The CLAS12 Barrel Micromegas Tracker:
Five years and counting of data taking

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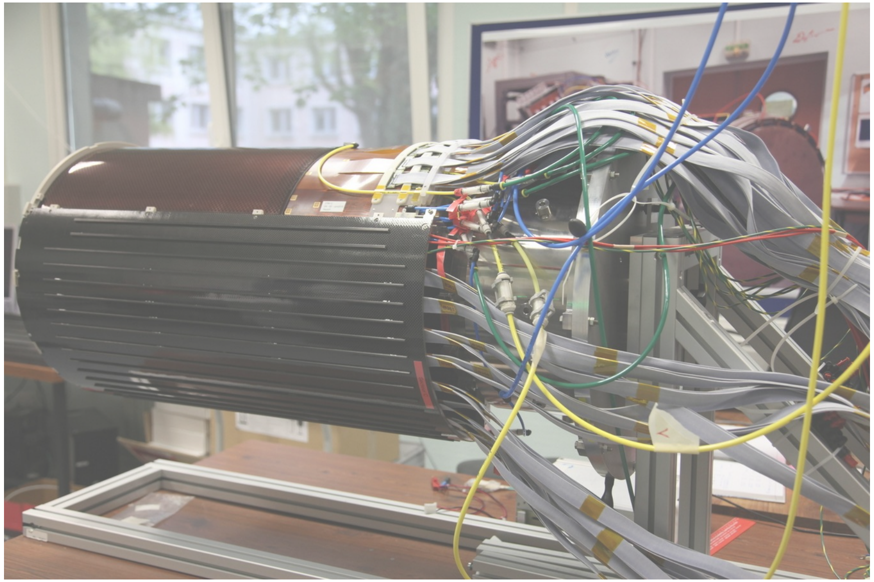
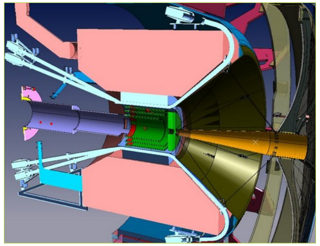
Outline

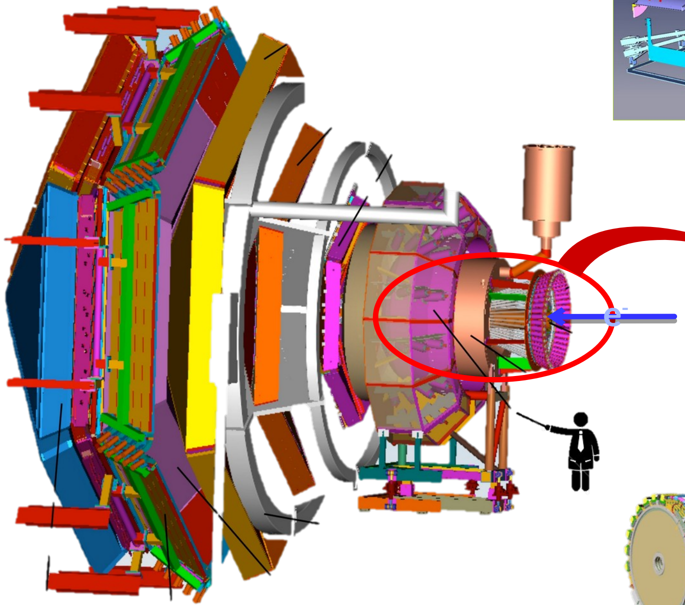
- The CLAS12 Experiment
- The Micromegas Vertex Tracker
- The barrel cylindrical detectors
- Performance and status in data taking

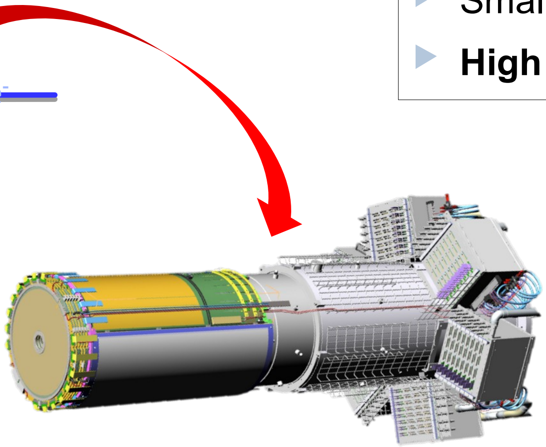


The CLAS12 Experiment

- Upgrade of the CLAS Experiment at Jefferson lab
- Study of the nucleon structure with 11 GeV electron beam at high luminosity (up to 10^{35} $cm^{-2}s^{-1}$)

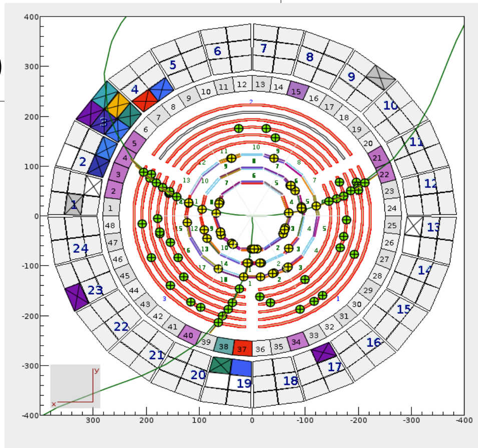




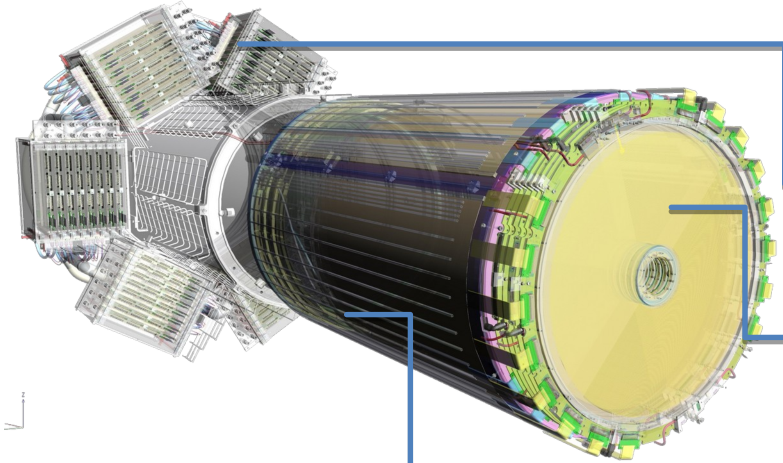


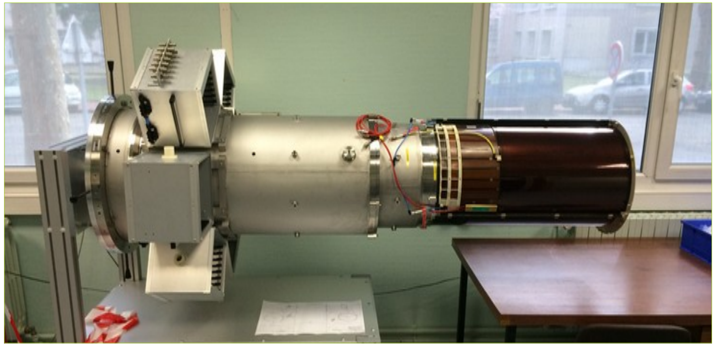
Micromegas Vertex Tracker :

- Improve the track reconstruction in the vicinity of the target
- **Reduced volume** between the magnet and the Silicon Vertex Tracker (SVT)
- **Large curved Micromegas**
- **5T field**
- Remote **off-detector frontend** electronics
- Small dead space
- **High particle rate** (30 MHz)



The Micromegas Vertex Tracker

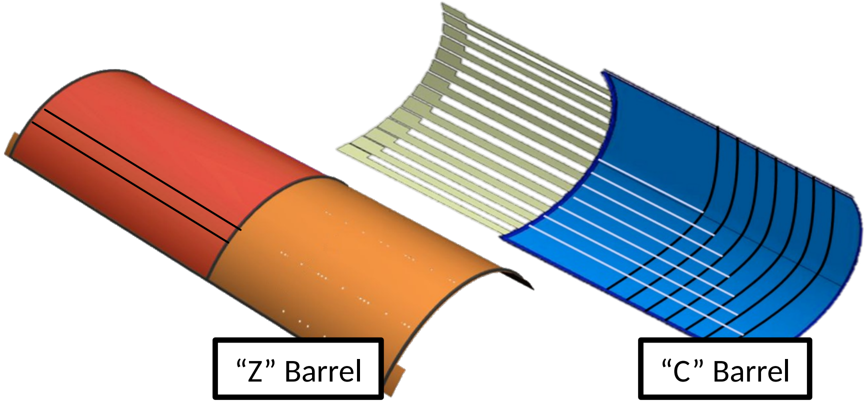


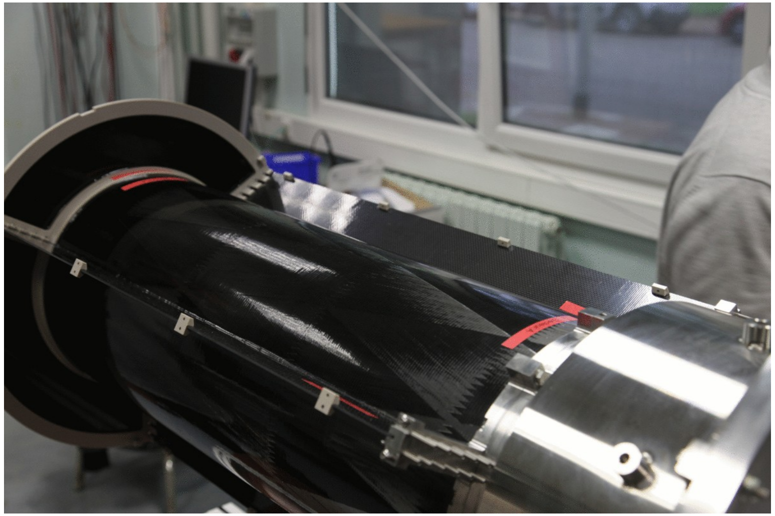


- 4 m² of Micromegas detectors to be installed in 2017
- **DREAM** based Front-End Electronics
- Remote off-detector frontend electronics connected with 2m micro-coaxial cables
- Forward Detectors
  - High particle rate (30MHz) => Fast detectors
  - Resistive strips divided in 2 zones inner/outer
  - Dimensions: 6x 430 mm diameter disk with a 50 mm diameter hole at the center
- Cylindrical Barrel
  - Low momentum particles => Light Detectors
  - Limited space of ~10 cm for 6 layers
  - High magnetic field (5T)
  - 6 Layers (18 Det.)

