La Thuile, 28 February 2011

The Early Days of QCD
(as seen from Rome)

Guido Altarelli
Roma Tre/CERN

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In honour of Mario Greco

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The Early Days of QCD
(as seen from Rome)

In honour of Mario Greco

or

QCD in Rome in the Seventies

Guido Altarelli
Roma Tre/CERN

I have a half-century-long friendship with Mario

We met when students at the University of Rome
in the early ‘60’s

Then I went to Florence and then to the USA

When back in Rome in ‘70 we came in close contact,
also with our families

At present we are both at Roma Tre and our offices are
a few meters away

Da sinistra: Mario Greco, Yogi Srivastava e Guido Altarelli nel 1979 all'Accademia dei Lincei, Roma.

One can say that the application of QCD starts with the Nobel winner papers by Gross & Wilczek and by Politzer in 1973

Ultraviolet Behavior of Non-Abelian Gauge Theories*

David J. Gross† and Frank Wilczek
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 27 April 1973)

It is shown that a wide class of non-Abelian gauge theories have, up to calculable logarithmic corrections, free-field–theory asymptotic behavior. It is suggested that Bjorken scaling may be obtained from strong-interaction dynamics based on non-Abelian gauge symmetry.

Reliable Perturbative Results for Strong Interactions?*

H. David Politzer
Jefferson Physical Laboratories, Harvard University, Cambridge, Massachusetts 02138
(Received 3 May 1973)

An explicit calculation shows perturbation theory to be arbitrarily good for the deep Euclidean Green's functions of any Yang-Mills theory and of many Yang-Mills theories with fermions. Under the hypothesis that spontaneous symmetry breakdown is of dynamical origin, these symmetric Green's functions are the asymptotic forms of the physically significant spontaneously broken solution, whose coupling could be strong.

Sure enough there has been a pre-history with very important works

Parton model

Bjorken
Paschos
Feynman
•••••

Ren. Group.

Gell-Mann-Low
Callan-Symanzik
•••••

Quarks

Gell-Mann
Zweig
Greenberg
•••••

QCD field theory

Fritzsch-Gell-Mann-Leutwyler
•••••

Short distance

Wilson
Brandt-Preparata
•••••

Asymptotic freedom

't Hooft
•••••

but the systematic application of QCD to physics started in ~'73

In '73 three groups were active in Rome at:
Roma 1 "La Sapienza", Istituto Superiore di Sanita' and Laboratori Nazionali di Frascati
(Roma 2 "Tor Vergata" was born in '82 and Roma Tre in '92)

Roma 1	Sanita'	Frascati
Altarelli	Maiani	Greco
Cabibbo	•••••	Pancheri
Petronzio		Parisi
•••••		Srivastava
		•••••

The QCD related activities had already started before Gross&Wilczek and Politzer

With Symanzik, Giorgio Parisi was very influential on the study of physical implications of anomalous dimensions

LETTERE AL NUOVO CIMENTO VOL. 7, N. 2 12 Maggio 1973

Deep Inelastic Scattering in a Field Theory with Computable Large-Momenta Behaviour.

G. PARISI

Laboratori Nazionali di Frascati del CNEN - Frascati

(ricevuto il 7 Febbraio 1972)

In this paper he studied structure functions in $\lambda\phi^4$ with $\lambda < 0$, a theory discussed by Symanzik as a field theory model for Bjorken scaling

This paper was cited by Gross & Wilczek
and by D. Gross, Asymptotic Freedom and QCD - a Historical perspective, Nucl. Phys. B (Proc. Suppl) 135(2004)193

Here limits on logaritmic scaling violations are derived from the existing data

Volume 43B, number 3 PHYSICS LETTERS 5 February 1973

EXPERIMENTAL LIMITS ON THE VALUES OF ANOMALOUS DIMENSIONS

G. PARISI

Laboratori Nazionali del C.N.E.N., Frascati, Italia

Received 31 October 1972

We show how to use the data on deep inelastic e–p scattering to put bounds on the values of the anomalous dimensions of the operators involved in the Wilson expansion of the product of two currents near the lightcone. Anomalous dimensions of the order of unity are found not to be in contradiction with present experimental evidence.

This paper was cited by Politzer

In '73 in our group we were studying hard processes in the parton model (with scaling)

Deep inelastic processes in ladder models.
Guido Altarelli, L. Maiani (Rome U.). 1973.
Published in **Nucl.Phys. B51 (1973) 509-534**

a $\lambda\phi^3$ field theory model for scaling

Deep-inelastic one-particle inclusive processes in the parton model.
Guido Altarelli (Rome U.), L. Maiani (Rome, ISS). 1973.
Published in **Nucl.Phys. B56 (1973) 477-492**

The Nucleon as a bound state of three quarks and deep inelastic phenomena.
Guido Altarelli (Rome U.), N. Cabibbo (CERN & Rome U. & INFN, Rome), L. Maiani (Rome, ISS & INFN, Rome), R. Petronzio (Rome U.). Aug 1973.
Published in **Nucl.Phys. B69 (1974) 531-536**

the nucleon is described in terms of constituent quarks, each of them with a parton structure. This idea is still viable.

