QCD Matrix Elements and Parton Showers

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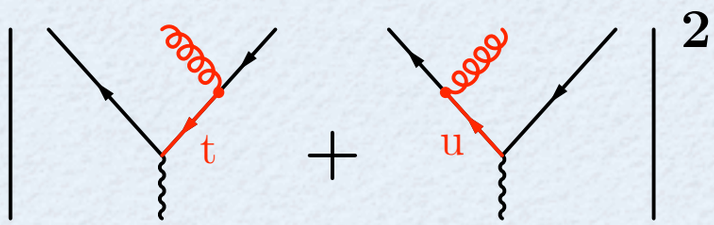
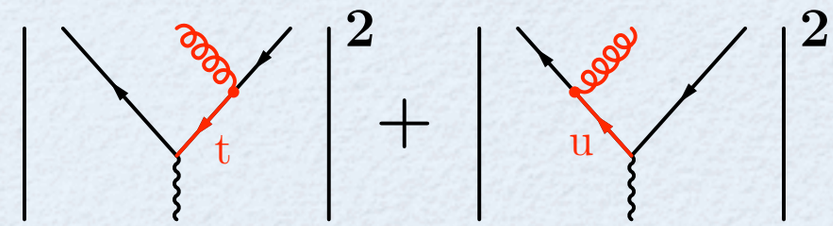
Brief Review: Why CKKW ?

Matrix Elements



- Exact to fixed order in the running coupling
- Include all quantum interferences
- Calculable only for low FS multiplicity (n≤6-8)

Parton Showers



$$d\sigma_{n+1} = d\sigma_n \otimes \sum_{a\in q,g} \frac{dt}{t} dz \frac{\alpha_s(t,z)}{2\pi} P_{a\to bc}(z)$$

- Resum all (next-to) leading logarithms to all orders
- Interference effects only through angular ordering

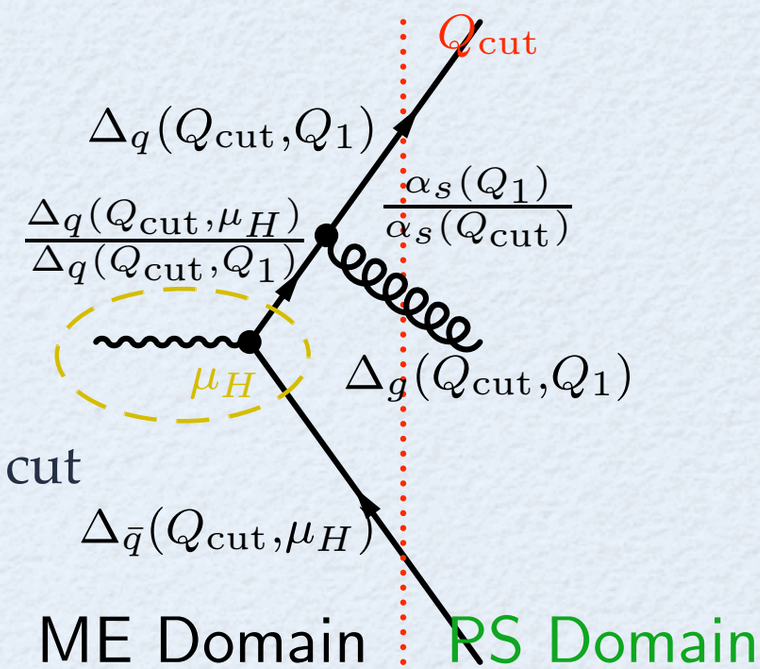
➡ Basic idea of CKKW: Combine both approaches to have

- Good description of hard / wide angle radiation (ME)
- Correct intrajet evolution (PS)

CKKW COOKING RECIPE

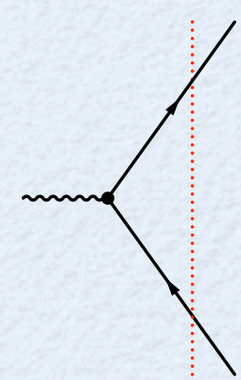
JHEP 0111 (2001) 063
JHEP 0208 (2002) 015

- Define jet resolution parameter Q_{cut} (Q-jet measure)
  ➡ divide phase space into regions of jet production (ME) and jet evolution (PS)
- Select final state multiplicity and kinematics according to σ 'above' Q_{cut}
- KT-cluster backwards (construct PS-tree) and identify core process
- **Reweight ME** to obtain exclusive samples at Q_{cut}
- Start the parton shower at the hard scale **Veto all PS emissions harder than Q_{cut}**



➡ This yields the correct jet rates !
Simple example: 2-jet rate in ee→qq

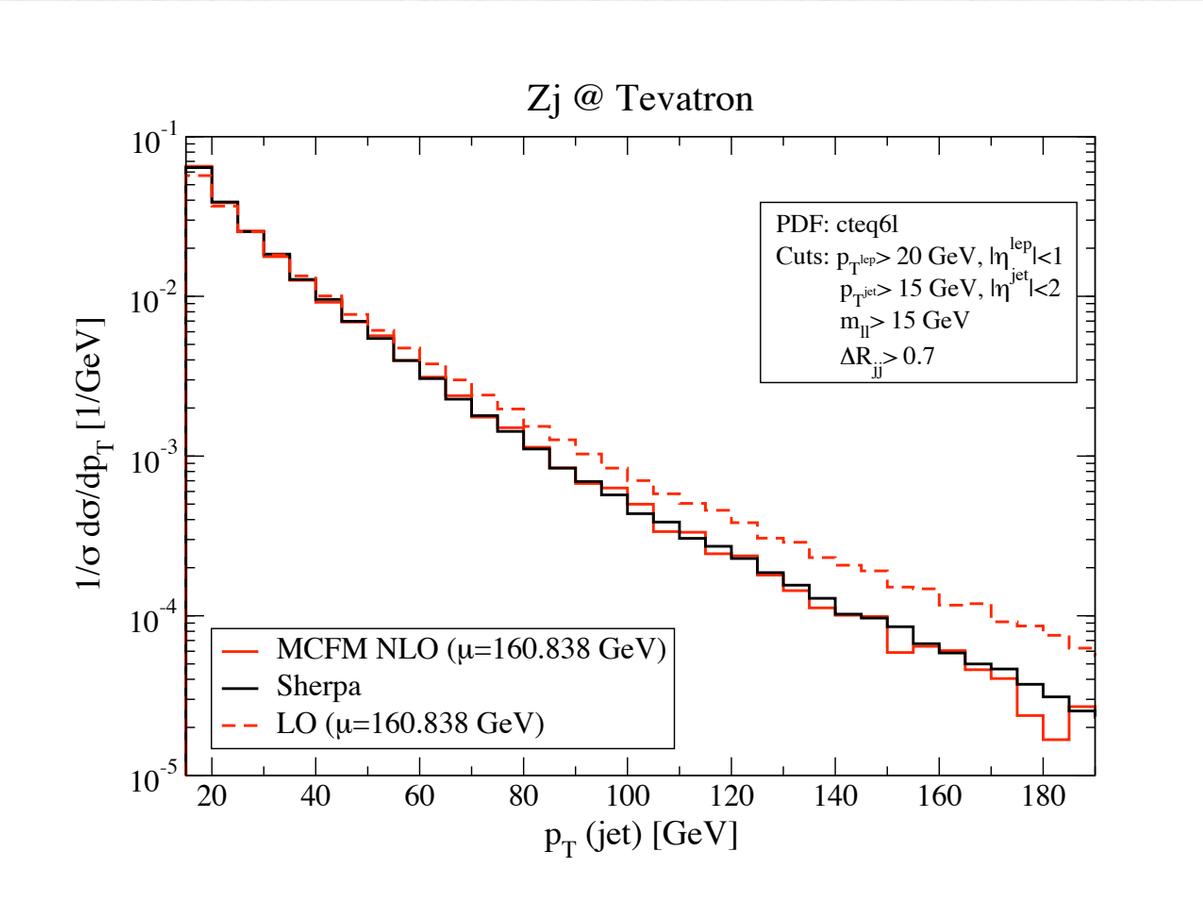
$$R_2(q) = \left(\Delta(Q_{cut},\mu_{hard})\,\frac{\Delta(q,\mu_{hard})}{\Delta(Q_{cut},\mu_{hard})}\right)^2$$

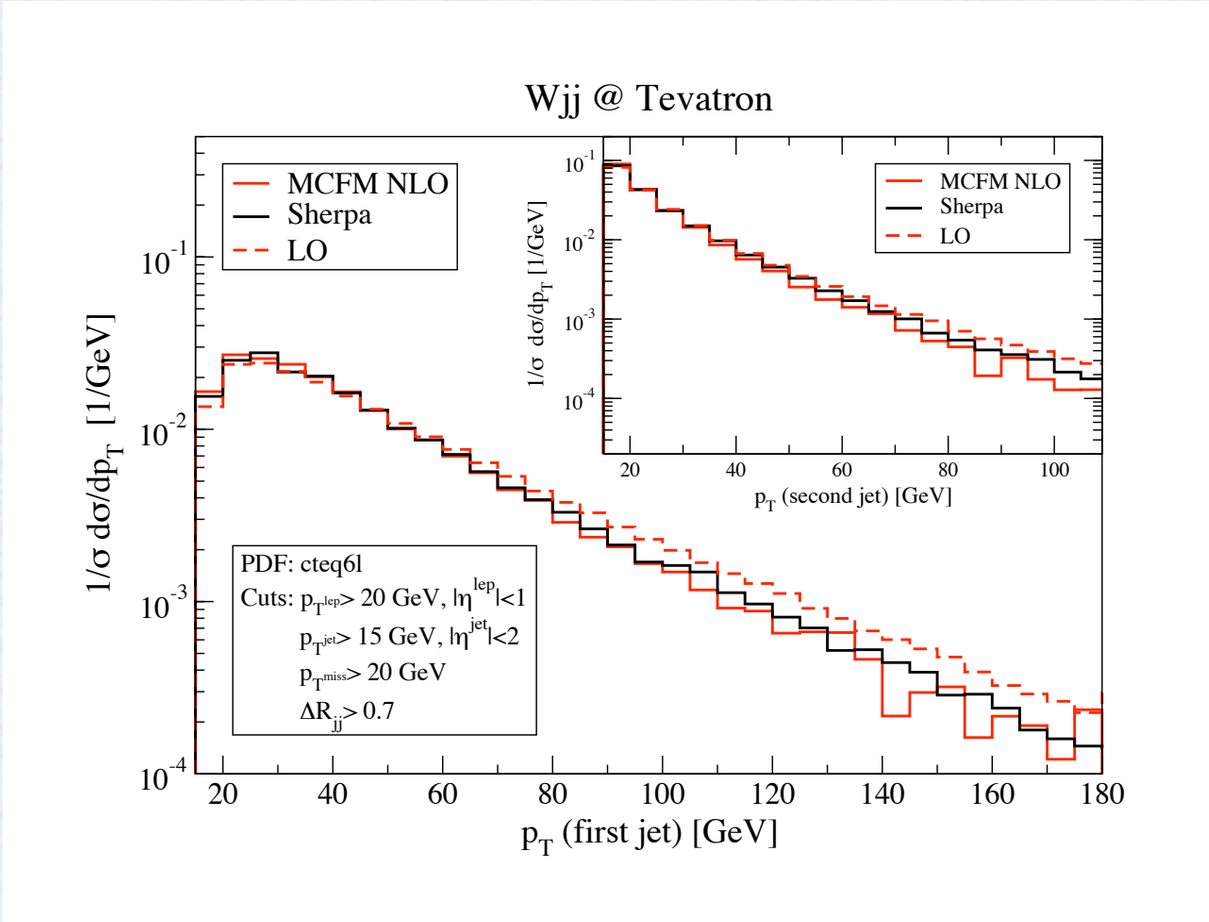


Reweighted ME: AMEGIC

Phys. Rev. D70 (2004) 114009
JHEP 0202 (2002) 044

- Exclusive jet p_T in Z+1- and W+2-jet events
  Sudakov - & α_S - reweighted ME from **AMEGIC++**
  vs. **MCFM** (μ=160GeV)

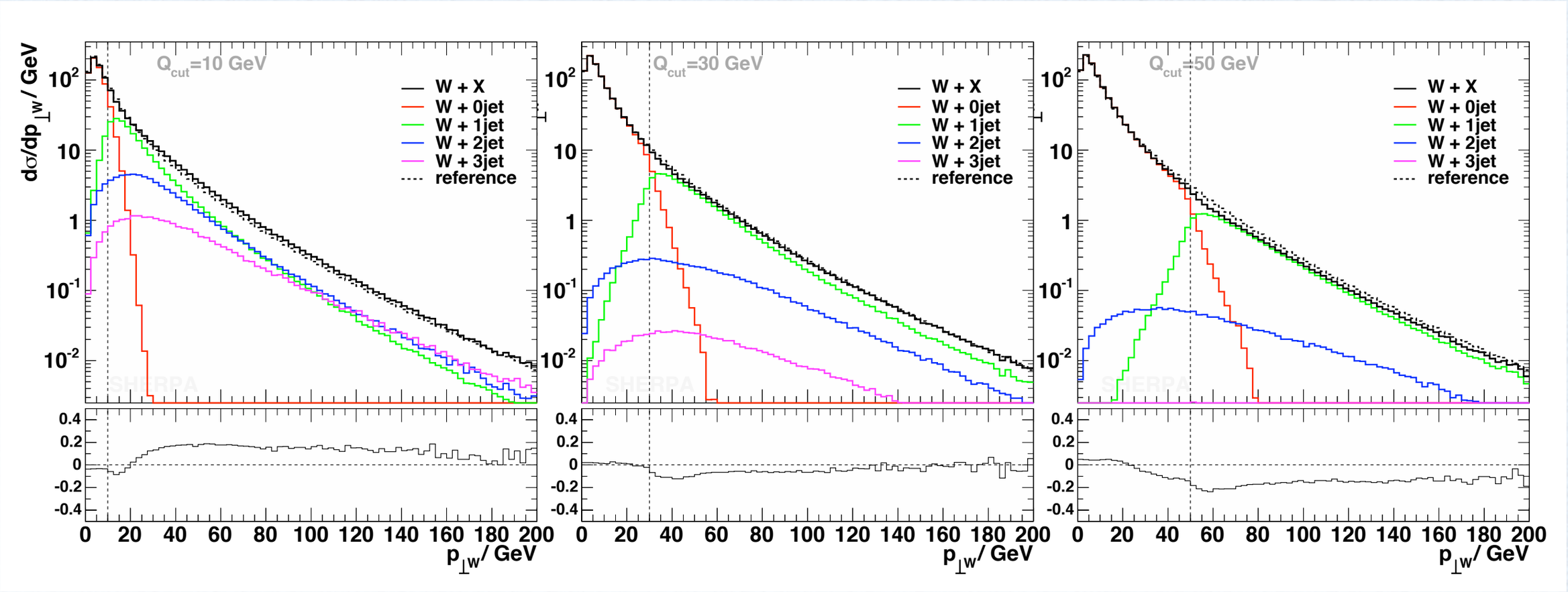




VETOED PS: APACIC

Phys.Rev.D70(2004)114009
Phys.Rev.D72(2005)054017

- W-p_T in W+jets production at Tevatron Run II
  Variation of phase space separation cut Q_{cut}
  W+0-jet subsample shows PS veto performance

