

RALLYE MONTE CARLO – GENEVA

MC Event Generators for the LHC

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DESY Hamburg, Earth



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The need for Event Generators

Matrix Element Generation

Phase Space Integration

Parton Showers

Matching/Merging and all that ...

Hadronization

Underlying Event

Overview over MC Generators

The Tool!

"Old and new workhorses"

Versatile Parton-Level Tools

NLO Tools

Summary

What is a Monte Carlo simulation (program)?

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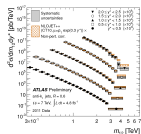
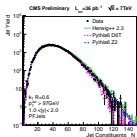
XXX ist ein Simulationsprogram für die Teilchenphysik. Dabei werden möglichst viele verschiedene Äste eines Zerfall-Baumes realisiert, indem man bei jeder Astgabel per pseudorandom einen Ast realisiert.

Lessons from LHC Run I

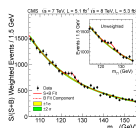
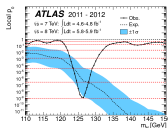
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- ▶ QCD is a precision tool

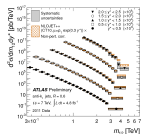
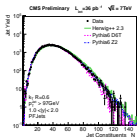


- ▶ Discovery of "a boson at 125-126 GeV" (a.k.a. Higgs?)

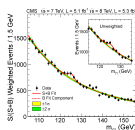
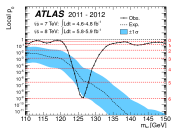


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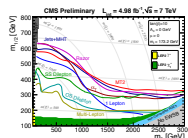
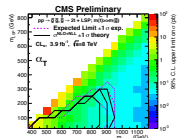
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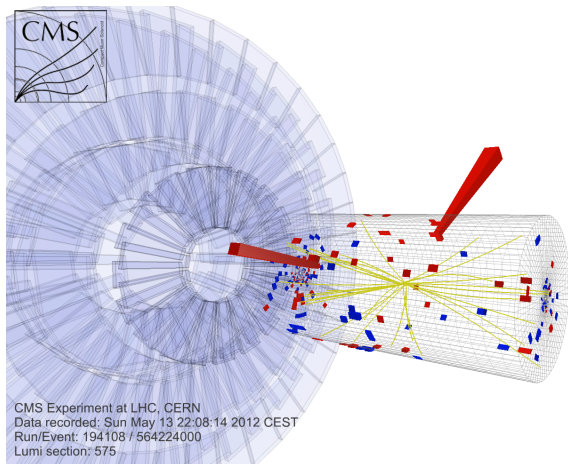


- ▶ Exclusion of most simple BSM scenarios below 1 TeV

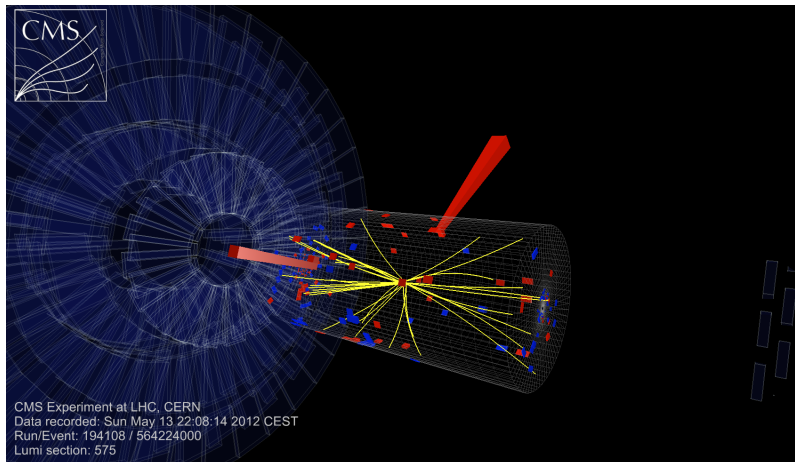


- ▶ All of them rely on Monte Carlos (even data-driven methods)

What is an event (experiment) ?



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What is an event (theory) ?

