PHYSICS AT THE TERA SCALE
Helmholtz Alliance

The Analysis Centre: Monte Carlo Group

DESY

Developing Monte Carlo tools and supporting the experimental activities

1996 Tevatron Era

In 1996 both CDF and D0 found big discrepancies between the data and the theory in the one-jet inclusive cross section. Some people were thinking about new physics. That time we didn't have systematic error estimates for the PDFs. The next dialog might have happened between an experimentalist (EXP) and a self respecting theorist (SRT):

EXP: "We JUST need A PDF that can describe the data."
SRT: "WRONG! You have to make predictions in perturbative QCD and understand how much variation is allowed by the data and theory in the gluon distribution."
EXP: "But we estimate the uncertainty by using CTEQ and MRST."
SRT: "How can you estimate and control this uncertainty systematically if you don't have the tool that can systematically consider error of the PDF functions"
EXP: .....

And the theorist was right. There wasn't new physics. It turned out the gluon distribution wasn't well constrained by the DIS data.

D. Soper, ICHEP-98, **Nucl.Phys.Proc.Suppl.**54A:97-101

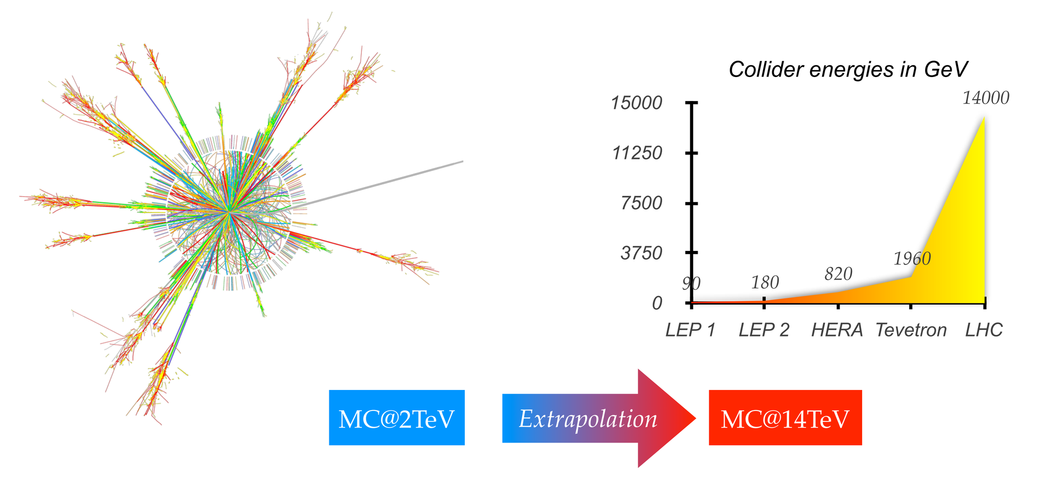
2009 LHC Era

The LHC is running and recently CMS have seen the first collisions. It seems to us that we are ready to discover new physics. Just like in 1996 the experimentalists and the theorists have very similar discussions:

EXP: "We JUST need A PROGRAM that can describe the data."
SRT: "WRONG, WRONG, WRONG! You need a program that can make predictions in perturbative QCD."
EXP: "But we estimate the uncertainty by running PYTHIA, HERWIG and their different versions."
SRT: "How can you estimate and control these uncertainties systematically if you don't have the tool that can make systematically improvable predictions?"
EXP: .....

We are looking forward to the data...

