# Upgrade of the NA61/SHINE facility for physics programme beyond 2020

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**for the NA61/SHINE Collaboration**

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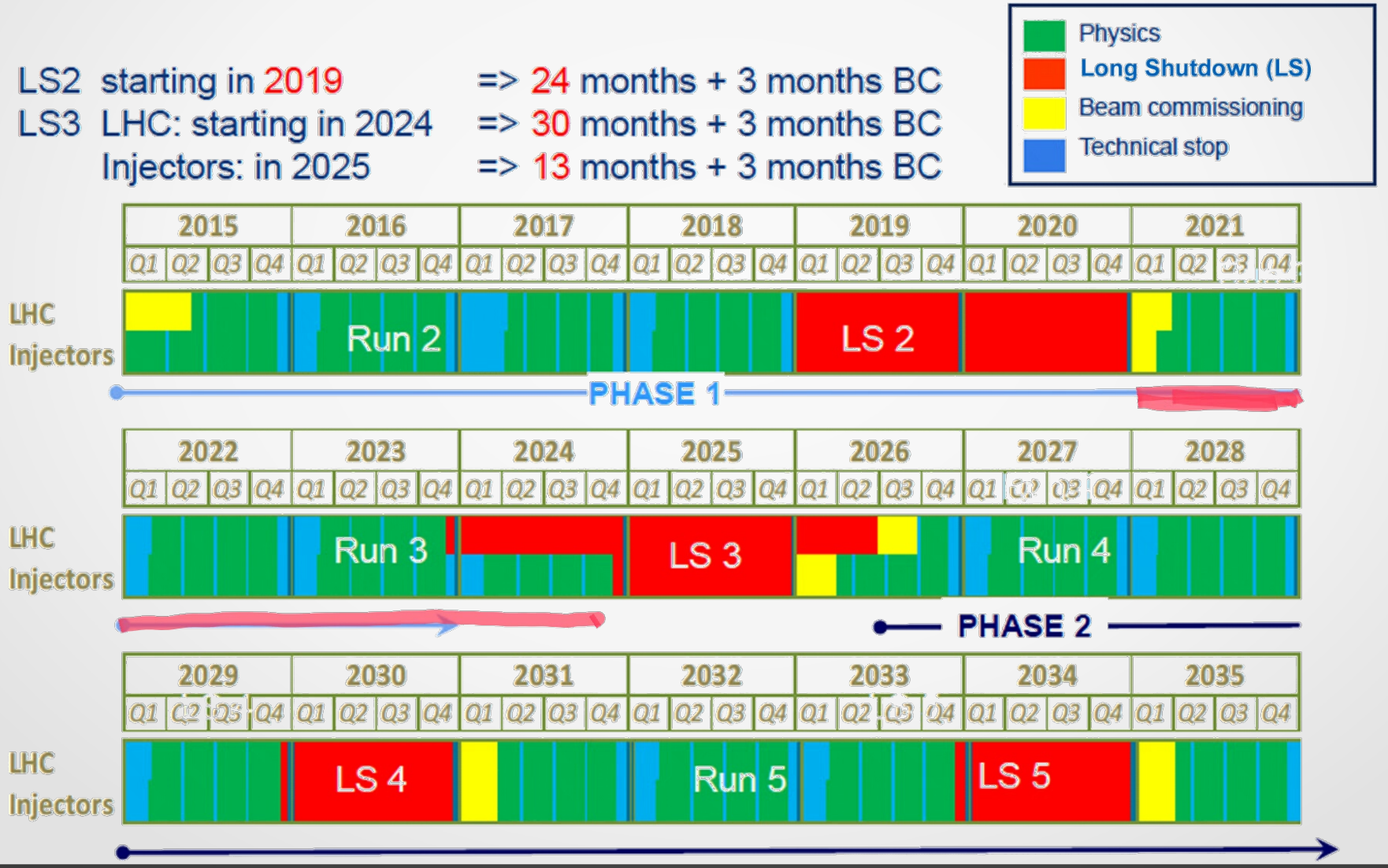
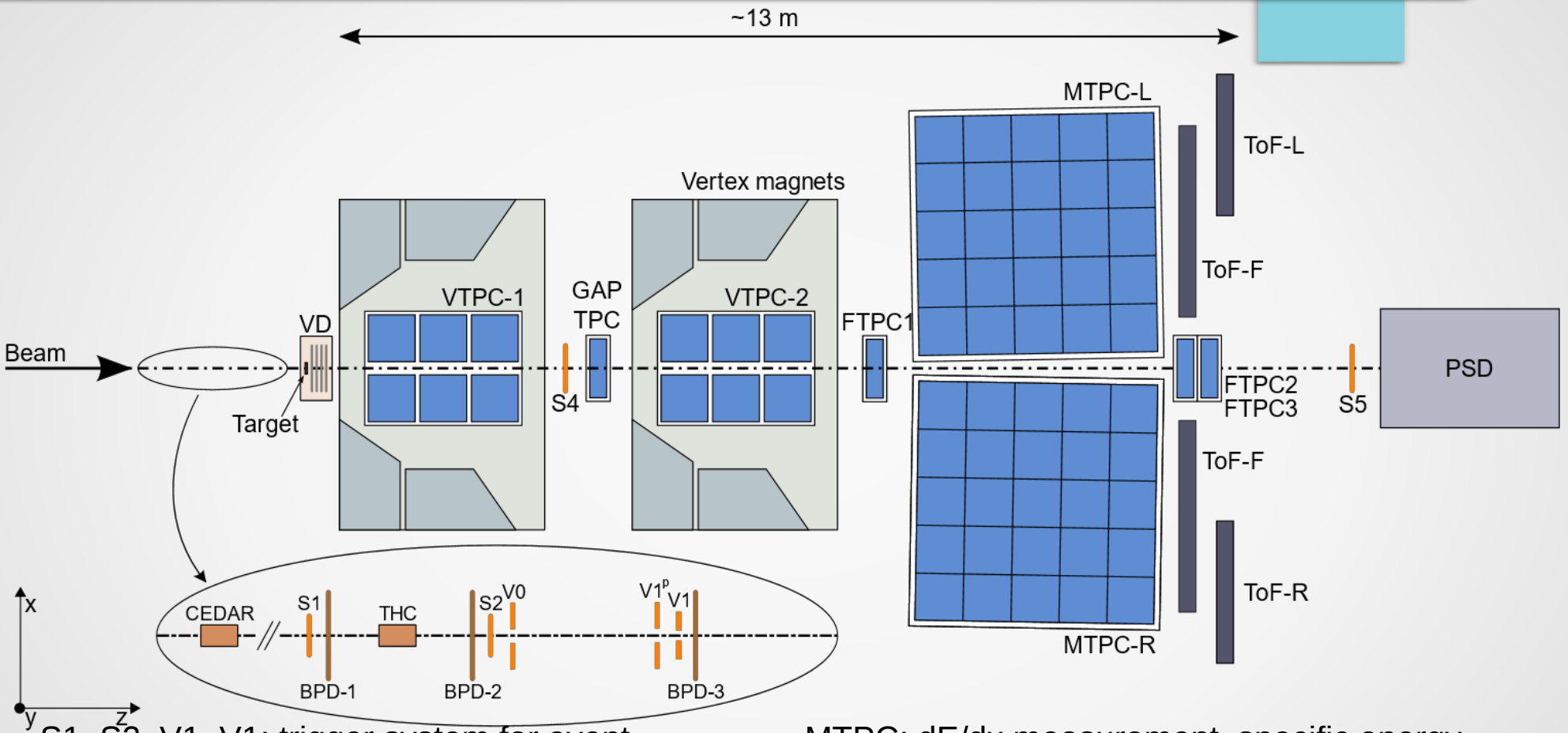
# Time scheduele

