LUND UNIVERSITY

CTEQ-MCnet School 2010
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Introduction to
Monte Carlo Event Generators

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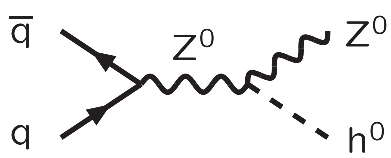
1. (Monday) Introduction and Overview; Monte Carlo Techniques
2. (Monday) Matrix Elements; Parton Showers I
3. (yesterday) Parton Showers II; Matching Issues
4. (yesterday) Multiple Parton–Parton Interactions
5. **(today) Hadronization and Decays; Generator Status**

Event Physics Overview

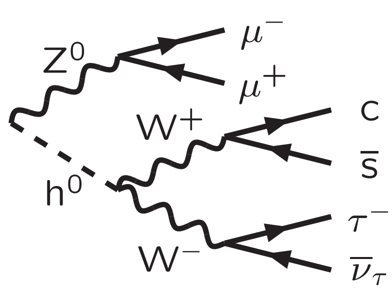
Repetition: from the “simple” to the “complex”,
or from “calculable” at large virtualities to “modelled” at small

Matrix elements (ME):

1) Hard subprocess:
$|\mathcal{M}|^2$, Breit-Wigners,
parton densities.

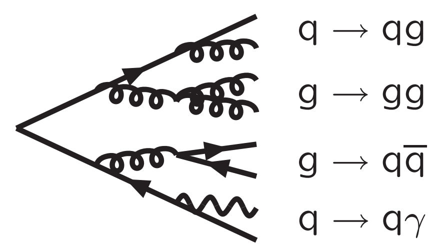


2) Resonance decays:
includes correlations.

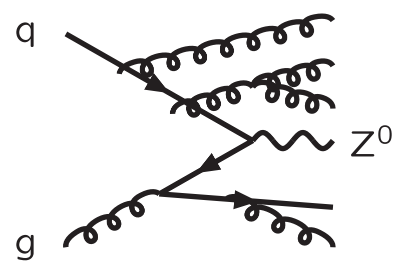


Parton Showers (PS):

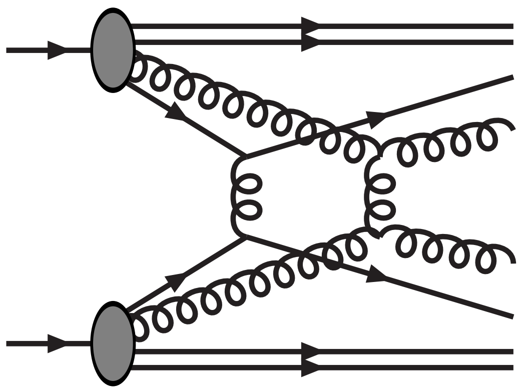
3) Final-state parton showers.



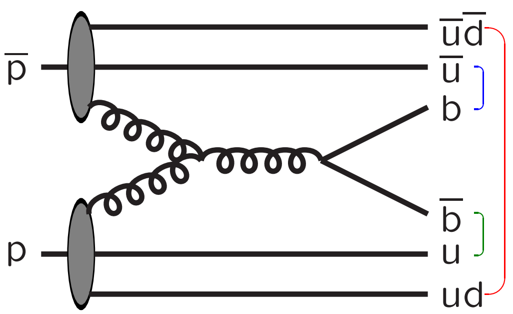
4) Initial-state parton showers.



5) Multiple parton–parton interactions.

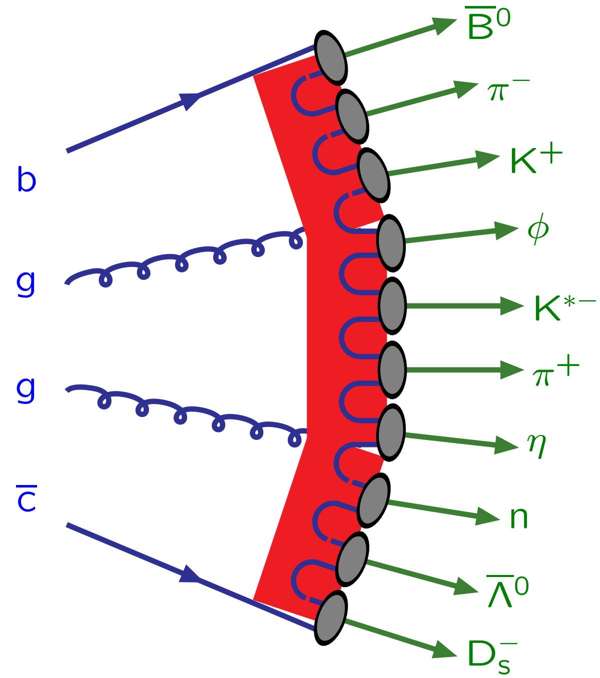


6) Beam remnants, with colour connections.

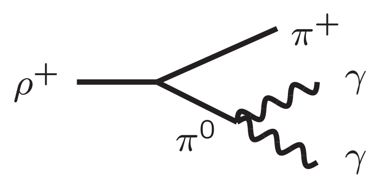


5) + 6) = Underlying Event

7) Hadronization



8) Ordinary decays: hadronic, τ, charm, . . .



Hadronization/Fragmentation models

$\boxed{\text{Perturbative} \longrightarrow \text{nonperturbative} \Longrightarrow \text{not calculable from first principles!}}$

Model building = ideology + “cookbook”

Common approaches:

1) **String** Fragmentation
   (most ideological)

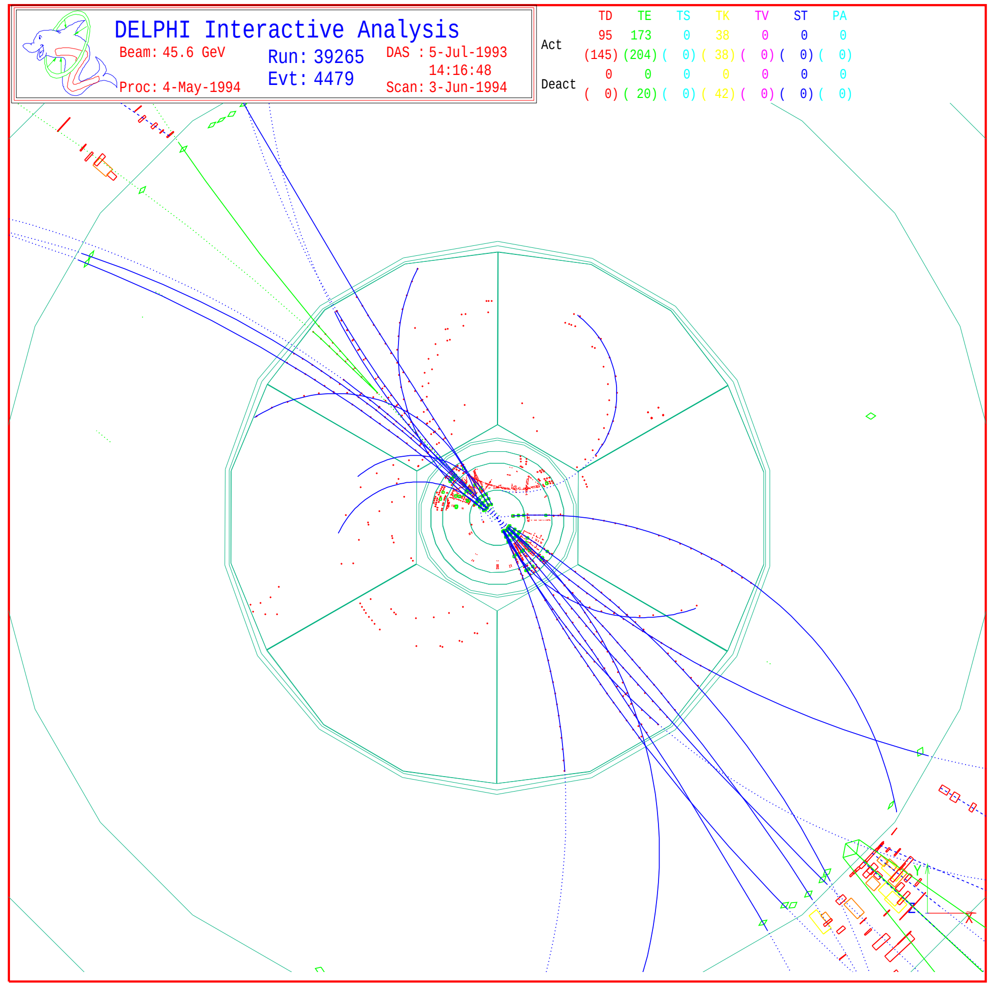
2) **Cluster** Fragmentation
   (simplest?)

3) **Independent** Fragmentation
   (most cookbook)

4) Local Parton–Hadron Duality
   (limited applicability)

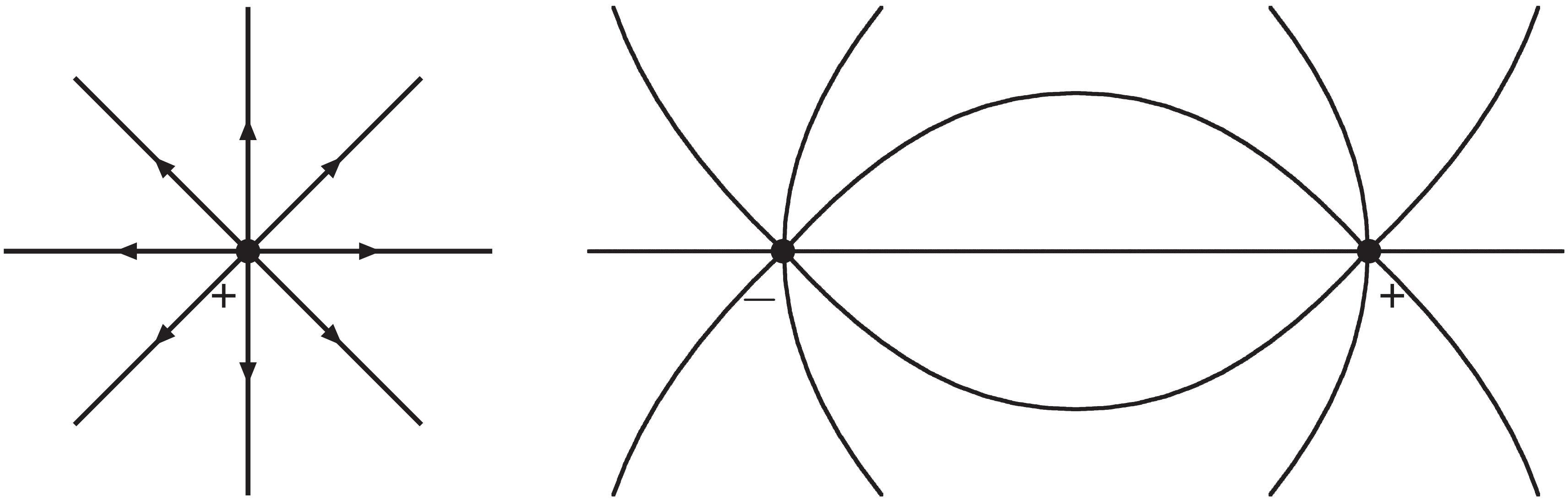
Best studied in

$$e^+e^- \to \gamma^*/Z^0 \to q\overline{q}$$



The Lund String Model

In QED, field lines go all the way to infinity

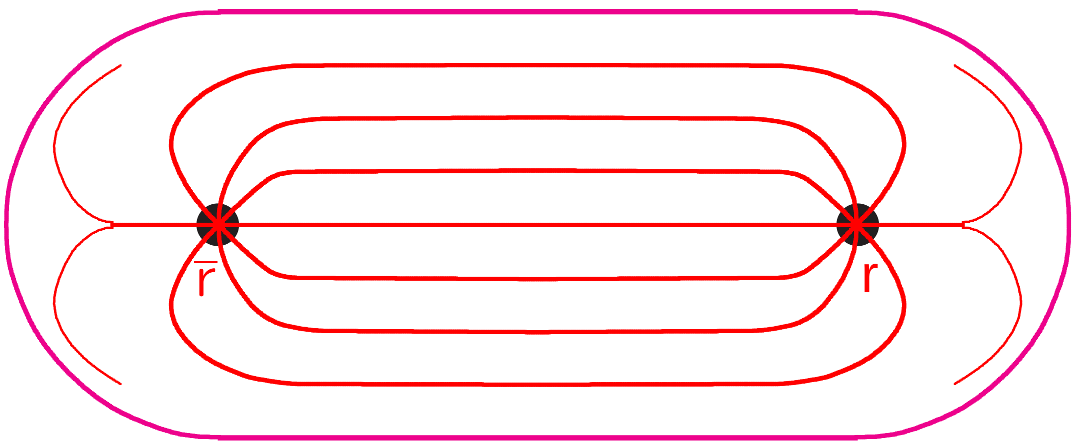


since photons cannot interact with each other.

