Closeout Report for CTEQ Summer School 2022

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Project Summary

The 2022 CTEQ school was held on the campus of the University of Pittsburgh during July 6-16, 2022. 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[1] is an informal group of 30+ 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, twenty eight of these CTEQ Summer Schools have been held: 16 in the United States, 9 in Europe, one in Mexico, one in South America, and one in Asia. Typically, the school alternates between a US and a foreign location. Since 2013, the University of Pittsburgh campus hosted our US-based schools, and these were funded by DOE at the level of approximately $30K per school.

[1]The Coordinated Theoretical-Experimental Project on QCD (CTEQ). http://www.cteq.org

The most recent schools were held in Pittsburgh (2022, 2019, 2017, 2015, 2013), Dresden Germany (Virtual 2021), Puerto Rico (2018), DESY, Hamburg Germany (2016), Beijing, China (2014). For the US-based schools, we typically have 60 students; the number for the foreign schools varies depending on the venue and other constraints. CTEQ has collaborated with the MCnet[2] collaboration for a number of our schools. In particular, the 2016 summer school was hosted jointly by CTEQ and MCnet, and featured very popular "hands-on" tutorial sessions working with the Pythia, Herwig, and Sherpa Monte Carlo programs. For 2022 we continued the "hands-on" 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 registration fee to partially 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.[3]

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

Agenda for the 2022 School

The 2022 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

[2]MCnet is a European Union funded Marie Curie Initial Training Network dedicated to developing and supporting general-purpose Monte Carlo event generators.
http://www.montecarlonet.org/

[3]An interesting anecdote came from a past 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.)

Topic	Hours	Speaker
Introduction to the Parton Model and Perturbative QCD	4	P. Nadolsky
Deeply Inelastic Scattering	2	P. Reimer
Higgs Boson	2	B. Mistlberger
Vector Bosons/Direct Photons	2	R. Boughezal
Production and Evolution of High Energy Jets	2	G. Sterman
Monte Carlo Introduction	3	P. Ilten
Monte Carlo & ML "Hands On" Tutorial	4	L. Gellersen
Experimental: Higgs and related	2	B. Mellado
Machine Learning	4	J. Isaacson
Experimental: QCD/Electroweak/Top	2	N. Bruscino
PDFs and Lattice QCD	1	H.-W. Lin
PDFs and Global Fits	1	C.P. Yuan
Neutrino Physics	2	T. Hobbs
Effective Field Theories	2	S. Dawson

Table 1: 2022 CTEQ summer school on QCD and Electroweak Phenomenology at the University of Pittsburgh, 6-16 July 2022.

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 2022 also followed the lines of previous schools, and a schedule with allocation of hours is included in Table 1. A series of introductory lectures on fundamentals of perturbative QCD is 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 2022 we again included hands-on tutorial sessions on both Monte Carlo event generator programs and Machine Learning as applied to HEP. 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.

A 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
2015	Pittsburgh, PA	7 - 17 July	PITT-PACC
2016	Hamburg Germany	6-16 July	DESY Laboratory
2017	Pittsburgh, PA	18-28 July	PITT-PACC
2018	Mayagüez, Puerto Rico	18-28 June	U Mayagüez, PR
2019	Pittsburgh, PA	16-26 July	PITT-PACC
2021	Dresden, Germany	5-16 September	MCnet
2022	Pittsburgh, PA	6-16 July	PITT-PACC

[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).

B Collected Feedback from 2022 School: Pittsburgh

Feedback form: Overall impression of the school: *Complete and unedited*

- Very good, and very helpful.
- Nice and relevant
- Good. There were definitely talks that will be useful:
- Interesting!
- Overall CTEQ is my favorite summer school. Lots of talks are relevant to my research for example MC generation, QCD, PDF, EW&Higgs, machine learning and lots of very good material.
- I got more than I expected.
- To me personally there was a lot of learning at the school. I came here with not much exposure to QCD, Higgs Physics, but overall I have learnt a lot after these many days of lectures and recitations. These learnings are definitely going to be a lot useful for my research in the coming days. Not just the knowledge aspect, but I also take with me motivation and excitement alongside new ideas towards my research. Certain lectures were absolutely useful to me and will be directly useful to my research work. Not just the physics, but I also take with me a new skillset for understanding and probably working in the future on MC generators and Machine Learning techniques which are again going to be a very aspect of a researchers skillset in the upcoming days. I'm also excited about probably collaborating with some of my peers and professors in the future. This way the CTEQ school has been a great experience for me personally.
- The overall organization and administration was impressive. Many lectures were directly and immediately relevant. Those that weren't were not distant either. I think the topic and content selection is quite streamlined and it's difficult to think of draws. I think it is most ideal to phenomenologists. I personally learned the most from the tutorials and would have liked more of it and more structure within them. Not a knock- just a personal preference.
- Overall I found the conference to be very interesting and thought provoking. The machine learning part I found the most interesting, even if it isn't directly relevant in my work in doing loop calculations.
- Talks were very helpful to get an overview over different topics!
- This was a great summer school was a solid variety of content. I look forward to attending CTEQ in the future.

