# Numerical Simulations for Collider Physics

## Scientific Achievement

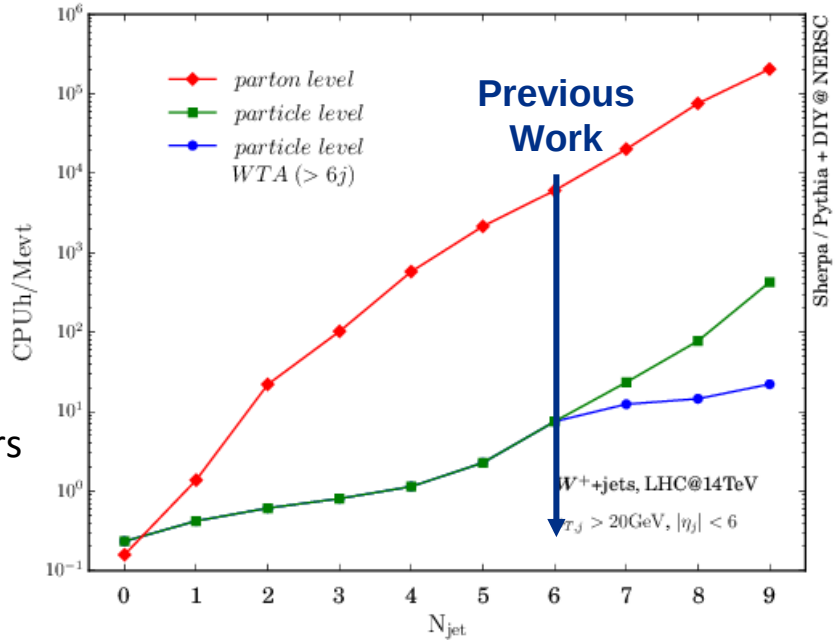
**Development of a scalable framework for simulation of particle collisions at highest energy, and support of the experimental user community**

## Significance and Impact

**New opportunities for experiments to probe high-multiplicity final states at the Large Hadron Collider and to test the validity of the Standard Model**

## Research Details

- Event generation will consume significant fraction of computing resources at Large Hadron Collider soon
- Among components of the simulation, computation of hard cross sections is most demanding and scales roughly exponential with final-state multiplicity
- Using MPI parallelization and optimized I/O, events can now be generated on high performance computers
- Scaling was demonstrated up to 2048 cores

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# First predictions for W/Z+9 jet production

