Reflections on Physics Instrumentation Standards 1964-2022

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Invited Talk

IEEEE NPSS Real Time Conference 2022

August 3, 2022

Foreword

- This presentation briefly summarizes experiences at SLAC National Accelerator Laboratory in helping to develop and apply Standard Modular Instrument solutions for the International Physics community since the Nuclear Instrument Module (NIM) emerged in 1964.
- I am indebted to SLAC, the IEEE Nuclear and Plasma Sciences Society and its NIM Committee for the privilege of associating with outstanding dedicated international colleagues for almost six decades.
- *-Ray Larsen, August 3, 2022*

Topics

- 1. Why Instrumentation Standards for Physics?
- 2. Standards summary:
  - a. NIM – Nuclear Instrument Module
  - b. CAMAC – Instrumentation and Interface Standard
  - c. FASTBUS – Modular High-Speed Acquisition and Control System
  - d. ATCA/MTCA–Advanced Telecom Computing Architecture
- 3. Progress in MTCA Standards and Acceptance
- 4. General Discussion of Costs and Risks of Standards
- 5. Conclusions- Lessons Learned

1. Why Instrumentation Standards for Physics?

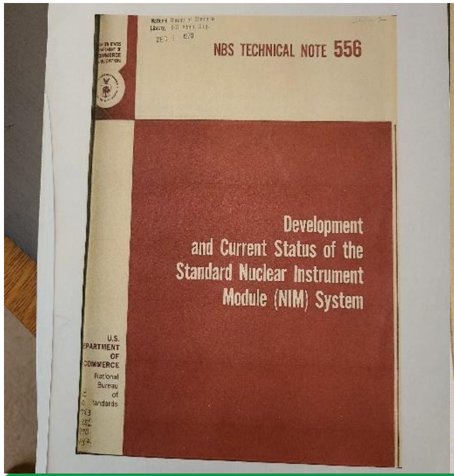
- General Observations
  - Modular Instrument Standards are designed to:
    - Provide a range of interchangeable configurable modules
    - Save costs of materiel, re-usability
    - shorten time to deploy, re-deploy new systems
    - raise system availability by fast interchangeability e.g. hot-swap
    - lower time to expand or contract new systems
  - How long can modular solutions last?
    - For accelerator controls, typically 30+ years e.g. CAMAC
    - For old style particle counting electronics, e.g. NIM, until technology renders obsolete
    - For very large Detectors, e.g. ATLAS ,until upgrades needed for productivity; front ends tend to be highly customized cards on or inside Detectors, not in standard racks outside
  - Conclusion:
    - Module market for vendors depends heavily on large infrequent projects, hard to predict future needs.

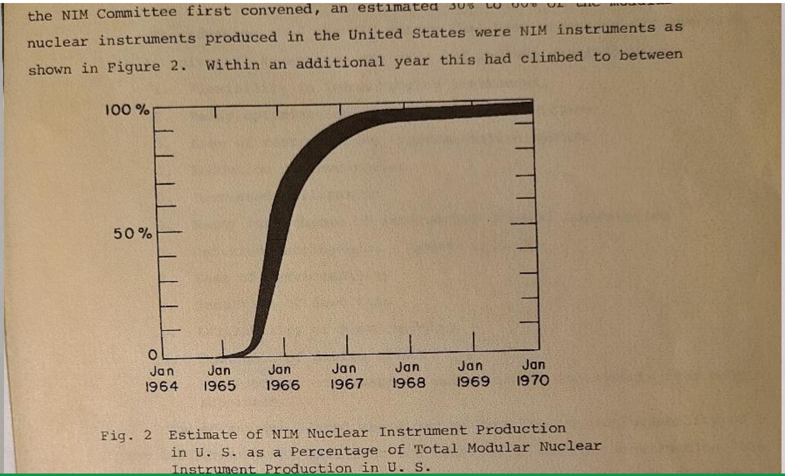
2. Physics Instrumentation Standards Summary

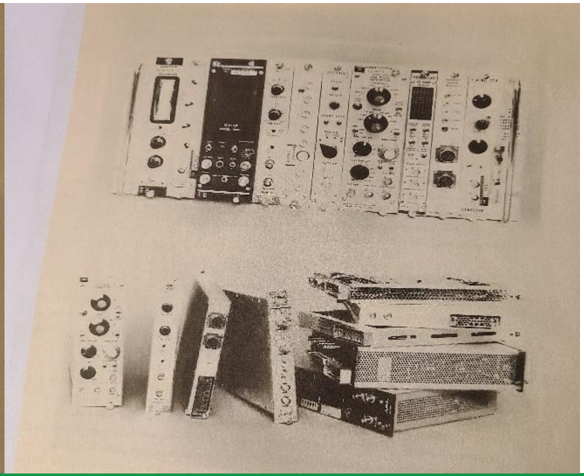
- **NIM**: Nuclear Instrument Module: 1964
- **Motivation**: NBS proposes to Atomic Energy Commission for interchangeability to nuclear field
- **Developer:** US National Bureau of Standards Committee of lab users & manufacturers
- **CAMAC:** Computer Automated Measurement and Control: 1971 (ESONE, ANSI Standard)
- **Motivation:** Emergence of microcomputers, IC'S and user demand for standard Dataway
- **Developer: Harwell UK & ESONE** – European Standards on Nuclear Instrumentation w/ Industry
- **VME & VXI**: Late 1970's to 2004
- **Motivation:** Same as CAMAC plus C-size card, crate w/VXI
- **Developer:** VITA (VME Industrial Trade Association)
- **FASTBUS**: 1988 (IEEE Standard)
- **Motivation**: Physics users to gain 32- bit bidirectional faster data rate, C-size boards 29/crate
- **Developer:** US NIM Committee of Labs & Industry
- **ATCA/MTCA:** Advanced Telecom Computing Architecture 2004 and MicroTCA 2019 (PICMG Std.)
- **Motivation:** Telecom Industry needs of maximum speed, highest possible availability (HA); Physics plans for 20-mile collider needing HA; Later DESY XFEL RF becomes lead driver
- **Developers:** PICMG (PCI Industrial Computer Manufacturer's Group) & int'l Lab-Industry Committee chaired by SLAC & DESY

