Status of GEM Trackers for Super Bigbite Spectrometer at JLab

Kondo Gnanvo (UVa)

On behalf of the SBS Collaboration

University of Virginia (UVa)

N. Liyanage, V. Nelyubin, H. Nguyen,

X. Bai, D. Di, R. Wang

INFN Roma, Catania, Genoa

E. Cisbani, P. Musico

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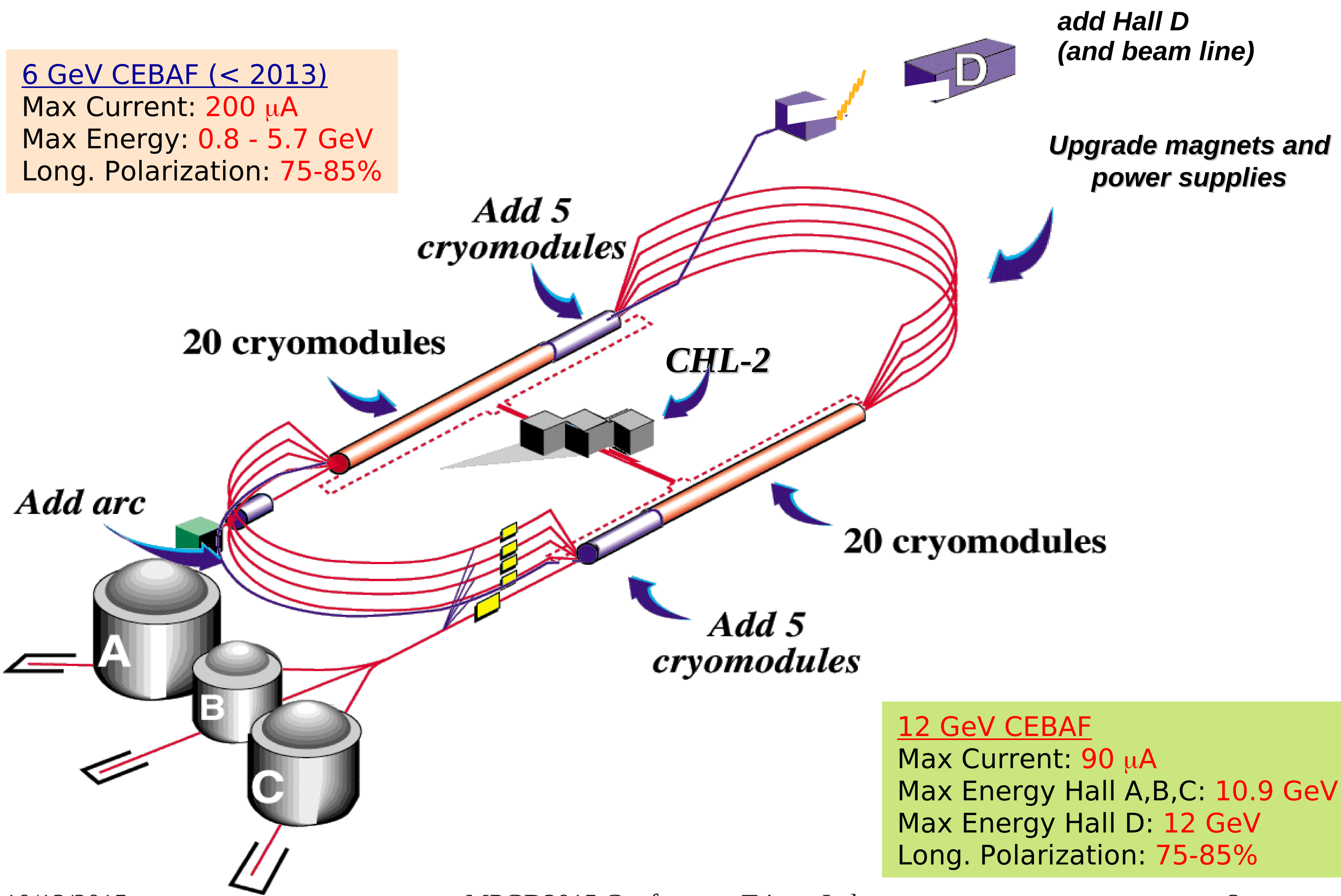
Outline

- GEM Trackers for Super Bigbite Spectrometer (SBS)
- Issues with large-area & light-weight GEM detectors
- APV25 readout electronics

The 12 GeV upgrade of CEBAF accelerator @ JLab

6 GeV CEBAF (< 2013)
Max Current: 200 μA
Max Energy: 0.8 - 5.7 GeV
Long. Polarization: 75-85%



12 GeV CEBAF
Max Current: 90 μA
Max Energy Hall A,B,C: 10.9 GeV
Max Energy Hall D: 12 GeV
Long. Polarization: 75-85%

Physics program in Hall A for the CEBAF 12 GeV era @ JLab

SBS physics program

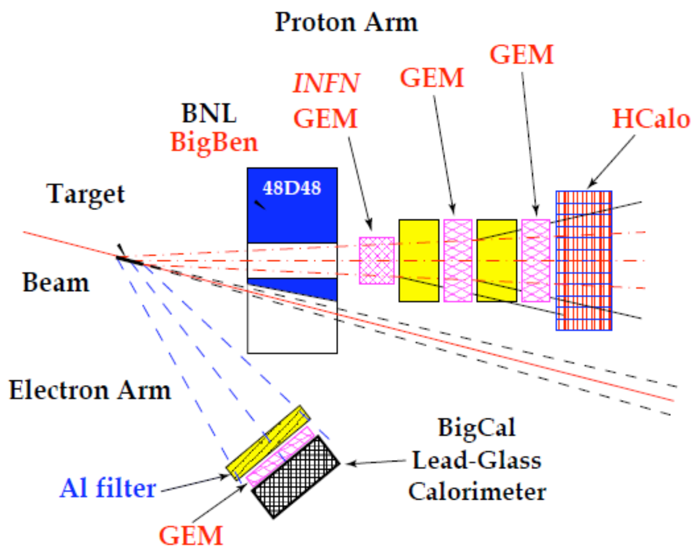
- **GEP** : 12 $(GeV/c)^2$
- GMN: 13.5 $(GeV/c)^2$
- GEN: 10 $(GeV/c)^2$
- SSA in nSIDIS: 30,000 gain vs HERMES

==================================

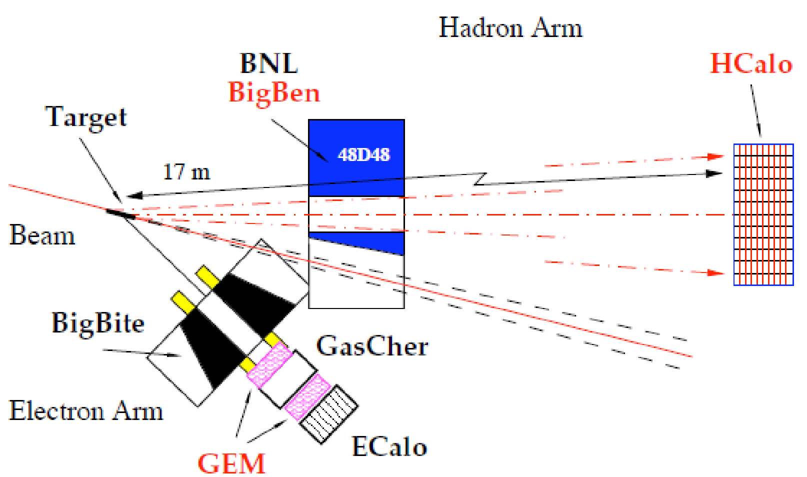
- **A1n**/d2n – gain ~ 20-30 compared with HMS/SHMS
- TDIS meson DIS
- WACS-ALL, full proposal, 100x gain in productivity
- GEnRP, ready for full proposal,10+x gain in productivity
- pol H(γ,φ p), H(γ,π^o p)
- PVDIS – gain 10-15 compared with two HRSs
- A1p/d2p – gain ~20-30
- D(e,e'd) - A,T20
- J/Psi as gluon probe of QCD – well matched to BB/SBS
- A(e,e'p), A(e,e'$\pi^{+/-}$)

- Nucleon Form Factors
- SIDIS, TMDs
- Nucleon Structures

Proton form factors ratio, GEp(5) (E12-07-109)

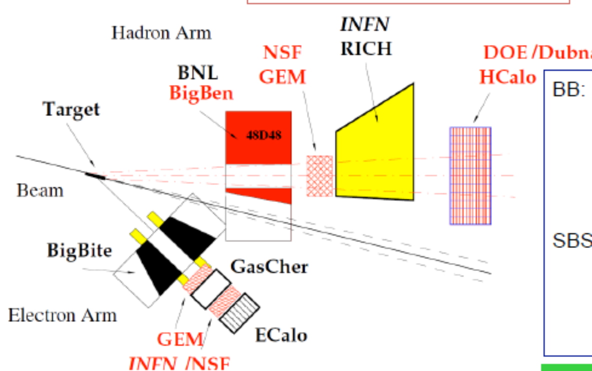


Neutron form factors, E12–09–016 and E12–09–019



SIDIS experiment (conditionally approved)

e+^{3}He↑→e'+π(K)$^{\pm}$+X



BB: e-arm at 30°
Ω = 45 msr
GEM Tracker
Gas Cherenkov
Shower
⇐ GMn/PR-09-019
SBS: h-arm at 14°
Ω = 50 msr
GEM tracker
excellent PID / RICH
Hadron CALO

Beam: 50 μA, E=8.8 and 11 GeV (80% long. Pol.)
Target: 65% polarized 3He ⇐ GEn(2)/PR-09-016
⇨ Luminosity: 1.4×10^{37} $cm^{-2}s^{-1}$, 0.05 sr

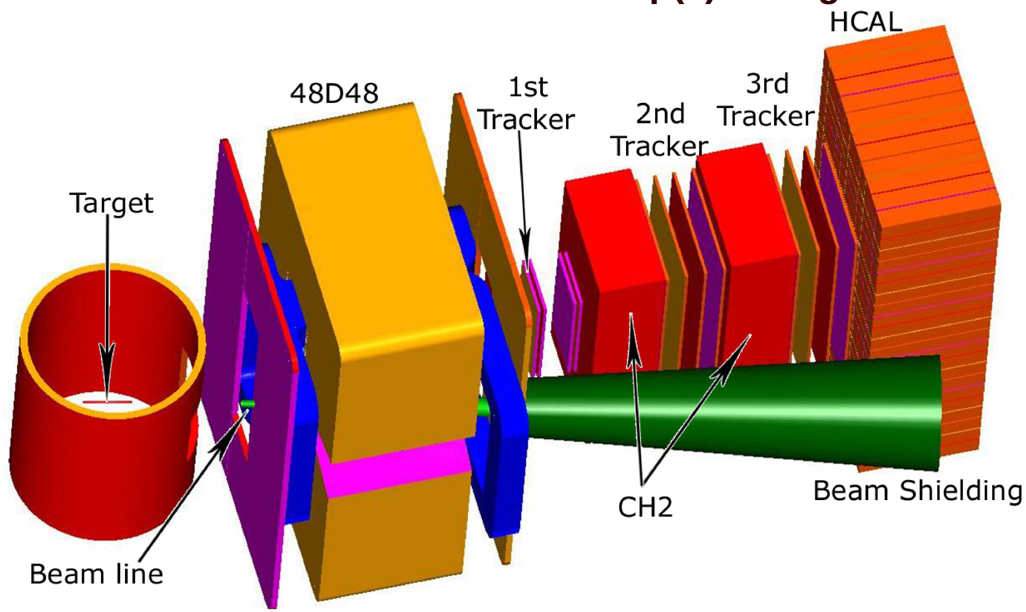
Event rate: ~10^4×HERMES
60 days of production
expected stat. accuracy:
1/10 of proton HERMES

Requirements for the Super Bigbite Spectrometer (SBS)

