Perturbative Stability of V + Jets Ratios and "Data Driven Background" Analyses

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NLO Parton-Level vs. Shower MCs

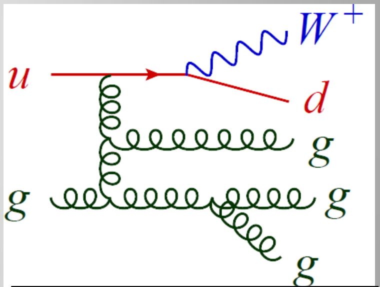
- Recent advances on Les Houches NLO Wish List all at parton level: no parton shower, no hadronization, no underlying event.
- Methods for matching NLO parton-level results to parton showers, maintaining NLO accuracy
  - **MC@NLO** Frixione, Webber (2002), ...
  - **POWHEG** Nason (2004); Frixione, Nason, Oleari (2007); ...
  - **POWHEG in SHERPA** Höche, Krauss, Schönherr, Siegert, 1008.5339
  - **GenEvA** Bauer, Tackmann, Thaler (2008)
- **However, none is yet implemented for final states with multiple light-quark & gluon jets**
- NLO parton-level predictions generally give **best normalizations** for total cross sections (unless NNLO available!), and distributions away from shower-dominated regions.
- Right kinds of **ratios** will be **considerably less sensitive to shower + nonperturbative effects**

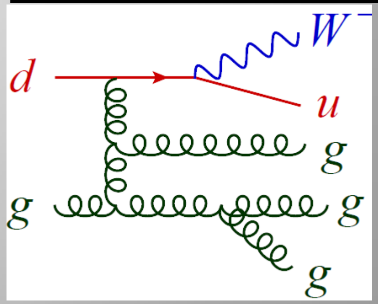
Simple yet robust ratio: W^{+} to W^{-}

Kom, Stirling, 1004.3404.

$$R^{\pm}(n) \equiv \frac{\sigma(W^{+} + n \text{ jets})}{\sigma(W^{-} + n \text{ jets})}$$

n	QQ	Qg	gg
0	100	0	0
1	18	82	0
2	21	73	6
3	23	70	7
4	25	67	8





- Very small experimental systematics
- (N)NLO QCD corrections quite small, 2% or less
- → Intrinsic theoretical uncertainty very small.
- PDF uncertainty also ~1-2%. Driven by PDF ratio

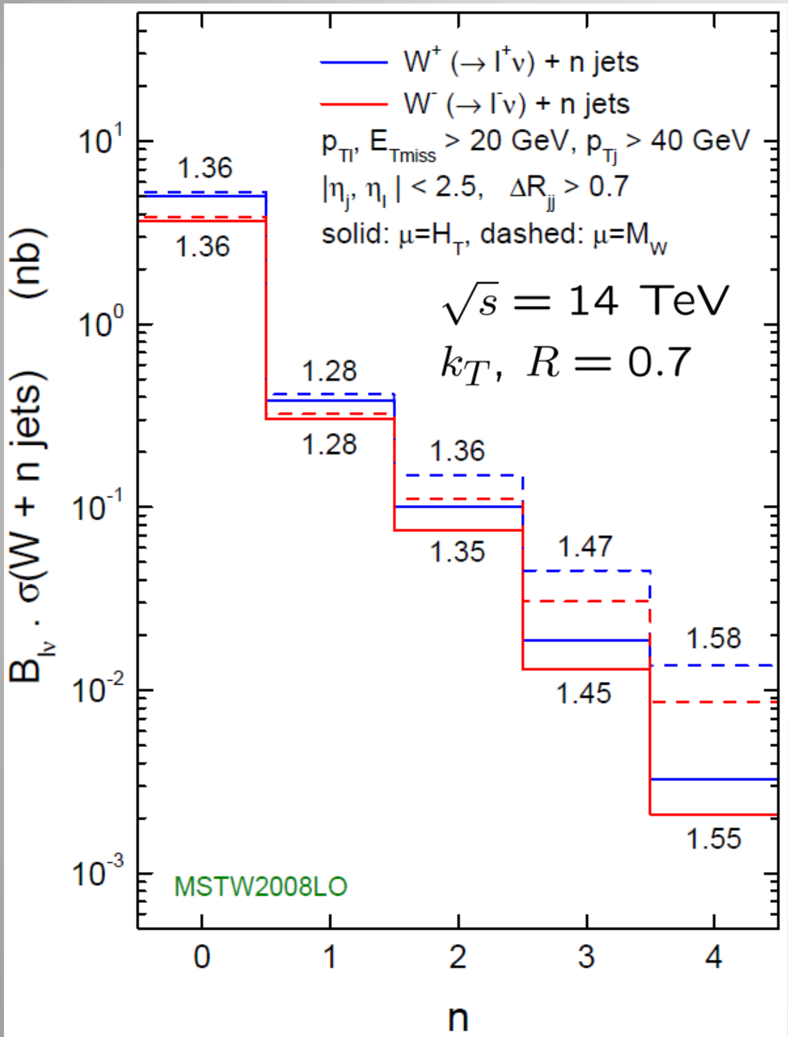
  $u(x)/d(x)$

  in well-measured valence region of moderate x.
- Sensitive to new physics (or Higgs, or top quark pairs) that produces W symmetrically
- Fraction of new physics in sample is:

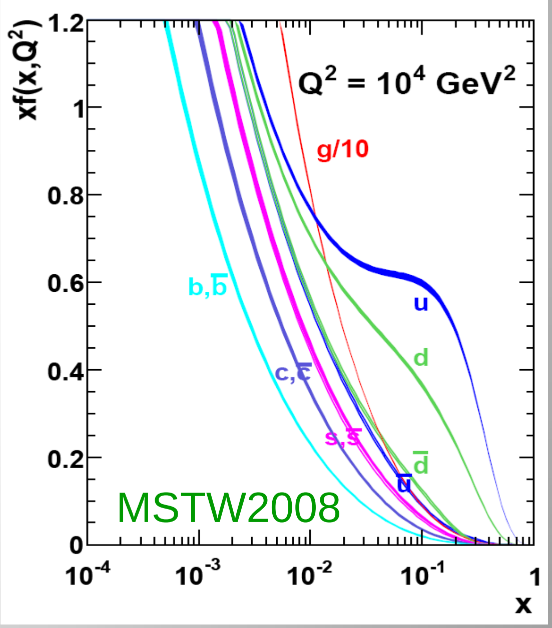
$$f_{\text{NP}} = \frac{2(R^{\pm}_{\text{SM}} - R^{\pm}_{\text{exp.}})}{(R^{\pm}_{\text{SM}} + 1)(R^{\pm}_{\text{exp.}} - 1)}$$

W^+ to W^- ratio at LO

Kom, Stirling, 1004.3404.



