Mid-Report of the Higgs & Standard Model Working Group (Theory Part)

the SMH theory conveners

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Scott Willenbrock (Illinois Univ., Urbana)

Contents

1 (Many-)Particle production at NLO

A lot of processes with $n \geq 3$ particles in final states only known at LO

$\hookrightarrow$ enormous amount of homework for theorists

State-of-the-art for NLO in theory:

- techniques for $2 \to 3$ processes established;
  results known for several processes at hadron colliders:

  $$\mathrm{pp} \to 3\mathrm{jets}, V{+}2\mathrm{jets}, V\mathrm{b\bar{b}}, \gamma\gamma{+}\mathrm{jet}, \mathrm{t\bar{t}H}, \mathrm{b\bar{b}H}$$

  $\hookrightarrow$ calculations still demanding

- $2 \to 4$ processes are technical frontier;
  only two results for EW corrections in $\mathrm{e^+e^-}$ physics:

  $\mathrm{e^+e^-} \to \nu\bar{\nu}\mathrm{HH}$, GRACE-1loop (Boujema et al.) '04

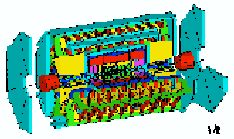
  $\mathrm{e^+e^-} \to 4f$ Denner et al. '05

  + some partial or toy-model results Bern et al., Binoth et al.

  $\hookrightarrow$ calculations very challenging + lengthy !

$\Rightarrow$ Theorists need a clear list of important processes including arguments for "why calculating what !?"

Joey Huston's wish list:



Experimental priority list

- Note have to specify how inclusive final state is
  - what cuts will be made?
  - how important is b mass for the observables?
- How uncertain is the final state?
  - what does scale uncertainty look like at tree level?
  - new processes coming in at NLO?
- Some information may be available from current processes
  - pp->tT j may tell us something about pp->tTbB?
    - j=g->bB
  - CKKW may tell us something about higher multiplicity final states

1. pp->WW jet
2. pp->tT bB
   1. background to tTH
3. pp->tT + 2 jets
   1. background to tTH
4. pp->WWbB
5. pp->V V + 2 jets
   1. background to WW->H->WW
6. pp->V + 3 jets
   1. beneral background to new physics
7. pp->V V V
   1. background to SUSY trilepton

Beyond the SM Workshop at Columbia

Reports on technical progress:

- G.Heinrich: "A complete formalism for one-loop multi-leg amplitudes"
  - ◇ formalism very general (massive/massless case; "arbitrary" # of legs)
  - ◇ basis integrals can be evaluated numerically or analytically
  - ◇ formalism ready for applications, but
    speed and stability of formalism not yet tested for realistic processes
- Z.Kunszt: "Improved Nagy-Soper method for numerical evaluation of 1-loop int's"
  - ◇ subtraction of UV and IR singularities in one-loop amplitudes
    before loop integration a la Nagy/Soper
  - ◇ numerical loop integration via contour deformation in Feynman-parameter *and*
    momentum space $\longrightarrow$ work in progress
- Y.Kurihara: "Automatic calculation of NLO-QCD cross sections with GRACE"
  - ◇ GRACE-LOOP successfully applied to EW corrections in $\mathrm{e}^+\mathrm{e}^-$ physics
    $\mathrm{e}^+\mathrm{e}^- \to \ldots, \nu\bar{\nu}\mathrm{H},\ \mathrm{e}^+\mathrm{e}^-\mathrm{H},\ \mathrm{t}\bar{\mathrm{t}}\mathrm{H},\ \mathrm{ZHH},\ \nu\bar{\nu}\mathrm{HH}$
  - ◇ generalization to NLO QCD for hadron colliders
    status: some $2 \to 2$ processes successfully reproduced
  - ◇ avoid double counting in combination of NLO QCD and QCD parton shower

