2015 CTEQ School

The Coordinated Theoretical-Experimental Project on QCD (CTEQ)
will organize and conduct the

2015 CTEQ School

on

QCD and Electroweak Phenomenology

at

University of Pittsburgh, PA, USA
7 - 17 July 2015

The school will be locally hosted by **PITT PACC**, and the Monte Carlo Tutorial Sessions will be organized with the cooperation of the **MCnet Collaboration**.

The School is ideally suited for advanced graduate students and recent PhDs.

Topics to be covered:

Focused Introductory Reviews:

- Introduction to the Parton Model & Perturbative QCD
- Monte Carlo Introduction
- Deeply Inelastic Scattering
- Higgs at Hadron Colliders
- Vector Bosons / Direct Photons
- Production and Structure of High Energy Jets
- Heavy Quarks

In-depth Analysis and Phenomenology:

- Monte Carlo Tutorial
- Experimental Results from LHC
- QCD/EWK/Top at Hadron Colliders
- PDFs and Global Fits
- Intensity Frontier: Neutrino Physics
- Intensity Frontier: Muon Physics
- The Standard Model and Beyond
- NLO Computation and Matching/Merging

Application Deadline: 31 March 2015

Website: **www.cteq.org** E-mail: **cteq2015@list.smu.edu**

Sponsors: Fermi National Accelerator Laboratory, National Science Foundation, U.S. Department of Energy, University of Wisconsin, MC-Net, & PITTsburgh Particle physics, Astrophysics, & Cosmology Center (PITT-PACC)

Organizing Committee: Ed Berger and Tom LeCompte (Argonne), Jorge Morfín (Fermilab), Laura Reina and Jeff Owens (FSU), Nikos Varelas (UI-Chicago), Frank Petriello (Northwestern/ANL), Zack Sullivan (IIT), Davison Soper (Oregon), Tao Han, Cynthia Cercone and Ayres Freitas (Pittsburgh), Fred Olness and Randall J. Scalise (SMU), Stefan Hoeche (SLAC), Joey Huston (MSU)

Closeout Report for CTEQ Summer School 2015

PI: Tao Han, on behalf of the CTEQ collaboration

Project Summary

The 2015 CTEQ school was held on the campus of the University of Pittsburgh during July 7−17, 2015. The school consisted of eight days of lectures and discussion where students interact closely with distinguished experts with a broad range of expertise.

The CTEQ schools have proven to be extremely useful for students involved at both the Intensity Frontier and the Energy Frontier. The audience for these schools is primarily the younger generation of high energy elementary particle physicists—typically advanced graduate students and postdocs, and are roughly evenly divided between experimental and theoretical disciplines.

The CTEQ schools provide the participants with a deeper understanding and improved competency of the fundamental ideas, tools, and techniques that serve as the foundation for all our current investigations of the Standard Model (SM) and beyond. The broader impact is conveyed through the students' strengthened awareness of the context of their research in the overall endeavor of fundamental physics. The interactive nature of the schools encourages the skills necessary for communicating the excitement and results within collaborations, and also to the wider public.

Traditionally, the CTEQ Summer Schools take place in the US in alternative years. In the other years, the Schools are organized by an Institute outside the US. Thus the US school funding is requested bi-annually.

The CTEQ Collaboration

The CTEQ Collaboration is an informal group of 37 experimental and theoretical high energy physicists from 20 universities and 5 national labs, engaged in a program to advance research in and understanding of QCD. This program includes the well-known collaborative project on global QCD analysis of parton distributions, the organization of a variety of workshops, periodic collaboration meetings, and the subject of this proposal: the CTEQ Summer Schools on QCD Analysis and Phenomenology.

Past Schools and Previous DOE support:

Since 1992, nineteen of these CTEQ Summer Schools have been held: ten in the United States, seven in Europe, one in Mexico, and one in South America. Typically, the school alternates between a US and a foreign location. Since 2002, the UW-Madison campus hosted our US-based schools, and these were funded by DOE at the level of $30K per school, except for this year 2015 with $5K.