- Updates should be ready by end of long shutdown (2020)



# The NA61/SHINE facility




- S1, S2, V1, V1: trigger system for event selection
- VD: high-precision determination of primary vertex
- VTPC: 1.5 T magnetic field, momentum measurement, resolution: $10^{-4}$
- MTPC: dE/dx measurement, specific energy loss
- ToF: Time-of-flight measurements, improves particle identification
- PSD: zero-degree calorimeter, determine forward energy

# Data taking capabilities

- Ion beams:
  - Primary: Ar, Xe, Pb 13*A* – 150/160*A* GeV/*c*
  - Secondary: Be from Pb fragmentation, 13*A* – 150/160*A* GeV/*c*
- Hadron beams:
  - Primary: proton 400 GeV/*c*
  - Secondary: hadron beams: pion, kaon, proton 13 – 400 GeV/*c*
- Targets:
  - Solid state from ~1 mm to ~1 m
  - Liquid hydrogen target 20 cm
- Data taking rate: 1 M events/day (currently)

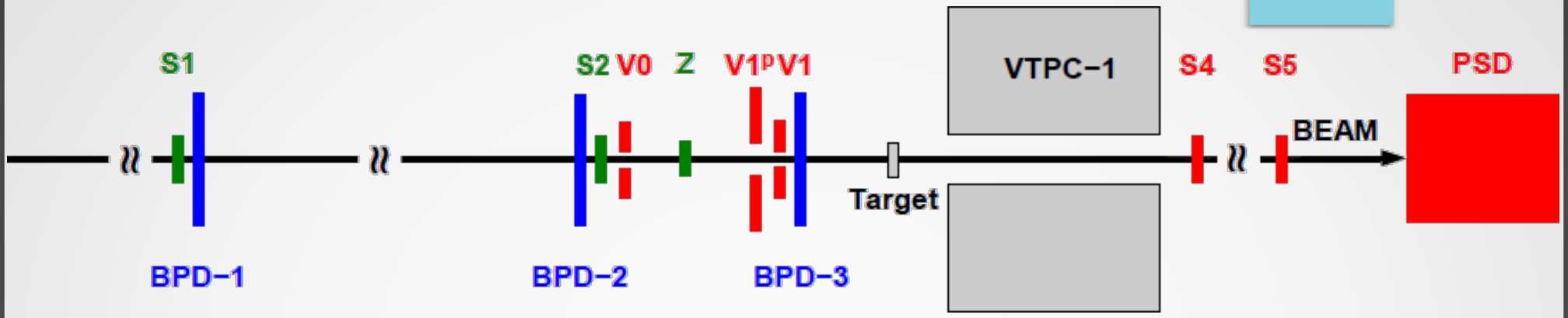
# Physics programme – current

- SHINE – Sps Heavy Ion and Neutrino Experiment
- Strong interaction programme:
  - Search for critical point
  - Study of onset of deconfinement
- Cosmic ray programme:
  - Measurements for simulations of cosmic ray shower (Pierre Auger Observatory, CASCADE)
- Neutrino programme:
  - Measurement for simulations of initial neutrino flux (T2K, Fermilab)

# Physics programme – updated

- NA61/SHINE has submitted an addendum for further physics measurements using the NA61/SHINE facility
  - Strong interactions: open charm measurements
  - Cosmic rays: light ion fragmentation with intergalactic matter
  - Neutrino: further reference measurements for T2K, Hyper-K, Dune targets
- Open charm requires significantly more statistics than current programmes
  - 80 Hz → 1 kHz
  - Also beneficial for other programmes
- An order of magnitude higer data taking rate must be accomodated by all detectors and sub-systems
  - The implications for each detector/system will be discussed on the following slides
  - Also much higer radiation dose must be accounted for

# Beam detectors & trigger system – current



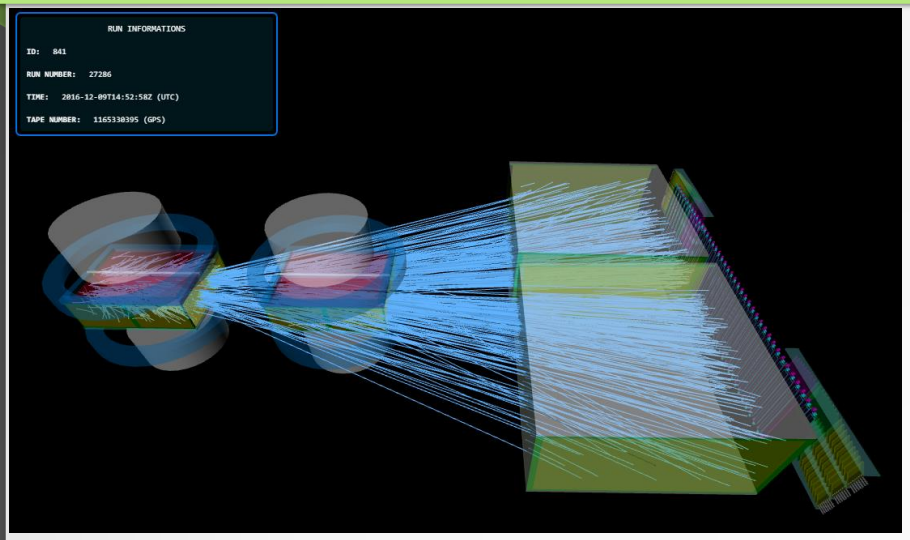

- Positive counters (S1, S2) – scintillators with PMTs, 30ps resolution
- Veto counters (V0, V1) – define beam profile
- Target
- Interaction counters (S4, S5) – lack of signal indicates interaction
- PSD – centrality trigger

