Study of Wjj at NLOwPS using aMC@NLO

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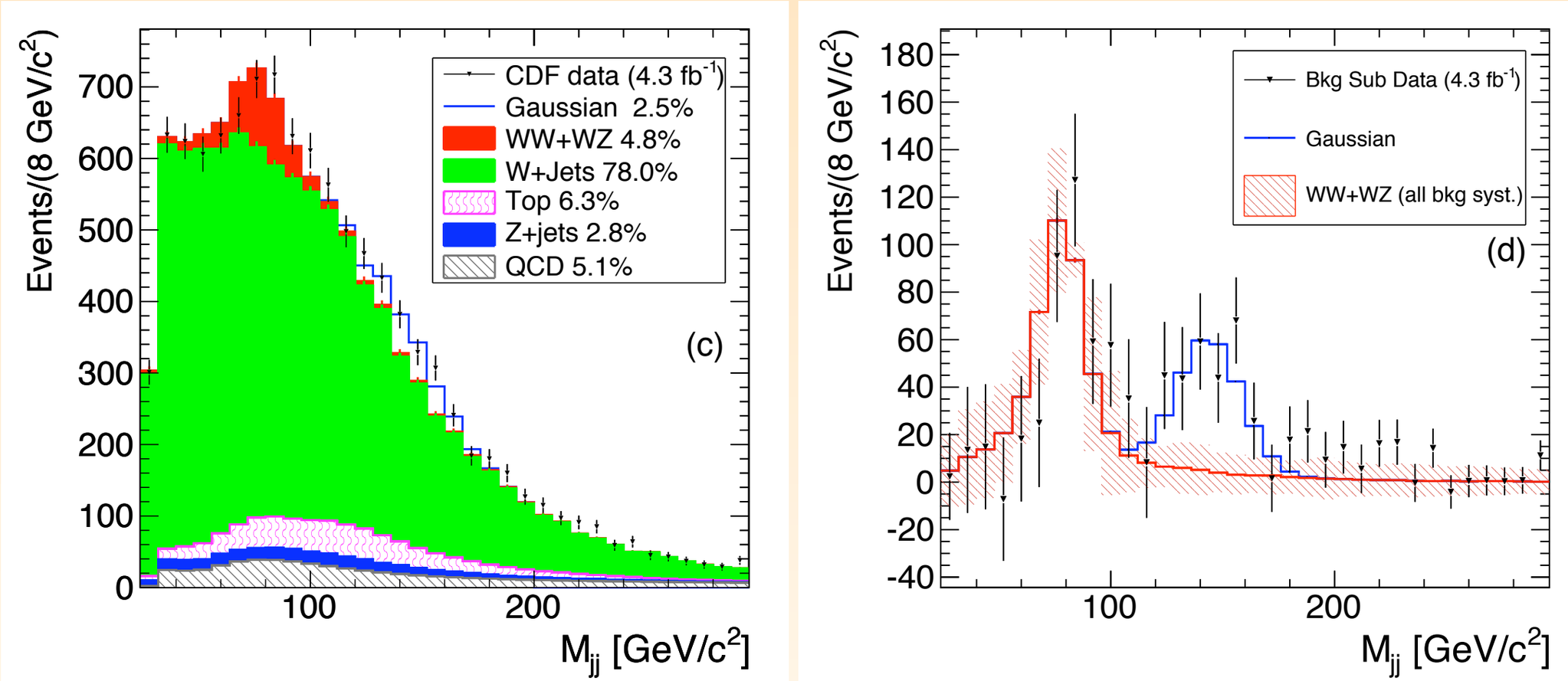
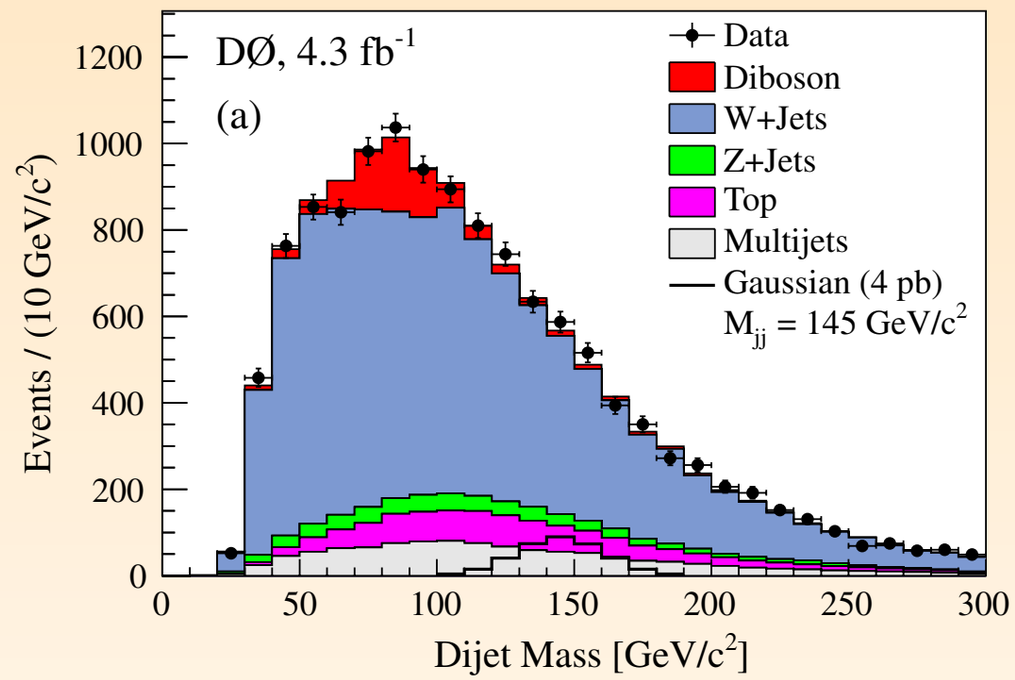
Wjj at CDF

