The Cross-Cut Group

Preliminary Assessment

Marcel Demarteau (ORNL)
Jim Fast (PNNL)
Peter Fisher (MIT)
Young-Kee Kim (Chicago)
Sunil Golwala (Caltech)
Abe Seiden (UCSC)

CPAD Meeting
Madison, WI
December 9, 2019

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

	Cross Cut PRD 1	Cross Cut PRD 2	Radiation Hardness	Topical Area	Technology	Requirements
3	Semiconductor Detectors	Microelectronics	Yes	Energy	Fine gained tracking	4D tracking - adding precision timing (5 ps) to precision (<5 um hit res) trackers
4	Semiconductor Detectors	Facilities/Capabilities	Yes	Energy	Radiation hardness	Up to 1E18 1 MeV-eq n/cm2, 300 MGy
5	Microelectronics	Semiconductor Detectors	Yes	Energy	Fine gained calorimetry	5D calorimetry - precision position (few mm), time (5 ps for neutrals), and extended energy range
6	Semiconductor Detectors	Liquid Noble	Yes	Energy	Fine gained calorimetry - ECAL	0.0025-0.01 radian cells (6-20 mm)
7	Semiconductor Detectors	Liquid Noble	Yes	Energy	Fine gained calorimetry - HCAL	0.025 radian cells (50 mm?)
8	Microelectronics	Engineering	Yes	Energy	Low power, low mass tracking	Pulsed power operations to reduce cooling/mass in tracking volume
9	Microelectronics		Yes	Energy	Integrated "TDAQ"	Integrated trigger elements on front end DAQ modules
10						
11	Physics			Neutrinos	multi-kT detection systems	
12	Physics		Yes	Neutrinos	high power neutrino beams	
13	Microelectronics			Neutrinos	LArTPC pixel readout (3D charge imaging)	large area, low power, low noise charge readout planes
14	Photodetectors			Neutrinos	LArTPC photodetectors	More light collection - any way you can maage it
15	Engineering			Neutrinos	LArTPC HV delivery	Stable HV feedthroughs and delivery systems
16	Photodetectors	Microelectronics		Neutrinos	Precision timing photodetectors	"ultrafast" timing over large areas (not specified, but detector mentioned is 100 ps)
17	Facilities/Capabilities			Neutrinos	Low threshold, low background	Ton-scale fiducial mass; Sub-keV threshold
18	Microelectronics			Neutrinos	Radio components	high gain antennas (in ice); DAQ/trigger with low power
19	Physics			Neutrinos	Optical	not specified
20	Physics			Neutrinos	Air shower arrays	not specified
21	Physics			Neutrinos	Radar	not specified
22						
23	Physics			Dark Matter	Lower thresholds	below the eV scale
24	Facilities/Capabilities			Dark Matter	Lower thresholds	calibration for low energy scale (down to sub-eV)
25	Facilities/Capabilities			Dark Matter	Background reduction	Access to radiopure materials
26	Facilities/Capabilities			Dark Matter	Background reduction	Access to screening/assay capabilities
27	Facilities/Capabilities			Dark Matter	Background reduction	Improved sensitivity assay techniques
28	Facilities/Capabilities			Dark Matter	Background reduction	Improved radon mitigation
29	Modeling			Dark Matter	Simulations	Improvements in low energy physics processes
30	Beyond Quantum Limit	Microelectronics		Dark Matter	Instrument sensitivity/backgrounds	Lower noise/thresholds in detectors/readout systems
31	Physics			Dark Matter	Extending G2 experiments	No details provided
32	Beyond Quantum Limit			Dark Matter	Single-photon counters for near IR - microwave	Single-photon counting to get beyond standard quantum limit. (micron-few mm wavelengths)
33	Semiconductor Detectors			Dark Matter	Indirect detection	Scalable (low cost) precise tracking (alternative to silicon)
34	Photodetectors			Dark Matter	Indirect detection	Low dark count UV photodetectors for fiber tracking and calorimetry for space-based instrument
35	Photodetectors			Dark Matter	Indirect detection	Improved photodetector light collection (SiPM, GaN coating)

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

- 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 Process

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

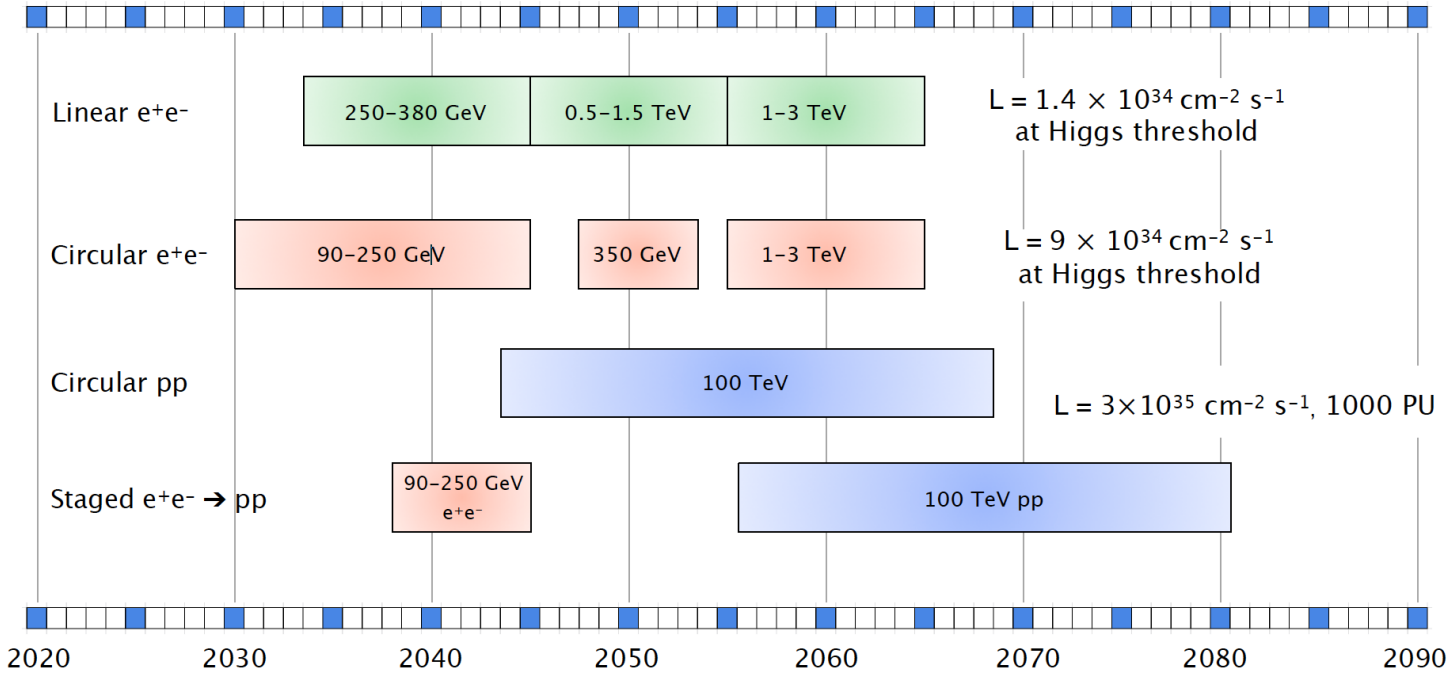
The Process

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

- The Technology groups could follow the process:

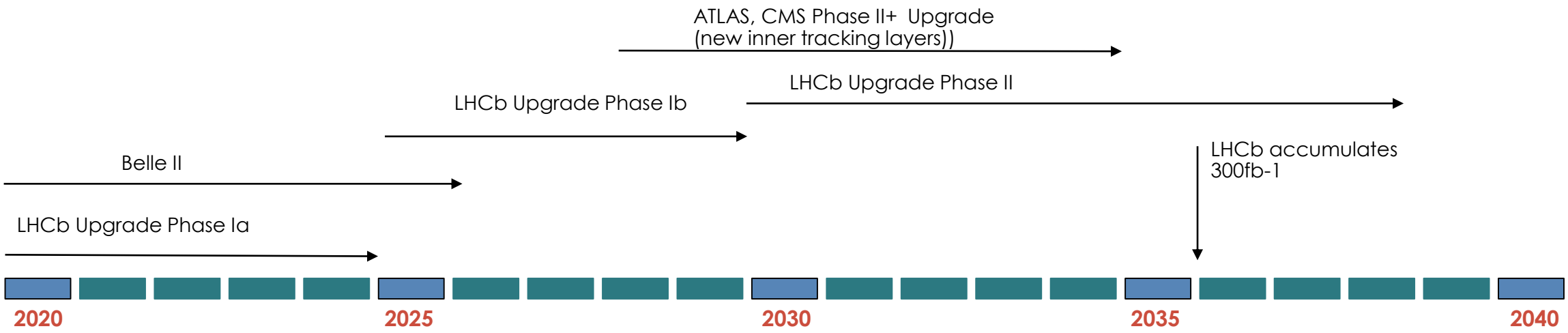
The Priority Research Directions

- 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



Tracking with high granularity and good time resolution

Calorimetry with high granularity and timing

Real Time Processing of large amount of data

Readout | PhotoDetectors | Quantum Sensors | Noble Liquids | Calorimetry | SS and Tracking | TDAQ

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
3. Novel scintillator materials --- Neutrinos, Energy Frontier, Dark Matter
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 -- Cosmic frontier
   Double the size of the observable universe
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.

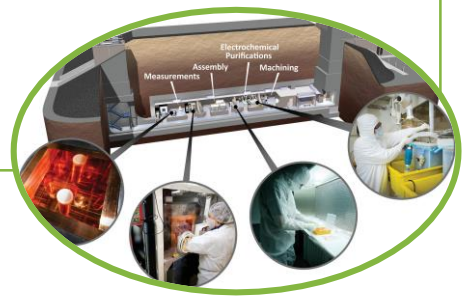
Facilities Support

- 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

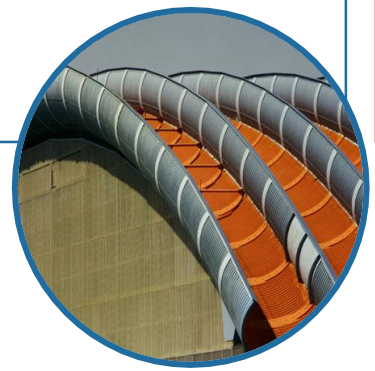
Critical need for low-background experiments



Test Beams

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

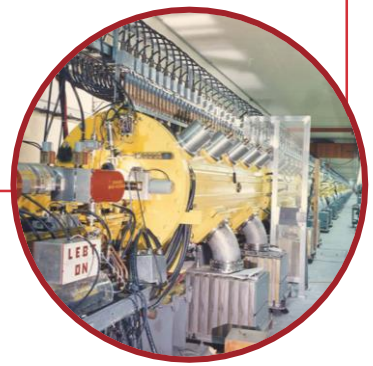
Critical need to explore new technologies



Irradiation Facilities

Provides facilities to validate radiation resistance to extremely high fluences

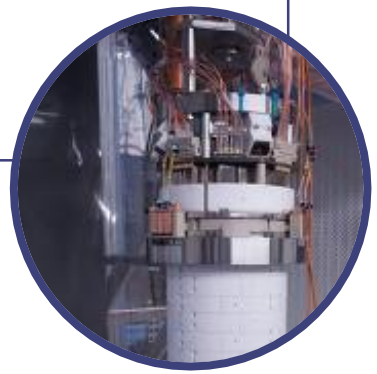
Essential for Energy and Intensity Frontier experiments



Characterization Platforms

Provides platforms for determining fundamental physics of materials

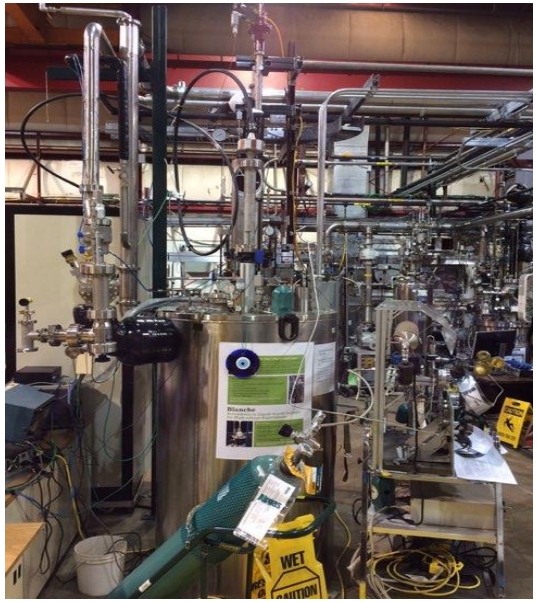
Vital for determining proof of principle and long-term viability of proposed materials and environments



Facilities Support: Characterization Platforms

Noble Liquid Platform

System test of components of noble liquid detectors under operating conditions



Calibration Platform

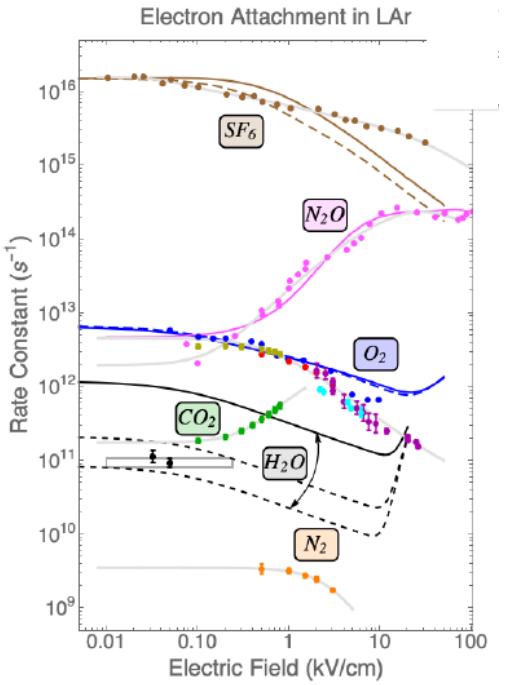
Calibration platform for various systems, such as liquid Argon field cage system to measure TPC field response