Sketch of a proton-proton collision at high energies

Initial state parton shower

Signal process = production of jets

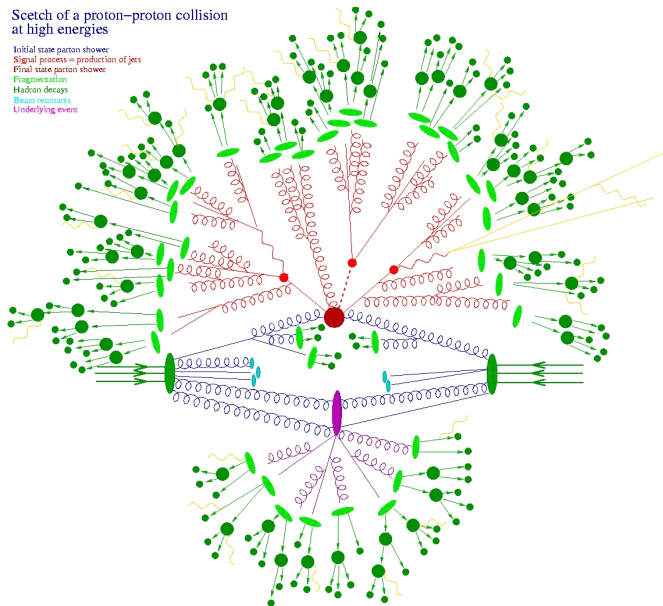
Final state parton shower

Fragmentation

Hadron decays

Boosted remnants

Underlying event



Definitions+Taxonomy: Monte Carlo/Event Generators

- ▶ **Full or Multi-Purpose MC Generator:**
only when containing showers and hadronization
(aka: as hadron level MC, opposite: parton level MC)
- ▶ **Shower Monte Carlo:** contains only showering
- ▶ **Event Generator:** only when generating positive weights
- ▶ **Multi-Particle Event Generator:** allows for at least 2 \rightarrow 6 processes
- ▶ **Generator Generator:** only when "arbitrary" processes can be chosen by the user
- ▶ **BSM MC:** must (OK: should) contain at least the MSSM, Z' , and one non-SUSY model
- ▶ **Dedicated tools:** designed for special purposes (NLO bkgd. processes, black holes, you name it)
- ▶ **Best tool on the market:** depends on who is giving the talk/what you wanna do/whom you ask

Components of MC/Connections to other topics

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taken from **PDF people** → (cf. Delgado's talk)

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- ▶ **Portability**
Programm needs to work \Rightarrow often practical, but not very physical solutions \rightarrow)

Matrix Element Generation of (tree) amplitudes

- ▶ Modern collider simulations need $2 \rightarrow 8$, even $2 \rightarrow 10$ processes (with radiation even $2 \rightarrow \mathcal{O}(100)$)
- ▶ **Number of Feynman diagrams grows factorially**
- ▶ **Berends-Giele Recursion Relations** Berends, Giele
 - ▶ manual calculations
- ▶ **HELAS** Hagiwara et al.,
 - ▶ manual partial common subexpression elimination
- ▶ **Madgraph** Stelzer et al., **AMEGIC++**, **COMIX** Krauss et al.:
 - ▶ partial common subexpression elimination
 - ⇒ **partial** elimination of redundancy
- ▶ **ALPHA** Caravaglios & Moretti:
 - ▶ tree level scattering amplitude is Legendre transform of Lagrangian
 - ▶ can be performed **numerically**, using only $P^*(n)$ independent variables
- ▶ **HELAC** Papadopoulos et al.:
 - ▶ ALPHA algorithm reformulated as recursive **numerical** solution of Schwinger-Dyson equ.
- ▶ **O'Mega** Ohl/JRR:
 - ▶ systematic elimination of **all** redundancies
 - ▶ symbolic, generation of compilable code

Efficient/optimal tree matrix elements

Moretti/Ohl/JRR, 2001; Kilian/Ohl/JRR/Speckner, 2012

⇒ Replace forest of tree diagrams by
Directed Acyclical Graph (DAG) of the algebraic expression.

Ω

$$ab(ab + c) = \begin{array}{c} \text{---} \times \text{---} \\ / \quad \backslash \\ \times \quad + \\ / \quad \backslash \quad / \quad \backslash \\ a \quad b \quad a \quad b \quad c \end{array} = \begin{array}{c} \text{---} \times \text{---} \\ / \quad \backslash \\ \times \quad + \\ / \quad \backslash \quad / \quad \backslash \\ a \quad b \quad a \quad b \quad c \end{array}$$

The diagram on the left shows a tree structure for the expression $ab(ab + c)$. The root node is a multiplication node (\times) with two children: a multiplication node (\times) and an addition node ($+$). The left multiplication node has children a and b . The right multiplication node has children a and b . The addition node has children c and the right multiplication node. The diagram on the right shows a Directed Acyclical Graph (DAG) for the same expression. It has a root multiplication node (\times) with children a and b . The multiplication node (\times) has children a and b . The addition node ($+$) has children c and the multiplication node (\times). A curved arrow indicates a dependency from the root multiplication node to the multiplication node (\times).

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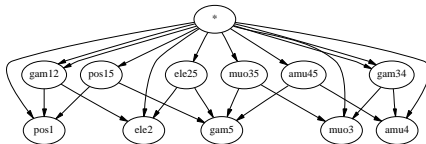
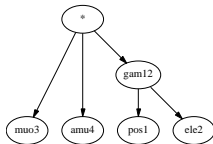
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- simplest examples: $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and



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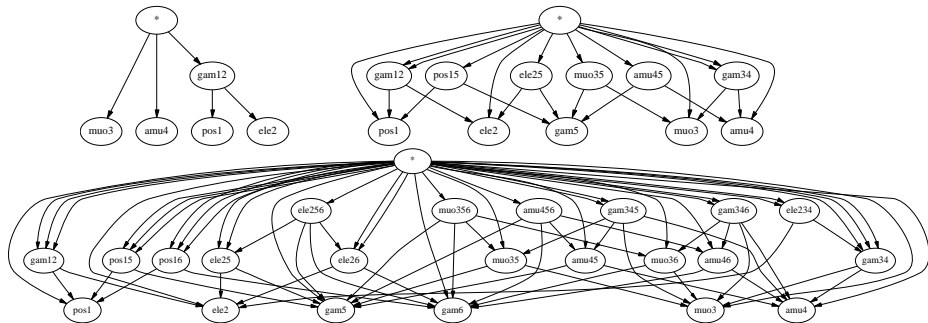
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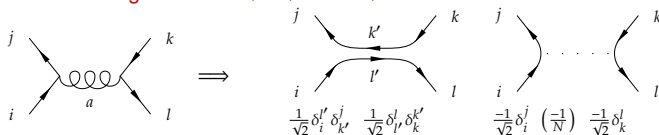
► simplest examples: $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and $e^+e^- \rightarrow \mu^+\mu^-\gamma\gamma$



Obstacles: Color / Flavor / Loops?