Experiments	Luminosity $(s\cdot cm^2)^{-1}$	Tracking Area (cm^2)	Resolution		
			Angular (mrad)	Vertex (mm)	Momentum (%)
GMn - GEn	up to $7\cdot10^{37}$	40x150 and 60x200	< 1	<2	0.5%
GEp(5) **Most demanding**	**up to $8\cdot10^{38}$**	40x150, 60x200 and 80x300	<0.7 ~1.5	~ 1	0.5%
SIDIS	up to $2\cdot10^{37}$ High rate	40x150 and 60x200 Large area	~ 0.5 Spatial resolution < 100 microns	~1	<1%

- Large luminosity
- Large acceptance
- Forward angles
- Re-configurable detectors
- Polarized Proton Target

Proton arm of the SBS in the Gep(5) configuration

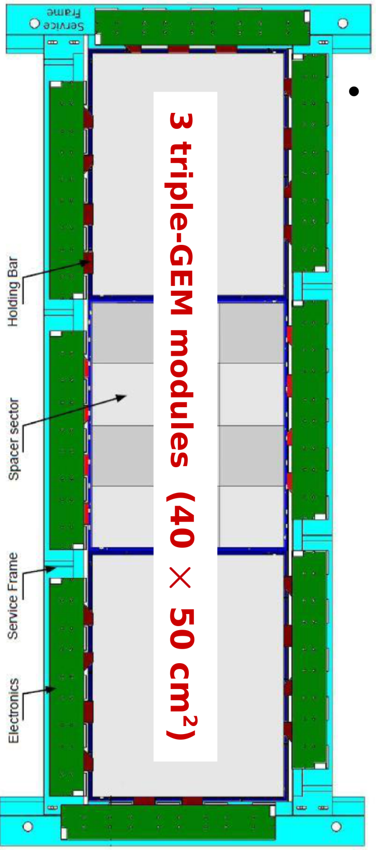


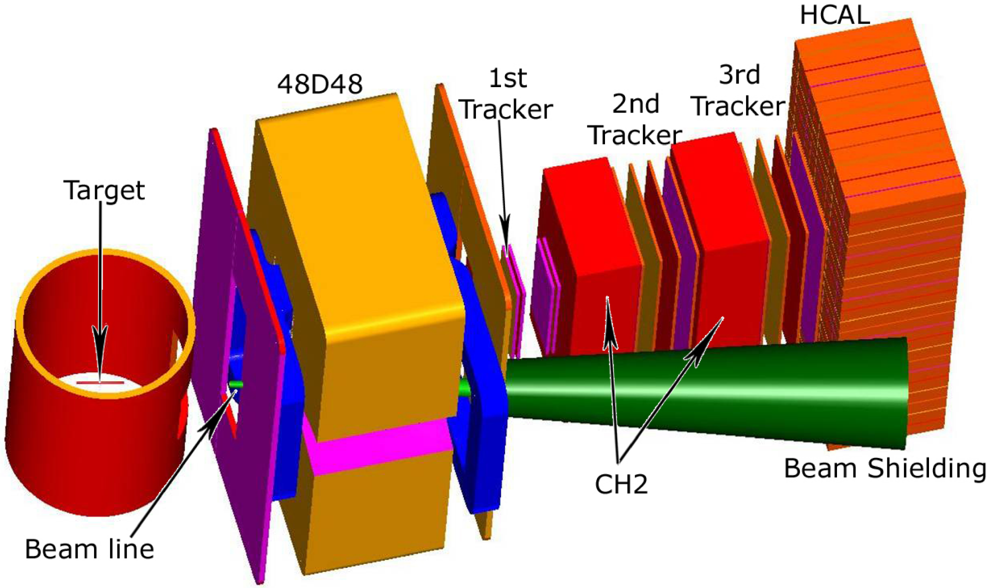
High photon backgound up to 250 MHz/cm^2 and electron background 160 kHz/cm^2

SBS GEM Trackers

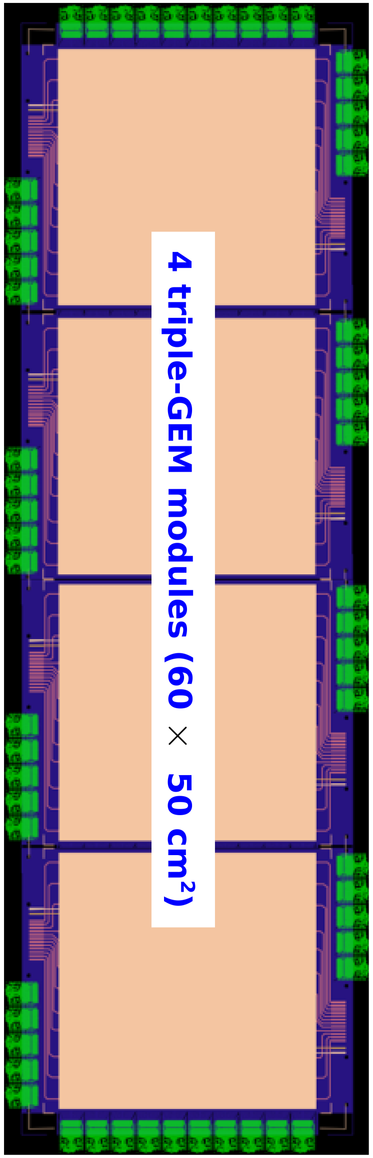
- **Front Tracker (FT): Track of the recoil protons**
  - 1st tracker: 6 GEM layers, active area of 150 × 40 cm^2
  - Each layers: vertical stack of 3 GEM modules (50 × 40 cm^2)
  - Total production of 18 modules
- **Back Tracker (BT): Proton Polarimetry**
  - Polarization of the recoil protons
  - 2nd & 3rd Trackers: 10 layers, active area of 200 × 60 cm^2
  - Each layer: vertical stack of 4 GEM modules (60 × 50 cm^2)
  - Total production of 40 (+ 5) modules

Front Tracker Layer,,INFN (Rome, Catania)



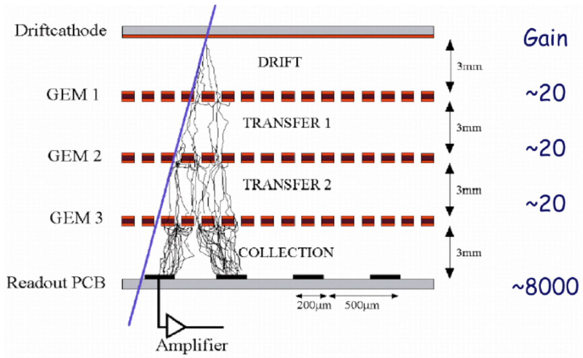


Back Tracker layer (UVa)



Assembly of the SBS Triple-GEM modules

Standard COMPASS triple-GEM

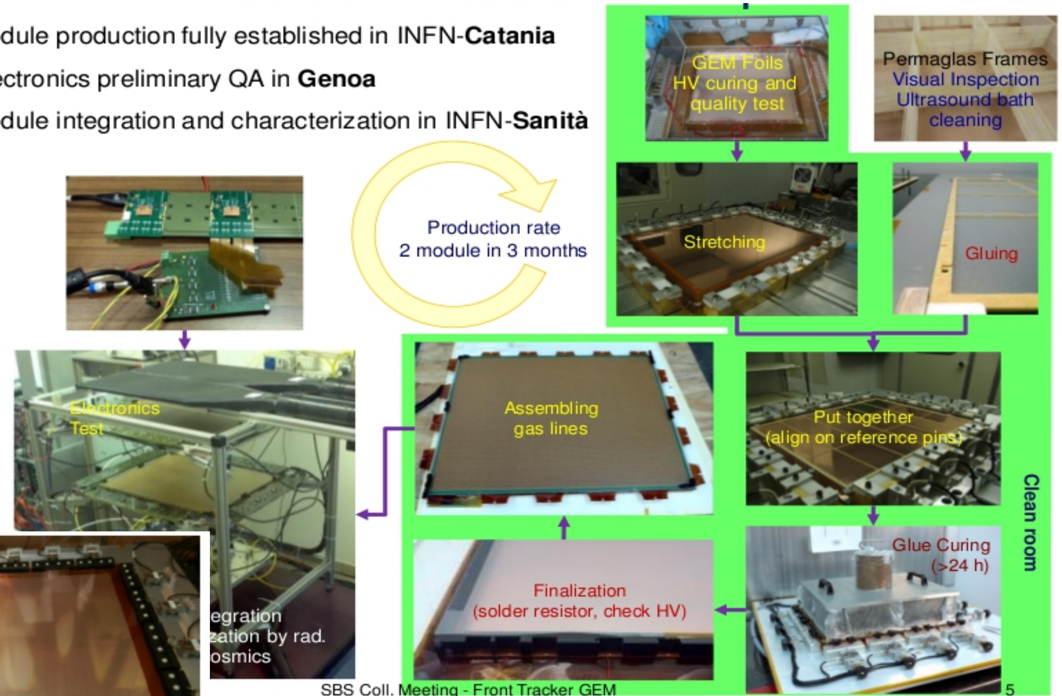


Assembly steps of the Front Tracker GEMs

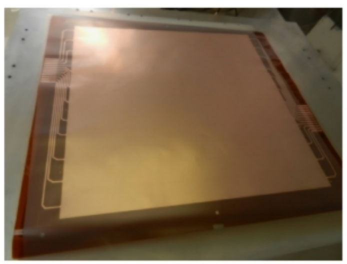
Module production fully established in INFN-**Catania**

Electronics preliminary QA in **Genoa**

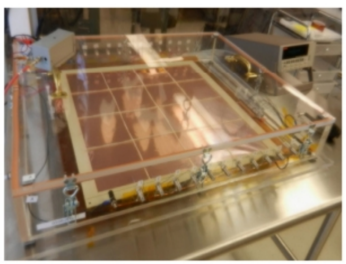
Module integration and characterization in INFN-**Sanità**



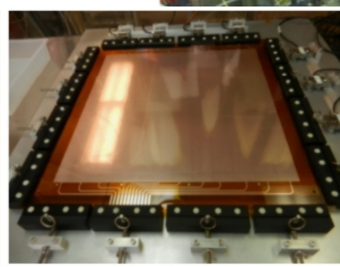
Parts of the Back Trackers Polarimeter GEM



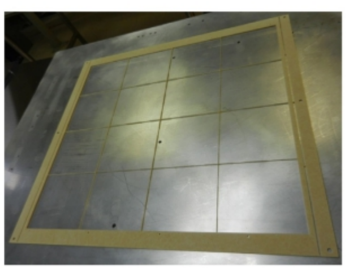
GEM foil with the visible contact of the HV sectors



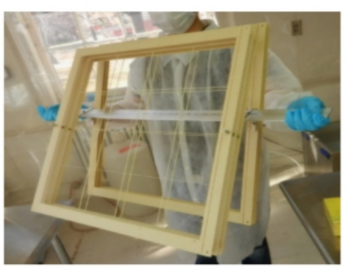
GEM foil in the N_2 box for leakage current test



