinear with proton in LO  
 $\Rightarrow$  Jets back-to-back in HCM  
 Higher order QCD radiation  
 $\Rightarrow k_{tg} \neq 0$  and  $\Delta\phi^* < 180^\circ$   
 Gluon propagators ordered in virtuality  
 $\Rightarrow k_{tg}$  ordered



**Small- $x$ :** New dynamics (BFKL, CCFM): 'random walk' in  $k_{tg}$   
 $\Rightarrow$  Broader  $\Delta\phi^*$  spectrum compared to DGLAP  
 uPDF  $\Rightarrow \Delta\phi^* < 180^\circ$  already in LO



**Azimuthal Decorrelations:**  
 $\Rightarrow$  Sensitive to different parton dynamics  
 $\Rightarrow$  Sensitive to unintegrated gluon density

# Selection

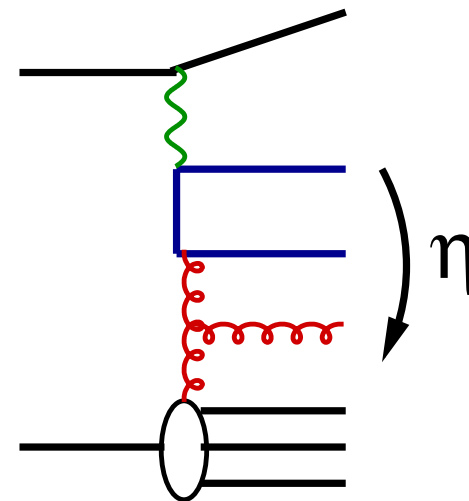
Using 1999/2000  $e^+p$  data,  $\mathcal{L} \simeq 64 \text{ pb}^{-1}$

## DIS Cuts

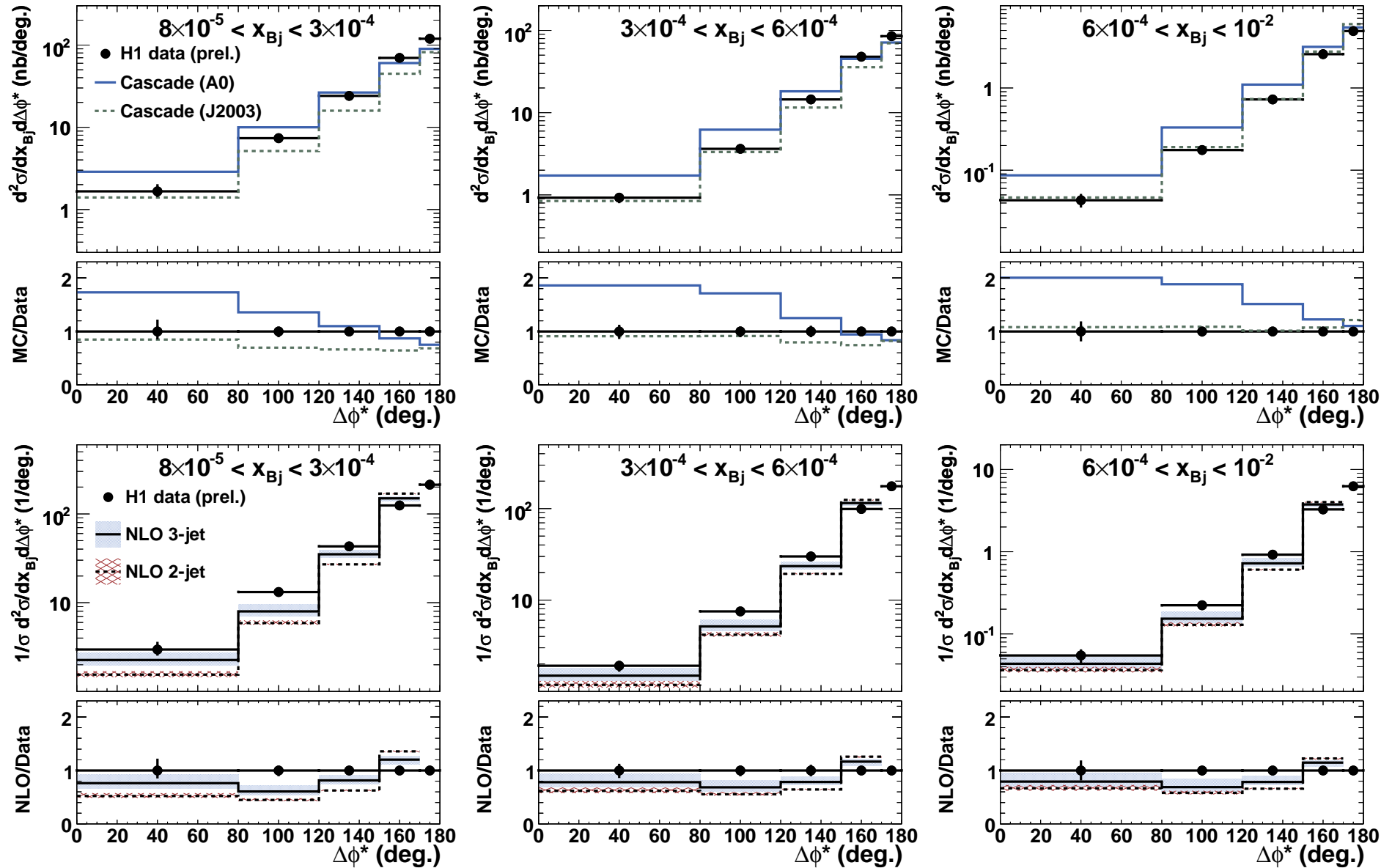
$5 \text{ GeV}^2 <$	$Q^2$	$< 100 \text{ GeV}^2$
$0.1 <$	$y$	$< 0.7$
$9 \text{ GeV} <$	$E_e$	
$156^\circ <$	$\theta_e$	$< 175^\circ$
$35 \text{ GeV} <$	$E - p_z$	$< 70 \text{ GeV}$
	$ z_{vtx} $	$< 35 \text{ cm}$
	$R_{clus}$	$< 3.5 \text{ cm}$
	$E_{had}$	$< 0.5 \text{ GeV}$
	$E_{veto}$	$< 1.0 \text{ GeV}$

## Dijet Cuts

$-1 <$	$\eta_j$	$< 2.5$
$5 \text{ GeV} <$	$E_{\perp j1,2}^*$	
	Sort in $\eta$	



Reminder:  $d^2\sigma/dx_{bj}d\Delta\phi^*$

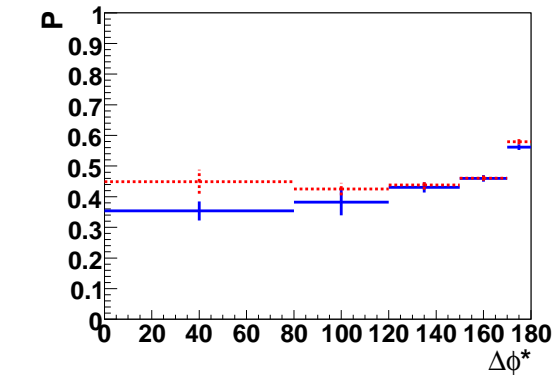
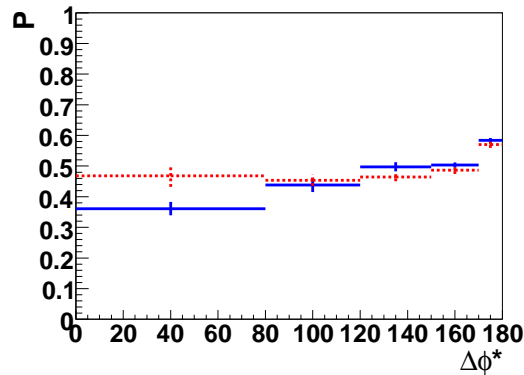
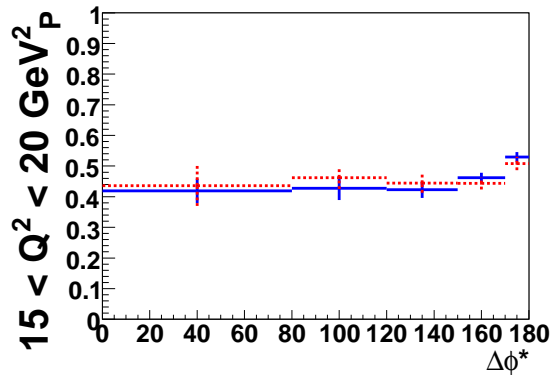
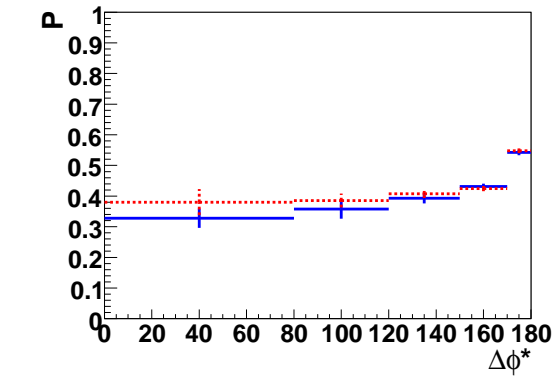
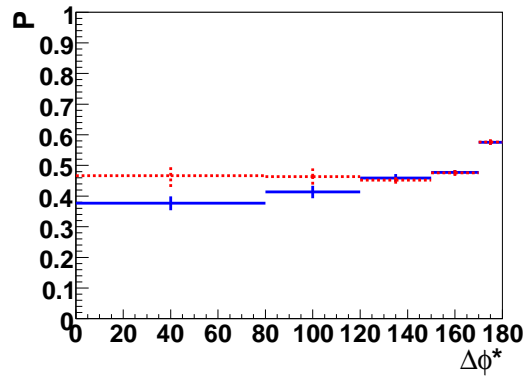
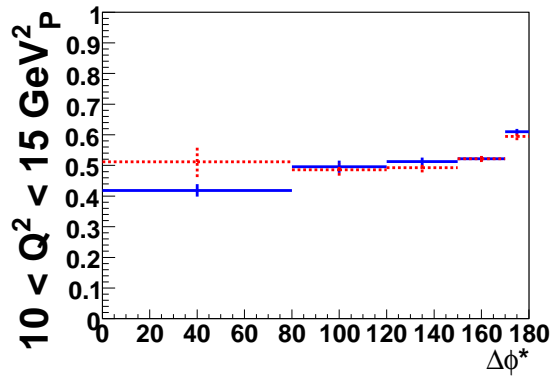
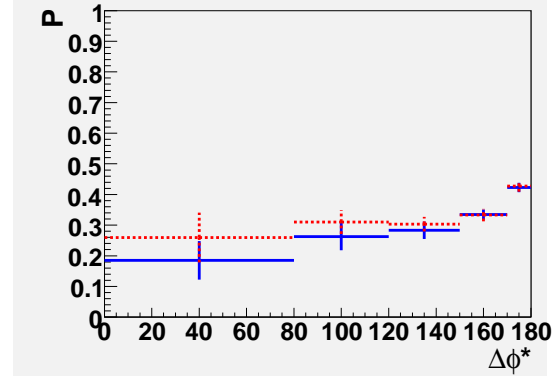
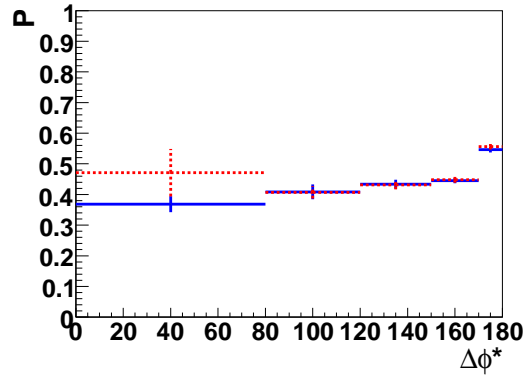
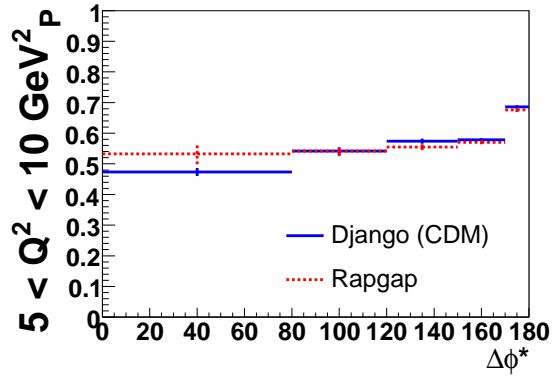


# $d^3\sigma / dx_{bj} dQ^2 d\Delta\phi^*$ Purity

$$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$$

$$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$$

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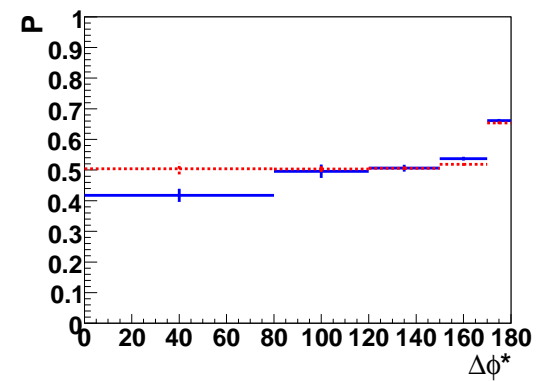
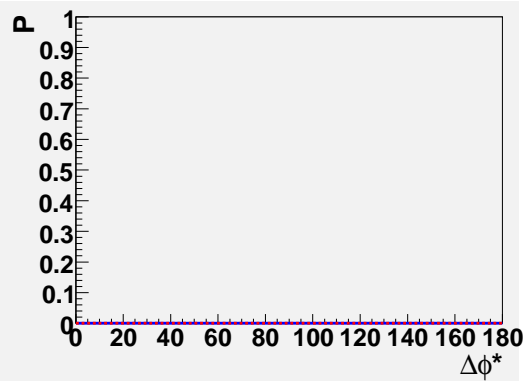
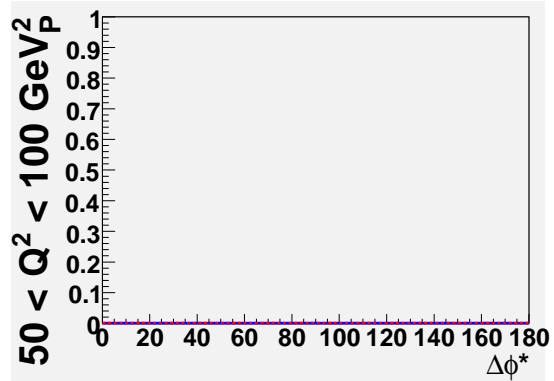
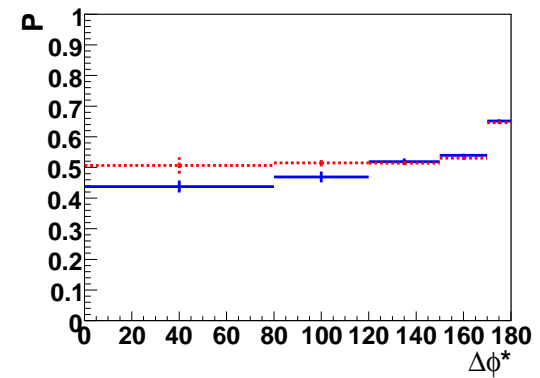
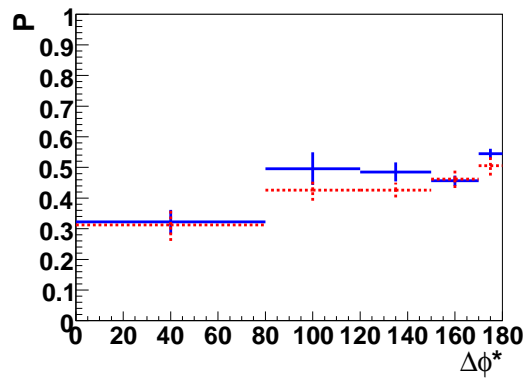
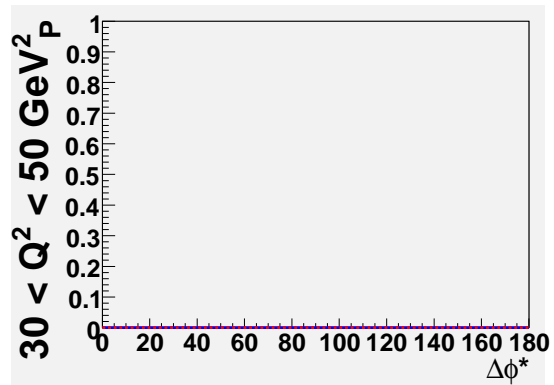
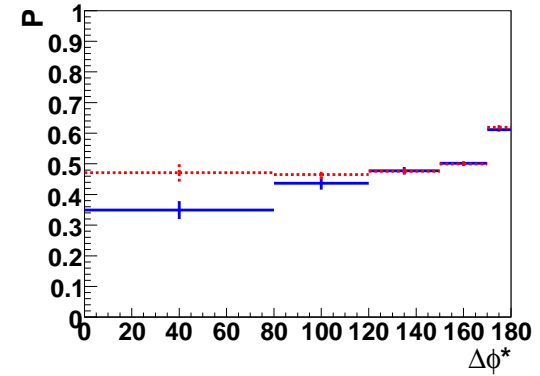
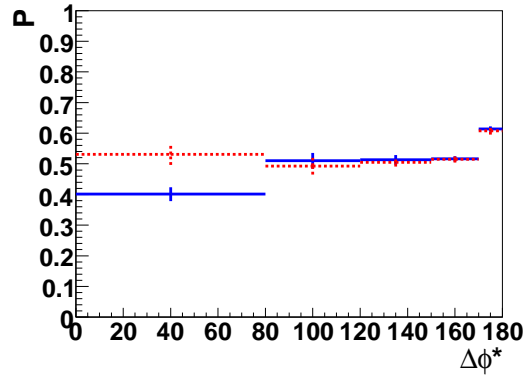
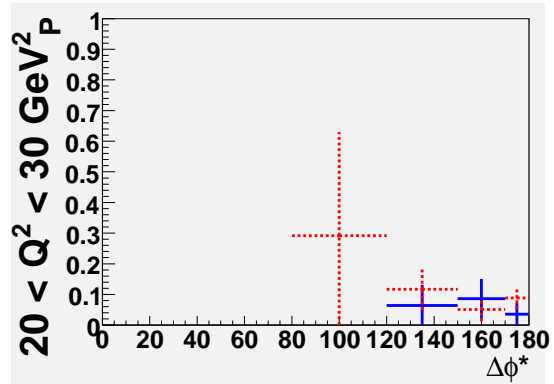


