Summary of the BRN report on low background and underground detectors

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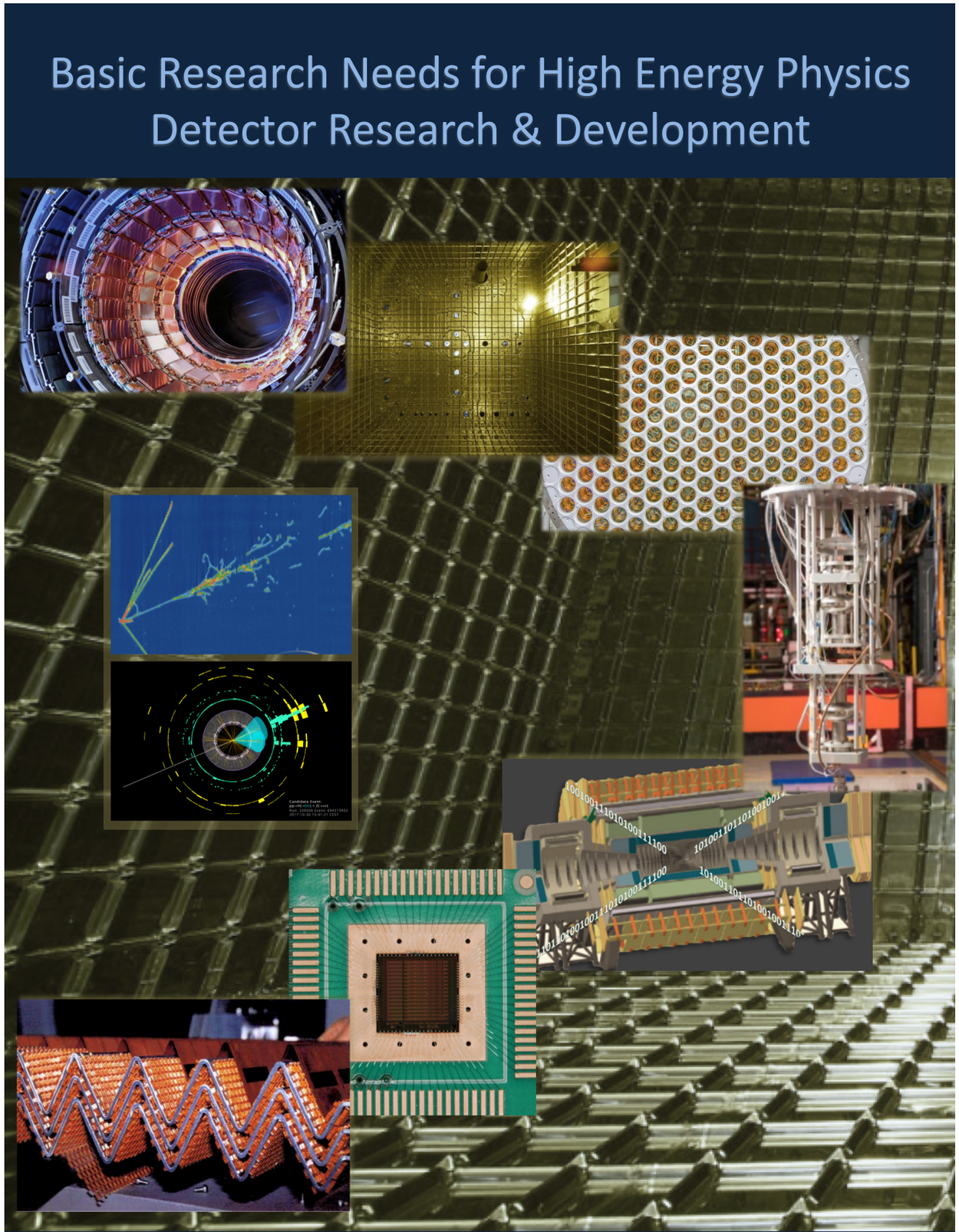

