Scientific Progress on MCnetITN3 projects

January 24, 2019
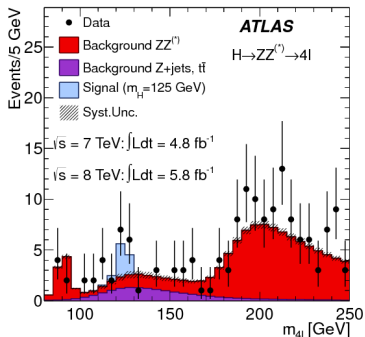
Monte Carlo Event Generators
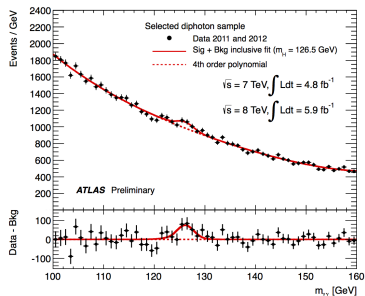
Event Generators - the work organised under the umbrella of MCnet and supported by **MCnetITN3**, are and have been essential for the success of modern day particle physics.
The predictions were heavily used for the **design of existing experiments** ATLAS, CMS, LHCb. The programs are used to **devise new strategies for analyses**, and for the **interpretation of data**.

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MCnet is so central to the LHC, that it is surprising 16% of the papers did not directly cite MCnet projects.

Many of these cite "Atlas generation framework and references therein", others are hard-ware specific papers, or CMS/LHCb PRLs which show results obtained with MCnet projects, but are 'short of space' for listing all references.

Report on the progress in the scientific projects within MCnet:

- Experimental measurements and analysis become increasingly accurate. The correct **interpretation requires matching progress in the theoretical descriptions obtained with Monte Carlo Generators**.
- **Fiercely competitive field**. It has benefited many areas of particle physics that the Monte Carlo community has pulled together and organised **summer schools, short term student ships** etc. This is a remarkable success of the efforts put into **MCnet**.

Recent Scientific Progress

Report on progress within:

- PYTHIA
- MADGRAPH
- SHERPA
- HERWIG
- PLUG-INS
- CEDAR

WP5: PYTHIA

40+ years of scientific studies, model building,
code writing, and support for experiments

Lund	Torbjörn Sjöstrand, Leif Lönnblad[+9], Stefan Prestel; Smita Chakraborty[+9], Leif Gellersen, Andrew Lifson[+6], Christine Rasmussen, Harsh Shah[+9], Marius Utheim
Copenhagen	Christian Bierlich
Birmingham	Philip Ilten
Jyväskylä	Ilkka Helenius
Melbourne	Peter Skands; Helen Brooks[+9], Cody Duncan[+6], Christian Preuss
Chicago	Stephen Mrenna
Mumbai	Nishita Desai

current MCnet PhD student, +# = also in WP#,
former MCnet student, or short-term visitor, or other ESR

Main PYTHIA news during MCnetITN3

- Four public update releases.
- New capability to handle pA/AA, with Angantyr model.
- Expanded internal shower capabilities, notably for ep.
- The VINCIA shower is being expanded to second-order perturbative corrections in the shower kernels.
- The DIRE shower is a joint PYTHIA/SHERPA project, now including exponentiated fully differential NLO calculations, paving the way towards consistently defined NLO showers.
- Colour ropes and shoving models developed to describe string interactions in dense systems, e.g. high-multiplicity pp.
- New assignment of production vertices for hadrons.
- Total and differential diffractive cross sections.
- Photoproduction and $\gamma\gamma$ physics, including diffraction.
- Deuteron production.

Angantyr (from 19th century Norse-style poem, like Fritiof.)

(a) (b) (a) (b)
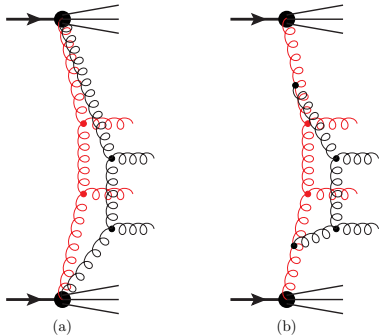
pp: MPIs naively attach multiple colour chains to remnants, but CR used/needed to reduce activity at large $|y|$.
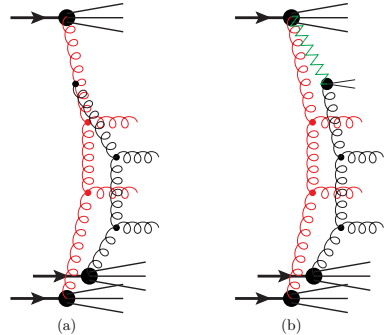
pd: similarly CR will reduce activity in p hemisphere; $\approx$ as one normal and one diffractive scattering.

