LOOPFEST : THE FIRST TEN YEARS

Ten years of LoopFest

- The LoopFest conference is ten years old
- LoopFest I was held at BNL; it was organized   by Doreen, Sally and Uli

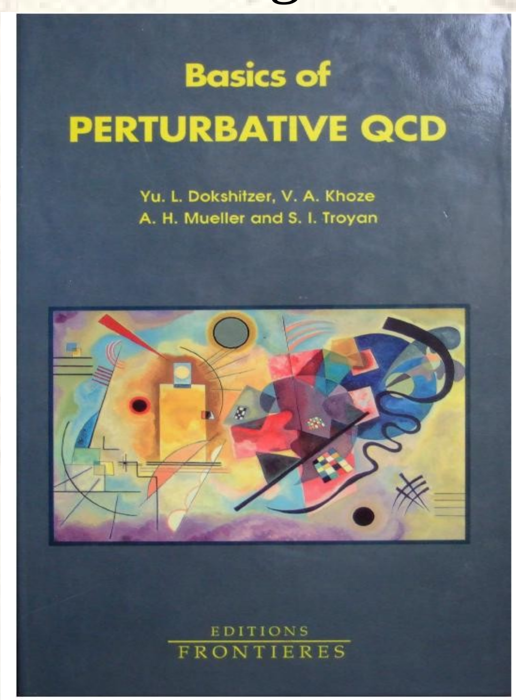
From Uli Baur talk at LoopFest 2001

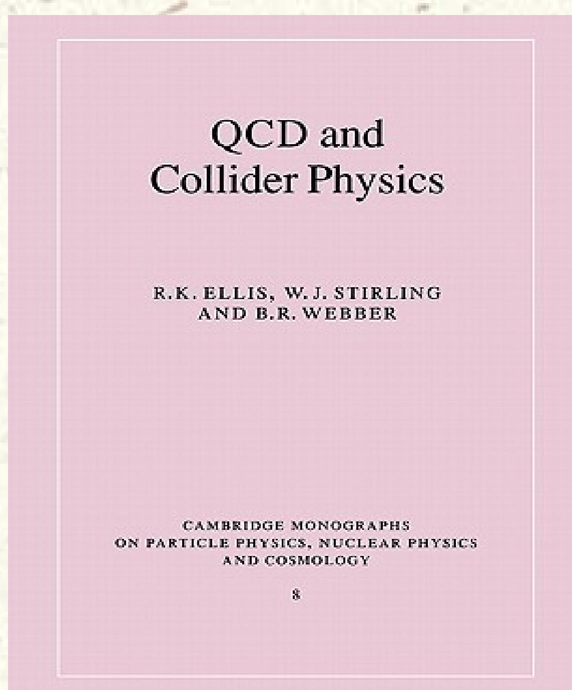
Ten years of LoopFest

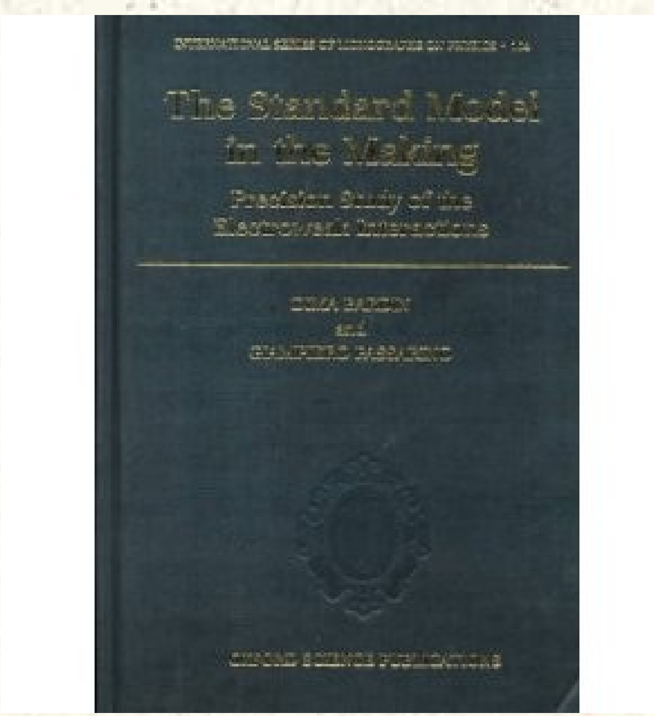
- LoopFest changed in a number of ways during these years
- LoopFest I was held in the ``plenary/parallel" mode that has been changed to the ``only plenary" mode already at LoopFest II
- LoopFest I agenda was dominated by physics of Future Linear Collider – there was not a single plenary talk on any other physics...
- First talks on hadron collider physics and B-physics appeared only at the LoopFest II
- The LoopFest broadened its scope significantly making it an important meeting for people who are involved with various aspects of Standard Model physics

What did we know in 2002?

- We came to 2002 following LEP and Run I Tevatron, with hopes for the Run II and in the middle of the successful B-physics program
- Absence of any large New Physics signal provided a strong boost for the development of our field throughout the LEP lifetime
- Deep understanding of perturbative QFT was developed before and during the LEP era

