All HEP Discussion Day

Radja Boughezal

November 6, 2019

Charge

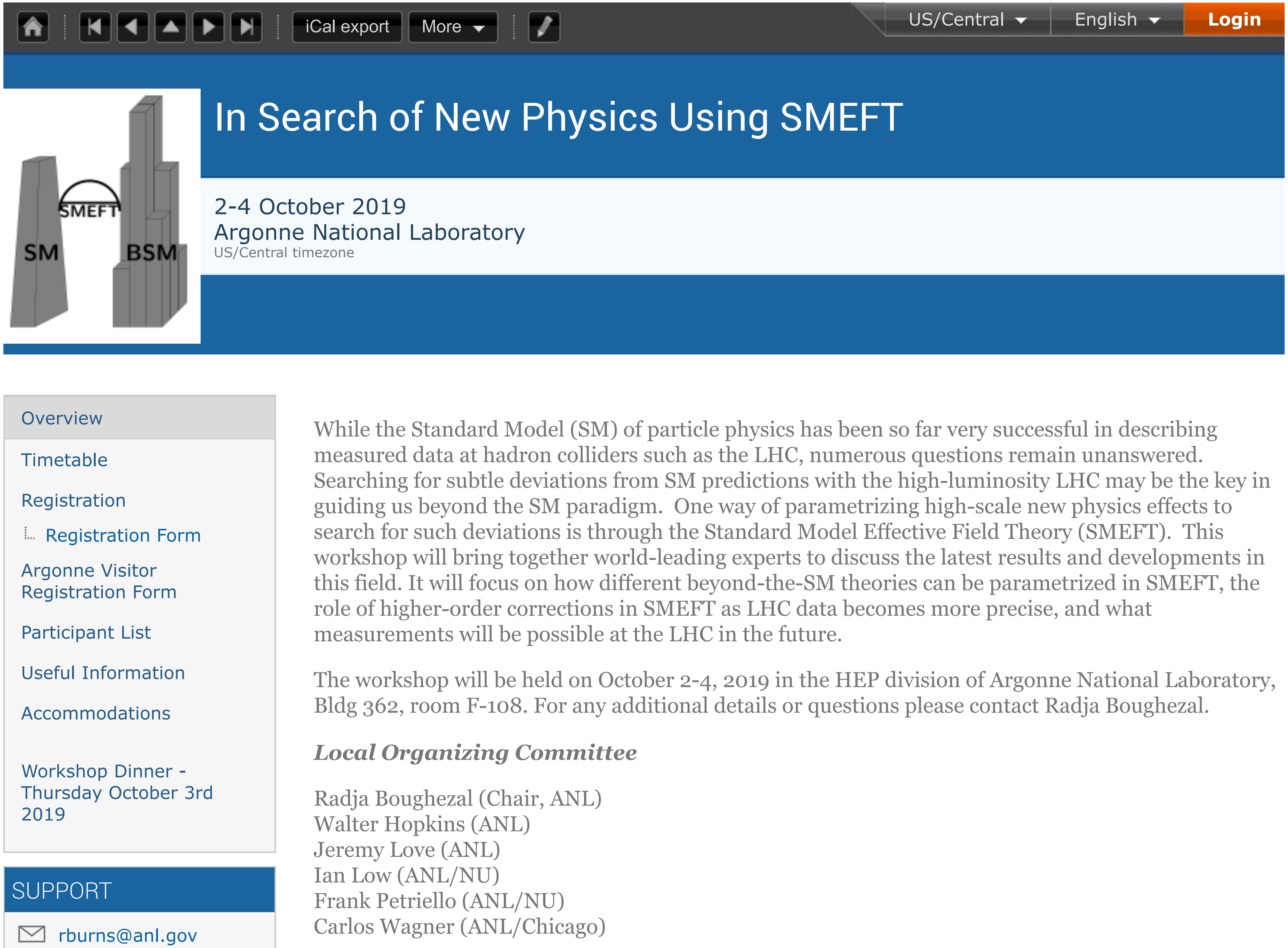
The Argonne HEP division has been charged by DOE HEP with the following:

• **HEP:** Having hired a new director of the High Energy Physics Division, it is now timely for the lab to articulate a vision for the future of ANL HEP. This plan should build on the multi-program capabilities of the Laboratory as well as the particular expertise and leadership of lab staff. The draft plan, suitable for external review, should be delivered to the HEP office by March 2020.