2 Predictions for Higgs production (and related background)

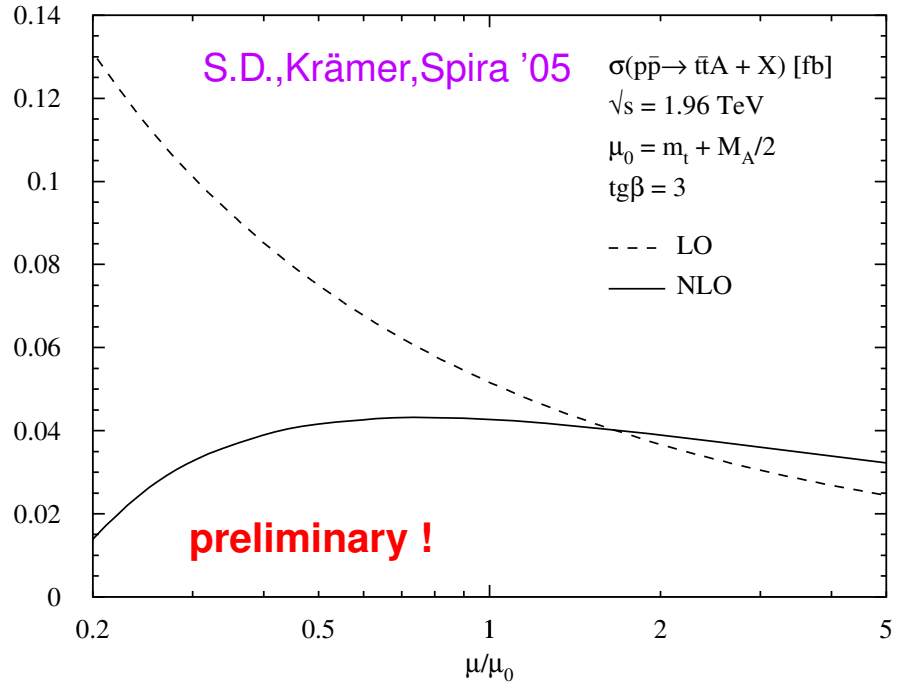
$\hookrightarrow$ state-of-the-art reviewed in introductory talks (Frixione/Dittmaier)

- P.Uwer: "Progress toward $\mathrm{pp} \to \mathrm{t\bar{t}} + \mathrm{jet}$ in NLO QCD"
  - ◇ in particular important background to $\mathrm{WW} \to \mathrm{H}$ and to $\mathrm{t\bar{t}H}$ production
  - ◇ real corrections completed and cross-checked
    (matrix elements, phase-space integration, dipole subtraction)
  - ◇ virtual corrections completed, but not cross-checked

- S.Dittmaier:
  "NLO QCD corrections to $\mathrm{p\bar{p}}/\mathrm{pp} \to \mathrm{t\bar{t}A}$"

  Results for Tevatron complete $\longrightarrow$

  for the LHC expected next week !



Transverse-momentum resummations

M. Grazzini

- Higgs qt-distribution

  NLL+LO and NNLL+NLO

  → HqT code

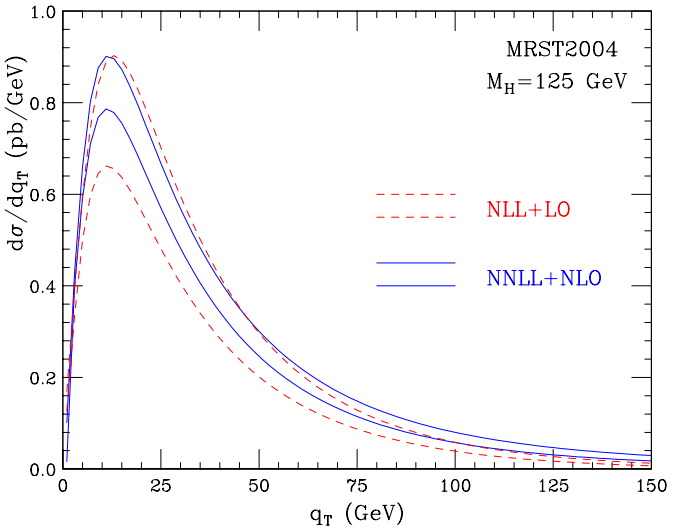
  Now available upon request

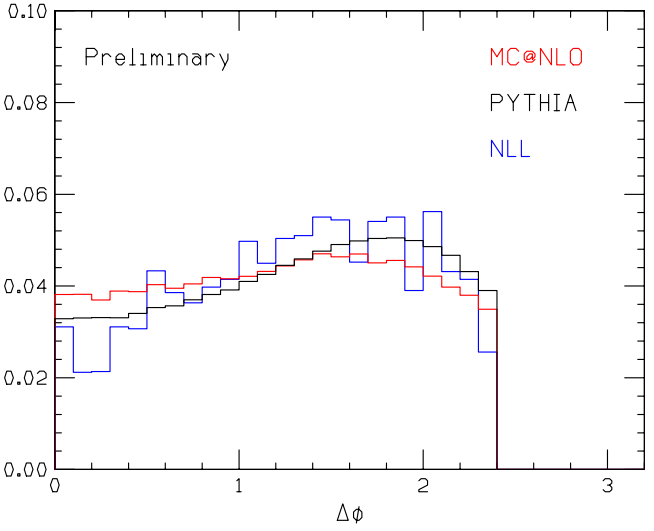
- NEW: NNLL+LO resummation in progress for WW production

  Full phase space generation

Spin correlations fully included: matrix elements from Kunszt et al.