Irradiation Evaluation Platform

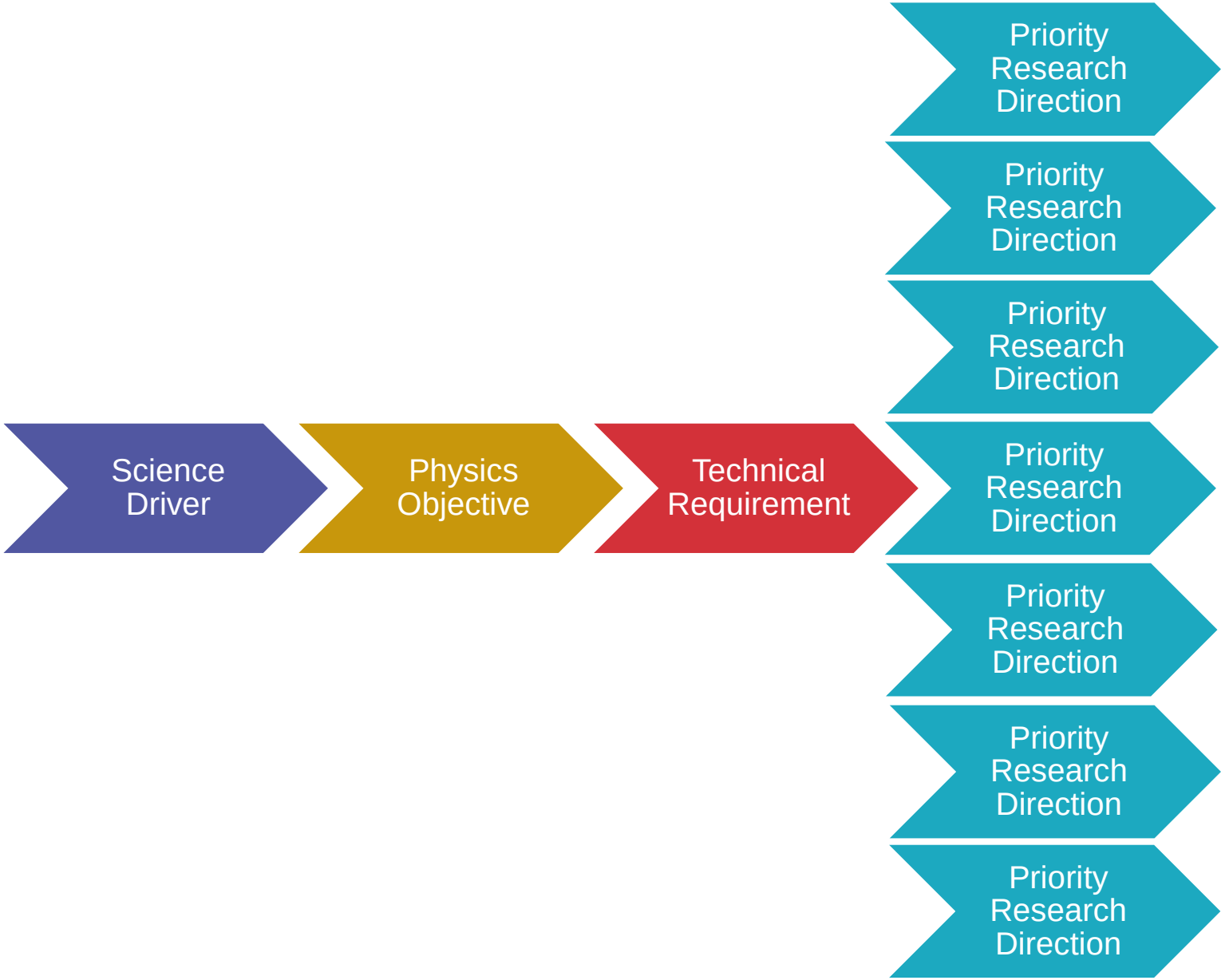
Evaluate radiation resistance of materials exposed to extremely high fluences for targetry

Fundamental Properties Platform

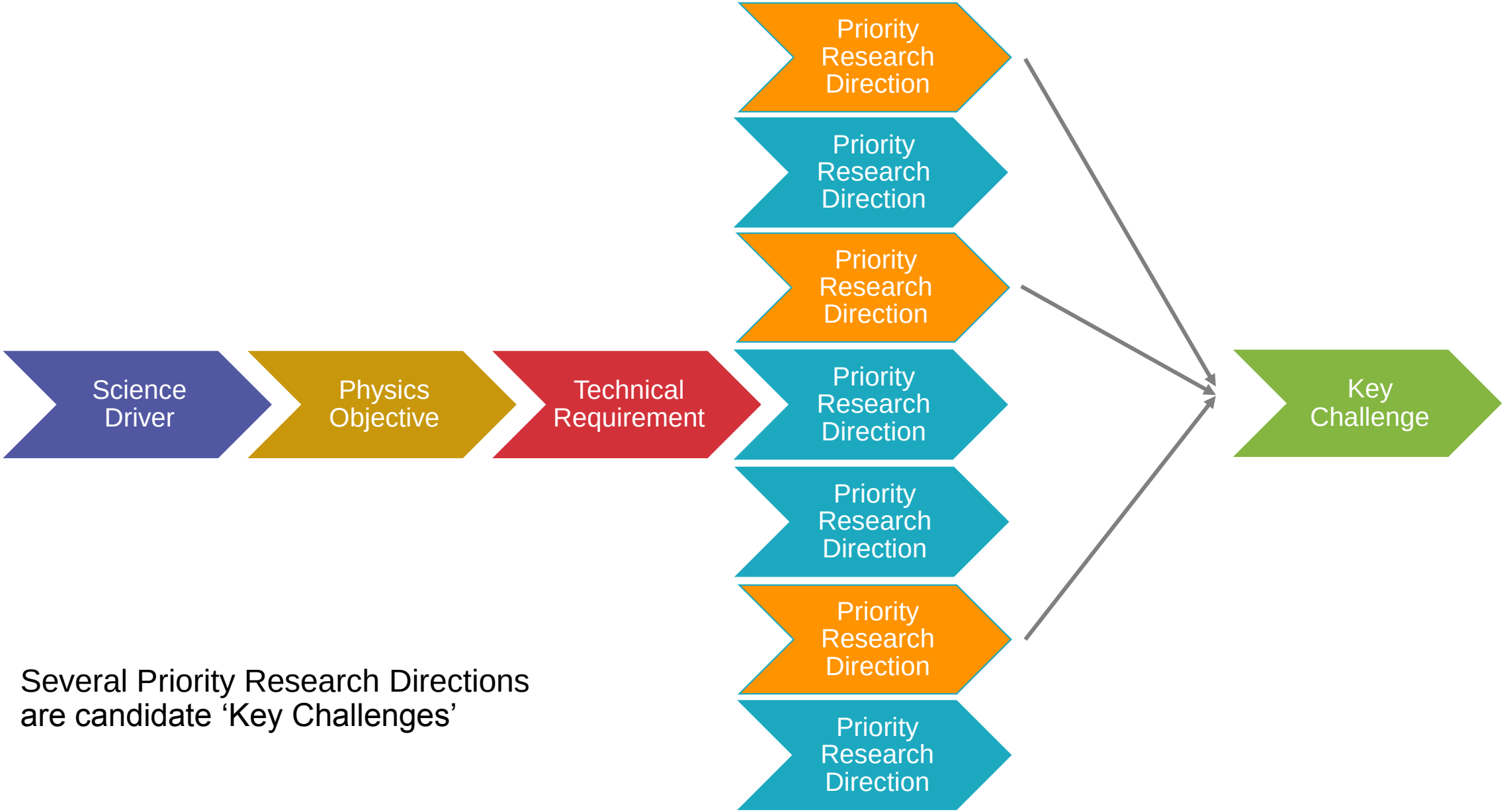
Platform for measurement of fundamental physics properties



