Detector & Computing: Research & Development

- Cross-community initiatives https://webcast.in2p3.fr/video/detector-r-d-and-computing
  - 8 Detector R&D (DRD) Collaborations

Gas | Liquid | Solid State | Photon & PID | Quantum | Calorimetry | Electronics Processing | Mechanics & Cooling

  - HEP Software Foundation / WLCG, including

Simulation | Generators | Analysis | Triggers & Tracking | GRID

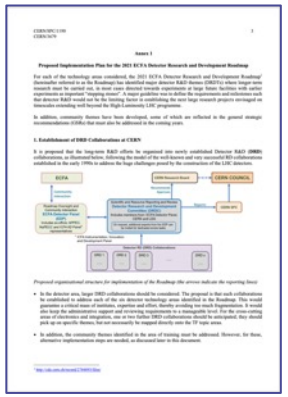
- UK Government & Societal Priorities Funding

Chris Parkes

Detector R&D & HEP Software Foundation

"The community should define a global detector R&D roadmap" ESPPU 2020

Roadmap **Implementation**



DRD 1 - 8

- 8 DRD collaborations
- Strategic recommendations
- Under ECFA auspices, CERN hosted

https://indico.cern.ch/category/6805/

- "Facilitates coordination and common efforts in HEP software and computing internationally"

Roadmap 2017 **Update 2025**

HSF
HEP Software Foundation

- 13 activity areas

http://hepsoftwarefoundation.org/

Evolve our computing infrastructure

WLCG
Worldwide LHC Computing Grid

Detector R&D – general themes

Gas | Liquid | Solid State | Photon & PID | Quantum | Calorimetry | Electronics Processing | Mechanics & Cooling

- **Precision timing** (10-50ps)
  - Separate LHC primary vertices, Particle ID
- **CMOS Detectors**
  - Integrated sensor & electronics
- **Novel technologies**
  - Quantum technologies

Strategic Recommendations

- Facilities (testbeam, irrad.)
- Engineering support
- Software support
- Industry engagement
- Training
- Open Science

- Environmental Impact

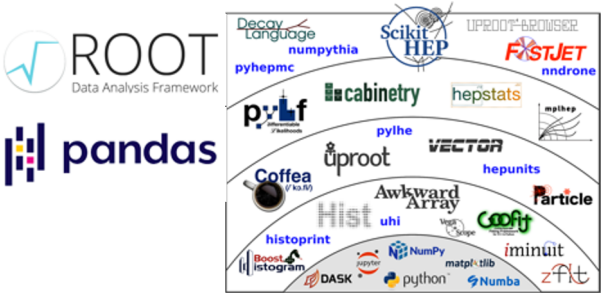
Computing – general themes

- Coordination and common efforts in HEP Software and infrastructure

- **GPUs**

Supercomputer list dominated by CPU-GPU systems

- **Machine Learning** (Triggers, Tracking)
- **Triggerless, Streaming readout**
- Cross-experiment collaboration, **interoperability**
  - Huge array of tools: community & industry



Gaudi

Key4hep

PyHEP

- International collaboration

only 36 FTE

DRD & European PP Strategy Alignment

- DRD 1st period of 3 years ends for many collabs late ‘26, early ’27
- Undergo renewal process – status reports, proposal updates
- Achieved clear priority project plans – while limited dedicated funding
- What is new: ESPP
- https://indico.cern.ch/event/1567686/contributions/7073080/attachments/3312005/5927464/PECFA_july2026_EDP_rizzo.pdf
- Collider side:
- “prioritise developments aiming for FCC-ee”
- Enhance interaction between: DRDs, FCC-ee Detector Concept & Subsystem WGs

DRD-UK Plans & Funding Proposals

https://drd.hep.ac.uk/

- Proposals submitted – positively reviewed; not funded (yet?)
  - SOI PPAN Science Board; Consolidated Grant
    - UK interests; industry; training (CDT)
  - Instrumentation summer school
- Proposals with funding
  - 5 early stage R&D grants submitted July 2024;
  - 2 funded January 2026 (following slides)
- Under consideration
  - EC INFRA-TECH proposal (AIDA successor, 2nd try)
  - International Science Partnerships Fund
    - £120M UKRI funds, submitted Jan. ‘26 Fergus Wilson for STFC


Bucket-hat

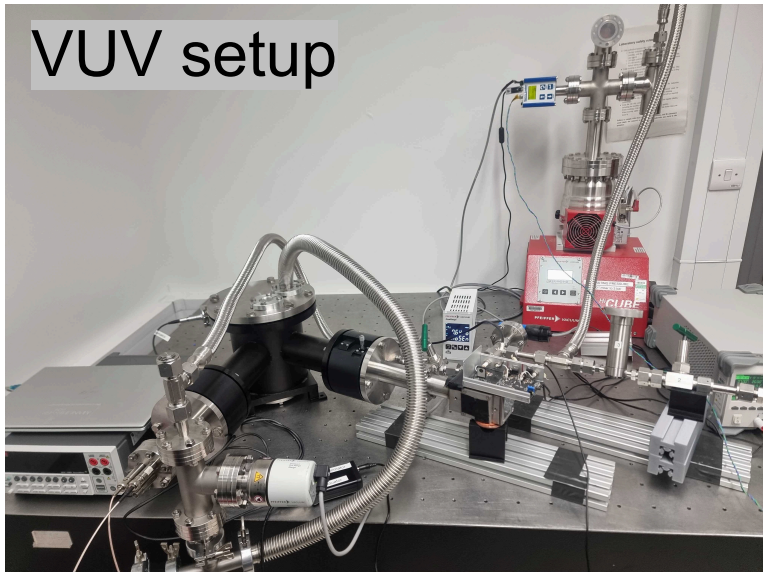
Early Stage R&D: Photon Detector for Vacuum Ultraviolet

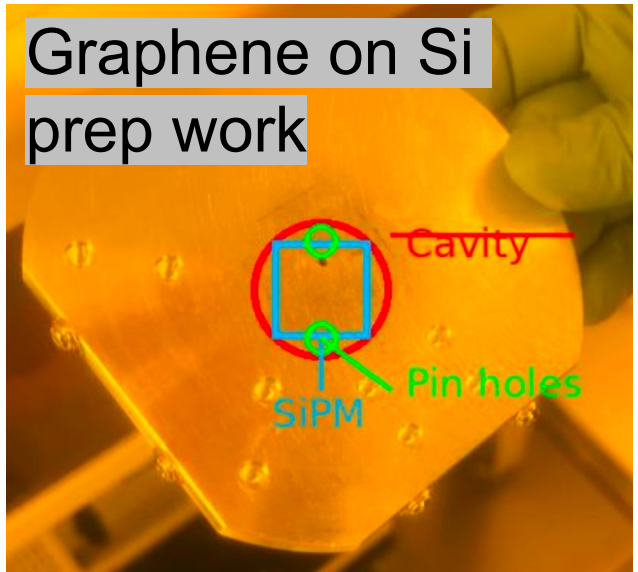
PI: Elena Gramellini (*JINST* **21** P01032, PhysB: Condensed Matter, Vol 739)

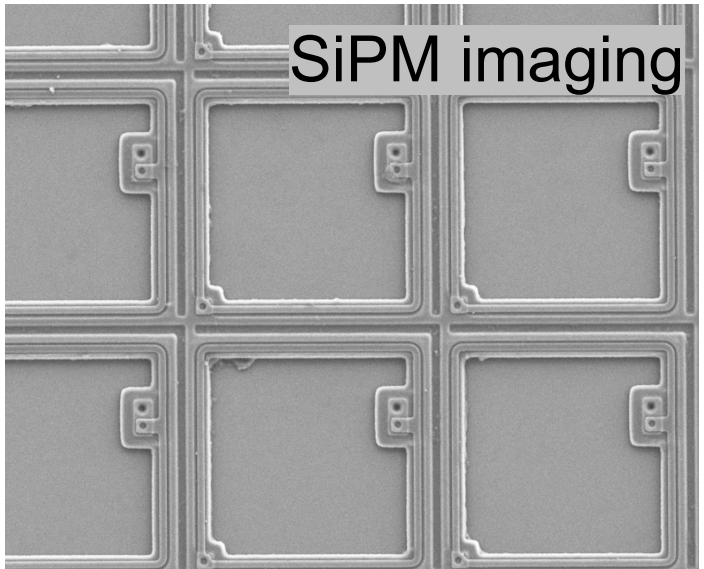
DRD2

Liquid

- Argon and Xenon mostly emit in the VUV (vacuum ultraviolet) range:
  - DUNE, DarkSide, LZ, nEXO…
- Silicon Photomultipliers (SiPMs) have typical efficiency < 20%:
  - aim for factor two (and potentially more) improvement
- Apply strategies proven in astro and medical:
  - CCD, quantum optics, and digital mammography.
- Use metasurfaces and novel graphene coatings on Si & Se