The Micromegas Vertex Tracker

- Total of 6 layers segmented in phi (3 x 120° sectors)
- 6 Different detector's radii
- 2 different types (C and Z types)
- Drift gap: 3mm; Amplification gap: 128um
- Mesh: 70/30
- Material (PCB/Bulk + Drift) from the CERN Workshop
- Assembly to cylindrical shape at Saclay
- Test and Characterization at Saclay before shipping to JLab

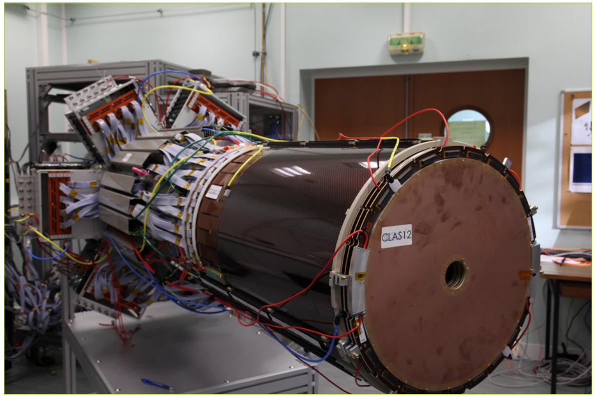




Layer	Detector	Radius (mm)	Length (mm)	Width (mm)	Channels	Active area Length (mm) x width (mm)	
6	CR6C	222.53	712	459	1152	445	438
5	CR6Z	207.54	712	427	768	445	407
4	CR5C	192.65	712	396	1024	420	376
3	CR5Z	177.57	712	364	640	421	344
2	CR4Z	162.56	712	333	640	373	313
1	CR4C	147.57	712	302	896	372	281

The DREAM FRONT-END electronics

- Signals are continuously pre-amplified, shaped, sampled at 20-30 MHz and kept in the circular analog memory
  - Deep enough to sustain 16 µs trigger latency
- At each trigger the 4 to 10 corresponding samples are readout and digitized
- Readout does not disturb sampling
- Retained samples are digitally processed
  - Pedestal equalization – online
  - Common noise subtraction – online
  - Zero suppression – online
  - Measure charge and time – off-line
- Micro-coax cables – 64 channels – low capacitance 43 pF/m



Parameter	Value
Polarity of detector signal	Negative or Positive
Number of channels	64
External Preamplifier option	Yes; access to the filter or SCA inputs
Charge measurement	
Input dynamic range/gain	50 fC; 100 fC; 200 fC; 600 fC, selectable per channel
Output dynamic range	2V p-p
I.N.L	< 2%
Charge Resolution	> 8 bits
Sampling	
Peaking time value	50 ns to 900 ns (16 values)
Number of SCA Time bins	512
Sampling Frequency (*WCk*)	1 MHz to 50 MHz
Triggering	
Discriminator solution	Leading edge
HIT signal	OR of the 64 discriminator outputs in LVDS level
Threshold Range	5% or 17.5% of the input dynamic range
I.N.L	< 5%
Threshold value	(7-bit + polarity bit) DAC common to all channels
Minimum threshold value	≥ noise
Readout	
Readout frequency	Up to 20 MHz
Channel Readout mode	all channels excepted those disabled (statically)
SCA cell Readout mode	Triggered columns only
Test	
Calibration (current input mode)	1 channel among 64; external test capacitor
Test (voltage input mode)	1 channel among 64; internal test capacitor (1/charge range)
Functional (voltage input mode)	1, few or 64 channels; internal test capacitor/channel
Trigger rate	Up to 20kHz (4 samples read/trigger).
Counting rate	< 50 kHz / channel
Power consumption	< 10 mW / channel

Table 1: Summary of the DREAM requirements.

16 x 64 ch. Micro-Coax cables (1.5 -2.2m)

Operations

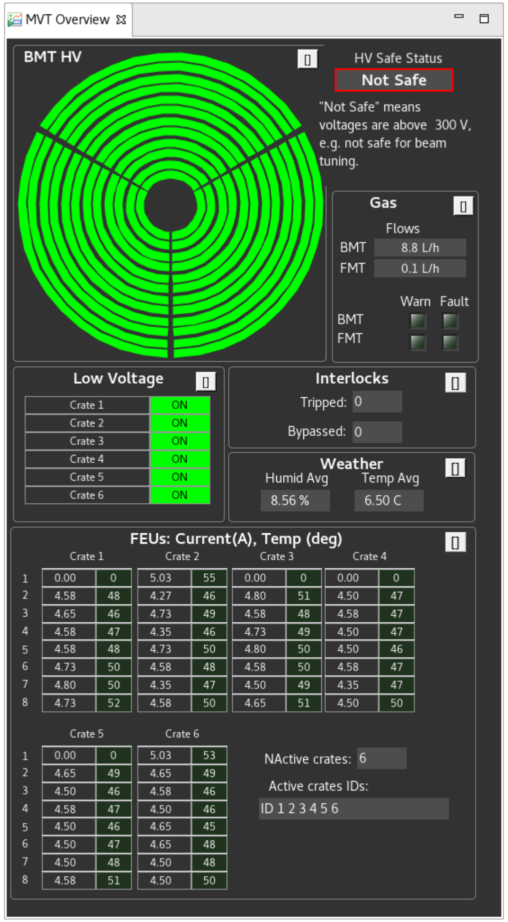
Latest snapshot of running parameters

Strip (+V)

L\S	1	2	3
1	500	500	500
2	500	500	500
3	500	500	500
4	490	480	500
5	480	150	500
6	510	520	510

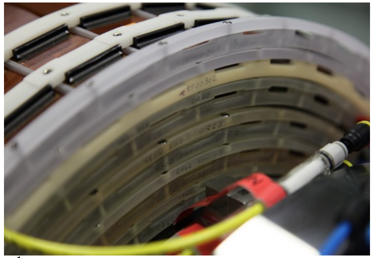
Drift (-V)

L\S	1	2	3
1	1400	1400	1400
2	1600	1600	1600
3	1400	1600	1600
4	1400	1400	1400
5	1130	1550	1400
6	1400	1400	1400

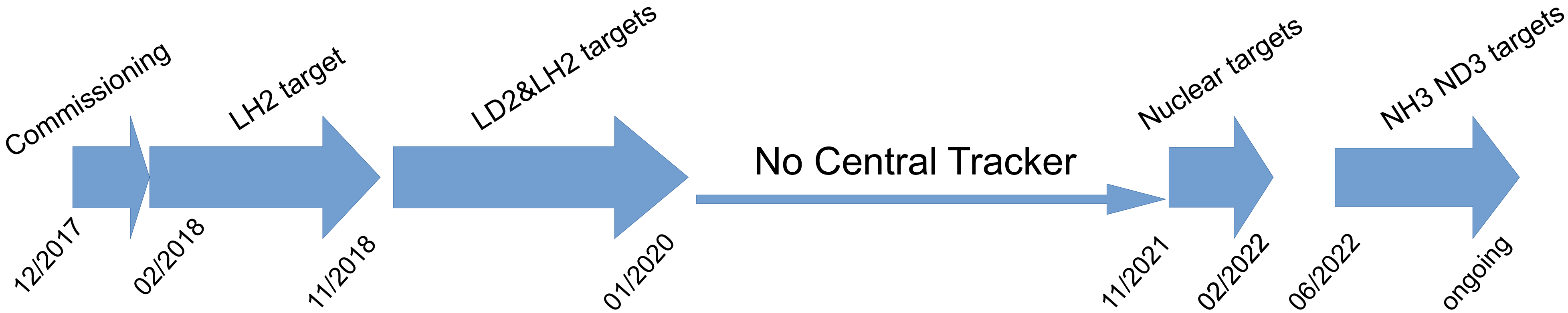


Gas:

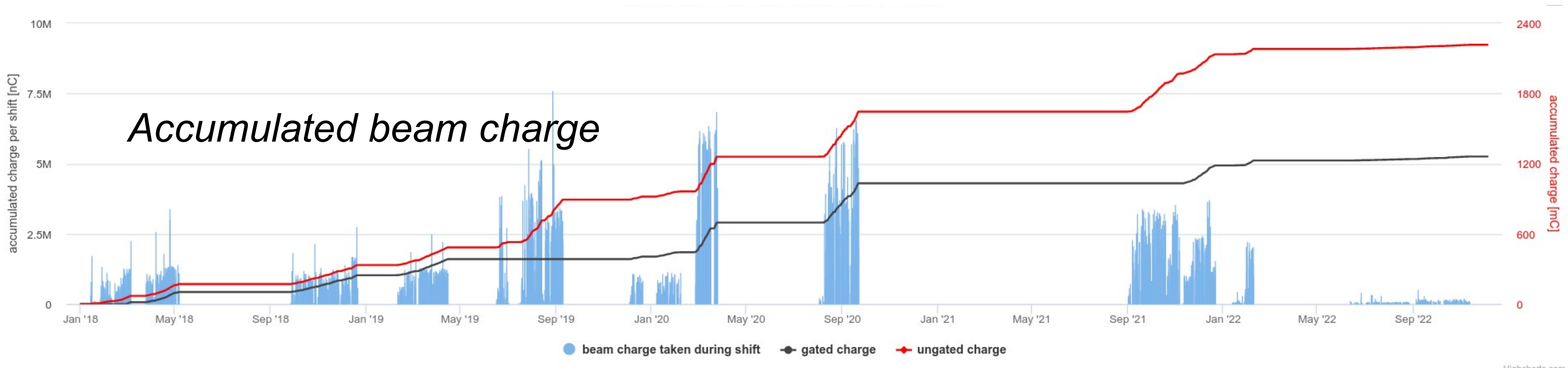
- Argon 95% – Isobutane 5%
- Total system flux: 8.8 l/h
- Each three tiles in series
  - Up to 2020, series per layer across sectors
  - From 2020, series per sector (1,2,3)(4,5,6)



Timeline



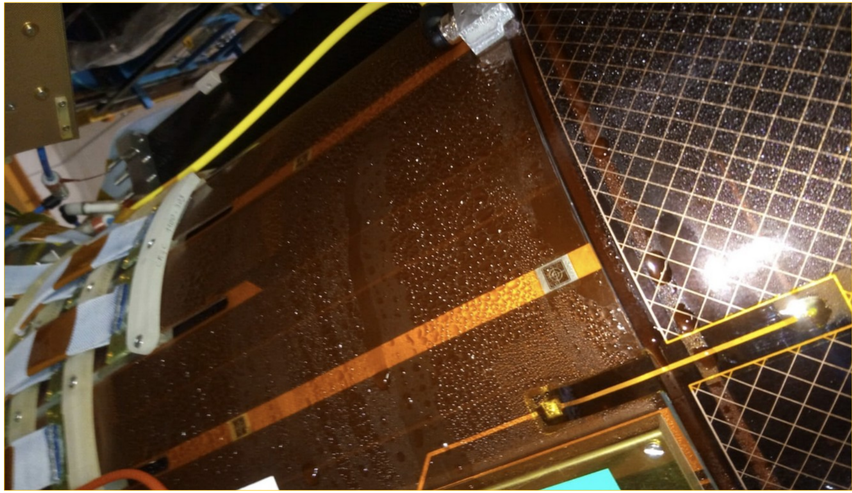
Commissioning
LH2 target
LD2&LH2 targets
No Central Tracker
Nuclear targets
NH3 ND3 targets
12/2017
02/2018
11/2018
01/2020
11/2021
02/2022
06/2022
ongoing



Accumulated beam charge
accumulated charge per shift [nC]
10M
7.5M
5M
2.5M
0
accumulated charge [mC]
2400
1800
1200
600
0
Jan '18
May '18
Sep '18
Jan '19
May '19
Sep '19
Jan '20
May '20
Sep '20
Jan '21
May '21
Sep '21
Jan '22
May '22
Sep '22
beam charge taken during shift
gated charge
ungated charge

Maintenance

- The Silicon Vertex Tracker (SVT) was designed to operate at room temperature
- During commissioning (early 2018), the higher than expected dose, forced to cool the SVT at -20C
- No thermal insulation was inserted between the SVT and the BMT
- Temperatures **dropped well below the dew point in the Micromegas envelope**
- Condensation in HV boxes caused corrosion and shorts of few tiles
- Few tiles shown sign of **mechanical deformation** of the PCBs

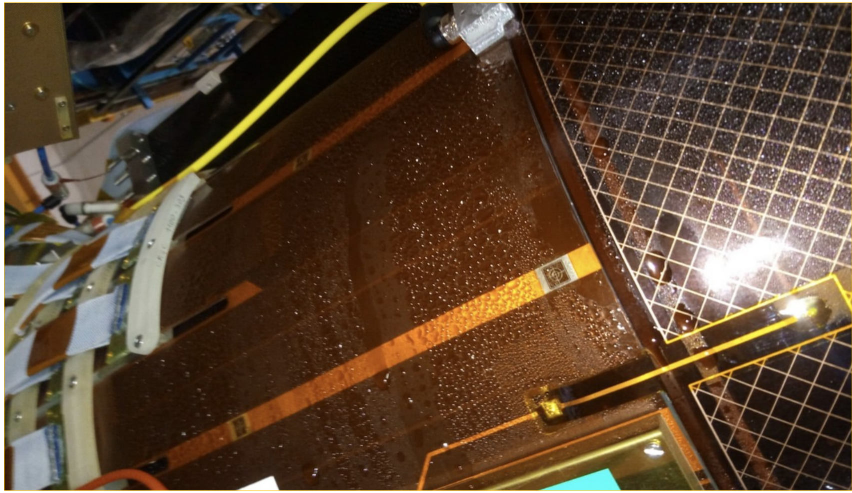


Condensation on barrel detectors

Maintenance

- Intervention in **Summer 2018** to install
  - **Dry air pipes** to flush the BMT volume
  - Humidity and temperature **sensors**
- Currently, the Micromegas are working a very dry environment (less than 10% relative humidity) with temperatures between 1C and 15C
- Protocols to prevent water condensation during maintenance and installations have been put in place

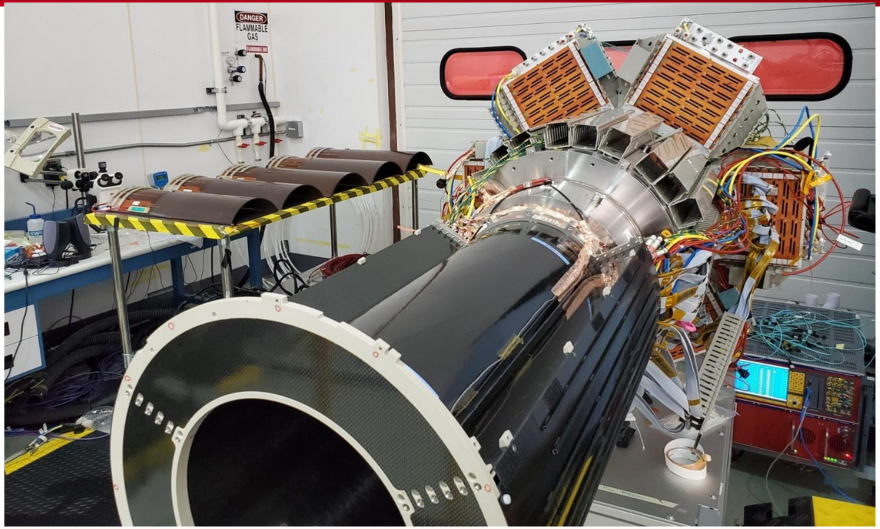
- **No issues with humidity after Summer 2018**

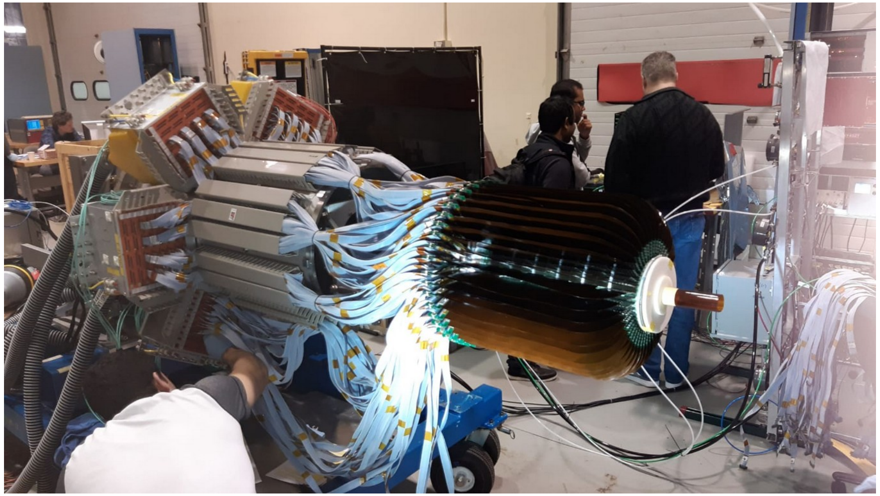


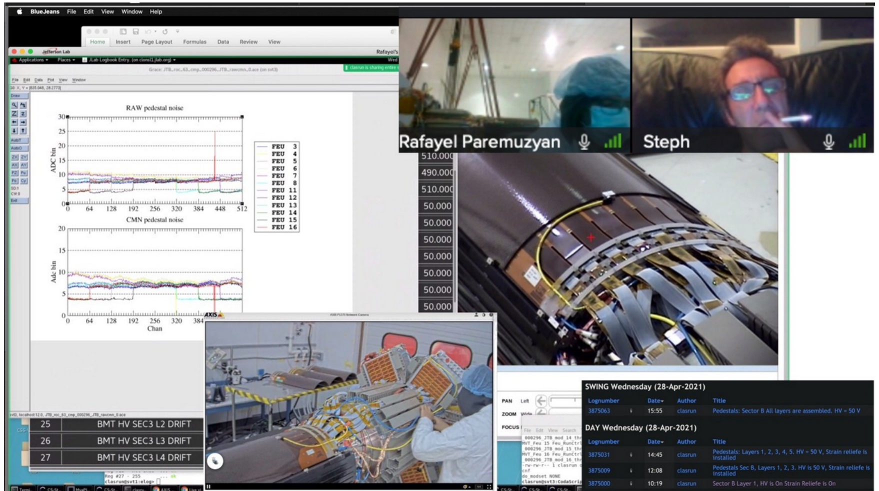
Condensation on barrel detectors

Maintenance

- Spring 2020 and Winter 2020: complete **disassembly and re-assembly** of the system to unplug the signal cables for the **Bonus experiment**
- Winter intervention done by **Jlab staff remotely guided by Saclay's expert**

