Topical Group TF06: Theory Techniques for Precision Physics

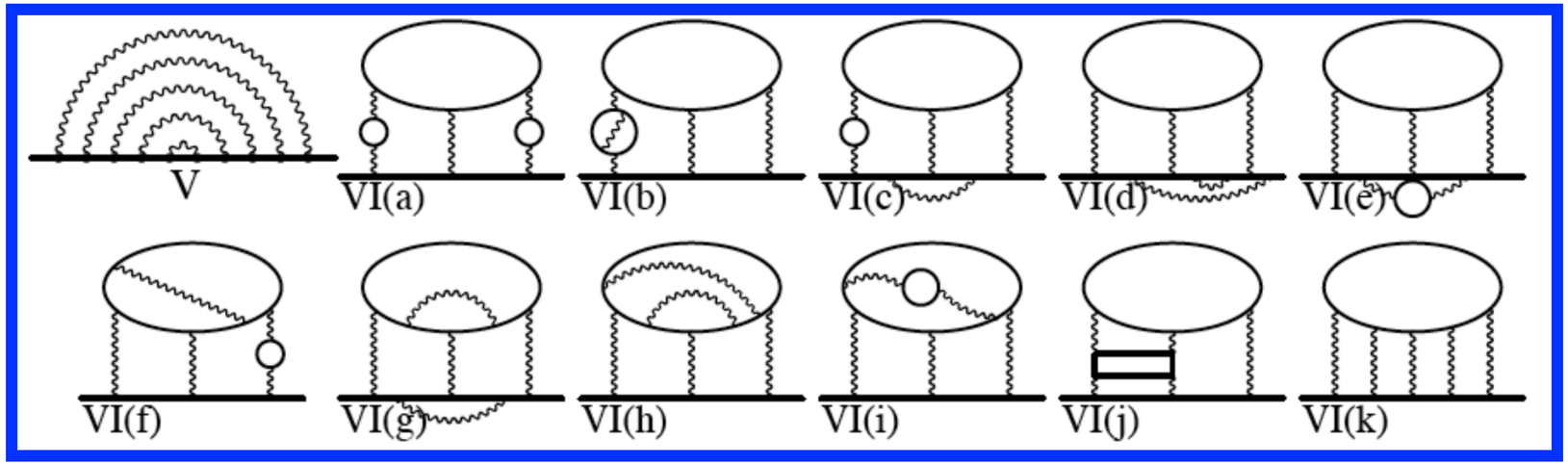
Co-conveners: Radja Boughezal (ANL), Zoltan Ligeti (LBNL)
https://snowmass21.org/theory/precision

Radja Boughezal

Snowmass 2021 Planning, Theory Frontier Town Hall Meeting, July 30, 2020

Precision theory

- Precision theory has a dual role in HEP: leads to new ideas that motivate experimental studies, and supports the experimental program in its search for BSM
- Inherently multidisciplinary: ties together advanced mathematics and high-performance computing with HEP theory and experimental measurements
- Precision theory has motivated experiments: an example is the electron and muon g-2s. These experiments were originally motivated by Schwinger's calculation of the QED radiative corrections.



Now known at the level of 5-loop QED, together with electroweak and hadronic effects

