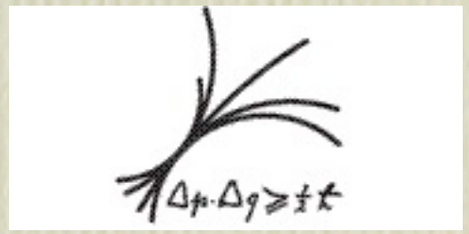
Les Houches 2011

Summary (part I)

June 8, 2011

Gudrun Heinrich



LES HOUCHES

centre de physique

2011 winter workshop

topics covered in this summary

- NLO calculations and techniques
  - ★ automation
  - ★ theory uncertainties
  - ★ interplay with resummation
  - ★ results & ongoing studies
- photons
- NNLO
- wishlist

NLO: Automation

	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

R.Pittau, S.Frixione, F.Maltoni

MAX-PLANCK-GESELLSCHAFT

Current Status (Comparisons)

1. $\gamma\gamma \to \gamma\gamma$
2. $\bar{u}d \to e^-\bar{\nu}_e$
3. $\bar{u}u \to \bar{d}d$
4. $dg \to dg$
5. $u\bar{d} \to e^+\nu g$
6. $u\bar{d} \to e^+\nu s\bar{s}$
7. $u\bar{d} \to e^+\nu gg$
8. $d\bar{d} \to e^+e^-g$
9. $d\bar{d} \to W^+W^-$ (1)
10. $d\bar{d} \to t\bar{t}$
11. $bg \to Hb$
12. $u\bar{u} \to g\gamma$
13. $ug \to u\gamma$
14. $gg \to g\gamma$
15. $gg \to gZ$
16. $gg \to gg$
17. $gg \to ZZ$ (1)
18. $gg \to W^+W^-$ (1)
19. $e^+e^- \to Z^* \to \bar{d}dgg$
20. $u\bar{d} \to \bar{c}se^+\nu_e\mu^+\nu_\mu$
21. $u\bar{d} \to \bar{s}ce^-\bar{\nu}_e\mu^+\nu_\mu$
22. $pp \to b\bar{b}b\bar{b}$

(1): with and without leptonic decays

GoSam

Golem/Samurai (GoSam)

Golem/Samurai

G.Luisoni, N.Greiner, GH, P.Mastrolia, G.Ossola, T. Reiter, F.Tramontano

We aim to . . .

- provide a tool for stable evaluation of one-loop matrix element
- be generic (QCD, EW, BSM)
  e.g. through interfaces with LanHep and FeynRules
- not to create a monolythic NLO black-box
  instead plug-in for existing tools like MadEvent, Sherpa, PowHEG, . . .
- nevertheless, we aim for seamlessness
- build upon open source tools only (Samurai, Golem95, QGraf, Form, Spinney, Haggies, QCDLoop, OneLOop)
- support open standards (BLHA, SLHA)

Where we are. . .

- fairly automatic setup → later in this talk
- successful completion of $pp \to b\bar{b}b\bar{b}$
- successful comparison for many processes → next slide
- complex masses: Golem95 (public) and Samurai (next release)
- automatic detection and rescue system for small det G
- advanced diagram selection

$pp \to VVV$ in vbfnlo at NLO QCD

Karlsruher Institut für Technologie

- $pp \to W^+W^-Z \to l_1^+\nu_1 l_2^-\bar{\nu}_2 l_3^- l_3^+$ (Higgs resonance+AC)
- $pp \to W^\pm W^\mp W^\pm \to l_1\nu_1 l_2\nu_2 l_3\nu_3$ (Higgs resonance+AC)
- $pp \to ZZW^\pm \to l_1^- l_1^+ l_2^- l_2^+ l_3\nu_3$ (Higgs resonance+AC)
- $pp \to W^+W^-\gamma \to l_1^+\nu_1 l_2^-\bar{\nu}_2\gamma$
- $pp \to ZZ\gamma \to l_1^- l_1^+ l_2^- l_2^+\gamma$
- $pp \to W^\pm Z\gamma \to l_1^+\nu_1\gamma$
- $pp \to W^\pm\gamma\gamma \to l_1\nu_1\gamma\gamma$
- $pp \to Z\gamma\gamma \to l_1^- l_1^+\gamma\gamma \quad (\bar{\nu}\nu\gamma\gamma)$
- $pp \to \gamma\gamma\gamma$

Photon isolation via Frixione criterion

$pp \to VVj$ in vbfnlo at NLO QCD

- Full off-shell effects and decay correlations for leptonic decays of leptonic decays of weak boson
  - $pp \to W^+Zj \to l_1^+ \nu_1 l_2^+ l_2^- j$
  - $pp \to W^-Zj \to l_1^- \bar{\nu}_1 l_2^+ l_2^- j$
  - $pp \to W^+\gamma j \to l_1^+ \nu_1 \gamma j$
  - $pp \to W^-\gamma j \to l_1^- \bar{\nu}_1 \gamma j$
- Anomalous gauge boson couplings included
- Photon isolation via Frixione criterion

First results for VVVj soon:FC,Englert,Rauch,Zeppenfeld

Availability of automated NLO codes

(disclaimer: only very few codes, those with representatives in Les Houches who made statements about public availability, in the context of automation, are listed)

VBFNLO:

http://www-itp.particle.uni-karlsruhe.de/~vbfnloweb

BlackHat:

Root Ntuples (see later)

GoSam (Golem/Samurai):

samurai-1.0 and
golem95C library:

http://projects.hepforge.org/

full package later this year

aMC@NLO : Plans

- MadGraph v4 **(NOW) :** specific process codes as well as their use from the web will be make public. Event files to be showered also public.

