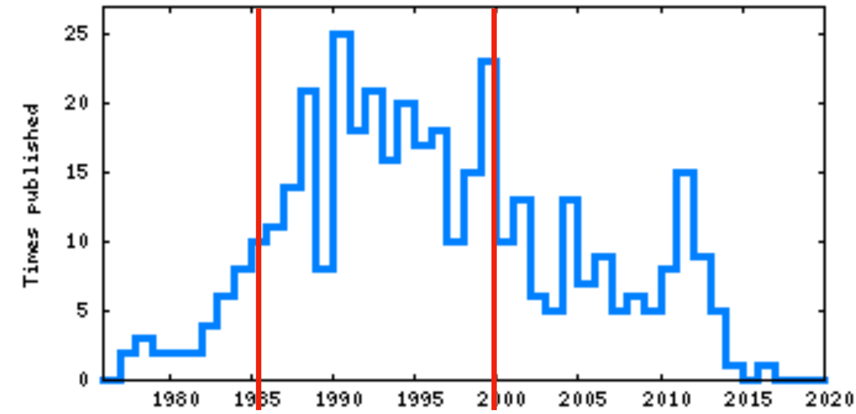
James W. Stirling Memorial Conference, Durham
September 17-19, 2019

Multijets and Higgs

Zoltan Kunszt
ITP, ETH

18.09.2019

His research focused on confronting theory with experiment and on efficient techniques of calculating hard scattering cross-sections



Years 1985-2000

1980 1985 1990 1995 2000 2005

Durham, Seattle, Durham, CERN Durham……………………………………………………………………….

………Sppbar……

……………….LEP…………………

……………….SLC…………………

……………………………HERA………………………………………………

……………………………Tevatron………………………………………………….

…………………………Workshops…Developing LHC…and LEP……………………………………………….
Lausanne, La Thuille, Aachen, CERN

QCD improved parton model,
SU(2)xU(1) Standard Model, jet phenomenology at LEP,SLC.

Develop precision calculations for hadron colliders:
helicity method,multi partons, MRS,MRST parton densities,NLO for DY, Jets, V+jets ,Higgs

Multijets

By 1984 at the Sppbar clear signals W, Z as well as jets have been found.

It was very natural to begin the description of multijet production with or without W, Z,H and top. quark

.....the UA1 incident...

The UA1's missing transverse energy events

These events were presented at the 4th Topical Workshop on Proton – Antiproton Collider Physics in Bern, Switzerland, 5 – 8 March 1984, and published soon after.

Preliminary results were presented at the 5th Topical Workshop on Proton – Antiproton Collider Physics, Saint Vincent, Aosta Valley (Italy), 25th February – 1st March 1985

Alterelli's coctail

THE STANDARD MODEL AND MISSING E_T
OR
THE MANY ROADS TO PARADISE

Stephen D. Ellis ‡

CERN – Geneva

Physics Letters B
Volume 153, Issues 4–5, 4 April 1985, Pages 265-273

Supersymmetry at bay?

H. Baer [1], John Ellis [1], D.V. Nanopoulos [1], Xerxes Tata [1]
CERN, CH 1211 Geneva, Switzerland

Received 10 December 1984, Available online 18 October 2002

MISSING TRANSVERSE ENERGY EVENTS AND THE STANDARD MODEL

S.D. ELLIS [1,2], R. KLEISS and W.J. STIRLING
CERN, CH 1211 Geneva, Switzerland

Received 16 April 1985

The processes $p+\bar{p} \to W^{\pm}, Z^0 + 0,1,2$ jets are studied in the light of recent observations of events with large missing transverse momentum at the CERN $p\bar{p}$ collider. We find that a nontrivial number of such events can arise from the leptonic decays $Z^0 \to \nu\bar{\nu}$ and $W^{\pm} \to \ell^{\pm}\nu$ where the charged lepton escapes identification. In both cases the number of events with one jet and with two jets are comparable. By correlating these decay modes with those where the leptons are observed we can, in principle, eliminate the theoretical uncertainties inherent in such perturbative QCD calculations.

The spinor techniques

SPINOR F.A. Berends, R. Kleiss, P. de Causmaecker, R. Gastmans and T.T. Wu, Phys. Lett. 103B (1981) 124;
P. de Causmaecker, R. Gastmans, W. Troost and T.T. Wu, Nucl. Phys. B206 (1982) 53;

R. Kleiss, Nucl. Phys. B241 (1984) 61.
Z. Xu, D.H. Zhang and Z. Chang, Tsinghua University preprint TUTP-84/3 (1984).

We prese[...] many scattering processes in the high-energy limit. As an illustration of the method, these are applied to the diagrams for $p\bar{p} \to V + 0$, 1 or 2 jets, where $V = W^{\pm}$ or Z^0. The form of the results lends itself to immediate numerical eval[...]

J.F. Gunion and Z. Kunszt, Phys. Lett. B 159 (1985) 167.

