Results from WP 5.2
Online data acquisition and remote controls
(focus on Belle II)

Jens Sören Lange (Giessen University)

4^{th} JENNIFER2 Project General Meeting
Pisa, Italy
03.04.2025

Slide shown at Jennifer-2 Kickoff Workshop

Vienna, 12.–13.09.2019

WP 5.2

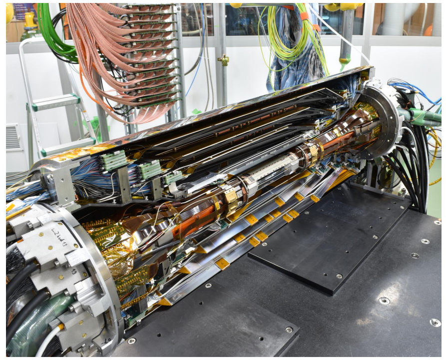
b) Online data acquisition and remote controls

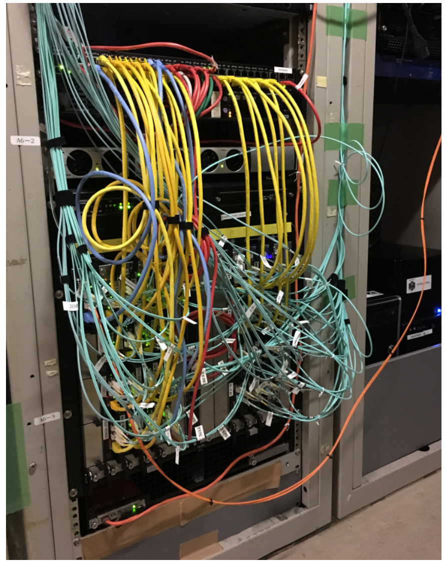
- new hardware technologies for high bandwidth data transfer
  - optical technologies (16.3 Gbps)
  - 10 Gbps ethernet
- precise timing distribution in sub-nanosecond regime
- intelligent realtime algorithms for online data reduction
  - Belle II – background rejection on FPGAs
  - HyperK – vertexing on trigger level ($t < 10$ ns) on GPUs
- novel programming and DAQ software techniques
  - parallelisation on both FPGAs or GPUs
  - methods of artificial intelligence* for trigger decisions
  - integrated dynamic service discovery, monitoring, fault tolerance, dynamic routing and remote control.

} TASKS

*more appropriately called "MACHINE LEARNING"

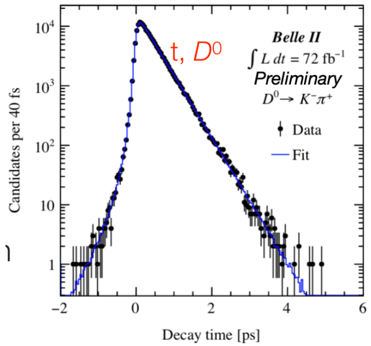
WP 5.2 | Belle II PXD DAQ operation





- RUN 1 from 10/2019 to 06/2022
- 89.5% data taking efficiency (even during pandemic)
- 300 TB zero-suppressed data recorded
- 400+ Million events recorded
- Triggerrate up to 8 kHz
  (design 30 kHz, short tests run up to 35 kHz)
- 2.472.019 truncated events have been detected
  (during injection, PXD occupancy rises to more than 10%)
- 35 Single Event Upsets detected
- Physics results: some of worlds most precise lifetimes (permille accuracy)

Particle	Measured lifetime	Reference
Λ_c^+	203.2 ± 0.9 ± 0.8 fs	Phys. Rev. Lett 130 (2023) 071802
Ω_c^0	243 ± 48 ± 11 fs	Phys. Rev. D 107 (2023) L031103
D^0	410.5 ± 1.1 ± 0.8 fs	Phys. Rev. Lett. 127 (2021) 211801
D^+	1030.4 ± 4.7 ± 3.1 fs	Phys. Rev. Lett. 127 (2021) 211801
D_s^+	499.5 ± 1.7 ± 0.9 fs	Phys. Rev. Lett. 131 (2023) 171803
B^0	1499 ± 13 ± 8 fs	Phys. Rev. D 107 (2023) L091102



Ph. D. thesis Simon Reiter, secondments in Jennifer 1 & 2, recent secondment in 02/2025

WP 5.2, TASK: Intelligent realtime algorithms for online data reduction

Belle II PXD – background rejection on FPGAs

Event filtering on High Level trigger
(operation during physics data taking)

