Review of appropriate simulations

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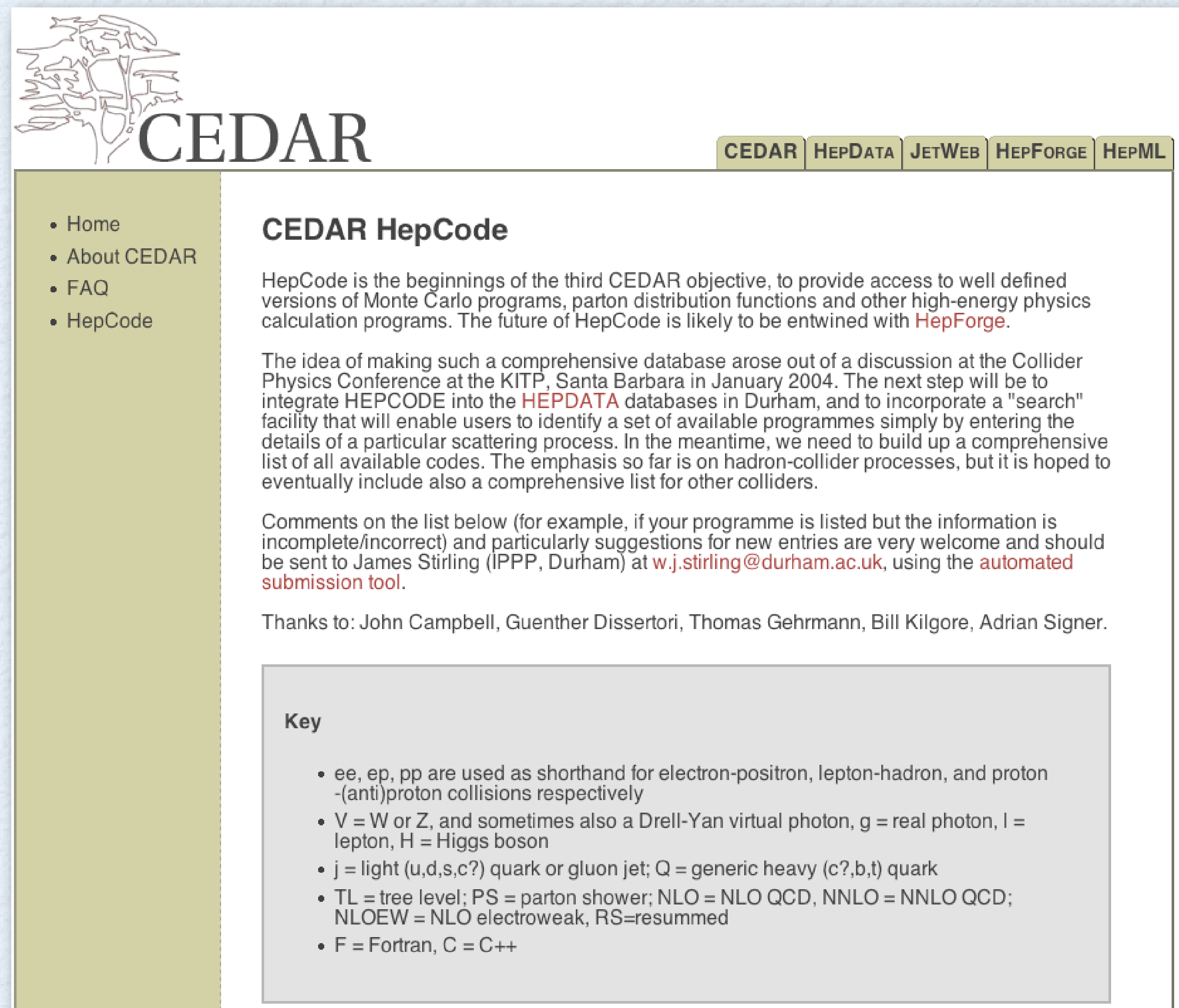
HEPCODE DATABASE

- Further information about many of the tools which I will discuss here is available at the CEDAR HepCode page.
- The aim is to provide a central repository of information (but not the codes themselves) so that interested experimenters/ phenomenologists can keep abreast of the latest theory predictions available.
- The codes span the breadth of theory available (fixed order, parton showers as well as resummation) and pertain to electron-positron, electron-proton and hadron colliders.



CEDAR

CEDAR | HepData | JetWeb | HepForge | HepML

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CEDAR HepCode

HepCode is the beginnings of the third CEDAR objective, to provide access to well defined versions of Monte Carlo programs, parton distribution functions and other high-energy physics calculation programs. The future of HepCode is likely to be entwined with HepForge.

The idea of making such a comprehensive database arose out of a discussion at the Collider Physics Conference at the KITP, Santa Barbara in January 2004. The next step will be to integrate HEPCODE into the HEPDATA databases in Durham, and to incorporate a "search" facility that will enable users to identify a set of available programmes simply by entering the details of a particular scattering process. In the meantime, we need to build up a comprehensive list of all available codes. The emphasis so far is on hadron-collider processes, but it is hoped to eventually include also a comprehensive list for other colliders.

Comments on the list below (for example, if your programme is listed but the information is incomplete/incorrect) and particularly suggestions for new entries are very welcome and should be sent to James Stirling (IPPP, Durham) at w.j.stirling@durham.ac.uk, using the automated submission tool.

Thanks to: John Campbell, Guenther Dissertori, Thomas Gehrmann, Bill Kilgore, Adrian Signer.

Key

- ee, ep, pp are used as shorthand for electron-positron, lepton-hadron, and proton -(anti)proton collisions respectively
- V = W or Z, and sometimes also a Drell-Yan virtual photon, g = real photon, l = lepton, H = Higgs boson
- j = light (u,d,s,c?) quark or gluon jet; Q = generic heavy (c?,b,t) quark
- TL = tree level; PS = parton shower; NLO = NLO QCD, NNLO = NNLO QCD; NLOEW = NLO electroweak, RS=resummed
- F = Fortran, C = C++

http://www.cedar.ac.uk/hepcode/

MADGRAPH

- Matrix elements are evaluated using conventional methods, taking advantage of the helicity amplitude evaluations of HELAS.