Possible Process Train

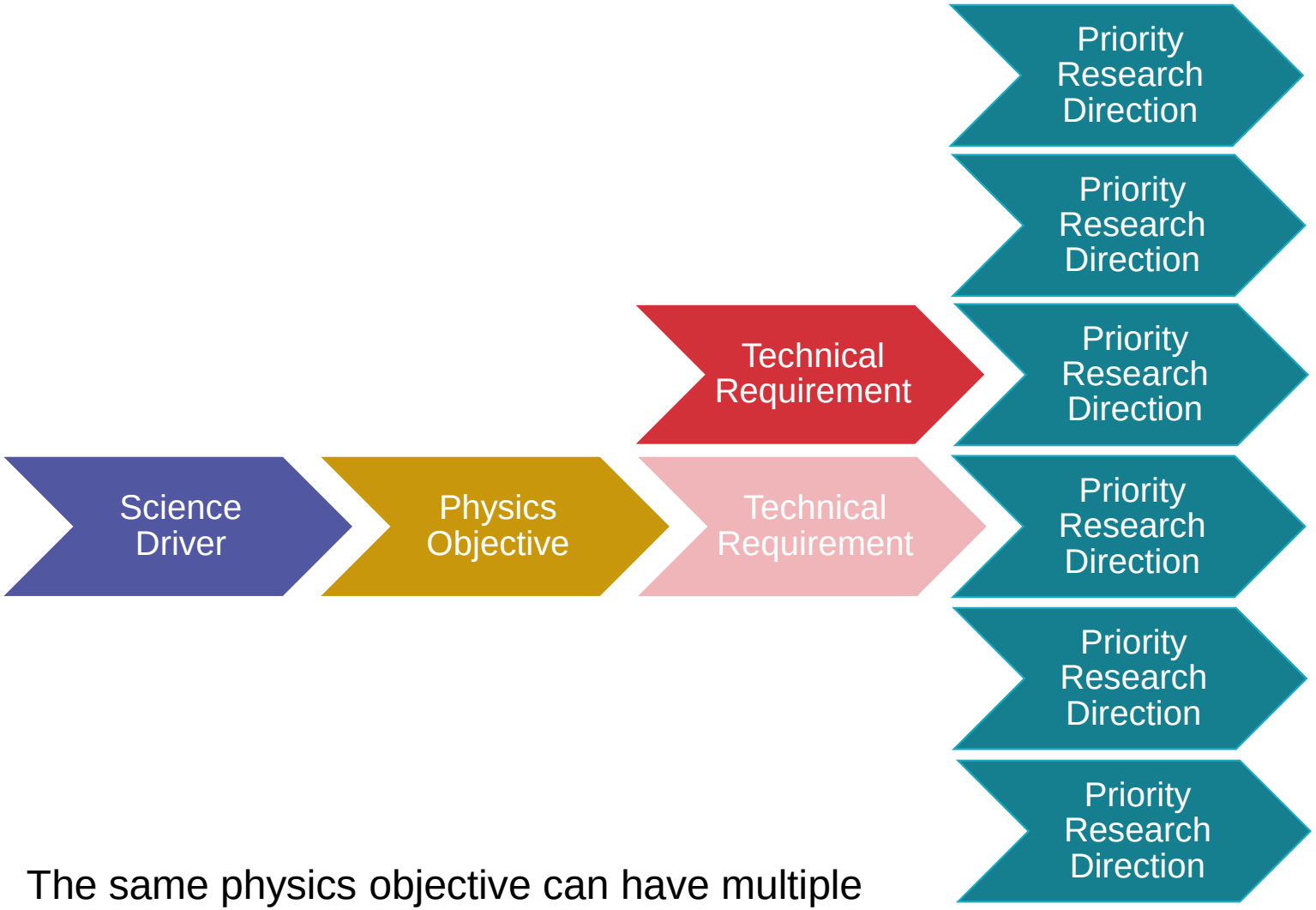


Anticipated Process Train



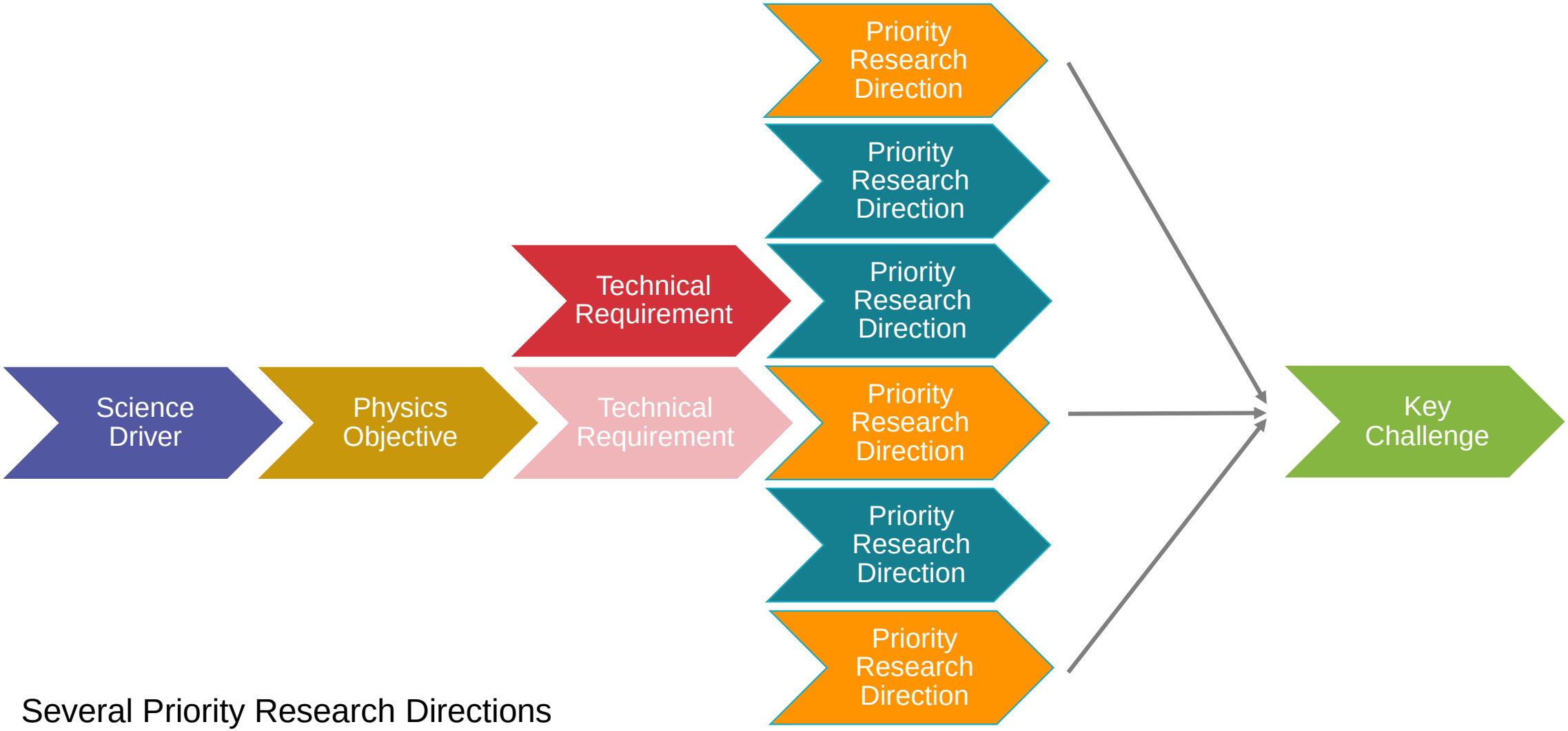
Several Priority Research Directions are candidate ‘Key Challenges’