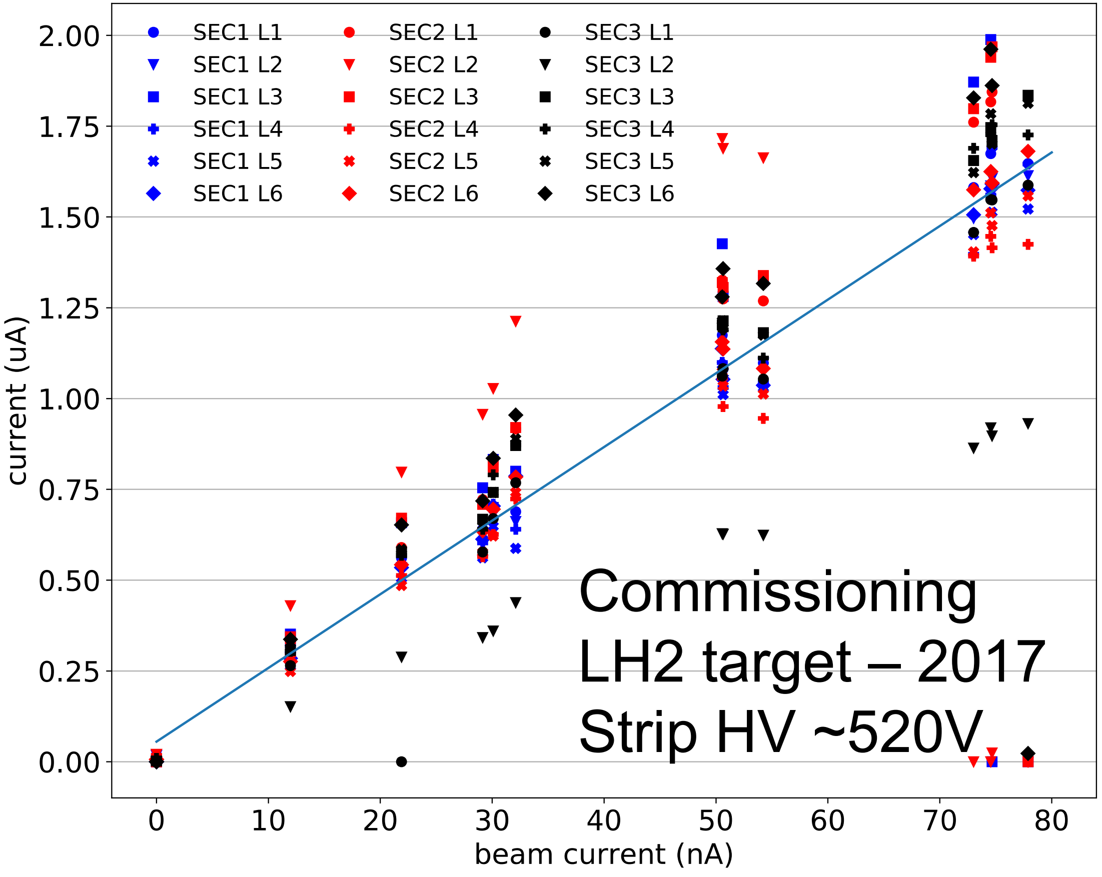






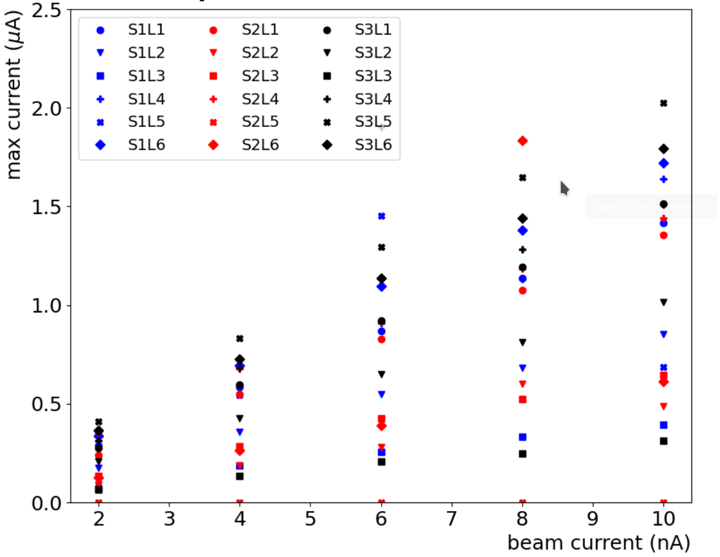
<- expert

Currents

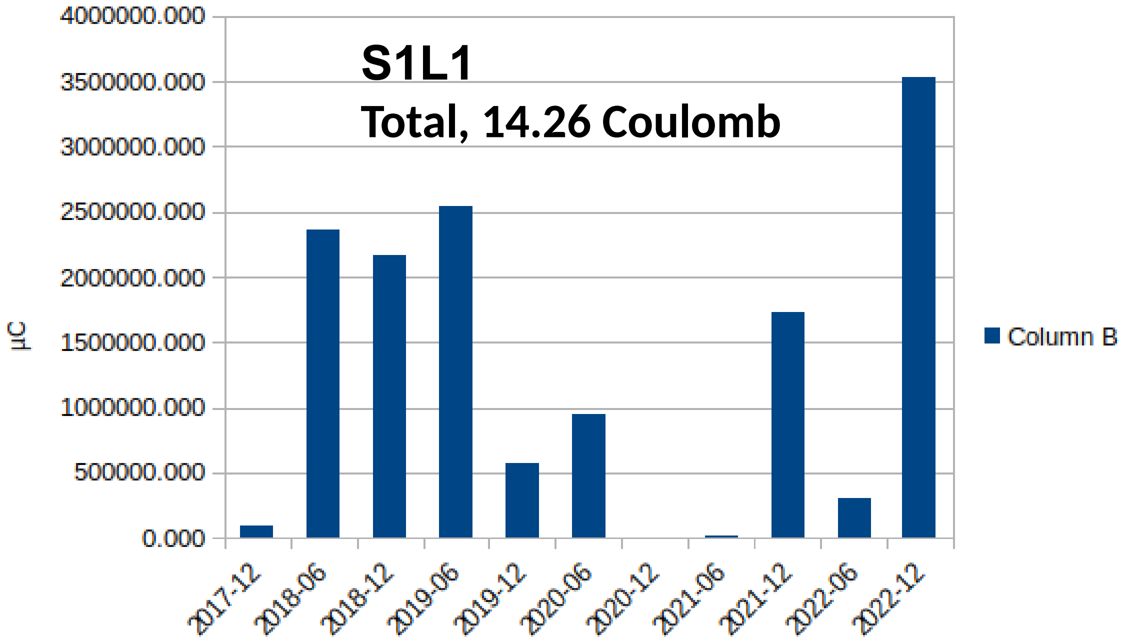


- **Clear correlation** between the instantaneous luminosity (beam current) and the strip currents
- In data taking, currents between **0.5 and 1.5µA**

