

Theory Frontier Planning Session @ Snowmass CPM

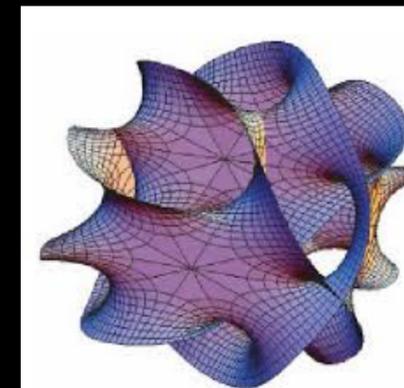
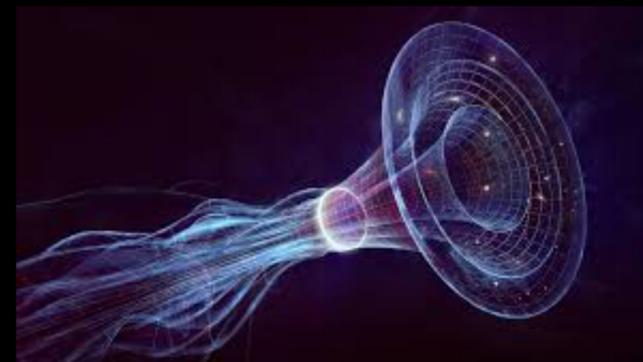
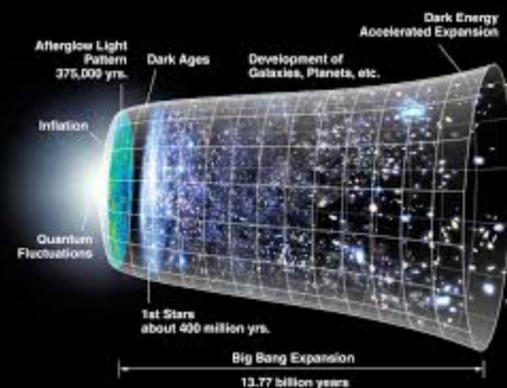
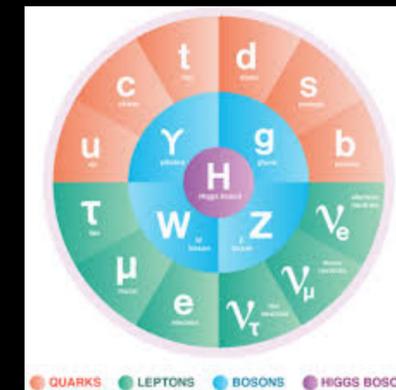
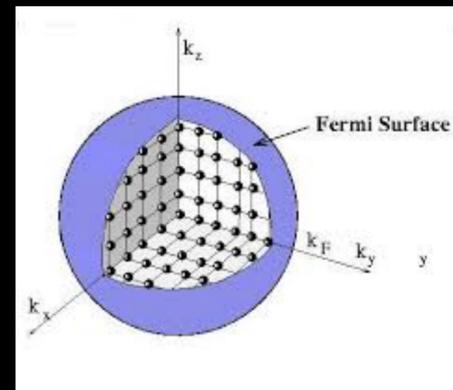
Introduction and status reports from the Topical Groups

Csaba Csaki, October 7, 2020

TF01: String theory, quantum gravity, black holes

(Conveners: Daniel Harlow, Juan Maldacena & Shamit Kachru)

The topic offers broad scope:



Accordingly, we have divided it into six sub-topics, in each of which we are “commissioning” a white paper:

<https://snowmass21.org/theory/string>

- Quantum aspects of black holes and the emergence of spacetime
- New ideas for many-body quantum systems from string theory and black holes
- String theory and particle physics: compactification and unification
- String theory and early universe: conceptual and phenomenological questions
- New ideas in classical gravity from quantum fields and strings
- New discoveries in mathematics from string theory and quantum field theory

We anticipate significant overlap with topics covered by e.g. TF03, TF09, TF10,...and are planning accordingly with those co-conveners.

TF02: Effective field theory techniques

Patrick Draper and Ira Rothstein conveners

Primary focus: foundations of EFT, developing new EFTs, novel applications

Many relevant topics, including

- SCET
- SMEFT
- Naturalness/Hierarchy problems
- Swampland/WGC
- EFTs from Amplitudes
- Connections to CMT
- Generalized symmetries
- EFT for inflation
- EFT for Dark Matter
- NRGR

EFT is a broad topic relevant for many other **TF topical groups** and **Project Frontiers**.

