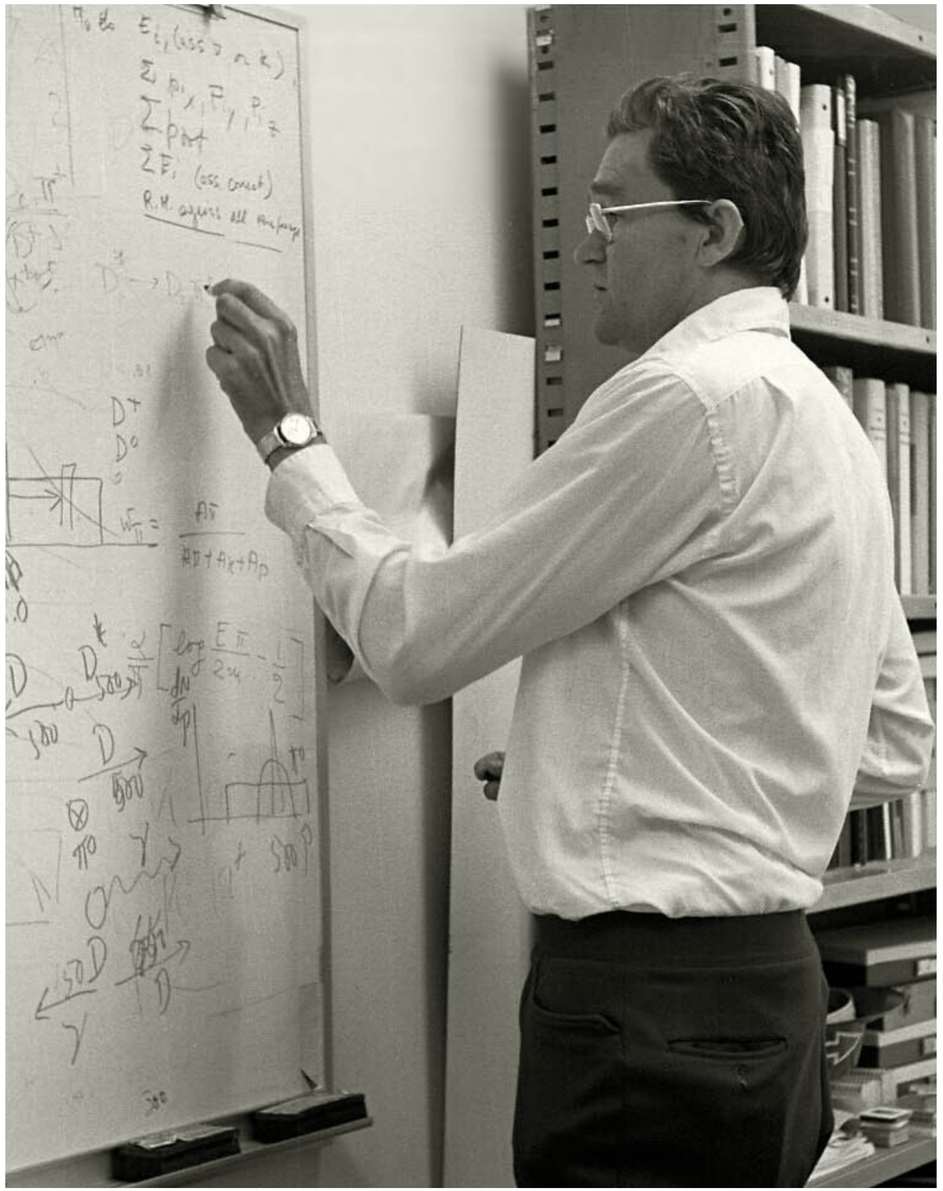
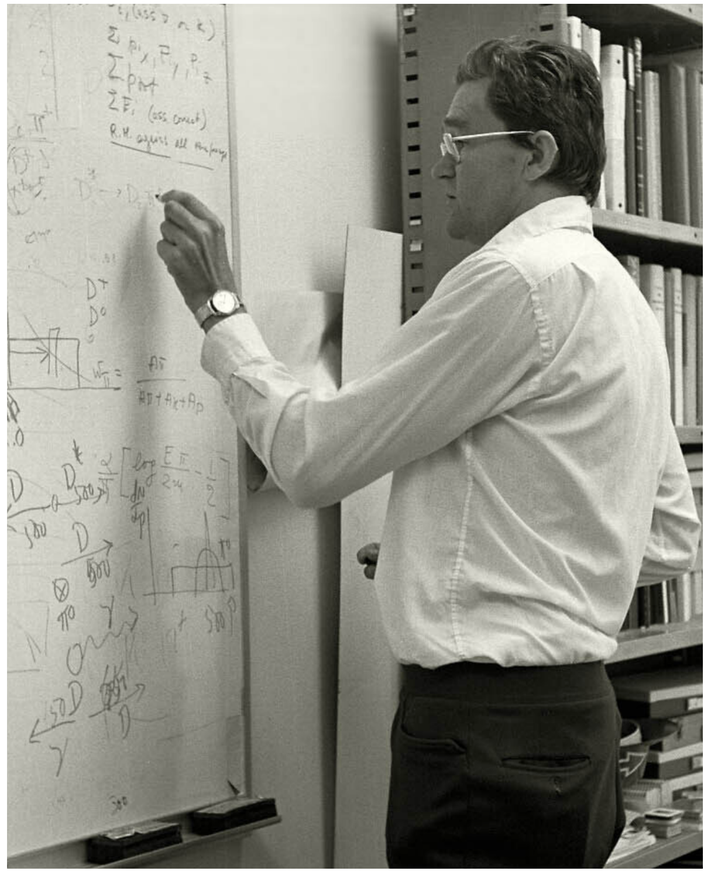
Remembering Bj: a Symposium in Honor of James Bjorken



Stan Brodsky

SLAC NATIONAL ACCELERATOR LABORATORY

Bjorken's pioneering work on deep inelastic scattering led the foundations for major innovations in high energy physics in the 1970's,
including signals for quark and gluon production, especially jet structure
and many fundamental analytic tools for QCD:
structure functions, distribution amplitudes, evolution equations
consequences of color confinement
quark and gluon jets vs. alternative "statistical" models
rapidity distributions in different domains
scaling laws underlying both inclusive and exclusive cross sections
gluonium production
polarization phenomena
sum rules