Scientific Program

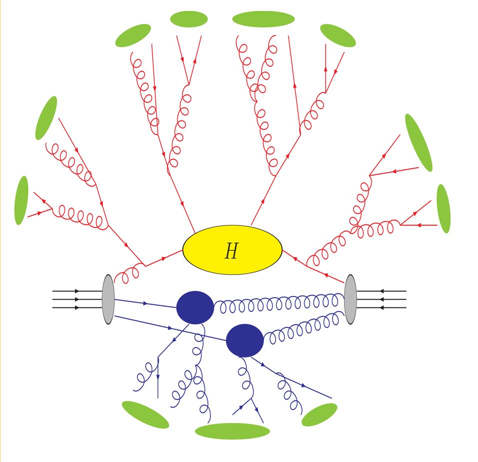


The LHC will collide hadrons, bound states of coloured partons. Therefore every analysis, whether a measurement or a search for new physics, needs an understanding of QCD dynamics. QCD effects can be important in the production and/or decay of the particles being measured or sought and in calculating the (often huge) backgrounds. Now the question is whether or not our existing QCD tools are ready for the LHC. It is hard to say but certainly there is a **great danger that existing tools will fail for the LHC**. They are tested and tuned at relatively low energies (≤ 2TeV) compared to the LHC energy (14TeV) and they are being extrapolated over a large range where we don't have any direct information about their performance. The message is clear: **we have to prepare for the unexpected** and aim for the maximum precision that we can achieve in our MC tools.

In the Monte Carlo calculation we have chance only for the hard part and the parton shower to calculate them from the first principles (perturbative QCD). Parton shower algorithms are derived from perturbative QCD but we cannot consider them as providing systematic theoretical predictions because they use additional, rather nonsystematic, approximations, which neglect potentially important quantum effects. The theory activity of the group is focusing on the parton shower part of the MC tools. Our effort is to make the parton shower algorithms more predictive.

The other major activity of the group is to tune and validate the long distant physics part (PDFs, hadronization, underlying events) of the Monte Carlo calculations. We are working on PDF fits those are more suited for Monte Carlo calculations (PDF4MC) and we are investigating new directions such as unintegrated PDF (uPDF). We are working on softer packages development for tuning (PROFIT) and for validation (HEPMCANALYSIS) and provide direct support.

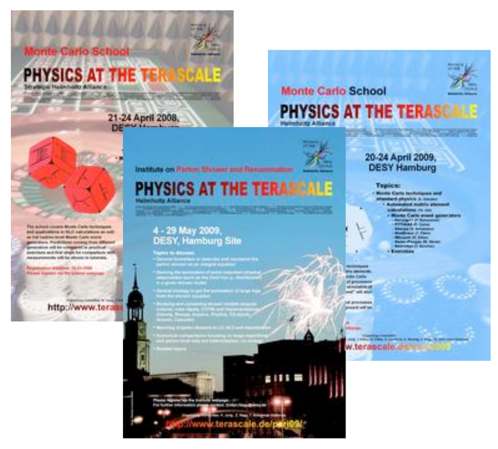
The structure of the Monte Carlo event generators is very complicated:



1. Incoming hadron (gray bubbles)
   ➪ Parton distribution function
2. Hard part of the process (yellow bubble)
   ➪ Matrix element calculation, cross sections at LO, NLO level
3. Radiations (red graphs)
   ➪ Parton shower calculation
   ➪ Matching to the hard part at LO and NLO level
4. Underlying event (blue graphs)
   ➪ Models based on multiple interaction
5. Hardonization (green bubbles)
   ➪ Universal models

Well defined — Systematicaly improvable in perturbative QCD — Only model. This is the only tunable part in this equation.

Schools, Workshops, Seminars

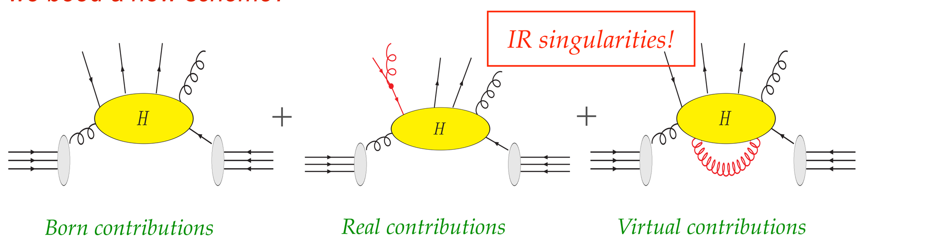


- Yearly MC school, and typically 1-2 QCD/MC block courses.
  - 2008: Focus on Standard Model MC Tools.
  - 2009: Focus on Beyond Standard Model MC Tools.
  - 2010: Joint CTEQ+MCNet+Helmholtz Alliance School on QCD and Monte Carlos
- Diploma and PhD students, Post Docs.
- This (last) year we had 3 (2) summer students connected to the MC group.
- Parton Shower and Resummation Institute
- Pheno weeks (Typically two days meetings with talks, discussions, lectures, exercises)
  - G. Marchesini "Dipole approach to parton cascades" ➠ *Outcome:* 2 published paper (**JHEP 0905:088** and **Phys.Rev.D79:074021**)
  - PDF with J. Huston
  - Rivet with Andy Buckley
  - Small-x meeting with Lund group
- Studentship program
- Regular Monte Carlo Group every second week. *It is broadcasted on EVO, everybody is welcome to join.*
- *Intended collaboration between the Analysis Center Monte Carlo Group and MCNet.*