Early Stage R&D: RAD-PIX

DRD-3

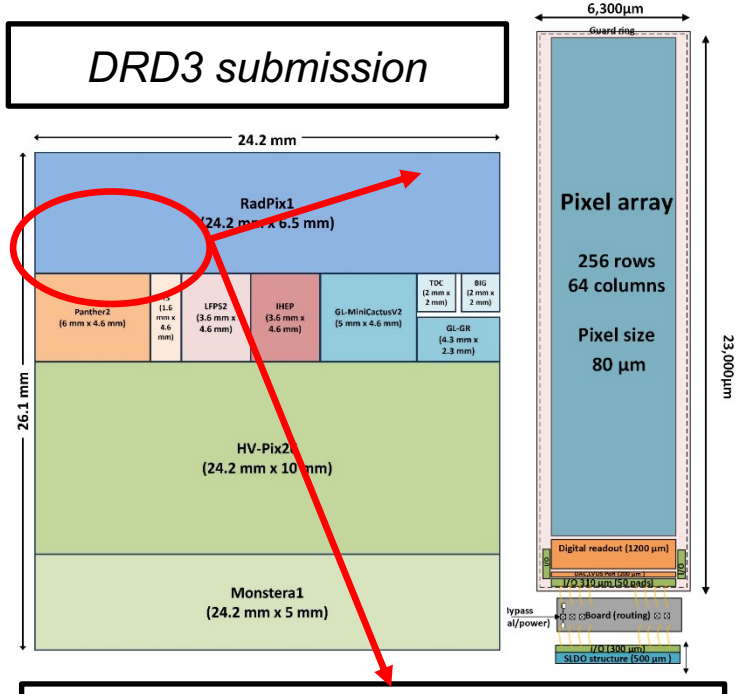
Solid State

RADiation-tolerant monolithic PIXel

PI: Eva Vilella (Liverpool); *design team:* Liverpool, STFC TD, IRFU-CEA, UAB Barcelona, Glasgow, and Cambridge; many others have expressed interest in contributing to the *evaluation* of the fabricated chips.

- Programme to develop High Voltage CMOS devices for HL-LHC upgrades and for applications beyond physics
- RadPix1 submission review in May 2026 (link here)
- Submission currently in progress (included in DRD3 community shared submission to LFoundry), and wafer delivery expected by the end of 2026 (commitment to deliver 15 wafers)

DRD3 submission

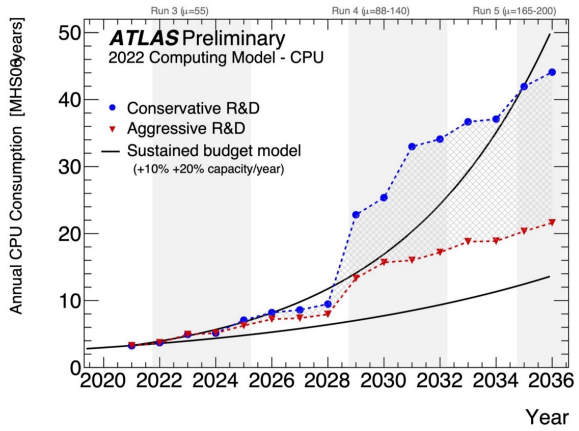


Pixel array and voltage regulator submitted as two separate chips to enable more flexibility. Voltage regulator chip will be used to power the pixel array.

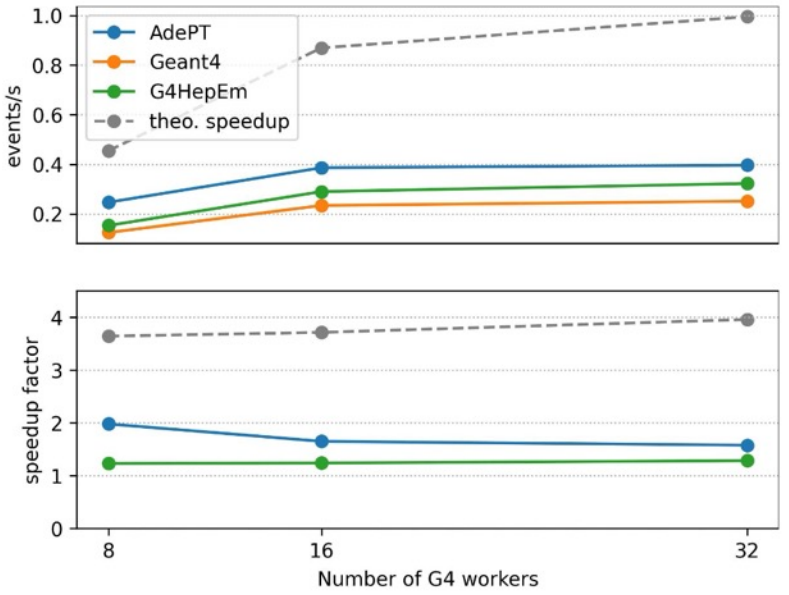
SwiftHEP aims & accomplishments

Input from Davide Costanzo

- SwiftHEP has funded UK contributions to innovative software
  - 2nd phase not funded (would have started October 2025)
- Key goal:
  - addressing estimated CPU shortfall in HL-LHC era



- Example area:
- EM showers: up to $\frac{2}{3}$ of run time in collider expts (G4HepEm)
- Photons: 99% of run-time neutrino, dark-matter, LHCb RICH
- GPU-CPU combined architectures
  - **Geant4 plugins** (AdePT, Celeritas, ML approaches), promising, geometry bottleneck



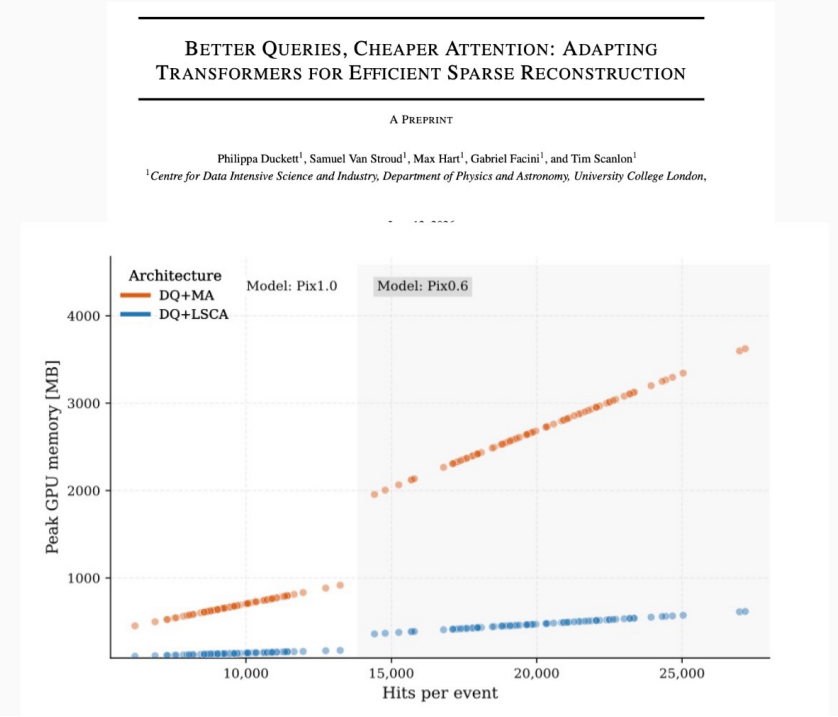
https://indico.cern.ch/event/1528440/

AI4HEP: short term low-level UKRI funded projects

https://ai.hep.ac.uk/projects/

Input from Davide Costanzo

- AI Inference as a Service deployment at a WLCG Tier-2
- AI-enhanced 2D to 3D pattern recognition in LArTPCs
- PHAZE-1: Validating Early Predictive Sufficiency for Low-Latency Foundation Models
- Smart Monitoring: AI-Driven Analysis of Distributed Systems
- Pandora Deep Learning for Interaction Vertex Reconstruction in SBND
- **Cross-experimental Tools and Open-source Datasets**