Some of Bj's highly cited publications

Asymptotic Sum Rules at Infinite Momentum

#1

J.D. Bjorken (SLAC) (Sep, 1968)

Published in: *Phys.Rev.* 179 (1969) 1547-1553

pdf links DOI cite claim reference search 2,065 citations

Inelastic Electron Proton and gamma Proton Scattering, and the Structure of the Nucleon

J.D. Bjorken (SLAC), Emmanuel A. Paschos (SLAC) (Apr, 1969)

Published in: *Phys.Rev.* 185 (1969) 1975-1982

pdf links DOI cite claim reference search 1,835 citations

Inclusive Processes at High Transverse Momentum

#4

S.M. Berman (SLAC), J.D. Bjorken (SLAC), John B. Kogut (SLAC) (Aug, 1971)

Published in: *Phys.Rev.D* 4 (1971) 3388

pdf links DOI cite claim reference search 820 citations

Some of Bj's highly cited publications

Elementary Particles and SU(4) #5

J.D. Bjorken (Bohr Inst.), S.L. Glashow (Bohr Inst.) (1964)

Published in: *Phys.Lett.* 11 (1964) 255-257

DOI cite claim reference search 795 citations

Inelastic Scattering of Polarized Leptons from Polarized Nucleons #6

J.D. Bjorken (SLAC) (Nov, 1969)

Published in: *Phys.Rev.D* 1 (1970) 1376-1379

pdf links DOI cite claim reference search 758 citations

Statistical Model for electron-Positron Annihilation Into Hadrons #7

J.D. Bjorken (SLAC), Stanley J. Brodsky (SLAC) (Oct, 1969)

Published in: *Phys.Rev.D* 1 (1970) 1416-1420

pdf links DOI cite claim reference search 586 citations

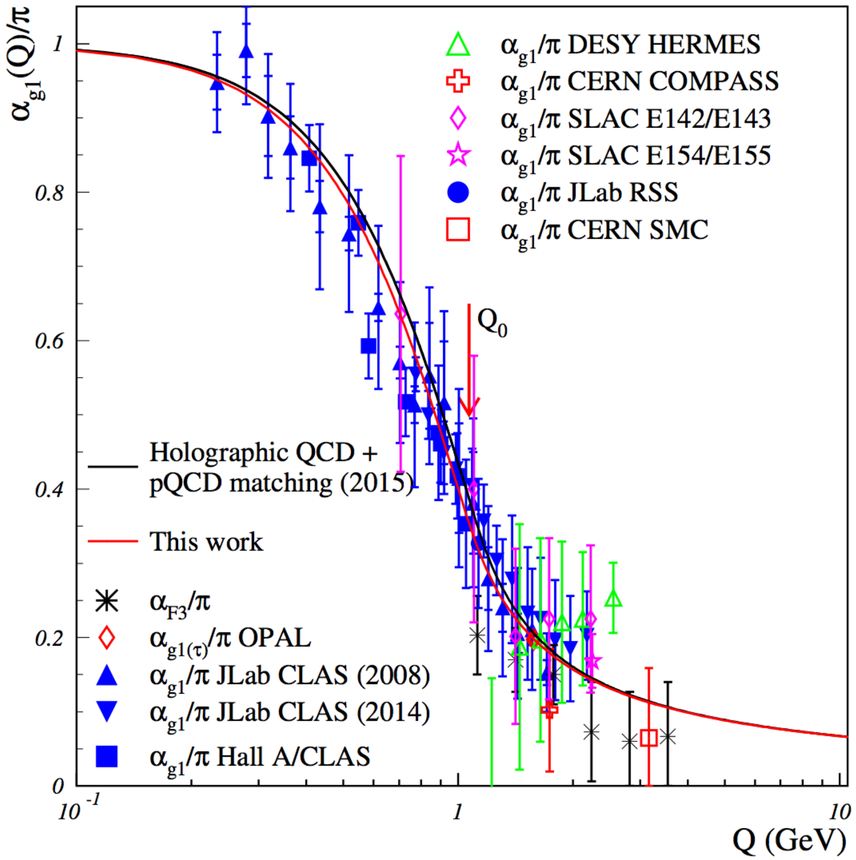
Quantum Electrodynamics at Infinite Momentum: Scattering from an External Field #8

J.D. Bjorken (SLAC), John B. Kogut (SLAC), Davison E. Soper (SLAC) (Oct, 1970)

Published in: *Phys.Rev.D* 3 (1971) 1382

pdf links DOI cite claim reference search 514 citatic

The Famous BJ Sum Rule underlies the QCD Running Coupling obtained at all scales from Color-Confining Light-Front Holography



Bjorken sum rule:

$$\frac{\alpha_{g_1}(Q^2)}{\pi} = 1 - \frac{6}{g_A}\int_0^1 dx\, g_1^{p-n}(x,Q^2)$$

