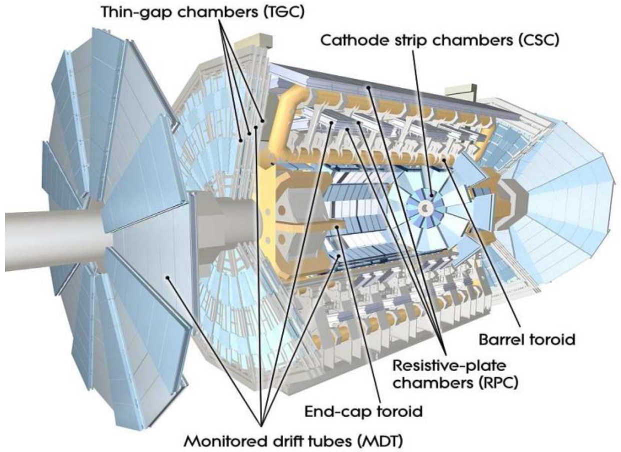
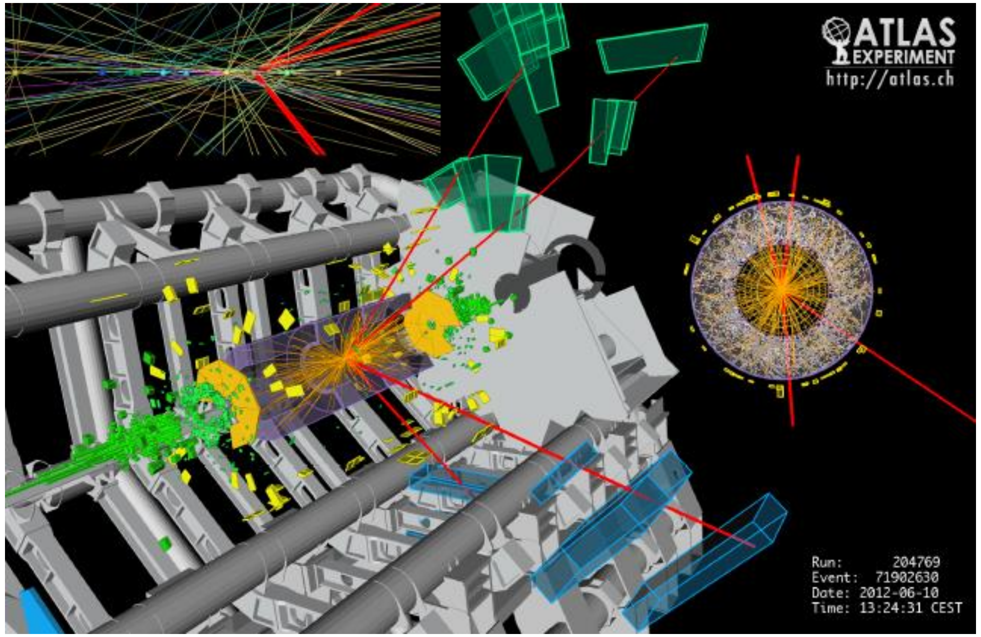
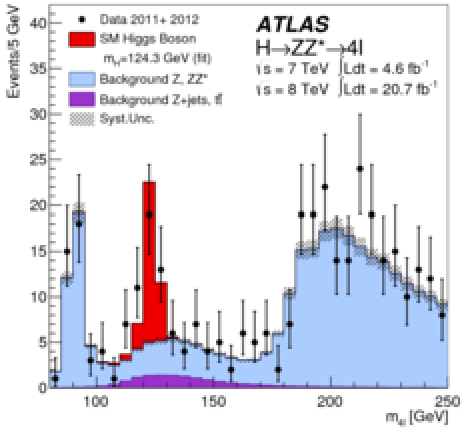
Design Optimization and Construction of the ATLAS NSW
The Chilean participation

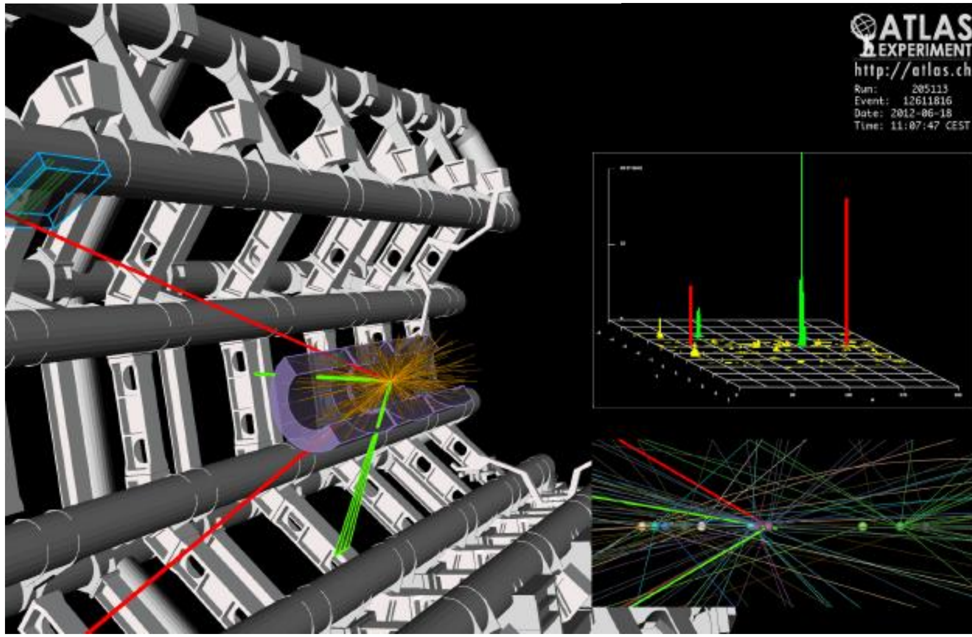
- Description of the μ trigger; the TGC system in the End-Caps.
- Why one needs additional input to reduce the background ?
- Optimization of the detector parameters.
- Test and more test.
- The Chilean participation and how to ensure a reliable contribution.
- Too many chiefs can lead to wrong decision.
- The detector is installed, try to make it work…
- General recommendations for you that are the future of the field.

2011-2012 The Higgs has been discovered



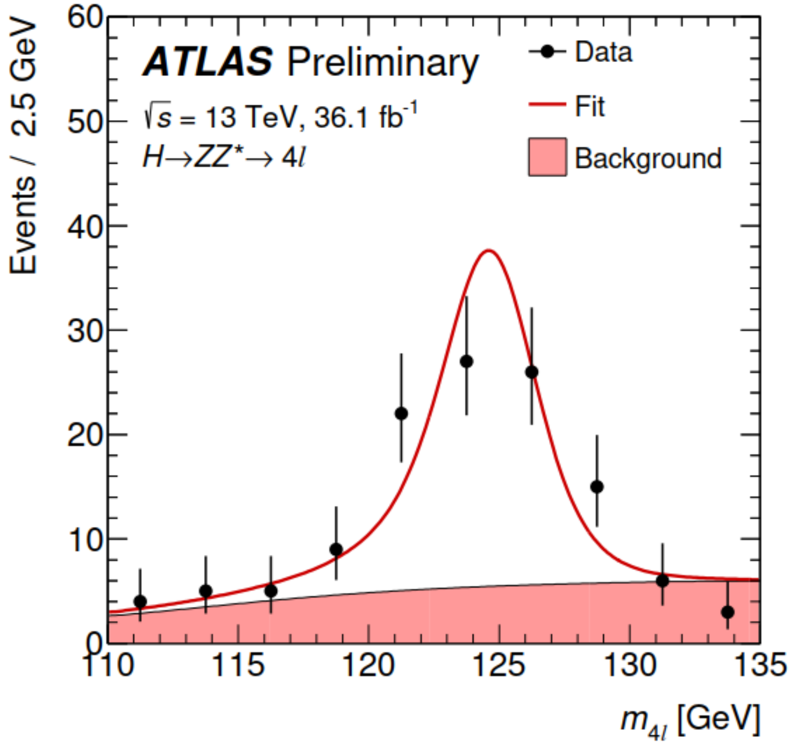






The most important discover in Particle Physics in the last 30 years
The Higgs Brout Englert mechanism provides the mass to point-like particles

The real H mass measurement from Run2

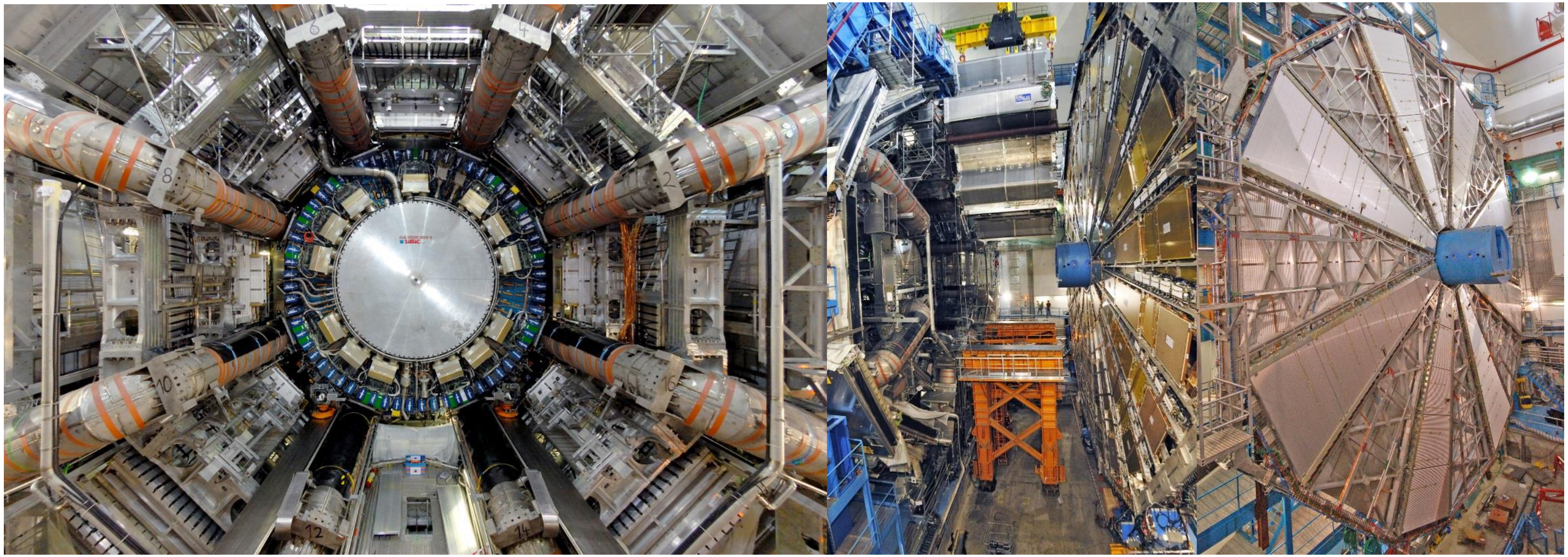


$$m_H^{ZZ^*} = 124.88 \pm 0.37\ \text{(stat)} \pm 0.05\ \text{(syst) GeV} = 124.88 \pm 0.37\ \text{GeV},$$

Systematic effect	Uncertainty on $m_H^{ZZ^*}$ [MeV]
Muon momentum scale	40
Electron energy scale	20
Background modelling	10
Simulation statistics	8

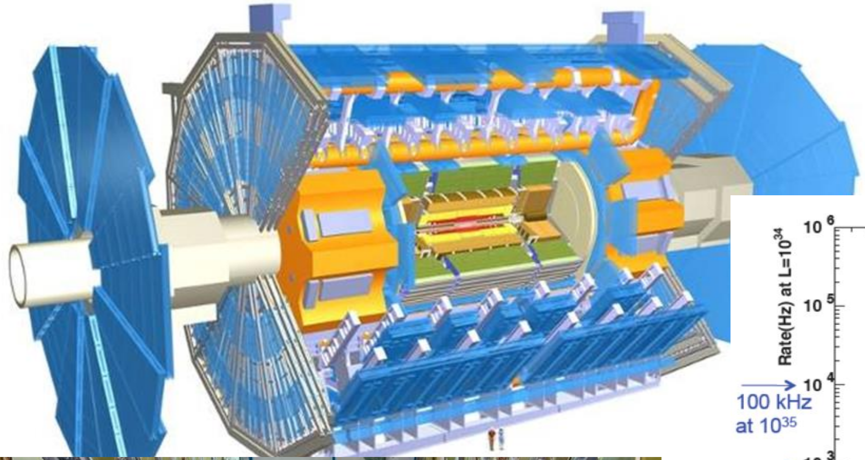
- It is impressive that in such a complex experiment like ATLAS, one is able to keep the systematics to the level of 0.4‰, thanks to a small group of very dedicated and inventive physicists that keep the individual detectors running with ~1% failure rate, the complex magnetic field under control, follow the positioning and deformations of the detectors at the 50μm level and produce the calibrations almost on-line.

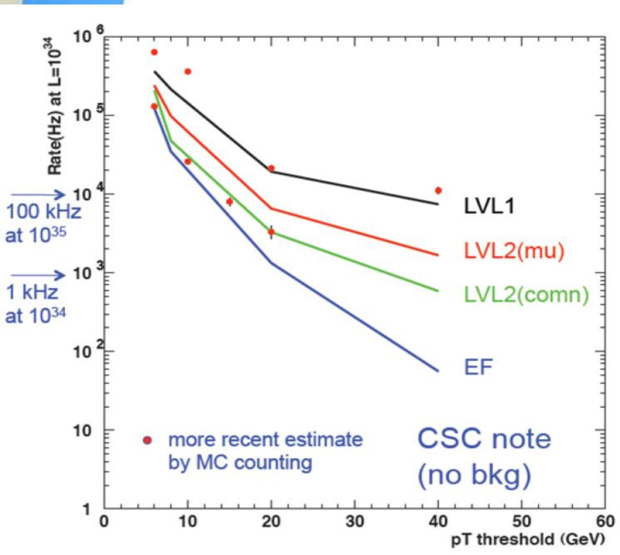
Conclusions as seen from the MUONs

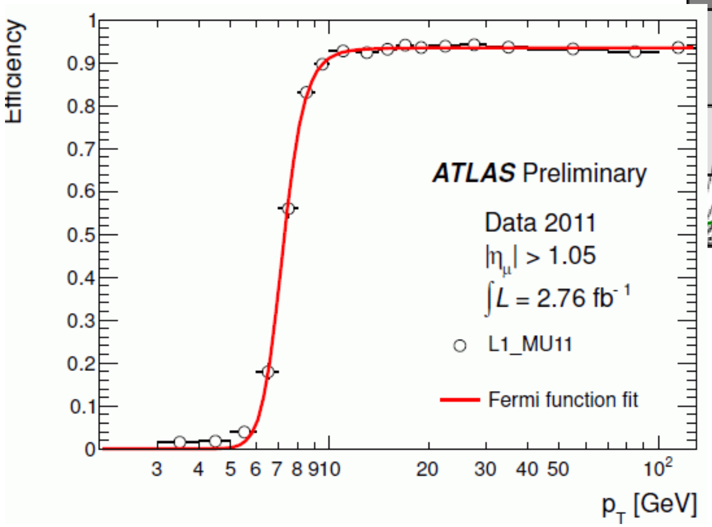


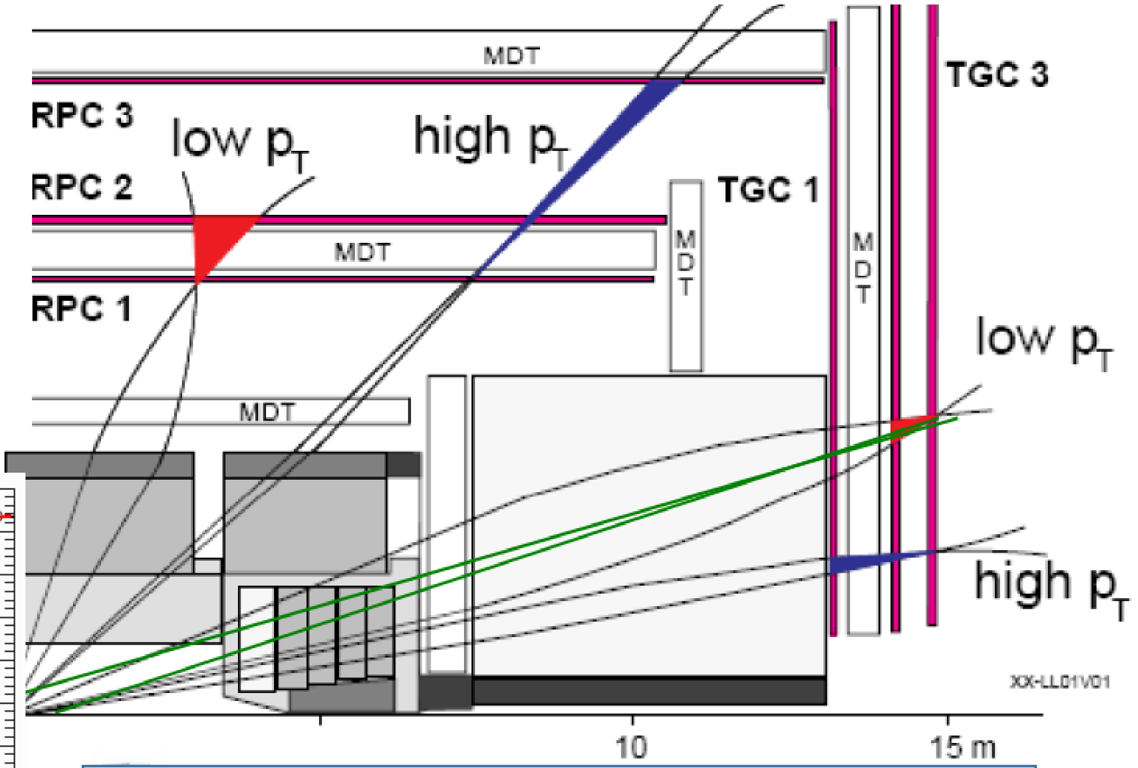
- **I think that we should all feel very proud of having participating in the conception, development construction, commissioning and exploitation of one of the most complex scientific enterprises of mankind.**
- Whenever showing visitors the ATLAS MUON Spectrometer, people have a hard time to believe that the instrumentation constructed by the 49 MUON Institutions around the world fit with each other with mm precision and failure rates in the range of 10^{-2} , providing precise (~100µm) measurements in such a large volume. This is due to a relatively small group of people that feel RESPONSIBLE and have made of **ATLAS the project of almost ½ of their scientific life.**
- **We should all feel proud of what we have accomplished in the last 25 years**

Description of the μ trigger





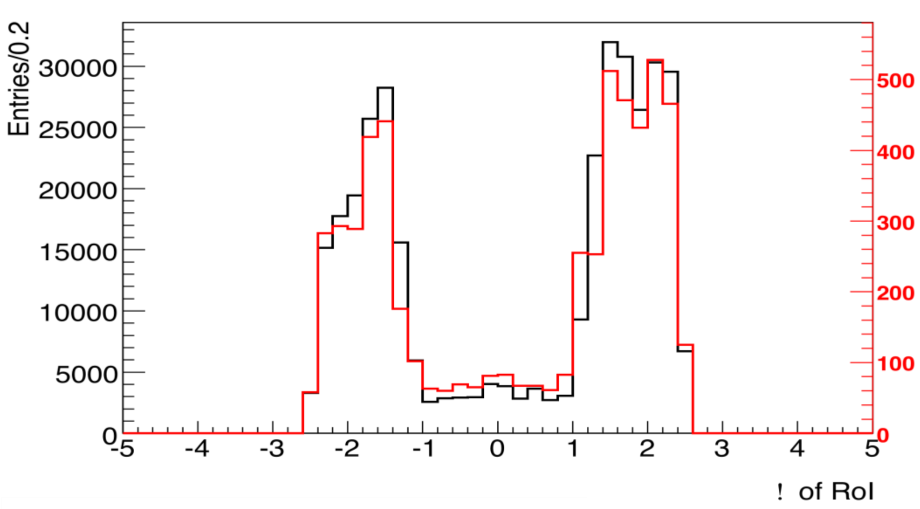


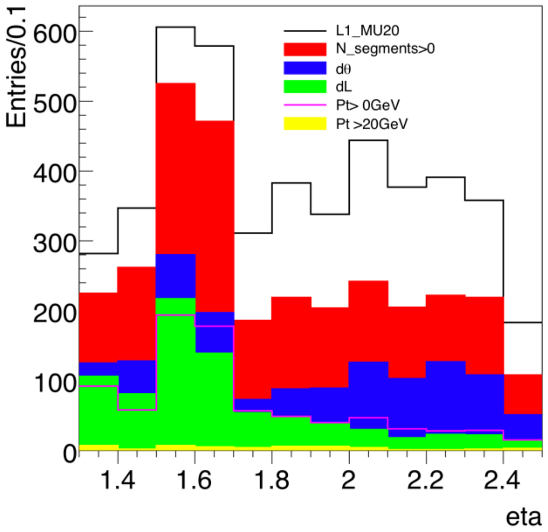


Changing the opening angle of the coincidence cone defines the momentum acceptance