Potential is simply additive:

$$V(\mathbf{x}) \propto \sum_i \frac{1}{|\mathbf{x} - \mathbf{x}_i|}$$

In QCD, for large charge separation, field lines seem to be compressed to tubelike region(s) $\Rightarrow$ **string(s)**



by self-interactions among soft gluons in the "vacuum".

(Non-trivial ground state with quark and gluon "condensates".

Analogy: vortex lines in type II superconductor)

Gives linear confinement with string tension:

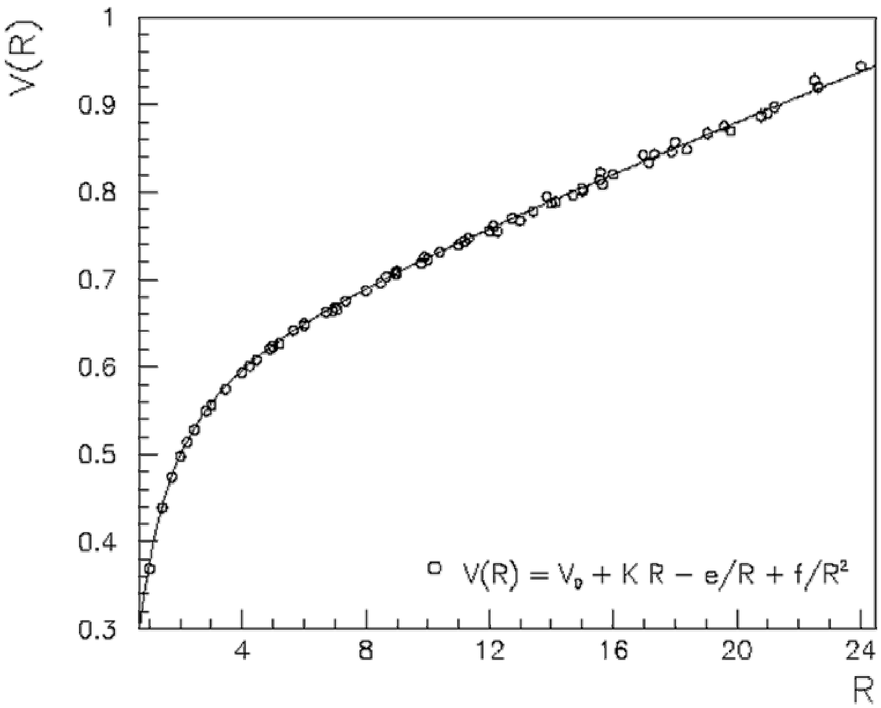
$$F(r) \approx \text{const} = \kappa \approx 1~\text{GeV/fm} \quad \Longleftrightarrow \quad V(r) \approx \kappa r$$

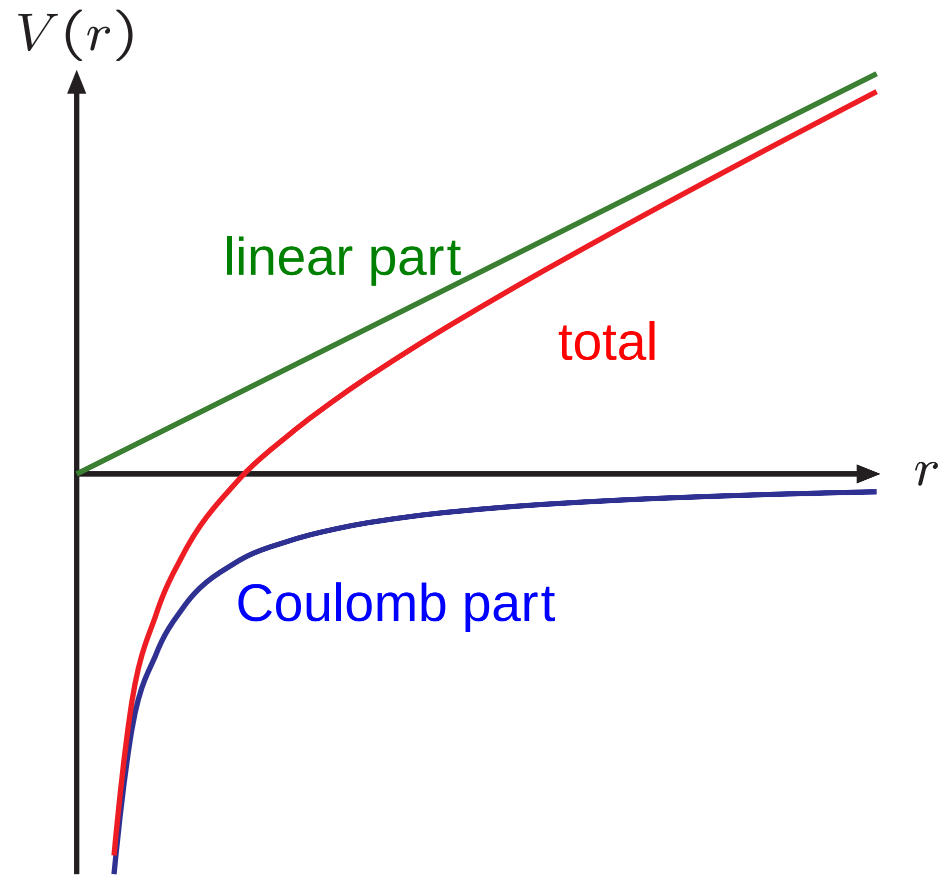
Separation of transverse and longitudinal degrees of freedom

$\Rightarrow$ simple description as 1+1-dimensional object – string –

with Lorentz invariant formalism

Linear confinement confirmed e.g. by quenched lattice QCD





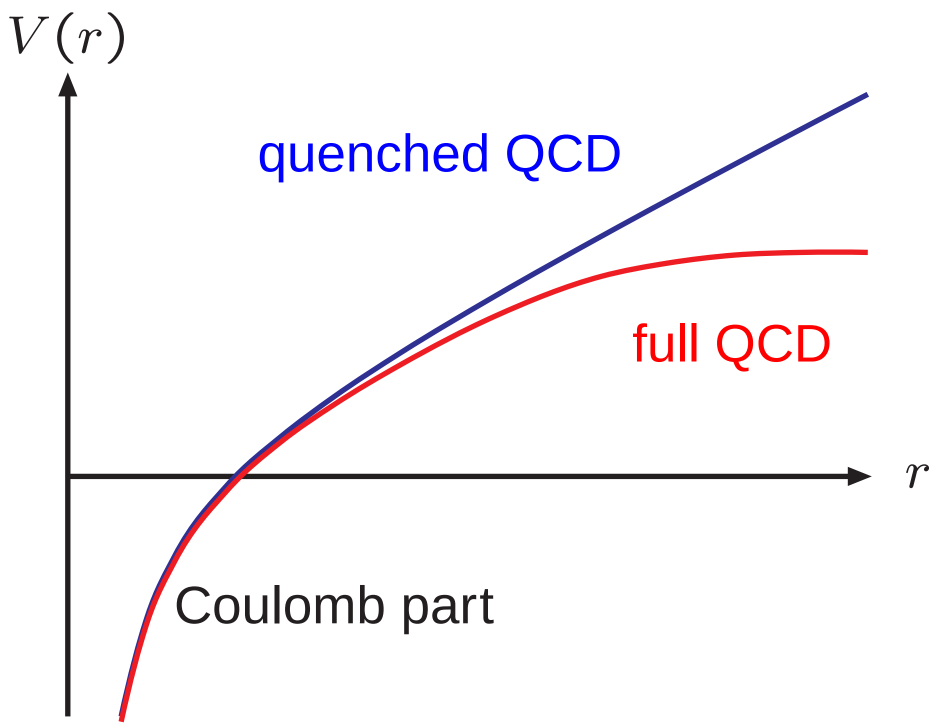
$$V(r) \approx -\frac{4}{3}\frac{\alpha_s}{r} + \kappa r \approx -\frac{0.13}{r} + r$$

(for $\alpha_s \approx 0.5$, r in fm and V in GeV)

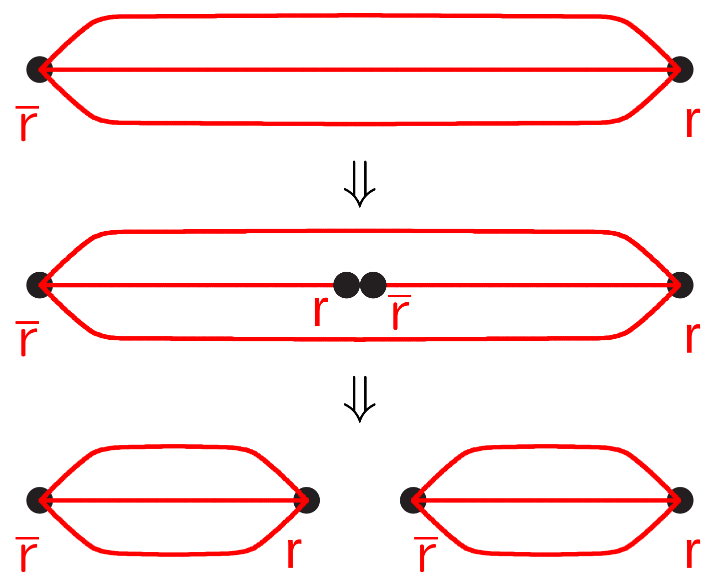
$V(0.4\,\mathrm{fm}) \approx 0$: Coulomb important for internal structure of hadrons, not for particle production (?)

Real world (??, or at least unquenched lattice QCD)

$\Longrightarrow$ nonperturbative string breakings $gg\ldots \to q\overline{q}$



simplified colour representation:

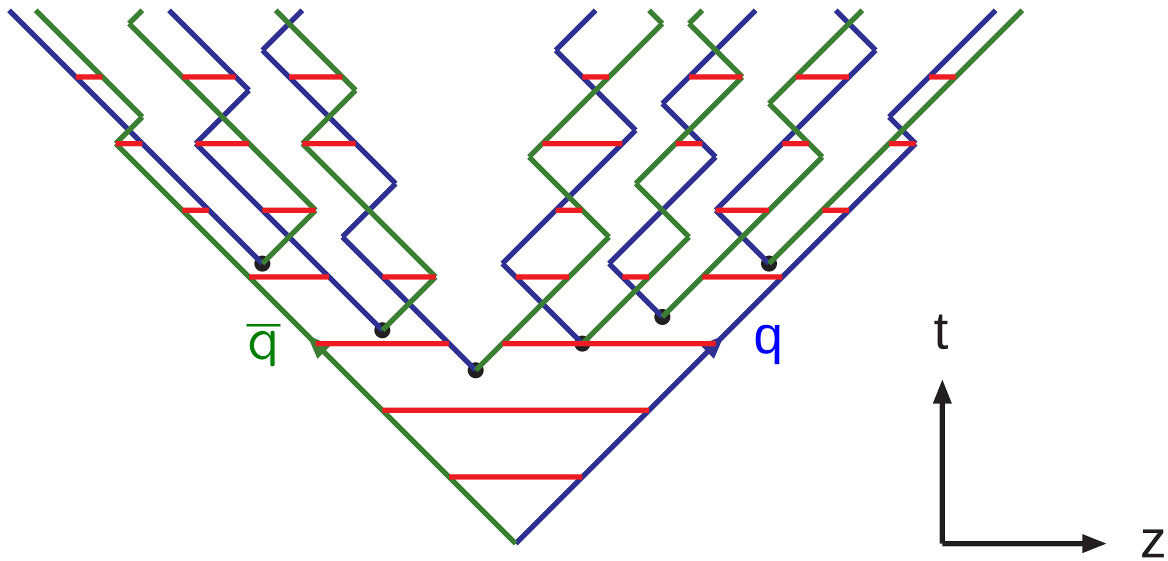


Repeat for large system $\Rightarrow$ *Lund model*

which neglects Coulomb part:

$$\left|\frac{\mathrm{d}E}{\mathrm{d}z}\right| = \left|\frac{\mathrm{d}p_z}{\mathrm{d}z}\right| = \left|\frac{\mathrm{d}E}{\mathrm{d}t}\right| = \left|\frac{\mathrm{d}p_z}{\mathrm{d}t}\right| = \kappa$$

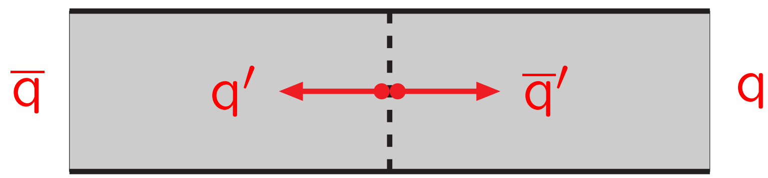
Motion of quarks and antiquarks in a $\mathrm{q\overline{q}}$ system:



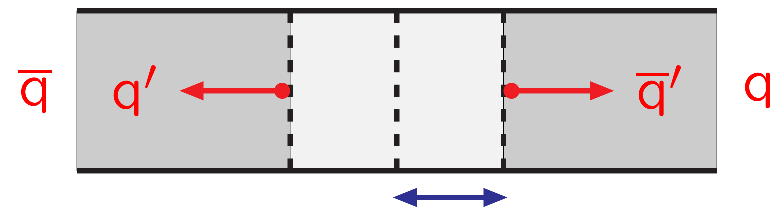
gives simple but powerful picture of hadron production

(with extensions to massive quarks, baryons, . . .)

