Detector Electronics at ESS for Neutron Scattering

RD51 Mini-Week WG 5 Meeting

February 15th 2021

Dorothea Pfeiffer (ESS/Milano-Bicocca/CERN)

Steven Alcock (ESS)

Richard Hall-Wilton (ESS/Milano-Bicocca)

Neutrons as a probe

More info: https://indico.cern.ch/event/979864/

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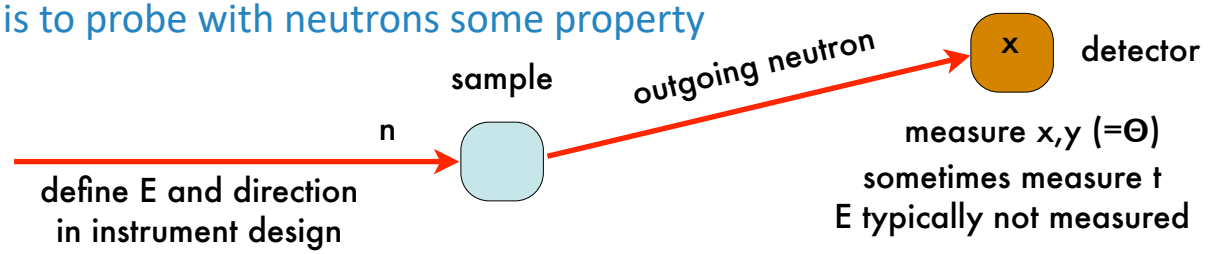
- The purpose of the instruments is to probe with neutrons some property of a sample

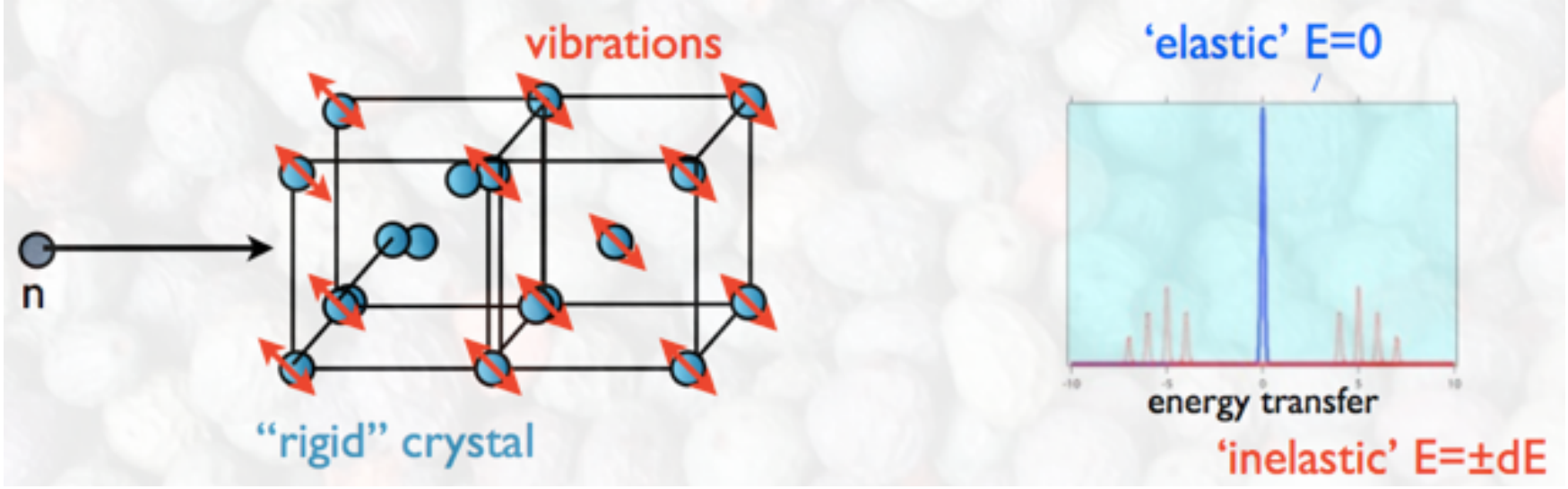


- Very generically, this can be divided into elastic and inelastic categories
  - elastic: gives information on where atoms are
  - inelastic: gives information on what atoms do (i.e., move)

elastic $\frac{d\sigma}{d\Omega}(\lambda, 2\theta, \psi)$

inelastic $\frac{d^2\sigma}{d\Omega dE}(\lambda_{in}, \lambda_{sc}, 2\theta, \psi)$

Elastic vs Inelastic



NSS Project scope: *15 neutron instruments + test beamline + support labs*

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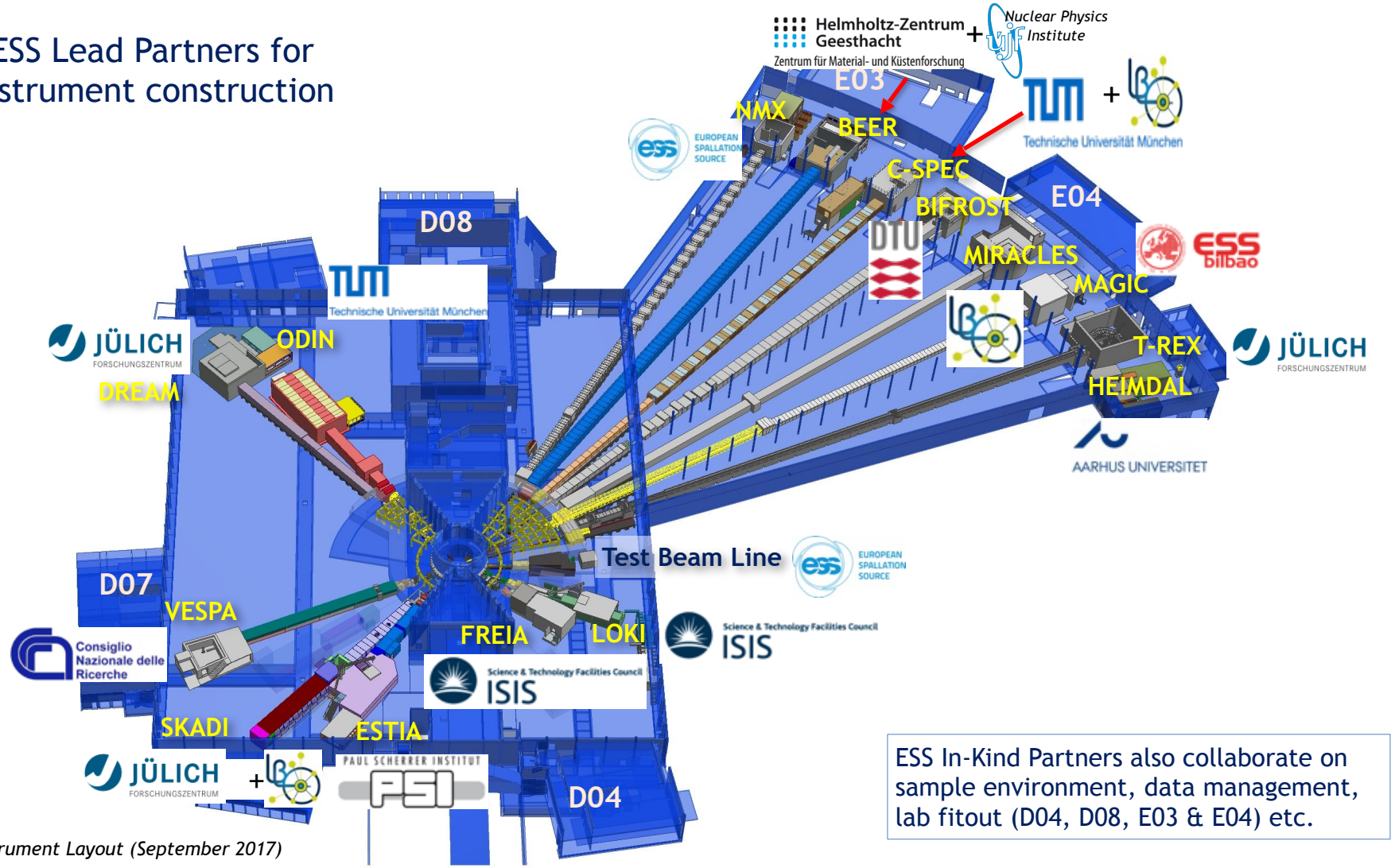
ESS Lead Partners for instrument construction



ESS Instrument Layout (September 2017)

ESS In-Kind Partners also collaborate on sample environment, data management, lab fitout (D04, D08, E03 & E04) etc.

