Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

DE LA RECHERCHE À L'INDUSTRIE

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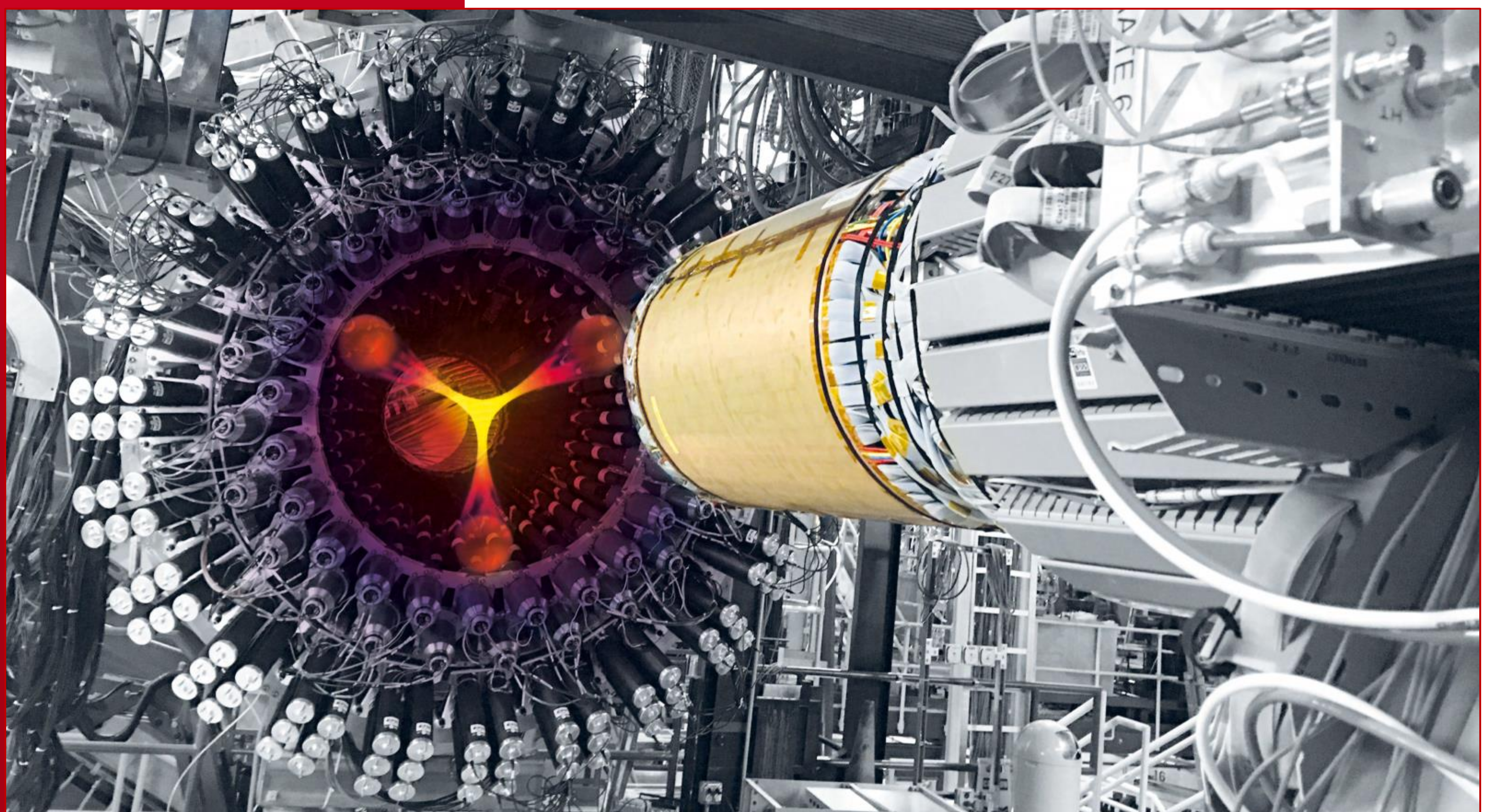
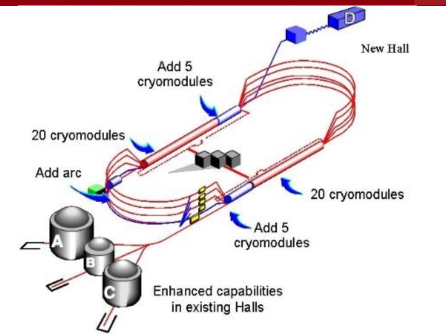
RD51 Collaboration Meeting, Munich, June 2018

Micromegas Vertex Tracker For CLAS12



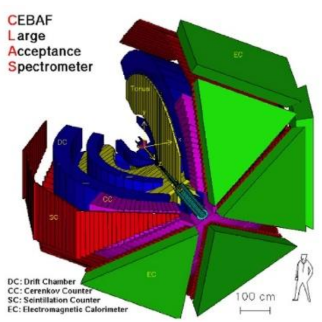
3D Nucleon imaging with CLAS12

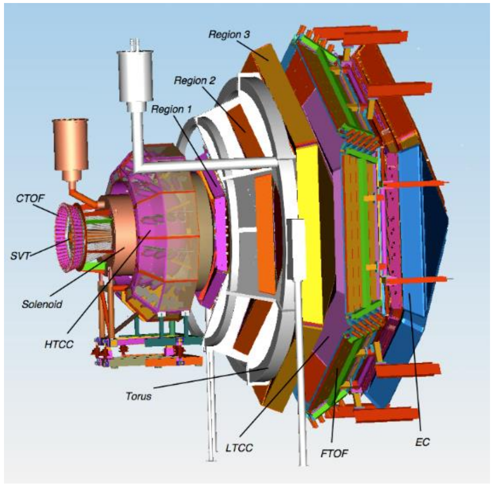
- Electron beam energy **from 6 to 12 GeV** at Jefferson Lab.



- Upgrade of the experimental Halls.
  In Hall B, from CLAS to **CLAS12, almost complete new spectrometer.**

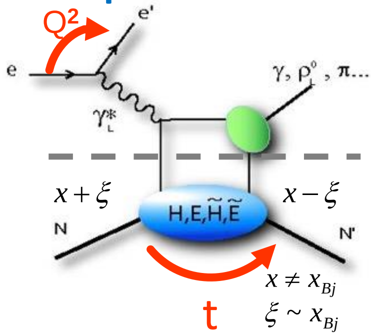
- Study of generalized parton distributions (**GPDs**) encoding correlations between **transverse position and longitudinal momentum of partons.**

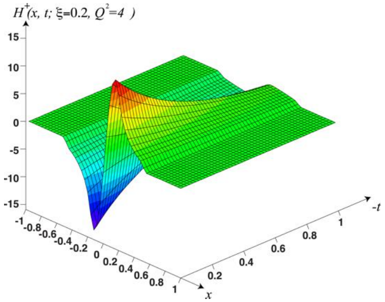


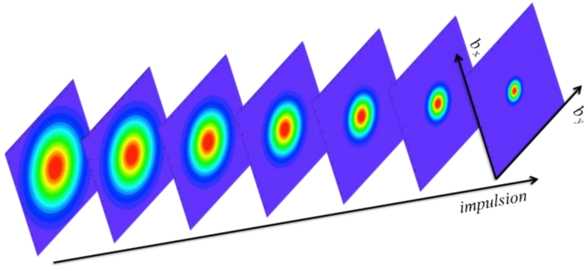


- JLab group of **Saclay is GPD-program leader** with CLAS12.

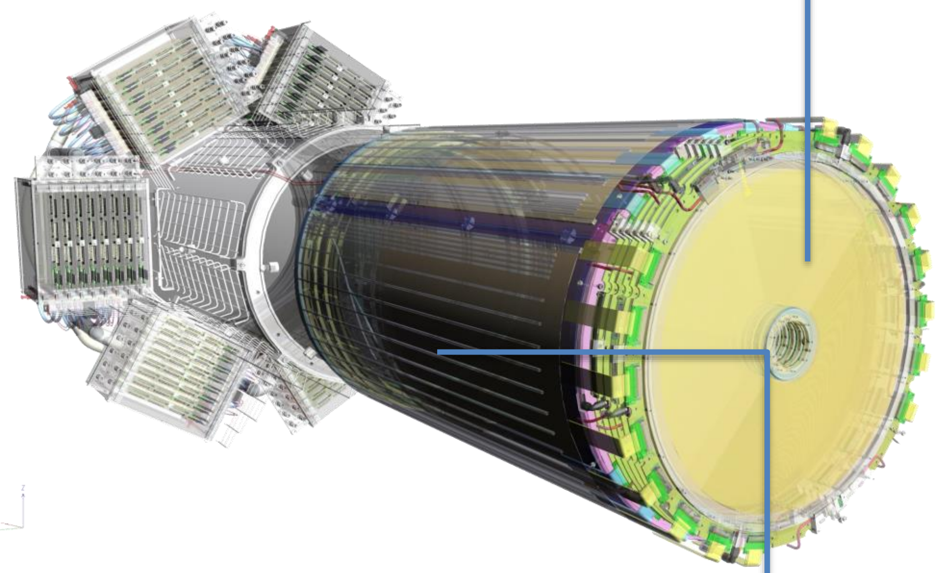
- Recoil proton from photon electroproduction event is mostly sent in central tracker.
  All experiments will use the central tracker.