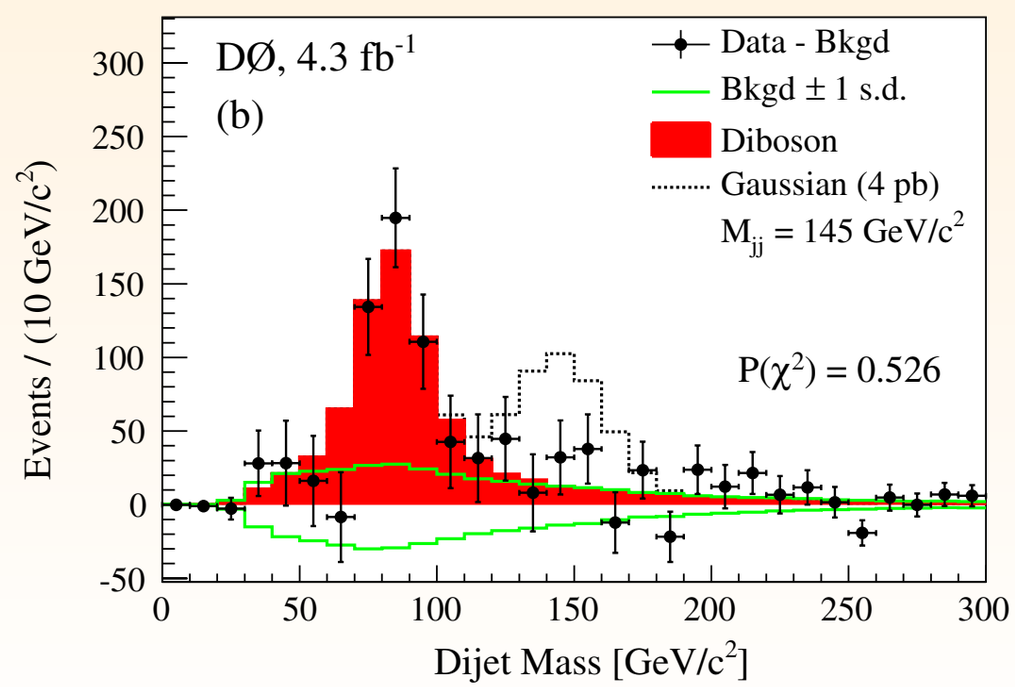


- In April CDF reported an excess of events with 3.2 standard deviation significance in the dijet invariant mass distribution (with invariant mass 130-160 GeV) for Wjj events
- The update in June (using 7.3 fb^{-1} of data) increased significance of the excess to 4.1 standard deviations

Response...

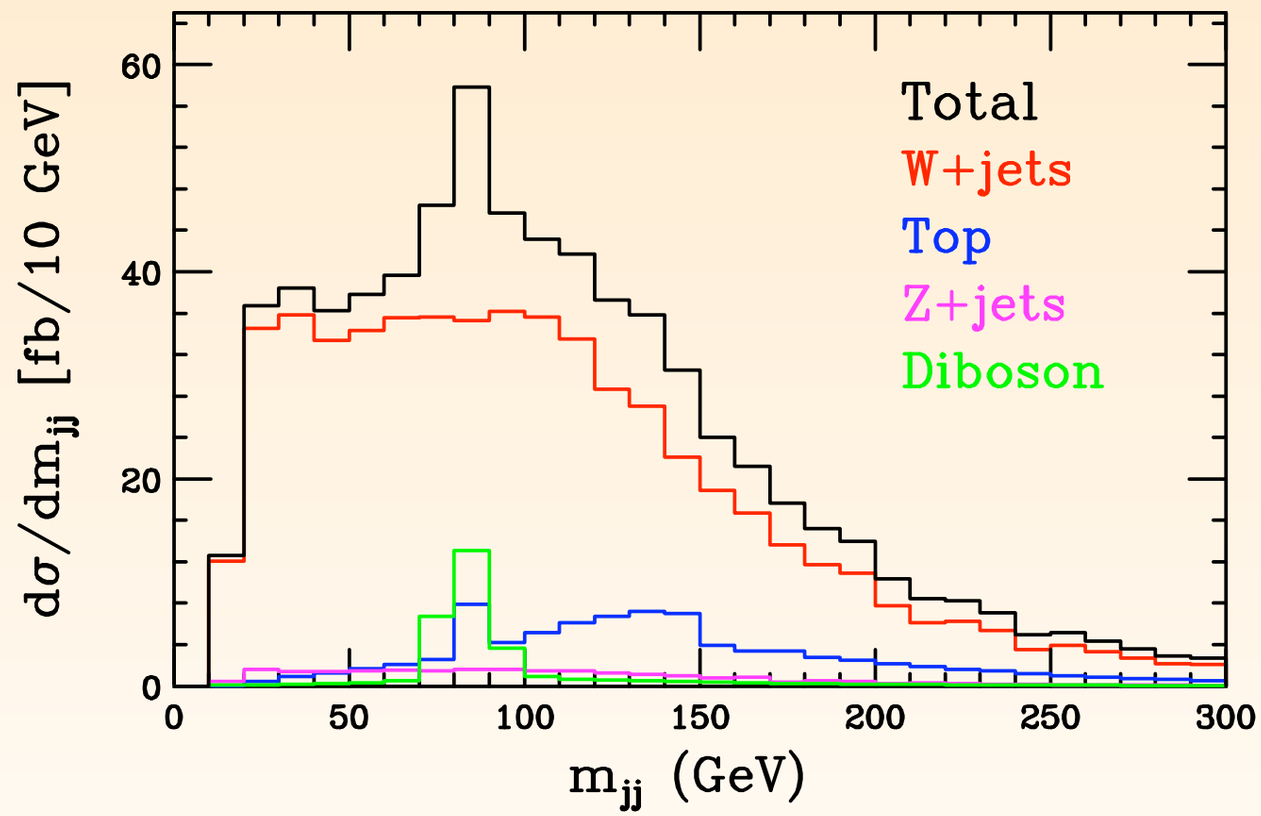
- By now more than 60 papers have appeared trying to explain this excess by introducing BSM physics
- 2 papers tried to explain the results within the SM (by addressing issues in the top quark sector)
- CDF's results are not confirmed by DØ