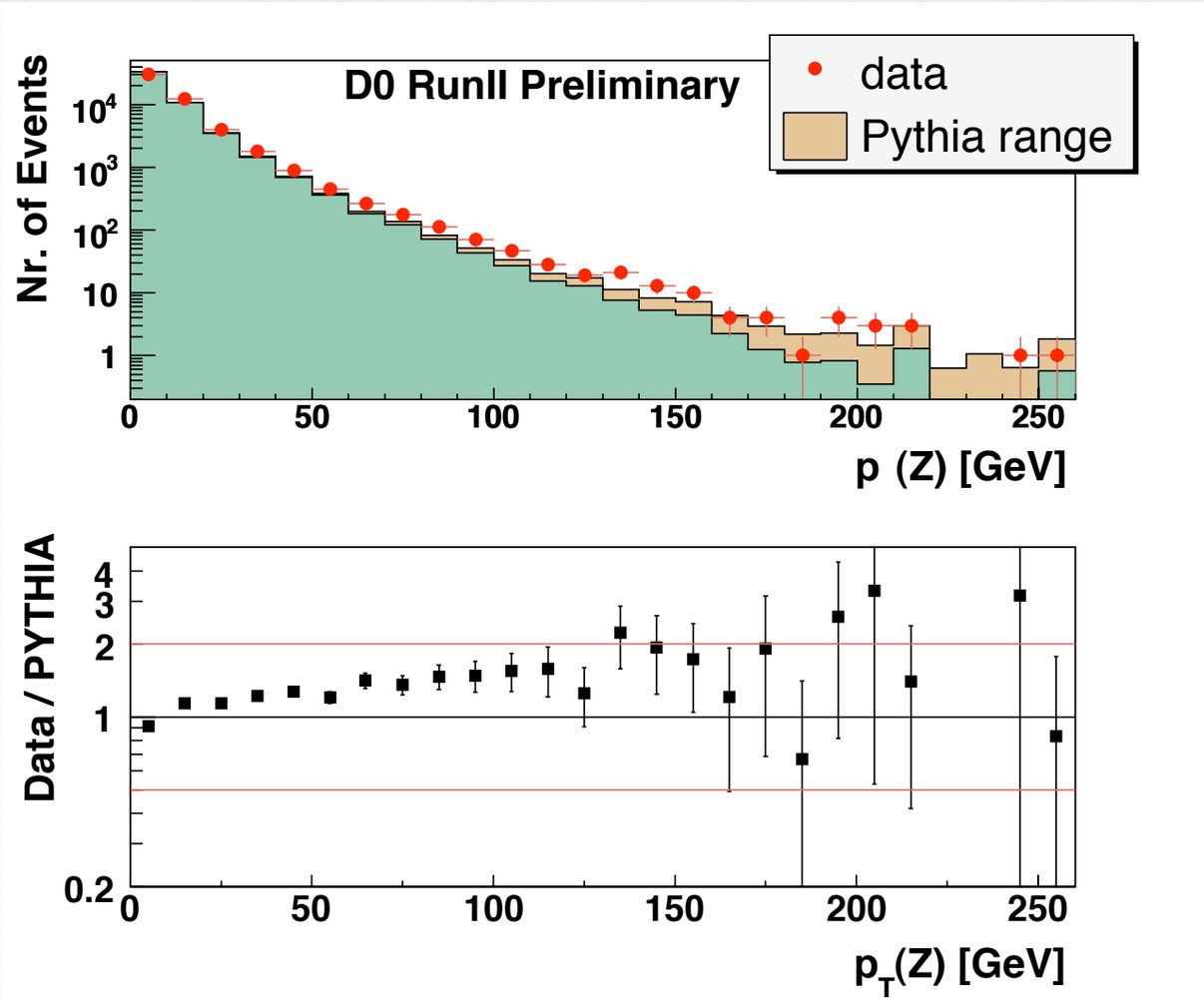


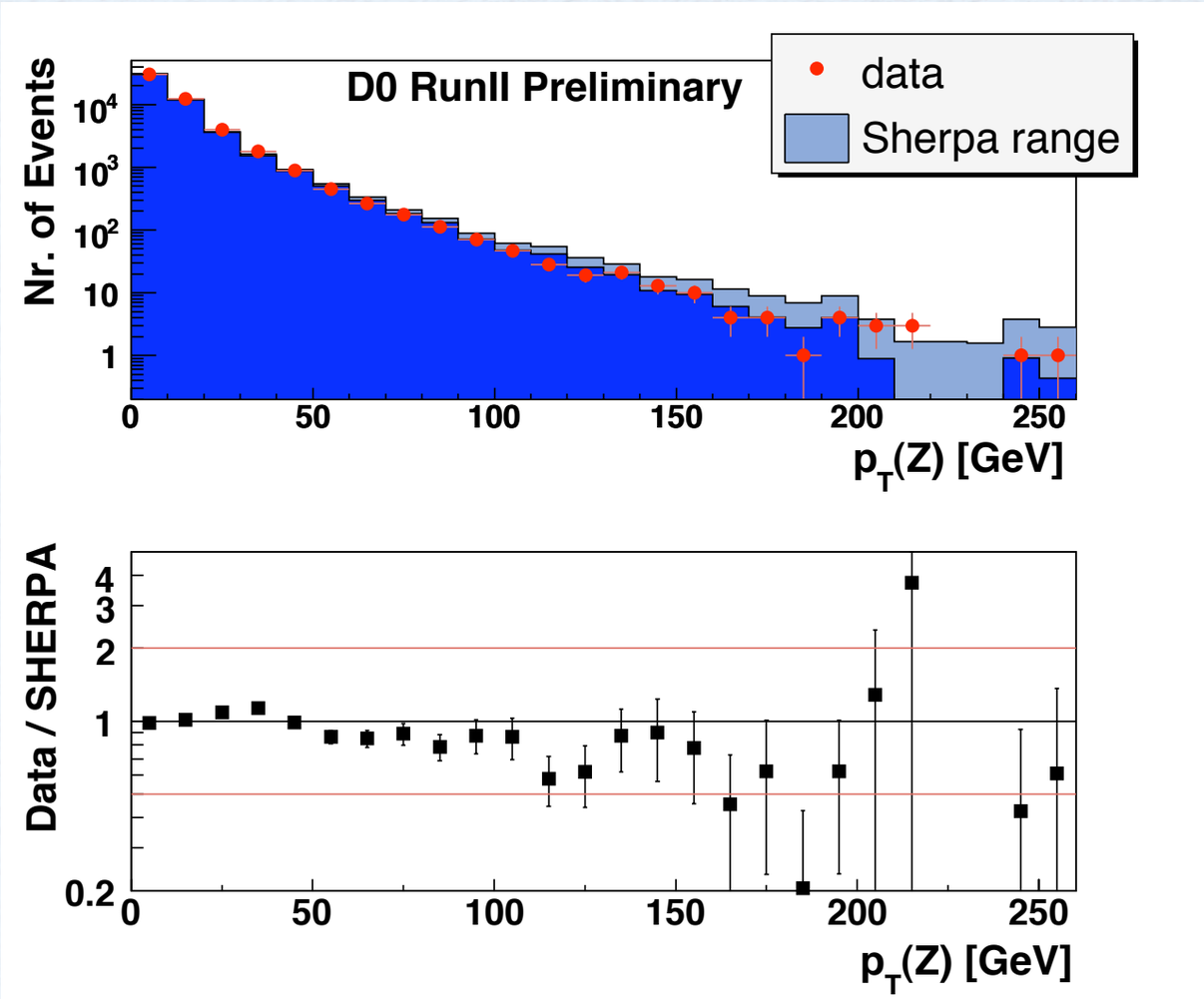
- Global K-factor

MC RESULTS VS. DATA

The DØ collaboration, DØ note 5066-CONF

- Z-p_T





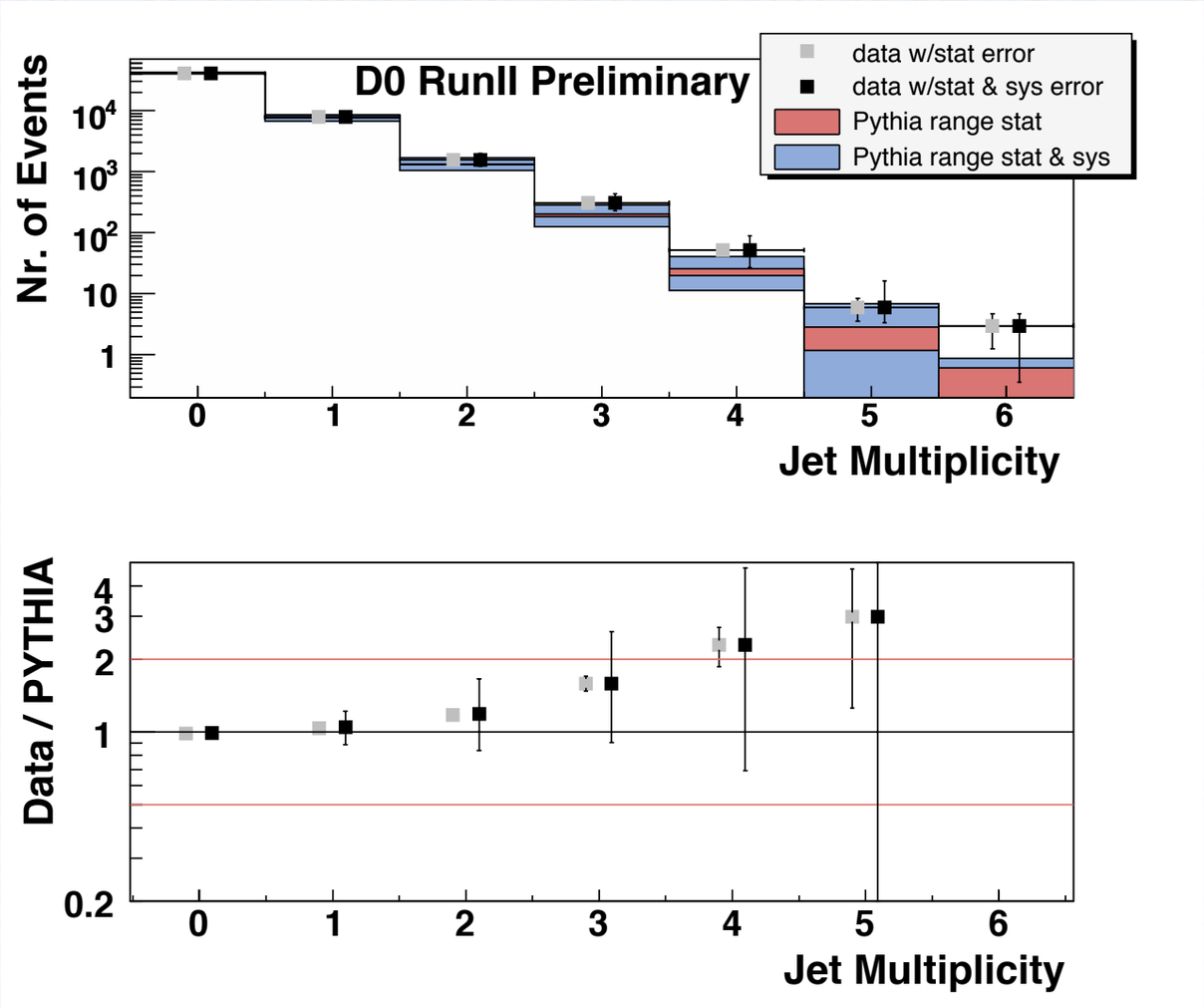
- Pythia 6.2
  normalized to data

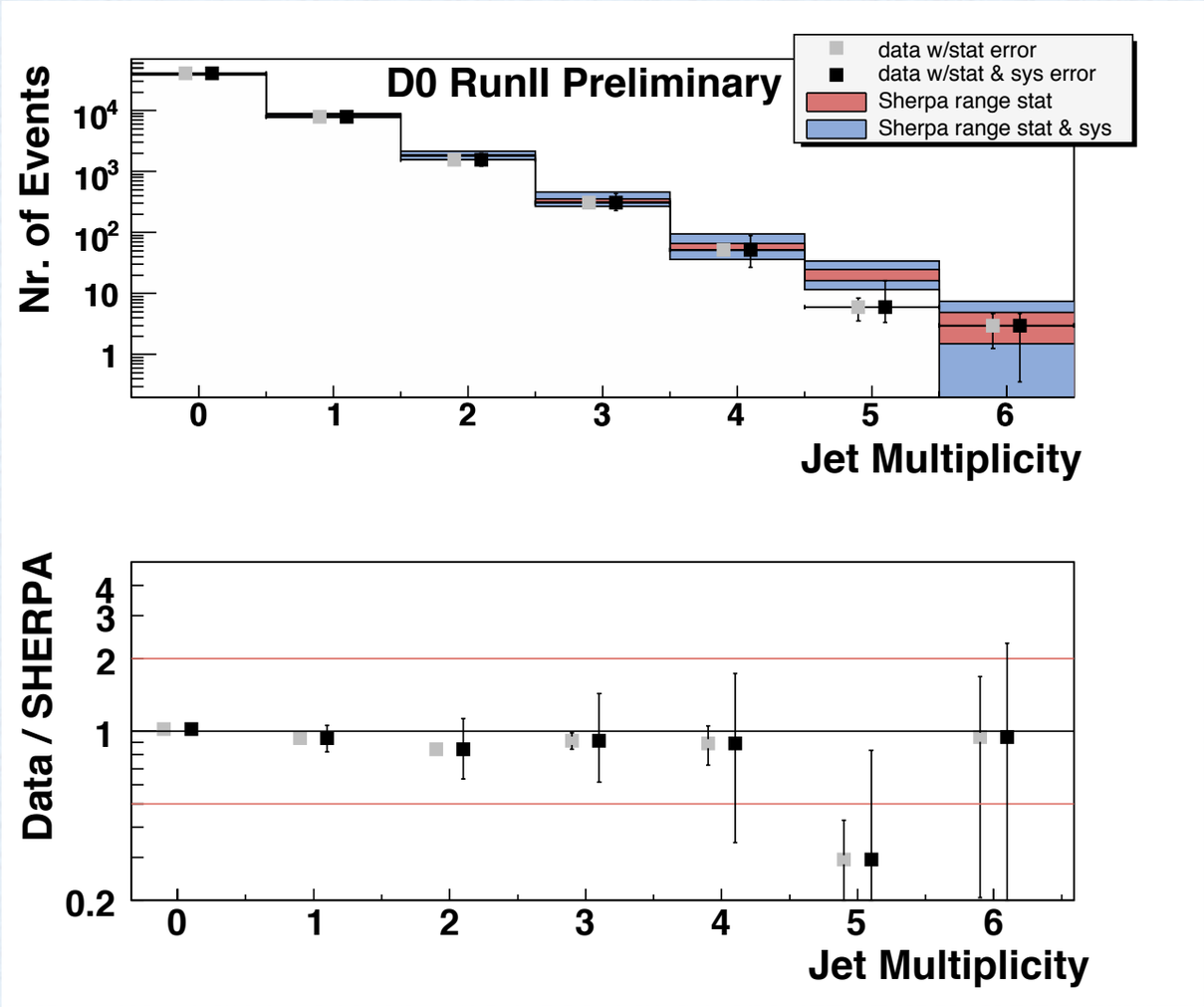
- Sherpa 1.0
  normalized to data

MC RESULTS VS. DATA

The DØ collaboration, DØ note 5066-CONF

- Jet multiplicity