Adapting to sparse environments leads to a factor of 10 decrease in memory usage

Community initiatives to build on this

- https://indico.cern.ch/event/1692147/contributions/7115253/attachments/3296522/5895746/AI4HEP-UK_20260616-Intro.pdf

Applications for UKRI advisory panel members (STRIKE) open

- https://www.ukri.org/who-we-are/work-for-us/join-an-advisory-committee-panel-or-network/ukri-digital-research-infrastructure-pool-strike-member-vacancies/
- Similar for EC **RAISE** https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/launch-call-experts-join-raise-high-level-academic-advisory-board-2026-06-15_en

Opportunity to inform UKRI of needs regarding Digital Research Infrastructure (DRI), shaping DRI Programme's future actions (ASCEND)

- https://engagementhub.ukri.org/ukri-infrastructure/ascend-process/

- Forthcoming UKRI calls:
  - Advancing Sustainable AI Technology. August 2026. 500k grants
  - Next Generation AI: explainable AI. 500k grants
  - AI for Science Pump Priming: September 2026. 250k grants.
    - "for science" typically means aligned with IS-8
- EU
  - RAISE pilot – science for discovery
  - AI in fundamental physics: https://eucaif.org/
  - Multiple cost actions (schools, visits) [EPIGRAPHY, AIFORIA, MLQC4FC)

GridPP: Status

- GridPP7 ends in **March 2028**.
- In normal times, the GridPP8 proposal would be written this Autumn. Not all the previously agreed capital was provided; without those funds GridPP will:
  - almost provide the 2027 pledges (UK fair-share of LHC) but be missing £0.25m to update core Tier-1 network switches.
  - only deliver 80-90% of the 2028 pledges.
- For 20 years, the UK has been regarded as a totally reliable partner and has never failed to provide the UK fair-share in the spirit of the MoU signed by PPARC.
- Ramp-up of resources for HL-LHC will start with the 2029 pledges, which will require capital funding in 2028. ATLAS (largest UK commitment) will require **~4x the current** resources by 2032: funding ramp-up needed from 2028-2031.
- Forward costing of hardware is currently very imprecise but likely to be much, much, more expensive than hoped.

GridPP: Funding Opportunities outside STFC

Dave Britton

- GridPP provides infrastructure for data-centric, high-throughput, computing.
  - largely orthogonal to UKRI focus on AI-facilities, pre-ExaScale HPC, and NCRs.
- bid-and-allocate access model for NCRs (National Compute Resources), is **completely unsuitable** for 24x7x365 data reconstruction and simulation, or for meeting long-term international obligations, and the scale of the NCRs is small compared to GridPP.
- UKRI DRI focus is on compute and not storage;
  - HEP costs are 2/3 storage and 1/3 compute.
- GridPP initiated dialogue with UKRI to try to better align UKRI DRI with PPAN needs, but their response was not encouraging.
- Possible to present our data archival services (Tape) as an NCR in a future round – already used by many, but UKRI is unlikely to subsidize GridPP much - no other sources identified.

Industrial Strategy IS-8 & UKRI

https://assets.publishing.service.gov.uk/media/69256e16367485ea116a56de/industrial_strategy_policy_paper.pdf

- **Advanced Manufacturing; Creative Industries; Life Sciences; Clean Energy; Defence; Digital & Technologies; Professional & Business Services; Financial Services; Foundational Industries**
- **Each "Government and Societal Priority" area is led in UKRI by one of the Research council chairs**

IS-8 Area	Research Council Lead
Advanced Manufacturing	Innovate UK (business)
Creative Industries	Arts & Humanities RC
Clean Growth & Energy	Natural Env. RC
Defence	**EPSRC**
Engineering Biology	Biotech & Bio Sci RC
Artificial Intelligence	**EPSRC**
Quantum Technologies	**EPSRC**
Advanced Communication Technologies; Semiconductors; Cybersecurity	**EPSRC**
Financial Services; Professional & Business Services	Economic Social RC
Life Sciences	Medical RC
Space	**STFC**

UK Government

THE UK'S MODERN INDUSTRIAL STRATEGY

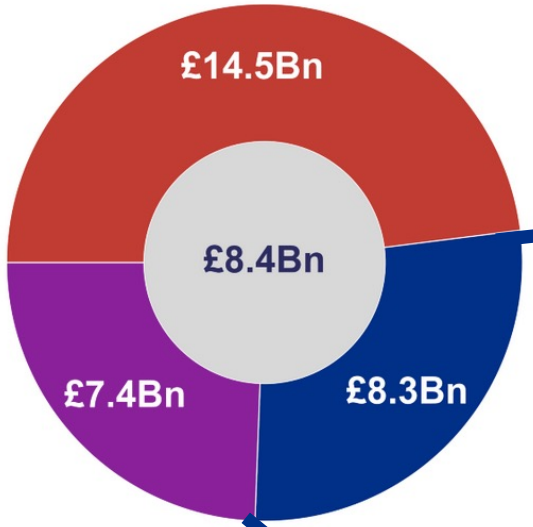
Kick-the-Bucket

Bucket 2

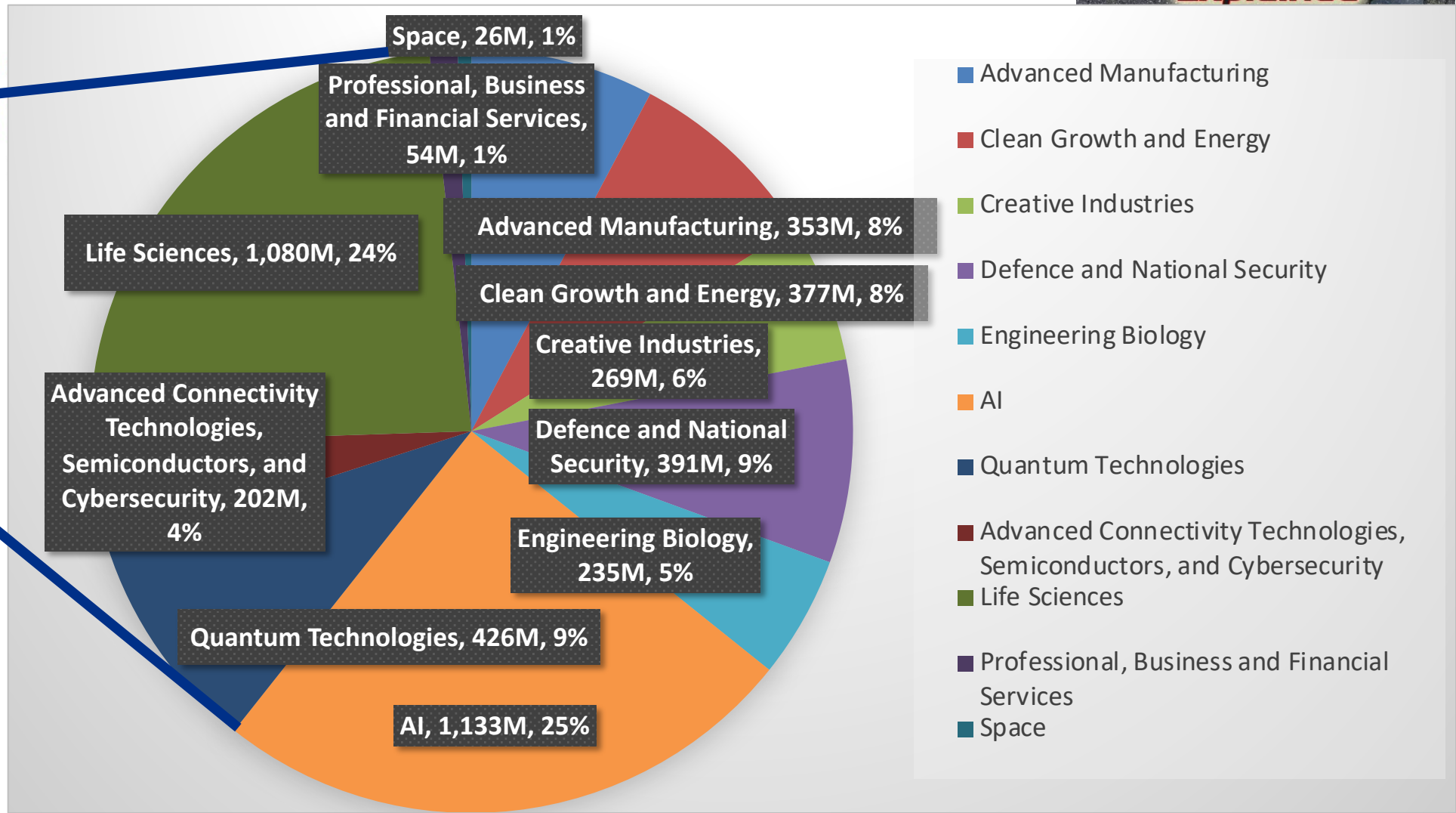
https://www.ukri.org/publications/explainer-ukri-budget-allocations/budget-allocations-for-uk-research-and-innovation/

