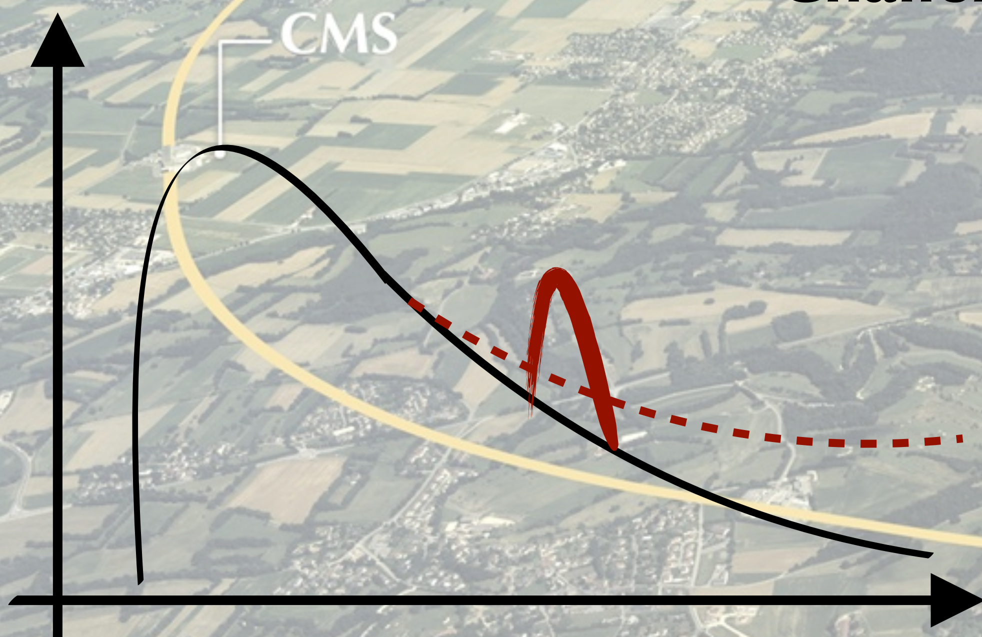
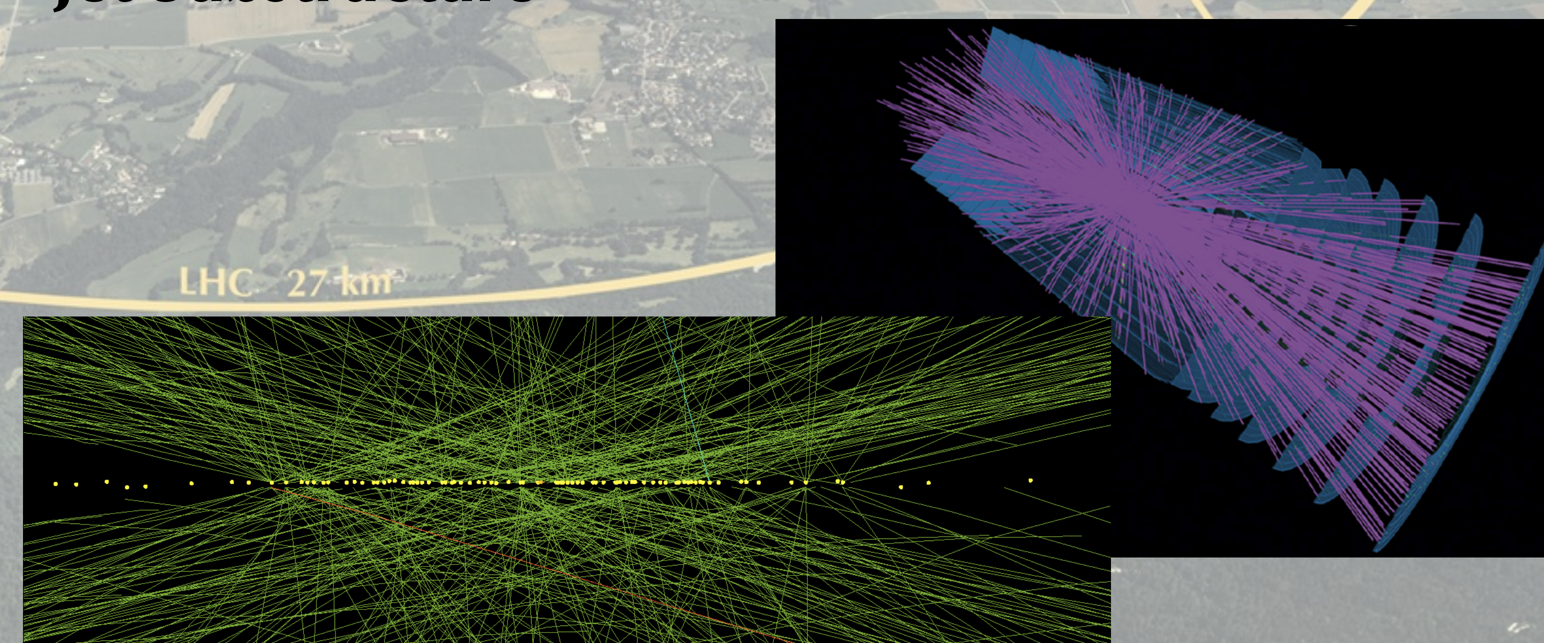
West Coast LHC Jamboree

