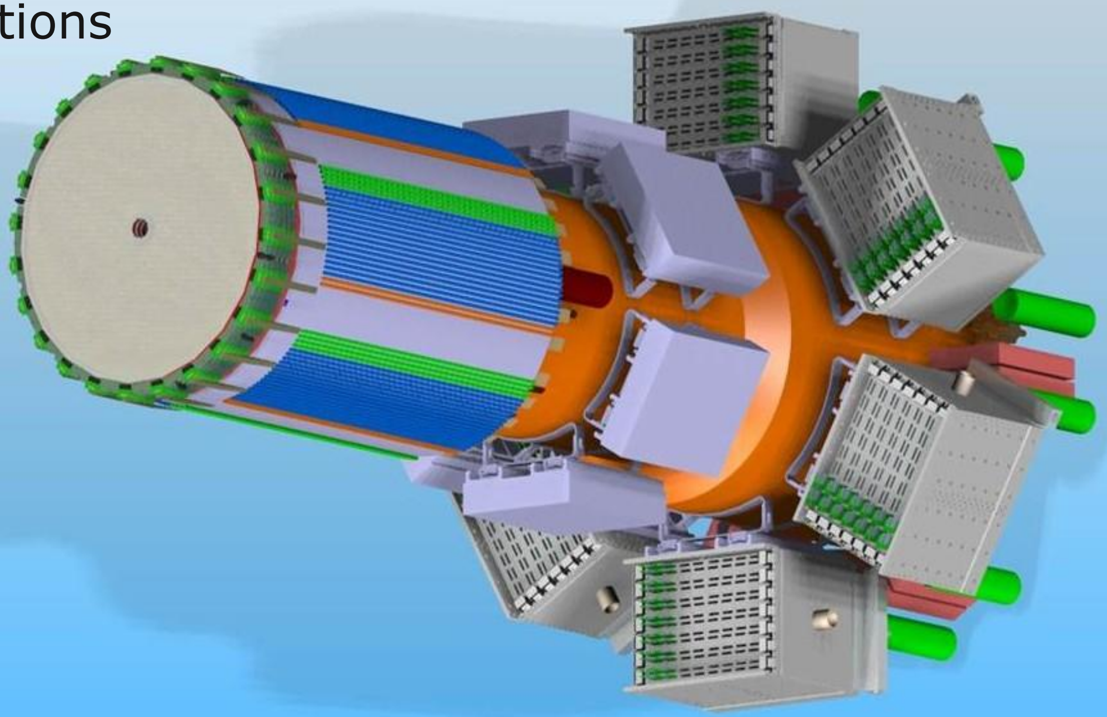
A High Rate Micromegas Tracker for CLAS12

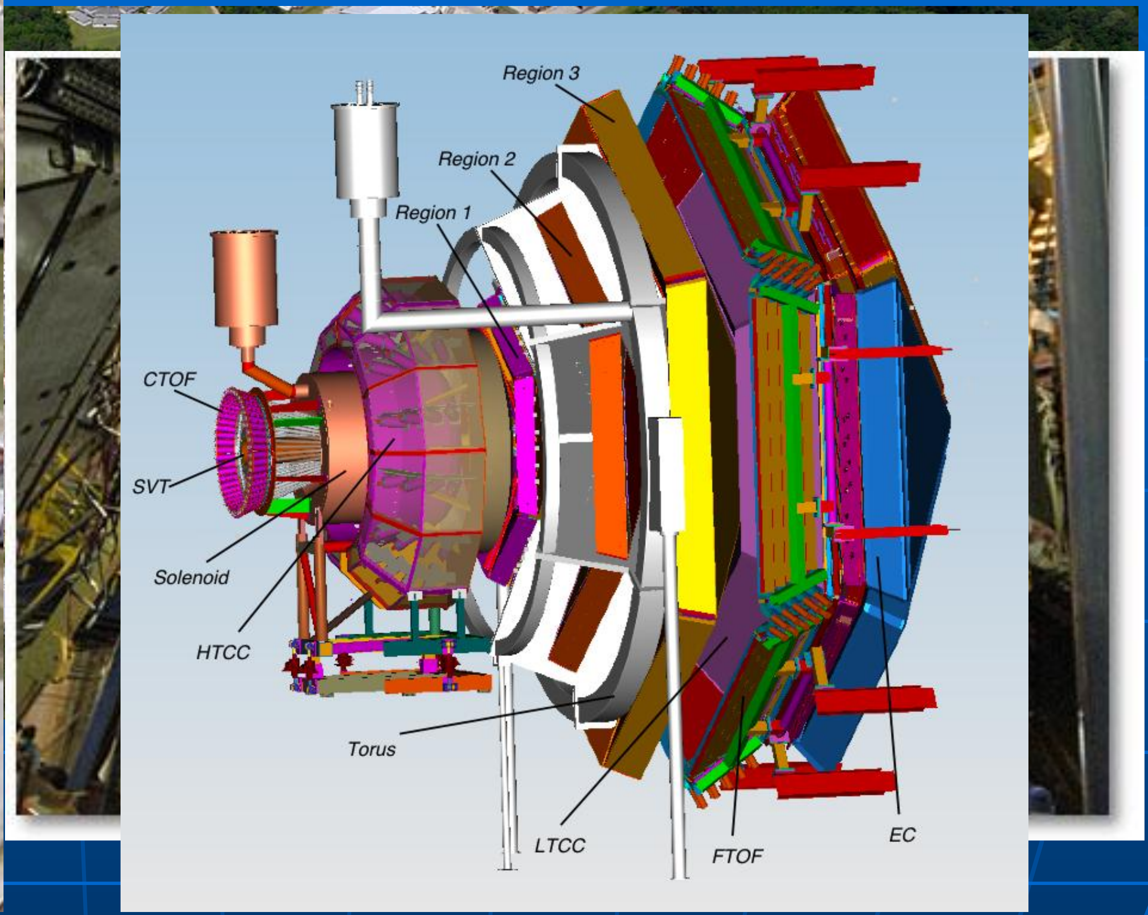
Project description

Issues and solutions

Electronics



CLAS12 @ JLab



CLAS12 (Large acceptance and high luminosity - **$L=10^{35}$ cm^{-2}s^{-1}**) to provide a new reach in Hadron Physics

Physics with CLAS12

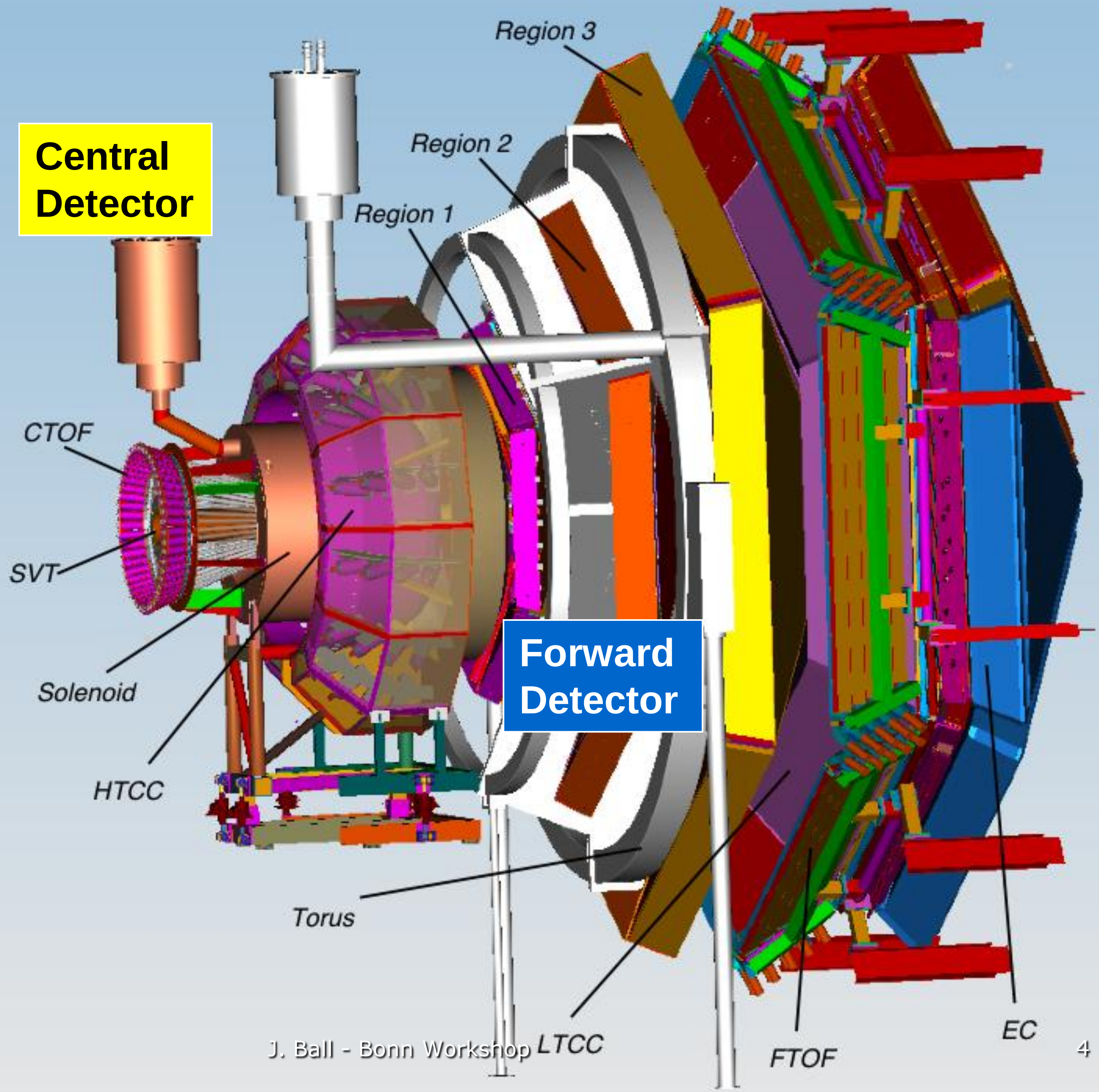
- 3D Structure of the Nucleon –
  High precision measurements of exclusive et semi-inclusive processes - Generalized Parton Distributions (GPDs) and Transverse Momentum Dependencies (TMDs).
- Precise Measurements of structure functions
- Elastic and Transition Form Factors at high moment transfer
- Hadronization and Colour Transparency.
- Spectroscopy – heavy baryons, hybrid mesons.

5 years of beam already scheduled for JLab PAC approved experiments.