In '72 Mario evaluated the hadronic contribution to a_μ from e+e- crossections

HADRONIC CONTRIBUTIONS TO THE MUON ANOMALOUS MAGNETIC MOMENT

A. BRAMÒN *, E. ETIM ** and M. GRECO
Laboratori Nazionali del CNEN, Frascati, Italy

Received 9 March 1972

The hadronic contribution to the muon anomalous magnetic moment is calculated using recent results from colliding beam experiments; a value of $(68 \pm 9) \times 10^{-9}$ is obtained.

they found: $a_\mu = 68 \pm 9 \ \ 10^{-9}$

Davier et al '10 (ArXiv:1010.4180): $a_\mu = 69.23 \pm 0.42 \ \ 10^{-9}$

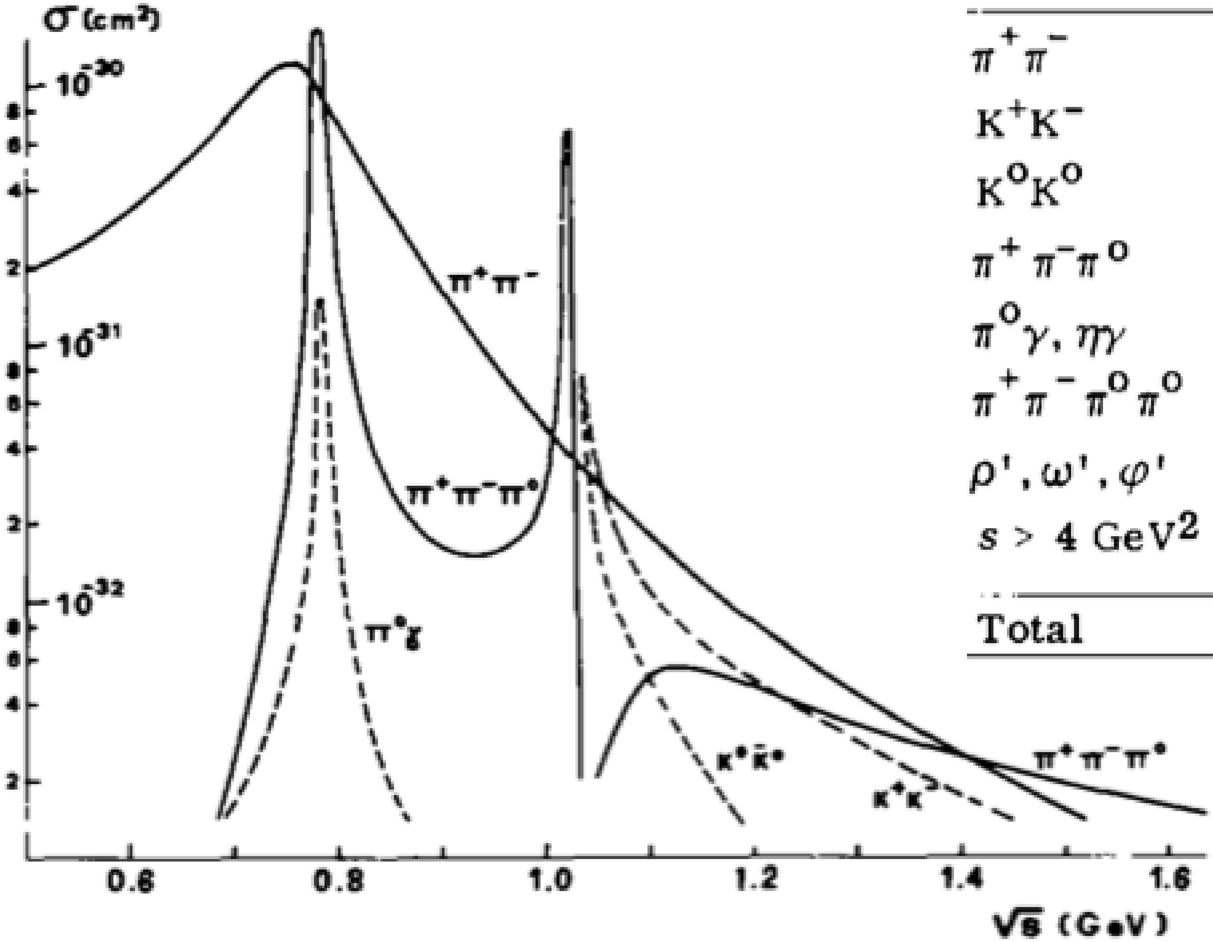


Table 1

f	$a_\mu(f) \times 10^9$
$\pi^+\pi^-$	49.4 ± 5.7
K^+K^-	2.2 ± 0.2
K^oK^o	1.5 ± 0.2
$\pi^+\pi^-\pi^o$	6.5 ± 0.9
$\pi^o\gamma, \eta\gamma$	0.5 ± 0.1
$\pi^+\pi^-\pi^o\pi^o$	0.9 ± 0.2
ρ', ω', φ'	5.3 ± 1.5
$s > 4$ GeV^2	~ 1.5
Total	68 ± 9

Note: with errors in quadrature it would be $a_\mu = 68 \pm 6 \ \ 10^{-9}$

see next talk by Bramon

At that time Mario was interested in hard processes and was advocating a model based on extended vector boson dominance

Nuclear Physics B63 (1973) 398–412. North-Holland Publishing Company

DEEP-INELASTIC PROCESSES

M. GRECO*

CERN, Geneva and Laboratori Nazionali del CNEN, Frascati, Italy

Received 12 February 1973

e+e- annihilation, DIS, Drell-Yan were studied in this paper

Couplings vs mass of vector bosons chosen to get scaling

It was a competitive model for some time cited 171

But predicted no jets in e+e-, and no suppressed σ_L/σ_T in DIS, so it was later abandoned

After Gross&Wilczek and Politzer we immediately turned to study the implications of QCD

Volume 52B, number 3 PHYSICS LETTERS 14 October 1974

OCTET ENHANCEMENT OF NON-LEPTONIC WEAK INTERACTIONS IN ASYMPTOTICALLY FREE GAUGE THEORIES

G. ALTARELLI

Istituto di Fisica dell'Università di Roma, Rome, Italy

L. MAIANI

Lab. di Fisica, Istituto Superiore di Sanità, Rome, Italy
and Ist. Naz. di Fisica Nucleare, Sezione Sanità, Rome, Italy

Received 22 June 1974

cited 863

Octet enhancement of weak non leptonic amplitudes is found to occur in asymptotically free gauge theories of strong interactions, combined with unified weak and e.m. interactions. The order of magnitude of the enhancement factor for different models is discussed.