Rik's charge to us:

- General status of the current program and future planning
- "AI for Science": and computing across frontiers
- Direction of particle theory in the next phase and connections to experiments
- Detector R&D
- Advances in Cosmology (including connection to neutrino experiments)
- Future of Advanced Accelerator R&D

- One possible idea that was suggested by Rik is a joint effort centered around Standard Model Effective Field Theory (SMEFT). This is a topic that some of us theorists are interested in, and we just organized a workshop about it.



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SMEFT
SM
BSM

In Search of New Physics Using SMEFT

2-4 October 2019
Argonne National Laboratory
US/Central timezone

- Overview
- Timetable
- Registration
  - Registration Form
- Argonne Visitor Registration Form
- Participant List
- Useful Information
- Accommodations
- Workshop Dinner - Thursday October 3rd 2019

SUPPORT

rburns@anl.gov

While the Standard Model (SM) of particle physics has been so far very successful in describing measured data at hadron colliders such as the LHC, numerous questions remain unanswered. Searching for subtle deviations from SM predictions with the high-luminosity LHC may be the key in guiding us beyond the SM paradigm. One way of parametrizing high-scale new physics effects to search for such deviations is through the Standard Model Effective Field Theory (SMEFT). This workshop will bring together world-leading experts to discuss the latest results and developments in this field. It will focus on how different beyond-the-SM theories can be parametrized in SMEFT, the role of higher-order corrections in SMEFT as LHC data becomes more precise, and what measurements will be possible at the LHC in the future.

The workshop will be held on October 2-4, 2019 in the HEP division of Argonne National Laboratory, Bldg 362, room F-108. For any additional details or questions please contact Radja Boughezal.

Local Organizing Committee

Radja Boughezal (Chair, ANL)
Walter Hopkins (ANL)
Jeremy Love (ANL)
Ian Low (ANL/NU)
Frank Petriello (ANL/NU)
Carlos Wagner (ANL/Chicago)

What is SMEFT ?

SMEFT = Effective Field Theory with SM fields + symmetries

a systematic expansion in canonical dimensions $(v, E/\Lambda)$:

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \dots$$

$\mathcal{L}_n = \sum_i C_i \mathcal{O}_i^{d=n}$

C_i free parameters (Wilson coefficients)

$\mathcal{O}_i$ invariant operators that form a complete basis

- any UV compatible with the SM in the low energy limit can be matched onto the SMEFT
- a convenient phenomenological approach: systematically classifies all the possible new physics signals

Ilaria Brivio

Why SMEFT ?

Ilaria Brivio

Why SMEFT ?

a **smart framework** for data recording and interpretation

↓

a general, powerful tool for handling future data

the only QFT providing **a systematic classification** of all the UV effects compatible with SM symmetries + field content