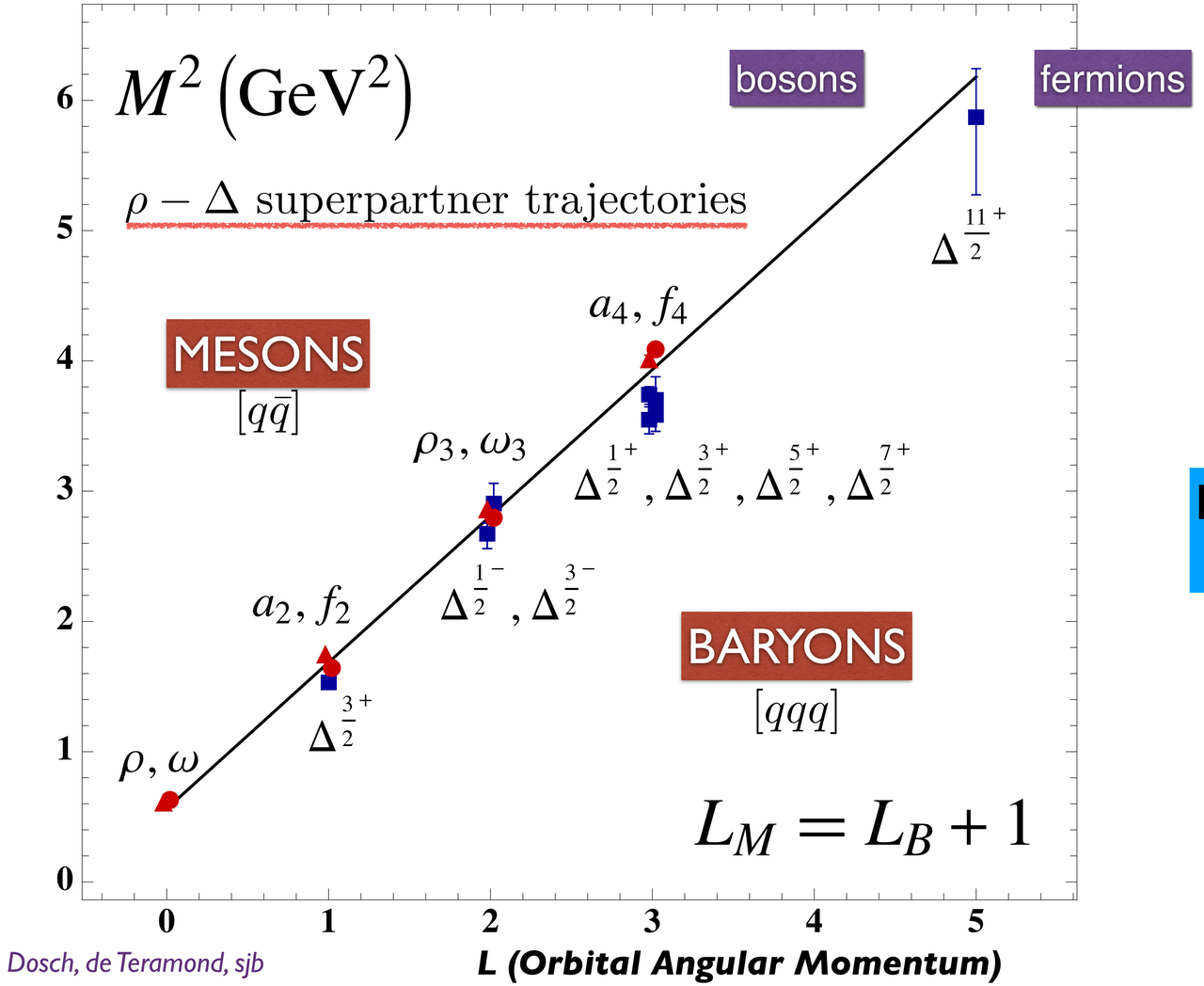
Effective coupling in LFHQCD (valid at low-Q^2)

$$\alpha_{g_1}^{AdS}(Q^2) = \pi \exp\left(-Q^2/4\kappa^2\right)$$

Imposing continuity for α and its first derivative

A. Deur, S.J. Brodsky, G.F. de Téramond,
Phys. Lett. B 750, 528 (2015); J. Phys. G 44, 105005 (2017).

Analytic, defined at all scales, IR Fixed Point
Single Fundamental Scale



Dosch, de Teramond, sjb

Fermion-Boson Supersymmetry for all hadronic trajectories

Universal Regge Slopes

Bj:

A THEORIST's VIEW OF e+e- ANNIHILATION*

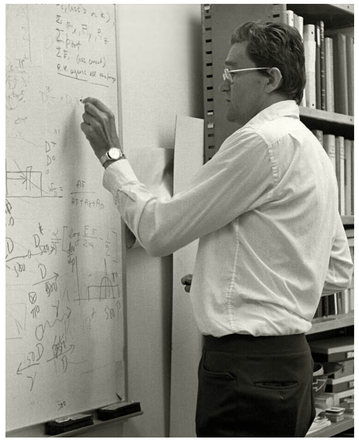
Just after the collision, wee partons have been heated (excited)
and no hadrons have been emitted.

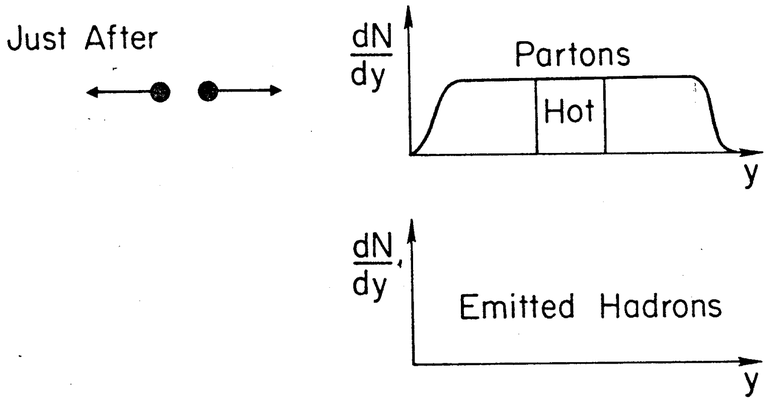
As time goes on, the wee partons rapidly cool by emitting wee hadrons and by heating the neighboring non-wee partons.

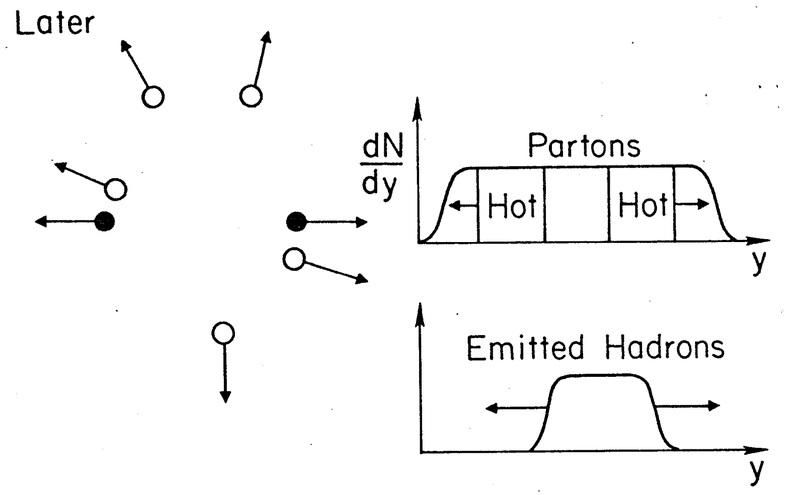
These in turn cool by emitting non-wee hadrons and again heating their neighbor partons in rapidity-space.

