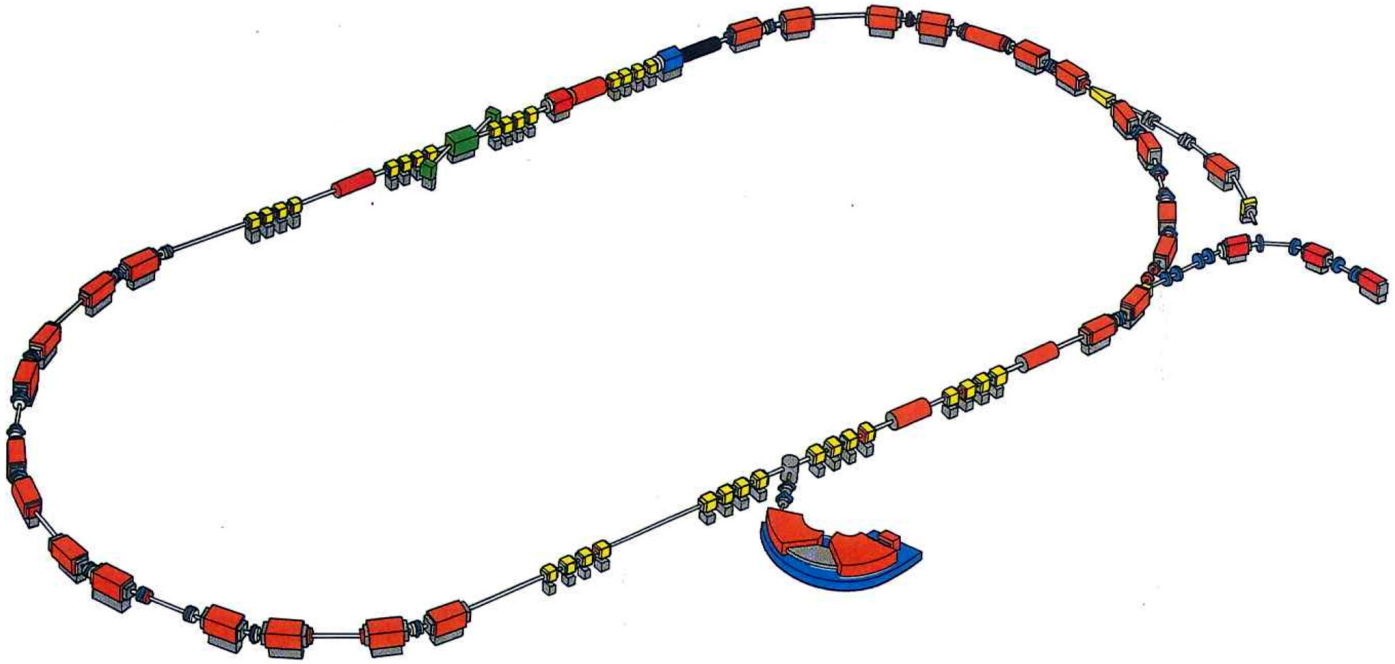
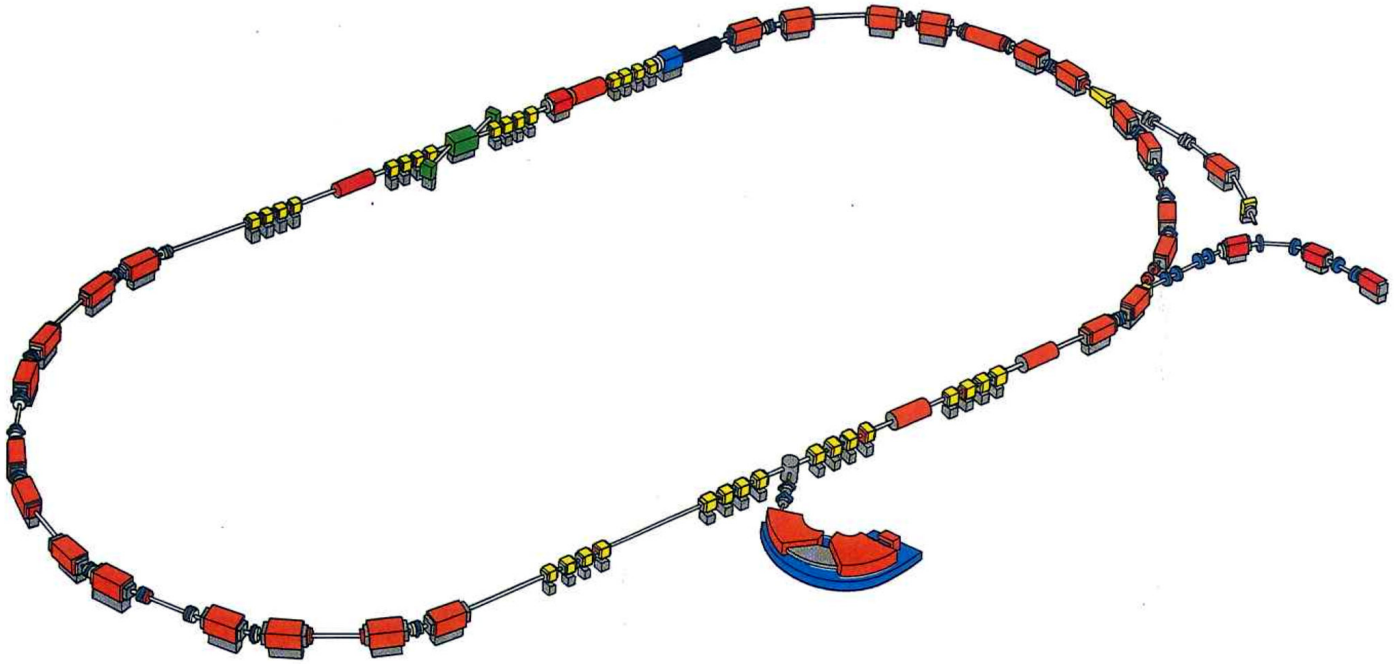


# New developments and experience with real-time signal processing for beam diagnostics at COSY.

April 16, 2018 | Ilja Bekman, Karl Reimers | IKP-4

# Outline

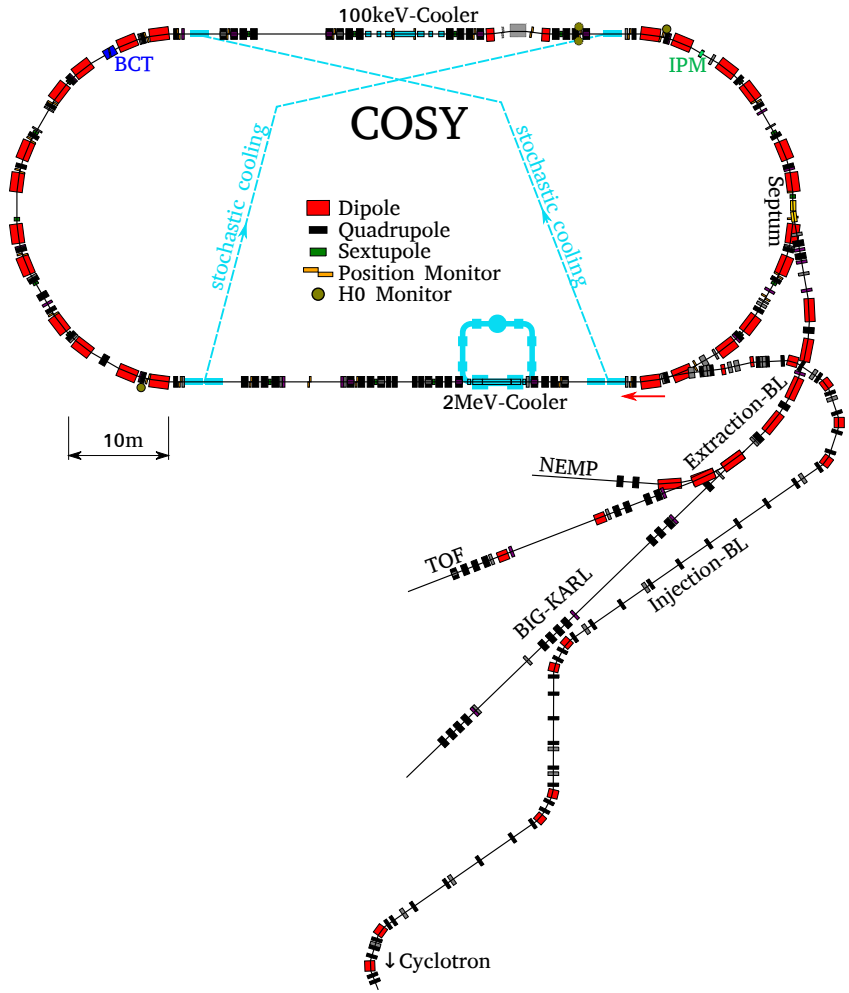
- Introduction to COSY
- Beam Diagnostics at COSY
- Components in Detail
  - EPICS control system
  - FPGA usage cases



# Part I: Introduction

# Introduction to COSY

- by Institute of nuclear physics
- COoler SYnchrotron (COSY)
- Cyclotron JULIC
- 184 m circumference
- storage ring for p+ and deuterons
- polarized and unpolarized beams
- 294 MeV/c up to 3.65 GeV/c
- stochastic and 2x electron cooling
- EDM precursor experiment



