Muon scattering tomography with resistive plate chambers

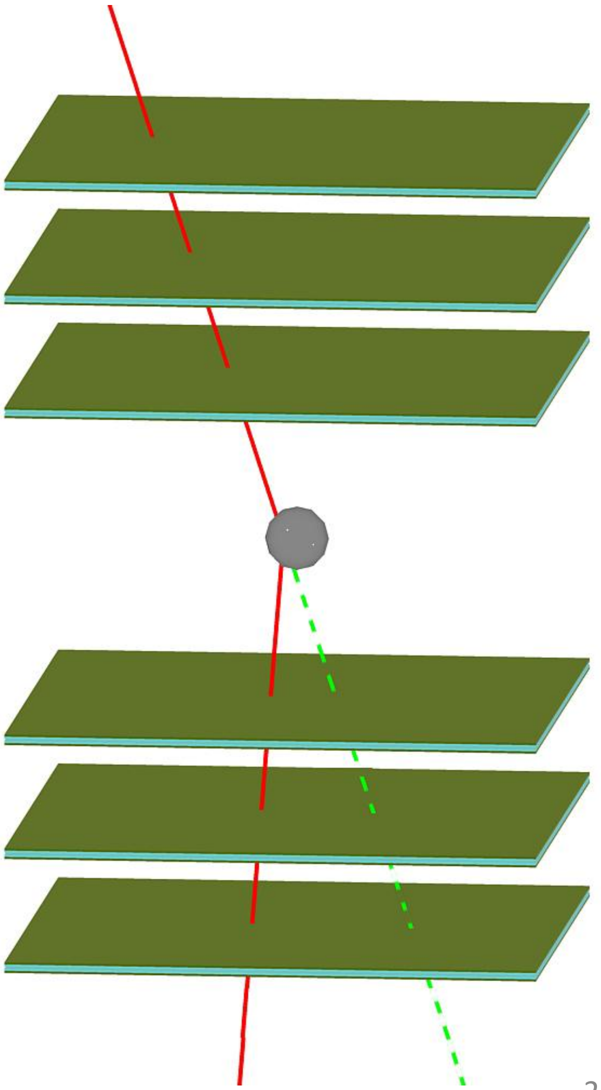
RPC2012 - XI Workshop on Resistive Plate Chambers and Related Detectors

Speaker: Paolo Baesso – University of Bristol

David Cussans – University of Bristol
Christian Thomay – University of Bristol
Jaap Velthuis – University of Bristol
Steve Quillin – Atomic Weapon Establishment
Stacey Robertson – Atomic Weapon Establishment
Chris Steer – Atomic Weapon Establishment

Outlook

- Introduction
  - Muon scattering tomography
  - Detector requirements
- Setup overview
  - Hardware
  - RPC
  - Electronics
  - DAQ
- Data
  - Peak distribution
  - Summary of read-out performance
  - Tracks
  - Reconstruction
- Current developments
- Summary

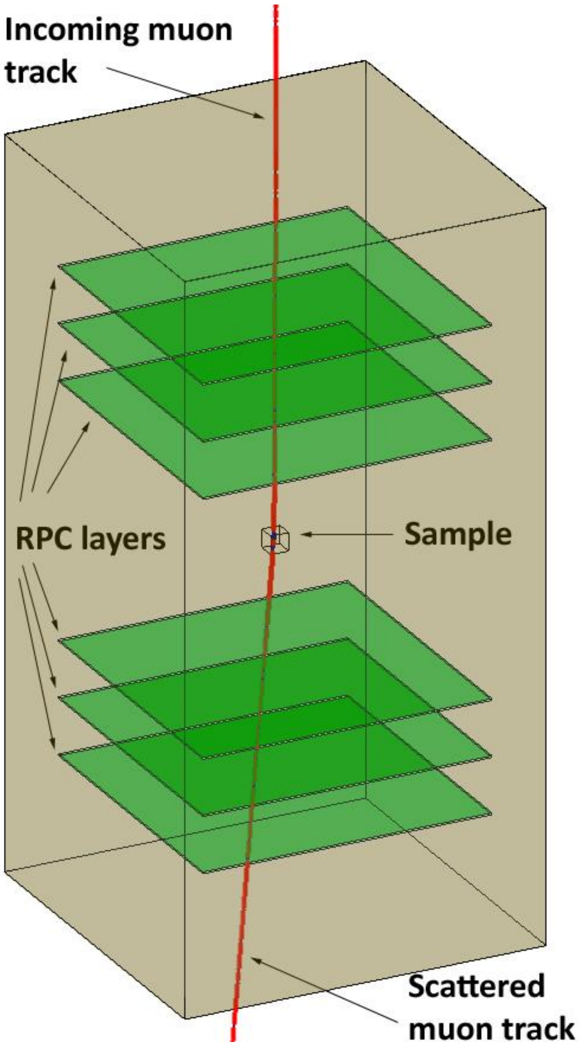


Introduction

- University of Bristol (UoB) and Atomic Weapon Establishment (AWE) partnership to build and study a prototype scanner for Muon Scattering Tomography (MST).
- The prototype is used to scan a target volume in search of high-Z materials.

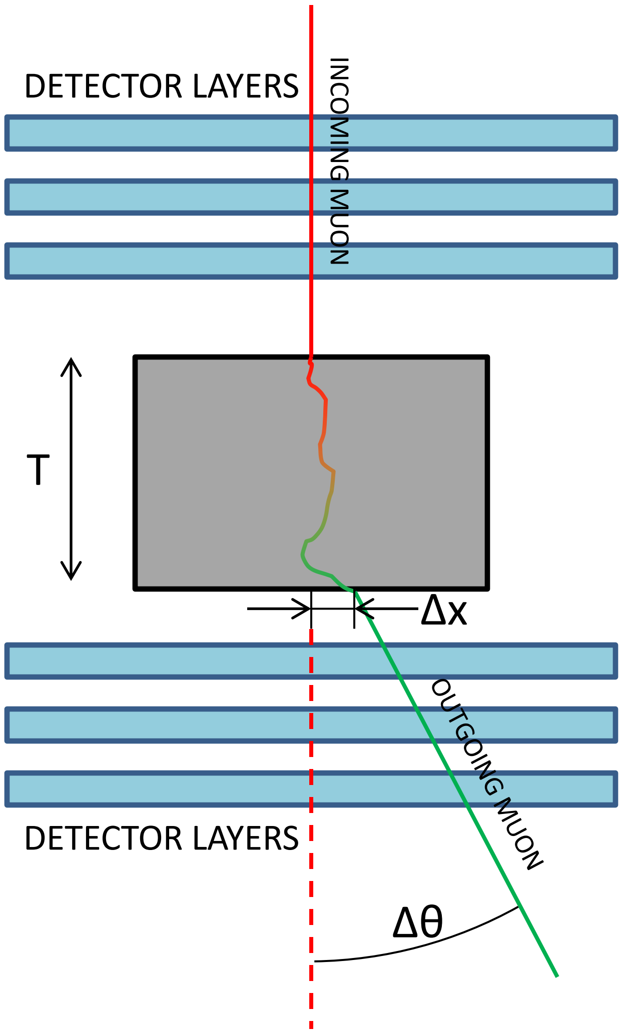
Why?

- Muons are excellent probes:
  - Readily available, with flux of ~100 Hz/m^2 and energies from 0.1 GeV to 10 GeV.
  - Virtually impossible to screen against, since for 1 GeV muons dE/dx ~ 2 MeV·g^{-1}·cm^2.
  - Charged; can be easily detected.
  - No radiation hazard for the scanner operators.
  - MST is undetectable by the object being scanned, since no extra radiation is introduced.



Muon scattering tomography

- Muons undergo multiple coulomb scattering within the detector volume.
- The angular distribution can be assumed to be Gaussian, with σ_0 depending on the radiation length X_0 (and ultimately on Z).
- Muon tracks scattering within the target volume provide information of its content.

