MPI modelling in MC event generators

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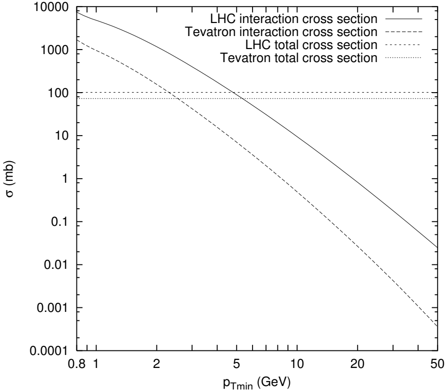
Introduction



$$\sigma_{\mathrm{h}}(p_{\perp,\mathrm{min}}) = \int_{p^2_{\perp,\mathrm{min}}}^{s/4} \mathrm{d}p_\perp^2 \frac{\mathrm{d}\sigma}{\mathrm{d}p_\perp^2}$$

- $\sigma_{\mathrm{h}}(p_\perp) > \sigma_{\mathrm{ND}}$ for perturbatively large $p_\perp$

$\rightarrow$ multiple parton-parton scattering

Double hard scattering and the underlying event

Terminology

UE: additional QCD activity in events containing a hard (signal) process

experimental observation

MPI: multiple partonic scattering in hadronic interaction

interpretation of UE

DPS: double hard parton scattering

characterised by σ_{eff}

Modelling in MC event generators

- UE modelled by MPI
- assume indepentent partonic scatterings $\rightarrow$ Poisson distribution
- DPS: hard tail of MPI

Model without impact parameter dependence

- partonic scatterings ordered in $p_\perp$
- generate sequence in $p_\perp^2$ to form factor

$$\Delta(p_{\perp,\mathrm{prev}}, p_\perp) = \exp\left\{-\frac{1}{\sigma_{\mathrm{ND}}}\int_{p_\perp}^{p_{\perp,\mathrm{prev}}} \mathrm{d}p'_\perp \frac{\mathrm{d}\sigma}{\mathrm{d}p'_\perp}\right\}$$

- smooth IR-regularisation of cross section
- ensure energy-momentum conservation in each step

$\rightarrow$ $\langle n(p_{\perp,\mathrm{min}})\rangle < \dfrac{\sigma_{\mathrm{h}}(p_{\perp,\mathrm{min}})}{\sigma_{\mathrm{ND}}}$

- additional partonic scatters: $2 \rightarrow 2$ QCD processes
- allow for parton showering
  - PYTHIA: interleaved showering
  - SHERPA: showering in CKKW framework to allow for merging

Adding impact parameter dependence

- matter overlap:
  $\mathcal{O}(b) = \int \mathrm{d}t\mathrm{d}^3x\, \rho(x, y, z)\rho(x + b, y, z + t)$
- form of ρ: guess (e.g. double Gaussian)
- form factor becomes

$$\Delta(p_{\perp,\mathrm{prev}}, p_\perp; b) = \exp\left\{ -\frac{\mathcal{O}(b)}{\langle\mathcal{O}\rangle} \frac{1}{\sigma_{\mathrm{ND}}} \int_{p_\perp}^{p_{\perp,\mathrm{prev}}} \mathrm{d}p'_\perp \frac{\mathrm{d}\sigma}{\mathrm{d}p'_\perp} \right\}$$

- for first scattering choose $p_\perp$ and b simultaneously
- for subsequent scatterings keep b fixed
- hard first interaction favours small $b \to$ more MPI

Interleaved showering

- intial state radiation (of signal process and MPI) and additional scattering compete for phase space

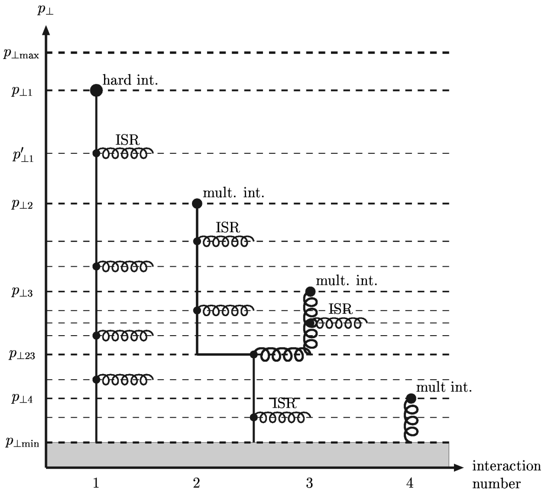
$\rightarrow$ order matters

- can define $p_\perp$ to be similar in MPI and ISR
- order ISR and MPI in one sequence

$$\Delta(p_{\perp,\text{prev}}, p_\perp) = \exp\left\{ -\int_{p_\perp}^{p_{\perp,\text{prev}}} \mathrm{d}p'_\perp \left[\frac{\mathrm{d}\mathcal{P}_{\text{MPI}}}{\mathrm{d}p'_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\text{ISR}}}{\mathrm{d}p'_\perp} \right] \right\}$$