An important aspect of phenomenological work is the fact that in any experimental analysis in which QCD effects are important, small changes in the analysis procedure can have a large impact on the accuracy with which theoretical calculations can be made. Therefore it is important to have active **communication between theorists and experimentalists** to maximize the theoretical understanding that can be gained from the experimental data. The Analysis Center is a perfect place to be active in this regard.

Theory and MC program development

NLO scheme We are woking on a new subtraction scheme for NLO fixed order calculations. This is not a new problem and there are several scheme available in the literature.
Why do we beed a new scheme?



$$\sigma_{\rm NLO} = \int_N d\sigma^B + \int_{N+1}\left[d\sigma^R - d\sigma^A\right]_{\epsilon=0} + \int_N \left[d\sigma^V + \int_1 d\sigma^A\right]_{\epsilon=0}$$

$$d\sigma^A \sim d\Gamma(\{p\}_{N+1})\, V \otimes |\mathcal{M}(\{\tilde p\}_N)|^2\, F_J(\{\tilde p\}_N)$$

Based on soft and collinear factorization

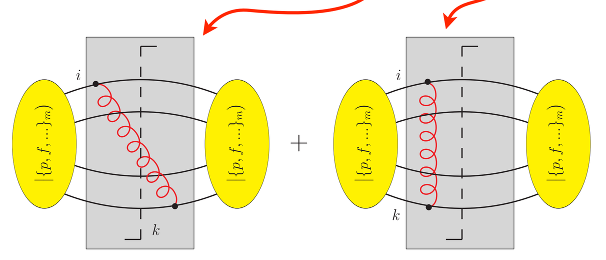
- We need an efficient scheme for high multiplicity processes. (The number of the subtraction terms $\sim N^2/2$, while in the Catani-Seymour scheme it is $\sim N^3/2$.)
- We need a scheme that is defined for the quantum density operator.
  - One can do MC sum of the spin and colors ➠ *It saves CPU time (a lot).*
  - It is important for matching to partons shower.
- In the subtraction terms we want to capture the soft and collinear physics *properly*.

Collaborating Alliance Institutes: RWTH Aachen, University of Wuppertal

Parton shower with quantum interference The current parton shower programs are based on simple probabilistic picture. This is possible because of additional, rather non-systematic approximations such as spin averaging, leading color approx., explicit angular ordering. This approximation could work for a certain class of the observables but in the general case we have to systematically treat the quantum correction in the parton shower.

Parton shower is a time ordered exponential of the splitting operators. These are operators in the color and spin space:

$$\mathcal{U}(t,t') = \mathbb{T}\exp\left(\int_{t'}^{t} d\tau\left[\mathcal{H}_I(\tau) - \mathcal{V}(\tau)\right]\right)$$



Z. Nagy and D. Soper: **JHEP** 0709:114 (2007), **JHEP** 0803:030 (2008), **JHEP** 0807:025 (2008)

- From simple estimates we know that even the very subleading color corrections (NNNNLC) can be five times bigger than the leading color contribution.
- It is important to have full control over the soft color correlations otherwise one can easily misidentify them as underlying event contributions.
- In heavy flavor (SUSY, BSM, top) physics the soft gluon corrections are the leading QCD contributions.
- Usually the electroweak decays are spin dependent. ➠ Important spin correlations.

Validation parton shower against QCD When, for a particular process, one knows the summation of large logarithms in full QCD, then it is of significant interest to investigate whether a given shower algorithm produces matching results. To do this, one needs to derive the corresponding summation in the shower model, deriving the appropriate evolution equation for the observable in question from the general evolution equation for the shower algorithm.