Anticipated Process Train



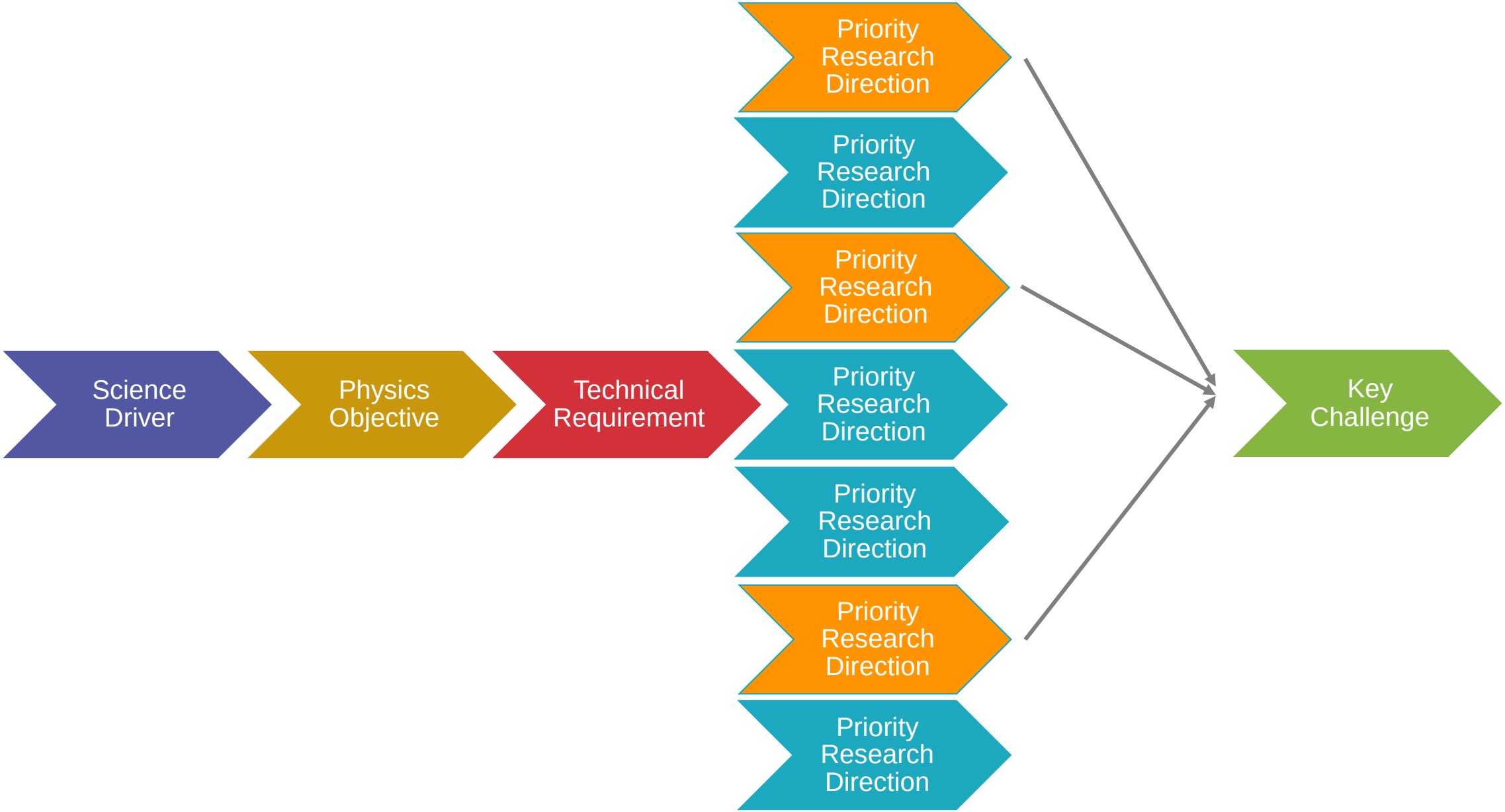
The same physics objective can have multiple technical requirements with other ‘Key Challenges’

Anticipated Process Train

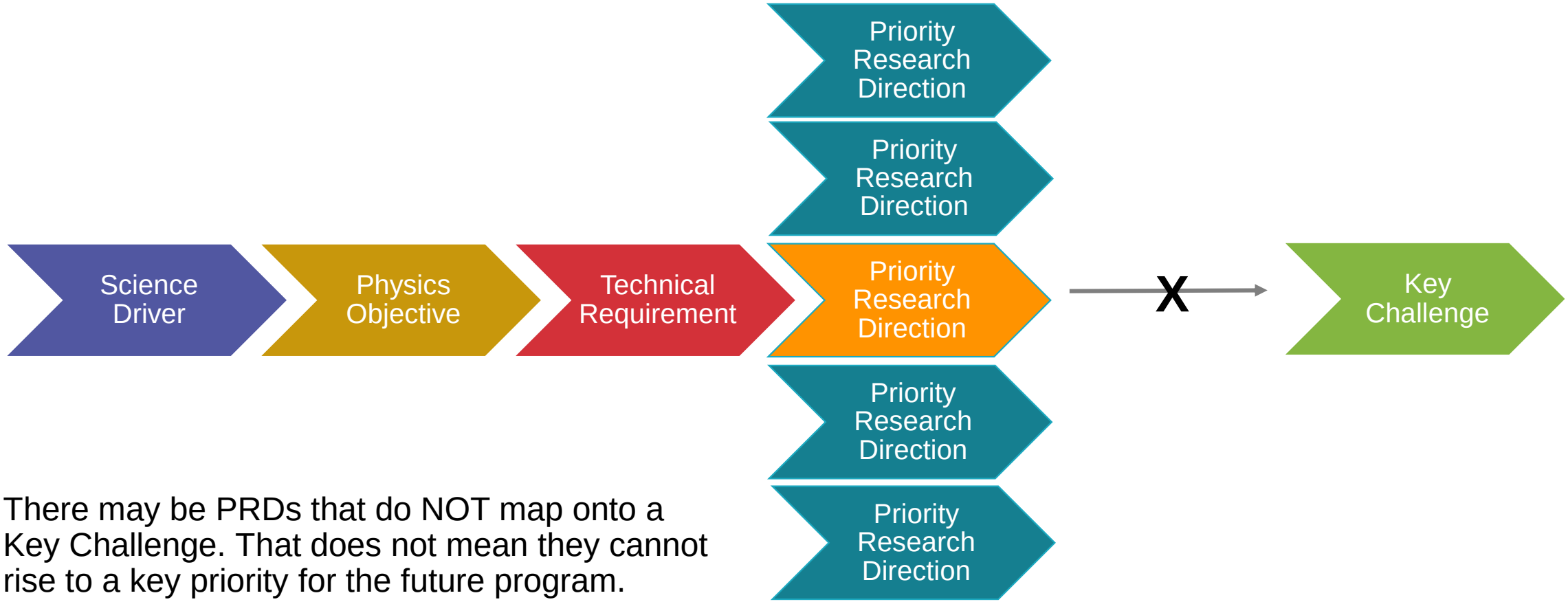


Several Priority Research Directions are candidate ‘Key Challenges’

