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)

$\sim$ 170 publications/workshop reports

$\sim$ 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)

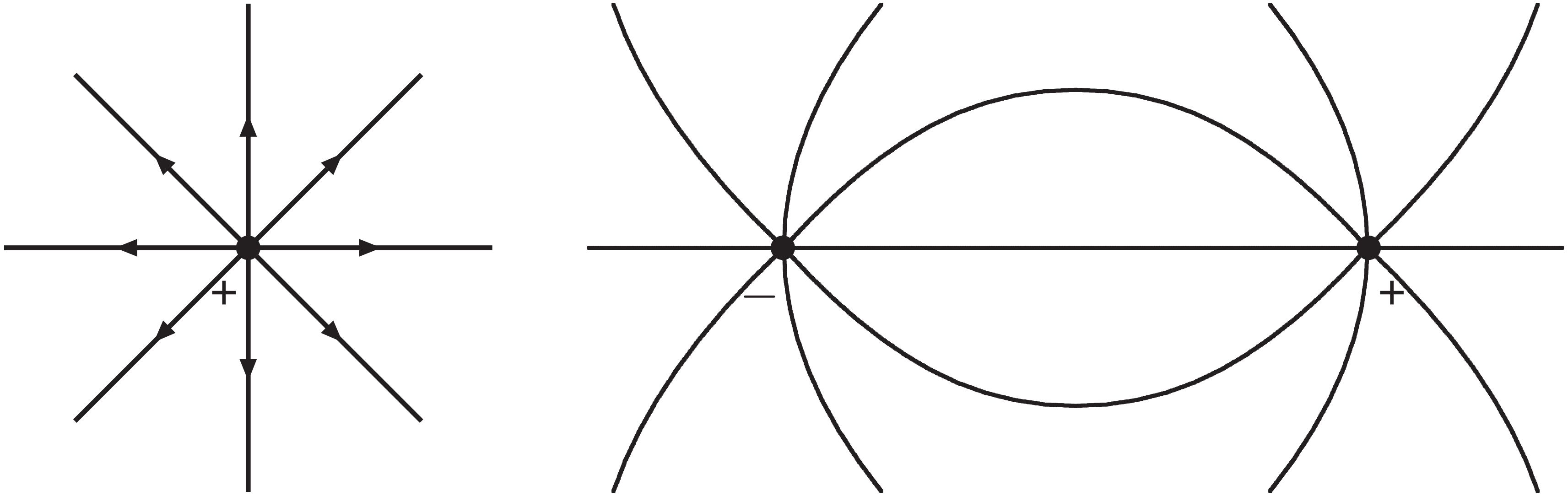
Gösta's fields of study:

- analyticity of the vertex function (1965)
- radiative corrections to β 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

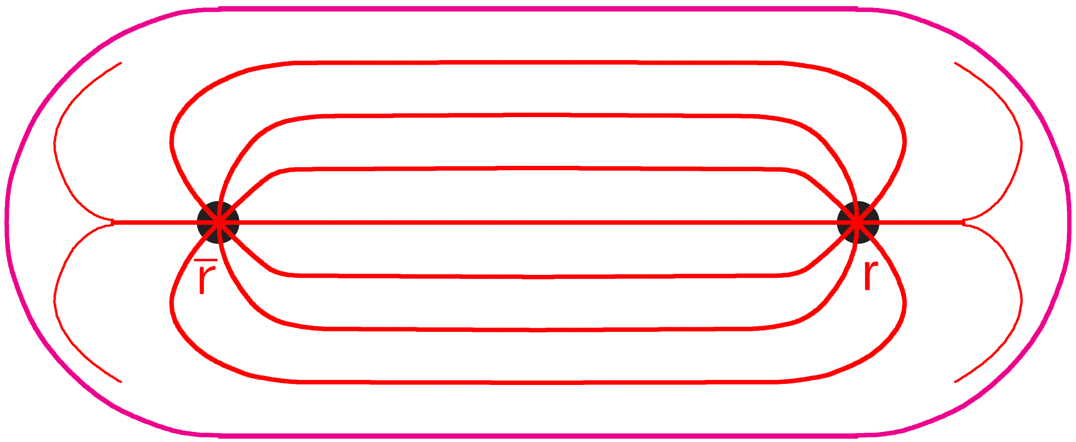
- deuteron production
- colour–separate singlets in e^+e^-
- colour reconnections and the W mass
- colour-suppressed effects in cascades
- a discrete–QCD formulation of cascades
- Bose–Einstein and Fermi–Dirac effects
- the relation between DGLAP/BFKL/CCFM evolution
- the Linked Dipole Chain model of 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 carreer,
that “Dipoles are Forever”:

QED: field lines go all the way to infinity



QCD: field lines are compressed to tubelike region(s) ⇒ **string(s)**

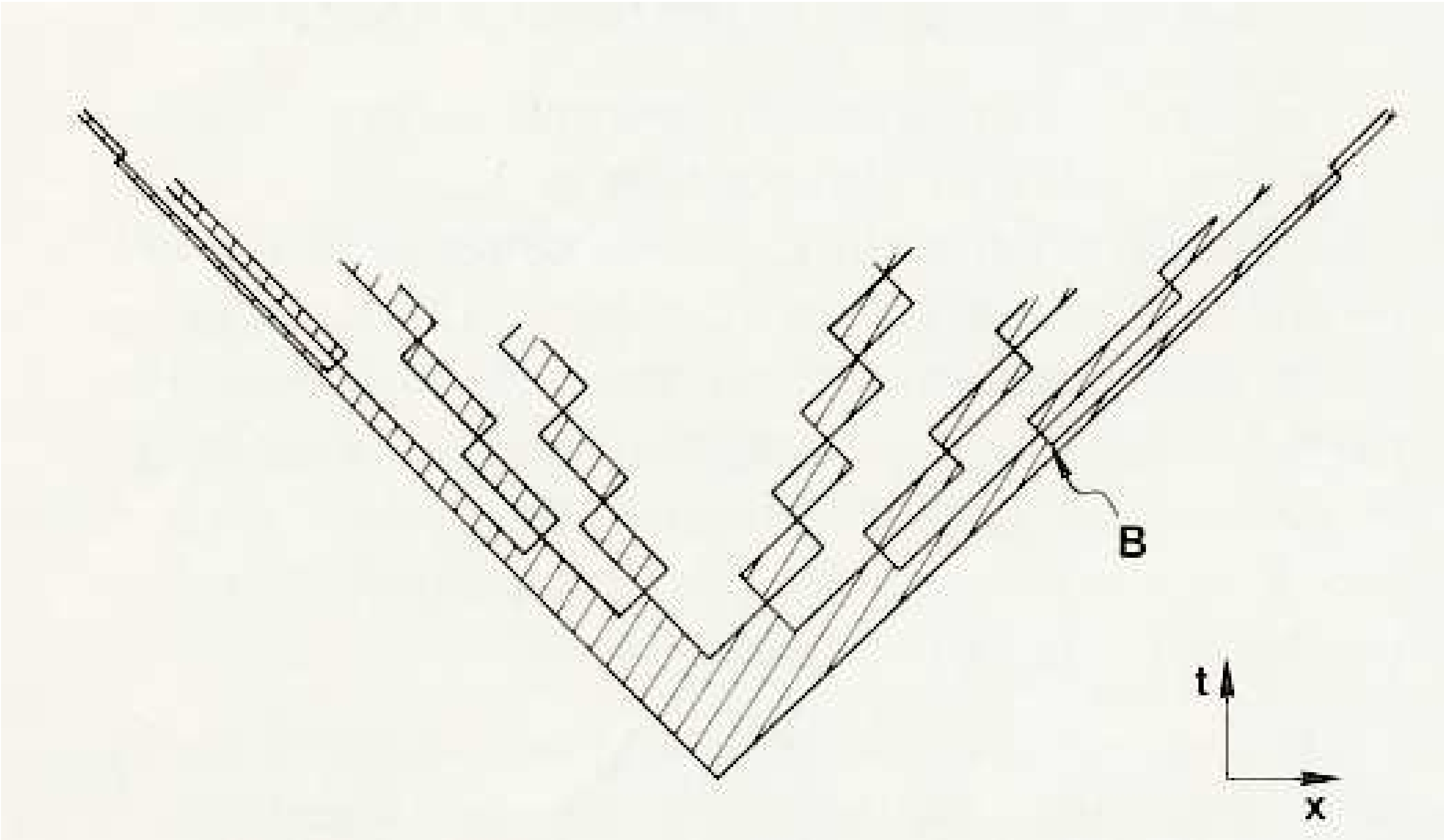


by self-interactions among soft gluons in the “vacuum”.
(Non-trivial ground state with quark and gluon “condensates”.
Analogy: vortex lines in type II superconductor)

