A silicon based cosmic ray telescope as an external tracker to measure detector performance

- An INFN-Pisa test bench for small tracking detector prototypes
- The facility
- Telescope set up
- Detector under test integration
- The MEGII drift chamber prototype characterisation

Luca Galli, INFN sezione di Pisa
Pisa, 25 November 2014

Credits

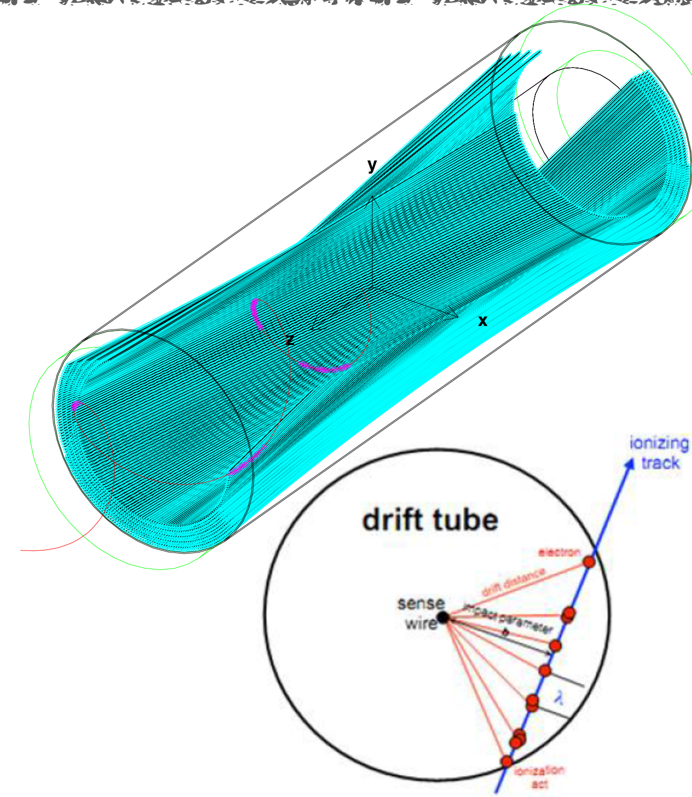
- The INFN telescope facility working group
  - *MEG II: Baldini, Bemporad, Cavallaro*, Cei, D'Onofrio, Dussoni, Galli, Grassi, Nicolò, Signorelli, Tenchini, Venturini*
  - *BaBar: Bettarini, Forti, Lusiani, Walsh*
  - *Electronics group: Avanzini, Morsani*
  - *High technology group: Bosi, Ceccanti, Mammini, Minuti*

- I am speaking on behalf of this group

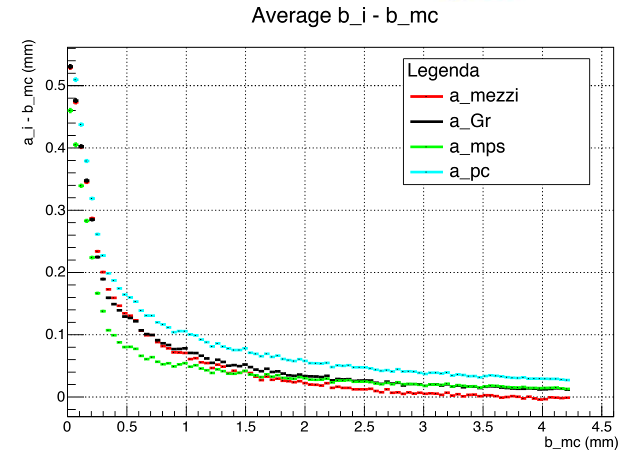
- *worked on the facility during his master thesis period

Decisive urge

- INFN took the responsibility to construct the new drift chamber for the MEG II experiment
  - *single volume wire chamber*
  - *stereo read out*
  - *low mass ionising gas He:IsoButane (85:15)*
    - important to study the position resolution with such a low ionising density: 1.29 cluster/mm
    - the measurement based only on the first ionisation cluster is biased



- Pisa has the leadership, Marco Grassi is the responsible
  - *need for a test bench to study the single hit resolution for small prototypes*



The idea behind the facility

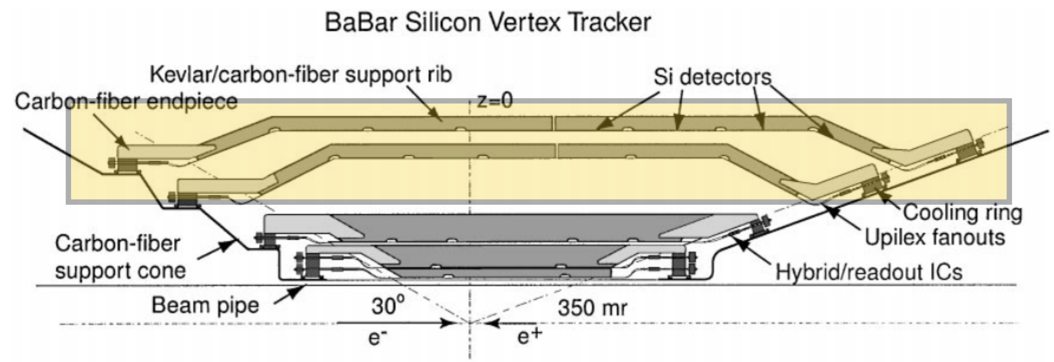
- Despite it is built to serve an experiment, it has to be as general purpose as possible
  - *designed to accommodate small and medium size detector under tests (DUT)*
  - *flexible DAQ scheme to include the DUT read out in the telescope code*
- Effective test bench for tracking detectors
  - *high resolution: resolution a the DUT plane of ~20-30 μm*
- Cheap, "fast" and efficient solution
  - *free beam line: cosmic muons!*
  - *make use of spare modules of the BaBar SVT stored here in Pisa*
    - single hit resolution match the requirements
  - *design a new version of the read out electronics to be more compact and allow a multiplexed read out*
    - DAQ carried out by a CPU

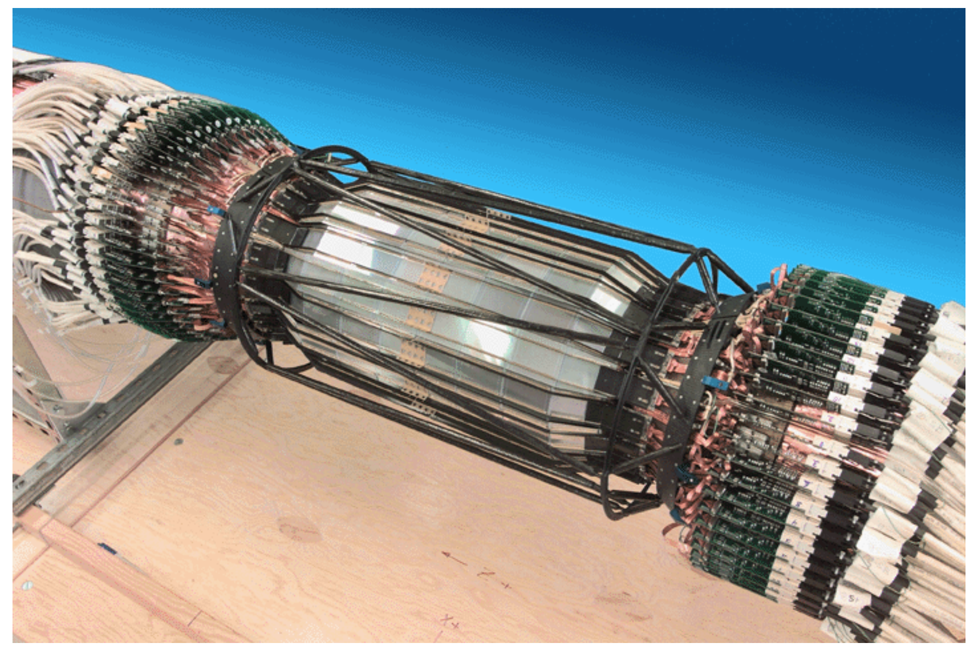
BaBar Silicon Vertex Tracker: Layer 4 and 5

- Operated five years at PEP-II in the BaBar experiment
  - *inner tracker: b-tagging*
    - z-vertex resolution 250 μm, same as B^0 mean path length
  - *95-99% single hit efficiency*

- Five layers from the assembly of six wafer types
  - *thickness 300μm*
  - *double sided read out*
    - Type IV-V (used in the L4-5) pitch x-z = 100-210 μm
    - Layer 4 active area ~ 5 x 30 cm^2
    - Layer 5 active area ~ 5 x 40 cm^2

- Layer 4 and 5 spare modules are stored at INFN Pisa and ready to be used
  - *what about muon tracking with L4 and L5?*



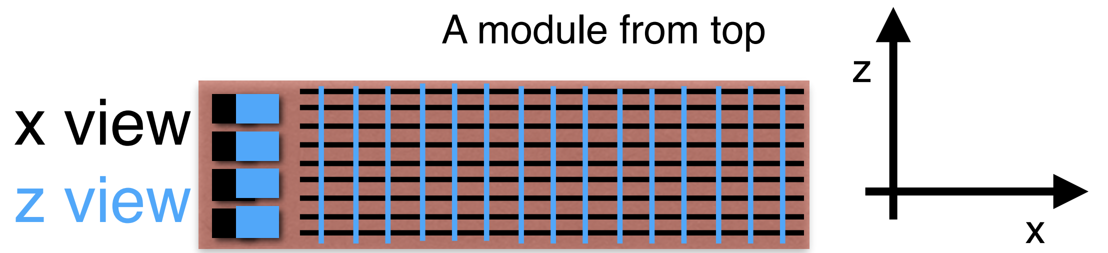


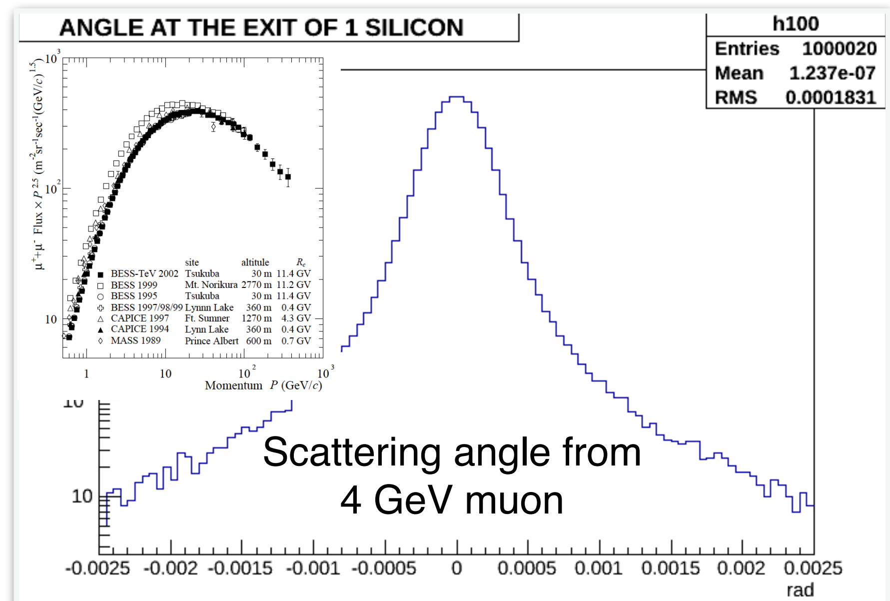
C. Bozzi, et al., "The BaBar silicon vertex tracker", NIMA, vol 453, pp 78-83, year 2000.

B. Aubert, et al (Babar Collaboration),"The BaBar Detector", NIMA, vol 479, pp 1-116, year 2002.

Performance

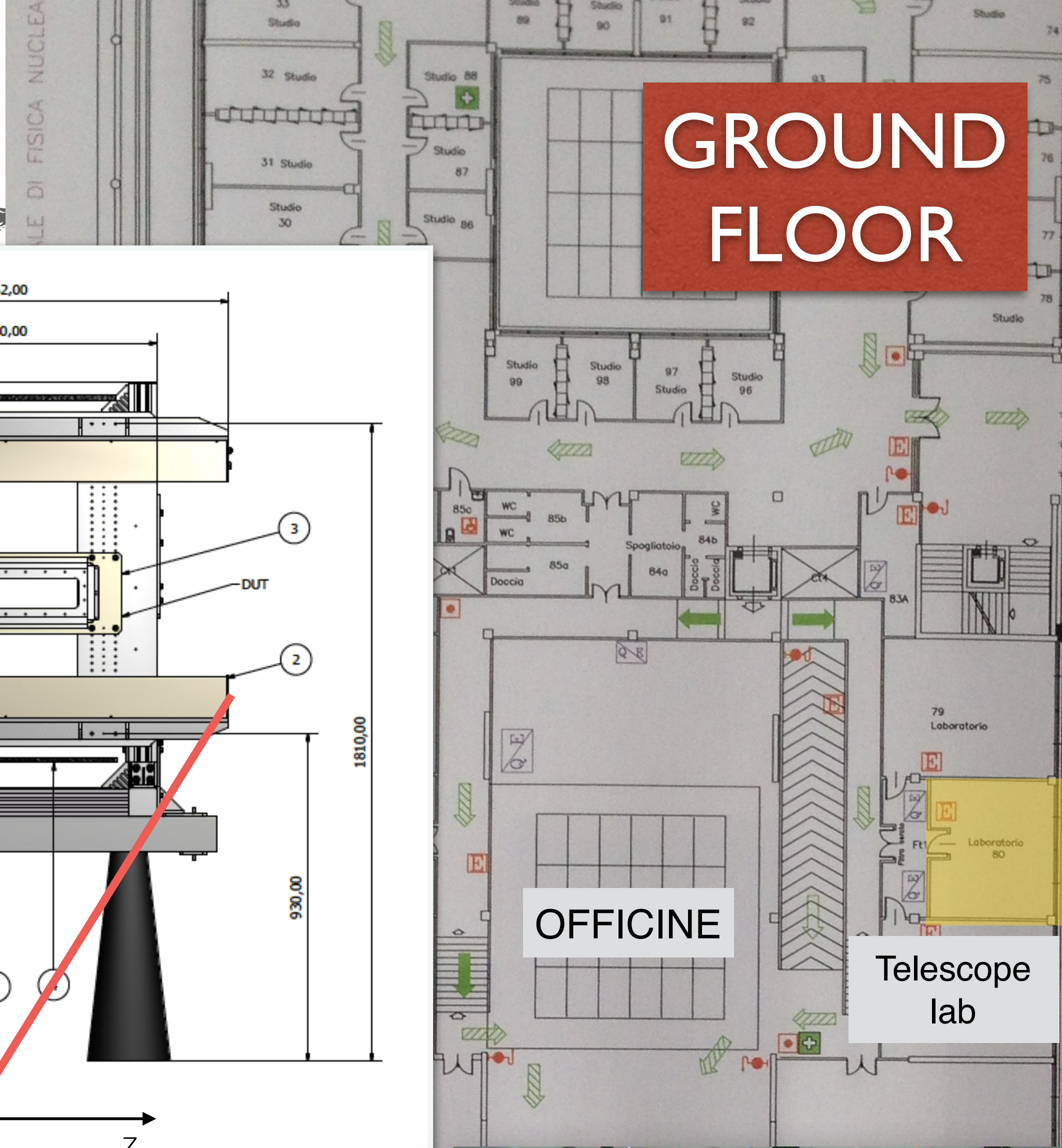
- Tracking precision as a function of
  - *single hit resolution*
    - 29 μm x-, 61μm z-view
      - *tracking precision from single hit resolution (using 4 points) at DUT plane 15μm x- and 30 z-view*
  - *multiple scattering sources*
    - telescope
      - *main contribution by the SVT modules, 300 μm Si*
    - DUT
- Resolution and MS is adequate to the goal
  - *but the DUT design must follow resolution requirements*
- Let's assemble it!!