Anticipated Process Train

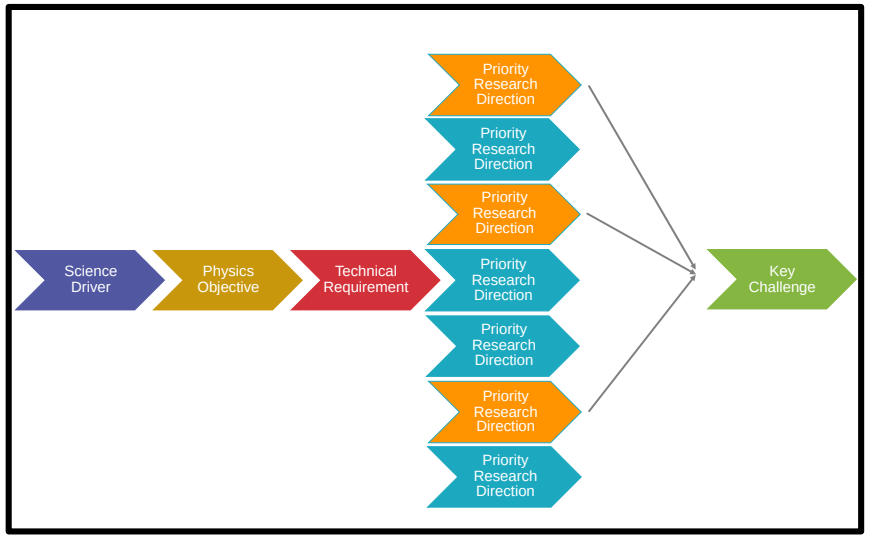


Anticipated Process Train

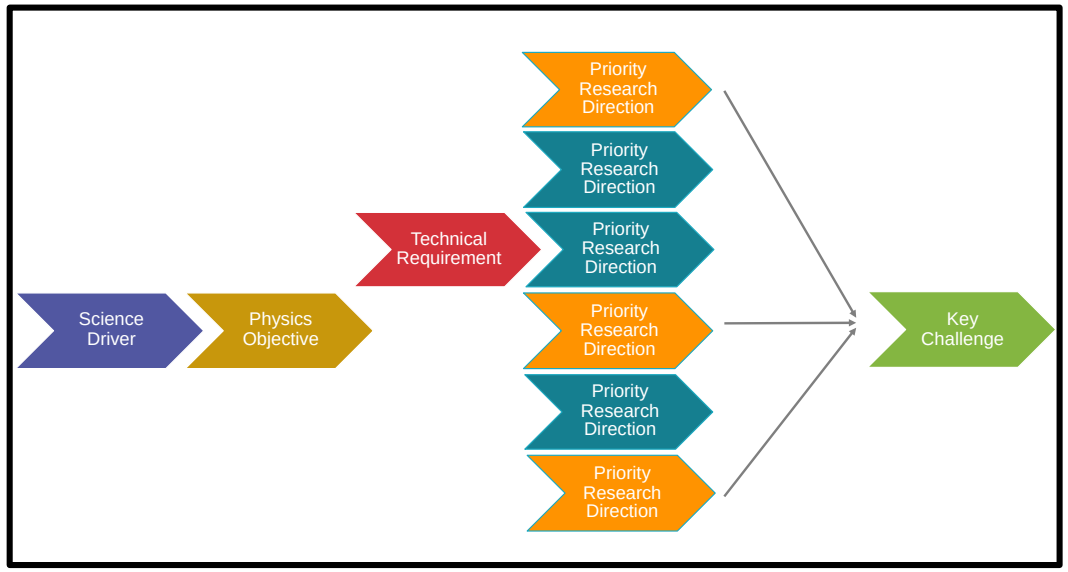


There may be PRDs that do NOT map onto a Key Challenge. That does not mean they cannot rise to a key priority for the future program.

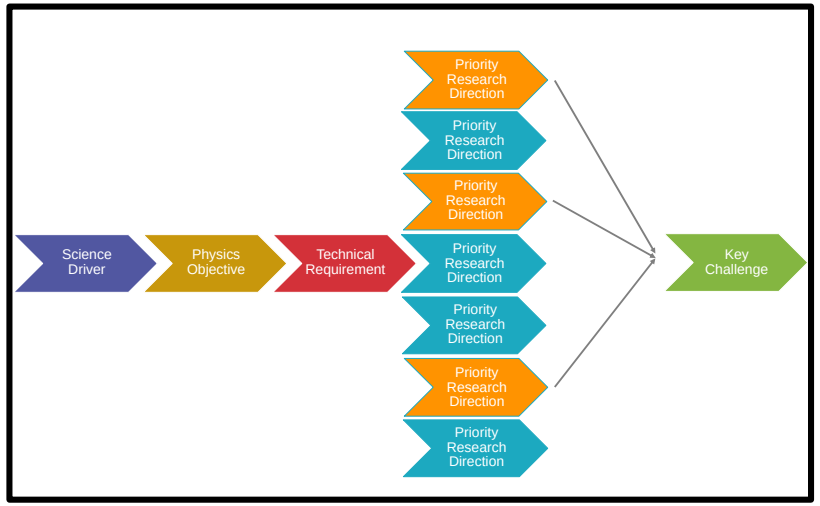
Process gets carried out by all groups



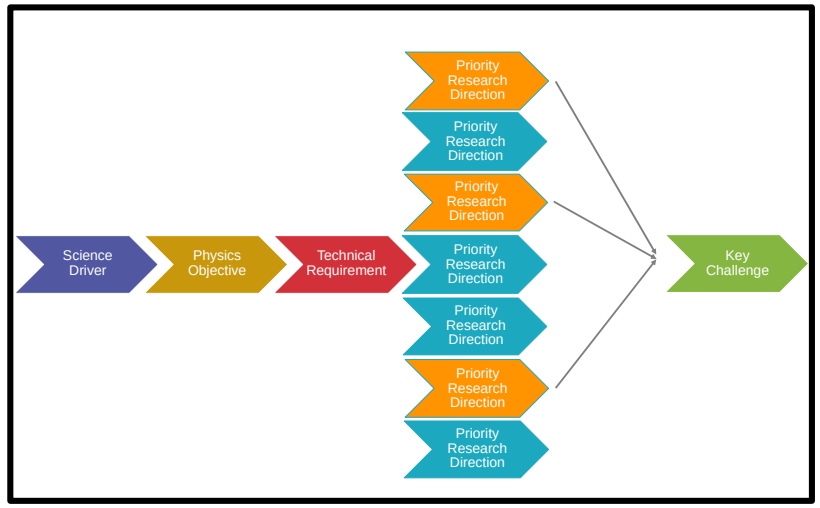
Science Driver
Physics Objective
Technical Requirement
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Key Challenge



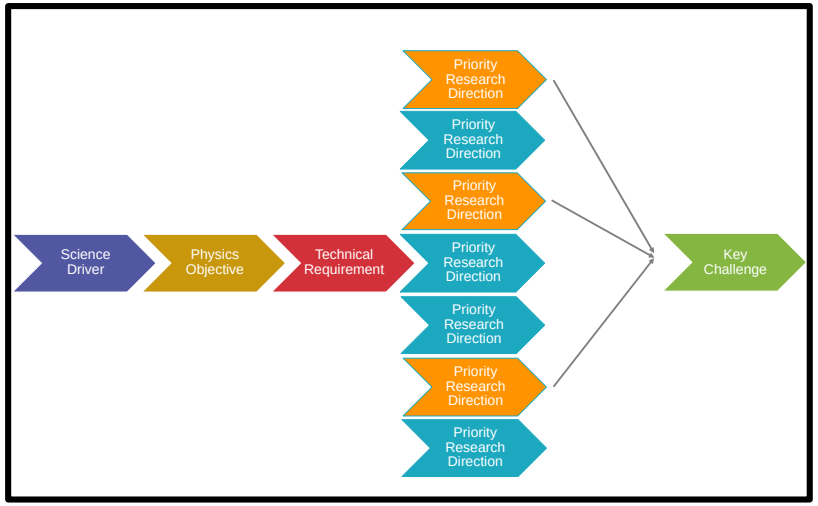
Science Driver
Physics Objective
Technical Requirement
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Key Challenge