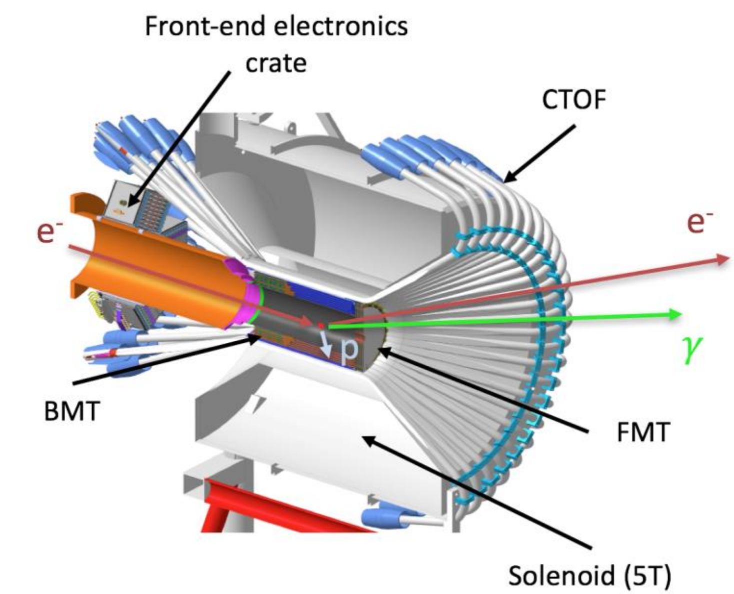






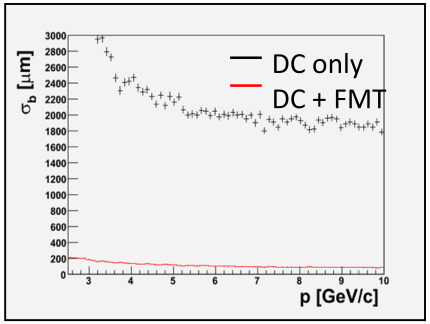
The Micromegas Vertex tracker

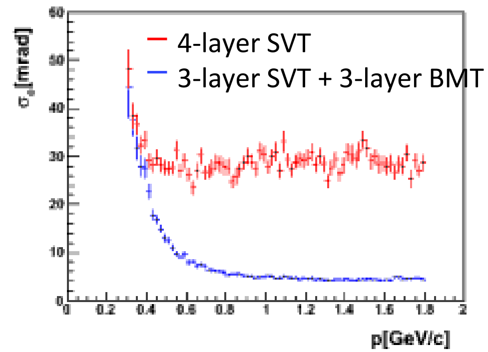




Forward Detectors

- 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

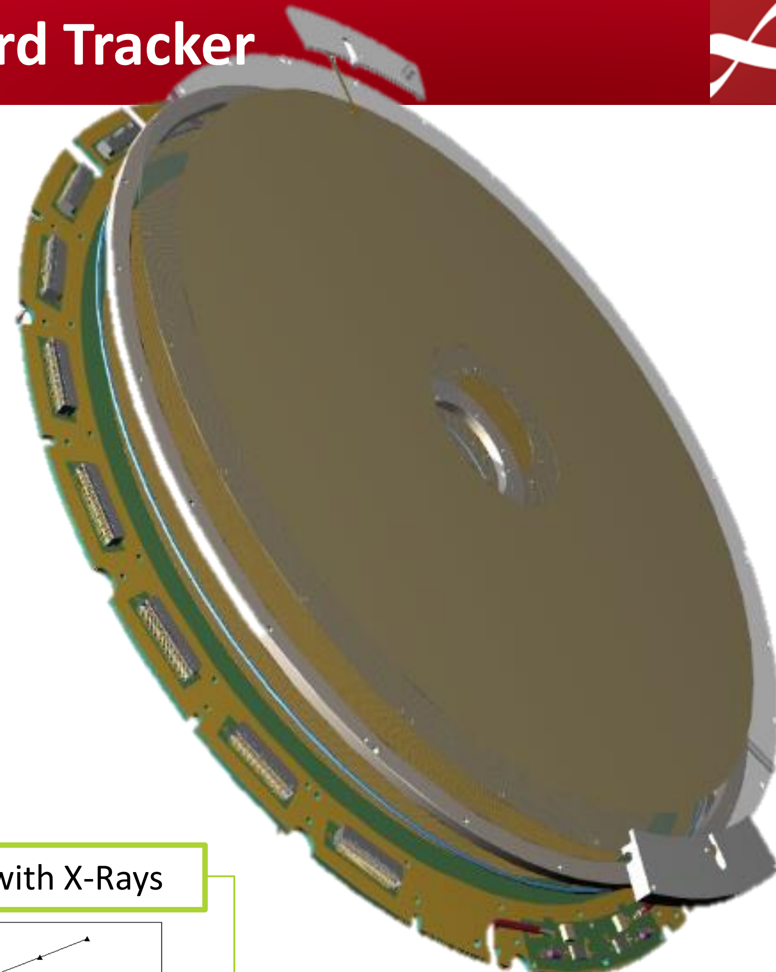




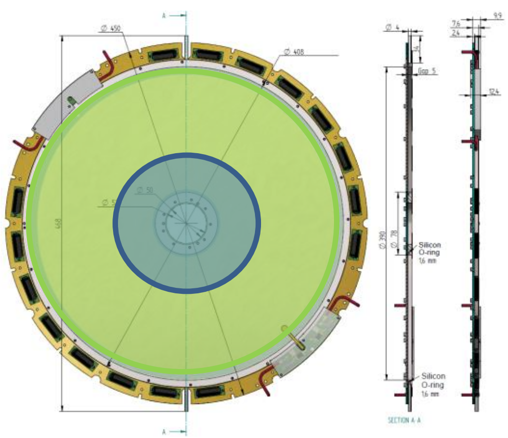
Cylindrical Barrel

- Low momentum particles => Light Detectors
- Limited space of ~10 cm for 6 layers
- High magnetic field (5T)
- Phase 1 (2016) : 2 Layers (6 Det. of 120°)
- Phase 2 (2017) : 6 Layers (18 Det.)

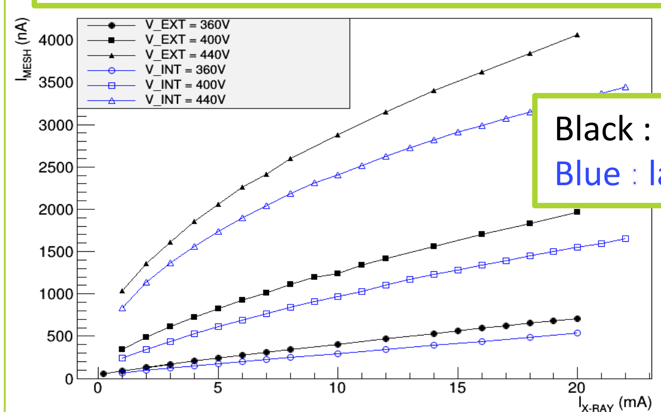
CLAS12 MM Forward Tracker



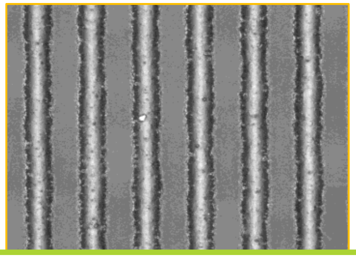
- 6 layers of Micromegas with 1D strips alternatively rotated at 0°, 60°, 120°
- 86 mm to 380 mm diameter active area
- Bulk MM + Resistive Layer
- Same detector design for the 6 detectors :
  - Dimensions: 430 mm diameter disk with a 50 mm diameter hole at the center; 5mm drift gap
  - 100 µm PCB glued 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

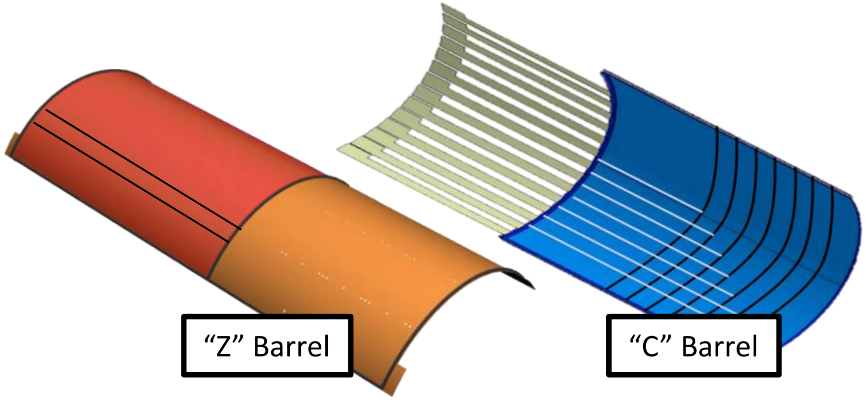


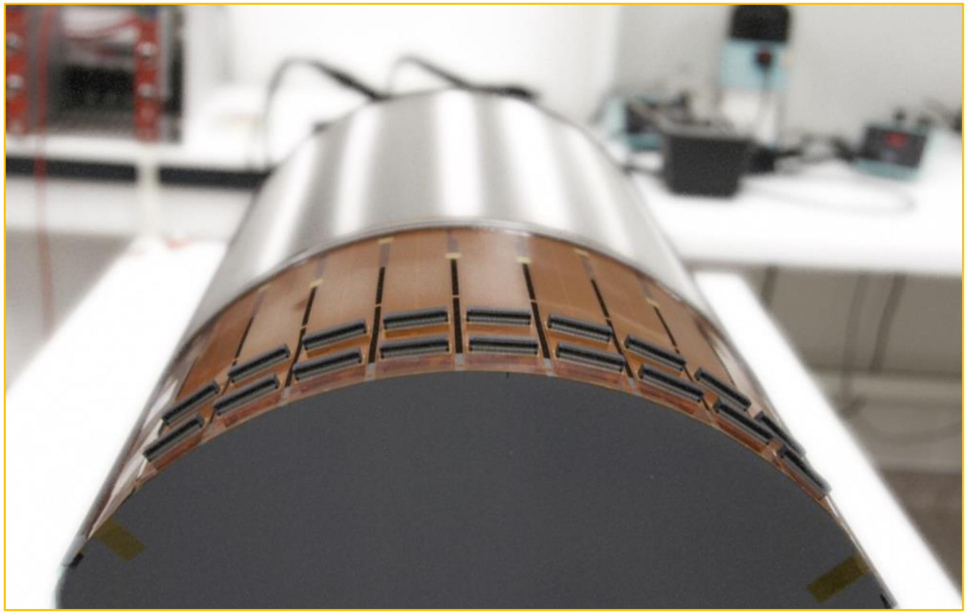
Black : no ladders
Blue : ladders



Resistive Strips w/o interconnections (ladders)

CLAS12 MM Barrel Detectors



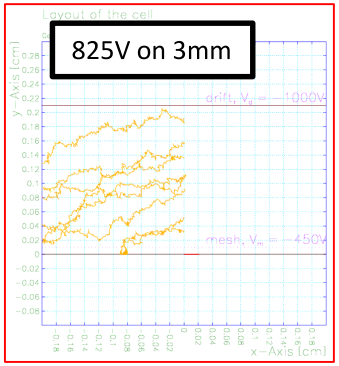


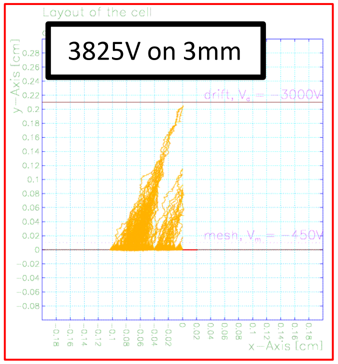
- Total of 6 layers segmented in phi (3 x 120° sectors)
- 6 Different detector's radii
- 2 different types (C and Z types)
- Material (PCB/Bulk + Drift) from the CERN Workshop
- Assembly to cylindrical shape at Saclay
- Test and Characterization at Saclay before shipping to J-Lab
- 8-9 days to assemble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

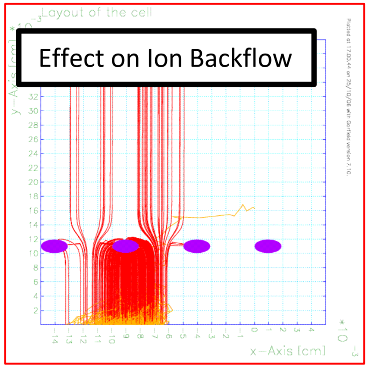
Layer	Production	ch.	Radius	Length	Width
CR4-C	3 + 1spare	896	146mm	712mm	302mm
CR4-Z	3 + 1spare	640	161mm	712mm	333mm
CR5-Z	3 + 1spare	640	176mm	712mm	364mm
CR5-C	3 + 1spare	1024	191mm	712mm	396mm
CR6-Z	3 + 1spare	768	206mm	712mm	427mm
CR6-C	3 + 1spare	1152	221mm	712mm	459mm
CR6-C new	3 spare	1152	221mm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

Operation in CLAS12 and the 5T magnetic field

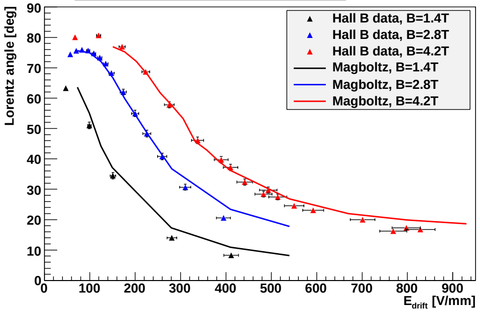
- Small volume for instrumentation (6x15mm)
- Remote off-detector frontend electronics using 2.2m long coaxial cable + DREAM FEE
- No fan for cooling
- EM Shielding challenging
- Lorentz Angle
  - Slow gas to reduce drift velocity
  - Small drift gap
  - High electric field
    - 6kV/cm for C
    - 5kV/cm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



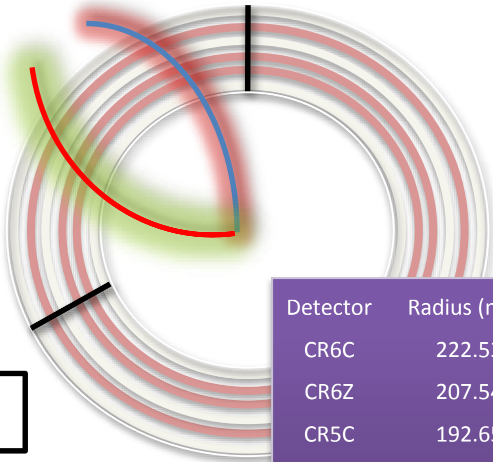




Lorentz Angle Vs HV



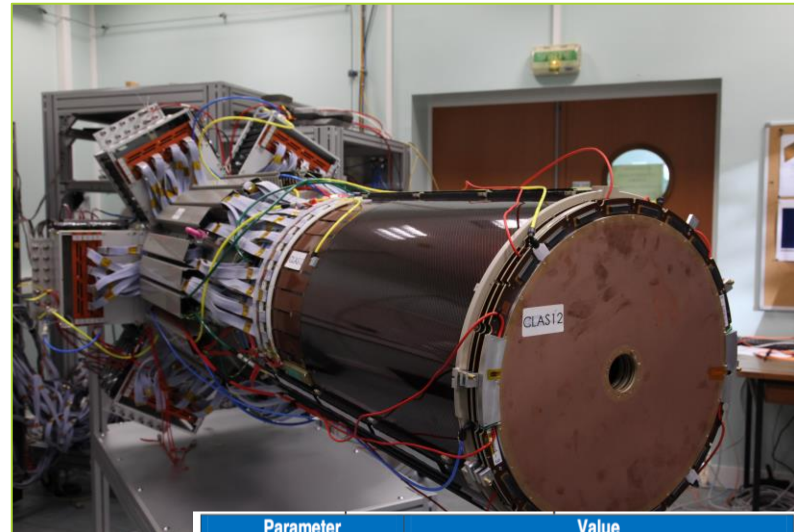
=> Clas-note 2007-004: Simulations of Micromegas detectors for the CLAS12 experiment (S. Procureur)



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

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

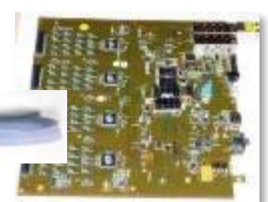


Parameter	Value
Polarity of detector signal	Negative or Positive
Number of channels	64
External Preamplifier option	Yes; access to the filter or SCA inputs
Charge measurement	
Input dynamic range/gain	50 fC; 100 fC; 200 fC; 600 fC, selectable per channel
Output dynamic range	2V p-p
I.N.L	< 2%
Charge 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.