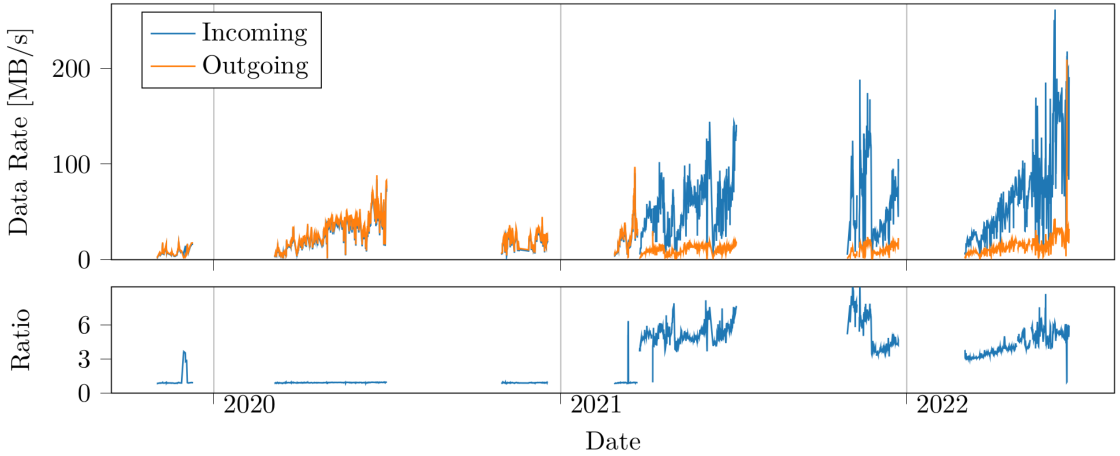
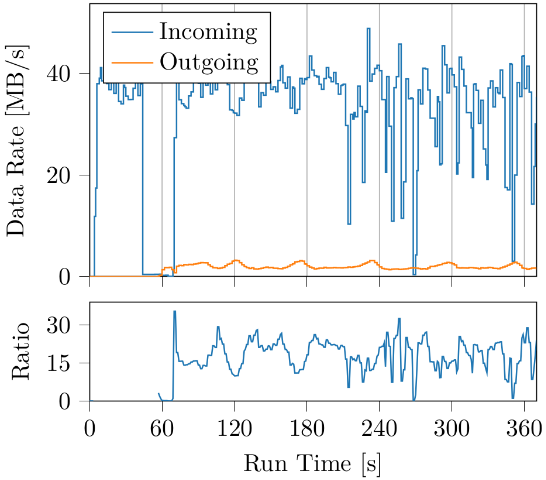


Figure 6.2: Comparison between input and output data rates of ONSEN averaged for each physics run. The highest input data rate was reached near the end at peak luminosity in 2022 with over 250 MB/s. In the lower part the fraction is shown. During 2021 the *event filtering* was enabled, which results in a permanent increase of the ratio.

Regions-of-interest (prototype run)
not enabled yet due to low luminosity

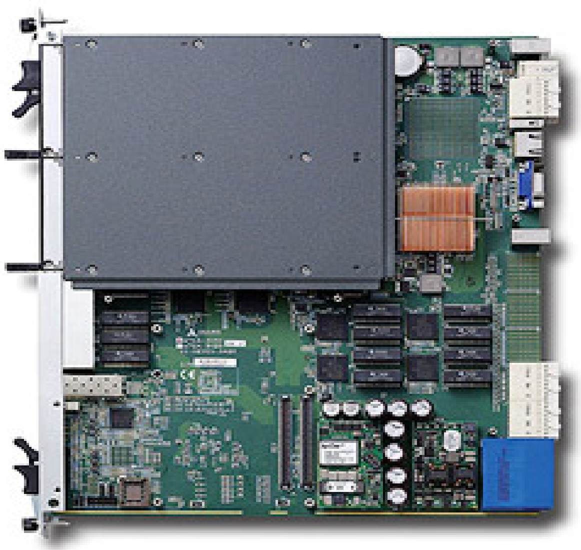


Ph. D. thesis Simon Reiter, secondments in Jennifer 1 & 2, recent secondment in 02/2025

