Mini TPC @ Saclay

Boris Tuchming

CEA Irfu/Dphp

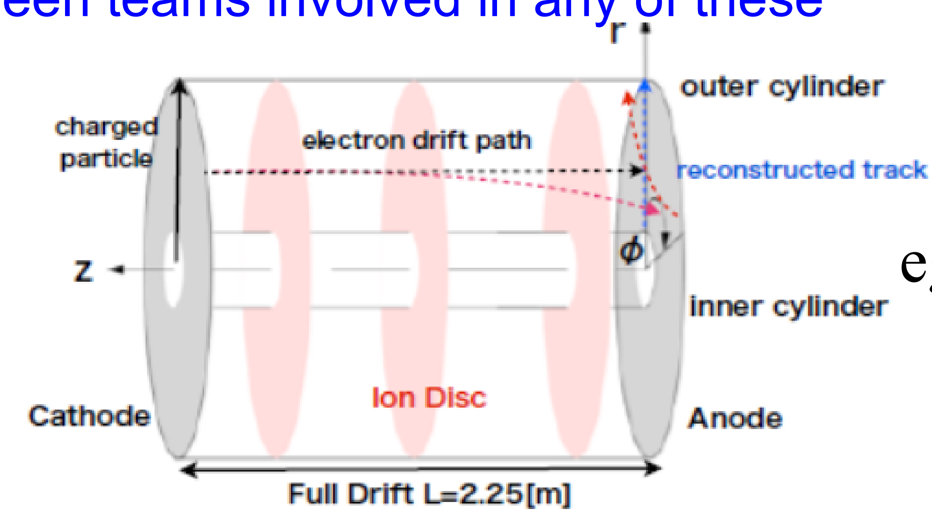
Paris-Saclay (France)

Outline

- Ion back flow issue in TPC for future e+e- collider
- Description of the TPC test-bench project
- Running TPC
- First results
- Summary/Todo

Ion-Back-Flow issue at e+e- collider

- Time Projection Chamber suffers from spatial charge built up
  - induced by
    - ions from primary ionization
    - secondary (amplification) ion back-flow (IBF)
- Spatial charge yields distortions for track reconstruction
- Details upon spatial charge depend upon
  - beam bunch structure, beam background, luminosity
  - Magnetic field
  - Detector: amplification gain, Ion back flow rate
  - Gating
- Issue is present for all projects of future e+e- collider
  - CEPC, ILC, FCC-ee
  - Collaboration possible between teams involved in any of these projects
    - Saclay officially involved in
      FCC, ILC, RD51



eg : ILC

Charge space in TPC at e+e- collider

At Saclay MC study to estimate (primary) space charge at FCC-ee

Main source identified as hadronic Z at L=10 ^{36} cm^{2}s^{-1}

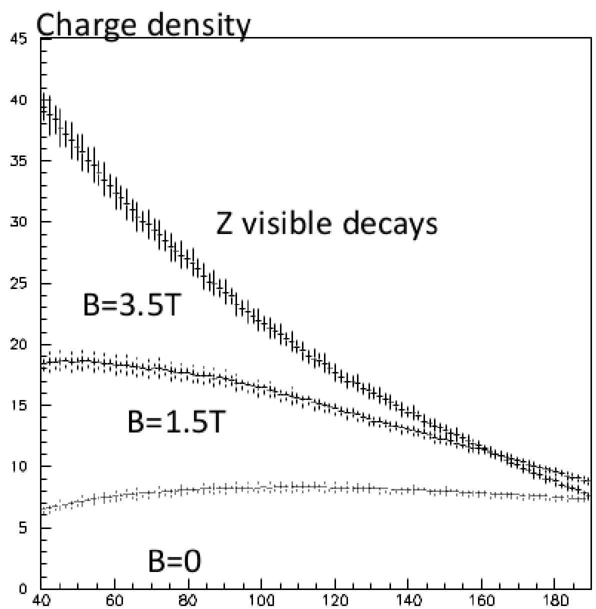
- primary ions
- secondary (amplification) ion back-flow
  - Here assume (agressive) 1 electron → 1 ion back flow

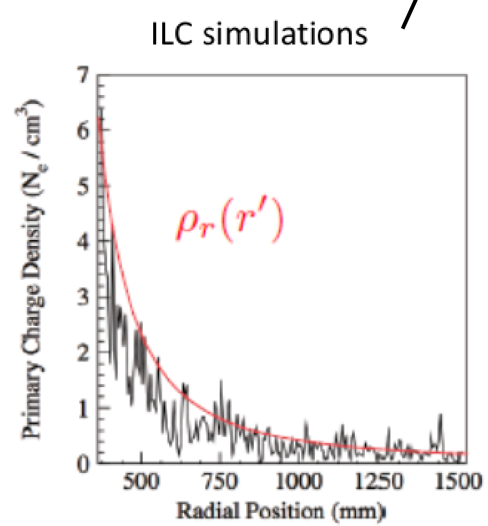
X 2 to account for ion backflow

Qualitative comparison Tlep/ILC

for Fcc-ee

Sergei Ganjour
Philippe Schwemling
(Feb 2014)





for ILC

Charge Density (per 100 bunches

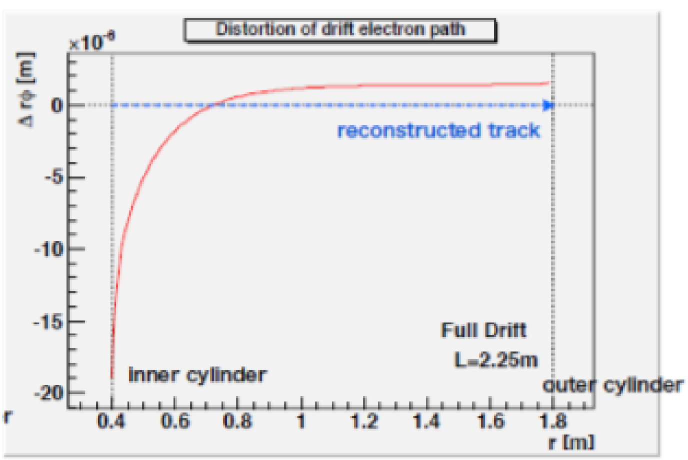
Charge distributions quite different,
ILC simulation more peaked at low radius : Inclusion of low Pt backgd ?

Tracking distortions

MC-based estimate of distortions

- Space charge induced by
  - primary ions
  - secondary (amplification) ion back-flow
    - Here assume (agressive) 1 electron → 1 ion back flow

for ILC



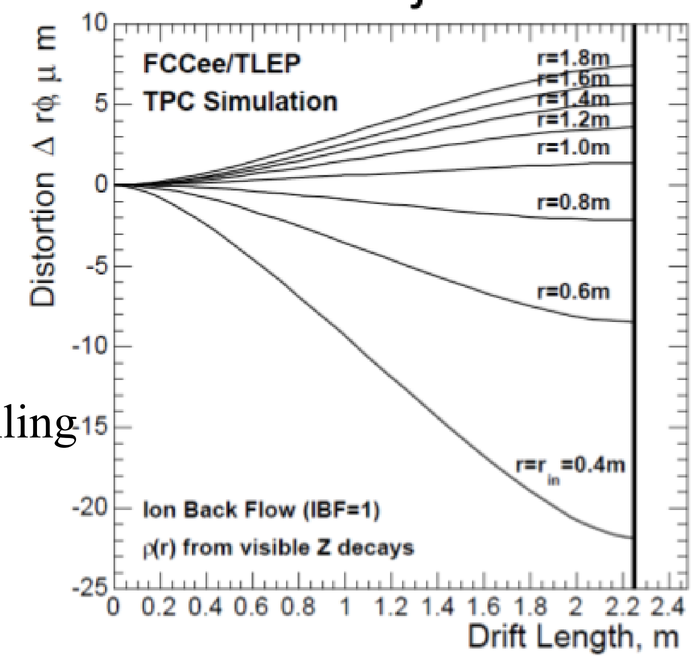
Distortion of drift electron path (Full drift)

Arai Daisuke
2012/February/23 @ WP meeting

for Fcc-ee

Sergei Ganjour
Philippe Schwemling

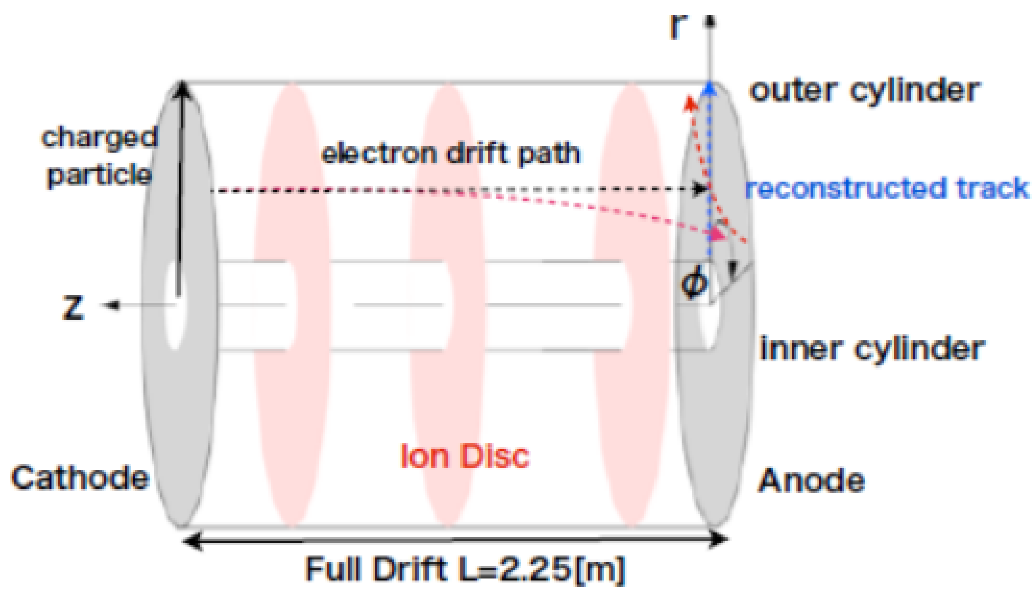
Electron trajectories



up to 20 μm distortions

Project at Saclay

- Test TPC tracking reconstruction performance in the presence of spatial charge using cosmic data.
  - Spatial charge induced by
    - primary ions
    - secondary (amplification) ion back-flow (IBF)
- Compare to simulation
- The primary goal is not to measure IBF property of the detector
  - We want to measure tracking performance
  - We need to monitor the spatial charge in the TPC.



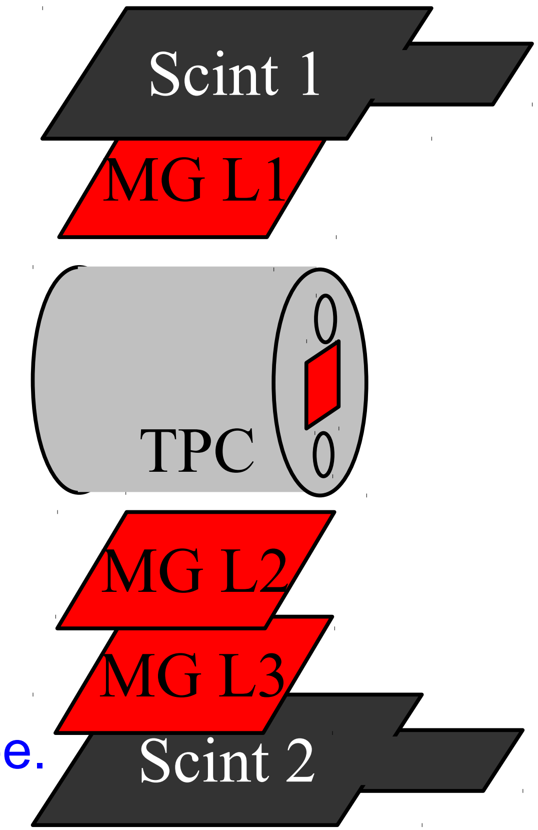
Mini-TPC project

Goal: test TPC tracking performance in the presence of space charge to check/tune simulation of space charge effect

- Recycle existing chamber present at Saclay
  - Use resistive micromegas module as TPC pads
    - Detector+electronics (AFTER)+DAQ developed for T2K and ILC-TPC
  - New TPC end-plate to plug the micromegas device

- Transparent viewport to send UV-rays through the chamber
  - UV rays yield photo-electrons at the cathode level
  - Photo-electrons drift toward micromegas
  - Micromegas amplification yields ion back-flow in drift space

- Measure tracking performance with cosmic muons
  - Trigger with 2 scintillators
  - Use 3 large area micromegas chambers as hodoscope.