2022 – Carbon target
Strip HV ~500V



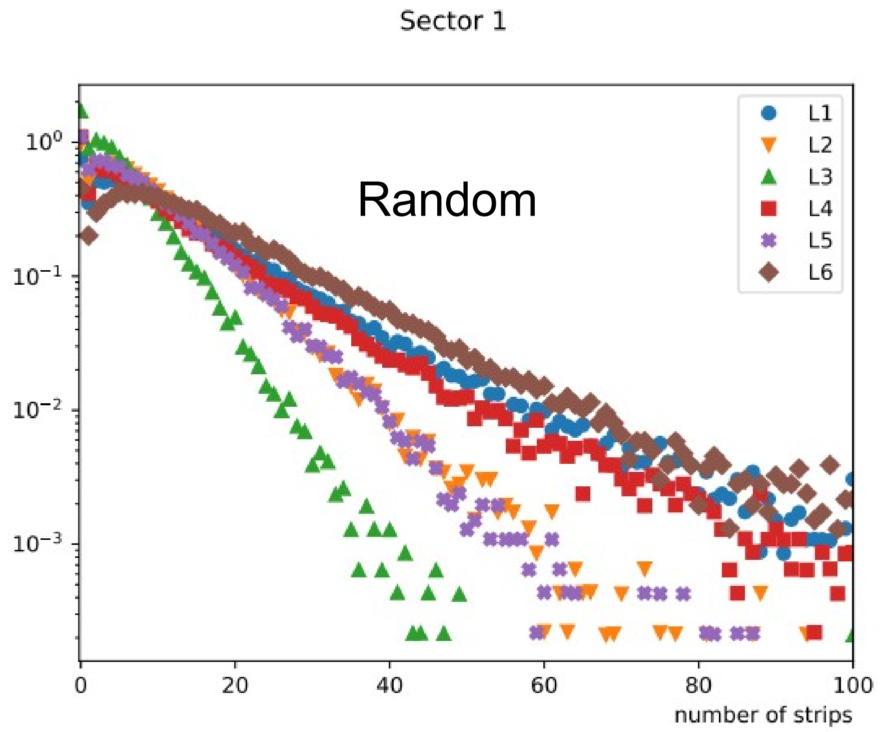
Integrated currents

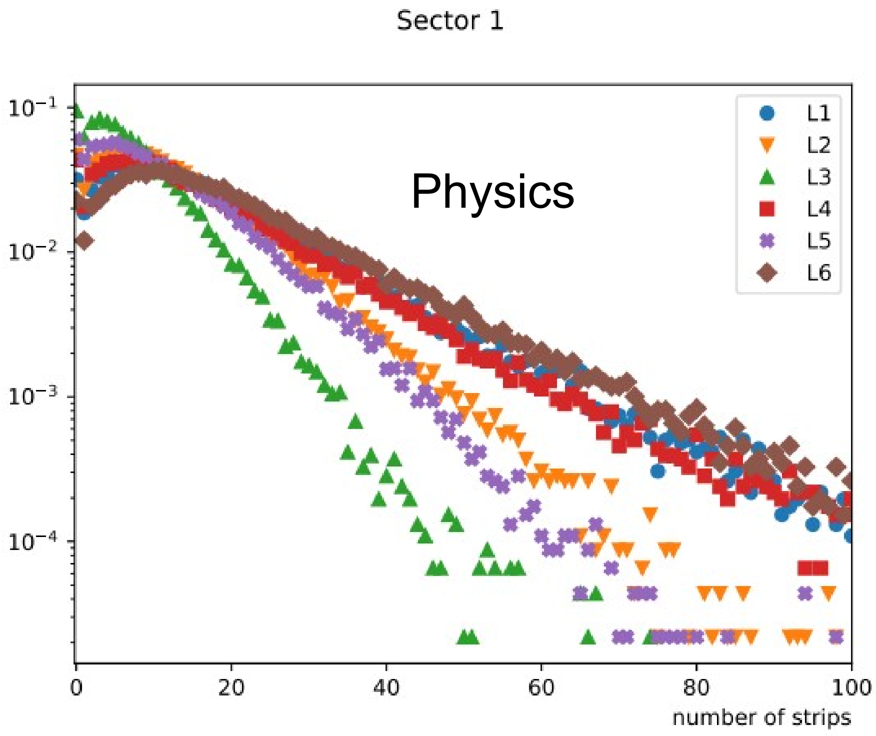


- Strip currents integrated over the whole data taking activity
- Between 10 and 20 C
- Depending on the tile gain and surface
- Surface: 0.1m^2 (L1) – 0.2m^2 (L6)

Occupancy

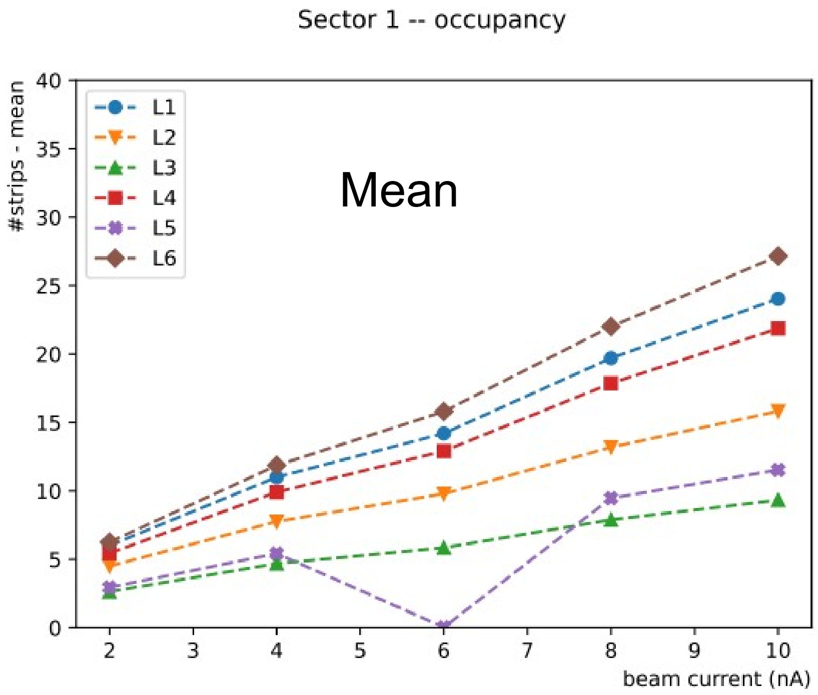
- Data taking with polarized NH3 target showed the largest occupancy
- At 8nA with the NH3 target
- 1.2% occupancy in random events
- 1.8% occupancy with physics trigger

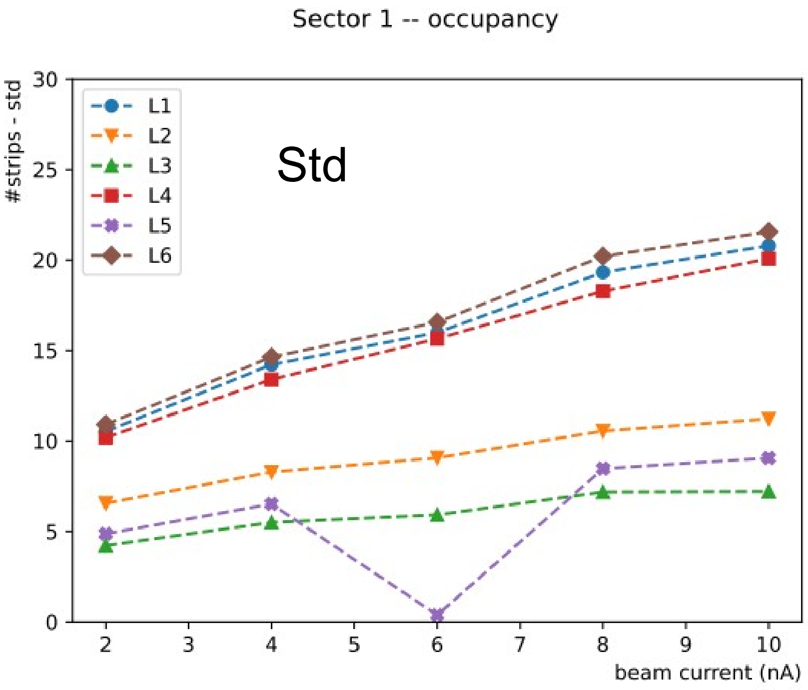




Occupancy

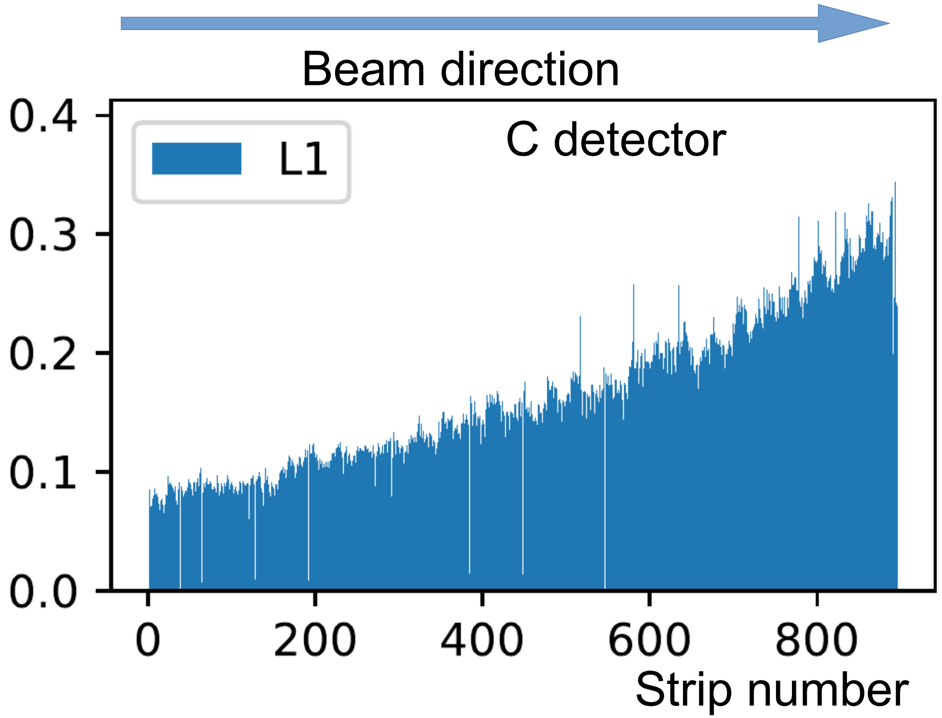
- Linear dependence of the occupancy with the beam current, i.e. the luminosity