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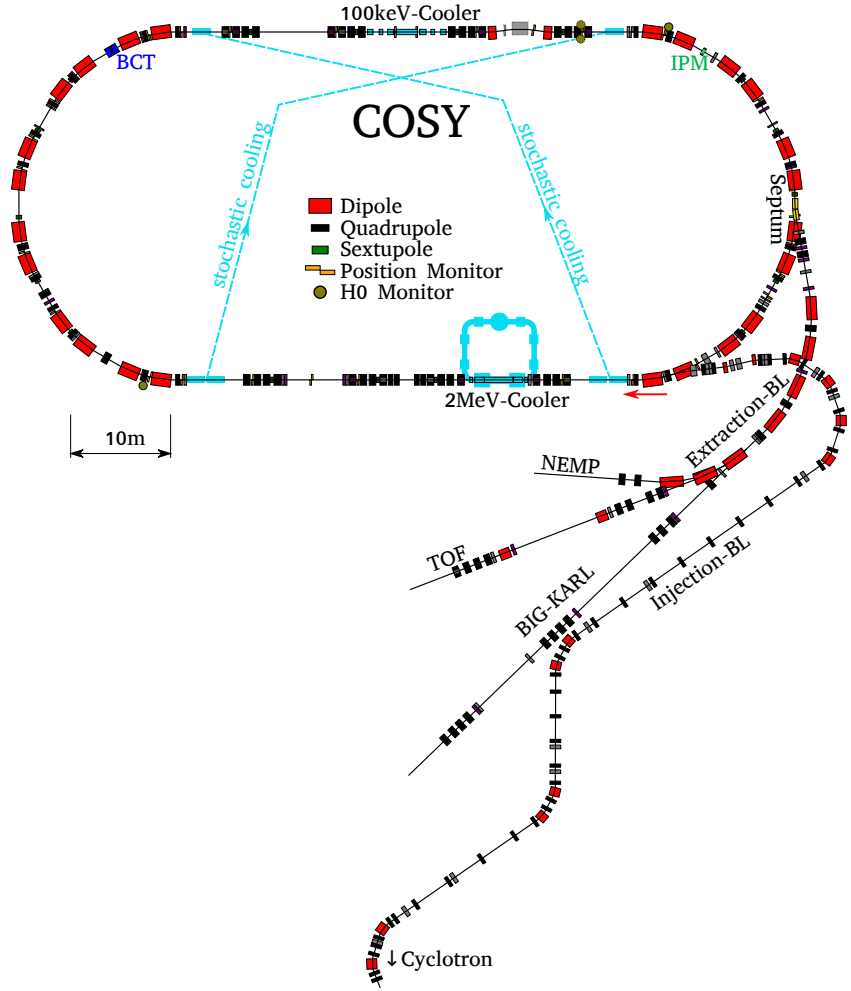
# Diagnostics at COSY: Highlights

- Control and diagnostics of the beam ensure the beam delivery
- Several diagnostic systems are operating at COSY:



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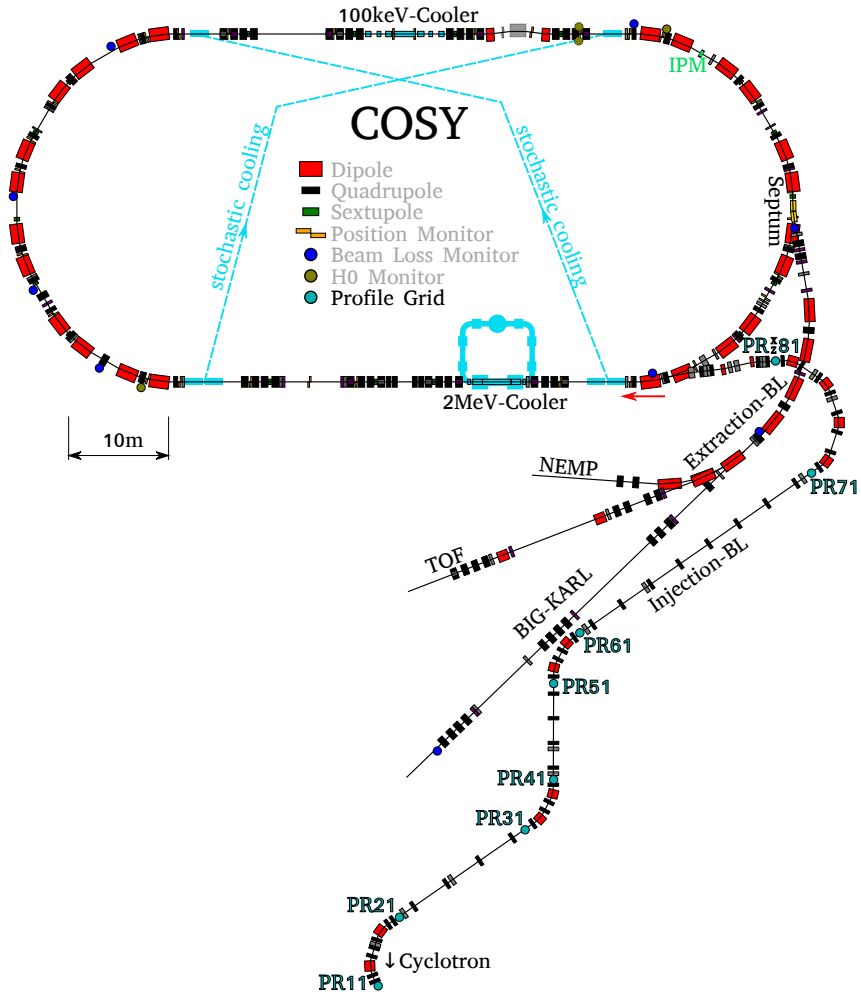
# Diagnostics at COSY: Highlights

- Control and diagnostics of the beam ensure the beam delivery
- Several diagnostic systems are operating at COSY:
  - Profile Grids
- EPICS used.



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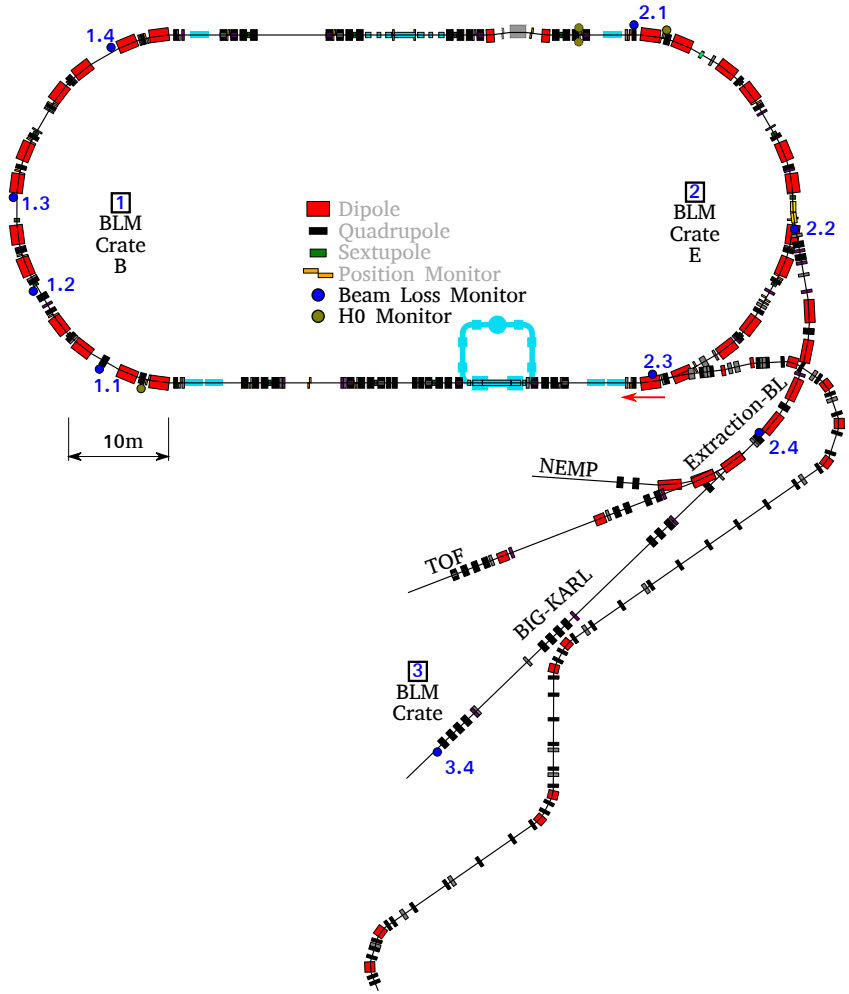
- Control and diagnostics of the beam ensure the beam delivery
- Several diagnostic systems are operating at COSY:
  - Profile Grids
  - Beam Loss Monitor




- EPICS used.
- FPGA used.



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# Diagnostics at COSY: Highlights

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  - Profile Grids
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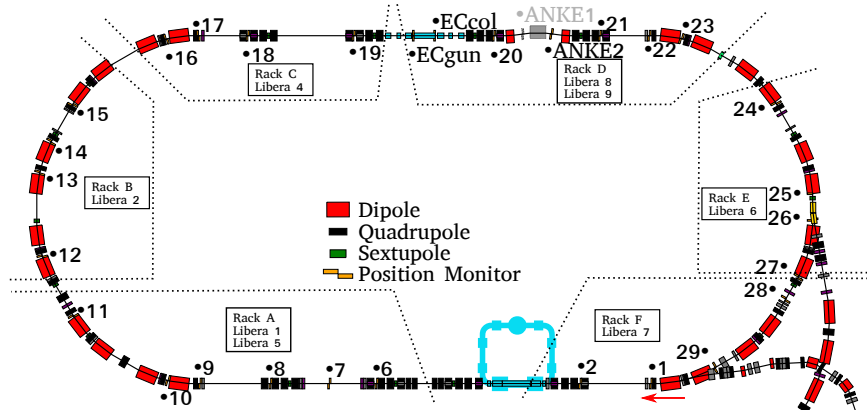
  - Beam Position Monitor




- EPICS used.
- FPGA used.



