Snowmass Theory Frontier

S. Dawson

Dec 17, 2021

* Slides from N Craig presentation

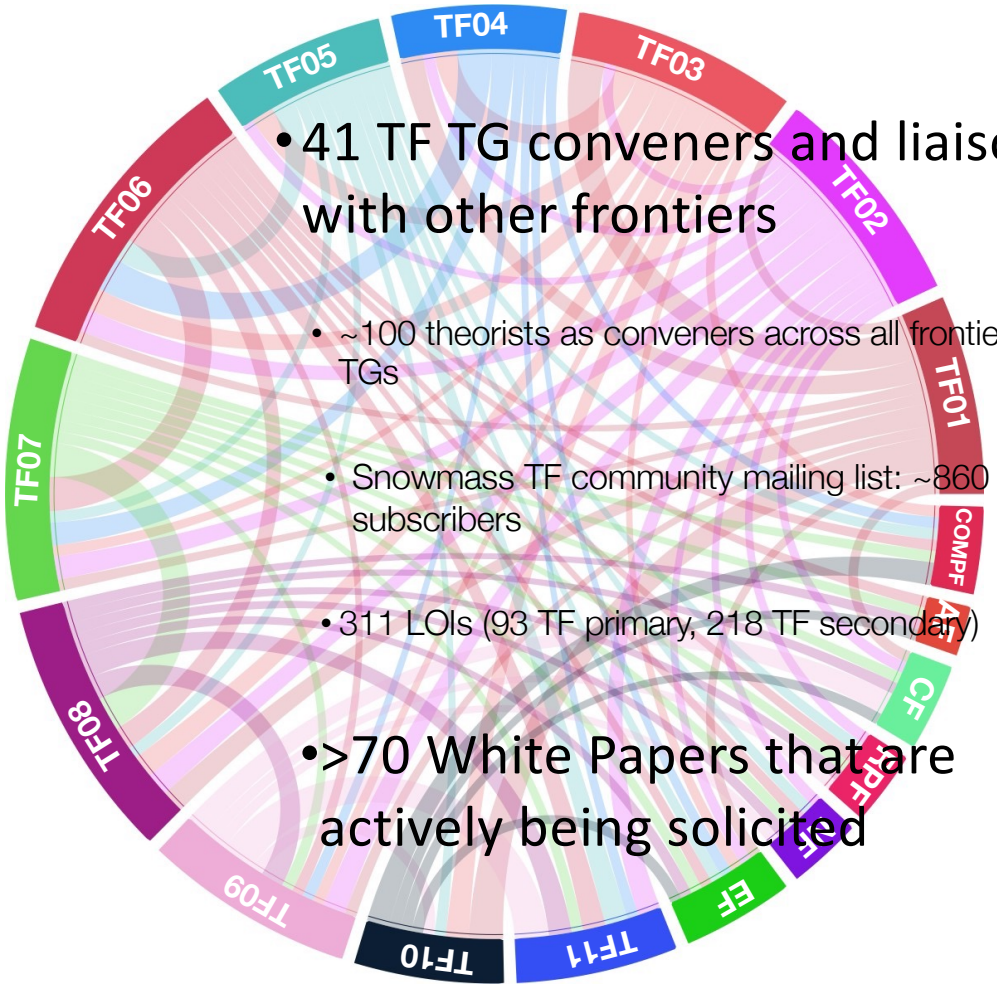
Aida El-Khadra
UIUC

Csaba Csaki
Cornell

Nathaniel Craig
UCSB

Topical Group		Topical Group Conveners			
TF01	String theory, quantum gravity, black holes	Daniel Harlow	Shamit Kachru	Juan Maldacena	
TF02	Effective field theory techniques	Patrick Draper	Ira Rothstein		
TF03	CFT and formal QFT	David Poland	Leonardo Rastelli		
TF04	Scattering amplitudes	Zvi Bern	Jaroslav Trnka		
TF05	Lattice gauge theory	Zohreh Davoudi	Taku Izubuchi	Ethan Neil	
TF06	Theory techniques for precision physics	Radja Boughezal	Zoltan Ligeti		
TF07	Collider phenomenology	Fabio Maltoni	Shufang Su	Jesse Thaler	
TF08	BSM model building	Patrick Fox	Graham Kribs	Hitoshi Murayama	
TF09	Astro-particle physics and cosmology	Dan Green	Joshua Ruderman	Ben Safdi	Jessie Shelton
TF10	Quantum information science	Simon Catterall	Roni Harnik	Veronika Hubeny	
TF11	Theory of Neutrino Physics	André de Gouvêa	Irina Mocioiu	Saori Pastore	Louis Strigari