The most recent schools were held in Pittsburgh (2015, 2013), Beijing, China (2014), Lima, Peru (2012), Madison, Wisconsin (2011, 2009), and Lauterbad, Germany near Karlsruhe (2010). For the US-based schools, we typically have 60-80 students; the number for

the foreign schools varies from 60 to 90 depending on the venue and other constraints.4 CTEQ has collaborated with the MCnet5 collaboration for a number of our schools. In particular, the 2008 and 2010 summer schools were hosted jointly by CTEQ and MCnet, and featured very popular Òhands-onÓ tutorial sessions working with the Pythia, Herwig, and Sherpa Monte Carlo programs. For 2015 we continued the Òhands-onÓ tutorial sessions as an integral component of the school.

The Students:

Most participants at these schools are advanced graduate students (beyond their course work) and postdocs who pay a significant registration fee to cover their room, board, coffee breaks, and incidentals; they are also responsible for covering their travel. Typically each year, a small number of students pleading financial hardship are awarded fellowships to the school which cover half of the registration fee; we do not cover any travel for students.

The international reputation of the School is evidenced by the substantial participation from Europe and Asia, and by the desire of other countries/institutions to host future schools; typically, one third of the students come from abroad for schools held in the United States.

Interaction with Lecturers

An essential element of the CTEQ Schools is complete immersion in the topics. Everyone—both students and lecturers—participates in the lectures, meals, recitations, and evening session. This interaction provides the students with an opportunity to think and discuss the day's lecture topics in an informal setting where they can revisit points that may be confusing, and dig into questions that are relevant for their own research. This interaction between students and lecturers is one of the hallmarks of the CTEQ summer schools.[1]

Following the School, we ask the students for feedback regarding the lectures, and we list some sample comments from our most recent school in the Appendix. In particular, many students commented about the interaction with the lecturers.

[1] An interesting anecdote came from the 2009 summer school. A student asked a question of one of the lecturers (Scott Dodelson) during a recitation; Scott said that this was a fairly basic question, but one which no one had thought to ask before. The resultant paper based on the question has now been published in PRL. (Dodelson & Vesterinen, Phys. Rev. Lett. 103 (2009) 171301.)

Agenda for the 2015 School

Topic	Hours
Introduction to the Parton Model and Perturbative QCD	4
Deeply Inelastic Scattering	2
Higgs Boson	2
Vector Bosons/Direct Photons	2
Production and Evolution of High Energy Jets	2
Heavy Quarks	2
Monte Carlo Introduction	2
Monte Carlo "Hands On" Tutorial	2
Experimental: Higgs and related	2
Experimental: QCD/Electroweak/Top	2
PDFs and Global Fits	2
Neutrino Physics	2
Higher Order Tools and Methods	2
Intensity Frontier	2
The Standard Model & Beyond	2

2015 CTEQ summer school on QCD and Electroweak Phenomenology at the University of Pittsburgh, 7-17 July 2015.

The 2015 CTEQ Summer School followed the very successful format of previous schools consisting of 8 days of lecture, split into two 4-day halves with one free day in the middle. A typical day consists of 4 full hours of lecture, a 1.5 hour "recitation" session where students can ask questions they typically are reluctant to ask during lectures, and a concluding 1.5 hour "nightcap" where all participants mix in a relaxed setting to continue discussions on a personal level one-on-one or in small groups. Including arrival and departure days this calls for a ten night stay at the school.

The physics program for 2015 also followed the lines of previous schools, and a draft schedule with allocation of hours is included in the Appendix. A series of introductory lectures on fundamentals of perturbative QCD will be followed by a more advanced component of specialized and contemporary topics–a format which has proven to be extremely effective. Slides of lectures from the previous schools are available at the CTEQ web page during and after the schools and illustrate the careful presentation by the lectures as well as the breadth and depth of the content.

In 2015 we again included hands-on tutorial sessions on Monte Carlo event generator programs. These sessions were well received at past schools, and we are coordinating with the members of the MCnet Collaboration. These lectures complemented and broadened the discussion of hadron collider topics.

Lecturers were invited from the CTEQ Collaboration and from the worldwide QCD communities. This mix proved effective to ease the pedagogical integration of the lectures, in

particular at the introductory level. Lectures were held in University of Pittsburgh conference facilities.

Value of the School

Since 1992, the CTEQ Summer School on QCD Analysis and Phenomenology has provided a unique opportunity for young experimentalists and theorists to learn the important ideas, tools, and techniques from experts in the field.

