LUND UNIVERSITY

MCnet Scientific results

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Outline

- What is an Event Generator
- The MCnet Projects
- Outlook

What is an Event Generator?

How do we go from this:

$$
\begin{aligned}
\mathcal{L} &= \bar{U}(\delta_\mu - ig_s G^a_\mu T^a)\gamma^\mu U \\
&+ \bar{D}(\delta_\mu - ig_s G^a_\mu T^a)\gamma^\mu D \\
&- \frac{1}{4} W^{\mu\nu}_a W^a_{\mu\nu} - \frac{1}{4} B^{\mu\nu} B_{\mu\nu} \\
&+ \overline{Q}_i i\not{D} Q_i + \overline{L}_i i\not{D} L_i \\
&- \frac{1}{2}[(\delta_\mu - iW^a_\mu t^a - iB_\mu)\phi]^2 \\
&- \frac{\mu^2}{2}\phi^\star\phi - \frac{\lambda}{4}(\phi^\star\phi)^2 \\
&+ \cdots
\end{aligned}
$$

What is an Event Generator?

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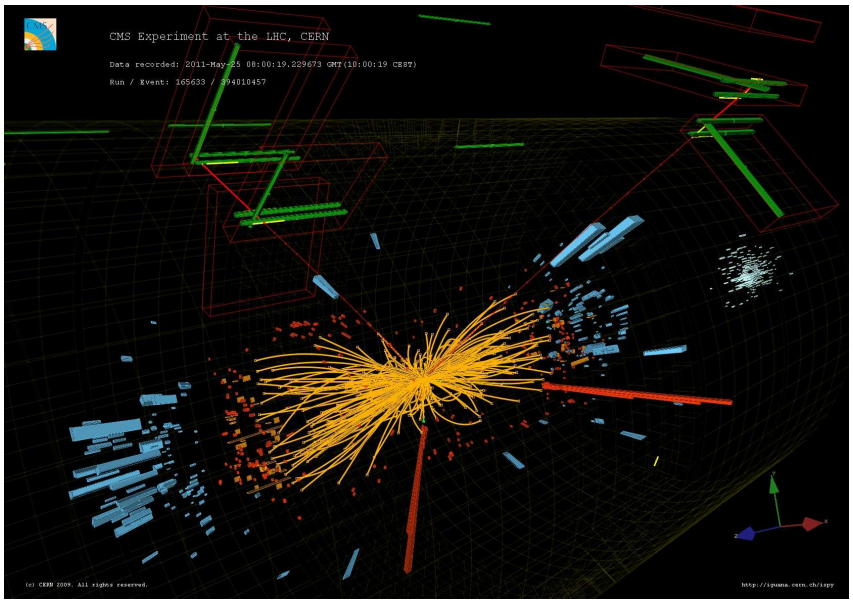
&- \frac{1}{2}[(\delta_\mu - iW^a_\mu t^a - iB_\mu)\phi]^2 \\
&- \frac{\mu^2}{2}\phi^\star\phi - \frac{\lambda}{4}(\phi^\star\phi)^2 \\
&+ \cdots
\end{aligned}
$$

. . . to this:



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Hundreds of particles are produced in each collision.
Impossibly to calculate analytically.

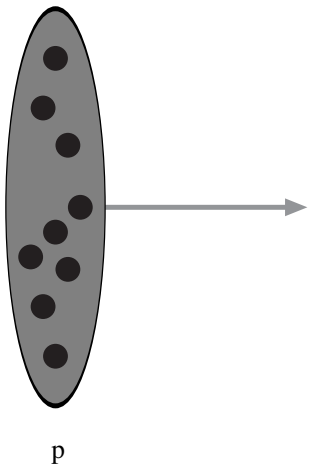
Divide and conquer

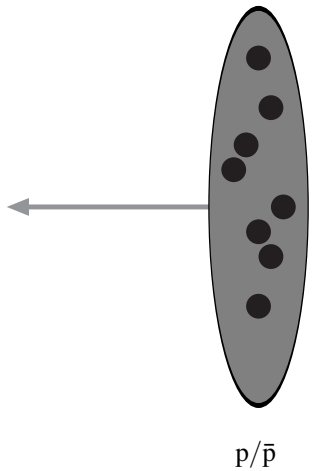
Look at the time scales involved and divide up in simpler tasks.

Each step involves randomness from quantum mechanics so we throw dice each step to see what happens next.