October 22-23 SLAC

Precision — Higgs & SM
BSM Higgs
BSM direct searches
LLPs

Challenges ahead for Run 3 and Run 4:
Trigger
Tracking
Jet Substructure





thanks!

This meeting

- **Thanks to you all** for joining and contributing to the very interesting discussions
- Next one will be in Spring 2020
  - We will circulate a doodle to find the best dates
  - Please fill the survey and provide feedback *https://indico.cern.ch/event/848030/surveys/1163*

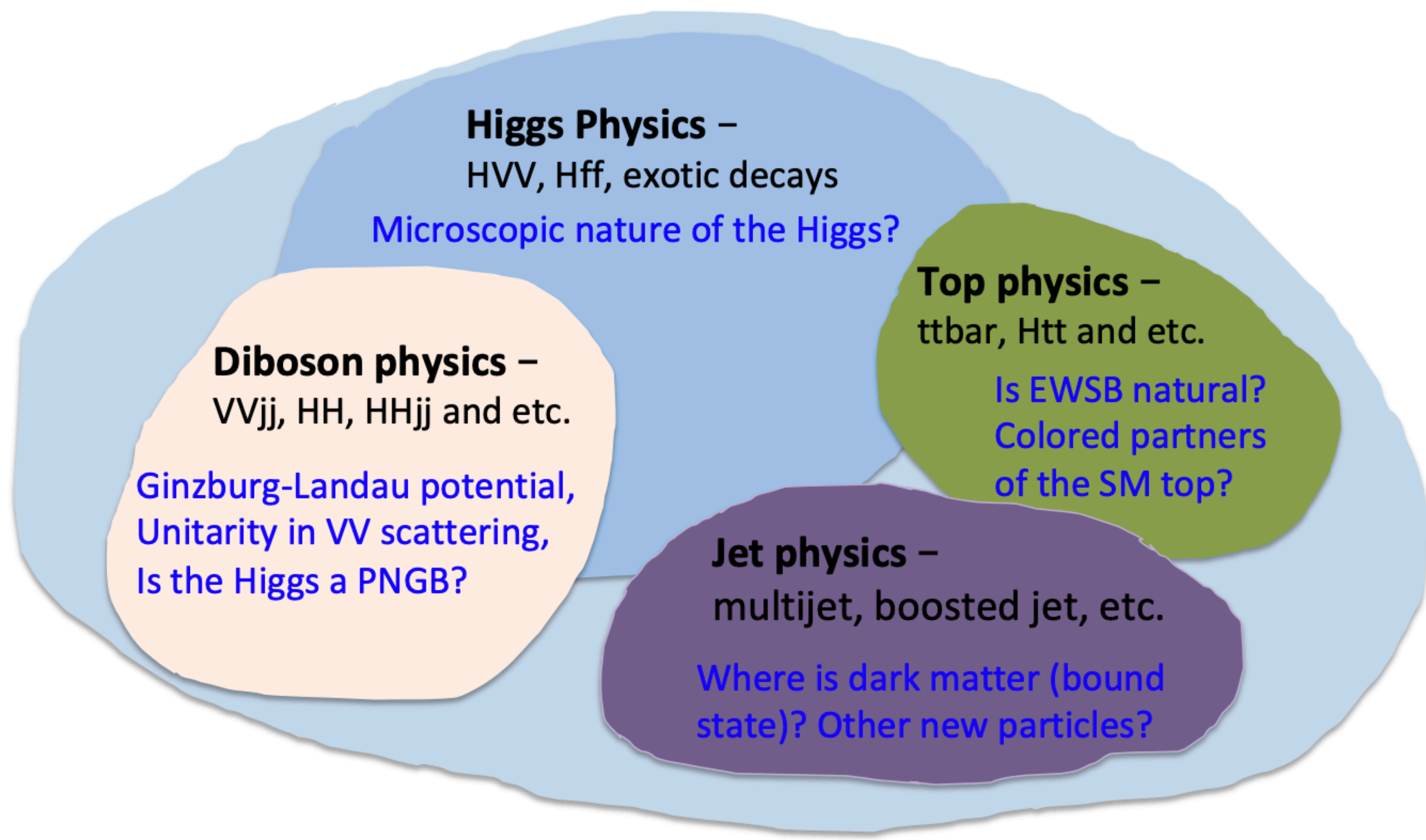
Summary …

Ian Low

- The Higgs boson is the most exotic state of matter in Nature.
- The electroweak criticality is the most bizarre type of quantum criticality.
- Our understanding is still preliminary, at the level of Ginzburg-Landau picture for the superconductivity.
  Need to pin down a microscopic picture.

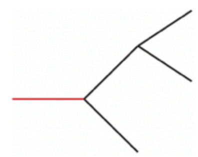
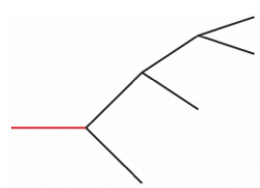
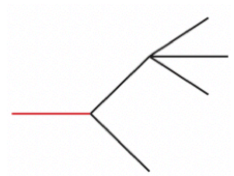
The LHC has only collected 5% of its designed luminosity. The work has really just begun!