NLO effects

- Both CDF and DØ estimates their backgrounds using LO SMC programs (Alpgen+Pythia & Sherpa) normalized to (N)NLO or to the data
- J. Campbell, A. Martin & C. Williams have looked at the same distribution at parton level to study the impact of NLO corrections on differential distributions



- Using the newly developed tool, aMC@NLO, we would like to address the main background, W+2j, at the NLOwPS level to see how well LOwPS or fixed order NLO describe this distribution

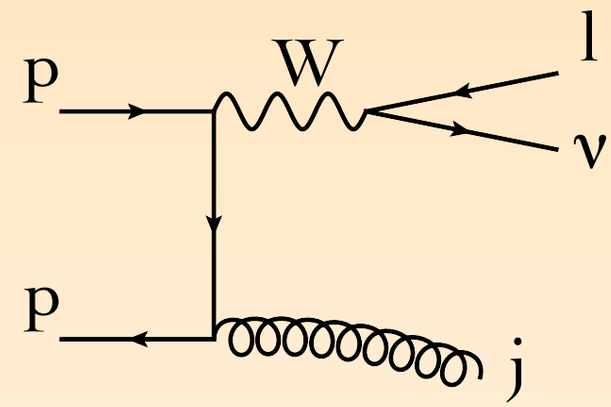
Outline

- Validation of aMC@NLO using W+1j
- Special care for LOwPS and W+2j
- Validation results for W+2j at NLOwPS
- Dijet invariant mass at NLO matched to PS

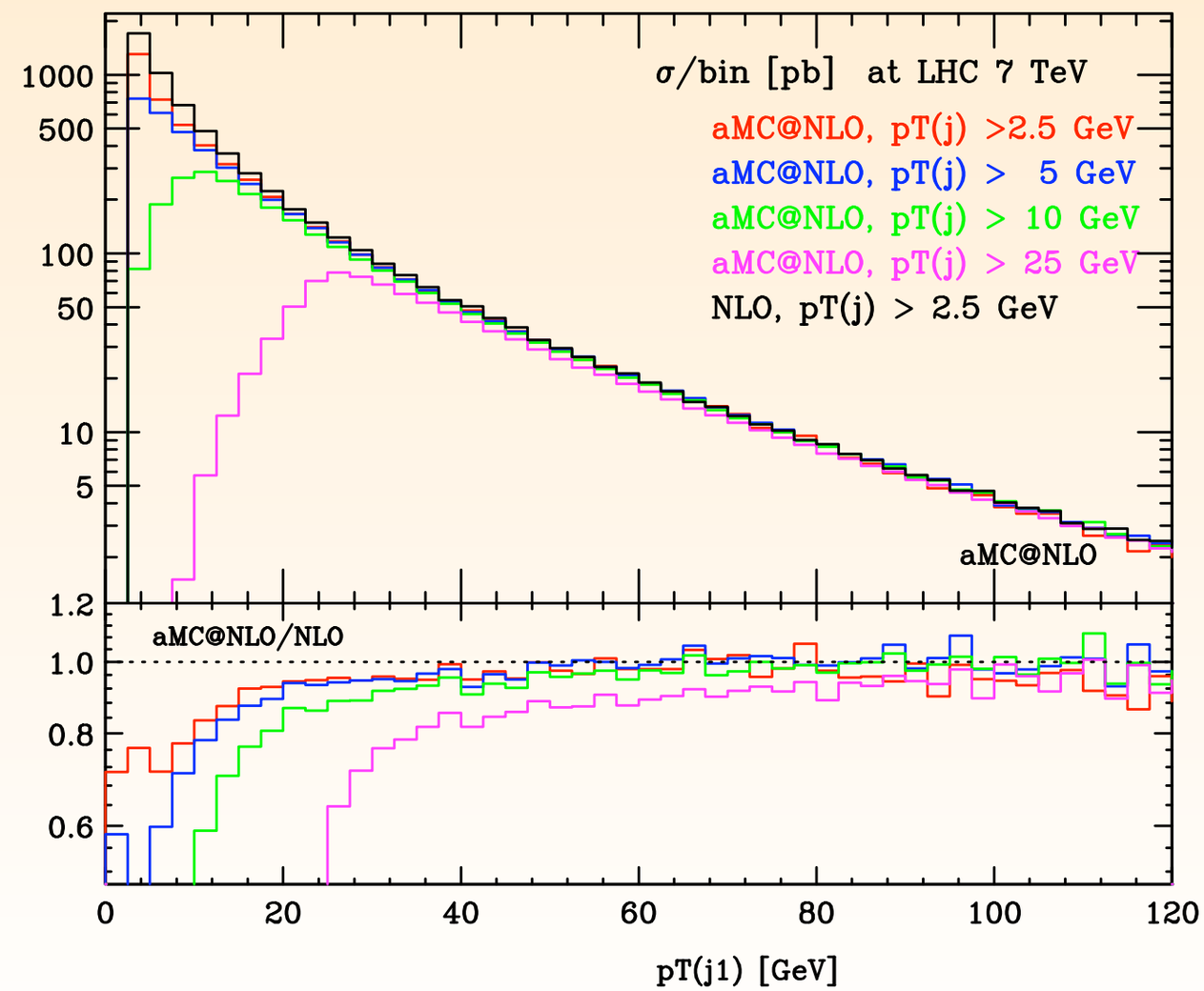
Computational challenge

- This is the first time that such a process with so many scales and possible (IR) divergences is matched to a parton shower at NLO accuracy
- Need to be sure that what we are doing is correct
- Start with W+1j production to validate processes which need cuts at the matrix-element level
- To check the insensitivity to this cut:
  - generate a couple of event samples with different cuts and show that the distributions after analysis cuts are statistically equivalent