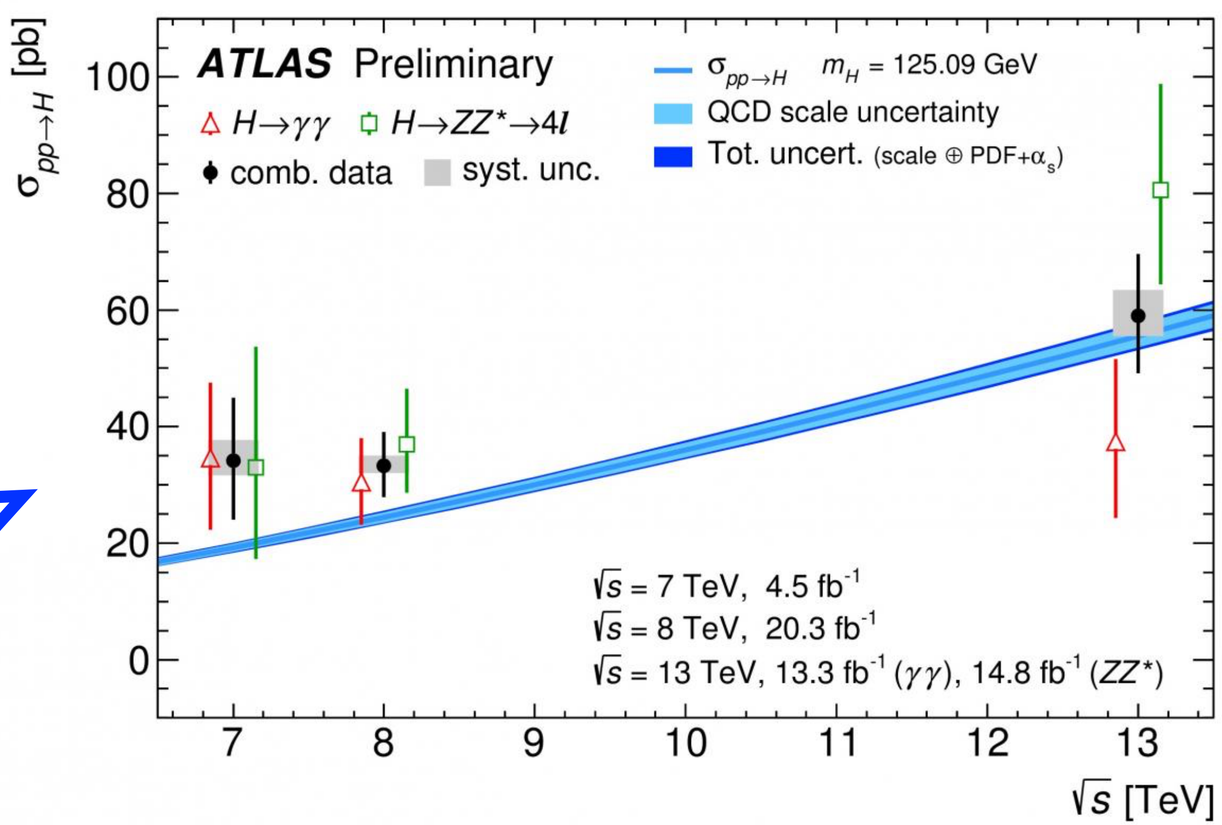
Precision predictions

- All aspects of theory need to be controlled for a precision prediction which can be reliably compared with data

