BASKET+

Triggerless, intelligent DAQ for the BASKET detector at P2

as a small-scale prototype for future particle detectors

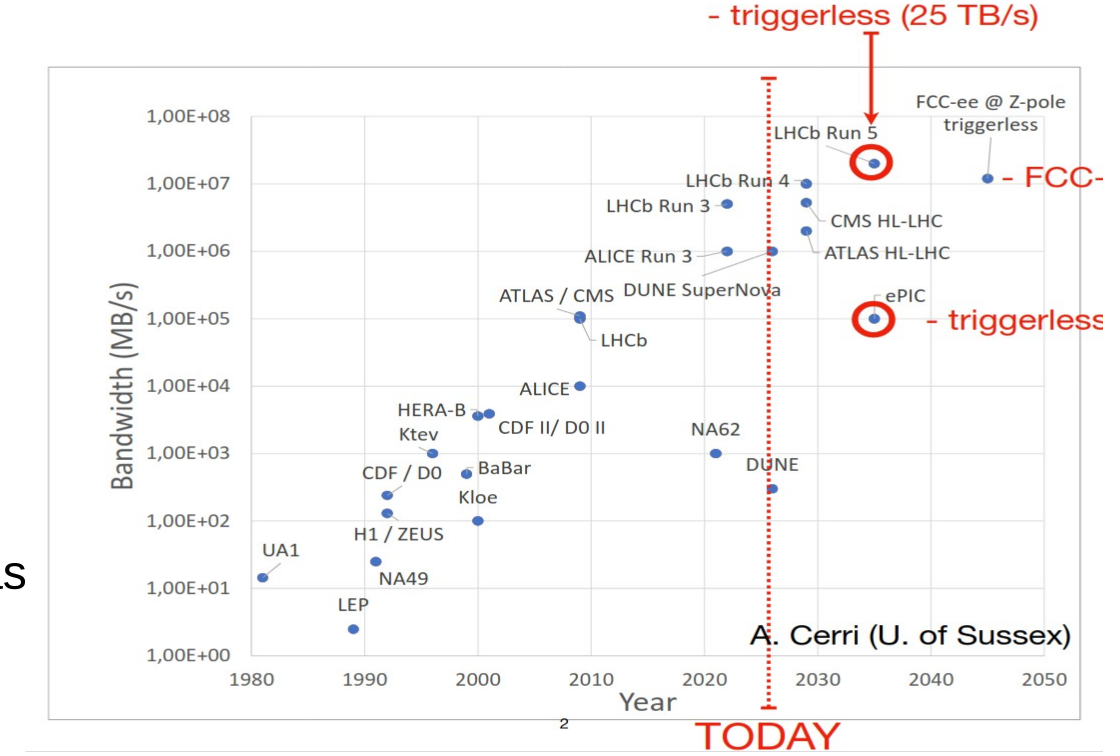
- Modern readout strategies
- The BASKET detector for the P2 experiment at MESA
- Future applications

- H. Le Provost, I. Mandjavidze, M.Vandenbroucke, M.Boonekamp, CEA/IRFU

Read-out demands of modern experiments

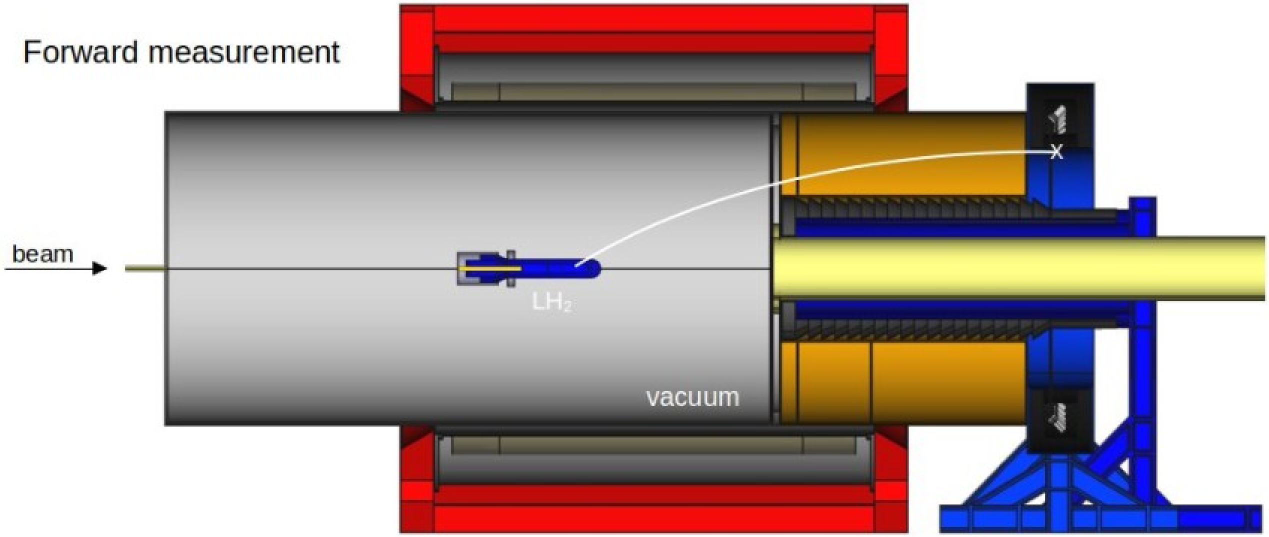
- Future hadron- and particle-physics experiments (FAIR@GSI, eIC/ePIC, AMBER, tau/charm factories, LHC/FCC….) expect event rates exceeding that of their predecessors by orders of magnitude, often reaching Terabytes/s