Over spending review - 2030

3.3bn applicant led



Bucket 2
£6.8 billion
Industrial
Strategy and
government
priorities



PPAN for Prosperity

Aligning Particle, Astrophysics, Accelerator and Nuclear physics communities with the UK's Societal & Industrial Strategy Missions

- In-principle agreement with Charlotte Deane (EPSRC) to hold a workshop late this year
- Sheila Rowan has kindly agreed to co-host
- **Plan: programmes; skills; examples previous projects; parallels on key IS-8 to pitch ideas**

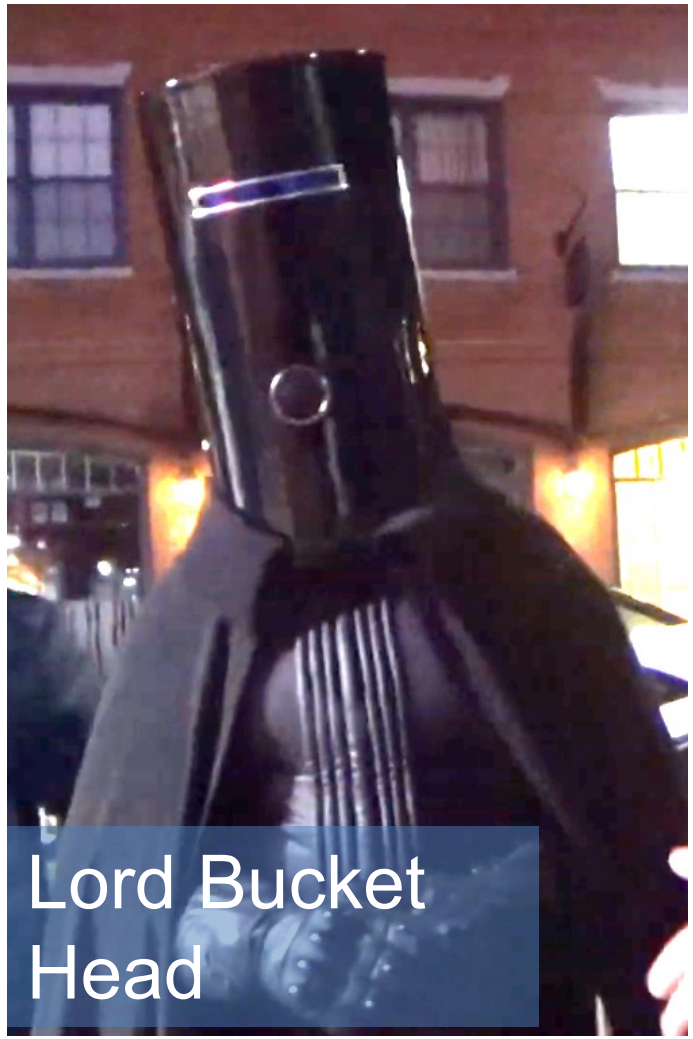
- This is **not** alternative funding for PPAN research
- This is about the use of our community's skills for IS-8 areas
  - In context of major cuts;
  - demonstrating our ongoing engagement

UKRI Industrial Strategy-8 Programme Directors

- Dr Justin O'Byrne, Programme Director, Advanced Connectivity Technologies, Cybersecurity and Semiconductors
- Dr Samantha Francis, Programme Director, Artificial Intelligence (AI)
- Dr Kathryn Magnay, Programme Director, National Security and Defence
- Dr Derek Craig, Programme Director, Quantum Technologies

Summary

- We have little STFC funding for general detector technology or computing/software R&D
- We have strong community roadmaps should options become available
  - Align with FCCee on collider side
- There is £6.8bn funds in industrial/ government priorities in bucket 2
  - Not for PP but could align with skill sets and we are faced with major job losses
  - Likely much already allocated in short term
- Agreement to hold a “PPAN for Prosperity” meeting



Backup

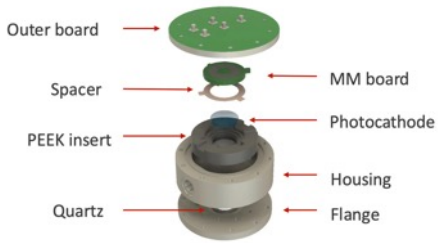
DRD1: Gaseous Detectors

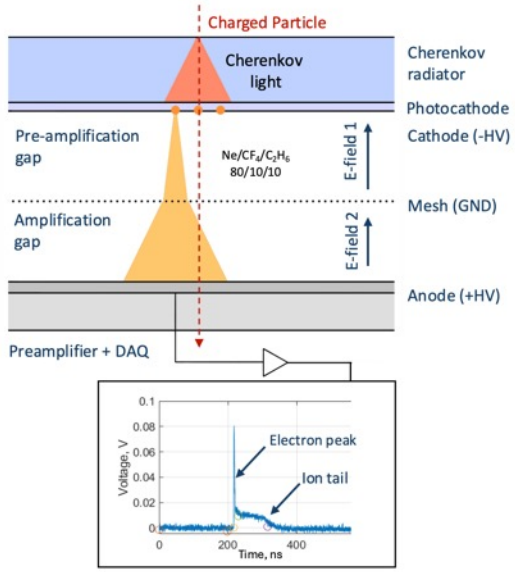
DRD1 Gaseous Detector Technologies

- 130 Institutes (prior to MoU signing) ,30 countries
- Established from previous RD51 – enlarged scope
- First to proceed with **Memo. of Understanding**

