New tools for automatic cross section calculation

Frank Krauss

Institute for Theoretical Physics, TU Dresden

Why automation ?

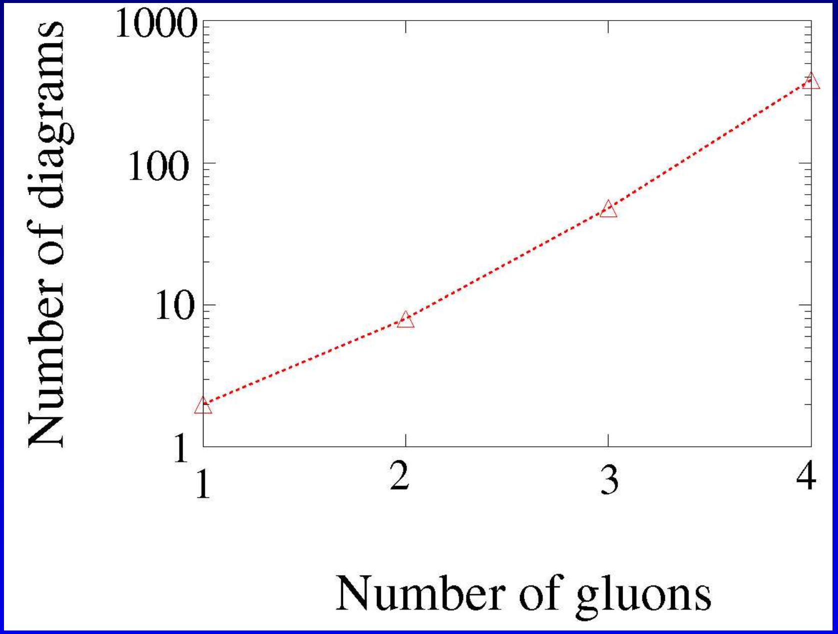
Signals with few ($\mathcal{O}(6)$) separated particles

$\Longrightarrow$ Want to use exact matrix elements for signals!

Basic difficulty: Factorial growth of diagrams

Illustration : $e^+e^- \longrightarrow q\bar{q} + ng$

n	diags
1	2
2	8
3	48
4	384



Why automation ?

- Large number of terms $\Longrightarrow$ automation.
- Different approaches
  basic problems: amplitudes + phase space
- A number of codes available for tree-level:
  1. Alpgen: uses Dyson-Schwinger + hand-made PS mappings
  2. Helac/Phegas/JetI: uses Dyson-Schwinger + automatic PS mappings
  3. MadGraph/MadEvent: uses helicity amplitudes + automatic PS mappings
  4. AMEGIC++: uses helicity amplitudes + automatic PS mappings

Amplitude generation

- Problem: Factorial growth of Feynman diagrams contributing with increasing number of outgoing particles

$e^+e^- \to$	Feynman diagrams
e^+e^-	4
$e^+e^-\mu^+\mu^-$	50
$e^+e^-e^+e^-$	144
$e^+e^-e^+e^-\mu^+\mu^-$	3690
$e^+e^-e^+e^-e^+e^-$	13896

traditional method of summing and squaring inappropriate

Amplitude generation

Tame the factorial growth: "Super-amplitudes"

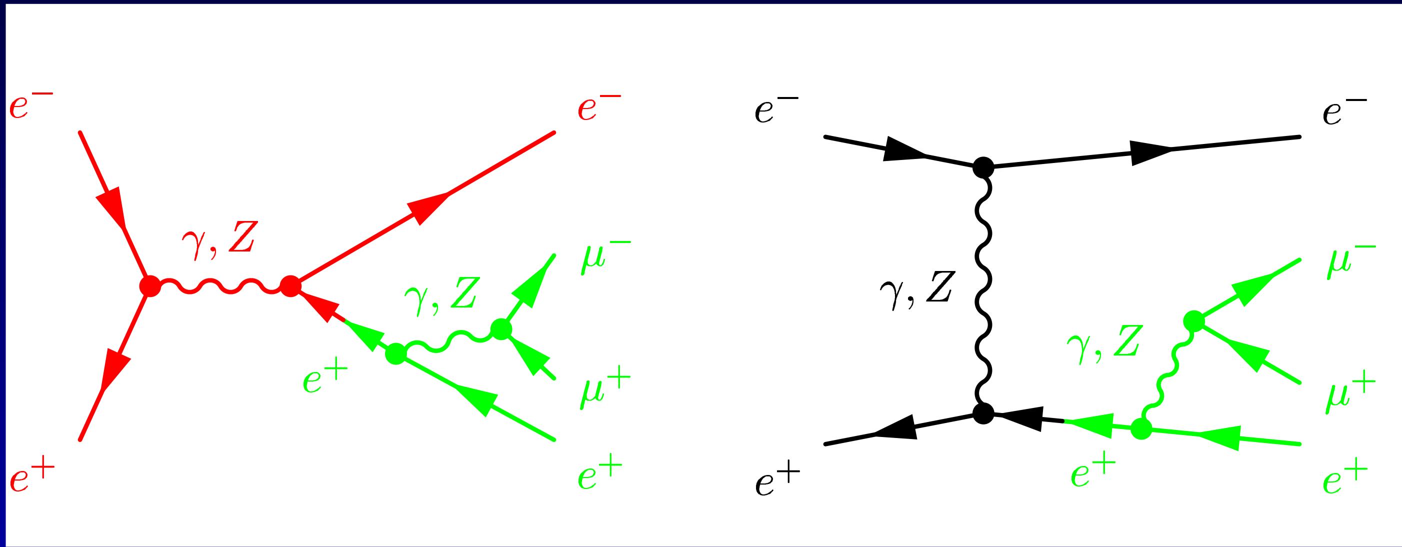
$e^+e^- \rightarrow$	Feynman diagrams	Super-amplitudes
e^+e^-	4	4
$e^+e^-\mu^+\mu^-$	50	10
$e^+e^-e^+e^-$	144	9
$e^+e^-e^+e^-\mu^+\mu^-$	3690	261
$e^+e^-e^+e^-e^+e^-$	13896	323