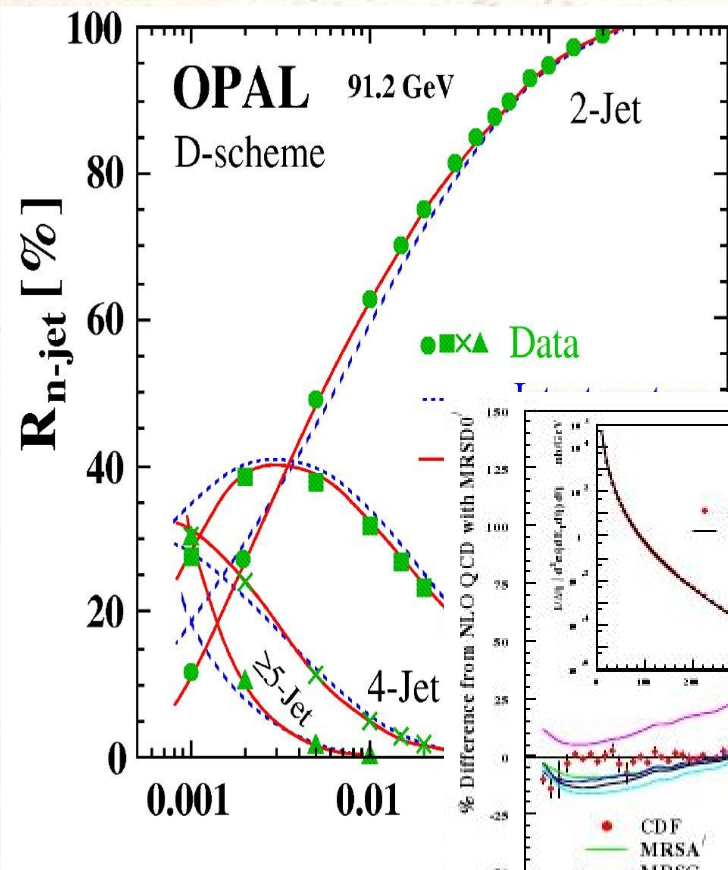


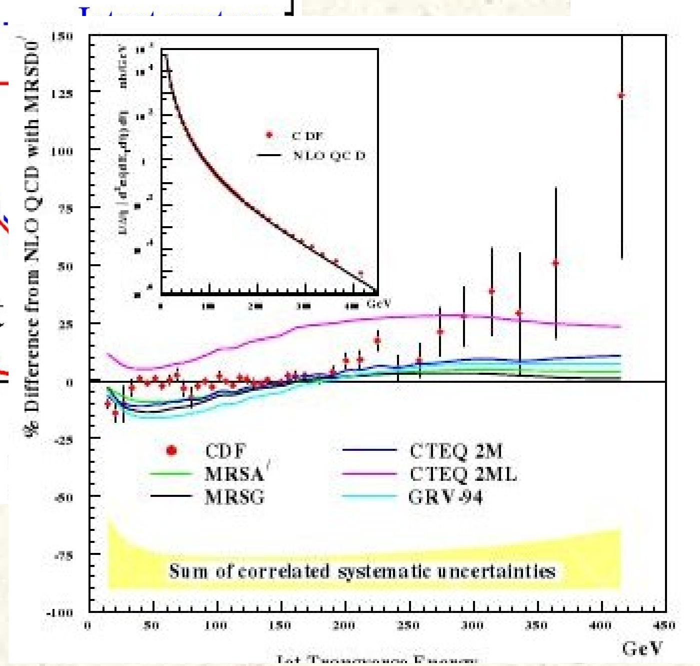


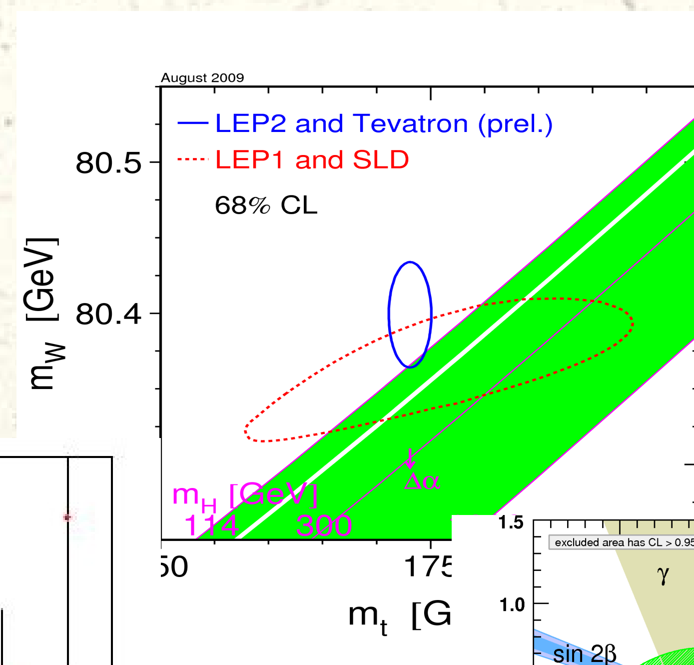


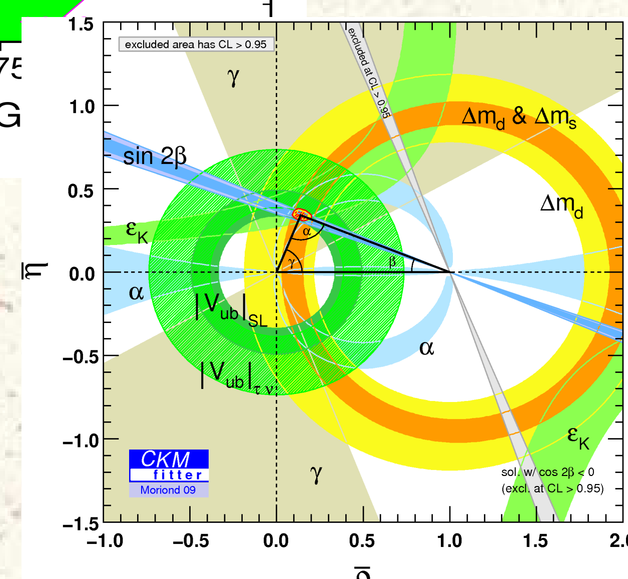
What did we know in 2002?

- Variety of particle physics results indicated a consistent picture, with a healthy fraction of three sigma fluctuations

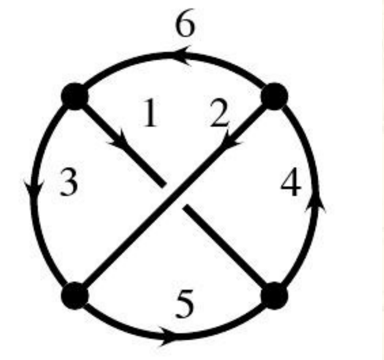








What did we know in 2002?



- Integration-by-parts — Tkachov, Chetyrkin
- Laporta algorithm — Laporta
- Three-loop massless graphs (Mincer) — Larin, Vermaseren, Gorishni
- Three-loop vacuum bubbles (Matad) — Steinhauser
- Asymptotic expansions , strategy of regions — Smirnov, Beneke
- Spinor-helicity methods — Berends, Wu
- Color decomposition — Berends, Giele, Mangano
- Recursion relations — Berends, Giele
- Unitarity ideas — Barbieri, Remiddi; van Neerven; Bern, Dixon, Kosower
- Subtraction methods for NLO — Catani, Seymour, Frixione, Kunszt, Signer
- CKKW algorithm — Catani, Krauss, Kuhn, Webber
- Many two-loop amplitudes for 2 → 2 parton scattering — Smirnov, Tauks, Anastasiou, Glover, Oleari, Gehrmann, Remiddi

$$A_{jk}^{\mathrm{MHV}} = i\frac{\langle jk\rangle^4}{\langle 12\rangle....\langle n1\rangle}$$

What did we know in 2002?

- Four-loop QCD beta-function, quark mass anomalous dimension etc.
  Van Ritbergen, Vermaseren, Larin
- Two-loop QED corrections to muon lifetime
  Van Ritbergen, Stuart
- Four-loop and three-loop QED and two-loop electroweak corrections to the muon magnetic anomaly
  Kinoshita; Remiddi, Laporta, Czarnecki, Marciano, Krause
- Top threshold at NNLO ; Upsilon sum rules at NNLO, NRQED
  Beneke, Smirnov, Signer, Hoang, Teubner, Yakovlev
- QCD resummations, jet algorithms etc.
  Catani, Seymour, Sterman, Collins, Soper
- NLO QCD results for four-jet production in e+e- annihilation, three-jet production in hadron collisions
  Dixon, Signer, Giele, Kosower, Kilgore
- NNLO QCD corrections to Drell-Yan total production cross-section
  van Neerven
- NNLO QCD for inclusive Higgs production
  Harlander, Kilgore, Anastasiou, K.M.

What did we learn since 2002?

- What has changed in the past ten years?
- What new knowledge has been created?
- What can we do now that we were unable to do before?

Eligibility requirements:

Must be part of N=0 sector of a perturbative QFT

Must have phenomenological applications

Must be considered nearly impossible by experts

Must be completed between 2002 - 2011

Top10 songs www.top10songs.com

#10 Bhabha scattering at two loops

- $e^+e^- \to e^+e^-$ is a process used to monitor luminosity at e+e- colliders

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\alpha^2}{s}\left(\frac{1-x+x^2}{x}\right)^2\left[1+\left(\frac{\alpha}{\pi}\right)\delta_1+\left(\frac{\alpha}{\pi}\right)^2\delta_2+\mathcal{O}(\alpha^3)\right]$$

$$\delta_1 = \left(4L_{\mathrm{soft}}+3+\frac{2}{3}N_f\right)\ln\left(\frac{s}{m_e^2}\right)+\delta_1^{(0)},$$

Berends, Kleiss; Remiddi et al. 1983

- The two-loop QED corrections were obtained in 2001 by Z. Bern, L. Dixon and A. Ghinculov, in the massless approximation

- A. Penin used the universality of soft and collinear limits to translate those massless results into a results where the electron mass is the collinear regulator

- This work motivated A. Mitov and S. Moch to derive general formula the connects massive and massless amplitudes, in QED and QCD

$$\mathcal{M}(m) = \Pi\sqrt{Z_i(m)}\mathcal{M}(0)+\mathcal{O}\left(m/\sqrt{s}\right)$$

