UNIVERSITÄT
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Belle 2 PXD DCS

Schaltungstechnik
und Simulation

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Joint CBM / PANDA Topical Workshop
on Detector Control Systems Aspects

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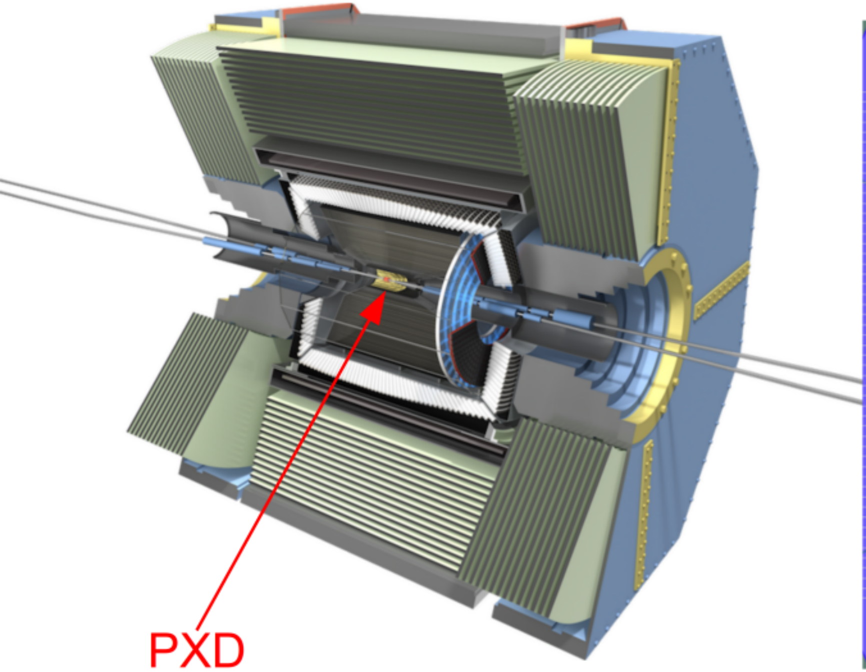
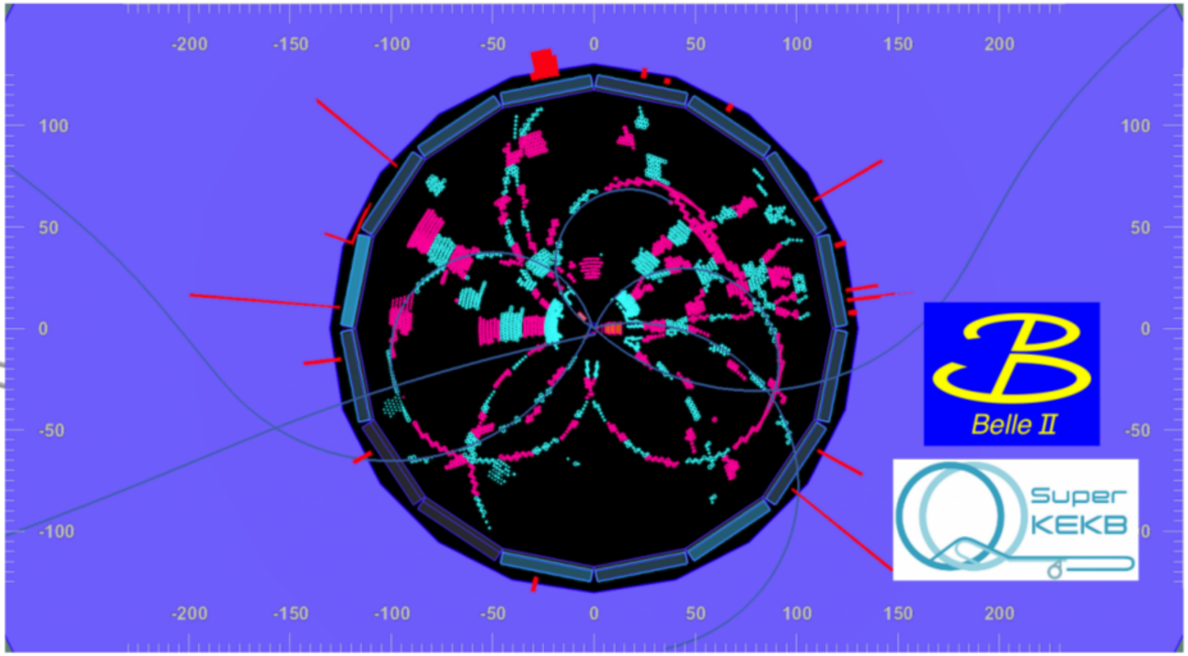
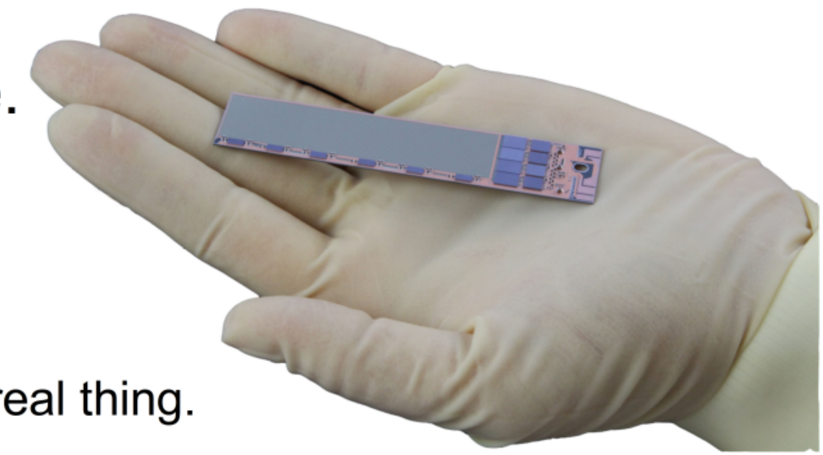
- Sole experiment at the SuperKEKB B-factory in Tsukuba, Japan.
- Target: $8\times10^{35}/cm^2/s$ instantaneous luminosity, $50ab^{-1}$ integrated.
- First collisions on April 25th. Currently commissioning @ $2.5\times10^{33}/cm^2/s$.