Intellectual Merit:

Physicists analyzing data from high energy elementary particle experiments require a good working knowledge of QCD. This is inevitable, because the constituent particles of hadrons, quarks and gluons, have strong interactions, and many of the new particles that we would like to find are also strongly interacting. For all high-energy experiments initiated by a hadron or nucleus (including those at the Tevatron, RHIC, JLAB, HERA and the LHC), an understanding of PDFs and associated QCD issues is absolutely indispensable. Equally important for experimentalists and theorists alike is a familiarity with calculations that account for the emission and exchange of quarks and gluons. The role of the CTEQ Schools is even more critical as we advance the frontiers and seek breakthroughs in our understanding of the basic nature of matter and energy, at the highest energies and densities. Adequate training of young experimentalists and theorists will be critical for the success of these programs.

Broader Impact:

The CTEQ Schools address the pressing educational needs of junior physicists involved in front-line search to incisively test the Standard Model and search for new physics, and demonstrates the inextricable role of QCD in their experimental results. The format of this educational enterprise fosters student–lecturer interaction and provides the students a deeper understanding of the fundamental physics. We believe this experience benefits our students both as they complete their experimental/theoretical analysis and toward their pursuits outside of science.

Final Budget Report for 2015 CTEQ Summer School

Expenses	**Notes**		**$54,126**
Students (52), Lecturers (15)	Room & Board 10 Days	$30,345	
External Lecturers (7)	Hotel	$4,300	
External Lecturers	Travel expenses	$2,090	
Participants (74)	Breaks/Recitation Sessions	$9,916	
Participants	Free Day events & backpacks	$3,675	
Students	8 scholarships, $350 each	$2,800	
Collins-Soper-Sterman Fest		$1,000	

Income			**$53,230**
DOE		$5,000	
NSF		$10,000	
MSU transfer	saving (NSF)	$10,000	
PITT PACC	Local contribution	$2,663	
Fees, Excursion & credits		$1,262	
Student Registration		$24,305	

The 2015 school received $5K from DOE, much less than the norm of $30K. Consequently, the budget was very tight and we had to reduce the number of student scholarships to eight, for 1/2 the registration fee for those students with financial hardship. We do not support any student travel. We charged a $700 registration fee for the students; this fee includes the bulk of their room and board.

We provide the students with a shared dorm room and they can pay the differential for a private room if they desire. The school has 32 hours of lecture; most of the lectures are 2 hours with the exception of the 4-hour intro sequence. Thus, we had 15 total lecturers, 8 by CTEQ lecturers and 7 external. For the CTEQ lecturers we estimate expenses based upon an average 7-day stay with a private dorm room and no travel expenses.[2] Other costs include the recitation and evening discussion sessions, and also transportation on the arrival day, departure day, and for the free-day in the middle of the school.

[2]The dorm rooms are cheaper than the hotel, so this saves us money. Also, we generally ask the CTEQ member to cover their travel expenses to and from the school.

A Membership of the CTEQ Collaboration

Name	**Institution**	**Experiment/Theory**
Alberto Accardi	JLab/Hampton	Theory
Edmond Berger	Argonne	Theory
John Campbell	Fermilab	Theory
John Collins	Penn State	Theory
J. William Gary	UC Riverside	Opal, CMS
Walter Giele	Fermilab	Theory
Tao Han	U Pittsburgh	Theory
Kenichi Katakeyama	Baylor	CMS
Joey Huston	MSU	E706, CDF, ATLAS
Cynthia Keppel	JLab/Hampton	JLab
Karol Kovarik	Muenster	Theory
Steve Kuhlmann	Argonne	CDF, DES
Tom LeCompte	Argonne	CDF, ATLAS
Bruce Mellado	UW Madison	ATLAS
Jorge Morfin	Fermilab	MINOS, MINERvA
Steve Mrenna	Fermilab	Theory
Pavel Nadolsky	SMU	Theory
Fred Olness	SMU	Theory
Joseph Owens	FSU	Theory
Frank Petriello	Northwestern	Theory
Jon Pumplin	MSU	Theory
Jianwei Qiu	BNL	Theory
Laura Reina	FSU	Theory
Heidi Schellman	Oregon State	NuTeV, D0
Jack Smith	Stony Brook	Theory
Davison Soper	U. of Oregon	Theory
George Sterman	Stony Brook	Theory
Dan Stump	MSU	Theory
Zack Sullivan	IIT	Theory
Nikos Varelas	U. Ill. Chicago	D0, CMS
Werner Vogelsang	Tubingen	Theory
Doreen Wackeroth	SUNY at Buffalo	Theory
C. P. Yuan	MSU	Theory
Dieter Zeppenfeld	Karlsruhe	Theory
Marek Zielinski	Rochester	E706, D0

