university of groningen

kvi - center for advanced radiation technology

Streaming readout for the PANDA experiment

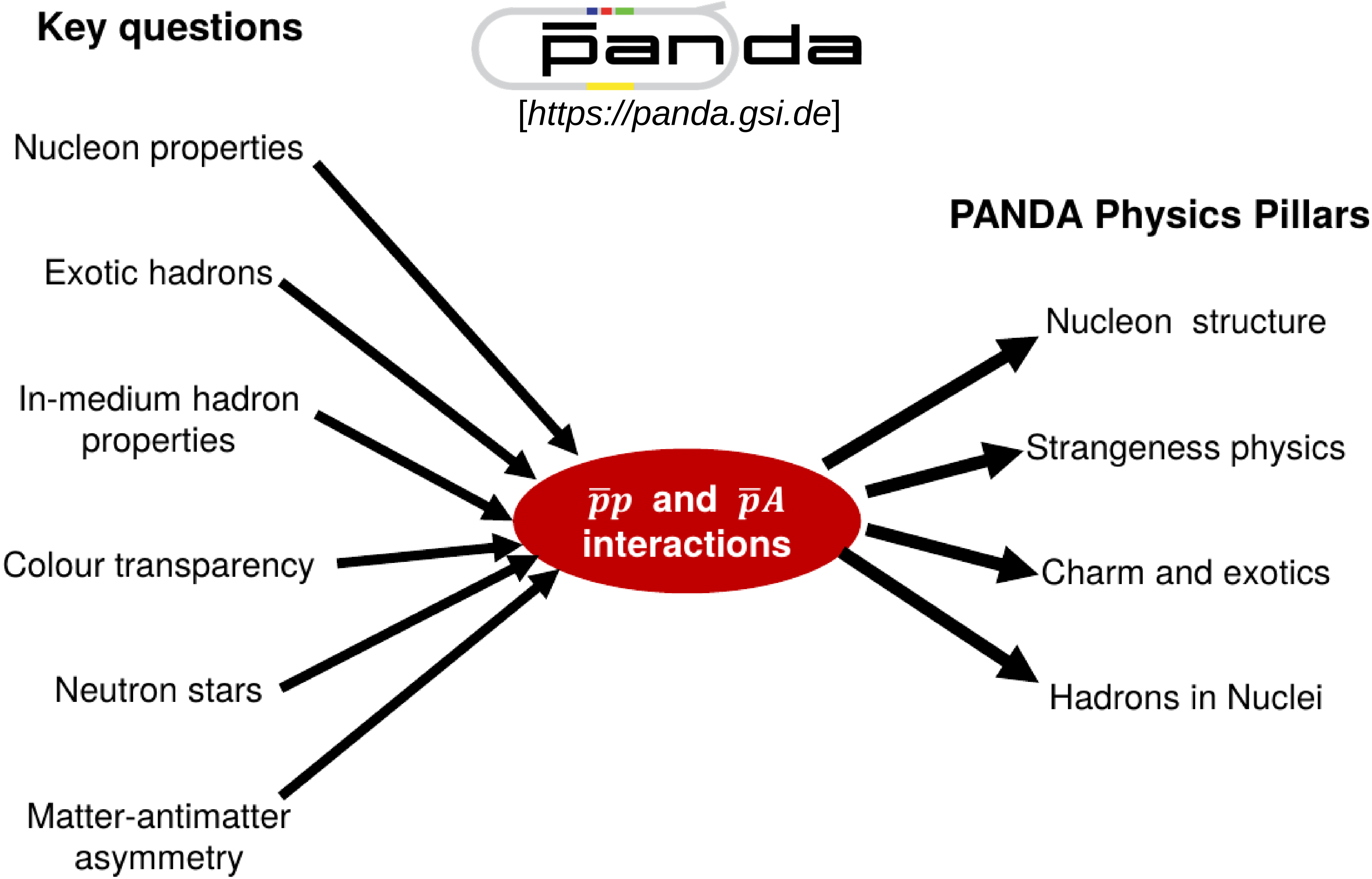
M. Kavatsyuk

KVI-CART, University of Groningen

for the PANDA collaboration

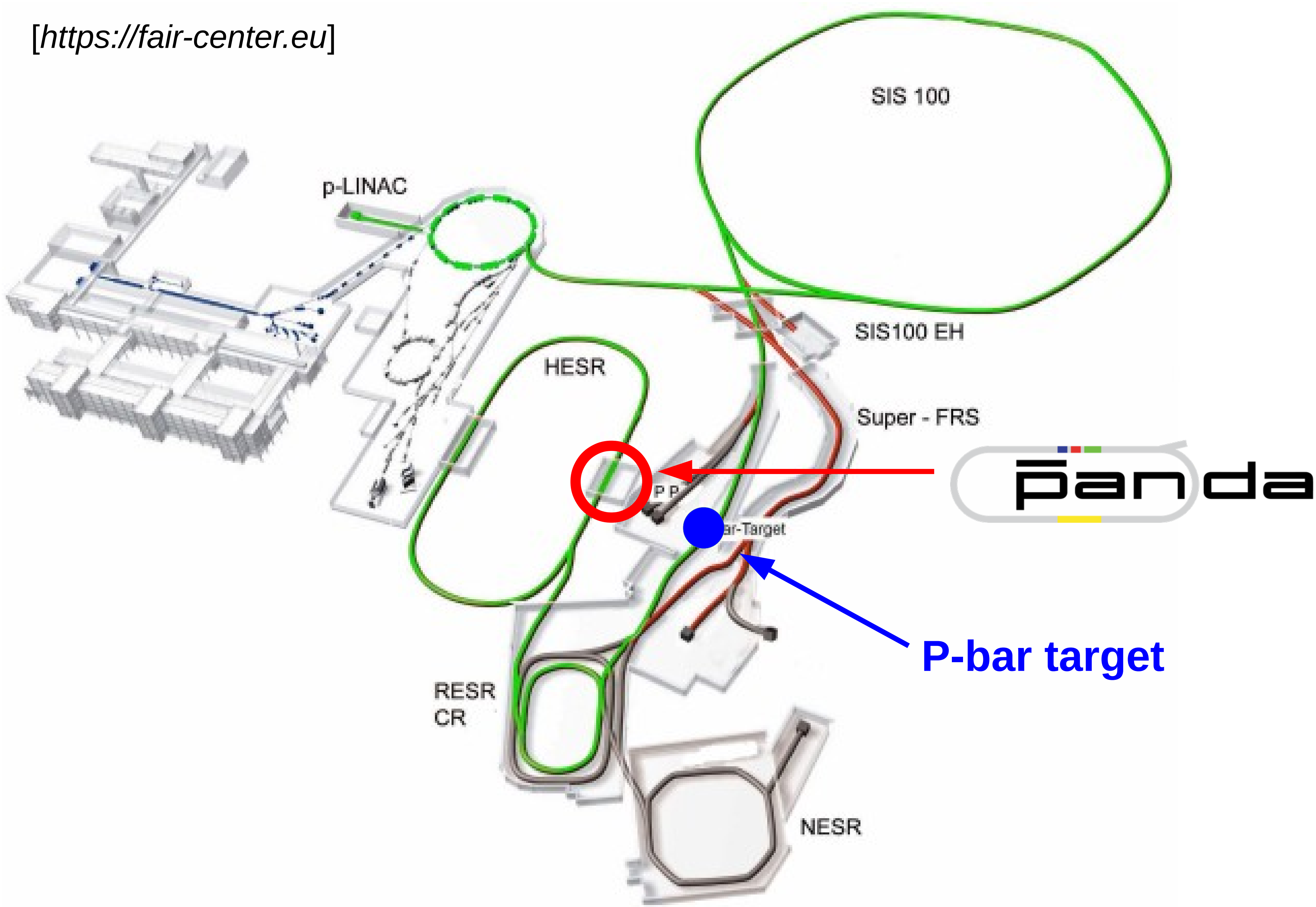
AntiProton Annihilation at DArmstadt (PANDA)

[*https://panda.gsi.de*]

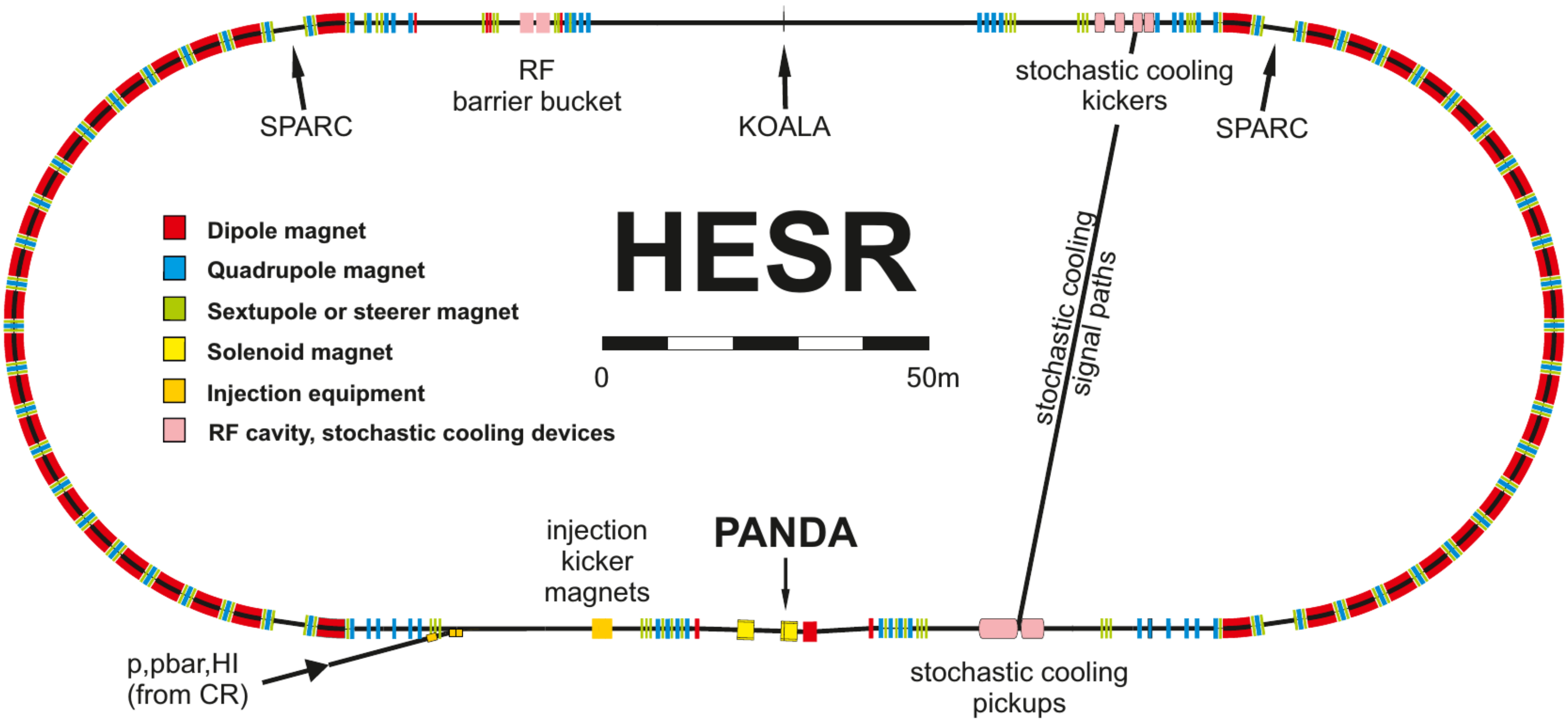


[*Karin Schoenning*]

PANDA at FAIR



Precision antiprotons:
High Energy Storage Ring (HESR)



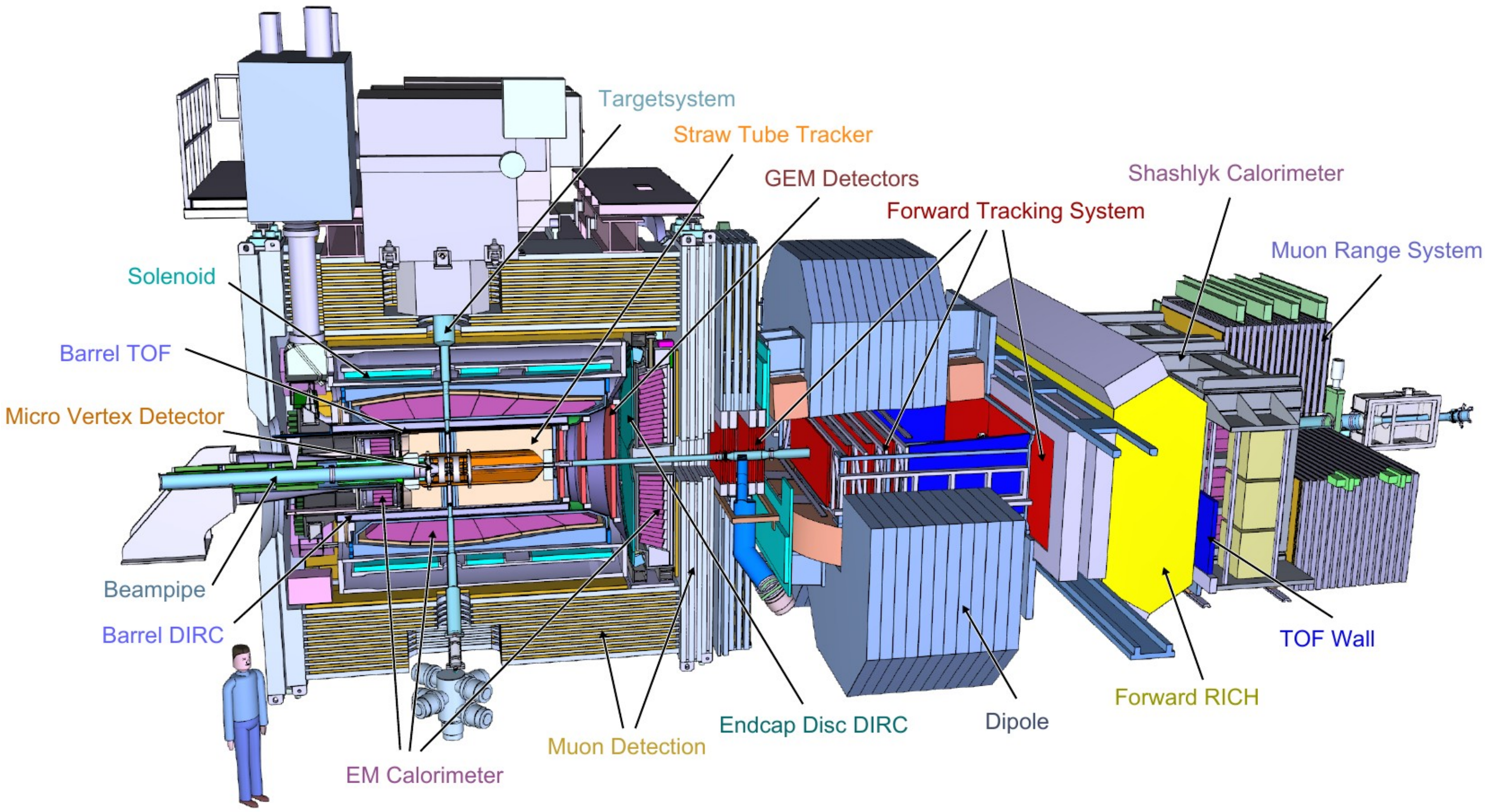
High resolution mode:

- e^- cooling: p<8.9 GeV/c
- 10^{10} antiprotons stored
- Luminosity up to 2×10^{31} cm^{-2} s^{-1}
- $dp/p = 4 \times 10^{-5}$

High intensity mode:

- Stochastic cooling: p<15 GeV/c
- 10^{11} antiprotons stored
  (10^{10} phase 1+2)
- Luminosity up to 2×10^{32} cm^{-2} s^{-1}
- $dp/p = 2 \times 10^{-4}$

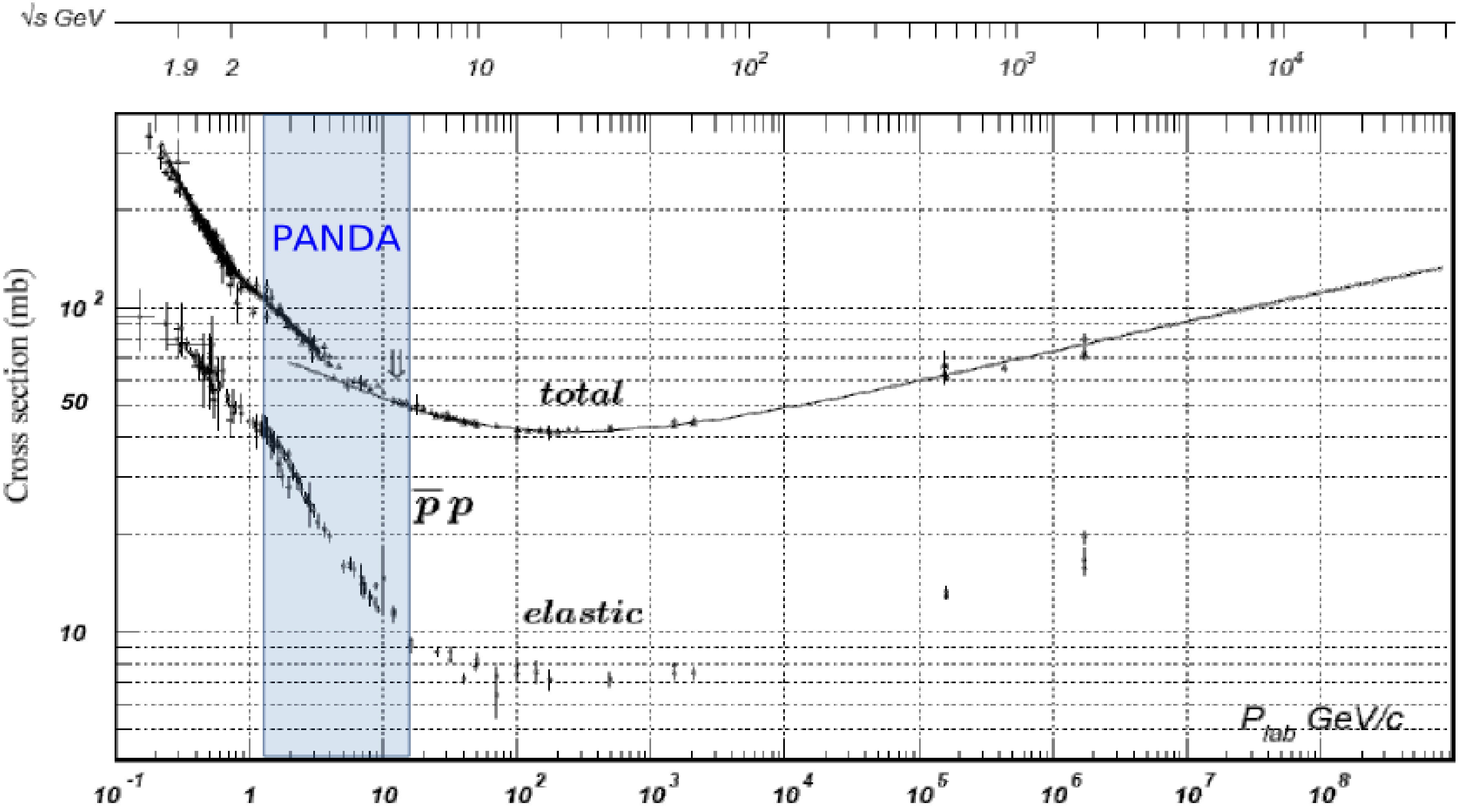
The PANDA detector



- 4π acceptance
- high rate capability (average interaction rate 20 MHz)
- excellent tracking capabilities, momentum resolution 1%
- Vertex reconstruction for D, K_s, hyperons
- good PID (e, μ, π, K, p)
  → Čerenkov, ToF, dE/dx
- γ detection 10 MeV- 15 GeV
  →PWO crystal calorimeter
- no hardware trigger, intelligent on-line event selection

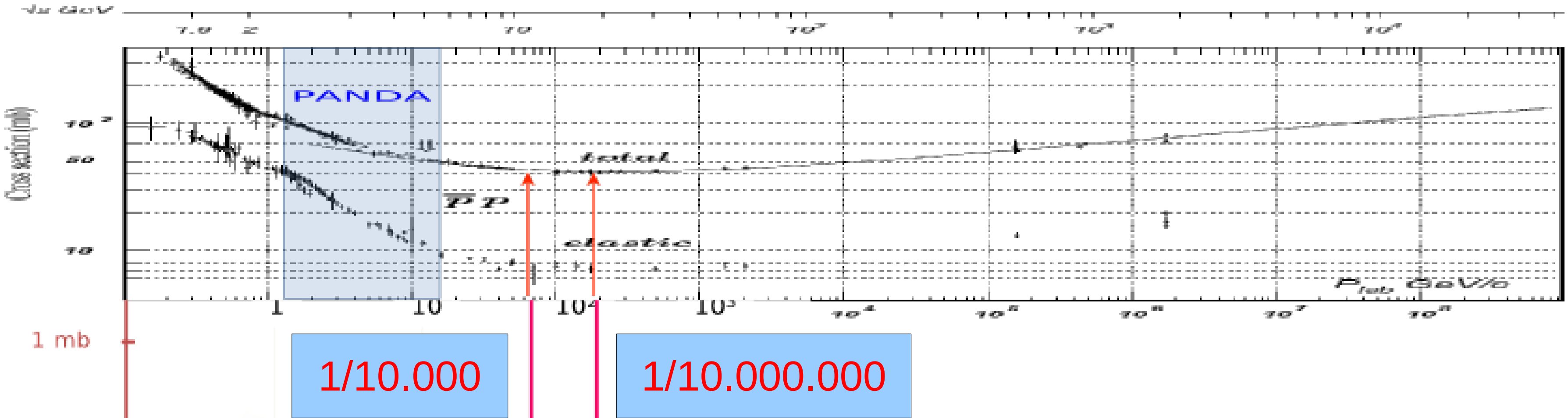
Challenge for PANDA

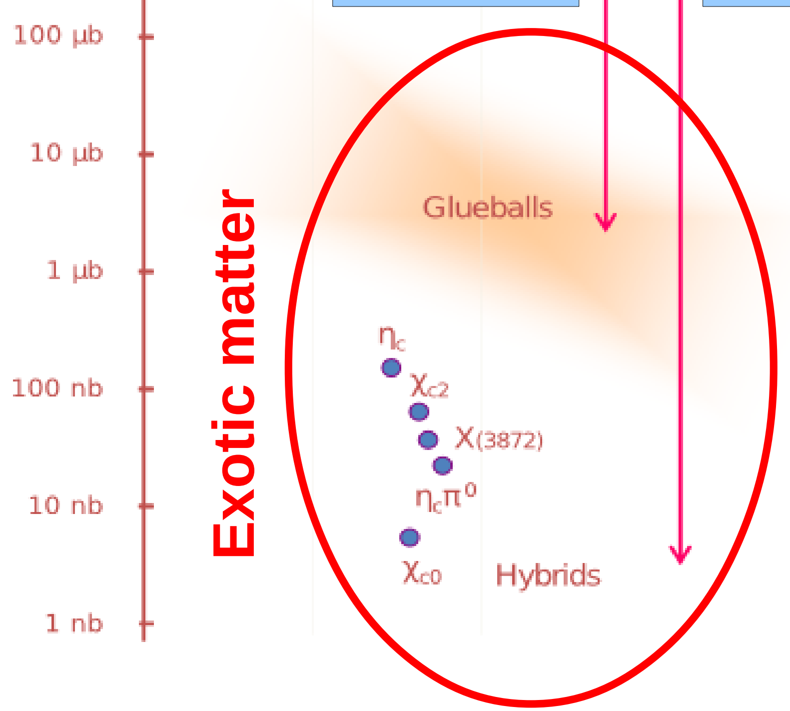
Cross section for proton-antiproton collisions



Challenge for PANDA

Cross section for proton-antiproton collisions





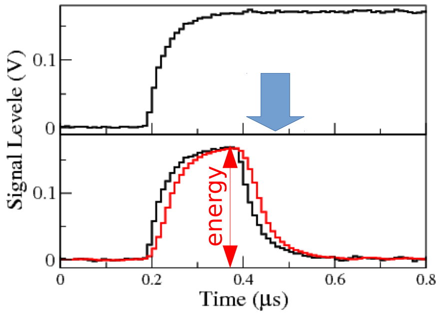
We need high-resolution detector capable of:

- **high primary interaction rate (10 MHz) and larger event size (~20 kB);**
- **smart data filtering: BG events have similar topology with the events of interest;**

Data-reduction rate by a factor of 1000 is required!

Readout Approach for PANDA

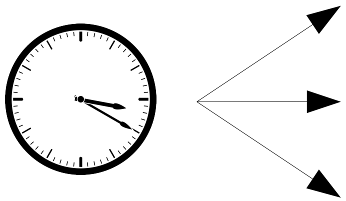
The PANDA readout consist of:



- **Intelligent self-triggered front-end**:
  autonomous hit detection and data pre-processing (e.g. based on
  Sampling **A**nalogue to **D**igital **C**onverter)

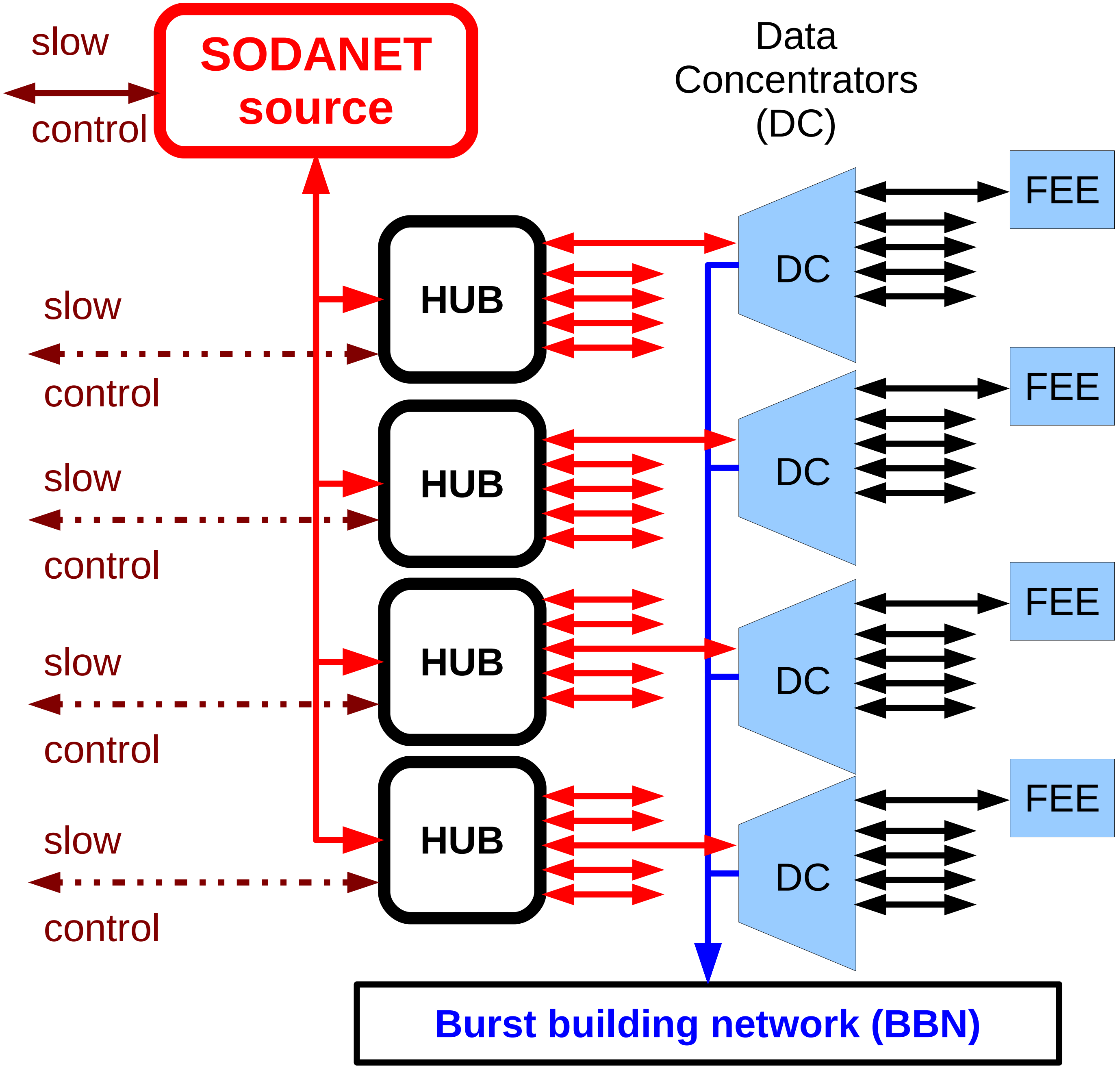
100101101

- **a very precise time distribution system (Synchronization Of DAq NETwork)**:
  single clock-source for PANDA (event correlation)



- **time-sorting and processing data in real-time**:
  processing in FPGA (**F**ield-**P**rogrammable **G**ate **A**rray)

SODANET Topology



SODANET link:

- Bidirectional
- Synchronous (only in one direction)
- Transfer:
  - source → DC: synchronization information and FEE configuration
  - DC → source: slow control, used for time calibration

Data link (DC → BBN):

- Unidirectional

Link DC ↔ FEE:

- Bidirectional, synchronous
- Protocol up to subsystem

SODANET

SODANET provides:

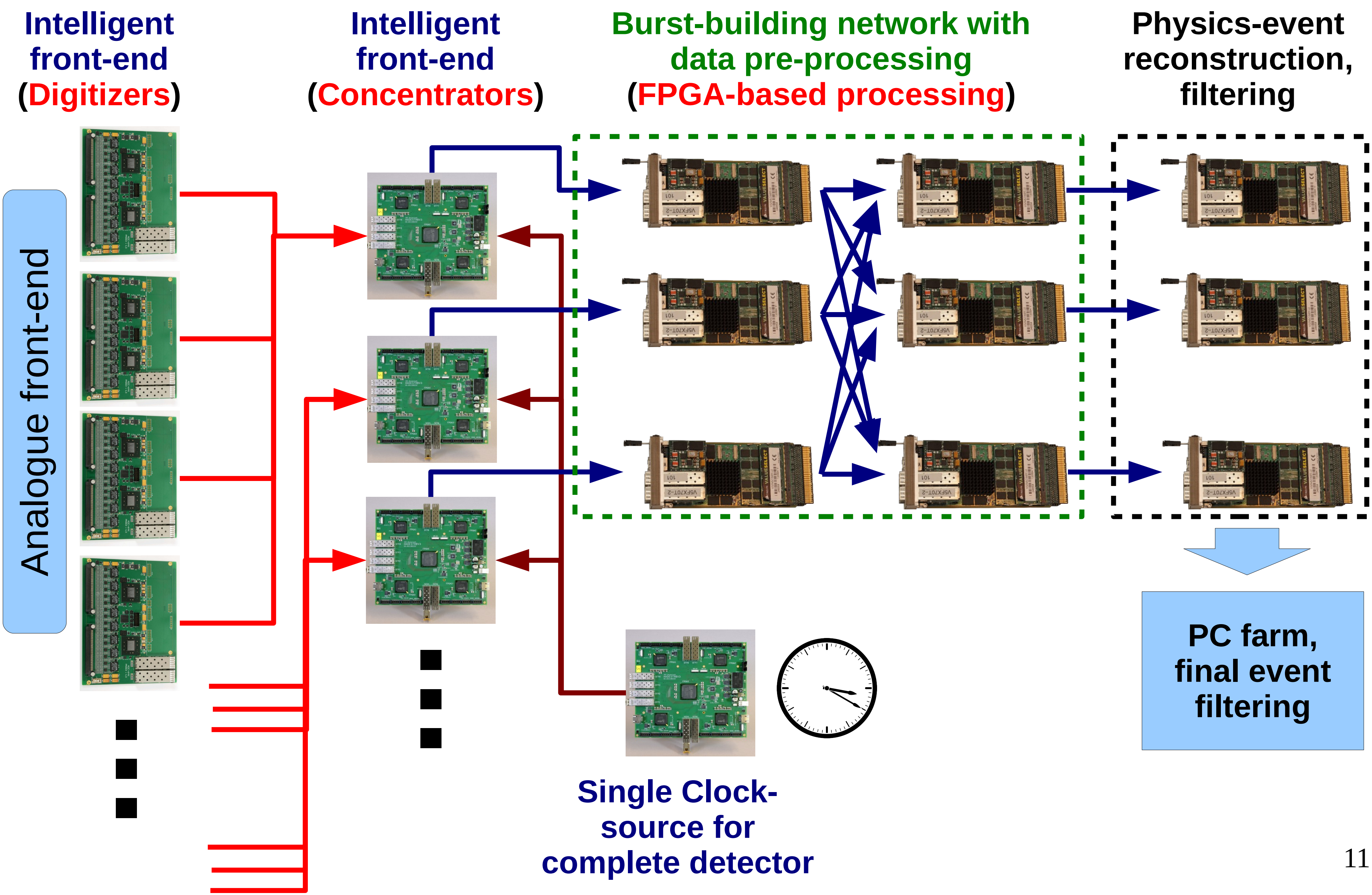
- **Clocking and synchronisation**
- **Slow control of FEE**
- **Bunching of collected data**

SODANET implemented for FPGA-based electronics interconnected with optical (serial) links:

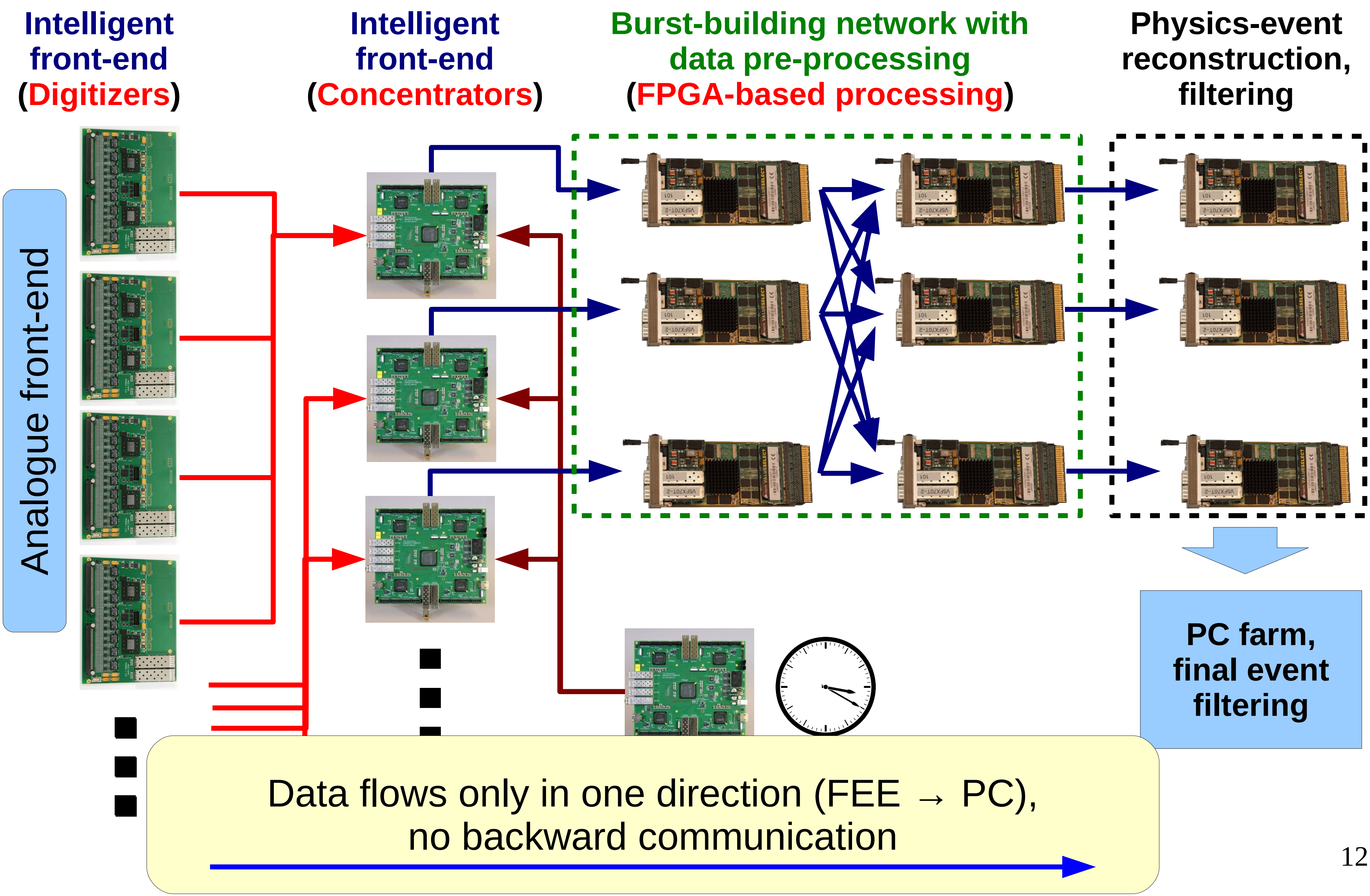
- **Lattice ECP3**
- **Xilinx Kintex 7**
- **Xilinx Virtex 6**

The SODANET system is stable in long terms with precision ~30 ps

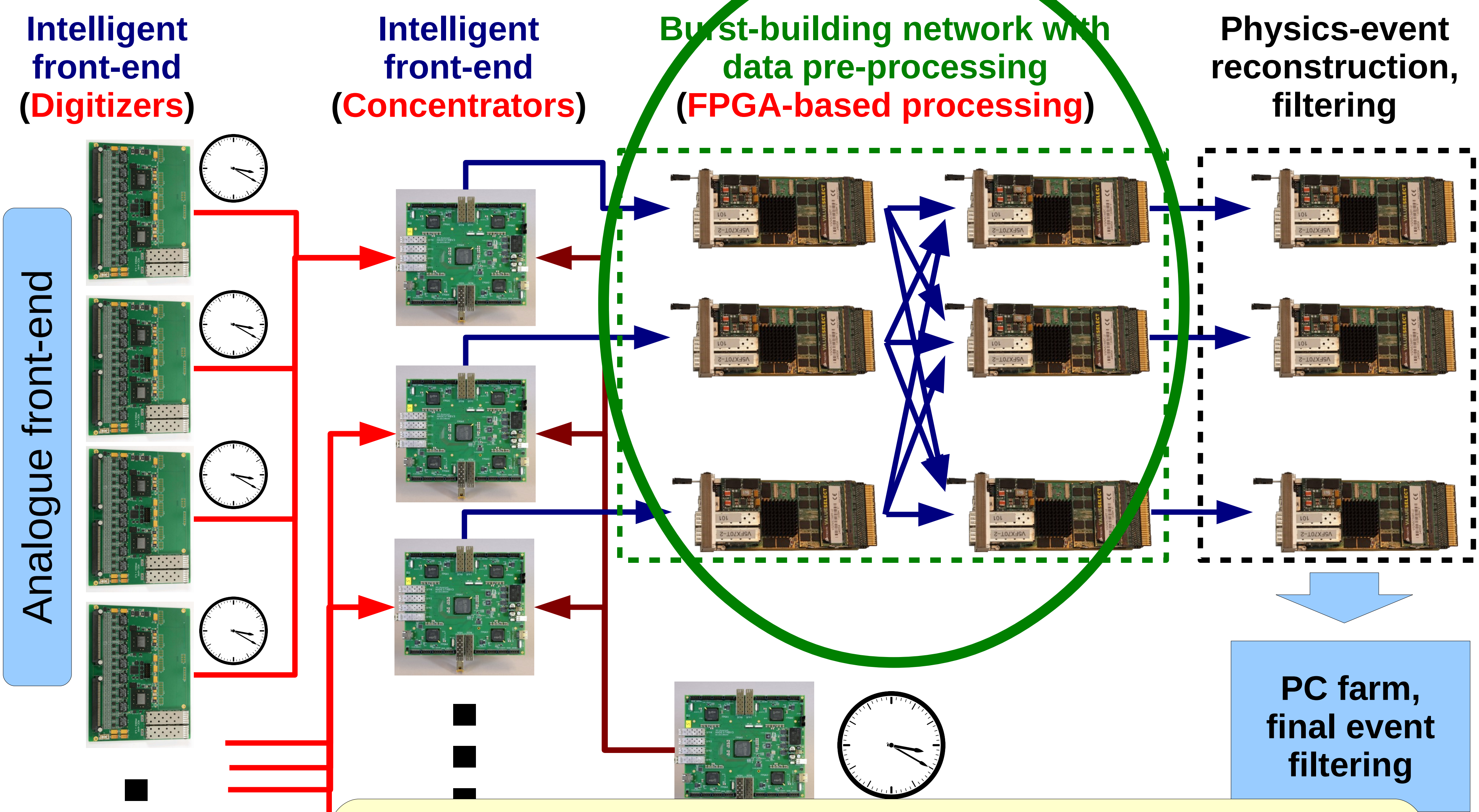
Push-Only Readout



Push-Only Readout

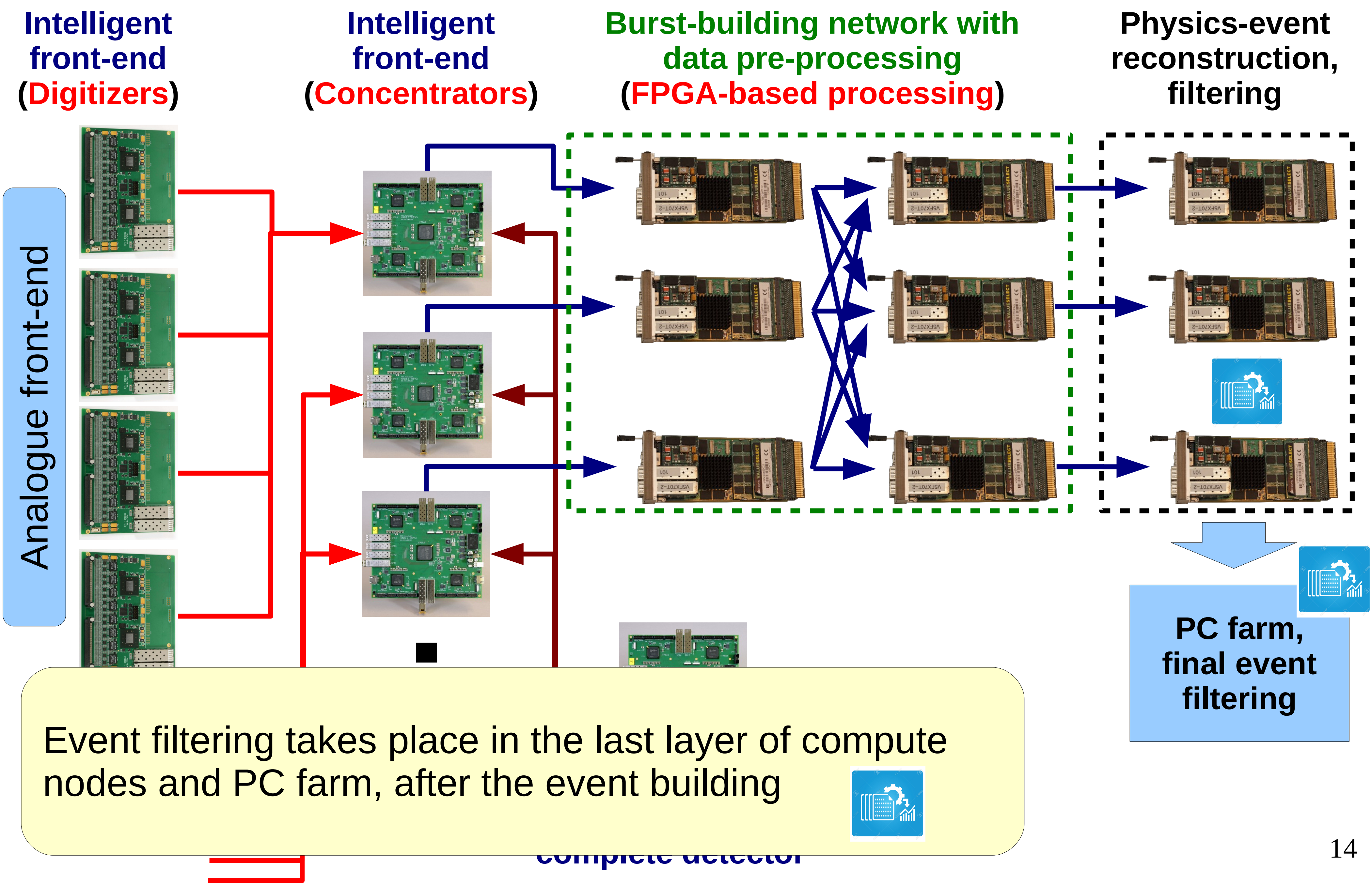


Push-Only Readout



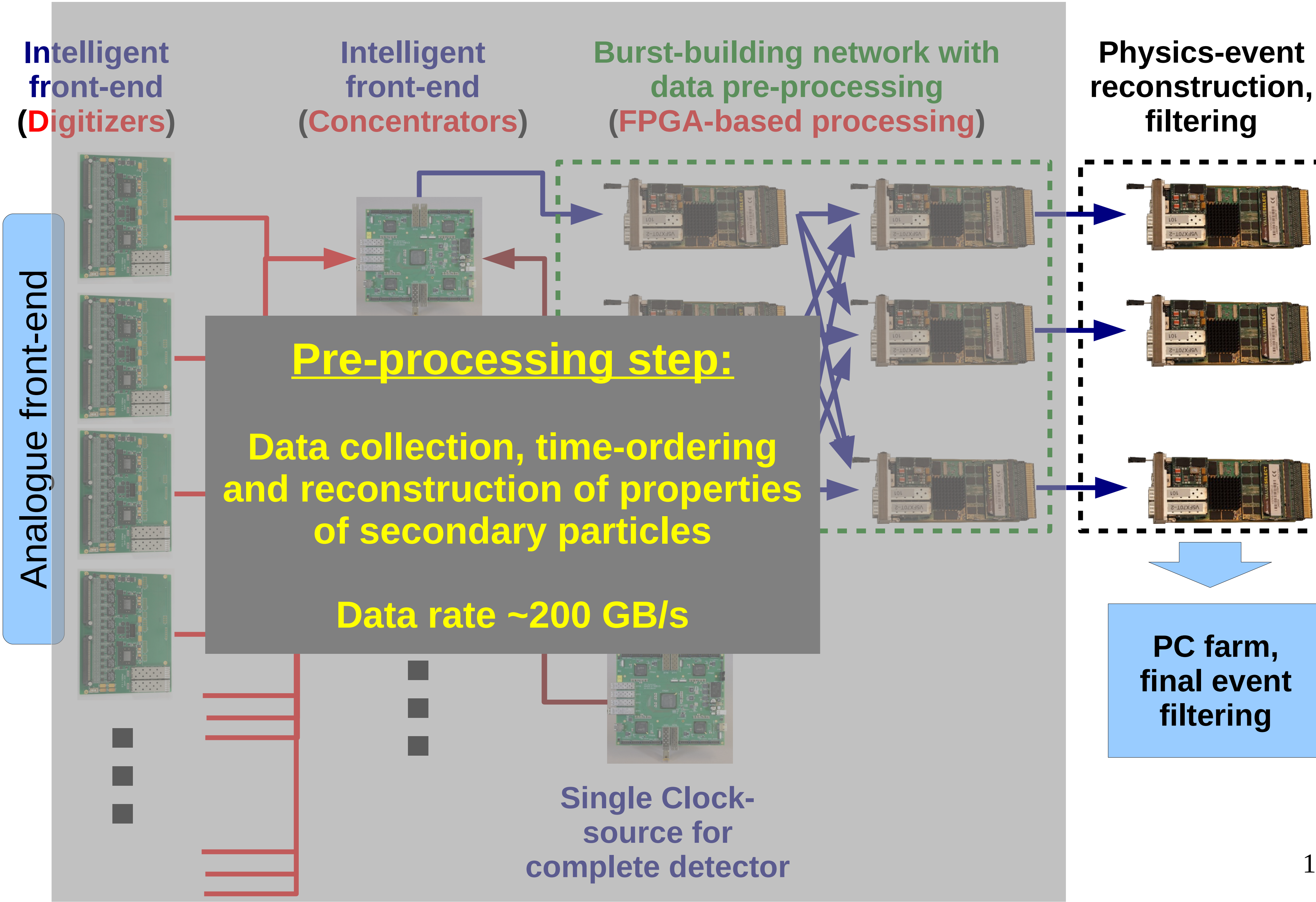
All hits have precise time-stamps which are used for **event building (SODANET)**