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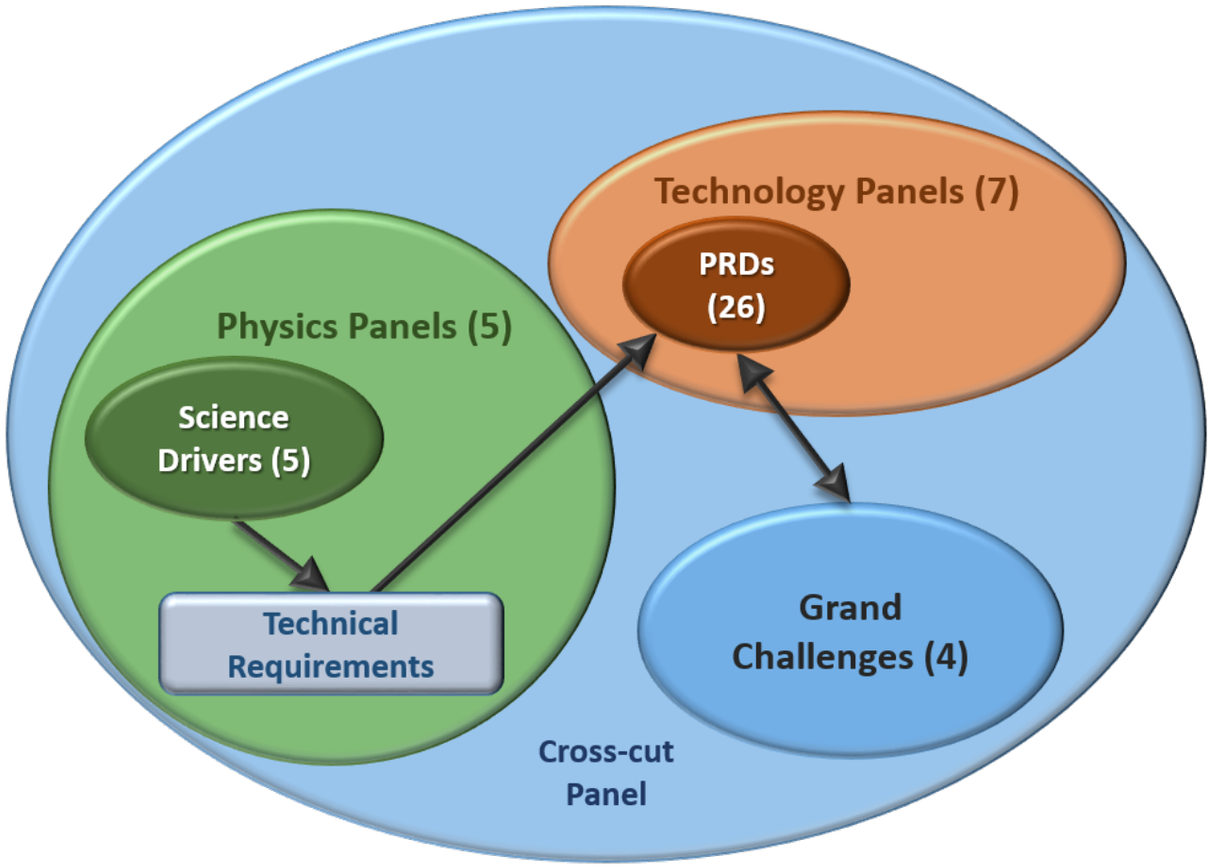
Some words on the BRN organisation and report

- Groups were divided by **A) Science** (Higgs & Energy Frontier, Neutrinos, Dark Matter, Cosmic Acceleration: Dark Energy and Inflation, Explore the Unknown), **B) Technology** (Calorimetry, Noble Elements, Photodetectors, Quantum Sensors, Readout & ASICS, Solid State and Tracking, TDAQ, cross cutting) and **C) Facilities**

- Main product of the reports is the identification of 4 Grand Challenges, 26 Priority Research Directions (PRDs) tied to Technical Requirements from Science needs