► Color

- Most programs use color algebra decomposition $\text{tr}[T^a T^b T^a T^b] = -\frac{1}{4}(N - 1/N)$
- Not possible for recursive algorithms
- Solution: **color-flow algorithm** 't Hooft, 1974; Maltoni et al., 2003



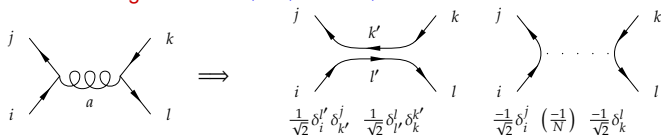
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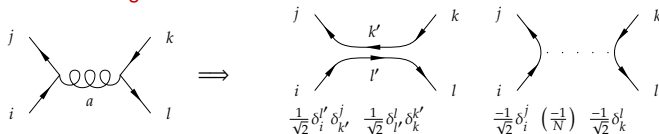
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► Loops

- simple tree level algorithm $n \rightarrow n + 1$ **doesn't work for loop diagrams** because of non-uniqueness of loop representation
- most efficient, but black-box tool for multi loop diagrams **QGRAF** [Nogueira, 1991](#)
- Approaches for loops by trees (Feynman's tree theorem) [Catani et al., Kilian et al.](#)
- Efficient tree-level diagrams \Rightarrow Unitarity cuts, OPP methods** [Ossola/Papadopoulos/Pittau,](#)

[hep-ph/0609007](#)

cf. Pozzorini's talk

Phase Space Generation/Integration

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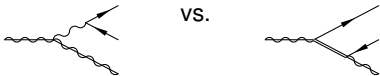
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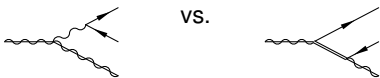
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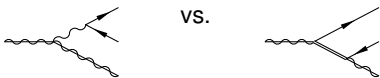
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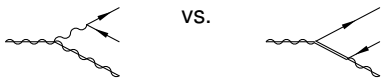
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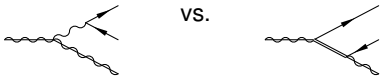
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- ▶ Radiation-like setup: QCD shower/dipole phase space etc.
- ▶ **Final (most costly) step: unweighting events** ⇒ adapted grids should map integrand as close to a constant as possible

Parton Shower

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Parton Showers

- ▶ Problem: need to describe $2 \rightarrow 10 - 100$ QCD processes
- ▶ MEs may available in leading color: PS not
- ▶ QCD emission dominated by large logs: $\alpha_s^n \log^{2n} \frac{Q}{Q_0} \sim 1$:

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Universal DGLAP splitting kernels for collinear limit:

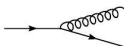
$$d\sigma = \sigma_0 \sum_{\text{jets}} \frac{d\theta^2}{\theta^2} \frac{\alpha_s}{2\pi} P(z) dz$$



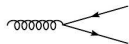
$$P_{q \to qg}(z) = C_F \frac{1+z^2}{1-z}$$



$$P_{g \to gg}(z) = C_A \frac{(1-z)(1-z)^2}{z(1-z)}$$



$$P_{q \to gq}(z) = C_F \frac{1+(1-z)^2}{z}$$



$$P_{g \to qq}(z) = T_R(1-2z(1-z))$$

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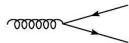
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$$P_{g \rightarrow gg}(z) = C_A \frac{(1-z(1-z))^2}{z(1-z)}$$



$$P_{q \rightarrow gq}(z) = C_F \frac{1+(1-z)^2}{z}$$



$$P_{g \rightarrow qq}(z) = T_R(1-2z(1-z))$$

- ▶ Many possible evolution variables: θ , Q , p_\perp , \tilde{q} , t
 - ▶ θ : HERWIG
 - ▶ Q : PYTHIA ≤ 6.3 , SHERPA, WHIZARD (analytic)
 - ▶ p_\perp : PYTHIA ≥ 6.4 , ARIADNE, CS-SHERPA, WHIZARD
 - ▶ \tilde{q} : HERWIG++

- ▶ Independent collinear emission: probabilistic picture/Sudakov factor

$$dP(\text{next emission at } t) = \frac{dt}{t} \int_{z_-}^{z^+} \frac{\alpha_s(z, t)}{2\pi} \hat{P}(z, t) dz \quad \exp \left[- \int_{t_0}^t \frac{dt}{t} \int_{z_-}^{z^+} \frac{\alpha_s(z, t)}{2\pi} \hat{P}(z, t) dz \right]$$

- ▶ Soft emission: angular ordering \rightarrow color coherence: important effects

- ▶ 1 \rightarrow 2 splitting: **tweaked kinematics**

- ▶ 2 \rightarrow 3 splitting: "exact" kinematics, recoil

Catani-Seymour/dipole shower

Lönnblad, 1992; Schumann/Krauss, 0709.1027

antennae showers

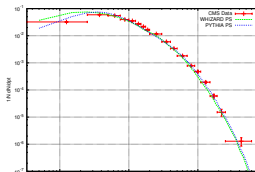
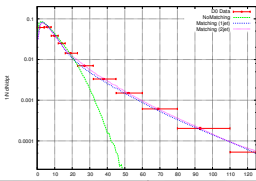
Giele/Kosower/Skands, 0707.3652

- ▶ Generally: veto approach (store weights: [Giele/Kosower/Skands, 1102.2126](#))

- ▶ **Heuristics:** scale, evolution param., avail. PS, integr. limits, regularization, ...

