Decorrelation of Dijets at Low x and Q^2 and a Fit of the Unintegrated Gluon Density

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HaQ Meeting, Sept 4 2007

Outline

⇒ Motivation & Selection

⇒ $\dfrac{d^2\sigma}{dx_{bj}d\Delta\phi^*}$ and $\dfrac{d^3\sigma}{dx_{bj}dQ^2d\Delta\phi^*}$:

Purity, Stability, Unfolding, Systematic Uncertainties, Cross sections

⇒ Fit of the Unintegrated Gluon Density to $\dfrac{d^3\sigma}{dx_{bj}dQ^2d\Delta\phi^*}$

⇒ Summary & Outlook

Motivation

DGLAP:

Gluon collinear with proton in LO

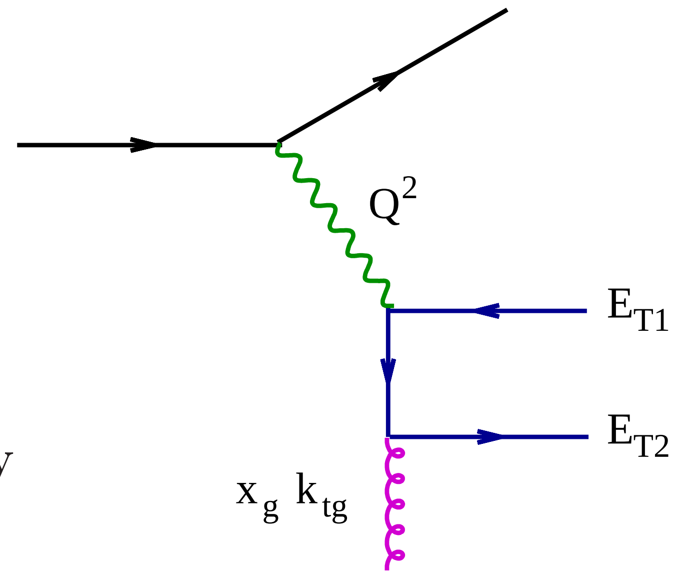
$\Rightarrow$ Jets back-to-back in HCM

Higher order QCD radiation

$\Rightarrow k_{tg} \neq 0$ and $\Delta\phi^* < 180°$

Gluon propagators ordered in virtuality

$\Rightarrow k_{tg}$ ordered

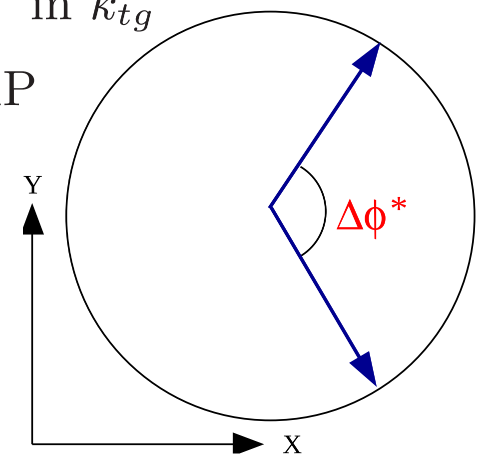


Small-x:

New dynamics (BFKL, CCFM): 'random walk' in k_{tg}

$\Rightarrow$ Broader $\Delta\phi^*$ spectrum compared to DGLAP

uPDF $\Rightarrow \Delta\phi^* < 180°$ already in LO



Azimuthal Decorrelations:

$\Rightarrow$ Sensitive to different parton dynamics

$\Rightarrow$ Sensitive to unintegrated gluon density

Selection

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

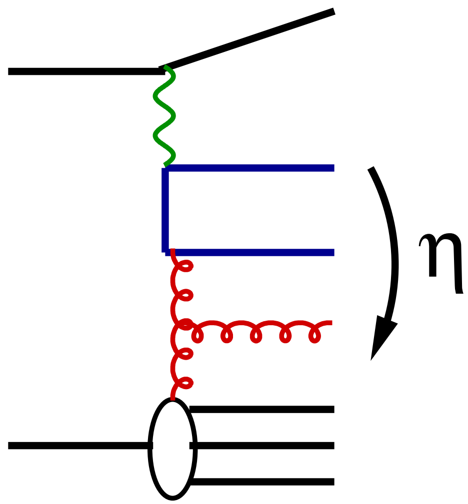
DIS Cuts

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

Dijet Cuts

-1 <	η_j	< 2.5
5 GeV<	$E^*_{\perp j1,2}$	

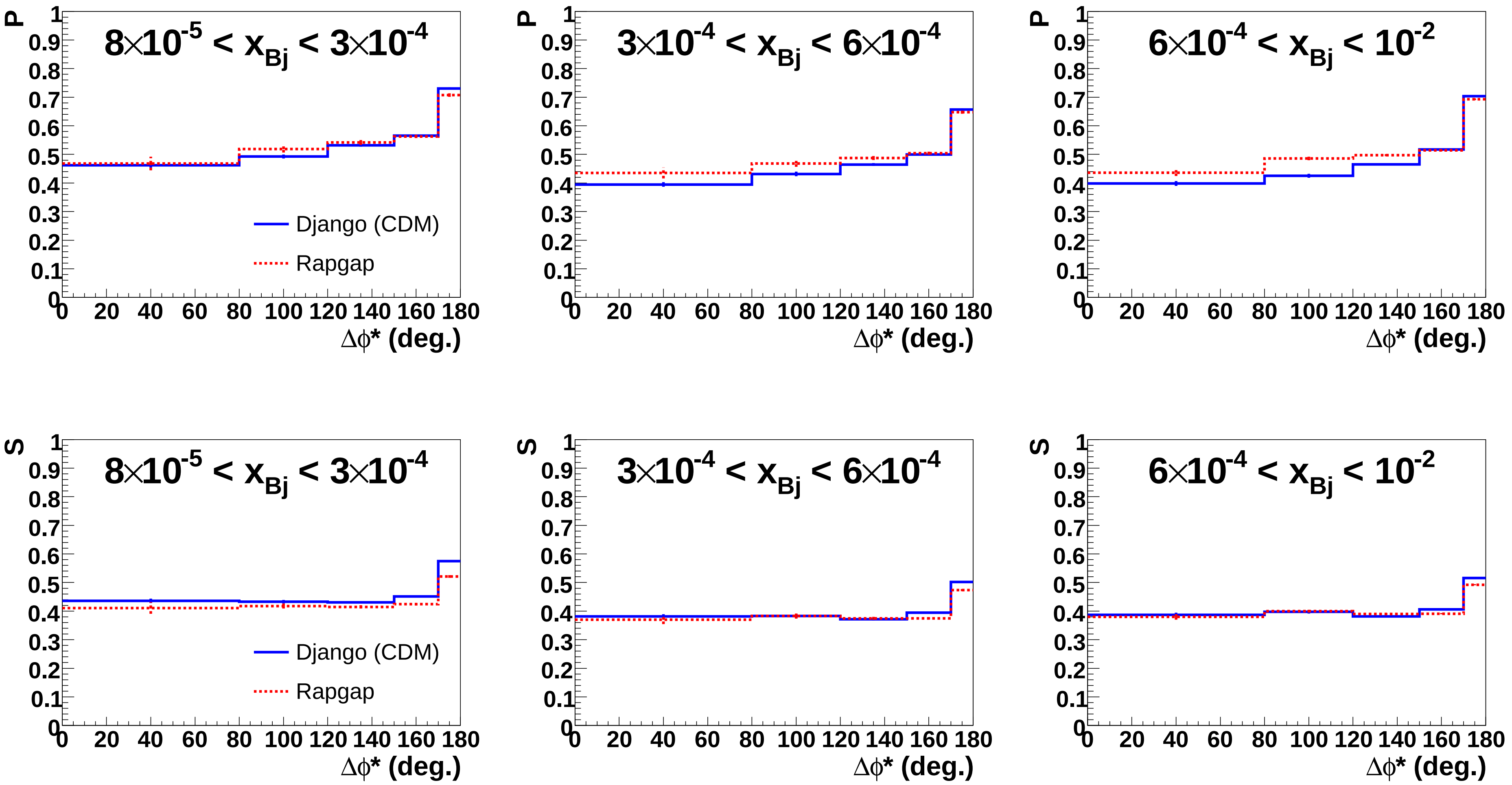
Sort in η



$$P = \frac{N_{DET\&\&HAD}}{N_{DET}}$$

$$\frac{d^2\sigma}{dx_{bj}\,d\Delta\phi^*}\text{: P \& S}$$

$$S = \frac{N_{DET\&\&HAD}}{N_{HAD}}$$



$$P = \frac{N_{DET\&\&HAD}}{N_{DET}}$$

$\frac{d^3\sigma}{dx_{bj}\,dQ^2\,d\Delta\phi^*}$: P & S

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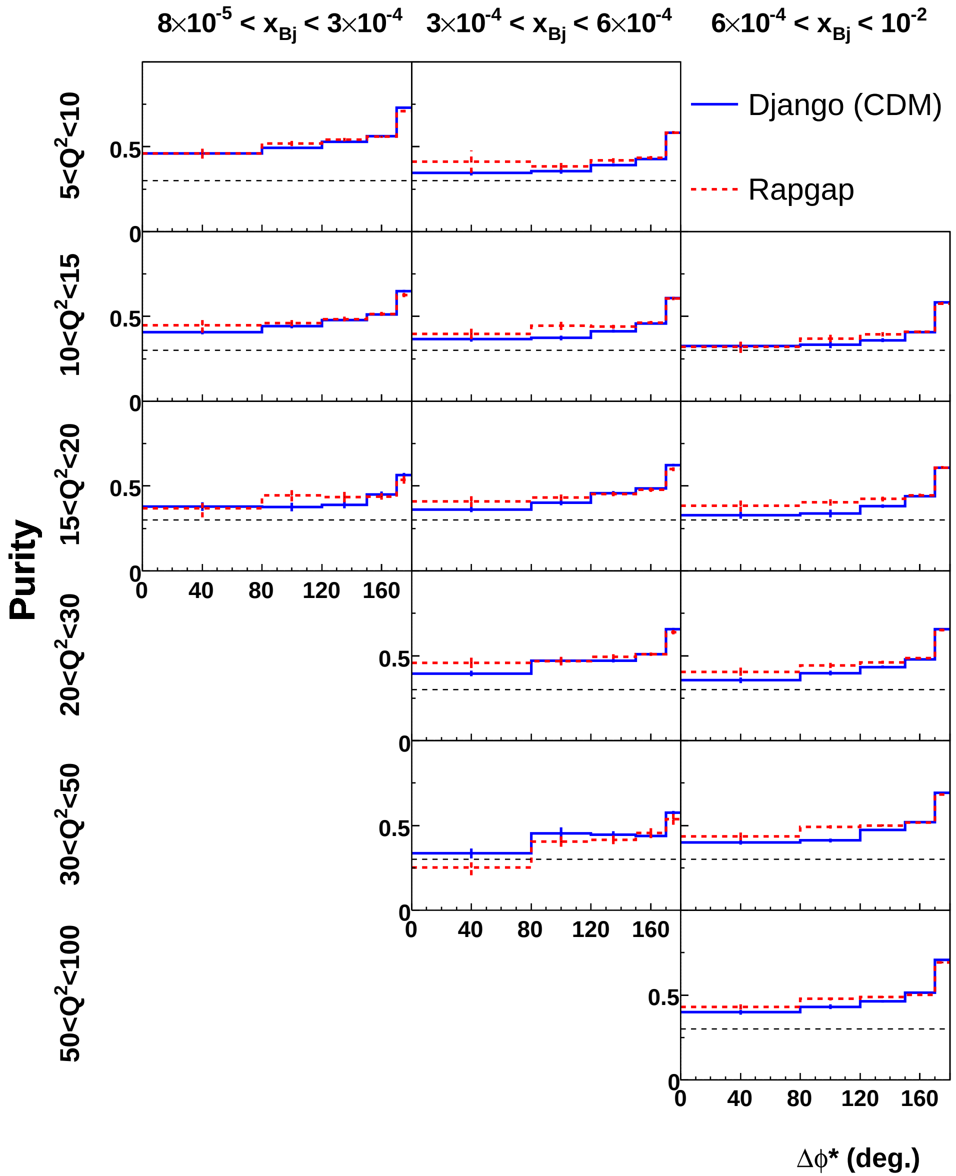
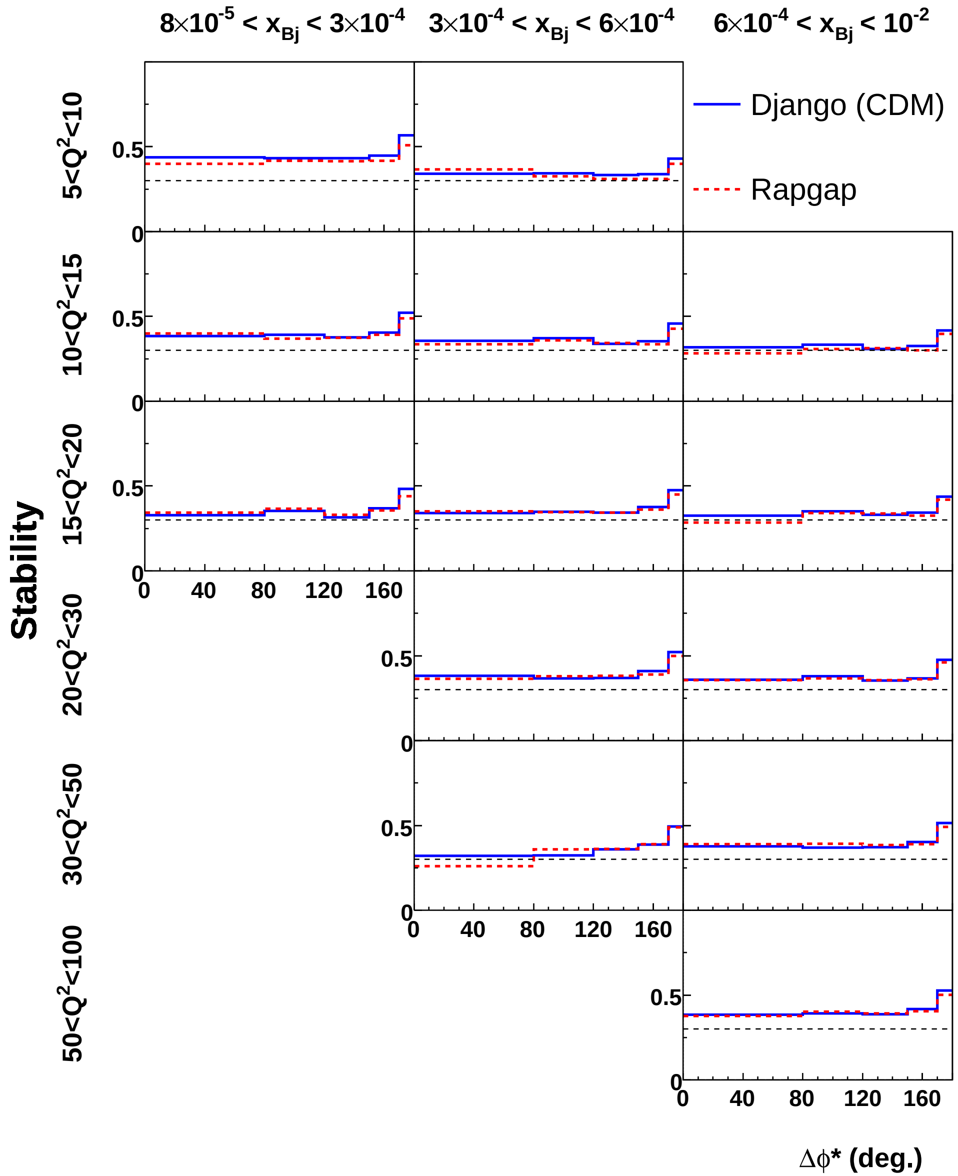




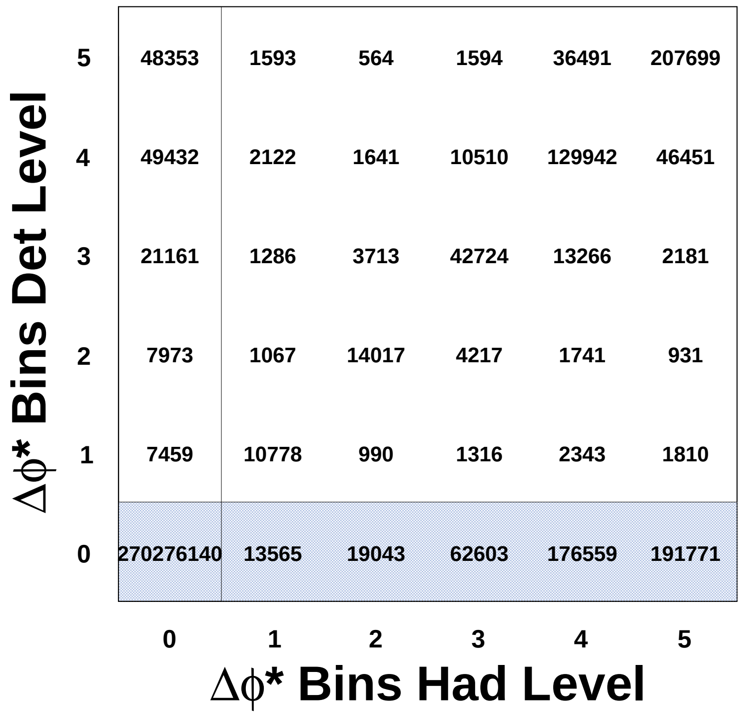
Bayes Unfolding

- Unfolding of data using iterative Bayesian unfolding
- Based on Bayes' theorem

$$P(C_i|E_j) = \frac{P(E_j|C_i) \cdot P(C_i)}{\sum_{l=1}^{n_C} P(E_j|C_l) \cdot P(C_l)}$$

- $P(C_i|E_j)$: Probability that Effect j was produced by Cause i
- $P(E_j|C_i)$: Probability that Cause i will produce Effect j
  Smearing Matrix - Describes detector responce
  Estimated using Monte Carlo
- $P(C_i)$: Probability of Cause i. Is unknown.
  Make a first guess, then iterate unfolding and update $P(C_i)$
  in each iteration
- Properly takes into account migration effects

⇒ Example of Smearing Matrix $P(E_j|C_i)$:



Large fluctuations because of many events in background bins

Excluded in Bayes unfolding - Correct for these using bin-by-bin method

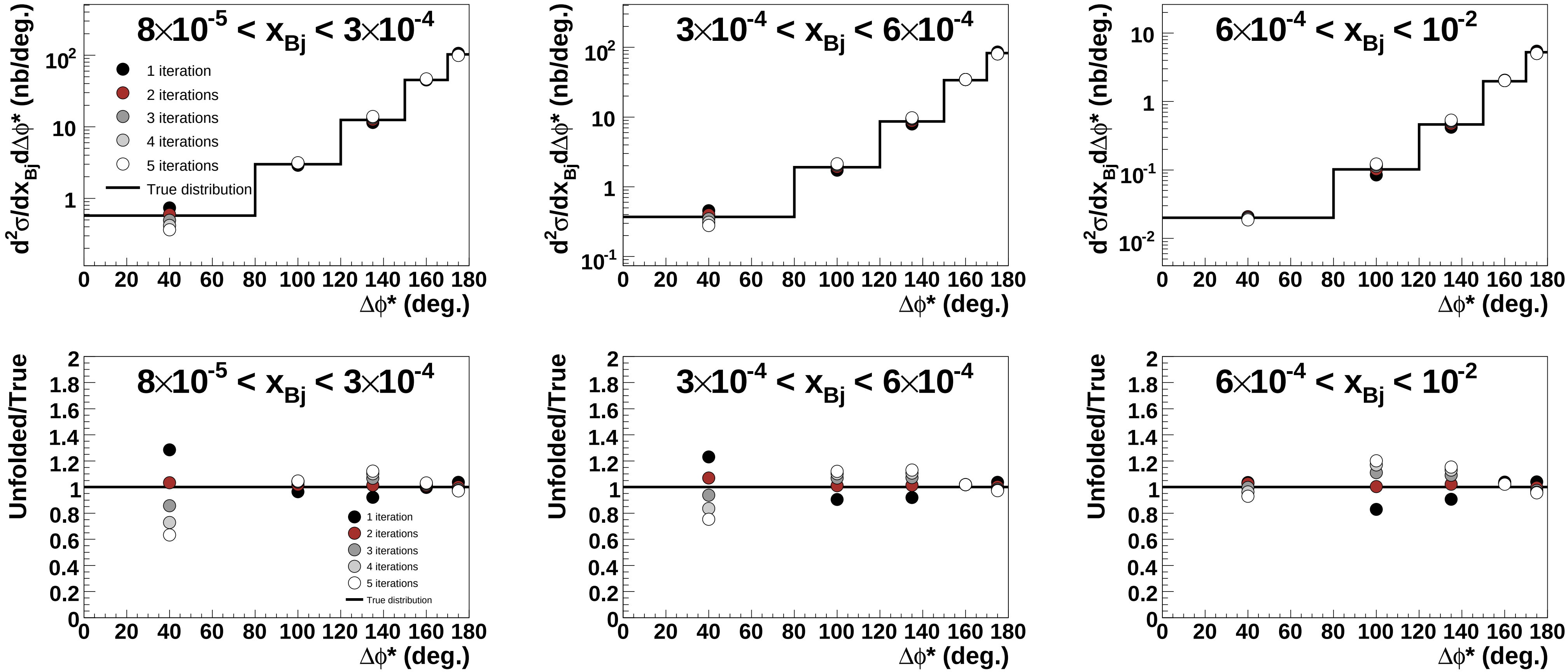
Also QED effects corrected bin-by-bin

⇒ First guess of $P(C_i)$: Hadron level distribution of MC used for unfolding

Bayes Unfolding

Must determine best number of iterations:

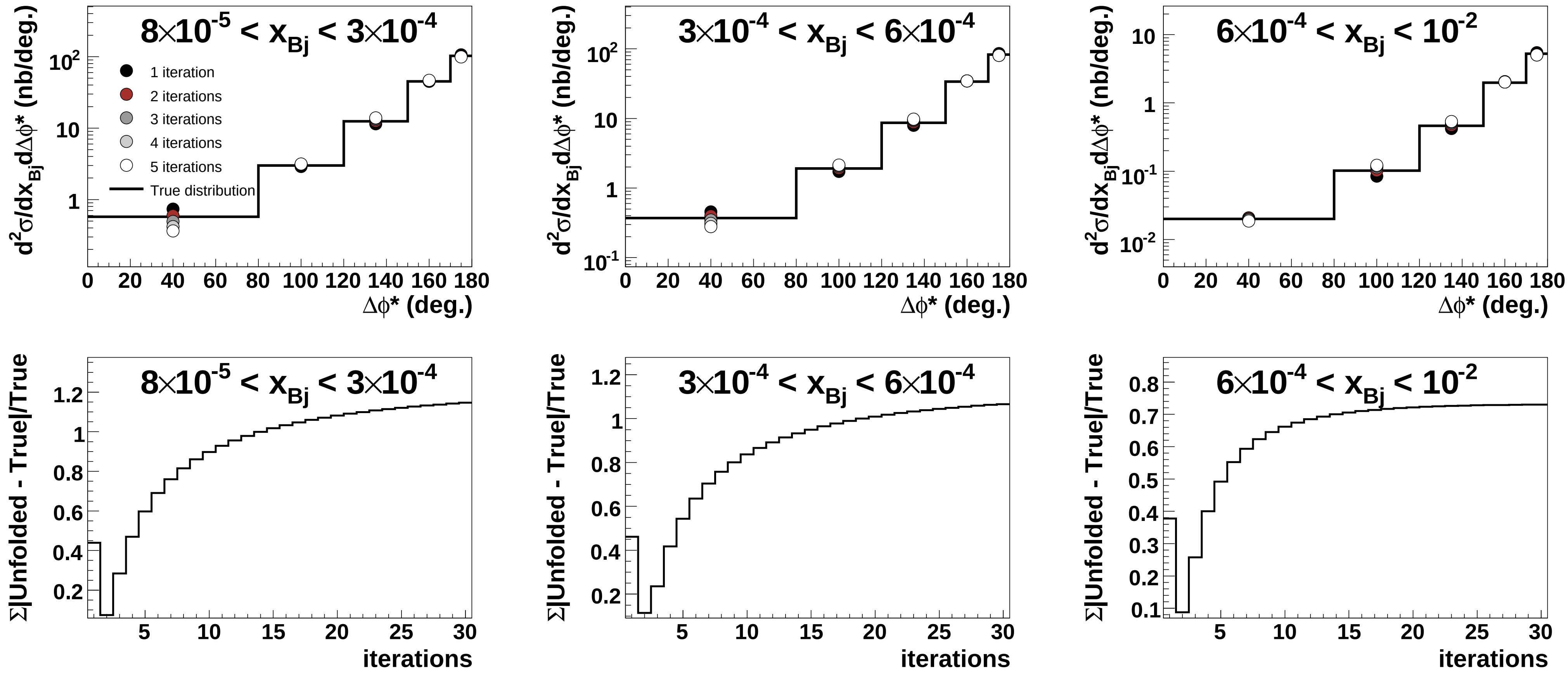
Unfold Rapgap using Django and compare to Rapgap hadron level