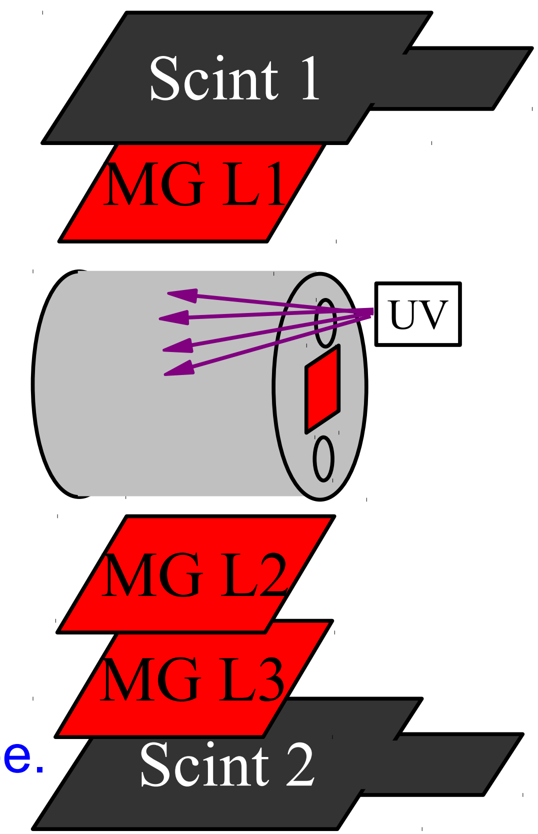
Mini-TPC project

Goal: test TPC tracking performance in the presence of space charge to check/tune simulation of space charge effect

- Recycle existing chamber present at Saclay
  - Use resistive micromegas module as TPC pads
    - Detector+electronics (AFTER)+DAQ developed for T2K and ILC-TPC
  - New TPC end-plate to plug the micromegas device

- Transparent viewport to send UV-rays through the chamber
  - UV rays yield photo-electrons at the cathode level
  - Photo-electrons drift toward micromegas
  - Micromegas amplification yields ion back-flow in drift space

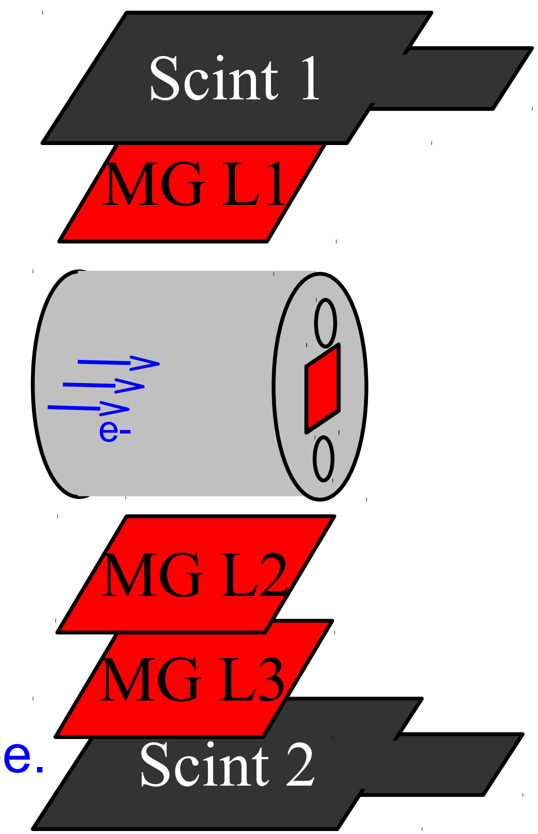
- Measure tracking performance with cosmic muons
  - Trigger with 2 scintillators
  - Use 3 large area micromegas chambers as hodoscope.



Mini-TPC project

Goal: test TPC tracking performance in the presence of space charge to check/tune simulation of space charge effect

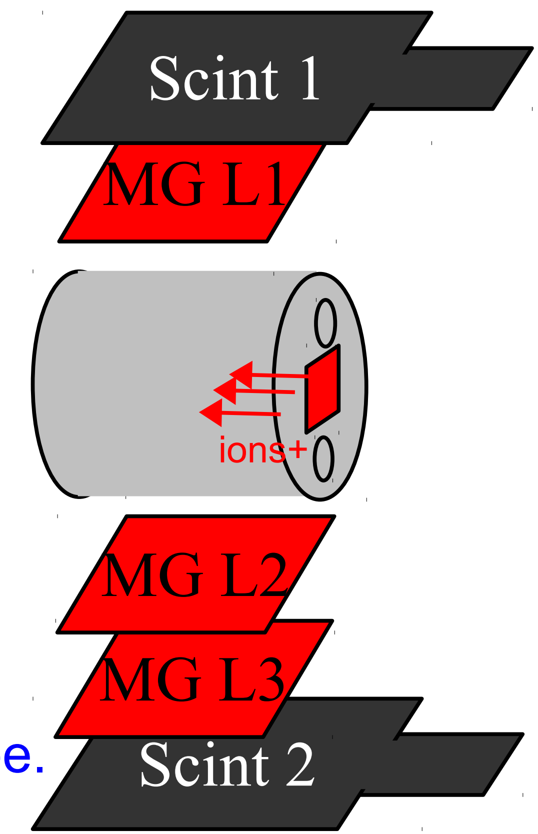
- Recycle existing chamber present at Saclay
  - Use resistive micromegas module as TPC pads
    - Detector+electronics (AFTER)+DAQ developed for T2K and ILC-TPC
  - New TPC end-plate to plug the micromegas device
- Transparent viewport to send UV-rays through the chamber
  - UV rays yield photo-electrons at the cathode level
  - Photo-electrons drift toward micromegas
  - Micromegas amplification yields ion back-flow in drift space
- Measure tracking performance with cosmic muons
  - Trigger with 2 scintillators
  - Use 3 large area micromegas chambers as hodoscope.



Mini-TPC project

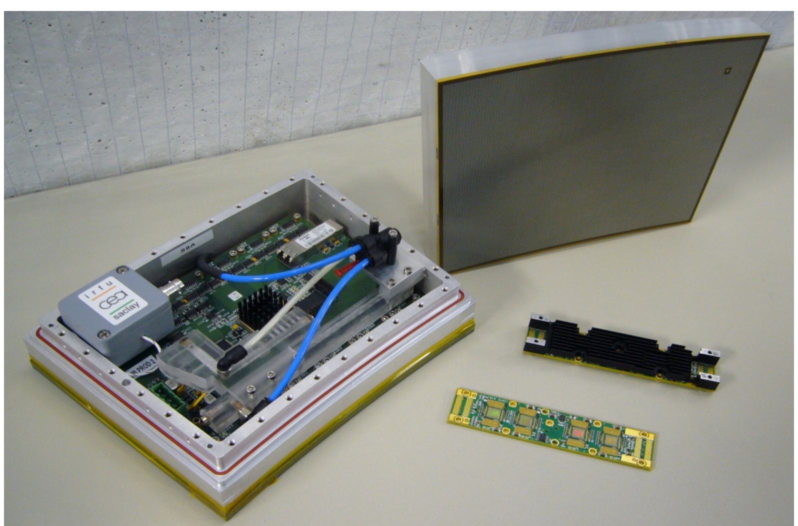
Goal: test TPC tracking performance in the presence of space charge to check/tune simulation of space charge effect

- Recycle existing chamber present at Saclay
  - Use resistive micromegas module as TPC pads
    - Detector+electronics (AFTER)+DAQ developed for T2K and ILC-TPC
  - New TPC end-plate to plug the micromegas device
- Transparent viewport to send UV-rays through the chamber
  - UV rays yield photo-electrons at the cathode level
  - Photo-electrons drift toward micromegas
  - Micromegas amplification yields ion back-flow in drift space
- Measure tracking performance with cosmic muons
  - Trigger with 2 scintillators
  - Use 3 large area micromegas chambers as hodoscope.



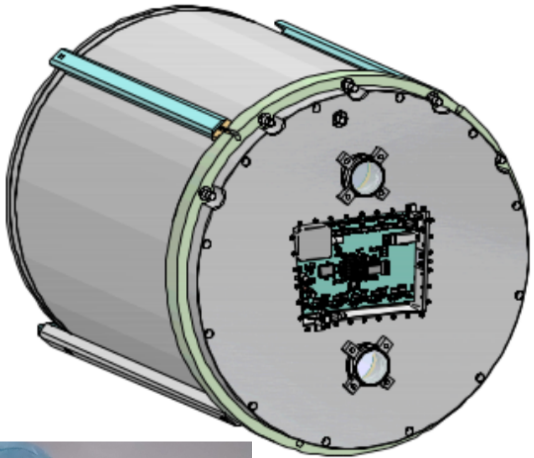
Mini-TPC test bench

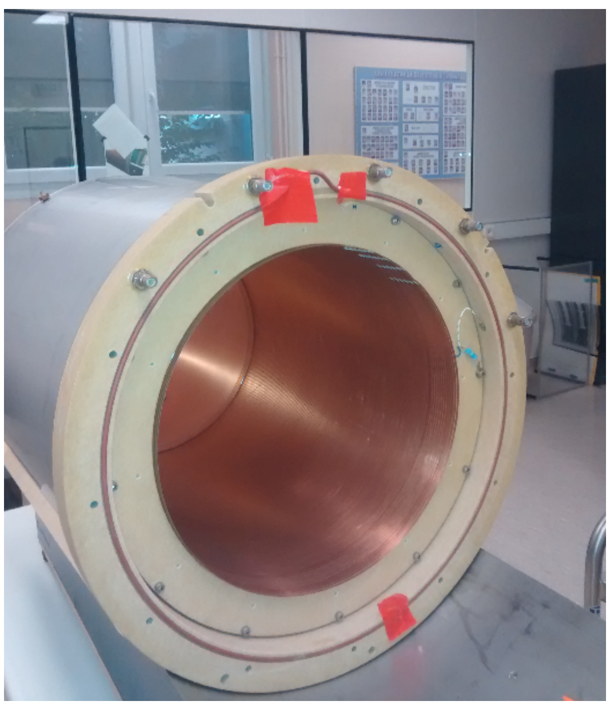
- TPC:
  - Δz TPC =48cm
  - D = 50 cm
- Micromegas (ILC) modules:
  - Resistive layer
  - 17cm * 23 cm^2
  - 1748 (72*24) channels
- 3 Multigen chambers
  - 50x50 cm^2 1024x1024 channels

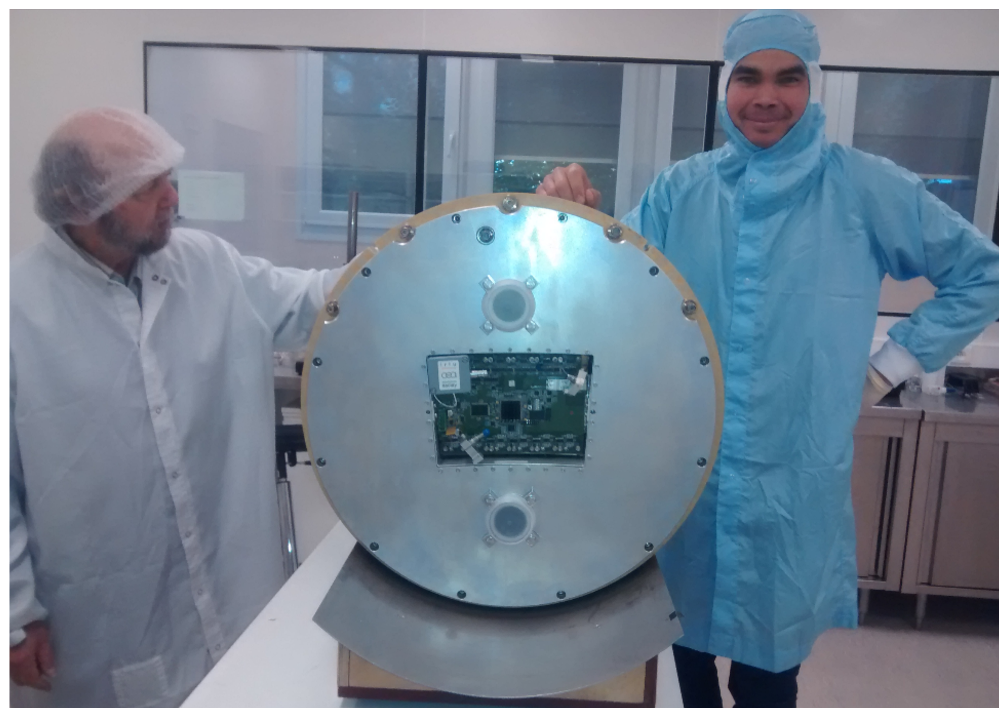


TPC assembly

- Endplate designed with two CaF_2 viewport of diameter 3.8cm
- Assembled Winter 16
- First Data in September 16

