Data Acquisition and Event Filtering

PANDA Physics

- HADRON SPECTROSCOPY
  - CHARMONIUM
  - GLUONIC EXCITATIONS
  - OPEN CHARM
  - STRANGE AND CHARMED BARYONS
- NUCLEON STRUCTURE
  - GENERALIZED DISTRIBUTION AMPLITUDES (GDA)
  - DRELL-YAN
  - ELECTROMAGNETIC FORM FACTORS
- HYPERNUCLEAR PHYSICS
- HADRONS IN THE NUCLEAR MEDIUM

Physics Performance Report for:

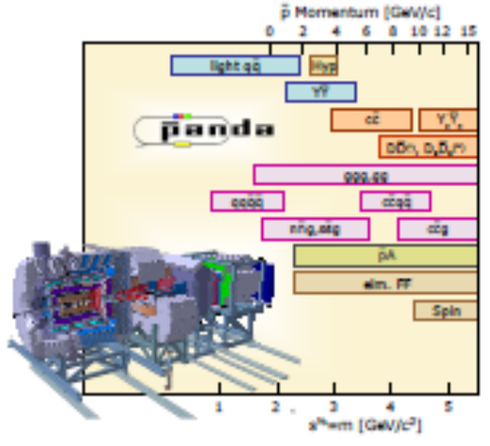
$\overline{\text{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

$\overline{\text{P}}$ANDA Collaboration

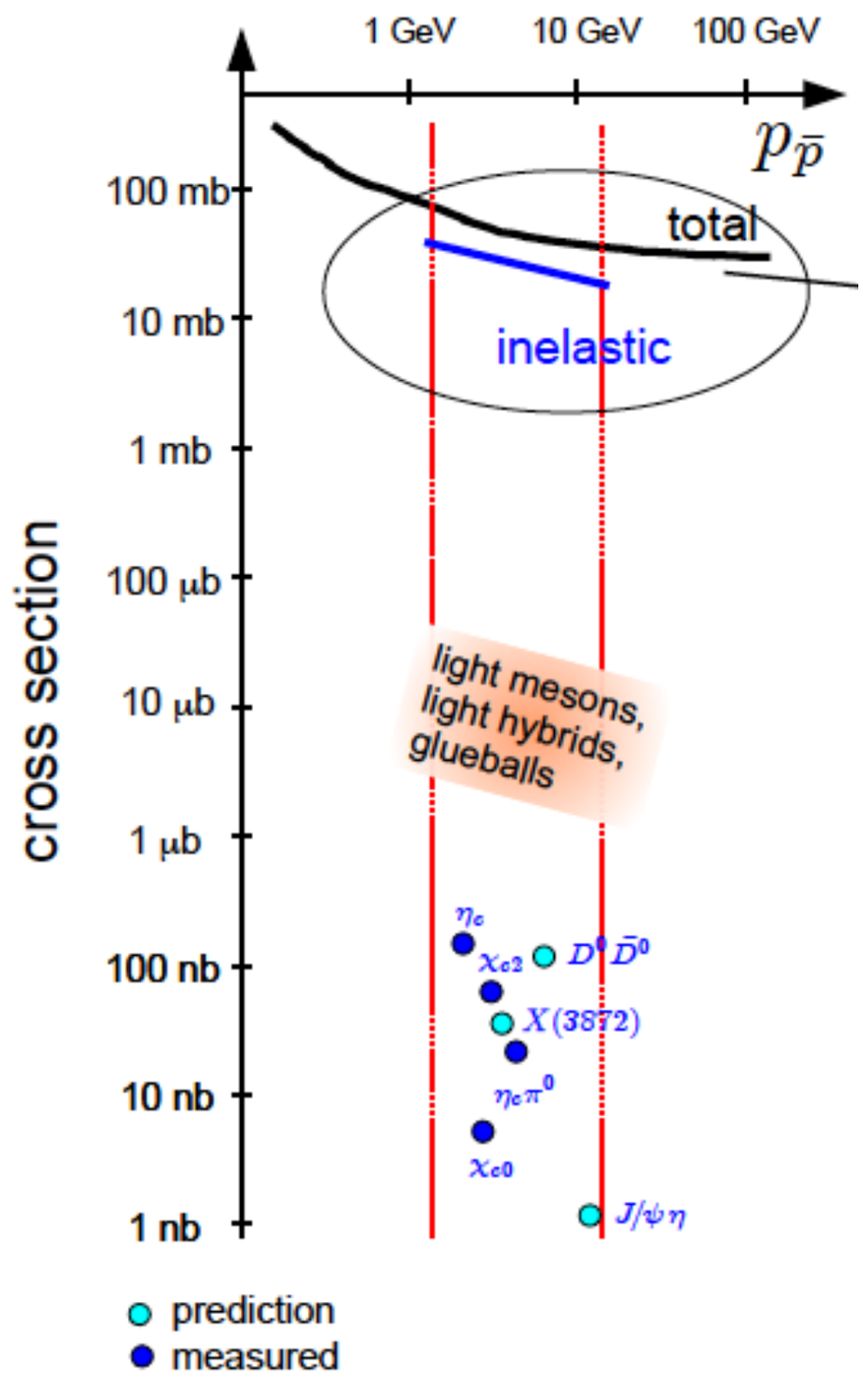
To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\text{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\text{P}}$ANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at $\overline{\text{P}}$ANDA and what performance can be expected.



ArXiV:0903.3905

Panda Physics, Data Acquisition and Event Filtering

- Problem: finding the needle in the haystack
- total inelastic cross section
  - 50 mb
- Interesting physics
  - many channels < 100 nb
- $2x10^6$ interactions /s
- Data rate after FEE reduction: 200 GBytes/s
  - 17 PBytes/day
- Goal for online event filtering:
  - reduce "background" by factor of 1000

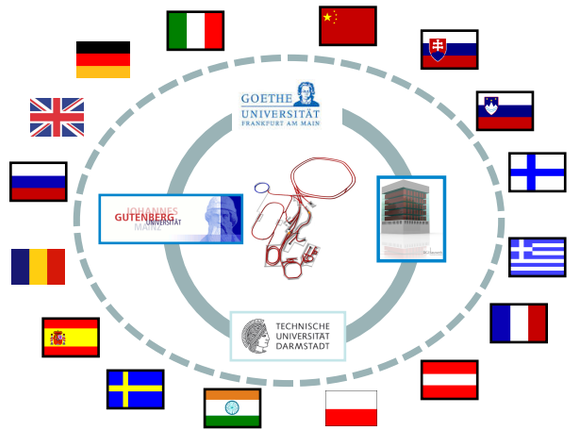


FAIR Tier 0 Data Center

Estimated total for full FAIR
FAIR Tier 0

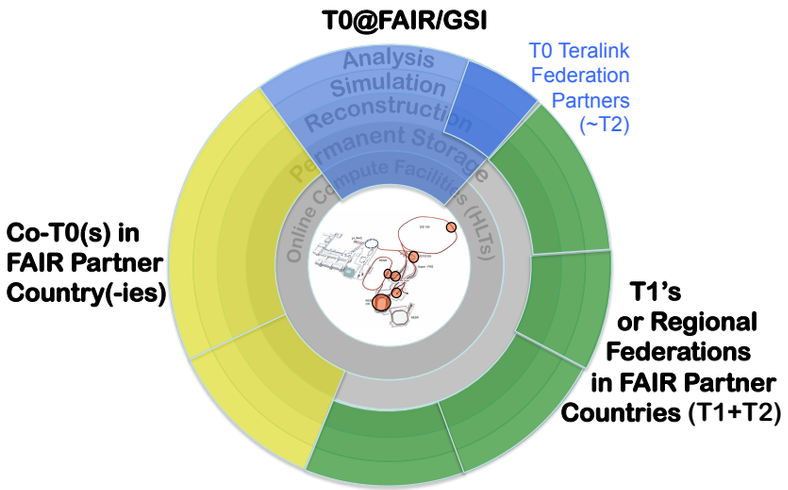
- 300.000 CPU-cores
- 35 PByte/year Online-Storage (HDD)
- 30 Pbyte/year Permanent-Storage (Tape)