- ▶ **New approach: "analytic PS" (Geneva algorithm)** [Bauer/Schwartz/Tackmann/Thaler](#)

- ▶ Analytic determination of shower weights
- ▶ allows reweighting on an event-by-event basis
- ▶ Full FSR, generalization to ISR [Schmidt/JRR/Kilian/Wiesler; 1112.1039](#)



Matrix element/parton shower matching/merging

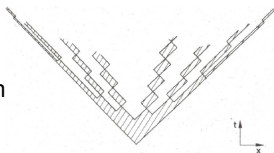
- **Problem:** Additional hard jet produced by the parton shower
 - ▶ Jets generated in regions where soft-collinear approx. invalid
 - ▶ not the whole phase space populated (dirty trick: Power Shower)
 - ▶ General rule: matrix element OK for high p_T , overshoot infrared, showers OK in the infrared, undershoot high p_T
- Solution: **Merge ME and PS:**
- Explicit corrections of $2 \rightarrow 2$ +PS with $2 \rightarrow 3$ MEs (PYTHIA/HERWIG)
- Matching with LO MEs:
 - ▶ CKKW(-L): [Catani/Krauss/Kuhn/Webber, Lönnblad](#)
 - ▶ first hardest emission by full MEs
 - ▶ preserve shower-evolution equations (logarithmic accuracy)
 - ▶ phase-space slicing to avoid double counting \Rightarrow veto shower emissions above scales
 - ▶ reweight MEs with pseudo-shower history (Sudakov factors)
 - ▶ MLM: [Mangano](#)
 - ▶ generate all shower history, throw away those that run into ME region
 - ▶ new CS-inspired phase-space separation criterion (SHERPA)
 - ▶ Matching allows samples of different jet multiplicity:

$$W + X|_{\text{incl.}} = W + 0j|_{\text{incl.}} + W + 1j|_{\text{incl.}} + W + 2j|_{\text{incl.}} + \dots$$
- Merging with NLO MEs: [Lavesson/Lönnblad, 0811.2912](#); [Höche/Kraus/Schönherr/Siegert, 1111.1220, 1207.5030/1](#); [Plätzer/Gieseke, 1109.6256](#); [Torrielli/Frixione, 1002.4293](#); etc. etc.
 - ▶ MC@NLO
 - ▶ POWHEG scheme
 - ▶ Catani-Seymour dipoles/Antennae

Hadronization: Lund or Cluster or What?

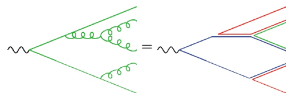
- ▶ Old models: flux tubes, independent fragmentation
- ▶ Independent fragmentation: dresses bare quarks

"last quark", Lorentz invariance, infrared safety



- ▶ **Lund string model:** based on old string model for strong interactions
 - invented without PS in mind
 - strong physical motivation
 - universal description of data (ee fit \rightarrow hadron)
 - Plethora of parameters: $O(1) \sim$ per hadron

- ▶ **Cluster fragmentation model:** (uses preconfinement)
 - ▶ Parton shower orders partons in color space
 - ▶ Large N_C limit: planar graphs dominate
 - ▶ Cluster is continuum of high-mass resonances, then decays into hadrons
 - ▶ No spin info, just phase space
 - ▶ Suppression of heavier particles (esp. baryons)
 - ▶ Cluster spectrum determined by parton shower (pert. theory)



- ▶ **Summary:** All programs use either Lund or cluster (independent fragmentation only for inclusive cross sections)

Hadronic decays

$$B^{*0} \rightarrow \gamma B^0$$

$$\hookrightarrow \bar{B}^0$$

$$\hookrightarrow e^- \bar{\nu}_e D^{*+}$$

$$\hookrightarrow \pi^+ D^0$$

$$\hookrightarrow K^- \rho^+$$

$$\hookrightarrow \pi^+ \pi^0$$

$$\hookrightarrow e^+ e^- \gamma$$

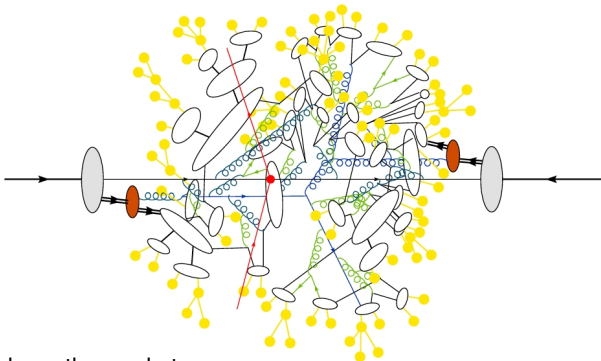
- ▶ radiative EM decay
- ▶ weak mixing
- ▶ weak decay
- ▶ strong decay
- ▶ weak decay, ρ mass smeared
- ▶ ρ^+ polarized, angular correlations
- ▶ Dalitz decay, m_{ee} peaked

100s of particles, 1000s of decay modes, form factors, PDG unitarity violation,
...

with courtesy from S. Gieseke

Underlying Event (aka Multiple Interactions, UE/MI)

- ▶ Various definitions:
 - ▶ everything that is not of interest
 - ▶ multiple parton interactions (MPI) from same bunch
 - ▶ beam remnants: soft interactions and ISR



- ▶ Many models on the market:
 - ▶ Eikonal approximation of optical theorem
 - ▶ Adding more than one hard interaction
 - ▶ Lots of dirty details: what to do about???
- ▶ Still best reference: PYTHIA manual !!!

