GEM Detectors for SuperBigbite

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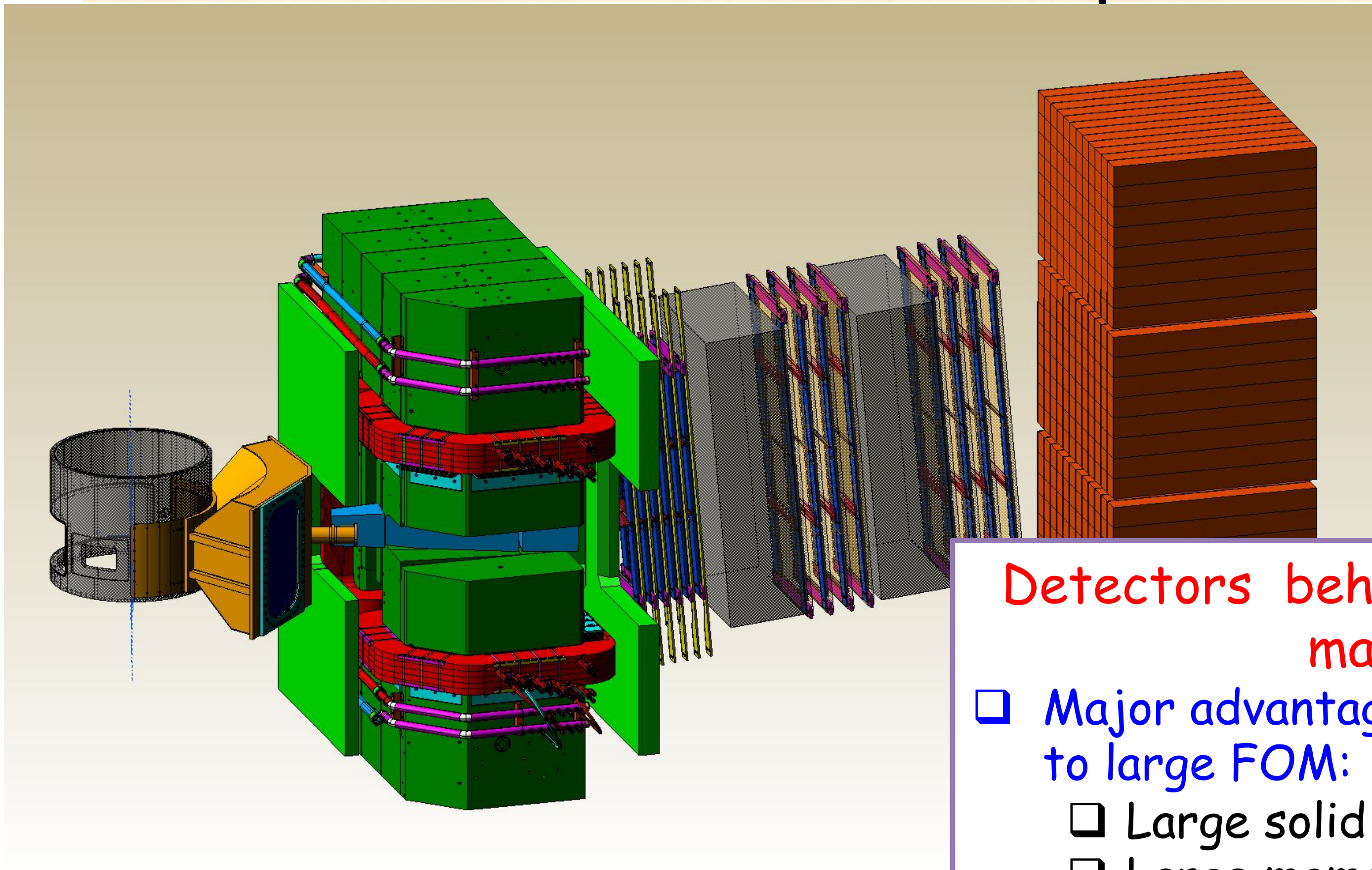
Outline

- SBS tracking concept
- SBS GEM tracker overview
- Back tracker GEM module production Status.
- Front tracker GEM module production Status.
- GEM readout electronics.
- Conclusion

SBS Concept



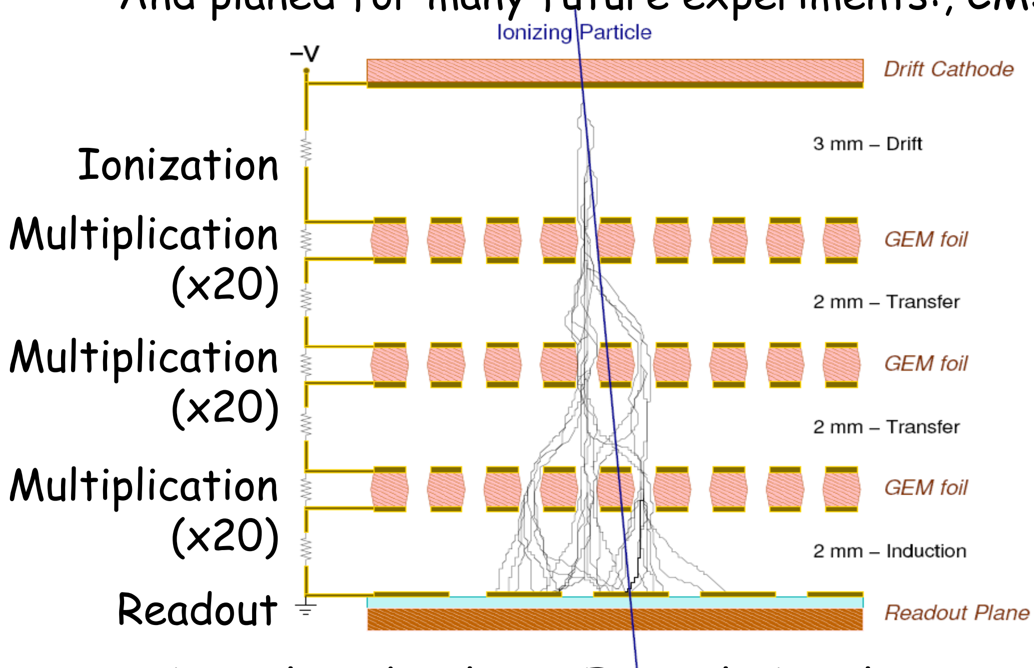
Detectors behind a large dipole magnet:

- Major advantages which pave way to large FOM:
  - Large solid angle
  - Large momentum bite
  - Straight line track analysis.
  - Detectors shielded from charged particle background.
- Consequences:
  - High rates at detectors.
  - Need good coordinate resolution.

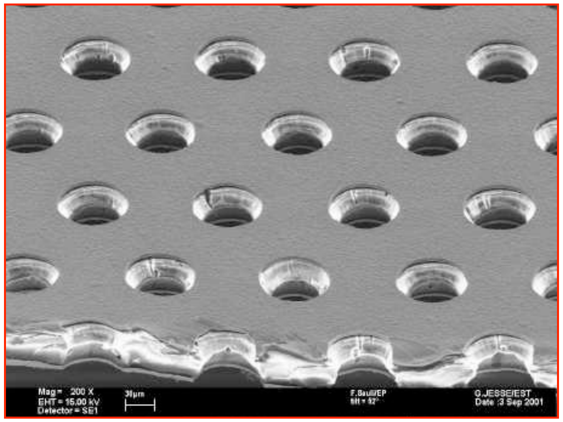
Why GEMs ?

- Super Bigbite Spectrometer concept leads to high rate in trackers: up to 500 kHz per cm^2 in the front detector, and requires good resolution.
- Gas Electron Multiplier (GEM) detectors provide a cost effective solution for high resolution tracking under high rates over large areas.

- Rate capabilities higher than many MHz/cm^2
- High position resolution (< 75 μm)
- Ability to cover very large areas (10s – 100s of m^2) at modest cost.
- Low thickness (~ 0.5% radiation length)
- Already Used for many experiments around the world: COMPASS, Bonus, KLOE, TOTEM, STAR FGT, ALICE TPC, pRAD etc.
- And planed for many future experiments:, CMS upgrade, SoLID, Moller, P2 @ Mainz



GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch



Novel technology: F. Sauli, Nucl. Instrum. Methods A386(1997)531

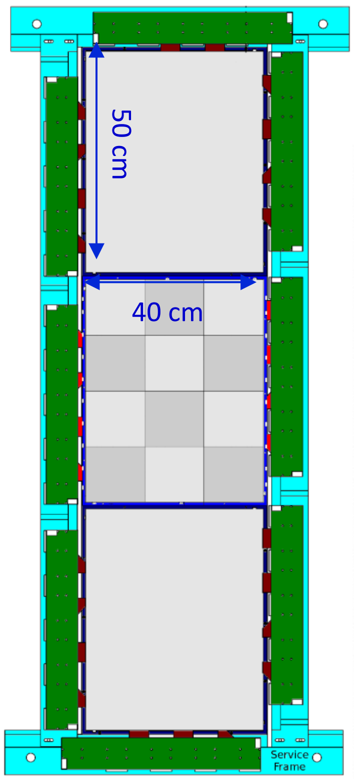
GEM Trackers for SBS

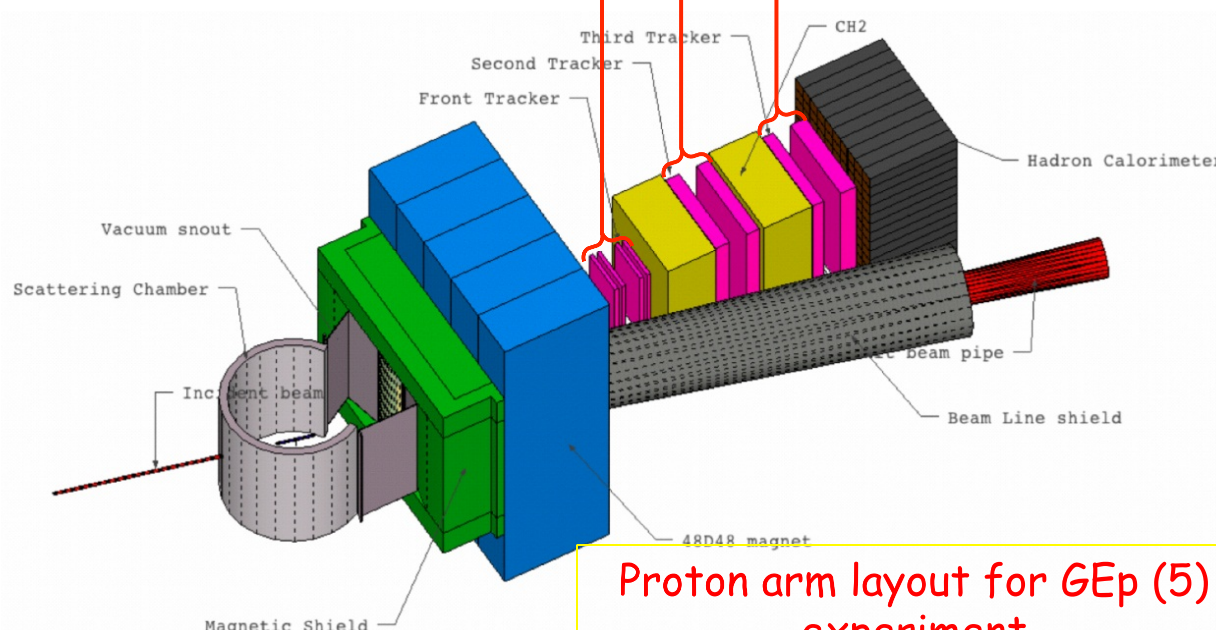
Front Tracker

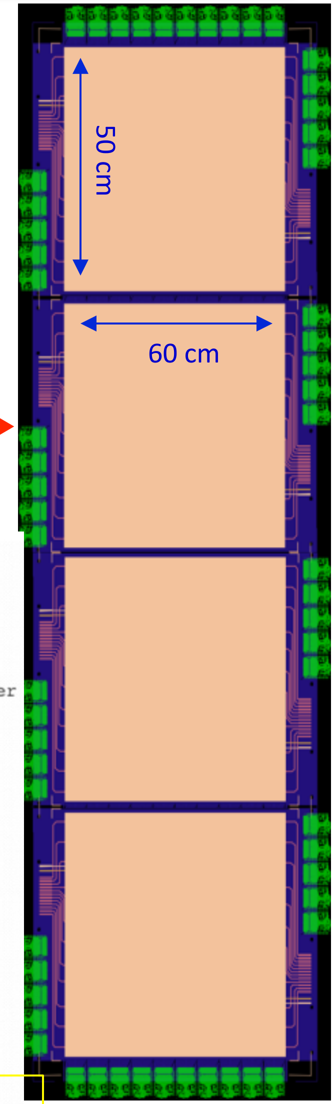
- 6 GEM Layers (150 × 40 cm^2)
- Each layer = 3 GEM modules (50 × 40 cm^2)
- 0.4 mm strip pitch
- 41 k readout channels
- INFN Funding: being built in Italy – (E. Cisbani and collaborators)
- 18 modules.

Back Tracker

- 10 GEM Layers (200 × 60 cm^2)
- Each Layer = 4 GEM modules (50 × 60 cm^2)
- 0.4 mm readout pitch
- 124 k readout
- SBS project: built in Virginia
- 40 modules + plan for 8 spares







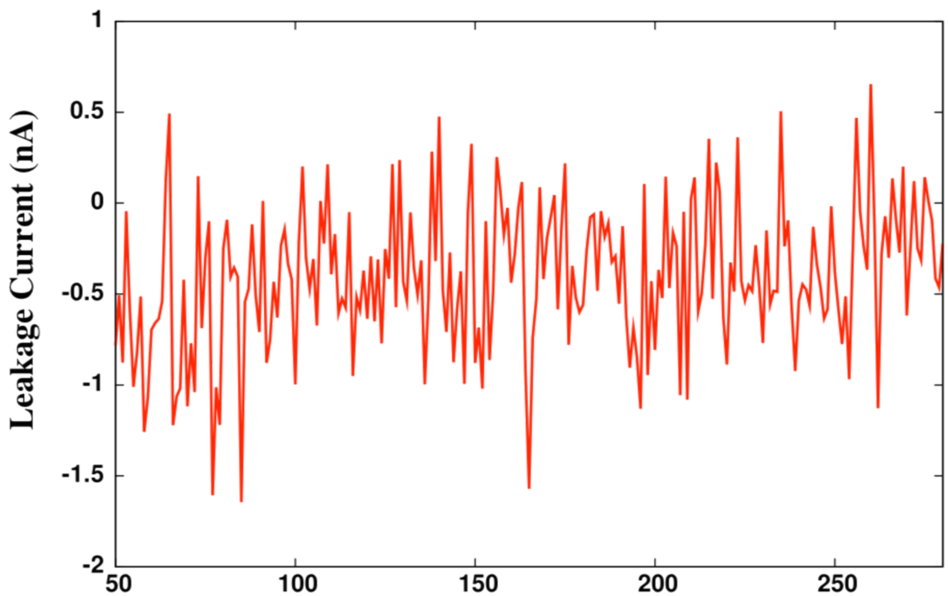
Proton arm layout for GEp (5) experiment

UVa Team members: NL, Dr. Kondo Gnanvo, Dr. Vladimir Nelyubin, Dr. Huong Nguyen, Xinzhan Bai, Danniung Di, Rong Wang, Siyu Jian

SBS GEM module technical requirements

All GEM modules must be constructed such that:

- all foils have an average dark current of less than 5 nA for each 20 x 5 cm^2 sector at 550 V across the foil.
- a gain of at least 5000 at the operational voltage in a gas mixture of 70% Argon and 30% CO_2
- a track efficiency of at least 95%, averaged over the module, in cosmic tests
- a position resolution of $\sigma < 100\ \mu m$.
- A timing resolution of $\sigma < 25$ ns.



Current Status of UVa GEM production

GEM module Production Status

- In the final stretch now
- 37 modules completed.
- 35 modules fully tested:
  - 33 modules 100% operational.
  - 2 modules have one bad sector each. 97% of active area operational.
- Modules #36 and #37 prepared for testing now.
- Module # 38 under construction now
- Moving forward at the rate of 2 chambers per month
- Expected completion of 40 modules by January 2016.
- Five modules: 12-17 moved to Jlab for beam tests
- All material for 8 spare modules have been ordered; expect to complete 8 spare modules by May 2017.

X 4

Path to 40 modules

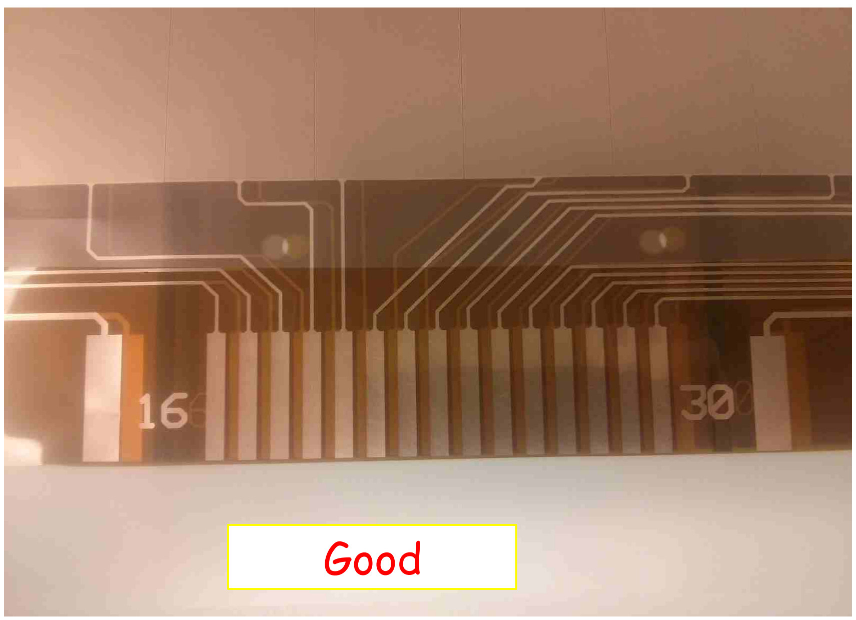
Module #	Status
36	Construction complete; prepared for final testing in x-ray box
37	Construction complete; prepared for final testing in x-ray box
38	3 GEM foils at UVa, RO at UVA
39	3 foils and 1 RO to be included in the shipment in the week of Nov. 13
40	3 foils and 1 RO to be included in the shipment in the week of Nov. 13

- GEM foils:
  - 147 ordered (need 120 + 24 spares)
  - 127 received and tested: 113 accepted.
    - 20 bad foils with issues (7 repaired: 13 TDB)
    - 1 foils sent back for inspection (re: low gain issue): will be replaced.

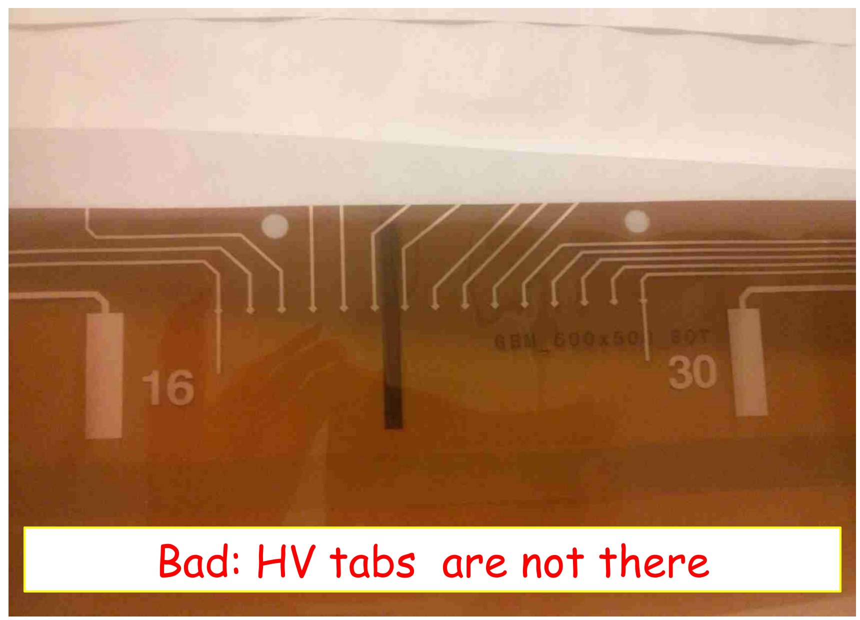
- Readout foils:
  - 48 ordered (need 40 + 8 spares)
  - 42 received: 38 accepted so far
  - One with minor issues sent back for repair
  - 3 unacceptable quality (too much Kapton as reported last year); CERN will replace these.