It manifestly implements helicity conservation at vector and axial vector vertices and fixes relative phase of spinors

Rambo

A NEW MONTE CARLO TREATMENT OF MULTIPARTICLE PHASE SPACE AT HIGH ENERGIES

R. KLEISS, W.J. STIRLING
CERN, Geneva, Switzerland

and

S.D. ELLIS *
Dept. of Physics, University of Washington, Seattle, WA 98195, USA

Received 16 December 1985

All 6-leg QCD amplitudes have been clculated

Phenomenology:

Missing E_T events are not anomalous

Predicting multijet production at hadron colliders

Theory:

Amplitude for n Gluon Scattering

S. J. Parke, T.R. Taylor. March 1986

Berends-Giele recursion relations

FOUR-JET PRODUCTION AT HADRON COLLIDERS

Z. KUNSZT [1] and W.J. STIRLING [2]

CERN, CH-1211 Geneva 23, Switzerland

Received 4 February 1986

The central question is wether any of the standard "new physics" process can be obtained in their purely jet channels. We have been unable to identify any process which could easily detected this way

Some of the characteristic features are examined of four-jet production at hadron colliders given by QCD ($2 \to 4$) subprocesses. It is found that the universal behaviour of parton scattering subprocesses – which is a good approximation for ($2 \to 2$) subprocesses and to a lesser extent for ($2 \to 3$) subprocesses – is violated more significantly in the case of the ($2 \to 4$) parton scattering processes. Methods are suggested for testing if the four-jet data sample receives additional contributions from double hard parton scattering.

Multijet phenomenology

Multijet cross-sections at hadron collider,
Z. Kunszt, J.W.Stilring, September 1987

UA1,UA2 collaborations

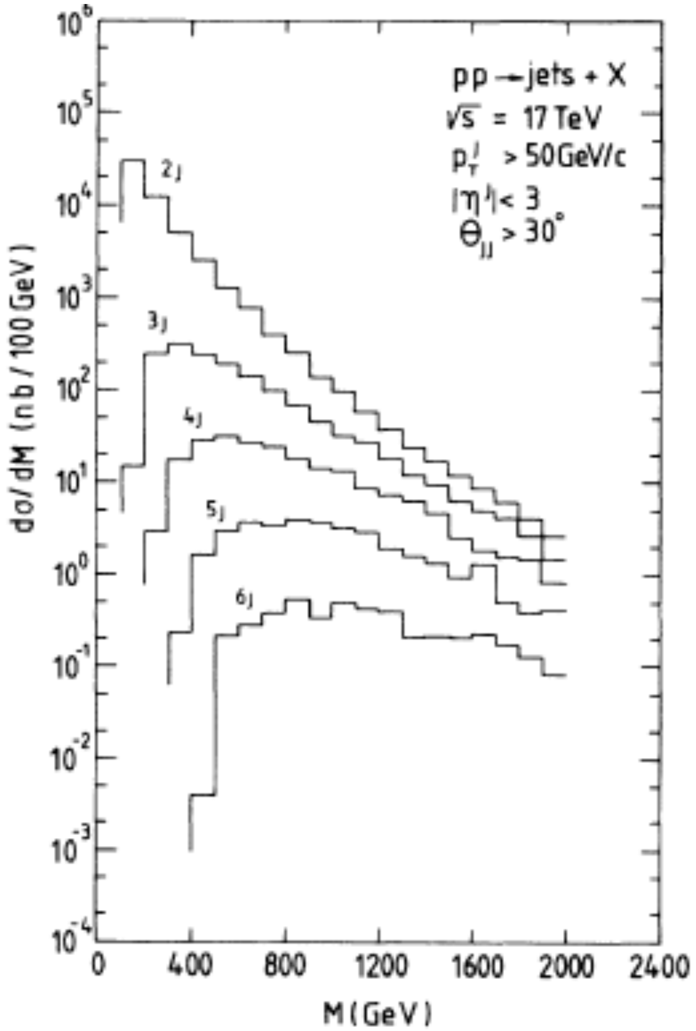
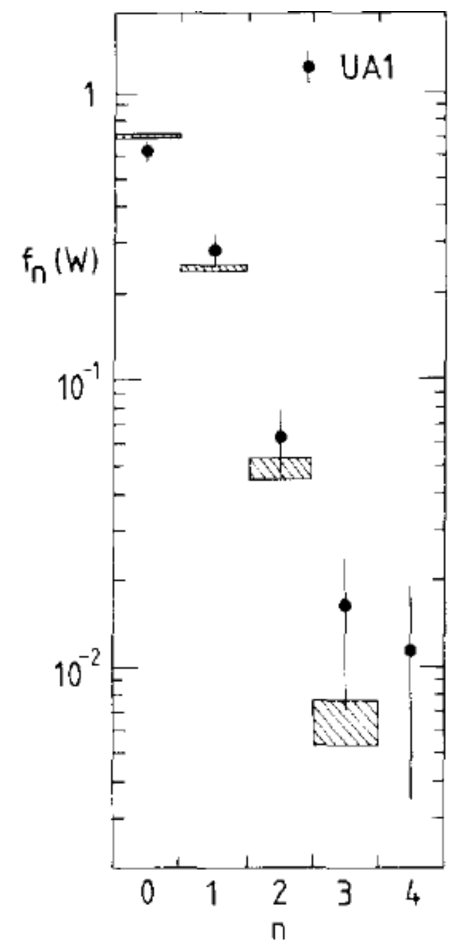


FIG. 3. Multijet cross sections in pp collisions at $\sqrt{s}=17$ TeV with the jet cuts of Eq. (8), as a function of the total jet invariant mass.



