Update on ePIC MPGD readout

Readout architecture
Components
Powering
2025
Planning

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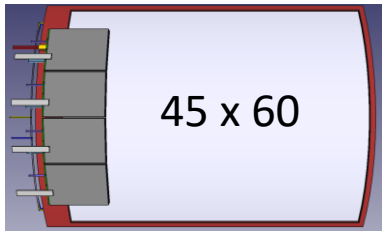
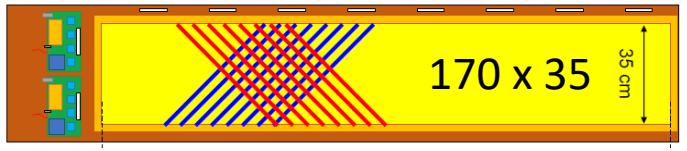
Reminder on MPGD sub-systems and channel counts

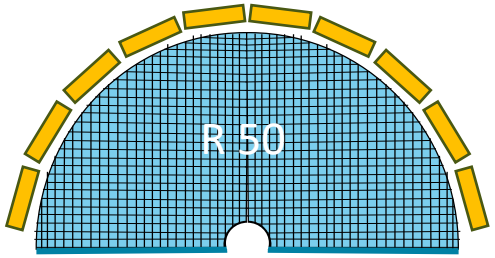
- Cylindrical Micromegas Barrel Layer : CyMBaL : ~30k channels
  → 32 tiles of 1024 channels each



- µRWELL Barrel Outer Tracker : µRWell-BOT : ~100k channels
  → 24 modules of 4 096 U-V strips each

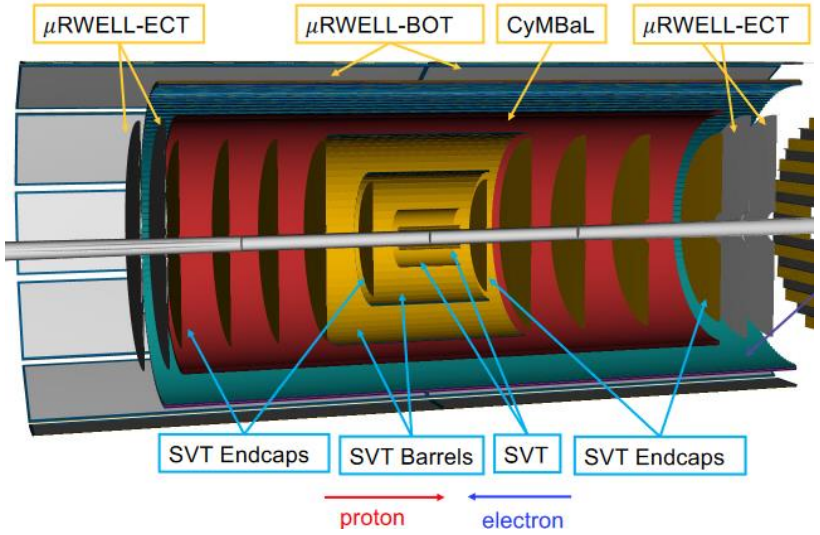


- µRWell End Cap Tracker : µRWell-ECT : ~30k channels
  → 8 half-disks of 4 000 X-Y strips each



- ~160k-channel heterogeneous system
  → Micromegas, µRWell, barrel, endcap, curved, planar, circular

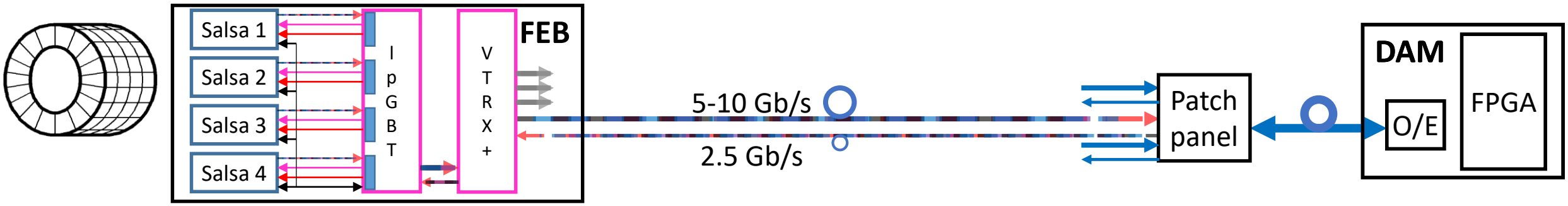
- Common approach to acquire data from different types of ePIC MPGDs
  → Use same frontend ASIC
    - Salsa – under development
  → Share frontend design between groups
    - Adapt form factor if needed