This is an important paper (together with the work by M. K. Gaillard and B. W. Lee, Phys. Rev. Lett. 33(1974)108)
Cited by D. Gross, Asymptotic Freedom and QCD - a Historical perspective, Nucl. Phys. B (Proc. Suppl) 135(2004)193

It was the first calculation of QCD corrections to the coefficients of the Wilson expansion in the product of two weak currents

TUM-HEP-343/99

hep-ph/9901409

January 1999

A quote from A. J. Buras

Operator Product Expansion, Renormalization Group and Weak Decays *

Andrzej J. Buras

am convinced that OPE will play an important role in the next 10 years in the field of weak decays as it played already in almost 25 years since the pioneering applications of this very powerful method by Gaillard and Lee [5] and Altarelli and Maiani [6].

Application to charm decay

ENHANCEMENT OF NON-LEPTONIC DECAYS
OF CHARMED PARTICLES

G. ALTARELLI
*Laboratoire de Physique Théorique de l'Ecole Normale Supérieure, Paris, France**
Istituto di Fisica dell'Università, Roma, Italy

N. CABIBBO
Istituto di Fisica dell'Università, Roma, Italy
CERN, Genève, Switzerland

L. MAIANI
*Laboratoire de Physique Théorique de l'Ecole Normale Supérieure, Paris, France**
Laboratori di Fisica, Istituto Superiore di Sanità, Roma, Italy

Received 14 October 1974

before charm was discovered!!

Mario Greco graduated with a thesis on $e^+e^- \to e^+e^-\gamma\gamma$ with B. De Tollis

Then, in Frascati, working with Touschek (and Pancheri, Srivastava, Etim), Mario became an expert in QED radiative corrections and the resummation of soft photons

Here are two papers on the QED corrections near the J/Ψ

Radiative Effects for Resonances with Applications to Colliding Beam Processes.
Mario Greco, G. Pancheri-Srivastava, Y. Srivastava (Frascati). LNF-75/9-P. Feb 1975. 12 pp.
Published in **Phys.Lett. B56 (1975) 367**

Radiative Corrections for Colliding Beam Resonances.
Mario Greco, G. Pancheri-Srivastava, Y. Srivastava (Frascati). LNF-75/23-P. May 1975. 42 pp.
Published in **Nucl.Phys. B101 (1975) 234**

With the advent of QCD Mario naturally turned into resumming soft gluons (see later)

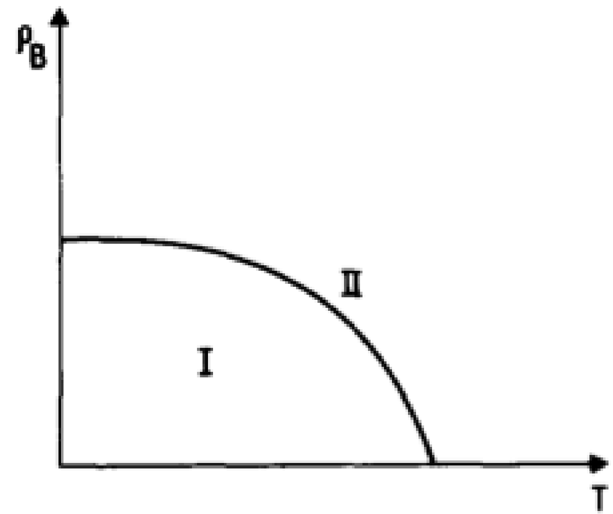
Volume 59B, number 1 PHYSICS LETTERS 13 October 1975

EXPONENTIAL HADRONIC SPECTRUM AND QUARK LIBERATION

N. CABIBBO
Istituto di Fisica, Universitá di Roma,
Istituto Nazionale di Fisica Nucleare, Sezione di Rome, Italy

G. PARISI
Istituto Nazionale di Fisica Nucleare, Frascati, Italy

Received 9 June 1975



One of the first papers where quark deconfinement is discussed

It is shown that an exponentially growing hadronic spectrum (a' la Hagedorn) could be associated to a 2nd order phase transition into the quark-gluon plasma

Volume 63B, number 2 PHYSICS LETTERS 19 July 1976

CHARMED QUARKS AND ASYMPTOTIC FREEDOM IN NEUTRINO SCATTERING

G. ALTARELLI, R. PETRONZIO
Istituto di Fisica, Roma, Italy
Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy

and

G. PARISI
Istituto Nazionale di Fisica Nucleare, Frascati, Italy

Received 24 March 1976

Asymptotic freedom and charm production are both important ingredients for a theoretical analysis of neutrino cross sections. We study in detail the Q^2 dependence of integrated quantities like cross sections, y-distributions and $\langle x \rangle$ values. Deviations from scaling are quite substantial in the present energy range.

This paper contributed to downgrading the "y-anomaly" from a signal of new physics (right-handed charged currents) down to a charm threshold + QCD-logs effect

