Matching Fixed Order and Parton Showers

Bryan Webber
University of Cambridge

- Lecture 1: Matching Parton Showers to Next-to-Leading Order (NLOPS)
- Lecture 2: Merging Parton Showers with Multijet Matrix Elements (MEPS)

Outline 2

- Merging PSMC with Multijet Matrix Elements (MEPS)
  - CKKW-L
  - MLM
- Combining MEPS with NLOPS (MENLOPS)

MEPS

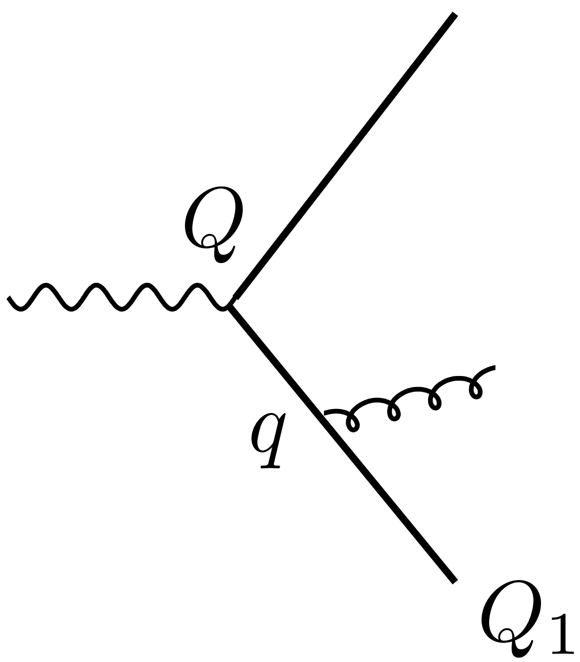
- Objective: merge n-jet MEs with PSMC such that
  - Multijet rates for k_t-resolution > Q_{cut} are correct to LO
  - PSMC generates jet structure below Q_{cut}
  - Q_{cut} dependence cancels to NLL accuracy

CKKW: Catani et al., JHEP 11(2001)
-L: Lonnblad, JHEP 05(2002)063
MLM: Mangano et al., NP B632(2002)343

Example: $e^+e^- \to$ hadrons

- 2 & 3-jet rates at scale $Q_{cut}=Q_1$

$$
\begin{aligned}
R_2(Q,Q_1) &= \left[\Delta_q(Q,Q_1)\right]^2 \,, \\
R_3(Q,Q_1) &= 2\Delta_q(Q,Q_1)\int_{Q_1}^{Q} dq\, \frac{\Delta_q(Q,Q_1)}{\Delta_q(q,Q_1)}\Gamma_q(Q,q) \\
&\quad \times\Delta_q(q,Q_1)\Delta_g(q,Q_1) \\
&= 2\left[\Delta_q(Q,Q_1)\right]^2 \int_{Q_1}^{Q} dq\,\Gamma_q(Q,q)\Delta_g(q,Q_1)
\end{aligned}
$$



$$\Gamma_q(Q,q) = \frac{2C_F}{\pi}\frac{\alpha_S(q)}{q}\left(\ln\frac{Q}{q}-\frac{3}{4}\right)$$

$$\Delta_q(Q,Q_1) = \exp\left(-\int_{Q_1}^{Q} dq\,\Gamma_q(Q,q)\right)$$

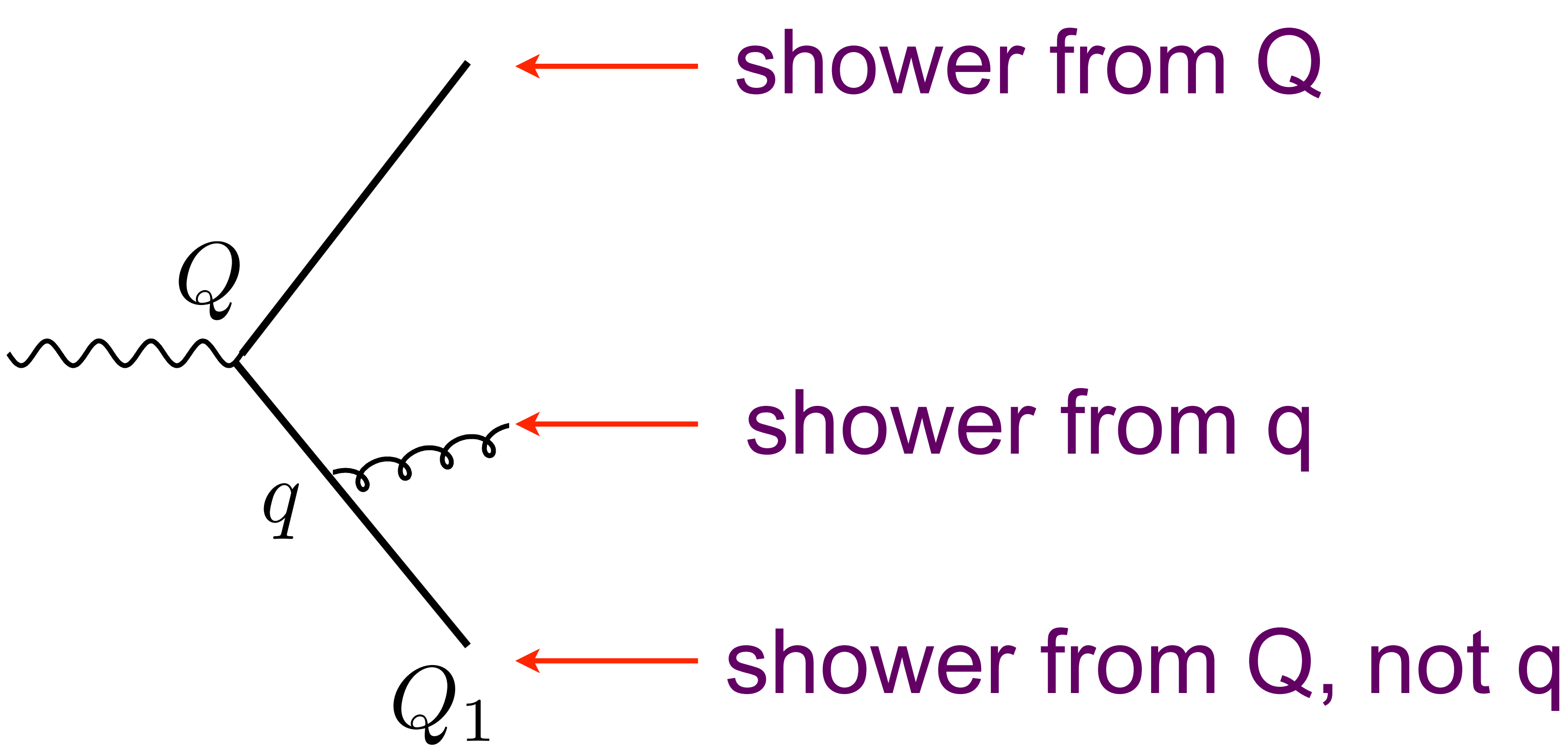
CKKW reweighting

- Choose n according to $R_n(Q, Q_1)$ (LO)
  - use $[\alpha_S(Q_1)]^n$
- Use exact LO ME to generate n partons
- Construct "equivalent shower history"
  - preferably using k_T-type algorithm
- Weight vertex at scale q by $\alpha_S(q)/\alpha_S(Q_1) < 1$
- Weight parton of type i from Q_j to Q_k by

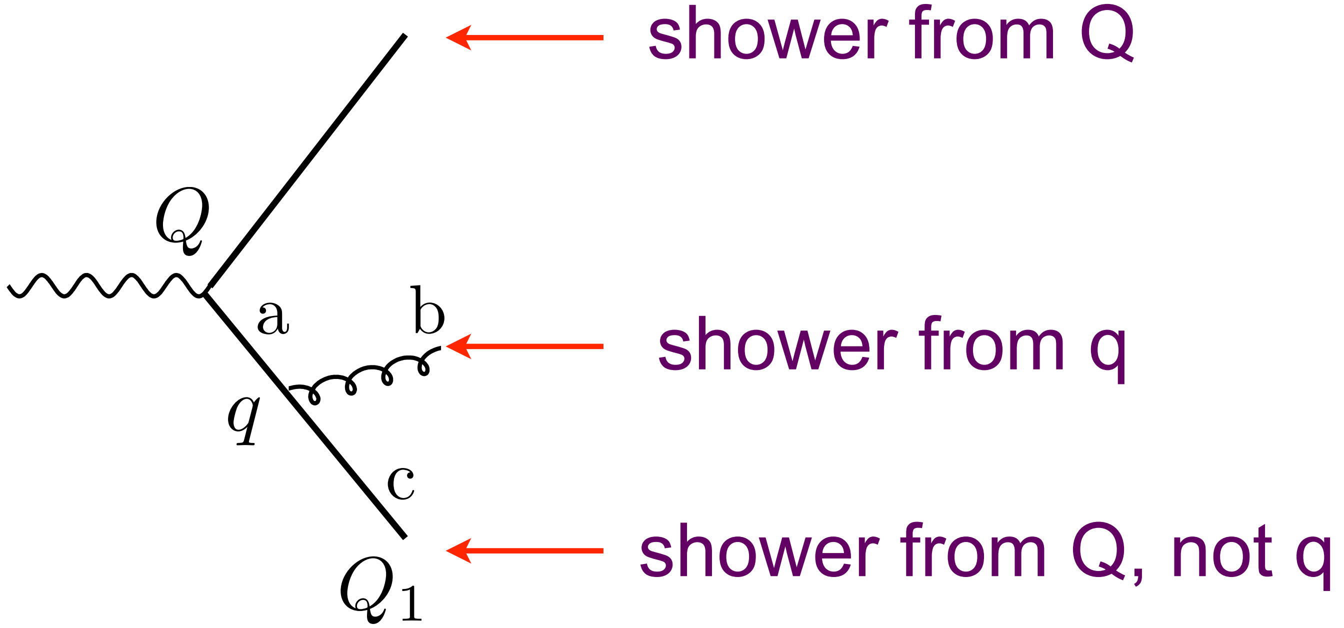
$$\Delta_i(Q_j, Q_1)/\Delta_i(Q_k, Q_1)$$

CKKW shower veto

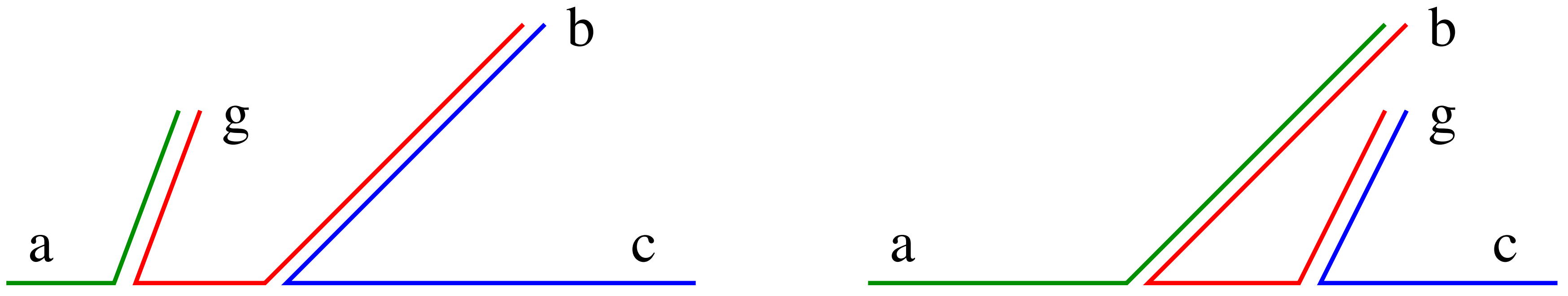
- Shower n partons from "creation scales"
  - includes coherent soft emission
- Veto emissions at scales above Q_1
  - cancels leading (LL&NLL) Q_1 dependence