Most of the μ triggers come from the End-Cap

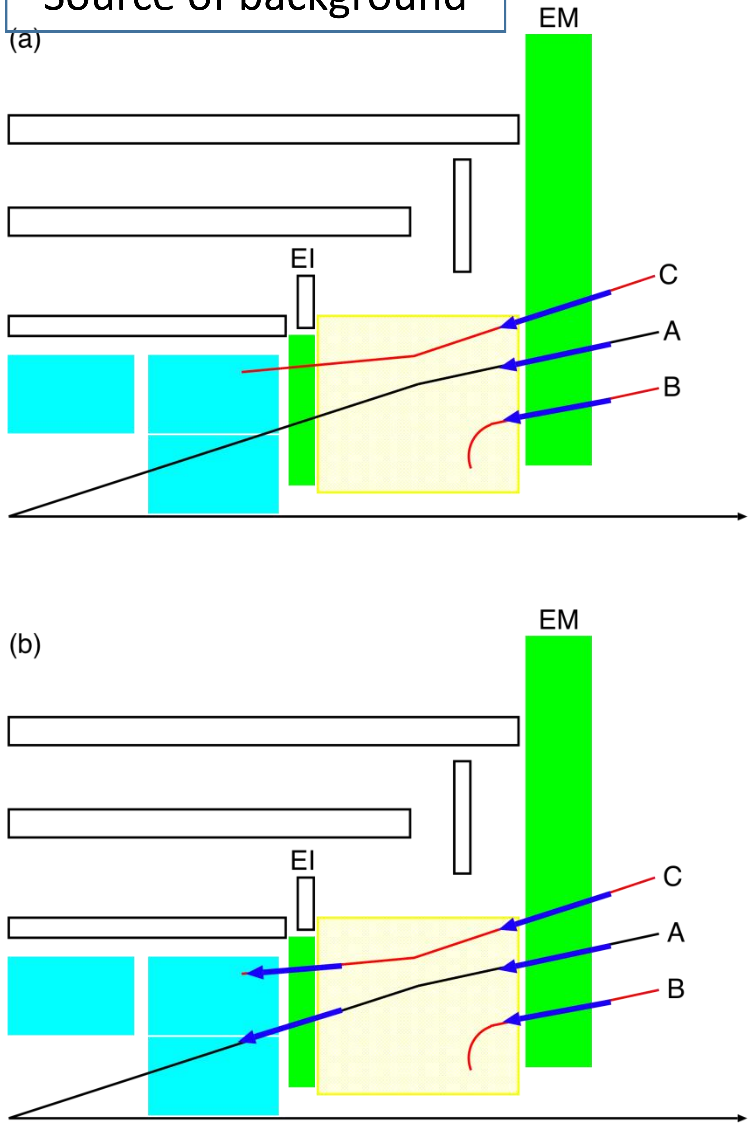
trigger rate as function of η





- High μ trigger in End-Caps due to backgrounds.
- Including innermost layer will improve rates by 100.
- Need high resolution (<1mrad)

Source of background



General requirements for the New Small Wheel

- 1mrad resolution is a very hard requirement, try to simplify the system by requiring 1 trigger track in a small ROI=>use pads to define your interest and simple logic.
- Try to have as many as possible layers to quickly discard bad single layer measurement; normally not possible by using one parameter (PH). Also assume that some layers will fail during the running of the experiment =>4+4 layers with pads in each layer.
- Try to keep uniformity with the BW-TGC in the trigger system and add a dedicated tracking device.
- Use potentiality of high resolution position measurement of TGC (optimization to be shown in the next slides) to complement the tracking device.
- Make sure that the device can run in a high background environment with a high flux of photons and neutrons (many tests).
- Make sure that the detector will be able to run for 20 years under high background irradiation.
- Make sure that you can have RELIABLE partners to construct the detectors.

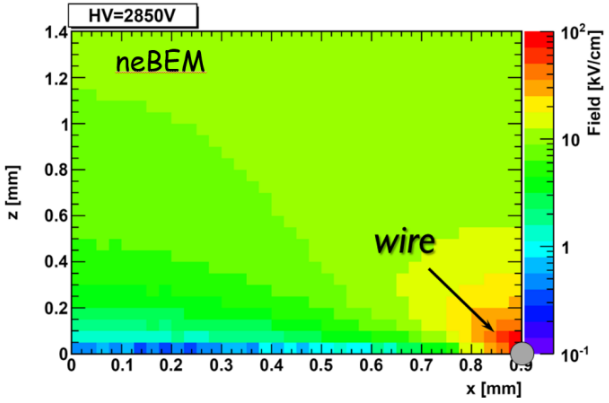
Characteristics of the TGCs

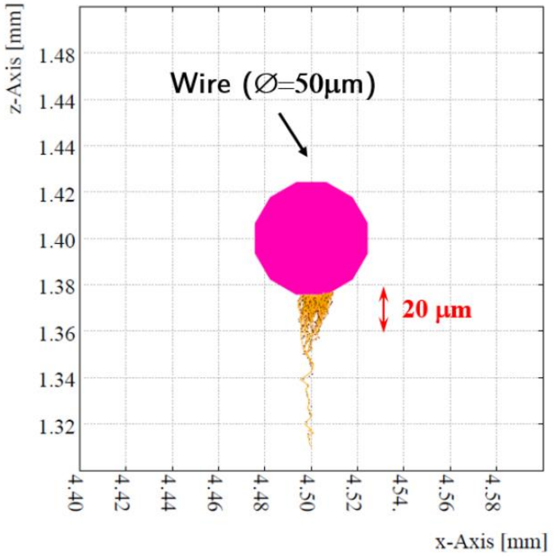
Make the gas gap as small as possible to avoid low energy particles stopping in the gas (Bragg peak)

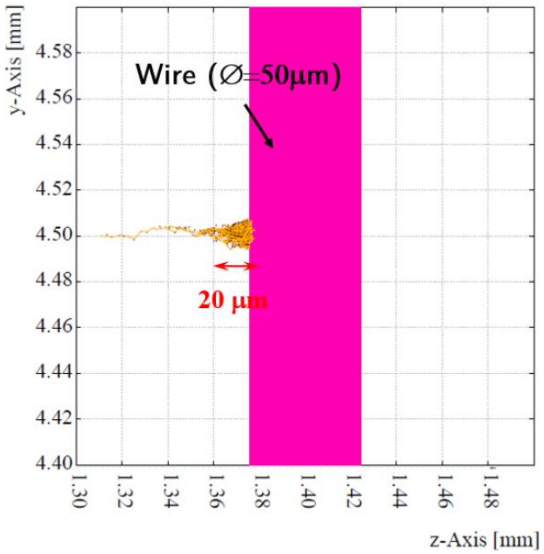
Have a high field close to the wire, to avoid sensitivity to the gap spacing.

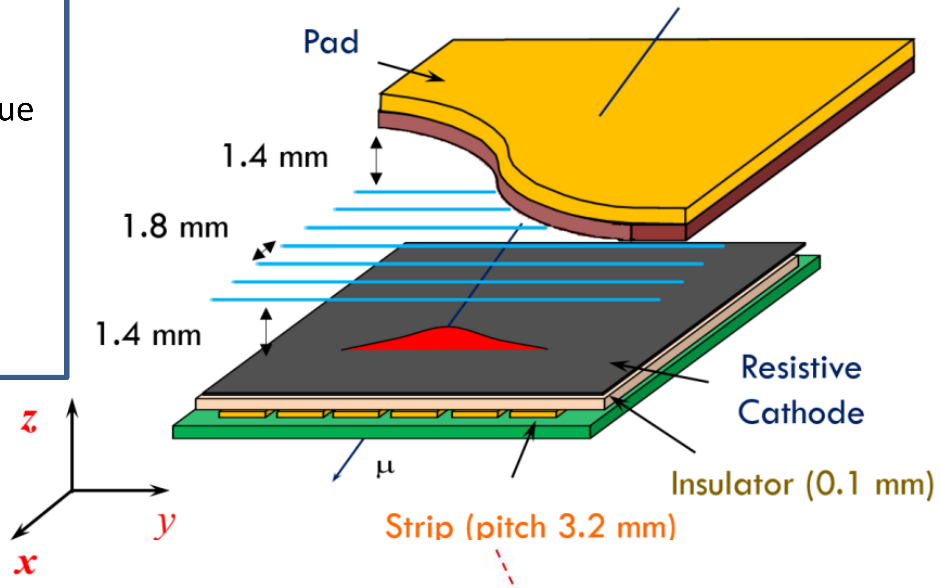
Use a resistive uniform cathode to avoid sparks due to non-uniformities.

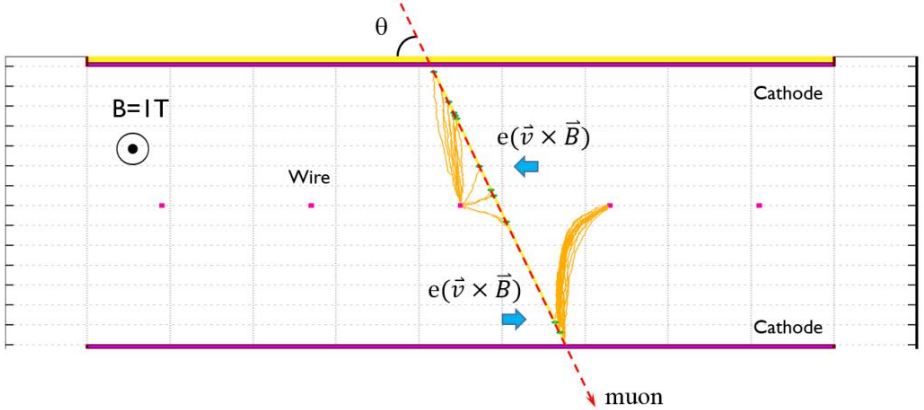
Use a gas with high ionization to obtain many ionization clusters for MIP's





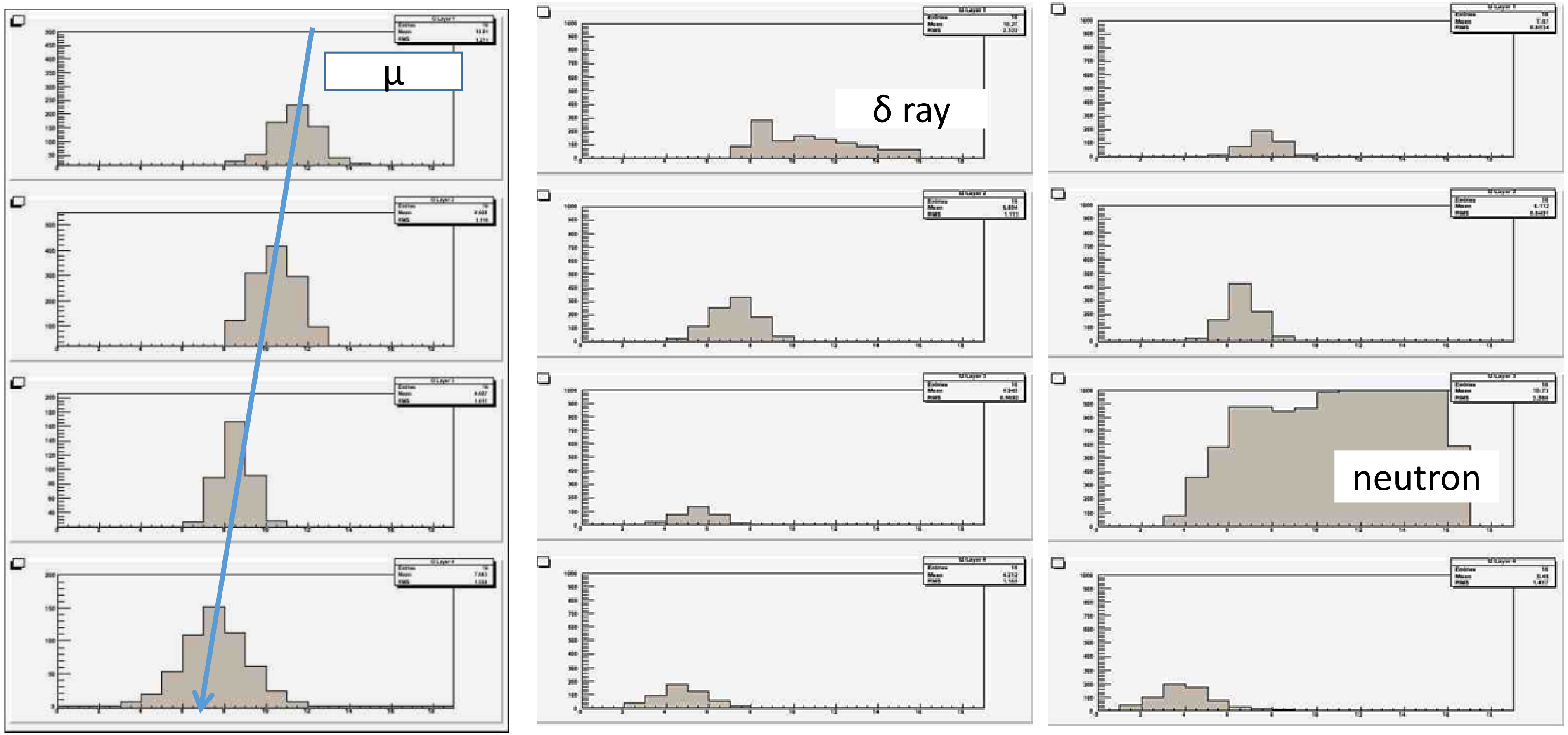






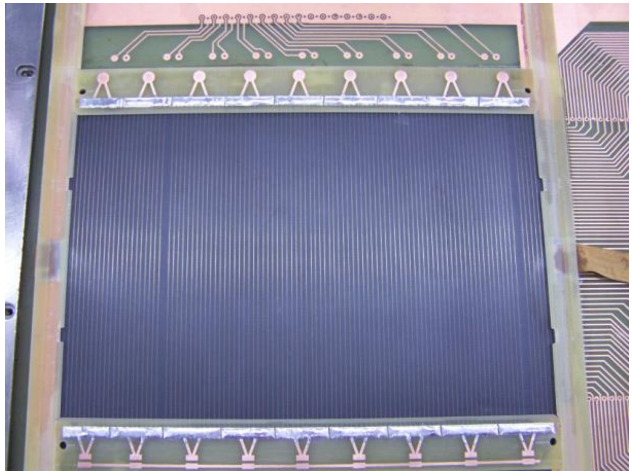
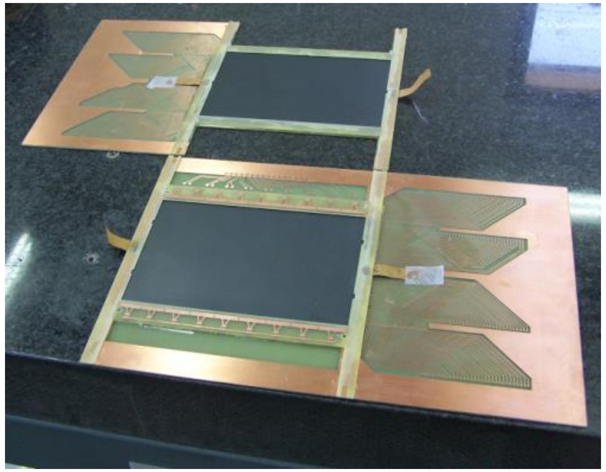
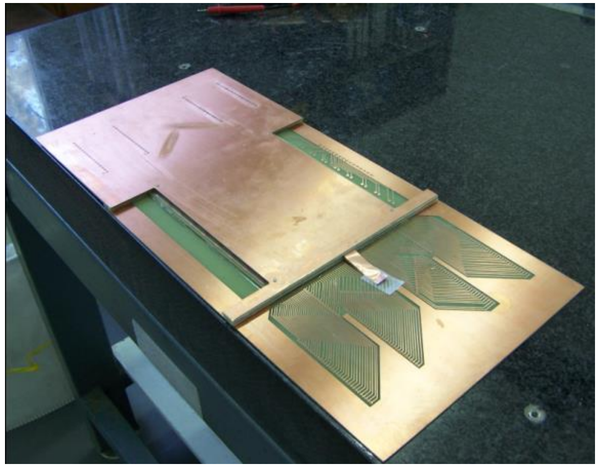
Problems encountered on single layer measurements

need to reject individual layer measurements to get good coordinates

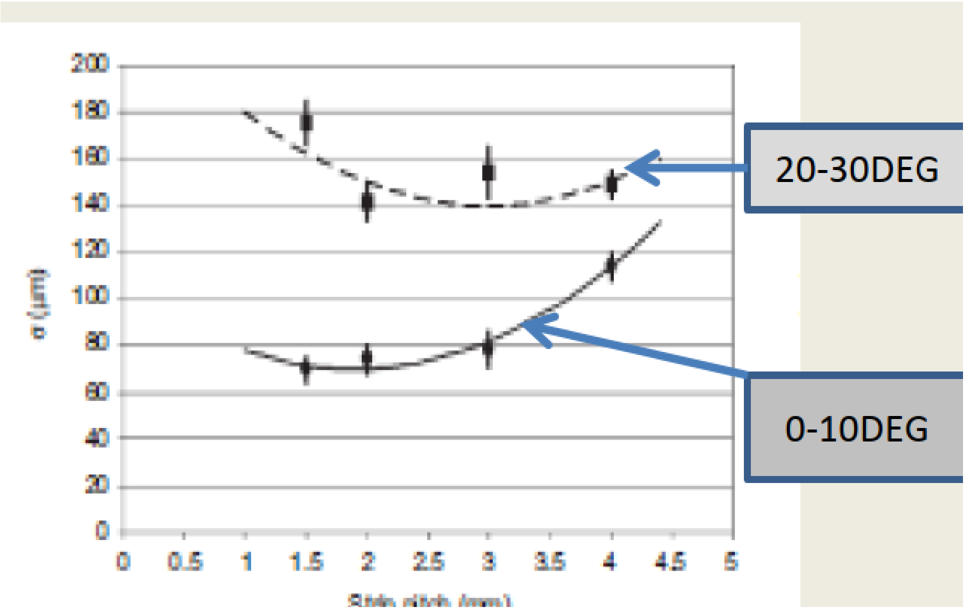


- This classification can be achieved using FPGAs + the Time-Over-Threshold (with the necessary time resolution 4ns).