How does the string break?



$m_{\perp q'} = 0$



$d = m_{\perp q}/\kappa$

$m_{\perp q'} > 0$

String breaking modelled by tunneling:

$$\mathcal{P} \propto \exp\left(-\frac{\pi m_{\perp q}^2}{\kappa}\right) = \exp\left(-\frac{\pi p_{\perp q}^2}{\kappa}\right) \exp\left(-\frac{\pi m_q^2}{\kappa}\right)$$

1) common Gaussian $p_\perp$ spectrum

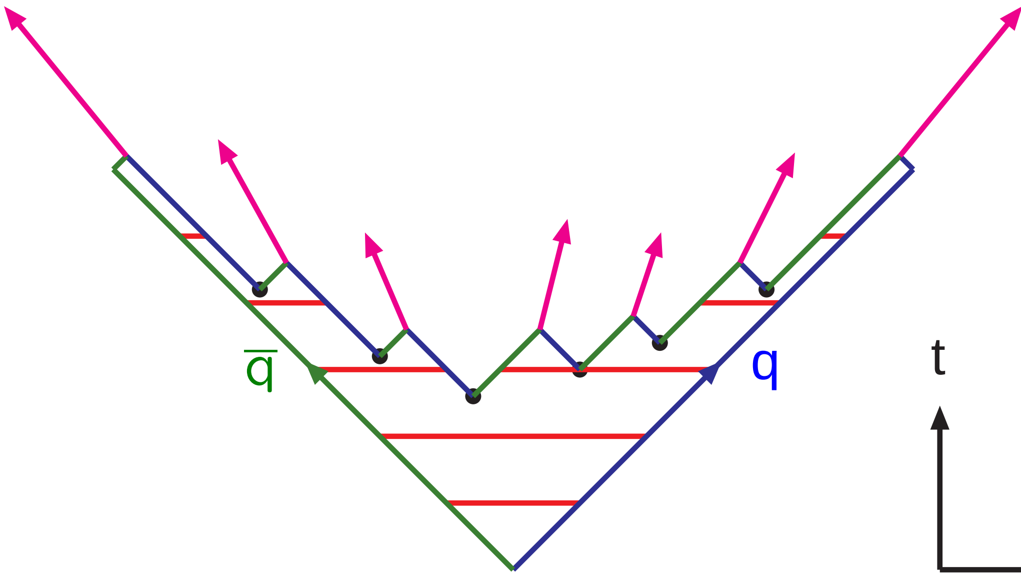
2) suppression of heavy quarks $u\overline{u} : d\overline{d} : s\overline{s} : c\overline{c} \approx 1 : 1 : 0.3 : 10^{-11}$

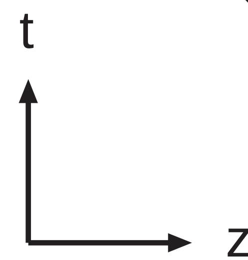
3) diquark $\sim$ antiquark $\Rightarrow$ simple model for baryon production

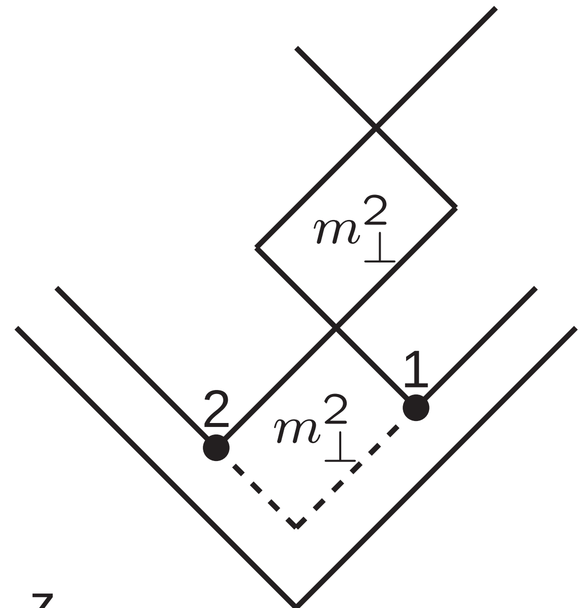
Hadron composition also depends on spin probabilities, hadronic wave functions, phase space, more complicated baryon production, . . .

$\Rightarrow$ "moderate" predictivity (many parameters!)

Fragmentation starts in the middle and spreads outwards:







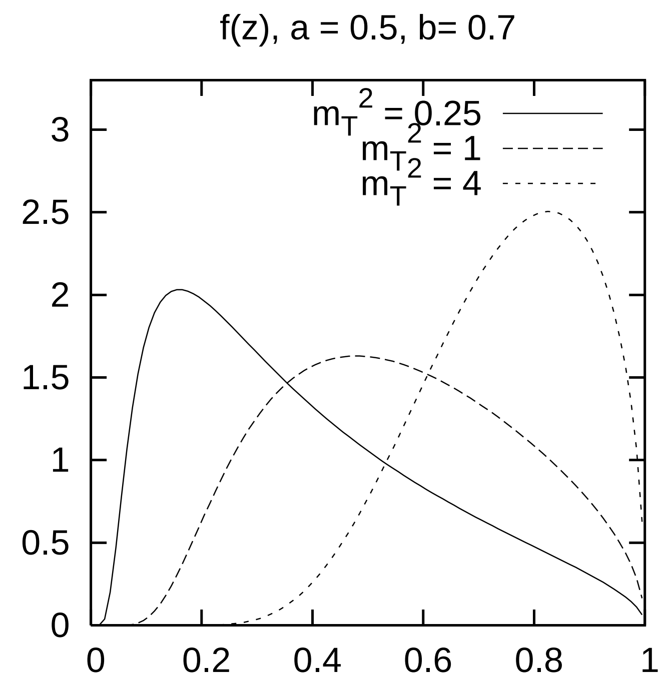
but breakup vertices causally disconnected

$\Rightarrow$ can proceed in arbitrary order

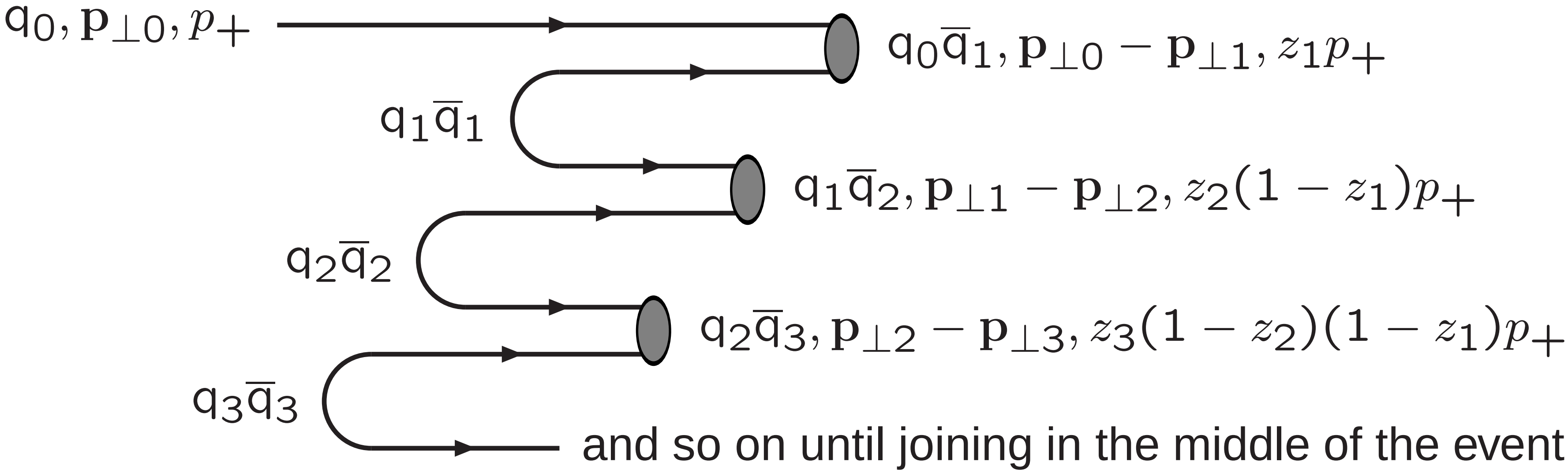
$\Rightarrow$ *left–right symmetry*

$$\begin{aligned} \mathcal{P}(1,2) &= \mathcal{P}(1) \times \mathcal{P}(1 \to 2) \\ &= \mathcal{P}(2) \times \mathcal{P}(2 \to 1) \end{aligned}$$

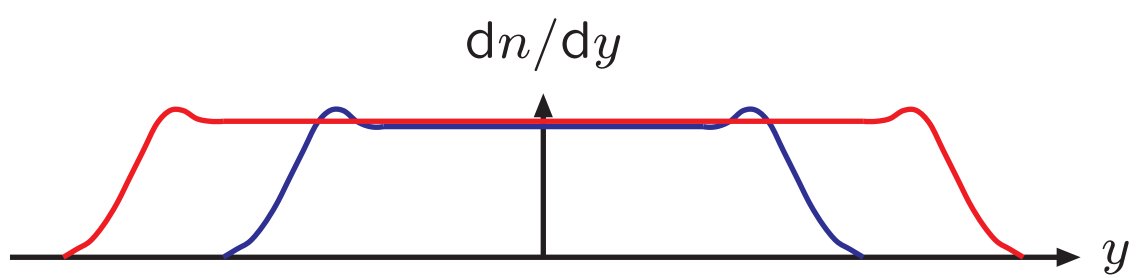
$\Rightarrow$ Lund symmetric fragmentation function
$f(z) \propto (1-z)^a \exp(-bm_\perp^2/z)/z$



The iterative ansatz



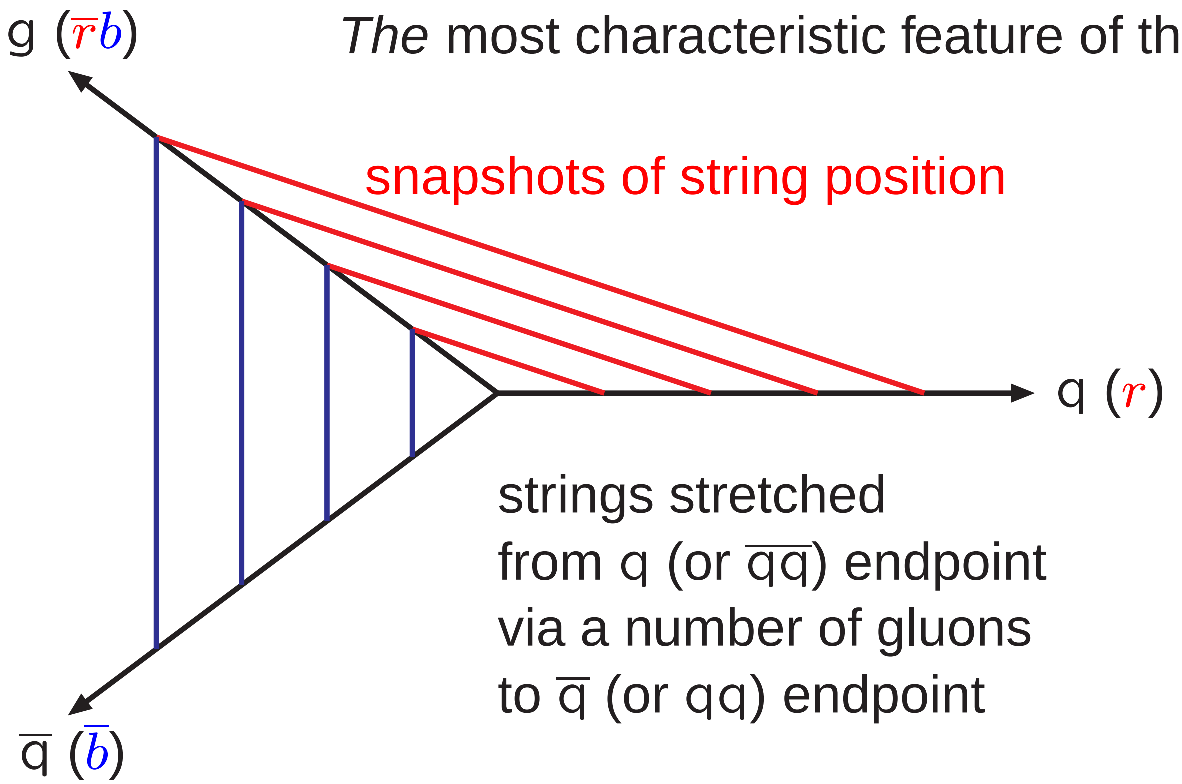
Scaling in lightcone $p_\pm = E \pm p_z$ (for $q\overline{q}$ system along z axis) implies flat central rapidity plateau + some endpoint effects:



$\langle n_{\mathrm{ch}} \rangle \approx c_0 + c_1 \ln E_{\mathrm{cm}}$, $\sim$ Poissonian multiplicity distribution

The Lund gluon picture

The most characteristic feature of the Lund model



Gluon = kink on string, carrying energy and momentum

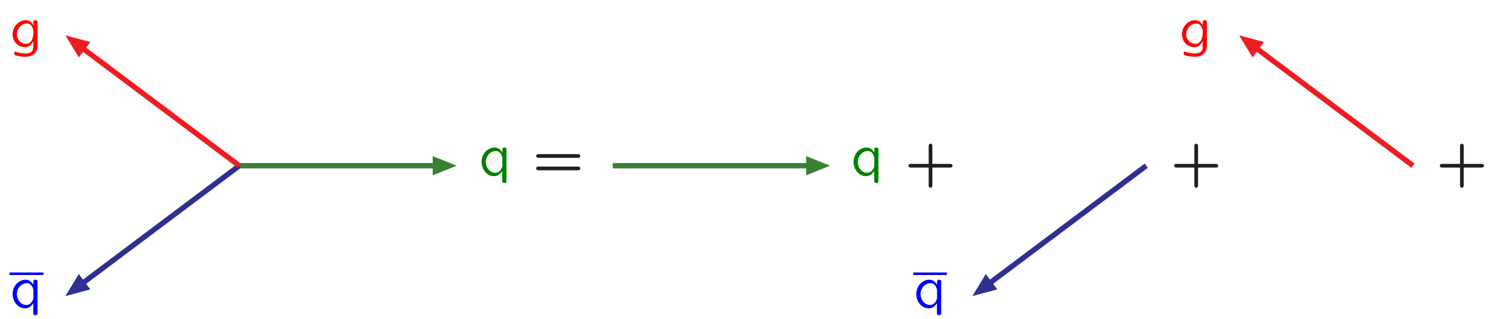
Force ratio gluon/ quark = 2, cf. QCD $N_C/C_F = 9/4$, $\rightarrow$ 2 for $N_C \rightarrow \infty$

No new parameters introduced for gluon jets!, so:

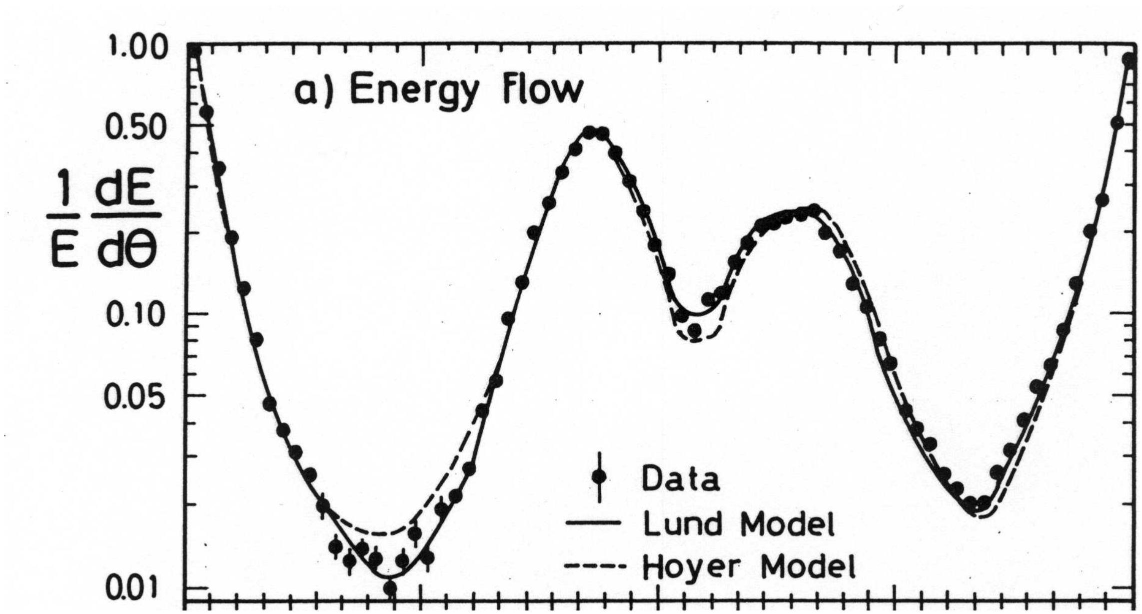
- Few parameters to describe energy-momentum structure!
- Many parameters to describe flavour composition!

Independent fragmentation

Based on a similar iterative ansatz as string, but



minor
corrections
in middle

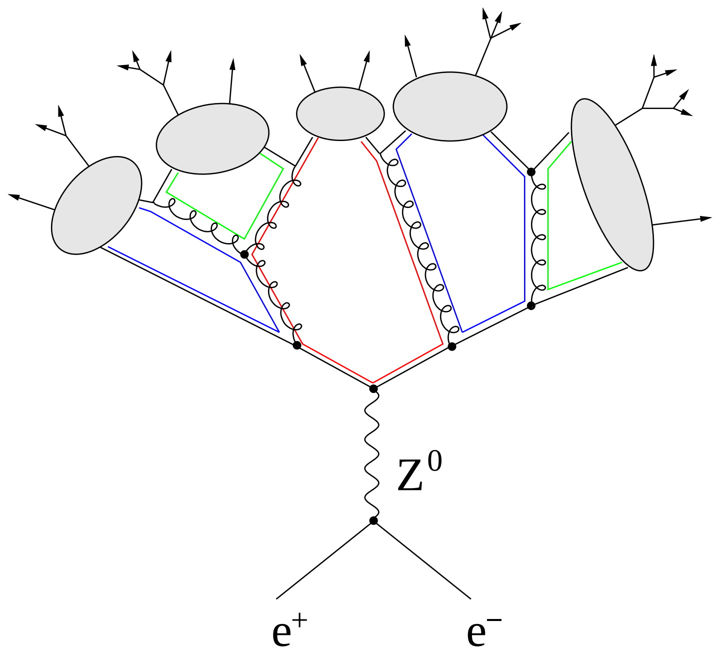


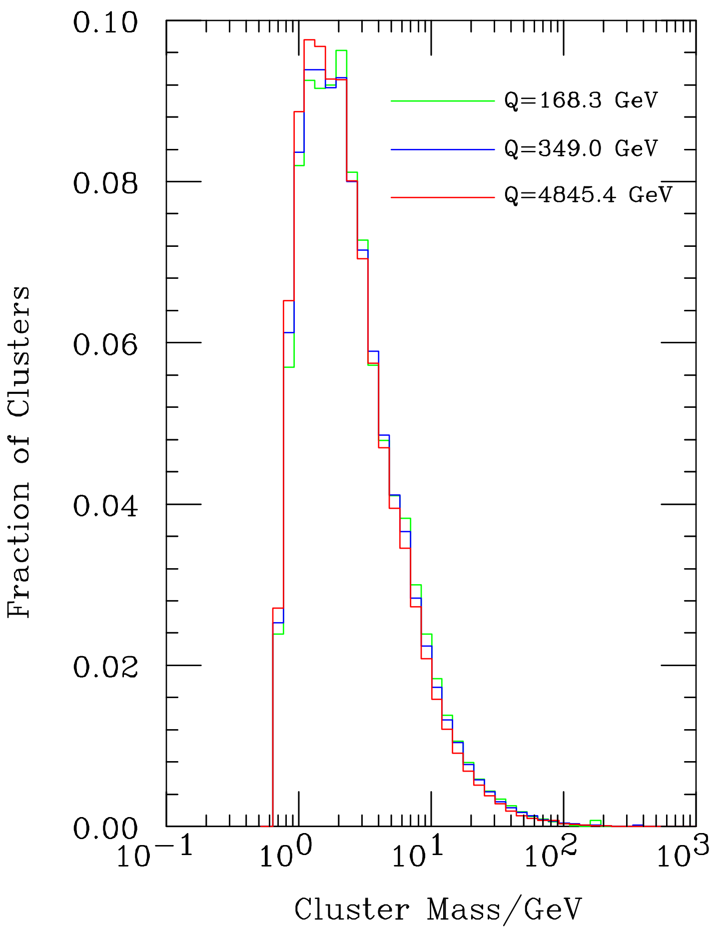
String effect
(JADE, 1980)
≈ coherence in
nonperturbative
context

Further numerous and detailed tests at LEP favour string picture . . .
. . . but much is still uncertain when moving to hadron colliders.

The HERWIG Cluster Model

“Preconfinement”:
colour flow is local
in coherent shower evolution





1) Introduce forced $g \rightarrow q\bar{q}$ branchings

2) Form colour singlet clusters

3) Clusters decay isotropically to 2 hadrons according to phase space weight $\sim (2s_1 + 1)(2s_2 + 1)(2p^*/m)$

simple and clean, but . . .

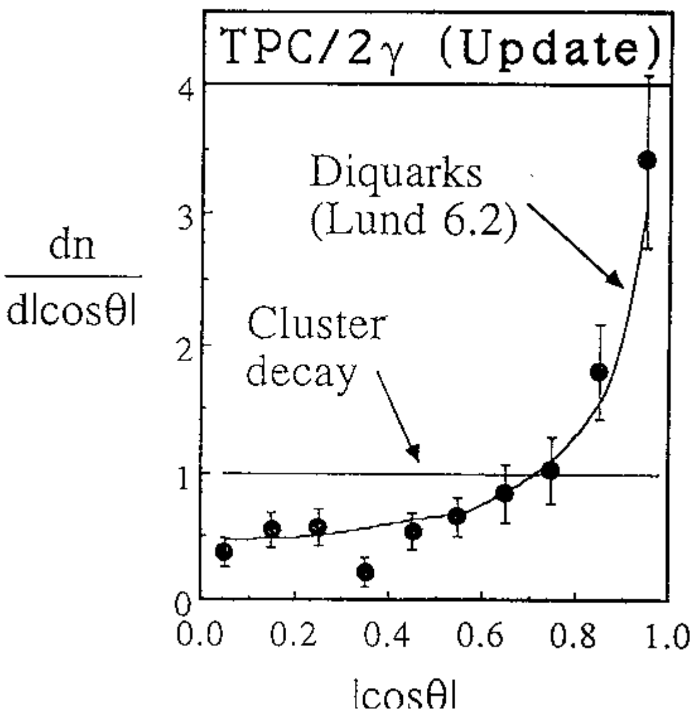
1) Tail to very large-mass clusters (e.g. if no emission in shower);
if large-mass cluster $\longrightarrow$ 2 hadrons then
incorrect hadron momentum spectrum, crazy four-jet events
$\Longrightarrow$ split big cluster into 2 smaller along “string” direction;
daughter-mass spectrum $\Rightarrow$ iterate if required;
$\sim$ 15% of primary clusters are split, but give $\sim$ 50% of final hadrons

2) Isotropic baryon decay inside cluster
$\Longrightarrow$ splittings $g \to qq + \overline{qq}$

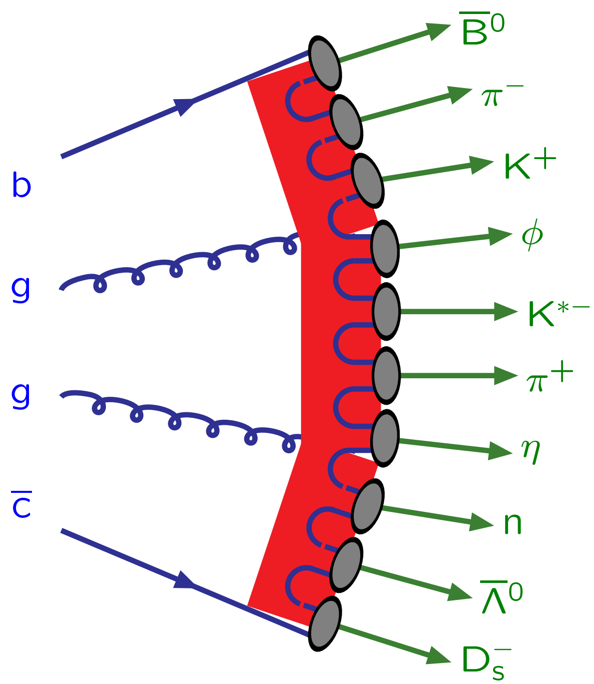
3) Too soft charm/bottom spectra
$\Longrightarrow$ anisotropic leading-cluster decay

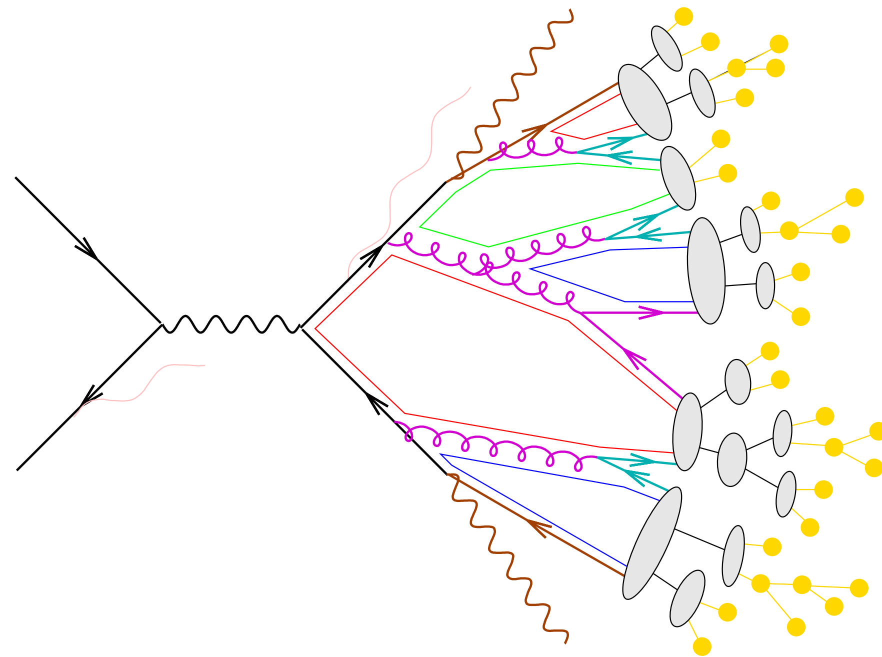
4) Charge correlations still problematic
$\Longrightarrow$ all clusters anisotropic (?)