PP → WJ



- For W+1j the easiest cut would be in on the p_T of the W boson
- However, for validation purposes it is more appropriate to apply this cut on the jet instead (because that is what we'll be doing in W+2j). Same at LO, but different at NLO
- Different cuts at generation level yield the same distributions at analysis level if the analysis level cut is 3-4 times larger



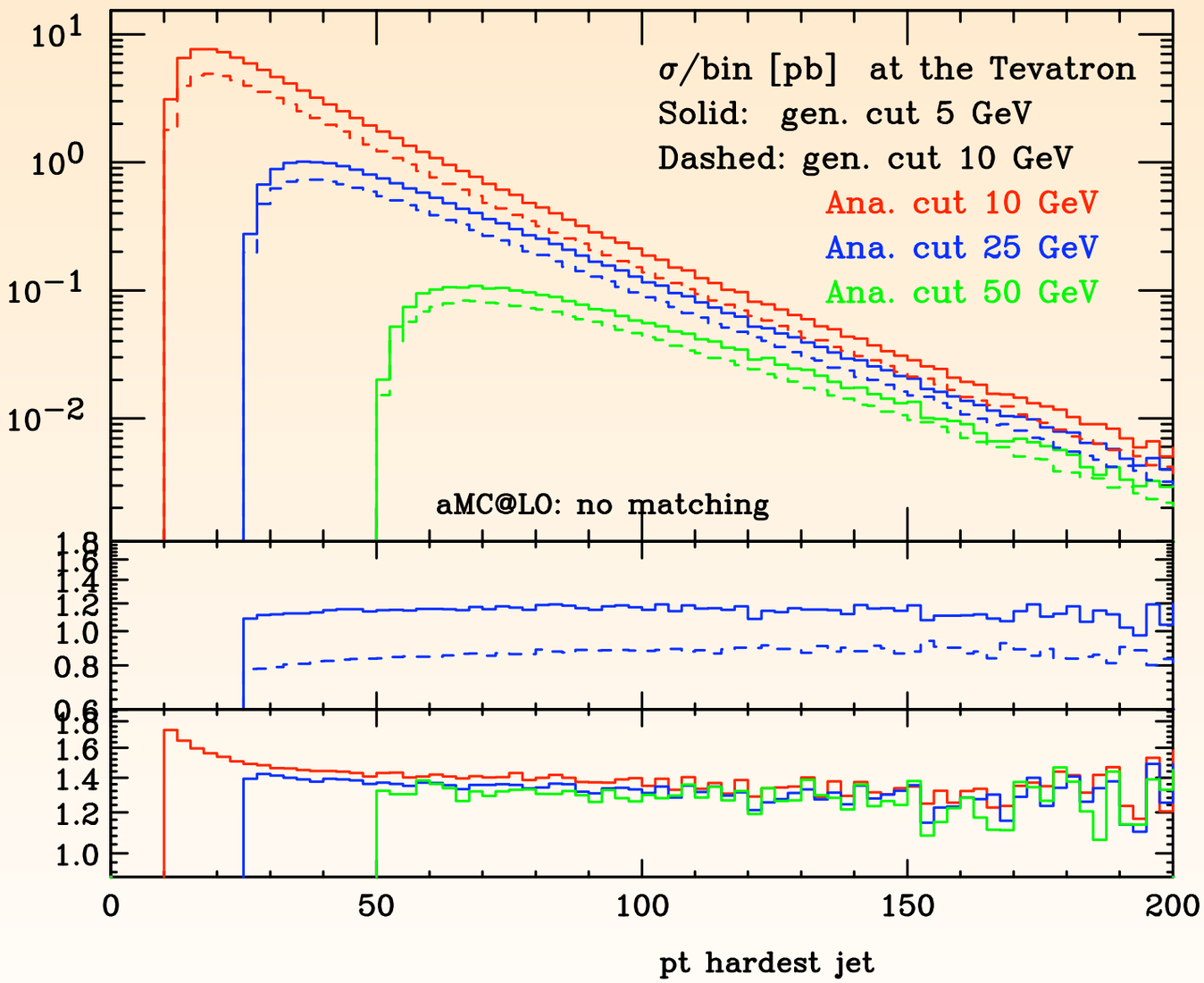
pp → Wjj Set-up

- Two event samples with 5 GeV and 10 GeV p_T cuts on the jets at generation level, respectively, each with 10 million unweighted events
- Renormalization and factorization scales equal to $\mu_R = \mu_F = H_T/2$

$$2\mu_R = 2\mu_F = H_T = \sqrt{(p_{T,l\nu}^2 + m_{l\nu}^2)} + \sum |p_{T,i}|$$

  where sum is over the 2 or 3 partons (and the matrix element level)
- Jets are defined with anti-k_T and R=0.4
- MSTW2008(N)LO PDF set for the (N)LO predictions (with $\alpha_s(m_Z)$ from PDF set using (2)1-loop running)
- m_W = 80.419 GeV,
  $G_F = 1.16639 \cdot 10^{-5}$ GeV^{-2},
  $\alpha^{-1} = 132.507$,
  Γ_W = 2.0476 GeV