Optimizing the position resolution

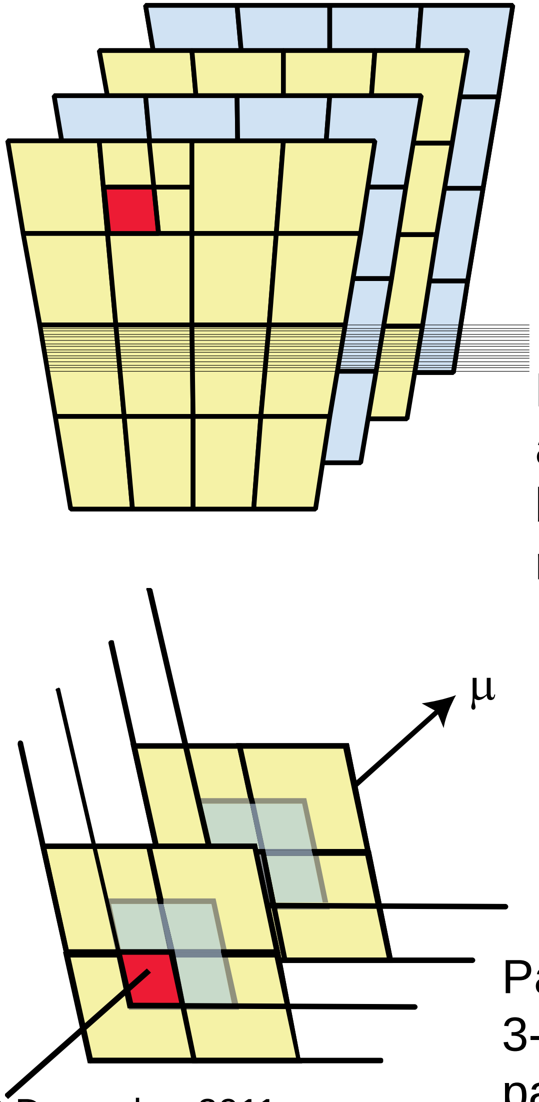
  

- Test performed at the T9 beam line (10GeV hadrons), 31/10-5/11/07
  - 2 small TGC's each equipped with identical strips on each side to determine the noise.
  - Resistivity: 200K-Ohm and 70K-Ohm.
  - TGC-ASD with analog output, integration time 70ns.
  - Strip width varying from 1.5mm to 2mm that could be ganged together.
  - Measured resolution by (Pos1-Pos2)/Sqrt(2)
  - Results directly from on-line



Reduce the number of input signals (strips) by knowing which group to read (pads)

sTGC quadruplet

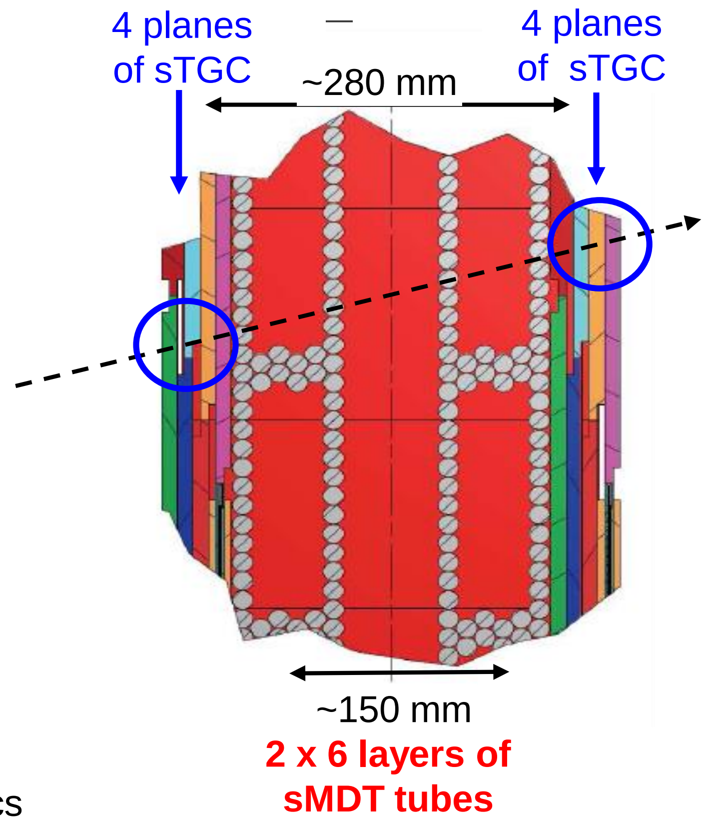


Physical pads, each layer staggered by ½ pad in both directions

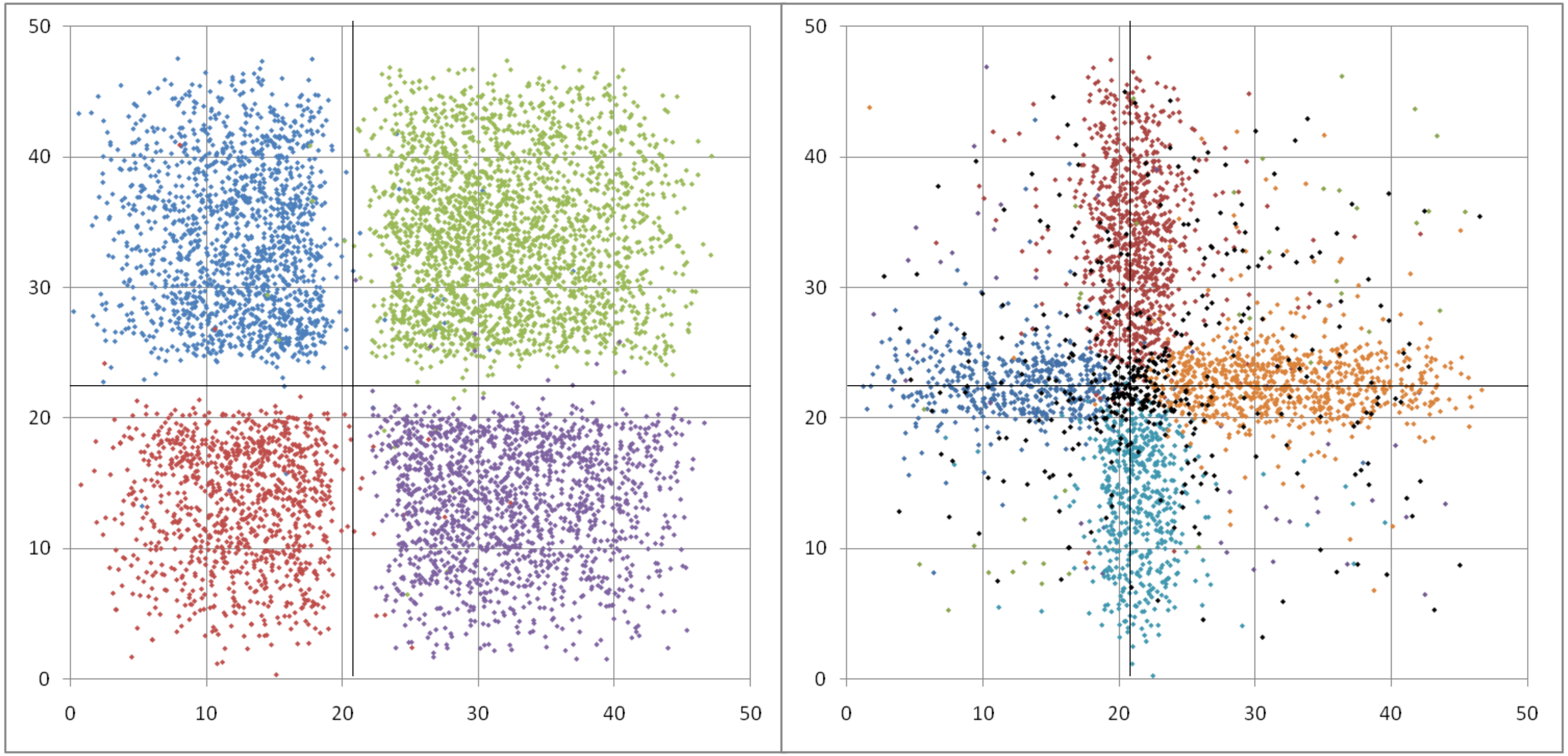
Logical pad-tower defined by projection from 4 layers of staggered pad boundaries

Pad trigger selects a band of strips under row of logical pads

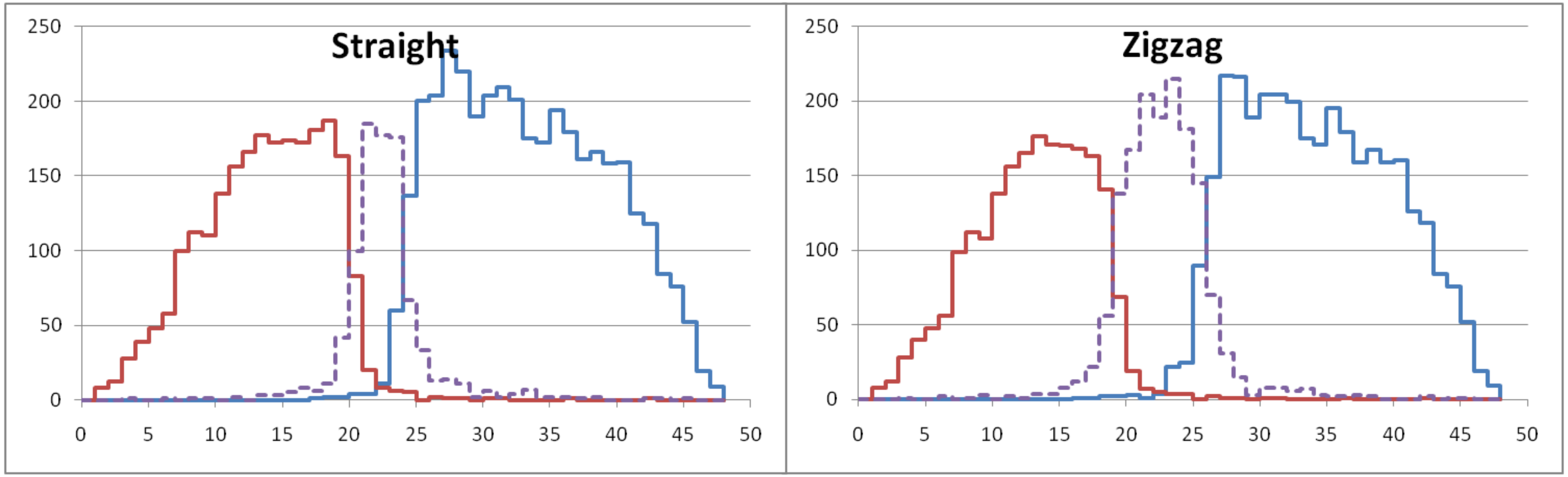
Pad-tower coincidence = 3-out-of-4 overlapping pads



But pads have edges, make sure that one can deal with them when making a coincidence in space



Overlaps – various shapes



Extending the gap to 0.5mm reduces all cross-talk and allows for a 4mm region where the charge is shared.

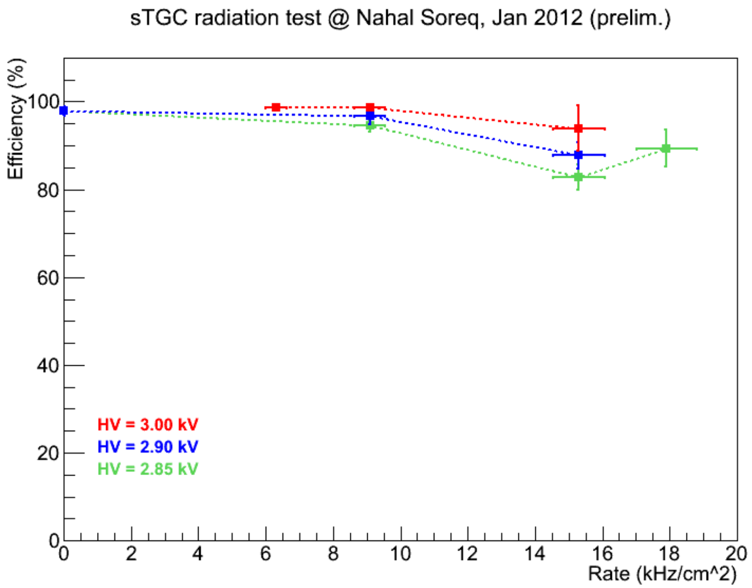
This will be shown later to work in a large size detector

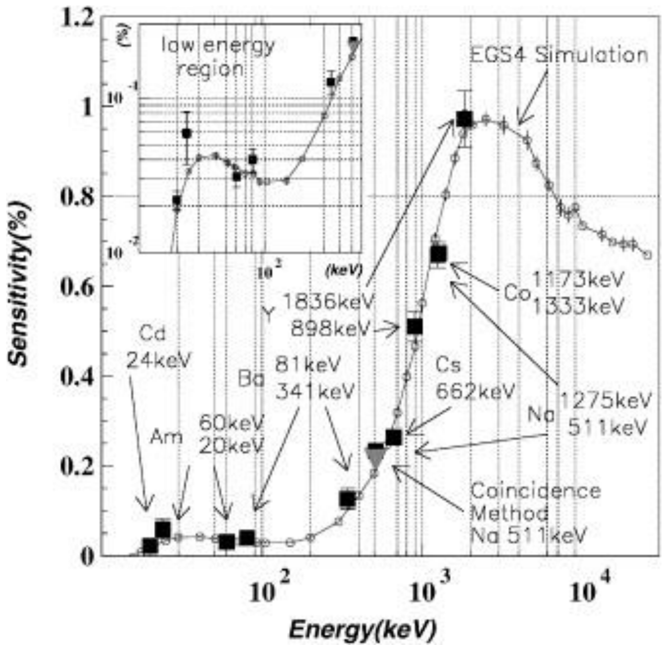
Testing

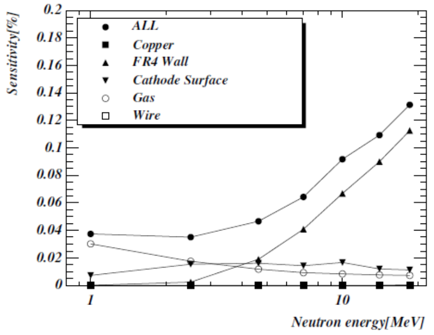
- Although one is trying to improve on an existing technology, a lot is based on tests performed in the past for ATLAS-LHC, in particular for neutrons, extensive tests were performed by our Japanese colleagues:
  - H. *Nanjo* et al., Nucl. Instr. and Meth. A 543 (2005), p. 441.
  - H. Oshida et al., Nucl. Instr. And Meth. A 587 (2008), p 259.
- Long term irradiations using photons have been performed (6 Coulomb/cm) and are being performed together with the Chilean colleagues.
- Strong activity started by the Israeli groups (4 full time technical staff and 10 Physicists and PhD Students working between 50 to 100% in the project), already from Summer 2007.
- Much of the work would not have been possible without the strong help of the Japanese groups in providing a large part of the electronics and modifying it according to the needs.
- A long series of test have been performed:
  - In Summer 2007 at T9 to evaluate position resolution.
  - In December 2008 with 14 MeV neutrons (Soreq Nuclear Center) to gain confidence in the operation with high neutron flux.
  - In February 2009 with a Co(60) source giving 30KHz/cm^2 on a large area detector.
  - In June 2009 at H8, to obtain position resolution in a large area detector.
  - In July 2009, again with a Co(60) source to get efficiencies at high rate.
  - In September 2009 a neutron test was performed at Demokritos with 5.5-6.5MeV neutrons.

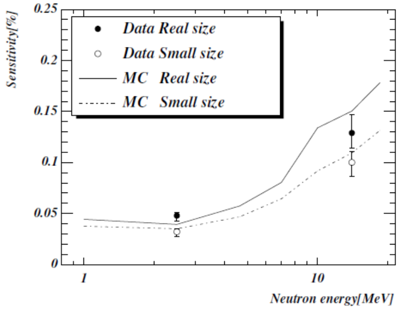
Single layer efficiency is good enough

- If your start time is within 25ns, single γ background is not a serious problem (~6%) but δ rays (in time) is more of a problem.
- Photon efficiency is different for different detectors (TGC is more like CSC’s=> expect ½ of the rate.
- Most of the high Energy neutron sensitivity comes from the cathodes.
- Due to the quasi-saturated operation of the TGC, the response is 3-5 times lower than the ionization deposits.
- Single layer inefficiency in the presence of ATLAS-like neutrons <6%.



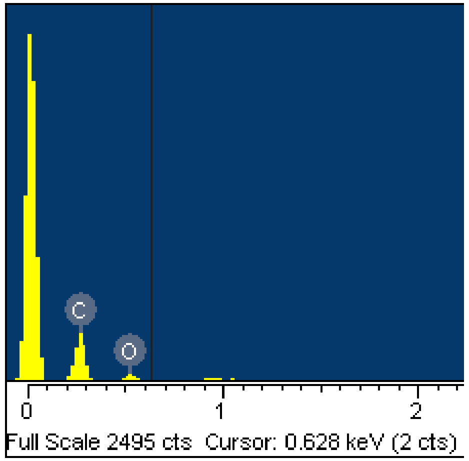




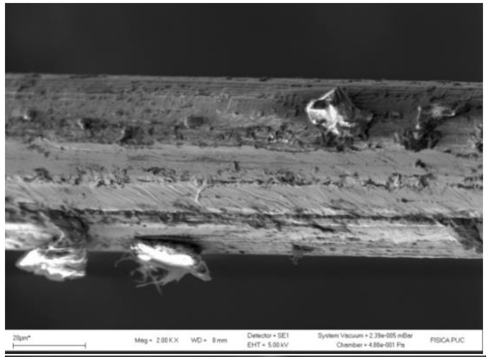


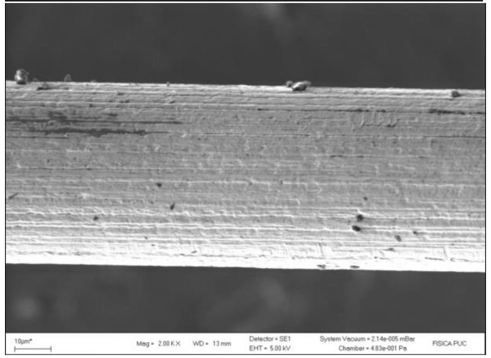
Aging tests (II)

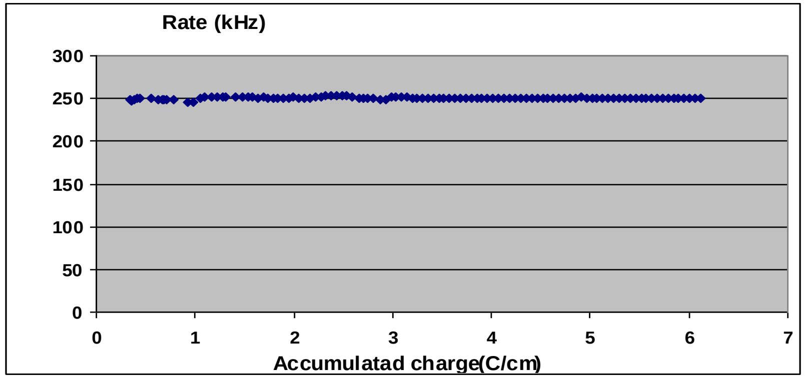
- By going to a low resistivity cathode (100KOhm/square), one can increase the rate capabilities to <30 KHz/cm^{2}.
- Both elements have been implemented in 10 small prototypes that have been tested during one year.
- Most important, they need to be able to take the high radiation levels of SLHC.
- A small chamber has accumulated 6 Coulomb/cm, without any deterioration= 20 years at SLHC with safety factor 5.
- Anode and cathodes were analyzed for deposits in Chile, where a new Lab was established to continue radiation tests.