Comparable resources in FAIR partner countries

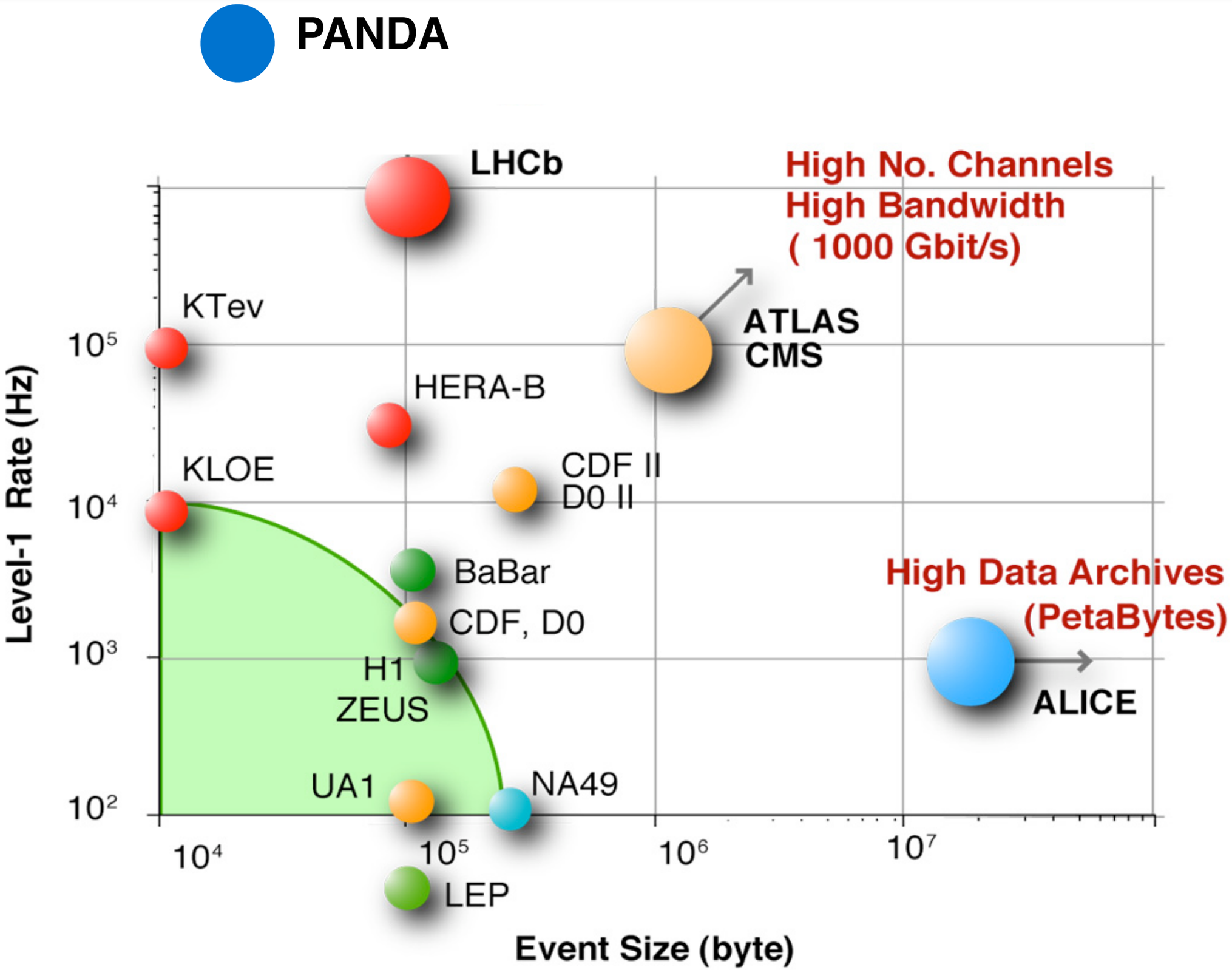


Key Points

- Few big, highly efficient data centers
- Further partner connected via regional federations

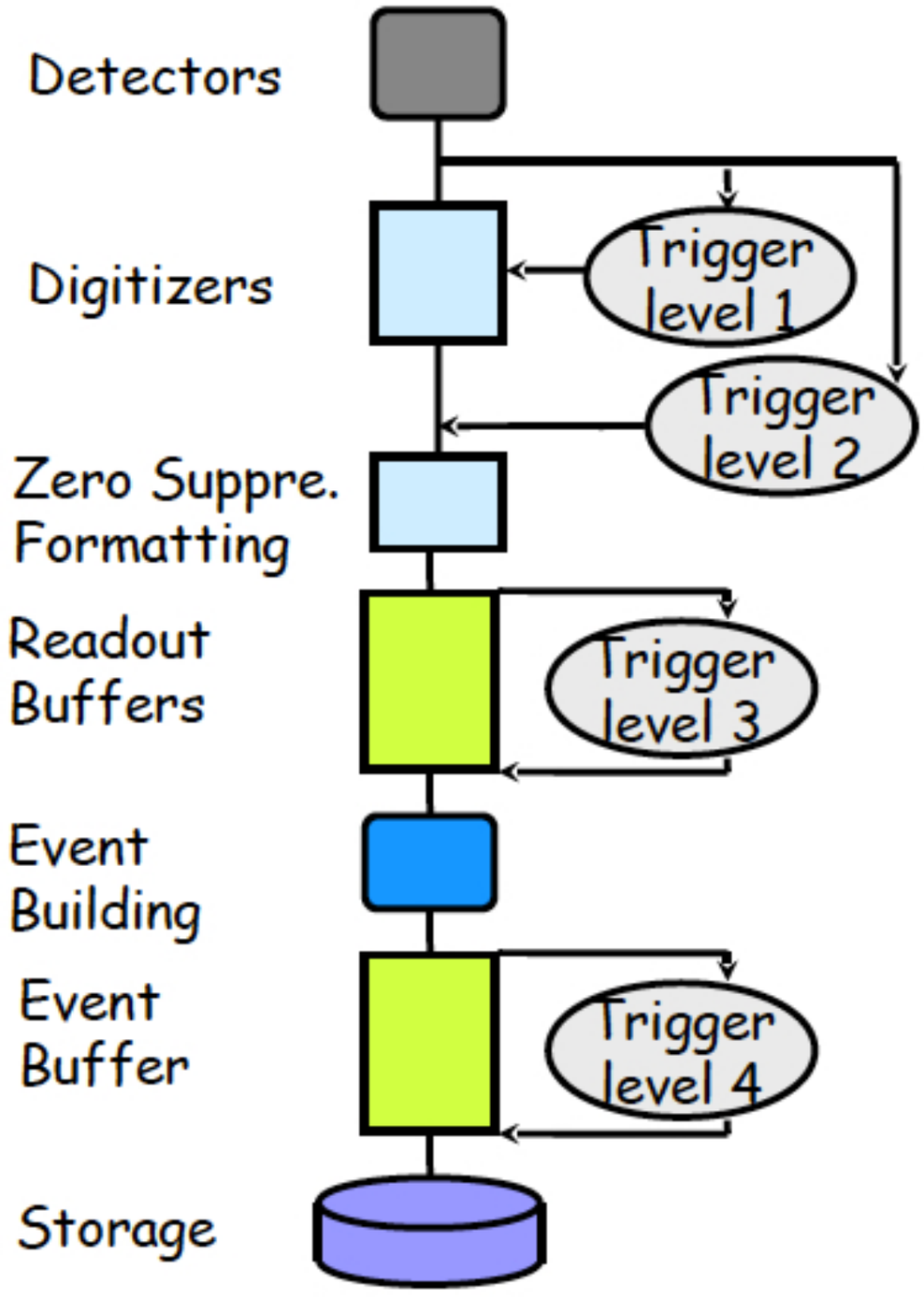


The PANDA DAQ Challenge



Conventional Approach

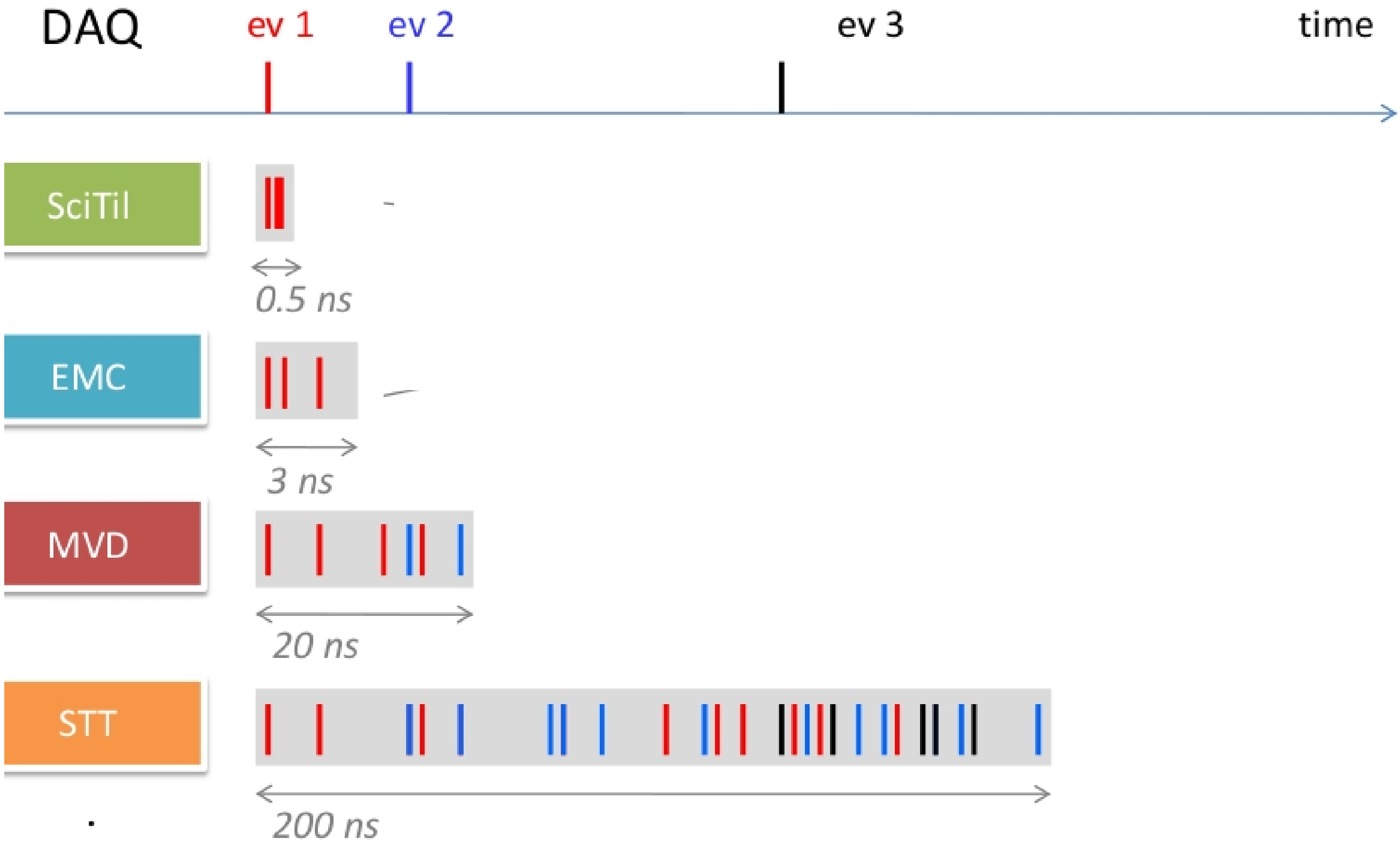
- Multi-level hardware trigger
  - Buffering at each level until trigger decisions are taken
- Works well, if physics provides clear and simple trigger signatures
  - **ATLAS / CMS** :
    - missing Et, high pt muons, jets, etc
- For some experiments, there are no such simple selection criteria
  - **LHCb**: look for B decays (secondary vertices)
  - **PANDA**: exclusive kinematic reconstruction of complete events (all reaction products measured)