Electroweak corrections @ 2loops

PDFs @ NNLO

Higgs production cross section as an example

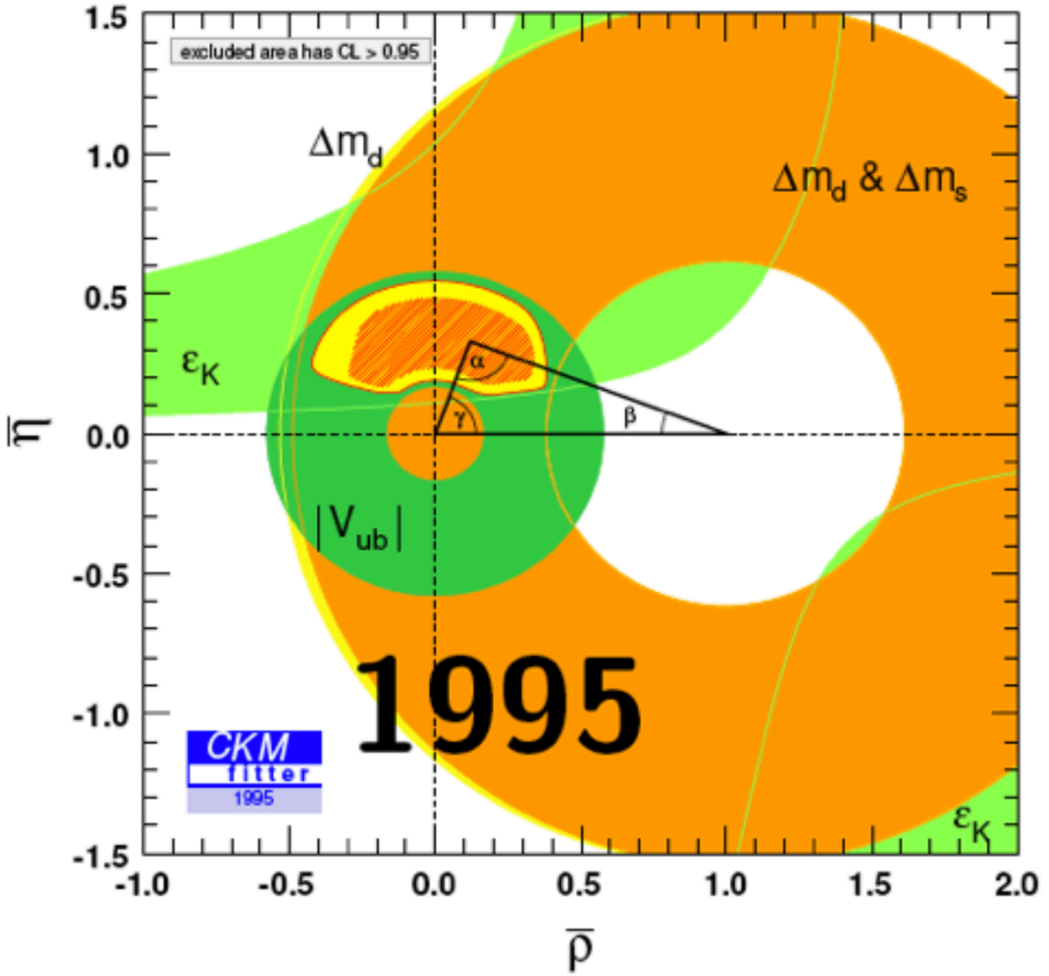


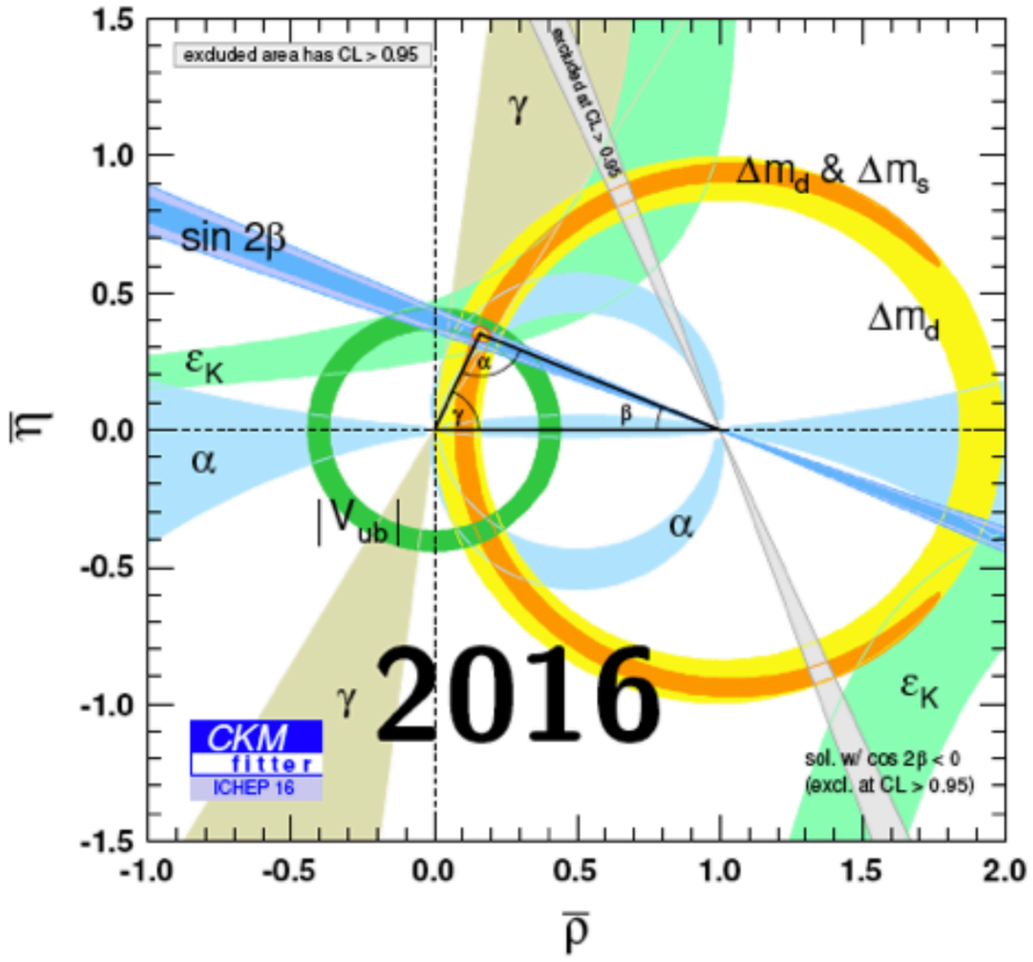
QCD@N^{3}LO

Precision extraction of αs

Flavor physics and precision

- Evolution of flavor physics measurements has sharpened our picture of the SM Yukawa sector





