Electronics and Data Processing

- Importance and motivation
  - Readout electronics and data processing systems are fundamental enablers for all HEP experiments
  - Next generations of detectors will pose extreme challenges for electronics
    - Arguable that for several future projects, this is *the* key R&D problem
  - Growing issues in accessing / using state-of-the-art industrial technology
    - The approach we took for LHC experiments will not work in the coming decades
- Requirements from experiments
  - Finer granularity, more channels, more precision in readout
    - Often driven by inclusion of timing information
  - Lower power dissipation, less material
  - Close coupling of readout ASICs to sensors
  - Ultra-high radiation hardness (in some cases) and exceptional reliability
  - Zero suppression and data processing on the detector
- Why start now?
  - Timeline for LHC developments shows R&D for next detectors should start now
  - For further generations, basic R&D is needed to demonstrate plausibility and fully test novel new approaches

Dave.Newbold@stfc.ac.uk

Summary of R&D Themes

		DRDT	SPS fixed target	Belle II	ALICE LS3	PIP-II/LBNF/DUNE	ALICE 3	LHCb (≥ LS4)	ATLAS/CMS (≥ LS4)	EIC	LHeC	ILC (Tracking)	ILC (Calorimetry)	FCC-ee (initial detectors)	CLIC (Tracking)	CLIC (Calorimetry)	FCC-hh (initial detectors)	FCC-eh (initial detectors)	Muon collider
			< 2030				2030-2035					2035-2040		2040-2045			> 2045		
Data density	High data rate ASICs and systems	7.1	Green	Green	Red		Red	Red *	Yellow				Yellow	Yellow		Yellow	Red		Orange
	New link technologies (fibre, wireless, wireline)	7.1	Green	Green	Green		Yellow	Yellow	Yellow		Yellow	Orange	Green	Green	Orange	Green	Red	Yellow	Orange
	Power and readout efficiency	7.1	Green	Green	Red		Red	Red *	Yellow	Yellow	Green	Orange	Orange	Yellow	Orange	Orange	Red	Green	Red
Intelligence on the detector	Front-end programmability, modularity and configurability	7.2												Red			Red		Red
	Intelligent power management	7.2			Red		Red	Red *				Orange	Orange	Red	Orange	Orange	Red		Red
	Advanced data reduction techniques (ML/AI)	7.2												Red			Red		Orange
4D-techniques	High-performance sampling (TDCs, ADCs)	7.3	Green	Green			Red	Red	Yellow			Orange	Orange	Red	Orange	Orange	Red		Red
	High precision timing distribution	7.3	Green	Green			Red	Red	Yellow	Orange	Yellow	Orange	Orange	Red	Orange	Orange	Red	Yellow	Red
	Novel on-chip architectures	7.3	Green	Green			Red	Red				Orange	Orange	Red	Orange	Orange	Red		Red
Extreme environments and longevity	Radiation hardness	7.4	Green	Green	Green		Red	Red	Orange			Green	Green	Green	Green	Green	Red		Orange
	Cryogenic temperatures	7.4				Green											Orange		Orange
	Reliability, fault tolerance, detector control	7.4	Green	Green	Green		Green	Green				Yellow	Yellow	Yellow	Yellow	Yellow	Red		Orange
	Cooling	7.4					Red	Red *		Green	Green	Green	Green	Green	Green	Green	Red	Green	Red
Emerging technologies	Novel microelectronic technologies, devices, materials	7.5	Green	Green	Red		Orange	Orange	Orange			Orange	Orange	Red	Orange	Orange	Red		Red
	Silicon photonics	7.5					Yellow	Yellow	Orange			Orange	Green	Red	Orange	Green	Red		Red
	3D-integration and high-density interconnects	7.5			Red		Red	Red *	Orange			Orange	Orange	Red	Orange	Orange	Red		Red
	Keeping pace with, adapting and interfacing to COTS	7.5	Green	Green	Green		Orange	Orange	Orange	Green	Green	Orange	Orange	Red	Orange	Orange	Red	Green	Red

Red: Must happen or main physics goals cannot be met
Orange: Important to meet several physics goals
Yellow: Desirable to enhance physics reach
Green: R&D needs being met