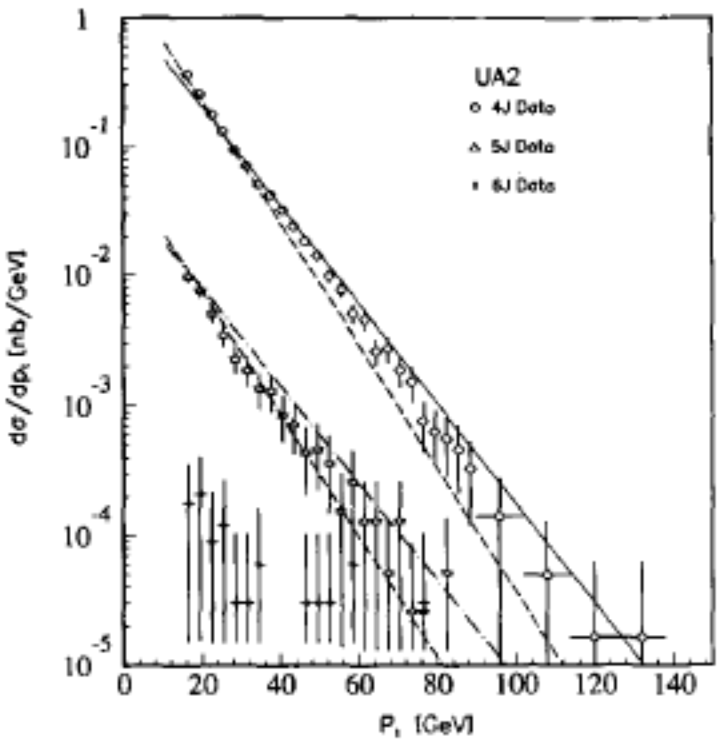


Fig. 4. Comparison of the inclusive p_T spectrum resulting from the approximate QCD calculations described in the text to the multi-jet data. The solid curve represents the calculation based on the work of ref. [8] for four jets. The dash-dotted line is the result of the ESFAG approximation of ref. [9], while the two dashed curves are the results of the parton level study of the NGLUON approximation of ref. [10].

$$f_{\rm eff}(x,Q^2)=f_g(x,Q^2)+\tfrac{4}{9}\sum_q\left[f_q(x,Q^2)+f_{\bar q}(x,Q^2)\right]$$

Approximate Multi - Jet Cross-Sections in QCD, M. L. Mangano, S. J. Parke. Aug 1988.
Exact and Approximate Expressions for Multi - Gluon Scattering, F. A. Berends, W.T. Giele, H. Kuijf. May 1989

MULTIJET PRODUCTION IN W, Z EVENTS AT $p\bar{p}$ COLLIDERS

F.A. BERENDS, W.T. GIELE [1], H. KUIJF
Instituut-Lorentz, University of Leiden, POB 9506, 2300 RA Leiden, The Netherlands

R. KLEISS
CERN, CH-1211 Geneva 23, Switzerland

and

W.J. STIRLING
Department of Physics, University of Durham, Durham DH1 3LE, UK

Received 28 March 1989

We calculate cross sections for the production of 0, 1, 2 and 3 jets in W, Z events at $p\bar{p}$ collider energies. Full leptonic decays of the weak bosons are included. We analyse in particular the relative rate of multijet production, the contribution of the different subprocesses and some overall properties of the events.

ON THE PRODUCTION OF A W AND JETS AT HADRON COLLIDERS

F.A. BERENDS, H. KUIJF and B. TAUSK*

Instituut-Lorentz, University of Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands

W.T. GIELE

Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510, USA

Received 5 November 1990

In this paper the evaluation of matrix elements for a vector boson decaying into n partons ($n \leqslant 6$) is presented. For this purpose recursive techniques and Weyl–van der Waerden spinor calculus are used. By appropriately crossing partons the amplitudes can be used to describe the production of a W and jets. The four-jet case is of particular interest as background to interesting physics signals. Numerical results are given for present and future accelerator energies. Also the signal versus background question for top quark search is briefly discussed.

