Snowmass 2021
EF09 - BSM

More general explorations

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https://snowmass21.org/energy/bsm_general

May 21st 2020
Energy Frontier Workshop

EF09 - BSM: General exploration

- This topical group aims to study the sensitivity of Beyond Standard Model (BSM) phenomena for future experiments in the energy frontier.
  - Particular emphasis is given to signatures that appear in a large variety of BSM extensions.

- Aim to collect and coherently organize studies on these broad set of topics

- Organization:
  - Kick-off meeting held on May 8th: https://indico.fnal.gov/event/24355/
  - Bi-weekly meetings on Fridays @ 12:00 (noon) Eastern time starting on May 29th
    - Can doodle new time later on if needed, depending on participation/interests
  - Meetings announced on the mailing list and on slack

- Please help us to reach out to the community and encourage participation!

EF09: Group's topics

Started with an *initial* set of broad topics that fit the purpose of this group

- New Fermions:
  e.g. Top partner, Sterile Neutrinos, excited quark/leptons, (contact interactions)

- New Bosons:
  e.g. W', Z', including diboson resonances

- Long-Lived Particles signatures

- Dark/Hidden sectors

- EFT interplay with BSM

- Model "agnostic/independent" searches

- ...

In the following, I will provide some selective summary results from recent planning activities. There are gaps and new opportunities to be identified by our collective work.
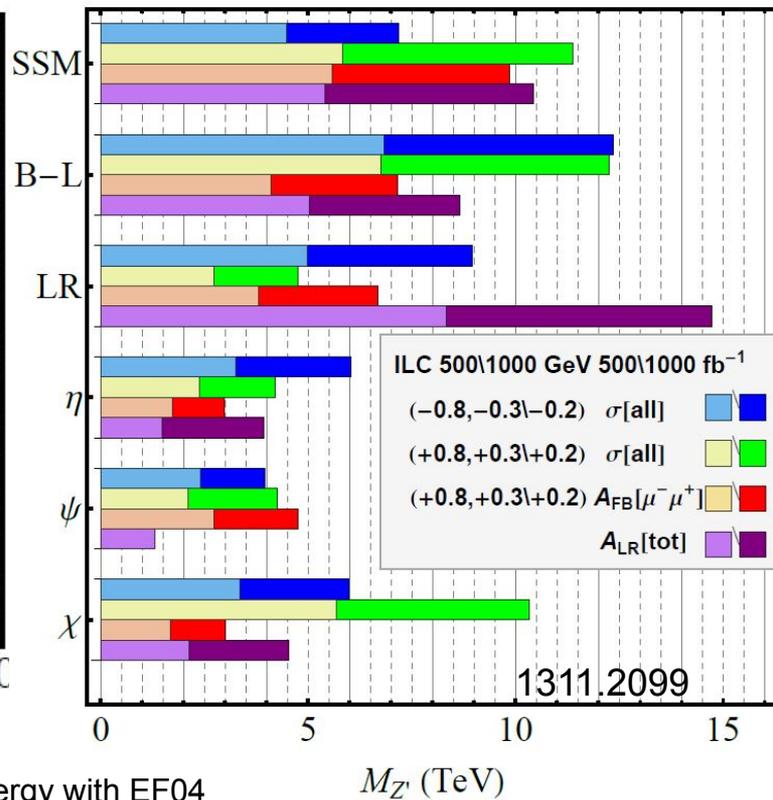
New Resonances