Colour Structure

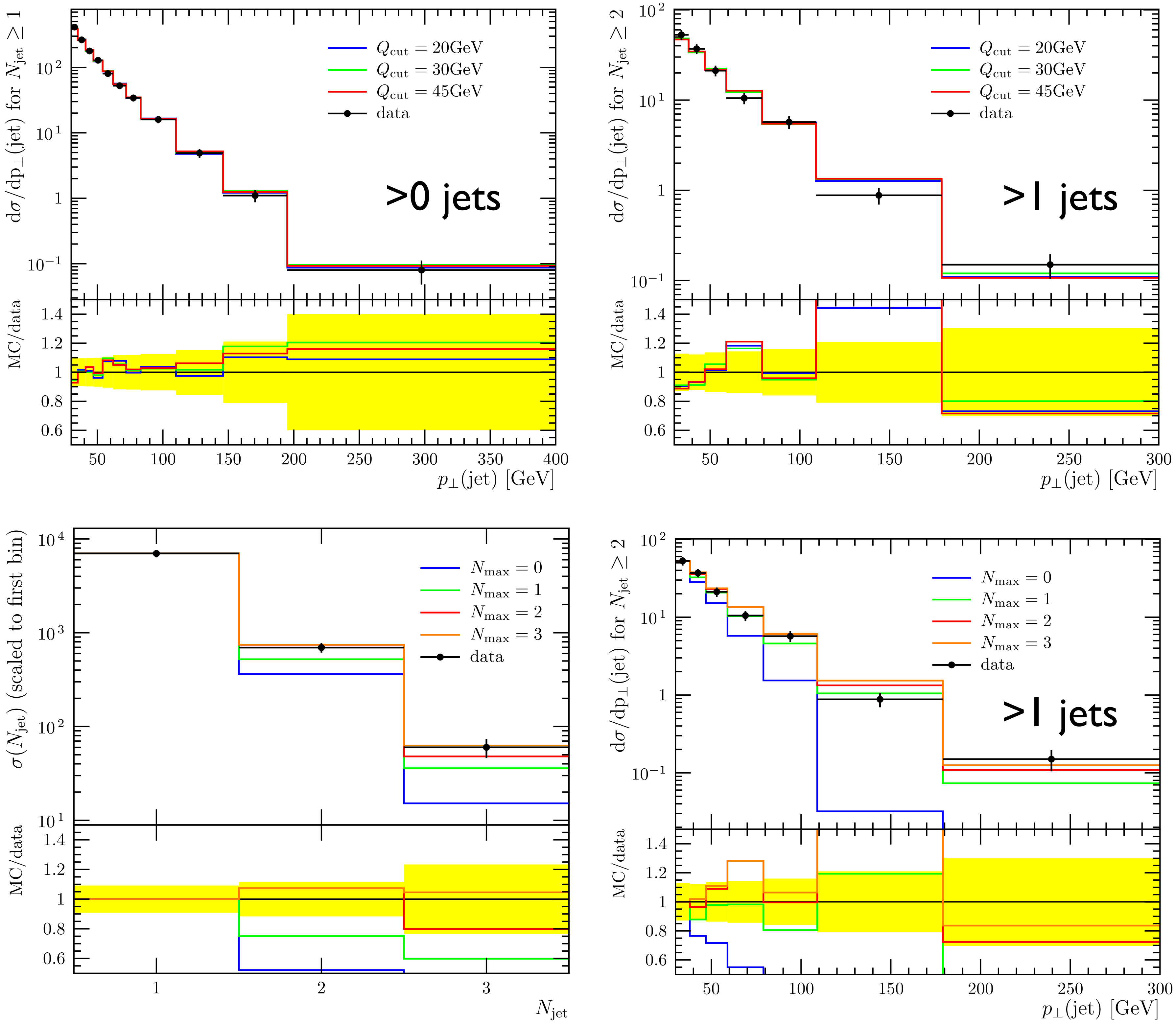


- But colour flow must obey angular ordering [(a) not (b)]



(a) (b)

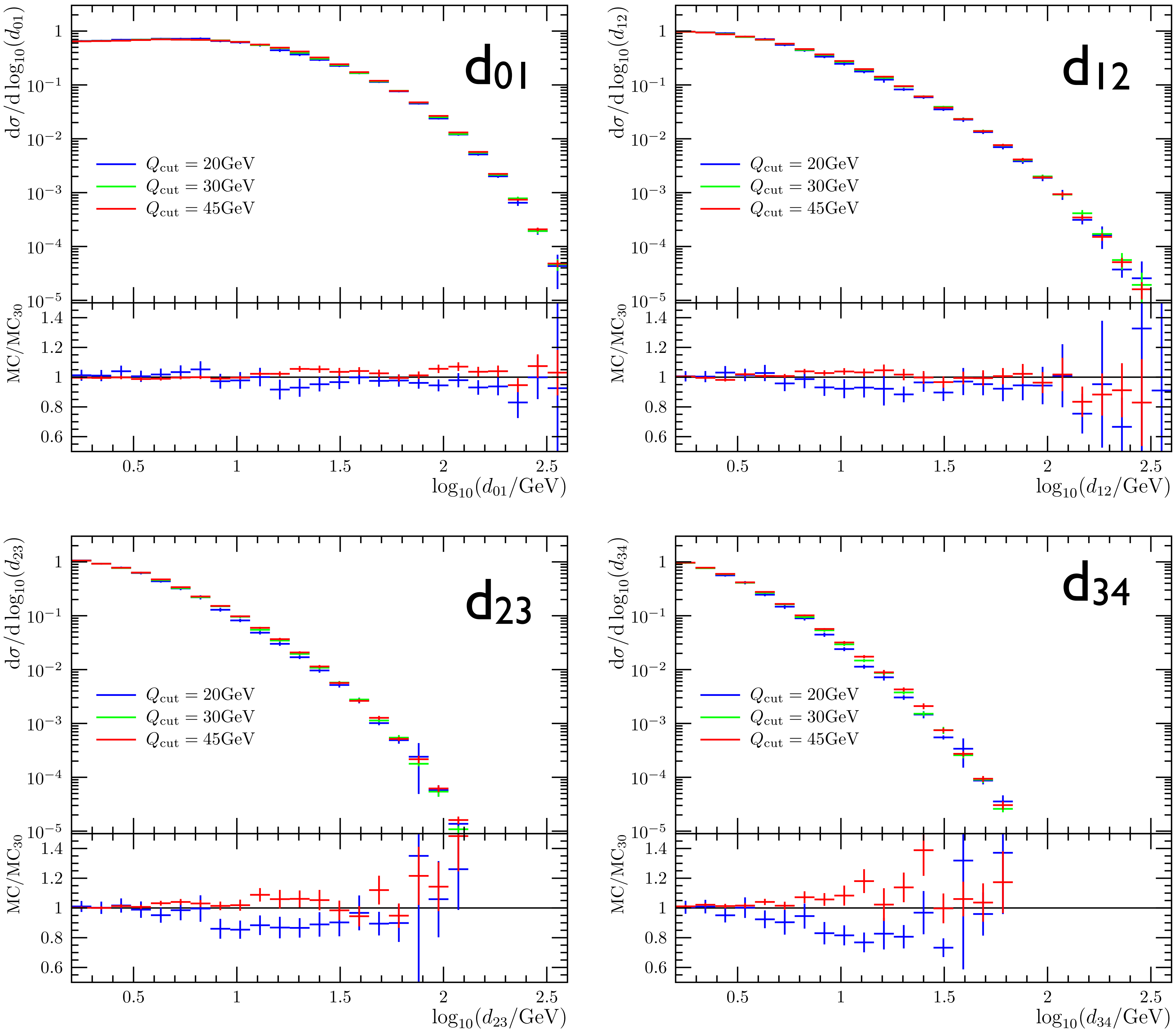
Z^0+jets MEPS at Tevatron



- CDF run II data
- Jet p_t and N_{jets}
- Insensitive to Q_{cut}
- Insensitive to N_{max}>1

Hoeche, Krauss, Schumann, Siegert, JHEP05(2009)053

Z^0+jets MEPS at Tevatron



- Differential jet rates (k_t-algorithm)

Hoeche, Krauss, Schumann, Siegert, JHEP05(2009)053

MLM Matching

- Use cone algorithm for jet definition:

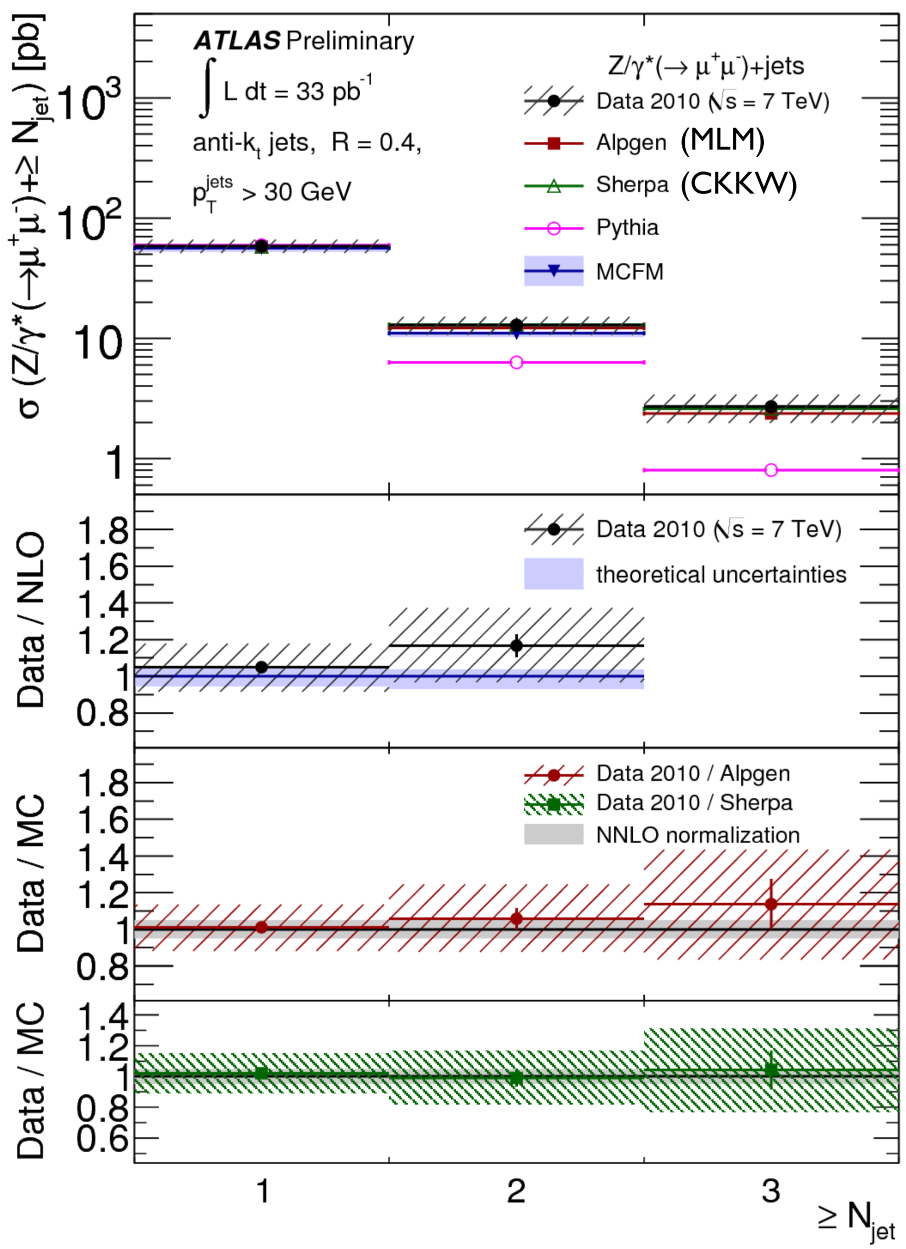
$$R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$$