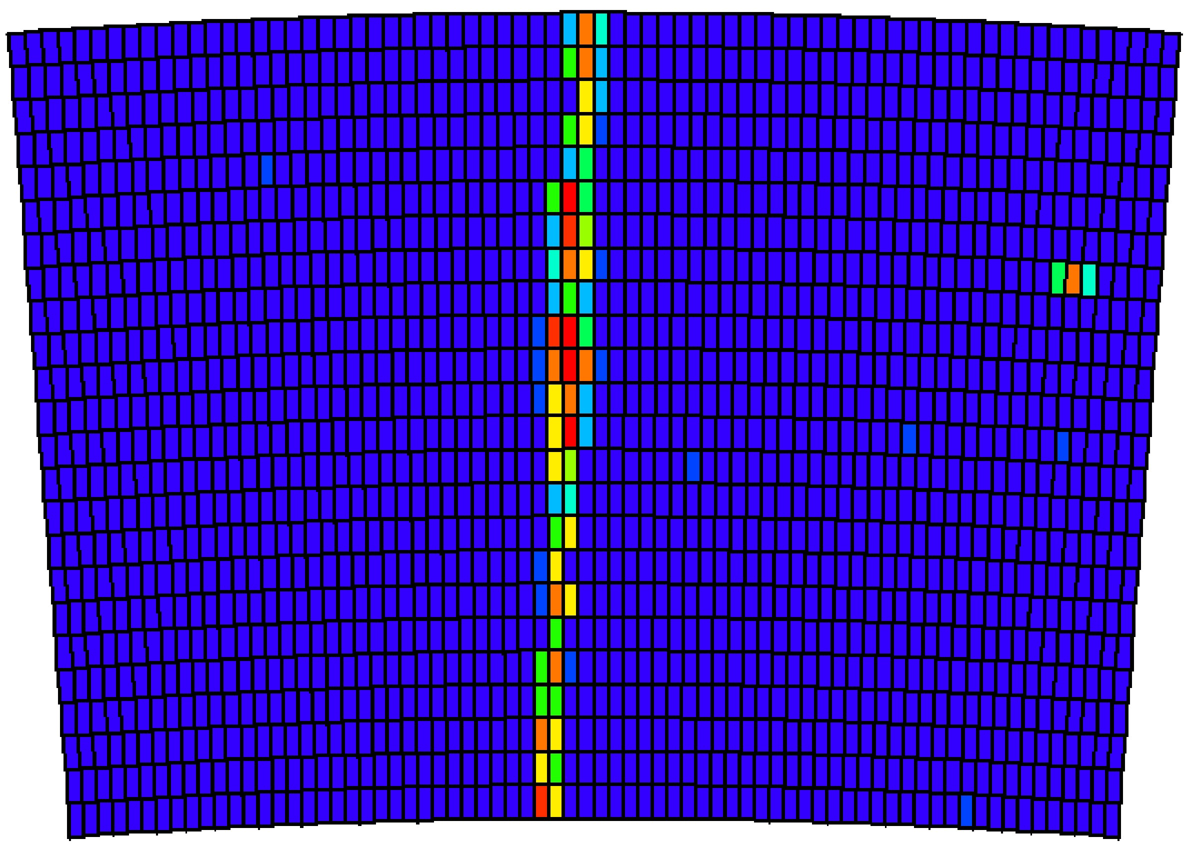


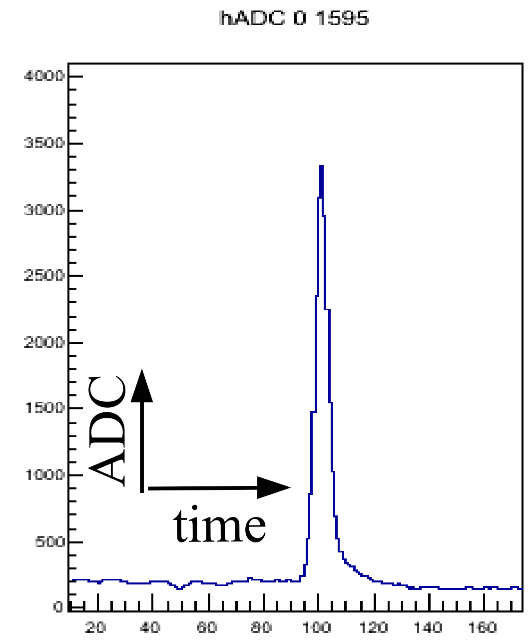




Running TPC

- Managed to take first cosmic data in September 16
  - 95% Argon + 5% Iso-C_4H_{10}

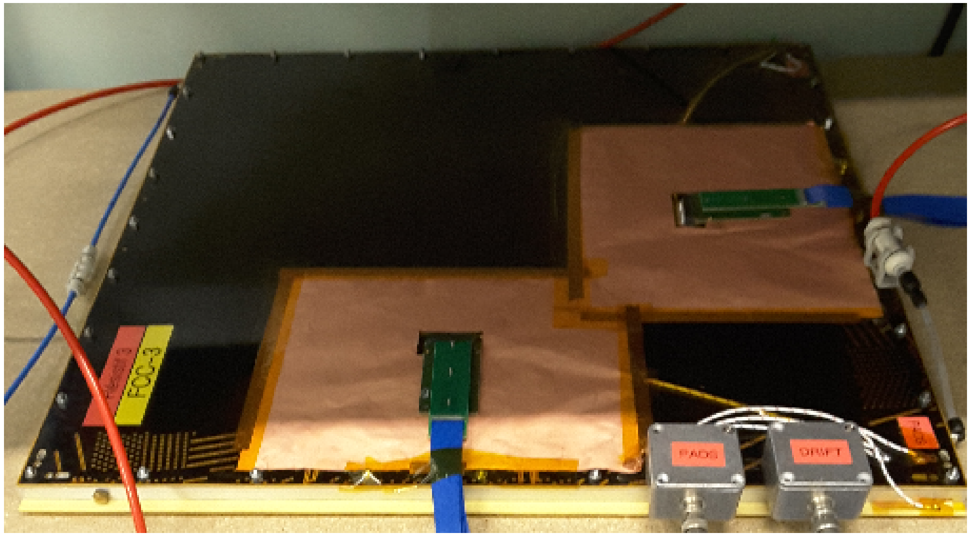


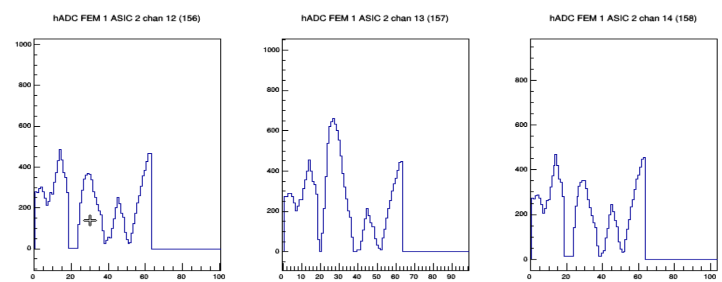


very clean signal

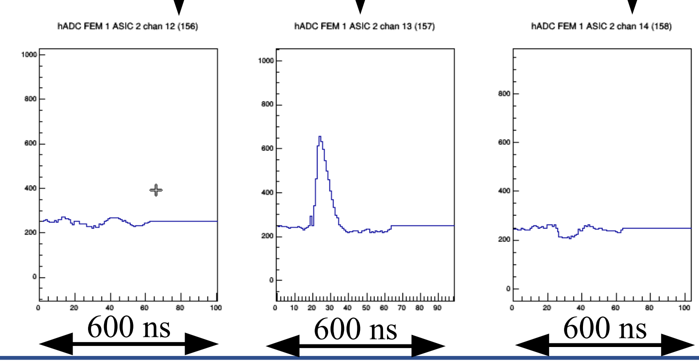
1728 channels
~22x17 cm^2

- Use three micromegas chambers as developed for M-Cube project = large area micromegas
  - 50 x 50 cm^2 coverage.
  - Two layers of orthogonal read-out strips
    - X x Y reconstruction.
    - 1024 strips x 1024 strips (Pitch: 486 μm.)
  - Genetic “multiplexing”
    - (Procureur et al, NIM A 729 (2013) 888)
    - 1024 strips $\rightarrow$ 61 readout channels
    - 122 channels per chamber
    - Somewhat complicate pattern recognition
    - Very large capacitance= very noisy
      - Sensitive to outside noise
      - Cross-talks between channels
      - “Common noise filtering” needed
  - ~500 μm resolution



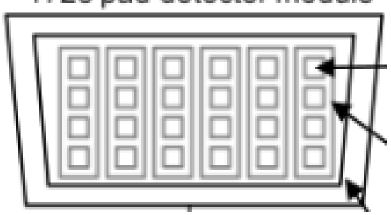


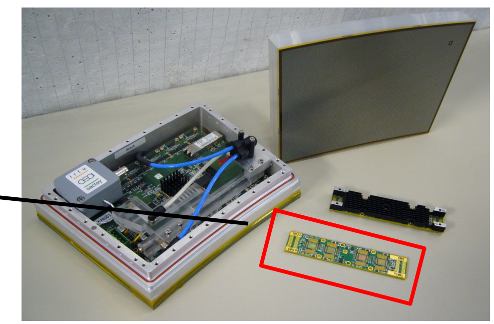
eg : noise filtering for 3 channels

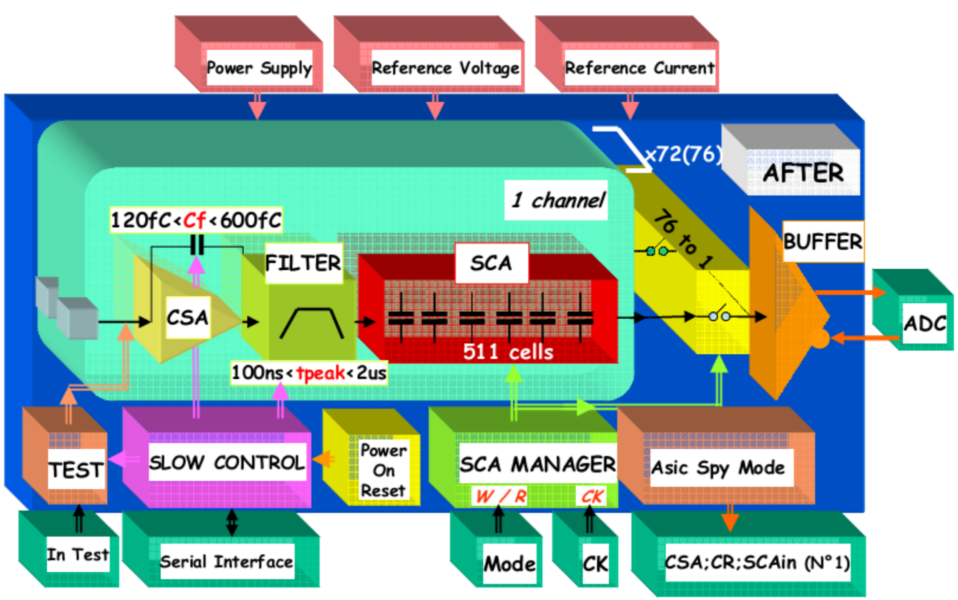


- Electronics front-end and back-end designed for ILC-TPC prototypes
  - After electronics (originally designed for T2K)
    - Can handle a few Hz event rates
    - Compacted to fit TPC modules → 24 ASICs on module
    - see P. Baron et al., IEEE TNS vol. 55, Issue 3, Part 3, June 2008, pp. 1744 – 1752. DOI:10.1109/TNS.2008.924067