The First Dipole Appearance

1978

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



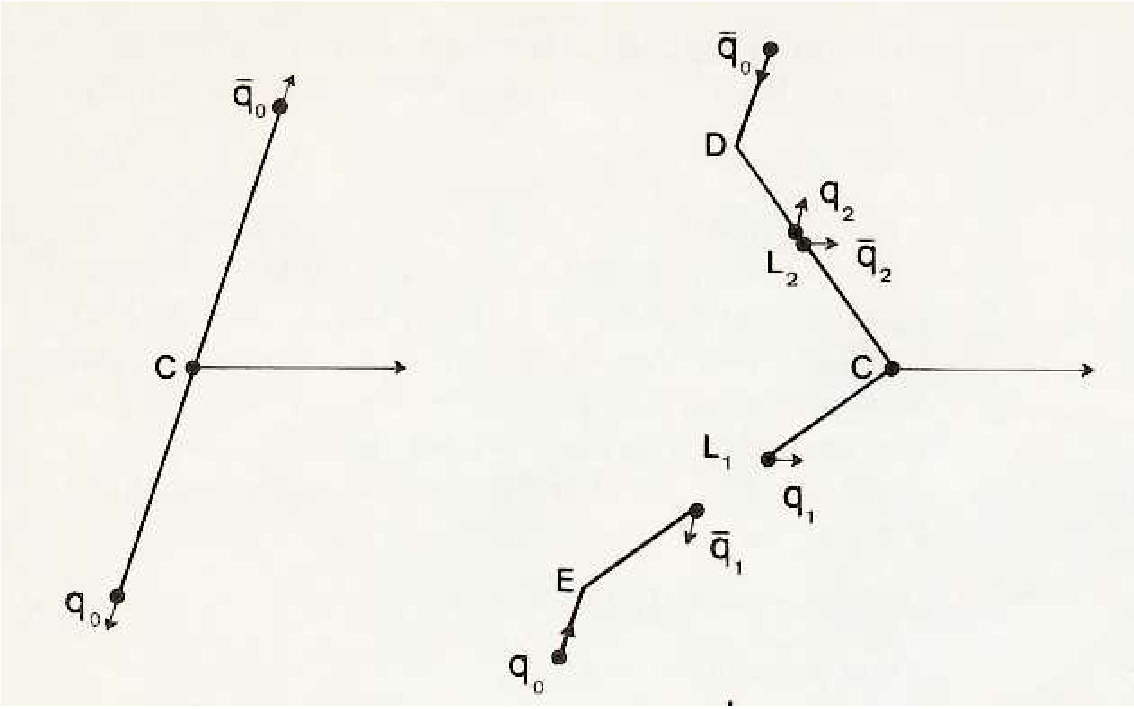
i.e. scheme for fragmentation of **dipole** $\rightarrow$ **dipole** $+$ **dipole**.