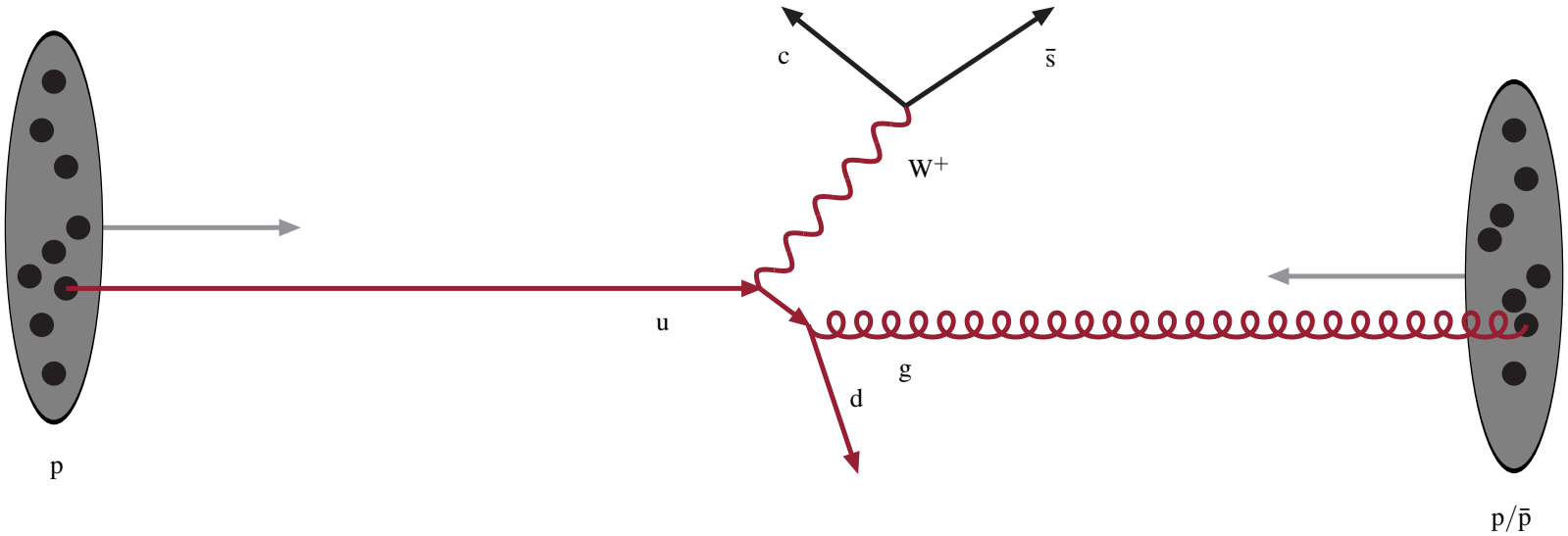
Monte Carlo

The structure of a proton collision

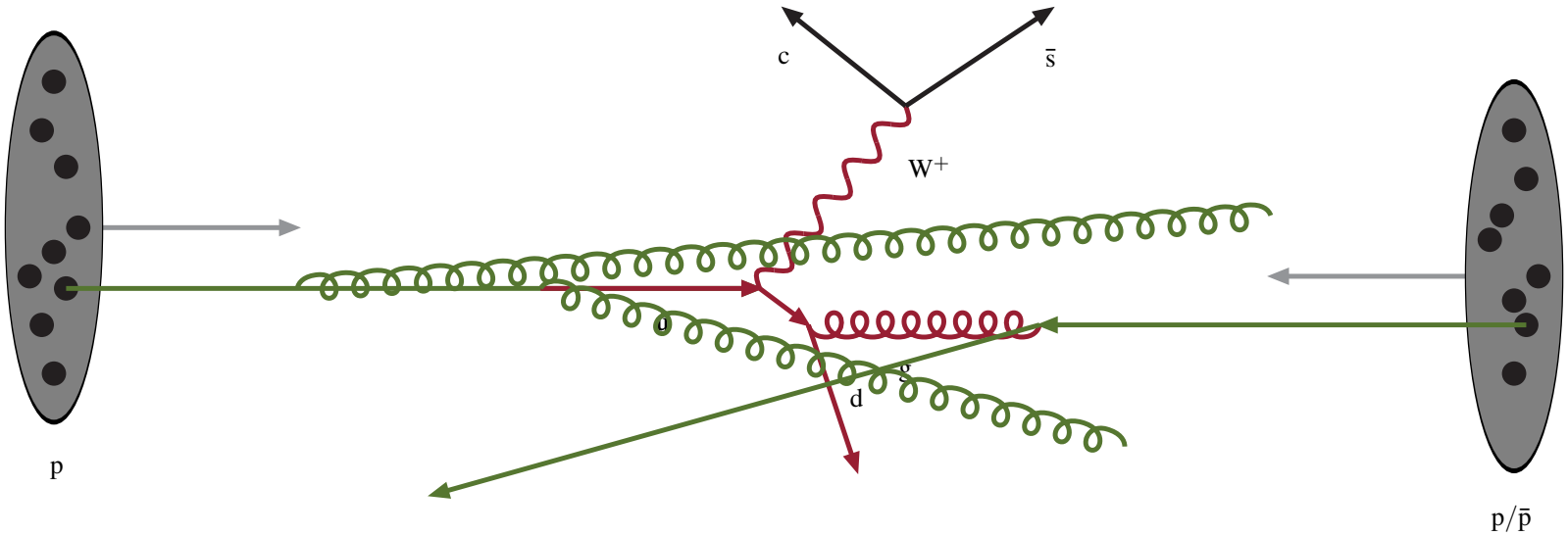




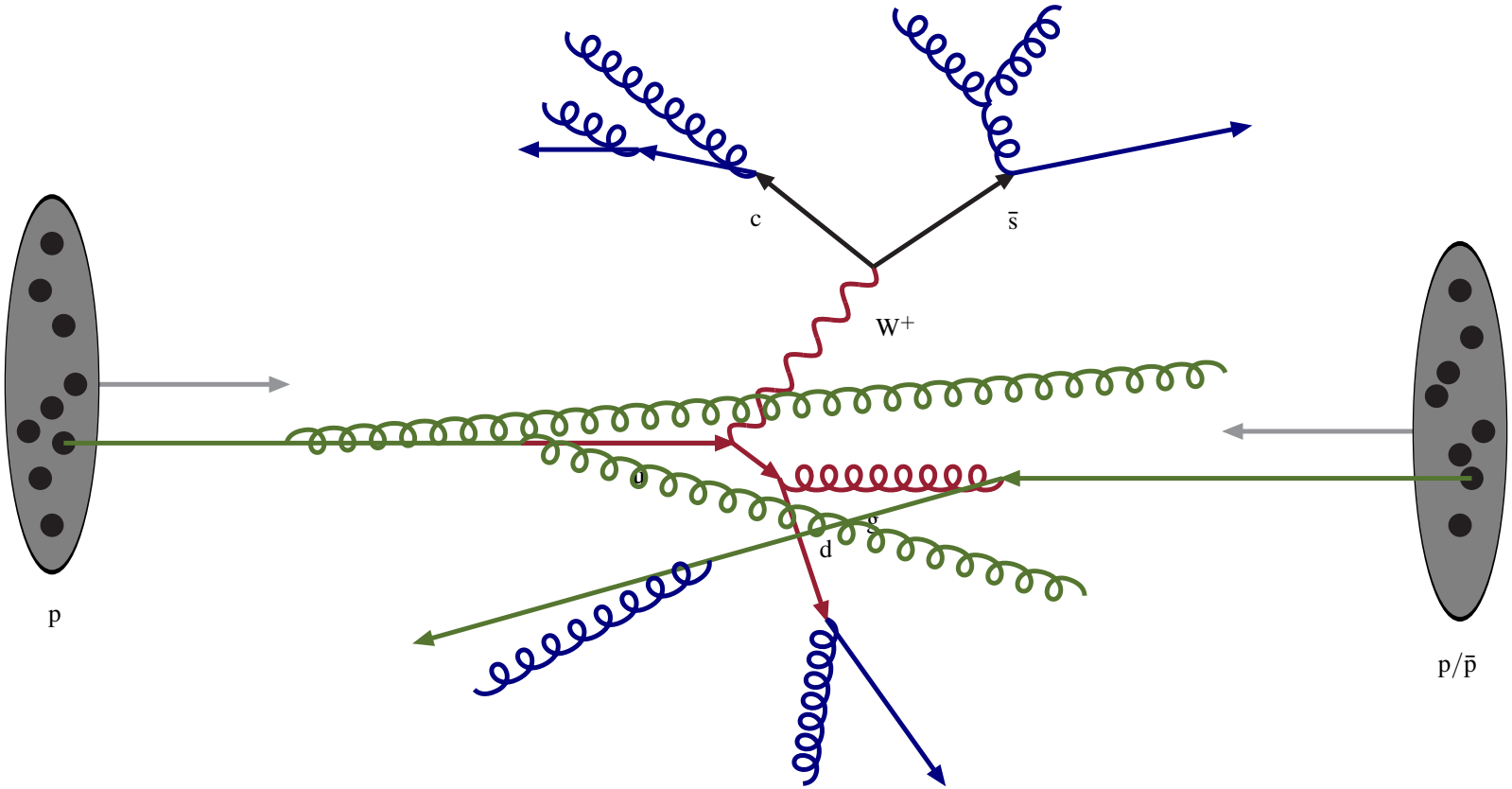
The hard/primary scattering



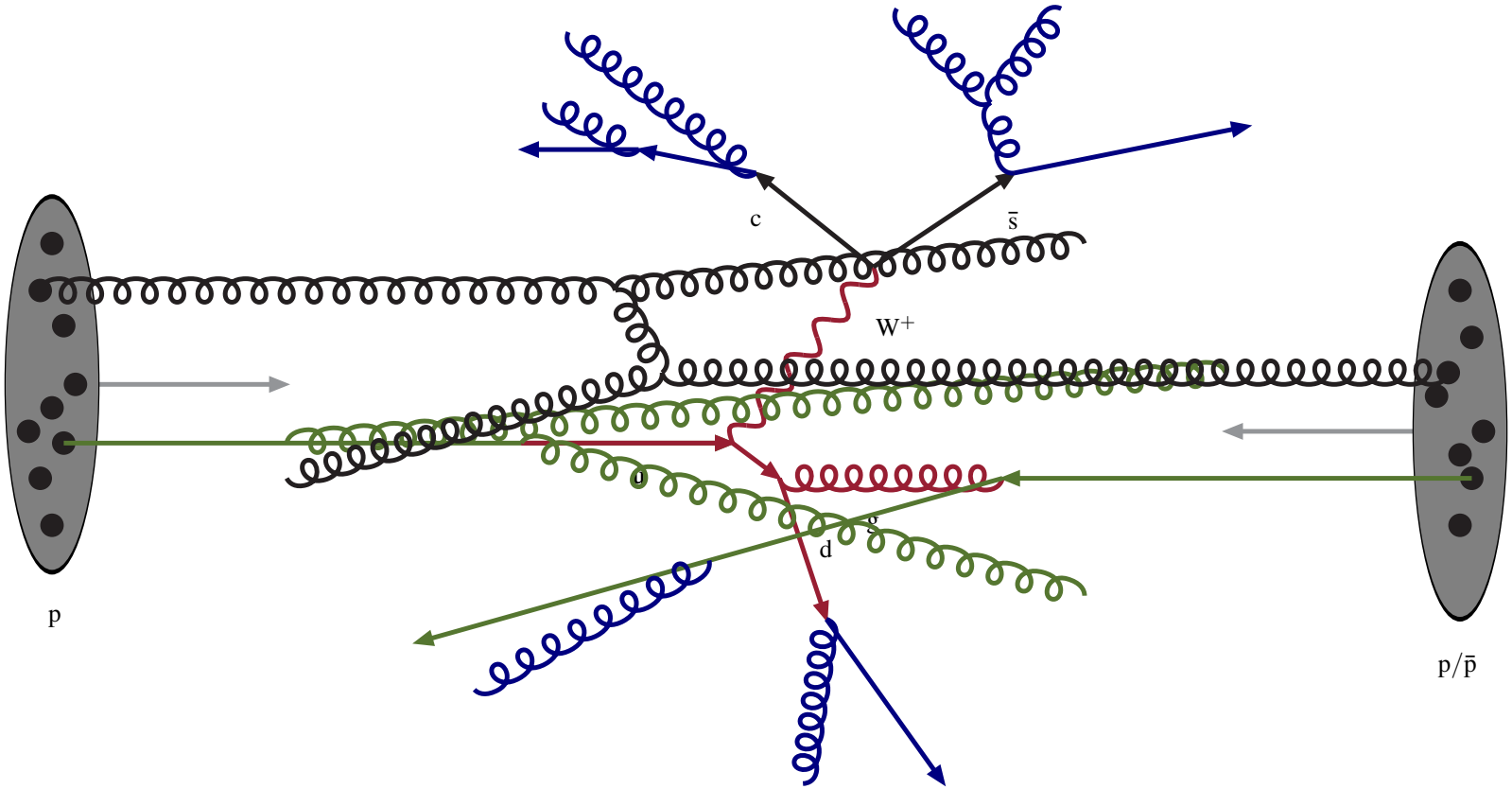
Radiation from particles before primary interaction