1728 pad detector module





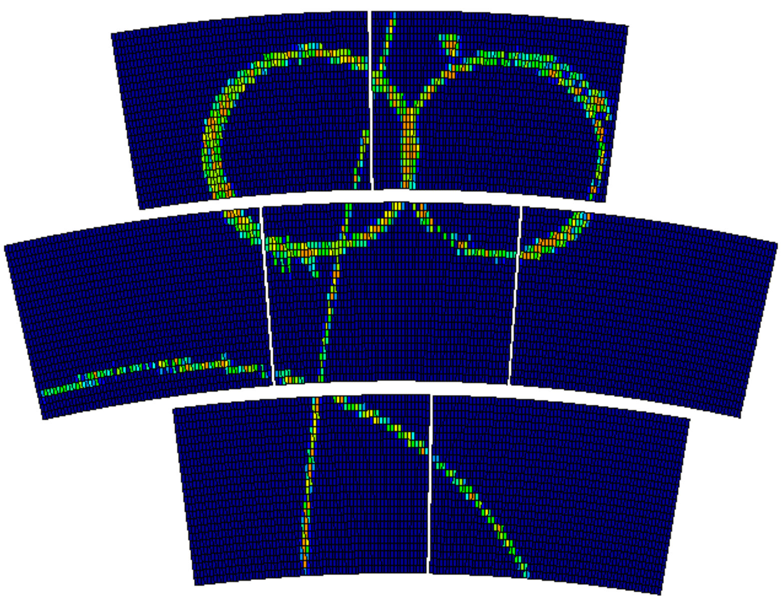


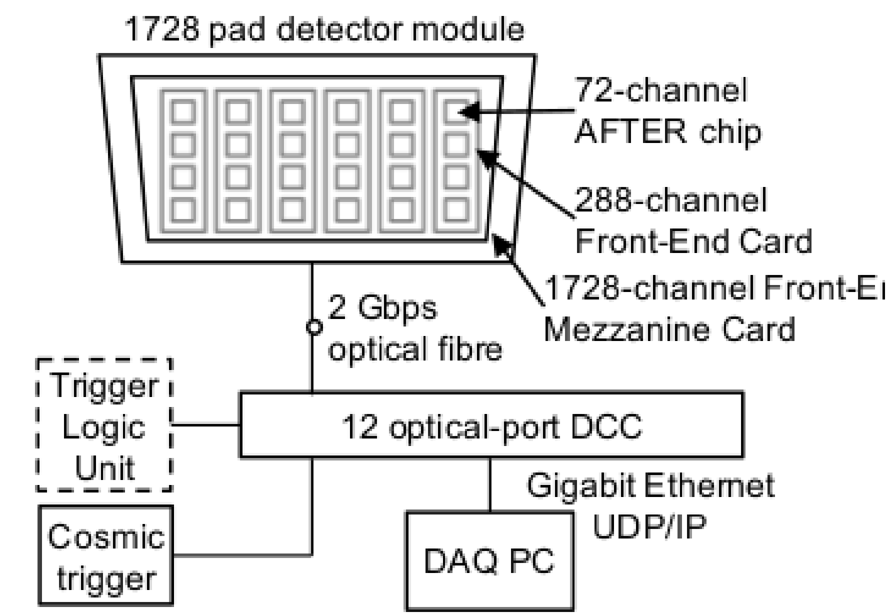
After ASIC

Parameter	Value
Number of channels	72
Samples per channel	511
Dynamic Range	2 V / 10 MIPs on 12 bits
MIP charge	12 fC to 60 fC
MIP/Noise ratio	100
Gain	4 values from 4 mV / fC to 18 mV / fC
"Detector" capacitor range	20 pF -30 pF
Peaking Time	100 ns to 2 µs (16 values)
INL	1% 0-3 MIPs ; 5% 3-10MIPs
Sampling frequency	1 MHz to 50 MHz
Readout frequency	20 MHz to 25 MHz
Polarity of detector signal	Negative (T2K) or Positive
Test	1 among 72 channels or all

Electronics and DAQ

- Electronic front-end and back-end designed for ILC-TPC prototypes
  - After electronics (originally designed for T2K)
    - Can handle a few Hz event rates
    - Compacted to fit TPC modules → 24 ASICs on module
    - see P. Baron et al., IEEE TNS vol. 55, Issue 3, Part 3, June 2008, pp. 1744 – 1752. DOI:10.1109/TNS.2008.924067
  - Back-end prototypes designed for ILC to handle 12 modules
    - see D. Attié et al., 18th IEEE-NPSS Real Time Conference, Berkeley, CA, 2012, pp. 1-5. doi: 10.1109/RTC.2012.6418152
  - DAQ software from T2K test prototypes

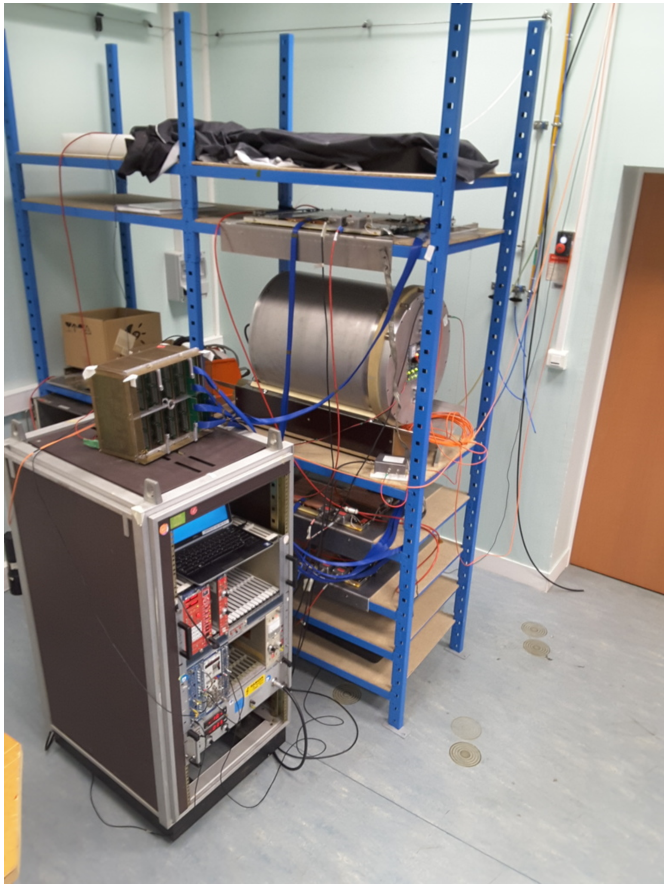




LC-TPC prototype at Desy
with 7 modules on test-beam (2015)

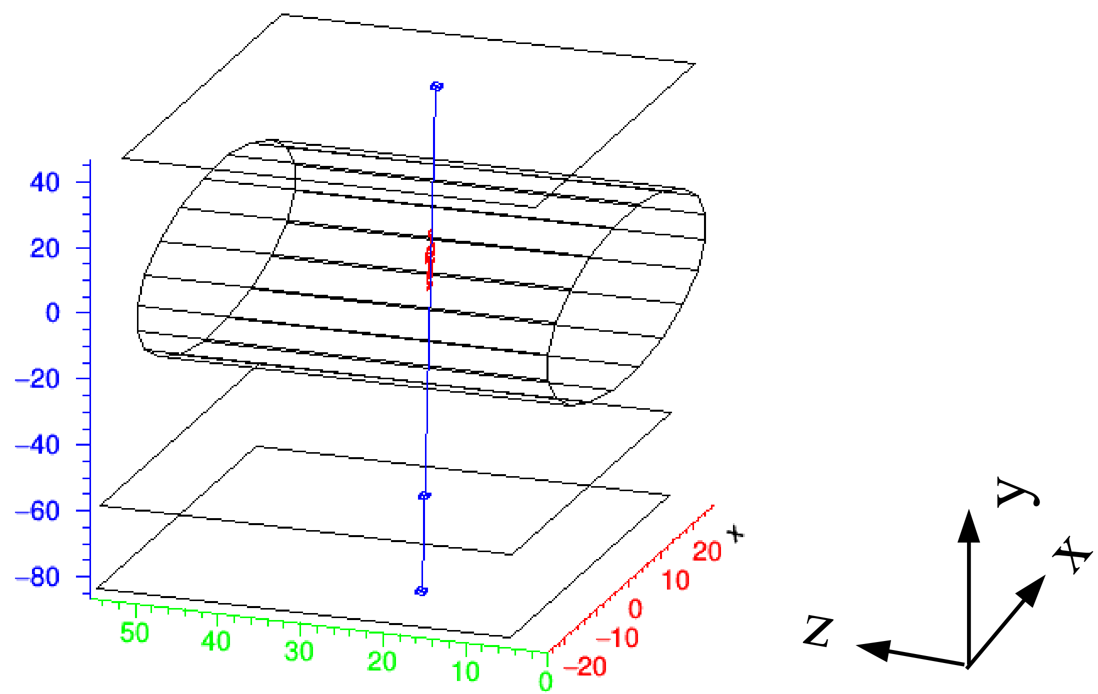
TPC+Multigen data

- Start data acquisition in January 2017
  - Use 95% Argon + 5% Isobutane
  - TPC
    - Mesh at -420 V (128 µm GAP)
    - Drift -10 kV / 48 cm → ~200 V/cm
  - Multigen chambers (MG)
    - strips at ~ 480 V
  - Typical trigger rate ~ 1.5 Hz
  - Typical rate for good events in 3 Multigen and TPC volume ~ 0.3 Hz
- Initial Plan:
  1) Take data in steady/stable state
  2) Measure resolution
  3) Turn-on UV light
     - measure resolution, space charge
  4) Compare to simulation
- Real world
  - Some issues regarding stability/gas/ noise
  - Lack of man power for the reconstruction and analysis
  - Reconstruction postponed till post-doc or PhD student joined the group → Arrival of Haiyun Wang (IHEP) in November 17 for 6 month