MPGD readout architecture based on lpGBT / VTRX+

On-detector

Low restriction area

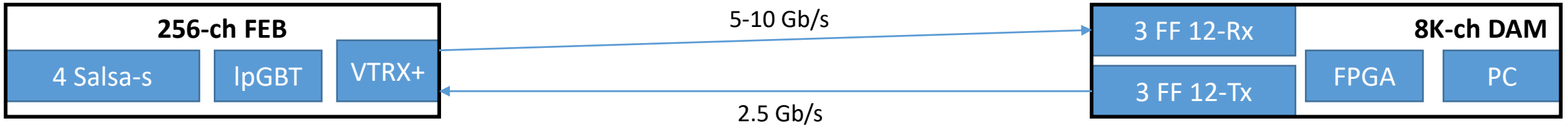


- 256-channel FEB with 4 Salsa-s per board

- Direct FEB-DAM connection avoiding intermediate RDO stage
  - → Downstream
    - Clock — Synchronous run-control commands — Async slow control and monitoring requests
  - → Upstream
    - — Physics and calibration data — Slow control and monitoring responses

  → For detailed discussion of the lpGBT use in MPGD readout see
  https://indico.bnl.gov/event/25106/contributions/97861/attachments/57983/99568/241017_IM_lpGbt2Salsa.pdf

160K-ch MPGD readout component count



- Operational quantities

	CyMBaL	µRWell-BOT	µRWell-ECT	Total
Channels	32K	96K	32K	**160K**
Salsa	512	1 536	512	**2 536**
FEB	128	384	128	**640**
DAM	4	12	4	**20**

- Production quantities
  - Including prototyping, test-bench and quality assurance needs

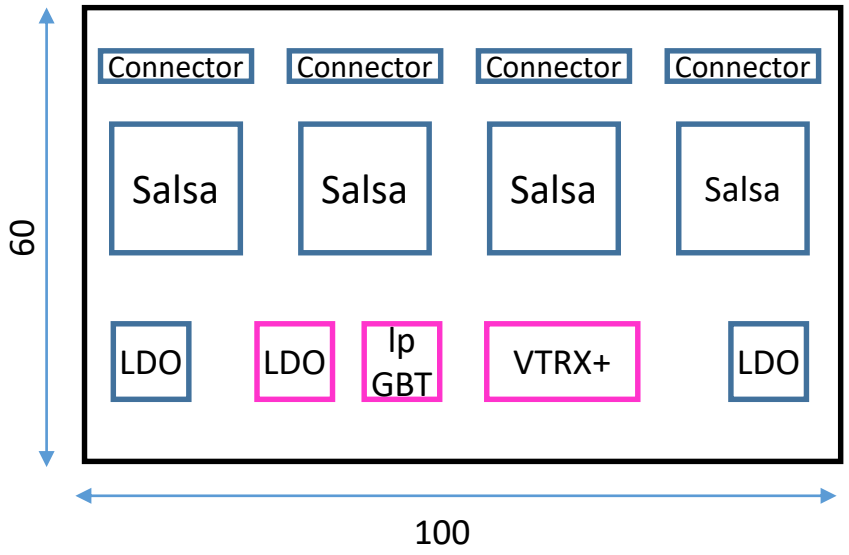
→ 4 000 Salsa-s

→ 750 FEBs
  - 750 VTRX+
  - 750 lpGBT

→ 23 DAMs
  - 70 12-Rx and 12-Tx FireFly modules

256-channel FEB power consumption

Component illustration for CyMBaL FEB



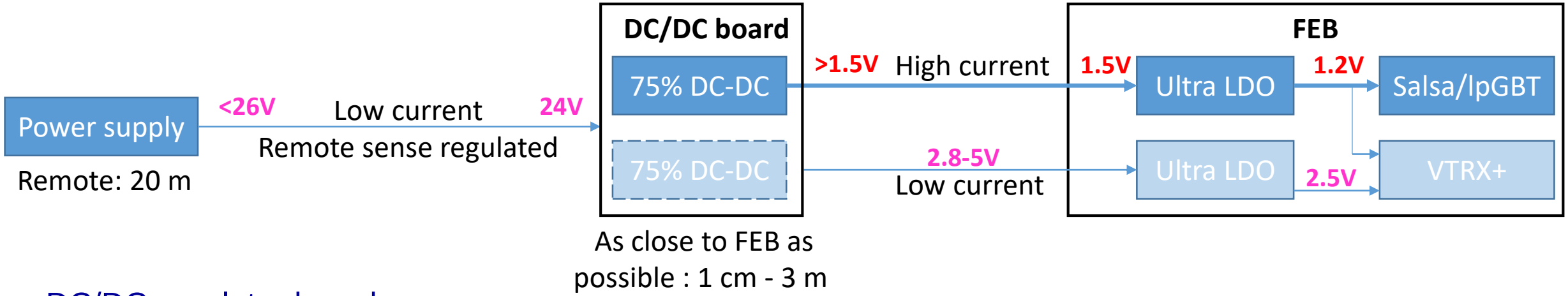
- Raw power budget with minimal margin : ~6.8 W
  → 27 mW / ch
- Assume 8.5 W for safety : 25% extra
  → 33 mW / ch
  → 1.5 V – 5.6 A
  → 2.8 V – 90 mA
- Cooling to be studied

