NLO results for $V+$ jets at the LHC

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What we calculate at NLO

$$pp \to W^{\pm} + 2 \text{ jets} \to \ell^{\pm}\nu + 2 \text{ jets}$$
$$pp \to Z/\gamma^{*} + 2 \text{ jets} \to \ell^{+}\ell^{-} + 2 \text{ jets}$$

including the heavy-flavor subsets
(and +0,1 jets for comparison)

- MC program MCFM
  (helicity amplitude, subtraction method)
  [Campbell & Ellis, PRD(65)113007 (2002)]

- previous results only for Tevatron

- Why do we care?
  Need good theoretical estimates for:
  $\to$ W, Z studies
  $\to$ QCD studies
  $\to$ luminosity cross-checks
  $\to$ $V+$ jets are bkgs for new physics!

We calculate cross sections including decays:

$$W^+ \to \nu e^+ \,, \quad W^- \to \bar{\nu} e^- \,, \quad Z/\gamma^* \to e^- e^+$$

(single-flavor; $m_l = 0$, so e, μ, τ equivalent)

We calculate *observable* cross sections,
i.e. with basic kinematic cuts:

(general ATLAS & CMS detector requirements)

$$\begin{array}{rr} p_T(\ell) > 15 \text{ GeV}, & |\eta_\ell| < 2.4 \\ p_T(j) > 20 \text{ GeV}, & |\eta_j| < 4.5 \\ \triangle R_{\ell j} > 0.4 \,, & \triangle R_{\ell\ell} > 0.2 \end{array}$$

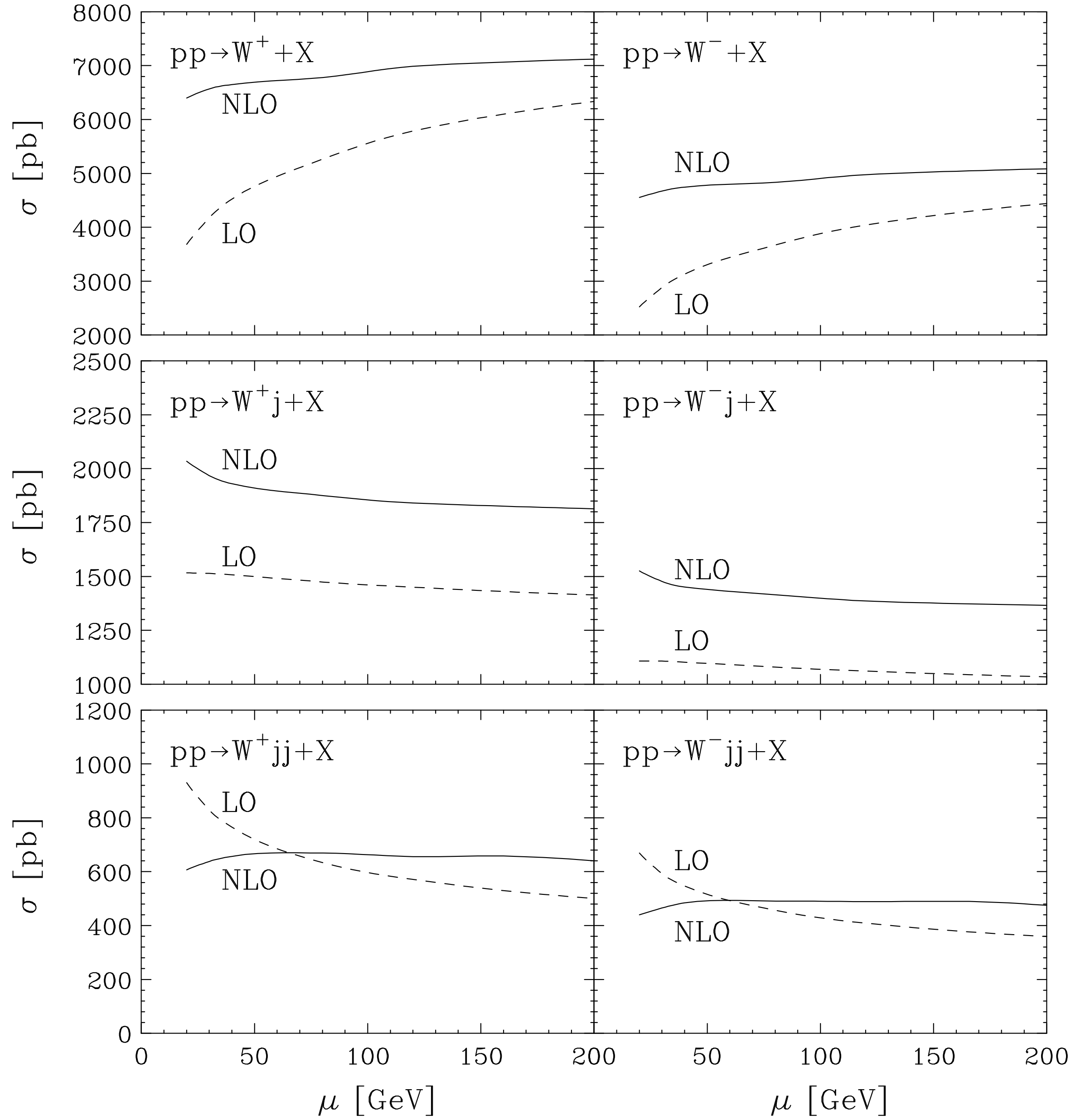
For heavy-flavor case (silicon requirements):

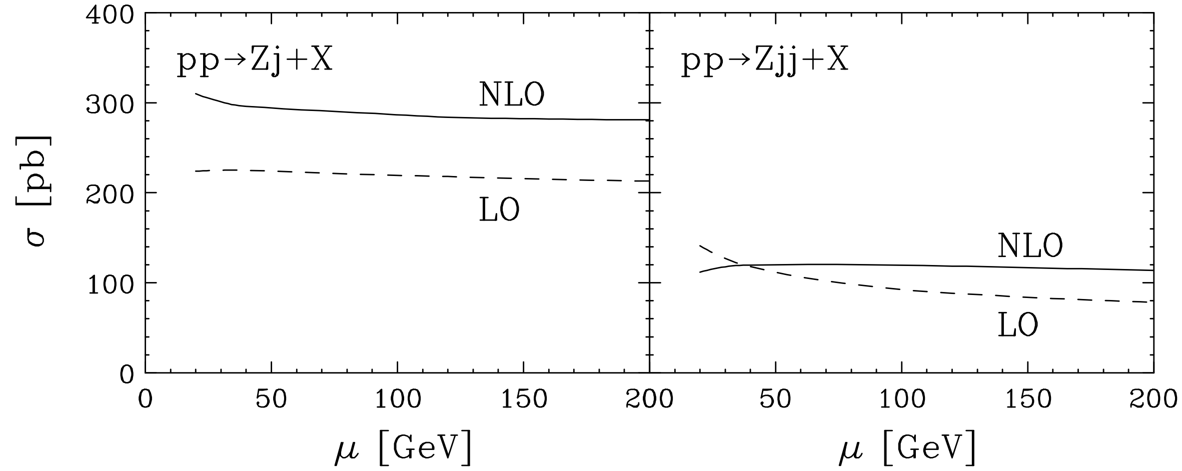
$$|\eta_b| < 2.5$$

We use CTEQ PDFs: 6L (LO), 6M (NLO)