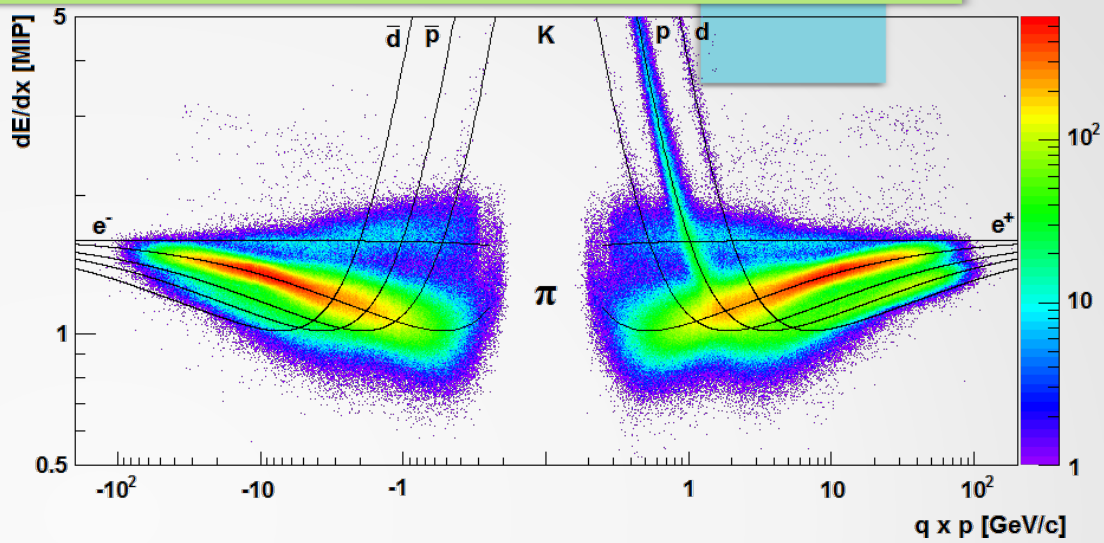
- Beam-Position Detectors (BPD-1, BPD-2, BPD-3)
  - Multiwire proportional chambers, 0.1 mm resolution on target

# Beam detectors & trigger system – update

- New trigger system based on VME FPGA logic module
  - Basic functionality will remain, but more compact (2 racks → 1 VME crate)
- New functionality:
  - On-line off-time rejection (remove events with off-time particles, saves 20-30 % of bandwidth/disk space)
  - Read-out of trigger counter ADCs changed from CAMAC to DRS4
  - Trigger delays programmable – cable lengths no longer critical
- BPDs will be replaced with scintillating fibre detectors
  - Can sustain higher beam intensities than current BPDs
  - Can be in vacuum, no need for entry/exit windows; less material

# Time projection chambers – current



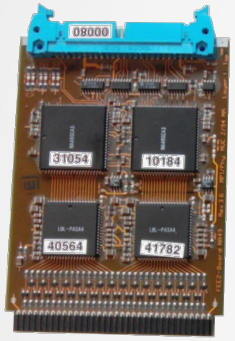

- 8 TPCs
  - VTPC (2), MTPC (2), GTPC (1), FTPC (3)
  - Measurement of momentum and dE/dx
  - 200 000 channels
  - Data taking rate 80 Hz
- VTPCs in magnetic field, others not
- Main tracking detectors of NA61/SHINE facility

# Time Projection Chambers - updated

- Current TPC electronics must be replaced to be able to read out 1 kHz
  - Current ALICE electronics capable of ~1kHz will be replaced during LS2
  - Re-using current ALICE electronics for NA61/SHINE most technically and economically feasible path
  - Agreement reached with ALICE to take over needed components
- Mechanically challenging to upgrade
  - VTPCs have to be temporarily removed from detector
  - Tight space for new electronics since new boards are larger than current
  - Custom adapter boards between NA61/SHINE TPC connectors and ALICE TPC connectors