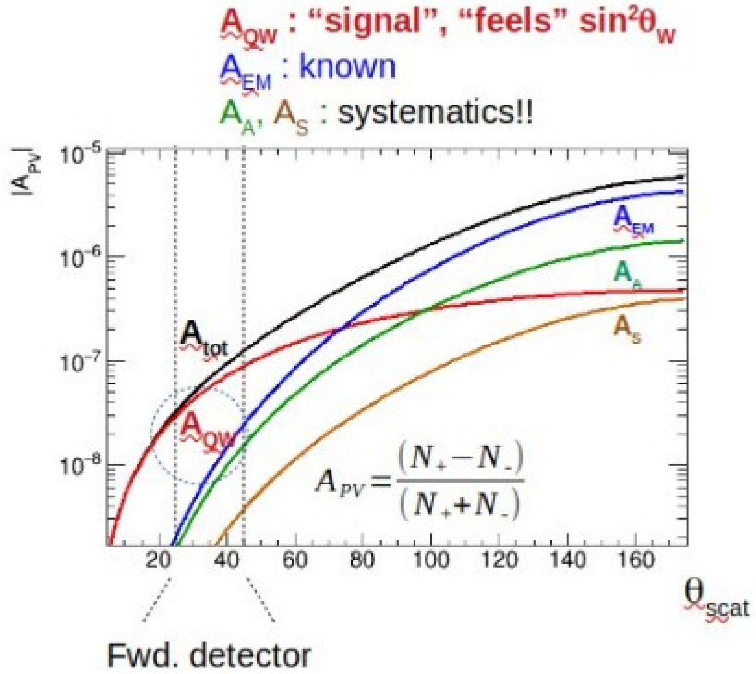
- Managing and interpreting such data volumes requires new strategies
- Trends:
  - On-chip, AI-assisted background rejection, reconstruction, data compression
  - Streaming (triggerless) DAQ
- This proposal aims at testing such ideas in the context of P2@MESA



The P2 experiment at MESA

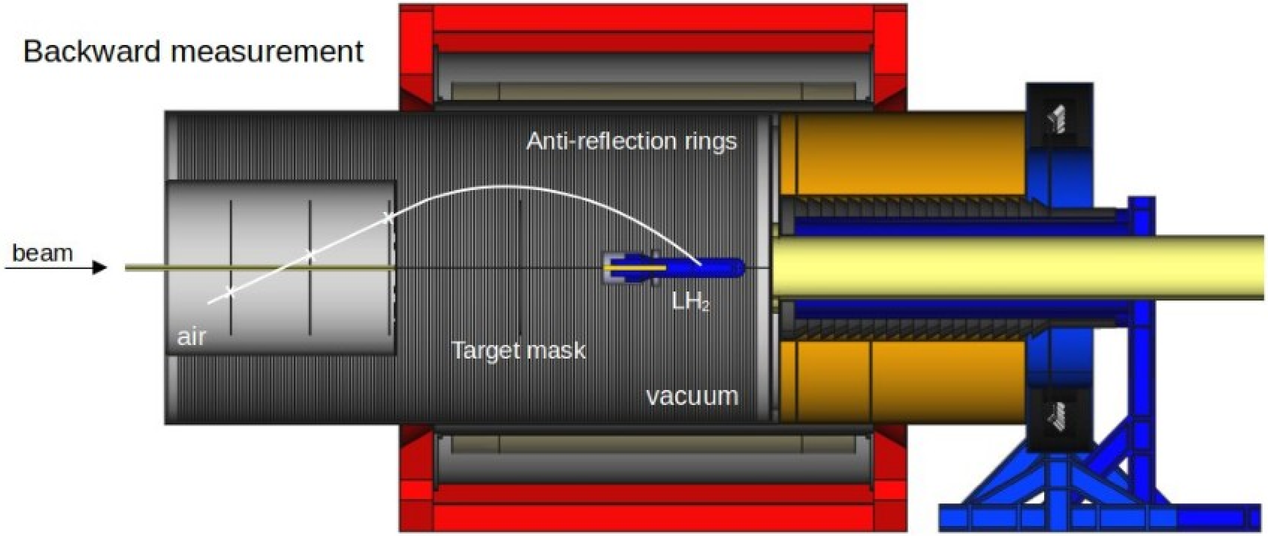
- Precise determination of $\sin^2\theta_W$ in parity-violating *ep* scattering at low energy
  - $A_{PV} \sim 5\times10^{-8}$, measured to ~1% → $\delta\sin^2\theta_W = 0.14\%$
  - 100 GHz of signal: scattered signal current integrated in <1 ms time intervals