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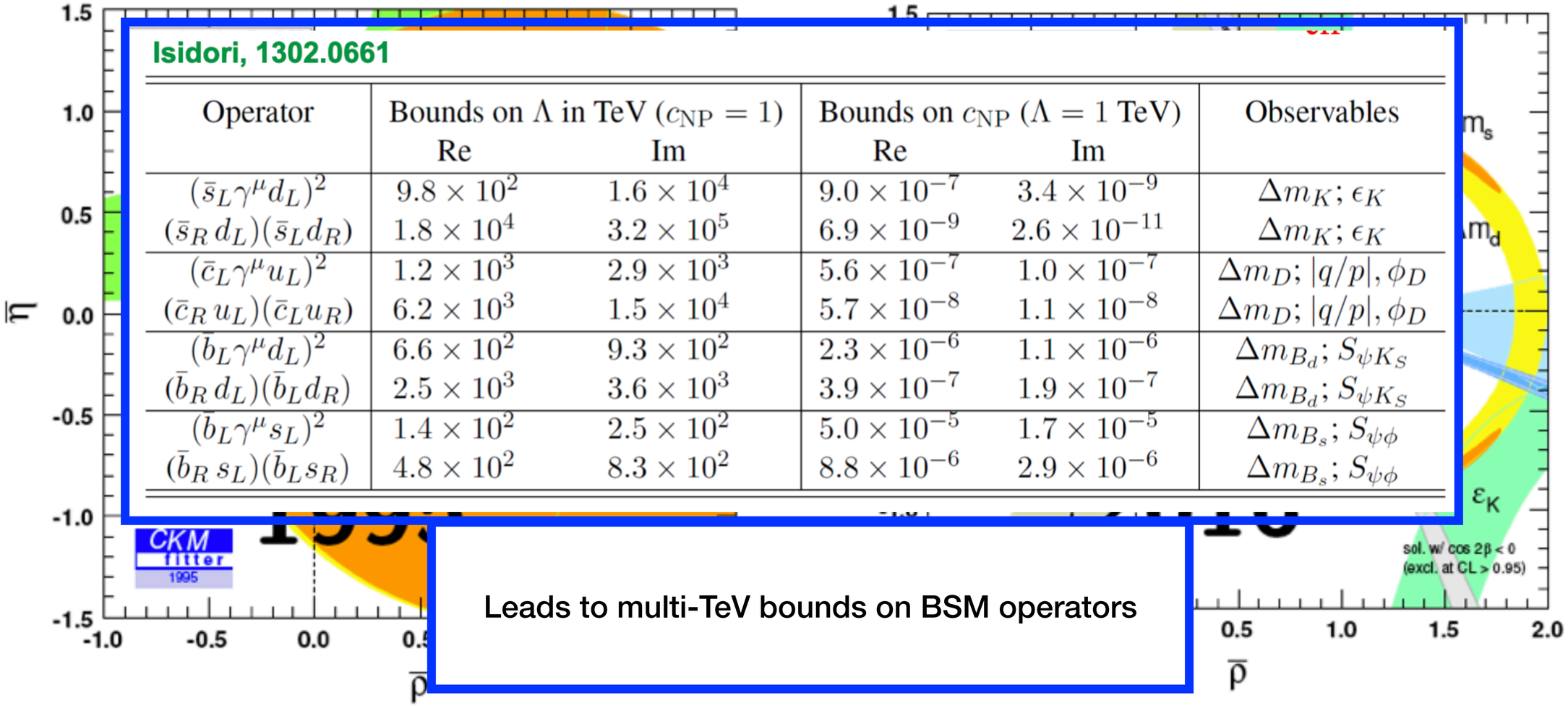