Thus the hadron plateau grows from the center outward.

The time at which partons of momentum p are heated is proportional to p (because of time dilation)
so that the total duration of the collision is $\Delta t \propto E_{CM}$



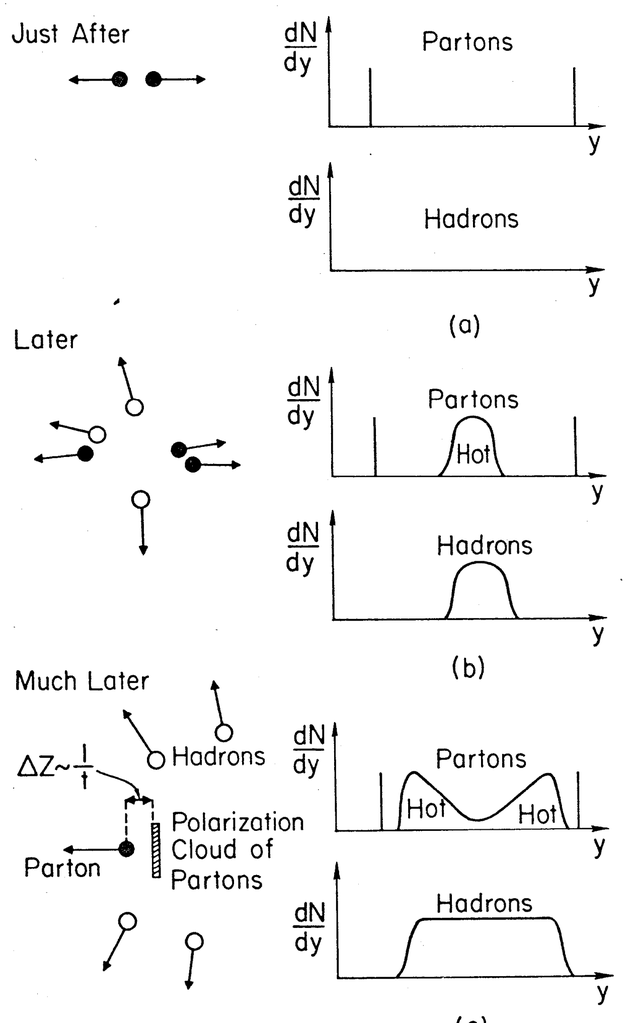




A THEORIST's VIEW OF e+e- ANNIHILATION*

J. D. Bjorken

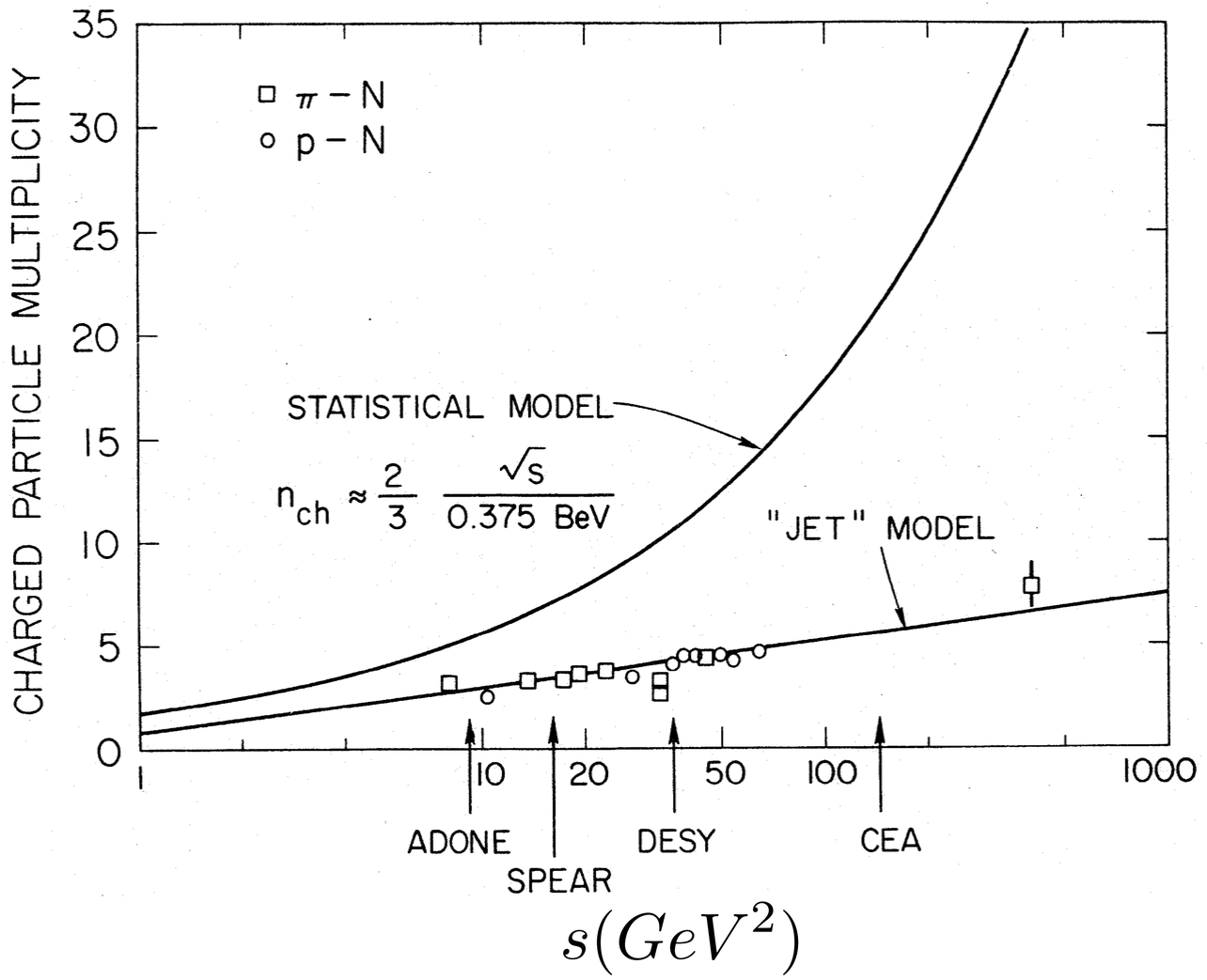
(Invited paper presented at the 1973 International Symposium on Electron and Photon Interactions at High Energies, \Bonn, Germany, August 27-31, 1973)