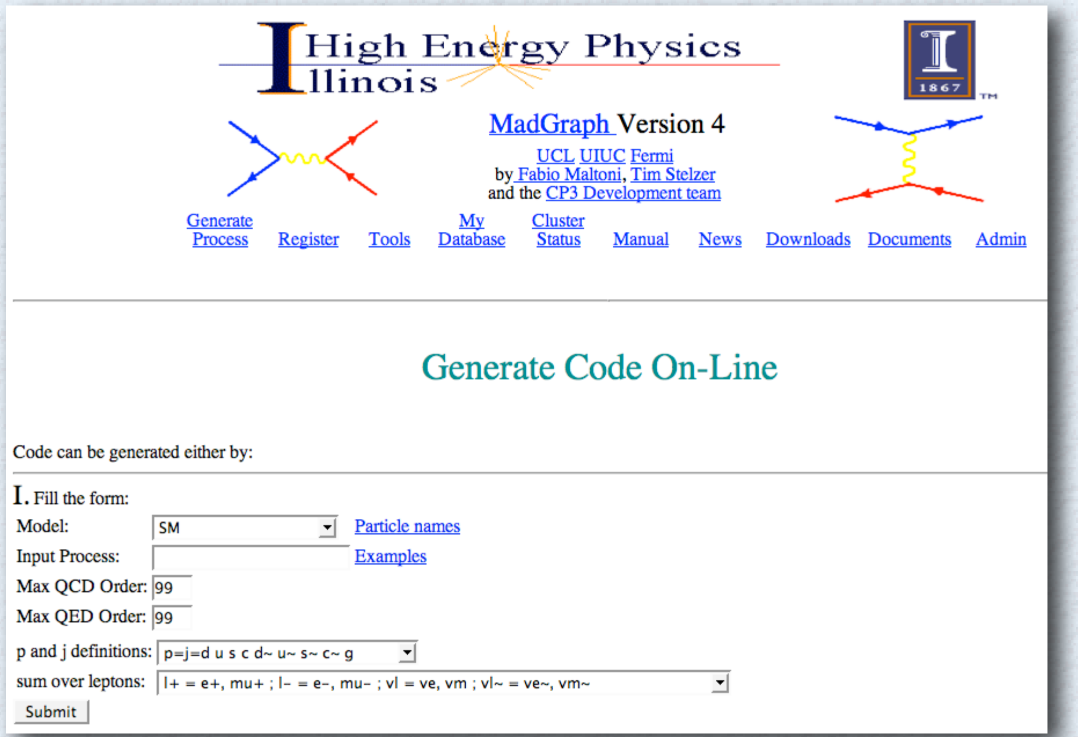
  H. Murayama, I. Watanabe and K. Hagiwara

- The original code was in the form of a Fortran program.

  T. Stelzer and W. Long

- The latest incarnation (MadEvent) provides an online interface for code and event generation, as well as a repository of pre-generated events.

  F. Maltoni and T. Stelzer



http://madgraph.hep.uiuc.edu/

- Any SM process can be calculated, with only practical limitations. Extensions beyond the SM require "only" the specification of all particles and their interactions.

Leading order: ✔ Most processes of interest ✘ Unreliable normalization

SMADGRAPH

http://www.ph.ed.ac.uk/~tplehn/smadgraph/smadgraph.html

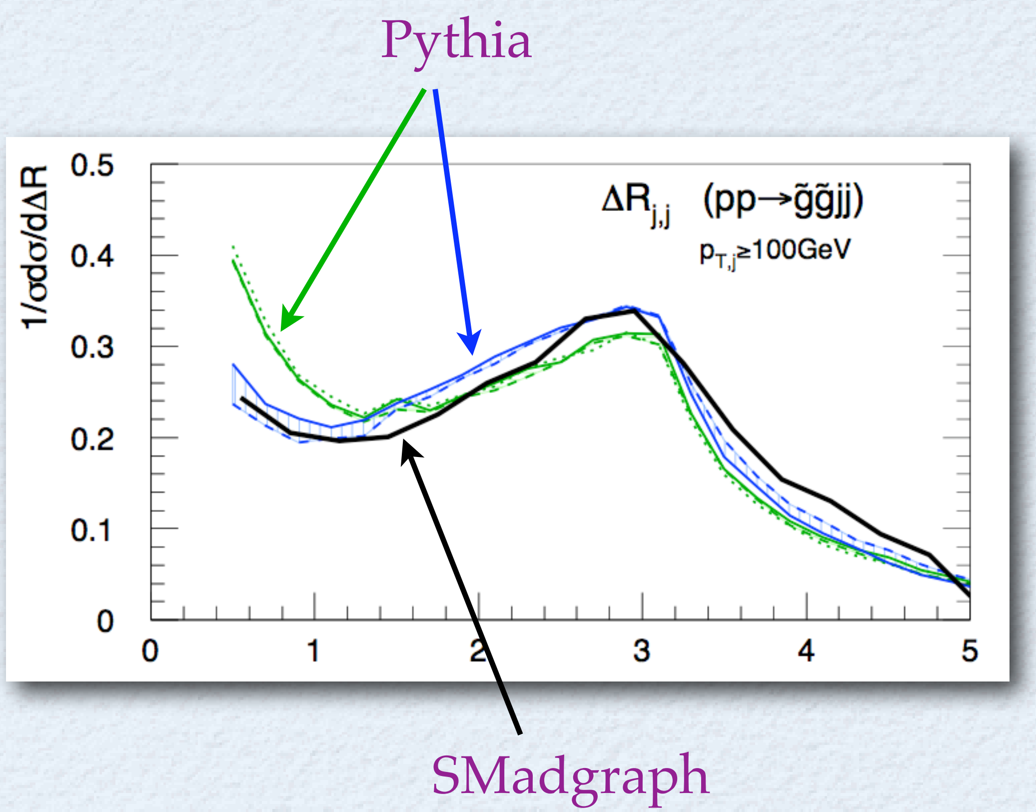
T. Plehn, D. Rainwater and T. Stelzer

- Extension of Madgraph to include the (R-parity conserving) MSSM. Particle spectrum is taken from your favourite spectrum generator and imported using the SUSY Les Houches Accord.

