The Cross-Cut Group

Preliminary Assessment

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Audience for the Report

• A primary audience for the BRN report is policy makers, which frames the front-end language and ambition of the report, the OHEP program managers and the community.

• The goal is to make a compelling argument to increase the funding for detector development for particle physics articulated in a way that appeals to policy makers and is aligned with current policy of OSTP.

• The P5 report provided a 10-year program with a 20-year vision and has been very successful with policy makers; we expect the P5 update to be equally successful. The P5 science drivers provide the long-term scientific motivation and the PRDs should build on these science drivers.

• The PRD should be ambitious and forward looking. The current set of projects that are at CD-1 or beyond should not be part of the PRDs. If there still is important R&D to be carried out, that simply has to be successfully completed to deliver the approved projects.
High-Priority Projects

- P5 supported directed R&D for the near future.
- Directed R&D has targeted current set of approved experiments:
  - The Phase-II upgrades of the LHC,
  - DUNE, module 1
  - G2 dark matter experiments,
  - CMB-S4
- Continued investments in these projects are expected, but the goal of the BRN is to expand the program with more forward leaning efforts.
- A long-term view should be taken for the PRDs
The Priority Research Directions

- The cross-cut group has distilled from the 3- and 6-pagers a total of about 120 PRDs

<table>
<thead>
<tr>
<th>Cross Cut PRD 1</th>
<th>Cross Cut PRD 2</th>
<th>Radiation Hardness</th>
<th>Topical Area</th>
<th>Technology</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Semiconductor Detectors</td>
<td>Microelectronics</td>
<td>Yes</td>
<td>Energy</td>
<td>Fine gained tracking</td>
<td>4D tracking - adding precision timing (5 ps) to precision (&lt;5 um hit res) trackers</td>
</tr>
<tr>
<td>4 Semiconductor Detectors</td>
<td>Facilities/Capabilities</td>
<td>Yes</td>
<td>Energy</td>
<td>Radiation hardness</td>
<td>Up to 1E18 1 MeV-eq n/cm², 300 MGy</td>
</tr>
<tr>
<td>5 Microelectronics</td>
<td>Semiconductor Detectors</td>
<td>Yes</td>
<td>Energy</td>
<td>Fine gained calorimetry</td>
<td>5D calorimetry - precision position (few mm), time (5 ps for neutrals), and extended energy range</td>
</tr>
<tr>
<td>6 Semiconductor Detectors</td>
<td>Liquid Noble</td>
<td>Yes</td>
<td>Energy</td>
<td>Fine gained calorimetry - ECAL</td>
<td>0.0025-0.01 radian cells (-6-20 mm)</td>
</tr>
<tr>
<td>7 Semiconductor Detectors</td>
<td>Liquid Noble</td>
<td>Yes</td>
<td>Energy</td>
<td>Fine gained calorimetry - HCAL</td>
<td>0.025 radian cells (50 mm?)</td>
</tr>
<tr>
<td>8 Microelectronics</td>
<td>Engineering</td>
<td>Yes</td>
<td>Energy</td>
<td>Low power, low mass tracking</td>
<td>Pulsed power operations to reduce cooling/mass in tracking volume</td>
</tr>
<tr>
<td>9 Microelectronics</td>
<td>Yes</td>
<td>Energy</td>
<td>Integrated &quot;TDAQ&quot;</td>
<td>Integrated trigger elements on front end DAQ modules</td>
<td></td>
</tr>
</tbody>
</table>

- Physics

<table>
<thead>
<tr>
<th>Physics</th>
<th>Neutrinos</th>
<th>multi-kf detection systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutrinos</td>
<td>Yes</td>
<td>high power neutrino beams</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>LArTPC pixel readout (3D charge imaging)</td>
<td>large area, low power, low noise charge readout planes</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>LArTPC photodetectors</td>
<td>More light collection - any way you can manage it</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>LArTPC HV delivery</td>
<td>Stable HV feedthroughs and delivery systems</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>Precision timing photodetectors</td>
<td>&quot;ultrafast&quot; timing over large areas (not specified, but detector mentioned is 100 ps)</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>Low threshold, low background</td>
<td>Ton-scale fiducial mass; Sub-keV threshold</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>Radio components</td>
<td>high gain antennas (in ice); DAQ/trigger with low power</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>Optical</td>
<td>not specified</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>Air shower arrays</td>
<td>not specified</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>Radar</td>
<td>not specified</td>
</tr>
</tbody>
</table>