Statistical Model for electron-Positron Annihilation Into Hadrons

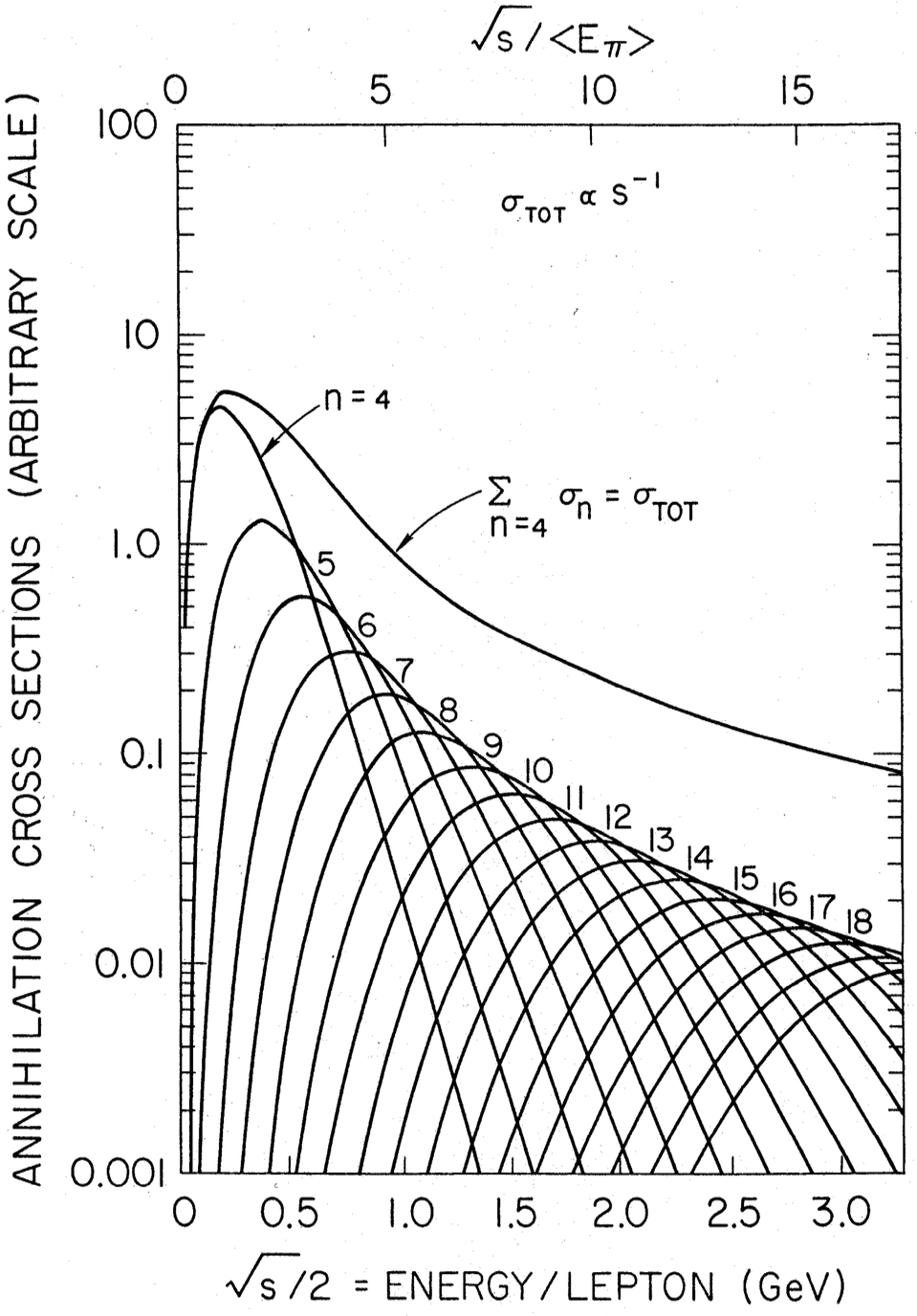
J.D. Bjorken (SLAC), Stanley J. Brodsky (SLAC) (Oct, 1969)

Published in: *Phys.Rev.D* 1 (1970) 1416-1420



Key Comparison:

Helped to establish Jet Physics


$\sqrt{s}/\langle E_\pi \rangle$
0
5
10
15
100
10
1.0
0.1
0.01
0.001
$\sigma_{TOT} \propto s^{-1}$
n = 4
$\sum_{n=4} \sigma_n = \sigma_{TOT}$
5
6
7
8
9
10
11
12
13
14
15
16
17
18
ANNIHILATION CROSS SECTIONS (ARBITRARY SCALE)
0
0.5
1.0
1.5
2.0
2.5
3.0
$\sqrt{s}/2$ = ENERGY/LEPTON (GeV)