On the shoulders of GEANT

On the shoulders of GEANT

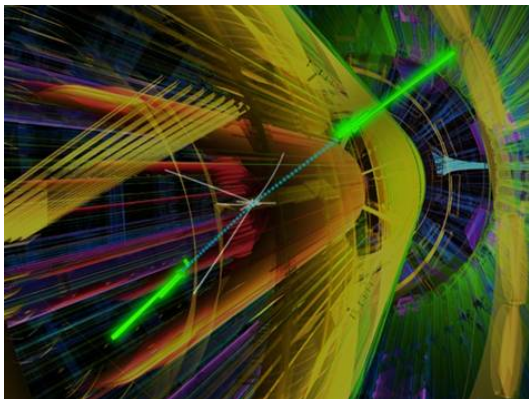
The logo for Geant 4, featuring the word "Geant" in a stylized, bold, brown font with a slight shadow, followed by the number "4" in a similar font. The entire logo is set against a light yellow rectangular background.

- ▶ Full detector simulation: **GEANT4**, <http://geant4.cern.ch>

On the shoulders of GEANT

Geant 4

- ▶ Full detector simulation: **GEANT4**, <http://geant4.cern.ch>
- ▶ **Basis for fast and successful data analysis by LHC experiments!**

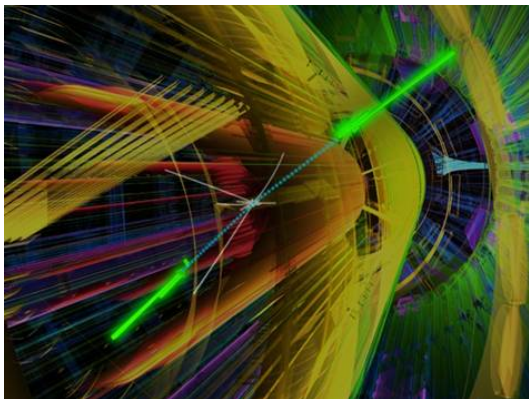


- ▶ E.g.: electromagnetic shower shapes in $H \rightarrow \gamma\gamma$

On the shoulders of GEANT

Geant 4

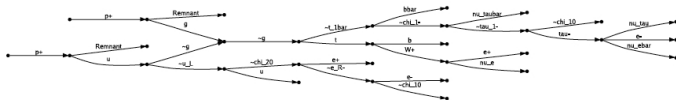
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- ▶ E.g.: electromagnetic shower shapes in $H \rightarrow \gamma\gamma$
- ▶ Versatile tool beyond particle physics (3500 citations)

HERWIG++

- ▶ **Acronym: Hadron Emission Reactions With Interfering Gluons**
- ▶ **Authors/location:** S. Gieseke, P. Marchesini, P. Richardson, M. Seymour, B. Webber + postdocs/PhDs;
Durham/Manchester/Karlsruhe
- ▶ **Current version 2.6.0** <http://projects.hepforge.org/herwig>
- ▶ **Reference** [arXiv:0803.0883](https://arxiv.org/abs/0803.0883)
- ▶ **Prog. language:** C++ (new adaptation of older FORTRAN 77 program)
 - contains parton shower (angular ordered), POWHEG matching
 - contains hadronization (cluster fragmentation model)
 - contains multiple interactions/UE (JIMMY)
 - No arbitrary processes: hardcoded library for SM processes (but: BSM chains)
 - BSM: MSSM/UED/RS, FeynRules, only as decay chains with spin correlations
 - No multi-leg matrix elements: cascade set-up, but including spin density matrices



PYTHIA (6 vs. 8)



- ▶ **Acronym: none (wise and mighty seer from the ancient times)**
- ▶ **Authors/location:** T. Sjöstrand, S. Mrenna, P. Skands et al.; Lund/Fermilab/CERN
- ▶ **Current version: 6.4.26 + 8.1.70** <http://projects.hepforge.org/pythia6> and <http://home.thep.lu.se/~torbjorn/pythia.html>
- ▶ **Reference:** [arXiv:hep-ph/0603175](https://arxiv.org/abs/hep-ph/0603175) and [arXiv:0710.3820](https://arxiv.org/abs/0710.3820) [hep-ph]
- ▶ **Prog. Language:** FORTRAN 77 (PYTHIA 6) C++ (PYTHIA 8)
- parton shower (virt. $\rightarrow p_{\perp}$ ordered, dipole shower [v8])
- Hadronization (Lund string model)
- No arbitrary processes: fixed process library
- BSM: in v6 a bit everything, not yet in v8
- ▶ **Remarks:**
 - ▶ Most (fine???) tuned tool of the world
 - ▶ based on the JETSET jet simulator
 - ▶ no automatized ME/PS matching yet