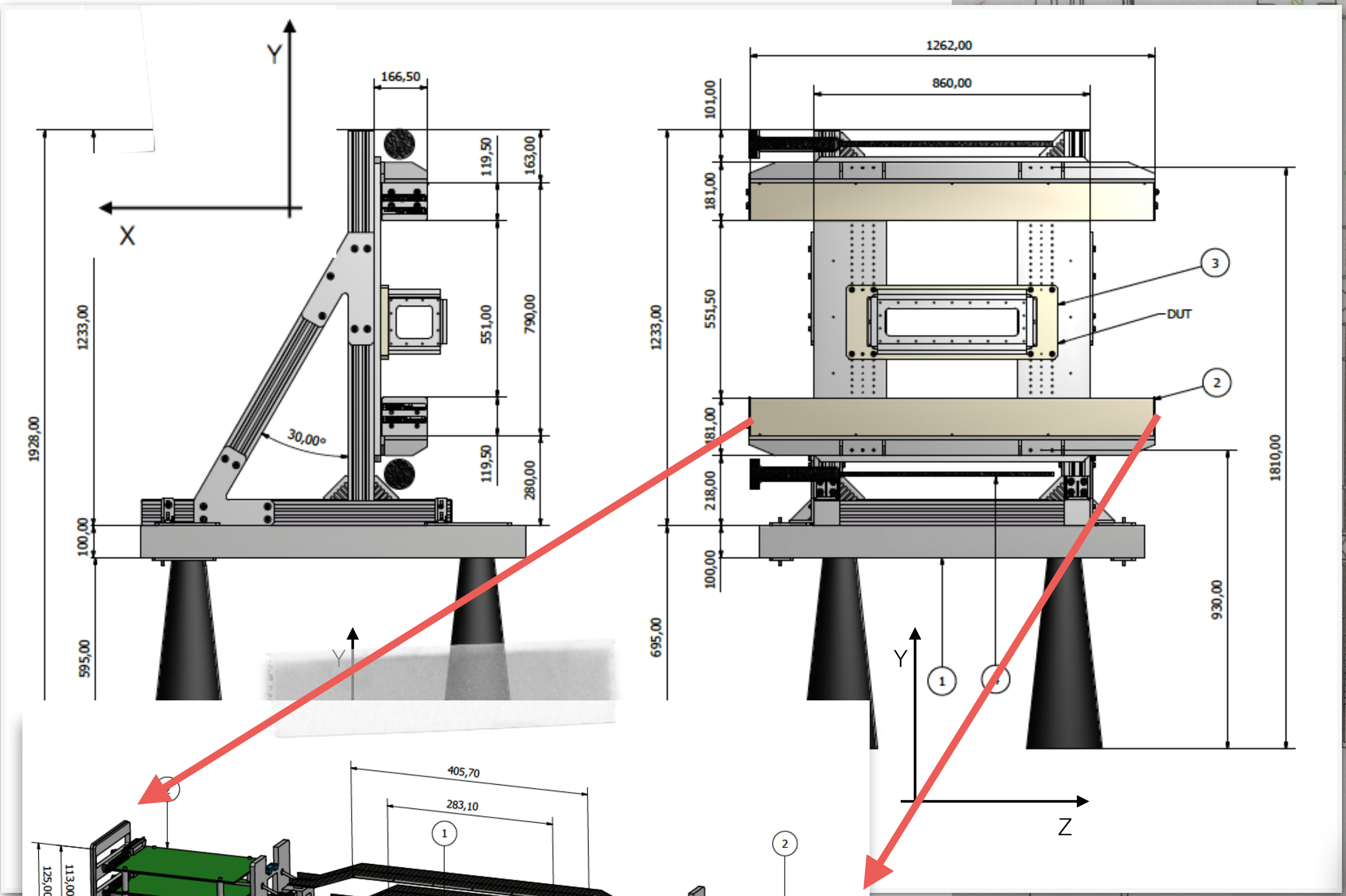


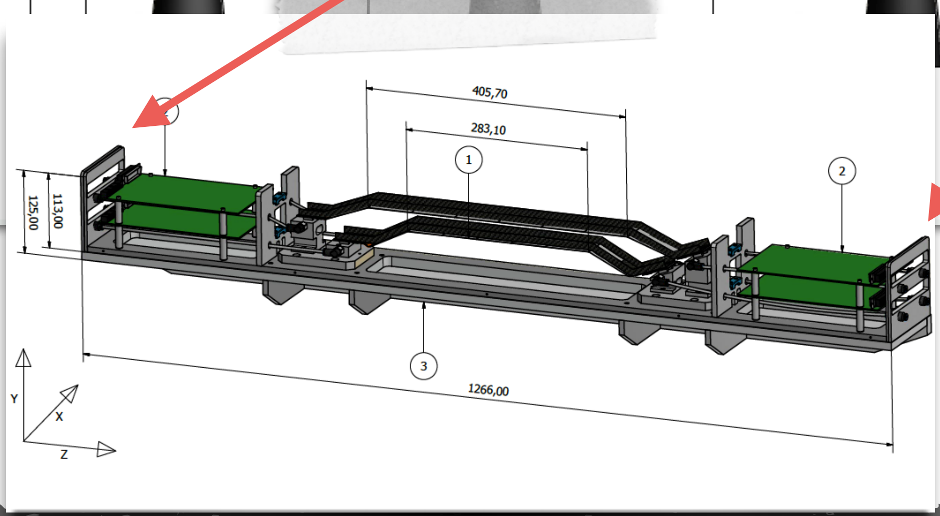


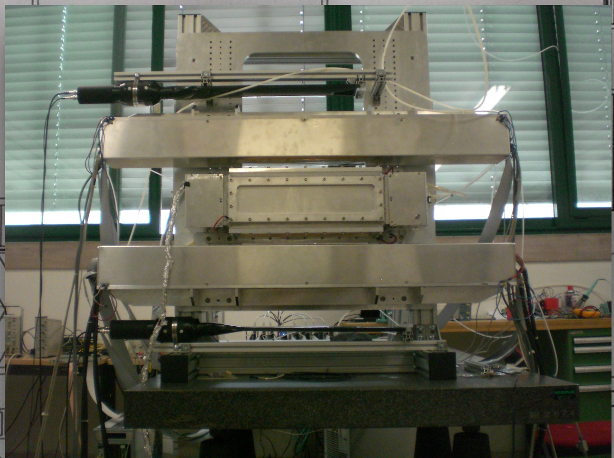
DUT thick (# SVT)	MS-uncert. (μm)	σ (μm, x — z views)
0	2	15 — 30
1	13	20 — 32
2	18	24 — 35
4	26	30 — 40

Design and location

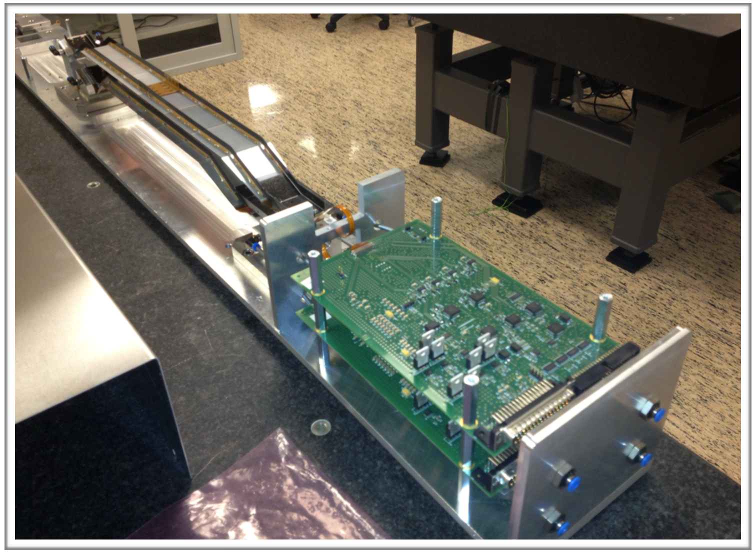


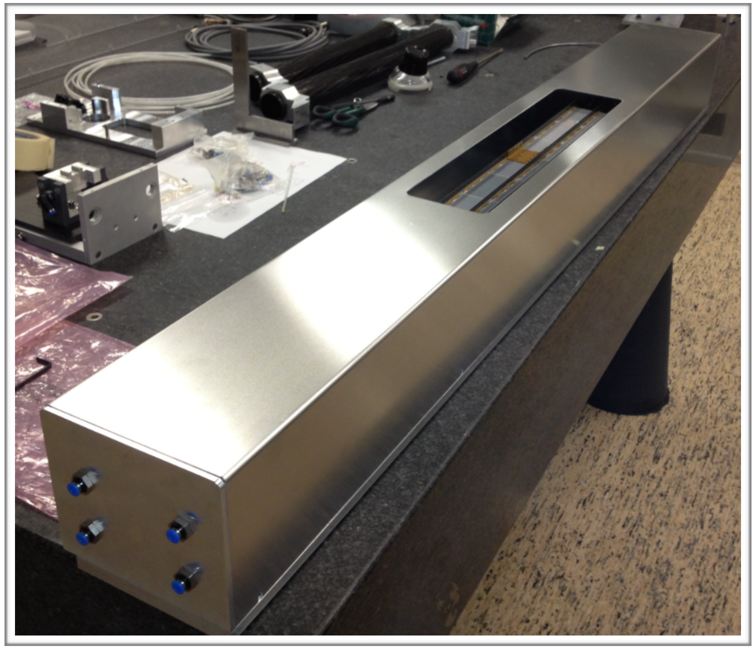






Box design

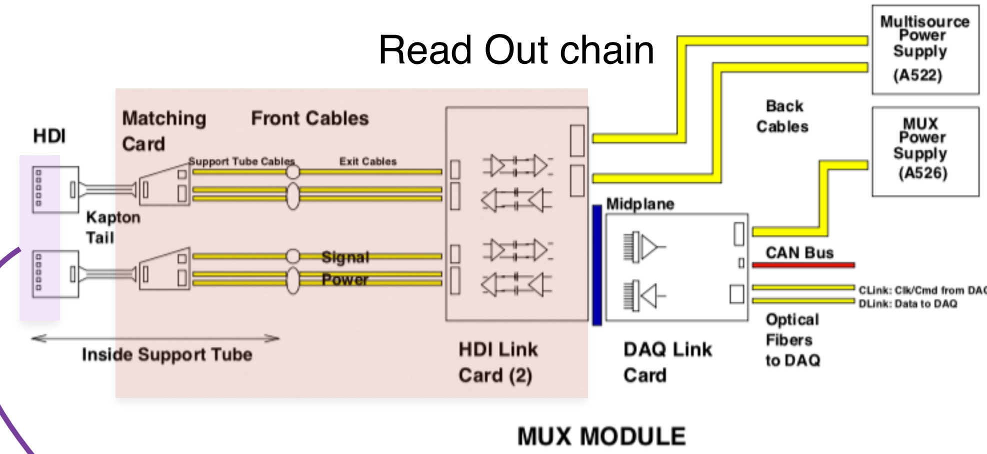


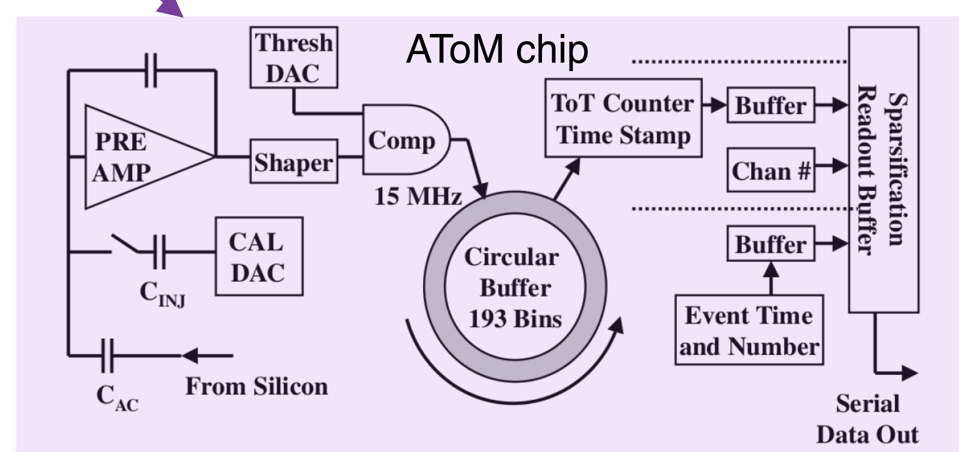


- Designed on the model of the spare module holders to host
  - *a layer4 (below) and a layer5*
  - *custom boards*
    - one each detector halves
- the box provides
  - *cooling with water pipes*
  - *dry air*
  - *light tightness*
  - *thin window in the telescope acceptance*
    - 20 μm aluminated-Mylar
- position relative to marker on the box plate with optical survey
  - *~100 μm accuracy*

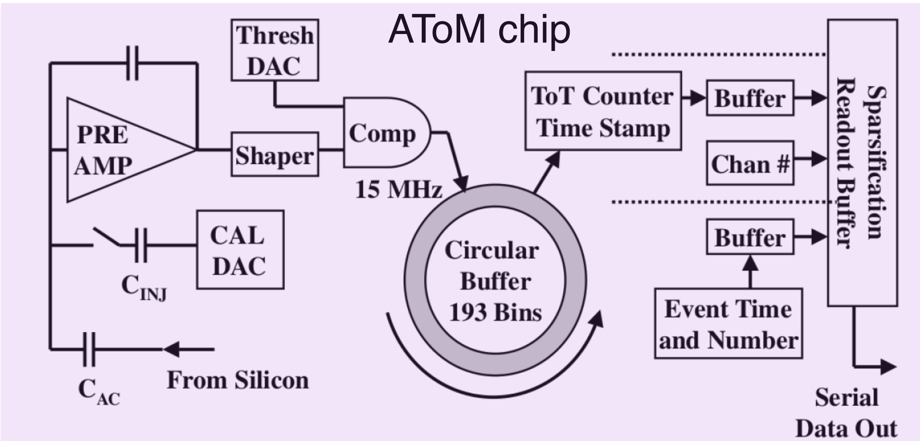
Original electronics

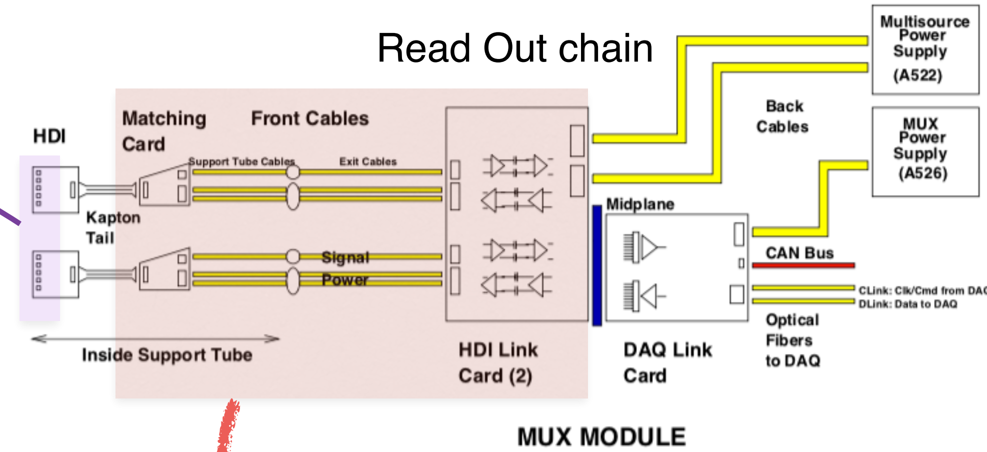
- DAQ card - **no usable anymore**
  - *generate clk and command signals and interpret the data back from AToM*
  - *connected to a SUN workstation*
- HDI link card + Matching card - **no usable anymore**
  - *connected to the detectors with kapton tails*
  - *handles signal distribution*
  - *supply to AToM*
- AToM read out chip - **attached to Si modules**
  - *A Time over threshold Machine*
    - connected to 128 channels
    - given an external trigger the list of the fired channels in output
    - internal calibration circuit



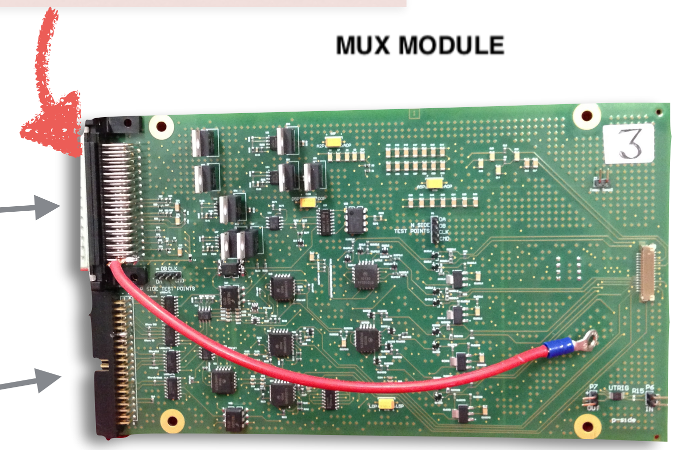


Custom board

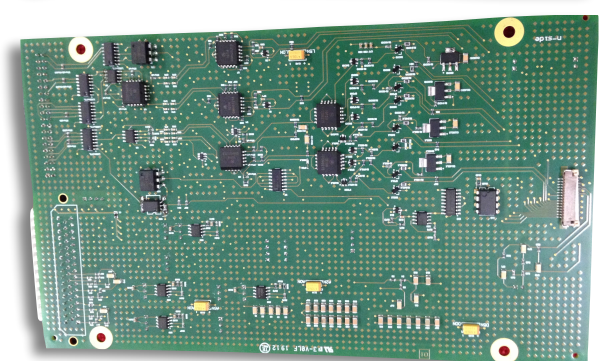




- Analog, digital and bias voltage supplier
  - *connected to original HV module*
- clk and serial lines translator
  - *LVDS signals from lower connector converted to PECL AToM standard and vice versa*
    - electric scheme partially taken from original project
- connected to AToM chips with kapton tail
  - *one custom per half a detector*
  - *a tail per side*
- placed inside the box close to the SVT module