Push-Only Readout

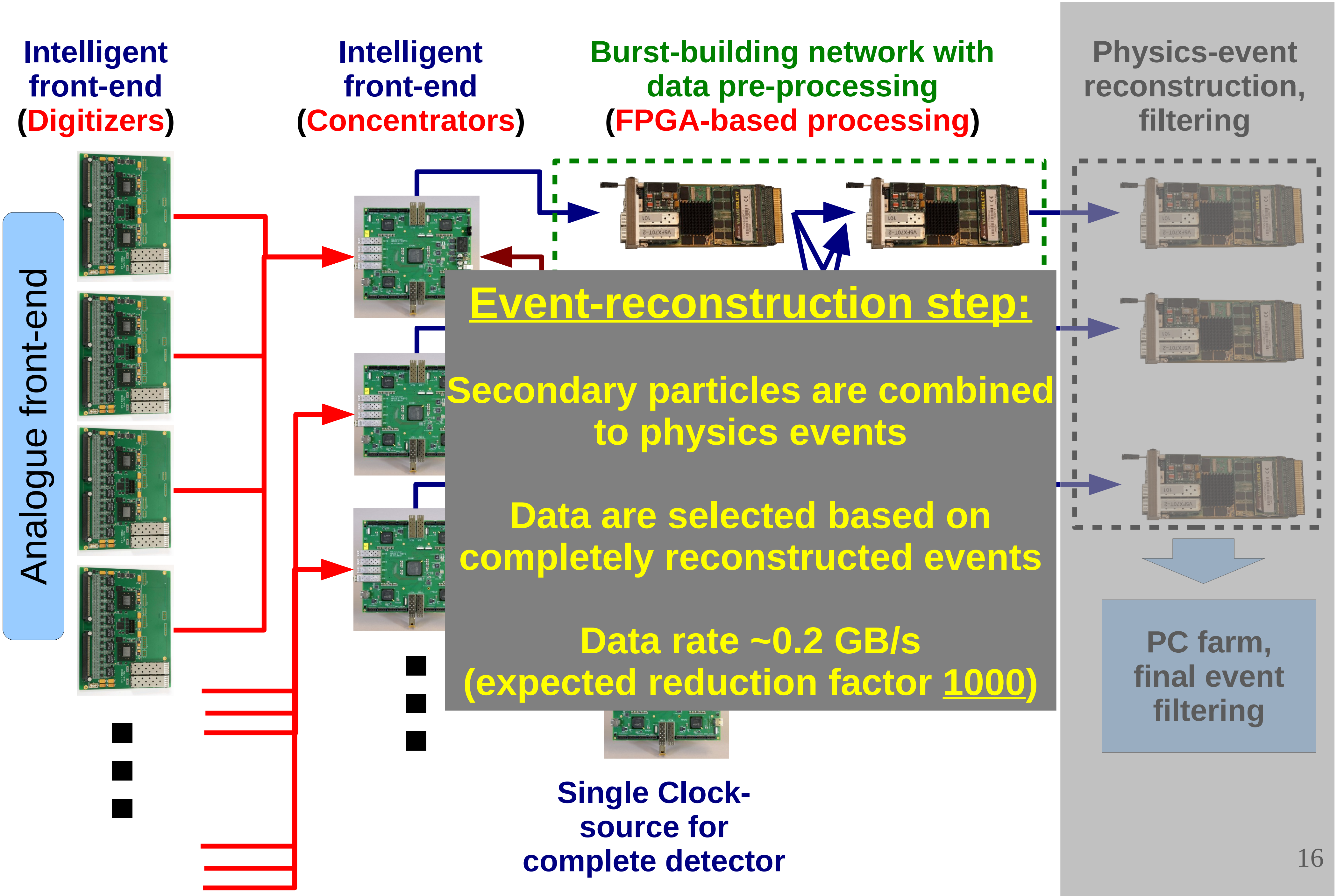


Event filtering takes place in the last layer of compute nodes and PC farm, after the event building

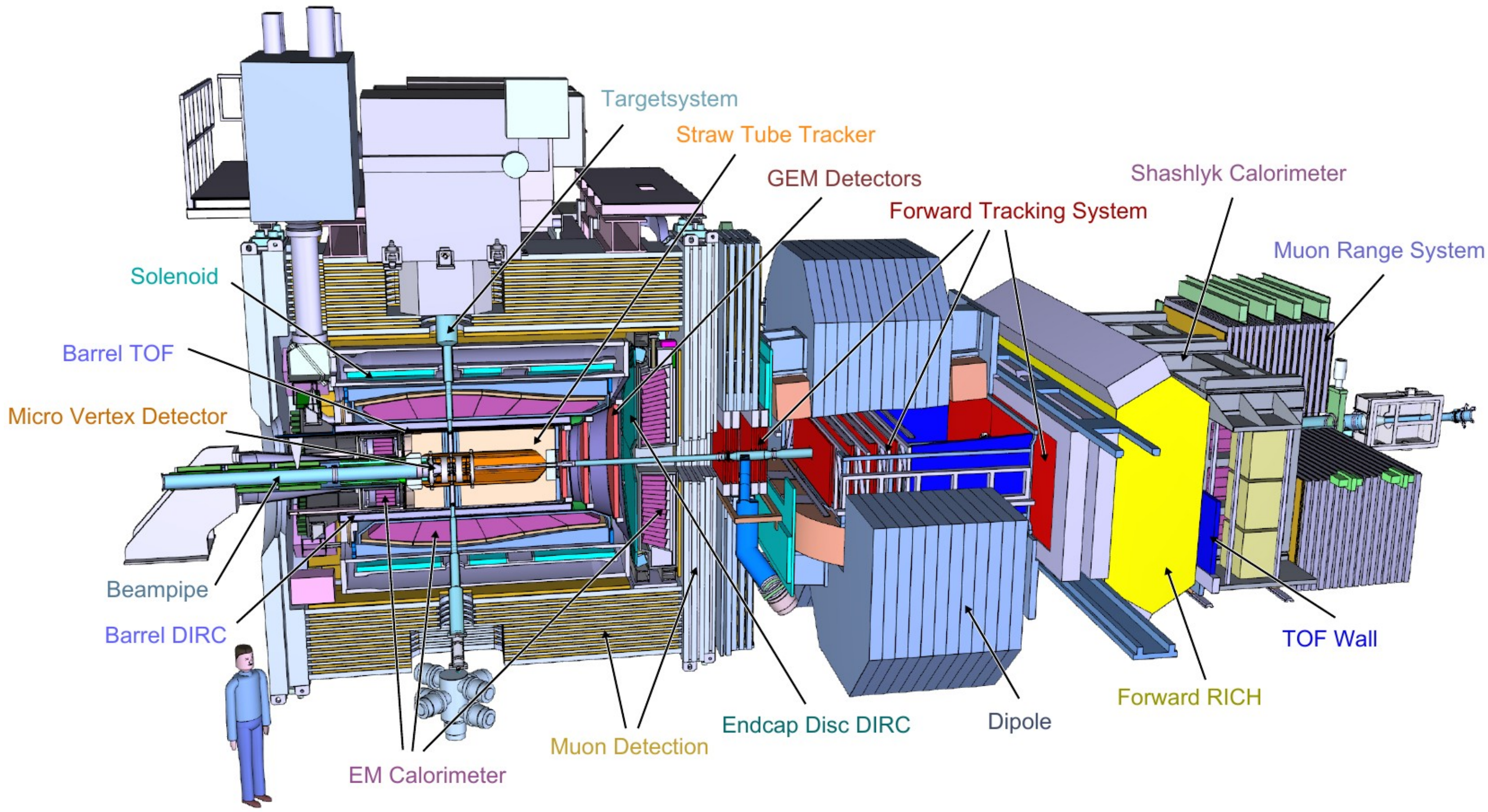
Push-Only Readout



Push-Only Readout



The PANDA detector



Readout of the ElectroMagnetic Calorimeter (EMC)

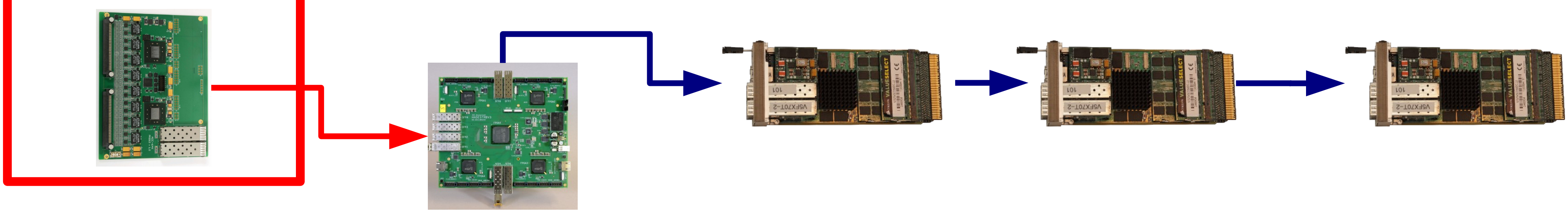
EMC Front-End Electronics

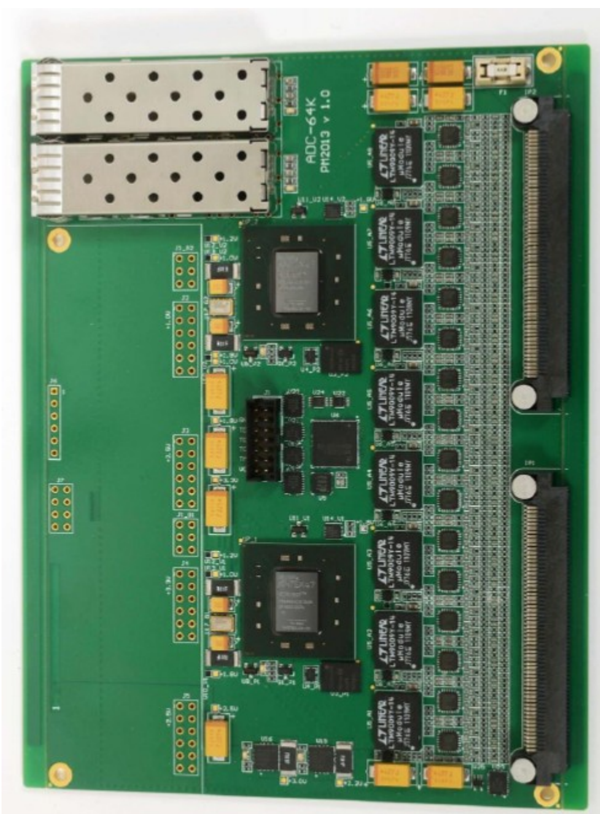
Intelligent front-end (Digitizers)

Intelligent front-end (Concentrators)

Burst-building network with data pre-processing (FPGA-based processing)

Physics-event reconstruction, filtering

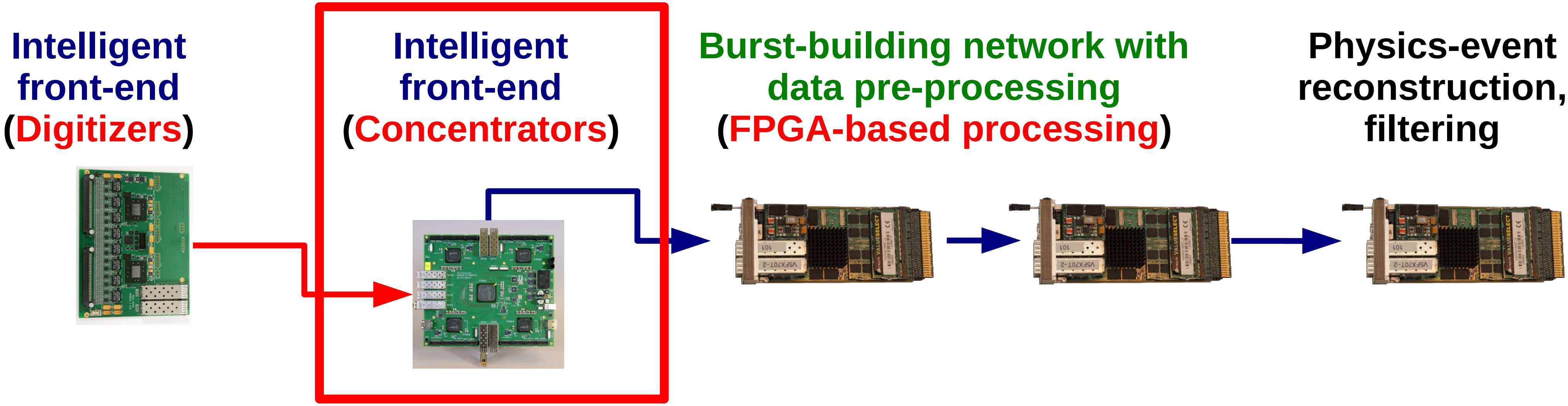




EMC intelligent front-end:

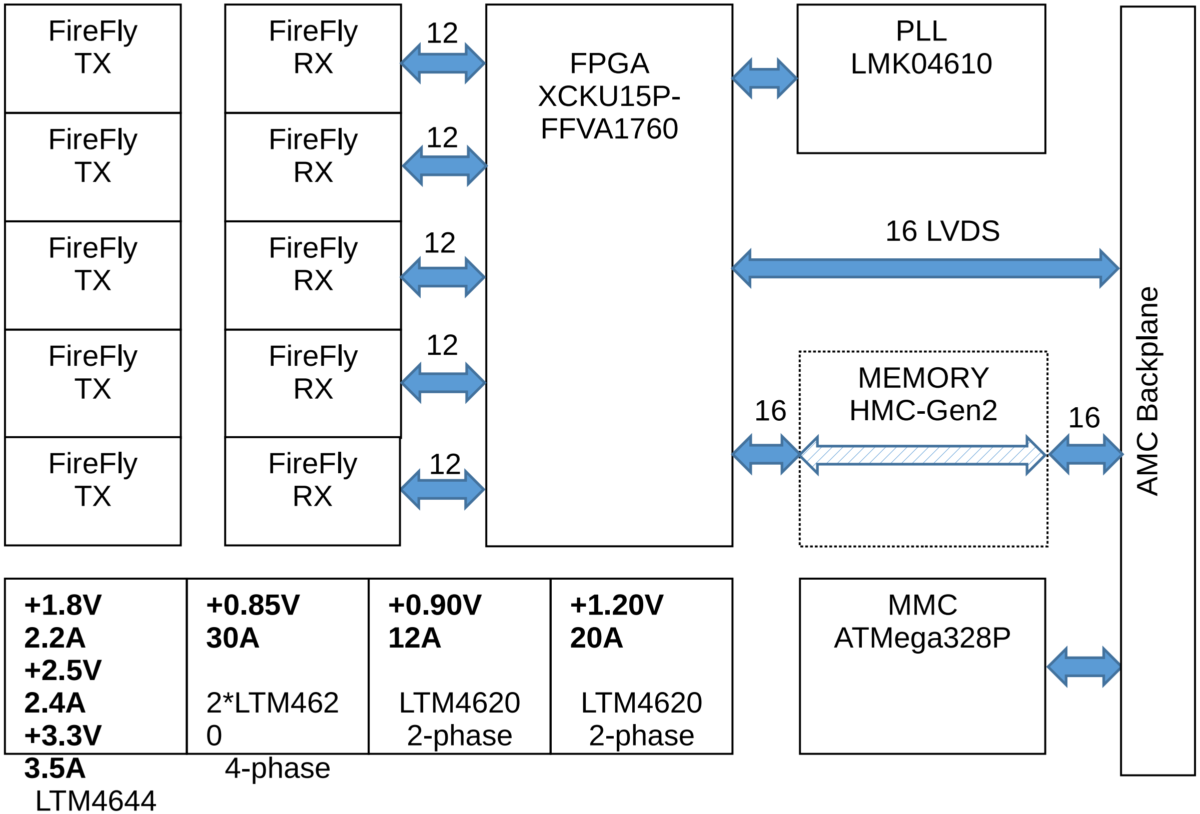
- MWD filtering (programmable)
- Base-line follower
- Pulse detection
- Pile-up detection and recovery
- Precise time
- Precise energy (amplitude, integral)
- Diagnostics: Possibility to readout raw ADC data (access to the noise-level measurement)
- Controlled readout of waveforms
- Self-monitoring for configuration errors, fast recovery procedure

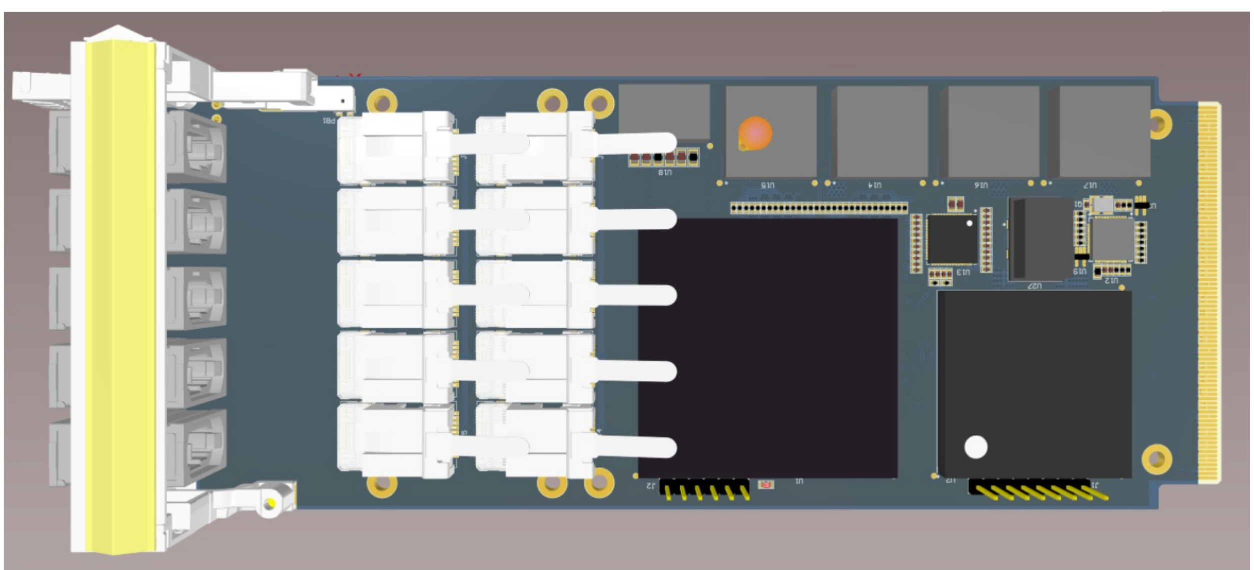
Data Concentrator



- **Data concentrator:**
  - Running on TRB3 and **Xilinx Kintex-7 development** boards
  - Receiving Waveforms and Hit-data over fiber from FEE
  - **Energy calibration for each ADC channel**
  - **Packet building (per burst)**
  - **Slow Control with SODANET**
  - **Combine hits from two digitizers corresponding to the same crystal**
  - Additional features: on-line histogram, data monitoring (hits and waveforms), error detection and counting
  - **Pre-clustering**

Data-Concentrator Hardware





Hardware specifications:

- AMC board
- Kintex Ultrascale+ FPGA
- 60 optical links (12 Gbit/s)
- 16 high-speed serial links to backplane

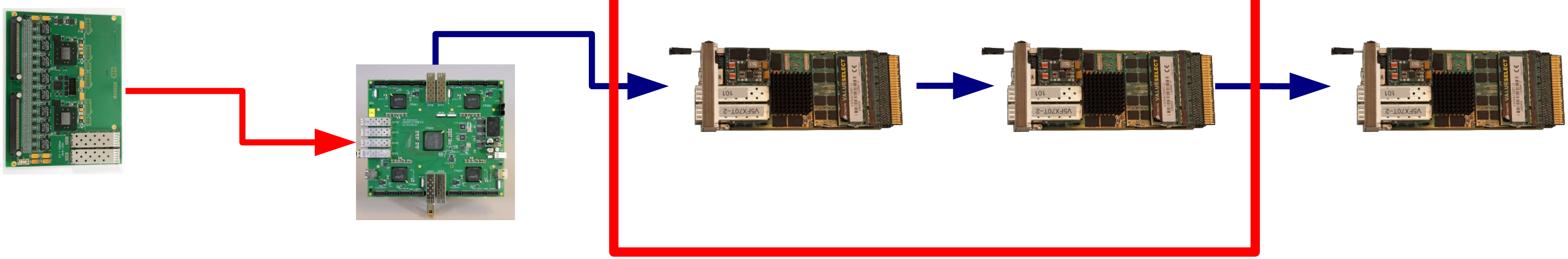
Data-Concentrator Hardware

Intelligent front-end (Digitizers)

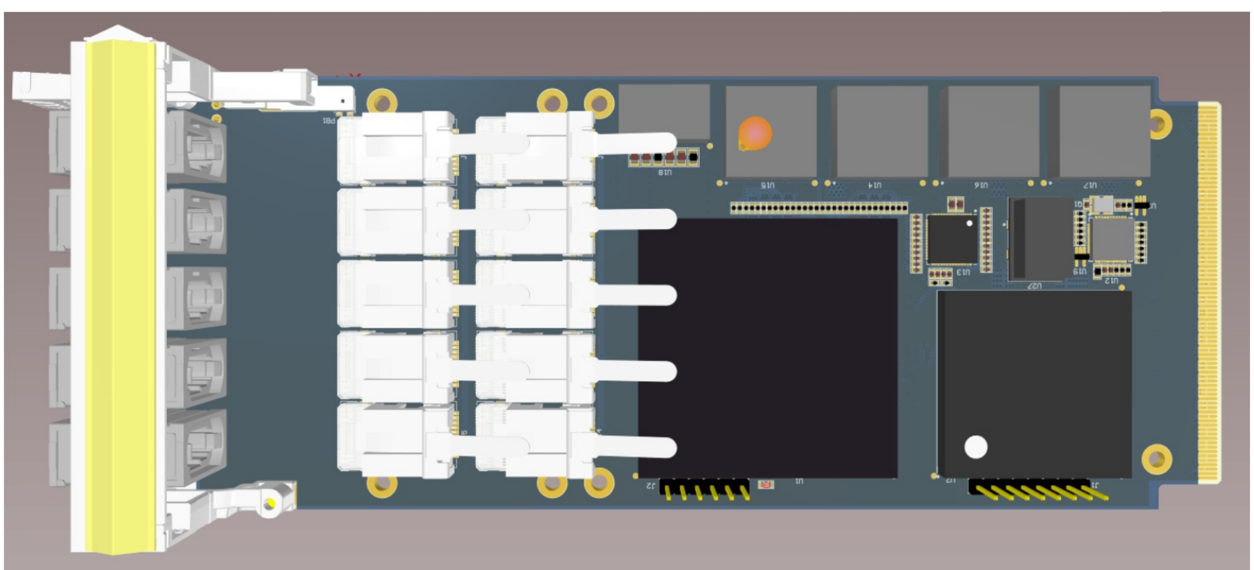
Intelligent front-end (Concentrators)

Burst-building network with data pre-processing (FPGA-based processing)