FEB components and their power consumption

Component	Vin V	Current mA	Power mW	Comment
Salsa 1	1.2	1 000	1 200	15 mW/ch
Salsa 2				
Salsa 3				
Salsa 4				
lpGBT	1.2	420	500	Overestimated
VTRX+	1.2	20	25	
	2.5	70	175	
LDO Salsa 1-2	1.5	2 000	600	LDO / Salsa to avoid hotspots ?
LDO Salsa 3-4				
LDO lpGBT/VTRX+	1.5	440	130	
LDO VTRX+	2.8	70	20	

FEB powering in ~1.8 T magnetic field

- DC/DC-based LV distribution: to be magnetic field tolerant
  - → Remote power supply distributes 12-24V with a low voltage drop over ~20 m cables
  - → Low cross-section power cables



- DC/DC regulator board
  - → Might be bulky and a source of EMI
    - Space + extra material for shielding
  - → Delivers high current for 1.2V
    - Should be close to FEBs
      - Avoid significant power drop and power dissipation in cables
      - Avoid pickup noise and ground-loops

- Studies within the ePIC collaboration to have common approach to power the frontends
  - → Lead by Tim Camarda and Gerard Visser
    - https://indico.bnl.gov/event/25107/contributions/97957/attachments/58092/99814/power_distribution_10_24_2024_RevA.pdf
    - https://indico.bnl.gov/event/25107/contributions/97957/attachments/58092/99805/241024_IM_PowerAndVtrx.pdf
  - → Adapt proposed solution to MPGDs

CERN components

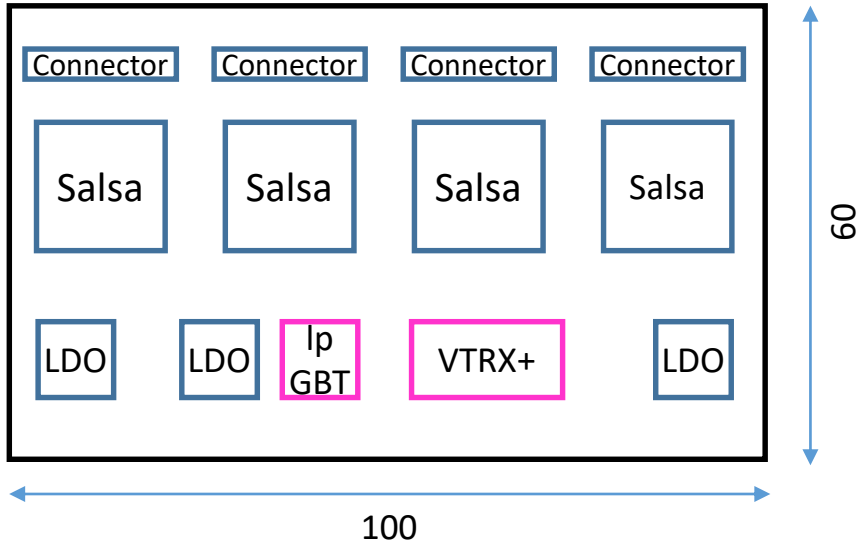
- Current VTRX+ procurement includes MPGD needs
  → We opted for 20 cm pigtails mainly to be compatible with other subsystems

- Current lpGBT procurement does not include MPGD needs
  → We need to make sure our request is taken into account by the project
  → lpGBT V2 production for users other than Atlas and CMS – presumably during 2026
    - Fits EIC schedule
    - V1 should be available for prototyping during 2025

- LV distribution
  → CERN radiation hard DC/DC and linear LDO regulators available for ePIC / EIC
    - bPOL48, bPOL12, linPOL12
    - If needed even CMS HgCaL LDO can be available
    - Determine quantities and make sure our request is taken into account by the project

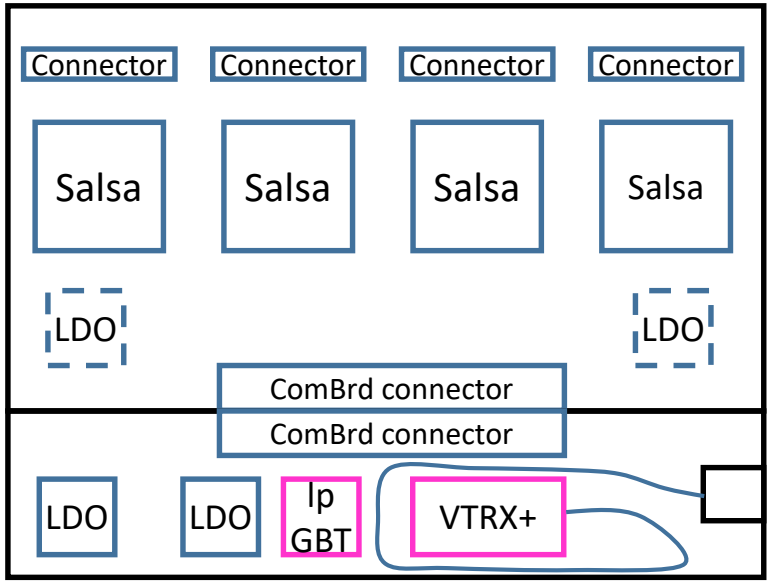
Illustration of CyMBaL lpGBT-based FEB organization options

- Single board



→ Complex high density high speed
→ MPGD-specific form factor

Companion board approach



→ FEB board
→ Low density low speed
→ MPGD-specific form factor

→ Communication board
→ high density high speed
→ Common to all MPGDs ?