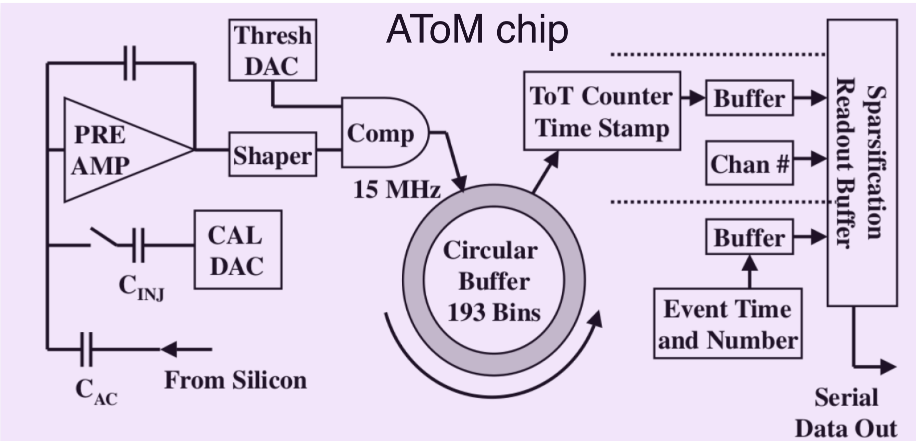


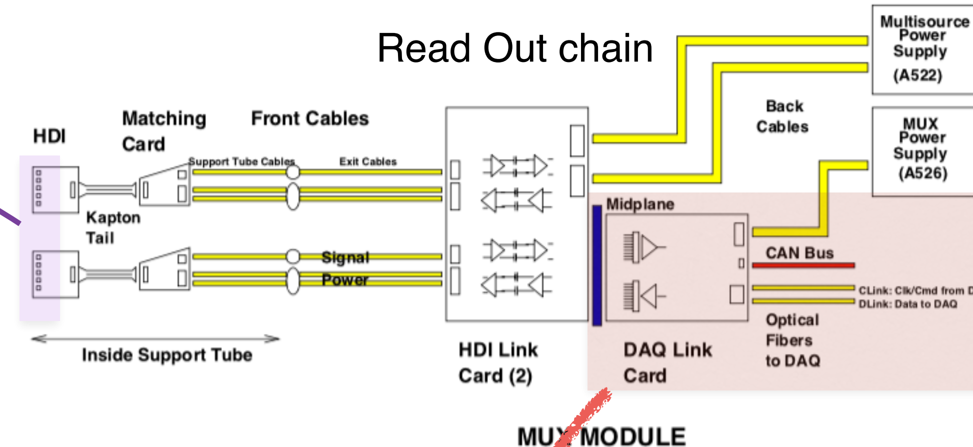
p-side

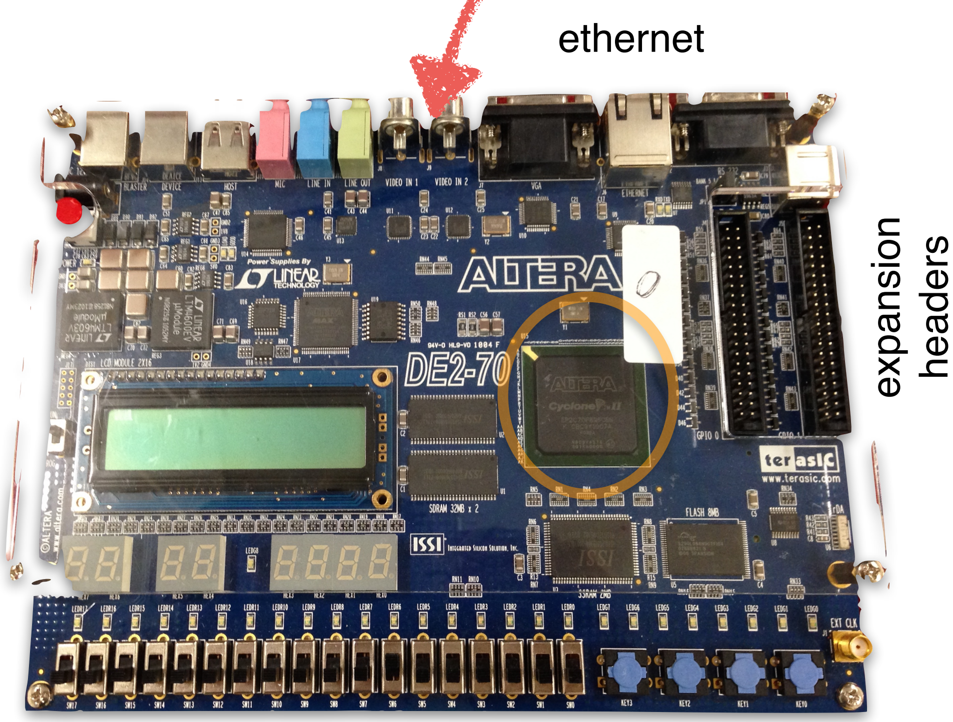


n-side

Terasic board



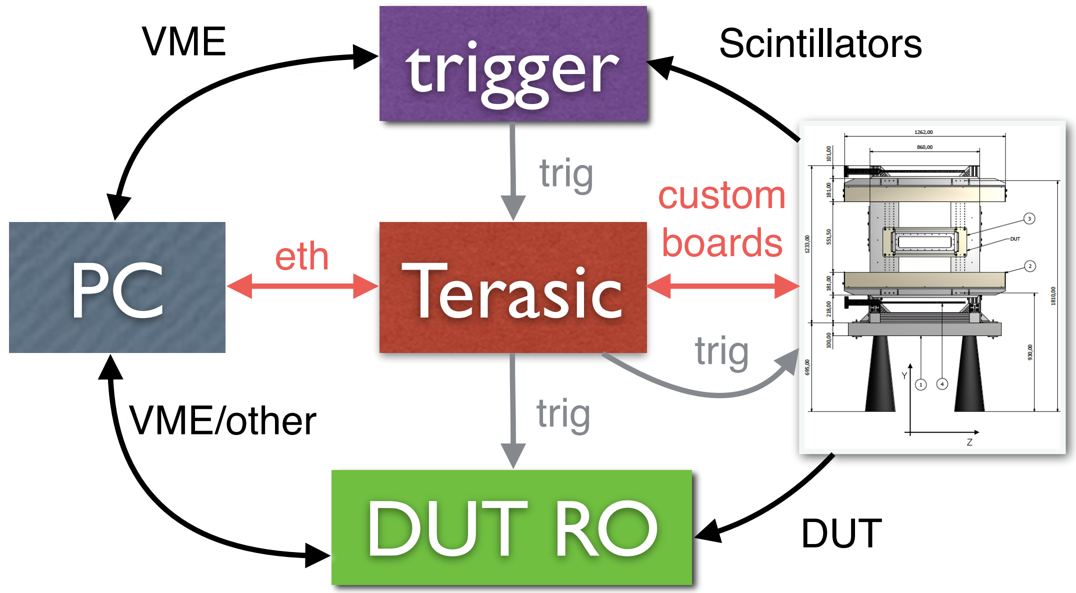


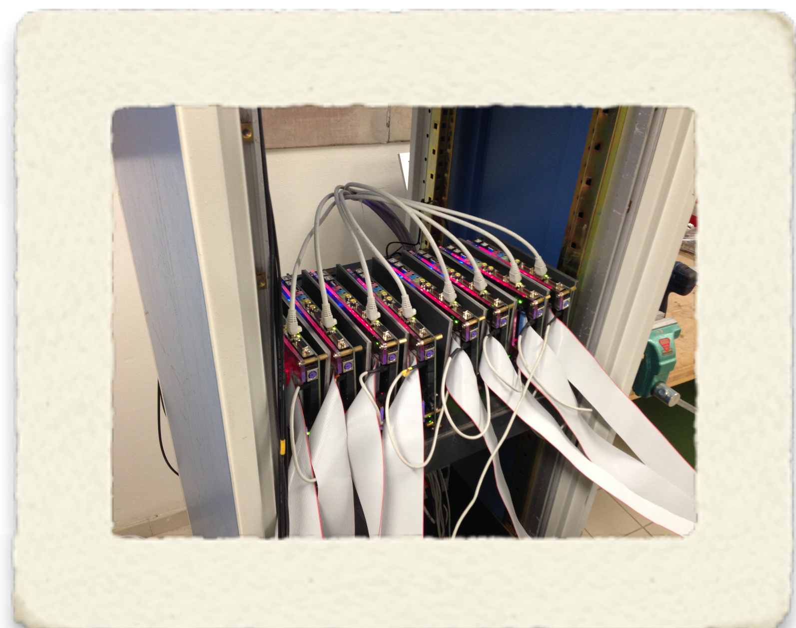


- Educational board with CycloneII FPGA to handle communication from DAQ PC to modules
  - *expansion header for the connection to a custom board*
  - *ethernet to an internal network*
    - network the master DAQ PC
- AToM communication protocol programmed in the FPGA
- Ethernet link with the NIOSII processor

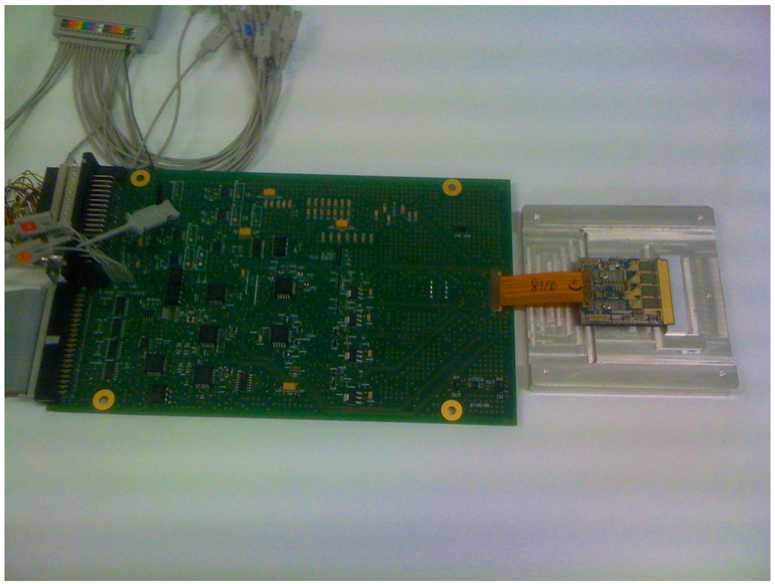
DAQ scheme

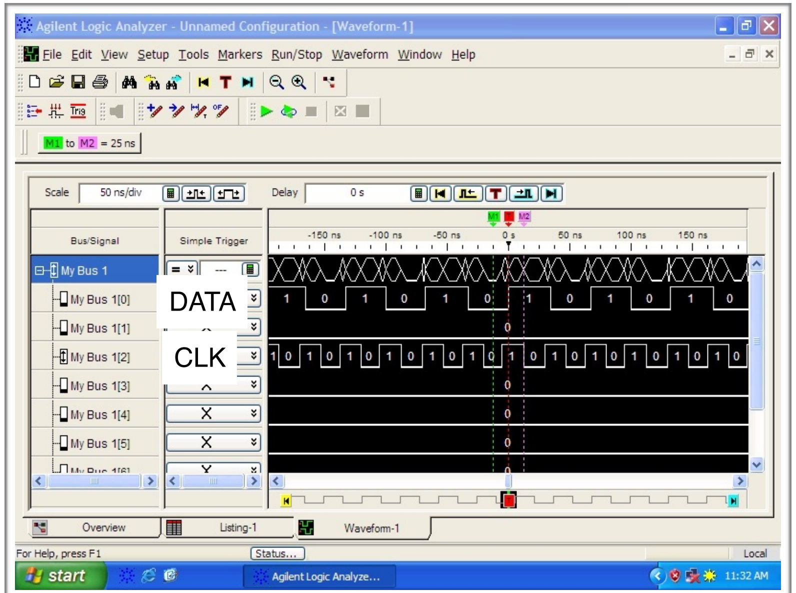
- PC - master
  - *unique DAQ supervisor*
    - no busy and event building issues
  - *C++ code*
    - server based ethernet connection
    - VME link
      - *trigger management*
    - high flexibility to accept many DUT read out
- Terasic boards
  - *client, send out data only upon request*
  - *linked to the detector halves/custom boards*
- Trigger
  - *MEG trigger VME board*
    - search for coincidence between the scintillators
    - programmable selection in case of other applications
  - *LVDS signal to stop AToM and DUT electronics*



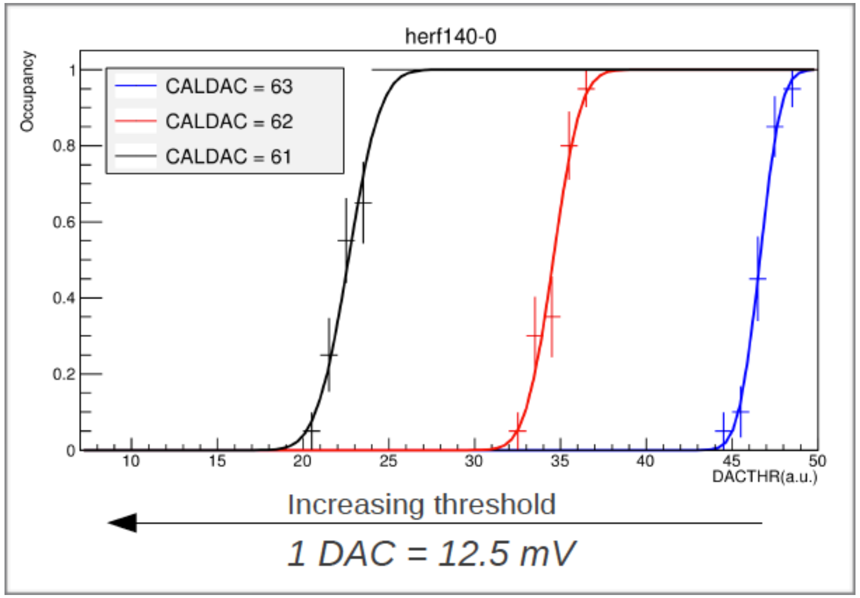


Tests with naked hybrid



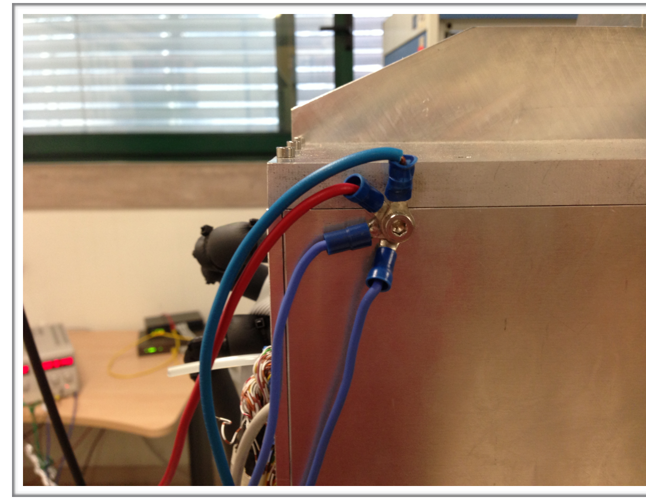


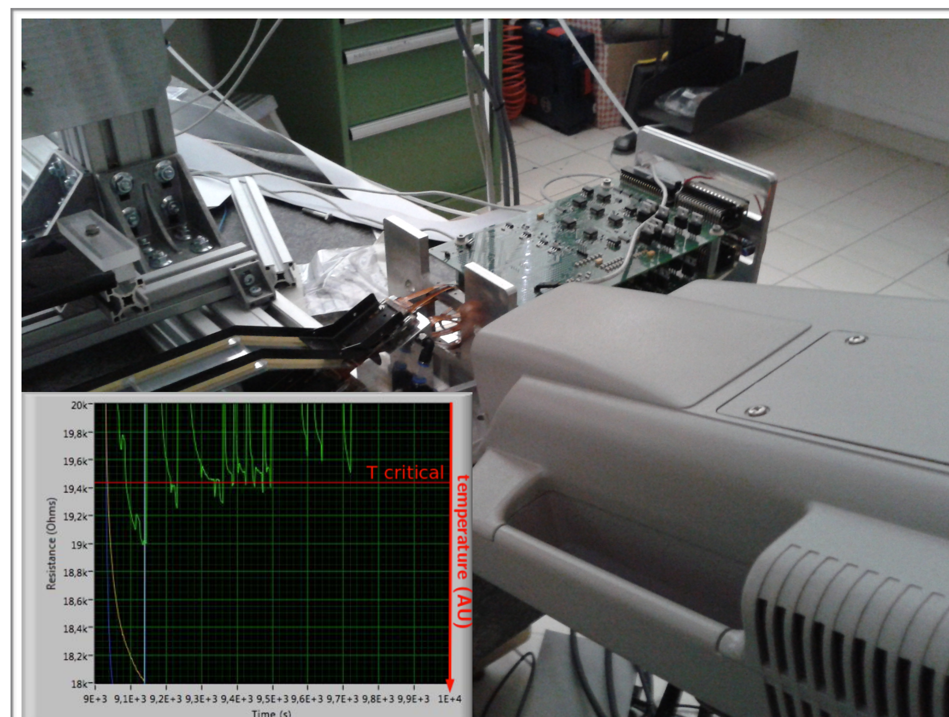
- First implementation of PC-Terasic-custom-AToM communication chain
  - *AToM answered to CLK THROUGH command*
    - debugging with logic state analyser
    - great success!!!
- Firmware development
  - *full calibration of the naked hybrid*
    - ECN measurement
    - discriminator linearity