VECBOS

Higgs-search

Branching rations and cross sections

Focusing on the $H \to \gamma + \gamma$ **signal**

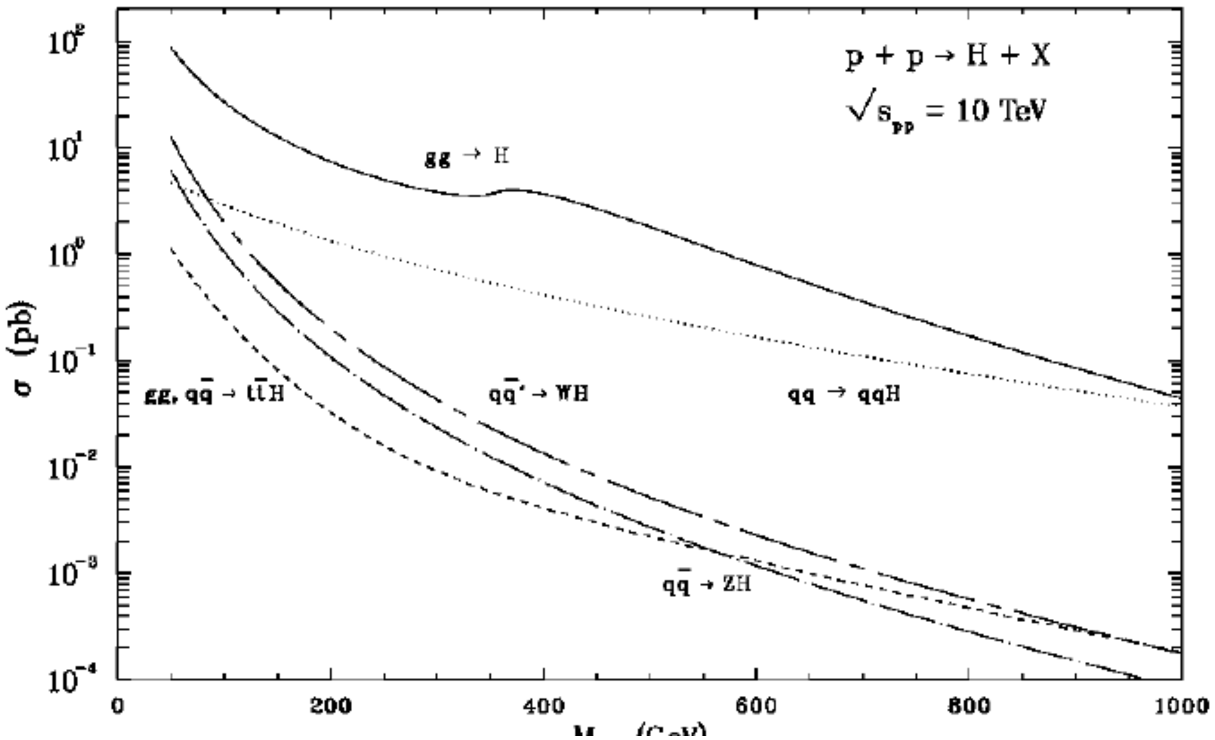
in the mass range $M_Z < M_H < 150$ GeV

Signal and background calculations for Higgs production at the Tevatron and at the LHC

Gunion, Haber, Kane, Dawson:

The Higgs Hunter's Guide

Jun 1989 - 404 pages



Higgs boson production at the LHC

M. Spira[a], A. Djouadi[b,c], D. Graudenz[d], P.M. Zerwas[c]

Nuclear Physics B 453 (1995) 17–82

Larger than factor of 2 K-factor

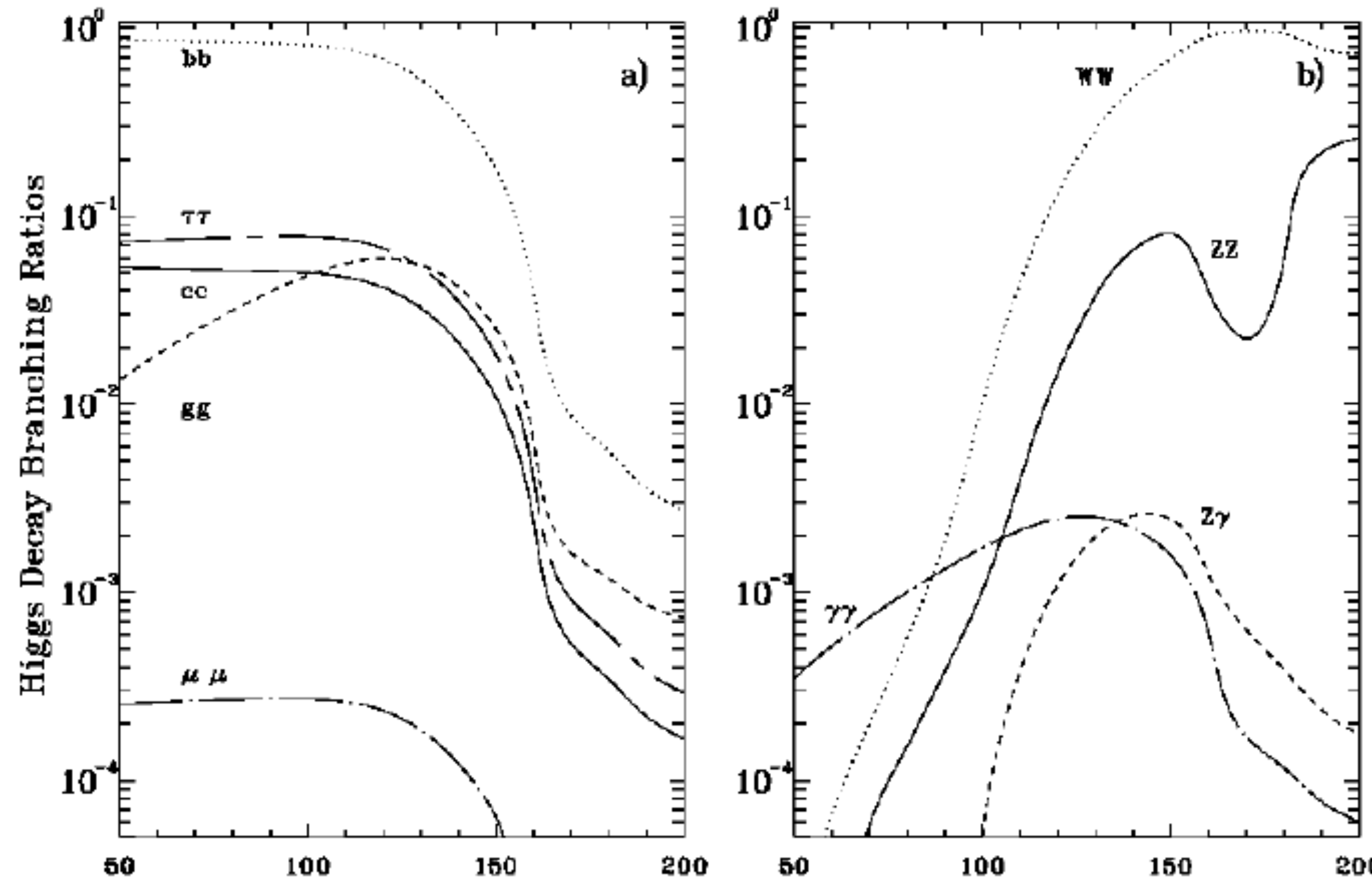
The Standard Model Higgs at LHC: Branching Ratios and Cross-Sections

