Simulating minimum bias (Soft scattering) with PYTHIA & PHOJET

Overview

Inspired by the paper:
"Prediction for minimum bias and the underlying event at LHC energies"
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- **Soft scattering**
- **How PYTHIA deals with soft scattering**
- **How PHOJET deals with soft scattering**
- **Comparing PHOJET and PYTHIA**
- **Summary**

Soft scattering

Soft scattering is interaction with small momentum exchange.

Here it is bound to the transverse momentum exchange.

One talks of soft scattering for $\mathbf{p_t < 2GeV}$.

The interaction cross-section above any chosen p_{tmin}, given by perturbative QCD, is written as:

$$\sigma_{int}(p_{t_{min}}) = \int_{p_{t_{min}}^2}^{s/4} \frac{d\sigma}{dp_t'^2} dp_t'^2$$

Soft scattering

In the p_t-region of soft scattering perturbative QCD has **two serious problems:**

1) at $\mathbf{p_t}$ **~ 2GeV** the interaction cross-section exceeds the total cross-section.

2) for $\mathbf{p_t} \rightarrow \mathbf{0}$ the differential cross-section diverges like $dp_t^{\,2} / p_t^{\,4}$

$$\sigma_{\text{int}}(p_{t_{min}}) = \int_{p_{t_{min}}^2}^{s/4} \frac{d\sigma}{dp_t'^2} dp_t'^2$$

How PYTHIA deals with soft scattering

The first problem (p_t ~ 2GeV) is solved in **PYTHIA** by using the concept of **multiple parton interactions**:

At high-energy, each incoming hadron is viewed as a partonic beam.

So there is a possibility of having several parton – parton interactions when the hadrons collides.

Those events with $\sigma_{\text{int}}(p_{t_{min}}) > \sigma_{\text{tot}}$ are interpreted as having **N** parton – parton interaction.

$$N = \frac{\sigma_{\text{int}}(p_{t_{min}})}{\sigma_{nd}}$$

σ_{nd} = non-diffractive inelastic interac. cross-section.

How PYTHIA deals with soft scattering

The second problem ($p_t \rightarrow 0$) is handled by using the **Lund model**.

There are two different scenarios, one called “**simple**” and the “**complex**” scenario.

It uses a cut-off parameter $\mathbf{p_{tmin}(s)}$.

$$p_{t_{min}}(s) = (1.9\,\mathrm{GeV}) \left(\frac{s}{1\,TeV^2} \right)^{0.08}$$

The complex scenario:

The divergences at $p_t \rightarrow 0$ are corrected by multiplying the matrix elements by a factor $p_t^4/(p_t^2+p_{t_{min}}^2)^2$.

and replacing p_t^2 *by* $(p_t^2+p_{t_{min}}^2)$ in α_s.

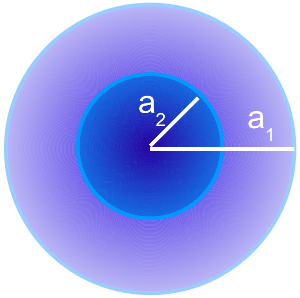
In this scenario, the impact parameter **b** and the probability of multiple interaction is correlated to the chosen matter distribution of the Hadron.

One can chose between three matter distributions:

- Poissonian distribution
- Gaussian distribution
- Double Gaussian distribution

Double Gaussian matter distribution:

$$\rho(r) \propto \frac{1-\beta}{a_1^3} \exp\left[\frac{-r^2}{a_1^2}\right] + \frac{\beta}{a_2^3} \exp\left[\frac{-r^2}{a_2^2}\right]$$



Hadrons described by this distribution have a small **core region** of **radius a_2**, containing a **fraction β** of the total hadronic matter.

This core is embedded in a **larger volume** of **radius a_1** containing the remaining fraction of matter.

One can control β and the ratio a_2/a_1, to tune PYTHIA.

Switches for the scenarios:

MSTP(82) = 1	simple scenario –	multiple scattering, hard cut-off at ptmin.
MSTP(82) = 2	complex scenario –	Poissonian distribution
MSTP(82) = 3	complex scenario –	Gaussian distribution
MSTP(82) = 4	complex scenario –	double Gaussian Distribution.

PARP(83) – controls β
PARP(84) – controls the ratio a_1/a_2

How PHOJET deals with soft scattering

PHOJET has a different concept. It is a **two-component** MC event generator.