Science Driver
Physics Objective
Technical Requirement
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Key Challenge

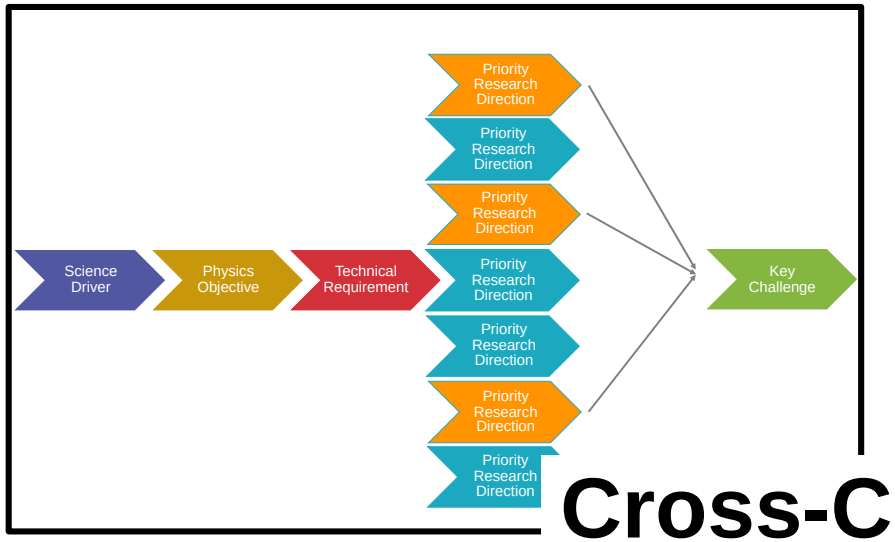


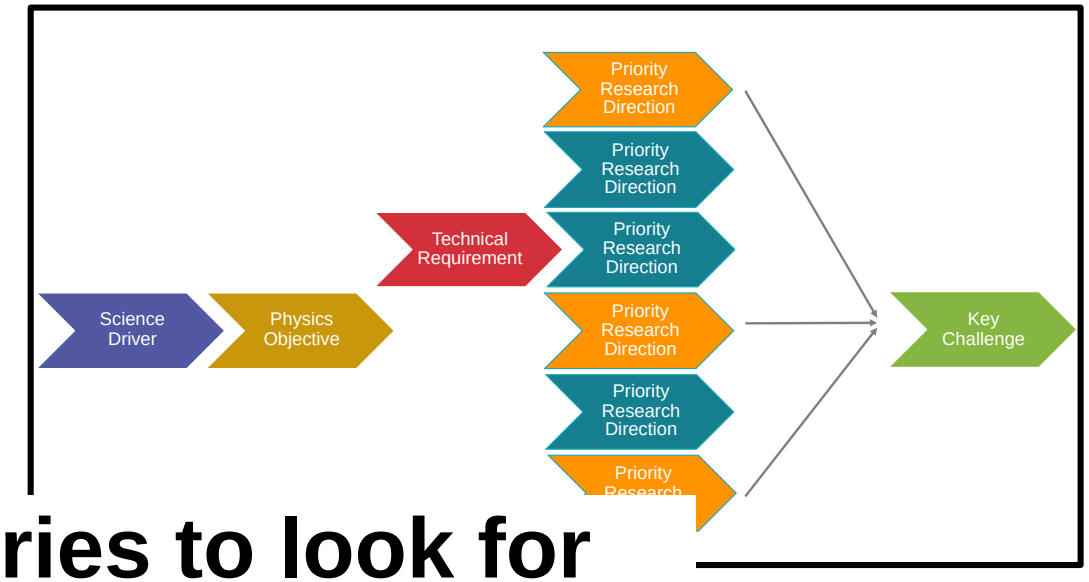
Science Driver
Physics Objective
Technical Requirement
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Key Challenge



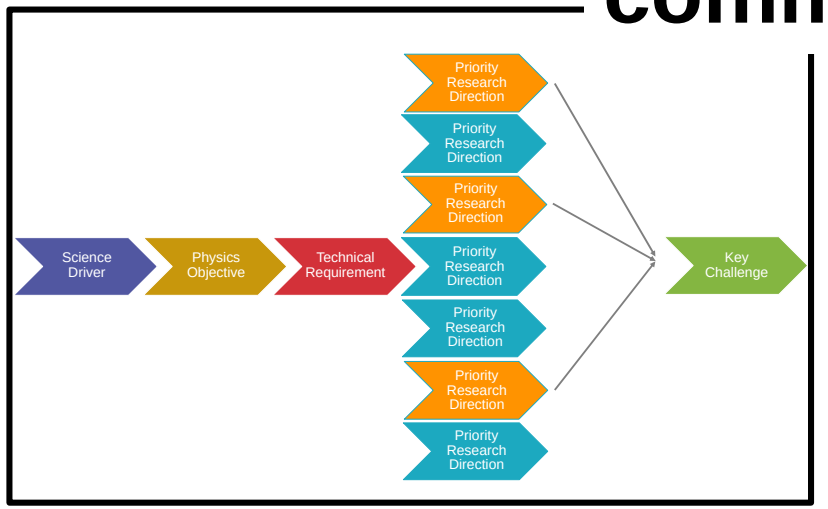
Science Driver
Physics Objective
Technical Requirement
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Priority Research Direction
Key Challenge