SHERPA



- ▶ **Acronym: Simulation of High-Energy Reactions with PArticles**
- ▶ Authors/location: [F. Krauss, S. Höche, S. Schumann, et al.; Durham/SLAC/Göttingen](#)
- ▶ **Current version 1.4.1** <http://projects.hepforge.org/sherpa>
- ▶ Prog. language: C++ (1st program in community!)
- ▶ Reference [arXiv:0811.4622 \[hep-ph\]](#)
- Several parton showers (p_{\perp} ordered, Catani-Seymour)
- Hadronization package (cluster fragmentation)
- Multiple Interactions: several independent approaches
- Arbitrary processes: a generator generator
- BSM: MSSM, UED, RS, FeynRules
- ▶ Remarks:
 - ▶ First program to implement CKKW matching
 - ▶ Very serious work towards inclusion of NLO MEs

CompHep/CalcHep

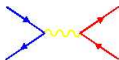


- ▶ Acronym: **COMP**utations/**CALC**ulations in **HIGH-ENERGY** **PHYSICS**
- ▶ Authors/location: E. Boos, S. Sherstnev, S. Pukhov, A. Belyaev et al.; Moscow/Southampton/Pittsburgh
- ▶ Current version 4.5.1/3.3.6 <http://comphep.sinp.msu.ru>
- ▶ Reference [arXiv: hep-ph/0403113](https://arxiv.org/abs/hep-ph/0403113)
- ▶ Prog. language: FORTRAN 77
- no parton shower
- no hadronization
- Arbitrary processes: a generator generator
- BSM: MSSM, Little Higgs, UED, Moose Models, FeynRules, own Feynman rules generator (LANHEP)
- ▶ Remarks:
 - ▶ very easy BSM model file syntax
 - ▶ uses trace technology: limited to $2 \rightarrow 3 - 4$
 - ▶ has to use FORM to simplify

ALPGEN

- ▶ Acronym: **ALPHA Generator**
- ▶ Authors/location: [M. Mangano, M. Moretti, F. Piccinini, R. Pittau; CERN](#)
- ▶ **Current version 2.14** <http://mlm.home.cern.ch/mlm/alpgen>
- ▶ Reference [arXiv: hep-ph/0206293](#)
- ▶ Prog. language: FORTRAN 77 (partially FORTRAN 95)
- no parton shower
- no hadronization
- no arbitrary processes: library of fixed processes
- no BSM
- ▶ Remarks:
 - ▶ first to implement MLM ME/PS matching
 - ▶ Take care: no complete jet processes: not more than 3 quark pairs!
 - ▶ very fast and efficient ME (plus importance sampling over subprocesses)

MadGraph/MadEvent



- ▶ Acronym: **MA**trix element and **DI**agrams for **EV**ENT generation
- ▶ Authors/location: [T. Stelzer/F. Maltoni/J. Alwall/R. Frederix et al.](#); Illinois/Louvain/Taiwan
- ▶ **Current version 5** <http://madgraph.hep.uiuc.edu>
- ▶ Reference [arXiv:1106.0522 \[hep-ph\]](#)
- ▶ Prog. language: FORTRAN 77, Python
- no parton shower
- no hadronization
- Arbitrary processes: a generator generator (Madgraph)
- BSM: MSSM, 2HDM, FeynRules
- ▶ Remarks:
 - ▶ no longer based on the HELAS library
 - ▶ Webinterface for easy usage
 - ▶ ME/PS matching implemented
 - ▶ MadDipole/MadLoop etc. aiming at inclusion of NLO calculations
 - ▶ Many tools/interfaces for e.g. analyses

Helac/PHEGAS

- ▶ Acronym: **PH**ase **E** space **Gen**er**A**tor for **S**imulations
- ▶ Authors/location: [C. Papadopoulos, M. Worek, A. Cafarella; Athens/Wuppertal](#)
- ▶ **Current version 1.2.2** <http://helac-phegas.web.cern.ch/helac-phegas>
- ▶ Prog. language: FORTRAN 95
- ▶ Reference [arXiv:0710.2427 \[hep-ph\]](#)
- no parton shower
- no hadronization
- Arbitrary processes: a generator generator (HELAC)
- No BSM
- ▶ Remarks:
 - ▶ Contains very fast and efficient matrix elements (in a numerical form)
 - ▶ MLM matching scheme implemented
 - ▶ MC over helicities and colors