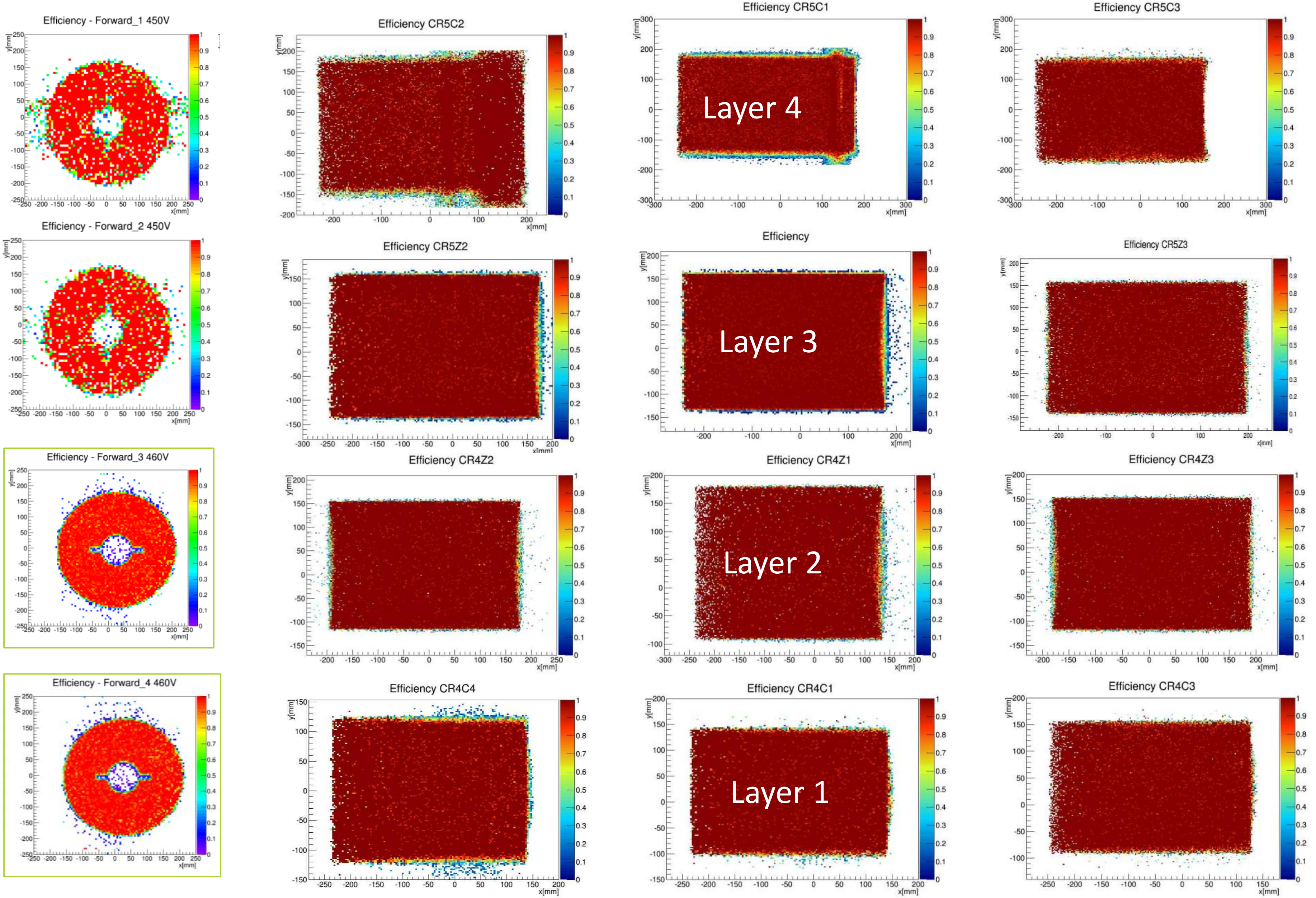
~1K ch. Detector

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



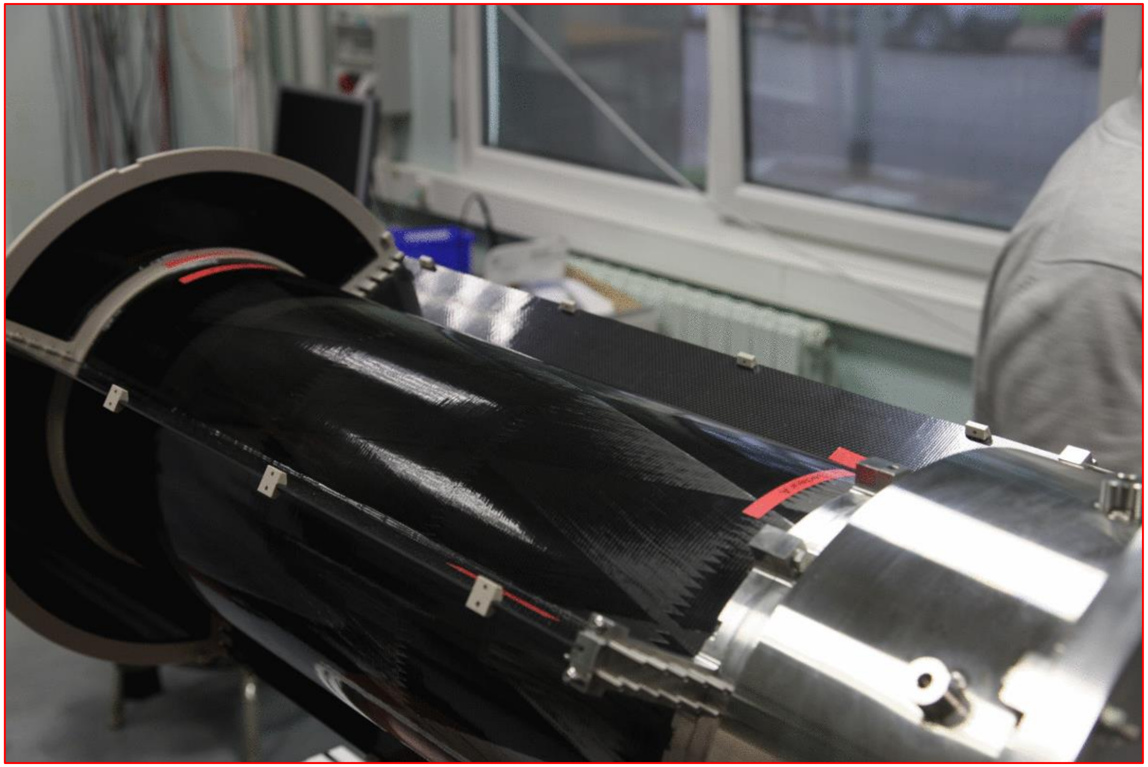
2 x 512 ch. Front-End Unit

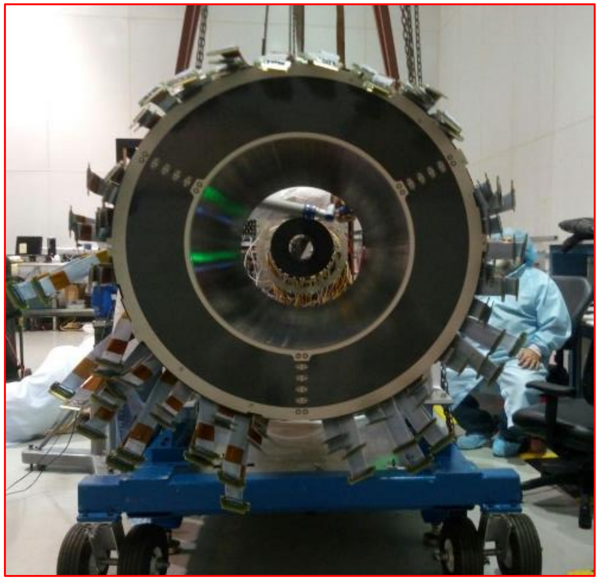
Cosmic Ray characterization at Saclay



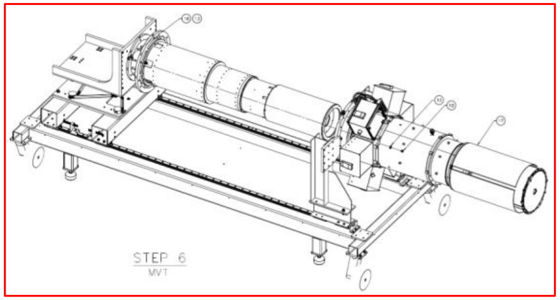
Assembly of the MVT and delivery at Jefferson Lab

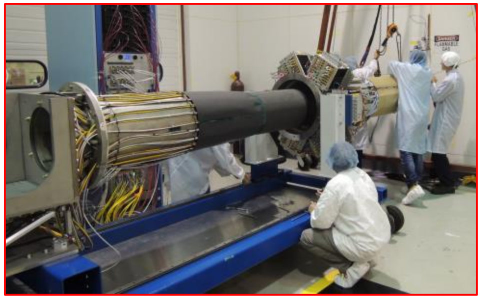
- The MVT was delivered **at Jefferson Lab in June 2017**.
- A team of 10 people from Saclay assembled the MVT in two weeks.