Y−Universal Z', 2σ

1910.11775

ILC 500\1000 GeV 500\1000 fb⁻¹

1311.2099
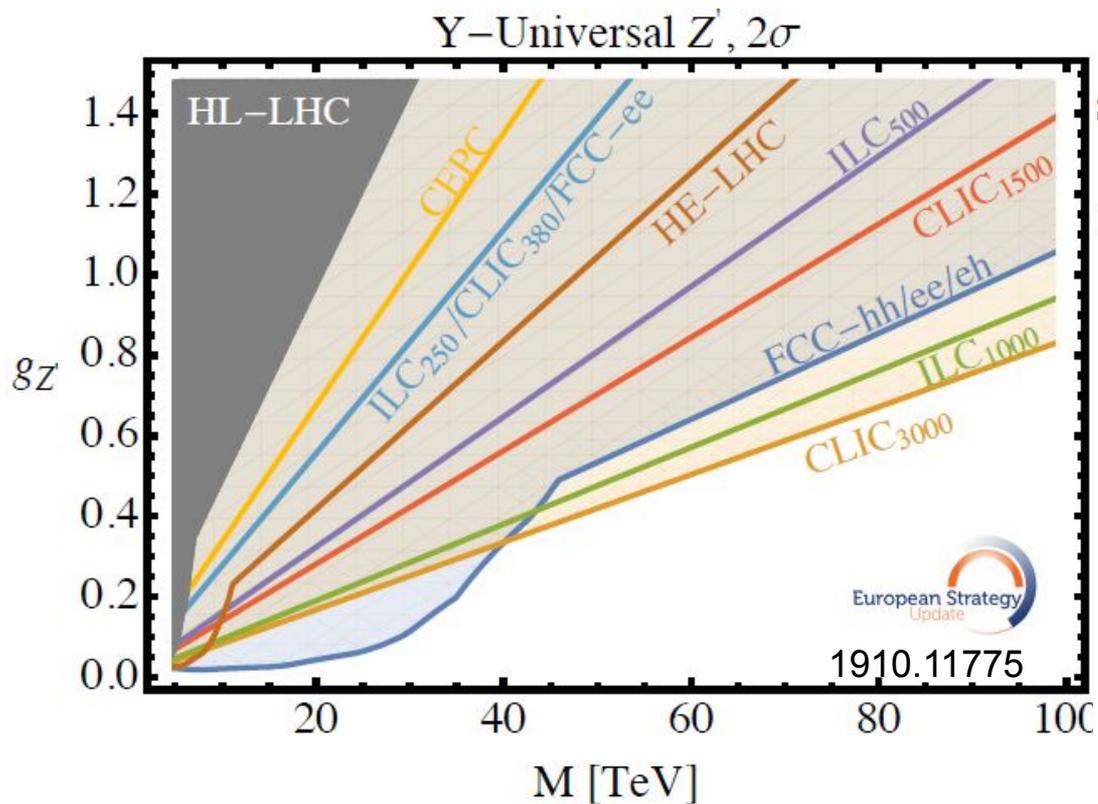
Synergy with EF04

New Resonances

Rich future programs

Resonance v.s. Precision

Many different channels

- Leptophobic scenarios (Z'→tt, W' →tb, …)
- Diboson resonance searches
- Searches with 3rd generation particles (Z' → tau tau)
- ….

Important to address experimental challenges e.g. high pT lepton reconstruction, fully exploit boosted topologies, develop state-of-the-art W/top/Higgs taggers.

FCC-hh / HE-LHC Simulation (Delphes)