Like PYTHIA it uses perturbative QCD for hard interactions.

PHOJET also uses multiple scattering in the region
$\mathbf{p_t \sim 2GeV}$

For the region $\mathbf{p_t \leq 2GeV}$ it switches to the
Dual **P**arton **M**odel (**DPM**) to generate soft scattering events.

There are almost no parameters for tuning.

How PHOJET deals with soft scattering

Dual **P**arton **M**odel (**DPM**):

DPM provides a complete phenomenological description of soft scattering processes in high-energy hadron collisions.

DPM combines non-perturbative topological expansions of QCD with generally accepted theoretical principles like

- duality,
- unitarity,
- Regge behavior
- parton structure of hadrons.

In DPM the main part for softs scattering processes is given by the mechanism of **Pomeron exchange**.

PYTHIA vs. PHOJET

PHYTIA has a more sophisticated model to describe soft scattering.
The model gives many options for tuning but it is more parameter fitting then a theoretical model

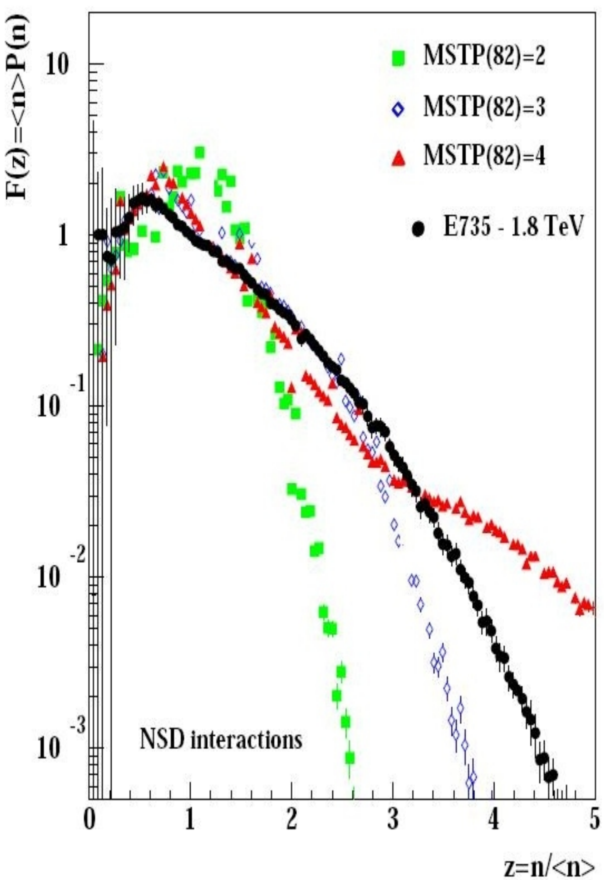
PHOJET uses the DPM which combines several theoretical accepted principles to describe soft scattering.
It has real tuning parameters.

Both generators are able to reproduce the minimum bias data taken by the CDF at Tevatron.

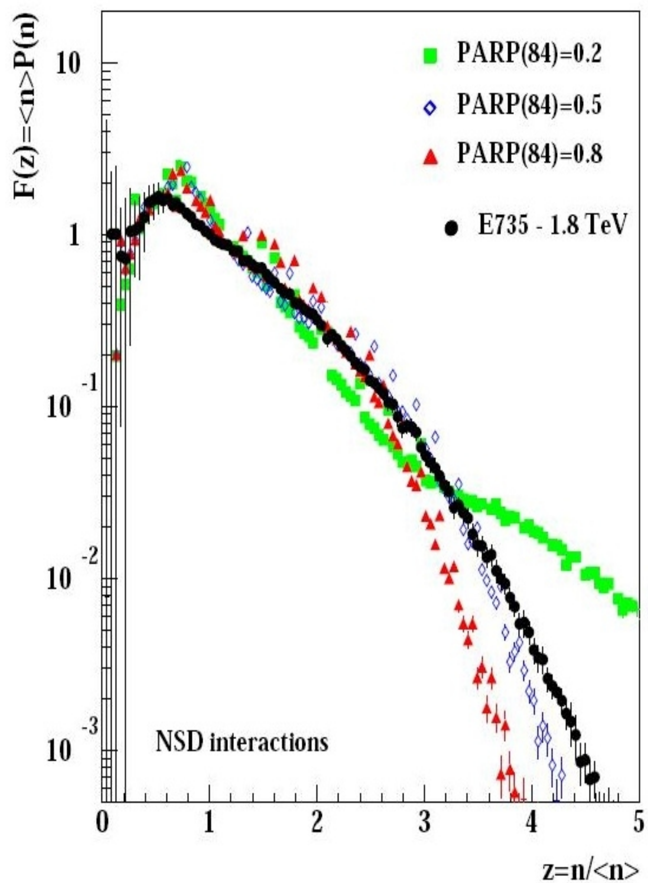
PYTHIA vs. PHOJET

Charged multiplicity distributions:

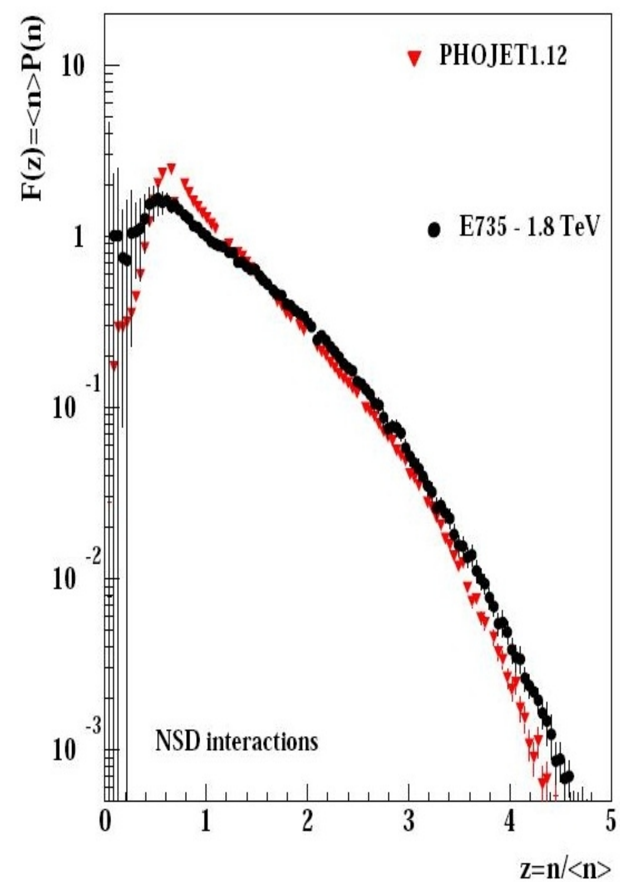
Var. mod complex scenario



Var. matter density in d. Gaus.