Bayes Unfolding

Calculate $\sum_{bins} \frac{|true - unfolded|}{true}$ for each iteration

$\Rightarrow$ Best agreement after 2 iterations



Similar result if unfolding Django using Rapgap, and for $\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$ and $\frac{d^3\sigma}{dx_{bj} dQ^2 d\Delta\phi^*}$

Systematic Uncertainties

Estimated using Rapgap, except:

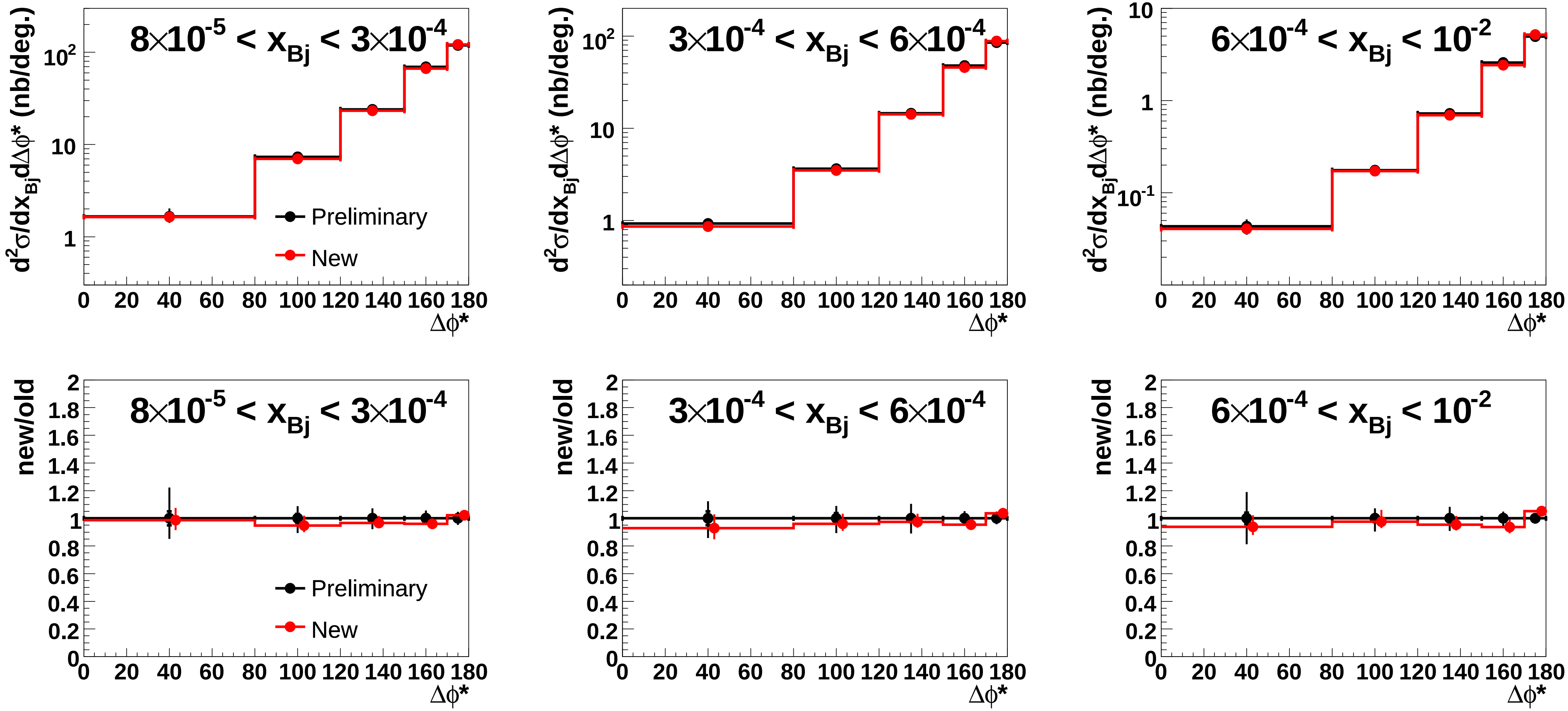
Model Dependence: $\frac{|C_{Rapgap}-C_{Django}|}{2}$

Unfolding Bias: Unfold Rapgap using Django and compare to true Rapgap distribution ($\Rightarrow \Delta\sigma_{Rapgap}$) and vice versa

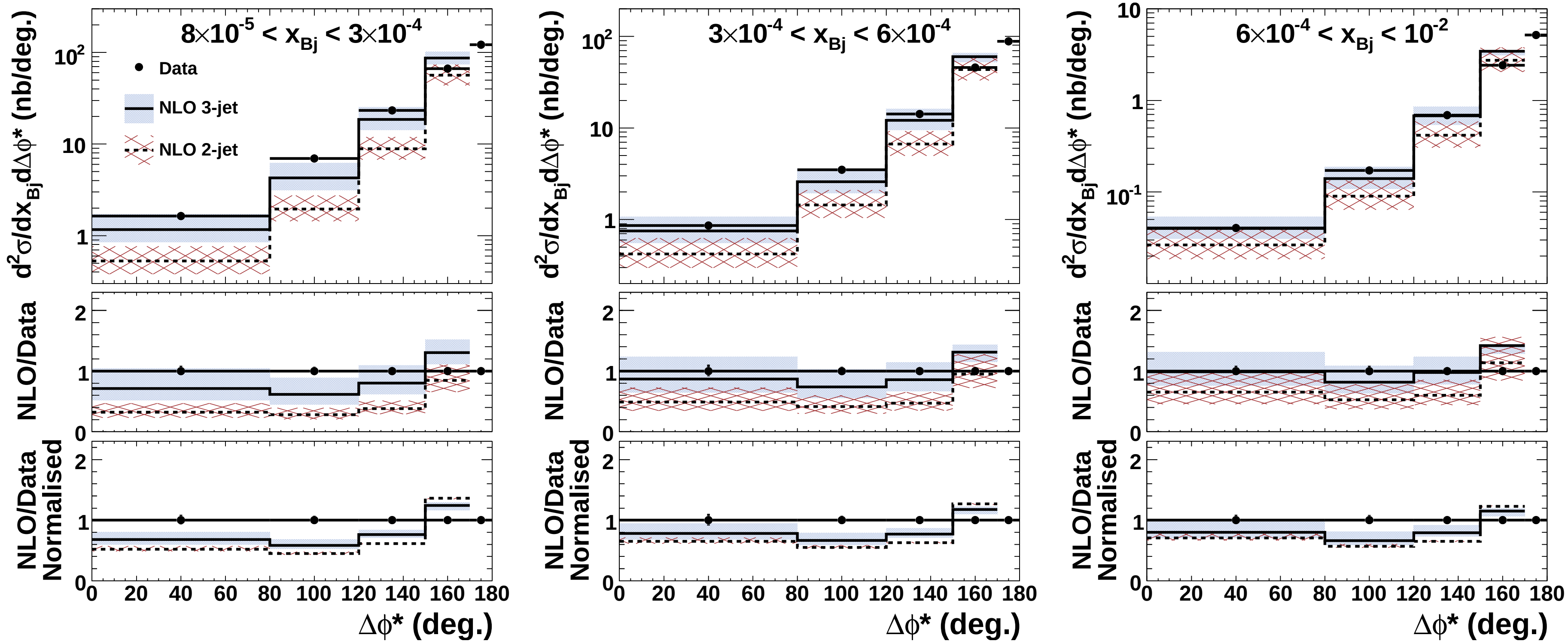
Source	Uncertainty	Typical $\Delta\sigma$ $\frac{d^2\sigma}{dx_{bj}d\Delta\phi^*}$	Typical $\Delta\sigma$ $\frac{d^3\sigma}{dx_{bj}dQ^2d\Delta\phi^*}$
SPACAL electromagnetic energy scale	$\pm$ 1%	0.5-2%	1-3%
Polar angle of scattered electron	$\pm$ 1 mrad	$<$1%	0.5-2%
LAr hadronic energy scale	$\pm$ 4%	2-7%	2-10%
Track momentum	$\pm$ 3%	$\ll$ 1%	$\ll$ 1%
Model uncertainty	$\frac{|C_{Rapgap}-C_{Django}|}{2}$	0.5-2%	1-4%
Unfolding bias	$\frac{\Delta\sigma_{Rapgap}+\Delta\sigma_{Django}}{2}$	1-4%	1-7%
Photoproduction background		$\ll$ 1%	$\ll$ 1%
Luminosity		1.5%	1.5%

$$\frac{d^2\sigma}{dx_{Bj}\,d\Delta\phi^*}$$

New Cross sections compared to preliminary (DIS06)



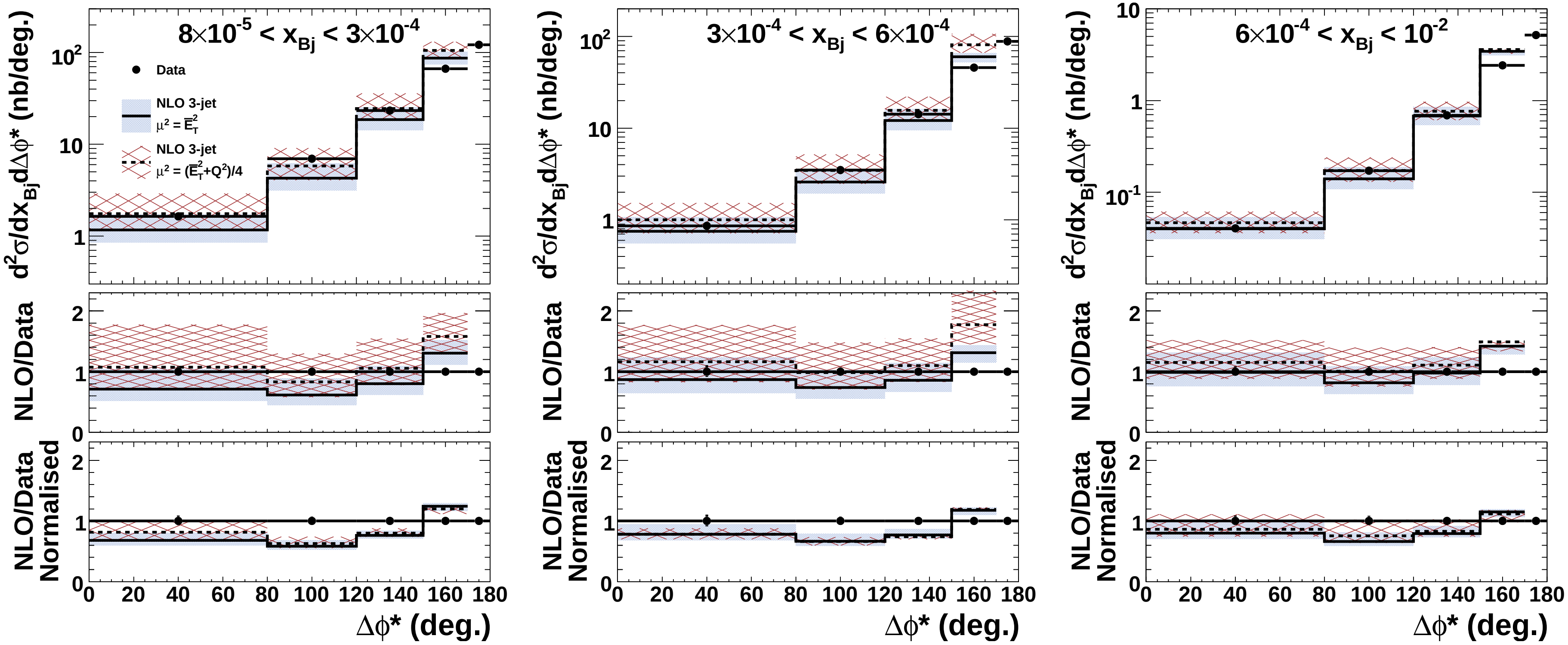
$$\frac{d^2\sigma}{dx_{Bj}\,d\Delta\phi^*}$$



“Normalised” means that distributions are normalised to the cross section between $0 < \Delta\phi^* < 170°$ before calculating ratio

$\Rightarrow$ Partial cancellation of scale uncertainties.

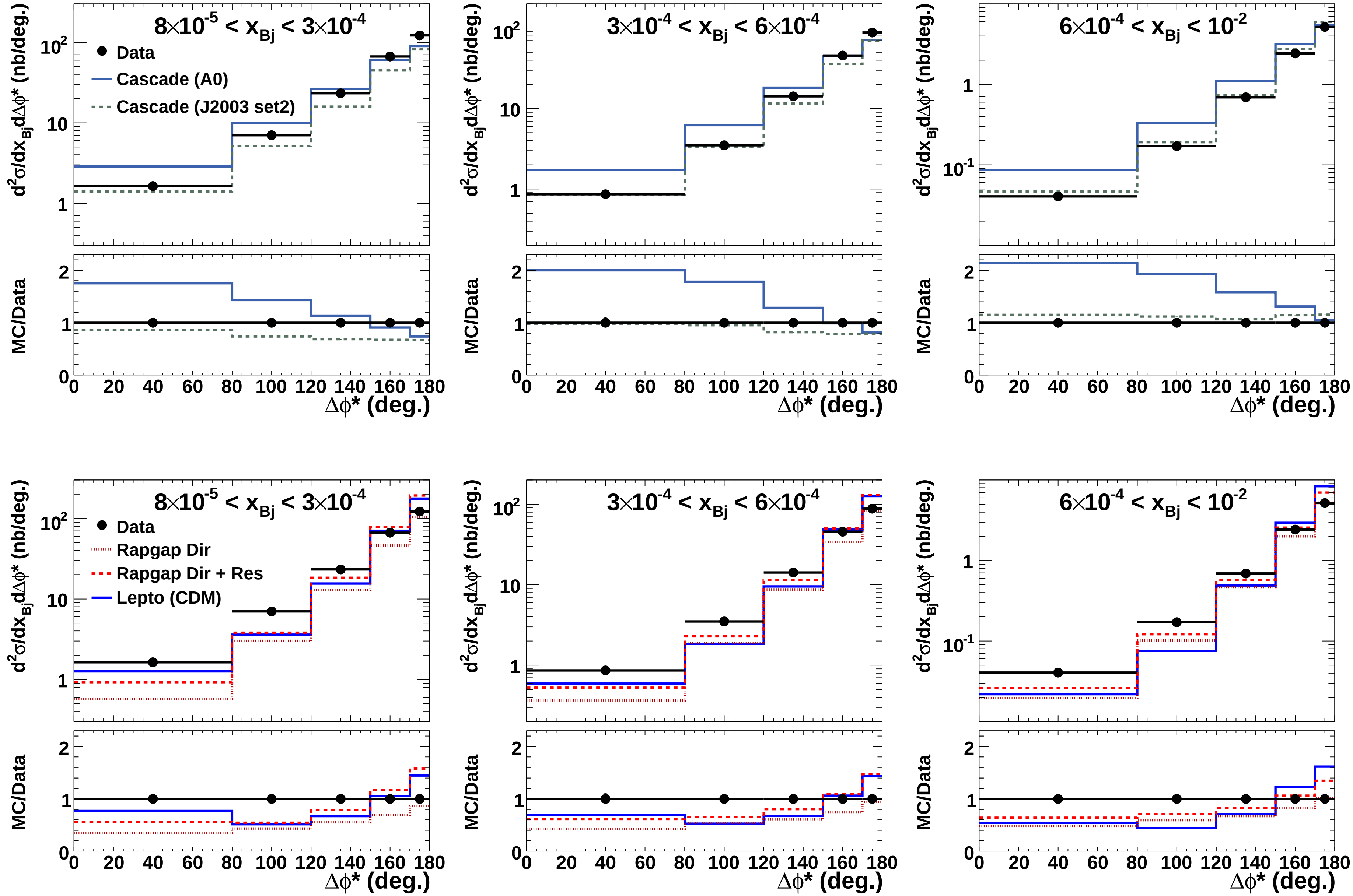
$\frac{d^2\sigma}{dx_{Bj}d\Delta\phi^*}$: Scale comparison



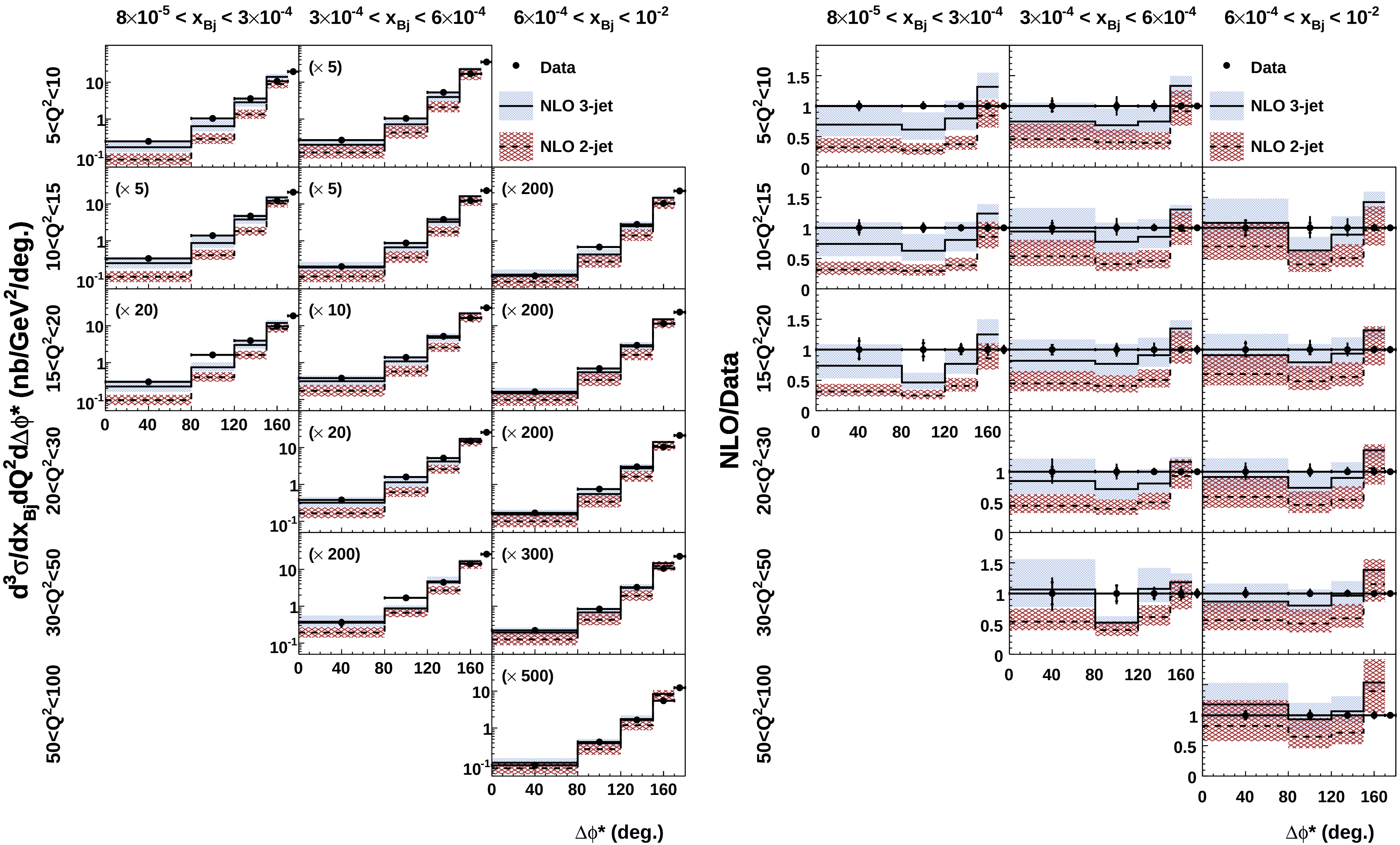
$\mu^2 = \bar{E}_T^2$ used in this analysis

$\mu^2 = (\bar{E}_T^2 + Q^2)/4$ used in e.g. ZEUS analysis 0705.1931 [hep-ex]
(Multijets at low x_{Bj}, including $\Delta\phi^*$ cross sections)
$\Rightarrow$ Larger cross sections and scale uncertainties

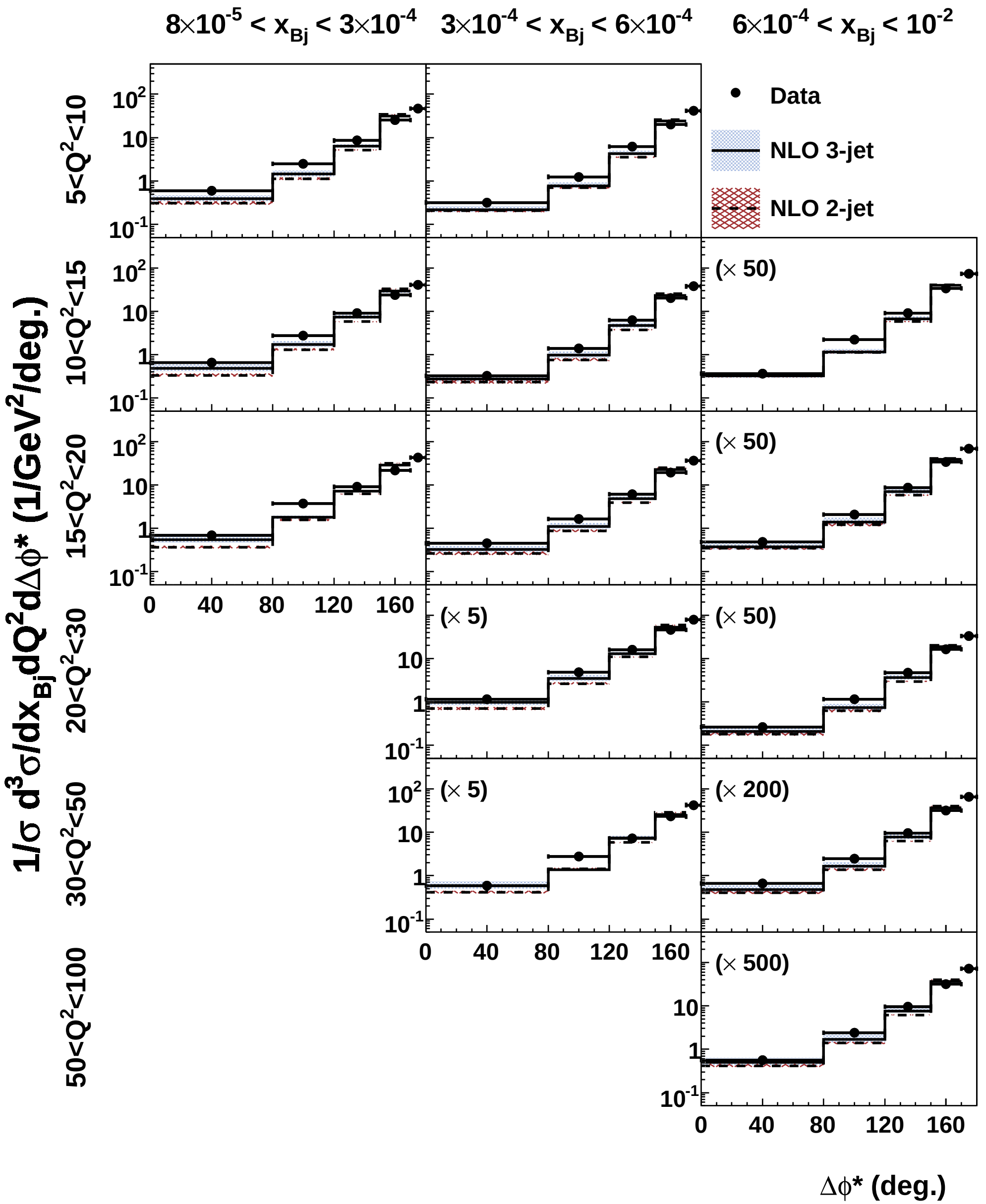
$$\frac{d^2\sigma}{dx_{Bj}\,d\Delta\phi^*}$$

