SSI-2016 Projects

1. LIGO has recently observed gravitational radiation from ~20 solar mass black hole mergers at a distance of over ~10^9 light years. Circulating proton beams in an accelerator can also produce gravitational radiation at higher frequency. To be specific, consider a 100 TeV pp collider with a luminosity of $5x10^{35}$ cm^2 s^{-1} (and with the other parameters as for the FCC-hh). Assuming they are coherently produced, determine if a gravitational wave detector with 10x the LIGO sensitivity in the relevant frequency range could detect this radiation at a distance of 10^3 km; make any suitably justifiable approximations.

2. A 100 TeV hadron collider, even with very low integrated luminosities, would greatly extend the discovery reach for many kinds of new physics beyond that of the 3 ab^{-1} HL-LHC. However some kinds of NP might be more easily found by the HL-LHC with this lumi than at a 100 TeV collider with a much lower lumi, say 10 fb^{-1}. Give 3 examples of this type of NP explaining why this happens in each case and then show where the 'break-even' points are, i.e., where the 100 TeV machine with increasing lumi would finally surpass the reach of the HL-LHC.

3. Searches for vector-like quarks (VLQ) at the LHC usually assume that they decay via mixing with the Standard Model (SM) quarks of the 3rd generation. (a) How would such searches be altered if they decayed instead to the 1st generation? Estimate the corresponding search reaches in this case by employing the results of the existing searches performed by ATLAS & CMS. (b) VLQ searches also assume that these particles only decay into W, Z or Higgs final states so that the sum of the corresponding branching fractions is unity and this is used in combining the search results. How would this combination of results change if this strong assumption were to be dropped, e.g., there was a fourth possible final state?

4. Imagine that a new Z' boson is discovered at the LHC in the dilepton channel with a mass of 3.5 TeV & with a cross section of 0.5 fb. Many theories predict such states & the HL-LHC will eventually provide integrated luminosities of ~3 ab^{-1} that can be used to learn about it. To determine which, if any, of these theories is correct we need to measure the many couplings of this Z'. Search the literature & survey the set of such Z' models. Which measurements would you make to do this and roughly what would you expect for the measurement errors? Can these results tell us the Z' identity uniquely among the models you've surveyed? What non-hadron collider measurements in the future, if any, could be provide additional information?

5. If there turned to be a family of such Z’ bosons as in the previous question, with the next in the series having a mass of 10 TeV, what detector design challenges can you foresee

if you intend to fully explore the properties of such a Z' decaying into various final states at a 100 TeV pp collider ?

6. In the Type-I See-Saw mechanism, the small masses of the Standard Model Majorana neutrinos are generated through the existence of potentially TeV-scale right-handed neutrinos which are SM singlets. Such new particles are usually part of a more general theoretical structure. How can this picture be probed in detail at the LHC and/or at a possible future ~100 TeV collider? In particular what are the possible set of signals one might expect and at what rates? Can an e+e- collider be useful to elucidate this situation?

7. As the integrated luminosity of the LHC increases the mass reach for many kinds of new physics(NP) can 'saturate', i.e., the adding of more lumi does not significantly improve the mass reach (without a significant change in the analysis and/or detector). Develop a variable which can be employed as a measure of this effect. Using this quantifier, consider the following sample NP scenarios and determine where the mass reach plateaus are in each of the following cases for the 13 TeV LHC using current LHC search results as input:
   a) a Z' with SM couplings,
   b) a gluino decaying to jets + MET,
   c) a new heavy quark decaying to the 3rd generation,
   d) an excited quark formed as a resonance in gluon-quark fusion.

8. The observation of a signal in the monojet channel (single hard jet + missing transverse energy=MET) could be the first signal of Dark Matter(DM) production at the LHC or ~100 TeV collider. Imagine such a signal is observed at the 13 TeV LHC with a cross section of 0.3 fb after requiring at least 1 TeV of MET. Interpret this result within the framework of a Simplified Model which you construct and show how this DM scenario can be tested (or not) by the 500 GeV ILC and by direct & indirect DM detection experiments. What additional information would be obtainable from the ~100 TeV collider?

9. In the popular search for dark photons as a result of a simple U(1) extension of the SM with a small mixing to regular photons, how can ATLAS/CMS complement the many low energy experiments to cover the parameter space ? Any experimental strategy adjustment or upgrade opportunities can potentially extend the capabilities of ATLAS/CMS in this arena ?

10. Measurements of Hbb coupling so far are consistent with Standard Model expectations within errors, but the central values of signal strength μ are consistently below one. For example, the

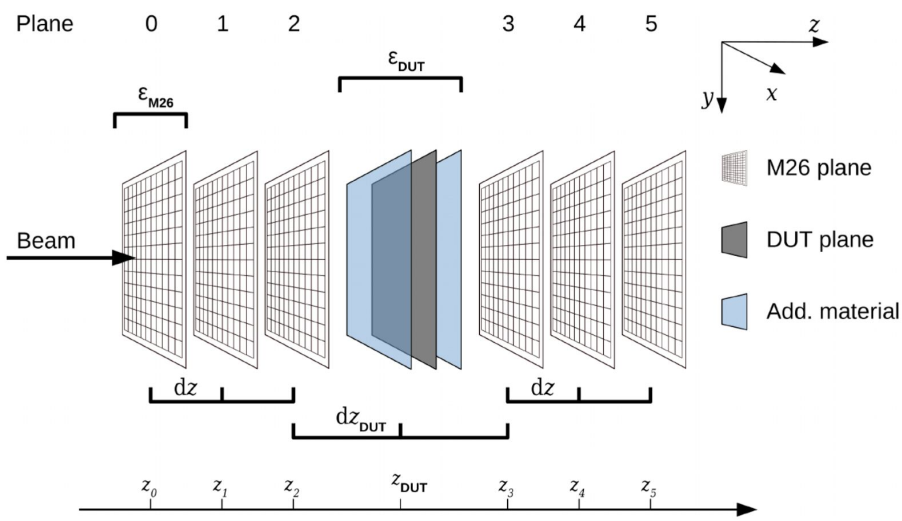
combined ATLAS+CMS Run 1:	μ	= 0.70 + 0.29 - 0.27
ICHEP ATLAS 2016:	μ(VH)	= 0.21 + 0.51 - 0.50