# TPC upgrade implementation

**Present NA61 Front-End Card**

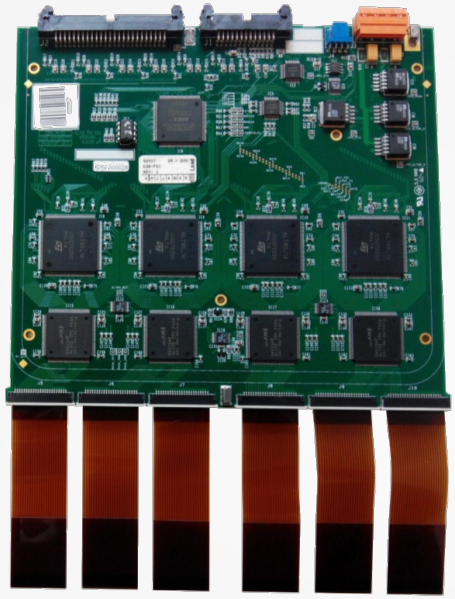


**32 channels**

⬇

**1 NA61/SHINE TPC connector**

**ALICE Front-End Card**



**128 channels**

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**ALICE TPC connectors**

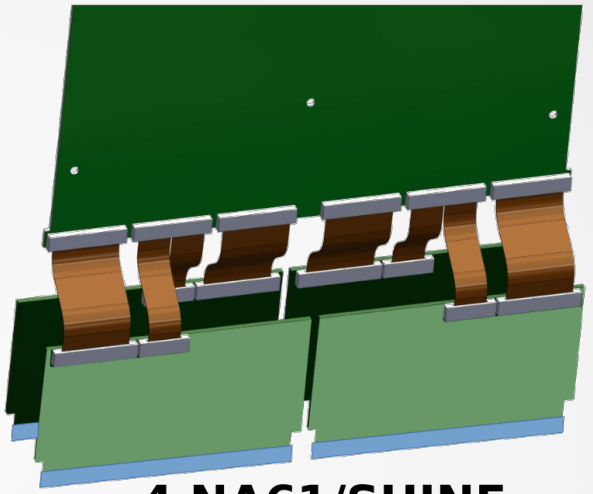
⬇

**Adapter board**

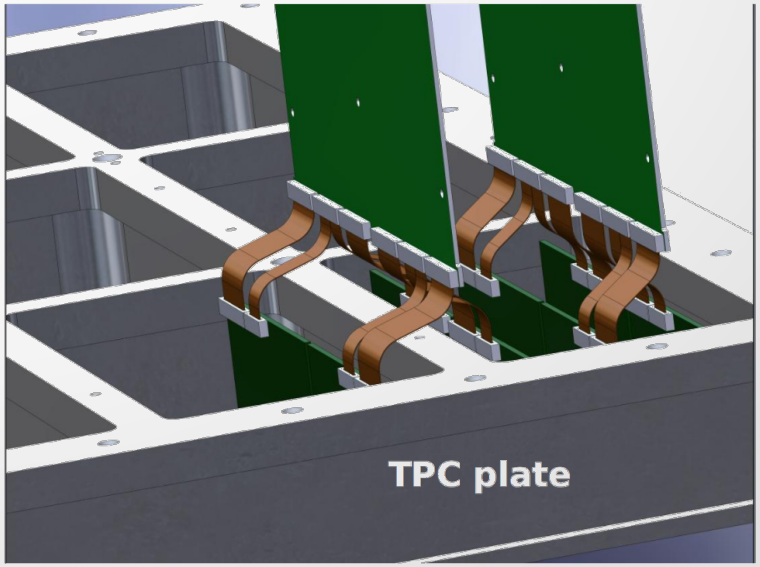
⬇

**4 NA61/SHINE TPC connectors**

**ALICE Front-End Card**

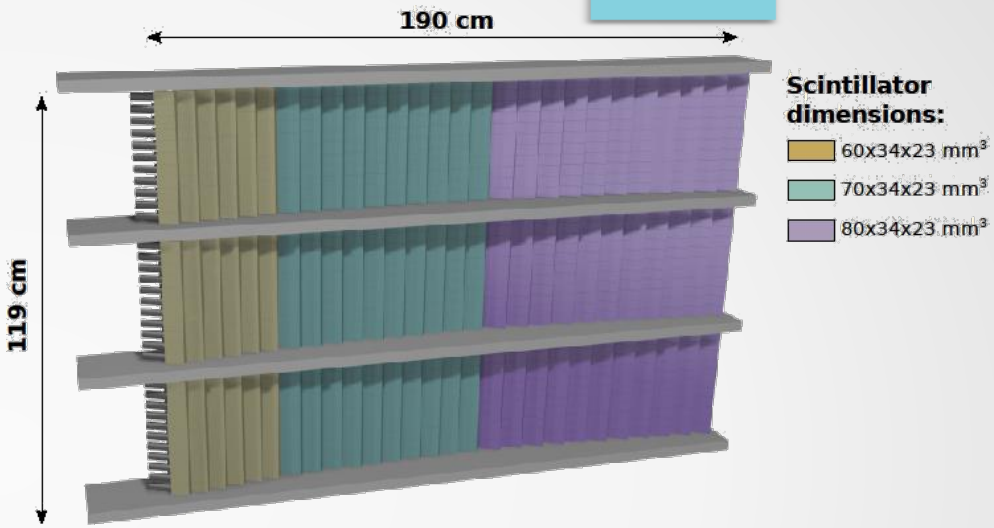


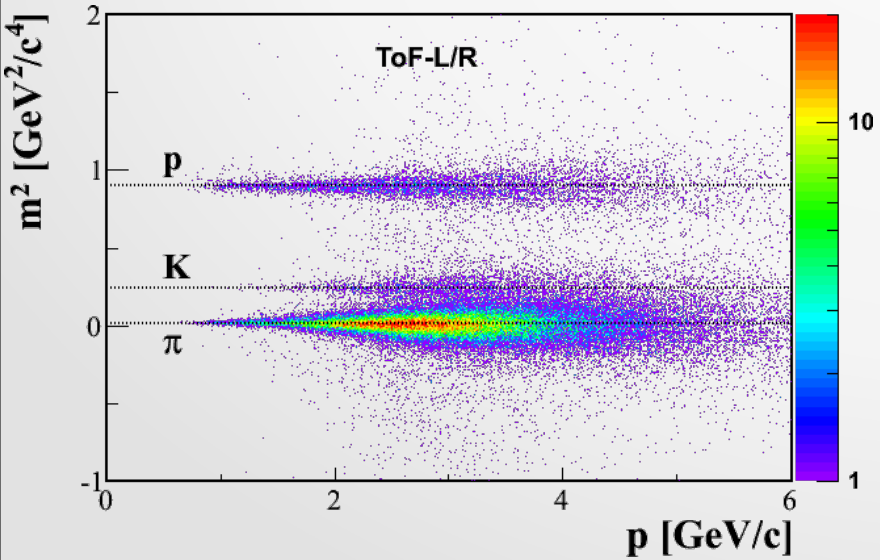

**4 NA61/SHINE TPC connectors**



# Time-of-Flight – current

- Important for particle identifcation
- Three walls:
  - ToF-left & ToF-right:
    pixel scintilators and PMTs
    – optimised for identifying kaons
    at mid-rapidity
  - Forward-ToF:
    scintilator bars and PMTs – optimised for low momentum particle identification