2a. NIM Nuclear Instrument Module- 1965

- NIM modules in particle detectors are very simple nanosecond speed analog systems where all results go counters read digitally. Only power and exterior coaxial cables need to be provided. Other major users were nuclear labs, reactors and researchers.
- The Business case for NIM was driven by National Bureau of Standards and the funding agency, Atomic Energy Commission. It was a brilliant idea supported by suppliers and lab customers and within 4 years dominated the nuclear research market. NIM supported a range of instruments, not just pulse counters. Today however the remaining market is mainly for legacy systems.



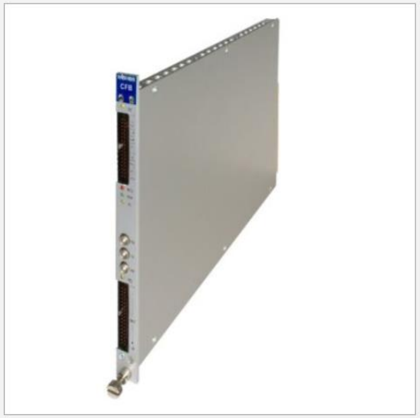




2b. CAMAC - 1972

- CAMAC was a highly successful leading-edge product for control systems when IC's and Microprocessors became available to support a fast data bus,(whereas NIM was basically a hard-wired analog front-end system with no data bus until much later. It was first thought that CAMAC would be too digitally noisy to support ADC systems but that proved wrong. On the other hand, it was limited for critical applications with extremely low noise requirements. In the US both SLAC and Fermilab adopted CAMAC for major control systems.

CQ16 / 16A channel Charge Integrating ADC



CFB CAMAC-to-FERA Bridge

CAMAC Crate CERN-CE 600W

CMDGG8 – CAMAC Multifunctional Logic Unit

Footnote on “Fast CAMAC”

- As utilization of CAMAC increased, the limited bus data rate became a problem causing users to seek other solutions. However, a group headed by S. Dhawan of Yale working with Joerger and LeCroy companies came up with a solution to increase the rate by 2.5X with the standard drivers, and up to 10X with tristate drivers. Several new 10X products were built but did not succeed due to the higher cost. (S. Dhawan)

2c. FASTBUS 1985

- In the early 1980s the NIM Committee received mounting pressure from a few US experimenters that we desperately needed a new standard to keep up with advances in mainframes that offered much more computing power with 32- bit wide bidirectional higher speed data buses; and if we did not respond the physicists would take it on themselves. Sensing disaster, we responded with the *FAST System Design Group*, which I chaired, which included Working Groups for Software, Mechanical and Power Supplies, a Goals Group, and a NIM Executive Committee for FASTBUS, chaired by the indefatigable Lous Costrell. The IEEE Standard, F*ASTBUS Modular High Speed Data Acquisition and Control System*, was issued December 12, 1985.
- [Since SLAC had close ties with IHEP in Beijing, a Chinese translation was also published, and I was asked to visit and give seminars on it. My Department had hosted 4 engineers who spent 2 years building hybrid IC's for the Detector for their replica of SLAC's SPEAR colliding beam Storage Ring. Another group of 20 replicated the entire CAMAC control system hardware and software.

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FASTBUS Crate Types

- The FASTBUS standard included both a vertical air-cooled (Type A) and a water cooled (Type W Chassis, the latter by the original group of physics proposers. Each module had a metal cover plate that wedged to a rear cold plate. The system was designed at BNL and reportedly worked well in several experiments but went no further.
- The largest user was SLD at SLAC that used Type A crates, but data on other users seems to be not documented.

