HEP Theory Group Activities : Third Quarter 2015

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 :

Axial vector meson production

A paper "Peak locations and relative phase of different decay modes of the a_1 axial vector resonance in diffractive production", arXiv:1504.05955, by Ed Berger and collaborator Jean-Louis Basdevant of l'Ecole Polytechnique was published this quarter in Physical Review Letters **114**, 192001 (2015). This work concerns axial-vector meson production in high energy hadronic scattering. In the paper, Berger and Basdevant demonstrate that the isospin $I = 1$ spin-parity $J^{PC} = 1^{++}$ $a_1(1260)$ resonance can be split into two states: $a_1(1260)$ decaying into an S-wave $\rho\pi$ system, and $a_1'(1420)$ decaying into a P-wave $f_0(980)\pi$ system. This one resonance produces two peaks at different locations in the two channels, with a rapid increase of the phase difference between their amplitudes arising mainly from the structure of the production process itself. In ongoing work, Berger and Basdevant are addressing the a_1 produced in the decay of the τ heavy lepton: $\tau \to a_1\nu$, with the goal of providing a consistent description of both the hadronic data and the τ decay data. Very high statistics on $e^+e^- \to \tau \to a_1\nu \to 3\pi\nu$ have been published by the CLEO, ALEPH, and BELLE collaborations. Related to this research, Berger presented a series of invited lectures at the "2015 International Summer Workshop on Reaction Theory", June 8-19, 2015, at Indiana University in Bloomington, IN. In these lectures, he described the exclusive production dynamics of three body systems in hadronic reactions, including the roles of unitary and analyticity, final state interactions, and coupled-channel systems.

Fragmentation Contributions to Quarkonium Photoproduction

This work, carried out by Geoff Bodwin and Hee Sok Chung, in collaboration with Jungil Lee and U-Rae Kim (Korea University), was described in the previous quarterly report. During the current reporting period, a paper describing these results was written and posted on the arXiv (arXiv:1504.06019 [hep-ph]).

Fragmentation Contributions to Prompt , χ_c, and $\psi(2S)$ Production

In previous work by Geoff Bodwin and Hee Sok Chung, in collaboration with Jungil Lee and U-Rae Kim (Korea University), leading-power fragmentation contributions to J/ψ production at the Tevatron and the LHC were computed. These new contributions seem to resolve the discrepancy between theory and experiment with regard to the polarization of the J/ψ. In a new study, described in the first quarterly report of FY15, Geoff Bodwin and Hee Sok Chung, in collaboration with Jungil Lee and U-Rae Kim (Korea University), Kuang-Ta Chao (Peking University), and Yan-Qing Ma (Maryland University), are extending this earlier analysis of leading-power fragmentation contributions to the χ_c and $\psi(2S)$ states and are including feeddown from those states in the computation of prompt J/ψ production. During the last quarter, preliminary calculations for this project were completed. Further checking of the preliminary results is ongoing, and a paper describing these results is in a draft stage..

More Precise Predictions for $H \to V\,\gamma$

As was first pointed out by Bodwin, Petriello, Stoynev, and Velasco, the Higgs decay to $J/\psi + \gamma$ provides one of only two known ways to measure the $Hc\bar{c}$ coupling at the LHC. In work described in previous reports, Geoff Bodwin, Hee Sok Chung, Frank Petriello, Jungil Lee (Korea University), June-Haak Ee (Korea University) computed the relativistic corrections to Higgs-boson decays to $J/\psi+\gamma$ and $\Upsilon(nS)+\gamma$. This work removed the largest theoretical uncertainty in the prediction for the rate for $H \to J/\psi + \gamma$.

A recent paper by König and Neubert makes a further improvement in the precision of the

theoretical prediction for $H \to J/\psi + \gamma$. This paper incorporates a next-to-leading log (NLL) summation of large logarithms of m_H^2/m_Q^2 that goes beyond the leading-log resummation that was used in previous work. The NLL resummation produces a significant shift in the prediction.