Grand Challenges and PRDs

1. Advancing HEP detectors to new regime of sensitivity

2. Using integration to enable scalability for HEP sensors

3. Building the next-generation HEP detectors with novel materials and advanced techniques

4. Mastering extreme environments and data rates in HEP experiments

	PRD: Priority Research Direction	Grand Challenge
Calorimetry	PRD 1: Enhance calorimetry energy resolution for precision electroweak mass and missing-energy measurements	1
	PRD 2: Advance calorimetry with spatial and timing resolution and radiation hardness to master high-rate environments	1,4
	PRD 3: Develop ultrafast media to improve background rejection in calorimeters and particle identification detectors	1,3,4
Nobles	PRD 4: Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity	1,2
	PRD 5: Develop new modalities for signal detection	1
	PRD 6: Improve the understanding of detector microphysics and characterization	1
Photodetectors	PRD 7: Extend wavelength range and develop new single-photon counters to enhance photodetector sensitivity	1,3
	PRD 8: Advance high-density spectroscopy and polarimetry to extract all photon properties	2,3
	PRD 9: Adapt photosensors for extreme environments	2,4
	PRD 10: Design new devices and architectures to enable picosecond timing and event separation	1,2,4
	PRD 11: Develop new optical coupling paradigms for enhanced or dynamic light collection	1,2,3
Quantum	PRD 12: Advance quantum devices to meet and surpass the Standard Quantum Limit	1,3
	PRD 13: Enable the use of quantum ensembles and sensor networks for fundamental physics	1,2
	PRD 14: Advance the state of the art in low-threshhold quantum calorimeters	1,3
	PRD 15: Advance enabling technologies for quantum sensing	1,2,3
ASIC	PRD 16: Develop process evaluation and modeling for ASICs in extreme environments	3,4
	PRD 17: Create building blocks for Systems-on-Chip for extreme environments	1,4
SolidState	PRD 18: Develop high spatial resolution pixel detectors with precise high per-pixel time resolution to resolve individual interactions in high-collision-density environments	1,4
	PRD 19: Adapt new materials and fabrication/integration techniques for particle tracking	2,3
	PRD 20: Realize scalable, irreducible-mass trackers	2,3
TDAQ	PRD 21: Achieve on-detector, real-time, continuous data processing and transmission to reach the exascale	2,4
	PRD 22: Develop technologies for autonomous detector systems	2
	PRD 23: Develop timing distribution with picosecond synchronization	1
Xcut	PRD 24: Manipulate detector media to enhance physics reach	1,3
	PRD 25: Advance material purification and assay methods to increase sensitivity	1,2,3,4
	PRD 26: Addressing challenges in scaling technologies	2,3

Relation to Low backgrounds and Underground Detectors

- **Science**: Neutrinos & Dark Matter
  - Push the three-flavor paradigm into the regime of high-precision measurements of all parameters.
  - Explore unknown territory in neutrino energy range, types of neutrino sources, and faint source intensities.
  - Hunt for evidence of new particles and phenomena in the neutrino sector, and in other sectors using neutrino detectors.

