PERFORMANCES OF THE MICROMEGAS VERTEX TRACKER AT THE CLAS12 EXPERIMENT FOR THE 2017-2018 PHYSICS RUN

MPGD CONFERENCE 2019,

LA ROCHELLE, FRANCE

MAXENCE VANDENBROUCKE

ON BEHALF OF **THE MVT GROUP AT SACLAY** :

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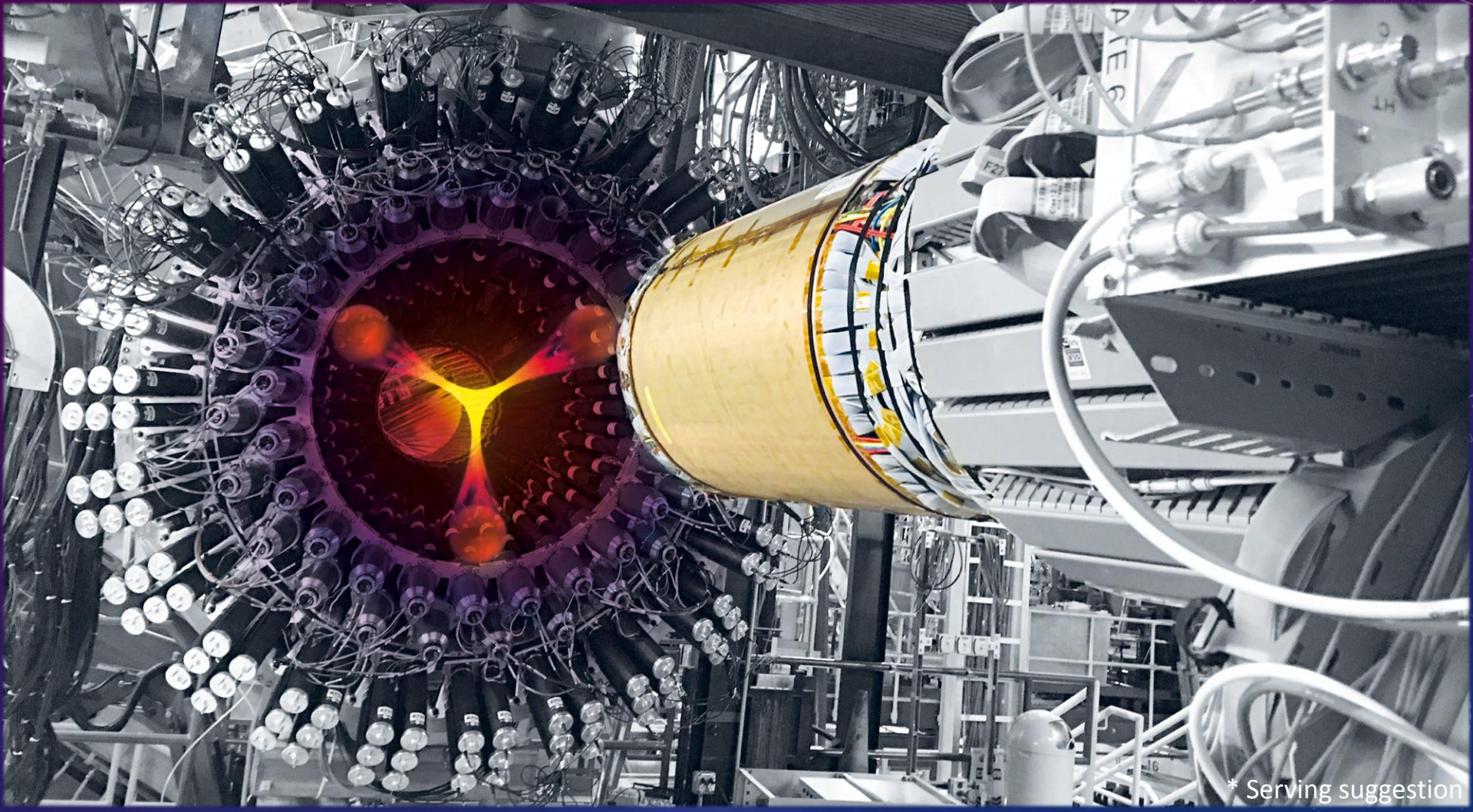
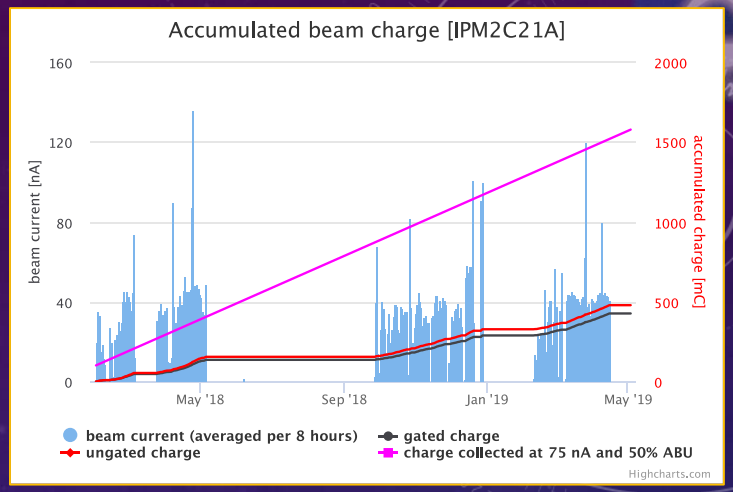
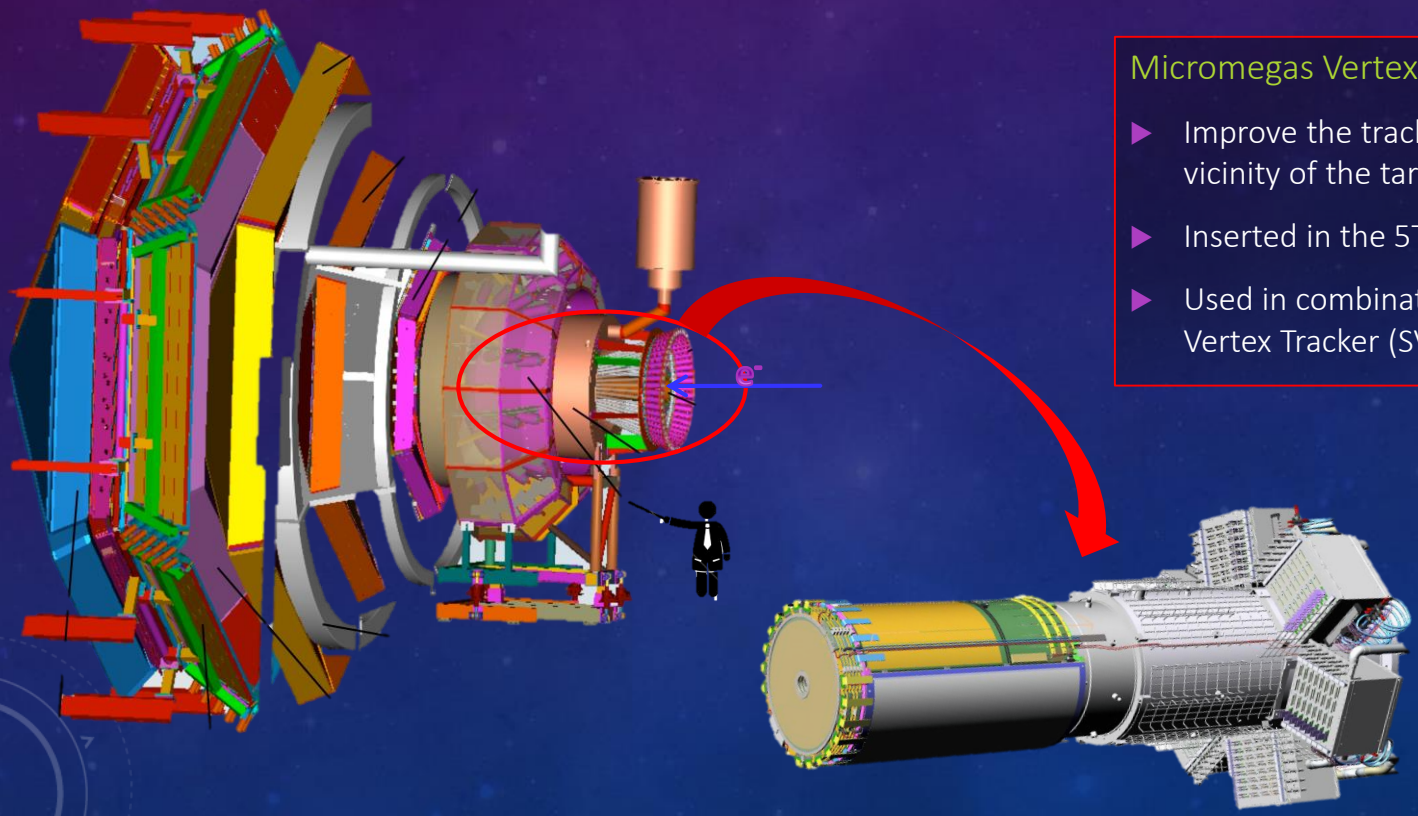


- The CLAS12 Experiment at Jefferson Lab
- The Micromegas Tracker, Forward Detectors, and Cylindrical Detectors
- Installation in the CLAS12 spectrometer
- First results after data taking

THE CLAS12 EXPERIMENT

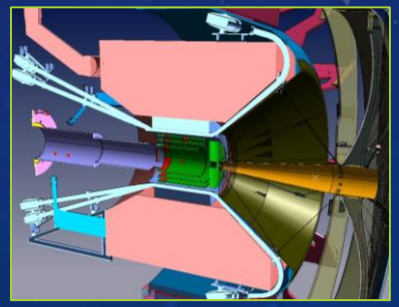
- Upgrade of the CLAS Experiment at Jefferson lab
- Study of the nucleon structure with ~11 GeV electron beam at high luminosity (10^{35} $cm^{-2}s^{-1}$)
- Targets : liquid hydrogen (protons), liquid deuterium (neutrons), other nuclei in the future





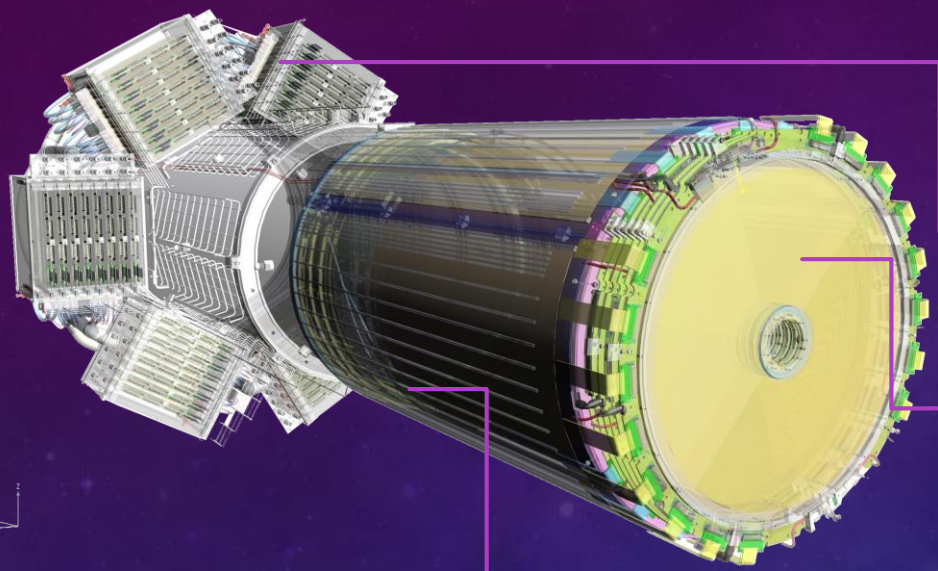
Micromegas Vertex Tracker (MVT) :

- Improve the track reconstruction in the vicinity of the target
- Inserted in the 5T solenoid
- Used in combination with the Silicon Vertex Tracker (SVT)



Solenoid + Central Tracker

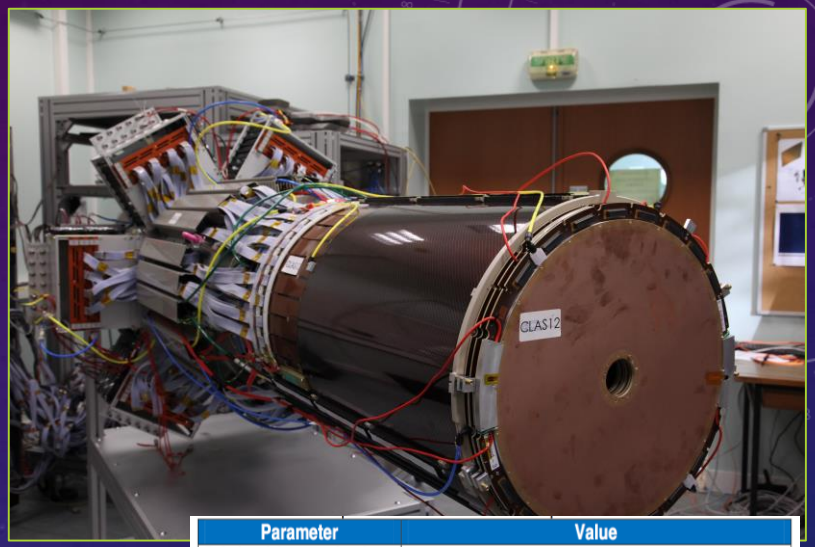
THE MICROMEGAS VERTEX TRACKER



- 4 m² of Micromegas detectors
- DREAM based Front-End Electronics ~ 20k ch.
- Remote off-detector frontend electronics connected with 2m micro-coaxial cables
- Forward Detectors (Disks)
  - High particle rate (30MHz)
  - 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 (Curved Tiles)
  - Low momentum particles => Light Detectors
  - Limited space of ~10 cm for 6 layers
  - High magnetic field (5T)
  - Phase 1 (2016) : 2 Layers (6 Det. of 120°)
  - Phase 2 (2017) : 6 Layers (18 Det.)

THE DREAM FRONT-END ELECTRONICS

- Signals are continuously pre-amplified, shaped, sampled at 20-30 MHz and kept in the circular analog memory 512 cells deep
  - Covers 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.