CLAS12

Forward spectrometer:
- *TORUS*
- *HT Čerenkov*
- *Drift chambers*
- *LT Čerenkov*
- *Forward ToF*
- *Preshower Calorimeter (6 sectors)*
- *E.M Calorimeter. (EC)*

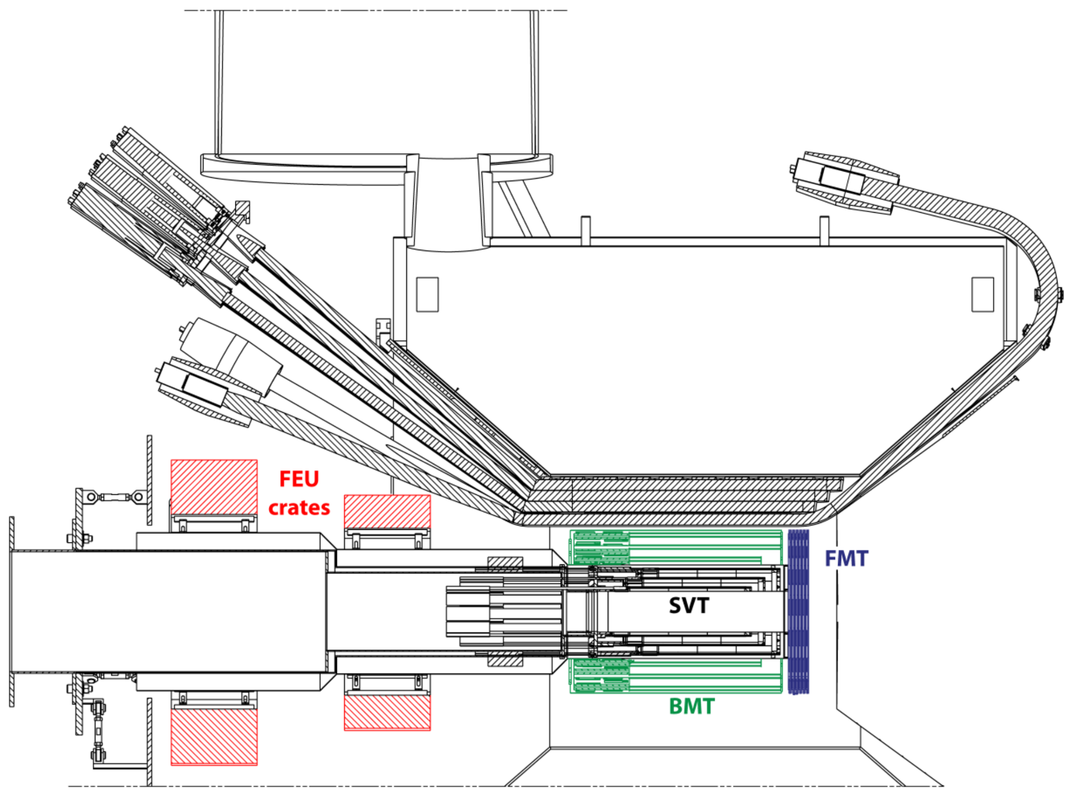
Central Detector:
- *SOLENOID*
- *Tracker Barrel Micromegas/Silicon*
- *Forward Tracker*
- *Central ToF*



Micromegas Tracker

Central Detector

- SVT – **MVT** :
  Charged particles Tracking
  from 35 to 125° and 5 to 35°(**FVT**)
  Vertexing
- CTOF, ΔT < 60psec for particle id
- Neutron counter
- 5T Solénoid,
  Active shielding vs Moller electrons
  $\Delta B/B < 10^{-4}$ in a 2.5x4 cm^2 cylinder
  for target polarisation



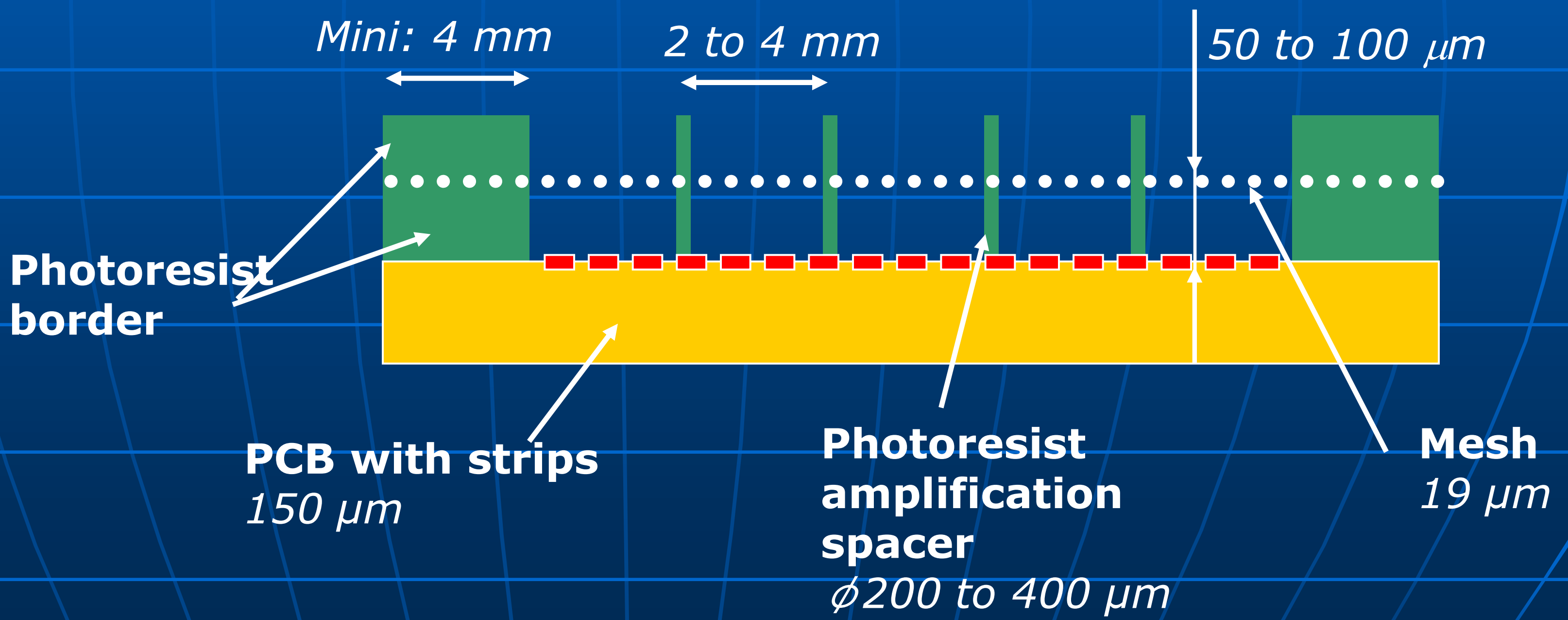
Barrel: 3 cylindrical double layers (Z,C) *bulk Micromegas* around 3 SVT double layers

Forward: 3 double disc shaped *bulk Micromegas*

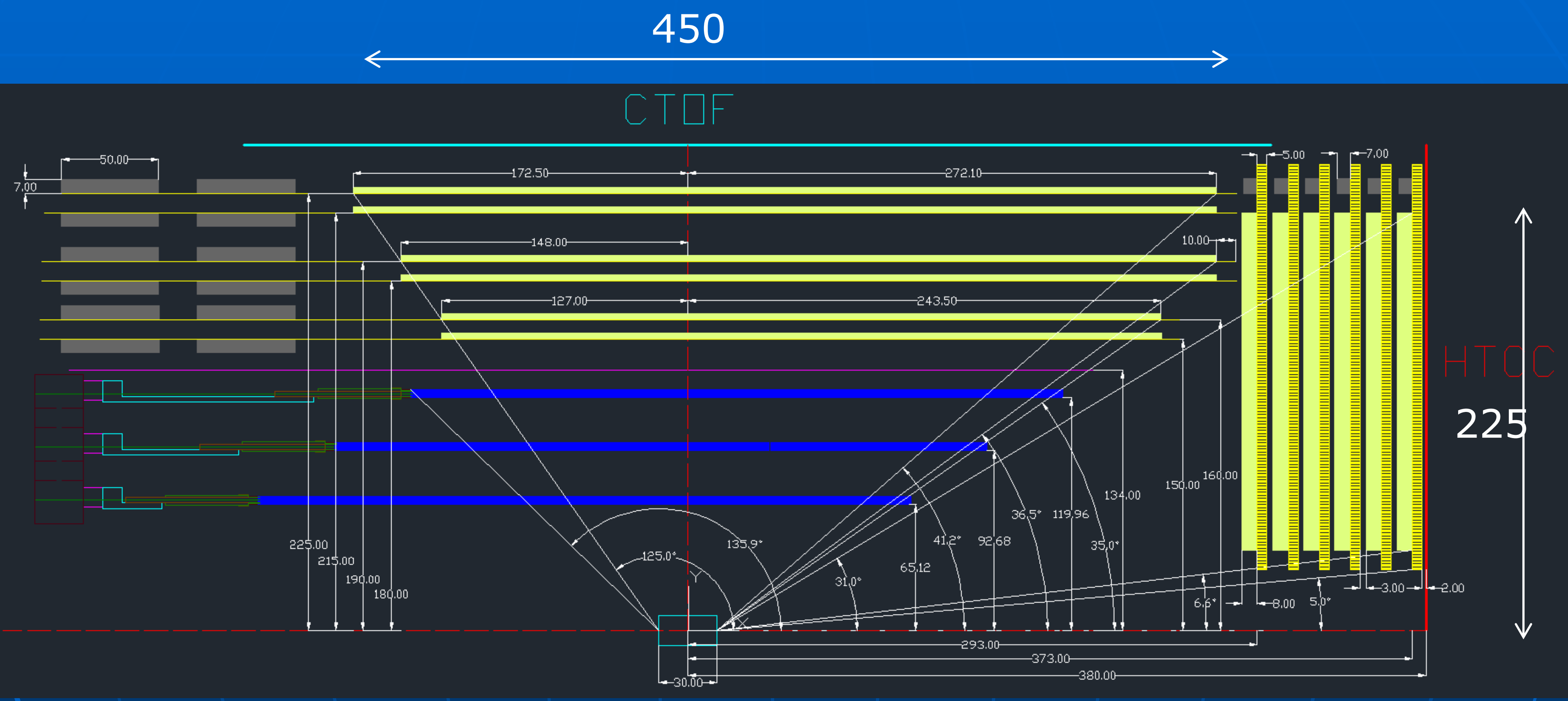
Bulk Micromegas

The bulk concept has been developed using PCB techniques :

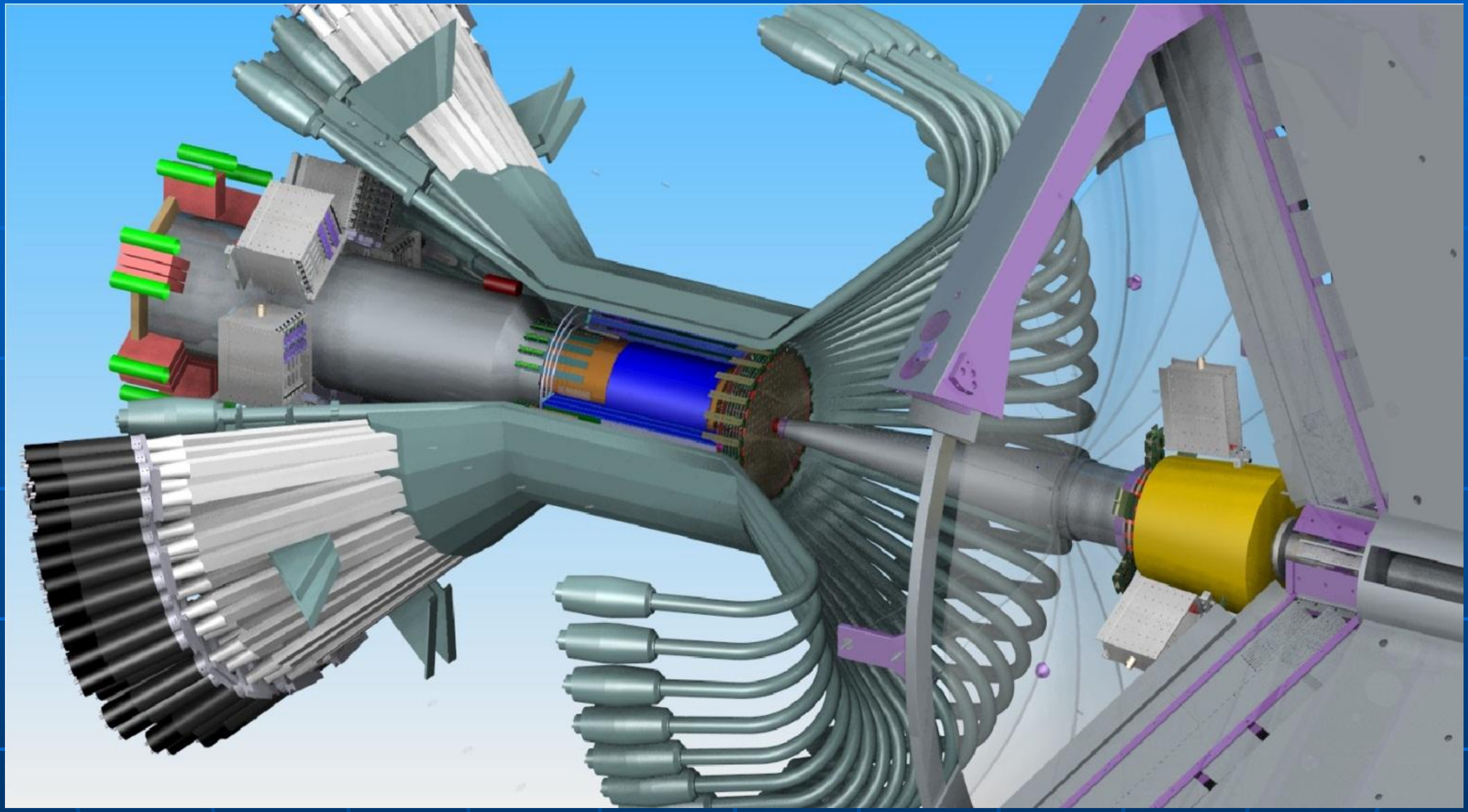
- Two Photoresist films to permanently hold the mesh between two arrays of spacers. The whole detector (pad or strip array and mesh) is in one piece, a bulk after lamination, insulation and chemical treatment.
- The same process can be applied to embed the drift plane too, thus providing a full bulk detector.