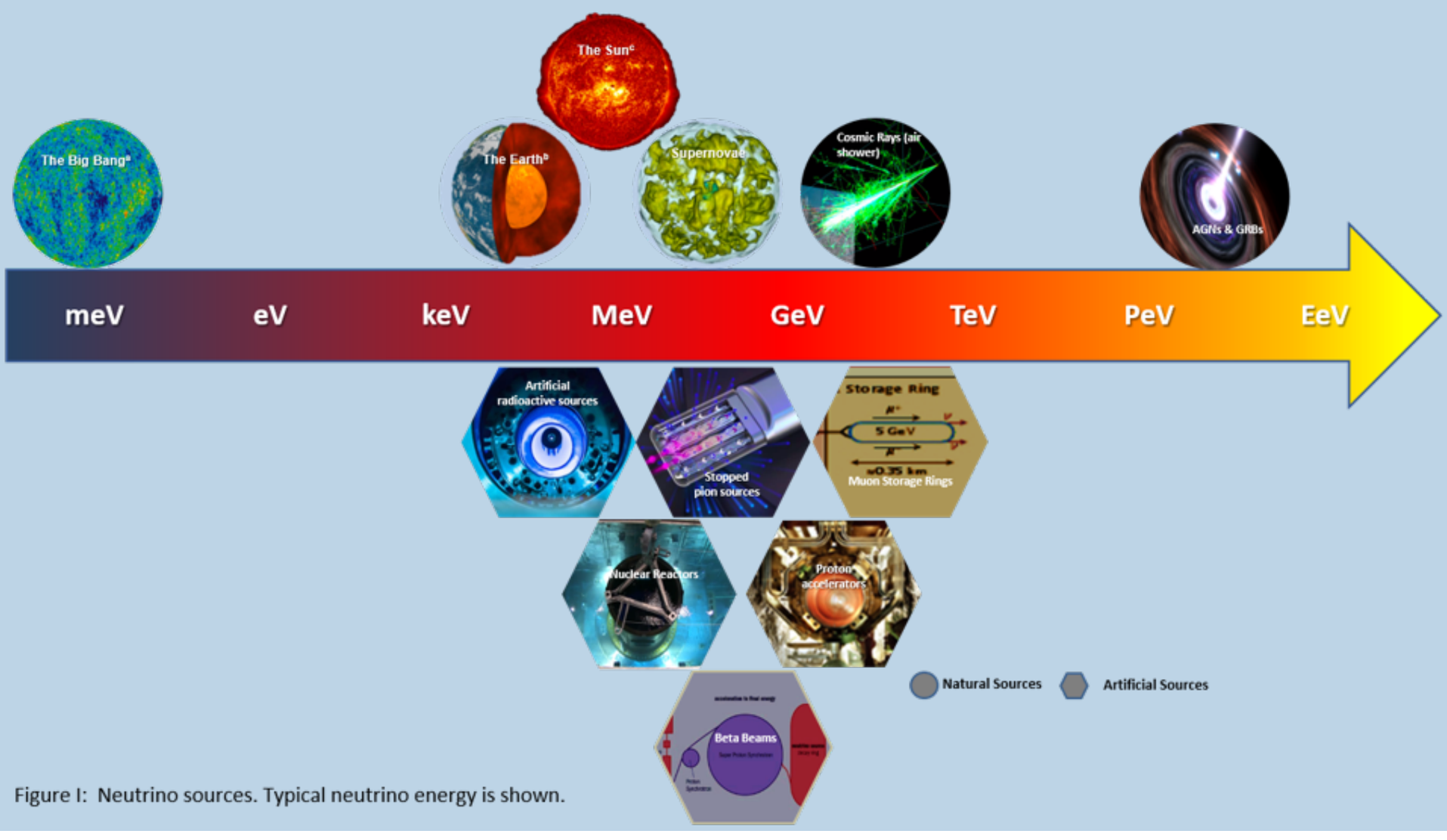