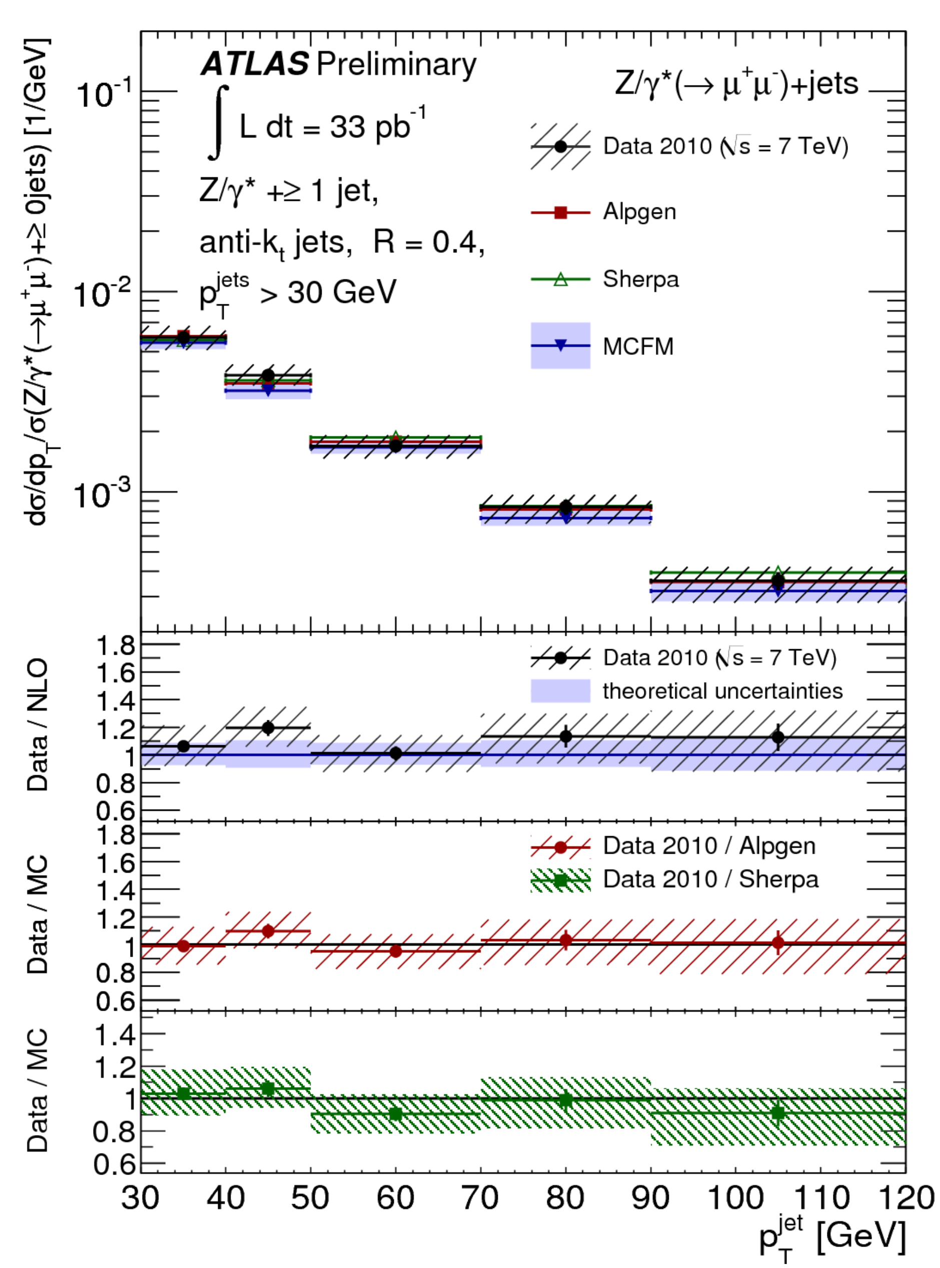
$$E_{Ti} > E_{Tmin}, \;\; R_{ij} > R_{min}$$

- Generate n-parton configurations with (no Sudakov weights) $E_{Ti} > E_{Tmin}, \;\; R_{ij} > R_{min}$
- Generate showers (no vetos)
- Form jets using same jet definition
- Reject event if $n_{jets} \neq n_{partons}$ ← mimics Sudakov+veto

Mangano, Moretti, Piccinini, Treccani, JHEP01(2007)013

Z^0+jets at LHC (ATLAS)





- Inclusive jet rates (anti-k_t-algorithm)
- Good agreement with MEPS predictions
- PS alone starts to fail for $N_{jet} \geq 2$

N Makovec, Moriond 2011

MENLOPS

$$d\sigma_{\rm TOT} = d\sigma_{\rm NLOPS}(0\,{\rm jets}) + K_1\, d\sigma_{\rm NLOPS}(1\,{\rm jet}) + K_2\, d\sigma_{\rm MEPS}(\geq 2\,{\rm jets})$$

- Assume ≥ 2 jets have K-factor

$$K_2 = \sigma_{\rm NLOPS}(\geq 1\,{\rm jets})/\sigma_{\rm MEPS}(\geq 1\,{\rm jets})$$

- To retain NLO accuracy we need

$$\sigma_{\rm TOT} = \sigma_{\rm NLOPS}(0\,{\rm jets}) + \sigma_{\rm NLOPS}(\geq 1\,{\rm jets})$$

- Therefore

$$K_1 = \frac{\sigma_{\rm MEPS}(1\,{\rm jet})}{\sigma_{\rm MEPS}(\geq 1\,{\rm jets})} \Bigg/ \frac{\sigma_{\rm NLOPS}(1\,{\rm jet})}{\sigma_{\rm NLOPS}(\geq 1\,{\rm jets})}$$

Hamilton & Nason, JHEP06(2010)039

Hoeche, Krauss, Schumann, Siegert, 1009.1127

MENLOPS

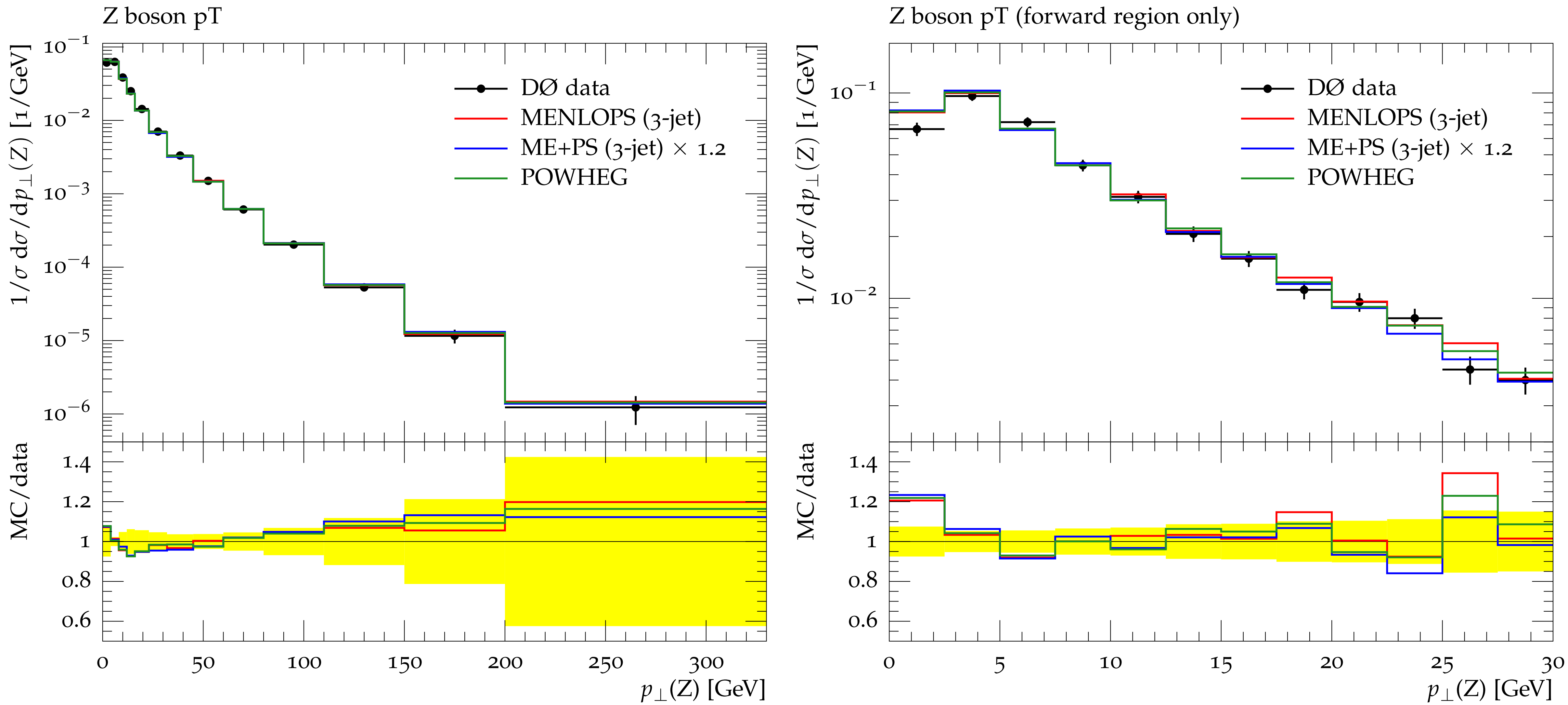
$$d\sigma_{\mathrm{TOT}} = d\sigma_{\mathrm{NLOPS}}(0\,\mathrm{jets}) + K_1\, d\sigma_{\mathrm{NLOPS}}(1\,\mathrm{jet}) + K_2\, d\sigma_{\mathrm{MEPS}}(\geq 2\,\mathrm{jets})$$

$$K_2 = \sigma_{\mathrm{NLOPS}}(\geq 1\,\mathrm{jets})/\sigma_{\mathrm{MEPS}}(\geq 1\,\mathrm{jets})$$

$$K_1 = \frac{\sigma_{\mathrm{MEPS}}(1\,\mathrm{jet})}{\sigma_{\mathrm{MEPS}}(\geq 1\,\mathrm{jets})} \Big/ \frac{\sigma_{\mathrm{NLOPS}}(1\,\mathrm{jet})}{\sigma_{\mathrm{NLOPS}}(\geq 1\,\mathrm{jets})}$$

- Choose Q_{cut} such that $\sigma_{\mathrm{MEPS}}(\geq 2\,\mathrm{jets}) \leq \mathcal{O}(\alpha_{\mathrm{S}})$
- Compute K_1, K_2 (in principle for each Born kinematics)
- Throw away MEPS 0- & 1-jet samples
- Replace them by NLOPS 0- & 1-jet samples