B Compilation of CTEQ Summer Schools

Year	Location	Date	Notes
1992	Mackinac Island, MI	27 May - 3 June	
1993	Lake Monroe, IN	25 July - 3 August	
1994	Lake Ozark, MO	10 - 18 August	
1995	Bad Lauterberg	17 - 25 July	DESY[a]
1997	Lake Como, WI	27 May - 4 June	
1998	Courmayeur, Italy	8-16 July	INFN[b]
2000	Lake Geneva, WI	30 May - 7 June	
2001	St. Andrews, Scotland	17 - 26 June	IPPP[c]
2002	UW-Madison, WI	2 - 10 June	
2003	Sant Feliu, Spain	22-30 May	IFAE[d]
2004	UW-Madison, WI	22-30 June	
2005	Puebla, Mexico	19-27 May	BUAP[e]
2006	Rhodes, Greece	1 - 9 July	
2007	UW-Madison, WI	30 May - 7 June	
2008	Debrecen, Hungary	8 - 16 August	MCnet[f]
2009	UW-Madison, WI	24 June - 2 July	
2010	Lauterbad, Germany	26 July - 4 August	MCnet
2011	UW-Madison, WI	10 - 20 July	
2012	Lima, Peru	30 July - 9 August	Fermilab & PUCP[g]
2013	Pittsburgh, PA	7 - 17 July	PITT-PACC[h]
2014	Beijing, China	8-18 July	University of Beijing

[a] Deutsches Elektronen-Synchrotron (DESY).
[b] Istituto Nazionale di Fisica Nucleare (INFN), Italy.
[c] Institute for Particle Physics Phenomenology (IPPP), University of Durham.
[d] Institut de Fisica d'Altes Energies (IFAE), Universitat Autonoma de Barcelona.
[e] Benemerita Universidad Autonoma de Puebla (BUAP)
[f] MCnet is a European Union funded Marie Curie Research Training Network.
[g] Pontificia Universidad Católica del Perú (PUCP) Lima, Peru
[h] University of Pittsburgh (PITT) Particle physics, Astrophysics, and Cosmology Center (PACC).

C Collected Feedback from 2015 School: Pittsburgh

- Very interesting and covering a large range of topics in QCD.
- It was a good experience, I would certainly be able to use some of the things I learned for my thesis even though I am an experimentalist.
- I really enjoyed the school, despite coming in with little to no QCD background. There were talks that were useful, and I developed a nice broad knowledge. Some of the talks were taken to a level that was deeper than the students could really appreciate, mostly the theory talks (that's the sense I got from speaking to others, since my limited knowledge handicapped me from fully appreciating subtleties). A note of praise to Richard Ruiz, who really helped hold things together on the "student" end via his hosting abilities. The MCNet portion was a great idea.
- "The speakers were all very good. The whole school was set up amazingly. Almost every talk was useful for my research (except the ones on my own topic, but that is unavoidable).
- The only thing I could offer as a suggestion is to have the Q&A Sessions in a more informal way. For example ask question to each other per table and have lecturers walk around or have it in a smaller space such that it's easier to hear what people are saying."
- It is a wonderful experience. But most of the lectures are about QCD and related, not that much related to my research which is about the SUSY theory.
- Overall this was a very nice school. I learned about things I was not familiar with. Most of the talks are not directly relevant for my research at this moment, but I think exposure to the ideas is beneficial.
- The summer school is fit for advanced level grad student in pheno/theory/exp. There part that are more relevant to my research and there are less relevant but still interesting to see and learn
- The school was very useful for my research...very well structured
- "The contend presented was important and highly interesting, with the presenters being seasoned in the subject matter.
- However the exclusive slide presentations makes it hard to follow all the way through without prior knowledge. If the historic contend was to be compressed and instead more time used on black board presentations (at least for derivations) the amount of understanding taken away might increase significantly. "
- Highly efficient & purposeful school. Very relevant & useful talks for my research.