The space–time evolution of particle production

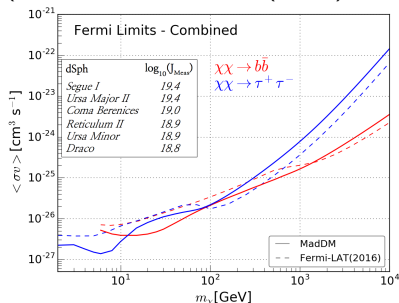Hadron production and decay on time scales from 1 fm to 1 m:
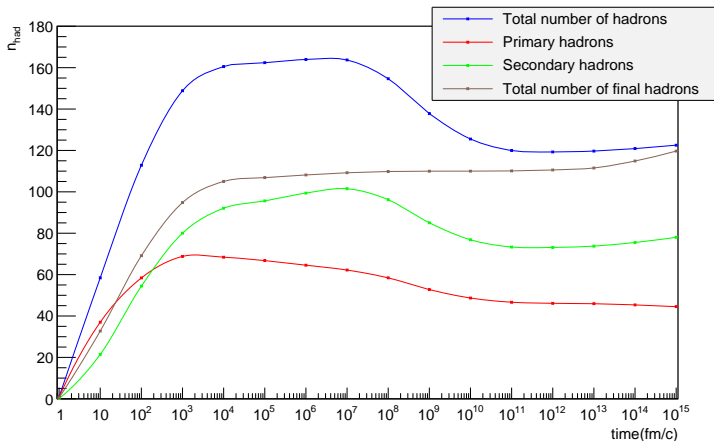
Entry point to studes of hadronic rescattering,
Bose–Einstein correlations, and more.

MadGraph - Recent Achievements

- Implementation of the SM Lagrangian including all operators at dim=6, the **SMEFT**, into Madgraph5_aMC@NLO framework, with **NLO accuracy in QCD**. Used in global fits.

- New capabilities of the code to applied for explicit studies of the EFT at 1-loop, in particular for the determination of the **Higgs self-coupling**.

- Full automation of the computation of **NLO corrections in EW** in the SM. Extension to e+e- colliders on going.

- Release v3 of the MadDM plugin to include **DM annihilation**.

- Release of **MadDump**; a new MC plugin to perform simulations for Beam Dump experiments.

- 2-loop capabilities have been developed which make possible new **NLO computations for loop-induced processes**.

MCnet

MadDM: Module for investigating indirect detection, including modelling of velocity averaged cross section at present time etc. (Phys.Dark Univ. 24 (2019) 100249)

The limits obtained in with the **automated procedure** are similar to those of the official Fermi-LAT analysis. Can furthermore take into account collider limits etc.

MadDump

MadDump: Module for DM searches at beam dump experiments
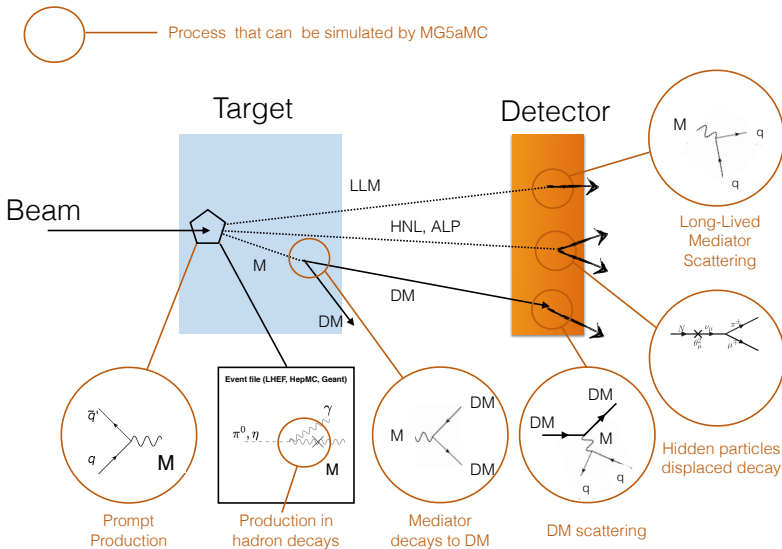
The Sherpa generator: recent developments

Higher-order perturbative corrections

- NLO EW now fully automated
- EW corrections in NLO QCD merging
- NNLO+PS for Drell-Yan, DIS
- perturbative uncertainty evaluations

Parton Shower & Resummation

- NLO QCD splitting kernels
- relate showers to analytic resummation
- resummation of QED/EW corrections

Collider Phenomenology

- Standard Model at 100 TeV pp collider
- EW NLO in $t\bar{t}$, VVV, $\gamma\gamma j$ production
- backgrounds for Dark Matter searches

