Introduction to Event Generators

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Topics of the lectures

1. Lecture 1: *The Monte Carlo Principle*
2. Lecture 2: *Parton level event generation*
3. Lecture 3: *Dressing the Partons*
4. Lecture 4: *Modelling beyond Perturbation Theory*

Thanks to

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Menu of lecture 4

- First considerations
- Hadronisation models

Prelude: Orientation

Event generator paradigm

Divide event into stages, separated by different scales.

- Signal/background:

  Exact matrix elements.

- QCD-Bremsstrahlung:

  Parton showers (also in initial state).

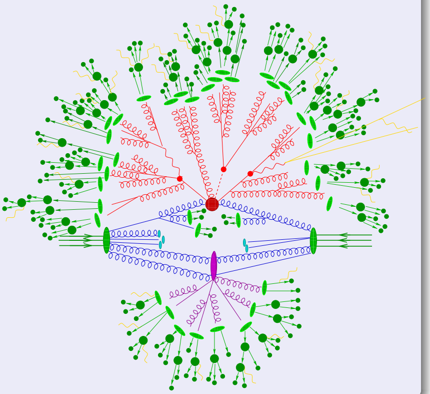
- Multiple interactions:

  Beyond factorisation: Modelling.

- Hadronisation:

  Non-perturbative QCD: Modelling.

Sketch of an event



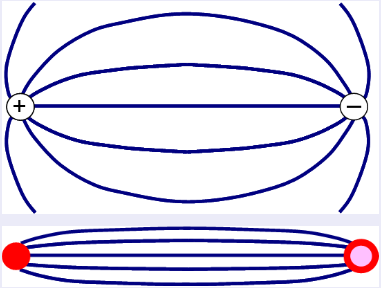
Hadronisation

Confinement

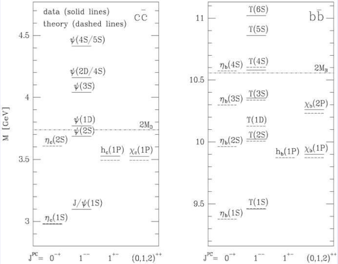
- Consider dipoles in QED and QCD

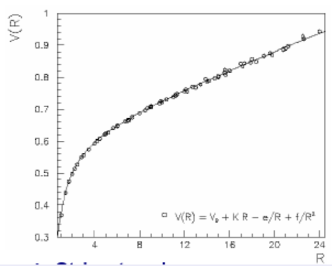
QED:

QCD:



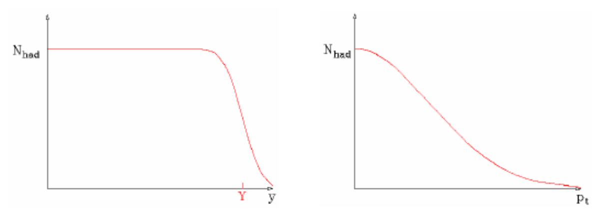
Linear QCD potential in Quarkonia





Some experimental facts → naive parameterisations

- In $e^+e^- \to$ hadrons: Limits $p_\perp$, flat plateau in y.



- Try "smearing": $\rho(p_\perp^2) \sim \exp(-p_\perp^2/\sigma^2)$

Effect of naive parameterisations

- Use parameterisation to "guesstimate" hadronisation effects:

$$\begin{aligned}
E &= \int_0^Y \mathrm{d}y\mathrm{d}p_\perp^2\,\rho(p_\perp^2)p_\perp\cosh y = \lambda\sinh Y \\
P &= \int_0^Y \mathrm{d}y\mathrm{d}p_\perp^2\,\rho(p_\perp^2)p_\perp\sinh y = \lambda(\cosh Y - 1) \approx E - \lambda \\
\lambda &= \int \mathrm{d}p_\perp^2\,\rho(p_\perp^2)p_\perp = \langle p_\perp\rangle\,.
\end{aligned}$$

- Estimate $\lambda \sim 1/R_{\rm had} \approx m_{\rm had}$, with $m_{\rm had}$ 0.1-1 GeV.
- Effect: Jet acquire non-perturbative mass $\sim 2\lambda E$ ($\mathcal{O}(10\mathrm{GeV})$ for jets with energy $\mathcal{O}(100\mathrm{GeV})$).

Implementation of naive parameterisations

- Feynman-Field independent fragmentation.