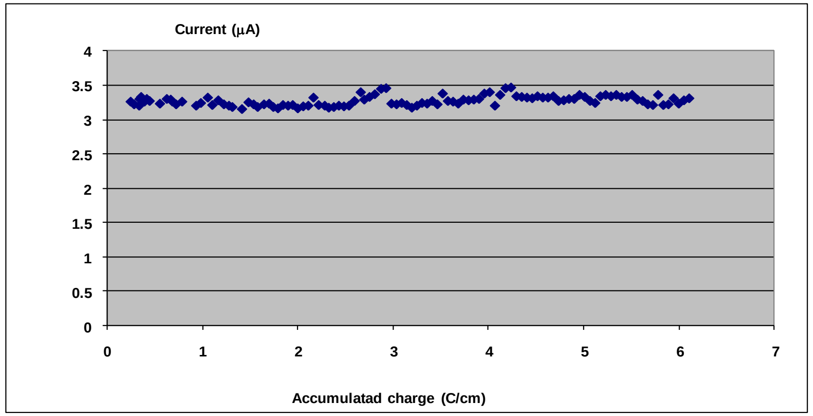


Deposits due mainly to Carbon and Oxygen

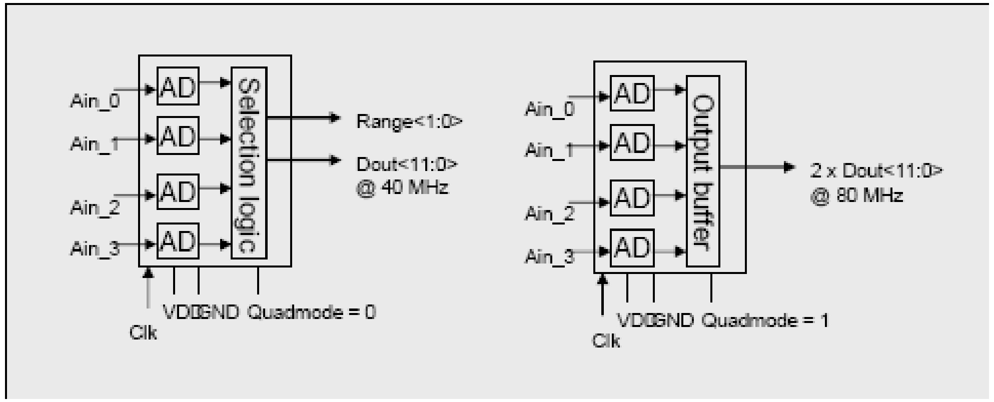


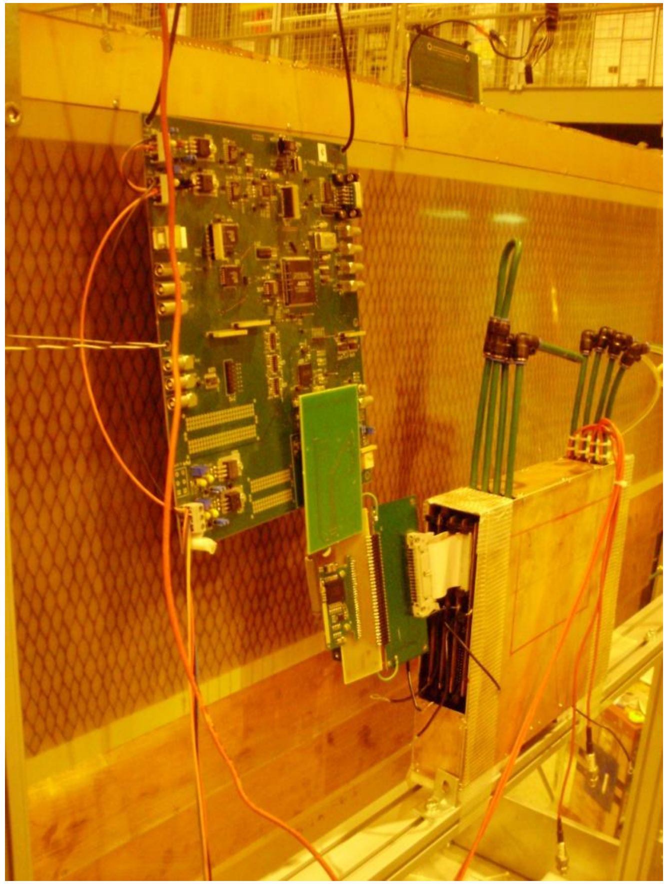






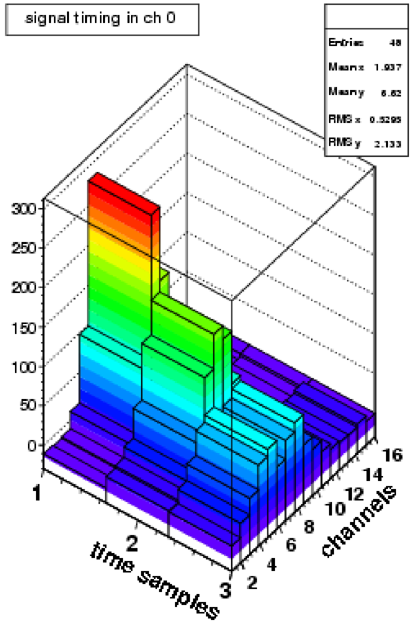
Understand the temporal behavior of the signal charge Tests with CMS Radiation Hard ADC's and sampling at 40MHz

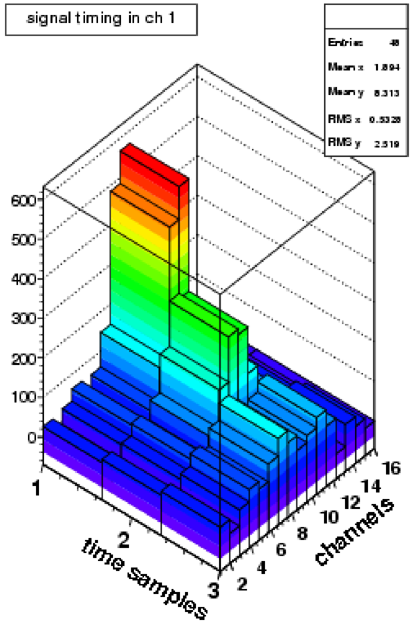


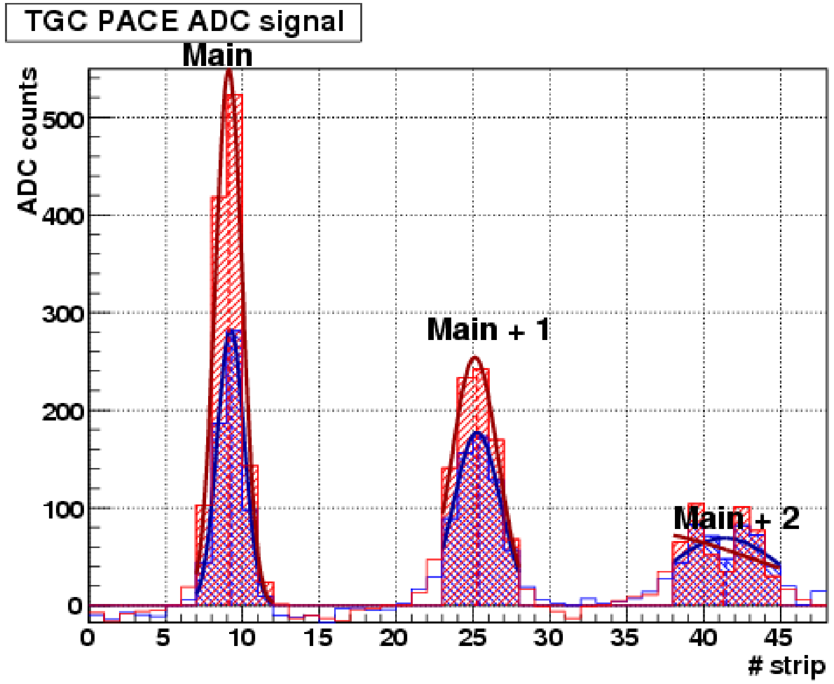


- 2 small chambers with 16 channel readout each (N. Lupu, A. Hershenhorn, N. Amram)
- Most of the results are almost on-line

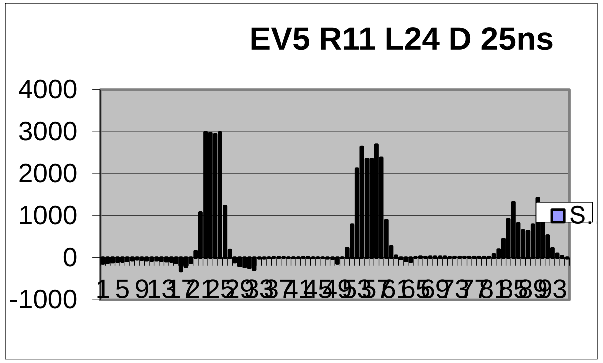
Typical PH spectra on 3 beam crossings

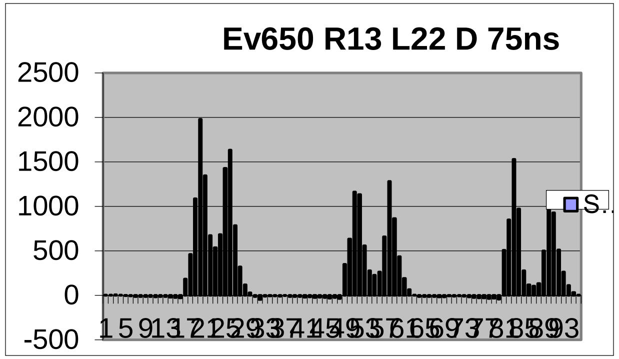


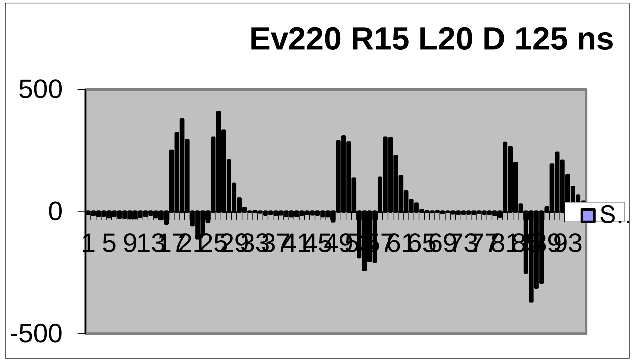




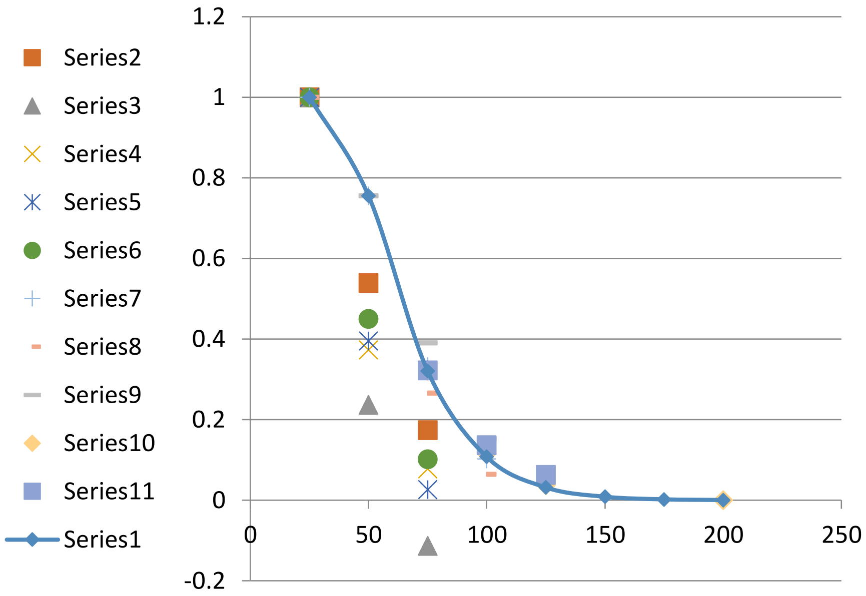
CMS pre-shower electronics



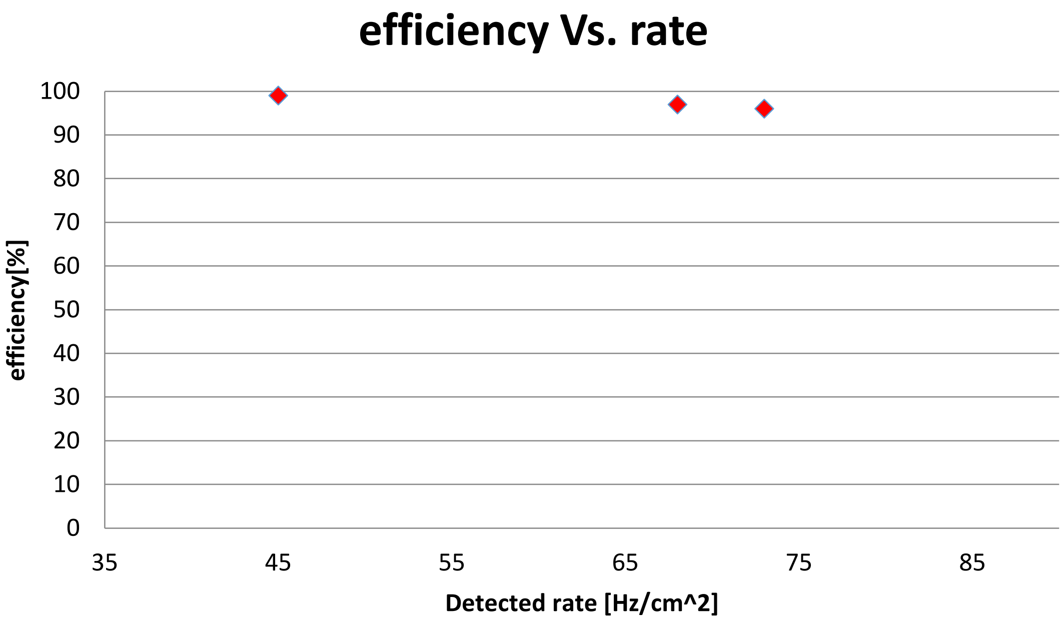




- By looking at the time evolution of the neutron signals using the CMS electronics, one determine the expected dead-time for a given set of strips.
- This will produce an inefficiency for a single plane (measured at 3 times the Phase 1 rate to be 4%, see next slide).
- For SLHC, having 8 layers is crucial to keep the high station efficiency.



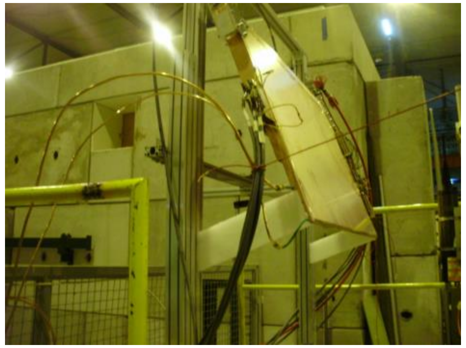
Single plane efficiency measured at Demokritos

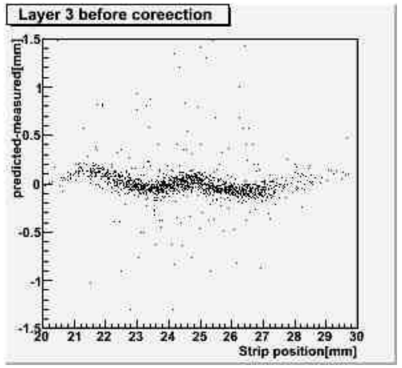


- At 2xLHC neutron rate, single plane eff.: 99%, while at 3xLHC reduced to 96%.
- Single layer resolution measured with limited statistics ~90µm at ~40^{o} incident angle with cosmics.

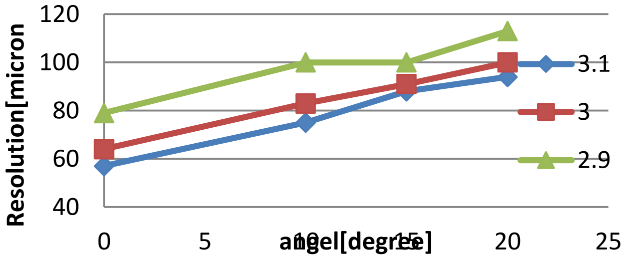
Some historical overview of test results

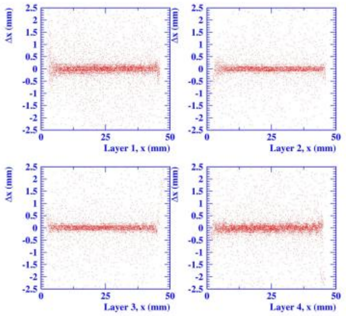
- 2009 Construct large (120X70cm²) quadruplet with 3.2mm strips 1.2m long with 0.2mm spacing and surface resistivity of 70KOhm/cm².
- Observed differential non-linearity on position, but obtained good position resolution after correction (60-80µm to 110µm as function of incident angle)
- Using TOT, obtained position resolution varying between 120 to 140µm as a function of angle.



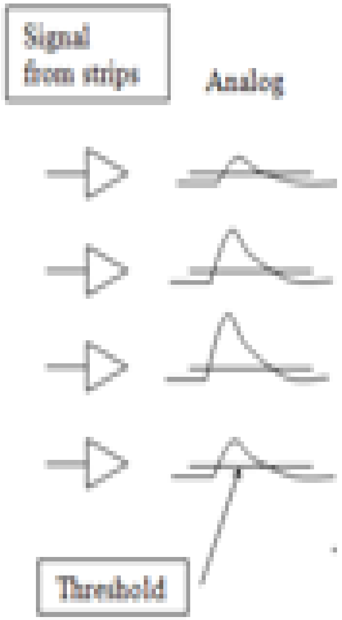


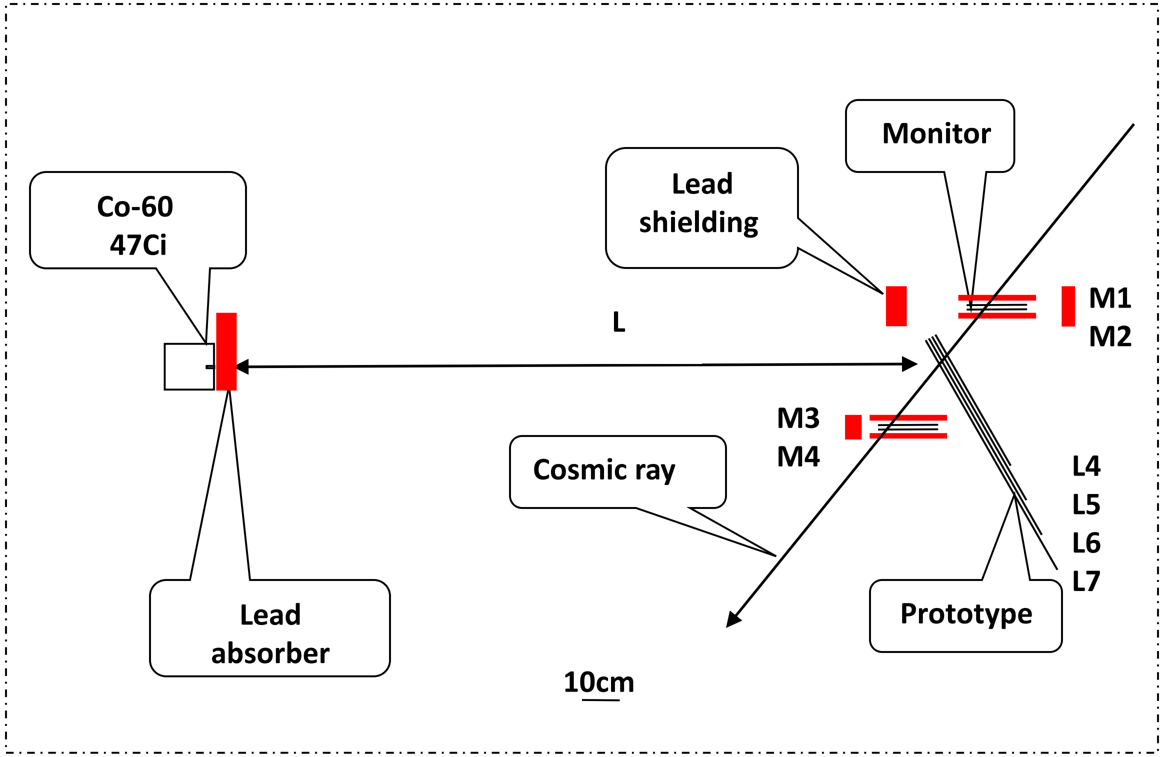
Resolution Vs. angle at different Hv (QDC)

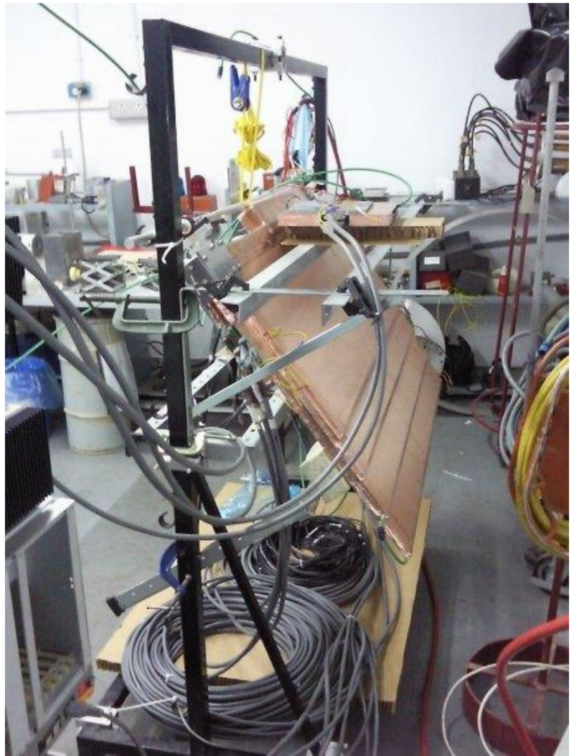




New test with Co(60)