- The parton shower algorithm Was interesting to me in particular. My overall impression is very good, I liked the recitaction classes(somehow I liked them more from Day 3 on, but maybe because I needed some time to feel comfortable for these open discussions)
- Yes, most of them is interesting. And several topics relevant to my research.
- The tutorial sessions were great. It was helpful to see how textbook QCD translates in experimental data.
- Awesome. Yes.
- Overall, I enjoyed the school. Many aspects were relevant or useful, maybe not always to my immediate research but it got me interested in things to move into after finishing this current project and possibly into a post-doc
- I truly enjoyed and liked the school. The topics presented were really interesting. Although I did not find a talk that was totally related to my research, many topics that are relevant to my research, were mentioned in the talks.
- Lots of talks were relevant for me, especially the theory ! Very good school
- it was very useful, i learned a lot from this school
- The school was very well versed and organized. I really liked the schedule's structure even tho it was admittedly tough. I am conflicted because on one hand, I would have wanted a bit more rest time but, on the other hand, I honestly don't know what I would have "sacrificed" for that. Every lecture was on point and extremely captivating and the recitation section was undoubtedly the most useful and interesting part. Overall, a great experience both from the scientific prospective and the human one.
- Interesting and engaging
- It was nice too hard for me but I definately learned something. I also met a lot of nice people
- Yes, I really liked the coverage of topics.
- The school was great. QCD, PDFs were relevant and Neutrinos and SMEFT were interesting.
- The school was excellent. All talks are beneficial for my research. Vector Boson and Monte Carlo lectures are relevant for my research.
- Loved the school but we should have the weekend off instead of Monday perhaps. Lectures were awesome though.
- Yes, they were very relevant to my research.

- Nice introduction and active discussion on QCD and PDF physics
- The school was great! I was able to learn a lot through the lectures and a lot of questions I had were cleared up
- The school was very good! There were plenty of different topics from theory and the right amount of experiment content to support it. Personally, there were no talks related to my research (heavy ions), but some mentions. However, the content was a good way of consolidate and know more about the state of the art in particle physics (both theory and experiment), and some insights on other topics will be useful for my research.
- Very good! some of the talks were closely related to my research, but even the ones that weren't gave me more insight into the field as a whole
- A very nice school for theory/pheno. For experimental hep, the format should be modified and include more experimentalist lectures covering more basics on detectors, data analysis, etc.
- The school was very good. I think the subject of the talks were relevant, but it was maybe at too high a level.
- Overall I liked the school very much. The organiszation was great and the topics interessting.
- Overall I think the school was very well organized and covered a nice breadth of topics through both experimental and theoretical perspectives. I did wish to have more topics specifically on scattering amplitudes and modern techniques for calculating higher order virtual corrections; it seemed a large focus was on PDFs and not so much on the amplitudes. I wondered how novel computing techniques could be applied for these complicated calculations. Since the school is focused on phenomenological applications, I understand that a focus on mathematical applications to calculating amplitudes would not be so relevant, but since my research is closer in that area I would have been interested to see more on the math side! Lectures on gravity would have also been interesting.
- Very useful, even for slightly more-advanced participants. (See below)
- The school was too advanced but it certainly makes you feel 5% smarter. Some of the theory lectures were highly relevant, useful, and complementary to my research.
- I loved the school and content. Having the diverse class body was very interesting to learn from different students given their different backgrounds and experience levels. I wish the school had more freetime though because I think interacting with the students and professors is the most important thing. Possibly structured social events could help students who are inclined to keep to themselves.

- The talks were useful even as a rising second year PhD student. Even with the amount of information I didn't understand, there was plenty that was relevant and digestible for my level.