1979

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,

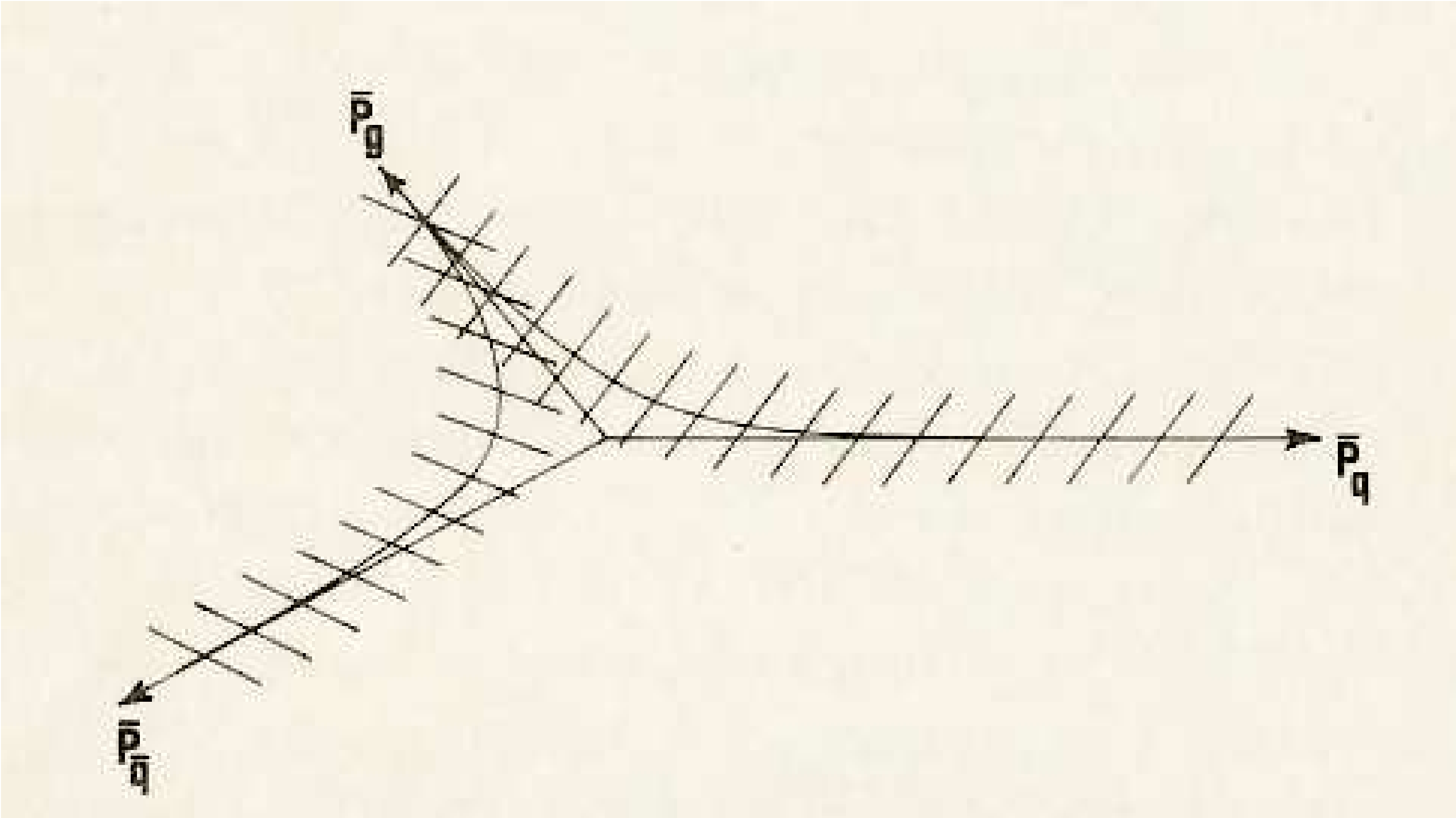
with one meson spanning the gluon kink.

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.