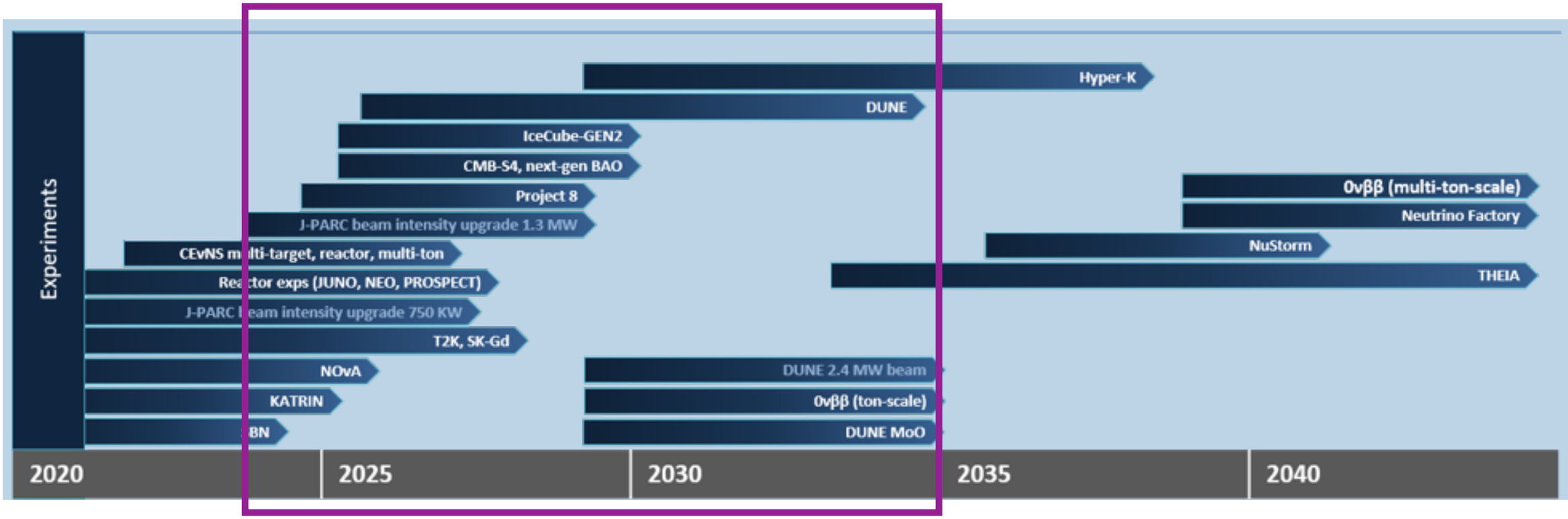