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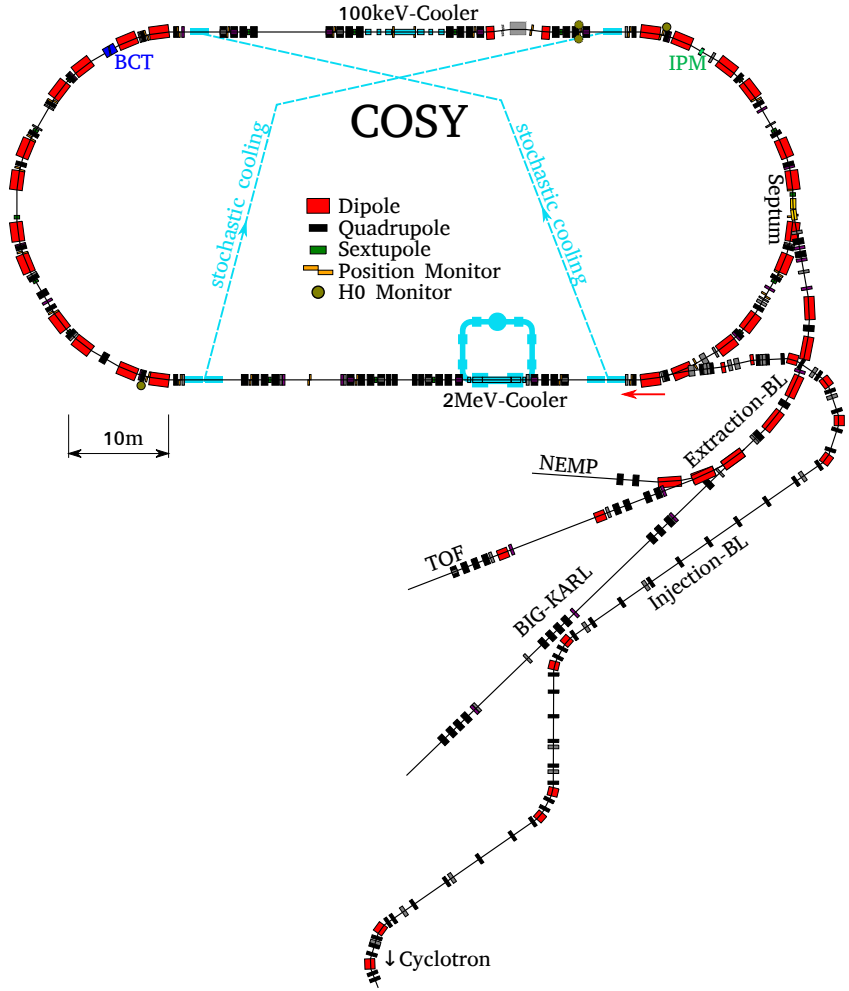
# Diagnostics at COSY: Highlights

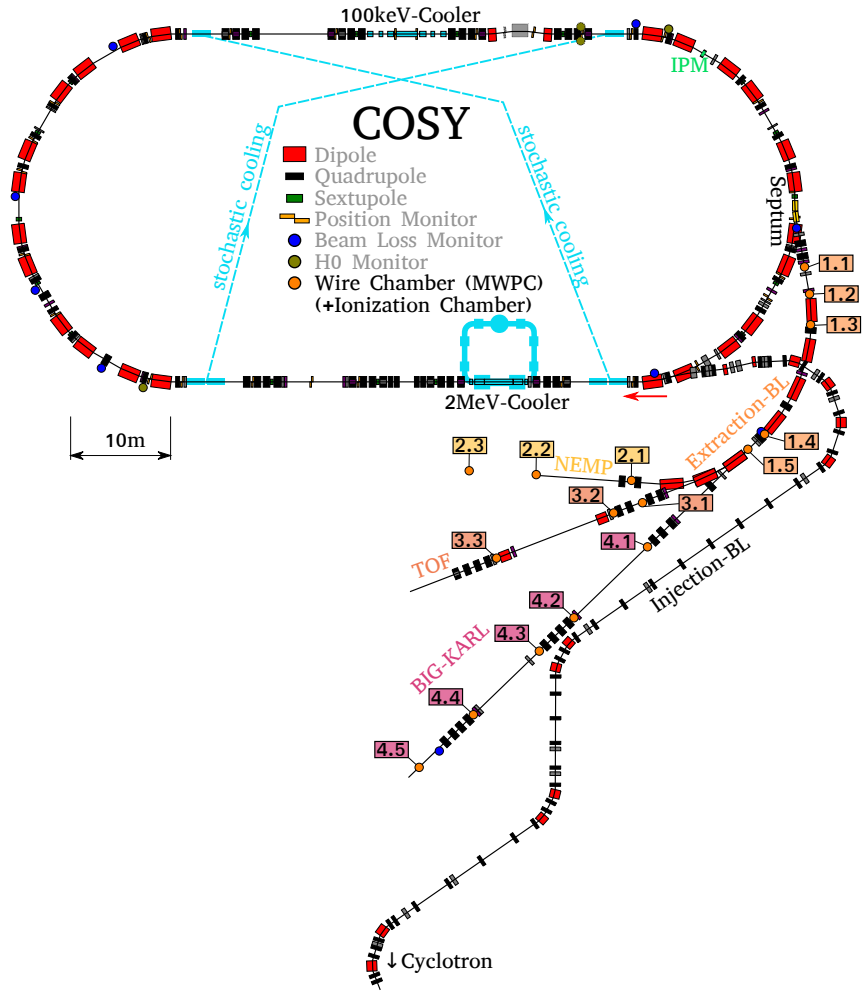
- Control and diagnostics of the beam ensure the beam delivery
- Several diagnostic systems are operating at COSY:
  - Profile Grids
  - Beam Loss Monitor
  - Beam Position Monitor
  - Ionization Profile Monitor
  - Beam Current Monitor




- EPICS used.
- FPGA usage envisaged.

# Diagnostics at COSY: Highlights

- Control and diagnostics of the beam ensure the beam delivery
- Several diagnostic systems are operating at COSY:
  - Profile Grids
  - Beam Loss Monitor
  - Beam Position Monitor
  - Ionization Profile Monitor
  - Beam Current Monitor
  - Multi Wire Proportional Chambers
  - Ionization Chambers
- EPICS used.
- FPGA used.



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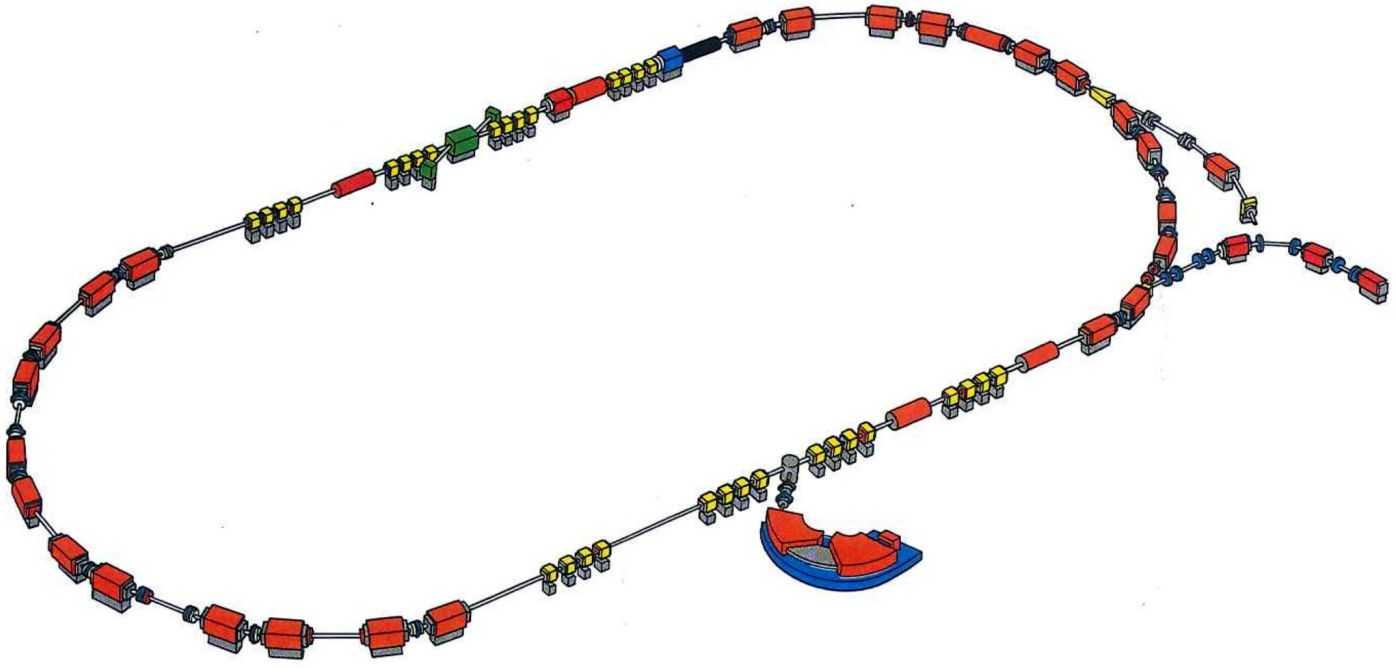


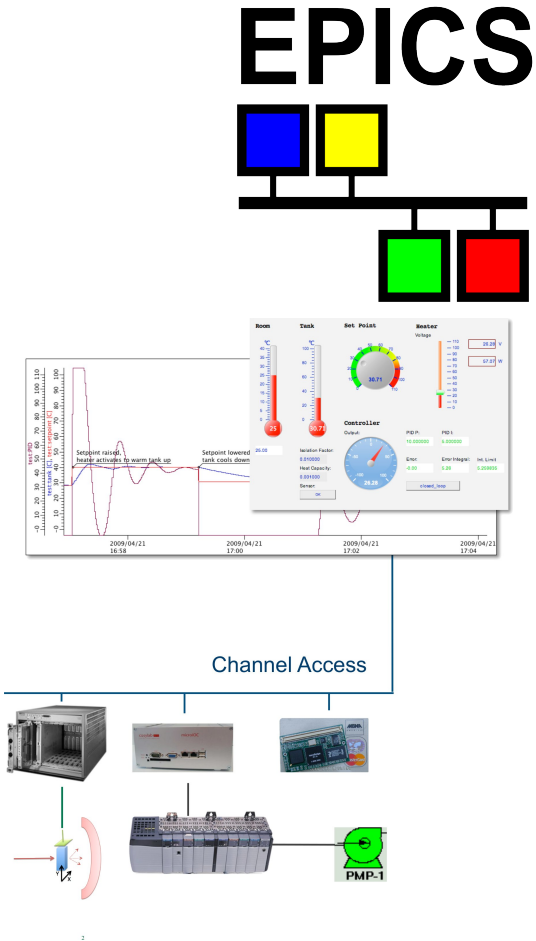
# Part II: EPICS

# EPICS: Intro

## Experimental Physics and Industrial Control System

- distributed control system open-source software
- server-client nodes on top of standard network infrastructure via **C**hannel **A**ccess protocol