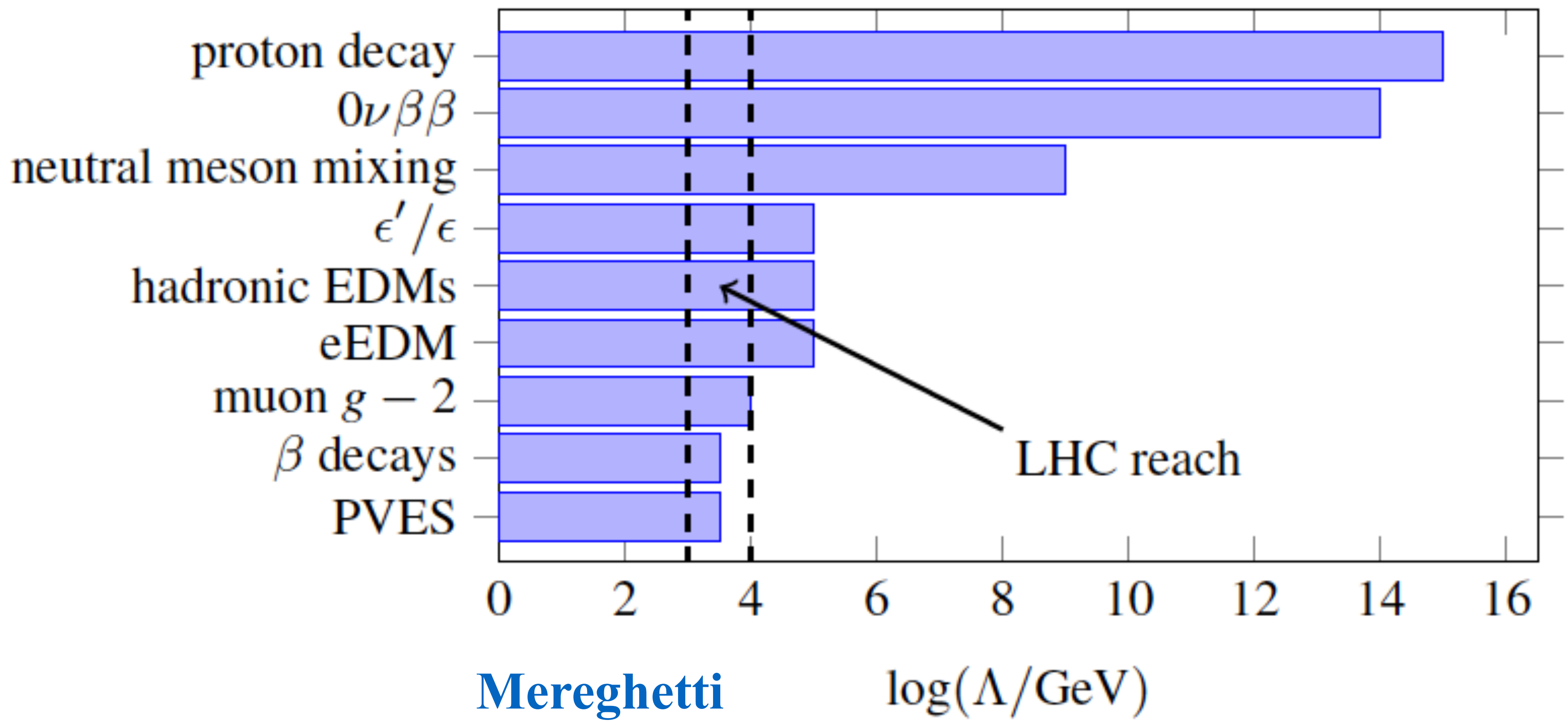
knowledge of UV <u>not</u> required

↓

well suited for the current situation

Why else is SMEFT interesting?

- It connects low and high energy experiments; allows one to compare constraints from both energy ranges using a single framework.



Mereghetti

- low energy probes provide a complementary window on BSM physics
- reach scales naively[1] much larger or competitive with LHC
- intense experimental activity

Highlights of the current direction of the field

Global Fitting

SMEFiT Analysis: Top Sector

Ethier

Notation	Sensitivity at $\mathcal{O}(\Lambda^{-2})$ ($\mathcal{O}(\Lambda^{-4})$)								
	$t\bar{t}$	single-top	tW	tZ	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}H$	$t\bar{t}t\bar{t}$	$t\bar{t}b\bar{b}$
OQQ1								✓	✓
OQQ8								✓	✓
OQt1								✓	✓
OQt8								✓	✓
OQb1									✓
OQb8									✓
Ott1								✓	
Otb1									✓
Otb8									✓
OQtQb1									(✓)
OQtQb8									(✓)
O81qq	✓				✓	✓	✓	✓	✓
O11qq	[✓]				[✓]	[✓]	[✓]	✓	✓
O83qq	✓	[✓]		[✓]	✓	✓	✓	✓	✓
O13qq	[✓]	✓		✓	[✓]	[✓]	[✓]	✓	✓
O8qt	✓				✓	✓	✓	✓	✓
O1qt	[✓]				[✓]	[✓]	[✓]	✓	✓
O8ut	✓					✓	✓	✓	✓
O1ut	[✓]					[✓]	[✓]	✓	✓
O8qu	✓					✓	✓	✓	✓
O1qu	[✓]					[✓]	[✓]	✓	✓
O8dt	✓					✓	✓	✓	✓
O1dt	[✓]					[✓]	[✓]	✓	✓
O8qd	✓					✓	✓	✓	✓
O1qd	[✓]					[✓]	[✓]	✓	✓
OtG	✓		✓		✓	✓	✓	✓	✓
OtW		✓	✓	✓					
ObW		(✓)	(✓)	(✓)					
OtZ				✓		✓			
Off		(✓)	(✓)	(✓)					
Ofq3		✓	✓	✓					
OpQM				✓		✓			
Opt				✓		✓			
Otp							✓		