- Huge scale dependence at LO cancels in ratio
- Increases with *n* due to increasing *x*



W^+ to W^- ratio at NLO

Berger et al. [BlackHat+SHERPA]1009.2338

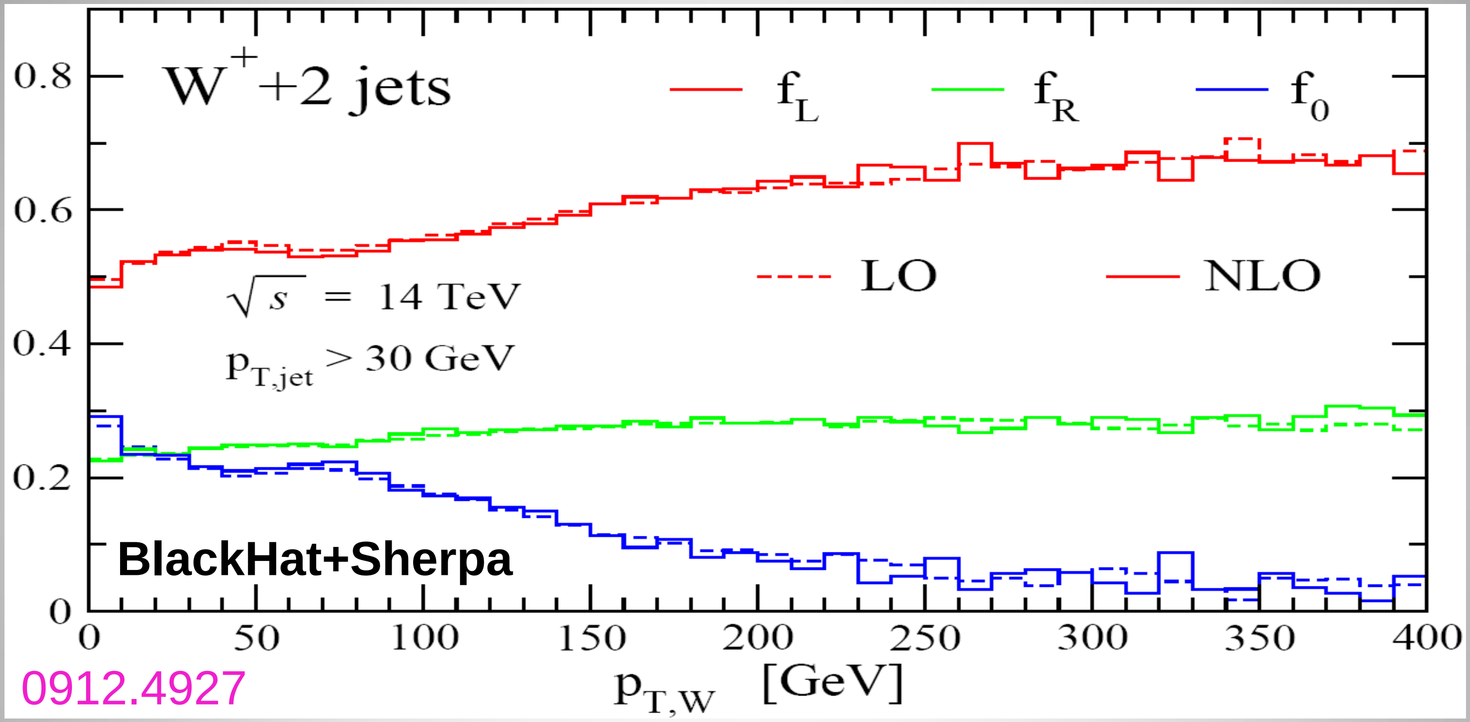
$\sqrt{s} = 7$ TeV
anti-k_T, $R = 0.5$
$p_T^{\text{jet}} > 25$ GeV

- Moderate scale dependence at NLO again cancels in ratio
- Increases with *n* due to increasing *x*, but a little more slowly than at LO.

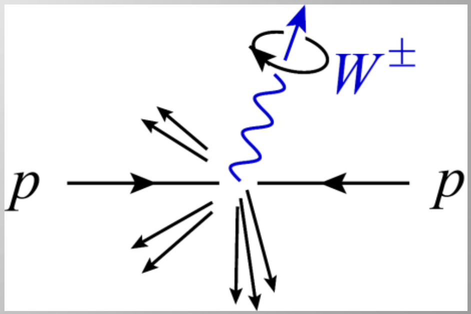
no. jets	W^- LO	W^- NLO	W^+/W^- LO	W^+/W^- NLO
0	$1614.0(0.5)^{+208.5}_{-235.2}$	$2077(2)^{+40}_{-31}$	$1.656(0.001)$	$1.580(0.004)$
1	$264.4(0.2)^{+22.6}_{-21.4}$	$331(1)^{+15}_{-12}$	$1.507(0.002)$	$1.50(0.01)$
2	$73.14(0.09)^{+20.81}_{-14.92}$	$78.1(0.5)^{+1.5}_{-4.1}$	$1.596(0.003)$	$1.57(0.02)$
3	$17.22(0.03)^{+8.07}_{-4.95}$	$16.9(0.1)^{+0.2}_{-1.3}$	$1.694(0.005)$	$1.66(0.02)$
4	$3.81(0.01)^{+2.44}_{-1.34}$	$3.56(0.03)^{+0.08}_{-0.30}$	$1.82(0.01)$	—

NLO W^+ + 4 jet computation still being completed

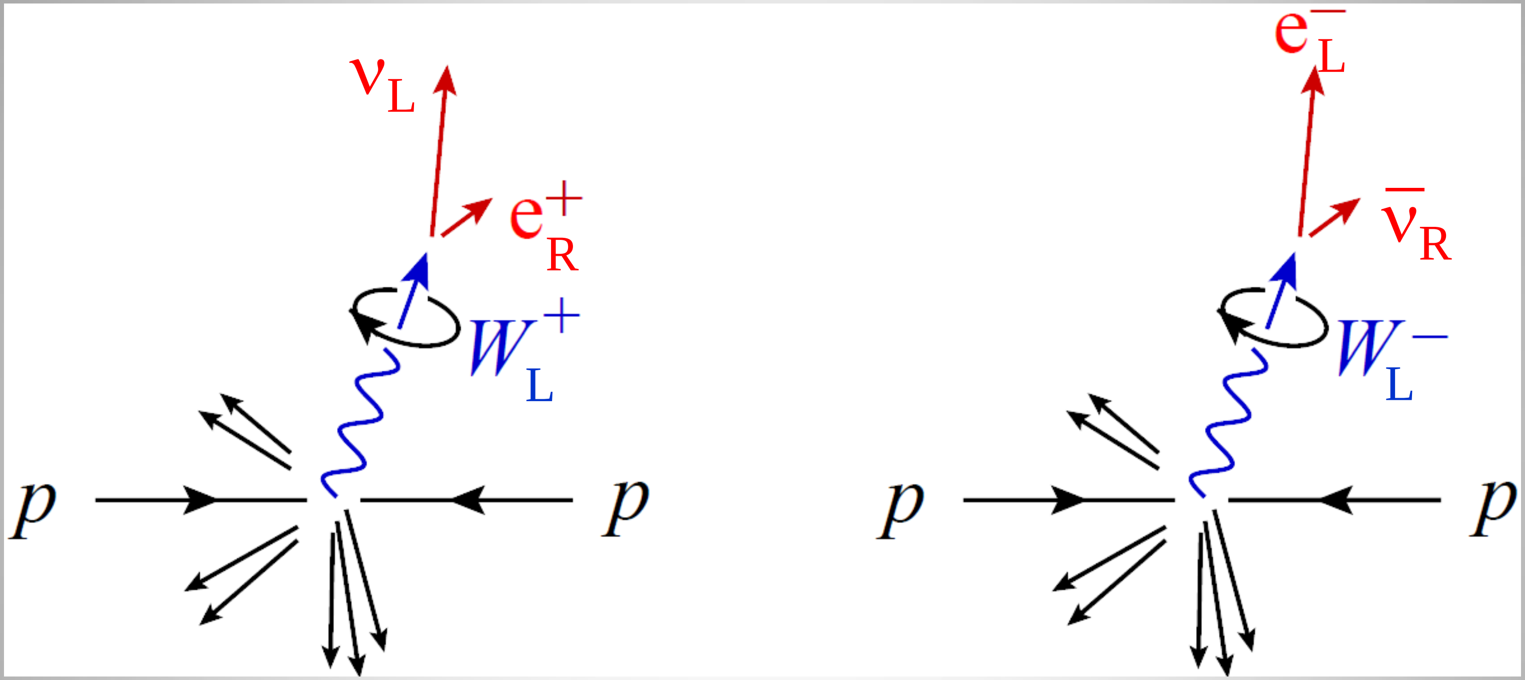
W polarization fractions at moderate p_T