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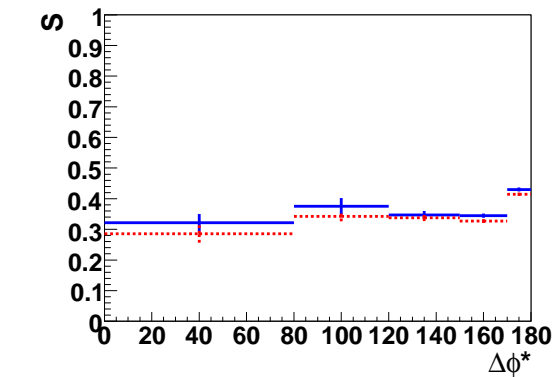
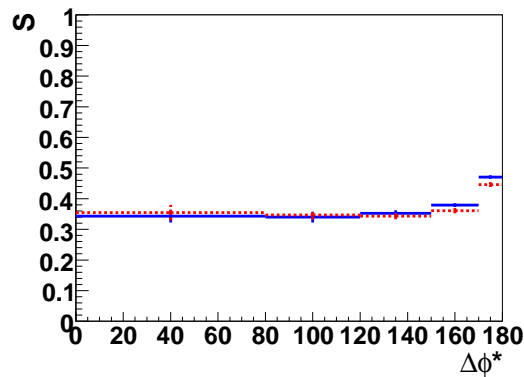
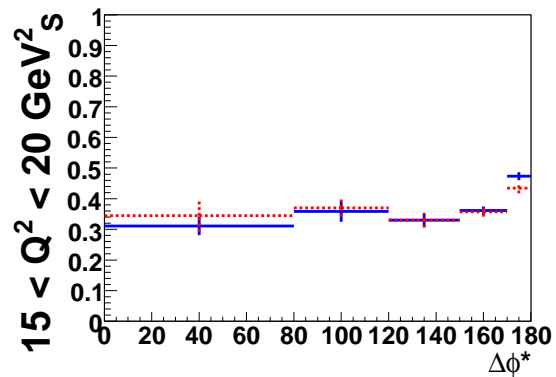
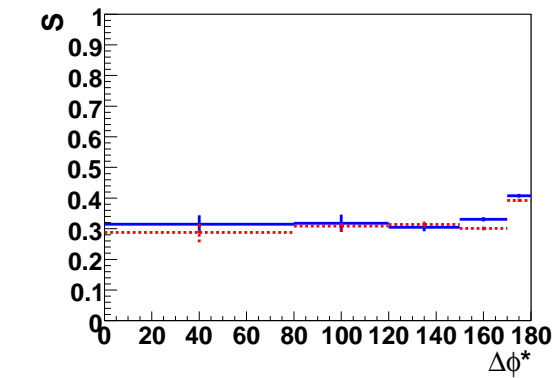
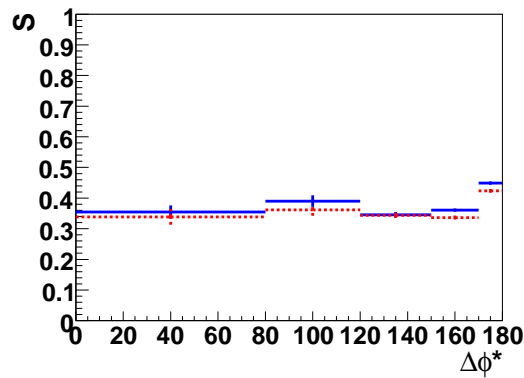
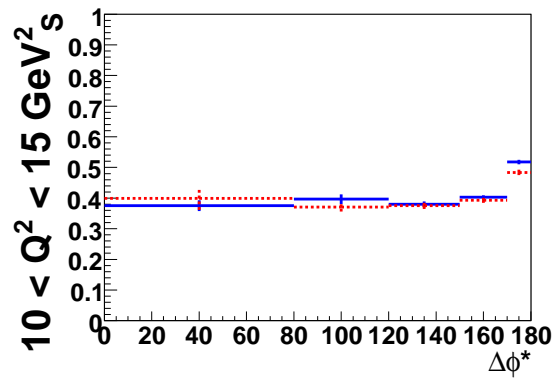
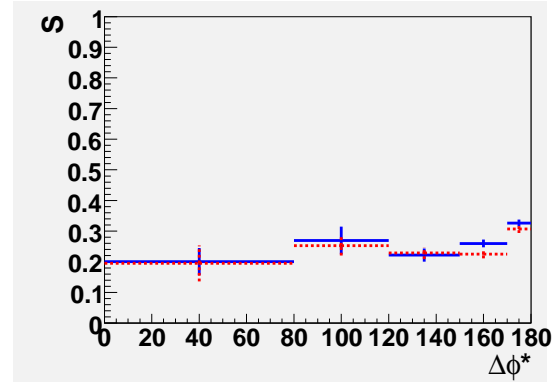
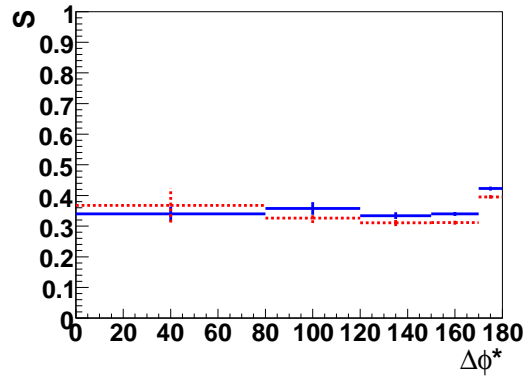
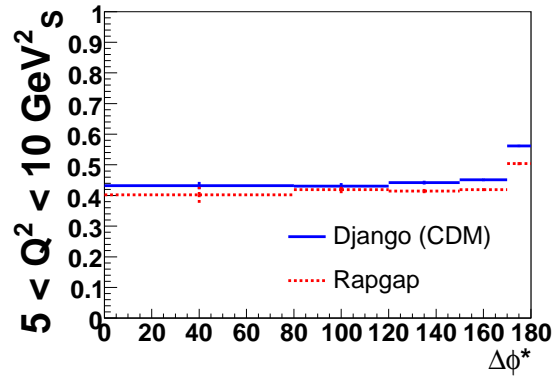


# $d^3 \sigma / dx_{bj} dQ^2 d\Delta\phi^*$ Stability

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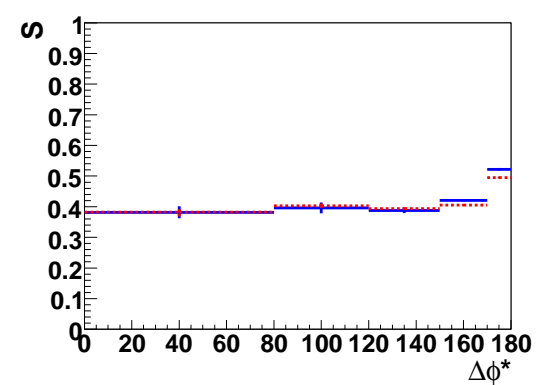
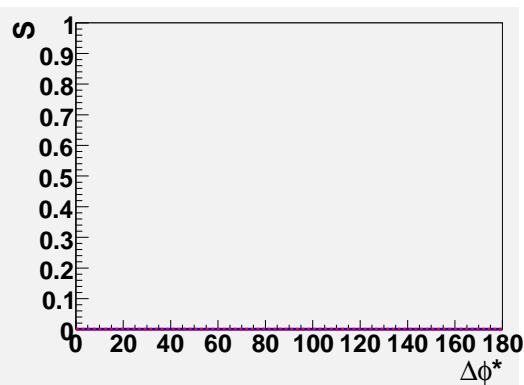
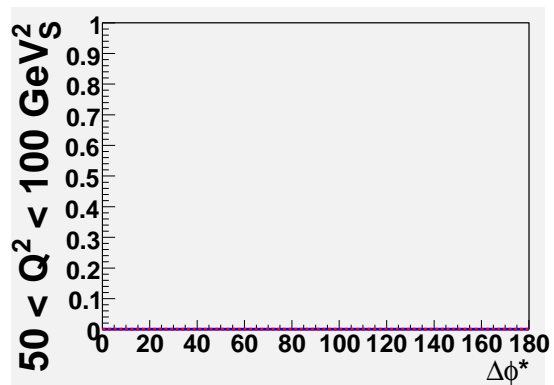
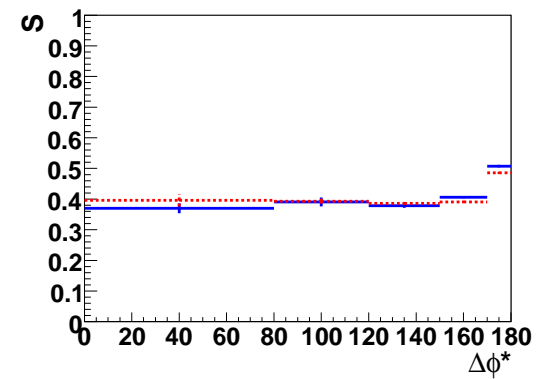
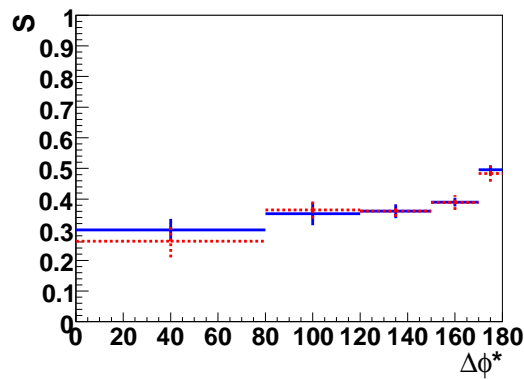
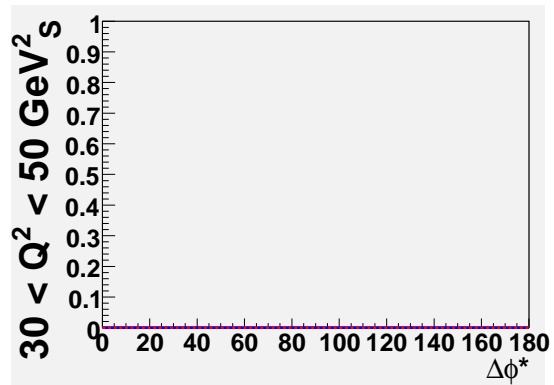
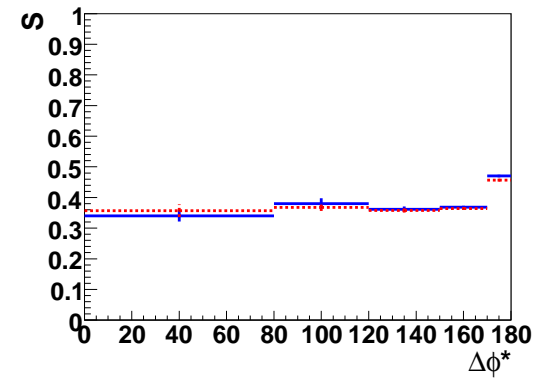
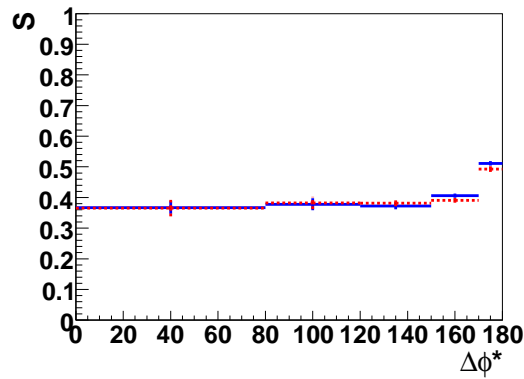
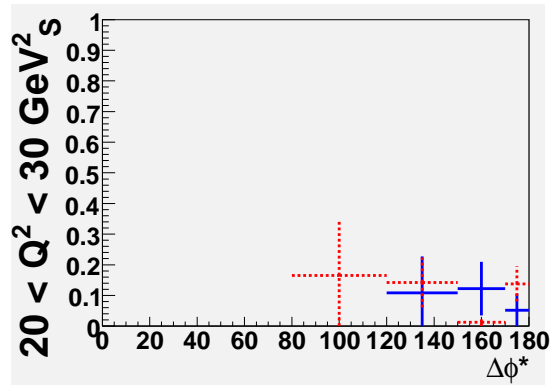


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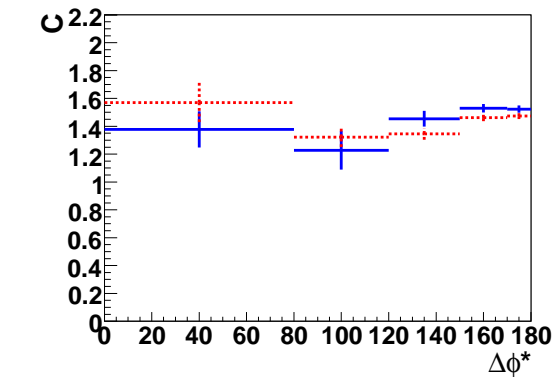
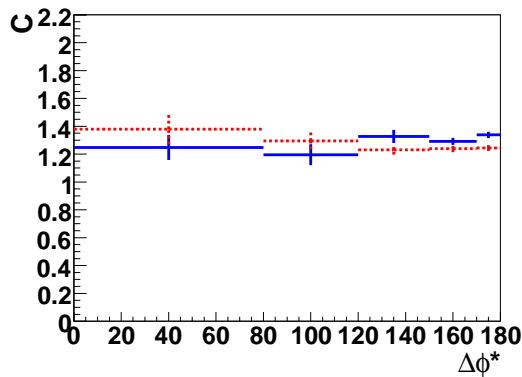
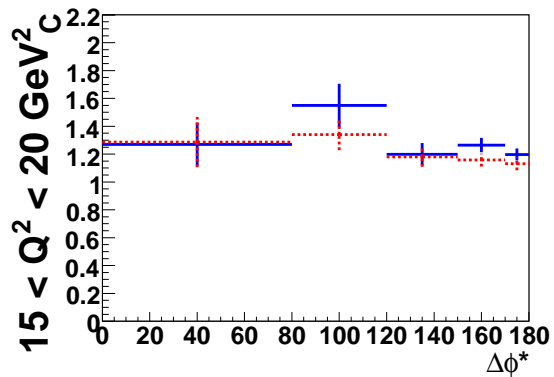
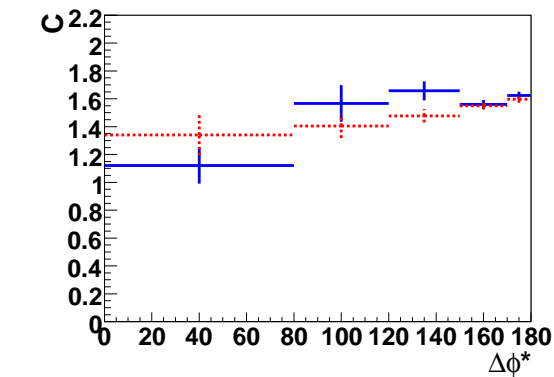
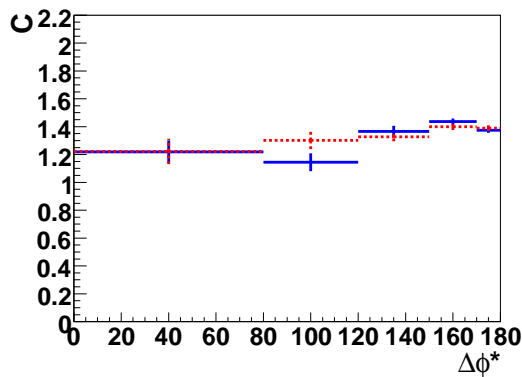
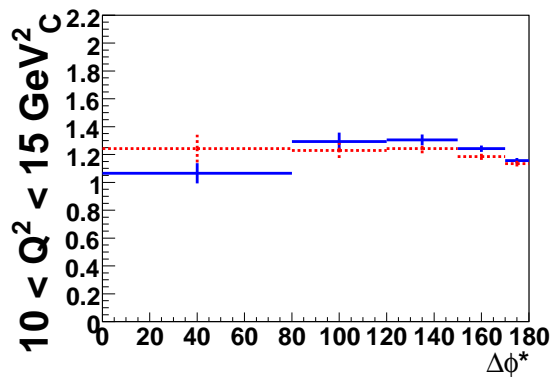
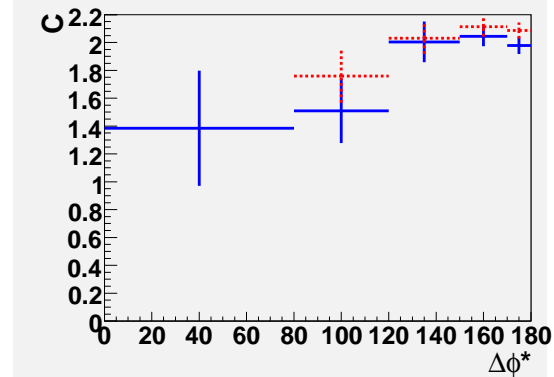
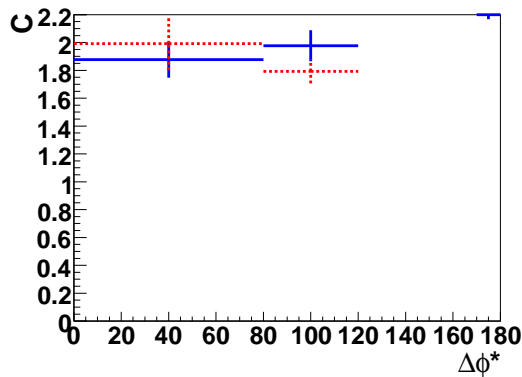
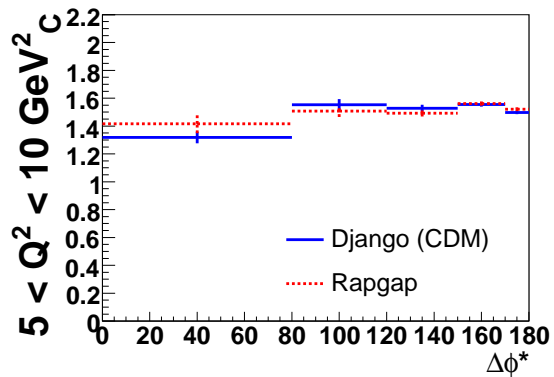