- Total of 34 free parameters:

  → 11 from 4-heavy operators

  → 14 from 2-heavy-2-light operators

  → 9 from 2-heavy with boson/Higgs interaction

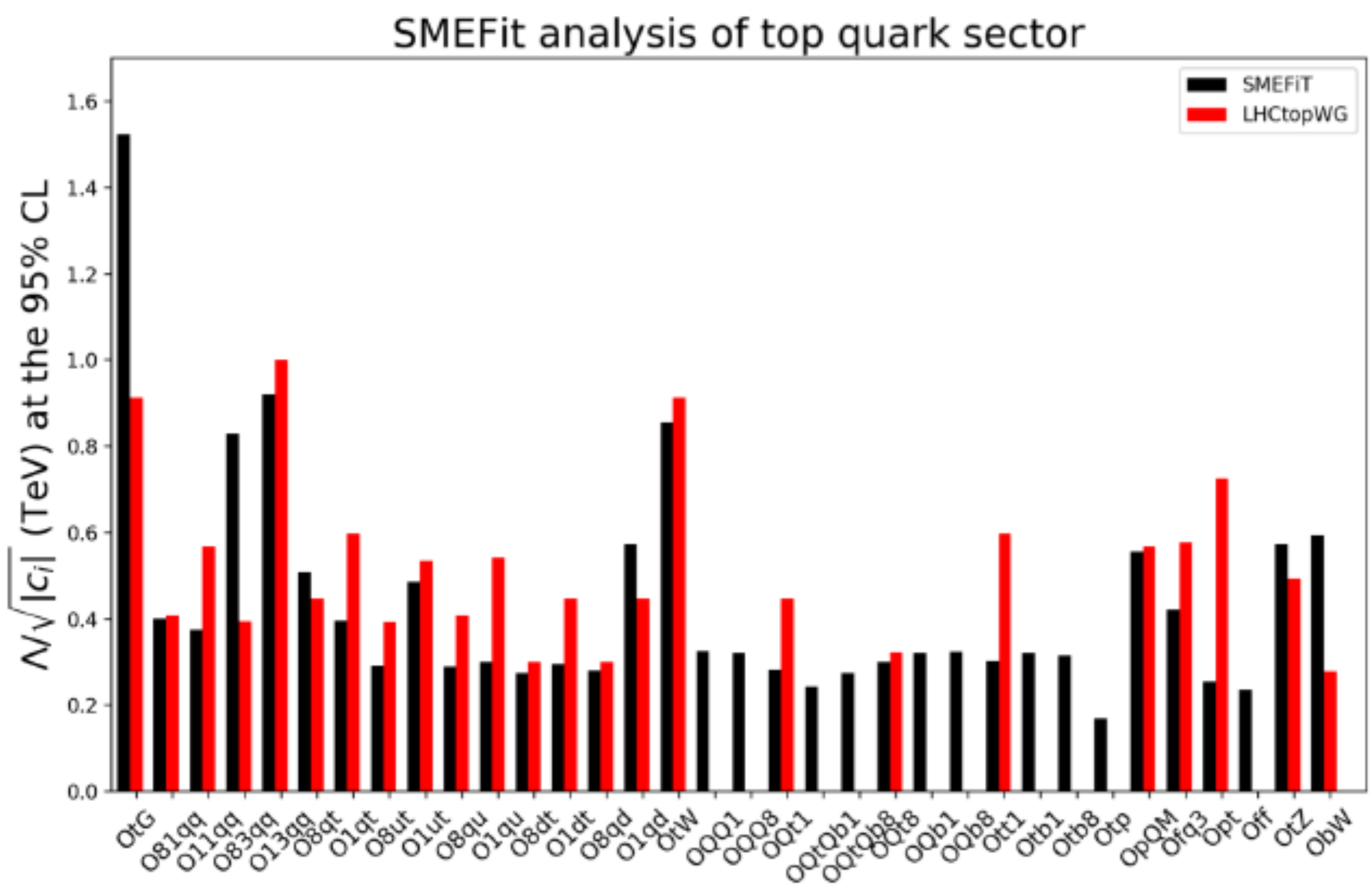
- Each operator enters different processes (and also different orders)