$\alpha_s(M_Z) = 0.118$

Scale dependence of cross sections ($\mu \equiv \mu_f = \mu_r$)

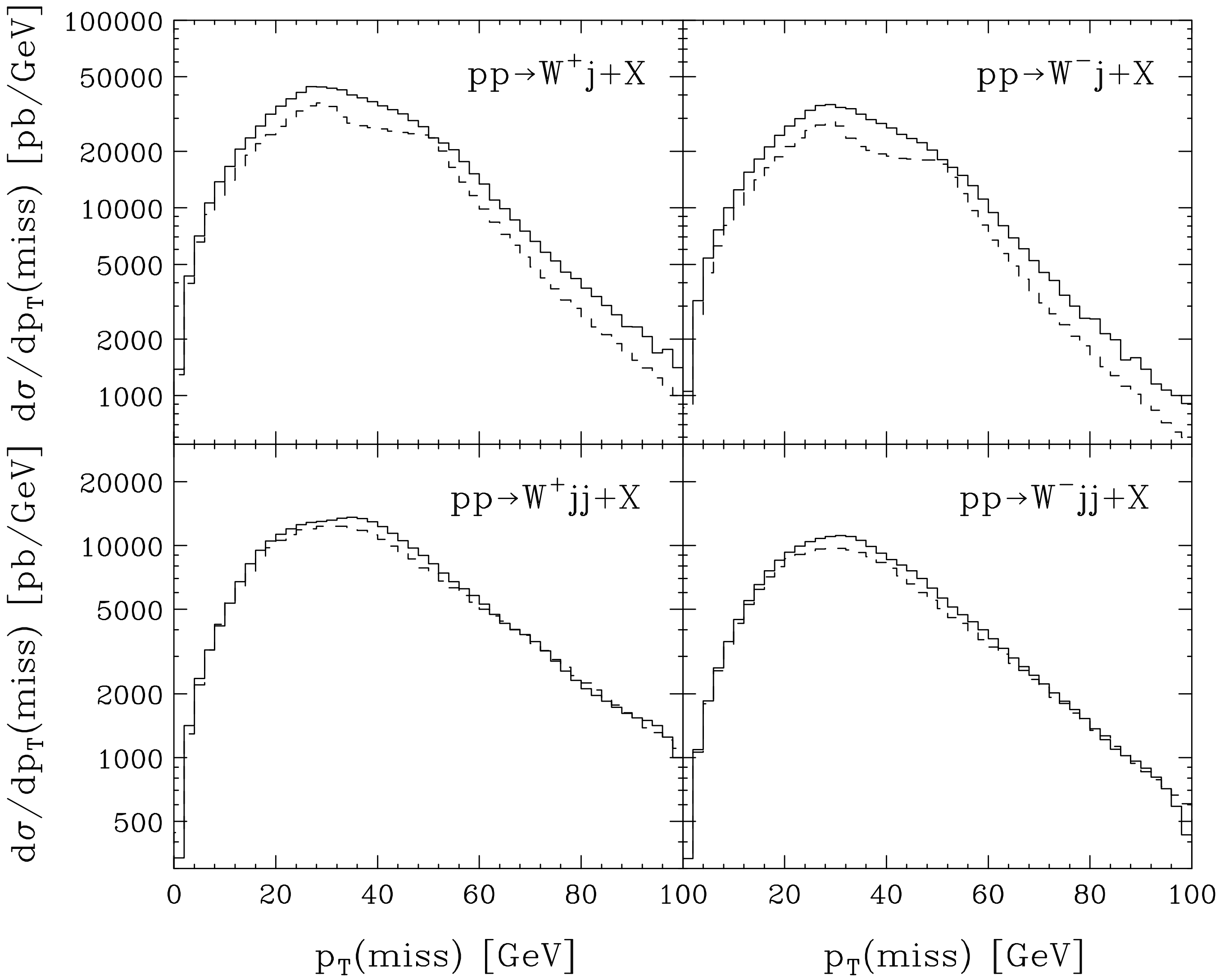




$\longrightarrow$ theoretical uncertainties reduced

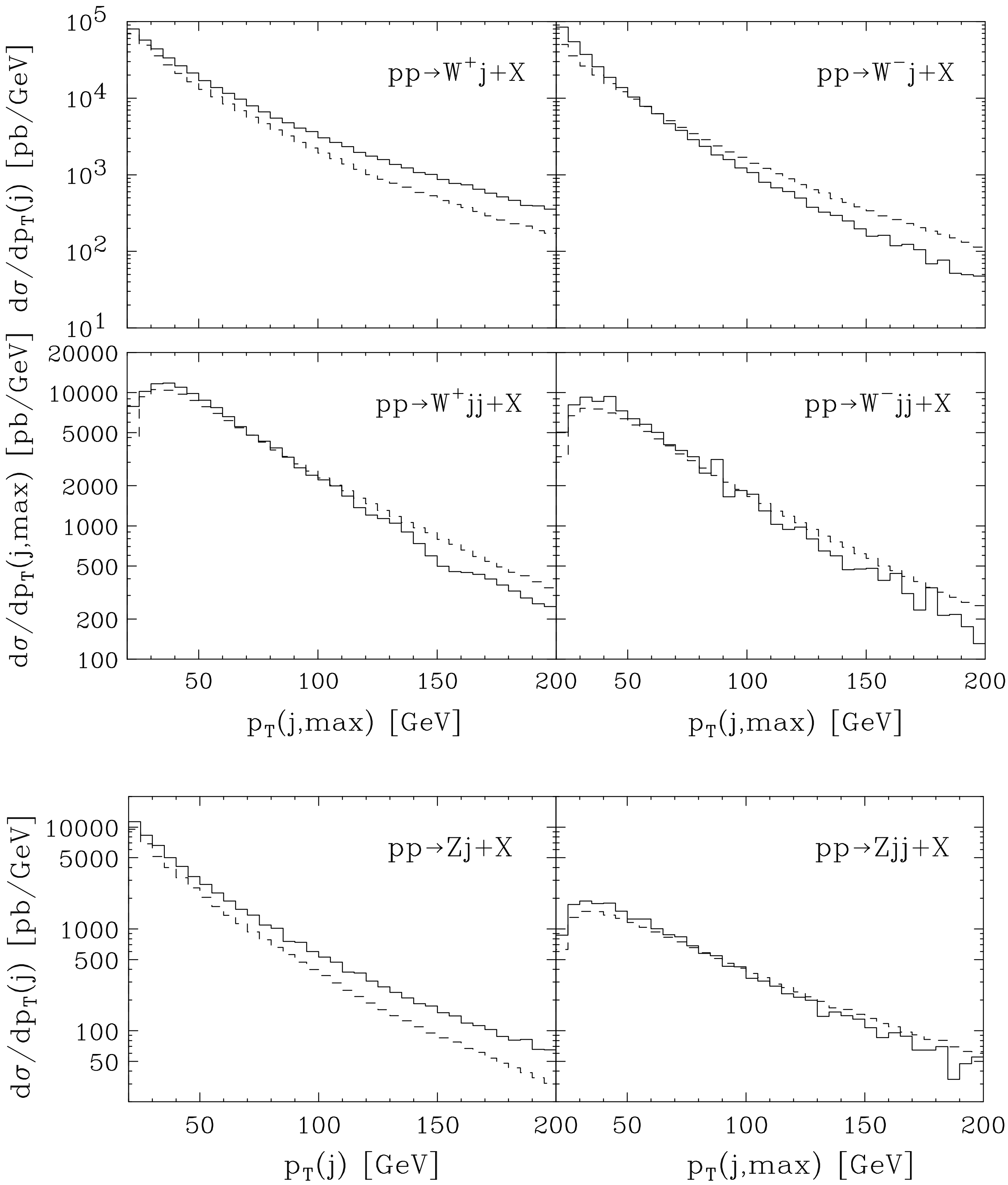
$\not{p}_T$ distributions for $W+$ jets

We don't cut on this variable since LHC analyses use varying $\not{p}_T$, and requirements change at high-lumi.