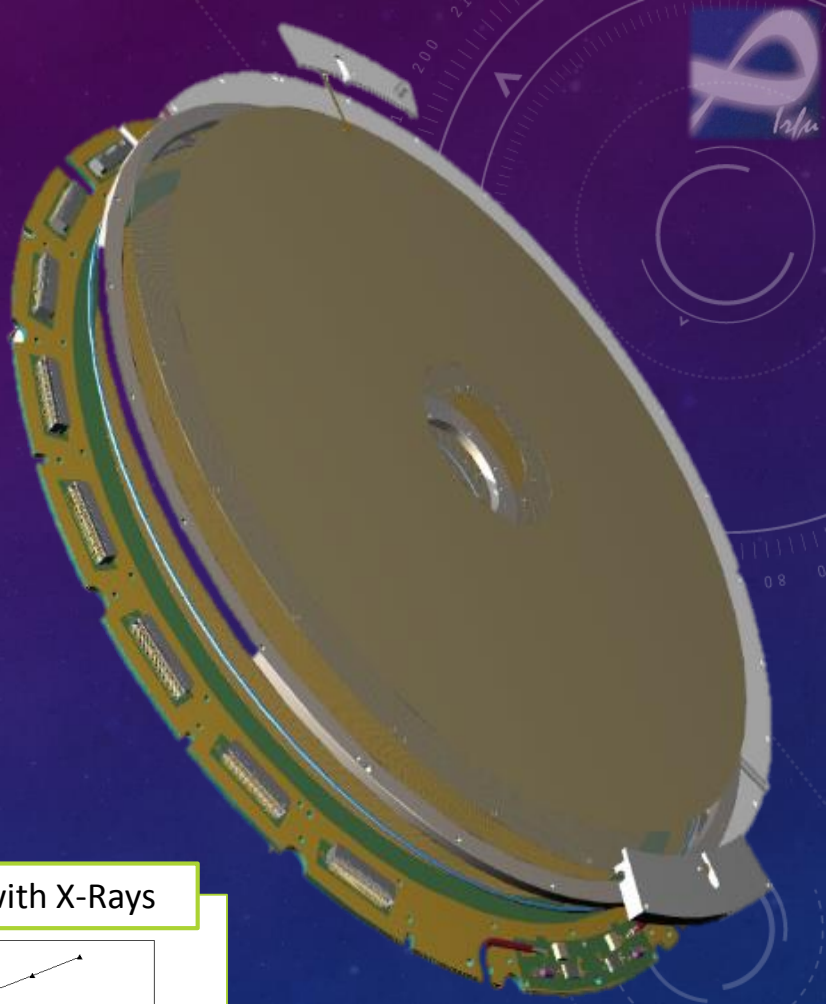
~1K ch. Detector

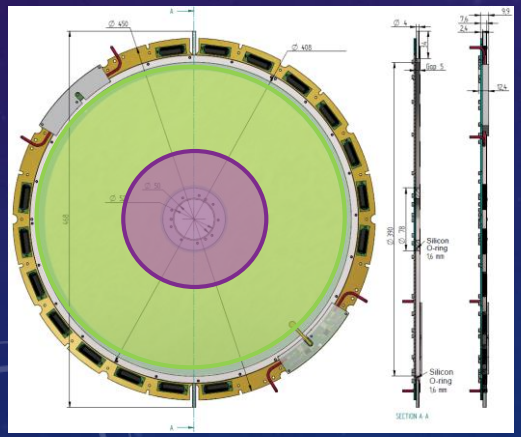
16 x 64 ch. Micro-Coax cables (1.5 -2.2m)

2 x 512 ch.
Front-End Unit

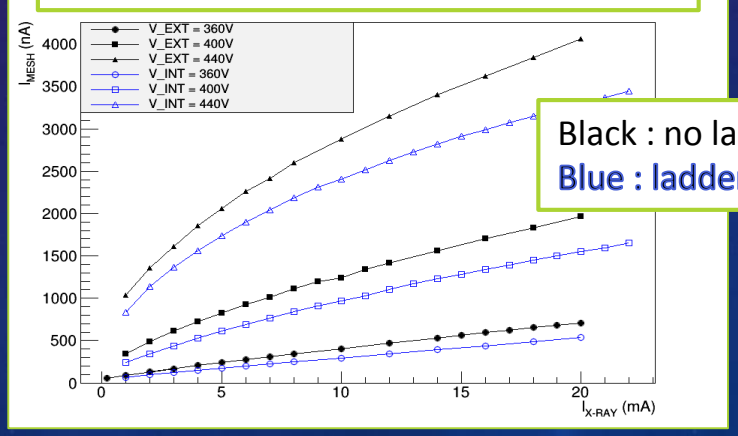
CLAS12 MM FORWARD TRACKER

- 6 layers of Micromegas with 1D strips alternatively rotated at 0°, 60°, 120°
- 86 mm to 380 mm diameter active area
- Bulk MM + Resistive Layer
- Same detector design for the 6 detectors :
  - Dimensions: 430 mm diameter disk with a 50 mm diameter hole at the center; 5mm drift gap
  - 100 µm PCB glued on ROHACELL
  - 525 µm pitch, with 120 µm between two strips, 1024 strips
  - 2 independent resistive strips zones (inner/outer)

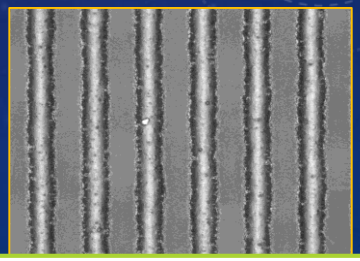




Charging up effect studies with X-Rays

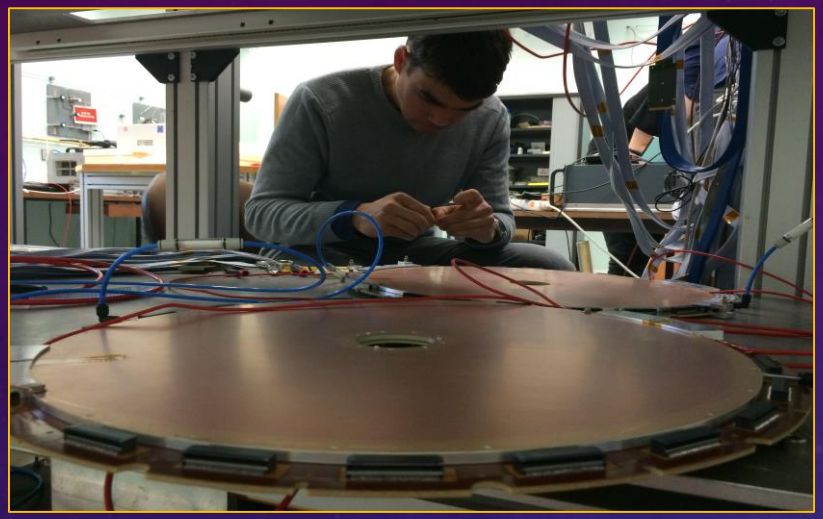


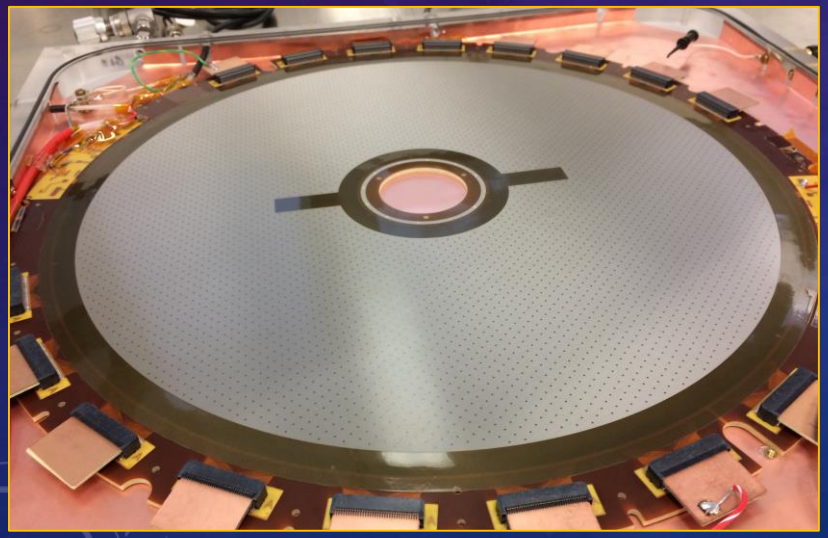
Black : no ladders
Blue : ladders



Resistive Strips w/o interconnections (ladders)

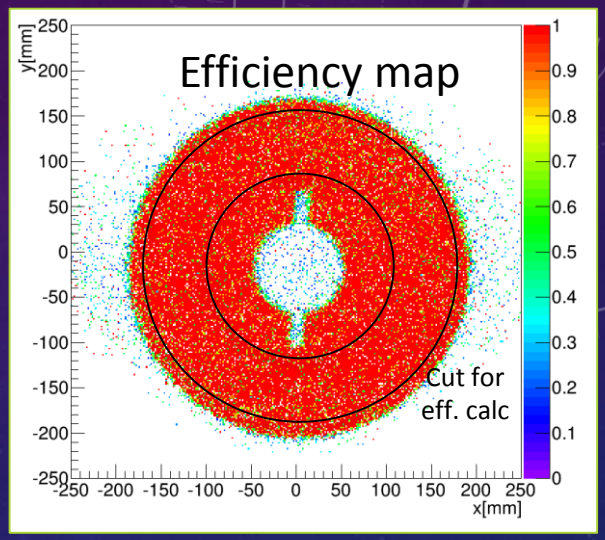
FORWARD DETECTORS IN COSMIC TEST BENCH

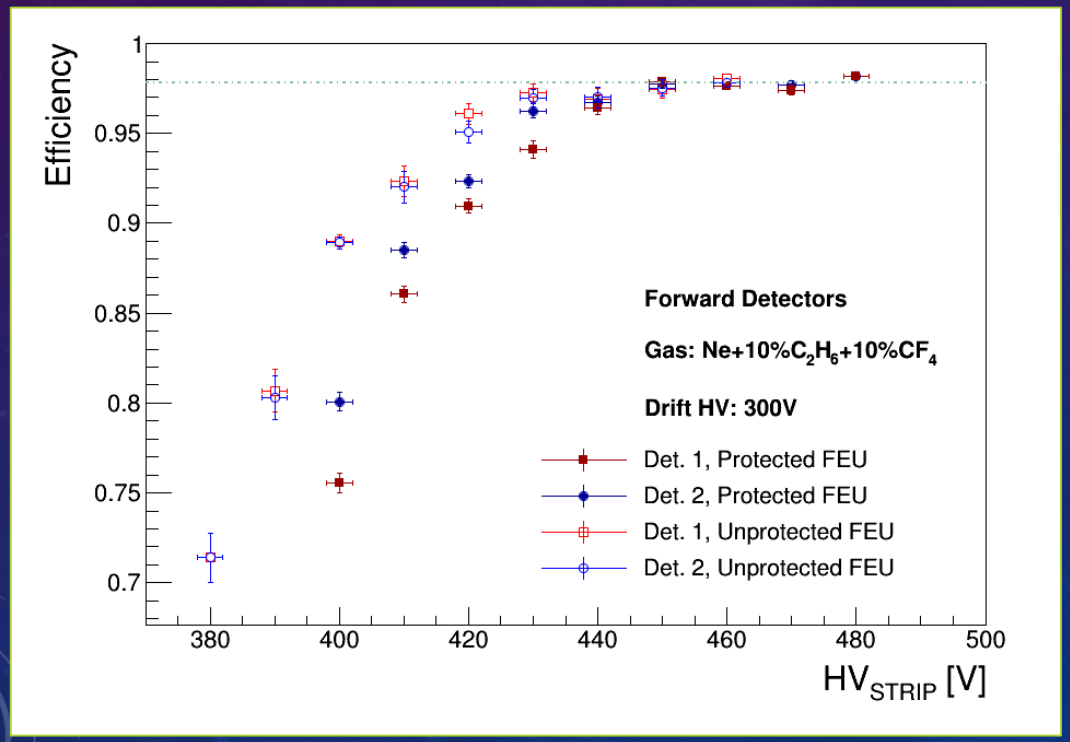


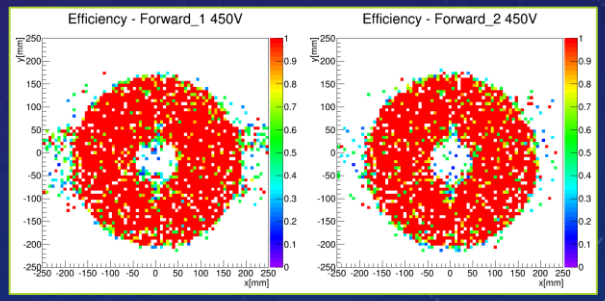


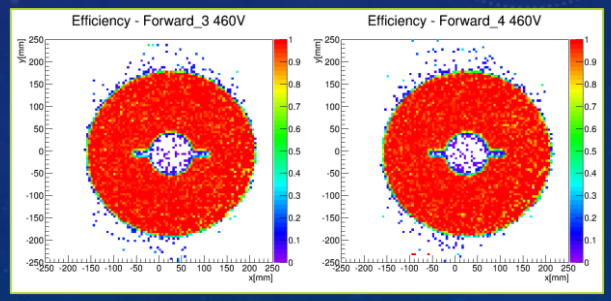
FORWARD DETECTOR COSMIC RAYS TEST

- 6 Detectors fully operational with no current on the resistive layer after many cleaning procedures
- 6 Detectors have been delivered to J-Lab in Sept. 2016
- Radiation length of 0.70% X/X0 => To be be lowered for the next run
- Close to full efficiency (98%) in the active area
- Resolution better than 200 µm (limited by tracking of the test-bench)
- Time Resolution better than 20 ns (same)