- Modular, flexible and scalable; connecting and controlling computers and hardware
- CSS GUI (Control System Studio), Archiver appliance
- Dedicated user community, meeting 2x per year; commercial support
- Used at ESS, PSI, APS, NSLS-II, SNS, COSY and others

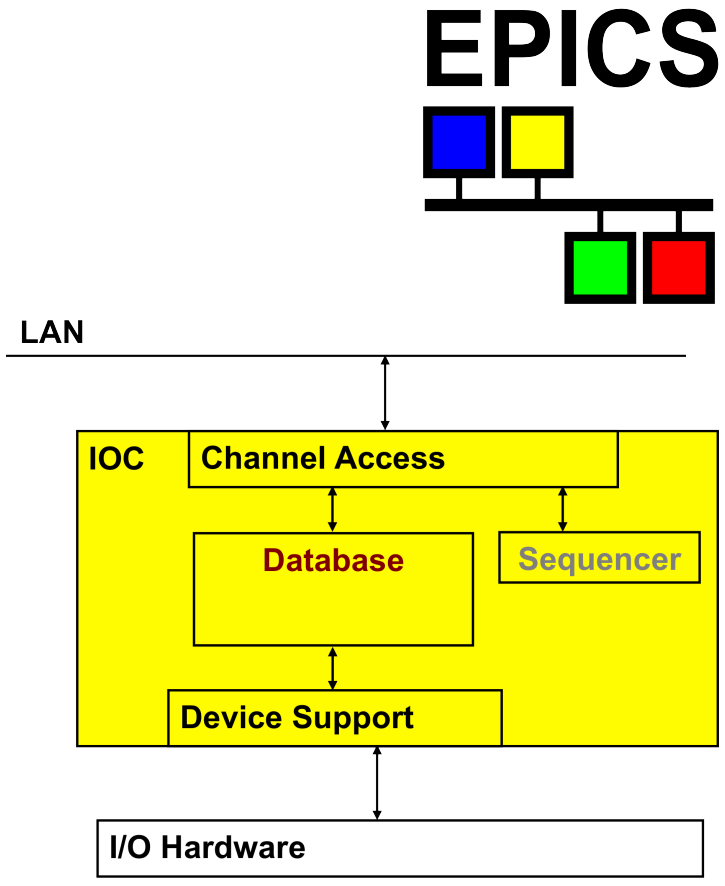



Ref: [1]

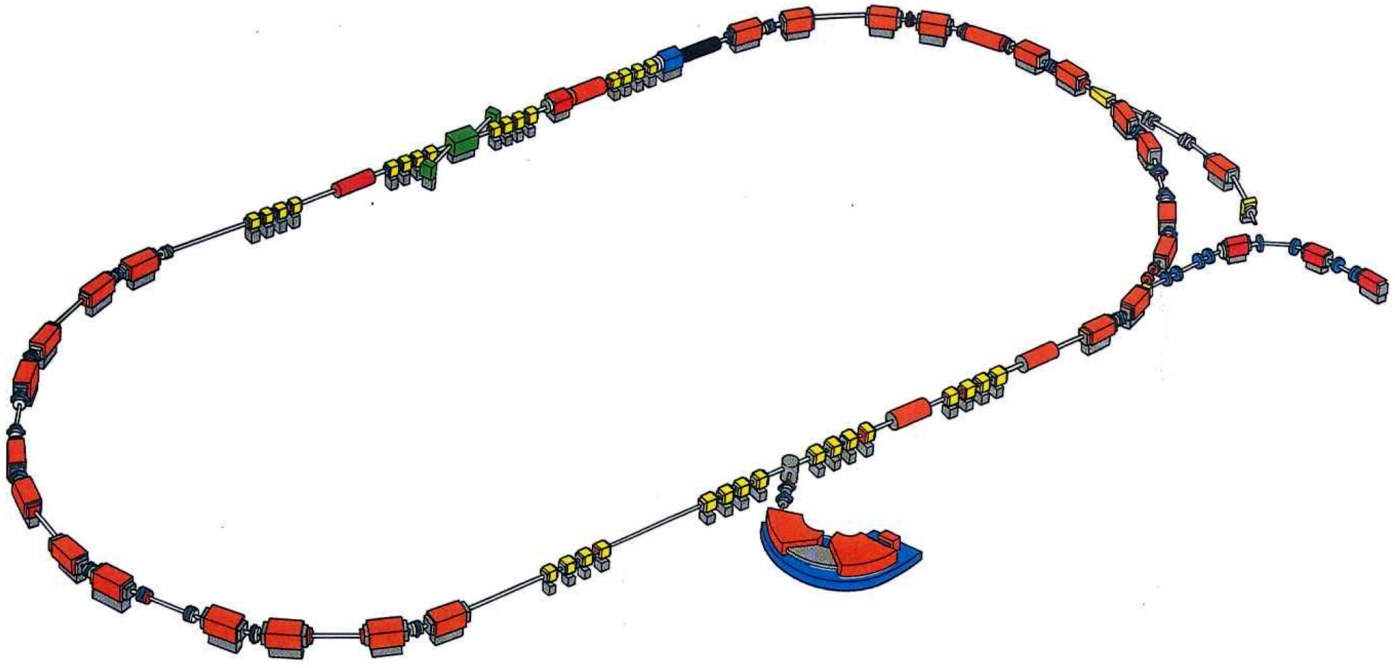
# EPICS: **IOC**

## Input/Output Controller

- A server unit interfacing actual hardware and performing controlling tasks
- Database of **P**rocess **V**ariables, data/control interface
- Event/changes driven




- soft IOC or custom device support in multiple programming languages (C, Python, LabView)
- Written and cross-compiled linux driver (memory-map) for custom SoC firmware to be accessible via EPICS

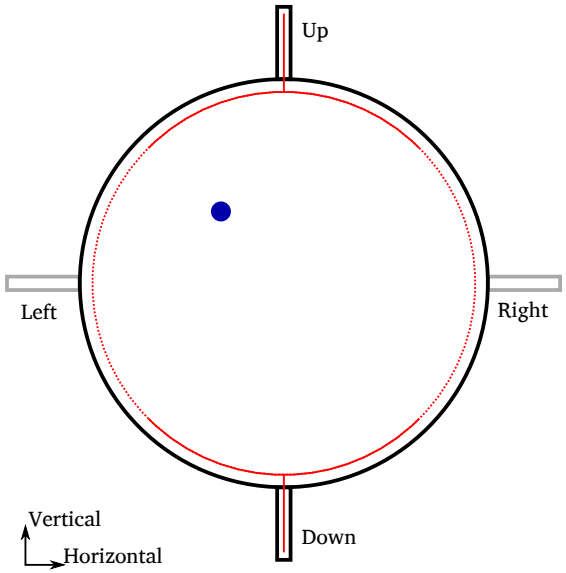


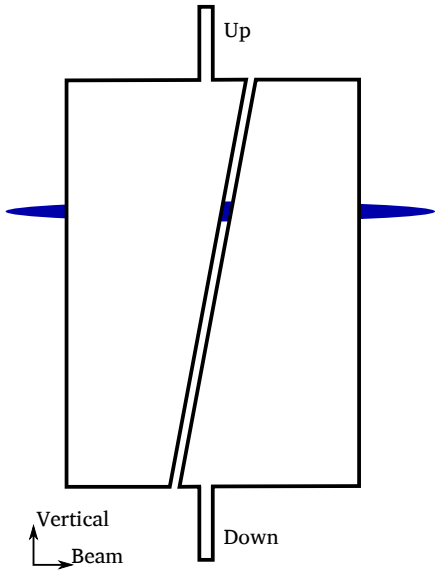
# Part III: Beam Position Monitor

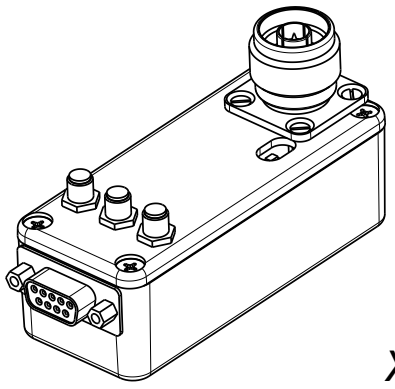
# Beam Position Monitor

## Principle

- Two electrodes per direction sense charges induced by bunched beam
- 4x capacitive pickup amplifiers the signals



- Gain of the amplifiers is calibrated and controlled remotely

$$X_{\mathrm{vert}} = K_{\mathrm{vert}} \frac{U_{\mathrm{down}} - U_{\mathrm{up}}}{U_{\mathrm{down}} + U_{\mathrm{up}}} + X_0$$



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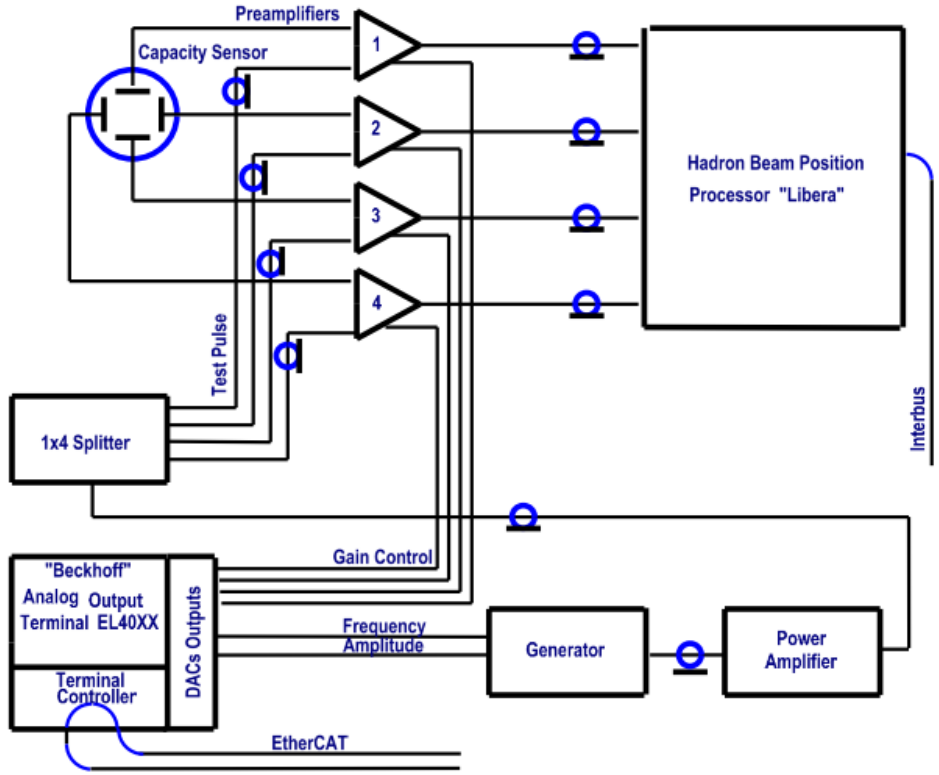
# Beam Position Monitor: DAQ

