Integration

Tim

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timjones@liverpool.ac.uk

My background

- History
  - RAL (‘87-91): ALEPH Endcap ECAL (QC, installation, commissioning & operations)
  - Liverpool (91-): Detector R&D, SDC(☹), ATLAS SCT Endcap C

- Day Job
  - ATLAS ITK Barrel Strip Local Supports (stave cores)
  - ATLAS ITK Pixel Endcap (pixel half-rings & support structures)

- Generic low mass mechanics (CFRP) development – with Liverpool AML
  - Can you just try and do this …?

- ‘Consultancy’
  - Cooling system design for NA62 KTAG
  - Cooling design & straw-tube prototyping for g-2 trackers

Apologies now for failing to do justice to all your past & current work!

Integration

- Integration =
  - Mechanical design & manufacture
  - On-detector services (power, data & cooling)
  - Sub-system assembly & testing
  - Installation & commissioning

- General observations
  - Integration has always been a real UK-wide strength – should be a source of pride.
    - As an early-80's PhD student at CERN witnessed respect non-UK collaborators had for "PAG".
  - UK PP continues to lead the field 40 years later
    - From LEP-era on, integration has become (almost completely) de-centralized.
      - Sounds like an oxymoron but expertise spread across the whole community with activity distributed according to size & facilities.
      - Facilities at DL, RAL, universities & host lab used for systems integration during production
    - Frequent UK presentations on mechanics & systems integration at FTDM/TWEPP/… workshops

Mechanical Design & Manufacture

- UK maintains good level of strength (eg ATLAS ITk, LHCb, DUNE, Mu3e, g-2, …)
  - Perhaps too focussed on tracking detector mechanics
- My guess is that there are 25-ish FTE of mechanical engineering effort across the community. Effort is spread around to some degree (roughly 3-way even split between TD (RAL/DL), few big groups, rest). Some groups have no mechanical engineers. Even lone engineers (i.e. a group's only mechanical engineer) do make effective contributions to major projects.
  - Opportunities to employ & develop engineers needed
- For manufacturing, 2 large facilities in university groups, RAL/DL workshops, smaller university workshops. Lone machinists (staff often in dual roles) make effective contributions. Specialize in limited quantities of high-precision components or assembly tooling. Mass manufacture in (UK) industry.
  - Apprentice training programmes (e.g. Liverpool - 4 over 8 years moving on to project funding, engineering degree & Royal Navy)
- Novel Materials: For LHC –only use of UK-made CFRP was LHCb VeLo (use of US-made CFRP in RICH). Major increase for HL-LHC programme through extensive use in tracker mechanics for ATLAS ITk (& probably LHCb MT). Existing investment in small scale CFRP manufacturing facilities (1-2m scale autoclaves) probably sufficient for development needs.
- Small amount of generic work on low-mass mechanics for tracking funded (eg SiC foam structures, curved silicon). Currently dormant or very low level activity – piggy-backing on mainstream programmes – leadership lost – should try and catch up.

Scope for generic development limited to (advanced) materials technology & concepts but needs access to a long-term generic funding stream. Gut feeling is that progress would be limited by composites design (FEA, evaluation) expertise. Mechanics for PP provides excellent training opportunities should be promoted. Generic development will not sustain the wider community – need opportunities to work on a stream of shorter-term detector construction projects.

On-Detector Services: Power, Data & Cooling

- Historically
  - Not seen as being particularly interesting
  - Probably the hardest part of building a detector!
  - UK expertise in system architecture, data links, serial powering, DAQ, etc…

- Development for HL-LHC – “Local Supports”
  - Development of integrated multi-module systems – essentially ‘ladders’ but services incorporated by design. Eg: ATLAS ITk strip staves
    - Low-mass support structure (CFRP, thermally conductive foam, honeycomb)
    - Dual phase cooling (CO_2 in fully-welded titanium cooling tubes)
    - Cable cross-section efficient powering: LV (DCDC, SP), HV (multiplexed)
    - CLK/CMD distribution, data multiplexing, opto output

    True community-wide expertise needed !
  - ATLAS ITk pixels violates local supports paradigm due to technical limitations in data multiplexing (at data rates expected at HL-LHC) and opto conversion (due to radiation dose).

Clear directions for generic development – particularly for high-speed data transmission (ASICs and medium) and cooling technology. Multiple options for each. Past UK interest would tend to favour data transmission & powering. New initiatives in cooling system technology would be strategic.

Sub-system Assembly & Testing

- Another strong-point for UK PP with major deliverables completed across wide range of projects.
  - Large scale (5-10yr): ALICE (ITS ladder assembly at DL), ATLAS (ID, ITk), CMS (Tracker, ECAL), LHCb(VeLo, RICH) , DUNE(APA factory at DL). (Scope of delivery might be < 100%).
  - Small-scale: (2-5yr):NA62, g-2, Mu3e … (I'm sure there are 10's of these!)