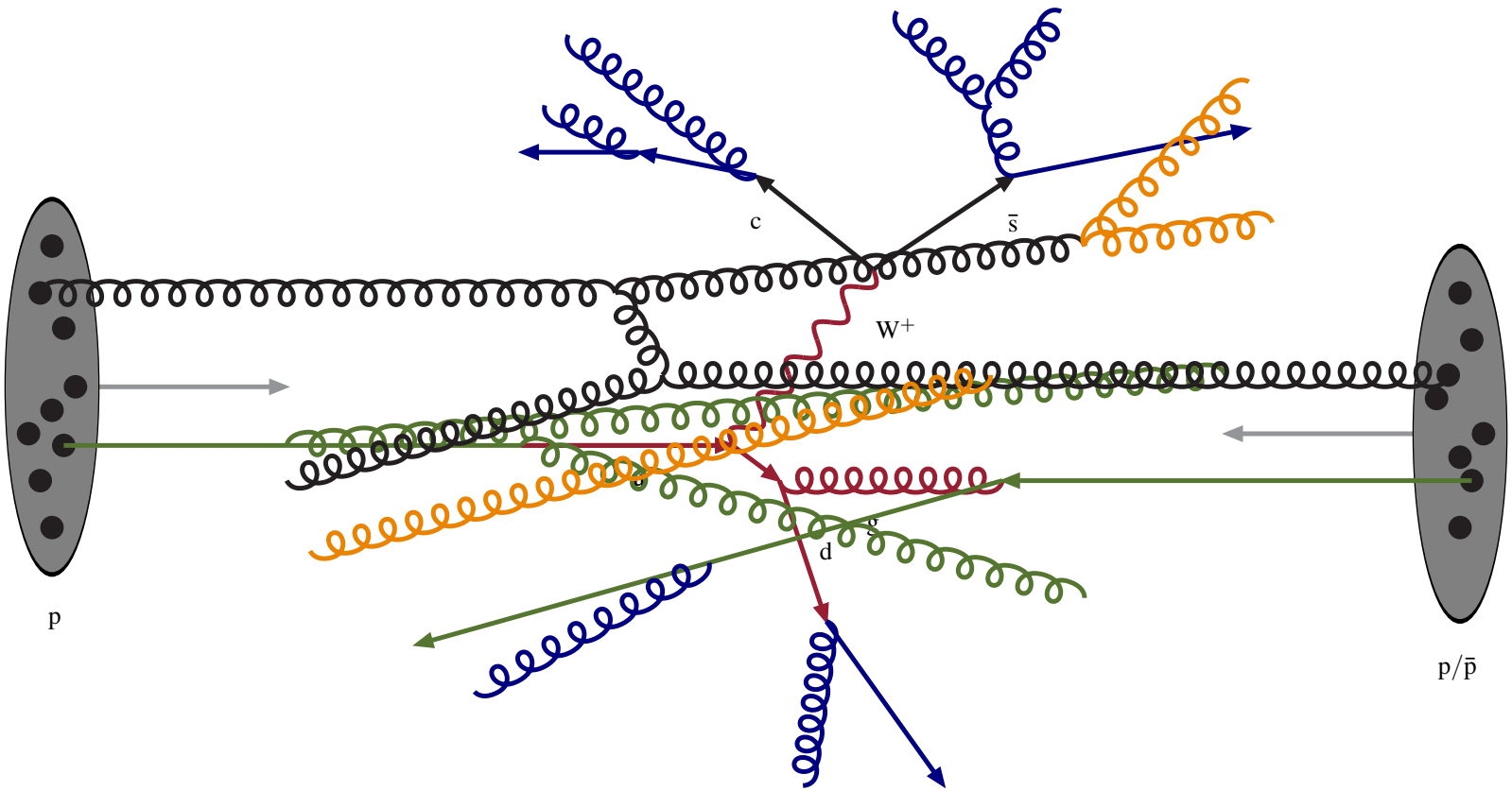
Radiation from produced particles



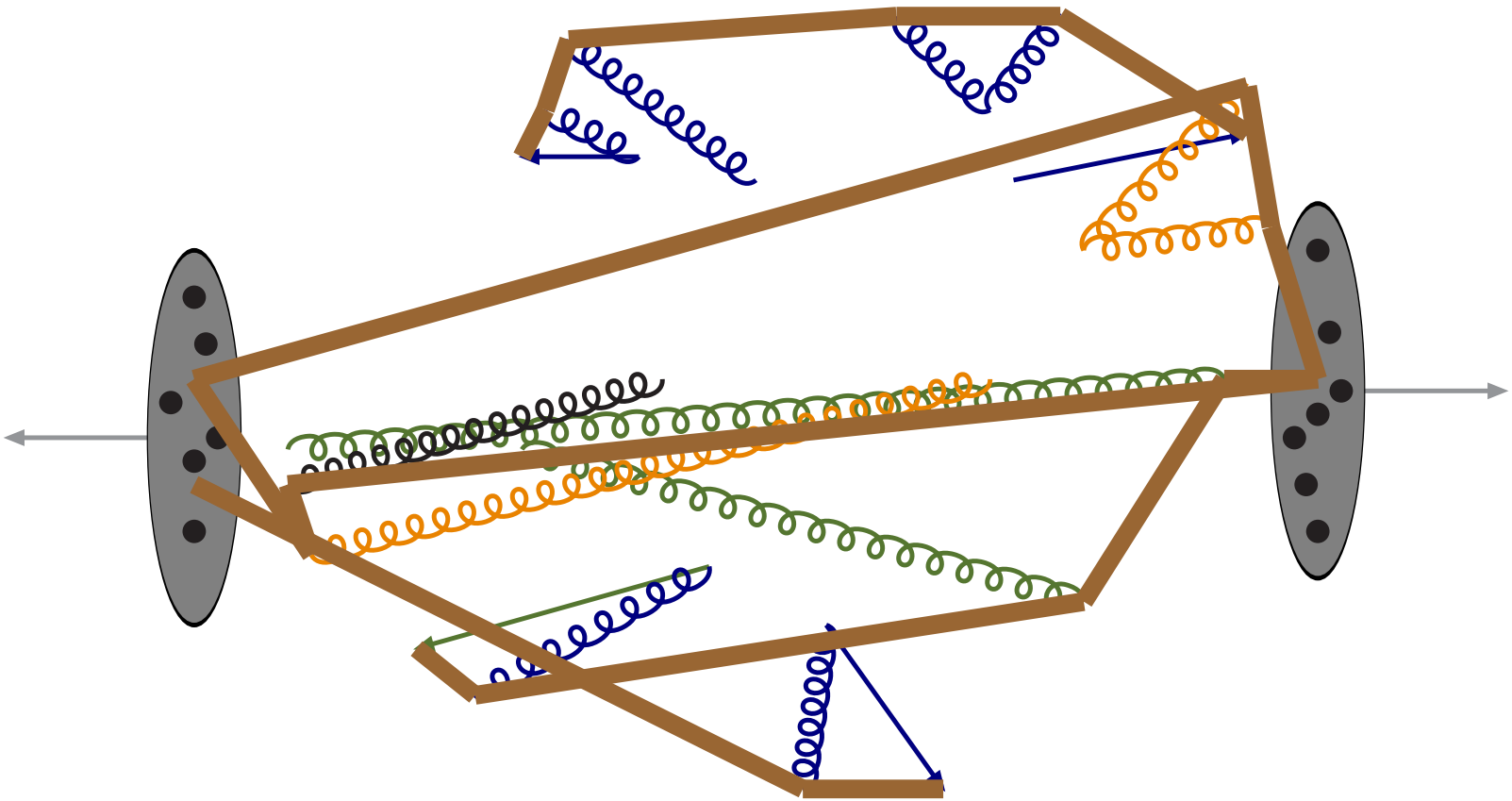
Additional sub-scatterings



. . . with accompanying radiation



Formation of *colour strings*



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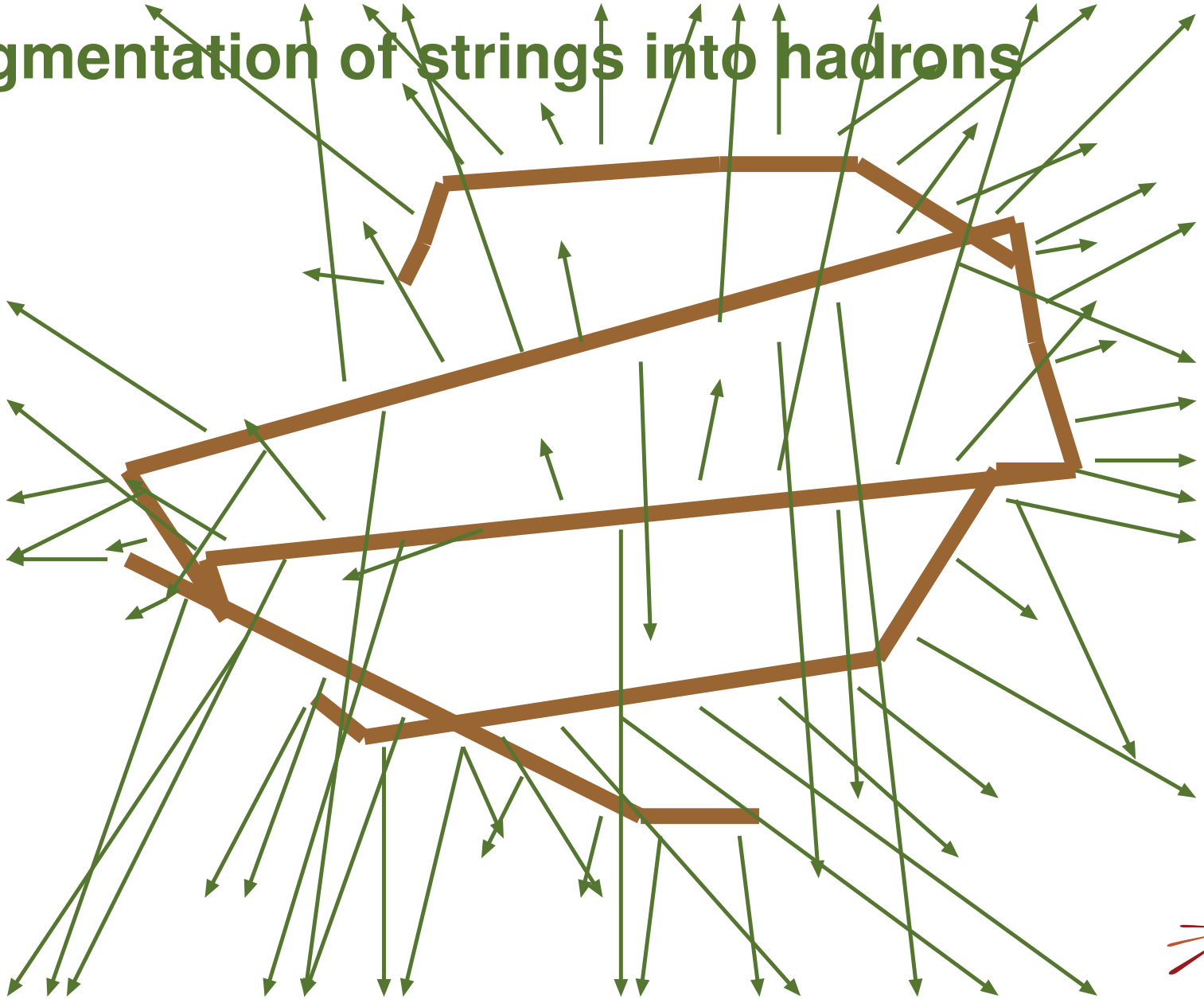
Fragmentation of strings into hadrons



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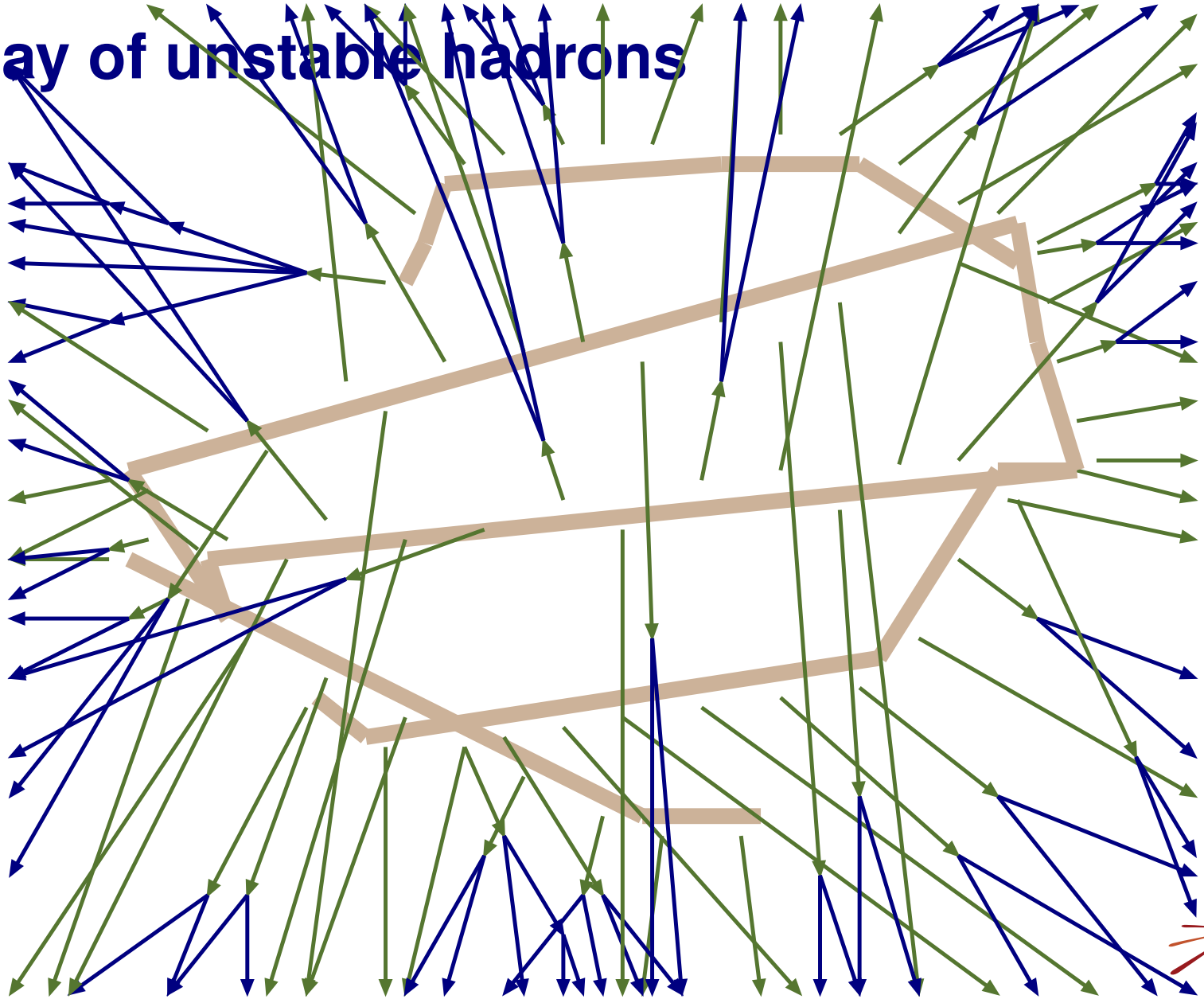
Decay of unstable hadrons



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Calculation of experimental observables

To make simplifications we use *Perturbation theory*

$$\langle \mathcal{O} \rangle = c_0 + c_1\alpha + c_2\alpha^2 + c_3\alpha^3 + \cdots$$

As long as α is small, we can stop the expansion at a fixed order and have a controllable precision of or calculation.