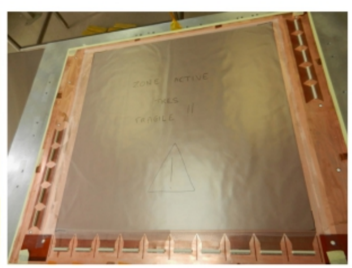
GEM foil on the mechanical stretcher



Support frame for GEM with 300 μm spacers inside the active area

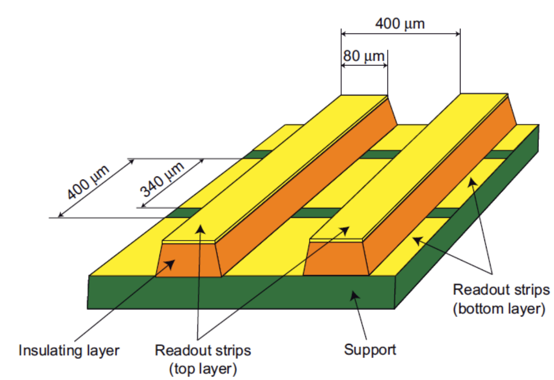


Frames on a custom holder for cleaning in Ultrasonic bath



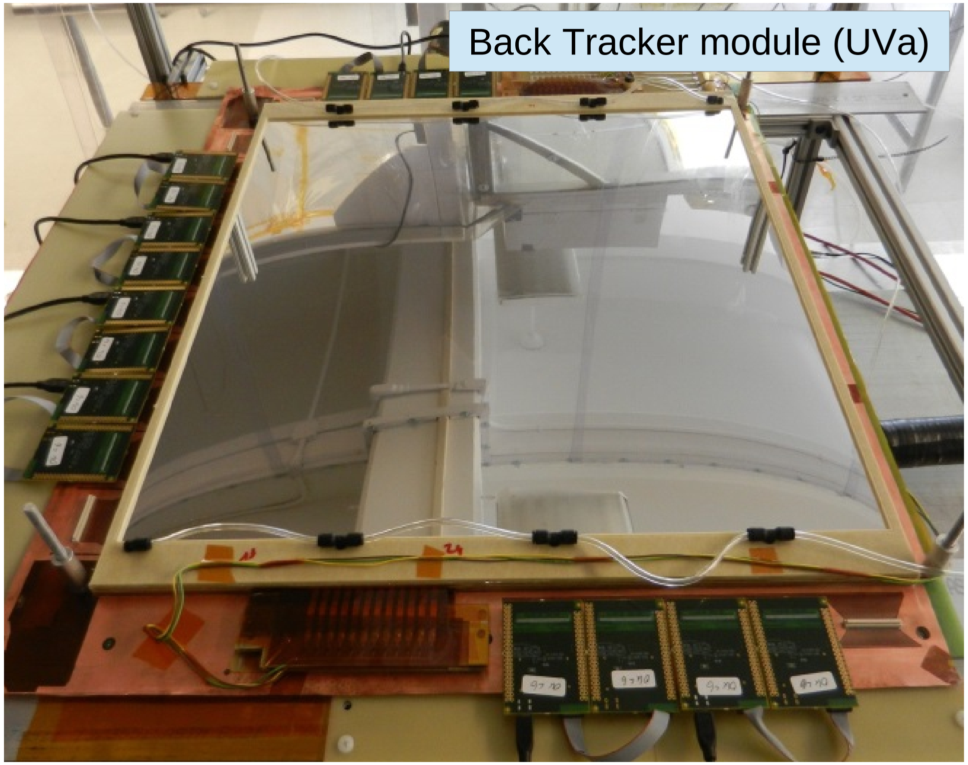
Two dimensional flexible readout board

Standard COMPASS 2D readout board



SBS GEM modules

- Spatial resolution < 0.1 mm; high radiation tolerance
- Lightweight triple-GEM detectors (0.7% radiation length)
- Readout layer: 2D x/y strip ala COMPASS (0.4 mm pitch)
- APV25-based electronics with VME64x modules (total channels > 120K channels)



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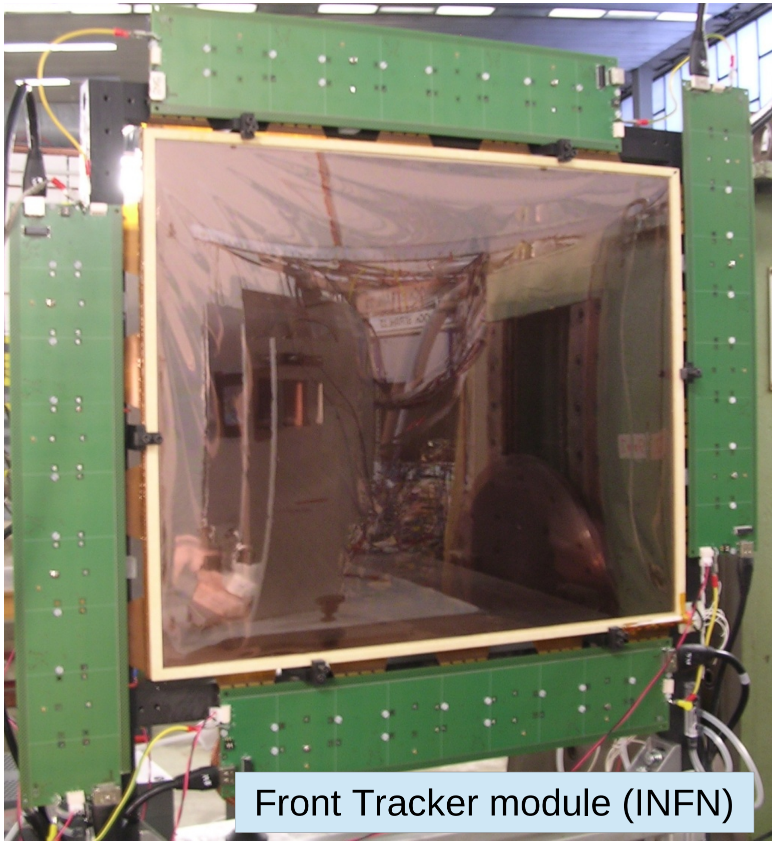
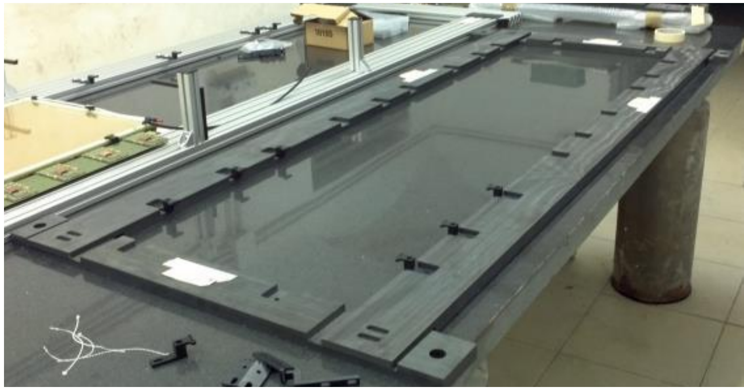


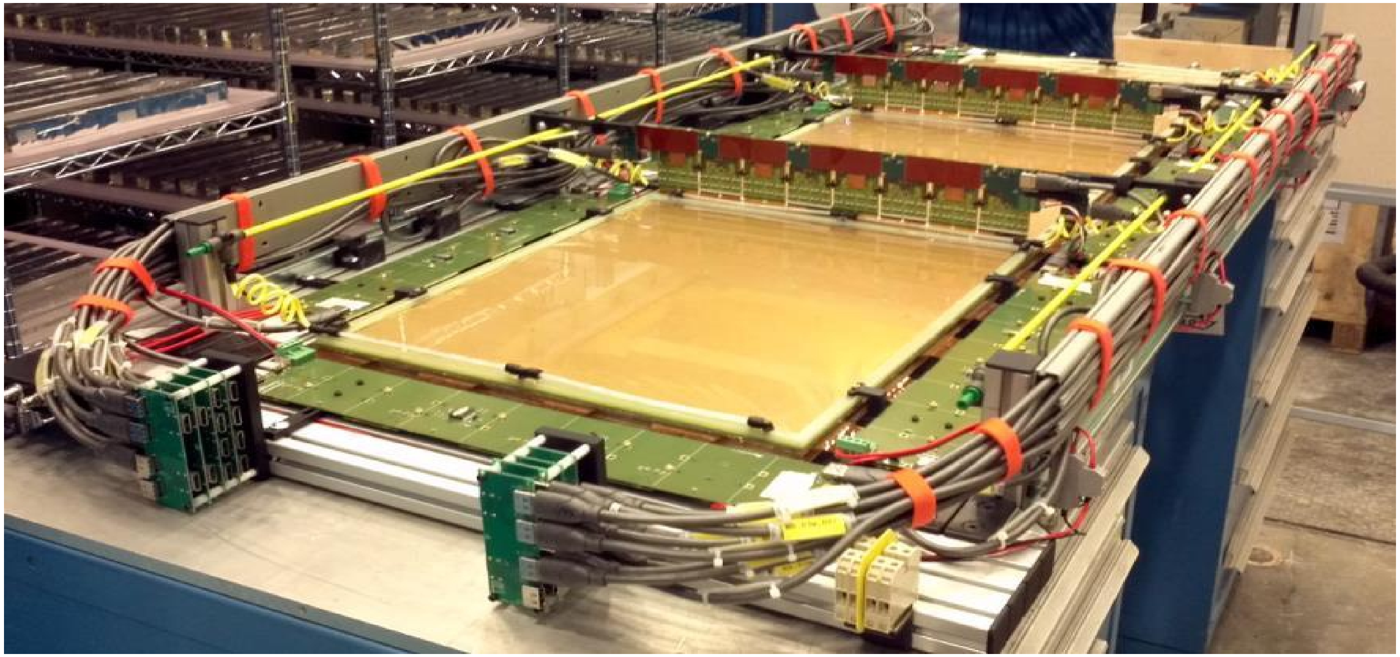
Production Status



Carbon fiber Holding frame
More compact and more rigid option
minimize thermal deformation

Front Tracker GEMs

- 18 modules to be completed by mid 2017
- 8 modules already assembled with 4 tested
- One full layer integrated with APV25 cards @ JLab
- 4 layers expected by end 2016



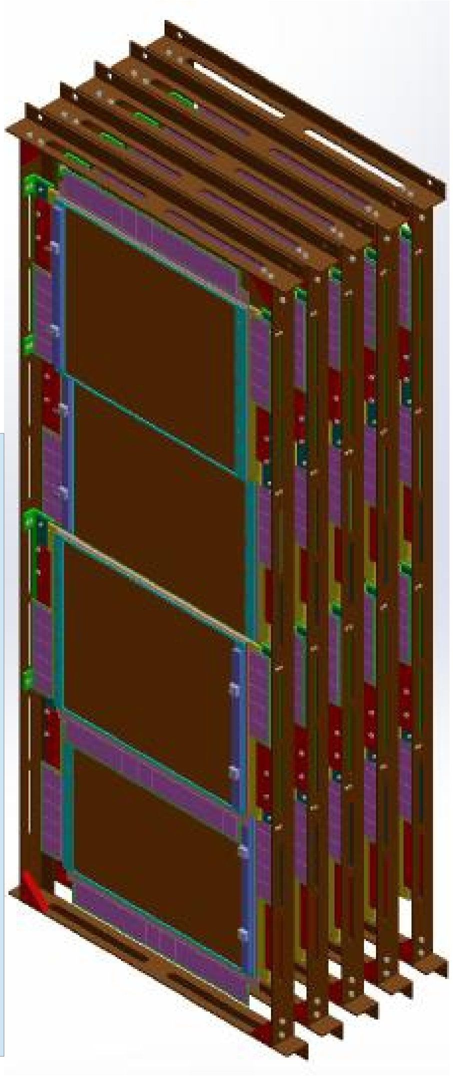
Production Status

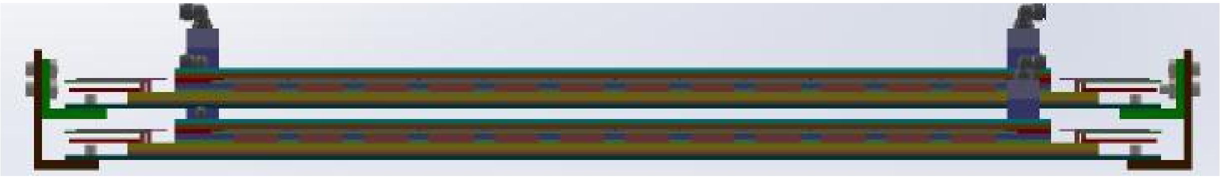
Back Tracker GEMs

- 45 modules to be completed by mid 2017
- Production rate of 2 modules / month
- 19 modules successfully tested as of Oct. 2015

Holding frame:

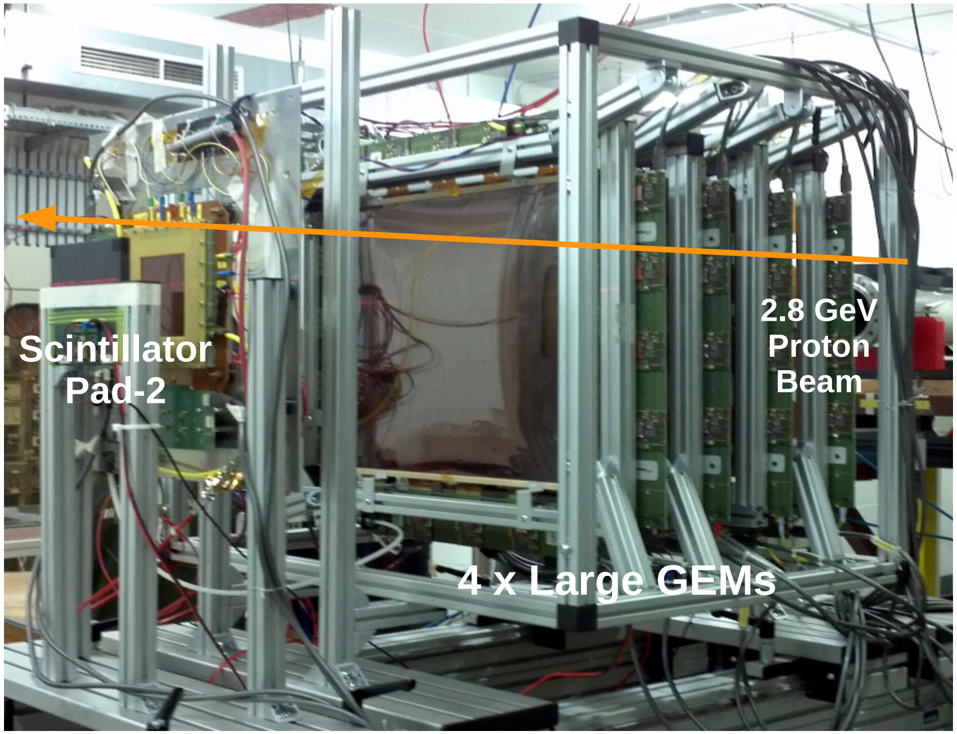
- 4 modules: 2 modules sitting directly on the frame (bottom plane), other 2 modules on L-shape (top plane)
  - This minimizes dead area
  - And allow easy replacement of the modules and of the FE cards
- The holding frames are under production @ JLab

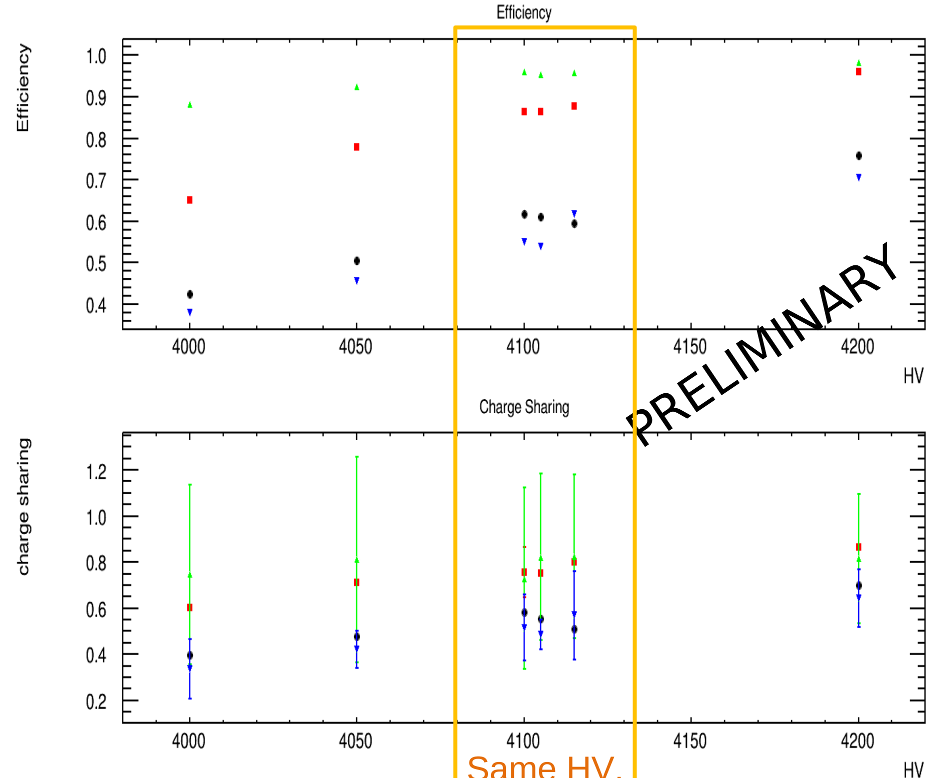




Performance in Test Beam

FT GEM modules high Intensity Proton beam in Julich COSY Test Beam (Oct. 2014)





Black – low gain (m1)
Red – moderate gain (m2)
Green – normal gain (m3)
Blue – very low gain (m4)

- Study GEM response in high intensity proton beam (small spot ~ few cm^2)
- Different dividers on different module
- Investigate HV and gas flow

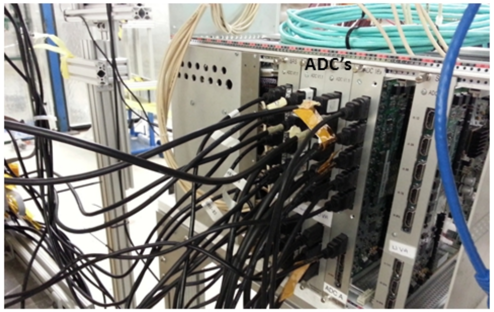
- Efficiency slightly affected by the high beam intensity
- No noticeable effects from gas flow rate

Performance in Test Beam

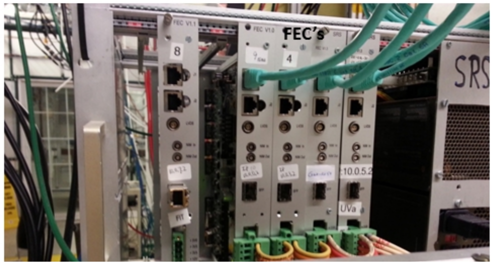
BT GEM modules in Test Beam @ FNAL (Oct. 2013)

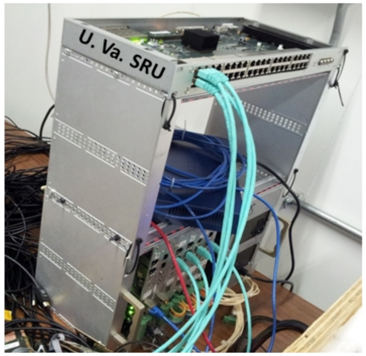
- Two SBS BT GEM prototypes tested at FTBF
- APV25-SRS electronic tested at trigger rate 400 Hz
- Data analysis for spatial resolution, gain efficiency, gain uniformity, timing of the APV25 signal …
- FNAL test beam data reveals big issues (Gas flow, Quality of X/Y readout board etc)

SRS + SRU Readout using DATE @ FTBF

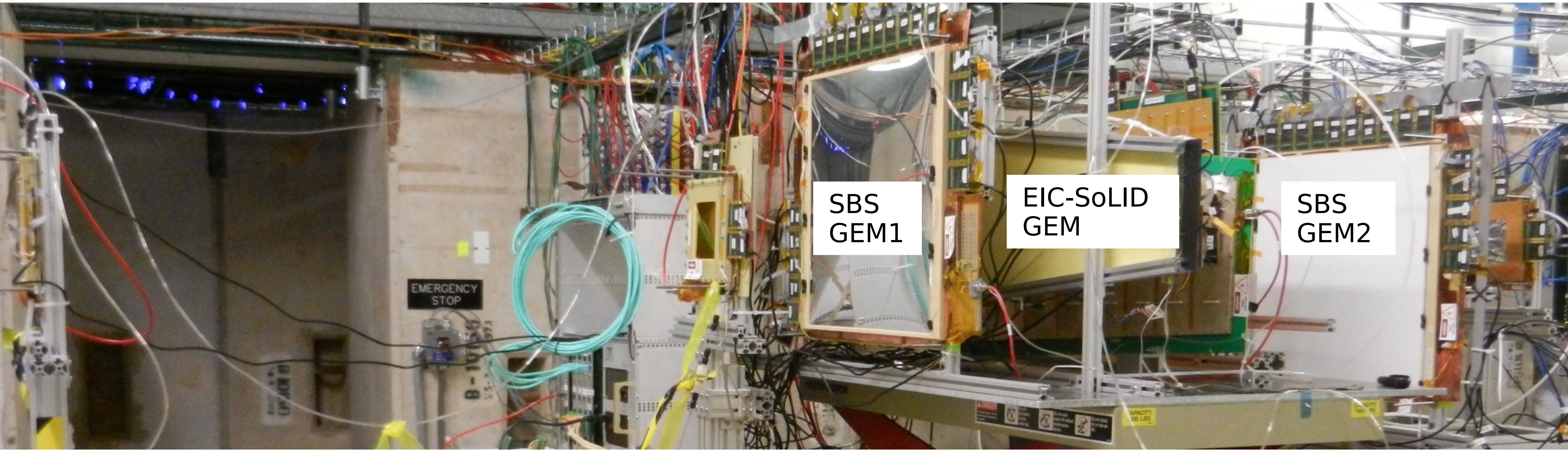


- 64 APV's read out by SRS
- Acquiring data from FECs with an SRU
- Current DAQ rate is ~150 Hz
- Using 6-9 25ns time slices for digitization
- Beam structure: 4s spills, 1min rep. time, 10 - 20k particles/spill
- Trigger: coincidence of 3 scintillators