Liaisons	**Accelerator** Lian-Tao Wang (U Chicago)	**Community Engagement** Devin Walker (Dartmouth)	**Computational** Steven Gottlieb (Indiana U)
Cosmic Flip Tanedo (UC Riverside)	**Energy** Laura Reina (Florida State U)	**Neutrino Physics** Irina Mociouiu (Penn State U) & Kaladi S. Babu (Oklahoma State U)	**Rare Processes and Precision** Alexey Petrov (Wayne State)



- 41 TF TG conveners and liaisons with other frontiers
  - ~100 theorists as conveners across all frontiers and TGs
  - Snowmass TF community mailing list: ~860 subscribers
  - 311 LOIs (93 TF primary, 218 TF secondary)
- >70 White Papers that are actively being solicited

Our goal: articulate recent advances & future opportunities in all aspects of theory relevant to HEP, including particle theory, formal/foundational theory, cosmological and astro-particle theory, and quantum information science.

TF01: String theory, quantum gravity, black holes

Daniel Harlow, Shamit Kachru, and Juan Maldacena

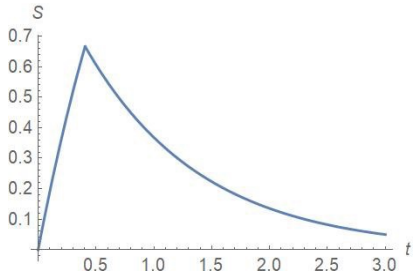
Recent progress on the black hole information problem

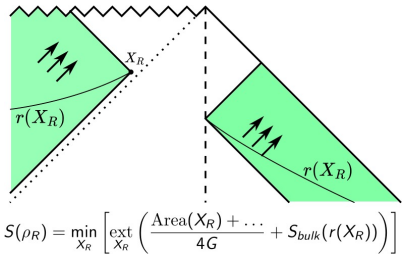
1976: Low-energy physics of black holes seems to lead to a contradiction with quantum unitarity (Hawking).

1996: Entropy of some BHs can be counted in string theory (Strominger & Vafa).

1997: AdS/CFT correspondence (Maldacena) indicates black hole evaporation is apparently unitary.

Page curve remains elusive: the plot of the von Neumann entropy of the radiation of an evaporating black hole as a function of time. A major milestone on the way to solving the information problem



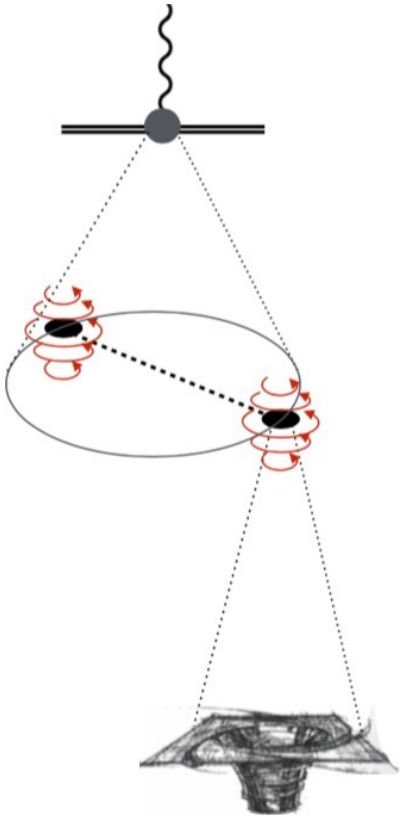


2019: The quantum extremal surface formula of AdS/CFT is powerful enough to compute the Page curve for certain evaporating black holes (Penington and Almheiri/ Engelhardt/Marolf/Maxfield)

>100 papers clarifying and extending these results. Key lesson: extraordinary power of the Euclidean gravity path integral, which through "replica wormholes" gives one rather general motivation for the quantum extremal surface formula. Does not rely on the details of AdS/CFT, and thus can be used to explore the non-perturbative physics of black holes in more realistic backgrounds.