MVT integrated with the silicon tracker

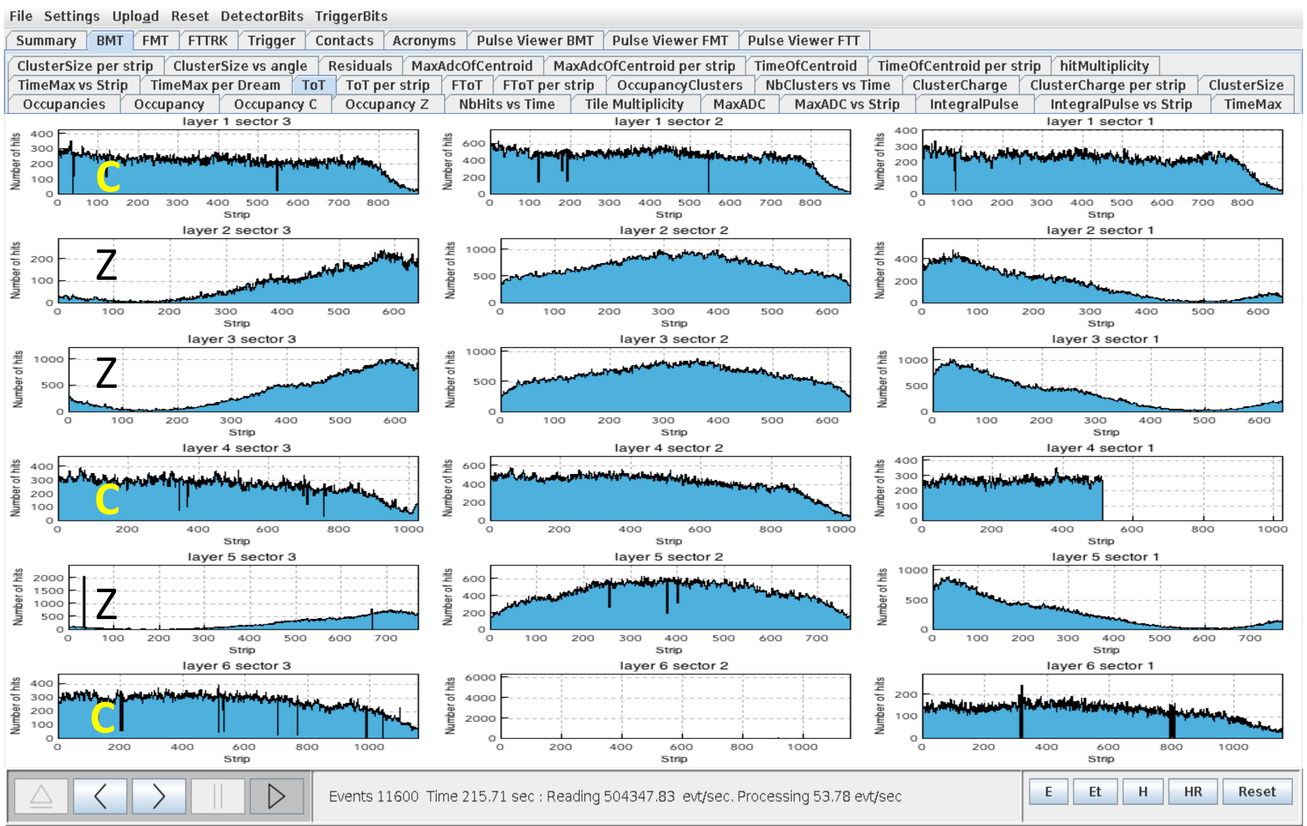


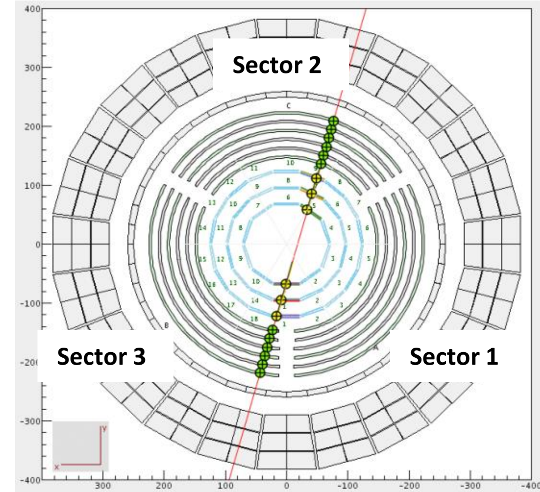


MVT assembled at JLab by CEA Saclay

Commissioning with cosmic rays in clean room

- The commissioning with cosmic rays in clean room focused on:
  - **Development of slow controls** for HV, LV, gas distribution system, interlock system.
  - **Implementation of a monitoring suite** to study the detectors responses.
  - **Tests of the detectors**, including noise and efficiency studies.
  - Collecting **cosmic data for alignment** purposes.

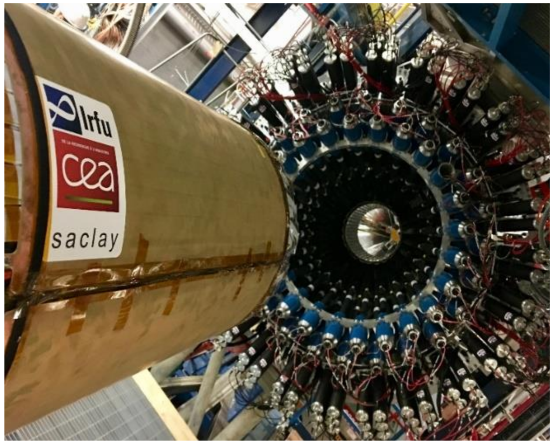


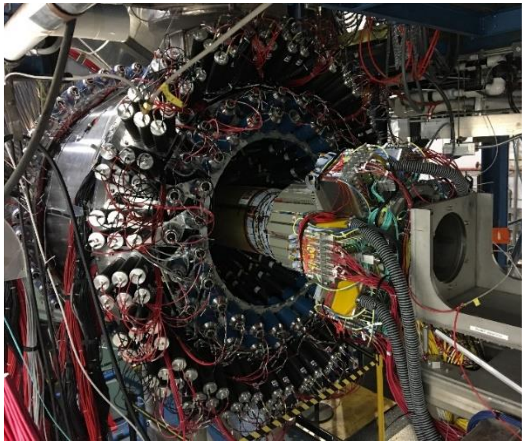


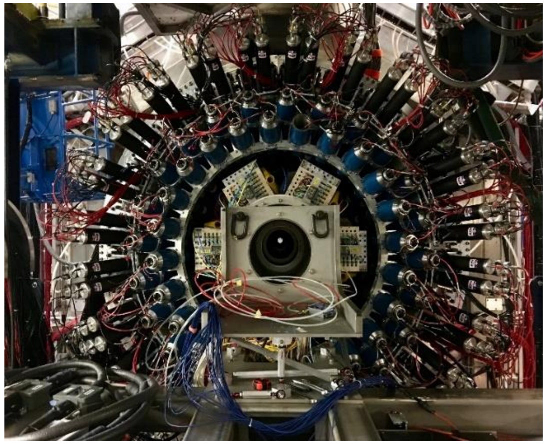
- All the tabs on this screenshots display a set of histograms for all tiles and disks.
- In the clean room, the trigger was provided by the SVT. The occupancy in the barrel is the result of the **convolution between the trigger acceptance and the cosmic ray distribution**.
  => No acceptance for FMT.

Installation in the Hall

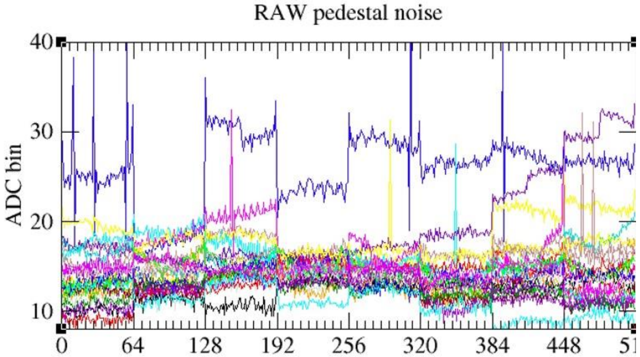
- First insertion of CVT inside CTOF slowly performed:
  Only a 5-mm clearance with CTOF on drawings => **2-mm clearance in reality**.

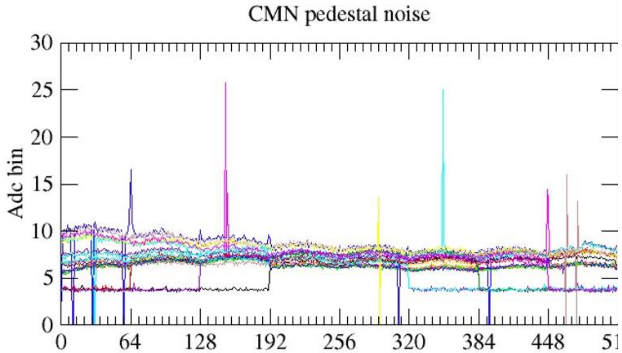






- Then **noise levels were checked** in different conditions:
  -Inside/Outside the solenoid.
  -At 0 et 5T.
  - With surrounding detectors On and Off.
  After Common noise subtraction, noises are as low as in gray room (much quieter environment).





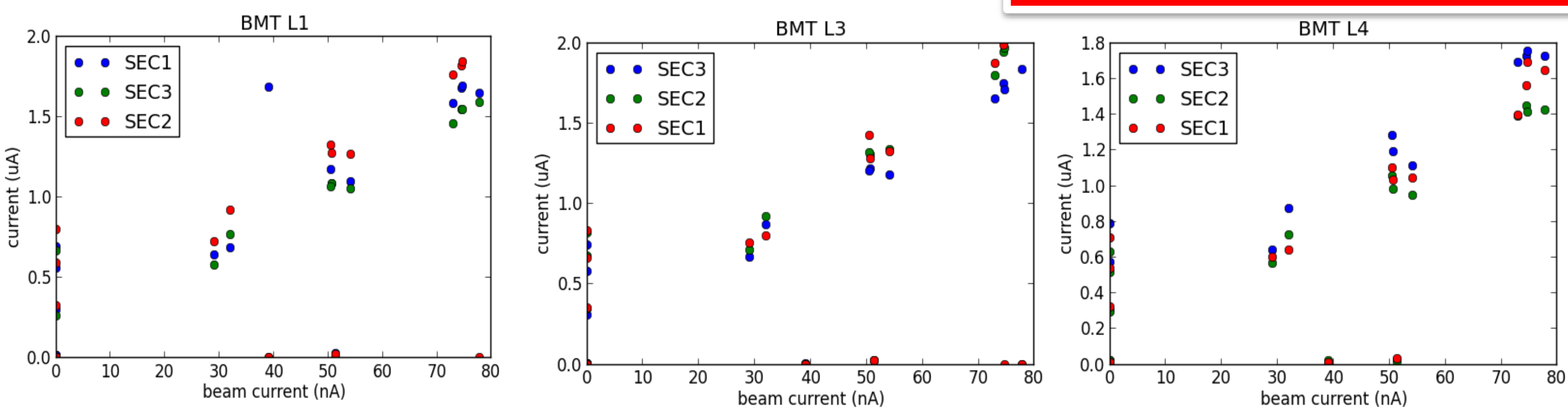
- First beam at **10.6 GeV** with intensity of **5nA**, **empty target** and **5T** solenoid. Before turning ON the HV on Micromegas, Beam must be stable and well centered.

- -**Drifts at nominal**: 1500V (5kV/cm) for C- and 1800V (6kV/cm) for Z-tiles, 600V (1kV/cm) for FMT.
  -**Current limit to trip HV set at 0.5 uA** for both strips and drifts.

- HV on strip **was gradually increased**.
  We reached **520V for BMT strips**, beginning of efficiency plateau determined with cosmic-ray commissioning. **FMT strips reached 460V**.

- Afterwards, the target was filled and a luminosity scan was performed.
  The currents on strips scale with the beam current. Threshold for tripping HV were increased accordingly to work at 4.5uA.

=> Barrel detector operates at ~2µA



- Once the latency and nominal HV settings are found, the **occupancies as a function of the luminosity** were studied. They are **found higher than expected** rate (a factor 3 for BMT).

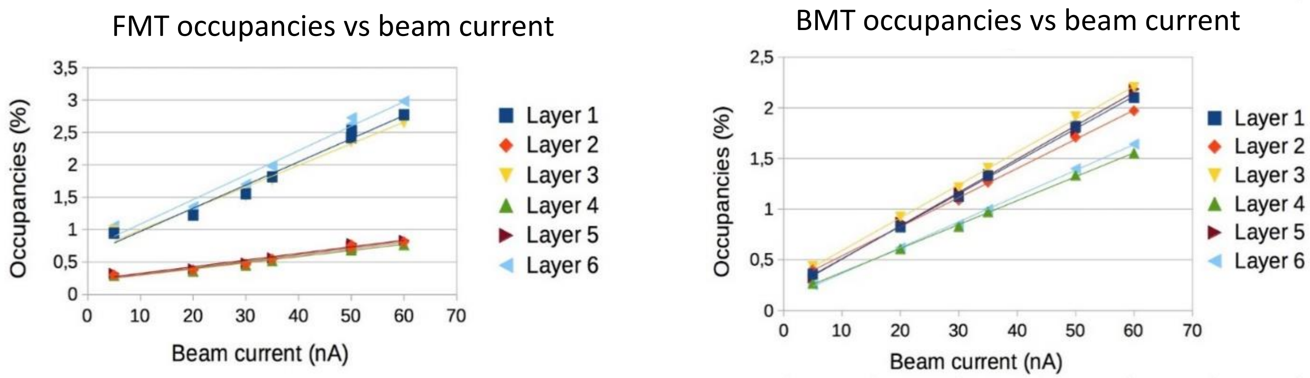


Figure 16: Occupancies of FMT (left) and BMT (right) as a function of the beam current. Half of the FMT disks has a lower occupancy since only their inner region is active.

- Data were taken at **2.2 GeV and 6.4 GeV for calibration and alignment**. The recoil proton is clearly visible at 2.2 GeV in the occupancies of C-tiles.