- Unfortunately, at present the package is only available as a downloadable stand-alone Fortran code.

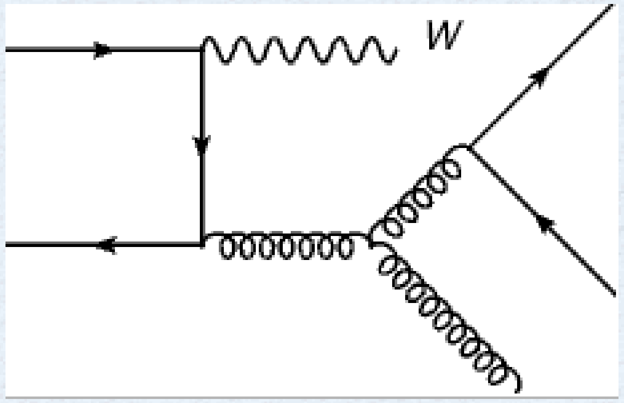
- Over 500 SUSY processes have been cross-checked against other codes.

- Especially powerful for investigating high-multiplicity final states for which predictions were previously unavailable.



Parton showers

- Parton showers provide a popular alternative approach to fixed order.
- They start from a relatively small number of hard (2→2 or 2→3) processes and develop additional QCD radiation stochastically.
- This is possible because of the factorization properties of QCD matrix elements in the soft and collinear limits.



a further parton is obtained by splitting a gluon into a quark pair

- Unfortunately, this means that events generated in this way may not sufficiently describe all areas of phase space (for example, large energy and wide-angle gluon emission).

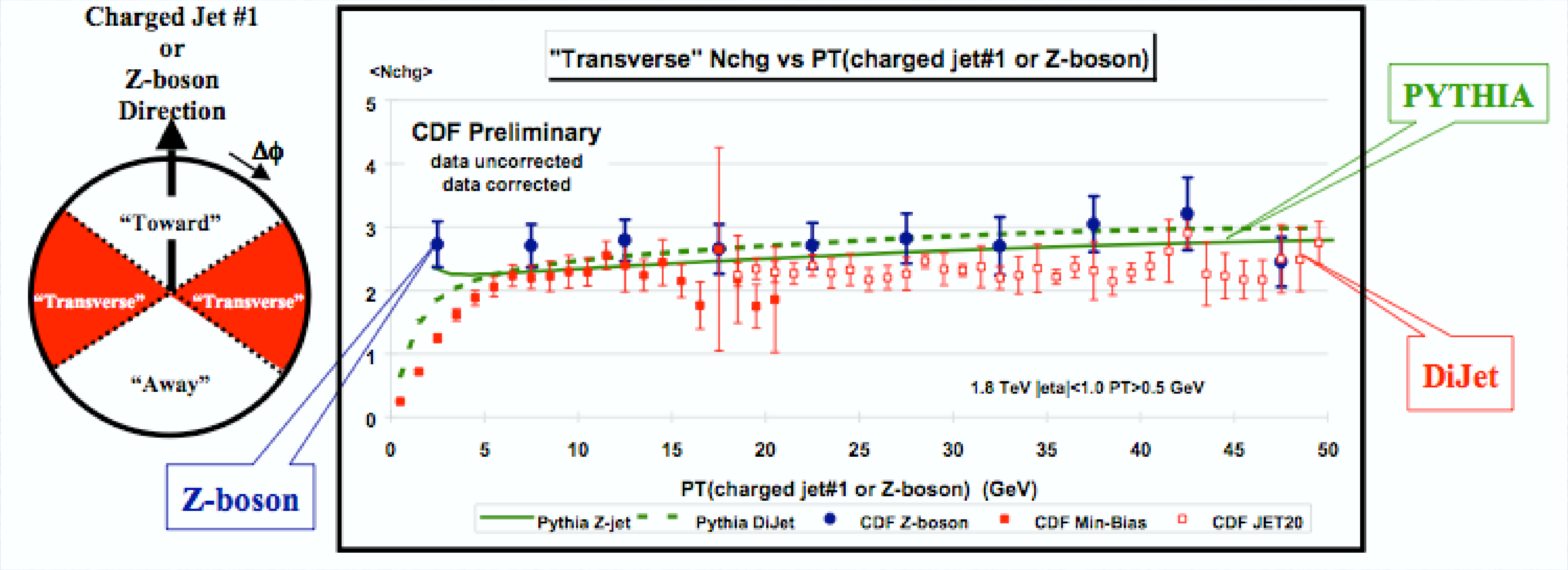
✔ Generate complicated final states ✘ Unreliable normalization

✔ Good for full detector simulation ✘ Need to remember approximations

Pythia and Herwig

http://www.thep.lu.se/~torbjorn/Pythia.html	http://hepwww.rl.ac.uk/theory/semour/herwig
T. Sjöstrand, S. Mrenna, P. Skands	B. Webber, K. Odagiri, P. Richardson, M. Seymour, et al.

- Current version: Pythia 6.410, Fortran 77 code.
- Multiple interaction models, underlying event, SUSY interface.
- Goal: Production release of Pythia 8 in C++ by late 2007, in time for LHC startup.