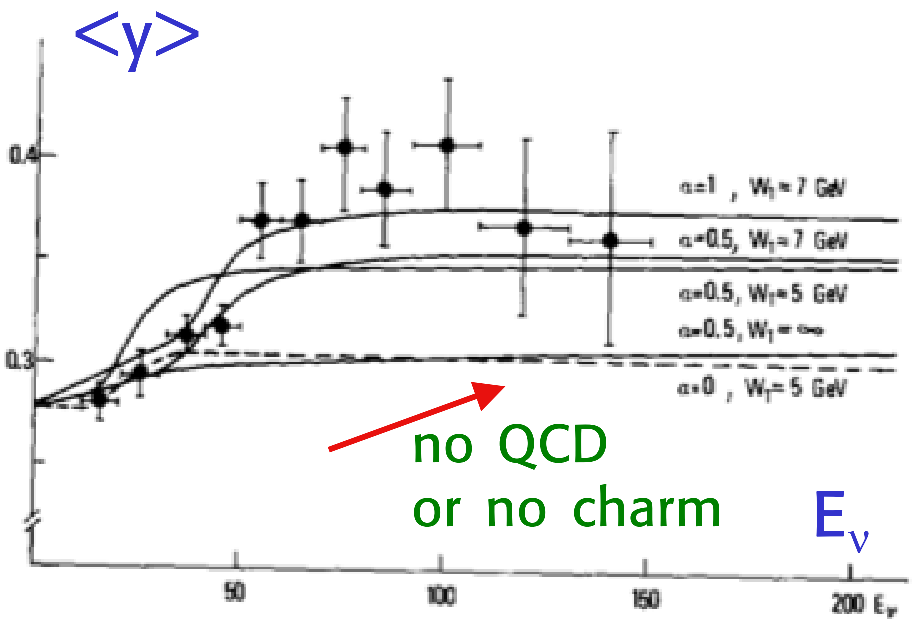
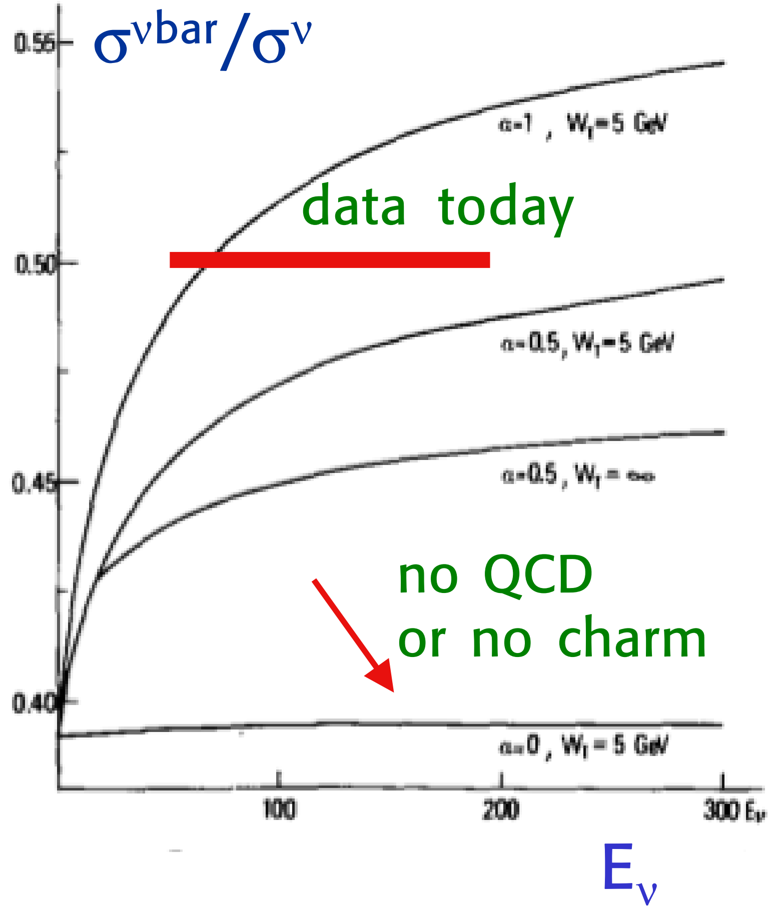


Fig. 3. Average value of y for antineutrinos for different values of $\alpha \equiv \alpha_S(\mu^2)$ and W_T, the effective invariant mass for charm threshold. $\alpha = 0$ corresponds to Q^2 independent parton distributions. $W_T \to \infty$ corresponds to neglecting effects from charm production. Both effects seem to be needed to reproduce the data. $\alpha = 0.5$ is the value suggested in the text, while $\alpha = 1$ is reported for comparison.



Nuclear Physics B126 (1977) 298–318

ASYMPTOTIC FREEDOM IN PARTON LANGUAGE

G. ALTARELLI *
*Laboratoire de Physique Théorique de l'Ecole Normale Supérieure **, Paris, France*

G. PARISI ***
Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France

Received 12 April 1977

cited 4080

$$\frac{dq^i(x,t)}{dt} = \frac{\alpha(t)}{2\pi}\int_x^1 \frac{dy}{y}\left[\sum_j^{2f} q^j(y,t)\, P_{q^i q^j}\!\left(\frac{x}{y}\right) + G(y,t)\, P_{q^i G}\!\left(\frac{x}{y}\right)\right] \quad (22)$$

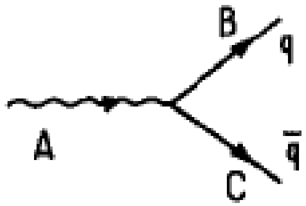
$t=\ln Q^2/\mu^2$

$$\frac{dG(x,t)}{dt} = \frac{\alpha(t)}{2\pi}\int_x^1 \frac{dy}{y}\left[\sum_j^{2f} q^j(y,t)\, P_{Gq^j}\!\left(\frac{x}{y}\right) + G(y,t)\, P_{GG}\!\left(\frac{x}{y}\right)\right] \quad (23)$$

The QCD evolution equations hand-written by me on the '77 preprint (scanned by KEK)

In our paper, formulated in parton language, with running coupling, the splitting functions are derived directly from the QCD vertices, making clear they are the same for all processes (factorisation)

$$P_{\mathrm{BA}}(z) = \tfrac{1}{2}\, z(1-z) \overline{\sum_{\text{spins}}} \frac{|V_{\mathrm{A}\to\mathrm{B+C}}|^2}{p_\perp^2} \qquad (z<1)$$



$$\overline{\sum_{\text{pol}}} |V_{\mathrm{q}\to\mathrm{G+q}}|^2 = \frac{2p_\perp^2}{z(1-z)} \frac{1+(1-z)^2}{z} C_2(\mathrm{R})$$

$$P_{\mathrm{Gq}}(z) = C_2(\mathrm{R}) \frac{1+(1-z)^2}{z}$$

$$P_{\mathrm{qq}}(z) = C_2(\mathrm{R}) \frac{1+z^2}{1-z} \qquad (z<1)$$

$$P_{\mathrm{qq}}(z) = C_2(\mathrm{R}) \left[\frac{1+z^2}{(1-z)_+} + \tfrac{3}{2}\,\delta(z-1) \right]$$

The polarized splitting functions were also derived by us (not considered by DGL) in agreement with Ahmed&Ross and Sasaki (operator method)

The evolution equations are now often called DGLAP

DEEP INELASTIC ep SCATTERING IN PERTURBATION THEORY

V. N. GRIBOV and L. N. LIPATOV

Leningrad Institute for Nuclear Physics, USSR Academy of Sciences

Submitted October 18, 1971

Yad. Fiz. 15, 781—807 (April, 1972)

before G&W and P!