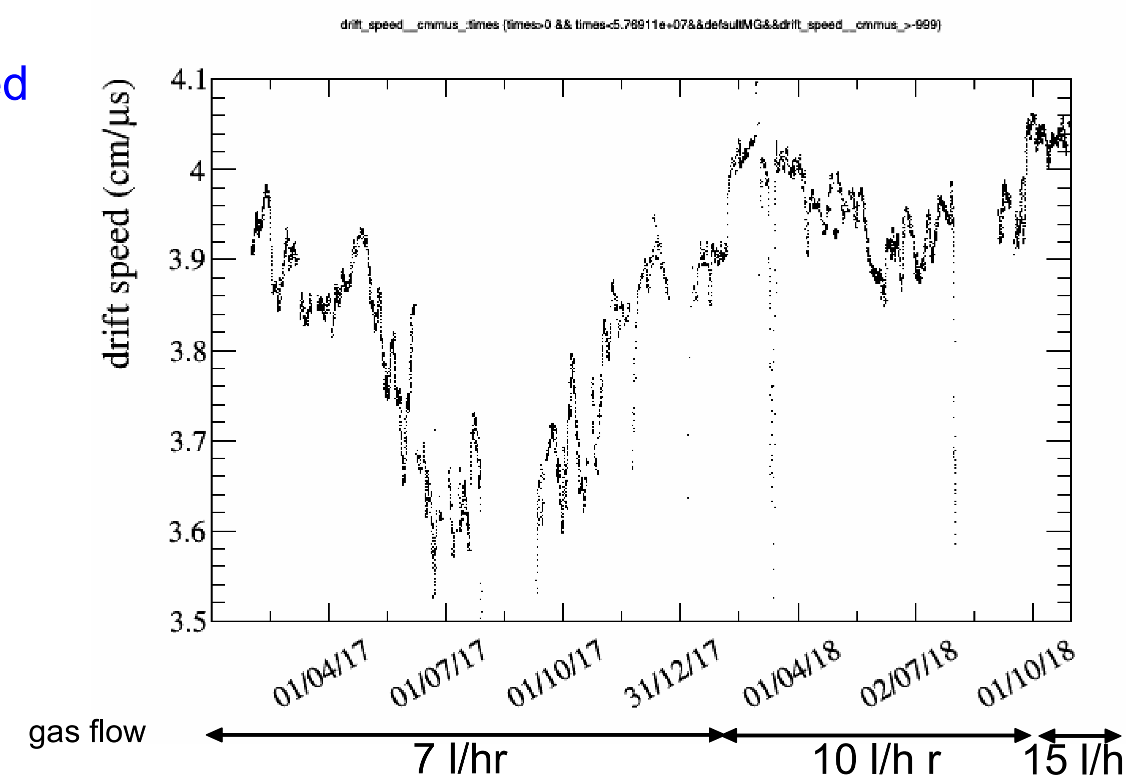
Alignment

- Perform alignment using as input lengths
  - Multigen pitch = 486.26 microns
  - Pad geometry
  - T0 of TPC fixed
- Quick fit
  - Define track from 2 hits from outermost Multigen (Layer 1 and 3)
  - Compute residuals for the hits in TPC and MG Layer 2
  - Fit (z,x,y) of 3 Multigens
  - Fit 1 rotation (around Y) of TPC relative to Multigens
  - Fit drift velocity



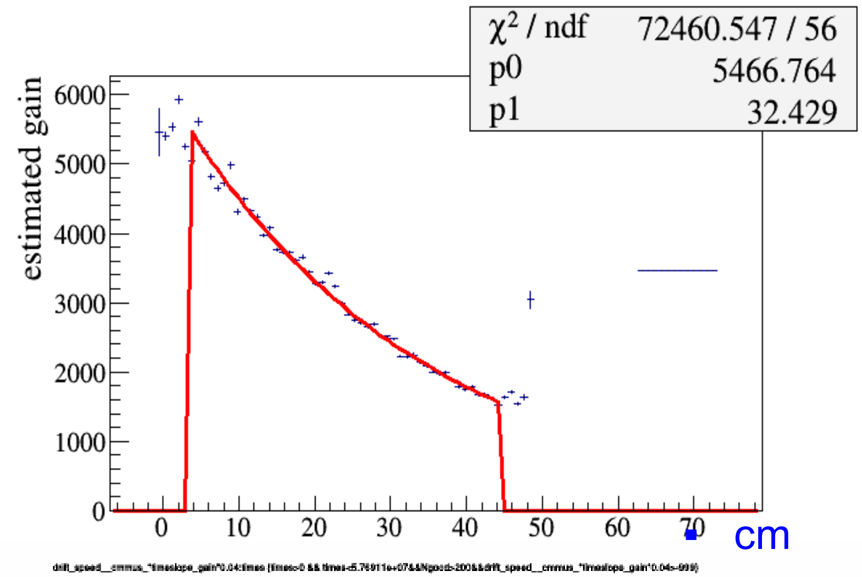
Monitoring Data: drift velocity

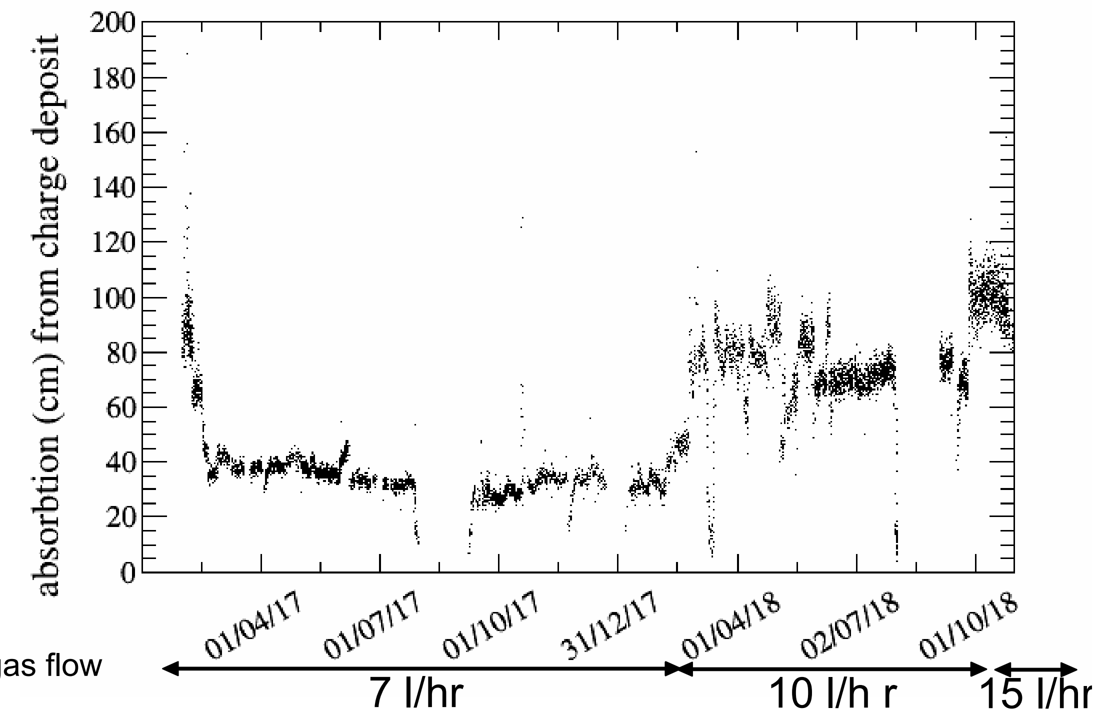
- Methods
  - Several possible methods to measure drift velocity.
    - Eg: study time for tracks going through anode or cathode of TPC
  - Most sensitive: Use overall alignment including Multigen detectors. Fit drift velocity to minimize residuals
- Results
  - Large variations observed
  - Smaller variations with higher gas flow
    - 10 % variation over 6 month between april 2017 – July
    - Two local minima in drift speed July 2017, July 2018.
- Not understood yet
  - seasonal variation ?
  - H20 from outside humidity coming through PCB ??



Data quality: attachment

- Main issue has been e- attachment in gas
  - Measured in charge deposit vs drift time
- Possible candidate: presence of O2
  - TPC outgasing ?
  - gas leak ? gas quality ?
  - pipes (~1m of polyurethane and ~10m of polyamide 4-6 mm) ?
- Monitoring:
  - typical length of absorption was ~ 35 cm for while
    - Absorption depends on gas flow
      - 7 l/hr in TPC   → ~35cm
      - 10 l/hr in TPC → ~75cm
      - 15 l/hr in TPC → ~100cm
    - NB TPC volume ~ 100 l
- Last month:
  - a leak found using a gas sniffer
  - Plan to repair next month

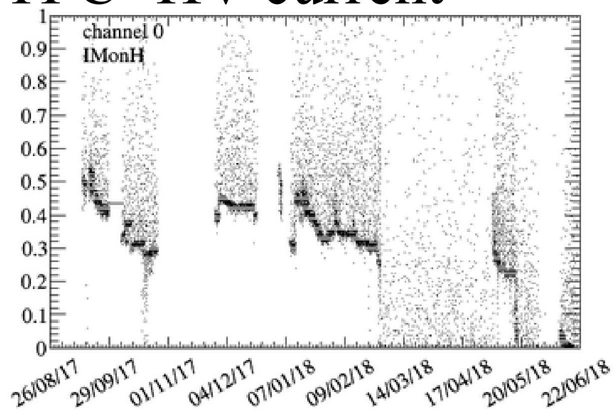




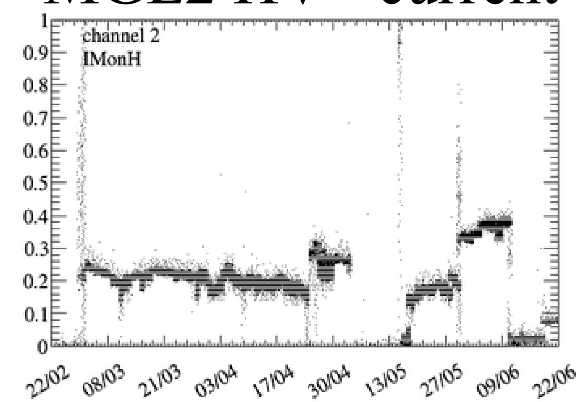
Issues with electronics/power supply

- High Voltage power supply log over last year
  - Sizable current seen by power-supply when the “gain” is low
    - Note that this current is +/- independent of the High voltage setting
    - Charge build-up (??) between micromegas mesh and anodes that changes the gain ?
  - Some work with grounding strip in June. This seems to improved things now. Got stable gain in July

