On the readout of the ePIC MPGD detectors

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Outlook

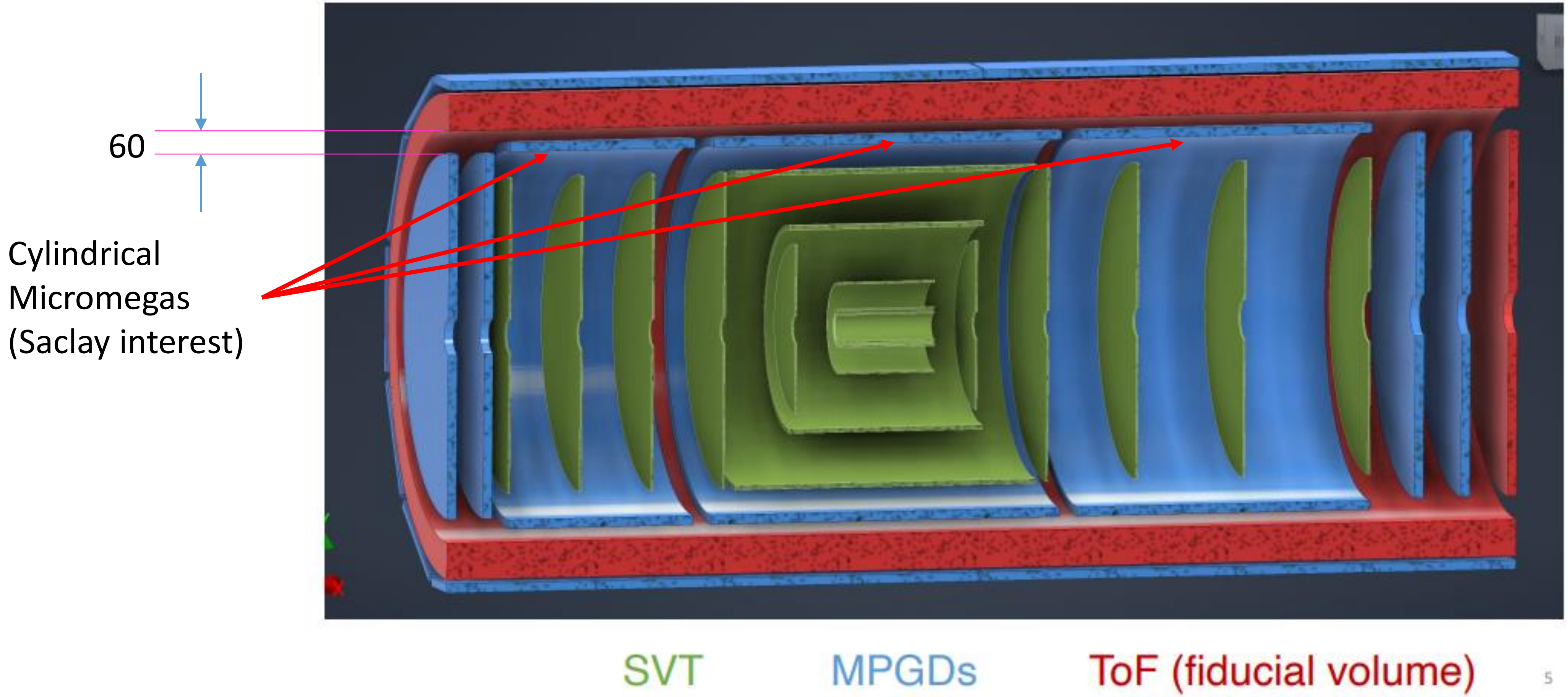
- Preamble
  - → Will need to come out with functional and physical organization
  - → This presentation is oriented towards physical organization
    - Environmental and spatial constraints may require redistribution of functionality among the readout actors

- Reminder of the MPGD environment
- Reminder of the ePIC detector readout organization
- Frontend organization options
  - → 5 options studied for CyMBaL tracker based on system considerations approach
    - Bandwidth and functional considerations
    - Mechanical, radiation, magnetic field and power constraints
  - → Studies applicable to all MPGDs
- Outcome