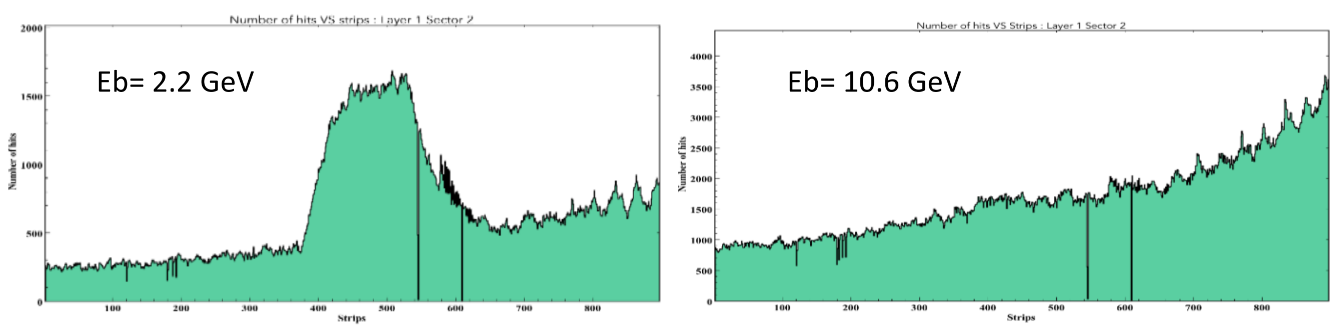
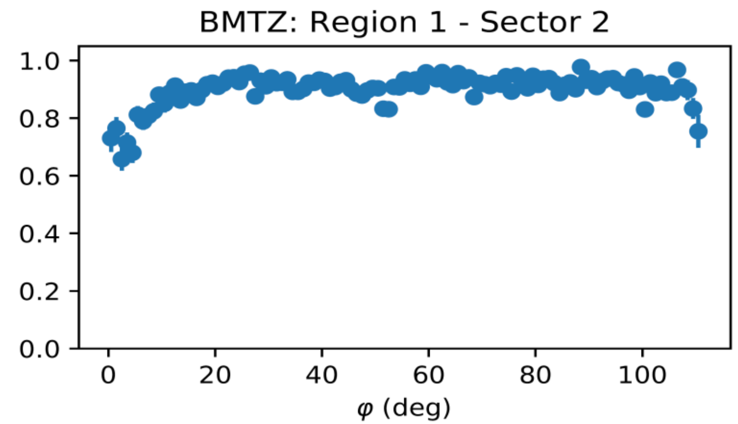


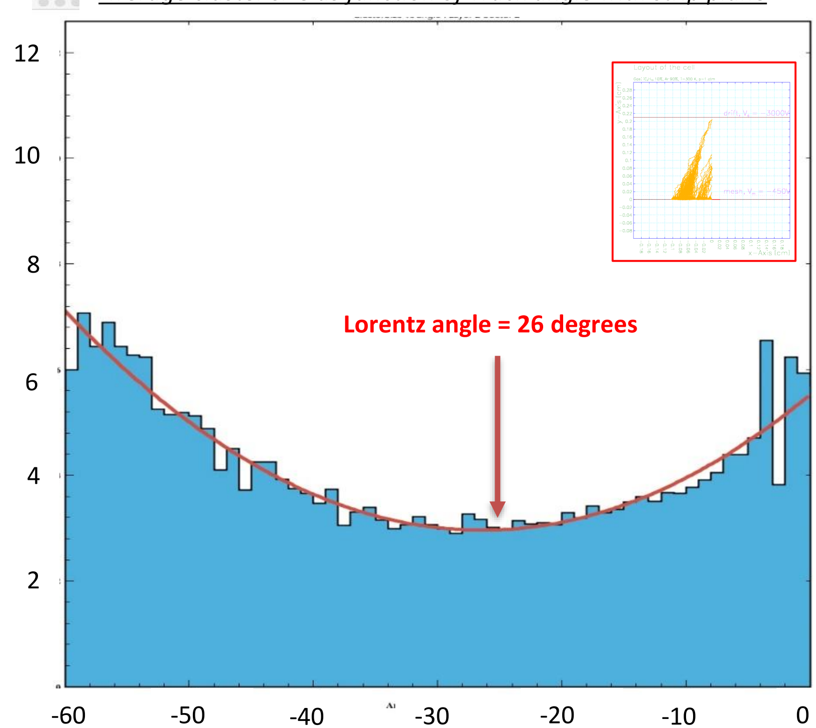
Figure 17: Hit occupancies for C-tiles at 2.2 GeV (left) and 10.6 (right). The elastic recoil protons are responsible for the large excess of events at 2.2 GeV, between strip number 400 and 500. The cross sections is too small at 10.6 GeV to see the protons.

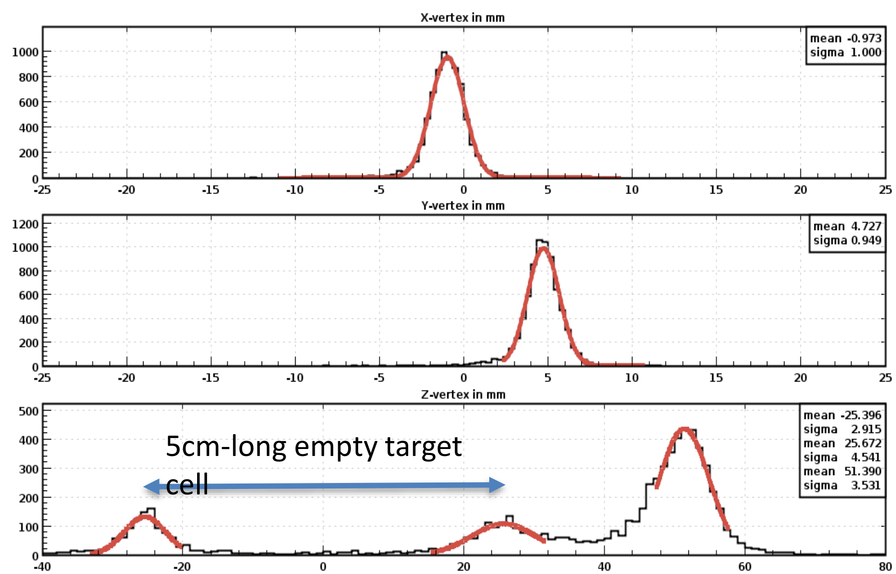
Caracterization/Commissioning

- Current **tracking efficiency is estimated at 70%** (a tungsten foil was added around the target to shield SVT).
- **First efficiency studies** have started… Although a lot of validation still needs to be done concerning the tracking.
- **Measurement of Lorentz Angle** using negatively charged particle: It is in agreement with the computed value currently used in the reconstruction.
- **First resolution studies** using data at **low beam current**, with **no magnetic field** and **empty target**
  - **150 µm resolution** in the barrel before fine alignment



Average cluster size as function of Track angle with strip plane



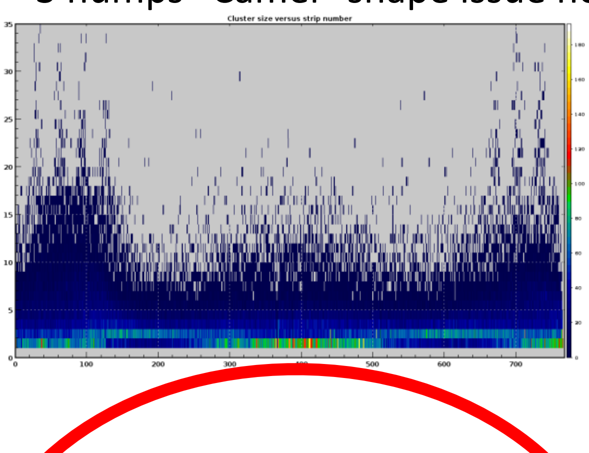


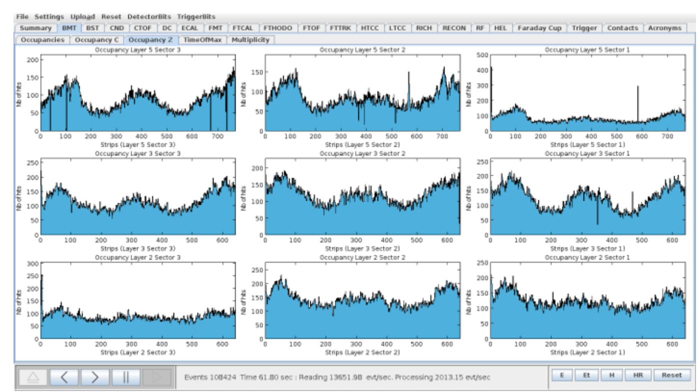
Barrel Detectors status / stability

	Sector 1	Sector 2	Sector 3
Layer 1 (C)			
Layer 2 (Z)			
Layer 3 (Z)			
Layer 4 (C)	Drift (1300V)		
Layer 5 (Z)	Drift + Strips	Drift (1000V)	Drift
Layer 6 (C)			


CR5Z1 Strips current

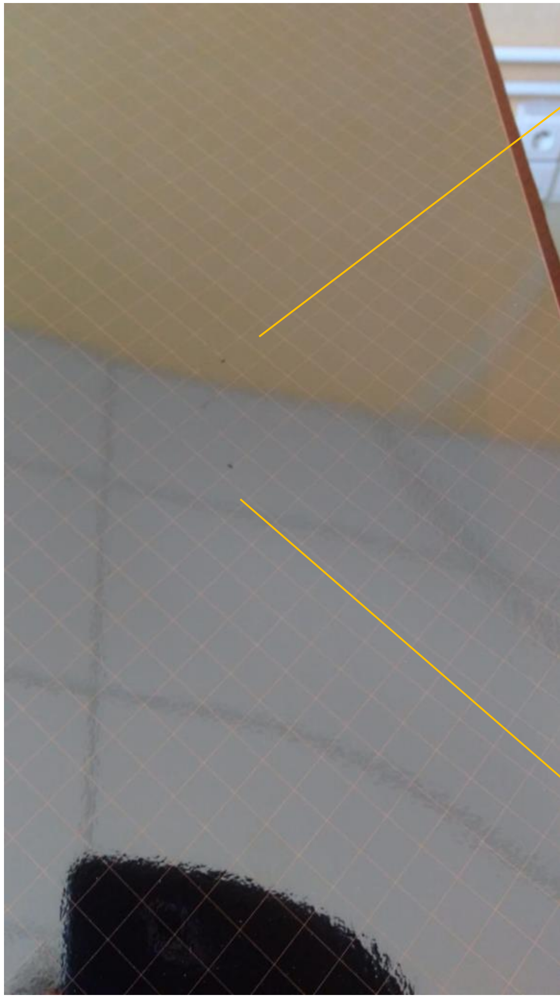
- **One detector has developed large current on the strips** during the first 6 months (consequence of intermittent gas flow ?)
- **4 have drift sparks** starting much lower than expected (~1kV instead of 2kV operational point)
- 3 humps “Camel” shape issue not understood : large and big signals excess in the

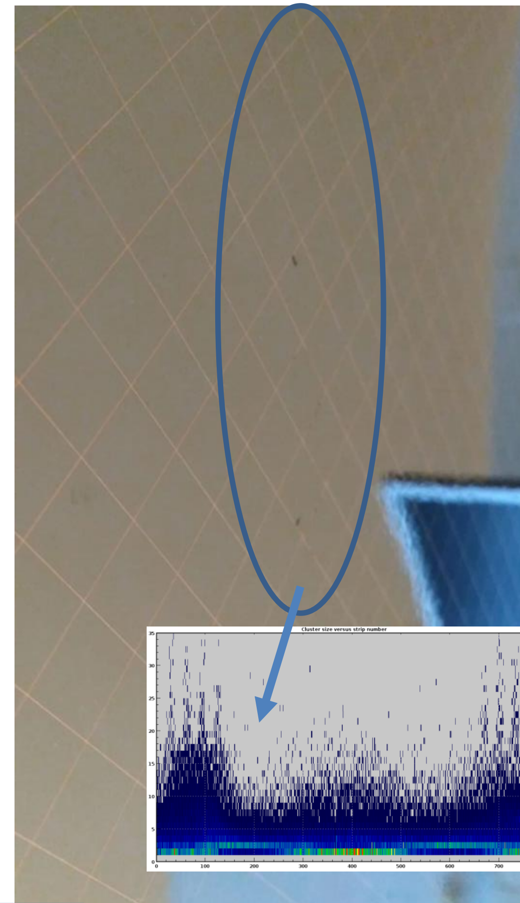



Physics or Random trigger

Barrel Detectors status / stability

- **4 have drift sparks** starting much lower than expected (~1kV instead of 2kV operational point)
- One detector has been opened :