Gold-Plated T

Comments or

Leptons: Old

New Quarks

Higgs

Gluonium

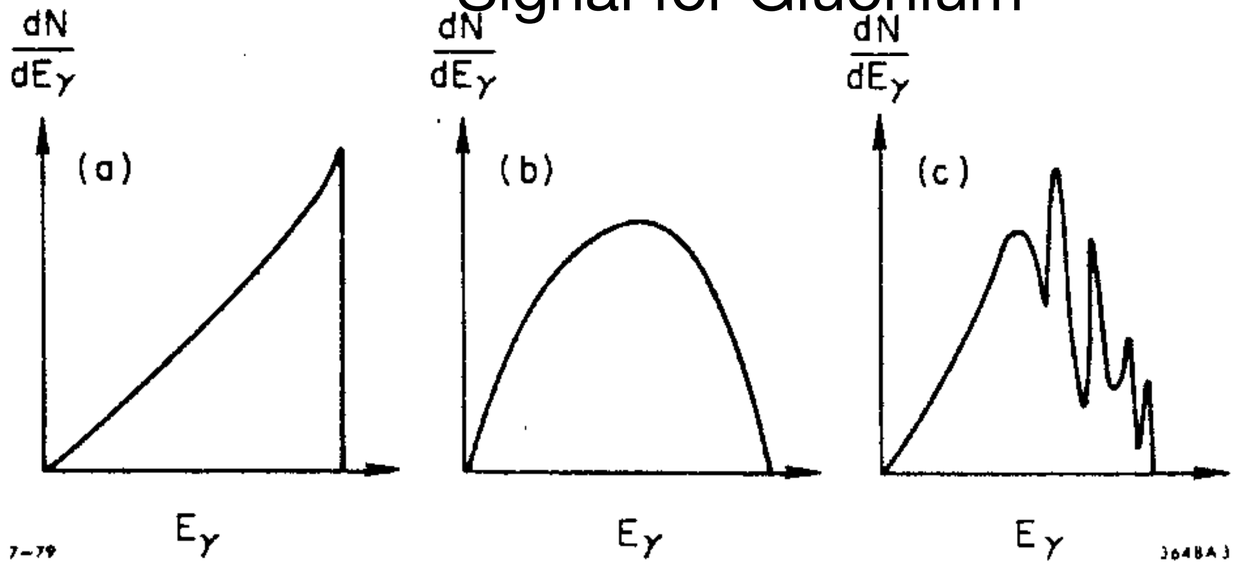
Unconfined C

ELECTRON-POSITRON ANNIHILATION: SOME REMARKS ON THE THEORY*

James D. Bjorken

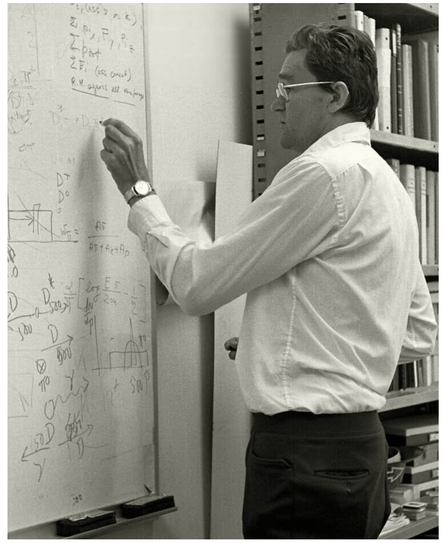
SLAC-PUB-2366. August 1979

Signal for Gluonium



(a) Lowest-order γ spectrum as calculated for $\psi \to \gamma gg$.
(b) The γ-spectrum (schematic) only after radiative corrections.
(c) The conjectured real spectrum after inclusion of gluonium resonances (with use of duality).

LEPTON-HADRON PROCESSES AT HIGH ENERGY



By J. D. BJORKEN

(Presented at the 5th Cracow School of Theoretical Physics, Zakopane, June 12-26, 1970)

1.Phenomenology, .

2 Current commutators and light cone behaviour, .

3 Dynamical models, .

4 ***Quantum electrodynamics at infinite momentum. —> Light Front Quantization***

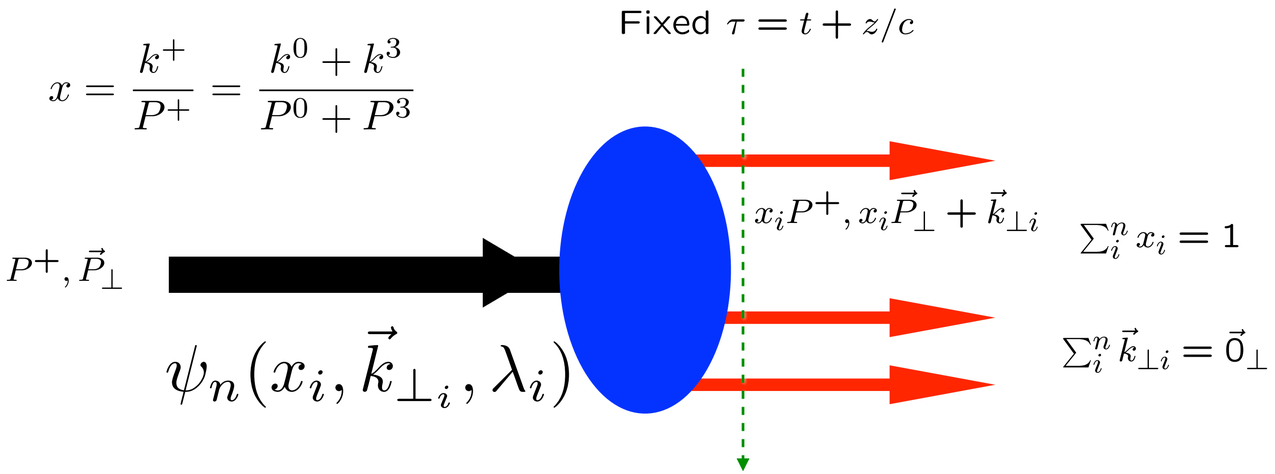
Bj: High energy physics at the present time finds itself at a threshold of great expectations. Not in a decade — perhaps never — has there appeared such a great leap forward as will soon appear in that most basic commodity of the field energy. At present, relatively little has been explored beyond 30 GeV. The Serpukhov machine at 70 GeV, NAL at 200, 400and eventually 500 GeV, the CERN ISR at lower intensity but a still higher equivalent laboratory energy of over 1500 GeV herald an increase in available energy of between one and two orders of magnitude.

Electron-positron colliding beam facilities under construction wil reach into a new high-energy regime. From the present region of s = EM ~ 1 GeV dominated by the vector-meson production, the new rings wil attain an s ~ 15-30 GeV with CEA capable of reaching s~ 10 GeV?. In this high energy region very little theoretical insight exists (other than for the pure electrodynamic processes) on what even the qualitative features will look like.