Time + Space | dE/dx | Environment | TPCs

Picosec





- Cherenkov Radiator ~ 20ps

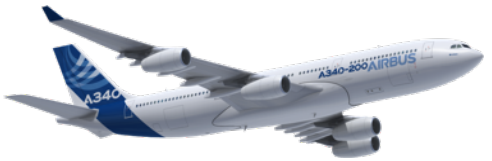
Beyond HEP WP

- Muography
- Medical
- Neutron

Training

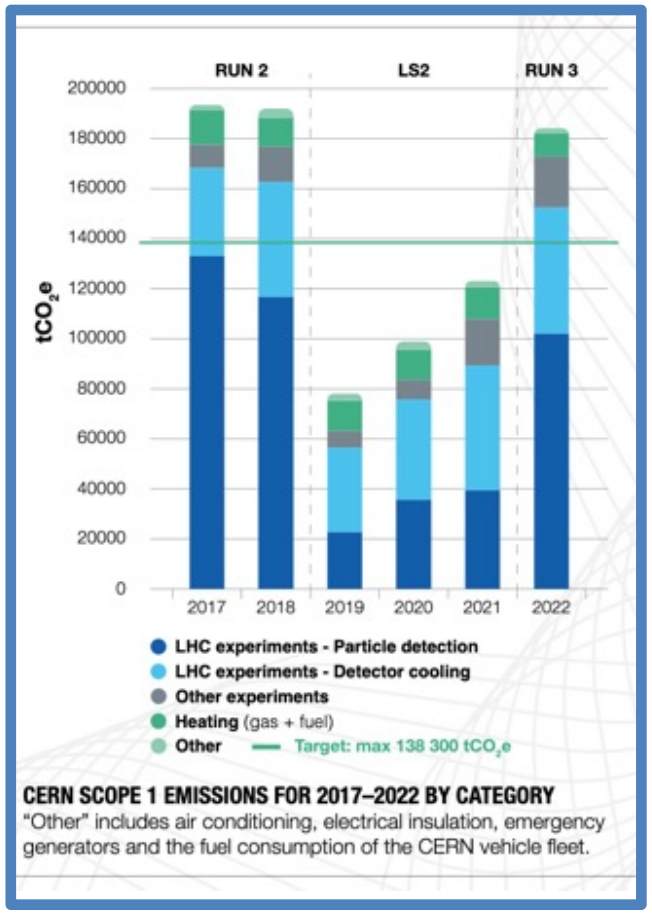
Environmental Impact

- Largest detector/computing impact is high global warming potential gas emissions (80% LHC – ATLAS/CMS RPCs)



100,000 tCO2e /annum =
fully occupied A340 London → New York per day

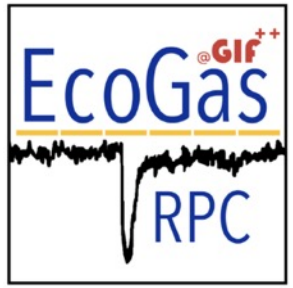
CERN Environment Report 2021-2022



5th DRD1 Collaboration Meeting and Topical Workshop Towards Sustainable Gas Mixtures for Future Detectors

- Sealing
- Recirculate Recuperate
- Alternative Gases

- SF6 GWP 23,000
- ATLAS alternative gas, 25% GWP reduction
- Continued use of technology mandates replacement

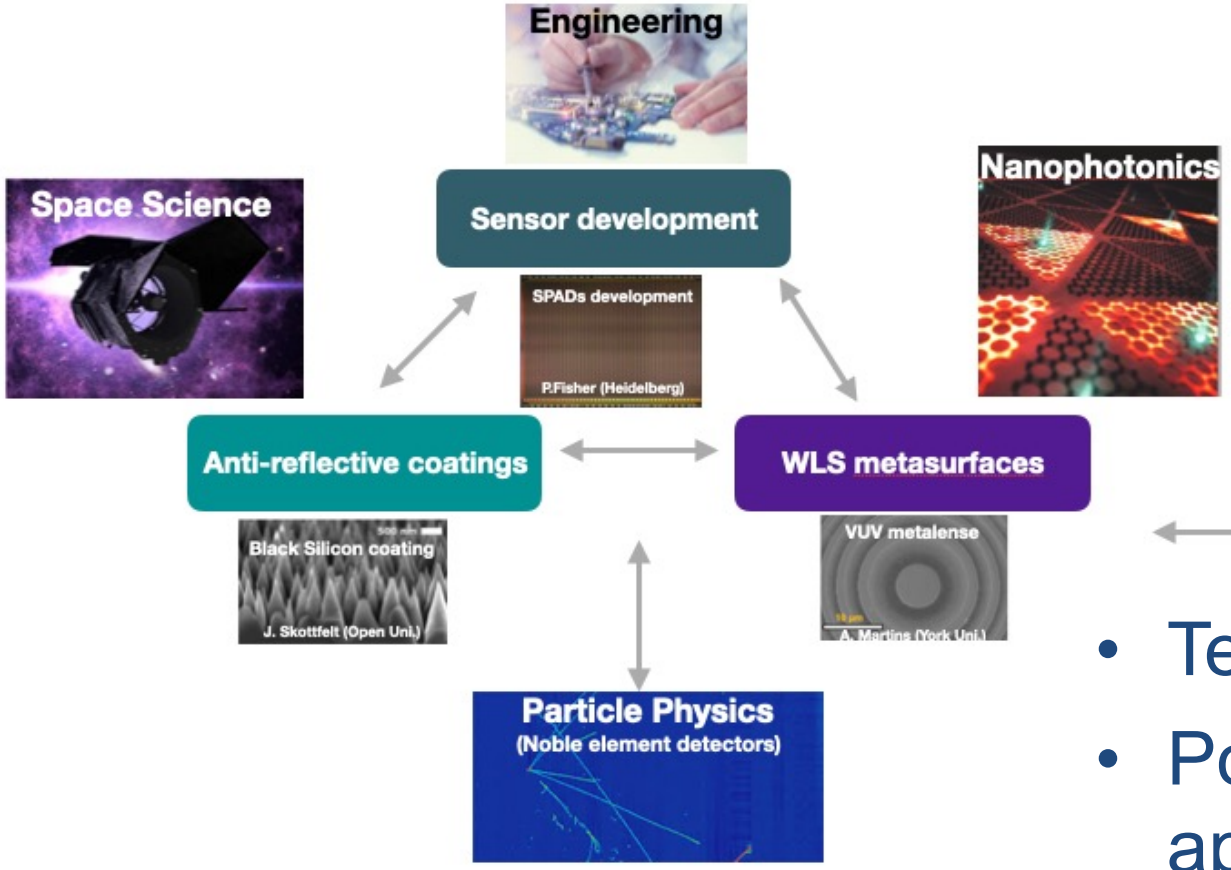


Liquid

DRD2: Liquid detectors

DRD2 LIQUID DETECTORS

- 86 institutions,17 countries
- **Diverse communities** & facilities **working together** as network (neutrino, dark matter), new collaborations & funding applications