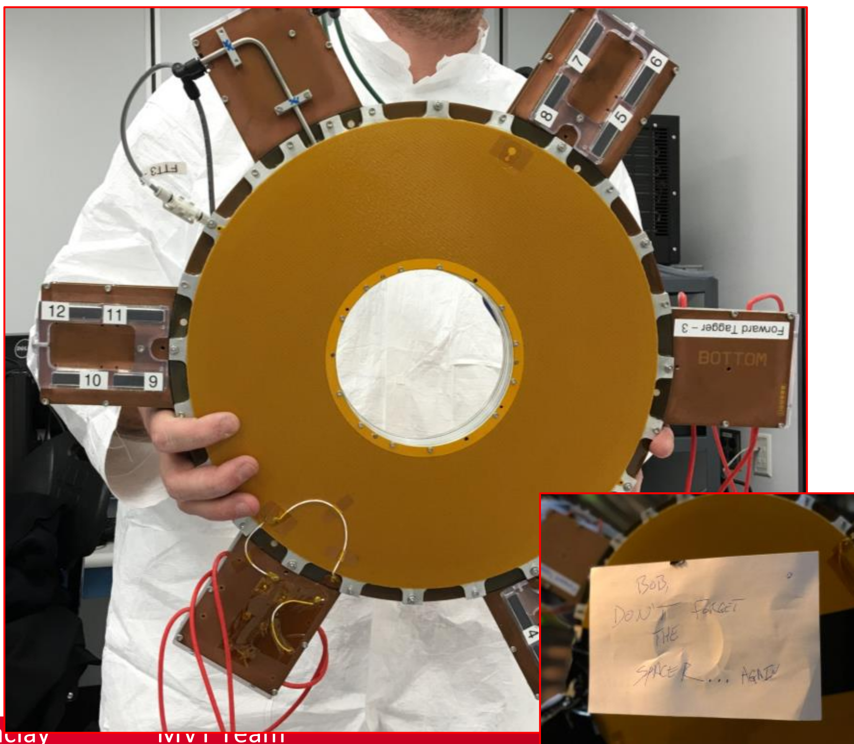


Might come from the chrome drift, might come from deformation
=> production of copper drifts

Forward Detectors status / stability

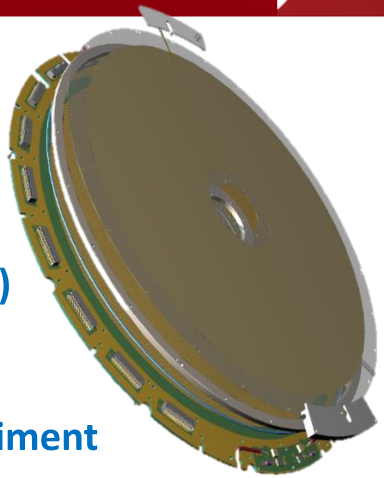
	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6
IN	I leakage					
OUT	Strip	HV loose		I leakage		I leakage

- **Disks 1, 4, 6 are being diagnosed in Saclay.** Disk 1 needs to be opened to understand why strips do not sustain HV anymore (>7uA at 50V).
- 3 disk have **a current leakage at capacitor level** due to the use of soldering flux (5um copper impose a 280 degree max for soldering) => **easy repair**



- **The Forward Tagger Tracker** is a 4 layers tracker of 1.5Kch with a design close to the fw det (better structure, no copper reduction)
- **One chamber had to be replaced** after an incident during CLAS12 assembly
- **No stability issue during the full run**

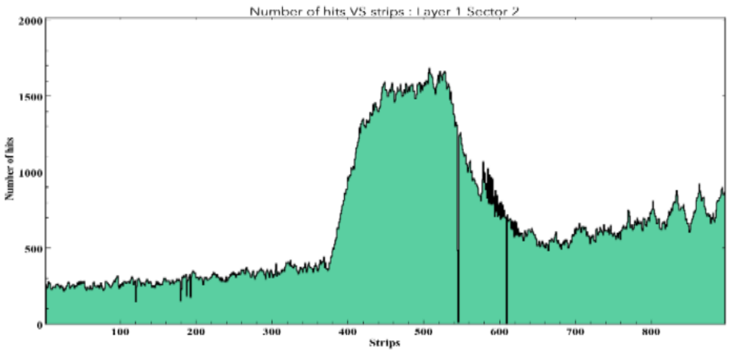
Status

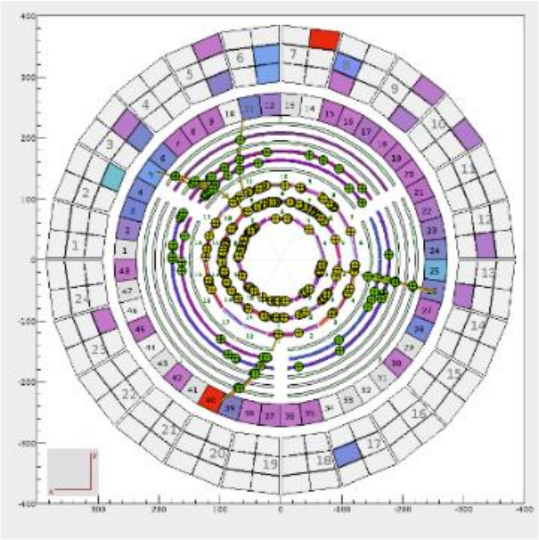


- 6 Disks have been built and installed on the CLAS12 experiment
- 3 had current leakage and being repaired
- 1 with serious current at the strips level (will be replaced by a spare or clean)

- 18 cylindrical Micromegas have been built and installed on the CLAS12 experiment
- 4 shows limitation on drift electrodes, chrome drift are under investigations
- 1 with serious current at the strips level is under reparation (will be replace by a spare or clean)

- Besides the faulty chambers, the MVT operates as expected in the though conditions of the clas12 experiment.

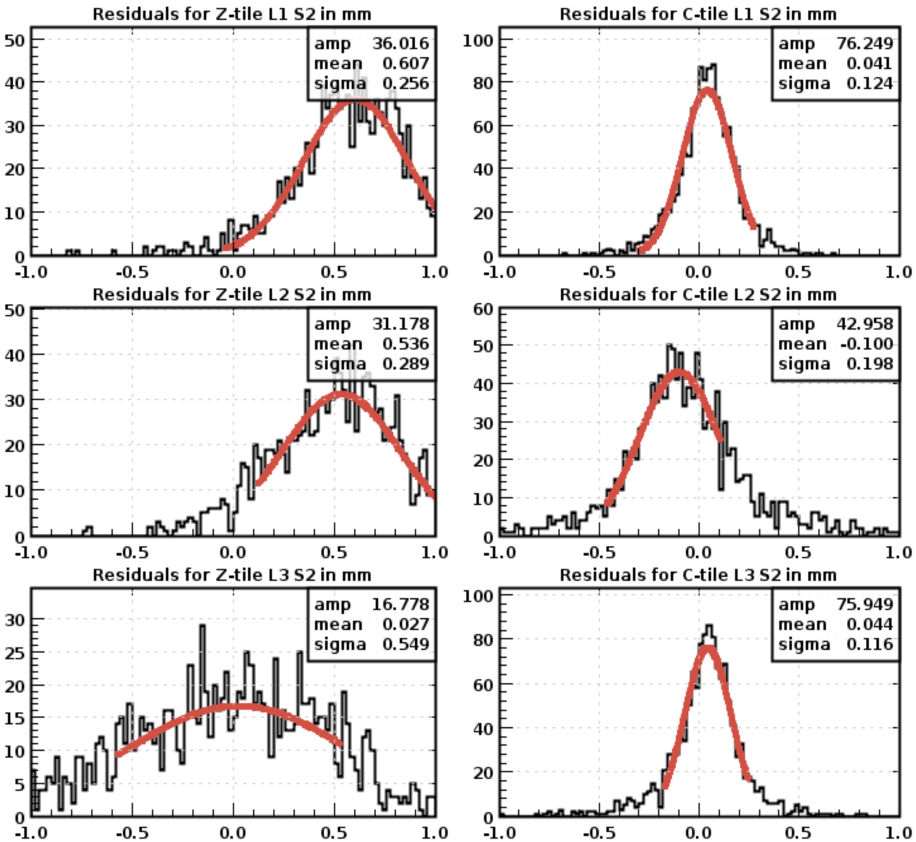


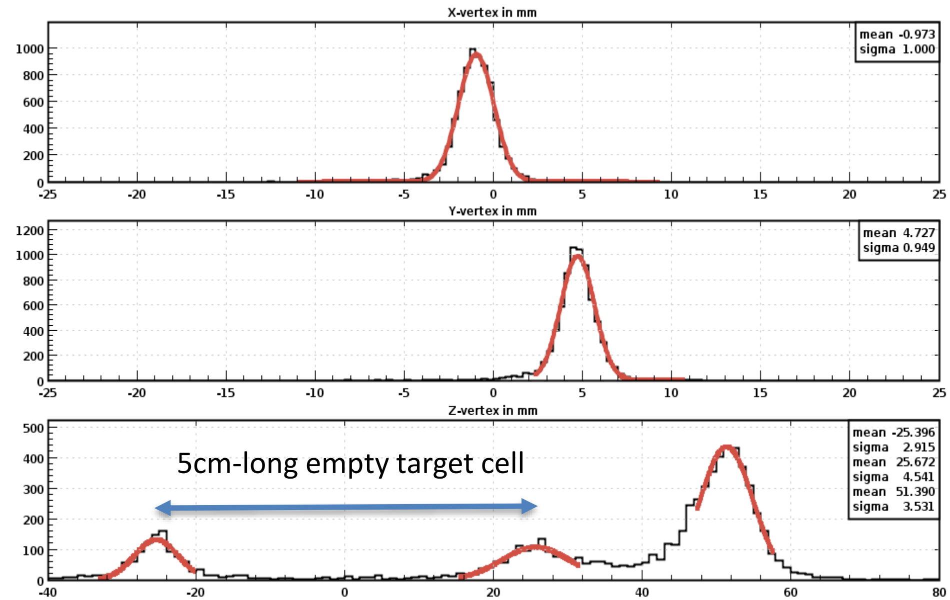


Thank you!

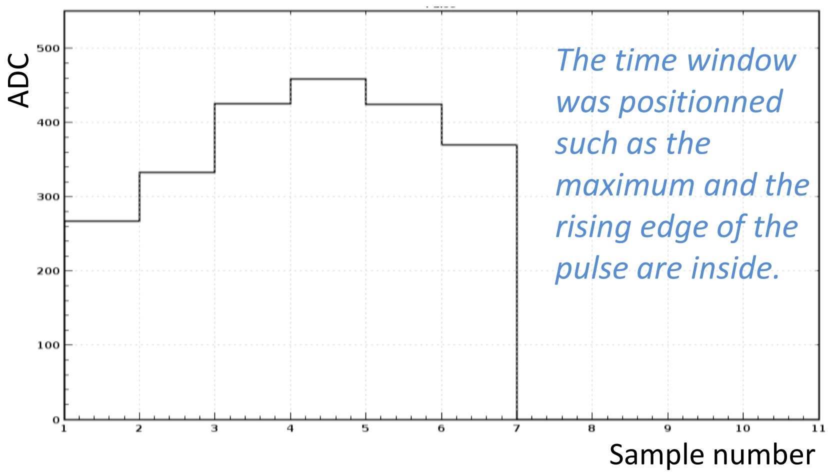
Resolutions and misalignments

- Data at **low beam current**, with **no magnetic field** and **empty target**, were taken for alignment purposes.
- Beam position appears to be vertically shifted by 5-mm w.r.t. to CVT axis.





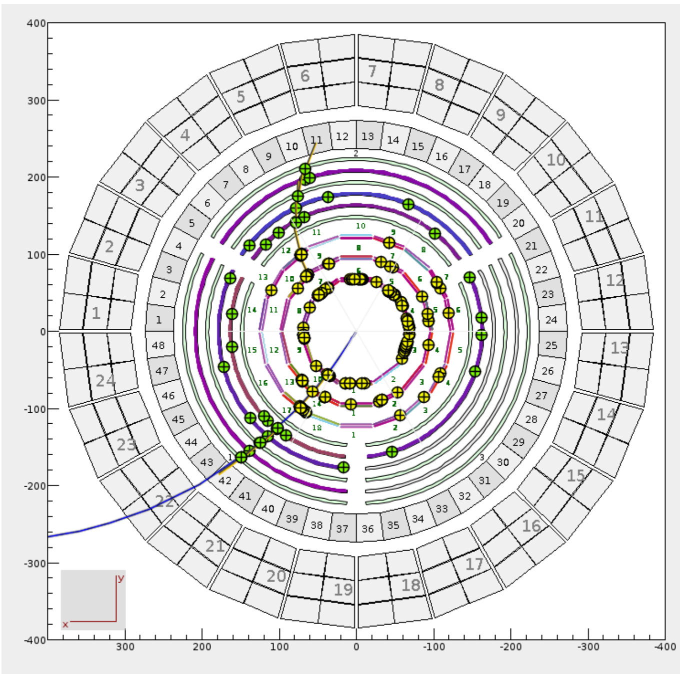
- **Tracking with both SVT+MVT**.
- SVT do not constrain much polar angle, so **C-tile residuals are sensitive to their own misalignment**. 150 um for residual (pitch/$\sqrt{12}$ ~ 150 um for Z and C).
- For **Z-tiles**, high sensitivity to **misalignments of MVT versus SVT**.