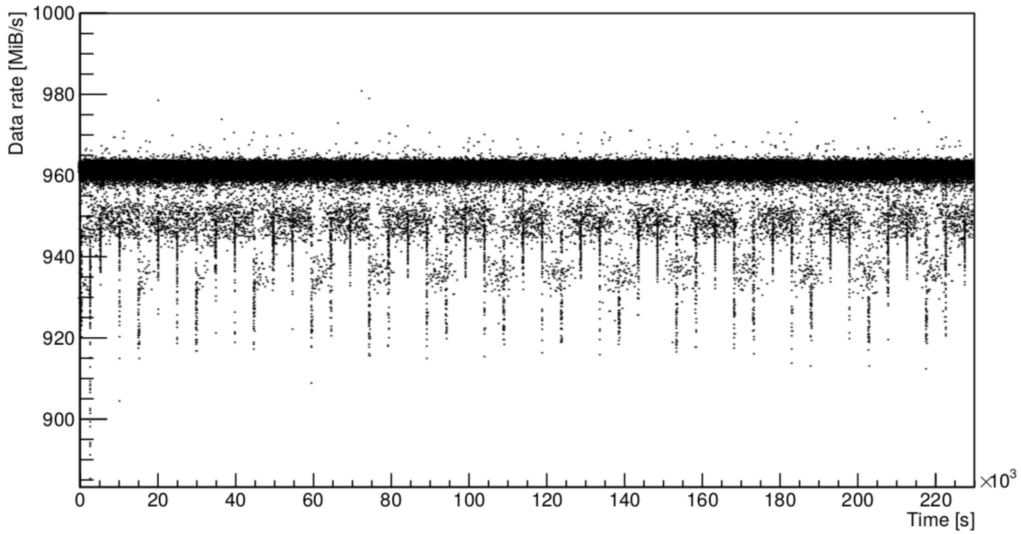
WP 5.2, TASK: New hardware technologies for high bandwidth data transfer

- **Optical technologies (16.3 Gbps):** new generation of carrier board, factor ~2.5 higher link bandwidth, new firmware: link layer protocol changed from Aurora to AXI Stream (Matthäus Krein, secondment 2024, test at KEK)
- **10G ethernet:** PXD MC data streamed through uplink of ATCA switch, stress test, factor 2 overload @ input (Klemens Lautenbach, secondments in Jennifer 1 & 2)

New carrier board
Kintex Ultrascale 060



ATCA ADLINK aTCA-3150
10G Uplink



WP 5.2, TASK: Precise timing distribution in sub-nanosecond regime

- LVDS links, clock/data phase shift is compensated by delay, automatic tuning in firmware implemented (routing and temperature variation)