Top 10 songs www.top10songs.com

#9 MCFM: the flower o' Scotland

J. Campbell, R.K. Ellis

MCFM Summary - v. 3.4

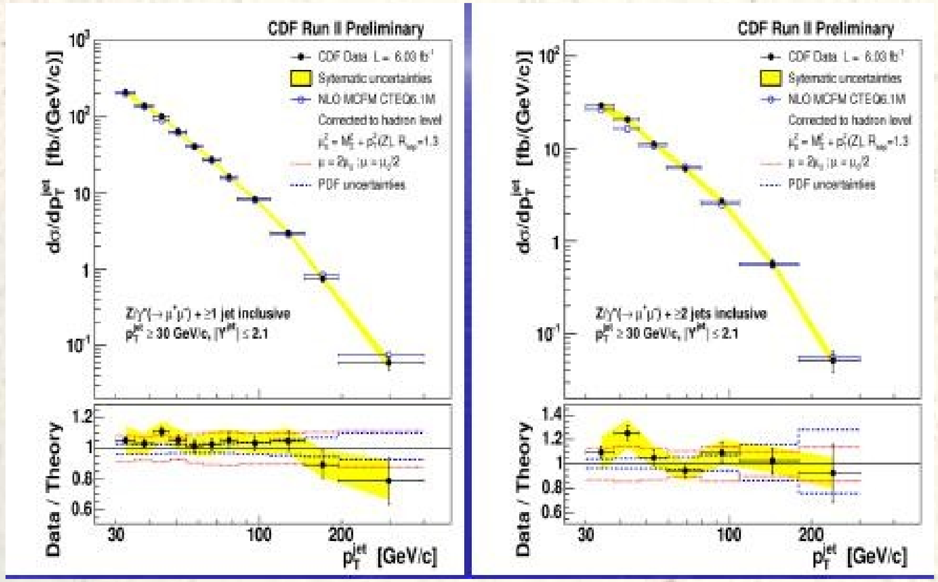
$p\bar{p} \to W^\pm/Z$	$p\bar{p} \to W^+ + W^-$
$p\bar{p} \to W^\pm + Z$	$p\bar{p} \to Z + Z$
$p\bar{p} \to W^\pm + \gamma$	$p\bar{p} \to W^\pm/Z + H$
$p\bar{p} \to W^\pm + g^\star (\to b\bar{b})$	$p\bar{p} \to Zb\bar{b}$
$p\bar{p} \to W^\pm/Z + 1$ jet	$p\bar{p} \to W^\pm/Z + 2$ jets
$p\bar{p}(gg) \to H$	$p\bar{p}(gg) \to H + 1$ jet
$p\bar{p}(VV) \to H + 2$ jets	

- MCFM aims to provide a unified description of a number of processes at NLO accuracy.
- Various leptonic and/or hadronic decays of the bosons are included as further sub-processes.
- MCFM version 2.0 is part of the CDF code repository.

MCFM Information

- Version 3.4 available at: **`http://mcfm.fnal.gov`**
- Improvements over previous rele
  - more processes
  - better user interface
  - support for PDFLIB, Les Hou
  - ntuples as well as histogram
  - unweighted events
  - Pythia/Les Houches generator interface (LO)
- Coming attractions:
  - even more processes, photon fragmentation etc.

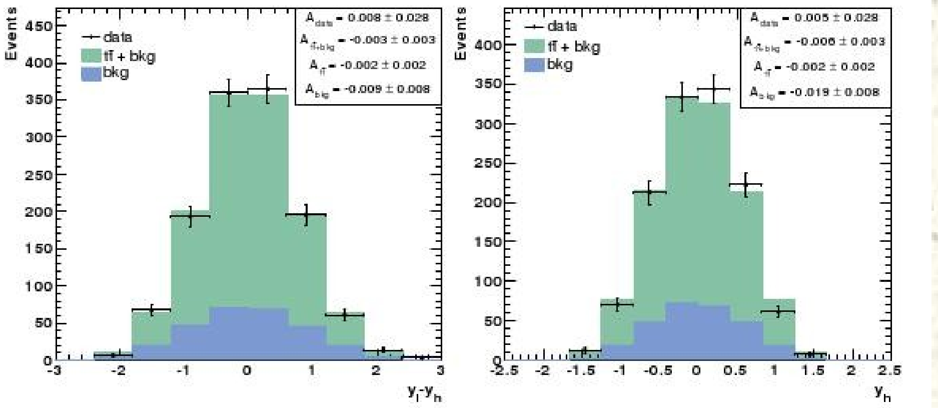
K.Ellis, Loopfest 2003 talk



#8 Parton shower MC and NLO

- Parton showers and NLO calculations first combined by
  S. Frixione and B. Webber – MC@NLO
- NLO normalization for cross-sections, smooth continuation of distributions from hard regions, controlled by the NLO, to soft regions, controlled by MC

model	level	$A^{p\bar{p}}$	$A^{t\bar{t}}$	$A^{p\bar{p}}/A^{t\bar{t}}$
MCFM	parton	0.038 ± 0.006	0.058 ± 0.009	0.66 ± 0.10
MC@NLO	parton	0.032 ± 0.005	0.052 ± 0.008	0.62 ± 0.09
MC@NLO	$t\bar{t}$	0.018 ± 0.005	0.024 ± 0.005	0.75 ± 0.11
MC@NLO	$t\bar{t}$+bkg	0.001 ± 0.003	0.017 ± 0.004	0.06 ± 0.01



Further developments – POWHEG, MEnloPS

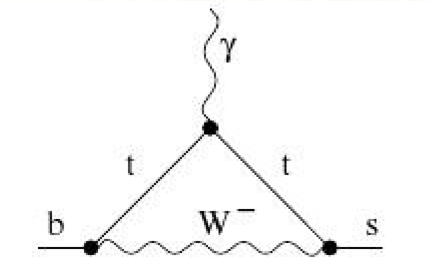
P. Nason, C. Oleari

Further challenges:
more complex processes,
CKKW@NLO

MC@NLO Is heavily used by the experimentalists

#7 $b \longrightarrow s\gamma$ at NNLO in QCD

- The first step in this story is to justify connecting B-hadron to b-parton
- NNLO branching fraction for $\bar{B} \to X_s\gamma$
- Truly gigantic effort
  - up to three-loop matching;
  - up to four-loop anomalous dimension $\mu = m_b$
  - up to two-loop matrix elements at



$$\mathcal{B}(\bar{B} \to X_s\gamma)_{\rm exp} = (3.55 \pm 0.24) \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_s\gamma)_{\rm th} = (3.15 \pm 0.23) \times 10^{-4}$$

M. Misiak, H. Asatrian, K. Bierl, M. Czakon, A. Czarnecki, T. Ewerth, A. Ferroglia, P. Gambino, M. Gorbahn, C. Greub, U. Haisch, A. Hovhannisyan, T. Hurth, A. Mitov, V. Poghosyan, M. Slusarczyk, M. Steinhauser; M. Neubert, T. Becher

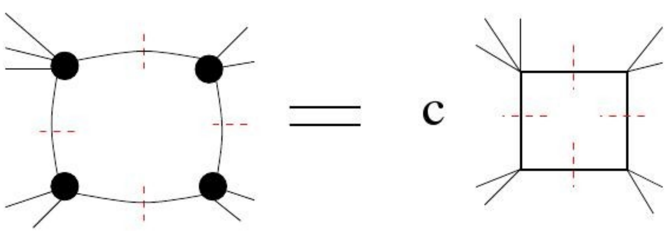
Further work to estimate the quality of the charm mass extrapolation

#6 The BCF and the OPP

- R. Britto, F. Cachazo and B. Feng observed that any box integral reduction coefficient can be obtained from a quadruple cut

Box Coefficients from Quadruple Cuts

(RB, Cachazo, Feng)



Generalized Unitarity: Try replacing all four propagators by delta functio

This operation isolates any given box.

In four dimensions, these four delta functions localize the integral completely. This computation is very easy!