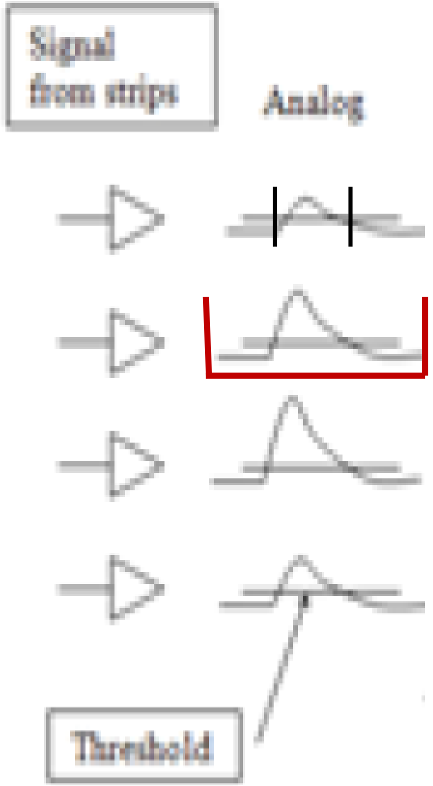


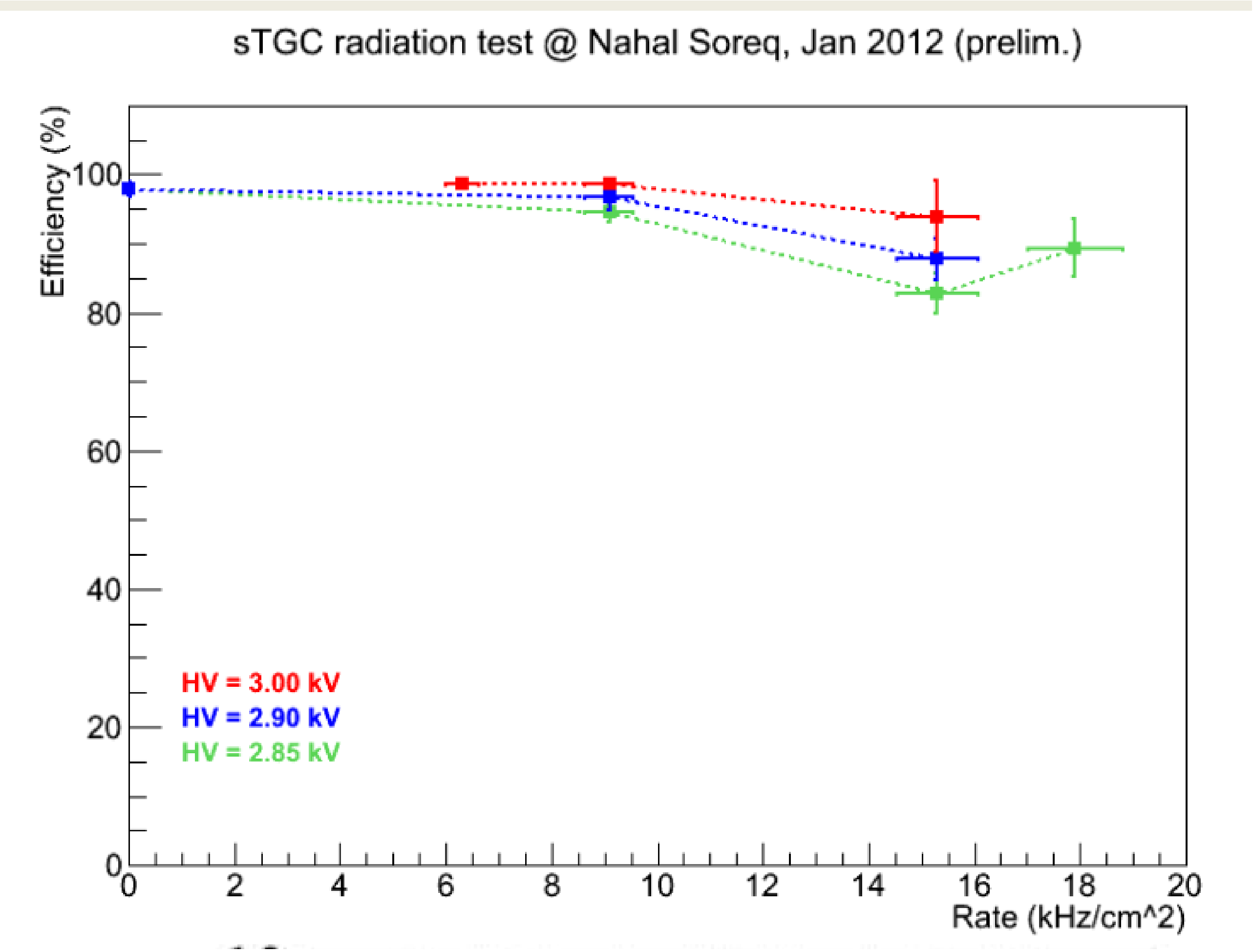


- The readout was done with T-o-T electronics
- On the high rate values, we were limited by the power supplies current limit (1mA, while voltage drop is ~70V)

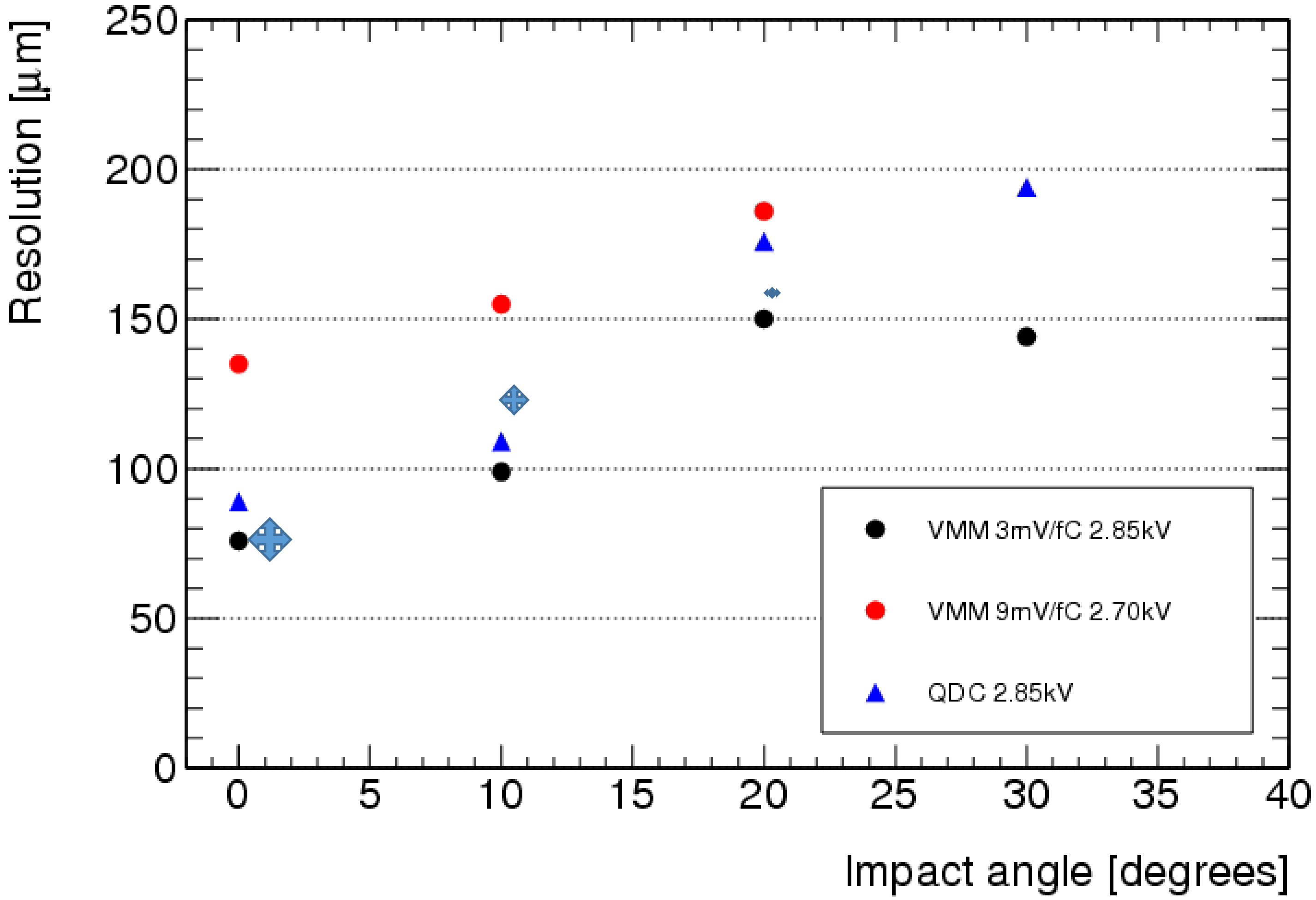
Measured inefficiency due to background photon rate

- Different type of electronics to measure charge on short time:
- TOT: start and stop over threshold.
- QDC:total charge on a given time (slow).
- VMM: charge at the peak, using flash ADC.

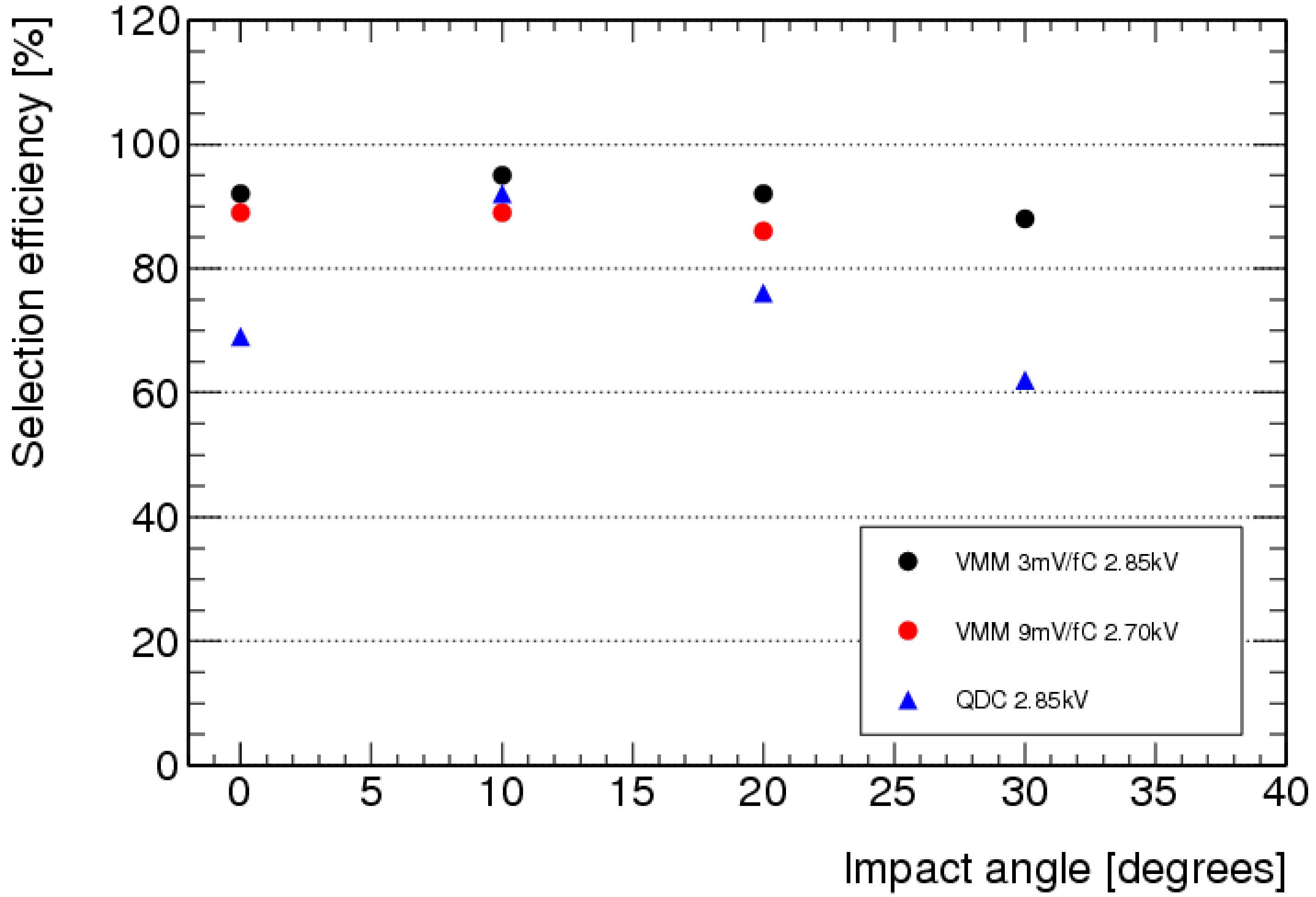




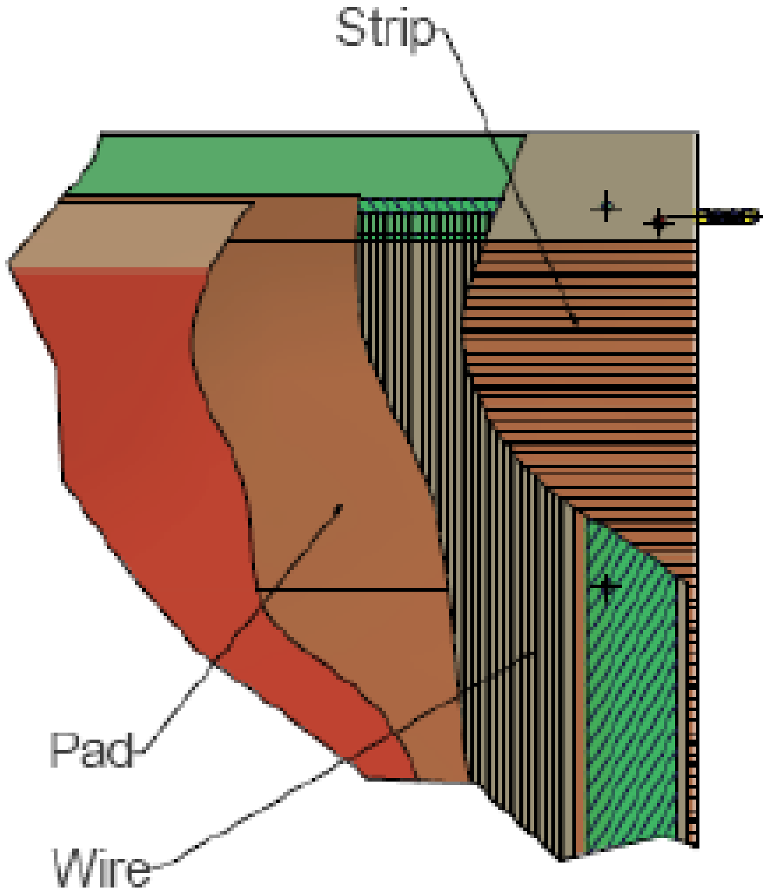
Resolution (after correction) for various impact angles

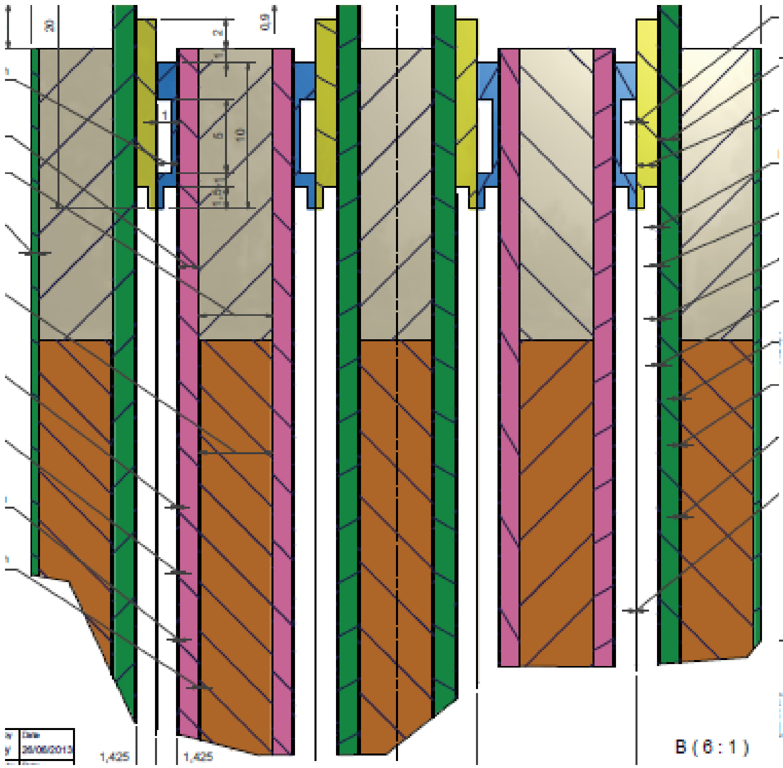


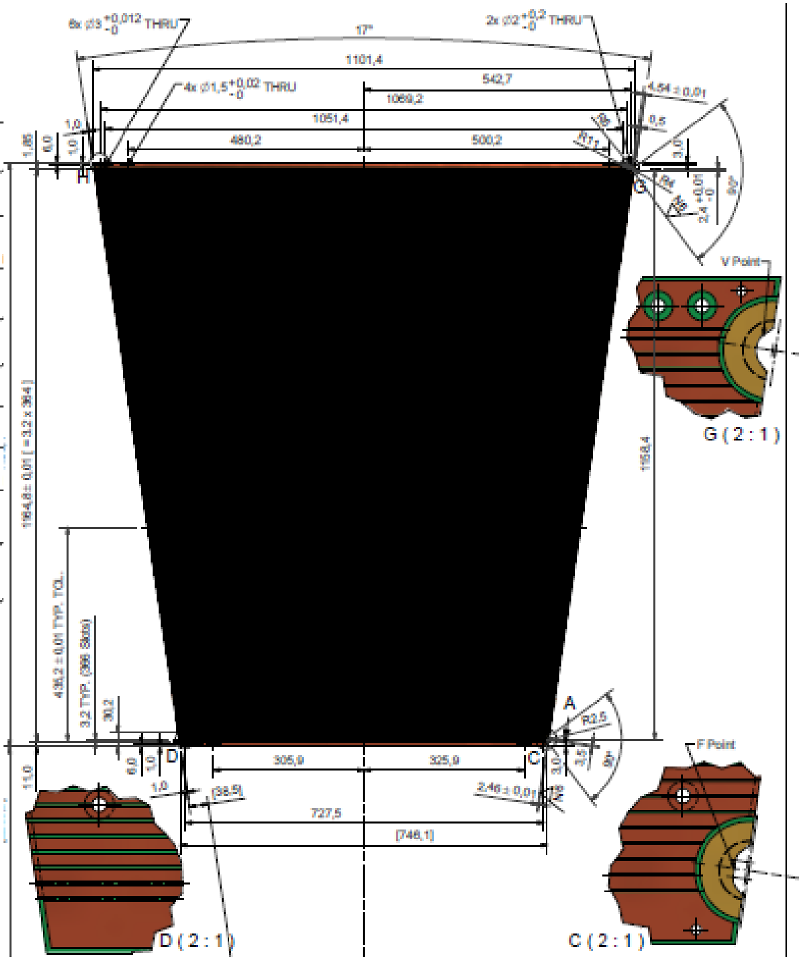
With a very high efficiency/plane for >2strips