  → Can provide insight *a priori* to the level of constraint

Global Fitting

SMEFiT Analysis: Top Sector

Ethier

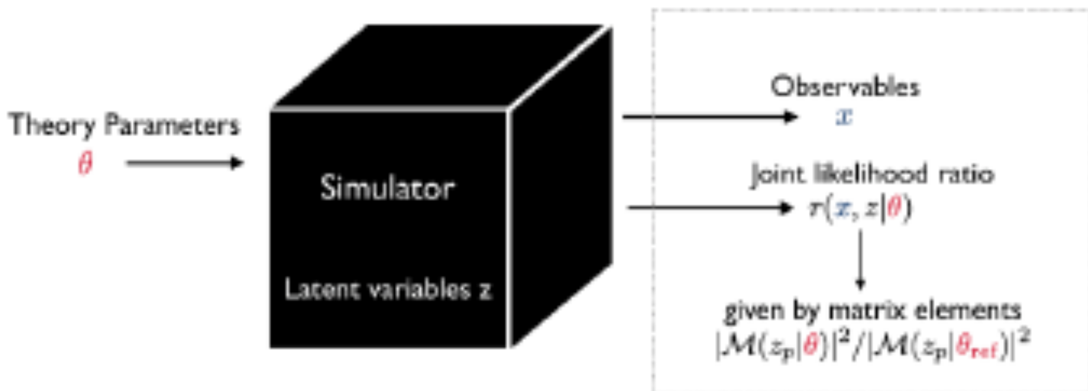


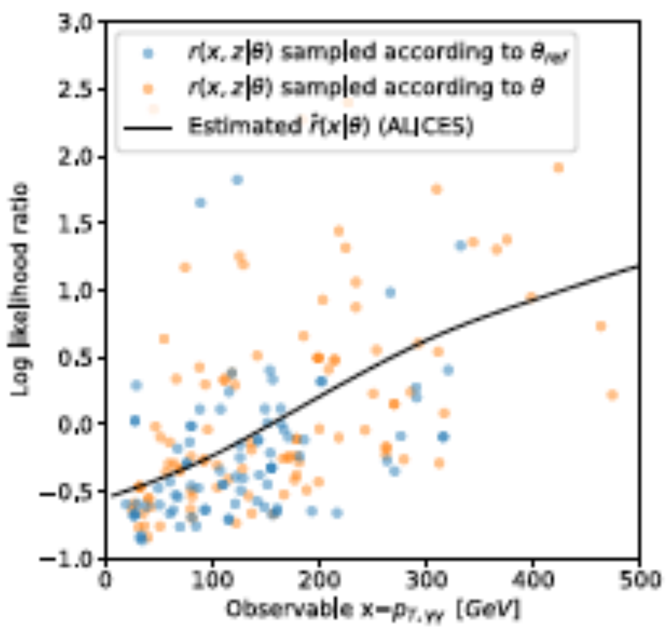
N. Hartland et. al. JHEP 1904 (2019) 100

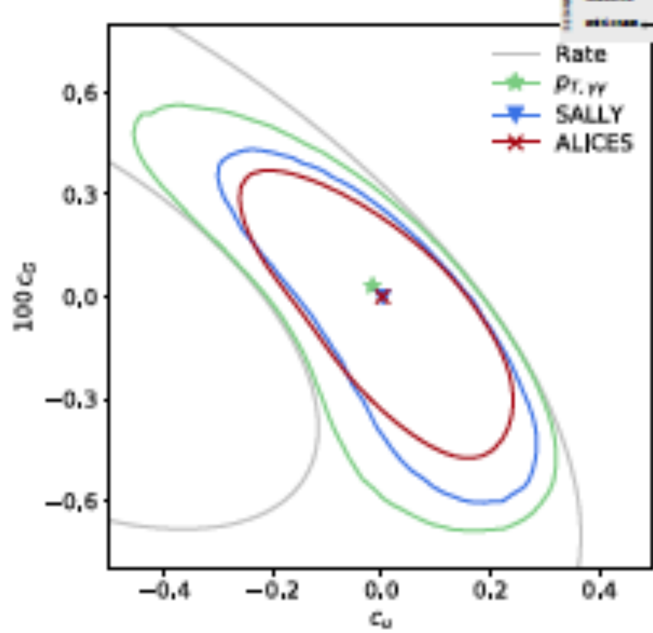
- Effective reach in energy (TeV)