Idea: Factorise out common Helicity building blocks
of different amplitudes

$\Rightarrow$ reduce the number of complex multiplications

Amplitude generation

Tame the factorial growth: “Super-amplitudes”



Features of the algorithm:

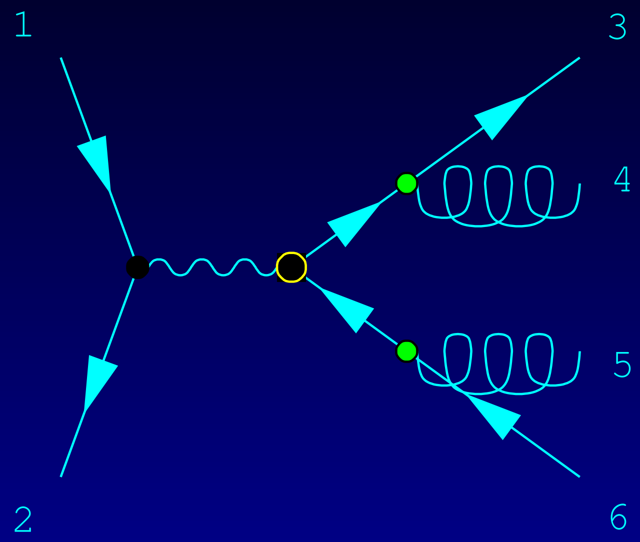
- Amplitudes that differ only by boson props. are combined
- s- and t-channels can be combined as well
- So far only for amplitudes with equal colour structure

Phase space integration

Amegic uses Multi-channel method

- Analyse peak structure of amplitudes
- Amplitudes $\longrightarrow$ modular channels
- Each channel covers full phase space
- Channel weighted according to contributions (self-adaption)

Phase space integration



P_0 massless propagator

D_S symmetric decay

D_A asymmetric decay

$$\sim P_0(34)\, P_0(56)\, D_S(34,56)\, D_A(3,4)\, D_A(5,6)$$

Implementation in `AMEGIC++`

Programming features

1. Automatic generation of amplitudes & integration channels
2. $\approx$ 30000 lines of core code
3. Writes out library files for processes
4. Parallelisation

Physics features

1. Standard Model implemented and tested
2. MSSM implemented and tested
3. ADD implemented and tested
4. Different PDF's, beam spectra, etc..
5. Part of the SHERPA framework (allows for fragmentation)

Results with `AMEGIC++`

AMEGIC++ successfully tested for:

- $e^+e^- \to 4/6$ massive or massless jets/fermions
- $\gamma\gamma \to 4f$
- numberless sparticle production and sparticle decay channels

Validation for LHC purposes during (and after) the MC4LHC workshop at CERN summer 2003

- $e^-\bar{\nu}_e$, $e^+\nu_e$, e^-e^+, $\nu_e\bar{\nu}_e$, + up to 4jets
- $e^-\bar{\nu}_e b\bar{b}$, $e^-e^+b\bar{b}$, + up to 2jets
- γ, $\gamma\gamma$, + up to 3jets
- $t\bar{t}$, $b\bar{b}$, + up to 2jets
- 2-, 3-, 4-jet production