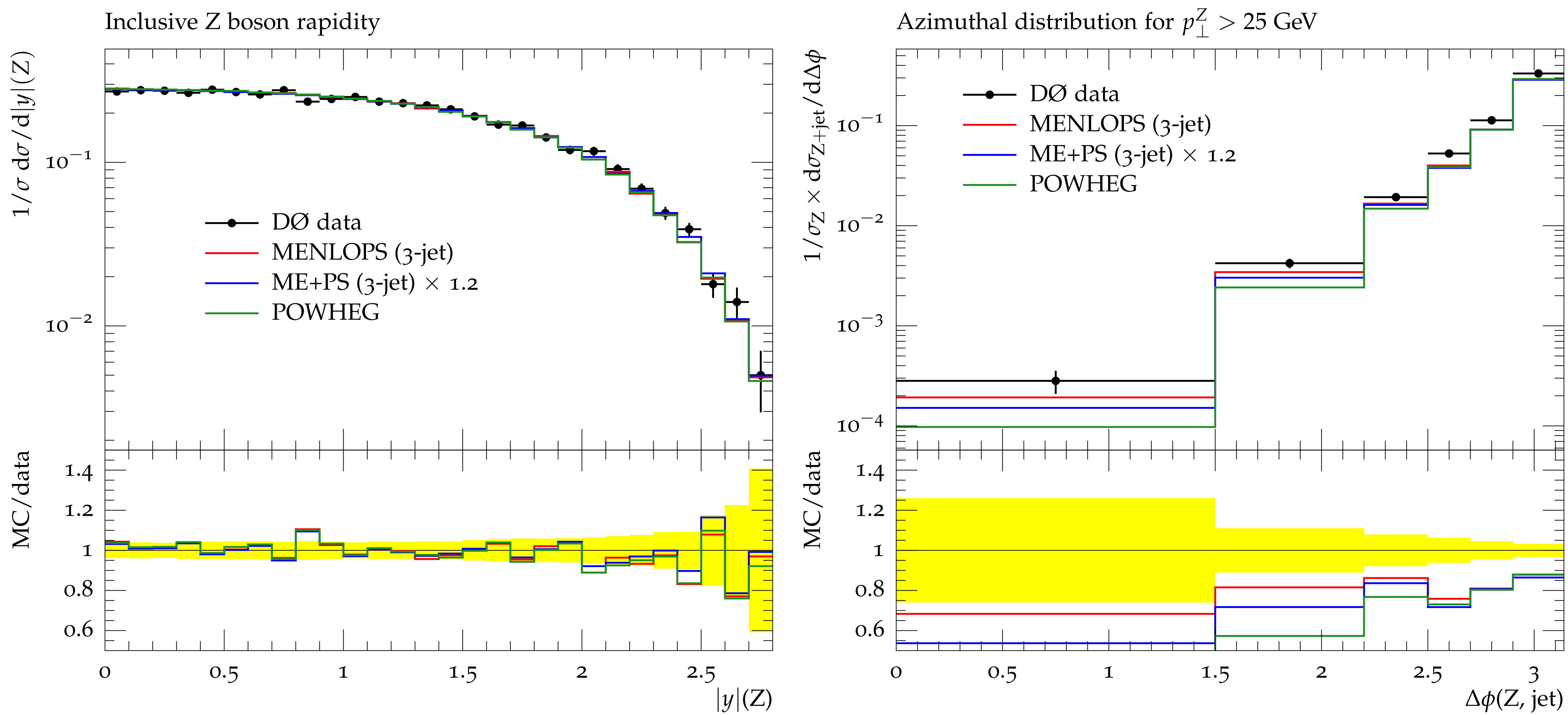
Z MENLOPS at Tevatron



- All treatments agree (MEPS rescaled)

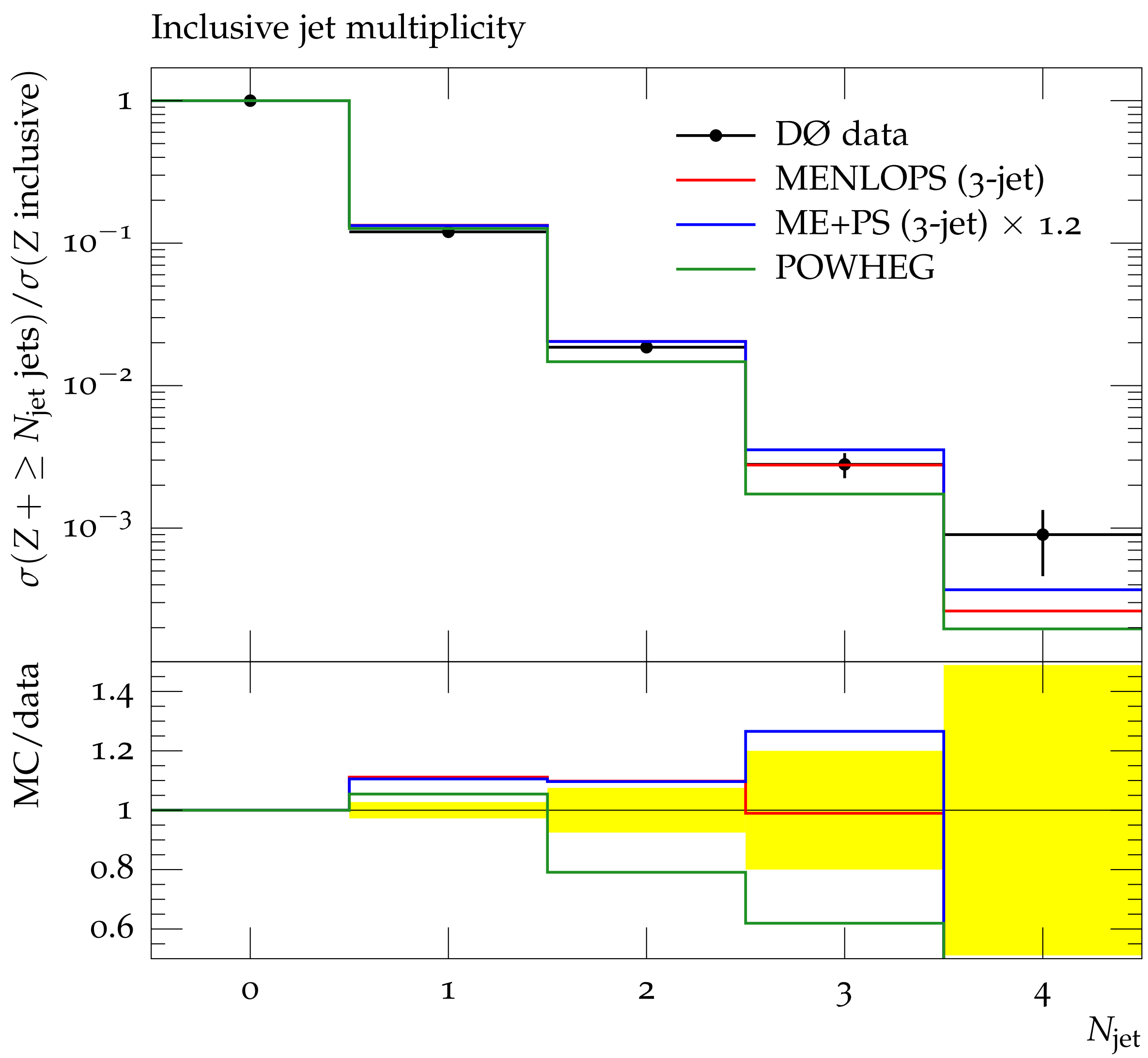
Hoeche, Krauss, Schumann, Siegert, 1009.1127