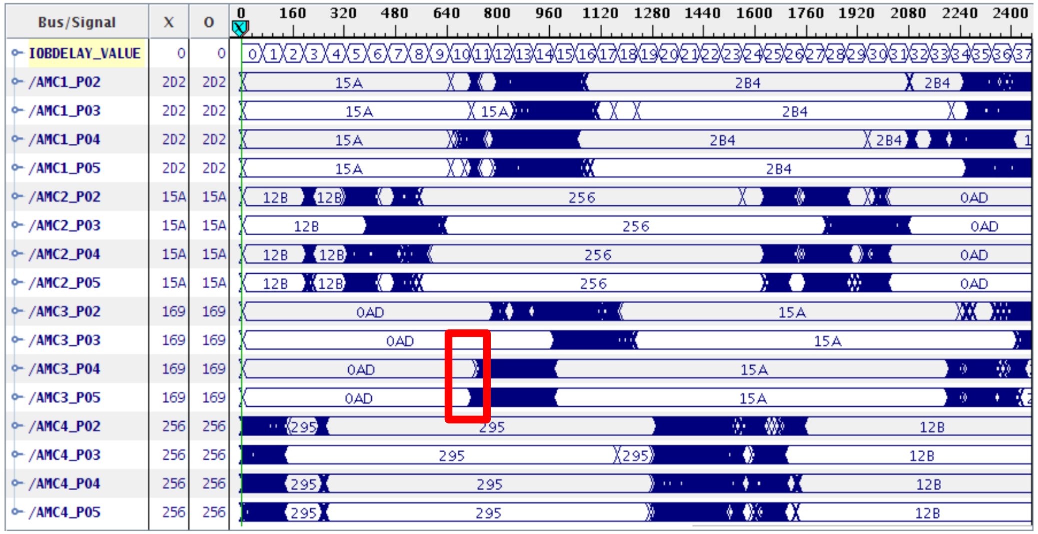
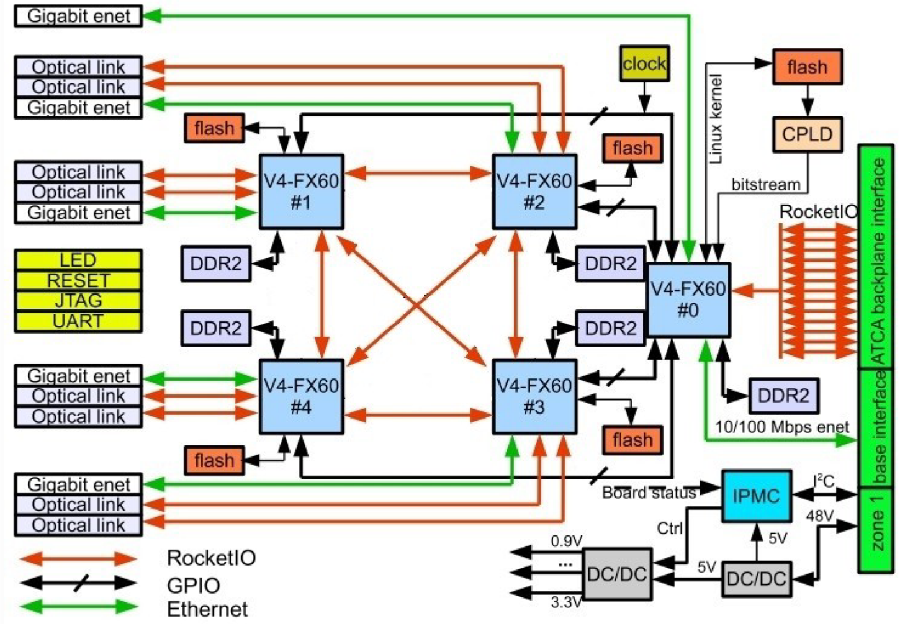
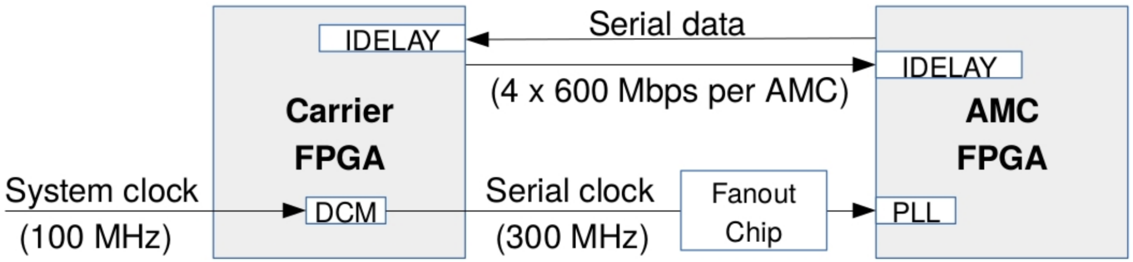


Figure 5.8: Waveforms of the deserialized LVDS data-streams, sent from the four xFP FPGAs to the Switch FPGA and sampled with varying input-delay values. The first row shows the current delay-tap value. Other rows show multiple data words, sampled at each delay value, for the four LVDS links from each xFP. For each link, valid-data windows with stable reception can be clearly discerned from the invalid phases. (Created with Xilinx Chipscope)



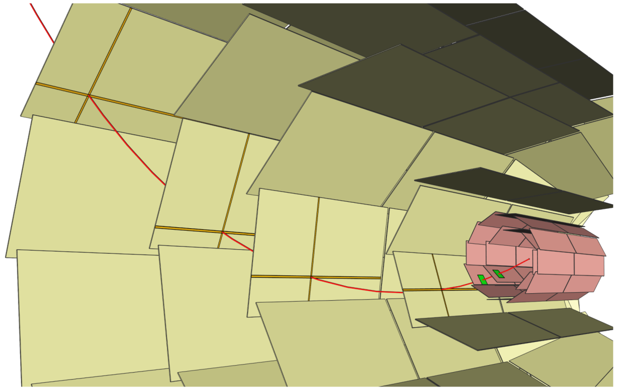


ONSEN xTCA carrier card
v3.3 (final)
Virtex-4 FX60 (switcher to ATCA backplane)
GbE
add-on: RTM board power supply board

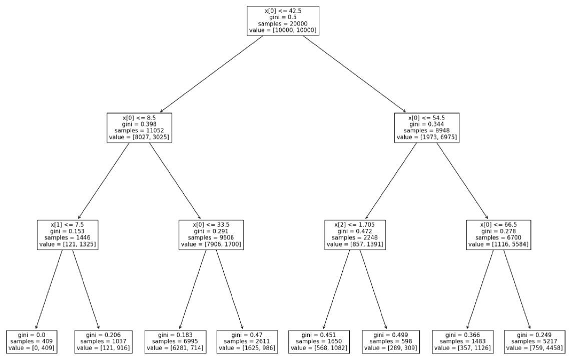
Thomas Geßler, secondments in Jennifer 1, now integral part of PXD operation