Z. Kunszt
Theoretical Physics, ETH,
Zurich, Switzerland,

and

W.J. Stirling
Departments of Physics and Mathematical Sciences,
University of Durham,
Durham, England.

Aachen, 4–9 October 1990



Spira H-decay

Aachen, 4–9 October 1990

First, we have re-analysed the Higgs branching ratios including the effects of the *running* b quark mass, and have discovered that the suppression of the $H \to b\bar{b}$ partial width that this induces, increases the $H \to \gamma\gamma$ branching ratio to about a factor two higher than the canonical value of 10^{-3} found in the literature [10]. The partial decay width of the Higgs bo-

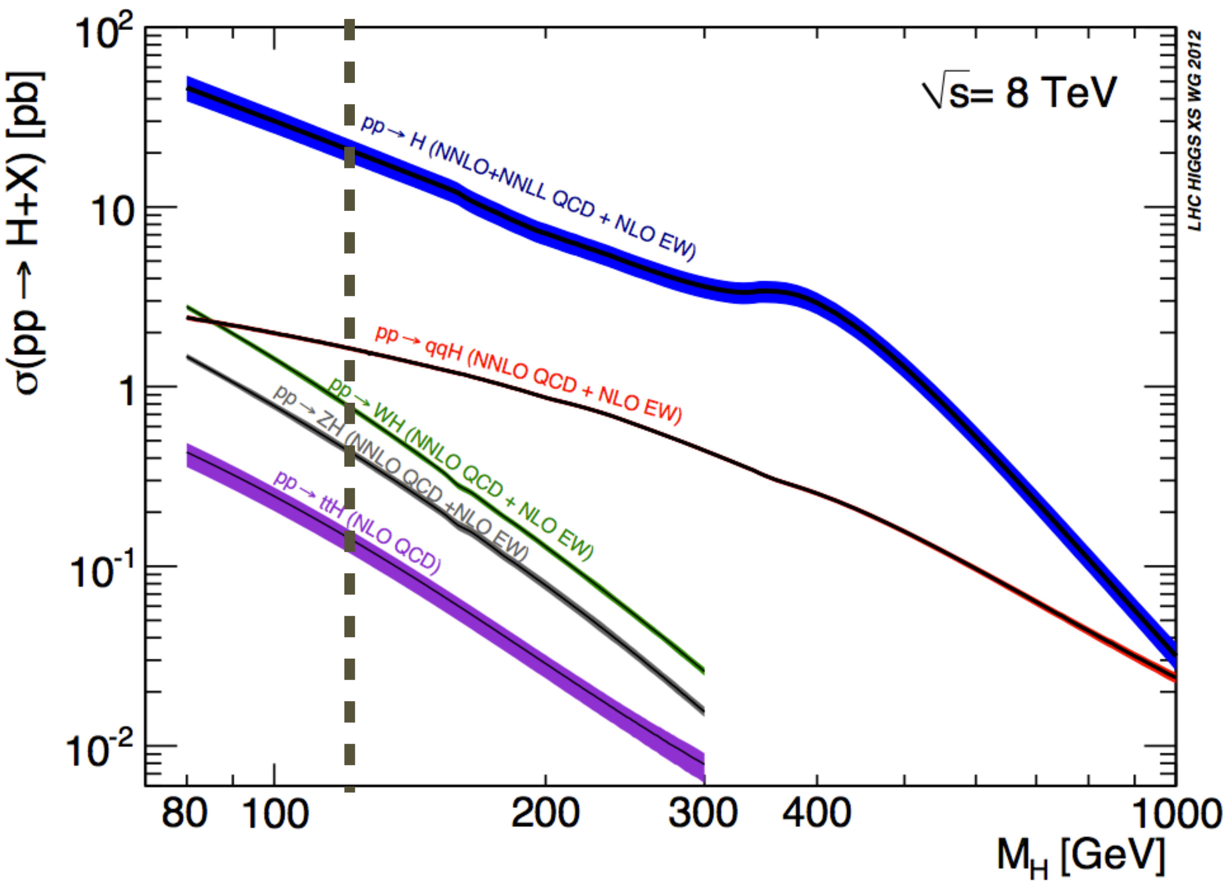
Higgs Production at the LHC: an Update on Cross Sections and Branching Ratios[1]