The calculation of c_n becomes extremely complicated for large n.

Buzzwords:
Matrix element generation, PDF, BSM, LO, NLO, NNLO

In many cases one finds that the c_n coefficients grow larger at each order, sometimes even faster than the α^n becomes smaller.

In this case we cannot cut off our series at any fixed n.

But we can calculate some parts of the fastest growing terms of all c_n. This means we can **re-sum** parts of the perturbative expansion.

Buzzwords:
Parton Shower, QCD, jets, resummation, matching, merging

But we are in any case left with a **non-perturbative** correction which typically arises in the later stages where the α grows large.

For this we need informed guesswork and models which several free parameters which have to be **tuned**.

$$\langle \mathcal{O} \rangle = \left(c_0 + c_1 \alpha + c_2 \alpha^2 + c_3 \alpha^3 + \cdots \right) \times NP$$

Buzzwords:
Hadronization, multi-parton interactions, underlying events

The Scientific Objectives

- to develop and support the new generation of event generators intended for use throughout the LHC data analysis era and beyond;
- to play a central rôle in the analysis of LHC data and the discovery of new physics there; and
- to extract the maximum potential from existing data to constrain the modeling of the data from the LHC and future experiments.

The Projects

Three general purpose generators

- Herwig++
- Pythia
- Sherpa

One matrix element generator

- Madgraph

Additional Parton Shower generators

- Ariadne

Interface to Experiments

- CEDAR

Herwig++

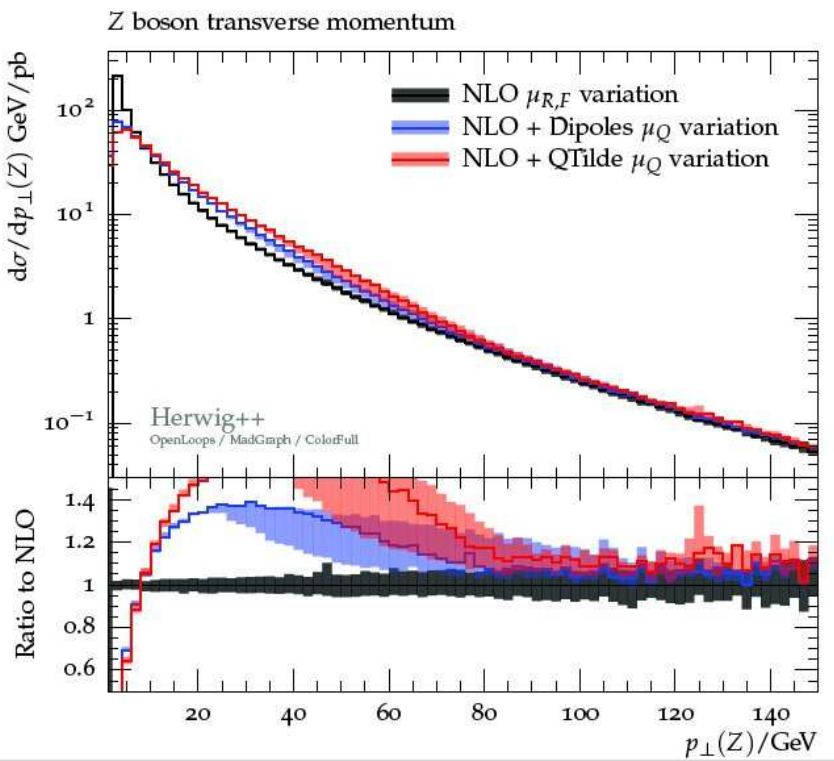
One of the first general purpose generators.
Rewritten from scratch for LHC.

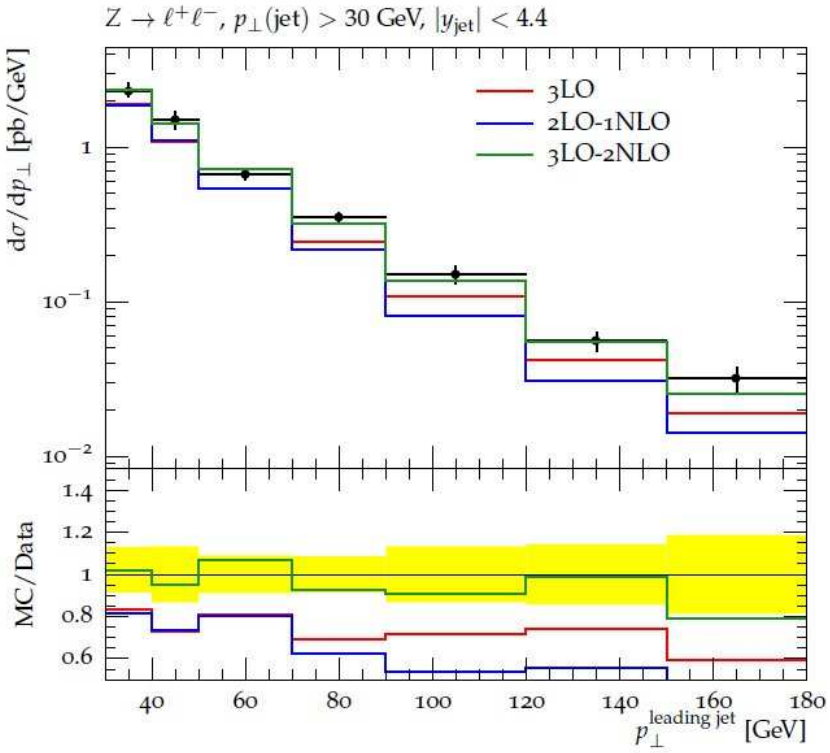
Network nodes: Durham, Karlsruhe, Manchester, UCL, (DESY)

Main emphasis: Perturbative QCD

New developments: MATCHBOX NLO matching

Herwig++


Z boson transverse momentum
NLO $\mu_{R,F}$ variation
NLO + Dipoles μ_Q variation
NLO + QTilde μ_Q variation
Herwig++
OpenLoops / MadGraph / ColorFull
$d\sigma/dp_\perp(Z)$ GeV/pb
Ratio to NLO
$p_\perp(Z)$/GeV


$Z \to \ell^+\ell^-$, $p_\perp$(jet) > 30 GeV, $|y_{jet}| < 4.4$
3LO
2LO-1NLO
3LO-2NLO
$d\sigma/dp_\perp$ [pb/GeV]
MC/Data
$p_\perp^{leading\ jet}$ [GeV]

Pythia

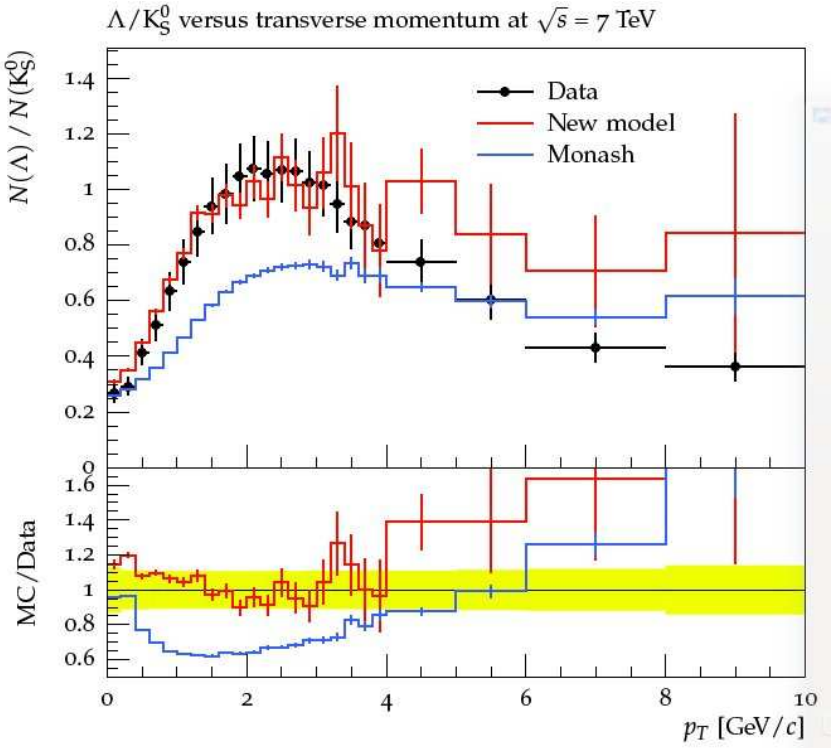
The first general purpose generator.
Rewritten from scratch for LHC.