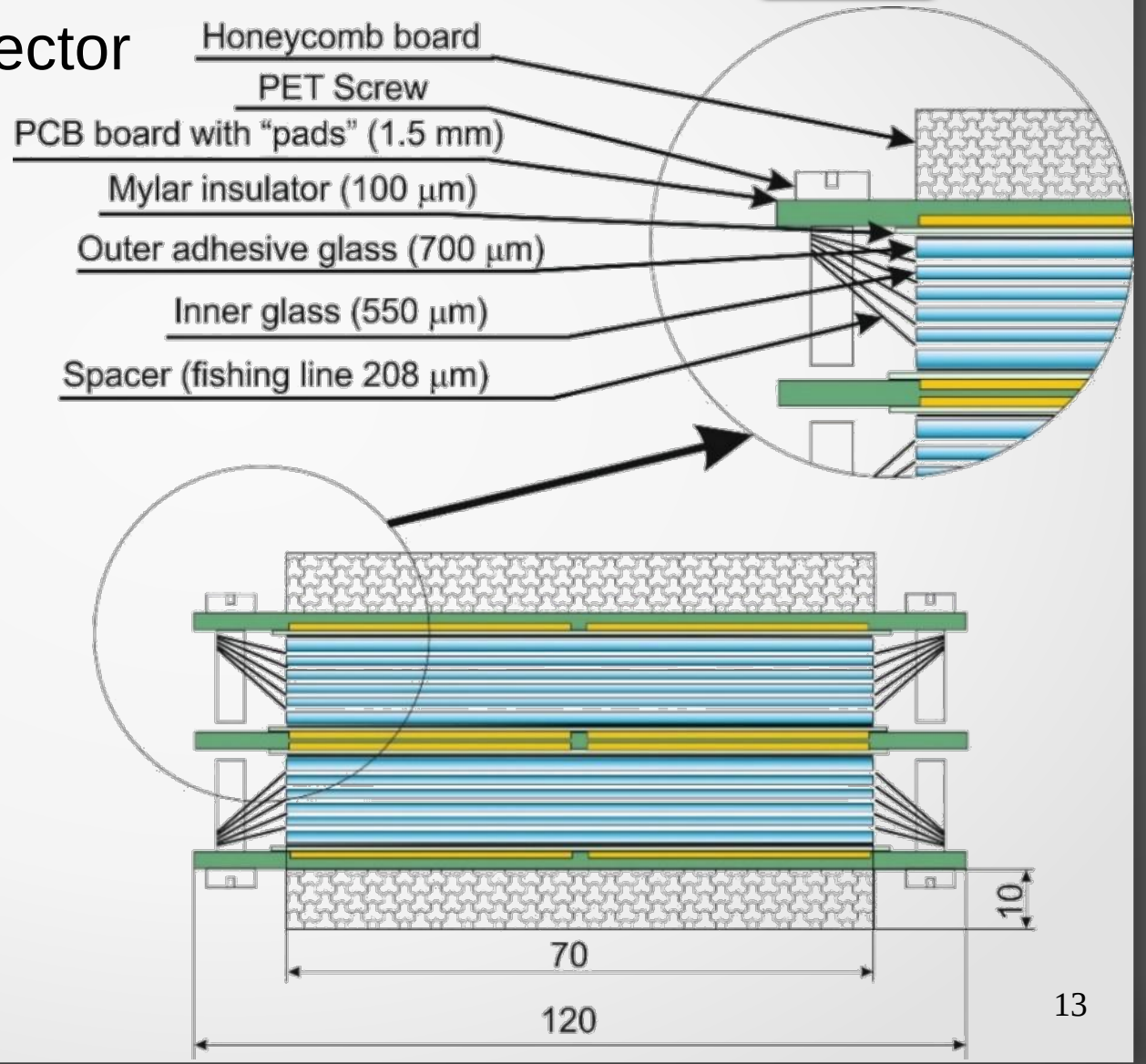



- Drawbacks:
  - ToF-left & ToF-right performance quickly decays due to ageing
  - Forward-ToF only operates at low multiplicities

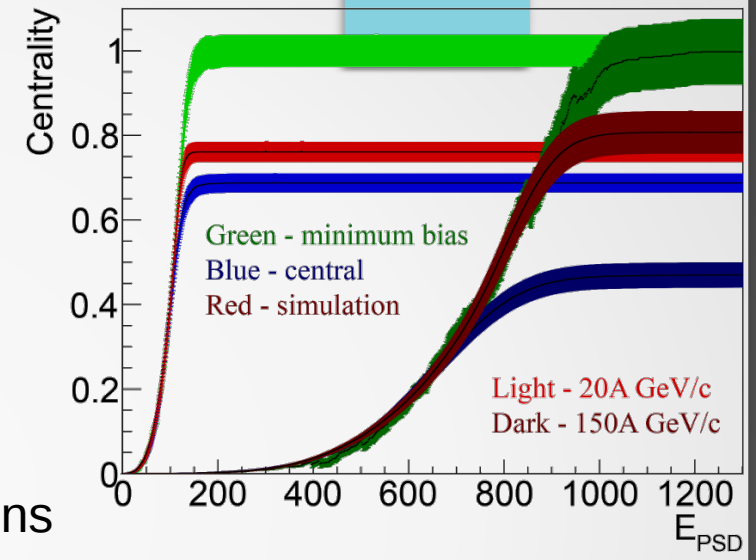
# Time-of-Flight – update

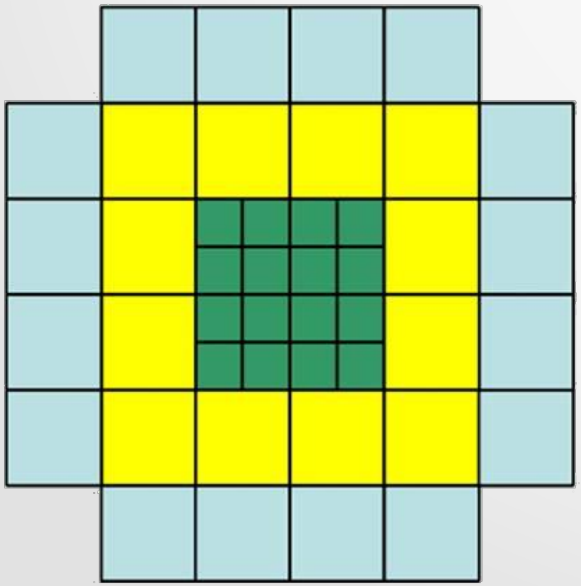
- Completely new detector
- Based on MRPC (gas detector)
- 50ps time resolution achieved in test of prototype in NA61/SHINE experiment