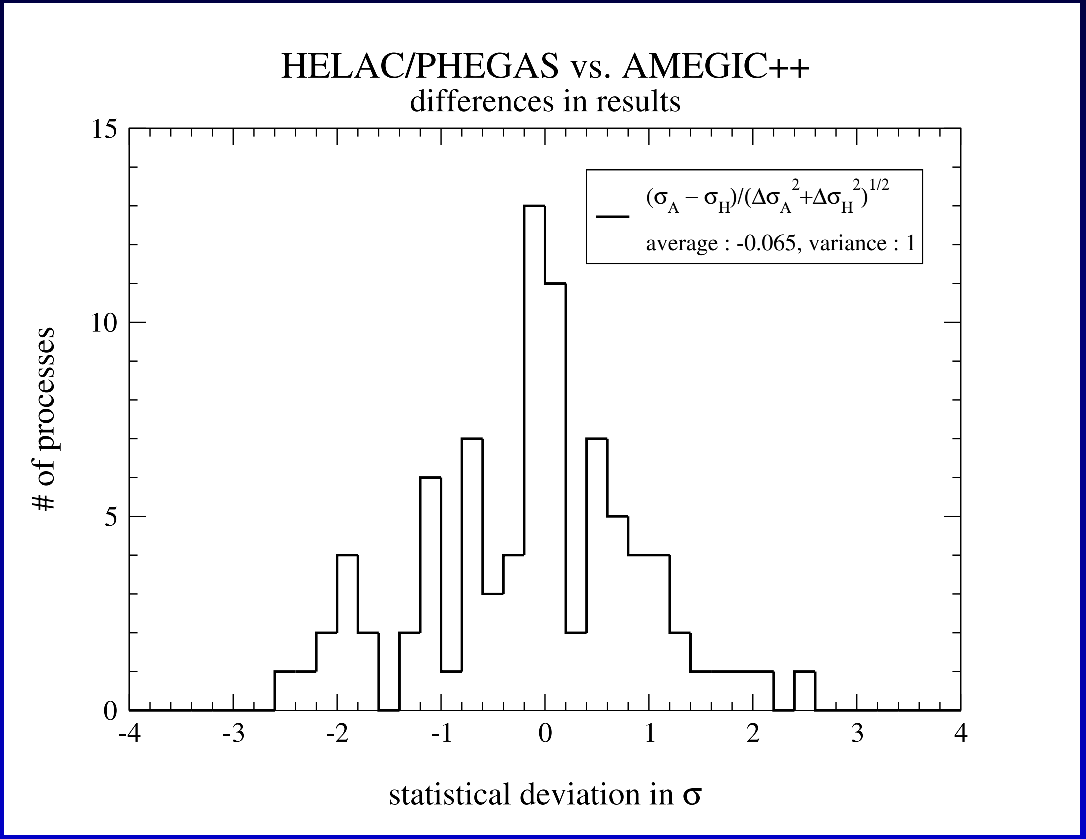
Results with AMEGIC++

Top-quark channels (e^+e^-, 500 GeV)

final state	QCD	AMEGIC++ [fb]	HELAC [fb]
$b\bar{b}u\bar{d}d\bar{u}$	yes	49.74(21)	50.20(13)
	no	49.42(44)	50.55(26)
$b\bar{b}u\bar{u}gg$	–	9.11(13)	8.832(43)
$b\bar{b}gggg$	–	24.09(18)	23.80(17)
$b\bar{b}u\bar{d}e^-\bar{\nu}_e$	yes	17.486(66)	17.492(41)
	no	17.366(68)	17.353(31)
$b\bar{b}e^+\nu_e e^-\bar{\nu}_e$	–	5.954(55)	5.963(11)
$b\bar{b}e^+\nu_e\mu^-\bar{\nu}_\mu$	–	5.865(24)	5.868(10)
$b\bar{b}\mu^+\nu_\mu\mu^-\bar{\nu}_\mu$	–	5.840(30)	5.839(12)

Results with AMEGIC++

Comparison with HELAC/PHEGAS:



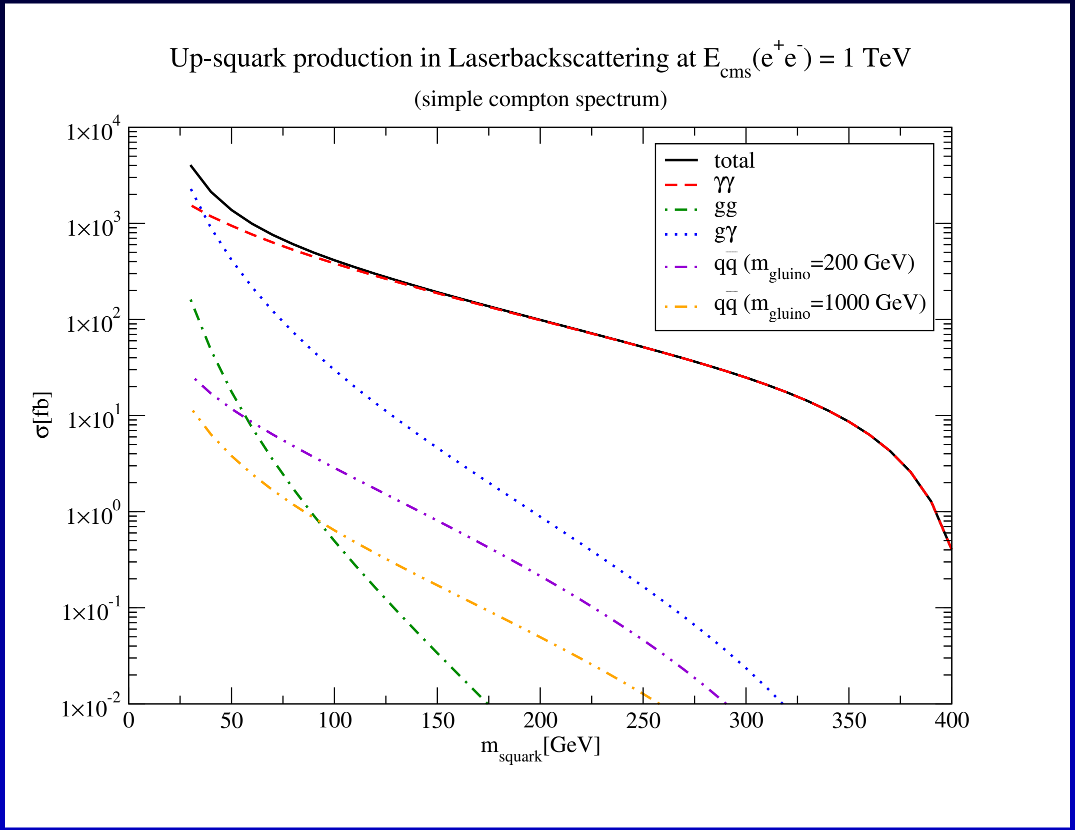
Results with AMEGIC++

X-sects (pb)	Number of jets						
$e^- \bar{\nu}_e + n$ QCD jets	0	1	2	3	4	5	6
Alpgen	3904(6)	1013(2)	364(2)	136(1)	53.6(6)	21.6(2)	8.7(1)
CompHEP	3947.4(3)	1022.4(5)	364.4(4)				
MadEvent	3902(5)	1012(2)	361(1)	135.5(3)	53.6(2)		
Amegic++/Sherpa	3908(3)	1011(2)	362(1)	137.5(5)	54(1)		

X-sects (pb)	Number of jets				
$e^- \bar{\nu}_e + b\bar{b}$	0	1	2	3	4
Alpgen	9.34(4)	9.85(6)	6.82(6)	4.18(7)	2.39(5)
CompHEP	9.415(5)	9.91(2)			
MadEvent	9.32(3)	9.74(1)	6.80(2)		
Amegic++/Sherpa	9.37(1)	9.86(2)	6.87(5)		