The loop momentum solution

The box coefficients computed from quadruple cuts are given by

$$c = \frac{1}{2} \sum_{\mathcal{S}} A_1^{\rm tree} A_2^{\rm tree} A_3^{\rm tree} A_4^{\rm tree}$$

$\mathcal{S}$ is the set of all solutions of the on-shell conditions for the internal lines.

$$\mathcal{S} = \{ \ell \,|\, \ell^2 = 0, \quad (\ell - K_1)^2 = 0, \quad (\ell - K_1 - K_2)^2 = 0, \quad (\ell + K_4)^2 = 0 \}$$

Can these equations always be solved?

In complexified momentum space, there are exactly 2 solutions.

(Note: nonvanishing 3-point amplitudes.)

From R. Britto talk, LF 2008

#6 The BCF and the OPP

- G. Ossola, R. Pittau and K. Papadopoulos came up with a semi-analytic method to perform a reduction of one-loop integrals

$$
\begin{aligned}
N(q) = & \sum_{i_0<i_1<i_2<i_3}^{m-1} \left[d(i_0 i_1 i_2 i_3) + \tilde{d}(q; i_0 i_1 i_2 i_3) \right] \prod_{i \neq i_0, i_1, i_2, i_3}^{m-1} D_i \\
& + \sum_{i_0<i_1<i_2}^{m-1} \left[c(i_0 i_1 i_2) + \tilde{c}(q; i_0 i_1 i_2) \right] \prod_{i \neq i_0, i_1, i_2}^{m-1} D_i \\
& + \sum_{i_0<i_1}^{m-1} \left[b(i_0 i_1) + \tilde{b}(q; i_0 i_1) \right] \prod_{i \neq i_0, i_1}^{m-1} D_i \\
& + \sum_{i_0}^{m-1} \left[a(i_0) + \tilde{a}(q; i_0) \right] \prod_{i \neq i_0}^{m-1} D_i
\end{aligned}
$$

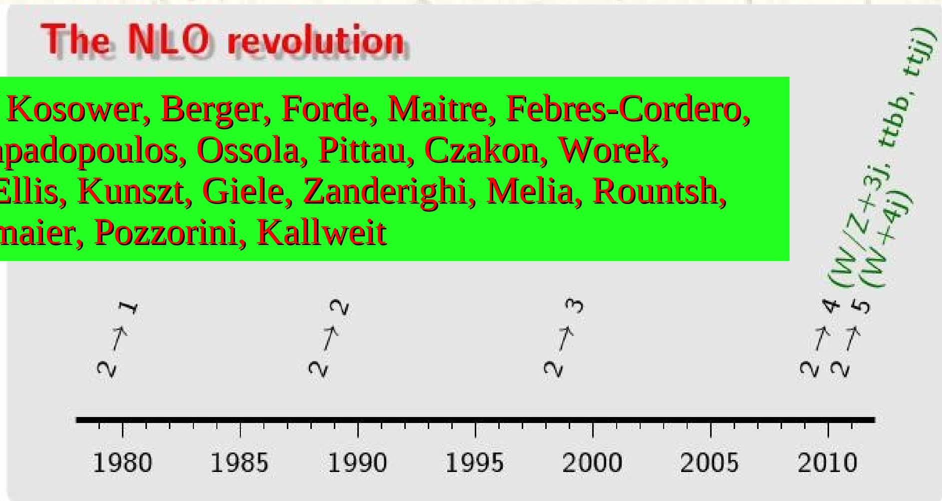
	Process	μ	n_{lf}	Cross section (pb)	
				LO	NLO
a.1	$pp \to t\bar{t}$	m_{top}	5	123.76 ± 0.05	162.08 ± 0.12
a.2	$pp \to tj$	m_{top}	5	34.78 ± 0.03	41.03 ± 0.07
a.3	$pp \to tjj$	m_{top}	5	11.851 ± 0.006	13.71 ± 0.02
a.4	$pp \to t\bar{b}j$	$m_{top}/4$	4	25.62 ± 0.01	30.96 ± 0.06
a.5	$pp \to t\bar{b}jj$	$m_{top}/4$	4	8.195 ± 0.002	8.91 ± 0.01
b.1	$pp \to (W^+ \to)e^+\nu_e$	m_W	5	5072.5 ± 2.9	6146.2 ± 9.8
b.2	$pp \to (W^+ \to)e^+\nu_e\, j$	m_W	5	828.4 ± 0.8	1065.3 ± 1.8
b.3	$pp \to (W^+ \to)e^+\nu_e\, jj$	m_W	5	298.8 ± 0.4	300.3 ± 0.6
b.4	$pp \to (\gamma^*/Z \to)e^+e^-$	m_Z	5	1007.0 ± 0.1	1170.0 ± 2.4
b.5	$pp \to (\gamma^*/Z \to)e^+e^-\, j$	m_Z	5	156.11 ± 0.03	203.0 ± 0.2
b.6	$pp \to (\gamma^*/Z \to)e^+e^-\, jj$	m_Z	5	54.24 ± 0.02	56.69 ± 0.07
c.1	$pp \to (W^+ \to)e^+\nu_e b\bar{b}$	$m_W + 2m_b$	4	11.557 ± 0.005	22.95 ± 0.07
c.2	$pp \to (W^+ \to)e^+\nu_e t\bar{t}$	$m_W + 2m_{top}$	5	0.009415 ± 0.000003	0.01159 ± 0.00001
c.3	$pp \to (\gamma^*/Z \to)e^+e^- b\bar{b}$	$m_Z + 2m_b$	4	9.459 ± 0.004	15.31 ± 0.03
c.4	$pp \to (\gamma^*/Z \to)e^+e^- t\bar{t}$	$m_Z + 2m_{top}$	5	0.0035131 ± 0.0000004	0.004876 ± 0.000002
c.5	$pp \to \gamma t\bar{t}$	$2m_{top}$	5	0.2906 ± 0.0001	0.4169 ± 0.0003
d.1	$pp \to W^+W^-$	$2m_W$	4	29.976 ± 0.004	43.92 ± 0.03
d.2	$pp \to W^+W^-\, j$	$2m_W$	4	11.613 ± 0.002	15.174 ± 0.008
d.3	$pp \to W^+W^+\, jj$	$2m_W$	4	0.07048 ± 0.00004	0.1377 ± 0.0005
e.1	$pp \to HW^+$	$m_W + m_H$	5	0.3428 ± 0.0003	0.4455 ± 0.0003
e.2	$pp \to HW^+\, j$	$m_W + m_H$	5	0.1223 ± 0.0001	0.1501 ± 0.0002
e.3	$pp \to HZ$	$m_Z + m_H$	5	0.2781 ± 0.0001	0.3659 ± 0.0002
e.4	$pp \to HZ\, j$	$m_Z + m_H$	5	0.0988 ± 0.0001	0.1237 ± 0.0001
e.5	$pp \to Ht\bar{t}$	$m_{top} + m_H$	5	0.08896 ± 0.00001	0.09869 ± 0.00003
e.6	$pp \to Hb\bar{b}$	$m_b + m_H$	4	0.16510 ± 0.00009	0.2099 ± 0.0006
e.7	$pp \to Hjj$	m_H	5	1.104 ± 0.002	1.036 ± 0.002

Table 2: Results for total rates, possibly within cuts, at the 7 TeV LHC, obtained with MadFKS and MadLoop. The errors are due to the statistical uncertainty of Monte Carlo integration. See the text for details.