WHIZARD

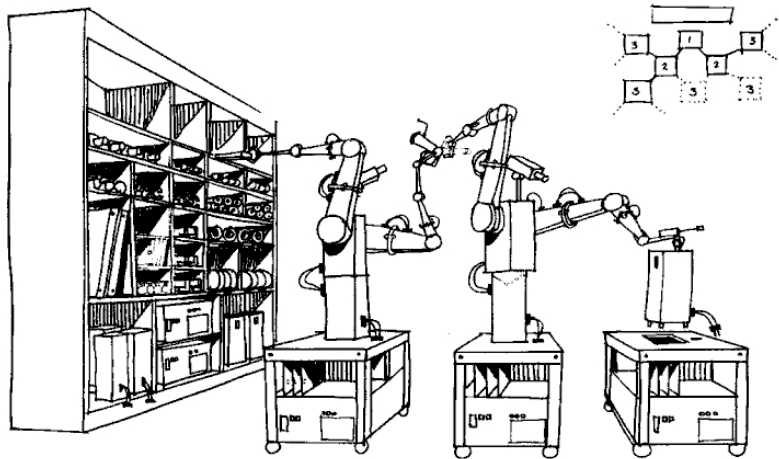


- ▶ Acronym: **W**, **H**iggs, **Z**, **A**nd **R**espective **D**ecays (deprecated)
- ▶ Authors/location: [W. Kilian, T. Ohl, JRR + PhDs; DESY/Freiburg/Siegen/Würzburg](#)
- ▶ **Current version: 2.1.1** <http://projects.hepforge.org/whizard> and <http://whizard.event-generator.org>
- ▶ Reference [arXiv: 0708.4233 \[hep-ph\]](#)
- ▶ Languages: OCaml and FORTRAN 2003
- parton shower (p_{\perp} ordered) and analytic
- no hadronization
- underlying event: preliminary version in v2.1.1
- Arbitrary processes: a generator generator (O'Mega)
- BSM: (N)MSSM, UED, Little Higgs, Moose Models
- ▶ 2.0 features: ME/PS matching, cascades, new versatile user interface and syntax, WHIZARD as a shared library

Dedicated NLO Tools

- ▶ A lot of tools on the market: just a sketchy overview here
- ▶ **MCFM** (**Monte Carlo for FeMtobarn processes**)
 - ▶ K. Ellis, J. Campbell, C. Williams (Fermilab/Glasgow), <http://mcfm.fnal.gov>, FORTRAN 77 v6.3 (several sub-publications)
 - ▶ parton-level NLO tool for W, Z, H and jets at hadron colliders (can be linked to hadronic tools)
 - ▶ important: contains spin correlations for decays
- ▶ **MC@NLO**
 - ▶ S. Frixione, F. Stoeckli, B. Webber, C. White (Cambridge/Glasgow), <http://www.hep.phy.cam.ac.uk/theory/webber/MCatNLO>, v4.09, FORTRAN 77 [arXiv: hep-ph/0204244](https://arxiv.org/abs/hep-ph/0204244)
 - ▶ needs HERWIG for parton shower
 - ▶ contains a working prescription for matching NLO calculations and parton showers ("MC@NLO scheme")
 - ▶ does not contain decays of particles/spin correlations only partially
- ▶ **VBFNLO** (parton-level NLO MC for vector boson fusion)
 - ▶ D. Zeppenfeld + 16 people (Karlsruhe et al.), <http://www-itp.particle.uni-karlsruhe.de/~vbfnlweb>, v2.6.1, FORTRAN 77 [arXiv:1207.4975 \[hep-ph\]](https://arxiv.org/abs/1207.4975)
 - ▶ based on the HELAS library
 - ▶ includes strong NLO/EW corrections, all decays with full spin correlations
- ▶ many, many more!!! (HAWK, FEWZ, GRACE, GR@PPA, etc. etc.)

Automat(izat)ion of NLO



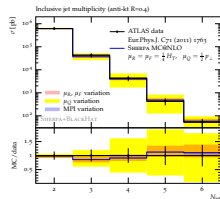
Automat(izat)ion of NLO

- Attempts to automatize NLO (QCD) corrections
- Agreement to talk between MC and NLO: **BLHA**, [Binoth et al., 1001.1307](#)
- **Implementations rely on subtraction formalism:** [Catani/Seymour, hep-ph/9605323](#)
 - ▶ Sherpa implementation [Gleisberg/Krauss, 0709.2881](#)
 - ▶ Helac implementation [Czakon/Papadopoulos/Worek, 0905.0883](#)
 - ▶ AutoDipole [Hasegawa/Moch/Uwer, 0911.4371](#)
 - ▶ MadDipole [Frederix/Gehrmann/Greiner, 1004.2905](#)
 - ▶ WHIZARD implementation [Speckner, only QED yet](#)

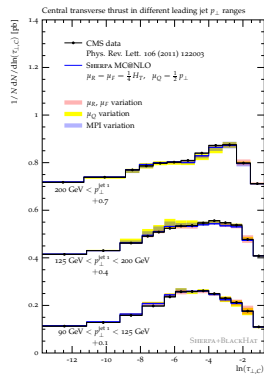
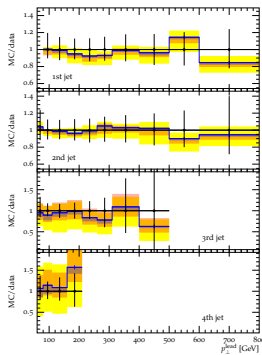
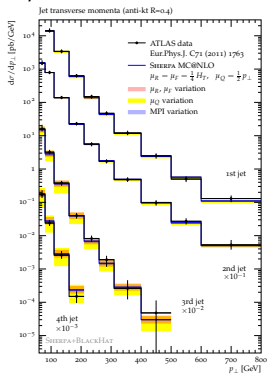
 - ▶ More schemes: FKS, antenna subtraction and implementation
- NLO matrix elements from specialized packages:
combinations: **Sherpa/BlackHat**, **aMC@NLO**, **MadGolem**, more ...
- No real automation yet:
But incredible progress (joint effort of many people)