Time plan

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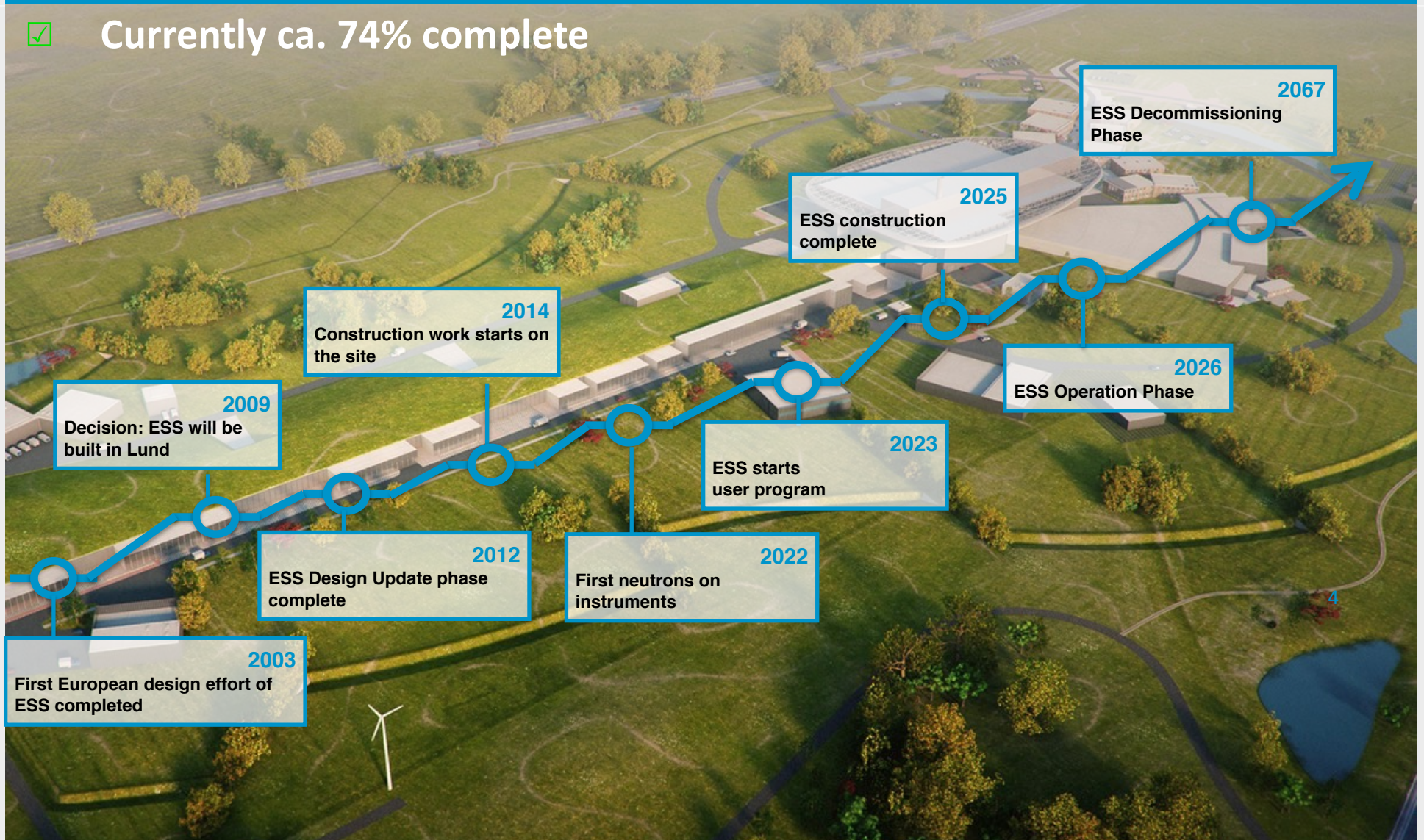
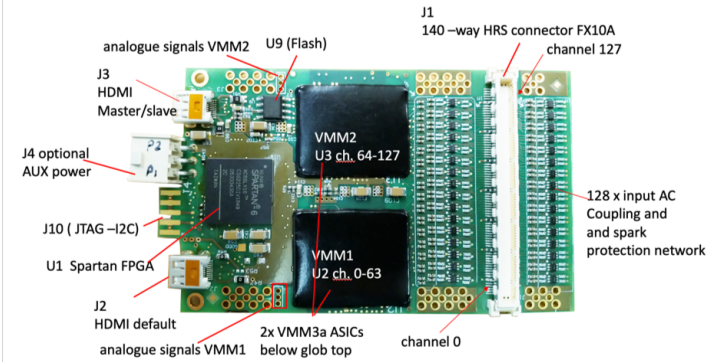
☑ Currently ca. 74% complete



Front End Electronics: VMM3A ASIC

- VMM3a is the 4th version of an ASIC developed by Brookhaven National lab for the ATLAS New Small Wheel upgrade at CERN
- ASIC developed to read out Micro Pattern Gaseous detectors (MPGD)
- ASIC is high rate, sub-ns time resolution

- RD51 VMM3A hybrid common ESS-CERN project: successful integration of the VMM3a ASIC into the CERN Scalable Readout System (SRS) during BrightnESS
- 7.3 Mhits/s per VMM3a ASIC
- Per single VMM3a channel 4 Mhits/s
- Works well also for wire-based gaseous detectors

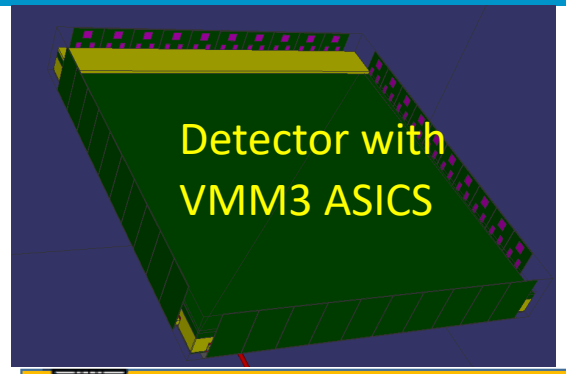


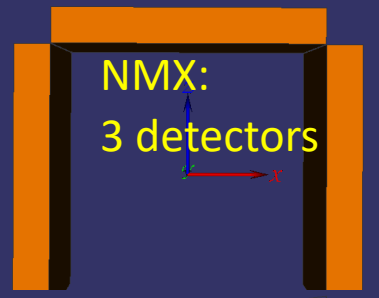
- First 57 available now
- 75% yield of highest quality hybrids

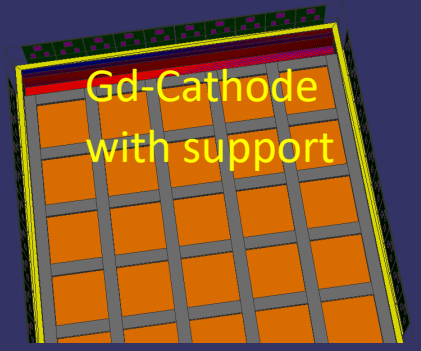
- Use initially for 5 instruments + testbeam line

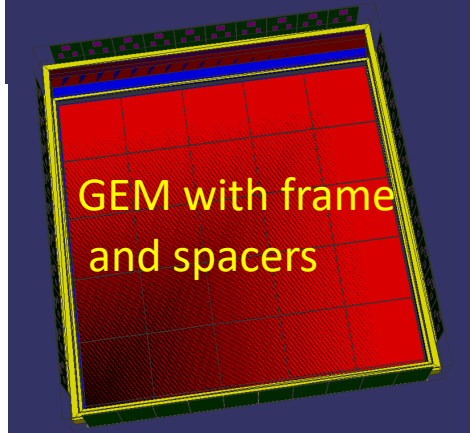
VMM3a
Gd-GEM for NMX

- Detector Demonstrator Zita
- 80 VMM3a per detector (5120 channels per detector)
- 3 detector panels

