PARTICLE THEORY AT SMU

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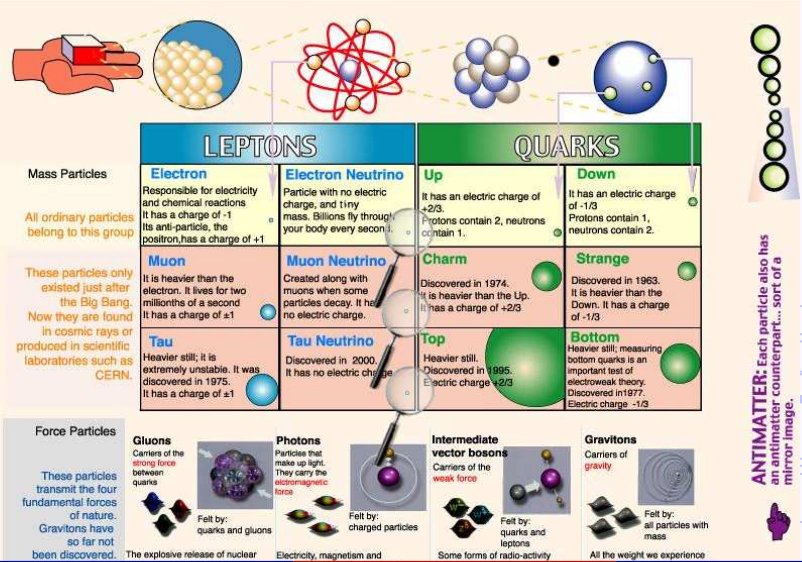
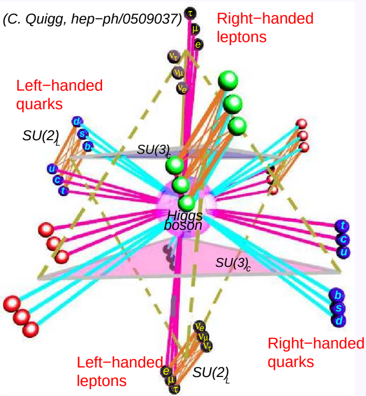
SMU group of particle phenomenology

- Phenomenology = particle theory applied to collider experiments
  - A highly demanded topic in the era of the Large Hadron Collider
- Members of our group include Guzzi, Dalley, Nadolsky, Olness, Park
  - funding for graduate students will be available starting in 2011
- Research topics cover
  - theory of high-energy hadronic (both strong and electroweak) interactions
  - factorization in quantum chromodynamics (QCD)
  - all-order summation of perturbative theory
  - computer simulations for collider experiments

Standard Model: a successful effective theory of elementary particles

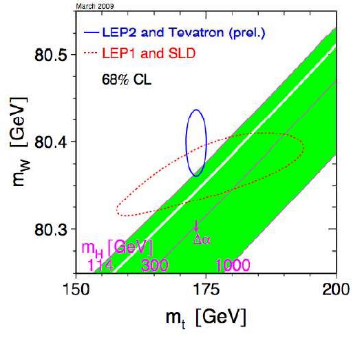


Symmetries of standard model



- Forces between SM particles emerge from the local $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ symmetry of SM Lagrangian
- Mass terms relate left- and right-handed fermions; arise as a result of the $SU(2)_L \otimes U(1)_Y \to U(1)_{EM}$ symmetry breaking, induced by the existence of Higgs scalar field doublet(s)
  - Nature of the electroweak breaking mechanism is still uncertain

Higgs sector in SM and minimal supersymmetry



Green band: $114 \leq M_H \leq 1000$ GeV

SM: 1 Higgs doublet, one boson H

- Direct search: $m_H > 114$ GeV at 95% c.l.
- indirect: $M_H = 80^{+39}_{-28}$ GeV at 68% c.l.

MSSM: 2 Higgs doublets; h^0, H^0, A^0, $H^{\pm}$

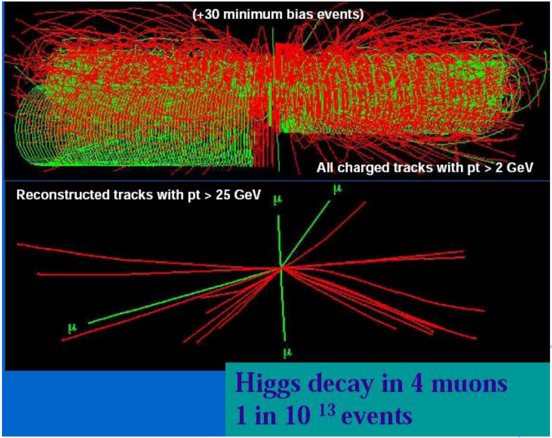
$m_h \leq m_Z |\cos 2\beta| + \text{rad. corr.} \lesssim 135$ GeV

- In these models, expect one or more Higgs bosons with mass below 140 GeV
- Many other possibilities for EW symmetry breaking exist!