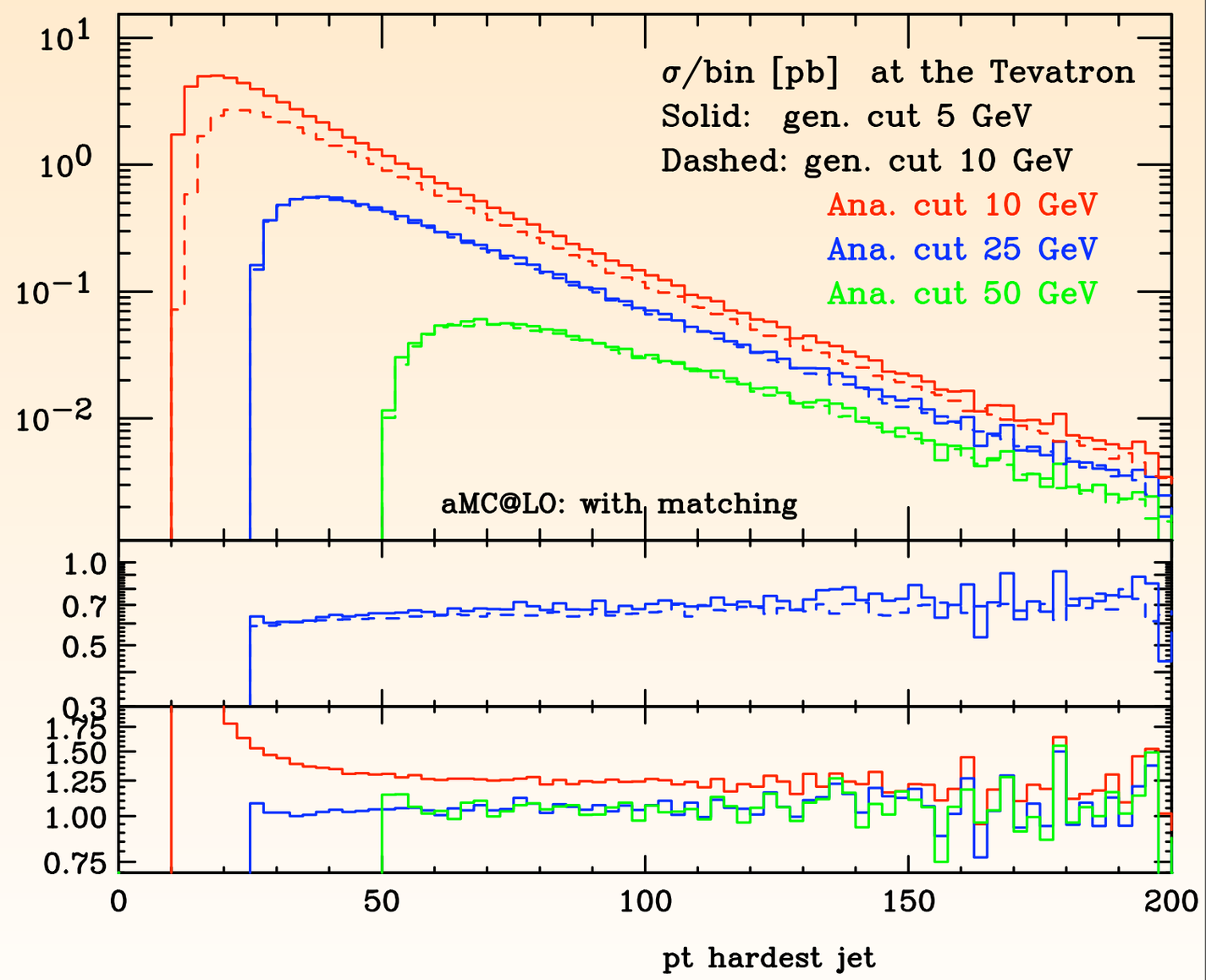
pp → Wjj LOwPS



- The two generation-level cuts do not lead to the same distributions at the analysis level...
- Middle plot is the ratio with the fixed order
- Lower plot is the ratio of the two generation level cuts
- There is a possible double counting from jets from matrix elements and jets from parton shower: should apply a matching prescription

pp → Wjj
LO -- with matching

- Apply MLM matching prescription
  - The two partons (generation level) should match the two hardest jets (before hadronization), i.e., $\Delta R < 1.5\ R_{jet}$ and α_s reweighting according to "most-likely parton shower history"
- The two generation level cuts now agree. However, the overall normalization has not yet been fully understood