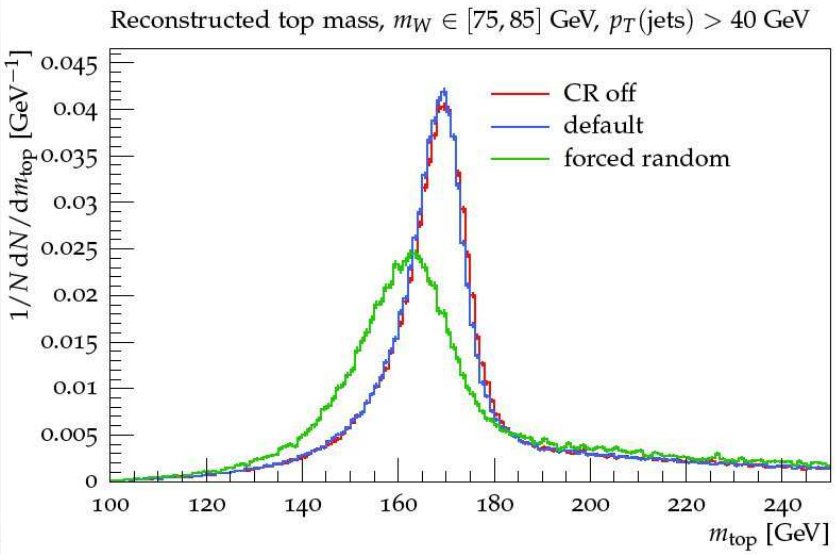
Network nodes: Lund, (CERN), (DESY)

Main emphasis: Hadronization and multi-parton interactions

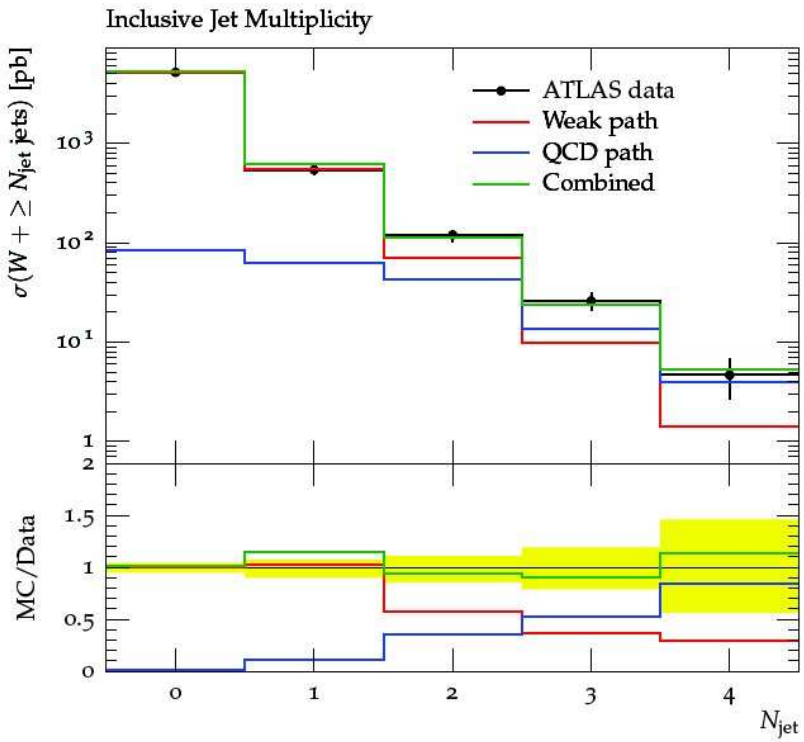
New developments: Colour re-connections, weak showers

Pythia


Λ/K^0_S versus transverse momentum at $\sqrt{s} = 7$ TeV
$N(\Lambda) / N(K^0_S)$
Data
New model
Monash
MC/Data
p_T [GeV/c]


Reconstructed top mass, $m_W \in [75, 85]$ GeV, p_T(jets) > 40 GeV
$1/N\, dN/dm_{top}$ [GeV^{-1}]
CR off
default
forced random
m_{top} [GeV]

Pythia


Inclusive Jet Multiplicity
ATLAS data
Weak path
QCD path
Combined
$\sigma(W + \geq N_{\text{jet}}\ \text{jets})$ [pb]
10^3
10^2
10^1
1
MC/Data
1.5
1
0.5
0
0
1
2
3
4
N_{jet}

Sherpa

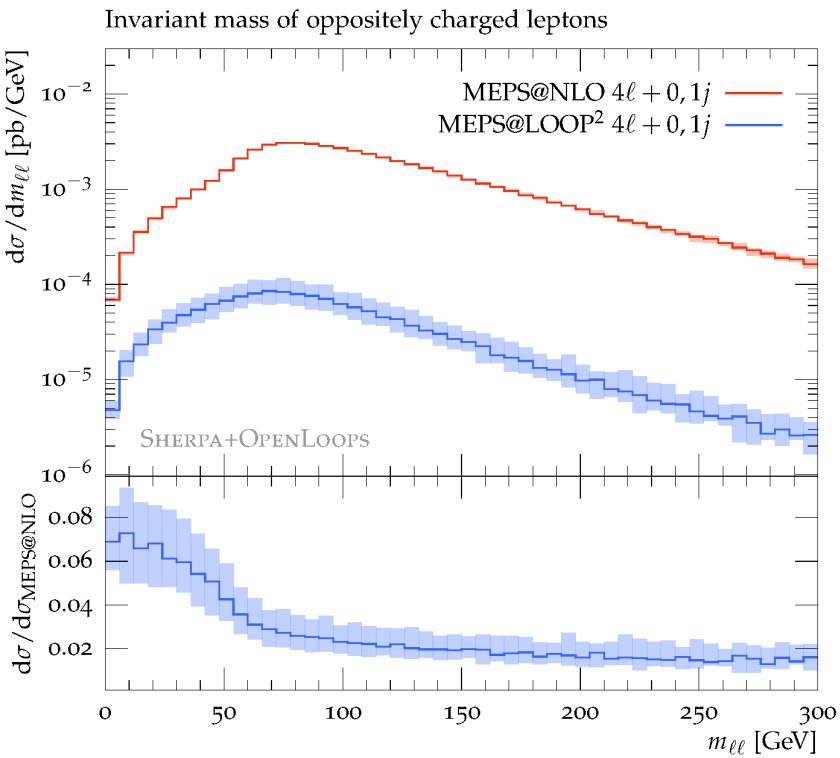
The newest general purpose generator.