Thanks to Volker Drollinger

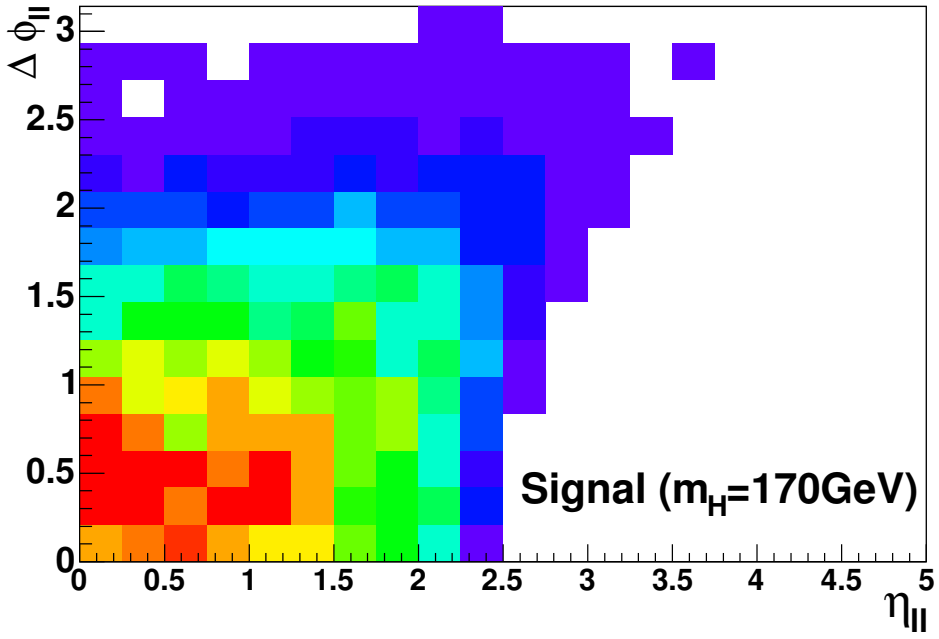




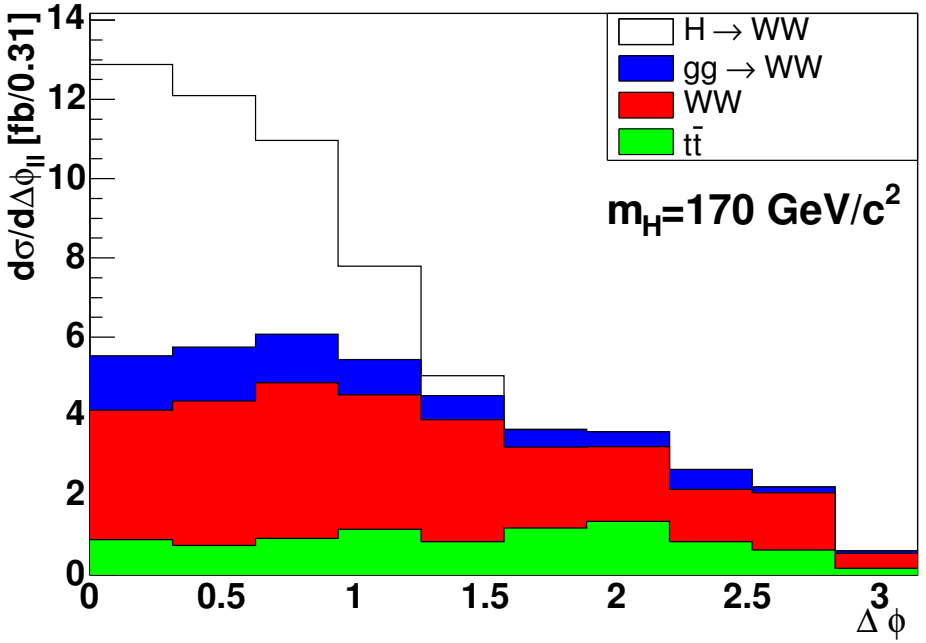
The $gg \to \mathrm{WW}$ background to $gg \to \mathrm{H} \to \mathrm{WW}$ (talk by M.Dührssen)