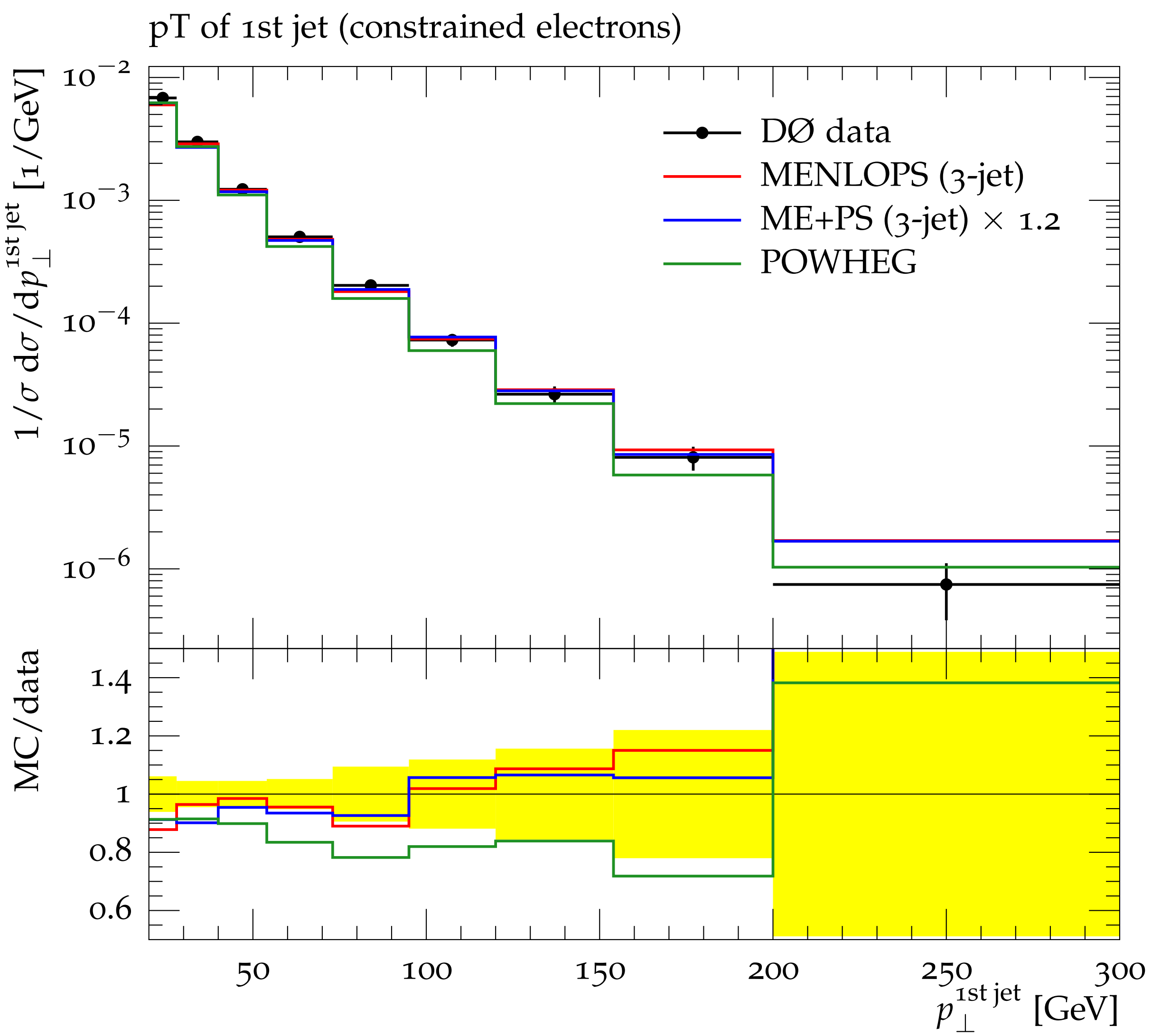
Z MENLOPS at Tevatron



- MENLOPS best for $\Delta\phi(Z, \text{jet})$

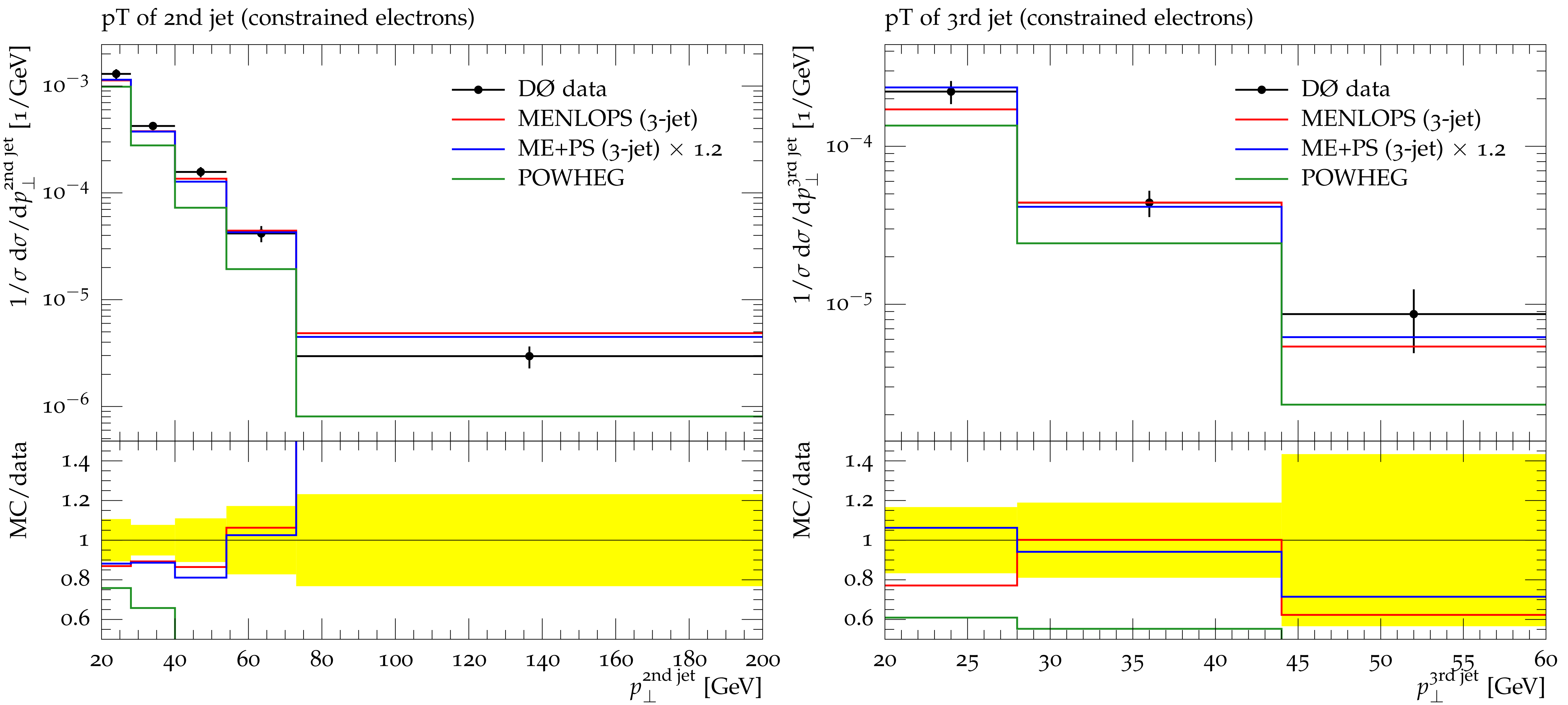
Z MENLOPS at Tevatron





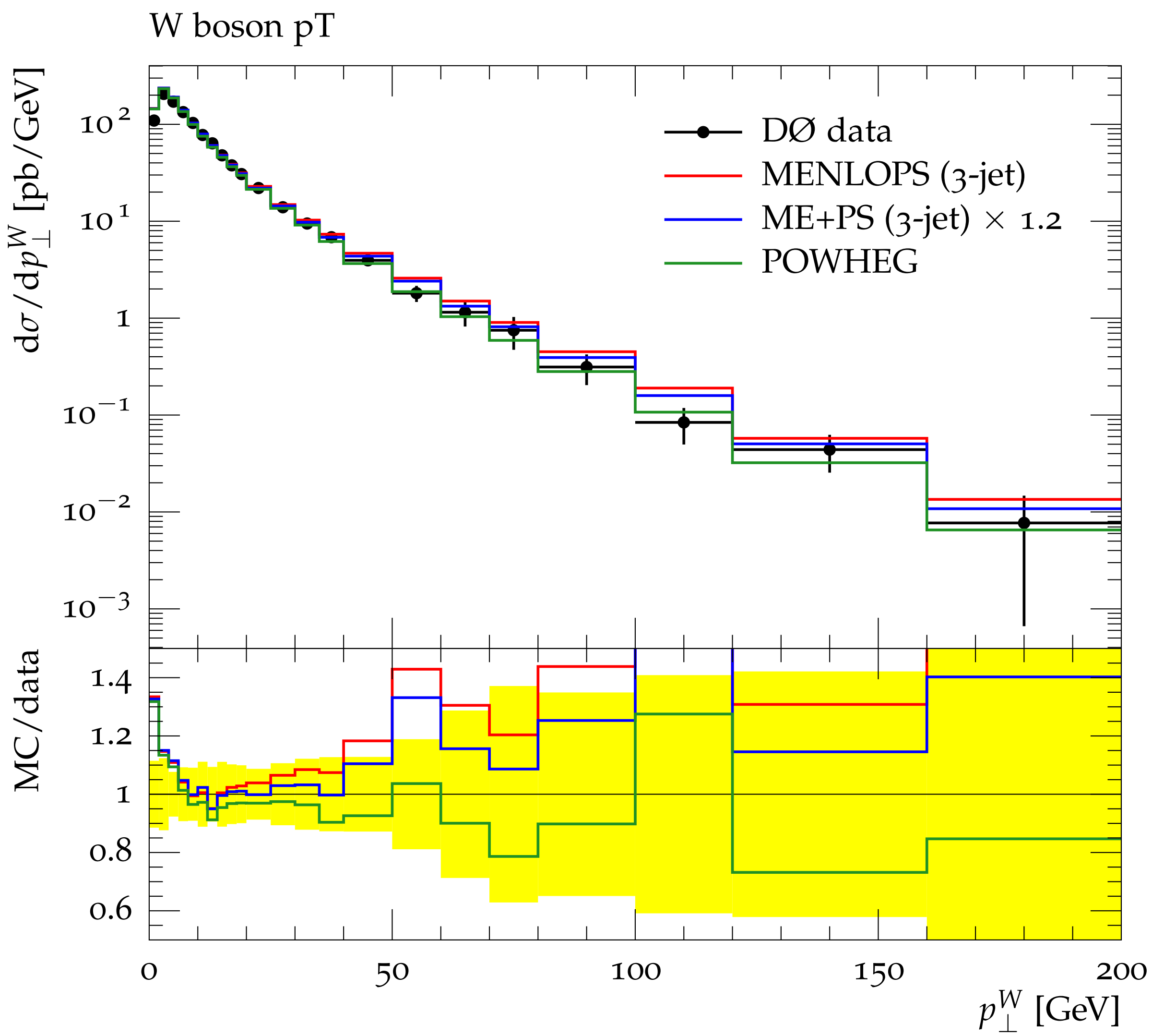
- MENLOPS good for N_{jet}=1,2,3 (no ME for 4)