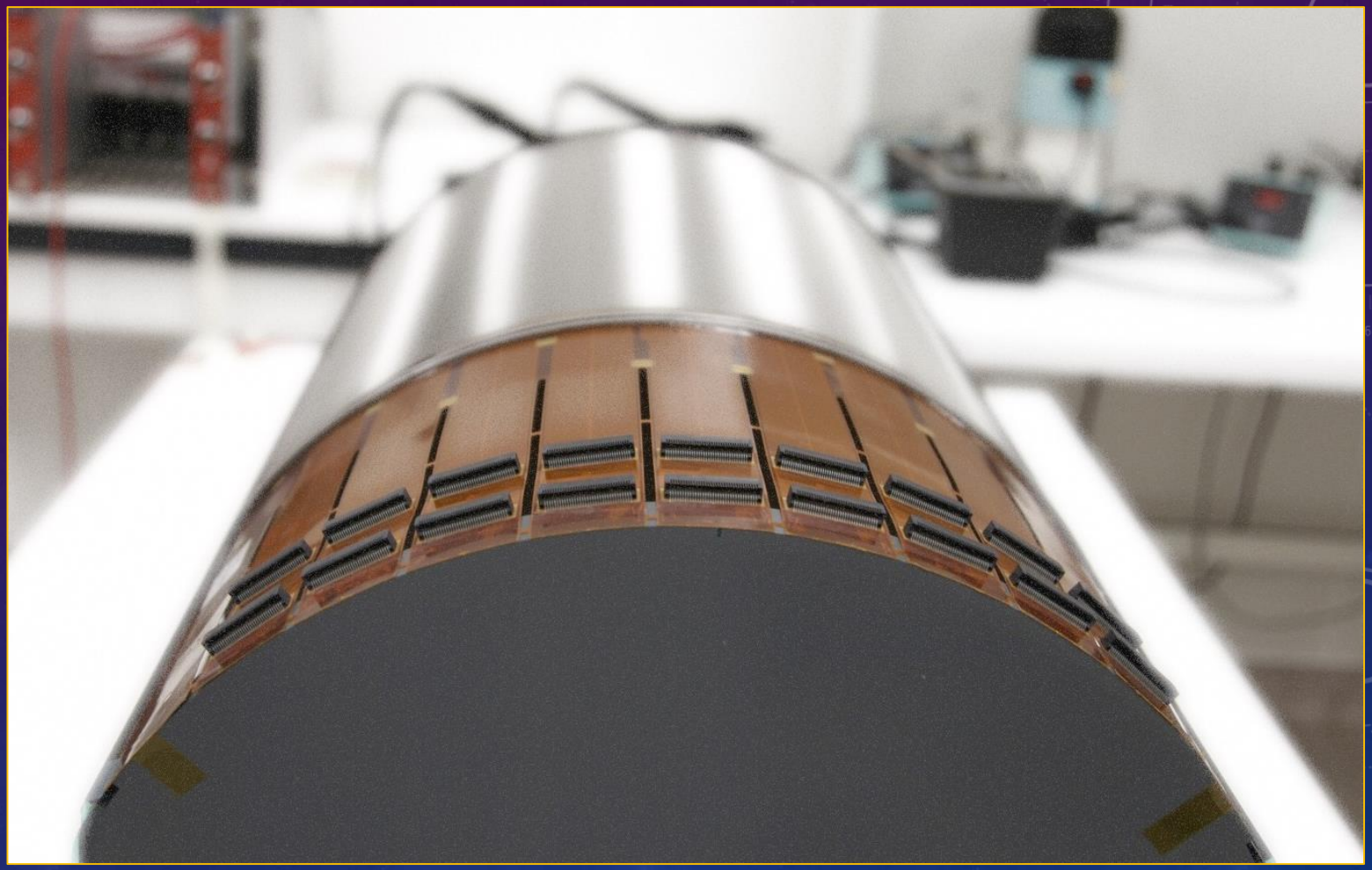






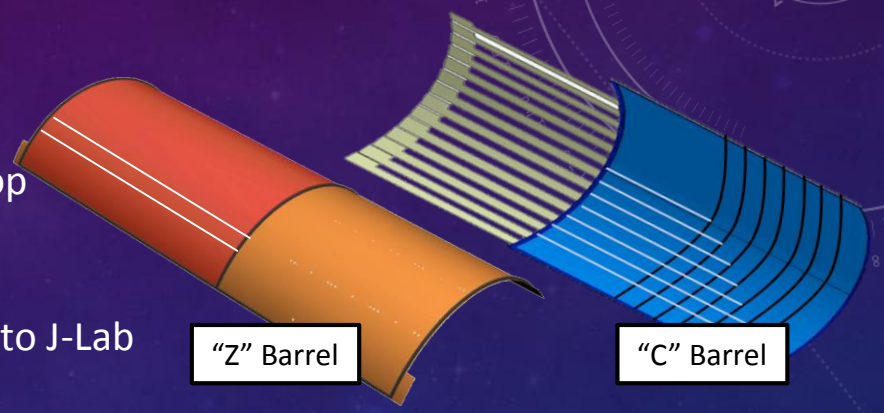


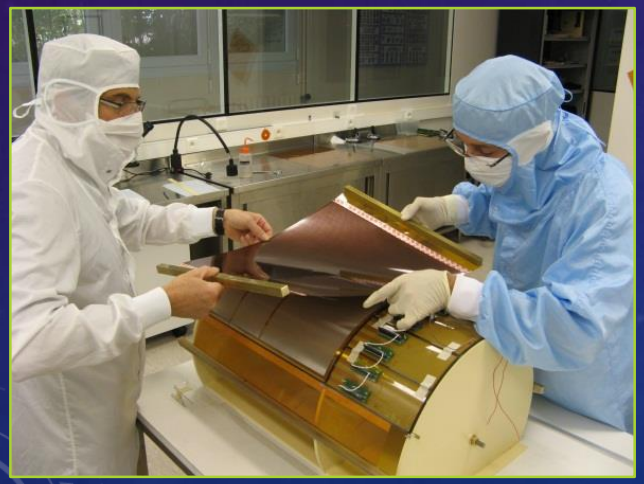
CLAS12 BARREL DETECTORS



CLAS12 BARREL DETECTORS PRODUCTION

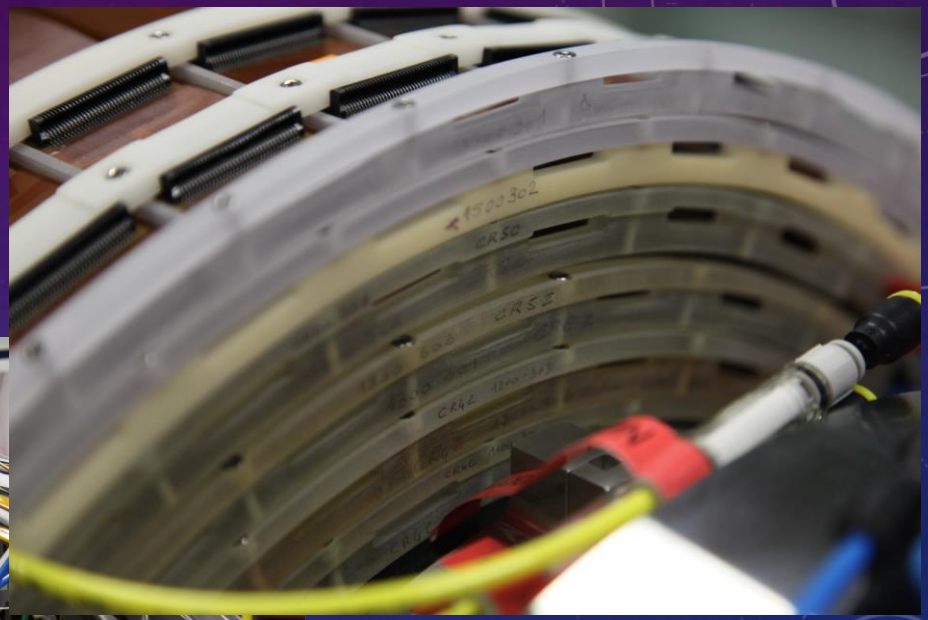
- Total of 6 layers segmented in phi (3 x 120° sectors) = 18 detectors total
- 6 Different detector's radii
- 2 different types (C and Z types)
- Material (PCB/Bulk + Drift) from the CERN Workshop
- Assembly to cylindrical shape at Saclay
- Test and Characterization at Saclay before shipping to J-Lab
- 8-9 days to assemble one detector + 1 week of test

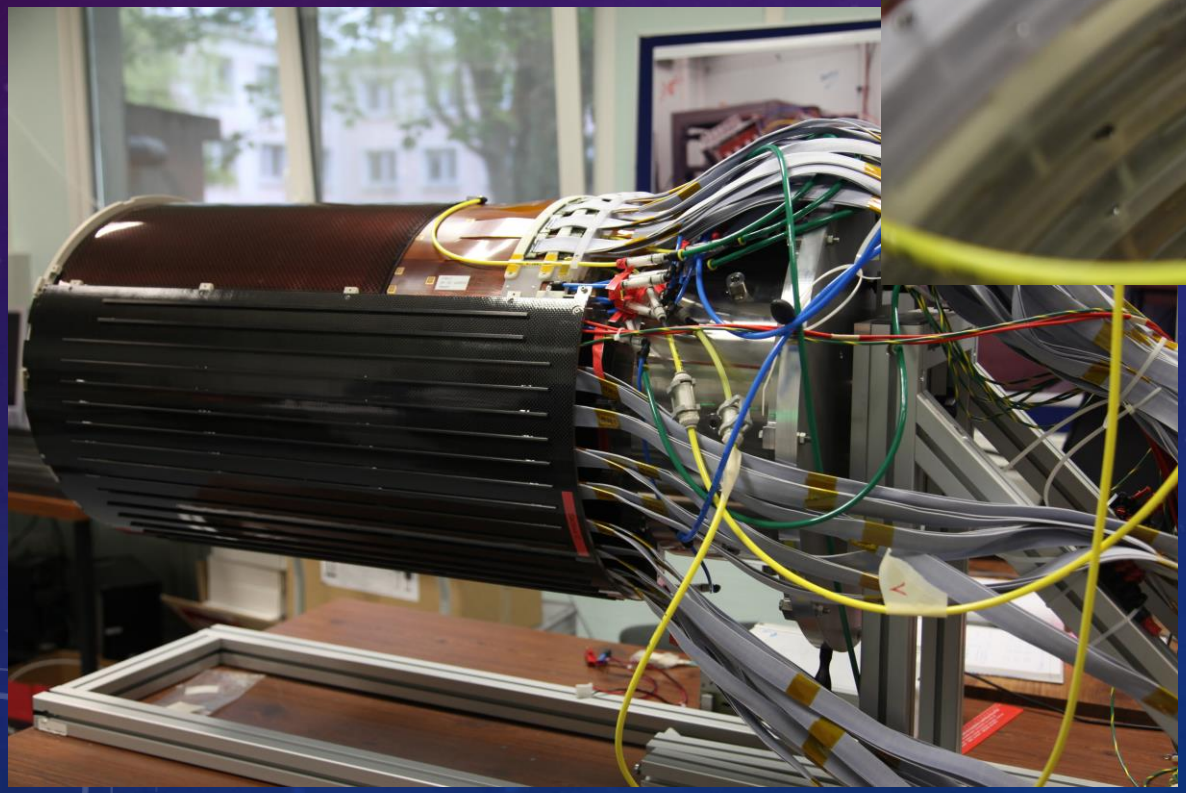




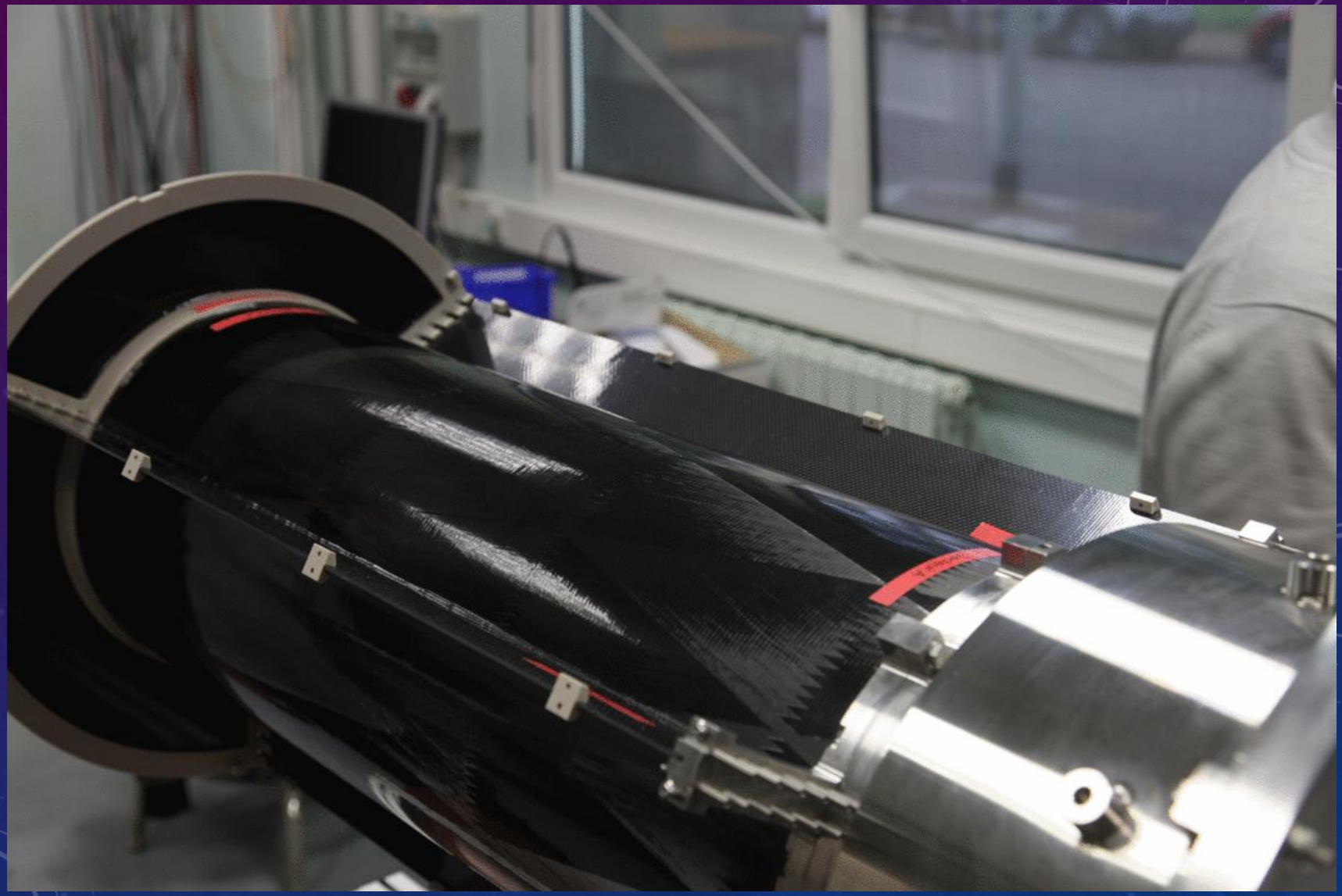
Layer	Production	ch.	Radius	Length	Width
CR4-C	3 + 1spare	896	146mm	712mm	302mm
CR4-Z	3 + 1spare	640	161mm	712mm	333mm
CR5-Z	3 + 1spare	640	176mm	712mm	364mm
CR5-C	3 + 1spare	1024	191mm	712mm	396mm
CR6-Z	3 + 1spare	768	206mm	712mm	427mm
CR6-C	3 + 1spare	1152	221mm	712mm	459mm
CR6-C new	3 spare	1152	221mm	712mm	459mm

COMPACT DESIGN





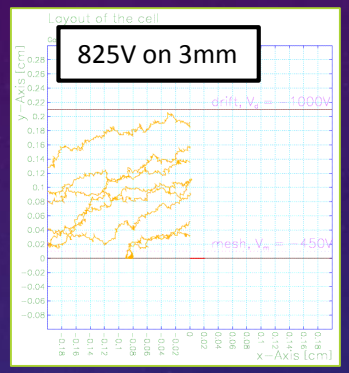
INTEGRATION OF ONE 120° SECTOR

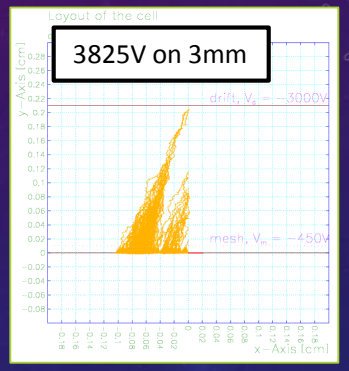


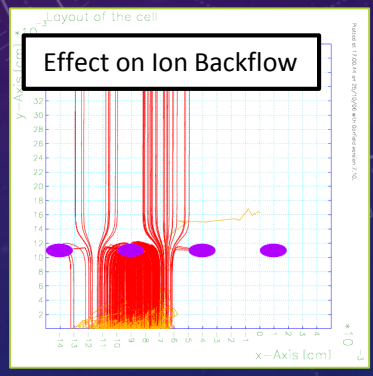
OPERATION IN CLAS12 AND THE 5T MAGNETIC FIELD

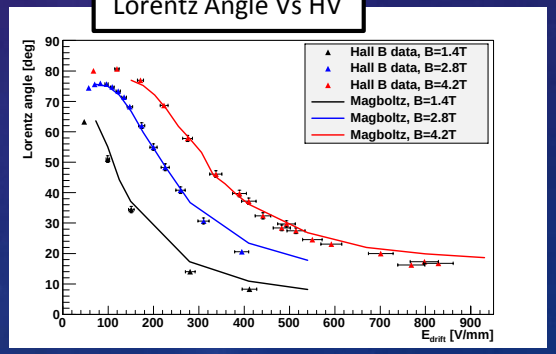
- Small volume for instrumentation (6x15mm)
- Remote off-detector frontend electronics using 2.2m long coaxial cable + DREAM FEE
- No fan for cooling
- EM Shielding challenging
- Lorentz Angle
  - Slow gas to reduce drift velocity
  - Small drift gap
  - High electric field
    - 6kV/cm for C
    - 5kV/cm for Z
  - Degradation of spatial resolution
  - Effect depends on the charge

  of the particle
  - Modify transverse diffusion

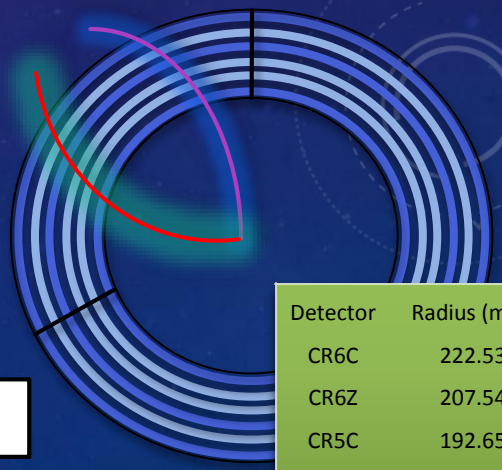








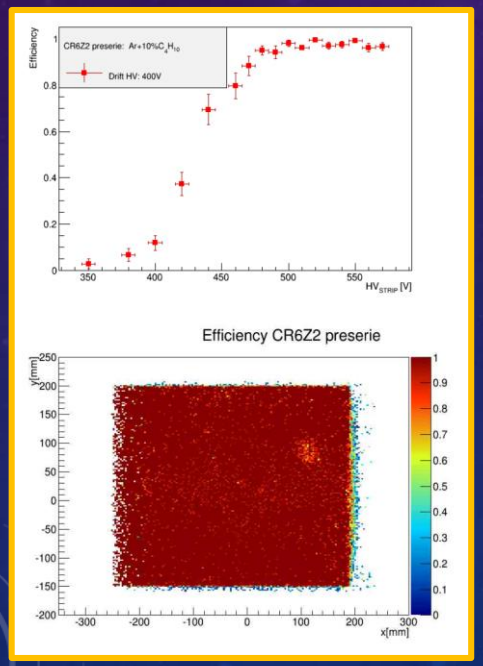
=> Clas-note 2007-004: Simulations of Micromegas detectors for the CLAS12 experiment (S. Procureur)