# $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ Correction factors

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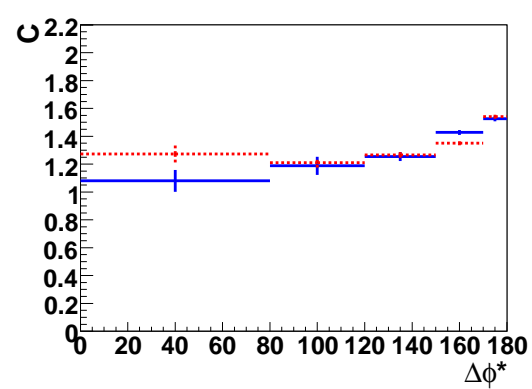
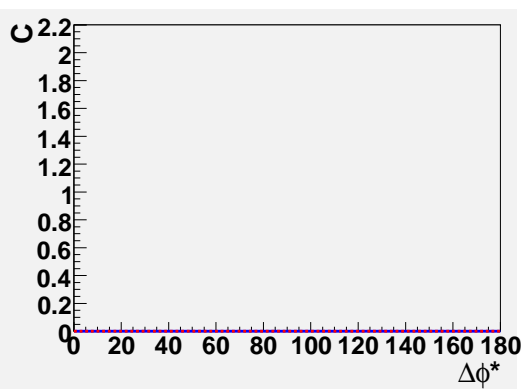
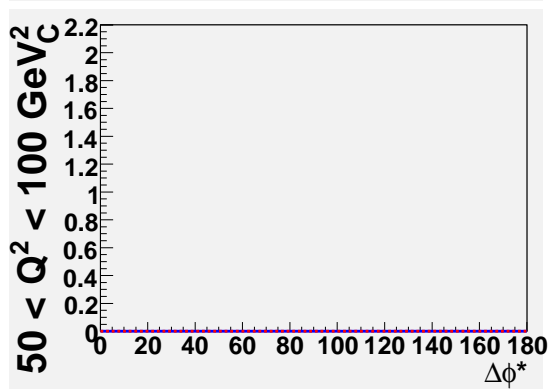
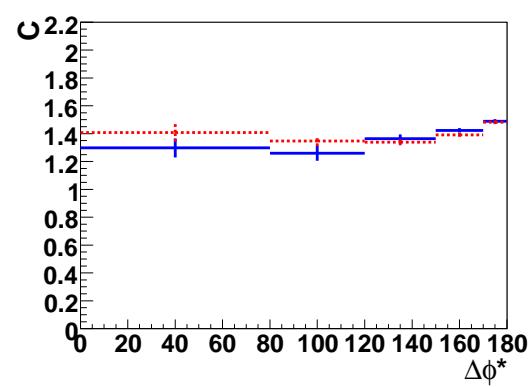
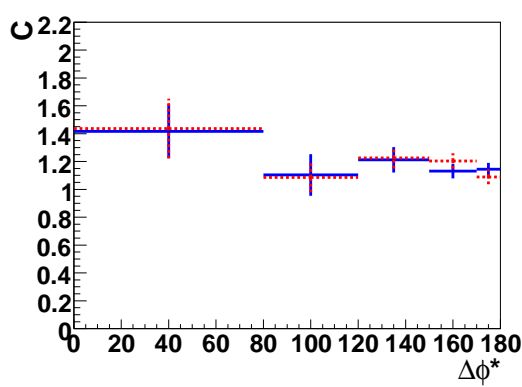
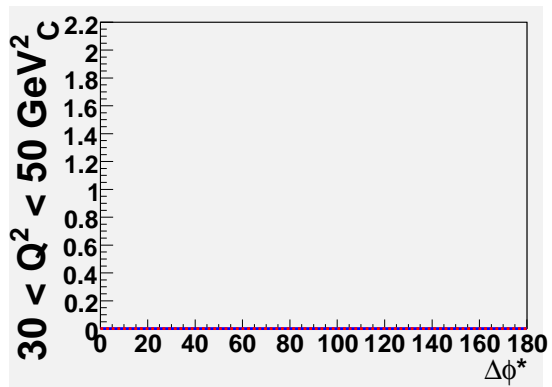
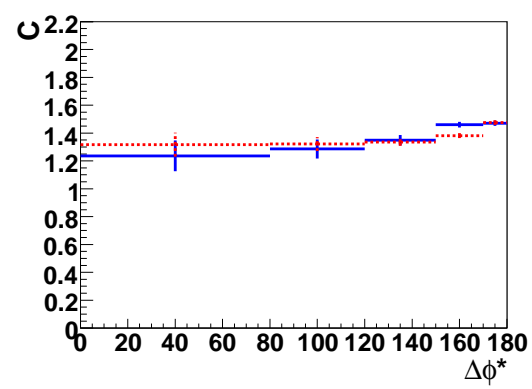
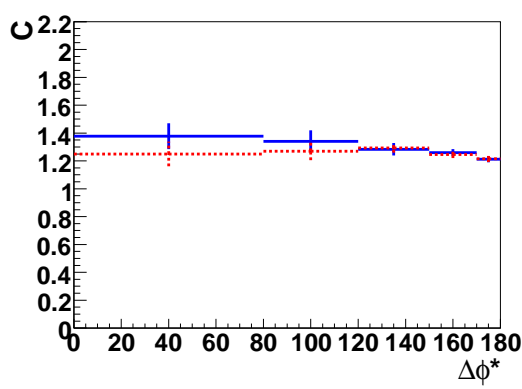
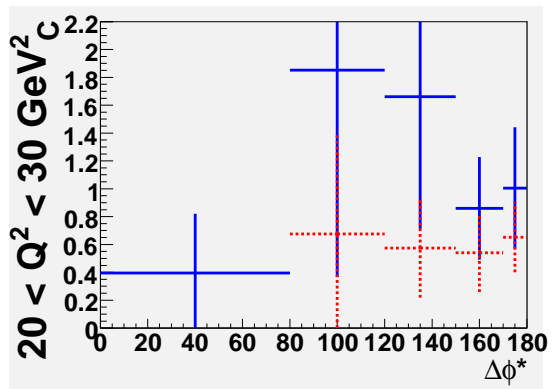


# $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ Correction factors

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$$d^3\sigma / dx_{bj} dQ^2 d\Delta\phi^*$$

## Systematic Uncertainties

Estimated using Rapgap

... except model dependence:  $\frac{|C_{Rapgap} - C_{Django}|}{2}$

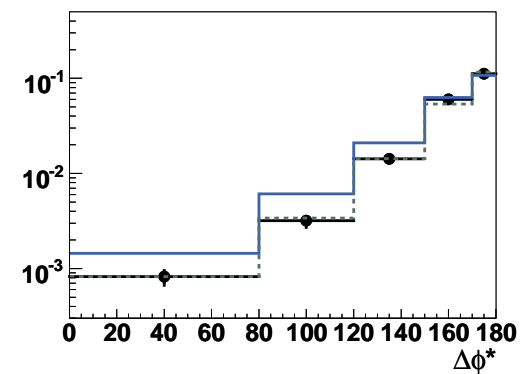
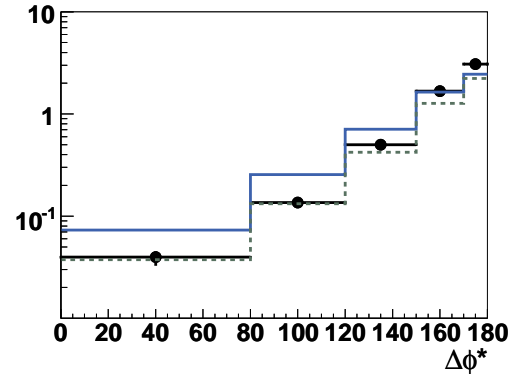
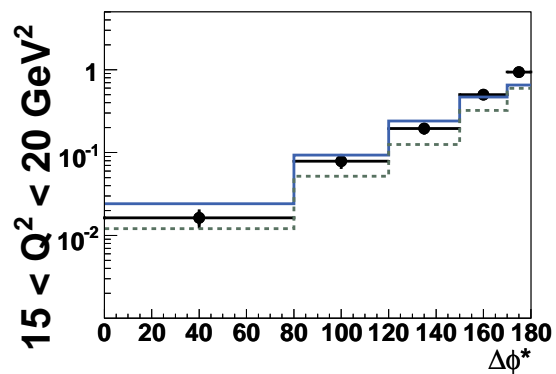
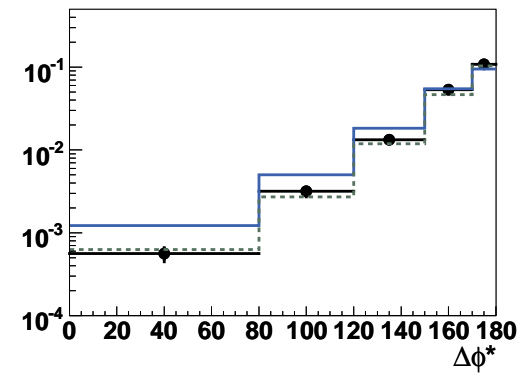
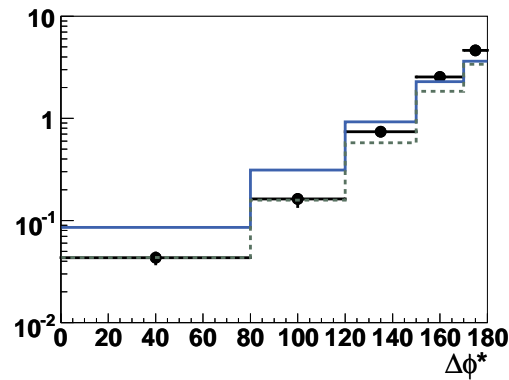
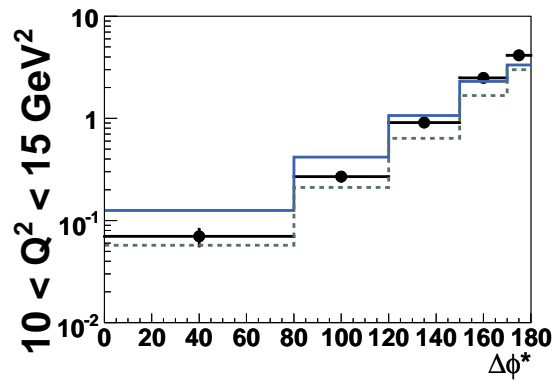
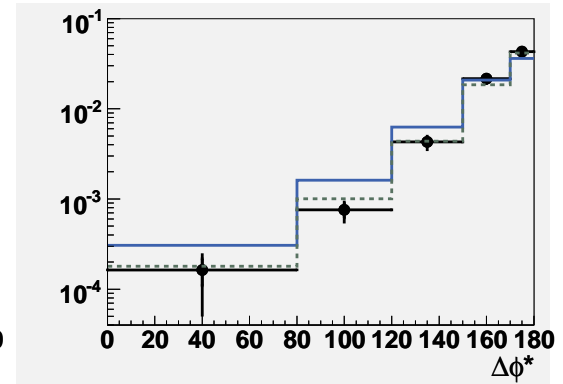
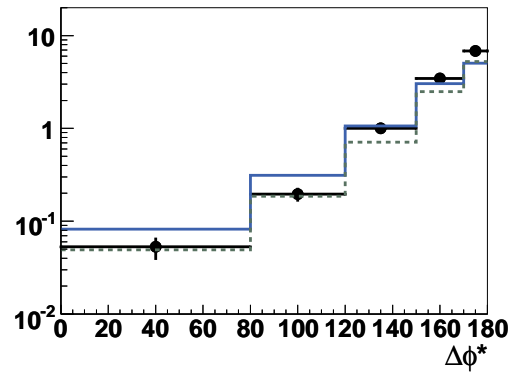
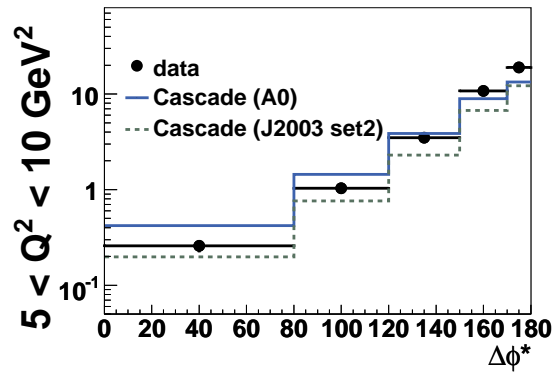
Source		Typical Uncertainty
Electron Energy	$\pm 1\%$	1 - 4 %
Electron Polar Angle $\theta_e$	$\pm 1$ mrad	1 - 2 %
LAr Hadronic Energy	$\pm 4\%$	5 - 15 %
Track Momentum	$\pm 3\%$	$\approx 0$
Luminosity	$\pm 1.5\%$	1.5 %
Model Dependence		2 - 7 %

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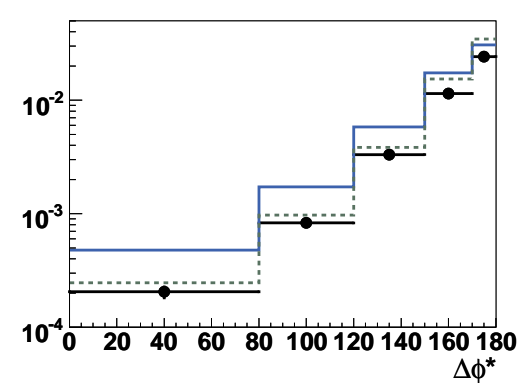
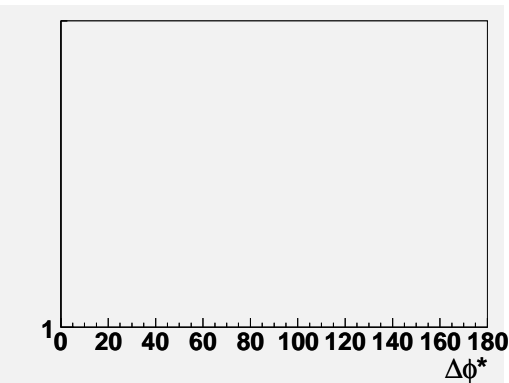
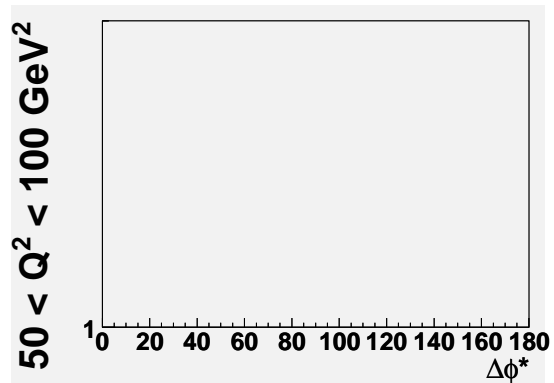
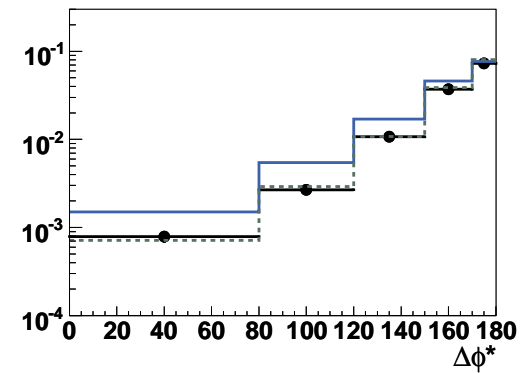
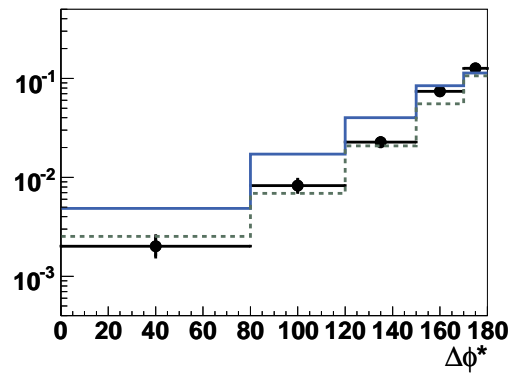
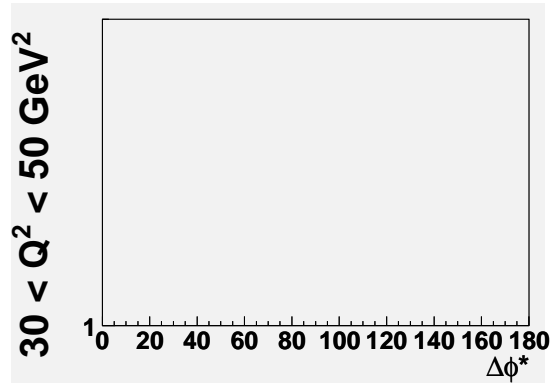
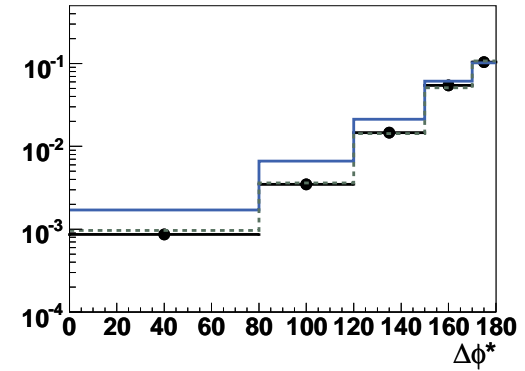
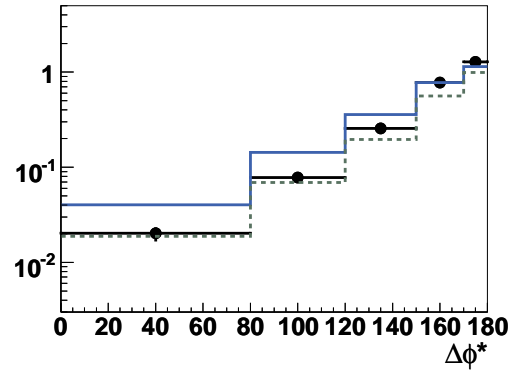
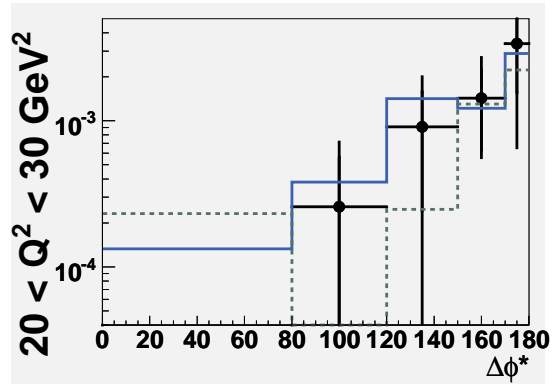


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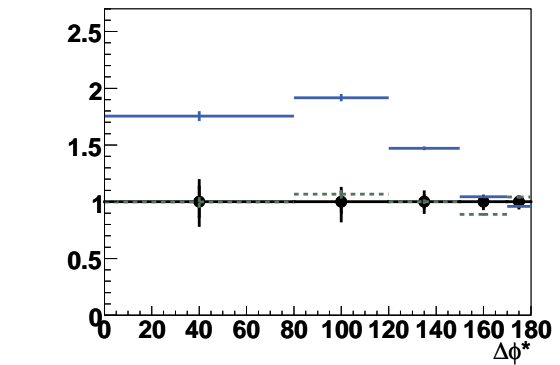
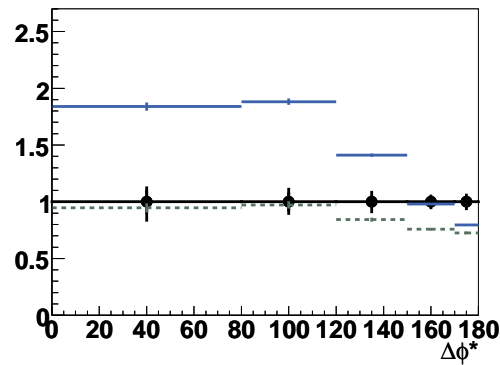
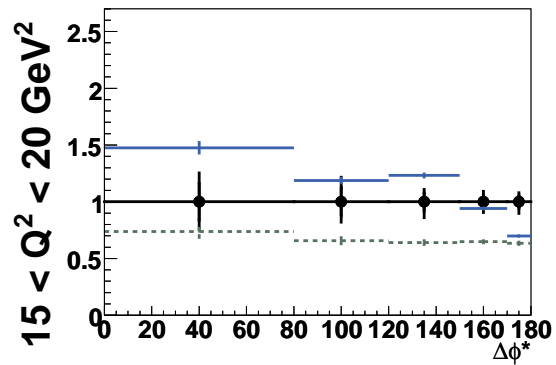
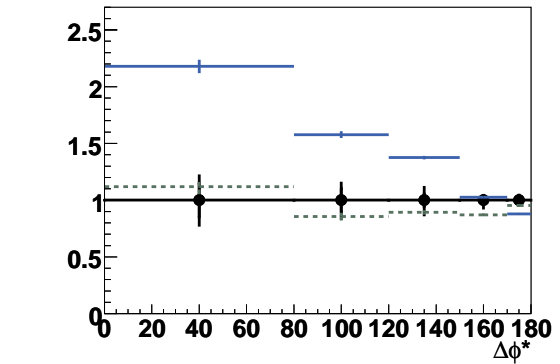
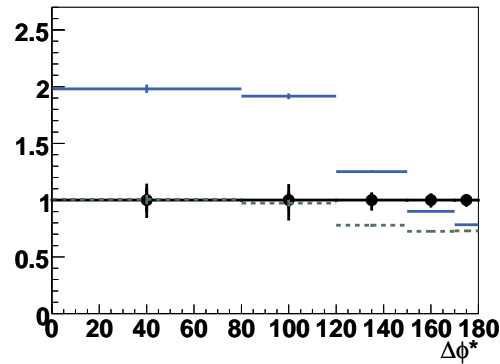
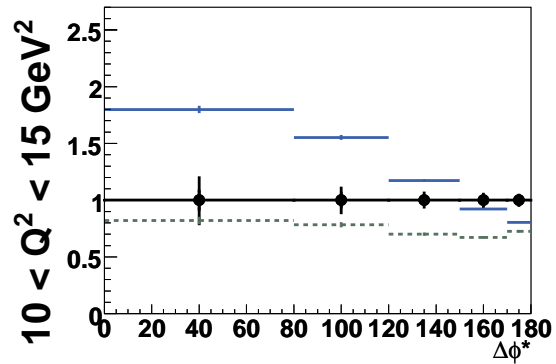
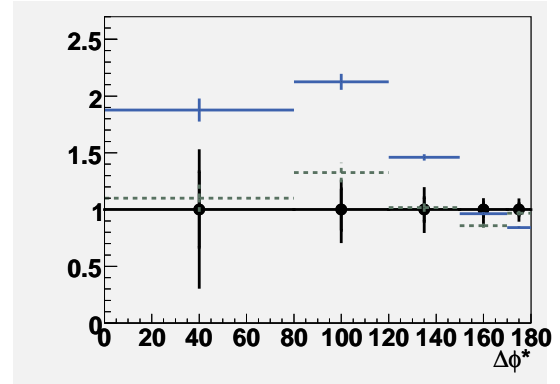
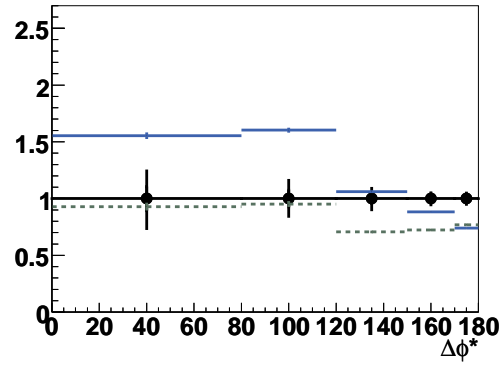
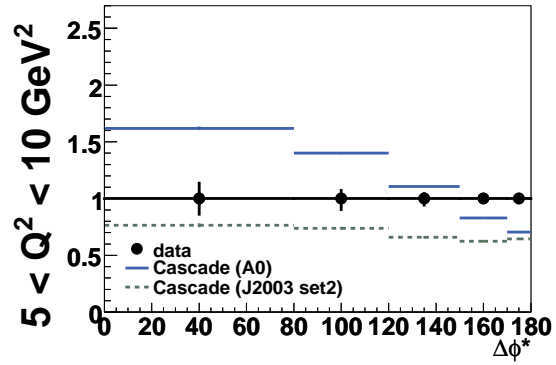