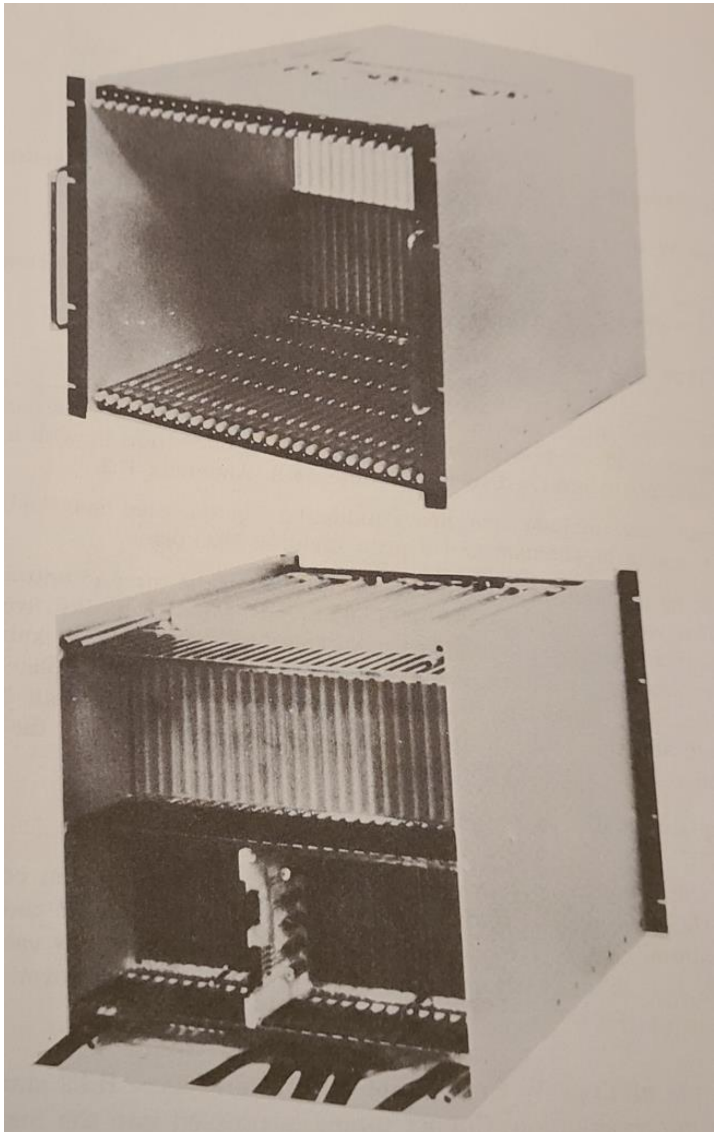


Fig H.1.2
Typical Type W Crate Implementation

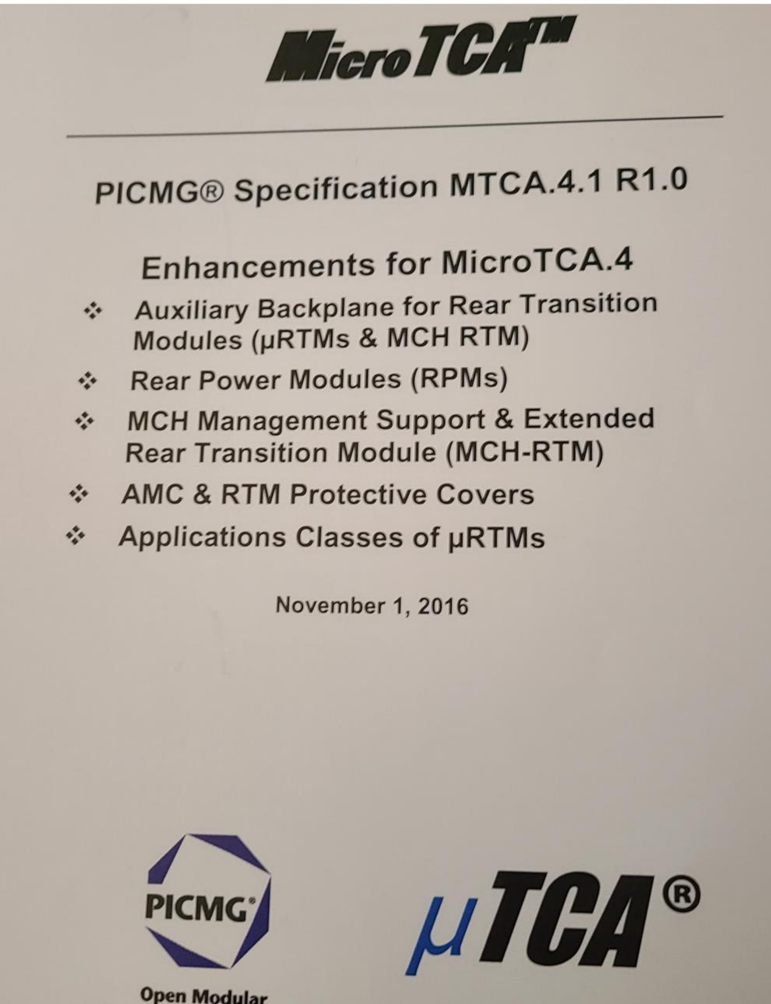
ATCA & MTCA for Physics -- Origins

- The **ATCA** Standard by **PICMG** (PCI Industrial Manufacturer's Group) was first brought to our attention by Robert Downing of U of Illinois, retired, former member of the NIM Committee and very active on CAMAC. After NIM Bob remained active and served 2 terms as Chair of VITA, the VME Industrial Trade Association. The tip about PICMG came from Bob's neighbor friend who he knew from VITA. He proposed that this could be a solution for the Next Linear Collider (**ILC**) Controls. To draw PICMG to the attention of the community Bob and I submitted a paper to the NSS-MIC in Rome in November **2004.**
- However, at the **2005 Snowmass** Physics community meeting on ILCI, I gave a paper on ILC Controls proposing ATCA and our rival from DESY Kay Rehlich gave a strong proposal *also based on ATCA*. From that point on we became collaborators.
- In **2007**, **PICMG** offered presenters for a n initial workshop meeting at Fermilab which also attracted vendors from the Physics world.
- After Snowmass, the competition for the ILC RF system was decided and the DESY superconducting RF cavities won over the SLAC warm copper approach, and in parallel the DESY XFEL came to life. As a result, there was now pressure to form the xTCA collaboration which DESY management had supported over a VME solution.
- Finally, at the **2009** *IEEE NPSS Real Time in Beijing* I agreed to chair the new standards committee, by now urgent for the XFEL Project, with Bob Downing leading the hardware team and Gus Lowell the software; other key players came later.
- Bob Downing became a consultant to SLAC for the duration of the standards efforts.
- PS: The **ILC** is still alive and looking for funding and a home; the main interest is in Japan.