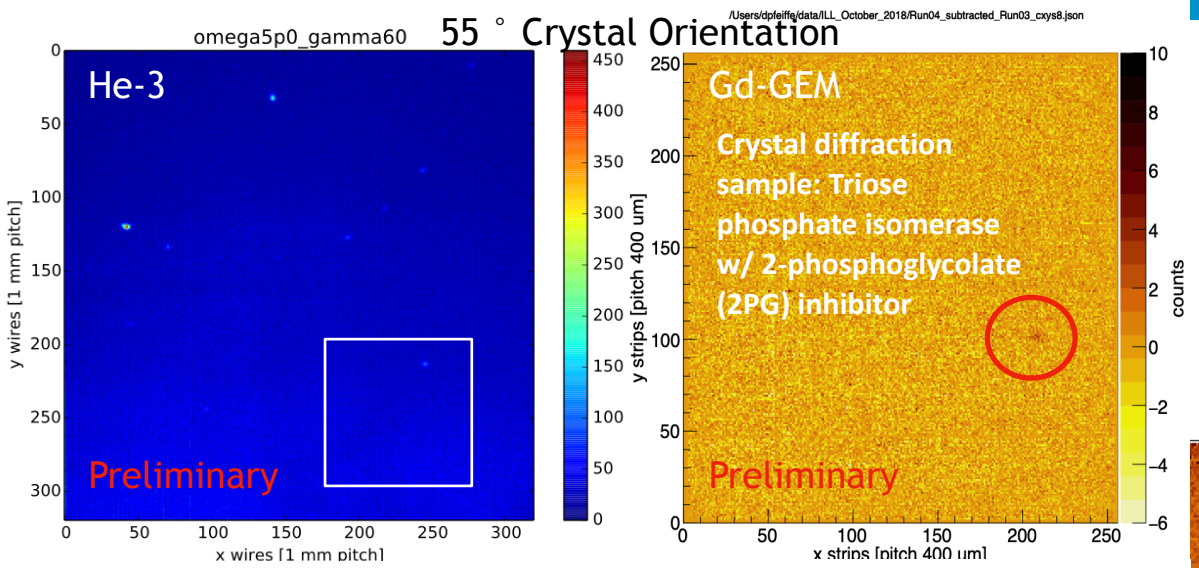


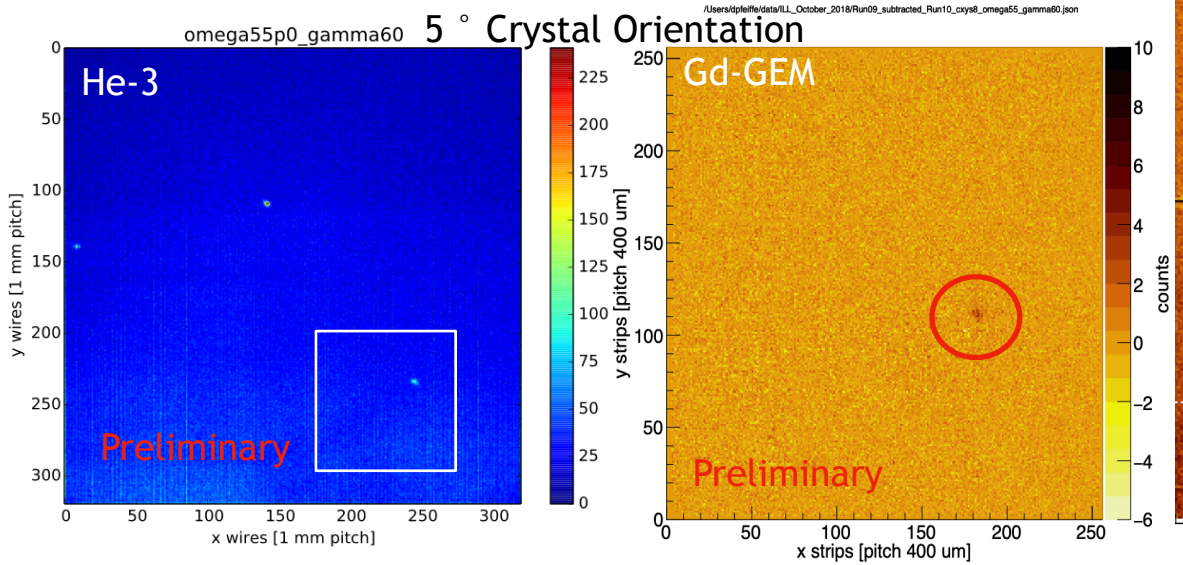






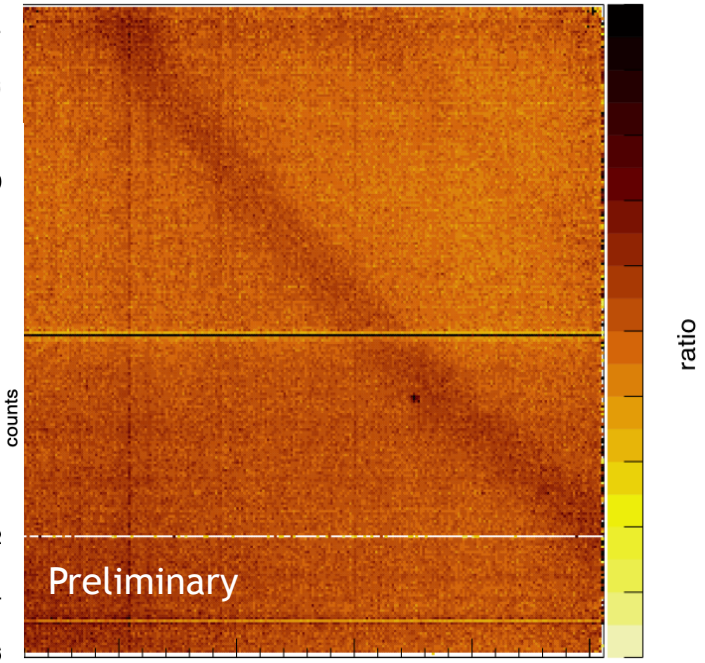
Gd-GEM Detector Demonstrator





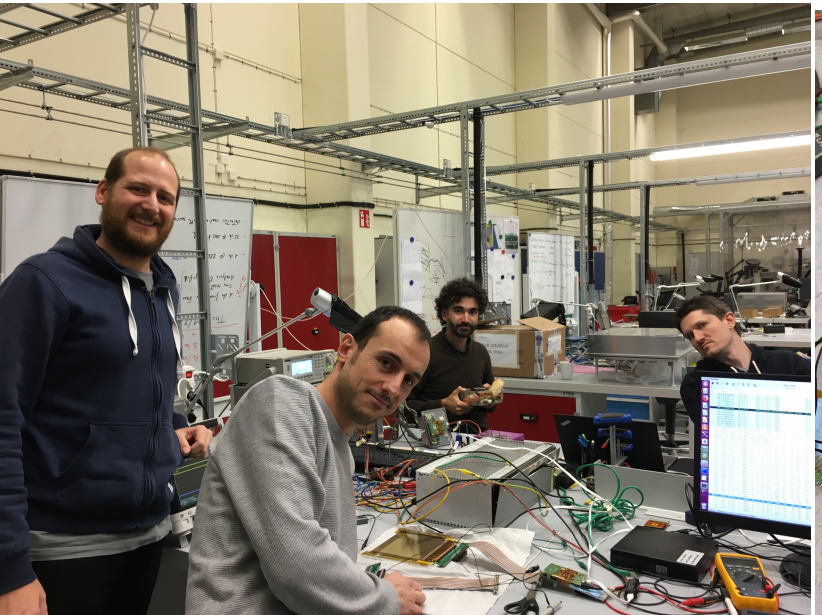
Detector and VMM3a performance sufficient to resolve weak reflections

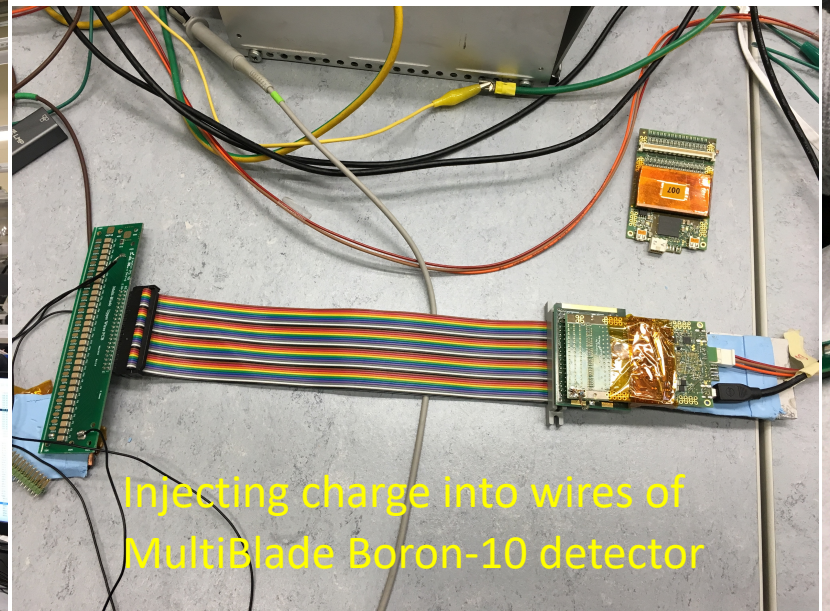
Powder diffraction with YIG powder in container