Detector assembly

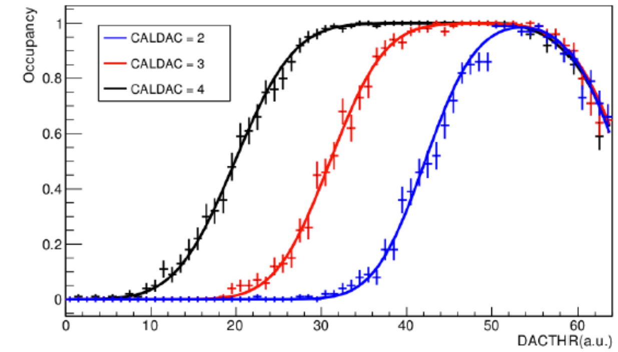
- Once each single module has been tested on bench we passed to detector assembly
- two major issues
  - *grounding*
    - suffering from ground loops
      - *in the test bench configuration the ground was the HV module*
      - *modified the HV module ground connection configuration and defined as aluminum support structure*
  - *chip temperature control*
    - the original chilling system not sufficient
      - *measured the hot point with thermal camera*
      - *at the T critical the communication with the module interrupted with severe risk of damage*
    - the solution was to install a dedicated air conditioning system to maintain the laboratory temperature around 24 degrees
      - *without up to 34 deg in summer…*
    - the temperature is monitored continuously during DAQ
      - *if it exceed the maximum value the HV system is shut down*

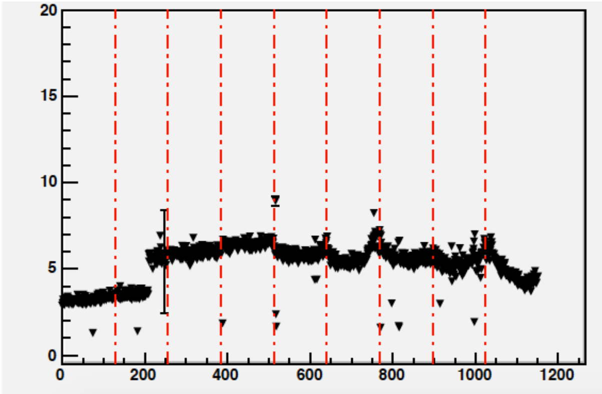


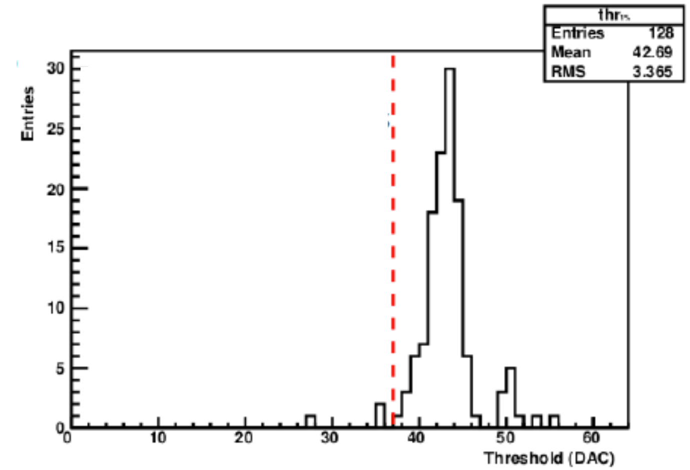


Module calibration

- Objectives
  - *dead channel list*
  - *set the chip discrimination threshold*
- Noise and gain from the excitation curves
  - *calculated for any of the 128 chip channels*
  - *threshold associated to a channel associated to the probability of noise induced hit < 1%*
  - *distribution threshold and definition of noisy channels*

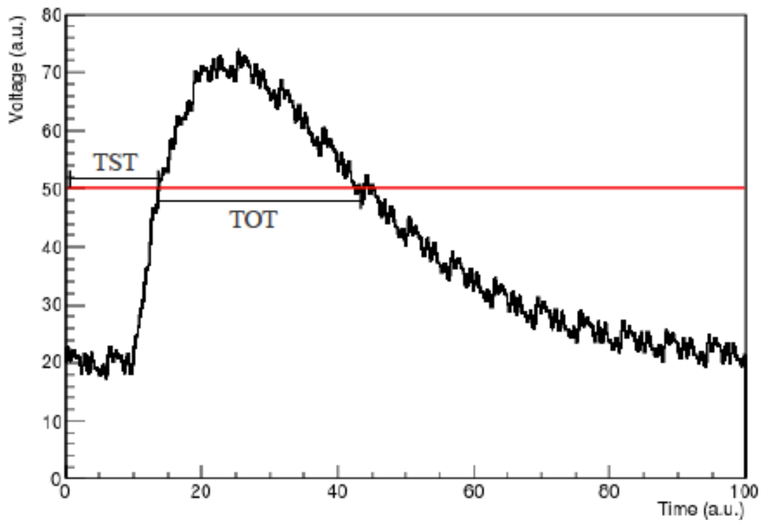


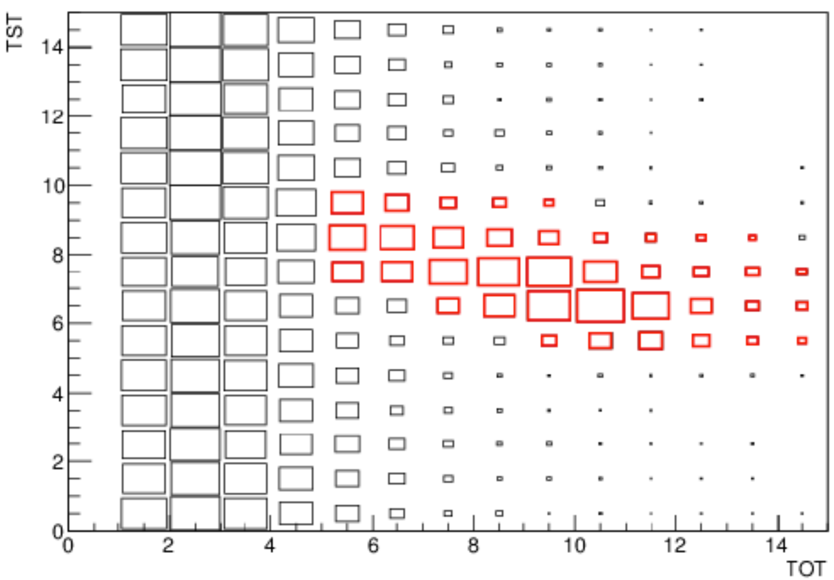




Hit selection

- Hit parameters
  - *Time Over Threshold*
    - proportional to the energy deposit
  - *Time STamp*
    - hit time
      - *used to find coincidence with the trigger*
    - TST peak used to calibrate the trigger latency
- Safe hit selection as a starting point fro track reconstruction
  - *high charge and in time with the trigger*
    - red region



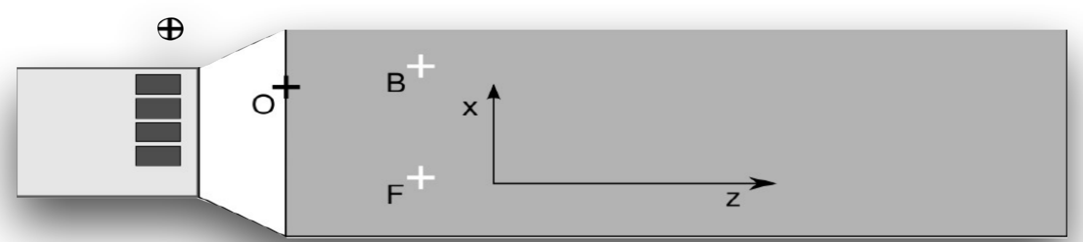


From number to tracks…

```
root [7] rec->Scan("","tot>4&&tst<13&&tst>3&&nhit<100")
```

Row	Instance	run	eve	typ	nhit	boa	chi	cha	tot .tot
0	20	3027	0	0	63	0	4	61	9
0	21	3027	0	0	63	0	4	61	9
0	22	3027	0	0	63	0	6	88	10
0	23	3027	0	0	63	1	3	52	8
0	24	3027	0	0	63	1	3	52	8
0	25	3027	0	0	63	1	3	53	5
0	26	3027	0	0	63	1	3	53	5
0	28	3027	0	0	63	1	6	80	7
0	53	3027	0	0	63	6	1	122	11
0	59	3027	0	0	63	6	7	4	9
0	60	3027	0	0	63	7	4	60	9
0	61	3027	0	0	63	7	4	60	9
0	62	3027	0	0	63	7	7	12	11
2	2	3027	2	0	57	0	3	5	11
2	3	3027	2	0	57	0	3	5	11
2	14	3027	2	0	57	0	8	75	7
2	15	3027	2	0	57	0	8	76	6

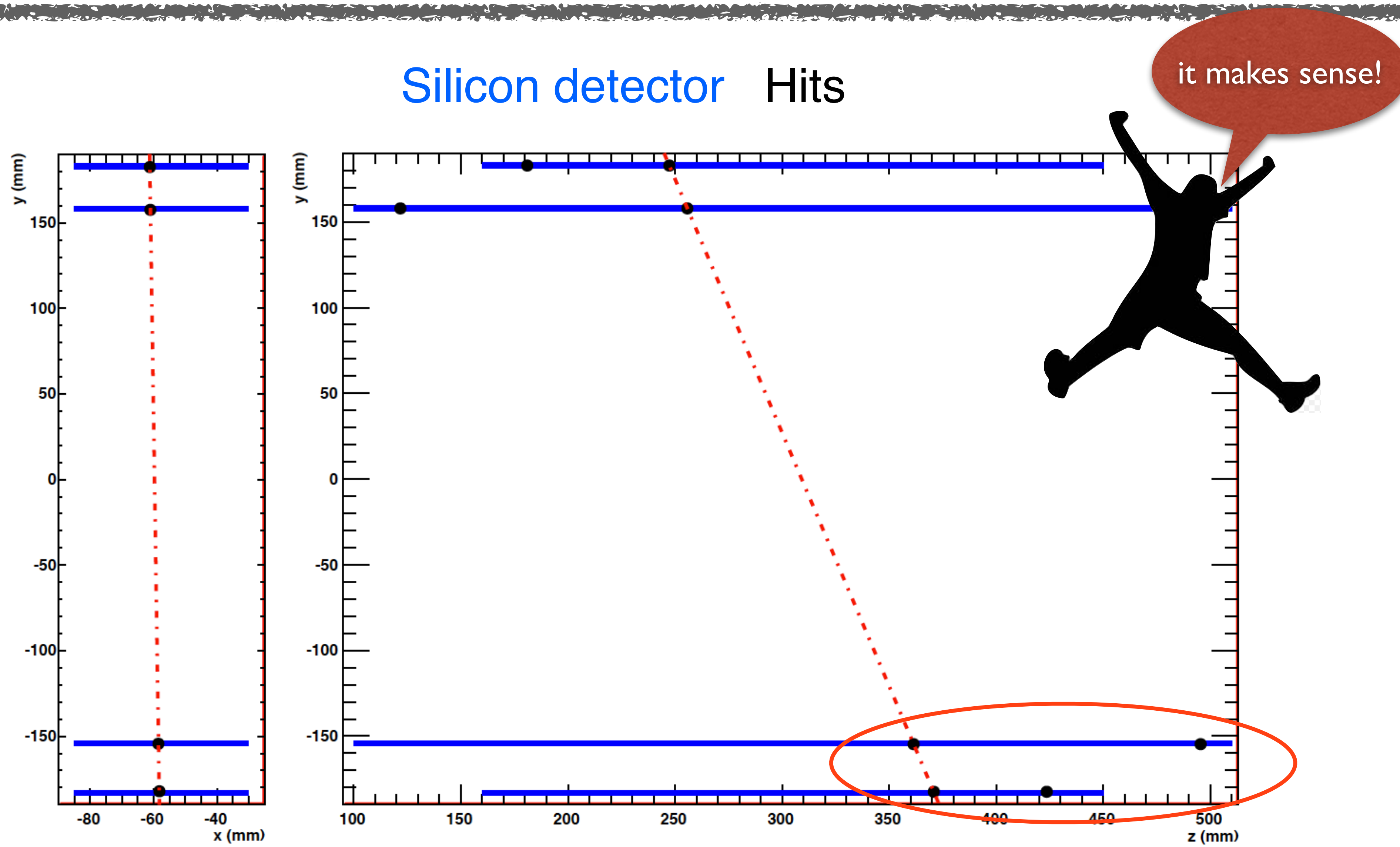
- The first tracks…
  - *hit on 4 different boards*
    - 4 SVT modules
  - *both p- and n-side*
    - by looking at chip number



- We always require for a 8-hit track to push at the best the tracking performance
- Local coordinates to telescope with rotations and translations

A track!

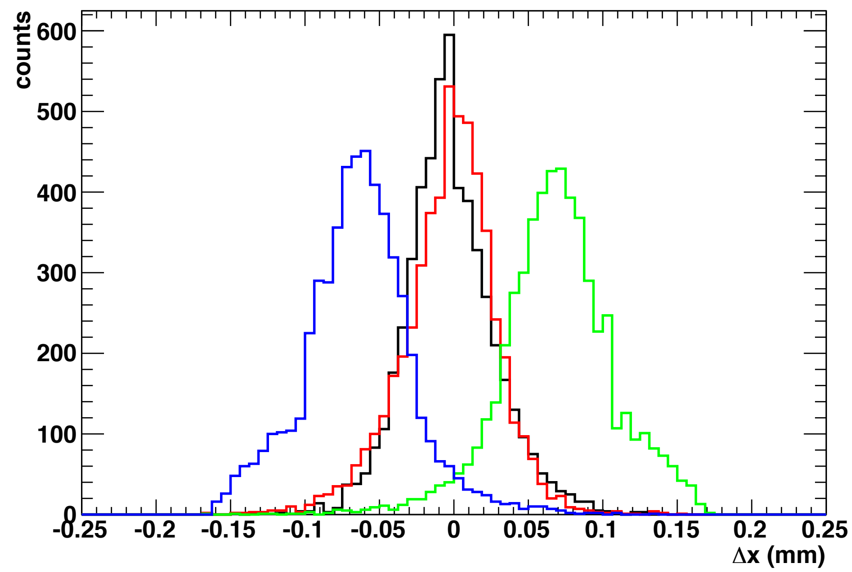
Silicon detector Hits

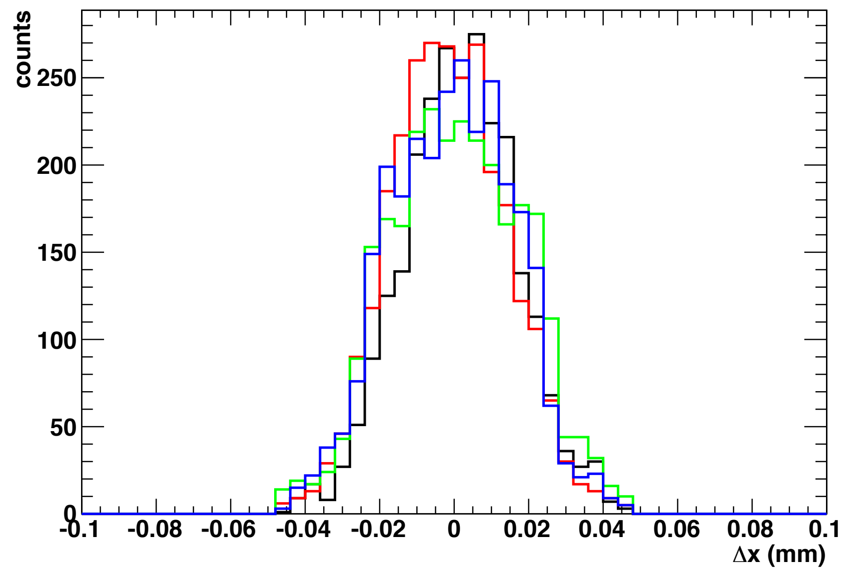


HW ambiguity, 1 AToM channel associated to 2 different strips

Telescope alignment

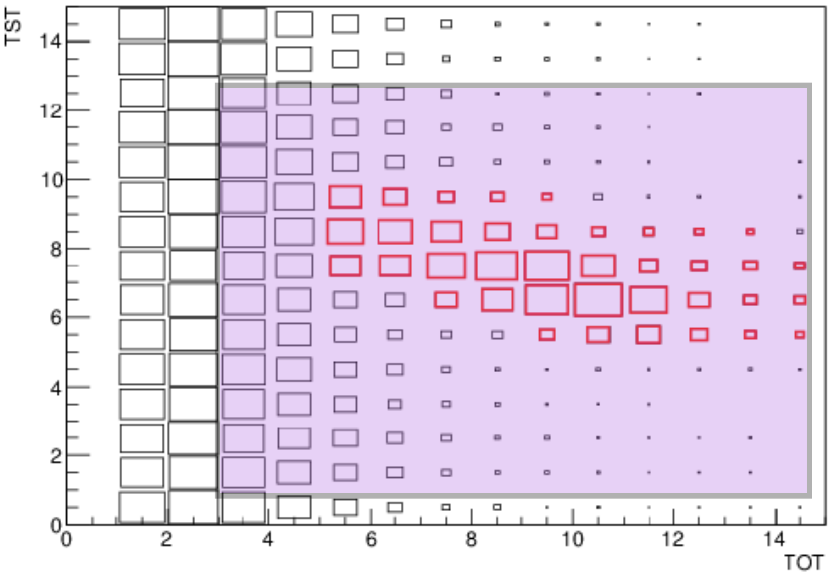
- Optical survey accuracy 100 μm
  - *need of software alignment*
- Track selection with rather relaxed chi2 cut
  - *we expect "large" residuals*
    - we do see up to ~100μm shifts
- alignment by
  - *shift in x-z directions*
- After SW alignment
  - *all residual centered at 0*
  - *gaussian distribution and sigma ~hit resolution: ~20μm*