95% CL Limit
- 1 ab⁻¹
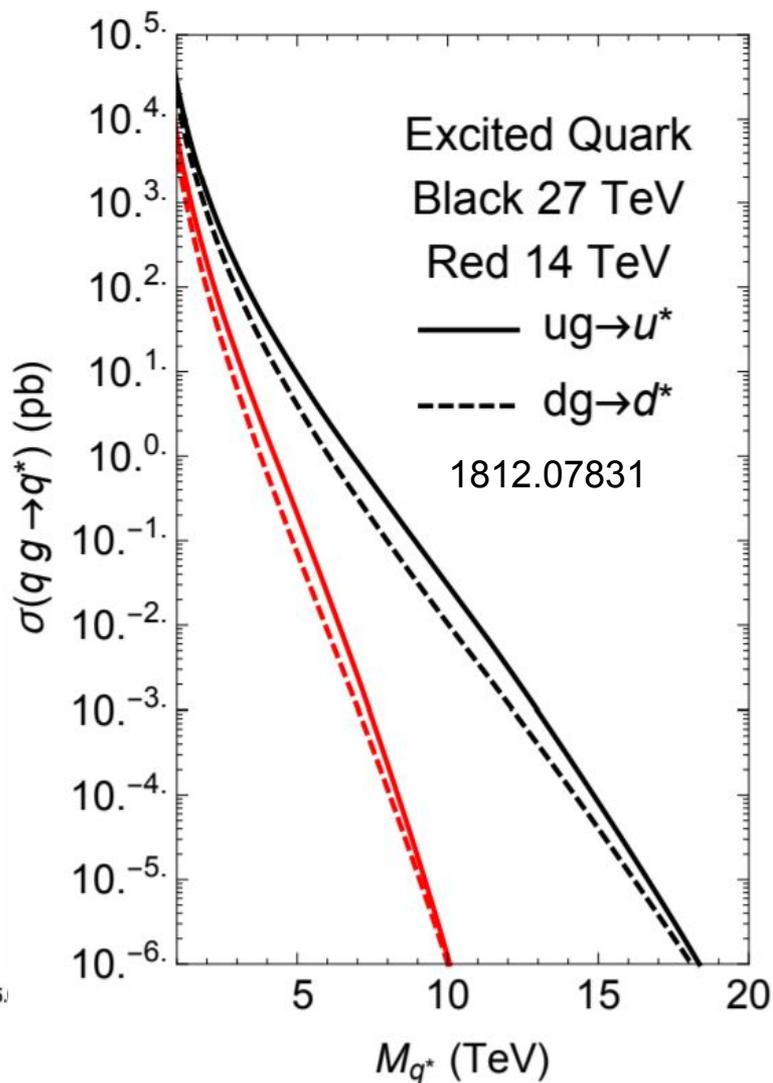- 2.5 ab⁻¹
- 15 ab⁻¹
- 30 ab⁻¹
- 100 ab⁻¹
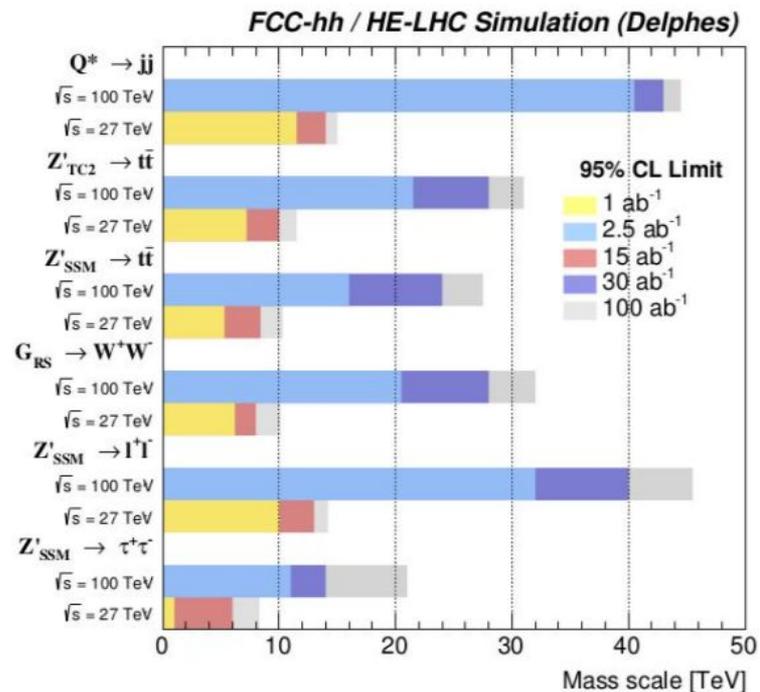
New Resonances (fermions)

- Excited quarks/leptons
- Top partners (e.g. Vector-like quarks)
- ...