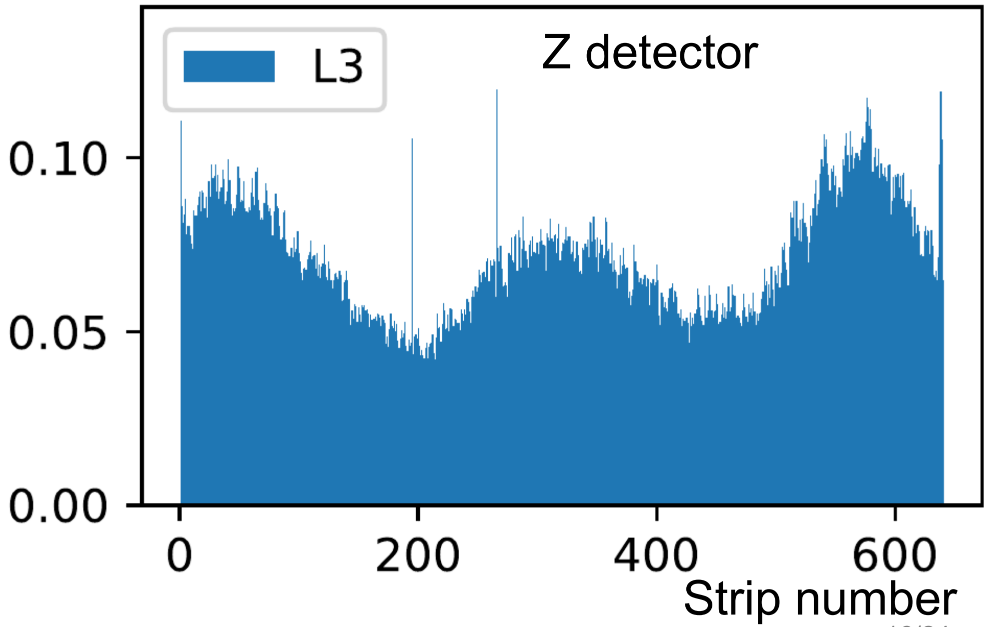




Hit distributions

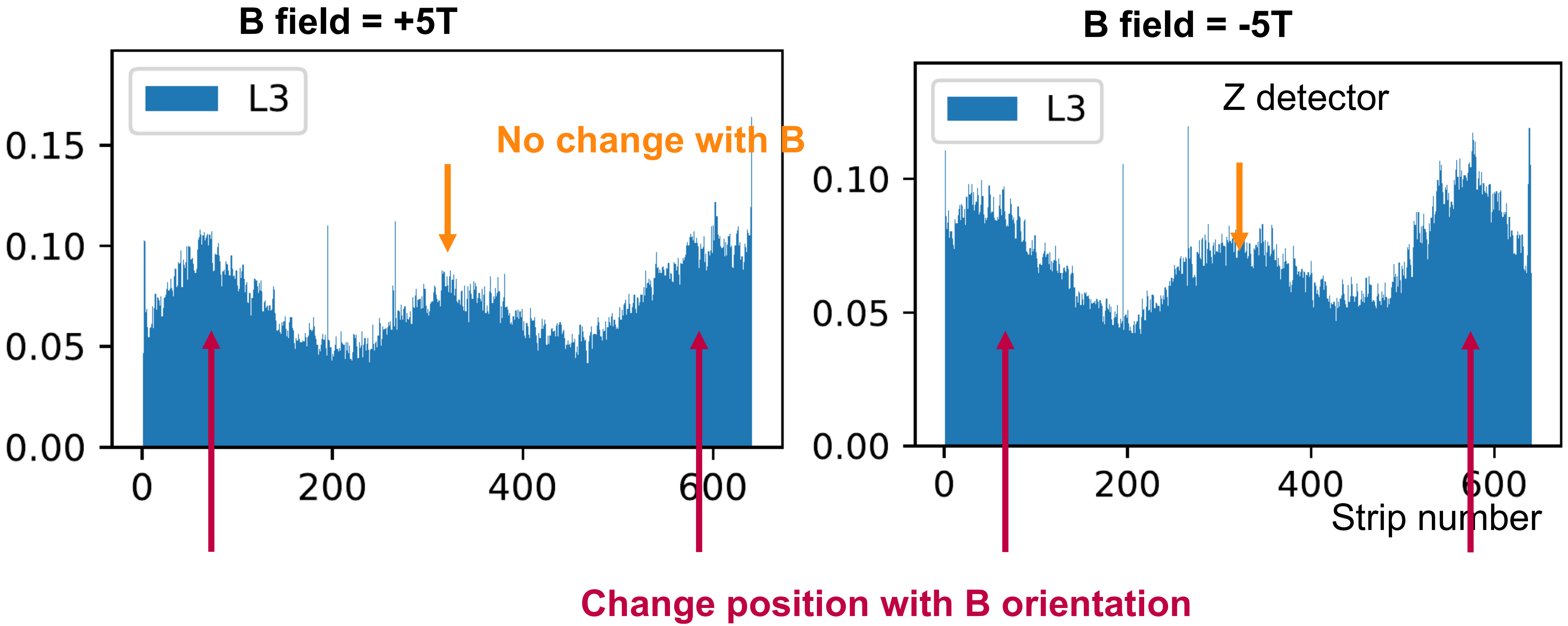
- The hit distribution for C detectors tight to the fixed target event topology: more particle downstream the target
- Z detectors hit distribution is expected to be uniform
- Structures related to detector effects, not fully understood





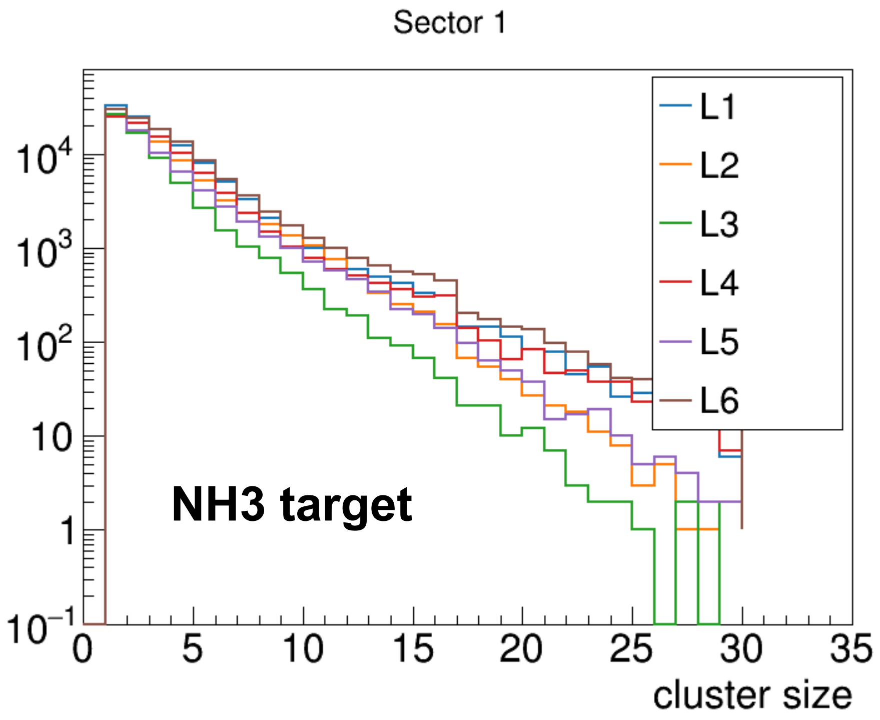
Hit distributions

Hit distribution in Z detectors still under investigation

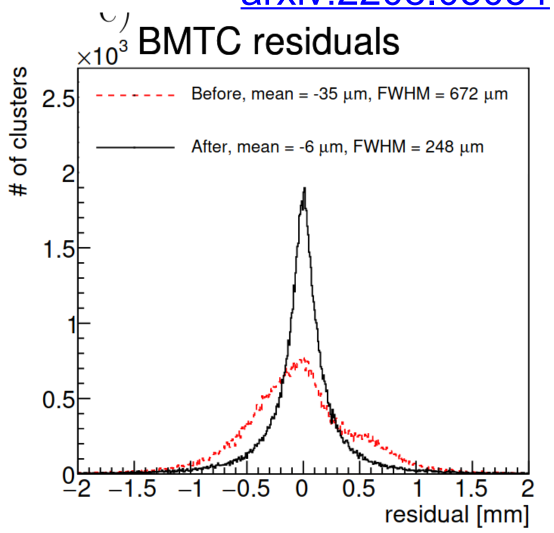


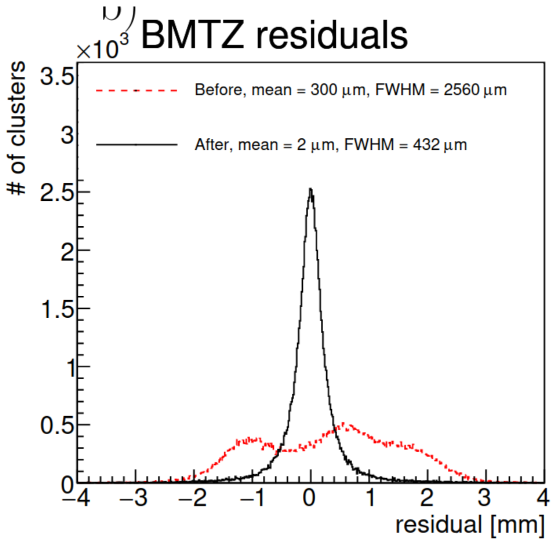
Clusters

- Average cluster size: ~4
- Centroid residuals after alignment:
  - Z detectors: 432μm
  - C detectors: 258μm