WP 5.2, TASK: Novel programming and DAQ software techniques

- **Parallelisation on FPGAs**
  Region-of-interest selection (ROI), parallised up to 32 ROIs per FPGA module,
  compared to emulator, factor ≤355 faster than single core PC (Intel i7, 3.4 Ghz)
  Simon Reiter (Giessen), recent secondment in 02/2025



- **Methods of artificial intelligence for trigger decisions**
  “rescue pixels” of e.g. slow pions, which are otherwise deleted online by ROI selection (HLT “anti-trigger”)
  - significant progress during Jennifer2
  - ~10 algorithms tested and compared,
    winner fixed: decision tree (only requires if-statements on FPGA, no matrix multiplication)
  - offline implementation in basf2
    (multi-step processing logic)
  - achieved efficiency ~80%, purity ~80% (vs. QED background)
  - work still ongoing: beam background generates many “fake” ROIs



Johannes Bilk (Giessen), recent secondment in 03/2025

WP 5.2 DELIVERABLE
Realtime Workshop

- April 8–11, 2024
- Hybrid mode:
  - 48 registered participants, about 20 at Giessen campus
  - Remote talks from Japan, Switzerland, US, UK

https://indico.belle2.org/event/10782/

Workshop // on // Fast Realtime Systems // and // Realtime Machine Learning

8–11 Apr 2024
Heinrich-Buff-Ring 58
Europe/Berlin timezone

Enter your search term

- Overview
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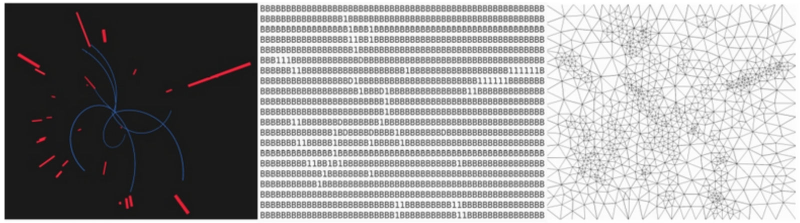
- Timetable
- Contribution List
- My Conference
  - My Contributions
- Registration
- Participant List
- Confirmed speakers and/or participants
- Travel
- Accomodation and Lunch
- Map (from Giessen train station to Campus)



https://display.belle2.org/ https://asciiart.club/ http://mfviz.com/triangulate/

Jennifer2 Workshop on fast Realtime DAQ and Trigger Systems

(April 8 and 9, 2024)

This part of the workshop is supported by JENNIFER2, the evolution of the former JENNIFER project (Japan and Europe Network for Neutrino and Intensity Frontier Experimental Research), funded under the Horizon2020 program of the European Uniion as a Marie Slodowska Curie Action in the RISE program under grant n.822070. For further information see http://www.jennifer2-project.eu .

Workshop on Realtime Machine Learning

(April 10 and 11, 2024)

This part of the workshop is supported by DIG-UM (Digital Transformation in the Research of Universe and Matter) and the ErUM-Data-Hub. For further information see https://erumdatahub.de/en/dig-um/.

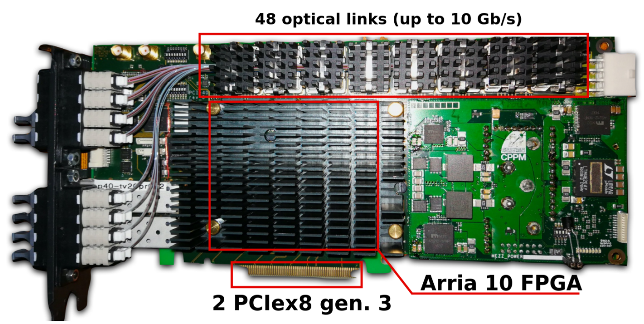
The workshop with both parts will be organized in hybrid format. Participation on-site and participation remote by video will be available. However, we encourage participants to consider to come to Giessen and a number of key speakers already confirmed attendance in person.

We are aiming in enlarging the network of collaboration and the interdisciplinarity of the field. We therefore especially invite people from other ErUM communities to join the workshop. While a number of key presentations will cover approaches and results from particle, hadron and nuclear physics, we explicitely welcome contributions from method scientists as well as adjacent scientific fields.