Challenges: Chamber Components

- Major delay in CERN GEM foil and readout plane production : due to some thickness irregularities found in the raw material foil used for GEM production. (worked closely with Dick Majka and colleagues to identify problem)
- We had some foils in reserve; however in many occasions have had to wait for the GEM foils and readout.
- Sent back a batch of questionable foils for repair; some were fully repaired.
- Discovered a previously unobserved issue with 6 foils: positive current spikes with arc discharges around GEM holes: have not been fixed after repair;
- Major and unfortunate issue with the bath received on 11/01
- All problem foils and 1 RO shipped back to CERN on 11/03

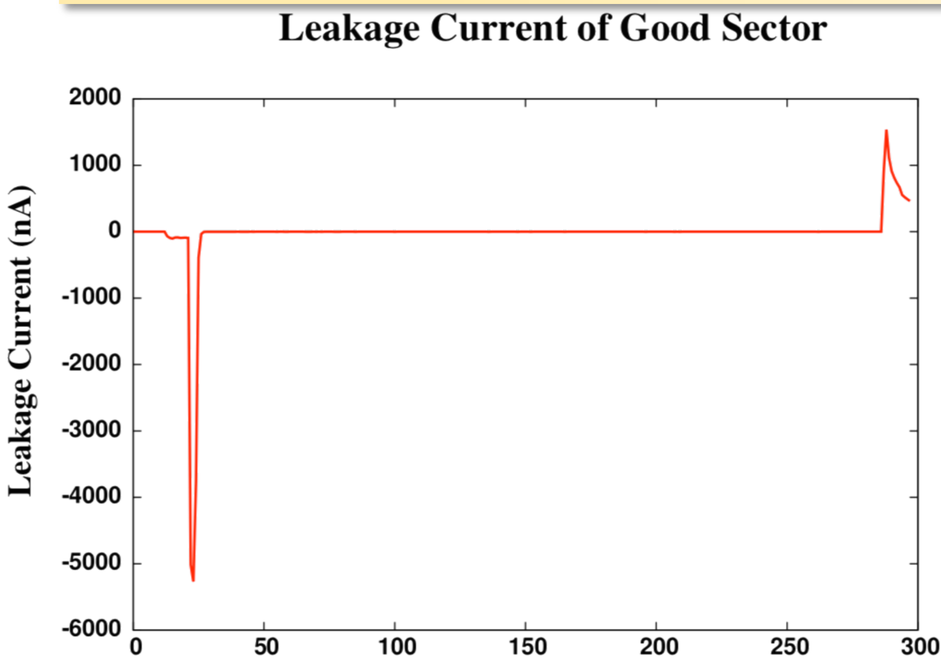


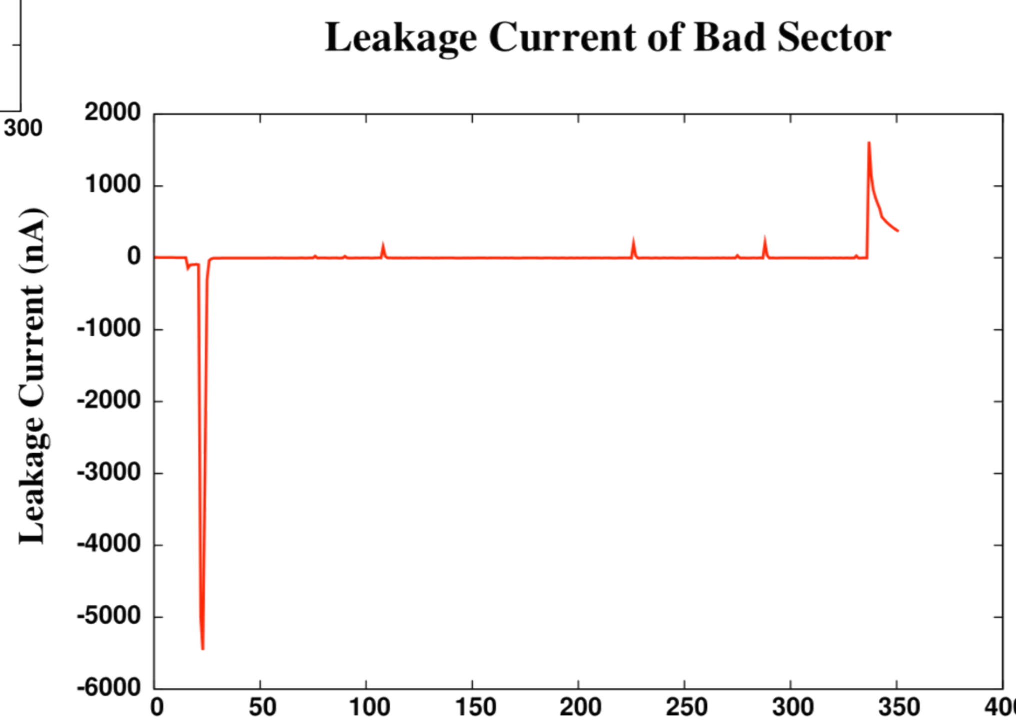
Good



Bad: HV tabs are not there

Positive current spike issue



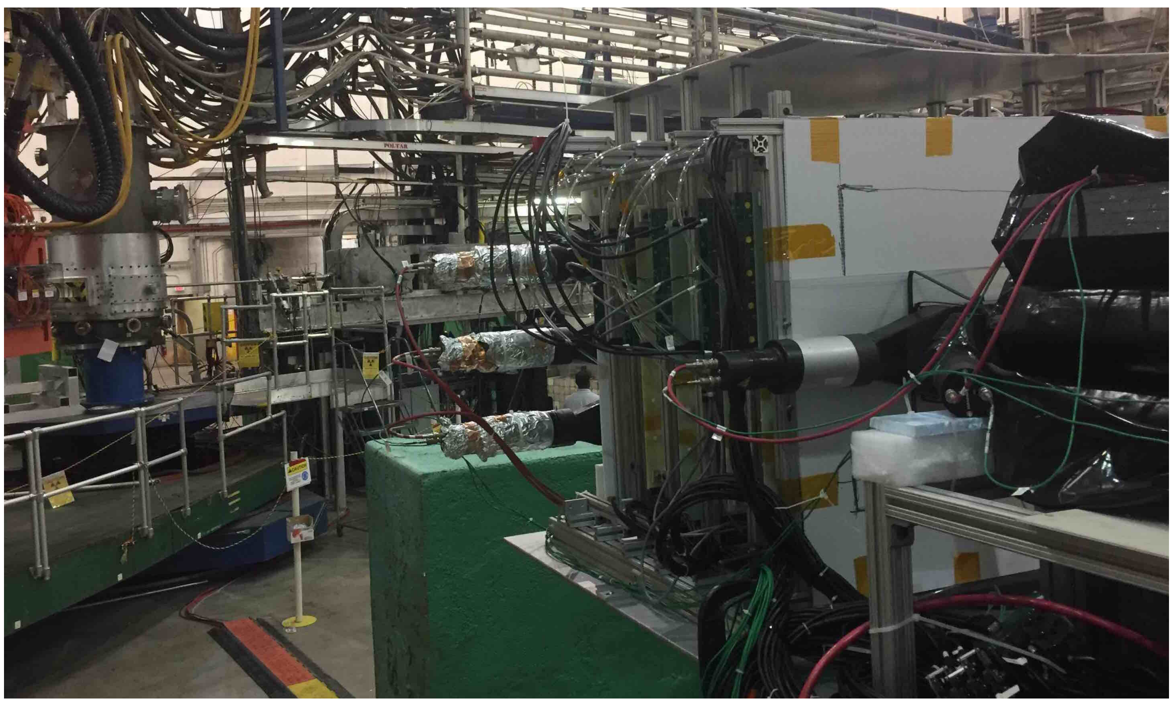


Challenges

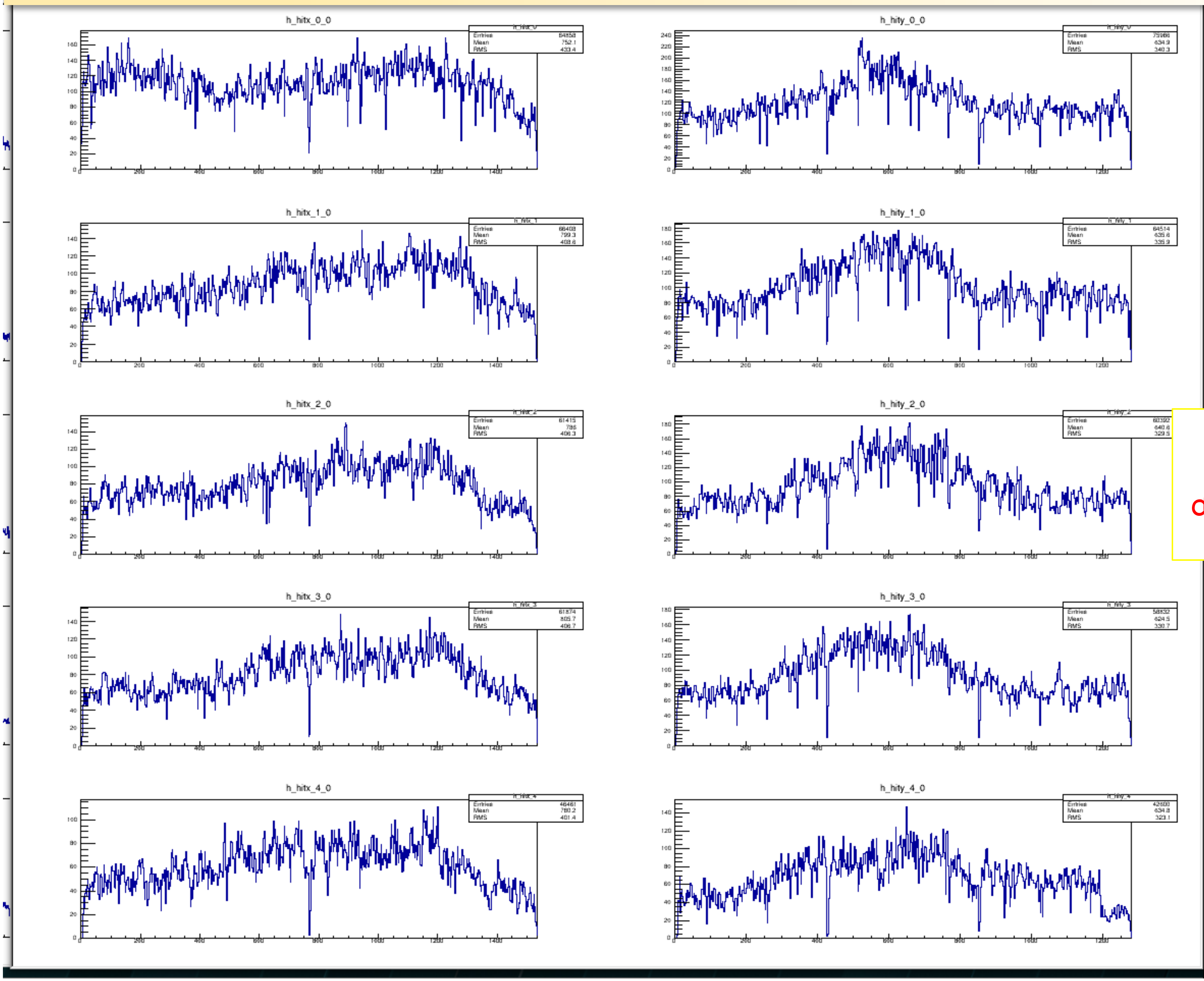
- ~ 1 month unexpected delay due to frame coating varnish going bad.
  - Specific Varnish from a Swiss company, certified by CERN re: chamber aging.
  - Hazardous liquid; so shipping, customs clearance takes 1 month (and ~ $2k).
  - Arrived in early October
- Chinese visiting student left in June: production slowed down while new student was coming up to speed.
- Will complete all 40 modules and couple of spares by project end date; but need to figure out manpower for ~ 6 spare modules .