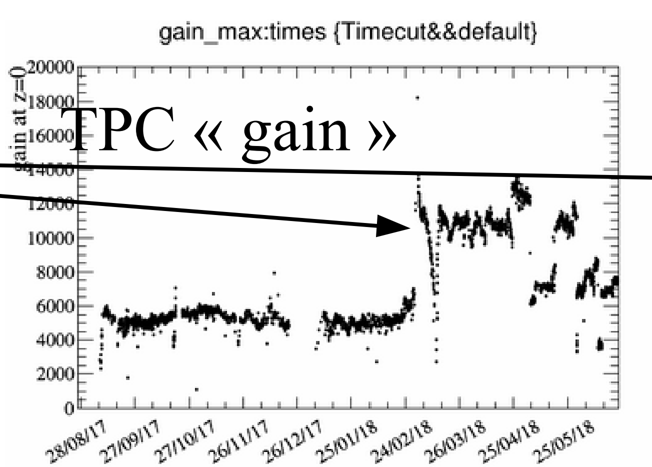
TPC -HV current

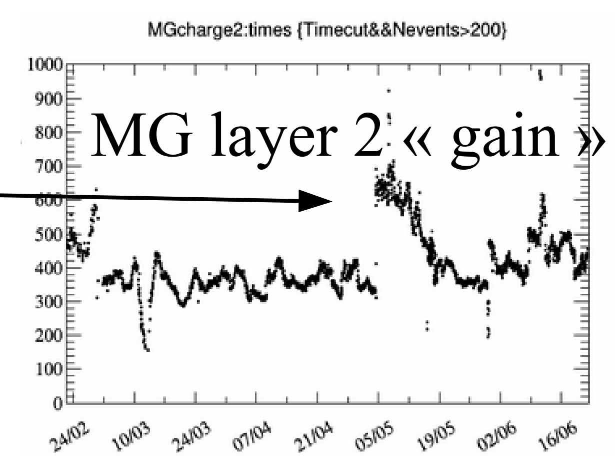


MGL2 HV - current



Jump in gain related to current drop

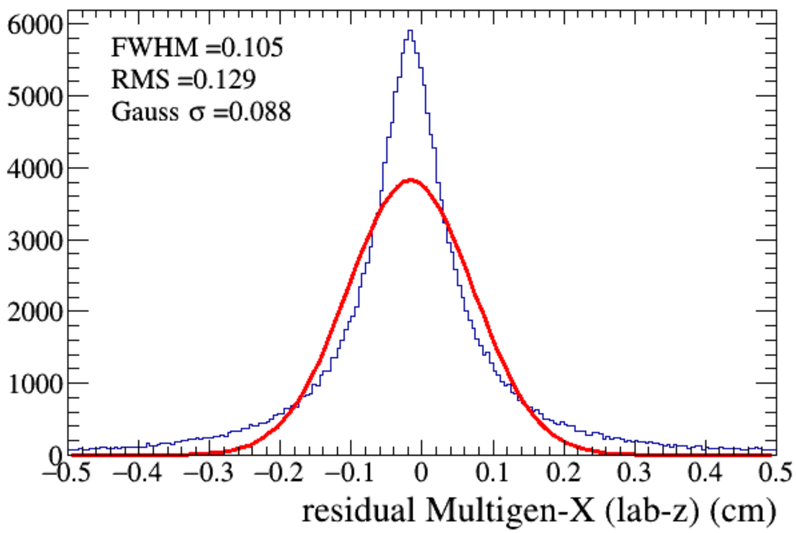


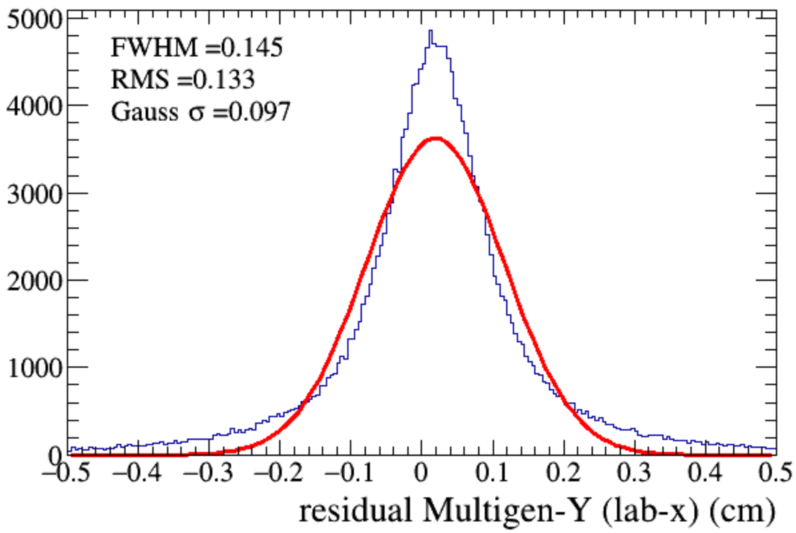


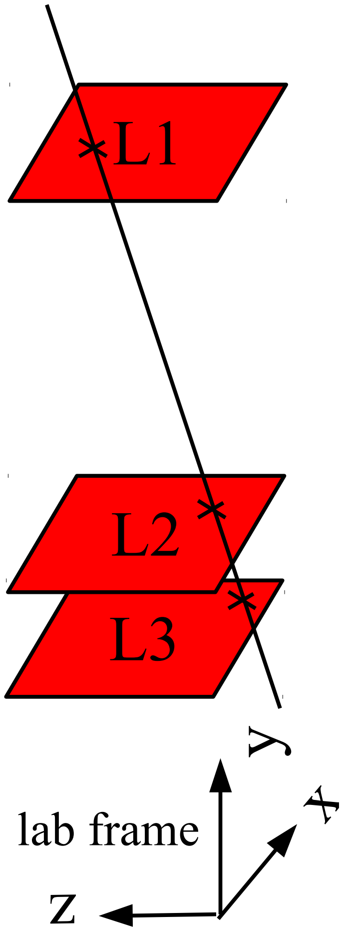
Tracking

Multigen resolution

- Residual: Layer 2 vs extrapolation from (Layer1,Layer3)
- Here we see convoluted resolution between L1,L2,L3





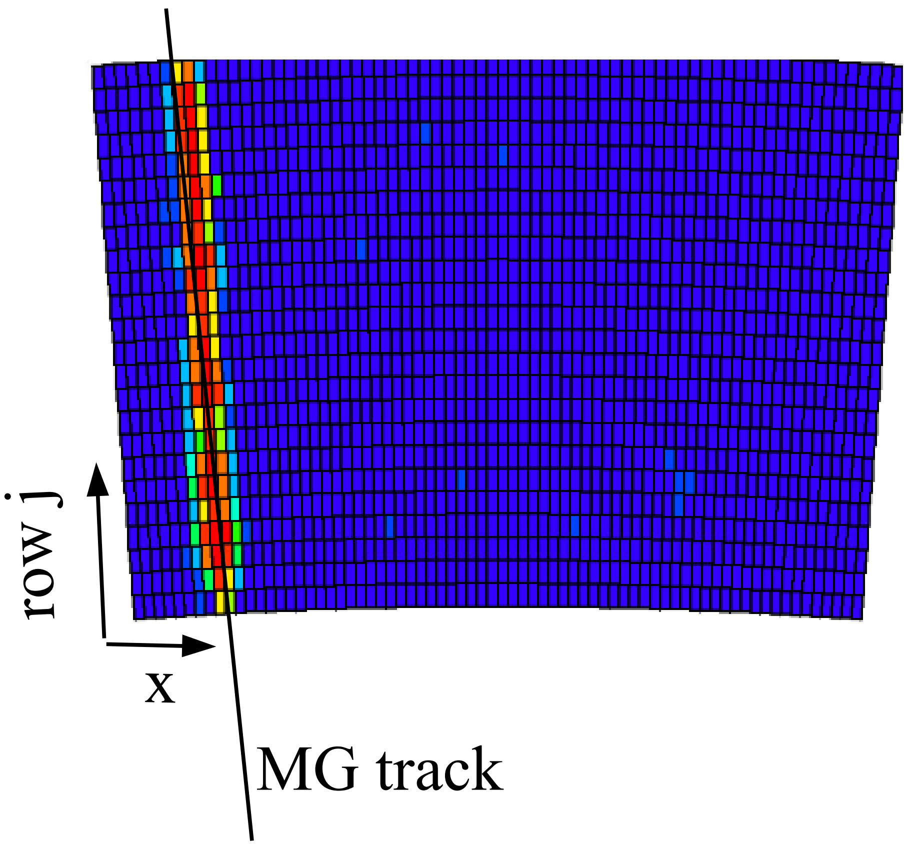


- Important Non Gaussian tail
- Individual Multigen FWHM
  - ~ 800 µm in X
  - ~ 1100 µm in Y

TPC Pad resolution

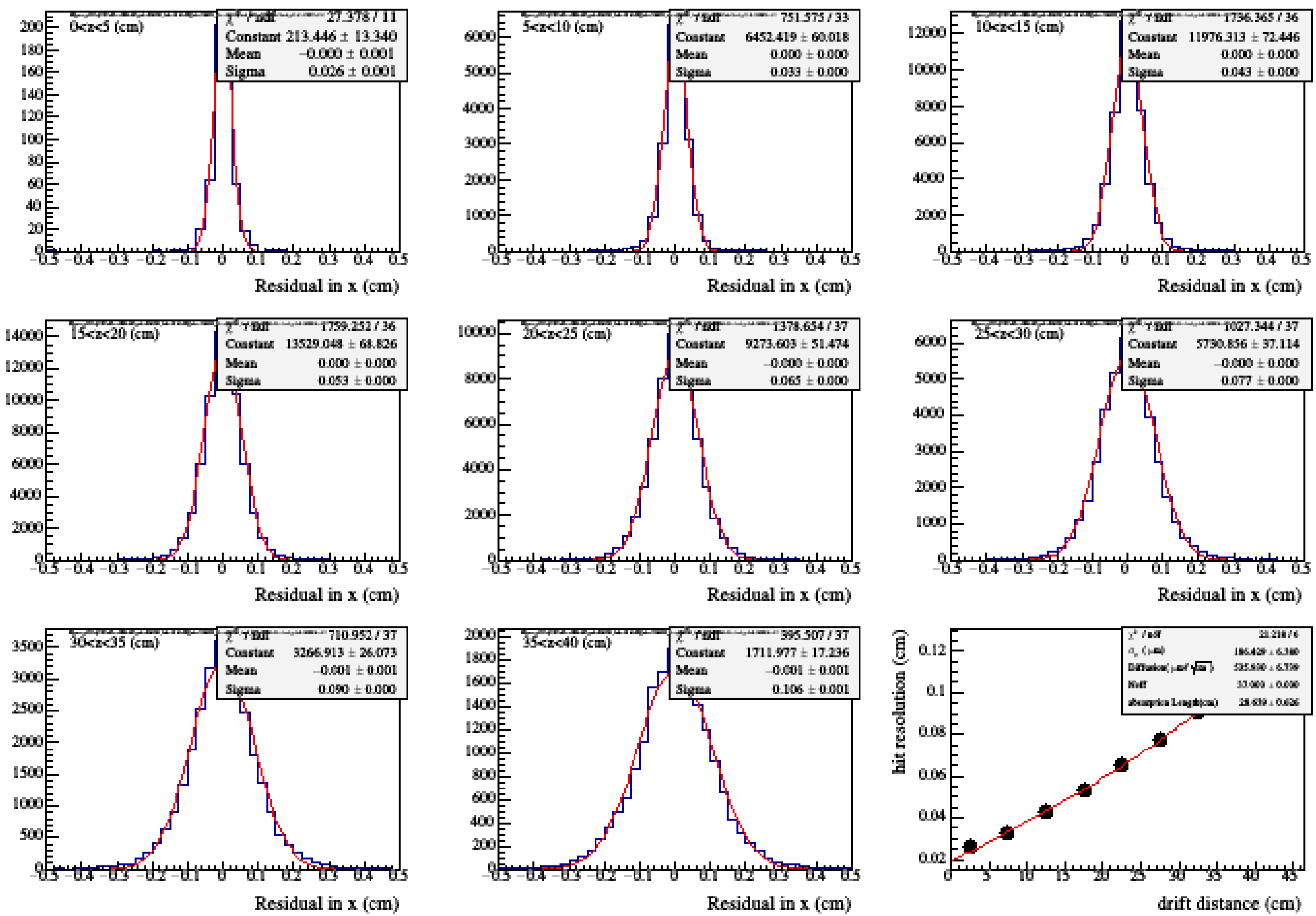
- Hit reconstruction
  - Firstly, use simple algorithm: charge-weighted average coordinate for each row j $\rightarrow$ hit position x_j
- Residual relative to multigen track
  - $Res_j = x_j - x_{track at\ row\ j}$
  - Problem: wide distribution

    because of poor multigen resolution
- Use double difference
  - $Res_{j+1} - Res_j = (x_{j+1} - x_j) - (x_{track\ j+1} - x_{track\ j})$
    - This cancel multigen resolution
    - The term $(x_{track\ j+1} - x_{track\ j})$ is needed to cancel angular effect