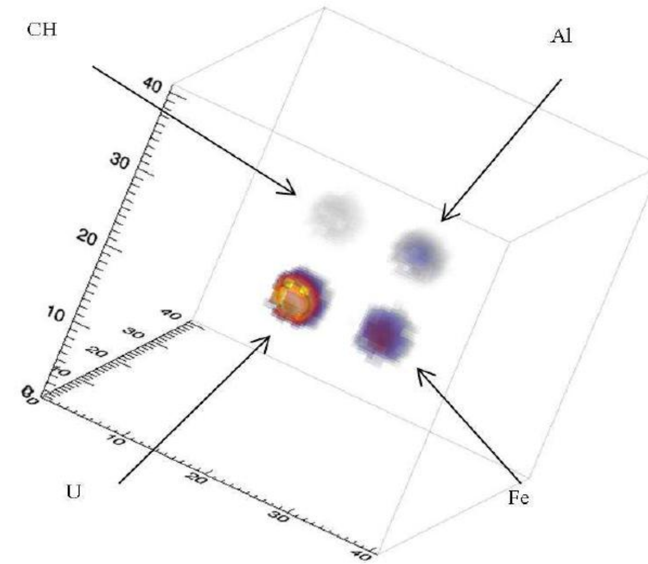


$$\sigma_0^2 \approx \left(\frac{15MeV}{pc\beta}\right)^2 \frac{\mathrm{T}}{\mathrm{X}_0}$$

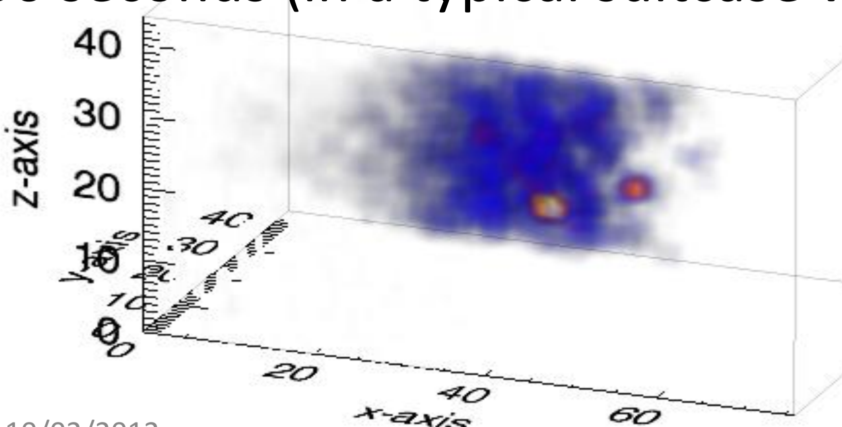
$$X_0 \approx \frac{A \cdot 716.4 g / cm^2}{\rho \cdot Z \cdot (Z+1) \ln(287/Z)}$$

Detector requirements

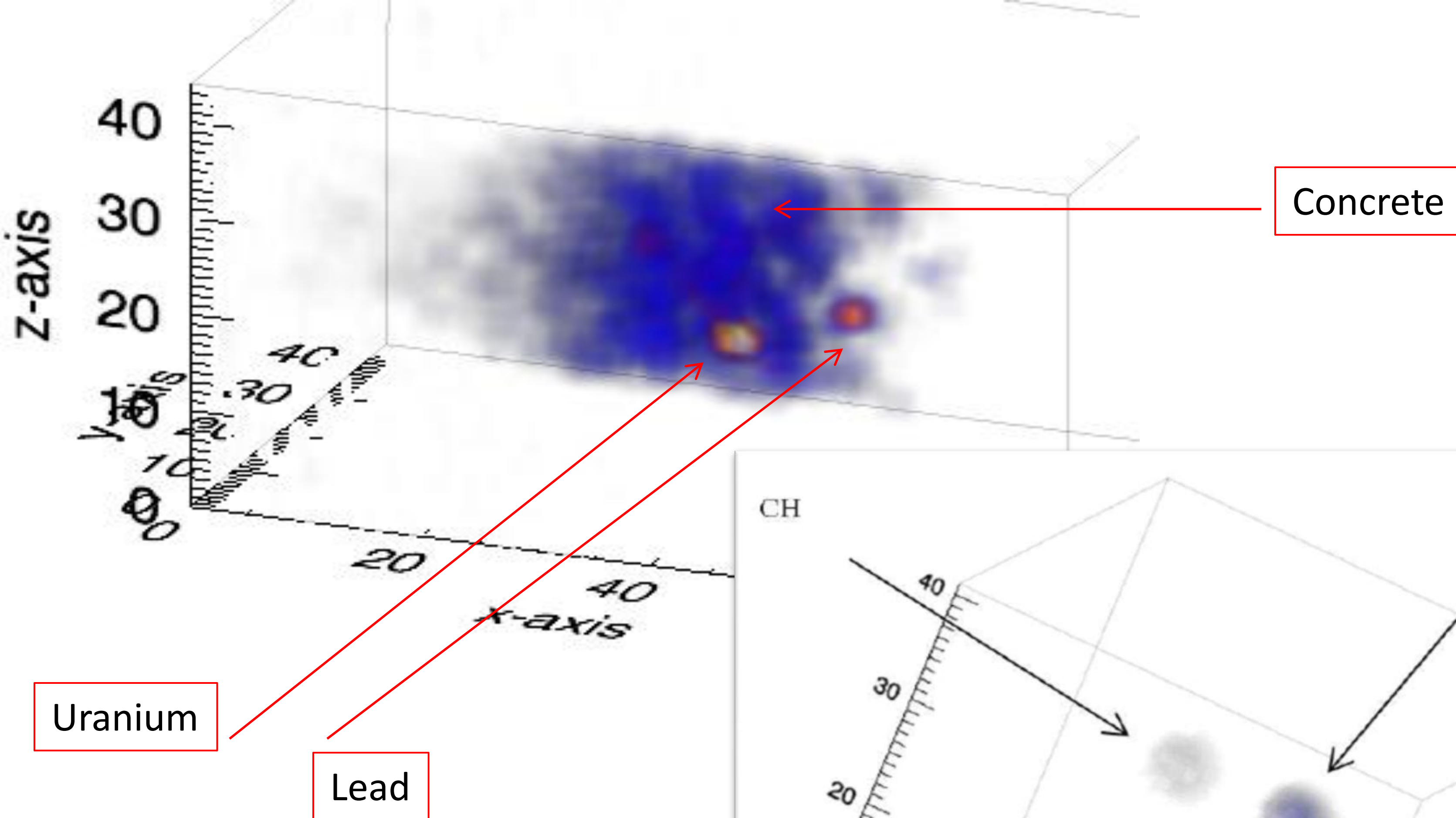
- AWE simulations provide indications for the detectors
  - Angular resolution: ~ 1 mrad (spatial resolution of ~500 µm in our setup)
  - Time resolution: ~ ns
  - Efficiency: above 90 %
- With these features it is possible to reconstruct a tennis ball sized object within 30 seconds (in a typical suitcase volume).

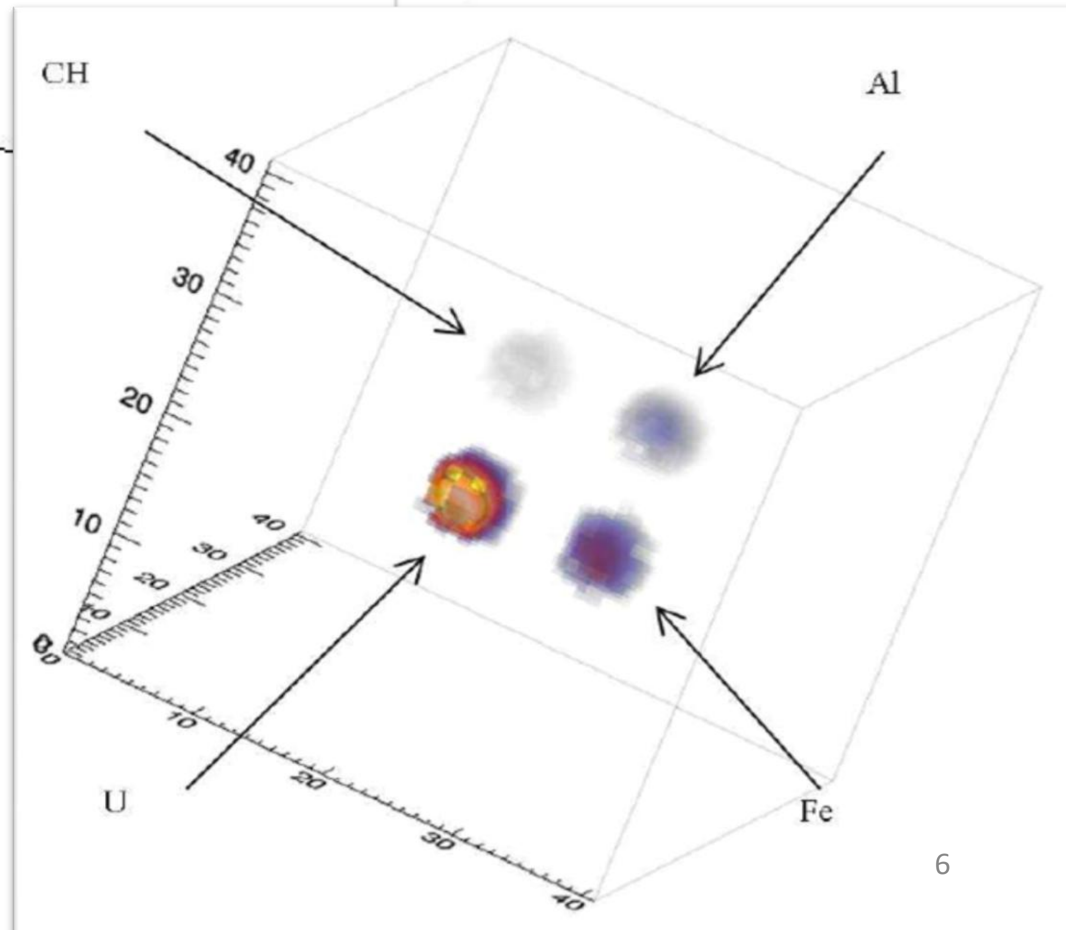


Reconstructed image showing muon scattering from tennis ball of different materials in a typical suitcase volume (courtesy AWE).