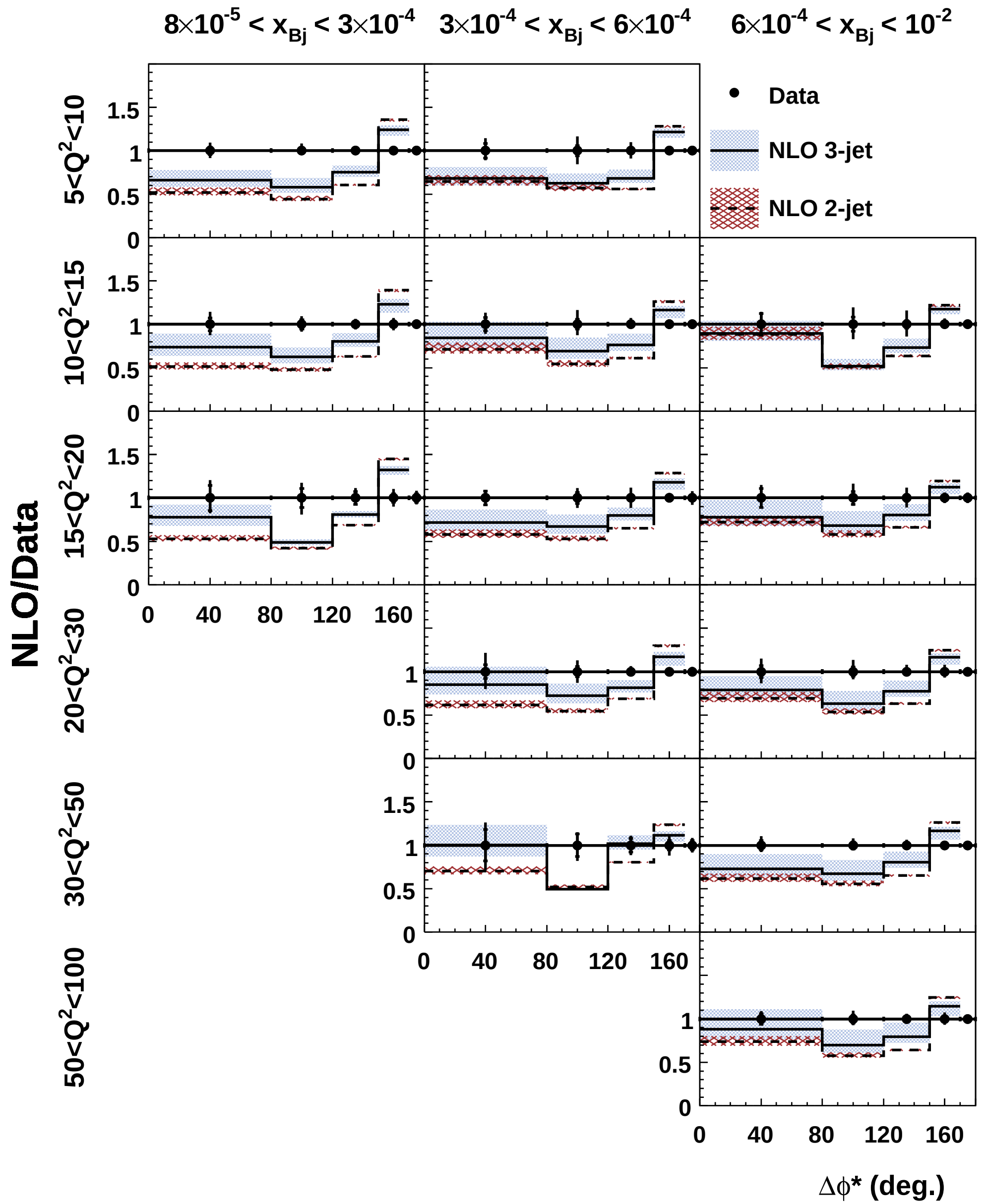


$$d^3\sigma / dx_{Bj} dQ^2 d\Delta\phi^*$$

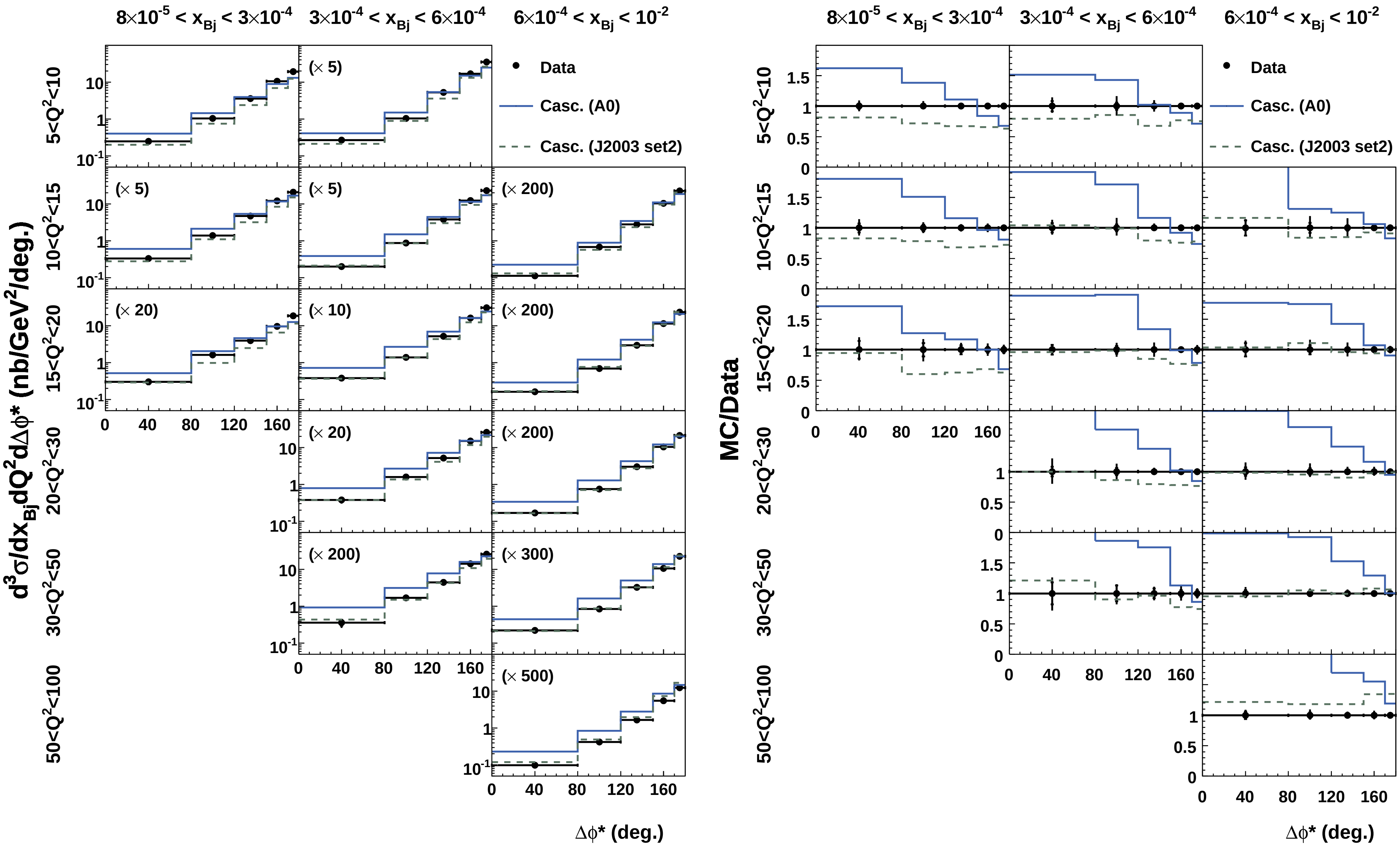


$$\frac{1}{\sigma}\ d^3\sigma/dx_{Bj}dQ^2d\Delta\phi^*$$

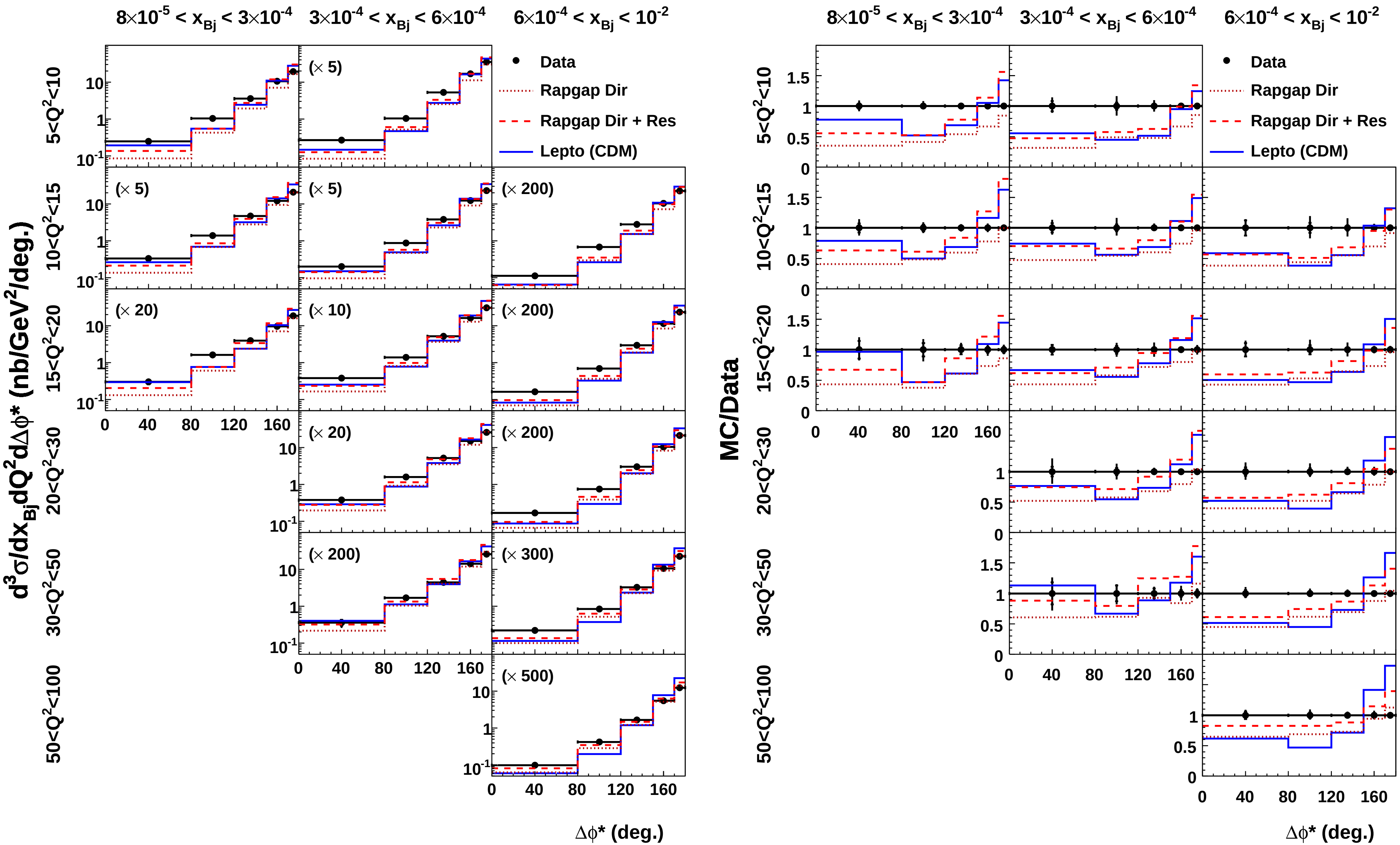




$d^3\sigma/dx_{Bj}dQ^2d\Delta\phi^*$



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



Fit Procedure

- Only use gluon densities
- Select starting distribution $x\mathcal{A}_0(x, k_\perp, \bar{q}_0)$
- Simulate events using CASCADE MC generator, uPDF is evolved using CCFM according to

$$x\mathcal{A}(x, k_\perp, \bar{q}) = \int dx' \mathcal{A}_0(x', k_\perp, \bar{q}_0) \cdot \frac{x}{x'} \tilde{\mathcal{A}}(\frac{x}{x'}, k_\perp, \bar{q})$$

- Minimize χ^2 by varying parameters in starting distribution $x\mathcal{A}_0(x, k_\perp, \bar{q}_0)$ using HZTOOL and MINUIT

Fit Procedure

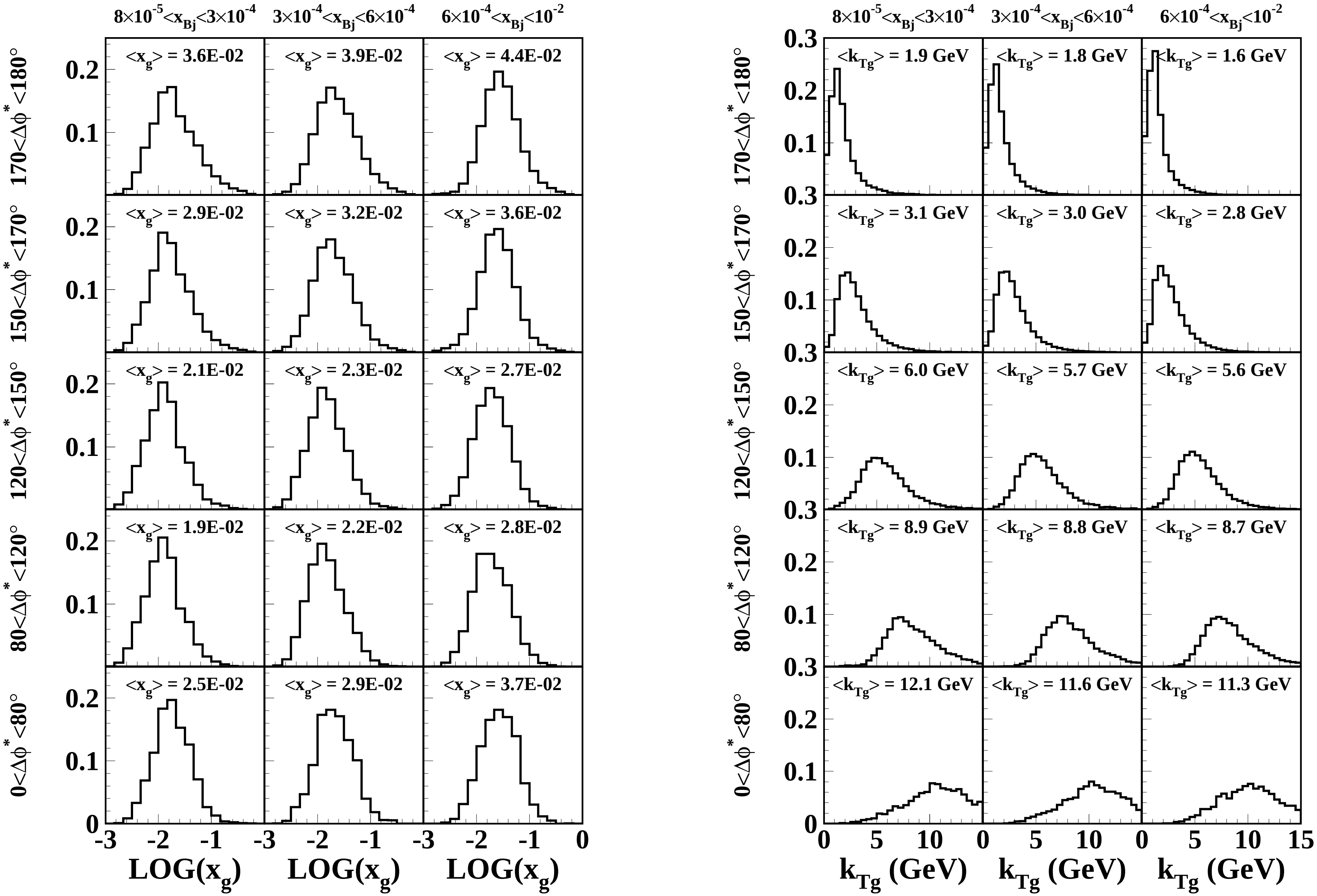
- Starting distribution:

$$x\mathcal{A}_0(x, k_\perp, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^4 \cdot exp(-(k_\perp - \mu)^2/2\sigma^2)$$

  where N, B, μ and σ are free parameters

- Using full splitting function, i.e. including non-singular terms
- One-loop α_s with $\lambda_{QCD}^{[4]} = 0.13$ GeV
- Starting scale of evolution: $\bar{q}_0 = 1.2$ GeV
- $\chi^2 = \sum_i \left(\frac{(T_i - D_i)^2}{\sigma_{T,i}^2 + \sigma_{D,i}^2} \right)$
- Fit to $\dfrac{d^3\sigma}{dx_{bj}dQ^2d\Delta\phi^*}$

Sensitivity to uPDF



$\Rightarrow$ Large sensitivity to $k_{T,g}$

uPDF Fit

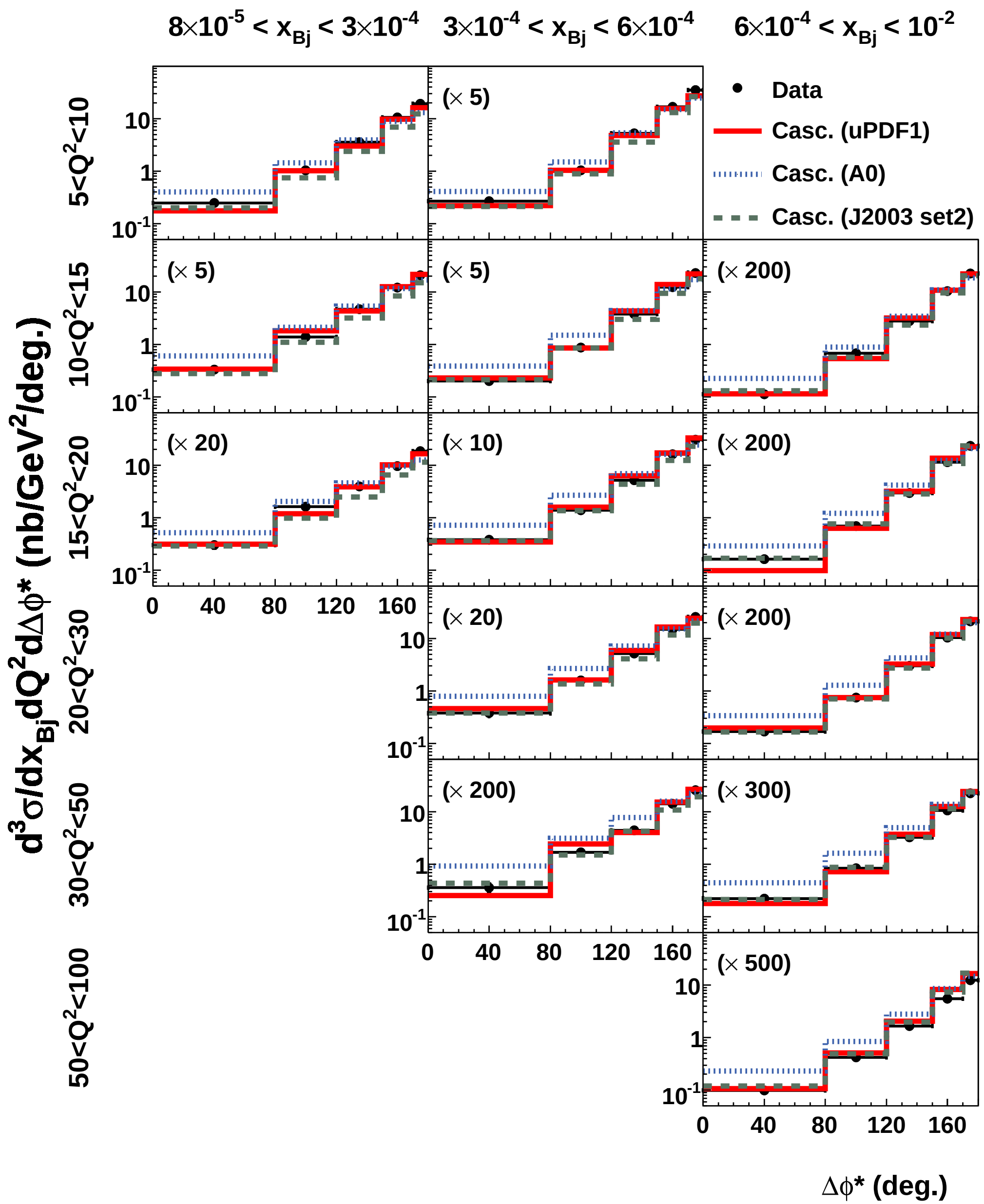
Best fit (uPDF1) compared to J2003set2 and A0

χ^2:

	χ^2/ndf	χ^2	ndf
uPDF1	3.0	186	61
J2003set2	12.5	762	61
A0	32.4	1974	61

Parameters:

	N	B	σ (GeV)	μ (GeV)
uPDF1	0.25	0.29	1.1	1.5
J2003set2	?	0.00	0.9	0.0
A0	?	0.00	0.8	0.0