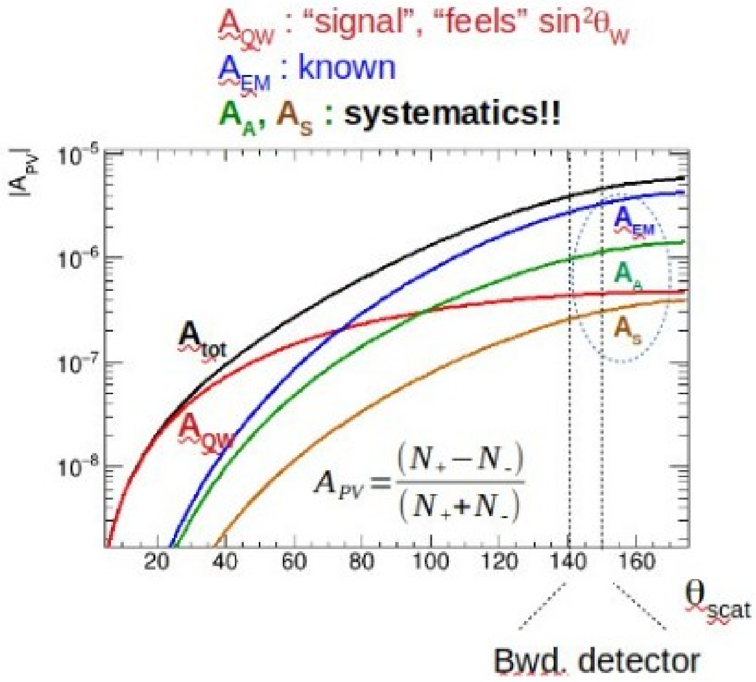




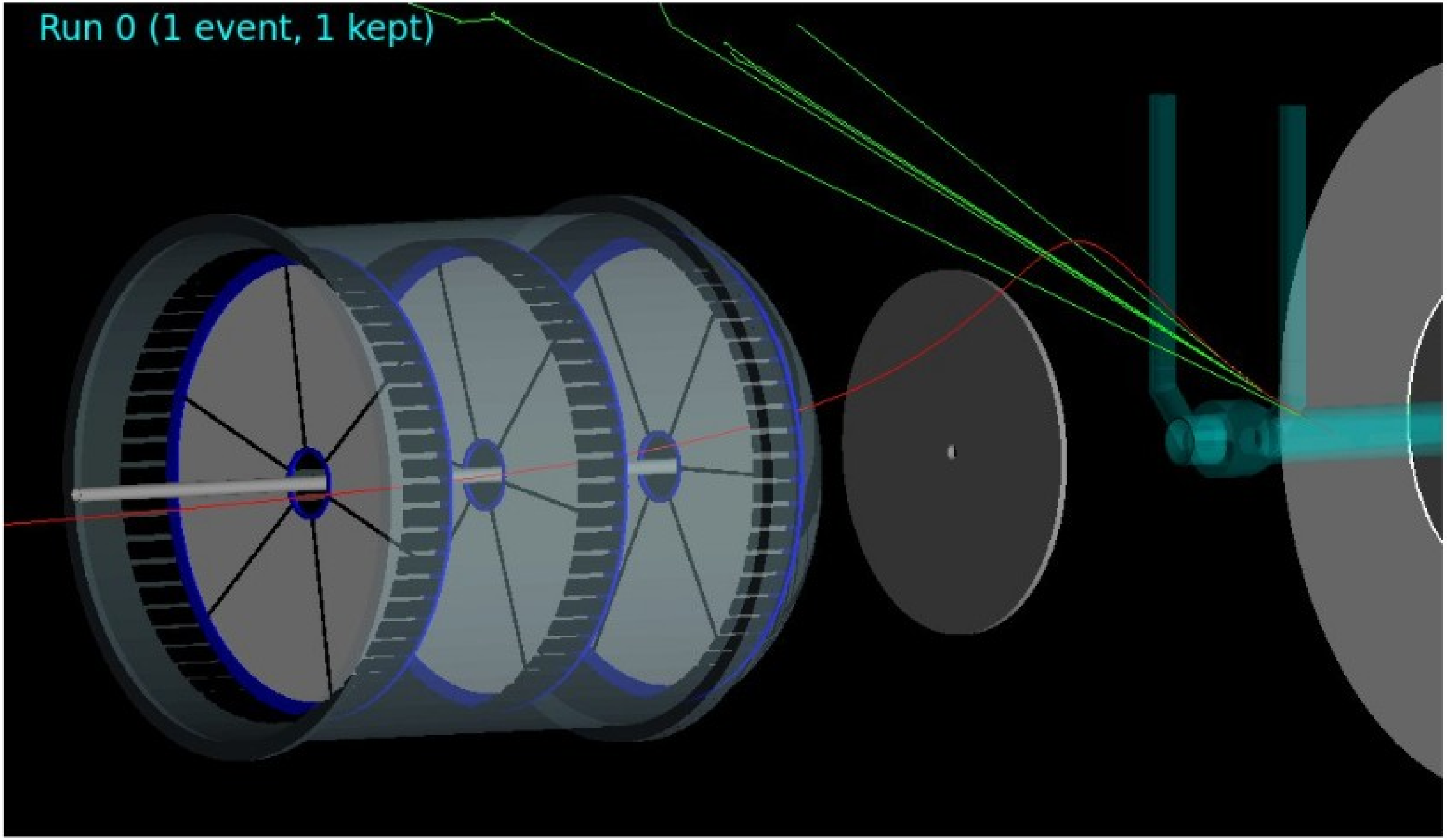
The BASKET tracking detector for P2

- Complementary measurement at backward angles
  - reduces systematic uncertainties from proton form factors
  - ~100 MHz signal rate : event-by-event track reconstruction