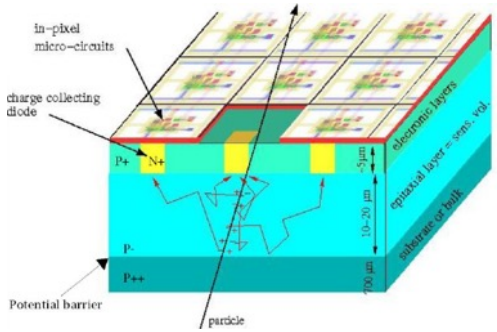


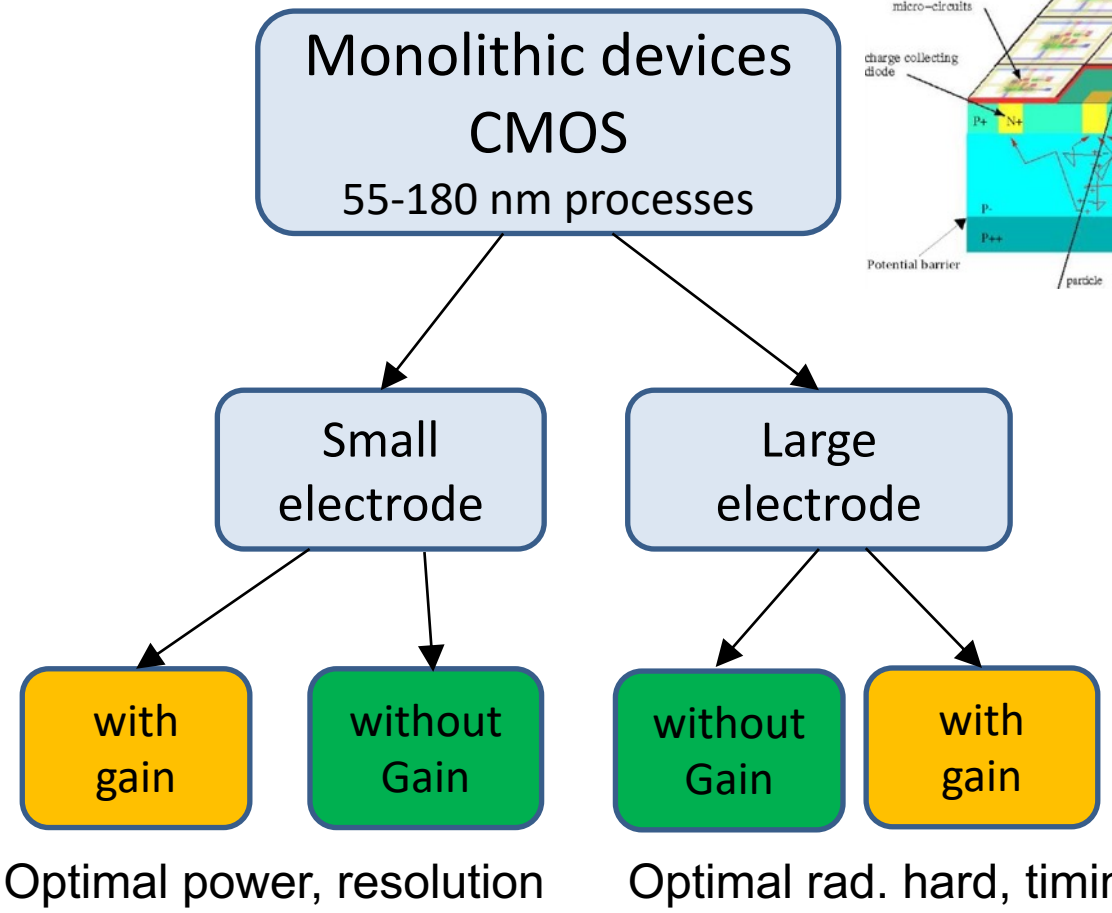
- Vacuum ultra-violet sensors
  - Detector eff. typically ~20% thus not suited to Ar/Xe detectors

- Team attacks this from multiple angles
- Potential space-science & commercial applications

DRD3: Solid State Detectors

- 146 institutes, 30 countries
- Formed from RD50 (rad hard Si) & RD42 (Diamond)



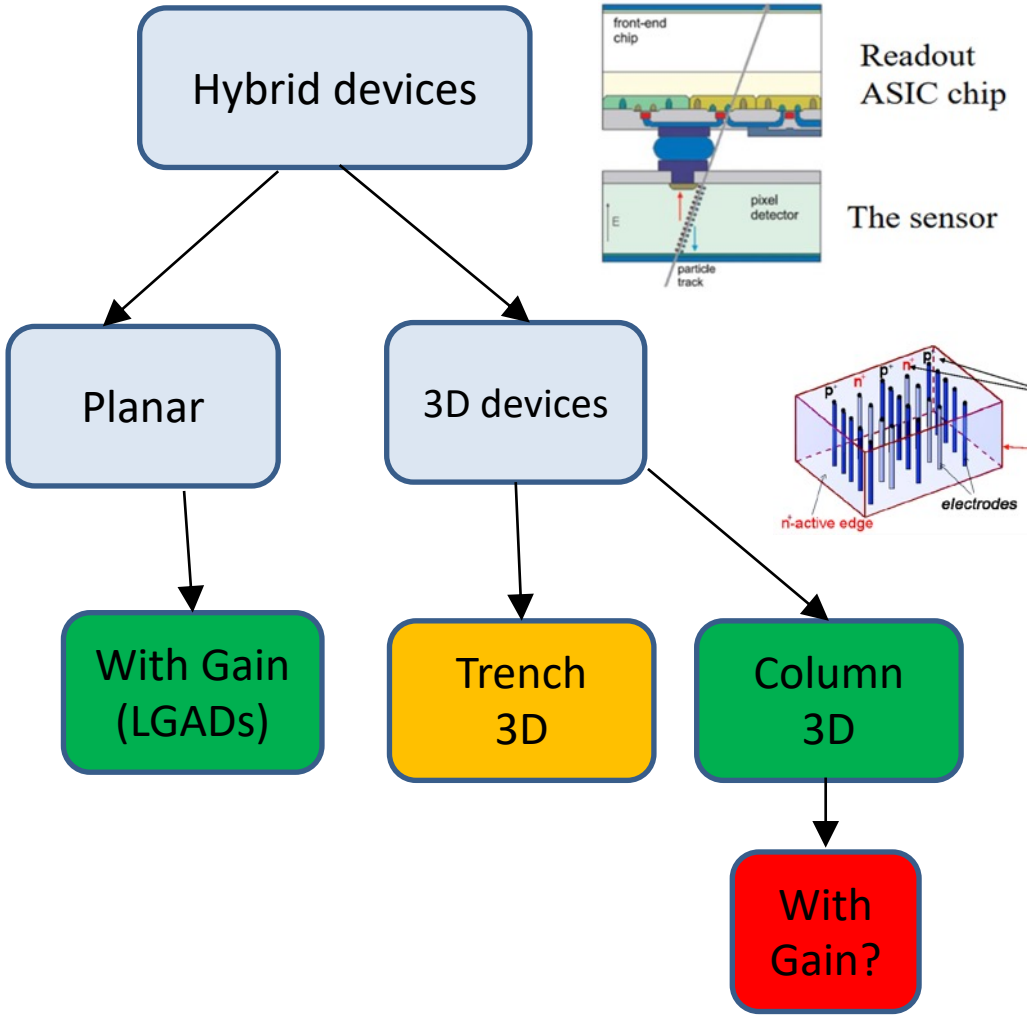


- Monolithic sensor & readout for tracking
  - high spatial resolution
  - high data rate
  - high radiation tolerance
  - Uniform eff. over cell
  - Timing capabilities, gain layer

ideas
recent
demonstrated

DRD3: Solid State Detectors

- 146 institutes, 30 countries
- Formed from RD50 (rad hard Si) & RD42 (Diamond)



- Towards 4D tracking

Dense tracking environment, PID

  – 10x10x10 **µm²**, **ps**

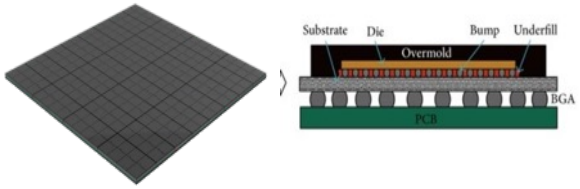
- **LGADs:**
  – fill factor, radiation hardness
- **3D:**
  – Cell size, column width

ideas
recent
demonstrated

DRD4: Photon Detectors & Particle Identification

Photon & PID

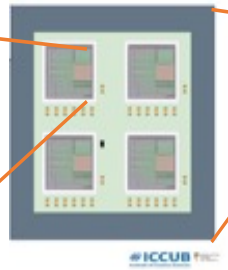
- 67 institutes, 20 countries
- RICH detectors as a main focus
- also includes Scintillating Fibre & Transition Radiation Tracking



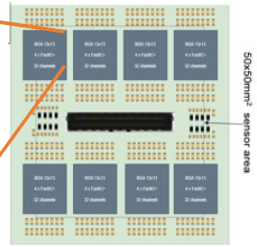
3x3mm2 SiPM Array

FastIC+ (collab. CERN ICCUB) Low power Chip

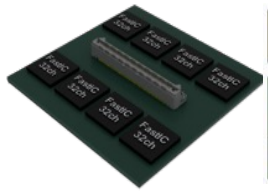
2024 Produced and

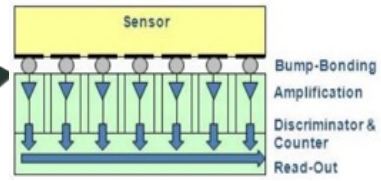


design & luction end of 2025



256 Ch 5x5cm2 Module proposal





Ultra granular SiPMs

Long term goal
1x1mm2 SiPM array

- SiPM use becoming widespread – replacing vacuum and gas based detectors in some applications
  - Improving timing of SiPMs ~ 20ps
  - Vertical integration to Front End Electronics
  - Integration with integrated cooling

Quantum

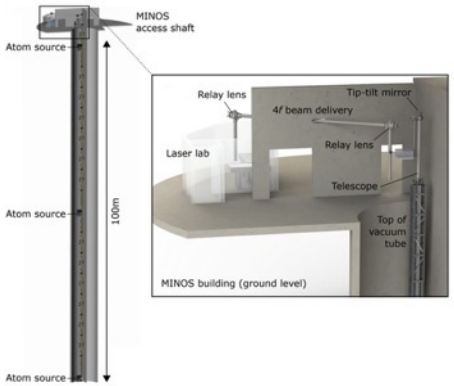
DRD5: Quantum & Emerging Technologies

- 112 institutes, 26 countries and growing…..wide community outside HEP
- Quantum detectors – e.g. below ionisation limit

Cryogenic | Superconducting | Spin-based NV-diamond | Metamaterials 0,1,2 D materials

Dedicated Experiments e.g.