Standard Model



Zhen Liu
Wolfgang Altmannshofer
SLAC

Coverage & Potential

Decay Topologies	Decay mode $\mathcal{F}_i$
 $h \to 2$	$h \to \not{E}_T$
$h \to 2 \to 3$ 	$h \to \gamma + \not{E}_T$
	$h \to (b\bar{b}) + \not{E}_T$
	$h \to (jj) + \not{E}_T$
	$h \to (\tau^+\tau^-) + \not{E}_T$
	$h \to (\gamma\gamma) + \not{E}_T$
	$h \to (\ell^+\ell^-) + \not{E}_T$
$h \to 2 \to 3 \to 4$ 	$h \to (b\bar{b}) + \not{E}_T$
	$h \to (jj) + \not{E}_T$
	$h \to (\tau^+\tau^-) + \not{E}_T$
	$h \to (\gamma\gamma) + \not{E}_T$
	$h \to (\ell^+\ell^-) + \not{E}_T$
	$h \to (\mu^+\mu^-) + \not{E}_T$
$h \to 2 \to (1+3)$ 	$h \to b\bar{b} + \not{E}_T$
	$h \to jj + \not{E}_T$
	$h \to \tau^+\tau^- + \not{E}_T$
	$h \to \gamma\gamma + \not{E}_T$
	$h \to \ell^+\ell^- + \not{E}_T$

Still a lot of uncharted territory for new searches!

Can be conquered using upcoming LHC runs with advanced <u>analysis tools</u> and <u>new detectors</u>.

For existing searches, there are new possibilities such as unequal masses, etc.