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
JENNIFER2 EU grant n.822070
ERUM DATA HUB
Bundesministerium für Bildung und Forschung

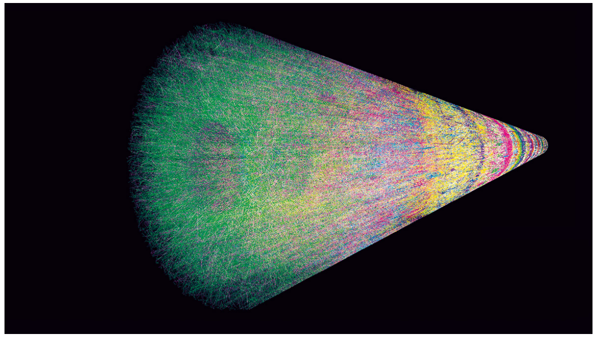
Realtime Workshop 8.–11.04.2024 (Jennifer2 WP 5.2 Deliverable)

PCIe40 Hardware

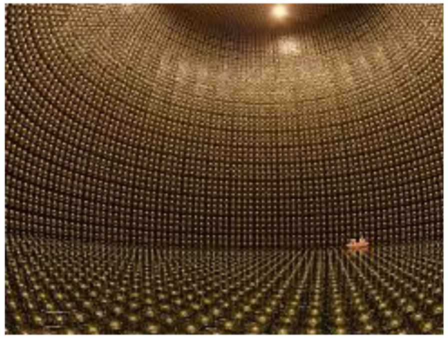


See detailed report
by Dmytro Meleshko (Giessen)
at Jennifer2 Project General Meeting
June 2, 2024 @ KEK

[click here for pdf]



Continous data stream
of overlapping events
in ALICE TPC (50 kHz Pb + Pb)

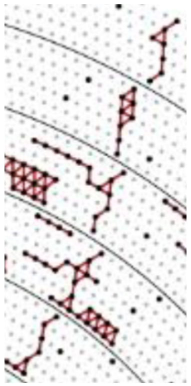


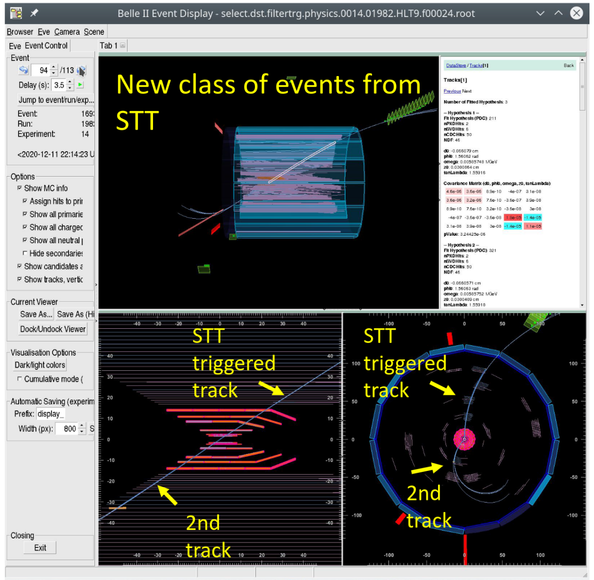
Super-k (~20,000 pmts)

TOPICS:

- **Belle II and Neutrino DAQ Systems**
- **Untriggered readout systems (up to Tbytes/s),**
- **FPGA systems (TDC, ADC, new platforms e.g. PCIe40, new system-on-a-chip architectures, earthquake detection)**
- **Neural Networks on trigger level (latency down to 10 ns)**