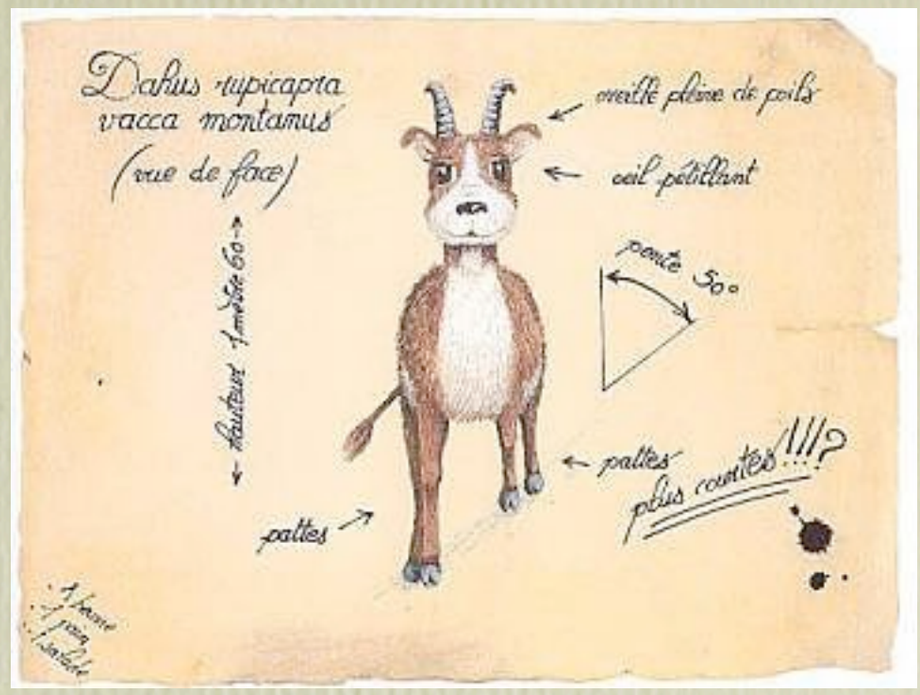
- MadGraph v5 **(SOON) :** `open-aMC@NLO` will be public by the summer (hopefully): Born+Reals+FKS+shower counterterms. **Any** loop amplitude (also in SUSY) can be easily interfaced via the Binoth Accord and promoted to a full MC@NLO.

- MadGraph v5 **(LATER) :** `Full aMC@NLO` (open + MadLoop) will be made public as soon as fully tested for SM (including multi-parton processes) and SUSY.

http://amcatnlo.web.cern.ch/amcatnlo

output formats

BlackHat: Daniel Maitre knows the Dahu



Root ntuples available for

- W+ 0,1,2,3,4 jets
- Z + 0,1,2,3 jets

advantages:

- code does not have to be rerun for change of pdfs, scale variations, cuts, studies on jet size/algorithms
- code is only run by "experts"
- "centuries of CPU time" → "best timing on the market" if you divide by number of plots produced from ntuples

disadvantage: LARGE files

no problem, disk space is cheap ... but ...

sometimes there are transfer problems ...

Numerical NLO QCD calculations

Proceed through the following steps:

1. Local subtraction terms for soft, collinear and ultraviolet singular part of the integrand of one-loop amplitudes

2. Contour deformation for the 4-dimensional loop integral.

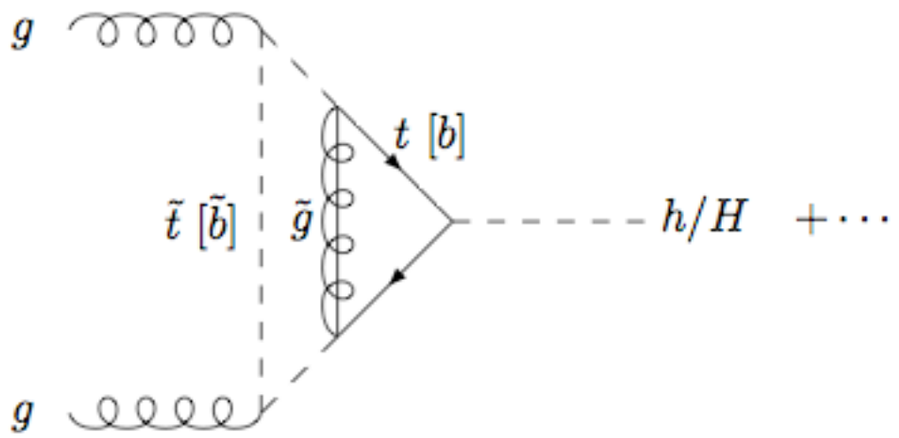
3. Numerical Monte Carlo integration over phase space and loop momentum.

Not a new idea: Nagy and Soper proposed in '03 this method, working graph by graph.
(see also: Soper; Krämer, Soper; Catani et al.; Kilian, Kleinschmidt)

What is new: The IR-subtraction terms can be formulated at the level of amplitudes, no need to work graph by graph.

The IR-subtraction terms are universal and amasingly simple.

genuine SUSY–QCD corrections: $gg \to h/H$



Harlander, Steinhauser, Hofmann
Degrassi, Slavich
Anastasiou, Beerli, Daleo
Mühlleitner, Rzehak, S.

- 5-dimensional Feynman integrals → endpoint subtractions:

$$\int_0^1 dx \frac{f(x)}{x(1-x)} \;\to\; \int_0^1 dx \left\{ \frac{f(x)}{x(1-x)} - \frac{f(0)}{x} - \frac{f(1)}{1-x} \right\}$$

⇒ isolation of singularities

- thresholds for $M_H > 2m_Q$ → numerical instabilities → partial integrations:

$$\int_0^1 dz \frac{f(z)}{a+bz} \;=\; \frac{f(z)}{b} \log(a+bz)\Big|_0^1 - \int_0^1 dz \frac{f'(z)}{b} \log(a+bz)$$

⇒ thresholds in arguments of logs ⇒ stabilization
[more involved for quadratic polynomials]

More on NLO

S. Frixione: FKS tutorial

S. Pozzorini:
comparison of WW bbar (with leponic decays of W's)
with Helac-NLO (Bevilaqua et al.)
(pp to ttbar to WWbbar to leptons bbar)

insights about non-resonant diagrams and corrections to top width

assessment of numerical uncertainties

Testing and Rescuing

- Two *numerical tests* are performed by `CutTools`:
  1. $N(q) = N_{rec.}(q)$
  2. By shifting *all* denominators $D_i \to D_i + M^2$ the *same* set of one-loop coefficients can be obtained by means of an independent numerical procedure:

$$\mathcal{S}' = \begin{cases} d'(i_0 i_1 i_2 i_3), & c'(i_0 i_1 i_2), \\ b'(i_0 i_1), & a'(i_0), \qquad R' \end{cases}$$

  `CutTools` then tests if $|A - A'| << A$

- `CutTools` *rescues* the inaccurate points by recomputing the coefficients in *multiprecision* (but MadGraph $\Leftrightarrow N(q)$ remains in double precision) and redoing the above checks