ATCA & MTCA Standards Progress

- 1. **Advanced TCA Rear Transition Module Zone 3A**
- **Sept 5, 2011**: New connector to backplane or direct to Rear Transition Module
  - *Feature did not exist on PICMG version but vital for Physics. Being used at SLAC for LCLS II superconducting linac upgrade.*
- 2. **MicroTCA.4 Enhancements, Nov. 1, 2016**
  - See list & Examples Next Slide
  - ***Enhancements*** were derived from needs for RF System, plus other foreseeable uses.
  - ***Classes*** *of Enhancements expanded ed to accommodate many otherwise conflicting applications and make system flexible long-term*.

List of xTCA Enhancements & Examples



MicroTCA™

PICMG® Specification MTCA.4.1 R1.0

Enhancements for MicroTCA.4

- Auxiliary Backplane for Rear Transition Modules (μRTMs & MCH RTM)
- Rear Power Modules (RPMs)
- MCH Management Support & Extended Rear Transition Module (MCH-RTM)
- AMC & RTM Protective Covers
- Applications Classes of μRTMs

November 1, 2016

PICMG

Open Modular

μTCA®

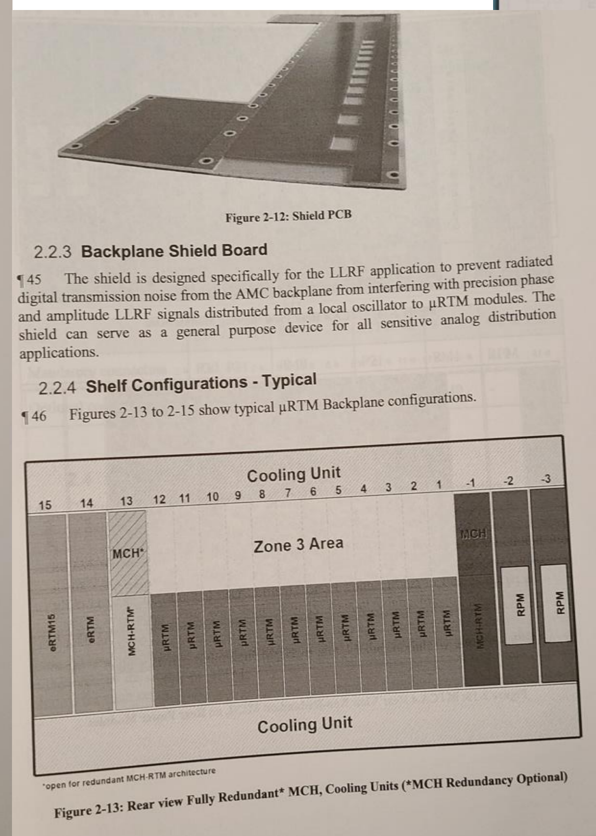


Figure 2-12: Shield PCB

2.2.3 Backplane Shield Board

¶45 The shield is designed specifically for the LLRF application to prevent radiated digital transmission noise from the AMC backplane from interfering with precision phase and amplitude LLRF signals distributed from a local oscillator to μRTM modules. The shield can serve as a general purpose device for all sensitive analog distribution applications.

2.2.4 Shelf Configurations - Typical

¶46 Figures 2-13 to 2-15 show typical μRTM Backplane configurations.

Figure 2-13: Rear view Fully Redundant* MCH, Cooling Units (*MCH Redundancy Optional)