A CyMBaL tracker reminder to illustrate MPGD environment

Spatial constraints for inner barrel cylindrical tracker

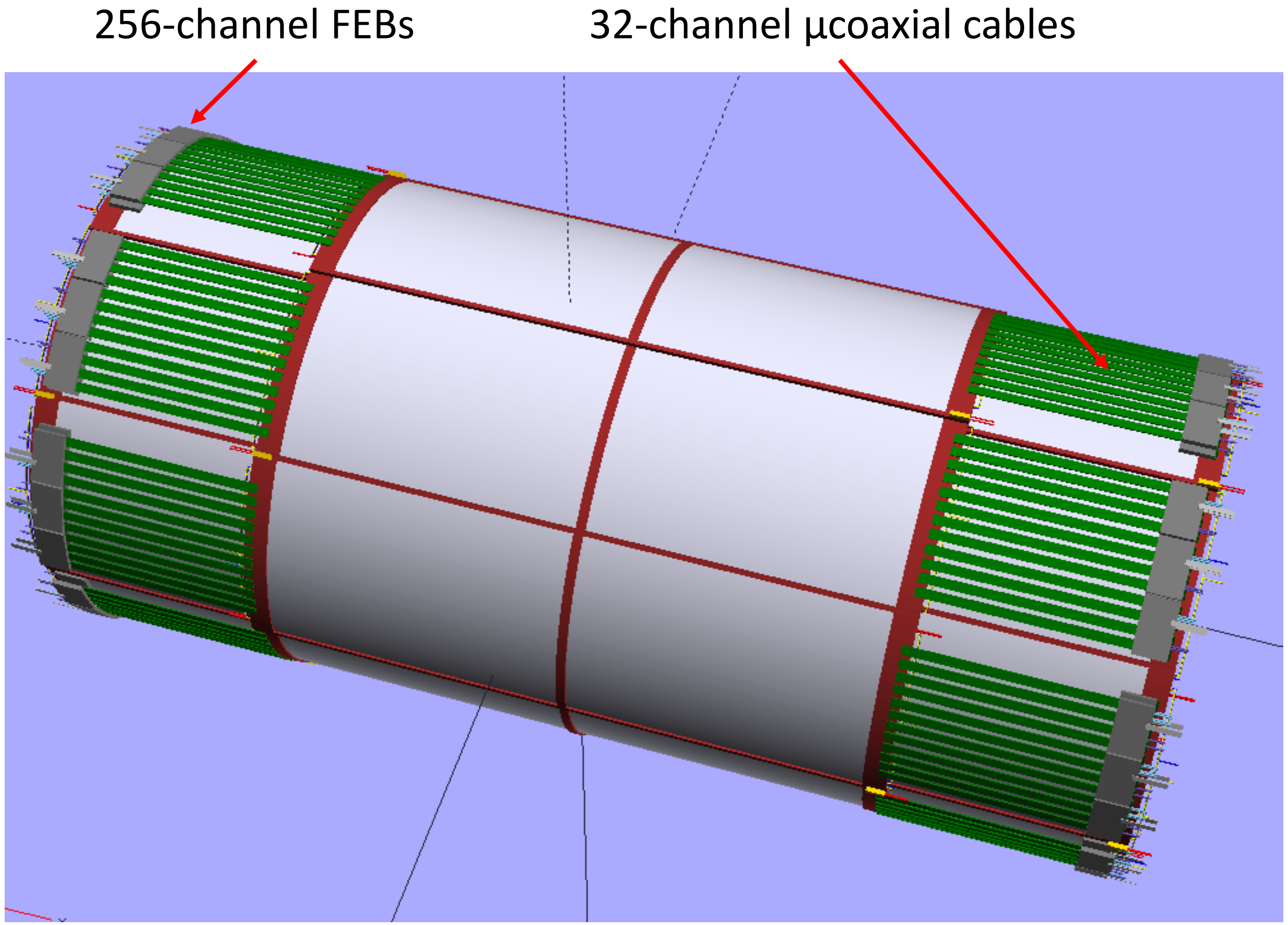
- Space is stringent: 6 cm
  → Detectors, gas pipes, HV cables



- On detector frontend electronics
  → FEBs + LV distribution + RDO interface cabling + cooling

Example of CyMBaL: one of the possible configurations under study

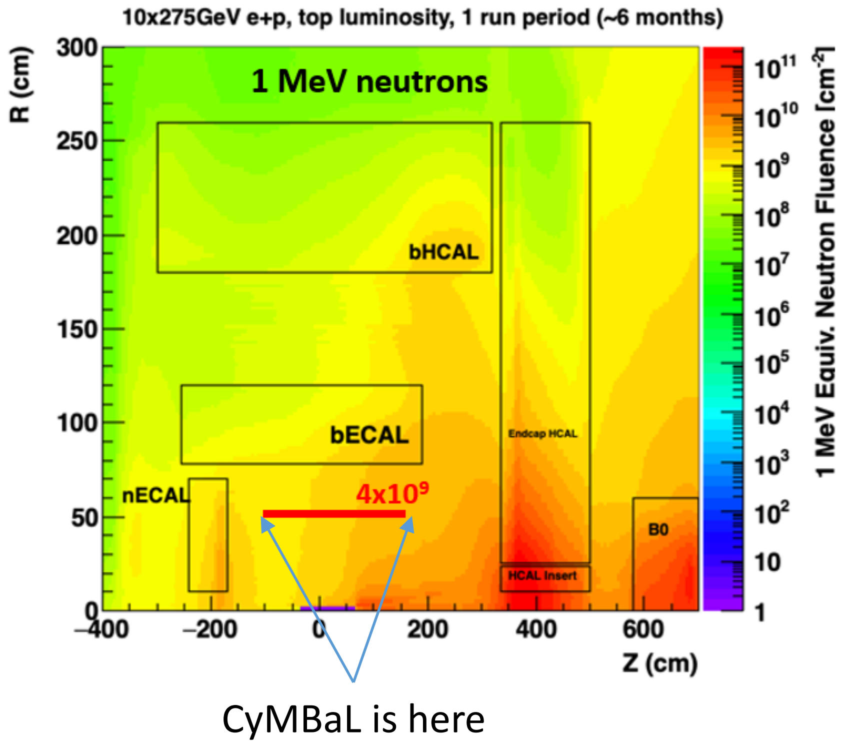
- Still under torment of optimization
  - → Just a snapshot to give an idea
- 32K channels
- 128 256-channel FEBs
  - → Only central detector FEBs visible
    - Peripheral FEBs in a row bellow
    - Or in a second row
- 32 1024-channel RDOs
  - → 4 FEBs per RDO
- Where to place RDOs not really clear
  - → Electrical FEB-RDO interface : 5-6 m
    - 16 on either side of Barrel
  - → Optical FEB-RDO interface : no limit
    - Attractive option