- "George Sterman Talks were very good !
- Karol Kovarik talk is useful!
- The summary talk on higgs by Sally Dawson was good
- John Collins explanations during the Q&A are very useful
- I also liked so much James Wells talks on naturalness"
- Very good speakers, very relevant talks. I did not like the recitation sessions. The group was too big to facilitate discussions, so I would recommend that next time you do the recitations in small groups of maybe 5-7 people, each with a lecturer present for answering questions. The lecturers can then rotate either during the night or during the days.
- My overall impression of the school is great. It was a good opportunity to interact with other students and talk about our research and learn from the speakers in the several areas that were covered.
- "The school was pretty decent I thought. Excellent array of top quality speakers, at this school in particular.
- I guess it's sometimes hard for the speakers to know what to talk about given the limited time they can speak for.
- I did find the school useful. Considering my knowledge of perturbative QCD was actually pretty poor before coming to the school I now feel more comfortable with many of the concepts."
- "Great school!
- I really liked the recitation/nightcap as those provide a easy way to approach the lecturers with ""stupid"" questions. They also facilitate exchange between students (which some other school lack)."
- "The school was a really good experience ! I liked the interactive atmosphere very much. There was ample scope to interact among the students which were very helpful.
- Most of the talks were very good, informative and interesting. Though they were not directly related to my research, they were very helpful as introductory lectures. "
- "I would suggest having more order on what is presented and maybe prior coordination among the lecturers such that the school feels like it is flowing smoothly.
- Some of the theory lectures are really hard to follow because there are a lot of equations per slide and few time to go over them and understand them, I feel like it would be more helpful if the theory lectures were old style, without slides."

- Kovarik's talks were far and away my favorite. I found he was one of the few that kept things at a level that I could follow. I wish he had gone first, as the knowledge he introduced allowed me to follow more closely the rest of the talks (and applied some perspective to the other talks). Sterman's talks were good, but I found the pace a bit too accelerated for me. Collins and Soper, while obviously excellent speakers, went far above the level of the average student. Discussing with other students, no one I spoke with felt like they had gained much from their talks because they were lost after only a few slides.

- The speakers were all very good. I didn't really like the philosophical discussion of the SM & Beyond talk and would have rather seen for example what other models are being explored at the moment, but that's just personal preference.

- I think the lectures are all good, but too focused on the QCD. It can be much broader.

- I was expecting the lectures to be at a more basic level. The students have diverse backgrounds. It often happens that theory talks are understandable only for theorists, experiment talks are understandable only for experimentalists, and MC talks are understandable only for those who work on MC every day. There are lectures that really benefit all students (e.g. Prof. Huston's and Prof. Wells' lectures), but not all of the lectures do. Also, perhaps more options could be offered for the MC tutorial sessions, with various levels of difficulty. There could be pedagogical exercises for those who have little background, and intermediate- and advanced-level exercises for those who already have some experience with MC.

- "I do Higgs precision and more than 40% of the lectures are really relevant for my work and I think I benefit a lot.

- The MC Tools tutorial are quite helpful and efficiently offered.

- Through the (un/)organized interaction among lecturers and students I am also exposed to other areas and topics.

- I appreciate a lot all I learned through this summer school. Thank you!"

- "All the lectures are very good-specially SM & Beyond (Wells).

- But I would like to comment on few lectures which was too much for two hours lecture -- neutrino theory, MC Matching. I personally prefer to have chalk-board lecture rather than powerpoint slides. Sometimes it is very hard to follow every equation in powerpoint."

- Theory was at the right level. Some experimental talks may have been too detailed hard to follow. MC sessions were at the right level

- "The school was good, I am a theorist I learned many concepts in the theoretical side, and the discussions with the lecturers were useful.