- Physics

| Dark Matter | Lower thresholds | below the eV scale |
| Dark Matter | Lower thresholds | calibration for low energy scale (down to sub-eV) |
| Dark Matter | Background reduction | Access to radiopure materials |
| Dark Matter | Background reduction | Access to screening/assay capabilities |
| Dark Matter | Background reduction | Improved sensitivity assay techniques |
| Dark Matter | Background reduction | Improved radon mitigation |
| Dark Matter | Simulations | Improvements in low energy physics processes |
| Dark Matter | Instrument sensitivity/backgrounds | Lower noise/thresholds in detectors/readout systems |
| Dark Matter | Extending G2 experiments | No details provided |

- Beyond Quantum Limit

<table>
<thead>
<tr>
<th>Microelectronics</th>
<th>Dark Matter</th>
<th>Single-photon counters for near IR - microwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-photon counting to get beyond standard quantum limit. (micron-few mm wavelengths)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark Matter</td>
<td>Indirect detection</td>
<td>Scalable (low cost) precise tracking (alternative to silicon)</td>
</tr>
<tr>
<td>Dark Matter</td>
<td>Indirect detection</td>
<td>Low dark count UV photodetectors for fiber tracking and calorimetry for space-based instrument</td>
</tr>
<tr>
<td>Dark Matter</td>
<td>Indirect detection</td>
<td>Improved photodetector light collection (SiPM, GaN coating)</td>
</tr>
</tbody>
</table>

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Key Challenges

- It is suggested to have **3 to 5 key instrumentation challenges** that can be captured in catchy statements.

- **The key challenges are the ambitions of the field that cross-cut technologies**

- Template key challenges:
  - Breaking the picosecond time barrier
  - Quantum-enhanced photoproduction and photodetection over the full frequency spectrum
  - Sub-eV and below the standard quantum limit detectors
  - 5D Calorimetry over five orders of dynamic range
  - Functionally integrated detectors
  - The ultimate transparent charged particle tracker
  - Advanced semi-conductor detectors and devices
  - Single-quantum sensitive non-demolition probes
The Flow

• Many areas are very thin on requirements, or are absent all together. We need help!
• The “flow” that we believe will be helpful to frame the discussions:
The Flow

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• The “flow” that we believe will be helpful to frame the discussions:
The Process

• A possible natural way for the science groups to articulate their thinking follows the process:
The Process

- A possible natural way for the science groups to articulate their thinking follows the process:

  - Key Challenge
  - Priority Research Direction
  - Requirement
  - Physics Objective
  - Science Impact

- The Technology groups could follow the process:
The Priority Research Directions

• Each technology group is asked to identify 3 to 5 Priority Research Directions with a quantified physics motivation for each PRD.

• We believe that the timelines identifying the technology challenges will be very helpful to identify the PRDs and help identify the cross-cut PRDs.

• Higgs timeline is a great start, but technology challenges should be added.
Example from Exploring the Unknown: Flavour Physics

- LHCb Upgrade Phase Ia
  - Tracking with high granularity and good time resolution

- LHCb Upgrade Phase Ib
  - Calorimetry with high granularity and timing

- LHCb Upgrade Phase II
  - Real Time Processing of large amount of data

- Belle II
- ATLAS, CMS Phase II+ Upgrade (new inner tracking layers)
- LHCb accumulates 300fb-1

Timeline:
- 2020
- 2025
- 2030
- 2035
- 2040
Sample Priority Research Directions for Discussion and Framing

1. Enhanced photo-production and photo-detection.

PRDs

1. Higher QE VUV sensitive detectors --- Neutrinos, Dark Matter,
2. Water-based Liquid Scintillators --- Neutrinos
4. Superconducting single-photon nanowires --- Dark Matter, QIS, …. 
5. ....

PRDs could be quantitative and indicate what science regime is made accessible.
Sample Priority Research Directions for Discussion and Framing

2. **Advanced semi-conductor devices and detectors**

**PRDs**

1. IR sensitive Ge CCD development  
   Double the size of the observable universe  
   -- Cosmic frontier
2. 12” rad hard Si technology for 5D imaging calorimetry  
   -- Energy frontier
3. Thinned MAPS technology with 5micron pixel size, 1μW/pixel  
   -- Energy frontier
4. 28nm ASIC technology with integrated wireless transmission  
   -- Intensity, Energy frontier
5. Cryogenic pixelated LAr readout with aA sensitivity, ...  
   -- neutrinos,
6. ...