Micromegas Tracker



The tracker in its environment



CLAS12 Tracking specs

Specification	Forward	Central
Angular Acceptance	5-35°	35-125°
σ_p/p	< 1%	< 5%
σ_θ	< 1 mrad	< 5-10 mrad
σ_φ	< 3 mrad	< 5 mrad

Resolutions comparison

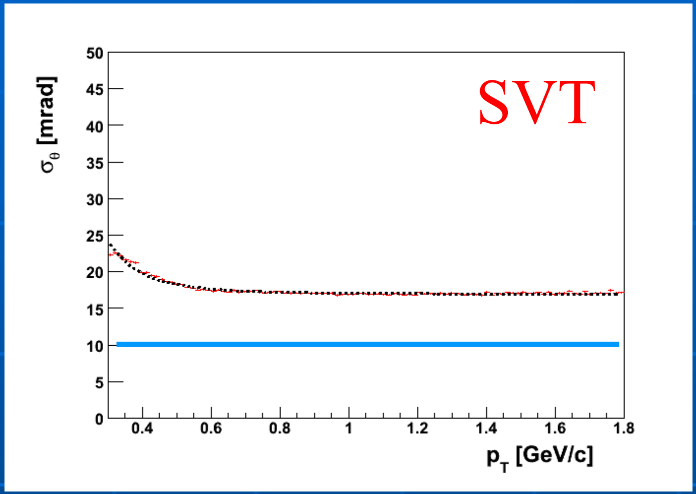
(for π @ 0.6 GeV/c , θ = 90°)

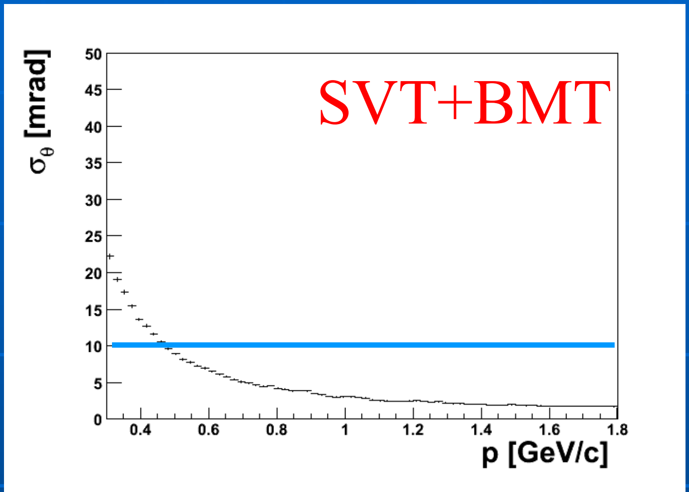
	4 x 2MM	4 x 2SI	2 x 2SI + 3 x 2MM	Specs.
σ_{pT}/p_T (%)	2.9	2.1	1.6	5
σ_θ (mrad)	1.3	15.1	1.4	10
σ_φ (mrad)	10.9	2.9	2.6	5
σ_z (µm)	212	1522	267	tbd.

→ Mixed solution benefits from advantages of both MM and Si

→ The full Si solution is **never** the best

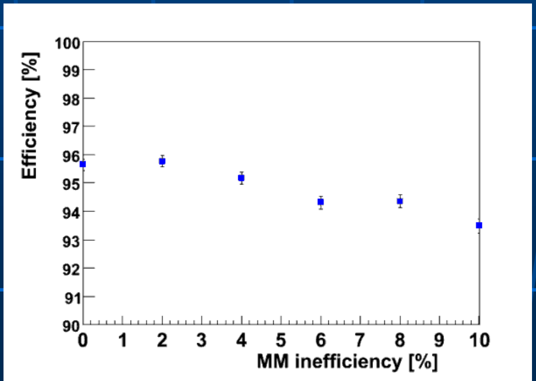
CLAS12 tracking with Barrel MM + Si



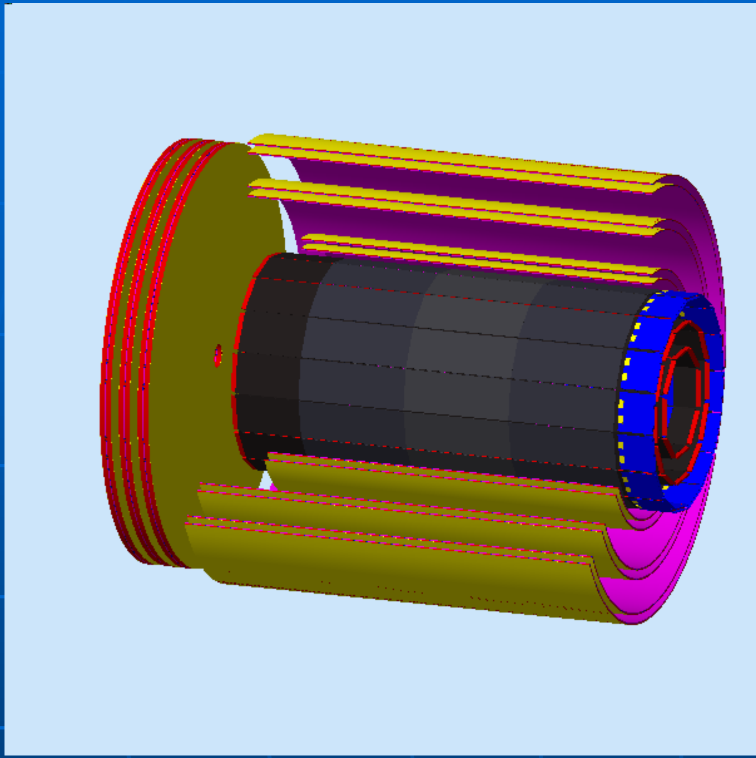


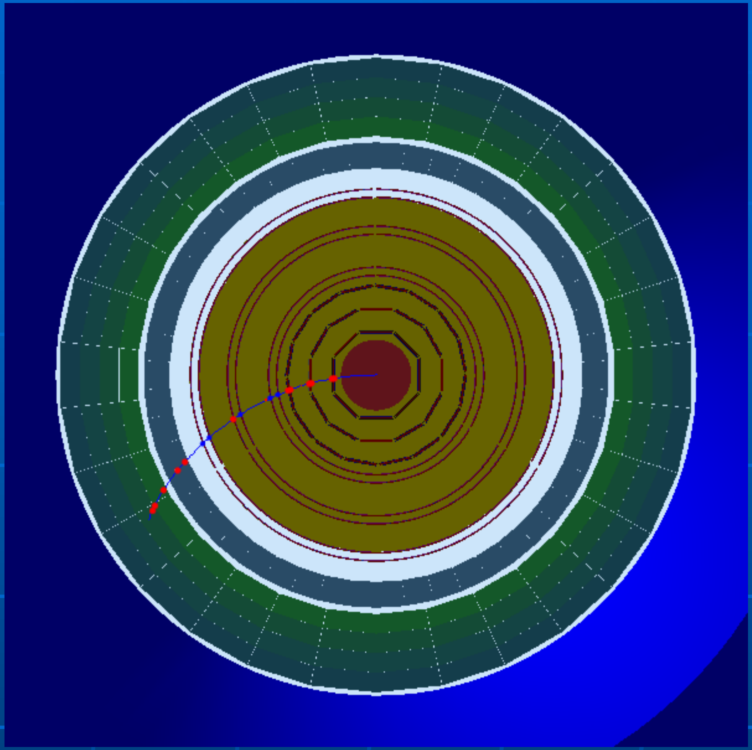
⇒ SVT + BMT best solution to reach spec on θ

→**Very good tracking efficiency thanks to redundancy**:



Geant4 Simulations - Barrel





© S. Procureur

Background noise (MHz)

Si	Layer 1	Layer 2	Layer 3	Layer 4
e-/e+	3.9	3.7	4.3	4.3
photon	30.5	22.0	25.7	20.0
hadron	1.6	1.3	1.7	1.5
total	36.2	27.0	31.9	26.0

MM	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
e-/e+	1.27	2.73	1.14	2.92	1.70	3.68
photon	0.08	0.03	0.07	0.06	0.09	0.08
hadron	0.96	0.95	1.13	1.11	0.91	0.84
total	2.40	3.80	2.40	4.15	2.77	4.66

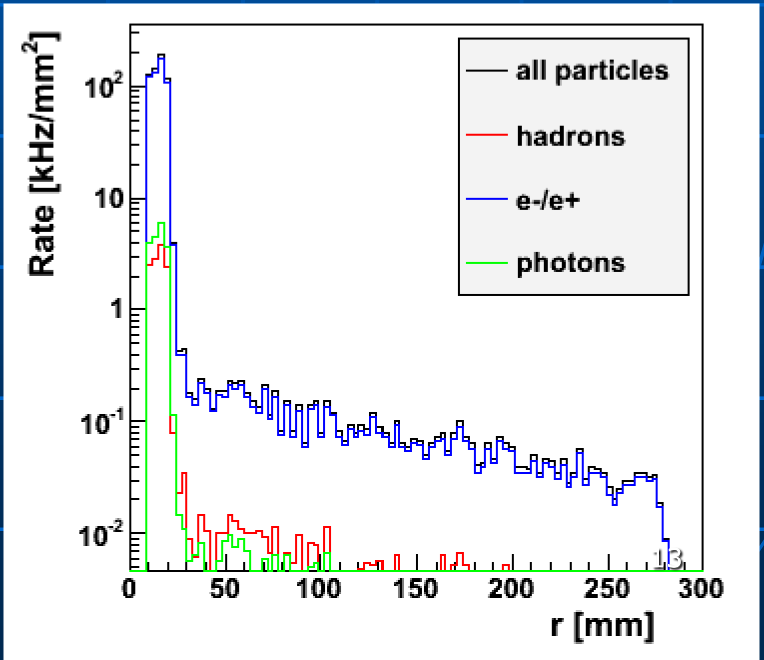
Simulations Geant4 - Forward

Rates in MHz

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
e-/e+	7.6 (7.5)	4.7 (6.4)	4.7 (6.6)	4.0 (7.3)	4.0 (7.2)	3.6 (7.5)
photon	2.0 (13.9)	0.2 (11.3)	0.2 (9.5)	0.1 (8.3)	0.1 (7.1)	0.1 (5.7)
hadron	2.2 (1.6)	2.1 (1.5)	2.0 (1.4)	2.0 (1.4)	1.9 (1.4)	1.8 (1.3)
total	12.0 (23.1)	7.2 (19.3)	7.0 (17.7)	6.2 (17.1)	6.1 (15.8)	5.5 (14.6)