From shower equation

$$\frac{d}{dt}(x,q|\mathcal{U}(t,t')|M_2) = (x,q|[\mathcal{H}_I(t)-\mathcal{V}(t)]\mathcal{U}(t,t')|M_2)$$

Z. Nagy and D. Soper: **JHEP 0905:088,2009**, **DESY 09-201**

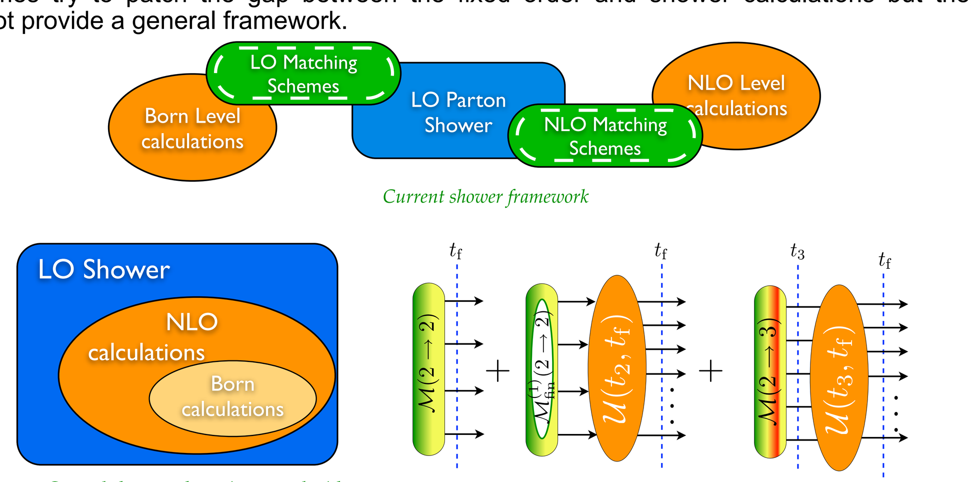
to DGLAP — *No approximation and assumptions. Only algebraic manipulations.*

$$\frac{d}{dt}D_q(t,t',x) = \int_x^1 \frac{dz}{z} P_{qq}(z) D_q(t,t',x/z) + \mathcal{O}(e^{-t})$$

- We have shown that all the parton shower algorithms correctly reproduce the evolution of the energy distribution of an final state parton (DGLAP). This is an very inclusive quantity and it provides very little control on the parton shower algorithms. *We need more exclusive tests!*
- We have shown that a virtuality ordered parton shower (*Z. Nagy and D. Soper:* **JHEP** 0709:114) can sum up correctly the large logarithms of the Drell-Yan pT distribution at NLL level. We have found that the showers based on Catani-Seymour factorization fail even at LL level.
- We are working on a general validation procedure and a general shower scheme that can provide a unified theoretical framework for the further MC developements.

Collaborating Alliance Institute: RWTU Aachen

Matching parton showers to fixed order calculations is a long outstanding problem. There are solutions in the literature but their applicability and precision are limited. The current matching schemes try to patch the gap between the fixed order and shower calculations but they cannot provide a general framework.

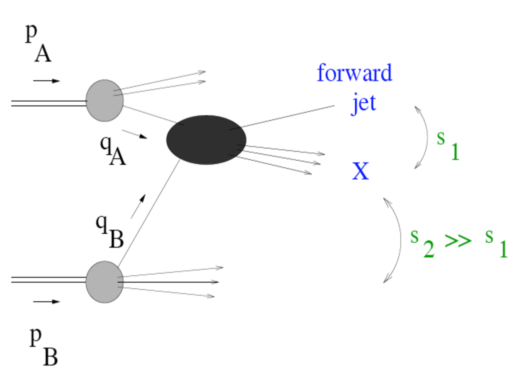


General shower scheme integrated with fix order calculations — *Structure of NLO+Parton Shower cross section. This structure is consistent with LO+Parton Shower (a.k.a. CKKW).*

- We need a shower scheme in which one can make prediction for the shape and normalization of the physical quantities.
- It must be precise and consistent with pQCD. The cross sections must be accurate at least at next-to-leading logarithmic level (NLL).
- Matching scheme must be systematically defined at LO and NLO level.
- Matching at quantum level. Dealing with non-global observable.