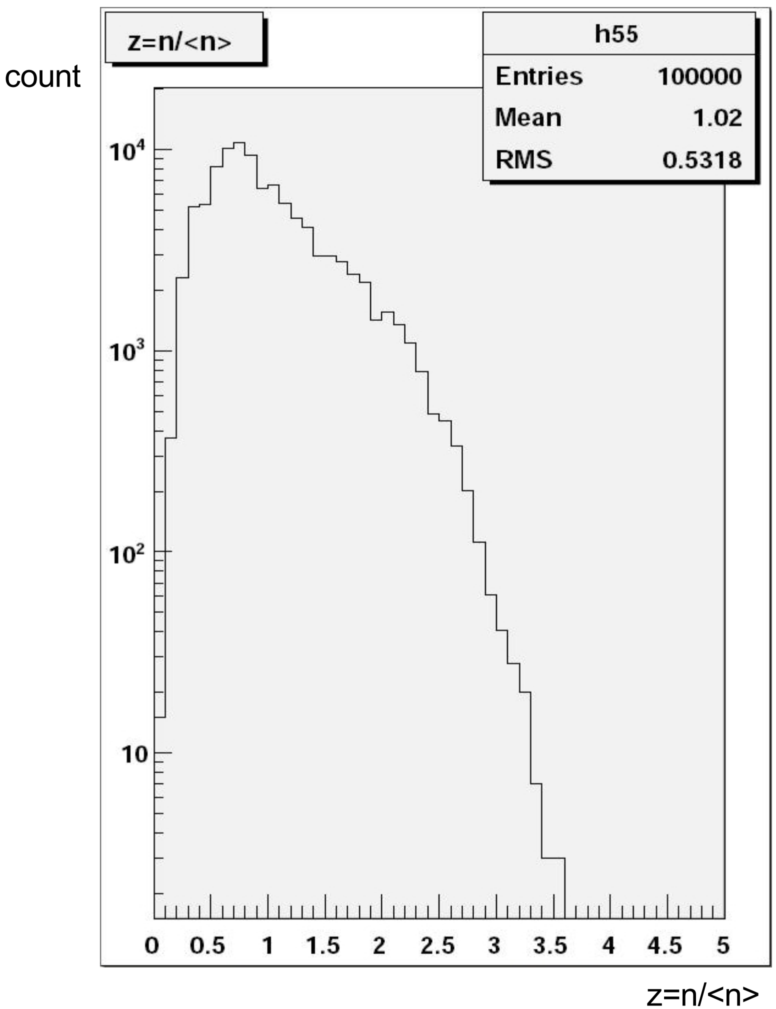
PHOJET



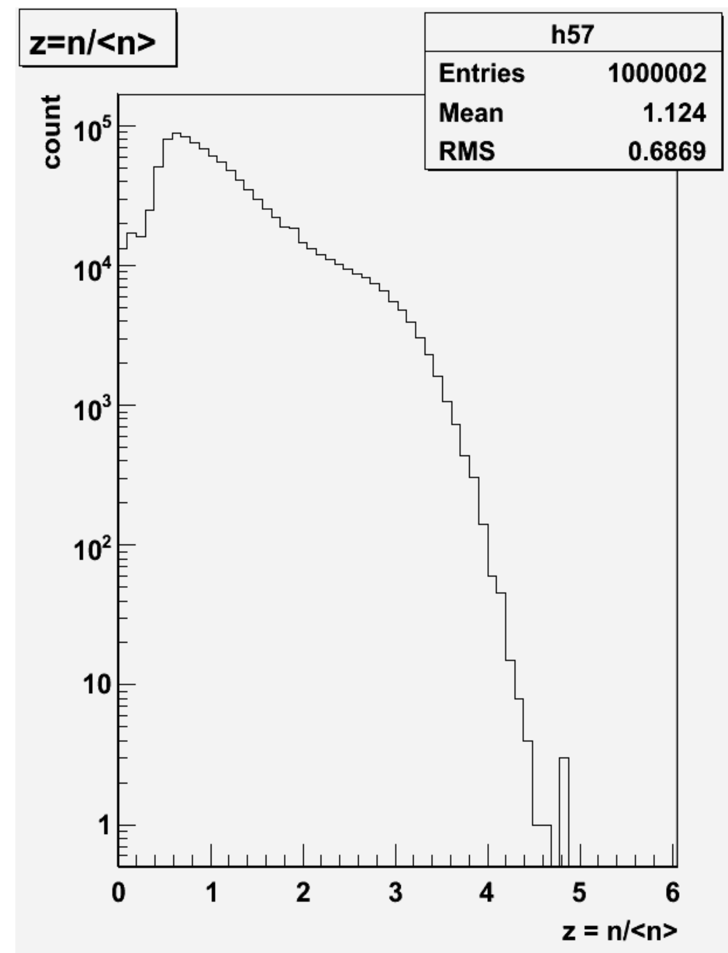
PYTHIA vs. PHOJET

My graphs at 14TeV:

PYTHIA charged particle multiplicity



PHOJET charged particle multiplicity



Summary

PHYTHIA is able to reproduce the data from the CDF-Detector, but a tuning is necessary.

PHOJET reproduces the data a little better and needs no tuning.

For prediction at **LHC-energy** both deliver different data.
It seems that PYTHIA needs a new tuning with the first real data.

PHOJET is not implemented in **ATHENA** for the time being**.**
For minimum bias event generation PHOJET is interesting, so I will work on the implementation.

THANK YOU!

The simple scenario:

It uses multiple scattering and a sharp cut-off at p_{tmin}.

That means: $$\frac{d\sigma}{dp_t^2}=0 \; for \; p_t < p_{t_{min}}$$

This is equivalent to a maximum impact parameter b_{max}, above which there is no interaction.

This may also be interpreted as a consequence of the parton confinement.

How PHOJET deals with soft scattering

Multiple scattering is also introduced in PHOJET

Both cross-sections, for soft- and hard-scattering (σ_s and σ_h) increases with the center-of-mass energy as a power of s.

The total cross-section σ_{tot} increases like (ln s)2.

$s \rightarrow \infty$: $\sigma_s, \sigma_h > \sigma_{tot}$ ==> Multiple scattering

So for high energy the soft- and hard-cross-sections would exceed the total cross-section.
To solve this problem, PHOJET uses multiple parton scattering.