Physics-event reconstruction, filtering



Same hardware will be used to construct the "burst-building" network



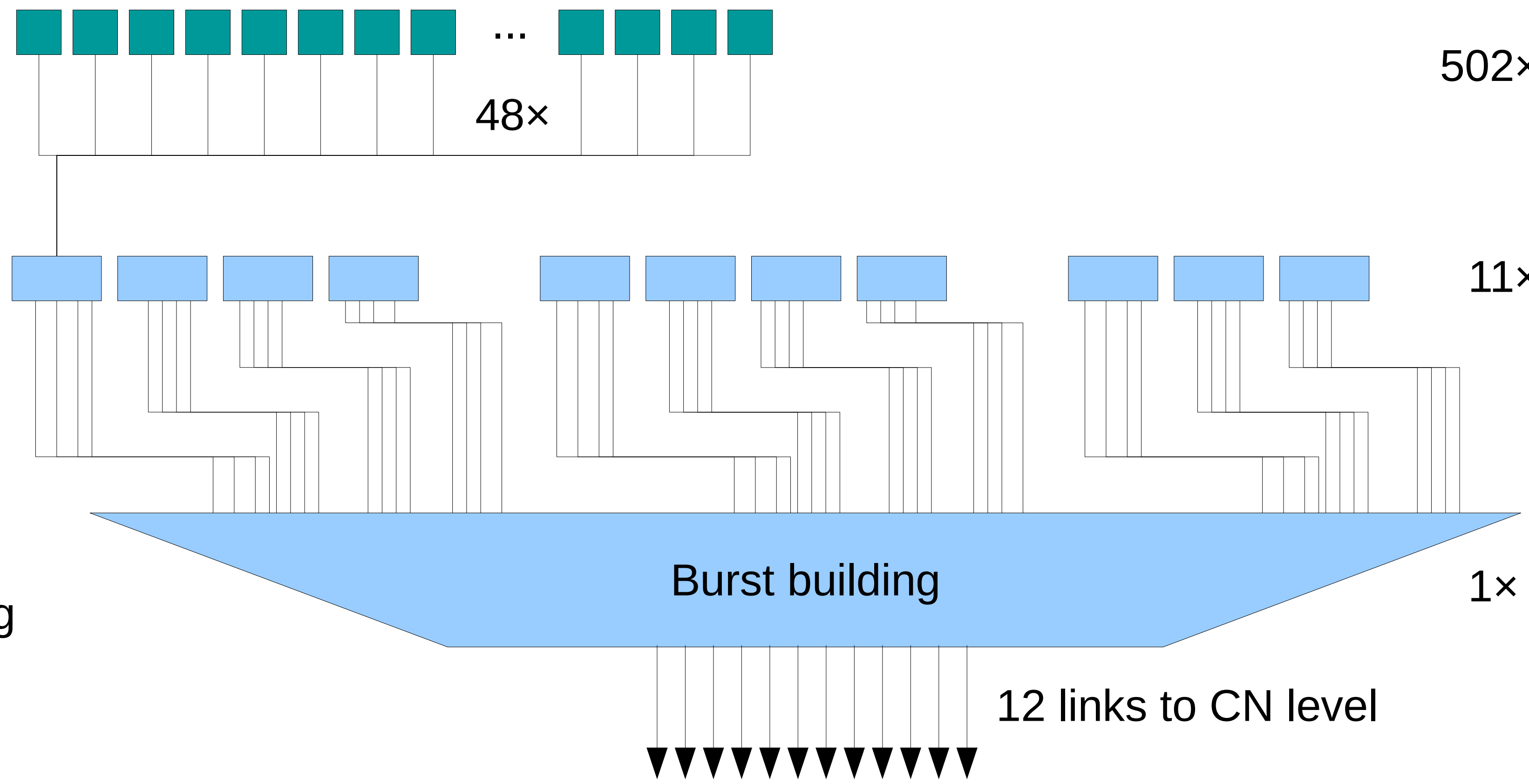
Readout Overview

DAQ level | **Connection topology** | **Hardware**

Digitizers, hit-detection readout units — 502× RU

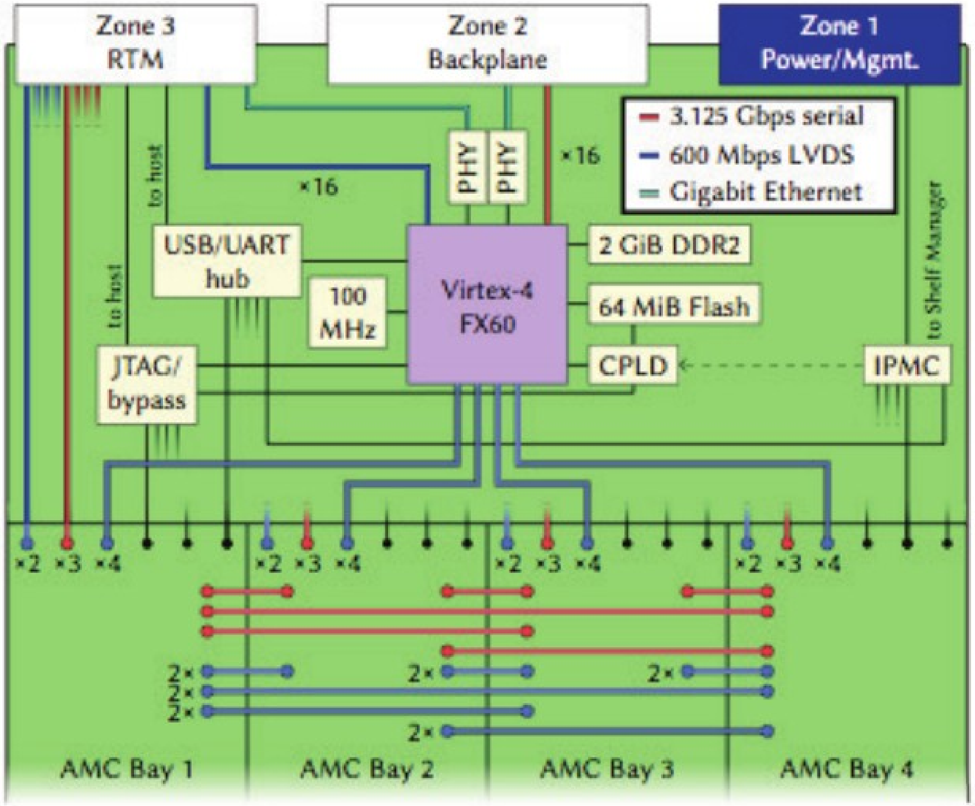
Data concentrators — 11× DC

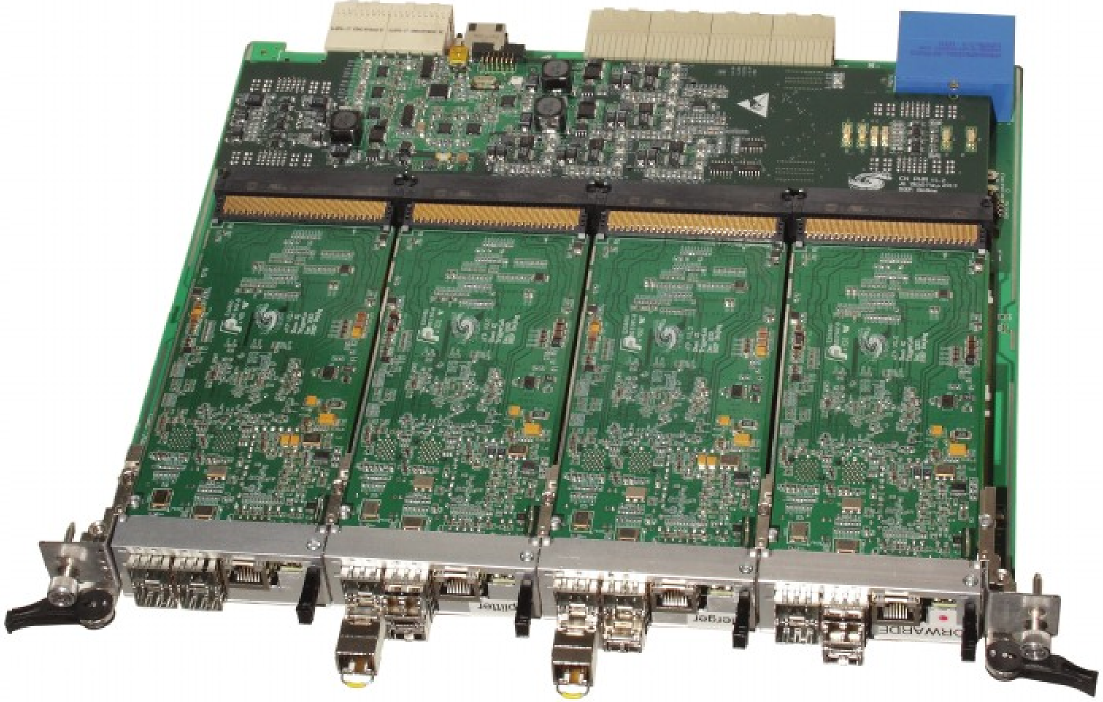
Burst building — 1× DC

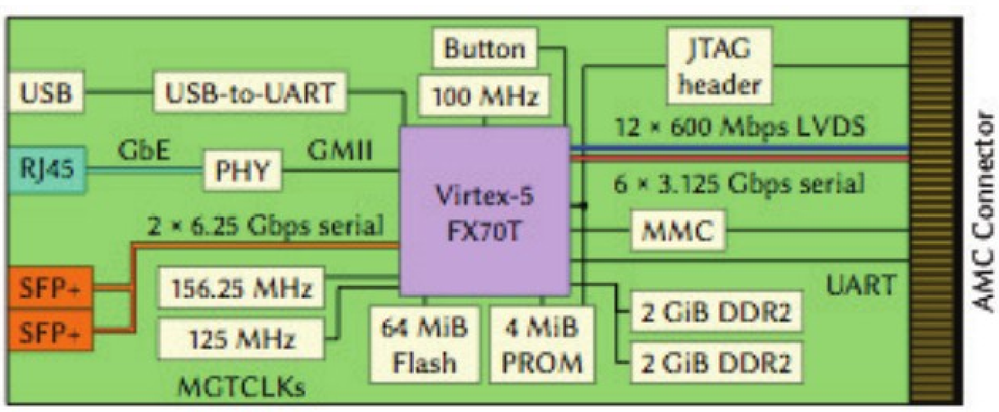


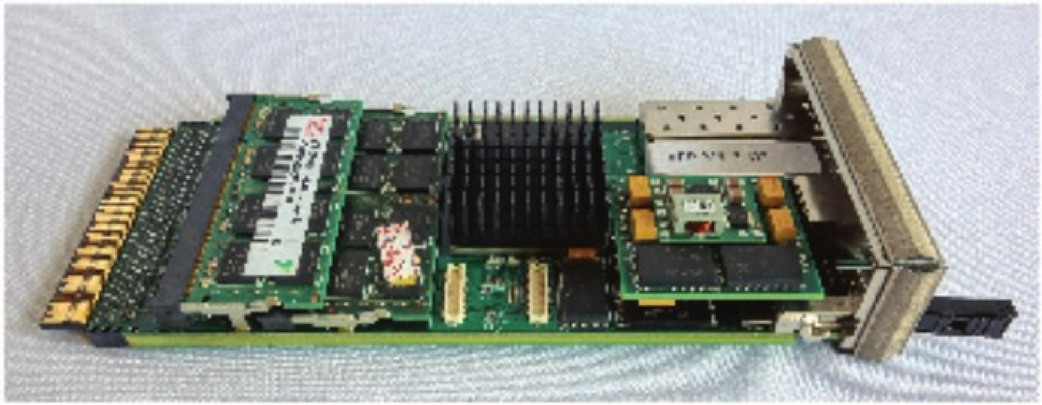
Final clustering and event selection is performed at the Compute-Node level