PYTHIA AND HERWIG

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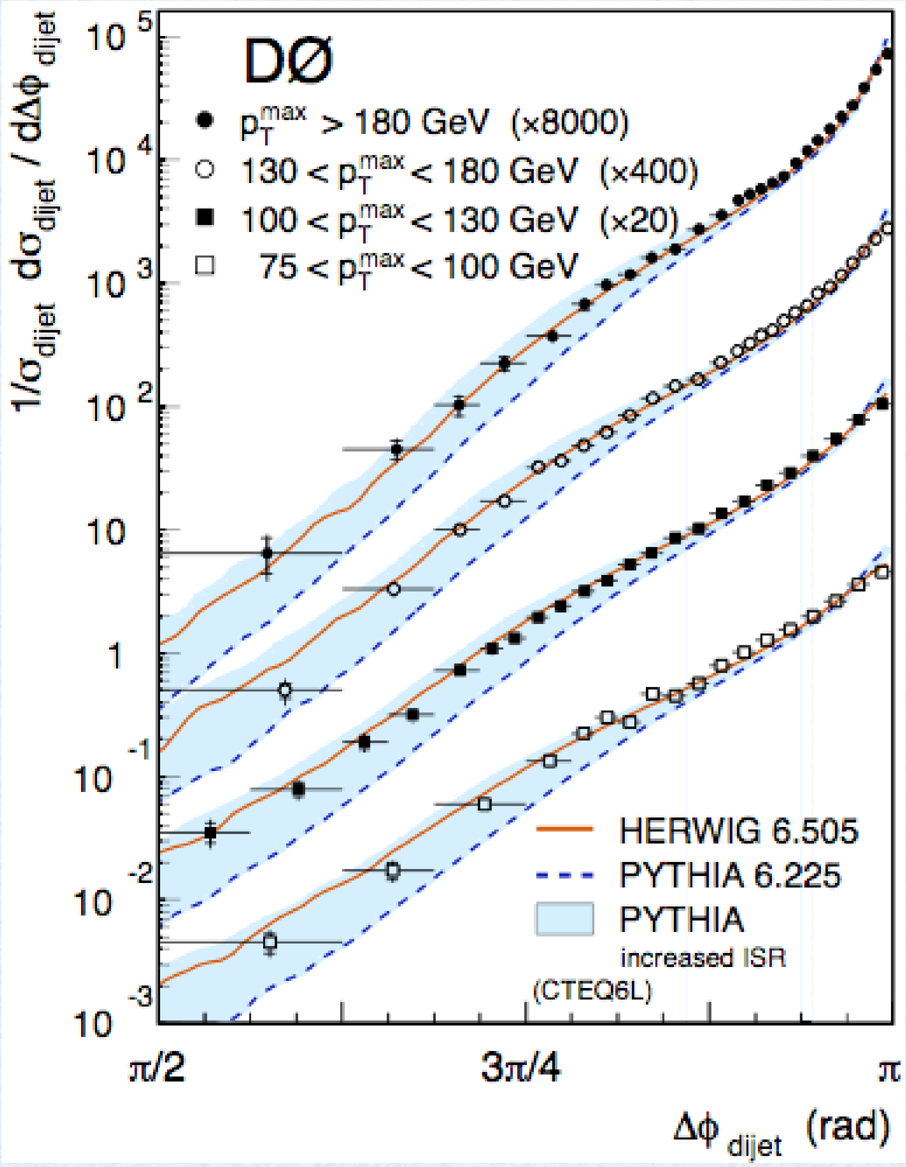
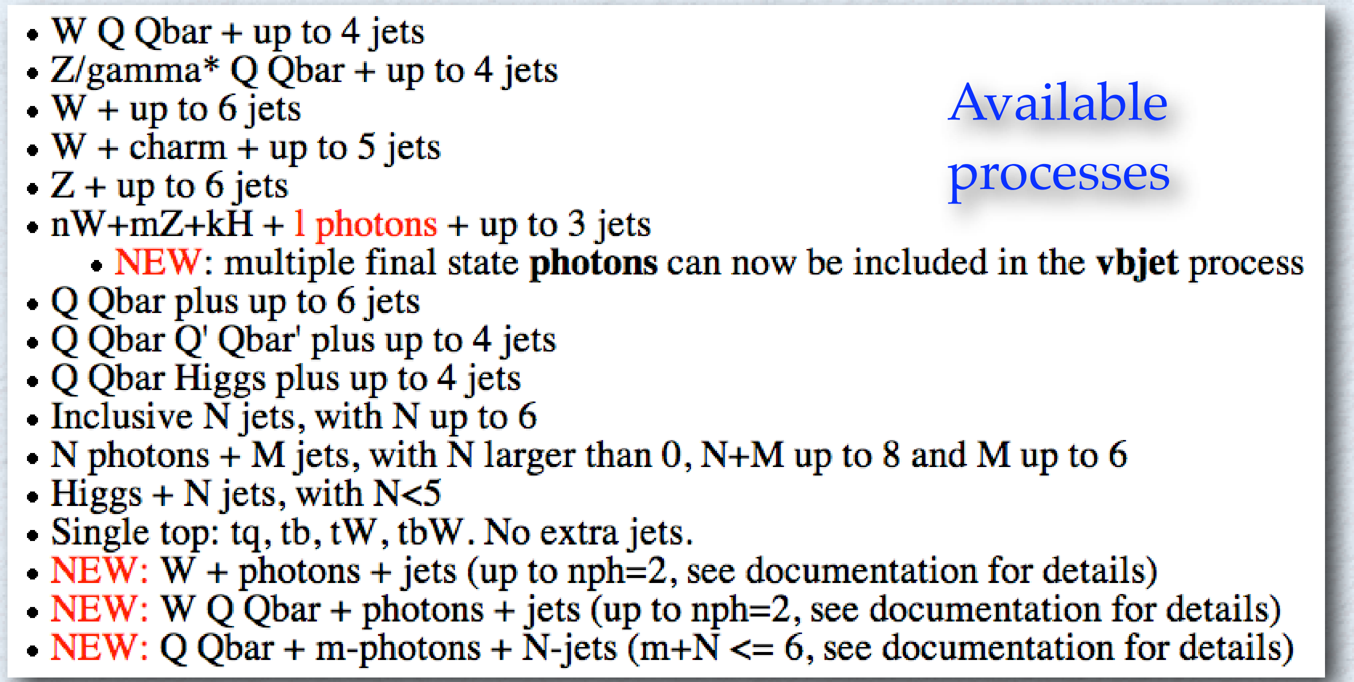


- Current version: Herwig 6.510, Fortran 77 code.
- Interface to JIMMY generator for multiple interactions and underlying event, supersymmetry via ISAWIG.
- Version 2.0 of HERWIG++ now available for simulation of hadron collider physics (initial state showers, some ME's).