Inner detector fronted environment

- Stringent space
- Restricted material budget including for cooling
- Magnetic field
- Radiation

- Example of CyMBaL tracker environment
  - → TID after 10 years : 10 krad
  - → Neutron fluence after 10 years: 10^{11} n_{eq} / cm^2
  - → 20 MeV proton flux: 100 particle / cm^2 / s
  - → Magnetic field: 1.9 T



- Most probably similar radiation and magnetic field environment for other MPGD detector frontends
- What about the radiation and magnetic field environment of other inner detector frontends ?

Brief recap on EIC ePIC readout organization

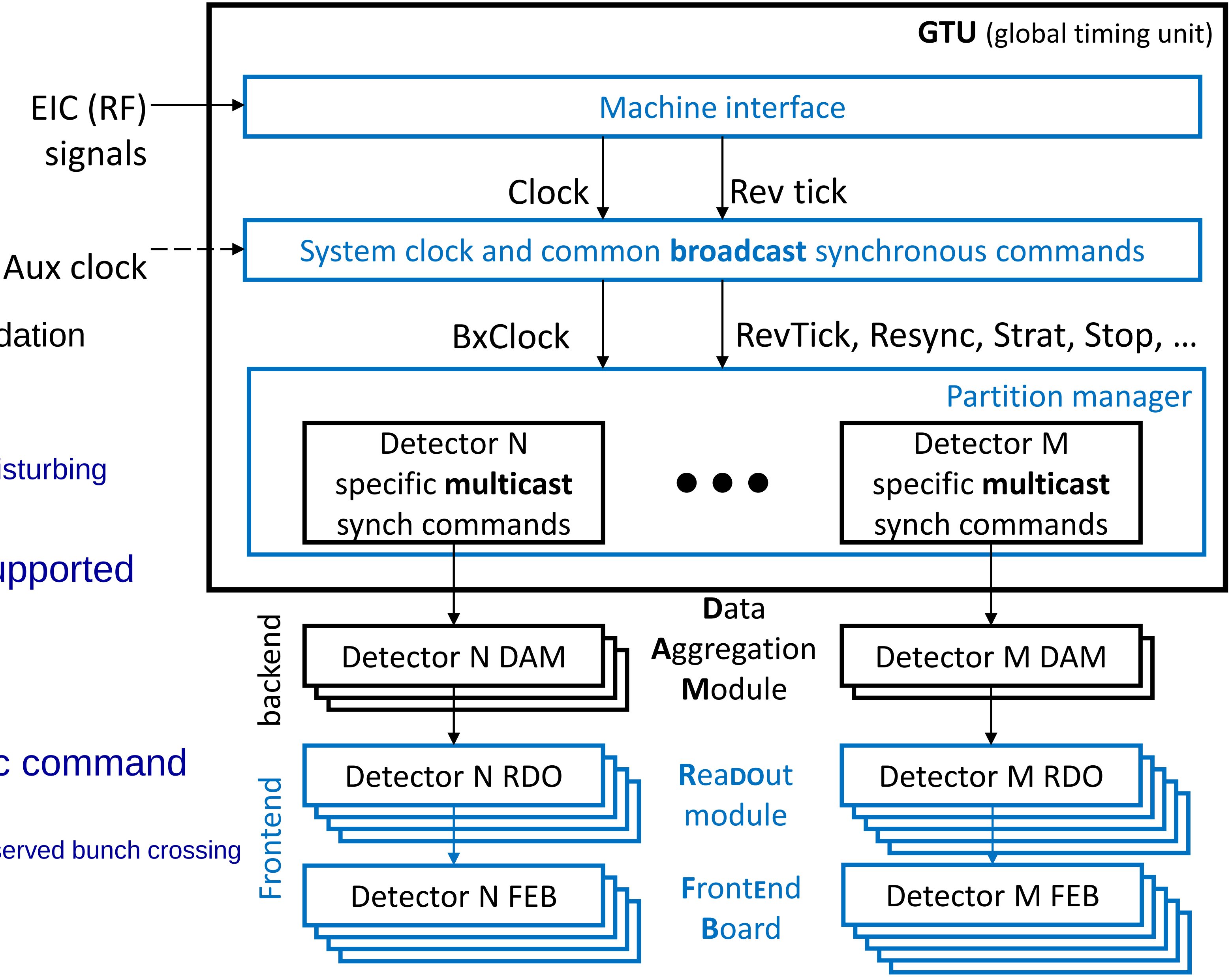
ePIC readout organization

- My assumption on distribution of
  - → System clock
  - → Synchronous commands

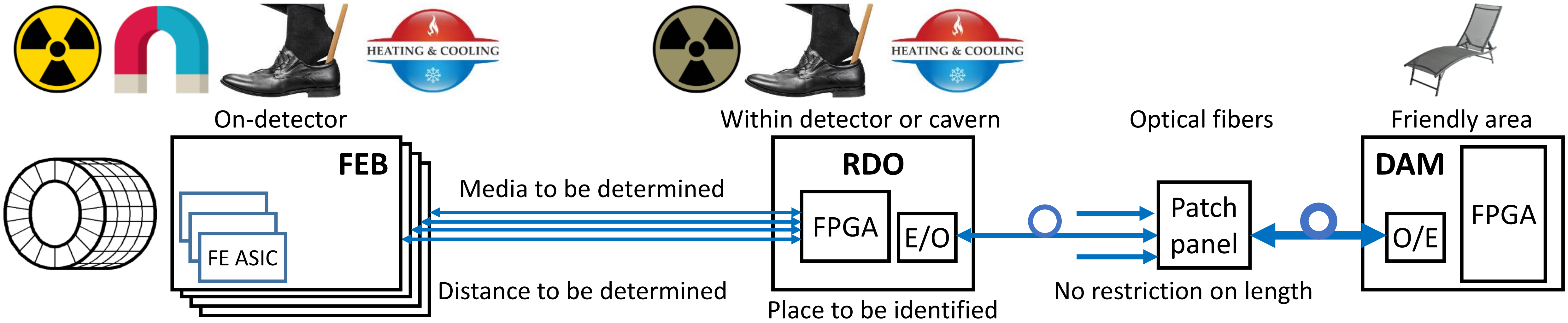
- Partitioning supported
  - → Independent data taking for testing, validation
    - *e.g.* cosmic runs
  - → Spying while the rest is taking data
    - *e.g.* performance, data quality without disturbing

- Detector specific multicast commands supported
  - → Calibration
    - *e.g.* take non-ZS data

- Identify and define protocol for each sync command
  - → Few examples in backup
    - *e.g.* Expected action @ frontend, particular reserved bunch crossing