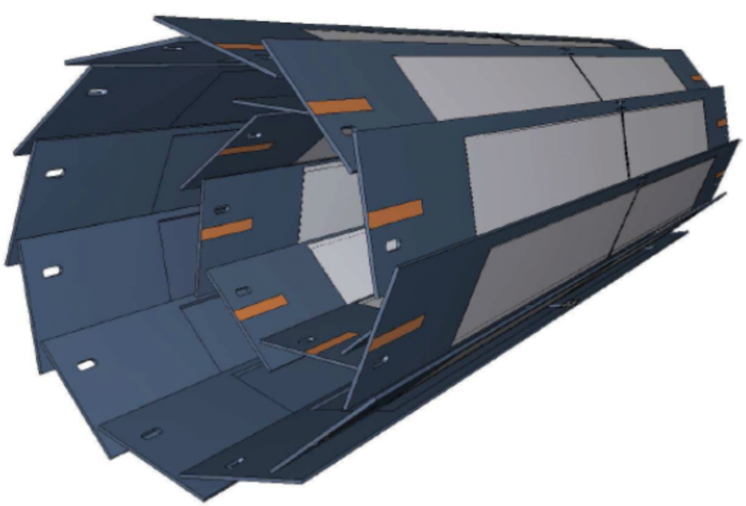
Belle 2 Pixel Detector (PXD)

- German contribution: PXD detector based on DEPFET sensors.
- Two layers @ r=1.4 cm, r=2.2 cm.
- 40 modules, 16M pixels.
  - Four modules during SuperKEKB commissioning phase.
- Thinned to 75 µm in the active area.
- 50 kHz frame rate, ~ 1 GB/s to storage.
  ⇒ ~⅓ of all of Belle 2's data.



The real thing.

„Artist's illustration"



Many Protocols

- The Challenge: Lots of devices, each communicating in a different way.