5) Sensitivity to particle content
$\Longrightarrow$ only include complete multiplets



String vs. Cluster





program	PYTHIA	HERWIG
model	string	cluster
energy–momentum picture	powerful predictive	simple unpredictive
parameters	few	many
flavour composition	messy unpredictive	simple in-between
parameters	many	few

"There ain't no such thing as a parameter-free *good* description"

Local Parton–Hadron Duality

Analytic approach:
Run shower down to to $Q \approx \Lambda_{\text{QCD}}$
(or m_{hadron}, if larger)

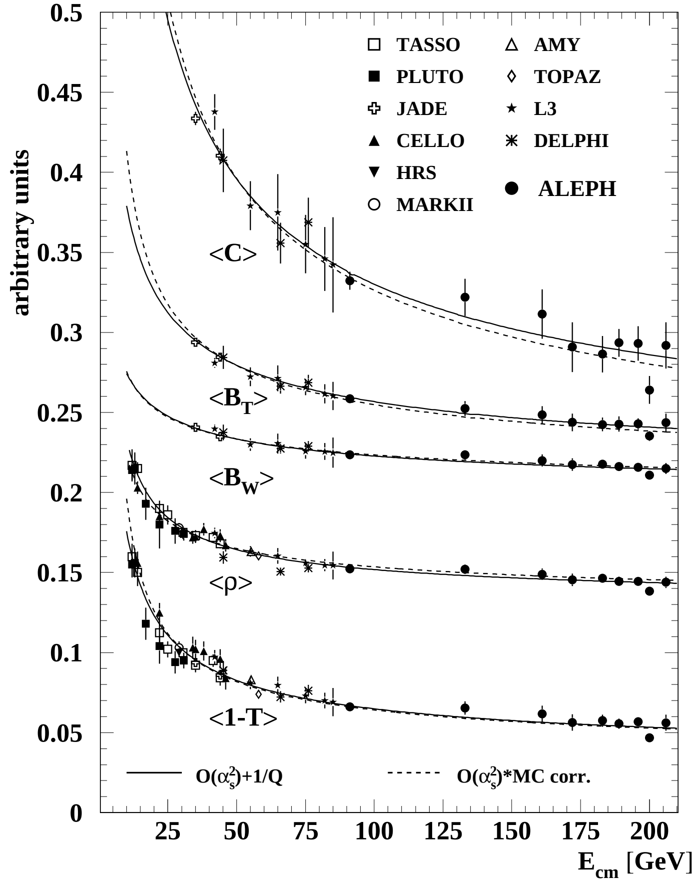
"Hard Line": each parton $\equiv$ one hadron

"Soft Line": local hadron density
$\propto$ parton density

describes momentum spectra $\mathrm{d}n/\mathrm{d}x_p$
and semi-inclusive particle flow,
but fails for identified particles

+ "renormalons" (power corrections)

$$\langle 1 - T \rangle = a\,\alpha_{\text{s}}(E_{\text{cm}}) + b\,\alpha_{\text{s}}^2(E_{\text{cm}}) + c/E_{\text{cm}}$$

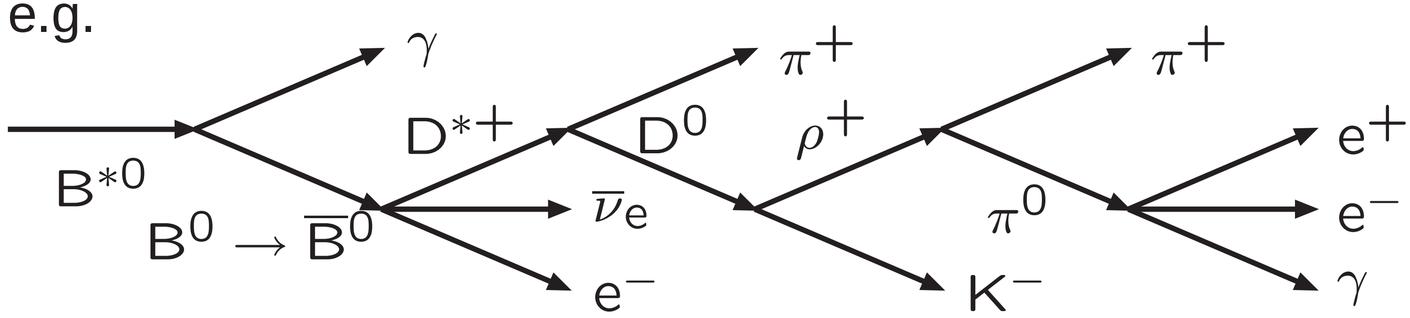


Not Monte Carlo, **not** for arbitrary quantities

Decays

Unspectacular/ungrateful but necessary:
this is where most of the final-state particles are produced!
Involves hundreds of particle kinds and thousands of decay modes.

e.g.



- $B^{*0} \to B^0\gamma$: electromagnetic decay
- $B^0 \to \overline{B}^0$ mixing (weak)
- $\overline{B}^0 \to D^{*+}\overline{\nu}_e e^-$: weak decay, displaced vertex, $|\mathcal{M}|^2 \propto (p_{\overline{B}}p_{\overline{\nu}})(p_e p_{D^*})$
- $D^{*+} \to D^0\pi^+$: strong decay
- $D^0 \to \rho^+K^-$: weak decay, displaced vertex, ρ mass smeared
- $\rho^+ \to \pi^+\pi^0$: ρ polarized, $|\mathcal{M}|^2 \propto \cos^2\theta$ in ρ rest frame
- $\pi^0 \to e^+e^-\gamma$: Dalitz decay, $m(e^+e^-)$ peaked

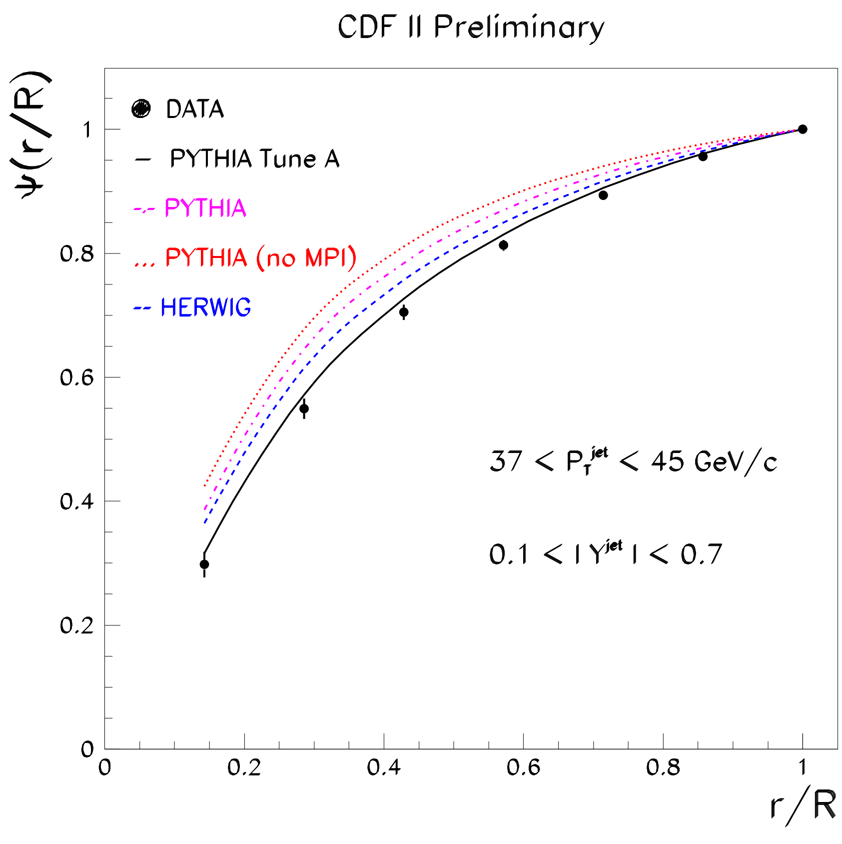
Dedicated programs, with special attention to polarization effects:
- EVTGEN: B decays
- TAUOLA: τ decays

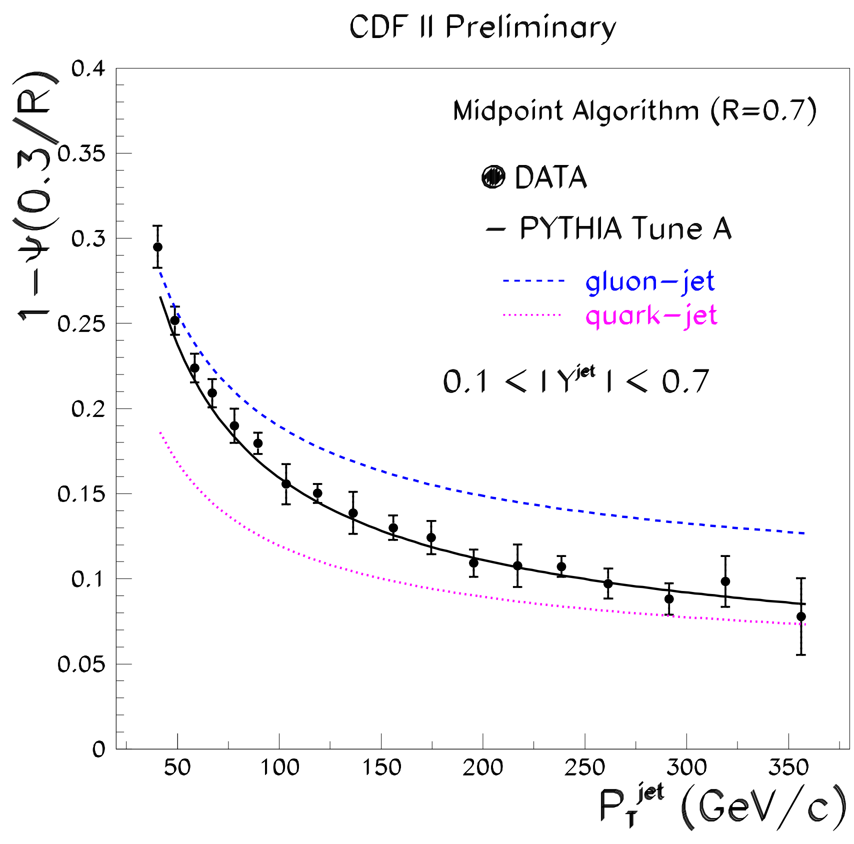
Jet Universality

Question: are jets the same in all processes?