Isidori, 1302.0661

Operator	Bounds on Λ in TeV ($c_{\rm NP}=1$) Re	Im	Bounds on $c_{\rm NP}$ ($\Lambda=1$ TeV) Re	Im	Observables
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	$\Delta m_K;\ \epsilon_K$
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	$\Delta m_K;\ \epsilon_K$
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	$\Delta m_{B_d};\ S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	$\Delta m_{B_d};\ S_{\psi K_S}$
$(\bar{b}_L\gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	$\Delta m_{B_s};\ S_{\psi\phi}$
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	$\Delta m_{B_s};\ S_{\psi\phi}$

Leads to multi-TeV bounds on BSM operators

TF06 focus

- The Theory Frontier is a new addition to the Snowmass planning process, with a goal to articulate recent advances and future opportunities in all aspects of theory relevant to HEP

- Within this context, TF06 will survey theoretical techniques developed to meet precision demands of current and planned experiments in the energy and intensity frontiers. We would also like to discuss novel theoretical developments that may open the door to new levels of theoretical understanding. We have identified several initial broad discussion topics:

TF06 focus

- **Effective field theories of QCD:** our focus will be on Soft-Collinear-Effective-Theory (SCET)
  - Formal aspects of SCET
  - New collider observables
- **Multi-loop techniques:** a vital field with connections to the study of amplitudes and mathematics.
  - New mathematical structures
  - Calculational techniques
- **Next-to-next-to-leading order and beyond:** for many core processes the precision frontier is evolving from NNLO to N3LO and extensions of the current theoretical techniques are critical to achieve results that allow an incisive comparison with data.
  - Extension of IR subtraction schemes to N3LO
  - Calculation of the relevant amplitudes.
- **Flavor physics:** its precision understanding leads to strong multi-TeV bounds on models of new physics
  - Rare decays
  - CP violation
  - Light sector searches

TF06 focus

- **Theoretical improvements in Monte Carlo event generators:** accurate MC tools are important for a realistic description of hadronic final states
  - Current improvements in perturbative matching and merging techniques
  - Improved description of non-perturbative effects
  - Interplay of resummation accuracy with parton shower algorithms
- **Standard Model Effective Field Theory (SMEFT):** an important EFT framework in which future precision measurements maybe interpreted.
  - Study of proposed methods for estimating theory uncertainties in this framework
  - Impact of dim-8 operators at the HL-LHC and potential complementary constraints from future colliders such as the EIC
- **Non-perturbative effects in high energy collisions:** an important topic to discuss due to the rapid improvements in the experimental precision which made previously negligible effects relevant at high energies.
  - Power corrections in EFTs
  - Hadronization in Monte Carlo event generators

