Coordinating **P**anel for **A**dvanced **D**etectors (**CPAD**): Detector R&D coordination in the US

https://cpad-dpf.org/

Jonathan Asaadi
University of Texas at Arlington

Caveat

I’m going to be “wearing multiple hats” during this talk

CPAD co-chair

RDC 1 co-coordinator

Instrumentation Enthusiast

Opinionated physicists

I’ll do my best to clarify the positions I’m expressing as I go through the talk

High Energy Physics

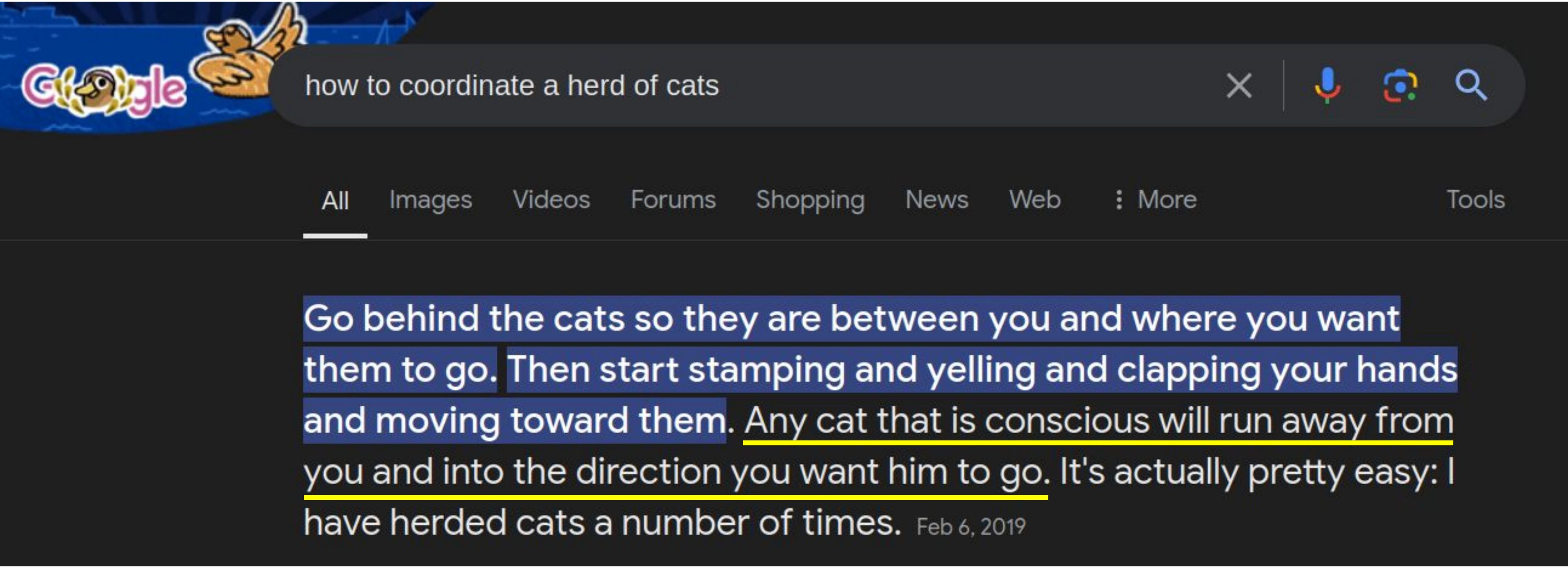
A not uncommon characterization of the High Energy Physics Community often brings to mind an image of a herd of cats

I think this image is even more true when it comes to instrumentation R&D and detector development

And the sisyphean task of trying to coordinate them is often seen as trying to “herd” cats

Which wikipedia quotes as: **“denoting a futile attempt to control or organize a class of entities which are inherently uncontrollable”**

So of course, I just ask Google how to do this….



Herding cats to a goal

So if the goal is to build to build a next-generation collider and experiment, than CPAD can play a role by helping coordinate and communicate efforts across all efforts (e.g MuC, FCC, etc), can help identify and promote technologies which lead to next generation detectors (fast timing, precision calorimetry, high granular tracking, radiation hardness, etc…) and potential breakthroughs in physics

The American Physics Society (APS) and Division of Particles and Fields (DPF) Coordinating Panel for Advanced Detectors (CPAD)

CPAD Mission and Goals:

- The Coordinating Panel for Advanced Detectors (CPAD), seeks to promote, coordinate and assist in the research and development of instrumentation and detectors for high energy physics experiments.
- By helping to coordinate the development of both evolutionary and transformative detector instrumentation across the national laboratories and with the university community, CPAD works to ensure the future of high-energy physics experiments.

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It is out of these aspects of CPAD's mission and goals and the work of the Snowmass process which the concept of the formation of Research and Development Collaborations (RDC's) within CPAD was born

Snowmass IF Recommendations

IF-1 Advance performance limits of existing technologies and develop new techniques and materials, nurture enabling technologies for new physics, and scale new sensors and readout electronics to large, integrated systems using co-design methods.