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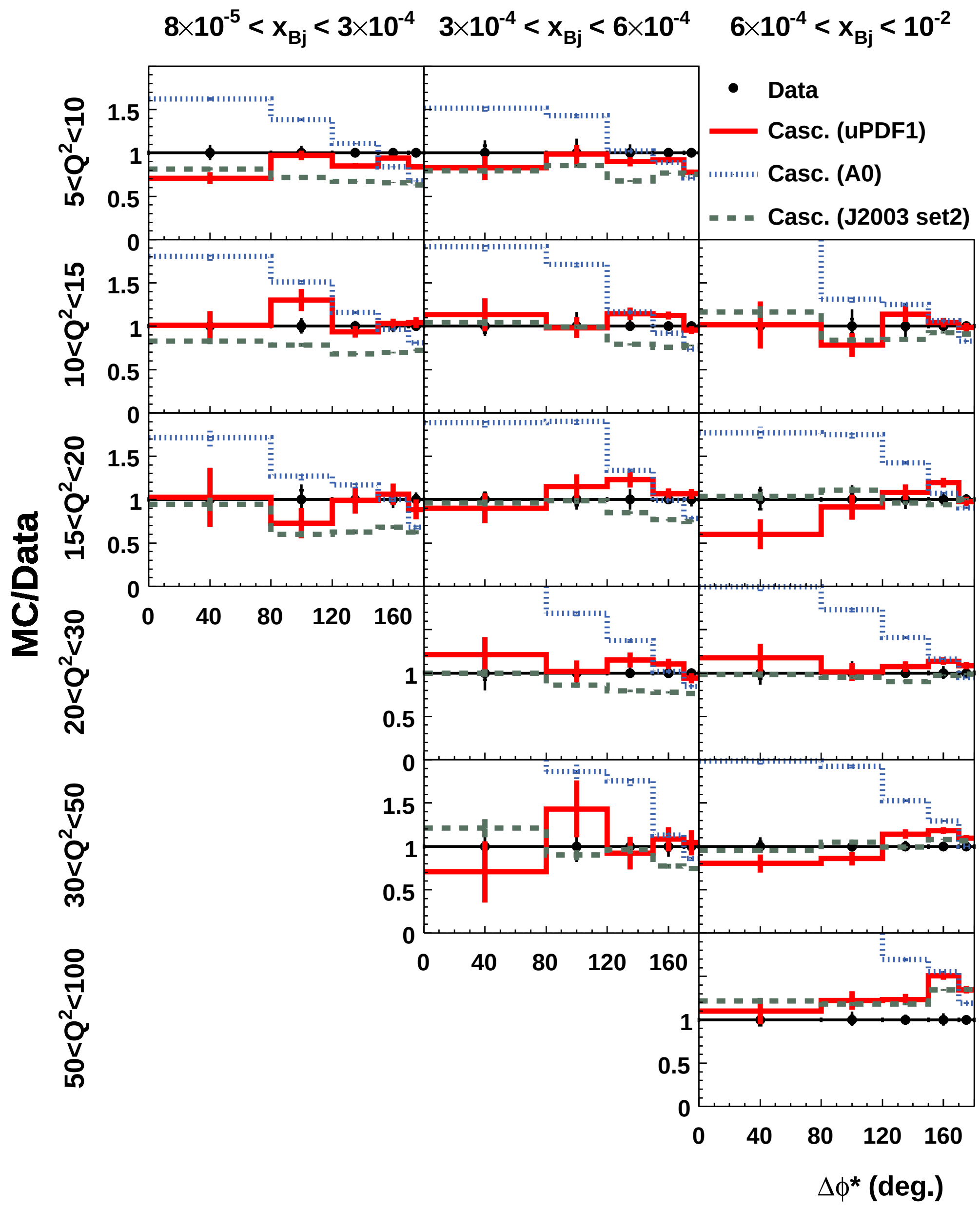
⇒ uPDF1 better than J2003set2 at small x_{Bj} and Q^2

⇒ Largest x_{Bj} and Q^2 bin contribute $\chi^2 = 89$

⇒ Exclude largest x_{Bj} and Q^2 bin gives $\chi^2/\text{ndf} = 97/56 = 1.7$



uPDF Fit

χ^2 profile around the minimum

Vary one parameter at the time

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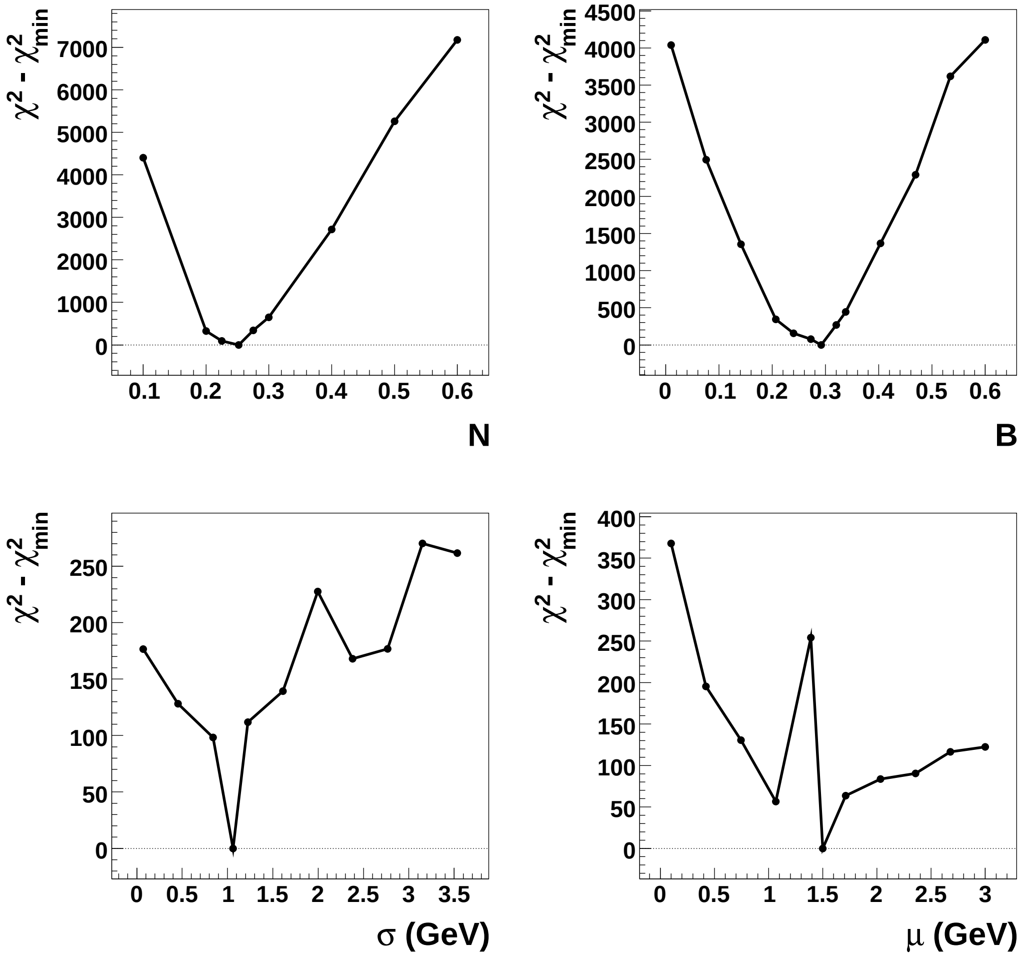
⇒ N and B well behaved, with one global minimum

⇒ Complex behaviour of μ and σ, with local minima



uPDF Fit

$$xA_0 = Nx^{-B}(1-x)^4 exp(\frac{-(k_\perp - \mu)^2}{2\sigma^2})$$

Compare shapes of uPDF1, A0 and J2003set2 (at $\bar{q} = 4$ GeV)

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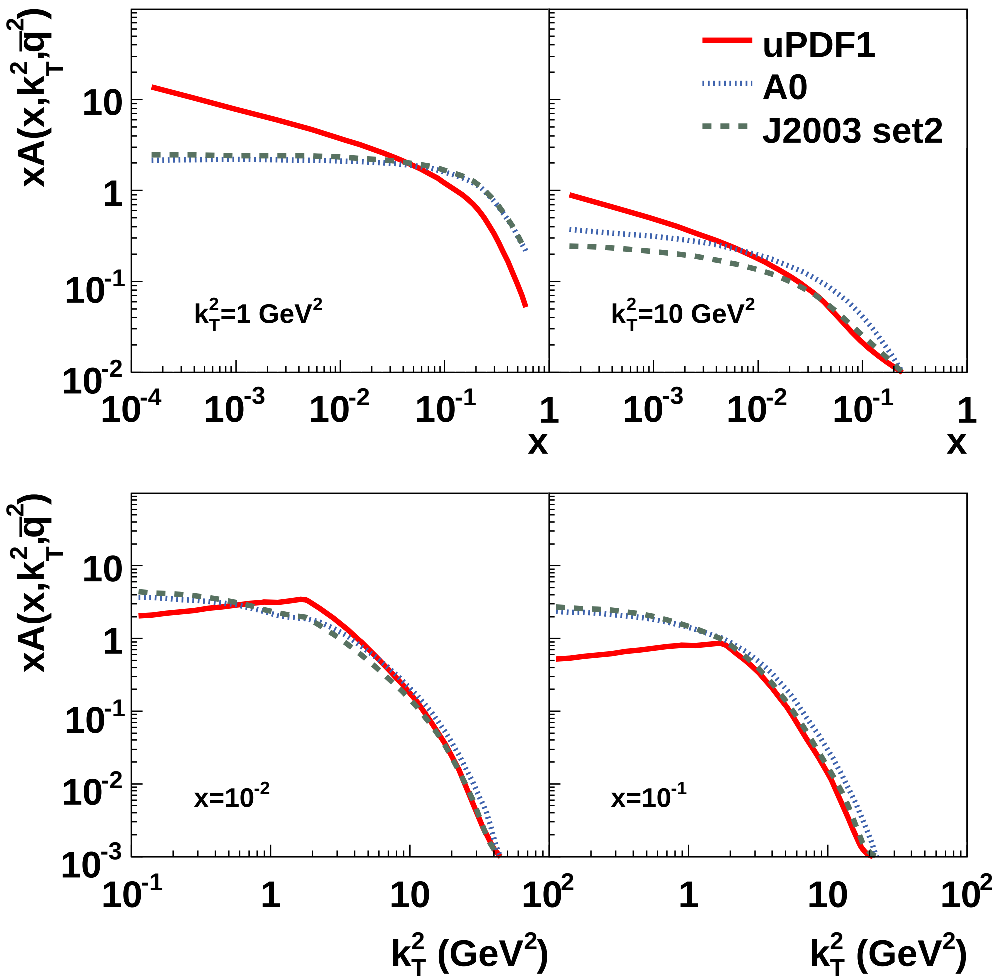

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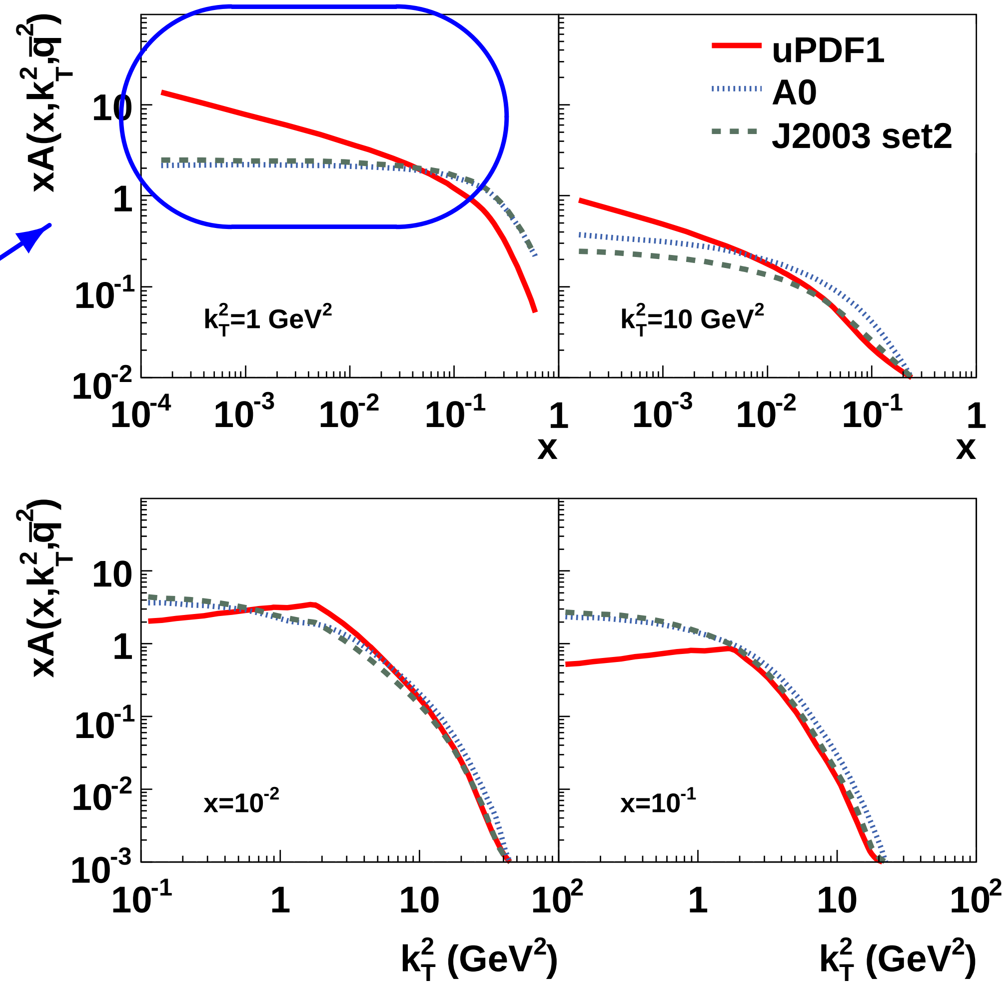
$\Rightarrow$ $B > 0$ gives steeper rise toward small x



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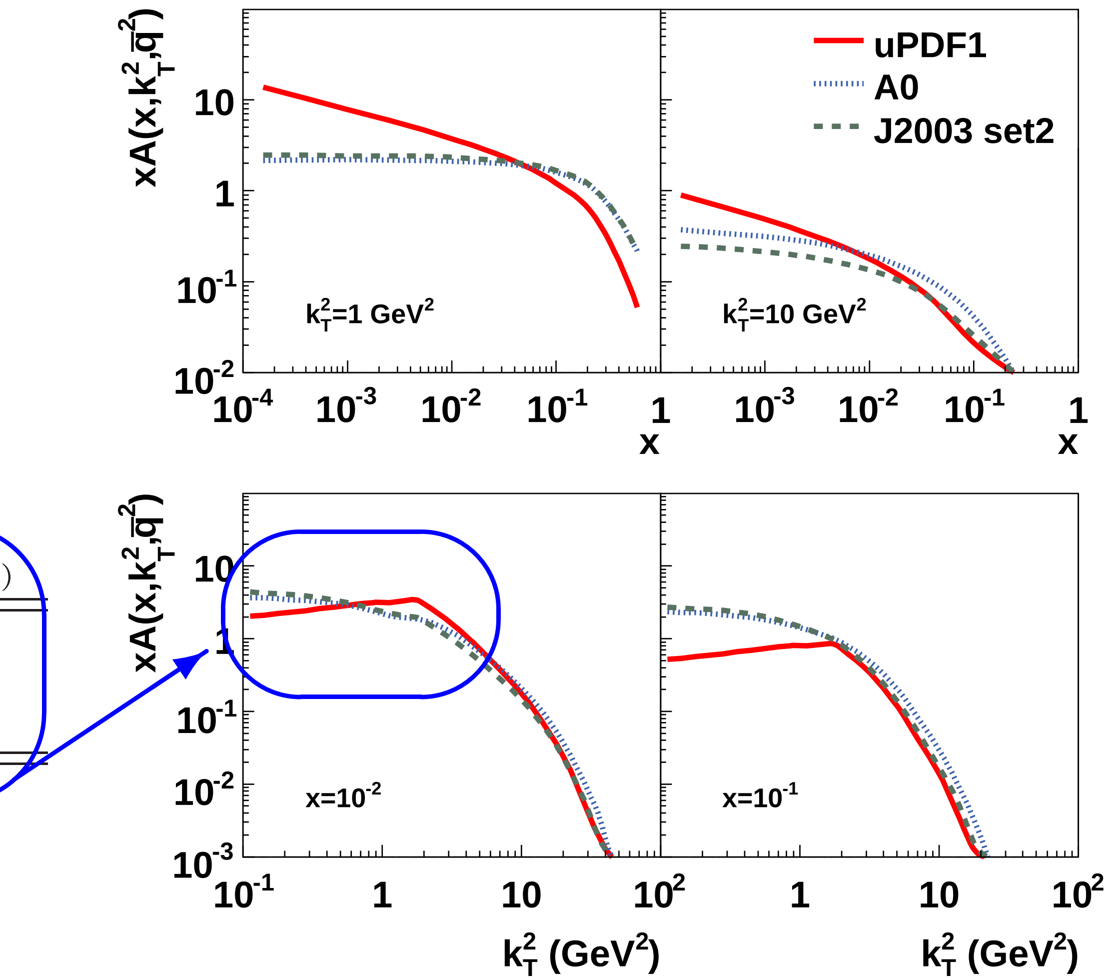


⇒ $B > 0$ gives steeper rise toward small x

⇒ $\mu > 0$ gives decreasing uPDF as $k_T \to 0$

Summary

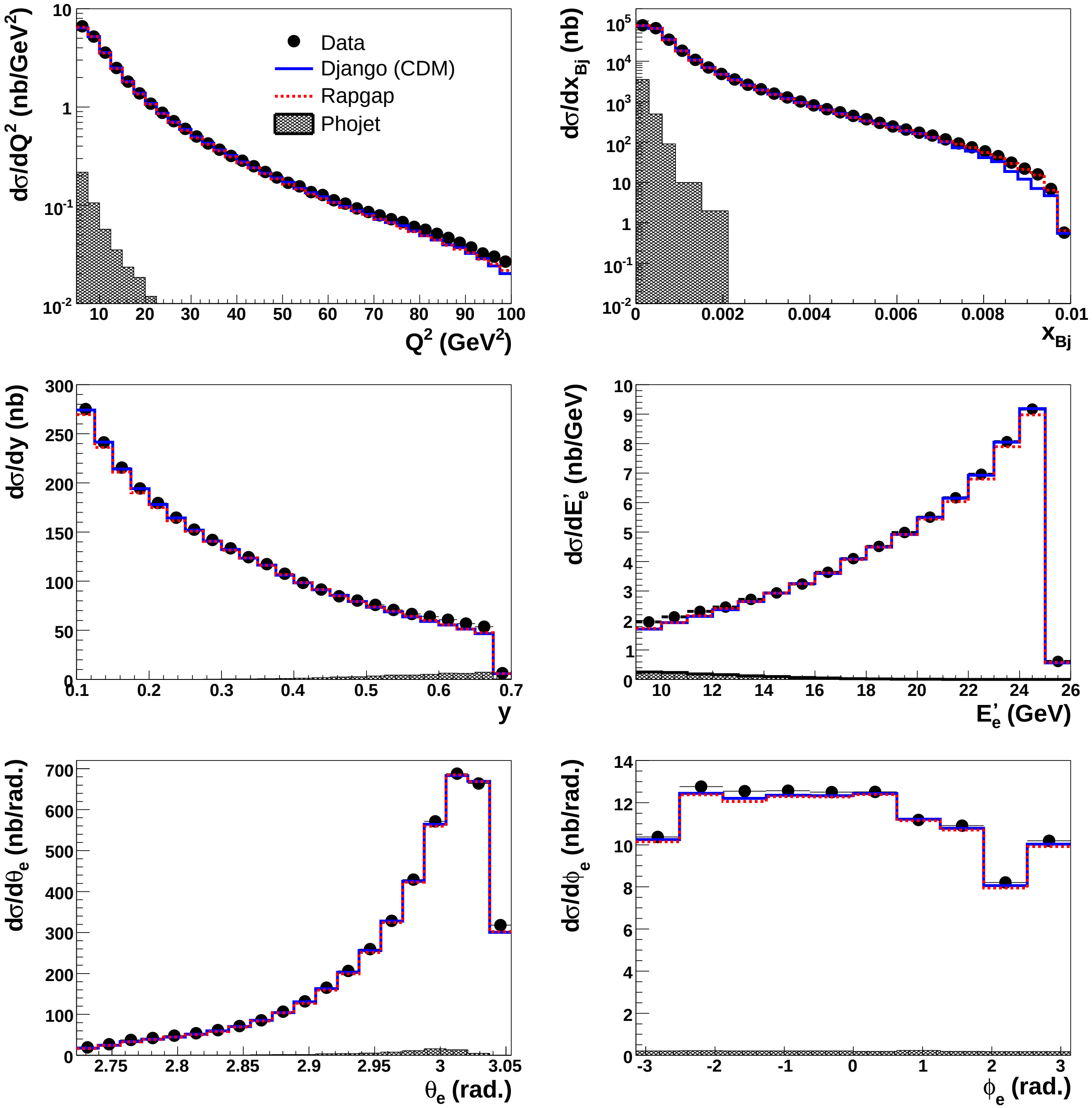
- Azimuthal correlations $\frac{d^2\sigma}{dx_{bj}d\Delta\phi^*}$ and $\frac{d^3\sigma}{dx_{bj}dQ^2d\Delta\phi^*}$ presented
  - $\Rightarrow$ NLO 2-jet and 3-jet calculations not able to fully describe data
  - $\Rightarrow$ Higher order contributions important
  - $\Rightarrow$ Rapgap DIR, Rapgap DIR+RES and Lepto(CDM) fail to describe data
  - $\Rightarrow$ Cascade with J2003set2 gives correct shape, while A0 predics too much decorrelation
  - $\Rightarrow$ Sensitivity to uPDF
- uPDF fitted to $\frac{d^3\sigma}{dx_{bj}Q^2d\Delta\phi^*}$
  - $\Rightarrow$ Data prefer steeply rising gluon at low x and decreasing gluon as $k_T \rightarrow 0$

- Draft in preparation. Distributed to HaQ group within a few days.
- T0?