An incomplete list:

Hardware	Protocol
Cooling Plant	modbus
Power Supply Units	custom protocol
„DHH“, „DATCON“ DAQ systems	IPbus (CERN)
ATCA crates	IPMI
fibre optical sensors	TCP-based custom protocol
„ONSEN“ DAQ system	EPICS on FPGA PowerPC
Belle 2	NSM2 (KEK)
temperature sensors	i²c
primary power supplies	GPIB-over-TCP

And the number is still growing…

- The unifying standard: **EPICS** as the common protocol.

Overall Organization

- Well-defined SC installations, based on Scientific Linux.
- Centralized, automatic, build system for RPMs for EPICS base, modules + our own IOCs.
- Centralized build of a CSS (an EPICS GUI) version preconfigured with PXD settings.
- IOC (~ device driver) for „finished“ hardware — mostly off-the-shelf products — done by a small group of core developers.
- IOC development for own hardware by the hardware developers.
  - Provide a basic IOC with all required protocols implemented.
  - But have them fill in and maintain all the hardware details.
    ⇒ Faster turnaround. Adding a register be done within one group.
    ⇒ Easier for them to develop with an always-up-to-date SC system.
- More or less „free“ development within a (wide) set of guidelines, e.g. GUI design, use of the EPICS PV namespace.

- Two Belle 2-wide systems to integrate the PXD SC into:

Power Supply Control

Sensor Power

Power Off

⇅

LV On, Injection Allowed

⇅

Sensors Active, Injection Prohibited

+ error states

Run Control

DAQ Operation

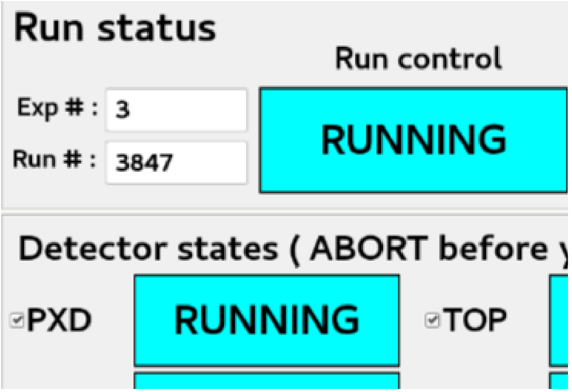
Off

⇅

Standby for Run

⇅

Running



- Higher radiation levels during beam injection.
  ⇒ Protect the detectors by switching off HV during injection.
- Some discussions were required to fit the Belle operations scheme to PXD, esp. for the Power Supply Control.
  - Most other subdetectors have some sort of HV voltage.
  - PXD: Complex sequence (O(100) steps) to power and configure the ASICs on the modules, and the modules themselves.
    ⇒ Digital configuration in step 1, module power in step 2.

Detector Control Implementation

- Several levels in the hierarchies:
  - Belle 2
  - Subdectors: PXD, SVD, CDC, …, Trigger (RC), Storage (RC), …
  - @PXD: individual modules (PSC) / DAQ compomenents (RC)
- On each level, modules from the lower level can be excluded.

  ⇒ Local control of these excluded components.
- @PXD: Implemented using the EPICS seq module.
  - One IOC per level in the hierarchy.
  - NSM2-to-EPICS bridge for connection to Belle 2 level.
- Typical problems encountered during development:
  - Recovery procedure from error states.
    ⇒ Discussion with Belle 2 SC responsibles.
  - Hardware interfaces to other systems controlled outside PXD SC.
    ⇒ Make no assumptions about anything outside your control.
    ⇒ Provide clear information, which side is currently failing.
  - Undetected changes in the actual hardware status.
    ⇒ best practice: WHEN_ERROR macro in each state.

```
#define WHEN_ERROR \
  when (PSoff) state ERROR; \
  when (detector_burning) state FIRE;
```

So That Was the Plan…

What could have gone better?

And what Lessons have been learned?