A few PS points remain unstable

$\Rightarrow$

assessment of numerical uncertainties

Precision Tests in samurai

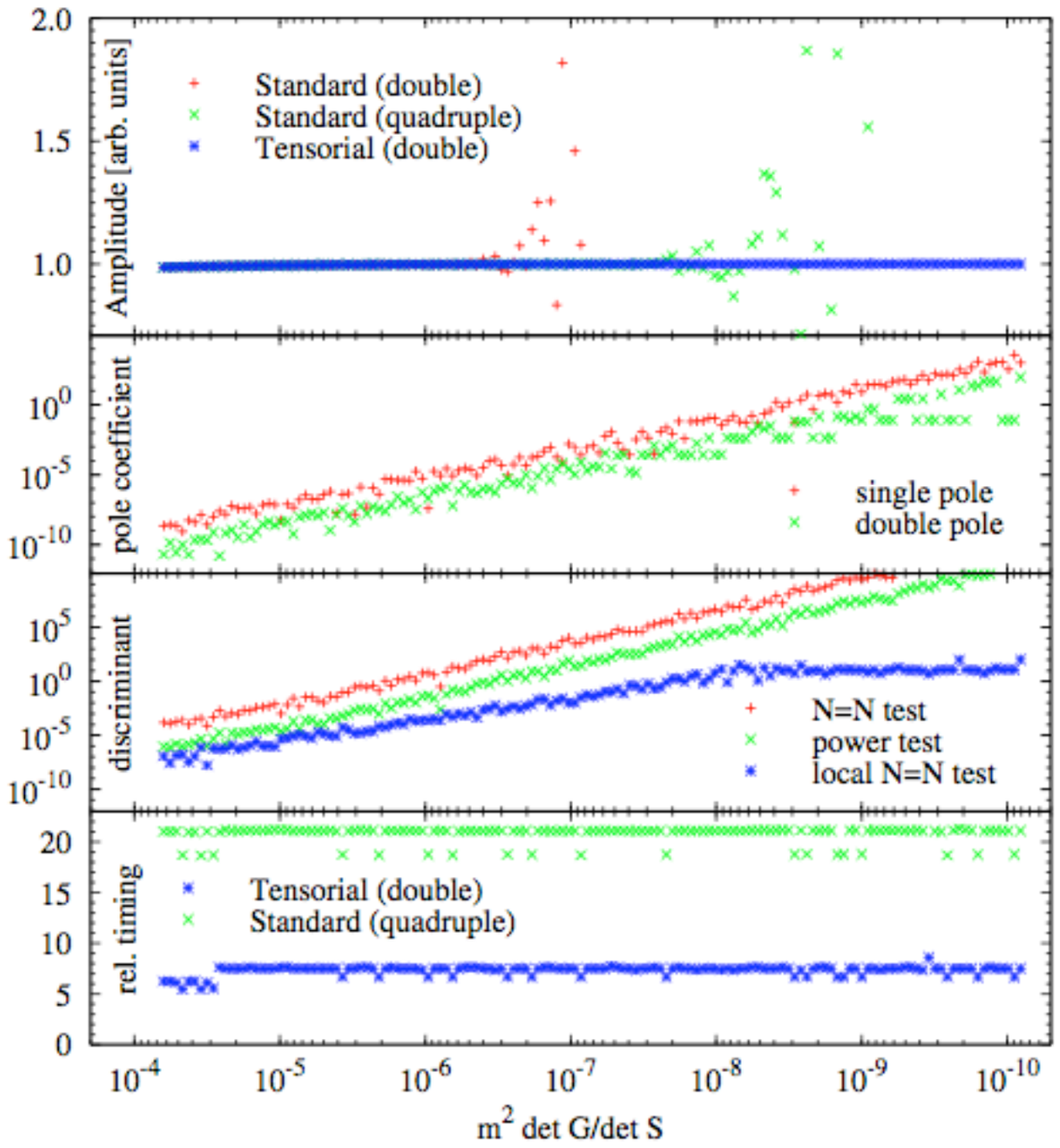
We use again the decomposition of $N(\bar{q})$ after determining all coefficients

$$
\begin{aligned}
N(\bar{q}) \;=\; & \sum_{i<<m}^{n-1} \Delta_{ijk\ell m}(\bar{q}) \prod_{h\neq i,j,k,\ell,m}^{n-1} \bar{D}_h + \sum_{i<<\ell}^{n-1} \Delta_{ijk\ell}(\bar{q}) \prod_{h\neq i,j,k,\ell}^{n-1} \bar{D}_h + \\
& + \sum_{i<<k}^{n-1} \Delta_{ijk}(\bar{q}) \prod_{h\neq i,j,k}^{n-1} \bar{D}_h + \sum_{i<j}^{n-1} \Delta_{ij}(\bar{q}) \prod_{h\neq i,j}^{n-1} \bar{D}_h + \sum_{i}^{n-1} \Delta_{i}(\bar{q}) \prod_{h\neq i}^{n-1} \bar{D}_h
\end{aligned}
$$

1. **Global $(N = N)$-test**
2. **Local $(N = N)$-test**
3. **Power-test**

Are those methods **reliable** in detecting **unstable phase space points**?

Approaching the Gram - II



unstable points

Roberto's suggestion:

quantify numerical error stemming from unstable points

(done so in MadLoop)

project initiated in Les Houches:

different groups come up with a set of "bad points"

check what fraction of these points are classified as "bad" by other codes as well

