SCET and HQET for the LHC: a Chinese Perspective

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QCD

low energy effective field theories (EFTs)

Isgur, Wise, Eichten, Hill, Georgi, …

HQET

SCET

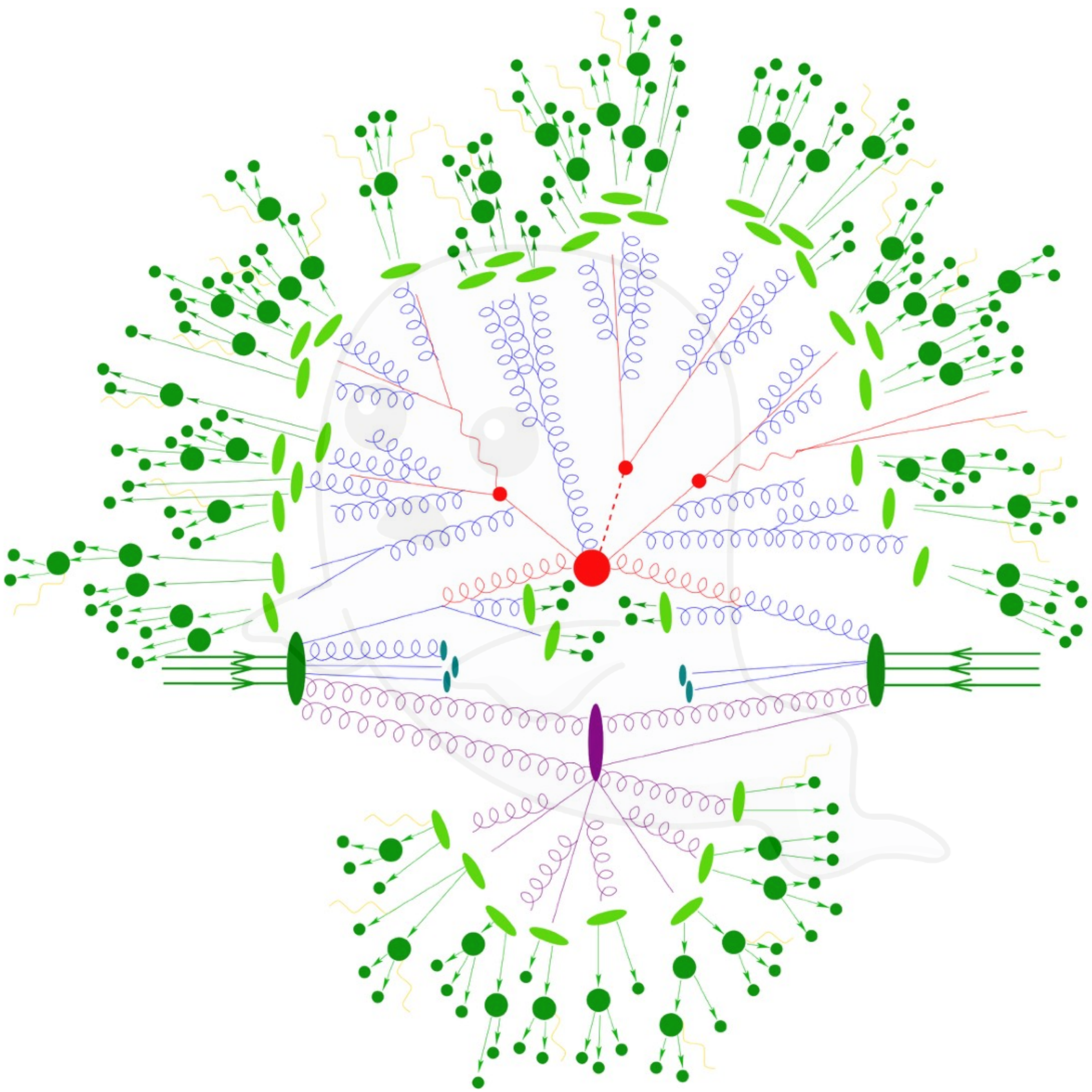
Bauer, Flemming, Pirjol, Stewart; Beneke, Chapovsky, Diehl, Feldmann; …

Important tools for proving **factorization formulas** and resumming **large logarithms**

Originally developed in charm and beauty physics

See plenary talk by Xinqiang Li

The LHC: a Logarithms-Haunted Collider



EFTs are useful!