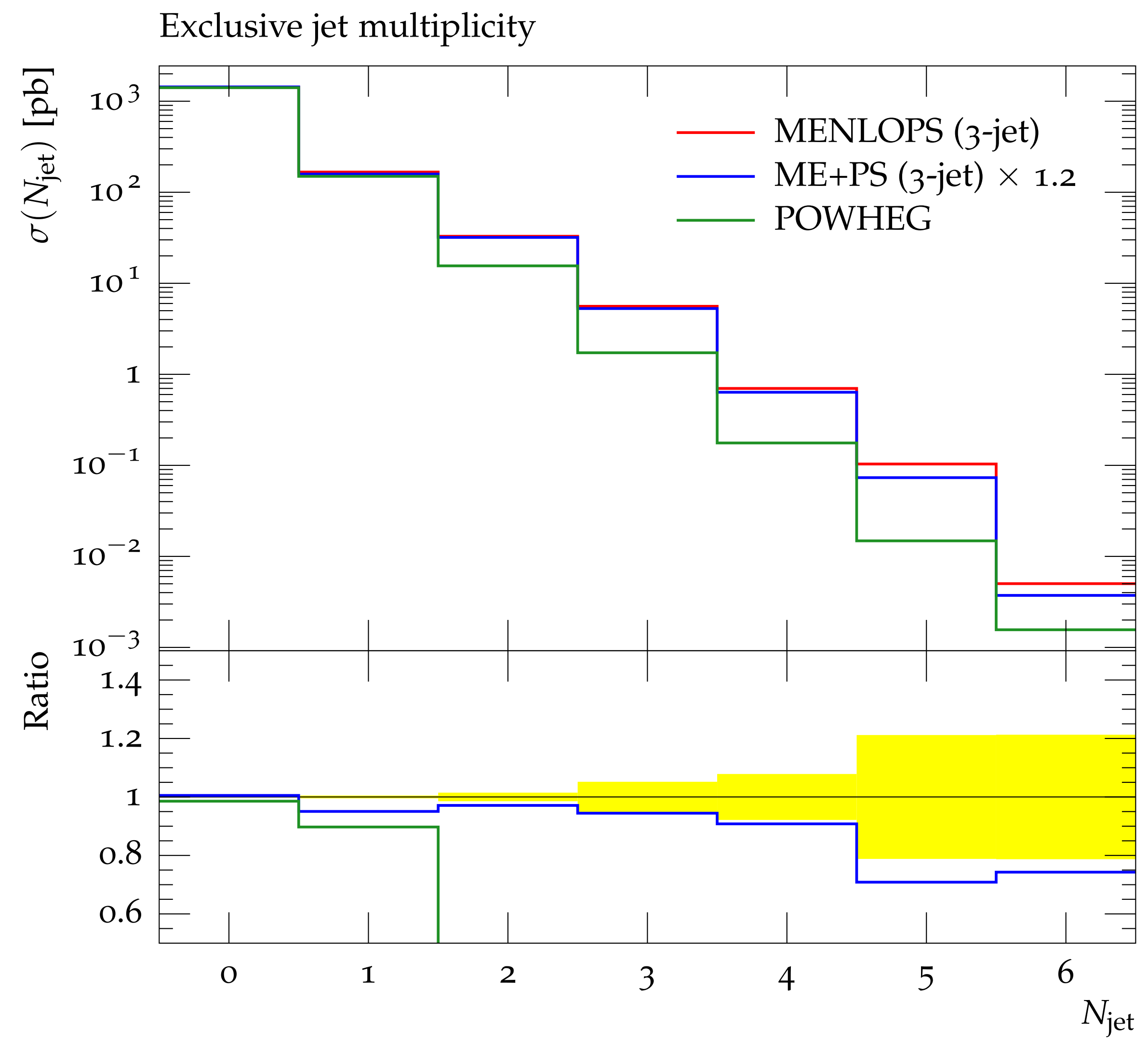
Z MENLOPS at Tevatron



- MENLOPS best for jets 2 & 3

W MENLOPS at Tevatron

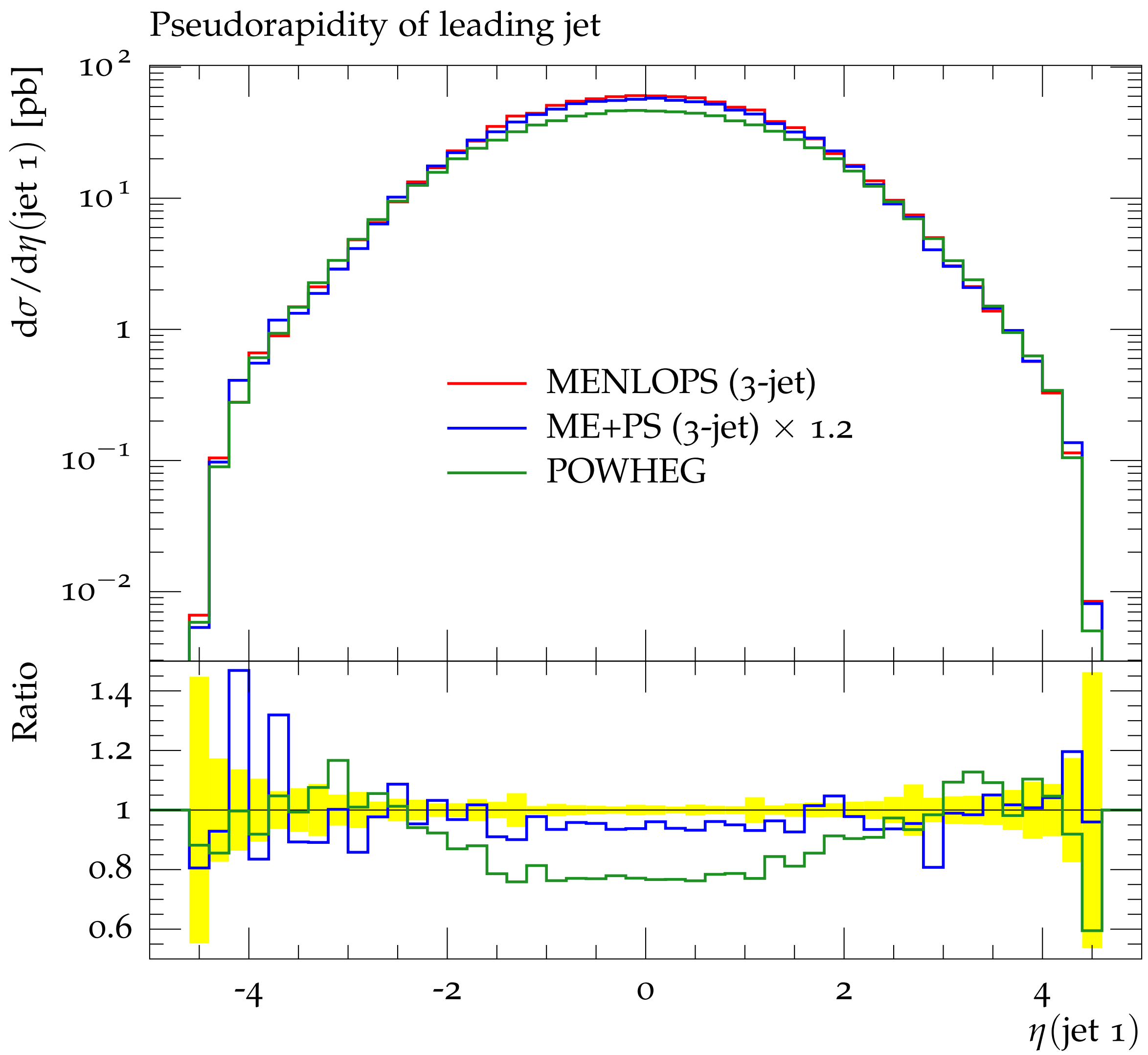


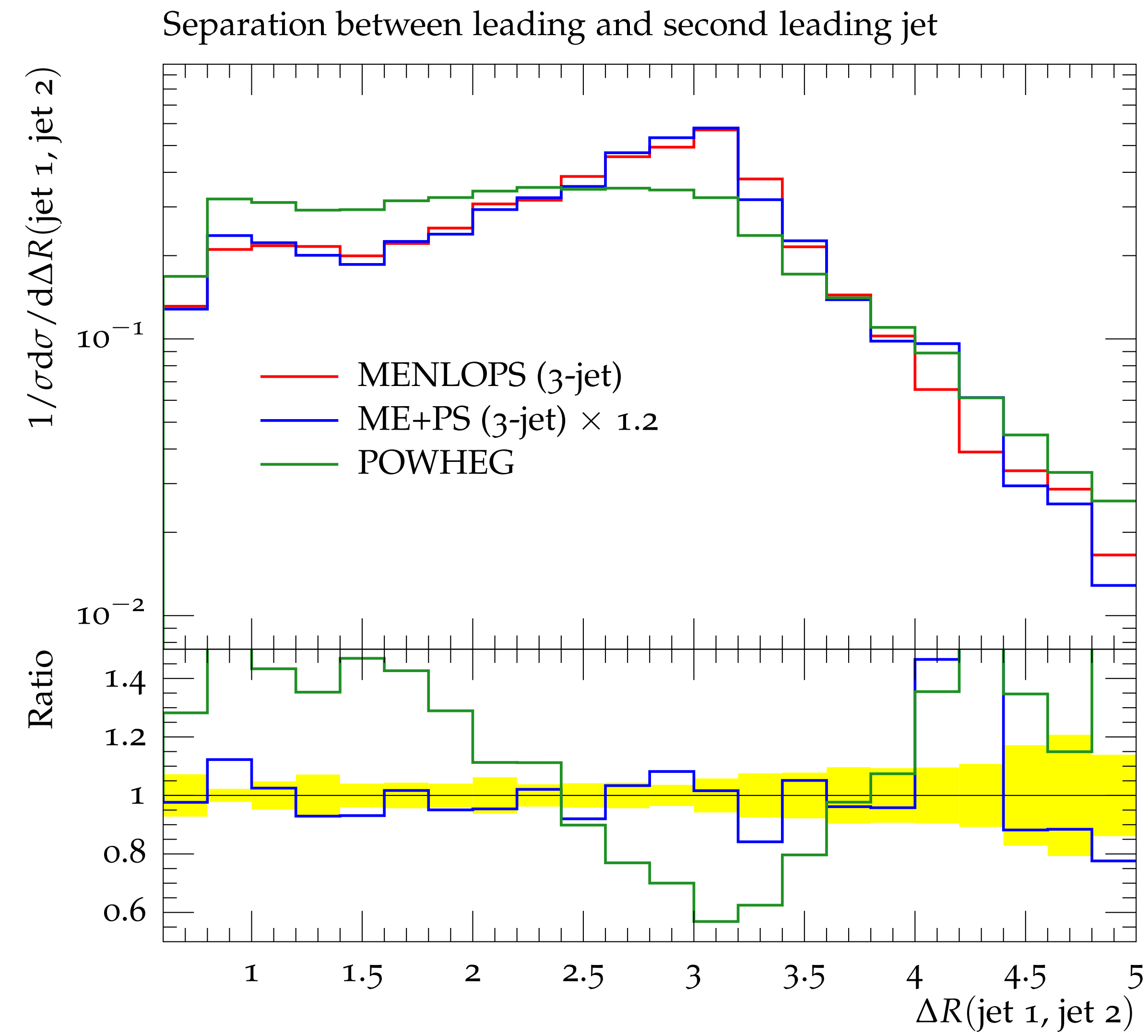


- POWHEG best for $p_t(W)$, lacks ME for $N_{jet}>1$

Hoeche, Krauss, Schumann, Siegert, 1009.1127

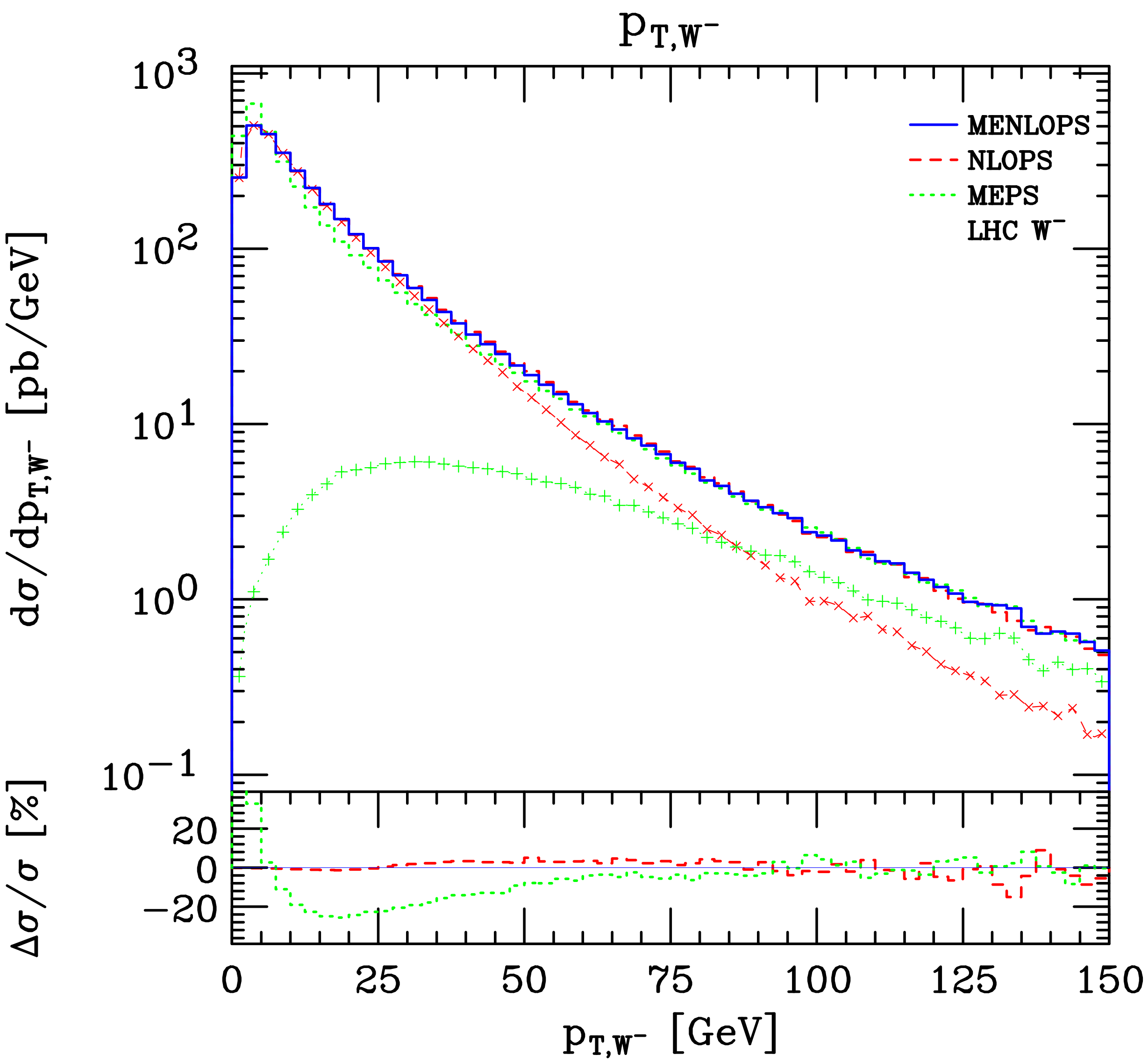
W MENLOPS at Tevatron

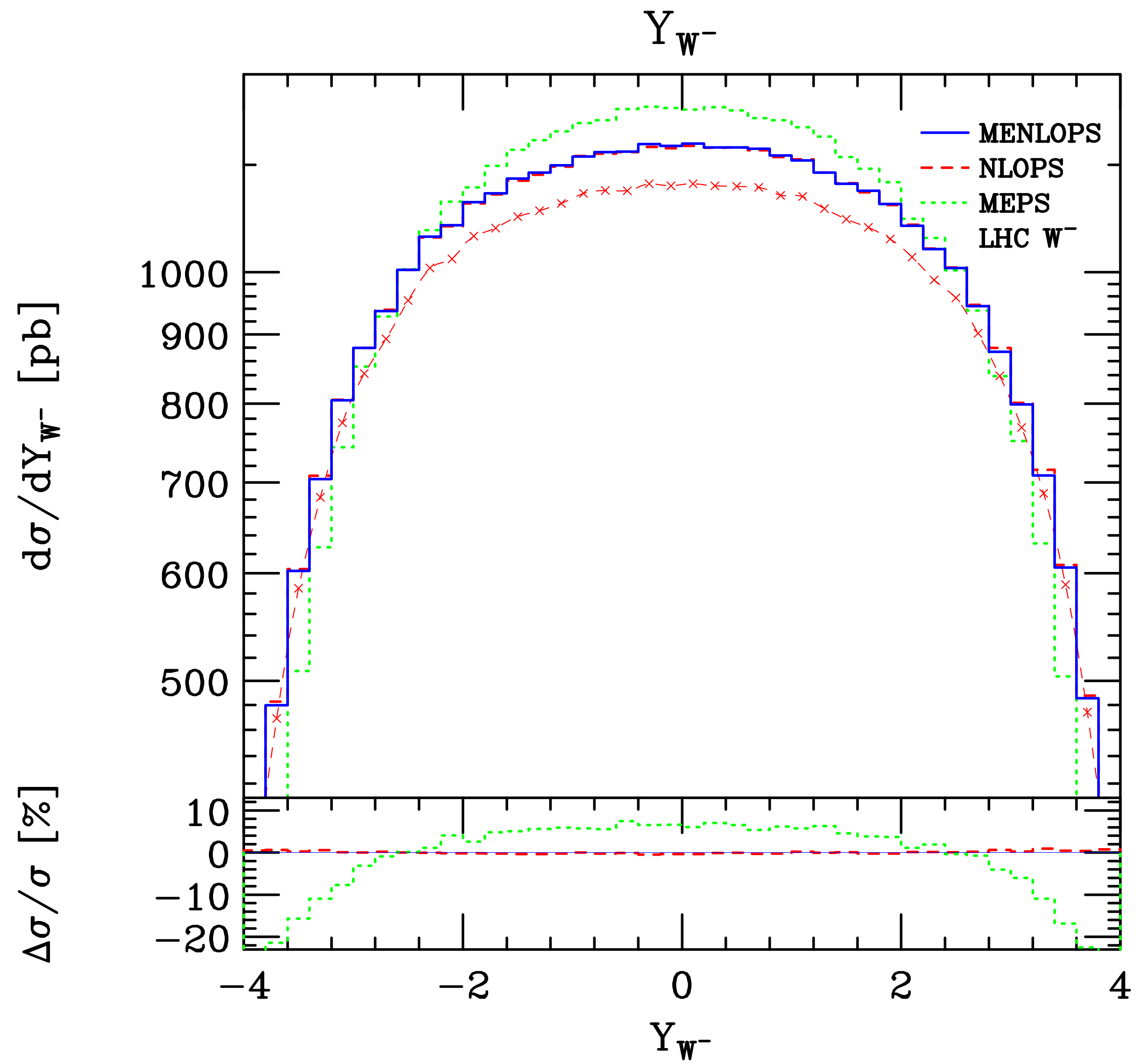