While the greatest of expectations lies in the anticipation of production of new kinds of particles (W's, quarks, monopoles, heavy leptons, hadronic leptons) or observation of new classes of interactions, or maybe even something present concepts are insufficient to deal with, there are other new classes of phenomena which are still not so unfamiliar as to be impossible for the theoretician ot try ot discuss. A major area of this nature and the subject of these lectures is that of lepton-induced hadron reactions at high energies.

Bj's infinite momentum analysis is equivalent to light-front quantization, Dirac's ``Front Form"

$$x = \frac{k^+}{P^+} = \frac{k^0 + k^3}{P^0 + P^3}$$



Eigenstate of LF Hamiltonian

$$H_{LF}^{QCD}|\Psi_h> = \mathcal{M}_h^2|\Psi_h>$$

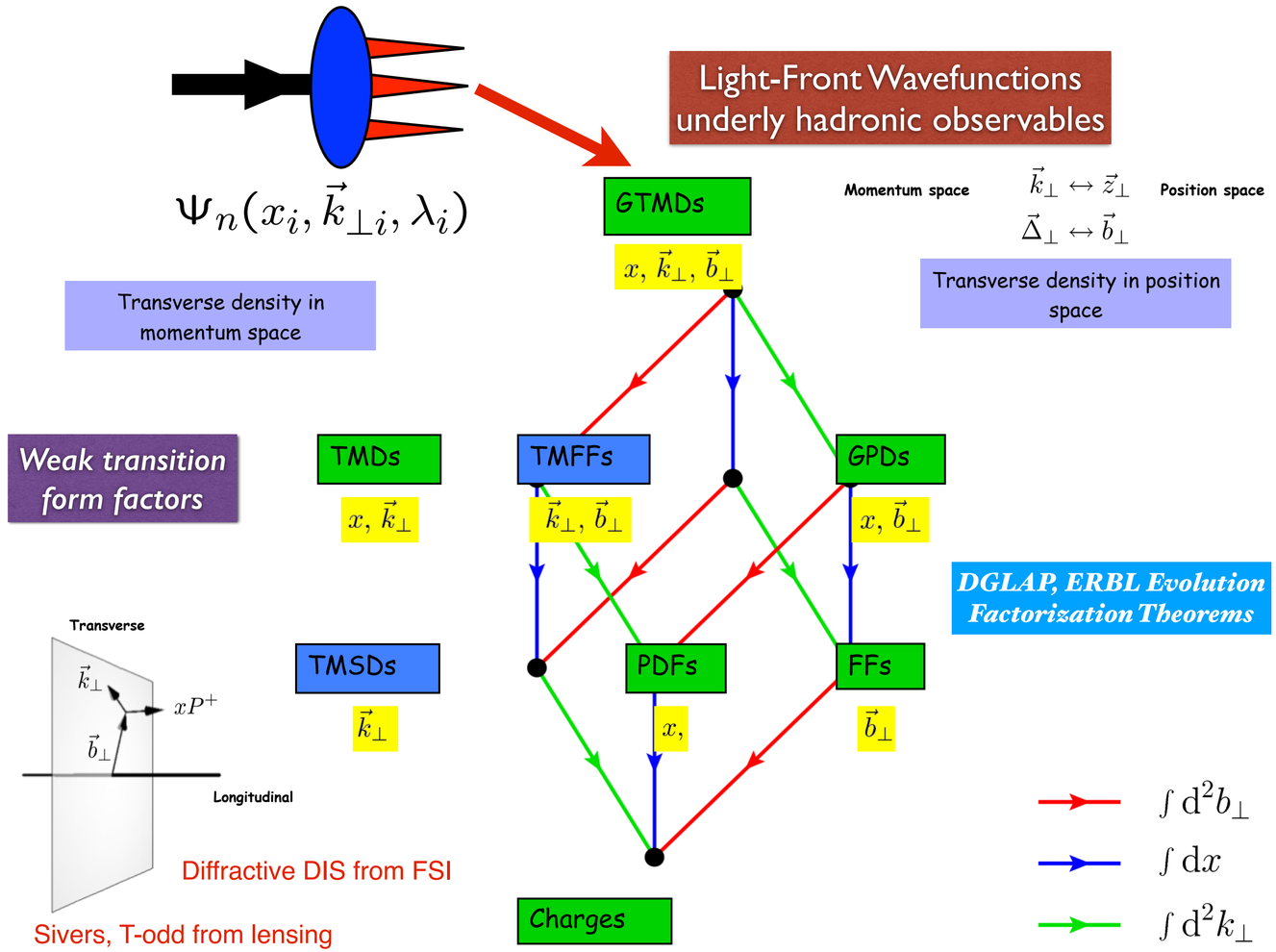
$$|p, J_z> = \sum_{n=3} \psi_n(x_i, \vec{k}_{\perp i}, \lambda_i)|n; x_i, \vec{k}_{\perp i}, \lambda_i>$$

Invariant under boosts! Independent of P^μ

Causal, Frame-independent. Creation Operators on Simple Vacuum, Current Matrix Elements are Overlaps of LFWFS

Light-Front Wavefunctions: rigorous representation of composite systems in quantum field theory

Lorce, Pasquini

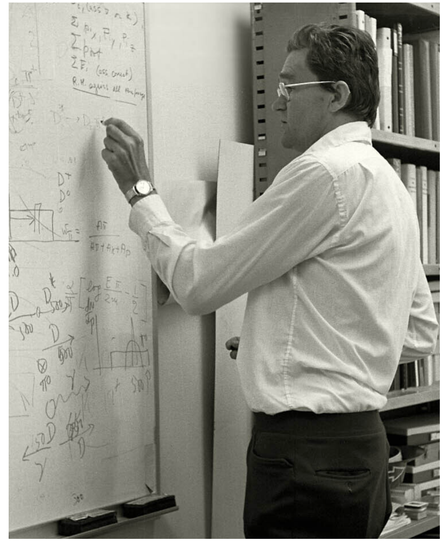


Bj's infinite momentum analysis is equivalent to light-front quantization, Dirac's ``Front Form"