1980

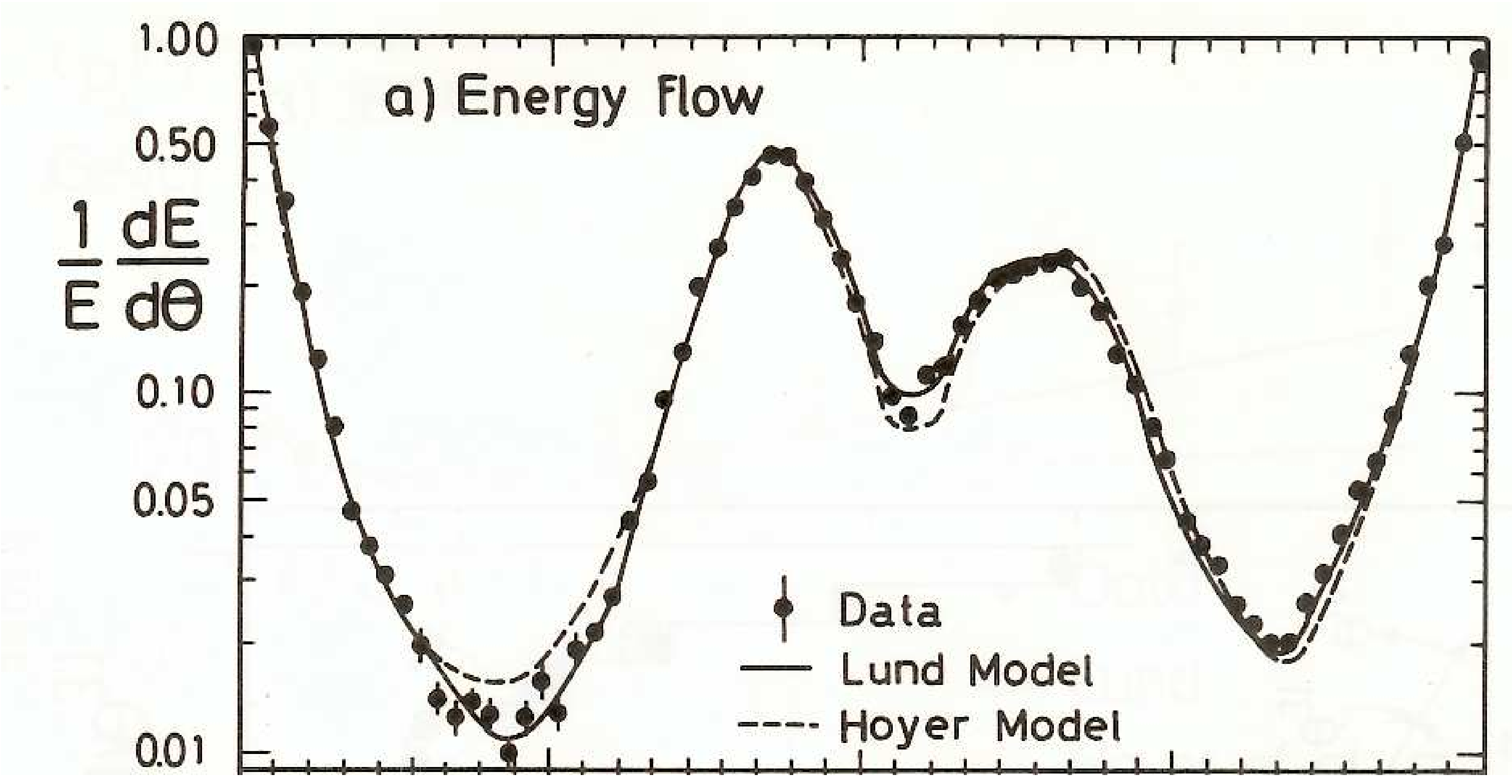
Apply this gluon picture to $e^+e^- \to q\bar{q}g$:



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.

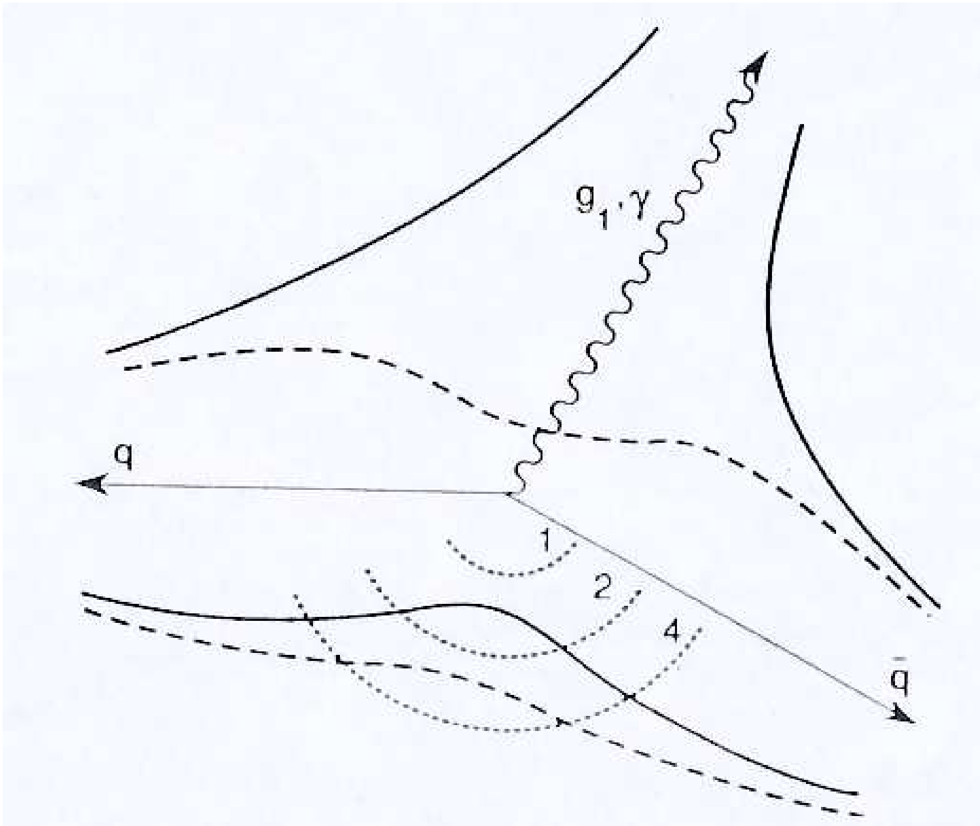
Today: conventional wisdom.