However, there is room for further improvement in the König-Neubert result in several respects: (1) it uses a model light-cone distribution amplitude (LCDA) to compute the relativistic corrections and some of the order-α_s corrections, instead of computing them from first principles; (2) it does not contain a complete computation of all of the NLL corrections, omitting those that are associated with the evolution of the light-cone distribution amplitude; and (3) the starting scales that are taken for the evolution/resummation are different from the characteristic momentum scales of the relevant subprocesses.

Preliminary work by Geoff Bodwin, Hee Sok Chung, Jungil Lee, and June-Haak Ee indicates that the model LCDA of König and Neubert does not give an accurate estimate of the corresponding relativistic and order-α_s corrections and that choices of starting scales that match the characteristic subprocess momenta shift the predictions significantly from the König and Neubert results. Further work on resummation of NLL corrections to the LCDA is underway.

W-boson production in association with a jet at next-to-next-to-leading order in perturbative QCD

In arXiv:1504.02131, Boughezal and Petriello, in collaboration with the PhD student Chris Focke, presented the complete calculation of W-boson production in association with a jet in hadronic collisions through next-to-next-to-leading order in perturbative QCD. To cancel infrared divergences they introduced a new subtraction method that exploits the fact that the N-jettiness event-shape variable fully captures the singularity structure of QCD amplitudes with final-state partons. This method holds for processes with an arbitrary number of jets, and is easily implemented into existing frameworks for higher-order calculations. They presented initial phenomenological results for W+jet production at the LHC. The NNLO corrections are small and lead to a significantly reduced theoretical error, opening the door to precision measurements in the W+jet channel at the LHC. This work was accepted for publication in Phys. Rev. Lett.

N-jettiness soft function at next-to-next-to-leading order

In arXiv:1504.02540, Boughezal and Petriello presented a general framework for the calculation of soft functions for $SCET_I$ observables through next-to-next-to-leading order (NNLO) in the strong coupling constant. As an example of their formalism they showed how it can be used to obtain the complete NNLO soft function for the N-jettiness event shape variable. They presented numerical results for two examples with phenomenological impact: the one-jettiness soft function for both electron-proton and proton-proton collisions. This work was accepted for publication in Phys. Rev. D.

Higgs Boson Production in Association with a Jet at Next-to-Next-to-Leading Order

In arXiv:1504.07922, Boughezal and Petriello presented precise predictions for Higgs boson production in association with a jet. Their calculation is accurate to next-to-next-to-leading order (NNLO) QCD in the Higgs Effective Field Theory and uses the sector-improved residue subtraction to remove the infra-red singularities. It includes all relevant phenomenological channels and describes fully-differential observables as well as total cross sections for the LHC. Their NNLO predictions reduced the unphysical scale dependence by more than a factor of two and enhanced the total rate by about twenty percent compared to NLO QCD predictions. Their results demonstrate for the first time satisfactory convergence of the perturbative series. This work was accepted for publication in Phys. Rev. Lett.

Higgs boson production in association with a jet using jettiness subtraction

In arXiv:1505.03893, Boughezal and Petriello in collaboration with the graduate student Chris Focke, used their recently proposed jettiness-subtraction scheme to provide the complete calculation of Higgs boson production in association with a jet in hadronic collisions through next-to-next-to-leading order in perturbative QCD. This method exploits the observation that the N-jettiness event-shape variable completely describes the singularity

structure of QCD when final-state colored particles are present. Their result constitutes the first complete NNLO computation for Higgs production with a final-state jet in hadronic collisions. It is in agreement with their recent computation of the gg and qg partonic initial states based on sector-improved residue subtraction. They presented phenomenological results for both fiducial cross sections and distributions at the LHC. This work was accepted for publication is Phys. Lett. B.

Hadronic production of W and Z bosons at large transverse momentum

The recent paper "Hadronic production of W and Z bosons at large transverse momentum", arXiv:1503.08836 [hep-ph], by Ed Berger and Argonne postdoc Jun Gao, along with external collaborators Zhong-Bo Kang (Los Alamos), Jian-Wei Qiu (Brookhaven), and Hao Zhang (UC Santa Barbara) was published this quarter in Phys. Rev. D **91**, 113001 (2015). In this paper, the authors introduce a modified factorization formalism in quantum chromodynamics for hadronic production of W and Z bosons at large p_T. When p_T is much larger than the invariant mass Q of the vector boson, this new factorization formalism systematically resums the large fragmentation logarithms, $\alpha_s^m \ln^m(p_T^2/Q^2)$, to all orders in the strong coupling α_s. Using their modified factorization formalism, they are currently undertaking the calculation of inclusive top quark production at very large transverse momentum.