Calculations from two groups:

- Binoth, Ciccolini, Kauer, Krämer
  Off-shell Ws, only light quarks in the loop
- Marquard, van der Bij (Dührssen, Jakobs)
  On-shell Ws, heavy quark loop



$\Delta\Phi_{ll}$ vs. η_{ll} (Pythia)



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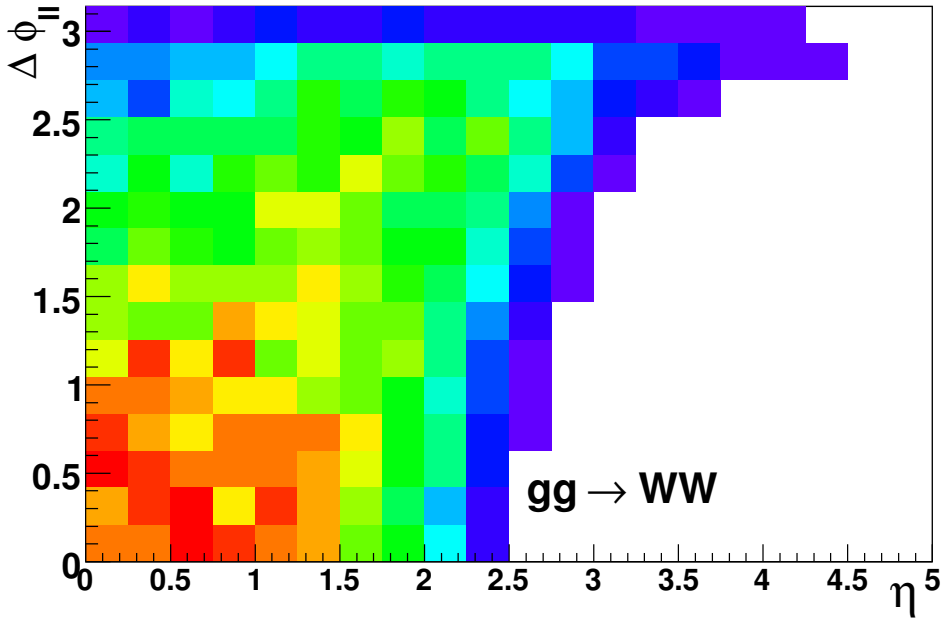

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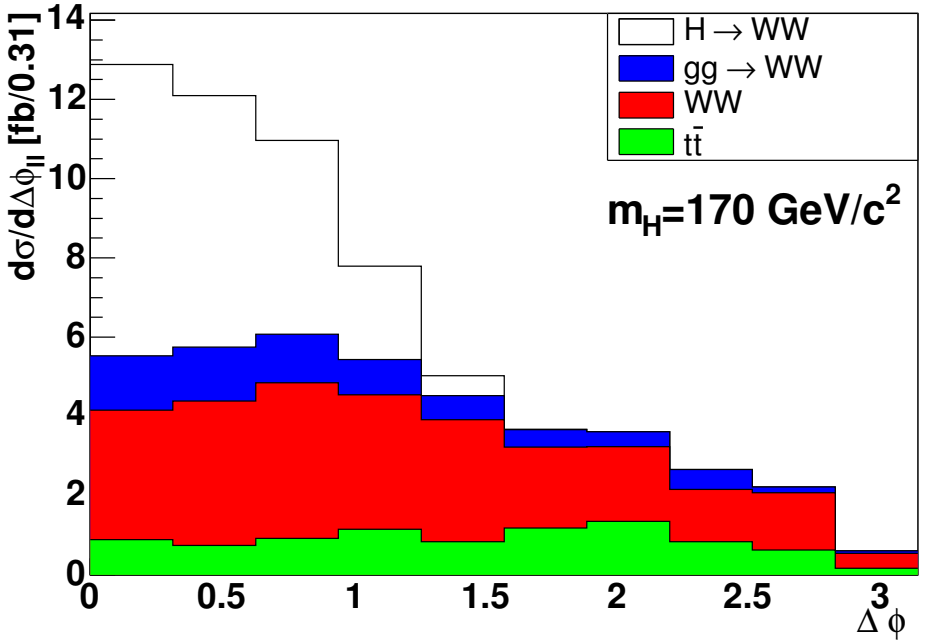

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NLO (=2-loop!) calculation for $gg \to \mathrm{WW}$ highly desirable