FPGA-based Compute Node

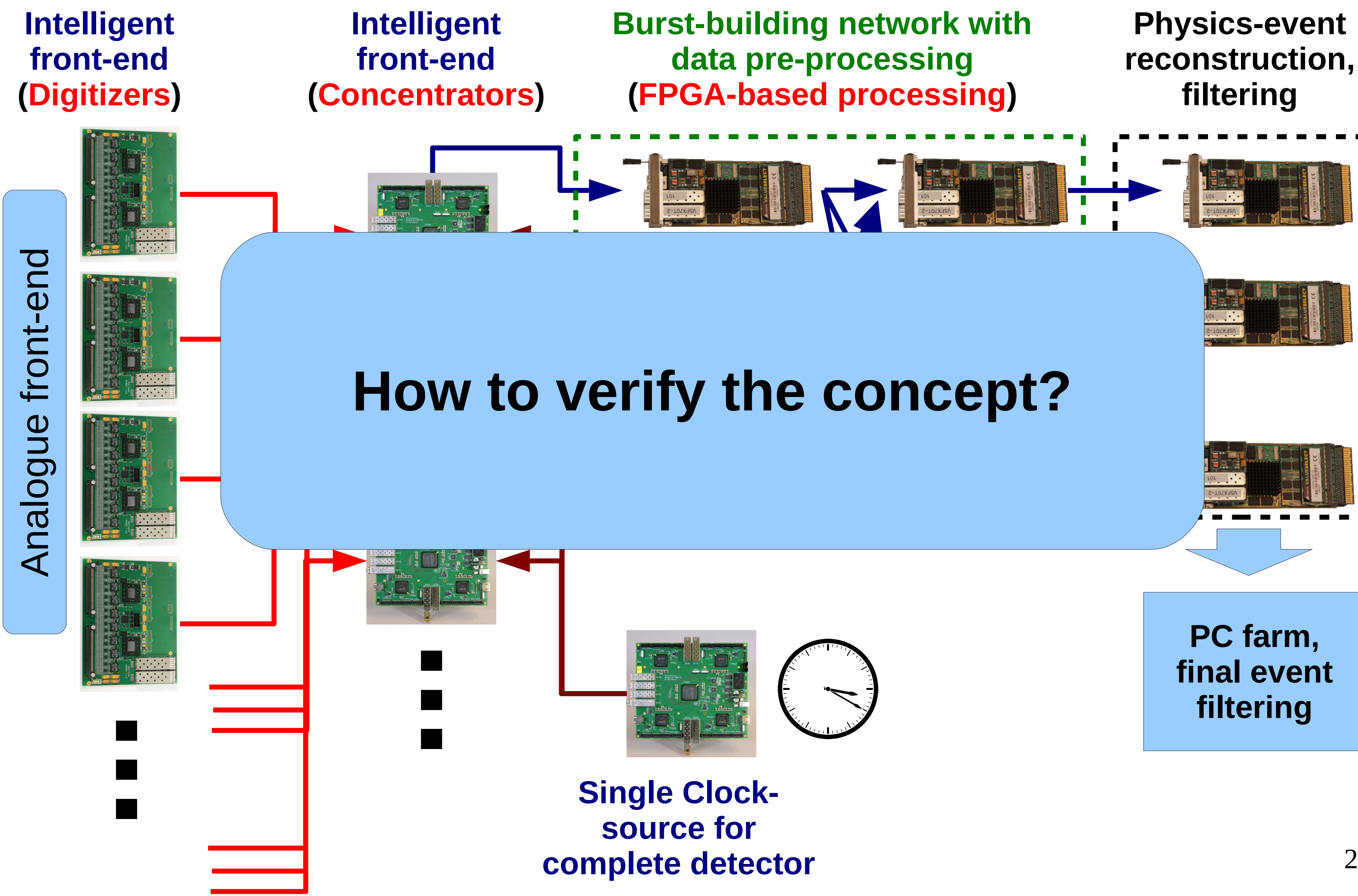




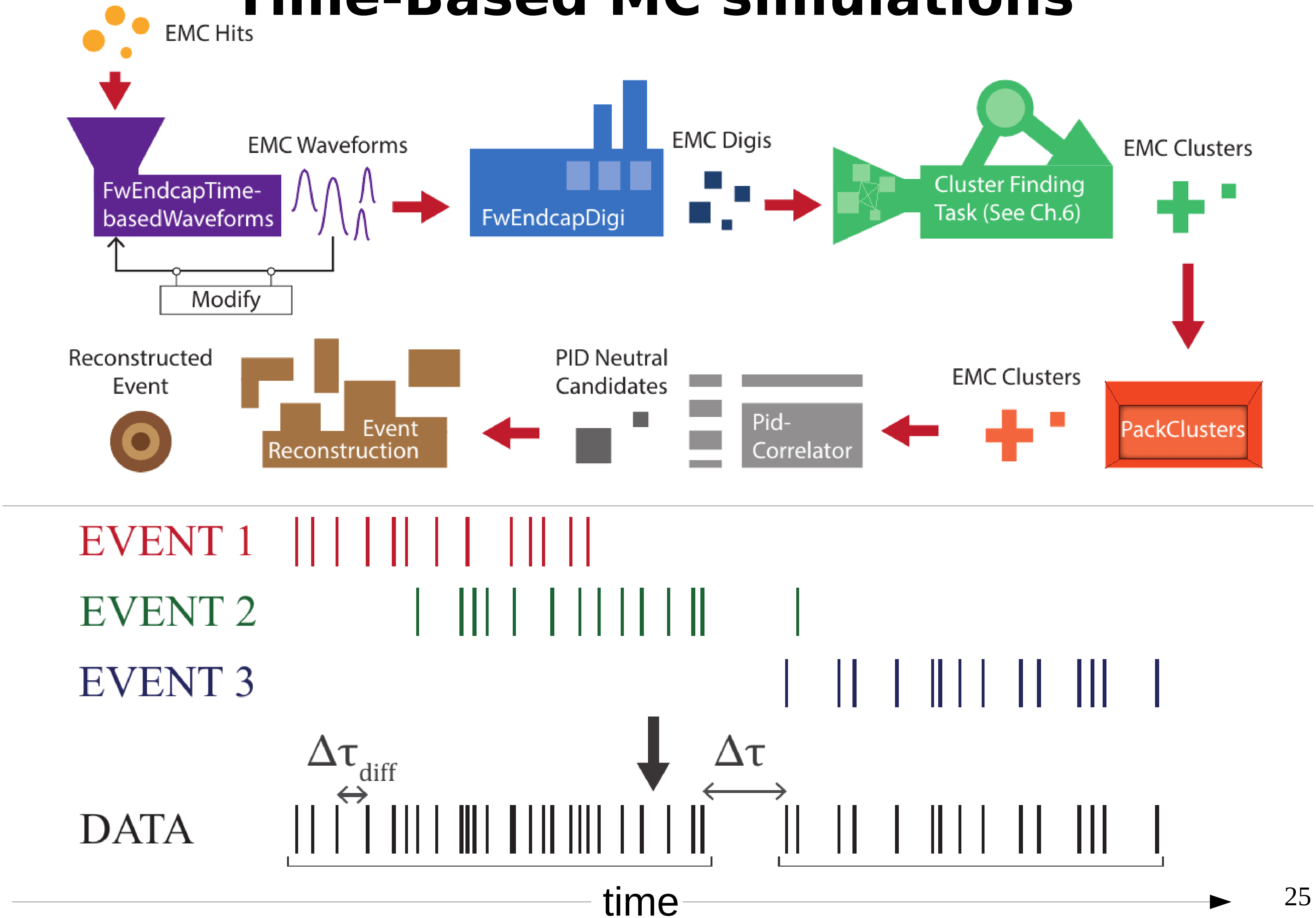




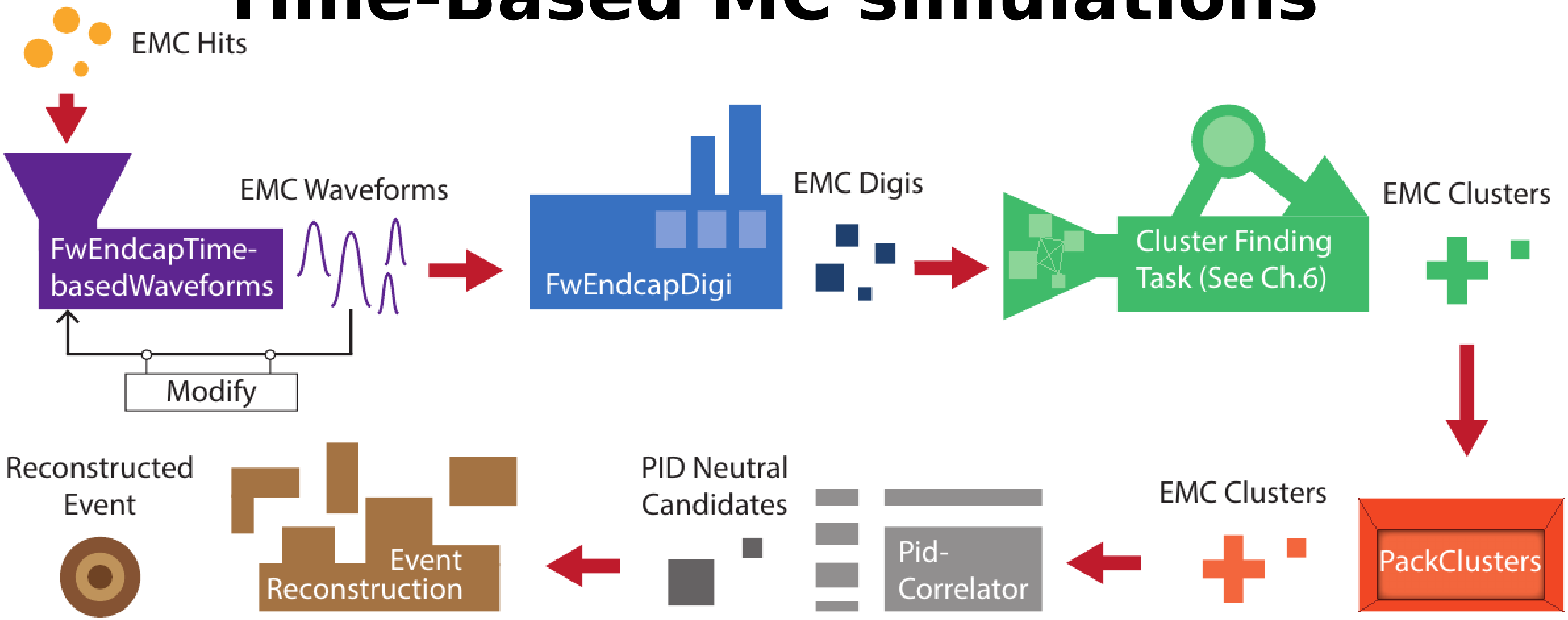
Push-Only Readout

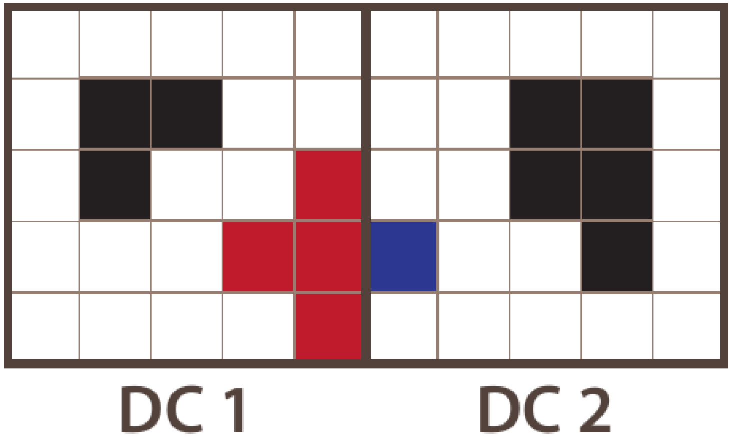


Time-Based MC simulations



Time-Based MC simulations



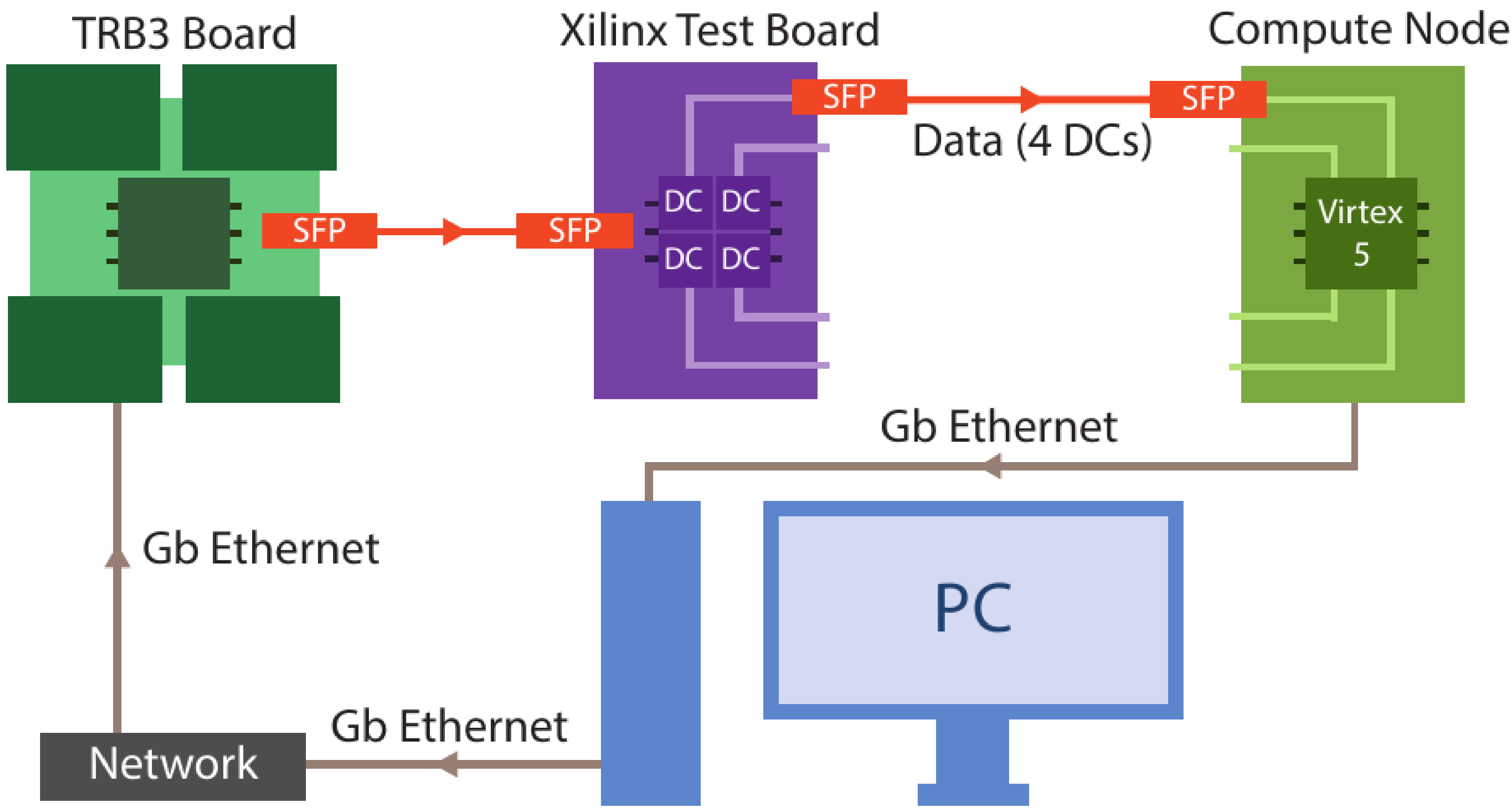


EMC clustering:

- Pre-clustering at the level of DC
- Final clustering in CN

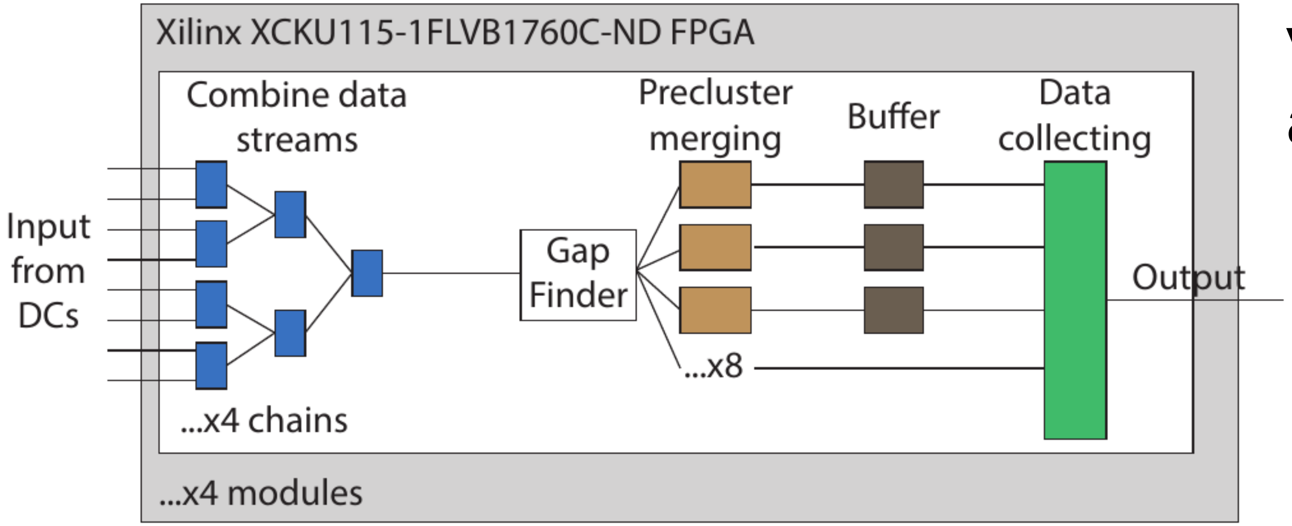
Readout Verification (EMC clustering)

Block-diagram of the verification setup



Input generated with the time-based MC simulations …
Output of hardware to be compared with offline processing ...

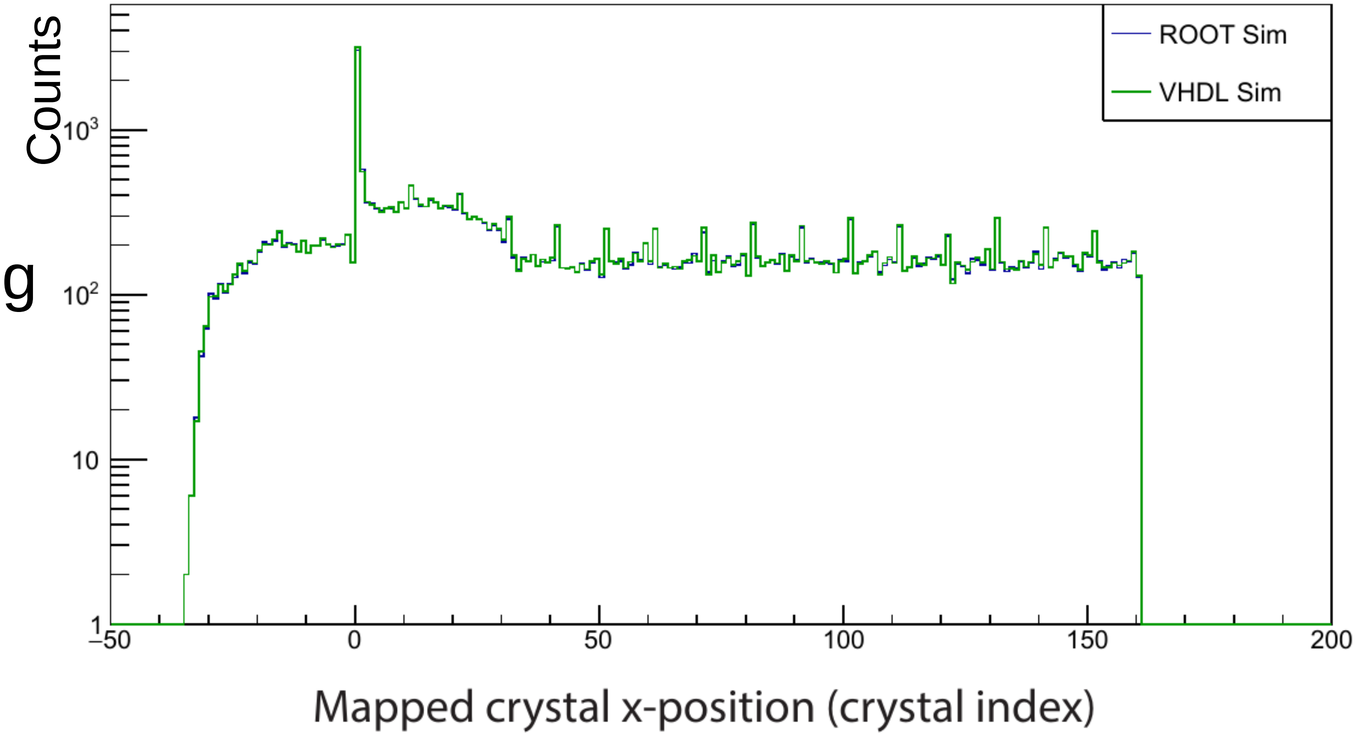
Readout Verification (EMC clustering)



VHDL implementation of a clustering IP core

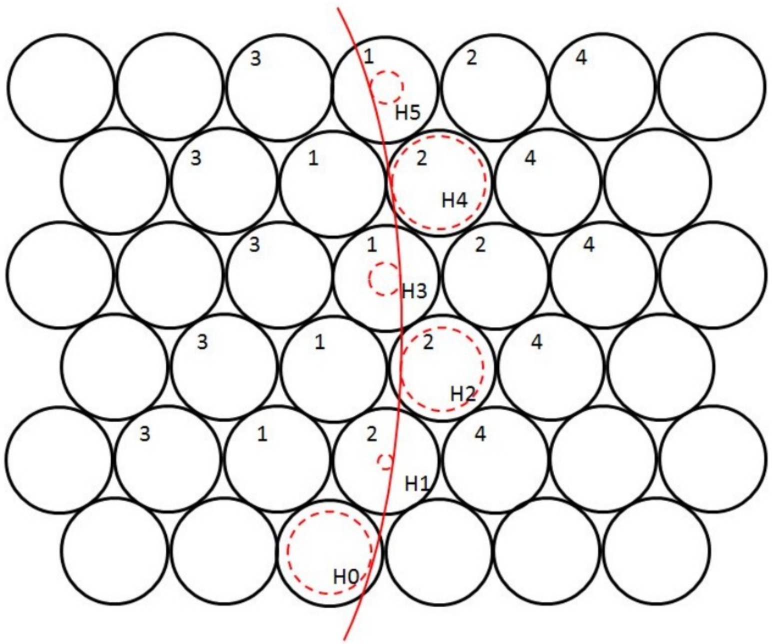
Comparison of:

- offline analysis;
- Hardware processing

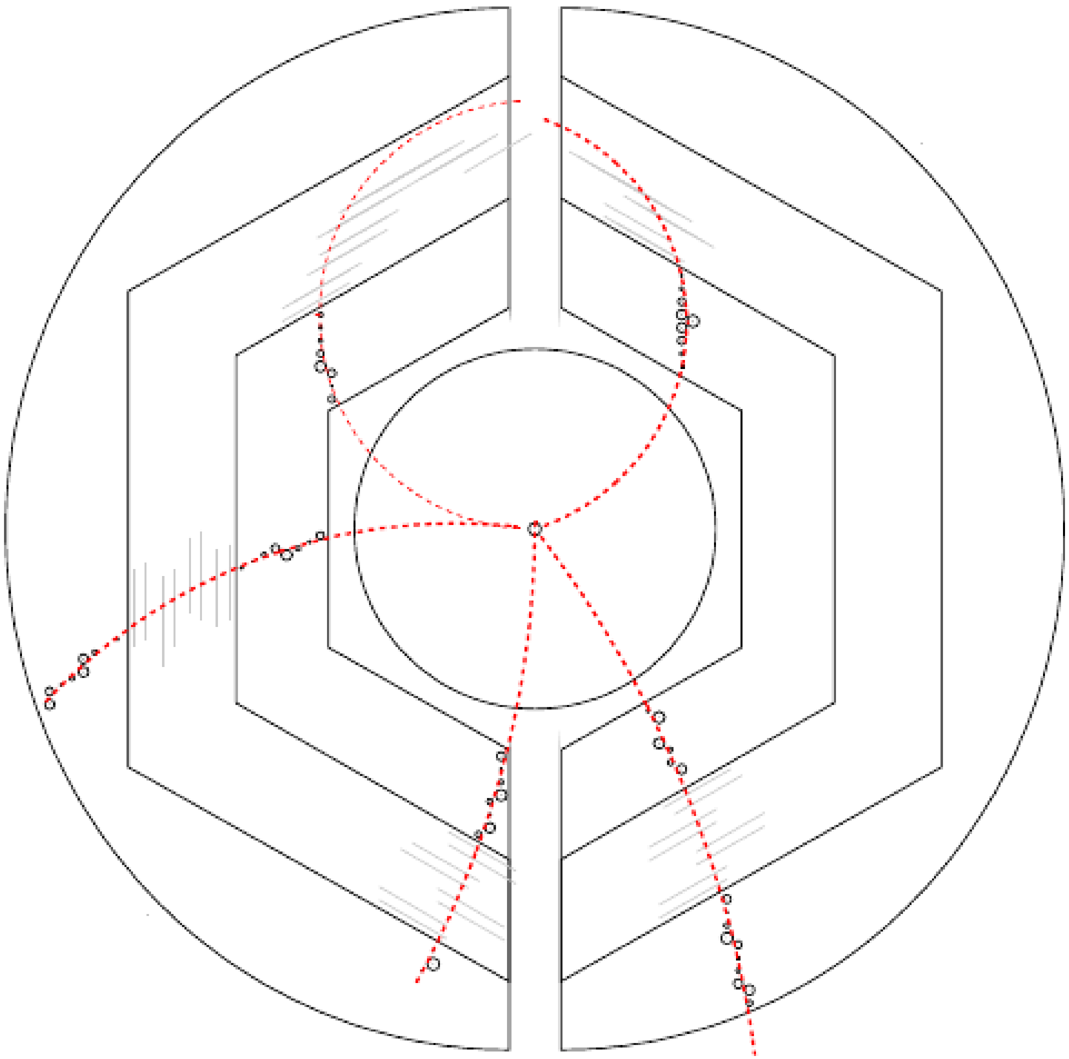


Readout Verification (STT tracking)