→ board-to-board or board-to-cable (flex) connections

- Evaluate pros and cons of multi-board approach
- Understand if a common communication board can suit all MPGD sub-systems

- See some more examples of MPGD FEE partitioning in
  → https://indico.bnl.gov/event/25807/contributions/100250/attachments/58955/101236/241205_IM_MpgdDsc_Feb.pdf

Activities over 2025

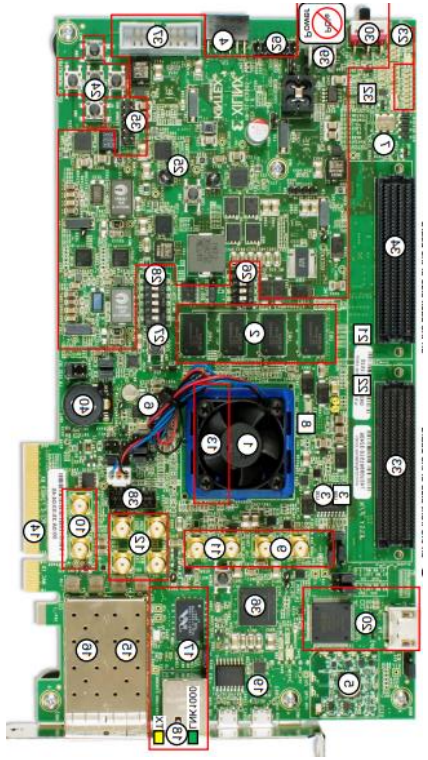
- Readout architecture
  - → Agree on the choice of the lpGBT-based readout
- Consolidate readout specifications – mostly concerns Salsa
  - → Make sure they suit MPGD requirements
  - → Make sure envisaged calibration and monitoring means are adequate
- FEB
  - → Form-factors and partitioning opportunity based on space constraints
  - → Possibly FEB and communication board prototyping
- DC-DC based low voltage powering
  - → Expect support from groups actively involved in powering studies
  - → Adaptation for MPGD
- Colling
  - → No particular studies have been conducted so far
- System-level
  - → DAM-FEB communication and data collection
  - → Run control, slow control and monitoring

Setup for system-level studies

- FEB – DAM protocol development
  - → Downstream synchronization and slow control
  - → Upstream data collection
  - → Run control state machine

FEB

SalsaEmulator



AMD / Xilinx dev kit
with MGTs
KCU105

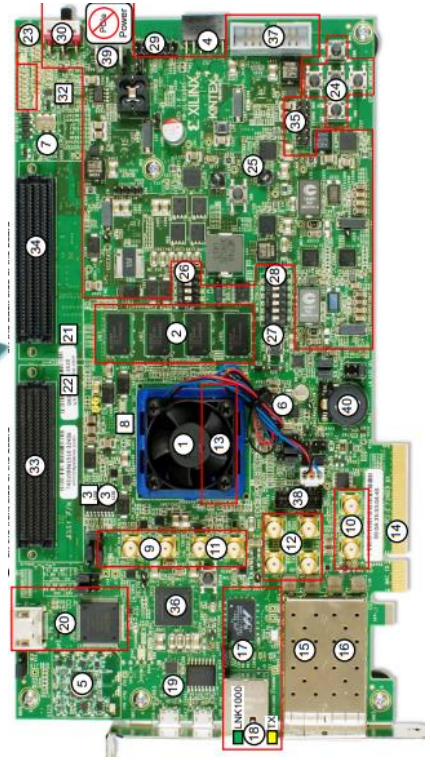
VLDB+
lpGBT & VTRX+ board
(available at Saclay)