Jets in DIS @ HERA

full NLO QCD & EW loops
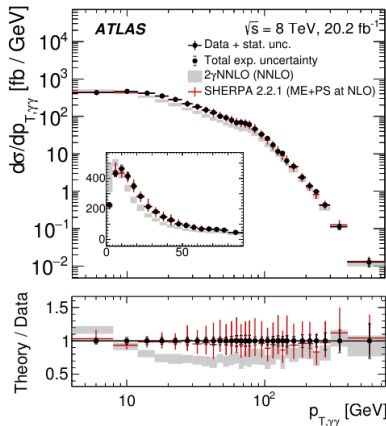
Herwig: Recent progress

Developments

- **Colour Rearrangements** for Dipole Showers
- **Spin Correlations** in Parton Shower Simulations
- **Soft gluon evolution** and non-global logarithms
- **Colour matrix element corrections** for parton showers
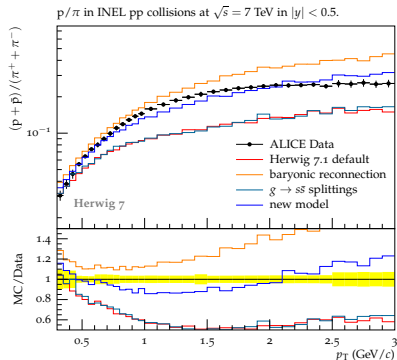- **Baryon production** from cluster hadronisation

Studies:

- Parton Shower and Matching Uncertainties in **Top Quark Pair Production**
- Stress testing the **vector-boson-fusion approximation** in multijet final states
- **Colour Reconnection** from Soft Gluon Evolution
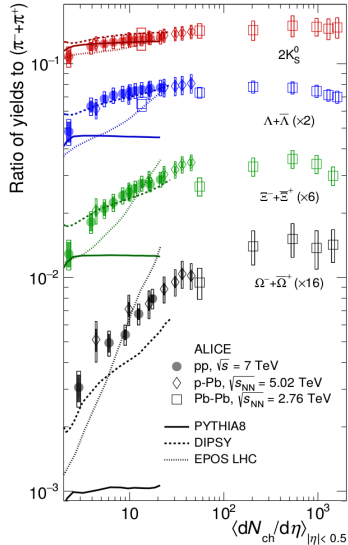- On the **Cutoff Dependence of the Quark Mass** Parameter in Angular Ordered Parton Showers

Colour reconnection and soft model improvements
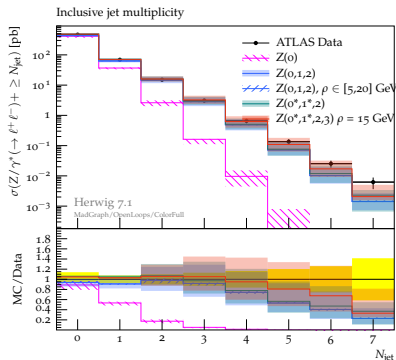
- NLO matching for angular ordered and dipole shower
- MC@NLO-type and Powheg-type algorithms
- Matchbox central

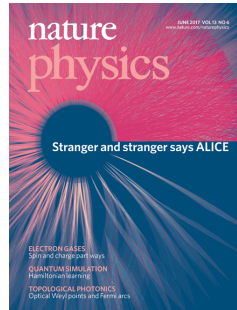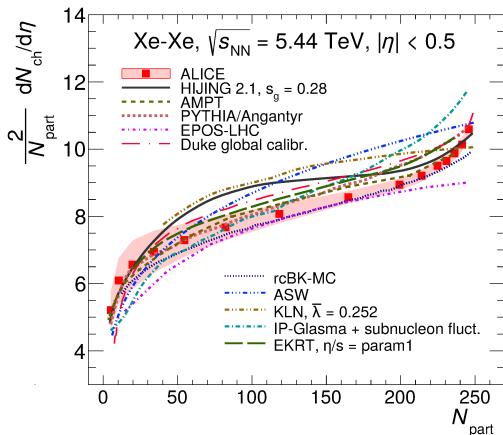Strangeness enhancement is one effect of interactions between strings in events with high density of partons/particles.

[*Nature Phys.* **13** (2017) 535-539]

First General Purpose Event Generator for pA and AA collisions.