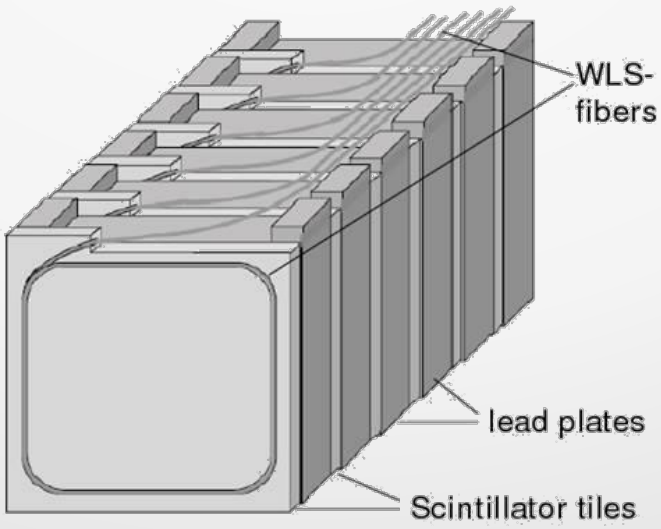


# Projectile-Spectator Detector – current

- Zero-degree calorimeter
  - Forward energy determination (collision violence)
  - event plane determination
- 446 measurements of deposited energy
  - 44 transverse modules with 10 longitudinal sections
  - Additional small short module with 6 sections in front

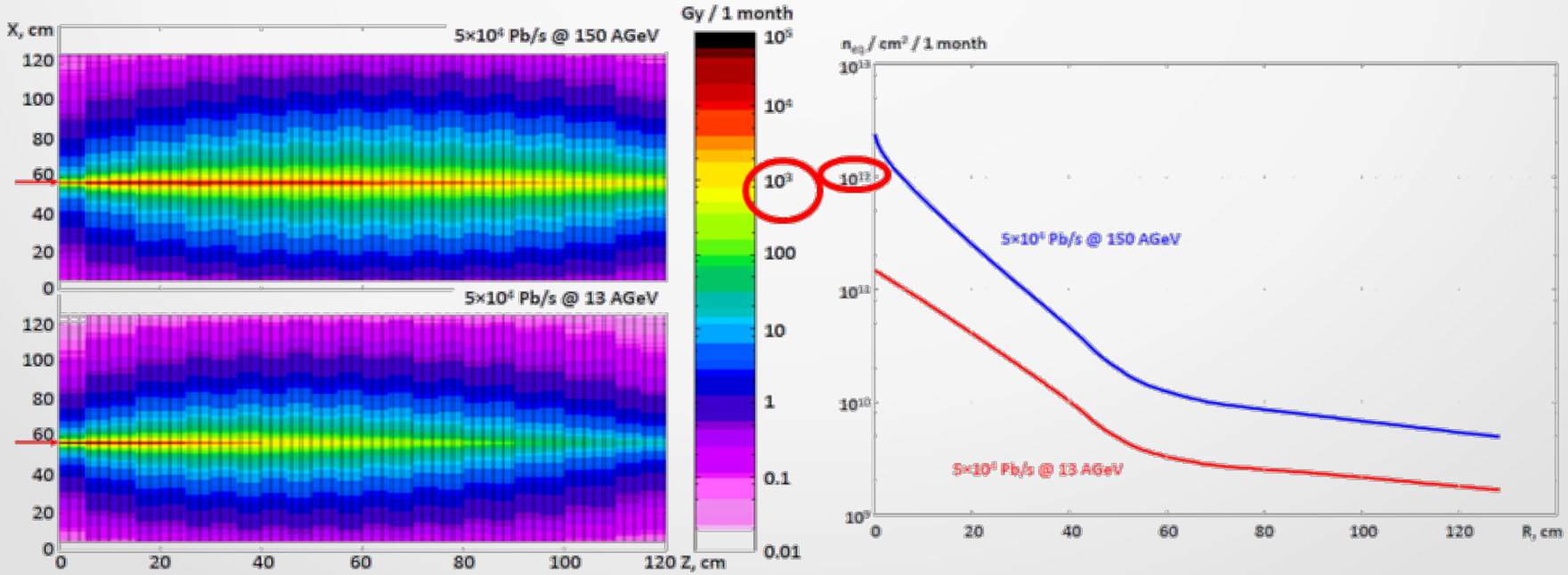




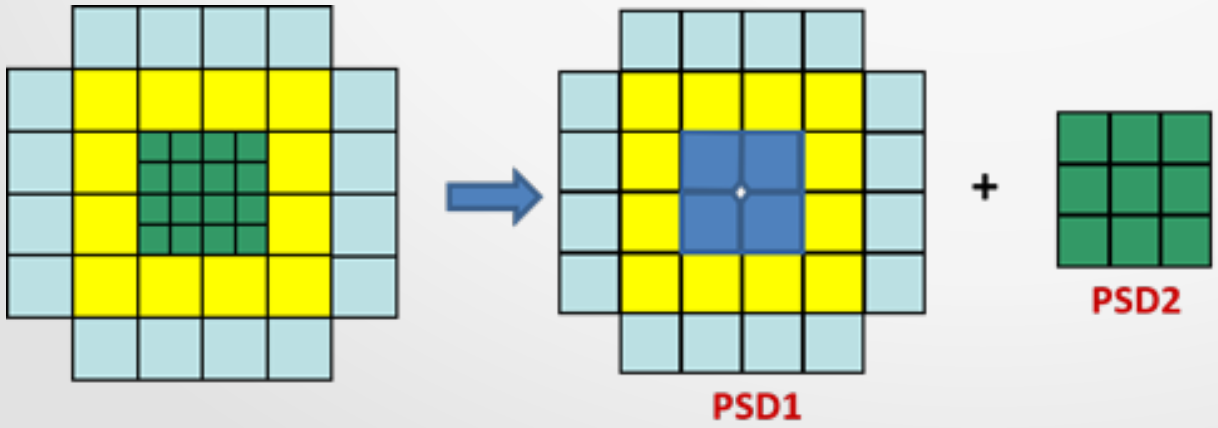

# Projectile-Spectator Detector - update

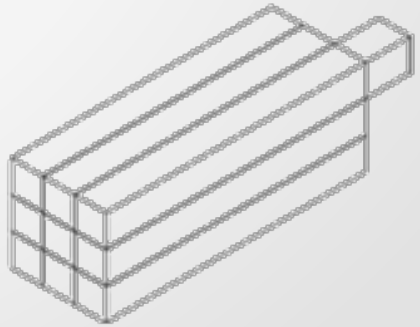
- Increase of read-out rate requires faster signal read-out
  - New read-out electronics
  - Readout either by DRS4, or by custom chips from Dubna
- Increased beam intensity may damage PSD
  - Design needs to be modified (next slide)