TF02: Effective Field Theory Techniques

Patrick Draper and Ira Rothstein



EFT approach to Gravitational Physics

Gravitational wave observations have expedited the need for precise calculations involving gravitational interactions between compact objects. Such observations are a window on fundamental physics (exotic states of matter, QCD in extreme conditions, black hole horizon physics)

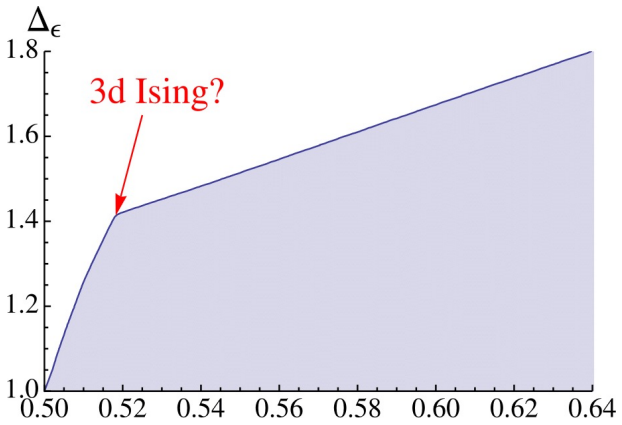
EFT methods have proven useful in various aspects of the calculation of gravitational wave templates, and has generated synergy between various sub-fields in HEP-TH.

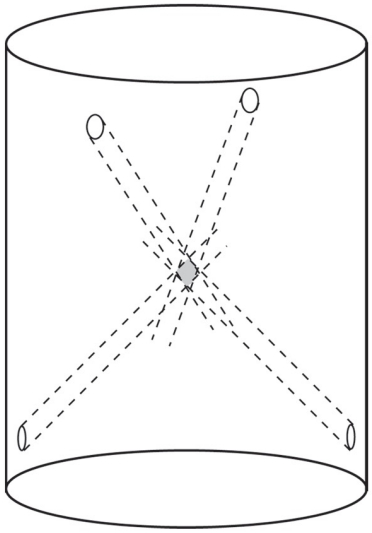
- Higher order calculations within the Post-Newtonian (NR) and Post-Minkowskian (Expansion in G)
- EFT dynamics of QCD in extreme conditions
- Response functions for Exotic Matter

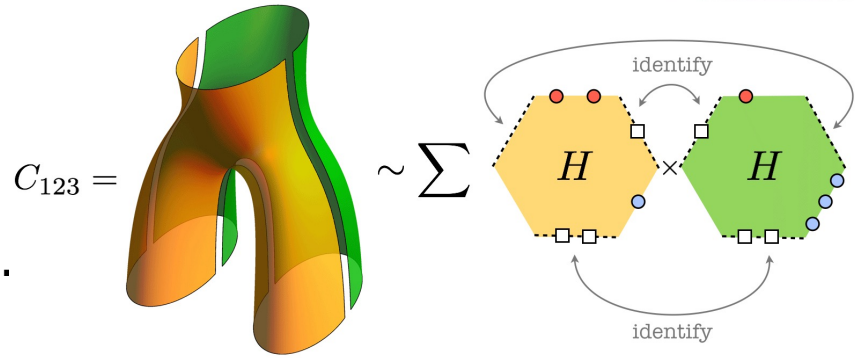
TF03: CFT and formal QFT

David Poland and Leonardo Rastelli

- **Many different "Bootstrap" programs:**
  - Conformal Bootstrap
  - Modular Bootstrap
  - S-Matrix Bootstrap
  - Integrable (Hexagon) Bootstrap
  - SCFT Operator Algebra Bootstrap
  - String Amplitudes Bootstrap
  - Cosmological Bootstrap
- **Numerous synergies, overlaps, shared techniques, intuitions, sources of inspiration, …**