The parton model and perturbation theory

L. N. Lipatov

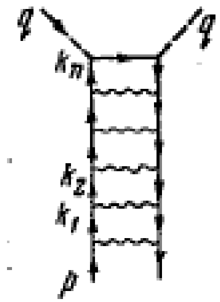
Leningrad Institute of Nuclear Physics, USSR Academy of Sciences

(Submitted November 5, 1973)

Yad. Fiz. 20, 181–198 (July 1974)

These papers refer to an abelian vector theory $H_{int} = g\bar{\psi}\gamma_{\mu}\psi V_{\mu}$
and also to a pseudoscalar theory

They ask the right question and extract the relevant terms from the dominant class of diagrams



But from their presentation it is very difficult to extract the useful results (for the vector theory).

$$\frac{dD_i^j(x)}{\partial\Lambda} = -D_i^j(x)\, w_j(g_\Lambda^2)\frac{1}{\Lambda} + \sum_{j'}\int_x^1 dx' D_i^{j'}(x')\, w_{j'\to j}(x', x)\frac{1}{\Lambda},$$

$$D_i^j(x)|_{\Lambda=m^2} = \delta(x-1)\delta_{ij},$$

$$w_{N\to N}(x', x_N) = w_{\bar{N}\to\bar{N}}(x', x_N) = \frac{g_\Lambda^2}{16\pi^2}2\frac{1}{(x')^2}\frac{x'^2+x_N^2}{x'-x_N}$$

$$w_{N\to M}(x', x_M) = w_{\bar{N}\to M}(x', x_M) = \frac{g_\Lambda^2}{16\pi^2}2\frac{1}{(x')^2}\frac{x'^2+(x'-x_M)^2}{x_M}.$$

Calculation of structure functions of deep-inelastic scattering and e^+e^- annihilation by perturbation theory in quantum chromodynamics

Yu. L. Dokshitser

Leningrad Institute of Nuclear Physics, USSR Academy of Sciences

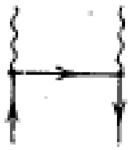
(Submitted April 20, 1977)
Zh. Eksp. Teor. Fiz. 73, 1216–1240 (October 1977)

Exactly contemporary to us

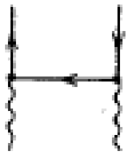
$$\equiv V_F^F(x) = 2\,\frac{1+x^2}{1-x},$$

The limit x->1 is not made explicit

More explicit than G&L



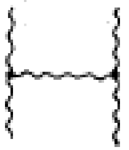
$$\equiv V_F^G(x) = 2\,\frac{1+(1-x)^2}{x},$$



$$\equiv V_G^F(x) = 2\left[x^2+(1-x)^2\right],$$

He knew G&L who are quoted in the refs.:

non abelian



$$\equiv V_G^G(x) = 4x(1-x)\left[1+\frac{1}{x^2}+\frac{1}{(1-x)^2}\right]$$

[7]V. N. Gribov and L. N. Liparov, Yad. Fiz. **15**, 781, 1218 (1972) [Sov. J. Nucl. Phys. **15**, 438, 675 (1972)].
[8]L. N. Lipatov, Yad. Fiz. **20**, 181 (1974) [Sov. J. Nucl. Phys. **20**, 94 (1975)].

This is the D. result “equivalent” to the evolution equations

$$W_q(\omega_k, \xi_k; \xi) = \frac{e_q^2}{d_F(\xi)}\,\delta\left(1 - \frac{1}{\omega_k}\right) + \int_{\xi_k}^{\xi} d\xi' \int_0^1 \frac{dx}{x}\,\Phi_F^F(x)\cdot$$

$$W_q(x\omega_k, \xi'; \xi) + \int_{\xi_k}^{\xi} d\xi' \frac{d_G(\xi')}{d_F(\xi')} \int_0^1 \frac{dx}{x}\,\Phi_F^G(x)\,\tilde{W}(x\omega_k, \xi'; \xi),$$

$$\tilde{W}(\omega_k, \xi_k; \xi) = \int_{\xi_k}^{\xi} d\xi' \int_0^1 \frac{dx}{x}\,\Phi_G^G(x)\,\tilde{W}(x\omega_k, \xi'; \xi)$$

$$+ \int_{\xi_k}^{\xi} d\xi' \frac{d_F(\xi')}{d_G(\xi')} \int_0^1 \frac{dx}{x}\,\Phi_G^F(k) \sum_{q,\bar{q}=1}^{n_f} [W_q(x\omega_k, \xi'; \xi) + W_{\bar{q}}].$$

$$\xi = \frac{1}{16\pi^2} \int_{\mu^2}^{|q^2|} \frac{dk^2}{k^2}\,\bar{g}^2(k^2)$$