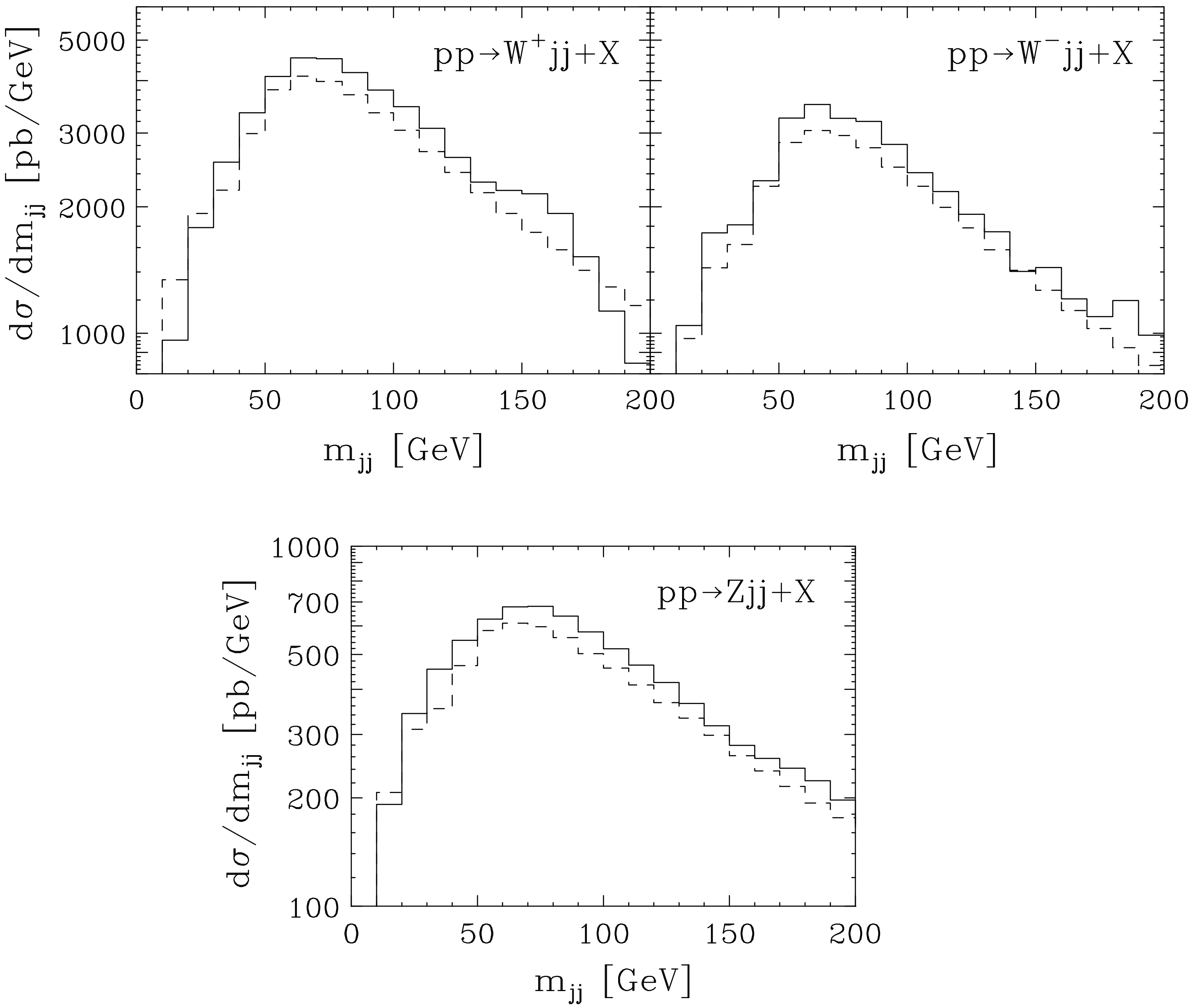
→ little change at NLO

Leading jet p_T distributions



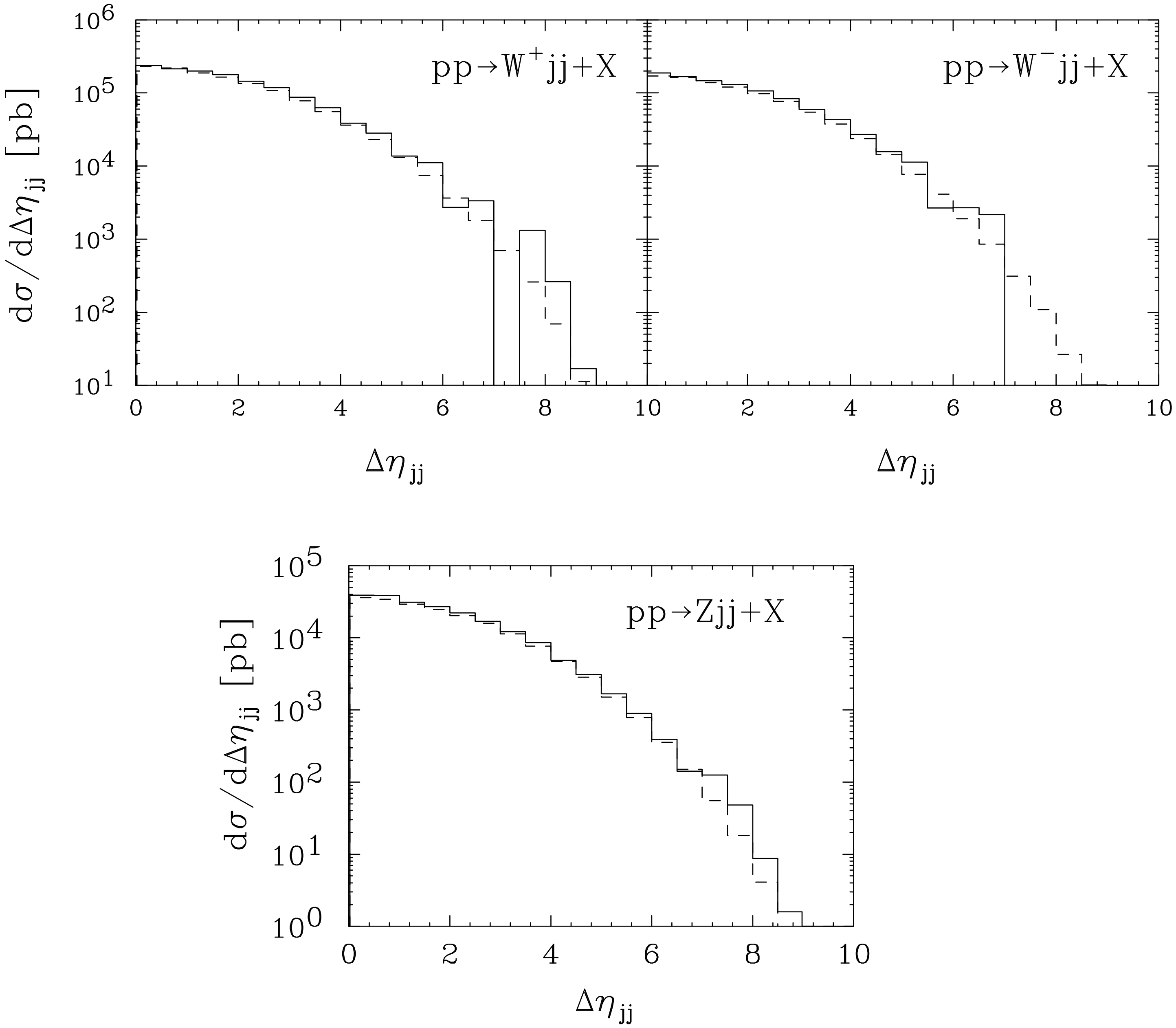
$\rightarrow$ shifts Vjj dists to lower p_T

Dijet m_{jj} distributions



→ mostly an overall enhancement

Dijet η-separation distributions



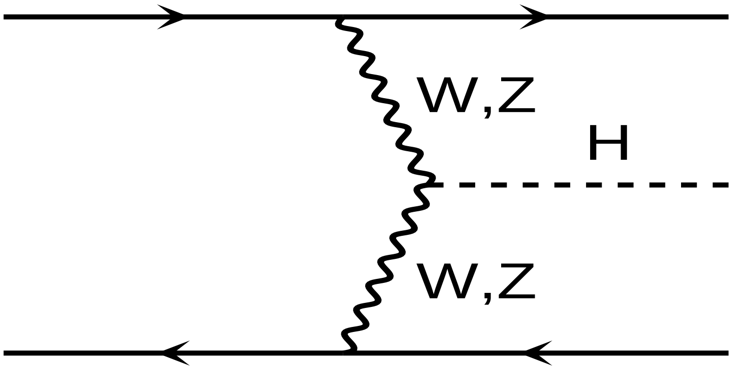
$\rightarrow$ essentially no shape change

Zjj background to Hjj

We can apply this to Higgs bkgs at LHC

Principal interest:

$$qq' \to Hq''q''' \; ; \quad H \to \tau^+\tau^-$$



EW process, WW scattering:
detector sees q'', q''' as far-forward jets:
$< |\eta_j| > \sim 3$, $\qquad |\eta_{j1} - \eta_{j2}| \sim 5 - 6$

QCD NLO corrections driven by P.S. of jets;
impose "WBF tagging jets" cuts:

$$p_T(j) > 20 \text{ GeV}, \quad |\eta_j| < 4.5, \quad \Delta R_{jj} > 0.4$$

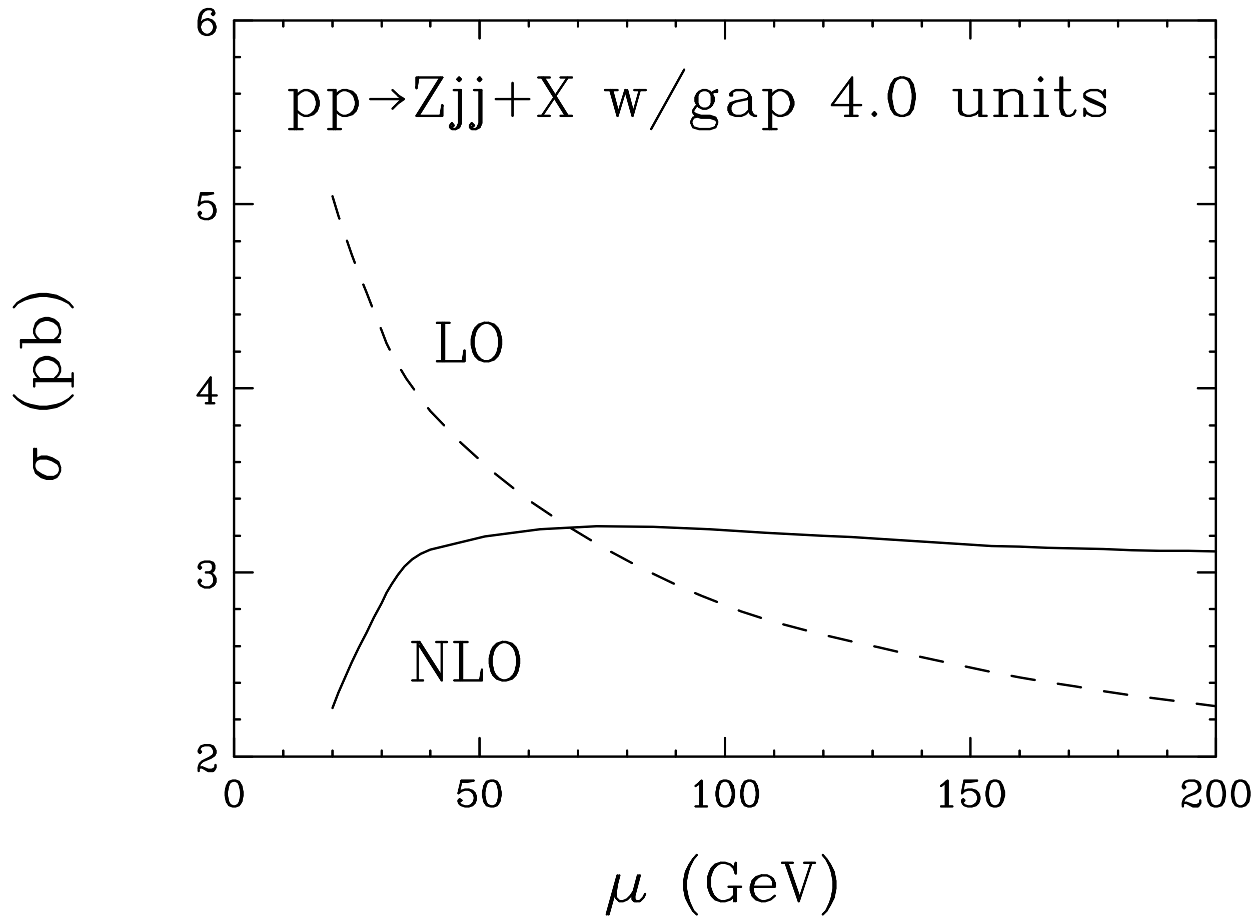
$$|\eta_{j1} - \eta_{j2}| > 4.0, \quad \eta_{j1} \cdot \eta_{j2} < 0$$