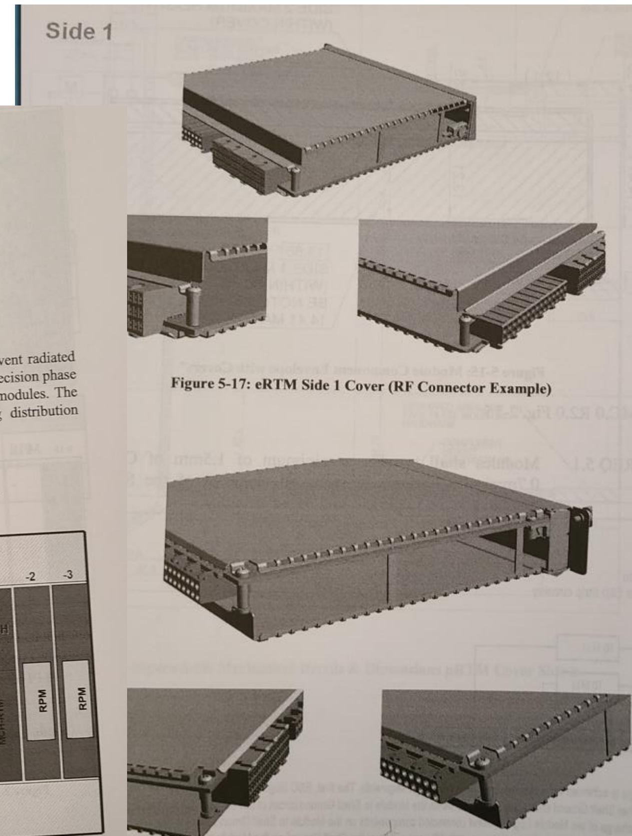
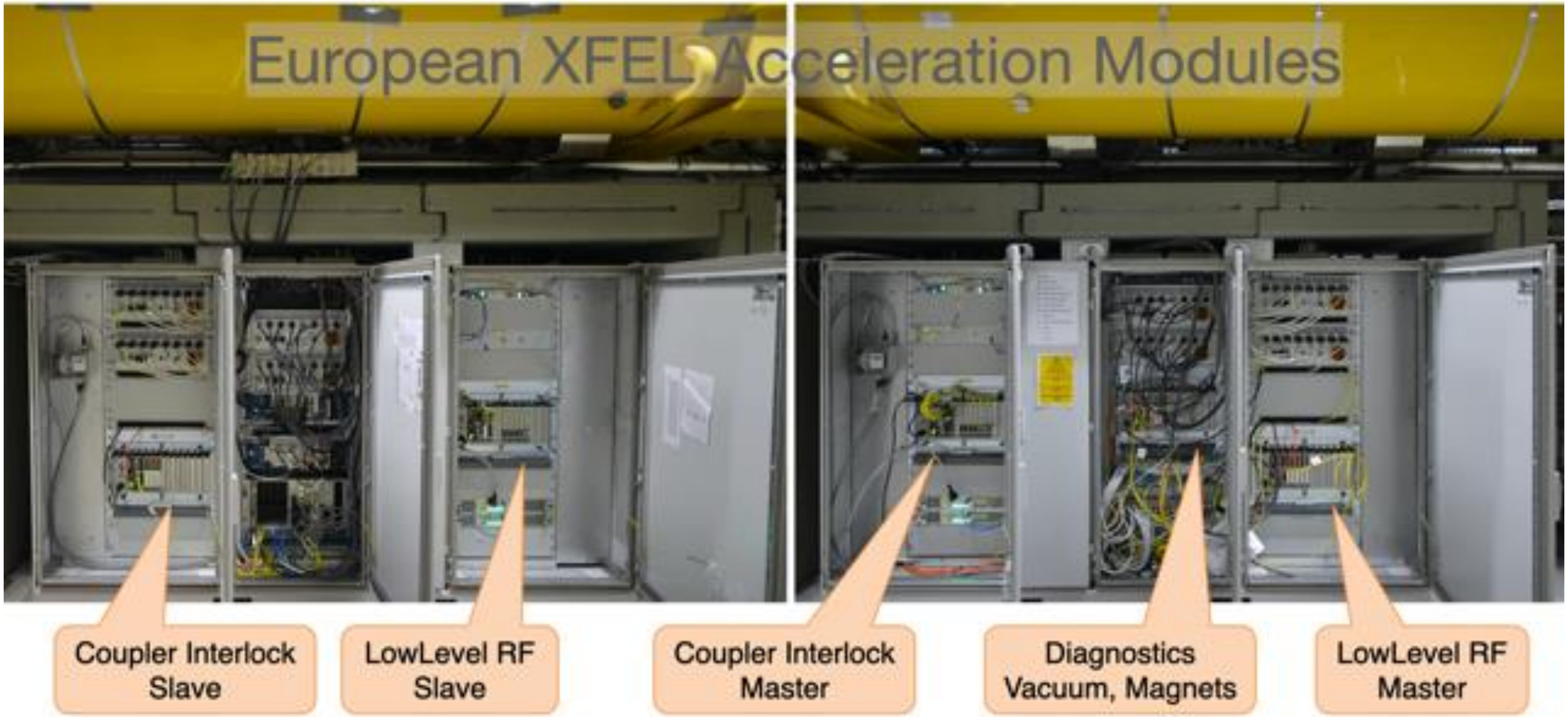


Figure 5-17: eRTM Side 1 Cover (RF Connector Example)

Standards Progress & Acceptance 2

- Progress on the necessary standards has been outstanding with key help from Industry members from Schroff, Elma and many others, Bob Downing and Gus Lowell and the PICMG organization.
- The annual December collaboration meetings at DESY along with collaboration with Industry and the support of its funding agency have all been crucial to keeping XFEL on track.
- *The following four slides, courtesy of Kay Rehlich, key project lead, illustrate the XFEL team's dramatic progress.*