arxiv:2208.05054

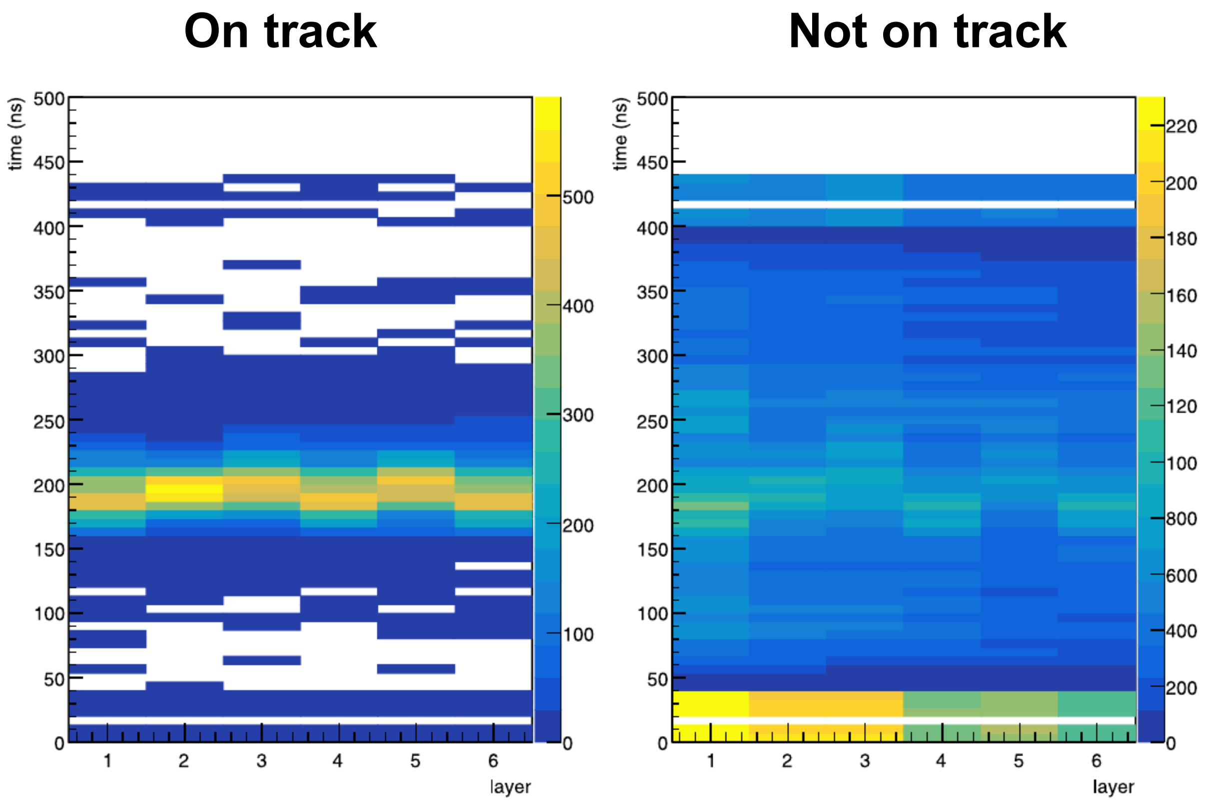




Clusters – Time distributions

- Time of a hit: time of the signal peak with respect to the trigger
- Tmin of the cluster: the smallest hit time
- Clear correlation of the Tmin for clusters attached to a track
- Background hits are not correlated with the trigger

LH2 target, 50nA

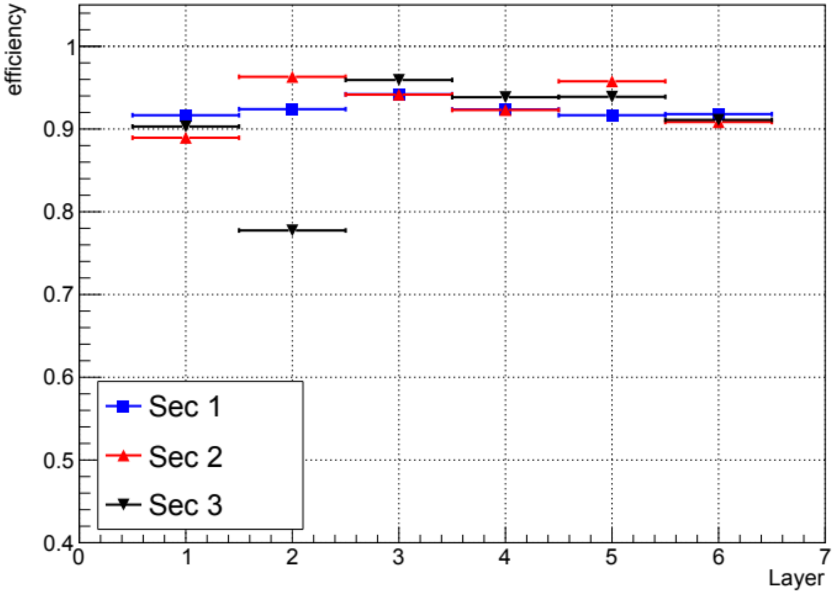


Efficiency

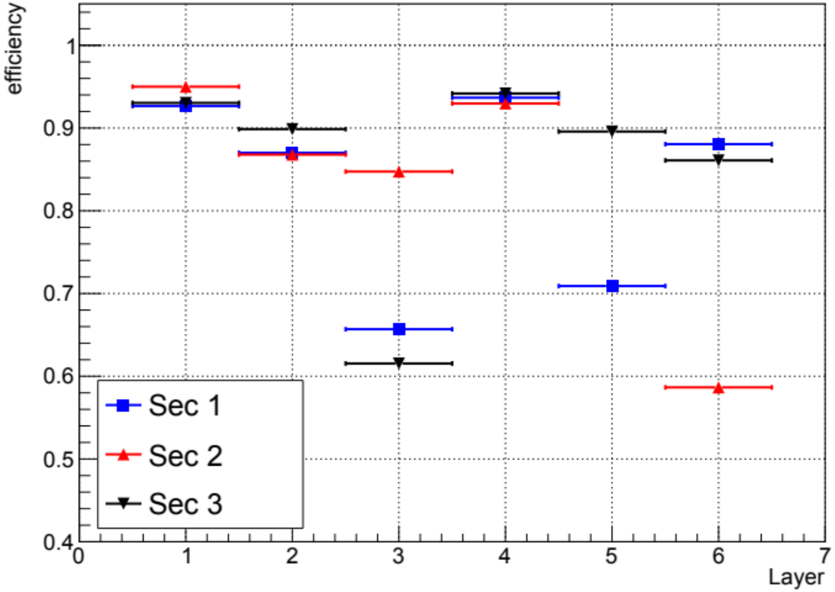
- Efficiencies above 90%

- Lower efficiencies in 2022 due to:
  - Different gas distribution (under investigation)
  - Adjusted HV strip settings to cope with higher rates

2019, LH2, 50nA

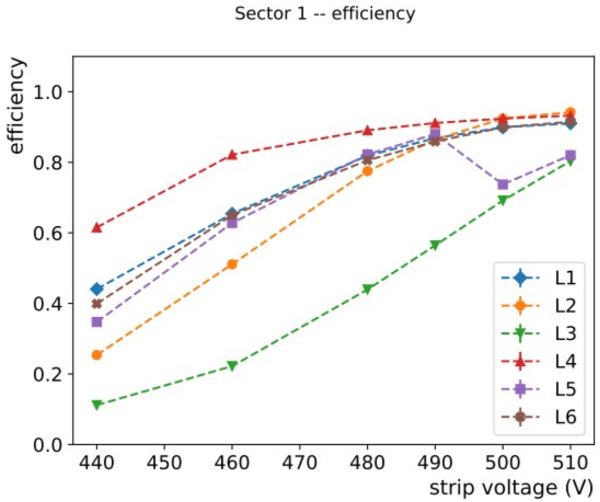


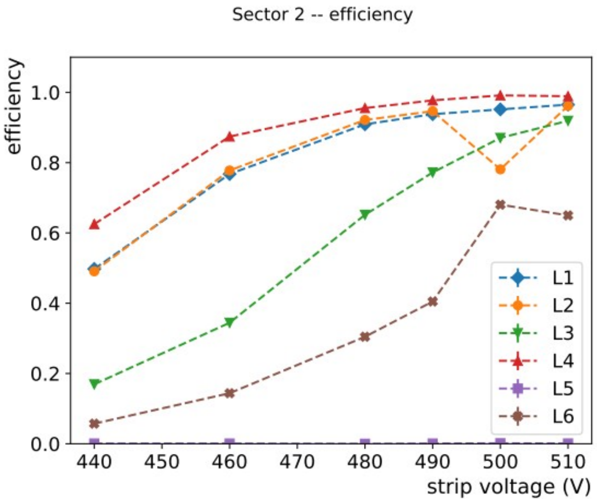
2022, NH3, 8nA

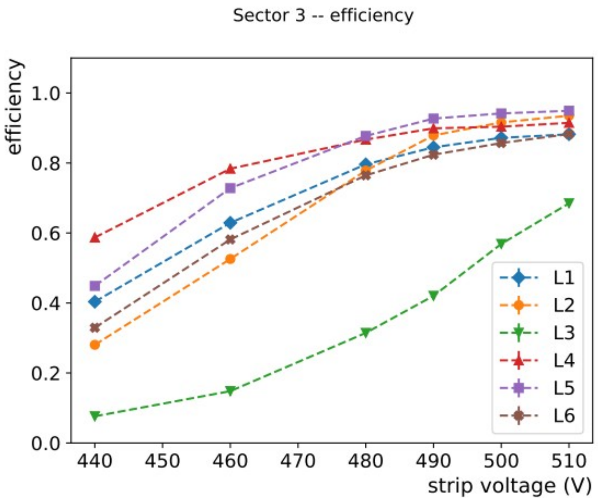


Efficiency

- Efficiency scan in August 2022
- Most of the tiles reach the plateau around 500V on the strip
- Layer 3 and Layer 6 at 500V still rising
- They are the last in the gas distribution series
- Modifications to the gas distribution under discussion