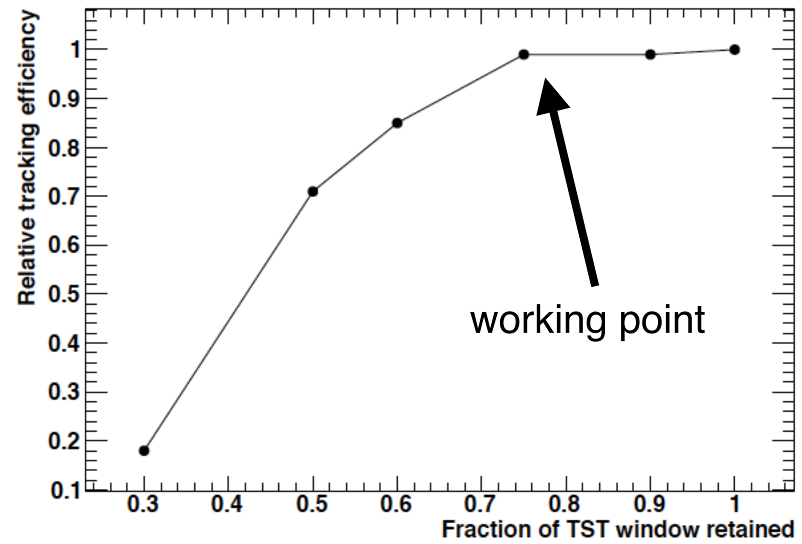




Relative tracking efficiency

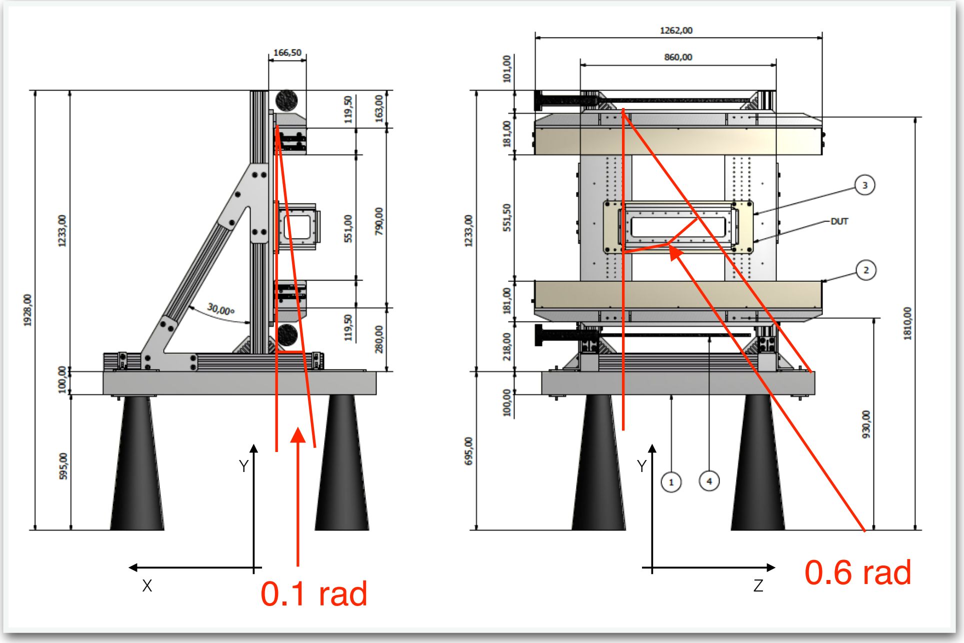
- Reconstruction code training with clean events
  - *very low noise-hit contamination*
  - *looks for the best chi-square combination*
    - not sophisticated but adequate to this system
- aim at highest efficiency
  - *relax hit selection condition*
  - *looking for saturation of the relative tracking efficiency*
    - no performance degradation looking at residuals and chi-square

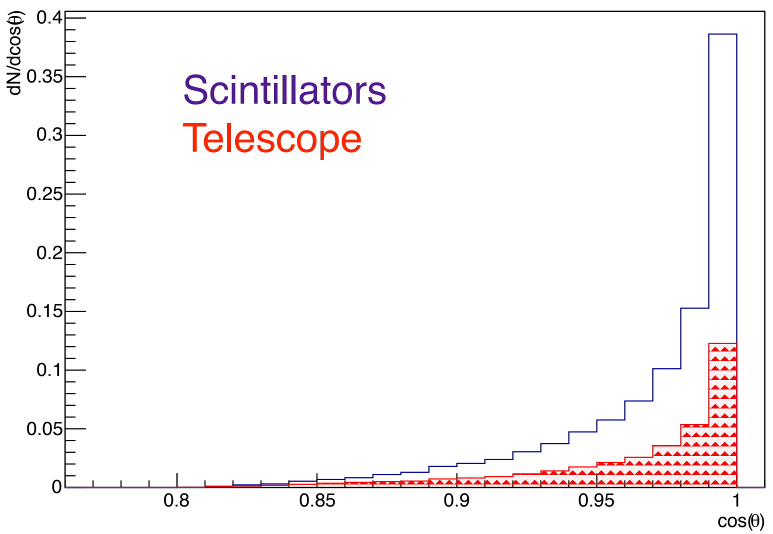




Rate and acceptance

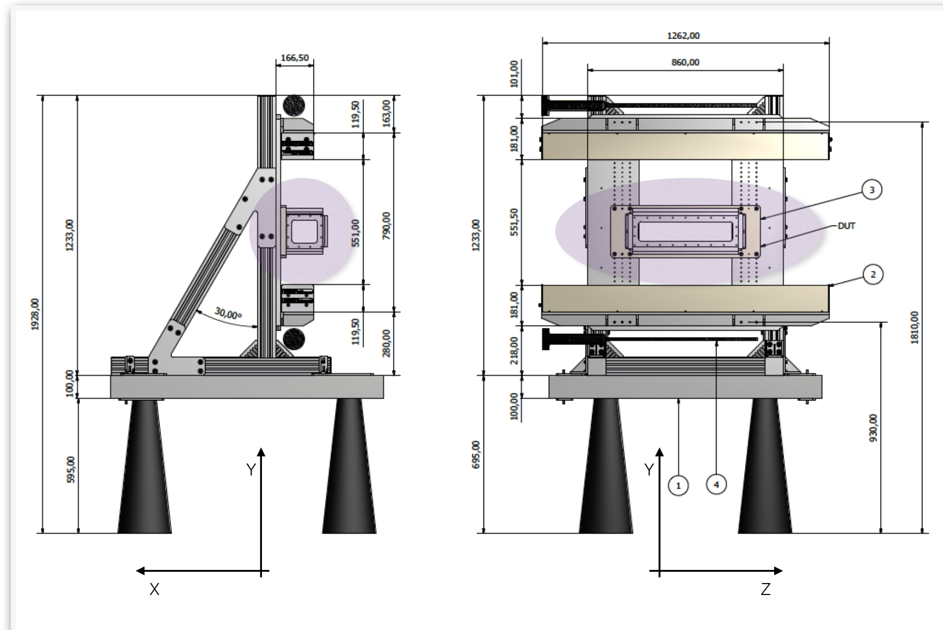
- Numbers computed with 50cm gap between the box
- Small telescope acceptance
  - *max angle = 0.1 rad in the x-y view*
  - *0.6 rad in the z-y*
- expected (and measured) rate ~0.3Hz
- 30% relative scintillator - telescope acceptance
  - *order of 130 reconstructed tracks/run*
    - we can extract each plane efficiency to be larger than 90%
- At the DUT plane
  - *~3 tracks/hour/cm^2*
    - ~500 tracks/week/cm^2





The DUT in the telescope

- Small size detector
  - *the telescope active area 5x20 cm^2*
  - *take care about thickness*
    - it can degrade the performance
  - *largest box distance allowed: ~50 cm*
- Read out
  - *ideally linkable to master PC*
    - busy and event building not an issue…
      - *VME*
      - *ethernet*
      - *USB*
      - *…*
  - *if not possible, solution tailored on needs*
    - hardware and software modifications



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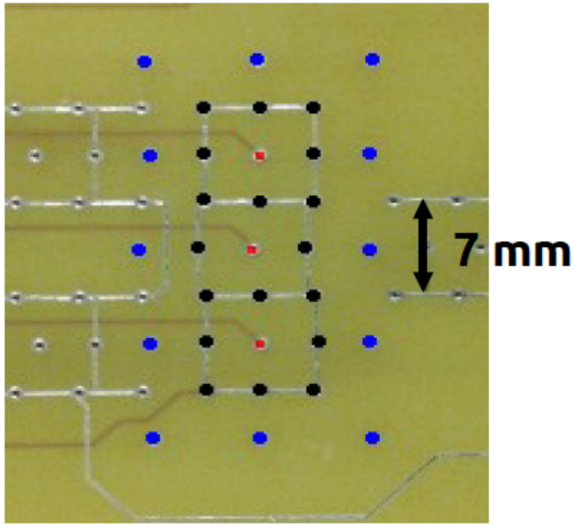
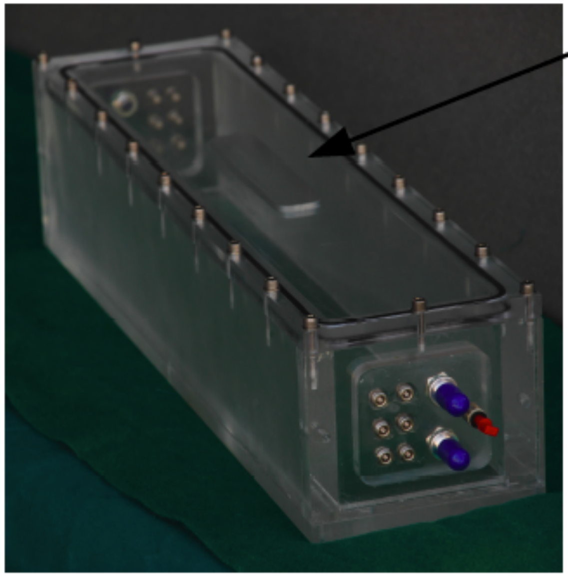
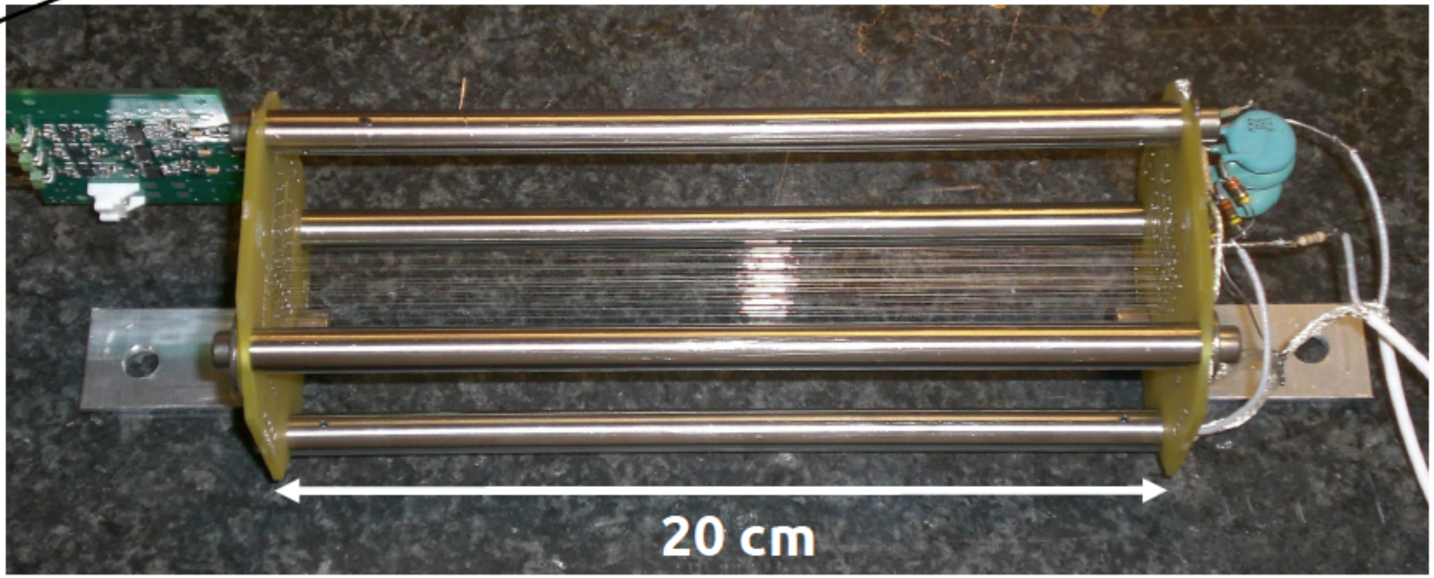
The MEG II prototype

- squared cells, 7x7 mm^2, drift tube length ~20cm
- staggered cells for self tracking capability
- light gas admixture: He-Isobutane 85:15 : 12.9 cluster/cm
- HV 1600-1700 V, max drift time ~150 ns
- MEG II fast pre-amplifier, BW ~1GHz for cluster identification
- Gas tight plexiglas box with 1mm window in the active region

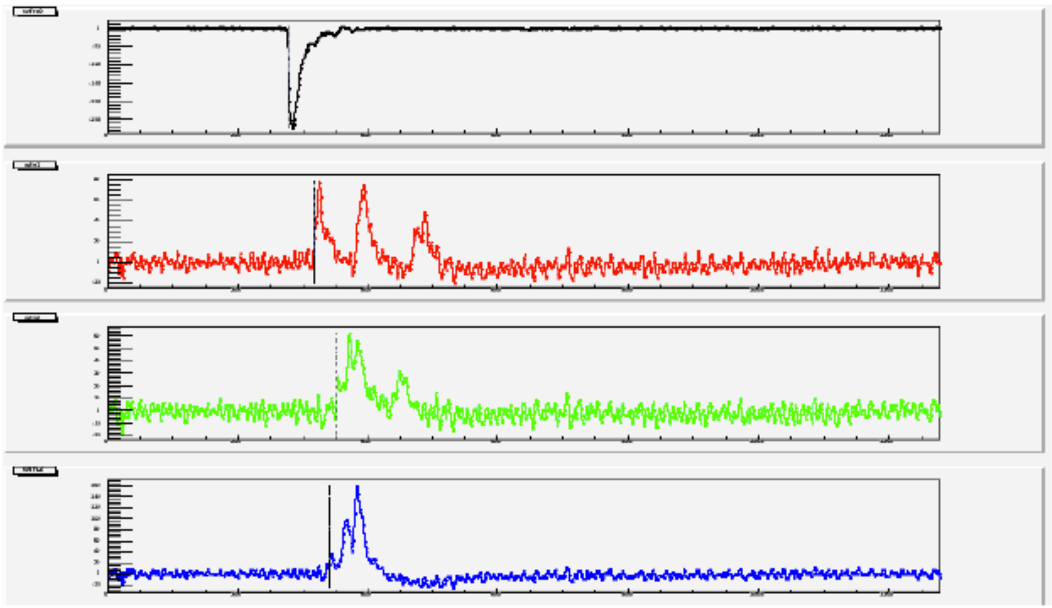


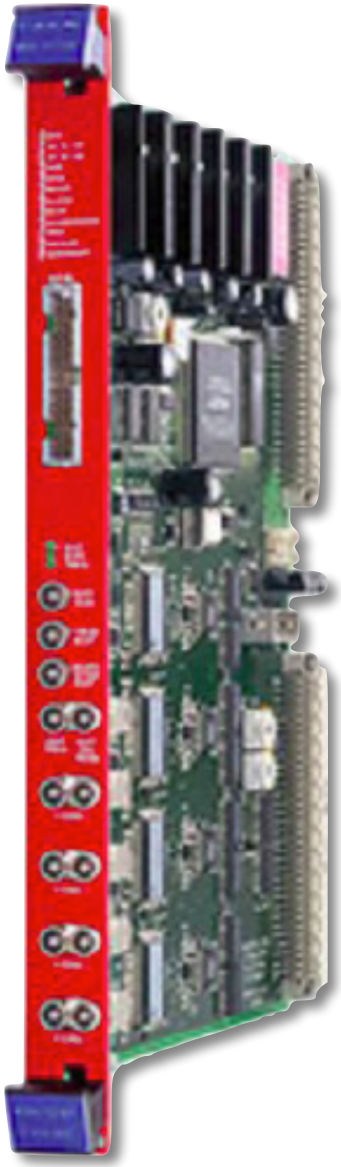




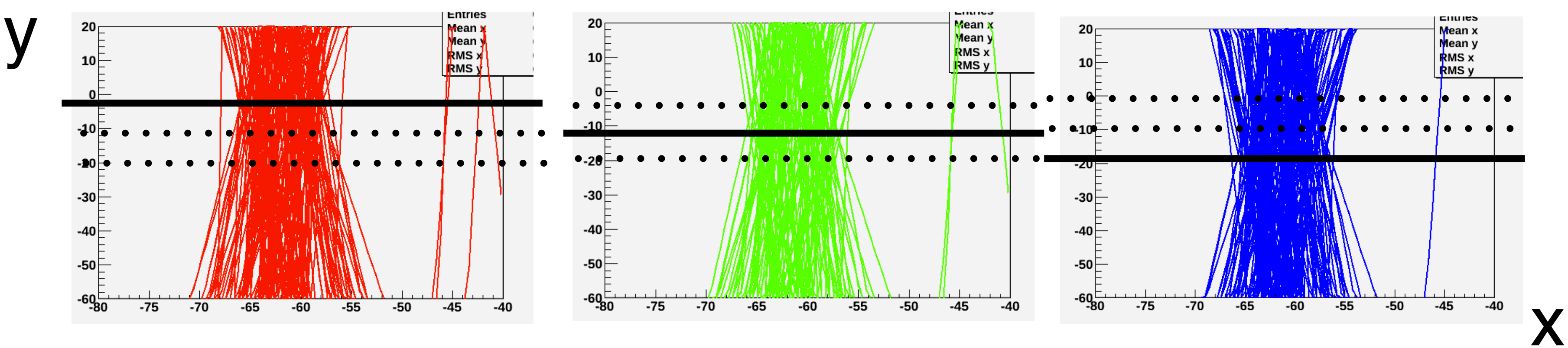
Read out

- Read out with VME CAEN V1729
  - *12 bit*
  - *2 GSPS*
  - *300 MHz BW*
  - *differential input*
- configuration and data transfer code into telescope C++ DAQ
  - *upper scintillator PMT digitised for track T0*