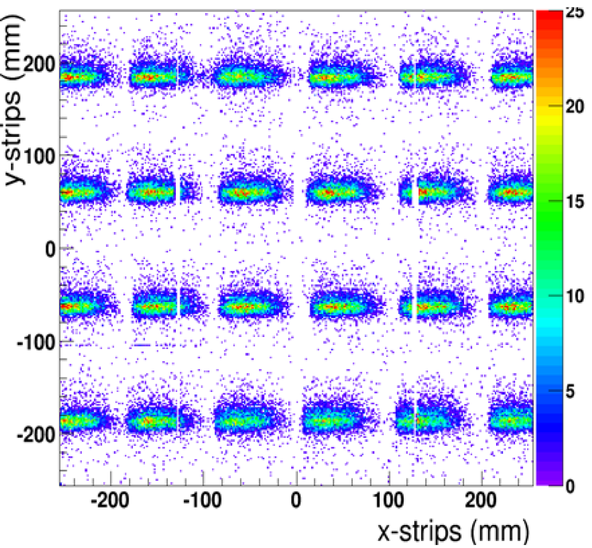


Large GEM Test Beam Setup @ (FNAL) UVa & FIT

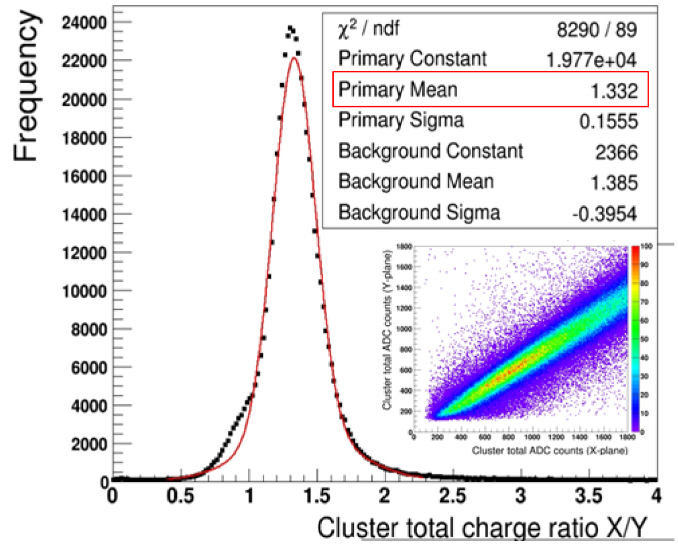


Performances in test Beam

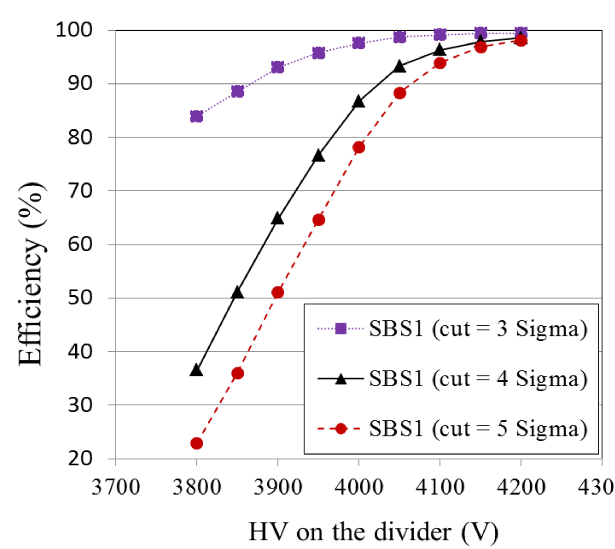
Hadron beam reconstruction



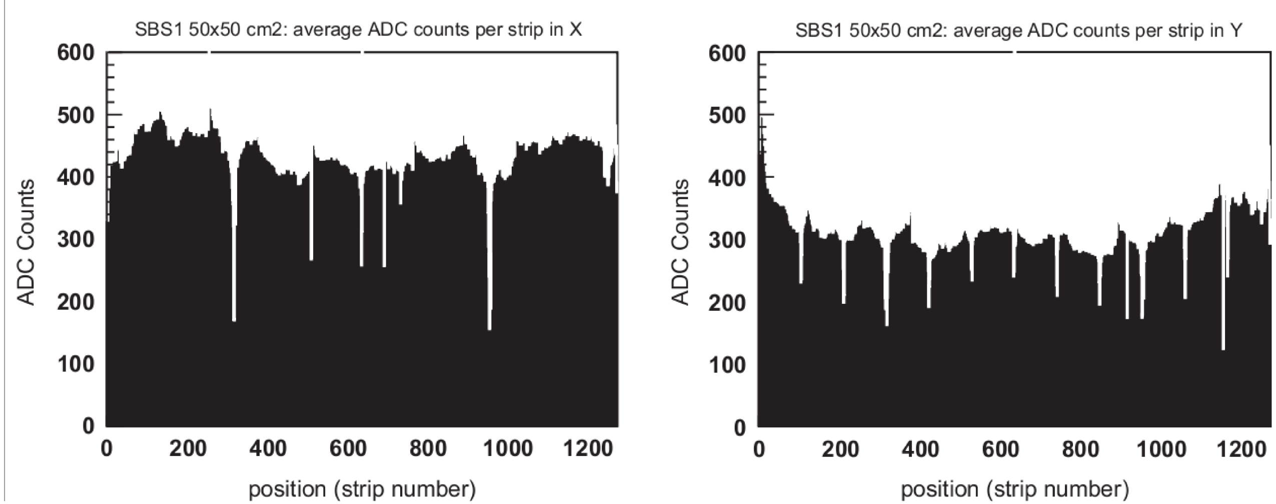
Charge sharing



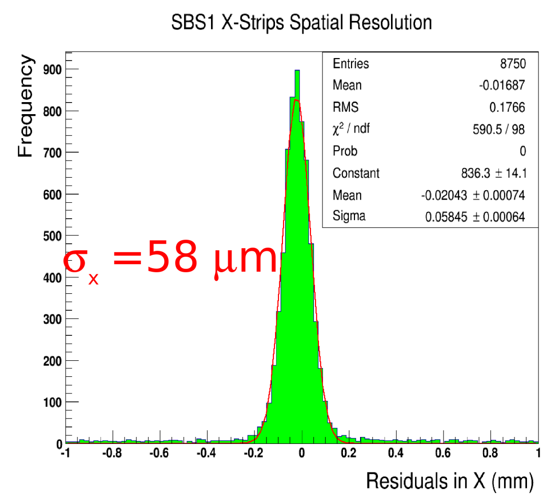
Efficiency curve vs. HV



Gain uniformity



Spatial resolution



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Outline

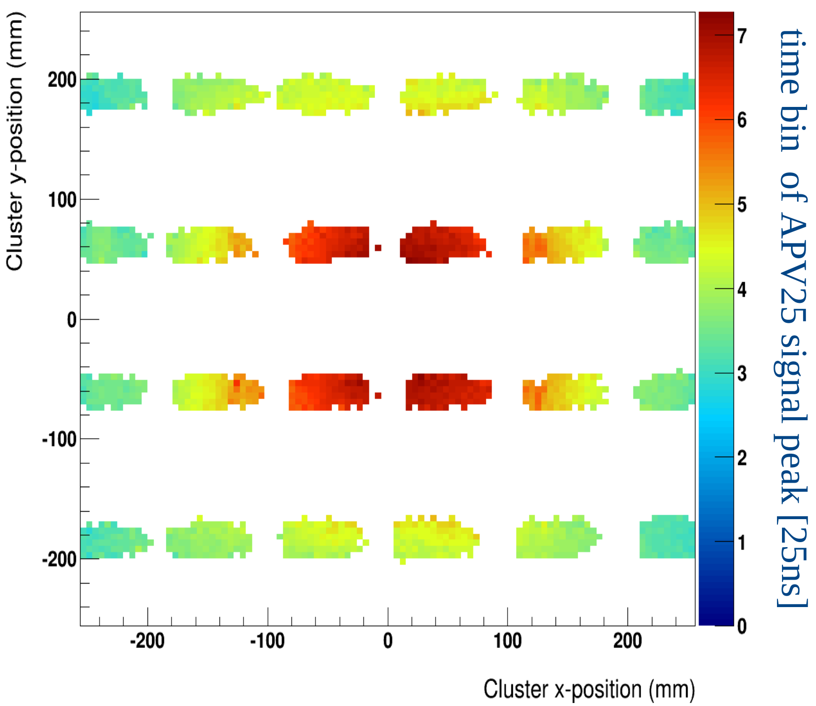
- GEM Trackers for Super Bigbite Spectrometer SBS
- Issues with large-area & light-weight GEM detectors
- APV25 readout electronics

Deformation of the readout board

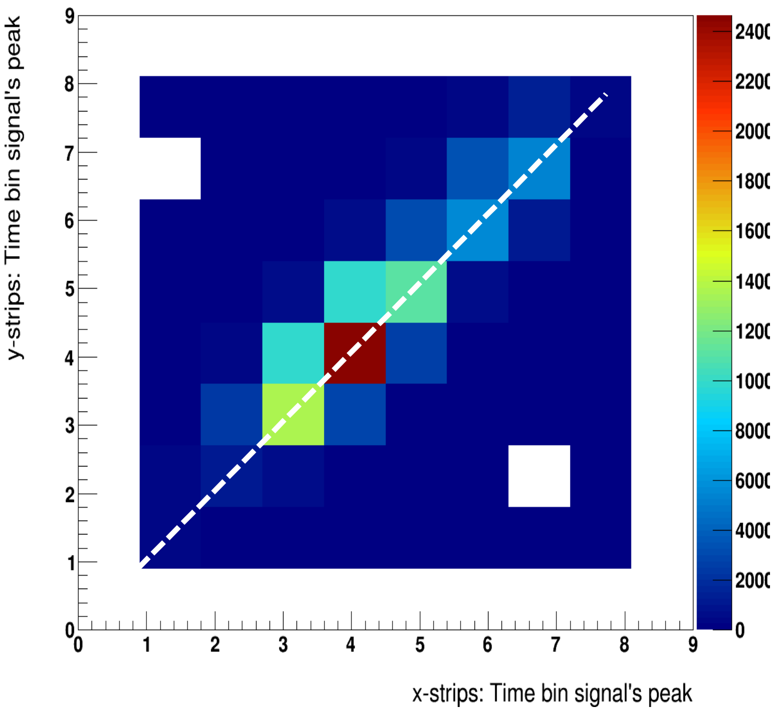
Analysis of the APV25 signal timing from the FNAL Test Beam data

- We looked at the spatial distribution of the the APV25 signal peak w.r.t. the trigger delay (arbitrary reference)
- Strong spatial non uniformity of the signal timing ➔ Induced charge signal collected later by the readout strips in the center of the detector than at the edges.
- Difference as high as 4 time bins (100 ns) between center and edges
- Excellent timing correlation of the signal in x-strips and y-strips ➔ the readout electronics not the source

Distribution of time bin of the signal peak



X-Y correlation of the time bin of the signal peak

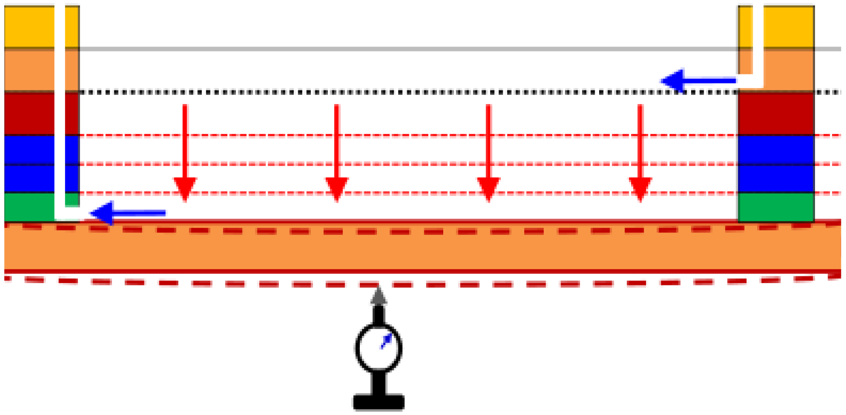


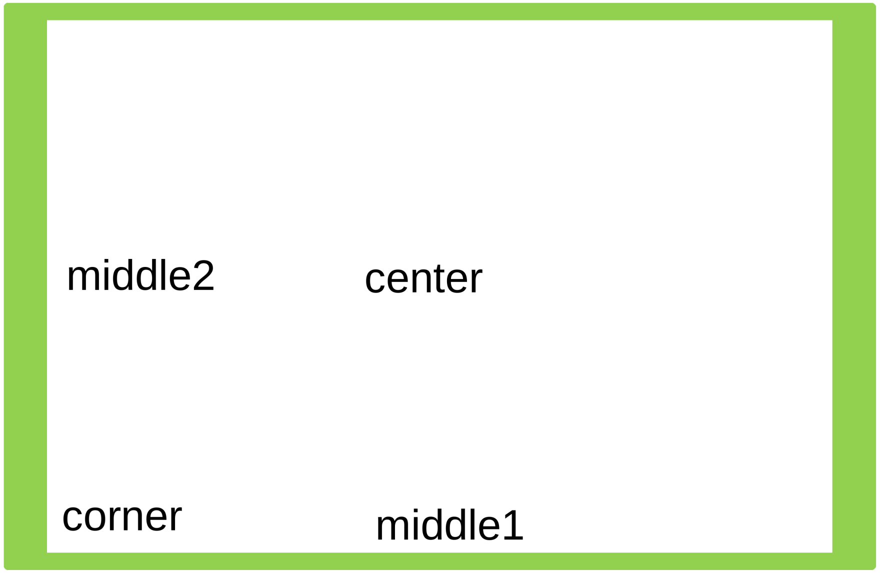
Cause: Deformation of the readout board due to over pressure caused by the gas flowing inside the detector