PANDA Approach

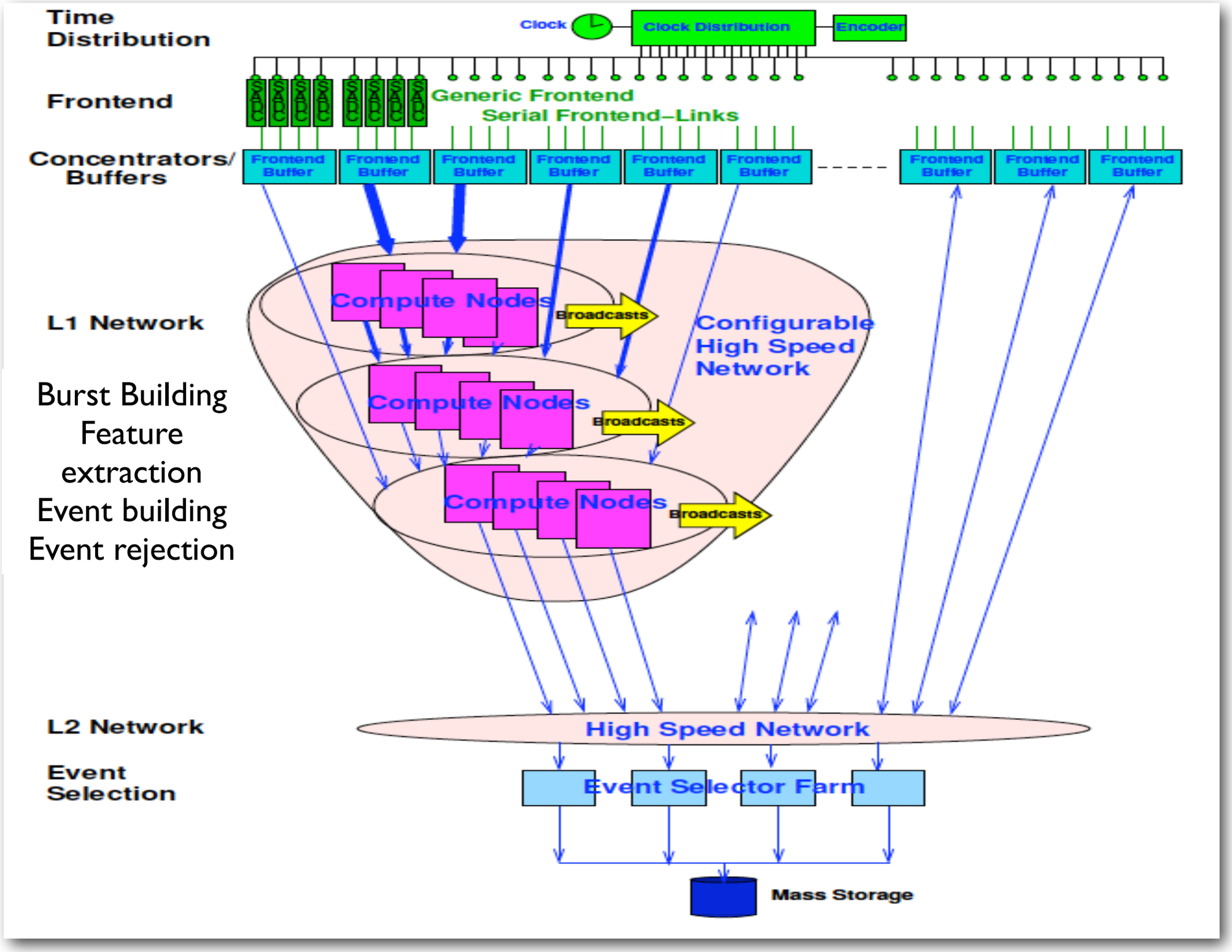
- Freely streaming data :"Trigger - less"
  - No hardware triggers
    - However, there will be event filtering, we do not record everything !!
- Autonomous FEE, sampling ADCs with local feature extraction
- Time-stamping (SODA)
  - Data fragments can be correlated for event building
- Caveat: the high-rate capability implies overlapping events !!!
  - average time between two events can be smaller than typical detector time scales
  - This "pile-up" has to be treated and disentangled
  - Real-time event selection in this environment is very challenging and requires a lot of studies

Overlapping Events (Time-based simulations)



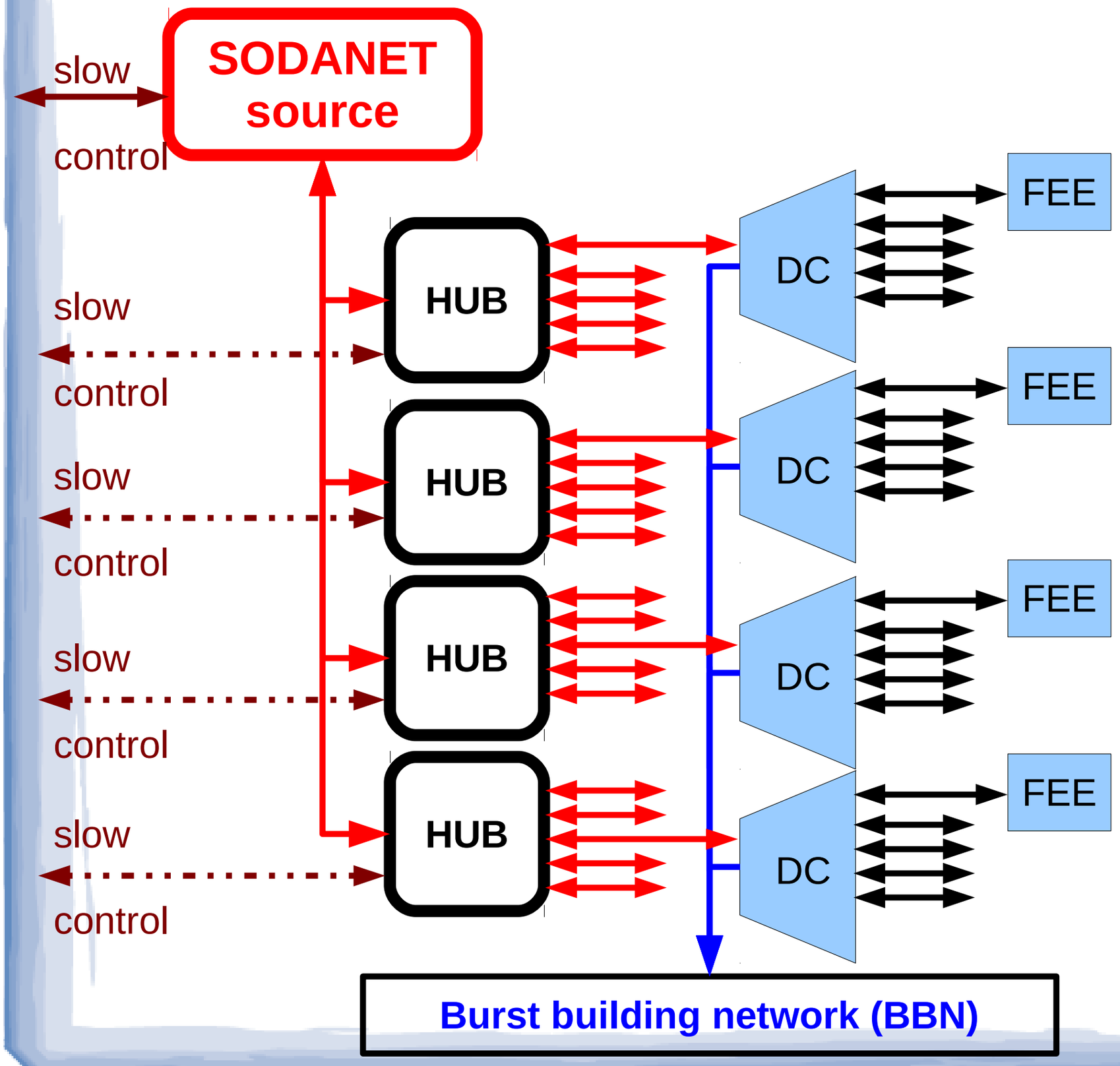
Challenges

- How much can we reduce the primary data rate ?
  - Software trigger group (principal physics simulations)
    - Answer: maybe up to factor 1000, some loss of efficiency
- Caveat: event based estimate, but overlapping data @ 20 MHz
  - A priori, there are no "events", there is just a stream of "data" from each sub-system
  - Worst case: if we cannot assemble events online, we have to store everything, because we cannot reject anything !
    - 200 GB/s -> 17 PB/day, compare to 30 PB mass storage/year @ FAIR Tier 0
      - Impossible !
  - Even running at 200 KHz only would exceed the available yearly storage capacity
- **The PANDA physics program is not feasible without effective filtering, reducing the event rate by more than 2 orders of magnitude**
- This works only if we are able to reconstruct most of the raw data in realtime. Massive challenge !
  - We need full time-based simulation and reconstruction software to judge feasibility and determine required resources (work in progress !!!)