ALPGEN

http://mlm.home.cern.ch/mlm/alpgen/

M. Mangano, M. Moretti, F. Piccinini,
R. Pittau and A. Polosa


• W Q Qbar + up to 4 jets
• Z/gamma* Q Qbar + up to 4 jets
• W + up to 6 jets
• W + charm + up to 5 jets
• Z + up to 6 jets
• nW+mZ+kH + l photons + up to 3 jets
    • NEW: multiple final state **photons** can now be included in the **vbjet** process
• Q Qbar plus up to 6 jets
• Q Qbar Q' Qbar' plus up to 4 jets
• Q Qbar Higgs plus up to 4 jets
• Inclusive N jets, with N up to 6
• N photons + M jets, with N larger than 0, N+M up to 8 and M up to 6
• Higgs + N jets, with N<5
• Single top: tq, tb, tW, tbW. No extra jets.
• NEW: W + photons + jets (up to nph=2, see documentation for details)
• NEW: W Q Qbar + photons + jets (up to nph=2, see documentation for details)
• NEW: Q Qbar + m-photons + N-jets (m+N <= 6, see documentation for details)

Available processes

- Not based on a traditional Feynman diagram evaluation, matrix elements are obtained from a Legendre transformation of the effective action.

- Recursive evaluation using the ALPHA algorithm.
  F. Caravaglios, M. Moretti

- Matrix element/parton shower matching is possible for most processes, so that observed jets may be generated either as part of the hard matrix elements or from the parton shower.

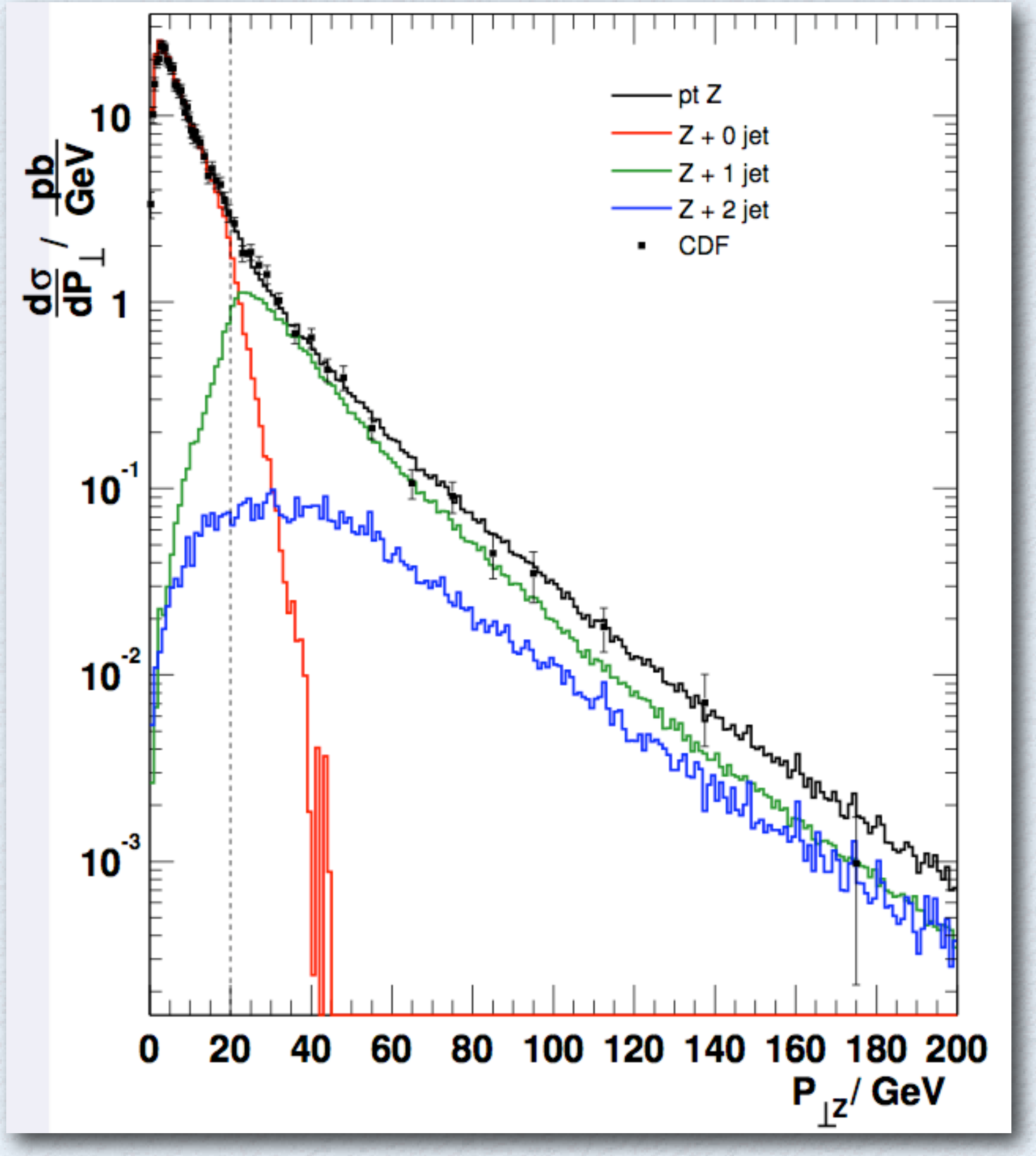
SHERPA

http://projects.hepforge.org/sherpa/dokuwiki/

F. Krauss and T. Gleisberg, S. Höche,
S. Schälicke, S. Schumann, J. Winter

- Full simulation of events at all collider types, present and future.
- Combination of packages:
  - matrix element generator (AMEGIC++) for SM, MSSM, ADD models.
  - final and initial-state parton shower (APACIC++)
  - merging via CKKW.