The BASKET tracking detector for P2



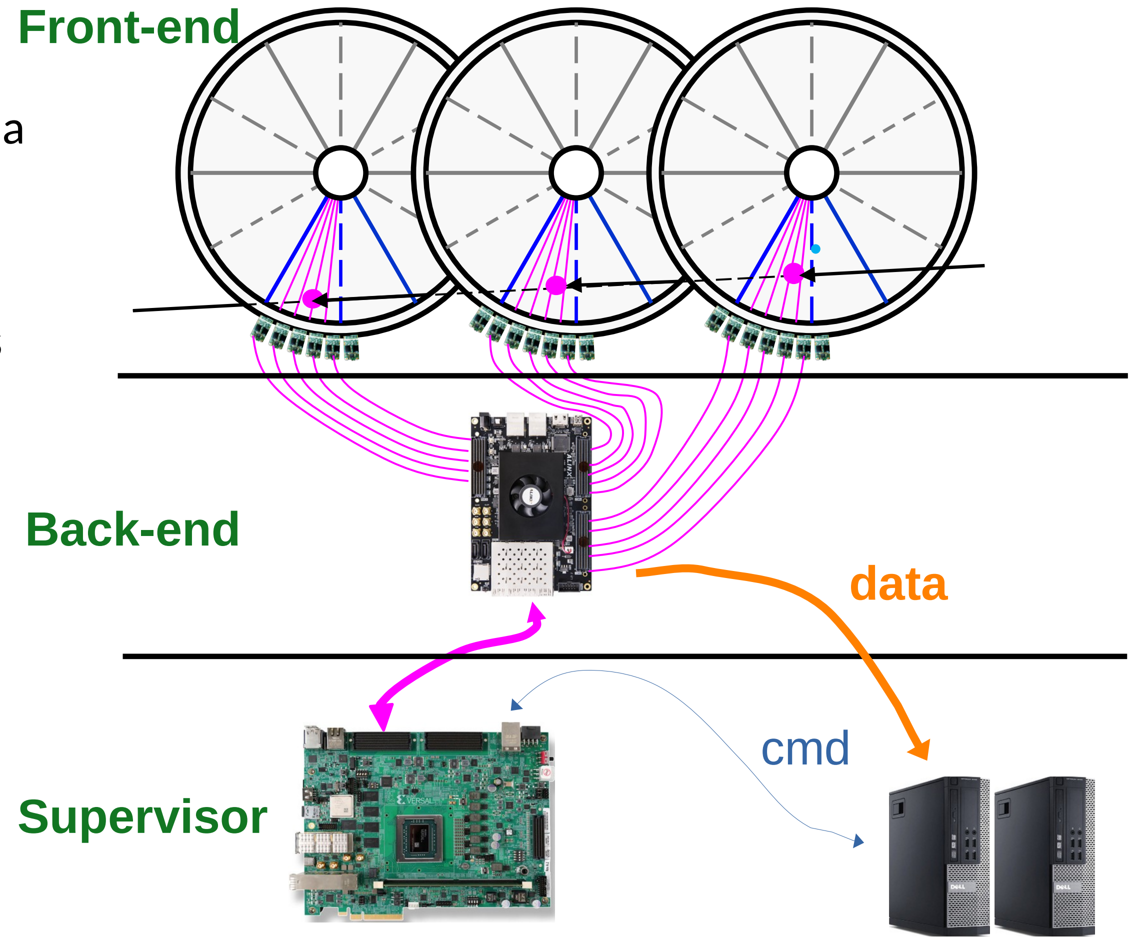
Readout challenges and strategy

- 100 MHz of BASKET data, for ~2 months of data taking, leads to a raw data volume of about 10 Petabytes : impractical for both storage and offline processing
  - online pattern recognition, track reconstruction, background rejection, and histogramming
  - objective of data compression factor of about ~100
- Present BASKET readout design : above strategy implemented only for tracks that traverse the same angular sector in the three successive detector planes
  - Adequate for physics, but limits the readout acceptance
- BASKET+ : using a high-capacity supervisor board, extend the algorithm to non-aligned sectors
  - Enhanced read-out capacity → enables runs at non-nominal MESA energies
  - Larger acceptance → enhanced physics output