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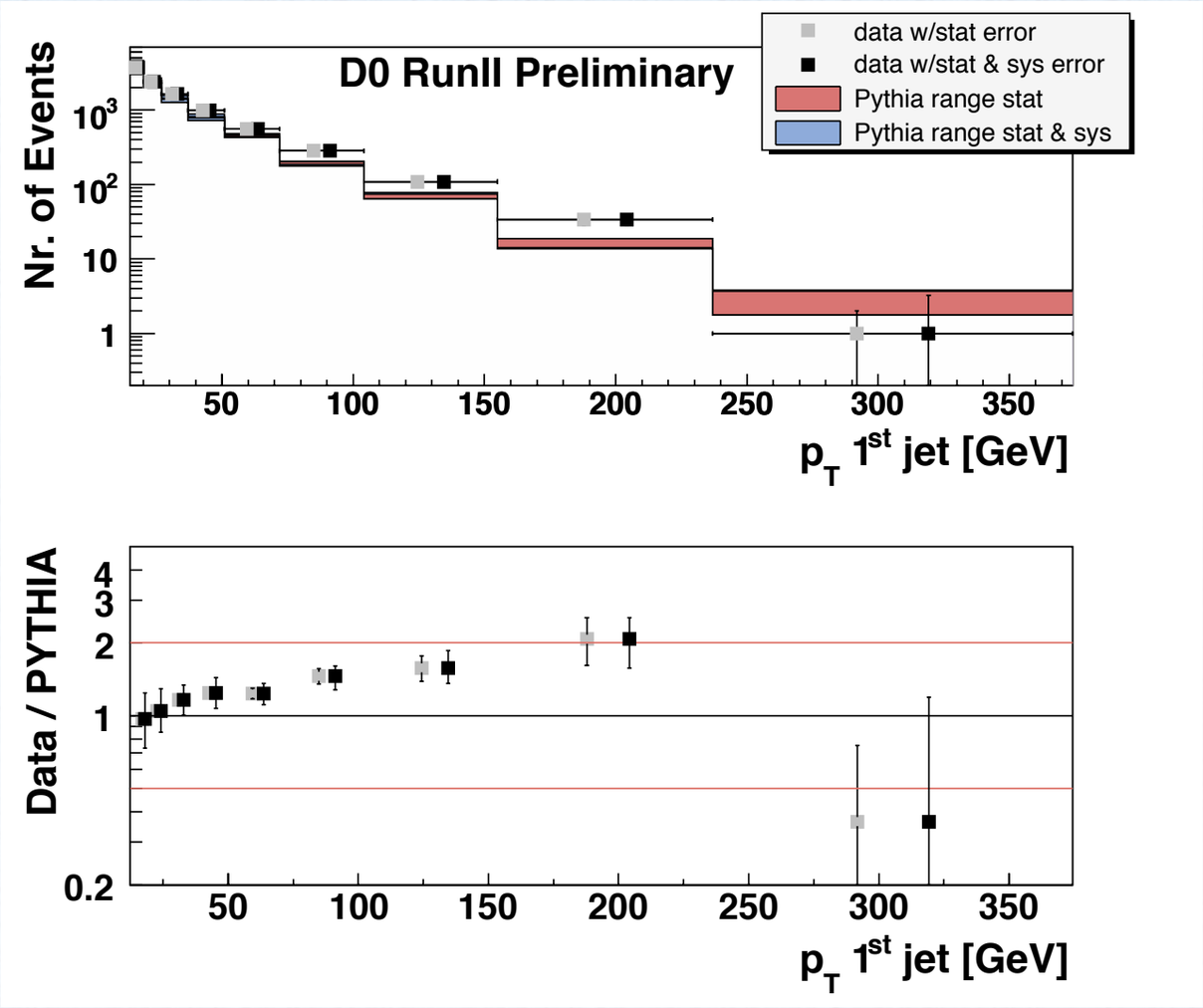
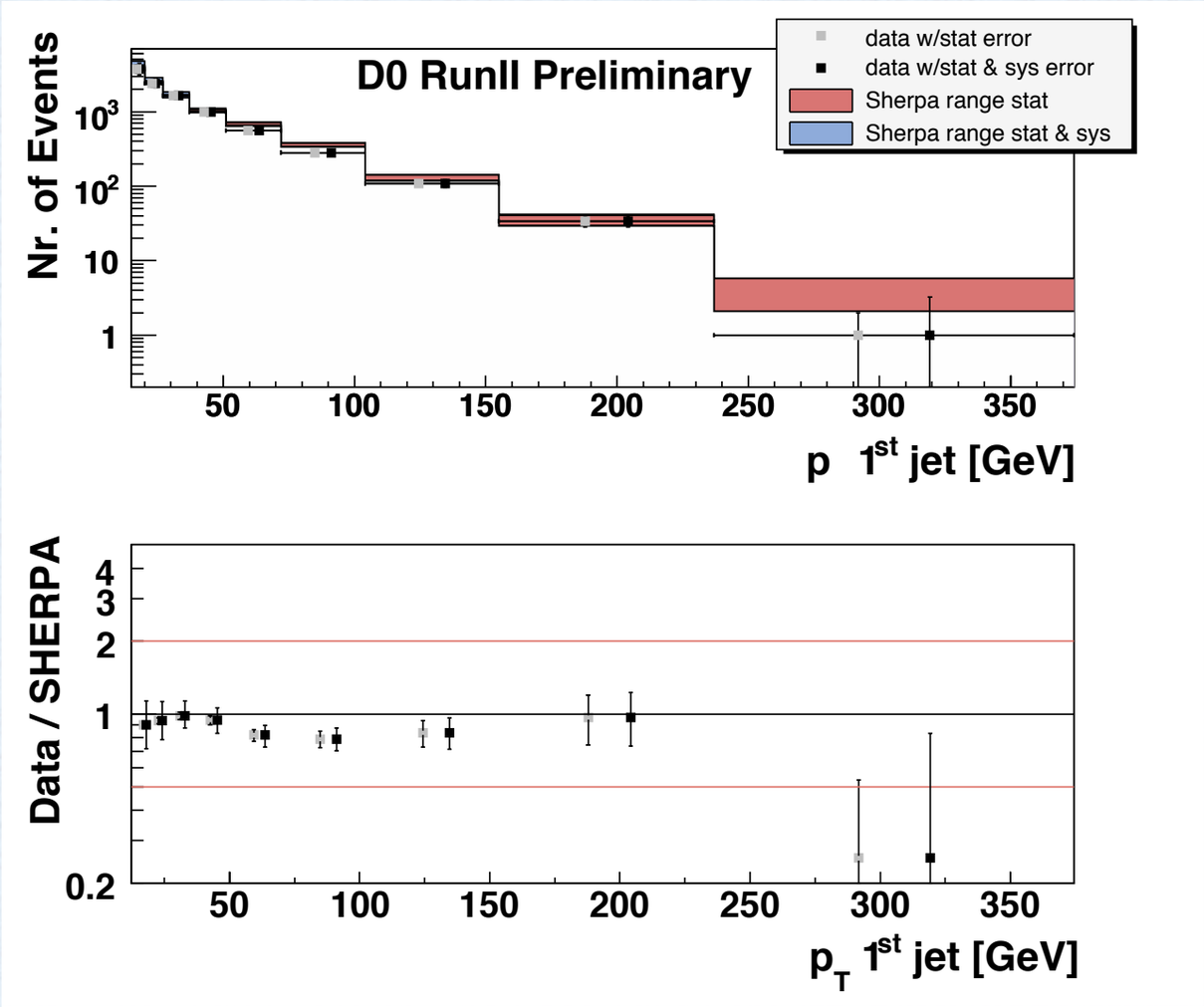
MC RESULTS VS. DATA

The DØ collaboration, DØ note 5066-CONF

- Jet-p_T, jet 1





- Pythia 6.2
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- Sherpa 1.0
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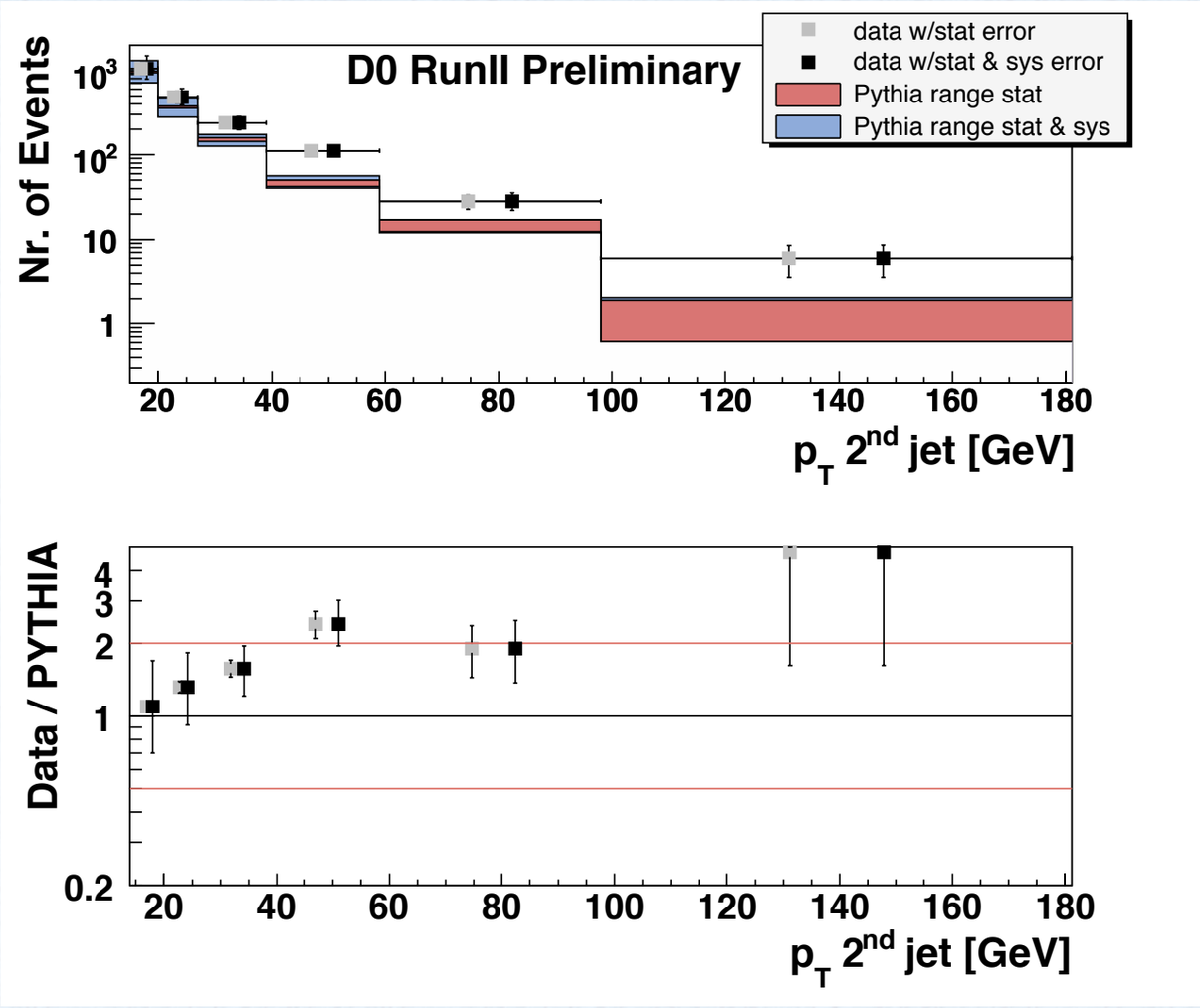
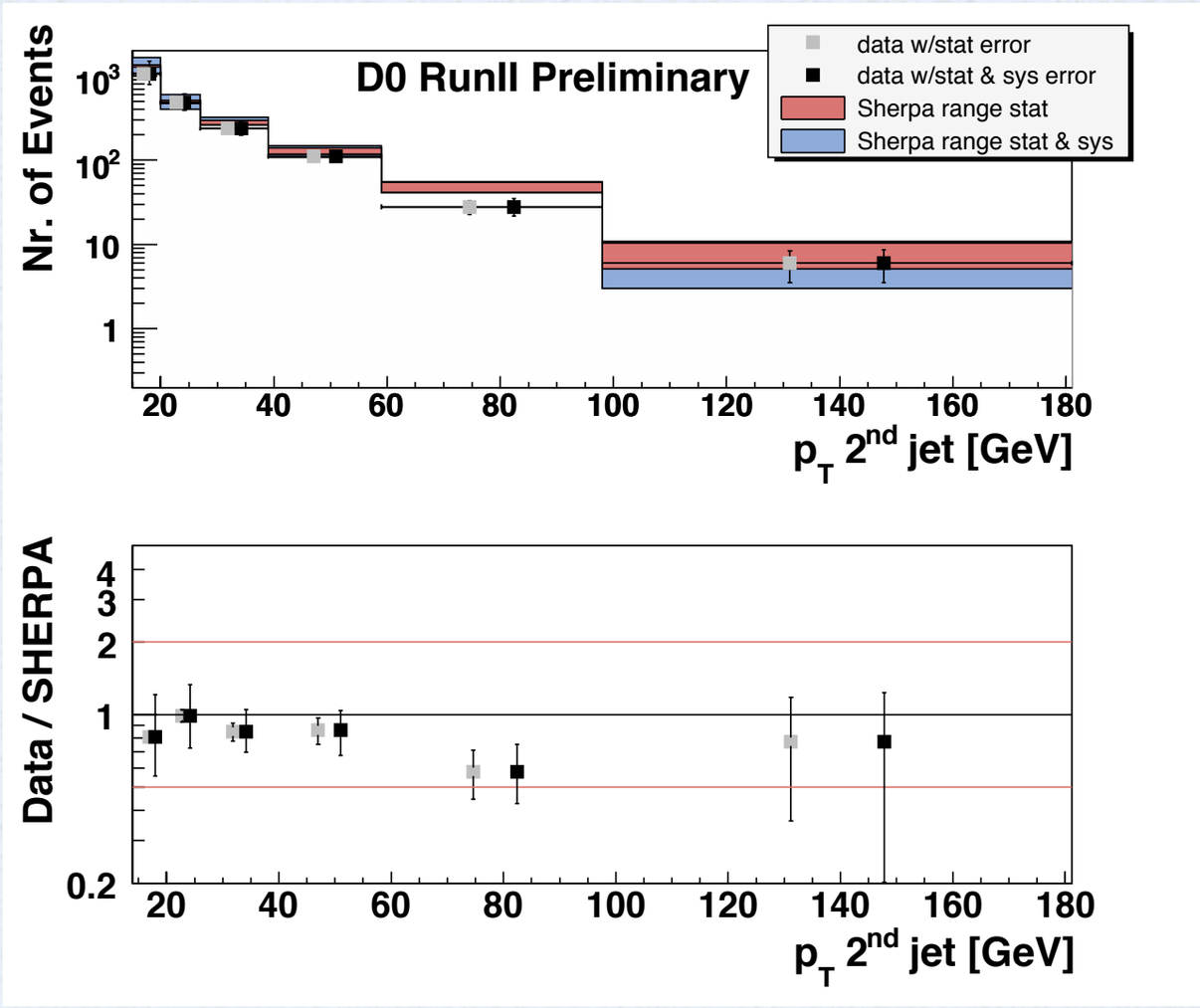
MC RESULTS VS. DATA