Several questions to address incl how to fully exploit boosted topologies, develop state-of-the-art W/top/Higgs taggers

VLQ X(5/3) discovery reach (pair production)

Preliminary, Granada 2019

European Strategy Update

Mass [TeV]

Excited Quark
Black 27 TeV
Red 14 TeV

$ug \rightarrow u^*$
$dg \rightarrow d^*$

1812.07831

$\sigma(q\,g \rightarrow q^*)$ (pb)

M_{q^*} (TeV)
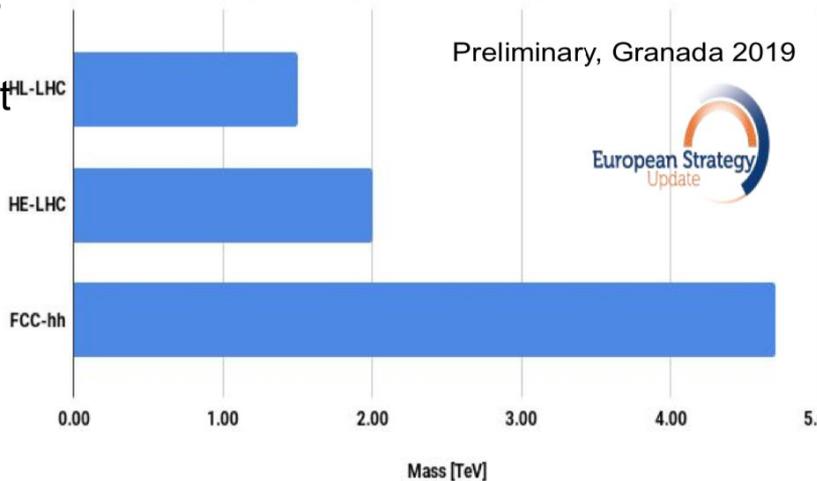
General Long-Lived Particles

- A lot of growing interest especially in the recent years
  - Many results from LHC, but also from b-factories and dedicated experiments
  - The field has grown a lot since the last Snowmass report
- Many signature-driven searches, depending among other things on:
  - Charge: +-1, neutral, multiply-charged, fractional, m/μ-charged,..
  - Lifetime compared to experiment size
  - "Peculiar" properties, e.g. "monopoles", quirks, ...
- Strong interplay with detector design!
  - how to reasonably approach projection for detectors at early stage of design?
  - how can we take advantage and/or shape future development in detector technology?
- Use existing experience to agree on benchmarks for comparisons
- Inter-experimental efforts exist
  - LHC LLP, Physics-Beyond-Colliders,..
  - Also large interplay with other Snowmass frontiers

LLP spectra

- Interplay with "prompt" searches
  - "Prompt" search probes shortly long-lived regime
  - MET + X: interplay with DM searches (synergy w EF10)
- "Direct" detection, charged massive particles:
  - Disappearing track, highly ionizing particles
  - Signature for minimal Dark Matter, as well as Wino and Higgsino considerations (synergy w EF08)
  - Room for new ideas and complementary probes (e.g., appearing tracks);
- "Indirect" detection through decay products
  - Non-pointing / delayed photons
  - Displaced lepton(s) / jets / etc.. detected with Various sub-detectors (tracker, calo, muons, …)

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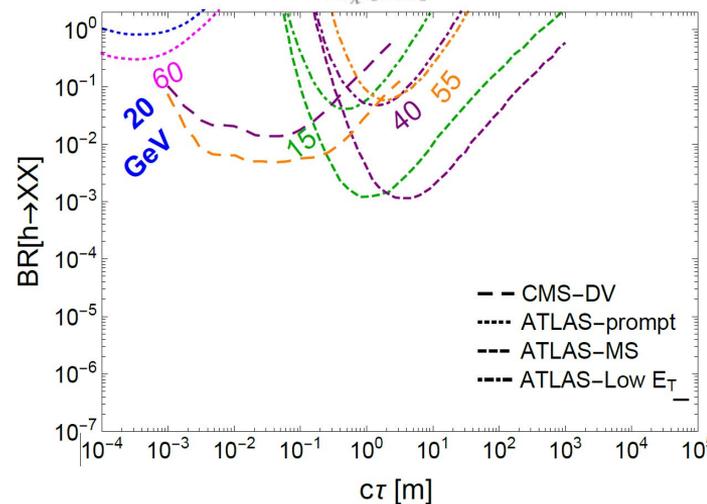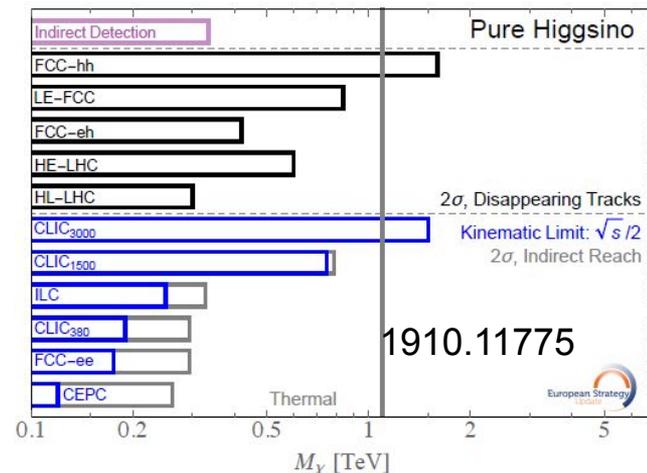
LLP spectra