Large Hadron Collider at CERN
(pp collision energy 10-14 TeV)

- is quickly ramping up
- search for new physics! (SM parameters constrained at the other colliders; or so we think...)

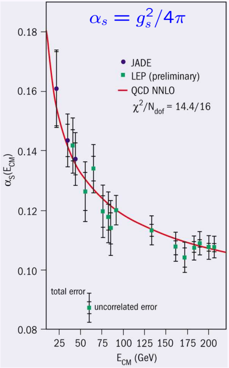
A typical Higgs production event at the LHC



Production of high-energy particles can be systematically described in perturbation theory, in contrast to messy production of low-energy particles

Asymptotic freedom of strong interactions

- Strong interactions are extremely intensive at small energies; weaken at large energies



- At $E > 1\text{GeV}$, the proton is a loosely bound system of partons (quarks and gluons)

- hard scatterings of partons are independent from one another

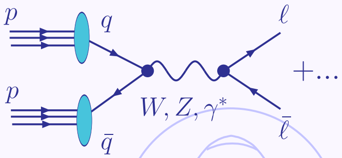
- emission of each additional parton tends to strongly reduce probability of the scattering (suppression by g_s)

PDFs and QCD factorization

According to QCD factorization theorems, typical cross sections (e.g., for vector boson production $p(k_1)p(k_2) \to \left[V(q) \to \ell(k_3)\bar{\ell}(k_4)\right] X$) take the form

$$\sigma_{pp\to\ell\bar{\ell}X} = \sum_{a,b=q,\bar{q},g} \int_0^1 d\xi_1 \int_0^1 d\xi_2 \widehat{\sigma}_{ab\to V\to\ell\bar{\ell}} \left(\frac{x_1}{\xi_1}, \frac{x_2}{\xi_2}; \frac{Q}{\mu}\right) f_{a/p}(\xi_1,\mu) f_{b/p}(\xi_2,\mu)$$
$$+ \mathcal{O}\left(\Lambda^2_{QCD}/Q^2\right)$$

- $\widehat{\sigma}_{ab\to V\to\ell\bar{\ell}}$ is the **hard-scattering cross section**
- $f_{a/p}(\xi,\mu)$ are the **PDFs**
- $Q^2 = (k_3+k_4)^2$, $x_{1,2} = \left(Q/\sqrt{s}\right) e^{\pm y_V}$ — measurable quantities



- ξ_1, ξ_2 are partonic momentum fractions (integrated over)
- μ is a factorization scale (=renormalization scale from now on)
- Factorization holds up to terms of order Λ^2_{QCD}/Q^2

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Purpose of this arrangement:

- Subtract large collinear logarithms $\alpha_s^n \ln^k(Q^2/m_q^2)$ from $\widehat{\sigma}$
- Resum them in $f_{a/p}(\xi,\mu)$ to all orders of α_s

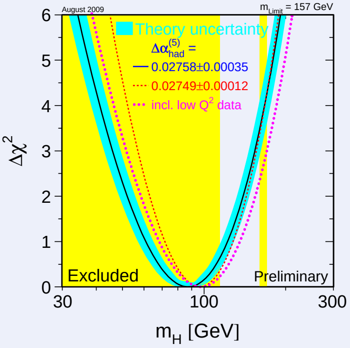
How our group contributes

- **Perturbative** calculations for collider scattering processes
  - W, Z, and Higgs boson production
  - Scatttering of heavy quarks (c and b)
  - All-order summation of perturbative contributions
- Determination of CTEQ **nonperturbative** parton distributions
  - The energy (μ) dependence of $f_{a/p}(x,\mu)$ is known;
  - $f_a(x,\mu)$ can be "measured" (constrained) in a few precise processes (DIS, lepton pair production,...) and used for predictions for all other processes
- Our group is among the world leaders in the determination of PDFs
  - has an important impact on most experimental analyses of high-energy hadronic scattering

Key Tevatron/LHC measurements require trustworthy QCD calculations

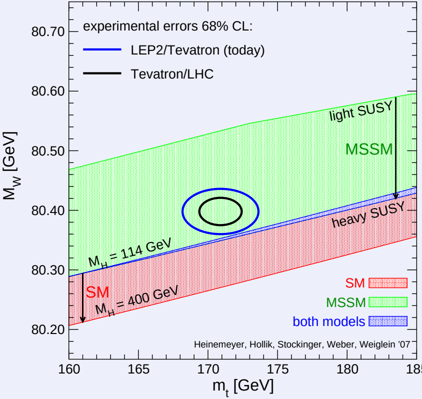
For example, leading syst. uncertainties in tests of electroweak symmetry breaking are due to uncertainties in QCD inputs