Attachements:

- List of Students
- 2022 CTEQ School poster

Last Name	First Name	Institution
Alcerro Alcerro	Luis Fernando	University of Kansas
Ally	Daniel	University of Tennessee - Knoxville
Belvedere	Alberto	DESY
Billingsley	Sully	Southern Methodist University
Bolich	Jessica	University of Oklahoma
Brancaccio	Colomba	RWTH Aachen University
Cammarota	Justin	William & Mary
Carey	Sam	Wayne State University
Chen	Tinghua	Wichita State University
Clarke	Emma	Carnegie Mellon University
Delgado	Dylan	SUNY Buffalo
Dong	Zhongtian	University of Kansas
Fabry	Florian	DESY Hamburg - Theory Group
Falcao	Alexandre	University of Bergen
Fernez	Alex	University of Maryland
Figueiredo	Gustavo	Florida State University
Fiore	Gabriele	University at Buffalo
Garg	Diksha	The University of Iowa
Ge	Shiyuan	University at Buffalo
Ghira	Andrea	Università degli Studi di Genova
Gu	Tianping	University of Pittsburgh
Guadagni	Flavio	University of Zurich
Guglielmi	Valentina	DESY CMS
Haidet	Alex	Florida State University
Huang	Wenjie	University of Pittsburgh
Jentsch	Alexander	Brookhaven National Laboratory
Joshi	Bhargav	University of Minnesota
Kaladharan	Ajay	Oklahoma State University
Kapitanova	Lucia	University of Pittsburgh
Ke	Yan	Stony Brook University
Kim	Youngwan	Seoul National University
Klimenko	Valerii	University of Connecticut
Knauss	Matthew	William and Mary
Kotz	Lucas	Southern Methodist University
Kuschick	Mathias	Westfälische Wilhelms-Universität Münster
Léger	Chloé	LPSC Grenoble
Leys	Monica	University of Pittsburgh
Ma	Yang	University of Pittsburgh
Mangedarage	Mithila	Illinois Institute of Technology
McGovern	Bobby	University of Pennsylvania
Moos	Valentin	University of Regensburg
Mullins	Austin	Southern Methodist University
Murthy	Sindhu	Carnegie Mellon University
Nanda	Shirsendu	University of Illinois at Chicago
Navarro	Alberto	Oklahoma State University
Neuwirth	Alexander	Institut für Theoretische Physik, WWU Münste
Oh	Byunghun	Seoul National University
Osojnak	Lauren	University of Pennsylvania
Rainaldi	Tommaso	Old Dominion University
Redouane Salah	Essma	University of Msila
Roman	Irene	Florida State University
Sekhar	Sanjana	Johns Hopkins University
Shrestha	Utsav	University of Connecticut
Simon	Lukas	RWTH Aachen University
Simsek	Kagan	Northwestern University
Smylie	Matthew	The Ohio State University
Song	Qian	University of Pittsburgh
Thornberry	Benjamin	University of Tennessee, Knoxville
Wang	Erfei	University of Pittsburgh
Wang	Si	University of Pittsburgh
Youssef	Ahmed	University of Cincinnati

2022 CTEQ School

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

2022 CTEQ School
on
QCD and Electroweak Phenomenology
at the
University of Pittsburgh, PA, USA
06-16 July 2022

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
- Deeply Inelastic Scattering
- Vector Bosons / Direct Photons
- High Energy Jets
- Neutrinos

In-depth Analysis and Tutorials:
- Monte Carlo Introduction & Tutorial
- Machine Learning Techniques
- Higgs at Hadron Colliders
- Experimental Results from QCD/EWK/Top
- PDFs and Global Fits
- Dark Matter

Review of Applications Begins: 31 March 2022

Website: **www.cteq.org** E-mail: **cteq.school@gmail.com**

Sponsors: U.S. Department of Energy, National Science Foundation, Fermi National Accelerator Laboratory, MCnet, Pittsburgh Particle physics, Astrophysics, & Cosmology Center (PITT PACC)

Organizers: Brian Batell, Tao Han, Joni George, Ken Hatakeyama, Stefan Hoeche, Joey Huston, Cynthia Keppel, Huey-Wen Lin, Jorge Morfín, Pavel Nadolsky, Fred Olness, Paul Reimer, Ingo Schiengein, Dave Soper, George Sterman, Zack Sullivan, Doreen Wackeroth