Beam Test in Hall A

- Currently ongoing
- Five modules separated by 10 cm each: very similar to a SBS tracker.
- Triggered by a lead-glass matrix at center
- Goals: Identify good tracks in a high rate background, study effectiveness of timing and charge correlation cuts to suppress background
- Currently at 70°, occupancy is ~ 1.2%; going to a smaller angle this week to get higher

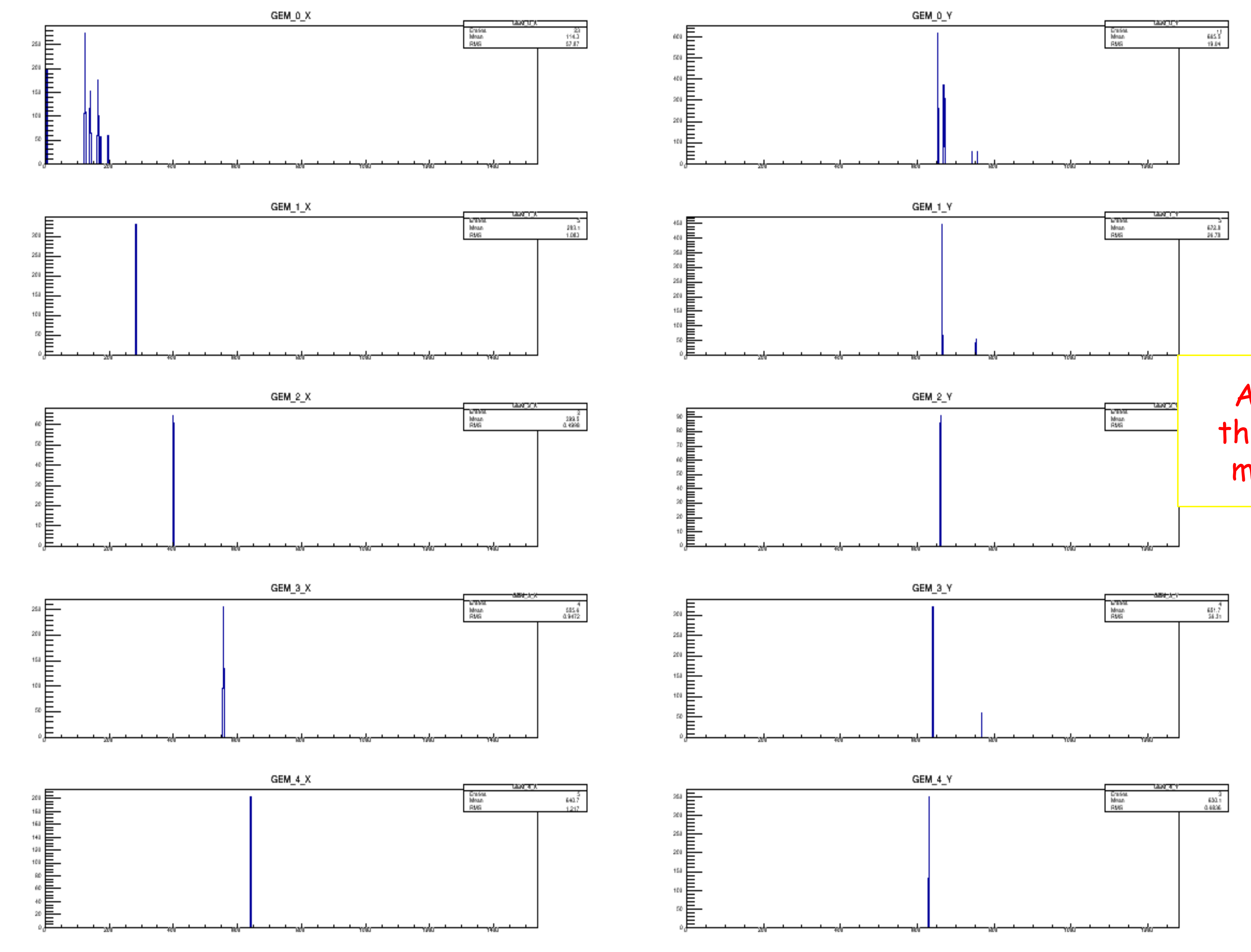


Beam Test in Hall A



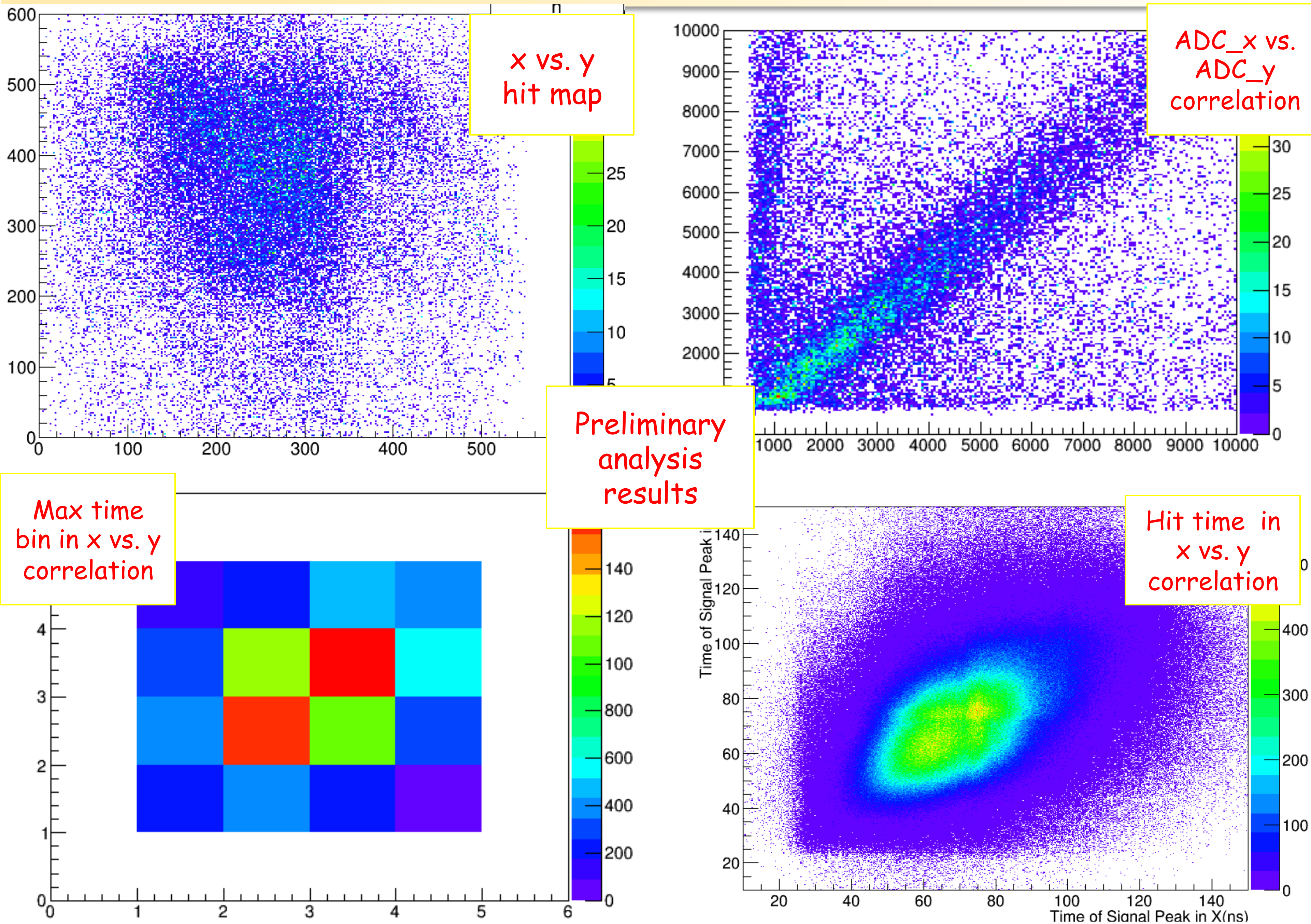
