Theory activities for the LHC

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LHC expectations

UNDERSTAND THE MECHANISM OF ELECTRO-WEAK SYMMETRY BREAKING

DISCOVER DARK PARTICLE (with some luck)
TEVATRON Higgs boson experience

Already, the Tevatron is becoming sensitive to mainly:

$$pp \rightarrow H \rightarrow WW \rightarrow ll\nu\nu$$

A channel which can yield a $\sim160$ GeV Higgs boson discovery with little luminosity at the LHC

Dittmar, Dreiner; Davatz, Dittmar, Giolo-Nicollerat

ICHEP 08, Matt Herndon
Cross-section with cuts

$$p\bar{p} \rightarrow H + X \rightarrow WW + X \rightarrow \mu^+\mu^-\nu\bar{\nu} + X$$

Veto on two-jets / cuts on missing transverse momentum / lepton invariant mass, $p_T$, and rapidity

- Large $K$-factor for total cross-section
- Smaller $K$-factor for cross-section after cuts

Currently validating MC@NLO, HERWIG, vs NNLO for this process
How good are generators?

CA, Dissertori, Stoeckli, Webber

Generators (MC@NLO & HERWIG) agree very well with NNLO efficiencies

LHC: We can approximate:

$$\sigma_{cuts} \approx \sigma_{\text{nnlo cuts}} \approx \sigma_{\text{generator}} \times \frac{\sigma_{\text{nnlo incl}}}{\sigma_{\text{inc}}}$$
Higgs boson: a pseudo-Goldstone?

Hard to satisfy Electroweak Precision Tests and associate the Electroweak Symmetry Breaking with strong dynamics at Mw

Strong dynamics and an “effective” Higgs boson is possible:
- Little Higgs
- Warped extra dimension

Common effective theory for Higgs and SM gauge boson/fermion interactions

Giudice, Grojean, Pomarol, Rattazzi

Strong dynamics at a (not so high) scale with a global symmetry. This is broken spontaneously: Goldstone boson
A subgroup is gauged under SU(2) x U(1) + Yukawa interactions of SM and strong sector particles: massive (pseudo) Goldstone
Common phenomenology

All couplings of the Higgs boson to other SM particles may be suppressed by a factor: \( \sqrt{1 - \frac{v^2}{f^2}} \)

\[ f \approx 500 \text{GeV} \quad \sigma_{WBF} \approx 75\% \quad \sigma_{SM}^{WBF} \]

Increase with center of mass energy of WW scattering and Higgs pair production amplitudes:

\[ A \left( Z^0_L Z^0_L \rightarrow hh \right) = A \left( W^+_L W^-_L \rightarrow hh \right) = \frac{c_H S}{f^2} \]

Ongoing studies: Contino, Grojean, Moretti, Piccinini, Rattazzi
Model dependent pheno

Large global symmetry and symmetry breaking may vary but introduce new particles. E.g. a minimal SO(5)/SO(4) symmetry breaking pattern with custodial symmetry predicts top-partners with charge 5/3.

Models are compatible with electroweak precision data and B-physics constraints

Mark Gillioz

ongoing: CA, Furlan, Santiago

Complete verification will come with the LHC by observing such heavy quarks. Ongoing studies on single “Top” production.

Mrazek, Wulzer
Dark matter in composite Higgs models

Panico, Ponton, Santiago, Serone

- Warped extra dimensions provide a calculable framework for Composite Higgs Models
- Dark Matter usually not present
- Can be included using a discrete exchange symmetry \( G \times U(1)_A \times U(1)_B \)
Dark matter in composite Higgs models

- Realistic models with $H$ as a composite pseudo Goldstone boson
- Correct EWSB, DM and EWPT in the same region of parameter space

Panico, Pontón, Santiago, Serone, PRD (08)
The SUSY paradigm

- It solves the hierarchy problem
- Gauge coupling unification
- Dark matter
- Rich but also very difficult phenomenology
Rich Higgs boson sector

QCD and SUSY QCD NLO corrections for associated production

Dittmaier, Haefliger, Spira, Kraemer, Walser

$pp \to Q\bar{Q}'\phi$

$Q = Q' = t, b \quad \phi = h, A, H$

$Q = t, \quad Q' = b \quad \phi = H^\pm$

Both particles and sparticles in loops contribute significantly.