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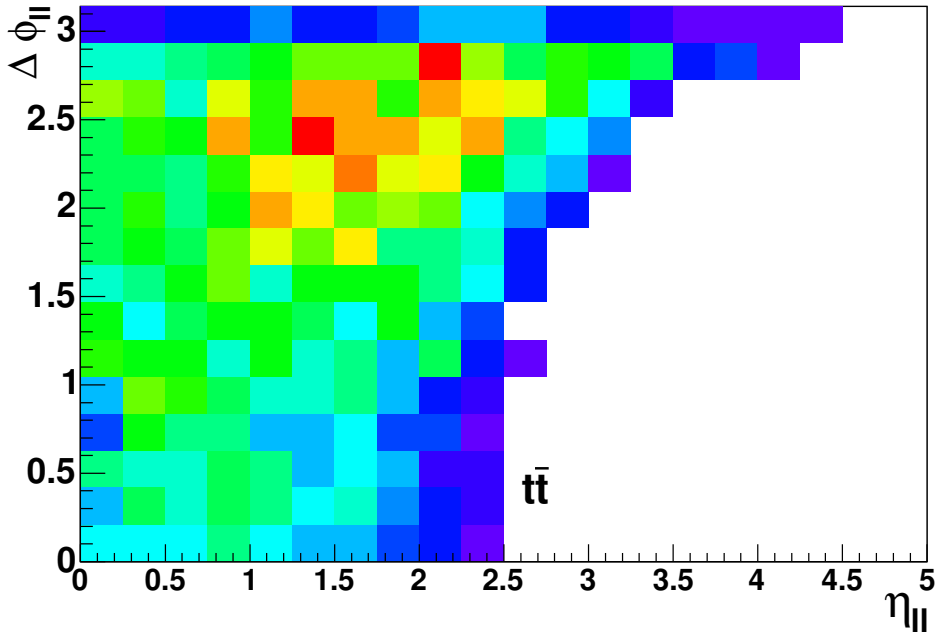

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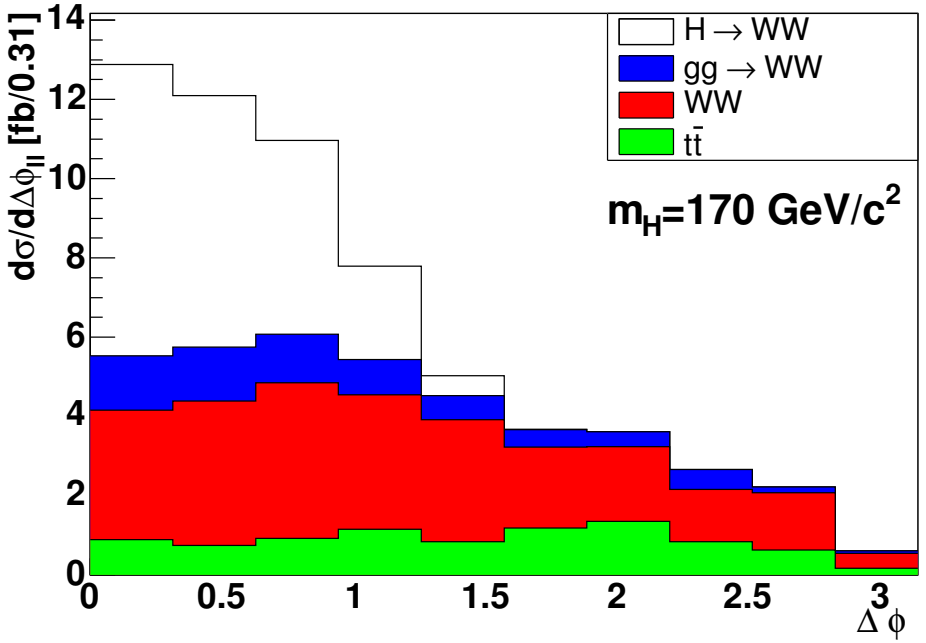