TF02: Effective field theory techniques

- Solicited 7 whitepapers & community input
- Cross-listed in 23 LOIs
- Co-organizing 3 breakout sessions at CPM (SMEFT, gravitational waves, formal theory)

Going forward:

- Respond to community expressions of interest to expand whitepaper solicitations
- Organize sessions @ TF meeting
- Connect whitepaper writers to counterparts in other relevant TGs and frontiers
- Summary document will emphasize importance of foundational EFT research and synergies with many branches of HEP

TF03: CFT and formal QFT

David Poland and Leonardo Rastelli

- CFT, conformal bootstrap, and related ideas; including interfaces with the S-matrix bootstrap and quantum gravity/string theory via holography
- SUSY in various dimensions; including exact results, localization, integrability, decoupling limits of string theory
- IR phases, topological QFT; including generalized symmetries, interfaces with condensed matter, and related aspects of entanglement
- General nonperturbative methods in QFT; including resurgence, truncation methods, functional RG, dualities, interface with lattice QFT
- Interfaces between QFT and quantum information; including entanglement structure of QFTs, information-theoretic approaches to c-theorems, QNEC
- Interfaces between QFT and mathematics

TF03: CFT and formal QFT

David Poland and Leonardo Rastelli

Working to solicit whitepapers (*=confirmed) on:

- *Superconformal Field Theories
- Bootstrap (*Numerical/*Analytic/S-Matrix/Strings)
- *Generalized Symmetries and IR Phases
- Integrability (* $\overline{\text{TT}}$ /N=4 SYM)
- Resurgence
- New Large-N Limits
- Large Charge Expansion
- Entanglement in QFT
- Moonshine
- Open Questions in Mathematical Physics

Relevant LOIs:

- Lattice Field Theory for Conformal Systems
- Perturbative Calculations of Anomalous Dimensions in CFTs

Relevant Breakout Sessions:

- 105: The Reach of Formal Theory
- 84: Computing Requirements & Opportunities in Theory
- 124: Lattice Gauge Theory

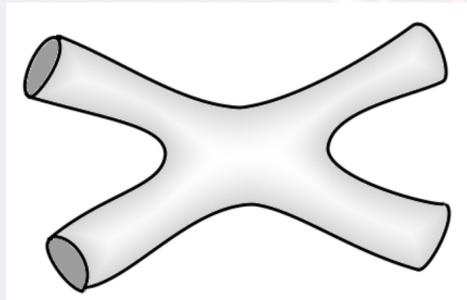
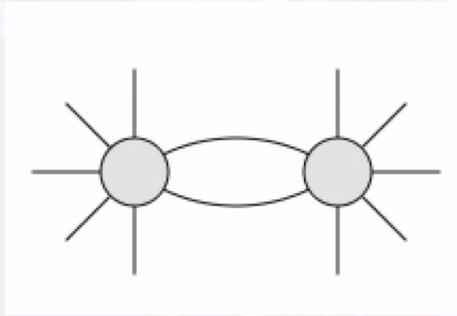
Future

- Theory Frontier Meeting

TF04: Scattering amplitudes

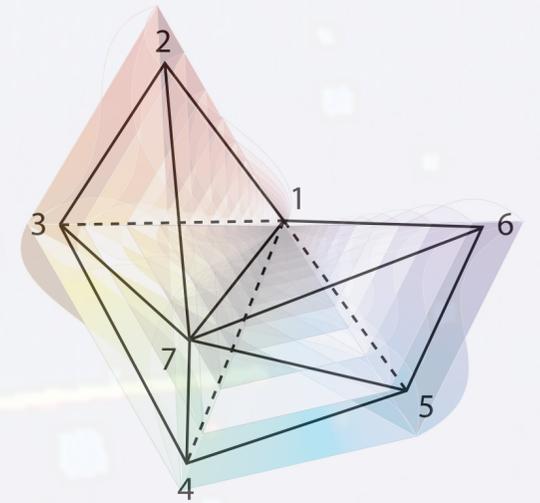
Conveners: Zvi Bern, Jaroslav Trnka

<https://snowmass21.org/theory/scattering>



Motivations:

- Develop new efficient methods to calculate amplitudes
- Apply to important physical problems - LHC, gravitational physics
- Use S-matrix as a probe to study new structures in quantum field theory



Subtopics to be explored:

- Analytic properties of perturbative scattering amplitudes
- Efficient methods to construct scattering amplitudes in general quantum field theories
- Geometric picture for amplitudes: Amplituhedron, cluster algebras, hexagon bootstrap, symbols.
- Connections to string theory, CHY constructions.
- Color-kinematics duality, construction of gravity multi-loop integrands.
- New applications of amplitude methods to LIGO physics and to Standard Model Effective field theory.

TF04: Scattering amplitudes

Snowmass activity so far:

15 LOIs submitted to TF04

Color-Kinematics Duality, Double-Copy Construction, and the Web of Theories:
Letter of Interest for Snowmass 2021

Solving Scattering in $\mathcal{N} = 4$

Snowmass2021 Letter of Interest
Amplitudes Beyond

Kurt Hinterbichler,^{a,*} Mar
James Bonifacio,^{a,†} Garrett Goon
Riccardo Penco,^{c,e,||} and Ra

We highlight a continuing program of research into
super-Yang-Mills theory, for its intrinsic understanding and

Snowmass2021 - Letter of Interest

On-Shell Methods for the SMEFT

Thematic Areas:

(TF02) Effective field th
(TF04) Scattering amp
(TF06) Theory techniqu
(TF07) Collider phenom

Contact Information

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Functions Beyond Polylogarithms in Scattering Amplitudes