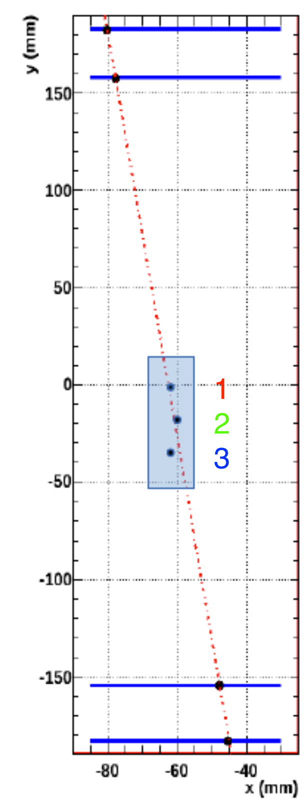




Telescope - DUT coincidence

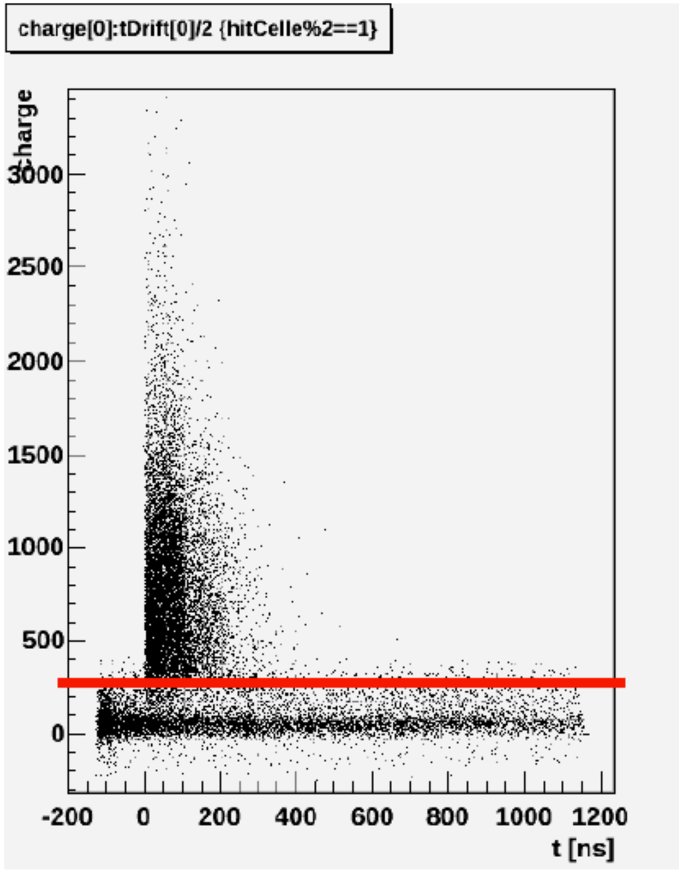


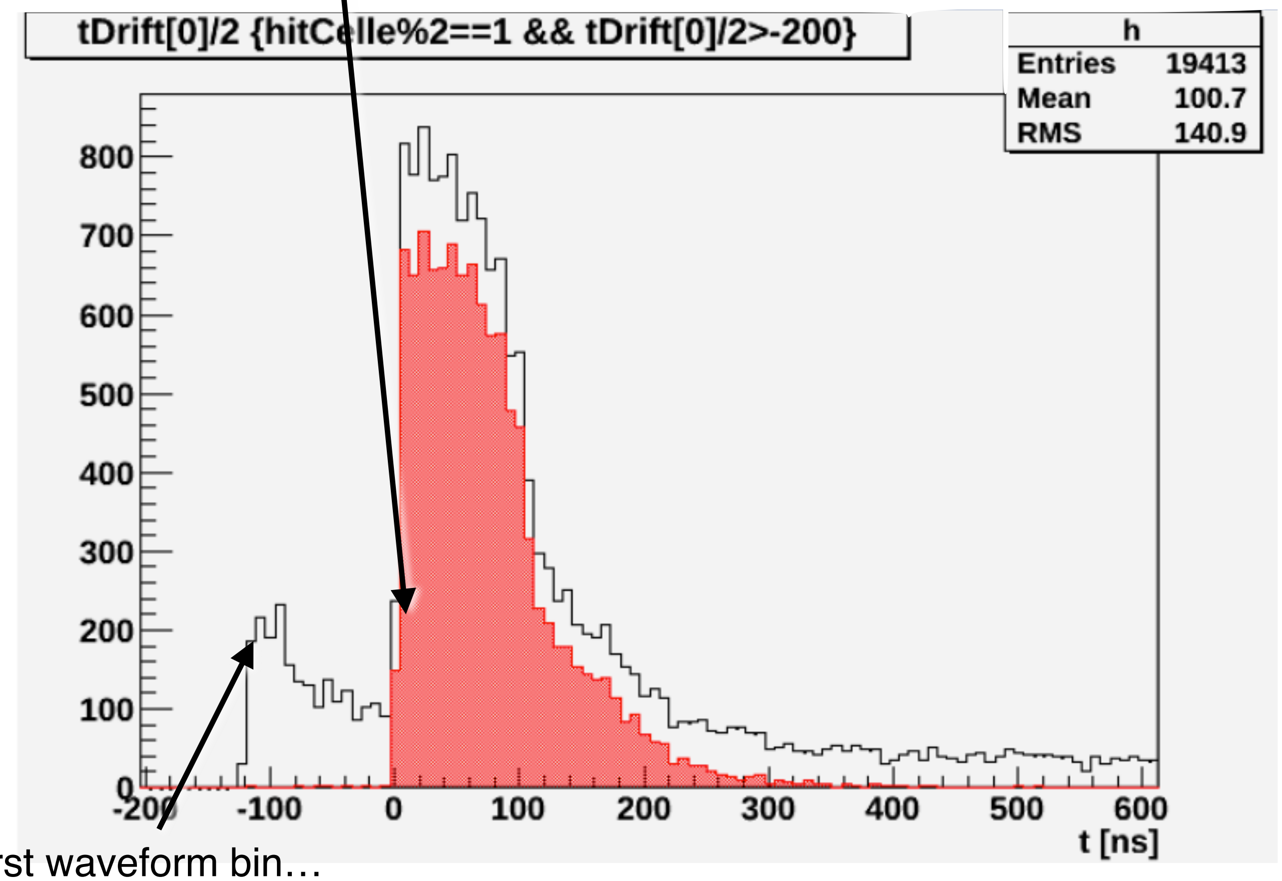
- The cell position in the y coordinate can be identified by looking at the distribution of the tracks having an hit on the cells (1 2 3)
  - *shift in y visible by eye*
    - it has to be with a properly working telescope!
  - *x-stagger not visible (only 500 μm…)*
    - this is not the right way to look at it



Time offset calibration

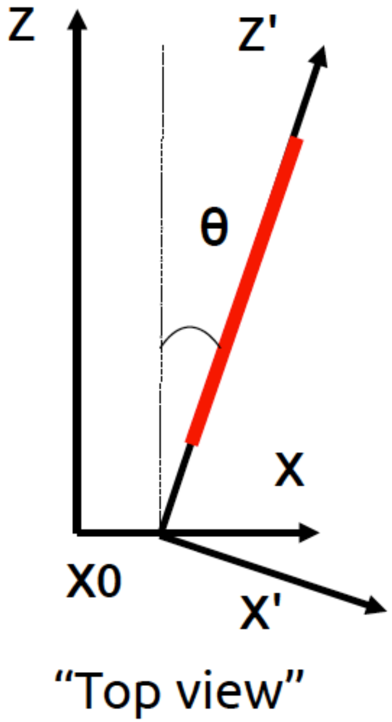
- Time offset calibration w.r.t. PMT reference
    - *time from SW double threshold discriminator*
    - *noise rejection looking at charge*
        - we present a set of run with high noise (grounding lost), it is usually much better



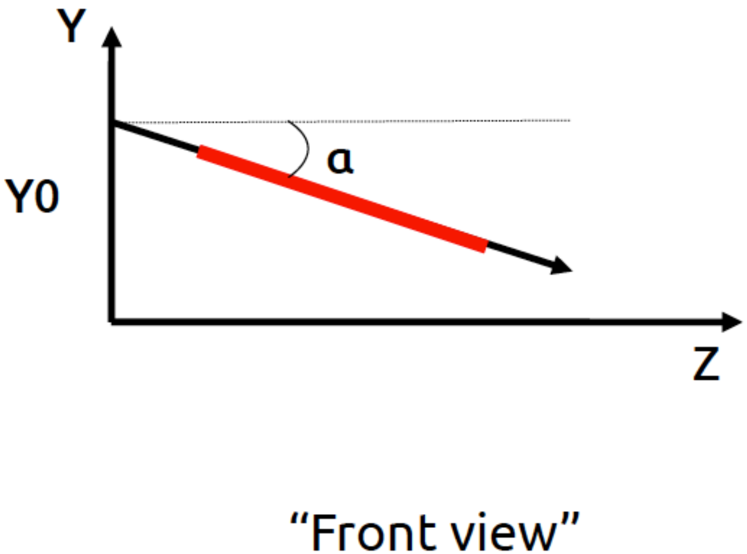


DUT alignment

- wire equation in the telescope reference system to compute the impact parameter b
  - *top view: wire imaging*
  - *front view: strabismus effect*

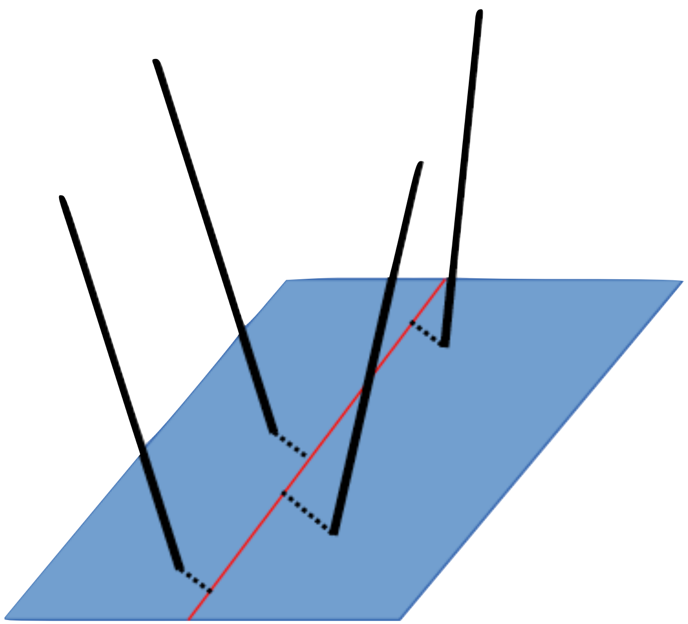


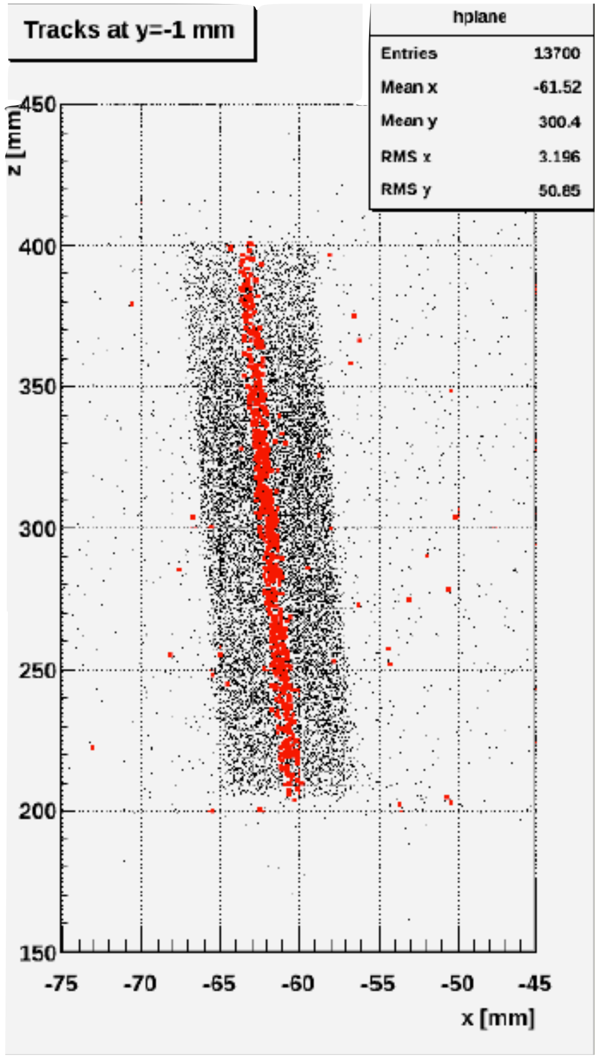
4 parameters: (θ, X0, α,Y0)

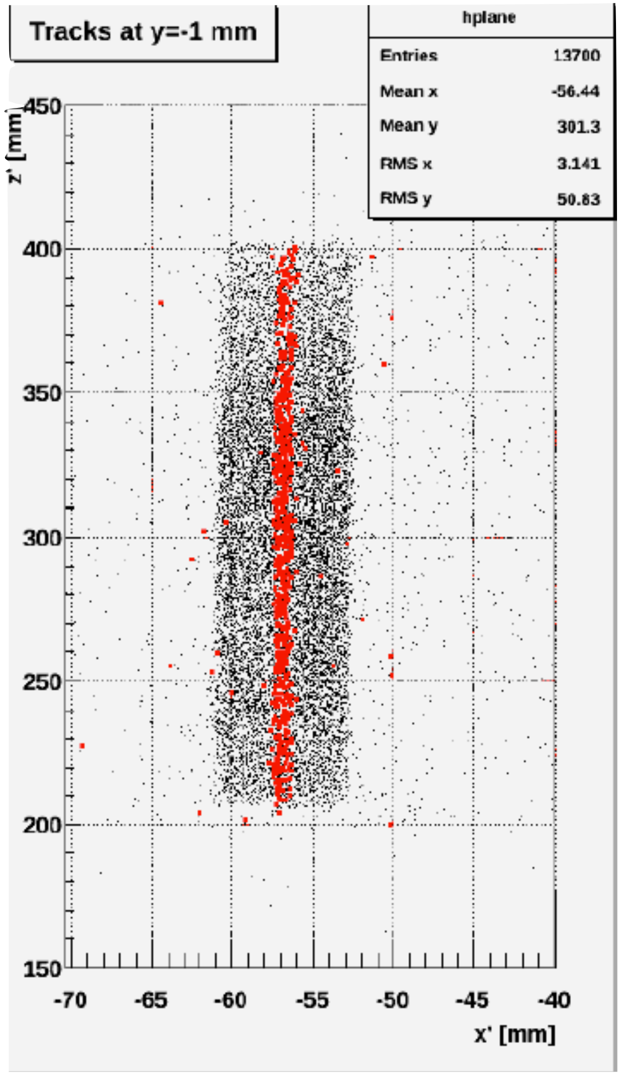


DUT alignment: x-z plane

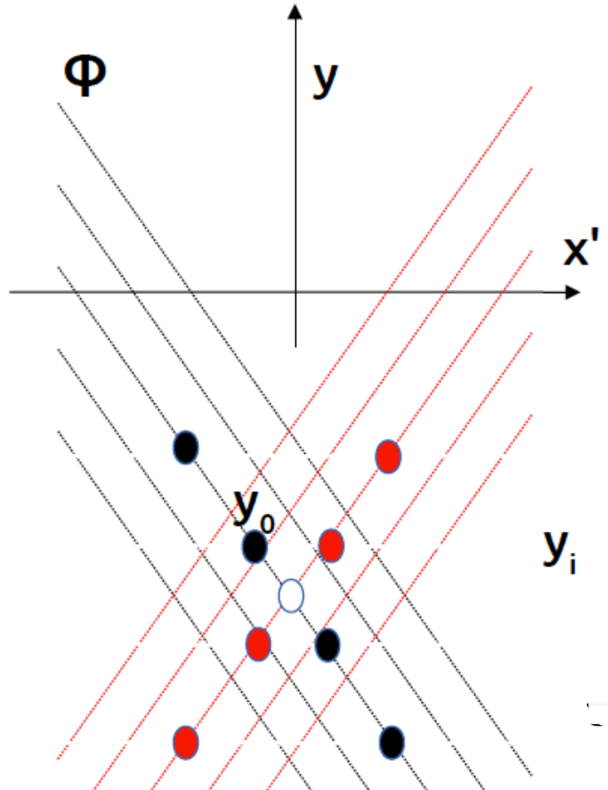
- event with small drift time: t<5ns
    - *wire imaging*
- outliers from noise in the DUT
    - *less than 1%*



