The Underlying Event from Tevatron to LHC

P. Skands (CERN)

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Minimum-Bias

Study fragmentation: Compare to ee!

Study hadron collisions: Scaling, Soft-QCD, High Multiplicity, Diffraction, ...

No hard scale → all observables depend significantly on IR physics
10-20% precision is very good
**Minimum-Bias**

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- Compare to ee!

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- Soft-QCD
- High Multiplicity
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- ...

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**Underlying Event**

**Pedestal effect** → larger than min-bias

**Multiple parton interactions** → multiple (mini)jets

**Large fluctuations**

Hard scale present, but look at observables that don’t (explicitly) involve it

10-20% precision is very good
The Pedestal Effect
and Multiple Parton-Parton Interactions
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MINIMUM BIAS

\[ \sigma_{\text{parton-parton}} > \sigma_{\text{hadron-hadron}} \]

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PERIPHERAL
\[ \langle \text{MPI} \rangle = 1 \]

CENTRAL
\[ \langle \text{MPI} \rangle = 3 \]

\[ \langle \text{MPI} \rangle = 6 / 4 = 1.5 \]
Statistically biases the selection towards more central events with more MPI.

The assumed shape of the proton affects the rise and $\langle UE \rangle / \langle MB \rangle$.

$\langle MPI \rangle = 4 / 2 = 2$
The Pedestal Effect
and Multiple Parton-Parton Interactions

Can we tell the difference?

Statistically biases the selection towards more central events with more MPI

The assumed shape of the proton affects the rise and $\frac{<\text{UE}>}{<\text{MB}>}$

$\text{JET} > 5 \text{ GeV}$

$\text{CENTRAL}$ $<\text{MPI}> = 3$

$\text{PERIPHERAL}$ $<\text{MPI}> = 1$

$\frac{<\text{MPI}>}{2} = 2$
Dissecting the Pedestal

Statistically biases the selection towards more central events with more MPI

The assumed shape of the proton affects the rise and \( \langle \text{UE} \rangle / \langle \text{MB} \rangle \)

\[ \langle \text{MPI} \rangle = \frac{4}{2} = 2 \]
Possible to do at Tevatron?

Transverse Region Variances

S.D. lower than mean, but more than square root of mean.

Suggests tracks not independently produced (not Poisson distribution).

S.D. provides a additional constraint on generator tunes
Possible to do at Tevatron?

**Transverse Region Variances**

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Suggests tracks not independently produced.

**Analyzing the Pedestal?**

Initial rise & $<\text{UE}>/\langle\text{MB}\rangle$ → “average” proton shape

Focus on specific x range (pick jet $p_T$ and y, for given collider energy)

Scan over transverse activity → b dependence for that x

And/or look for abundance of minijets in transverse region
A New Look?
A New Look?

Hard Jets

Soft Jets, Jet Shapes, Sum(\(p_T\))

Tracks

Matrix Elements

Parton Showers MPI

Remnants Hadronization

\[ Q >\Lambda_{QCD} \]
\[ Q/Q_{\text{hard}} \sim 1 \]

\[ Q >\Lambda_{QCD} \]
\[ Q/Q_{\text{hard}} << 1 \]

\[ Q \sim \Lambda_{QCD} \]

Factorization Scale

P. Skands
A New Look?

MINIMUM BIAS

Hard Jets

Soft Jets, Jet Shapes, Sum(pT)

Tracks

Factorization Scale

Matrix Elements

Parton Showers

MPI

Remnants Hadronization

Q ~ Λ_{QCD}
MPI models rooted in pQCD
→ Suggest can still take AN ORGANIZED VIEW
Order observables according to IR sensitivity
An Organized View

1. Where is the energy going?

*Sum*(p_T) densities, event shapes, mini-jet rates, energy flow correlations… \( \approx \) sensitive to pQCD + pMPI

2. How many tracks is it divided onto?

\( N_{\text{tracks}}, \frac{dN_{\text{tracks}}}{dp_T}, \text{Associated track densities, track correlations} \ldots \approx \text{sensitive to hadronization + soft MPI} \)

3. What kind of tracks?

Strangeness per track, baryons per track, beam baryon asymmetry, … s-baryons per s, multi-s states, s-sbar correlations, … \( \approx \) sensitive to details of hadronization
Can we be more general than this-tune-does-this, that-tune-does-that?