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Solicited 9 white papers

1. **Bootstrapping N=4 sYM.** Coordinator: Lance Dixon (SLAC)
2. **Positive geometry of scattering amplitudes.** Coordinator: Nima Arkani-Hamed (IAS)
3. **Effective field theories and amplitudes.** Coordinator: Henriette Elvang (Michigan)
4. **Amplitudes and Gravitational waves.** Coordinator: Radu Roiban (Penn State)
5. **The double copy and its applications.** Coordinator: John Joseph Carrasco (Northwestern)
6. **Amplitudes and SMEFT.** Coordinator Julio Parra-Martinez (UCLA)
7. **Functions Beyond Polylogarithms in Scattering Amplitudes.** Coordinator: Andrew McLeod (NBI)
8. **Precision collider Physics.** Coordinator: Fernando Febres Cordero (FSU)
9. **Amplitudes beyond GR.** Coordinator: Mark Trodden (U Penn), Kurt Hinterbichler (Case Western)

This meeting

**#92: Non-perturbative QCD
dynamics at colliders**

**#128: From Amplitudes to Precision
Theory for Future Colliders**

**#141: Gravitational wave source
modelling**

Interested?

Slack channel: #tf04-amplitudes

Email list:

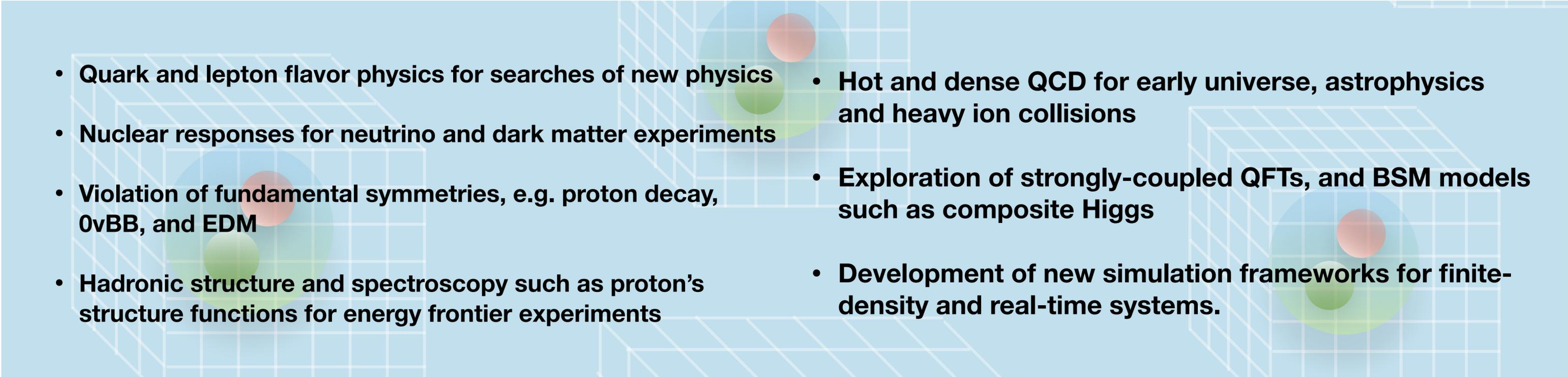
SNOWMASS-TF-04-AMPLITUDES@fnal.gov

THANK YOU!

TF05: Lattice gauge theory

Zohreh Davoudi, Ethan Neal and Taku Izubuchi conveners

- **LGT:** Numerical non-perturbative methods for reliable calculations in strongly-coupled quantum field theories. Provides *ab initio* predictions for processes involving QCD.
- Strong overlap with a number of topics in various frontiers, primarily in EF, RF, NF, and CompF, as well as other topical areas in the TF. Received ~60 LOI as primary or secondary listing.
- Subtopics that are being considered:

- 
- Quark and lepton flavor physics for searches of new physics
 - Nuclear responses for neutrino and dark matter experiments
 - Violation of fundamental symmetries, e.g. proton decay, $0\nu\beta\beta$, and EDM
 - Hadronic structure and spectroscopy such as proton's structure functions for energy frontier experiments
 - Hot and dense QCD for early universe, astrophysics and heavy ion collisions
 - Exploration of strongly-coupled QFTs, and BSM models such as composite Higgs
 - Development of new simulation frameworks for finite-density and real-time systems.

TF05: Lattice gauge theory

- Topical group activities so far:
 - Town hall meeting on 7/30, ~35 members of the community attended. Mainly organizing for the LOI process.
 - Parallel session #124 yesterday, 10/6 on “Lattice Gauge Theory for High Energy Physics”, and presence in sessions #40, #41 and #84.
 - Not a TF05 activity, but a [recent set of whitepapers](#) was written by the USQCD collaboration [the largest community of lattice-gauge theorists in the U.S.], titled “Opportunities for Lattice Gauge Theory in the Era of Exascale Computing” [[The European Physical Journal A](#) volume **55** (2019)]. TF05 whitepaper production process will focus on complementing, expanding, and updating this work.
- Coming up:
 - Initial talks for a joint TF05/TF10/TF11/EF05/EF06/EF07/NF06/RF01/RF03/RF7/CompF02/Comp03/CompF06 one-week workshop on “Lattice Gauge Theories: new goals, new opportunities, new tools” in late fall/early winter to coordinate Snowmass targeted studies.
 - Joint RF01/TF05/TF06 workshop on determinations of $|V_{ub}|$ and $|V_{cb}|$ in mid-November
- Information channels:
 - Join the mailing list SNOWMASS-TF-05-LGT@FNAL.GOV and the Slack channel **#tf05-lattice** for further announcements!