- Higgs physics
- Top quark physics
- Jet physics
- Parton shower
- Parton distribution and fragmentation
- IR subtraction
- …

The story begins

PHYSICAL REVIEW D **66**, 014017 (2002)

Hard scattering factorization from effective field theory

Christian W. Bauer,[1,*] Sean Fleming,[2,†] Dan Pirjol,[1,‡] Ira Z. Rothstein,[2,§] and Iain W. Stewart[1,||]

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(Received 5 March 2002; published 31 July 2002)

In this paper we show how gauge symmetries in an effective theory can be used to simplify proofs of factorization formulas in highly energetic hadronic processes. We use the soft-collinear effective theory, generalized to deal with back-to-back jets of collinear particles. Our proofs do not depend on the choice of a particular gauge, and the formalism is applicable to both exclusive and inclusive factorization. As examples we treat the π-γ form factor ($\gamma\gamma^* \to \pi^0$), light meson form factors ($\gamma^* M \to M$), as well as deep inelastic scattering ($e^- p \to e^- X$), the Drell-Yan process ($p\bar{p} \to X l^+ l^-$), and deeply virtual Compton scattering ($\gamma^* p \to \gamma^{(*)} p$).

PHYSICAL REVIEW D **72,** 114020 (2005)

Transverse momentum resummation in soft collinear effective theory

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(Received 21 July 2005; published 27 December 2005)

We present a universal formalism for transverse momentum resummation in the view of soft-collinear effective theory (SCET), and establish the relation between our SCET formula and the well known Collins-Soper-Sterman's pQCD formula at the next-to-leading logarithmic order (NLLO). We also briefly discuss the reformulation of joint resummation in SCET.

PHYSICAL REVIEW D **73,** 074017 (2006)

Threshold resummation effects in direct top quark production at hadron colliders

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[2]*Center for High Energy Physics and Department of Physics, Tsinghua University, Beijing 100084, China*

(Received 21 February 2006; published 20 April 2006)

We investigate the threshold-enhanced QCD corrections to the cross sections for direct top quark productions induced by model-independent flavor changing neutral current couplings at hadron colliders. We use the soft-collinear effective theory to describe the incoming massless partons and use the heavy quark effective theory to treat the top quark. Then we construct the flavor changing operator based on the

Generic structure of infrared singularities

- Crucial property of Yang-Mills theory
- Massless parton scattering: understood at two loops and beyond
  Catani, Sterman, Tejeda-Yeomans, Aybat, Dixon, Becher, Neubert, Gardi, Magnea, …
- Massive(+massless) parton scattering
  - One-loop known since 2001 Catani, Dittmaier, Troscanyi
  - Two loops?