[*Phys. Lett.* **B790** (2019) 35-48]

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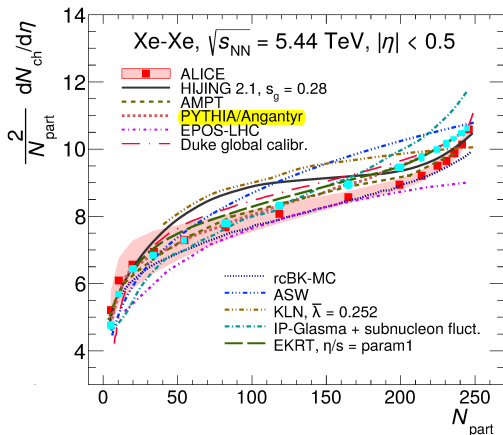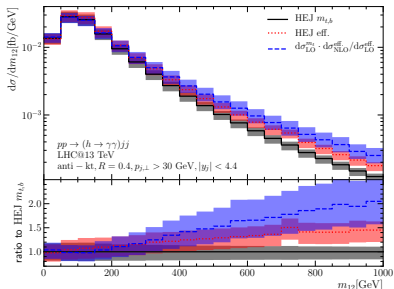

[*Phys. Lett.* **B790** (2019) 35-48]

Plugins: High Energy Jets

Full quark-mass dependence in high-energy resummation for $H + 2j$
All-order resummation hardens Higgs boson spectrum. Mass dependence of quark-mediated Higgs-coupling therefore increased (to 10%).
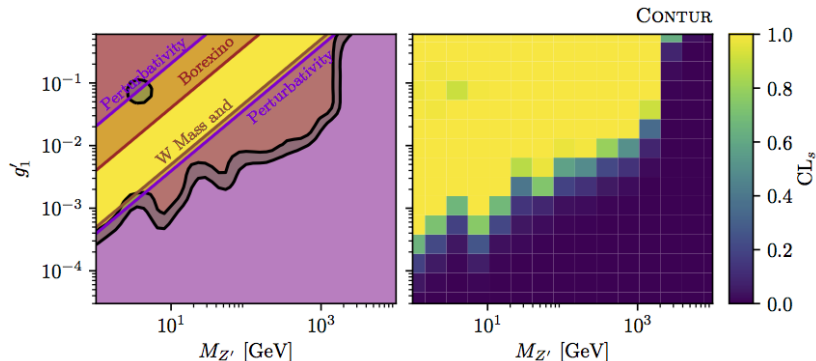
$\log(s/p_t^2)$-terms halves cross section within VBF-cuts compared to fixed-order estimate
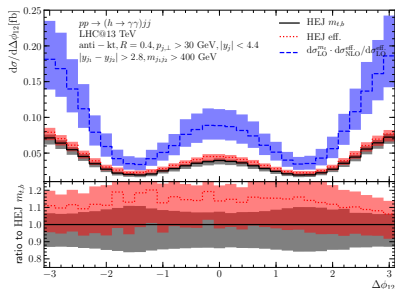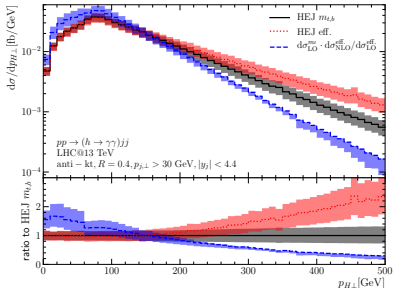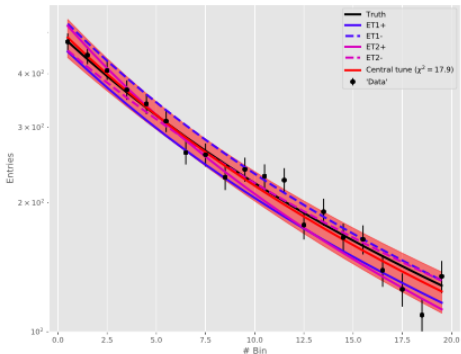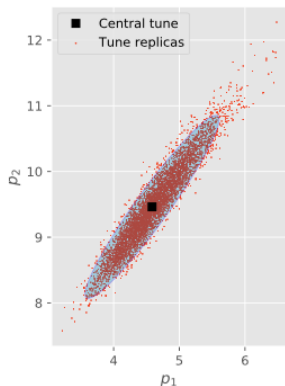
CEDAR: Rivet for BSM & Contur

Detector smearing included in Rivet from release 2.5.0. Allows LHC uncorrected searches to be used in Rivet, in addition to particle-level measurements.

Existing measurements can be used to set limits on new models

gauged $B - L$

Automation and **error estimation** for MC tuning

Statistical analysis of tunes using replicas

Conclusions

Progress pushed by increasing accuracy on data and new analyses.

- Higher formal accuracy: Electroweak corrections, Higher perturbative orders in evolution and in matching, new logarithms, subleading colour

- New physical processes explored: Dark Matter, Heavy Ion

We are constantly faced with **new challenges from data and theory**. Despite huge progress over decades, we are still challenged by both experiments and ourselves to further improve the description and understanding of the fundamental processes.
We have as detailed already at this point delivered on many of the research objectives:

- To develop the next generation of higher precision event generators and support them for use throughout the LHC era and beyond

- To play a central rôle in the analysis of LHC data and the discovery of new physics there

- To extract the maximum potential from existing data to constrain the modeling of the data from the LHC and future experiments

MCnet