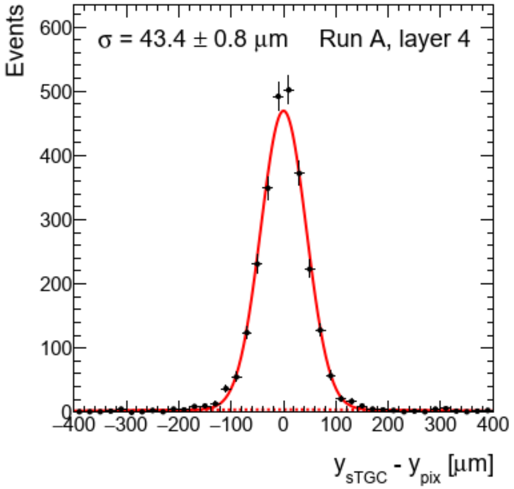
Internal detector structure

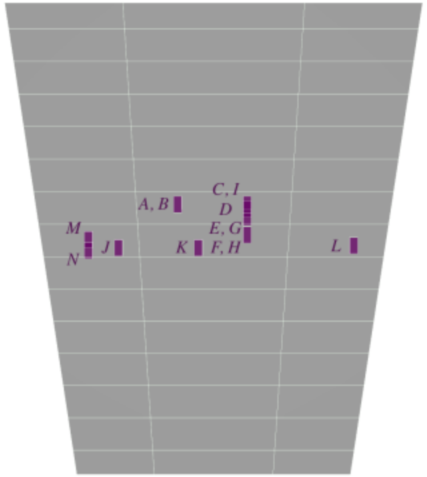


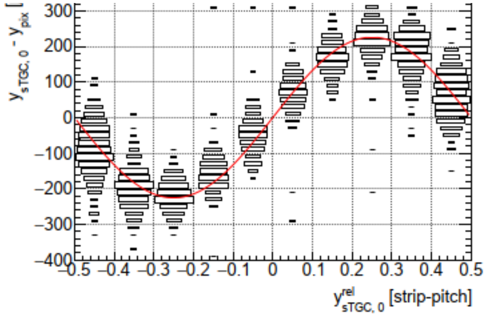


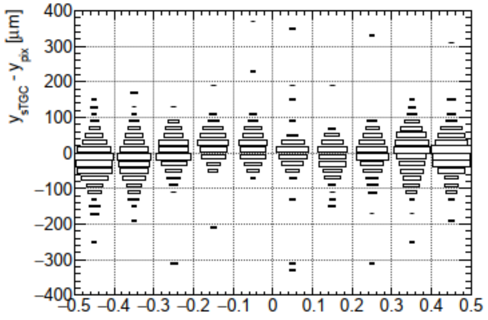


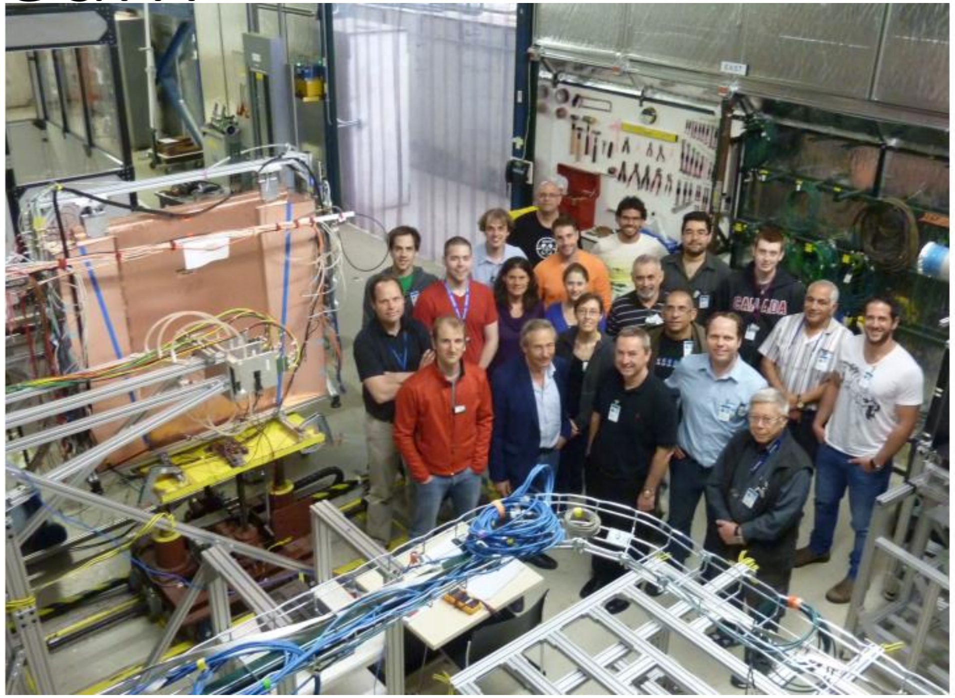
FERMILAB Test Beam

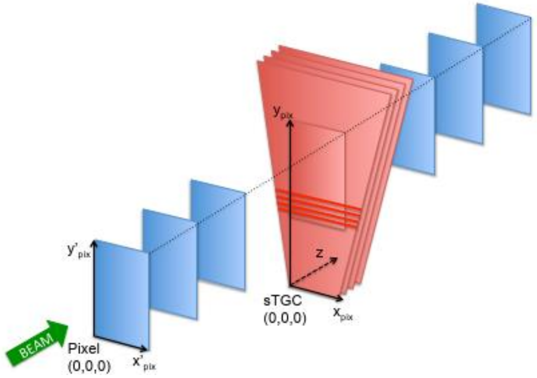




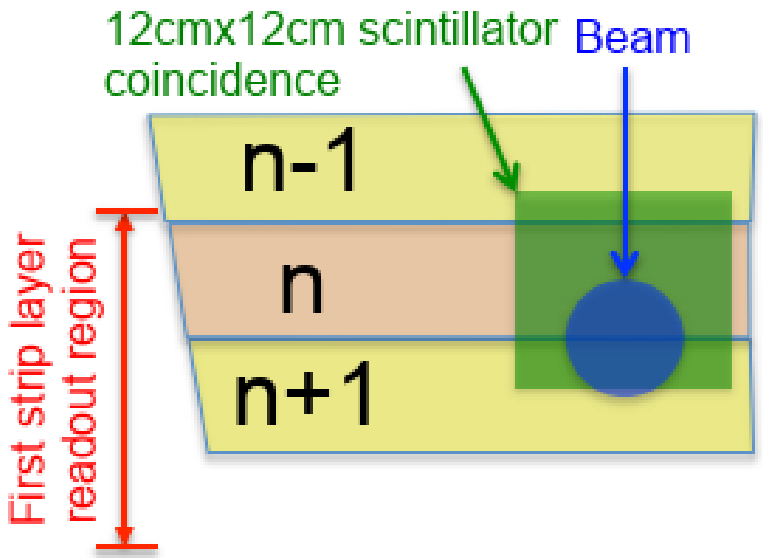


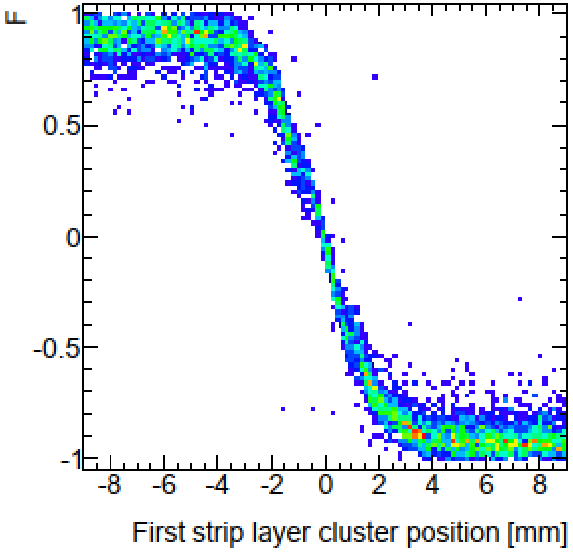






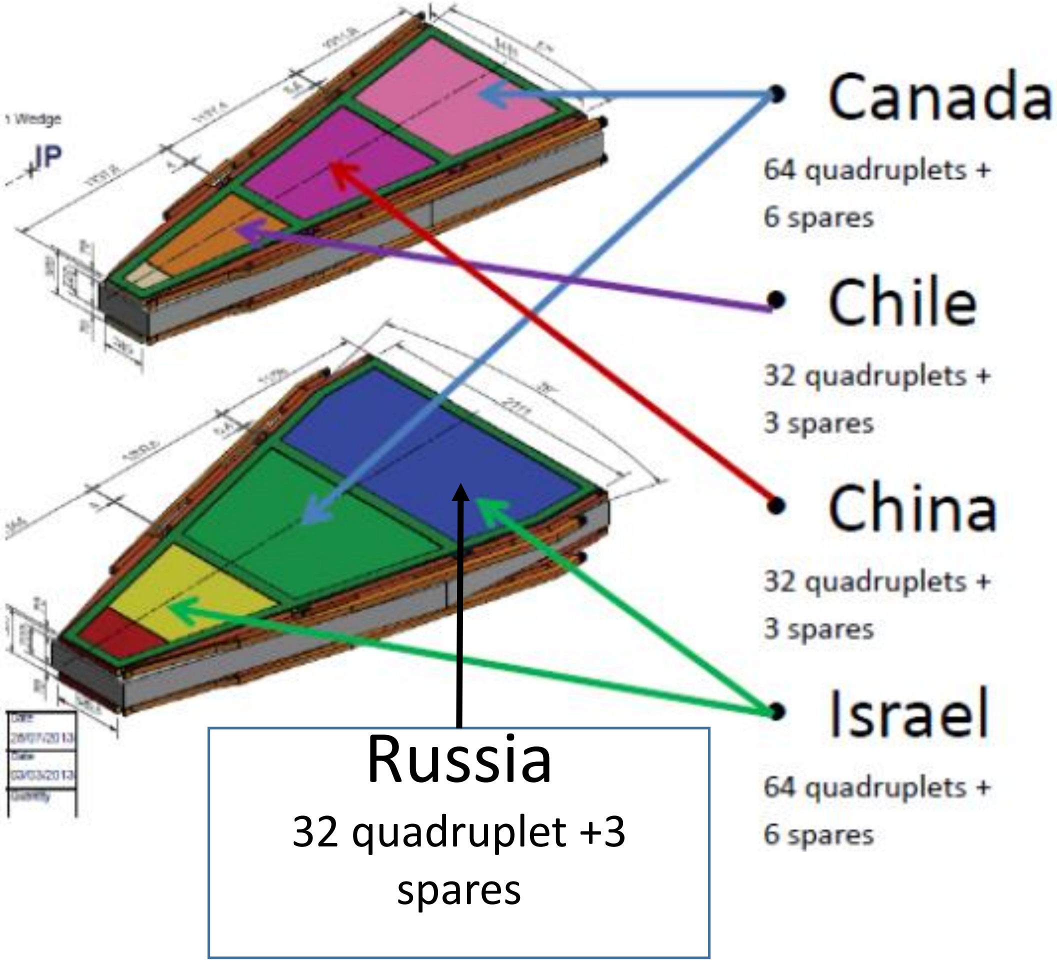
Pad Response



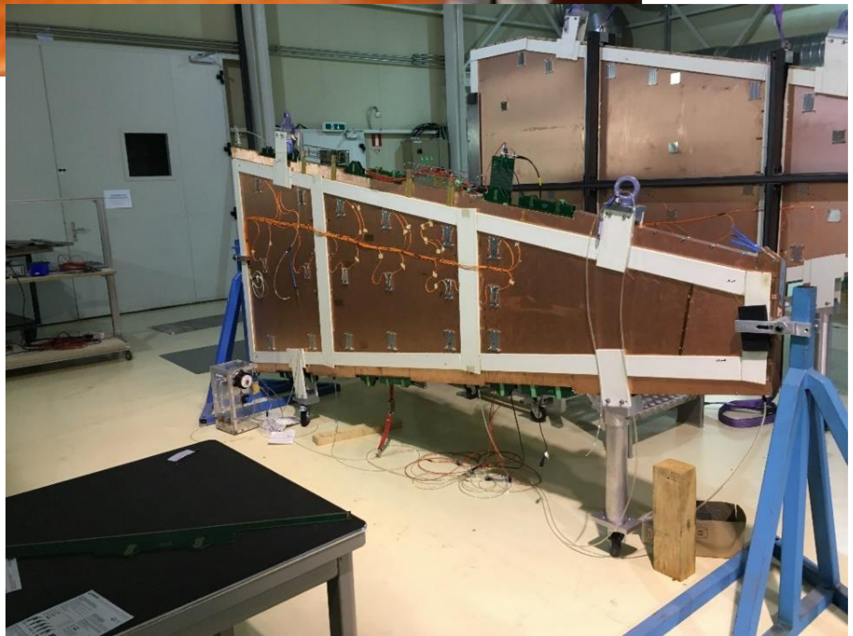


- Pads efficiency was understood by looking at the analog signals on the scope and finding out when front-end was dead (100% efficiency).
- Cross-talk between pads was found to be less than 5%.
- Signal in the transition region between pads was found to extend over +/-2mm, as expected from the simulations.
- Publication is almost ready.

It is doable, make a credible collaboration to construct it and get political backing

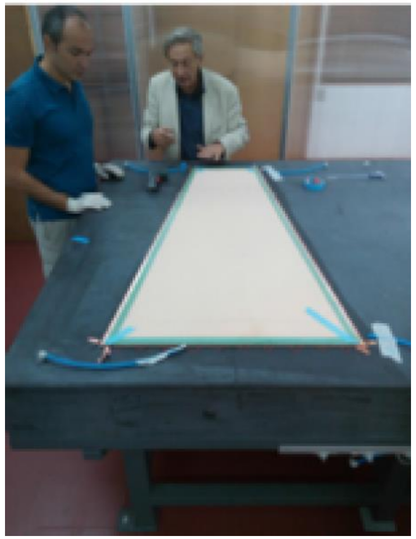


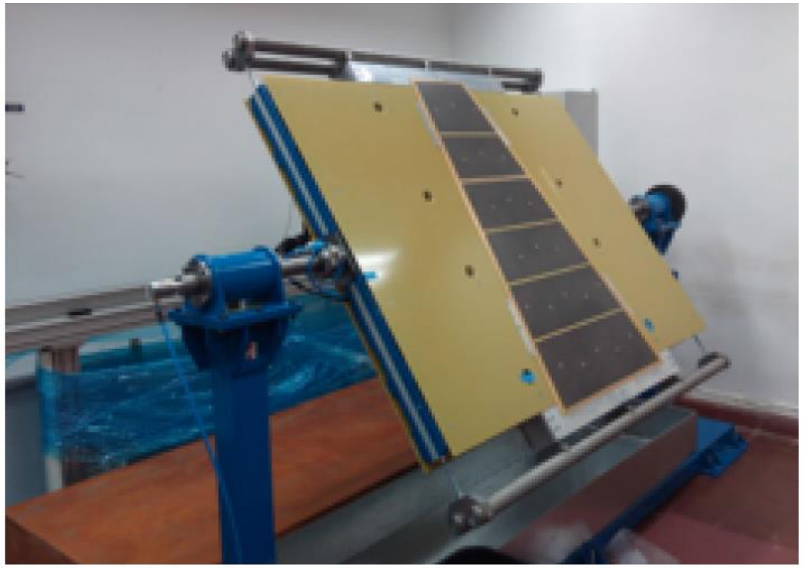
El primer detector que pasa todos los test fue construido en Chile



Y aun con todos los problemas sociales (Universidades cerradas) y pandemia, Chile y el común esfuerzo de la UTFSM y PUC lograron completar su parte del projecto

Construction in Chile

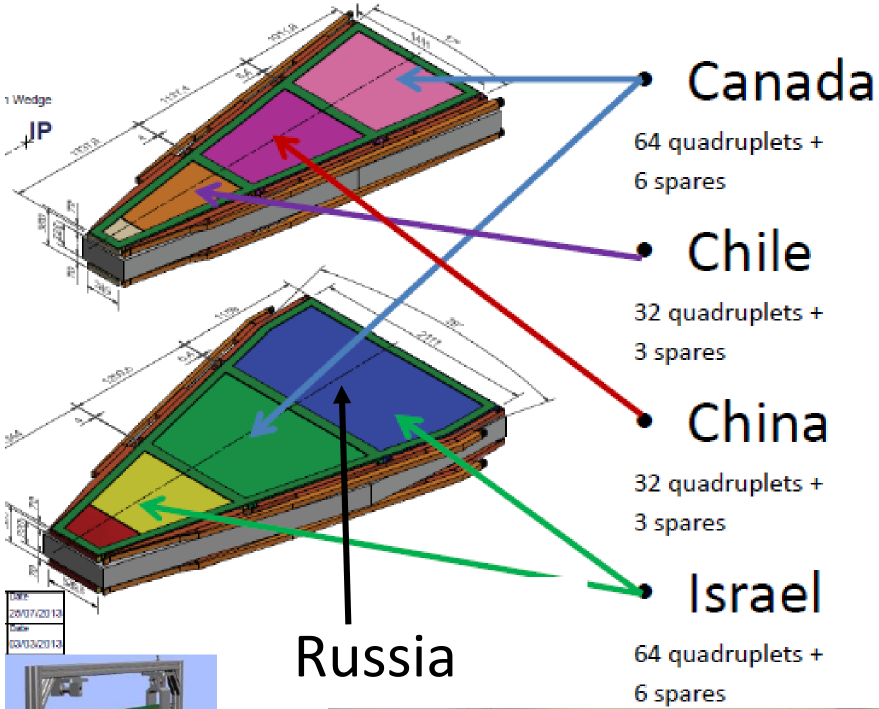


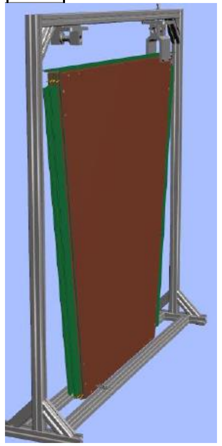


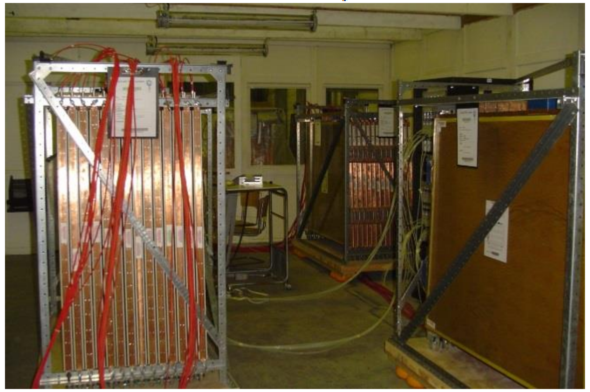
But even with social demonstrations and Covid the 2 Universities made special arrangements to allow on-time delivery of their detectors

Proposed sTGC tests at GIF++

- Quadruplets of sTGC's will be constructed in 5 different Laboratories.
- Need to pass final testing before being assembled into wedges.
- They will typically come in pallets of 10 Quadruplets.
- 21 such pallets of quadruplets will be tested at GIF++ between august 2015 to August 2017 (or 1/month).