Universal two-loop IR

Utilizing SCET and HQET

PRL **103,** 201601 (2009) PHYSICAL REVIEW LETTERS week ending 13 NOVEMBER 2009

Two-Loop Divergences of QCD Scattering Amplitudes with Massive Partons

Andrea Ferroglia, Matthias Neubert, Ben D. Pecjak, and Li Lin Yang
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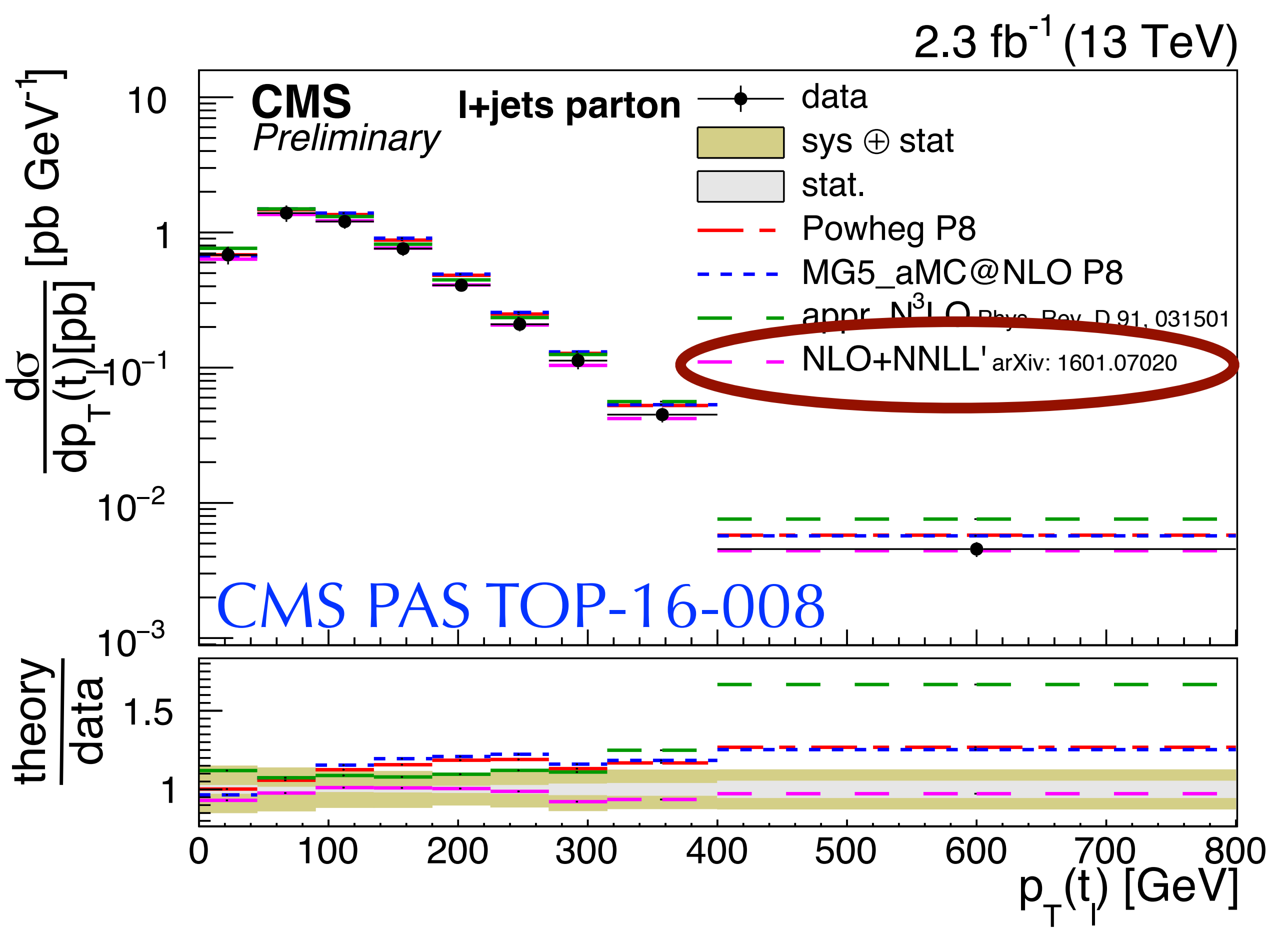
$$\begin{aligned}\Gamma = &\sum_{(i,j)} \frac{\boldsymbol{T}_i \cdot \boldsymbol{T}_j}{2} \gamma_{\rm cusp}(\alpha_s) \ln\frac{\mu^2}{-s_{ij}} + \sum_i \gamma^i(\alpha_s) - \sum_{(I,J)} \frac{\boldsymbol{T}_I \cdot \boldsymbol{T}_J}{2} \gamma_{\rm cusp}(\beta_{IJ}, \alpha_s) + \sum_I \gamma^I(\alpha_s) + \sum_{I,j} \boldsymbol{T}_I \cdot \boldsymbol{T}_j \gamma_{\rm cusp}(\alpha_s) \ln\frac{m_I \mu}{-s_{Ij}} \\ &+ \sum_{(I,J,K)} i f^{abc} \boldsymbol{T}_I^a \boldsymbol{T}_J^b \boldsymbol{T}_K^c \gamma_{hhh}(\beta_{IJ}, \beta_{JK}, \beta_{KI}) + \sum_{(I,J)} \sum_k i f^{abc} \boldsymbol{T}_I^a \boldsymbol{T}_J^b \boldsymbol{T}_k^c \gamma_{hhl}\Big(\beta_{IJ}, \ln\frac{-\sigma_{Jk} v_J \cdot p_k}{-\sigma_{Ik} v_I \cdot p_k}\Big).\end{aligned}$$