IF-2 Develop and maintain the critical and diverse technical workforce, and enable careers for technicians, engineers and scientists across disciplines working in HEP instrumentation, at laboratories and universities.

IF-3 Double the US Detector R&D budget over the next five years, and modify existing funding models to enable R&D consortia along critical key technologies for the planned long term science projects, sustaining the support for such collaborations for the needed duration and scale.

IF-4 Expand and sustain support for blue-sky R&D, small-scale R&D, and seed funding. Establish a separate agency review process for such pathfinder R&D, independently from other research reviews.

IF-5 Develop and maintain critical facilities, centers and capabilities for the sharing of common knowledge and tools, as well as develop and maintain close connections with international technology roadmaps, other disciplines and industry.

These are where the CPAD RDC's come in

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Some critical aspects from the P5 report

The particle physics community has identified the need for stronger coordination between the different groups carrying out detector R&D in the US. We strongly support the R&D Collaborations (RDCs) that are being established and will be stewarded by CPAD, the Coordinating Panel for Advanced Detectors, overseen by the APS/DPF. The RDCs are organized along specific technology directions or common challenges, and aim to define and follow roadmaps to achieve specific R&D goals. This coordination will help to achieve a more coherent detector instrumentation program in the US, and will help to avoid duplication while addressing common challenges. International collaboration is also crucial, especially in cases where we want to have technological leadership roles. Involvement in the newly established Detector R&D Groups at CERN is encouraged, as are contributions to the design and planning for the next generation of international or global projects. Targeted future collider detector R&D in particular, such as for Higgs factories or a muon collider, is covered in Section 6.5.

The RDC's are in the P5 report as is participation in the CERN based Detector R&D (DRD's)

Area Recommendation 6: Increase the budget for generic Detector R&D by at least $20 million per year in 2023 dollars. This should be supplemented by additional funds for the collider R&D program.

Area Recommendation 7: The detector R&D program should continue to leverage national initiatives such as QIS, microelectronics, and AI/ML.

Principal Ideas behind the RDCs

Detector R&D in many different technology areas is essential to realize many of the future planned experimental efforts spanning all of the frontiers in High Energy / Nuclear Physics

Much of the efforts needed require **collaboration** and **coordination** in order to realize the technologies required

- **Collaboration**: The required expertise/resources/new ideas often live within multiple people, institutions, labs and only by bringing these pieces together can we hope to realize the technological challenges
- **Coordination**: We live in a resource limited funding environment and so we need efforts to be coherent, minimize duplication, and to build off of progress happening elsewhere (both in other technologies and in other places)

Principal Ideas behind the RDCs

Detector R&D in many different technology areas is essential to realize many of the future planned experimental effort… / Nuclear Physics

> **Collaboration**
>
> Where the RDC's can work to identify needed R&D, work together to assemble proposals, and aid in the execution of the work

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Coordination

This is what CPAD is meant to help provide and why these collaborations are being formed within our structure/charge

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R&D Collaborations (RDCs) - Status

RDC	Topic	Coordinators
1	Noble Element Detectors	Jonathan Asaadi, Carmen Carmona
2	Photodetectors	Shiva Abbaszadeh, Flavio Cavanna
3	Solid State Tracking	Sally Seidel, Tony Affolder
4	Readout and ASICs	Angelo Dragone, Mitch Newcomer
5	Trigger and DAQ	Jinlong Zhang, Zeynep Demiragli
6	Gaseous Detectors	Prakhar Garg, Sven Vahsen
7	Low-Background Detectors	Noah Kurinsky, Guillermo Fernandez-Moroni, Daniel Baxter
8	Quantum and Superconducting Detectors	Aritoki Suzuki, Rakshya Khatiwada
9	Calorimetry	Marina Artuso, Minfang Yeh
10	Detector Mechanics	Andy Jung, Eric Anderssen
11	Fast Timing	Gabriele Giacomini, Matt Wetstein

See the backup slides for details about each RDC

What will the RDC's do?

Long term goal:

- **Establish collaborations** which can link together facilities, expertise, people, and experience to tackle technology challenges across HEP/NP
- **Facilitate new funding** mechanisms for R&D related to a specific technology area which will take place as part of the collaborations' activities
- Work with the CPAD executive committee, ECFA DRDs, and the broader R&D community to **foster a collaborative, supportive, and coordinated environment for new ideas, blue sky efforts, and non-project specific R&D**

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You might ask yourself, what does this aspect of the RDC's mean….