S. Catani, F. Krauss, R. Kuhn, B. Webber



NEXT-TO-LEADING ORDER

- There are many implementations of NLO matrix elements, mostly scattered across many codes
- Too many to cover properly here, I'll only mention a few.
- A program that tries to include a number of NLO calculations in one package is MCFM.

  http://mcfm.fnal.gov/

- Flagship processes are W/Z+2 jets and H+2 jets via gluon fusion (not yet available publicly - slow compared to the other calculations included).

$p\bar{p} \to W^{\pm}/Z$	$p\bar{p} \to W^{+} + W^{-}$
$p\bar{p} \to W^{\pm} + Z$	$p\bar{p} \to Z + Z$
$p\bar{p} \to W^{\pm} + \gamma$	$p\bar{p} \to W^{\pm}/Z + H$
$p\bar{p} \to W^{\pm} + g^{\star}\,(\to b\bar{b})$	$p\bar{p} \to Zb\bar{b}$
$p\bar{p} \to Zb$	$p\bar{p} \to Wb$
$p\bar{p} \to Zbj$	$p\bar{p} \to Wbj$
$p\bar{p} \to W^{\pm}/Z + 1$ jet	$p\bar{p} \to W^{\pm}/Z + 2$ jets
$p\bar{p}(gg) \to H$	$p\bar{p}(gg) \to H + 1$ jet
$p\bar{p}(VV) \to H + 2$ jets	$p\bar{p} \to t\bar{t}$
$p\bar{p} \to tX$ (t and s-channel)	$p\bar{p} \to t + W$
$p\bar{p}(gg) \to H + 3$ jets,(LO)	$p\bar{p} \to t\bar{t}g$,(LO)

J.C., K. Ellis

(+ F. Tramontano, F. Maltoni, S. Willenbrock)

✔ More reliable normalization

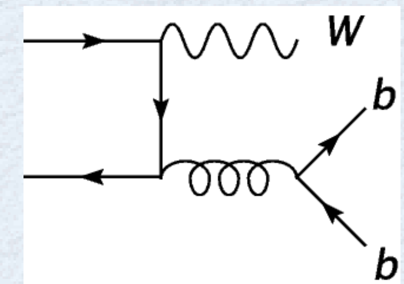
✔ Good for measurements, backgrounds

✘ Limited no. of processes available

✘ Hard to feed into simulation

Bosons + Heavy Quarks

- At the threshold of the current reach of NLO predictions, due to the number of particles and the quark masses.



- W production with bottom quarks is a large background to many searches because of top decays, t → Wb.

F. Febres Cordero,
L. Reina, D. Wackeroth

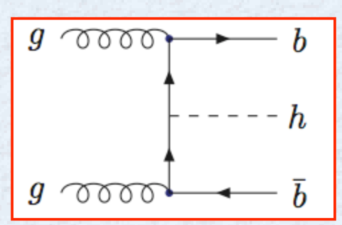
- This calculation built on earlier work computing the NLO corrections to Higgs boson production with heavy quarks, which is relevant for studies at the LHC.

S. Dittmaier, M. Kramer,
B. Plumper, M. Spira,
P. Zerwas

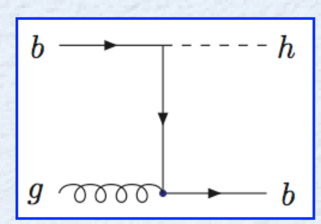
S. Dawson, C. Jackson, L. Orr,
L. Reina, D. Wackeroth

  - Top → SM discovery (although difficult).
  - Bottom → BSM enhanced coupling, e.g. large tanβ

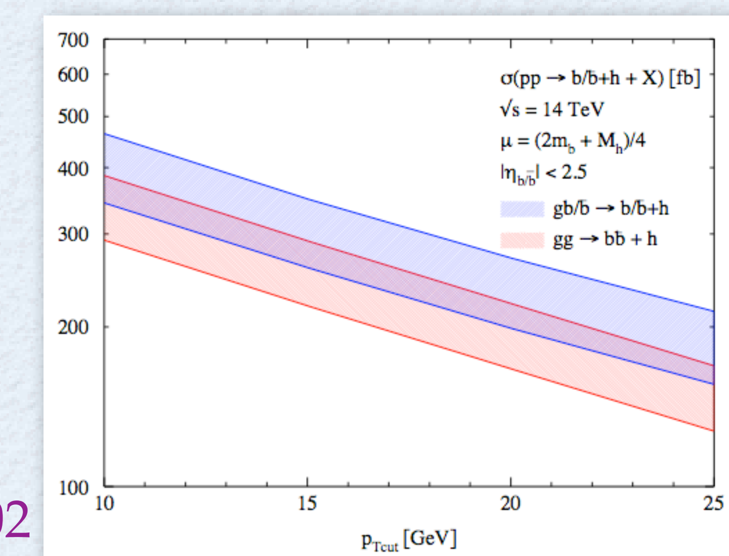
- Intrinsic interest as a probe of QCD perturbation theory and the *b*-quark PDF.



vs.