- ## Heavy Stable Charged Particles
  - Fractional charged and millicharged will also be interfacing with other topical groups from Rare Processes & Precision Frontier and Accelerator Frontier;

- ## Neutral particles
  - Interplay again with MET+X
  - New trigger & analysis ideas
  - Additional "external" detectors
    - Many could be realized already during HL-LHC!
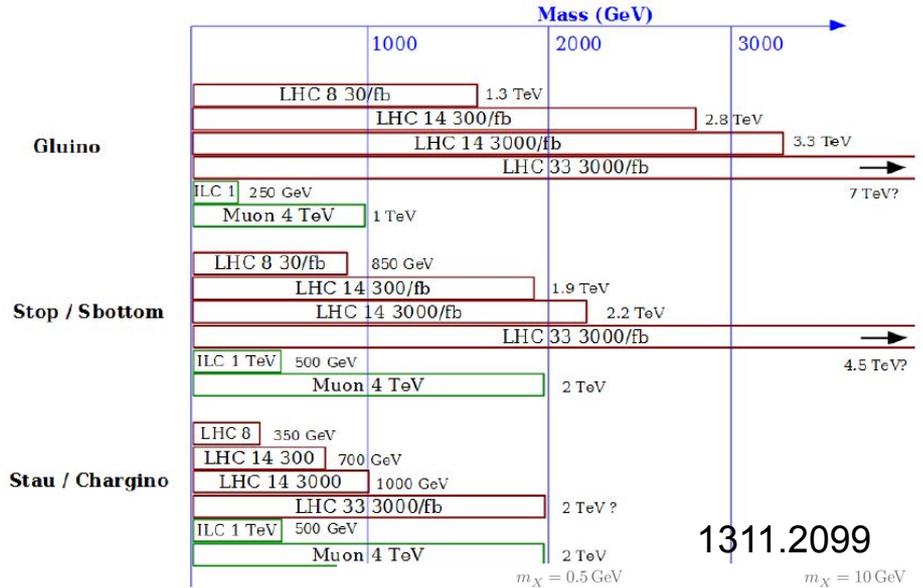
1311.2099
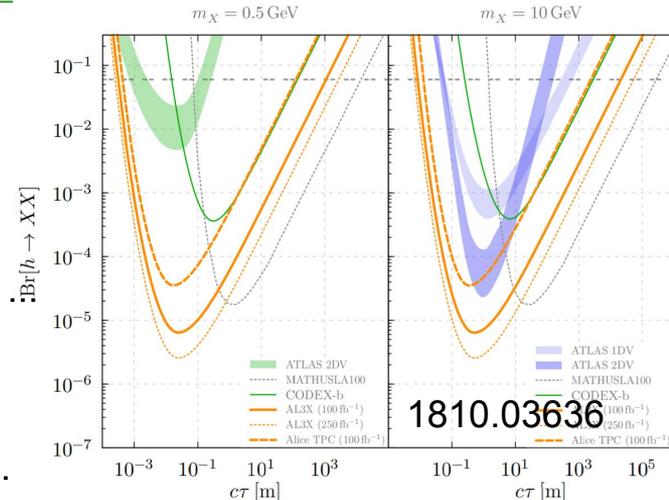
MTD, HGTD, HGCal, ...
FASER, MilliQan,
Codex-B, Mathusla,
AL3X, ANUBIS, ...
SHiP, LBNE, NA62, ...