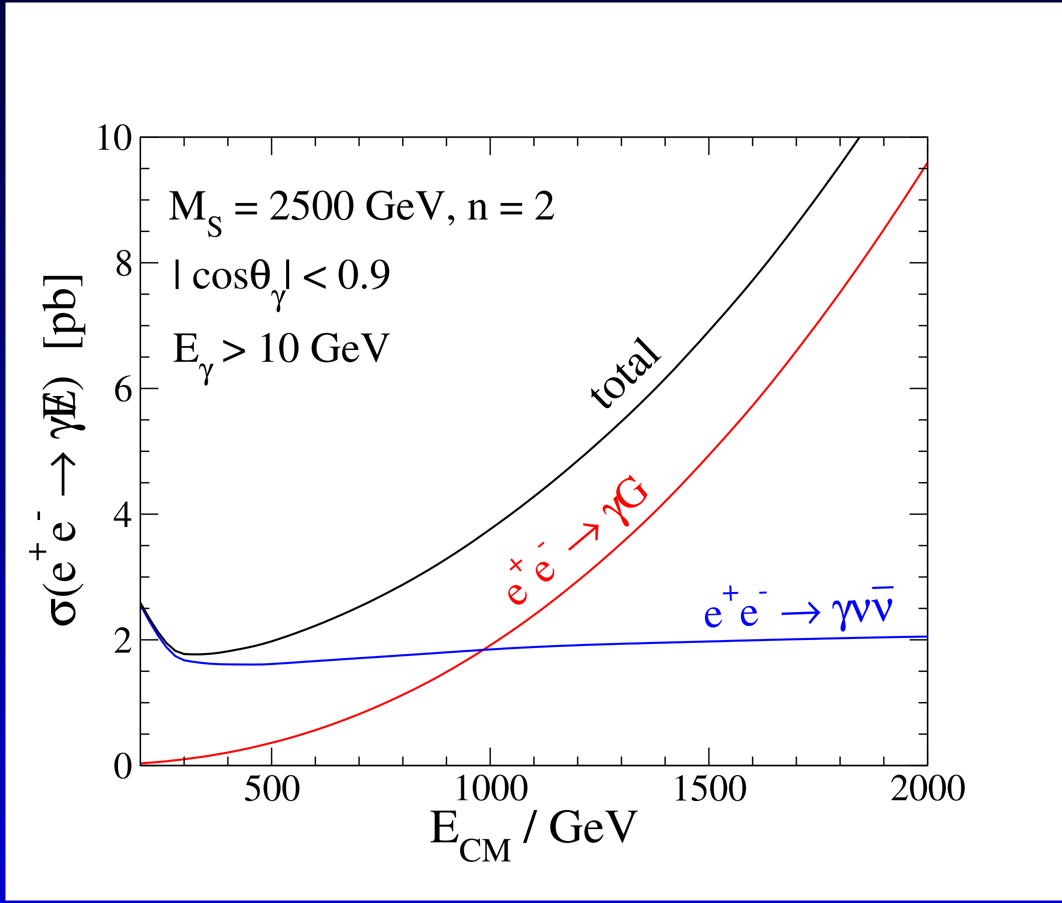
Results with AMEGIC++

Squark-pair production in $\gamma\gamma$ at NLC, 1 TeV



Results with AMEGIC++

Graviton-photon production at e^+e^-



Combining ME and PS

S. Catani,F. Krauss, R. Kuhn, B. Webber, JHEP 0111:063,2001

F. Krauss, JHEP 0208:015,2002

Aim:

- Good description of soft and hard region
- Universality of fragmentation (energy independent)

Solution:

- Divide multi-jet phase space into two regimes
  - Jet production by ME (if available)
  - Jet evolution down to fragmentation scale by the PS
- Reweight ME's for exclusive samples at a resolution scale
- Veto on PS configurations included in higher order ME

Combining ME and PS

Method:

- Select a jet multiplicity with probability:

$$P_n = \frac{\sigma_n}{\sum_{i=0}^{N} \sigma_i}$$

  where σ_n is the n-jet matrix element at $y_{cut} = Q_{jet}^2/Q^2$. Use Q_{jet} as scale for PDF's and α_S.

- Final state momenta p_i according to the ME
- k_T cluster backwards initial and final state particles
- Recalculate α_S for each vertex at the corresponding k_T scale
- Apply Sudakov weights
  - $\Delta_{q,g}(Q_{\rm jet}, Q_{\rm prod})$ for outgoing partons
  - $\Delta_{q,g}(Q_{\rm jet}, Q_{\rm prod})/\Delta_{q,g}(Q_{\rm jet}, Q_{\rm dec})$ for intermediate lines

Combining ME and PS

The method has been implemented in Sherpa in full generality

- Proofed to be successful in e^+e^- collisions

  (comparable in event shapes etc., but better description for four-jet correlations etc.)
- Study of systematics of method is still ongoing
  - Vary choice of scales (functional form)
  - Different jet measures
  - Different treatment of highest multiplicity ME
- Extensions to study systematic errors in event generation (e.g. global scale factors, etc.)

  after all, it's only LO !