Blue Sky R&D

What do we mean here…

We typically use

“I know it when I see it”

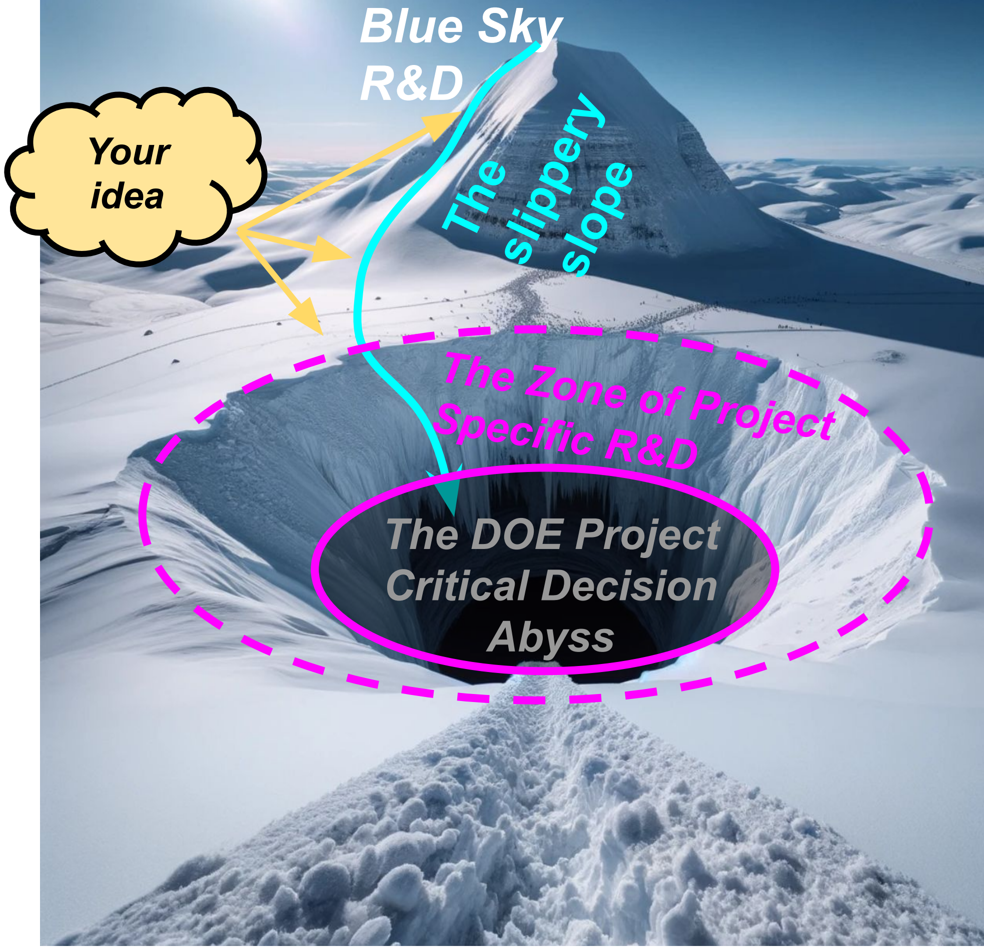
which isn’t great…

Thinking about “Blue Sky”

- **There is this “slippery slope” between what some call “Blue Sky” and what people call “Project Specific” which makes defining what we mean difficult**
- **A few points on this**
  - Just because R&D is “Project Specific” doesn’t mean it it won’t be transformational!
    - Sometimes solutions to one persons problems end up being the solution we didn’t know we were looking for!
  - Just because R&D is “blue sky” doesn’t mean it won’t be applied to a project
    - If the idea is ends up being as good as one hopes, it could change the way we build detectors

Thinking about "Blue Sky"

- Where your idea lives on this mountain can be somewhat subjective and is often debated
- CPAD and the RDC's aim to work with proponents to target the most "blue-sky" version of your ideas
- I expect that much of the required instrumentation R&D needed at this stage for MuC is higher on the mountain and "in common" with other collider efforts than one might initially think



So what do we mean (a loose and untested definition)

And I'm sure many will disagree with this attempt to define it….