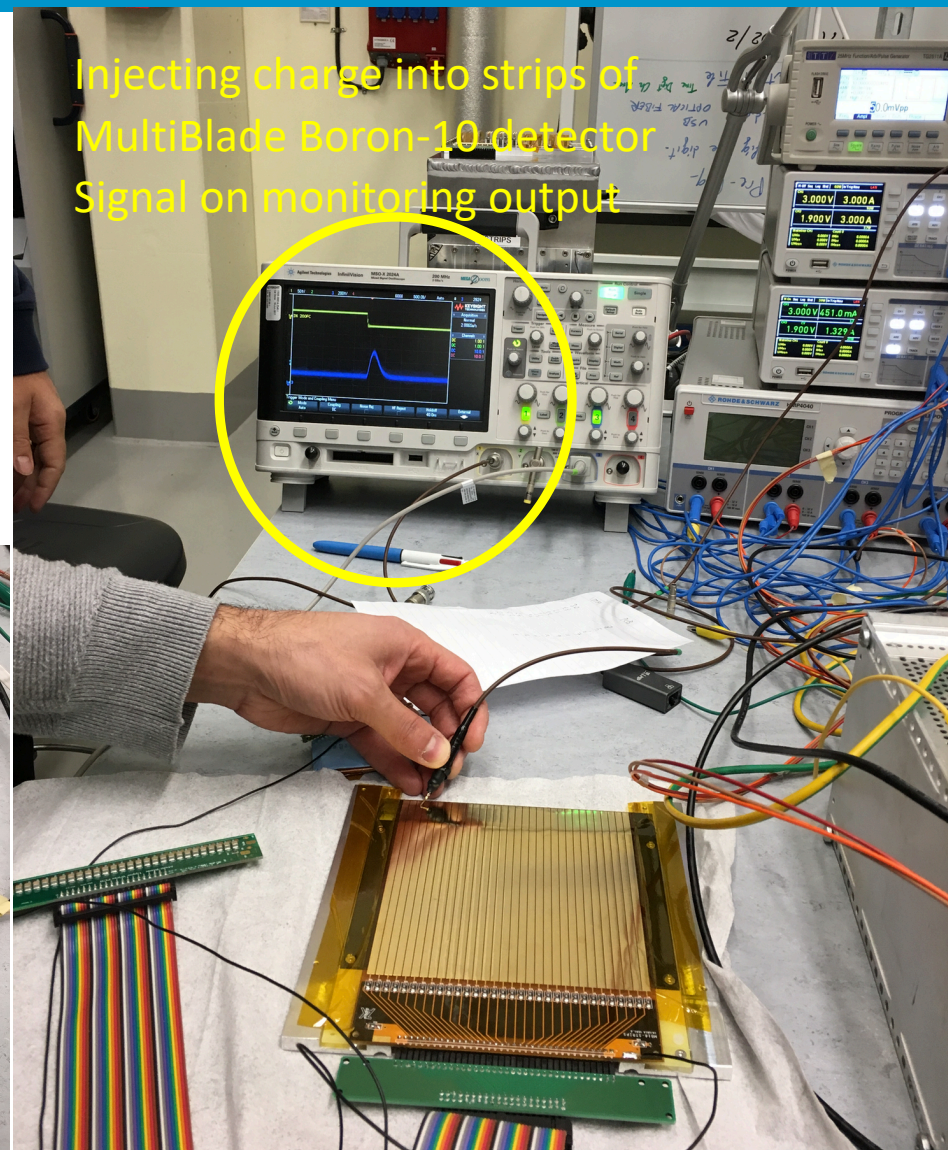


VMM3a
Multiblade test at Utgard December 2018

- Successful test of VMM3a hybrid with MB
- MB: Charge injection into:
  - Wires (negative polarity, AC coupled)
  - strips (positive polarity, DC coupled)
- Successfully read out with VMM3a via analog monitoring output and digital data in continuous mode
- Gain 1 mV/fC , 200 ns shaping time

