Underlying Event & Soft Inclusive Physics
Part II
Andrzej Siódmok
CERN, Theory Division & IFJ, Cracow

Monte Carlo School NCC/ICTP-SAIFR School and Workshop,
São Paulo, 30th April 2015
The first lecture:

- Definition and Motivation
- Example of MPI model - MPI in Herwig++
- Colour structure of an event
- Summary

Today's lecture:

- Short reminder
- Tuning tools - Professor
- Overview of MPI models and comparison with some LHC data
- CDF Min Bias “factorization” mystery
- Outlook
- MCnet studentship and MCnet School
Underlying event in Herwig++ - key components

**Matter distribution ($\mu^2$)**

![Graph showing matter distribution with $\mu^2 = 2$ GeV$^2$ and $\mu^2 = 0.71$ GeV$^2$.]

**Extension to soft MPI ($p_t < p_{t\text{min}}$)**

![Graph showing extension to soft MPI with momentum transfer $p_t$.]

**Colour structure ($p_{\text{reco}}, p_{CD}$)**

![Diagram illustrating colour structure with $p_{\text{reco}}$ and $p_{CD}$.]

**Main parameters:**

- $\mu^2$ - inverse hadron radius squared (parametrization of overlap function)
- $p_{t\text{min}}$ - transition scale between soft and hard components \(\Rightarrow p_{t\text{min}} = p_{t,0} \left(\frac{\sqrt{s}}{E_0}\right)^b\)
- $p_{\text{reco}}$ - colour reconnection
- $p_{CD}$ - colour structure of the Soft UE
MC models have parameters such as pT cutoff, energy evolution, colour-reconnection... + many parameters of hadronization models

Tuning (fixing) of soft QCD parameters required to constrain models in order to

- understanding/exploring the physics of soft QCD
- data mimicking for best experimental unfolding

Lots of correlated parameters, 200k-10M events per run (kin. binning): tuning is non-trivial. Brute-force grid-scans: tough in higher dimensions of parameter space (limited data sets and model’s parameters)

No unique way of tuning: which data samples should be used? divide and conquer (split parameters in subgroups which can be tune separately) ...

“manual” tuning - hard and inefficient - lots of time and man and CPU power needed.

new tools help to automatize this process -> however still you need to think it is not “Fire-and-forget”
Rivet and Professor

- Sherpa
- Herwig++
- Pythia8

Beam parameters
Number of events to generate
Generator specific parameters

AGILe

Rivet

Analyses:
- Hadron multiplicities
- Event shape variables
- Z-Boson $p_T$ distribution

Histograms

Professor
random parameter sampling
perform tuning
Rivet and Professor

**Tuning procedure in Professor (1D, 1Bin)**

1. Random sampling: $N$ parameter points in $n$-dimensional space
2. Run generator and fill histograms
3. For each bin: use $N$ points to fit interpolation (2nd or 3rd order polynomial)
4. Construct overall (now trivial) \[ \chi^2 \approx \sum_{\text{bins}} \frac{(\text{interpolation} - \text{data})^2}{\text{error}^2} \]
5. and Numerically *minimize* pyMinuit, SciPy

![Diagram showing random sampling and interpolation](image)
Rivet and Professor
Rivet and Professor

Observables and Weights

- This is what Professor minimises: $\chi^2(\vec{p}) = \sum_\mathcal{O} \sum_b \in \mathcal{O} w_b \frac{(f^{(b)}(\vec{p}) - R_b)^2}{\Delta_b^2}$
- Slightly more art than science
- Garbage in, garbage out
- Use weights $w_b$ to:
  - emphasize certain observables
  - emphasize certain bins of an observable
  - switch off single bins (e.g. MinBias region for Jimmy Herwig)

- No MinBias physics in Jimmy Herwig
- Cannot get first 3 bins or so right
- Transition from MinBias to UE type physics
- $\Rightarrow$ Exclude these bins from Professor minimisation
Rivet and Professor

prof-I

Usage: prof-I --datadir .
Rivet and Professor

**PROF-I**

**Usage:** prof-I --datadir .
Semi hard underlying event

Taken from Peter Skands:

QCD ANALOGUE:
Parton Showers: resum divergent perturbative emission cross sections
MPI: resum divergent perturbative interaction cross sections

MINIMUM BIAS

PERIPHERAL
\(<\text{MPI}\> = 1\)

CENTRAL
\(<\text{MPI}\> = 3\)

\(\text{pt} \geq \text{1}\)

\(<\text{MPI}\> = 6 / 4 = 1.5\)

\[
f_a(m_{\text{cut}}) \equiv \frac{N_a(m_{\text{cut}})}{\sum_{b=h,i,n} N_b(m_{\text{cut}})} = \frac{N_a(m_{\text{cut}})}{N_{\text{cl}}}, \tag{1}
\]

Since these n-clusters can lie at very different rapidities (the extreme case being the two opposite beam remnants), the strings or clusters spanned between them can have very large invariant masses (though normally low $p_T$), and give rise to large amounts of (soft) particle production.
Since these \textit{n}-clusters can lie at very different rapidities (the extreme case being the two opposite beam remnants), the strings or clusters spanned between them can have very large invariant masses (though normally low \(p_T\)), and give rise to large amounts of (soft) particle production.
MPI models overview and comparison with data