Graph Neural Network
for track finding

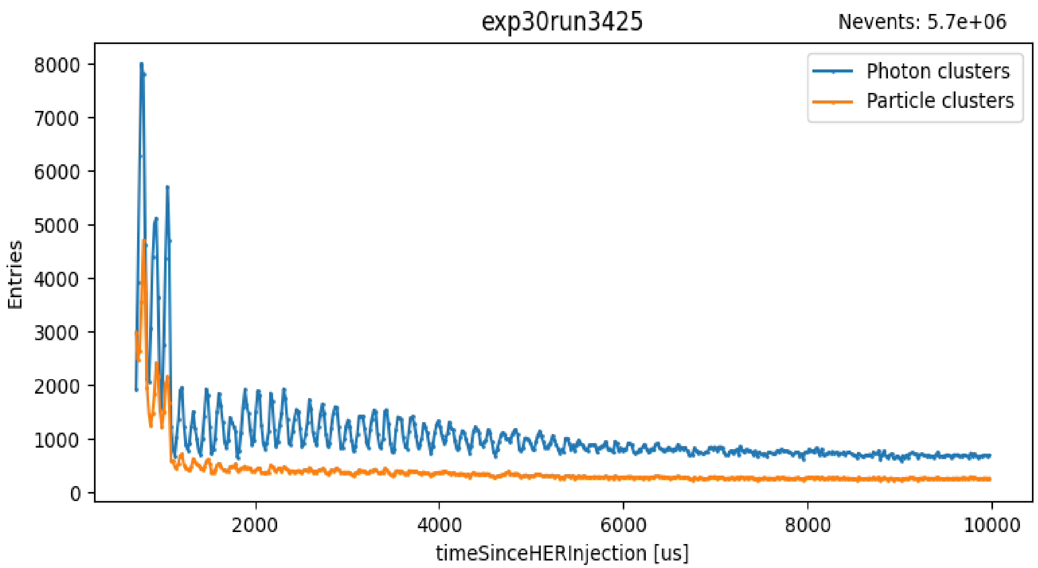


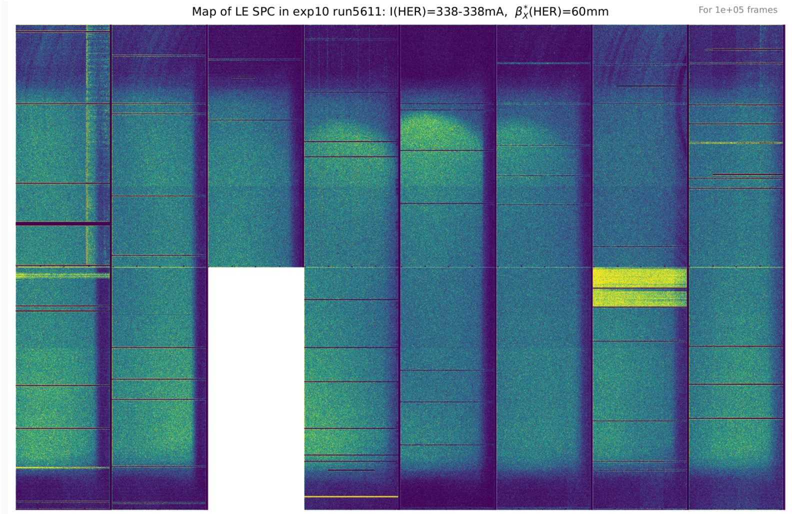


NEW 2024: Online monitor synchrotron radiation (SR) @ Belle II PXD

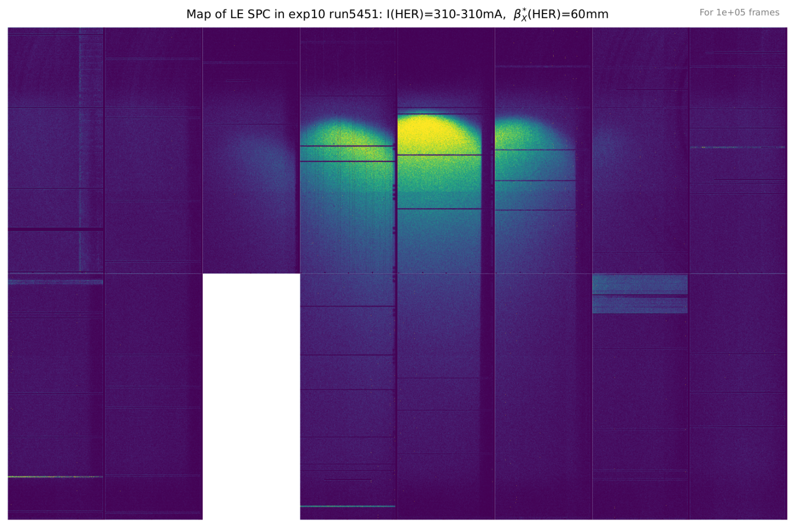
- Reminder: SR killed the first Belle SVD in 1999

  (radiated from a dipole magnet ~35 m from the experiment)
- PXD monitoring required, photon counting areas updated from run I to run II
- 7 kHz betatron oscillation visible @ injection





Note: This is the first run after the change of the beam orbit (0.42 mrad rotation and vertical adjustment).



Note: This is the first, at least 10 min long, run after the change of optics (β^*_X(HER) = 80 → 60mm) with all subdetectors included.