1810.03636

Dark Sector, light resonance & LLPs

A "standard" set of portals exists

Coupling structure very rich

Very active field:

- New trigger & analysis ideas
- (New) satellite exp proposals
- Interfacing with other frontiers (e.g., Rare & Precision frontier, cosmo frontier)

Q: How to coordinate different groups to ensure a consistent (e.g., background estimation) output?

Portal	Coupling
Vector (Dark Photon, A_μ)	$-\frac{\varepsilon}{2\cos\theta_W}F'_{\mu\nu}B^{\mu\nu}$
Scalar (Dark Higgs, S)	$(\mu S + \lambda_{HS}S^2)H^\dagger H$
Fermion (Sterile Neutrino, N)	$y_N LHN$
Pseudo-scalar (Axion, a)	$\frac{a}{f_a}F_{\mu\nu}\tilde{F}^{\mu\nu}, \frac{a}{f_a}G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}, \frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$

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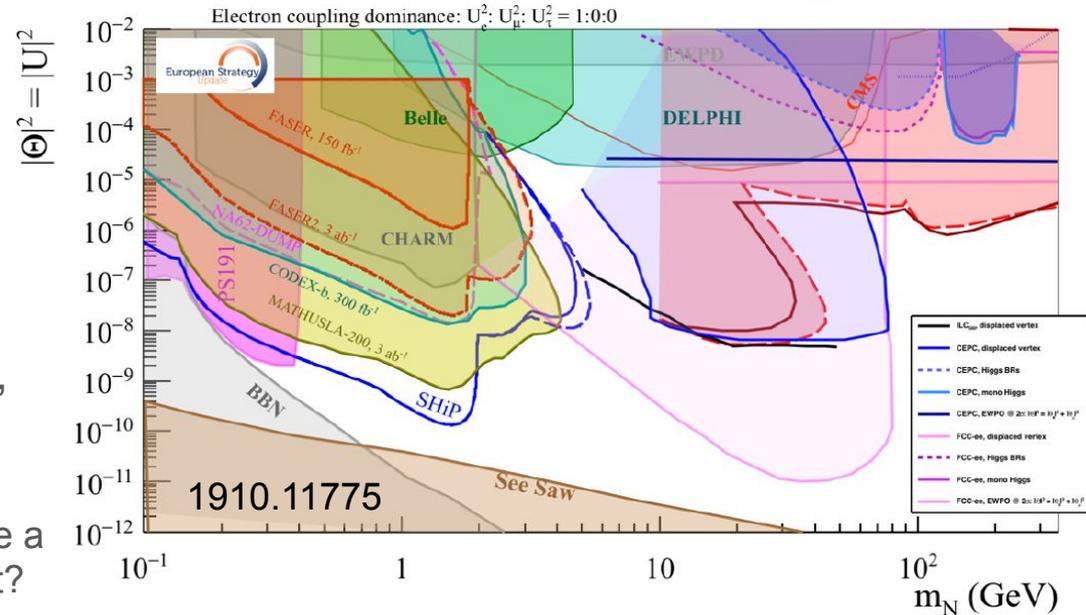
Model Agnostic Searches

Lot of interest in using Machine Learning/AI techniques

Anomaly detection at both trigger and analysis level

Also other techniques for special, unexpected signals:

Zero-bias events, data parking, early-alarming, etc.