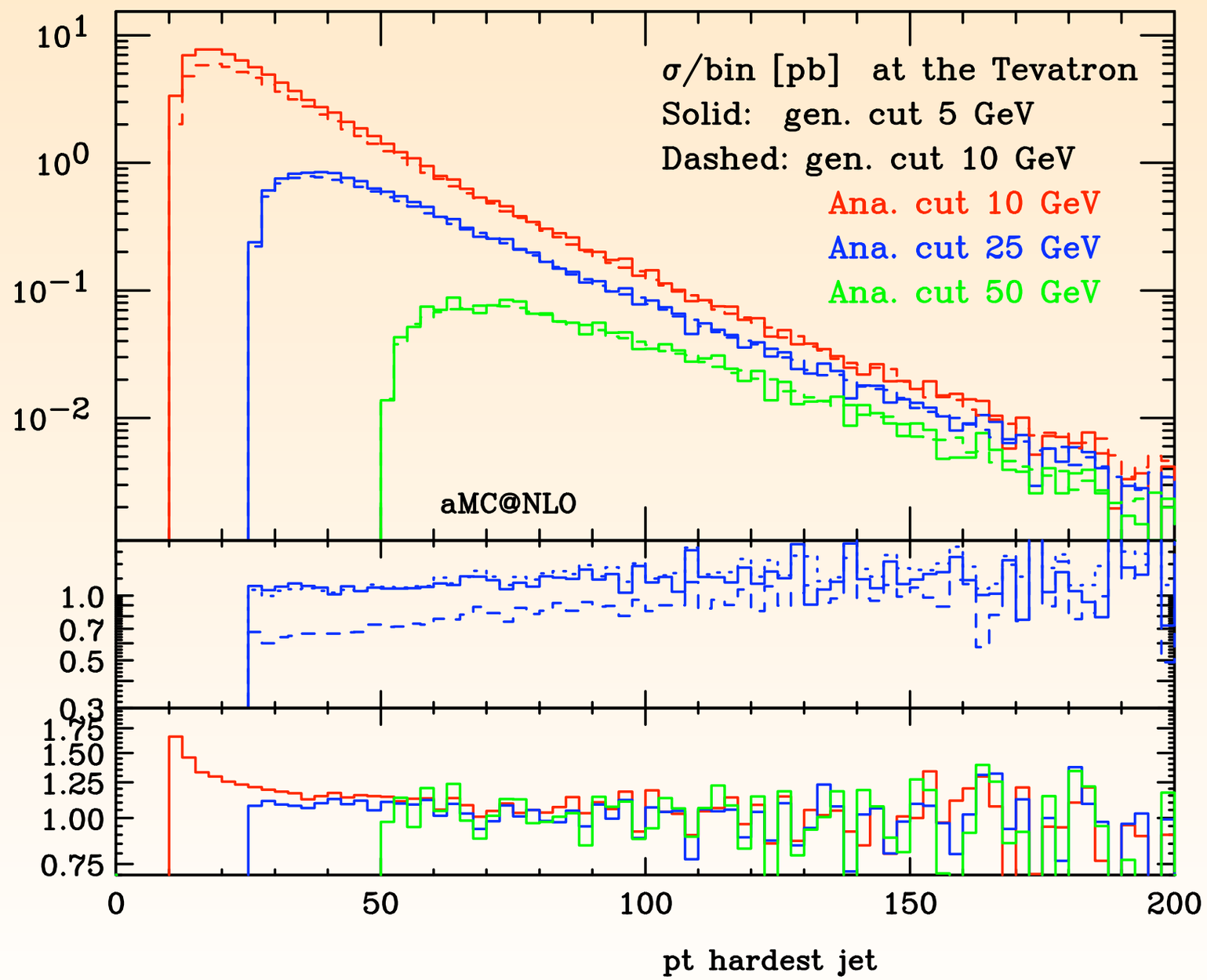


pp → Wjj
NO MLM matching at NLO

- There is no need for a MLM or CKKW matching prescription when already matching with MC@NLO:
  - **The first emission from the PS is already properly matched with the real-emission matrix elements**
  - Another hard jet from the PS is very unlikely (in particular at the Tevatron)

