Report from the Explore-the-Unknown Science Group:

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ETU Introduction

- Science Drivers
  - Beyond-standard-model physics via indirect (loop-induced) effects
  - Implies *precision measurements* looking for small deviations from the Standard Model
- Structure of parallel session
  - 4 talks in “Explore the Unknown” session (above)
    - Heavy quark physics (LHCb) [S.Stone]
    - Rare cLFV muon decays [S. Ritt]
    - Muon g-2 measurement [J. Kaspar]
    - Storage Ring EDM experiments (p, e, ^{2}H) [E. Stephenson]
  - 3 talks in joint session with Dark Matter
    - Axion searches [G. Carosi]
    - Dark matter searches [J. Mardon]
    - Ultralight dark matter searches [S. Rajendran]`

ETU Findings

- The exploration of small departures from SM is very active field making important contributions to particle physics.
- Loop-induced effects allow one to explore mass range of new particles well above collider reach.
- Experiments depend on intense beams and high interaction rates, so fast detectors and excellent time resolution are critical development areas for the future. Picosecond detectors are in demand.
- Picosecond time resolution not only reduces pileup, but also improves event reconstruction by giving an extra dimension in which to match objects (eg. photons to primary vertex, or hits to tracks).
- Tracking in cLFV muon experiments has similar challenges as LHC, but at much lower momentum (10-100 MeV/c).
- Planned accelerator upgrades will provide another x10-100 in intensity for potential next generation experiments (e.g. Mu3e phase 2, Mu2e-II).
- Accelerators are *the instrument* – not just a source – in (some) EDM searches.

ETU Comments

- Many interesting and challenging technical problems were discussed…
- Not all expressed technical needs were future-oriented… there are many powerful technologies available today…
- Current technology is still evolving and making big impact (eg. SiPMs)
- Some overarching themes emerged:
  - Picosecond time resolution
  - Streaming DAQ architectures
- These expts benefit from LHC instrumentation R&D, but still have to tailor results to their different needs

Identification of Risks and Opportunities

- The opportunities provided by planned accelerator improvements (e.g. HL-LHC, PIP-II, HiMB), and the returns on the substantial investment made, will not be fully realized without significant detector developments to match the accelerator upgrade.

- Advances in technology (largely paid for by consumers) make precision measurements possible today that simply were not possible in the past. Picosecond timing is a prime example.

Recommendations

- The funding agencies should be alert to R&D opportunities that address issues specific to these experiments so that next generation ETU experiments can take advantage of planned investments in accelerator upgrades
  - ie. LHC R&D only partially addresses the issues relevant for these experiments and some dedicated R&D efforts will be necessary

Possible Grand Challenge Ideas

(These ideas are not necessarily tied to the "Explore the Unknown" sessions.)

- **Novel Materials for Detectors**.
  - Lots to learn from our condensed-matter and nano-technology colleagues (graphene, nanoparticles,…)
- **Techniques for Low Mass Dark Matter Detection.**
  - The new push for underground experiments to probe sub-GeV masses, requires much lower thresholds and a leap in sensitivity & low-noise detection.
  - At ultra-low masses, axion and ALP searches have always depended on state-of-art, low-noise technology, and continue to push this frontier.
  - The intermediate range (1-100MeV) may also profit from new ideas
- **Fast Timing in Particle Detection**
  - The need, applications, and technical opportunities seem to be growing fast.
  - Advances will benefit *many* different detector technologies: calorimeters, tracking, particle ID,…

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