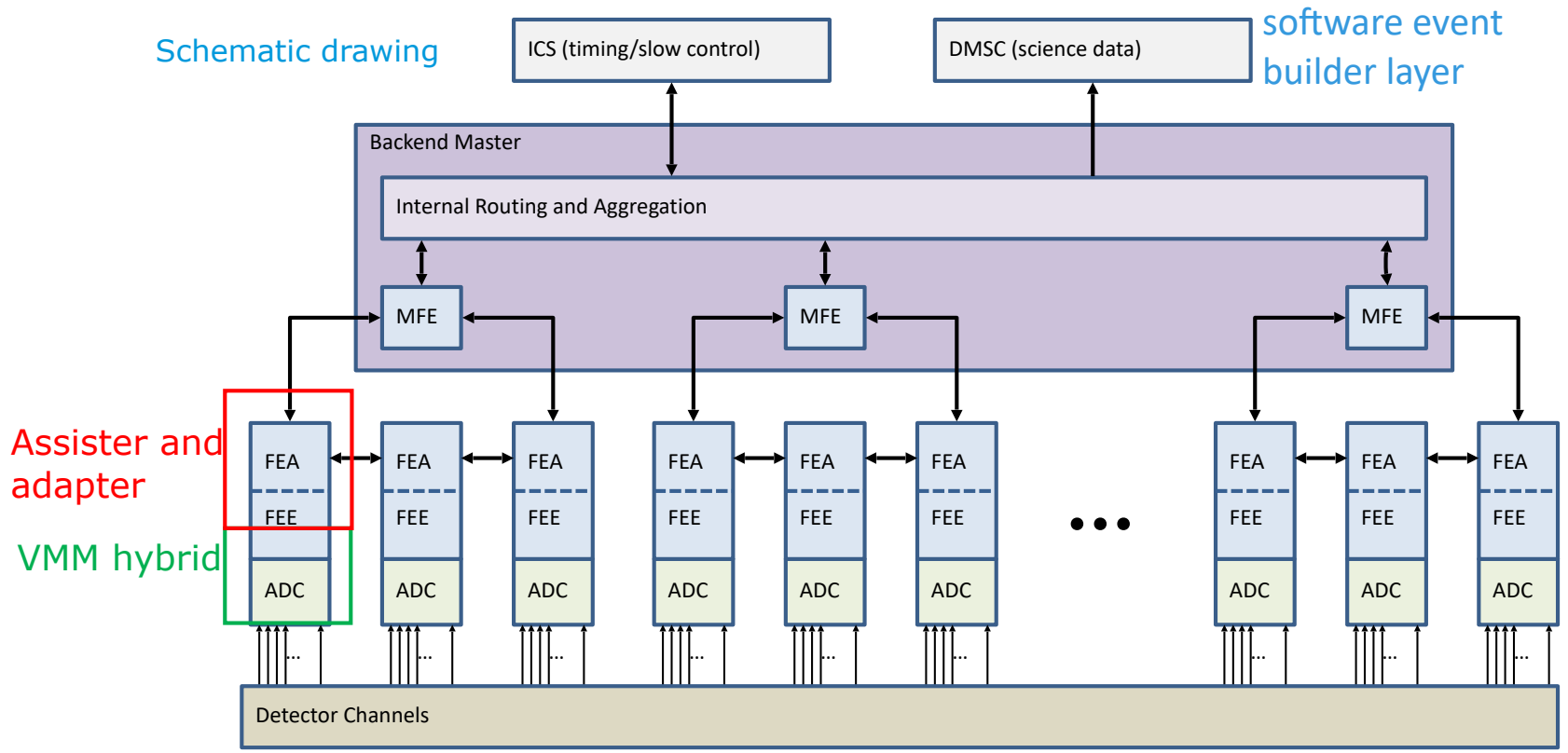






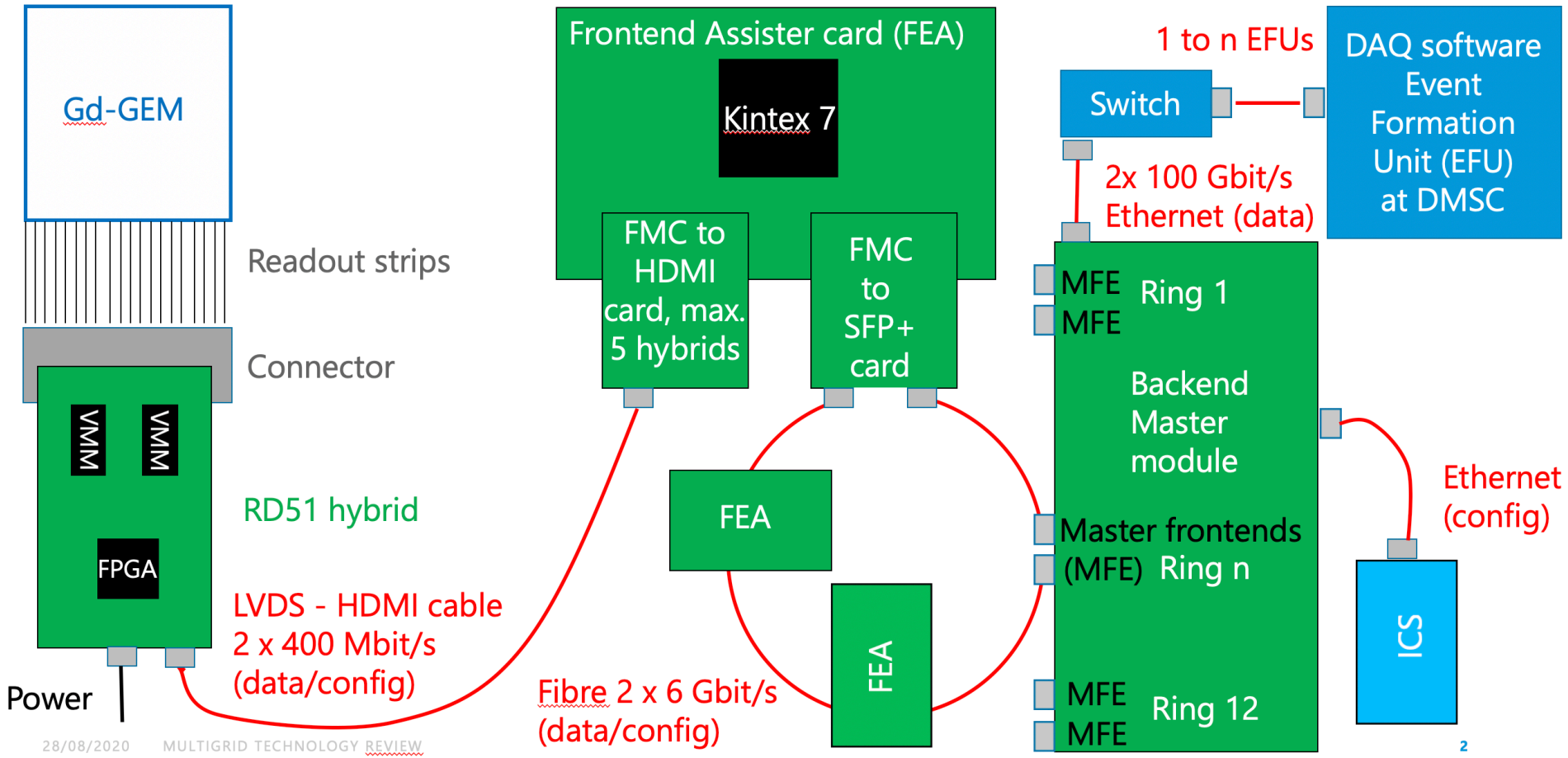
Detector Electronics

- Typical neutron instrument today maximum 100s of electronics channels
- Instruments at ESS > 10k electronics channels



Readout Architecture is described in BrightnESS Deliverable D4.1:
https://dx.doi.org/10.17199/BRIGHTNESS.D4.1

