HEP Theory Group Activities : Second Quarter 2014

The Theory Group continued its activities in a broad range of subjects, with emphasis on hadron collider phenomenology, Higgs, top-quark and quarkonium physics, as well as on fundamental processes. Examples of these works are the following :

Higgs boson physics and LHC phenomenology in an inverted hierarchy flavor symmetry model

Ed Berger and former postdoc Hao Zhang are nearing completion of their investigation of a model of BSM physics in which there is a new scalar, a flavon, and a new heavy fermion associated with the SM top-quark. This model arises from a simplified flavor symmetry framework with inverted hierarchy. The flavon mixes with the SM Higgs boson, and the heavy fermion alters the production and decay properties of the Higgs boson at the LHC, all in ways that are consistent with data at current levels of precision. The masses of flavon and the heavy fermion might appear at the hundreds GeV to TeV scale. There is a sizable allowed parameter space in which the constraints from electroweak precision observables and and flavor physics are satisfied. A paper is expected to be submitted for publication in April.

The mixing of the flavon, a SM gauge singlet scalar, with the $SU(2)_L$ doublet Higgs field produces several effects. Its influence on Higgs boson physics could be examined experimentally with more precise measurements of the SM Higgs-like scalar at 126 GeV. Moreover, the mixing makes it possible to produce and detect the flavon at the LHC.

In this NP model, the production cross section of the SM-like Higgs boson h at the LHC is suppressed by the square of the cosine of the mixing angle. However, neither mixing nor the triangle loop from the heavy fermion change the Higgs boson decay branching ratios significantly. The $h \to Z^0\gamma$ decay channel is an exception. With large mixing which is still allowed at the 3σ level, the branching ratio of this channel can be increased by about 20%. While not an easy task to measure this branching ratio precisely at the LHC, it would be possible to check the modification of the $hZ^0\gamma$ vertex at a future Higgs Factory.

The possibility to search for the flavon s at the LHC is explored in detail in the paper. The flavon decays to a SM Higgs-pair, $s \to hh$, and into the usual SM Higgs boson decay modes. Berger and Zhang investigated the $s \to Z^0Z^0$ discovery channel, in the $2\ell 2\ell'$ final state. At 7 and 8 TeV at the LHC, the Z^0Z^0 channel provides a stronger constraint than $s \to hh$ owing to limitations of integrated luminosity. At 14 TeV with 100 fb^{-1} integrated luminosity, they show that the small mixing region can be reached where the Z^0Z^0 decay channel is highly suppressed. In this region of parameter space, SM Higgs boson pair production $s \to hh$ in the $b\bar{b}\gamma\gamma$ final state is more important for discovery.

Fragmentation Contributions in Quarkonium Production at the LHC

As was described in the previous quarterly report, G. Bodwin and H.-S. Chung, in collaboration with J. Lee and U-Rae Kim (Korea University), have been carrying out a calculation aimed at summing the large logarithms of p_T^2/m_c^2 that appear in quarkonium-production cross sections at the LHC. This calculation has now been completed for J/ψ production.

It was found that the effects of resummation, beyond the fixed-order calculations through NLO, are not very large—less than 10% of the cross section. However, in carrying out this calculation, Bodwin, Chung and collaborators found a new, large, nonlogarithmic, fragmentation contribution. It arises from the convolution of $2 \to 1 + X$ parton scattering in order-α_s^3 with the fragmentation functions in order α_s^2 for a parton to fragment into a heavy quark-antiquark pair. This new fragmentation calculation goes beyond the existing NLO calculations, which are in order α_s^4. The fragmentation approximation is expected to be valid for p_T greater than about three times the quarkonium mass.

The new fragmentation contribution substantially alters the predicted shapes in the three principal color-octet production channels at high p_T. A combined fit to the CDF and CMS cross-section measurements is in good agreement with the data. The nonperturbative long-distance matrix elements that are obtained from this fit have been used to predict the J/ψ polarizations at CDF and at CMS. Because of the changed shapes in the principal color-octet production channels, the fits strongly constrain the ${}^3S_1$ and ${}^3P_J$ contributions to cancel, and the observed cross section derives almost entirely from the ${}^1S_0$ channel, which is unpolarized. As a result, the J/ψ polarization is predicted to be near zero, in agreement with the CDF

Run II and CMS measurements.

This is the first prediction in the NRQCD approach of near-zero J/ψ polarization. Previous calculations through NLO had predicted large, transverse J/ψ polarization at large p_T, in contradiction with the CDF Run II measurement and the CMS measurement. **The approach of Bodwin, Chung and collaborators may point the way to a solution of this long-standing problem in the theory of quarkonium production.** Computations to test the approach for additional charmonium and bottomonium states are under way.

A paper describing this work (arXiv:1403.3612) was written during the last quarter and has been submitted to Physical Review Letters.

Disentangling radiative corrections using high-mass Drell-Yan at the LHC

Future measurements of the Drell-Yan spectrum at a 14 TeV LHC will access an even larger kinematic range than what has been so far probed. Along with this larger phase space comes an increased sensitivity to a host of effects. In addition to QCD corrections through next-to-next-to-leading order (NNLO), electroweak Sudakov corrections become increasingly more important at high- energy colliders. Photon-initiated corrections also increase in importance at high energies, as has been recently emphasized for both Drell-Yan and W-pair production processes. The ATLAS collaboration has performed detailed studies showing the importance of these effects for a host of measurements in the Drell-Yan channel. One view of these corrections is that they represent additional sources of theoretical uncertainty which must be sufficiently controlled in order to perform interesting measurements. Sufficient understanding of electroweak (EW) corrections and photon-initiated processes, in addition to the usual QCD corrections, will be needed to interpret these measurements. The experimental control over the Drell-Yan channel allows such theoretical effects to be precisely validated before being applied to other processes.