Readout challenges and strategy

BASKET

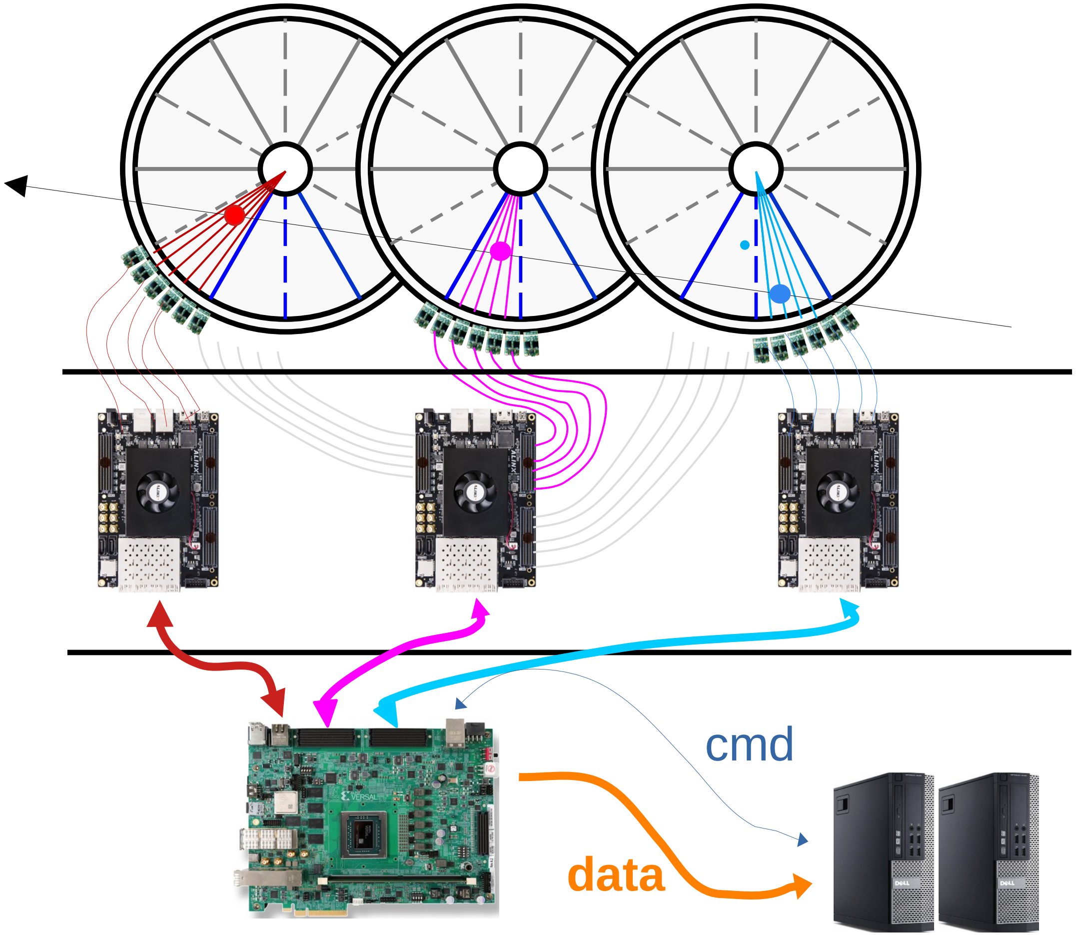
- Accepts tracks within the vision area of a single back-end board
- Back-end:
  - Readout of 3 projective 30° sectors
  - On-line track finding (Space-time criteria)
  - Sends track info to PC : channel triplet and time
- Supervisor:
  - Synchronize backends
  - Clock, cmd, beam state (polarity)



Readout challenges and strategy

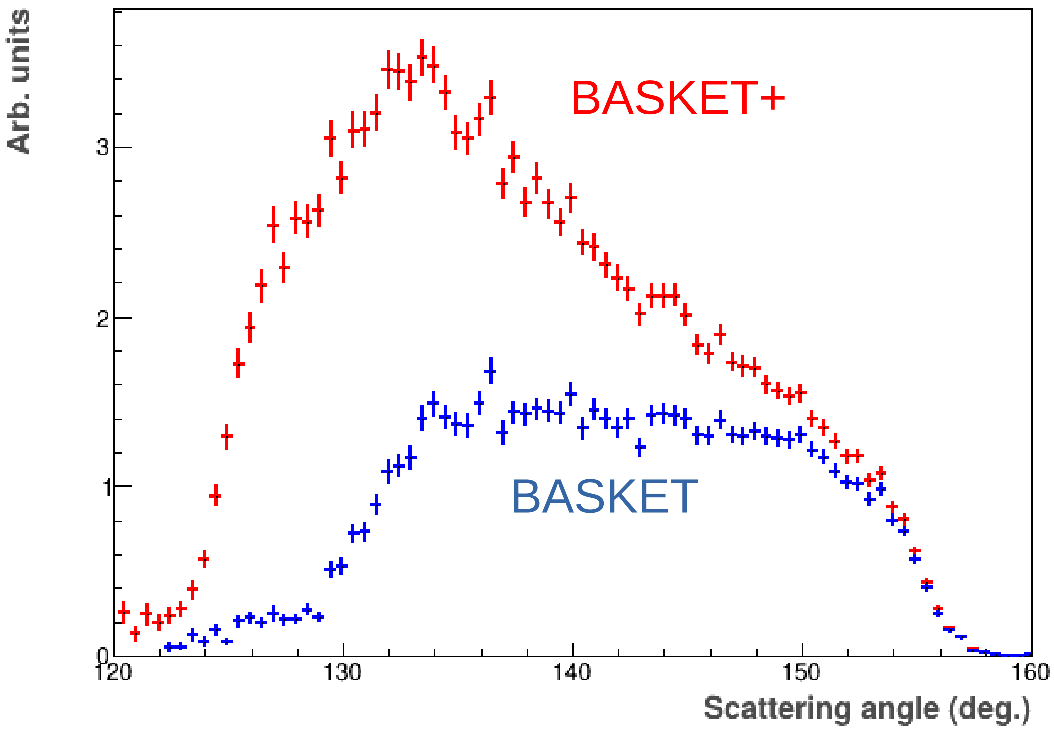
BASKET+

- Tracks span several backend vision areas
- Back-end:
  - Readout of 3 projective 30° sectors
  - Deliver data to supervisor after initial pre-processing
- Supervisor :
  - Synchronize backends
  - Clock, cmd, beam state (polarity)
  - On-line, AI-enhanced track finding and background rejection