Z. Kunszt[a], S. Moretti[b,c] and W. J. Stirling[d,e]

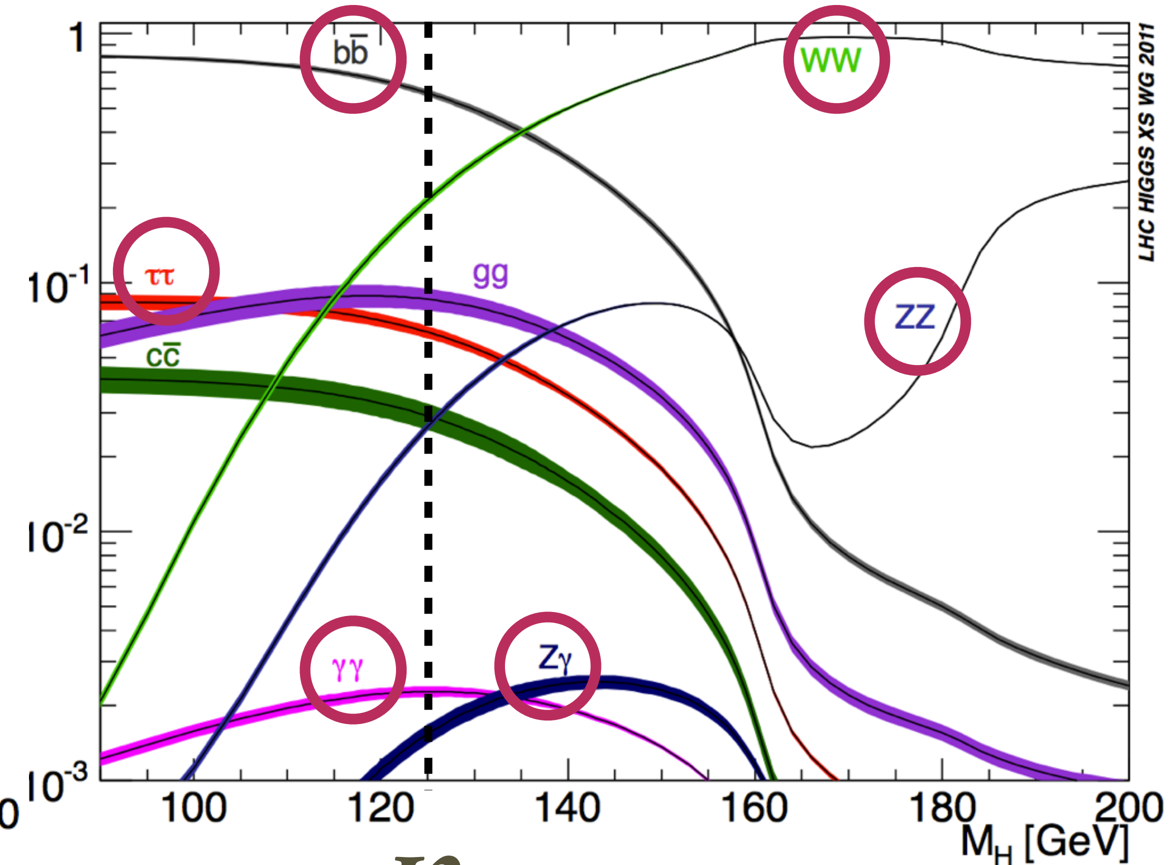
November 1996

Mass of the top quark , K-factors, LHC energy 10 TeV, 14 TeV

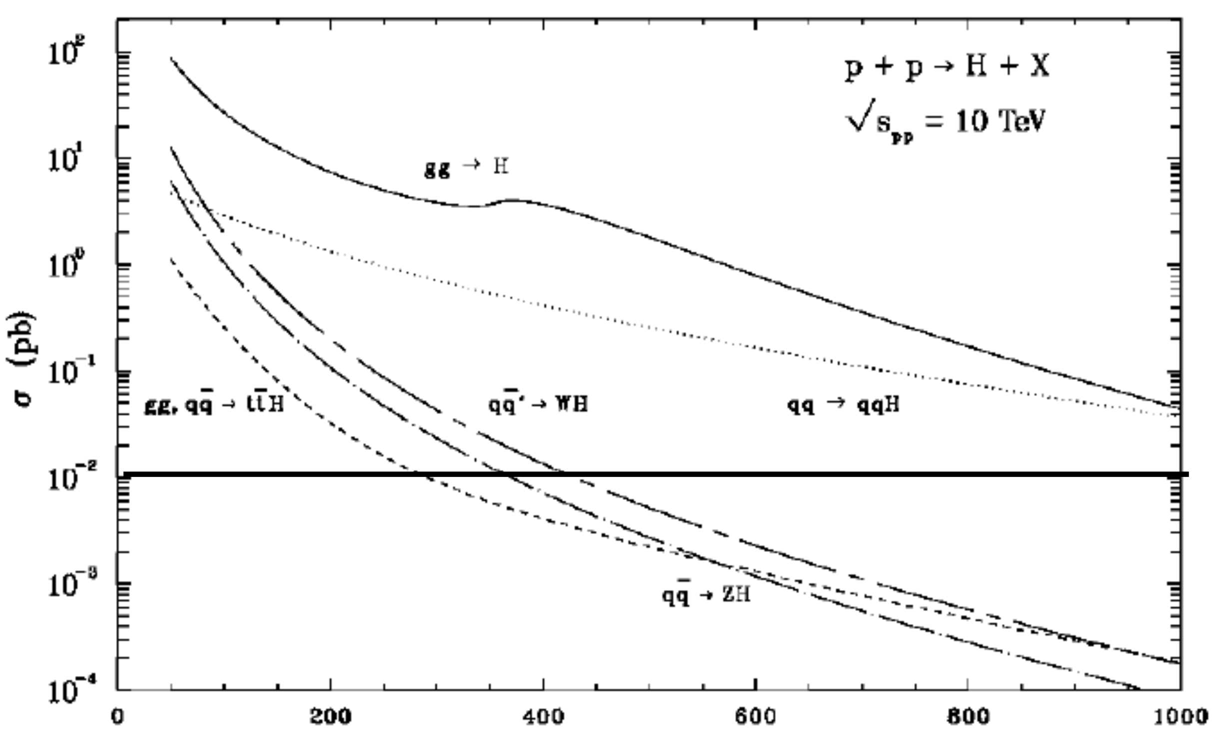
LUCKILY: LARGE QCD CORRECTIONS