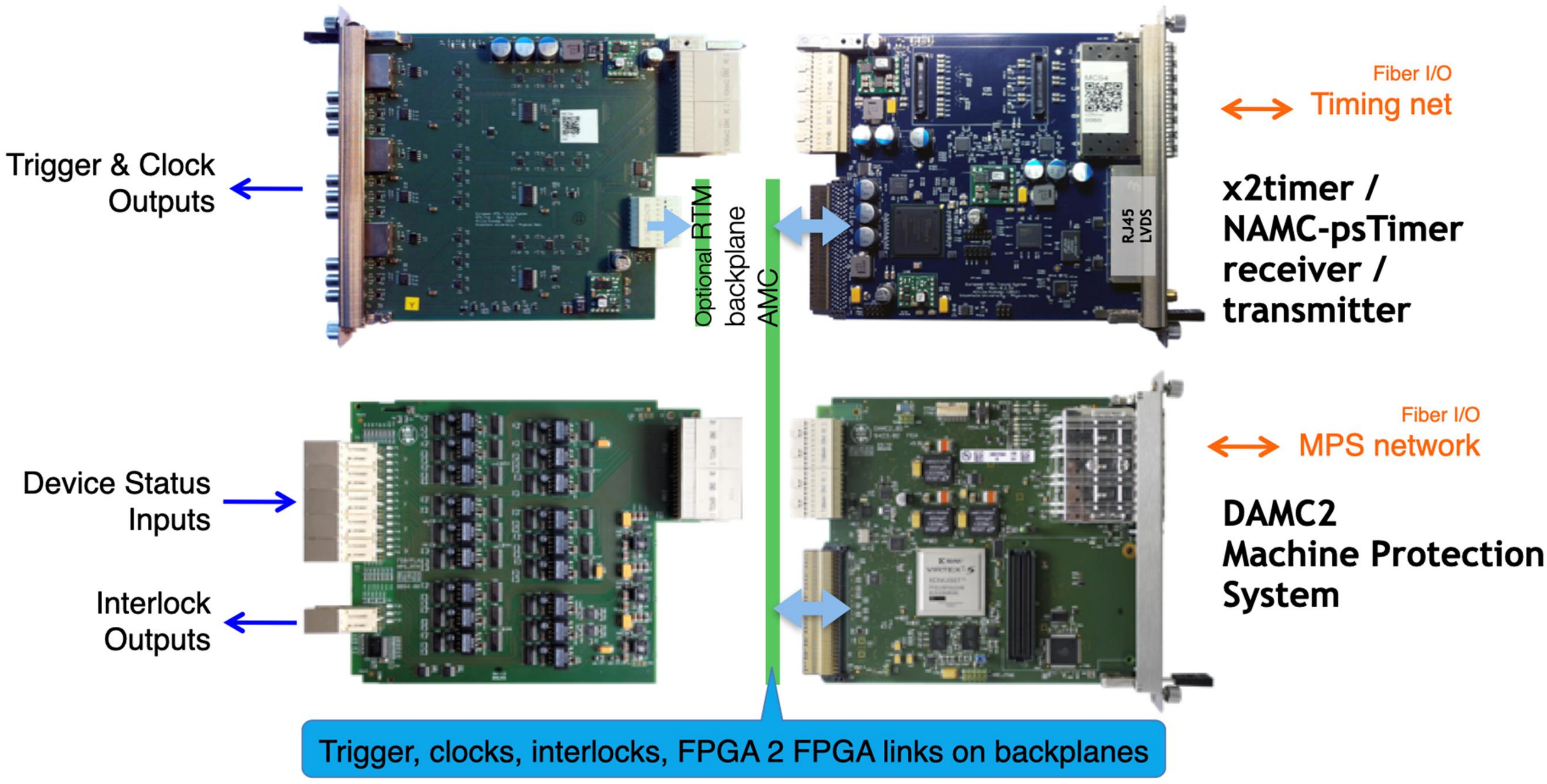
One RF Station (out of 24) = 4 Modules = 32 Cavities = 5 MicroTCA