Optical VTRX+ to FireFly fiber plant

DAM

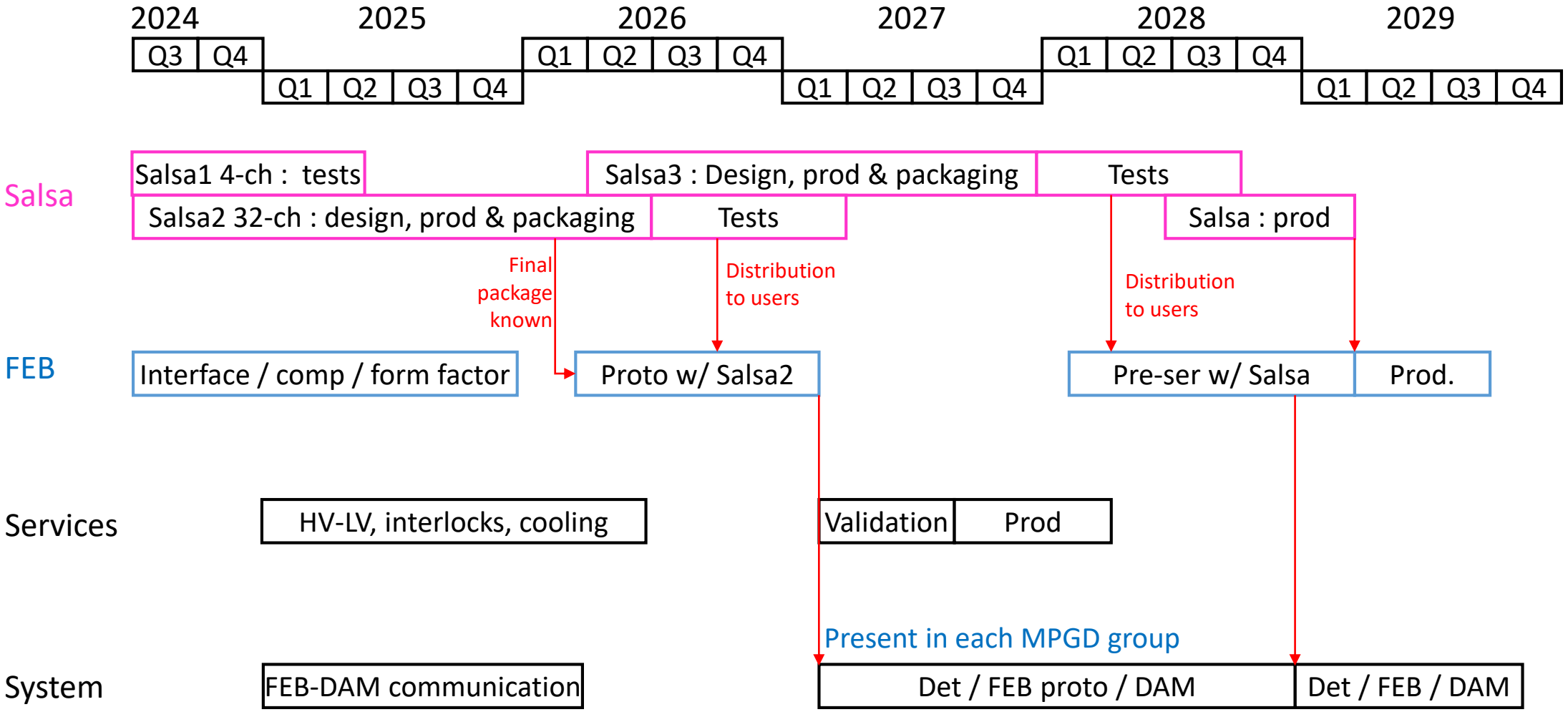
14 Gb/s FireFly
evaluation board
from Samtec

SalsaFPGA



AMD / Xilinx dev kit
with MGTs a FMC
KCU105

Planning



- Most important milestone is Salsa2 – determines the rest of the planning
- Check with the MPGD groups and ePIC if the proposed planning is suitable
- Salsa and FEB technical and production readiness reviews to be planned

Summary

- Pros of presented lpGBT-based readout architecture are convincing
  - → Remove intermediate RDO stage
  - → Approved rad-hard low-power design
  - → Embedded analog and digital monitoring reducing FEB component count
- 2025 workload is understood fairly well
  - → FEB form-factors and partitioning
  - → DC-DC powering
  - → Cooling
  - → FEB-DAM communication and ePIC protocol implementation for MPGDs
- Interaction with ePIC and EIC management
  - → Component procurement
  - → Timely access to the DAM ecosystem
- Workload sharing is welcome

Backup

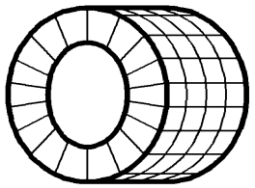
Readout alternatives

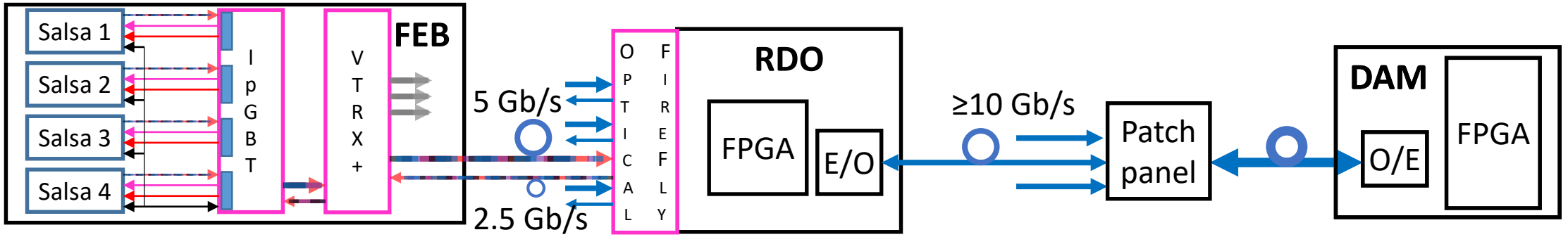
MPGD readout based on lpGBT & intermediate RDO