## Signal Processing

- `Libera Hadron` system records 2 signals per direction
- $\mu$TCA cards, 250MS/s 16bit ADCs, Virtex 6 on mezzanines, Linux OS on mainboard
- One unit for up to 4 BPM stations (X and Y)




- `EPICS` API used (more info in 3 slides)



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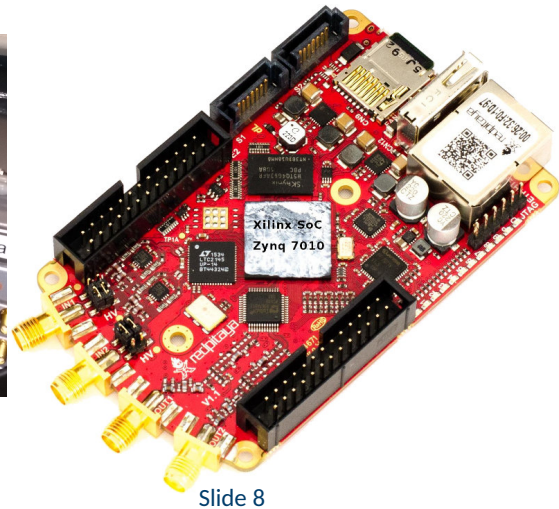
# Beam Position Monitor: Commissioning

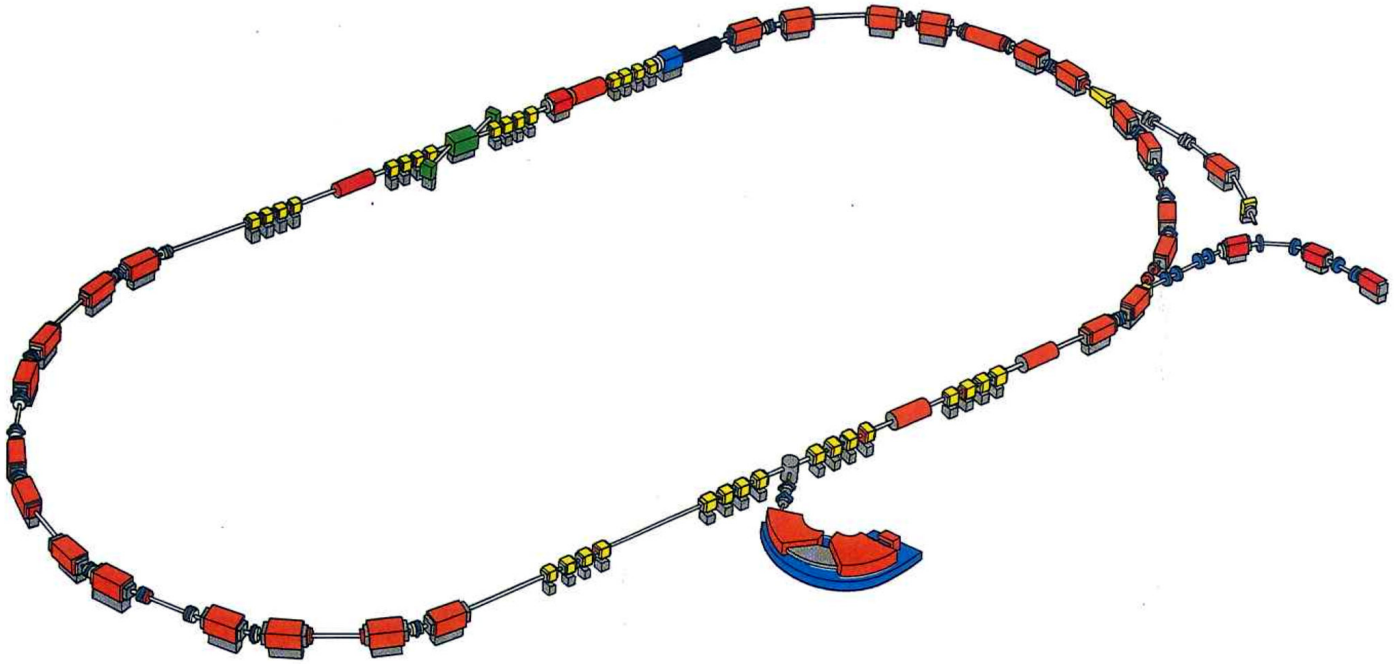
## Gate Generator

- `Red Pitaya` board used as gate and signal generator on test system
- same device for emulating:
  - 25sec + 5sec gate
  - 10MHz ref. clock
  - 1MHz machine clock
  - two 1MHz sine waveforms

## `Red Pitaya`

- Xilinx Zynq-7010 SoC
- 2x 14-bit ADC
- 2x 14-bit DAC
- 16x GPIO pins
- (125 MS/s, 50MHz BW)
- + periph. ; $\mathcal{O}$(300 Eur)



# Part IV: Multi Wire Proportional Chambers and Ionization Chambers

# Multi Wire Proportional Chambers

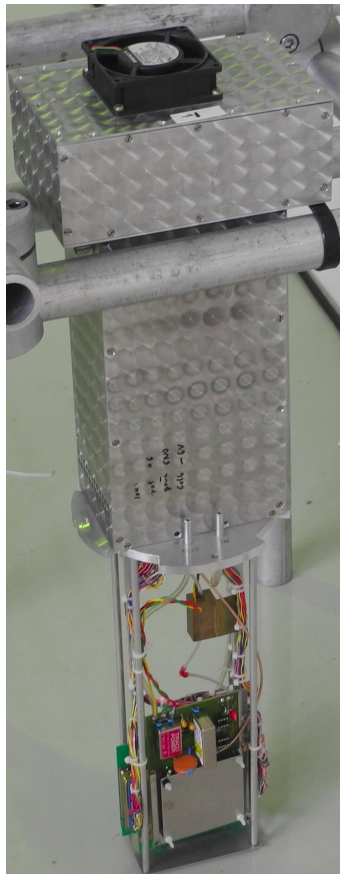
## Principle

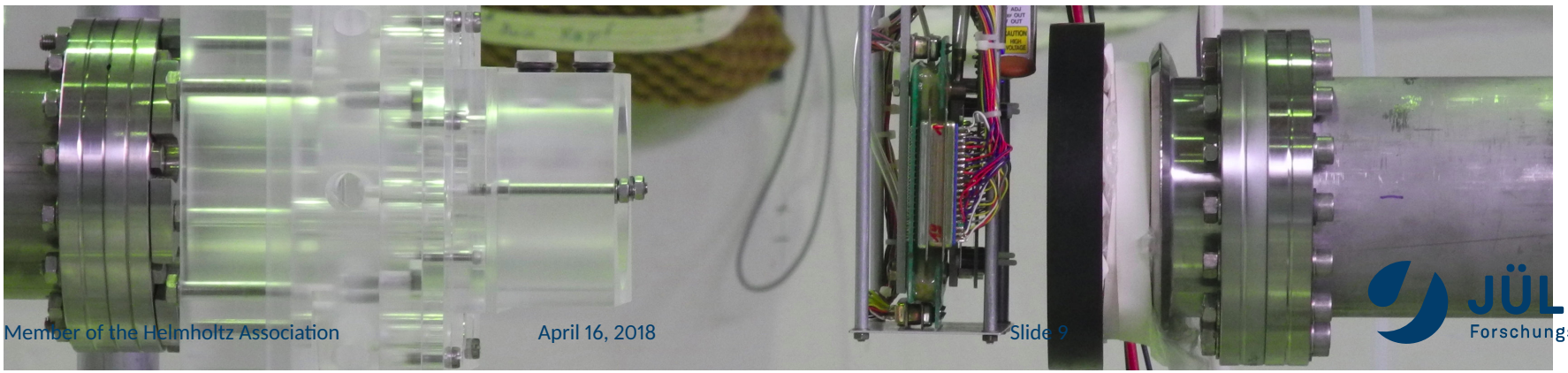
- Wires flushed with gas, at high potential to the chamber
- Signal proportional to energy deposit