* LHCb Velo

Dave.Newbold@stfc.ac.uk

Next Steps

- Clear motivations to proceed with R&D programme
  - Noting that funding for R&D is in tension with experiment projects
  - This will be a ramp-up process over the next few years
- There is a vibrant and active expert community across Europe
  - As evidenced by several hundred participants in the roadmap process
  - Deep expertise in all areas – but can it be maintained?
- Discussions of RD organisation will begin later in 2022
  - Strand A (2022): ensuring support and facilities for current developments and near-term R&D
    - Explicit cooperation between labs and institutes to provide access to latest process and tools
  - Strand B (2023): prioritisation and organisation of R&D work
    - Collaboration structure likely to be based on the R&D Themes already identified
  - Many opportunities for participation and leadership from the community
- Questions? Comments?
  - Contacts: dave.newbold@cern.ch or francois.vasey@cern.ch

Relevance to FCC in the UK

- New RD collaborations look likely to proceed
  - It would be strange indeed for the UK to have no participation in this…
    - Indeed I would claim that electronics / DAQ is an area we can continue to lead
  - One therefore assumes that money will be found within the programme
- Large overlap with UK expertise / interest in e+e-
  - Design and development of tracking system readout
  - Back-end DAQ and computing; triggering and data processing
  - Development of next-generation fully 4D / 5D detectors
- Situation in STFC (with a TF7 hat on)
  - PPTAP has finished and reported to TAAB / Executive Board
  - Clear recommendation to complement recent commitment on blue skies R&D with a corresponding programme of 'structured R&D'
  - We will see what happens in the coming year or so
- My view
  - The 'future e+e- detector' programme has to incorporate both 'generic' R&D and facility-specific studies on physics and experiments
  - Don't expect a revolution overnight, but we do need to be in at the start and leading

Additional Slides

Roadmap Process and Structure

- Three main topics
  - Front-end ASICs; Links, powering and interconnects; Back-end systems
  - Review of the state-of-the-art in each area
  - Examination of the main challenges for future projects
- Process and inputs
  - Experiment workshop defined the key technical challenges
  - Community workshop provided input on current and proposed R&D
    - Also the views of the community on prioritisation and working practices
  - A (detailed) survey of the community indicated broad agreement on the main challenges and opportunities
  - Panel of six experts constructed the final roadmap recommendations
- Final output
  - Development of five R&D 'work packages' with several areas each
  - Recommendations on working practices and collaboration
  - Input to the general recommendations of the overall roadmap

R&D Themes

- Data density
  - Dealing with the vastly increased channel count and data per channel
  - Requires work in on-detector processing, link technologies and power efficiency
- Intelligence on the detector
  - Advanced (incl. ML) data reduction techniques at the front end, and the technologies to enable this
- 4D techniques
  - Enabling and using 4D detector information for data reduction, triggering and reconstruction
- Extreme environments
  - Radiation; cryogenic conditions; reliability and robust controls
- Emerging technologies
  - New materials, devices and signalling methods
  - Interoperability with the industrial / commercial standards of the future
- Note that these challenges span the entire spectrum of HEP
  - Not just about collider experiments; significant challenges in neutrino, low-background and quantum detectors also

 Dave.Newbold@stfc.ac.uk

General Recommendations

- Novel developments vs 'structured R&D'
  - Clearly need both! But realistically, blue-skies work still depends on excellent labs and tools…
- Software and firmware
  - Electronics is not just about hardware
  - Many key development challenges in sw /fw (and verification)
- Collaborative model
  - Obvious need to avoid parallel and duplicate efforts; but allow contributions from the widest pool
    - Discussion of the 'hub and spoke' model facilitating intellectual input from all
- Demonstrators and common developments
  - Most electronics challenges are 'systems issues'; need to build demonstrator systems not necessarily focussed on specific experiments
  - Clear need for standardisation, sharing of IP, and common developments
    - Avoiding the tens-of-similar-projects issues seen on LHC
- Infrastructure
  - Support via tools, IP, engineering expertise, specialised labs, irradiation facilities, etc…
  - Traditionally provided via the major European labs
- Interaction with industry
  - Essential to track industry developments, and maintain access to cutting-edge technologies
  - Some things industry will simply not do for us, however…

 Dave.Newbold@stfc.ac.uk