Instrumentation Frontier

Summary

Draft

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This is a skeleton outline for the 30-page Snowmass summary report of the Instrumentation Frontier. Indicated are suggested topics to be included. It is expected that there will be many supporting whitepapers that will be referenced for further details. The breadth of topics is vast; some consolidation of sections is foreseen at a later stage, but we tried to be complete for the skeleton outline. Feedback is much appreciated.

1 Introduction

Despite the recent discovery of a fundamental scalar and despite the fact that only 4% of the matter and energy content of the universe can be described by the known laws of physics, a robust future for particle physics research in the United States is not guaranteed. Now, more than ever, we must work to ensure that the US continues to lead in innovation in the area of instrumentation for high-energy physics rather than lag behind it. The goal of this summary report is to outline the opportunities that exist for investment in the development of instrumentation for the various high-energy physics frontiers that would enable the field to take a leadership position in certain areas of particle physics and establish itself as an indispensable partner for projects based off-shore.

This report is organized as follows. The first section will .....

2 The Intensity Frontier

2.1 The Neutrino Sector

2.1.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table. This may be multiple parts based on the science goals such as neutrino mixing matrix, mass hierarchy, neutrino-mass, ... Separate section on ultra-high energy neutrinos and $0\nu\beta\beta$-decays? Some words about the Global Scene. What efforts are ongoing elsewhere and their competitive advantage or alternate approach.

2.1.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

2.1.3 Beyond The Next Decade

Description of the instrumentation development for next generation experiments around 2025.

2.1.4 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

2.2 Rare Decays

2.2.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table that also lists projects elsewhere, esecially Japan.

2.2.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

2.2.3 Beyond The Next Decade

Description of the instrumentation development for next generation experiments around 2025 if applicable.

2.2.4 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

2.3 LHCb

2.3.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table.

2.3.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

2.3.3 Beyond The Next Decade

Description of the science goals beyond the LHCb 2018 upgrade.

2.3.4 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

2.4 Heavy Flavor Factories

2.4.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table.

2.4.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

2.4.3 Beyond The Next Decade

Not clear if there is anything beyond (multiple) upgrades.

3 The Energy Frontier

3.1 ATLAS And CMS

3.1.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table.

3.1.2 Beyond The Next Decade

Description of the science goals beyond LHC Phase II and instrumentation development needed.

3.1.3 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

3.2 Lepton Colliders

3.2.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table. Expect overview of different stages of an ILC, CLIC and muon collider

3.2.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

4 The Cosmic Frontier

4.1 Ultra High Energy Cosmic Rays

See sample table

4.2 Ultra High Energy Neutrinos

See sample table

4.3 Dark Energy

4.3.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table.

4.3.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

4.3.3 Beyond The Next Decade

Description of the instrumentation development for

4.3.4 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

4.4 γ Rays

4.5 Directional Dark Matter

4.5.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table.

4.5.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

4.6 Light Dark Matter

4.6.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Preferably captured in a table.

4.6.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

4.7 A Dark Matter Observatory

Description of the instrumentation needs to measure dark matter properties if discovered.

4.7.1 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

4.8 Cosmic Microwave Background Radiation

4.8.1 Current And Planned Projects

Succinct description of science goal(s), methodology, reach and limitation. Table with current experiments and reach for all experiments world-wide. Note US leadership.

4.8.2 Key Issues and Next Steps

Description of the instrumentation development that is necessary to sustain the current and planned projects. Identification of developments that would increase the science reach or reduce the cost and the facilities needed to support this development. Description of alternative developments

4.8.3 Beyond The Next Decade

Description of the instrumentation development needs for the next decade.

4.8.4 Key Issues and Next Steps

Identification of the areas of investment for the US to take a leadership role in these next generation projects.

4.9 Axions

4.9.1 Current And Planned Projects

4.9.2 Key Issues and Next Steps

4.10 Tests of Space-Time

4.10.1 Current And Planned Projects

Holographic experiments. See sample table.

4.10.2 Key Issues and Next Steps

5 Beam Test And Underground Facilities

6 Emerging Technologies

7 Cross-cutting Technologies

This section addresses technologies that cut across all frontiers, such as ASIC design, optical sensors, low-mass materials, ...