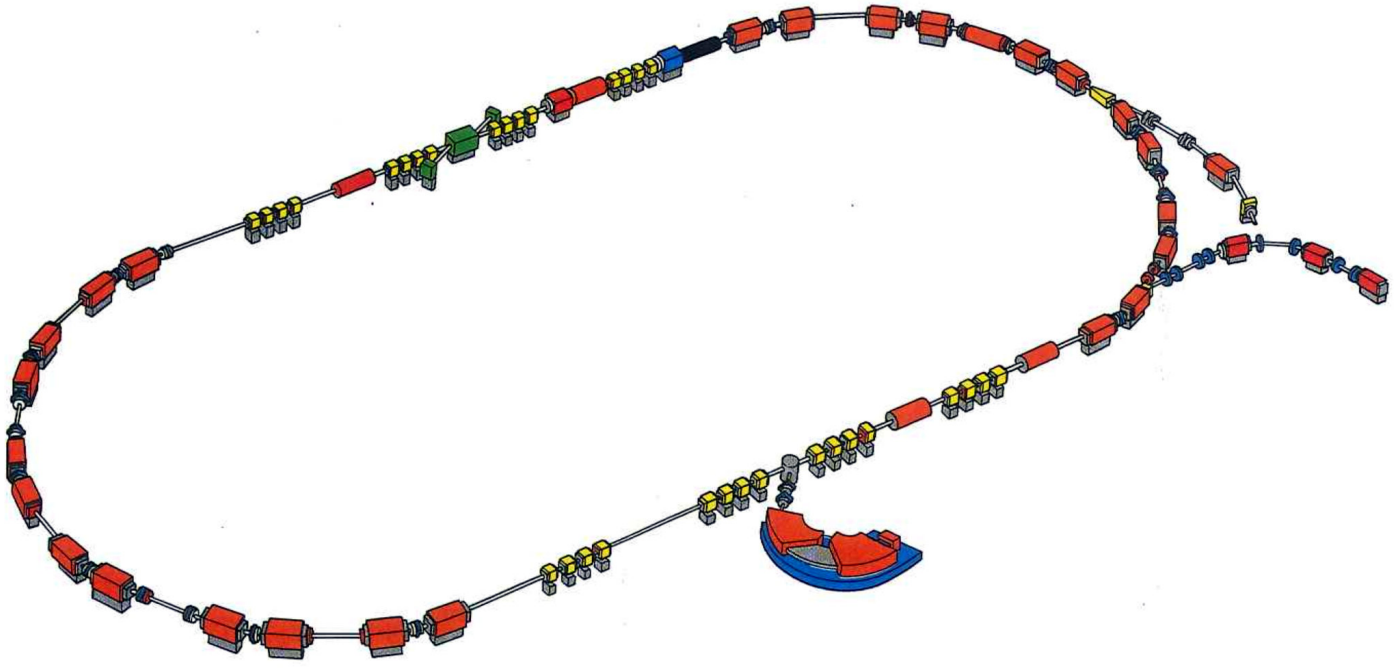
- Mixture 90%$\mathrm{Ar}$, 9%$\mathrm{CO_2}$, 1%$\mathrm{Heptan}$
- 64 wires per X and Y

## Read-Out

- ADC data processed by M68000; GPIB
- Profiles sampled 5Hz or up to 100Hz in bust mode
- Served via `EPICS`: readout, drivers, gas
- CSS GUI for operators/maintainers





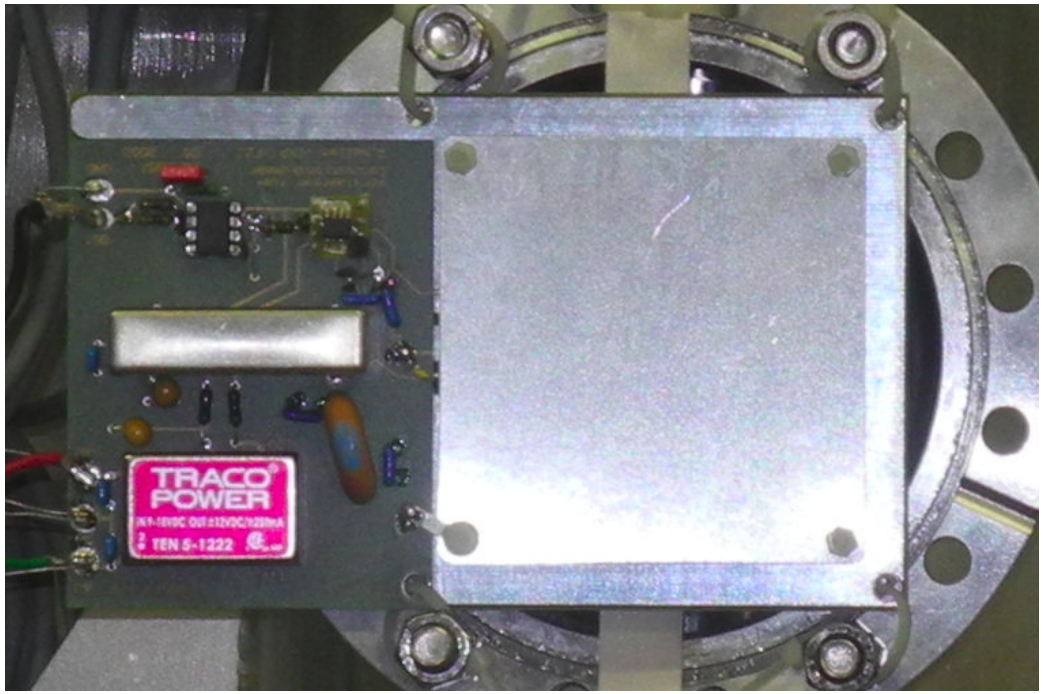


# Part V: Ionization Chambers

# Ionization Chambers

## IC: Principle

- Ionization between two electrodes under high voltage
- Measured current proportional to beam intensity

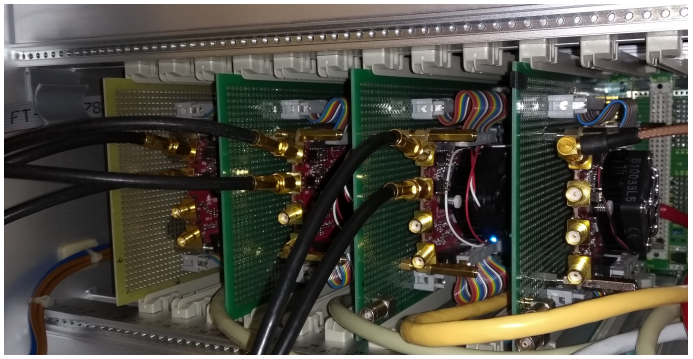


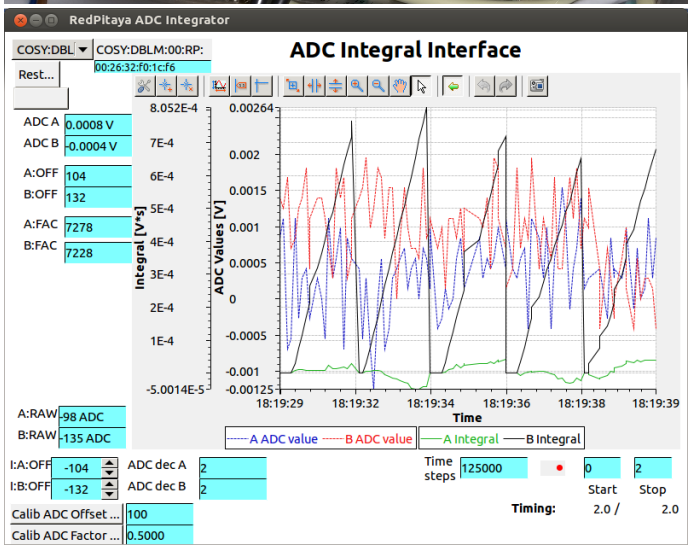

- Same containers as MWPCs

# Ionization Chambers: DAQ

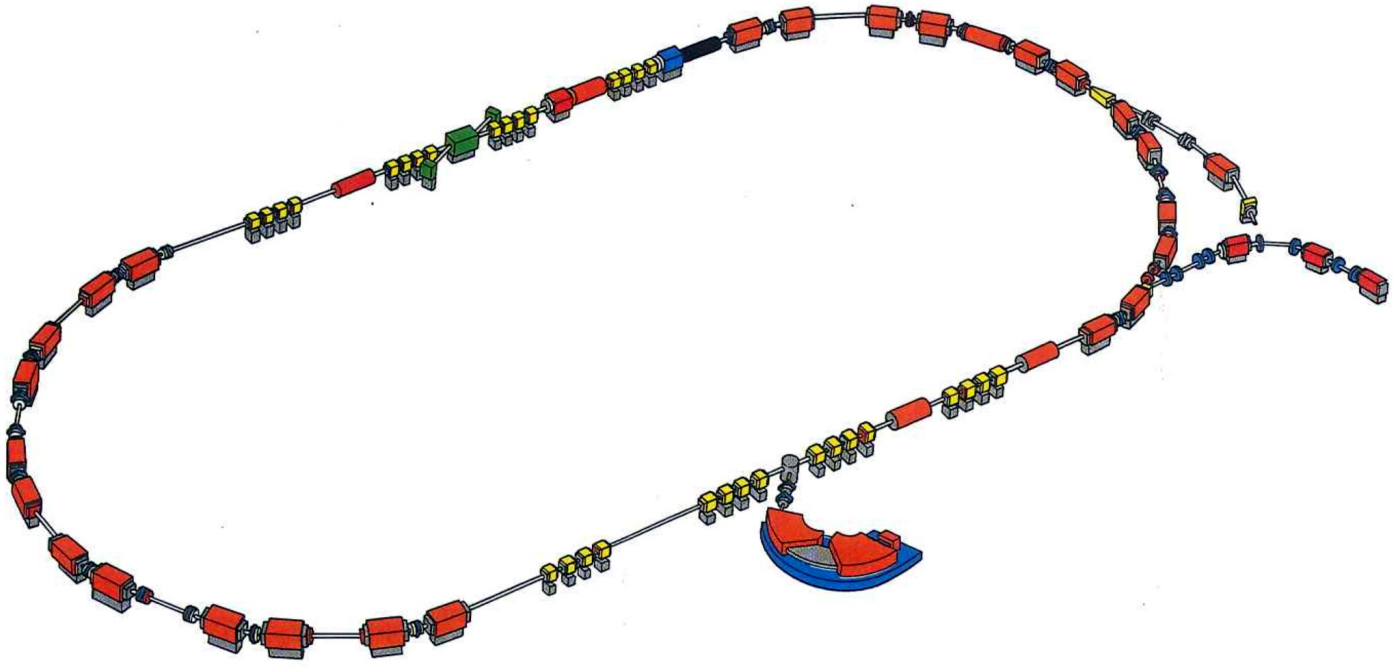
## Readout

- `Red Pitaya` ADC inputs are used for sampling
- Integration is performed on the PL of SoC






- Operator GUI; measured values archived
- Flexible parametrisation, transparent for the Oscilloscope function
  - 8ns-30s sampling period
  - adjustable ADC baseline
  - signed ADC value decimation (ignore 1,2,4,8,12 LSBs)
  - 10Hz integral value output