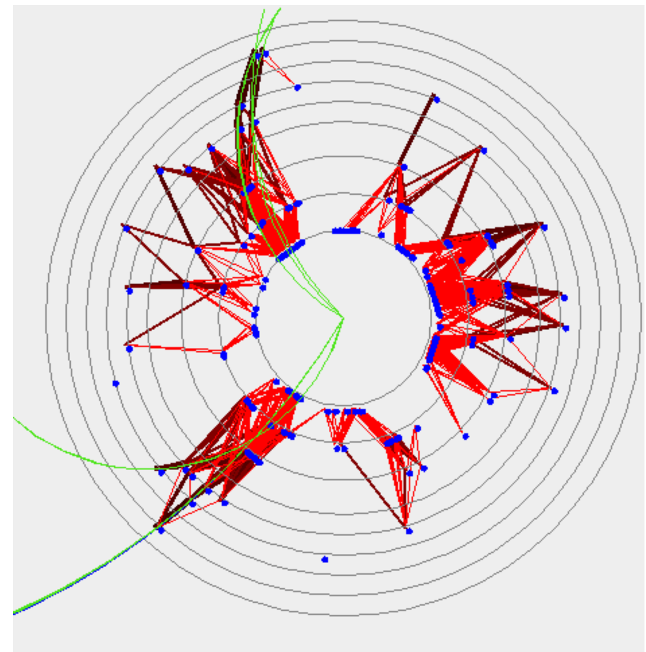

ADC
Sample number
The time window was positionned such as the maximum and the rising edge of the pulse are inside.

Developing new tracking algorithms

- The necessity of a central tracking being absolute to fully characterize the MVT, **we decided to involve ourselves** in its development.

- Pattern recognition was improved thanks to cellular automaton implementation. The efficiency of the algorithm **increased from <1% to 40%.**

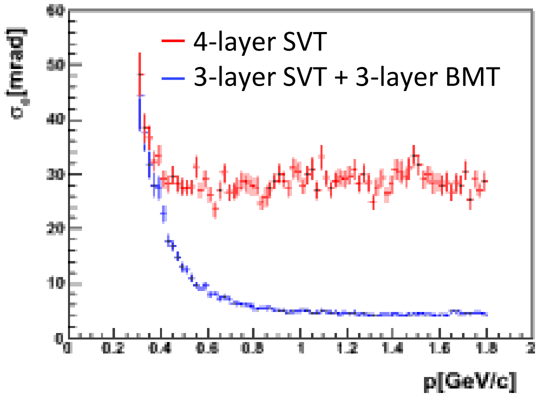


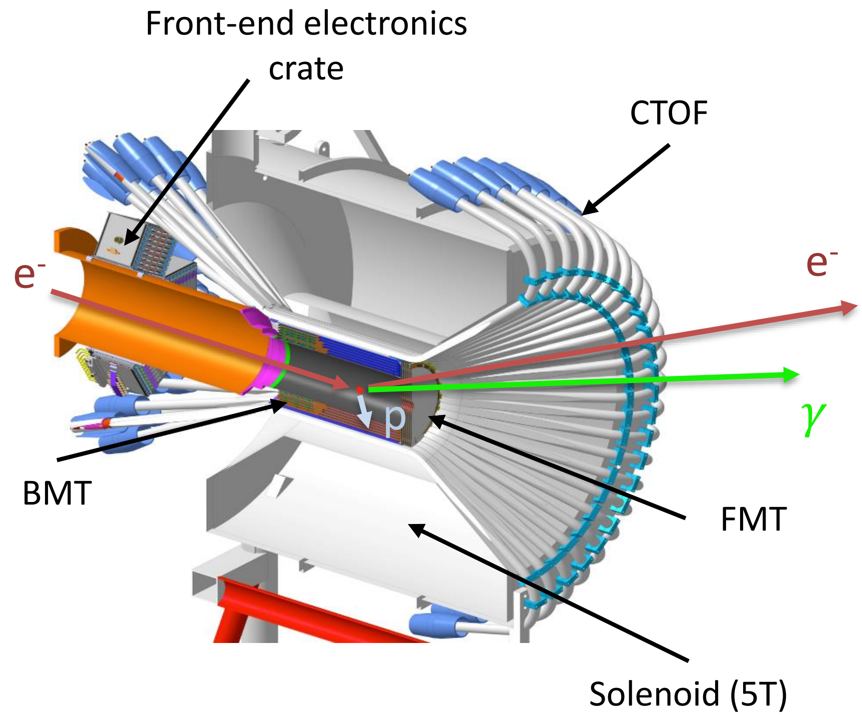


- **Alternative approach based on track-following pattern** recognition has started to be implemented. It is currently being used for straight line tracking, but could easily/will be adapted for helix tracks once the alignment is performed.

- Add permanently Micromegas detectors to the tracking of CLAS12.

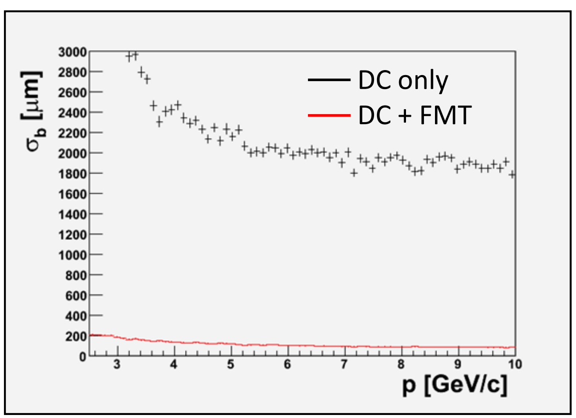
Why Barrel Micromegas (BMT) + 3-layer Silicon vertex tracker (SVT) over a 4-layer SVT (baseline design)?





Why Forward Micromegas (FMT) in addition to Drift Chambers (DC)?

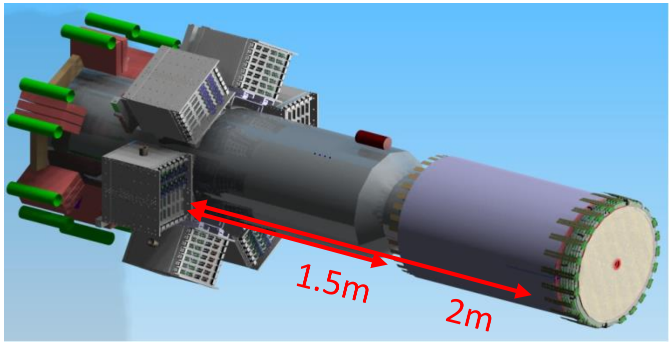
- Large improvement of vertex resolution (b, z) wrt DC alone



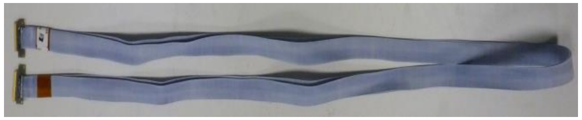
Constraints

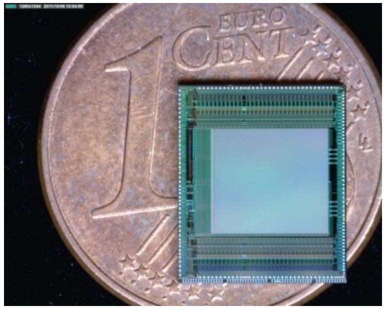
- High Singles Rate: 2 MHz (BMT), 10-20 MHz (FMT)
- Need lightweight detectors (300 MeV/c – 1 GeV/c)
- High magnetic field (5 T)
- No space for electronics close to the detector

MVT readout electronics designed at Irfu



- Requirements
  - → 9-10-bit charge measurement dynamic range
  - → ~20 ns timing resolution
  - → ~20 000 electronics channels
- Challenges
  - → Capacitive detectors with 100-200 pF strips
  - → 10-20 MHz physics background with strip hit rate of up to 60 kHz
  - → High trigger rate of 20 kHz and above with a deep 16 µs pipeline
  - → Stringent space constraints
  - → 5 T magnetic field
- Innovative readout system
  - → Off-detector frontend electronics 2 m away
    - Extensive R&D on micro-coaxial cables with low capacitance (~40 pF/m).
  - → Dream: new 64-channel ASIC based on switched capacitors array memories
    - Adapted to large range of input capacitances
    - Concurrent sampling and readout to stand high readout rates
  - → FEU: analog-digital 512-channel frontend unit
    - Common mode noise correction achieving S/N of 40 and above
    - Resistant to 1 T magnetic field

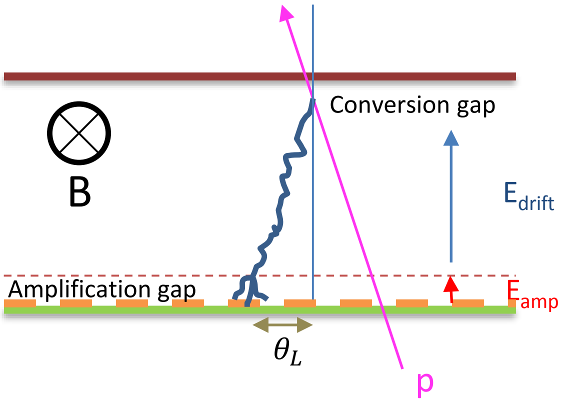


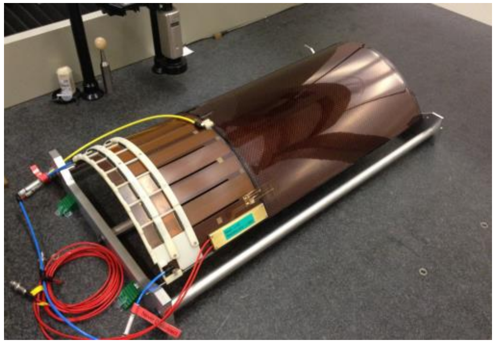


A versatile data acquisition system reused in many other experiments

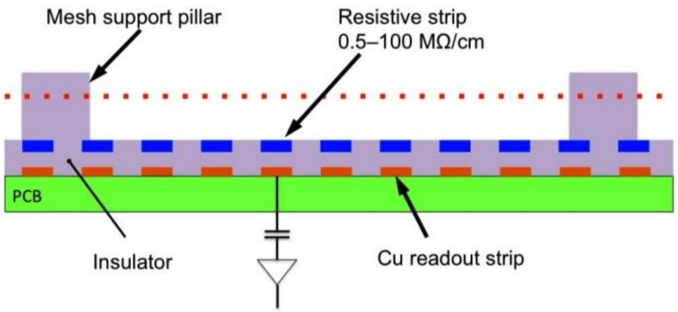
Innovative Micromegas detectors for CLAS12

- MVT seats in a **5T-magnetic field** generated by a solenoid.
  -> Drifting electrons will experience a Lorentz Force.
- Need to run at **high drift field (5kV/cm)** to reduce Lorentz angle.
- Thin drift gap (only 3mm) to reduce Lorentz drift.
- 90% Ar +10% iC4H10 for trade-off between gain and drift velocity.





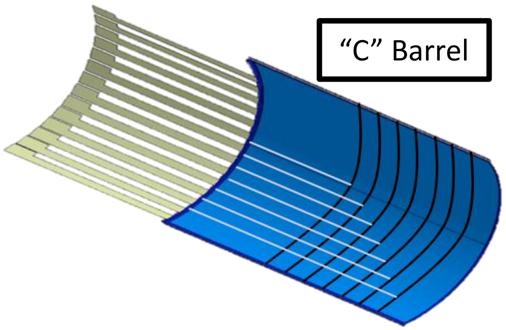
- **Lightweight Micromegas** detectors with carbon fiber structure for gas circulation and mechanical support.
- First cylindrical tracker using **curved Micromegas out of thin PCB**
- First **resistive Micromegas detectors** for physics experiment:
  - quenching sparks causing deadtime for metallic Micromegas,
  - allowing to reach higher voltage: Increase the gain and mesh transparency.