- Again, POWHEG lacks ME for 2nd jet

W MENLOPS at LHC

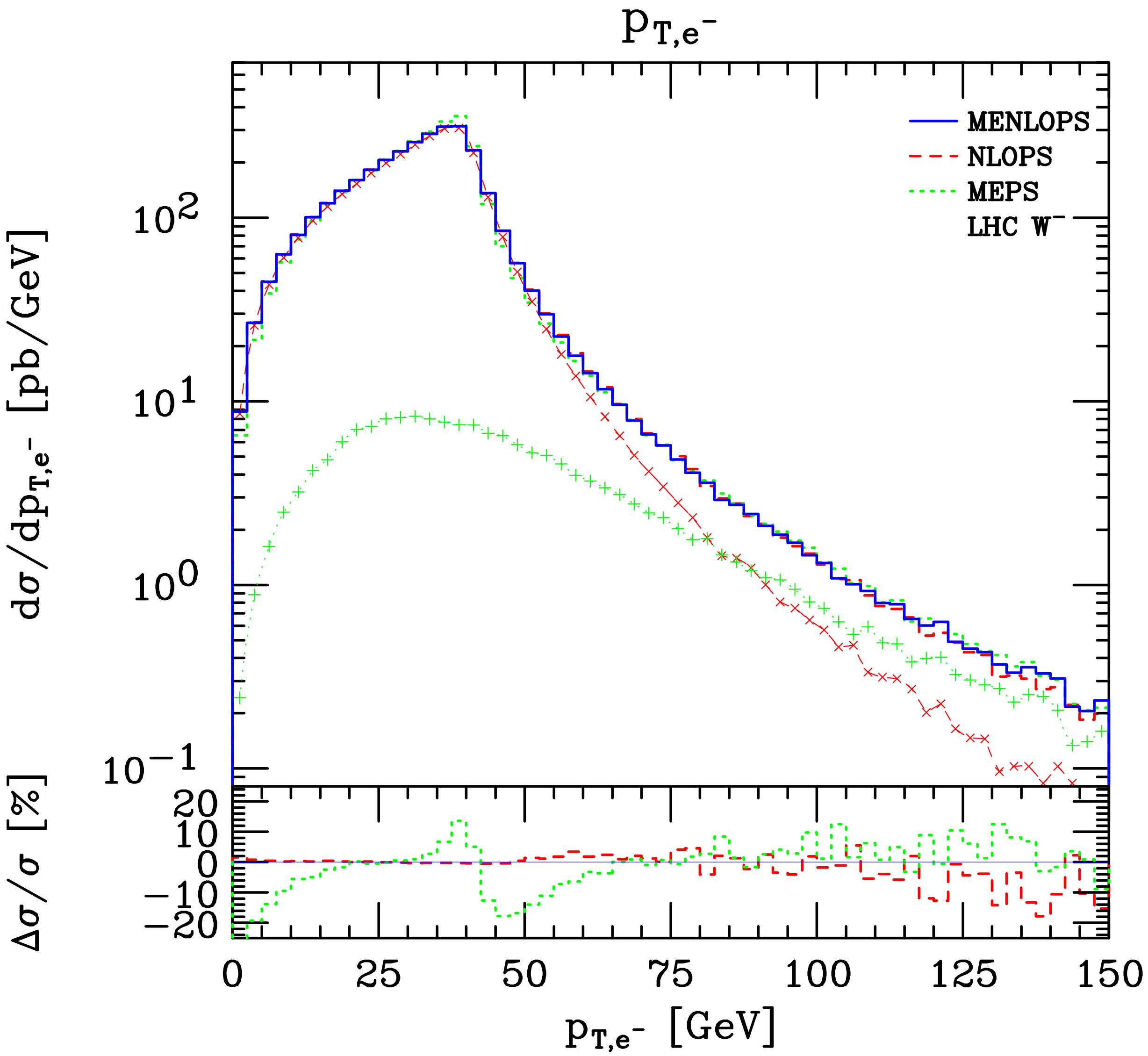


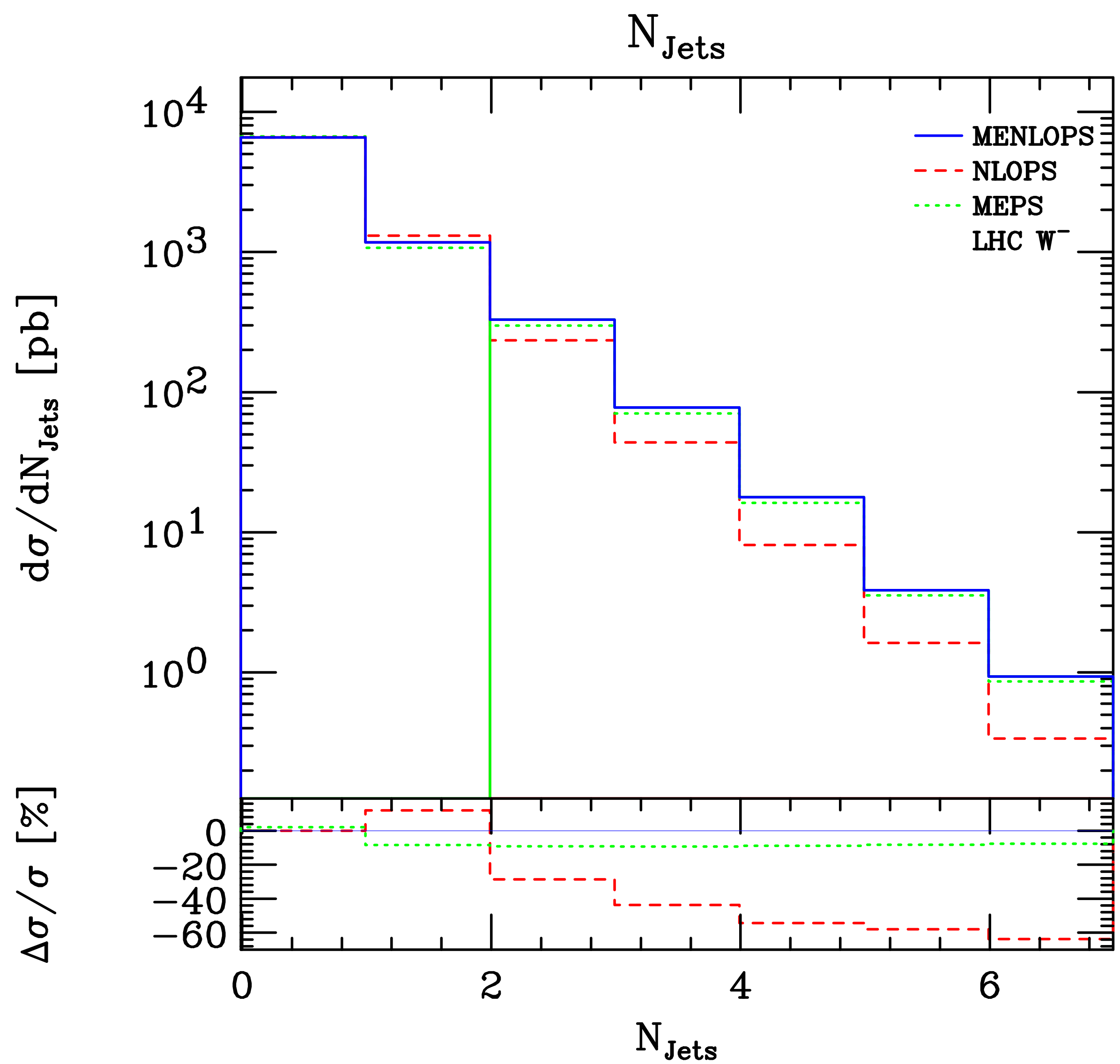


- Dashes are NLOPS & MEPS shapes
- Crosses are contributions to MENLOPS

Hamilton & Nason, JHEP06(2010)039

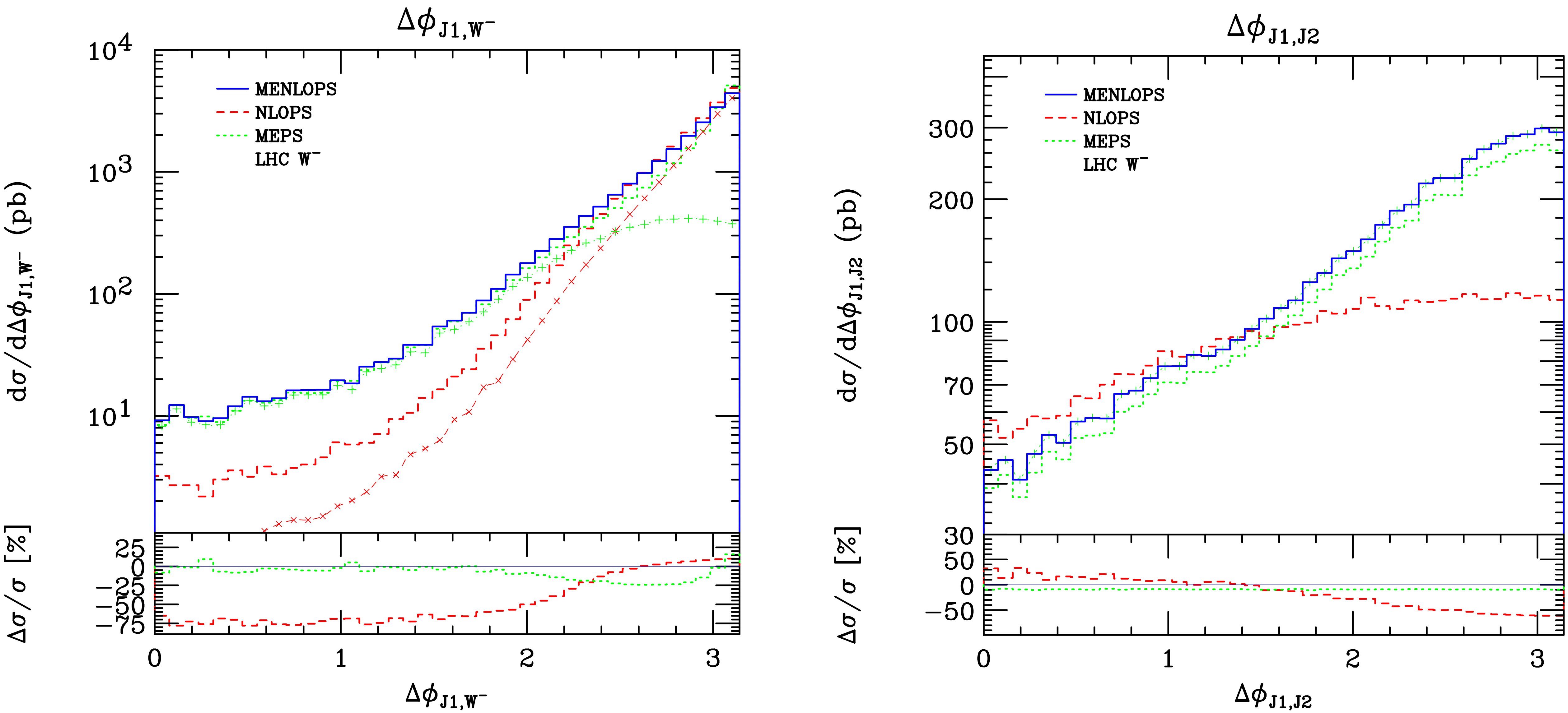
W MENLOPS at LHC





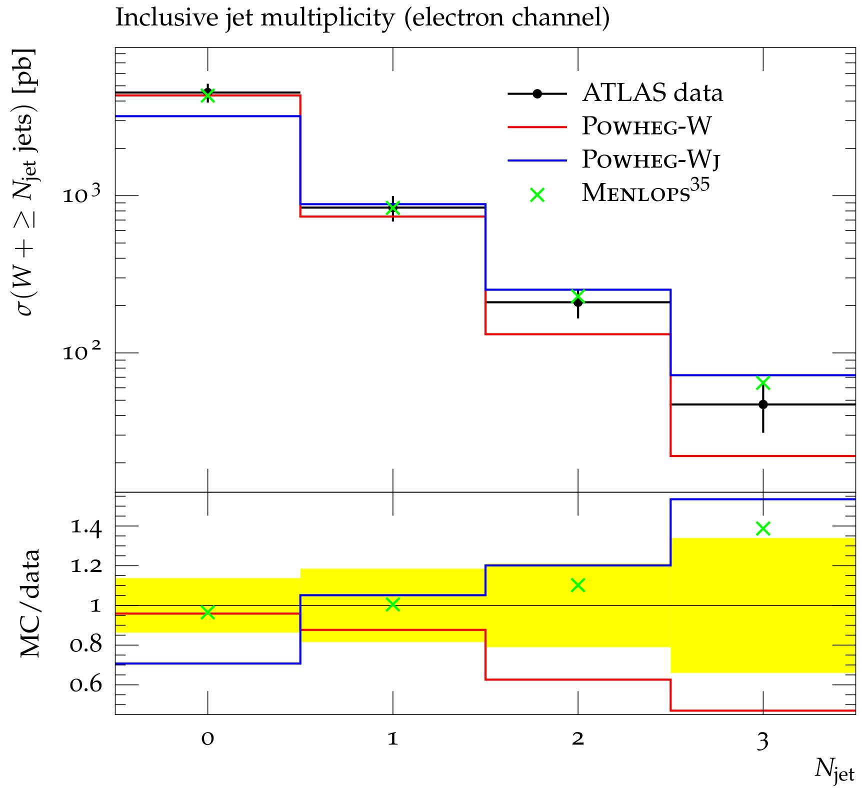
- NLOPS low for N_{jets}>1

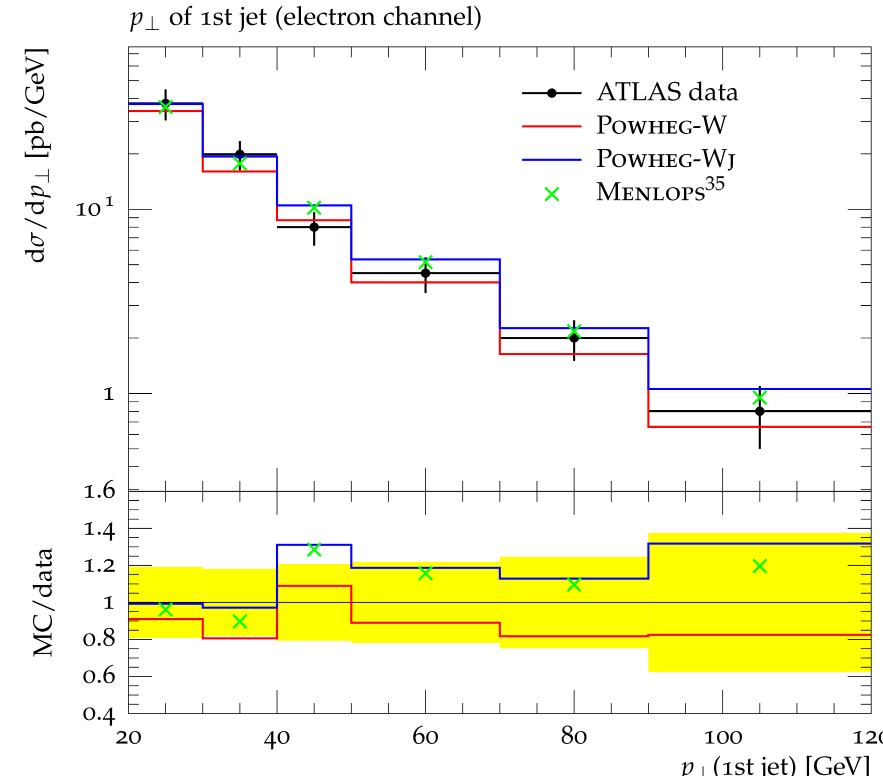
W MENLOPS at LHC