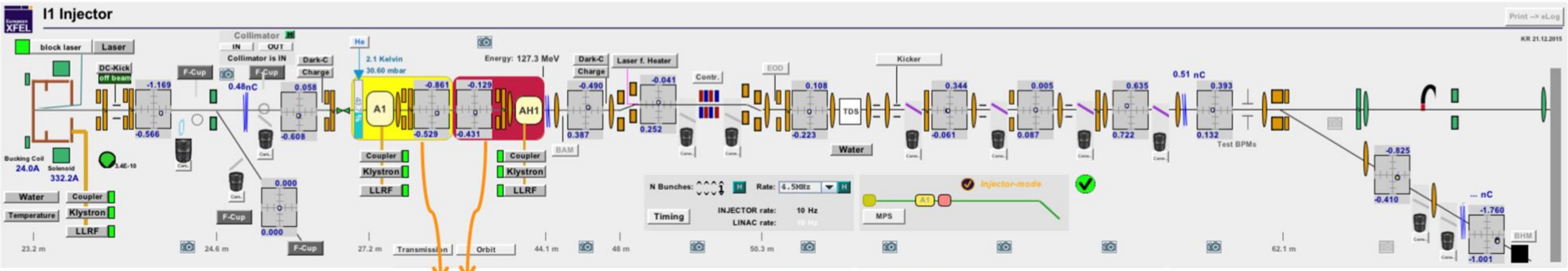
© Kay Rehlich, DESY

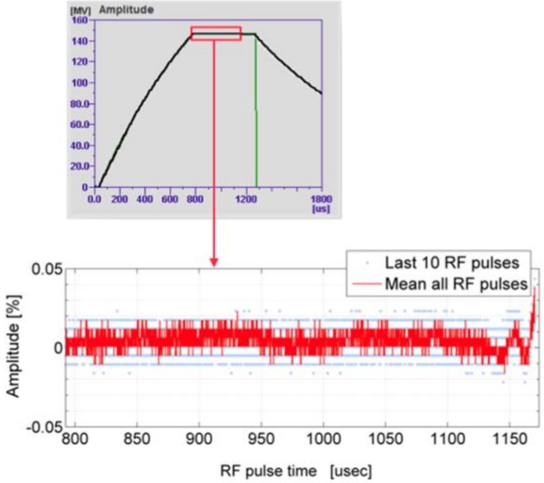
15

Timing and MPS



XFEL Injector: Controls Rack for 1.3 and 3.9 GHz

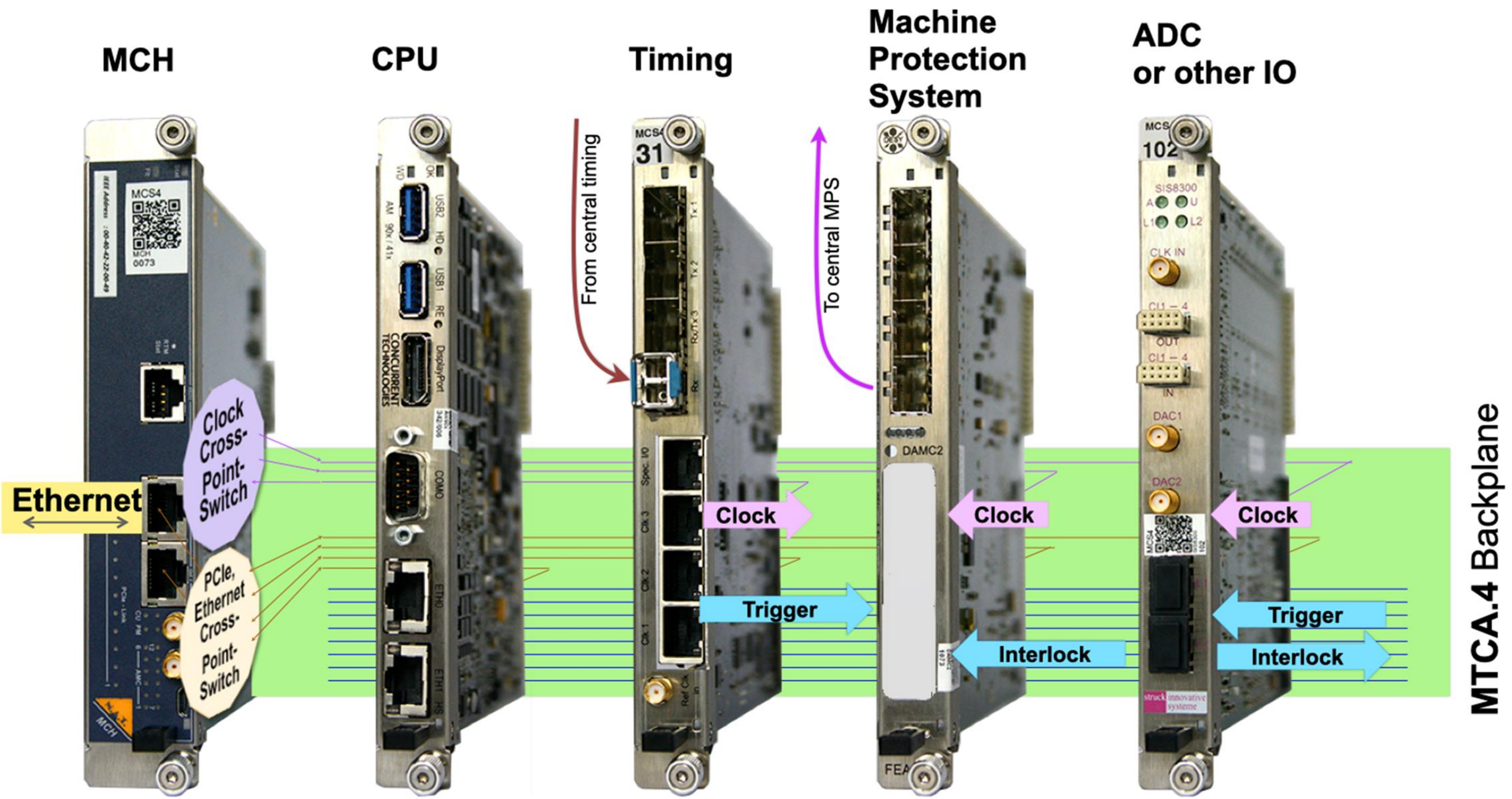




$\sigma(dA/A) = 0.0057\ \%$

Ray, here comes some XFEL material. I can easily modify it to better fit into your slides. Pls let me know what else you need.
Cheers, Kay

A Typical MicroTCA System @ XFEL



xTCA Progress and Acceptance 3

- Clearly XFEL is the flagship program that will determine the course of xTCA for physics for years to come. Particular key achievements are:
  - The development of RTM technology
  - The remarkable RF backplane enabling precision never seen before
  - Project- wide timing system
  - Diagnostic system-wide timing and hot swap software
  - Defining Classes of modules that can share the backplane
  - The outstanding International Team led by Kay and his management team to a plane rarely achieved.

xTCA Progress and Acceptance 4

- Although XFEL at DESY in Hamburg has been the Prime Mover of the largest program built on the new standard, , some other labs are following with other active programs including CERN in Geneva, the European Spallation Neutron Source in Lund Sweden, Pohang Light Source in Korea, and labs in China and Japan. On the ATCA side with the new RTM , SLAC is implementing new controls for the superconducting 2-mile LCLS-II nearing completion, and extension to finally replace CAMAC on LCLS-1 can be anticipated.

APPENDIX

- 5.1 Markus Joos 2017 summary evaluations of standards from CERN
- 5.2 General comments on risks

A comparative discussion of bus/crate standards and their use at CERN

Markus Joos

CERN

https://indico.cern.ch/event/673073/contributions/2770356/attachments/1553050/2440989/COMPASS_JOOS.pdf

This 2017 paper by Markus is an excellent analysis of CERN users and the various utilizations of a range of standards. Markus has kindly agreed to share with interested parties his excellent approach. Thank you, Markus.