CP-odd component of the lightest neutral Higgs boson in the MSSM

The Higgs sector of the Minimal Supersymmetric Extension of the Standard Model may be described with a two Higgs doublet model with properties that depend on the soft supersymmetry breaking parameters. For instance, flavor independent CP-violating phases associated with the gaugino masses, the squark trilinear mass parameters and the Higgsino mass parameter μ may lead to sizable CP-violation in the Higgs sector. Constraints on this possibility come from direct searches for non-standard Higgs bosons, precision measurements on the lightest neutral Higgs properties, including its mass, and electric dipole moments.

In a recent article, Wagner and University Chicago student Bing Li discussed these constraints within the MSSM. They showed that the values of the stop left-right mixing parameter that maximize the lightest CP-even Higgs mass lead to a suppression of the

dominant loop contribution to the CP-odd component of the lightest Higgs boson. Since for stop masses of order of the TeV scale, stop mixings close to the ones that maximize m_{H_1} are necessary in order to obtain SM-like Higgs masses of order of the one observed experimentally, the measured Higgs mass puts a significant constraint on the possible values of the H_1 CP-odd component. Moreover, they showed that large H_1 CP-odd components lead necessarily to a significant increase of the width of the lightest neutral Higgs decay into bottom quarks. Since the width of $H_1 \to b\bar{b}$ is the dominant decay width of H_1, this increase leads also to a significant modification of the branching ratio of the decays of H_1 to gauge bosons, what leads to a further constraint into large H_1 CP-odd components. This article appeared has recently been published in Phys. Rev. D **91**, 095019 (2015).

Same-Sign Dilepton Excesses and Light Top Squarks

Wagner has continued his analysis of anomalous events containing bottom quarks and leptons. Following his analysis with Argonne postdoc Peisi Huang of the edge in the dilepton invariant mass distribution observed by CMS, published recently in Phys. Rev. D91 (2015), 015014, Wagner has now concentrted on the excess in same-sign dilpeton production in association with bottom-quarks at the LHC. Indeed, Run 1 data of the Large Hadron Collider (LHC) contain excessive events in the same-sign dilepton channel with b-jets and missing transverse energy (MET), which were observed by five separate analyses from ATLAS and CMS collaborations. Wagner and Low, in collaboration with Argonne postdocs Huang and Ahmed, showed that these events could be explained by direct production of top squarks (stops) in supersymmetry. In particular, a right-handed stop with a mass of 550 GeV decaying into 2 top-quarks, 2 W bosons, and MET could fit the observed excess without being constrained by other direct search limits from Run 1. We propose kinematic cuts at 13 TeV to enhance the stop signal, and estimate that stops could be discovered with 40 fb^{-1} of integrated luminosity at Run 2 of the LHC, when considering only statistical uncertainties.

Program Chair, March and April General Meetings of the American Physical Society

In his roles as a member of the Program Committee of the American Physical Society and

Chair of the Invited Paper sessions for the Forum on International Physics (FIP), Ed Berger organized 3 FIP invited paper sessions for the April 11 - 14 meeting in Baltimore, Maryland. The well-attended sessions on "Models of International Partnership", featured outstanding speakers including David Gross (Santa Barbara), Sergio Bertolucci (CERN), Joseph Lykken (Fermilab), Thomas Glasmacher (FRIB, Michigan State), Roger Blandford (Stanford), Robert Iotti (Chair, ITER Council), and Gabriela Gonzalez (LIGO Spokesperson). A panel discussion followed the individual presentations. The Panelist included all the speakers plus William Colglazier (former high energy theorist, and recently the Science and Technology Adviser to the U.S. Secretary of State), Saul Gonzalez of the White House Office of Science and Technology Policy, and James Siegrist of the DOE Office of High Energy Physics.