The Second Dipole Appearance

1985

Lund picture “derived” in pQCD in terms of **dipole** radiation pattern:

around $q\bar{q}g$ and $q\bar{q}\gamma$



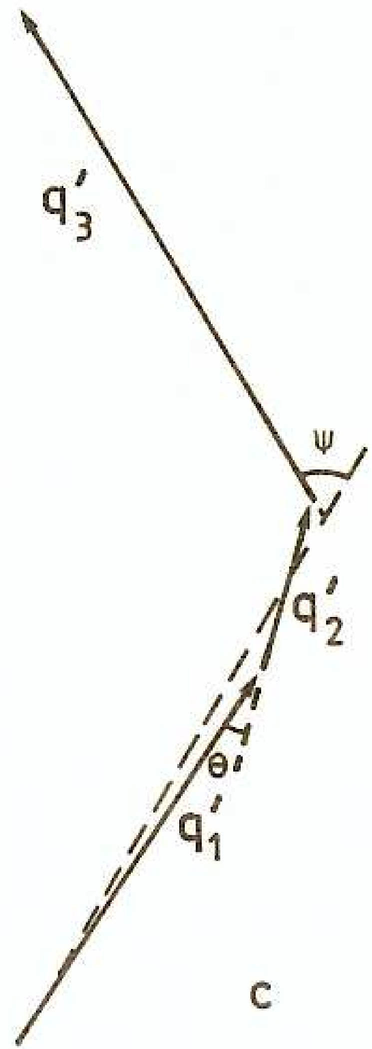
the “**Leningrad dipole**” (now St. Petersburg)

(Ya.I. Azimov, Yu.L. Dokshitzer, V.A. Khoze, S.I. Troyan)

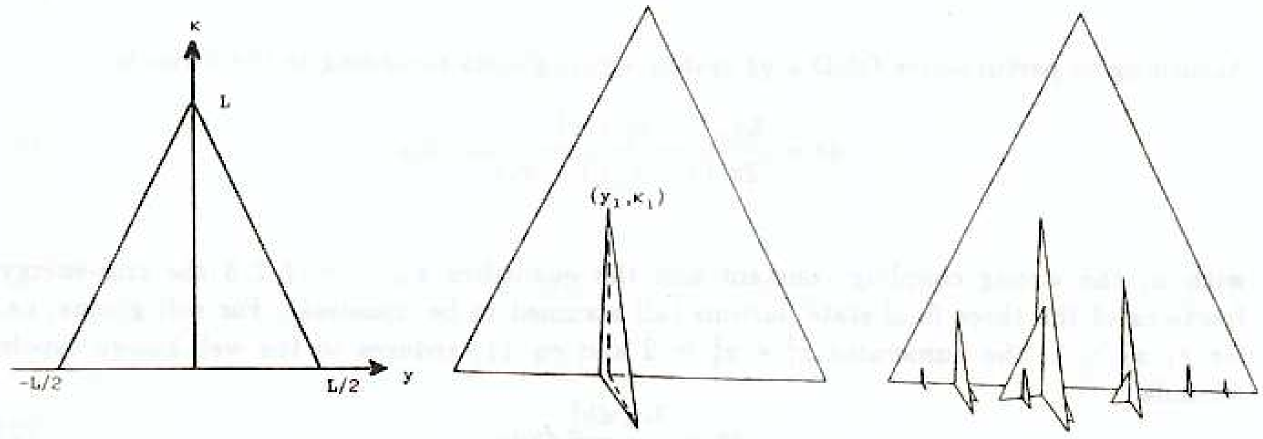
1986
A chain of dipoles offers
dual description to
a colour-ordered set of gluons.