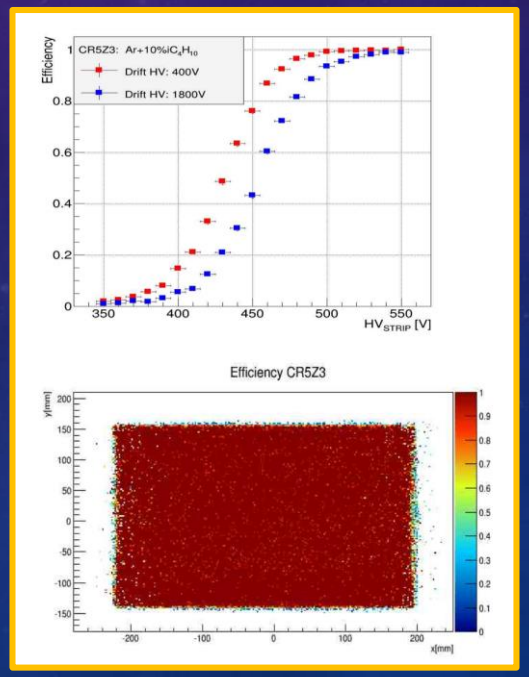
Detector	Radius (mm)
CR6C	222.53
CR6Z	207.54
CR5C	192.65
CR5Z	177.57
CR4Z	162.56
CR4C	147.57

BARREL DETECTORS: PERFORMANCE WITH COSMIC RAYS

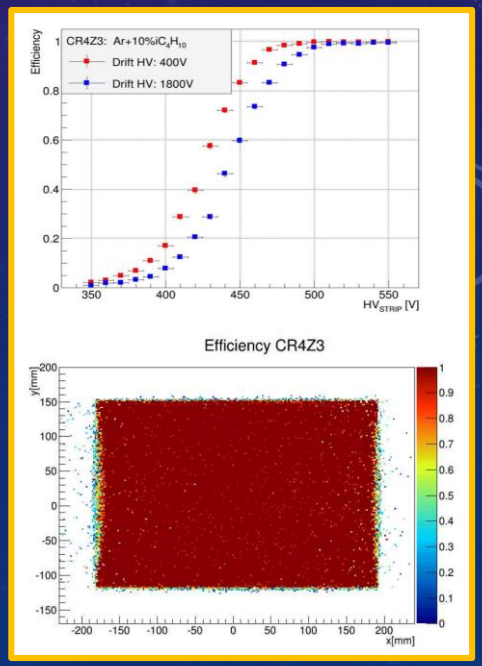
- 6 Layers of cylindrical detectors divided in 120° sectors = 18 Micromegas tiles
- Bulk + Resistive Micromegas
- Less than 0.5% of a radiation length per layer
- Cylindricity measured to be precise up to ~2mm in radius
- Resolution better than 200µm per layer with cosmic rays
- Time resolution of ~25ns with cosmic rays



LAYER 6



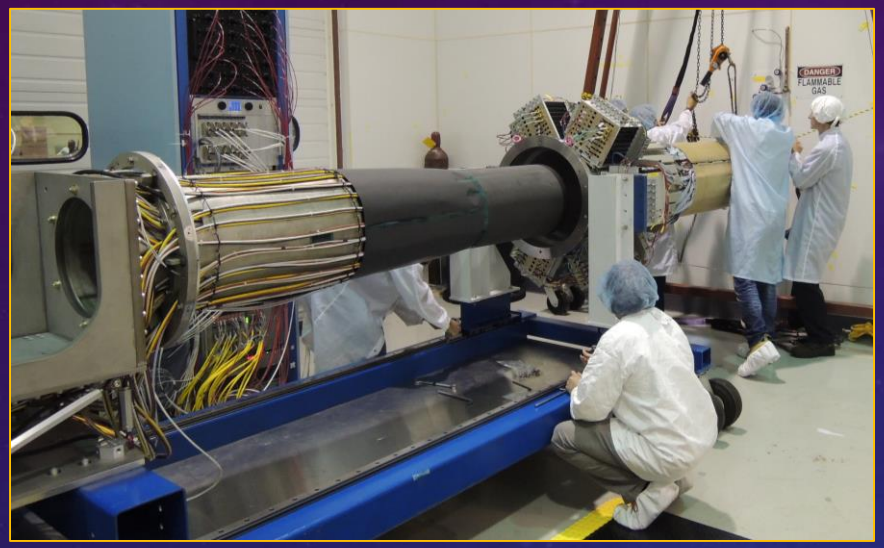
LAYER 5

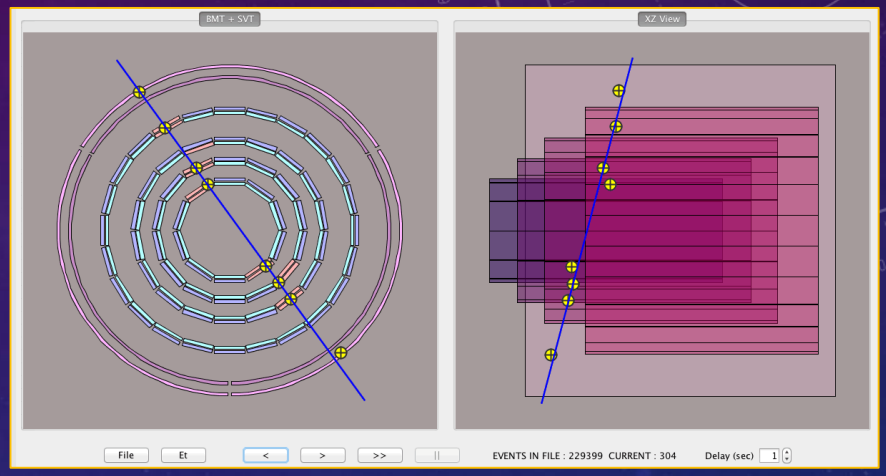


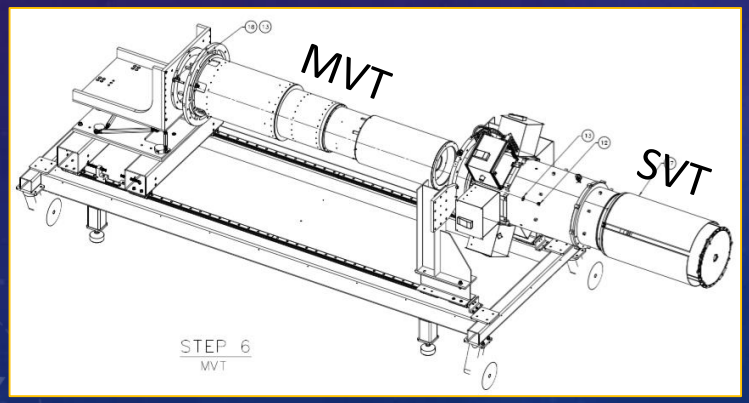
LAYER 4

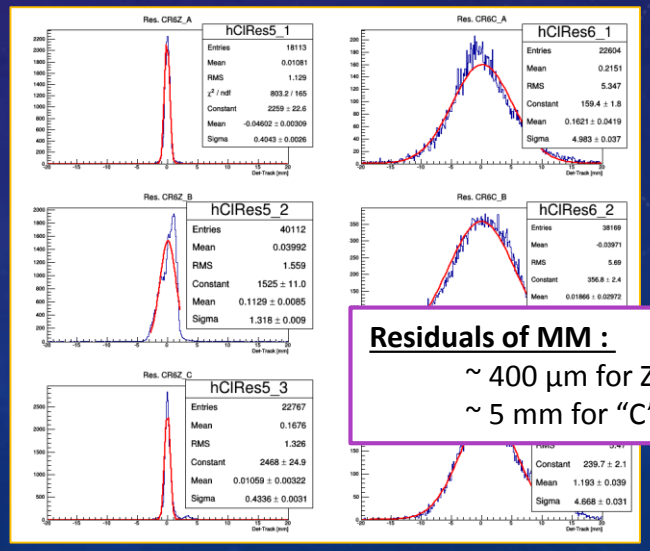
FIRST INTEGRATION AT J-LAB

In 2016 Successful integration at JLAB of **~1/2** of the layers together with the Silicon tracker and joint test with cosmic rays







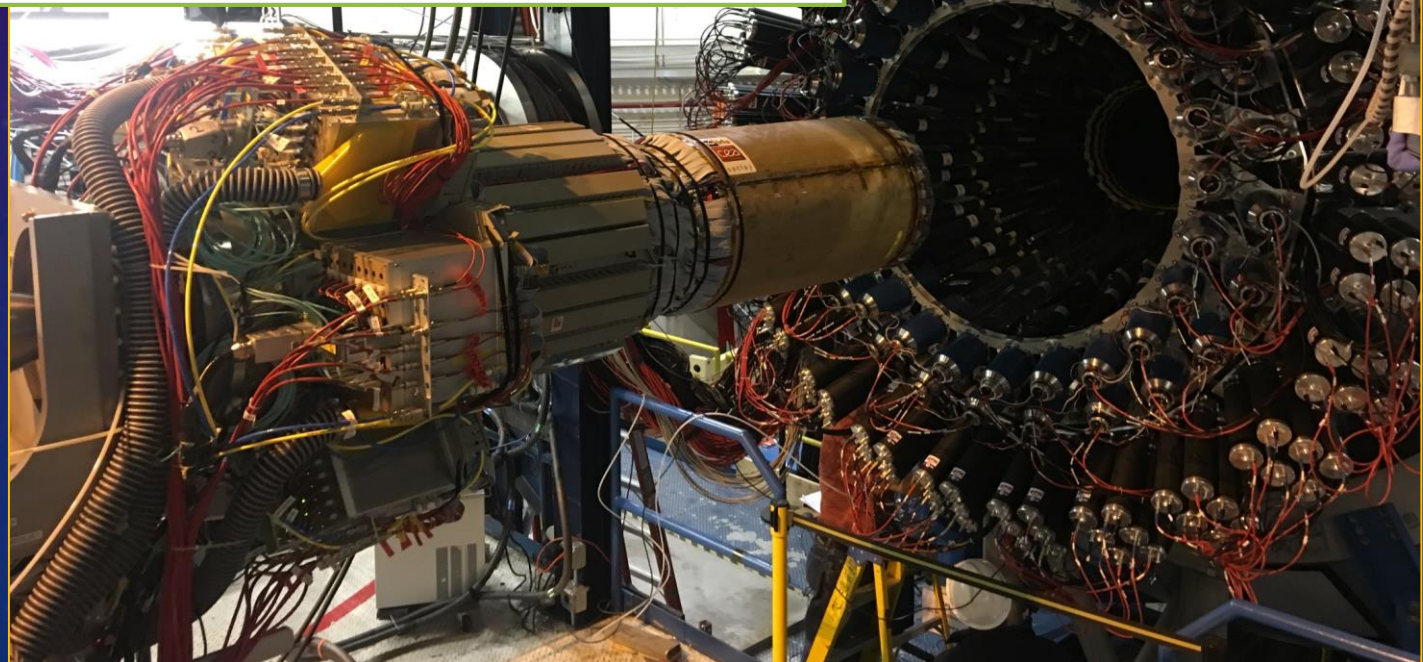


Residuals of MM :

~ 400 µm for Z det.

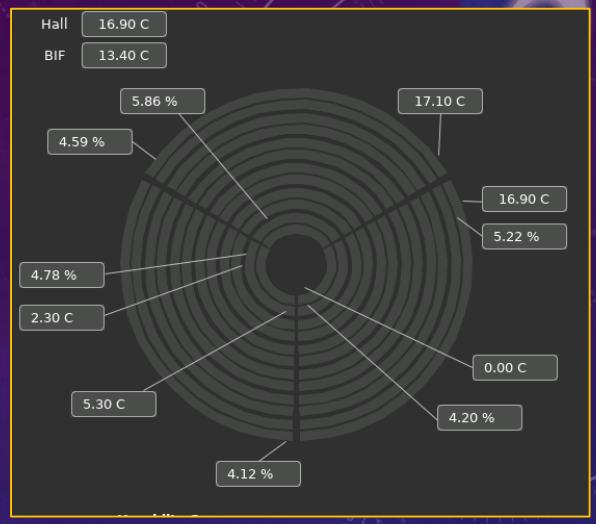
~ 5 mm for "C" det.

MVT ARRIVES AT CLAS12 IN FALL 2017

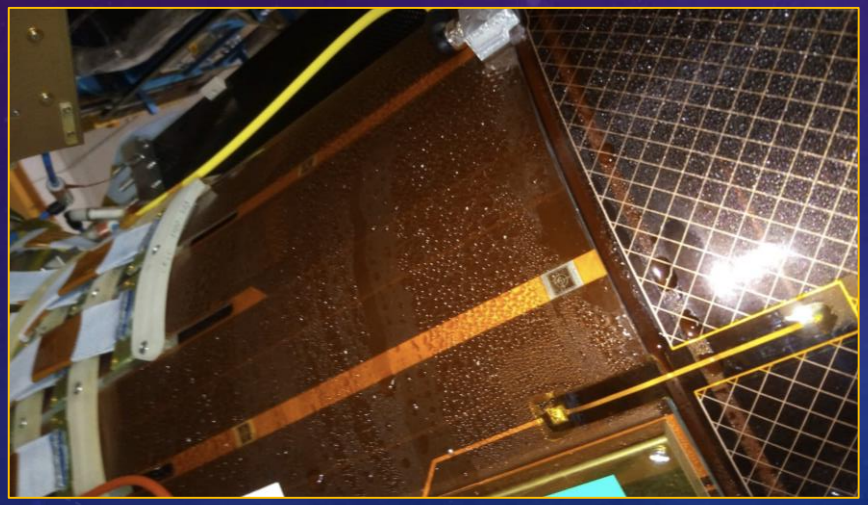


ENVIROMENTAL CHALLENGE

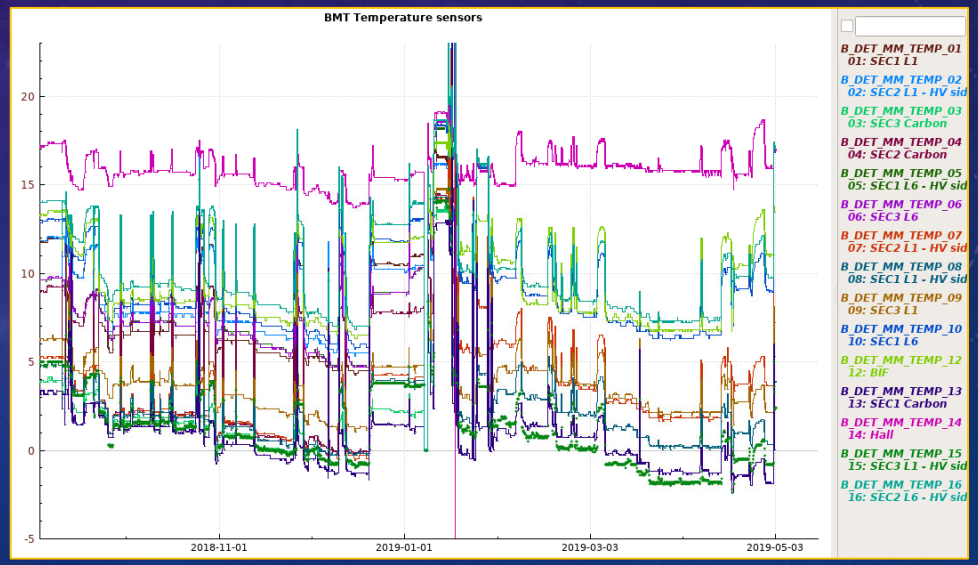
- Unexpected high background increased the silicon vertex tracker leakage current and force to increase cooling in the central tracker
- First cooling brought humidity issues fixed by nitrogen flushing
- A few detectors had to be replaced
- Micromegas tiles have been operated below freezing with no further issues