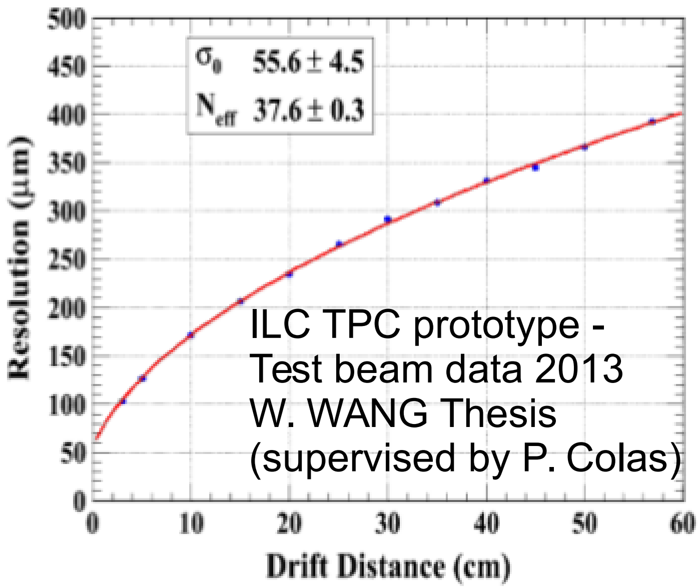
Pad resolution with double diff method

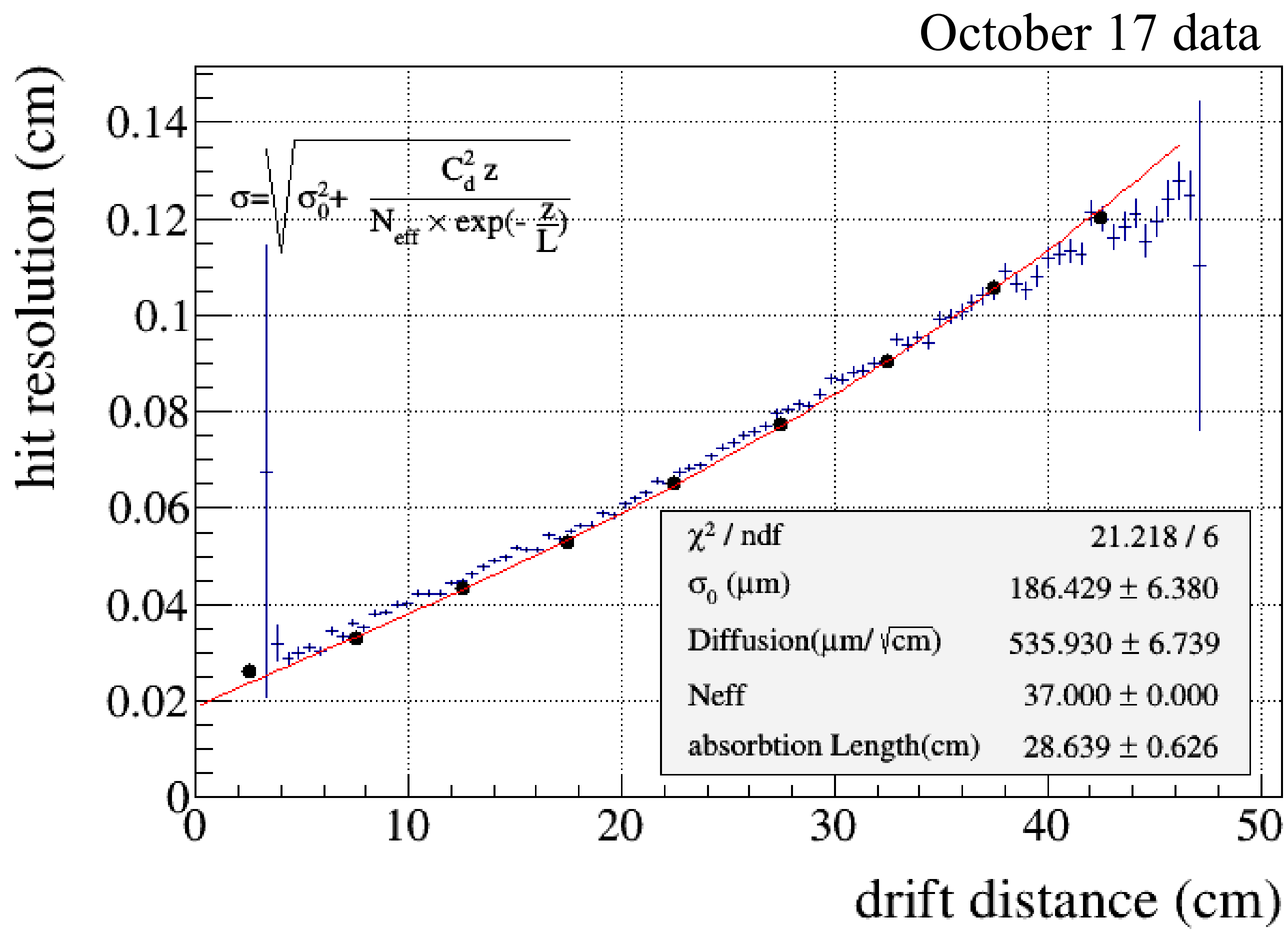
- Fit Gaussian resolution from double difference /sqrt(2), in bins of z



Pad resolution with double diff method

- Resolution vs z
  - Fit with standard form but adding an absorption (e- capture) term
  - Find similar absorption length as when studying charge vs time
- Resolution at z=0 ~ 200 µm.
  - Worse than ~ 60 µm obtained with state of the art hit reconstruction (based on pad response function) on test beam data by Colas et al.

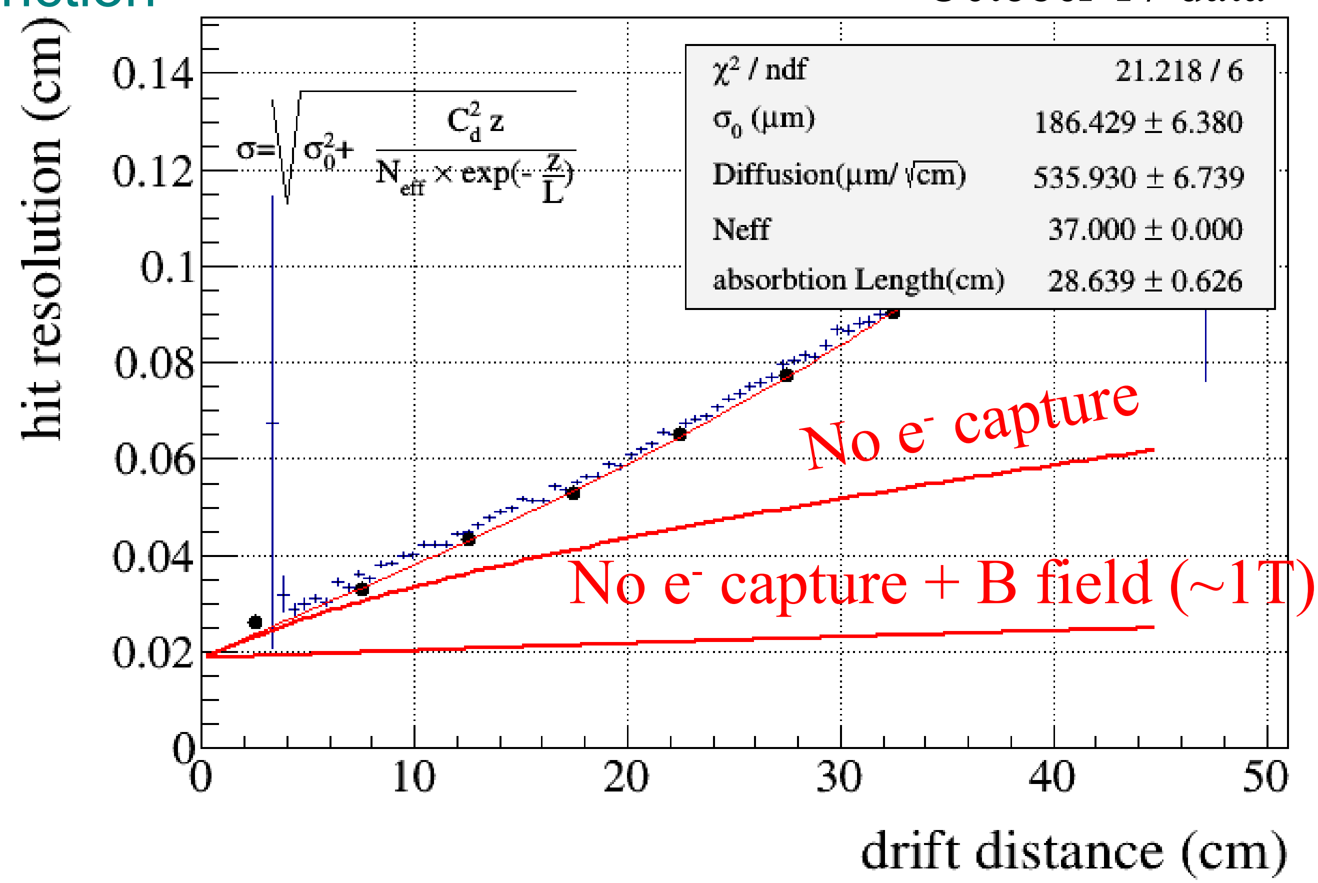




Pad resolution with double diff method

- Resolution vs z
  - Fit with standard form but adding an absorption (e- capture) term
  - Find similar absorption length as when studying charge vs time
- Resolution at z=0 ~ 200 μm.
  - Worse than ~ 60 μm obtained with state of the art hit reconstruction (based on pad response function) on test beam data by Colas et al.
- Extrapolate resolution function
  - No more e^- capture
  - In B field

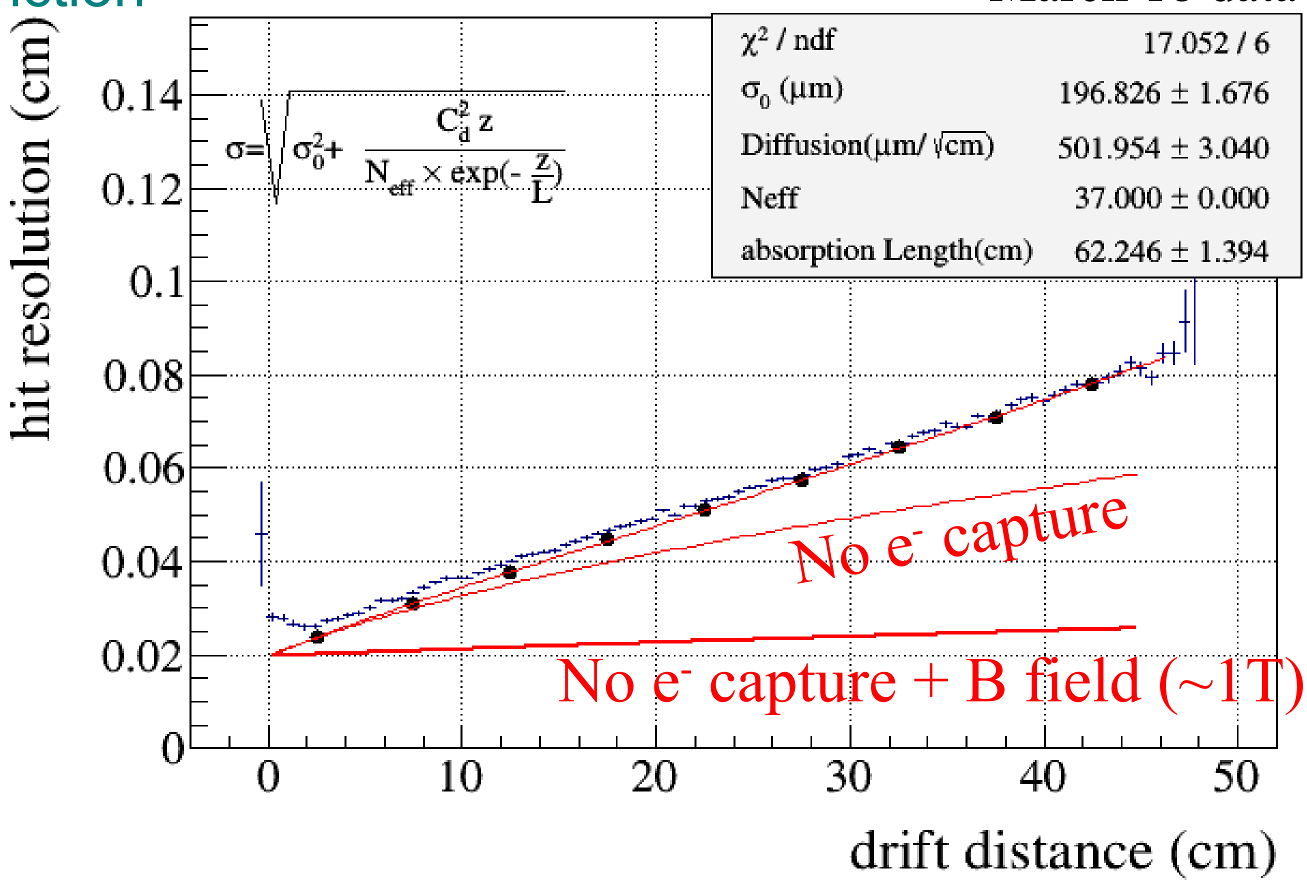
October 17 data



Pad resolution with double diff method

- Resolution vs z
  - Fit with standard form but adding an absorption (e- capture) term
  - Find similar absorption length as when studying charge vs time
- Resolution at z=0 ~ 200 µm.
  - Worse than ~ 60 µm obtained with state of the art hit reconstruction (based on pad response function) on test beam data by Colas et al.
- Extrapolate resolution function
  - No more e^- capture
  - In B field
- More recent data:
  - higher gas flow
  - better gas (?)
  - smaller dependence of resolution vs drift

March 18 data



Pad resolution using fitted track

- Haiyun Wang (IHEP) at Saclay Nov 2017 → April 2018
  - worked on track fitting algorithm using standalone TPC
    - First step: hits defined as charge-weighted average
    - Use fitted TPC track as reference to compute residual
    - Obtain similar result as double difference method