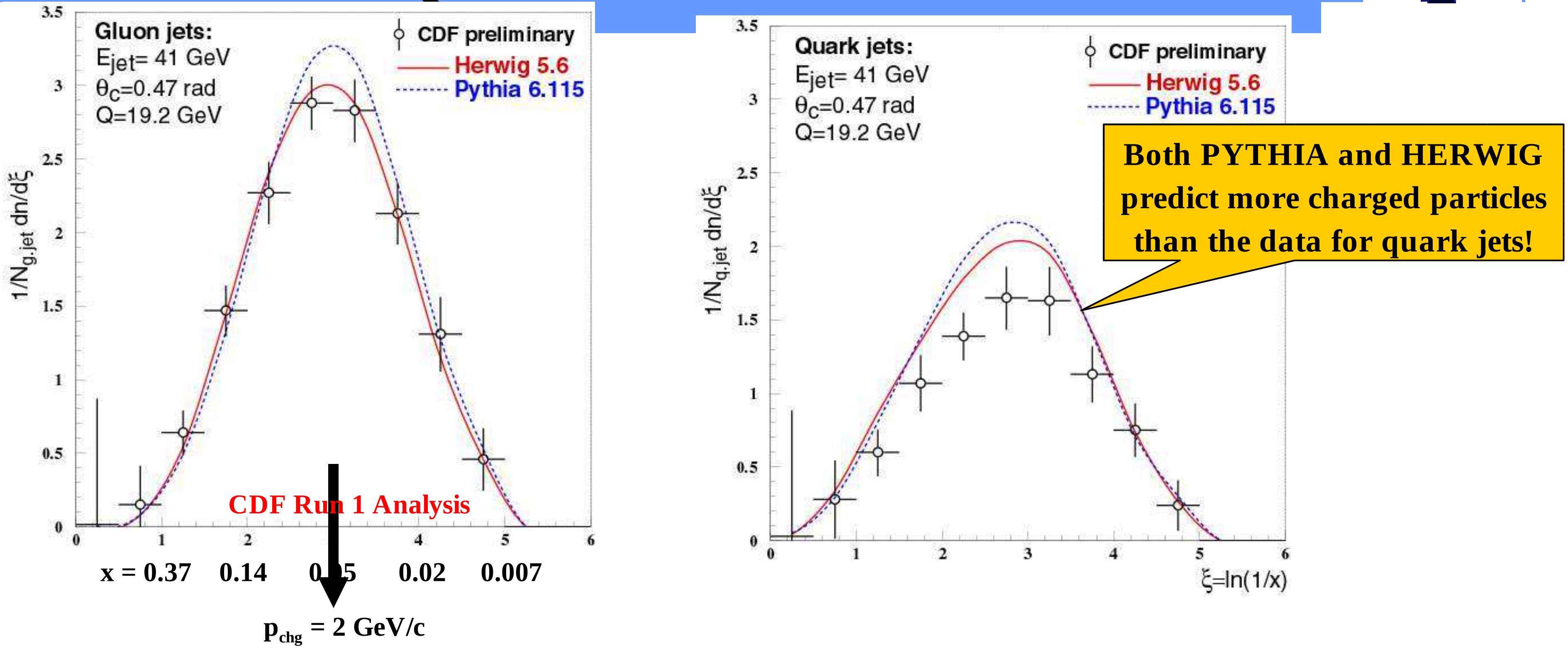
Answer 1: no, at LEP mainly quarks jets, often b/c,
at LHC mainly gluons, if quarks then mainly u/d.

Answer 2: no, perturbative evolution gives calculable differences.





Distribution of Particles in Quark and Gluon Jets



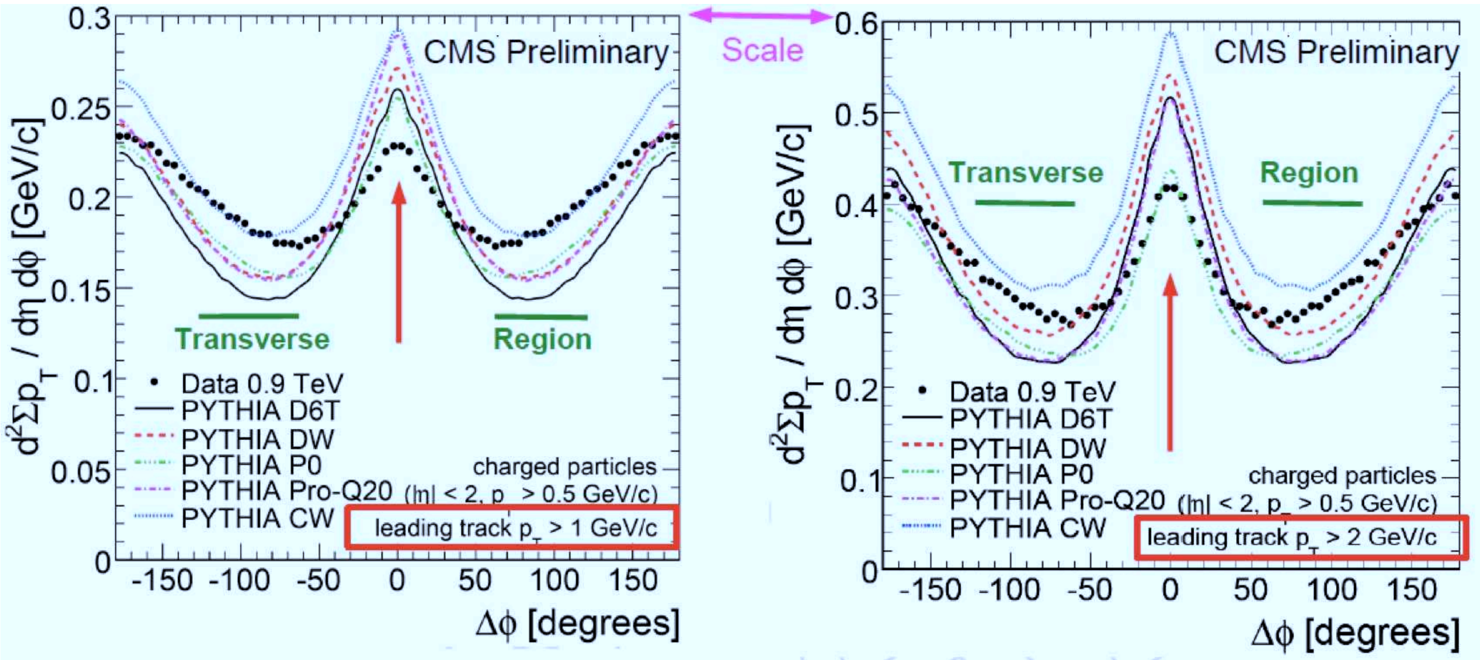
Momentum distribution of charged particles in gluon jets. HERWIG 5.6 predictions are in a good agreement with CDF data. PYTHIA 6.115 produces slightly more particles in the region around the peak of distribution.

Momentum distribution of charged particles in quark jets. Both HERWIG and PYTHIA produce more particles in the central region of distribution.

Distribution in Δφ

Sum pT density versus azimuthal angle with respect to leading object

Leading track or jet not included!

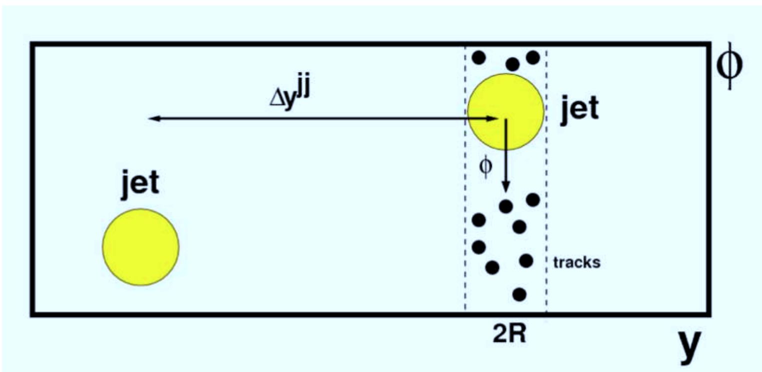


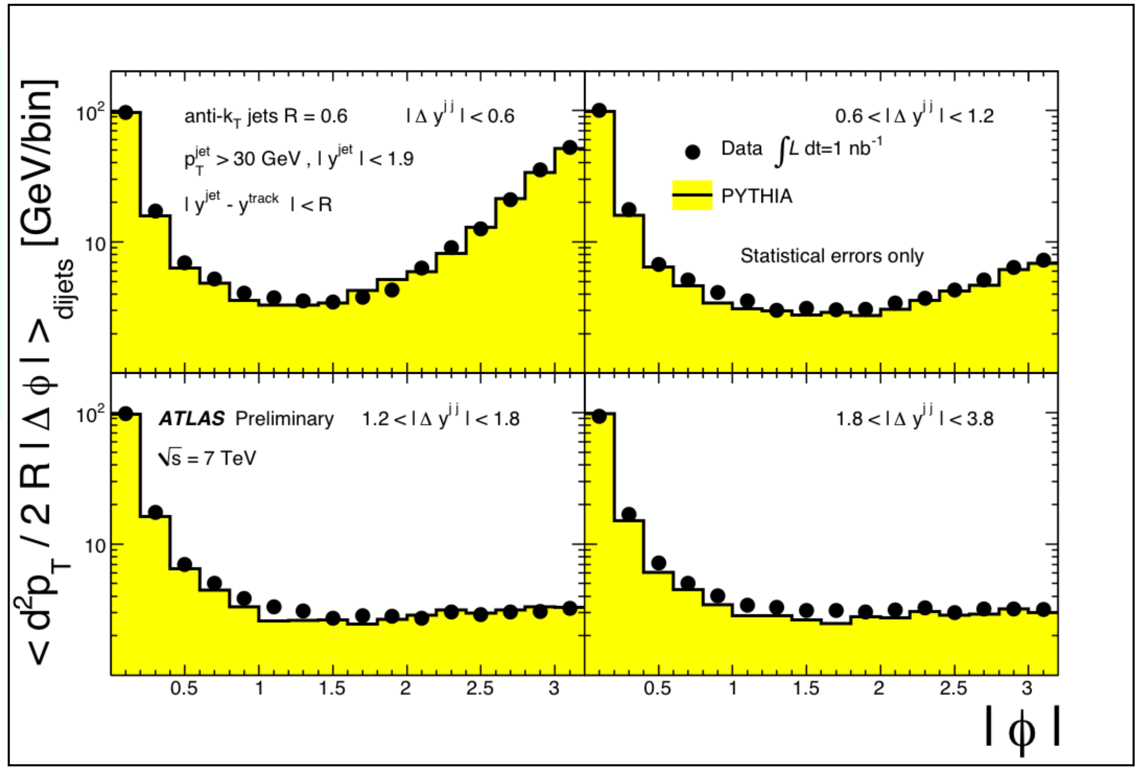
Perugia-0 (P0) good along the leading track direction.

•DW and CW better in the transverse region.

•Other tunes too low in transverse region

Charged particle flow in jets

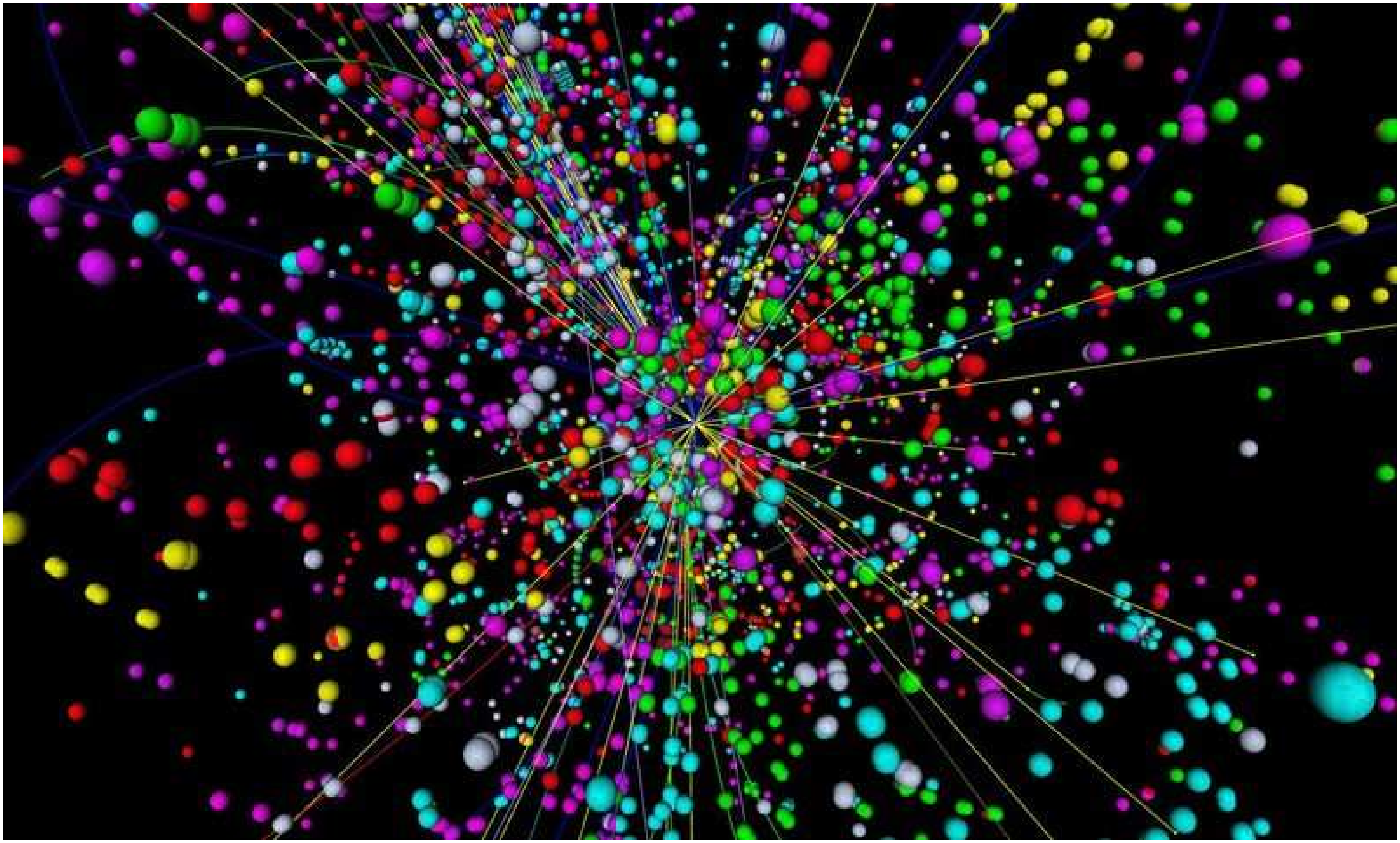




• Observed charged particle flow in inclusive dijet events for jets with p_T(jet) > 30 GeV and |y(jet) < 1.9, as a function of ϕ with respect to the jet direction and the rapidity separation between the two leading jets.