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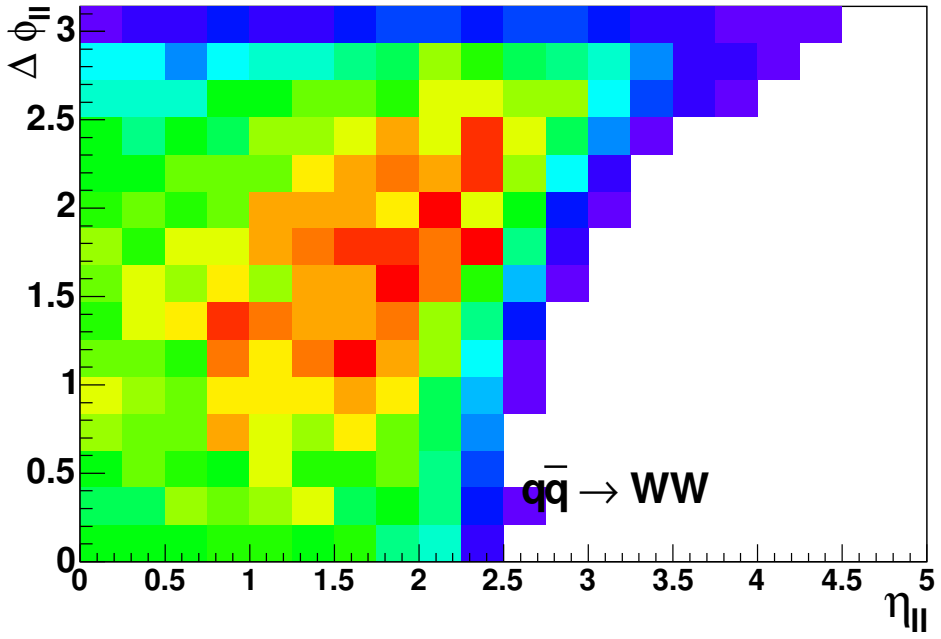

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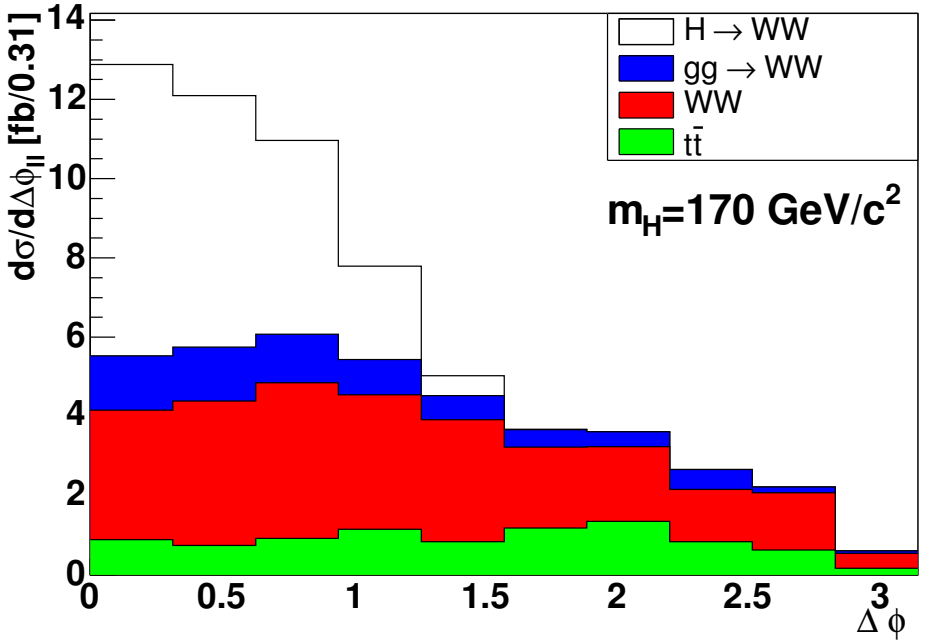


After all cuts but $\Delta\Phi_{ll}$ (Pythia)