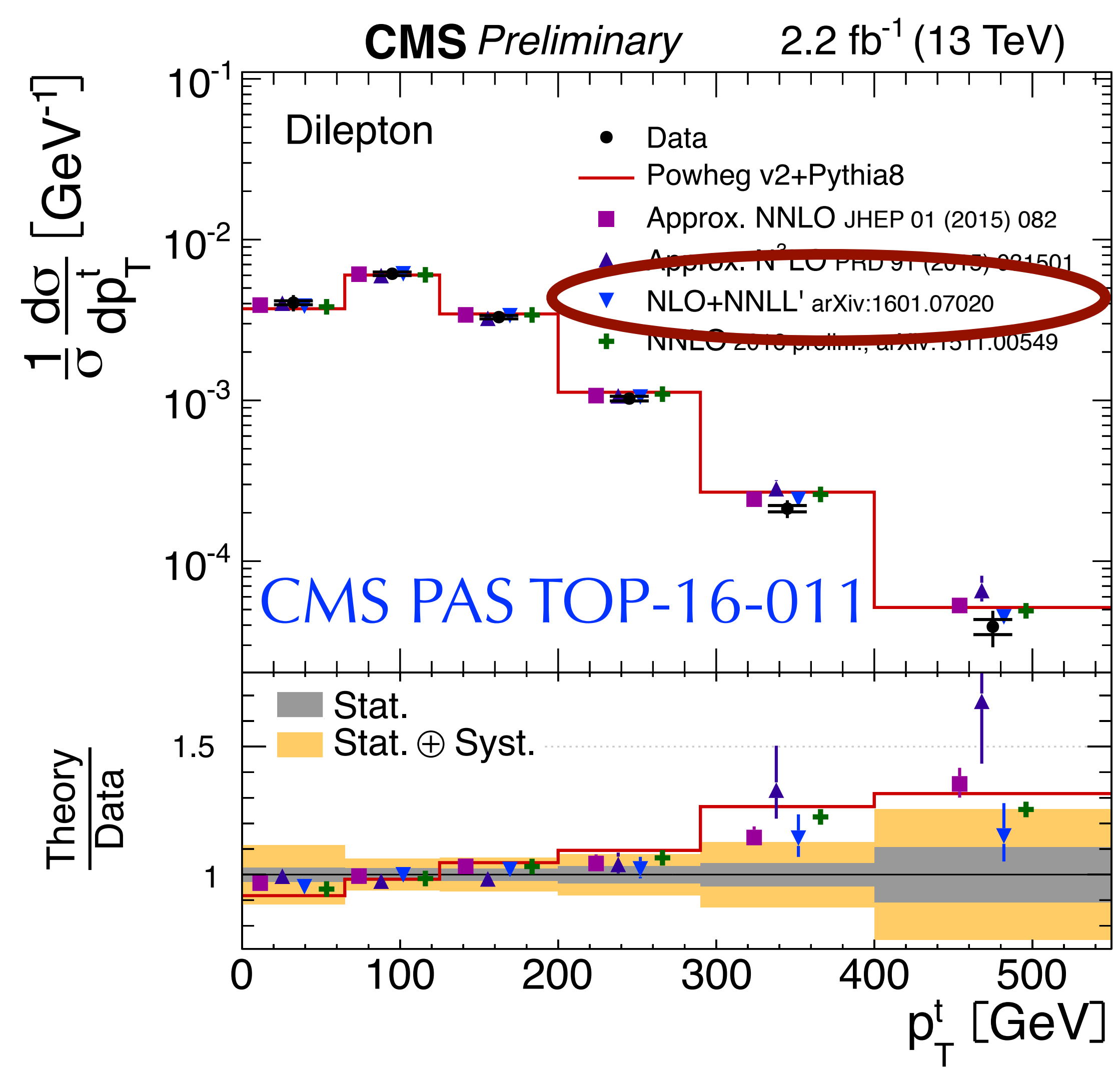
Important ingredient in NNLO calculations
for top quark pair production!