SMEFT and Machine Learning

Kling







Motivation: LHC probe high-dimensional theory space θ with high dimensional data x

* task: determine likelihood function p(x|θ)

Method: uses multivariate inference techniques leveraging information in matrix elements and power of machine learning

* estimate full likelihood ratio including correlations + systematics

* learn optimal summary statistics

* ideal for SMEFT measurements

Tool: MadMiner [Brehmer, Cranmer, Espejo, FK 1907.10621]

* python package

* MadGraph add-on

* automizes all steps of analysis

* already used for Pheno studies

[Brehmer, Dawson, Homiller FK, Plehn, 1908.06980]

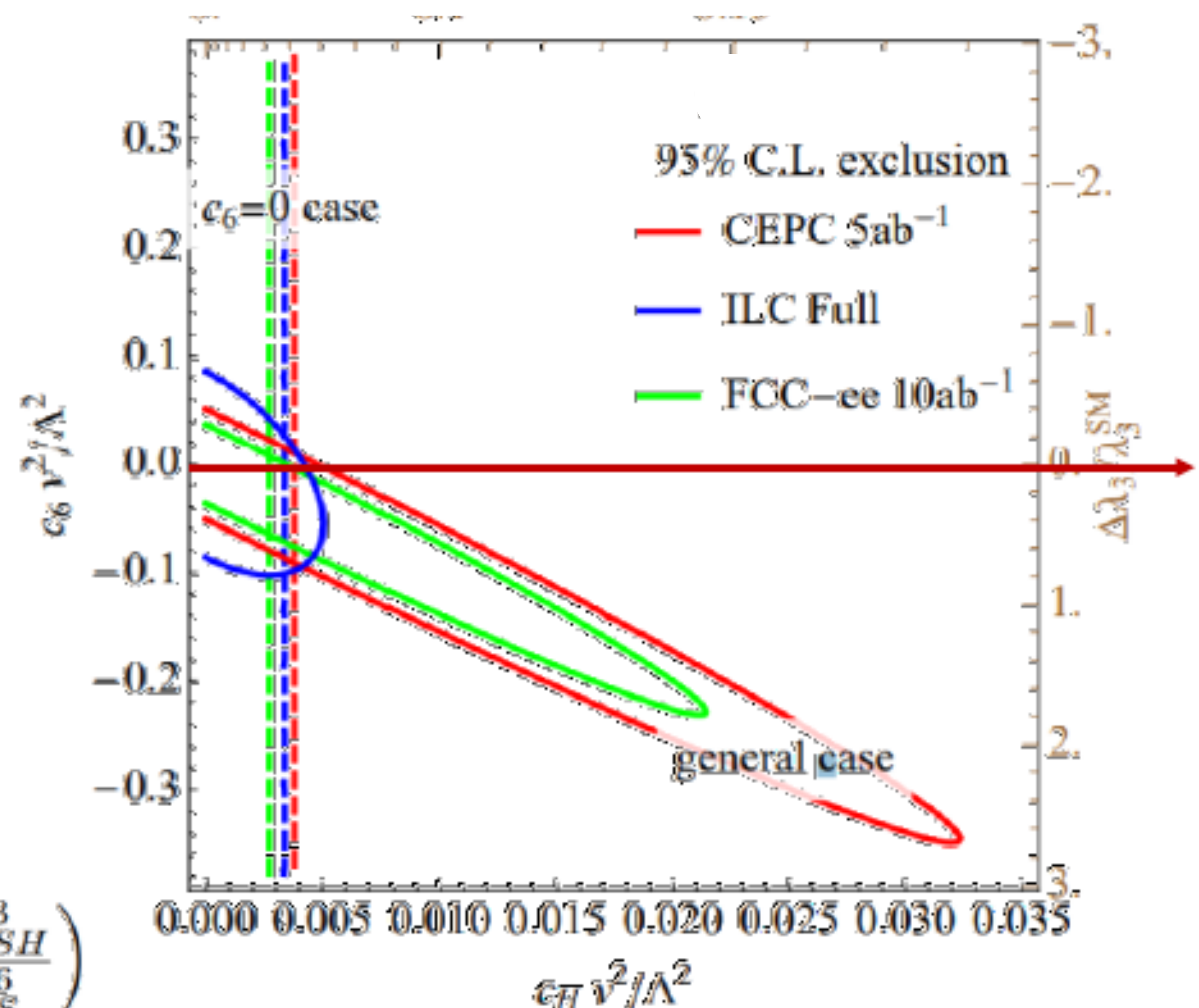
HL-LHC and future colliders

Zhen Liu

Operators generated at both tree-level (only in Z2 breaking) and loop-level (leading when Z2 present)

$$\frac{c_H}{\Lambda^2} = \frac{\lambda_{SH}^2}{48 m_S^2 \pi^2}, \qquad \frac{c_6}{\Lambda^2} = -\frac{\lambda_{SH}^3}{48 m_S^2 \pi^2}.$$

$$\frac{c_H}{\Lambda^2} = \frac{A_{SH}^2}{m_S^4}, \qquad \frac{c_6}{\Lambda^2} = \left(-\frac{\lambda_{SH} A_{SH}^2}{2 m_S^4} + \frac{A_S A_{SH}^3}{6 m_S^6}\right)$$



Input from division members

Neutrino physics cross sections

- Zelimir's proposal: focuses on enhancing the science portfolio of DUNE
  - Scientific goal: improve predictions for neutrino-argon cross sections. An open topic within the long-baseline community.
  - Potential multi-divisional, multi-institutional collaboration since broad expertise is needed: ANL HEP and FNAL for neutrino physics expertise, ANL PHY for nuclear cross section calculations, HPC expertise
  - Scientific steps: calculate "PDFs" for Argon; improve generators for particle propagation through nuclear media.
- Caveat: while neutrino-nucleus scattering is an interesting topic that can get traction with the DOE, it is not clear if there is expertise in HEP to do that.
- Peter Winter: potential input from EFTs used to describe muon capture that could be useful for neutrino scattering.

ATLAS & SMEFT

- Ongoing effort at ATLAS using SMEFT through the work of Jessica Metcalfe on Anomalous Gauge Couplings measurements.
- SMEFT framework currently used to put constraints on triple and quartic anomalous gauge couplings.
