(WG1) Advanced accelerator instrumentation and controls.

The research efforts should be presented in terms of the laboratory group's contributions (as applicable) along the following programmatic thrust lines:

- Accelerator and Beam Physics (including modeling, simulation as well as beam instrumentation and controls)
- Particle Sources and Targetry
- Advanced Accelerator Concepts
- RF Acceleration Technology (including SRF, NCRF and RF Sources)
- Superconducting Magnets and Materials
- Test Facility Operations

This is a first pass at a list.

- Happy to add suggestions
- Happy to flesh out what we have so far
- **Email suggestions to:** Minty, Michiko <minty@bnl.gov>; Philippe Piot <piot@nicadd.niu.edu>; Power, John <jp@anl.gov>

DRAFT

(WG1) Advanced accelerator instrumentation and controls.

WG1 focused on exploring possible roadmaps for instrumentation and controls beyond today's start of the art in support of the ABP Grand Challenges (GC). Instrumentations and Controls enter most of the GCs and need to support the generation and characterization of beams over a wide range of parameters (from quantum-degenerate electron beams to high-intensity hadron beams). The WG1 is divided into three main themes: “Control”, “Measurement”, and “Prediction”.

Theme 1: Control.

The control theme regards the development of the instrumentation (hardware and related techniques) used to set a parameter (e.g. temperature) to the desired set-point. Ideal instruments have wide dynamic range and low latency coupled with high accuracy and high precision and can be the backbone of fast-feedback algorithms. Given the complexity of large scale accelerators, with thousands of process variables, the set-points of the instruments via machine-learning (ML) has recently become an active area of research. Our roadmaps identify the beam or machine parameters that we seek improved control in the upcoming decade.

Decadal thrusts associated with the control theme are:

- RF phase/amplitude stability (e.g. 1e-3/1e-2)
- laser synchronization (e.g. at the sub-fs level)
- feedback to mitigate collective effects (space charge, multi-bunch interaction,...)
- ML-based control of accelerator parameters

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Theme 2: Measurement.

The measurement theme deals with developing diagnostics and techniques to characterize the beam's scalar macroscopic properties or phase-space distribution (either by direct observation or indirectly). Ultimately, diagnostics would be able to detect the location of each particle within the bunch to support the tailoring of a bunch at the single-particle-level (one of the GCs).

Decadal thrusts associated with the measurement theme

- Measure betatron functions of hadron beam with sub-% accuracy
- Measure mega-Ampere peak-currents, characterization of attosecond electron pulses,
- Characterization of ultra-low emittance at the Heisenberg-limit from source or after cooling
- Measurement of temporal shape with precision beyond the fs
- Measurement of halo with a large dynamical range in 6D: Halo can be measured with a high dynamical range in 1D but the dynamical range decreases with the dimensionality of the phase space
- Developing 6D (or projected) phase-space-distribution diagnostics capable of measuring complex correlations within the bunch
- Measure beam spin-polarization (what are the current limitations?)
- Simultaneous measurement of multiple beams (multiple species as in electron/hadron cooling section, or multiple same-species beams at different energies e.g. recirculating or energy-recovering linacs)

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Theme 3: Prediction.

The prediction theme entails the development of methods that can use observable signatures to predict the state of the accelerator or beam and possibly use this information to control the accelerator (feedback). This theme relies on the development of ML-based virtual diagnostics that can be used to indirectly infer non-directly observable quantities.

Decadal thrust associated with the prediction theme.

- Online modeling using simulations augmented with measured data
- Using machine learning to predict possible failures (e.g. resonator trip) and guide preventive action
- Development of advanced (virtual or improved) beam diagnostics
- Development advancedML-based feedback systems.
- Develop better Physics-informed models (e.g. proper modeling of fringe fields, etc…)
- Will ML demand higher precision of accelerator models and input measurements or will ML relax requirements of both?
- Explore whether ML be applied to optimization of beam polarization, beam halo, etc.
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