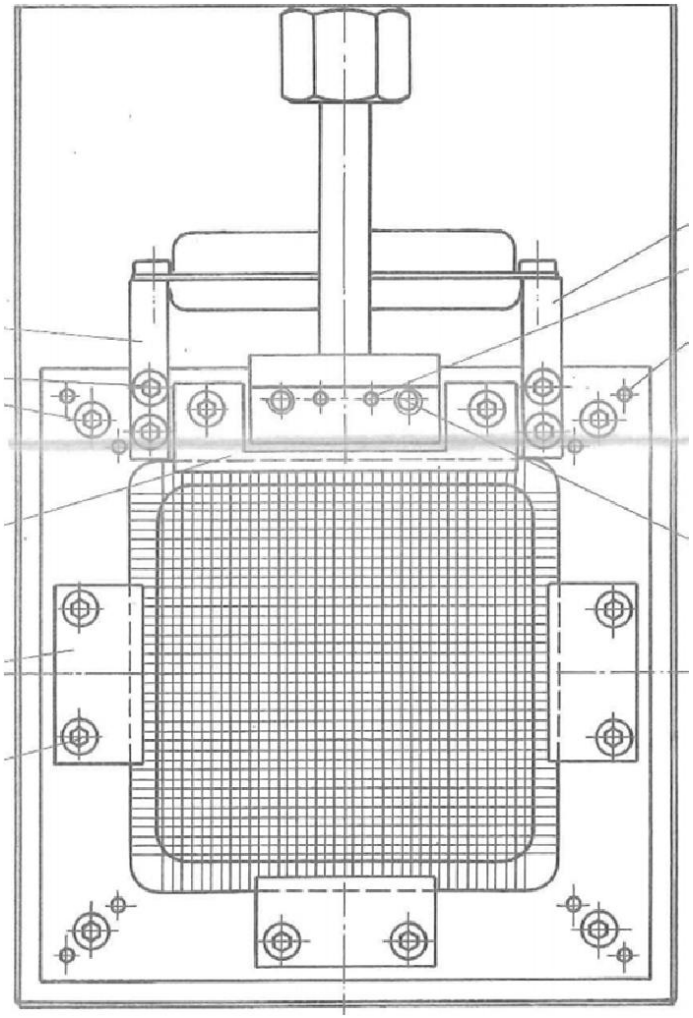
# Part VI: Profile Grids

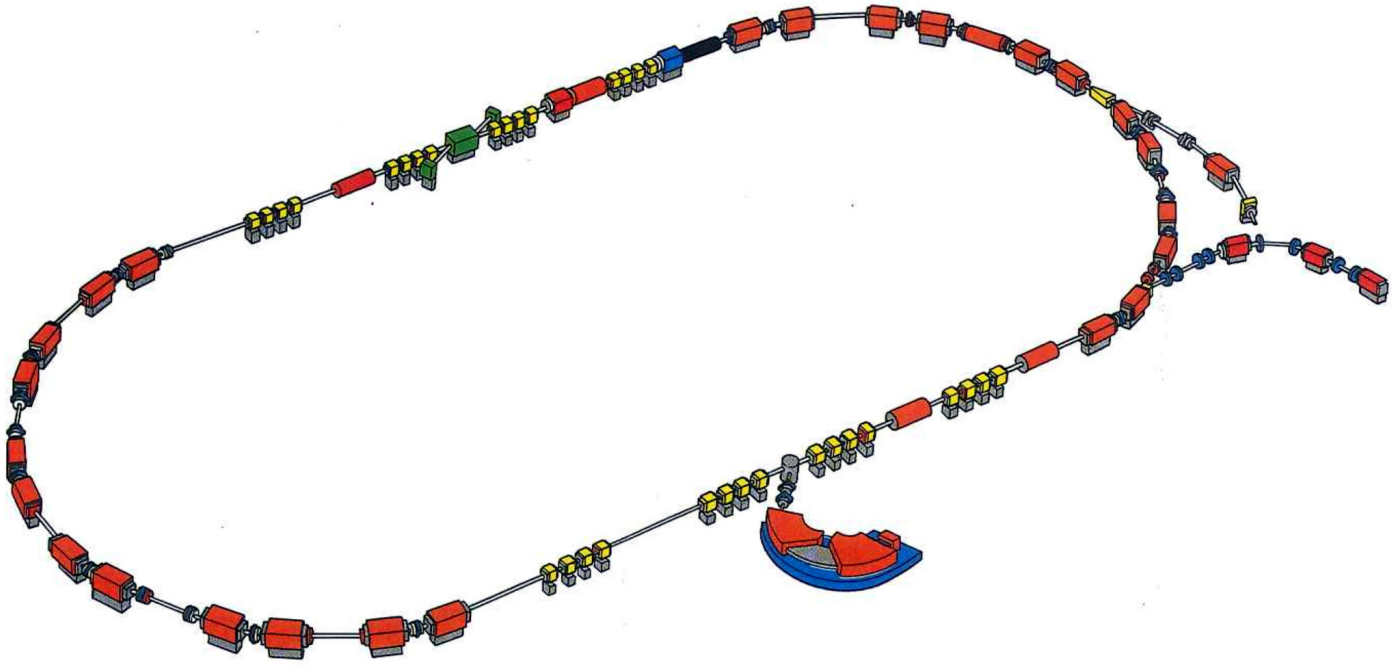
# (Profile) SEM Grids

## Principle

- Vacuum enclosed Harps collecting $\mathcal{O}$(pA) charges

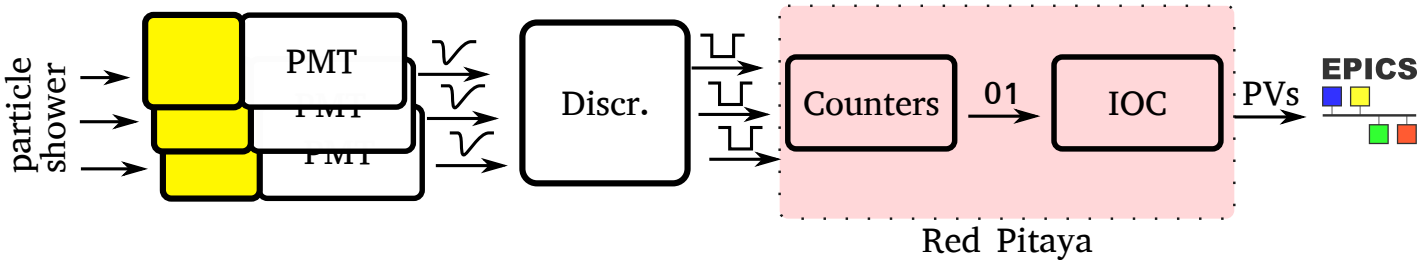
- two lateral directions are measured
- `Beagle Bone` single board computer for reading the ADC electronics runs `EPICS` IOC





# Part VII: Beam Loss Monitor

# Beam Loss Monitor



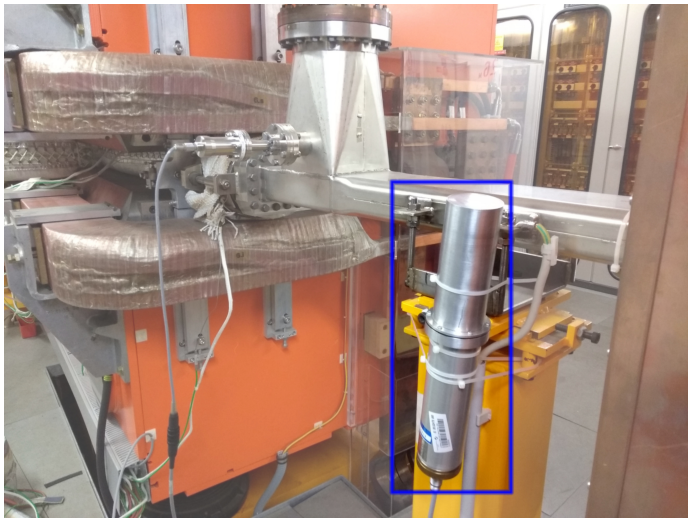

## Principle

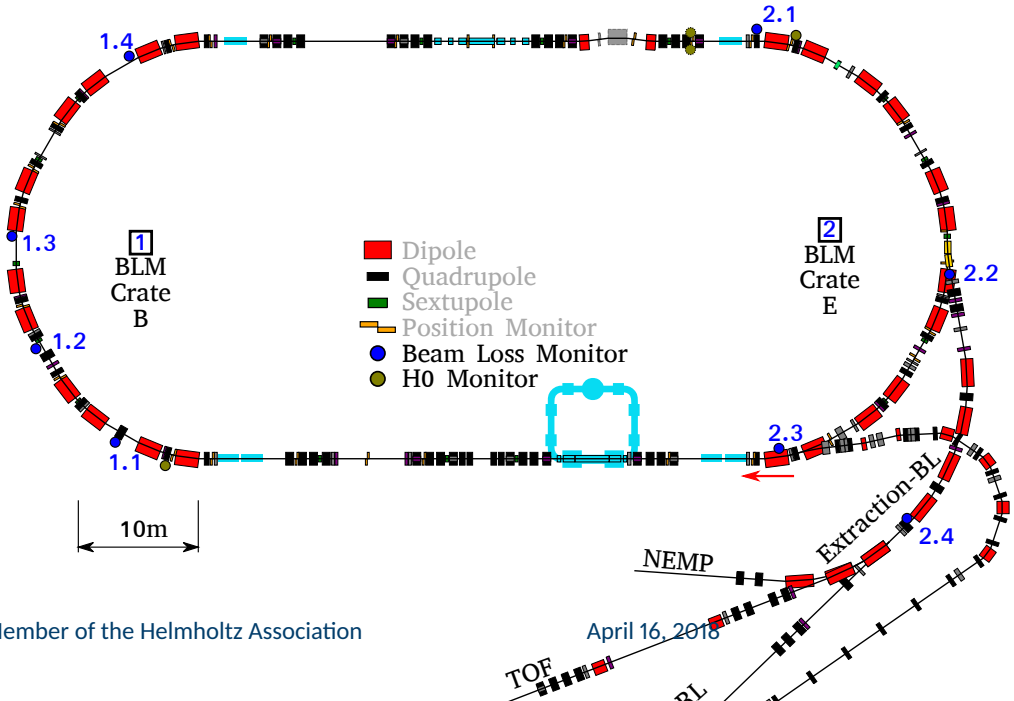
- Multiple reasons for beam losses, sometimes more sensitive than Beam Current Monitor.
- Signals from the photo-sensor with a scintillator are read out and processed.
- Counting particles (showers) escaping the beam line.
- Information from several location needed to oversee the beam losses.