$$p_T(\ell) > 15 \text{ GeV}, \quad |\eta_j| < 2.4, \quad \Delta R_{j\ell} > 0.4, \quad \Delta R_{\ell\ell} > 0.2$$

$$15 < m_{\ell\ell} < 200 \text{ GeV}$$

(minimal lepton cuts only)

Zjj *scale dependence w/ dijet gap*



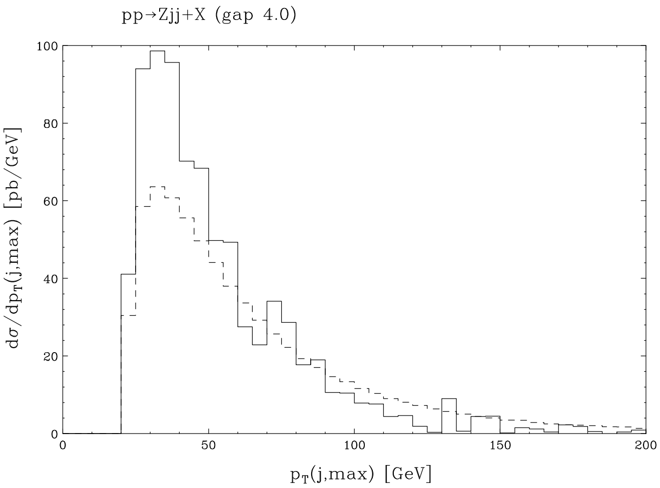
NLO stable in tiny "tagging" P.S. region

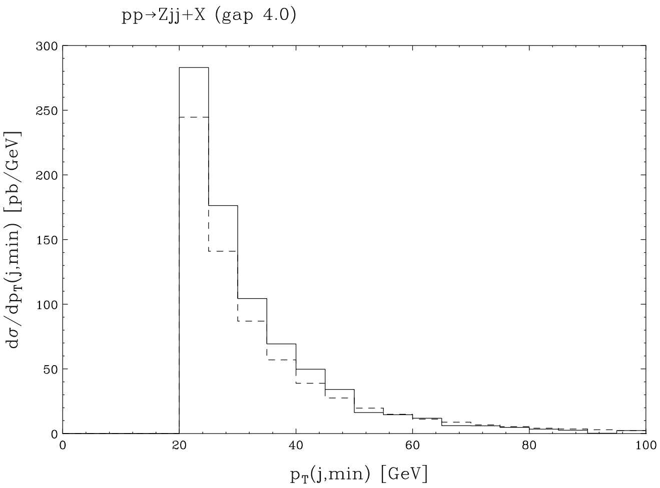
For $\boldsymbol{\mu \equiv \mu_f = \mu_r = M_Z}$:
2.92 pb (LO), 3.47 pb (NLO) $\rightarrow K = 1.19$

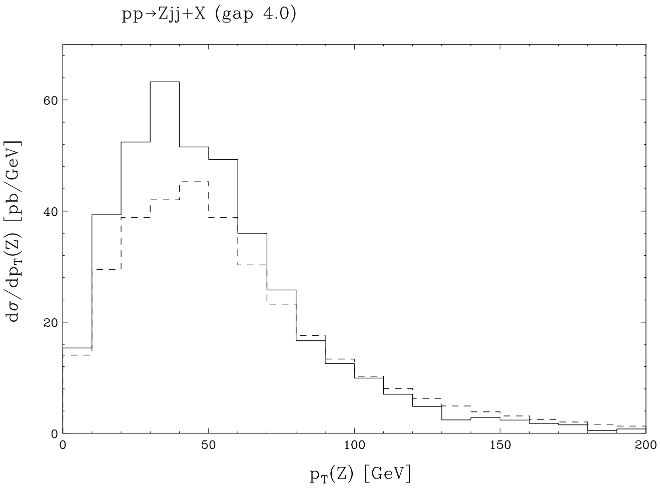
Note: Hjj sims use $\mu = p_T^{j,min}$ (dynamical)
$\rightarrow$ bkg down slightly from estimates