- **Strong left-handed polarization for W^+ and W^-**
- Increases slowly with W boson p_T and with number of jets, due to increasing parton x
- Very stable against QCD corrections

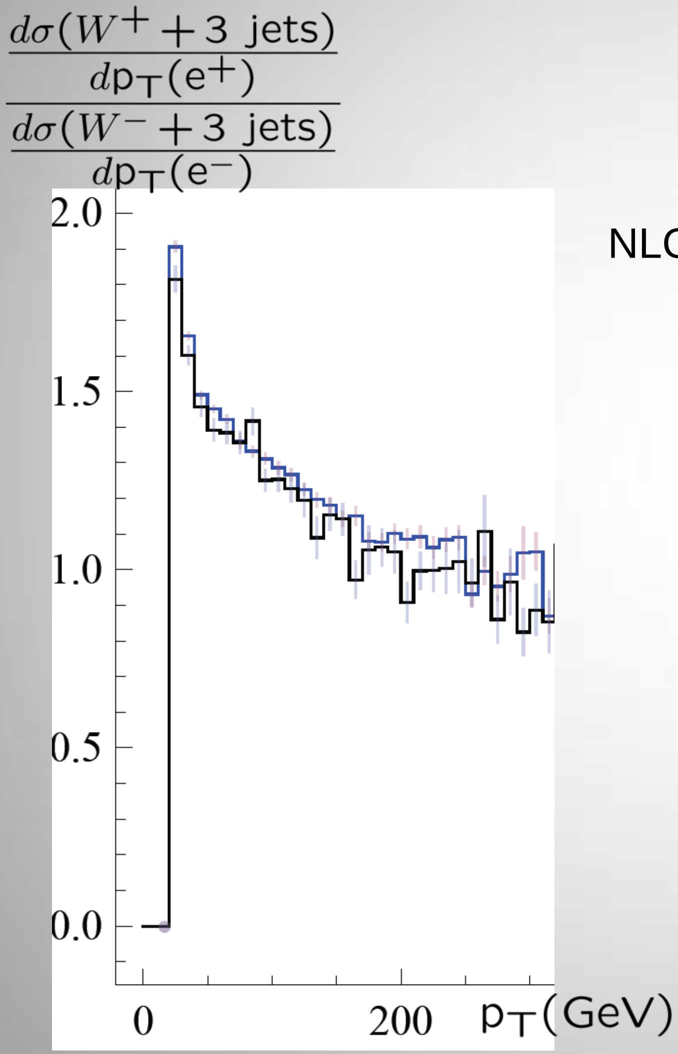


W polarization analyzed by leptonic decay

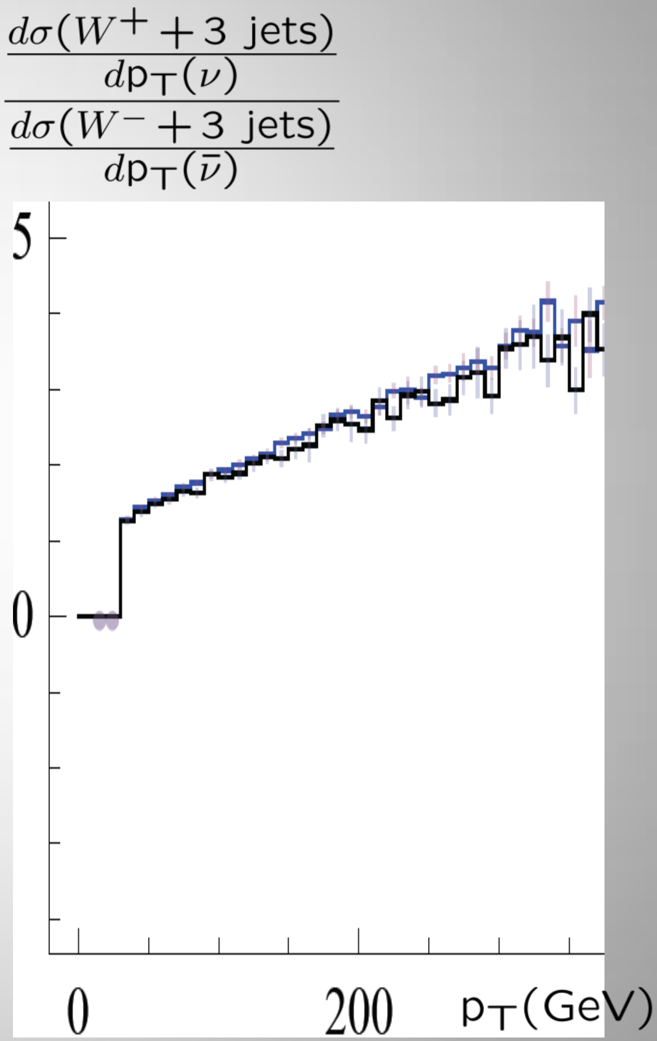


- **Left-handed polarization translates into:**
  - larger p_T for ν_L (missing E_T) in W^+ events
  - larger p_T for e_L in W^- events
- **$SU(2)_L$ pure V-A → 100% analyzing power**

$W^{+/-}$ + 3 jets: lepton p_T ratios



NLO LO



Top quark pairs very different

Main production channels are C invariant:

$$gg \to t\bar{t} \qquad\qquad q\bar{q} \to t\bar{t}$$

Semi-leptonic decay involves (partially) left-handed W^+

$$t\bar{t} \;\to\; bW^+\bar{b}W^- \;\to\; b\,e^+\nu\,\bar{b}jj$$

But charge conjugate decay involves (same degree) right-handed W^-

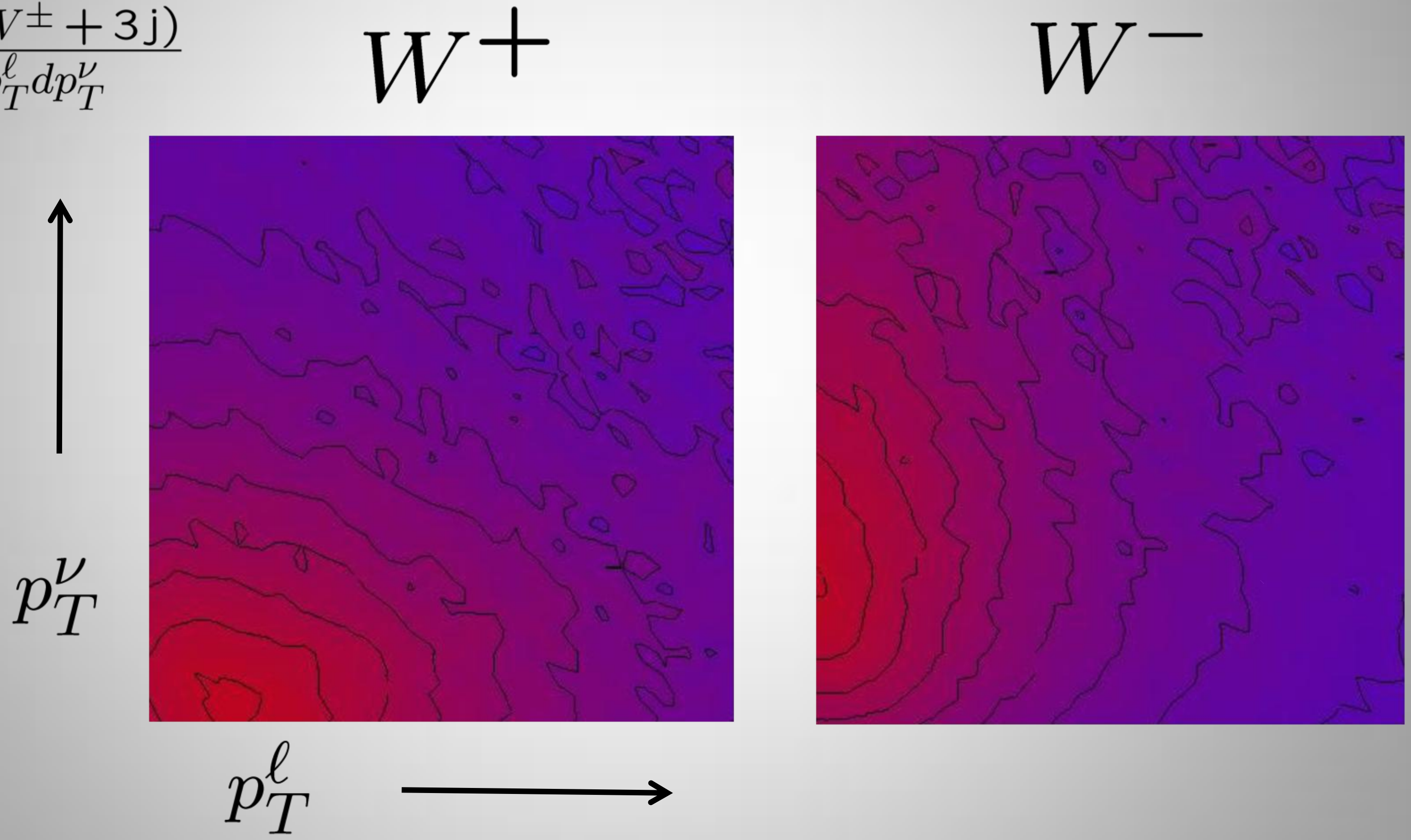
$$t\bar{t} \;\to\; bW^+\bar{b}W^- \;\to\; bjj\,\bar{b}\,e^-\bar{\nu}$$

→ electron and positron have almost identical p_T distributions

→ Nice handle on separating W + jets from semileptonic top pairs

Semi-leptonic tops vs. $W + 3$ jets

$$\frac{\dfrac{d^2\sigma(t\bar{t}\to W^{\pm}+3\mathrm{j}+X)}{dp_T^{\ell}\,dp_T^{\nu}}}{\dfrac{d^2\sigma(W^{\pm}+3\mathrm{j})}{dp_T^{\ell}\,dp_T^{\nu}}}$$



What about new physics?

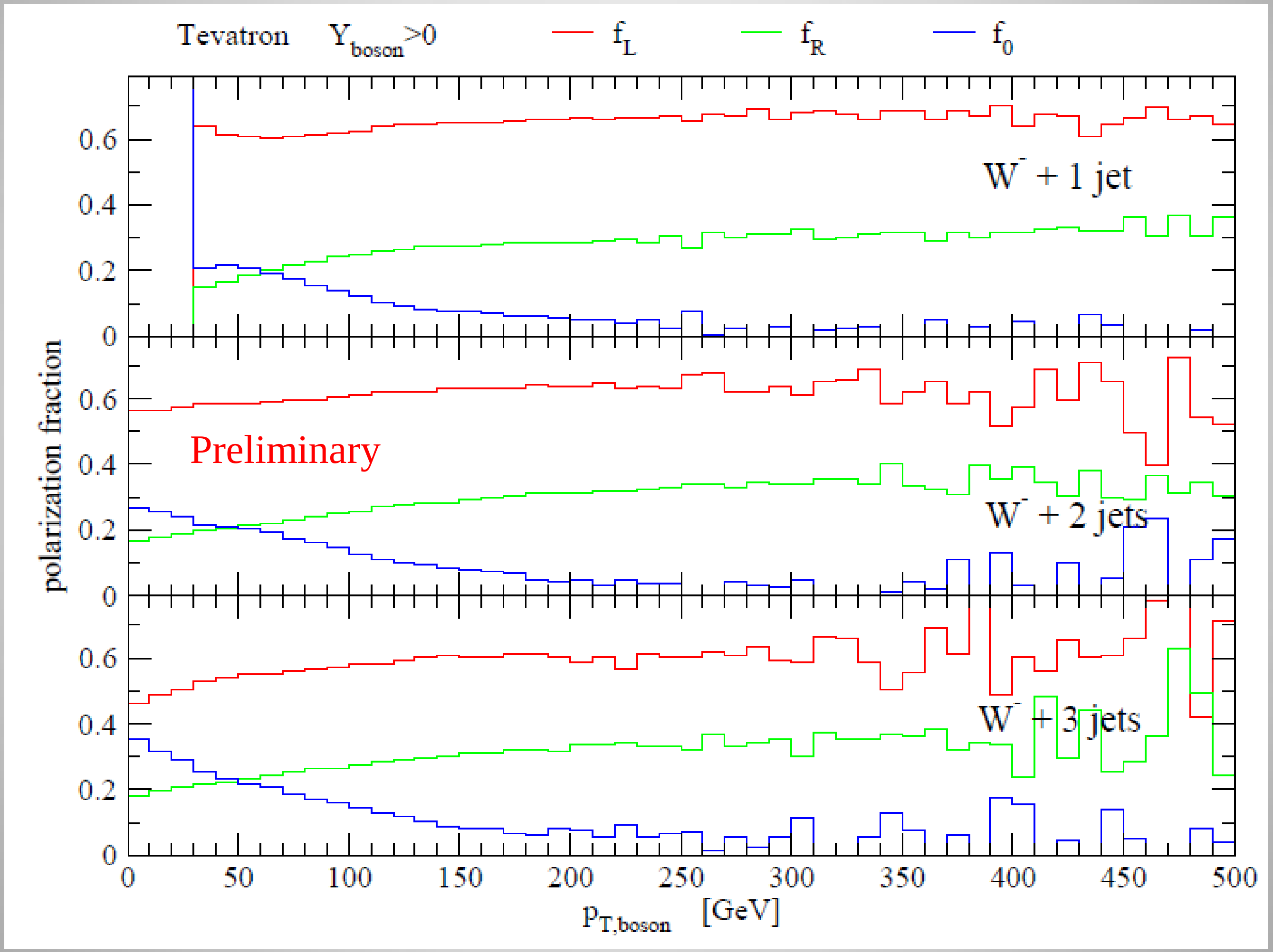
Whether e^+ looks like e^- depends on production channels involved