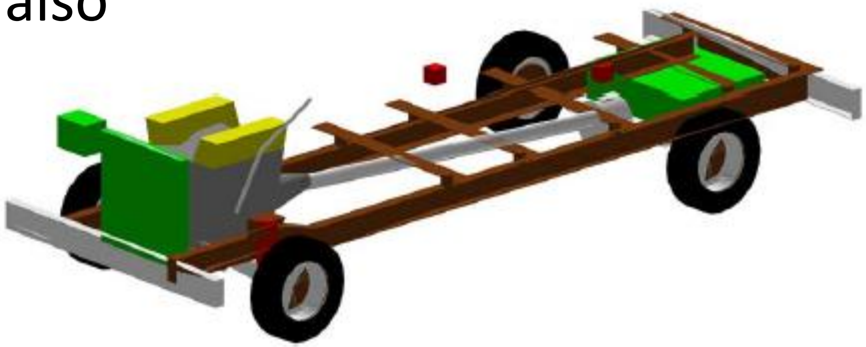
Reconstructed image of a waste drum filled with concrete and containing cubes of iron, lead, uranium and air. The cubes made of U and Pb are easily identified (courtesy AWE).

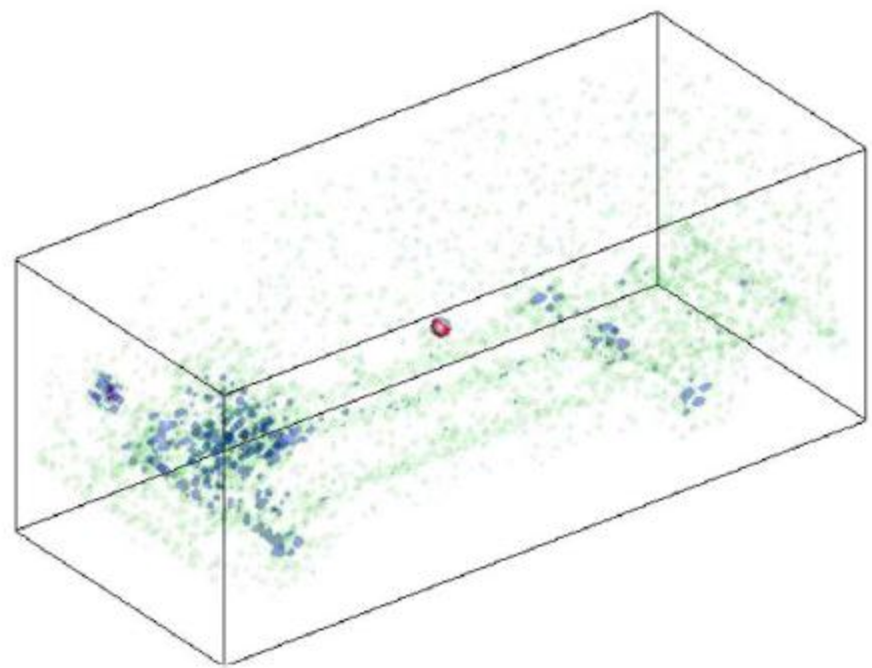

z-axis
40
30
20
10
0
y-axis
40
30
20
10
0
x-axis
20
40
Concrete
Uranium
Lead


CH
Al
U
Fe
40
30
20
10
0

Detector requirements

- Applying MST to homeland security also introduces some additional requirements for the detector:
  - Large area (shipping containers, trucks)
  - Scalability
  - Low cost per unit area
- RPC are a very good option for MST



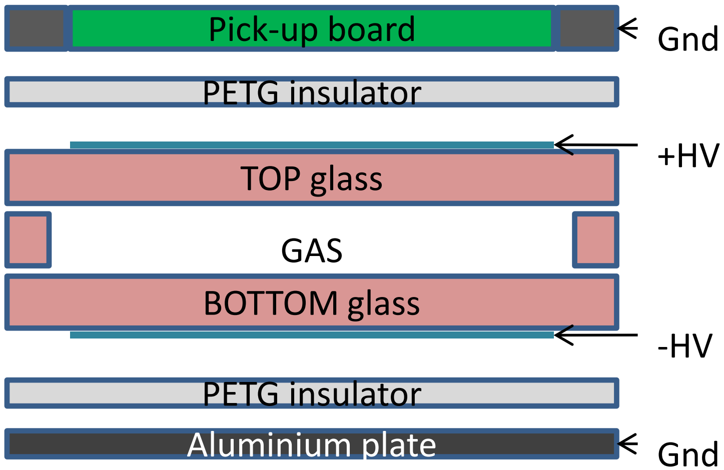


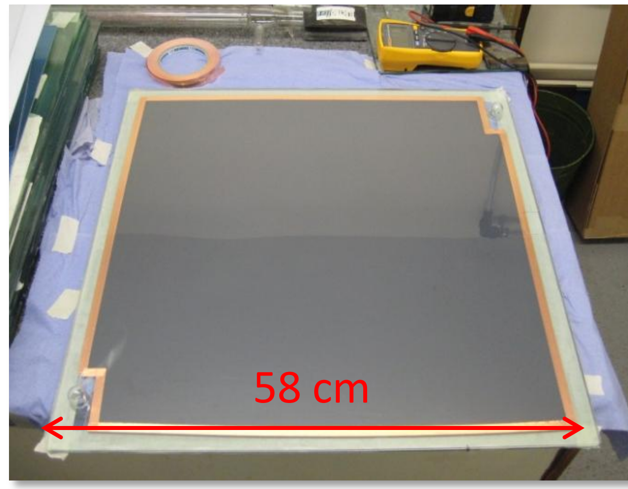
Top:
Simulation of a passenger van containing a tungsten block (10 cm x 10 cm x 10 cm).
Bottom:
Reconstruction of 1 minute of simulated muon exposure for the van above. The tungsten block is clearly visible.
(source: Schultz et al., *"Statistical Reconstruction for Cosmic Ray Muon Tomography",* IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 16, NO. 8, AUGUST 2007

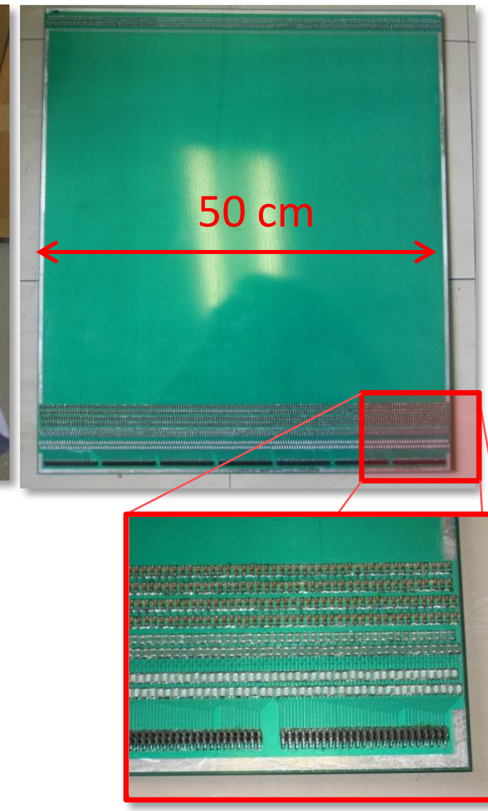
Setup – Hardware overview

- 6 readout planes (cassettes):
  - 2 glass RPC per cassette (X,Y)
  - Front-end electronic (Helix)
  - Auxiliary electronics
  - Gas and high voltage connectors
  - Easy to swap/change configuration
- The cabinet includes the gas mixing rig and HV distribution.
- Cabinet size:
  - ~100 cm x 100 x 250 cm
- Scanning volume:
  - ~50 cm x 50 cm x 100 cm