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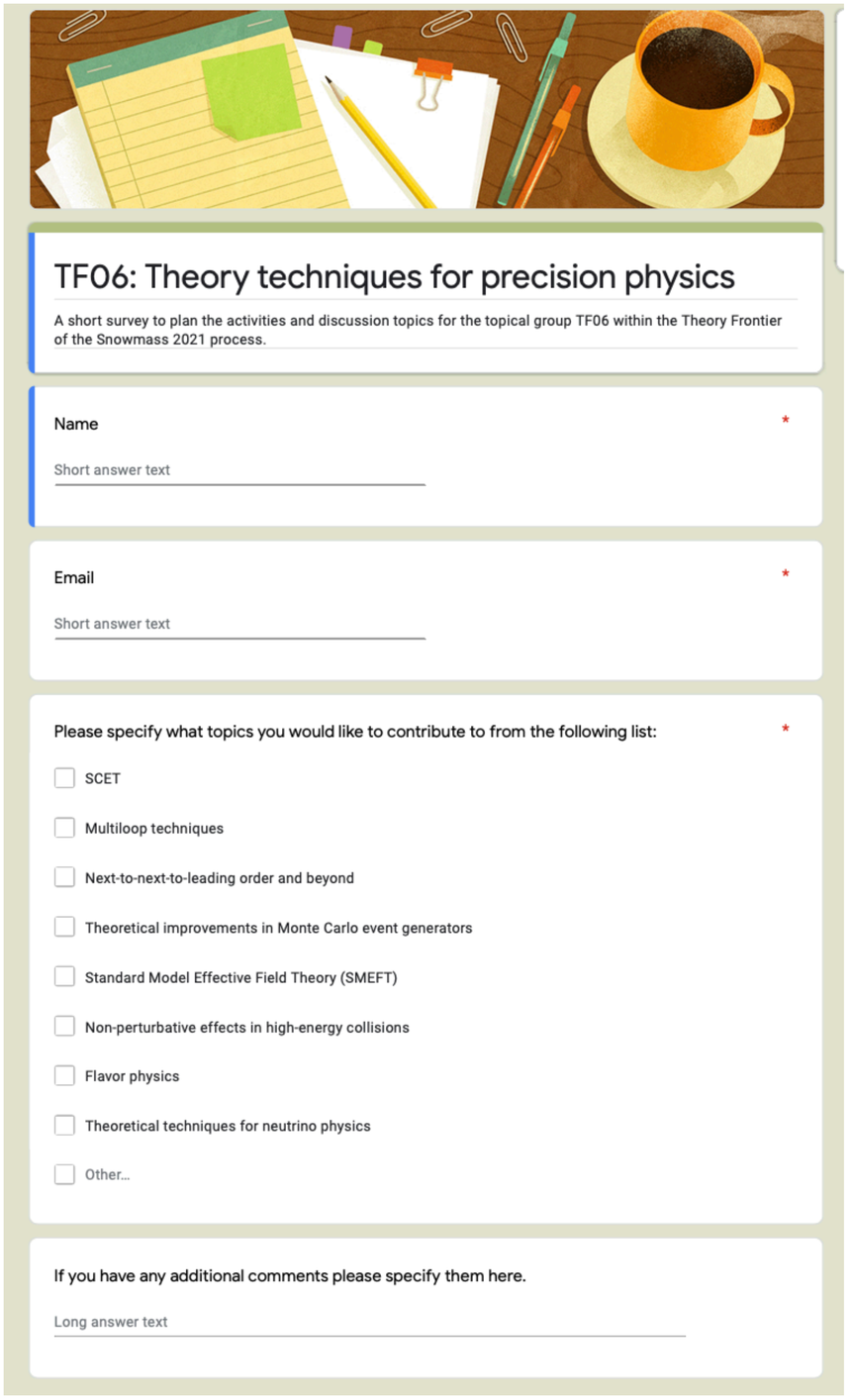
These were few proposed discussion directions. Please feel free to add other topics of interest that fit within the scope of our topical group!