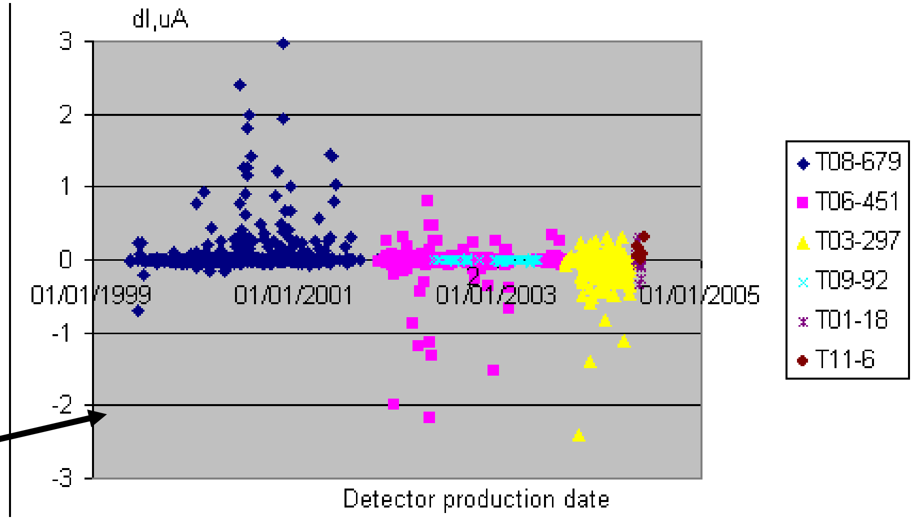




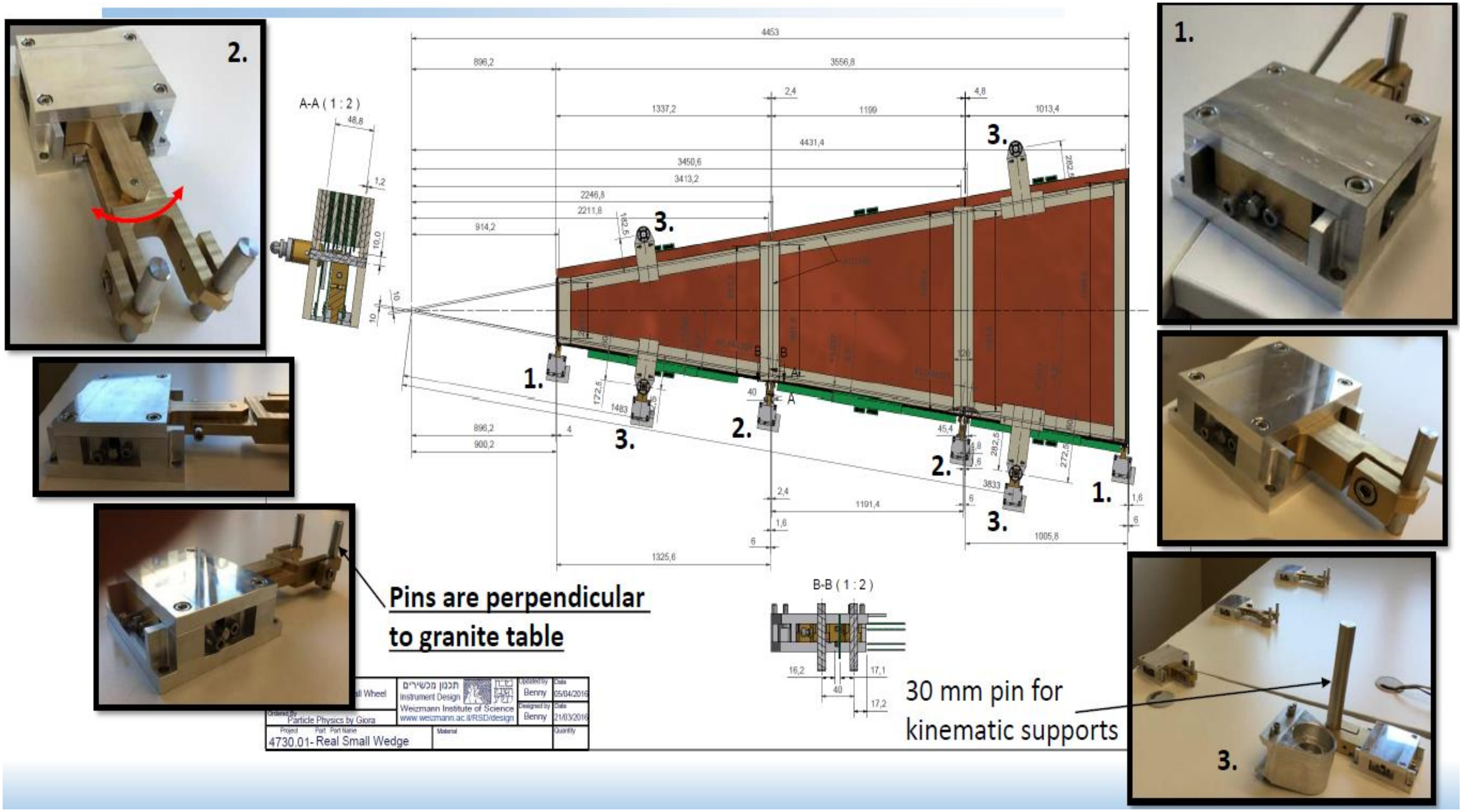


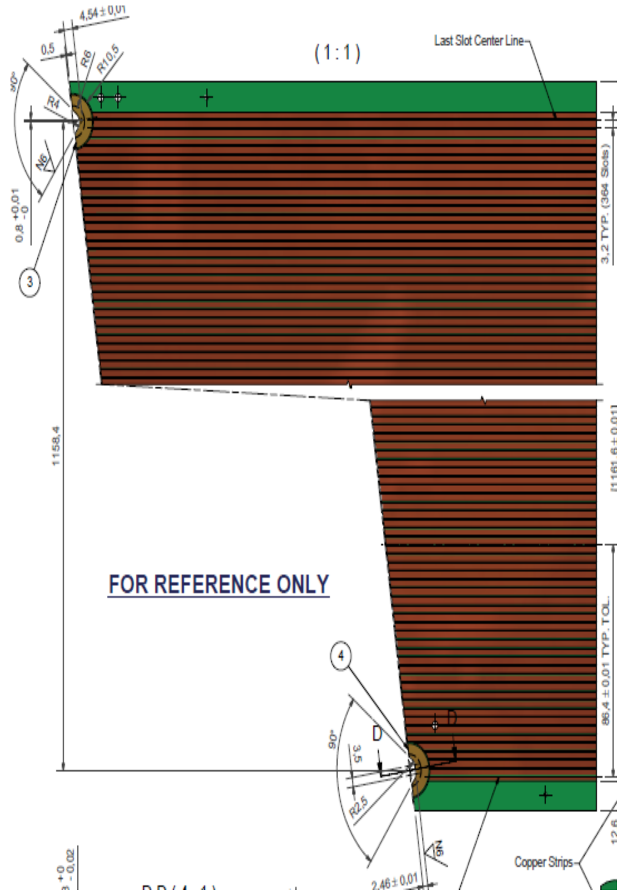
Tests to be performed at GIF++

- Every detector of the quadruplet should be irradiated uniformly at a rate of 3-4MHz/cm² for a period of 1/2hr.
- The HV current is measured before, during and after the irradiation (similar to the test previously done for Big Wheels TGC's)
- If the HV current after the irradiation does not go back to the original current to within 0.5μAmp, then reject the quadruplet (to be fixed).

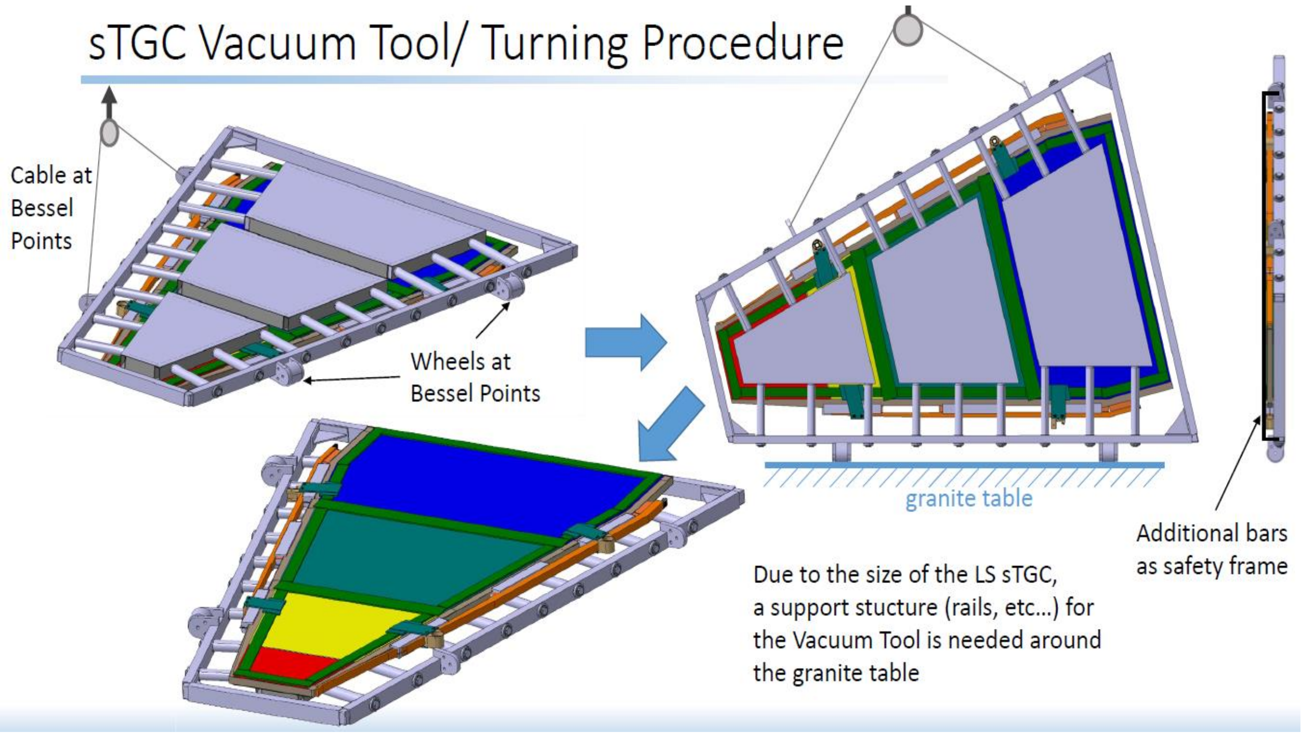


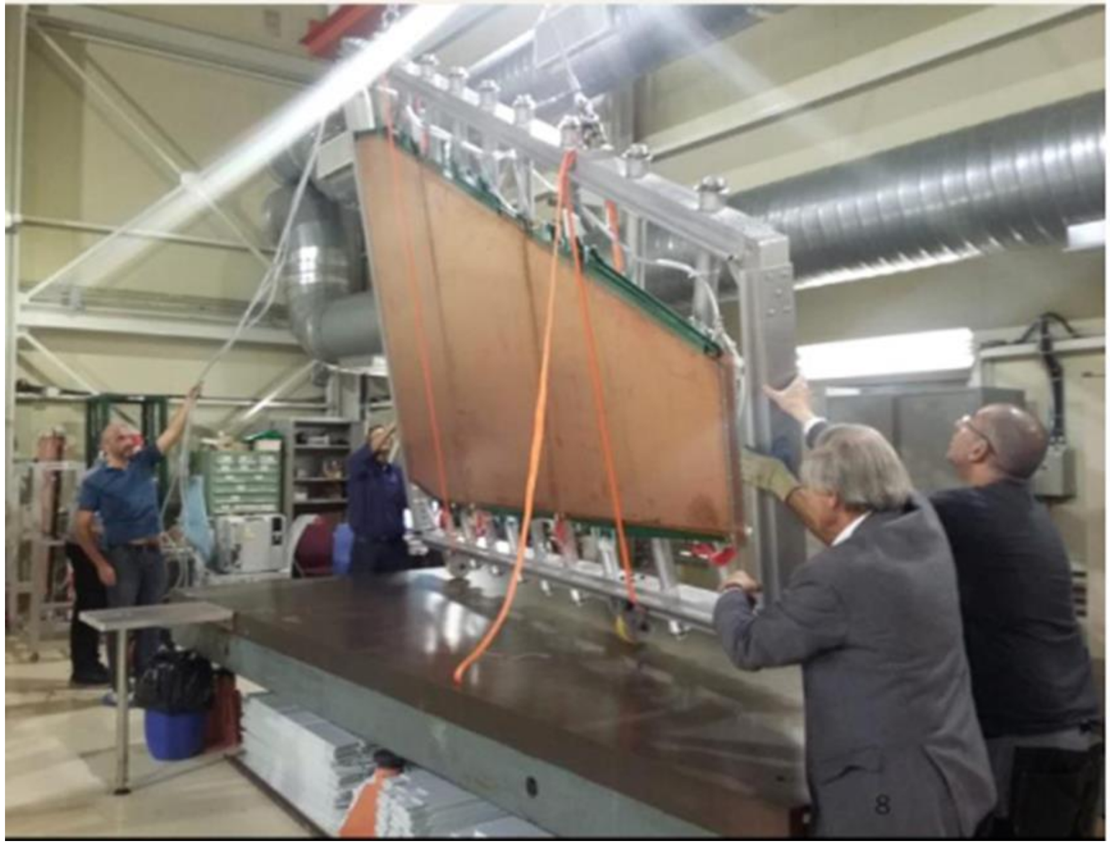
Following the high radiation test, detectors were assembled into wedges





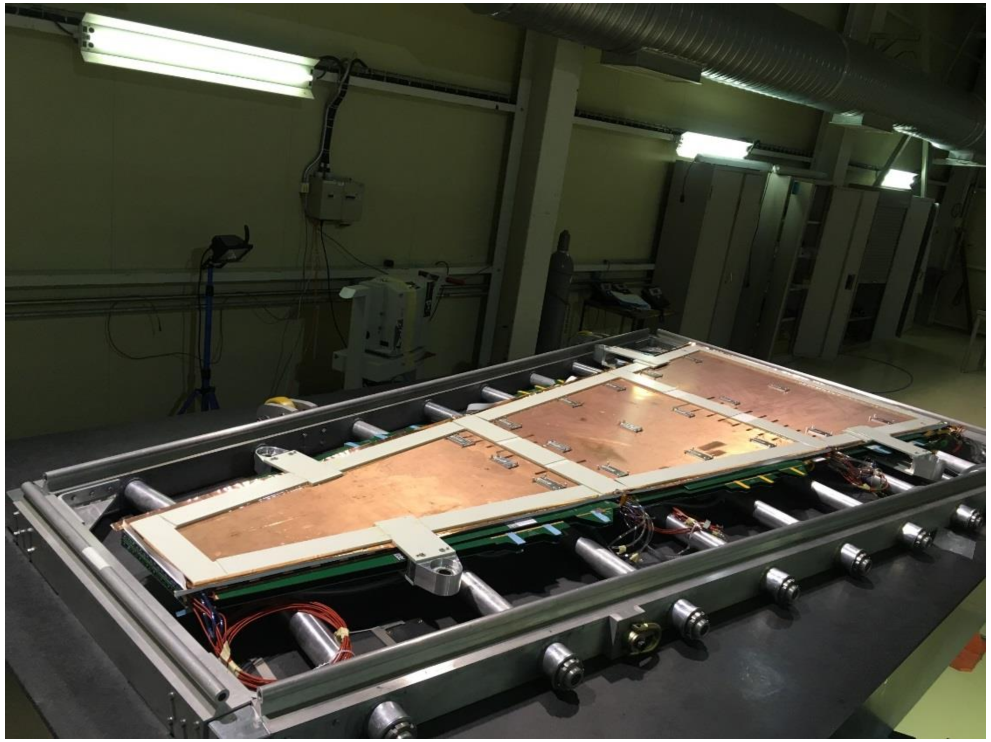
Turning devise using vacuum to keep the position of the individual detectors





Method of shims applications and the implications on the turning device.

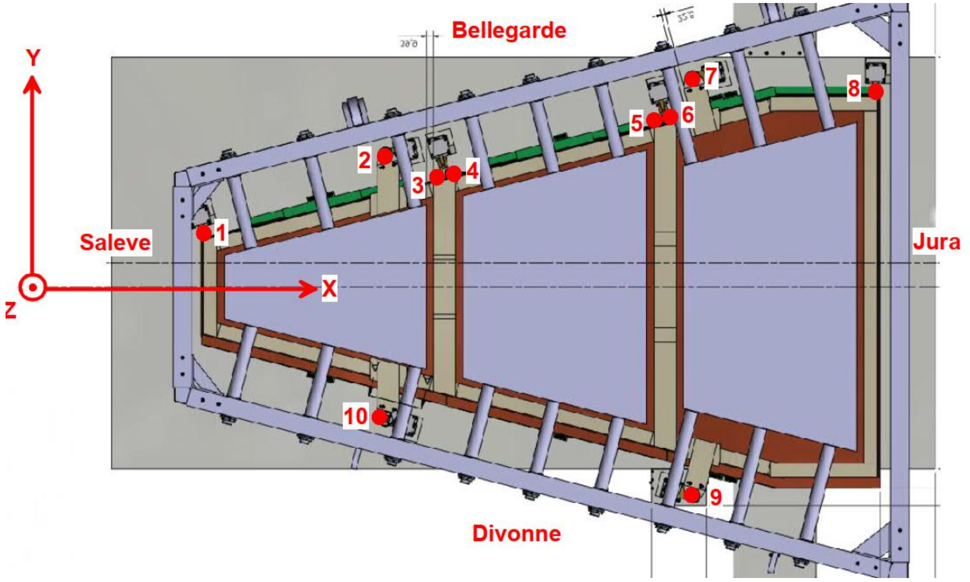
- Thickness variations between different quadruplets reach 0.6mm (could be up to 1mm in the large wedges)
- It was decided to keep this variation one-sided (i.e. alignment platform side flat, while placing shims on the other side to compensate for thickness variations). To be presented by Yan.
- Glue thickness to glue the outer frame was kept bellow 0.2mm (creeping of the glue will always be bellow 20% of the glue thickness, or 0.04mm variations with time)
- Turning device has to have the possibility to adjust every honeycomb height to compensate for the different heights.
- When turning the wedge, the honeycomb blocks do not lay on the granite table
- Deformations of the turning device at the honeycomb blocks <0.1mm

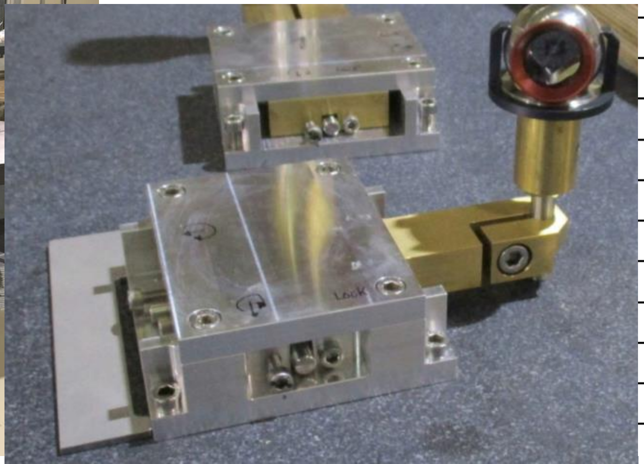


Adjust the heights of each honeycomb, with vacuum applied

Precision of the assembly procedure

- The precision of the assembled wedge, depends on the precise placing of the individual quadruplets against pins on the Fe/Granite table.
- The pins are mounted on high precision adjustable platforms, and provided that both (table and platform) are clean (this is done before placing the platforms), the pins are perpendicular to the table surface.