Sensors on BMT



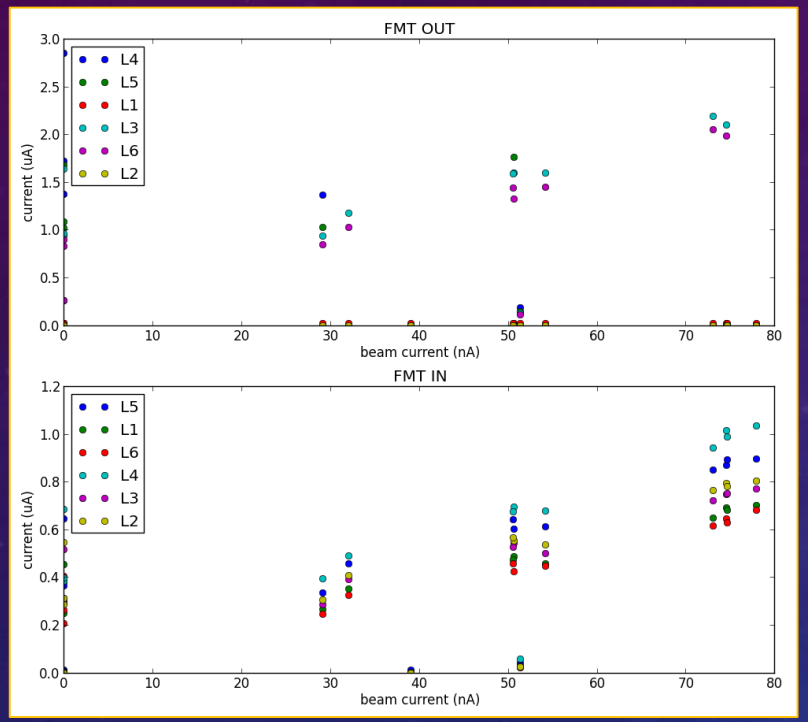
Humidity on barrel detectors

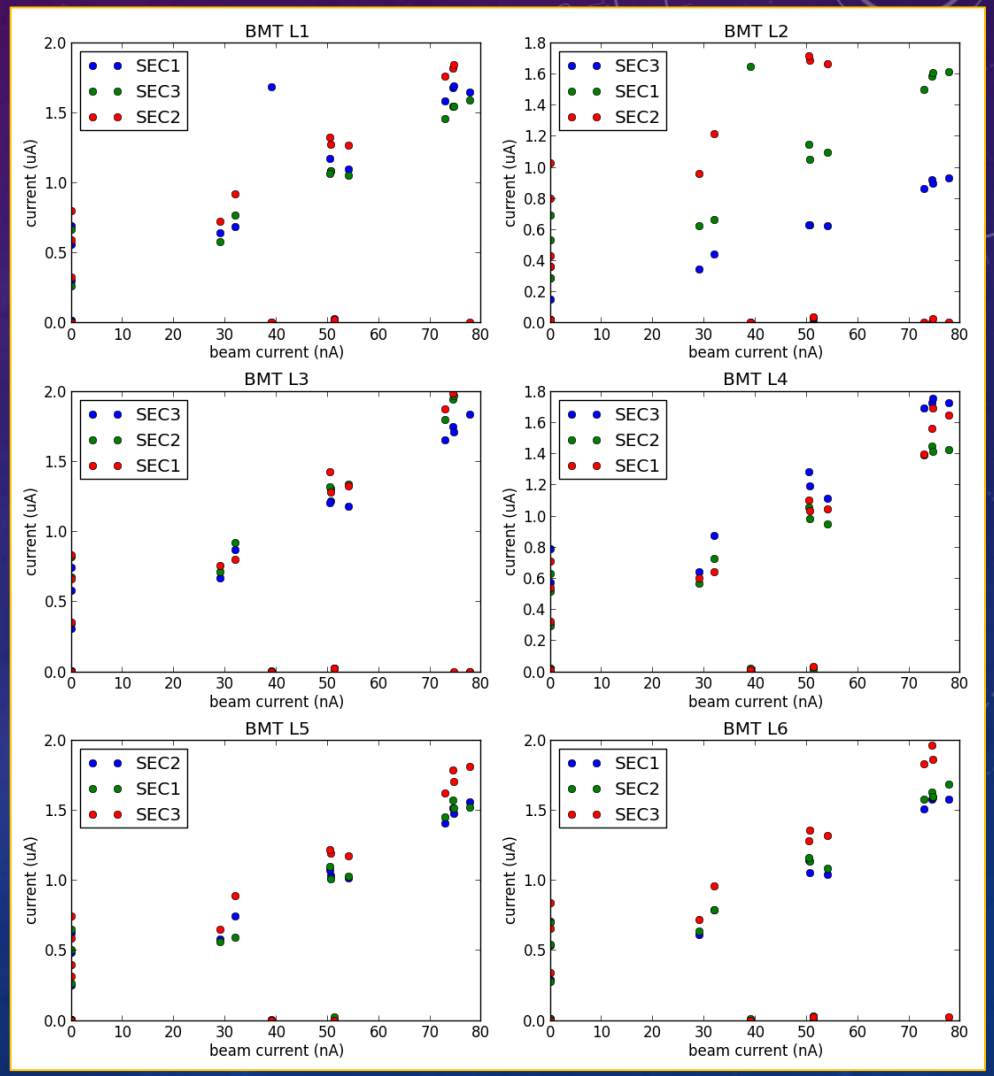


Temperature recorded on the detectors for 2018-2019

DETECTOR CURRENT

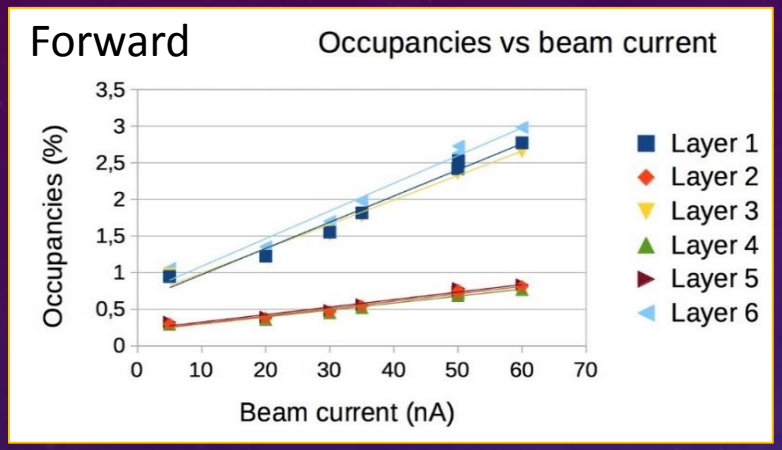
- Detector current vs beam luminosity

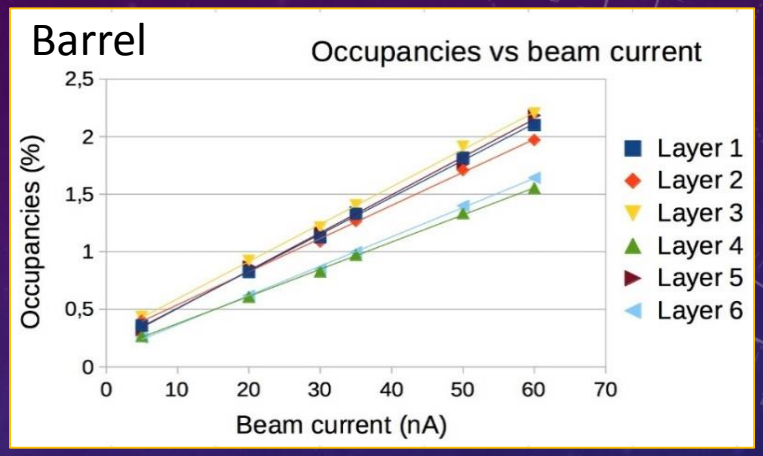




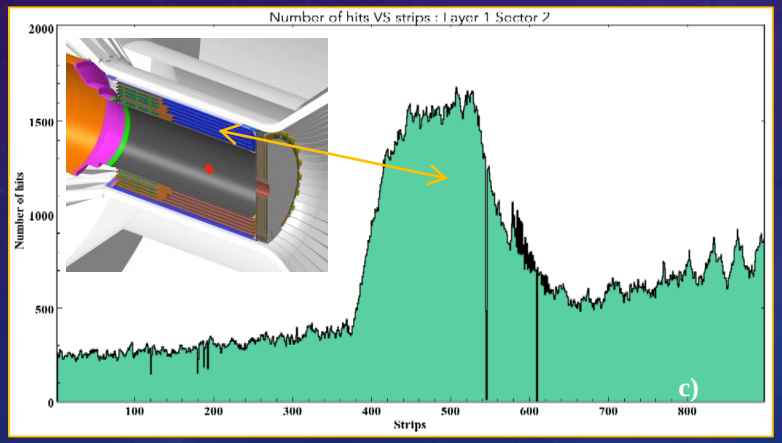
Up to 2µA per Micromegas at nominal beam intensity

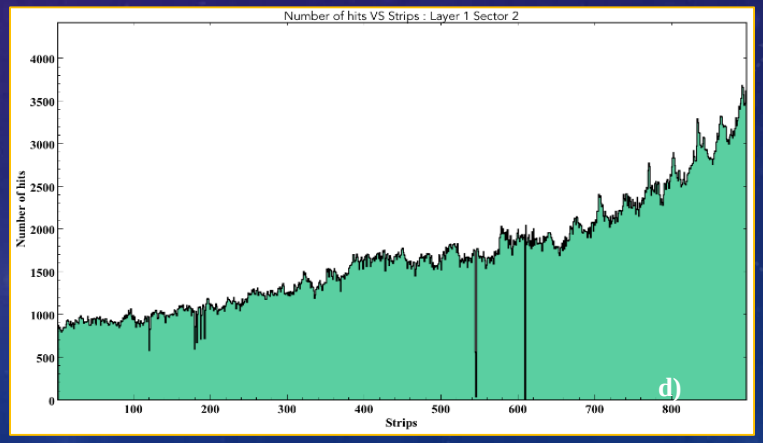
DETECTOR OCCUPANCY WITH BEAM





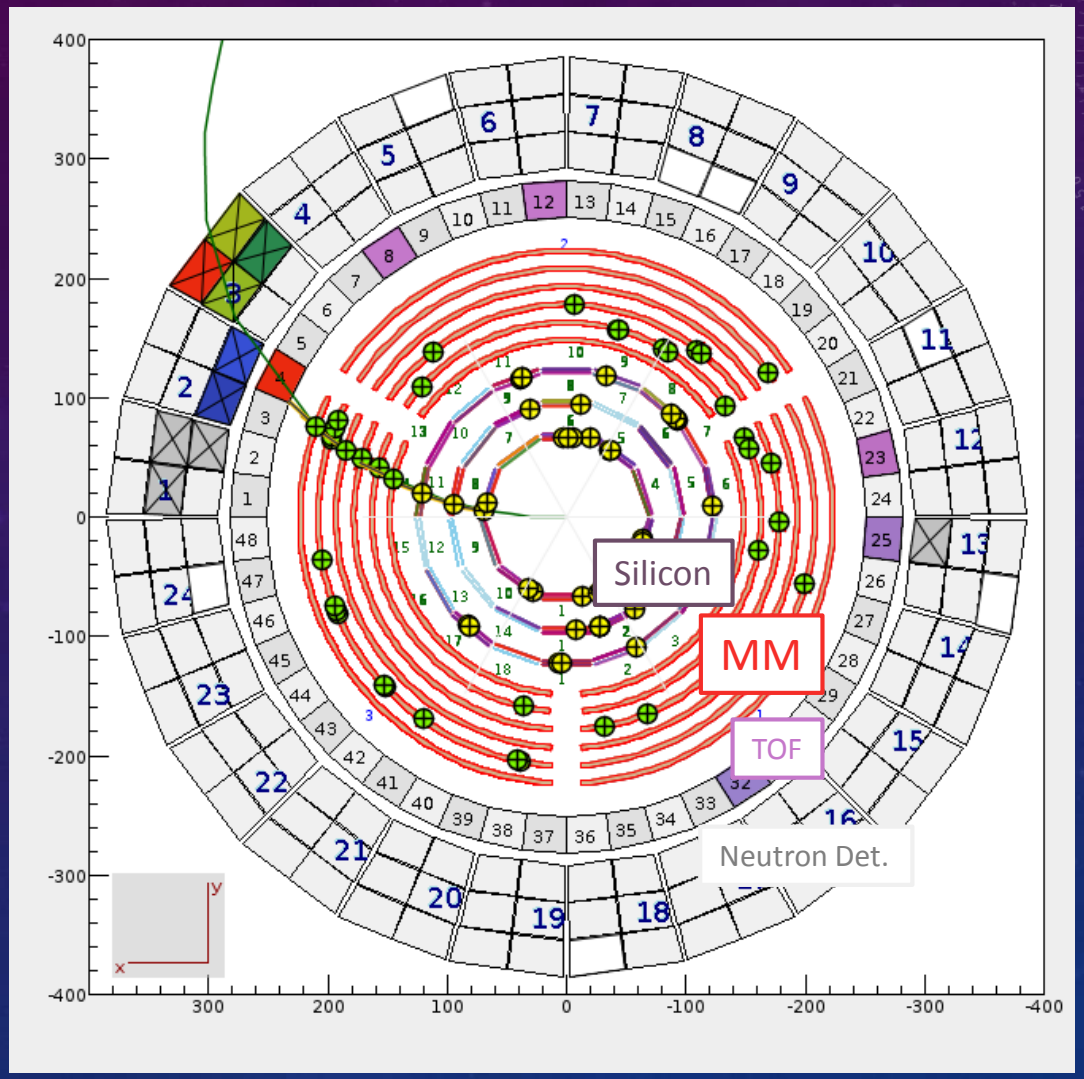
Occupancies of FMT (left) and BMT (right) as a function of the beam current. Half of the FMT disks has a lower occupancy since only their inner region is active.





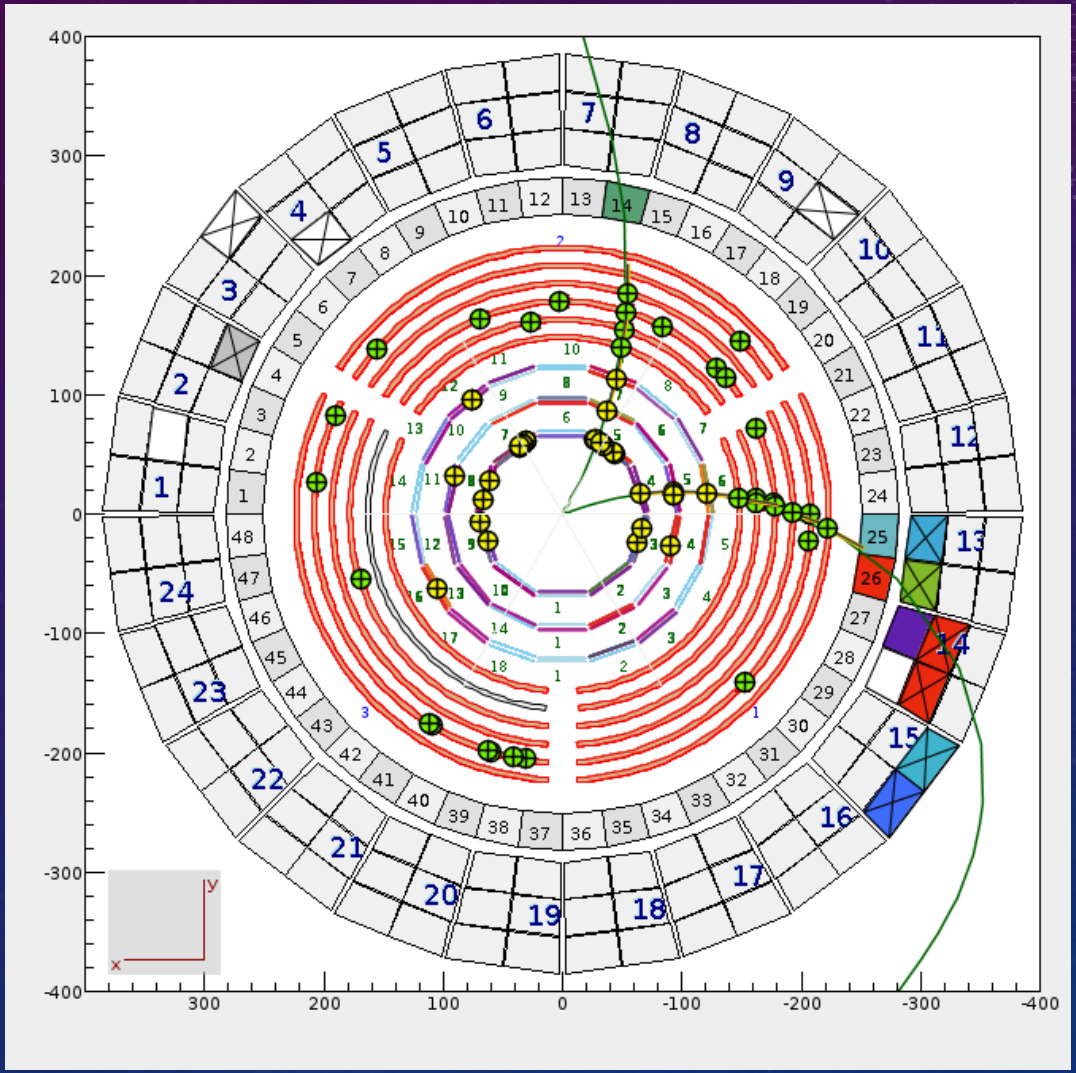
Hit occupancies for C-tiles at 2.2 GeV (left) and 10.6 (right). The elastic recoil protons are responsible for the large excess of events at 2.2 GeV, between strip number 400 and 500. The cross sections is too small at 10.6 GeV to see the protons.