• Particle flow in data slightly higher than in MC

Event Generator Developments



MCnet

• “Trade Union” of (QCD) Event Generator developers •

• Collects HERWIG, SHERPA and PYTHIA •

• Also ThePEG, ARIADNE, VINCIA, . . . •

• Also generator validation (RIVET) and tuning (PROFESSOR) •

(CERN, Durham, Lund, Karlsruhe, UC London, + associated)

• Funded by EU Marie Curie training network 2007–2010 •

• 4 postdocs & 2 graduate students: generator development and tuning •

• MCnet studentships for short-term visits: winding down •

• Annual Monte Carlo school: •

Durham, UK, 18 – 20 April 2007

CTEQ – MCnet, Debrecen, Hungary, 8 – 16 August 2008

Lund, Sweden, 1 – 4 July 2009

CTEQ – MCnet, here and now

Manchester, UK, 2011 (?)

+ Lectures on QCD & Generators at many other schools +

The workhorses: what are the differences?

HERWIG, PYTHIA and SHERPA intend to offer a convenient framework for LHC physics studies, but with slightly different emphasis:

PYTHIA (successor to JETSET, begun in 1978):
- originated in hadronization studies: the Lund string
- leading in development of multiple parton interactions
- pragmatic attitude to showers & matching

HERWIG (successor to EARWIG, begun in 1984):
- originated in coherent-shower studies (angular ordering)
- cluster hadronization & underlying event pragmatic add-on
- large process library with spin correlations in decays

SHERPA (APACIC++/AMEGIC++, begun in 2000):
- own matrix-element calculator/generator
- extensive machinery for CKKW matching to showers
- hadronization & min-bias physics under development

PYTHIA & HERWIG originally in Fortran, SHERPA in C++ from onset

HERWIG

Herwig++

Peter Richardson

IPPP, Durham University

Parton Shower

- The new Herwig++ parton shower is still angular ordered but:
  - Uses quasi-collinear splitting functions to improve the treatment of mass effects;
  - A Sudakov decomposition to give better theoretical control.
- Gieseke, Stephens, Webbers JHEP 0312:045,2003
- Gives better description of B hadron fragmentation functions
- Makes matching the shower to hard matrix elements easier.

Multiple Scattering

- In FORTRAN HERWIG there was a built in soft model for the underlying event and the option of using the JIMMY multiple parton interaction model.
- In Herwig++ we use a improved version of the JIMMY MPI model including a soft component.
- Bahr, Butterworth, Seymour JHEP 0901:065,2009, Bahr, Gieseke, Seymour JHEP 0807:076,2008

Hard Radiation

- Much of the research in Monte Carlo simulations in recent years has involved matching the parton shower to fixed order matrix elements at both:
  - NLO to improve the overall normalisation and description of the hardest jet in the event;
  - Leading order to matrix elements with higher multiplicities to improve the simulation of events with many hard jets.
- There are many improvements in Herwig++ to include both types of approach.

NLO Processes

- There are now a range of processes accurate to NLO in current version of Herwig++:
  - W/Z production;
  - $gg \rightarrow h^0$;
  - Higgs production in association with $W^\pm$ and Z^0.
- In addition the next version will include:
  - DIS;
  - Higgs production via VBF;
  - Vector Boson pair production.

QED Radiation

- FORTRAN HERWIG did not simulate QED radiation from charged leptons
- Important for the simulation of W and Z leptonic decays.
- In Herwig++ we simulate this using the YFS formalism.

K. Hamilton and PR hep-ph/0603034, JHEP 0607:010, 2006.

BSM Physics

- In Herwig++ use a different approach so only the Feynman rules for a new model need to be coded.
- Automatically calculates the 2→2 scattering processes, 1→2 and 1→3 decays and generates all the spin correlations.
- Currently in addition to the SM the
  - MSSM
  - Minimal UED model
  - RS model

  are available.

BSM Physics

- The NMSSM and anomalous gauge boson couplings will be available in the next release.
- In the near future we will shift to an interfere to FeynRules to make adding new models even easier.

Hadronization

- The main improvements in the hadronization are designed to improve the simulation of
  - the production of bottom and charm hadrons
  - Baryons
- Mainly through the introduction of flavour specific parameters in the hadronization model.

Hadron and Tau Decays

- Herwig++ includes a sophisticated simulation of non-perturbative hadron and tau decays.
- Main concentration on
  - Tau Decays
  - Light mesons and baryons
  - General properties of heavy meson and baryon decays rather the rare B decays and mixing.
- Includes correlations and allows communication with the perturbative stage of the event for tau decays.

Herwig++

- The new Herwig++ program now provides a full simulation of lepton-lepton, lepton-hadron and hadron-hadron collisions with many improvements over its FORTRAN predecessor:
  - New angular ordered parton shower with better theoretical control and mass treatment;
  - Many processes at NLO in the POWHEG approach;
  - Multiple scattering model of the underlying event;
  - Better treatment of BSM physics models;
  - Improved simulation of tau and hadron decays.

SHERPA
Status and prospects

Frank Krauss[1]

IPPP Durham

CERN MC4LHC - Tools readiness workshop - 29.3.2010

www.ippp.dur.ac.uk

[1] for the Sherpas: J. Archibald, T. Gleisberg, S. Höche, H. Hoeth, F. Krauss, M. Schönherr, S. Schumann, F. Siegert, J. Winter, and K. Zapp

A brief introduction

- SHERPA has been under development since the late 1990's
  - In the beginning, borrowed and re-implemented physics from others: virtuality-ordered parton shower - APACIC++, underlying event like PYTHIA 6.2
  - Helicity amplitudes for matrix elements - AMEGIC++
  - Fragmentation/hadron decays through link to PYTHIA routines
- Constructed from scratch, in C++
  - Mainly done by diploma and PhD students
- Replaced physics modules one-by-one.
- Status in SHERPA 1.2: by now independent of other code
  - Virtuality-ordered shower replaced by dipole shower,
  - Berends-Giele matrix elements,
  - Own version of cluster fragmentation AHADIC++,
  - Huge own library of hadron and τ-decays,
  - QED radiation through YFS formalism,
  - Only UE modelling still along the line of Sjostyrand-van der Zijl, PYTHIA 6.2.
- A full-fledged independent event generator

High multiplicity matrix elements

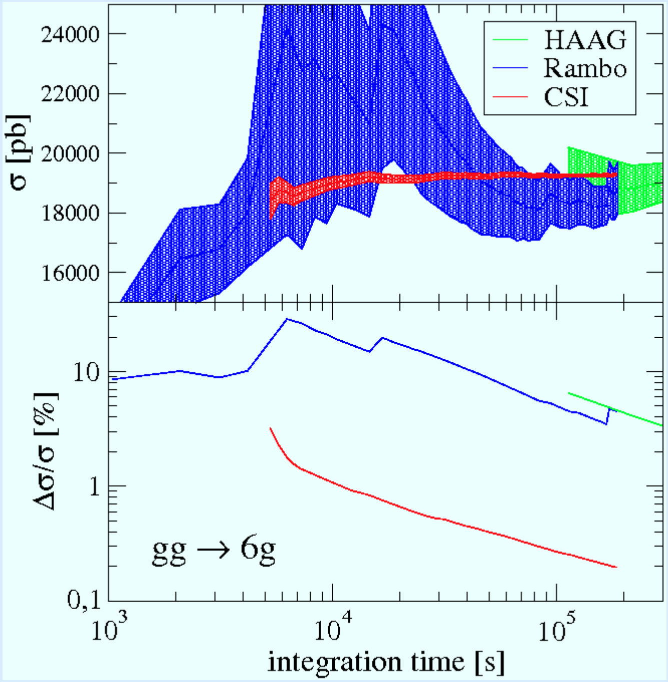
Matrix element generation in SHERPA 1.2

- Provides three kinds of matrix elements:
  - Since 1.2.0: COMIX- mainly SM, can handle up to 8-10 final state particles
    (implementations for BSM-relevant methods have low priority in COMIX.)
  - AMEGIC++- SM & BSM generator, up to 6 final state particles
    (development stalled, will eventually move to COMIX.)
  - specific, hard-coded ME's
- Using COMIX makes SHERPA even easier to handle:
  no more libraries written out to be compiled in intermediate step.
- SHERPA/AMEGIC++ support FEYNRULES
  (a tool to generate Feynman rules directly from Lagrangians - a new standard to propagate BSM models?)
- No support for LHA - considered pointless by SHERPA.

SM matrix element generator COMIX

T.Gleisberg & S.Hoeche, JHEP **0812** (2008) 039

- Colour-dressed Berends-Giele amplitudes in the SM
- Fully recursive phase space generation
- Example results (phase space performance):



BSM matrix element generator AMEGIC++

F.K., R.Kuhn, G.Soff, JHEP **0202** (2002) 044.

- Uses helicity/recursion methods;
- Helicity method supplemented with "factoring out" (taming the factorial growth)
- Phase space integration through multi-channeling (i.e. one phasespace mapping/Feynman diagram)
- Implemented & tested models: SM, SM+AGC, THDM, MSSM, ADD.
- Tested in > 1000 SM & > 500 MSSM channels.
- Recently: Automated dipole subtraction for NLO calculations

(Fully supports the NLO-LHA)

Parton showering in Sherpa 1.2

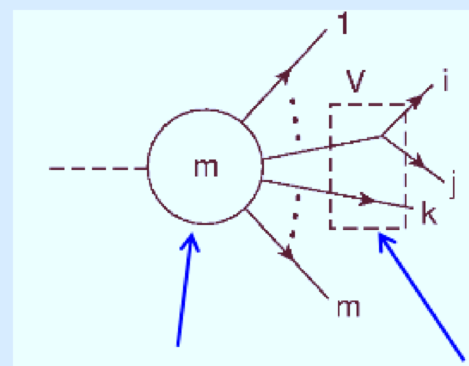
Parton shower based on Catani-Seymour splitting kernels

First discussed in: Z.Nagy and D.E.Soper, JHEP **0510** (2005) 024

Implemented by M.Dinsdale, M.Ternick, S.Weinzierl Phys.Rev.**D76** (2007) 094003

and S.Schumann& F.K., JHEP **0803** (2008) 038.

- Explicit use of factorization formulae for real emission process $\longleftrightarrow$ NLO dipole subtraction
- Full phase space coverage (invertible).
- Typically good approximation to ME.
- Project onto leading $1/N_c$ & employ spin-averaged dipole kernels.
- four types of splittings: FF, IF, FI, II.
- Recently: improved kinematics mappings to account for exponentiation properties



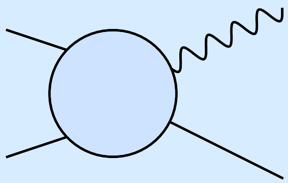
m-parton state splitting operator

(Work in progress.)

Merging for Prompt-Photon Production

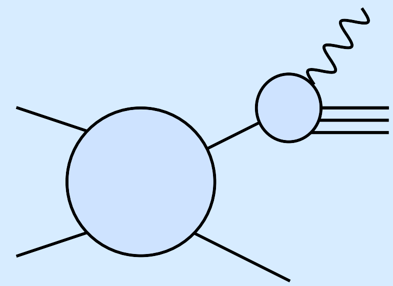
The perturbative QCD approach

Direct production



- fixed-order calculations
  - γ+jet @ NLO (JetPhox) [Catani et. al]
  - $\gamma\gamma$ @ NLO (DiPhox) [Binoth et. al]
  - $\gamma\gamma$+jet @ NLO [Del Duca et. al]
  - $gg \to \gamma\gamma g$ [de Florian et. al]

Fragmentation component



- QED $\gamma - q$ collinear singularity
- resummation to all orders α_s
- fragmentation function $D^{\gamma}_{q,g}$

- Apporach bases on IR safe xsec definition (photon isolation) [cone, smooth isolation, democratic approach]
- Assumption: non-prompt component, e.g. $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$, experimentally separable

A new model for Minimum Bias (and the underlying event)

Underlying ideas

- Multi-channel eikonal approach
  allows for natural description of low-mass diffraction
- Rooted in unitarisation by exponentiating eikonals
- BFKL-inspired interpretation: exchange of "ladders" (cut pomerons) between hadrons
- Naturally incorporates diffraction/diffractive parts in ladder dynamics

Conclusions

SHERPA v1.2 and beyond

- SHERPA v1.2 added enhanced physics and usability:
  higher multis, no more libraries, merging completely automatic
- New merging algorithm with improved features:
  - less merging scale uncertainty (below 10% in most cases), smooth transitions
  - has been extended to DIS ($\rightarrow$ VBF) and prompt photon production
- Added dipole subtraction for NLO calculations (LH accord)
- Will include new Minimum Bias model by summer
- First steps towards NLO precision under way.