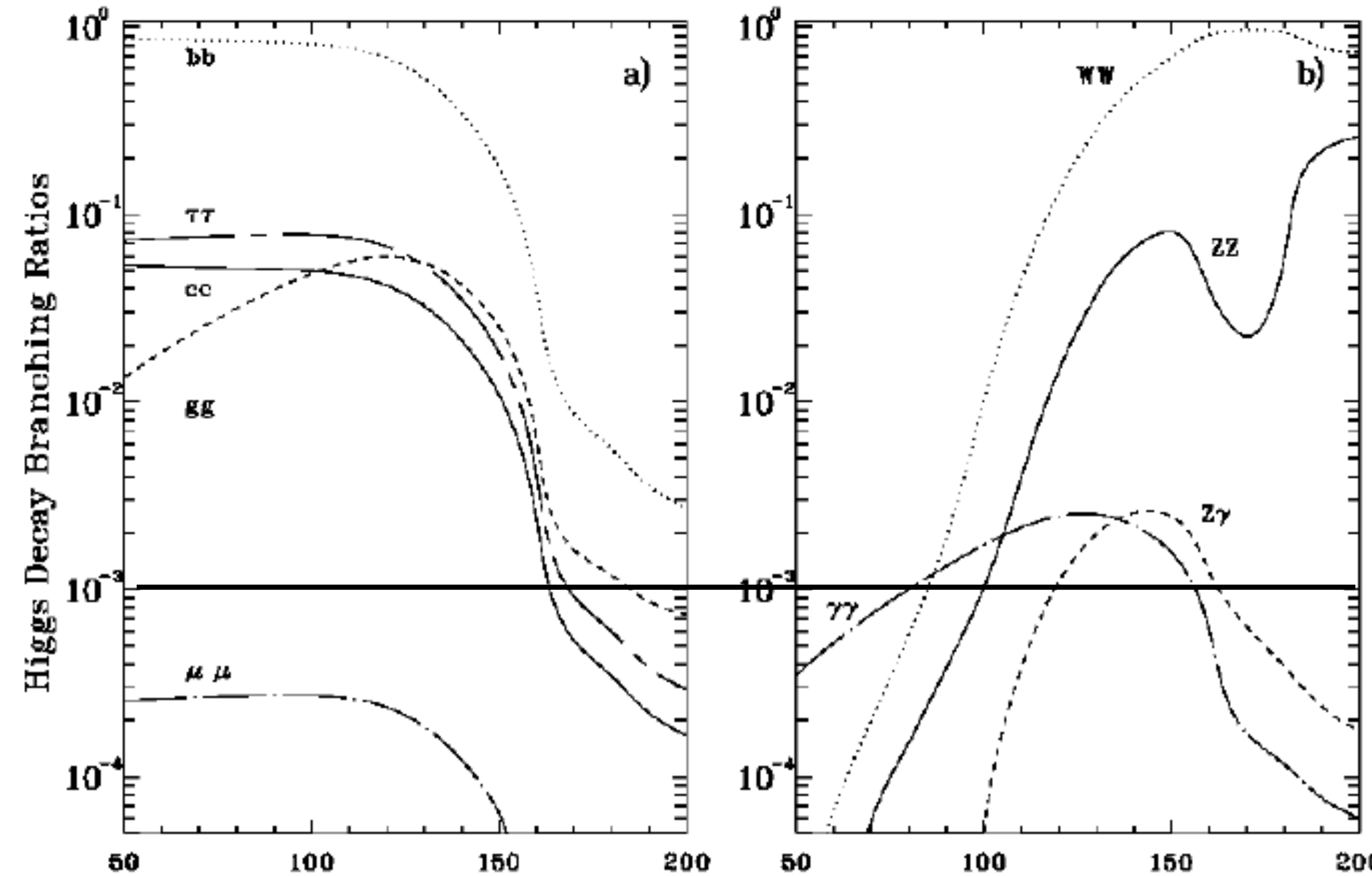
σ(pp → H+X) [pb]
√s= 8 TeV
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD + NLO EW)
pp → WH (NNLO QCD + NLO EW)
pp → ZH (NNLO QCD +NLO EW)
pp → ttH (NLO QCD)
LHC HIGGS XS WG 2012
M_H [GeV]