CENTRAL TRACKER– 1 TRACK EVENT



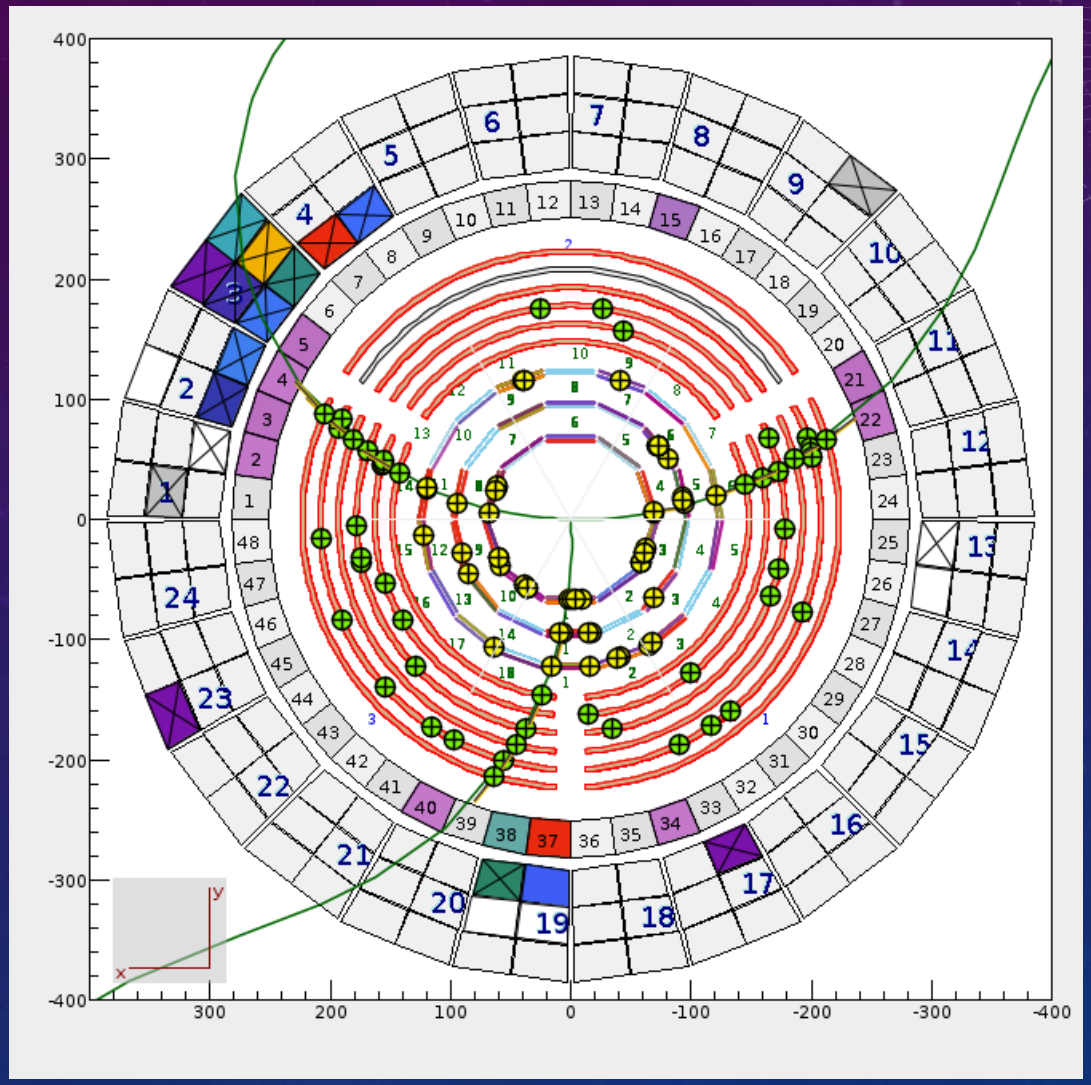
April 2019 - 10.2 GeV electron on LH_2 target

CENTRAL TRACKER– 2 TRACKS EVENT



April 2019 - 10.2 GeV electron on LH_2 target

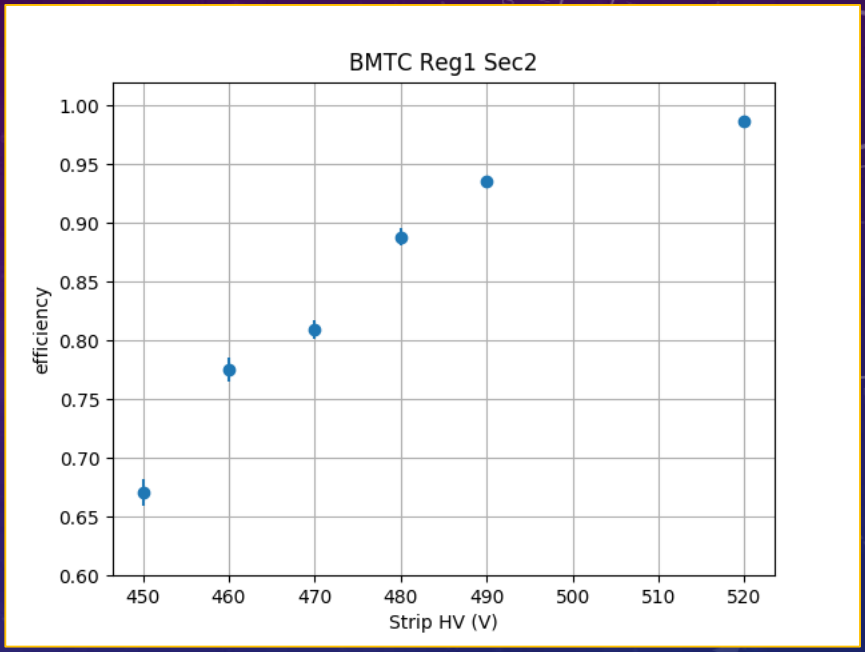
CENTRAL TRACKER– 3 TRACKS EVENT

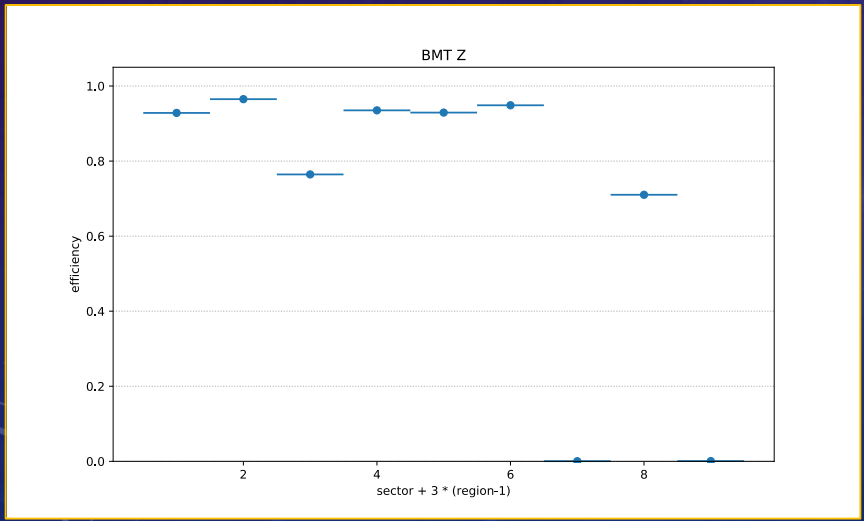


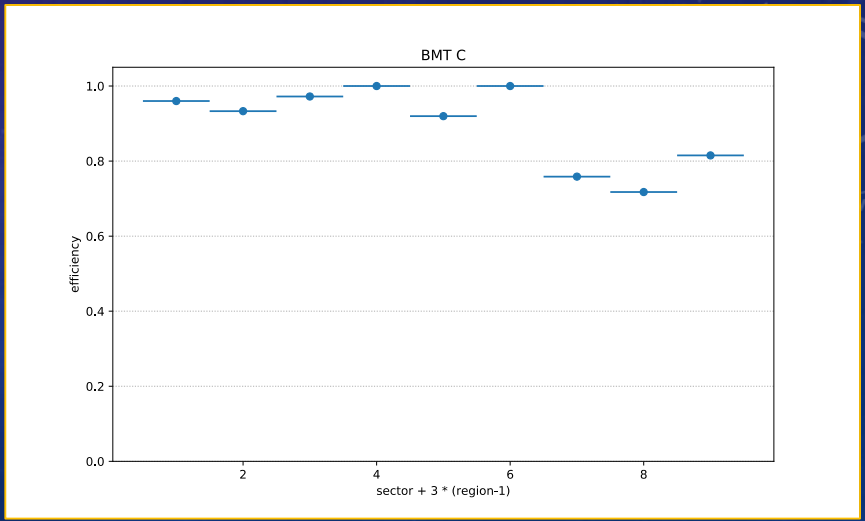
April 2019 - 10.2 GeV electron on LH_2 target

EFFICIENCY AND HV PLATEAU SCAN

- Tracking algorithms are not final yet
  => Very Preliminary Results
- 90%-100% efficiency reached in physics data taking conditions
- Working point for the mesh HV at ~500V in Ar:Iso 90:10







STATUS

- The CLAS12 experiment MM Vertex Tracker has been assembled and delivered to Jefferson Lab is on its way after 10 years since the first proposal
- Resistive Micromegas have been build and characterized
  - 18 + 6 (spares) cylindrical MM for the CLAS12 barrel detectors
  - 6 disks for the Forward Micromegas Tracker
- The Micromegas detectors have been taking data since fall 2017
- At nominal luminosity, detectors operate with a 2µA current on the mesh
- Unstable environmental conditions (temperature and discontinuous gas flow) damaged a few detectors that had to be placed
- Since December, we have stable condition and no detector issue

OUTLOOK

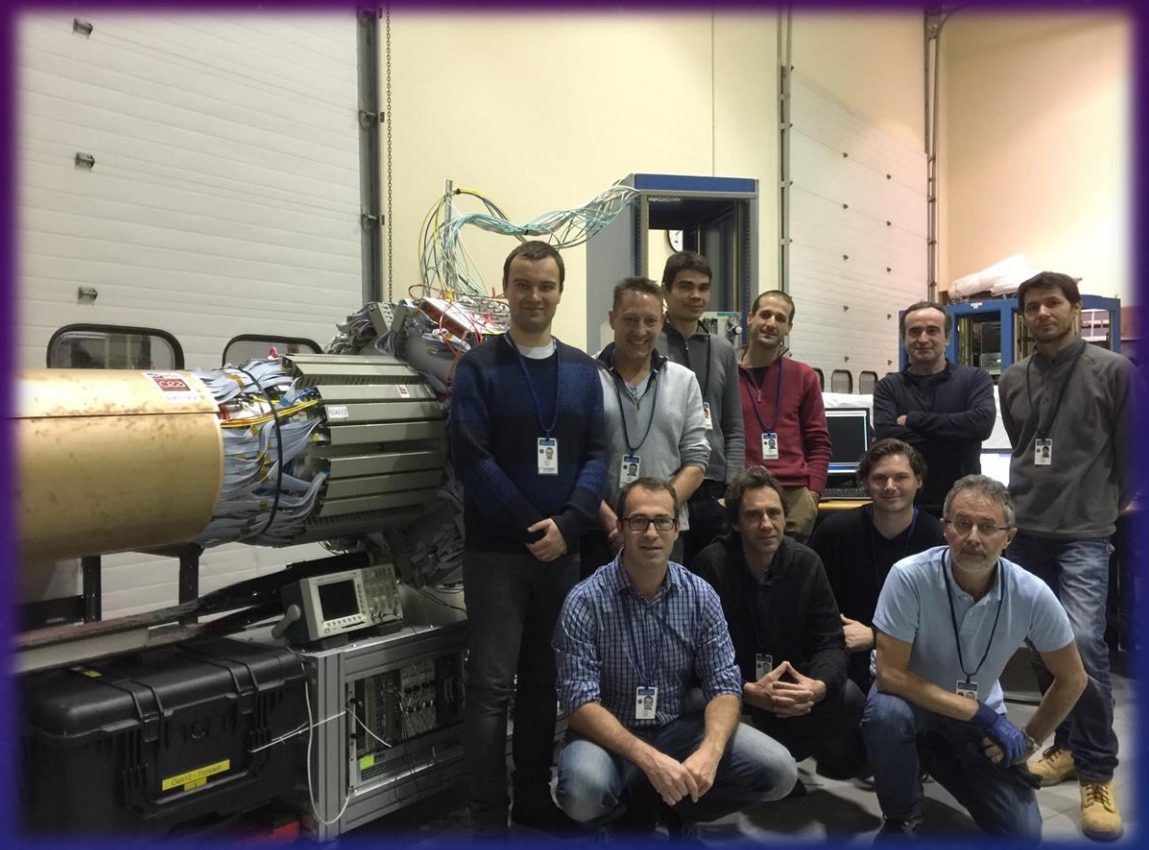
- Now CLAS12 is off for the HPS experiment (Heavy Photon Search)
- Fall 2019 : LD_2 data taking
- Winter 2019-2020 : replacement of the central tracker by a radial TPC using the same mechanics and DREAM electronics (BONUS)
- 2021 : Central tracker is put back and data taking with nuclear target (carbon, …)

FROM RESEARCH TO INDUSTRY

cea

CLAS12

Irfu



THE MVT GROUP AT SACLAY:

D. ATTIE, S. AUNE, J. BALL, Q. BERTRAND, F. BOSSU, G. CHRISTIAEN, M. DEFURNE, J. GIRAUD, R. GRANELLI,, I. MANDJAVIDZE, O. MEUNIER, Y. MOUDDEN, S. PROCUREUR, M. RIALLOT, J-Y. ROUSSE, F. SABATIE

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Contact : maxence.vandenbroucke@cea.fr

REQUIREMENTS

- **Compact tracker** => Cylindrical detectors
- **High magnetic field** => High lorentz Angle => small gap, slow gas, high drift field, high gain, deported electronics
- **Low Energy proton/electron** => Low X0
- **High rate in the forward region** => Low spark rate, fast gas

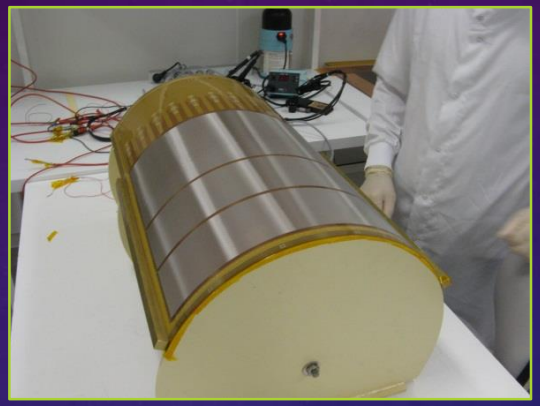
High gain, low spark => **Resistive MM**