Figure I: Neutrino sources. Typical neutrino energy is shown.

Relation to Low backgrounds and Underground Detectors

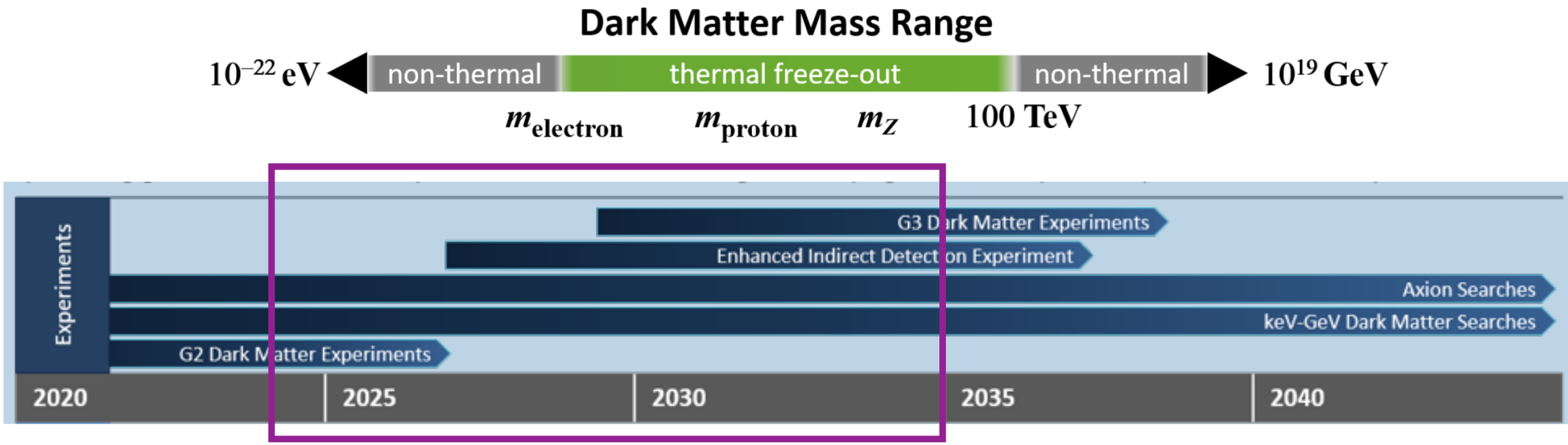
- **Science**: Neutrinos & Dark Matter



SNOWMASS 21 era

Relation to Low backgrounds and Underground Detectors

- **Science**: Neutrinos & Dark Matter
  - Searching for WIMP dark matter towards the neutrino floor
  - Searching for particle dark matter with low masses
  - Searching for wave-like dark matter
  - Searching for the annihilation or decay products of dark matter interactions



Mass > 10 GeV
TR 3.4(SI), TR 3.10(SD): Background rate < coherent scattering rate of atmospheric neutrinos

SNOWMASS 21 era

Mass 1 - 10 GeV
TR 3.1(SI),TR 3.7(SD): Background rate < coherent scattering rate of solar neutrinos

Near term

TR 3.14 Target Mass ~1 kg with negligible background

Long term

TR 3.16 Target Mass ~100 kg with negligible background

Relation to Low backgrounds and Underground Detectors

- **Technology**: Noble Elements, Photodetectors

Priority Research Direction (PRD)
PRD 4: Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity PRD 5: Develop new modalities for signal detection
PRD 6: Improve the understanding of detector microphysics and characterization to increase signal-to-noise and reconstruction fidelity
PRD 25: Advance material purification and assay methods to increase sensitivity
PRD 26: Addressing challenges in scaling technologies

Thrust 1: Improve and enhance light collection

Thrust 2: Improve and enhance charge collection

Thrust 3: Improve and enhance integration of charge and light collection

Thrust 4: Improve and enhance heat collection

Thrust 5: Enhance and develop doping and ion collection

Relation to Low backgrounds and Underground Detectors

- **Technology**: Noble Elements, Photodetectors

Priority Research Direction (PRD)	
PRD 7: Extend wavelength range and develop new single-photon counters to enhance photodetector sensitivity	**Thrust 1: Increased IR sensitivity** **Thrust 2: UV and VUV scintillation and Cherenkov photon detection** **Thrust 3: Single photon detection** **Thrust 4: Advanced materials for photodetectors**
PRD 9: Adapt photodetectors for extreme environments	**Thrust 1: Cryogenic operation at noble liquid temperatures** **Thrust 2: Low-radiological-background sensors and detector packages**
PRD 11: Develop new optical coupling paradigms for enhanced or dynamic light collection	**Thrust 1: Novel light propagation and collection systems**

Relation to Low backgrounds and Underground Detectors

- **Technology**: Cross cutting

PRD 24: Manipulate detector media to enhance physics reach

Thrust 1: Doping or enrichment to enhance interaction rate
Thrust 3: Doping for enhanced light or charge collection
Thrust 4: Doping to improve event localization
Thrust 5: Metastable systems

PRD 25: Advance material purification and assay methods to increase sensitivity

Thrust 1: Radiologically pure materials
Thrust 2: Enhanced capability for measurement and control of surface backgrounds
Thrust 3: Purification and storage of noble liquids
Thrust 4: Isotopic enrichment or rejection

Relation to Low backgrounds and Underground Detectors

- **Facilities**

✓ Test beams

✓ Simulation frameworks

✓ Ultra-low temperature test stands

✓ Specialized calibration facilities

✓ Low-background materials and assay

SURF copper electroforming facility


SURF low-bkg counting cleanroom

Summary

- BRN was a huge community-led effort on instrumentation
- Intent was to map out the future of HEP (near and longer) and its future instrumentation needs
- Intent was to keep room for new ideas, so we tried to remain generic as much as possible
- It should serve as an input for SNOWMASS
- If you notice that something was missing, you have a great opportunity to provide additional input
- I only gave an brief overview, more details can be found in the report

Thank You