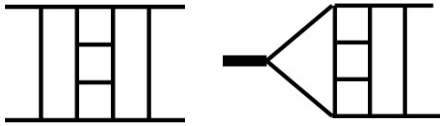




TF04: Scattering amplitudes

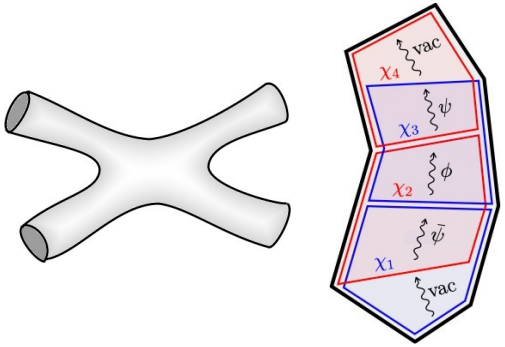
Zvi Bern and Jaroslav Trnka

Multi-loop amplitudes in QFT

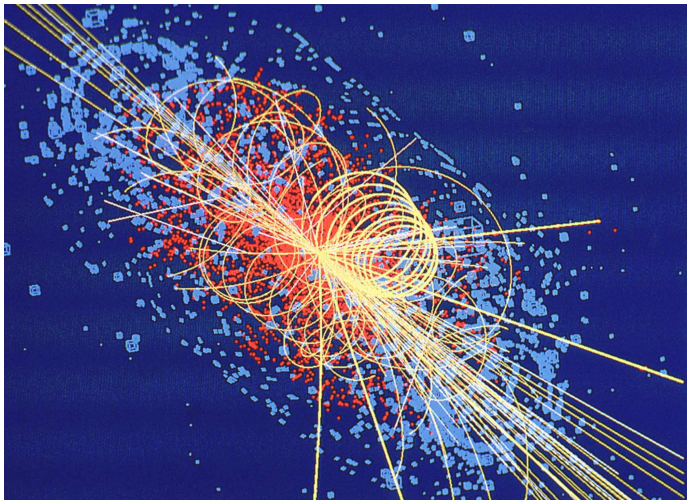


$$g^2 - 2\,\zeta_2\,g^4 + 22\,\zeta_4\,g^6 - \left[219\,\zeta_6 + 8\,(\zeta_3)^2\right] g^8 + \cdots$$

String amplitudes, integrability, solving N=4 SYM theory

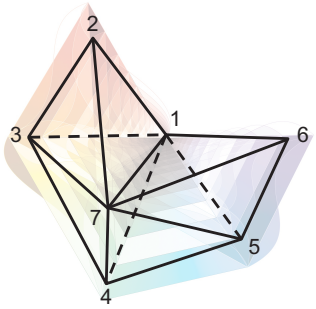


Particle scattering at colliders, LHC physics

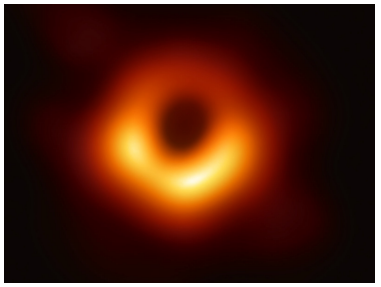


Color-kinematics duality

New mathematical structures, Amplituhedron



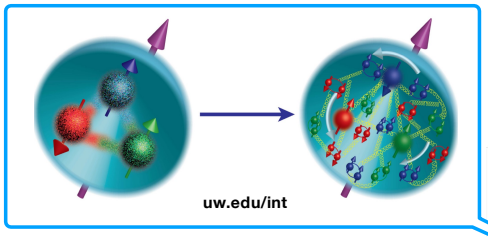
From amplitudes to classical gravity, LIGO physics