1 D hit distributions

Beam Test in Hall A

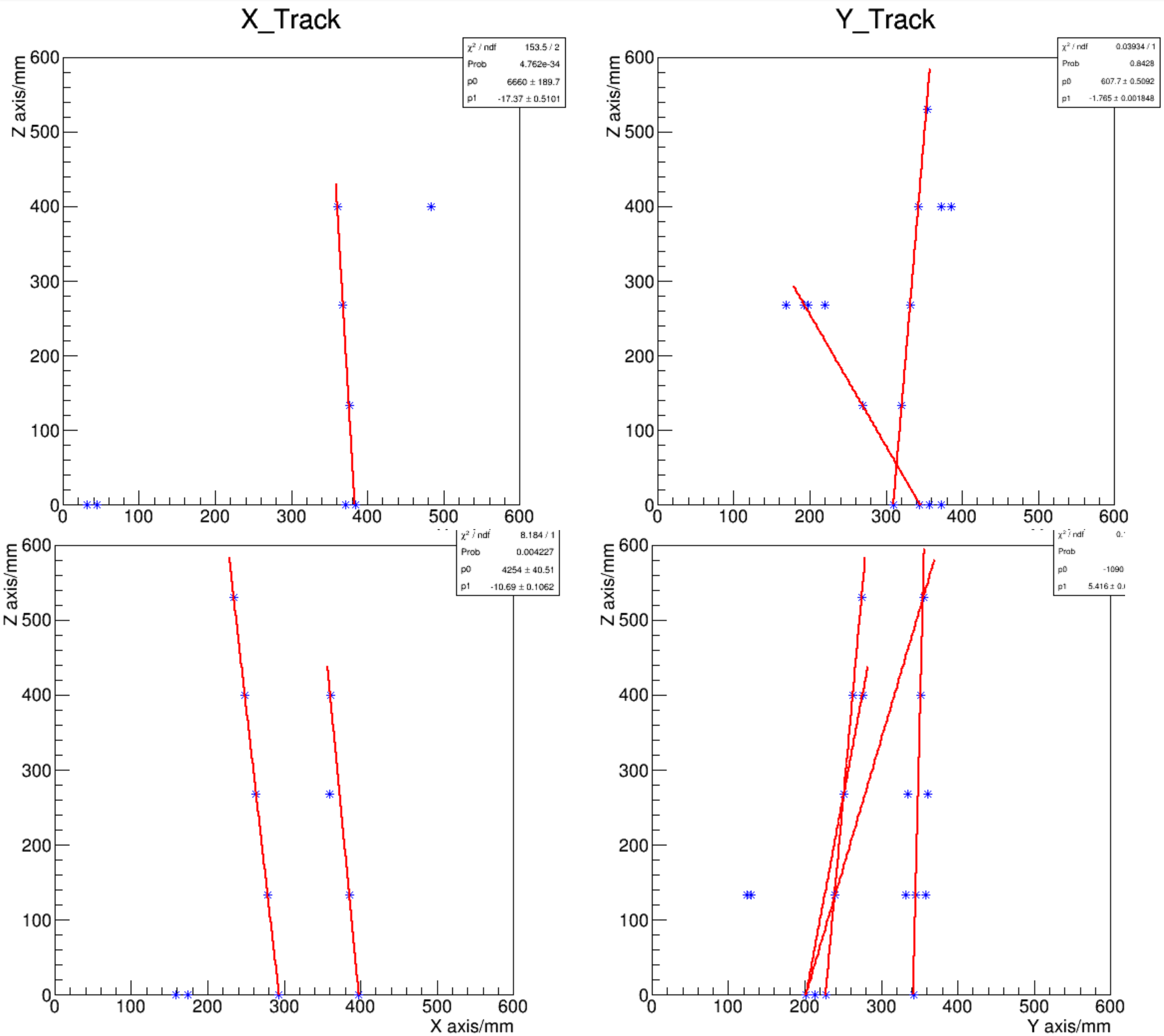


A track through 5 modules

Beam Test in Hall A

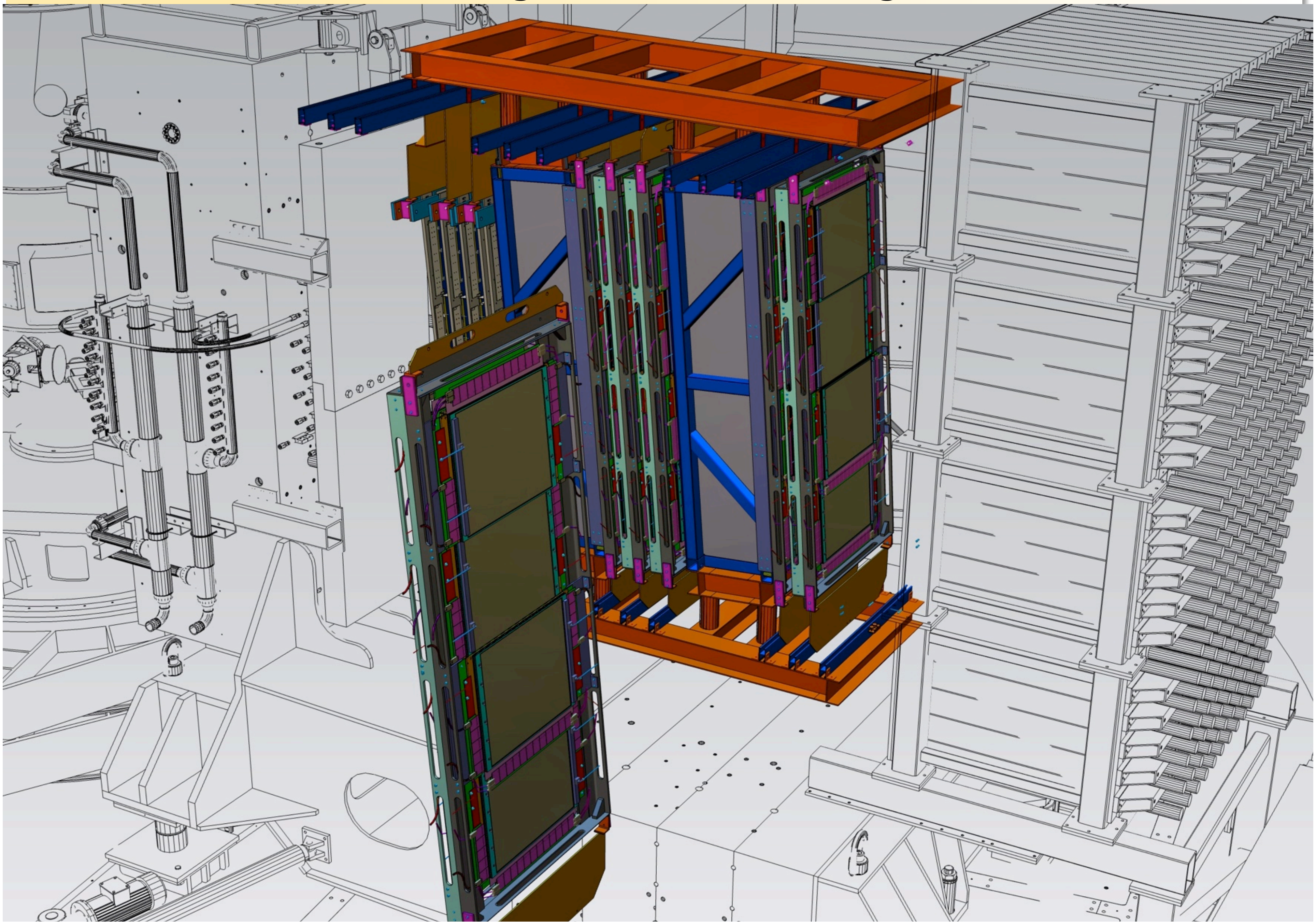


Beam Test in Hall A



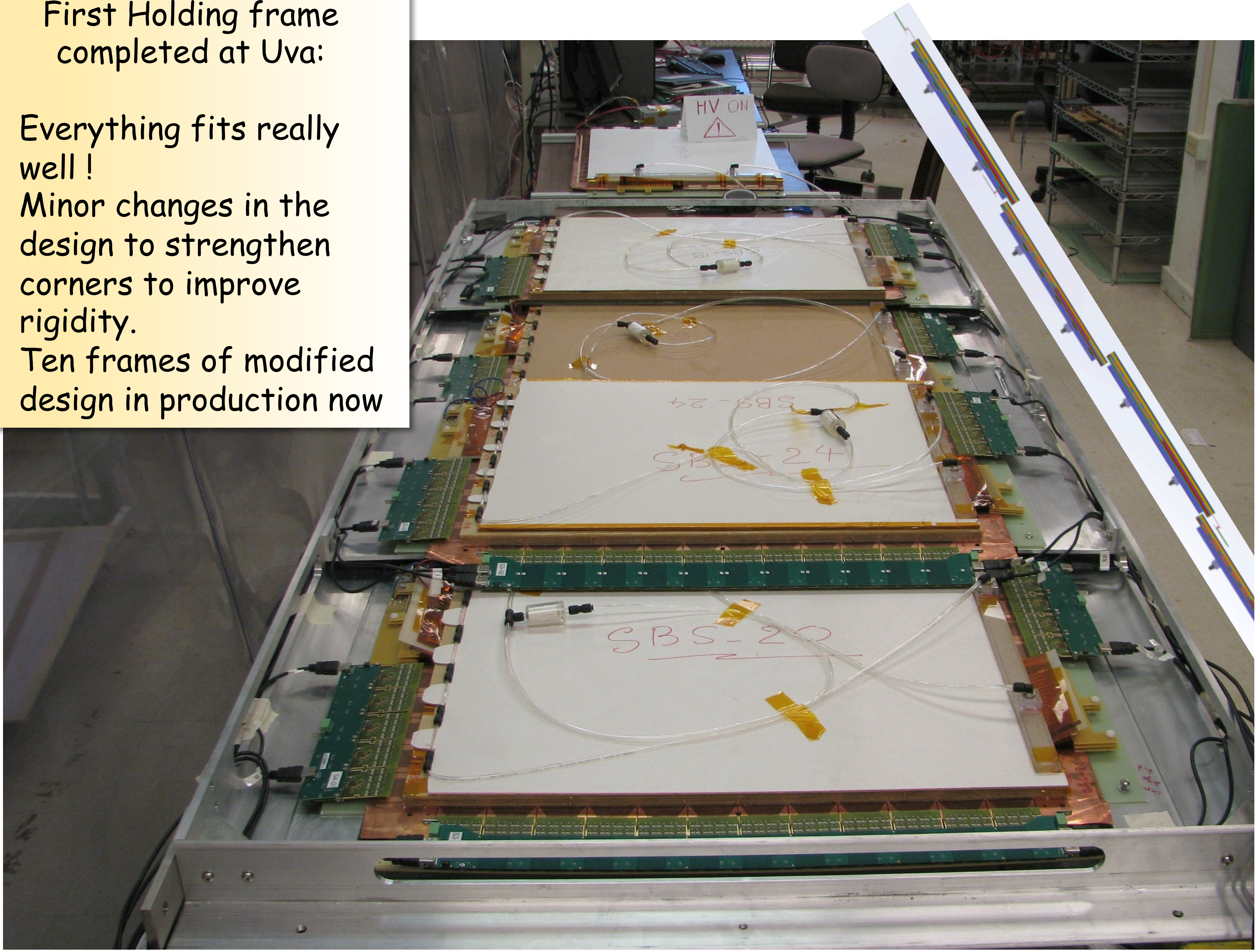
Preliminary analysis results

Work in Progress: GEM holding frame



First Holding frame completed at Uva:

- Everything fits really well !
- Minor changes in the design to strengthen corners to improve rigidity.
- Ten frames of modified design in production now