ATLAS - NSW Measurements (29.11.2018)								Measured - Theoretic		
Adjustment of pins for Large sTGC Wedges on Cast Iron Table in B180 clean room										
Name	Xloc (m)	Yloc (m)	Zloc (m)	Name	Xtheo (m)	Ytheo (m)	Ztheo (m)	DiffX (mm)	DiffY (mm)	Dif (m
Pins on Cast Iron Table										
1L	0.94349	0.27752	0.08228	1L	0.94351	0.27755	0.082	-0.02	-0.03	
2L	1.93567	0.72066	0.22724	2L	1.93567	0.72065	0.227	0.00	0.01	
3L	2.24546	0.60215	0.08210	3L	2.24544	0.60218	0.082	0.02	-0.03	
4L	2.28554	0.61215	0.08204	4L	2.28552	0.61209	0.082	0.02	0.06	
5L	3.44714	0.90170	0.08199	5L	3.44711	0.90172	0.082	0.03	-0.02	
6L	3.49261	0.91308	0.08193	6L	3.49265	0.91306	0.082	-0.04	0.02	
7L	3.61438	1.13923	0.22705	7L	3.61438	1.13924	0.227	0.00	-0.01	
8L	4.61300	1.05810	0.08189	8L	4.61301	1.05806	0.082	-0.01	0.04	
9L	3.61429	-1.13929	0.22606	9L	3.61432	-1.13924	0.227	-0.03	-0.05	
10L	1.93574	-0.72069	0.22739	10L	1.93571	-0.7207	0.227	0.03	0.01	

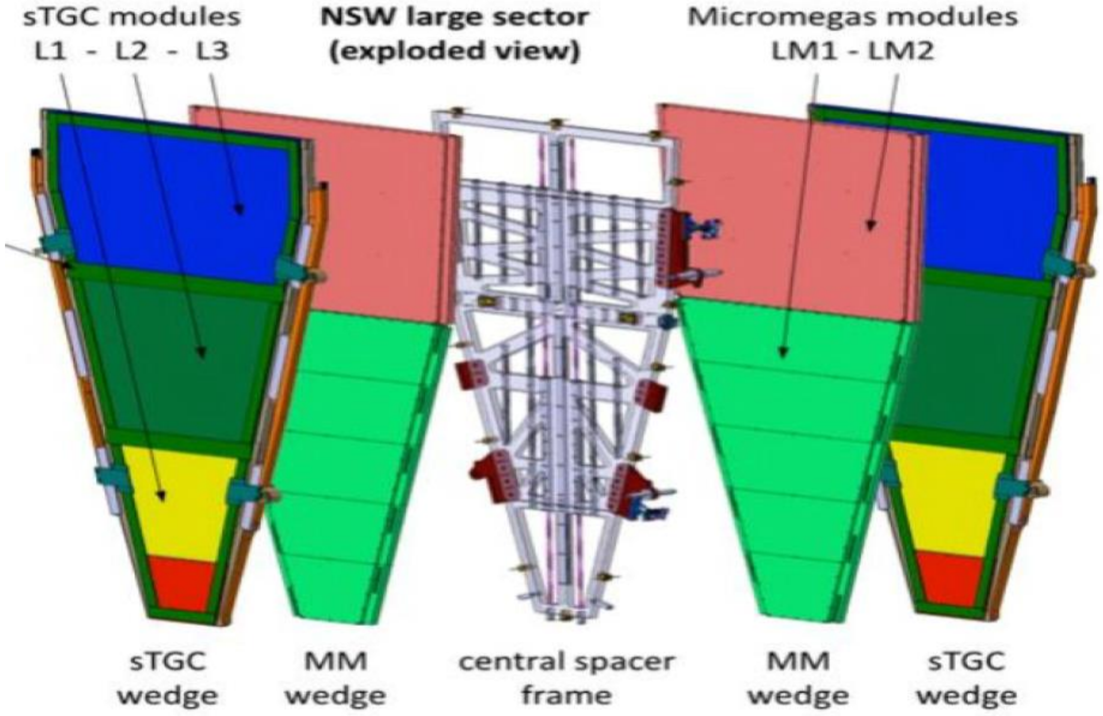
Environmental conditions for the gluing procedure

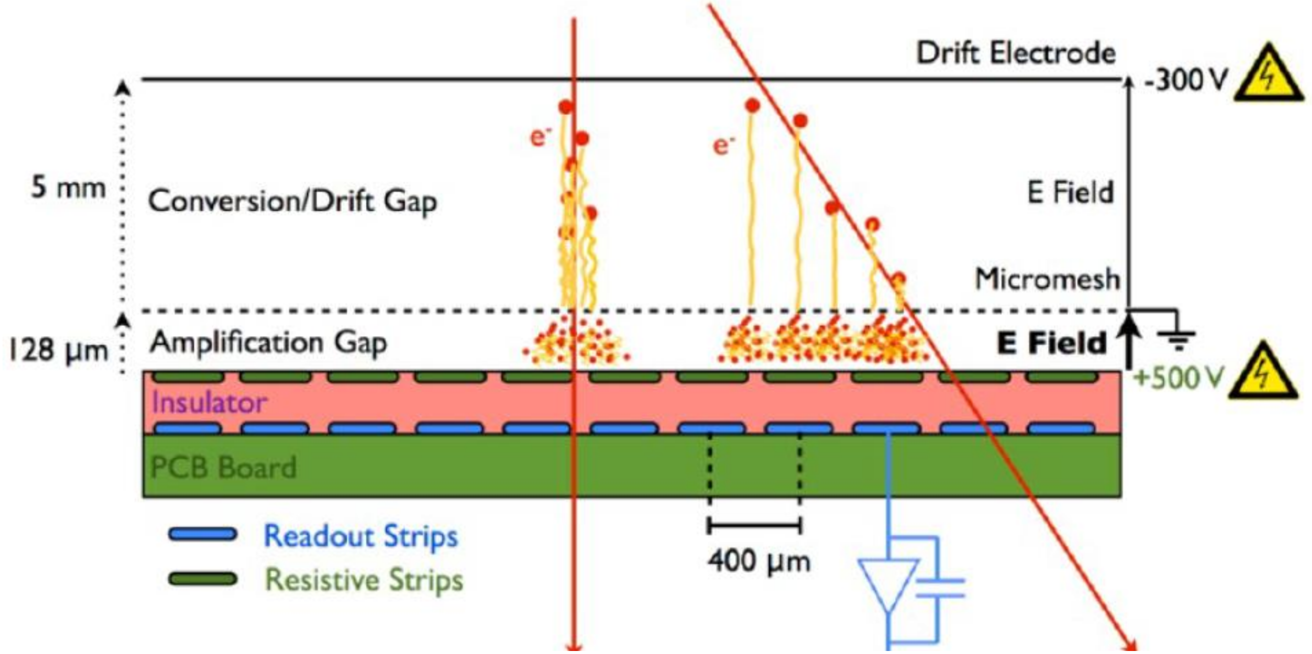
- All gluing operations are performed in a clean room with Temperature and Humidity controlled (22+/-1DEG); 38+/-5% RH during the gluing process.
- The gluing is performed with special guns that do the mixture, therefore no air bubbles are produced, and no mistakes in the mixture can occur.
- Glue is applied in excess, so it flows outside the frames (under weights), and the quality of the cured glue is then checked on the glue that has flowed out.

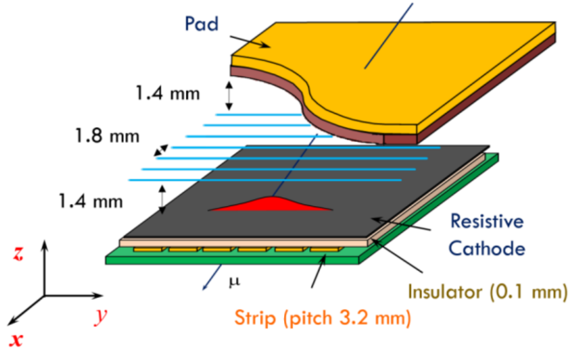
B sensors and alignment fibers

- The platforms containing the B sensors are glued using the same jig as the alignment platforms, ensuring their relative position with respect to the alignment pins
- The issue of the large volume of alignment fibers has been solved by using MTP connectors and specially made bundles of fibers.

But the NSW is not only sTGC's
New detector MicroMegas

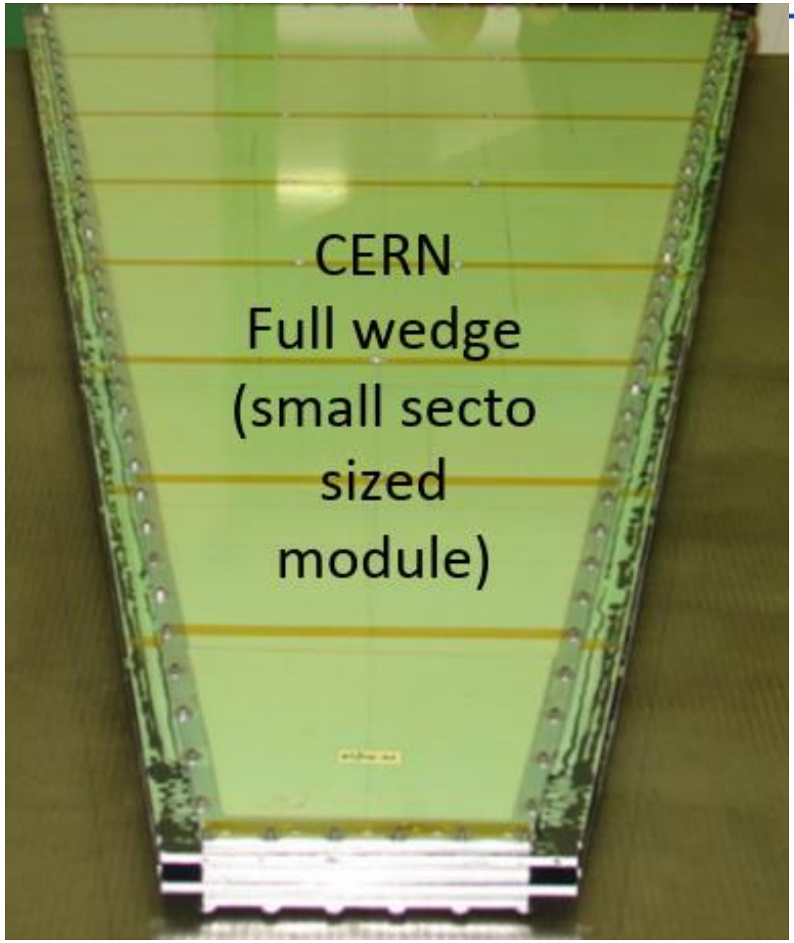


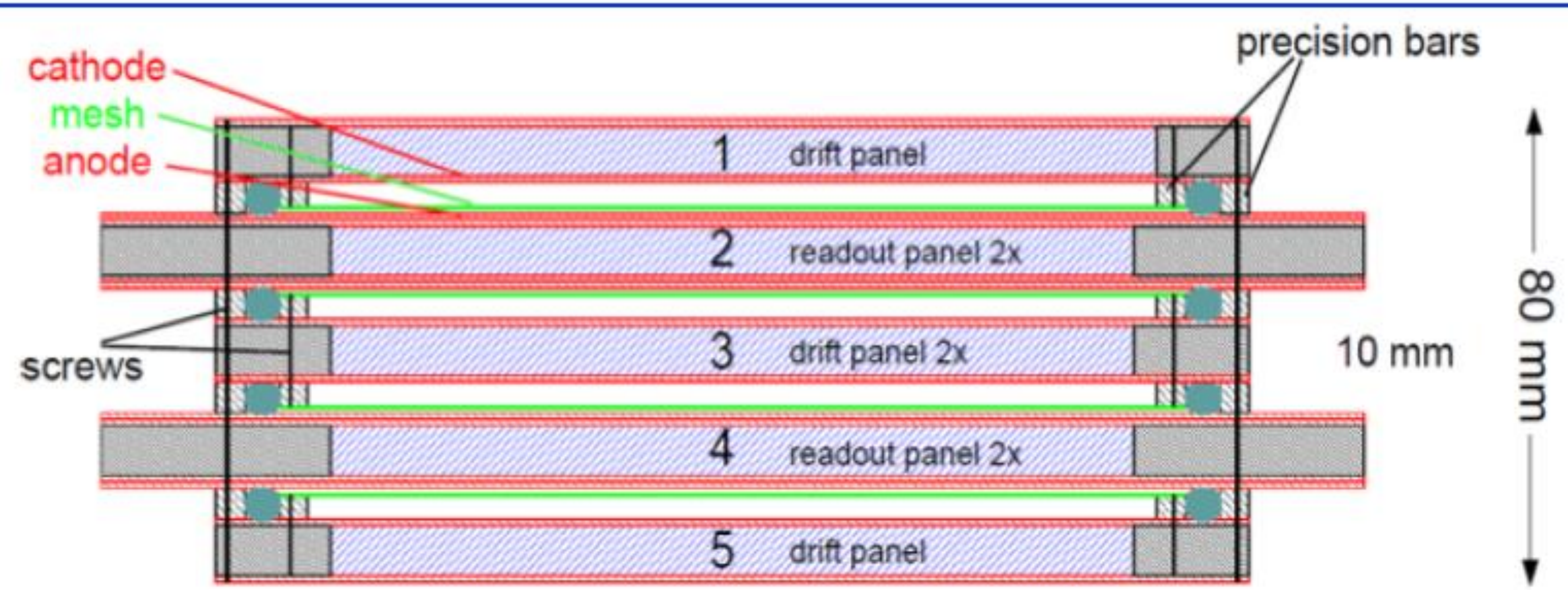


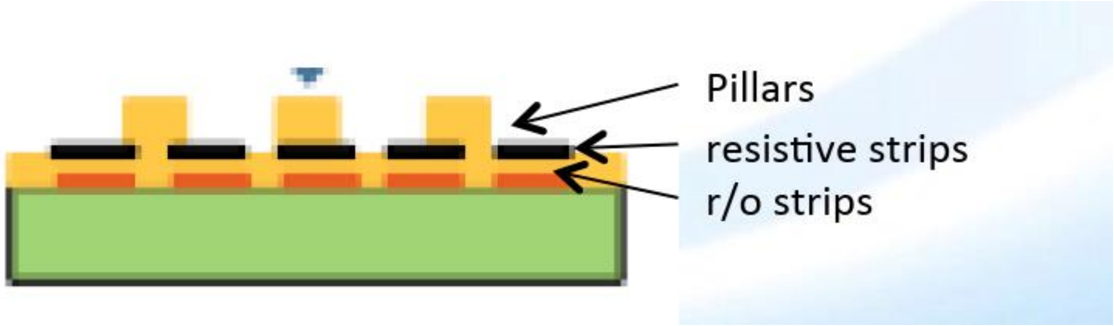


- The amplification is exponential, in a distance of 128µm, so any deviations of the gap of ~10µm leads to sparks.
- Solution is include a resistive layer that will reduce the effect of the sparks.
- Avalanches have a smaller dimensions, and therefore needs a large number of strips, this is intended for high rate detectors.

MicroMegas construction details



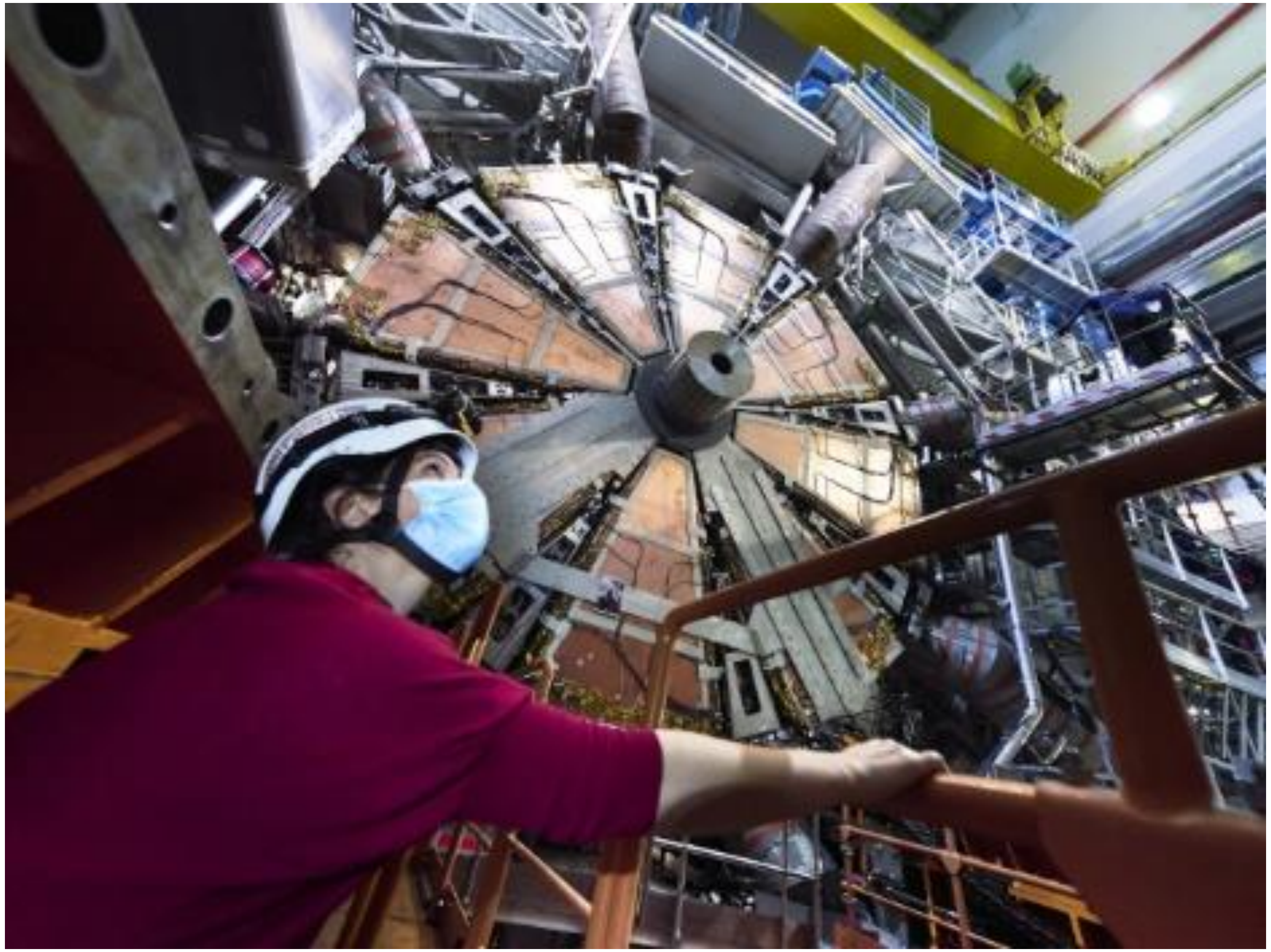




Major effort to have all the detectors completed, tested installed and debug in a period of 3 years, to be ready for installation in 2022.

Following a debugging stage in ATLAS, there are good signs that it will be operational in the 2023 LHC run

Fisicos y Ingenieros Chilenos no solo participaron en la construccion de los detectors pero juegan (y jugaron) un papel critico en todas las etapas del projecto

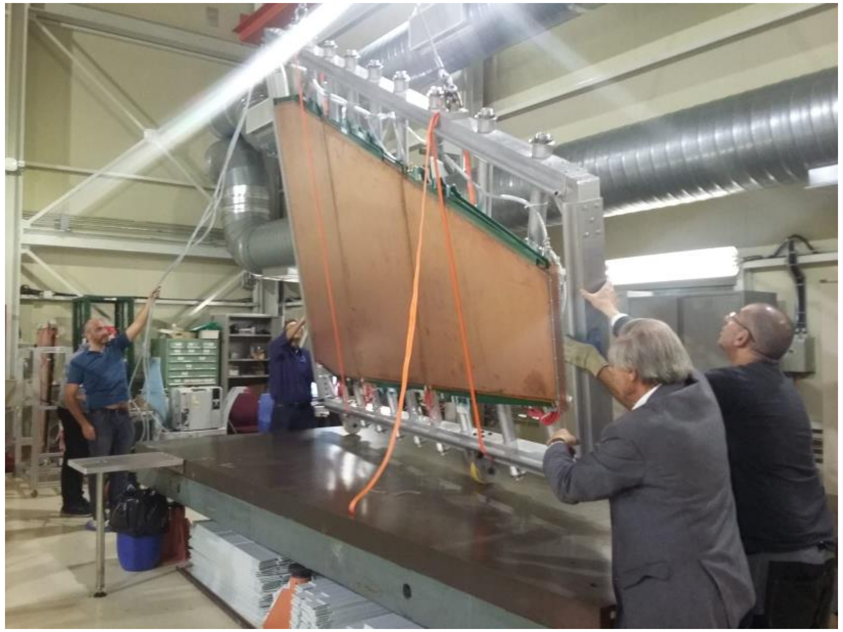


En particular:

Un ingeniero Chileno jugo un role central en la integracion mecanica de los detectors y luego en comprender el origen de los ruidos en la electronica.

Un ingeniero Chileno juega el role central para integrar este Nuevo detector en el Trigger de ATLAS y fue recientemente contratado para jugar un papel central en el futuro projecto del experiment.

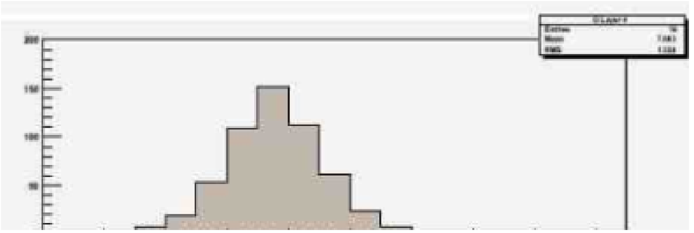
Un fisico Chileno es el coordinador de todas la actividades relacionadas a la integracion de los nuevos detectors en el experiment ATLAS



General recommendations for you that are the future of the field.

- There is a long tradition in various countries in Latin America to have a very high level of graduate studies. It is important to continue this tradition and not only give the tools to work without the basic knowledge behind.
- CERN being the largest scientific laboratory, where new technologies are being taken to their limits, provides the possibility to make use of this deep knowledge.
- In the case of Chile, this has been possible in this NSW project, but most of those that have been responsible for the success of the project have decided to stay abroad, It is very important to create the infrastructure in Latin-America (Chile) so they can continue to contribute.

General recommendations for you that are the future of the field.



- Do not take any recipe for granted: when you do a Gaussian fit, make sure that you know the origin of the errors; if you measure charge, the error IS NOT 1/sqrt(N).
- Do not use a Gaussian fit to parametrize a distribution that you do not understand: Find the origin or contributions to your distribution; UNDERSTANDING is critical in a world of only fits.
- All models are a result of an approximation, make sure that YOU and YOUR ADVISER are aware of what approximation is being used and of its limitations.
- DO NOT USE TOOLS BECAUSE THERE ARE EASY TO USE.
- When you are designing a detector, make sure that you understand all its elements and that you will be able to trace any problem that occurs =>SIMPLICITY.