The DØ collaboration, DØ note 5066-CONF

- Jet-p_T, jet 2





- Pythia 6.2
  normalized to data

- Sherpa 1.0
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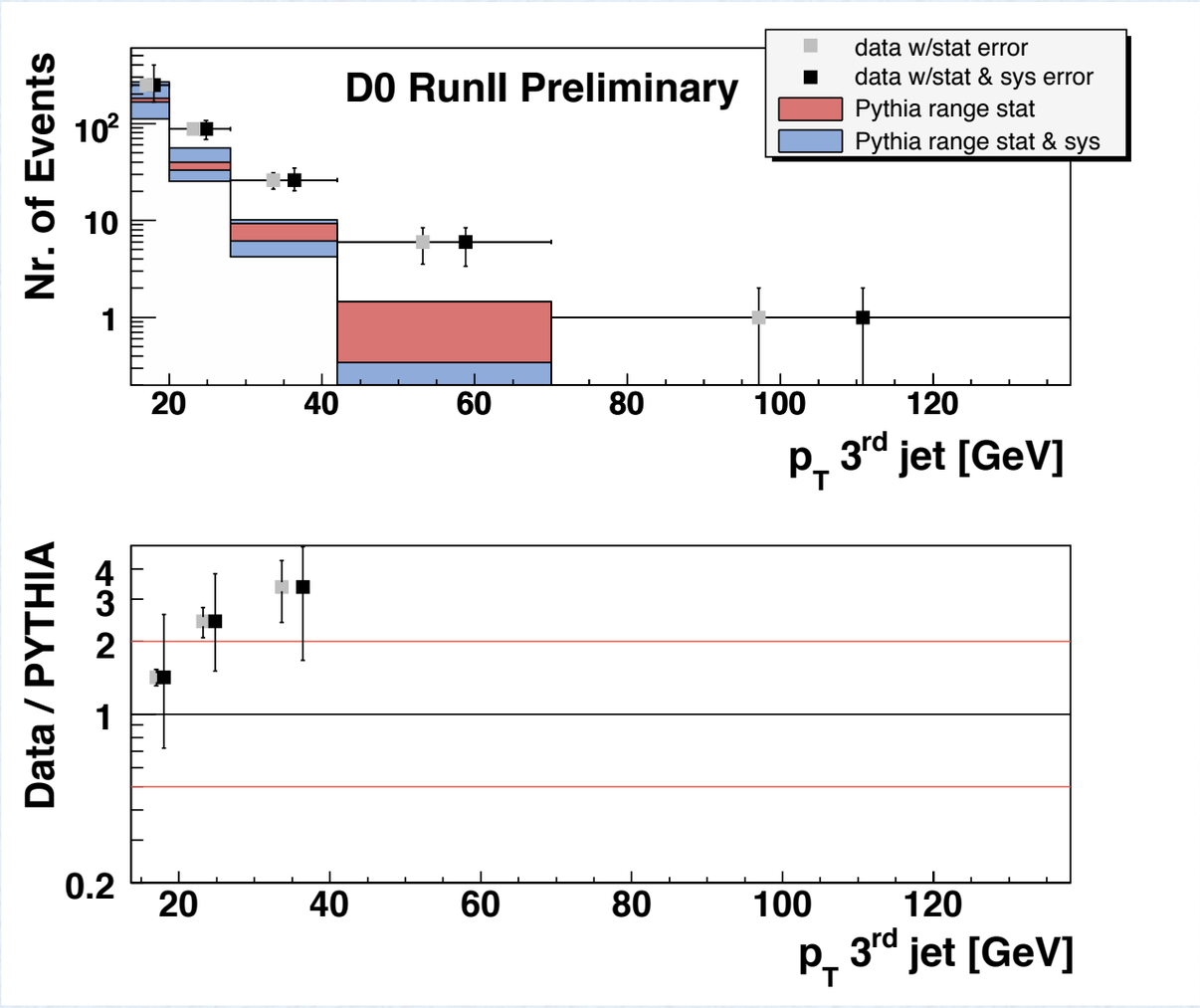
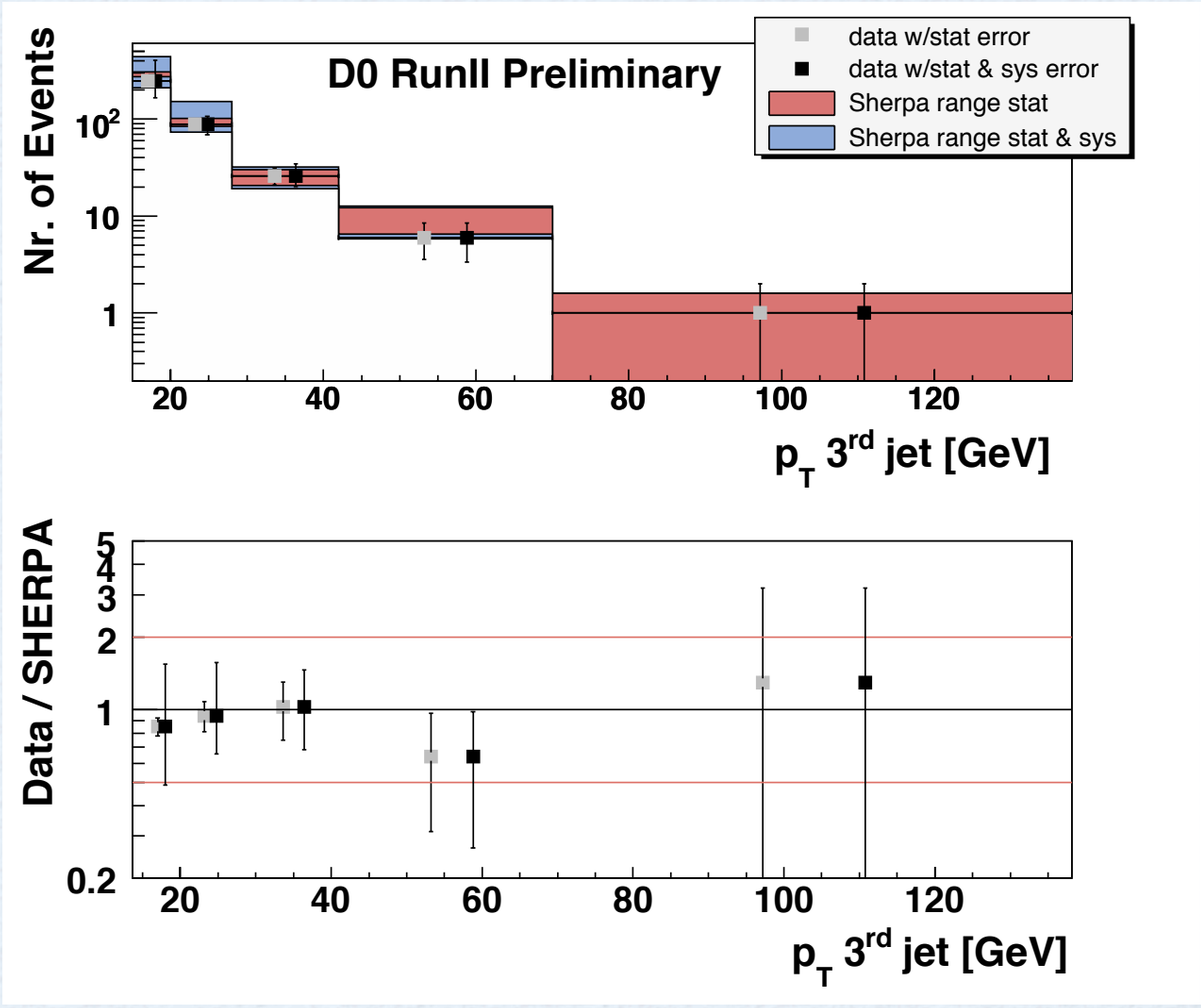
MC RESULTS VS. DATA

The DØ collaboration, DØ note 5066-CONF

- Jet-p_T, jet 3





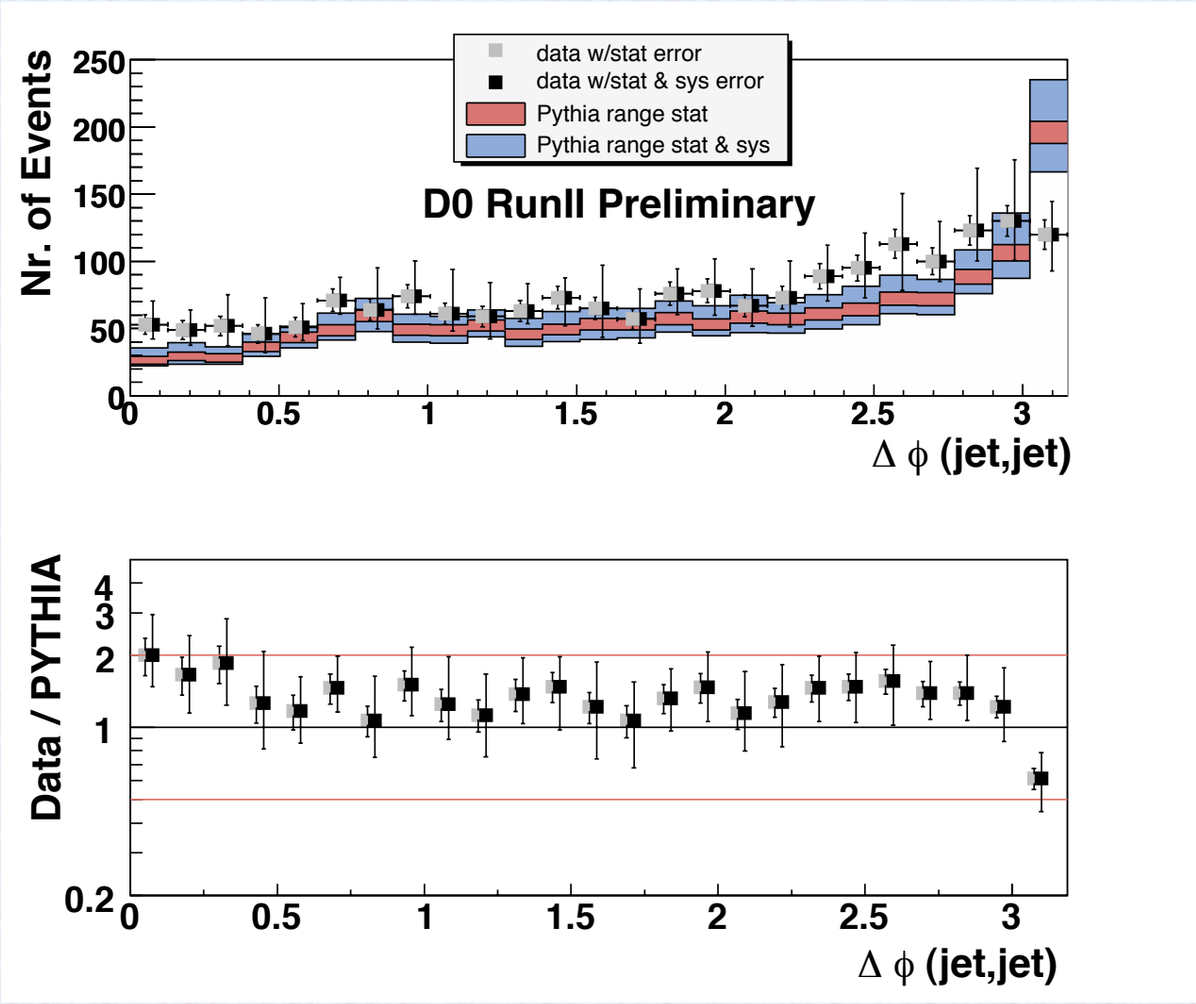
- Pythia 6.2
  normalized to data

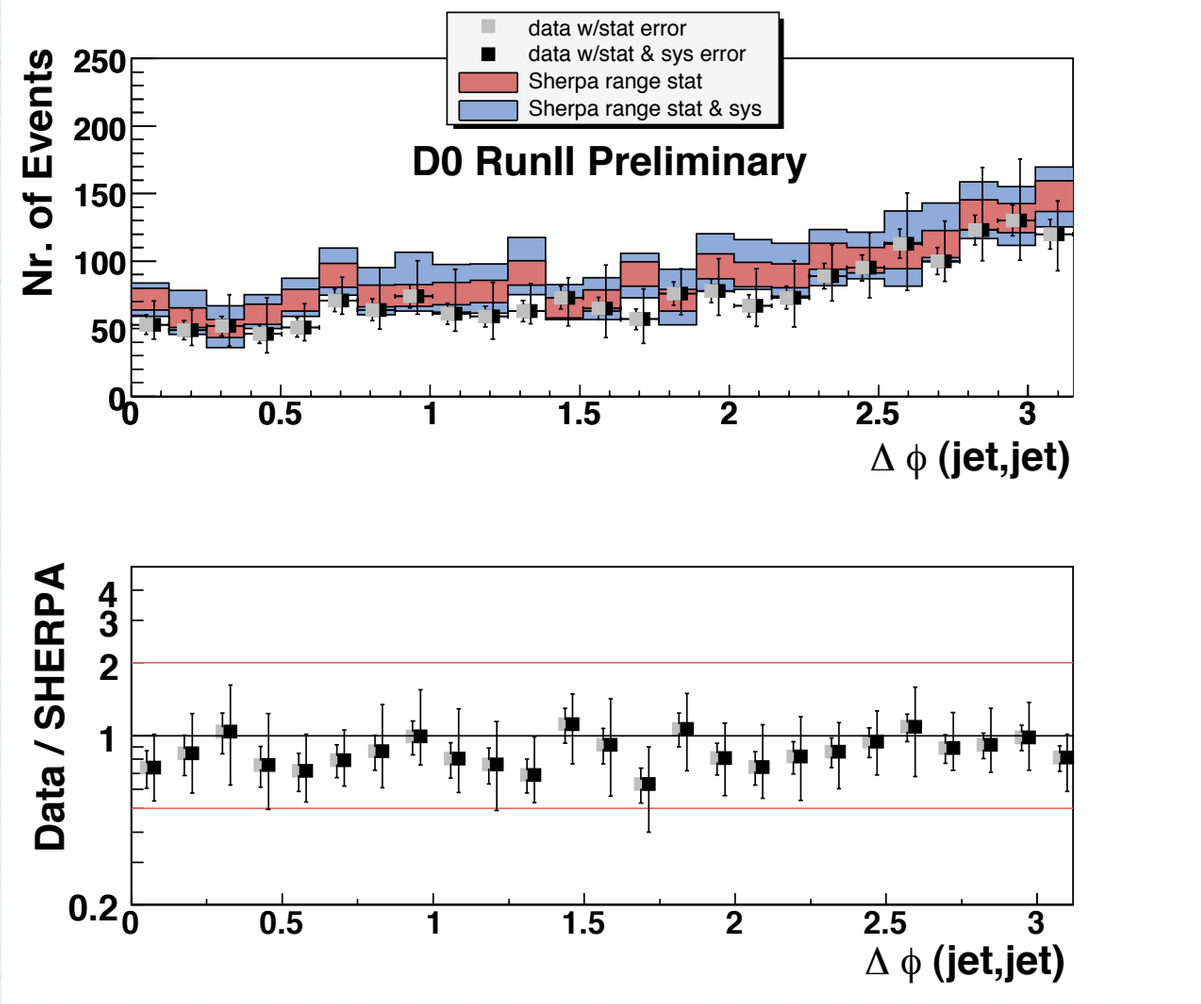
- Sherpa 1.0
  normalized to data

MC RESULTS VS. DATA

The DØ collaboration, DØ note 5066-CONF

- $\Delta\phi_{\mathbf{jet1,\,jet2}}$

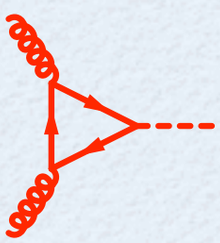




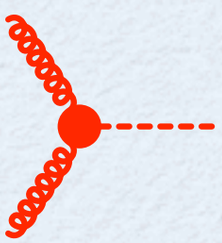
- Pythia 6.2
  normalized to data
- Sherpa 1.0
  normalized to data