Blue Sky R&D should have some number of these attributes

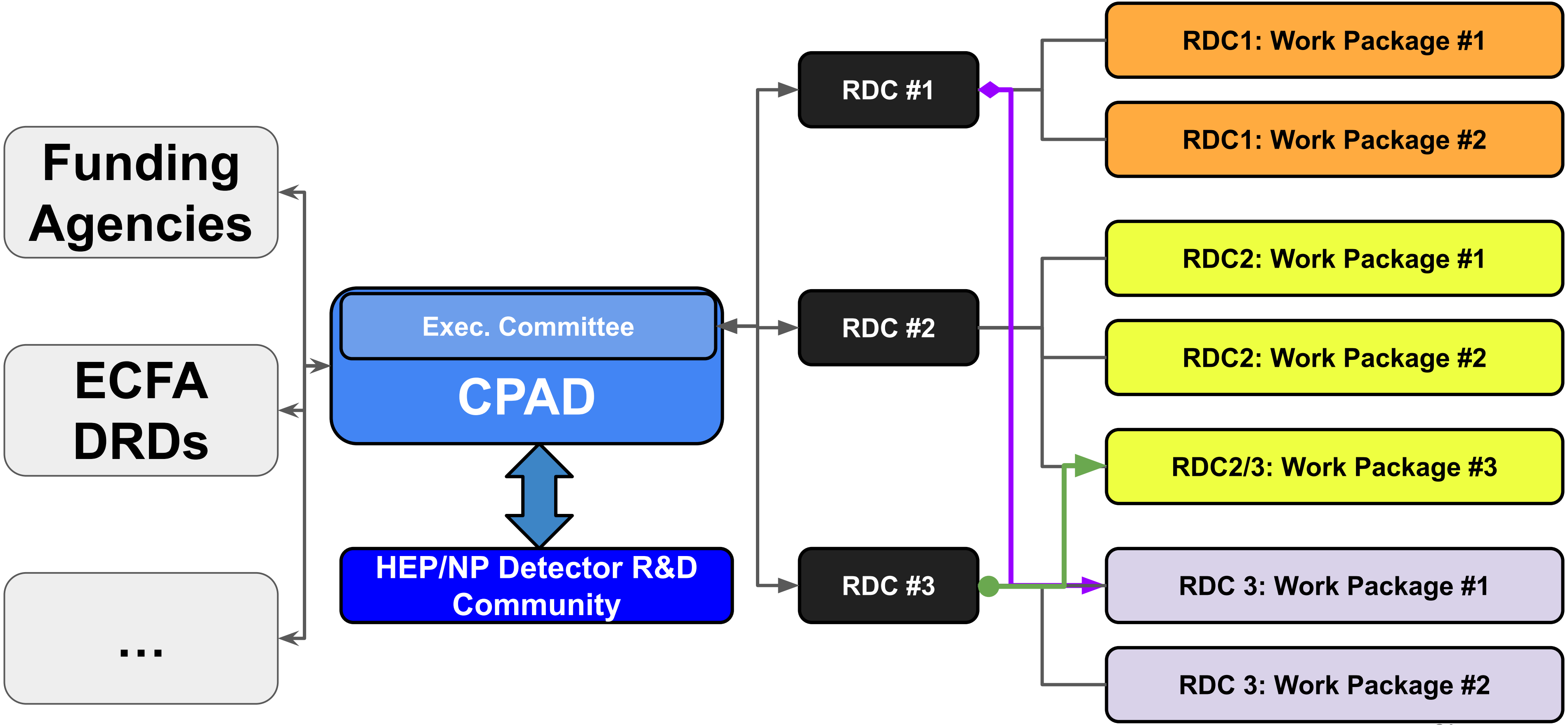
- The work has a speculative aspect which requires a group of people performing work to test the hypothesis that the proposed technology/technique/sensor/method/approach will address with the possibility of failure
  - "High Risk"
- The goal of the research, if successful, should be a new technology/technique/sensor/method/approach which would change the way we currently do some aspect of instrumentation in HEP
  - "High Reward"
- The project brings together different domains of expertise in a new or novel way
  - "Cross-cutting"
- This work can be in a direction where the immediate "real-world" applications are not apparent right now, but have a notional direction which seems promising and unexplored
  - "Basic Research"

What will the RDC's NOT do?

The RDC's will NOT:

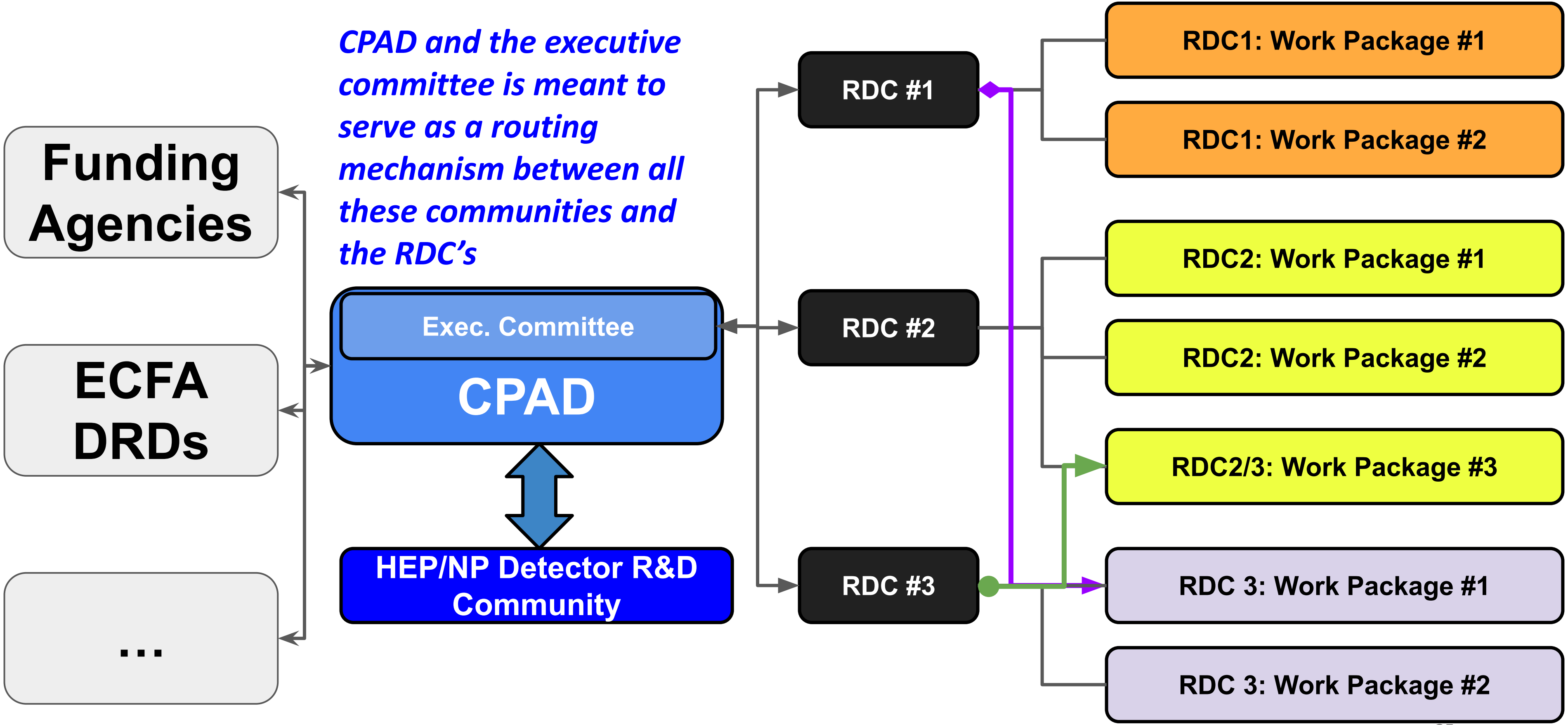
- **Discourage single/small team efforts in R&D**
  - We still need for individual PI's to be able to work in their labs on their favorite ideas and leave room for innovation and unexpected solutions
- **Break up existing organizations / structures**
  - We already have communities within HEP/NP which coordinate on specific technological challenges (e.g. HEP-IC) and we want to utilize/leverage these efforts and communities to help make the CPAD-RDC's successful
- **Discourage project specific R&D**
  - There is some R&D which will/has reach(ed) a level of maturity that it is time to realize it for a specific implementation and the RDCs should encourage this transition from generic to specific R&D

What is the envisioned structure (so far)



What is the envisioned structure (so far)

CPAD and the executive committee is meant to serve as a routing mechanism between all these communities and the RDC's



What CPAD has been doing in 2024 to jump start the RDC's

We started with what we had….

- **Long term: the aim is to have different supporting mechanisms for collaborative instrumentation R&D which may have its own dedicated Funding Opportunity Announcement (FOA) and dedicated (new) funding**
  - For FY2025 submission, this is not in place.
  - Therefore, we attempted to work with the community to start some of this type of collaborative R&D using the existing comparative review Funding Opportunity Announcement
  - In the future, the process by which CPAD RDC's work to put together these collaborative proposals will be different
    - This will also be informed by how well this year's process goes

What CPAD has been doing in 2024 to jump start the RDC's

- **A Reminder: At time of writing, there is no new funding available to the HEP budget for generic detector R&D. This means that new proposals for CPAD R&D collaborations (RDC's) that are to be submitted to the comparative review FOA need to be limited in number, structure, and scope.**

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  - Number: small; we expect that the RDCs and the community can converge on a few most suitable proposals for this year under these constraints
  - Structure: These should be university lead, multi-institutional proposals with a light-weight collaboration structure (not a structure like the very formal DRD collaborations)
    - These teams can include national labs
    - Where appropriate the multi-institutional teams should designate one lead institution with all other team members proposed as subrecipients.

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    - These teams can include national labs
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  - Scope: The proposals should focus on generic R&D (as opposed to project specific), ``blue-sky'' (having a high-risk high-reward outcome), and have limited but growing budget profile
    - The most important point is to develop the proposals with a strong and coherent technical scope
    - Very likely the most competitive proposals would have components that live in multiple RDC's and are coordinated by multiple RDC groups

What CPAD has been doing in 2024 to jump start the RDC's

- **Over the last 2-3 months, the RDC's have been working to collect a series of whitepapers and work with the community to both foster new collaborations and to draw attention to existing R&D efforts**
    - There have been some bumps along the way, but the community has been largely supportive, open, welcoming and vocal!
    - The landscape is continuing to change and evolve as new efforts, new coordination strategies, and new information about funding becomes available
        - We are working very hard to be agile with this as well
- **The RDC's collected ~34 whitepapers from across the community**
    - These whitepapers will be posted to the CPAD website shortly for the community to see
    - End of July we hosted a community workshop where we heard from a subset of these whitepapers (~15) on their proposed R&D (https://indico.fnal.gov/event/65448/)
- **We are now working with proponents to help the highest priority and best fit proposals (subject to 2024 constraints) to submit proposals to the DOE FOA**
    - Hopefully this converges later this week