© S. Procureur

→ **Very high rates in the central area**



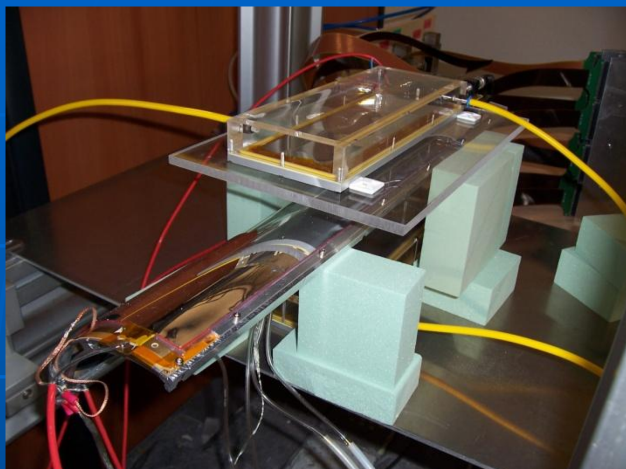
The Challenges

- Large Cylindrical detectors
- 5T Magnetic field environment
- High flux of particles
- Electronics requirements:

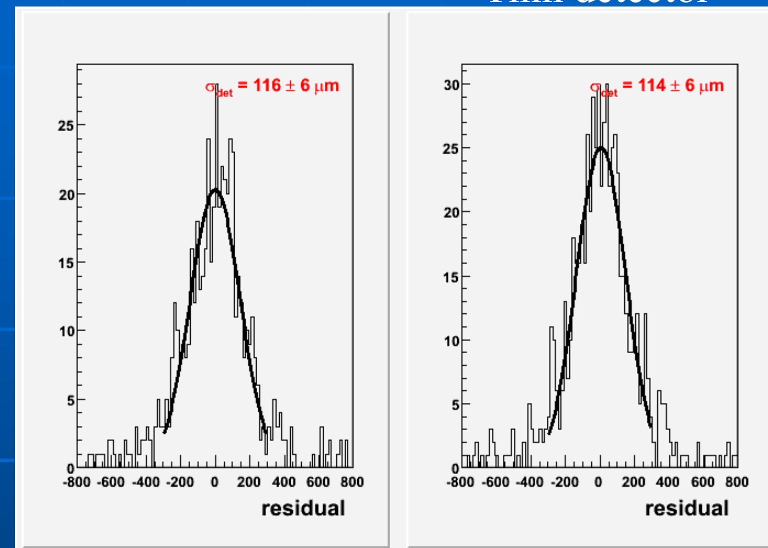
Background: 20 MHz
Hit rate: 60 kHz
Shaped signals of 250 ns to keep signal discrimination inefficiency low < 1.5%
Trigger rate: 20 kHz
Pipeline : 16 µs
Crowded location: deported electronics

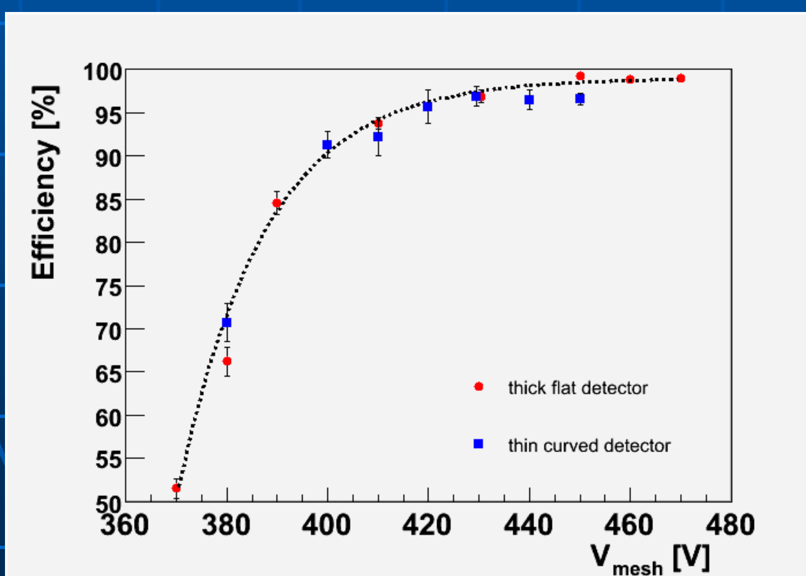
Cylindrical Micromegas

Performance compared to thick flat MM using cosmics



Thick detector Thin detector

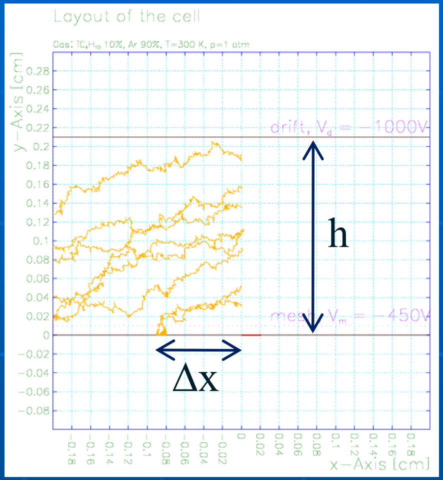




→ similar performance as thick detectors

5 Tesla magnetic field

Z tiles of **Barrel Micromegas** are sensitive to the Lorentz angle of drifting electrons

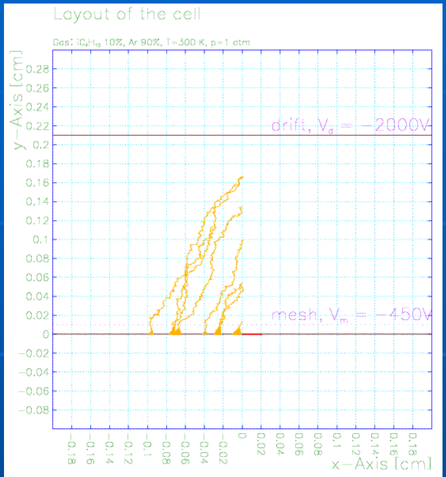


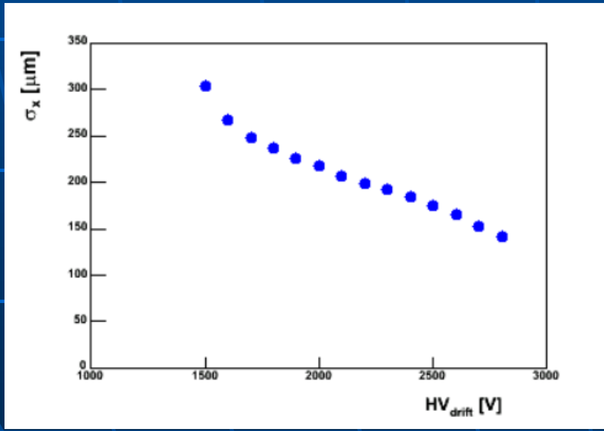
$$\Delta x = h \tan\theta = h\, v\, B / E$$

→ minimize h (but less signal)

→ use heavier gas (but more sparks)

→ increase E field (but lower transparency)

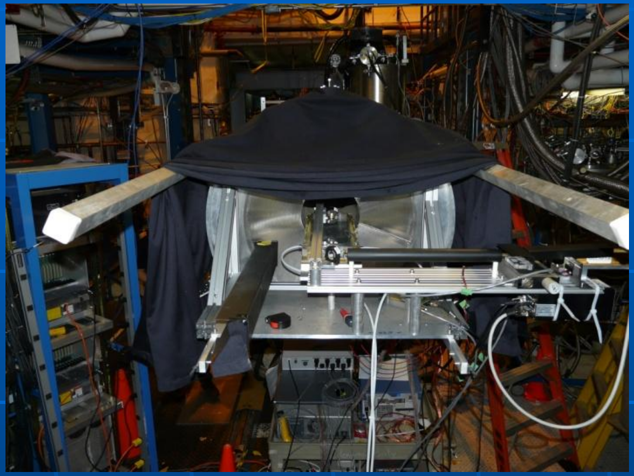




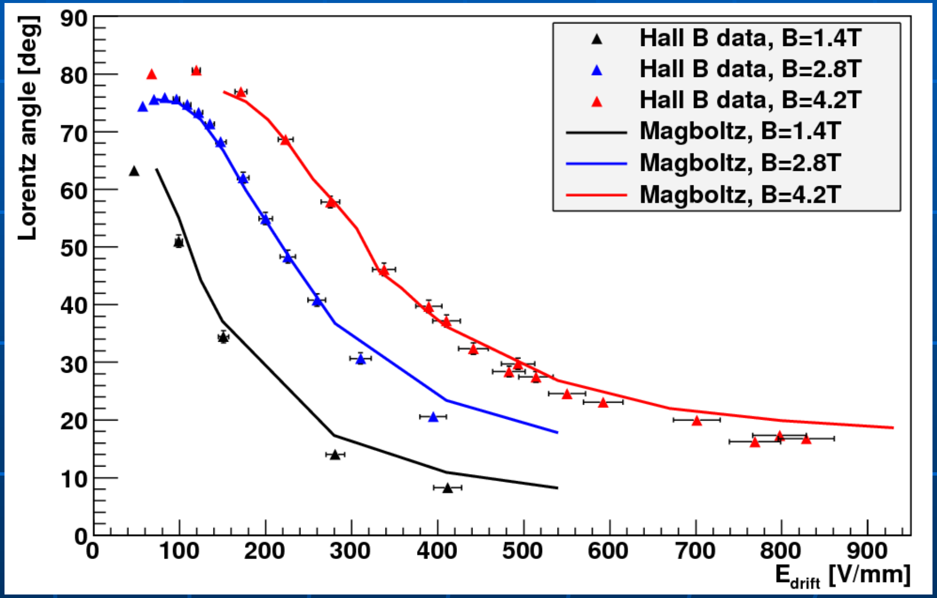
→ σ_z ~ 220 µm if θ can be lowered down to 20°

Spatial resolution in 5 T

Test to validate Garfield simulation with a Micromegas in dvcs magnet (Hall B)



→ **use of a focused UV laser to extract electrons from the drift electrode**

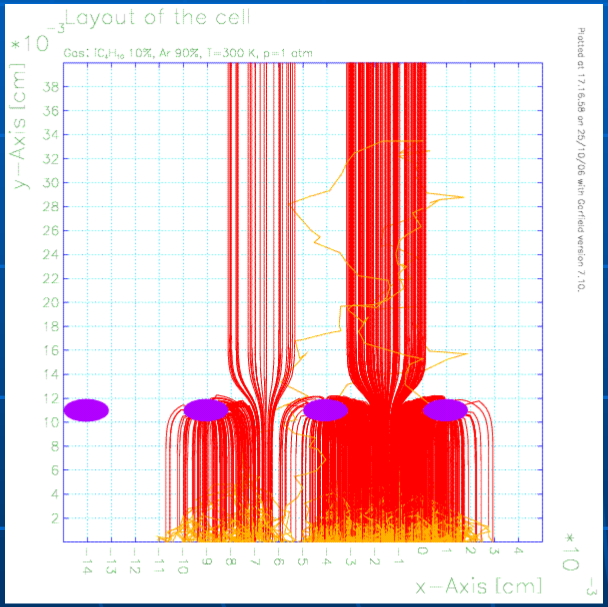


Garfield validated, θ can be as low as 20°

P. Konczykowski *et al.*, NIM A612 (2010), 274

Side effects of the magnetic field

- Ratio between fields in amplification gap and conversion gap > 8 to collect almost all the ions produced during the avalanche (~91%)
- In our case, ratio is ~ 5.5 and more than 20% of ions are not collected without magnetic field.