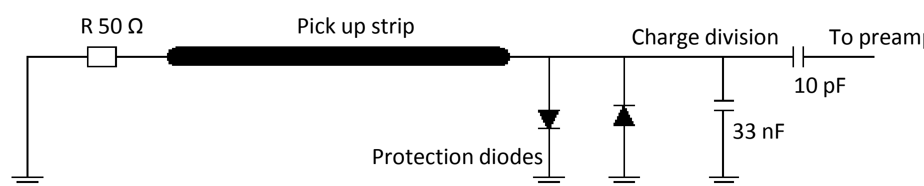
Setup - RPC







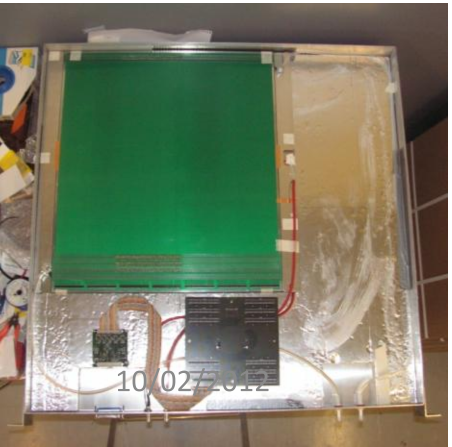
- Glass RPC
- 2 mm gas gap
- Argon, freon, iso-butane, SF_6 (60%, 30%, 10%, 0%)
- 50 cm x 50 cm active area
- 330 strips per RPC provide 1D readout
- Strip pitch: 1.5 mm
- Strip length: 40 cm
- Charge is reduced by 1/3000 before front-end



Setup - Electronics

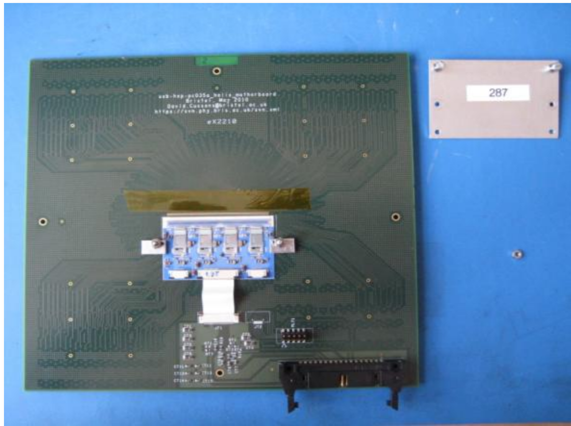
- Front-end: Helix chips.
  - Analog chips, originally developed for silicon microstrip detectors and microstrip gaseous chambers.
  - 128 analog inputs; 1 analog output.
  - Self trigger capability (not in our setup).
  - In our system 4 Helix are daisy-chained (hybrid): the samples from the 512 inputs are sent onto a single analog line.
- The 330 strips from an RPC are fed to one hybrid (some spare inputs).
- Analog data from the Helix chips are fed to CAEN ADC and digitized.

- Problem: no longer available (and not many spares). Need a replacement.

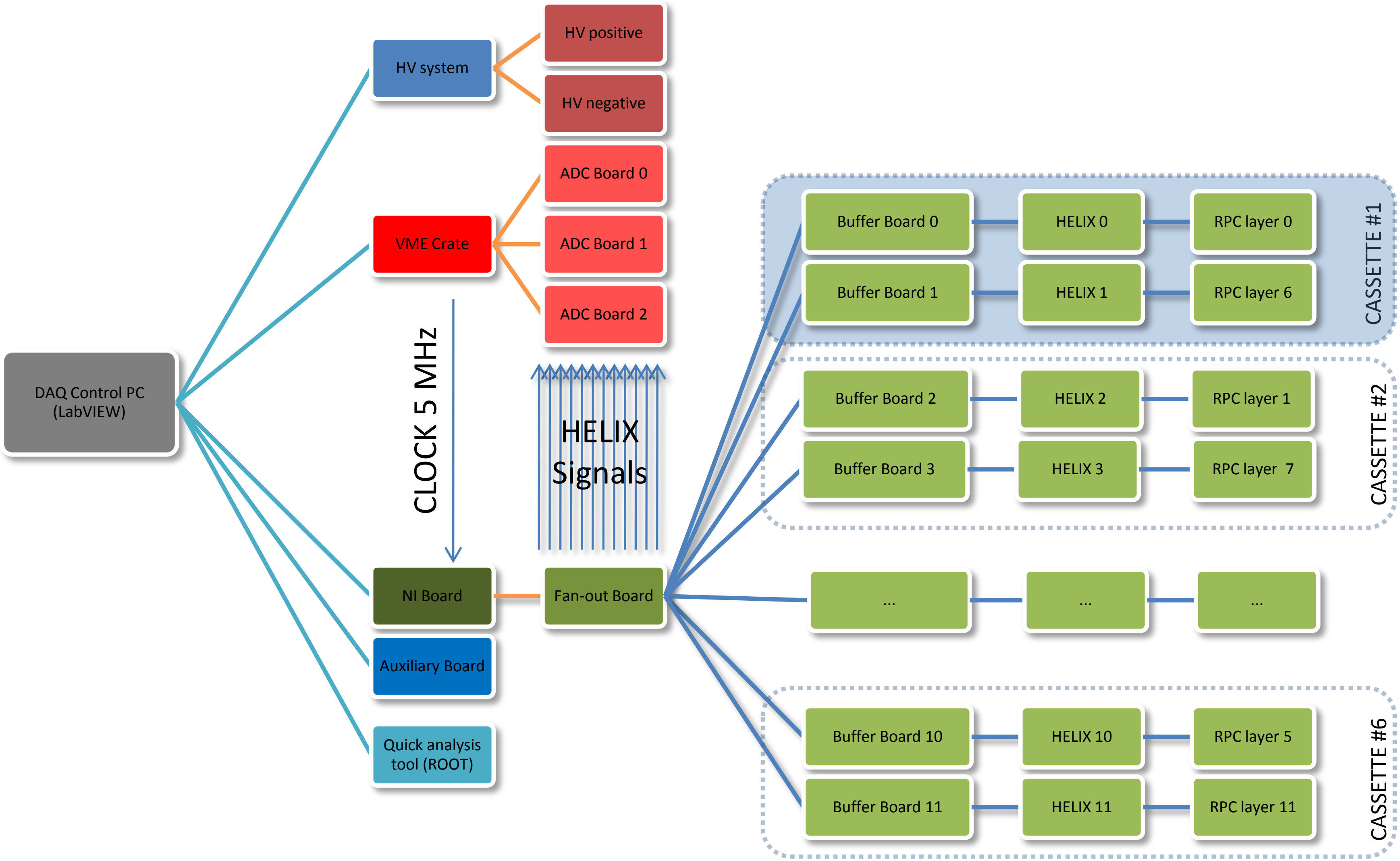


Left: Cassette with one of the two RPC already installed.

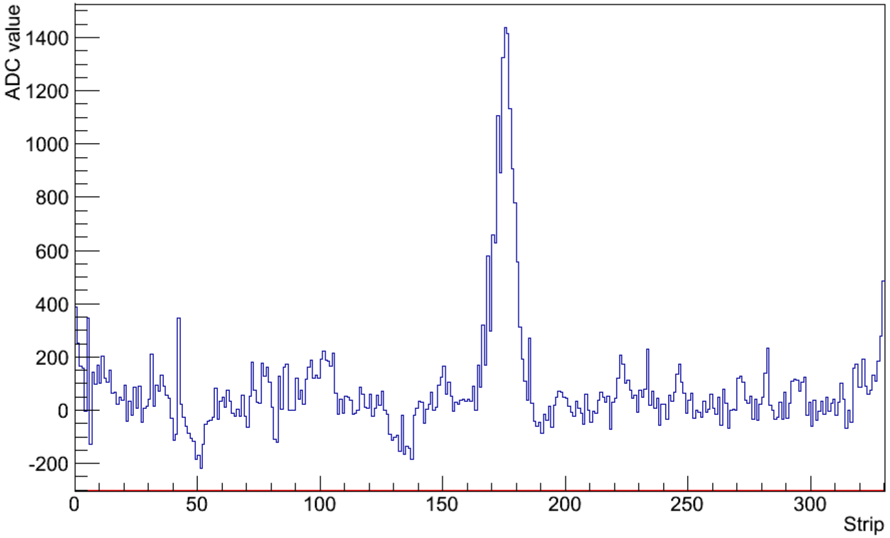
Right: HELIX mezzanine board provides connections between Helix inputs and RPC strips. The Helix hybrid is visible in the middle.