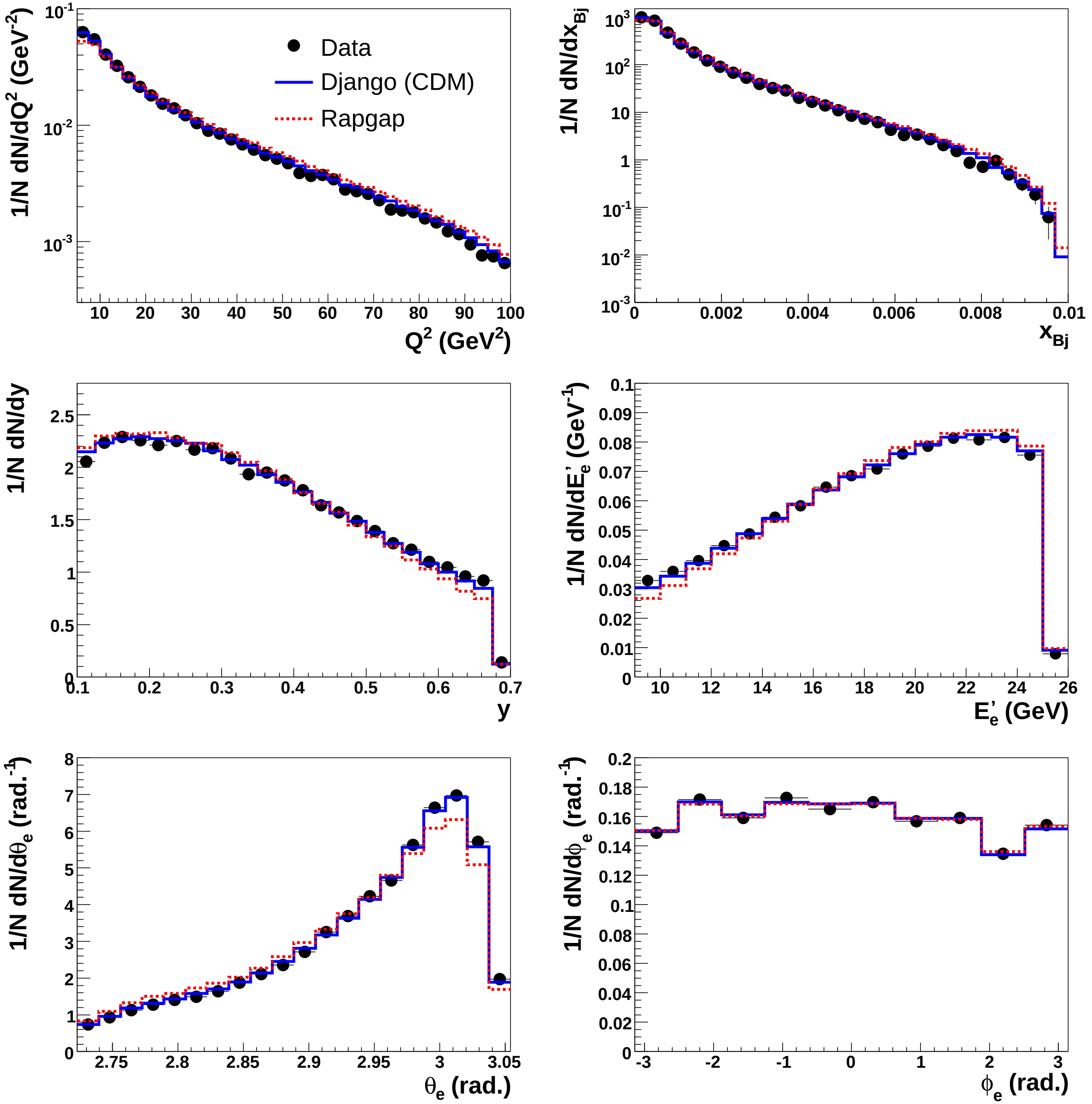
BACKUP

PLOTS

Control Plots DIS Sample



Control Plots Dijet Sample



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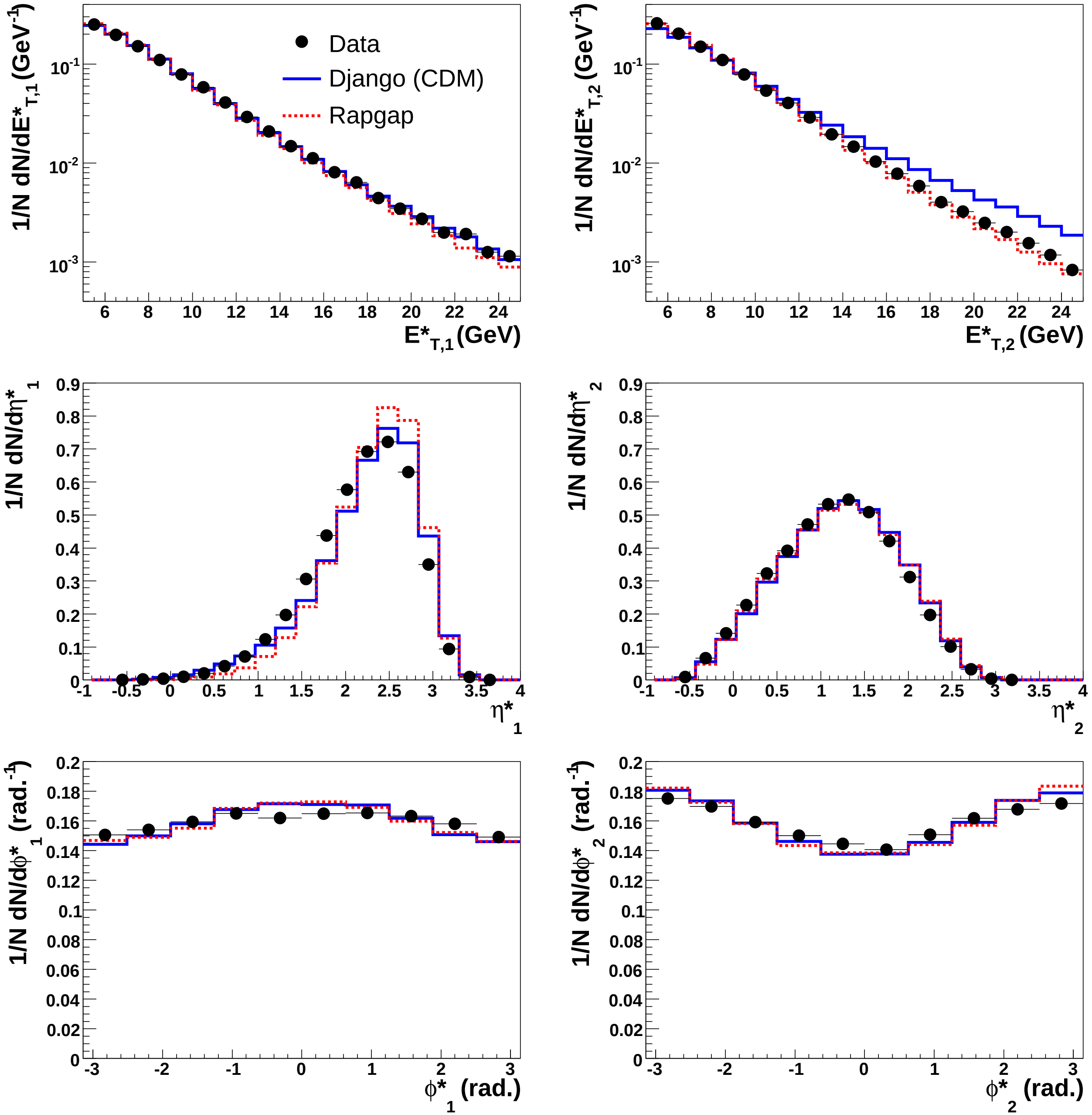
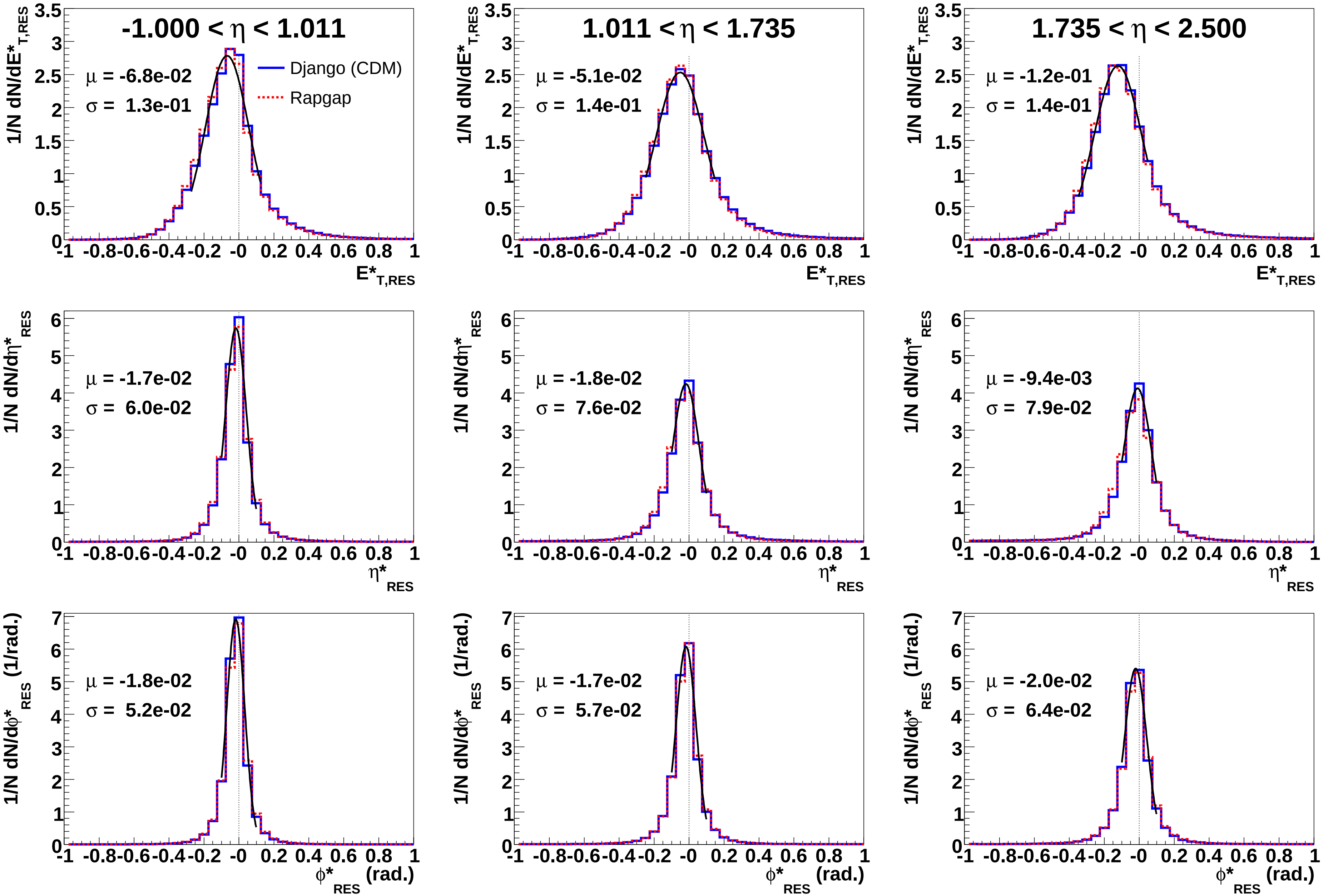
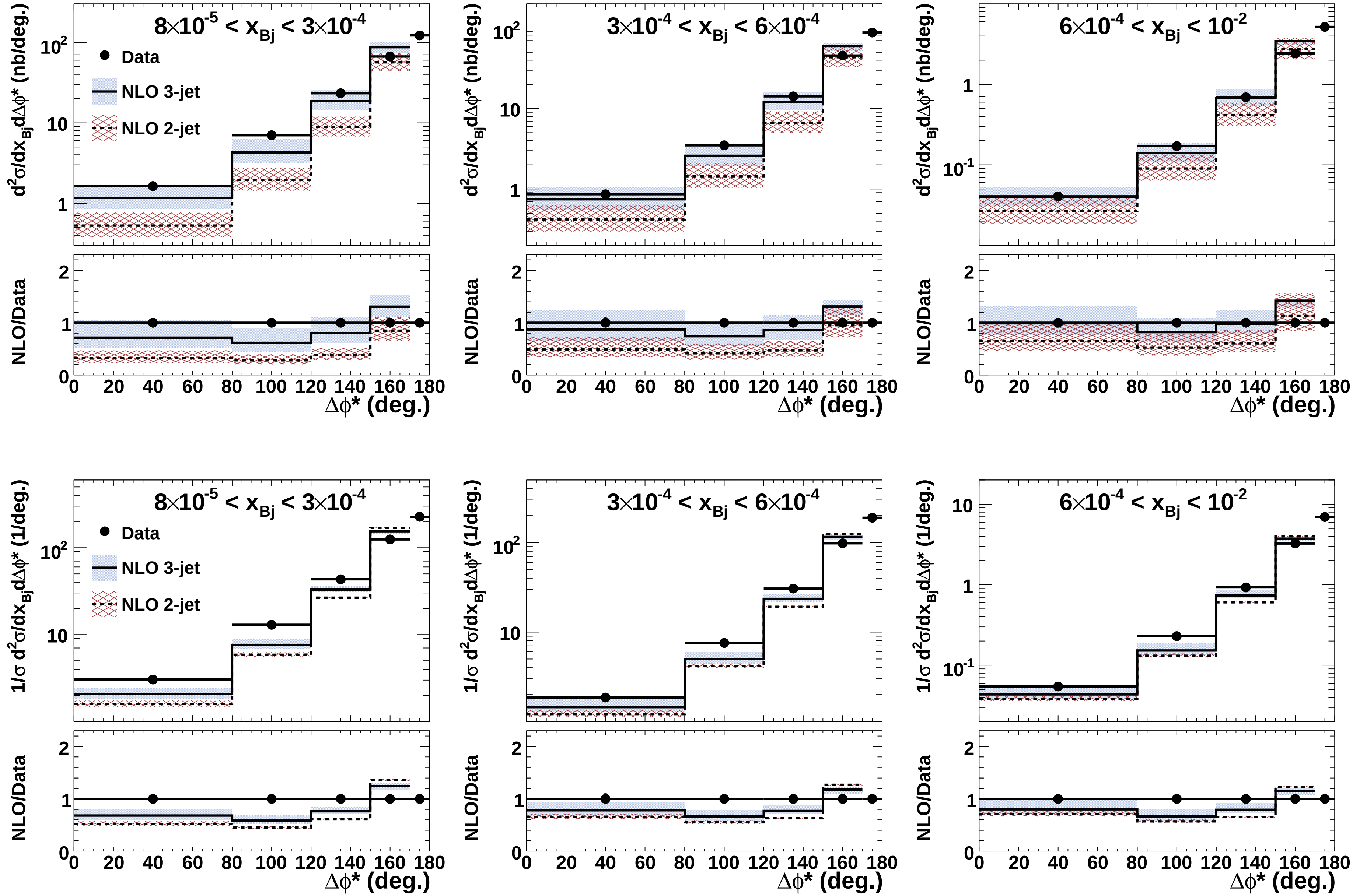


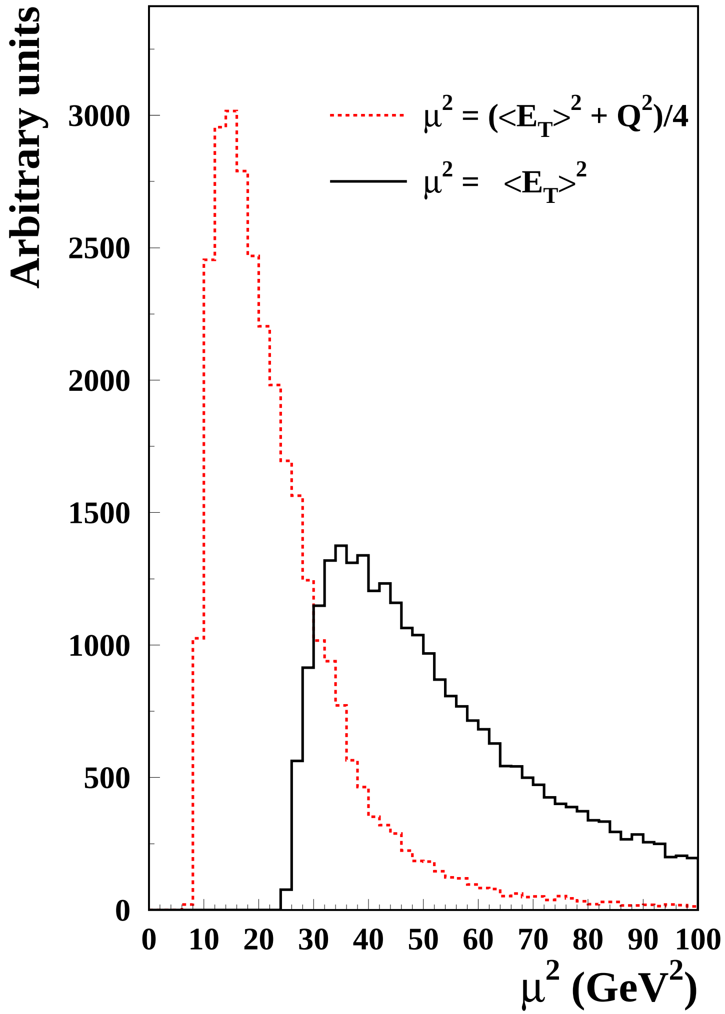
Jet Resolutions



$$\frac{d^2\sigma}{dx_{Bj}d\Delta\phi^*}$$

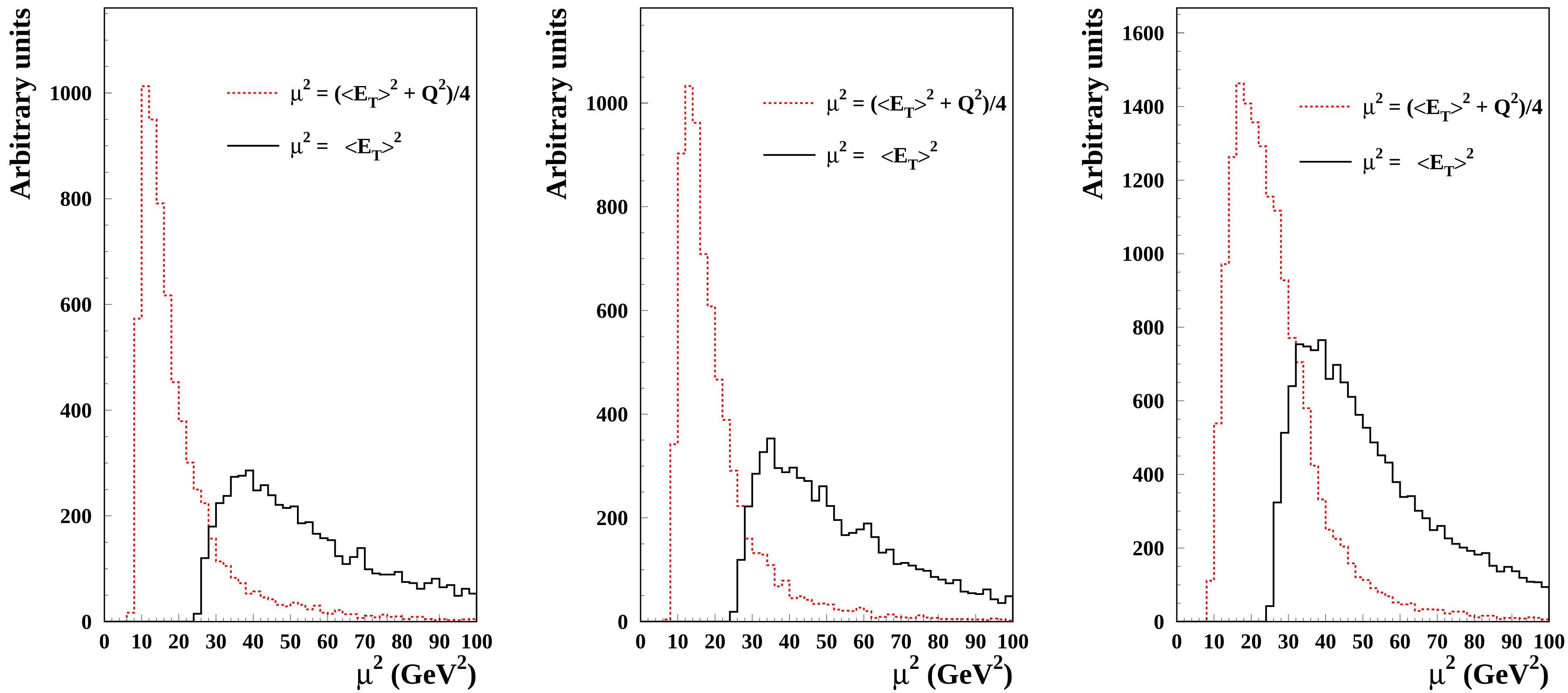


$\frac{d^2\sigma}{dx_{Bj}d\Delta\phi^*}$: Scale comparison



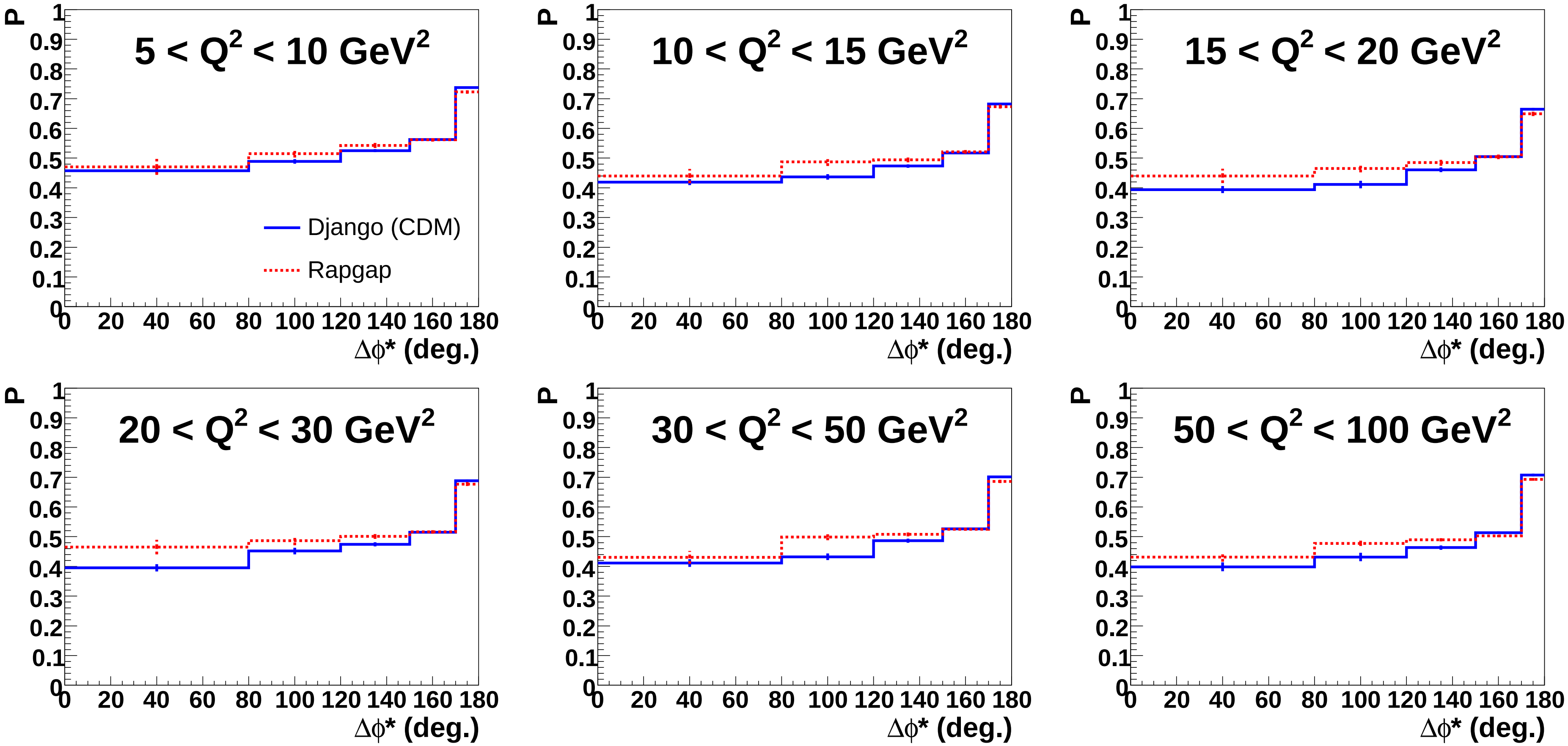
$$\frac{d^2\sigma}{dx_{Bj}\,d\Delta\phi^*}$$

x_{Bj} bins 1, 2, 3:



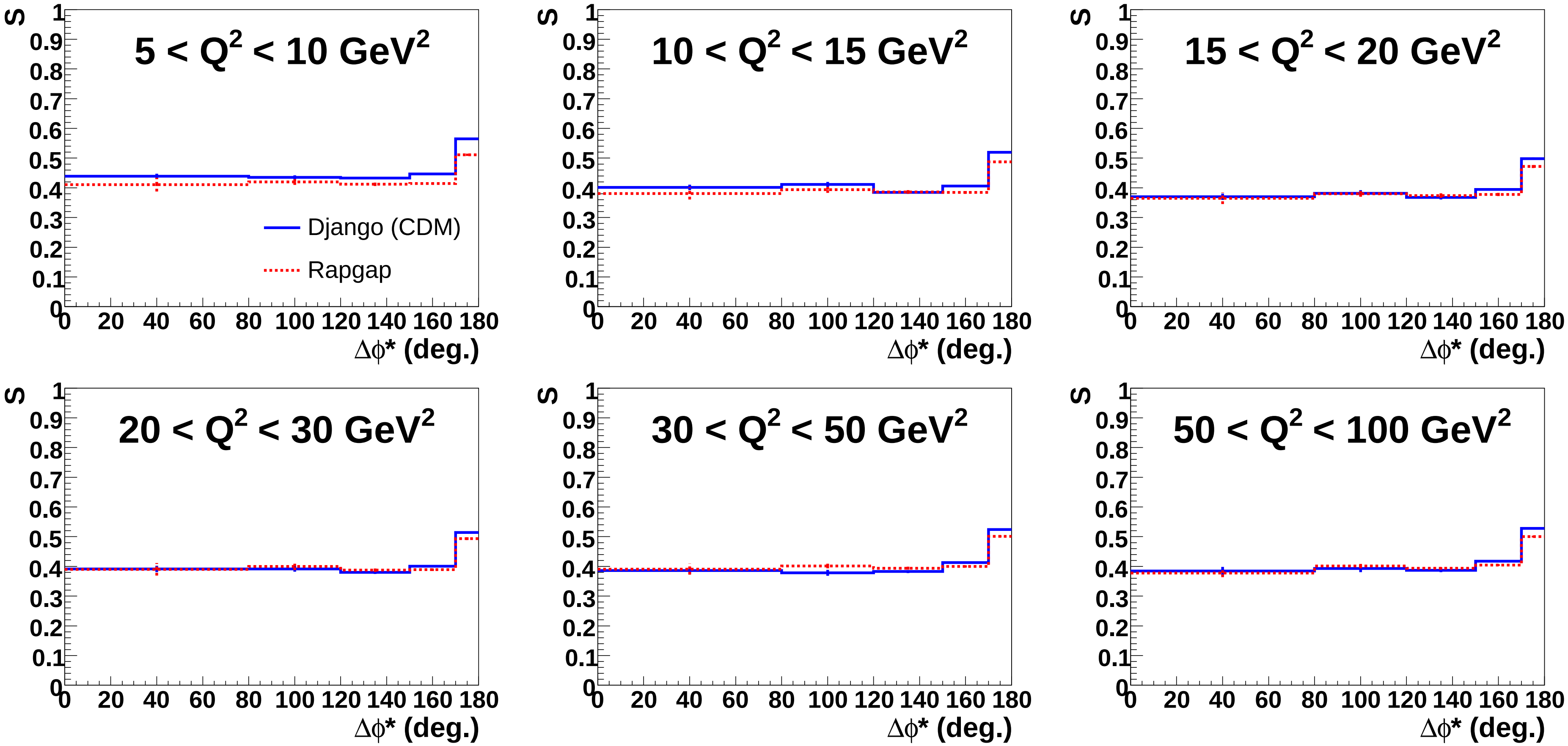
$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$: Purity

$$P = \frac{N_{DET\&\&HAD}}{N_{DET}}$$



$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$: Stability

$$S = \frac{N_{DET\&\&HAD}}{N_{HAD}}$$



Systematic Uncertainties

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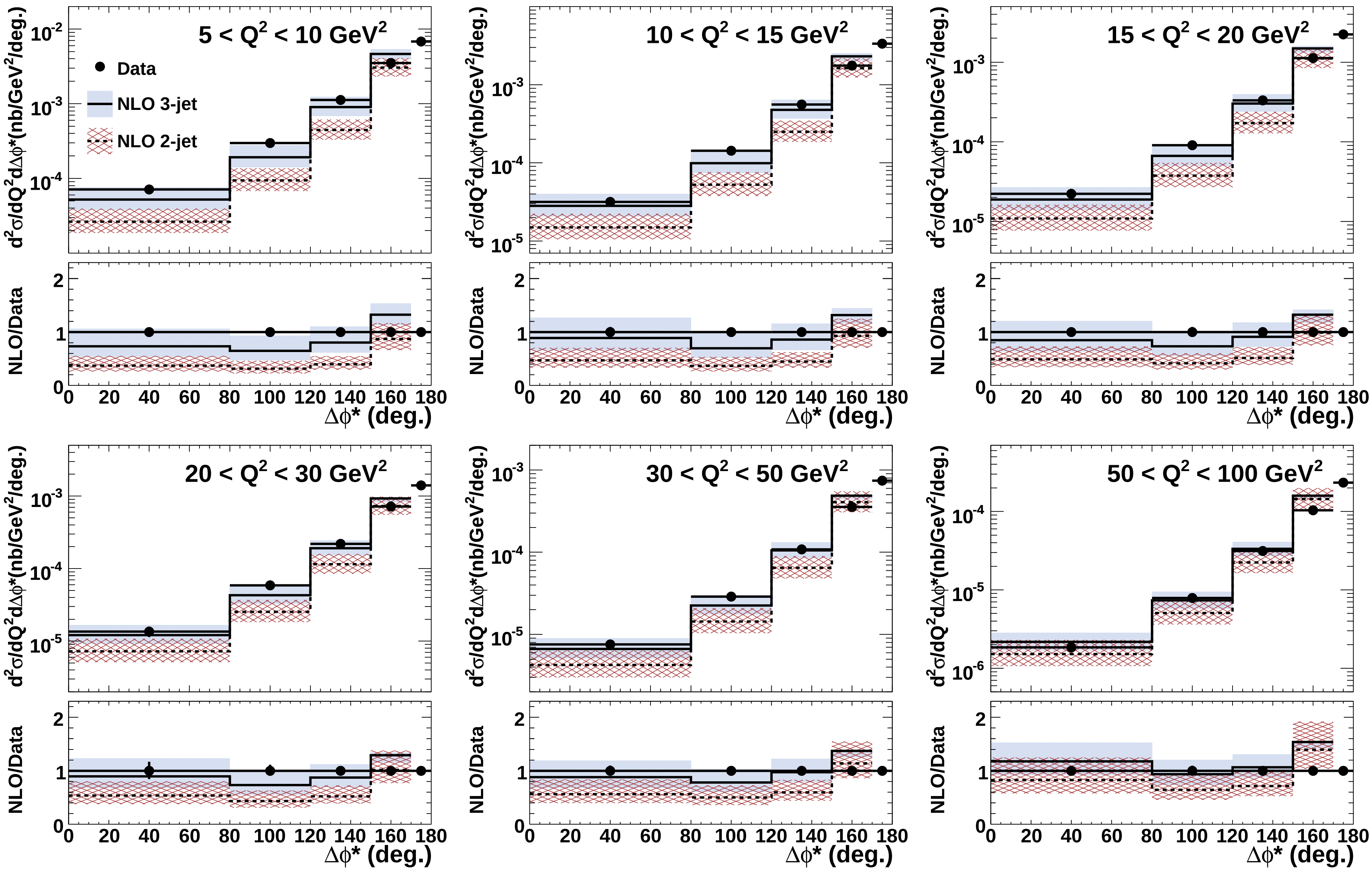
Model Dependence: $\frac{|C_{Rapgap} - C_{Django}|}{2}$

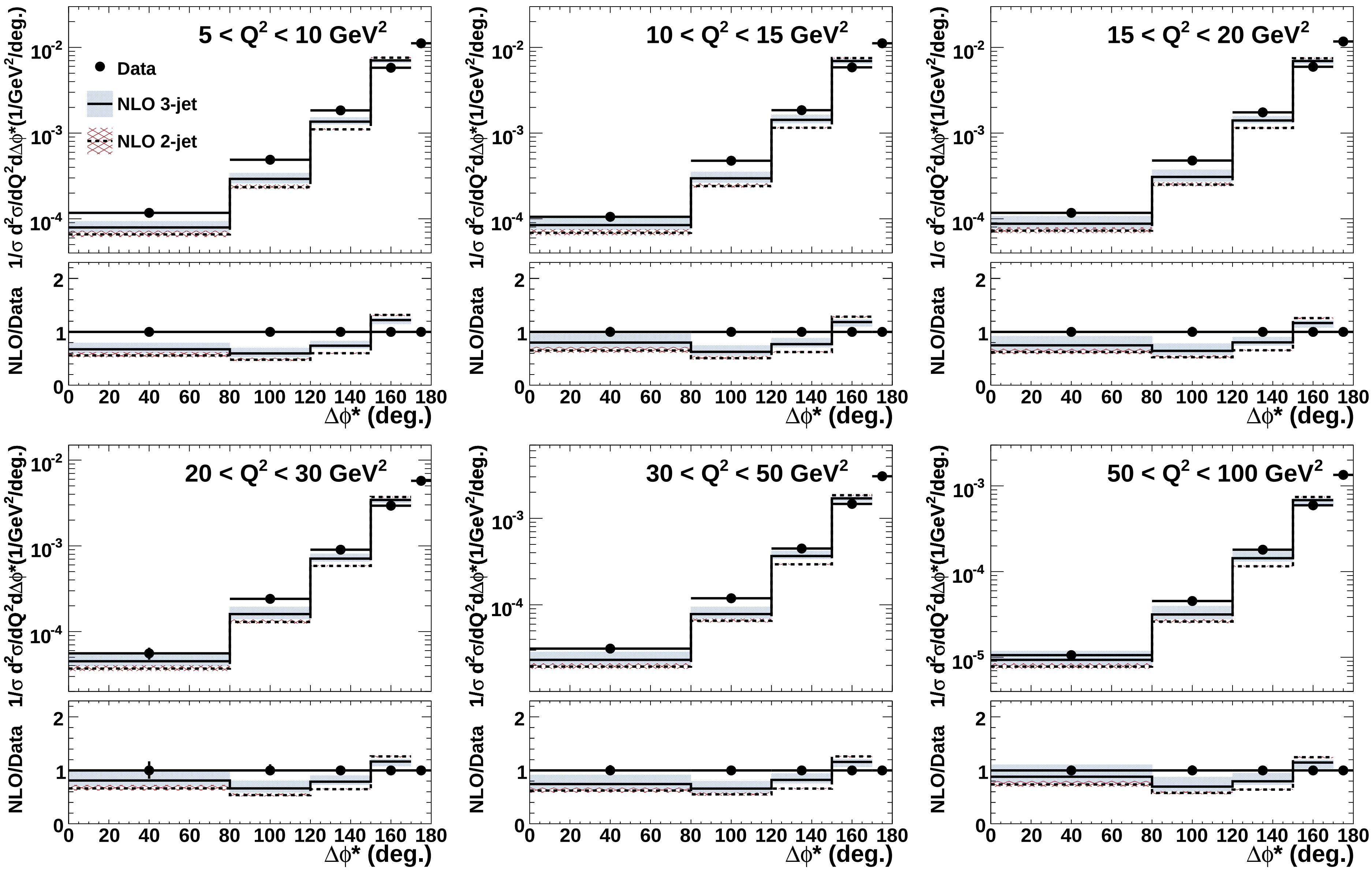
Unfolding Bias: Unfold Rapgap using Django and compare to true Rapgap distribution ($\Rightarrow \Delta\sigma_{Rapgap}$) and vice versa

Source	Uncertainty	Typical $\Delta\sigma$ $\frac{d^2\sigma}{dx_{bj}\,d\Delta\phi^*}$	$\frac{d^2\sigma}{dQ^2\,d\Delta\phi^*}$	$\frac{d^3\sigma}{dx_{bj}\,dQ^2\,d\Delta\phi^*}$
SPACAL electromagnetic energy scale	$\pm$ 1%	0.5-2%	0.5-2%	1-3%
Polar angle of scattered electron	$\pm$ 1 mrad	$<$1%	$<$1%	0.5-2%
LAr hadronic energy scale	$\pm$ 4%	2-7%	2-7%	2-10%
Track momentum	$\pm$ 3%	$\ll$ 1%	$\ll$ 1%	$\ll$ 1%
Model uncertainty	$\frac{|C_{Rapgap} - C_{Django}|}{2}$	0.5-2%	0.5-2%	1-4%
Unfolding bias	$\frac{\Delta\sigma_{Rapgap} + \Delta\sigma_{Django}}{2}$	1-4%	1-4%	1-7%
Photoproduction background		$\ll$ 1%	$\ll$ 1%	$\ll$ 1%
Luminosity		1.5%	1.5%	1.5%

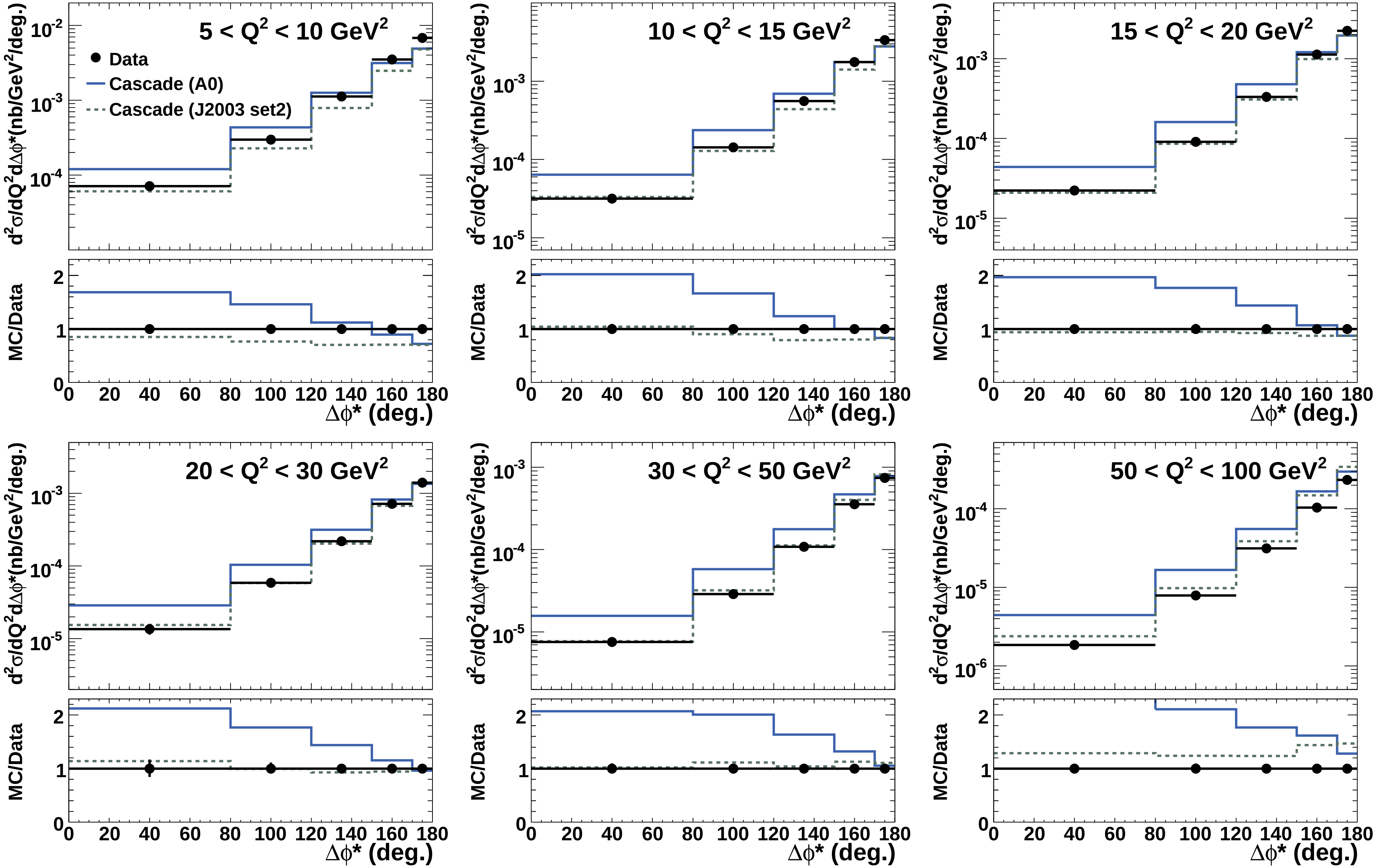
$$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$$



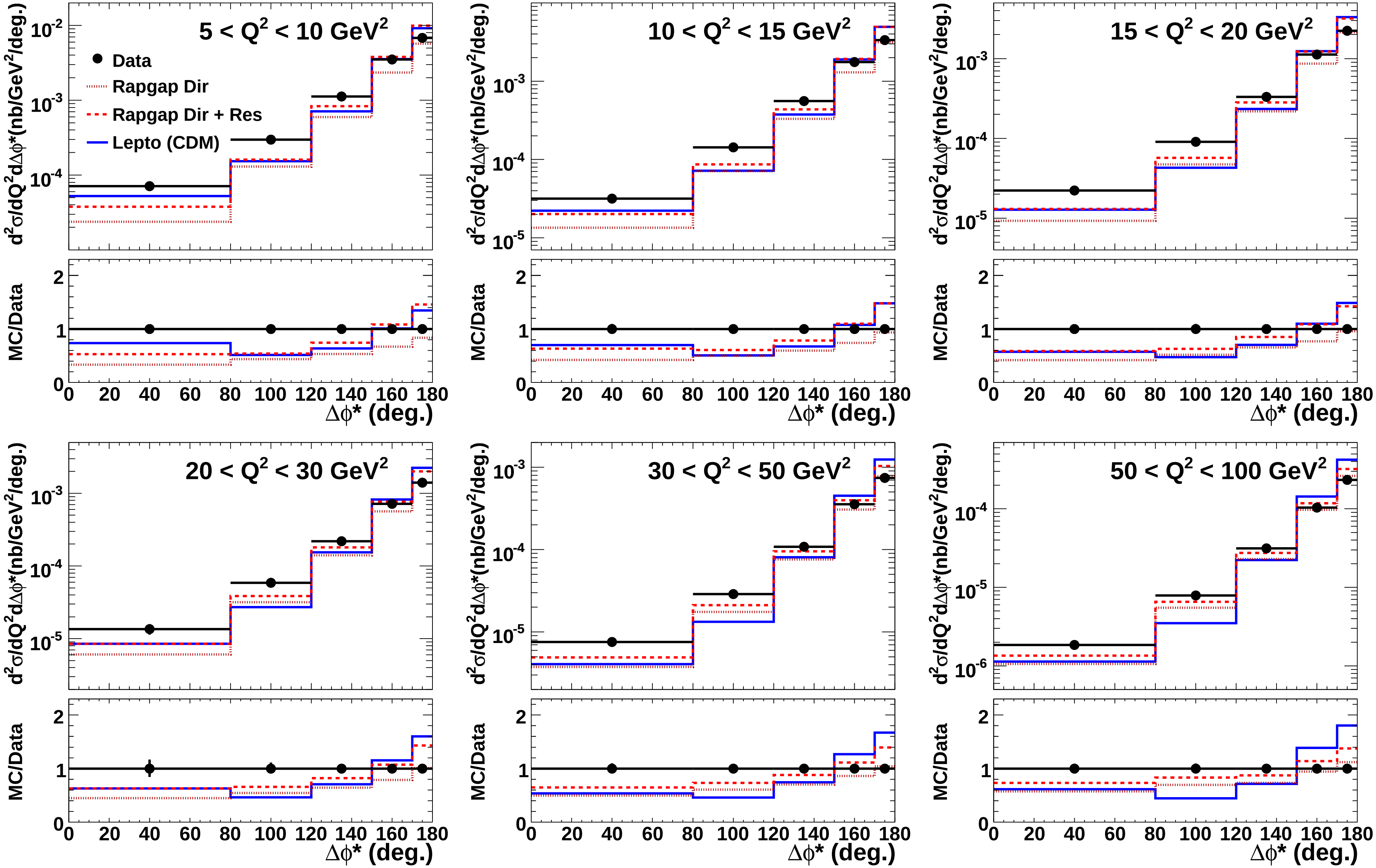
$$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$$



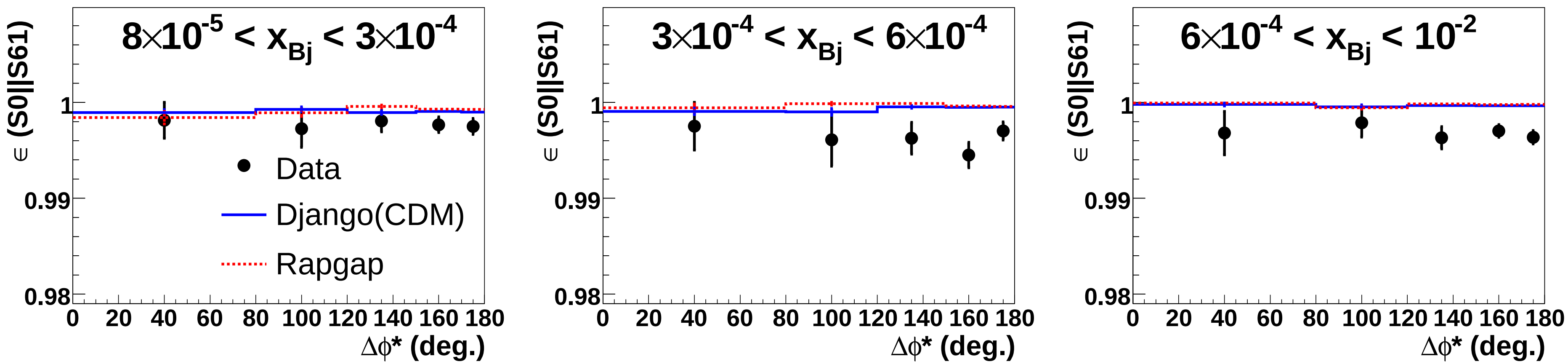
$$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$$



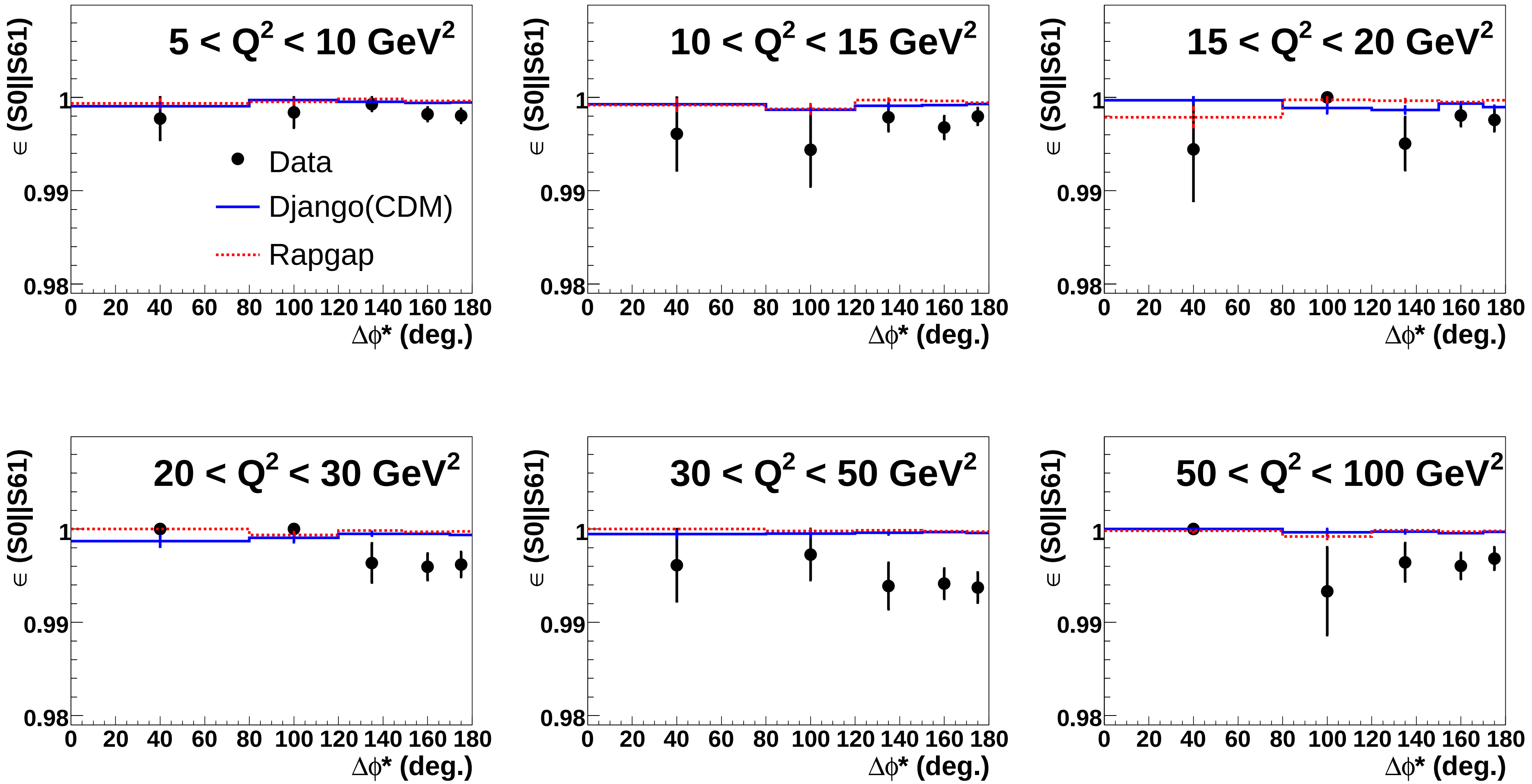
$$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$$