Results: CKKW vs. NLO (I)

Quality of CKKW as a scale setting prescription

ME + α_S and Sudakov reweighting vs. NLO results

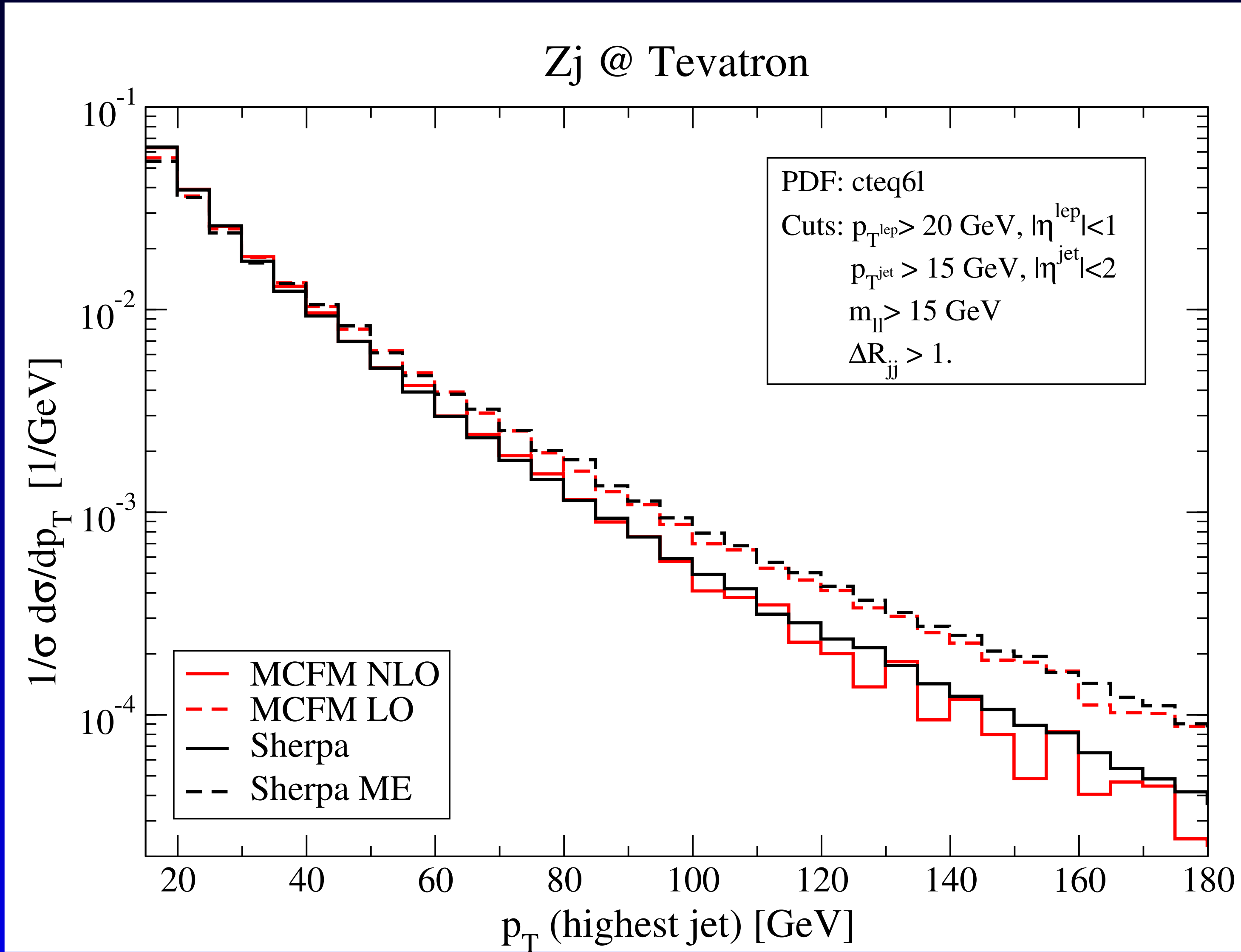
- Fully exclusive $W + 1/2$ jets and $Z + 1/2$ jets
- Compare to exclusive NLO ME predictions of MCFM

  (J.M. Campbell, R.K. Ellis, Phys.Rev.D65:113007 (2002), D68:094021 (2003))