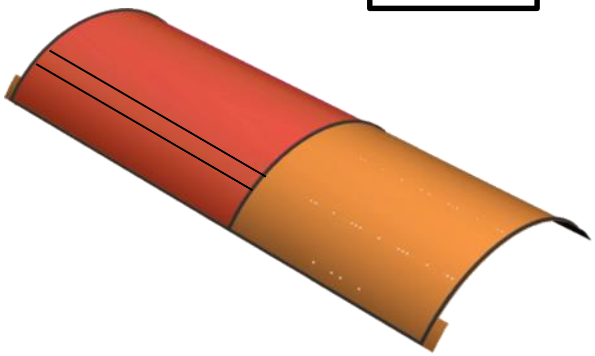
MVT description

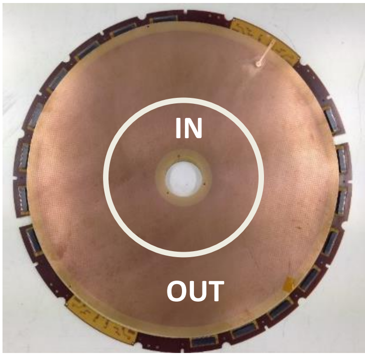
- Barrel Micromegas tracker is made of 6 layers with **radii from 140 mm to 225 mm**.
- Each layer is made of 3 tiles covering approximately 120 degrees.
- There are two kind of tiles for the **azimuthal (“Z”) and polar (“C”) angle**.
- **Z-tiles** have a constant pitch of about **500 um**.
  C-tiles have a varying **pitch from 330 to 600um**.
- The barrel represents 15360 channels.
- **0.3% X0** per tile.
- Forward Micromegas Tracker is made of 6 disks separated by 1.05 cm.
- A FMT disk has **1024 strips** with a pitch of 525um.
- The **strip plane is segmented** between an inner and outer areas:
  Adjustment of gain depending on the particle flux.
- From one disk to the next, the strip orientation is rotated by 60 degrees.
- **0.5% X0** per disk.

“C” Barrel

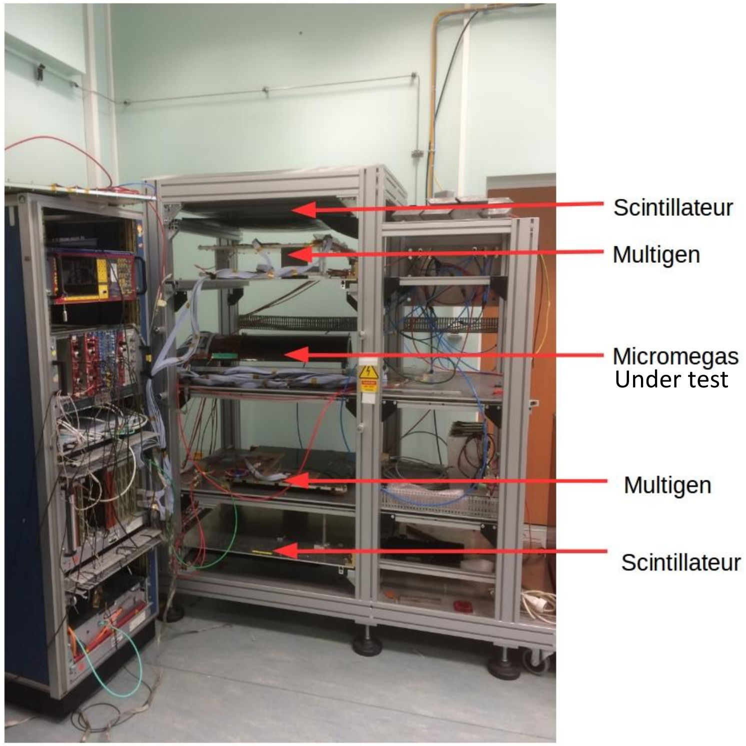


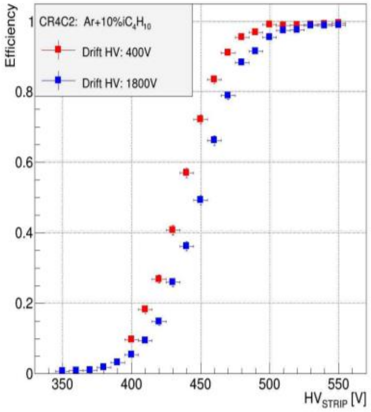
“Z” Barrel

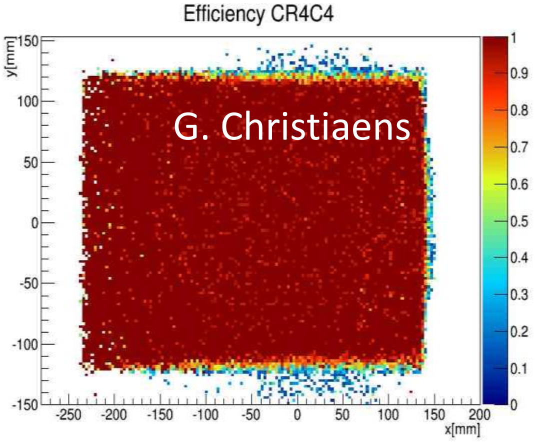




- Prior shipment to Jefferson Lab, all detectors (tile of BMT or disk of FMT) have been characterized using the cosmic bench at Saclay.
- Two scintillator detectors provide the trigger.
- Using Multigen detectors (2D Micromegas) we obtain the cosmic-ray track which fired the DAQ.
- Detectors to be characterized are placed in trays, in the middle of this cosmic bench.







- **All detectors were tested** with respect to:
  -The efficiency plateau.
  -The 2D efficiency map.
- **Resistive Micromegas** allows to extend the efficiency plateau by about 20V and thus **increase the gain by a factor of 2**.

About the physics analysis

- First **missing mass spectra indicating photon electroproduction events** obtained last week.

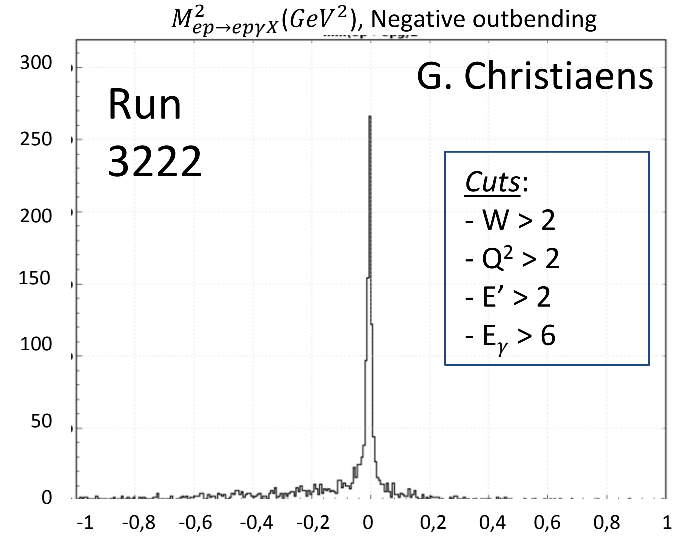
- Analysis team is composed of:
  - 2 PhD students.
  - 1 post-doc for 2 years starting in June.
  - 2.5 FTE for staff.

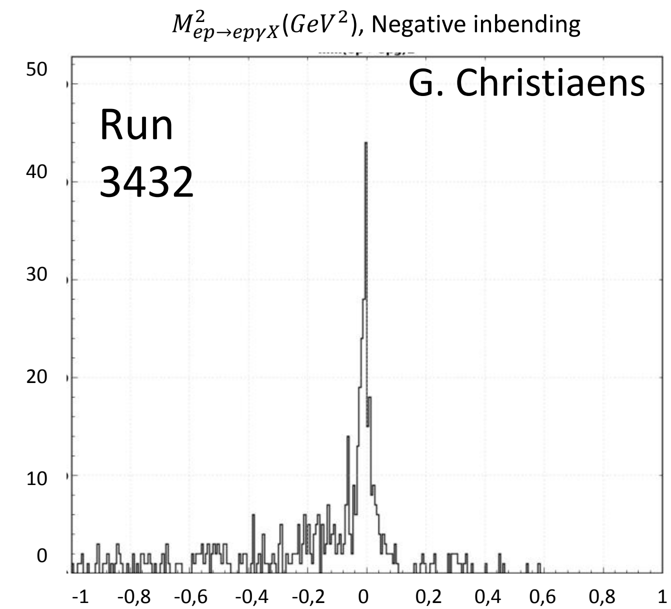
- Advanced machine-learning techniques to improve data analysis.

- **A lot of work is still needed** before any preliminary results
  - Alignment of central and forward trackers.
  - Correct magnetic field map for Torus and Solenoid
  - Calibration of Time-of-flight detectors,…

  => **an additional FTE (postdoc, possibly staff) is needed rather urgently.**

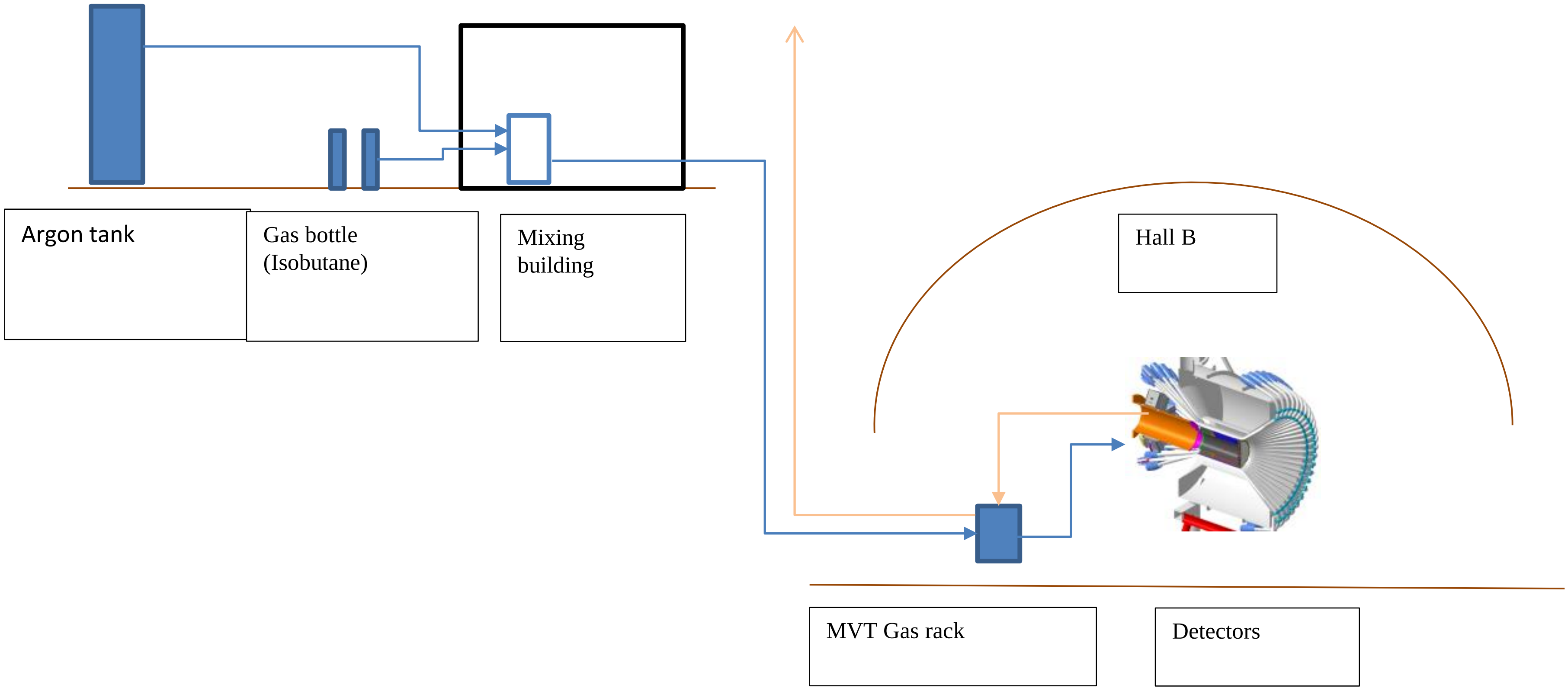
- GPD study and extraction from CLAS12 data thanks to ANR PARTONS: **DPhN leader of GPD phenomenology**.





Gas system : global view from gas shack to Hall B

Two types of gas will be used:
Ar 90% + Isobutane 10% (BMT)
Ar 80% + CF4 10% + Isobutane 10% (FMT)



A typical pulse

G. Christiaens
Glasgow/Saclay PhD student