See also works by Mitov, Sterman, Sung

Resummation for top pairs

Ferroglia, Neubert, Pecjak, **LLY**: 0907.4791
Ahrens, Ferroglia, Neubert, Pecjak, **LLY**: 1003.5827; 1105.5824; 1106.6051
Ferroglia, Pecjak, **LLY**: 1205.3662; 1207.4798; 1306.1537
Pecjak, Scott, Wang, **LLY**: 1601.07020 and forthcoming

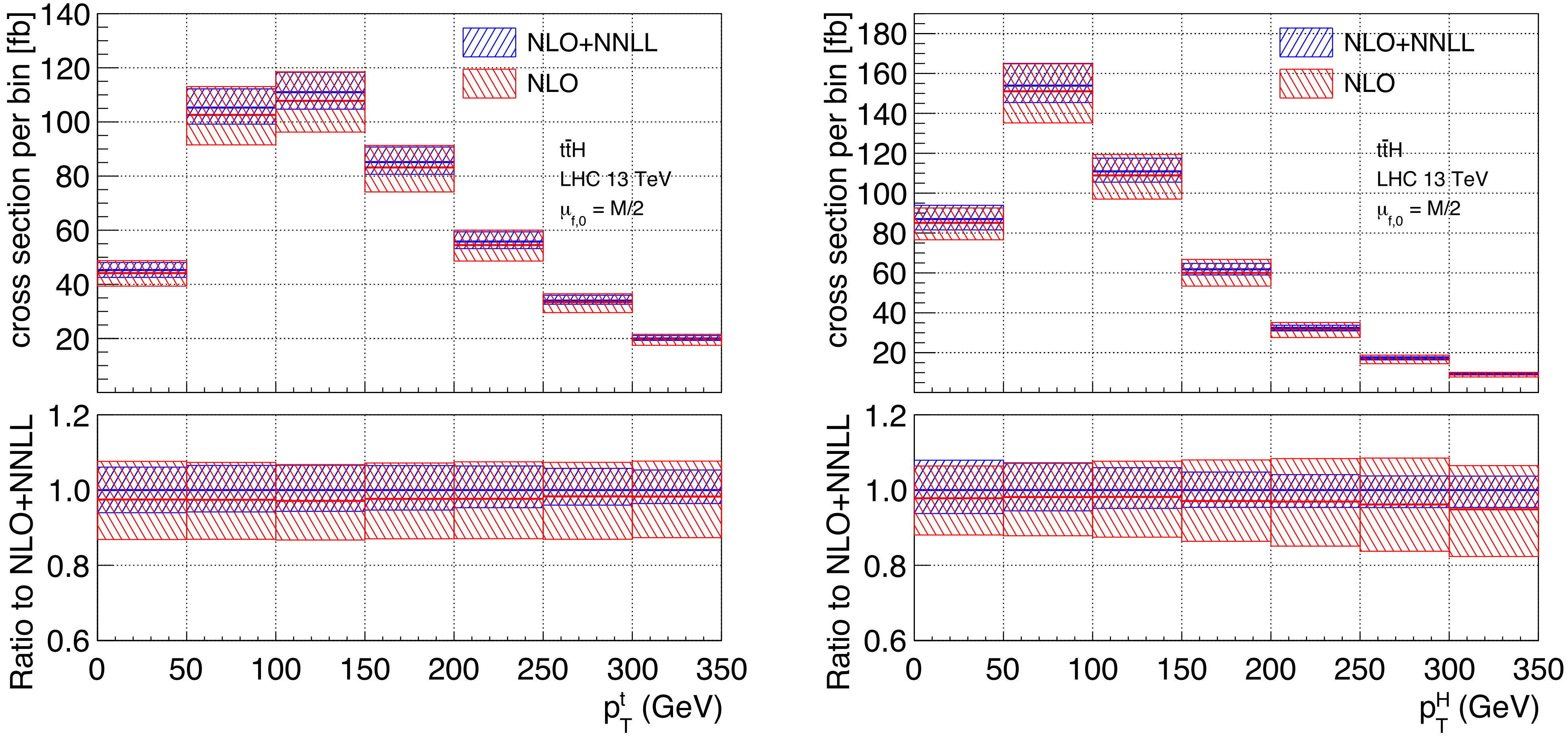




See talk by Xing Wang

Extend to ttH production

Broggio, Ferroglia, Pecjak, Signer,
LLY: 1510.01914, 1611.00049



Handbook of LHC Higgs cross sections:

4. Deciphering the nature of the Higgs sector

Report of the LHC Higgs Cross Section Working Group

A similar process

PHYSICAL REVIEW D **90**, 094009 (2014)

Renormalization group improved predictions for $t\bar{t}W^{\pm}$ production at hadron colliders

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Associated production of a top pair and a W boson at next-to-next-to-leading logarithmic accuracy

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[b]*Physics Department, New York City College of Technology, The City University of New York, 300 Jay Street, Brooklyn, NY 11201, U.S.A.*

[c]*The Graduate School and University Center, The City University of New York, 365 Fifth Avenue, New York, NY 10016, U.S.A.*

[d]*Institute for Particle Physics Phenomenology, Ogden Centre for Fundamental Physics, Department of Physics, University of Durham,*

JHEP09(2016)

Top pair p_T: new complications

Original formalism of Q_T resummation only works for colorless final states!

Collins, Soper, Sterman, Catani, de Florian, Grazzini, ...

New framework based on SCET and HQET, working for generic processes

PRL **110,** 082001 (2013) PHYSICAL REVIEW LETTERS week ending 22 FEBRUARY 2013

Transverse-Momentum Resummation for Top-Quark Pairs at Hadron Colliders

Hua Xing Zhu,[1,*] Chong Sheng Li,[1,2,†] Hai Tao Li,[1] Ding Yu Shao,[1] and Li Lin Yang[1,3,‡]
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(Received 4 September 2012; published 20 February 2013)

We develop a framework for a systematic resummation of the transverse momentum distribution of top-quark pairs produced at hadron colliders based on effective field theory. Compared to Drell-Yan and Higgs production, a novel soft function matrix is required to account for the soft gluon emissions from the final

Helping out NNLO calculations

EFT formalism provides new subtraction methods for NNLO calculations

PRL **110,** 042001 (2013) PHYSICAL REVIEW LETTERS week ending 25 JANUARY 2013

Top-Quark Decay at Next-to-Next-to-Leading Order in QCD

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PRL **116,** 212002 (2016) PHYSICAL REVIEW LETTERS week ending 27 MAY 2016

Charm-Quark Production in Deep-Inelastic Neutrino Scattering at Next-to-Next-to-Leading Order in QCD

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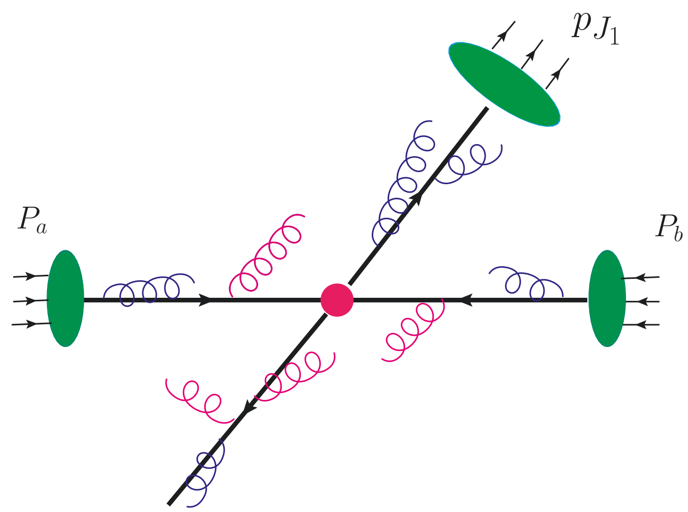
[2]*Department of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*
[3]*Center for High Energy Physics, Peking University, Beijing 100871, China*
[4]*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*

See plenary talk by Jun Gao

Also: N-jettiness subtraction etc.; see talk by Jian Wang

Jet physics



Resummation prediction on the jet mass spectrum in one-jet inclusive production at the LHC