For example supersymmetry: Depends on whether initial quarks are correlated with final leptons:

gg or $q\bar{q} \longrightarrow \tilde{g}\tilde{g}$ or $\tilde{q}\tilde{\bar{q}}$ $\qquad e^+ \approx e^-$ (at $O(\alpha_s^2)$)

$qg \longrightarrow \tilde{q}\tilde{g}$ $\qquad e^+ \neq e^-$

W polarization even large at Tevatron

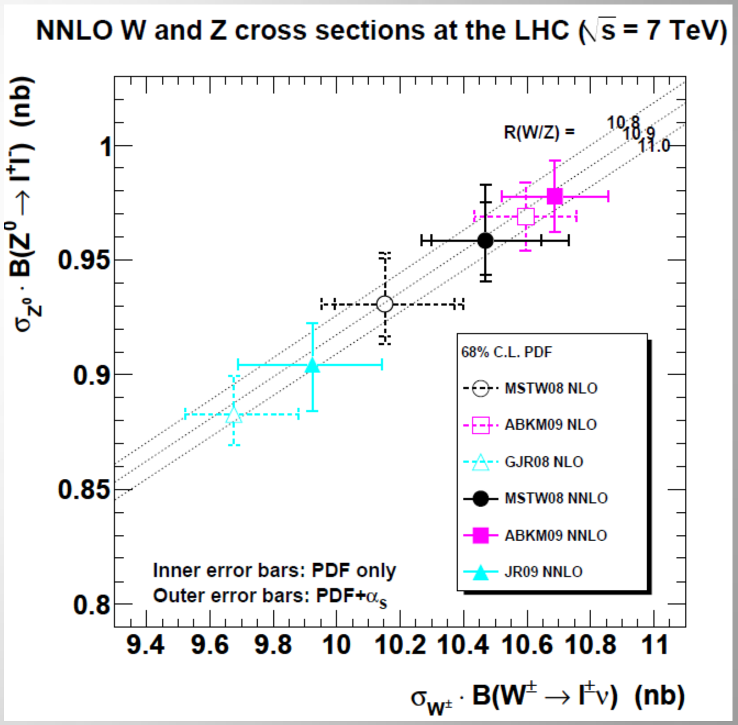


LO

W/Z ratios

$$R^{W/Z}(n) \equiv \frac{\sigma(W^+ + n \text{ jets}) + \sigma(W^- + n \text{ jets})}{\sigma(Z + n \text{ jets})} \frac{\text{Br}(W \to \ell\nu)}{\text{Br}(Z \to \ell^+\ell^-)}$$

- Like W^+/W^- ratio, stable against perturbative nonperturbative QCD effects, since $M_W \approx M_Z$
- Like W^+/W^- ratio, in inclusive case ($n = 0$) it's a precision observable, computable at NNLO, also including experimental cuts
- Perhaps not quite as clean experimentally as W^+/W^-, because W and Z selections are not identical, top background is different

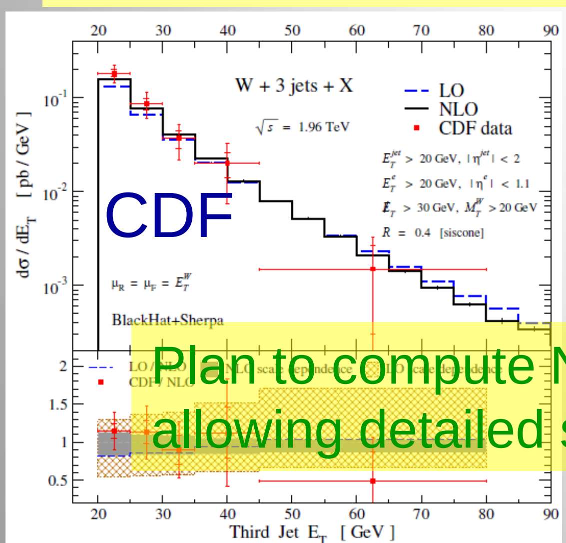


MSTW

W/Z ratios (cont.)

$$R^{W/Z}(n) \equiv \frac{\sigma(W^+ + n \text{ jets}) + \sigma(W^- + n \text{ jets})}{\sigma(Z + n \text{ jets})} \frac{\text{Br}(W \to \ell\nu)}{\text{Br}(Z \to \ell^+\ell^-)}$$

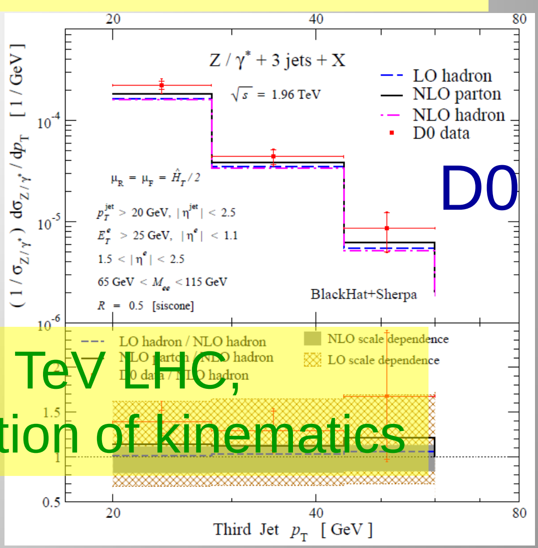
- Like ***W^+/W^-*** ratio, now computable at NLO for up to 3 associated jets [**BlackHat+Sherpa**]
- Use ratio, plus measurement of ***W ($\rightarrow l\nu$) + n jets*** to calibrate ***$Z(\rightarrow \nu\nu)$ + n jets*** bkgd to MET+jets searches [CMS analysis note]
- Much better statistics than ***$Z(\rightarrow l^+l^-)$ + n jets***



NLO

W + 3 jets Z + 3 jets

vs. Tevatron data



Plan to compute NLO W/Z + 1,2,3 jets for 7 TeV LHC, allowing detailed study of *W/Z* ratio as function of kinematics

One last ratio: Jet production ratio

"Folk theorem" – sometimes referred to as "Berends scaling":

Ellis, Kleiss, Stirling, PLB 154, 435 (1985); Berends, Giele, Kuijf, Kleiss, Stirling, PLB 224, 237 (1989); Berends, Kuijf, Tausk, Giele, NPB 357, 32 (1991); Abouzaid, Frisch, hep-ph/0303088; D0, hep-ex/0205019; CDF, hep-ex/0312008

Adding one more jet reduces the cross section by a constant factor (which depends on jet definition), i.e. uniform jet emission probability r.

Using *W* + n jets at NLO for n=1,2,3,4 we can test this scaling at NLO parton level.