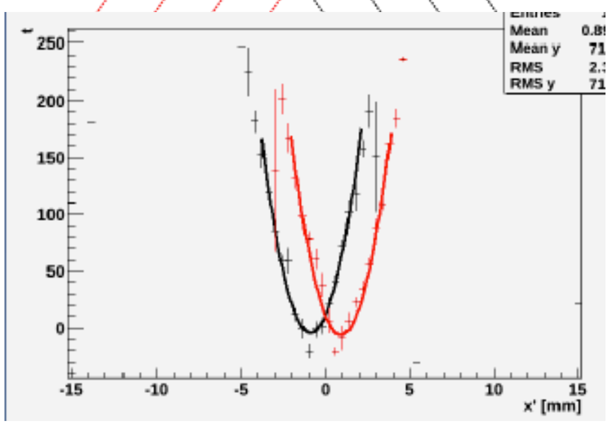


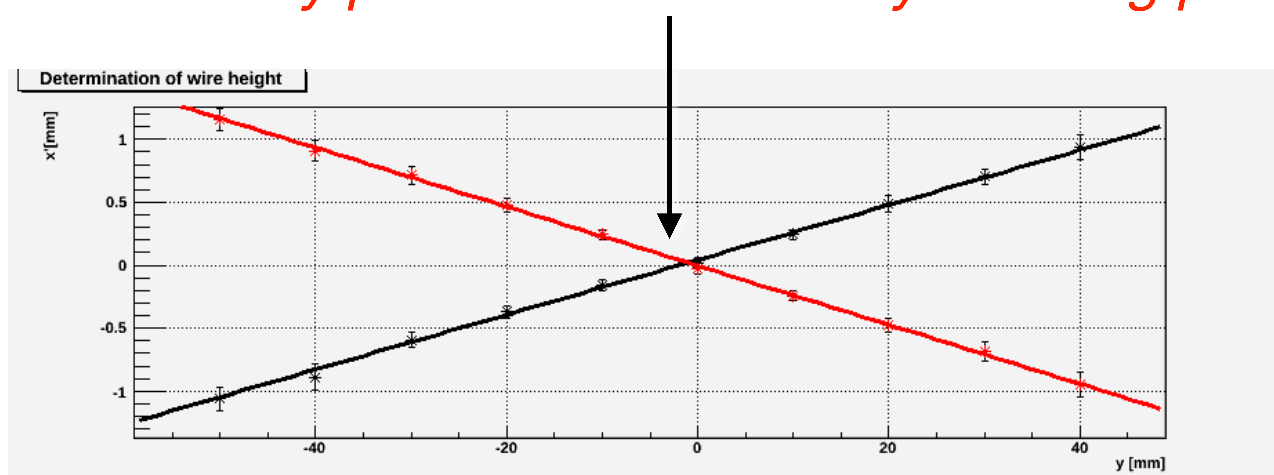


Strabismus effect

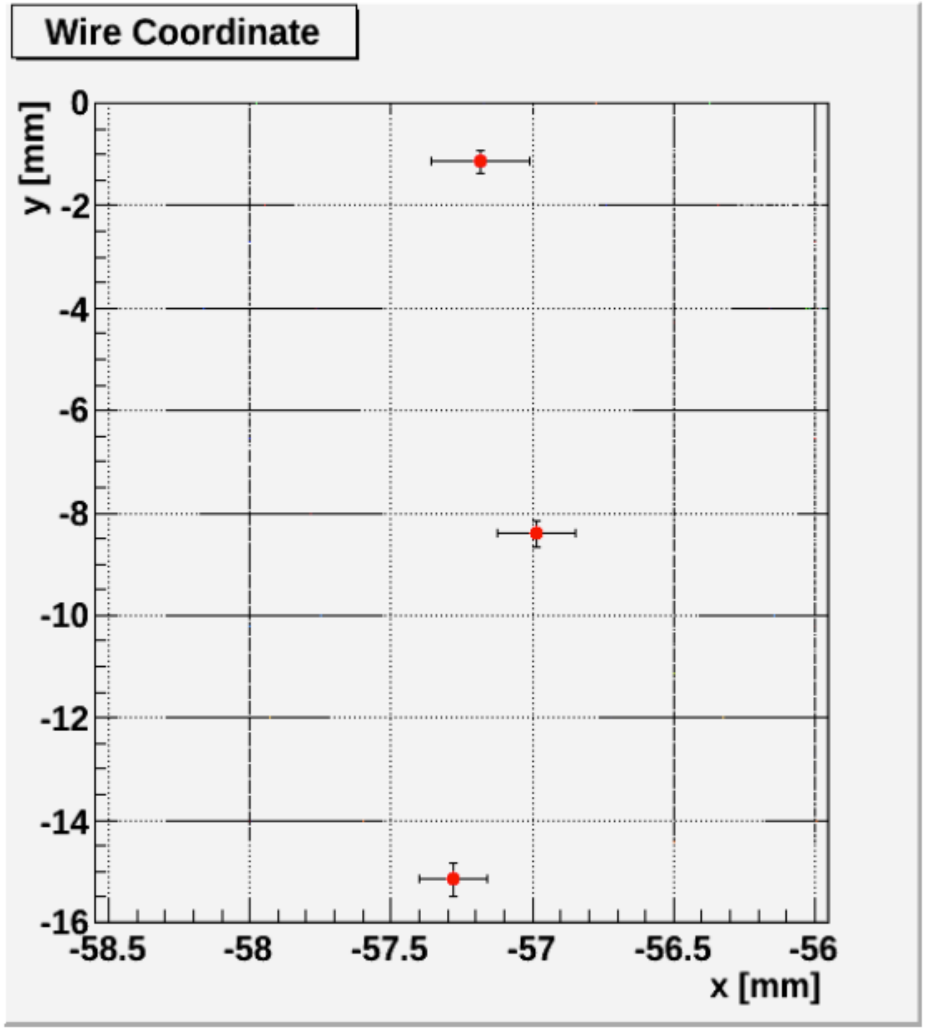


- use of tracks with φ = +- 100 mrad
  - *use of different nominal y planes and fit the x-t relation*
    - the parabola vertex is the wire position
    - the predictions do not agree if the y plane used in the projection is not the real wire position
  - *wire y position estimation by crossing point*

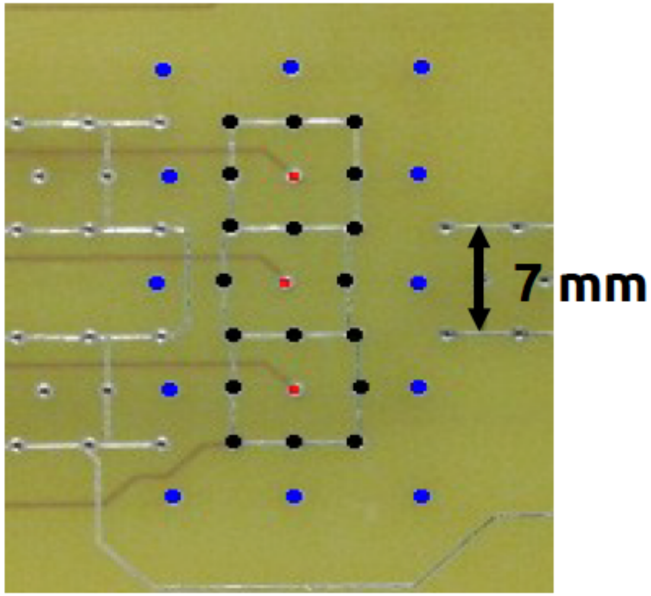




Reconstructed wire positions

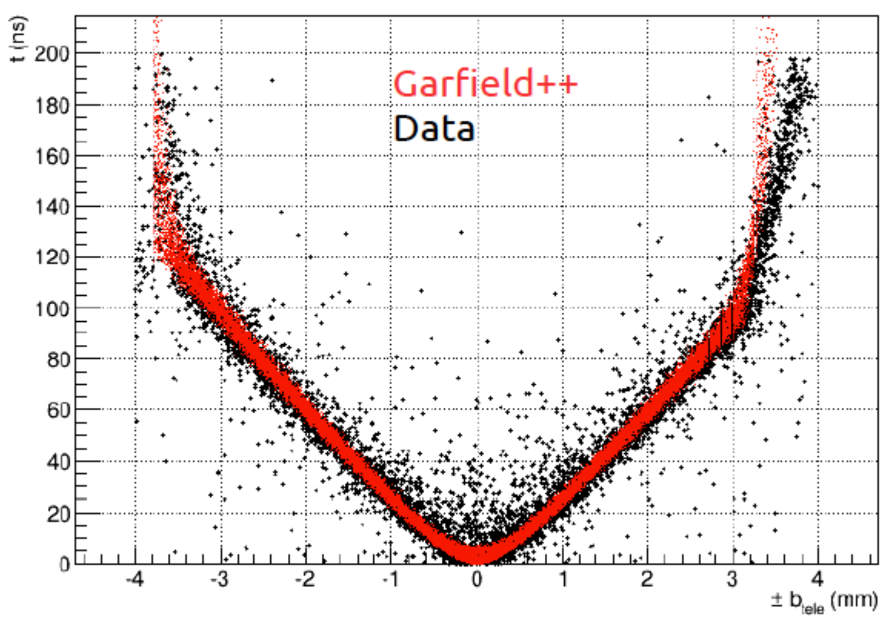


- 7 mm wire distance
  - *and 500 μm stagger*
- now we are confident to measure
  - *x-t relations*
  - *position resolution*

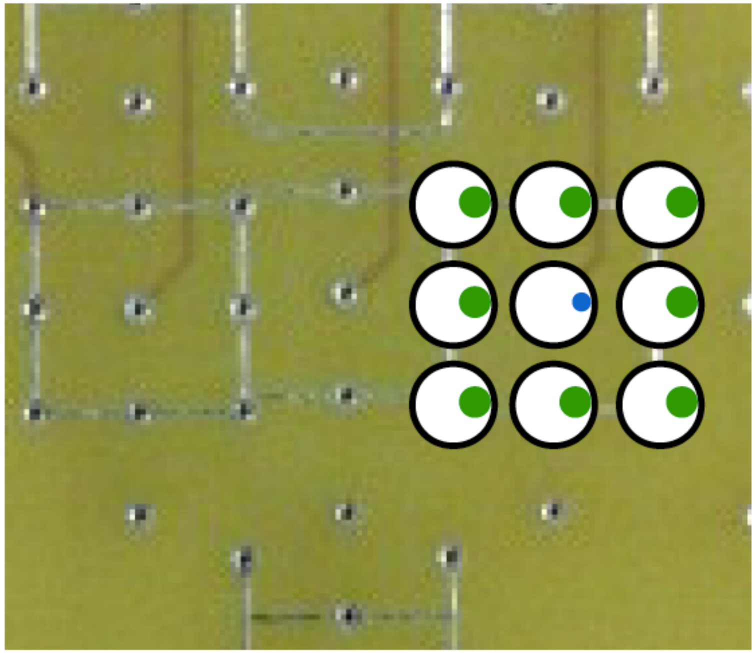


x-t relation

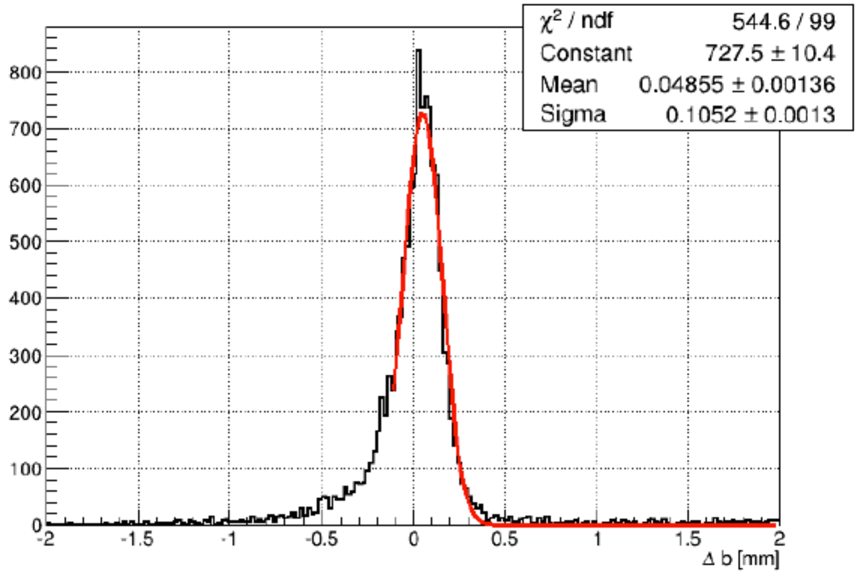
- used to convert time information in position
  - *agreement with garfield++ simulations*
  - *evidence of small cell asymmetries*
    - related to wiring procedure

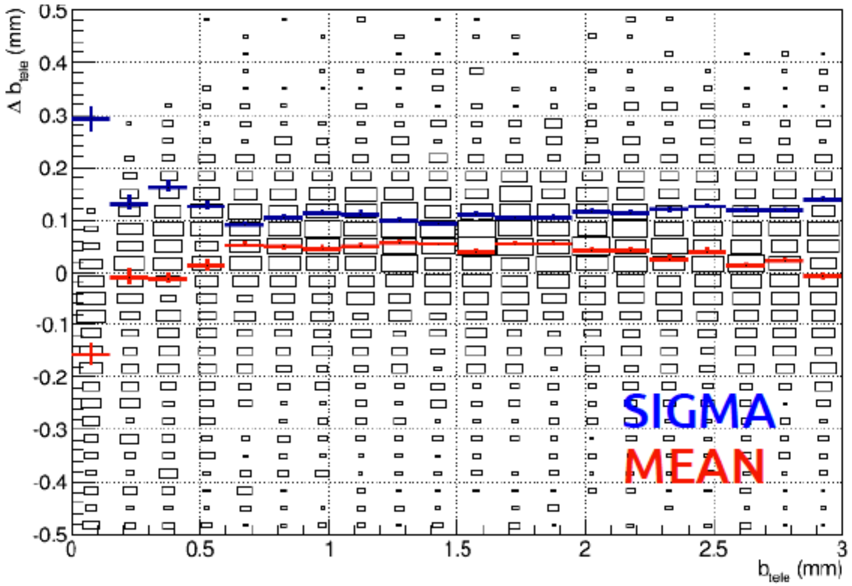


PCB hole: 500 μm
Sense wire: 20 μm
Field wires: 80 μm
(not in scale)