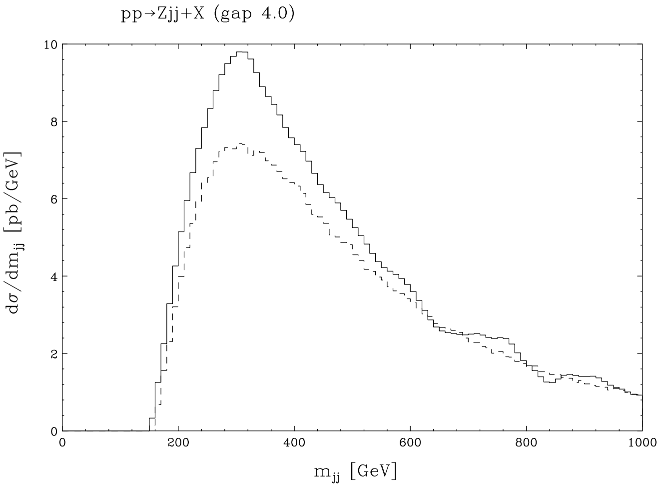
Still to come: minijet emission studies

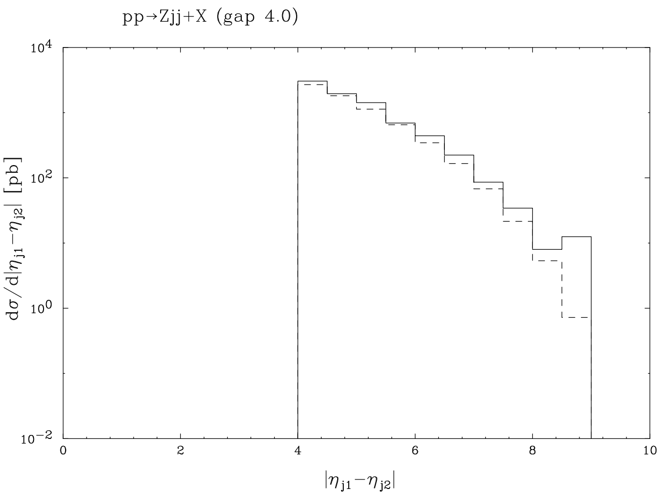
Zjj LO v. NLO distributions

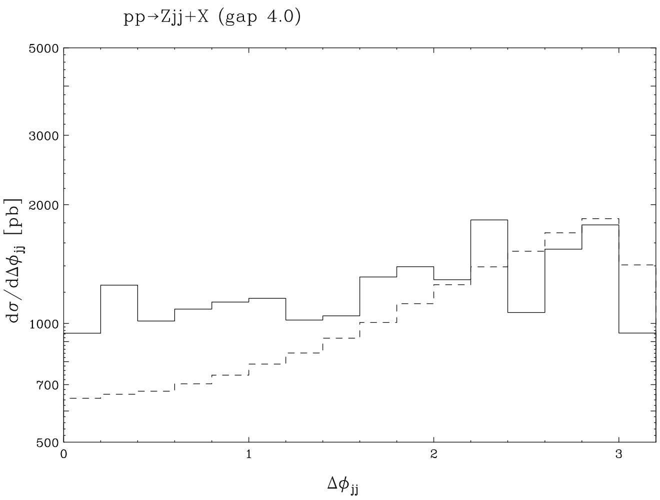










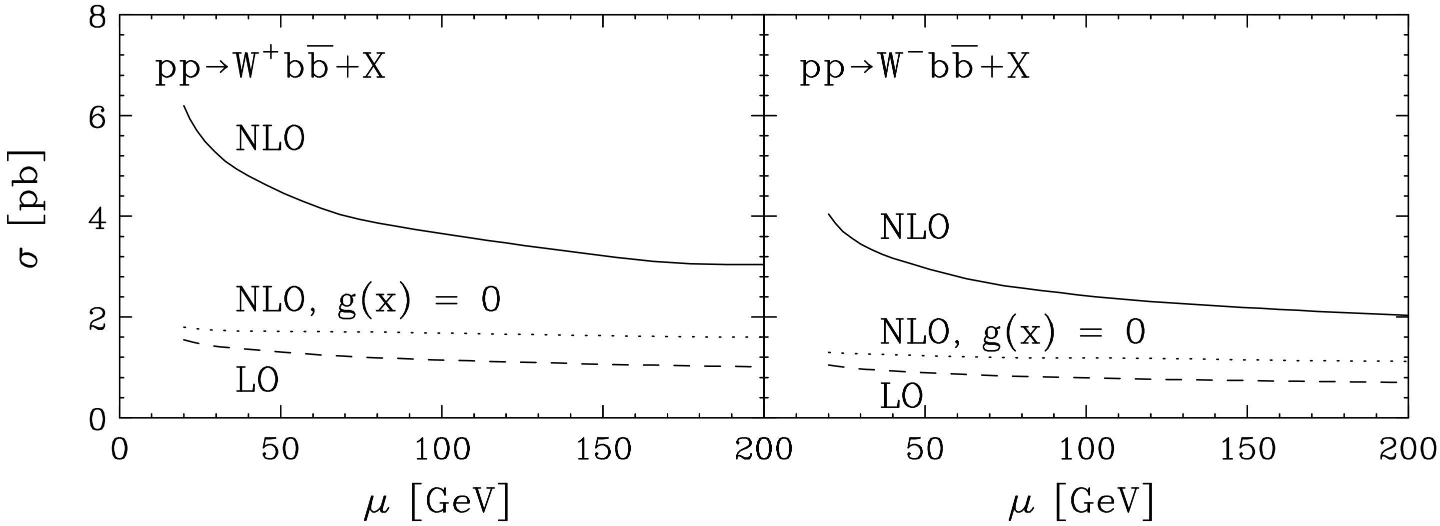


Heavy-flavor case

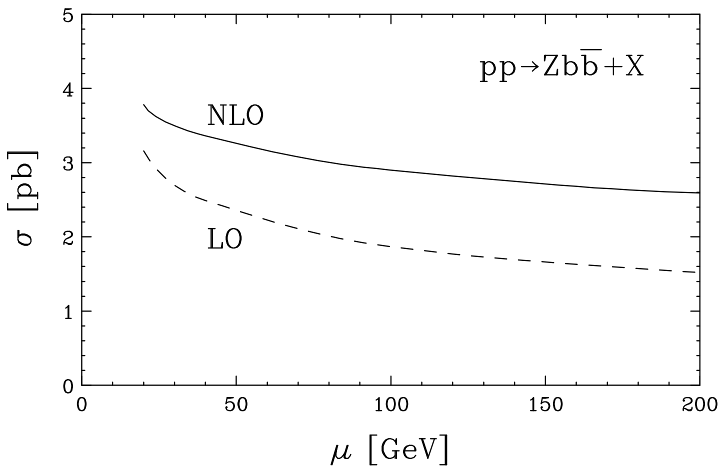
$\rightarrow$ heavy-flavor jets ($b(c)$) can be tagged

Want $\sigma_{Vb\bar{b}}$, and ratios $Vjj/Vb\bar{b}$.

$Wb\bar{b}$ corrections are enormous (factor ~ 3):

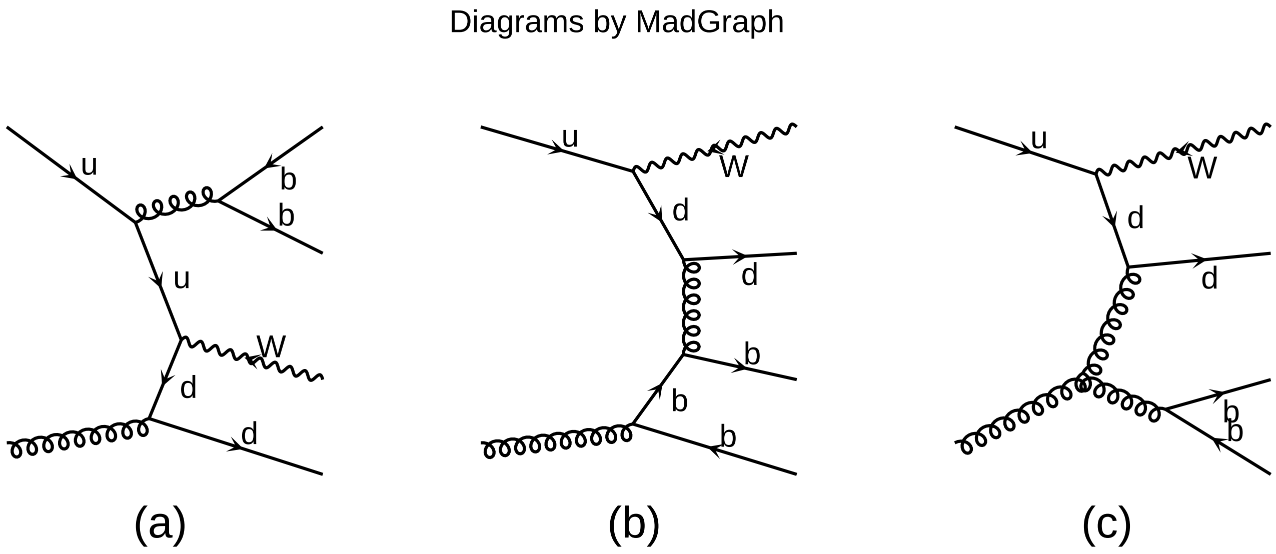


$Zb\bar{b}$, however, is well-behaved:



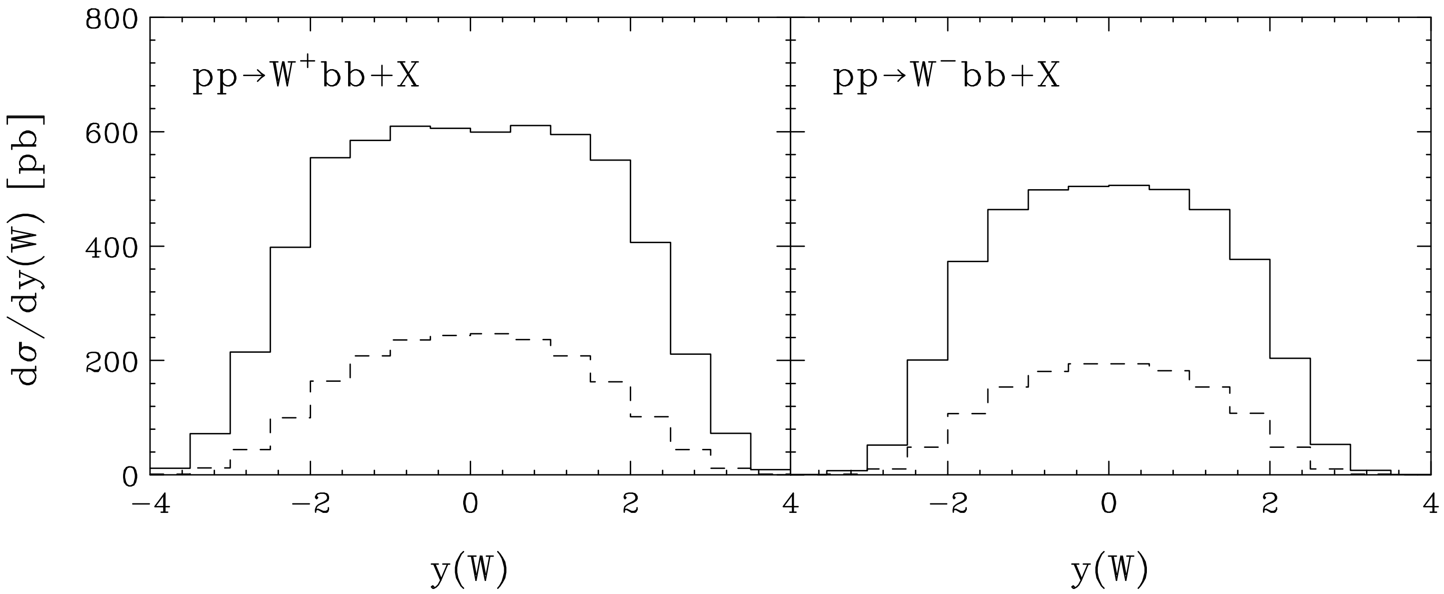
Why are the $W b\bar{b}$ corrections so large??

New, non-DY corr. LO diagrams (b,c):