The development of the ASIC technology is becoming more and more expensive. Careful thought needs to be given to university-lab balance and workforce development.

Need to develop contacts with foundries. Link to the Micro-electronics BRN needs to be established.
Sample Priority Research Directions for Discussion and Framing

• The PRDs should be a balance between transformative and incremental R&D, but in either case be ambitious

• Many other areas to be considered
  – AI and ML: receives a lot of support within the Office of Science. Including this as a PRD is expected to be well received. However, there are other venues for support.
  – Advanced manufacturing: additive and subtractive manufacturing techniques that work at the nanoscale level for functionalized materials.
  – A critically important issue is also the workforce development, which will have to be addressed in the report.

• We should keep a stage-approach in mind for our PRDs. Disruption is not the norm.
Facilities Support

• To deliver on the priority research directions, a key element is the availability of test facilities to support the instrumentation development, which will not be listed as a PRD

Low Background Facility
Provides support for low-background experiments in the areas of materials and assay

Critical need for low-background experiments

Test Beams
Provides high-quality beams and data taking infrastructure to develop and characterize new detector technologies

Critical need to explore new technologies

Irradiation Facilities
Provides facilities to validate radiation resistance to extremely high fluences

Essential for Energy and Intensity Frontier experiments

Characterization Platforms
Provides platforms for determining fundamental physics of materials

Vital for determining proof of principle and long-term viability of proposed materials and environments
Facilities Support: Characterization Platforms

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<tr>
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</thead>
<tbody>
<tr>
<td>System test of components of noble liquid detectors under operating conditions</td>
<td>Calibration platform for various systems, such as liquid Argon field cage system to measure TPC field response</td>
<td>Evaluate radiation resistance of materials exposed to extremely high fluences for targetty</td>
<td>Platform for measurement of fundamental physics properties</td>
</tr>
</tbody>
</table>

![Image of Noble Liquid Platform](image1.png)

![Image of Calibration Platform](image2.png)

![Image of Irradiation Evaluation Platform](image3.png)

![Graph: Electron Attachment in LAr](graph.png)
Possible Process Train
Several Priority Research Directions are candidate ‘Key Challenges’
Anticipated Process Train

The same physics objective can have multiple technical requirements with other ‘Key Challenges’
Several Priority Research Directions are candidate ‘Key Challenges’
Anticipated Process Train
There may be PRDs that do NOT map onto a Key Challenge. That does not mean they cannot rise to a key priority for the future program.
Process gets carried out by all groups
Process gets carried out by all groups

Cross-Cut group tries to look for commonality between the PRDs
The Flow

- Many areas are very thin on requirements, or are absent altogether. We need help!
- Example “flow”:

  - Higgs (self)-Couplings (5%) 1%
  - Event disambiguation
  - 5ps per hit timing resolution
  - Trackorimeter
  - Breaking the picosecond Time Barrier
The Flow

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• Example “flow”:
The Flow

• Many areas are very thin on requirements, or are absent all together. We need help!

• Example “flow”:
Report Structure

Exec Summary

• Audience: policy makers
• Length: ~1 page
• Describes the Key Challenges
Report Structure

**Exec Summary**
- Audience: policy makers
- Length: ~1 page
- Describes the Key Challenges

**Science Impact**
- Audience: Office of Science
- Length: ~5-10 pages
- Describes the new horizons that the technology development will open for science
- Describes the science impact “without numbers” in “catchy” phrases
- Emphasizes:
  - Need for facilities
  - Workforce development
  - Connection to other science disciplines
  - Connection to high priority topics: AI/ML, QIS
### Possible Graphic

<table>
<thead>
<tr>
<th></th>
<th>Higgs Boson</th>
<th>Neutrino Mass</th>
<th>Dark Matter</th>
<th>Cosmic Acceleration</th>
<th>Explore the Unknown</th>
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</thead>
<tbody>
<tr>
<td><strong>KC 1</strong></td>
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<tr>
<td><strong>KC 2</strong></td>
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<td><strong>KC 3</strong></td>
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<td><strong>KC 4</strong></td>
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<td><strong>KC 5</strong></td>
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Impact beyond HEP
## Report Structure

### Exec Summary
- **Audience:** policy makers
- **Length:** ~1 page
- **Describes the Key Challenges**

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### Panel Report
- **Audience:** OHEP and HEP community
- **Length:** ~100 pages
- **In-depth discussion – with specificity – of all the PRDs**
- **The PRDs have to be actionable**
Comments?