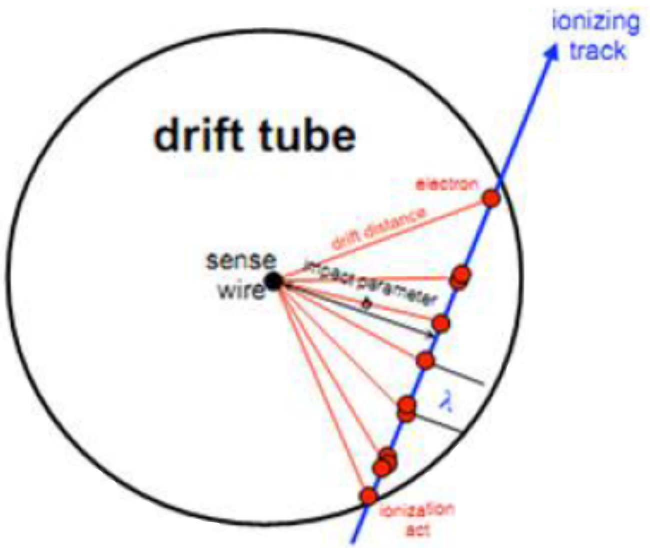


Resolution

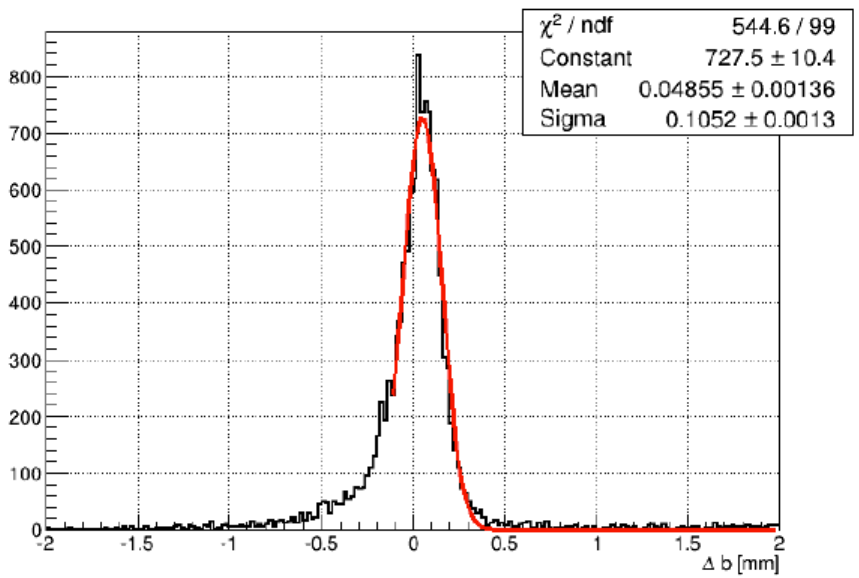


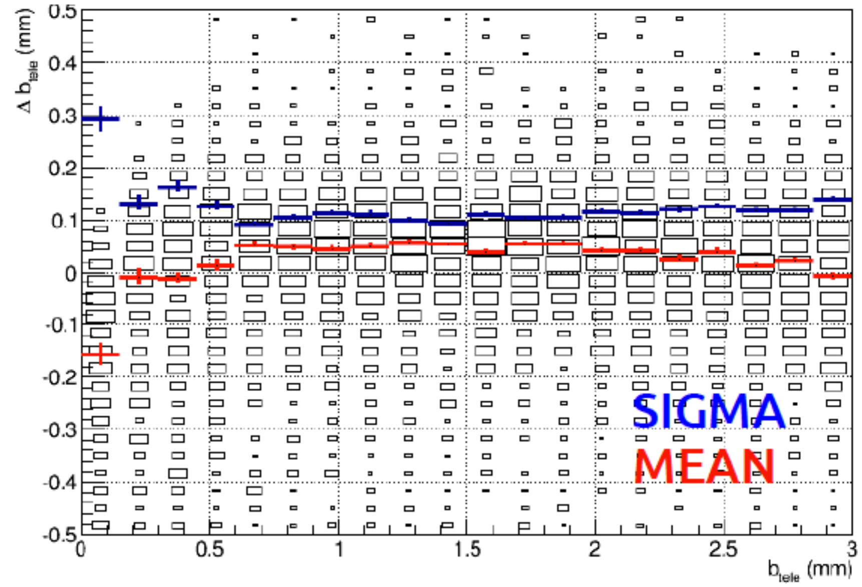


- Use of only first ionisation cluster
  - *evidence of bias for small impact parameters*
  - *resolution of ~110 μm as expected*
    - master thesis by A. D'Onofrio to study the resolution improvement by using the information of the other clusters ongoing



Resolution





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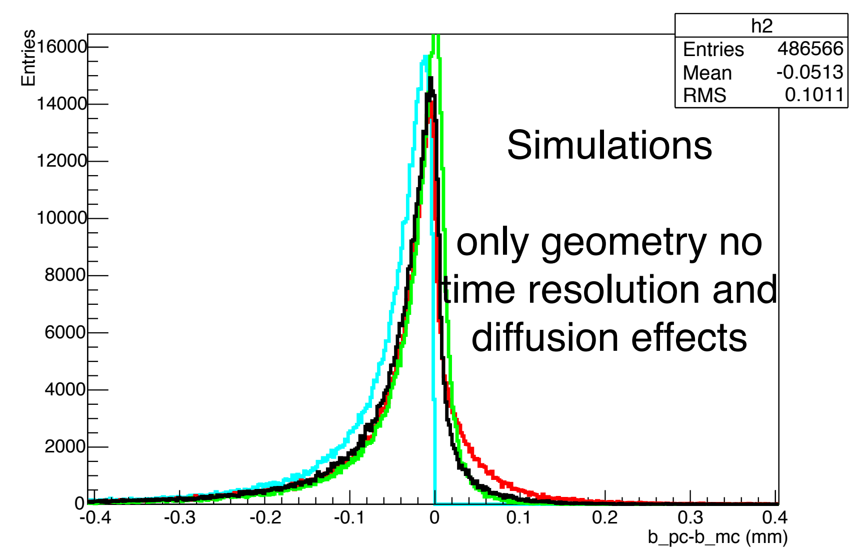
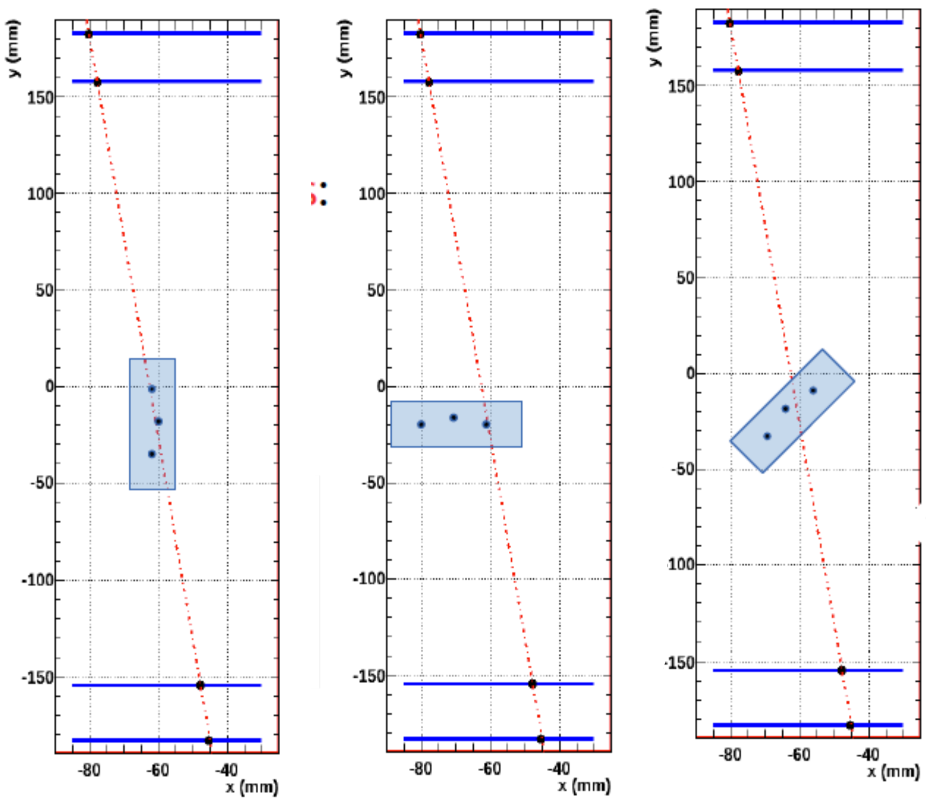
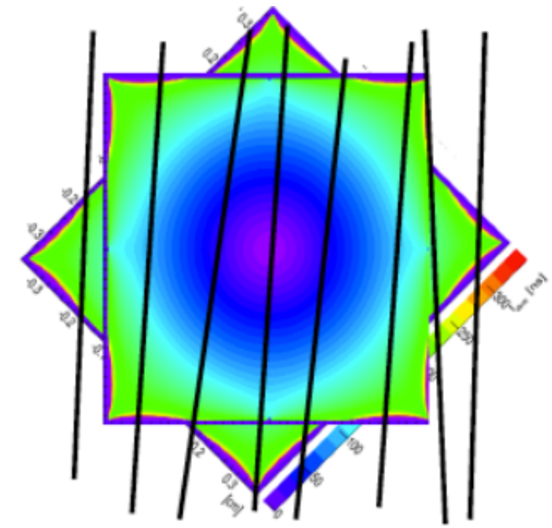
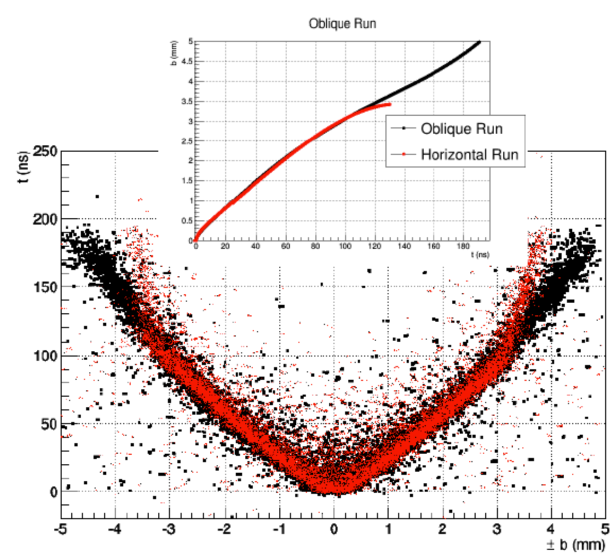


Configurations

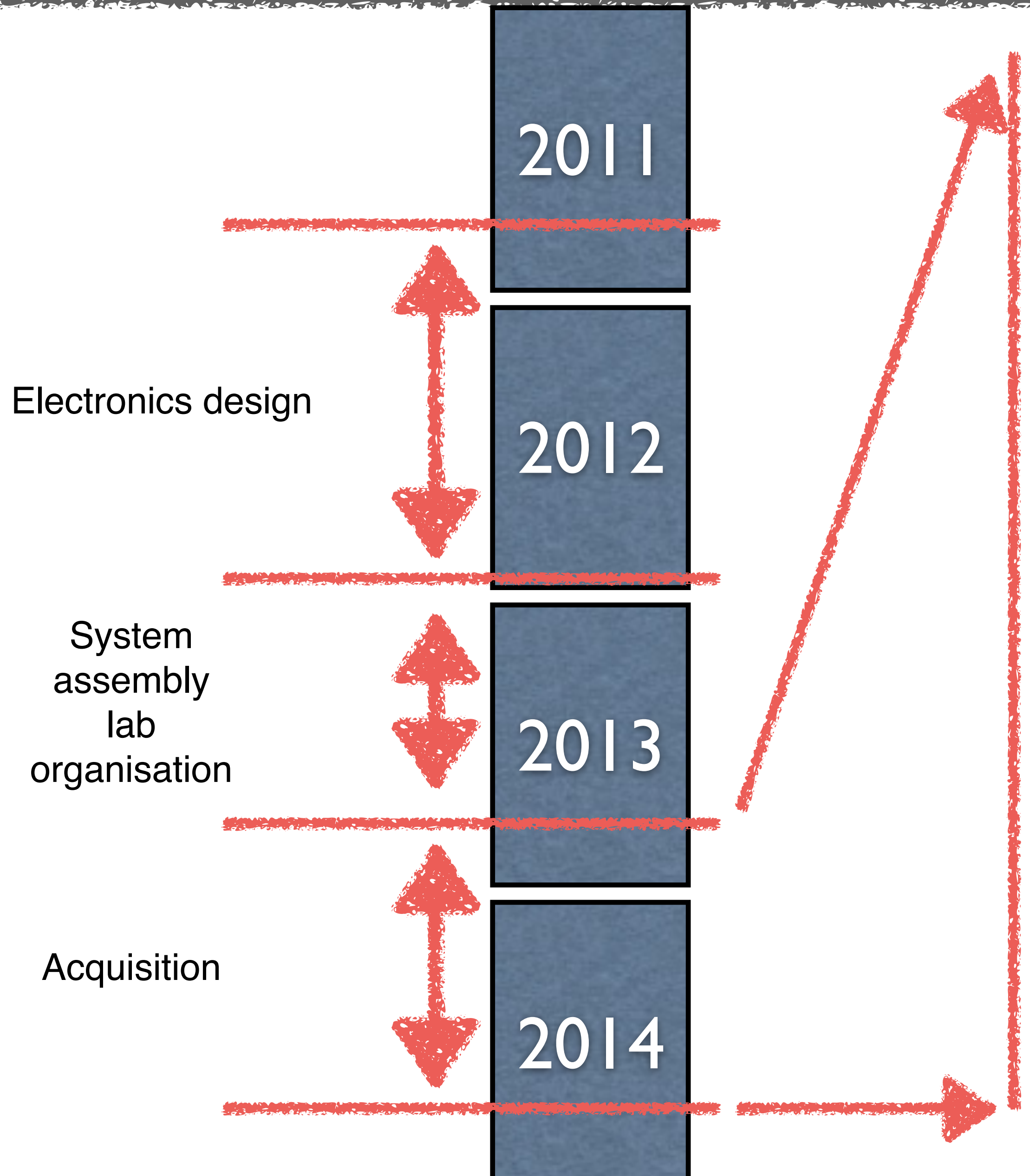
- The measurement was repeated in three configurations
  - *resolution cross check*
  - *x-t relation scan*







Acquisition time and history

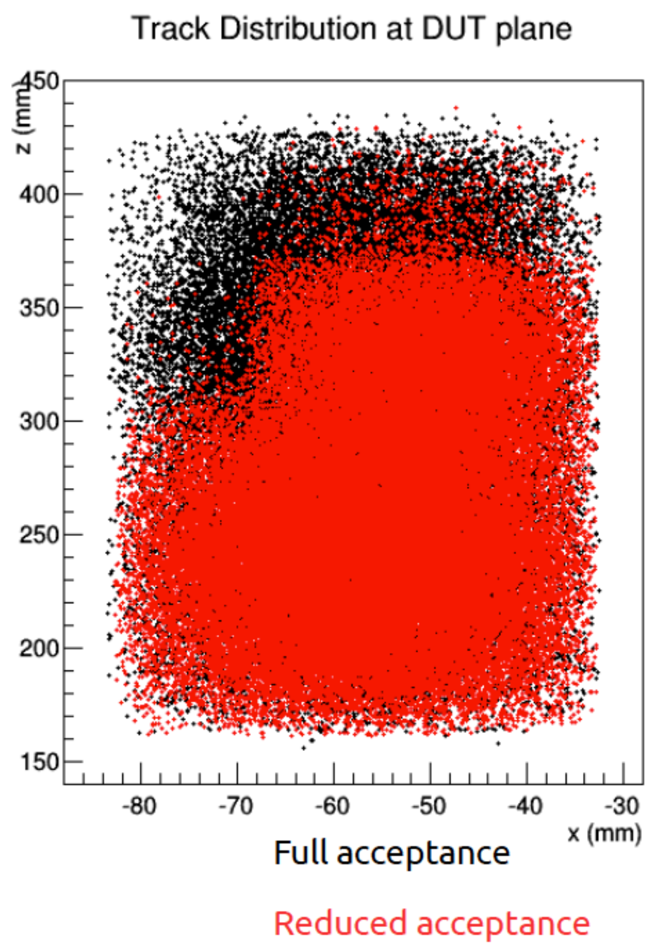


- DAQ kick off in November 2013
- each config ~ 500 runs, 1000 events each
  - *12 MB per run, 600 MB per config*
  - *~10000 events per cell*
- vertical run
  - *10 Nov - 17 Dec*
- horizontal run
  - *17 Jan - 11 Feb*
  - *20 Feb - 4 Apr*
    - stopped for problems with the telescope, see next slide
- oblique run
  - *25 Jul - 18 Sept*
    - longer run to check the cell corners
- ~ 3000 runs in total
- ~ 9 months of operation

Future plans

- The facility is operative
  - *in one year of operation no sign of performance degradation, but*
    - Suddenly lost of few chips in April
    - 4 chips on a L4 p-side (the whole side) and 2 chips on a L5 n-side (2/5 a side)
    - reason unknown
      - *no temperature variation*
      - *no loss of dry air*
      - *voltage spike?*
    - L4 substituted, L5 still there
- We have few spares for L5 and L4 (~ 4 modules per type)
  - *can be used if needed*
  - *less chips lower acceptance*
    - but telescope usable
  - *we could use 3 hits instead of four with a moderate performance loss*
- New run with MEG II prototype
  - *use of GHz electronics for refined cluster timing studies*

- Lifetime ~ 10 years
  - *responsible: Luca Galli*



Conclusions

- A Si-based cosmic ray telescope as an INFN sezione di Pisa facility
- New TDAQ and electronics to substitute the original from BaBar experiment
  - *no longer usable*
- A MEG II prototype characterised in many configurations
  - *both telescope and DUT resolutions as expected*
- New runs with fast electronics foreseen with MEG II prototypes
  - *the facility is available for any requirements from the groups of this section*
    - Avanzini, Spinella: micro-megas detector?