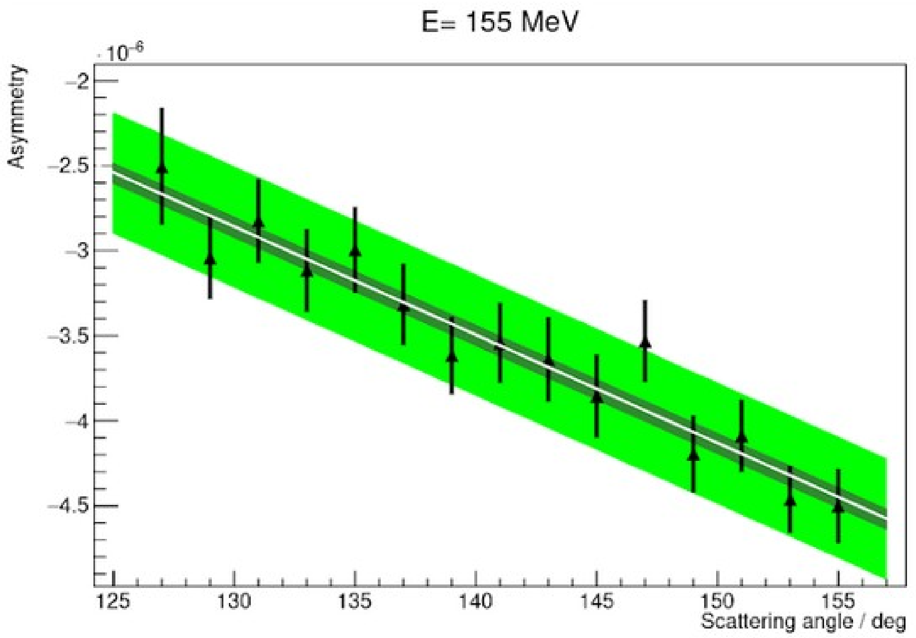


Impact

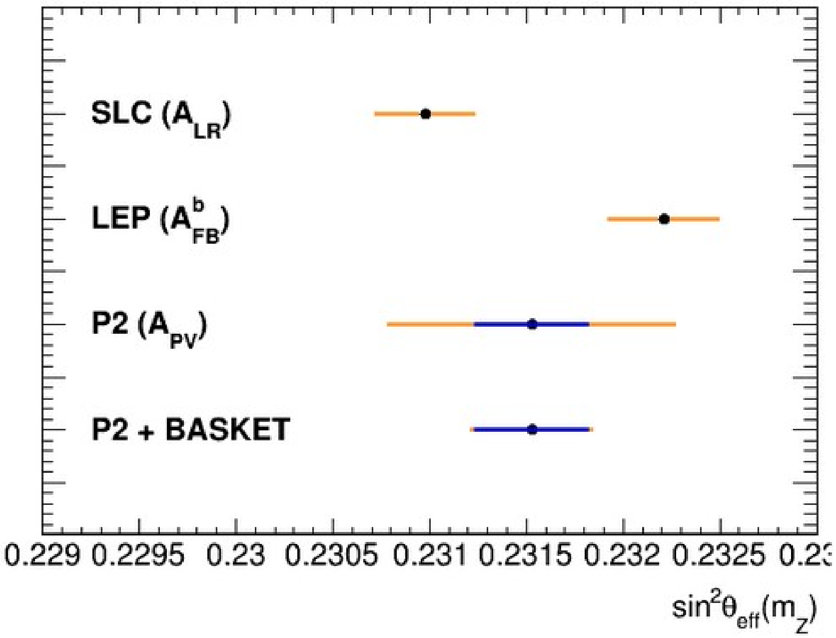
- Physics
  - Enhanced acceptance
  - Readout-rate x ~3
  - better measurement precision and determinations of the physical parameters
- Field
  - Many applications for DAQ at upcoming experiments :
    - GSI/FAIR (CBM and Panda)
    - EIC / ePIC
    - CERN (LHC, Amber; FCC)



Scientific goal



Form-factor uncertainty in A_{PV} at backward angles, **without** and **with** BASKET data