CPAD Workshop November 18th - 22nd

University of Tennessee, Knoxville

Hosted by UTK and ORNL

https://indico.phy.ornl.gov/event/510/

CPAD 2024

Conclusions

- **The US instrumentation community via CPAD is working to form collaborations to tackle the larger detector R&D challenges facing the HEP community**
- **It is my sincere hope that this can be done in collaboration and harmony with the CERN based DRD's as well as the long term high priority projects identified in the P5 report**
    - Identifying key areas of overlap and looking for areas of opportunity will be a big part of this process
        - You have an ally "on the inside" as I am playing a role in the DRD's, CPAD, and the RDC's
- **I hope the process can be done without a heavy hand, as the nature of this work is explorative, adaptive, and prone to failure (it wouldn't be R&D otherwise)**
    - Instead let us focus on bringing together the world experts to tackle some groundbreaking instrumentation. Let us bring together some of the cutting edge resources, processes, and collaborations to allow us to fulfill what only advances in instrumentation can do:

"Measure what is measurable, and make measurable what is not so"

We stand at a decade of HEP with immense ambition and challenge ahead of us to realize the next generation of facilities, detectors, sensors, and experiments which will light the way to the next major discoveries in physics

Backup Slides

RDC 1: Noble Element Detectors

- RDC Coordinator(s)
  - Name: Jonathan Asaadi
    - jonathan.asaadi@uta.edu
  - Name: Carmen Carmona
    - carmona@psu.edu
- **Areas of R&D Priorities:** In the broadest sense, these are rearticulations of the BRN 2019 report and Snowmass 2022 reports
  - **Topic Area #1:** Enhance and combine existing readout modalities
    - New ideas in charge detection
      - e.g. Pixels, extreme low threshold detection, charge gain, ion detection
    - New ideas in light detection **(Overlap with RDC2)**
      - e.g. new technologies, geometries, materials, WLS,
  - **Topic Area #2:** New modalities for signal detection
    - Going beyond the current paradigm just collecting electrons and photons
      - e.g. Meta-stable fluids, micron-scale tracking, combined multimodal sensors
    - Enhancement in the electronics and readout of the detectors **(Overlap with RDC 4,5)**
      - e.g. Photonic readout solutions, new/enhanced architectures at the front-end, AI/ML inside the detector
  - **Topic Area #3:** Challenges in scaling technologies
    - Scaling of purification, radiopurity, doping, high voltage, and other target challenges
      - e.g. Large scale purification, removing radioactive contaminants @ > ton scale
- We fully endorse the other identified challenges in the BRN and Snowmass reports, but have opted to focus on these topic areas as a place to start

RDC 2: Photodetectors

- RDC Coordinator(s)
  - Name: Shiva Abbaszadeh
    - sabbasza@ucsc.edu
  - Name: Flavio Cavanna
    - cavanna@fnal.gov

Areas of R&D Priorities

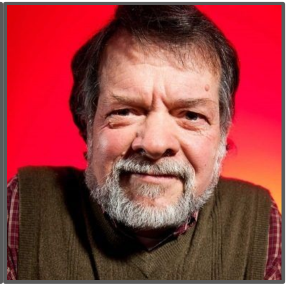
- **Innovative photosensor** (Blue skies research) technological breakthroughs for new science.
  - SNSPD: Superconductive Nanowires Single Ph Detector.
  - VUV sensitive detectors for low-light detection
- **Photosensor (& Instrumentation) development** to enhance experimental capabilities (eg improving Single Photon detection, timing, radiation hardness, ..).
  - SiPM - main stream in photosensors development (Radiation tolerance, Spectral sensitivity, correlated noise, … ultimately Digital SiPM).
  - MicroChannel Plate (MCP) PMT (—>LPPD) *[RDC#11 - Fast Timing]*
  - CCDs: Ge CCD or Skipper CCDs [*RDC#5 - Low-Background Detectors (incl. CCDs)]*
  - “Accessories”: Filters, Lenses, Wavelength shifters, Waveguides, Fibres, PoF, SoF, Optics.
- **Large Area PDSystems** (PhotoCollectors and integrated readout for photo-sensors) project specific R&D
  - R&D on scalability of light readout for current and future neutrino/DM experiments *[RDC#1 - Noble Element Detectors and RDC#10 - Detector Mechanics]*. Increase of photo-coverage to improve energy resolution and lower threshold. Dedicated developments should achieve applications in future detectors - ten to a hundred times larger, compared to the present (OptCoverage —> 10, 100 and ultimately 1000 m2). Noise hit rates, radiopure materials, power dissipation, large bandwidth signal transmission (readout channels and data volumes