$\frac{d^2\sigma}{dx_{Bj}d\Delta\phi^*}$: Trigger Efficiency



$\frac{d^2\sigma}{dQ^2 d\Delta\phi^*}$: Trigger Efficiency



Comparison to Published Data

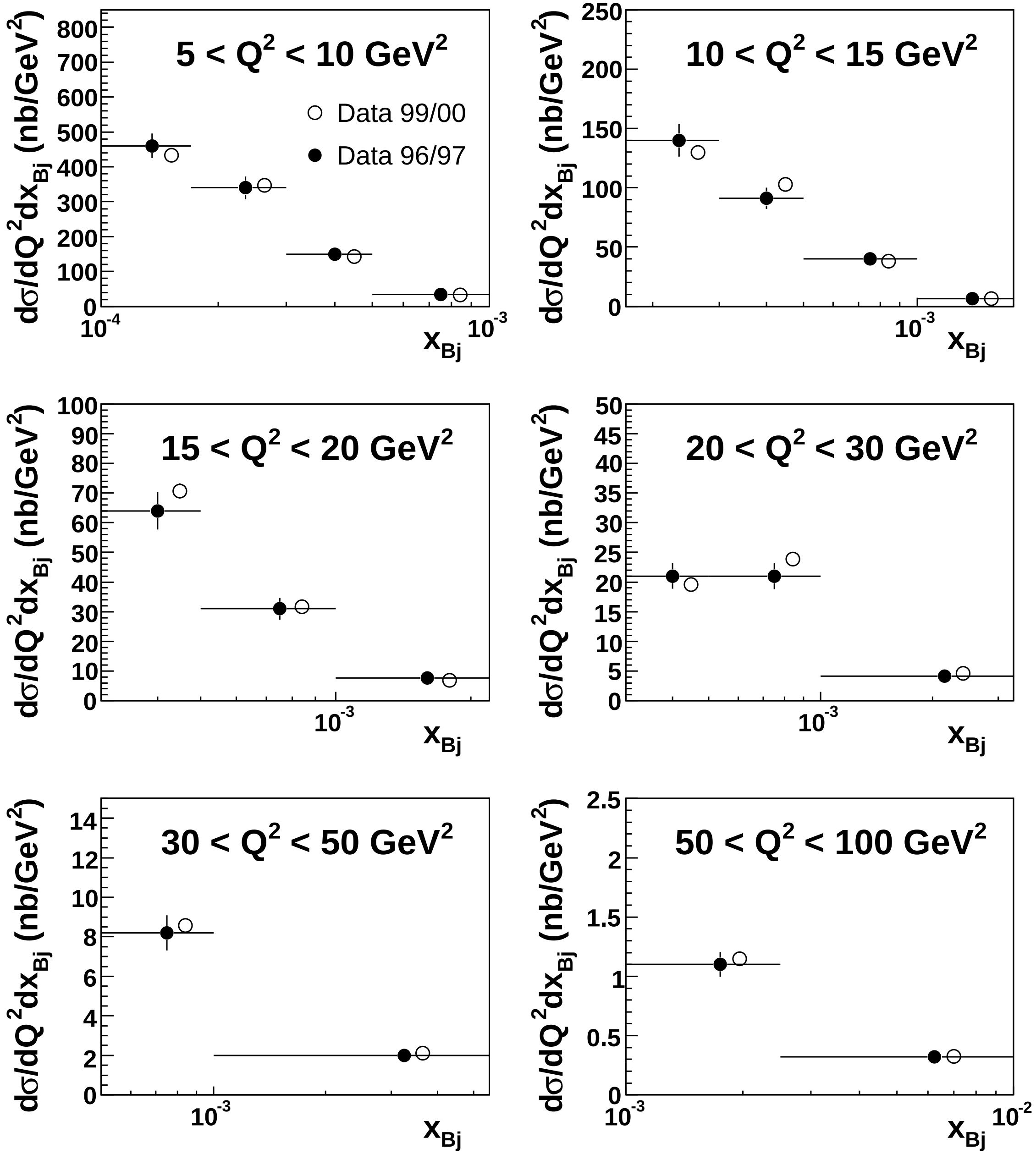
Inclusive Dijet Production at Low Bjorken-x in Deep Inelastic Scattering
Eur.Phys.J.C33:477-493,2004 (hep-ex/0310019)

- 96/97 H1 Data
- Dijets are two hardest jets in HCM
- Asymmetric cuts: $E^*_{T1} > 7$ GeV, $E^*_{T2} > 5$ GeV
- Cross Section: $\frac{d^2\sigma}{dQ^2 dx}$
- Azimuthal Jet Separation: $S = \frac{\int_0^{120^\circ} N_{dijet}(\Delta\phi^*, x, Q^2) d\Delta\phi^*}{\int_0^{180^\circ} N_{dijet}(\Delta\phi^*, x, Q^2) d\Delta\phi^*}$

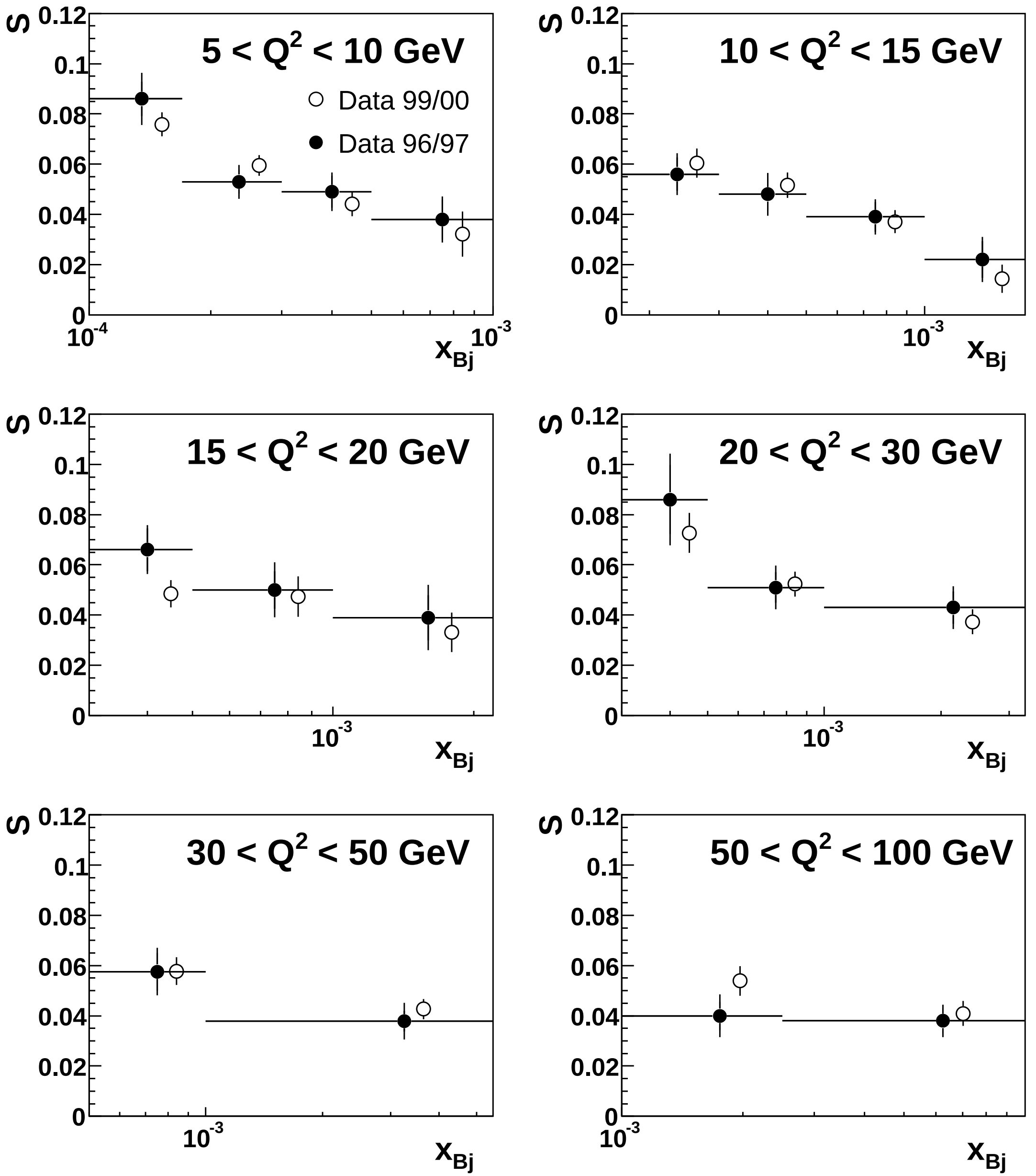
Correction for different proton energies made using Lepto

Statistical errors only for 99/00 data

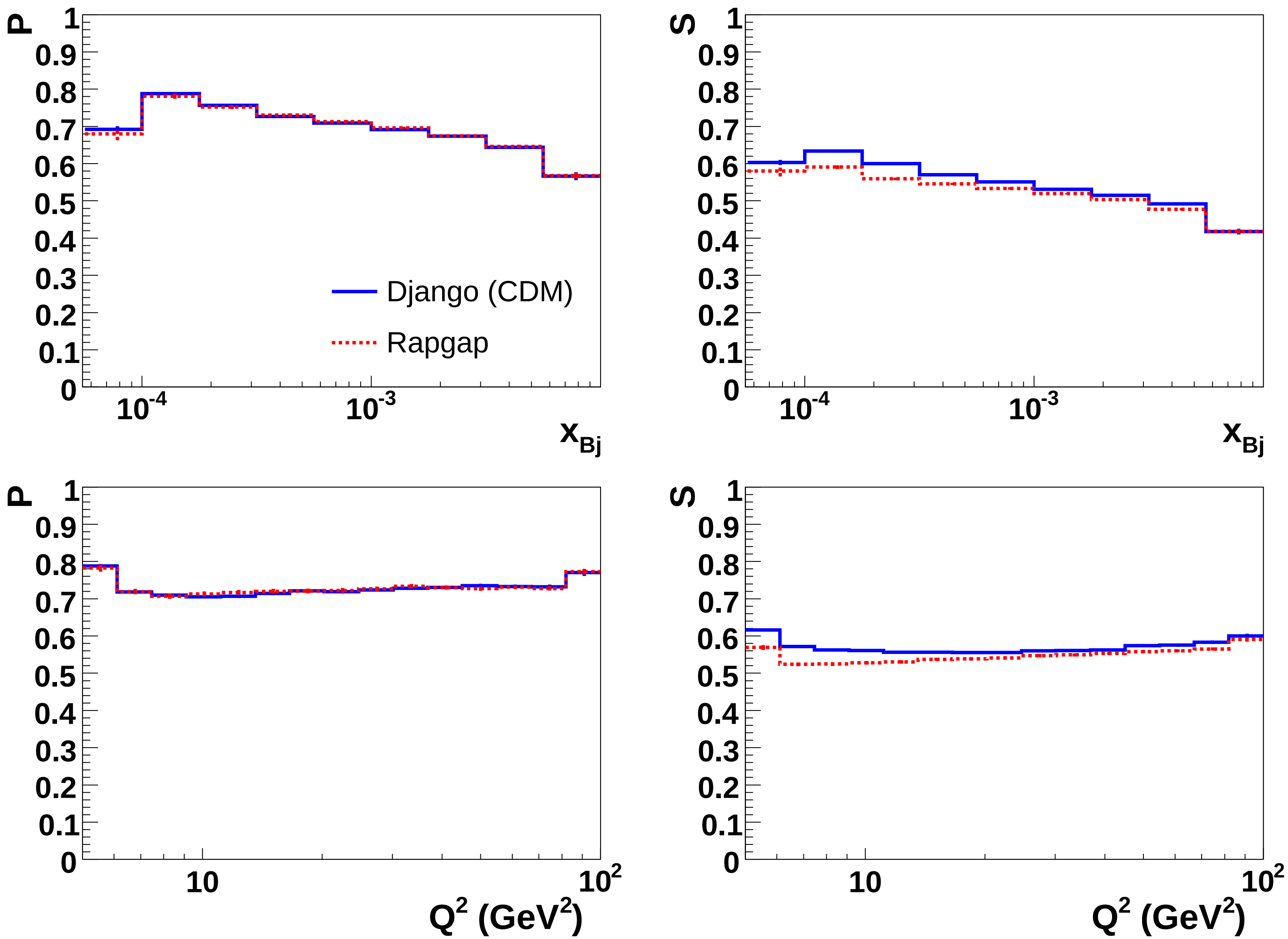
Dijet Cross Sections: 96/97 comp. to 99/00



Azimuthal Jet Separation: 96/97 comp. to 99/00

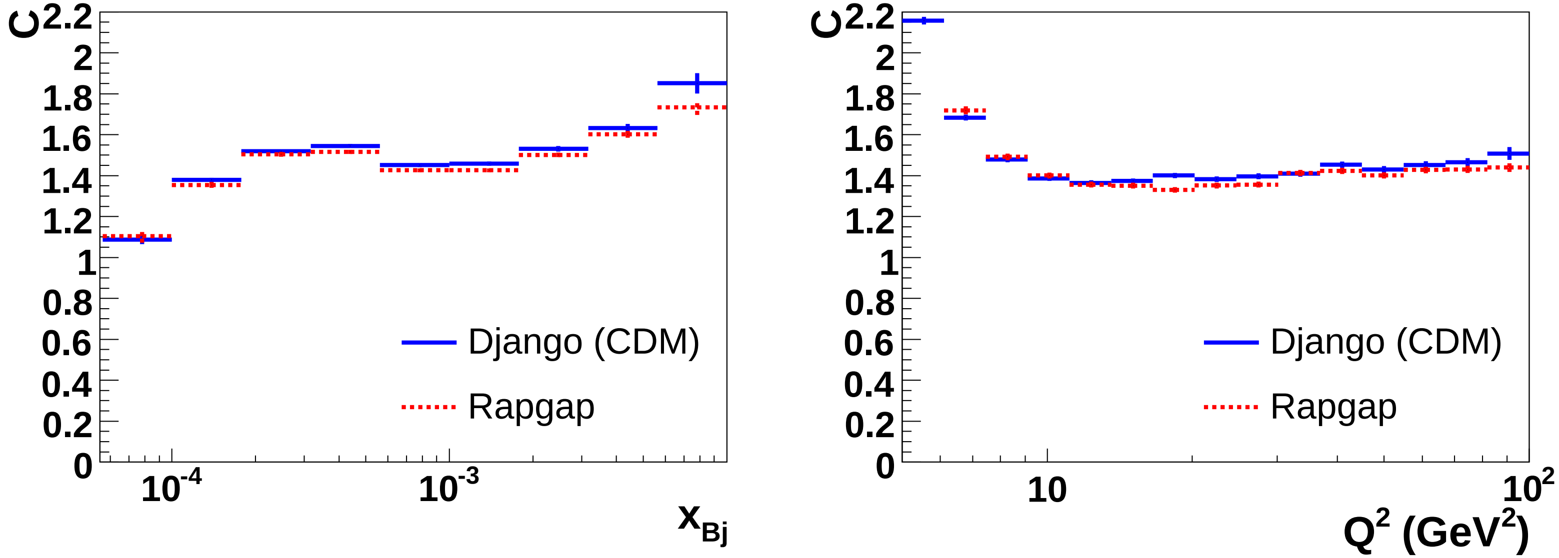


$\frac{d\sigma}{dx_{bj}}, \frac{d\sigma}{dQ^2}$: Purity & Stability



$\frac{d\sigma}{dx_{bj}}, \frac{d\sigma}{dQ^2}$: Correction

$$C = \frac{N_{HAD,NONRAD}}{N_{DET}}$$



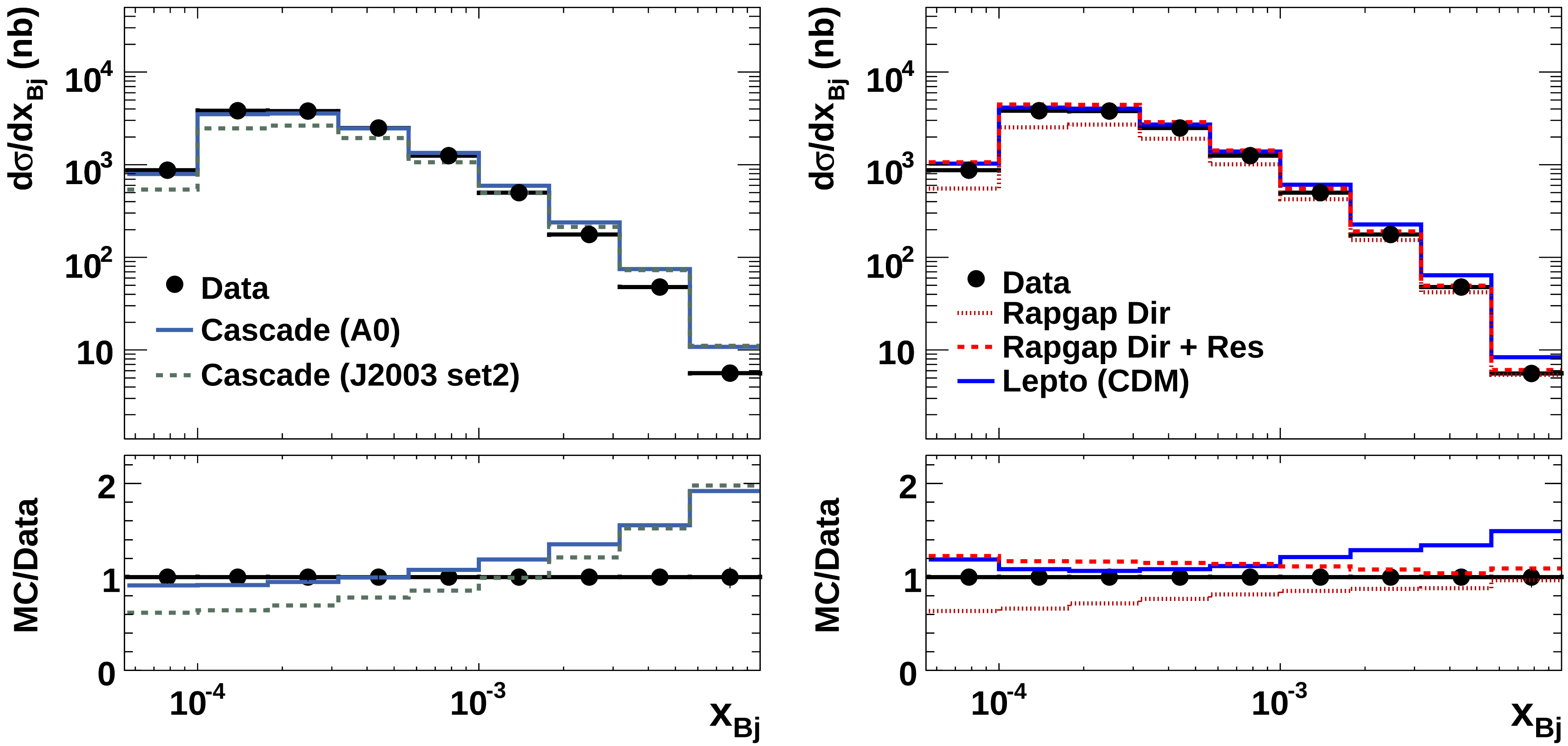
Systematic Uncertainties

Estimated using Rapgap, except:

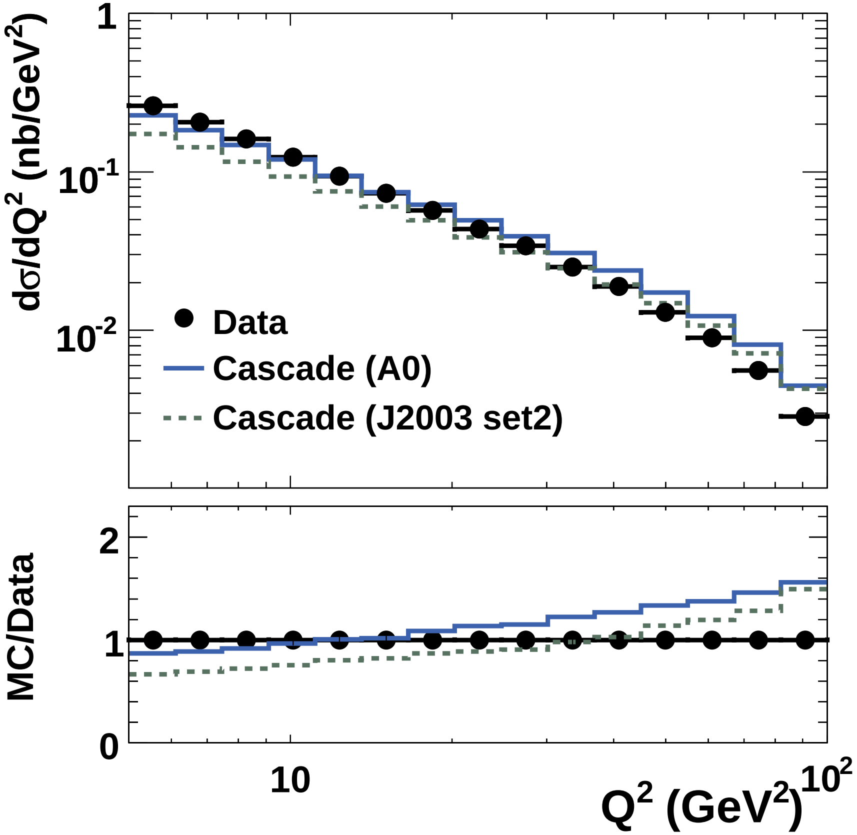
Model Dependence: $\frac{|C_{Rapgap} - C_{Django}|}{2}$