# $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ Ratio

$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

$6 \times 10^{-4} < x_{Bj} < 10^{-2}$

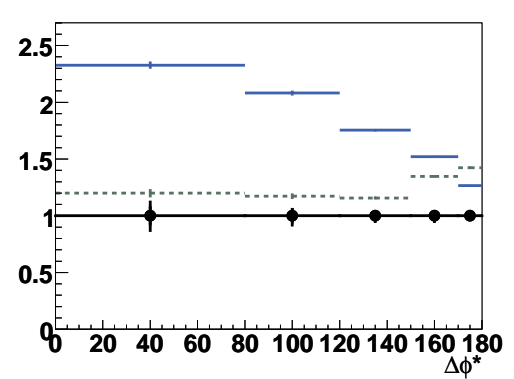
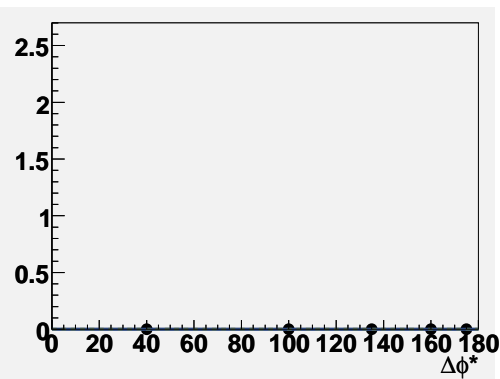
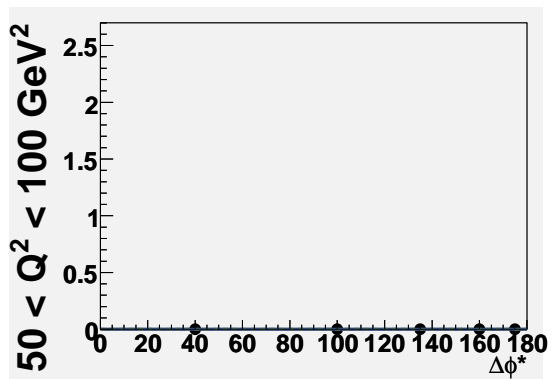
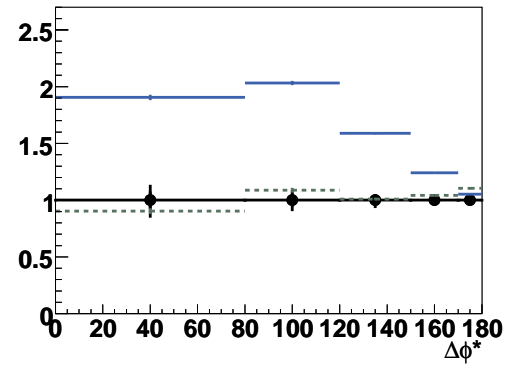
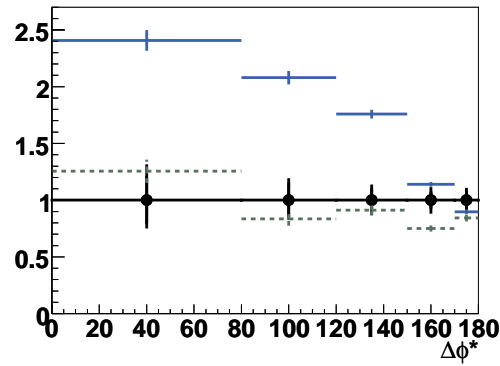
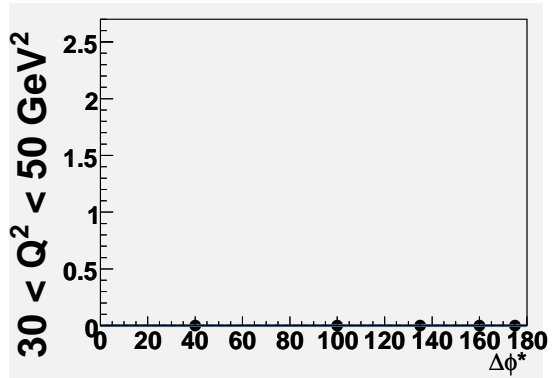
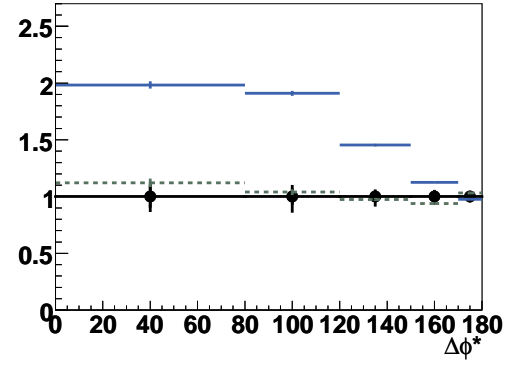
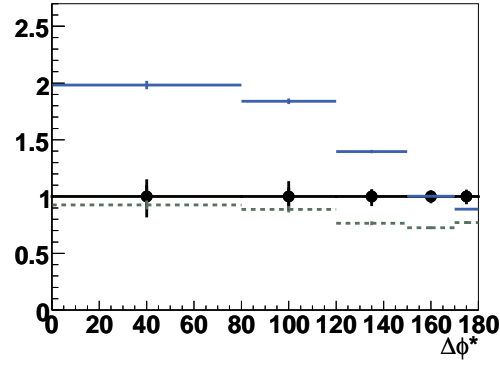
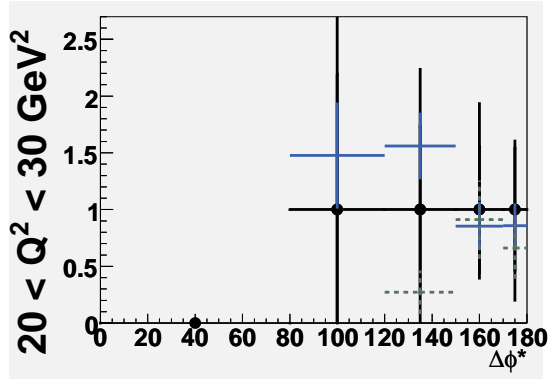


# $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ Ratio

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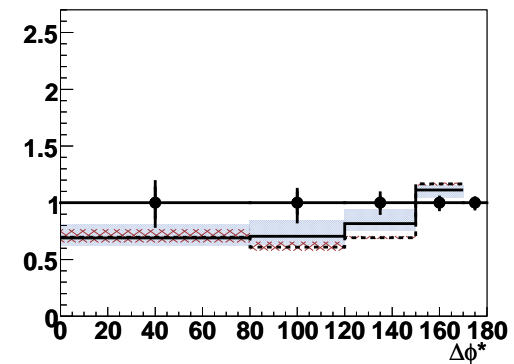
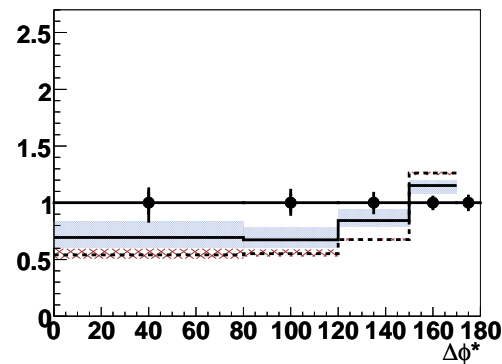
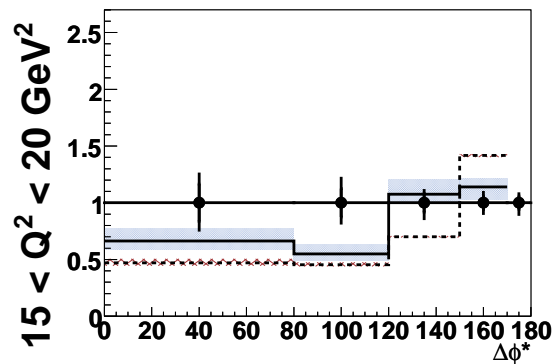
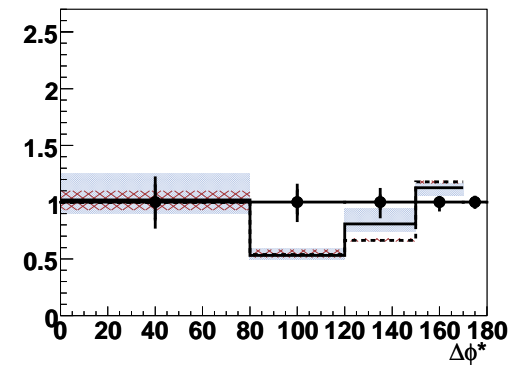
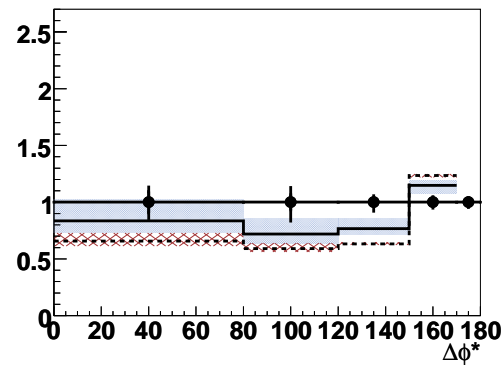
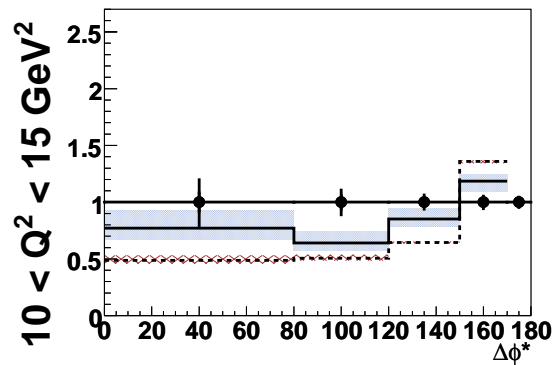
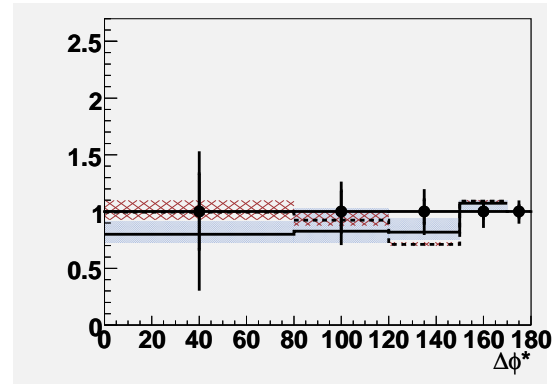
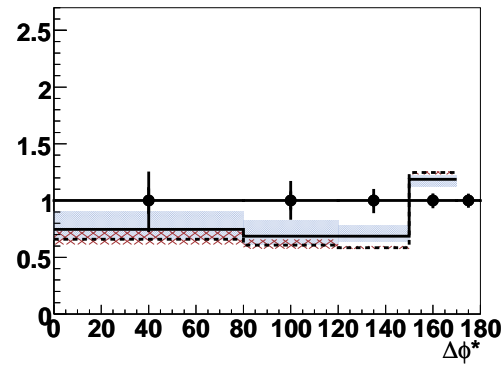
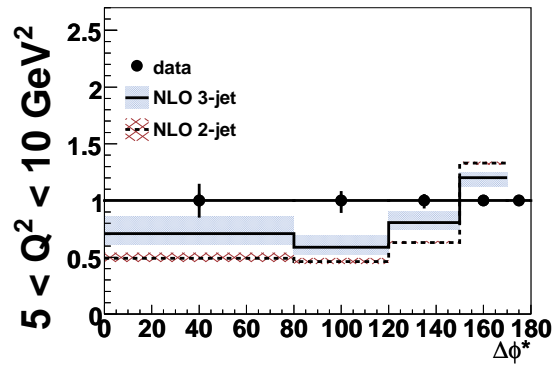


# $d^3\sigma/dx_{Bj}dQ^2d\Delta\phi^*$ Ratio. Norm to x-section between $0^\circ < \Delta\phi^* < 170^\circ$

$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

$6 \times 10^{-4} < x_{Bj} < 10^{-2}$

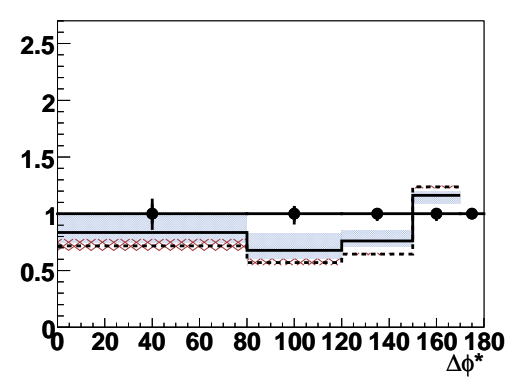
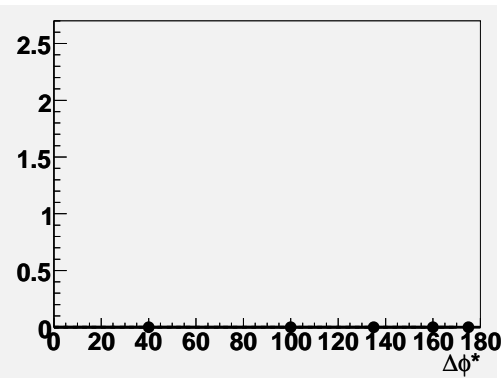
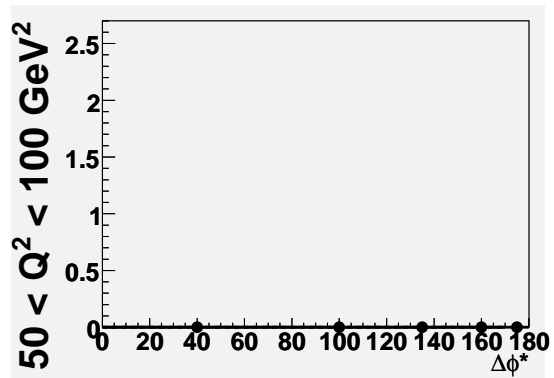
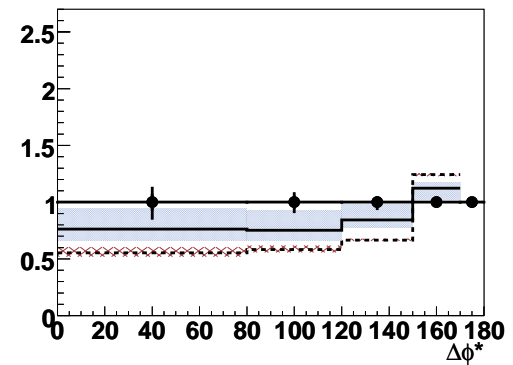
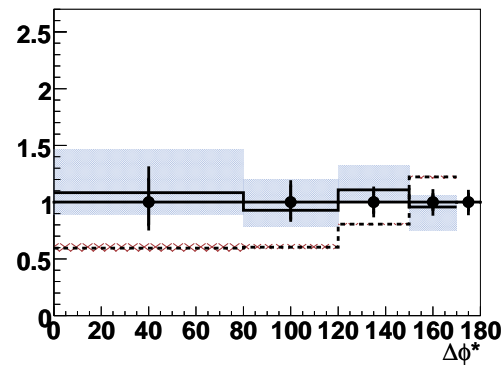
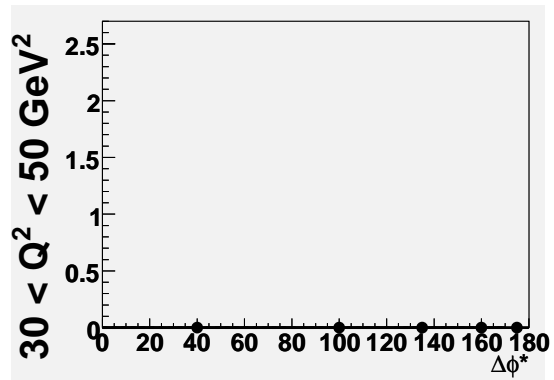
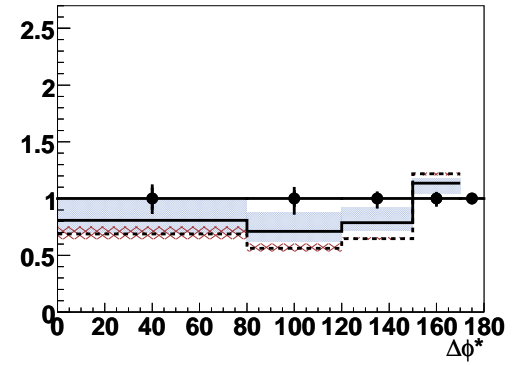
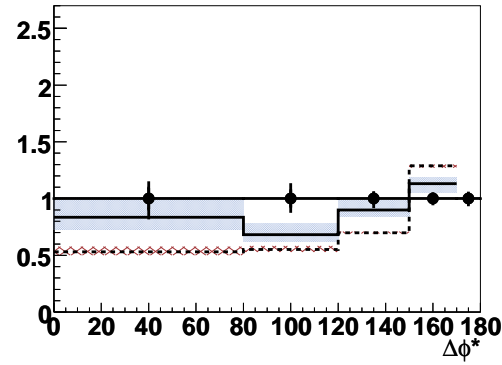
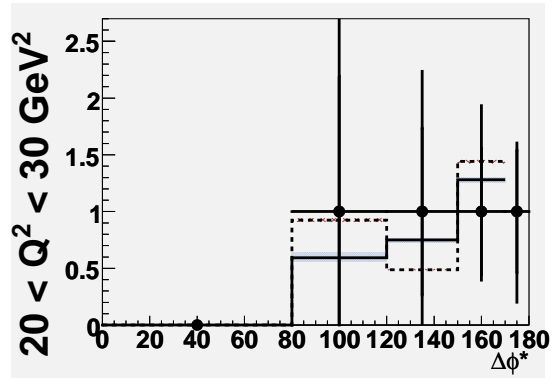