Note: $d_G/d_F\,\tilde{W}$ is what we call the gluon density in terms of partons

Volume 76B, number 1 PHYSICS LETTERS 8 May 1978

TRANSVERSE MOMENTUM OF JETS IN ELECTROPRODUCTION FROM QUANTUM CHROMODYNAMICS

G. ALTARELLI
Istituto di Fisica dell'Università, Roma, and Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy

and

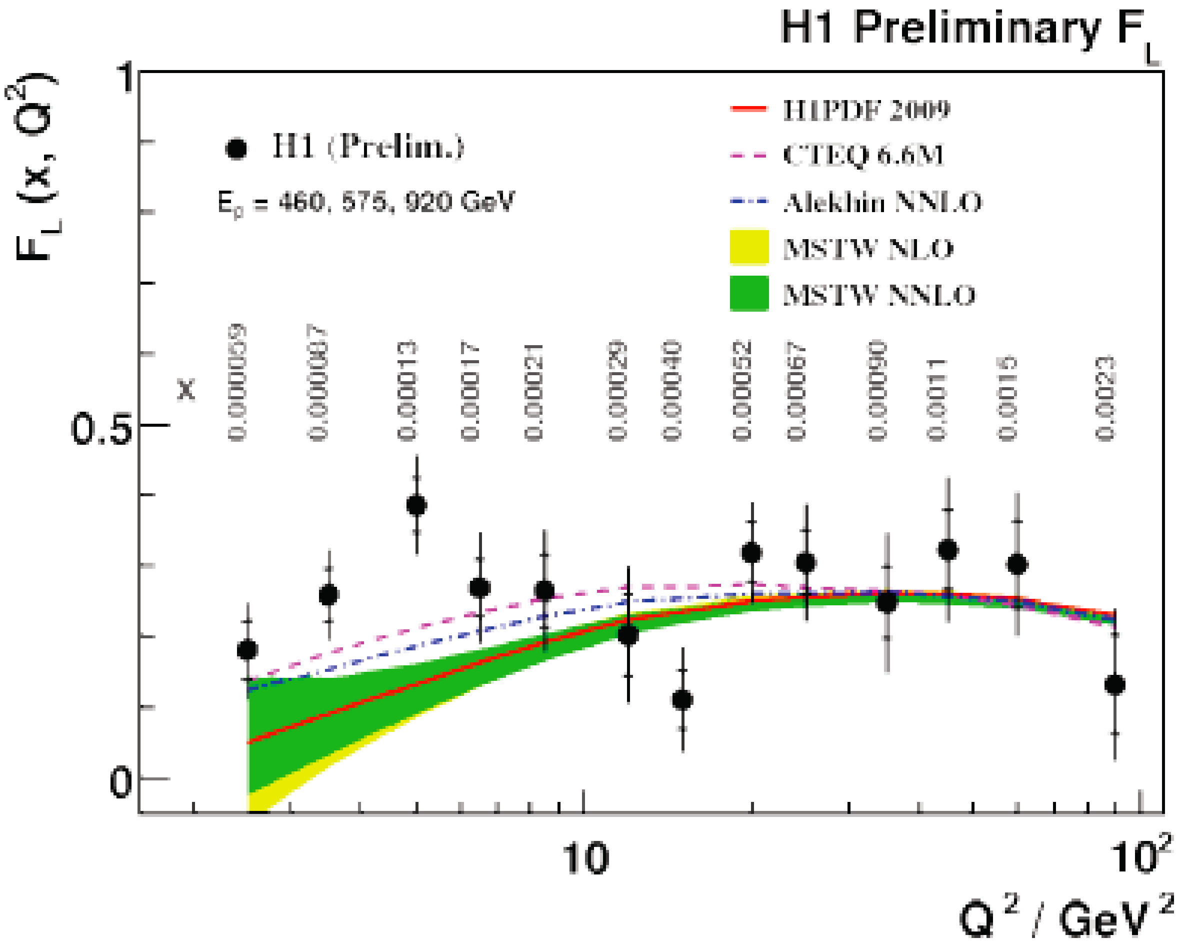
G. MARTINELLI
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, Italy

Received 26 January 1978

Among $o(\alpha_s)$ effects this formula for the longitudinal structure function was derived

$$F_L(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi} x^2 \int_x^1 \frac{dy}{y^3} \left[\frac{8}{3} F_2(y,Q^2) + \frac{40}{9} y g(y,Q^2)(1-\frac{x}{y}) \right]_{n_f=4}$$

It took ~40 years to get meaningful data on the longitudinal structure function!!



$$F_L(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi} x^2 \int_x^1 \frac{dy}{y^3} \left[\frac{8}{3} F_2(y,Q^2) + \frac{40}{9} yg(y,Q^2)(1-\frac{x}{y}) \right]_{n_f=4}$$

We said that in Frascati, working with Touschek (and Pancheri, Srivastava, Etim), Mario became an expert in QED radiative corrections and the resummation of soft photons

With the advent of QCD Mario naturally turned into resumming soft gluons

In a series of papers with Curci and Srivastava he applied those techniques to

- jets a la Sterman Weinberg
- resummation near the end point of phase space

$x \to 1$ in DIS, $\tau \to 1$ in Drell-Yan

[Unfortunately Giuseppe Curci is no more with us]

Here the QED formalism of coherent states is applied to QCD

Volume 77B, number 3 PHYSICS LETTERS 14 August 1978

COHERENT STATE APPROACH TO THE INFRA-RED BEHAVIOUR OF NON-ABELIAN GAUGE THEORIES

M. GRECO, F. PALUMBO, G. PANCHERI-SRIVASTAVA [1] and Y. SRIVASTAVA [1]
INFN, Laboratori Nazionali di Frascati, Rome, Italy

Received 31 January 1978

Volume 79B, number 4,5 PHYSICS LETTERS 4 December 1978

MASS SINGULARITIES AND COHERENT STATES IN GAUGE THEORIES

G. CURCI
CERN, Geneva, Switzerland

and

M. GRECO
Laboratori Nazionali dell'INFN, Frascati, Italy

Received 18 July 1978

Nuclear Physics B159 (1979) 451--468

QCD JETS FROM COHERENT STATES

G. CURCI
CERN, Geneva, Switzerland

M. GRECO and Y. SRIVASTAVA *‡
INFN, Laboratori Nazionali di Frascati, Frascati, Italy

cited 118

Received 27 February 1979

$k_{2T} = E$

$e^+e^- \to q\bar{q}$:

$$d\sigma_{super} = d\sigma_0 \exp\left\{-\frac{1}{\pi^2}\int_{\Delta\omega/E}^{1} dx\, \mathcal{P}_{gq}(x) \int_{k_{1T}}^{k_{2T}} \frac{d^2k_T}{k_T^2}\,\bar{\alpha}(k_T)\right\},$$