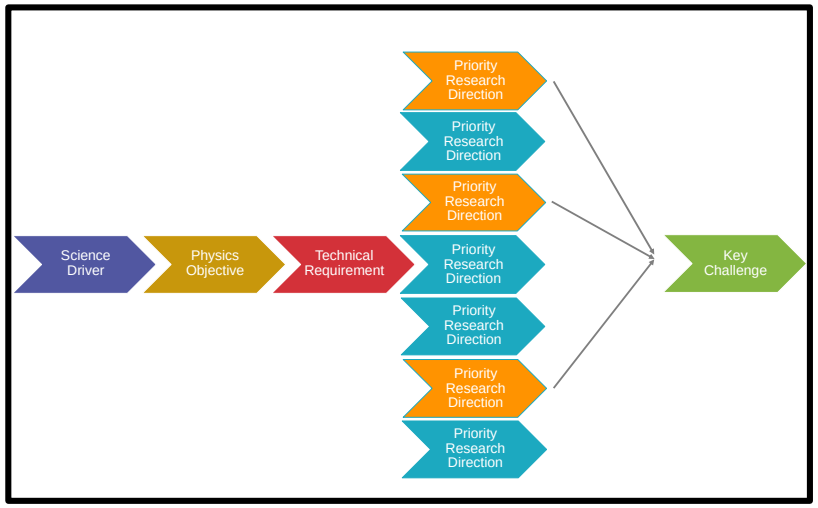
Process gets carried out by all groups

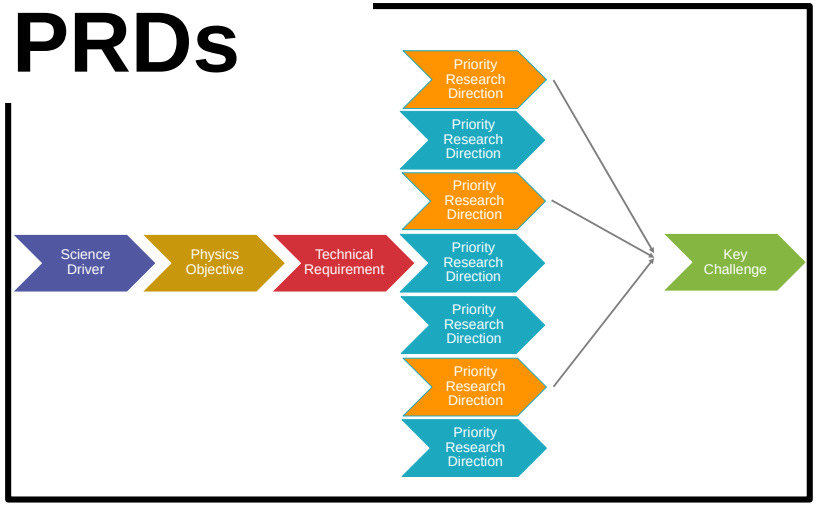




Cross-Cut group tries to look for commonality between the PRDs







The Flow

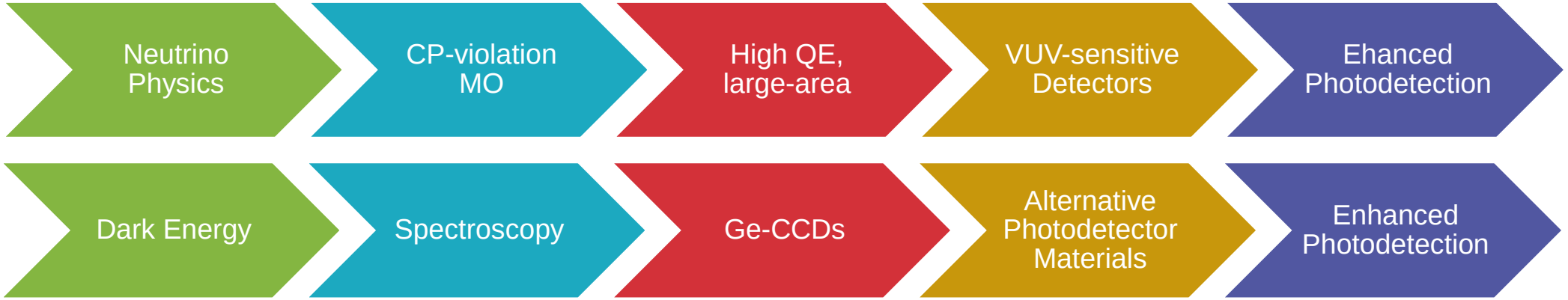
- Many areas are very thin on requirements, or are absent all together. We need help!
- Example “flow”:

The Flow

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

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

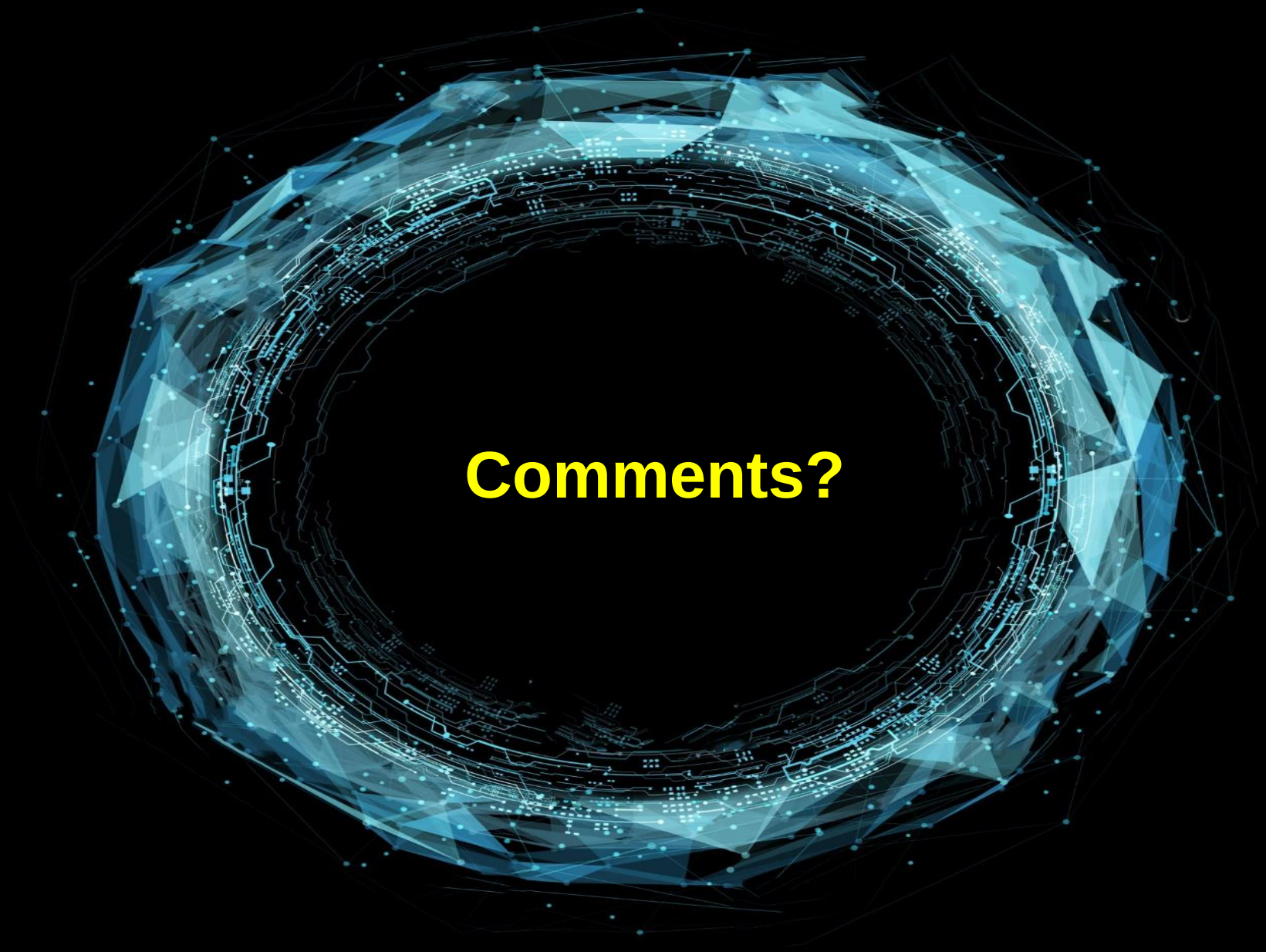
	Higgs Boson	Neutrino Mass	Dark Matter	Cosmic Acceleration	Explore the Unknown
KC 1	●	●			●
KC 2		●	●	●	●
KC 3	●				●
KC 4			●	●	●
KC 5	●	●	●	●	●

Impact beyond HEP

Report Structure

Exec Summary	Science Impact	Panel Report

• Audience: policy makers
• Length: ~1 page
• Describes the Key Challenges
	• 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
		• Audience: OHEP and HEP community
		• Length: ~100 pages
		• In-depth discussion – with specificity – of all the PRDs
		• The PRDs have to be **actionable**



Comments?