RDC 3: Solid State Tracking

- RDC Coordinator(s)
  - Name: Tony Affolder
    - affolder@ucsc.edu
  - Name: Sally Seidel
    - seidel@unm.edu
- Areas of R&D Priorities
  - Topic Area #1: Adapting non-silicon and novel-configuration sensors
    - Improved costs, area, radiation tolerance, performance
  - Topic Area #2: Scalable, low-mass detector systems
    - MAPs based tracking,
  - Topic Area #3: Trackers for Lepton Colliders
    - Similar requirements for timing and spatial resolution
  - Topic Area #4: Trackers for Hadronic Colliders
    - Extreme radiation with fine timing and spatial resolution
  - Topic Area #5: Advanced modeling

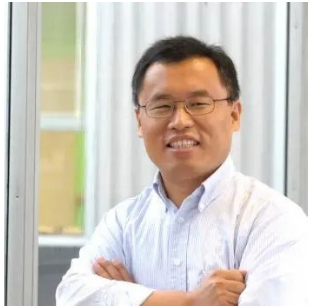
PRD	Thrust
PRD 18: Develop high spatial resolution pixel detectors with precise per-pixel time resolution to resolve individual interactions in high-collision-density environments	Thrust 1: Lepton colliders, requiring timing on the order of 10 ps; pixel pitch on the order of 10 microns Thrust 2: Hadron colliders, requiring timing resolution down to 1 ps to achieve HL-LHC-like pileup, in a high radiation environment (up to fluences in the order of $10^{18} n_{eq}/cm^2$)
PRD 19: Adapt new materials and fabrication/integration techniques for particle tracking	Thrust 1: Adapting non-silicon and novel-configuration sensors (diamond, large-bandgap semiconductors, thin film materials, nanotechnology, 3D sensors, new emerging materials) with new industrial partnerships Thrust 2: Development of readout electronics matched to new sensor characteristics, including new processing such as 3D-integration
PRD 20: Realize scalable, irreducible-mass trackers	Thrust 1: Highly integrated monolithic, active sensors Thrust 2: Scaling of low-mass detector system Thrust 3: Systems for special applications: space-based tracking detectors, and dedicated searches for rare processes and dark matter

RDC 4: Readout and ASICs

- RDC Coordinator(s)
  - Name: Angelo Dragone
    - dragone@slac.stanford.edu
  - Name: Mitch Newcomer
    - mitch@hep.upenn.edu
- Areas of R&D Priorities (preliminary and non-exhaustive)
  - Topic Area #1: Circuits and Architectures for 4D Tracking and Calorimetry
    - Picosecond Timing Circuits
    - Monolithic Readouts
    - Models and Techniques for extreme radiation
  - Topic Area #2: Big Data Management
    - Energy efficient architectures and circuits
    - On-Chip Computing
    - On-Chip AI/ML
    - Fast Interconnections and I/Os
    - Advanced Integration (3D, Photonics, Wireless)
  - Topic Area #3: Cryogenic and Deep Cryogenics
    - 4K Circuits and Architectures for QIS
    - Circuits and Architectures for Noble Liquid Detectors
    - Cryogenic Models and Libraries
  - Topic Area #4: Methodologies, Tools, and Workforce Development
    - Design for Verification methodologies
    - CAD Tools and Foundries shared joint access
    - Shared libraries and access model
    - Domain knowledge transfer and training

RDC 5: Trigger and DAQ



- RDC Coordinator(s)
  - Name: Zeynep Demiragli
    - zdemirag@bu.edu
  - Name: Jinlonng Zhang
    - zhangjl@anl.gov
- Areas of R&D Priorities
  - Intelligent data reduction and processing (with RDC4 ?)
    - Real-time / low-latency data reduction and feature extraction
    - Fast artificial intelligence and neuromorphic computing on real-time hardware
  - Link technology (with RDC4 ?)
    - High-bandwidth, rad-hard, low-power optical link (>50Gbps)
    - Wireless readout
  - Integrating modern computing architecture and emerging technologies
  - Self-running DAQ system
  - Timing distribution with picosecond synchronization (1ps over 1 km) (with RDC4 ?)

RDC 6: Gaseous Detectors


- RDC Coordinator(s)
  - Name: Prakhar Garg
    - prakhar.garg@yale.edu
  - Name: Sven Vahsen
    - sevahsen@hawaii.edu
- Areas of R&D Priorities
  (based on Snowmass report, highly preliminary, biased, and non-exhaustive)
  - **Topic Area #1:** Advance gas TPC readout to performance limits, enabling new experiments (DM, neutrinos, existing and future lepton colliders, EIC)
    - Maximize sensitivity by achieving 3d single electron counting (incl. via negative ion drift)
    - Minimize background by developing radio-pure MPGDs
    - Develop matching, highly scalable front-end electronics and readout systems
    - Develop on-detector AI/ML and trigger-driven, highly multiplexed readouts
  - **Topic Area #2:** Advance MPGDs for high-background environments (Nuclear physics and future hadron colliders)
    - Develop cylindrical and exotic-shape tracking layers
    - Develop pico-second timing layers
    - Improve radiation hardness, rate capability, robustness against sparking and aging
  - **Topic Area #3**: Establish MPGD development/prototyping(/production) facility in the US