One of the great virtues of the OPP is that it made generalized unitarity at one-loop fully derivable. It also helped, in tremendous way, to combine the speed and easiness of numerical calculations with the high degree of analytic control

MadLoop, Hirschi et al. 2011

#5 NLO QCD for multi-parton processes



Bern, Dixon, Kosower, Berger, Forde, Maitre, Febres-Cordero, Gleisberg, Papadopoulos, Ossola, Pittau, Czakon, Worek, Bevilacqua, Ellis, Kunszt, Giele, Zanderighi, Melia, Rountsh, Denner, Dittmaier, Pozzorini, Kallweit

An experimenter's wishlist

- Hadron collider cross-sections one would like to know at NLO

Run II Monte Carlo Workshop, April 2001

Single boson	Diboson	Triboson	Heavy flavour
$W + \leq 5j$	$WW + \leq 5j$	$WWW + \leq 3j$	$t\bar{t} + \leq 3j$
$W + b\bar{b} + \leq 3j$	$WW + b\bar{b} + \leq 3j$	$WWW + b\bar{b} + \leq 3j$	$t\bar{t} + \gamma + \leq 2j$
$W + c\bar{c} + \leq 3j$	$WW + c\bar{c} + \leq 3j$	$WWW + \gamma\gamma + \leq 3j$	$t\bar{t} + W + \leq 2j$
$Z + \leq 5j$	$ZZ + \leq 5j$	$Z\gamma\gamma + \leq 3j$	$t\bar{t} + Z + \leq 2j$
$Z + b\bar{b} + \leq 3j$	$ZZ + b\bar{b} + \leq 3j$	$WZZ + \leq 3j$	$t\bar{t} + H + \leq 2j$
$Z + c\bar{c} + \leq 3j$	$ZZ + c\bar{c} + \leq 3j$	$ZZZ + \leq 3j$	$t\bar{b} + \leq 2j$
$\gamma + \leq 5j$	$\gamma\gamma + \leq 5j$		$b\bar{b} + \leq 3j$
$\gamma + b\bar{b} + \leq 3j$	$\gamma\gamma + b\bar{b} + \leq 3j$		
$\gamma + c\bar{c} + \leq 3j$	$\gamma\gamma + c\bar{c} + \leq 3j$		
	$WZ + \leq 5j$		
	$WZ + b\bar{b} + \leq 3j$		
	$WZ + c\bar{c} + \leq 3j$		
	$W\gamma + \leq 3j$		
	$Z\gamma + \leq 3j$		

$$pp \to W(Z) + 3j$$

$$pp \to t\bar{t}b\bar{b}$$

$$pp \to t\bar{t}jj$$

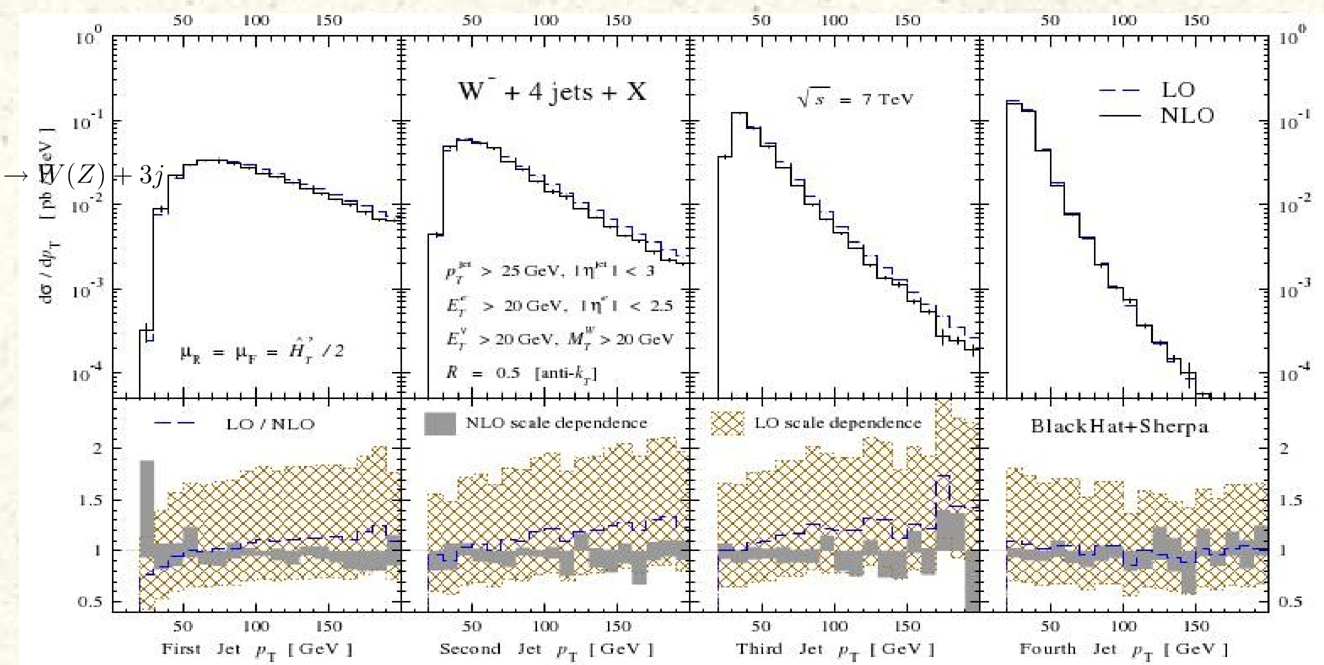
$$pp \to W^+W^+jj$$

$$pp \to W^+W^-b\bar{b}$$

$$pp \to W^+W^-jj$$

$$pp \to W + 4j$$

Blackhat collaboration, 2010



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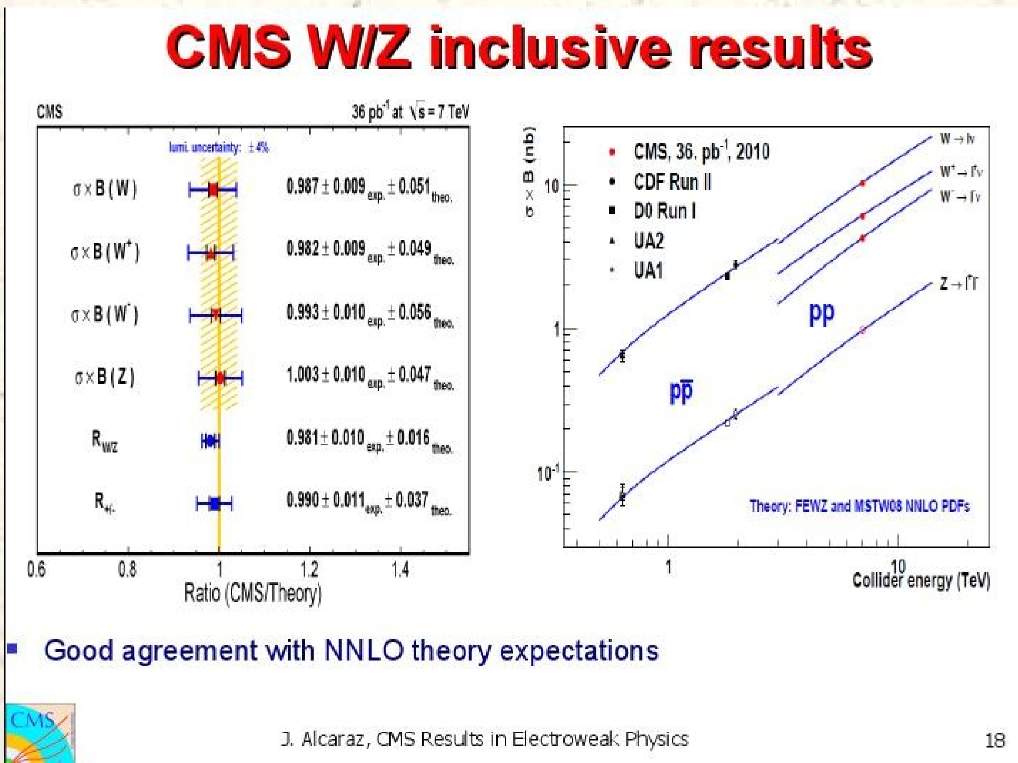
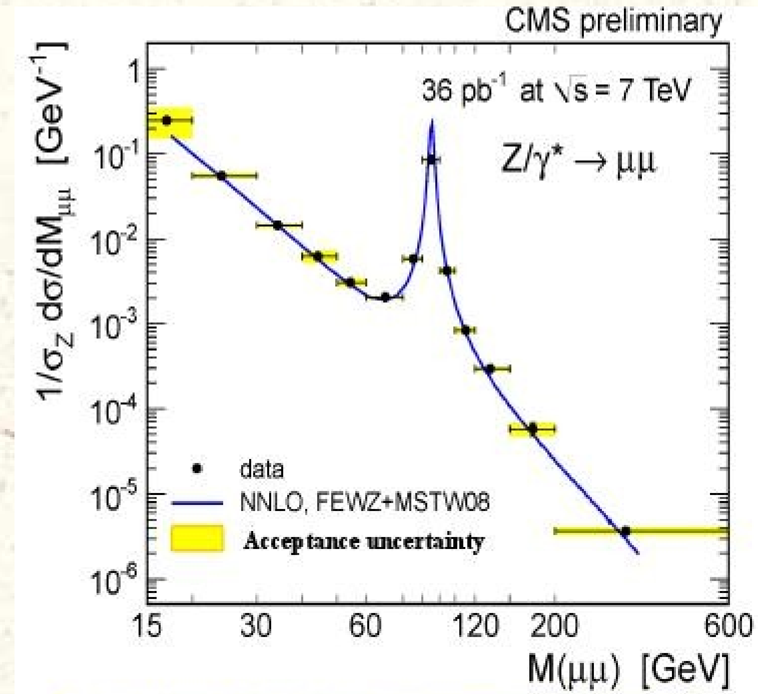
#4 NNLO for the Drell-Yan and the Higgs