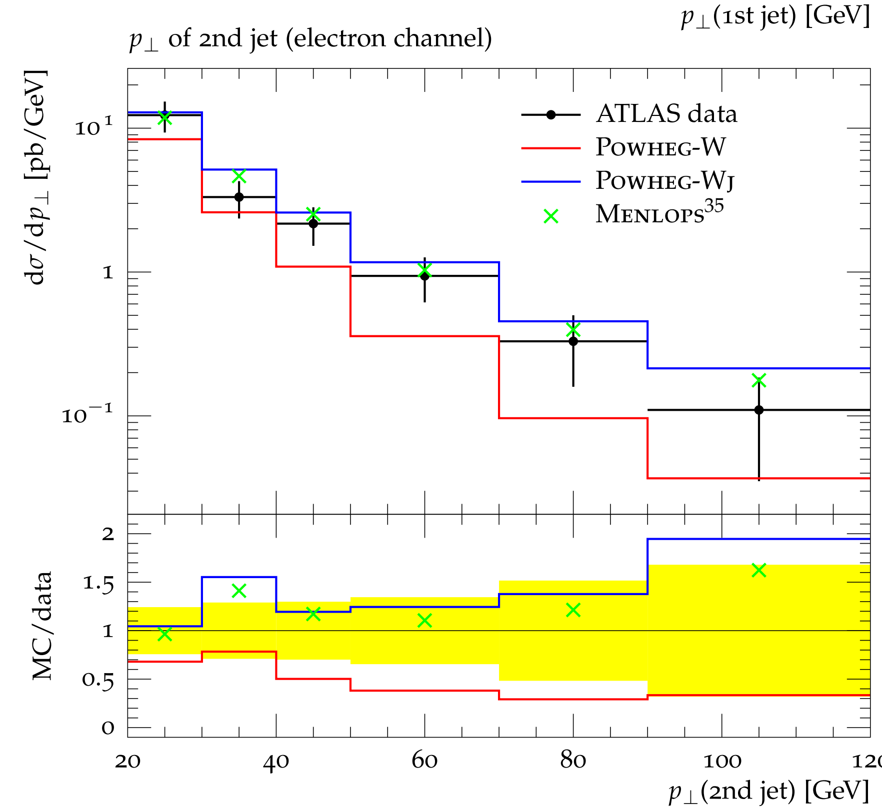


- Again MEPS dominates at small $\Delta\phi_{J1,W^-}$

W MENLOPS at LHC







- MENLOPS matched at p_t=35 GeV

Alioli, Hamilton & Re, 1108.0909

Summary of Lecture 2

- MEPS gives exclusive multijet rates to LO
  - Jet substructure generated with PS
  - CKKW-L uses Sudakov + PS veto
  - MLM uses jet matching
- Good agreement with multijet data
- MENLOPS also gives NLO cross section