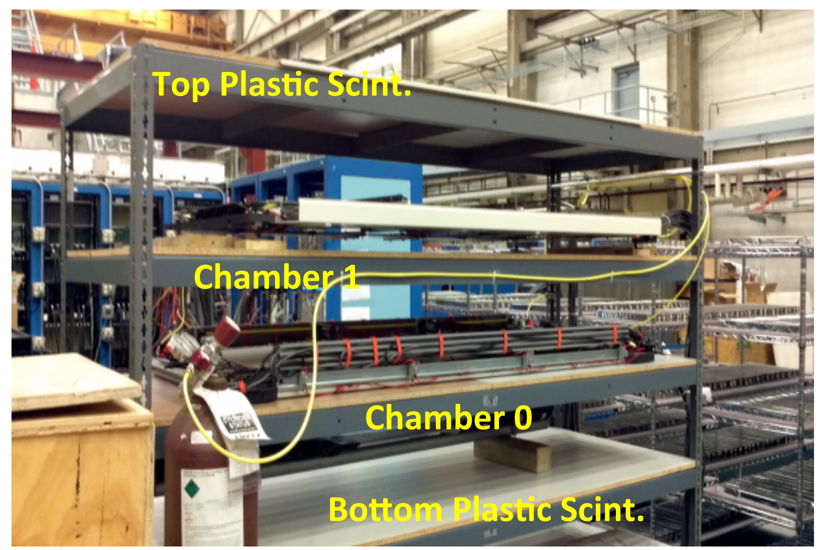
Front Tracker Status

FT - Production Summary and Plan

- 14 GEM modules produced, 2 under completition
  (out of 18 by end of 2016, 4 spare modules expected by spring 2017)
- 13 tested or under testing, 1 damaged during assembling, 3 with one GEM sector disconnected (work on fixing it)
- 2 full chambers assembled at JLab, need to be re-tested
- Improved cosmic test stand in Italy (top)
- Cosmic test stand at JLab under finalization (bottom)
- GEM readout integration in CODA/DAQ almost completed

One year plan:

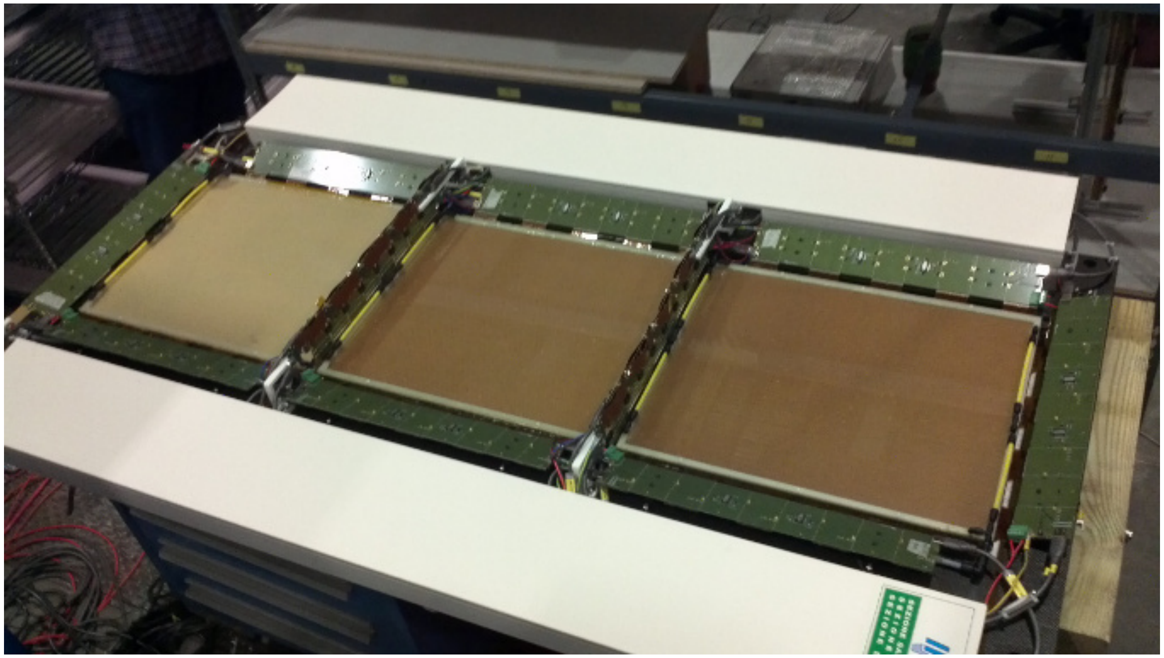
- Complete GEM modules assembling
  (including spares)
- Extended chamber cosmic test
- Complete data suppression in hardware and finalize integration in CODA/DAQ
- Implement robust tracking for FT

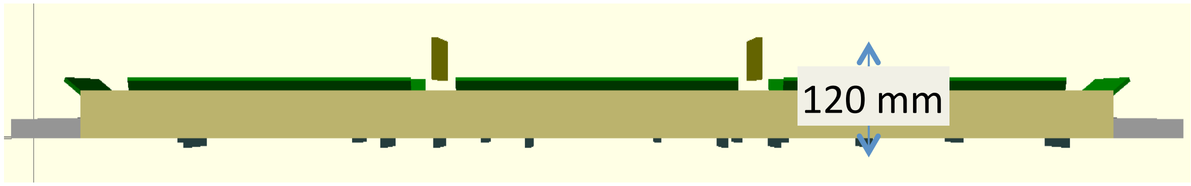


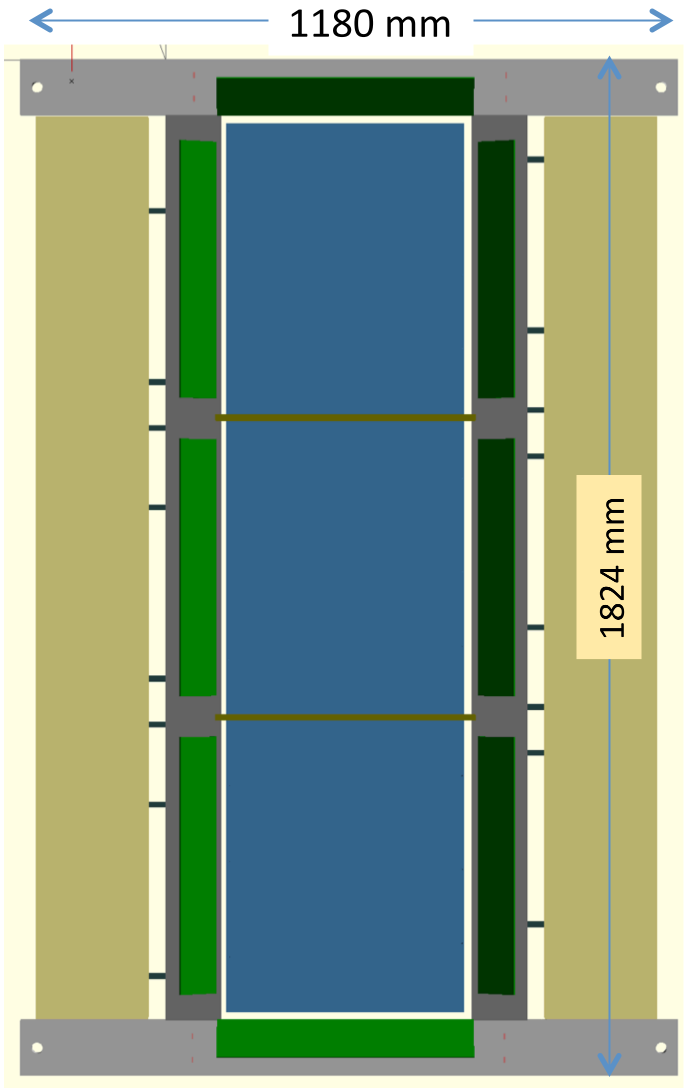
Second GEM Chamber at JLab (Nov 2015)

Carbon Fiber mechanical frame

Large extruded PVC Cable Tray



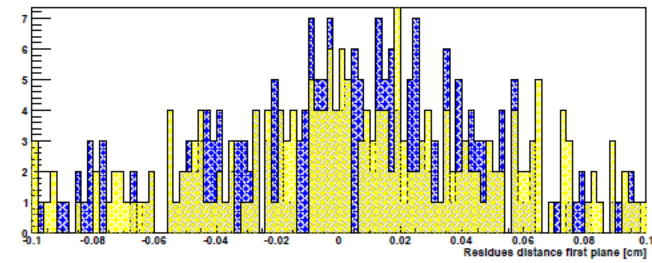


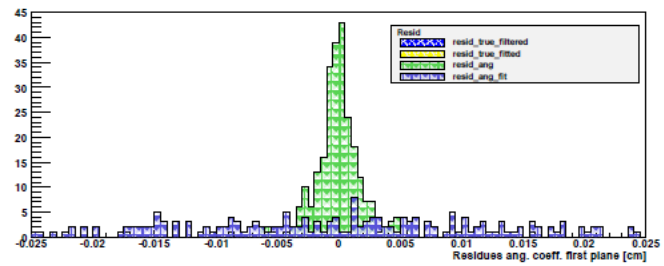


5 carbon frame structure under construction; next chamber expected end of 2016

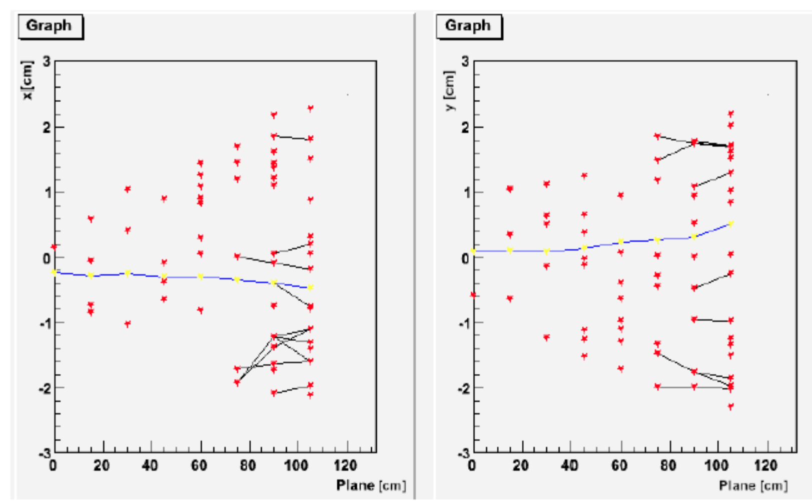
Study of robust FT Track Reconstruction

- Multistep approach:
  - Hit association: Neural Network (need smart energy function)
  - Precise tracking: Kalman filter (rather consolidated approach)