S.Badger, BlackHat, MadLoop, GoSam, VBFNLO, V.Yundin

assessment of scale uncertainties

F. Tackmann

Resummation of Jet-Veto Logarithms

$$L^2 = 2\ln^2\frac{p_T^{\text{cut}}}{m_H} \quad \text{or} \quad L^2 = \ln^2\frac{\mathcal{T}_{\text{cm}}^{\text{cut}}}{m_H}$$

$$\sigma_{\text{0-jet}} = 1$$

$$+\ \alpha_s L^2 + \alpha_s L + \alpha_s + \alpha_s n_1(\mathcal{T}_{\text{cm}}^{\text{cut}}) \qquad \text{NLO}$$

$$+\ \alpha_s^2 L^4 + \alpha_s^2 L^3 + \alpha_s^2 L^2 + \alpha_s^2 L + \alpha_s^2 + \alpha_s^2 n_2(\mathcal{T}_{\text{cm}}^{\text{cut}}) \qquad \text{NNLO}$$

$$+\ \alpha_s^3 L^6 + \alpha_s^3 L^5 + \alpha_s^3 L^4 + \alpha_s^3 L^3 + \alpha_s^3 L^2 + \alpha_s^3 L + \cdots$$

$$+\ \vdots + \vdots + \vdots + \vdots + \vdots + \vdots + \ddots$$

LL NLL NNLL N^{3}LL

Initial-state parton shower resums LL

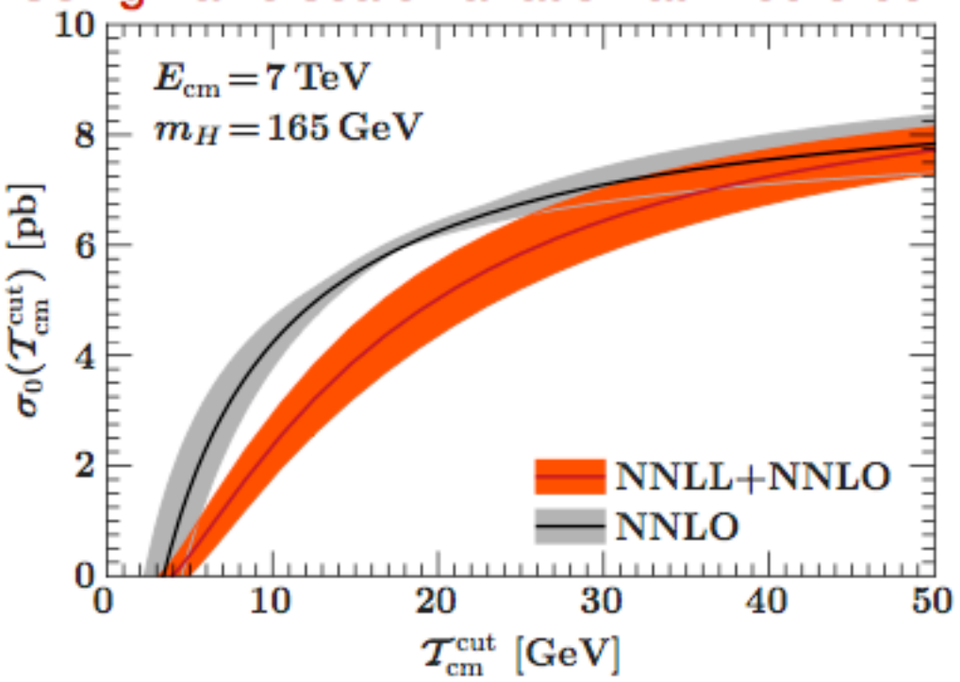
- Pythia/Herwig is LL (plus some NLL)
- MC@NLO, POWHEG: combine parton-shower LL with fixed NLO

Our calculation: NNLL+NNLO

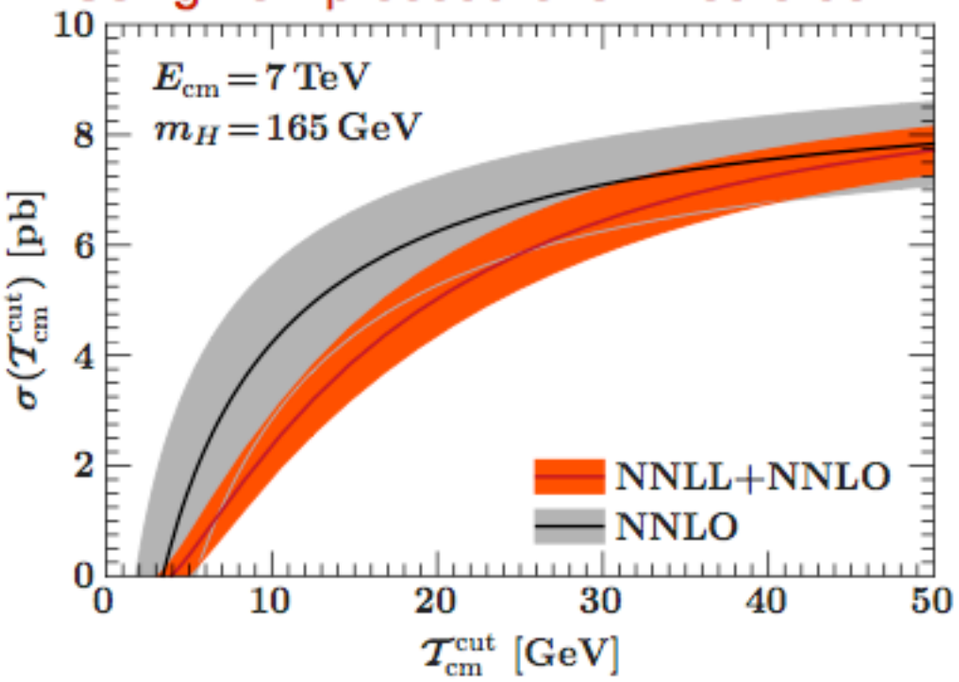
- Resummation using $\mathcal{T}_{\text{cm}}^{\text{cut}}$ and SCET $\rightarrow$ two orders beyond PS
- $n_{1,2}(\mathcal{T}_{\text{cm}}^{\text{cut}})$ numerically from FEHiP $\rightarrow$ reproduces full NNLO

Comparison to Old and New Fixed Order Uncertainties

Using naive scale variation at fixed order



Using new procedure for fixed order



- Naive scale variation at fixed order underestimates perturbative uncertainties
- New fixed-order procedure gives more realistic uncertainties

work done in LH/ongoing studies

Blackhat & LoopSim:

comparison of W+1,2 jets at a given order of α_s

D.Maitre, G.Salam, S.Sapeta

VBFNLO & LoopSim:

W $\gamma\gamma$ (jet)