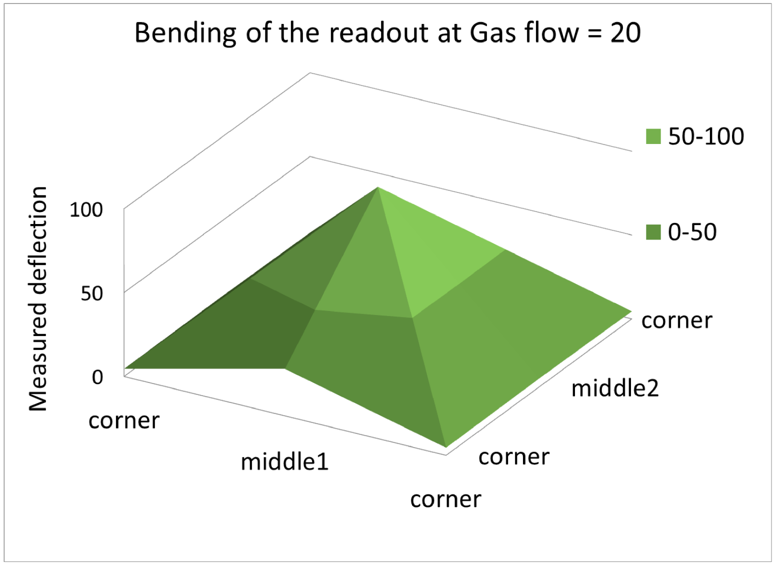
Deformation of the readout board

Measurement of the deformation of the readout board

- Setup of a test (see cartoon on the left) to measure the bending of the readout board (honeycomb support) with the Ar/CO_2 flow rate inside the chamber
- Measurement were taken at 4 location on the bottom side of the honeycomb support
- The measured deflection of 100 units is equivalent to 2.54 mm
- A gas flow = 10 units represent about 2 volumes (V) change / hour in the GEM chamber (V = 3.6 L)



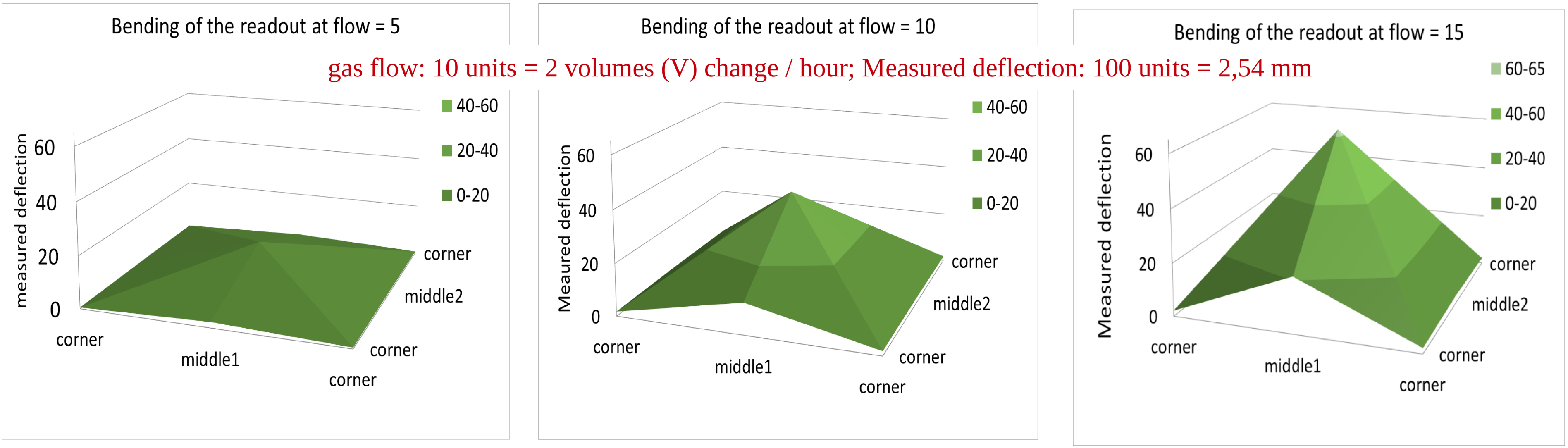


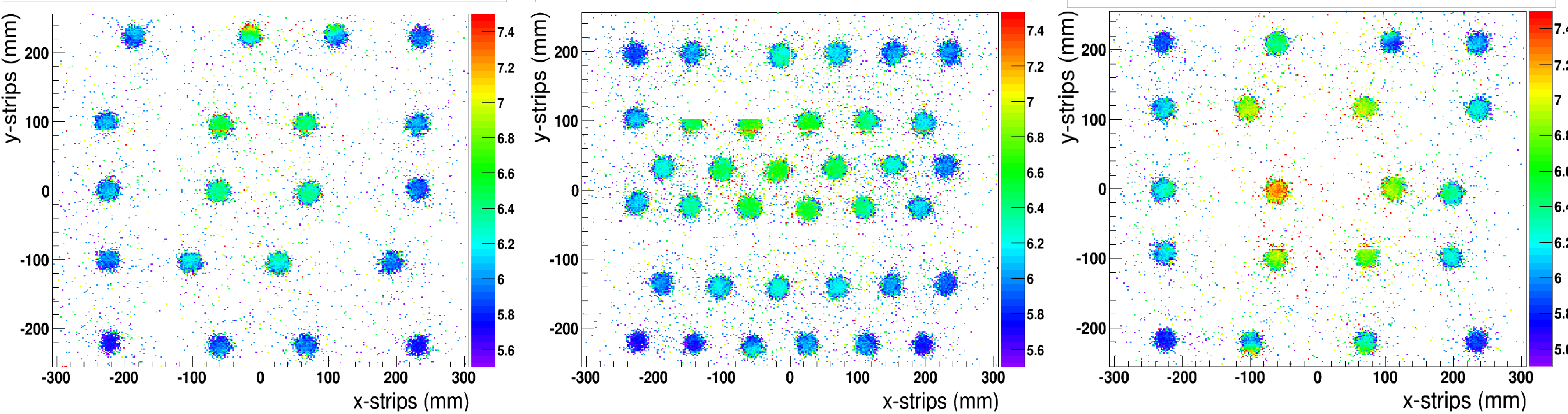


Deformation of the readout board

Measurement of the deformation of the readout board

gas flow: 10 units = 2 volumes (V) change / hour; Measured deflection: 100 units = 2,54 mm



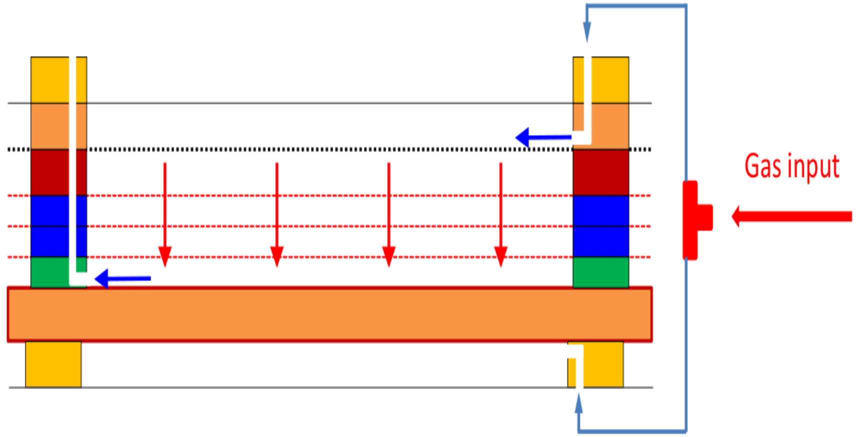


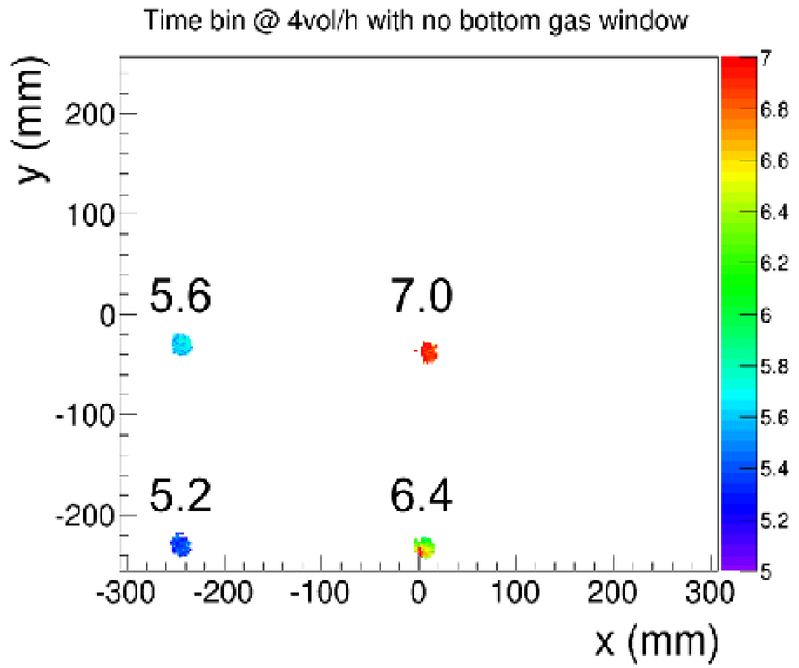
- APV25 signal peak time bin measured with Sr90 source at different flow rates.
- Amplitude of the non uniformity depend on the gas flow (more precisely built-up pressure in the chamber)
- Clear correlation between the time bin of signal peak and the deformation of the readout board

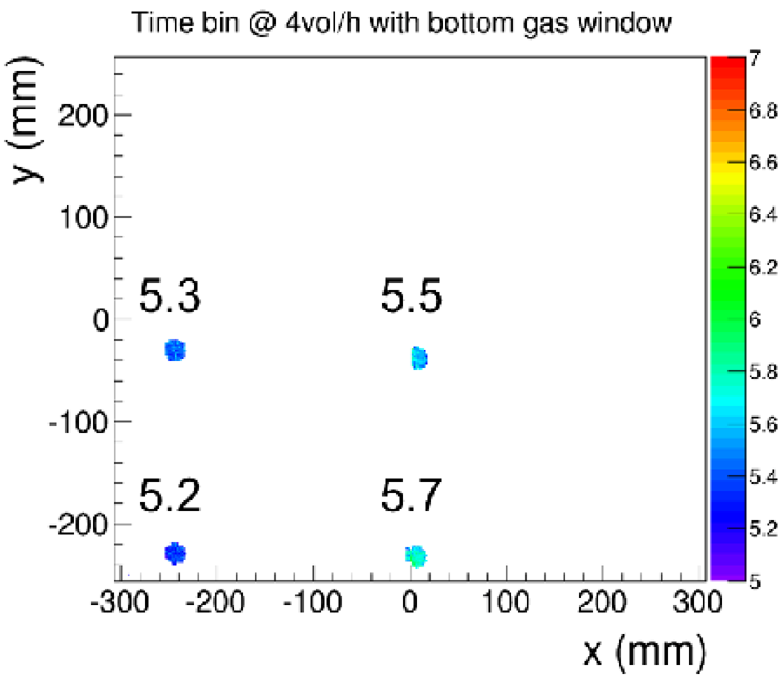
Deformation of the readout board

Solution: Compensate the deformation of the readout board with a bottom gas volume

- Adding the bottom gas window significantly reduce considerably the spatial non uniformity of the signal speak time bin at high gas flow rate
- In addition, we also slightly change the gas flow design of the chamber to reduce the pressure built-up inside the chamber







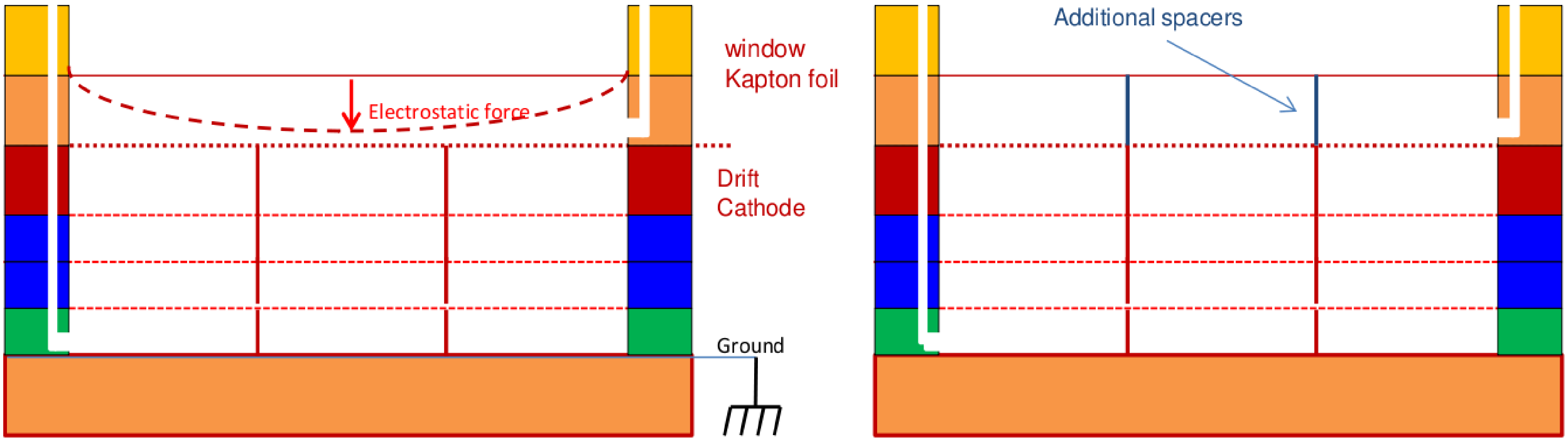
Entrance gas window foil collapse

Problem

- High particle rate over a large area of the detector ⇨ charging up of the Kapton foil ⇨ Strong electrostatic attraction between gas window & drift cathode
- Strong distortion of the APV25 signal (timing and shape)