PANDA DAQ / Event Filter

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

Next steps

- Discussion with CBM about common "FAIRnet" protocol and other common developments

- New hardware (TRB4) based on Kintex 7, suitable for all sub-systems not using radiation hard GBT links

- TRB3 - > TRB4 for all other sub-systems

  - Design by Pavel Maciniewski (Uppsala)

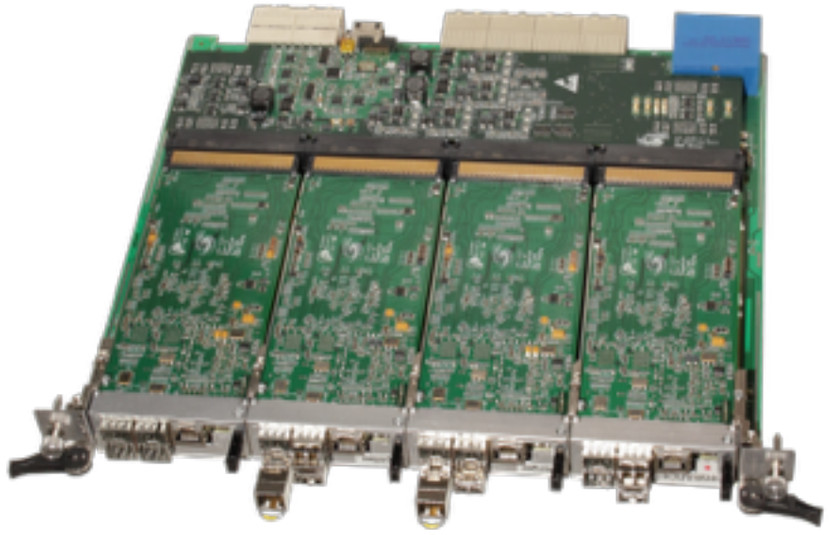
SODANET Functionality

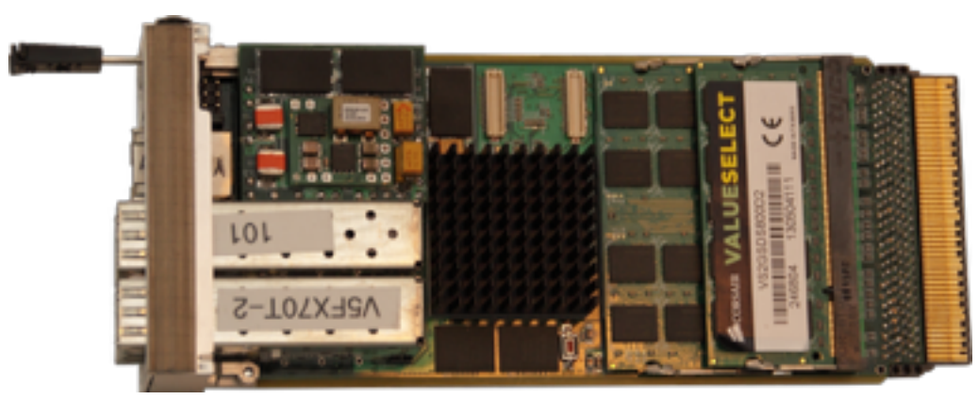
SODANET provides:

- synchronization of the FEE
- Continuous monitoring of the DC/FEE functionality
- Rough (initial) time calibration of the propagation time of the synchronization signal
- Transfer of a slow-control (FEE configuration/status) information: low priority, transmission of a slow-control package can be interrupted at any time by a synchronization package

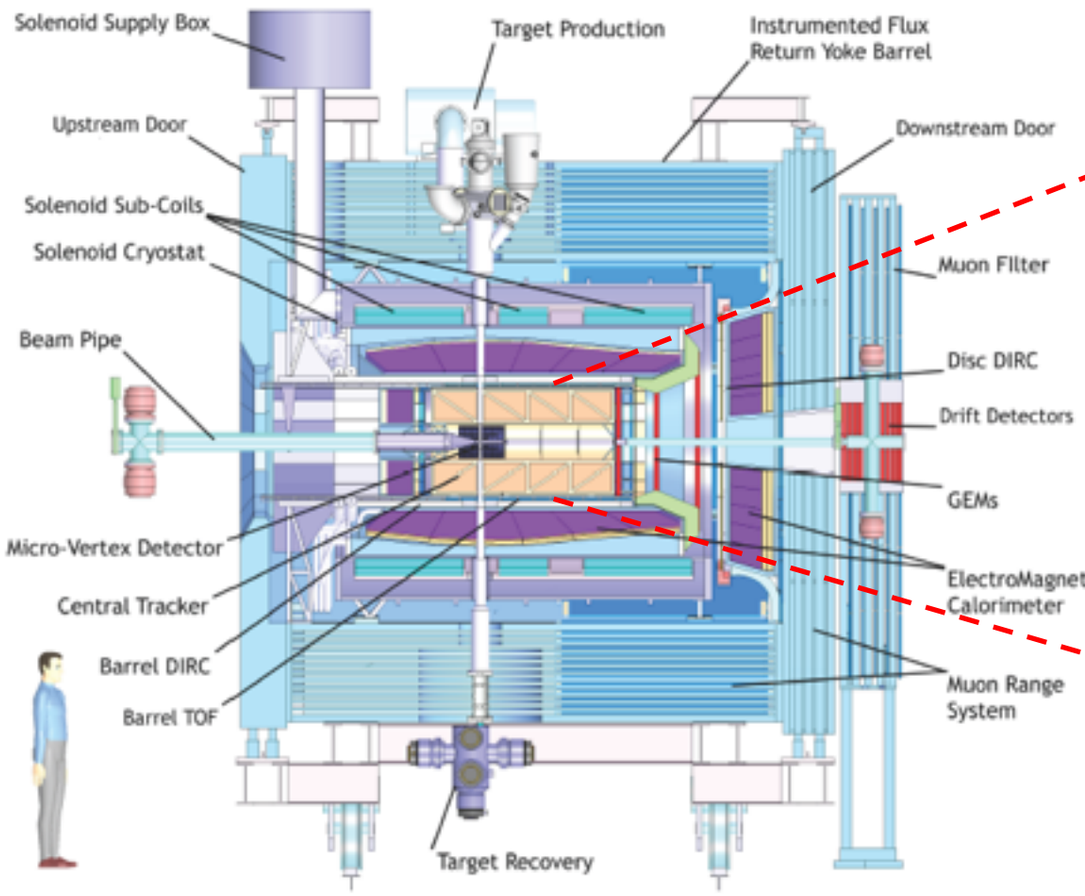
Compute Nodes (L1 network)