F.Campanario, G.Salam, S.Sapeta

Golem/Samurai & PGFry

interface of two different reduction codes

T.Reiter, V. Yundin

Golem/Samurai & Sherpa, Powheg, Madgraph

test of BLHA interface

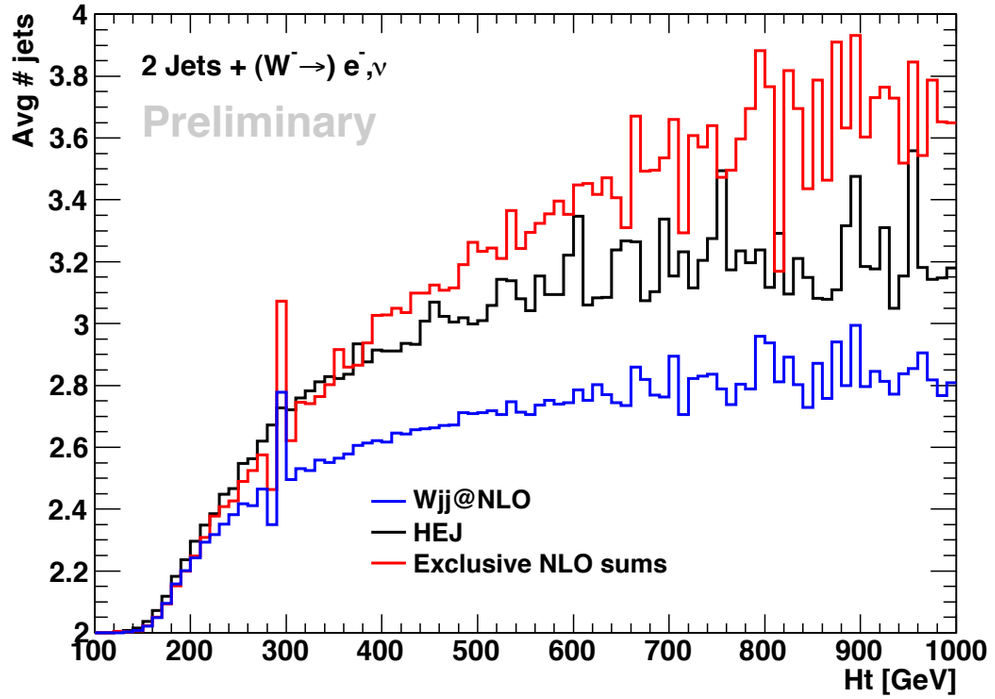
G.Luisoni, N.Greiner, GH, F.Krauss, E.Re, T.Reiter, G.Ossola, F. Tramontano

work done in Les Houches

W+jets with BlackHat+Sherpa and HEJ

Andersen, Dixon, Maître, Smillie

We compare the fixed order description of BHS with the high-energy resummation results in HEJ.



E.g. in average number of jets versus H_T, broad agreement. Significant differences in other variables.

Andersen, Maitre, Smillie

Photons

two main project areas:

- isolation
- codes/tools development

isolation:

studies on definitions more compatible between experiment and theory

- discretized Frixione cones
- “hollow” cones/annuli

do they produce better data/theory agreement?

studies before/in Les Houches and ongoing

N. Chanon, S.Gascon-Shotkin, J.Ph.Guillet, J.Huston, J.Leveque, P. Nadolsky, E.Pilon, M.Schwoerer, M. Stockton

Summary of results

- Frixione isolation
  - First studies used fixed E per cone
  - Later used pt: ε*pt[(1-cos r)/(1-cos R)]^n
  - Very small difference between number of cones (both)
  - Study of fragmentation fraction per cut compared to cone
- Scale error (dominant theory error):
  - See no saddle point, going to low pt nlo cross-section rapidly increases lo decreases
  - Prelim frixione isolation tests show the same
- Photon + jet
  - Changing the jet alg (Kt 0.3, .4, .5, .6 and cone .4, .5, .6) made little difference in jetphox (<1% for all 3 pt bins)

diphotons: codes

parton level:

- Diphox (Binoth, Guillet, Pilon, Werlen)
- ResBos (Balazs, Berger, Nadolsky, Yuan)
- gamma2MC (Bern, Dixon, Schmidt)
- 2gammaNNLO (Cieri, Catani, DeFlorian, Ferrera, Grazzini)
  under construction

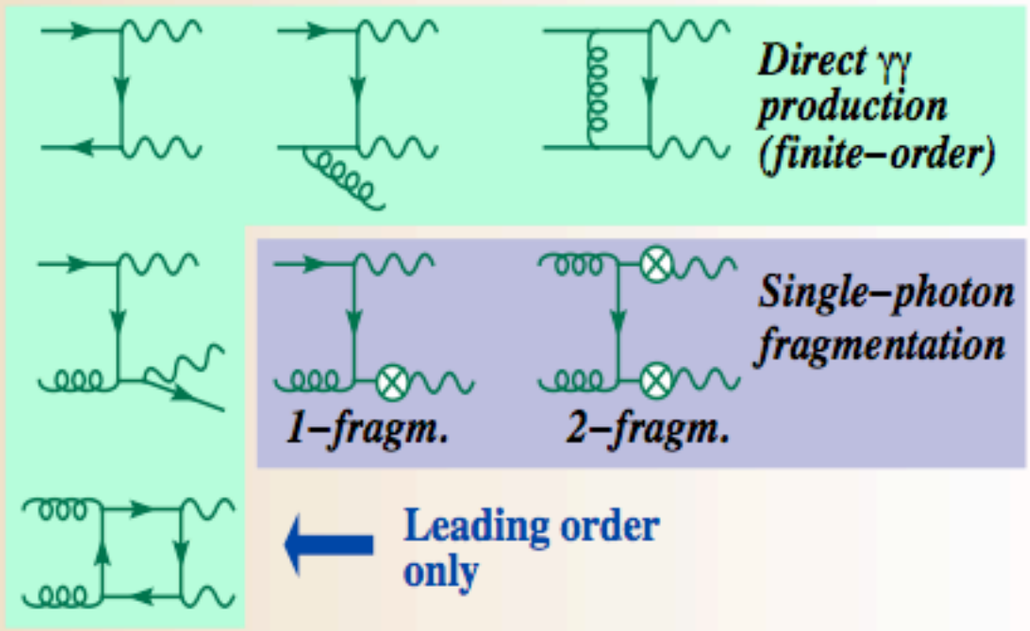
ME+shower:

- ME + Sherpa (Hoeche, Schumann, Siegert)
- Grappa + LLL shower (Kurihara et al.)
- project to include Diphox virtuals in Sherpa

(J.Ph. Guillet, F. Krauss, E.Pilon)

Our calculation vs. DIPHOX (T. Binoth et al.)