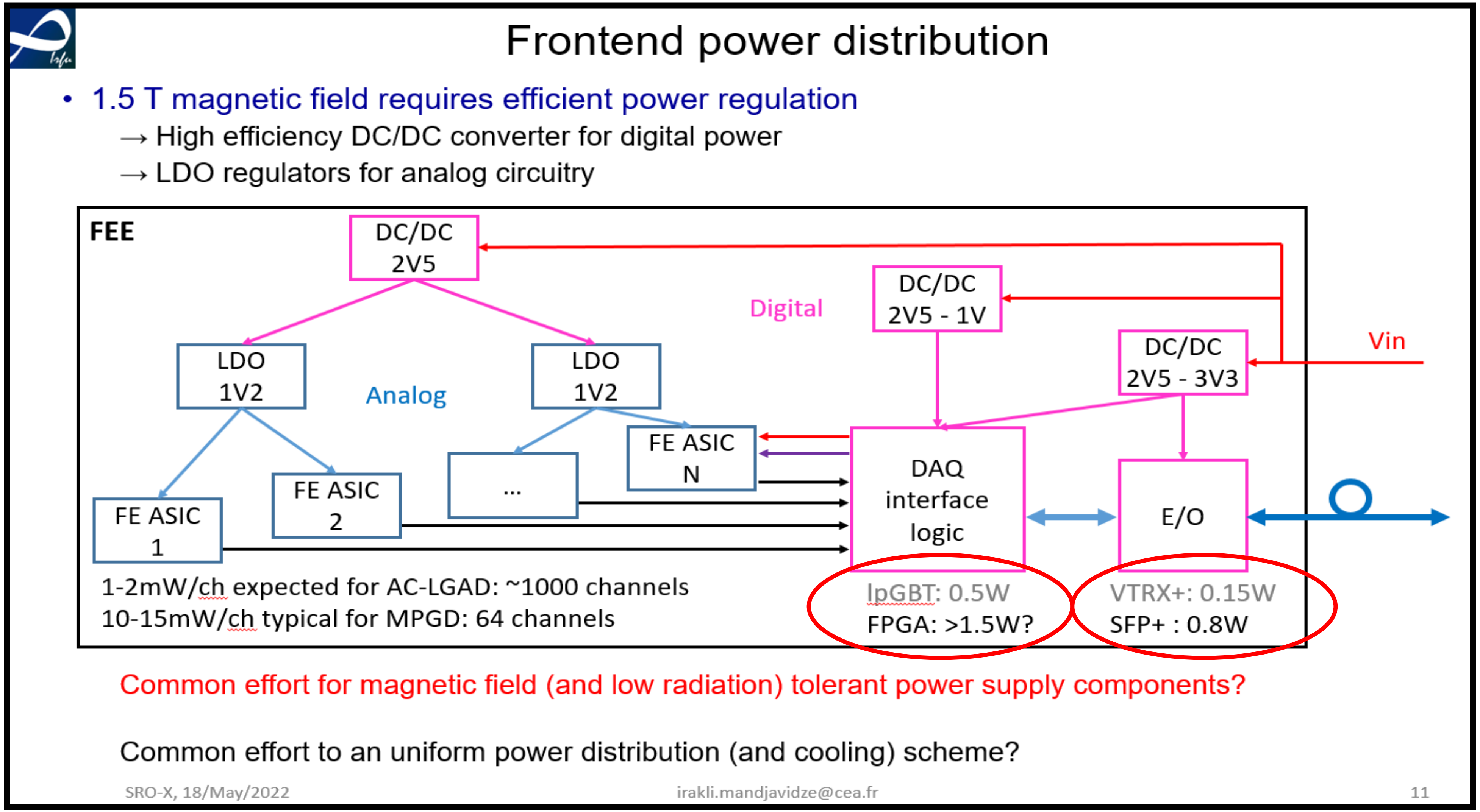
Actors



- FEB
  - → Number of rad-hard FE ASICs
  - → As low power consumption as possible
  - → ~2 T magnetic field
- RDO ↔ FEB link
  - → Downstream: clock & sync commands, configuration and monitoring requests
  - → Upstream: data, configuration and monitoring responses
  - → Over copper: 5-6 meters
    - RDO is in a restricted area inside the detector
      - Size / place / power
  - → Over fiber: no limit
    - RDO can be placed in a low restriction area in cavern
      - Or even omitted completely
- RDO
  - → Middle to low-end FPGA
  - → Distribute clock and synch commands to FEBs
  - → Configure and monitore of FEBs
  - → Receive data from several FEBs, format them and convey to DAMs
- DAM
  - → A powerful high-end FPGA capable to control few tens of RDOs and aggregate data from them