No magnetic field

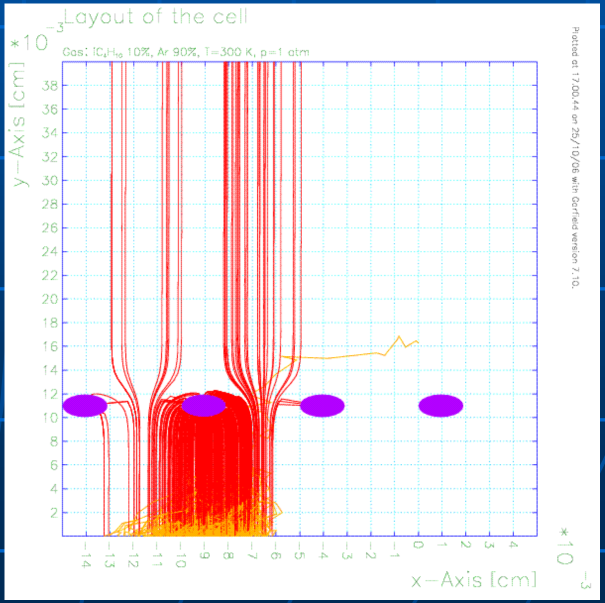
- Magnetic field modifies the drift lines of the electrons in the amplification region, a large part of the avalanche occurs closer to the mesh wires and only 11% ions escape

Mesh wire

Electrons

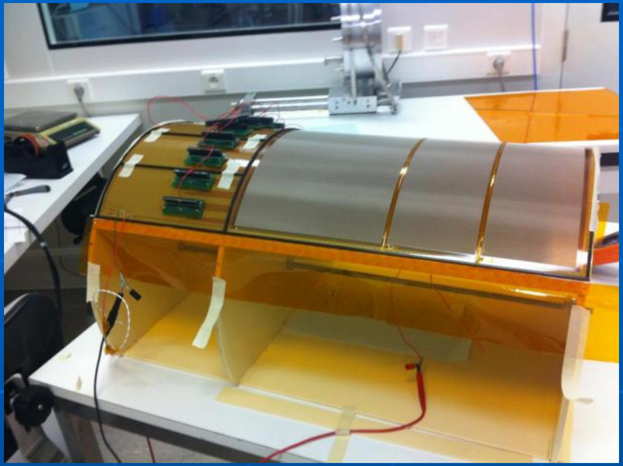
ions

5 T



Barrel detector: segmented or resistive

- Two kinds of pre production detectors are tested at Saclay Lab
  - Segmented bulk detector (5 detectors)
  - Resistive bulk detector (5 detectors)

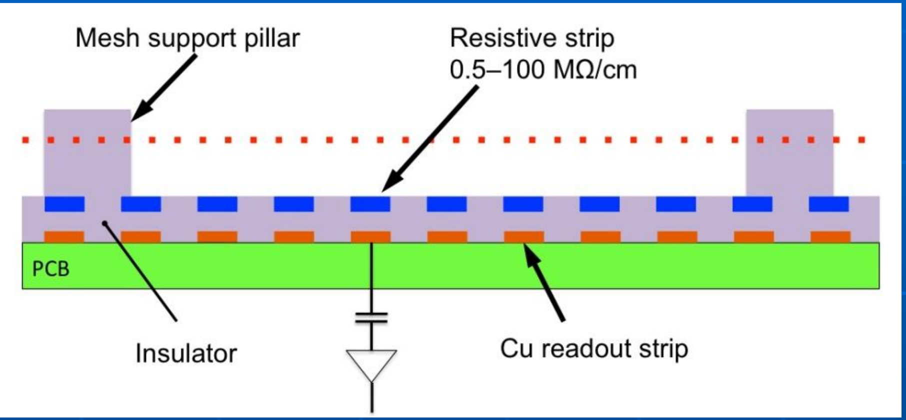


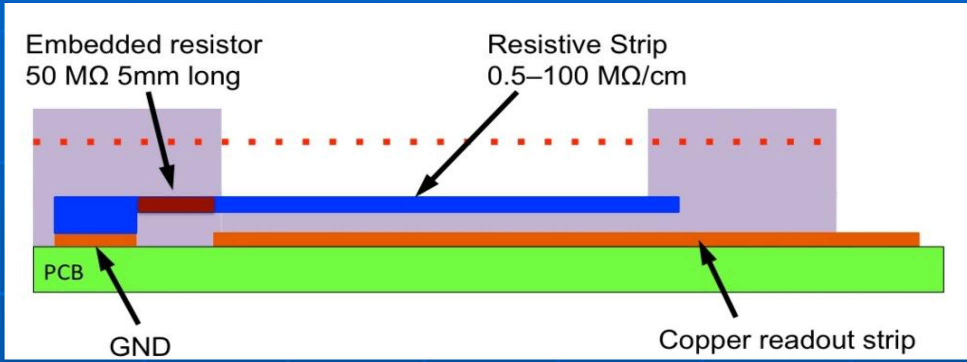
- The sizes of the two types, thus the mechanics, and their electrical connections are the same.

- **The main advantage of resistive bulk is the possibility to run without sparking.**
  - The resistive solution must be efficient on thin and curved detectors
  - Resistive detector should have reproducible characteristics
  - R & D still on going.

Resistive detectors

→ Resistive detectors planned for the Forward VT, and maybe the Barrel

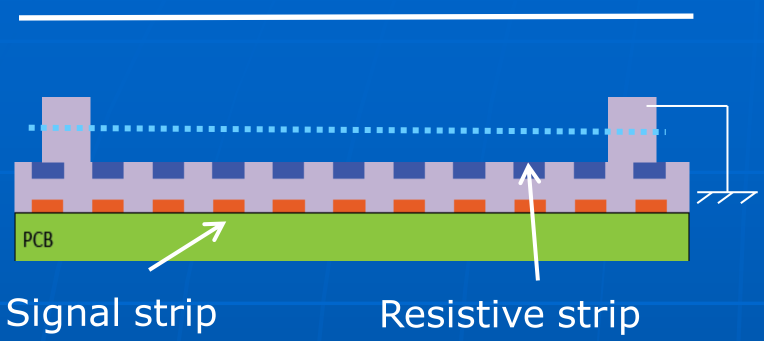




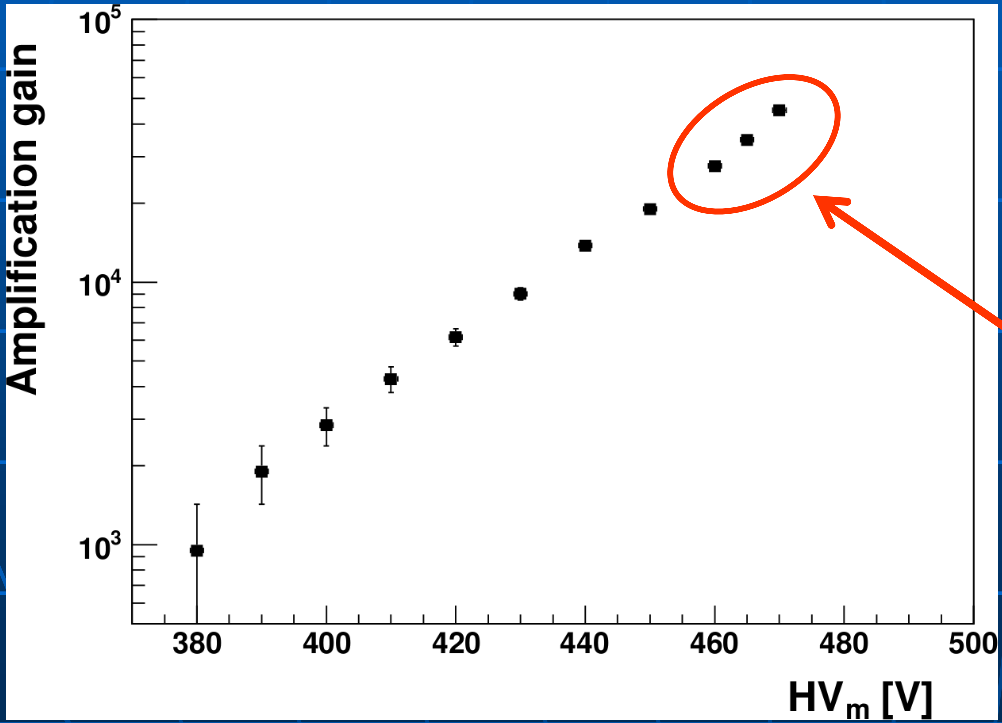
Sideview

- Same signal shape as for non resistive
- Excellent homogeneity so far
- Tests : gains, ageing, dead time

Resistive detectors



When a discharge occurs, the resistive strip voltage reaches very quickly the same value as the mesh. The mesh stays at its nominal setting even during sparking.



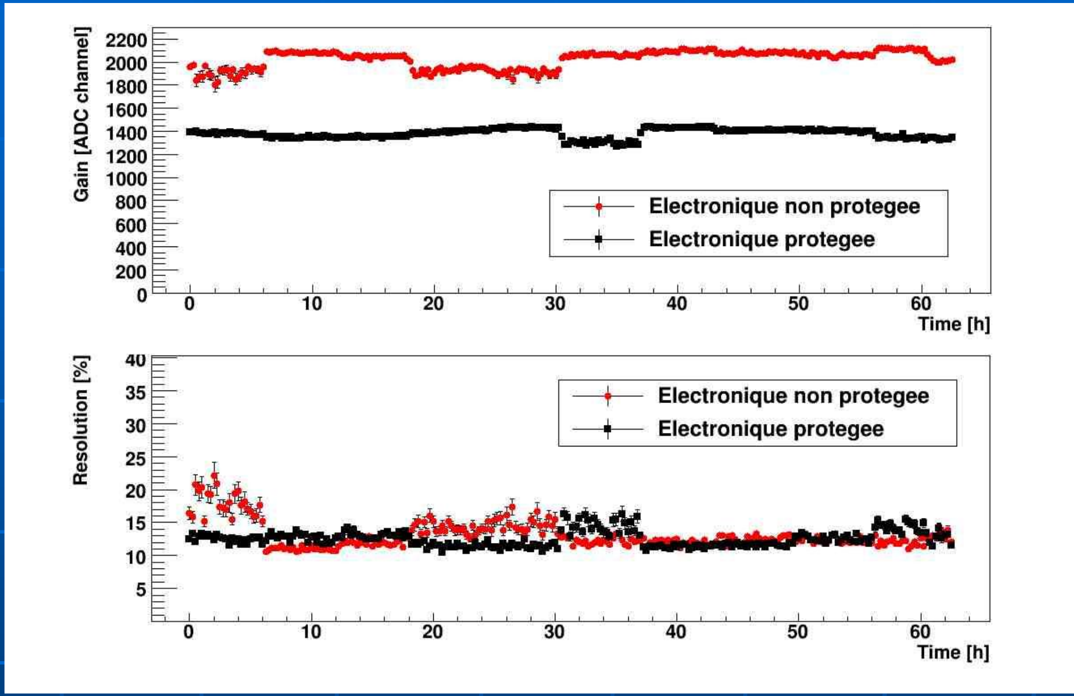
Resistive Micromegas can reach higher gains, yielding a better S/N ratio.

S. Procureur et al., NIM A, 688 (2012) 75-79

Resistive Micromegas : ageing

Voltage set to get continuous sparking for α emitted by an Am source put on a chosen area of the detector.

For the same strips, the signal induced by a Fe source is read by the electronics.



G. Charles, Micromegas detectors for CLAS12, NIM A (2012), 10.1016/j.nima.2012.08.060

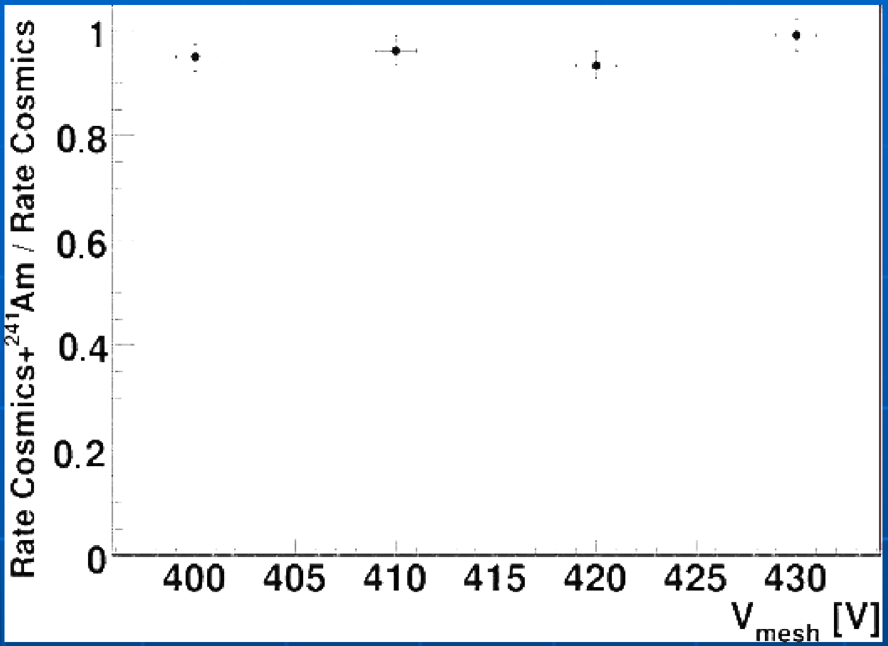
- After 60h testing, gain is unchanged on the average.
- S/N 17 % higher without protection
- Equivalent energy resolution with or without protection

Resistive Micromegas : dead time

Same setting as before to produce sparks with an Am source.