See e.g. Reviews by MCnet [arXiv:1101.2599] and KMR [arXiv:1102.2844]

A. Regge Theory

Optical Theorem
+ Eikonal multi-Pomeron exchanges

\[ \sigma_{\text{tot,inel}} \propto \log^2(s) \]
Froissart-Martin Bound

Cut Pomeron \rightarrow Flux Tubes (strings)
Uncut Pomeron \rightarrow Elastic (& eikonalization)
Cuts unify treatment of all soft processes
EL, SD, DD, ... , ND

(Perturbative contributions added above Q_0)

E.g., QGSJET, SIBYLL

B. Parton Based

\[ d\sigma_{2\rightarrow 2} \propto \frac{dp_{\perp}^2}{p_{\perp}^4} \]
⊗ PDFs

+ Unitarity & Saturation

→ Multi-parton interactions (MPI)
+ Parton Showers & Hadronization
Regulate do at low p_{T0} \sim few GeV
Screening/Saturation → energy-dependent p_{T0}

Total cross sections from Regge Theory
(e.g., Donnachie-Landshoff + Parametrizations)

E.g., PHOJET, EPOS, SHERPA-KMR

E.g., PYTHIA,
HERWIG, SHERPA

Only EPOS, Herwig++, Pythia (see Leif’s talk for details) and Sherpa used at the LHC.
Quite different model to Pythia/Herwig, for example no color reconnection but collective hadronization instead.
Quite different model to Pythia/Herwig, for example no color reconnection but collective hadronization instead.
Many LHC UE observables (not tuned since not available) and well described ...
Many LHC UE observables (not tuned since not available) and well described ...
Problems - very soft MinBias ATLAS

Need of the colour reconnection.
Problems - very soft MinBias ATLAS

Need of the colour reconnection. MB 7000 TeV, problem at low $p_T$, high Nch.

Epos seems to describe MB data but fails to describe UE data.
Problems - very soft MinBias ATLAS

Need of the colour reconnection. MB 7000 TeV, problem at low \( p_T \), high Nch. Epos seems to describe MB data but fails to describe UE data.
Problems - Identified particles

More plots: mcplots.cern.ch (and mcplots-dev.cern.ch less stable but more recent results)
Summary:

- Motivation and experimental evidence for MPI
- Underlying event model (MPI) is an integral part of MC event generators!
- Non perturbative regime -> need for models with several parameters, no unique way -> few models on the market
- Parameters constrained using data - new LHC results lead to new developments in MB/UE simulation. Good tunes available by now.
- Minimum bias/underlying event/diffraction under constant improvement (DIPSY, new MPI model Shrimps in Sherpa, improvements in Pythia and Herwig, Epos for LHC)!
- Good first round of LHC data well described...
- ... but still a lot space for improvements.
- Not-too-soft not-too-high-multiplicity physics under good control (if you use modern models with modern tunes).
- “It doesn’t matter how beautiful your theory/model is, it doesn’t matter how smart you are. If it doesn’t agree with experiment, it’s wrong“ Richard P. Feynman
Summary:

- Motivation and experimental evidence for MPI
- Underlying event model (MPI) is an integral part of MC event generators!
- Non perturbative regime -> need for models with several parameters, no unique way -> few models on the market
- Parameters constrained using data - new LHC results lead to new developments in MB/UE simulation. Good tunes available by now.
- Minimum bias/underlying event/diffraction under constant improvement (DIPSY, new MPI model Shrimps in Sherpa, improvements in Pythia and Herwig, Epos for LHC)!
- Good first round of LHC data well described...
- ... but still a lot space for improvements.
- Not-too-soft not-too-high-multiplicity physics under good control (if you use modern models with modern tunes).
- “It doesn’t matter how beautiful your theory/model is, it doesn’t matter how smart you are. If it doesn’t agree with experiment, it’s wrong” Richard P. Feynman (ok sometimes experiment is wrong ;))
- As LHC needs to study more rare phenomena and more subtle effects, generators must keep up by increased precision.
MCnet Short-term studentships

Monte Carlo training studentships

MCnet projects
- Pythia
- Herwig
- Sherpa
- MadGraph
- Ariadne
- CEDAR

3-6 month fully funded studentships for current PhD students at one of the MCnet nodes. An excellent opportunity to really understand and improve the Monte Carlos you use!

Application rounds every 3 months.

for details go to: www.montecarlonet.org
2015 MCnet Summer School
on Monte Carlo Event Generators for the Large Hadron Collider

The Ninth MCnet Annual School of Event Generator Physics and Techniques

Website:
www.monte-carlonet.org/lowyain2015

30 Aug - 4 Sep, Spa, Belgium

Main Lectures:
- Introduction to event generators
- NLO computations in QCD
- Model independent measurements
- From BSM simulations to recasting

Special topics:
- Analytic resummation and the link with MCs
- Proton beams for medical applications
- Dark Matter simulations
- The magic of color

Sponsors:
Thank you for the attention!