  - → O(10 Gbit/s) bidirectional serial link for clock, sync commands, data, configuration, monitoring

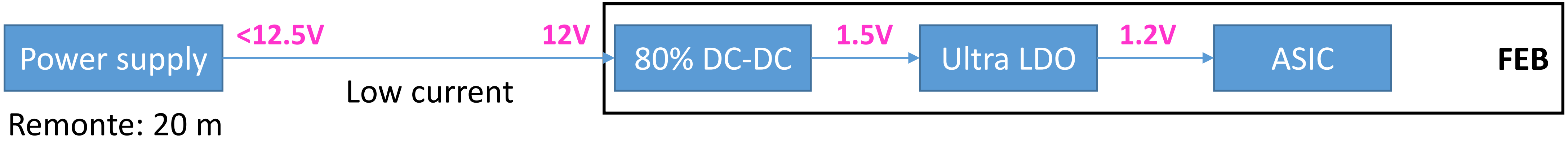
Power distribution: a reminder from the past

- Just for fun: presented on 18 may, 2022, during SRO-X workshop
  - → https://indico.jlab.org/event/519/contributions/9563/attachments/7748/10855/220518_SroX_FrontEnd_IM.pdf



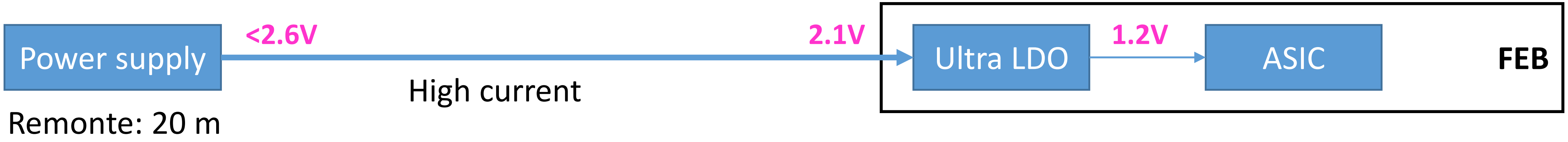
FEB power distribution options

- DC/DC-based LV distribution: to be magnetic field tolerant
  - → Remote power supply distributes 12V with voltage drop over 20 m cables < 0.5V



  - → Higher efficiency, low cross-section power cables, less mW/ch
  - → DC/DC regulators might be bulky and a source of EMI
    - Space + extra material for shielding