Initial proposed solution

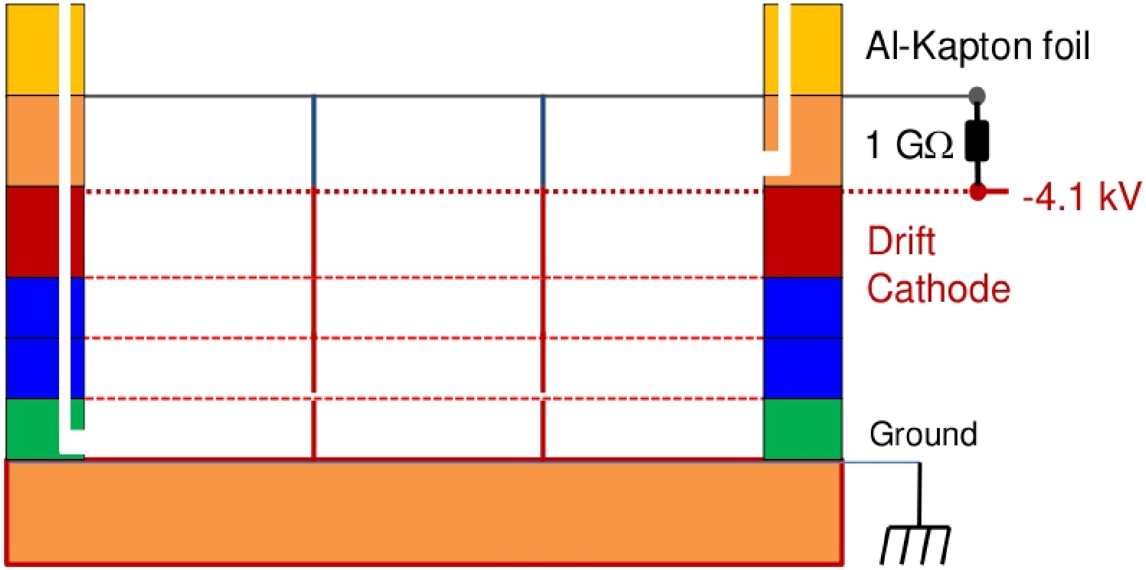
- A simple initial fix was to add some spacers in the gas window region of the chamber
- We saw a improvement but not sure about long term stability of the fix in high rate condition

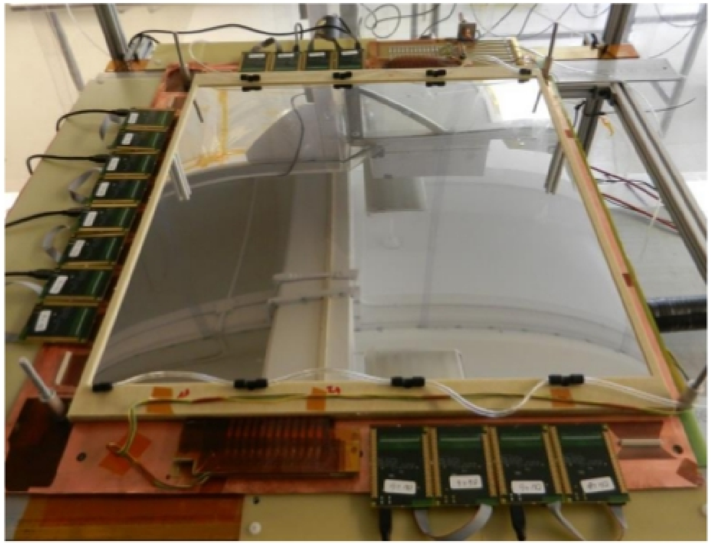


Entrance gas window foil collapse

Final proposed solution

- Use aluminized gas window foil and set it to the same potential as the drift cathode ➔ Faraday cage like to prevent charges accumulation on the gas window as well as the top layer of the drift
- Tested with SBS-BT-GEM with x-ray source at high rate > 1 MHz /cm2 equivalent MIP.
  - Without the HV on the gas window ⇨ foil collapse after a few hours of x-ray exposure
  - With the HV on, we did not observe any collapse after 5 days of almost continuous exposure





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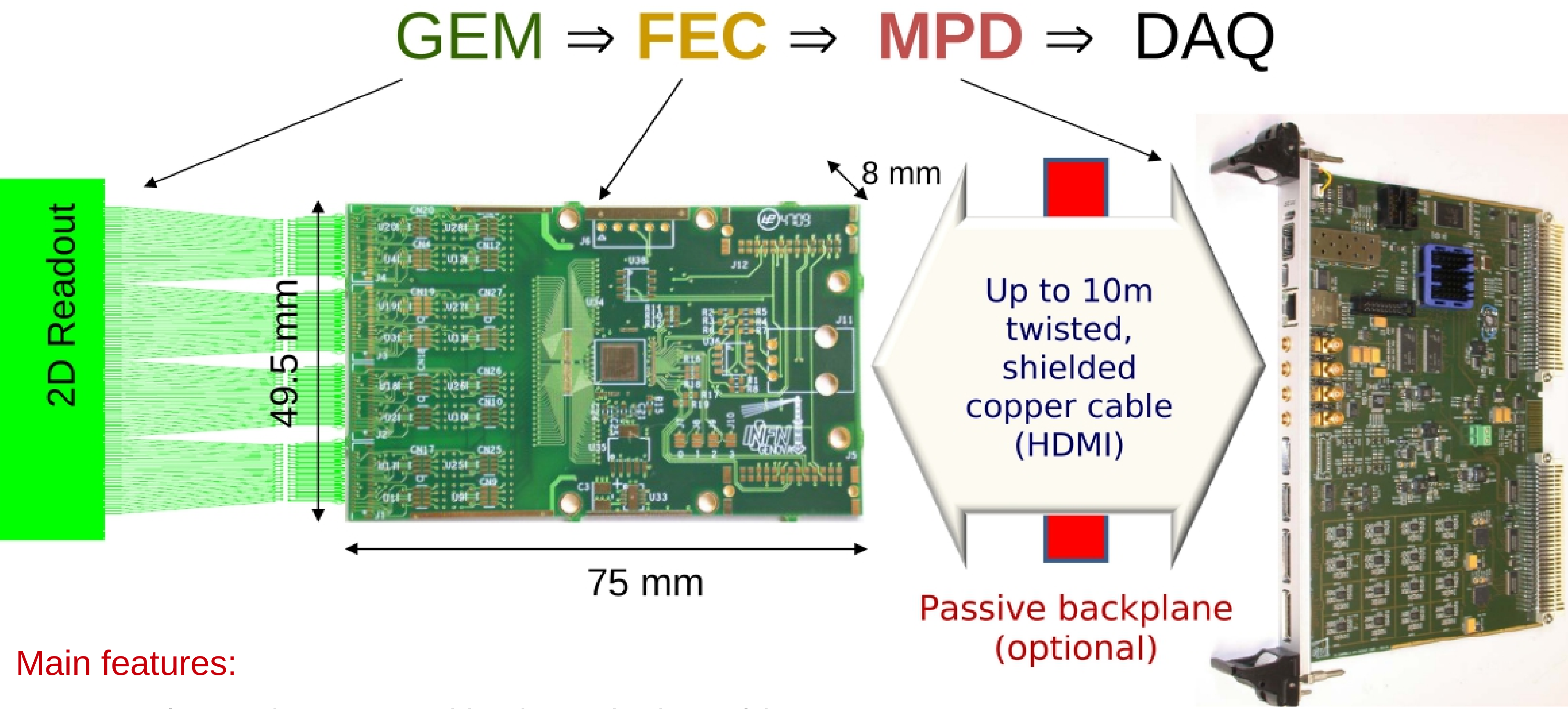
Readout electronics for SBS GEM Trackers



Main features:

- Use analog readout APV25 chips (> 100 k Channels)
- 2 actives components: APV25 Front end cards & VME64x module: Multi Purpose Digitizer (MPD)
- HDMI cables to transfer data between these two components

APV25 FE cards and Back planes

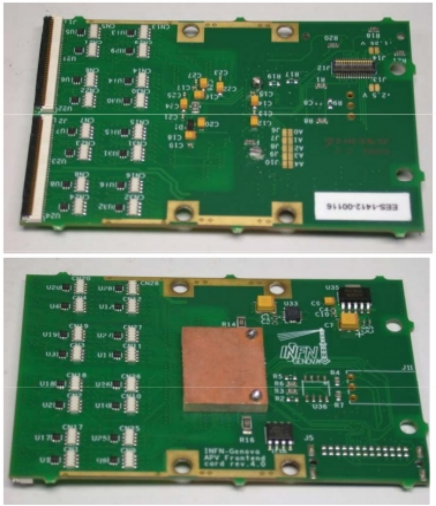
Different versions of the APV25 FE card produced

- v 4.10 with ZIF connectors for the FT Modules
- v 4.11 with Panasonic connectors for BT Modules

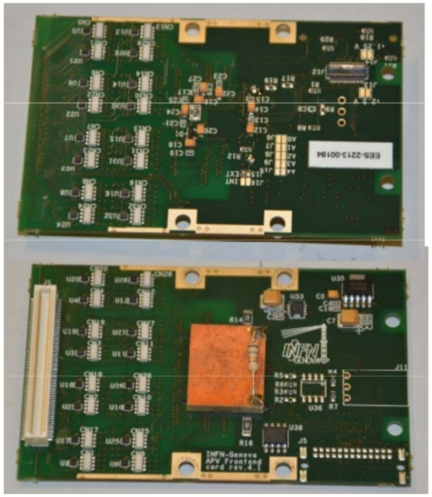
Different versions of the back planes

- 2 types for the Back Tracker GEMs: 5 and 12 slots
- 1 type for the Front Tracker GEM: long 5-slots

v 4.0
Front Tracker GEM

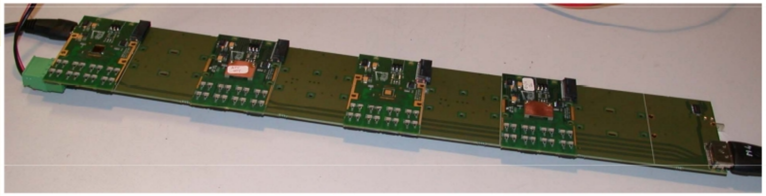


v 4.11
Back Tracker GEM (UVa)