Formulate a parton cascade
in terms of
dipole $\rightarrow$ **dipole** $+$ **dipole**
instead of g $\rightarrow$ 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 is a triangular region in the $y - \kappa$ plane ($\kappa = \ln k_\perp^2/\Lambda^2$).

(b) If one gluon is emitted at (y_1, κ_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.

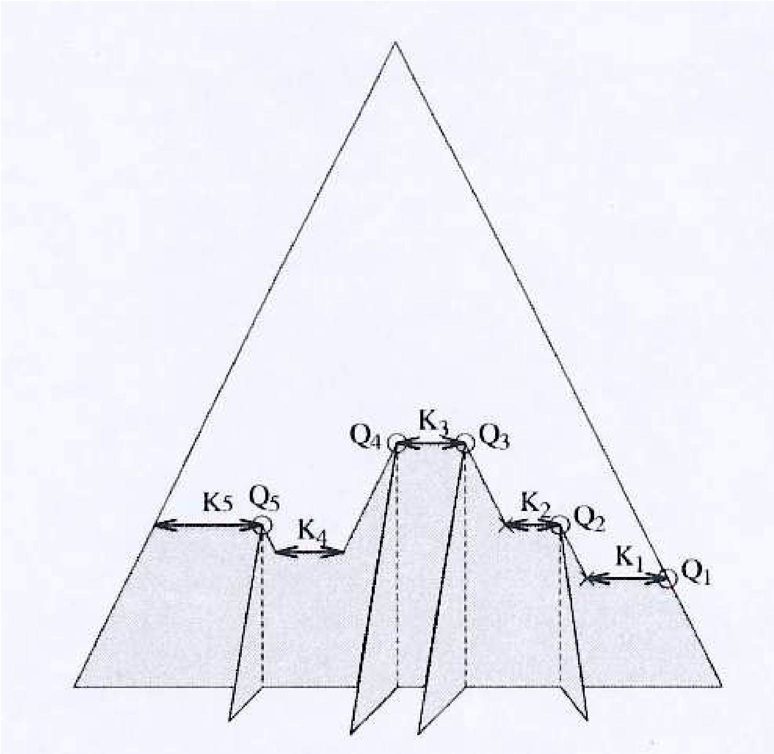
Has inspired current thinking on showers and NLO:

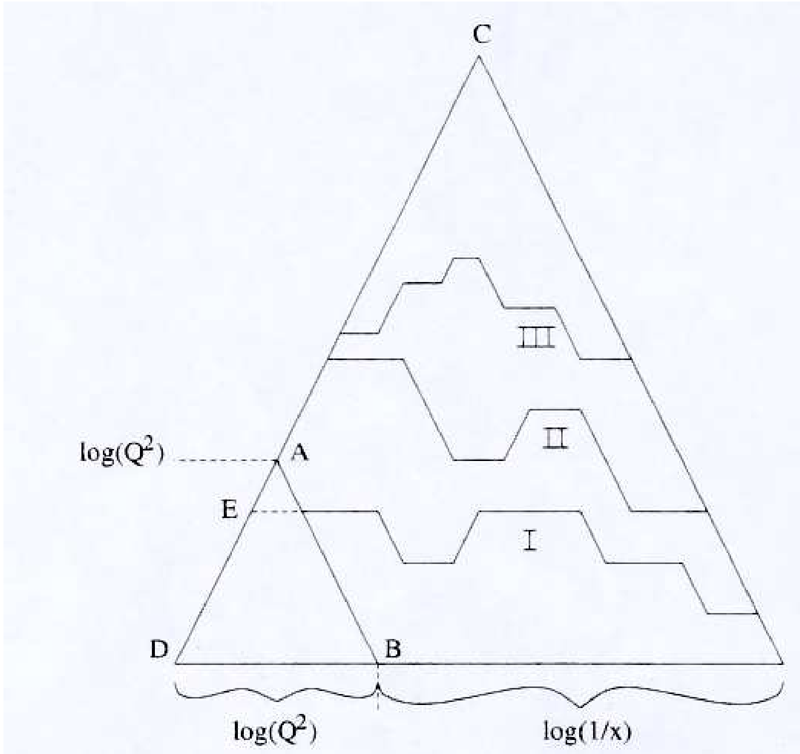
- ARIADNE
- Catani-Seymour dipoles
- PYTHIA (6.3 –)
- Nagy, Soper
- VINCIA (Giele, Kosower, Skands)
- SHERPA (Schumann, Krauss)
- SHERPA (Winter, Krauss)
- Dinsdale, Ternick, Weinzierl