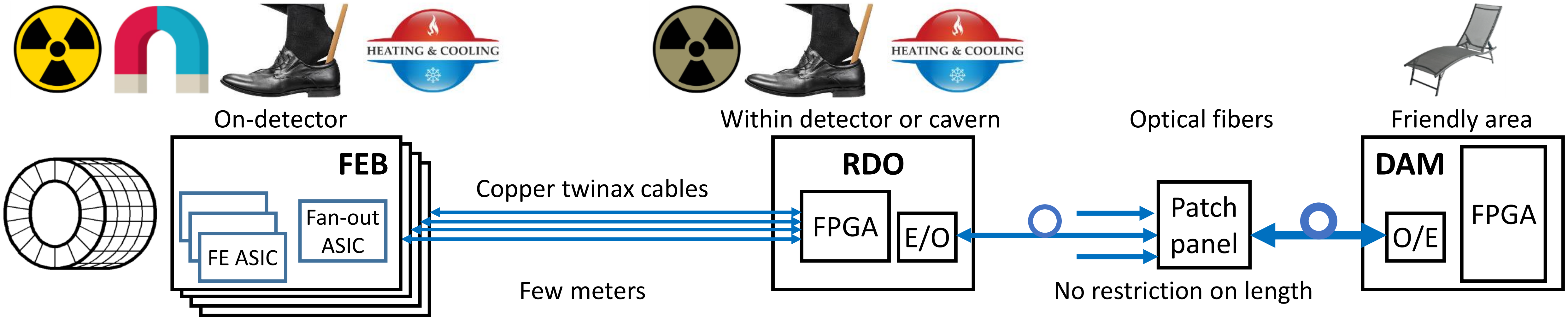
- LDO-based LV distribution
  - → Remote power supply distributes 2.1V with voltage drop over 20 m cables < 0.5V



  - → Lower efficiency, high cross-section power cables, more mW/ch
    - Space due to thick cables

FE organization options

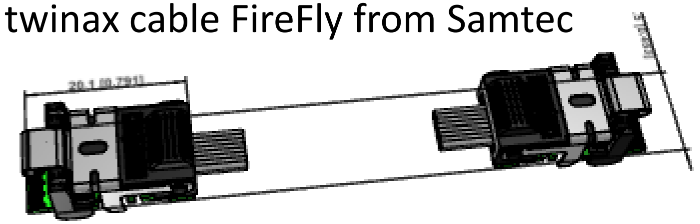
FEB with no on-board intelligence and electrical interface



- Passive electrical interface
  - → Downstream: clock, synch commands, asynchronous commands (I2C)
  - → Upstream: physics and calibration data, configuration and monitoring

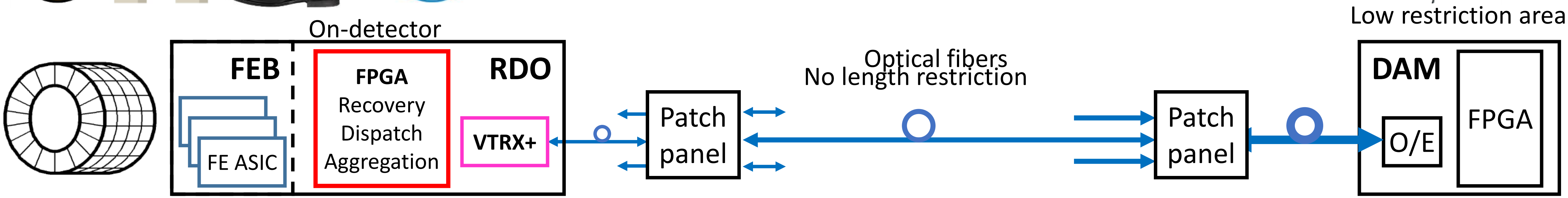
- FEB
  - → Radiation hardened ASICs
  - → Low active component count: minimal power consumption
    - ~30-35 mW / channel
    - 1 mm^2 (DC/DC + LDO) or 5.6 mm^2 (LDO only) wires to power a FEB
      - Caution: DC/DC regulators may be bulky and source of EMI

Passive 8-lane twinax cable FireFly from Samtec



- RDO: Is there any suitable place ?
  - → Overall integration issue

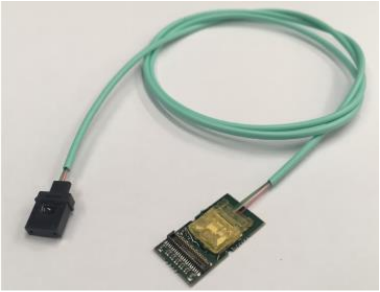
Merged FEB / RDO with optical VTRX+ interface