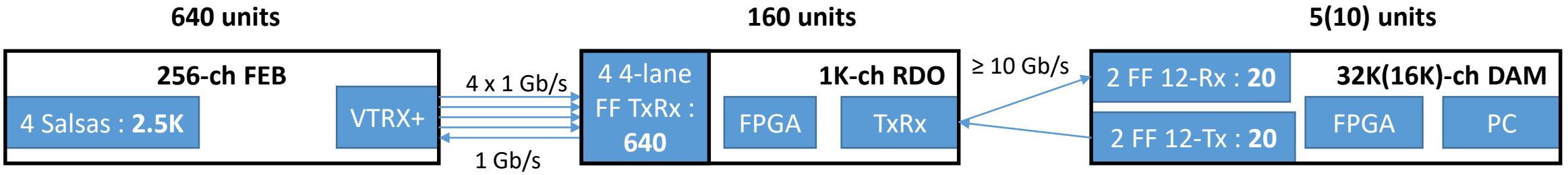
Low restriction area

Low restriction area

On-detector







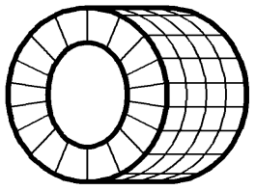
Intermediate RDOs system to design, debug, produce install, commission and maintain

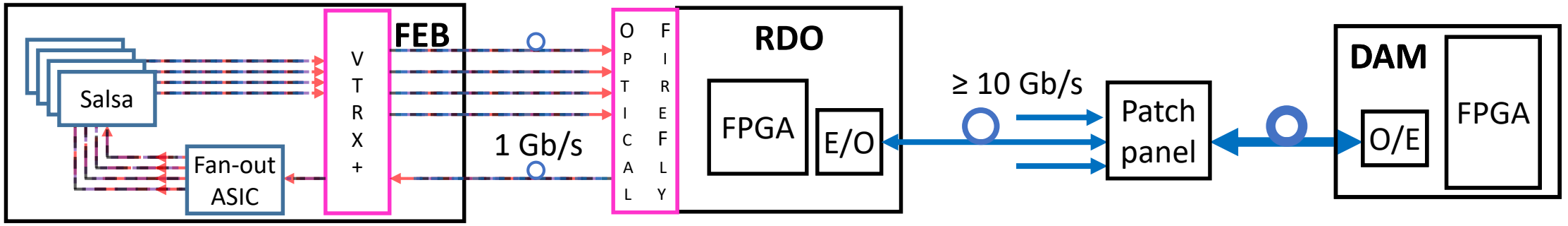
MPGD readout based on Salsa unified interface