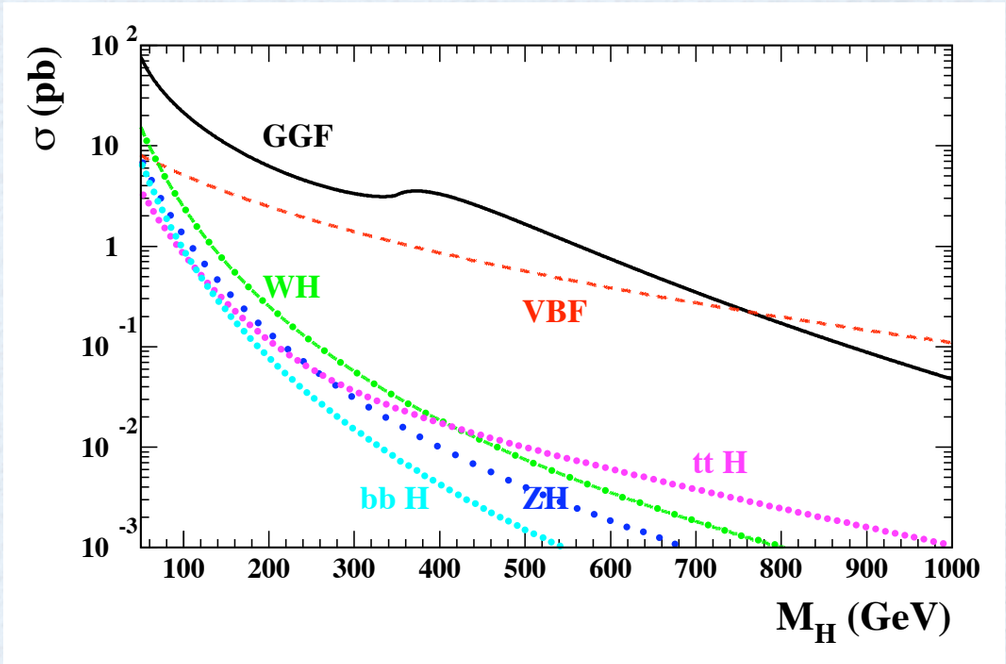
HIGGS PRODUCTION @ LHC

- Two major production mechanisms for SM Higgs at the LHC
  - Gluon fusion via heavy quarks

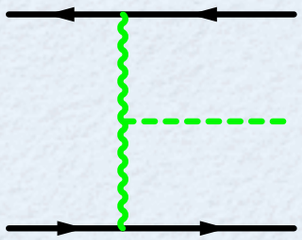


in limit $\mathbf{m_t} \gg \mathbf{m_H}$ described by effective Lagrangian (HEFT)



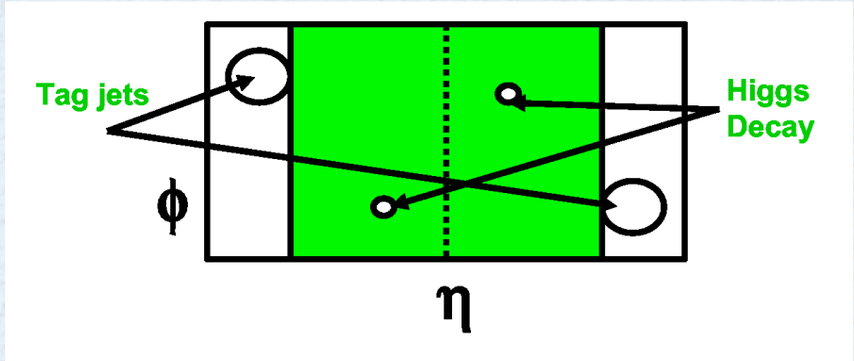


  - Weak Boson Fusion



promising channel due to rapidity gap

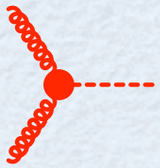
    - Two widely separated tag jets
    - **No central jet activity** at LO



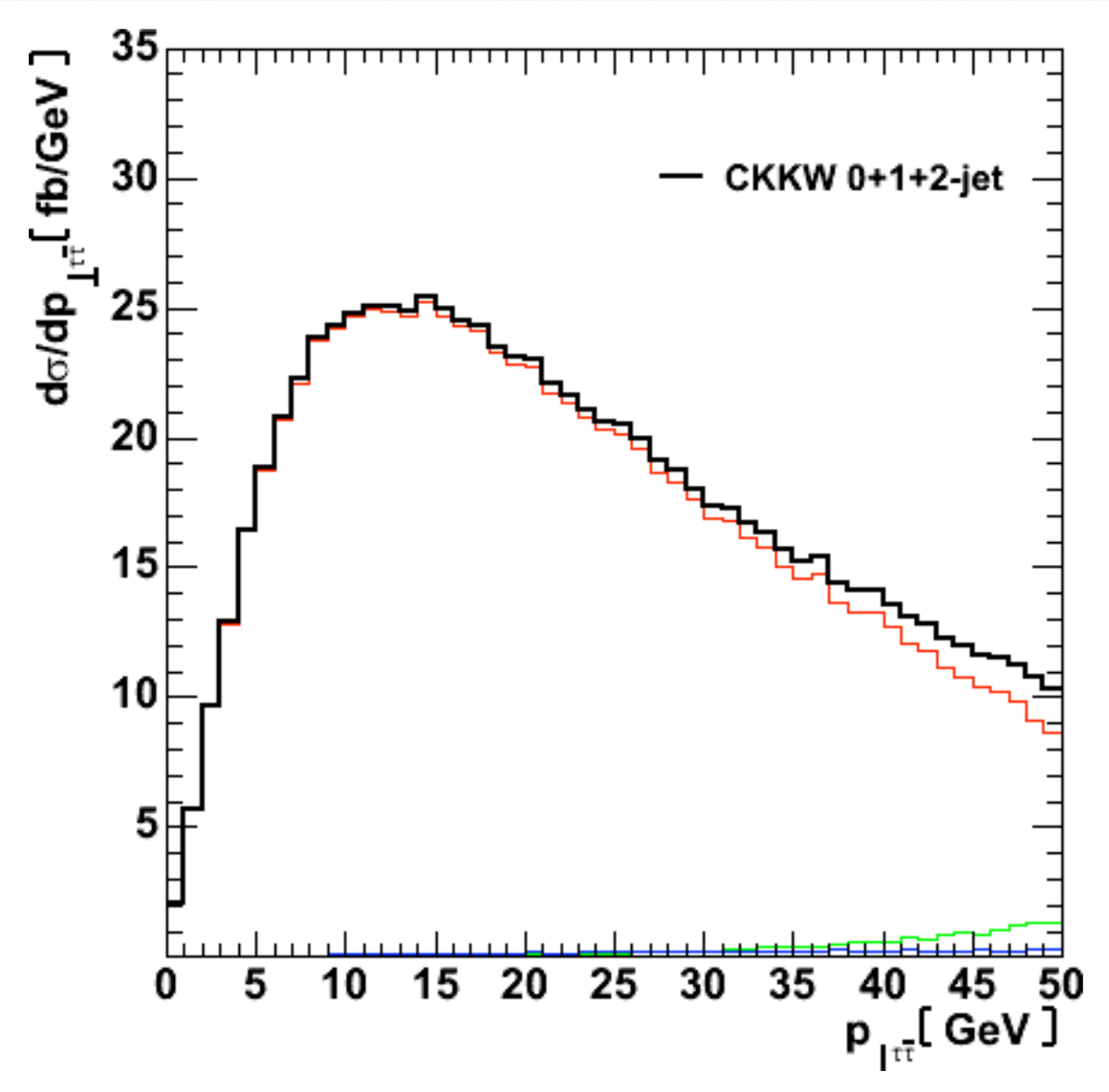
NLO corrections and influence of underlying event to be checked !