Decay mode $\mathcal{F}_i$
$h \to (b\bar{b})(b\bar{b})$
$h \to (b\bar{b})(\tau^+\tau^-)$
$h \to (b\bar{b})(\mu^+\mu^-)$
$h \to (\tau^+\tau^-)(\tau^+\tau^-)$
$h \to (\tau^+\tau^-)(\mu^+\mu^-)$
$h \to (jj)(jj)$
$h \to (jj)(\gamma\gamma)$
$h \to (jj)(\mu^+\mu^-)$
$h \to (\ell^+\ell^-)(\ell^+\ell^-)$
$h \to (\ell^+\ell^-)(\mu^+\mu^-)$
$h \to (\mu^+\mu^-)(\mu^+\mu^-)$
$h \to (\gamma\gamma)(\gamma\gamma)$
$h \to \gamma\gamma + \not{E}_T$
$h \to (\ell^+\ell^-)(\ell^+\ell^-) + \not{E}_T$
$h \to (\ell^+\ell^-) + \not{E}_T + X$
$h \to \ell^+\ell^-\ell^+\ell^- + \not{E}_T$
$h \to \ell^+\ell^- + \not{E}_T + X$

Zhen Liu Direct BSM WCJ@SLAC

For a comparative study wi

Many examples of models where other couplings dominate

- coupling to 2nd (or even 1st) gen. could dominate
  $c\bar{c} \to H \to \mu\bar{\mu}$?
- flavor violating couplings could be relevant
  $cg \to tH \to tt\bar{c}$? $H \to \tau\bar{\mu}$?
- exotic decays ($\to$ talk by Zhen Liu)
  neutralinos, staus, hidden sector glueballs, ...

Moving forward

Zhen Liu

Experimental Opportunities (or theory input pressures):
- Go differential;
- Go compressed & soft;
- Go complex (features or topology);
- Go exotic (with new search ideas);
- Go reference free (anomaly detection)(e.g., Collins, Howe, Nachman, 1805.02664, Hajer, Li, Liu, Wang 1807.10261);

Machine Learning can help handle (see B. Nachman's talk next) and Hardware (upgrades, triggers) are crucial for some of these challenging tasks (see Arial Schwartzmann, S. Pagan Griso, L. Tompkins et al's discussion)

What's next?

Can machine learning help?

Inference Techniques

Traditional

- use summary statistics
  * hand-picked observables x'
  * estimate p(x'|θ)
- information loss
- problem dependent

Examples:

- rate only (cut and count)
- histograms
- Approximate Bayesian Computation
- STXS

Machine Learning

- multivariate analysis
- works great for S vs BG
- struggles with S' vs S
  * large number of S'
  * very similar S', S

Examples:

- Neural Density Estimator
- ML Classifier

Matrix Element Based

- multivariate analysis
- uses $p(x|\theta) \sim |M(x|\theta)|^2$
- works great at parton level
  * S' vs S is easy
- requires approximations in reality
  * S vs BG can be hard

Examples:

- Matrix Element Method
- Optimal Observables

power of machine learning → **MadMiner** ← physics insight of matrix element information

[J. Brehmer, K. Cranmer, G. Louppe, J. Pavez 1805.00013, 1805.00020,1805.12244]

[J. Brehmer, FK, I. Espejo, K. Cranmer 1907.10621]

Are we triggering on New Physics?

- Run III: factor of ~three in luminosity - need to be creative
- Limitations from the L1 Trigger are present at least till we have the full detector in L1 in HL-LHC
- Before then focus on improvements targeting specific physics models
  - Long Lived particle searches are enabled by new L1 trigger paths that provide displaced muon triggers without a vertex constraint
  - New HLT capabilities with pixel tracks using GPU accelerators
  - Upgraded HLT scouting program with Particle Flow capabilities
  - L1 scouting at 40 MHz is an interesting new case but we need a physics case to motivate it

Michalis Batchis

L1 gives us a fundamental limitation but is there more we can exploit at the HLT? Can we make a (realistic) wish-list for triggerable characteristics of events?

Lauren Tompkins

New opportunities

Javier Duarte

- Particle physics experiments face **extreme trigger challenges** in the coming years
- Exploiting **new algorithms**, **new hardware**, and **machine learning** will be key to the success of next-gen experiments
- Open questions:
  - With more sophisticated algorithms at earlier trigger, how do we ensure performance/safety? backup triggers?
  - What community tools do we need to deploy ML at the trigger?
  - Which co-processors are best suited to which tasks for the high-level trigger?
  - How do we incorporate timing information at the trigger level?
  - What are the physics use-cases for L1 scouting at 40 MHz?
  - What can we do with the new trigger hardware capabilities which we aren't thinking about?
  - L1 gives us a fundamental limitation but is there more we can exploit at the HLT?
  - Can we make a (realistic) wish-list for triggerable characteristics of events?