TF06: Theory techniques for precision physics

Conveners: Radja Boughezal and Zoltan Ligeti

- 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 new physics.
- Inherently **multidisciplinary**: ties together advanced mathematics and high-performance computing with HEP theory and experimental measurements.
- **Focus of TF06**: survey theoretical techniques that enable current and planned precision measurements; discuss novel theoretical developments that may open the door to new levels of theoretical understanding.

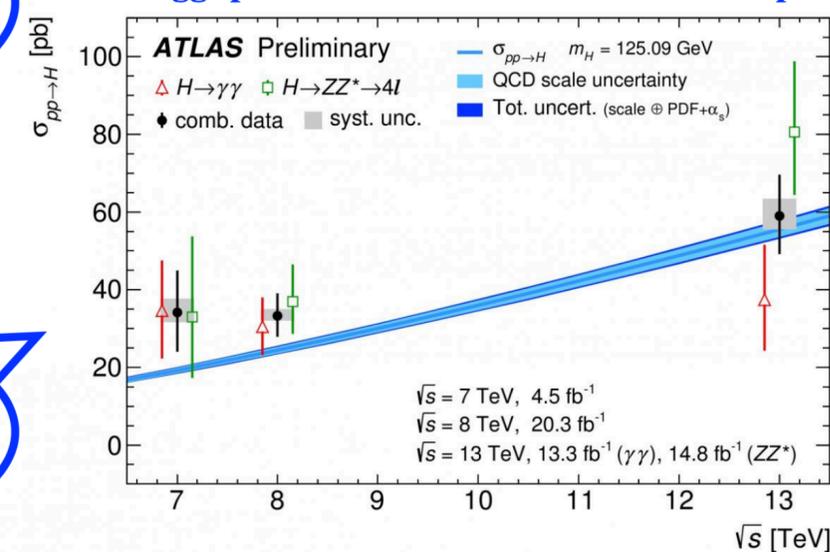
Topics:

- Effective field theories of QCD (in particular SCET)
- Next-to-next-to-leading order and beyond
- Flavor physics (rare decays, CP violation, ...)
- Theoretical improvements in Monte Carlo event generators
- Standard Model Effective Field Theory (SMEFT)

Electroweak
corrections @
2loops

PDFs @ NNLO

Higgs production cross section as an example



QCD@N³LO

Precision
extraction of α_s

TF06: Theory techniques for precision physics

- **LOI status:**
 - We have received 36 LOIs covering all proposed TF06 research directions.
 - 21 of them are TF06-led; most were solicited.
 - We will encourage their expansion into full Snowmass white papers through future topical meetings and breakout sessions during organized Snowmass events.
- **Organized meetings:**
 - Breakout session with invited review talks during the TF kickoff meeting to encourage LOIs
 - CPM session #125 "EFTs for new physics sensitivity"
 - CPM session #128 "From amplitudes to precision theory for future colliders"
 - CPM session #41 "Anomalies in flavor physics"
- **Future plans:**
 - Planned joint workshop with RF01/TF05/TF06 on precision CKM extractions in November.
 - After the CPM we will assess the situation and decide what other meetings are needed.
 - TF meeting in March 2021.

TF07: Collider phenomenology



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● Mailing list:

SNOWMASS-TF-07-COLLIDER_PHENO@fnal.gov

● Slack channel: [#tf07-collider](#)

Major Topics

<https://snowmass21.org/theory/phenomenology>

- Illustrate **exciting new directions** in collider phenomenology
- Establish **key connections** between cutting-edge theoretical advances and current and future experimental opportunities
- Identify the **most promising avenues** where major theory breakthroughs could take place in the coming years, which could lead to transformative concepts and techniques in collider phenomenology.

TF07: Collider phenomenology

What has happened so far?

- LOI: 10 TF07 lead LOIs, many cross listing LOIs
- Expression of interest: <https://docs.google.com/forms/d/1FSrSofOVgWi72QX9s-n5k46szQJKVd4KcTnJ42DtmnM>
- Contacted theorist conveners in other frontier coordinating activities
- Small meetings: [EW effects @ High energy, Sep 15](#)
- Breakout sessions @CPM
 - # 26: Energy frontier discovery machines
 - # 92: Non-perturbative QCD dynamics at colliders
 - # 99: Advances in event generation and detector simulation
 - # 126: BSM: direct and indirect searches
 - # 129: Higgs factories
 - # 132: Collider data analysis strategies