2ε

$k_{1T} = E\delta$

where the gluon distribution due to the quarks is [11]

$$\mathcal{P}_{gq}(x) = C_F\left\{\frac{1+(1-x)^2}{x}\right\},$$

Probability that a fraction ε of total energy 2E is outside a cone of semi-aperture δ (Sterman-Weinberg '77 resummed)

LARGE INFRA-RED CORRECTIONS IN QCD PROCESSES

G. CURCI and M. GRECO [1]
CERN, Geneva, Switzerland

cited 157

Received 29 November 1979

Resummation near the phase space end point is and important issue in QCD

DIS near x = 1

$$q(x,Q^2) \simeq \frac{1}{2\pi}\int_{-\infty}^{\infty} db\, e^{ib(1-x)} \exp\left\{ C_F \int_0^1 \frac{dz}{1-z} \int_{\lambda^2}^{k_{\perp\,\max}^2 = Q^2(1-z)} \frac{dk_\perp^2}{k_\perp^2} \frac{\alpha(k_\perp)}{\pi} \left[e^{-ib(1-z)} - 1\right] \right\}$$

Drell-Yan near $\tau = z = 1$

resummed π^2

$$\frac{d\sigma^{DY}}{dQ^2} = \frac{4\pi\alpha^2}{9SQ^2}\int \frac{dx_1}{x_1}\frac{dx_2}{x_2}\left[\sum_i e_i^2 q_i(x_1,Q^2)\bar{q}_i(x_2,Q^2) + (1 \leftrightarrow 2)\right]\tilde{f}(z,Q^2)$$

$$\tilde{f}(z,Q^2) = \left\{ \frac{1}{2\pi}\int db\, e^{ib(1-z)} \exp\left[2C_F \int_0^1 \frac{dy}{1-y} \int_{Q^2(1-y)}^{Q^2(1-y)^2} \frac{dk_\perp^2}{k_\perp^2} \frac{\alpha(k_\perp)}{\pi} \left(e^{-ib(1-y)} - 1\right) \right] \right\} \exp\{[\alpha(Q^2)/2\pi] C_F \pi^2\} \quad (16$$

Mario Greco
at a Moriond
meeting in '80

There he gave
the talk
"Soft gluon effects
in QCD processes".

The theory of Drell-Yan processes was much advanced in Rome

- Resummation

  Large π^2 terms — Parisi '80

  Logs of $(1-\tau)$ — Curci, Greco '80

- NLO QCD corrections — Altarelli, K. Ellis, Martinelli '78, '79

  The "K factor"

- Transverse momentum distribution

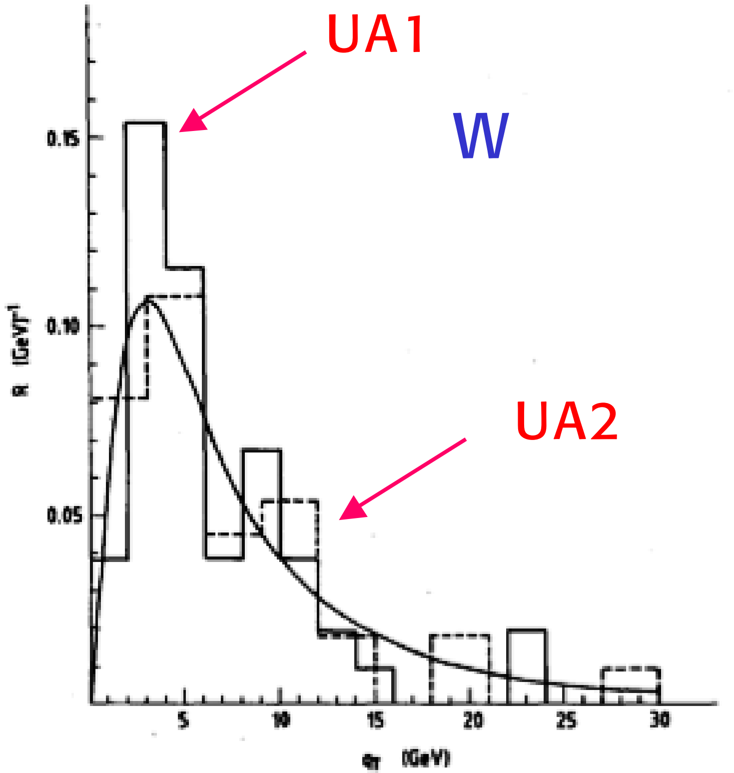
  Perturbative — Altarelli, Parisi, Petronzio '78; K. Ellis, Martinelli, Petronzio '81, '83

  Sudakov double logs — Parisi, Petronzio '79 (following and correcting Dokshitzer, Dyakonov, Troyan'78); Curci, Greco, Srivastava'79

  Matching of perturbative and Sudakov terms

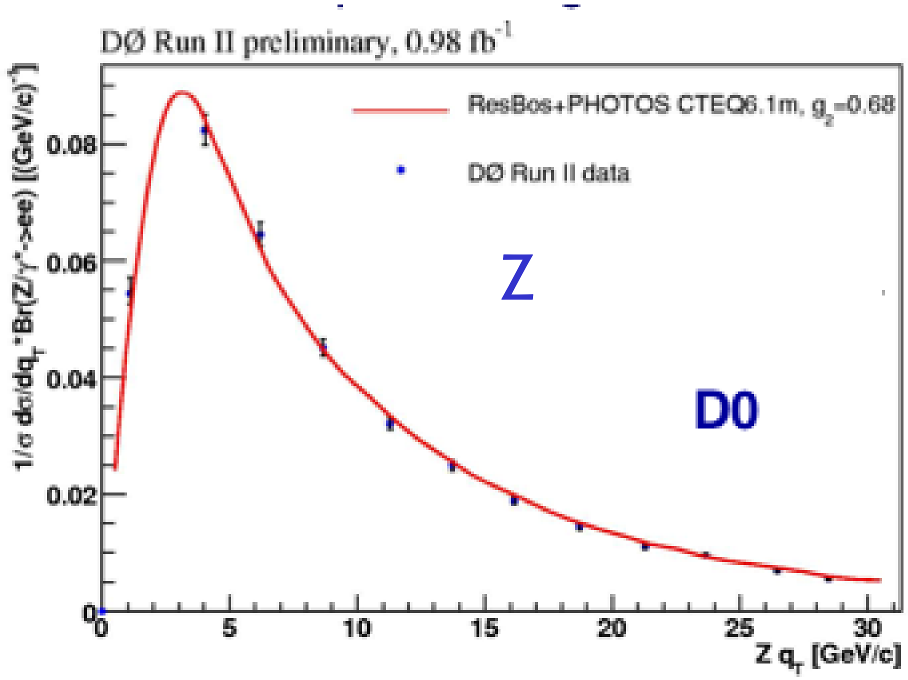
  Chiappetta, Greco '83, '84
  Altarelli, K. Ellis, Greco, Martinelli '84