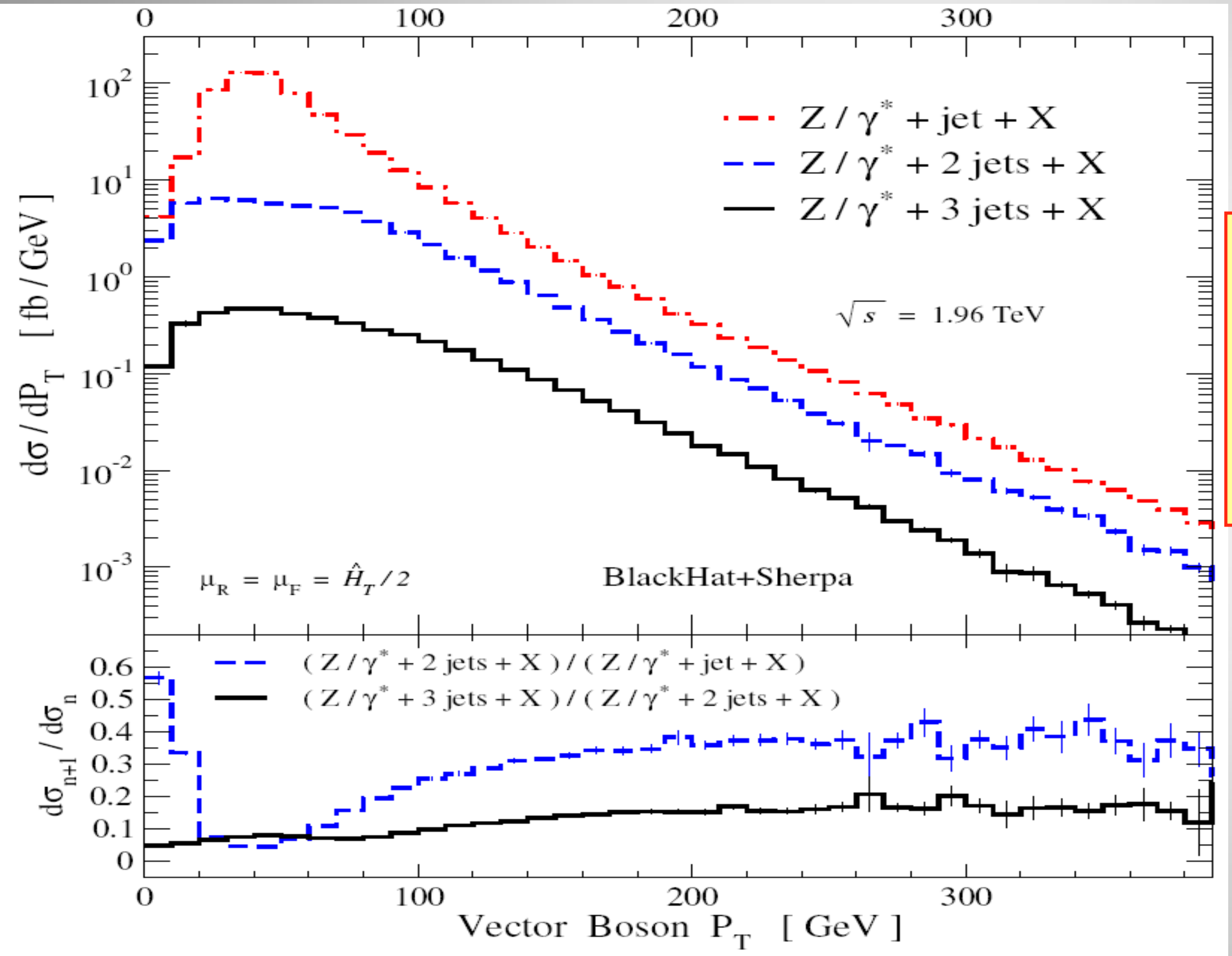
Jet-production ratios for $W + n$ jets at LHC

- These ratios are not as stable in perturbation theory as $W+/W-$ or W/Z.
- But more stable than $\sigma(W + \text{n jets})$.

no. jets	LO $W^- \; n/(n-1)$	NLO $W^- \; n/(n-1)$
1	$0.164^{+0.044}_{-0.031}$	0.159
2	$0.277^{+0.051}_{-0.037}$	0.236
3	$0.235^{+0.034}_{-0.025}$	0.216
4	$0.221^{+0.026}_{-0.020}$	0.211