VINCIA: towards NLO showers

Simple shower formalism based on $2 \to 3$ antenna factorization for arbitrary evolution variables, recoil maps, radiation kernels, etc.

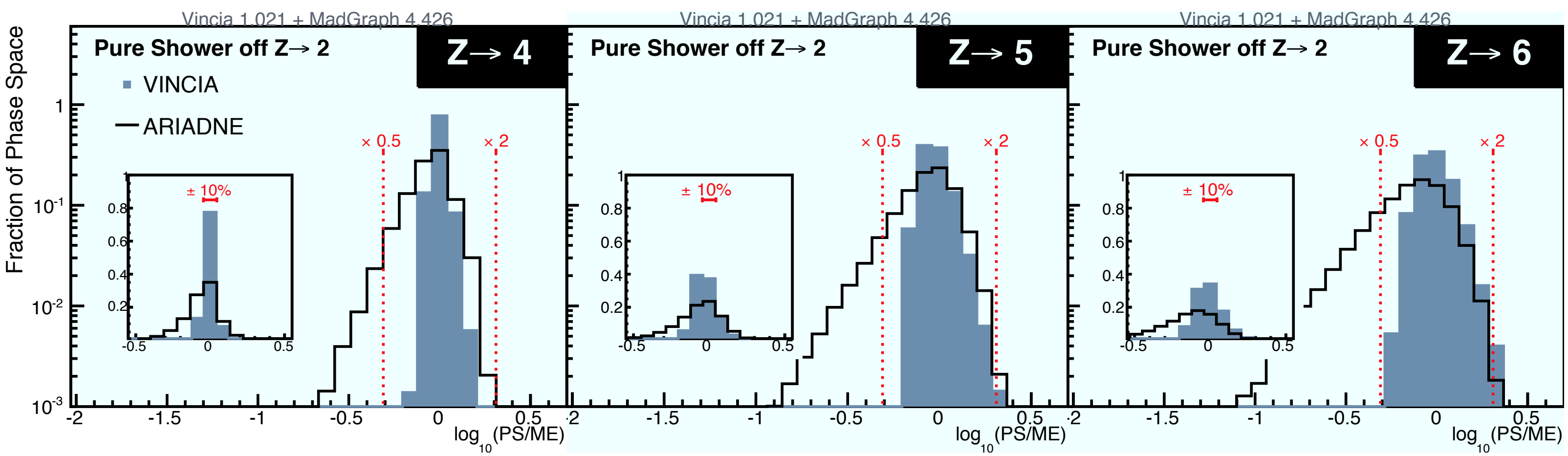
Matching = cancel dependence on free parameters to given order

+ *Exponentiate matching* = Use subleading logs in ME to improve resummation instead of destroying it (currently no "matching scale" needed before $\alpha_s^3 \times$ Born)

+ *Improve Shower* = No dead zones, Markov Ordering (+ partial NLL matching)

Tree-Level expansion vs MadGraph (flat phase-space scan, full color):

(Narrow distributions = good logarithmic precision)



Pure shower

<VINCIA> =

$|M_4|^2 \pm$ 8%

$|M_5|^2 \pm$ 20%

$|M_6|^2 \pm$ 25%

(+ can do matching, up through $Z \to 6$ is already in)

Current Version = 1.021: massless FSR (first public release Sep 2009).

- Short Term: Long writeup (shower + tree-matching + LEP Pheno study)
- This Summer: Massive quarks (with M. Ritzmann, A. Gehrmann-de-Ridder)
- Long Term: Initial-State Radiation and multijet 1-loop matching.

Current status of ARIADNE

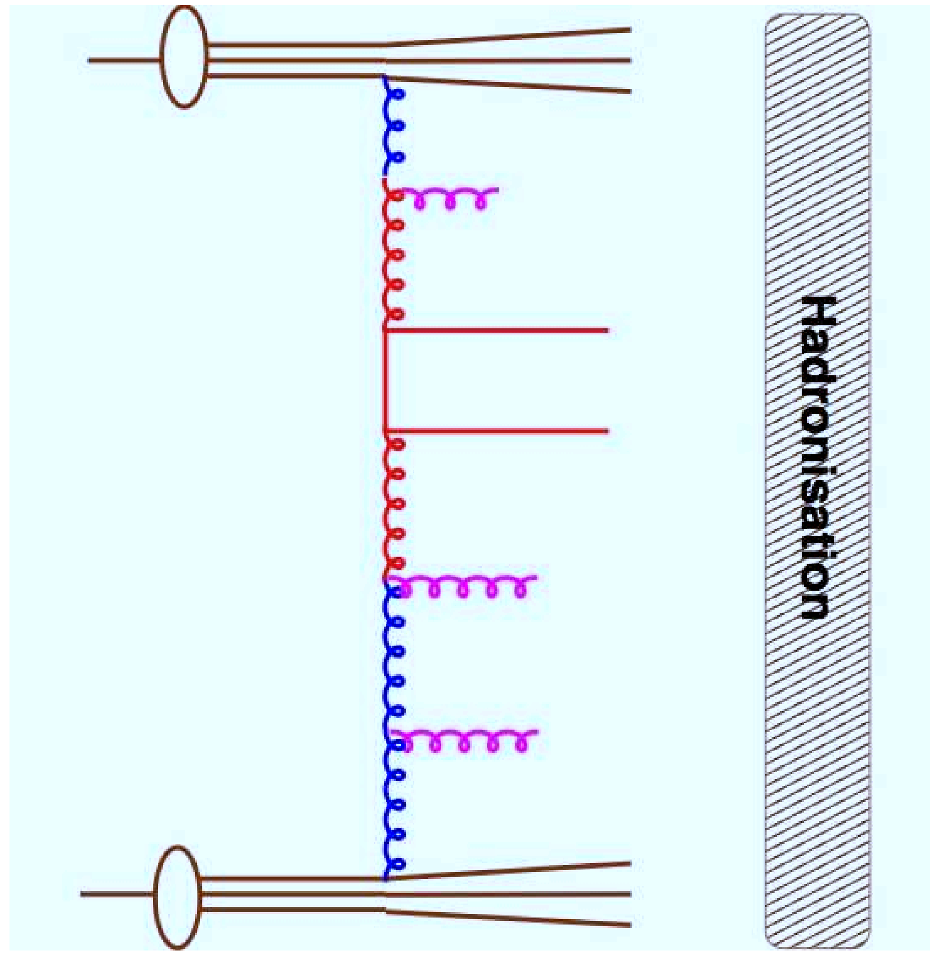
- Completely rewritten in C++ using THEPEG (main work by Nils Lavesson)
- Almost all components are in place
- Simple CKKW(L) matching
- $q \to g$ splitting included
- String fragmentation with PYTHIA8
- Validated for $\mathrm{e}^+\mathrm{e}^-$
- Modified model for initial-state radiation without recoil gluons needed.

Outlook

A completely new and perfect C++ implementation of ARIADNE with automatic tree-level and NLO merging, which perfectly describes all data as it comes out of LHC, will be available and fully documented by the 30th of June 2011.

CASCADE basic elements

- CASCADE elements are:
  - Matrix Elements:
    - ➔ on shell/off shell
  - PDFs
    - ➔ unintegrated PDFs
  - Parton Shower
    - ➔ angular ordering (CCFM)
- Proton remnant, final state PS and hadronization handled by standard hadronization program: **PYTHIA**



$$\sigma(pp \to q\bar{q} + X) \quad = \quad \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2 k_{t1} d^2 k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q})$$
$$\times x_{g1} \mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2} \mathcal{A}(x_{g2}, k_{t2}, \bar{q})$$

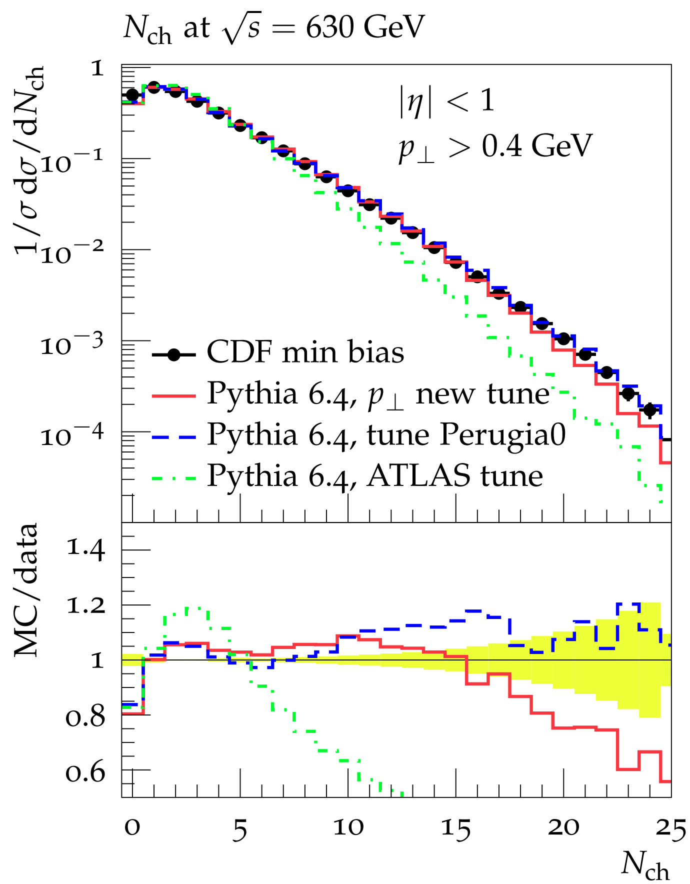
Outlook – future

- more processes to be implemented:
  - include all QCD also for large x and central region
    - need off-shell ME and quark uPDFs
  - more on DY
    - also for central region
  - more of Higgs — VBF
  - more on Onium production
  - speed up initial parton shower (A. Grebenyuk)
  - ....
- **major rewrite of CASCADE:**
  - to be part of ThePEG-"BC" for generators beyond collinear factorization (M. Kraemer)

Rivet

Tool for generator validation and comparisons with data:

- Analyses can be implemented in Rivet and applied to MC
- Uses HepMC $\Rightarrow$ generator-independent, perfect for comparisons
- Many key analyses are already implemented; many more to come.
- Important for keeping your data alive: Publish your numbers corrected to hadron level and implement your analysis in Rivet.



- Professor: smart exploration of parameter space for tuning

(borrowed from Hendrik Hoeth)

3 Kinds of Tuning

1. Fragmentation Tuning

Non-perturbative: hadronization modeling & parameters

Perturbative: jet radiation, jet broadening, jet structure

2. Initial-State Tuning

Non-perturbative: PDFs, primordial k_T

Perturbative: initial-state radiation, initial-final interference

3. Underlying-Event & Min-Bias Tuning

Non-perturbative: Multi-parton PDFs, Color (re)connections, collective effects, impact parameter dependence, ...

Perturbative: Multi-parton interactions, rescattering

(borrowed from Peter Skands)

Outlook

Generators in state of continuous development:

$\star$ better & more user-friendly general-purpose
matrix element calculators+integrators $\star$

$\star$ new libraries of physics processes, also to NLO $\star$

$\star$ more precise parton showers $\star$

$\star$ better matching matrix elements $\Leftrightarrow$ showers $\star$

$\star$ improved models for underlying events / minimum bias $\star$

$\star$ upgrades of hadronization and decays $\star$

$\star$ moving to C++ $\star$

$\Rightarrow$ always better, but never enough

But what are the alternatives, when event structures are complicated
and analytical methods inadequate?

Final words

“Good,” said the First Speaker. “And tell me, what do you think of all this. A finished work of art, is it not?”

“Definitely!”

“Wrong! It is not.” This, with sharpness. “It is the first lesson you must unlearn. The Seldon Plan is neither complete nor correct. Instead it is merely the best that could be done at the time.”

— *And Now You Don’t (Second Foundation), Isaac Asimov, 1949*

But it often happens that the physics simulations provided by the Monte Carlo generators carry the authority of data itself. They look like data and feel like data, and if one is not careful they are accepted as if they were data.

J.D. Bjorken

from a talk given at the 75th anniversary celebration of the Max-Planck Institute of Physics, Munich, Germany, December 10th, 1992. As quoted in: Beam Line, Winter 1992, Vol. 22, No. 4

Appendix: The Generator Exercises

Today: familiarize yourself with the generators standalone.
Pick either of HERWIG, PYTHIA or SHERPA,
and work through exercises (worksheets will be available).
When/if you feel you know enough, go on to another generator.

Friday: study production of Z + jets, comparing with RIVET data.
Combine in groups to share work,
and collect results for physics comparisons.

Monday: study minimum-bias and underlying-event models,
again compared with RIVET data, and again in groups.

Further instructions to follow in beginning of each session.