Boughezal and Petriello presented a detailed numerical study of lepton-pair production via the Drell-Yan process above the Z-peak at the LHC. Their results consistently combine next-to-next-to-leading order QCD corrections and next-to-leading order electroweak effects, and included the leading photon-initiated processes using a recent extraction of the photon distribution function. They focused on the effects of electroweak corrections and of photon-photon scattering contributions, and demonstrated which kinematic distributions exhibit sensitivity to these corrections. They showed that a combination of measurements allows these effects to be disentangled and separately determined. This article is published in Phys.Rev. D89 (2014) 034030.

Combining Resummed Higgs Predictions Across Jet Bins

Experimental analyses often use jet binning to distinguish between different kinematic regimes and separate contributions from background processes. To accurately model theoretical uncertainties in these measurements, a consistent description of the jet bins is required. Boughezal and Petriello, in collaboration with the postdoc Xiaohui Liu, presented a complete framework for the combination of resummed results for production processes in different exclusive jet bins, focusing on Higgs production in gluon fusion as an example. They have extended the resummation of the Higgs + 1-jet cross section into the challenging low transverse momentum region, lowering the uncertainties considerably. They provided combined predictions with resummation for cross sections in the Higgs + 0-jet and Higgs + 1-jet bins, and gave an improved theory covariance matrix for use in experimental studies. They estimated that the relevant theoretical uncertainties on the signal strength in the Higgs to WW analysis are reduced by nearly a factor of 2 compared to the current value.

Study of the Blind Spots for Neutralino Dark Matter in the MSSM

Wagner and Huang studied the spin-independent neutralino Dark Matter scattering off heavy nuclei in the MSSM. They identified analytically the blind spots in direct detection for intermediate values of m_A. In the region where the Higgsino mass parameter μ and the smallest of the gaugino masses $M_{1,2}$ have opposite signs, there is not only a reduction of the lightest CP-even Higgs coupling to neutralinos, but also a destructive interference between the neutralino scattering through the exchange of the lightest CP-even Higgs and that through the exchange of the heaviest CP-even Higgs. At critical values of m_A, the tree-level contribution from the light Higgs exchange cancels the contribution from the heavy Higgs, so the scattering cross section vanishes. They denote these configurations as blind spots, since they provide a generalization of the ones previously discussed in the literature, which occur at very large values of m_A. They showed that the generalized blind spots may occur in regions of parameter space that are consistent with the obtention of the proper neutralino relic density, and therefore may be very relevant for the MSSM phenomenology. This article is submitted to arXiv, arXiv:1404.0392, and will be sent for publication to PRD.

Generalized Focus Point in the MSSM

The Higgs mass parameter in the MSSM is insensitive to the ultraviolet physics and is only sensitive to the scale of soft supersymmetry breaking parameters. Present collider bounds suggest that the characteristic values of these parameters may be significantly larger than the weak scale. Large values of the soft breaking parameters, however, induce large radiative corrections to the Higgs mass parameter and therefore the proper electroweak scale may only be obtained by a fine tuned cancellation between the square of the Higgsino mass parameter μ and the Higgs supersymmetry breaking square mass parameter. This can only be avoided if there is a correlation between the scalar and gaugino mass parameters, such that the Higgs supersymmetry breaking parameter remains of the order of the weak scale. The scale at which this happens is dubbed as focus point. Wagner, in collaboration with A. Delgado and M. Quiros defined the general conditions required for this to happen, for different values of the messenger scale at which supersymmetry breaking is transmitted to the observable sector, and for arbitrary boundary conditions of the sfermion, gaugino, and Higgs mass parameters. Specific supersymmetry breaking scenarios in which these correlations may occur were also discussed. The related paper, arXiv:1402.1735, was accepted in JHEP and it will appear soon.

Computation of the Higgs Mass at higher loops in the MSSM

In supersymmetric models, very heavy stop squarks introduce large logarithms into the computation of the Higgs boson mass. Although it has long been known that in simple cases these logs can be resummed using effective field theory techniques, it is technically easier to use fixed-order formulas, and many public codes implement the latter. Wagner, in collaboration with his student Gabriel Lee and his former student Patrick Draper calculated three- and four-loop NNLL corrections to the Higgs mass and compare the fixed order formulas numerically to the resummed results in order to estimate the range of SUSY scales where the fixed-order results are reliable. They found that the four-loop result may be accurate up to a few tens of TeV. They showed an accidental cancellation between different three-loop terms, which persists to higher scales and becomes more effective with the inclusion of higher radiative corrections. One of the consequence of their analysis is that results in the literature based on partial three-loop calculations, and which include only one of the two canceling terms overestimate the Higgs mass. Wagner and collaborators presented analytic expressions for the three- and four-loop corrections in terms of Standard Model parameters and provide a complete dictionary for translating parameters between the SM and the MSSM and the MS and DR renormalization schemes. This article was accepted is now published in Phys. Rev. D89 (2014) 055023.

Forum on International Physics – American Physical Society

In late 2012 Ed Berger was elected to the Chair line of the Forum on International Physics (FIP) of the American Physical Society. Berger is now in the second year of his 4 year term, serving as Chair-Elect in 2014. FIP numbers 3739 physicists among its members in 2013, more than the membership of the Division of Particles and Fields. His responsibities have been notably time-consuming this quarter. These included assembling and chairing a multidisciplinary review panel that decided on the recipients of APS International Travel Grant Awards; serving as Chair of the Program Committee for FIP invited paper sessions for the APS 2015 March and April General Meetings; participating in the APS Leadership Convocation; and membership on the APS Committee on International Scientific Affairs.