Collaborating Alliance Institute: RWTH Aachen

CASCADE is a parton shower program based on unintegrated (kT dependent) parton distribution functions. So far only unintegrated gluons are considered (i.e. indirectly also sea quarks) in CASCADE. Valence quarks are expected to be relevant for LHC. For example high pT production:



- High sensitivity to parton dynamics.
- Quarks successfully implemented.
- The kT dependent quark PDF is taken from derivated CTEQ5.1.

Deak, Hautmann, Jung, Kutak: **arXiv**:0908.0538

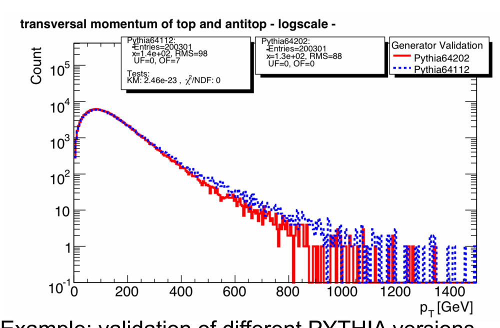
Two scale process with relevant physics for both x → 0 and x → 1.

Fitting, tuning, validation

HEPMCAnalysis is a tool for generator validation and comparisons

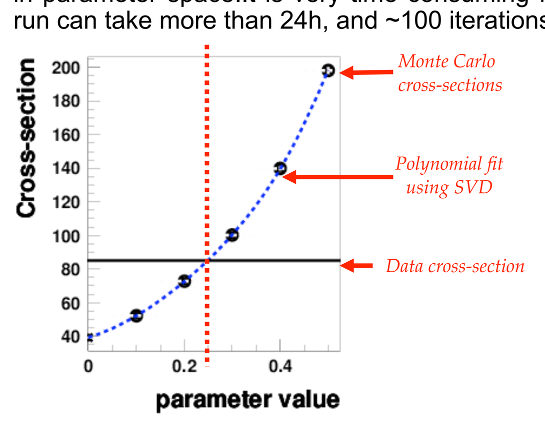
- Developed in the Statistics Tools group,
- Used in the MC group
- Used for validation of the GenSer library of all generators used by LHC collaborations
- Usable for all LHC generators!

HepMC Analysis



Example: validation of different PYTHIA versions (predictions for top-antitop pair transverse momentum).

PROFIT is a fitting tool for faster and high statistical fits for fast fitting and MC parameter extraction. Former fitting methods, based on running the generator in an iterative procedure in parameter space.It is very time consuming for exclusive final states. A high statistics MC run can take more than 24h, and ~100 iterations are needed.



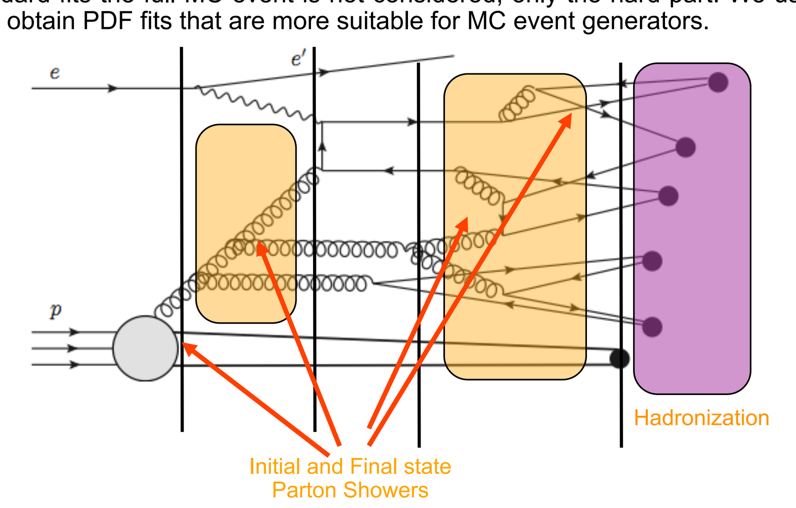
New Approach:

Describe parameter dependence before parameter fitting, by building up a grid in parameter space.

- The MC grid points can be calculated simultaneously.
- The fitting itself then takes a few seconds.