Signal Region **Sideband**
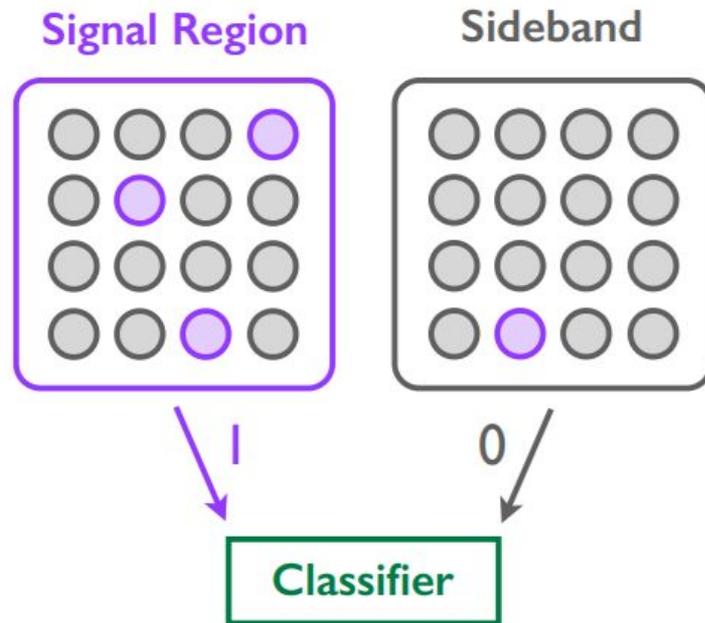
Classifier

With enough data, monotonic w.r.t. optimal classifier (!)

[Collins, Howe, Nachman, 1805.02664, 1902.02634; using Metodiev, Nachman, JDT, 1708.02949; see also Blanchard, Flaska. Handy. Pozzi. Scott. 1303.1208; Cranmer, Pavez, Louppe, 1506.02169]
D. Shih et al, 2001.05001, 2001.04990

Synergy with Theory Frontier & Computation Frontier

Fig. from J. Thaler's Pheno 2019 talk also M. Perelstein's ML4jets 2020 talk

Upcoming events

May 29th: New Resonances

June 12th: General Long-Lived Particles

June 26th: Exotica (incl. new fermions, new tools, …)

July 9-10th: two-day Energy Frontier workshop

July 23-24th: Dark Sector and light Long-Lived Particles (jointly with RF06 and EF10)

Snowmass is open to everyone and physics-oriented
Please join us!

Contributing to EF09

- Join our bi-weekly meetings!
  - Even if time is limited, ideas and critical reviews of other people's work and general discussions!
- Fill simple Google form "Express of Interest"
  - Study you're interested / planning to perform
  - Ideas for which you seek collaborators!
  - Topics you're interested in collaborating with others
  - https://forms.gle/1freqMHfTjAobga86
- Submit Letter-of-Intent: https://www.snowmass21.org/docs/upload.php

We've received ~35 EOI's, about 50% are dark sector+LLPs, 25% New Resonances, 25% Exotica (anomaly detection, new tools, etc.) We plan to make some of the information more public (upon agreement from the submitters) for easier formation of collaborations.

Expression of Interest: Snowmass 2021 - EF09

Please use this form to communicate your interest in either performing a study or join studies in a particular area.
For more information on activities covered by this group see also the twiki page:
https://snowmass21.org/energy/bsm_general

* Required

Email address *

Your email

Full name *

Your answer

Other Collaborators

Your answer

Topic (short) *

Your answer

Description or Comments (short paragraph)

Your answer

References (if any)

Your answer

Submit

Thank you!

Conveners	Tulika Bose, Zhen Liu, Simone Pagan Griso (more contact info)
Mailing-list	SNOWMASS-EF-09-BSM_GENERIC@FNAL.GOV (instructions)
Slack channel	ef09-bsm_generic (instructions)
Next Event	May 21st 8am ET, general Energy Frontier Kick-off Meeting
Expression of Interest	https://forms.gle/1freqMHfTjAobga86

EF09 synergies with other groups

Inevitable that topics overlap (bi-directionally) with other groups

- Example of topics EFX -> EF09
  - MET signature as mono-X (EF10: dark-matter)
  - EFT studies in the electroweak sector (EF04: EWK precision)
  - Etc.. etc..
- Example of topics EF09 -> EFY
  - SUSY Higgsino combinations incl. LLP (EF08: BSM model-specific)
  - Etc.. etc..