$d^3\sigma/dx_{Bj}dQ^2d\Delta\phi^*$  Ratio. Norm to x-section between  $0^\circ < \Delta\phi^* < 170^\circ$

$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

$6 \times 10^{-4} < x_{Bj} < 10^{-2}$



## $d^2\sigma/dx_{bj}dQ^2d\Delta\phi^*$ : Xg Definitions

Method:

1) Rapidity  $x_g = x_{bj} \left(1 + \frac{\hat{s}}{Q^2}\right)$       where  $\hat{s} = Q^2 \left(\frac{1-x_{bj}}{x_{bj}}\right) e^{-(\eta_1^* + \eta_2^*)}$

2) Energy  $x_g = x_{bj} \left(1 + \frac{\hat{s}}{Q^2}\right)$       where  $\hat{s} = (p_1 + p_2)^2$

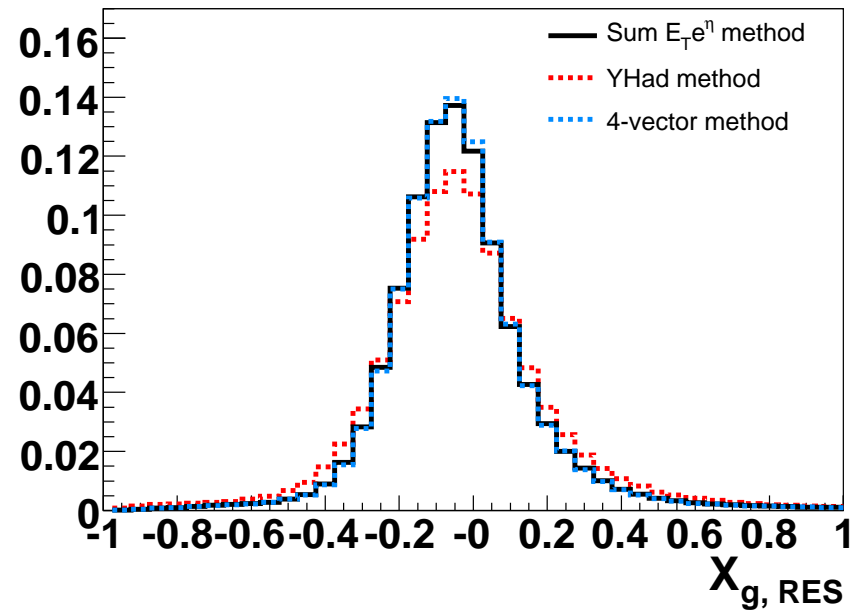
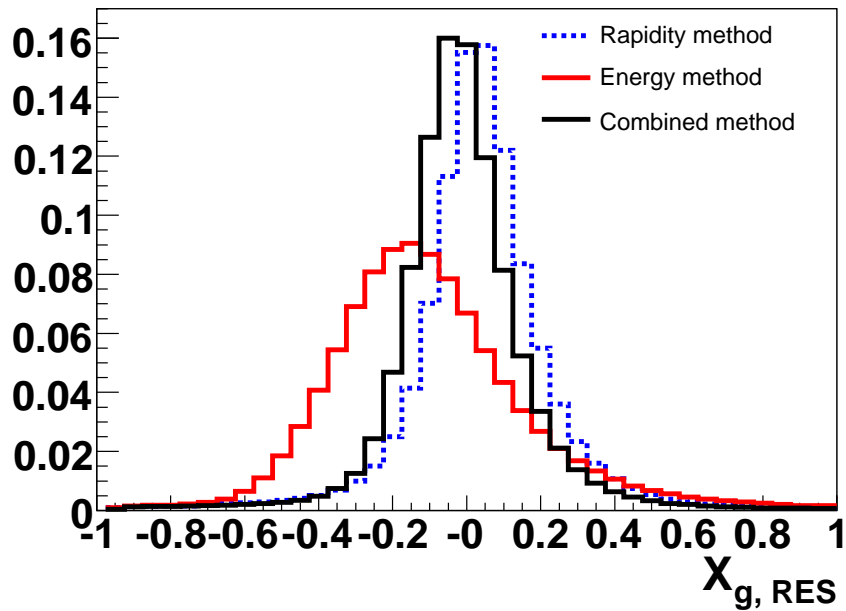
3) Combined  $x_g = \frac{x_{g,rapidity} + x_{g,energy}}{2}$

4) Sum  $E_T e^\eta$   $x_g = \frac{\sum_i E_{T,i}^* e^{\eta_i^*}}{2E_p^*}$       where  $i = 1, 2$

5) YHad  $x_g = x_{bj} + \frac{\hat{s}}{y_{had}s}$       where  $\hat{s} = (p_1 + p_2)^2$   
 and  $y_{had} = \frac{\sum_{HFS} E - p_z}{2E_e}$

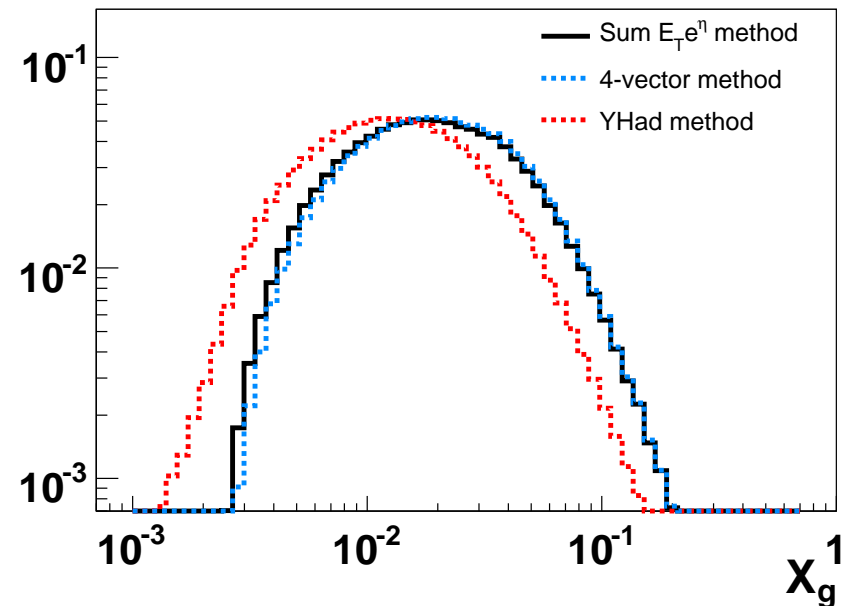
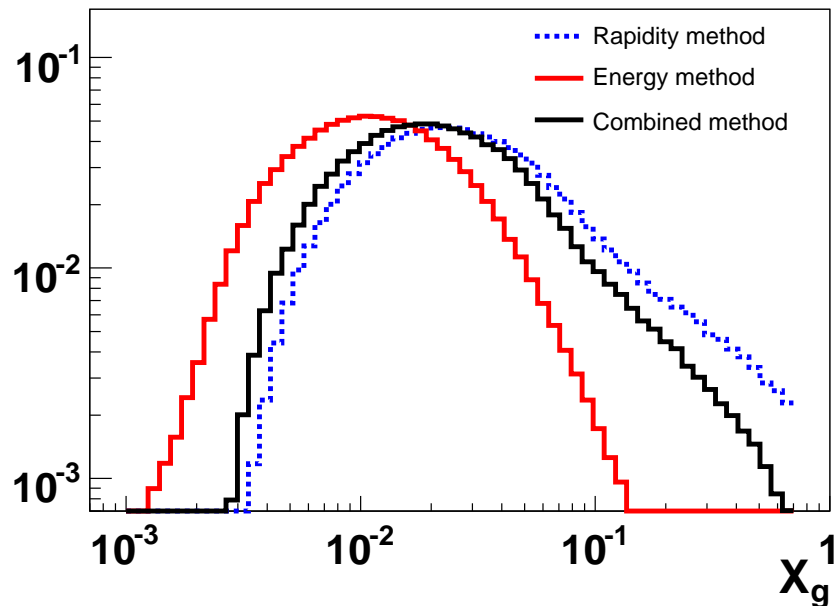
6) 4-vector  $x_g = \frac{E_g + |P_{z,g}|}{E_p + |P_{z,p}|}$       where  $P_g = P_{j1} + P_{j2} - P_\gamma$

# X<sub>g</sub> Resolutions



Method	mean	$\sigma$
Rapidity	0.03	0.09
EtSum	-0.06	0.13

## Xg Distributions (Hadron Level)



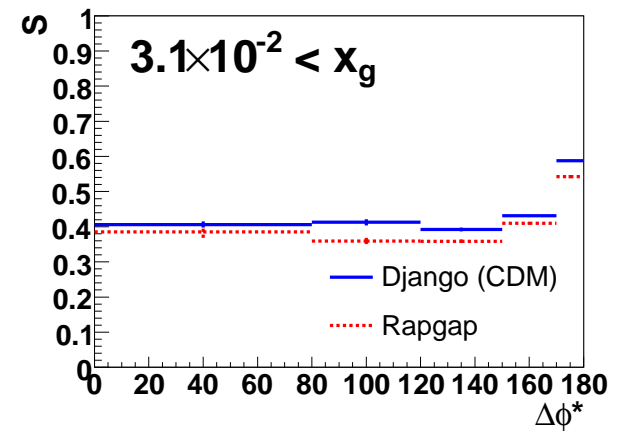
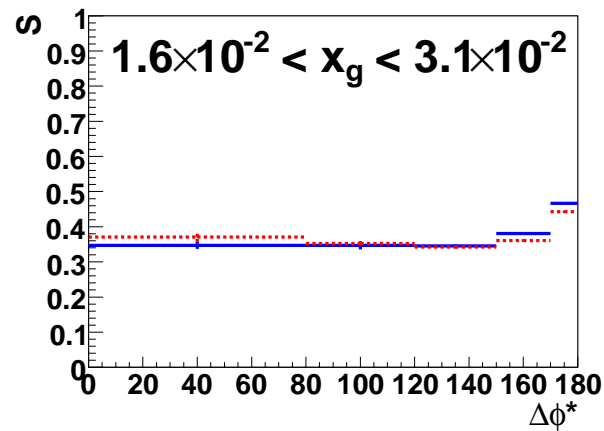
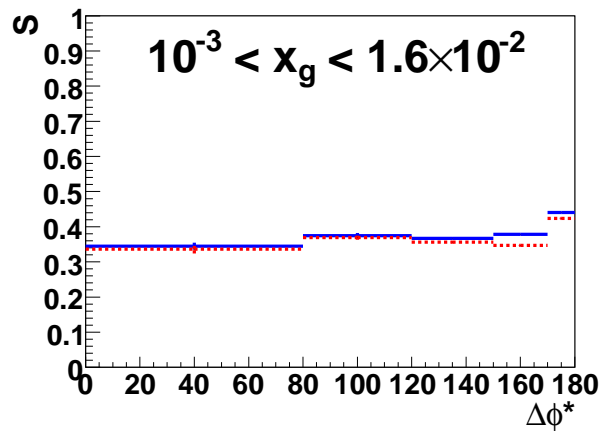
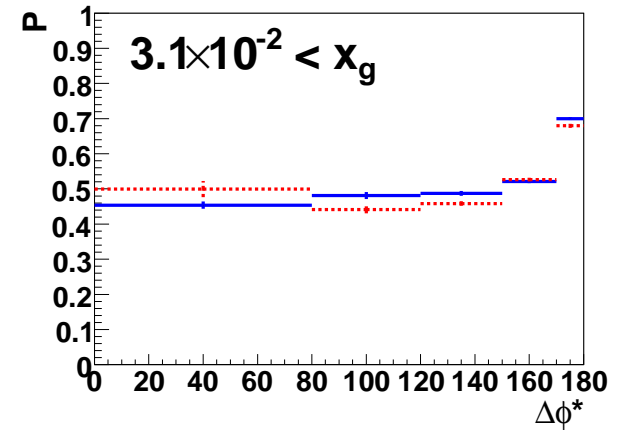
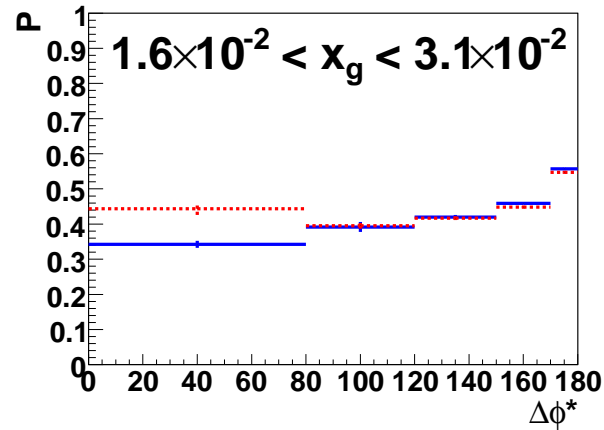
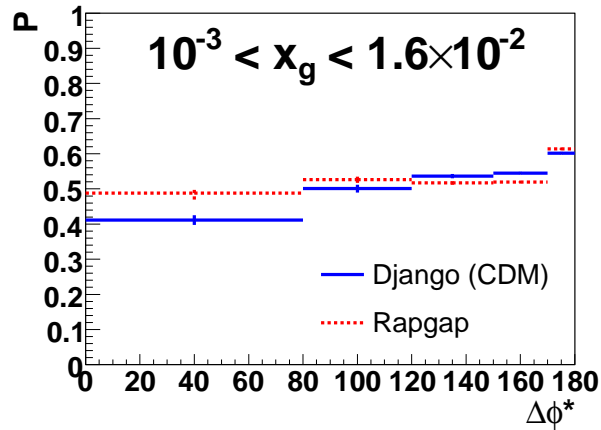
Energy method and YHad method agrees well ( $y_e \approx y_{Had}$  on Had level)

4-vector method and Sum  $E_T e^\eta$  method almost agrees (identical if  $P_g = P_{j1} + P_{j2}$ )

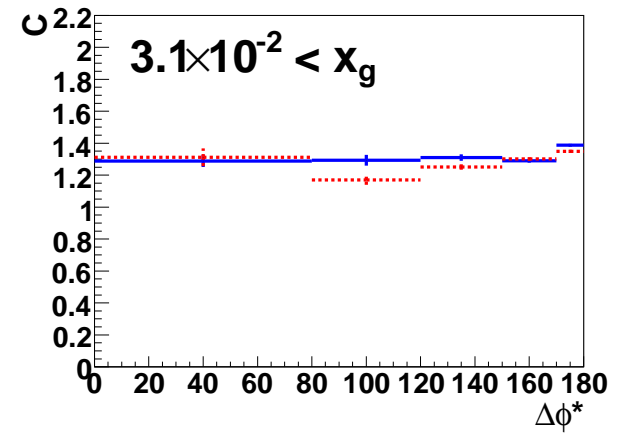
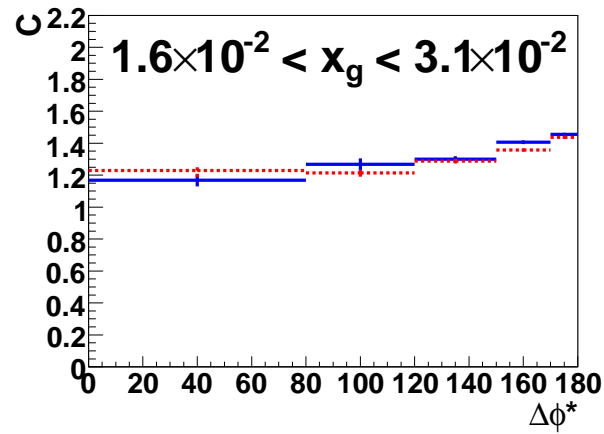
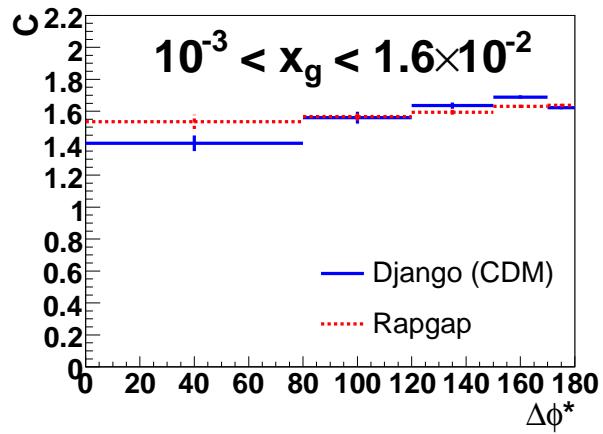
Combined and Sum  $E_T e^\eta$  method agrees for  $x_g < 0.07$

Use Sum  $E_T e^\eta$  method even though worse resolution (?)