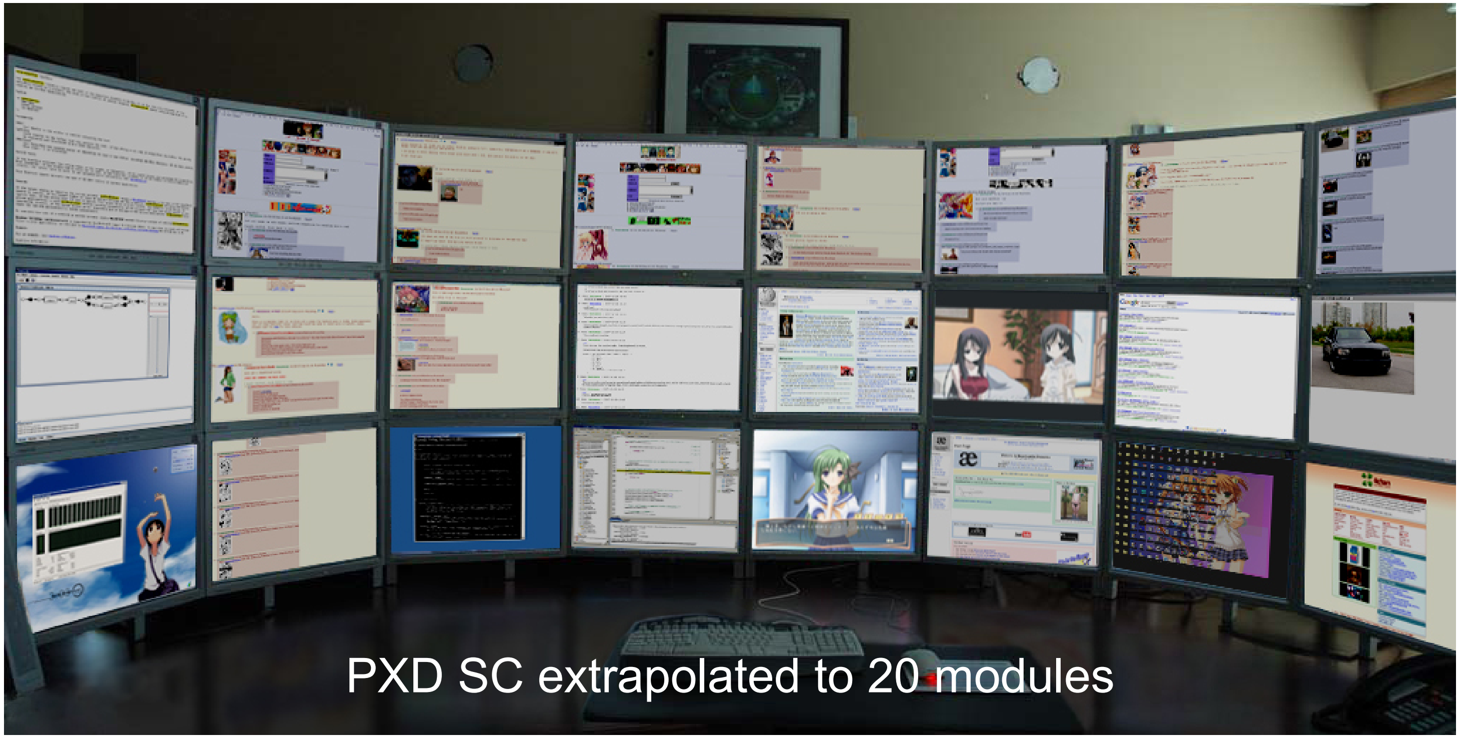
- There won't be any recommendations you are not aware of.
- But I'll try to add a new aspect to some of them.

Off-the-Shelf Devices Integrate Easier

- Of course, it's not always possible to buy standard hardware.
- But my experience is, standard devices use standard, „easy“ protocols, own developments often don't.
- Looking at the IOCs (device drivers) we are running, the most complex ones are the ones for PXD-developed hardware.
  - Partly because it's highly specialized hardware with special requirements.
  - But also partly because little-used protocols are implemented. E.g. IPbus (no EPICS driver) vs. Modbus (good EPICS driver).
- ⇒ Try to follow standards where applicable.
- This may require compromises on the device side, but I'd say a good case has to be presented to use anything else.

Old Habits Die Hard

- Change is only accepted slowly.
- „OK, we can do it like this for now, but we must be aware that this won't scale for the final system.“
  - A very bad sentence to say.
  - People will go to big lengths to *make* it scale, no matter how inconvenient.



Even when you do finally offer a better solution.