- Before I came to the school I was aiming to learn the event generators, However the tutorial wasn't useful, I tried to follow the instruction but it wasn't helpful, the tutorial was designed for students who already know how to use the event generator not for the beginners, there was no explanations in the board, especially Pythia tutorial was long not clear and some mistakes in the guide file
- " To me the MCnet stuff was too basic - but I have also been to the MCnet school before, where it is more in depth.
- Overall, the lectures were pretty good with a good variety on topics.
- "Intensity Muons had far too much experimental detail in it.
- Sterman's intro was good - a quick fire of the most important aspects of introductory QCD.
- Overall - pleased with the quality of the lectures."
- "The theory courses were quite nice and having all of CSS and other big names there gave an impressive overview. I would have liked some more technical/detailed theory talks on recent work (this would obviously only be relevant for students with previous knowledge and could maybe be an optional talk in the afternoon). The experimental talks have a good overview.
- Especially the muon talk seemed to be quite extensive and mostly listing experiments, so it was hard to keep up ones concentration for the whole time." "Overall experience for CTEQ 2015 was very good.
- Lectures of Nagy, Berryhill was not very useful or interesting !
- Krauss's lecture was quite hard to understand.
- Coloma was not very sure about her slides !
- I think MC tutorial session was not very useful for me. It is hard for me learn a software in such a little time !
- James's lecture was very interesting, I thing everybody enjoyed his lectures, quite motivational."
- "In general the lectures provided a good mix of experimental and theoretical topics. The experimental lectures were a bit too much on the easy/overview side except the on by Dawson which was very good.
- The format of the recitation was not ideal. The tables were a bit too far from each other so not all questions could be heard clearly. I would prefer that every table has one lecturer which would lead to smaller discussion groups and the some form of rotation."

- "The MC Tutorials are a brilliant portion of the school. Please continue these. My only gripes were that I found the tutorials quite simple and there wasn't much pressure applied to make the rest of the students work. Due to the ""hand-holding"" in the worksheets, it was simple to just write the code without any understanding, I put in extra work in the afternoons to truly understand what I had written, but many students lack this motivation and seem to have not gotten the most out of the tutorials. Stefan was a good host for this due to his enthusiasm.

- Also, the ""review of the subject"" talks, particularly those from the experimenters, should be revised. I understand why they do that (can't leave someone out!)... but it becomes a wash of just throwing plot after plot, and the students begin to zone out. The talks lack a cohesive ""plot"" that allows us to start at the beginning and learn something along the way. In particular, Berryhill's talks, while they contained many interesting plots, were difficult to follow. Before I got a handle on one plot, it was gone and a new one had taken its place. The students I spoke with found that these talks were difficult to follow, not because of difficulty, but because of the lack of a consistent narrative. A more narrow approach of, ""Let's look at one channel for Higgs production and see how experimenters do it from top to bottom, then do a quick discussion of other channels"" may have been more useful.

- Cheers for putting this together, I learned a lot along the way, despite how negative my comments seem, I really enjoyed the experience."

- I have never been such an amazing school. The lectures were great, the social program well organized and the atmosphere perfect. Thanks to all of the organizers for an amazing 10 days!

- It will be much better to start the lecture at 1:30 pm in the afternoon. Most people are very sleepy. Thank you very much for the hard work and the experience.

- I think an ice-breaker/self-introduction session on the first day would be very helpful. Also, the ideal schedule for me would be 9:30-12 in the morning, 1:30-4 in the afternoon, and 7-10 in the evening (I felt like not getting enough sleep at night).

- Thank you so much to the organizers for giving me this opportunity to explore QCD theory.

- Thank you very much for the good organization!

- Because there is a lot in the lectures each day, it's nice to be able to look over the slides and try things out during the free time in the afternoon. However this wasn't available in the second week during which tutorials took place which I think impacted the discussion sessions in the evening - there wasn't enough time to look over and formulate useful questions. "

- The CTEQ school was awesome and I will recommend any PhD student in my field to attend it. Nearly all lectures were on topics that affect my work at least in some extend. The MCnet Tutorial was very interesting and gave good insight into parton showers.

- As a suggestion it might be helpful to have the overall schedule a little earlier, i.e. the information whether one is excepted to the school and on which day/time one is expected to arrive. International students have to book flights which are cheapest probably three months before the school and it might take some time to get the travel approved by the institute.

- Another options one could consider is to have student presentations of some kind. Either posters/talks (optional for those who have material available) or at least some ""icebreaker"" session, where everyone gives a couple of sentences. I talked to most students over the time of the week, but having a quick start helps to learn the names and knowing the fields people work on gives a head start on discussing with people working on topics similar to the own one. Thanks for the school!