- Current analysis done turning one or two operators at a time. Can one perform a more global study with numerous operators on simultaneously?
- Jeremy and Frank: potential for further communications between ATLAS and theory regarding how SMEFT motivates new analyses; should be pursued further and conveyed to the DOE.

Additional feedback

- Carlos: could we use SMEFT to study future lepton collider phenomenology. Simpler cross sections to measure/calculate. How much has been done in this direction?
- Geoff: global fits of SMEFT are subject to many pitfalls, including flat directions, and will be difficult to pursue.
- Jeremy: ANL ATLAS would be happy to get theorist feedback regarding potential SMEFT operators that can be constrained and work together on that.
- Frank: look for smart observables to remove flat directions in SMEFT fits; may motivate experimental analyses that could be pursued jointly with ATLAS or other division experimental groups.
- Ian: need to find a niche to contribute to SMEFT, this effort has already started in Europe with bigger collaborations.
- Salman: presenting several topics that connect various efforts within the division and lab is what we are looking to tell the DOE. Machine learning is a potential area of overlap between cosmology and other efforts.

My take from our pre-meeting discussion

- SMEFT: an idea that parts of the division can have collaborative effort around. Potential areas of overlap are *Machine Learning* (ATLAS/Cosmology/Theory groups) to improve global fits of SMEFT parameters, *Higher Order Corrections* in SMEFT, and *novel measurements* inspired by SMEFT (Theory/ATLAS). These may also require large computing resources, allowing us to utilize ALCF resources and HEP expertise in this direction.

- Experimentally, a framework that would allow to preserve the plethora of information from the current and future precise data. Already being used by experimentalists.

- It is not a perfect formalism, still many areas of improvements. Global fitting for example is still at an early stage and we are still learning how to deal with the large parameter space of SMEFT to have realistic bounds. However smaller collaborations have been formed elsewhere to work on this, using Machine Learning as one of the sophisticated tools. We have expertise in this division in this direction.