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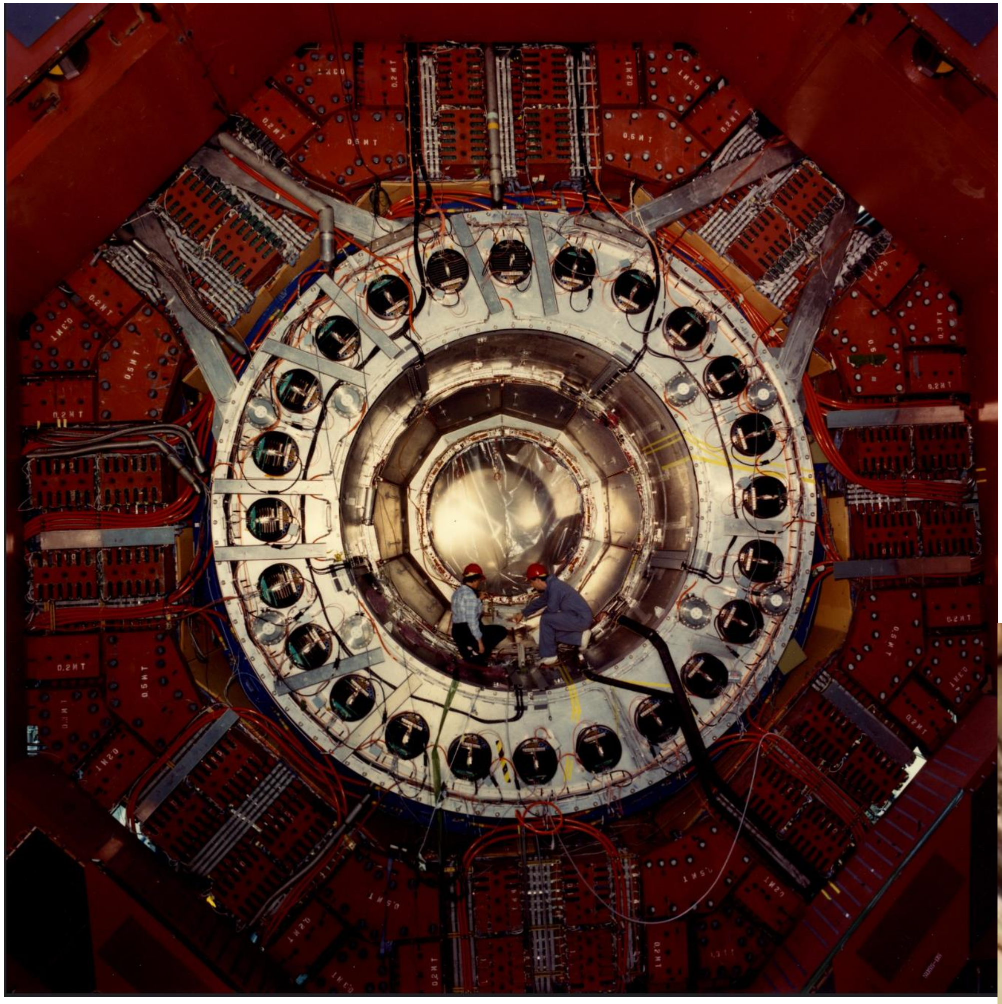
DAQ/FEE/Trigger for COMPASS beyond 2020 workshop – Prague – 10.11.2017

5.2 Comment re: Cost & Risks

"Are Standards worth the effort?"

- Risk must be measured differently by the development engineers and the physics machine and detector project leaders who are justifiably risk averse to added technical and cost risk. The attitude around SLAC has been after 30 years of running now, "CAMAC is working fine; there is no point of upgrading just because the engineers and technicians want newer shinier toys." Others feel that risks are increasing as people who know the systems retire and parts become scarcer, but risks can be made low with modest planned investment and performance improved enormously.
- Another key point is that a huge amount of the load on modules associated with Detectors has migrated via custom IC's to *inside* the detector structures, which eliminates a layer of complexity at the crate-based standard modular level and at the same time saves enormous size and costs of the detector's reduced iexternal signal-carrying cable plant. SLD was a great example with its fiber optic rear entry cable plant.
- A third point is that technology rather quickly becomes obsolescent or unavailable and that industry is driven not mainly by physics but by other industry and market forces outside of physics.
- A major step forward with MTCA for the planned 20-mile International Linear Collider (ILC), e.g. internal temperature monitoring and fan control at the module level to flag impending problems before shutdown of a $10 B production machine; this plus hot-swap can avoid downtime entirely.

SLAC SLD
Linear Collider Detector 1992



Courtesy SLD Project Co-Lead Prof. Martin Breidenbach

Major DAQ systems all in FASTBUS crates
Sub-systems front-end cards inside detector
Cable Plant fiber optics bundle to Rear Trans-ition FO plugs to FB Modules.

24

Acknowledgments

- The author recognizes the hundreds of pioneers in scientific laboratories and Industry dedicated to adapting the latest technologies to ever more capable and cost-effective tools for Physics that spin-off to many other scientific fields.
- Primary sources for this report are Louis Costrell (dec.), Nat'l Bureau of Standards; Robert Downing, U of Illinois (ret.) , main editor and hardware leader; Kay Rehlich, DESY , key XFEL MTCA controls developer & manager; Gus Lowell, Standards software leader; Prof. Martin Breidenbach (on SLAC (SLD FASTBUS System), Markus Joos et al, CERN, utilization of XTCA, other standards in use 2017- present.

-Ray Larsen, 08/03/2022

Thank you for your attention!