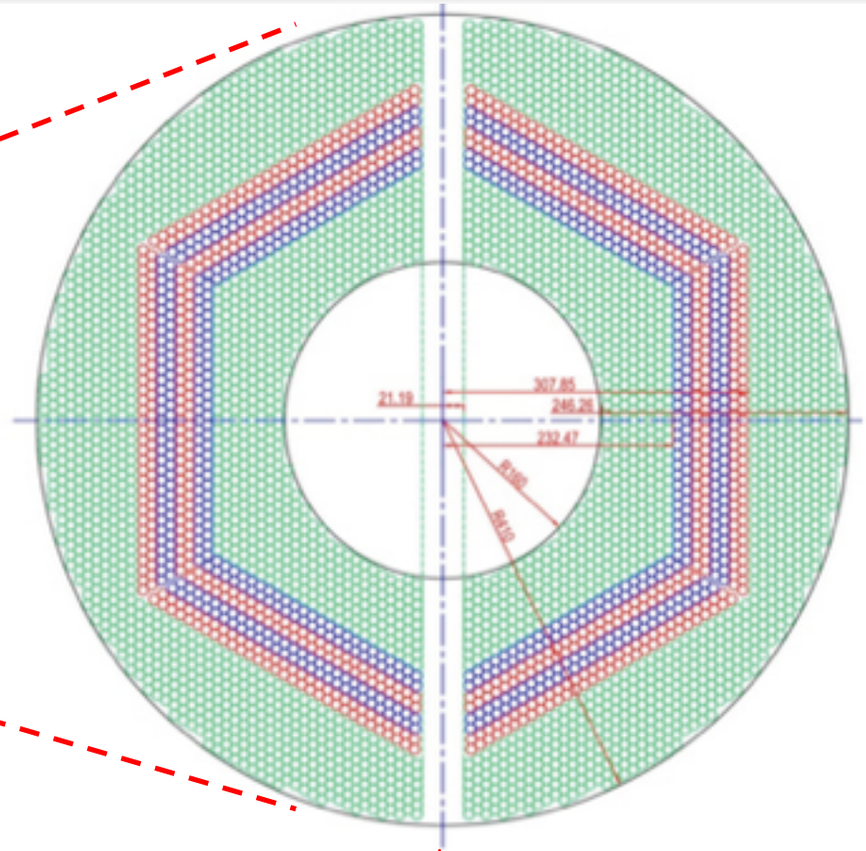
- Burst building, event building, first stage of event rejection based on kinematical event reconstruction
  - FPGA based Compute Nodes (CN)
  - ATCA standard, full mesh backplane
- 4 FPGA Virtex5 70FXT + 1 Virtex 4
  - 16 optical links, GbE
  - 18 GBytes DDR2
- Next steps, design currently under discussion (xFP card)
  - ATCA -> uTCA.4 ?
  - Virtex 5 -> Kintex 7
  - 4 GB DDR2 -> 8 GB DDR3
  - Gb Ethernet -> 10 Gb Ethernet ?
  - 4 SFP optical links -> 12 uPOD links

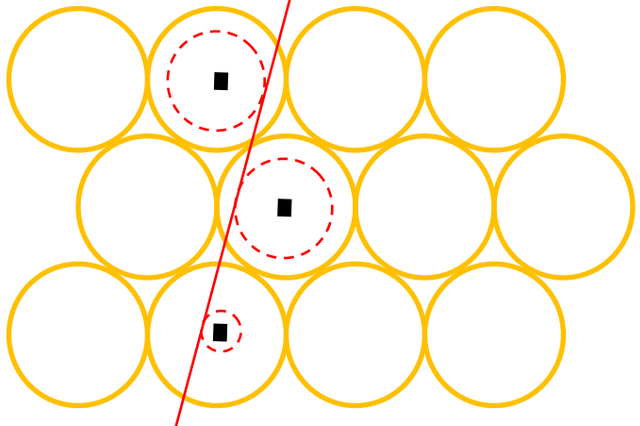




Application Example: Tracking for STT (Yutie Liang)







➢4636 Straw tubes

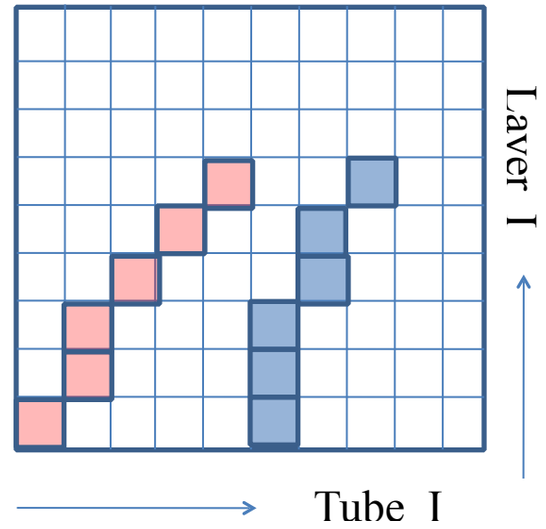
➢23-27 planar layers

- 15-19 axial layers (green) in beam direction
- 4 stereo double-layers for 3D reconstruction, with ±2.89 skew angle (blue/red)

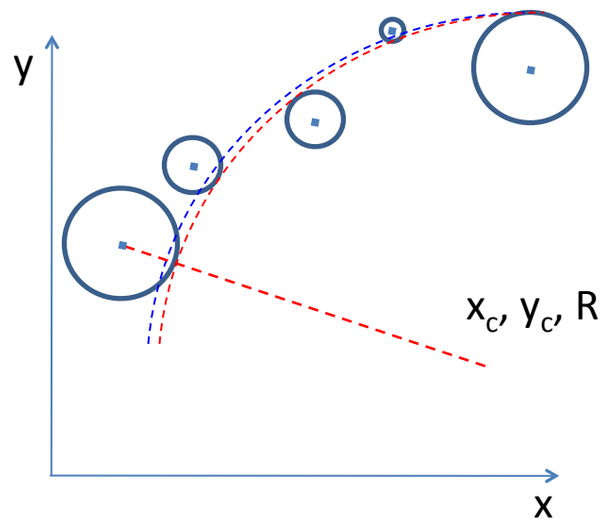
From STT : Wire position + drift time

Tracking algorithm

- "Road" search

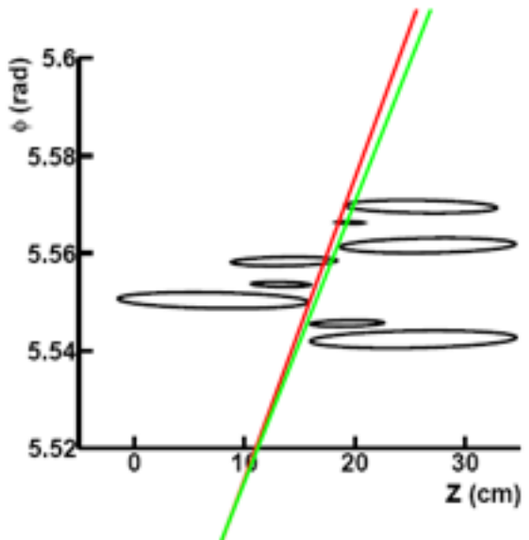


- Helix parameter determination



- Transverse momentum

- Longitudinal momentum

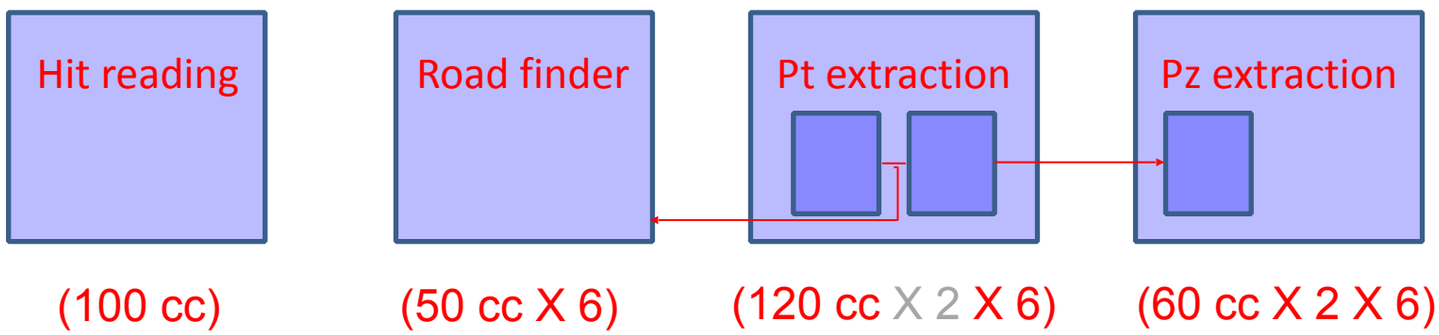


Results (VHDL implementation)

- Momentum resolution 3% @ 1 GeV/c

Device Utilization Summary			
Logic Utilization	**Used**	**Available**	**Utilization**
Number of Slice Flip Flops	25,022	50,560	49%
DCM autocalibration logic	14	25,022	1%
Number of 4 input LUTs	33,120	50,560	65%
DCM autocalibration logic	8	33,120	1%
Number of occupied Slices	21,563	25,280	85%