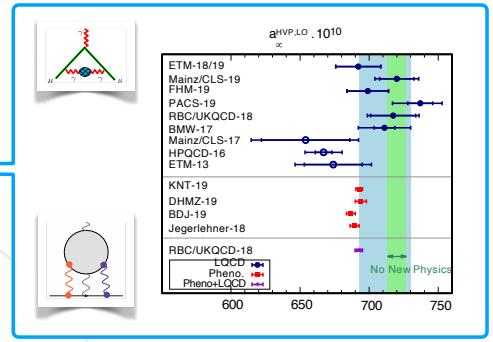
TF05: Lattice gauge theory

Zohreh Davoudi, Taku Izubuchi, and Ethan Neil

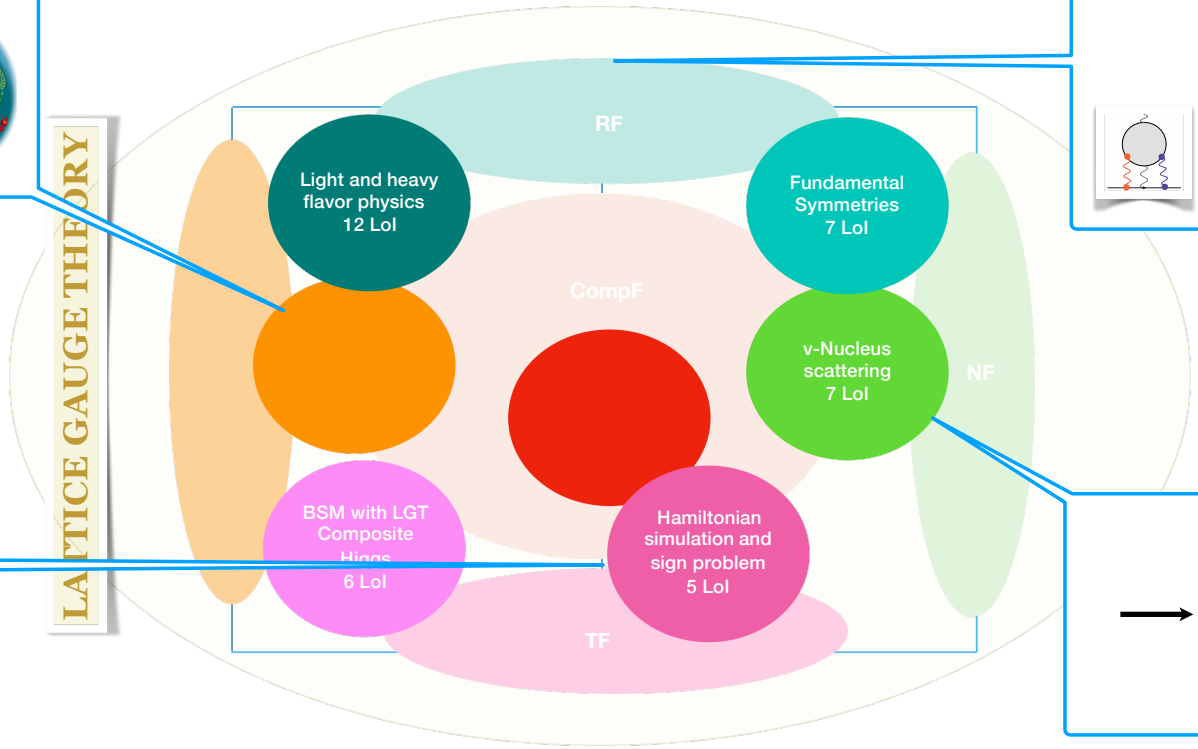
In addition to many existing exciting directions with direct impact on experimental program, a few new themes will become an integrated part of the LGT portfolio in the coming decade.

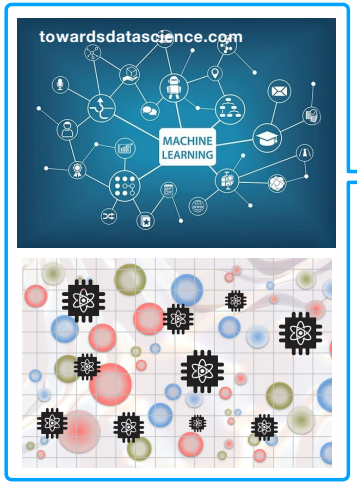


Structure functions, e.g., PDFs

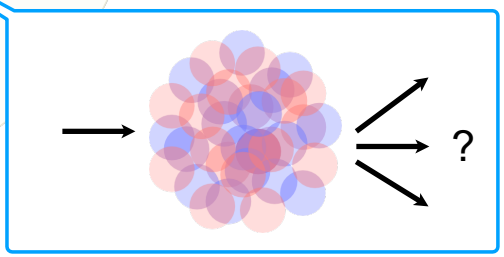


Hadronic contributions to muon anomalous magnetic moment





New strategies in computing and simulation, including the use of ML and quantum computing