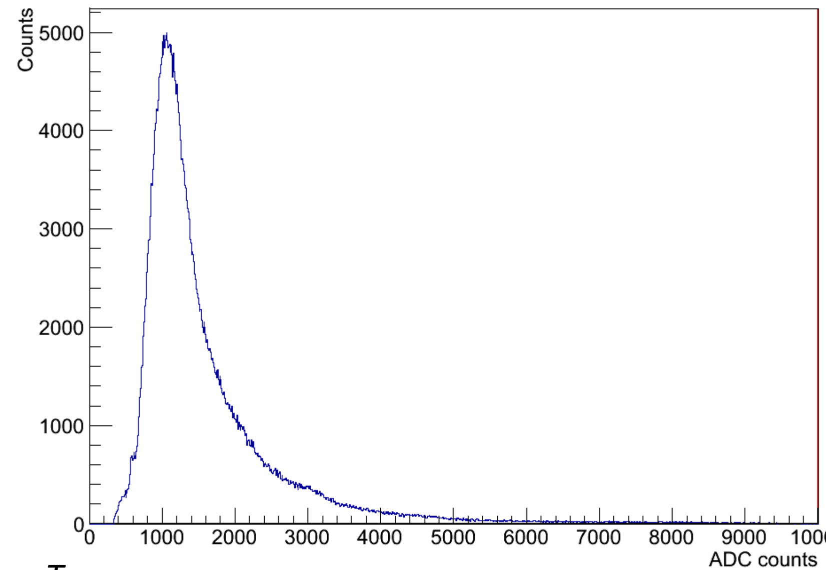
Setup – DAQ overview



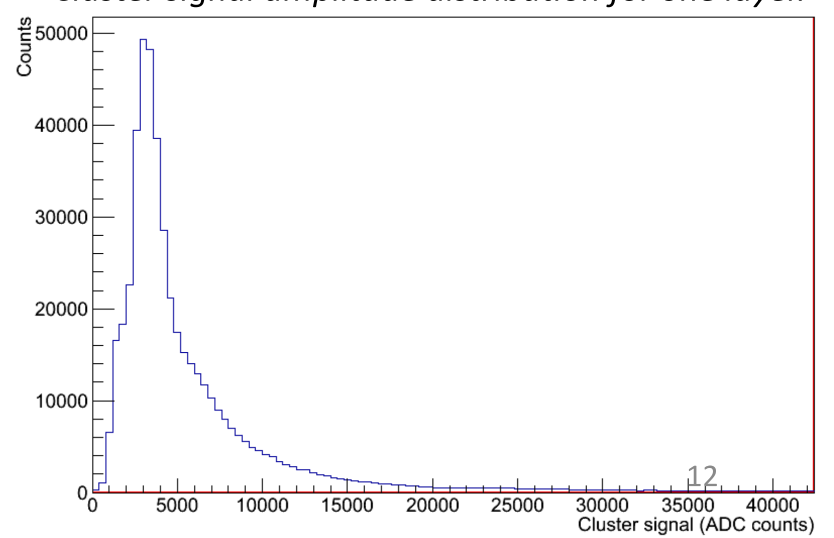
Peak distribution and cluster size



Signal induced on the strips. Pedestal subtracted.



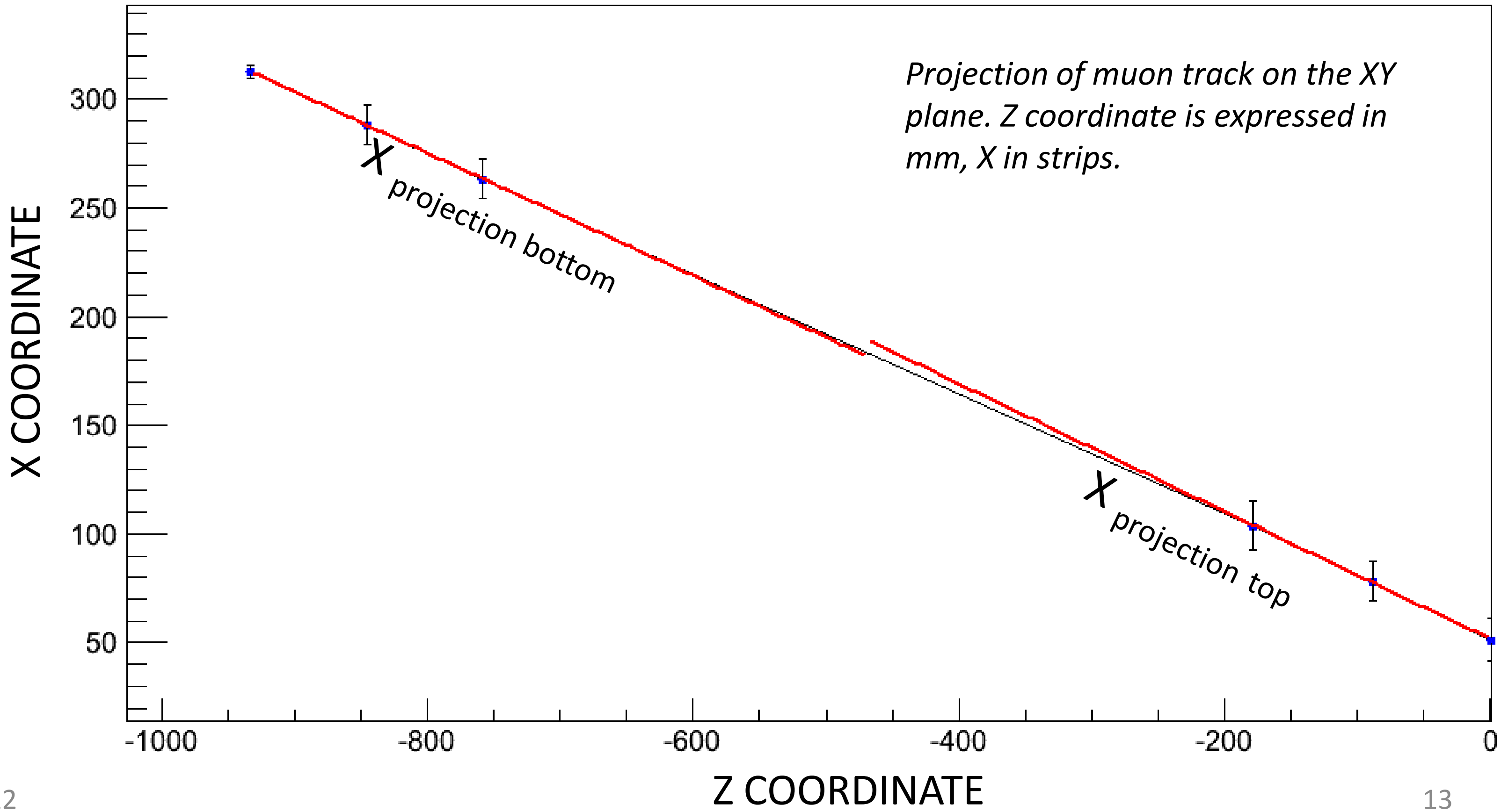
Top:
Peak amplitude distribution for one layer.
Bottom:
Cluster signal amplitude distribution for one layer.