Calculations in SUSY are more challenging than in the SM.
SUSY and gluon fusion

New numerical method for multi-loop amplitudes

Spira, Djouadi, Graudez, Zerwas
CA, Beerli, Bucherer, Daleo, Kunszt
Aglieti, Bonciani, Degrassi, Vicini
Spira, Muhlleitner

CA, Beerli, Daleo
NLO higgs cross-section in the MSSM

Preliminary

Cancelations needed to solve the hierarchy problem may reduce the gluon fusion cross-section

Low,Rattazzi

CA, Beerli, Bucherer, Daleo, Kunszt
Signals with dark matter candidates

Dark matter can be confused with neutrinos.

Missing energy measurement obscured by non-fixed collision energy and detector limitations

Masses of new particles and the dark particle may be reconstructible from “kinks” in pt-distributions

Barr, Gripaios, Lester
Dark backgrounds

\[ pp \rightarrow \nu \bar{\nu} + N_{\text{jets}} \]

- \[ p_t > 80 \text{ GeV}, \text{central} \ |\eta| < 2.5 \text{ jets} \]
- \[ \mu^2 = M_Z^2 + \sum_{\text{jet}} p_{t,\text{jet}}^2 \]

<table>
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<th>( N )</th>
<th>( \sigma(2\mu) \text{[pb]} )</th>
<th>( \sigma(\mu/2) \text{[pb]} )</th>
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Large backgrounds
POOR leading order predictions
Limited TEVATRON experience

NEED for NLO cross-sections of multi-leg processes

Alpgen
Multileg processes @ NLO

\[ M_{1-\text{loop}} = \sum_{i=1}^{4} c_i(\text{process}) I_i(\text{universal}) \]

An impressive set of solid techniques by Denner, Dittmaier

State of the art computation

Important background to associated Higgs production

Ongoing work: gluonic channel

Bredenstein, Denner, Dittmaier, Pozzorini
New powerful NLO method

Ellis, Giele, Kunszt, Melnikov, Zanderighi

Loop amplitudes are a sum of residues corresponding to poles from on-shell particles in the loops

On the mass shell, loop amplitudes are in practice tree amplitudes. We should not need anything more than tree generators (e.g. ALPGEN) to compute them.

Test performance beyond our wildest dreams!!!
But do not forget the "basics"

\[ pp \rightarrow WW \]
\[ pp \rightarrow tt \]
\[ pp \rightarrow tW \]

Tevatron gets only a glimpse of these processes....

Single top production is now simulated at NLO with matched parton-shower in MC@NLO

\textit{Frixione,Laenen,Motylinski,Webber,White}
Top-pair cross-section

Recent up to date study:

\[ \sigma_{t\bar{t}}^{NLO} (\text{LHC}, m_{\text{top}} = 171 \text{GeV}) = 875^{+102(11.6\%)}_{-100(11.5\%)}(\text{scales})^{+30(3.4\%)}_{-29(3.3\%)}(\text{PDFs}) \text{ pb} \]

Cacciari, Frixione, Mangano, Nason, Ridolfi

Negligible experimental statistical errors.

Early systematic errors of about 10%.
Will be reduced with larger luminosity

\[ \sigma_{NNLO} \]
NNLO experience

Heroic calculation of $e^+e^- \rightarrow 3\text{jets}$

Valuable accumulated knowledge of universal infrared radiation patterns at NNLO.

First determination of strong coupling with LEP data at NNLO

Gehrmann-De Ridder, Gehrmann, Glover, Heinrich

Dissertori, Gehrmann-De Ridder, Gehrmann, Glover, Heinrich, Henzel
Top cross-section @NNLO: first steps

Bonciani, Ferroglia, Gehrmann, Maitre, Studerus

“A long journey to ITHAKA”

CA, Aybat
Very important research I could not review

- Electroweak corrections for LHC processes (Denner, Jantzen, Pozzorini; Muck; ...)
- Theory developments on supersymmetry breaking (Rattazzi, Kim, ...)
- Minimal flavor violation in supersymmetry and RGEs (Colangelo, Nikolidakis, Smith)
- On UV completion of composite Higgs models (Gripaios)
- On neutrino physics and the LHC (Shaposhnikov)
- ...???
Conclusions

• A very active Swiss particle theory community with LHC physics being a very top priority.

• Very strong in model building and precision computations.

• Keep us motivated....with good discussions and data!