Cosmic rays signals are read simultaneously by the electronics on the same area.

Less than 10 % dead time, rate of the source being 350 Hz, about 0,3 ms maximum deadtime after each spark.

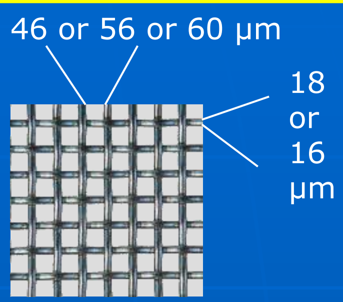


Resistive Micromegas look promising, tests still ongoing.

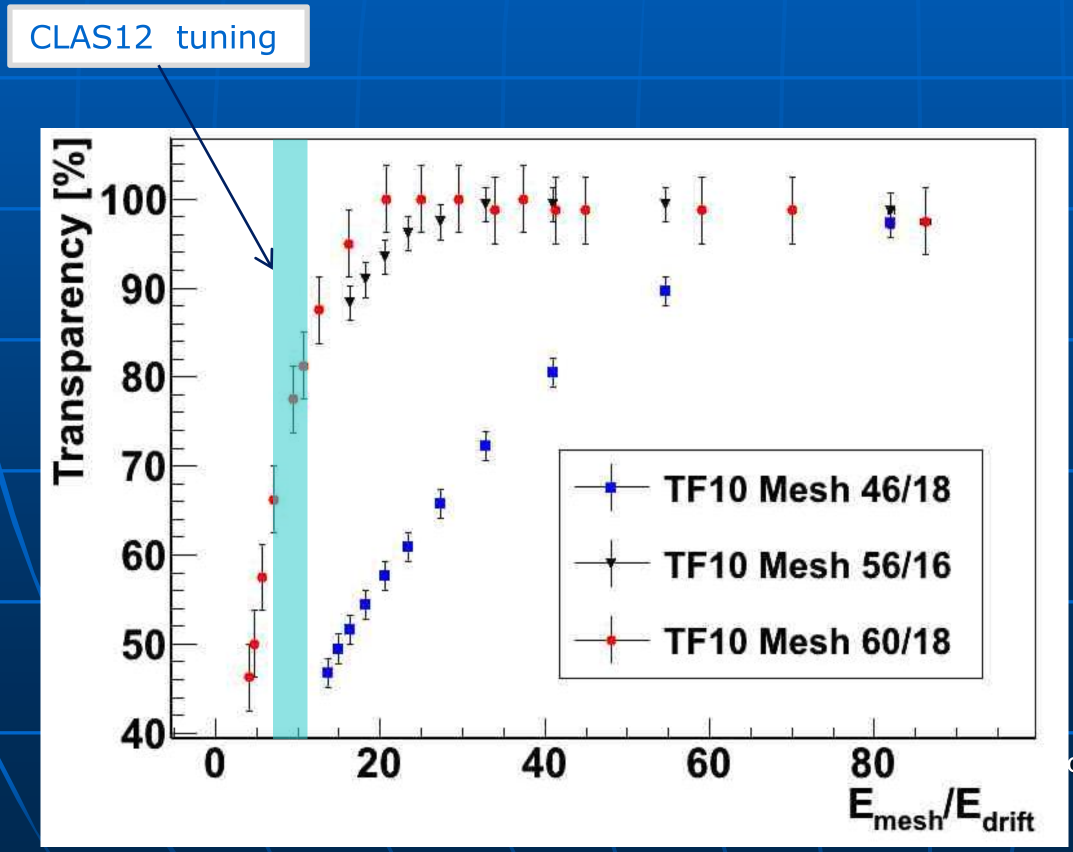
Tests of different meshes

Tests of meshes with different optical transparencies

- 46, 60 µm space between 18 µm wires
- 56 µm space between 16 µm wires



Goal : improve the gain of the detector to increase the S/N ratio.



Emesh/Edrift = 8 will be the setting point for some tiles of the barrel and using a fine mesh enables to reach higher gains.

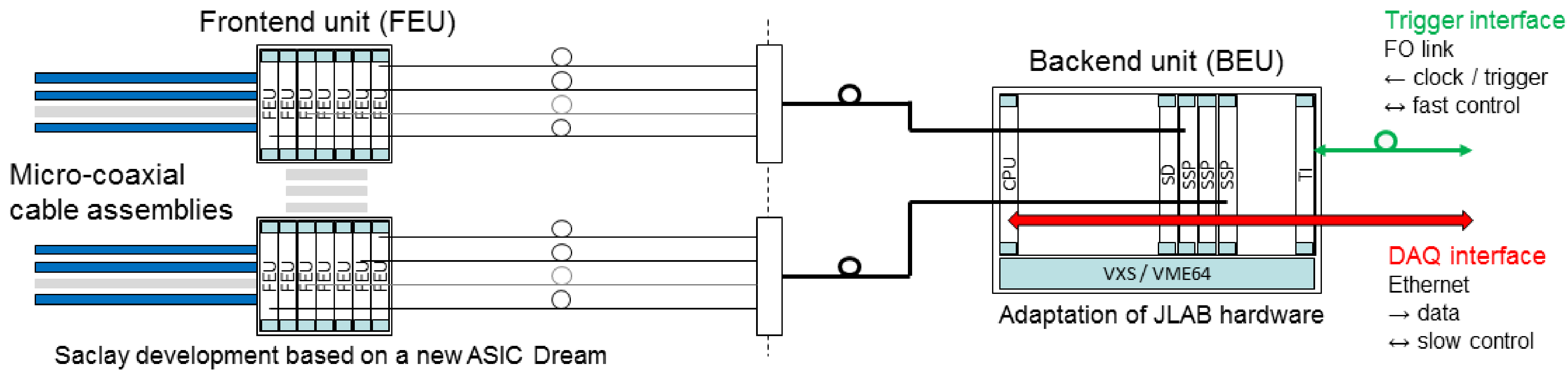
The 60/18 is to be used

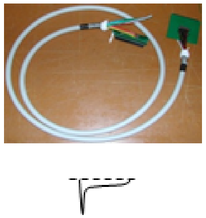
Working conditions

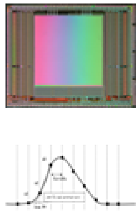
Parameter	Barrel MVT	Forward MVT
Effective Gain	5000	3000
Gas mixture	Ar + 10% iC_4H_{10}	Ne + 10% C_2H_6
Conversion gap	3 mm	5 mm
Drift field	8 kV/cm (Z) et 4 kV/cm (C)	1 kV/cm
Lorentz Angle	20° (Z) et 40° (C)	0°
Fields ratio	5,5 (Z) et 9 (C)	~ 50
Transparency	40% (Z) et 50% (C)	100%
X_0	0,3%	0,3%
Segmentation	Longitudinal in 3 parts	Annular in 3 parts
Maximum PCB size (capacitance)	45x43 cm² (16 nF / 3)	Φ 43 cm (12 nF / 3)
Particle rate / layer	4 MHz (incl. 1 MHz hadrons)	12 MHz (incl. 2 MHz hadrons)
Discharge rate/ mesh	1 Hz	1 Hz
Deadtime	< 2 %	< 2%
Detection efficiency	> 90%	> 95%
Pitch	540 µm (Z) et 270 µm (C)	500 µm
Spatial resolution	250 µm (Z) et 100 µm (C)	145 µm
Time resolution	10 ns	10 ns

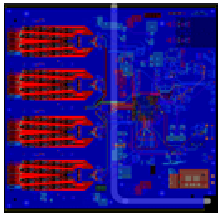
MVT readout system

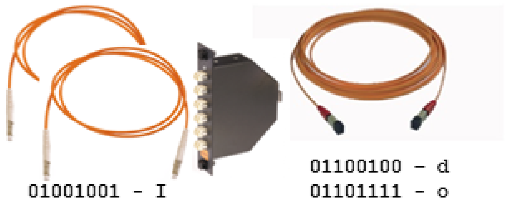
Detector links | Off-detector frontend electronics 1.5-2 m | Optical links | Data concentration backend electronics 10-15 m

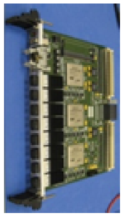












01000011 – C
01101100 – l
01100001 – a
01110011 – s
00110001 – 1
00110010 – 2

- 26k channels
- ~400 cable assemblies
- 54 512-channel FEUs
  - ~500 Dream ASICs
- 54 optical links @ 2.5Gbit/s
- 1 BEU (may be 2) with 3-4 SSPs

- **20 kHz trigger rate**
- **16 µs trigger latency**

64-channel Dream ASIC

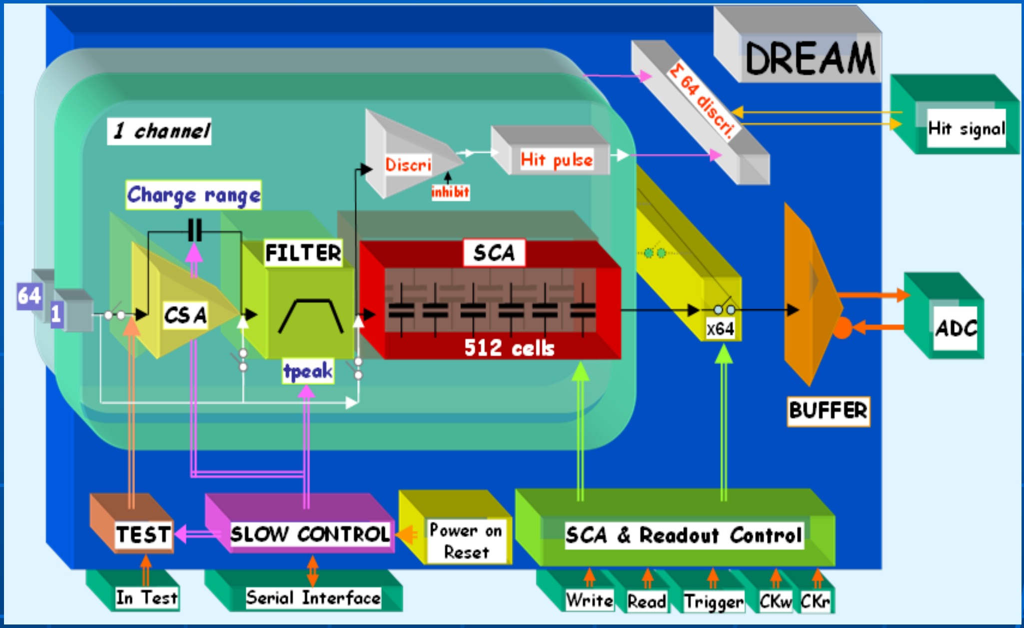
Dead-timeless **R**ead-out **E**lectronics **A**SIC for **M**icromegas

- Each of the 64 channels handles one detector channel. It integrates:

- A charge sensitive preamplifier (**CSA**) with programmable gain.

- **Analog filter** consists in Pole zero Cancellation stage followed by a 2-complex pole Sallen-Key low pass filter.

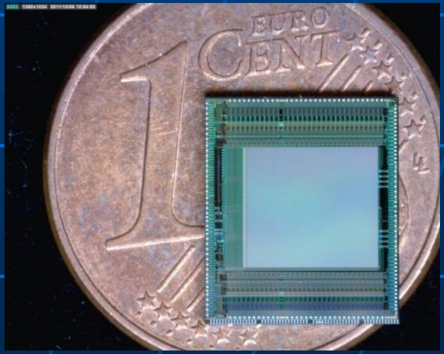
Peaking time of the global filter selectable among 16 values (50 ns to 1 µs).