$\sqrt{s} = 7$ TeV
anti-k_T, $R = 0.5$
$p_T^{\text{jet}} > 25$ GeV

$P_T(Z)$ distribution in $Z + n$ jets at Tevatron



jet production ratio certainly not uniform bin by bin in $P_T(Z)$

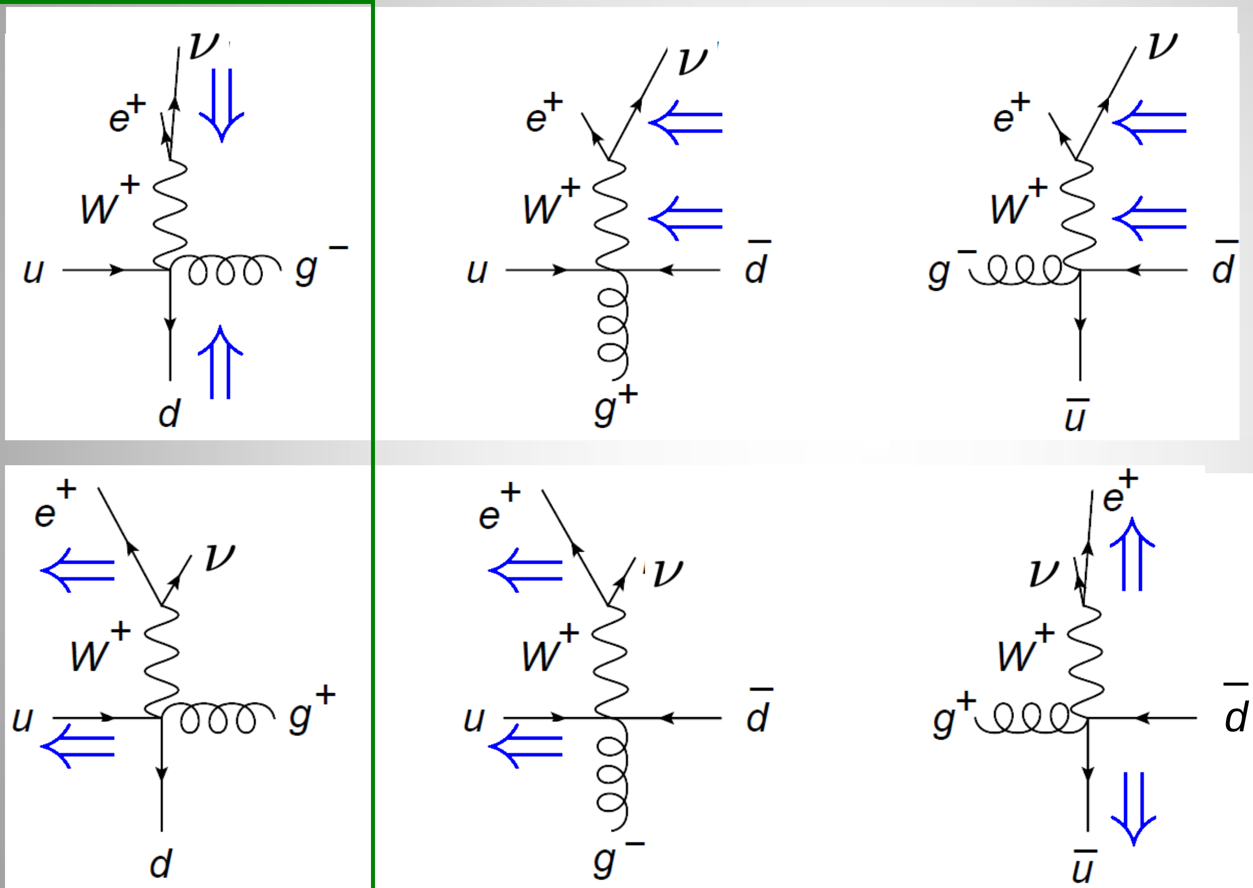
$$\sigma_n \neq C r^n$$

Conclusions

- State-of-art NLO V + 2,3,4 jet results are still at parton level, not embedded in a shower Monte Carlo
- Best use may be via **ratios** – aids to data-driven analysis of backgrounds.
- W^+/W^- ratio in presence of additional jets is nontrivial, well-determined, sensitive to new physics
- *(W + jets)/(Z + jets)* also interesting, but a bit harder experimentally.
- Left-handed *W* polarization is surprisingly large and very stable, leading to further charge-asymmetric effects in *W* + *n* jets
- "Jet production ratios" are less uncertain than individual multi-jet rates.
- Will be interesting to see how these predictions stand up against the first fb^{-1}

Origin of *W* polarization at LHC: Simplest case – LO *W* + 1 jet

SU(2)$_L$ + valence quark dominance



$$A^{\text{tree}} \propto \frac{\langle d\,\nu\rangle^2}{\langle u\,g\rangle\langle g\,d\rangle}$$

$$d\sigma \;\propto (k_d \cdot k_\nu)^2$$

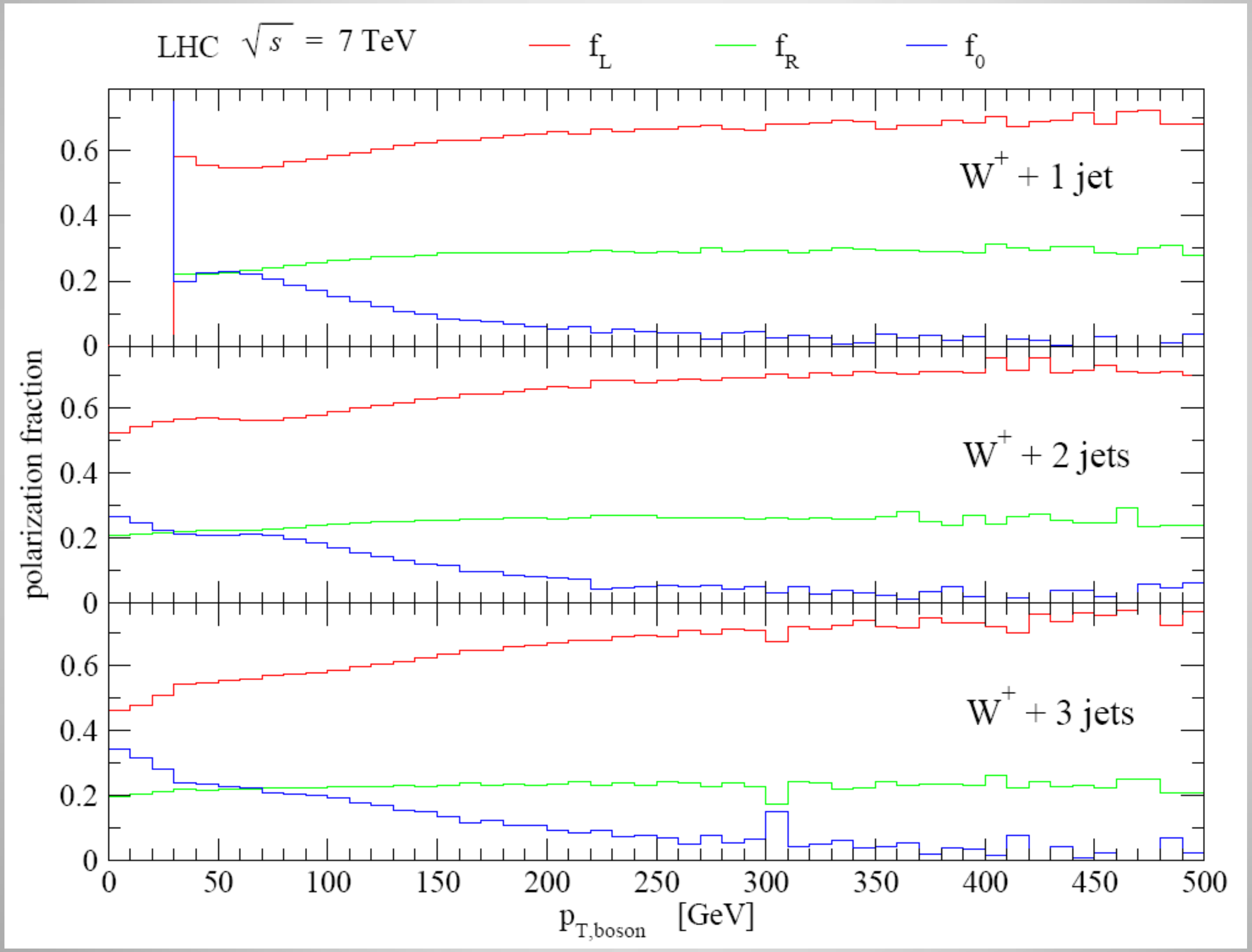
$$A^{\text{tree}} \propto \frac{[u\,e]^2}{[u\,g][g\,d]}$$