NLO (=2-loop!) calculation for $gg \to \mathrm{WW}$ highly desirable

3 Electroweak corrections for processes at hadron colliders

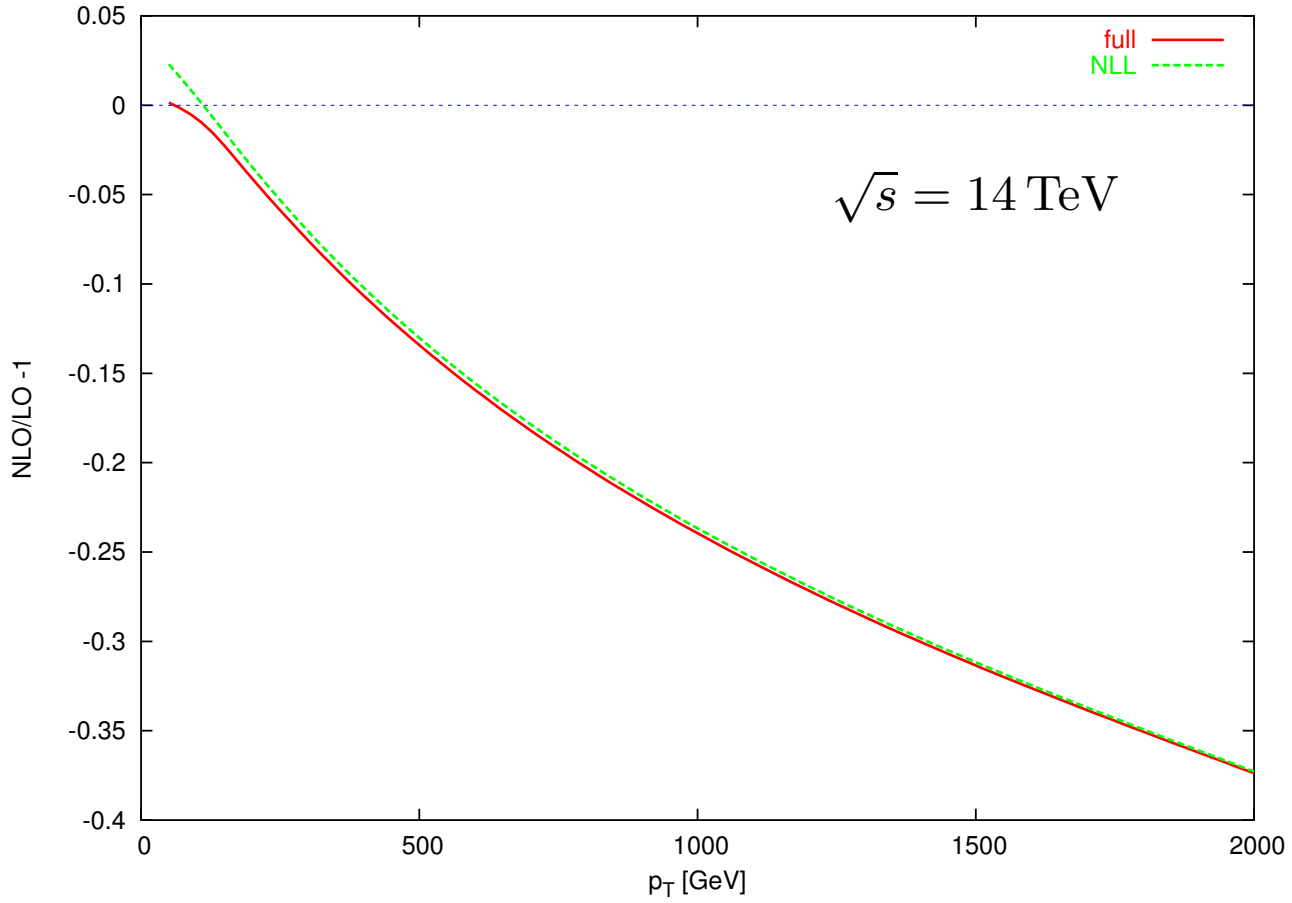
General considerations about EW corrections at hadron colliders:

- generic size: $\mathcal{O}(\alpha) \sim \mathcal{O}(\alpha_s^2)$, i.e. NNLO QCD $\sim$ NLO EW
- however: systematic enhancement of EW effects due to
  - ◇ logarithms $\alpha \ln^n(M_W/Q)$, $n = 2, 1$ (Sudakov and subleading) at high scales Q
    ↪ important for new-physics searches
  - ◇ kinematic effects from photon radiation off leptons (e.g. Drell–Yan)
    ↪ important for reconstruction of W's, Z's, etc.

Activities and presentations during the workshop:

- Comparison of precision EW calculations for single W and Z production initiated
  ↪ setup sent to participating groups: Arbuzov/Bardin, Baur/Wackeroth, Dittmaier/Krämer, Montagna et al., Jadach et al.
- S.Moretti: weak $\mathcal{O}(\alpha)$ corrections to high-E_T jet production
  ↪ presentation in 2nd LH session
- A.Kulesza: "Weak corrections to hadronic Z production at large p_T"

Weak corrections to $\mathrm{pp} \to \mathrm{Z} + \mathrm{jet}$ (presentation of A.Kulesza)



- good agreement with approximation by EW high-energy log's (NLL)
- result available in analytical form
- no significant corrections for Tevatron