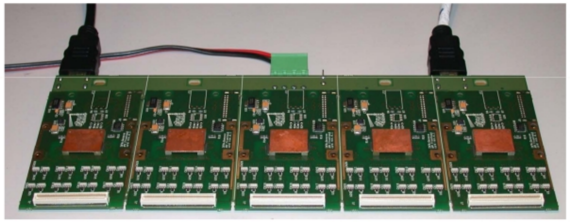


Backplanes

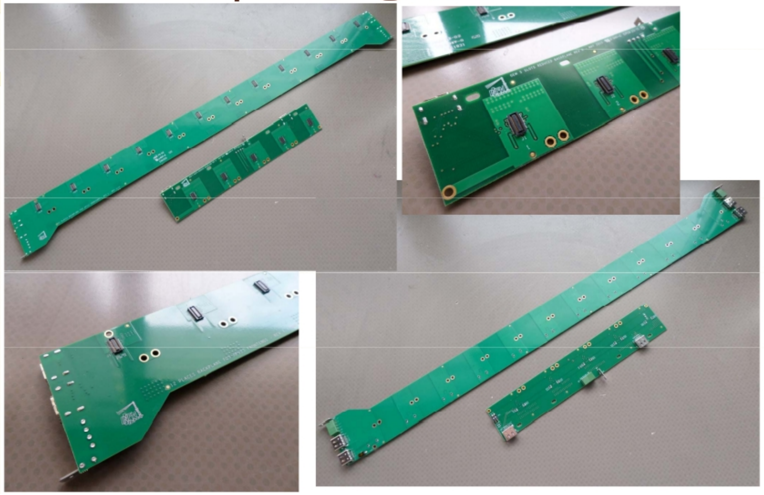
Used in the Front Tracker with RH LVPS



Original design for the Back Tracker (UVa) with RH LVPS



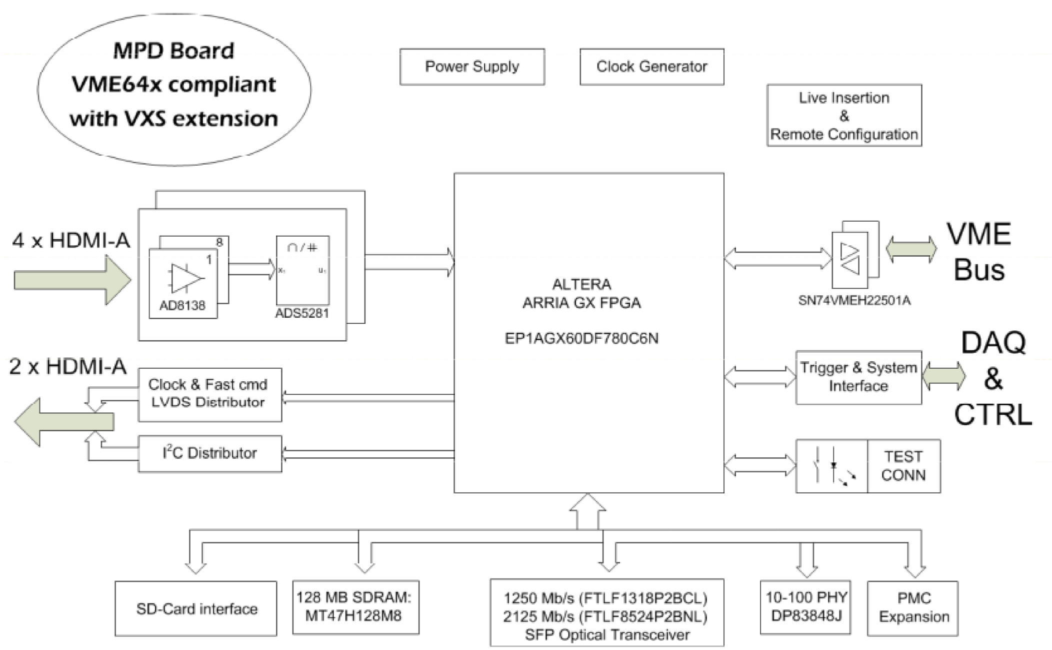
UVa Backplanes @ EES

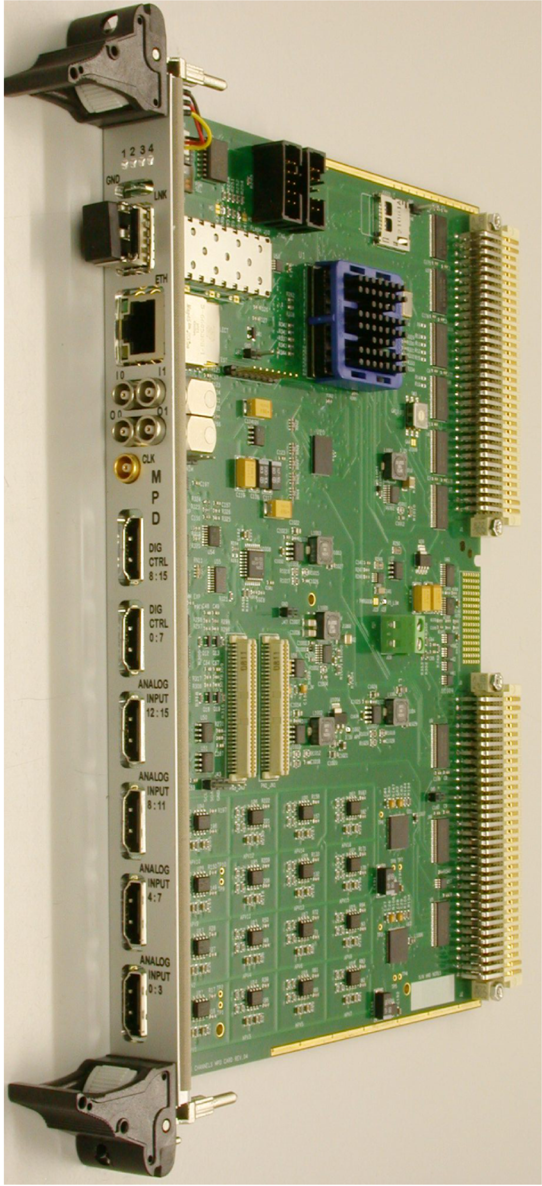


Multi Purpose Digitizer (MPD) card

- VME64x board perform the digitization of analog signals from the FE cards and handle the slow control signals
- DDR2 (128 MB), 110 MHz system clock
- Compliant with JLab VME64x VITA 41 (VXS) standard
- 6 HDMI-A connectors for data and sow control signals

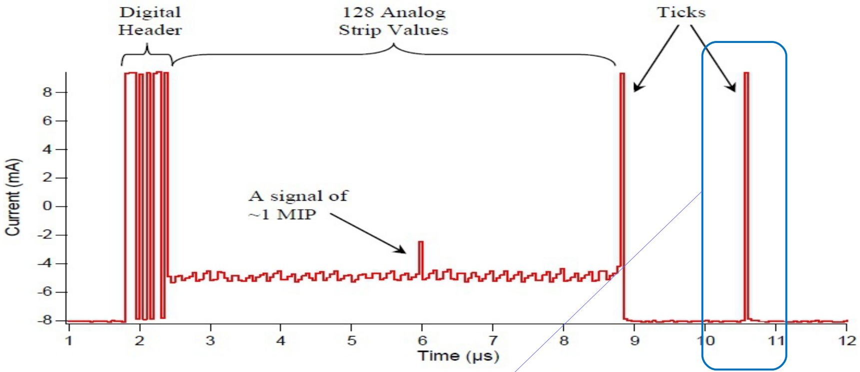
MPD block diagram

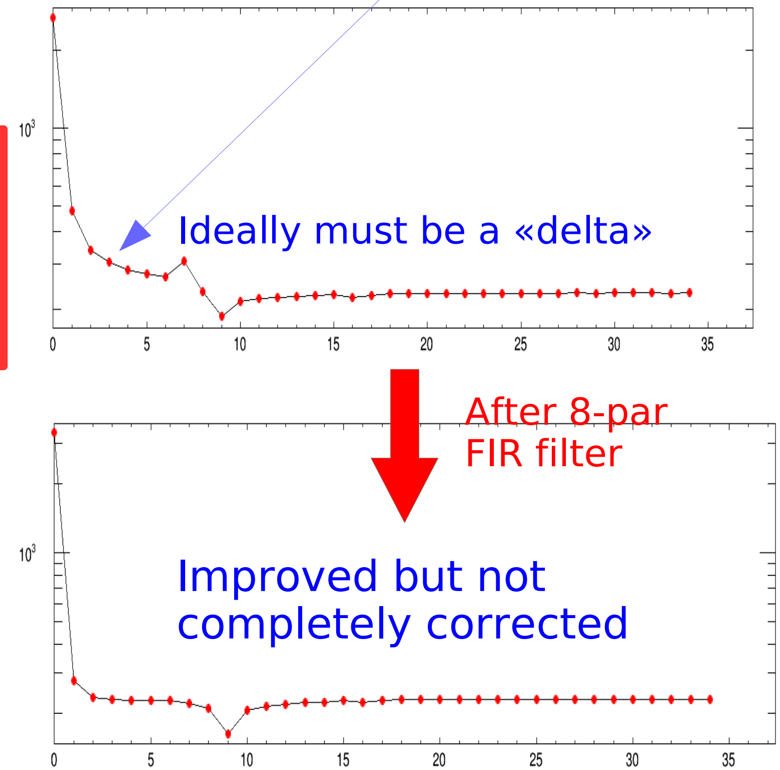


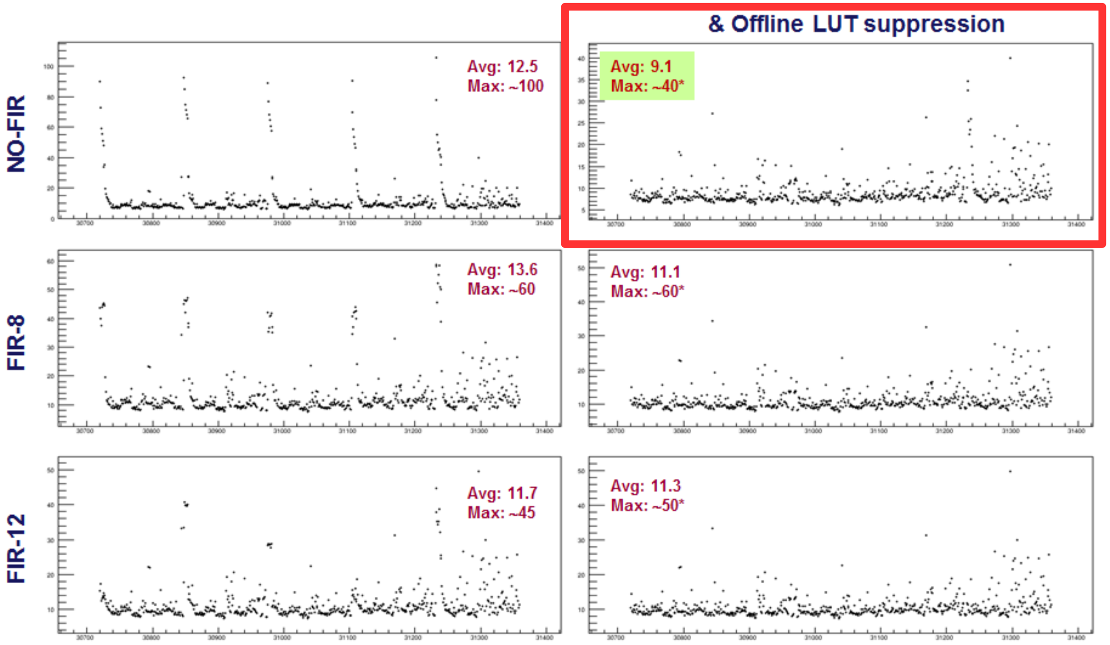


Long (23 m) HDMI cable effects on APV25 analog signal

- The large «binary» information (digital header) at the beginning of the analog signals of the APV introduce a large noise on the first (~20) channels of the frame
- Longer the cable larger the noise, higher the number of channel involved
- Belle (2012 JINST 7 C01082) proposed a 8-parameter FIR filter (12 m long cables) in firmware
- We added an off-line pedestal subtraction dependent on the digital header value (LUT suppression): very noisy channels **largely recovered**







Summary

- The Hall A equipment for the 12 GeV Upgrade of the CEBAF at JLab is the Super Bigbite Spectrometer (SBS).
- The 3 tracking stations of the SBS are equipped with large area and light weight GEM detectors.
- The construction and commissioning of all 60 GEM chambers is ongoing at University of Virginia and at INFN Catania & Roma.
- The MPD system, an APV25-based readout electronics is developed at the University of Genoa to read out the GEM trackers.
- The MPD is compliant with the JLab VME64x VITA 41 (VXS) standard