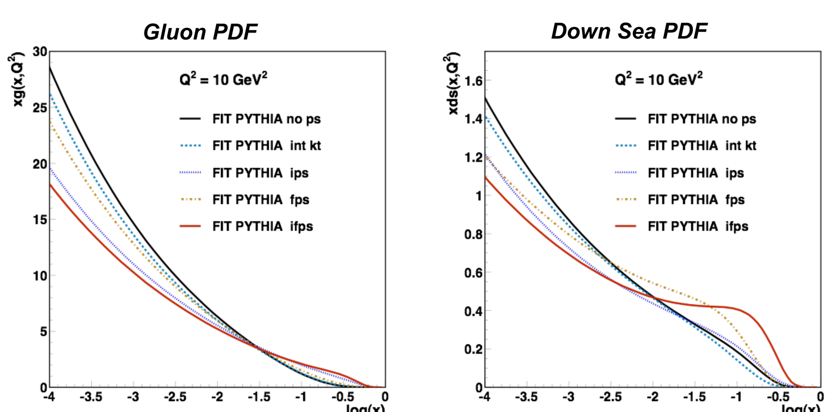
- A similar approach is used in the program PROFESSOR by the MCNet people.
- This method is used for multidimensional fits of the parameters in the uPDFs.

PDF4MC is an attempt to refine the PDF and unintegrated PDF fits for MC event generators. In the standard fits the full MC event is not considered, only the hard part. We use MC cross sections to obtain PDF fits that are more suitable for MC generators.



CTEQ6L refitted with PYTHIA to F_2 measurements from HERA

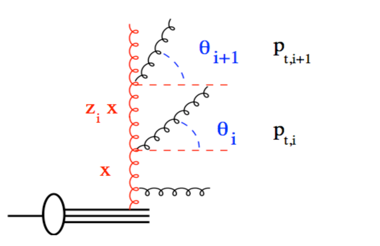
Refitted PDFs for different MC settings:
Black line – no parton showers, Red line – initial and final state PS



Unintegrated PDFs are k_T dependent. The standard PDFs (k_T-"integrated) are evolved with DGLAP equation, while the uPDFs are evolved with the CCFM evolution equation. The starting distribution, which is evolved to higher scales by the CCFM evolution equation, is

$$xA_0(x,k_T,\bar q_0) = N\cdot x^{-B}\cdot(1-x)^C\cdot exp\left(-\frac{(k_T-\mu)^2}{2\sigma^2}\right)$$

The parameters in the starting distribution have to be determined by fits to data.

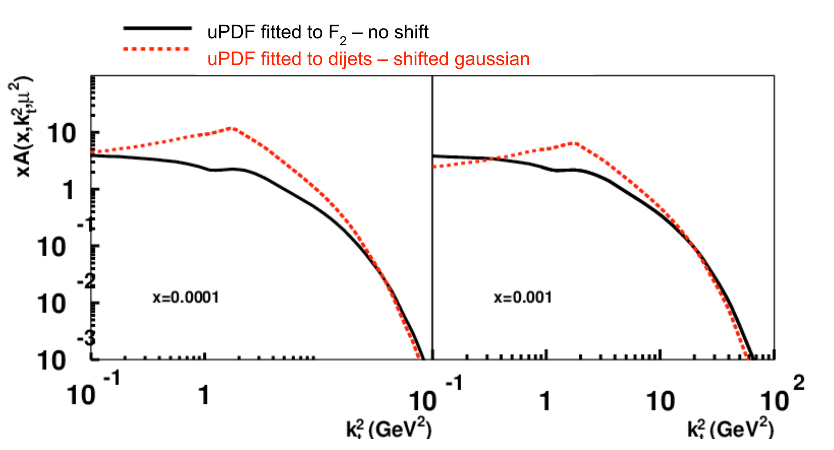


UPDFs properties:

- ordering of emitted gluon that provides color coherence but no explicit k_T-ordering.
- CCFM and uPDFs are fully implemented in the general purpose LHC MC generator CASCADE.

(H. Jung, Comput.Phys.Commun.143:100-111,2002)

Fitting the MC to di-jet data suggests a gluon PDF which is suppressed at low k_T (shifted Gaussian, $\mu = 3$)



With unintegrated PDF one can model and study saturation effects.

Jung, Kutak. arXiv 0812.4082

Contacts

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Monte Carlo Meetings:

EVO details

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