- First hadron collider processes for which NNLO QCD results for fully differential quantities became known ; widely used by the Tevatron and the LHC collaborations





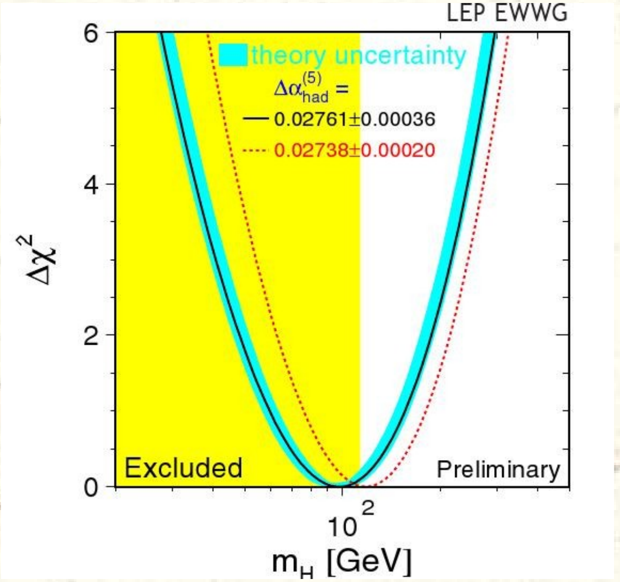
- Unfolded distribution, normalized to Z peak cross section and corrected for QED final-state radiation effects

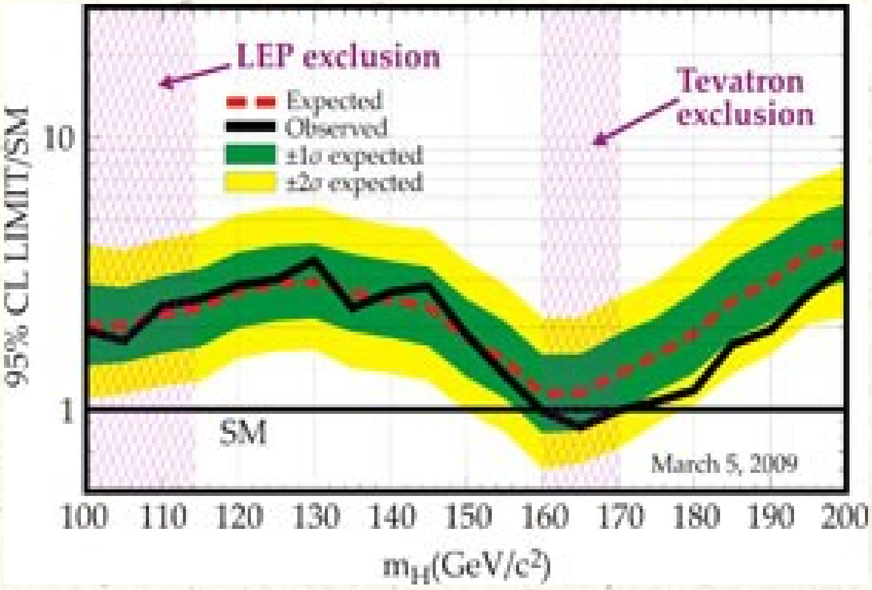
Good agreement with NNLO predictions within uncertainties

Original calculations: F. Petriello, K.M., M.Grazzini, S. Catani
Recent work: R. Gavin, Y. Li, F. Petriello, S. Quackenbush

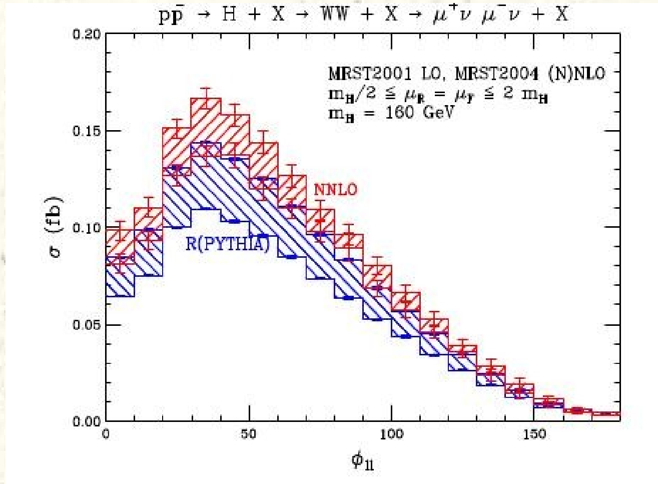
#4 NNLO for the Drell-Yan and the Higgs

- Acceptances, neural nets, exclusions and the big picture





PQCD computations verify event generators;
Event generators are used to feed neural nets
Neural nets give exclusion limits
Exclusion limits are fed into the BIG PICTURE....



Original calculations due to C. Anastasiou, F. Petriello, K.M., M. Grazzini, S. Catani

Anastasiou, Dissertori, Grazzini, Stoeckli, Webber

#4 NNLO for the Drell-Yan and the Higgs

- Interestingly– the technology behind these result may be more powerful than we thought
- M. Czakon pointed out that combining the idea of section decomposition for real-emission phase space with the idea of phase-space partitioning is very fruitful

Double-real radiation in hadronic top quark pair production as a proof of a certain concept

M. Czakon[a]

[a] *Institut für Theoretische Teilchenphysik und Kosmologie, RWTH Aachen University, D-52056 Aachen, Germany*

A new method for real radiation at NNLO

Charalampos Anastasiou

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, U.S.A.