$$d\sigma \;\propto (k_u \cdot k_e)^2$$

dominate due to PDFs

W + 2,3 jets is more complex still

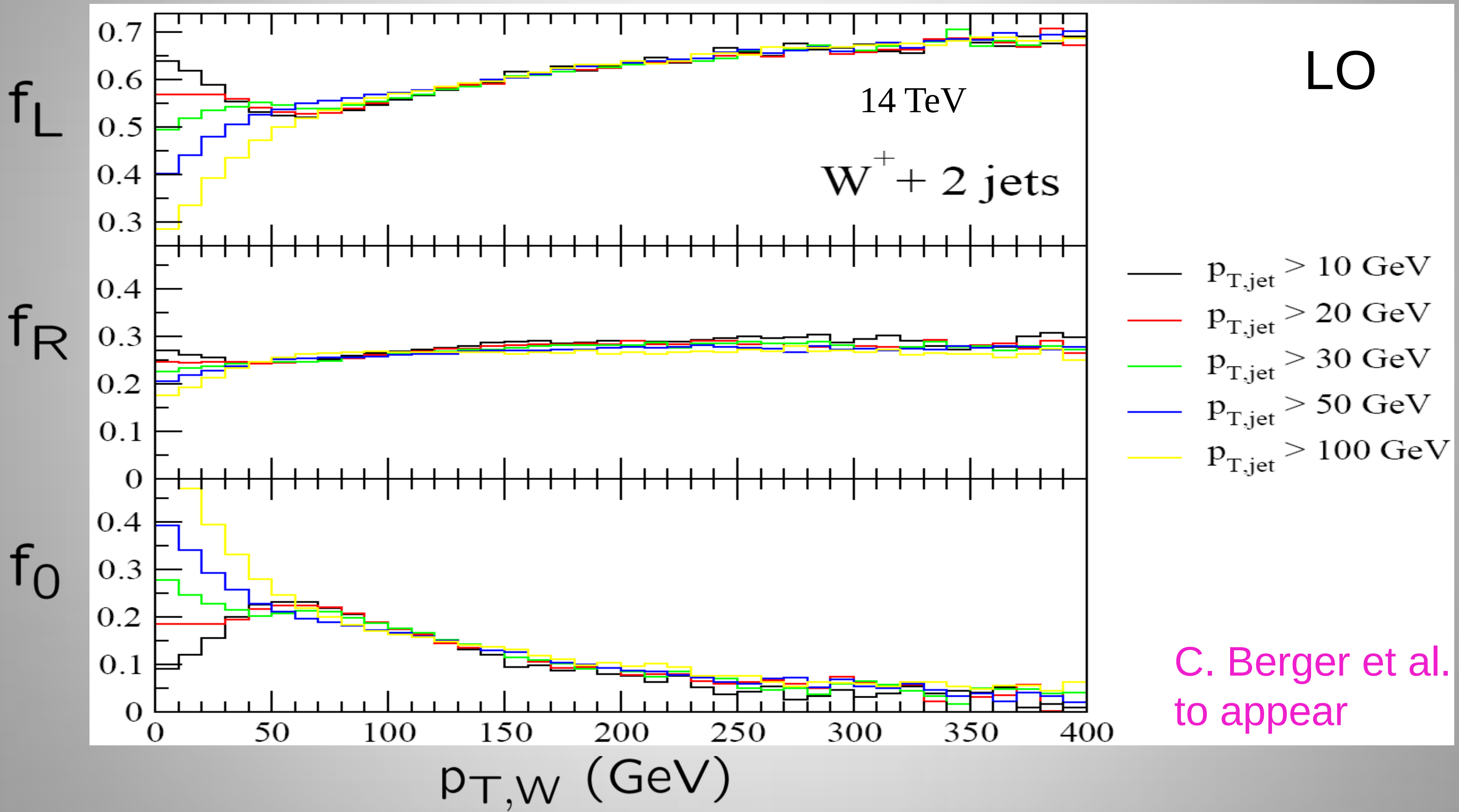
Polarization very similar for 1, 2 or 3 jets



LO

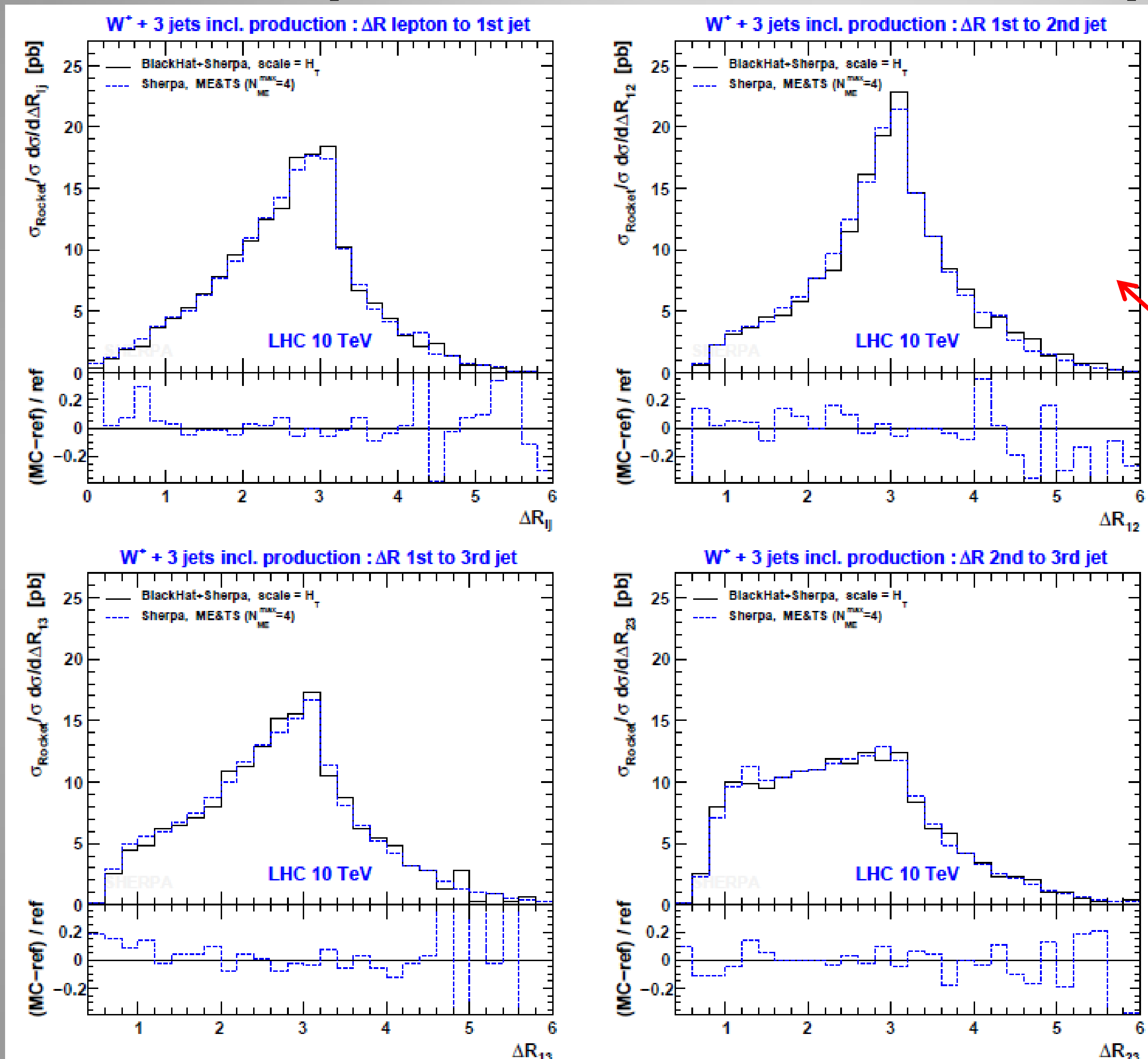
C. Berger et al. to appear

Polarization at moderate $p_{T,W}$ very stable *vs.* jet p_T cut



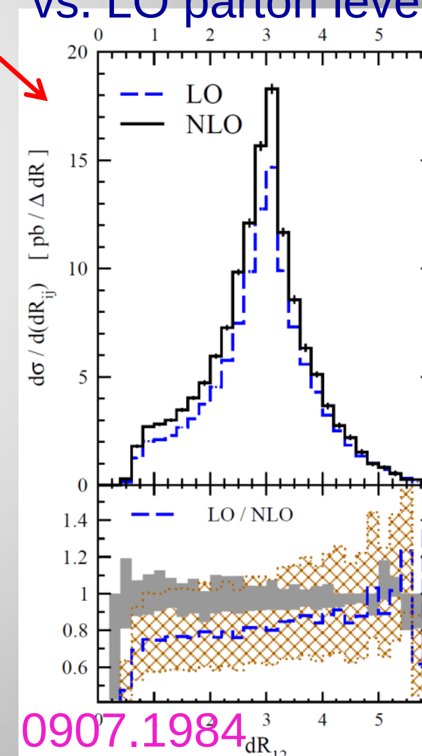
C. Berger et al. to appear

Jet Separations vs. Sherpa shower



Les Houches 2009
SM and NLO
working
group report,
1003.1241

vs. LO parton level



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