# Beam Loss Monitor

## Hardware

- Encapsulated scintillator and PMT
- External high voltage power supply, amplification and read-out
- Discriminator and `Red Pitaya` board for DAQ






- Same SD-card image on all devices
- Function dependent on position is encoded via MAC



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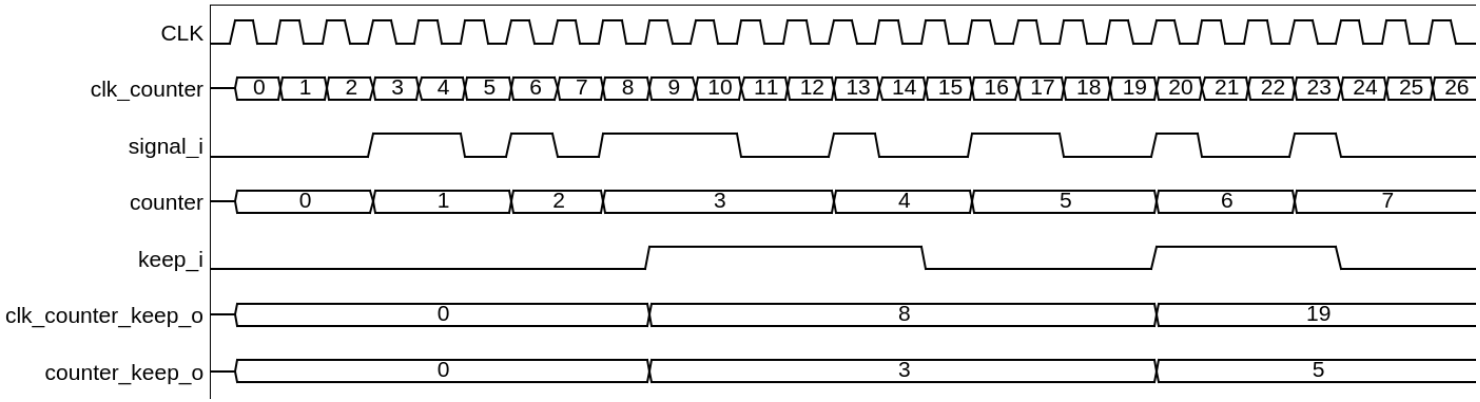
# Beam Loss Monitor: DAQ




## DAQ on SoC

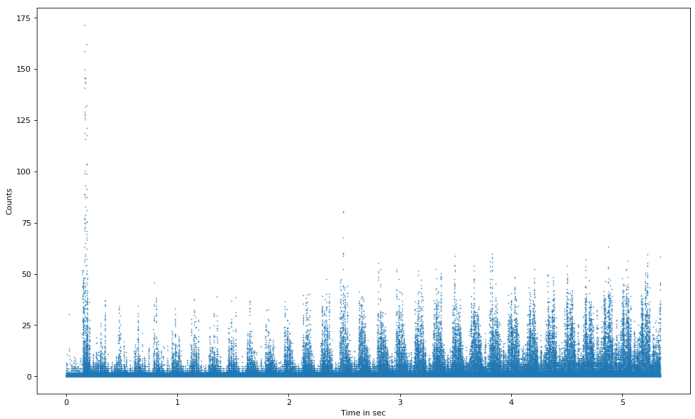
- rate counters for discriminated signals (internally or externally)
- FPGA sampling with 125 MS/s, bandwidths for $< 50$ MHz input rates
- sample-and-hold scheme for:
  - clock count
  - up to 16x GPIO counts
  - 2x ADC counts
  - (+2x integrals)

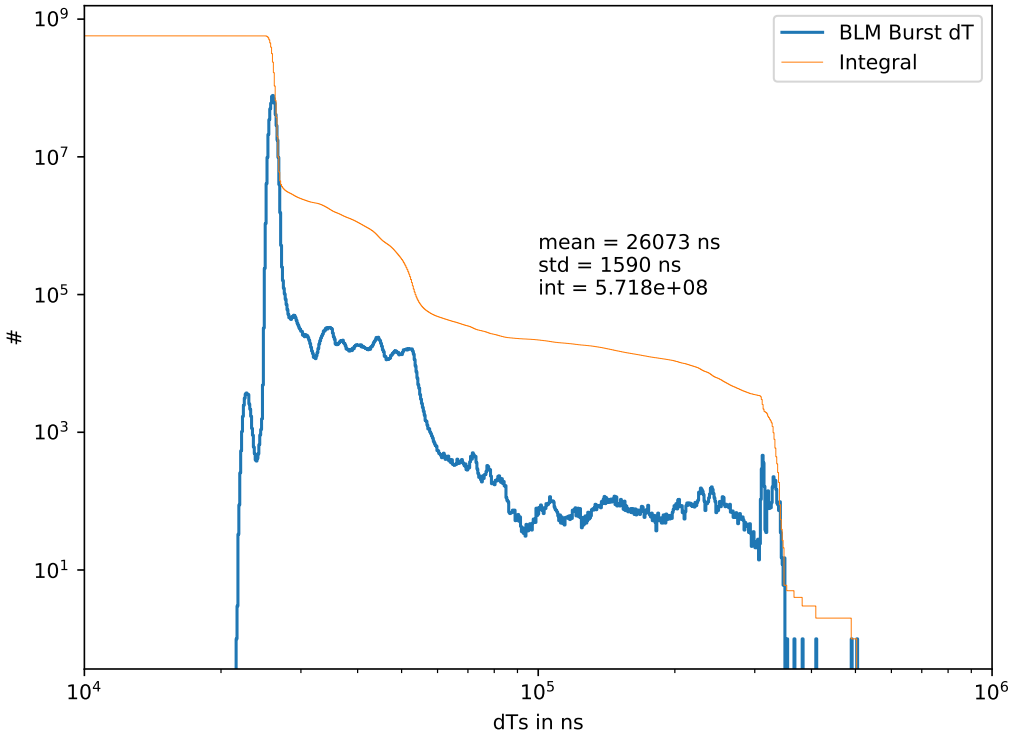
- toggle of the hold signal from application (IOC)
- adapted to `EPICS` 10Hz monitoring rate
- reliable rate estimation (#/t) independent of CPU occupancy

# Beam Loss Monitor: More than BLM DAQ

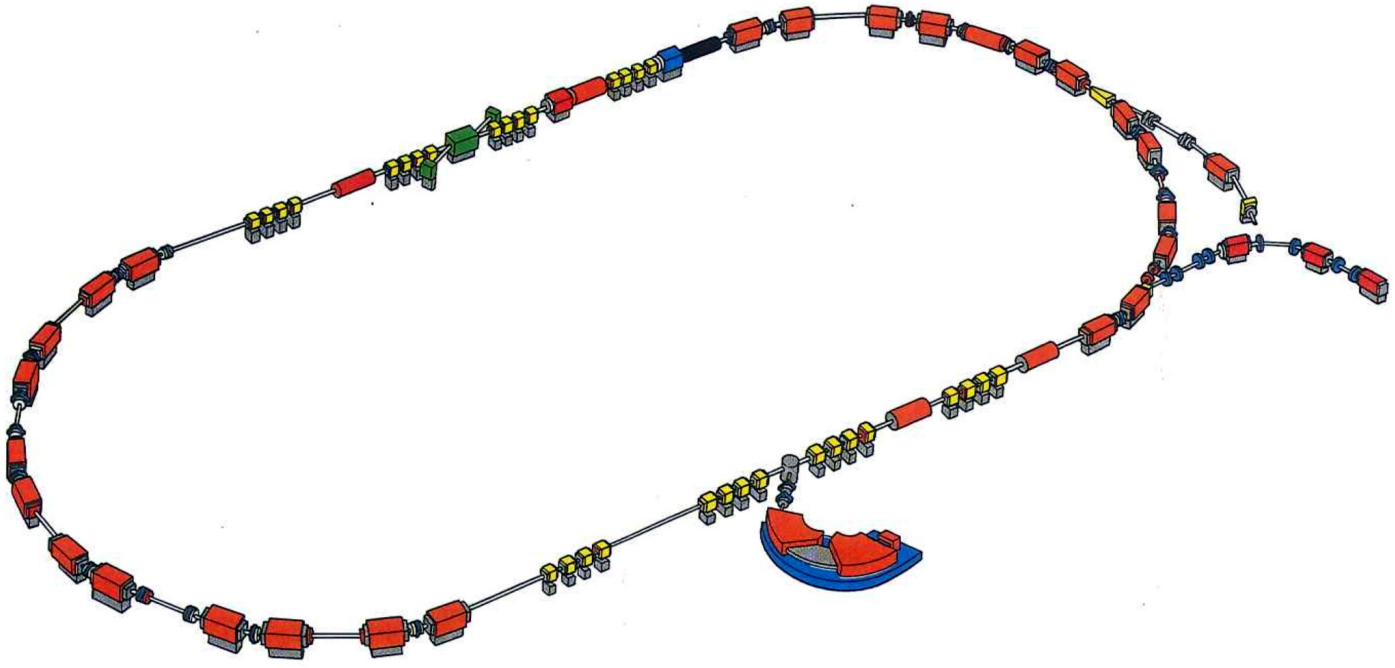
## Burst Mode

- For slow extraction beam time developed burst readout
- Scintillator or QFC usage
- PS limited to $\sim$ 38kHz sampling




- To move to AXI-4 S2MM transfer
- Pulse height/integral/dT analyser achievable



# Part VIII: Conclusion

# Summary

- COSY introduced
- Multiple upgrades of the diagnostics systems
- Operators using new hardware via `EPICS` control system
- To transfer more hardware to `EPICS`
- Usage of standardised SoC (`Red Pitaya`) with custom firmware and standard interface

# Backup information

## Contact

contact: i.bekman@fz-juelich.de , k.reimers@fz-juelich.de

## References and Further Reading

[1] "EPICS Database", Kasemir. K (SNS/ORNL), Sep. 2014, FRIB; East Lansing, MI, USA
[2] "Experimental Physics and Industrial Control System"; http://www.aps.anl.gov/epics
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[4] C. Böhme et al., "COSY Orbit Control Upgrade", Proceedings of IBIC2017, Grand Rapids, Michigan, USA.
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