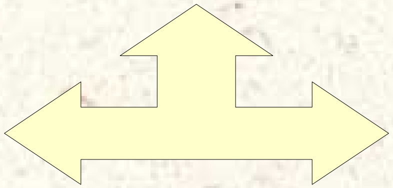
Kirill Melnikov

Department of Physics and Astronomy, University of Hawaii, 2505 Correa Rd., Honolulu, Hawaii 96822

Frank Petriello

Department of Physics, Johns Hopkins University, 3400 North Charles St., Baltimore, MD 21218

Abstract



December 1995

Three-jet cross sections to next-to-leading order

S. Frixione[a], Z. Kunszt

Theoretical Physics, ETH, Zurich, Switzerland

A. Signer[a]

SLAC, PO Box 4349, Stanford, CA 94309

#3 R(s) at four loops

- The e+e- annihilation cross-section to hadrons is a basic QCD observable; it was pushed to new limits by P. Baikov, K. Chetyrkin and J. Kuhn
- Non-trivial IBP reduction, based on the Laurant expansion around $D=\infty$ limit
- Unusual method to compute master integrals leads to enormous simplifications
- Important correction to tau-decays and precise determination of the strong coupling constant

$$R(s) = 12\pi \mathrm{Im}\Pi(-s-i\epsilon)$$

$$3Q^2\Pi(Q^2) = i\int \mathrm{d}^4 x e^{iqx} \langle 0|Tj_\mu(x)j_\nu(0)|0\rangle$$

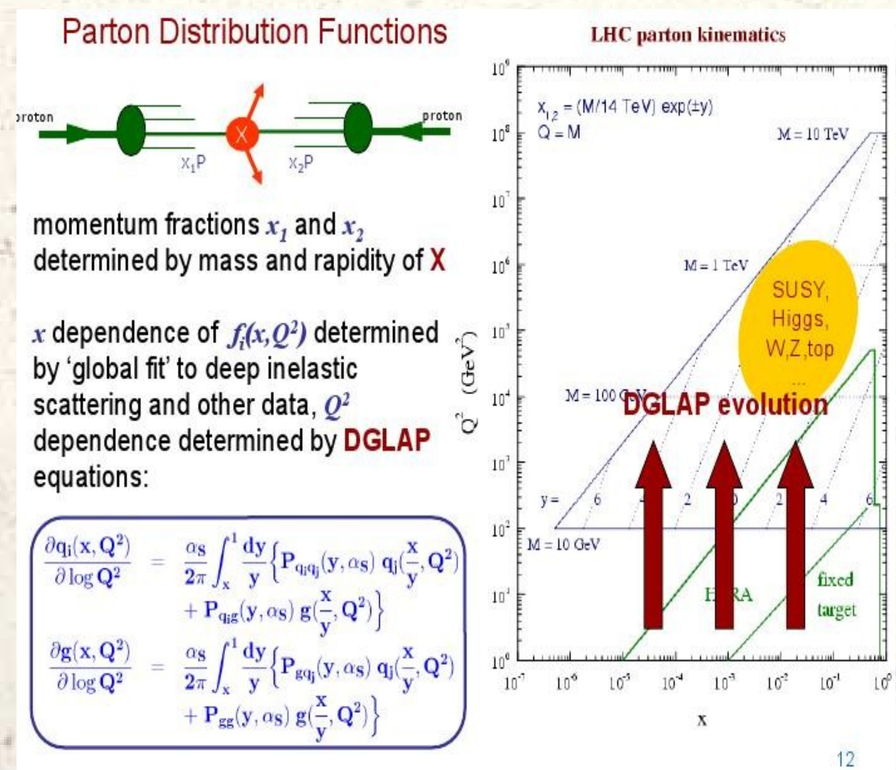
$$R(s) = 1 + a_s + 1.4097a_s^2 - 12.76703a_s^3 - 80.0075a_s^4..$$ for n_f = 5

$$\alpha_s(M_z)^{\mathrm{NNNLO}} = 0.1190 \pm 0.0026_{\mathrm{exp}}$$

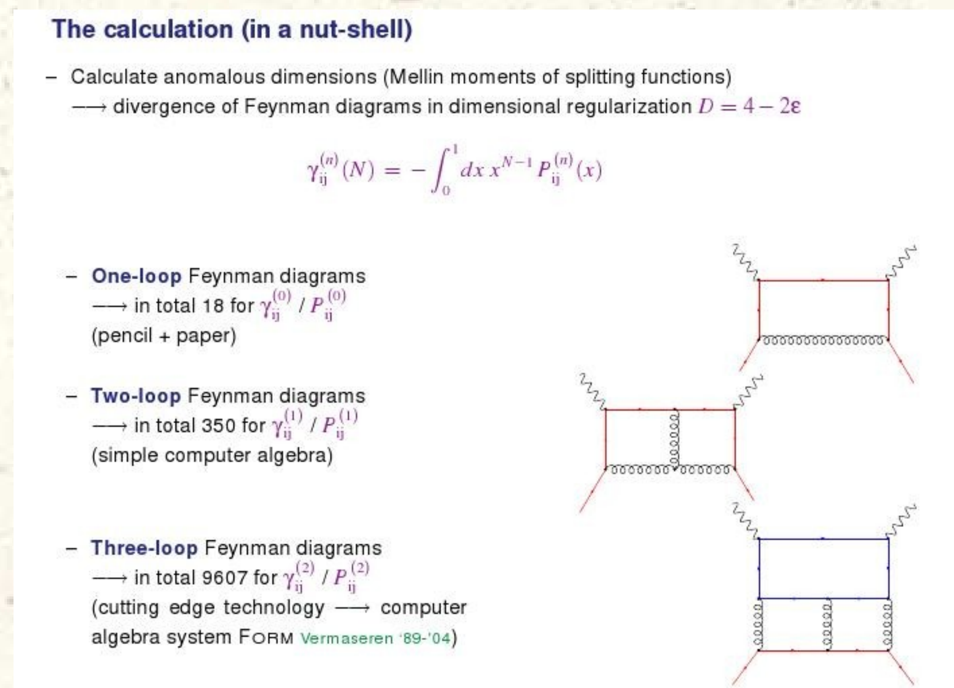
#2 Altarelli-Parisi kernels at NNLO

- Any higher-order calculation at a hadron collider requires parton distribution functions, fitted and evolved through a matching order
- Aiming at NNLO, need AP kernels with the matching accuracy. Those were obtained in a seminal paper by S. Moch, J. Vermaseren and A.Vogt in 2004

$$\mathcal{O}_N = \langle p|\bar{\psi}\gamma_{\mu_1}..\gamma_{\mu_N}\psi|p\rangle$$



J. Stirling, Zurich 2011



S. Moch talk

#1 NNLO for three jet observables

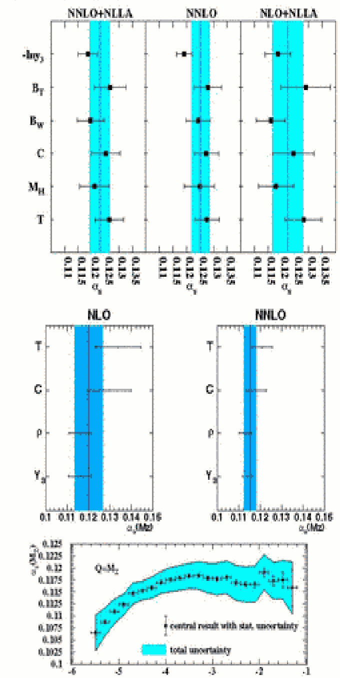
- Spectacular achievement by T. Gehrmann, A. Gehrmann, G. Heinrich, N. Glover and S. Weinzierl

Summary and Outlook

- completed calculation of NNLO corrections to event shapes and $e^+e^- \to 3j$
- improved theory uncertainty
  - by 30% (T, C) to 60% R_{3j}
- new extraction of α_s:
  - improved consistency between different shape variables
  - lower theory uncertainty
- more phenomenology to come
- Precision calculations for jet observables at LHC in progress