Atom Interferometry

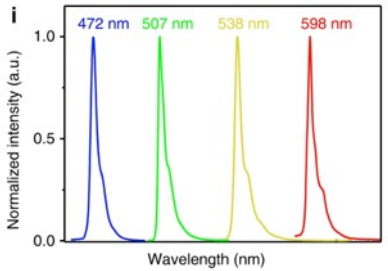


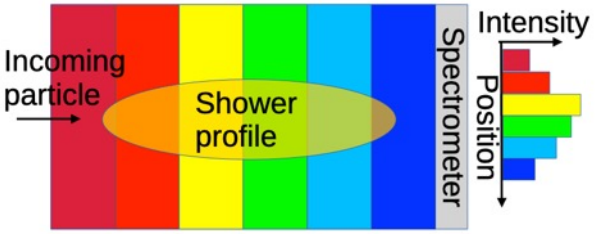
Absolute Neutrino mass

Axion tunable cavities

Technology Applications e.g.

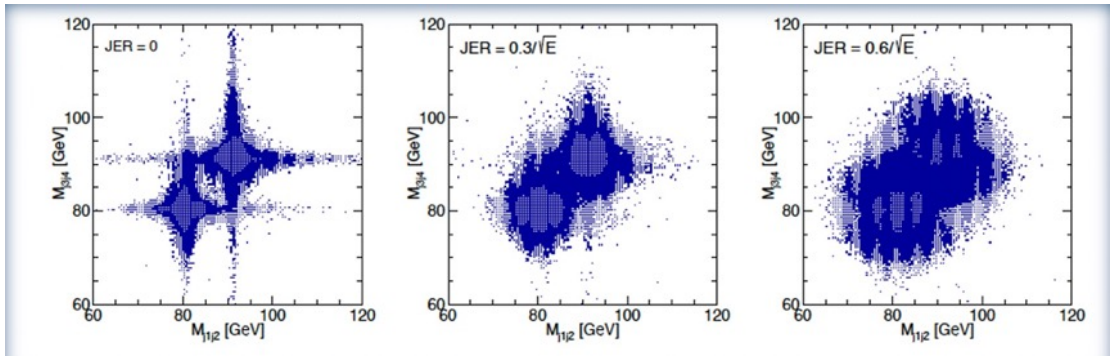
Quantum Dot Chromatic Calorimetry





DRD6: Calorimeters

- 128 institutes, 28 countries – component from CALICE but much wider
- Focus on calorimeters for future projects, FCC-ee a main driver



- Disentangle W/Z Peaks

Jet energy: $\delta E_{jet}/E_{jet} \simeq 30\% / \sqrt{E}$ [GeV]

Position (3D) | **Timing** | Energy

Gaseous →DRD1 | Solid State →DRD3 | Optical →DRD4 | Quantum Dots →DRD5 | Electronics →DRD7

Sandwich calorimeters with embedded electronics

Liquified Noble Gas calorimeter

Optical calorimeters

Electronics Processing

DRD7: Electronics and On-Detector Processing

- 67 institutes, 19 countries
- R&D not a service for other DRDs- Strong opportunities but high costs

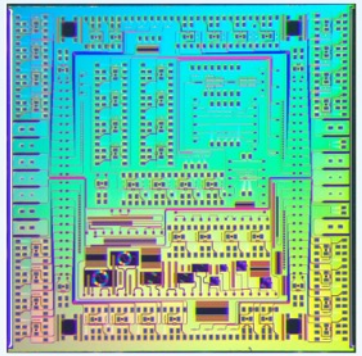
Some example developments

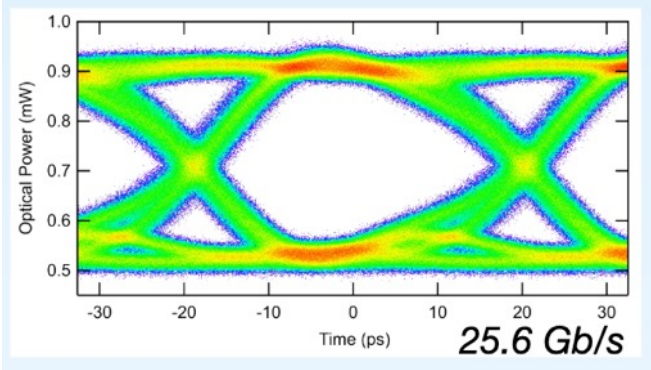
Silicon photonics
100Gb/s

Intelligence on Front End
Fewer more versatile FE electronics

Front End to DAQ
Custom off the shelf – "no back end"

Cryogenic operation





- ASIC development commonly schedule limiting for experiments
- **"Tools & Technologies" WG**
  - Accessing technologies, tools
  - Collaboration & coordination

  Of development & fabrication

DRD8: Mechanics & Cooling for Future Vertex and Tracking Systems

- 40 institutes, 14 countries and growing…
- Developed from Forum on Tracking Detector Mechanics
- Much is silicon det. driven – but expanding, interest large gas detectors

New materials
Additive manufacture

Global systems

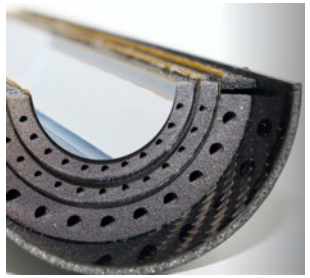
Low mass mechanics & thermal management

Cooling

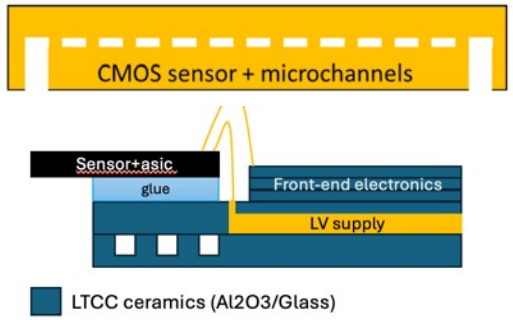
Design & Qualification Tools

example developments

Curved sensors
Hits closer to interaction point
Low mass mechanics



Microchannels
Integrated/ceramics



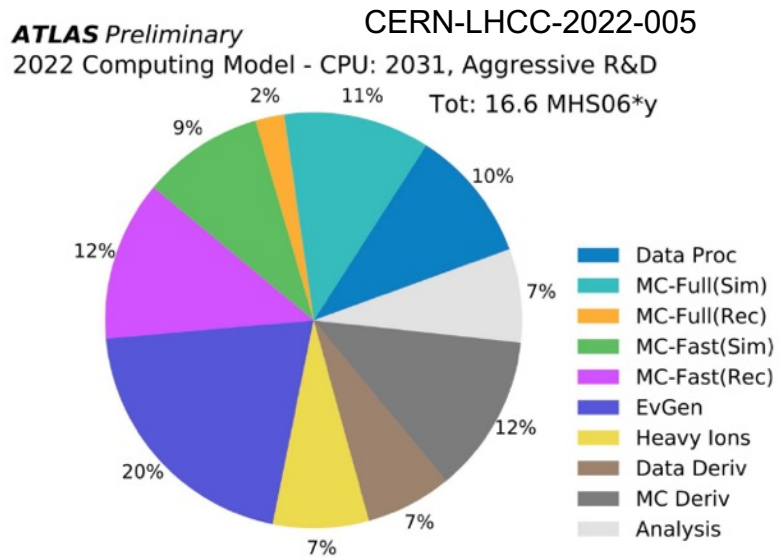
- Mechanics & Cooling a key detector performance driver
- **Schedule**: R&D continues much later in project than you think
  – share information