# Replacement of PSD inner modules

- Currently, PSD has 16 smaller inner modules
  - These will be replaced by 4 larger modules with chamfered corners to allow a 60x60mm hole for the beam
  - This hole will reduce the PSD sensitivity to radiation damage from the higher beam intensity
- A new Forward PSD module to be placed after current PSD (Main PSD) to measure particles going through hole
  - Forward PSD and Main PSD will have different dynamical ranges (Main PSD will measure produced particles, Forward PSD measure beam)



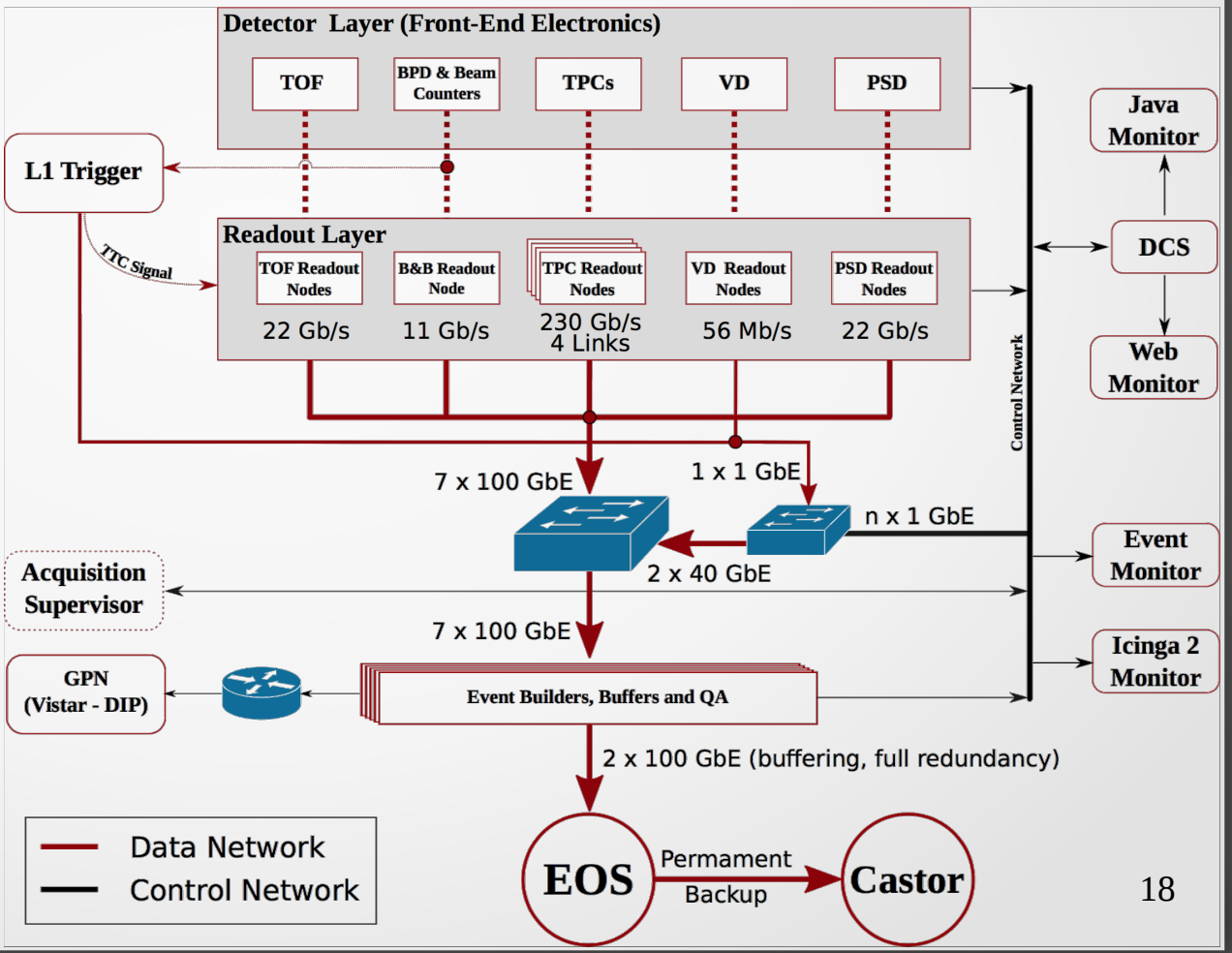



# Data acquisition system – current

- The upgrades will significantly increase the data rates to be handled by DAQ
- Current DAQ can not easily be expanded to handle NA61 beyond 2020 requirements
  - Difficult to add more detectors
  - Can not take advantage of parallel architectures
  - Generally challenging to expand and improve
- Conclusion:
  - New system needed