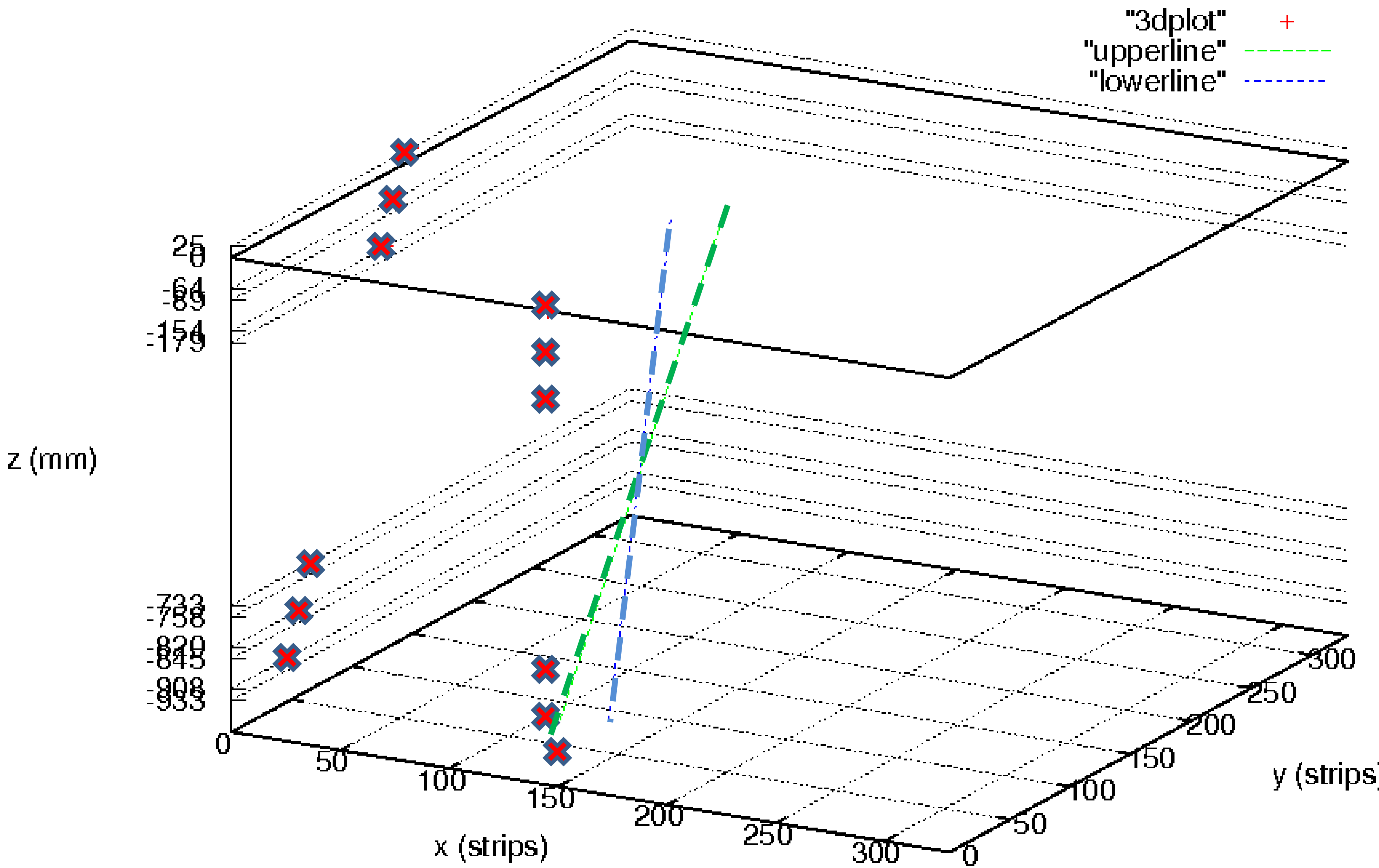


- A simple centre of gravity algorithm provides the hit position.
- 1000 ADC counts corresponds to ~ 50 pC on the strip.
- S/N varies between 25 and 90 among layers:
    - Mainly due to variations in the noise (Complicated common mode).

Tracks

- The points in a sector are used to produce two separate projections of the track in the XY plane (*right*) and in the YZ plane.
- The X and Y projections are interpolated to obtain 3D tracks in the two sectors (*next slide*).



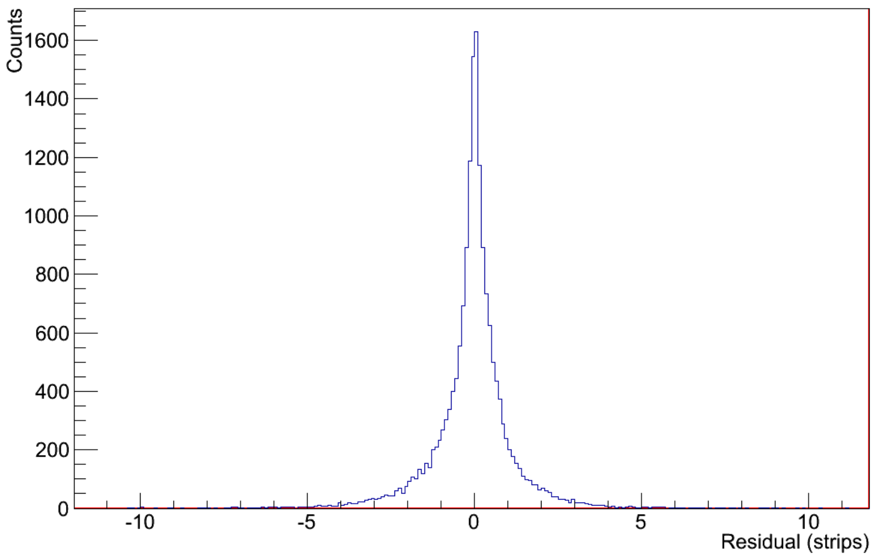


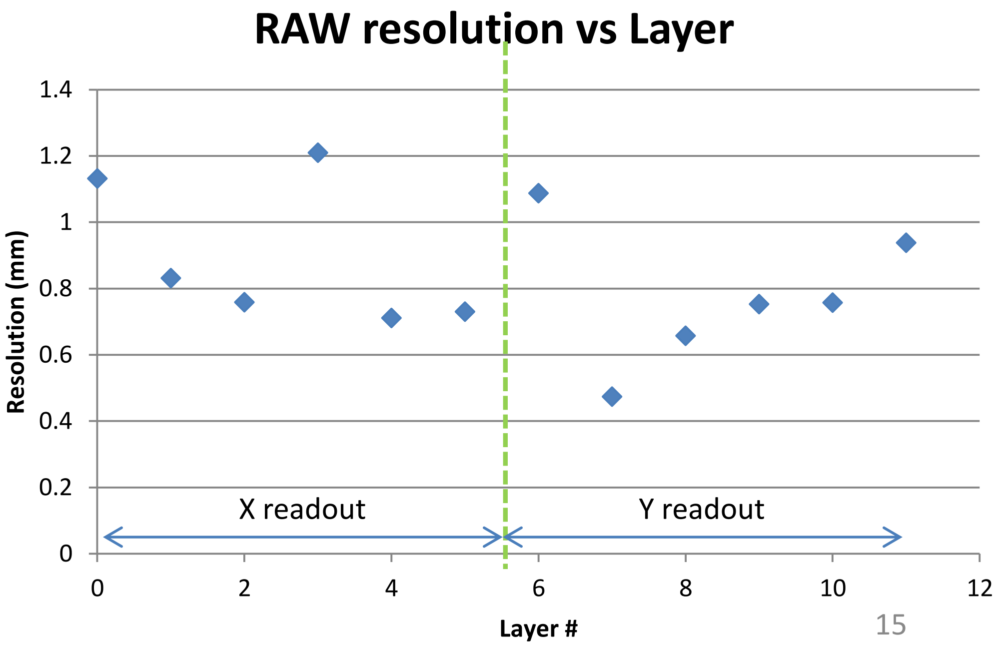
Visualization of a muon track. The incoming (green) and outgoing (blue) tracks are shown. These tracks are obtained by interpolating the projections on the XZ and YZ plane, indicated by red crosses.

Track residuals

• Raw difference between reconstructed track and hit position for one layer.
• Overall hit finding efficiency> 99%.

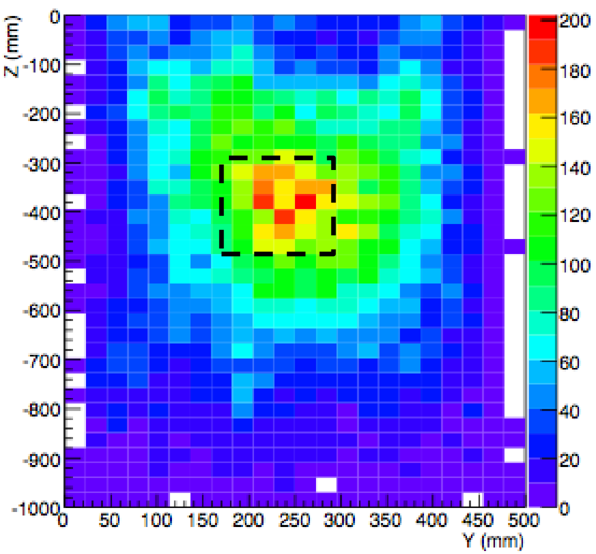
• Contribution of multiple scattering due to the detector material (σ_{scat}) is not taken into account. We are working on a Monte Carlo simulation to properly estimate this contribution.
• Also not accounted is the extrapolation error due to the position of the layer on the track.