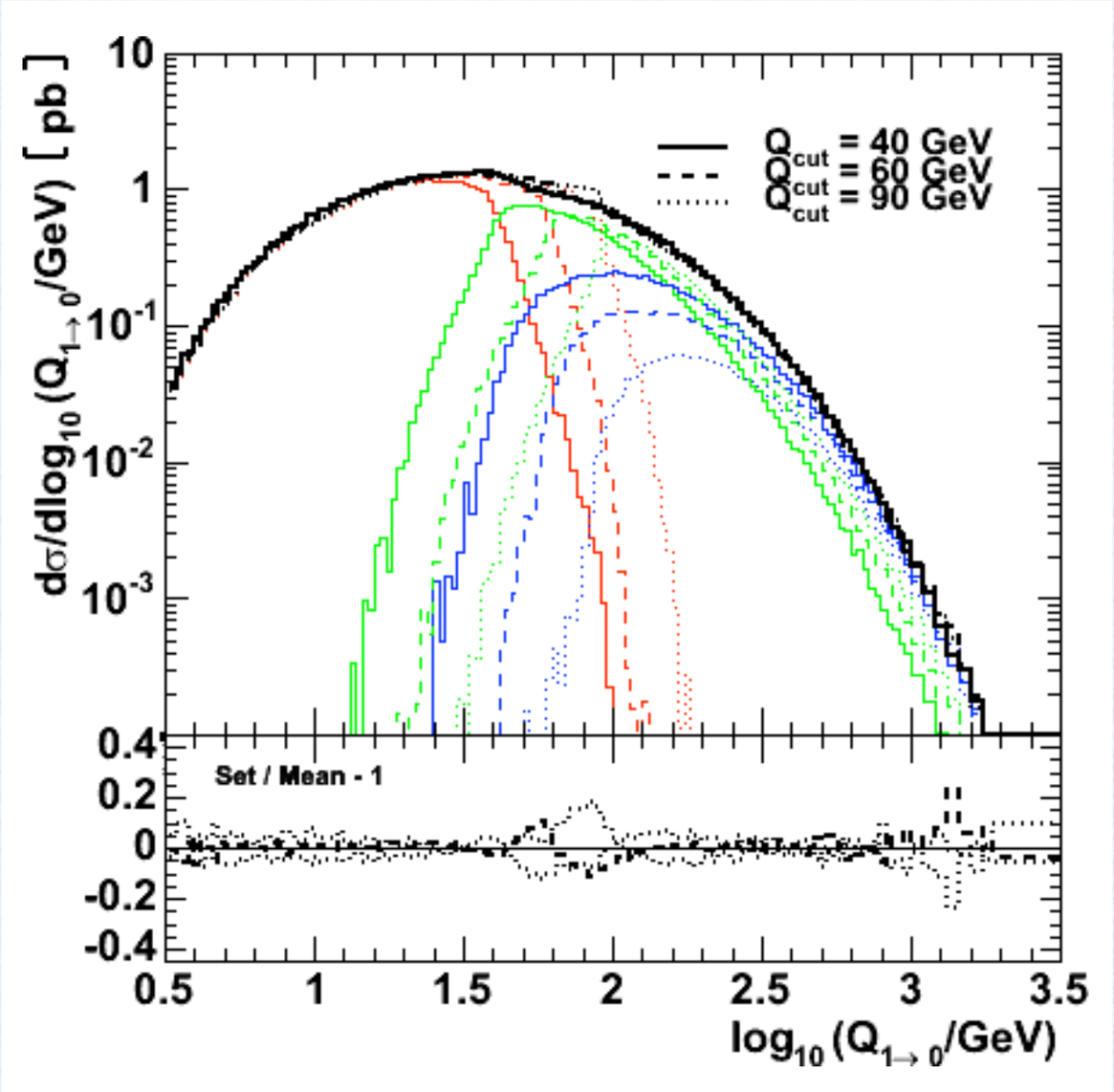
HIGGS PRODUCTION @ LHC

- Sherpa predictions for HEFT $(\mathbf{gg} \to \mathbf{H} \to \tau\bar{\tau})$

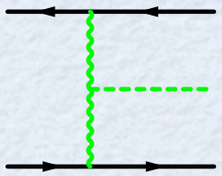


  - $p_{T,H}$
  - Differential 1➔0 jet rate

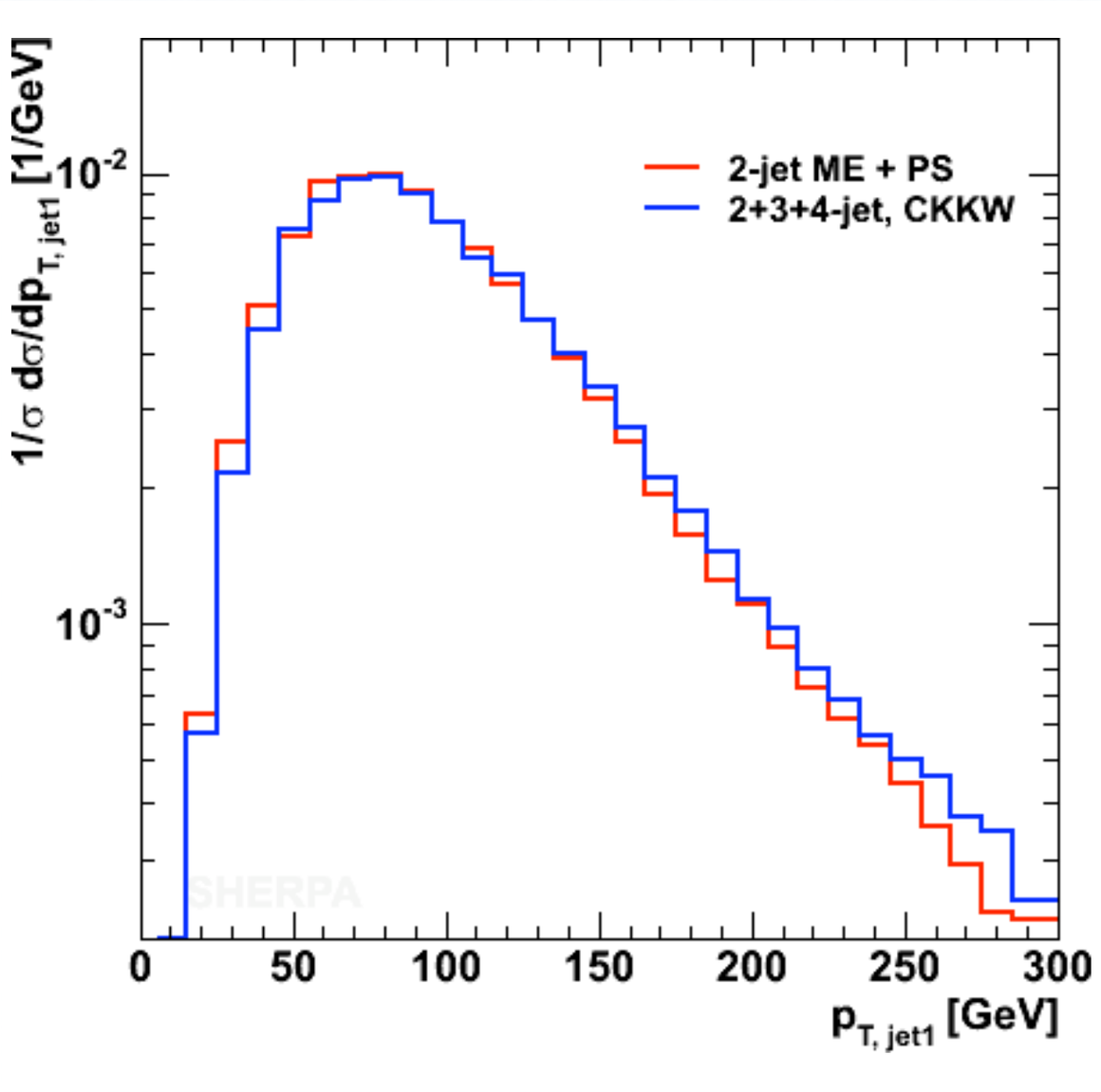


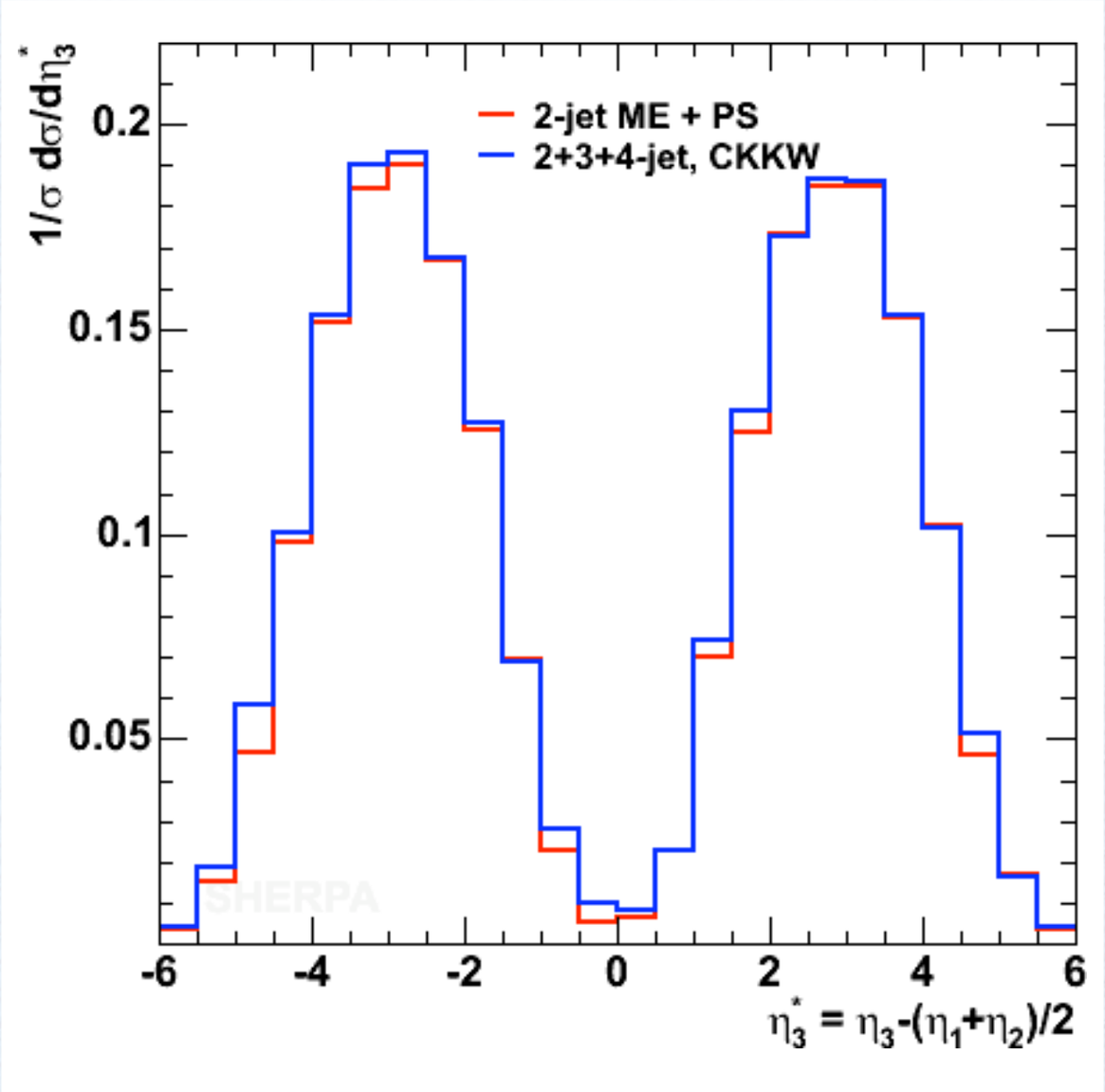


HIGGS PRODUCTION @ LHC



- Sherpa predictions for WBF $(|\eta_{j1} - \eta_{j2}| \geq 4.2,\ \eta_{j1}\eta_{j2} \leq 0)$
  - $p_{T,jet1}$
  - The Zeppenfeld plot

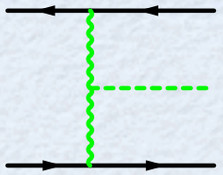




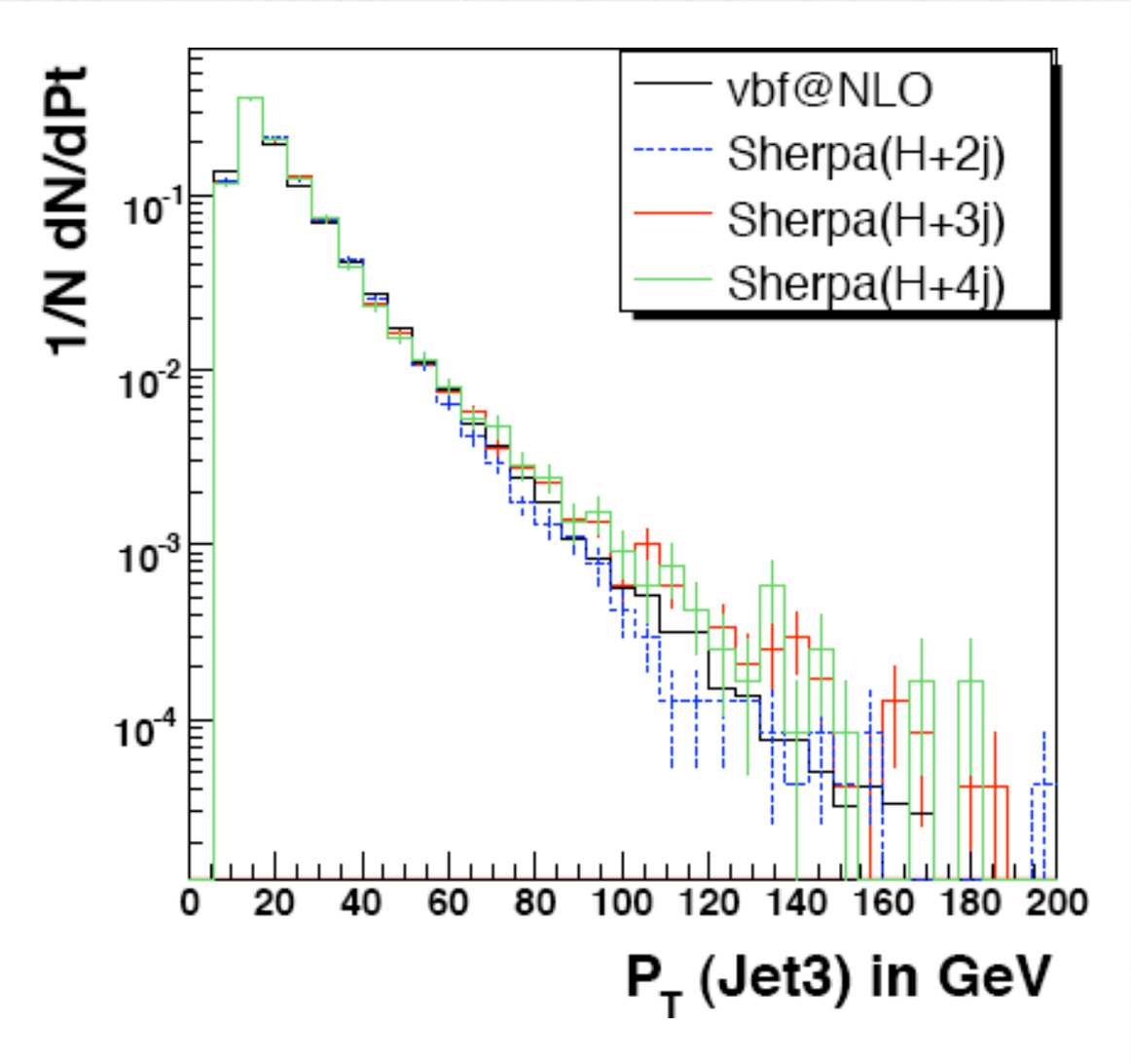
HIGGS PRODUCTION @ LHC

- Predictions for WBF (signal only)
  Generator level

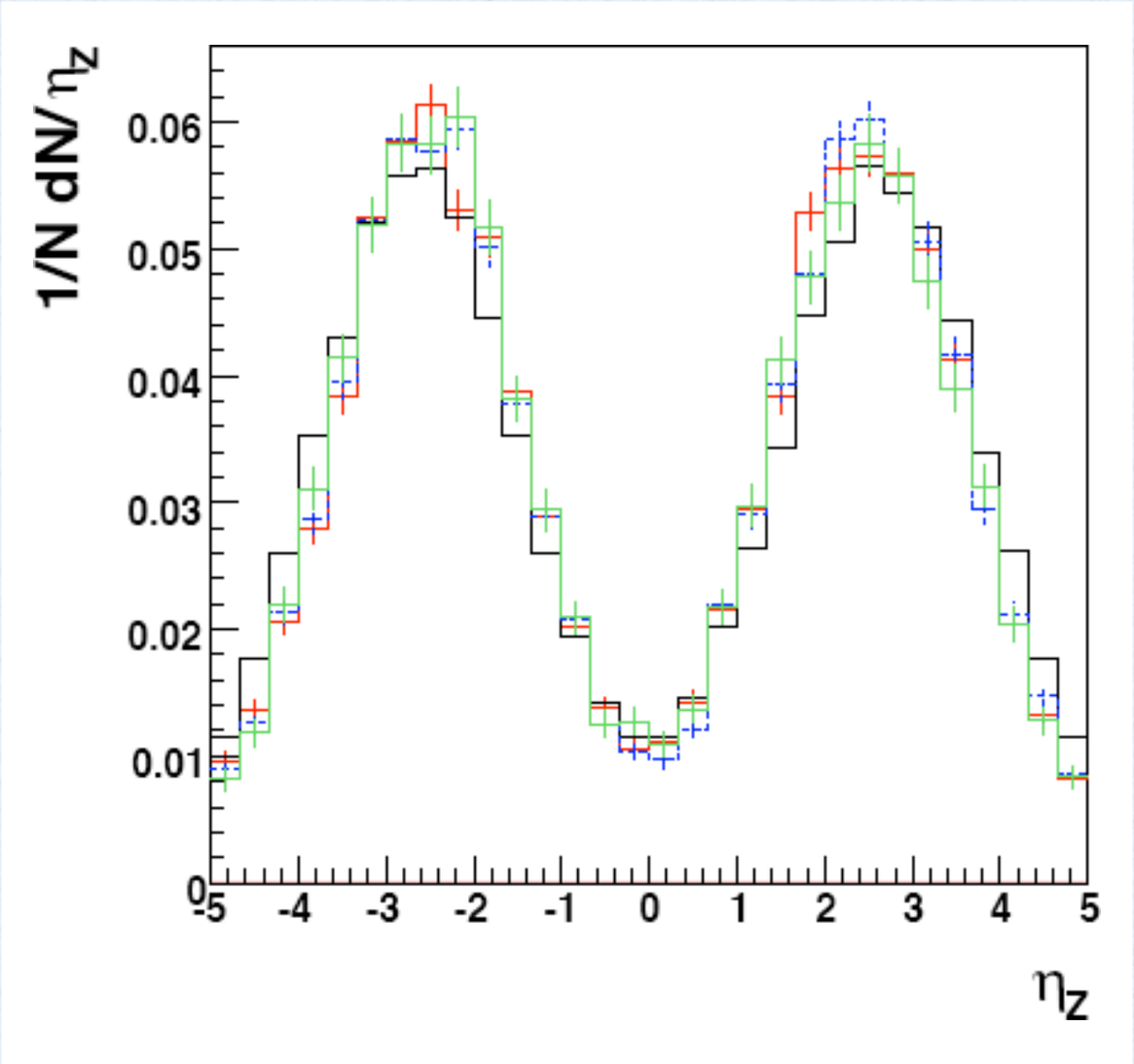
thesis by T. Köchling
supervisor M. Schumacher