- (Slow) work in progress:
  - Consolidate NN
  - Implementation of artificial RETINA approach (for hit association)



Alessio Del Dotto
Cristiano Fanelli

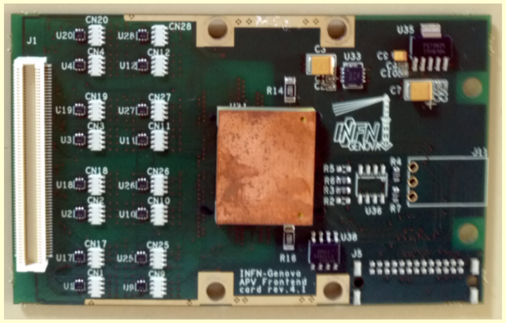
SBS Front Tracker - Workforce and funding

INFN Group	Researcher (Unit / FTE)	Tech. (Unit / FTE)	Role
Bari	1 / 0.3		Gas system and beam test
Catania	3* / 1.6	3 / 1.5	GEM module assembling, mechanics, beam test, analysis
Genova	1** / 0.3		Electronics design and test
Rome/Sanità	2 / 0.6	3 / 1.5	Coordination, design, test, chamber integration, analysis, *DAQ and track reconstruction*
Total	*7 / 2.8*	*6 / 3*	
Other support: CERN / UVa / JLab			

- *) one PhD student
- **) electronic engineer
- INFN/Funding:
  - Prototyping and Production (2008-2016): 900 kUSD
  - Commissioning and Maintainance (2017-2019): ~40 kUSD/year

GEM Readout Electronics

GEM – APV-MPD based Readout Electronics

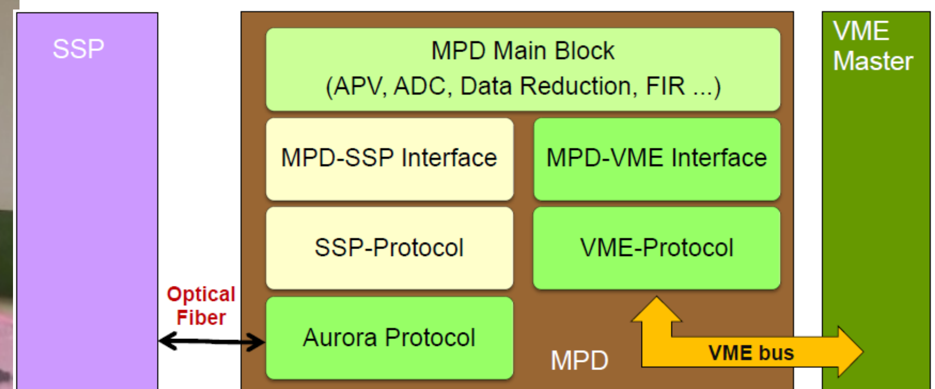


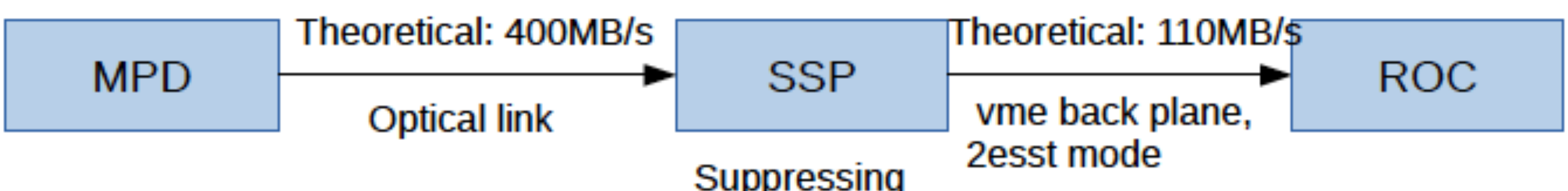
- 128 analog ch / APV25 ASIC
- 3.4 μs trigger latency (analog pipeline)
- Capable of sampling signal at 40 MHz
- Multiplexed analog output (100 kHz readout rate)

- **Up to 16 APV25 cards (2048 chs) on a single MPD (parallel readout)**
- Altera Arriga GX FPGA / RAM: DDR2 (128 MB)
- **Optical Fiber Link interface (Aurora ~2 Gb/s peak)**
- 100 MHz system clock and Front panel coax clock
- Used HDMI-A for analog and digital signals
- **VME/32, VME64, VME64-VXS compliant (up to 200 MB/s peak)**
- 4 high speed line on the VXS available for data transfer
- Firmware v. 4.0 (74% resources):
  - Finite-Impulse-Response Filter (16 parameters)
  - Zero Suppression (sparse readout)
  - Common mode and pedestal subtraction
  - Remore reconfiguration
  - ~2 ns trigger time resolution
  - VME / Optical Fiber simultaneous implementation

MPD Firmware latest status

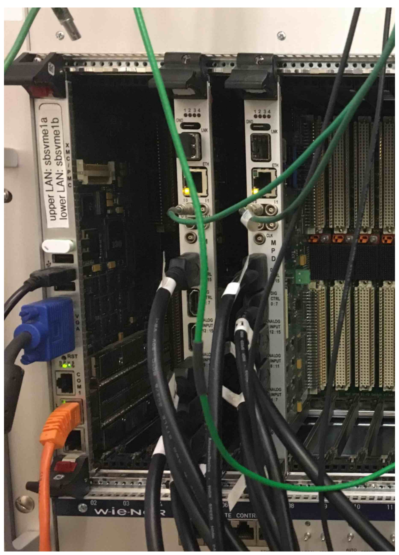
- Version 4.0 – 74 % FPGA resources used
- New (optimized and better organized) memory map tested succesfully
- All VME cycles tested; minor issue to be fixed
- Optical Link to SSP under deep testing (thanks to the CODA setup with SSP and Intel CPU recently installed in Italy)

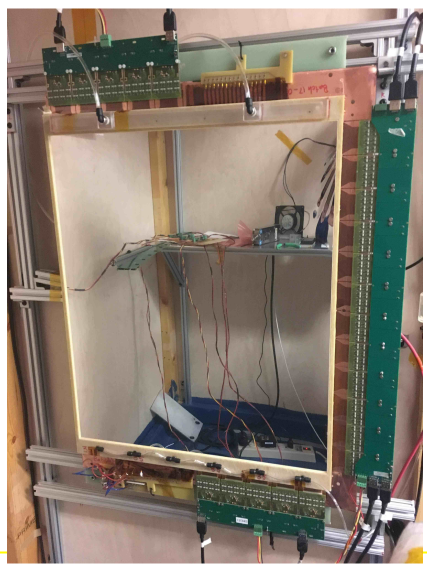


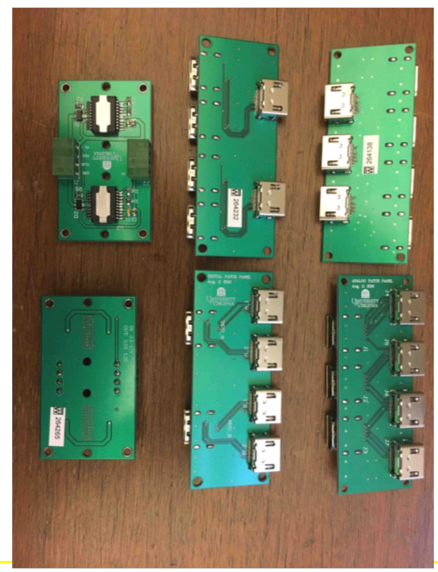


Back Tracker Electronics / as of Nov 2016

- 57 MPD ordered*: 57 delivered and tested
  - 3 MPD did not pass the test and sent back for repair: expected to befixable
- 925 APV cards ordered/ 927 delivered/880 needed
  - Testbench used in Italy with automated procedure mainly to identify bonding quality by SNR measurement; was able to test 50 to 80 cards/day. Each card has a pdf test report. A summary report is also generated
  - 147 tested so far; 7 with issues
- Received all backplanes: 42 long/82 short (40 short/80 long needed)
- All LV regulator boards and patch panels fabricated







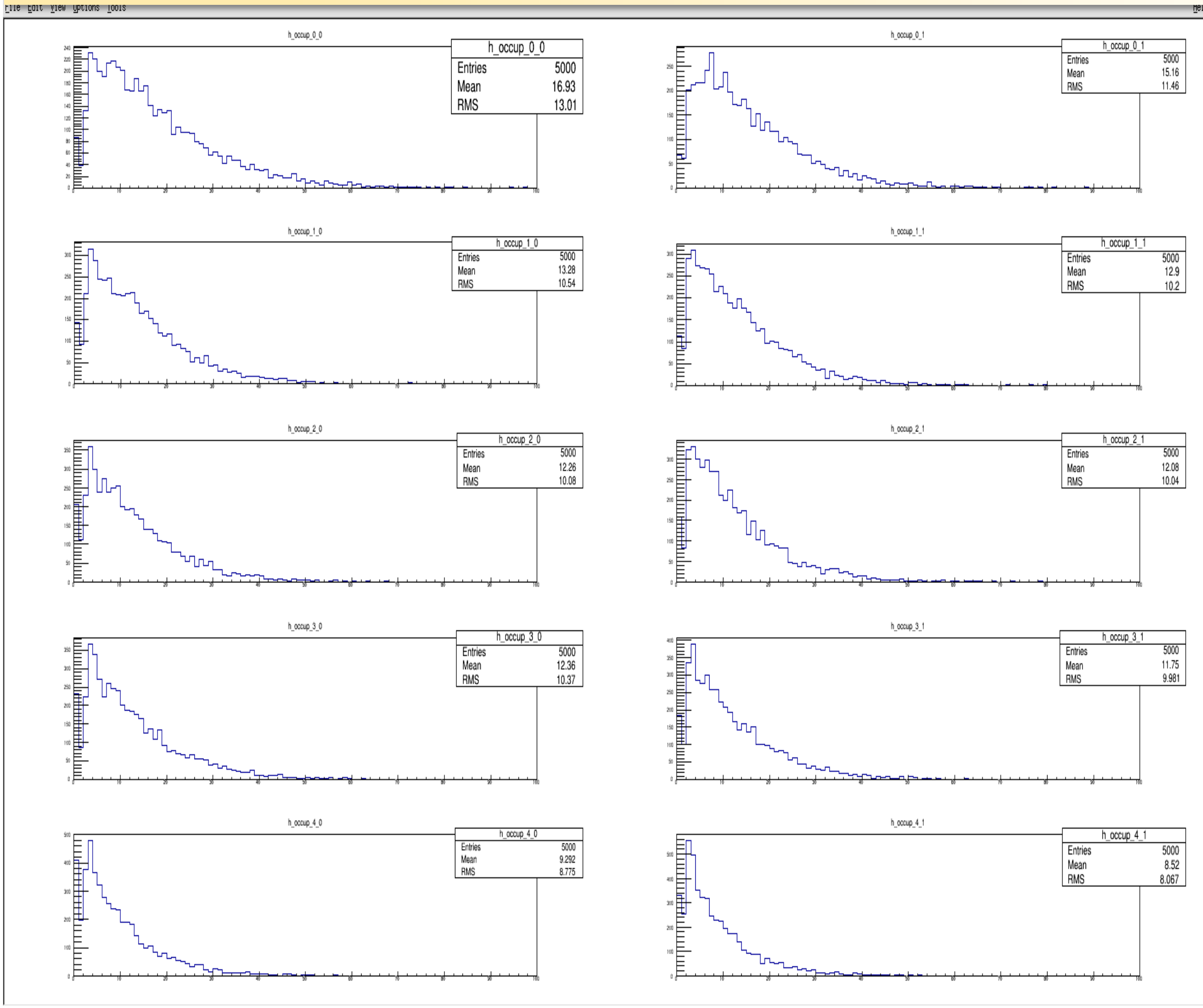
*Only 57 MPD are required to cover all channels; however optimum cabling arrangement requires 70 MPD. Plan to purchase 13 more MPD (+2 spares) using UVa funds