# $d^2\sigma/dx_g d\Delta\phi^*$ Purity & Stability



# $d^2\sigma/dx_g d\Delta\phi^*$ Correction factors



$$d^2\sigma / dx_g d\Delta\phi^*$$

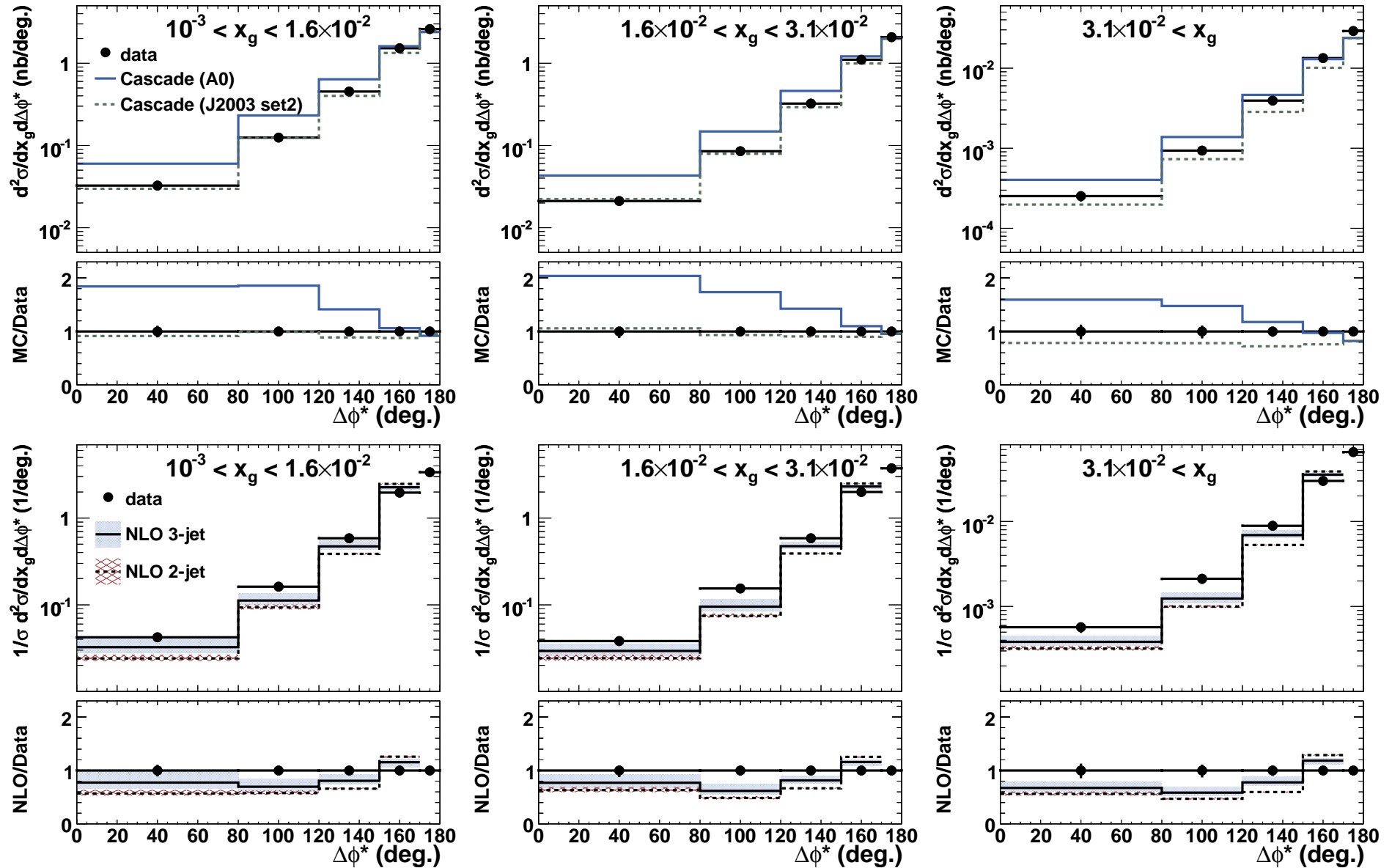
## Systematic Uncertainties

Estimated using Rapgap

... except model dependence:  $\frac{|C_{Rapgap} - C_{Django}|}{2}$

Source		Typical Uncertainty
Electron Energy	$\pm 1\%$	1 - 4 %
Electron Polar Angle $\theta_e$	$\pm 1$ mrad	$< 1$ %
LAr Hadronic Energy	$\pm 4\%$	3 - 12 %
Track Momentum	$\pm 3\%$	$\approx 0$
Luminosity	$\pm 1.5\%$	1.5 %
Model Dependence		1 - 6 %

# $d^2\sigma/dx_g d\Delta\phi^*$ Data Vs CASCADE



# Summary & Outlook

- New cross sections:

$$\Rightarrow d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$$

$$P, S > 0.3, C \approx 1.4$$

Cascade(A0) fails: Too hard  $k_t$  spectrum

Cascade(J2003set2) fails at low  $x_{bj}$  and at high  $x_{bj}$  and  $Q^2$

NLO 2-jet fails

NLO 3-jet fails at low  $x_{bj}$

$$\Rightarrow d^2\sigma/dx_gd\Delta\phi^*$$

$$P, S > 0.3, C \approx 1.4$$

Cascade(A0) fails: Too hard  $k_t$  spectrum

Cascade(J2003set2) fails at high  $x_g$ , describes data at low  $x_g$

NLO 2-jet fails

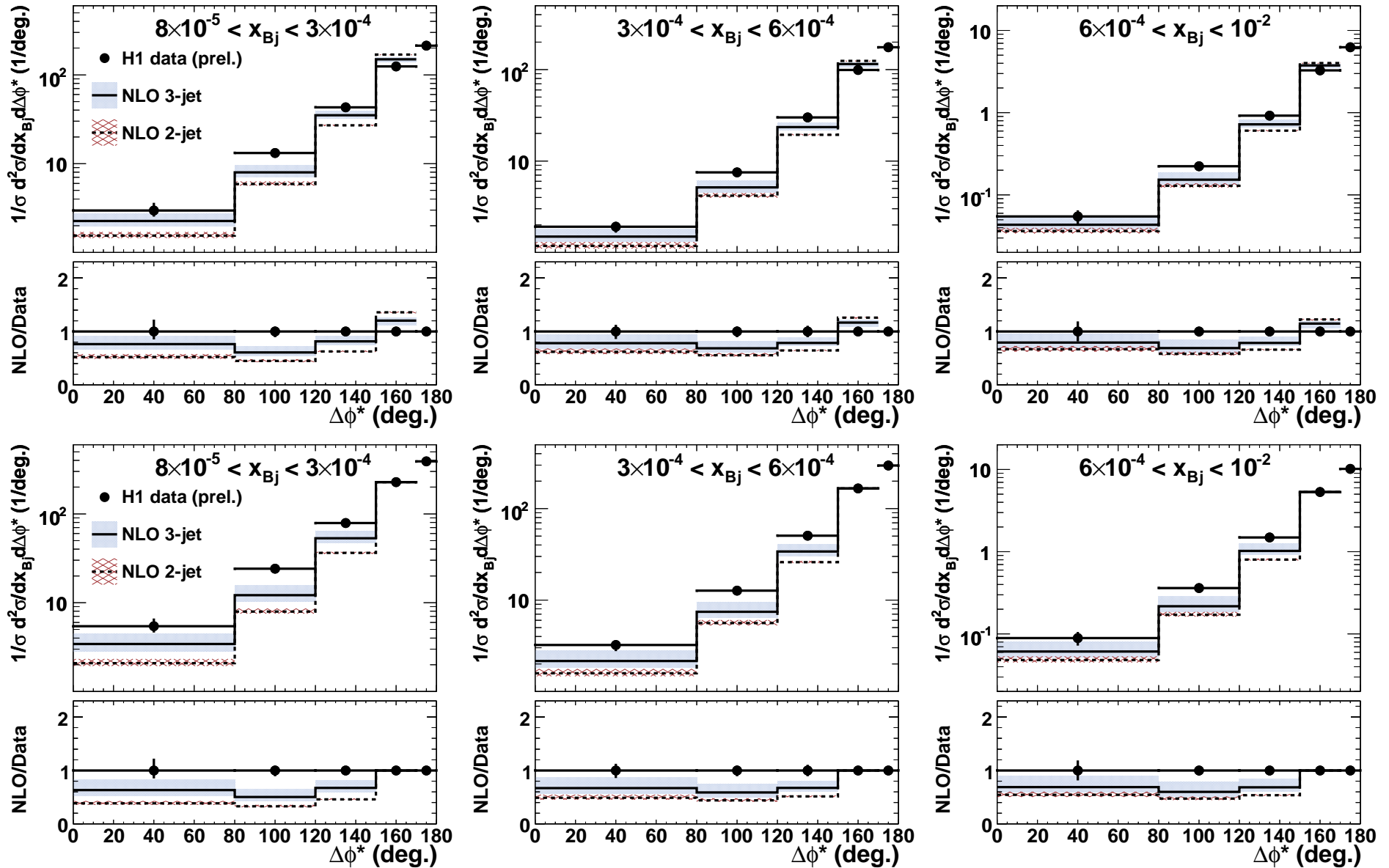
NLO 3-jet better at low  $x_g$  than high  $x_g$ .

- Get Bayes unfolding to work
- Need to finish Ph.D. in August/September

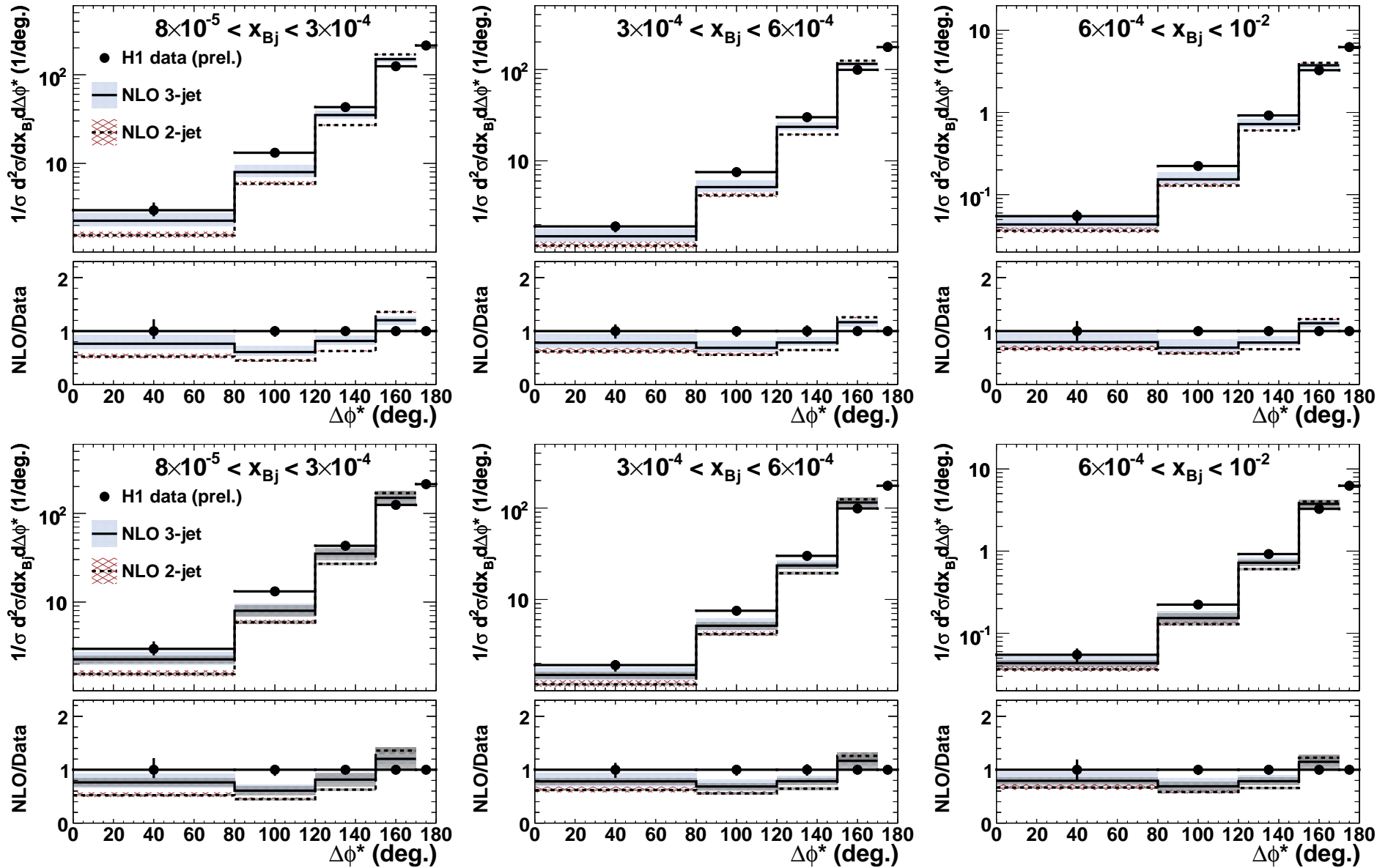


**BACKUP  
PLOTS**

# $d^2\sigma/dx_{bj}d\Delta\phi^*$ Data Vs NLO: Different Normalizations



# Data Vs NLO: PDF Uncertainty (CTEQ)

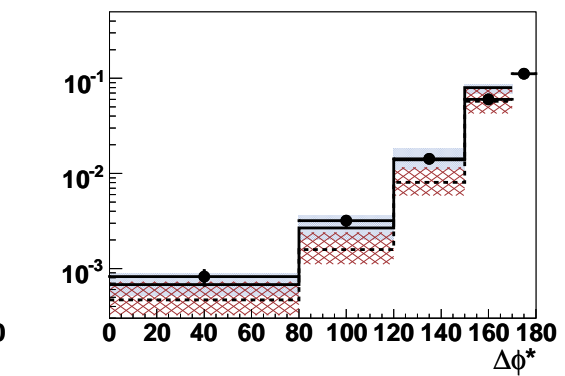
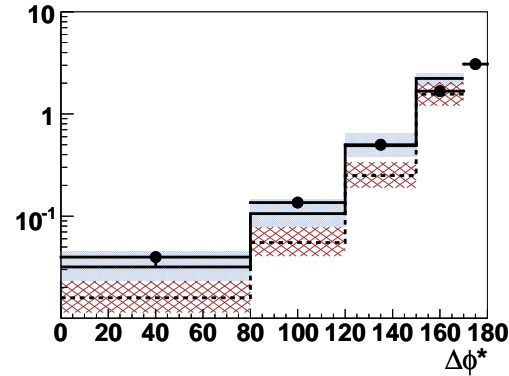
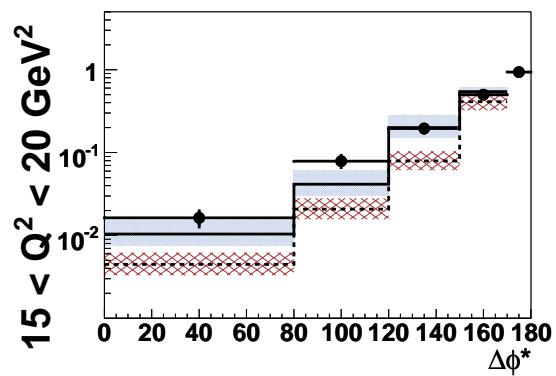
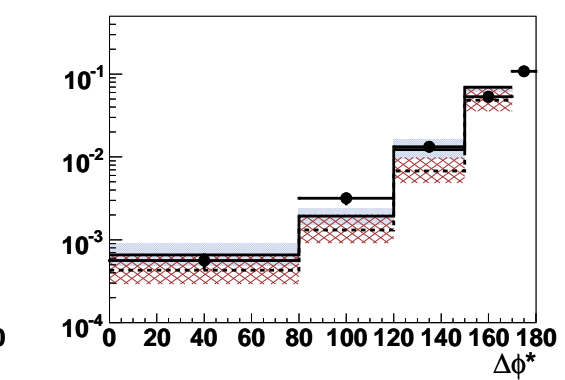
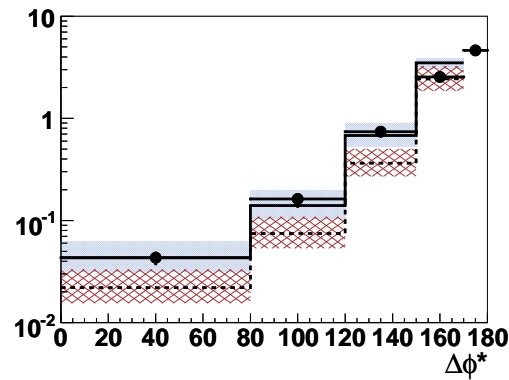
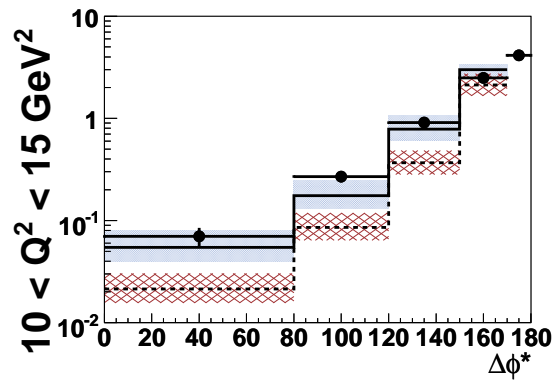
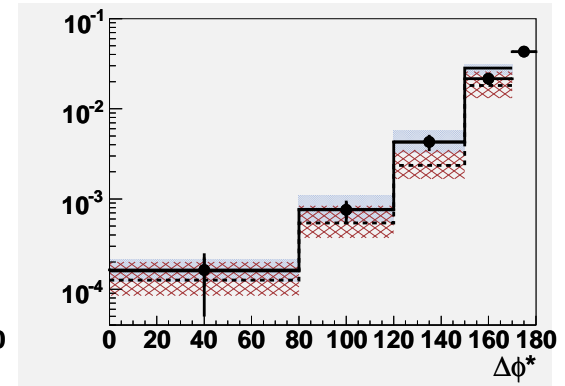
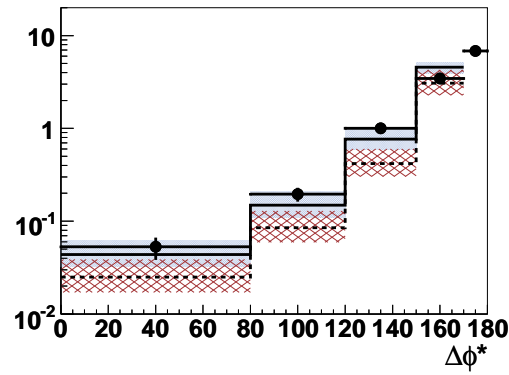
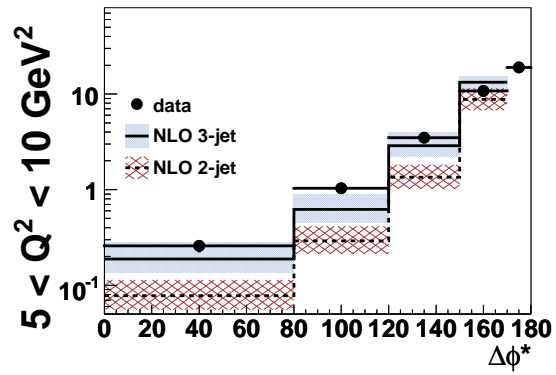