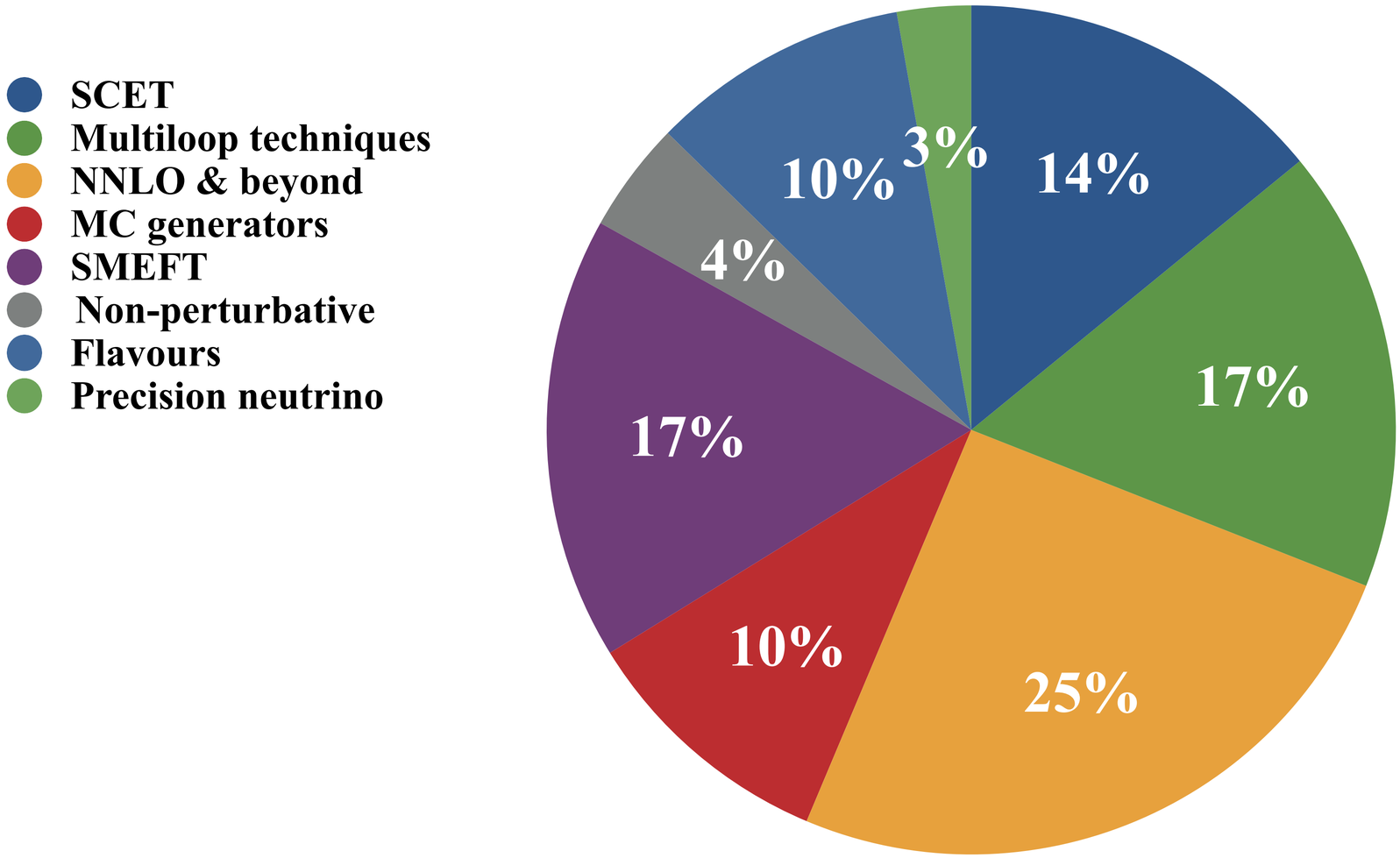
TF06 survey of interests

- In order to facilitate receiving your feedback we have created a short survey: https://tinyurl.com/Snowmass-TF06
- We thank all of those who provided their feedback. The survey is still open if you wish to send us your thoughts or provide additional feedback



TF06 survey results

- 50 expressions of interest in contributing to TF06, and 32 survey responses:



Communication

- Join our topical group mailing list to stay informed about future meetings and updates. Please send an email to listserv@fnal.gov with a blank subject line and the following text in the body of your message:
  SUBSCRIBE SNOWMASS-TF-06-PRECISION FirstName LastName

- We will post updates and we will be happy to receive your questions and participate in discussions through our slack channel: tf06-precision

- To stay informed about the Theory Frontier meetings and news, please join the mailing list: SNOWMASS-THEORY-FRONTIER-GROUP. More relevant information about the Theory Frontier structure and details can be found on the corresponding Snowmass 2021 wiki page: https://snowmass21.org/theory/start

How to contribute to TF06 activities

- Submit a **letter of interest (LOI)** to propose a topic that should be discussed as part of the Snowmass exercise. It will help us organize our activities and know what Snowmass white paper contributions to expect. LOIs should be up to 2 pages in length. Submission instructions and more details can be found in the following link: https://snowmass21.org/loi

- If you would like to give a presentation on a suggested topic for inclusion in TF06 activities, please let us know

- **Contributed papers:** they may include white papers that review specific scientific areas or technical articles presenting new results on relevant physics topics. They will remain part of the permanent record of Snowmass 2021. The deadline for a contributed paper is July 31, 2021. Submission details can be found in: https://snowmass21.org/submissions/start

TF06 kick-off meeting agenda

- We’re happy to have a variety of talks on several topics that we’d like to cover in TF06

- **Introduction to TF06 (R. Boughezal and Z. Ligeti)**
- **Mathematics of multi-scale loop integrals (S. Weinzierl)**
- **Precision jet physics at the LHC and the EIC (X. Liu)**
- **The push to the N3LO frontier (C. Duhr)**
- **Status of CP violation (Y. Grossman)**
- **Monte Carlo event generators (S. Hoeche)**
- **Theoretical uncertainties inherent in the SMEFT (W. Shepherd)**
- **Rare processes and precision (W. Altmannshofer)**
- **Prospects in precision neutrino interactions (O. Tomalak & R. Hill)**

Conclusions

- The success of the Snowmass planning process relies heavily on your contributions and engagement. You are welcome to contribute your work and thoughts individually or as a collaboration
- This is a global effort, we welcome contributions from U.S. and non-U.S. based scientists
- Theory has always been a vital part of high energy physics and it is important that we emphasize the progress made by our community and its impact on and relevance to the current and future HEP program
- Looking forward to your contributions!