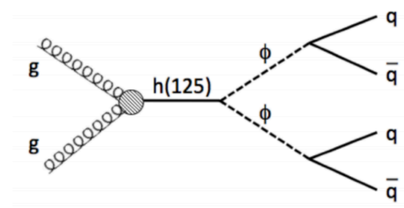
New opportunities

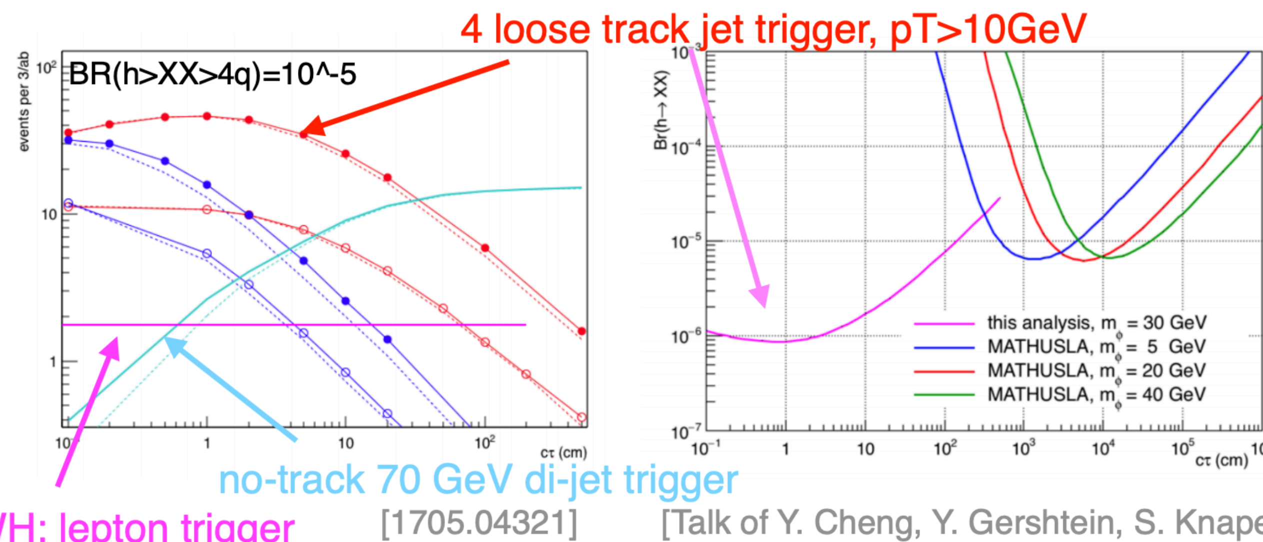
Felix Kling

Opportunities: Upgrades

Tracking in L1 Trigger

- considered by both ATLAS/CMS
  * mainly for pile up …
- CMS: use track stubs (pT>few GeV) at L1
- feasible to trigger on multiple soft track jets [1705.04321]
  * incl. displaced tracks to reduce rate



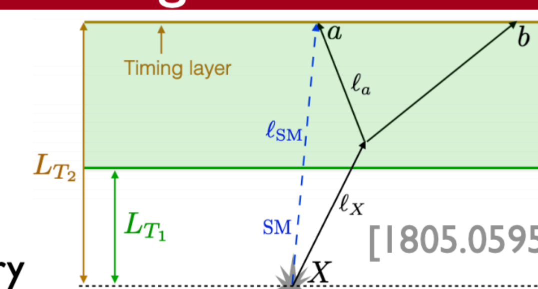


[1705.04321] [Talk of Y. Cheng, Y. Gershtein, S. Knapen]

Opportunities: Timing

Timing Layer and Delayed Searches

- 30ps resolution, mainly for pile up …
  * ATLAS High Granularity Timing Detector
  * CMS MPI Timing Detector
- delay due to heavy particle / longer trajectory
- timing for triggers?
- additional timing layers (around MS)?
- backgrounds?



[1805.05957]