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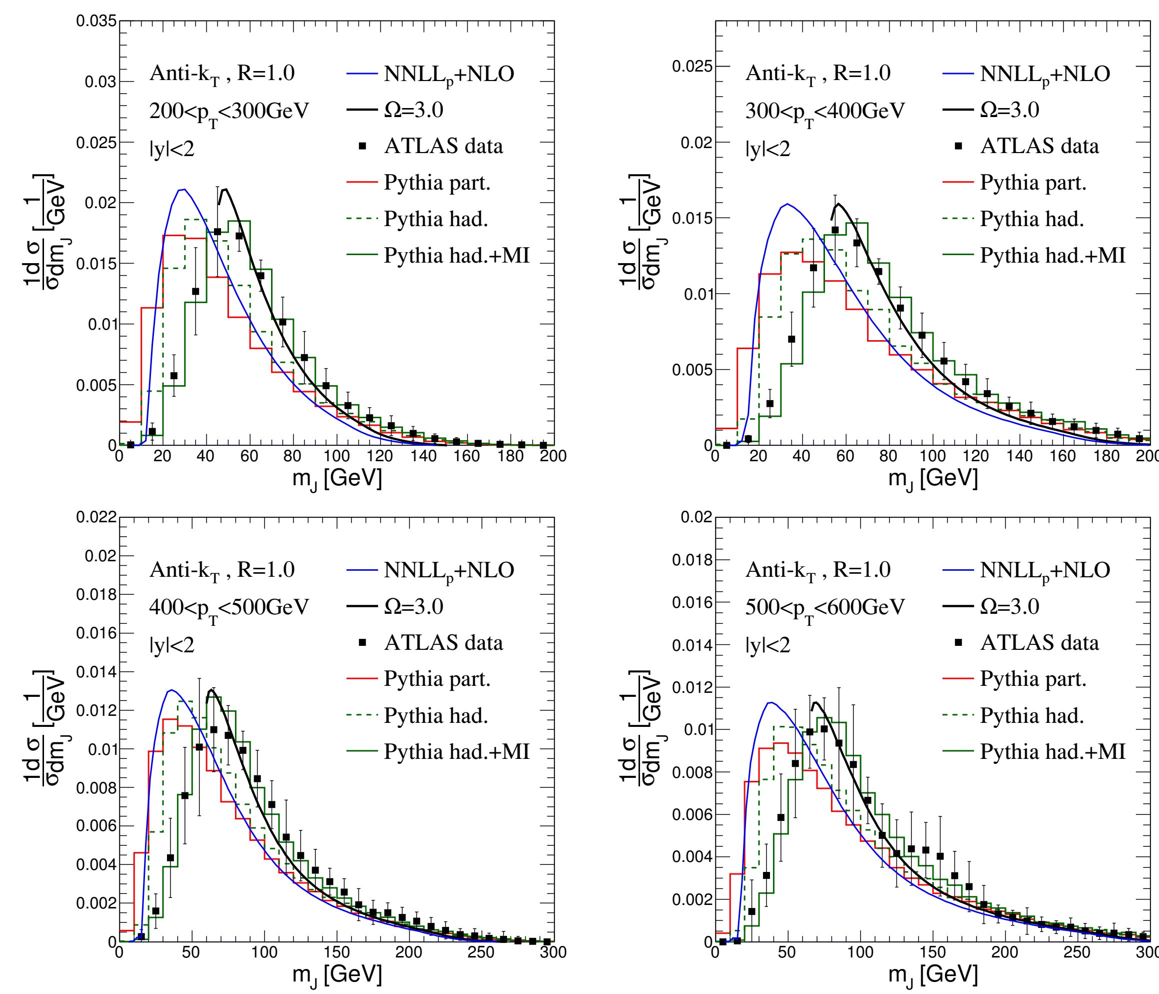
[b] *Center for High Energy Physics, Peking University,*



See also talk by Dingyu Shao

Summary

- SCET and HQET have become indispensable tools for LHC physics
- Notable contributions from Chinese physicists in various aspects: top quark physics, Higgs physics, jet physics, …
- Keep working!

Thank you for listening and happy 70th birthday to Prof. Chong Sheng Li!