Track fitting with the Straw-Tube Tracker

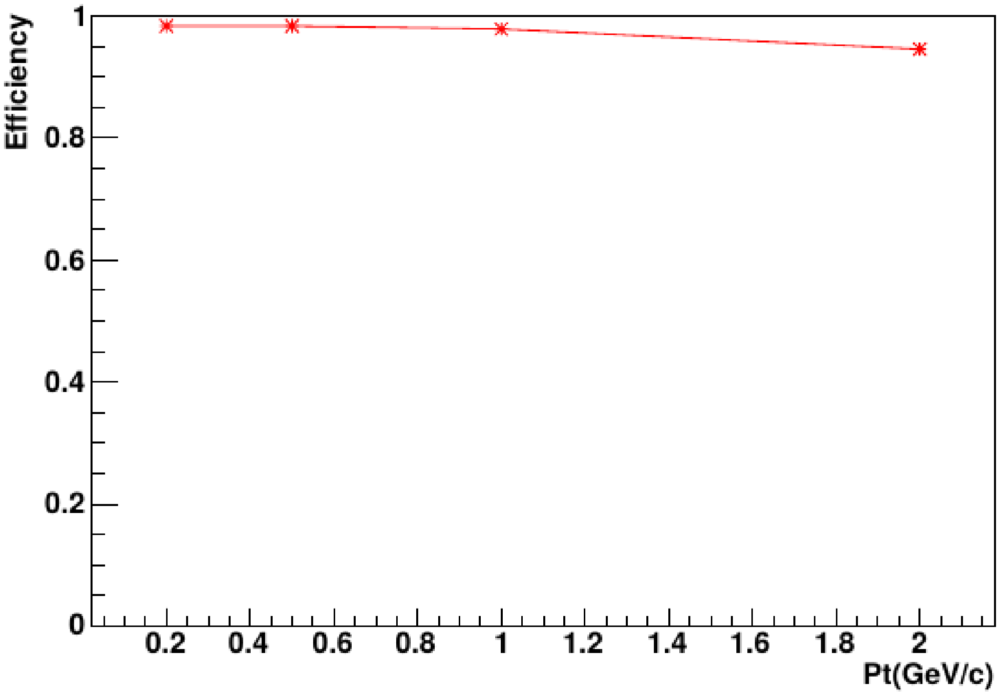


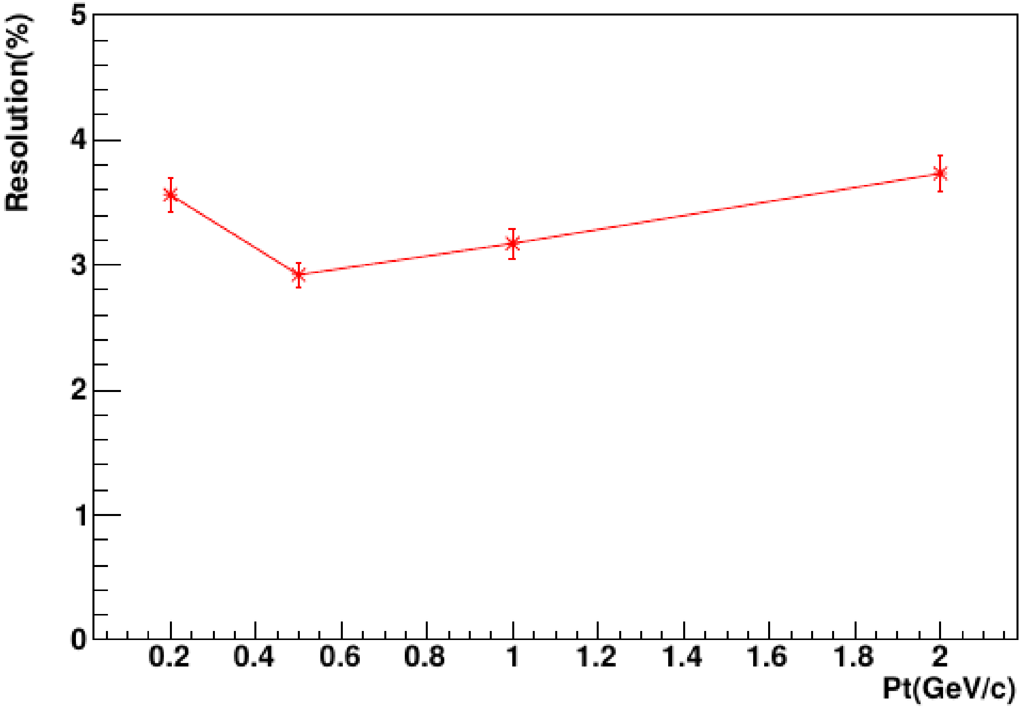
Typical fit performed by the online algorithm



Readout Verification (STT tracking)

The tracking efficiency and the resolution as a function of the transverse momentum.





Benchmark channels for event selection (low luminosity)

- Proof-of-principle benchmark channels
- Should cover various aspects of day-1 physics
- PhysCom decided on:

1. Small cross section case / charmonium:
   $\bar{p}p \rightarrow J/\psi(e^+e^- / \mu^+\mu^-)\ \pi^+\pi^-$ @ 3.872 GeV

2. Very small cross-section, exclusive / form factor physics:
   $\bar{p}p \rightarrow e^+e^-$ @ 2.254 GeV
   $\bar{p}p \rightarrow e^+e^-\ \pi^0$ @ 2.254 GeV

3. High cross section / hyperon physics:
   $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$ @ 2.304 GeV

- Single trigger lines (although should be simultaneous for J/ψ)
- Use mainly simple quantities, probably easy to determine online

Benchmark channels for event selection (low luminosity)

Goal: f_{tot} = 1000

Channel	Signal Efficiency ε_S[%]			BG suppr. f [×1000]		
	OFF	P1	D1	OFF	P1	D1
$\bar{p}p \rightarrow J/\psi(\mu^+\mu^-)\,\pi^+\pi^-$	56	56	56	38	34	**26**
$\bar{p}p \rightarrow J/\psi(e^+e^-)\,\pi^+\pi^-$	32	32	**25**	167	1000	1000
$\bar{p}p \rightarrow e^+e^-$	54	54	**41**	100	77	111
$\bar{p}p \rightarrow e^+e^-\pi^0$	36	36	**17**	3.8	3.7	6.4
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	30	30	30	**0.13**	**0.13**	**0.12**

- **We are convinced that for the phase-1 (low luminosity) the streaming-readout concept is working.**
- **For high-luminosity complete time-based simulations have to be used for the readout verification (event selection).**

PANDA physics

[*https://panda.gsi.de*]

Key questions

Nucleon properties

Exotic hadrons

In-medium [partly hidden]
properti[partly hidden]

Colour transp[partly hidden]

Neutron stars

Matter-antimatter
asymmetry

PANDA Physics Pillars

Nucleon structure

[partly hidden]ess physics

[partly hidden]and exotics

Hadrons in Nuclei

We are looking forward for the first results!

[*Karin Schoenning*]

Collaboration

UniVPM Ancona
U Basel
IHEP Beijing
U Bochum
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
U Cracow
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara

FIAS Frankfurt
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Gießen
U Glasgow
BITS Pilani KKBGC, Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
FH Iserlohn
FZ Jülich
IMP Lanzhou
INFN Legnaro
U Lund
HI Mainz

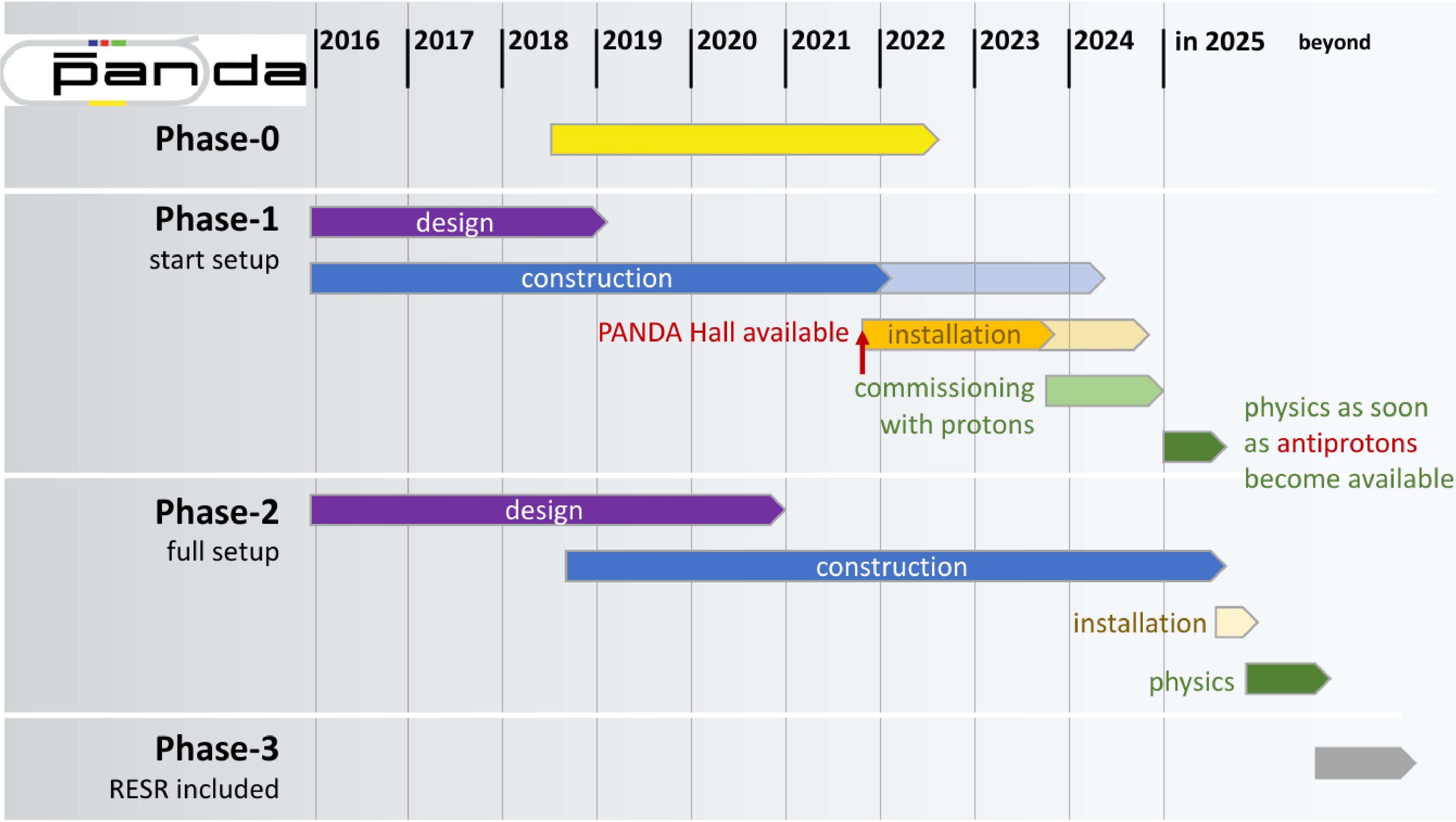
U Mainz
INP Minsk
ITEP Moscow
MPEI Moscow
BARC Mumbai
U Münster
Nankai U
BINP Novosibirsk
Novosibirsk State U
IPN Orsay
U Wisconsin, Oshkosh
U & INFN Pavia
Charles U, Prague
Czech TU, Prague
IHEP Protvino
Irfu Saclay
U of Sidney

PNPI St. Petersburg
West Bohemian U, Pilzen
KTH Stockholm
U Stockholm
SUT, Nakhon Ratchasima
SVNIT Surat-Gujarat
S Gujarat U, Surat-Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Uppsala
U Valencia
SMI Vienna
U Visva-Bharati
SINS Warsaw

more than 460 physicists from
from 75 institutions in 19 countries

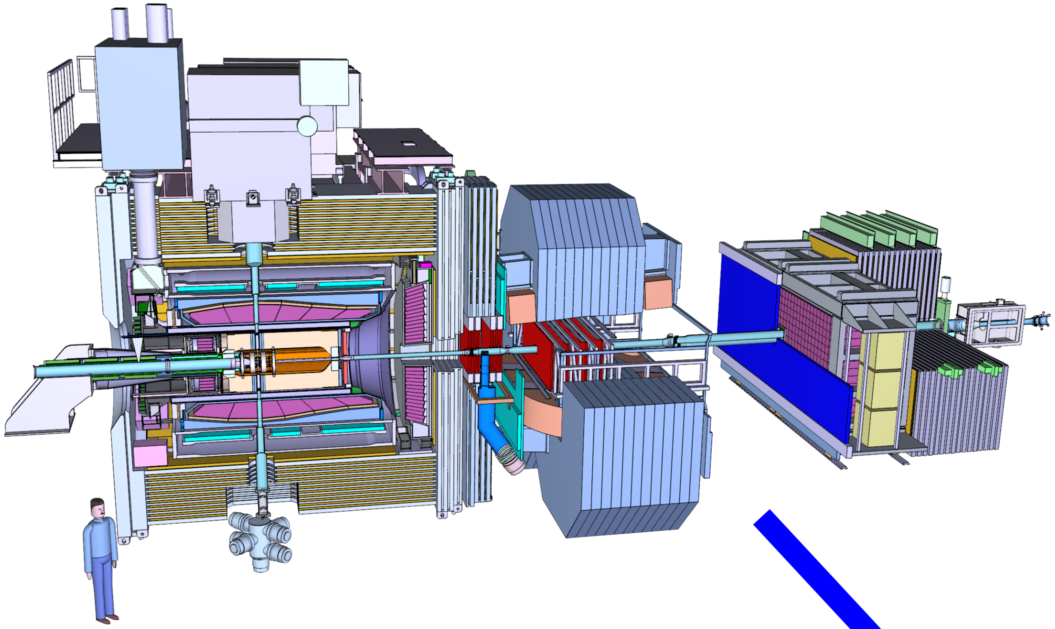
Thank you for your attention!

Planning



2016
2017
2018
2019
2020
2021
2022
2023
2024
in 2025
beyond
Phase-0
Phase-1
start setup
design
construction
PANDA Hall available
installation
commissioning
with protons
physics as soon
as antiprotons
become available
Phase-2
full setup
design
construction
installation
physics
Phase-3
RESR included

PANDA phases



PANDA start set-up
(phase 1, reduced luminosity)

PANDA full set-up
(phase 2, full luminosity)