	μ(VBF+$\gamma\gamma$)	= -3.9 +2.8 -2.7
ICHEP CMS 2016	μ(ttH)	= -2.0 +1.8 -1.8
	μ(VBF)	= -3.7 +2.4 -2.5.

For this exercise, assume that μ for the bb channel is in fact 0.7. Further assume that all other measured μ values are 1. How would you extend SM Higgs sector to accommodate this? What further measurements at LHC and future facilities could verify your conjecture?

11. If the LHC Run-2 searches for additional heavy Higgs bosons has developed some possible hint for something at ~600 GeV, what are the key production and decay modes to follow up? and what improved experimental handle could be particularly profitable to enhance sensitivity ? What's the prospect of studying such heavy Higgs bosons at future colliders ?

12. Beam telescopes are crucial tools for probing the spatial resolution of new tracking devices, by providing a precision reference track trajectory at test beam. The EUDET beam telescope has 3 planes of MIMOSA-26 CMOS devices before the Device Under Test (DUT) and another 3 planes after the DUTs, as shown in diagram below. Each EUDET plane has 3.5μm spatial resolution and 0.1% radiation length material.



Please recommend the EUDET plane separation (dZ) configurations to optimize the reference telescope track precision at DUT for the following test beam sites:

i) CERN: 200 GeV pions;

ii) SLAC: 11 GeV electrons;

iii) DESY: 5 GeV electrons.

for the situations of a) compact setup with dZ(DUT)=2cm and no additional DUT material; b) a cooled irradiated DUT setup with a wide foam DUT box that has dZ(DUT)=15cm to allow service connections and rotations of cooled DUTs inside the box.

13. Parton showers describe how jets are formed in particle collisions, and are thus an essential part of modern high energy physics simulations. In this project, you will develop and write your own parton shower model for lepton colliders. You will also improve the calculation directly by implementing your own next-to-leading order QCD calculation, matched to your parton shower (see http://www.slac.stanford.edu/~shoeche/mcnet16/ws/PS.pdf for details).

    Once you have mastered your tool, it will be time to develop your own improvement ideas and test their effect at a future high-energy e+ e- collider. Since you now have your own code at your disposal, there are many options how you can proceed. Be creative in testing your understanding of what you have learned! Improve your simulation with other processes for a more realistic model of high-energy lepton annihilation!

14. High precision timing detectors, in conjunction with tracking devices, can provide a new capability to identify and reject jets from pile-up at the HL-LHC and at future colliders. Assume that collision vertices are distributed in z and ct with σ ~ 5cm in both dimensions and that the timing detector can measure the time of arrival of individual particles with an accuracy of 10 to 30ps. A silicon tracker can separate particles only in the z direction, typically with a resolution of 1mm for distinguishing different vertices. With a high precision timing detector, it is possible to further resolve those vertices which are within 1mm in z. This can be seen clearly if one plots 200 random vertices in the z - ct plane. Using this plot, estimate how many vertices are left by using a tracker detector with a 1mm z resolution, a timing detector with a 10ps resolution, and a combination of both. Please note that the arrival time of particles consist of two terms: a time-of-flight (assuming particles travel at the speed of light) from the vertex z position to the detector, plus the actual time of the vertex, In order to compute the first term, one needs to define the geometry of the detector: the z position and radius, and the angle of the particle (eta). As a simplification, you can consider the case of particles with eta~infinity (traveling along z) and a detector plane at Z = 5m. In this way, the time of flight is simply given by (5m-z_particle).

15. Sequential recombination jet algorithms at hadron colliders provide a powerful way to organize and interpret hadronic final states. Jet algorithms can be thought as a special case of unsupervised learning algorithms that take as input calorimeter topological clusters (ATLAS) or particle flow objects (CMS). A brief overview of unsupervised clustering algorithms can be found at https://en.wikipedia.org/wiki/Cluster_analysis. Discuss examples of unsupervised learning clustering techniques that could be used at the LHC and how they would differ from standard jet algorithms. Are there advantages/disadvantages? Are these algorithms infrared and collinear (IRC) safe? To test the IRC safety of a jet algorithms, one can use the following Toy Monte Carlo procedure: First, generate an event made of three hard partons. All jet algorithms should

find three jets made of each of the partons. Second, contaminate the event with a large number of very soft pT~10^-100 GeV particles uniformly distributed in y-phi. You can project particles into a 0.1x0.1 grid in y-phi space, which is roughly the segmentation of hadronic calorimeters at the LHC. Then, compute the fraction of times the jet algorithms successfully cluster the hard partons into single jets. See arXiv:0906.1833 Figure 5 (caption) for a description and example on how to test IRC safety.