Plans for the future

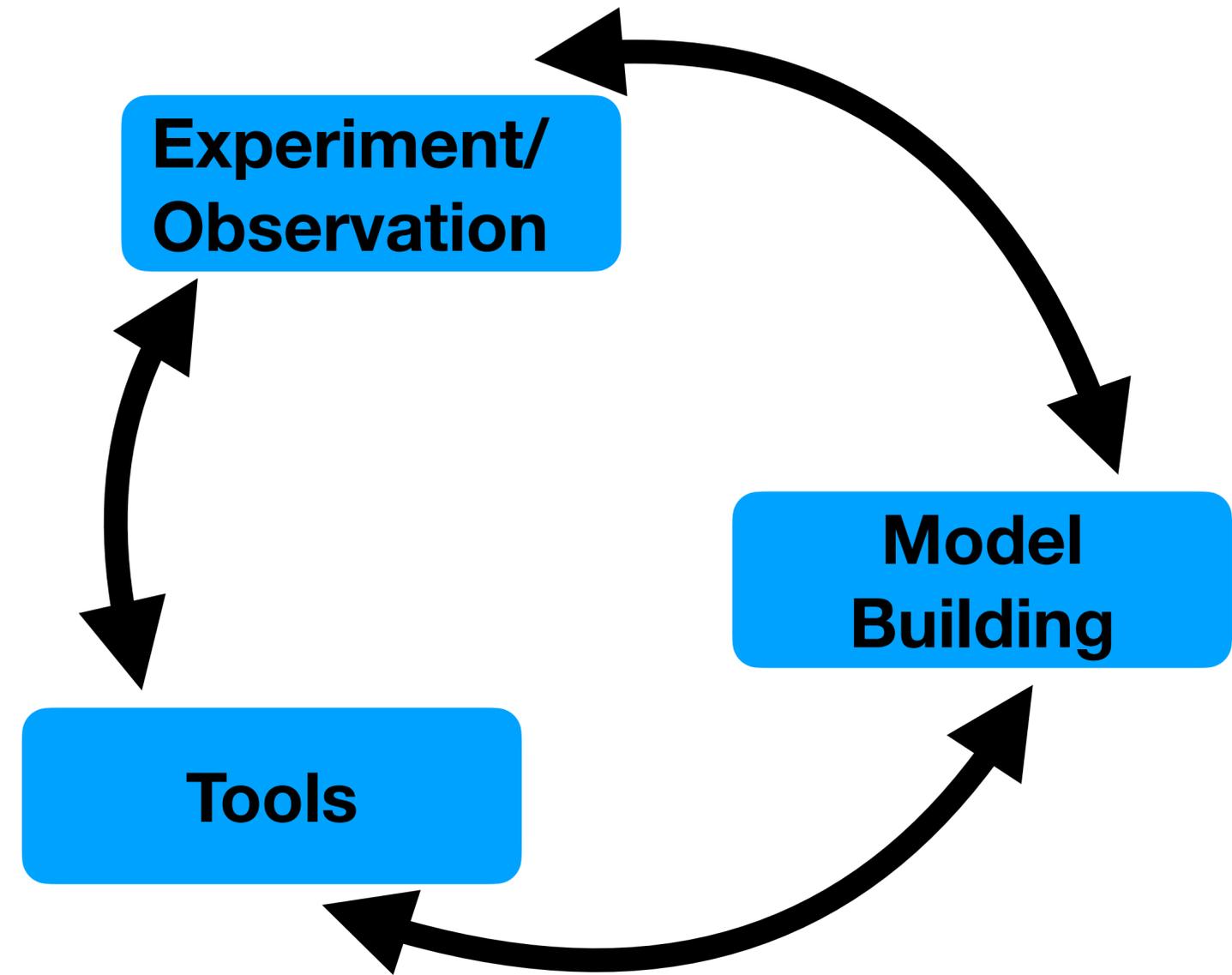
- White papers focus on topics of observables, calculations, generators, interpretations.
- Small meetings on white paper topics

TF08: BSM model building

Patrick Fox, Graham Kribs and Hitoshi Murayama conveners

Model building provides the tools to answer the big questions in physics e.g.

- Origin of fermion masses? What is dark matter? What provides the baryon asymmetry of the universe? Why is gravity so weak?
- We develop new theories to address these problems, confront them with data and refine theories further.



TF08: BSM model building

12 TF08 LOIs, 43 co-TF08 LOIs

White paper on early universe model building with TF09 started
Plans for joint white papers with EF/RF/CF

TF08 jointly organizing two parallel sessions:

126 — BSM: direct and indirect searches w/ EF08, EF09, RF **Tuesday 13:00-14:30**

101 — Higgs as a Probe of New Physics w/ EF01, EF02 **Tuesday 15:00-16:00**

Future Plans

**Develop the arguments for model building as an essential input to
guide the direction of the field**

TF09: Astro-particle physics & cosmology

Dan Green, Josh Ruderman, Ben Safdi and Jessie Shelton conveners

- Topics of interest:
 - Inflation and Connections to Formal Theory
 - Data-Driven Cosmology (CMB, LSS, BBN, 21cm)
 - Early Universe Model Building
 - Indirect Detection (Cosmology + Astrophysics)
 - Theory Meets the Lab