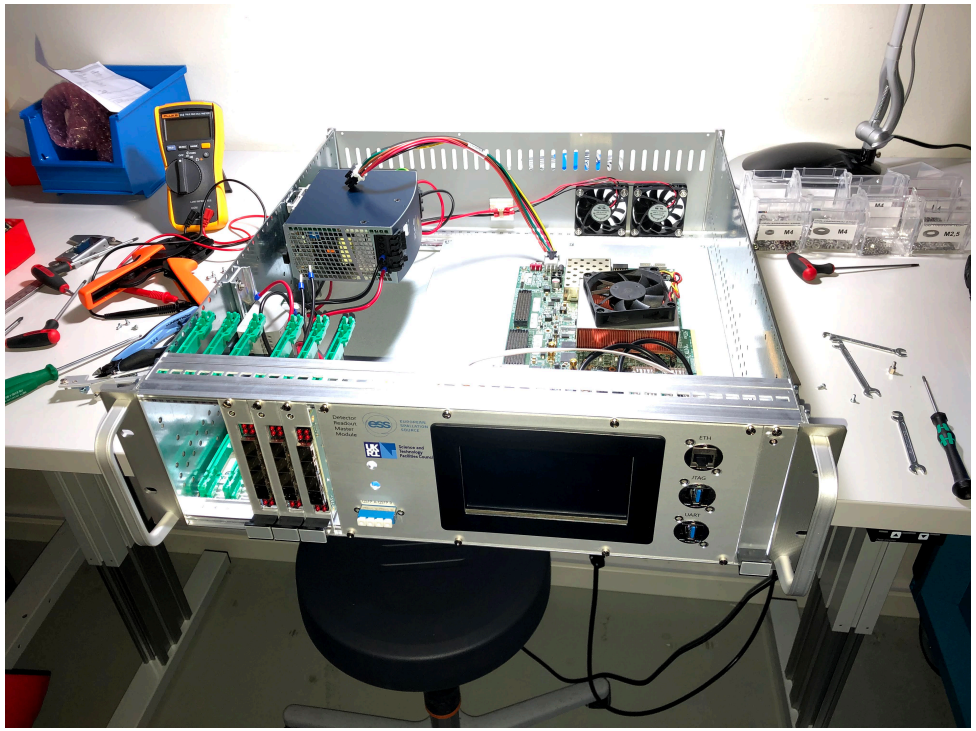
Readout chain NMX

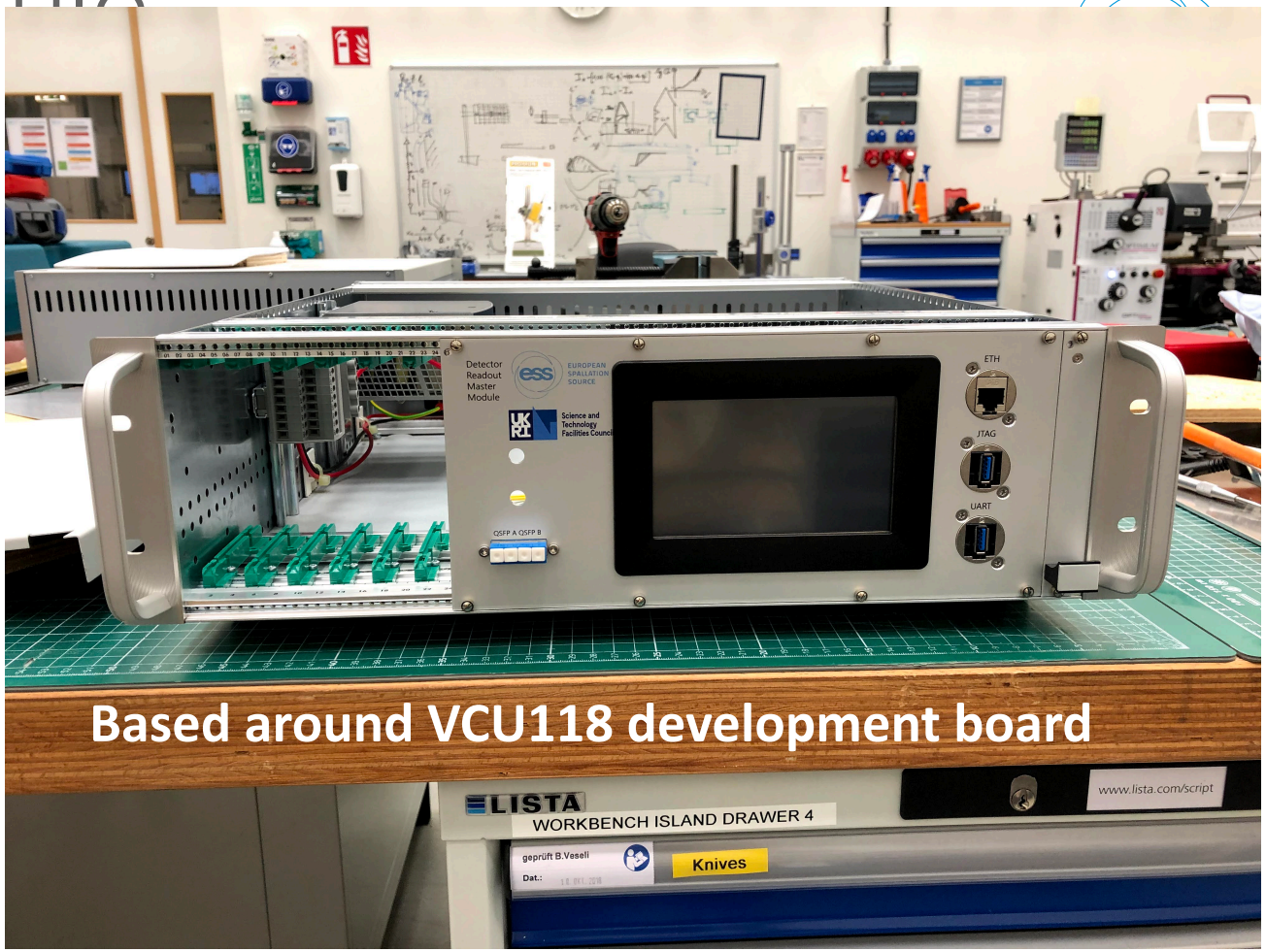


Hardware: Master Module

Back end electronics (ESS/STFC)

Final Back End Electronics crates being assembled - 5(+1) Master Module readout crates as prototypes for real items



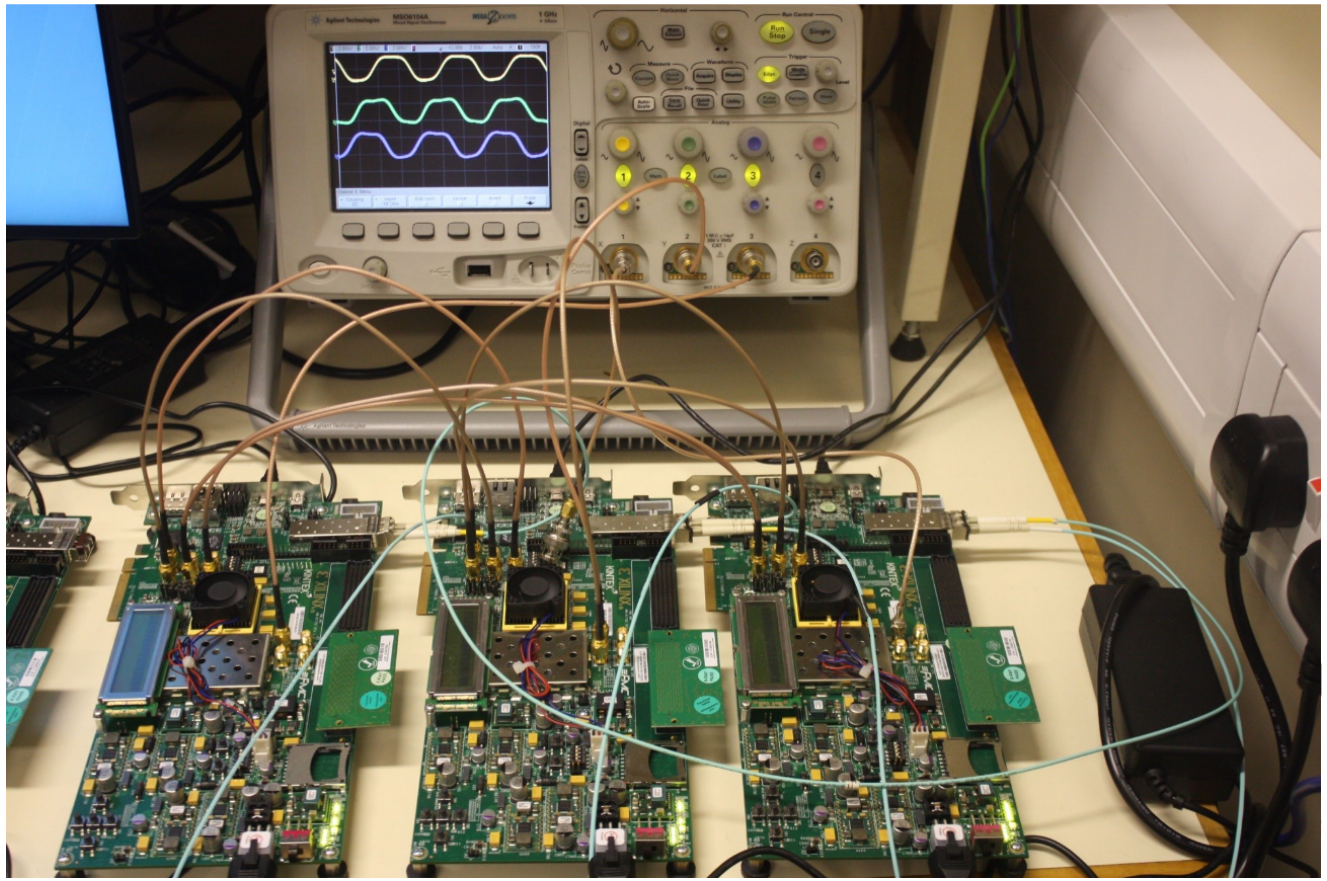


Based around VCU118 development board

Next:
Integration of front end electronics for instruments
Stress testing for 3-4 months
Production for instruments by end 2021