8 Infrastructure for Instrumentation Development

9 Partnerships

This section will address relations with industry, lab-university collaboration and relations with non-HEP science disciplines

10 Leadership Opportunities

11 Holy Grails

A list of breakthrough technologies considered holy grails. Below are exmples to get the discussion going.

Long Term:
Development of a CCD camera for cosmic frontier experiments capable of doing pixel by pixel spectroscopic analysis of incident light.

Development of wireless DAQ systems for HEP experiments. Satellite based Cosmic Frontier experiments have already developed wireless DAQ systems by necessity. Very large area experiments such as Auger have also developed wireless DAQ and control systems based on cell phone technology. However, there is no standard and about 20% of the cost of a large detector consists of making data readout connections and fixing mistakes in these readout connections and maintaining them.

Development of optical tracking chambers using large area photodetectors with mm spatial resolution and picoseconds or subpicosecond time resolutions and water based liquid scintillator.

Medium Term (?)
Development of a 10-5 pixel detector, that is, factor 10 improvement in five performance parameters such as radiation hardness, power consuption, material budget, data throughput, impact parameter resolution.

Sample Tables

Experiment	Location	Methodology	Target Mass	Reach	Limitation
CDMS	SNOLAB	non-therm. phonons + ionization ($\leq$ 50 mK)	1.5 kg Si; 10 kg Ge	....	Cost target mass
COUPP	SNOLAB	superheated liquid	60 kg Freon	...	...
MAJORANA	Sanford	ionization	40 kg HPGe		
XENON100	Gran Sasso	Scint. + ionization	100 kg LXe		

Table 1: Dark Matter Experiments

Area	Physics Goal	Methodology	Limitation	New Technology
UHECR	Identify sources and composition of UHECR study strong interactions at 100 TeV CM energies	H_2O Čerenkov tanks Fluorecence telescopes	Aperture e/μ separation	Radio detection
UHEν	Neutrinos are the only UHE messenger beyond local universe; study weak interactions at 100 TeV CM energies	optical Cherenkov	Limit in rate not scalable	Detection of coherent RF pulses (Askaryan)
Dark Energy	obtain spectroscopic information for LSST galaxies	multifiber spectrograph with CCDs	Not easily scalable to cover 50,000 galaxies per square.deg	multiplexed superconducting cryogenic detections (MKIDs)
γ Rays	Indirect DM detection Axion like particle searches Lorentz invanriance	H_2O tanks for air showers	Limited energy reach and sensitivity	Large area, fast, low noise + cheap photosensors H_2O based scintillators Distributed DAQ with radio communication Relative timing $\leq$ 1ns.
		Cherenkov telescopes	Limited energy reach and sensitivity	Large array of telescopes (CTA) Fast ADCs High resolution with FOV compact camera;

Table 2: Cosmic Frontier Experiments

Area	Physics Goal	Methodology	Limitation	New Technology
Directional DM	Measure sidereal anisotropy in nuclear recoils	Nuclear emulsions Low pressure TPC	Tension between increased mass and track range Not scalable	Columnar recombination detector
Light DM	Detection of low mass DM from 1 GeV to 10GeV mass	Low noise Ge detectors	Energy threshold electronic noise nuclear recoil calibration	Low noise CCD Si Detectors Cryogenic detectors with Luke gain
	Detection of low mass DM from 1 MeV to 1GeV mass		energy threshold	Single e-h Noble gas TPC detectors Single e-h semiconductor detector Single photon detection in cryogenic detector
DM observatory	Wimp spectroscopy after discovery	Assume G3 detectors	Mass vs. cross section degeneracy hard to overcome astrophysical uncertainties irreducible neutrino background	Develop program with multiple nuclear targets
CMB	Dawn of Universe	Satellites	Small size telescope High cost	multimode detectors; Engineered radiation coupling Microcalorimeter readout techniques
		Balloon	Telescope size limited focal plane size limited	
		Ground	Sensitivity limited by atmosphere	
Axions				
Spacetime	Study macroscopic quantum properties of geometry. Beyond quantum field theory.			Holometer

Table 3: Cosmic Frontier Experiments