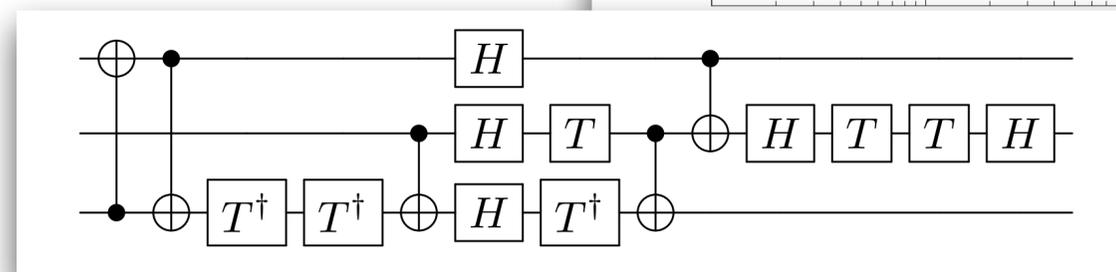
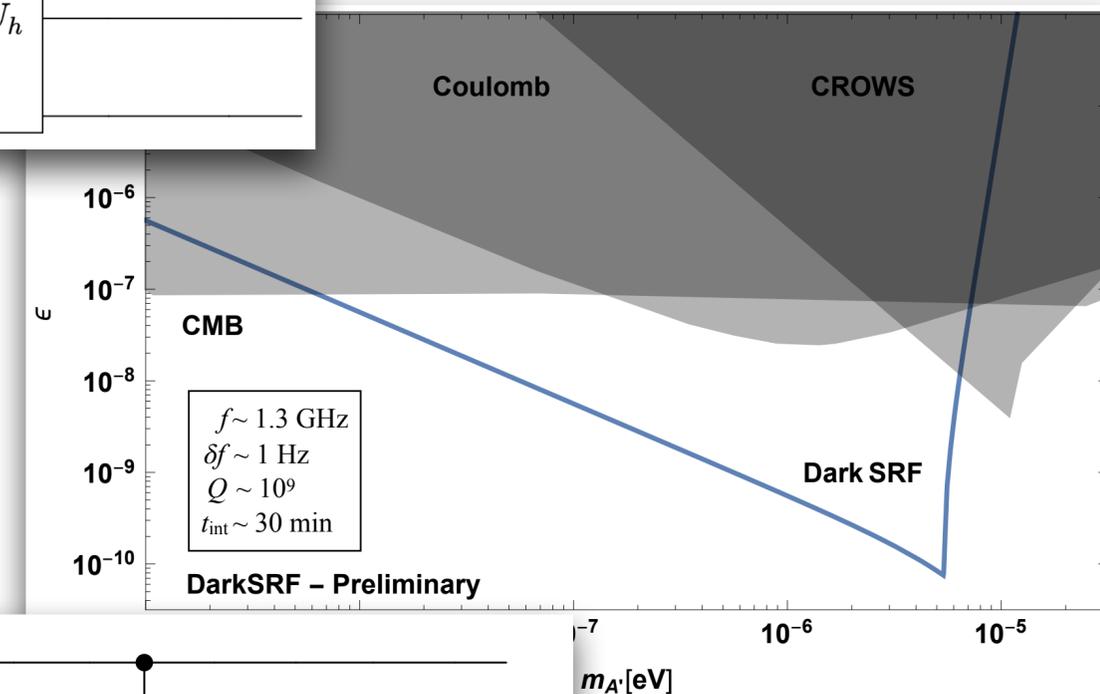
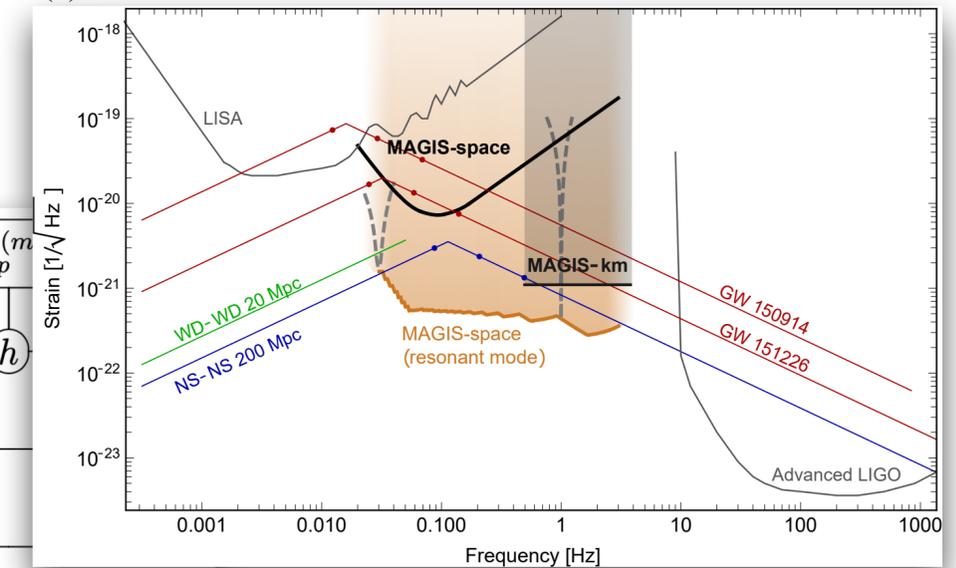
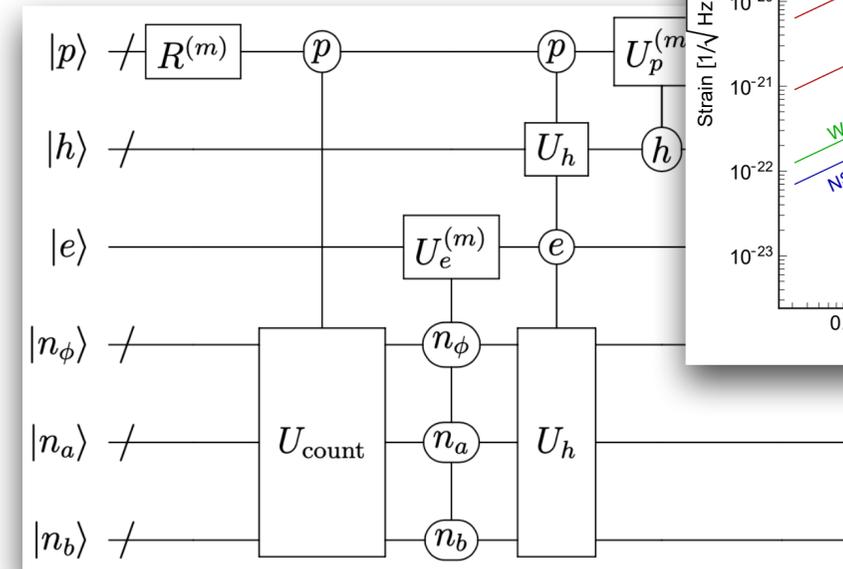
TF09: Astro-particle physics & cosmology