- ⇒ Insist on a scalable solution from day 1.

Documentation!

Documentation is **always** a good thing.

- But it's not a one-time thing.
- Make sure it is up to date.
  - Outdated, but still „similar“ documentation can very easily mislead the reader.

One more very important aspect to it:

- Key personel can move on at any time, often on very short notice. I heard “Next month/week(!) I'll be gone“ two times.
- When the day comes
  - Option a – No / outdated documentation: Hastily arrange a handover meeting.
  - Option b – Up to date documentation: Use the time to throw a goodbye party.

A System is Never Finished

- Any „complete“ list (requirements, hardware, …) will always be amended…
- E.g. even after installation, (small) new devices will creep in.
  - Latest example: A remote-controlled main power switch for hardware in the radiation exclusion zone.
  - They need network connectivity, aka. a switch port.
    ⇒ Always have some spares!
  - They need slow-control integration.
    ⇒ Be prepared to invent something on short notice.
- Side-aspect: You gotta love ~~pie~~ the Raspberry Pi.
  - Need a „PC“ to control a JTAG programmer? ⇒ use a Pi.
  - Need a „PC“ to do RS232 serial? ⇒ use a Pi.
  - i²c? ⇒ use a Pi…
  - **But:** Can you trust them? The quick fix is easy and cheap.
    But finding anything long-term can be really cumbersome.

Test Everything, or the True Story of a Firmware

- Task: Develop the µC firmware and PC control code (no EPICS at that time) for a power supply unit.
- 2011: Development outsourced.
- Since: Used during PS development.
  - Some small issues, but mostly OK.
- 2016: More than one unit in operation at the same time, in the same place.
  - Problems show up immediately.
  - Patched around in the PC-side code.
- 2017: It becomes clear that scalability is a major issue.
  - Detailed analysis of code and network traffic starts.

- They wouldn't… or would they…?

```
command_data_t *data =
    (command_data_t *)(xme_hal_sharedPtr_getPointer(dataHandle) + offset);
// Check if the command received is for the specific node or not.
if ((data->nodeNumber == node_Number) || (data->nodeNumber == 40)) {
  switch (data->commandType) {
  case START_UP_COMMAND_TYPE:
```

- Any command for one unit is sent (via TCP) to all units.
  ⇒ The traffic goes with the number of units **squared**.
  - A factor of 1600 for 40 units (one per PXD module).
  - The poor µC certainly can't handle that.
- 2018: All of the communication layer rewritten from scratch.
- At some sites, observed disconnections due to lost Ethernet frames.
  - Why didn't this happen before? Ah, it happened (a lot).
    The code just has very relaxed constraints.
  - What's the cause? Hardware issues? The jury is still out on that ATM.

Problem Analysis

So where did this go wrong?

- The coding was outsourced, but requirements were misunderstood.
  - „We need to be able to send a command to all units.“
    became
    „Send all command to all units.“
- The company produces a „Middleware for Cyber-Physical Systems“.
  - It (barely) fit the job, so they just used it.
  - But there's no knowledge about the framework outside that company. The one person somewhat knowledgeable in the project has long left (→ Documentation!).
- Hardware testing was one-unit-at-a-time.
  - The multi-unit issues remained undiscovered for quite a while.
- Possibly: „Fail-safe“ code hid hardware problems.
  - Failures happened all the time, but were automatically handled and never noticed.

Chain of Failures

⇒ A badly designed, overly complex system was developed.
- For comparison: Old code 230kB, new code 70kB binary size.

⇒ The code quality was never doubted. It works, so it must be OK!
- It worked when it was developed.
- An EPICS wrapper could be designed, so that also worked.
- Nobody expected problems in scalability.
  This is a middleware for distributed systems…

⇒ Problems were only discovered late.
- First signs were misinterpreted.
  After all they went away with a small patch.

⇒ Eventually, this problem significantly affected PXD operation until very recently.
- Only one out of four modules in Belle II could be ramped at a time.
- A shifter had to be present at all times. 24/7.
  Now: Normally **no night shift**, only on-call availability.

⇒ Originating in 2011, an undiscovered problem caused a lot of people a lot of headache in 2018.

Acknowledgments

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Thank you!