Courtesy: E. Delagnes

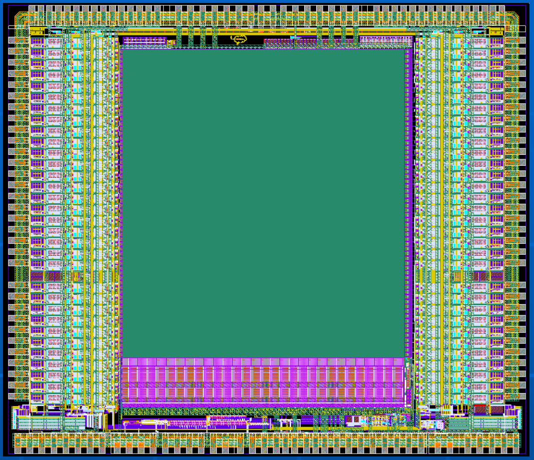
Filtered signal is sent to the analog memory and to the discriminator inputs.

- Analog memory is based on a Switched Capacitor Array Structure (**SCA**).



64-channel Dream ASIC
Dead-timeless **R**ead-out **E**lectronics **A**SIC for **M**icromegas

- Characteristics
  - 4 gain ranges: 60 fC, 120 fC, 240 fC, 1 pC
  - 16 programmable peaking times: from 50 ns à 1 µs
  - Sampling rate: 1- 50 MHz
  - 512-cell deep analog memory per channel
    - Trigger pipeline of 16 µs + derandomizing
  - Readout rate: 20 (40) MHz
  - 140-pin 0.4 mm package
    - Small 17 mm x 17 mm footprint
  - Adapted for different detector types

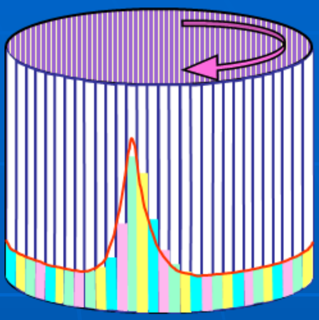


- Version 0 run successful
  - Operational ASICs

Courtesy: E. Delagnes

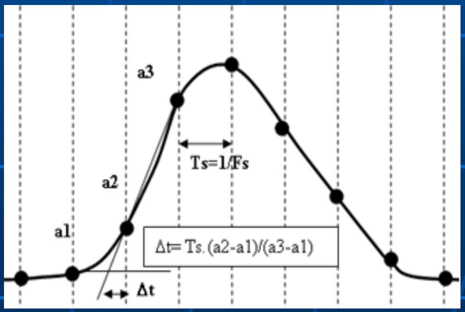
Readout principles

- 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



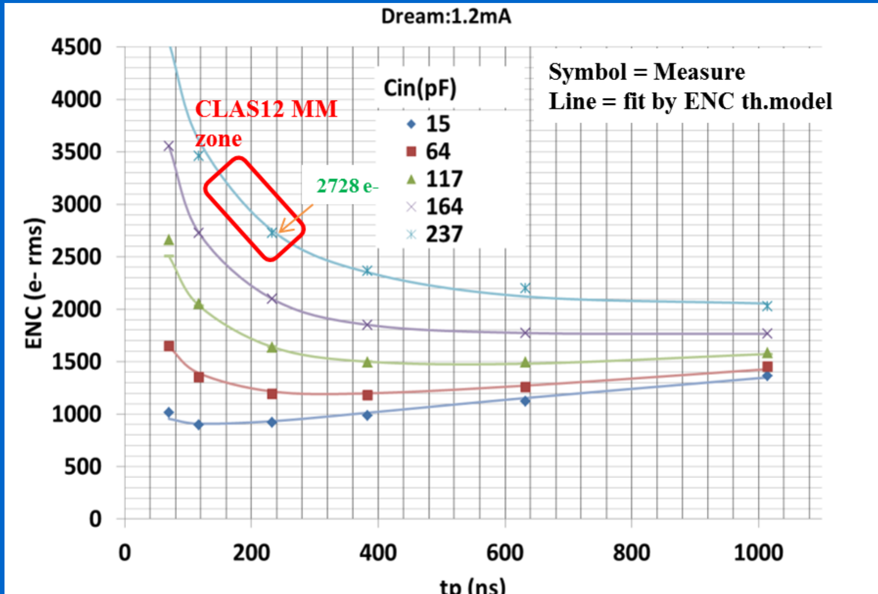
- At each trigger 4 - 6 corresponding samples are readout and digitized
  - Readout does not disturb sampling

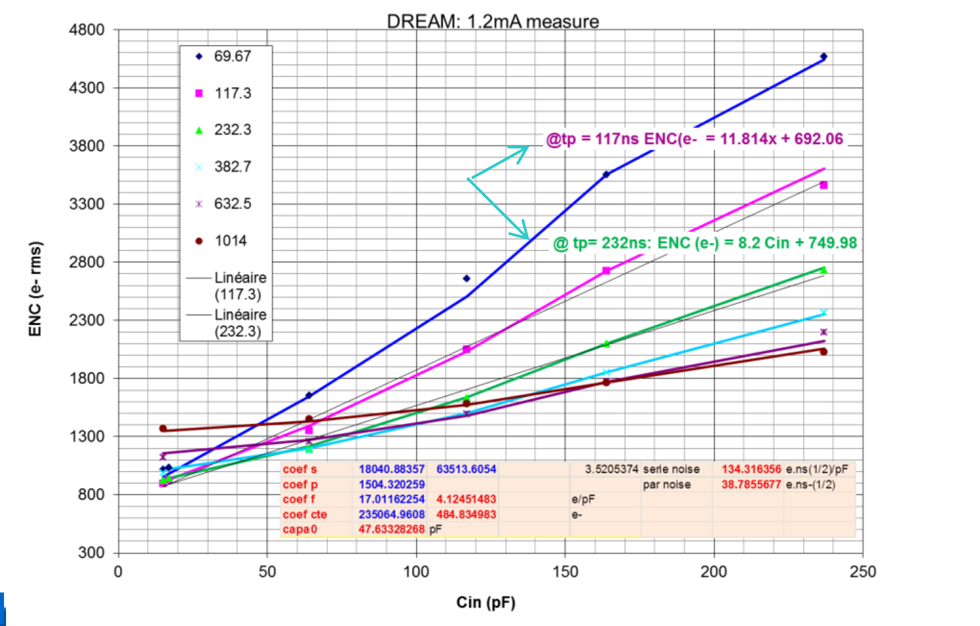
- Retained samples are digitally processed
  - Pedestal equalization – online
  - Common noise subtraction – online
  - Zero suppression – online
  - Measure charge and time – off-line



Courtesy: E. Delagnes

Dream: status

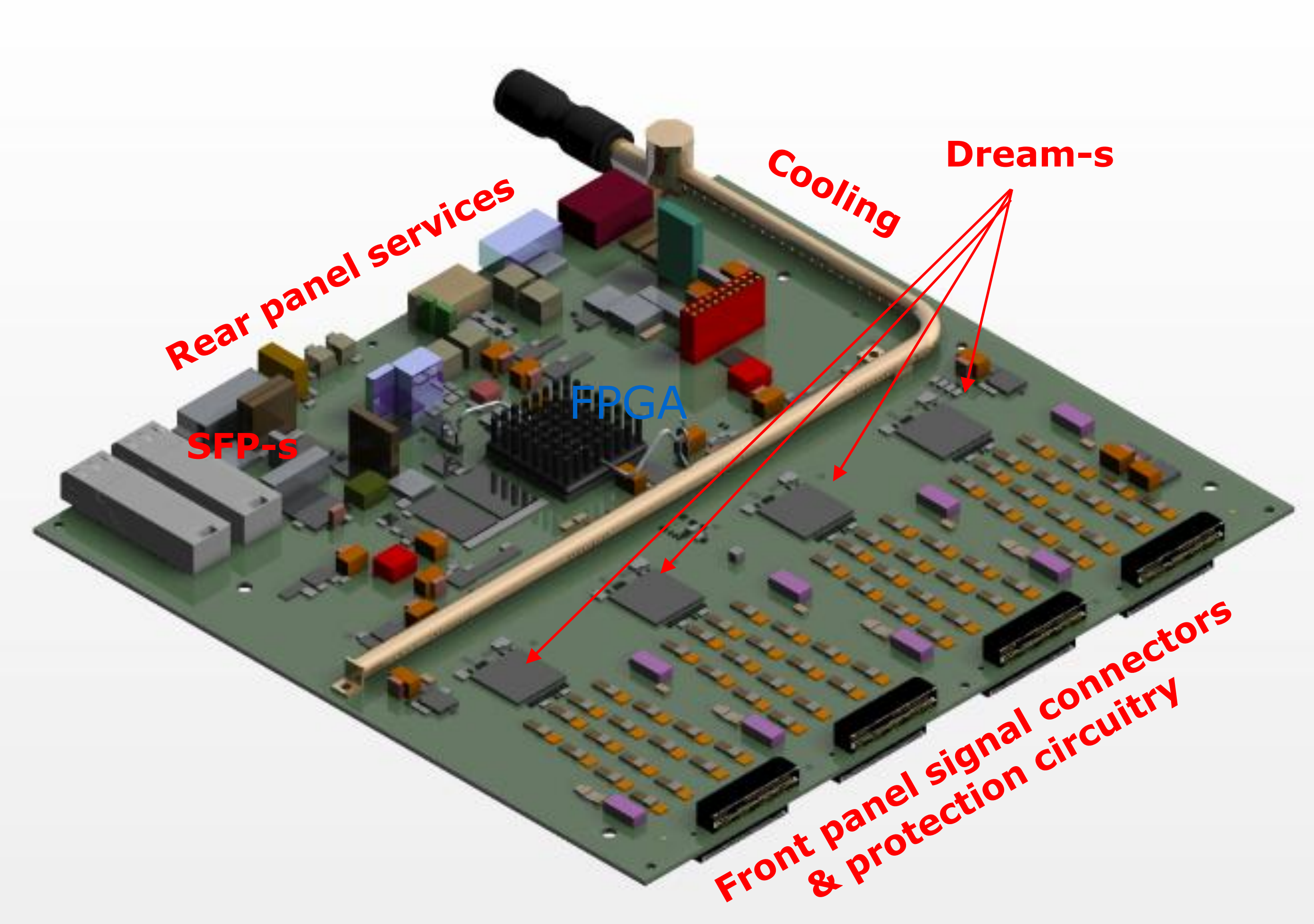




- Tailored for detectors with high capacitances
  - ~30% less noise compared to the previous generation **After** ASIC
  - Depending on Clas12 detector type ENC of 2000-2700 is expected from measurements
- Version 1 submitted
  - Added intermediate peaking times for more flexibility
  - Few minor bugs corrected
  - Packaged chips expected in May-June

512-channel FEU

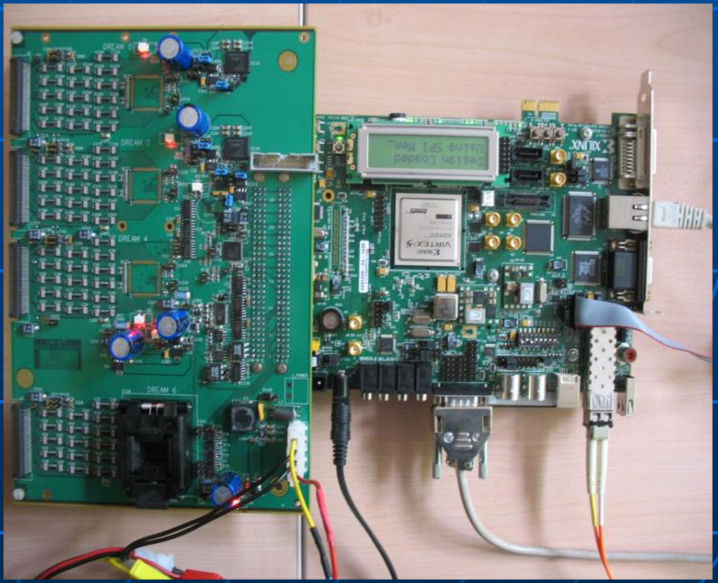
- Actives on top & bottom sides
  - 8 Dream ASICs
  - 8-channel 40 MHz ADC
  - Virtex-6 FPGA
  - SFP cages
    - 2.5 Gbit/s optical link
    - 1Gb Ethernet
  - JTAG based system monitor
- On-board air cooling pipes
  - Top & bottom
- Top / bottom shielding