Outlook: EIC

Motivation

- A full (no acceptance gaps) light-weight modular Micromegas barrel tracker to complement the silicon vertex detector

Needs

- Light cylindrical tiles (~0.5% X0 per layer)
- 2D readout: ~150µm resolution

Less challenging environment

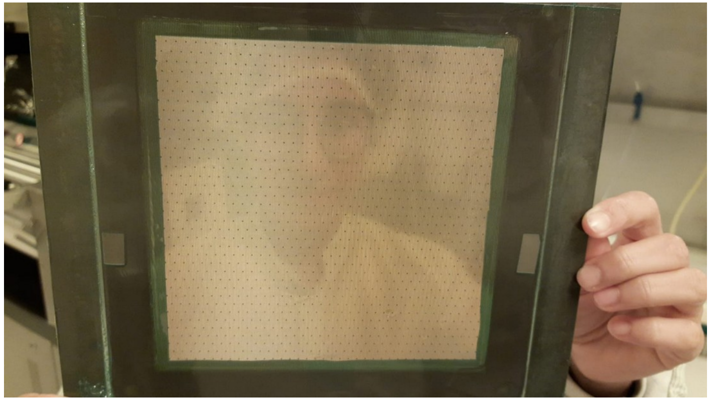
- B field up to 2T
- Particle rate at least 1000x less than CLAS12

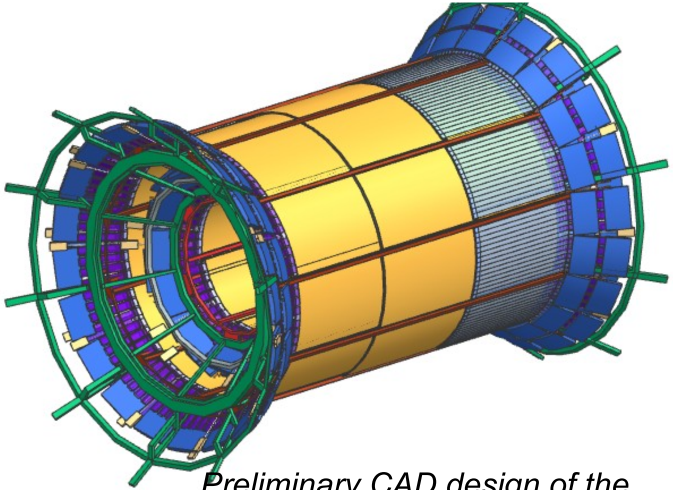
Upgrades CLAS12 MM to fit the EIC needs:

- **Simpler construction:**
  - about one module size bent at different radii
  - overlap tiles for no acceptance gaps
- **2D readout**: keeping the channel count as low as possible

Objectives

- 2022-2023:
  - Optimization of the 2D readout for low number of channels on small prototypes
- 2023-2024:
  - Build a full scale prototype of a Micromegas tile (50x70cm^2) with the chosen 2D readout

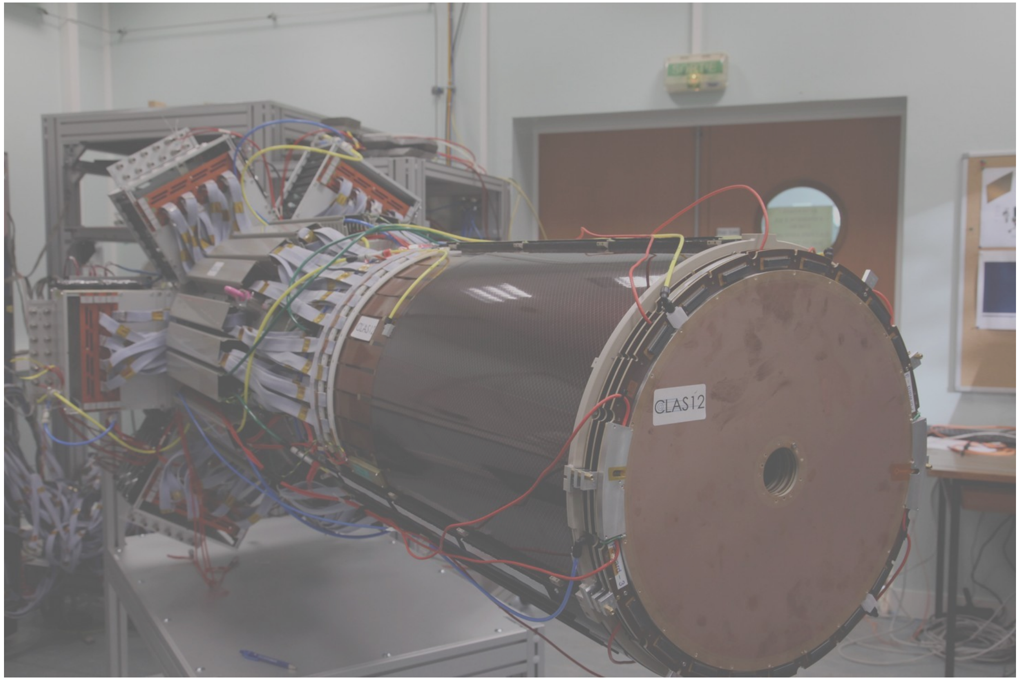




Preliminary CAD design of the MM tracker for ATHENA proposal

Summary

- **The low-mass CLAS12 cylindrical Micromegas Vertex Tracker is taking data since 2017**
- Challenging environment:
  - 5 T field
  - High flux of charged particles, resulting in integrated currents of several Coulombs
  - Temperatures as low as 1C due to the unforeseen silicon cooling
- **Overall performance are good:**
  - Efficiencies above 90%
  - Cluster sizes around 4
- Some “features” still under study
- Perspective:
  - This technology is well suited for the **EIC**



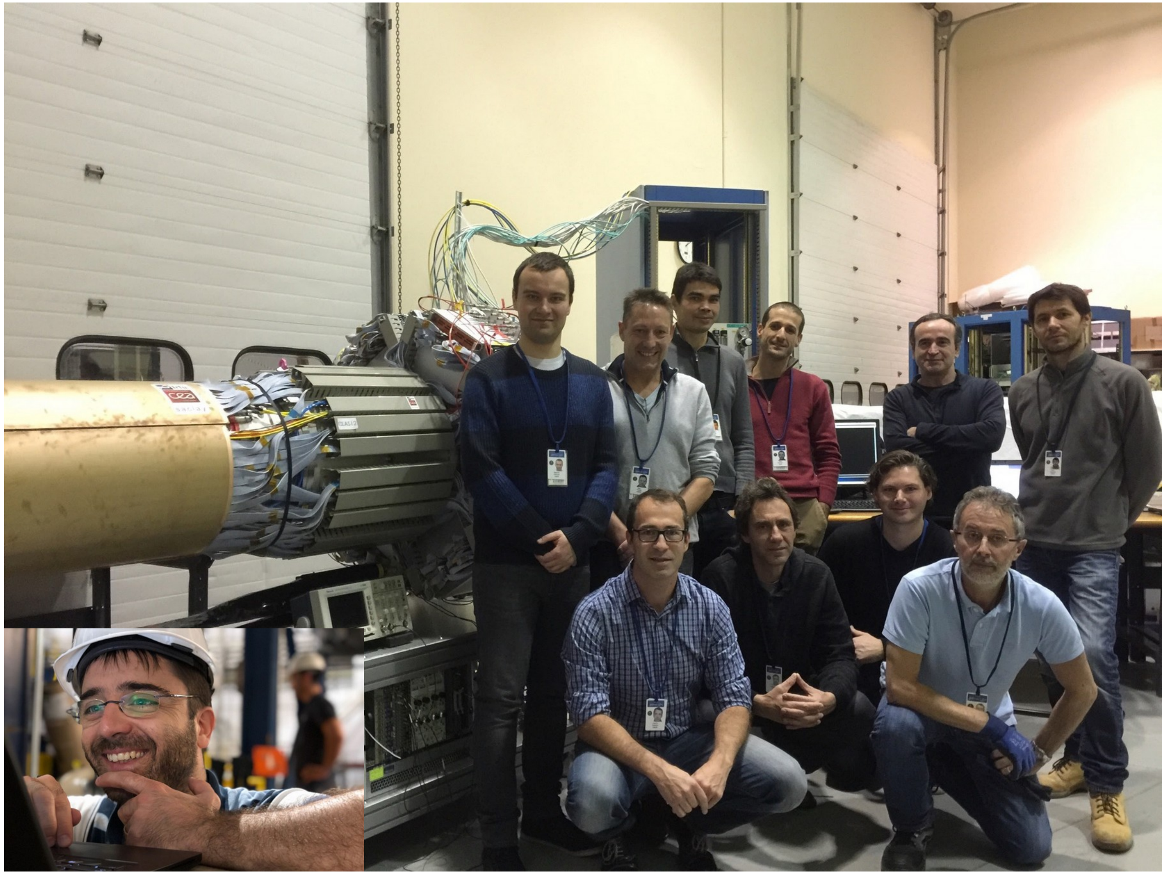
Summary

Thanks for the attention!

Further reading:

- The CLAS12 Micromegas Vertex Tracker, Nucl.Instrum.Meth.A 957 (2020) 163423
- Alignment of the CLAS12 central hybrid tracker with a Kalman Filter, e-Print: 2208.05054

Special thanks to Y. Gotra and R. Paremuzyan



The Saclay CLAS12 team