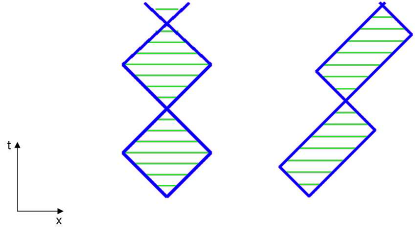
R.D.Field and R.P.Feynman, Nucl. Phys. B **136** (1978) 1

- Recursively fragment $q \to q' +$ had, where
  - Transverse momentum from (fitted) Gaussian;
  - longitudinal momentum arbitrary (hence from measurements);
  - flavour from symmetry arguments + measurements.
- Problems: frame dependent, "last quark", infrared safety, no direct link to perturbation theory, ...

Yoyo-strings as model of mesons

B.Andersson, G.Gustafson, G.Ingelman and T.Sjostrand, Phys. Rept. **97** (1983) 31.

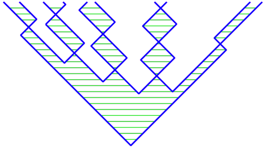
- Light quarks connected by string: area law $m^2 \propto$area.
- L=0 mesons only have 'yo-yo' modes:



Dynamical strings in $e^+e^- \to q\bar{q}$

B.Andersson, G.Gustafson, G.Ingelman and T.Sjostrand, Phys. Rept. **97** (1983) 31.

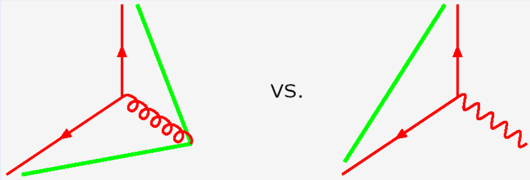
- Ignoring gluon radiation: Point-like source of string.
- Intense chromomagnetic field within string:
  More $q\bar{q}$ pairs created by tunnelling.
- Analogy with QED (Schwinger mechanism):
  $\mathrm{d}\mathcal{P} \sim \mathrm{d}x\mathrm{d}t\, \exp\left(-\pi m_q^2/\kappa\right)$, $\kappa =$ "string tension".



Gluons in strings = kinks

B.Andersson, G.Gustafson, G.Ingelman and T.Sjostrand, Phys. Rept. **97** (1983) 31.

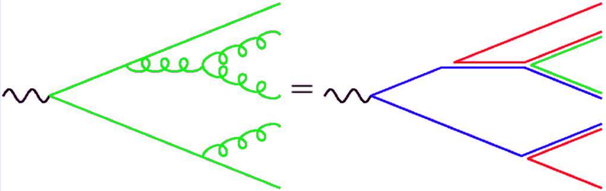
- String model = well motivated model, constraints on fragmentation (Lorentz-invariance, left-right symmetry, ...)
- Gluon = kinks on string? Check by "string-effect"



- Infrared-safe, advantage: smooth matching with PS.

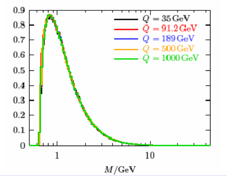
Preconfinement

- Underlying: Large N_c-limit (planar graphs).
- Follows evolution of colour in parton showers: at the end of shower colour singlets close in phase space.
- Mass of singlets: peaked at low scales $\approx Q_0^2$.



Primordial cluster mass distribution

- Starting point: Preconfinement;
- split gluons into $q\bar{q}$-pairs;
- adjacent pairs colour connected, form colourless (white) clusters.
- Clusters ("≈ excited hadrons) decay into hadrons



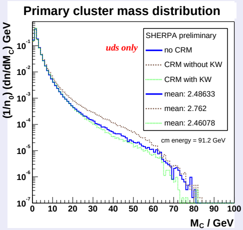
Cluster model

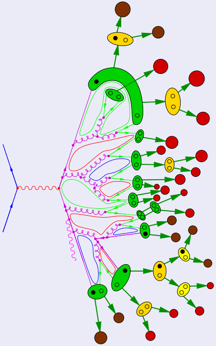
B.R.Webber, Nucl. Phys. B **238** (1984) 492.

- Split gluons into $q\bar{q}$ pairs, form singlet clusters:
  $\Longrightarrow$ continuum of meson resonances.
- Decay heavy clusters into lighter ones;
  (here, many improvements to ensure leading hadron spectrum hard enough, overall effect: cluster model becomes more string-like);
- if light enough, clusters $\rightarrow$ hadrons.
- Naively: spin information washed out, decay determined through phase space only $\rightarrow$ heavy hadrons suppressed (baryon/strangeness suppression).

Colour reconnections in the cluster model

- Maybe toy with phenomenological models of non-perturbative colour reconnection?





Summary of lecture 4

- Hadronisation
  - Various phenomenological models;
  - tuned to LEP data, overall agreement satisfying;
  - validity for hadron data not quite clear.

(beam remnant fragmentation not in LEP.)