~27 years ago at CERN we computed the W and Z p_T distribution in QCD



GA, K.Ellis, M. Greco, G.Martinelli '84

Here all relevant ingredients were assembled correctly. Later only refinements



In agreement with perturbative QCD augmented by Collins-Soper-Sterman (CSS) resummation at low q_T

J. Collins, D. Soper, G. Sterman, Nucl. Phys. B250 (1985) 199.

ResBos describes data well up to ~ 30 GeV

F. Landry, R. Bock, P.Nadolsky, C.P. Yuan Phys. Rev. D 67, 073016 (2003)

NNLO describes better above 30 GeV

K. Melnikov and F. Petriello Phys. Rev. D74 114017 (2006)

Yesterday the W&Z, today the Higgs!

Bozzi, Catani, De Florian, Grazzini'03-'08

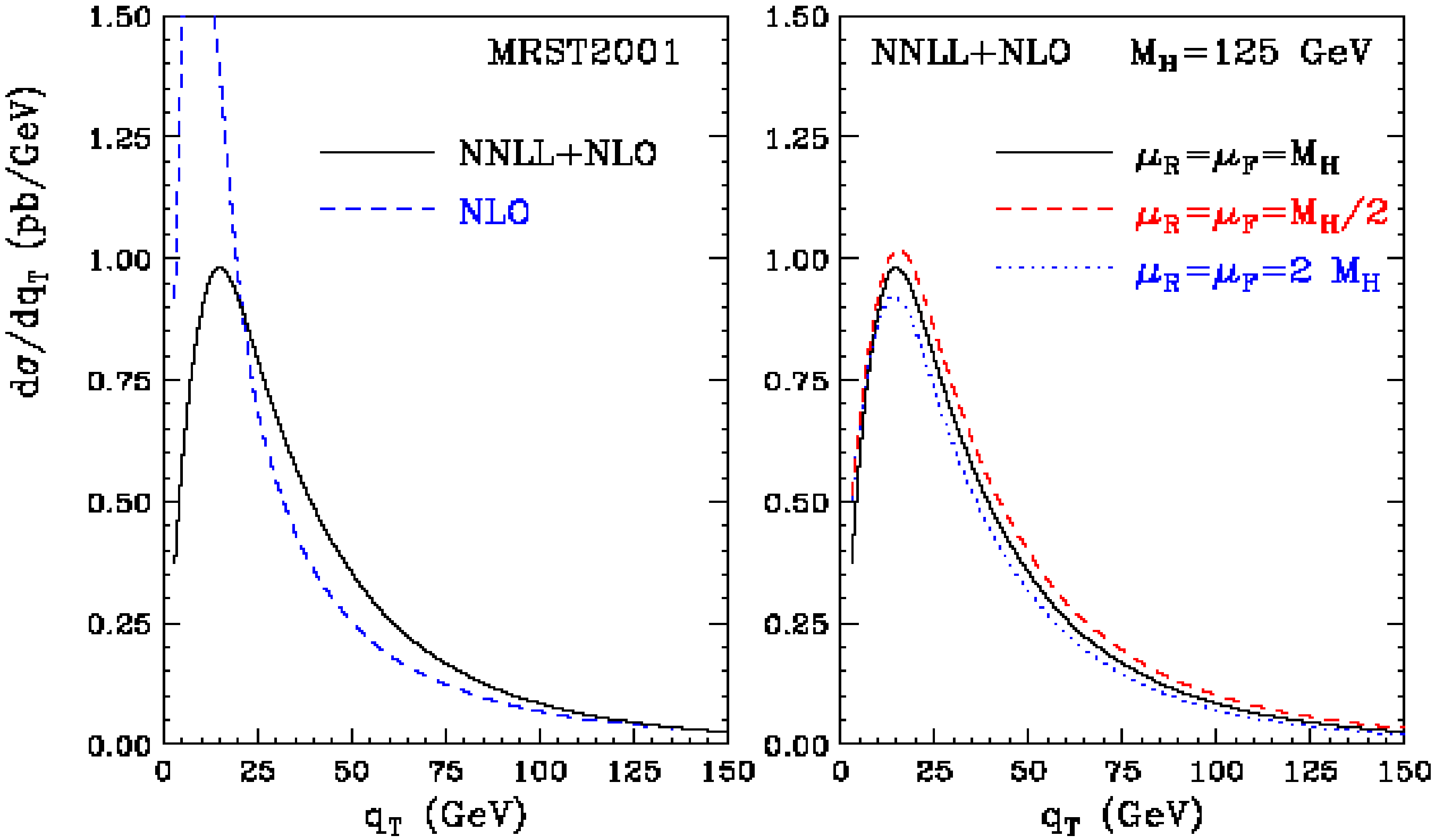


Figure 7. Resummed pQCD prediction for the Higgs transverse momentum distribution at the LHC, from Bozzi *et al.*[25]

I leave to the following speakers to describe other aspects of the scientific activity of Mario and also what he did later in QCD

I make to him my best wishes of a long and happy sequel of celebrations for 75, 80, 85,....100 anniversaries

And also I make to him my compliments for the co-foundation of these by now classical meetings in La Thuile

Thank you!