$$d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$$

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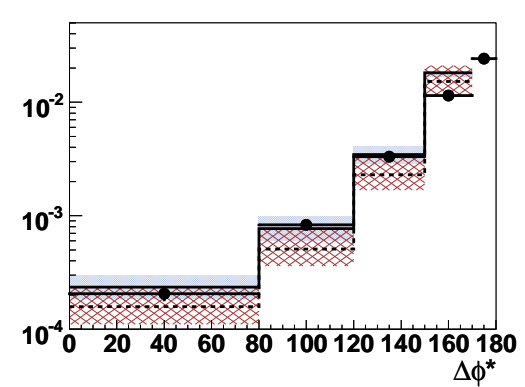
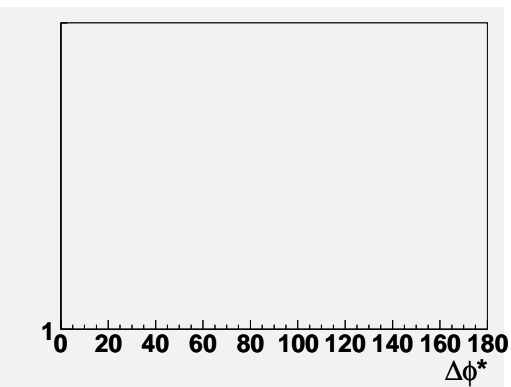
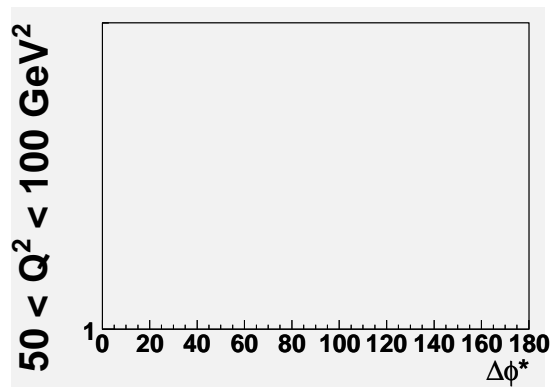
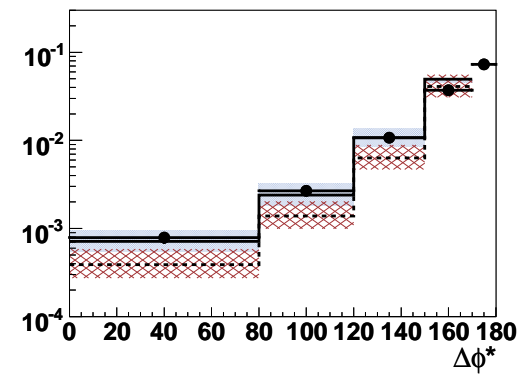
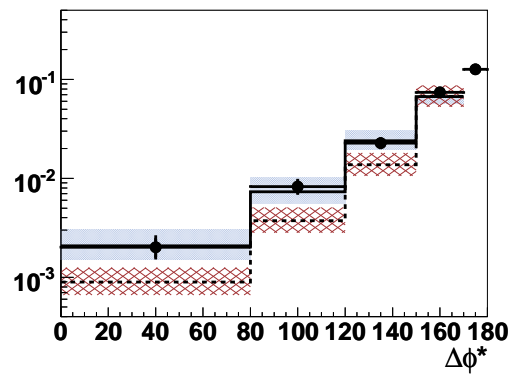
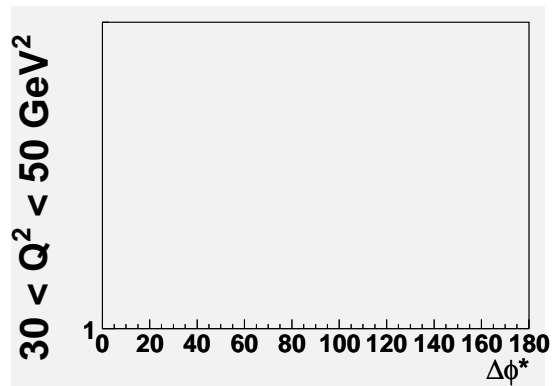
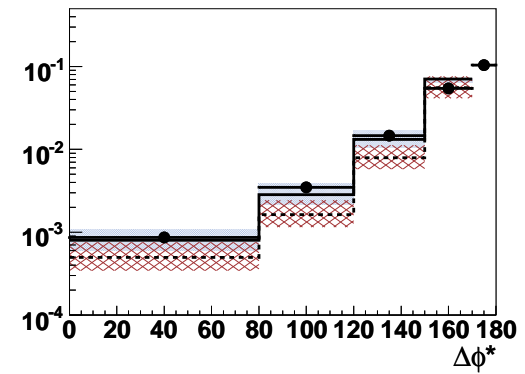
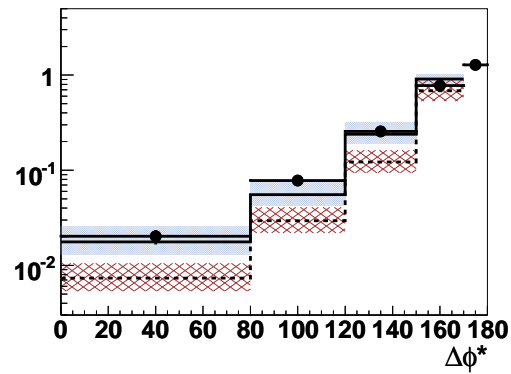
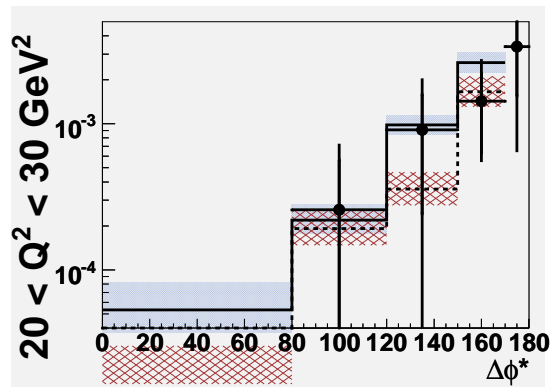


$$d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$$

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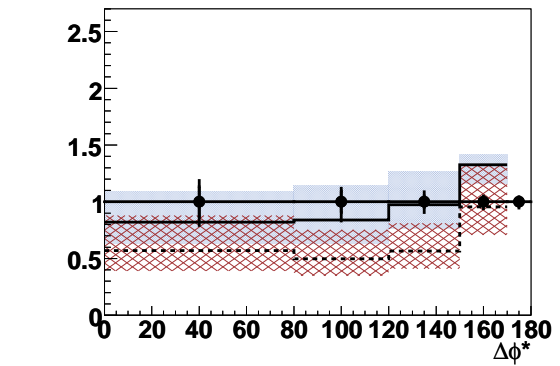
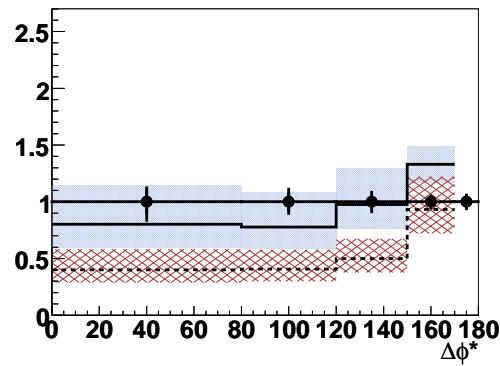
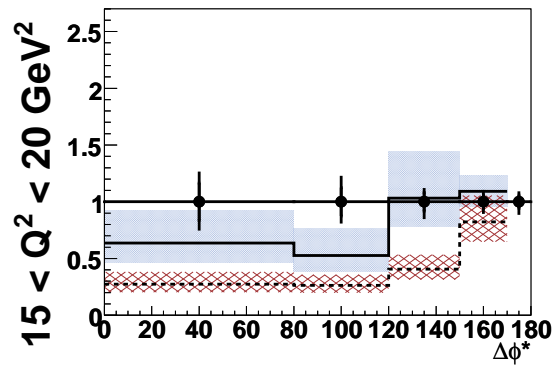
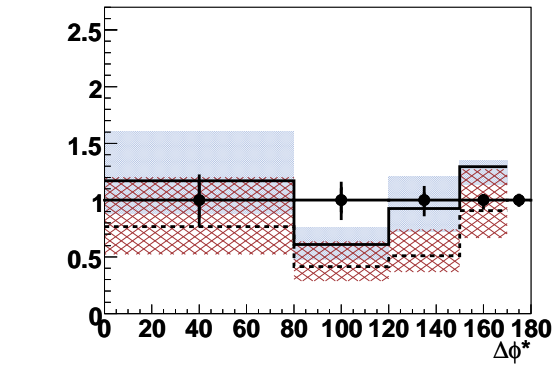
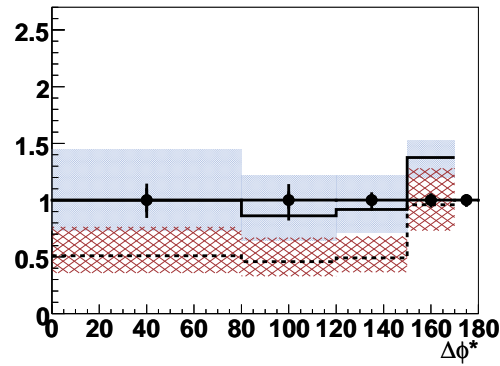
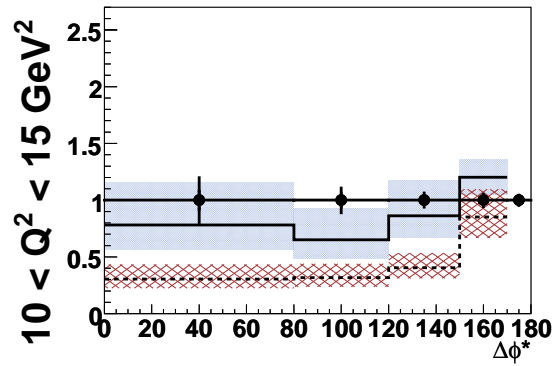
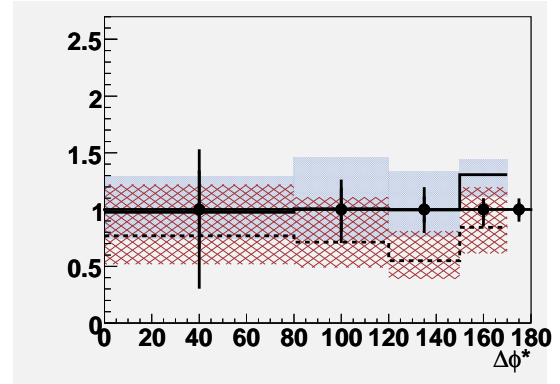
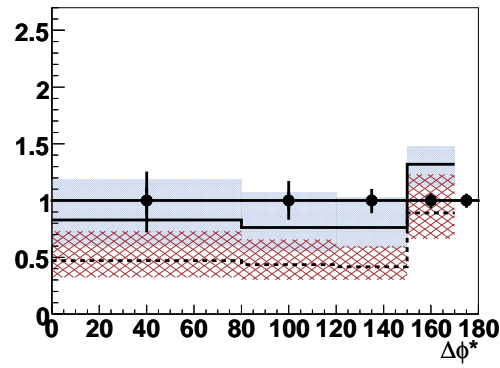
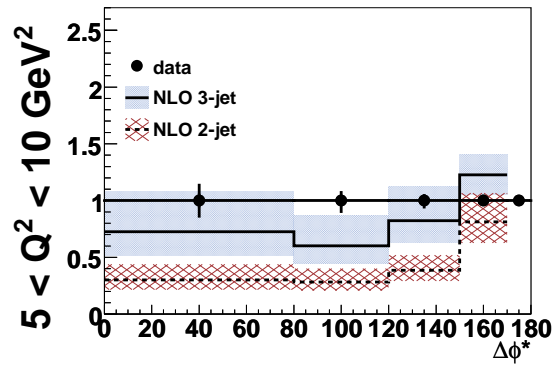


# $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ Ratio

$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

$6 \times 10^{-4} < x_{Bj} < 10^{-2}$

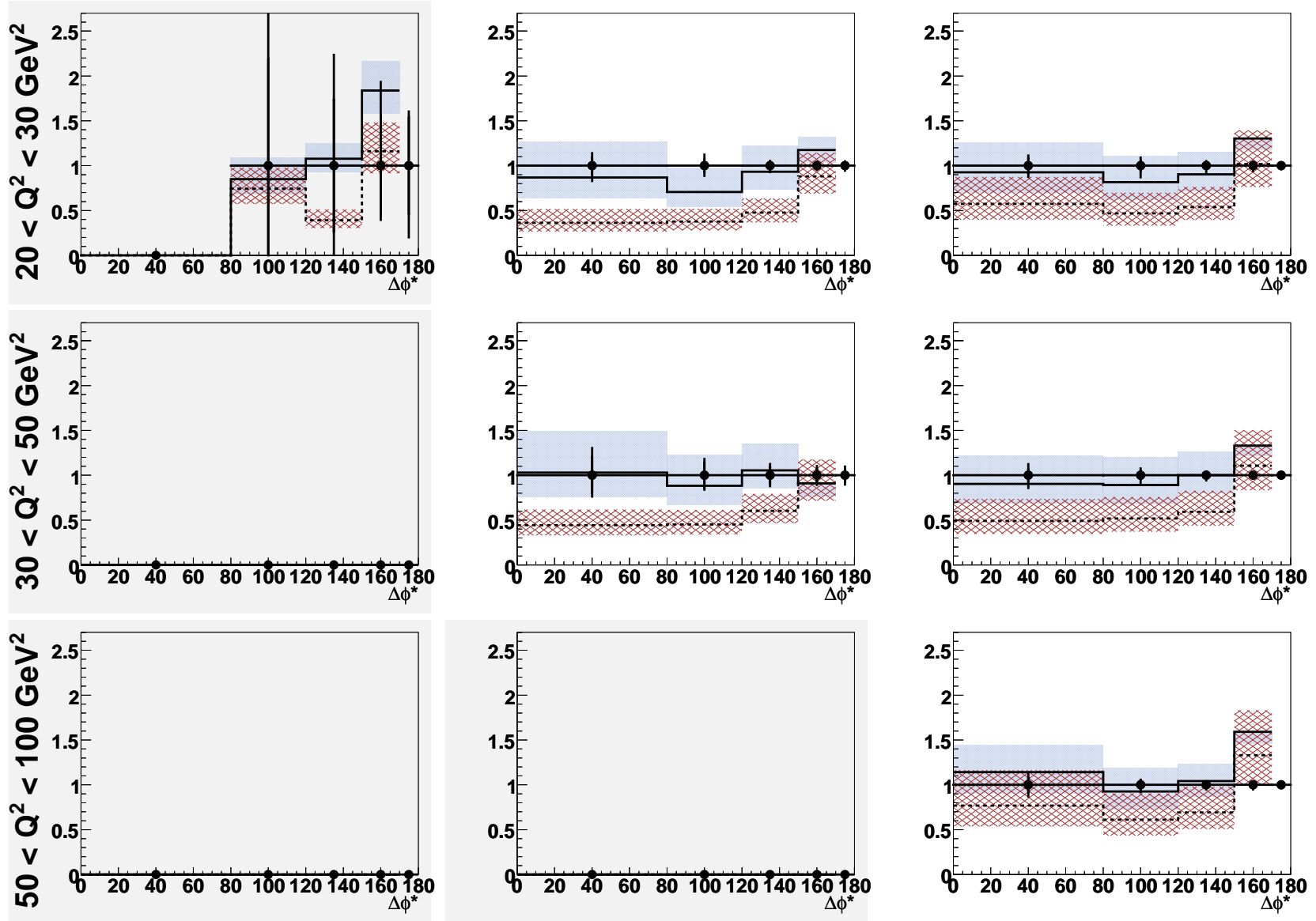


# $d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$ Ratio

$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

$6 \times 10^{-4} < x_{Bj} < 10^{-2}$

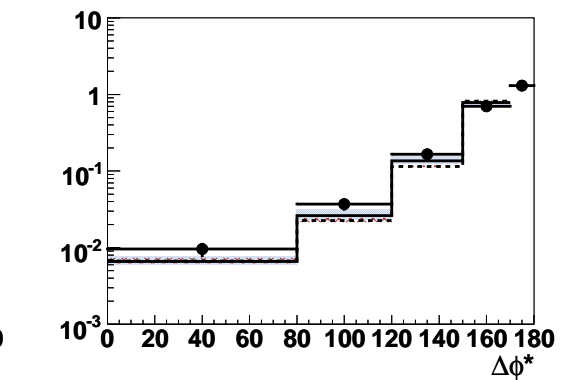
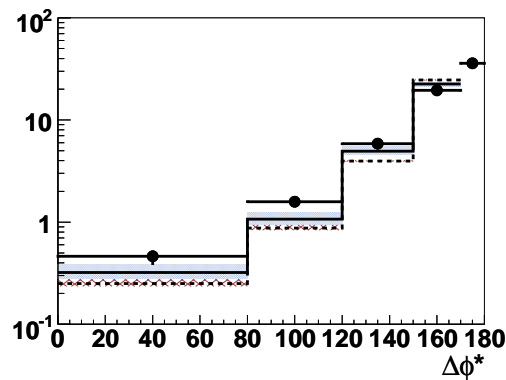
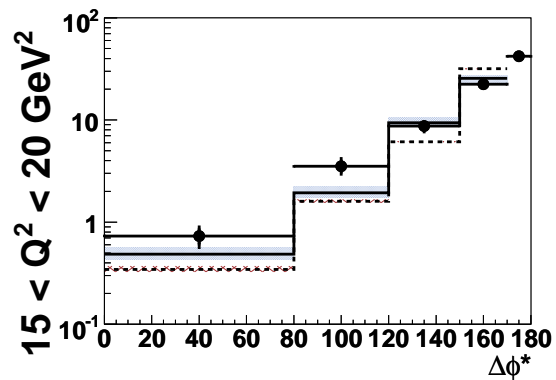
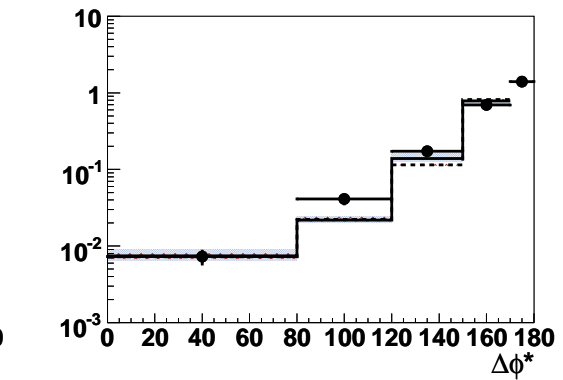
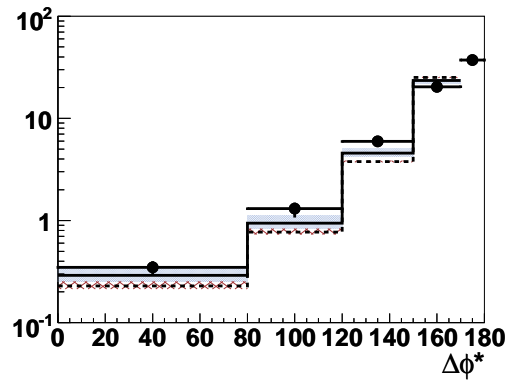
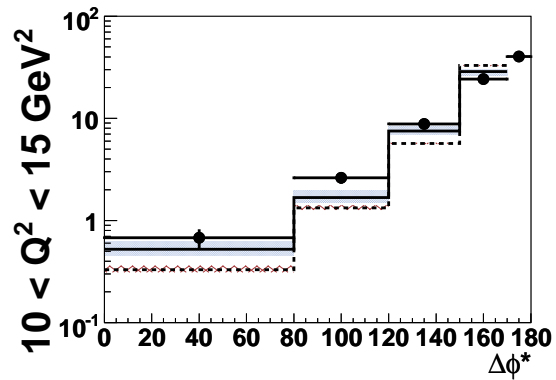
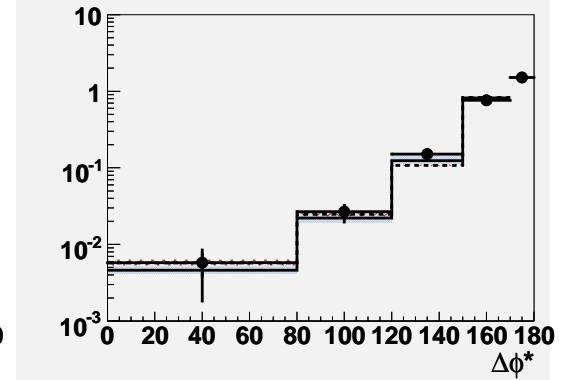
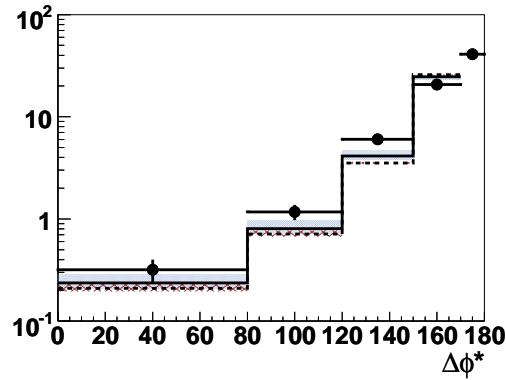
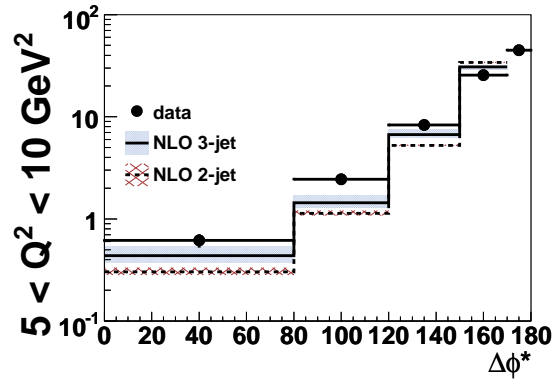


$d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$  Norm to x-section between  $0^\circ < \Delta\phi^* < 170^\circ$