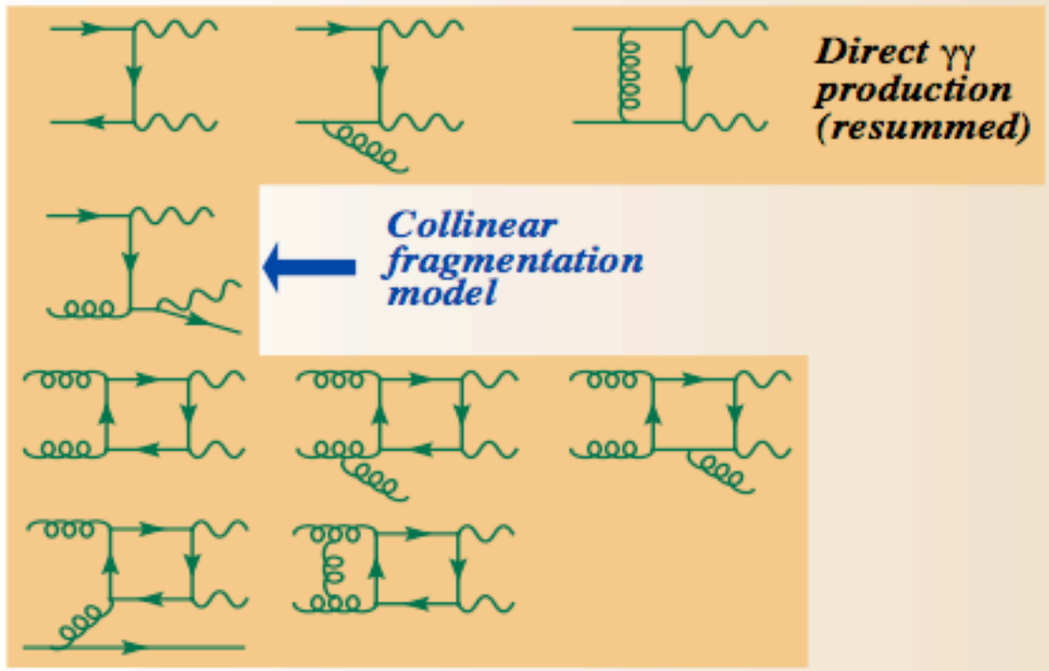
Binoth, Guillet, Pilon, Werlen, 2001



(+ NLO *gg* from Bern, Dixon, Schmidt)

- fixed order in α_s, no gq_s
- inclusive, large-Q_T rates OK
- singularities in $d\sigma/dQ_T$ at $Q_T \to 0$

Balazs, Berger, Nadolsky, Yuan, 2006



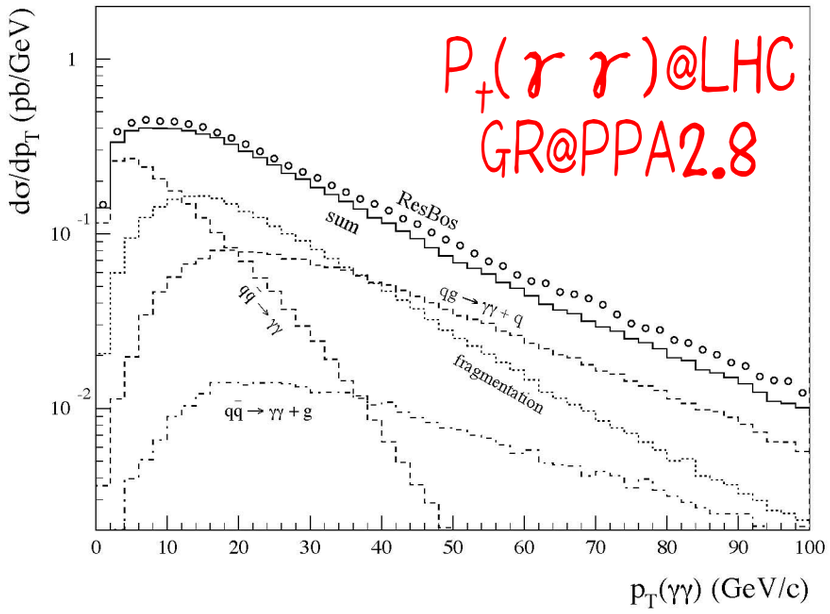
- resummed ISR
- a model for FSR
- agrees with the inclusive, large-Q_T rates from DIPHOX
- $d\sigma/dQ_T$ is finite everywhere