- $p_{T,jet3}$



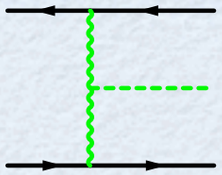
- The Zeppenfeld plot



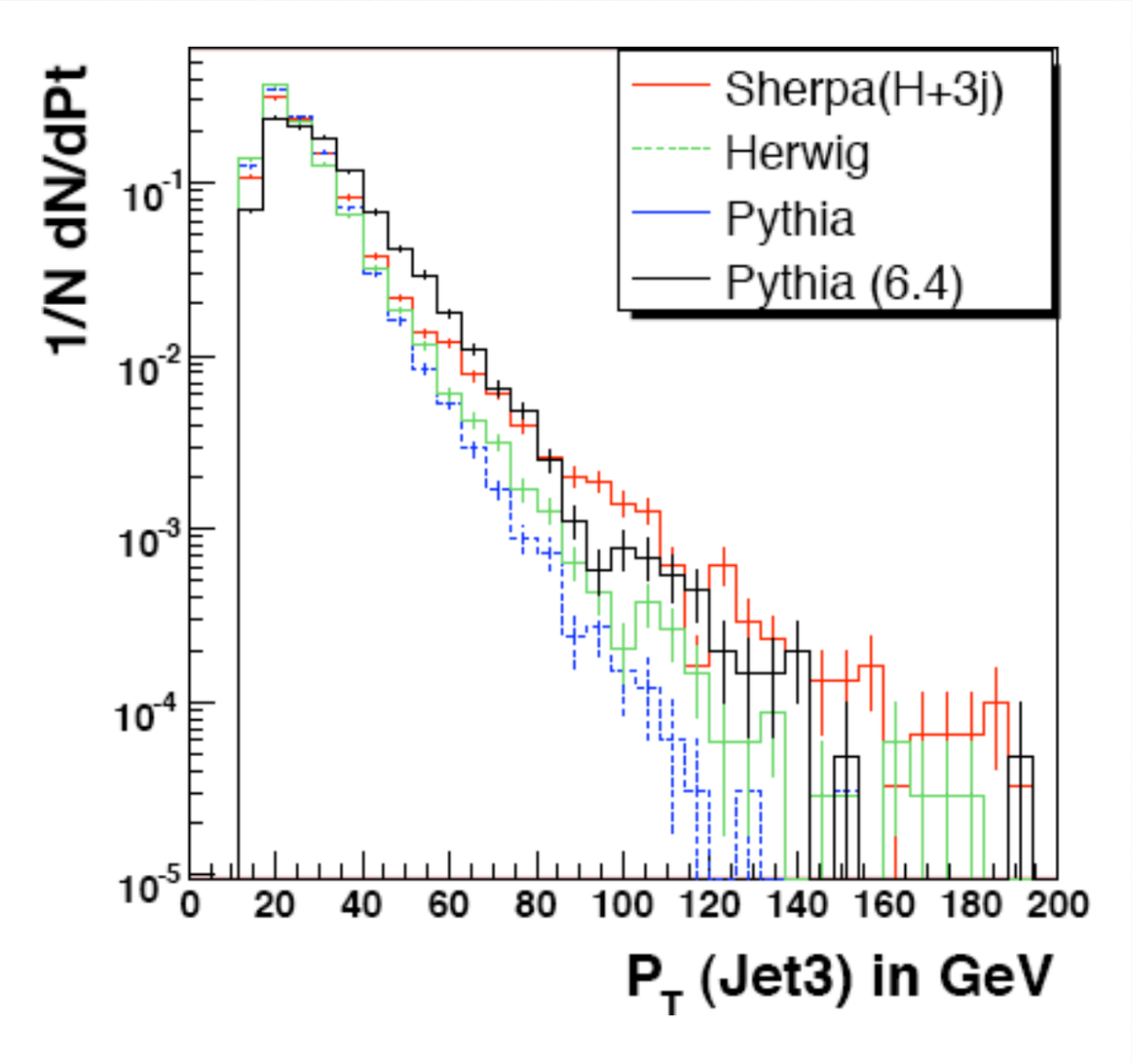
HIGGS PRODUCTION @ LHC

- Predictions for WBF (signal only)
  Detector level, incl. underlying event

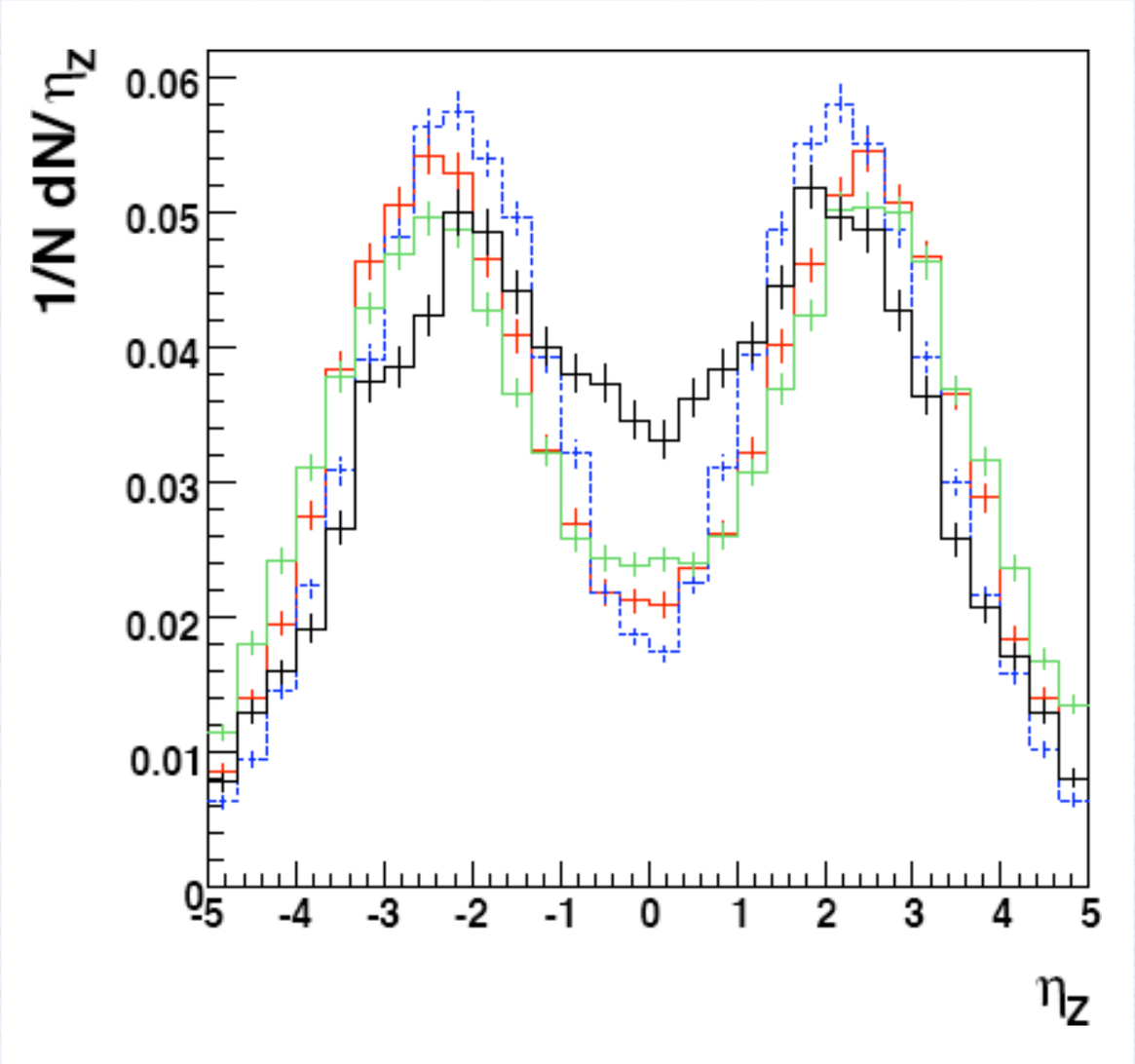
thesis by T. Köchling
supervisor M. Schumacher



- $p_{T,jet3}$



- The Zeppenfeld plot



HIGGS PRODUCTION @ LHC

thesis by T. Köchling
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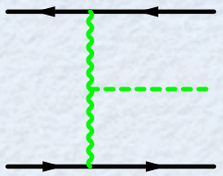
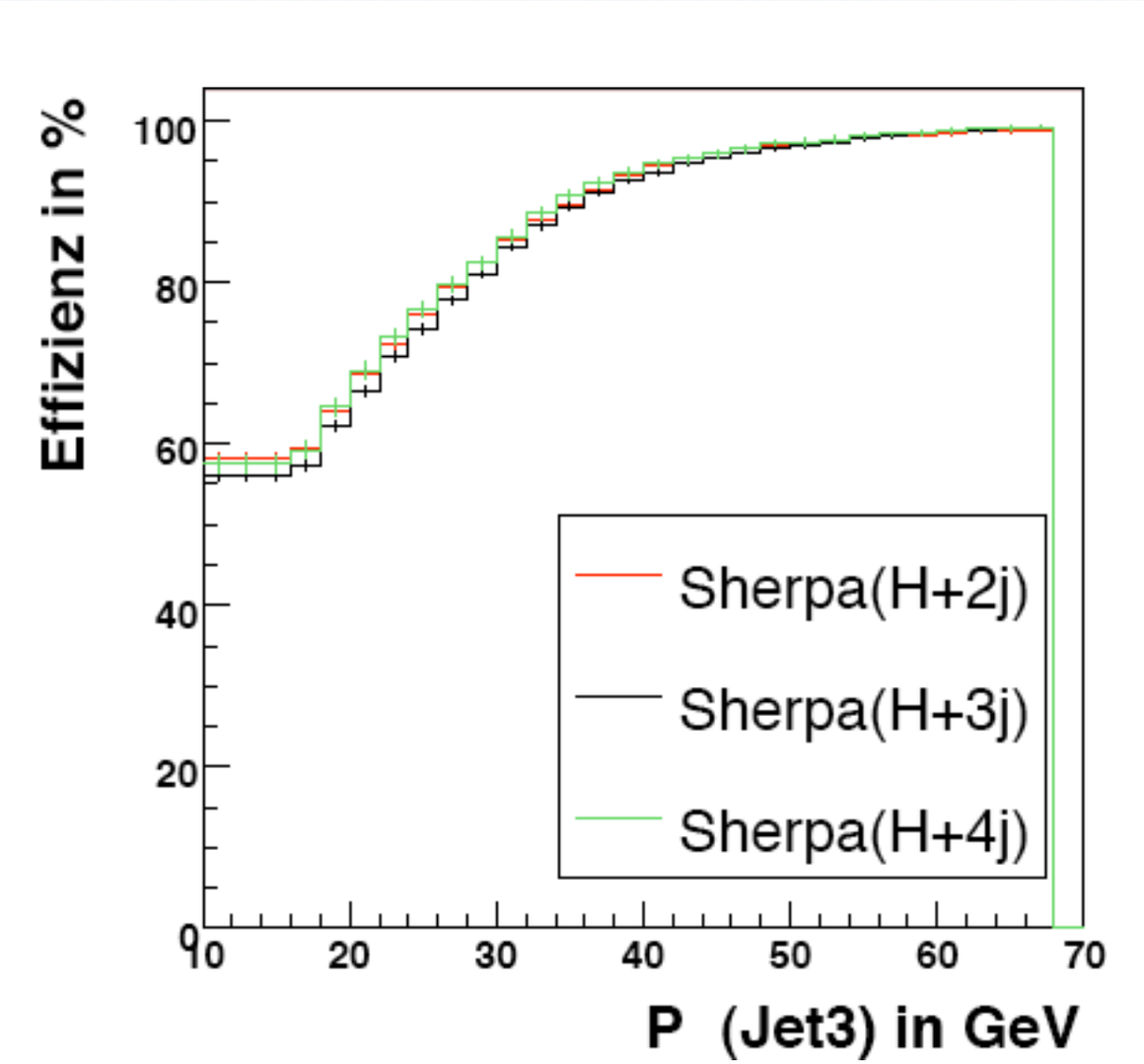
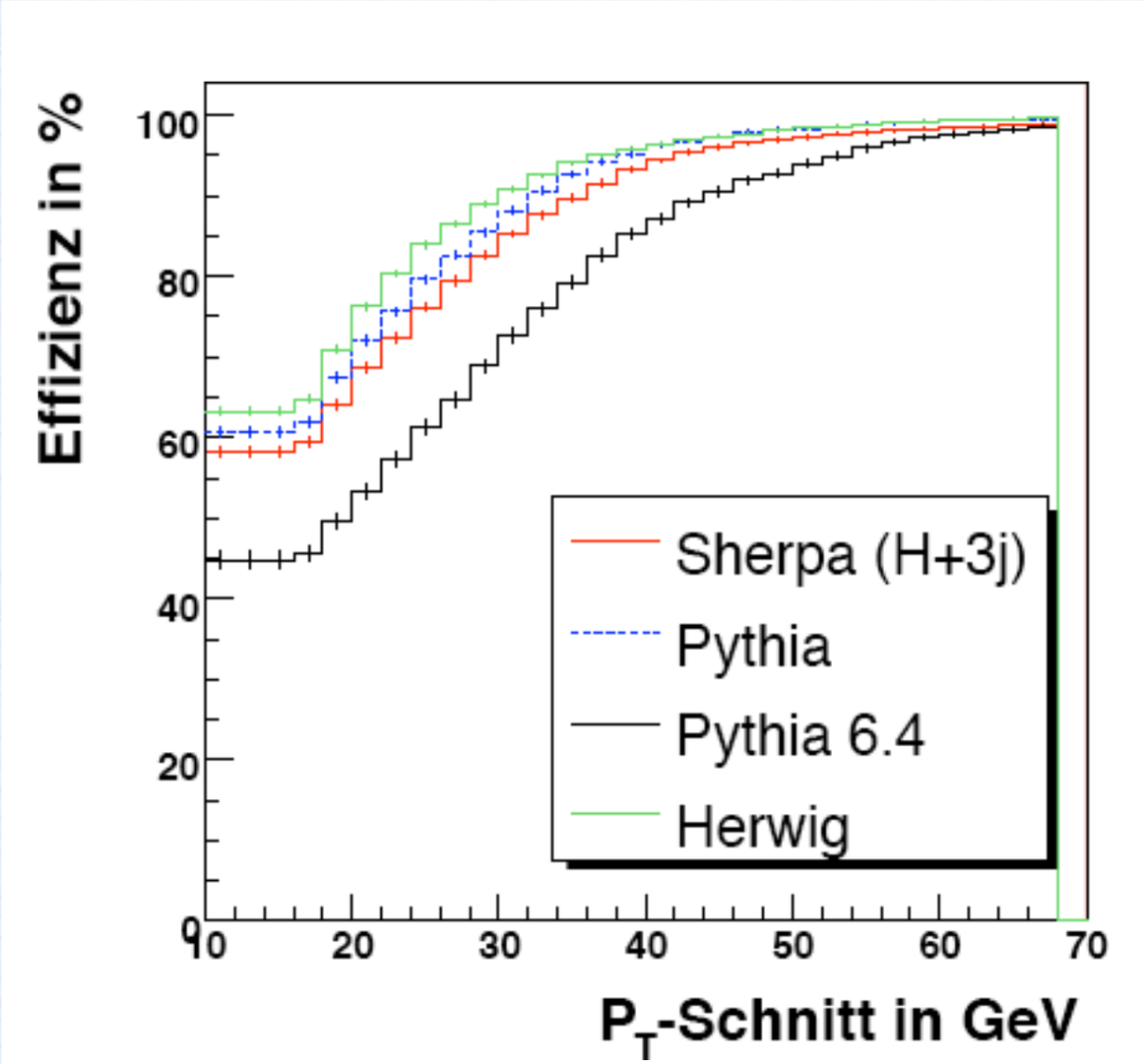


- Predictions for WBF (signal only)
  Detector level, incl. underlying event
  - Jet veto efficiency



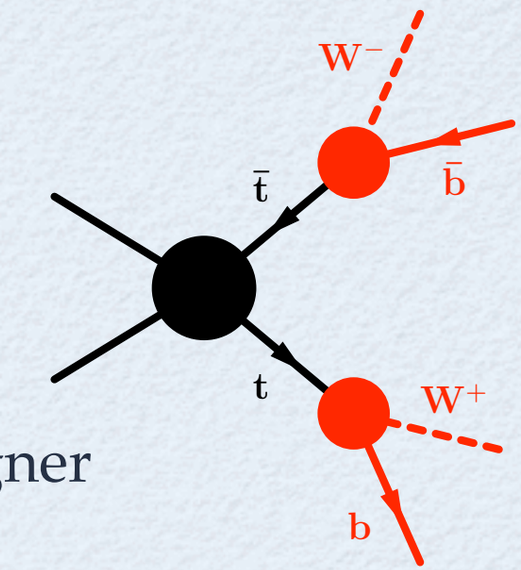
  - Jet veto efficiency



CKKW & HEAVY FLAVOURS

- Employ narrow width approximation to factorise matrix element into **production** and **decay** parts

Schematically: $\mathcal{A}^{(\mathbf{n})} = \mathcal{A}_{\mathrm{prod}}^{(\mathbf{n}_{\mathrm{prod}})} \otimes \prod_{\mathbf{i}\in\mathrm{decays}} \mathcal{A}_{\mathrm{dec},\mathbf{i}}^{(\mathbf{n_i})}$