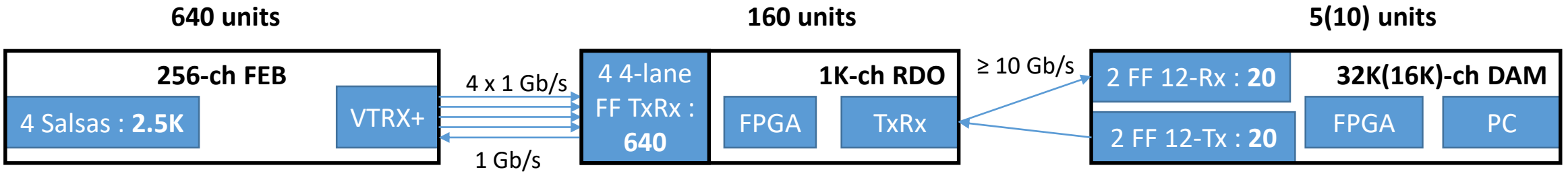
On-detector

Low restriction area

Low restriction area



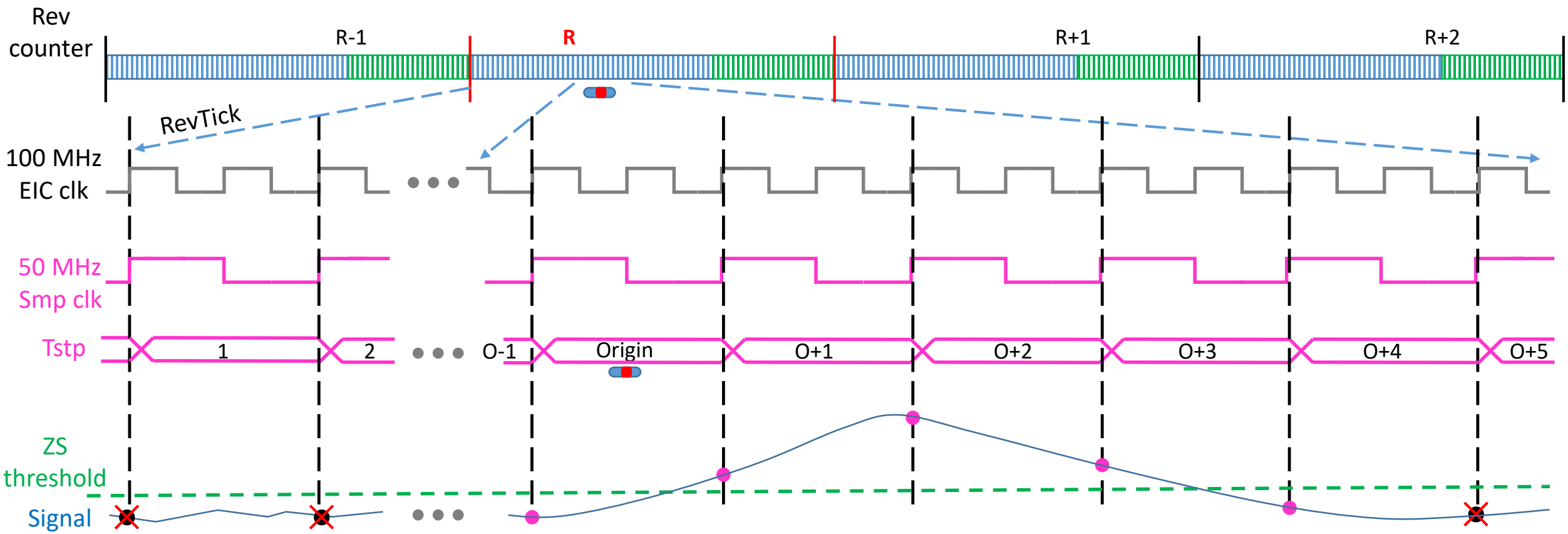




Intermediate RDOs system to design, debug, produce install, commission and maintain

Data and collection protocol

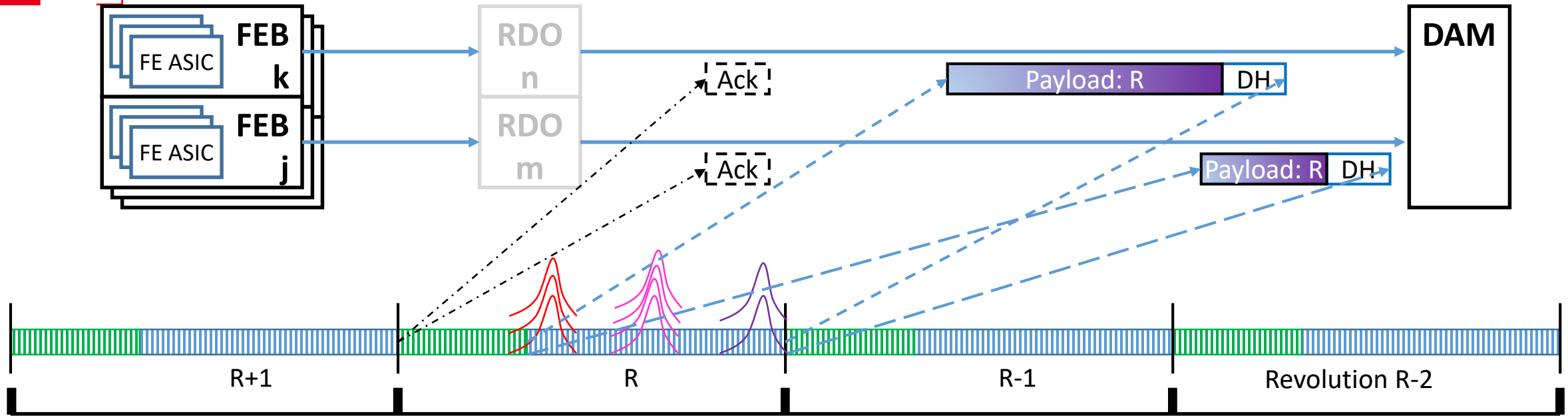
Data



- Regular “Sync” command generated synchronous to the EIC machine beam structure
  - → RevTick in this example
  - → Allows clock phase alignment and synchronization monitoring within Salsa and aggregators

- In this example Salsa is programmed to keep one sample before and after threshold crossing
  - → Salsa data (packet) for the signal : RevCounter, Tstp(O-1) Smp(O-1) Smp(Origin) Smp(O+1) Smp(O+2) Smp(O+3)