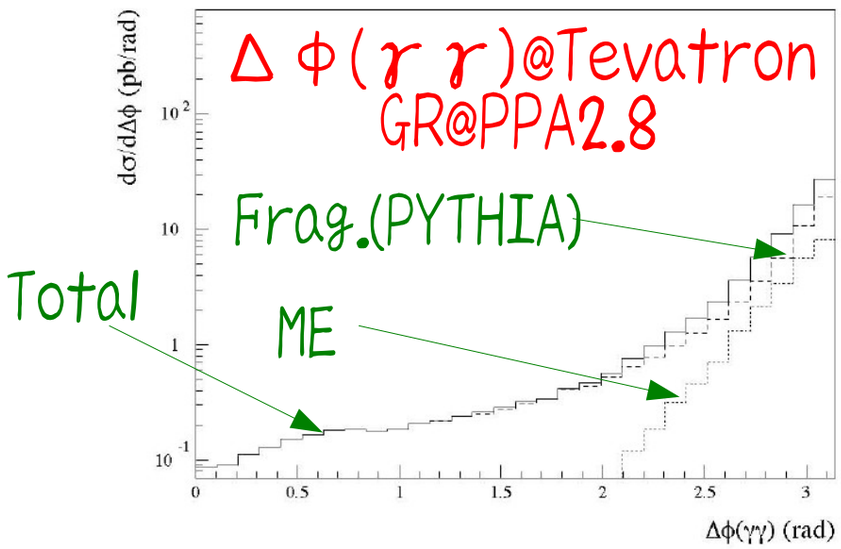
ResBos now also LHAPDF compatible

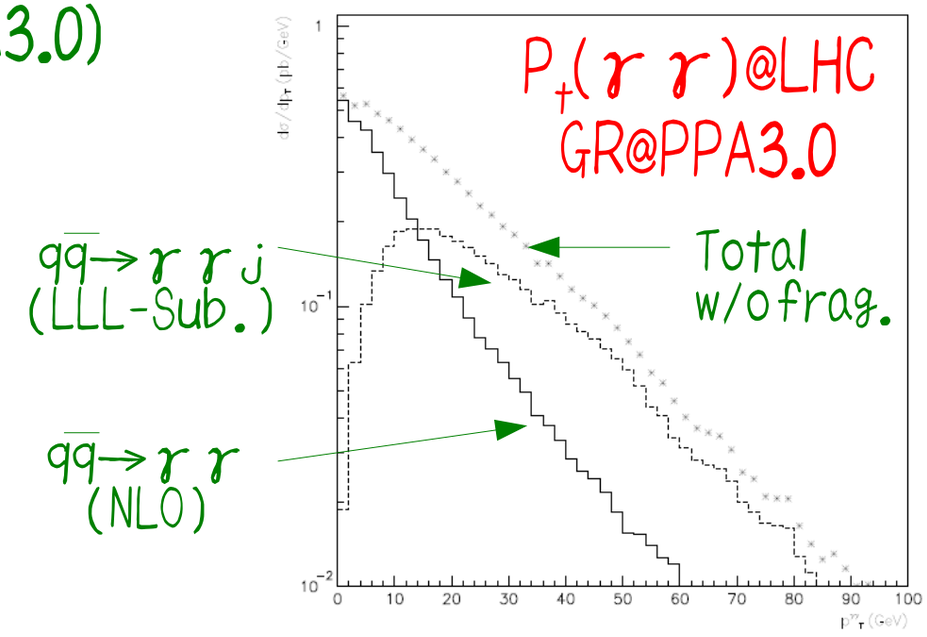
Y. Kurihara

GRACE/GR@PPA2.8 (3.0 will be open soon)

- $\gamma\gamma$+X, γ+X in GR@PPA
  - ME
    - LO (GR@PPA2.8), NLO (GR@PPA3.0)
  - PS
    - LL initial/final PS
  - ME/PS matching
    - QCD/QED LLL-Subtraction
  - Fragmentation
    - PYTHIA (GR@PPA2.8)
    - QED/QCD mixed PS (GR@PPA3.0)







photon(s)/V-bosons plus jet

(parton level NLO)

- Jetphox: γ + jet (Guillet et al)

  fragmentation also at NLO, discretized Frixione isolation criteria, LHAPDF

- γ γ + jet (Del Duca, Maltoni, Nagy, Trocsanyi)

  smooth Frixione isolation

- VBFNLO: (F. Campanario et al)

  smooth Frixione isolation

- vector boson fusion processes:
  - $\gamma\, j\, j$
  - H $\gamma\, j\, j$
- diboson + jet:
  - W $\gamma\, j$
- triboson (W$\to l\,\nu$, Z $\to l\,\bar{l}$) :
  - W W γ , Z Z γ , W Z γ
  - W γ γ , Z γ γ
  - γ γ γ

NNLO methods

expertise here in Les Houches:

- double real radiation:
  - sector decomposition A. Lazopoulos, GH, S. Weinzierl
  - fully local subtraction G. Somogyi, Z. Trocsanyi
  - antenna subtraction G. Luisoni, GH, S. Weinzierl

- two-loop integrals:

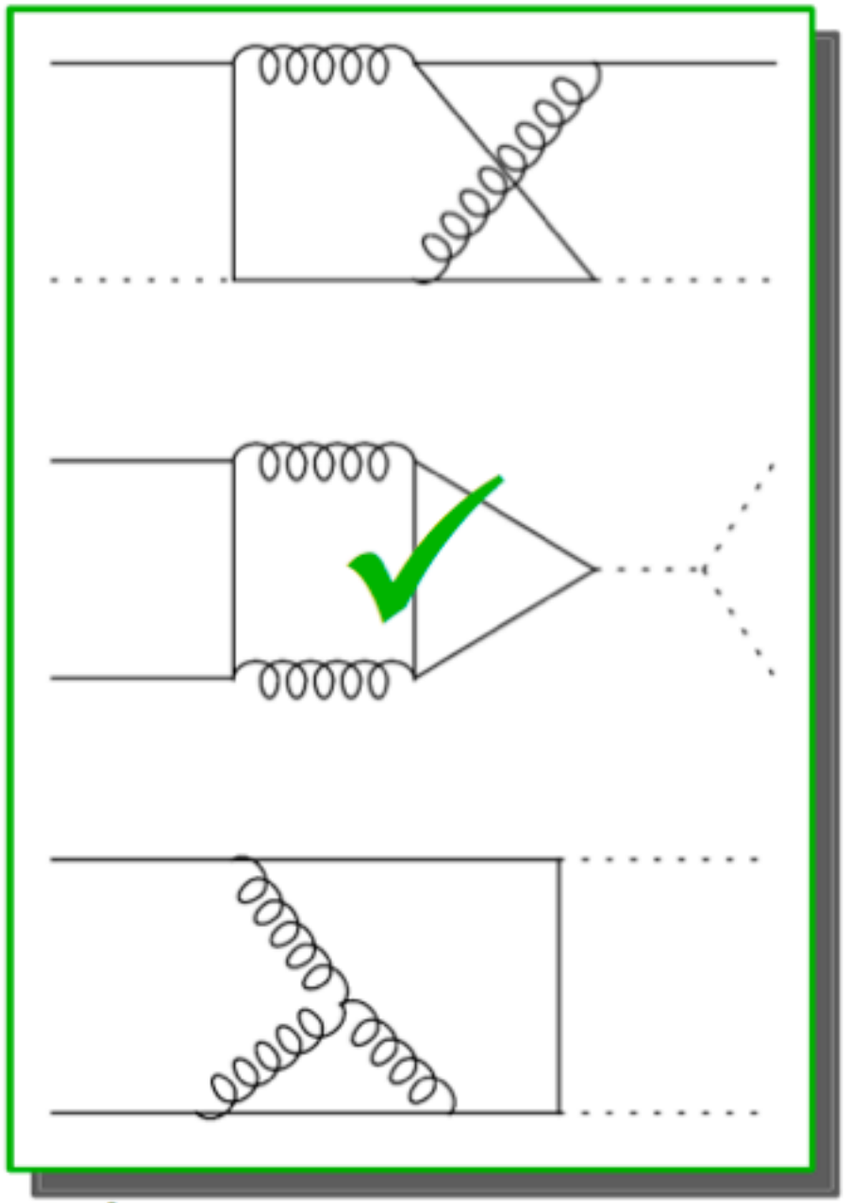
  WW: Mellin-Barnes and numerical solution of differential equations