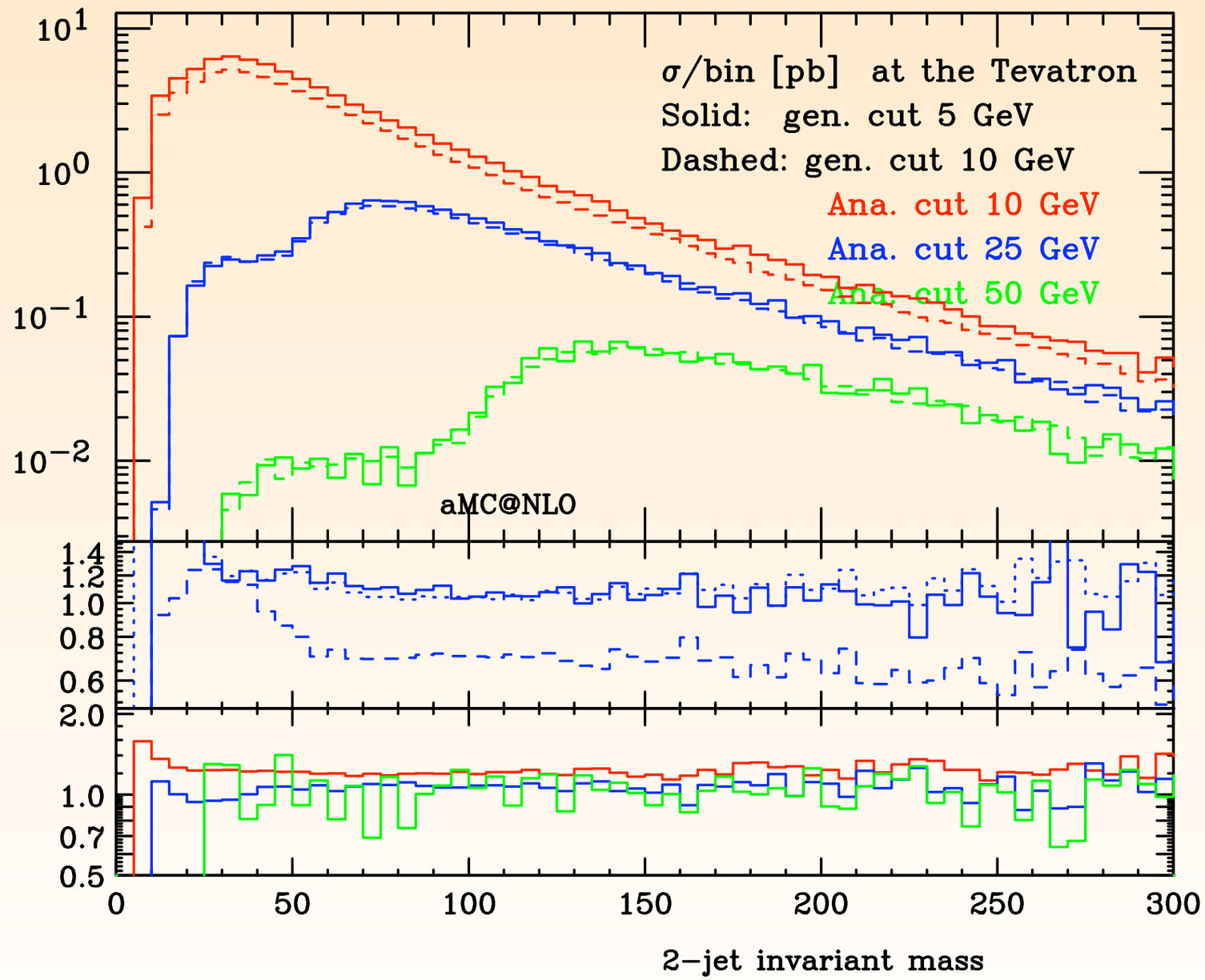
pp → Wjj Validation

- The two generation level cuts agree for high enough momenta (or harder analysis cuts)
- Middle plot shows ratio of NLO (solid), LO (dotted) and LOwPS (dashed) over aMC@NLO
- Good agreement with (N)LO, slight difference in shape
- Tails have low statistics, in particular for the 5 GeV generation cuts

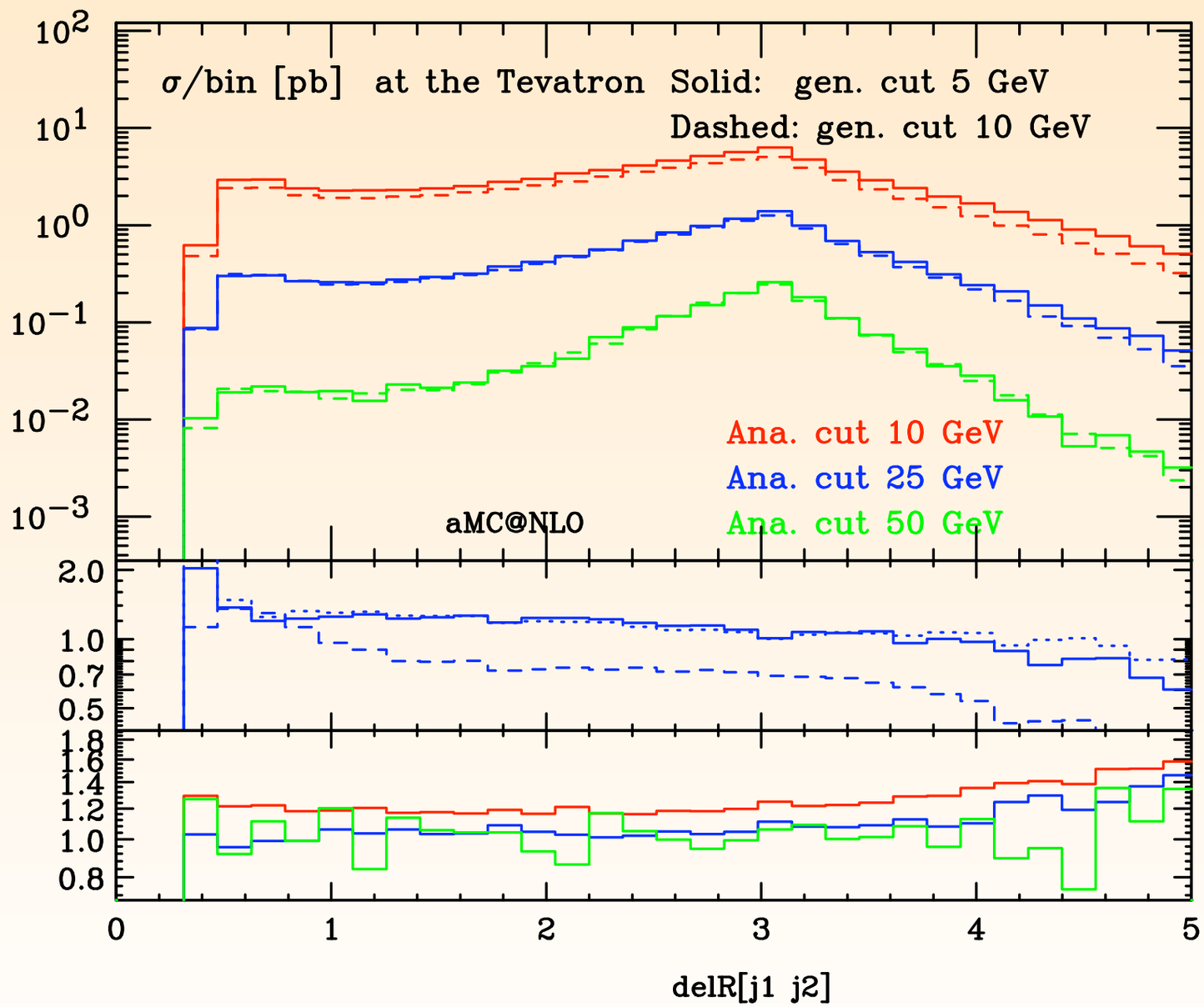


pp → Wjj Validation - II

- Dijet invariant mass
- For analysis cuts larger than 25 GeV the two event samples coincide (except for the very low mass region)
- For smaller analysis cuts the bias is flat in this distribution



pp → Wjj Validation - III



- Distance between the jets
- A small bias remains at 25 GeV analysis in the tail of the distribution, but reduced a lot from lower cuts analysis cuts
  - 5 GeV sample probably ok, 10 GeV gen. cut is a bit too hard
- Of all distributions we have looked at, this one shows the largest bias due to generation cut