- The story so far:
 - Commissioning 5 theory-centered white papers: organizers (mostly) in place
 - List of interested participants - plan to contact to solicit input for white papers
 - Tracking theory-led cross-frontier LOIs for additional input
 - Co-organizing 6 breakout sessions at CPM
- Future plans:
 - Theory frontier meeting
 - Summary white papers will use TF, theory-led CF (EF, RF, ...) white papers as input

TF10: Quantum Information Science

Simon Catterall, Roni Harnik and Veronika Hubeny conveners

- Identifying opportunities interface of QIS and HEP theory.
- Dramatic advances in quantum technology for computing and sensing.
- Benefits run both ways: (QIS for HEP) and (HEP for QIS), both in theory and in experiment.
- HEP theorists are charting the way for advances QIS. Involved in all five of the recently launched NQI centers.



Top to bottom: Grav. Wave reach for MAGIS, Toy Parton shower algorithm (Bauer et al), Dark SRF reach for Dark photons, D4 gauge theory (Lamm et al)

TF10: Quantum Information Science

- Probing fundamental physics with quantum systems, including searches for dark matter, new interactions beyond the SM, and gravitational waves.
- New representations of QFTs suitable for quantum computation eg. quantum link models, Hamiltonian lattice gauge theory, tensor networks.
- Quantum simulation of strongly coupled quantum field theories in real time and/or finite density, including scalar theories, abelian and non-abelian gauge theories.
- New classical algorithms for QFT computations eg. Tensor renormalization group.
- HEP data analysis techniques for QIS (e.g. error correction) and vice versa.
- Connections b/w tensor networks, tessellations of AdS space and holography.
- Role of entanglement structure in holography: emergence of spacetime and gravitational dynamics, quantum information in gravitational systems.

36 Lols submitted. Co-organizing sessions 77 (sensors) and 102 (QIS-HEP interplay).

More meeting to come.

TF11: Theory of neutrino physics

André de Gouvêa, Irina Mocioiu, Saori Pastore, and Louis Strigari

Topics studied within the group include:

1. What is the origin of nonzero neutrino masses? Open questions, models, and how can we learn more? How does this connect with other open questions in particle physics and cosmology (dark matter puzzle, baryogenesis, stability of the Higgs boson mass)?
2. What is the theory of flavor? How do we learn more? How well do we need to know the elements of the mixing matrix (including CP), and why? How are leptons and quarks connected?
3. Solving current (and future!) neutrino puzzles, including the short-baseline anomalies.
4. Understanding the impact of new neutrino properties in astrophysical sources and the early universe.
5. Computing, with enough precision, the cross-section for neutrino-matter scattering at different energy scales.
6. How to quantitatively extract neutrino properties from nuclear-physics probes, including neutrinoless double-beta decay.