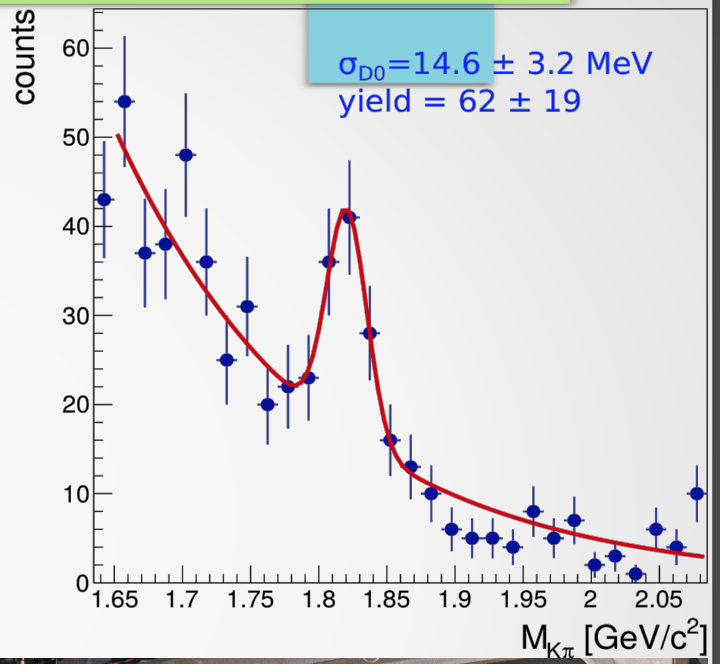
# Data acquisition system - update

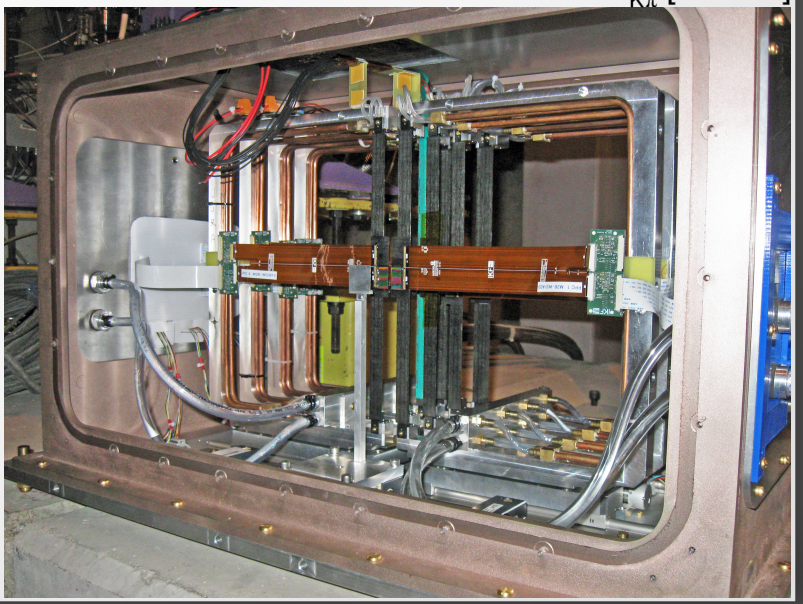
- New system capable of 1kHz read-out–rate
- Based on Ethernet both for read-out and control
- Event aggregation from various nodes throgh commercial Ethernet swiches
- Clear separation between DAQ framework and detectors
- Event builder with buffer to store data for >3 days in case delays in transfer to CASTOR
- On-line reconstruction needed to reduce data volumes



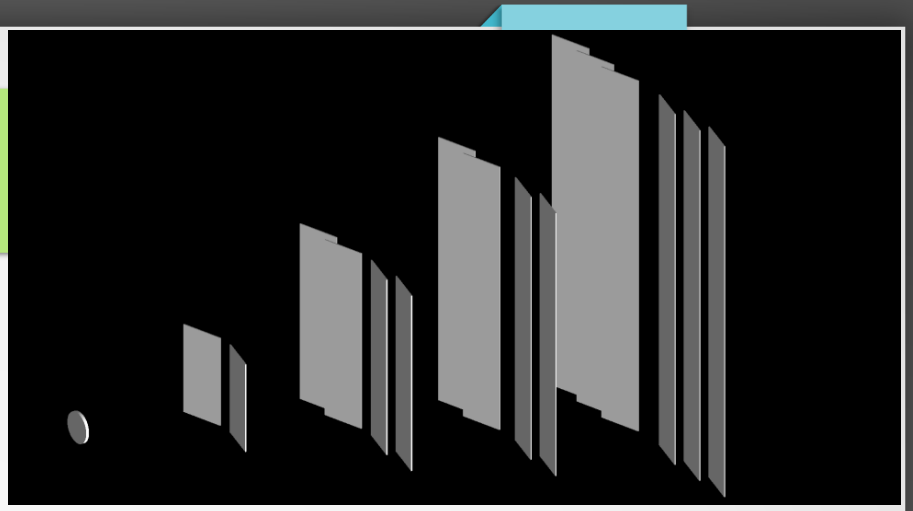
# Vertex Detector – current

- Small-Acceptance Vertex Detecor (SAVD)
- TPCs can not resolve primary vertex with good enough precision to reconstruct $D^0$
  - TPC resolution ~1 cm, required ~0.05 mm
- SAVD commissioned December 2016
  - 16 sensors, 4 stations, ~50 % $D^0$ phase space covered
  - Successfully used to take Pb+Pb, p+Pb and Xe+La data
  - $D^0$ peak observed



# Vertex Detector - update



- Upgraded Vertex Detector
  - Expanded version of current VD
  - 16 → 46 sensors, 80 Hz → 1 kHz read-out rate
  - Stations at spaced every 5 cm from target
  - General SAVD infrastructure will be reused
- Change of sensor technology from Mimosa26 → ALPIDE
  - Mimosa26 has too long read-out–time
  - Also relatively high noise levels
- Higher statistics will make spectra possible
- Longer detector will eneable reconstruction of (strange) particles with “long” life-time that will decay after 1$^{st}$ station
- See separate VD presentation by A. Merzlaya from 05.07

# Summary

- Current physics programme is close to completed, a new is proposed in an addendum
- The open charm measurements will require significantelly higher statistics
  - Data to be read out at 1k events/s
  - Practically all detectors and sub-systems must be upgraded
  - Will also benefit other programmes
- New or significantly improved detectors like LAVD will be introduced
- NA61/SHINE is currenty preparing detailed plans for each of these upgrades

# Contributors

- DAQ:
  - Jagiellonian University, Warsaw University of Technology, JINR Dubna
- DRS4 readout:
  - University of Geneva, University of Pittsburgh, University of Silesia, University of Warsaw
- SciFi BPDs:
  - University of Geneva, University of Silesia
- Trigger:
  - University of Silesia, University of Warsaw
- PSD:
  - INR Moscow
- ToF:
  - JINR Dubna
- LAVD:
  - Jagiellonian University, University of Frankfurt, University of St. Petersburg, University of Silesia
- TPC:
  - Jagiellonian University, University of Frankfurt, University of Warsaw, Warsaw University of Technology, University of Bergen