*HIGH TRANSVERSE MOMENTUM HADRON-HADRON COLLISIONS**

By J. D. BJORKEN

Stanford Linear Accelerator Center, Stanford, California**



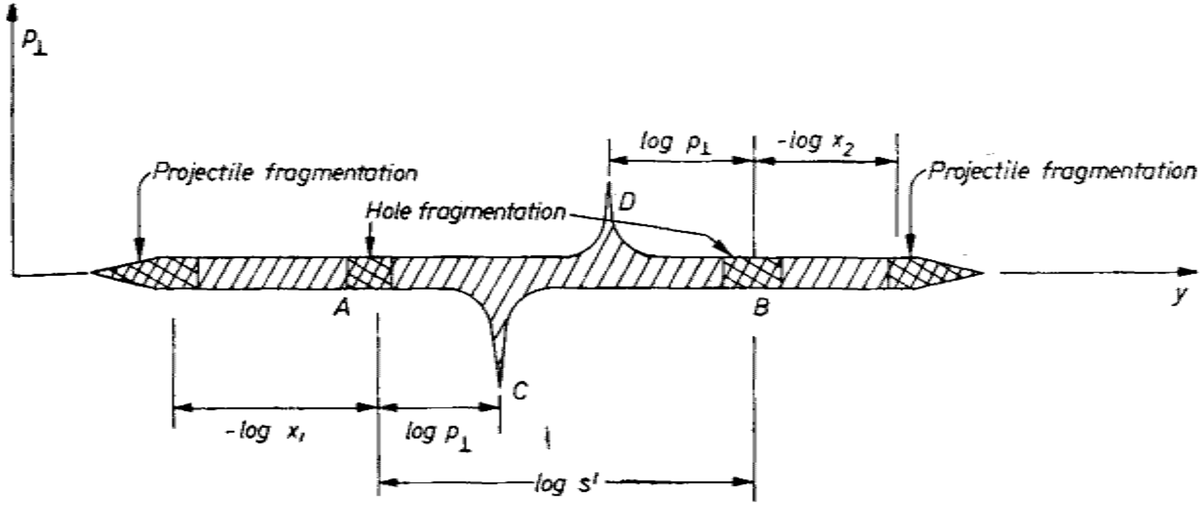
(Presented at the XVI Cracow School of Theoretical Physics, Zakopane, June 15-28, 1974)

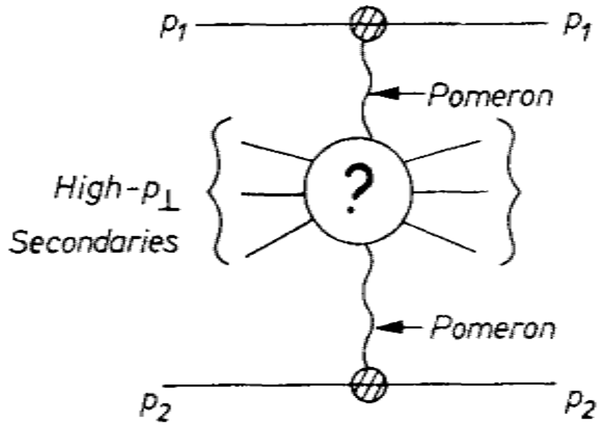
Some theoretical aspects of the subject of high-pT hadron production in strong interactions are discussed.

This includes properties of inclusive spectra, the parent-child relation and its applications to direct lepton and gamma-ray production.

Hypotheses regarding the phase-space populations of associated particles, correlations and production of jets.

Suggestions for future experimentation are listed.





Properties of Hadron Distributions in Reactions Containing Very Heavy Quarks

- J.D. Bjorken

Aug, 1977

We study, in the framework of the naive quark-parton model, production and decay dynamics for processes containing a very heavy quark Q of a new flavor, decaying via weak interactions. We argue the following. (i) The event-by-event distribution of hadrons is similar to what would exist in a similar direct process involving the same produced partons (with the same momenta), but not involving a cascade decay.
(ii) For neutrino production, electroproduction, and e+e− annihilation, at energies far above threshold, the inclusive momentum distribution of a stable hadron H containing the Q peaks near the maximum momentum, i.e., at values of the scaling variable z∼1. (iii) For events containing a nonleptonic decay of Q into ordinary quarks via $Q \to q\bar{q}q$, the leading hadron distribution is characterized by multiplicity ∼3 times normal multiplicity, as well as abnormally large transverse momenta.

Some of my collaborative articles with Bj:

J. D. Bjorken, S. J. Brodsky and A. Scharff Goldhaber, "Possible multiparticle ridge-like correlations in very high multiplicity proton-proton collisions," Phys. Lett. B **726**, 344-346 (2013)

J. D. Bjorken, S. J. Brodsky and H. J. Lu, "Rapidity gap events in e+ e- annihilation," Phys. Lett. B **286**, 153-159 (1992)

J. D. Bjorken and S. J. Brodsky, "Statistical Model for electron-Positron Annihilation Into Hadrons," Phys. Rev. D **1**, 1416-1420 (1970)

Bj's seminal contributions include:

The prediction of Bjorken scaling in deep inelastic scattering and its subsequent interpretation in terms of scattering from pointlike constituents inside the nucleon; this provided the crucial stepping stone for understanding of quark behavior and for construction of QCD the Quantum Field Theory of Strong Interactions.

The Bjorken Sum Rule for polarized deep inelastic scattering, derived from current algebra many years before it was feasible to test it experimentally; it has since been rigorously rederived from QCD and is now used as a sensitive experimental probe of the theory. In recent years the Bjorken sum rule has been the focus of an enormous experimental and theoretical activity, and has been essential for determining empirically how the nucleon spin arises from the spins of its constituents.

The prediction of the existence of the "charmed quark"; i.e., the fourth quark flavor (in collaboration with Sheldon Glashow).

Bj's work has had an enormous impact, both in steering the experiments into ground-breaking directions and in triggering theoretical research into the very foundations of elementary particle physics the quest for understanding the nature of quarks and the interactions between them.

Bj's papers have been cited thousands of times, but even this does not reflect the full impact of his work, since "Bjorken scaling in of deep inelastic scattering has become so standard a term that most papers which use these terms no longer refer to his original articles, just as no one provides the reference to the original articles in 1926 Annalen der Physik when solving the Schro¨dinger equation.

There are more than 21,000 papers dealing with various aspects of scaling and structure functions in deep inelastic scattering. None of this work would have been possible without the foundations laid down by Bjorken.