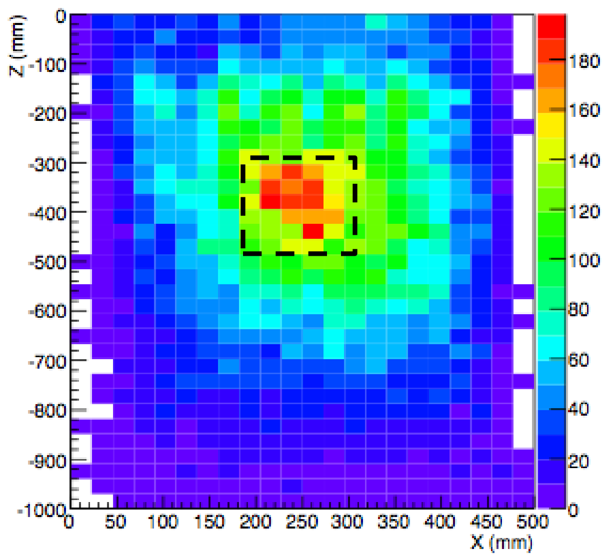


Test with lead blocks

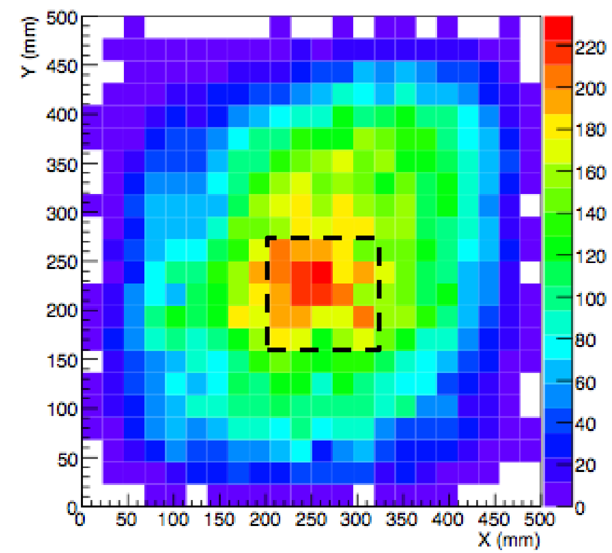
- 10 cm x 10 cm x 15 cm lead block.
- Point of closest approach algorithm (simple but effective for our tests).
- Cut on χ^2 of the tracks.
- Bin only tracks which show a scattering angle above 30 mrad.
- Simple analysis made in Bristol to check the detector.
- AWE will work on algorithms for proper tomography.
- Bristol to develop alternative techniques to complement the analysis.



YZ Plane



XZ Plane



XY Plane

Current developments

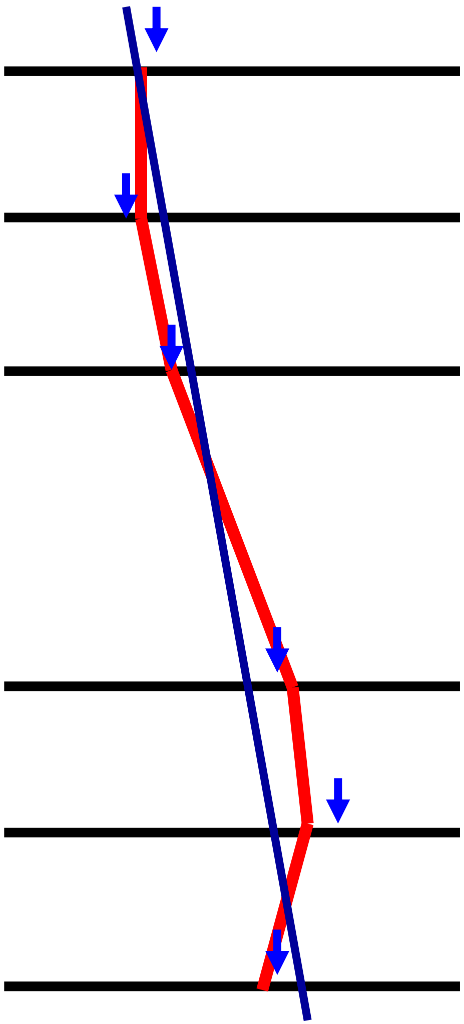
- Replace the readout chips:
  - Helix are obsolete and no longer available.
  - To expand our system we have chosen the MAROC chips (developed at LAL-France):
    - 64 inputs
    - Built-in 12 bit ADC converter
    - Self trigger capability
  - Early test on demo-board successful.
  - Bristol designed its own carrier board; currently under test.

Conclusions

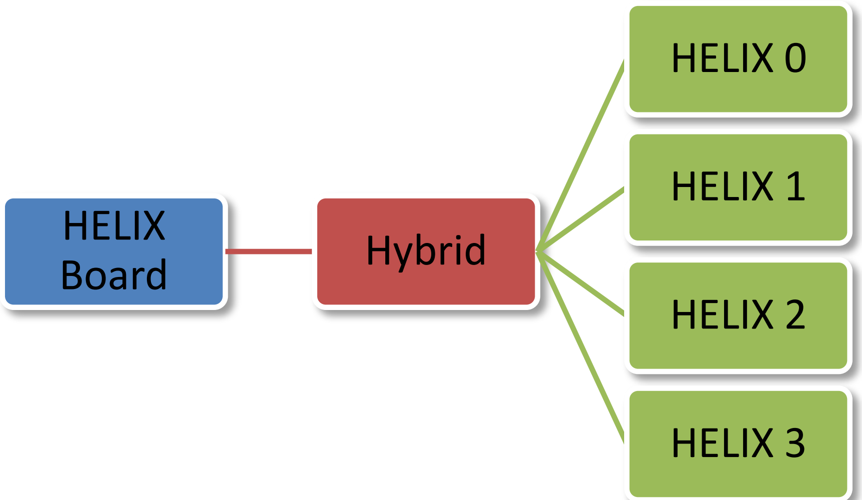
- We successfully built an tested a prototype to track muons with fine pitch RPC.
- The prototype is suitable to perform Muon Scanner Tomography:
  - The system behaves as expected.
  - Sub-millimeter spatial resolution; sufficient to detect high-Z materials.
  - Resolution can be further improved by tuning the analysis.
  - Can find lead bricks using simple PoCA algorithm.
- We are currently replacing the read-out chips and are embarking on additional studies:
  - Maximum strip length.
  - Optimal strip pitch.
  - Making the system portable.
- We look forward to further developing this project into a full scale container scanning system in collaboration with our industrial partner AWE.

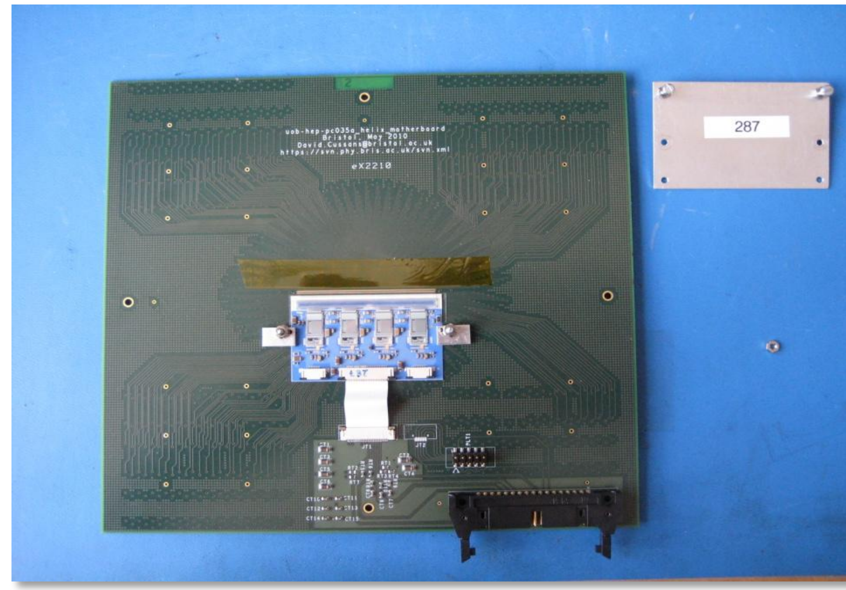

That's all Folks!