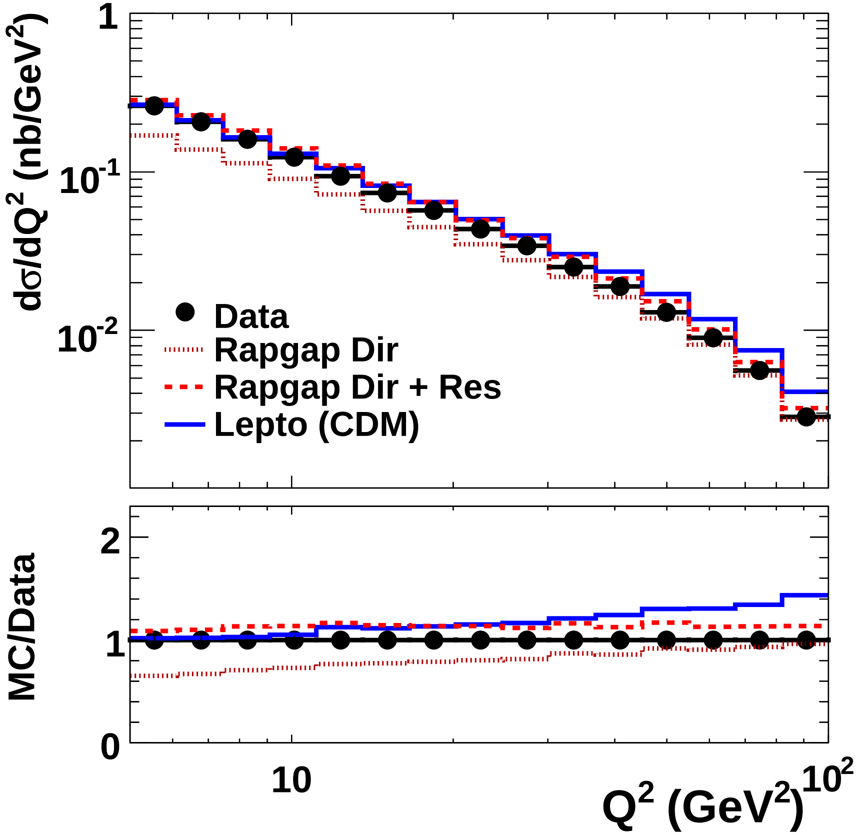
Source	Uncertainty	Typical $\Delta\sigma$ $\frac{d\sigma}{dx_{bj}}$	Typical $\Delta\sigma$ $\frac{d\sigma}{dQ^2}$
SPACAL electromagnetic energy scale	$\pm$ 1%	0.5-2%	0.5-2%
Polar angle of scattered electron	$\pm$ 1 mrad	$<$1%	$<$1%
LAr hadronic energy scale	$\pm$ 4%	2-5%	2-5%
Track momentum	$\pm$ 3%	$\ll$ 1%	$\ll$ 1%
Model uncertainty	$\frac{|C_{Rapgap} - C_{Django}|}{2}$	1-3%	1-5%
Photoproduction background		$\ll$ 1%	$\ll$ 1%
Luminosity		1.5%	1.5%

$$\frac{d\sigma}{dx_{bj}}$$

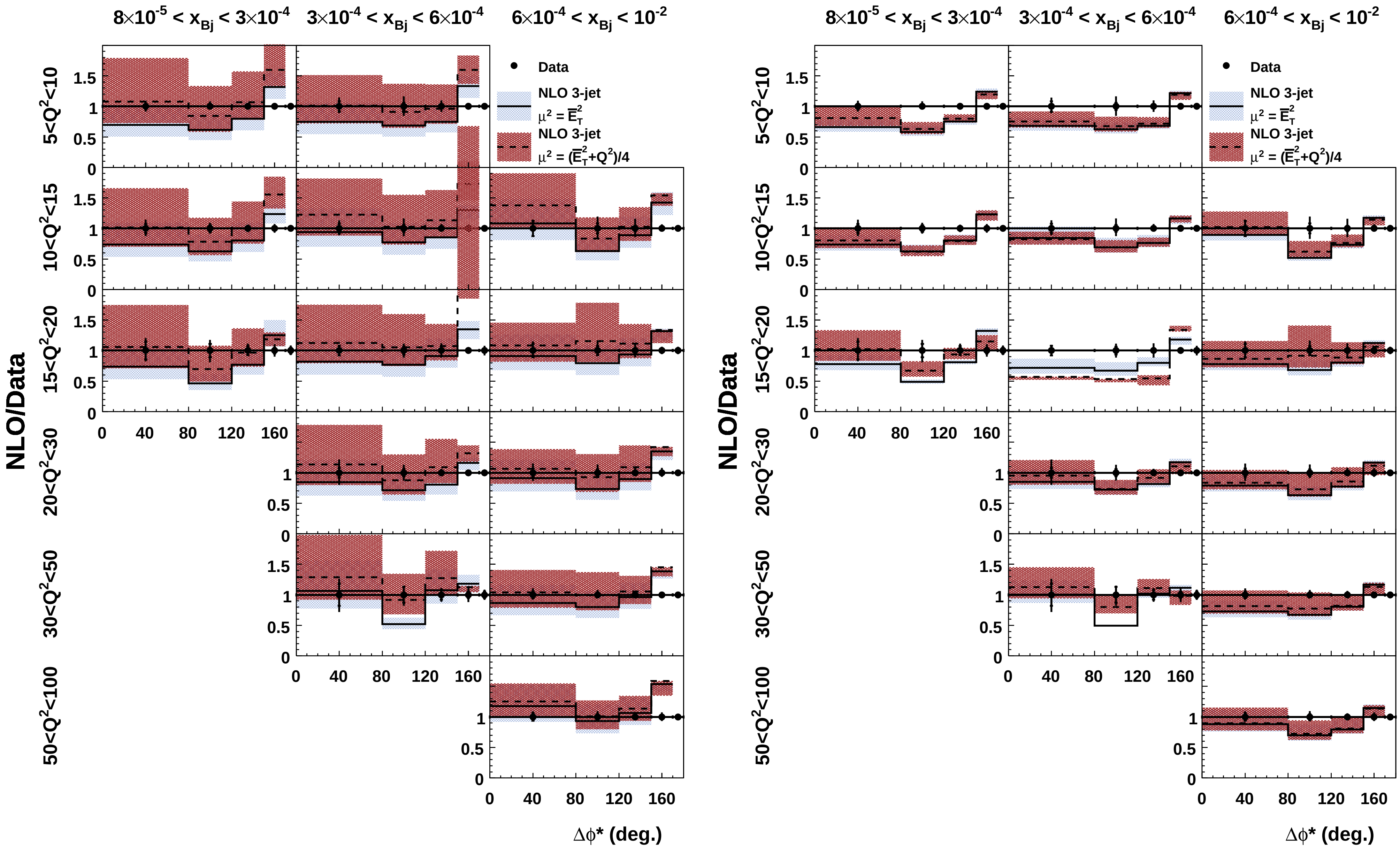


$$\frac{d\sigma}{dQ^2}$$

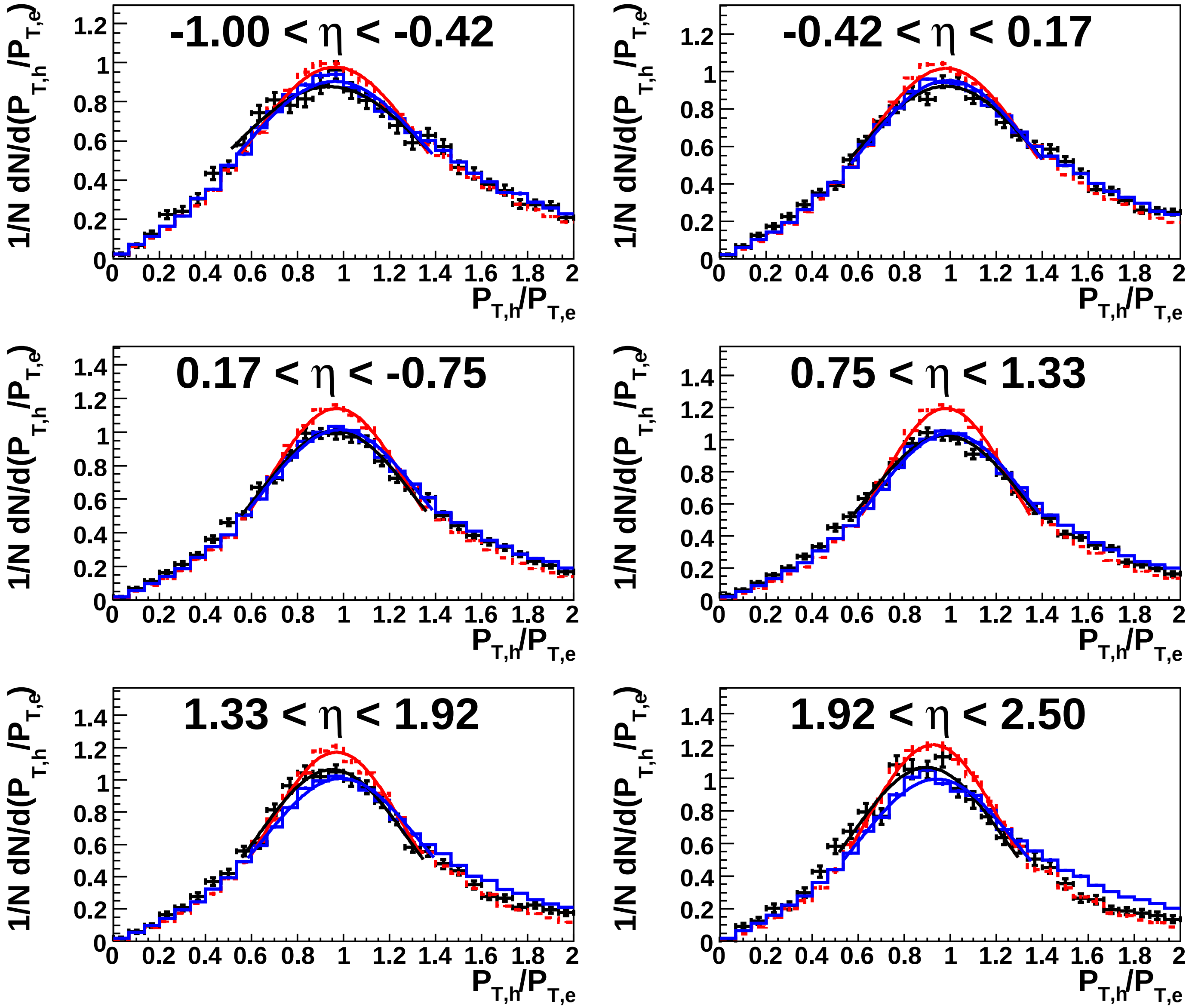




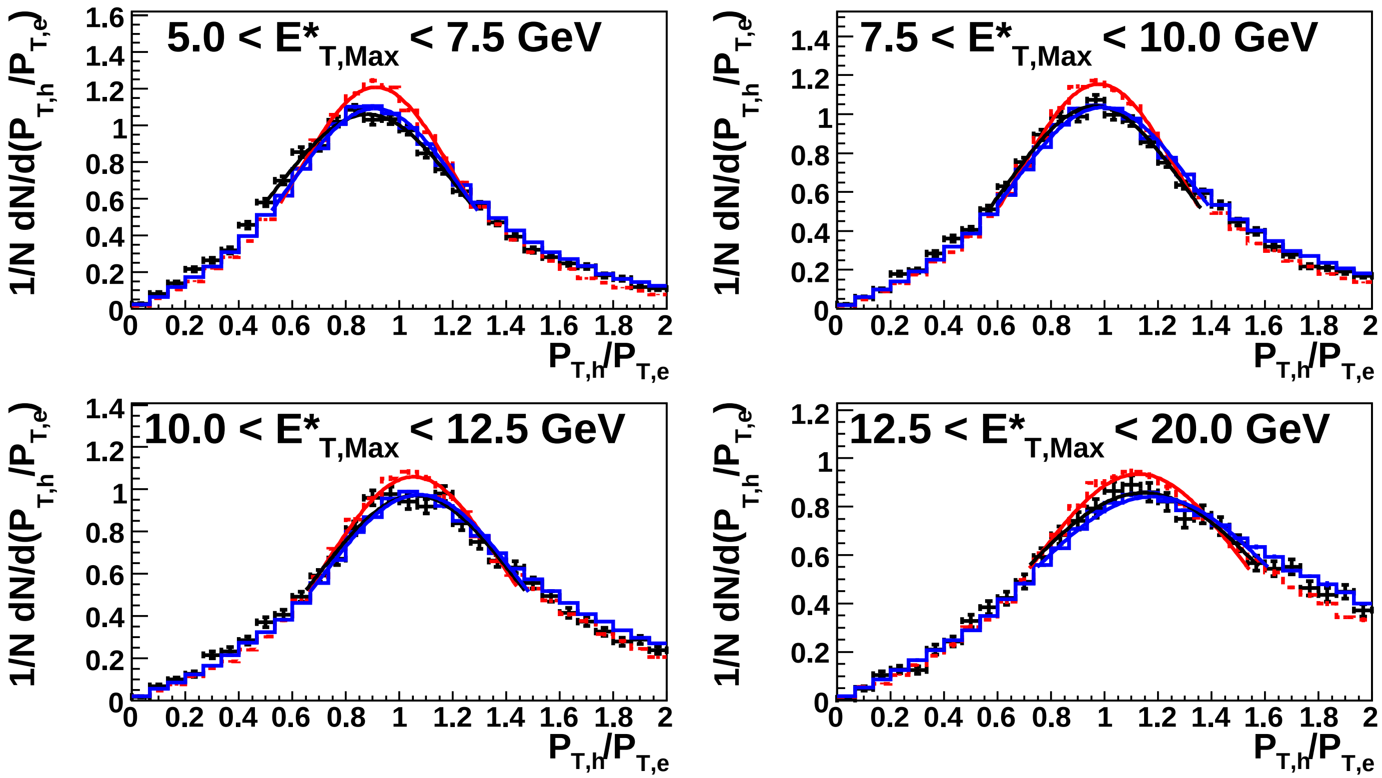
$d^3\sigma/dx_{Bj}dQ^2d\Delta\phi^*$: Scale Comparison



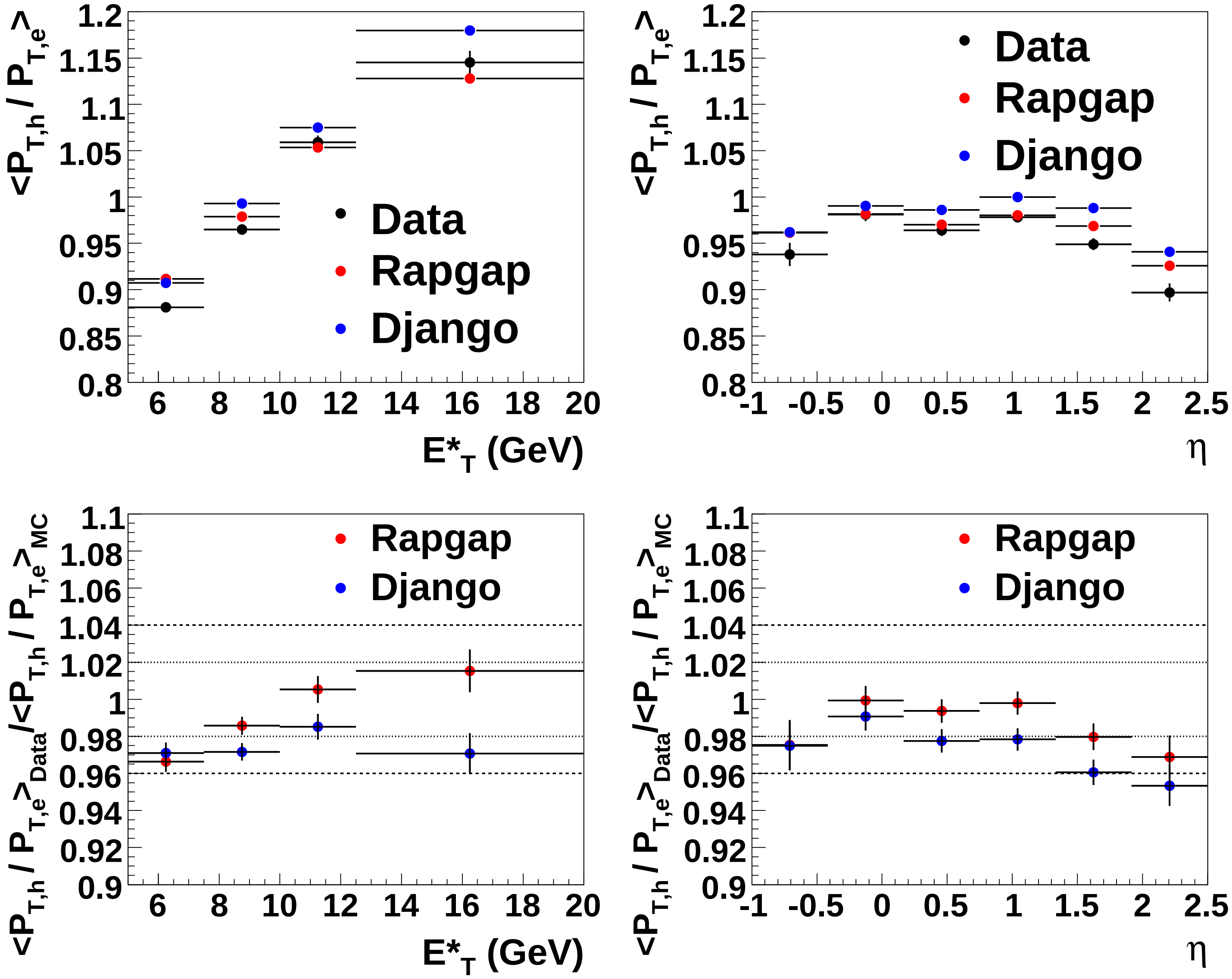
Systematic Uncertainties: LAr Energy Scale



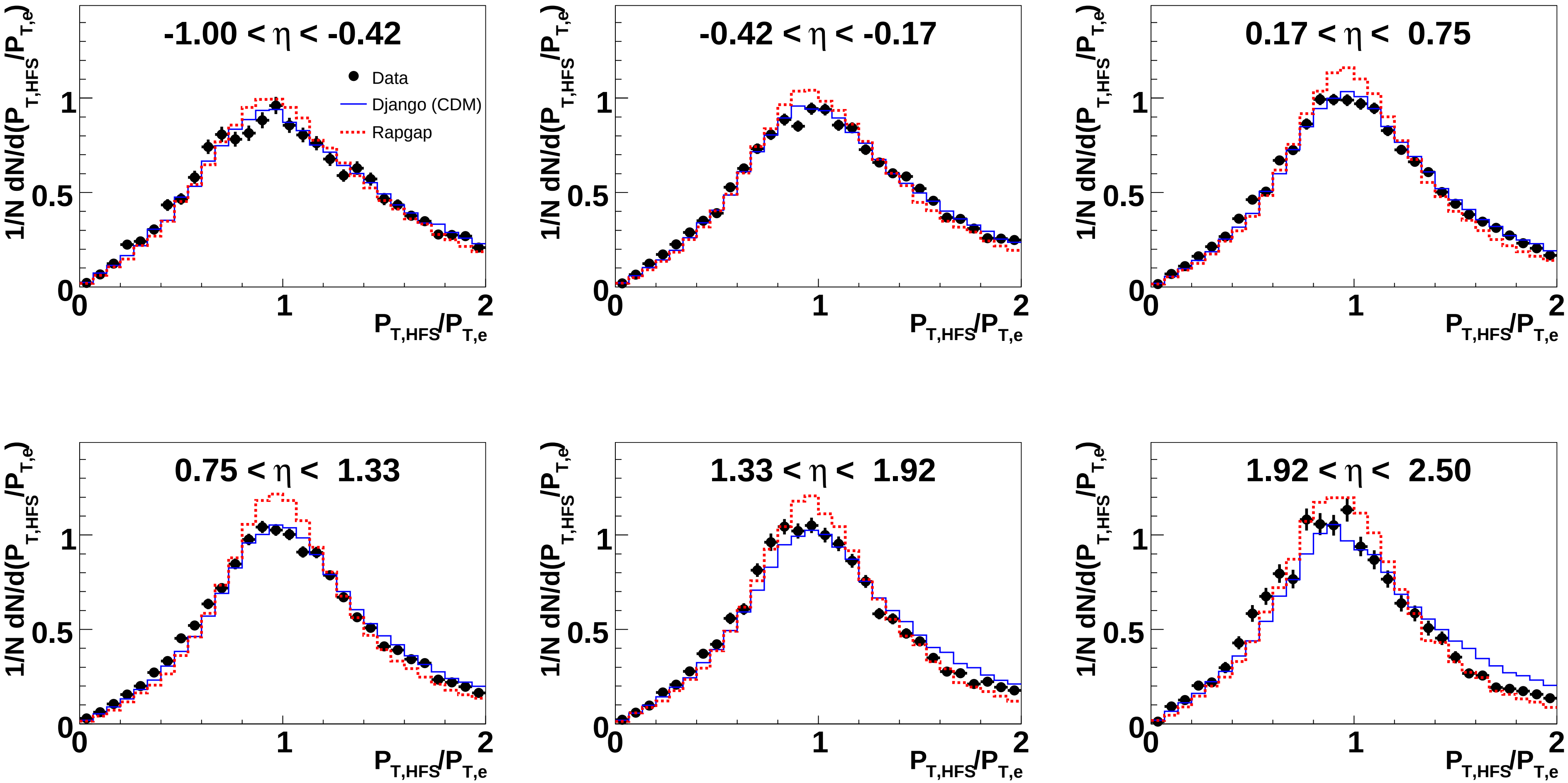
Systematic Uncertainties: LAr Energy Scale



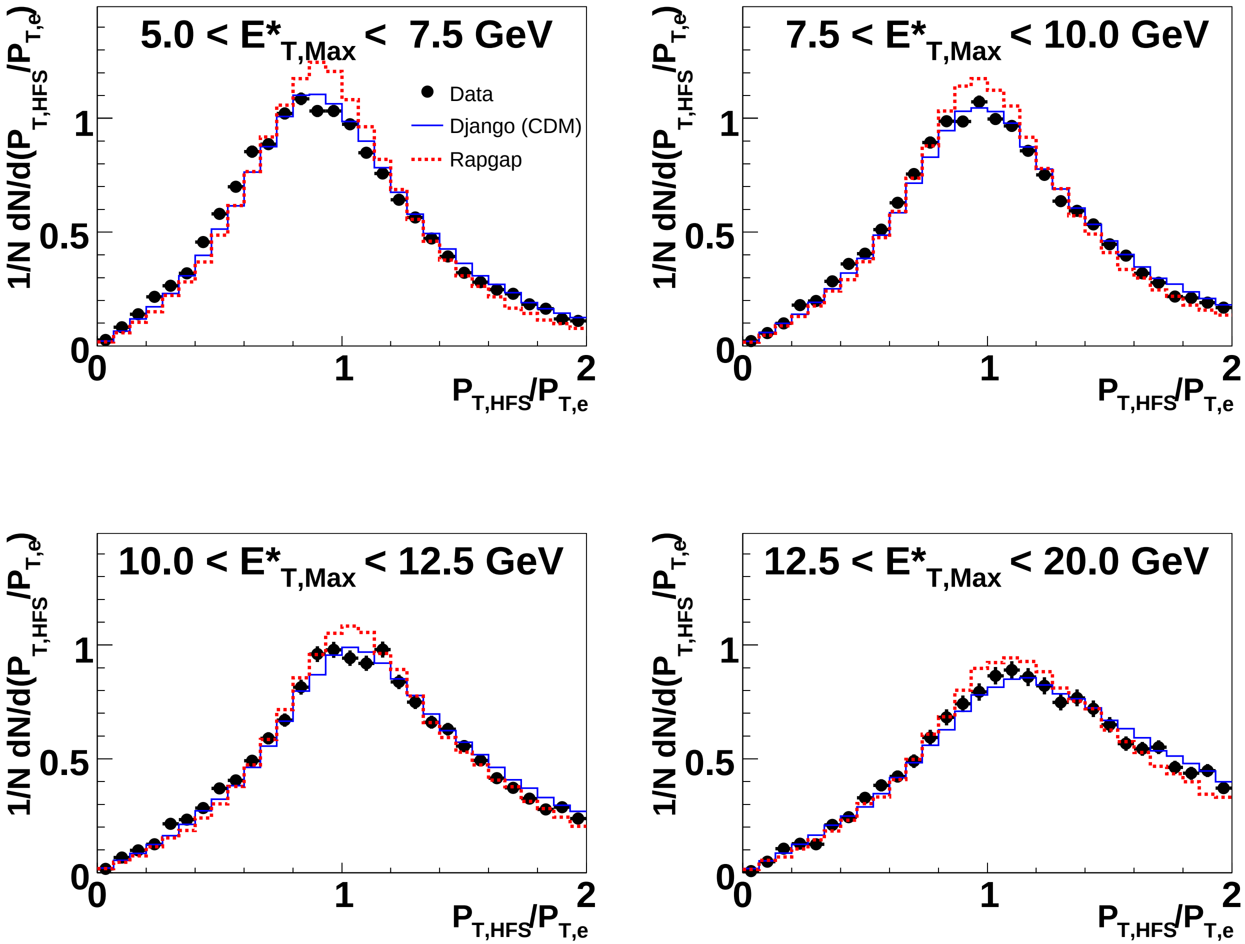
Systematic Uncertainties: LAr Energy Scale



Systematic Uncertainties: LAr Energy Scale



Systematic Uncertainties: LAr Energy Scale



Systematic Uncertainties: LAr Energy Scale