v-nucleus cross sections

TF06: Theory techniques for precision physics

Radja Boughezal and Zoltan Ligeti

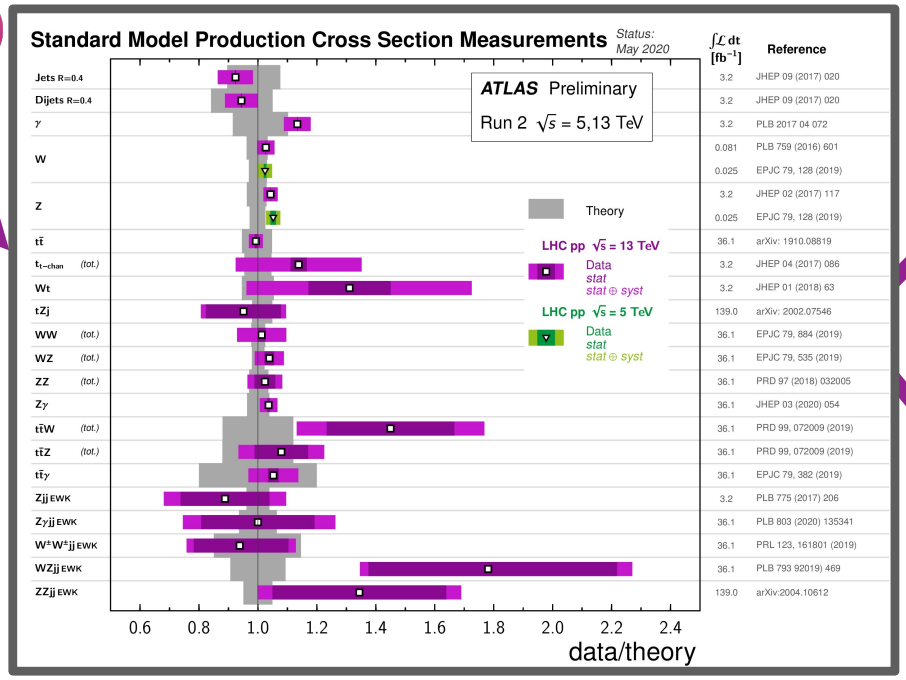
Advances in amplitudes

Multi-loop calculations

EFTs for new physics sensitivity

Monte Carlo event generators

Precision flavour physics



Enable current and planned precision measurements

Motivate new observables with enhanced sensitivity to new physics

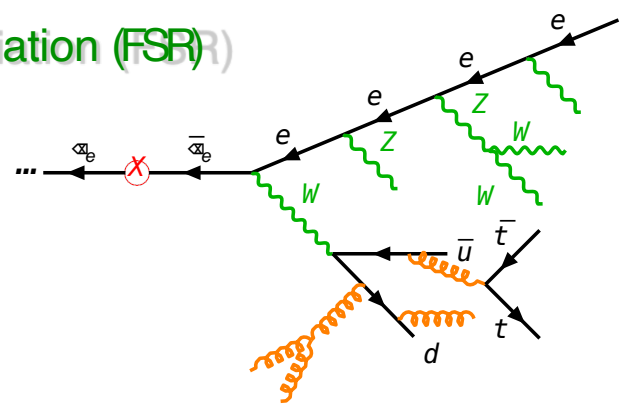
A broad variety of theoretical ideas and tools are vital to the success of our precision explorations for new physics !

TF07: Collider phenomenology

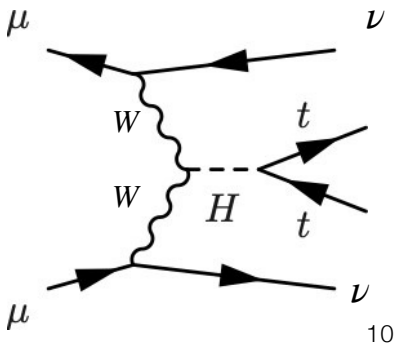
Fabio Maltoni, Shufang Su, and Jesse Thaler

Example Snowmass Focus Effort: Electroweak Effects at High Energy

- Final state radiation (FSR)



- Initial state radiation (ISR)



Electroweak (EW) effects can become quite large at high energies ⇒ O(1) impact for $Q \gg m_{W/Z}$

Currently: Many exploratory studies in the literature, with very different formal approaches, which have not been compared yet

Future target: Systematic studies to quantify EW effects in processes at very high energies, such as from very heavy dark matter annihilation (FSR) or at future multi-TeV lepton colliders (ISR)