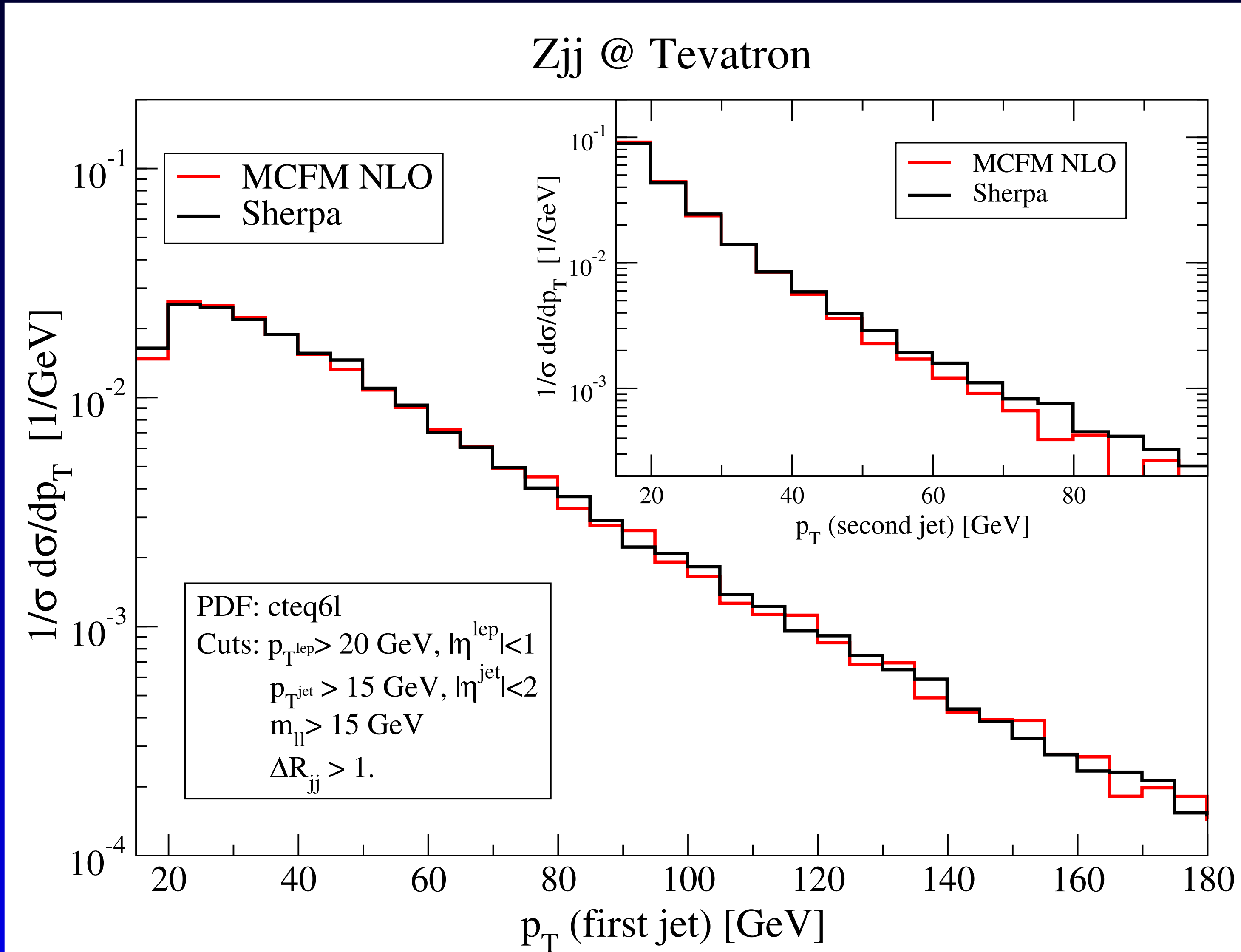
Setup:

- MCFM and Sherpa pure ME: $\mu_F = \mu_R = M_W$
- $y_{cut} = p_{\perp,min}$ of jets
- jets are defined by Run II K_T algorithm with $D = 1.$ (means $\Delta R_{jj} > 1.$)

Results: CKKW vs. NLO (I)



Results: CKKW vs. NLO (I)