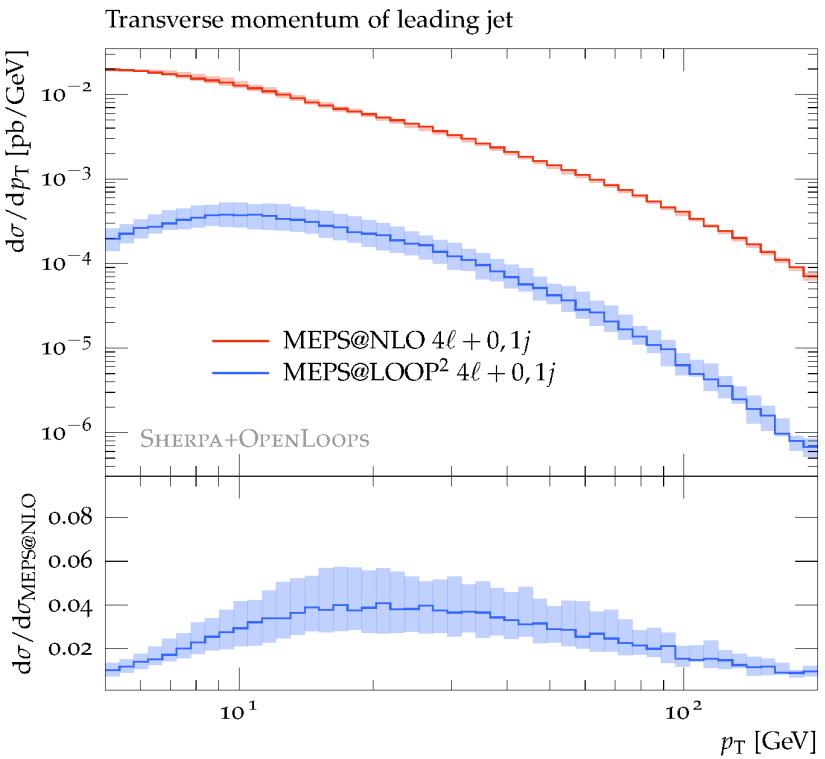
Network nodes: Durham, Göttingen

Main emphasis: Matrix elements matching and merging

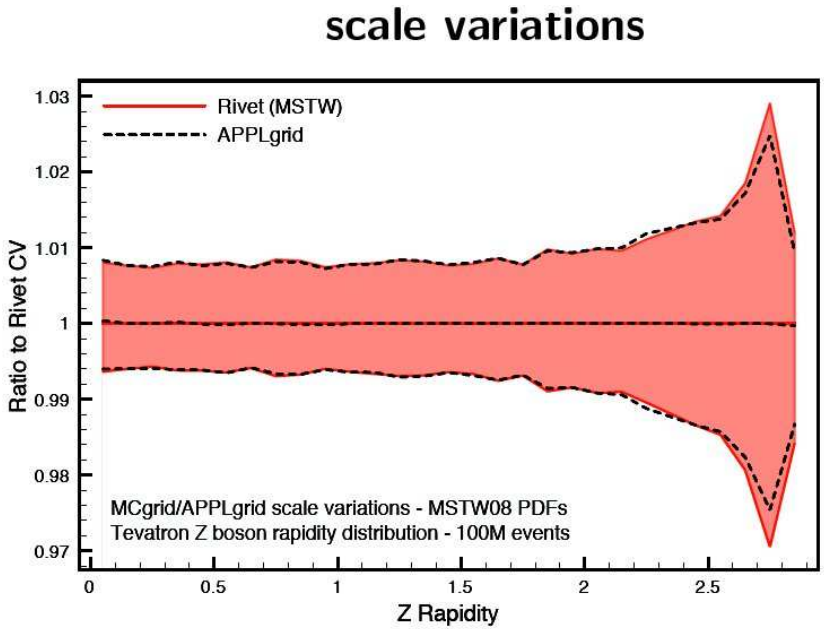
New developments: Multi-leg (N)NLO matching, MCgrid

Sherpa


Invariant mass of oppositely charged leptons
MEPS@NLO $4\ell + 0,1j$
MEPS@LOOP^2 $4\ell + 0,1j$
SHERPA+OPENLOOPS
$d\sigma / dm_{\ell\ell}$ [pb/GeV]
$d\sigma / d\sigma_{MEPS@NLO}$
$m_{\ell\ell}$ [GeV]


Transverse momentum of leading jet
MEPS@NLO $4\ell + 0,1j$
MEPS@LOOP^2 $4\ell + 0,1j$
SHERPA+OPENLOOPS
$d\sigma / dp_T$ [pb/GeV]
$d\sigma / d\sigma_{MEPS@NLO}$
p_T [GeV]

Sherpa/MCgrid



Madgraph

Fully automatized matrix element generator

Network nodes: Louvain, Göttingen, Durham

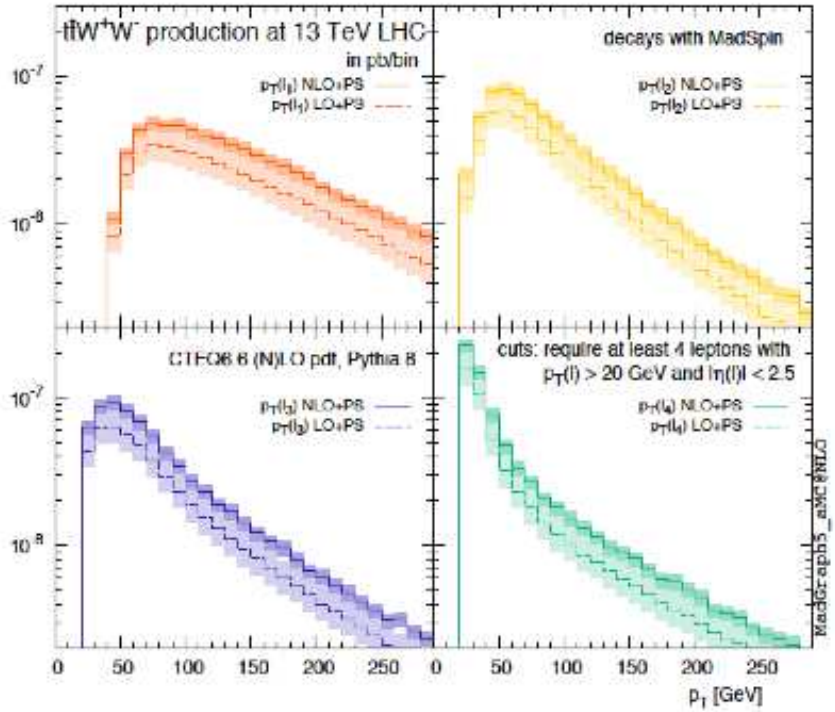
Main emphasis: Matrix elements, BSM, NLO

New developments: Automated NLO matrix element generation

Madgraph5_amc@nlo

Full automation of event generation at NLO in QCD

```
./bin/mg5_aMC
> generate p p > t t~ W+ W- [QCD]
> output ttw
> launch
```



Ariadne

One old parton shower program and several others

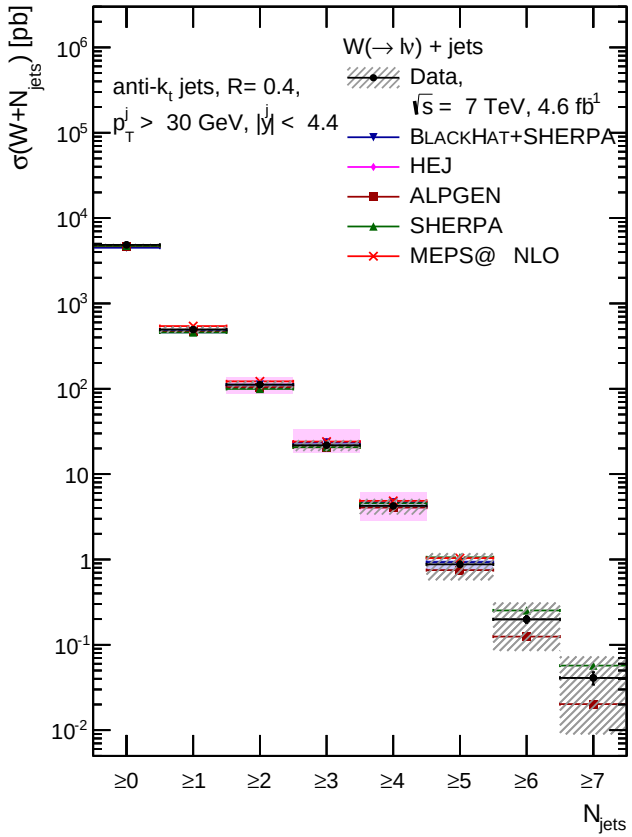
Network nodes: Lund, Durham, (DESY)

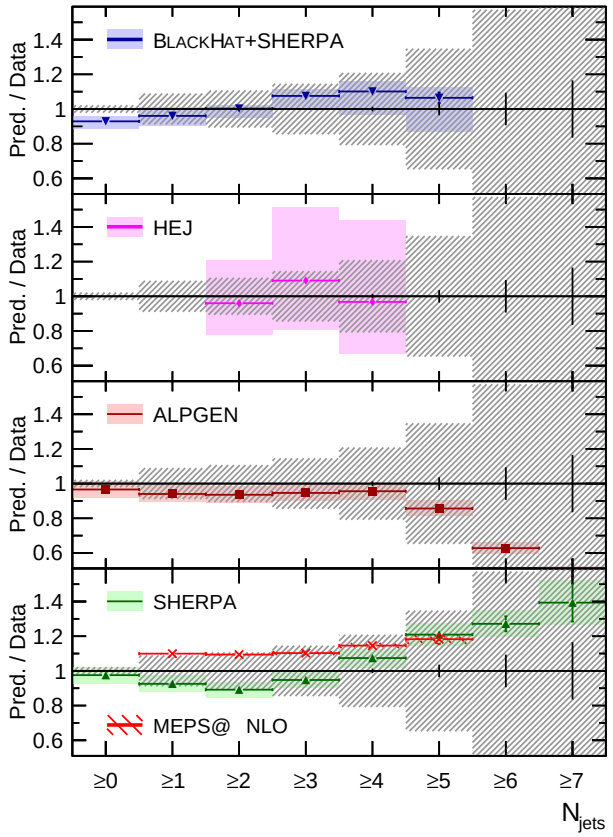
Main emphasis: Alternative parton shower and resummation strategies

New developments: The HEJ resummed matrix element generator, the DIPSY generator for proton and heavy ion collisions.