Spare slides



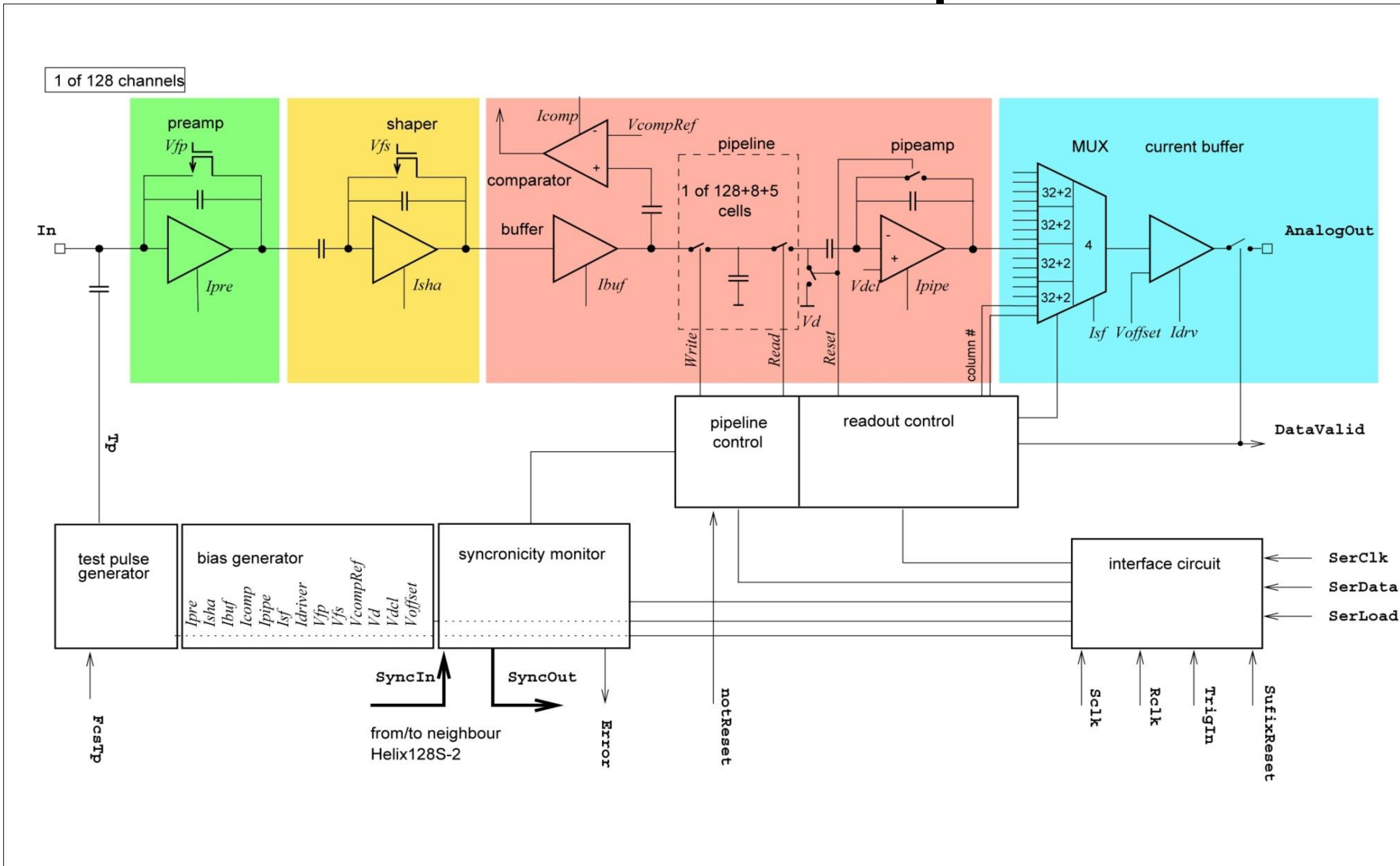
Read-out: HELIX hybrid and mezzanine



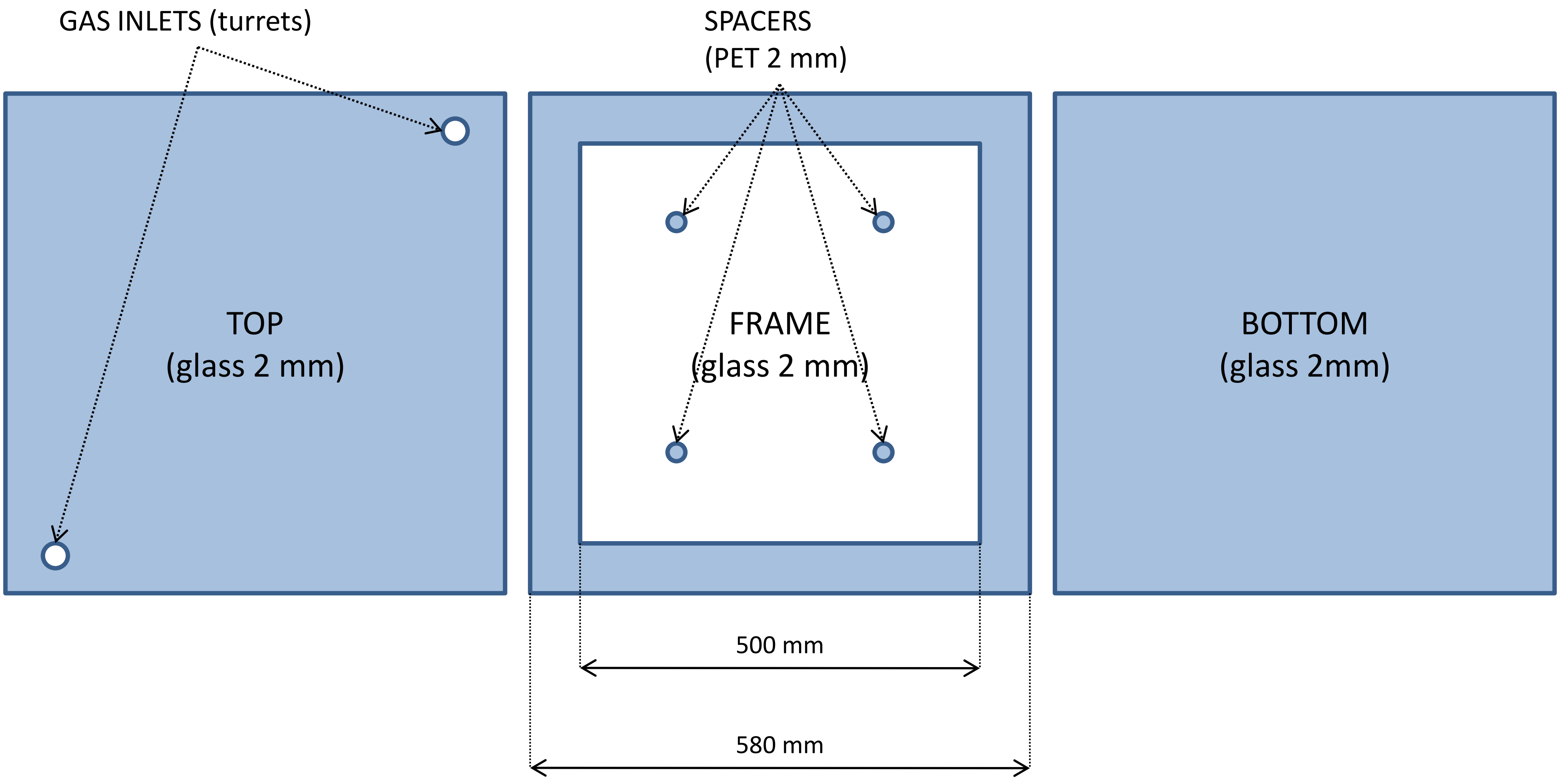


- 4 HELIX are daisy-chained and hosted on a hybrid chip: this is our basic front-end unit read-out
- Each hybrid has been wire bonded to a HELIX mezzanine board (designed in Bristol) which acts as an interface between the 100 µm pitch adaptor of the hybrid and the strip board
- Mezzanine:
  - 11 connectors (50-way, 1/10 inch pitch) to plug the strips in
  - Provide power to the HELIX
  - 1mezzanine: 1 RPC
  - Output samples, power and control signals are all transferred through the mezzanine

Read-out: the HELIX input circuit.



RPC: geometry



Summary of layer distributions

Layer	Peak (MPV)	Cluster (MPV)	Sigma Noise	S/N (averaged)
0	1364	6915	74	93
1	1342	3815	56	68
2	867	3350	58	58
3	1135	4138	60	69
4	1133	3923	90	44
5	889	3326	70	47
6	1151	4482	69	65
7	1144	3679	157	23
8	1058	3087	100	31
9	843	2887	61	47
10	791	3077	64	48
11	988	4007	74	54

Abstract

Resistive Plate Chambers are widely used in high energy physics experiments as reliable trigger systems due to their excellent time resolution and rate capability, while generally the track spatial information is obtained by means of different detectors. Studies show that it is possible to produce RPC with good spatial resolution (~ 0.5 mm) by appropriate choice of the pitch of the readout strips. High resolution RPC (HRPC) can be economically produced to cover large area and represent a valid alternative to more expensive detectors in applications when a spatial resolution of 0.5 mm is sufficient. Our group has successfully produced a Muon Scattering Tomography (MST) prototype based on 12 HRPCs which provide 3D information on muons scattering in a volume ~ 50 cm x 50 cm x 80 cm (suitable for scanning a suitcase). Both the incoming and the outgoing tracks of the muon are reconstructed. The required spatial granularity is achieved using ~300 readout strips per HRPC, with a pitch of 1.5 mm. All the strips from an HRPC are multiplexed into a single differential analog line by four Helix 3.0 chips daisy chained on a hybrid circuit. The detector has been collecting data since June 2011, with the HRPC showing an efficiency above 99% and purity above 98%. The spatial resolution on the tracks is ~0.8 mm. This is a preliminary measurement and includes the intrinsic detector resolution as well as the extrapolation errors due to multiple scattering in the detectors and separation of the planes. Additional results will be presented.