Cylindrical Det. => **Bulk**

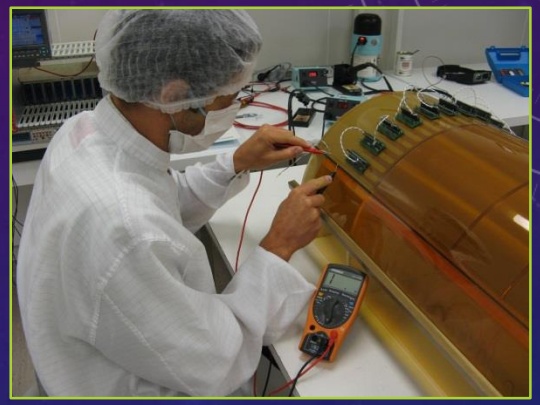
Low X0 => **Light material, glued**

CYLINDRICAL MICROMEGAS

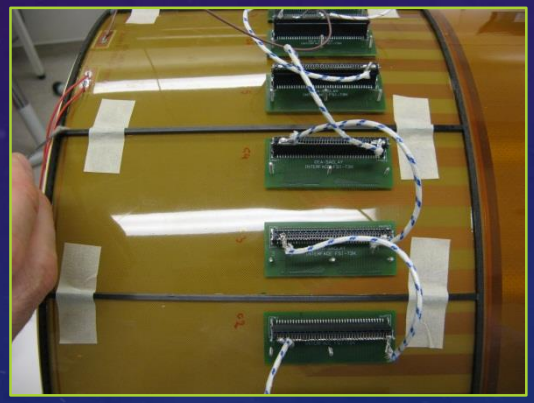
Segmentation and preparation



Gluing of the side carbon ribs on circular shape

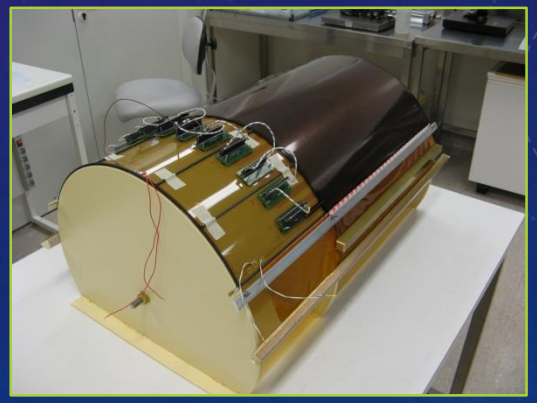


Electric leak test



Gluing of additional ribs

Setting drift plane



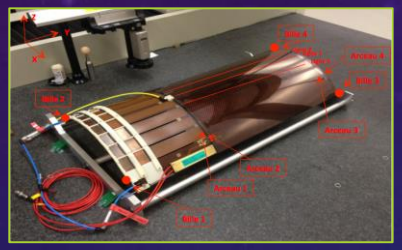
Gluing of the drift plane

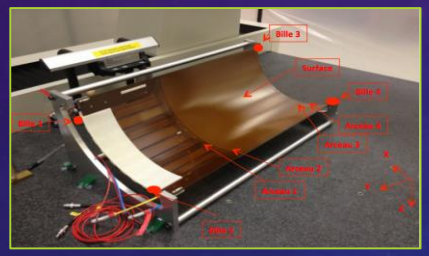
CLAS12 BARREL : GEOMETRY

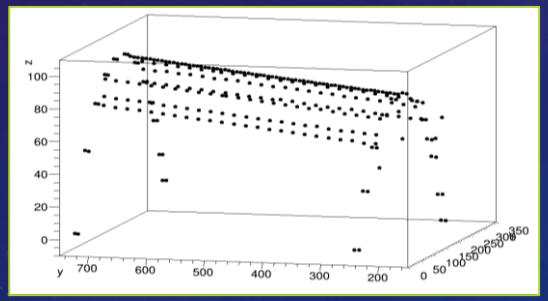
- 3D probing machine measuring points :
  - 270 points on top (drift side)
  - 120 points under (readout side)
- Cosmic rays data for cross-check

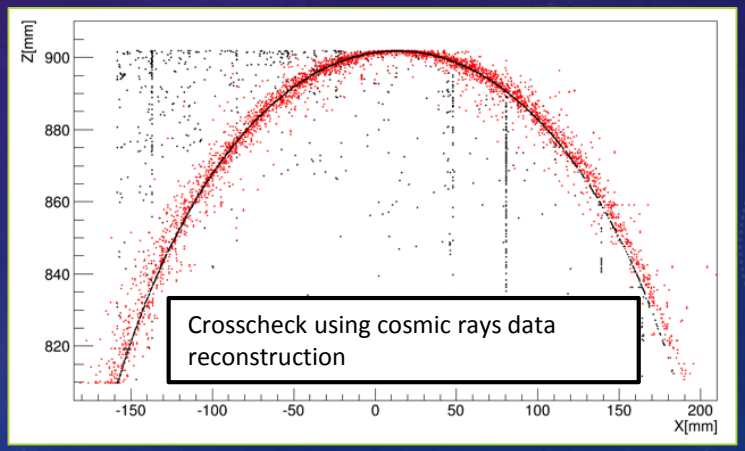
List of measured points			
	X	Y	Z
PT-Arceau1_1	-3.588	231.995	-0.005
PT-Arceau1_2	28.993	231.995	33.071
PT-Arceau1_3	64.992	231.994	57.126

…





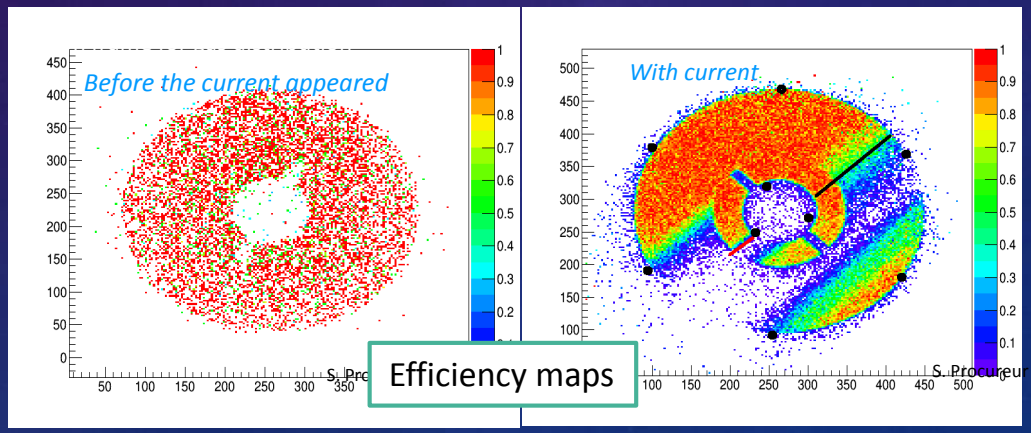




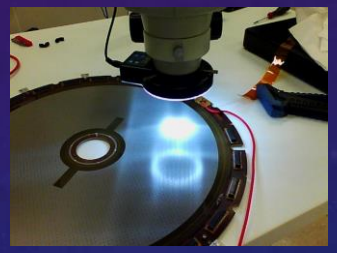
⇒ Mechanical precision up to ~2mm in radius

PRE-PRODUCTION FORWARD DISK FOR CLAS12:
ISSUE WITH RESISTIVE LADDERS

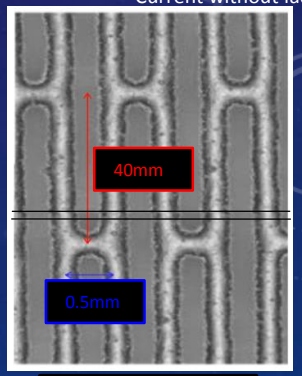
- 2 pre-production (2015) detector tested, One was not ok :
  - High current due to a contact in the active area (can't burn it with sparks)
  - Current flows from the contact to ground (black dots)
  - Large impacted zone due to ladders
  - Drift electrode glued (intervention impossible)
  -



Efficiency maps

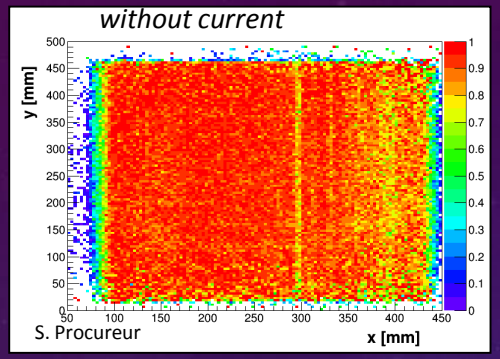


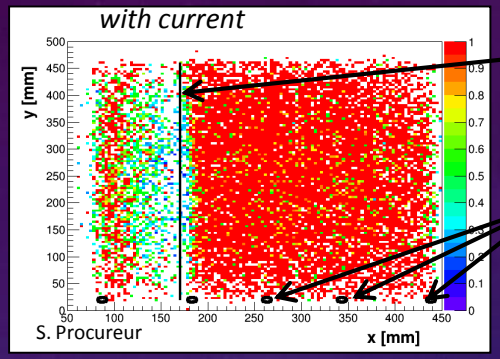
Current without ladders



Resistive Strips

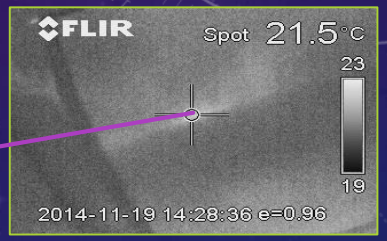
PRE-SERIE BARREL DETECTORS TEST





position of the noisy strip

position of resistive contacts



Zoom on a part of the CLAS12 Barrel with thermal cam, with HV on and current of about 300 µA

- Solutions :
  - No resistive interconnection (ladders)
  - Aluminum frame at the gas inlet
  - More ground connections
    - "C" Barrel detectors had no problem !
  - Fixing is possible by filing the area with a drop of polymer

Fixing Procedure :

A lot of HV Test -> Soft Cleaning (aspiration, antistatic roller)

imaging the problem -> HV + current (10-500µA) and IR imaging

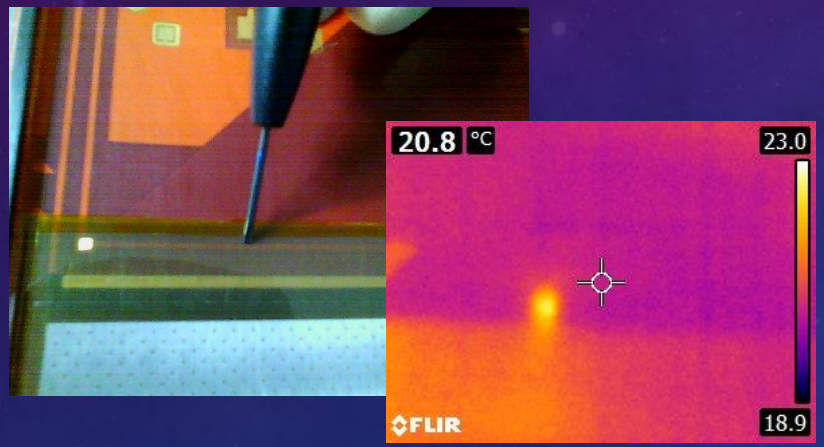
Cleaning -> water cleaning (karcher) -> drying (air+oven)

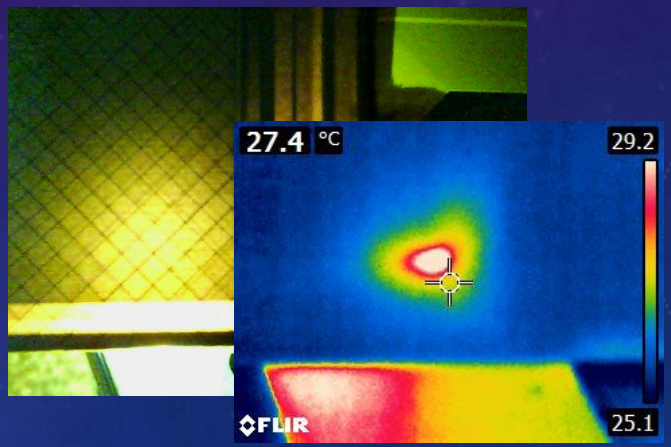
-> Sodium Chlorate 60ºC -> Trash

Or if possible -> passivation with a drop of glue

NEW CONNECTION SCHEME, NEW PROBLEMS SILVER PASTE ISSUE

- The CR4Z layer has been the first produced using this method
  - **=> All 4 of them died after ~2 weeks of tests**

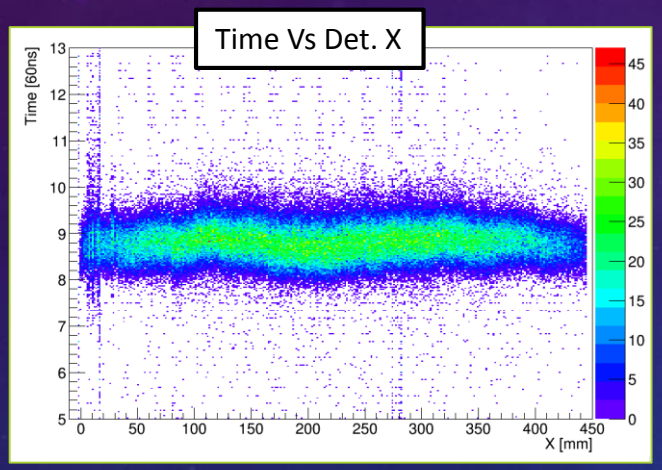


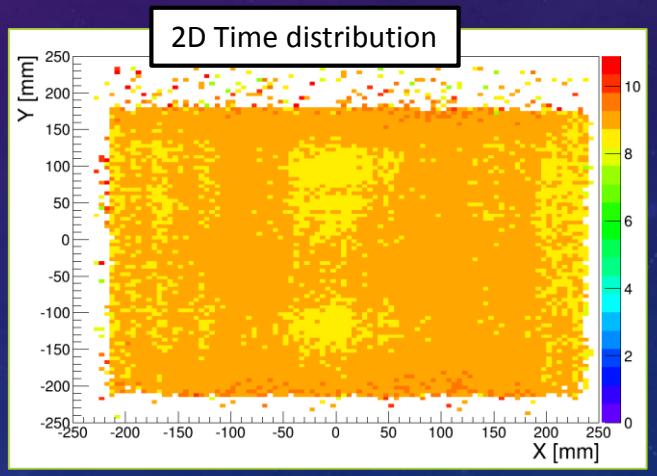


=> Thermal imaging shows that high current appeared on the silver paste connection between the resistive layer and the PCB

TIME RESOLUTION

- Time Resolution with resistive detectors is ~25ns instead of ~15ns (depending on the conditions)
- Time resolution not critical for the CLAS12 barrel
- Inhomogeneities over the detector surface observed

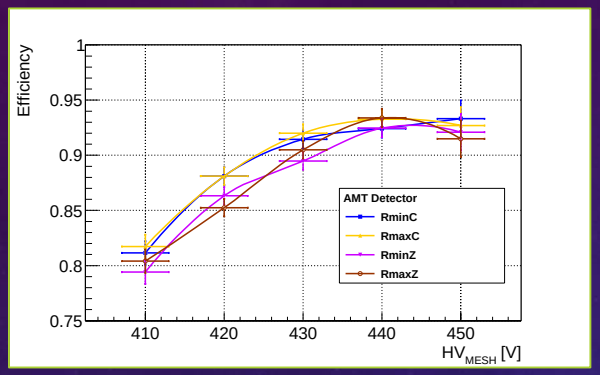


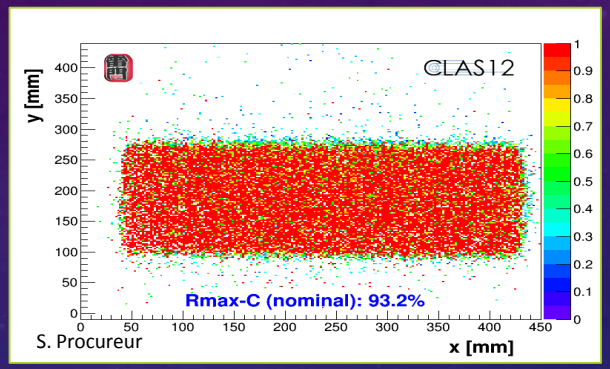


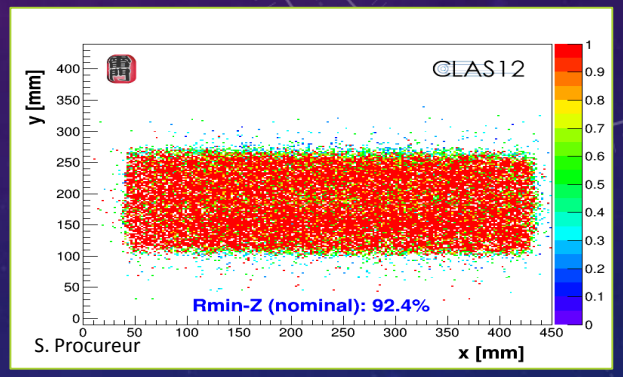
- Solutions :
  - Electronic parameters optimization (~3ns) - done
  - 1D (2D?) corrections (~5ns) but difficult with cosmic rays