Impact of BASKET data on the determination of $\sin^2\theta_W$

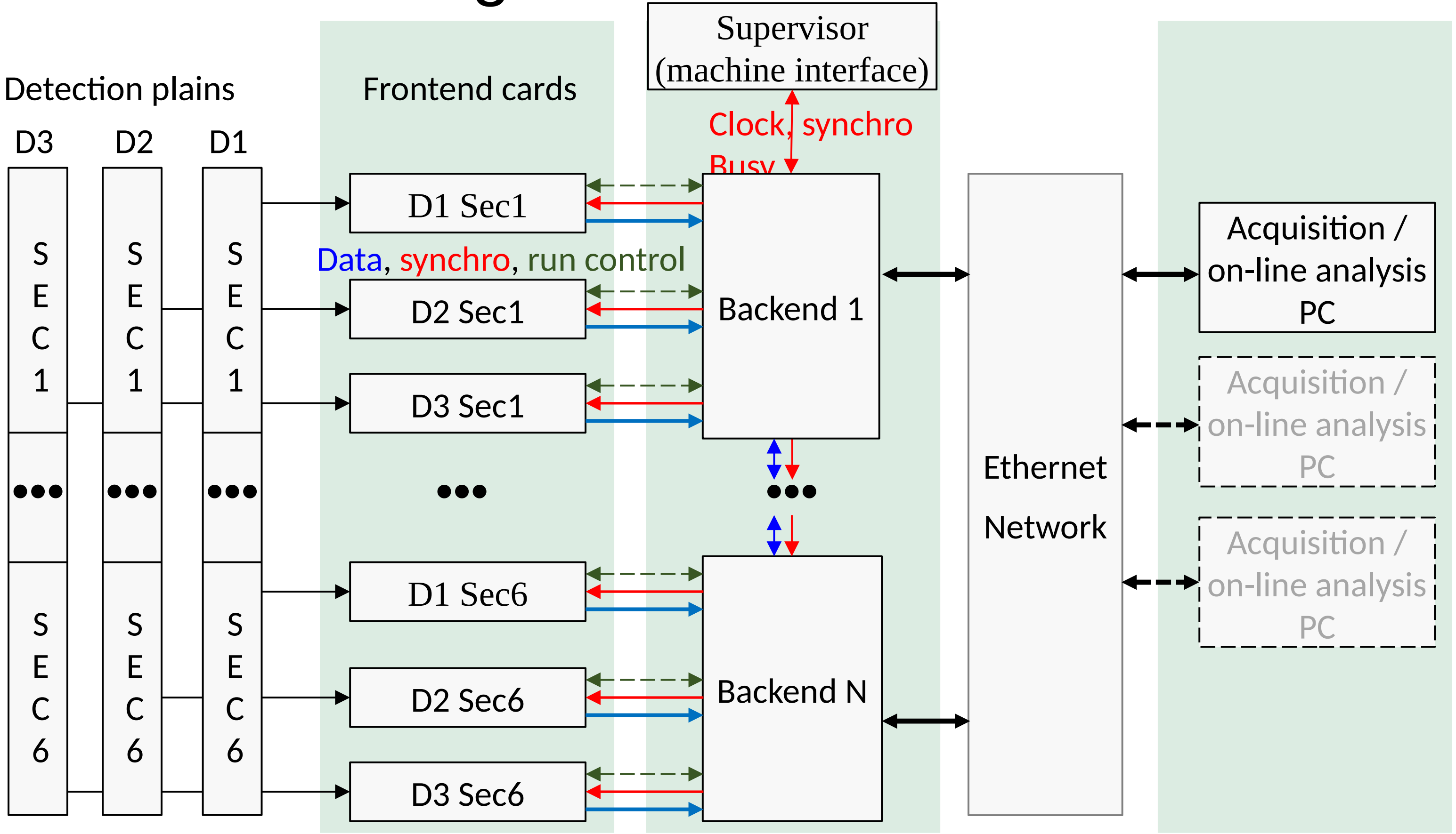
Summary

- Conclusions
  - Modern experiments expect very high rates, and rely on triggerless DAQ + intelligent data processing to manage the corresponding data volumes and ease offline analysis. New strategies are in order
  - BASKET is a high-rate tracking detector designed to measure elastic ep scattering with the P2 detector. BASKET+ is an opportunity to
    - Further enhance the potential of BASKET
    - develop and test ideas and architectures that will benefit the hadron- and particle-physics communities in the mid- and long-terms
- Request
  - 45 kE for three AMD boards, including one spare
  - 180 kE postdoc researcher or computing engineer, three years(DAQ/FPGA expertise)
  - 120 kE a PhD position for the scientific exploitation of BASKET+
  - 20 kE travel

→ Total 365 kE direct cost only; 456 kE including 25% indirect costs.

extra

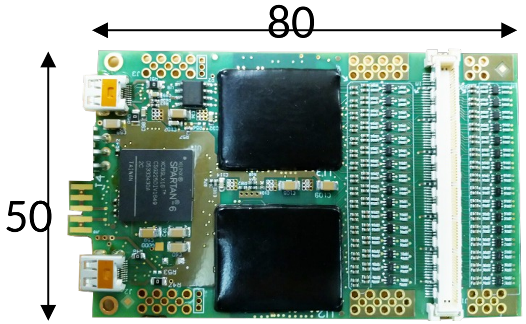
A 3-stage readout architecture



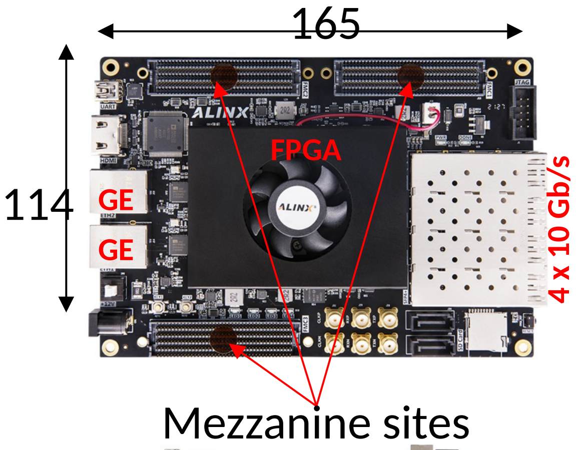
- Potential to perform on-line tracking in hardware
  - → A backend treats projective parts of all detectors and transfers only track candidates
  - → If needed, scale PCs to sustain on-line analysis