TF11: Theory of neutrino physics

André de Gouvêa, Irina Mocioiu, Saori Pastore, and Louis Strigari

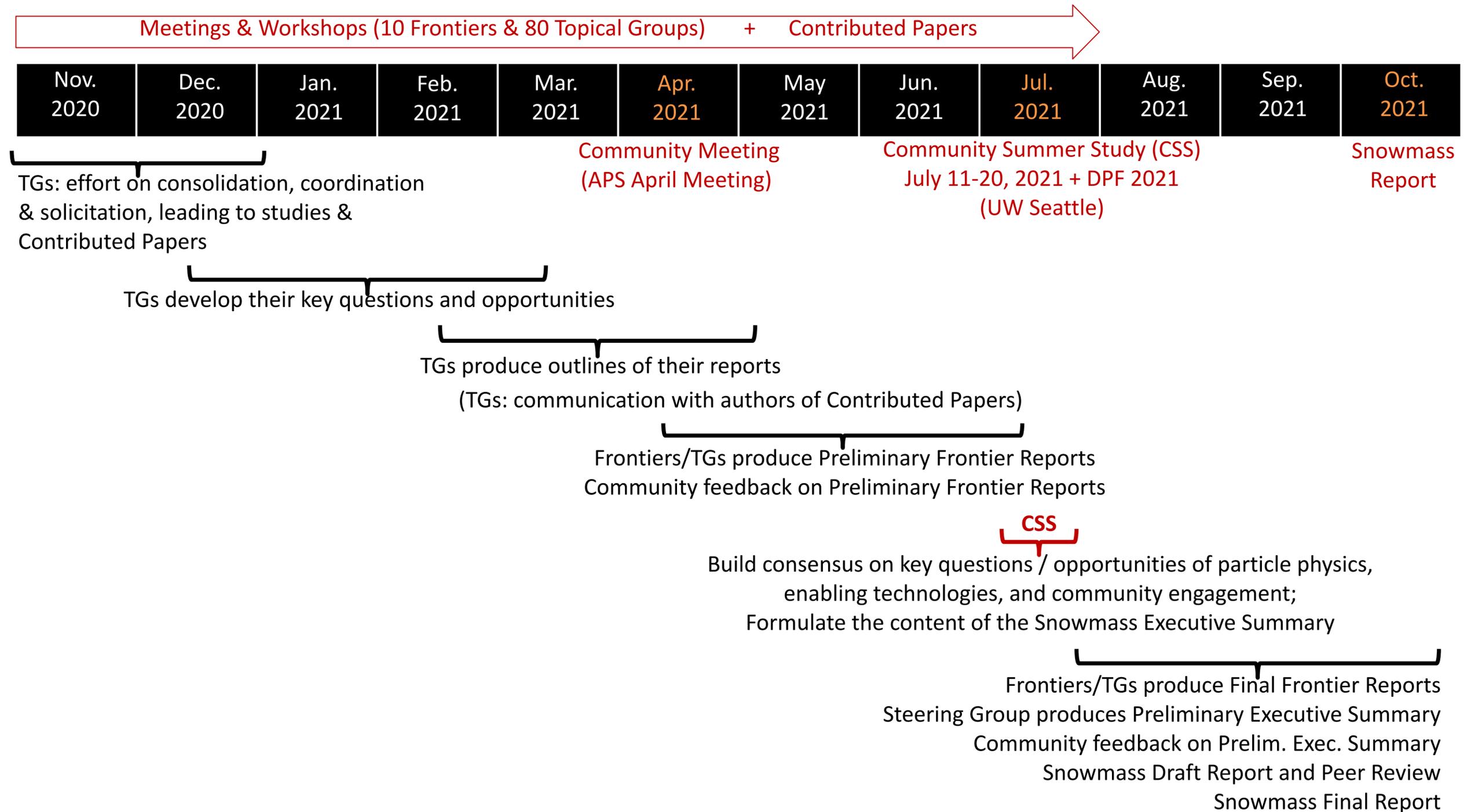
- On Sept. 9/21-9/23, TF11 hosted a **Neutrino Theory Mini-workshop**. The workshop comprised of both plenary and contributed talks. Topics covered by the workshop included **neutrinos in astrophysics & cosmology**, **neutrino cross sections**, **neutrinoless double-beta decay**, **oscillations**, **mass and flavor model building**, and **BSM physics at neutrino experiments**
- There were **194 participants** in the workshop. There were lively discussions on all three days, with discussions spilling over to the designated Slack workspace. This workshop is expected to be a launching point for whitepapers, which will be developed in collaboration with Theory and Neutrino Frontier conveners (rare processes? compF?)
- TF11 is organizing three breakout sessions at the CPM: **Neutrinos as Probes of Standard and BSM Particle Physics (97)**, **Neutrino mass and Dirac/Majorana Nature (109)**, and **High and Ultra-high energy neutrino experiments (137)**. These are in collaboration with Rare Processes and Precision Frontier, Neutrino Frontier, and the Cosmic Frontier.

Next steps for TF

- **Ongoing:** Focus on developing white papers. Interactions between TGCs and proposers/authors crucial. TGCs need to know about WPs in preparation.
- **Ongoing:** Additional small focused workshops by TGs
- **After CPM:** develop detailed timeline for TG summary drafts, TF summary drafts, gathering feedback from community

Preliminary Snowmass Timeline / Process

Starting point for discussion with the community during CPM



Next steps for TF

- **Ongoing:** Focus on developing white papers. Interactions between TGCs and proposers/authors crucial. TGCs need to know about WPs in preparation.
- **Ongoing:** Additional small focused workshops by TGs
- **After CPM:** develop detailed timeline for TG summary drafts, TF summary drafts, gathering feedback from community
- **March 17-19:** TF meeting @ KITP (hybrid or online TBD). Planning for this meeting should start soon after the CPM

Time for questions

**Q&A will also continue on
Slack channel**

#cpm_tf_intro_planning