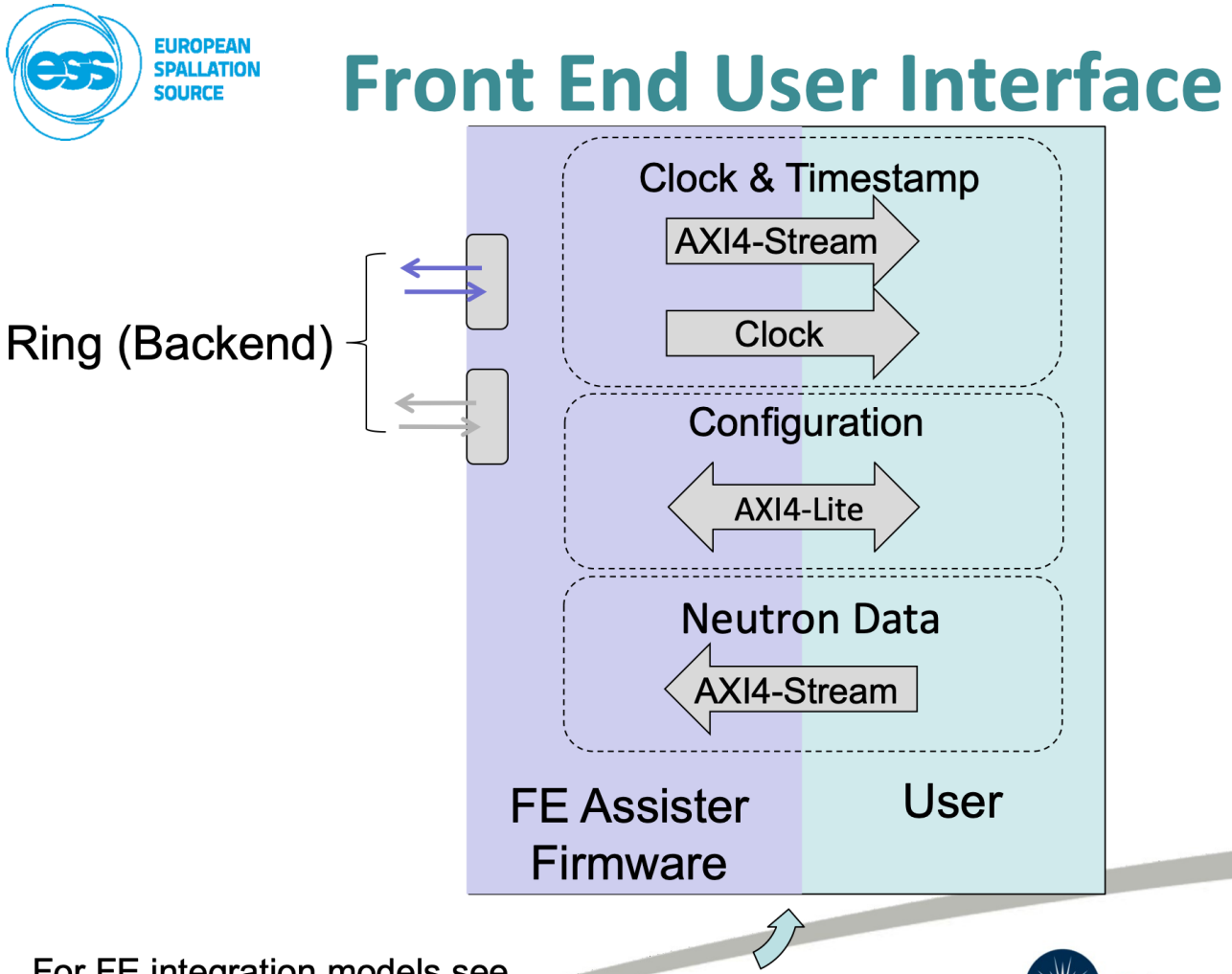
Timing distribution in rings

- Front ends (FEA/FEE) connected to Master (MFE) via 8b/10b encoded SFP+ links.
- ESS clock used to generate these links – can be recovered and forwarded by each front end (similar concept to Synchronous Ethernet).
- The ESS timestamp can therefore be forwarded to all the front ends, forming a single distributed synchronous system.



FE user interface

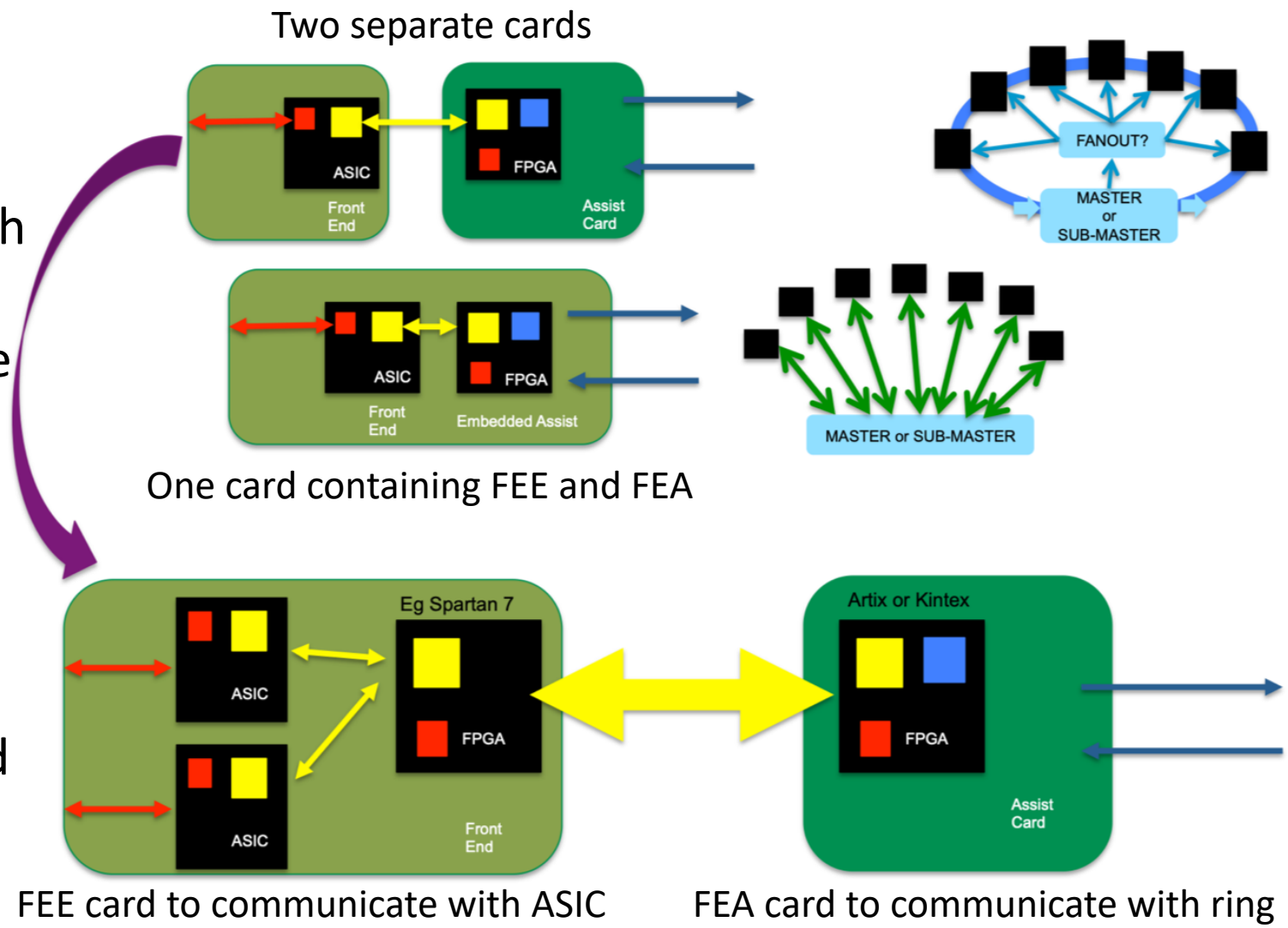
- FEA (front end assister) firmware communicates with the ring/backend
- FEE (front end user firmware) communicates with frontend ASIC like VMM3a or ADC
- FEA and FEE part of firmware communicate via AXI4 streams



For FE integration models see BrightnESS Deliverable Report: D4.1 – *Integration Plan for Detector Readout*. Scott Kolva et.al. 2017

Frontend (FEE) and assister (FEA): hardware and firmware modules

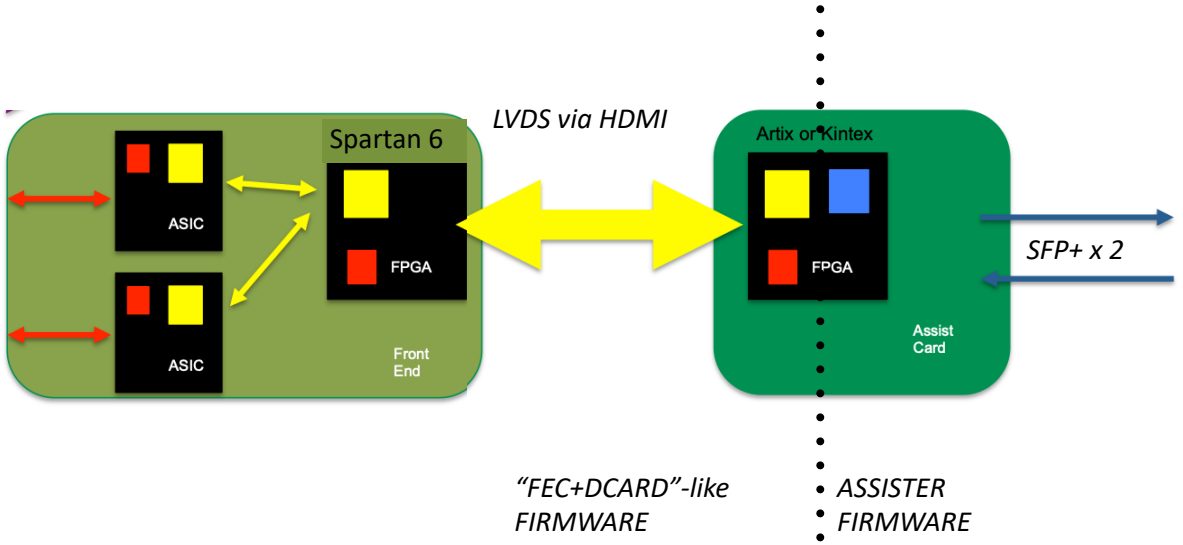
- Frontend FEE with firmware communicating with ASIC
- Frontend assister FEA with firmware to communicate with ring
- Could be in one FPGA and one card, or two FPGAs and two cards
- Advantages for two card solution: RD51 hybrid already exists, form factor of FEE card can stay small, heat dissipated on FEA card away from FEE