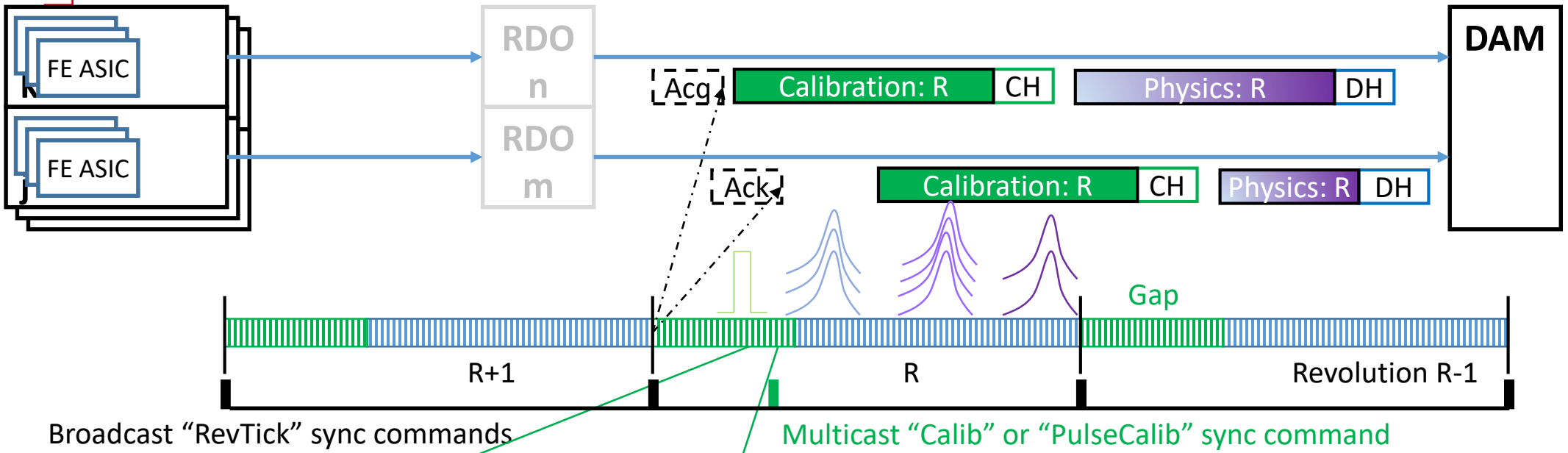
Data collection protocol

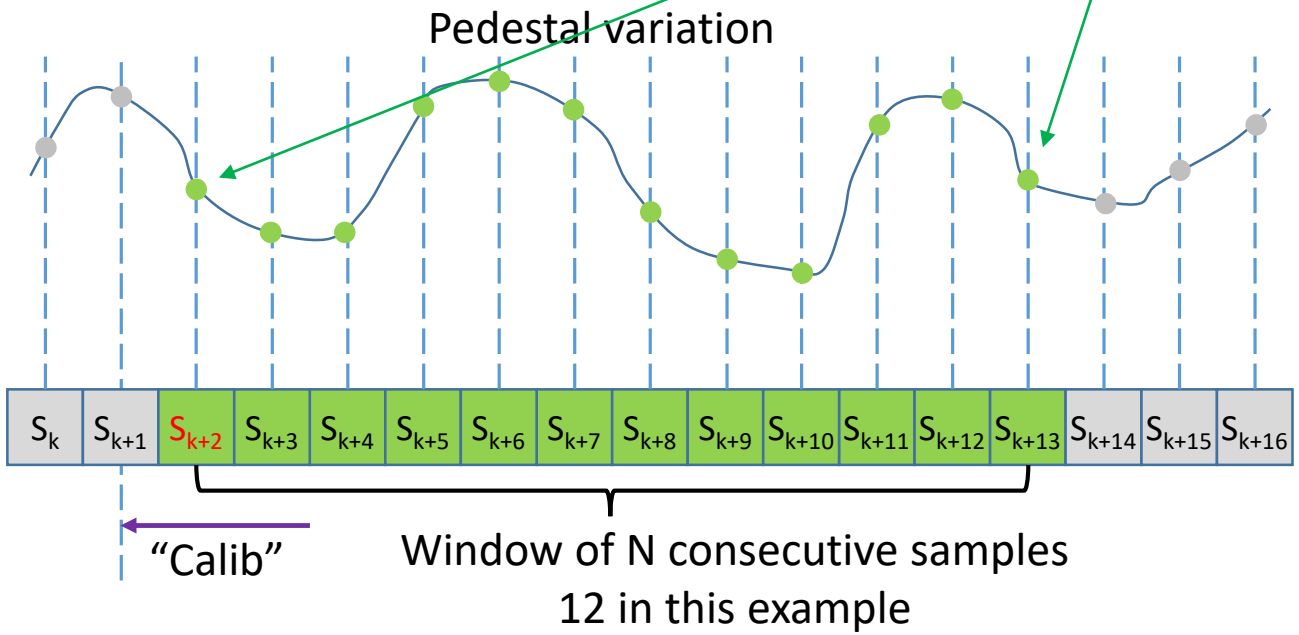


Broadcast “RevTick” sync commands

- Combine FEB (ASIC) data belonging to the same time frame – revolution in this example
  → RevTick Ack acknowledgement packet is sent after the last data within the revolution
- DAM performs revolution record building based on revolution numbers embedded in data
  → Acknowledgment packet is used as indication that no more data is expected for this revolution
- In this example, consider the RevTick as a 98.195 kHz constant rate trigger
  → Do classical event building in DAM with a readout window of ~12.7886 µs

Data collection including on-line calibration





- A "Calib" request results in a window readout
  → N consecutive non-ZS samples
  → Window size programmable
- A "PulseCalib" to fire an on FEB pulser
  → Read ASIC response to known charge