EW precision fits



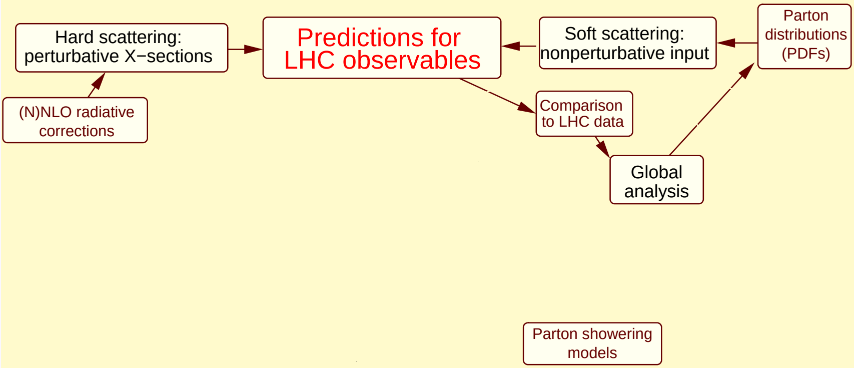
A large part of δM_H arises from $\delta_{PDF} M_W$

EW fits + direct Higgs searches



SM band: $114 \le M_H \le 400$ **GeV**
SUSY band: random scan

Global picture of QCD factorization at the LHC



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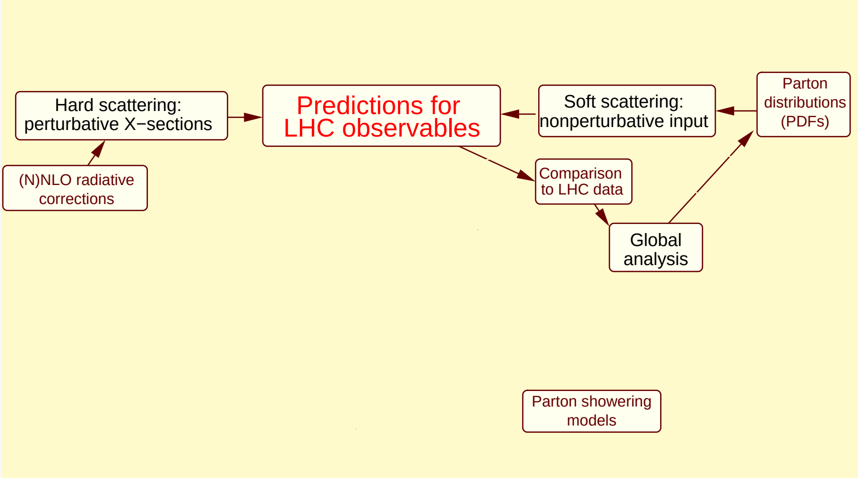
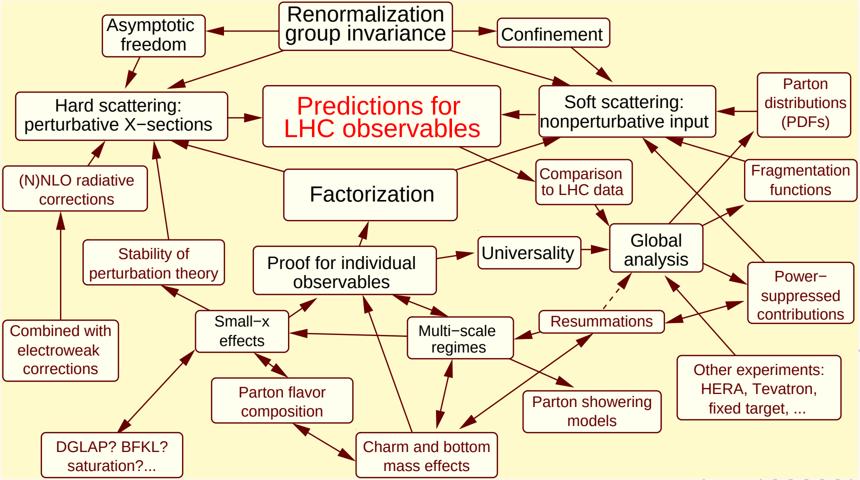


A relevant, yet incomplete, picture

Global picture of QCD factorization at the LHC



Global interconnections can be as important as (N)NLO perturbative contributions; are different at the LHC and Tevatron