α_s (M_Z) from NNLO jet observables

- event shapes at NNLO+NLLA
  - JADE (S. Bethke, S. Kluth, C. Pahl, J. Schieck)
    - 0.1172 ± 0.0006 (st) ± 0.0040 (sy) ± 0.0030 (th)
  - ALEPH (G. Dissertori, A. Gehrmann-De Ridder, E.W.N. Glover, G. Heinrich, G. Luisoni, H. Stenzel, TG)
    - 0.1224 ± 0.0009 ± 0.0015 ± 0.0035
- thrust at NNLO+N³LLA (T. Becher, M. Schwartz)
  - 0.1172 ± 0.0010 ± 0.0014 ± 0.0012
- thrust: NNLO+dispersive model (R. Davison, B. Webber)
  - 0.1164 ± 0.0027
- moments: NNLO+dispersive model
  - JADE/OPAL (M. Jaquier, G. Luisoni, TG)
    - 0.1153 ± 0.0017 (exp) ± 0.0023 (th)
- three-jet rate at NNLO
  - ALEPH (G. Dissertori et al.)
    - 0.1175 ± 0.0020 (exp) ± 0.0015 (th)



Status of QCD Calculations 6.4.2011 - KITP

T. Gehrmann talk, LF 2008

The three revolutions

- During the past ten years our field went through a remarkable transformation
  - the NNLO revolution
  - the NLO revolution
  - the parton shower revolution
- The short version of the NLO wishlist has been worked out
- NNLO results for fully differential computations became a reality and are heavily used in the experimental studies
- Parton showers are combined with NLO QCD computations and with high-multiplitiey leading order computations
- There is every reason for all of us to be proud of these accomplishments

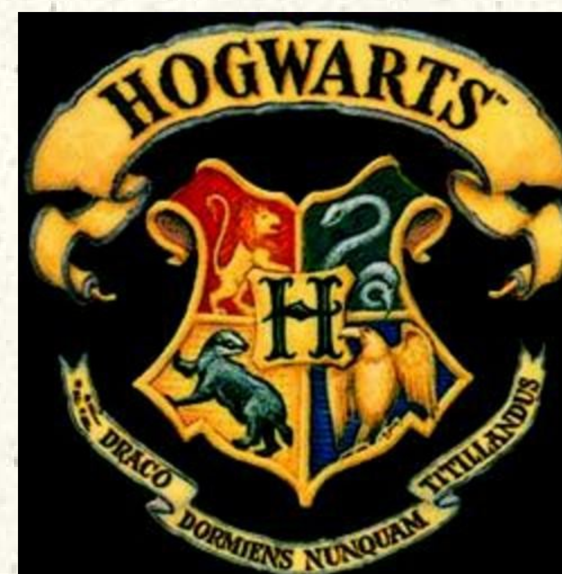
The power of simple ideas

- While we like to think about our field as the ``rocket science'', many of the key advances came from simple ideas
  - Berends – Giele recursion
  - Integration-by-parts and Laporta algorithm
  - Asymptotic expansions
  - Sector decomposition
  - BCF
  - OPP

In contrast to many other things in high-energy physics, it is easy to explain those . Progress seems to come from viewing a problem in an unorthodox way and focusing on physics that comes out of it

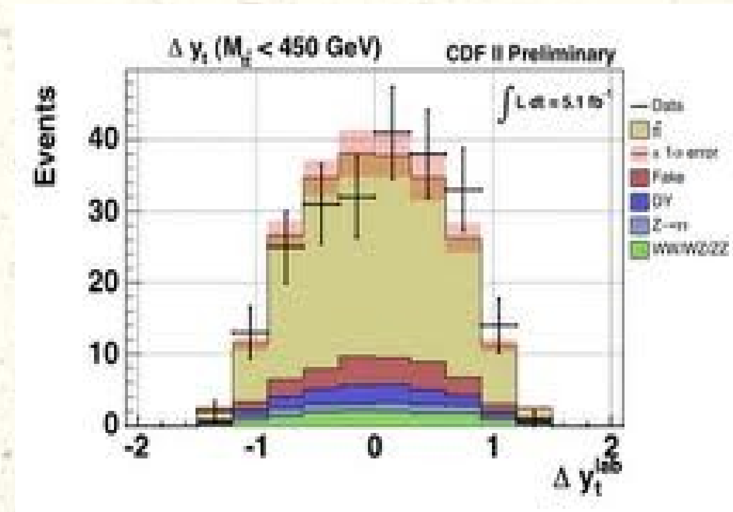
The power of not-too-simple ideas

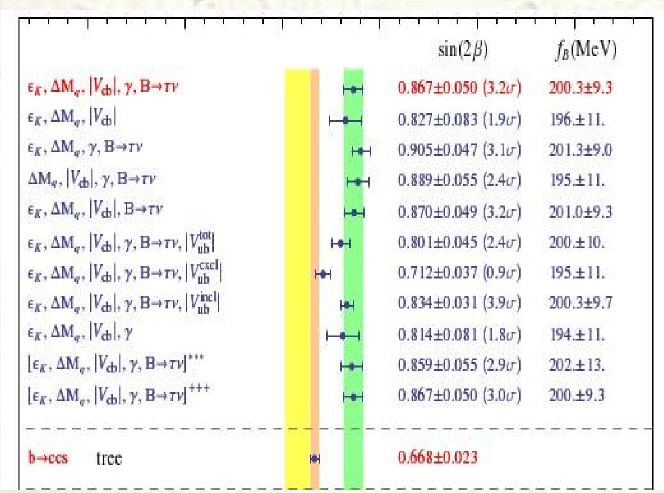
- Study of properties of scattering amplitudes in N=4 super Yang-Mills is a very active field now
- New symmetries, trivialization of cases that looks complicated, hopes to completely solve QCD@N=4
- Is there anything that can be used in real-life computations?
  - recurrence relations for the integrand and Feynman tree theorem
  - fast BCFW, Bern-Carrasco-Johansson relations
  - helicity states in higher-dimensional space times

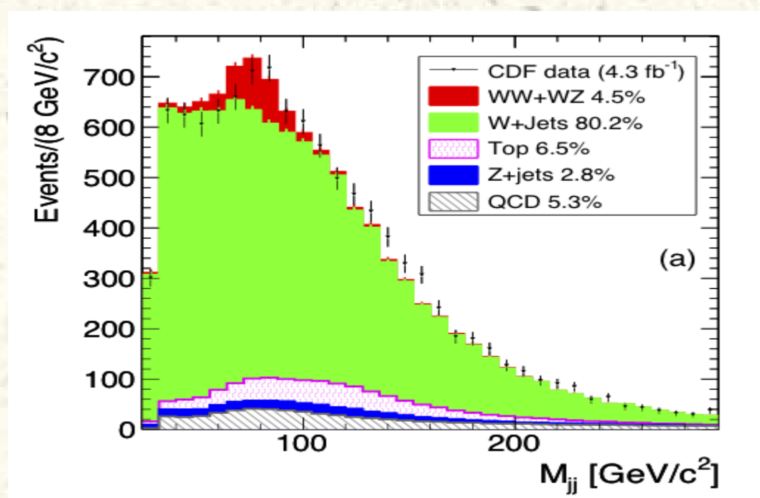


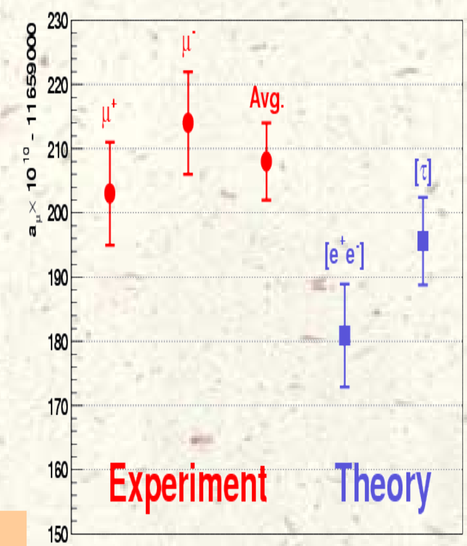
Puzzles: harbingers of New Physics?

- Top quark forward-backward asymmetry
- Feature in Wjj
- Demise of the CKM
- Proton charge radius in muonic hydrogen
- Muon anomalous magnetic moment









Real puzzles in real physics require real explanation

See you all the PhysicsFest 2012 !

Many thanks to the organizers – Doreen, Radja, Sally, Michael and Frank !