- events NOT incoherent sum of signal process and MPI

Interleaved showering



PDF's for MPI

PYTHIA

- in each step in interleaved evolution PDF's are rescaled

$$f(x) \to \frac{1}{1-\sum_i x_i} f\left(\frac{x}{1-\sum_i x_i}\right)$$

- when valence quark was scattered its contribution is subtracted
- when sea quark was scattered its 'companion quark' is added explicitely

$$q_c(x; x_s) \propto \int_0^1 \mathrm{d}z\, g(y) P_{qg}(z) \delta(x_s - zy)$$

- gluon and sea contribution are rescaled such that momentum sum rule is satisfied

PDF's for MPI

SHERPA

- no interleaved evolution: scattering generated and showered one after the other
- vetoed shower in CKKW framework
- after each scattering PDF's are rescaled

$$f(x) \to \frac{1}{1-\sum_i x_i} f\left(\frac{x}{1-\sum_i x_i}\right)$$

The JIMMY model

- eikonal model

$$\sigma_{\text{inel}}(s) = \int d^2\mathbf{b}\left[1 - e^{-2\chi(\mathbf{b},s)}\right]$$

- assuming factorisation of b and x dependence

$$\chi_{\text{QCD}}(\mathbf{b},s) = \frac{1}{2}A(\mathbf{b})\sigma_{\text{hard}}(s) \quad A(\mathbf{b}) = \int d^2\mathbf{b}' G(\mathbf{b}')G(\mathbf{b}-\mathbf{b}')$$

- matter distribution related to electromagnetic form factor

$$G(\mathbf{b}) = \int \frac{d^2\mathbf{k}}{(2\pi)^2}\frac{e^{i\mathbf{k}\cdot\mathbf{b}}}{(1+\mathbf{k}^2/\mu^2)}$$

- compute number of MPI from Poisson statistics
- MPI scatterings unordered
- phase space for MPI not restricted by previous processes
- regenerate scatterings violating energy conservation

The HERWIG++ model

- extension of JIMMY
- allows for soft MPI

$$\begin{aligned}\chi_{\text{tot}} &= \chi_{\text{QCD}}(\mathbf{b}, s) + \chi_{\text{soft}}(\mathbf{b}, s) \\ &= \frac{1}{2}\left[A(\mathbf{b})\sigma_{\text{hard}}(s) + A_{\text{soft}}(\mathbf{b})\sigma_{\text{soft}}(s)\right]\end{aligned}$$

- $A_{\text{soft}}(\mathbf{b})$ can have μ^2 different from hard component
- hard partons concentrated more towards centre of proton (hot-spot model)
- σ_{soft} determined from total cross section + elastic slope
- $p_\perp$ dependence: Gaussian

PDF's for MPI

- ISR evolution of signal process forced to end on valence quark
- remaining valence quarks form remnant
- MPI showering forced to end with gluon
- MPI matrix elements use unmodified PDF's
- for MPI shower evolution PDF's are rescaled and
- valence contribution is subtracted

Things I do not have time to discuss

Necessary ingedients to MPI MC's

- colour assignement for MPI
- primordial $k_\perp$
- beam remnant treatment (energy, colour, flavour)
- tuning

Colour reconnections

- non-perturbative re-arrangement of colour in final state
- not required for construction of models
- needed to describe data

Concluding remarks

- MPI is beyond factorisation theorems

$\rightarrow$ need to rely on phenomenological models

- models need to be tuned to data and
- are difficult to falsify
- estimate uncertainties by tune variations
- PYTHIA and HERWIG MPI models rather similar
- DPS sensitive to regime where modelling uncertainties are largest
- SHRiMPS: conceptually new minimum bias model in SHERPA will become new UE model
- might or might not yield new insight into MPI
- perhaps progress for DPS possible with double-parton-PDF's

References

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