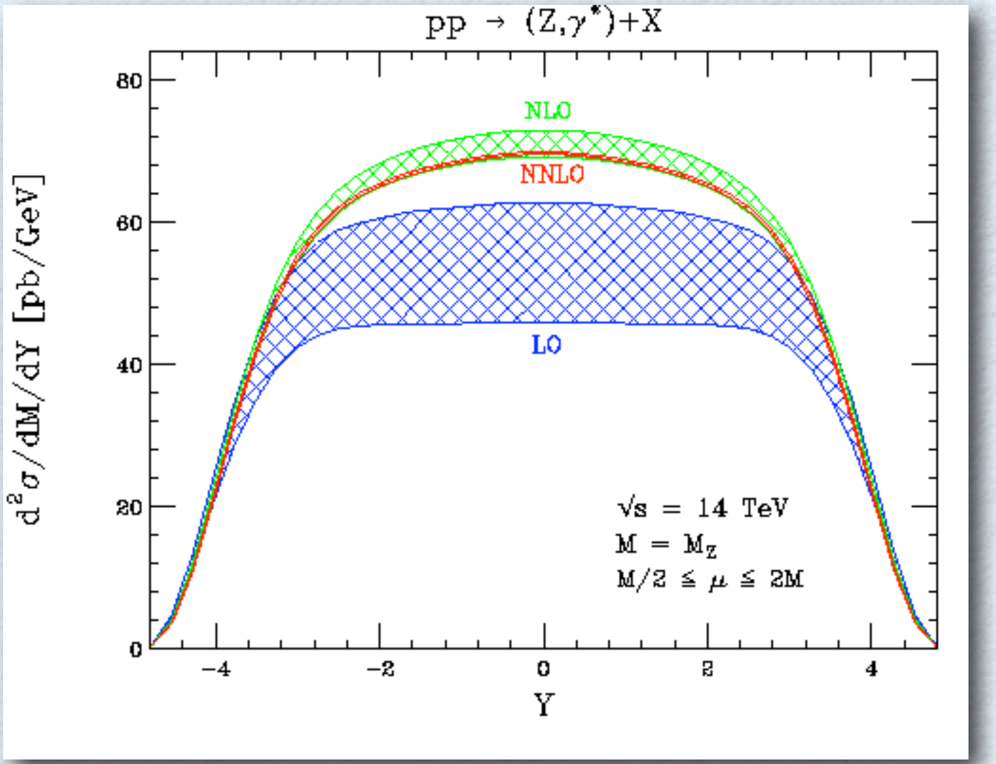
hep-ph/0405302



NNLO

- Next-to-next-to-leading order calculations are very few and far between.
- One of these is implemented in "VRAP", which computes production of lepton-pairs via virtual photons, W or Z bosons at hadron colliders.
- The first truly NNLO prediction of a differential quantity, but limited to rapidity and boson virtuality.

hep-ph/0312266



http://www.slac.stanford.edu/~lance/Vrap/

C. Anastasiou, L. Dixon, K. Melnikov, F. Petriello

✔ Best normalization, control of uncertainty
✔ High precision (e.g. luminosity)

✘ Very few processes
✘ Limited predictions

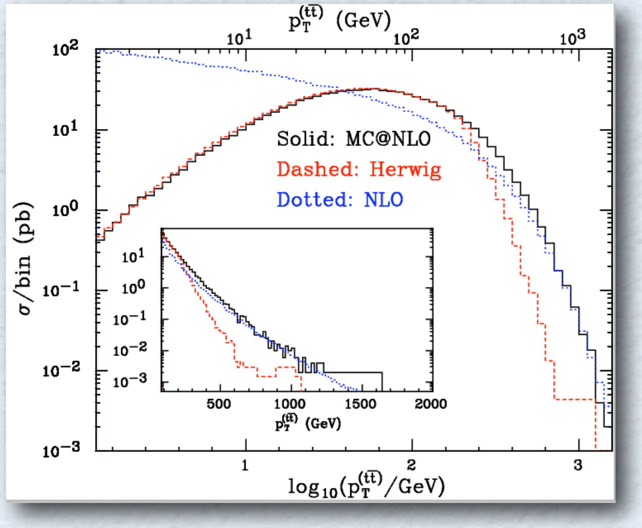
MC@NLO

http://www.hep.phy.cam.ac.uk/theory/webber/MCatNLO/

S. Frixione and B. Webber

- This is the first real merging of the NLO and parton shower approaches.

- It retains the best of both worlds. NLO normalization and scale dependence, together with the good infrared behaviour of the shower (and everything else).



hep-ph/0305252

smooth interpolation between the regions of greatest applicability

- Great care must be taken to ensure that there is no double counting between the real radiation at NLO and partons generated in the (HERWIG) shower.