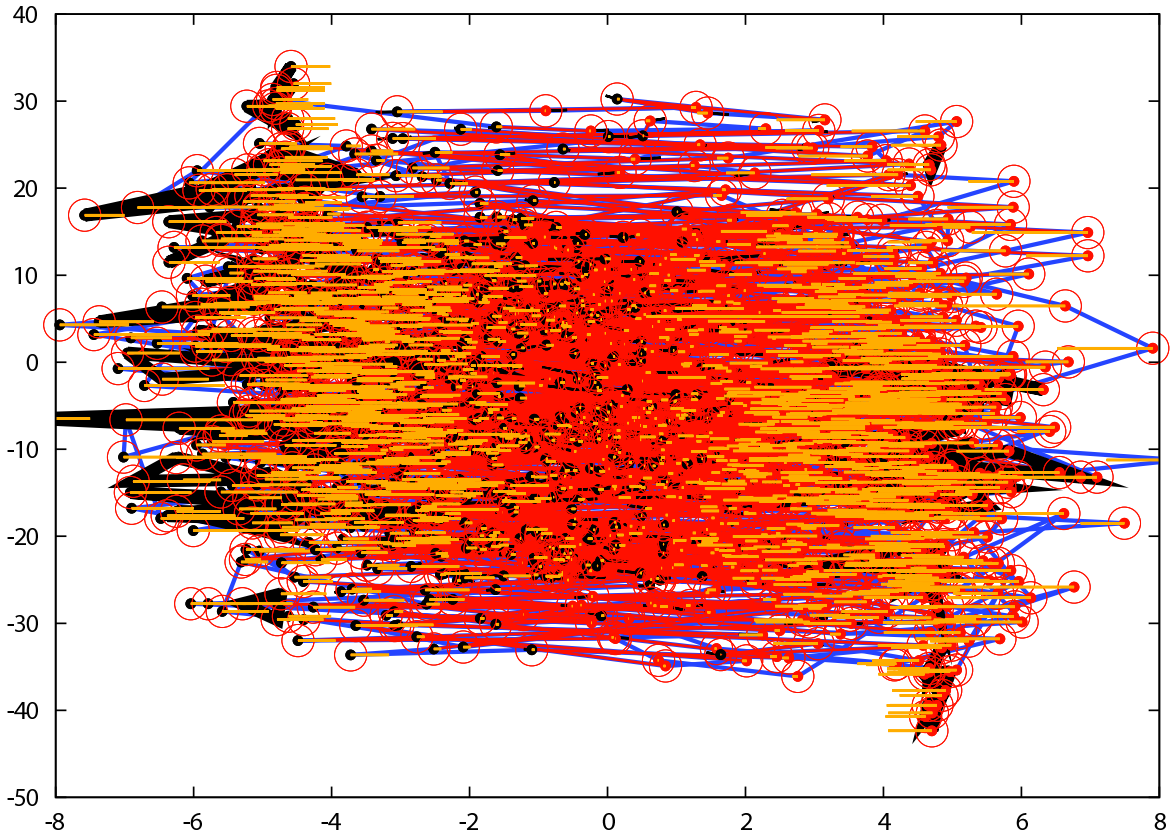
HEJ — High Energy Jets

Includes resummation in matrix element generation





DIPSY for heavy ion collisions



CEDAR

Our connection to the experiments

Network nodes: UCL, CERN, Durham,

Main emphasis: Comparing generators with data

New developments: RIVET updated

RIVET

- "Robust Independent Validation of Experiment & Theory"
- Fully generator independent
- Demand minimal model-dependence in measurements which must be corrected for detector effects
- Widely used in generator tuning and validation in MCnet and beyond
- A new way of publishing experimental results

Outlook

We are well under way to achieve our scientific goals.

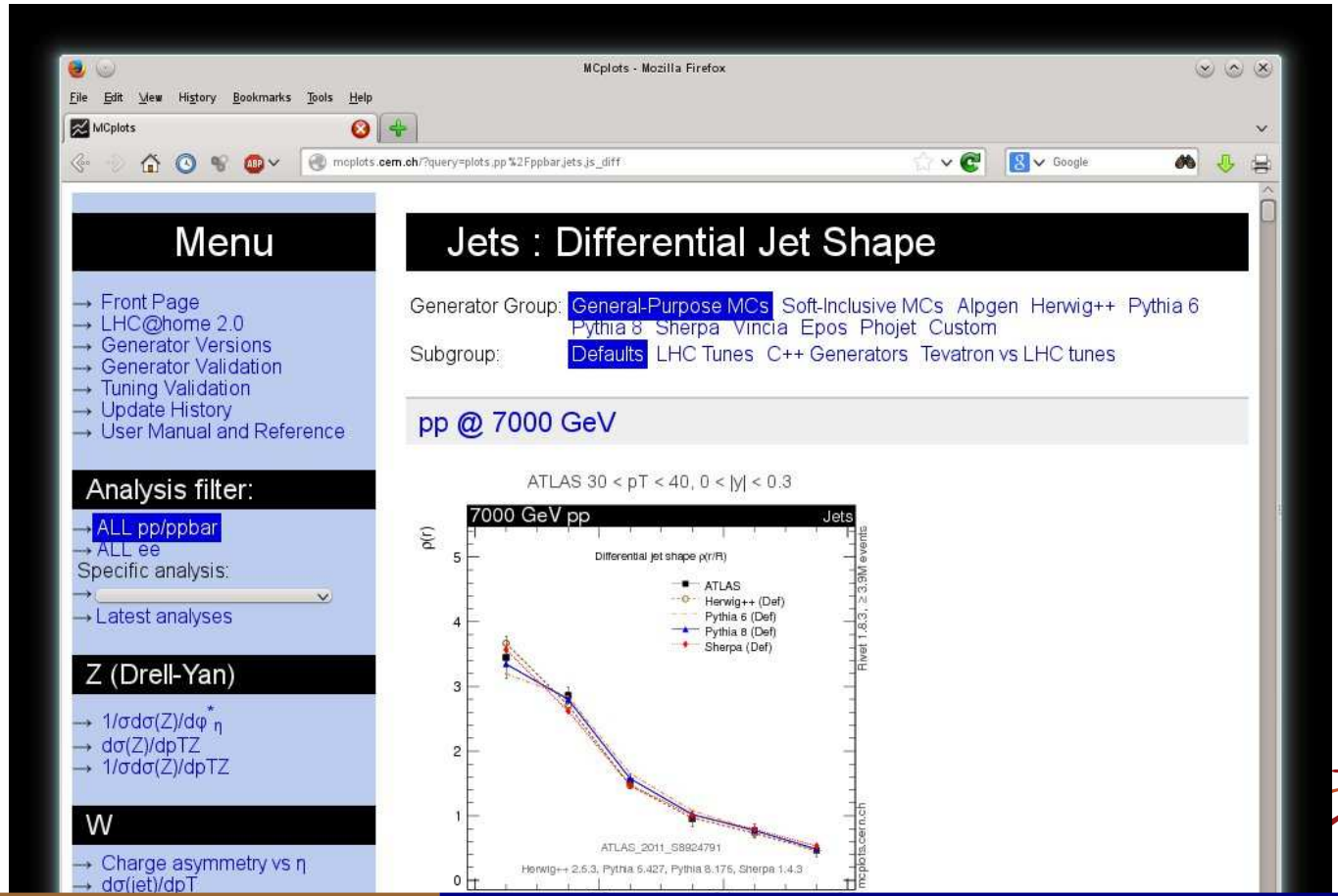
Last year we published 27 articles attracting over 300 citation.

This year we have published 26 so far and have almost 200 citations already

LHC restart next year will bring new challenges
(and maybe new physics!)

mcplots.cern.ch

One of our deliverables is to make a web-based 'Living review' of Monte Carlo physics and event generator results.




MCnet