While some initial effort was done to try to divide topics, it will really be a fluid discussion and close collaboration with various groups

EF09 synergies with other frontiers

Quite some synergy with other frontiers as well

- Intensity frontier, e.g.
    - complementarity in dark photon searches, e.g. LDMX
    - see also [Physics-Beyond-Colliders](#) CERN study group
- Instrumentation frontier
    - New detectors and capabilities that enable new signatures (e.g. triggering strategies for LLPs with timing detectors)
- Computational frontier
    - model-agnostic BSM physics using Machine learning techniques
- Theory frontier
    - Collider phenomenology, BSM model building, ...

For all synergistic activities, the aim is to follow the relevant developments and have dedicated reports/joint discussions when needed and beneficial.

Plans for next meetings

Initial planning for the upcoming meetings:

- Review of existing (e.g. European Strategy, CDRs, ..) studies for dedicated topics and collider/experiments options
  - Discussion and input from the community is critical to identify areas where further development is encouraged!
- Start discussion on some core common benchmarks that are critical for cross-experiment comparisons and define "must-have" studies for the report

EF09: Topics and plans

- Snowmass 2021 report target: Synthesis of existing (and new) studies - aim to have a set of core benchmarks that can give an overview and allow cross-comparison
  - Consistency of assumption plays a key role
- Equally important to highlight specific models/questions that can be particularly suited for approach/machine X
- In addition to existing future collider project, a natural fit for this group are "side-experiments" that maximize the reach of proposed colliders
  - An easy example are dedicated experiments searching for long-lived particles
    Examples from current collider: Faser, Mathusla, Codex-b, etc…
- Being a BSM "Generic" group, we welcome new ideas/experiments that fit the energy frontier topic and can bring excitement to the community!

Collider	Type	$\sqrt{s}$	$\mathcal{P}$ [%] $[e^-/e^+]$	N(Det.)	$\mathcal{L}_{inst}$ $[10^{34}]$ $cm^{-2}s^{-1}$	$\mathcal{L}$ $[ab^{-1}]$	Time [years]	Refs.	Abbreviation
HL-LHC	pp	14 TeV	—	2	5	6.0	12	[13]	HL-LHC
HE-LHC	pp	27 TeV	—	2	16	15.0	20	[13]	HE-LHC
FCC-hh$^{(*)}$	pp	100 TeV	—	2	30	30.0	25	[1]	FCC-hh
FCC-ee	ee	M_Z	0/0	2	100/200	150	4	[1]	
		$2M_W$	0/0	2	25	10	1–2		
		240 GeV	0/0	2	7	5	3		FCC-ee$_{240}$
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5		FCC-ee$_{365}$
							(+1)		(1y SD before $2m_{top}$ run)
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	[3, 14]	ILC$_{250}$
		350 GeV	±80/±30	1	1.6	0.2	1		ILC$_{350}$
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5		ILC$_{500}$
							(+1)		(1y SD after 250 GeV run)
		1000 GeV	±80/±20	1	3.6/7.2	8.0	8.5	[4]	ILC$_{1000}$
							(+1-2)		(1–2y SD after 500 GeV run)
CEPC	ee	M_Z	0/0	2	17/32	16	2	[2]	CEPC
		$2M_W$	0/0	2	10	2.6	1		
		240 GeV	0/0	2	3	5.6	7		
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8	[15]	CLIC$_{380}$
		1.5 TeV	±80/0	1	3.7	2.5	7		CLIC$_{1500}$
		3.0 TeV	±80/0	1	6.0	5.0	8		CLIC$_{3000}$
							(+4)		(2y SDs between energy stages)
LHeC	ep	1.3 TeV	—	1	0.8	1.0	15	[12]	LHeC
HE-LHeC	ep	1.8 TeV	—	1	1.5	2.0	20	[1]	HE-LHeC
FCC-eh	ep	3.5 TeV	—	1	1.5	2.0	25	[1]	FCC-eh

pp

ee

ep

Christophe Grojean   Higgs@Future Colliders WG