RDC 7: Low-Background Detectors (incl. CCDs)



- RDC Coordinator(s)
  - Name: Dan Baxter
    - dbaxter9@fnal.gov
  - Name: Noah Kurinsky
    - kurinsky@slac.stanford.edu
  - Name: Guillermo Fernandez-Moroni
    - gfmoroni@fnal.gov
- Areas of R&D Priorities
  - **CCDs for Rare Event Searches**: CCD R&D specific to low-backgrounds, lowering energy sensitivity, and minimizing dark rates. Moving to Ge CCDs, further development of skipper CCD infrastructure, utilizing novel substrates in industrial fabs.
  - **Monolithic Charge Readout**: R&D to lower thresholds and backgrounds for point-contact and contact-free charge readout schemes for monolithic crystals.
  - **Superconducting Phonon Sensing**: R&D specific to phonon sensing for low-background detectors targeting dark matter and neutrino scattering; includes TES, KIDs, Qubit-based Sensors, MMCs, and other novel techniques
  - **Radiopurity R&D**: Research to produce readout electronics and support infrastructure that are radiopure and consistent with needs of low-background experiments.
  - **Novel Materials for Rare-Event Searches**: New targets compatible with low-background searches at sub-eV scales for low-background experiments

RDC 8: Quantum and Superconducting Sensors

- RDC Coordinator(s)
    - Name: Rakshya Khatiwada
        - rkhatiw@fnal.gov
        - rkhatiwada@iit.edu
    - Name: Aritoki Suzuki
        - asuzuki@lbl.gov

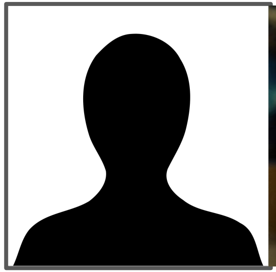
- Areas of R&D
    - Pairbreaking, Photon & Phonon Sensors
    - Coherent Wave Sensors
    - AMO, clocks, interferometry, NMR, Optomechanical Sensors
    - Theory, Simulation & Novel Material

- We will have RDC8 meeting soon to go over work package document

RDC 9: Calorimetry

- RDC Coordinator(s)
  - Marina Artuso:
    - martuso@syr.edu
  - Minfang Yeh:
    - yeh@bnl.gov
- Areas of R&D Priorities (Still under devlopment with the community)
  - From the BRN report three main broad R&D areas
  - Topic Area #1: Enhance calorimetry energy resolution for precision electroweak mass and missing-energy measurements
  - Topic Area #2: Advance calorimetry with spatial and timing resolution and radiation hardness to master high-rate environments
  - Topic Area #3: Develop ultrafast media to improve background rejection in calorimeters and particle identification detectors

RDC 10: Detector Mechanics



- RDC Coordinator(s)
  - Name: Eric Anderssen
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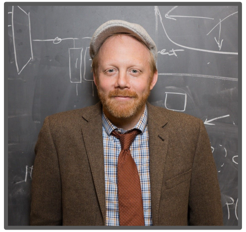
  - Name: Andy Jung
    - anjung@purdue.edu
- Aims at detectors for future colliders
  - FCC-ee, muon Colliders, and more
- Areas of R&D Priorities
  - Light-weight composite materials for detector support (radiation-hard, highly thermally conductive)
    - Dual-use, e.g. electronically or/& thermally conductive, etc. while providing structural support
    - Rails to support detectors
    - Mechanical & thermal finite element analysis for manufacturing or during operation (FEAs)
  - Detector cooling aspects (Pipe materials, connections, fittings)
  - System integration aspects, beampipe bakeout, beampipe interfaces
  - Alignment, shock & vibrations in-situ or transport or magnet discharge, etc.
  - Radiation aspects: epoxy, mechanics materials, access
  - Thermal expansion differences, issues due to humidity / outgassing
  - Failure management: Maintainability, services, maximum duty cycle
  - Magnet developments

12th Forum on Tracking Detector Mechanics:

- Sessions on RDC10 & DRD8
- 29-31 of May @ Purdue - **Register asap!**
- https://indico.cern.ch/event/1336746/

RDC 11: Fast Timing




- RDC Coordinator(s)
  - Name: Matt Wetstein
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  - Name: Gabriele Giacomini
    - giacomini@bnl.gov
- Topic Area #1: Picosecond timing
  - ~10ps for muon colliders, ~1ps for hadron colliders,while keeping ~10um of spatial resolution (or less)
  - <100 ps (single photoelectron) for neutrino experiments with sub-cm resolution
- Topic Area #2: new materials to reach ps timing
  - Expand from silicon (LGAD, 3D)
- Topic Area #3 Leveraging fast photodetection in cryogenic detectors
- Topic Area #4 High precise GPS-based synchronization and time stamping over long distances for neutrino applications
- Topic Area #5 Fabrication techniques to reduce costs (LAPPDs)
- Topic Area #6 integration with read-out electronics (fast MAPS, low capacitance hybrids, …), photosensor electronics