Monte Carlo N(N)LO event generators

- ~ 20% of CPU demands during HL-LHC

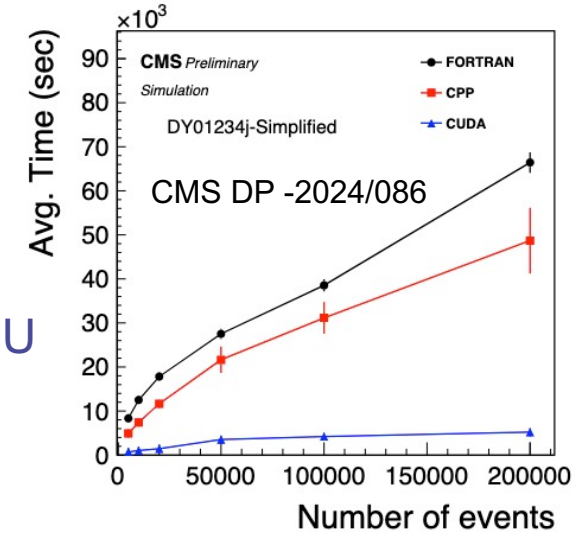
Approaches include:

- Reducing negative weights through weight redistribution
- **Matrix element calculations in GPUs**
- ML in event generation



MadGraph4GPU

7x speed up



User data analysis trends

- **What will an HL-LHC analysis look like ?**

Central Processing **OR** Distributed Resources that feel like

Single Machine Analysis

Analysis Grand Challenge
Analyst Surveys

- **Data access time – Disk / tape cost trends, round-robin access**
- **Interoperability** - wide range of tools in HEP today
- Languages: C++ performance, Python usability – interest in Julia
- Improving integration with computing infrastructure (multi-threading, distributed computing)
- Machine Learning – statistical inference, automatic differentiation
- Data and Workflow Management Systems,
- FAIR principles, open data, preservation
- Reinterpretation of results (RIVET)

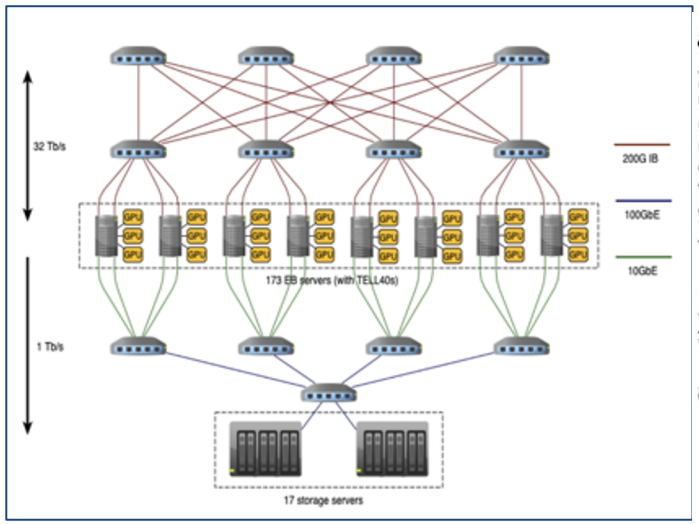
Software Triggers & Tracking

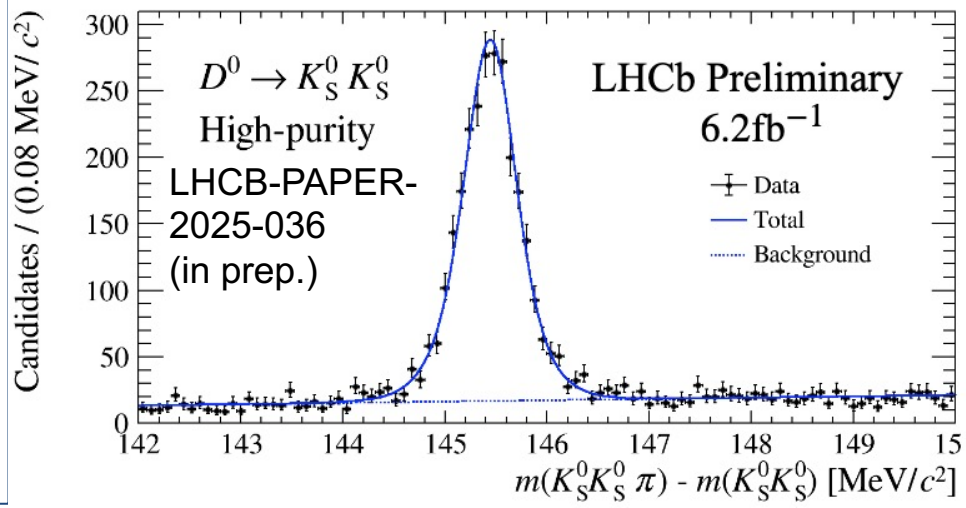
- Run 3 GPU Software Trigger Farms
  - Real time analysis, tracking & triggering
    - discard raw data, keep reconstructed data
- ML in trigger, including in FPGAs
  - Anomaly detection, b-tagging, Jet reconstruction….
- HI-LHC frontier – 4D tracking, hit-time information

Conifer

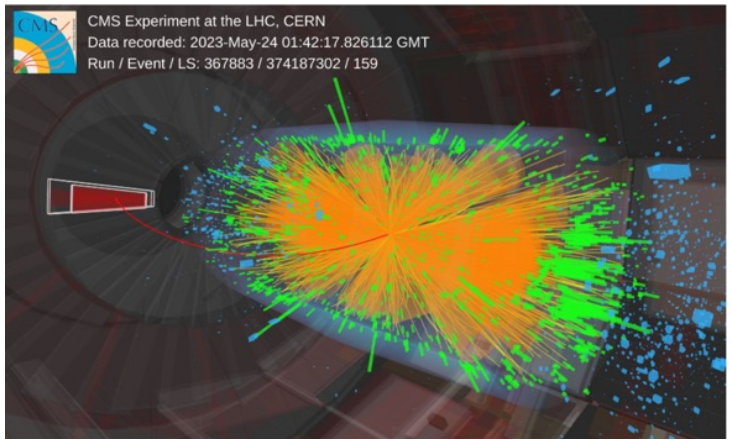
hls4ml

LHCb Run 3 Trigger/ Upgrade I – 3 x efficiency D→KsKs





CMS DP-2023/079
ML based trigger in FPGA



GRID – data centre h/w and our s/w

- Funding agencies favour interdisciplinary infrastructures
  - HPC centres as pledged resources or as opportunistic resources
- HPC centres increasingly offering GPU capacity
  - Demand from AI/ML communities.
  - Low precision GPU for ML training – poor match to simulation needs
- Our codebases generally optimized for x86 64 bit CPUs
  - require modernization to run efficiently on different architectures
  - Portability libraries will assist kokkos
- An opportunity:
  - millions of lines of software
    - streamline the code for maintainability
    - improve its performance

Training, Infrastructures, Industry, Societal Engagement

- Discoveries are facilitated by technologies
- Our funding mechanisms often under-emphasise leadership in detectors & computing – career paths
- Mutually beneficial relationship with industry
  - Skills pipeline - training
  - Collaborative developments

- Field-wide initiatives

often provide better mechanisms for training & industry Engagement at scale

THE CARPENTRIES

HSF Training Center

HSF

Training and educational material for the High Energy Physics community.