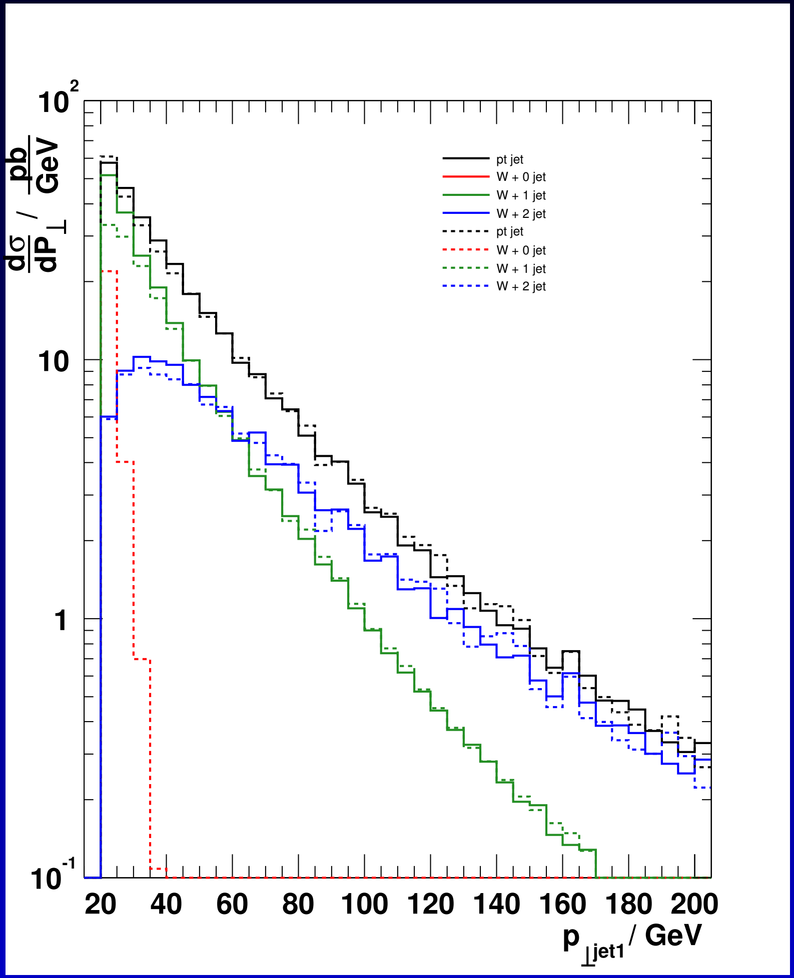
Results: self-consistency

Going inclusive: Turn PS on

$p_\perp$ distribution of leading jet in $pp \to e^+ \bar{\nu}_e\, j$ + X at LHC

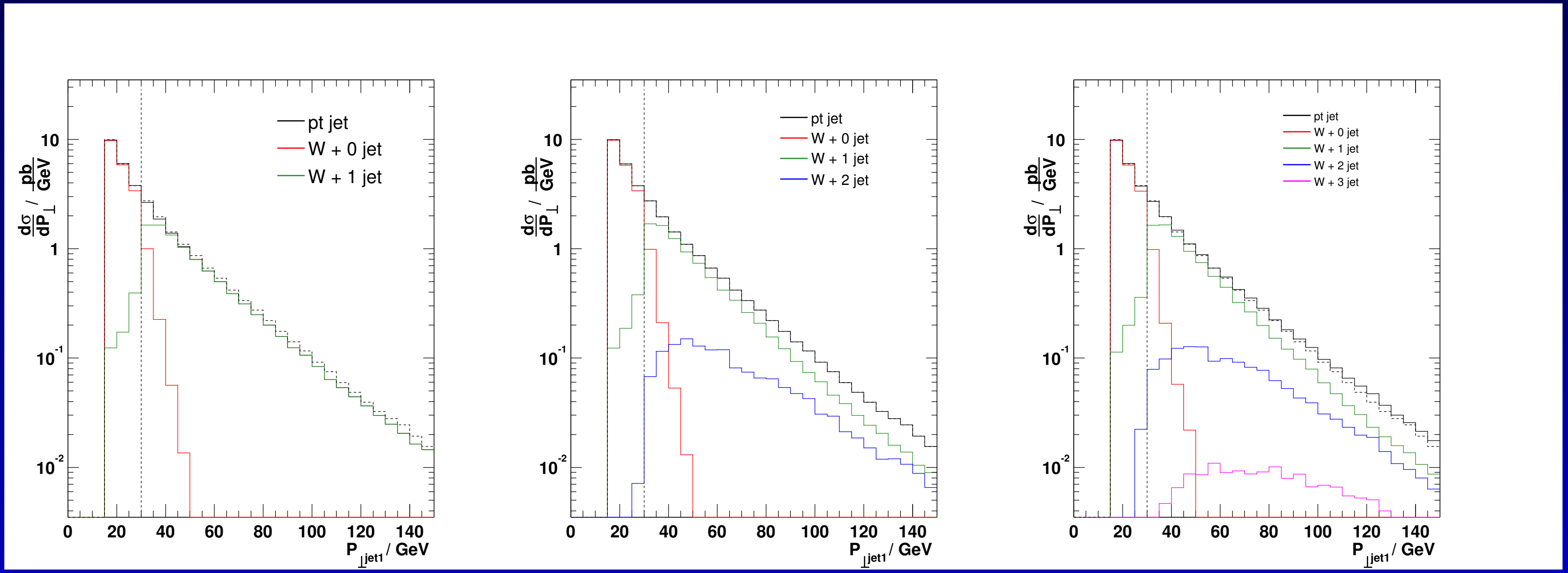
reweigthed ME's (solid) vs. ME+PS (dashed)

$\Longrightarrow$ consistent.



Results: self-consistency

Check highest jet treatment



Results: CKKW vs. NLO (II)