FEU functionalities

Protection	8 Dream ASICs	8-channel Flash ADC	FPGA	SFP transceiver
Against HV	Amplification Shaping Sampling Pipeline & derandomization	Digitization	Control Pedestal subtraction Coherent noise removal Zero suppression Derandomization	Optical link with BEU concentrator

- Firmware development and validation on the Dream test bench systems
  - Up to 6 Dreams
    - 5 soldered and 1 on socket
- Test bench systems are used for detector readout

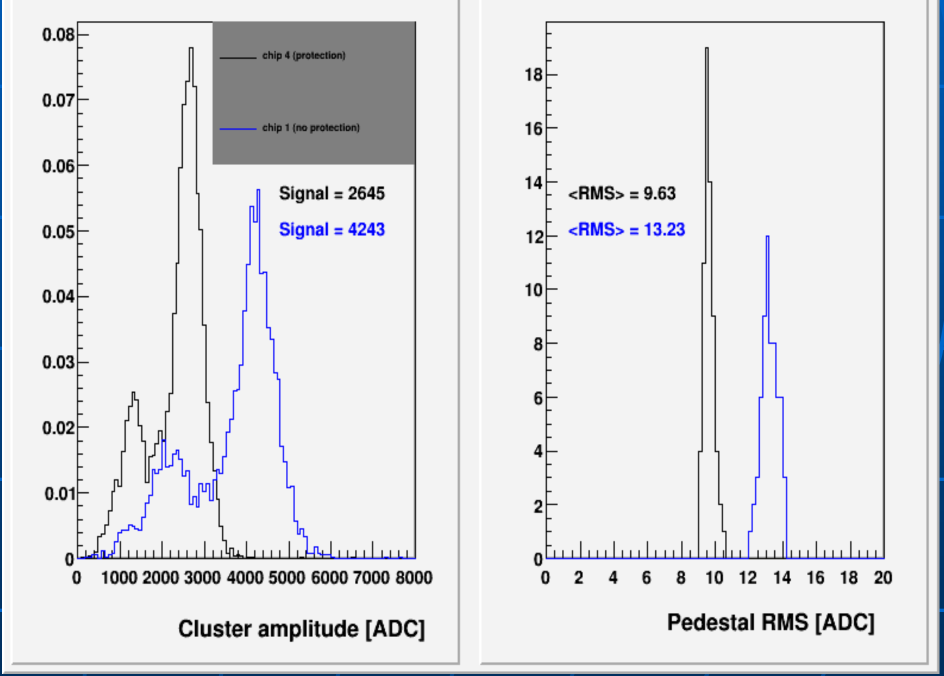


S / N

- Tests with previous generation After chip and Dream chip
  - Small (C_d=20pF) and large (CR-Z type, C_d=~60pF) detectors
  - 1.5-3 m long micro-coaxial cables
  - Dream: S/N improvement of 13-23%
    - The gain increases with C_d

- Tests with resistive MM detectors
  - No protections needed
    - Tested under conditions of heavy sparks
      - No damage to naked electronics
    - S/N improvement of ~15%
      - In addition to higher achievable gains
  - Forward MM detectors
    - Resistive
    - ~2m away from electronics

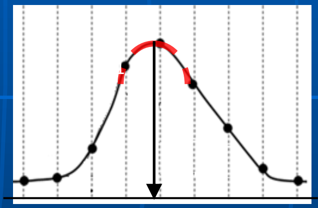
Fe source



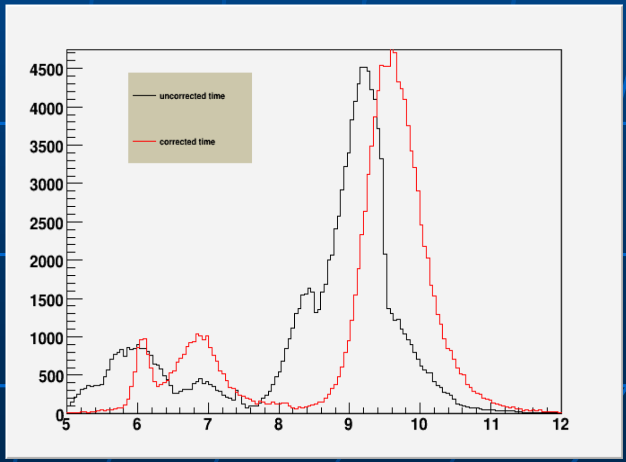
Courtesy: S. Procureur

Time resolution: preliminary

- Conditions:
  - Detector with large strips and large 10mm drift space
  - Tests with cosmic ray trigger
    - Walk of a few ns
  - Trigger sampling frequency 125 MHz (8 ns)
  - Dream sampling frequency 125 / 6 = 20.8(3) MHz (48 ns)
  - For each trigger firmware keeps a fine timestamp
    - Δt between rising edge of trigger and rising edge of Dream sampling clock
    - 6 different values is steps of 8 ns
- Analysis
  - Find max of "3-sample fit" around the signal max
  - Correct with fine timestamp



- 15ns time resolution



- Improvements:
  - 3mm drift space of target detectors
  - Timing of a cluster, not of a single strip
  - Synchronous trigger

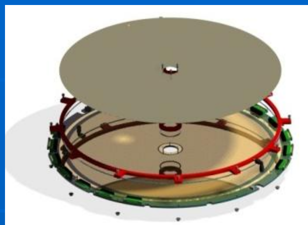
Courtesy: S. Procureur

Electronics status: Cables and ASIC

- Detector cables: Hitachi 40 pF/m cables
  - → Design validated
  - → Pre-series ordered

- 64-channel DREAM: fully operational ASIC
  - → 2800 ENC with 220 pF input capacitance
    - Compatible with aimed S/N 30 – 40
    - Minor modifications for final design
  - → Submission for series production next month
    - Software for automated test bench under development
    - 1 k ASICS to be delivered beginning of 2013

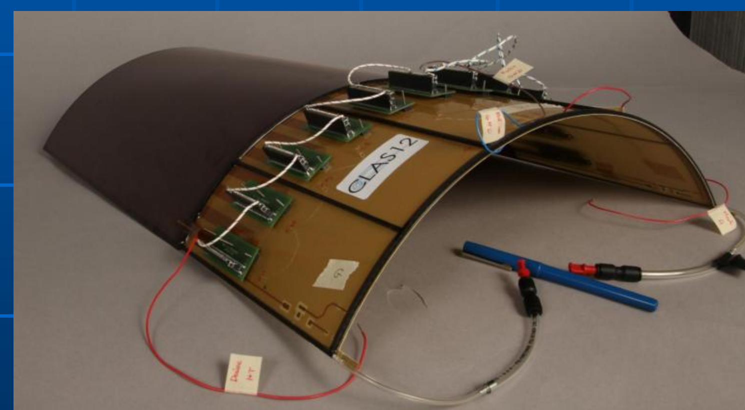
Next steps



Tests started on new forward resistive disk

R & D on serigraphy techniques to apply resistive layer on large areas.

Production of detectors to start in 2014… and delivery at Jlab during 2015



Irfu team:

Detectors Division: S. Aune, D. Attié, M. Boyer, E. Delagnes, A. Giganon, J. Giraud, R. Granelli, C. Lahonde-Hamdoun, I. Mandjavidze, O. Meunier.

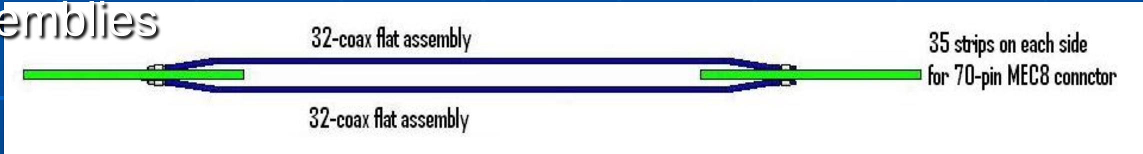
Nuclear Physics Division: J. Ball, G. Charles, M. Garcon, S. Procureur, F. Sabatié.

Back up

Detector links

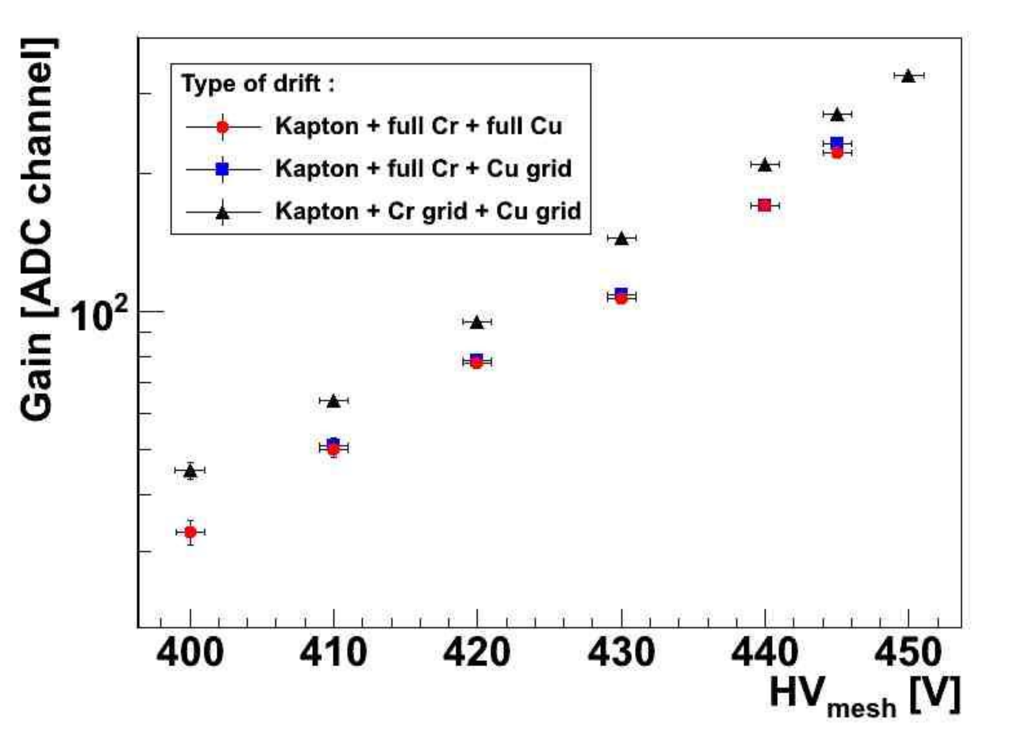
- 2011-2012 R&D:
  - Hitachi micro-coaxial cables
    - Round cable assemblies
    - 50 pF/m linear capacitance
    - 1.5m length
  - Can stand sparks
    - Tests equivalent of 5 years of operation

- Pre-series production
  - 64-channel flat cable assemblies
  - 8 g/m weight
  - 40 pF/m capacitance
  - Four 1.5 m long and four 2 m long cables
  - Expected this week
    - To be tested before green light for production



- Series production offer received
  - Forward tagger: 1m long – 80 units
  - Barrel MVT: 1.5m long – 400 units
  - Forward MVT: 2m long – 120 units

Drift foils tests



Tests were done on the same Z detector with different types of drift foils:

- Kapton fully copper coated, with a Cr sublayer.
- Kapton with a grid of copper
- Kapton with a grid of chromium and grid of Cr

The chromium grid foil could be used decreasing significantly the material budget. Further tests with cosmics are still ongoing and resistance towards sparks tests are also needed.