Step 1 (existing RD51 hybrid with Spartan6): Improve hybrid firmware, develop assister firmware

Start immediately

- Use existing RD51 VMM3a hybrid with Spartan 6
- RD51 hybrid firmware objectives:
  - Support high rate operations
  - Structure, clean up and document
- Use FPGA development board as assister platform
- Develop firmware for assister Artix7 FPGA



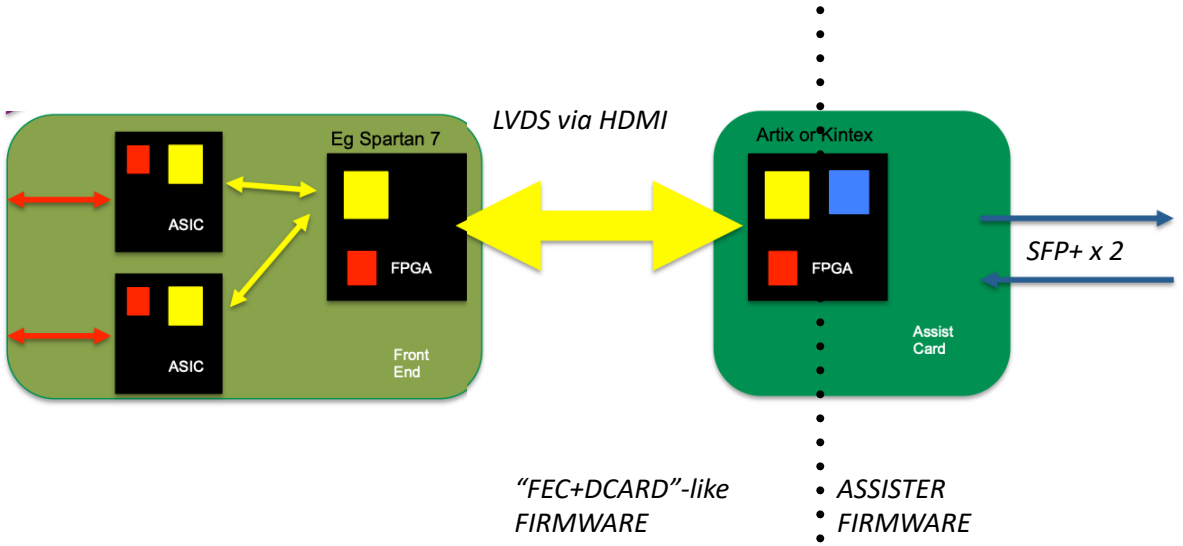
Step 1b (use dedicated assister hardware):

Within the next six months

- Use dedicated assister hardware

But … we probably won't do this at least initially

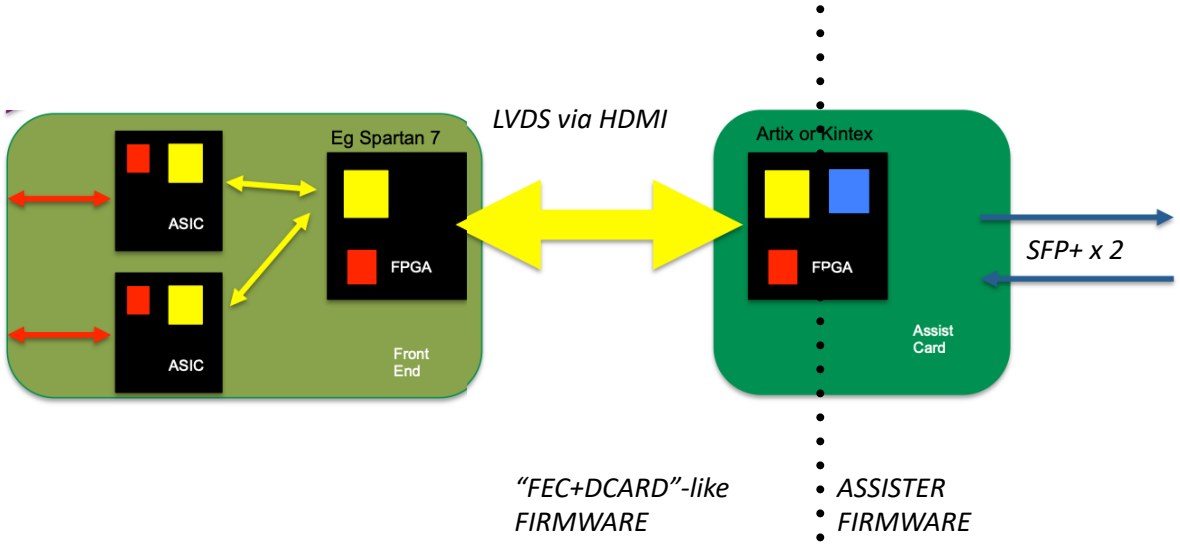
- Happy with KC705 development board as the assister so far …



Step 1c (upgrade RD51 hybrid with Spartan7 or Artix7):

More longterm

- Explore options to upgrade RD51 hybrid to use Series 7 FPGA
- Believe that prototype hybrid design modified by Alex exists
- We are very interested in this for future production
- Port firmware to Series 7 FPGA
- ESS is happy to fund this port / do it ourselves: discussions ongoing



ESS VMM3a status

- Received 46 hybrids from 2020A production run
- Just received 50 hybrids from 2020B production run
- Use outcome to determine yields and quality
- Quality Yield: 70-80% hybrids perfect according to our QA metrics
- Lower quality chips can be used for some purposes.

- 54 hybrids/wafer maximum
- Understand that 50 hybrids/wafer is Hans/Alex's recommendation
- Therefore we have decided that we will count on 32 perfect hybrids/wafer
- We have assumed a 64% yield - and hope to be pleasantly surprised.

- We want to order enough wafers/hybrids that we do not have to come back to top up in coming years.

ESS VMM3a expected numbers

- Known needs today:

Total Requirements:

Instrument	Initial Scope	Full Scope	Future Upgrade	Total (num of hybrids)
ESTIA	48	0	48	**96**
AMOR	6	0	0	**6**
CREMLINPlus	6	0	0	**6**
FREIA	32	0	0	**32**
CSPEC	108	54	48	**210**
TREX	48	72	0	**120**
NMX	120	0	0	**120**
Total	**368**	**126**	**96**	**590**

Wafer Quantites

- We assume that we will need all the existing wafers for R&D and integration activities

- We need ca. 600 perfect quality hybrids.
- Ca. 19 wafers
- **Therefore, we want to order 25 wafers in 2021. i.e. 1 unit of an engineering run.**
- Happy to modify this by a small number to help out RD51, if it helps the order process.

- We would like to make this order ASAP
- Delivery by EoY? **Need to get started ASAP**
- ESS happy to help Hans and RD51 with the technicalities of this order.

- Question: is there likely to a further wafer order in 2022?
- Worry: its really important to get going with this order. Last order took >1year …
- Wafer storage needs thought …

Hybrids

- We are interested in Series 7 hybrids for all our applications so that we are not supporting series 6 and 7 operationally

- We need ca. 600 perfect quality hybrids: That means ca. 1000 hybrids
- We would like to receive these by end 2022 or 2023Q2
- For the first production run of series 7 hybrids, want to order a moderate amount in case of modifications being needed
- Important for us to determine the expected production run schedule
- Indicative, assuming 2 production runs/year:

Production run	2021	2022-A	2022-B	2023-A	Total
Number of hybrids	100	300	300	300	1000

- Worry: again, its really important to get going with this order. Admin, finances, production take some time

Summary

- ESS has established that VMM3a works for wire chambers: VMM3a fulfills requirements for ESS detectors
- Frontend card is the collaboratively developed RD51 hybrid with Integration of RD51 hybrid into ESS readout
- Worry about VMM3a wafer production: need to start now
- Worry about timescale for next hybrid order: need to start now
- Its really important to get both 2021 orders and plan for 2022 production in place.
- Important to start now …
- Needs thought: there maybe more than1 cooling solution needed
- We need to power our hybrids independently to HDMI cable