- On-FEB RDO in a harsh environment

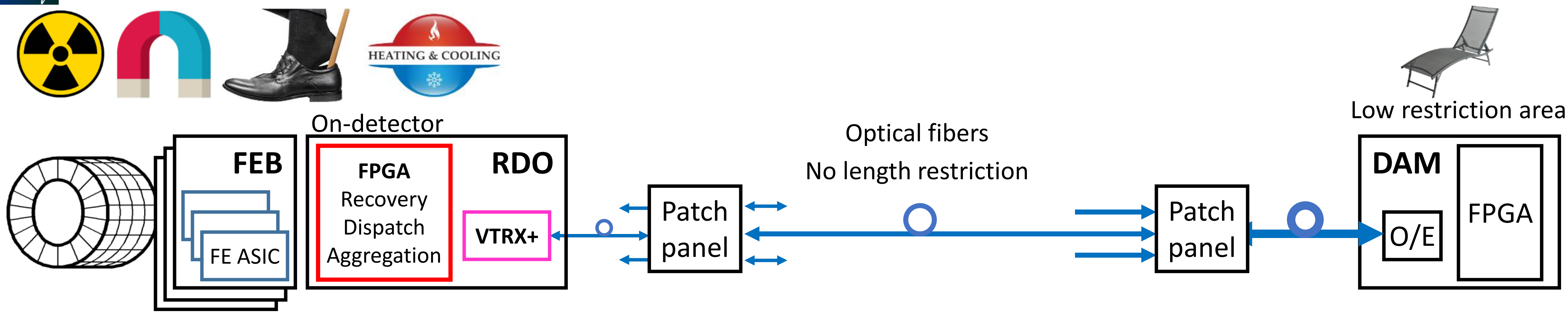
- FE ASICs are thought with “lpGBT / CERN” interfaces
  - → Separate lines for downstream interfaces: clock, synchronous commands, asynchronous configuration commands
  - → VTRX+ needs to be coupled with an on-RDO “intelligence” to recover this imbedded information
  - → CERN has lpGBT; ePIC counts on FPGAs

CERN VTRX+



- On FEB FPGA / VTRX+ combination
  - → SEU effects need to be understood, acceptable failure rates to be agreed on
    - ■ Estimation: 8h MTBF for entire CyMBaL with a low cost low profile Latice Nexus radiation tolerant FPGA
  - → Worst power consumption scenario
    - ■ Estimation: 45-50 mW / channel - 50% increase compared to electrical interface
    - ■ 1.5 mm^2 (DC/DC + LDO) or 8 mm^2 (LDO only) wires to power FEB
  - → Cooling and its additional infrastructure !

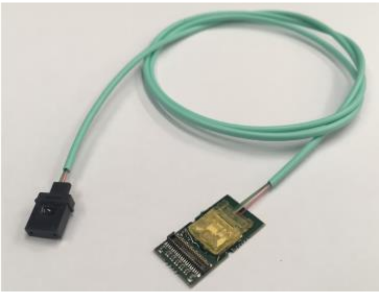
On-detector RDO with optical VTRX+ interface



- On-detector RDO per detector module
  - → 4 FEBs / RDO
    - ■ Higher integration: More optimal use of RDO resources : FPGA logic + VTRX
  - → Harsh environment
    - ■ Same SEU preoccupation as for merged FEB / RDO

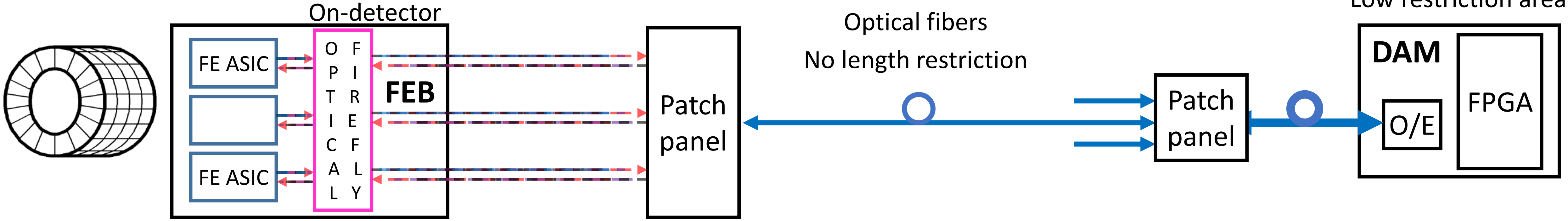
- Further studies needed to understand on-detector space constraints
  - → ~11% more power compared to lowest power option of a FEB with electrical RDO interface
    - ■ 33 – 37 mW / channel
    - ■ 1 mm^2 (DC/DC + LDO) or 6 mm^2 (LDO only) wires to power FEB
  - → Cooling and its additional infrastructure !