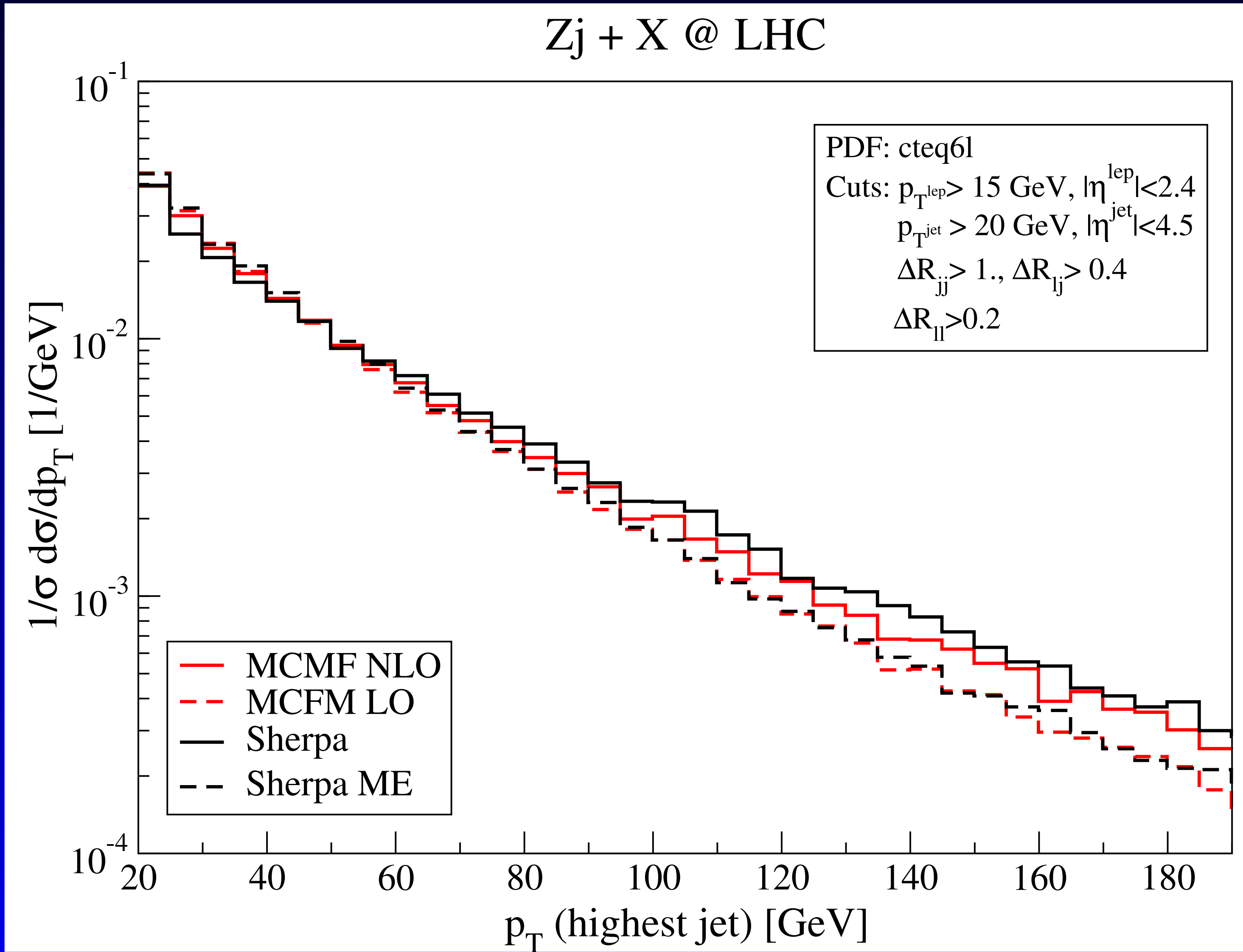
Going to inclusive jet distributions

- Take fully inclusive samples of W and Z plus jets including shower evolution
- Compare to inclusive NLO ME predictions of MCFM (featuring potentially one jet more)

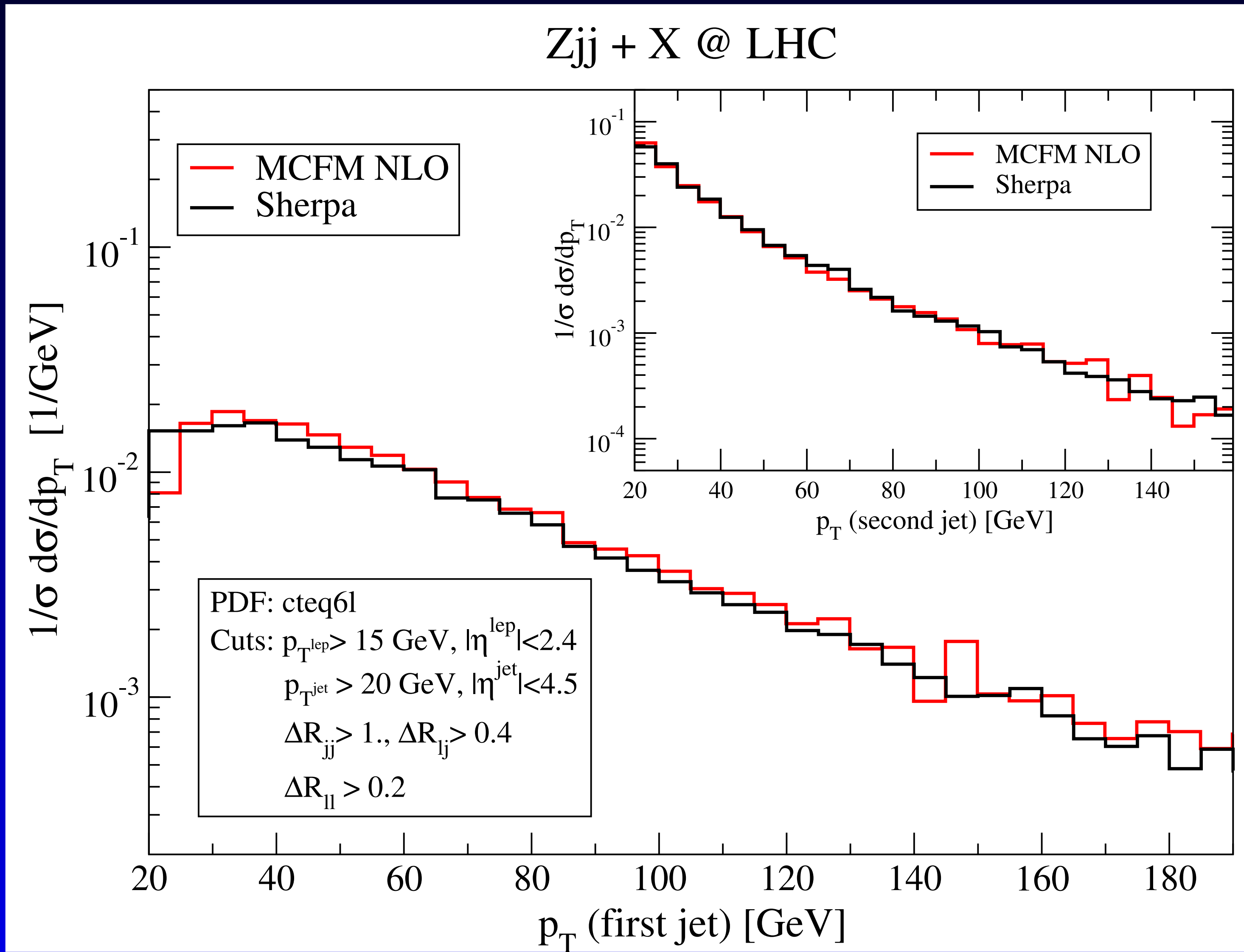
Setup:

- ME's considered: W/Z + 0,1,2,3 jets at LHC
- MCFM and Sherpa pure ME: $\mu_F = \mu_R = M_W$
- $y_{cut} = p_{\perp,min}$ of jets
- jets found by Run II K_T algorithm with $D = 1$.

Results: CKKW vs. NLO (II)



Results: CKKW vs. NLO (II)



Conclusion

- AMEGIC++ capable to calculate six-fermion and six-jet production processes
- Allows to study signal and associated backgrounds in one consistent framework
- Fermion masses can fully be taken into account
- Polarized cross sections enabled
- Performance comparable to that of dedicated programs
- The phase space will be revised to face eight-fermion processes
- CKKW reproduces NLO shapes for exclusive and inclusive $W/Z + X$ production
- CKKW reproduces nicely the data for the shapes
- However, the rates are not NLO !