  G.Chachamis

- from loop to phase space integration using loop-tree dualities

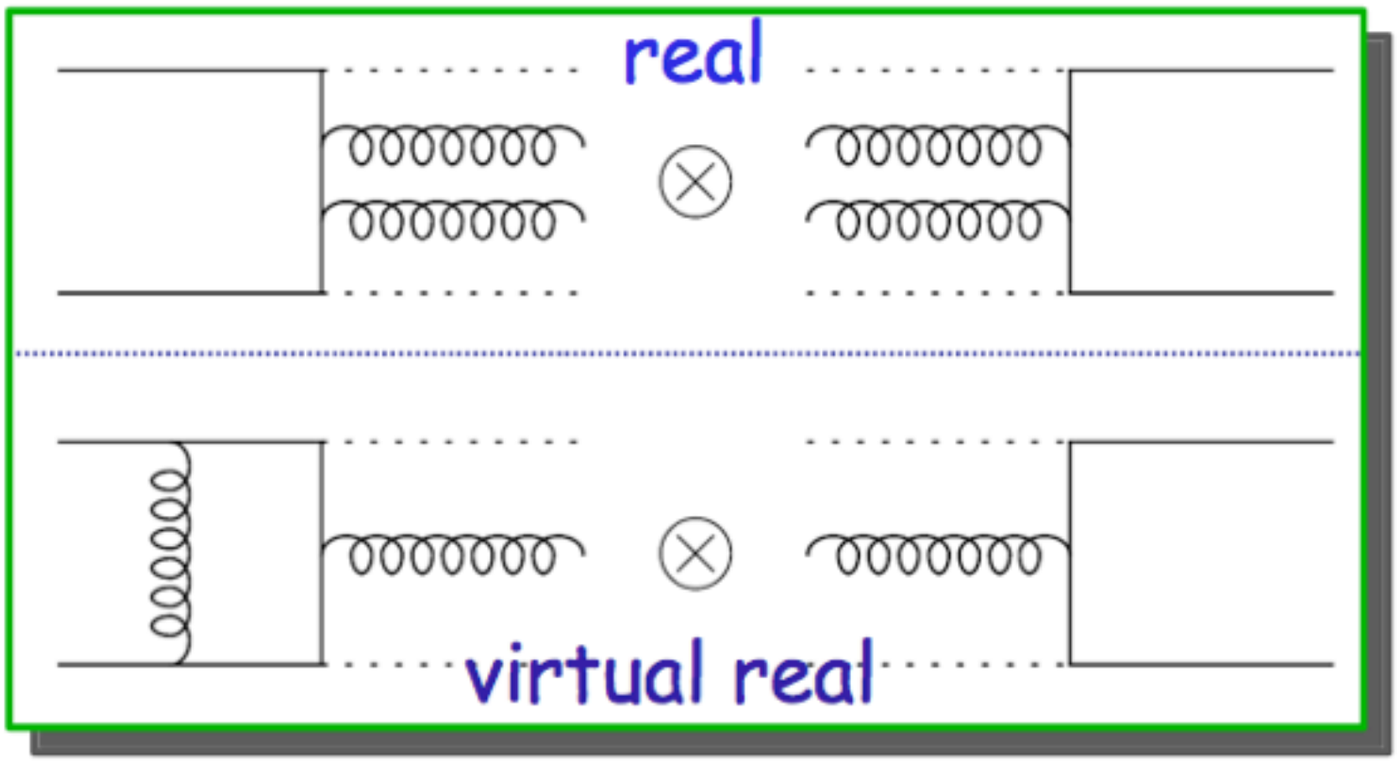
  P. Draggiotis

Check list:



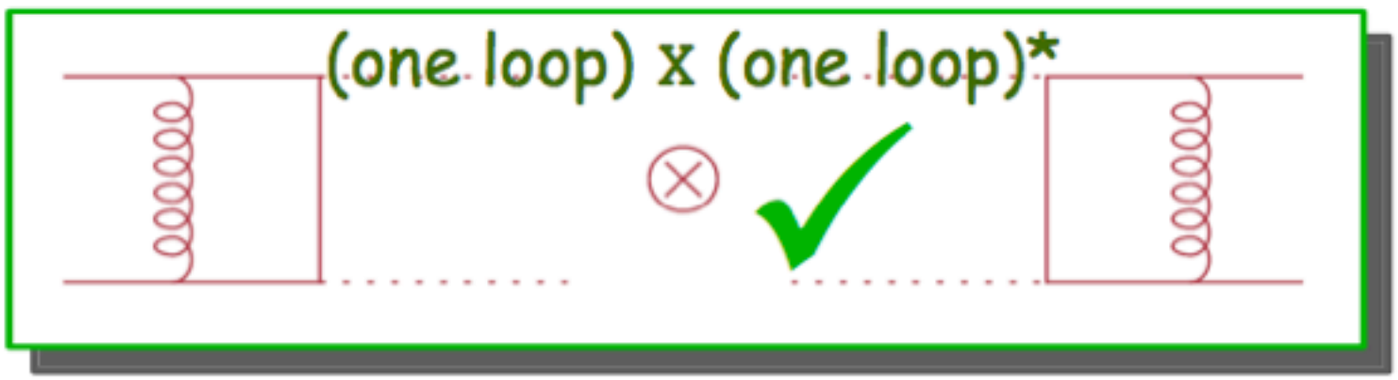
2 loop virtual

G.C., Czakon, Eiras ('08)



Campbell, Ellis, Zanderighi ('07)

Dittmaier, Kallweit, Uwer ('08,'09)



G.C., Czakon, Eiras ('08)

NNLO

wishlist : (LHC)

- ttbar
- WW G. Chachamis: two-loop virtual
- $\gamma\ \gamma$
- W/Z/γ + jet
- Higgs + jet
- dijet

NB: NLO wishlist is basically ticked!

more urgent:

- include decays
- signal/background interferences
- matching to parton shower
- assess systematic uncertainties

Blue sky at Les Houches 2011