1995 –

Extension to initial-state-radiation:

Linked Dipole Chain (LDC) model

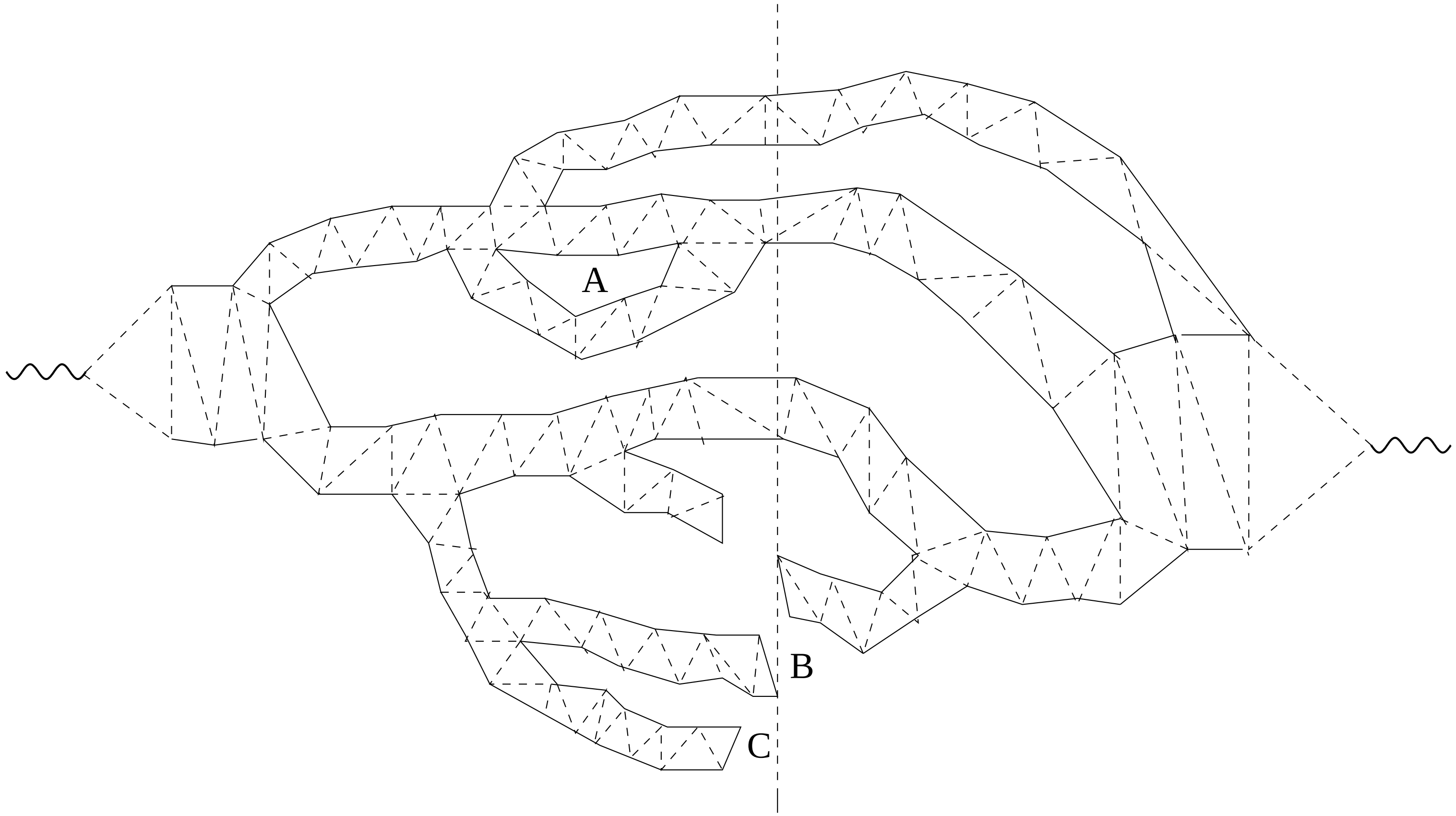




Important for understanding of small-x physics

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 carreer:

⋆ 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)