Conclusion

- The SBS back tracker production is going well
  - Now in the final stretch: 37 modules and counting.
  - Expect to complete 42 by end of January.
- Beam test with 5-module telescope currently going on
- Front tracker: 9/18 modules produced and one full chamber assembled.
- Most of the MPD electronics produced in Italy and received at UVa.
- Integration of GEM readout into CODA currently underway

Backup Slides

Beam Test in Hall A



SBS FT –Tracking Cosmic (preliminary)

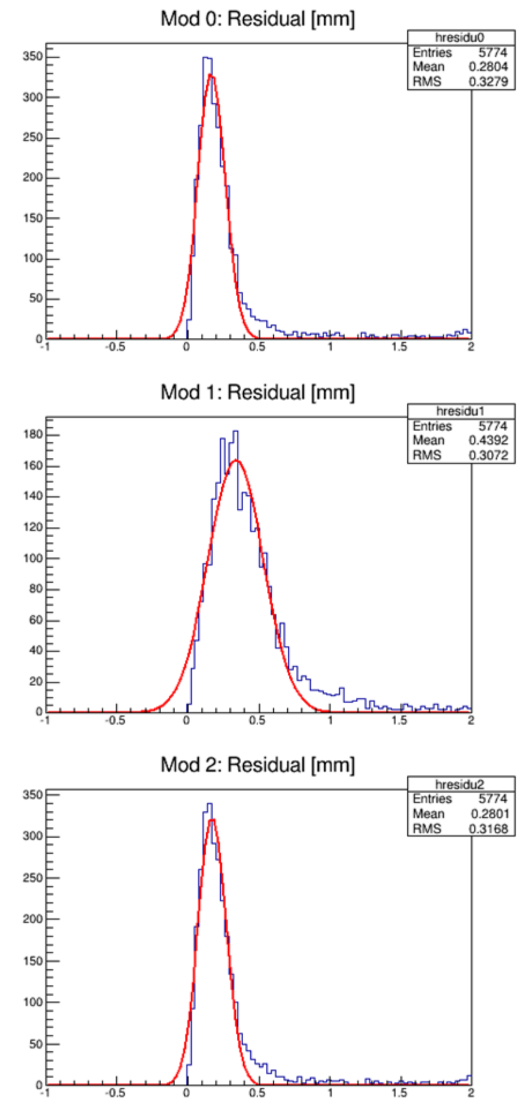
Tree GEM modules
1. Choose one GEM as «test» module and assume the other two as «calibrated»
2. Select «true» hits on the two «calibrated» modules
3. Compute the straight line passing for the two hits
4. Project the line on the third «test» module
5. Compute the 2D distance of the projected point from the measured hit (right)
6. Do 1. for each module

Raw manual alignment with accuracy at the level mm on each axis.

Measured 2D residues at the level of 0.3 mm:
- deconvoluting the error on each chamber: ≈1/sqrt(3)
- From 2D to single axis: ≈1/sqrt(2)

- Error on single axis: ≈ 0.3/sqrt(3*2) ≈ **0.12 mm**

Cosmic data taking with up to 7 modules in progress



2D distance between projected and measured points

MPD for SBS-BT-GEMs: Large production of MPD electronics

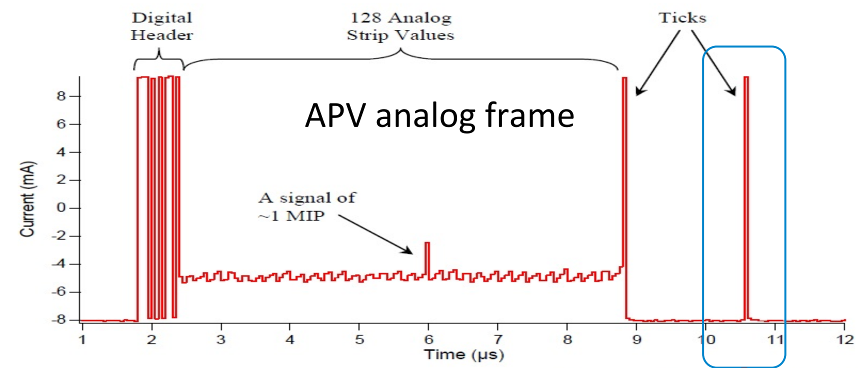
40 modules for the 2 Back Tracker stations (112,640) electronic channels to readout

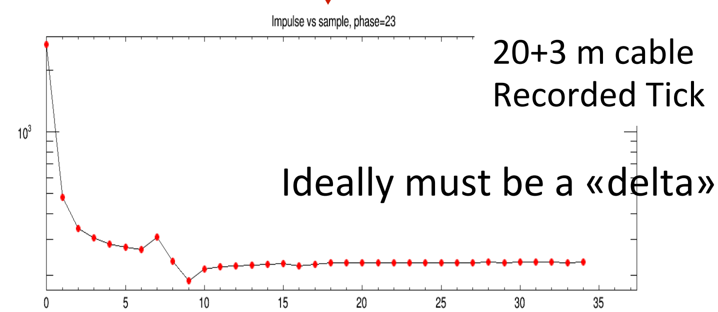
- Original option: combine two detector readout strips into one electronic channels
- A lot of concerns for this option:
  - Additional items: Need adapter 2-1 strips in addition to the back planes
  - electronic noise level, APV25 saturation, detector performance …
- Second option: Reading out all single detector strips
  - Safer option for performance and less development needed

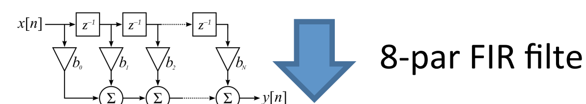
- Economies of scale and strong $ allow us to instrument all channels instead: big improvement.
- However: forcing us to really stretch the available resources.
- Including spares procuring 118 k MPD channels for the back tracker.
- Order for (almost) all components placed.
- 57 MPD units received and tested: two are bad, sent back for repair.
- All APV cards received; testing ongoing
- All back planes received.

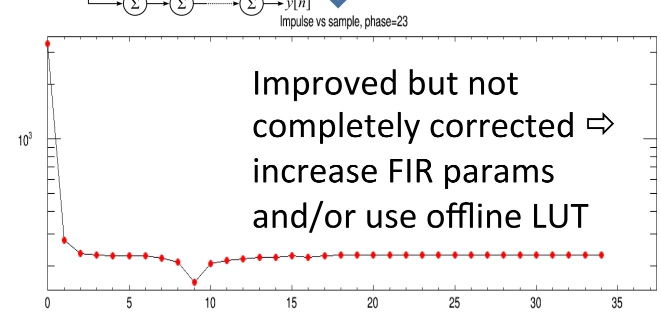
APV25 - Long (23 m) cable effects on analog signals

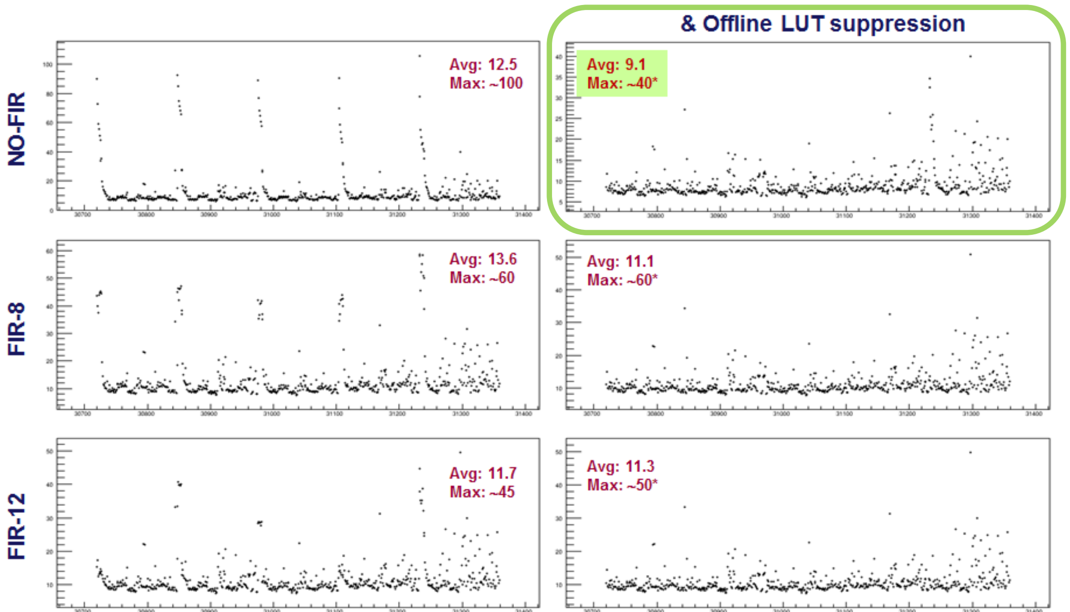
- Problem:
  - The large «binary» information (digital header) at the beginning of the analog signals of the APV introduce a large noise on the first (~20) channels of the frame
  - Longer the cable larger the noise, higher the numbe of channel involved
- Belle (2012 JINST 7 C01082) proposed a 8-parameter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











Pedestal RMSs of 5 APV25 – 23 m cables