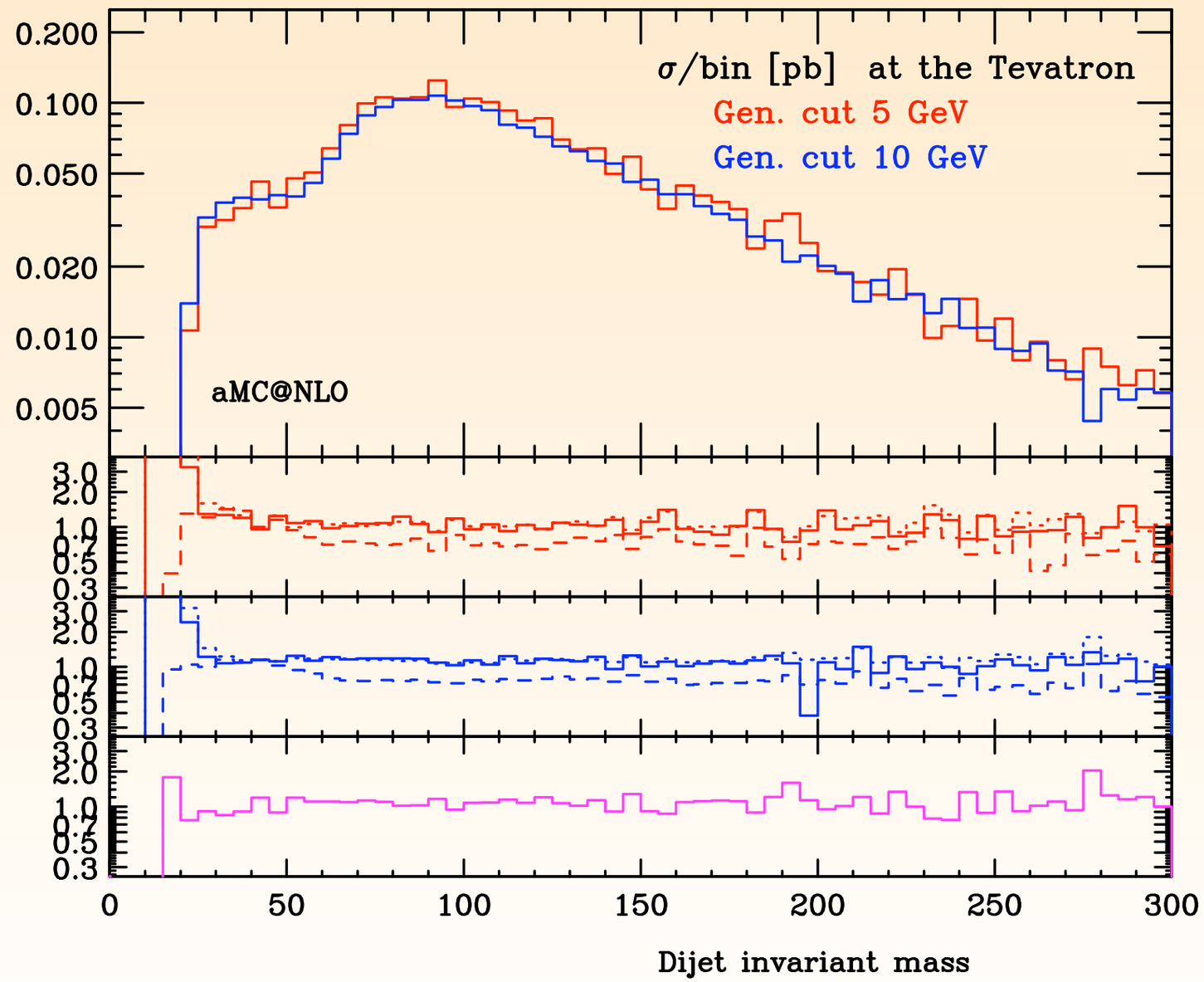
pp → Wjj
CDF/DØ analysis cuts

- minimal transverse energy for the lepton $E_T(l) > 20\text{GeV}$,
- maximal pseudo rapidity for the lepton $\eta(l) < 1$,
- missing transverse energy $\not{E}_T > 25\text{GeV}$,
- transverse W-boson mass $m^T_{l,\nu_l} > 30\text{GeV}$,
- jet definition: JetClu algorithm with 0.75 overlap and $R > 0.4$,
- minimal transverse jet momenta $p_T(j) > 30\text{GeV}$,
- maximal jet pseudo rapidity $\eta(j) < 2.4$,
- minimal jet pair transverse momentum $p_{T,jj} > 40\text{GeV}$,
- lepton isolation, hadronic energy smaller than 10% of the lepton energy in a cone with $R = 0.5$ around the lepton.

- To slightly simplify the analysis, the MC truth is used to assign the lepton (and neutrino) to the W-boson decay
- Only W^+ events (simply a factor 2)
- No underlying event

pp → Wjj
Dijet invariant mass

- Dijet invariant mass
- This is the distribution in which CDF found an excess of events around 130-160 GeV
- No differences in shape between the 5 and 10 GeV generation level cuts
- No sign of enhancement over (N)LO or LOwPS in the mass range 130-160 GeV



Conclusions

- We have matched W+2j for the first time to a parton shower at NLO accuracy using `aMC@NLO`
- Corrections to the fixed order and LOwPS are small
  - No enhancement at invariant masses of 130-160 GeV
  - It cannot explain the excess of events found by CDF
- Event samples will be available soon on the `aMC@NLO` website, http://amcatnlo.cern.ch