4 Progress at NNLO

State-of-the-art

- Complete NNLO calculations
  - ◇ Drell–Yan-like W/Z production: $\sigma_{\rm tot}$ and rapidity distribution
    Hambrg, v.Neerven, Matsuura '90; Harlander, Kilgore '02 Anastasiou et al. '03
  - ◇ Higgs production: total and fully differential cross sections
    Harlander, Kilgore; Anastasiou, Melnikov '02 Anastasiou, Melnikov, Petriello '04
  - ◇ $\mathrm{e}^+\mathrm{e}^- \to 3\mathrm{jets}$: $C_{\rm F}^3$ term Gehrmann, Gehrmann-de Ridder, Glover '04
- Two-loop matrx elements

  $gg \to gg, q\bar{q}, \gamma\gamma, \quad q\bar{q} \to \gamma\gamma, Vg, \quad \mathrm{e}^+\mathrm{e}^- \to 3\mathrm{jets}$

  Anastasiou, Bern, DeFreitas, Dixon, Garland, Gehrmann, Glover, Koukoutsakis, Oleari, Remiddi, Tejeda-Yeomans '00–'02

↪ see V.Del Duca's talk for more details

Subtraction formalisms for combination of virtual $\oplus$ real corrections at NNLO

$\hookrightarrow$ progress reported by M.Grazzini and V.Del Duca

NNLO cross sections: subtraction

- universal IR structure ⇒ process-independent procedure
- universal collinear and soft currents
  - 3-parton tree splitting functions

J. Campbell N. Glover 1997; S. Catani M. Grazzini 1998; A. Frizzo F. Maltoni VDD 1999; D. Kosower 2002

  - 2-parton one-loop splitting functions

Z. Bern W. Kilgore C. Schmidt VDD 1998-99; D. Kosower P. Uwer 1999; D. Kosower 2003

- universal subtraction counterterms
  - several ideas and works in progress
    but so far not yet completely figured out

D. Kosower; S. Weinzierl; the Gehrmanns & G. Heinrich 2003
S. Frixione M. Grazzini 2004; G. Somogyi Z. Trocsanyi VDD 2005
the Gehrmanns & N. Glover 2004-5

Precision SM Shapes

Assessing the state of the art for Z & h spectra at hadron colliders

Gieseke, Melnikov, Mrenna, Nadolsky, Skands, more?

- NNLO fully diff results available for Z, h. NN(N?)LL also available.
- But tools are either:
  - LO + (real) NLO + parton showers (Herwig, Pythia)
  - NLO + parton showers (MC@NLO)
  - LO + (real) NNNN...LO + parton showers (Sherpa, Patriot, Ariadne)
- Need to assess tools: what to use where, how good are they?
- Shapes & K-factors

Will Study Z & h + jets production, producing comprehensive comparisons

Sudakov Uncertainties

Gieseke, Huston, Mrenna, Sjöstrand, Skands

- Continuation of study by Gieseke (there, PDF uncertainties)
- Large phase space for radiation at LHC -> Want to understand uncertainties & differences between parton showers (new+old) -> realm of applicability:
  - General Studies: Herwig(++), Pythia 6.2/6.3, comparing to Fixed Order & Resummation calculations. Understanding "power showers" and "wimpy showers".
  - Black Sudakovs. Finite kT restriction in MC evolution -> mismatch with (longitudinal) PDF evolution. Different for each shower. How important?

MC@NLO: theoretical activity in Les Houches (S. Frixione)

One major goal achieved: feedback from experimenters

At the beginning of the first half, the promise was made to *start* new projects here.
Believe or not, it happened!

- Jets, dijets (S. Ellis, B. Kilgore, E. Laenen, P. Motylinski)
- Higgs in VBF (C. Oleari, V. del Duca)
- Anomalous TGC in WZ (A. Oh)

More work has been done on single top (E. Laenen, P. Motylinski), and the release of version 3.1 will occur soon

MC@NLO: what we need to do (S. Frixione)

The implementation of the new processes will require a bit of understanding

- Jets, dijets
  - Simultaneous presence of initial- and final-state collinear singularities (we shall learn from single top)
  - Cuts must be inserted at the level of matrix elements to prevent the Born cross section to diverge (may test this in $b\bar{b}$ production)
- VBF
  - Highest final-state multiplicity so far attempted in MC@NLO – need to work out the scales used by the shower

Many interesting issues not related to implementation have also been discussed here in Les Houches (role of primary partons, computation of ΔPDF, off-shell effects,...)

On May 17^{th}: standardization of MC's in C++