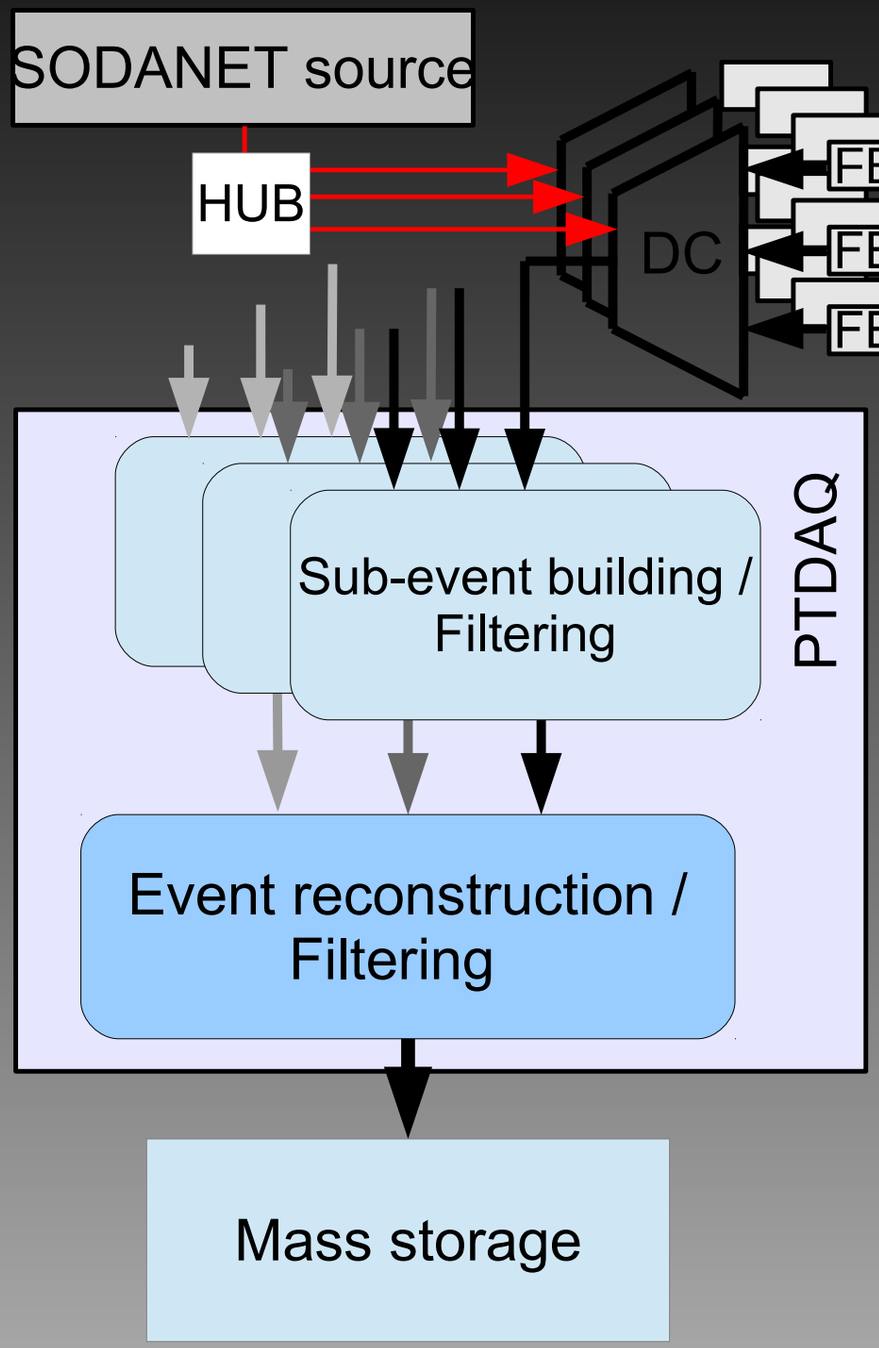
For one event with 100 hits (6 tracks): 7 μs



Current Activities

- Hardware
  - Set up toy DAQ system (PTDAQ) with scaled down architecture for detector prototype tests in realistic DAQ environment
    - Freely streaming, FEE feature extraction, event building, high level feature extraction on FPGA, L2 network processing with small farm for final event selection
  - Time-based simulations for full PANDA setup and critical benchmark channels
    - Determine realistic rejection rates at high luminosity
    - Define required bandwidth, computing resources and partitioning for L1/L2 networks
- Crucial input for DAQ TDR

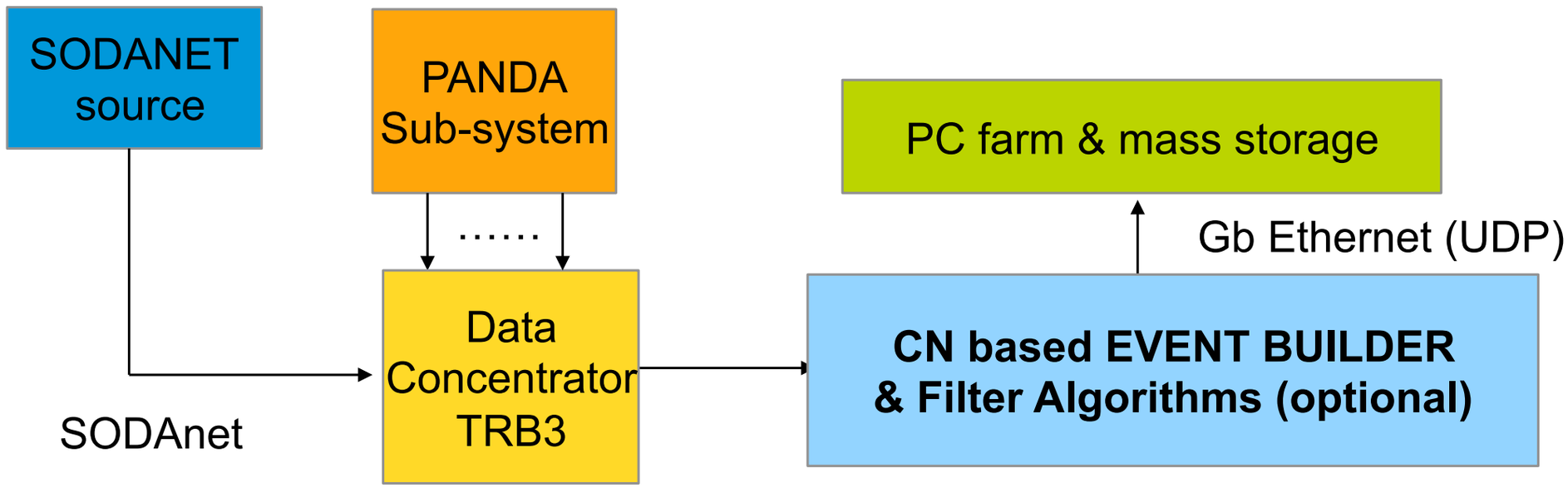
Prototype Trigger-less Data Acquisition (PTDAQ)



Functionality:

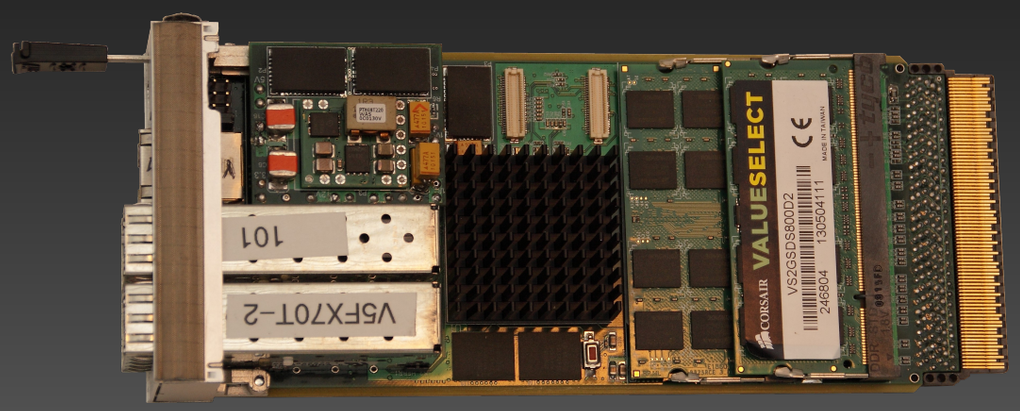
- Digitalized data front end electronic synchronized at data concentrator
- Sub-event building and first filter algorithm
- Event reconstruction and second stage of filter algorithm

Initial Setup (Toy DAQ) for Test Beams



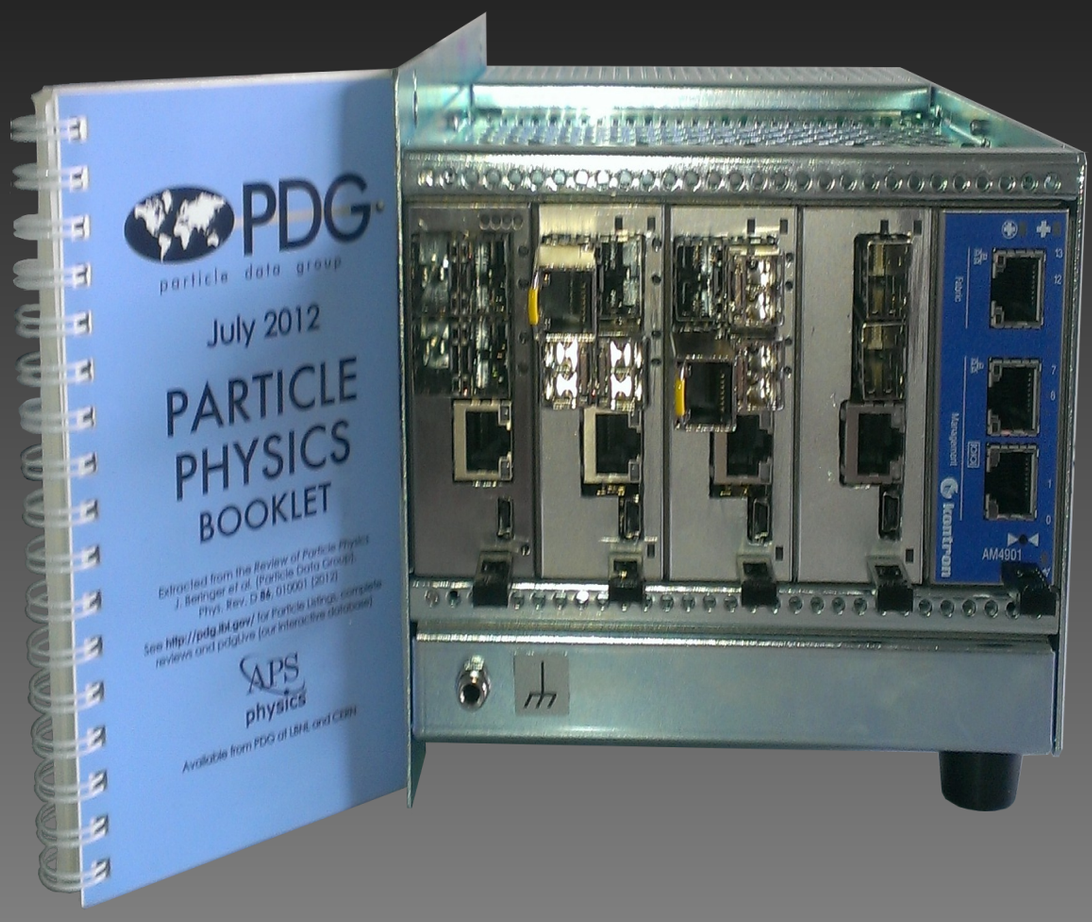
- uTCA shelf with 1 to 4 xFP cards
- Supports up to 9 optical connections to data concentrators
  - Basic configuration with single xFP: 4 optical inputs
  - Extended configuration with 3 xFP for data input and 1 xFP for event building
    - Tracking, EMC shower handling, filtering etc. as an option
- Output rate limited by Gb Ethernet : (< 120 GB / s)
- Basic slow control functionality via Ethernet/EPICS (start/stop DAQ, file handling, event counters etc.)