## Scientific Achievement

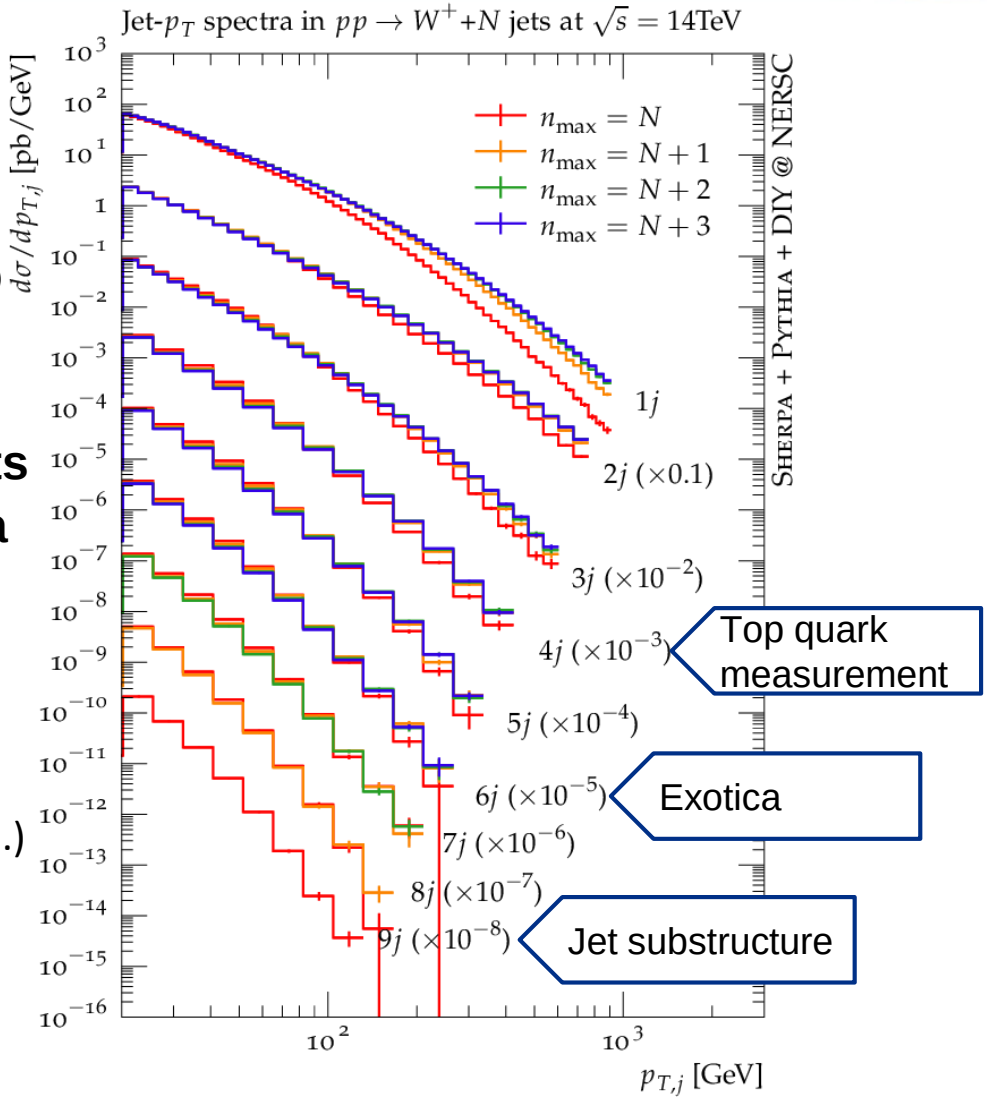
**Enabled by scalable framework for event simulation, predictions for W/Z+9 jet production were computed using leading-order perturbative QCD**

## Significance and Impact

**Opens possibility for LHC experiments to probe high multiplicity domain as a precision test of the Standard Model**

## Research Details

- W/Z+jets production is irreducible background to many other Standard Model measurements and new physics searches (top quark, exotica, ...)
- Simulation has so far been possible only in the crude parton-shower approximation
- Using NERSC resources, leading-order perturbative QCD predictions were computed
- Results and code were made publicly available

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# Event Generation with Normalizing Flows

## Scientific Achievement

**Development of a novel framework for collider event simulation based on Neural Networks and Normalizing Flow algorithms**

## Significance and Impact

**Allows to exploit developments in Machine Learning for accelerated numerical simulations at the Large Hadron Collider and future facilities**

## Research Details

- Created new open-source toolkit based on Tensorflow that can be used to perform adaptive Monte-Carlo integration in connection with any parton-level event generator
- Exemplified performance in connection with Sherpa framework for the most costly simulations at the LHC → W/Z + jets production at leading and next-to-leading order in QCD perturbation theory

| unweighting efficiency $\langle w \rangle / w_{\max}$ | | LO QCD $n=0$ | LO QCD $n=1$ | LO QCD $n=2$ | LO QCD $n=3$ | LO QCD $n=4$ | NLO QCD (RS) $n=0$ | NLO QCD (RS) $n=1$ |
|---|---|---|---|---|---|---|---|---|
| $W^+ + n$ jets | Sherpa | $2.8 \cdot 10^{-1}$ | $3.8 \cdot 10^{-2}$ | $7.5 \cdot 10^{-3}$ | $1.5 \cdot 10^{-3}$ | $8.3 \cdot 10^{-4}$ | $9.5 \cdot 10^{-2}$ | $4.5 \cdot 10^{-3}$ |
| | NN+NF | $6.1 \cdot 10^{-1}$ | $1.2 \cdot 10^{-1}$ | $1.0 \cdot 10^{-3}$ | $1.8 \cdot 10^{-3}$ | $8.9 \cdot 10^{-4}$ | $1.6 \cdot 10^{-1}$ | $4.1 \cdot 10^{-3}$ |
| | Gain | 2.2 | 3.3 | 1.4 | 1.2 | 1.1 | 1.6 | 0.91 |

C.Gao, S.Hoeche, J.Isaacson, C.Krausel, H.Schulz arXiv:2001.10028