Intermediate particle masses distributed according to Breit-Wigner

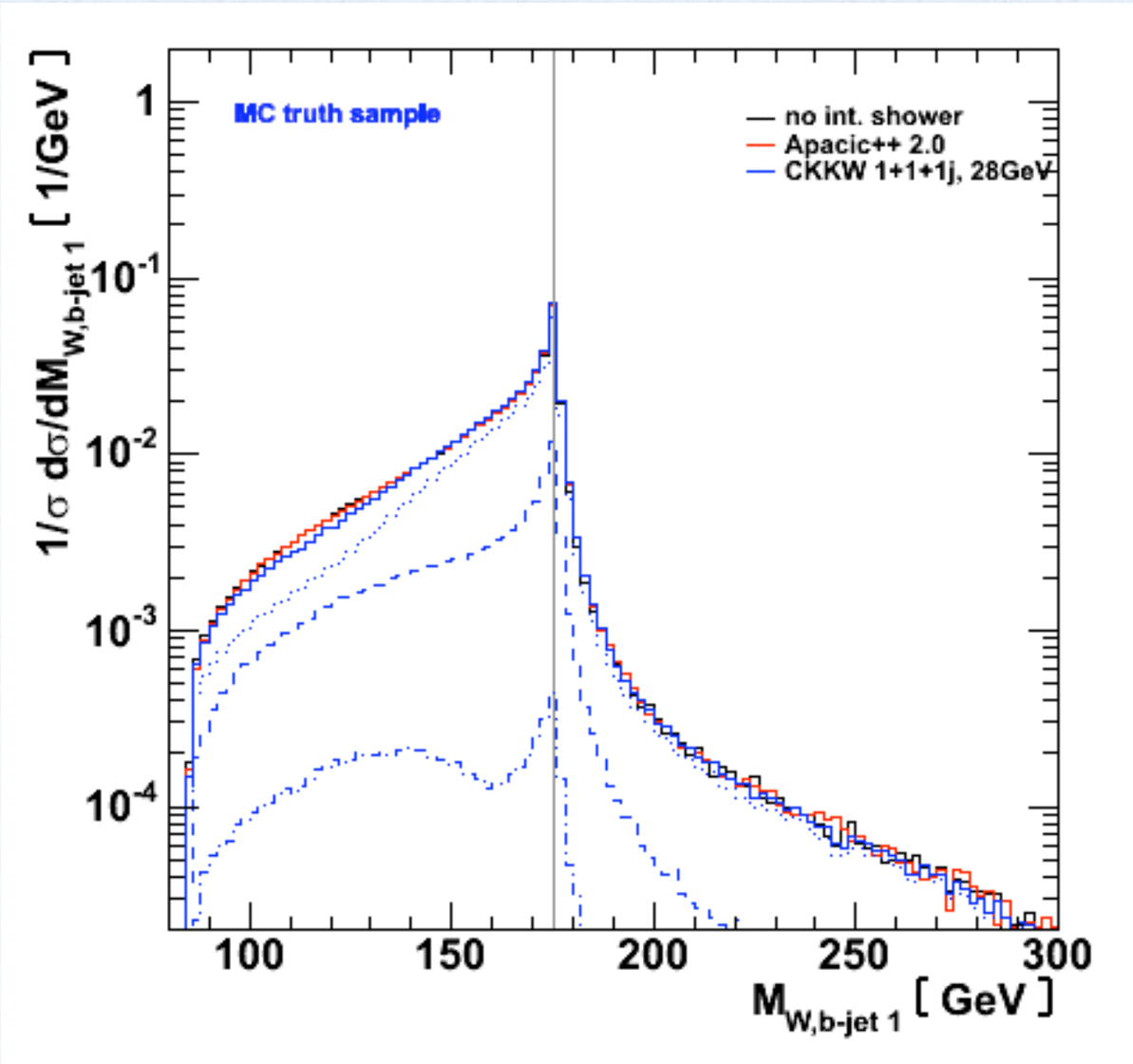
- AMEGIC++ provides decay chain treatment to project onto relevant Feynman diagrams
- APACIC++ allows production & decay shower off heavy partons
  - Ordinary FSR shower in production w/ appropriate boost of decay
  - ISR-like radiation pattern in decay w/ reconstruction of daughter system

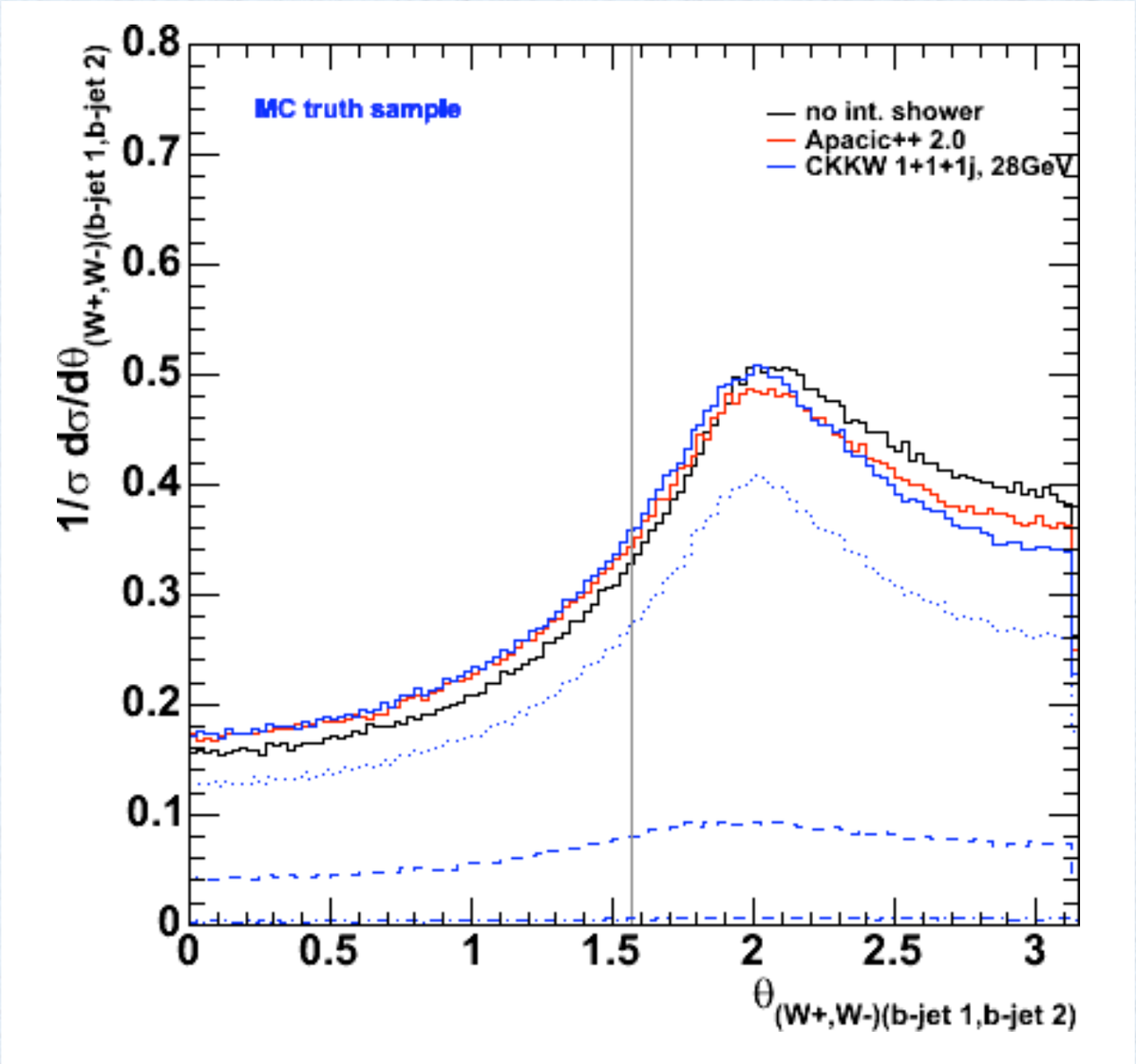
⚠ Check how much this procedure spoils correlations

- **CKKW applied separately and completely independent within production and each decay**

Top production in e^+e^-

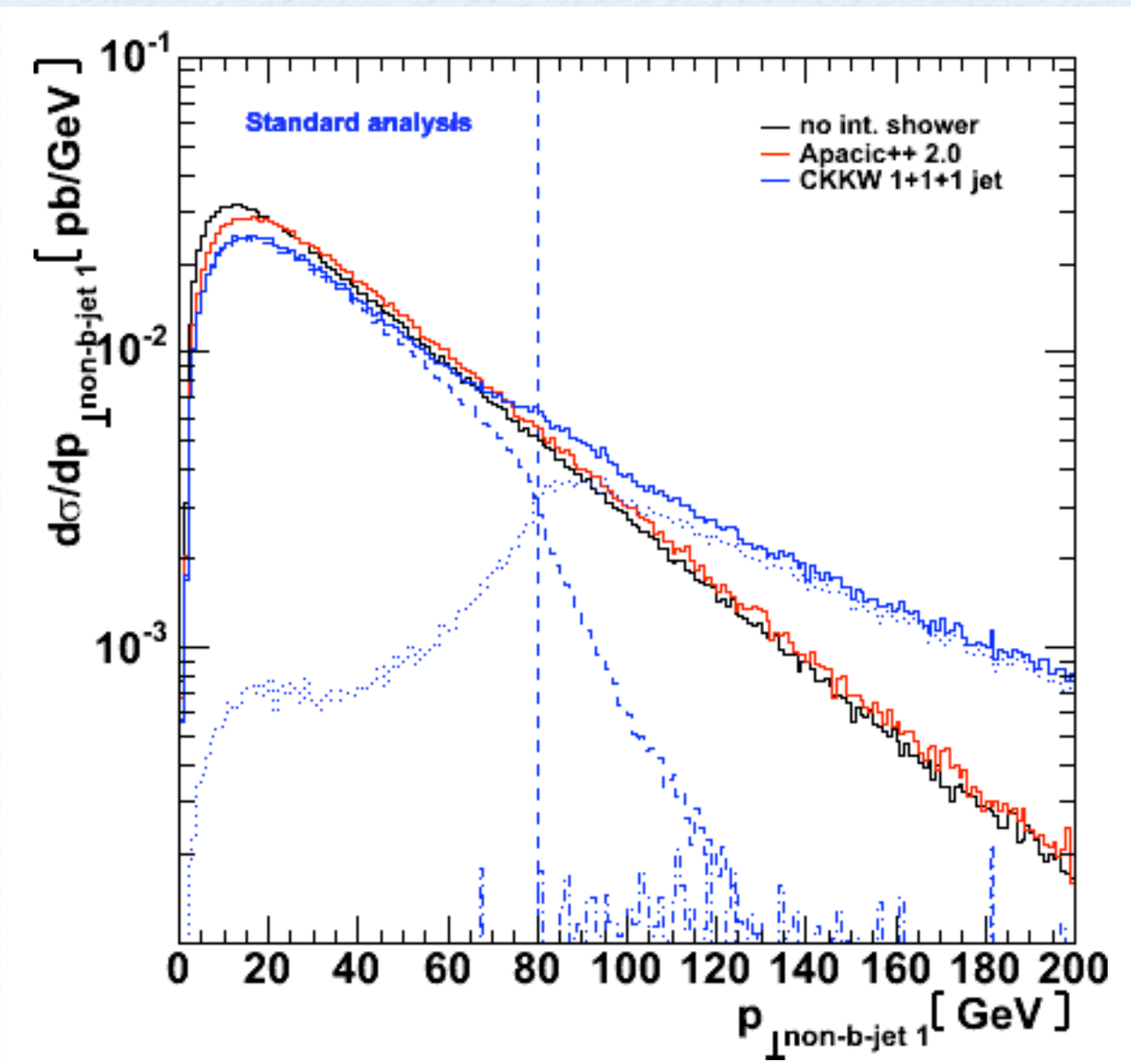
- Sanity check of procedure: Correlations in e^+e^-
  - Reconstructed top mass
  - Four particle plane angle

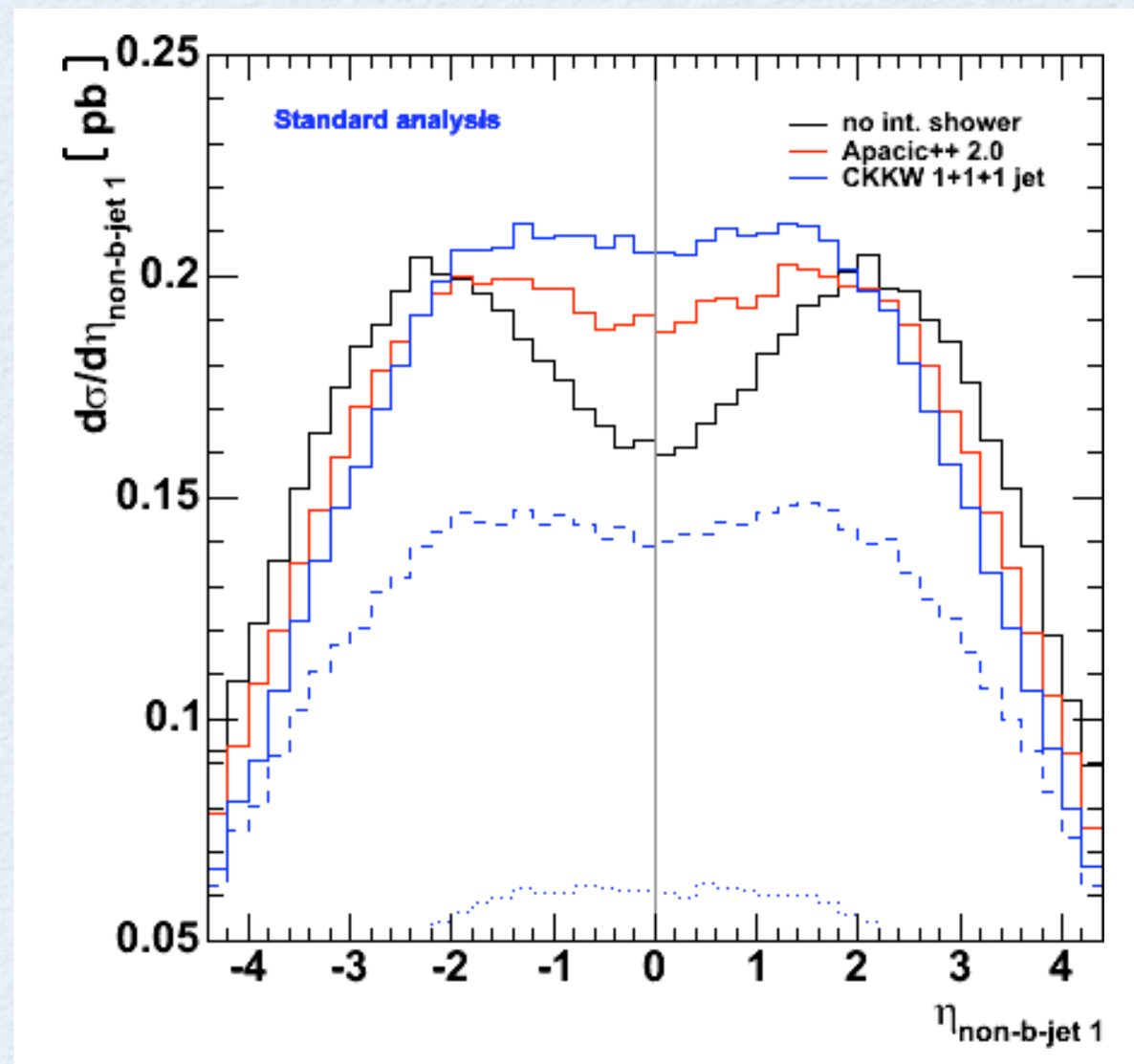




TOP PRODUCTION @ LHC

- Application: $t\bar{t}$ production at the LHC
  - $p_\perp$ of first extra jet
  - η of first extra jet





SUMMARY

So far ...

- CKKW in the Sherpa implementation
  has proven to be a powerful approach
  to describe present day LEP and Tevatron data
- Future collider's energies necessitate its application
  due to much larger available phase space

The cutting edge ...

- Extension to treatment of unstable particles
  currently under investigation
- Application to MSSM processes in preparation

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