CERN VTRX+



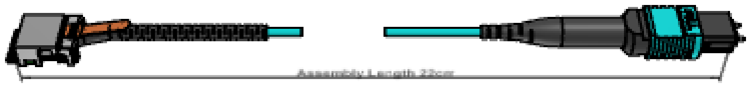
FEB with optical interface: COTS optical FireFly

Low restriction area



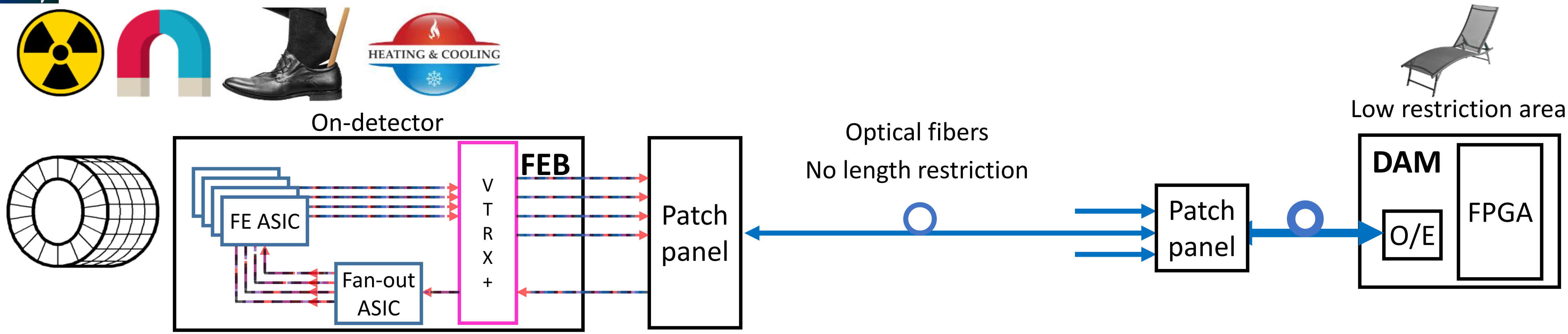
- FE ASICs are directly interfaced to 4-lane bidirectional parallel optic FireFly transceivers
  - → Requires an “innovative” ASIC interface: Rx line encoding clock and data (sync & async commands)
  - → Plus extra handy features:
    - A low speed embedded ADC for environmental monitoring
    - A GPIO outputs for on-board control

Optical 4 Tx & 4 Rx FireFly from Samtec



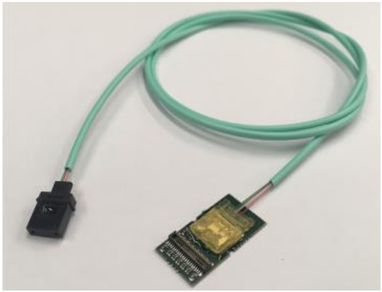
- FEB
  - → Radiation hardened ASICs
  - → Low active component count: minimal power consumption
    - ~35-37 mW / channel - 15% increase compared to pure electrical interface
    - 1 mm^2 (DC/DC + LDO) or 6 mm^2 (LDO only) wires to power FEB
- No RDO layer !

FEB with optical interface: VTRX+



- FE ASICs are directly interfaced to VTRX+
  - → Downlink with embedded clock / sync / async data distributed with high fidelity fan-out
  - → Requires an “innovative” ASIC interface
    - Working on CDR circuitry for Salsa

CERN VTRX+



- FEB
  - → Radiation hardened ASICs
  - → Minimal power consumption after electrical interface option: only VTRX+ consumption added
    - ~ 32-35 mW / channel - 8% increase compared to pure electrical interface
    - 0.9 mm^2 (DC/DC + LDO) or 5.8 mm^2 (LDO only) wires to FEB
- No RDO layer !

Outcome: mostly questions

- Our knowledge of the ePIC Inner detector in general and its MPGDs in particular is not mature
  - → Can the same FEB form-factor be used for all MPGDs ?
  - → Is the same integration level (256-channel FEB) necessary, adapted, handy to all MPGD detectors ?
  - → Do we have the place to house ~600 FEBs on detector ?
    - 128 for CyMBaL; 384 for µRWell-BOT; 80 for µRWELL-ECT

- Study of the FEB option with optical interface
  - → Can we enhance Salsa with clock-data recovery mechanism ?
  - → What will be an error rate due to the use of the COTS e/o transceiver in the mild ePIC radiation environment ?
  - → How the cooling can be organized to avoid the bulky radiator ?
    - In contact with Samtec to understand the possibility of the use of the optical FireFly components

- Studies are needed and ongoing within Elec/DAQ and Integration groups
  - → Can we use FPGAs within the inner detectors ?
  - → Can we use DC/DC regulators within the inner detectors ?
  - → What are the COTS components compatible with the low ePIC radiation environment ?
  - → Can we count on ePIC-wide access to CERNs radiation hardened, magnetic field tolerant powering components ?

  - → How close can be RDOs placed to FEBs ?
  - → How close can be LV power supplies placed to FEBs ?
  - → How the services can be delivered to frontend ?

Next steps

- Functional organization can be a subject for next presentation
  - → Synchronization
  - → Data collection
  - → Calibration

- Meantime collect the relevant information
  - → Channel hit rate
  - → Channel charge
  - → Amount of data
  - → Calibration

  - → Better knowledge of mechanical constraints

  - → Adding more questions
  - → Answers on some of the questions from the list