Components of the readout architecture

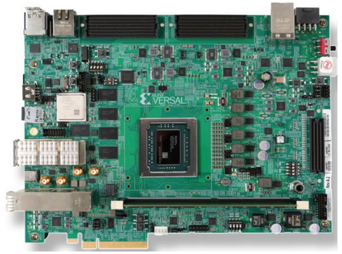
- Frontend: SRS 128-channel VMM-based hybrid
  - → Hosts two VMM3a ASICs (Atlas NSW)
    - ■ Flexible very-frontend with large choice in gain and shaping
    - ■ Streaming and triggered readout
    - ■ 400 Mbit/s link per VMM chip
    - ■ Few ns timing resolution
  - → Produced and commercialized by SRS Technology – spinoff from CERN



- Backend: Mid-end AXKU040 development board
  - → Hosts Xilinx Kintex UltraScale FPGA - XCKU040
    - ■ ~0.5M flip-flops; 21 Mbit RAM; 2k DSPs; ~500 IO
  - → 4 Gbyte DDR4 memory
  - → 10 Gbit/s and 1 GE interfaces
  - → 3 mezzanine connectors
    - ■ Possibility to aggregate up to 16 frontends
  - → Produced and commercialized by Alinx Electronic Limited

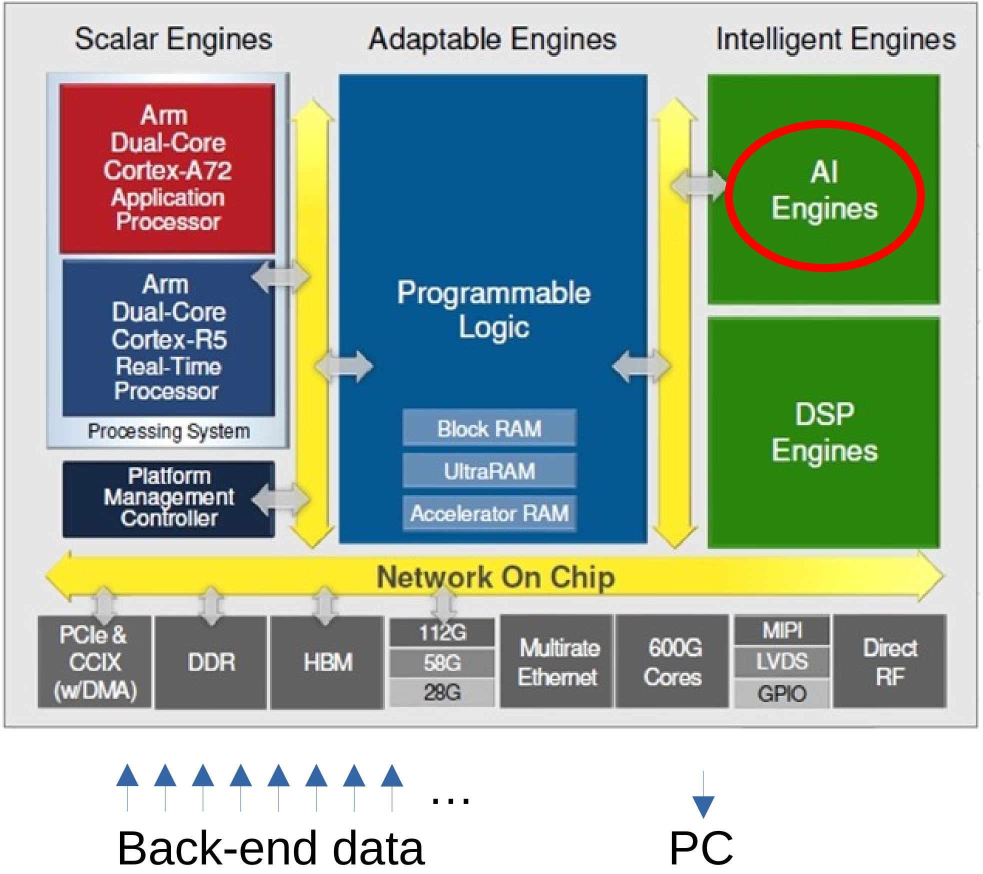


- Supervisor: High-end FPGA development kit
  - → Tradeoff between logic and AI engine resources
    - ■ e.g. AMD EK-VCK180 board – Logic-enhanced for traditional track finding
    - ■ e.g. AMD EK-VCK190 board – AI-boosted for ML-based track finding



AMD Supervisor board
Block diagram

- Firmware and software R&D : pushing the state of the art
  - High level synthesis approach
  - Use of cutting edge Versal ACAP devices from Xilinx / AMD
    - ACAP - Adaptive compute acceleration platform
  - Online track reconstruction using embedded AI engines



- IRFU is the world-leading laboratory for the construction of reliable, high-rate gaseous detectors
- This project aims at further enhancing the possible readout rates, to bring the techniques up to speed in view of future experiments
- A first implementation is proposed for the upcoming P2 experiment