Gösta and The Dipole

Lund University

Symposium
“Dipoles Are Forever”
Lund, 9 January 2008
Torbjörn Sjöstrand
Ph.D. in 1971:
‘Resonances and Dispersion Relations in Elementary Particle Physics’,
thesis advisors Gunnar Källén (Lund) and James Hamilton (Nordita)

~ 170 publications/workshop reports

~ 7000 citations

23 graduate students:
1977  Carsten Peterson
1980  Ingemar Holgersson
1982  Gunnar Ingelman
1982  Torbjörn Sjöstrand
1982  Olle Månsson
1983  Bo Söderberg
1983  Hans-Uno Bengtsson
1987  Bo Nilsson-Almqvist
1988  Ulf Pettersson
1989  Per Dahlqvist
1990  Leif Lönnblad
1992  Anders Nilsson
1992  Conny Sjögren
1993  Magnus Olsson
1995  An Tai
1996  Jim Samuelsson
1996  Jari Häkkinen
1998  Hamid Kharraziha
1999  Patrik Edén
2002  Gabriela Miu
2003  Fredrik Söderberg
2003  Sandipan Mohanty
2007  Emil Avsar
A Moment For Those Not With Us

Bo Andersson  (1937 – 2002)

Hans-Uno Bengtsson  (1953 – 2007)
Gösta’s fields of study:

- analyticity of the vertex function (1965)
- radiative corrections to $\beta$ decay
- two-body scattering processes and resonances
- vector meson production and SU(3) breaking
- diffractive processes, e.g. of charm
- the Lund model for quark and gluon jet fragmentation
- motion of the massless relativistic string
- dual description of a confined colour field
- local parton–hadron duality
- a colour dipole formulation of QCD cascades (Ariadne)
- parton and particle multiplicities in cascades
- fractal dimensions and intermittency in cascades
- hyperon polarization and other spin effects
- the FRITIOF model for heavy ion collisions (pp, pA, AA)
- prompt–photon emission
- baryon production mechanisms
- deuteron production
- colour–separate singlets in $e^+e^-$
- colour reconnections and the W mass
- colour-suppressed effects in cascades
- a discrete–QCD formulation of cascades
- Bose–Einstein and Fermi–Dirac effects
- the relation between DGLAP/BFKL/CCFM evolution
- the Linked Dipole Chain model of cascades
- gravitational scattering and black holes
- unintegrated parton densities and $k_\perp$ factorization
- proton structure at small $x$: energy conservation & saturation
- small-$x$ dipole evolution picture
- multiple interactions and minijets
- and more

so will only be able to highlight one thread in Gösta’s career, that “Dipoles are Forever”: 
QED: field lines go all the way to infinity

QCD: field lines are 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)
The First Dipole Appearance

1978
Describe fragmentation of the string stretched between a q and a $\bar{q}$ into smaller $q\bar{q}$ mesons:

i.e. scheme for fragmentation of $\text{dipole} \rightarrow \text{dipole} + \text{dipole}$.
A study of leptoproduction on a meson, for simplicity. When a meson/dipole is hit and a gluon is kicked out, it acts as a kink on the string stretched out:

Thus there are two string pieces/dipoles that can fragment, with one meson spanning the gluon kink. The force acting on a gluon is thus twice that on a quark, cf. $N_C/C_F = 3/(4/3) = 9/4$ in QCD.
Apply this gluon picture to $e^+e^- \rightarrow q\bar{q}g$:

The fragmenting systems are boosted away from the origin, giving a depletion in the angular region between the $q$ and the $\bar{q}$. 
1980 – 1983
Lund gluon picture supported by JADE observations with increasing statistics:

(JADE = A. Petersen, A. Wagner, R.D. Heuer + 66 more)

Many further developments and studies of string fragmentation.

Today: conventional wisdom.
The Second Dipole Appearance

1985
Lund picture “derived” in pQCD in terms of dipole radiation pattern: around $q\bar{q}g$ and $q\bar{q}\gamma$

the “Leningrad dipole” (now St. Petersburg)
1986
A chain of dipoles offers
dual description to
a colour-ordered set of gluons.

Formulate a parton cascade
in terms of
dipole → dipole + dipole
instead of g → g g.

Transverse-momentum-ordered
dipole showering
properly takes into account coherence,
equivalently with angular ordering.
Partons always on shell.
Advantages: geometric picture of evolution, fractal nature of cascade (intermittency)

(a) The phase space available for a gluon emitted by a high energy $q\bar{q}$ system in the $y - \kappa$ plane ($\kappa = \ln k_{T}^{2}/\Lambda^{2}$).

(b) If one gluon is emitted at $(y_1, \kappa_1)$ the phase space for a second (softer) gluon is represented by the area of this folded surface.

(c) Each emitted gluon increases the phase space for the softer gluons. The total gluonic phase space can be described by this multifaceted surface.

Has inspired current thinking on showers and NLO:

- ARIADNE
- Catani-Seymour dipoles
- PYTHIA (6.3 –)
- Nagy, Soper
- VINCIA (Giele, Kosower, Skands)
- SHERPA (Schumann, Krauss)
- SHERPA (Winter, Krauss)
- Dinsdale, Ternick, Weinzierl
1995 –
Extension to initial-state-radiation:
Linked Dipole Chain (LDC) model

Important for understanding of small-$x$ physics
The Third Dipole Appearance

1994: describe evolution of dipoles inside a hadron in coordinate space
(A.H. Mueller)
2004 –: studied in Lund

to provide improved understanding of small-$x$ evolution
w.r.t. energy conservation, saturation, colour-flow effects, . . .
Promising for better understanding of “soft” physics at LHC
Summary of a distinguished career:
★ many influential ideas ★
★ a productive thesis advisor ★
★ an excellent teacher ★
★ a great popularizer ★
★ a conscientious administrator ★

We wish you

Continued Physics Adventures

during the upcoming “sabbatical” in Hamburg and beyond

(we/I need you as bridge between the formal and the phenomenological communities working on multiple parton–parton interactions)