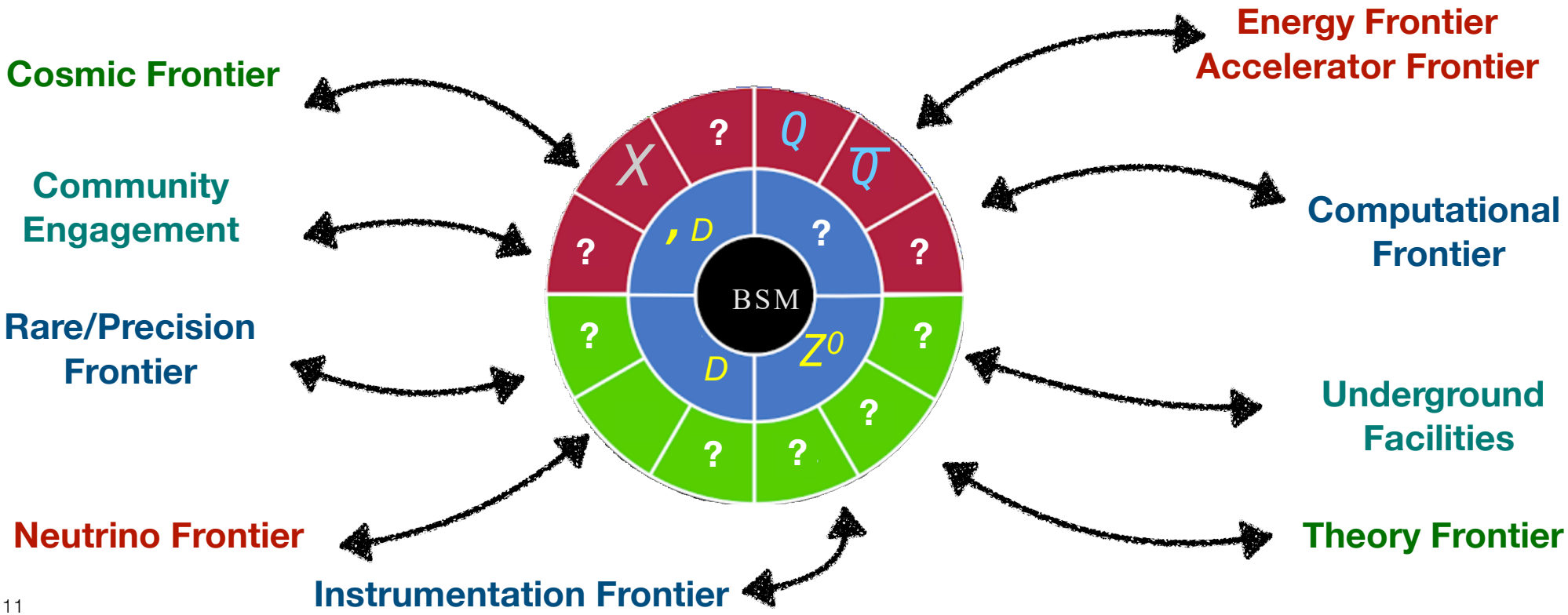
Future target: Complete implementation of EW showers in Monte Carlo generators (space-like and time-like)

First meeting held within TF07 with a lot of discussion and interest!

TF08: BSM model building

Patrick Fox, Graham Kribs, and Hitoshi Murayama

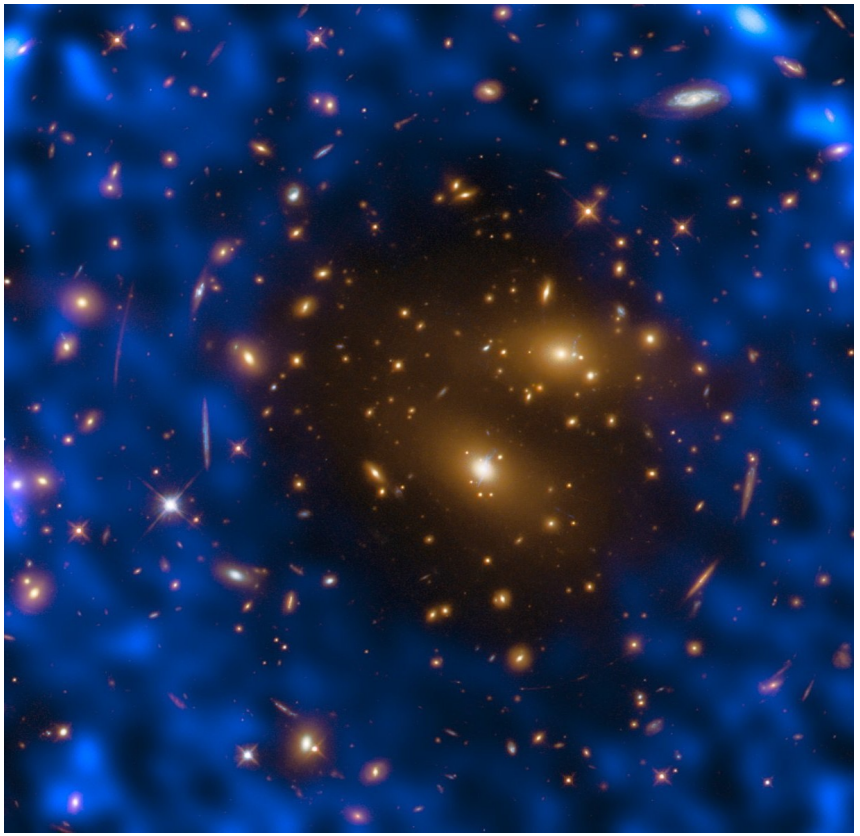
As the Lagrangian that describes New Physics (e.g. the dark sector) is uncovered, the major focus of TF08 becomes the focus of the whole field