Yes

The new automated tuning tools can be used to generate unbiased optimizations for different observable regions

Same parameters $\rightarrow$ consistent model (not just “best tune”)

Critical for this task (take home message):

Need “comparable” observable sets for each region

Example: use different collider energies as our “regions” $\rightarrow$ test energy scaling
Other complementary data sets could be used to test other model aspects
Used CDF, UA5, and ATLAS data

\[ P(N_{\text{ch}}), \frac{dN_{\text{ch}}}{dp_T}, <p_T>(N_{\text{ch}}) \]

+ for ATLAS: can even focus on \( N_{\text{ch}} \geq 6 \) separately! Possible to do at Tevatron too?

From 630 GeV to 7 TeV

(Unfortunately, did not have a complete obs set from STAR at 200 GeV)

Reduce model to 3 main parameters:

1. Infrared Regularization Scale
2. Proton Transverse Mass Distributions
3. Strength of Color Reconnections

Use Professor to do independent optimizations at each energy

Starting point = Perugia 0

\( p_T^{\text{min}} \) \( \mu \) \( \text{CR} \)
Infrared Regularization Scale

Model: \[ p_{\perp 0}^2(s) = p_{\perp 0}^2(s_{\text{ref}}) \left( \frac{s}{s_{\text{ref}}} \right)^{P_{90}} \] (power law)

No large deviation from the assumed functional form

(E.g., Tunes A, DW, Perugia-0 use \( \text{Exp} = \text{PARP}(90) = 0.25 \))

FIG. 8. Values for the cutoff parameter \( p_{T0} \) as a function of c.m. energy, as determined from comparisons with the average charged multiplicity. Dashed line, with a logarithmic extrapolation to higher energies, Eq. (138); dotted line, if assumed constant above 900 GeV.
A further important aspect of the model is the density, or shape, of the infrared regularization scale above as determining the average number of parton shower emissions. In the model we consider here, a smooth parameter for all models of this type, with low values yielding more soft MPI activity in the limit that the normalization of this distribution is fixed to unity. Note also that the remaining divergence, again similarly to how the nonperturbative cutoff in parton showers ultimately regulates the number of parton shower emissions.

The fact that long-wavelength gluons only see a coherent sum of strong coupling since we use the standard MC scale choice approximately regulates the number of parton shower emissions. In the model we consider here, a smooth parameter for all models of this type, with low values yielding more soft MPI activity in the limit that the normalization of this distribution is fixed to unity. Note also that the remaining divergence, again similarly to how the nonperturbative cutoff in parton showers ultimately regulates the number of parton shower emissions.

Transverse Mass Distribution:

Interesting to get more independent handles on $b$ distribution + make more use of 200 and 630 GeV data?

Hint of departure from Gaussian ($d=2$) at lower $E_{cm}$?

Different energies probe different effective $x$ ranges $\rightarrow$ different average $b$ profile?

Different energies probe different effective $x$ ranges $\rightarrow$ different average $b$ profile?
Model: \( P_{\text{keep}} = (1 - \zeta P_{78})^{n_{\text{int}}} \) (energy dependence implicit through \(<n_{\text{int}}>\))

Assumption of constant strength not supported by data!
Underscores the need for better physical understanding
The pedestal effect

Gives relation \( MB \rightarrow UE \), driven by proton shape

Tevatron tunes generally low at 7 TeV

But 20% not spectacular; can probably do better, but

Advocate more systematic approach to tuning & testing:

**Factorize:** Order observables from IR safe to IR sensitive

**Global View:** test models on many obs, not just one (duh!)

**Tuning Tools:** can be used for more than tuning

PS: Perugia 7-TeV prediction still untested: \( <N>_{pT>0.5, |\eta|<2.5, N\geq 4} = 14.45 \pm 1.26 \)