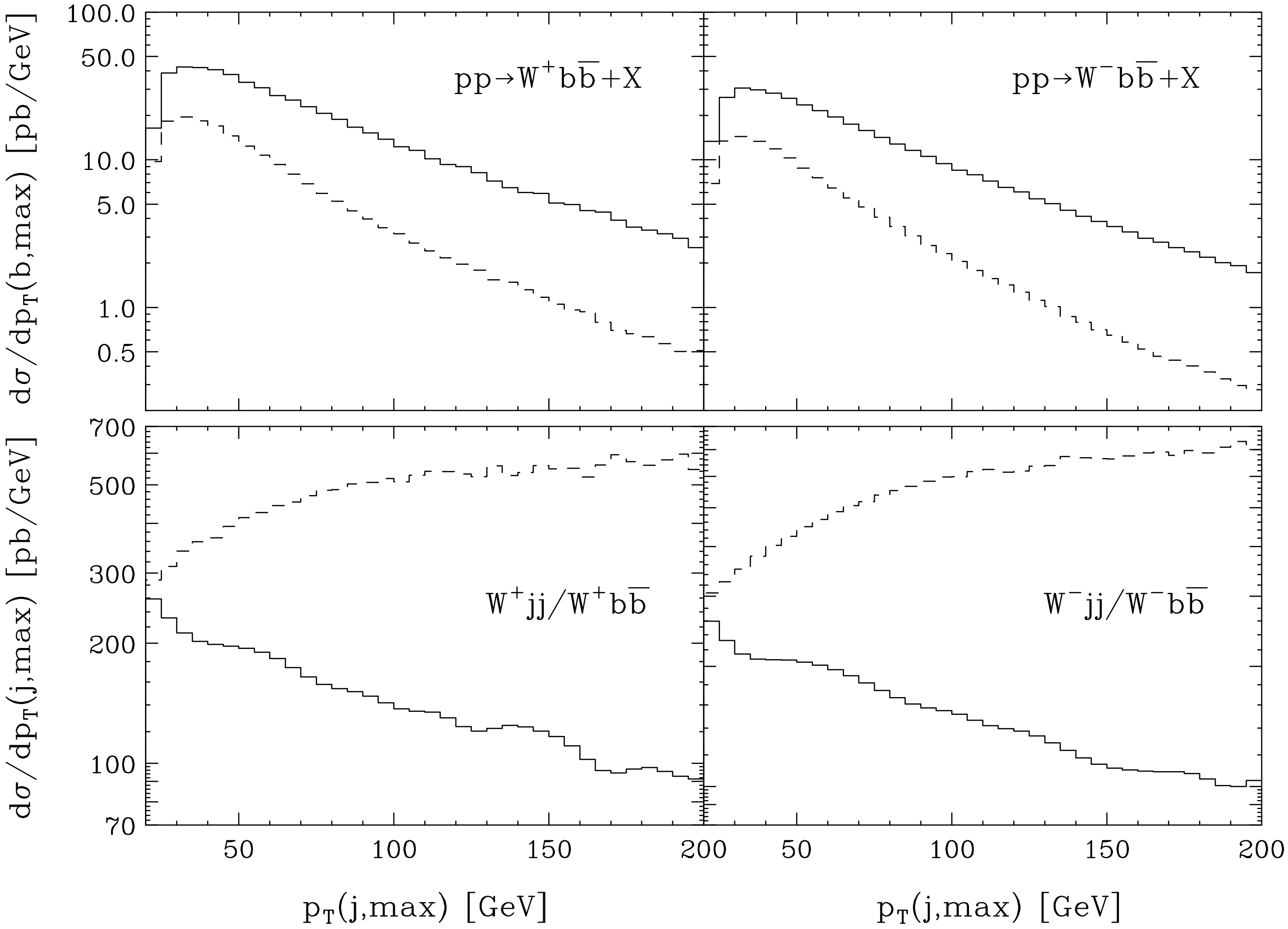


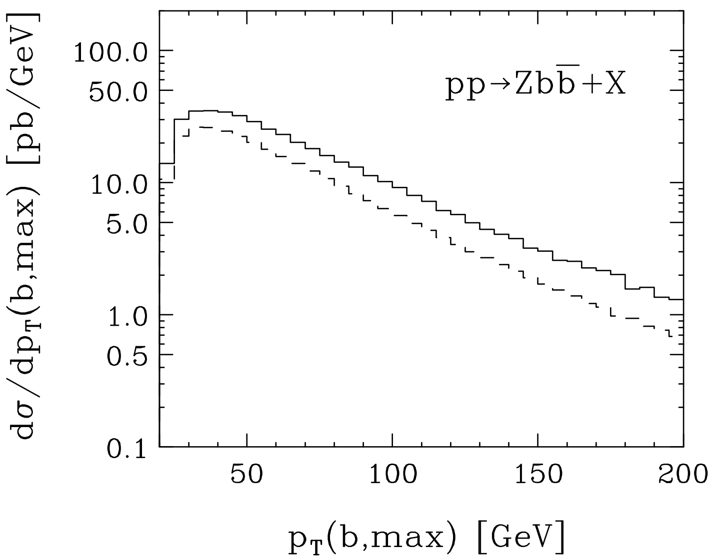
$\longrightarrow$ effects: more P.S.; 3-gluon Casimir

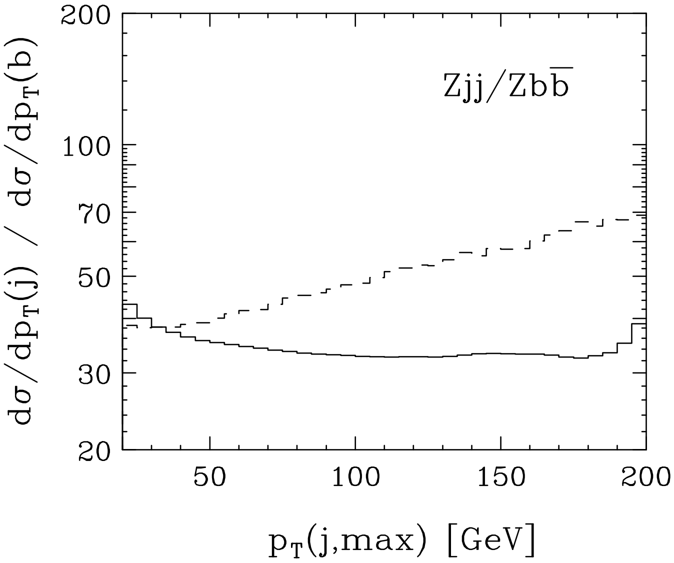
Plateau in y_W confirms our hypothesis:



Kinematic distributions for heavy flavor







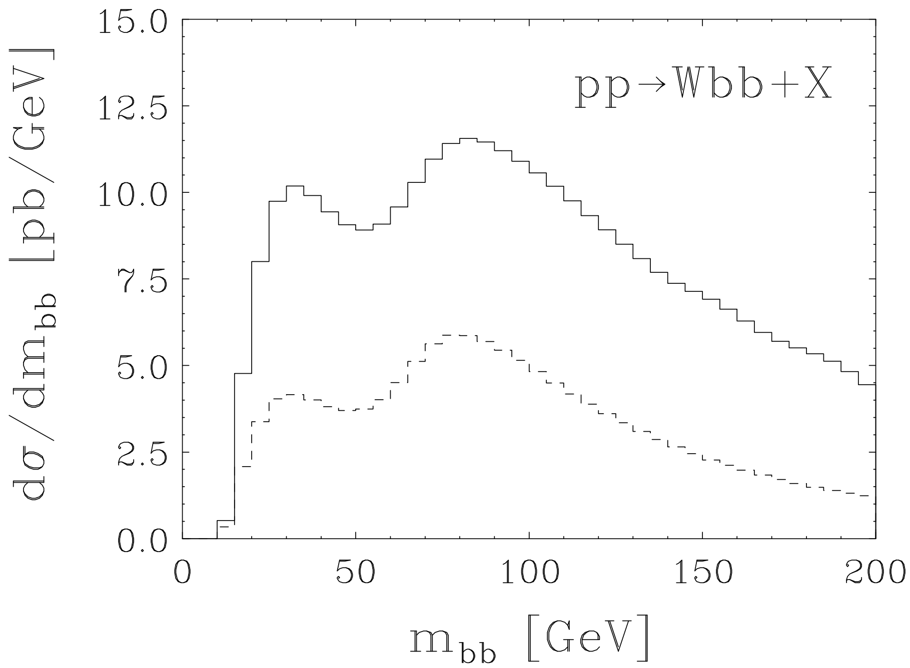
$Wb\bar{b}$ implications for WH, $H \to b\bar{b}$

WH; $H \to b\bar{b}$ gives access to Y_b;
QCD $Wb\bar{b}$ is dominant background

Impose cuts of CMS study
[Drollinger, Müller, Denegri, hep-ph/0201249]:

$$\begin{aligned} p_T(\ell) > 20 \text{ GeV}, &\qquad |\eta_\ell| < 2.4 \\ p_T(j) > 30 \text{ GeV}, &\qquad |\eta_j| < 2.5 \\ \triangle R_{\ell j} > 0.4\,, &\qquad \triangle R_{\ell\ell} > 0.2 \end{aligned}$$

Now plot m_{bb} distribution:



Use ± 20 GeV, $M_H = 120$ GeV: $K \sim 2.4$
$\to$ does not bode well for WH channel
$\to$ consider veto of extra jet (in progress...)

What you can take home

- $\sigma_{W^\pm jj}$,σ_{Zjj} known at NLO for LHC
  $\rightarrow \sigma_{Vjj} \sim \frac{1}{3}\sigma_{Vj} \gg \alpha_s \sigma_{Vj}$
  $\rightarrow$ little residual uncertainty:
  $\mathcal{O}(3\%)$ (Zjj), $\mathcal{O}(0.05\%)$ (Wjj)
- NLO Vjj kinematic dists similar to LO (some shifts present)
- NLO Zjj w/ dijet "gap" same/smaller than LO Hjj studies
  $\rightarrow$ different cuts being studies
  $\rightarrow$ minijet estimates unchanged
- $W^\pm b\bar{b}$ NLO corrections very large ($\sim 3\times$)
  $\rightarrow$ real effect; new diagrams/kinematics
  $\rightarrow$ residual uncertainty large
- $WH; H \rightarrow b\bar{b}$ affected; new study needed
- Open questions:
  · possible to veto additional jet of $Wb\bar{b}j$?
  · NLO Zjj w/ more extreme gap cuts
  · NLO Zjj $\triangle\phi_{jj}$ dist $\rightarrow$ Higgs CP