Hardware Components



xFP board:

- AMC form factor
- Xilinx Virtex 5FX70T-2
- 2 x 2 GB DDR2
- 4 SFP+ interfaces
  - 6.25 Gbit optical
- 1 Gb Ethernet

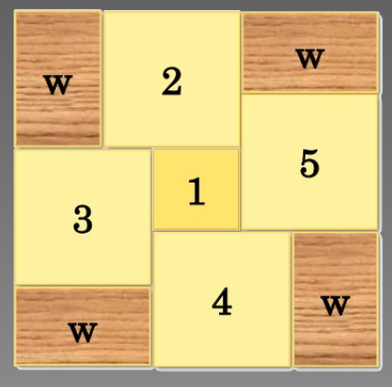


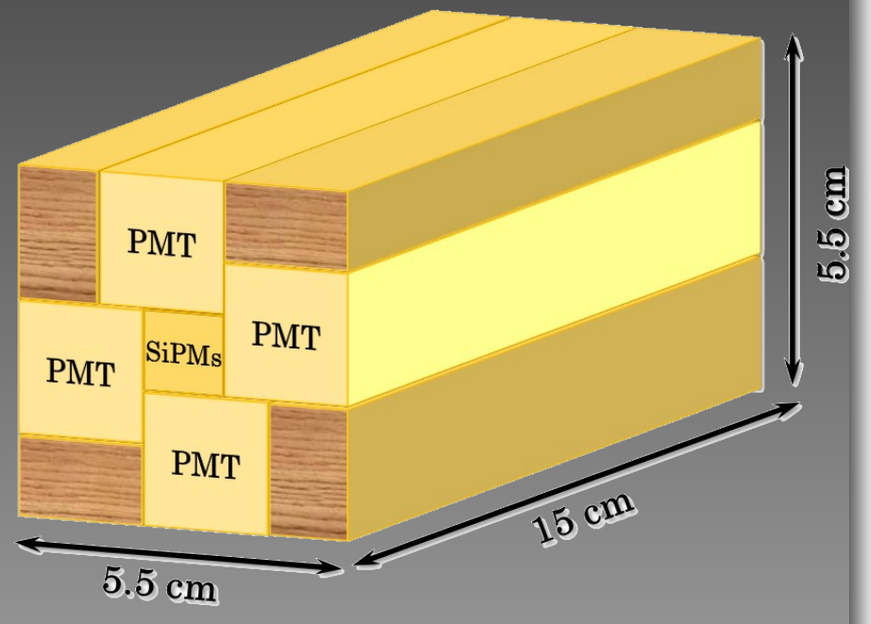
Micro TCA shelf:

- Up to 4 xFP
- Up to 9 data concentrators

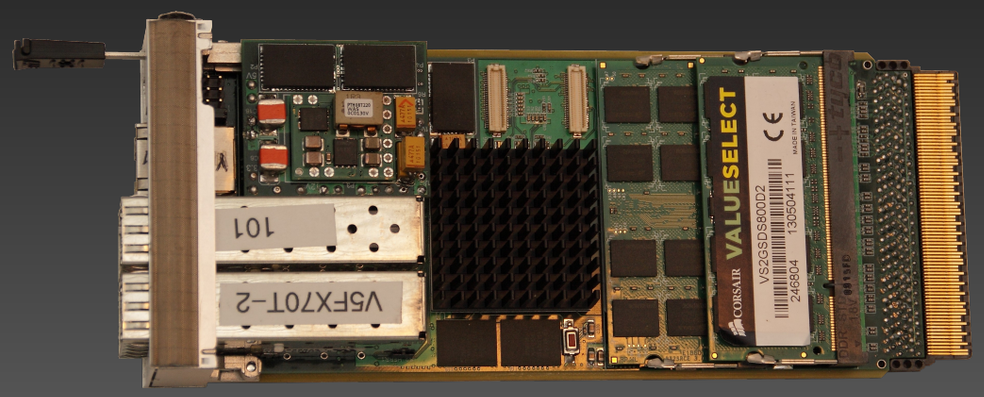
MAMI Test Setup

- Beam parameter:
  - 210 MeV electrons
  - 0.003 - 2 MHz event rate
- Detector:
  - 1 mini PWO crystal
  - 2 HAMAMATSU SI-PM
  - 4 $\overline{\text{P}}$ANDA crystals





Used Hardware



Sampling ADC (Uppsalla)

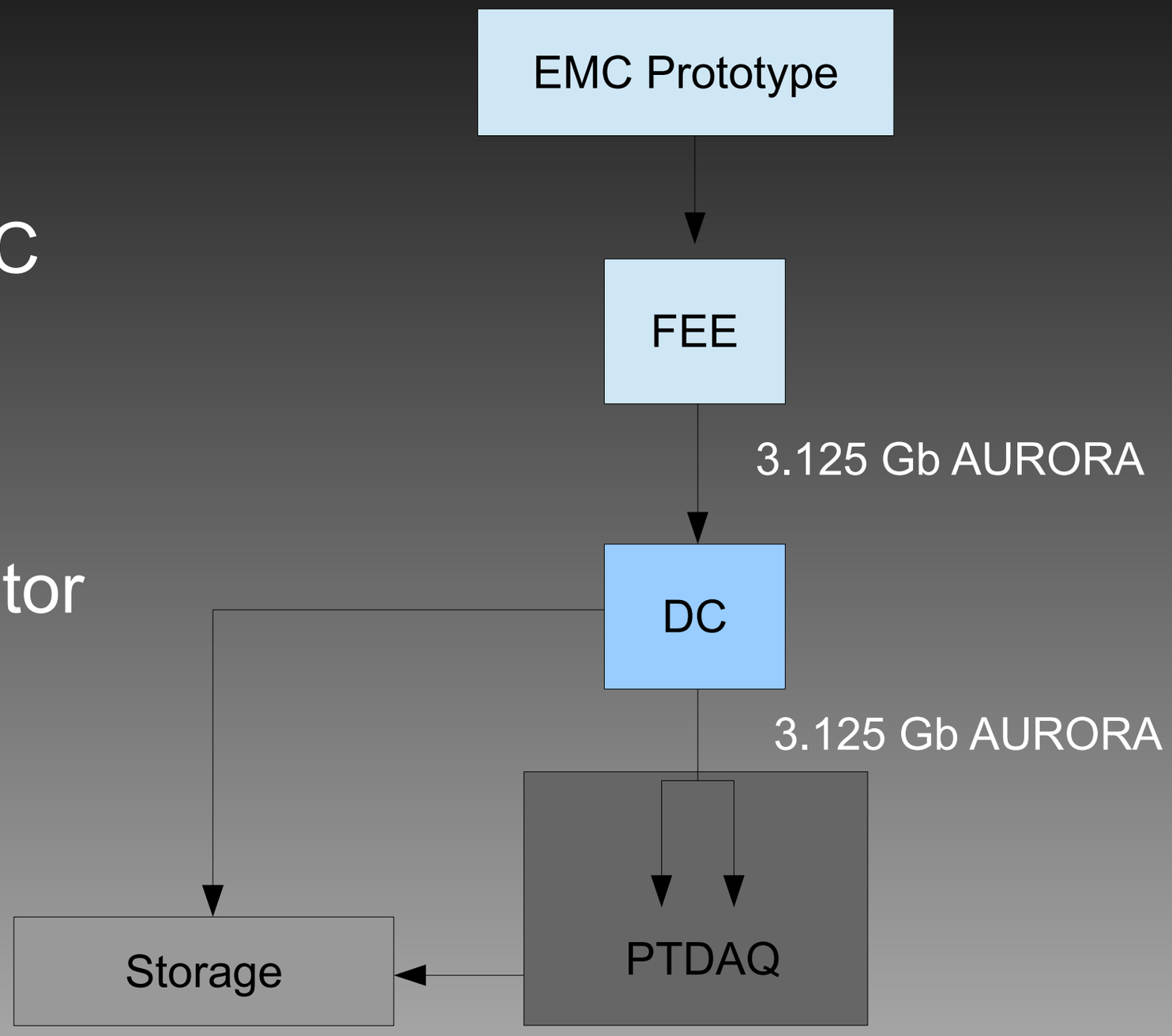
- Version 2011
- 16-ch, 14-bit
- 125 MSPS
- Virtex-5LX50

xFP board:

- AMC form factor
- Xilinx Virtex 5FX70T-2
- 2 x 2 GB DDR2
- 4 SFP+ interfaces
  - 6.25 Gbit optical
- 1 Gb Ethernet

MAMI Test Setup

- DAQ chain
  - 1 Sampling ADC
  - Pile-up mode
- 1 xFP version 2
  - Data concentrator
- 1 xFP version 3
  - Burst-builder

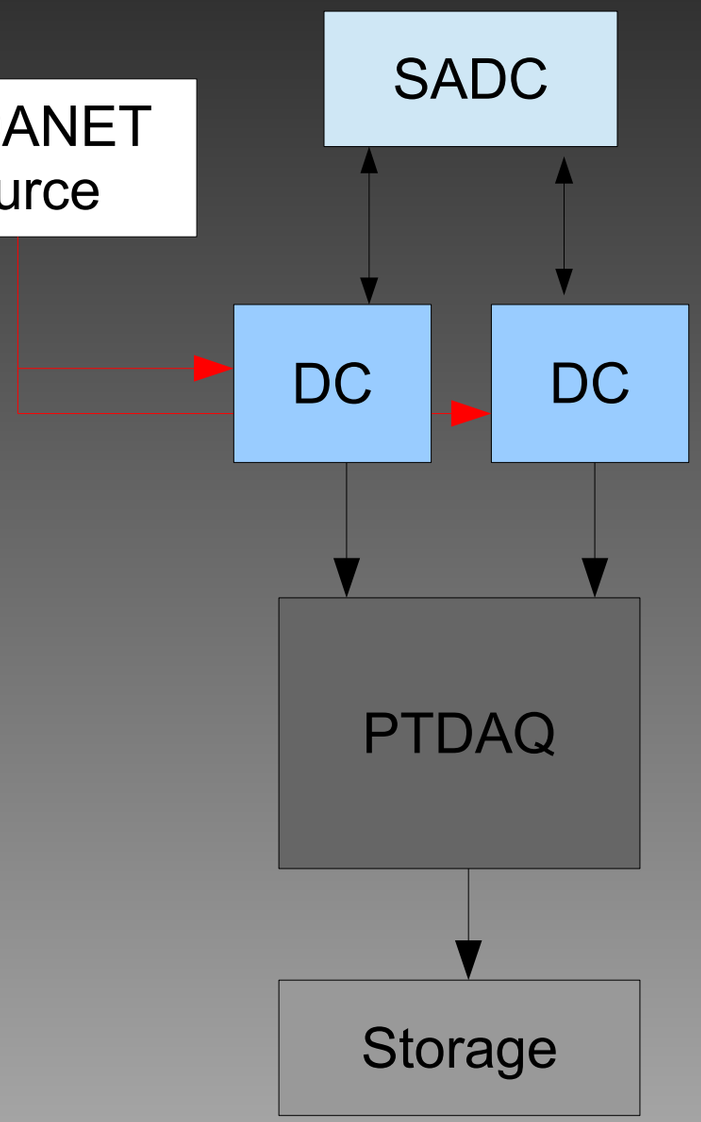


MAMI Test Results

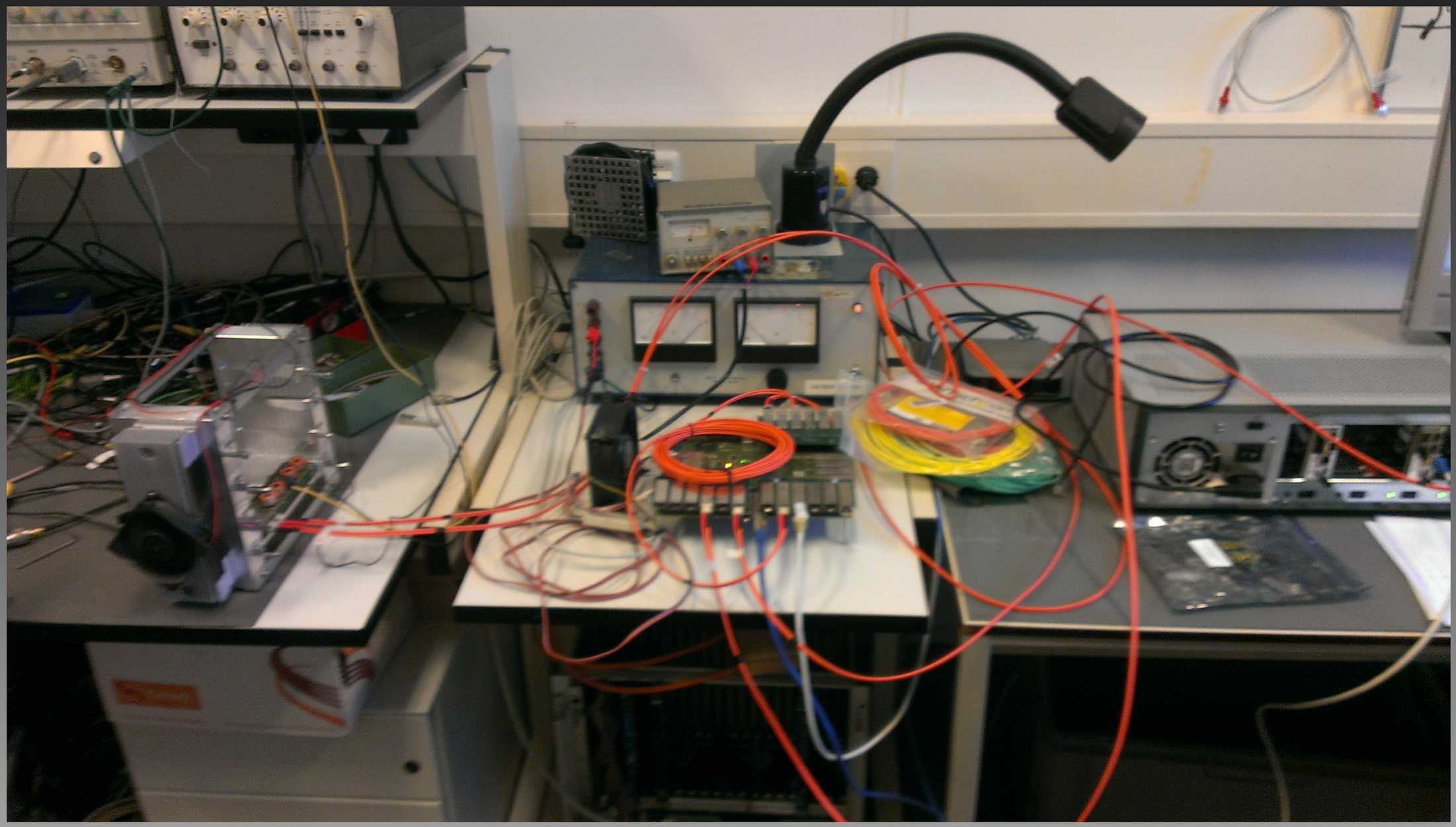
- Stable Connection between DC and xFP
  - 2-Input burst building successful
  - For ~ 15 * 10^6 Stable events
    - Event size ~ 700 Byte
  - Data rate of ~1 Gbit/s

Groningen SODANEt Connection Test

- DAQ chain
  - 1 Sampling ADC (Uppsala)
  - Feature extraction mode
- 1 TRBv3
  - 2 Data concentrator
  - 1 SODAnet source
- 1 xFP version 3
  - Burst-builder



Groningen SODAnet Connection Test



Results

Stable Connection between TRBv3 and xFP using SODANET

- Stable Connection without burst building
  - Several 100 * 10^6 events
  - Data rates between
    - 0.5 to 10 MB/s
- 2-Input burst building successful
- 1 * 10^6 Stable events
  - Event size ~ 60 Byte
- Data rate of ~ 0.5 Mbit/s

Conclusions

- Free-streaming DAQ with online event filtering is crucial prerequisite for our physics program
  - **Without effective event filtering, we can only run at low luminosity (a few times 10^{29} cm^{-2} s^{-1})**
    - Loss of major part of PANDA physics !!
- At this point, we do not have the necessary tools to design the filtering algorithms for high luminosity running with overlapping events
  - Lack of full time-based simulation and reconstruction software
    - Major issue for further development of PANDA DAQ
- Today, we have working prototype hardware available that allows to run test experiments with prototype detectors in a configuration that has all the essential ingredients of the final PANDA DAQ
- Hardware development is progressing, moving to new generations of FPGA based electronics

Next PANDA DAQ&FEE Workshop

- GSI Darmstadt, April 9/10 2015

- Please contact Angelo Rivetti or Miroslav Kavatsyuk if you would like to contribute to the FE electronics section

- Please contact me for contributions about DAQ/Event Filtering