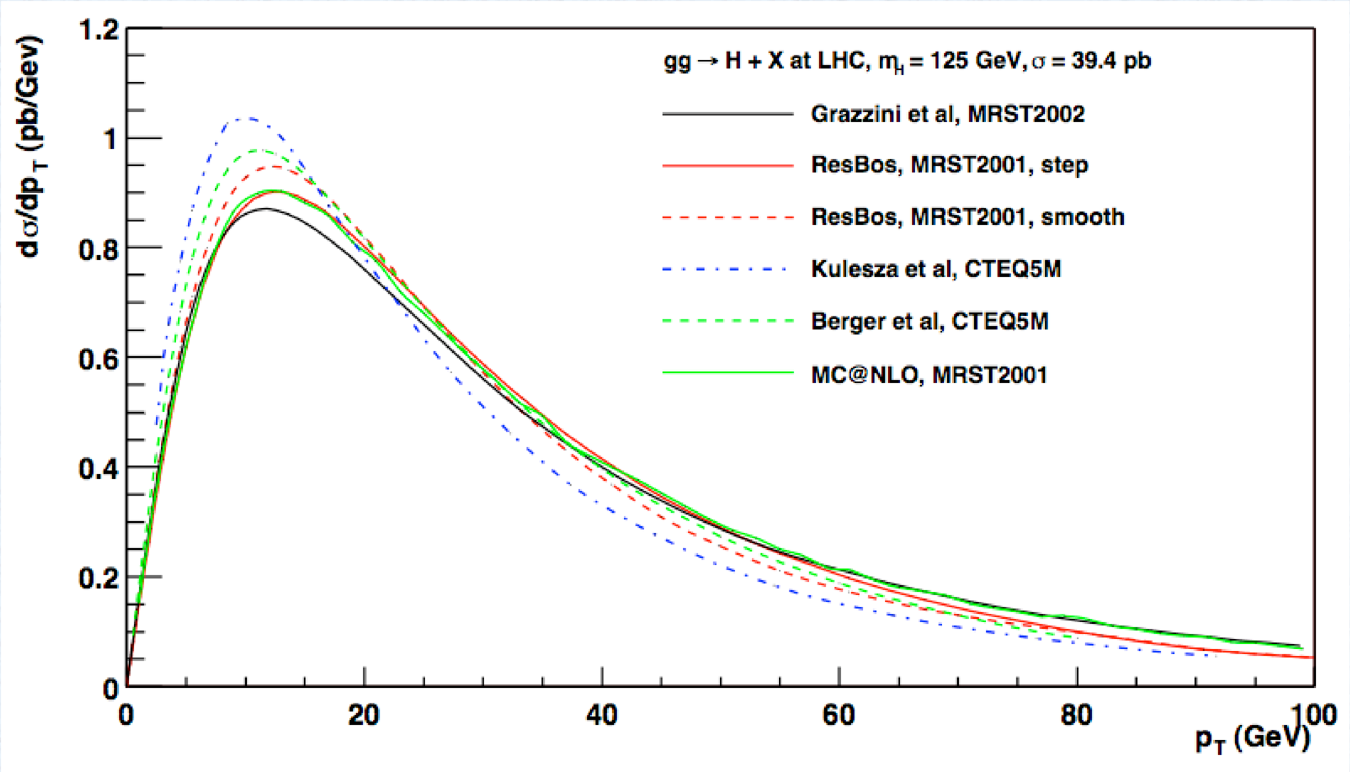
- The special technique to ensure that this is the case means that the number of processes calculable in this way is small, but steadily growing - Drell-Yan, boson pairs, heavy quark pairs and single top.

✔ Can have your cake and eat it (normalization and simulation)

✘ Small number of processes, hard to extend

Resummation

- In certain cases, the logarithmic singularities that occur can be identified and resummed to all orders.
- Renders cross sections finite in a similar way to parton showers, but applies beyond leading logarithms.
- For example, RESBOS produces produces resummed transverse momentum (or rapidity) distributions for Drell-Yan like processes (W,Z,γ,H,ZZ,γγ).



http://hep.pa.msu.edu/resum/index.html

Balazs, Nadolsky, Yuan

hep-ph/0403252

$$\alpha_S^n \left(\frac{1}{p_T^2} \log^m \frac{Q^2}{p_T^2} \right), \qquad n = 1, \ldots, \infty; \quad m = 0.\ldots, 2n-1$$

✔ All-orders treatments probe NP regions

✘ Limited ability to resum

CAESAR

- Event shapes were studied in great detail at LEP and HERA, via observables such as <*1-T*>. A good comparison of data with theory over a broad kinematic range is only possible with the help of resummation and power corrections.

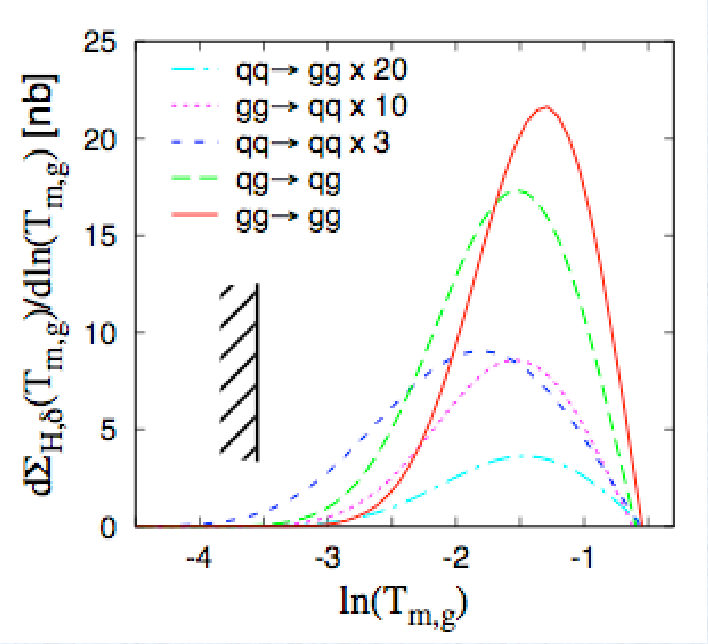
- At the LHC, such studies could help us to understand the process of perturbative parton showering and hadronization.

- These measurements are much harder to do in the hadronic environment. Quite recently it has become possible to perform such resummations in an automatic way for suitably-defined dijet observables.

- This is the remit of the CAESAR package.

Banfi, Salam, Zanderighi

www.qcd-caesar.org/



hep-ph/0407287

Summary

- In this talk I have tried to review the main types of theoretical predictions and simulations that will be compared with LHC data.
    - Apologies if your favourite one is missing!
- The domains of suitability and potential accuracy vary widely, but are often complementary.
- It is far easier than one might think to choose an *in*appropriate simulation for a particular process or kinematic region.
- One-size-fits-all solutions are few and far between, e.g. providing NLO normalization together with parton showering or resummation.
- Parton showers and LO predictions are still the most flexible approaches, but many analyses at the LHC will demand the higher precision and control of NLO and beyond.