TF09: Astro-particle physics & cosmology

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

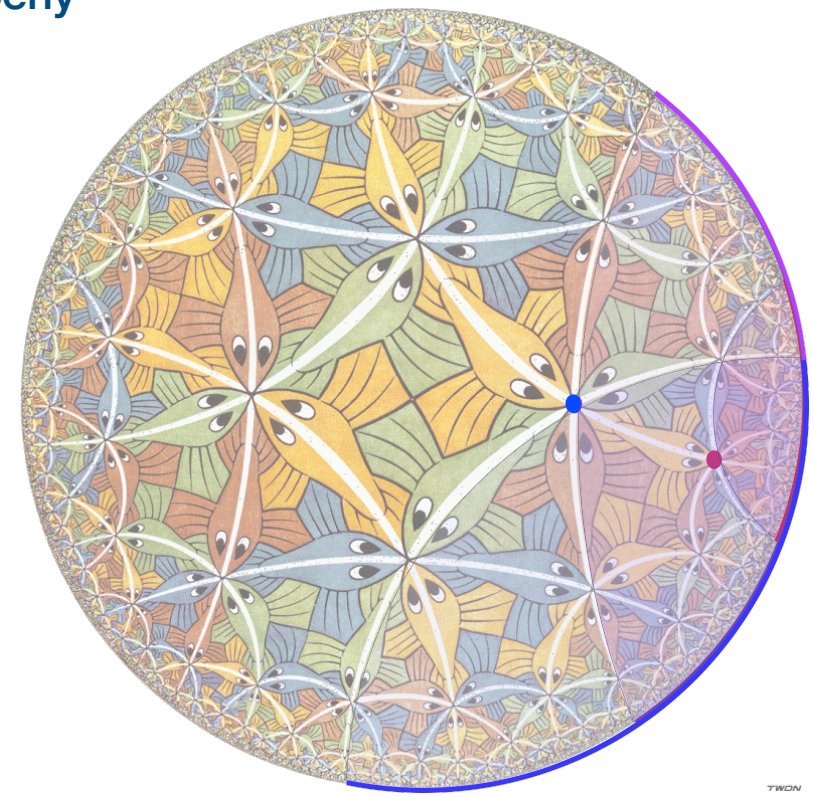
- Expanding and exploring new frontiers
  - Theory driving new experiments
  - Expanding uses of astrophysical data
  - Exploring new directions in theory space
- New theoretical tools
  - Emerging connections with formal theory (e.g., new uses of holography, bootstrap, EFT)
  - New directions in simulations



TF10: Quantum Information Science

Simon Catterall, Roni Harnik, and Veronika Hubeny

- Geometrization of entanglement:
  - Many aspects of quantum entanglement captured by simple geometric constructs in higher dimensional gravity.
  - Holographic encoding of bulk spacetime as a quantum error correcting code.
  - Novel insights into black hole information and spacetime emergence.
  - New teleportation protocols as spacetime wormholes.

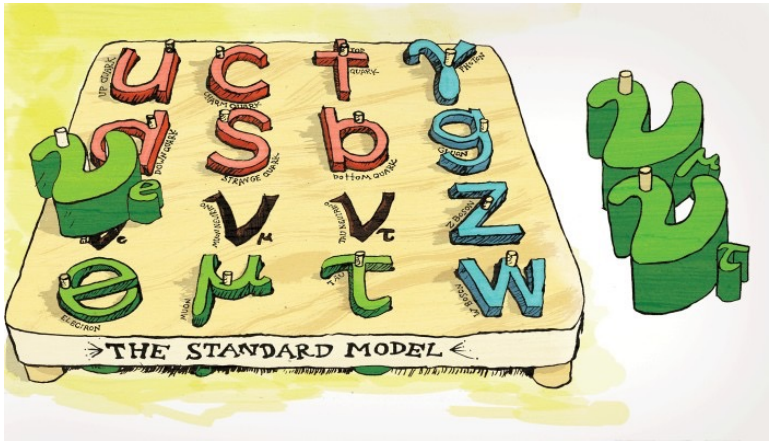


TF11: Theory of neutrino physics

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

Two key questions:

- How do we take full advantage of percent-level neutrino oscillation experiments? Can we determine neutrino-nucleus cross sections that are relevant for these experiments?



- Interplay with other areas of nuclear physics (neutrino properties from double beta decay), particle physics (links to dark matter and collider physics), astroparticle physics (ultra-high energy neutrinos and supernova neutrinos), and cosmology (neutrino properties from cosmic surveys, including effective numbers of neutrinos and neutrino masses).

Bottom line: Theory frontier

- Important for Snowmass summaries to emphasize the need for a strong theory underpinning
- Theory progress goes hand in hand with experiment