Success of Monte Carlo description

- ▶ Inclusive jet rates ATLAS
- ▶ Jet p_T ATLAS, Central transverse thrust CMS



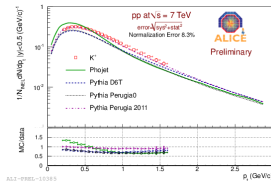
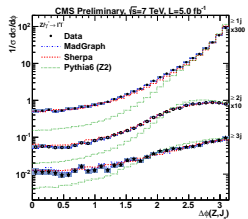
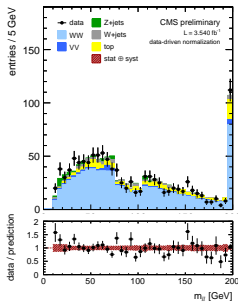
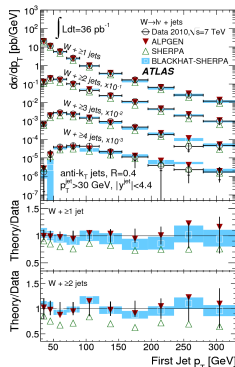
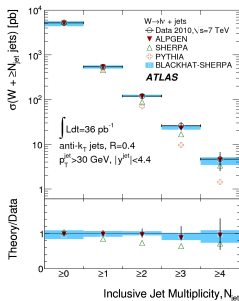
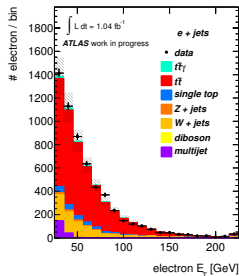
Höche/Schönherr, 1208.2815



- ▶ Very good agreement with experiments

Success of Monte Carlo description

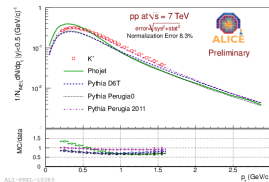
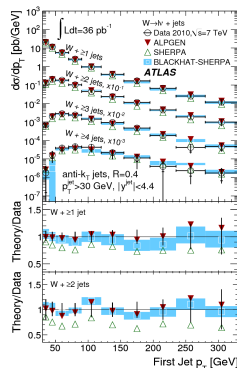
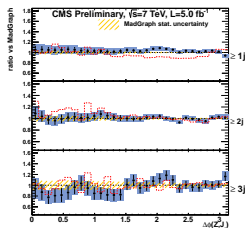
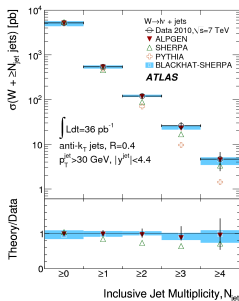
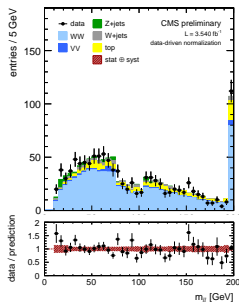
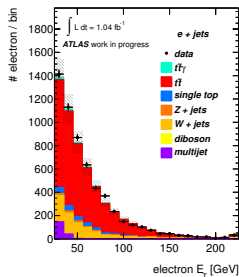
1201.1276,1206.5696,1209.3553,CMS-PAS-EWK-11-021



ALICE-PRE-10005

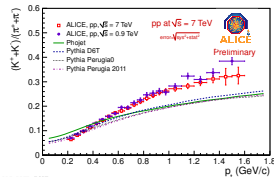
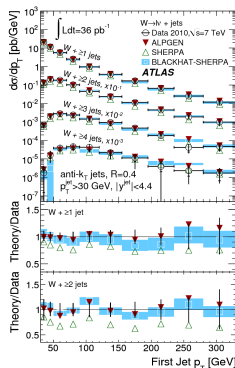
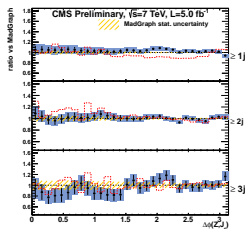
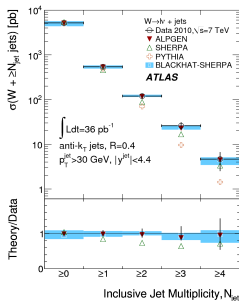
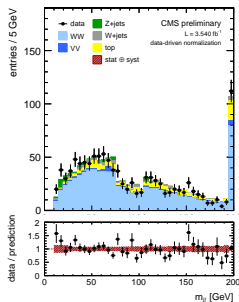
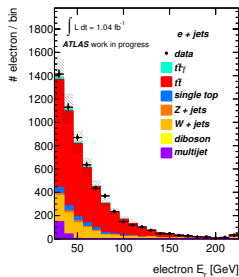
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1201.1276,1206.5696,1209.3553,CMS-PAS-EWK-11-021



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303-0995-0087

Summary


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- LHC demands for full analyses with spin corr., bkgd., hadronic environment


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 - ▶ Underlying Event, Tuning
 - ▶ Automat(izat)ion, NLO development
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- MC Advertisement:
 - ▶ MC Methods in Natural Sciences, Engineering, Economics, DESY, 15.-17.2.2013
 - ▶ MC4BSM 2013, DESY, 17.-19.4.2013

Monte Carlo: Battle of legs vs. loops

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