- Pre-cursor is often the 'System Test'
  - Proven to be essential in developing system architecture & driving development of on-detector services and DAQ systems
  - First experience of 'putting things together' (and making it work!)
  - Develops expertise for subsequent operations, calibrations, data quality, exploitation.
  - Helps to secure leadership roles in operations / event reconstruction / physics analysis

Wide scope for generic technology development (perhaps 3D-printed tooling, robotic assembly, DAQ). Very useful for developing expertise (eg mechanical assembly, metrology, DAQ, system-level testing, operations, calibration, etc..)

Installation & Commissioning

- Senior UK physicists, mechanical & electronic engineers & DAQ specialists have played major roles in installation & commissioning of large detector systems.
  - Close liaison with experiment site requires residency on medium (3-5yr) term
  - Good to have an effective UK team to work with

- UK supplies teams of systems specialists for installation & commissioning with heavy commuting / short term residency (1yr)
  - Broad range of skills needed to get systems up and running. Lone specialists have made major contributions.
  - Team members often become part of detector operations teams for data-taking and on-going maintenance.

At the highest levels, this is essentially a coordination role. People need the management skills to carry it out effectively. Naturally ‘self-selecting’ in the past – perhaps a bit more ‘strategic’ now. What does it mean to ‘manage’ disparate group of physicists, engineers, techs, PhD students… scattered across the UK/entire planet?

Priorities

1. Maintain a viable community capable of delivering state-of-the-art systems to PP experiments over the next 20 years
   - Complete deliverables for HL-LHC, DUNE, etc…
   - Deliver detector upgrades during HL-LHC operation phase and apparatus to ‘small-scale’ experimental programmes (aim to exploit developments in core technologies)

2. Core technologies – needed to demonstrate feasibility of doing physics at future colliders (lepton/hadron/linear/circular)
   - Identify ‘core technologies’ that could be applied to wide range of future projects
     - Mechanics (Low mass structures / stable structures / cryogenic systems)
     - Services (Data multiplexing, opto transmission, gas cooling, large-area micro-channels)
     - Assembly & Testing (Robotics, 3D printing, generic high-performance DAQ, facilities planning)
     - Installation & Commissioning (Project management, training)
   - Develop funding model to enable R&D over medium (5-7yr) term (i.e. 2023-30)
     - Include technical development PhD studentships
   - Expect emerging experimental proto-collaborations to take over (sub-set of) developments
     - What do we do if things we’re working on don’t get selected ?

3. Build strategic partnerships
   - Have spent > 20years with 75% of community tied to (HL-)LHC experiment collaborations.
     - Future preferred collaborators may not be the same
     - Should be ready for migration & see as opportunity rather than destructive.
   - Heritage helps but need bold plans backed up with resources to ‘buy in’ to emerging international R&D groups and proto-collaborations (eg wheeler-dealing when Eagle & Ascot begat ATLAS)

Summary

- UK PP has well deserved reputation in delivering major components of detector systems
  - Projects successfully coordinate the efforts of a widely scattered community
  - Very successful in distributing tasks according to locally available effort and facilities.
  - A lot of work done in UK industry

- I think we make it look ‘too easy’
  - It’s not – and we fool ourselves if we think we are the best and that’s that.
  - Mechanics, cooling, powering, data transmission, assembly, testing installation and commissioning are all major challenges and need the brightest minds if we are to develop systems that deliver physics in ever more challenging environments

- How to we transition to R&D focussed activity?
  - Not surprisingly, current integration experts are locked in to projects with 5yr horizon
    - The R&D phase for the GPDs for HL-LHC is over – but let’s not forget ALICE (ITS upgrade) and LHCb (MT development just starting, Timing VeLo)
    - The GPD integration community still has a mountain to climb.
    - Smaller-scale detector construction projects already in the pipeline

  - How do we make a start?
    - Suggest that the peak HL-LHC staff cost (i.e. core & project) FTE (AP, E) becomes the new norm and that as HL-LHC build activity tails away posts are refilled with people with skill-sets needed for long-term development programme (or staff re-trained).
    - Increase the number of dedicated hardware R&D PhDs
    - Defining a ‘generic sub-system’ concept for FCC-era (eg local support demonstrator, calorimeter demonstrator, PID, etc), & work towards defining requirements and developing R&D plan with intermediate outputs for near-term physics exploitation
    - Define generic R&D plan for specific areas in integration (eg low mass mechanics, robotic assembly) – again with intermediate outputs for near-term physics exploitation