bb̄
WW
ττ
gg
cc̄
ZZ
γγ
Zγ
LHC HIGGS XS WG 2011
M_H [GeV]



p + p → H + X
√s_pp = 10 TeV
gg → H
σ (pb)
gg, qq̄ → tt̄H
qq̄' → WH
qq → qqH
qq̄ → ZH



Higgs Decay Branching Ratios
bb
ττ
cc
gg
μ μ
a)
WW
ZZ
Zγ
γγ
b)

Photon decay modes of the intermediate mass Higgs

ECFA Higgs working group
C.Seez and T. Virdee
L. DiLella, R. Kleiss, Z. Kunszt and W. J.Stirling

Presented at the LHC Workshop, Aachen, 4 - 9 October 1990
by C. Seez, Imperial College, London.

A report is given of studies of:
(a) $H \to \gamma\gamma$ (work done by C. Seez and T. Virdee)
(b) $W H \to \gamma\gamma$ (work done by L. DiLella, R. Kleiss, Z. Kunszt and W. J. Stirling)
for Higgs bosons in the intermediate mass range ($90 < m_H < 150$ GeV/c^2).
The study of the two photon decay mode is described in detail.

- A superb electromagnetic calorimeter with a resolution of $\Delta E/E = 2\%/\sqrt{E} \oplus 0.5\%$ would be able to detect a very significant signal from standard model Higgs bosons in the mass range $100 < m_H < 150$ GeV/c^2 at LHC thus filling the gap between LEP II and $H \to ZZ^*$ at LHC.

II.1 $H \to \gamma\gamma$, WH with $W \to \ell\nu$, $H \to \gamma\gamma$, and ZH with $Z \to \ell\ell$, $H \to \gamma\gamma$

The search for the Higgs in its $\gamma\gamma$ decay mode, whether produced singly (mainly through gg fusion in this mass range) or in association with a W or Z boson, subsequently decaying leptonically, is reviewed in detail in these proceedings [3]. We shall only briefly summarise the main conclusions here.

The channel $H \to \gamma\gamma$ would allow discovery of the Higgs boson at LHC within the mass range, $m_Z \leq m_H \leq 150$ GeV if the following conditions are satisfied :

1) The available integrated luminosity is at least 10^5 pb^{-1}.
2) The diphoton signal from a narrow Higgs resonance can be extracted from the irreducible continuum $\gamma\gamma$ background. As discussed in detail in Ref. 3, this implies that the resolution, uniformity, and stability of the electromagnetic calorimeter are very good, and that the direction of the photons can be measured to better than ≈ 10 mrad, using the longitudinal segmentation in the electromagnetic calorimeter.
3) The potentially overwhelming background from electromagnetic jets, containing one or several leading π^0's can be reduced well below the $\gamma\gamma$ continuum background. This has been estimated possible if one achieves a rejection of the order of 10^4 per jet, which implies that close-by photon showers from π^0, η decay can be separated down to angles of about 5 mrad, using for example a highly segmented position detector after about four radiation lengths in the electromagnetic calorimeter.

Some final reflections

I was lucky that 35 years ago I had employment in the CERN Theory Division during about the same period as James. His brilliiant wisdom on issues of particle physics phenomenology made a big impact on me. He was a very nice person, with well coded humor. We lived in a breakthrough period with tremendous theoretical as well as experimental progress.

I recalled only limited amount of work James made in the period of 1984-2000. We gradually have anticipated that perturbative QCD with the accumulated phenomenological information on parton number densities is capable to provide us a with formidable theoretical tool to derive precision prediction for the vast number of data to be observed at the LHC.

James with his work on mulitjets enormously in our effort to develop precision hadron collider physics. We are grateful for this and we miss his wisdom.