THE ASACUSA MICROMEGAS TRACKER

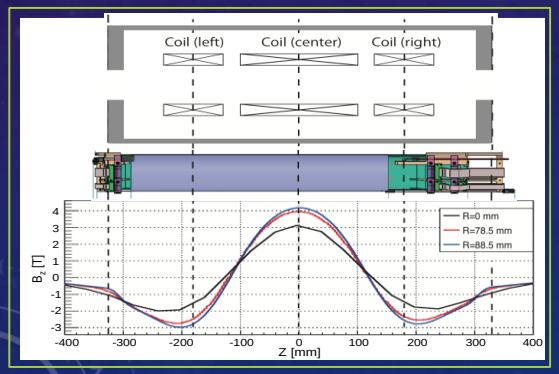
- Characterization at Saclay :



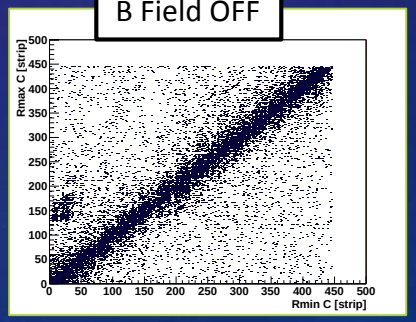




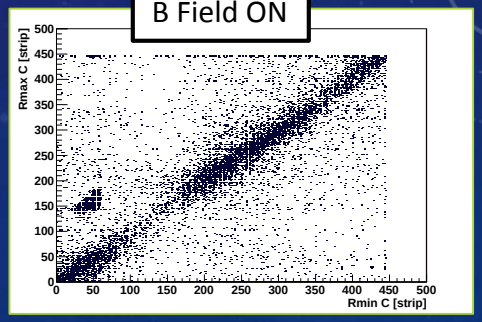
- 2 x 6 Months of smooth data taking !
- Effect of the magnetic field (80º Lorentz angle at low drift field)



B Field OFF

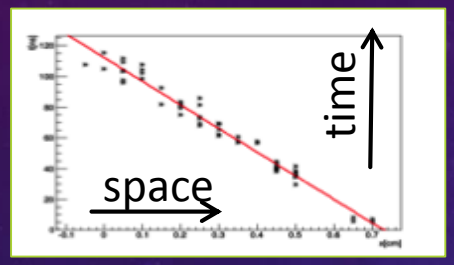


B Field ON

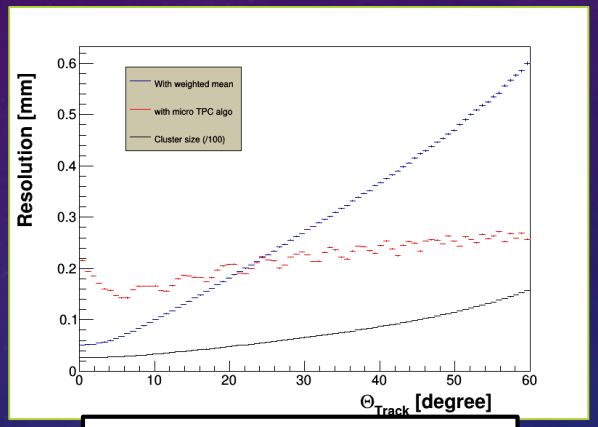


AMT – MICROTPC ALGORITHM

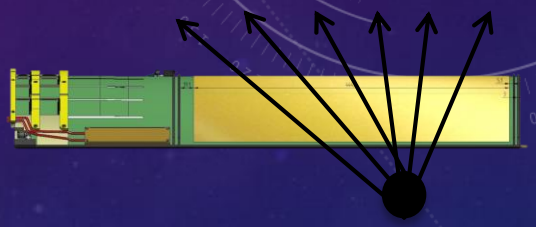
- The MicroTPC algorithm uses the time information on multi-strip clusters to extrapolate the track angle :



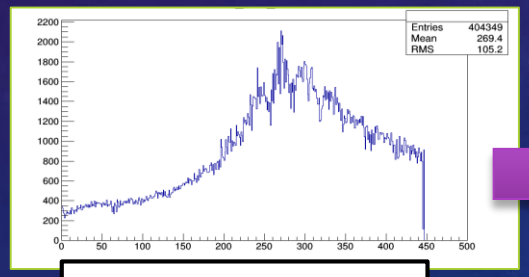
Fitted signal in the drift space



Resolution Vs Track Angle

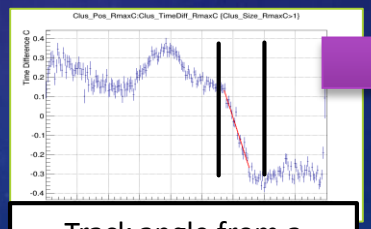


- MicroTPC algo on anti-p data :



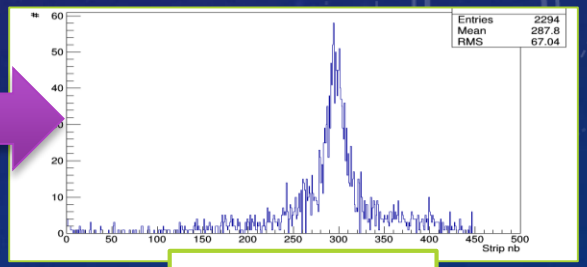
Antiproton distribution (calibration data)

µTPC



Track angle from a single layer barrel

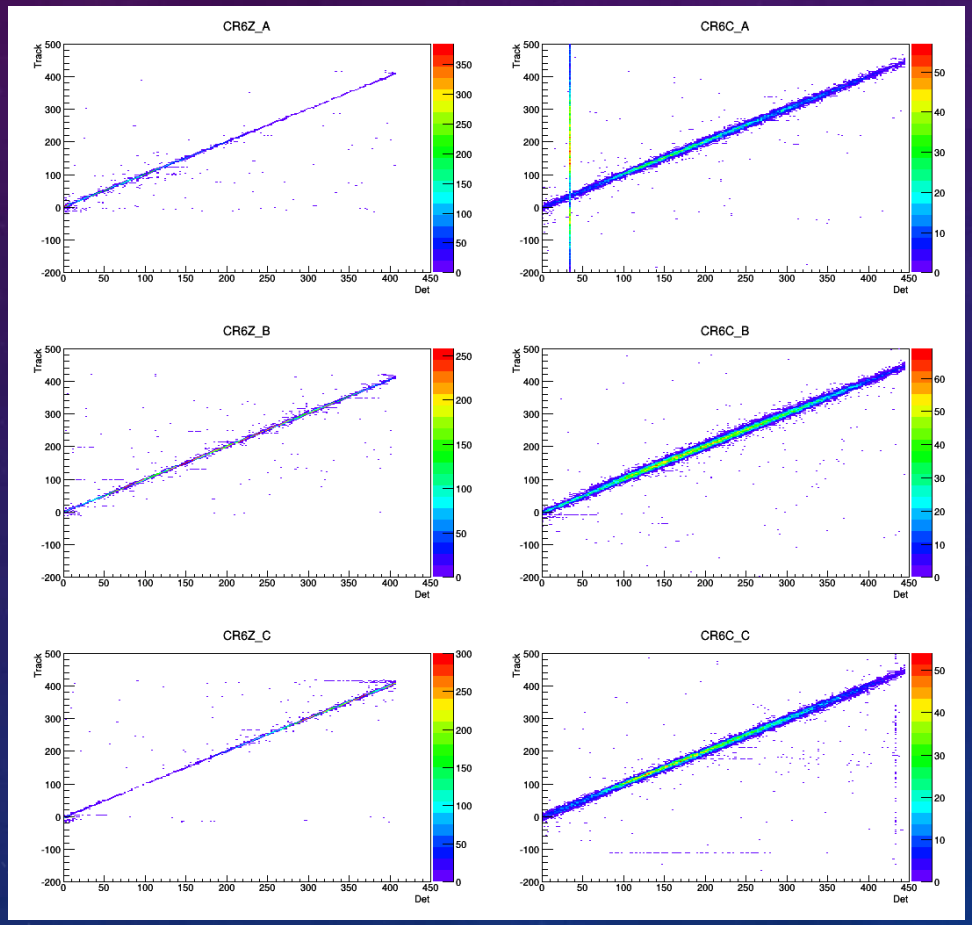
Cut



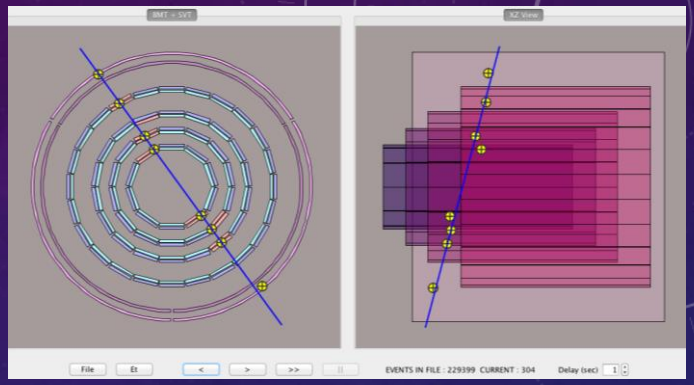
Filtered distribution

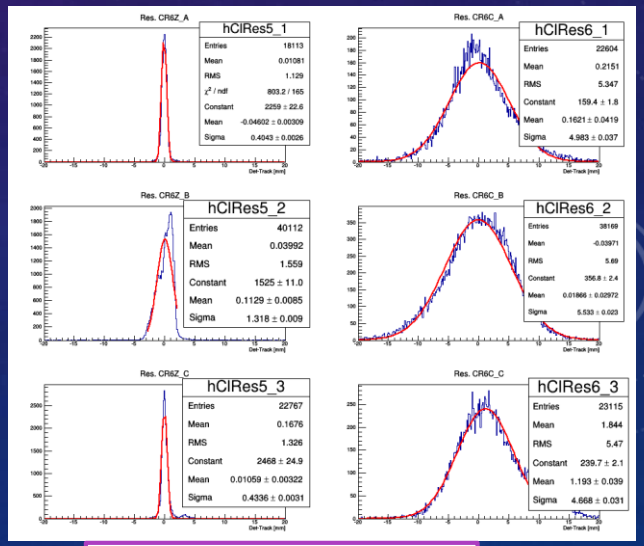
CORRELATION BETWEEN SVT AND MVT

- DAQ including both SVT and MVT data is working
- Mapping and Geometry understood
- Track reconstruction with cosmic rays is working



Correlation bet. SVT tracks and BMT in Micromegas coordinates





Residuals* :

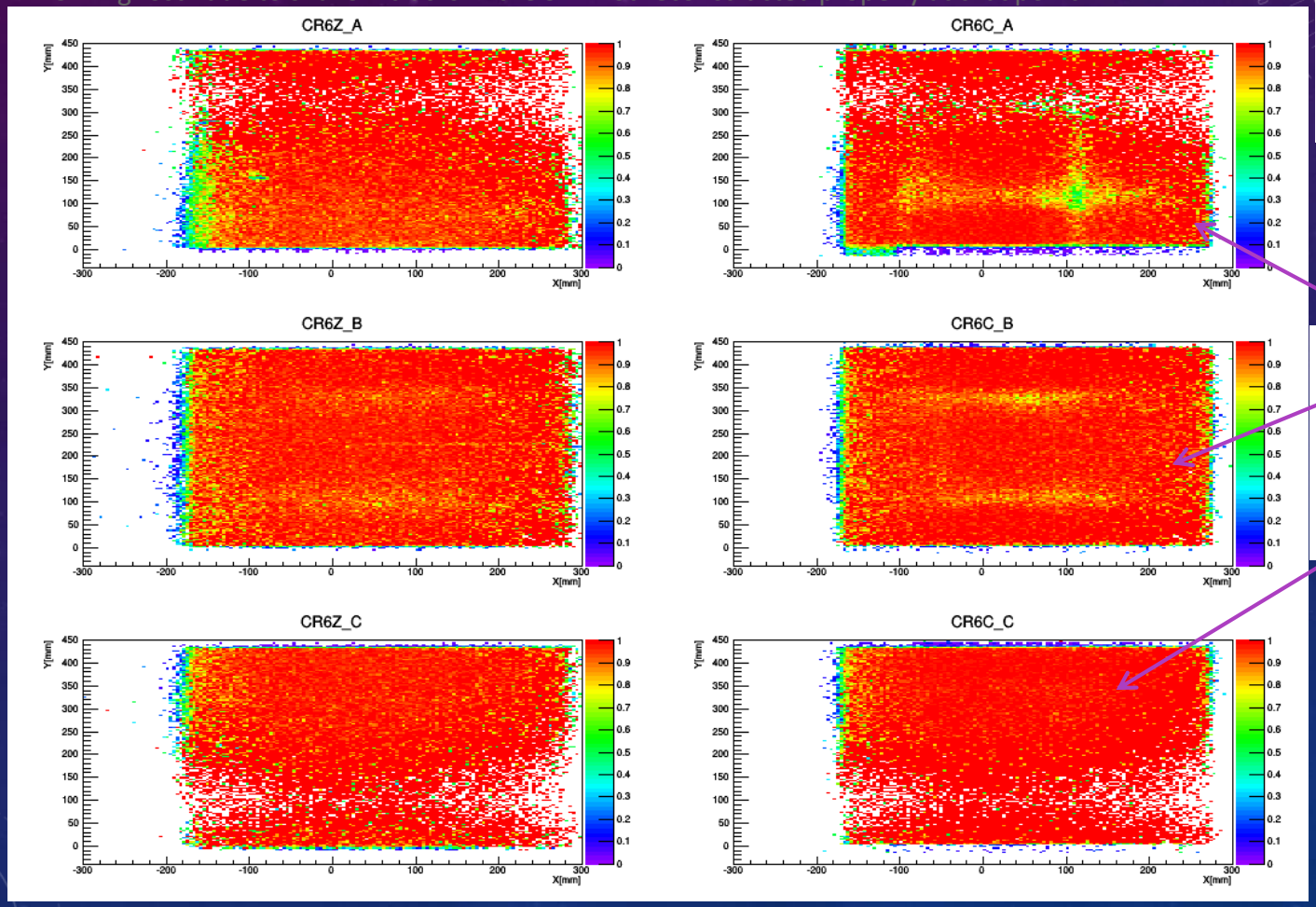
~ 400 µm for Z det.

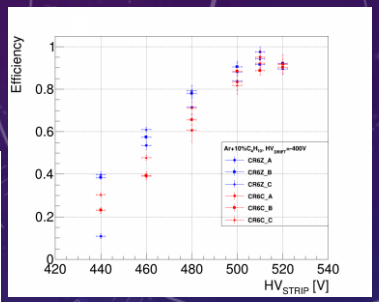
~ 5 mm for "C" det.

* MC simulations show that 400µm residuals correspond to a 350µm resolution

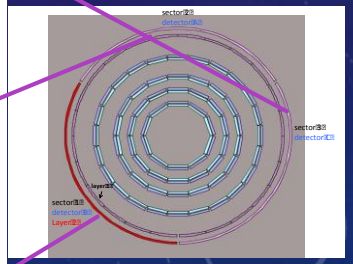
2D EFFICIENCY MAPS

- Detectors' efficiency with cosmic rays tracks from the SVT
- No major defect in BMT detectors
- SVT "ghost" due to shallow tracks in the SVT not reconstructed properly at that point





Eff. Vs HV (gain)



DREAM FRONT-END ELECTRONICS