$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

$6 \times 10^{-4} < x_{Bj} < 10^{-2}$

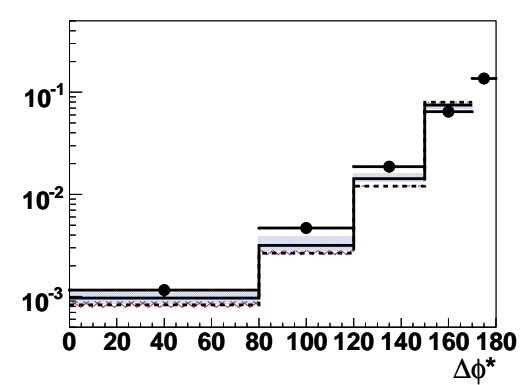
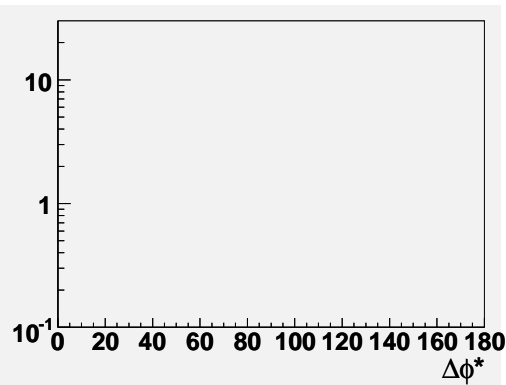
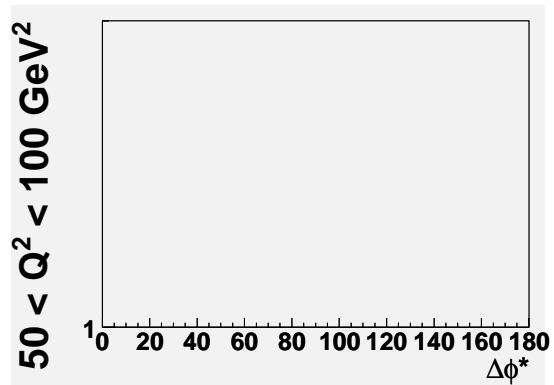
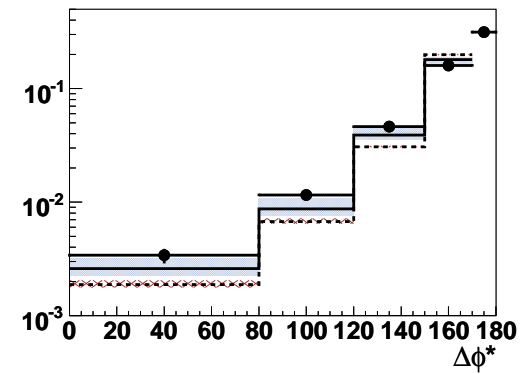
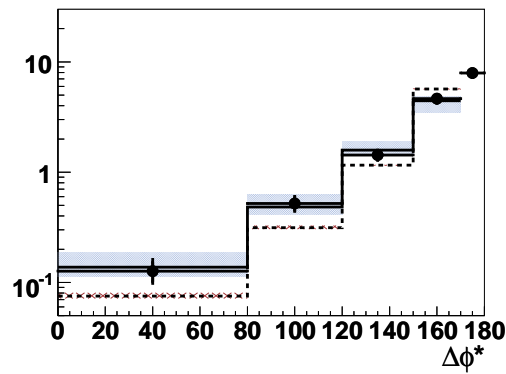
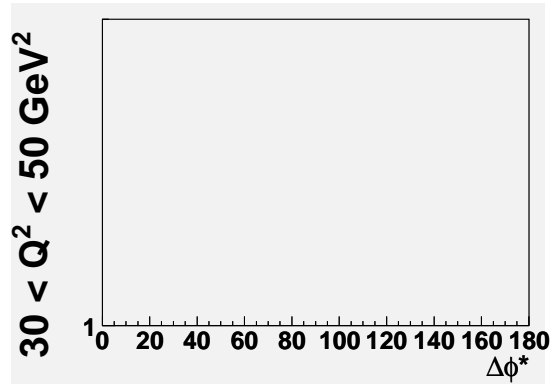
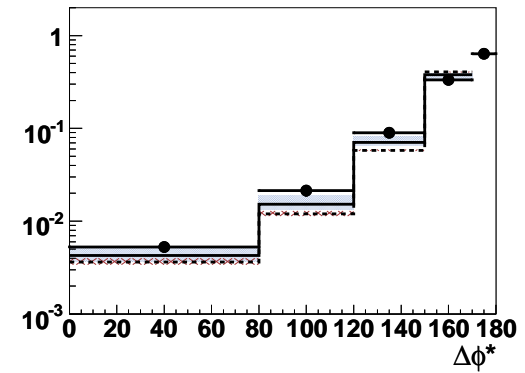
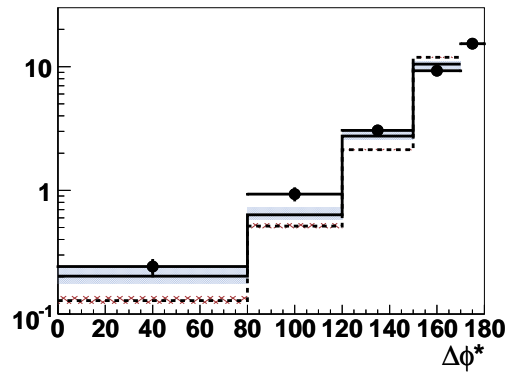
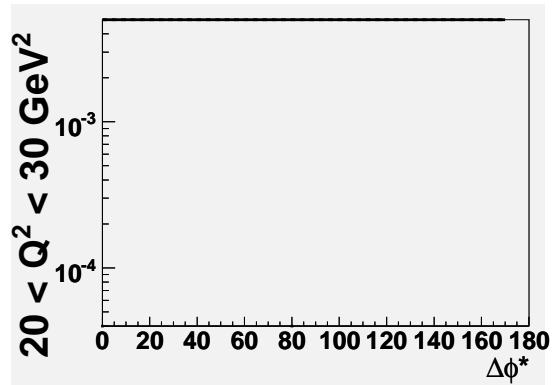


$d^3\sigma/dx_{bj}dQ^2d\Delta\phi^*$  Norm to x-section between  $0^\circ < \Delta\phi^* < 170^\circ$

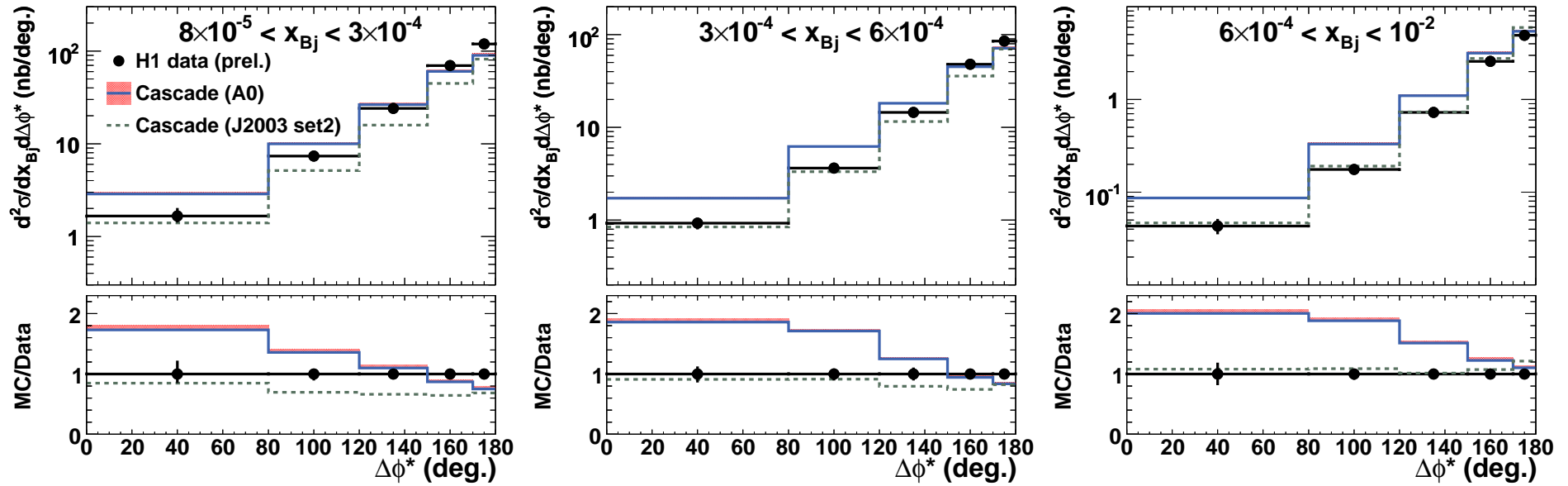
$8 \times 10^{-5} < x_{Bj} < 3 \times 10^{-4}$

$3 \times 10^{-4} < x_{Bj} < 6 \times 10^{-4}$

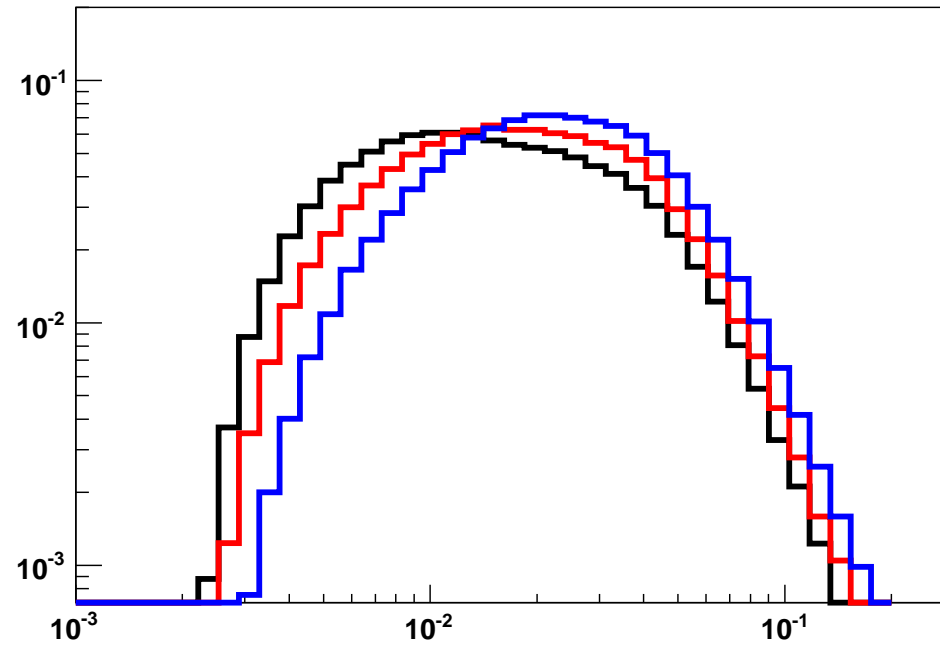
$6 \times 10^{-4} < x_{Bj} < 10^{-2}$



# Data Vs CASCADE: uPDF $\mu_r$ Uncertainty (A0+/-)

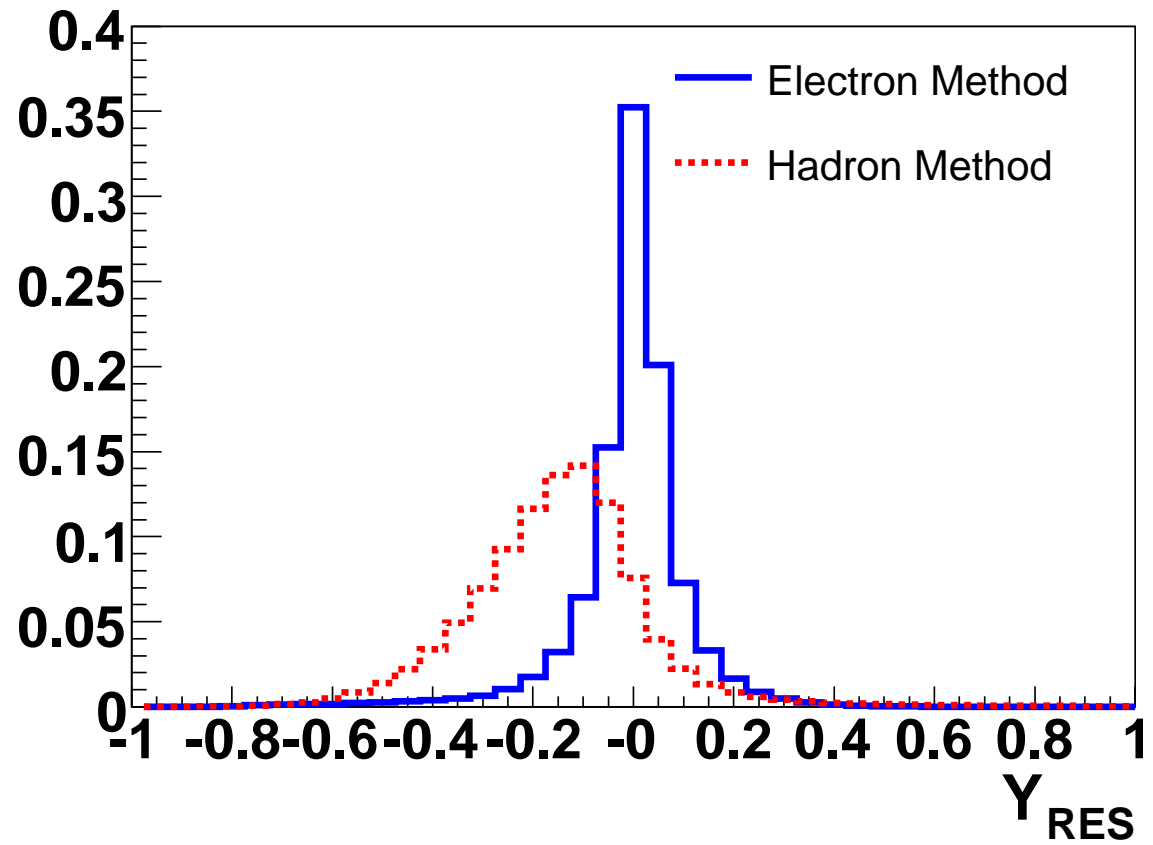


## Xg Distributions in $x_{Bj}$ bins (Hadron Level)

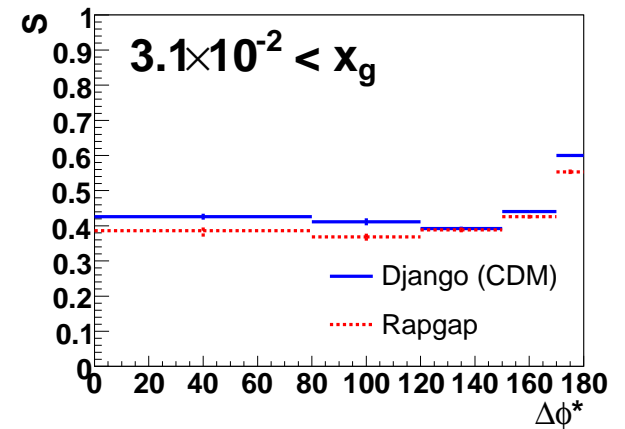
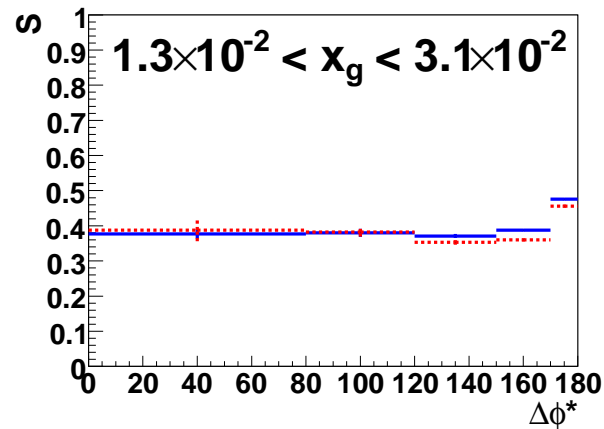
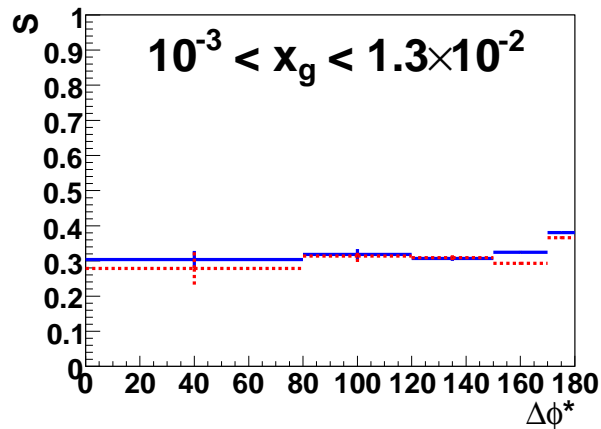
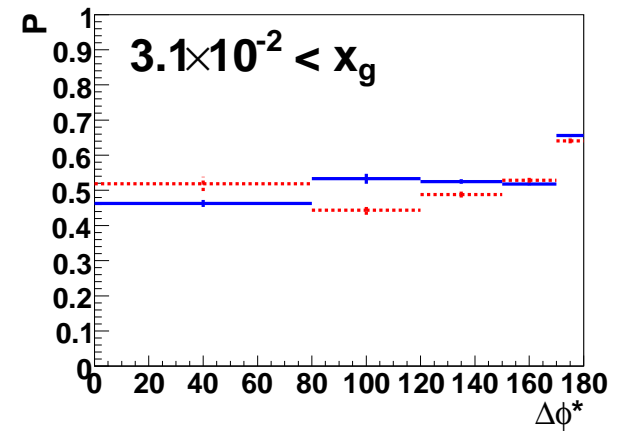
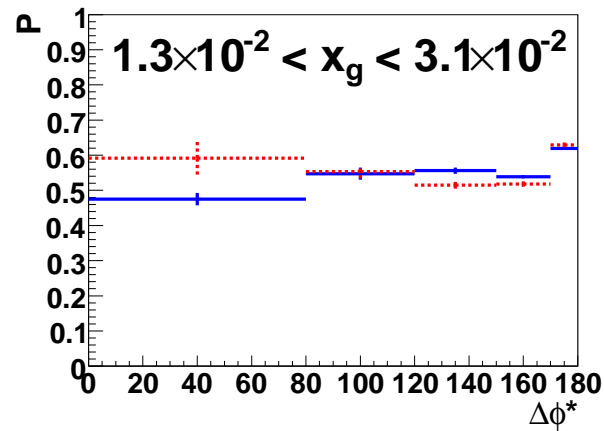
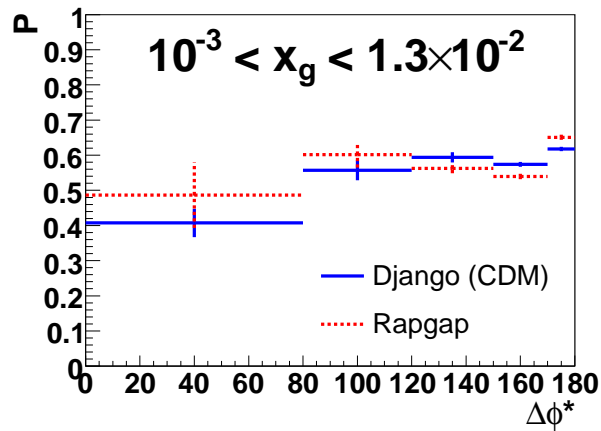


Mean: 0.0197, 0.0230, 0.0273

# Y Resolutions



# Purity & Stability (Rapidity method)



# $d^2\sigma/dx_g d\Delta\phi^*$ Data Vs NLO 2-jet, NLO 3-jet