Dmytro Meleshko (Giessen), recent secondment in 03/2025

New 2025: Decision tree on a ZYNQ7 FPGA

Testergebnis jupyter notebook

jupyter Untitled Last Checkpoint: 23.10.2022 (unsaved changes) Logout

File Edit View Insert Cell Kernel Widgets Help Trusted Python 3 (ipykernel)

Run Code Voilà

```
In [1]: from pynq import Overlay

In [2]: overlay = Overlay("../array_adder_22/design_1.bit")

In [3]: overlay?

In [4]: dma = overlay.axi_dma_0
        dma_send = overlay.axi_dma_0.sendchannel
        dma_recv = overlay.axi_dma_0.recvchannel
        hls_ip = overlay.askDecisionTree_0

In [5]: CONTROL_REGISTER = 0x0
        hls_ip.write(CONTROL_REGISTER, 0x81) # 0x81 will set bit 0"

In [6]: from pynq import allocate
        import numpy as np

In [7]: data_size_input = 24
        # Eingabepuffer mit float-Datentyp erstellen
        input_buffer = allocate(shape=(data_size_input,), dtype=np.float32)

        a1 = np.float32([
        6.4, 1.2, 20.1,
        7.2, 8.0, 90.45,
        20.7, 123.0, 567.5,
        40.8, 5678.34, 3421.10,
        50.1, 1700.0, 800.0,
        52.7, 50.0, 1750.0,
        60.75, 30.0, 40.0,
        70.80, 134.0, 170.0])

        np.copyto(input_buffer, a1)
        input_buffer

Out[7]: PynqBuffer([6.40000e+00, 1.20000e+00, 2.01000e+01, 7.20000e+00,
                    8.00000e+00, 9.04500e+01, 2.07000e+01, 1.23000e+02,
                    5.67500e+02, 4.08000e+01, 5.67834e+03, 3.42110e+03,
                    5.01000e+01, 1.70000e+03, 8.00000e+02, 5.27000e+01,
                    5.00000e+01, 1.75000e+03, 6.07500e+01, 3.00000e+01,
                    4.00000e+01, 7.08000e+01, 1.34000e+02, 1.70000e+02],
                   dtype=float32)

In [8]: hls_ip.register_map

Out[8]: RegisterMap {
          CTRL = Register(AP_START=1, AP_DONE=0, AP_IDLE=0, AP_READY=0, RESERVED_1=0, AUTO_RESTART=1, RESERVED_2=0, INTERRUPT=0, RESERV
        ED_3=0),
          GIER = Register(Enable=0, RESERVED=0),
          IP_IER = Register(CHAN0_INT_EN=0, CHAN1_INT_EN=0, RESERVED_0=0),
          IP_ISR = Register(CHAN0_INT_ST=0, CHAN1_INT_ST=0, RESERVED_0=0)
        }

In [9]: dma_send.transfer(input_buffer)
        dma_send.wait()

In [10]: output_buffer = allocate(shape=(data_size_input,), dtype=np.float32)

In [11]: dma_recv.transfer(output_buffer)
         dma_recv.wait()

In [12]: # Ergebnisse anzeigen\n",
         print("Ausgabe als float:")
         for i in range(data_size_input):
             print(output_buffer[i])

         Ausgabe als float:
         1.0
         1.0
         0.0
         0.0
         1.0
         1.0
         1.0
         1.0
         0.0
         0.0
         0.0
         0.0
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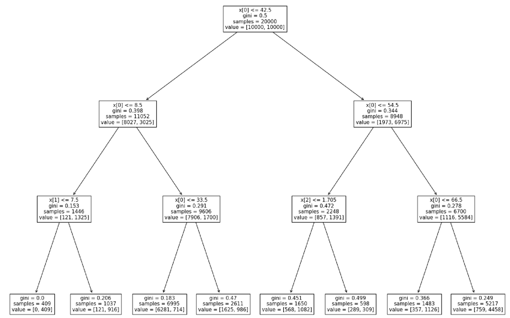


```
In [13]: del input_buffer, output_buffer
```

– Decision tree, executed on FPGA from Jupyter notebook
– Floating point processing (!)
– DMA (block data transfer)

Aaron Pieper, Nele Becker, Peter Lehnhard (Giessen)

Summary

- Successful Belle II PXD DAQ operation in Run I (400+ Million events recorded), thanks to support by Jennifer2
- FPGA-based readout, ATCA (Advanced Telecommunications Architecture), high speed links (16.3 Gbps optical, 10G), sub–nanosecond delays, parallelised by factor 32 (speedup factor 355 compared to PC)
- Machine learning (ML) algorithms for slow pions, 80% efficiency and 80% purity achieved, to be continued in Jennifer3 with more collaborators and many new tasks

THANK YOU

FOR YOUR ATTENTION