Haiyun Wang

New data(2018.03) analyzation

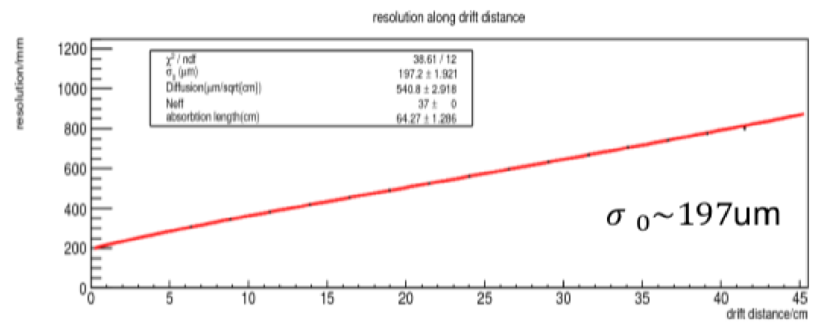
Fit function:

$$\sigma = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot z}{N_{eff} \cdot \exp(-\frac{z}{L})}}$$

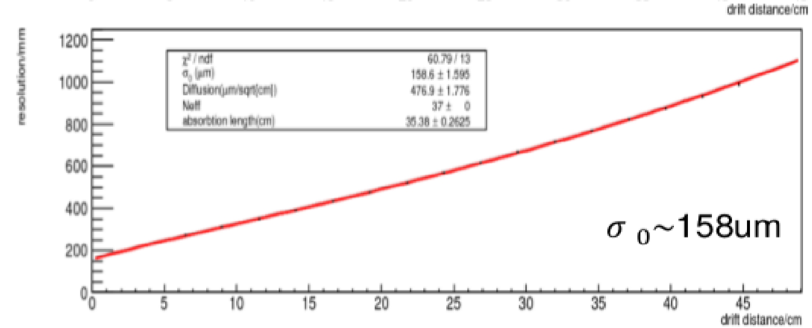
C_D, transverse diffusion constant,
σ_0, spatial resolution at $Z = 0$,
L, absorbtion length
N_{eff}, number of effective elctrons over the length of a pad

- ➢ resolution along Z/drift time
- rows: 12,13,14,15,16,17,18
- angle: ≤±5
- ➢ Data of 2018.03 v.s. data of 2017.10

2018.03



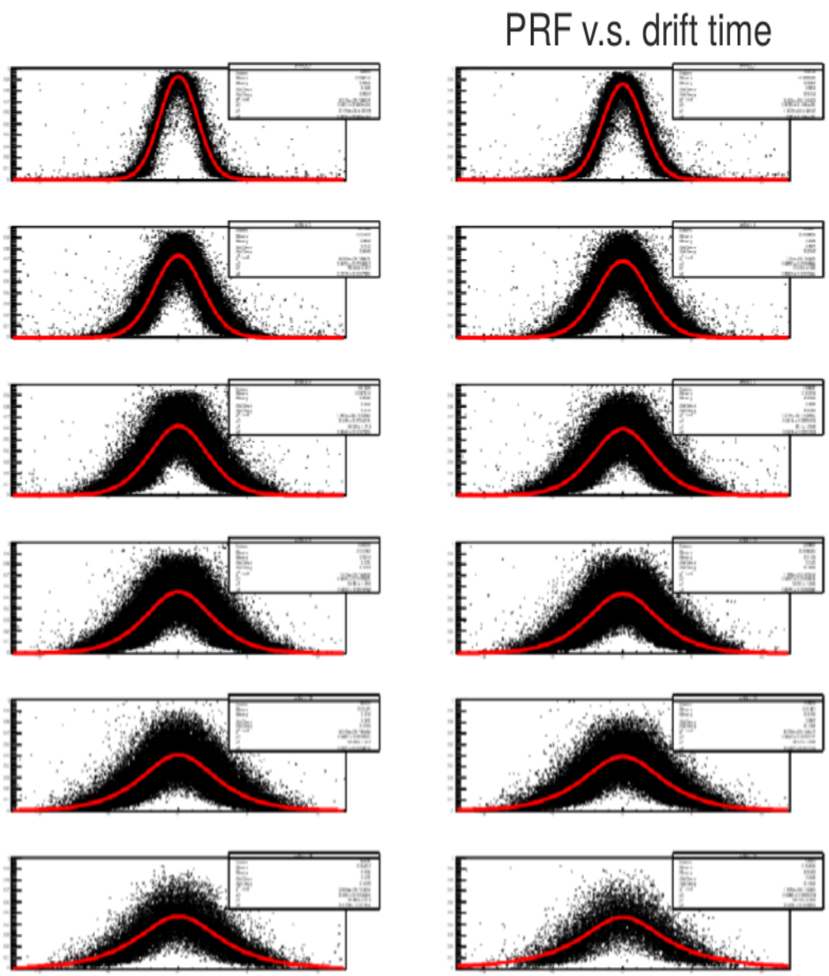
2017.10

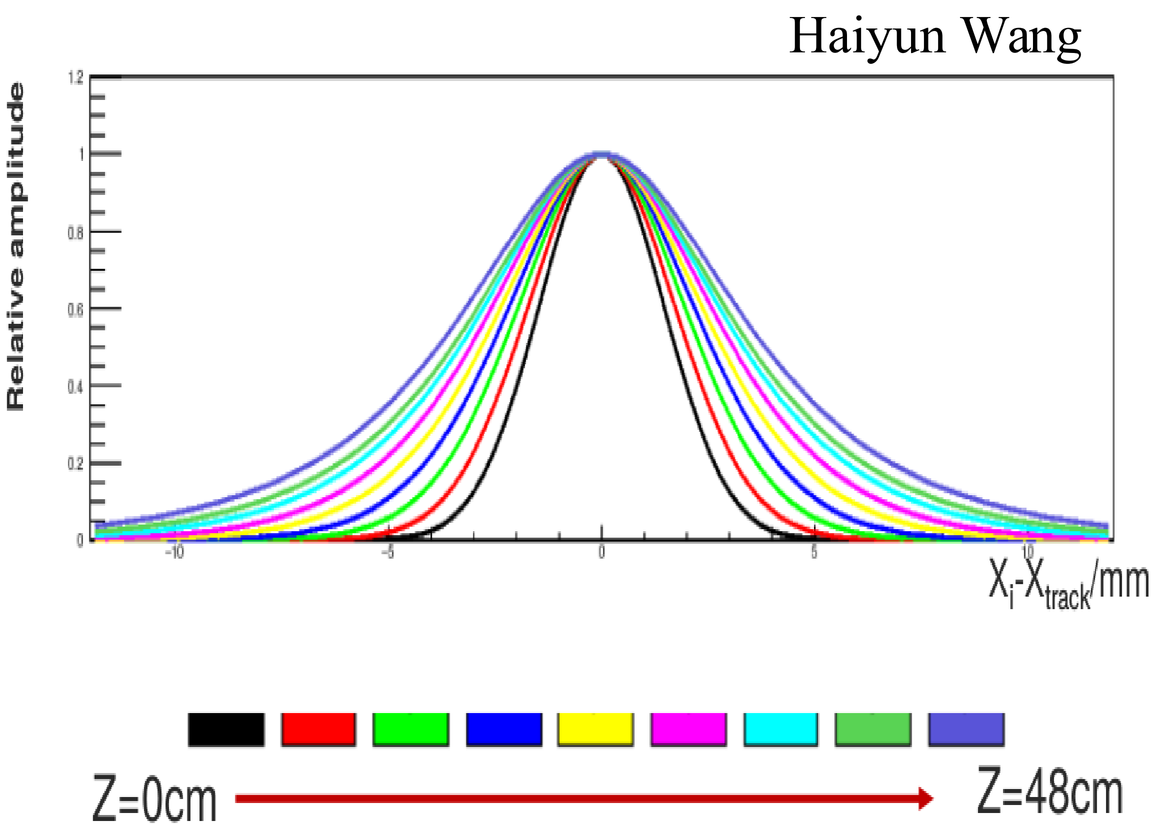


6/6/18

Improving resolution

- Study Pad Response Function to determine the hits
- PRF need to be determined as a function of drift distance z

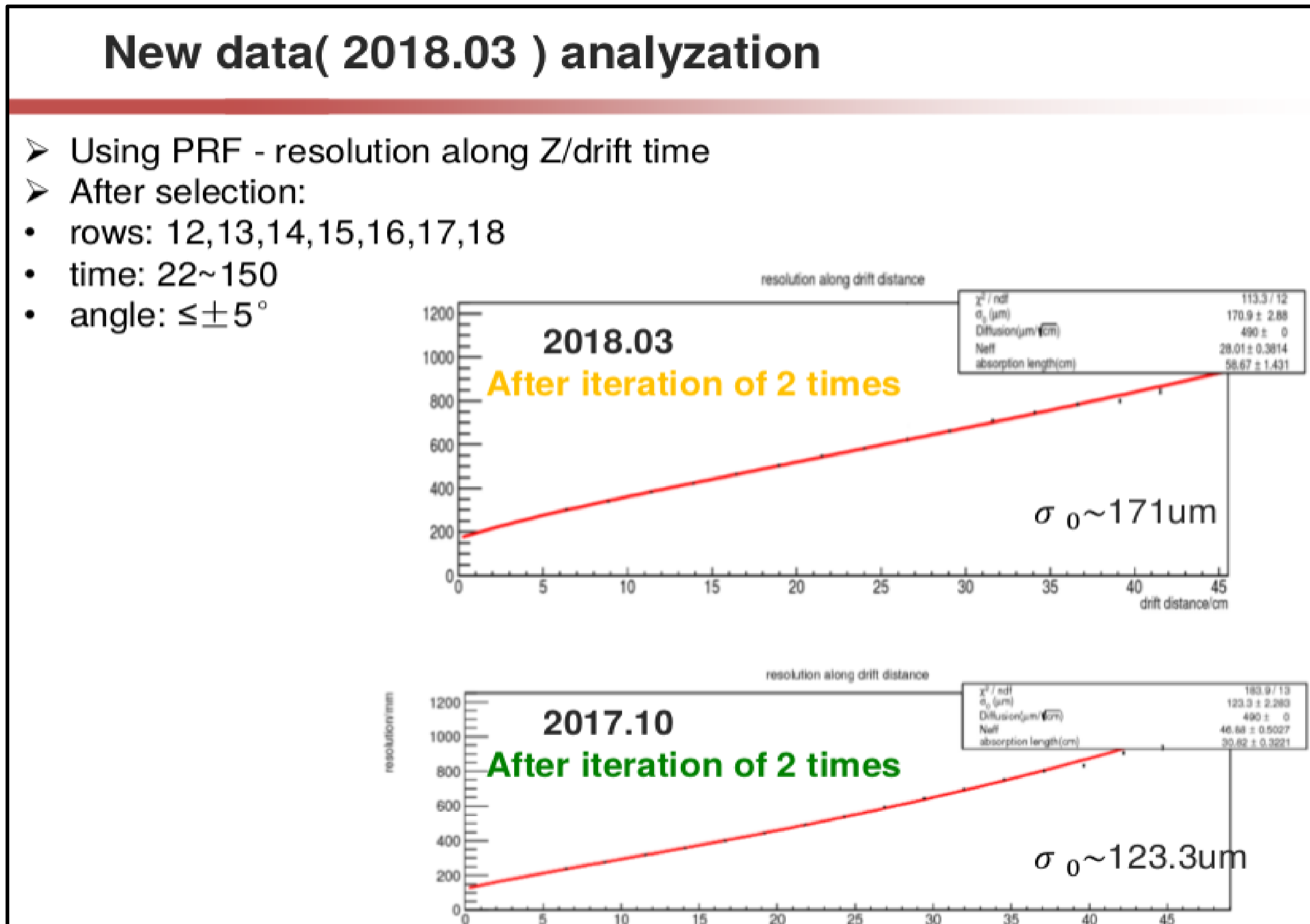




Pad resolution using fitted track

- Improved results using PRF.
  - However not fully understood
  - More studies needed

Haiyun Wang
June 18



Summary

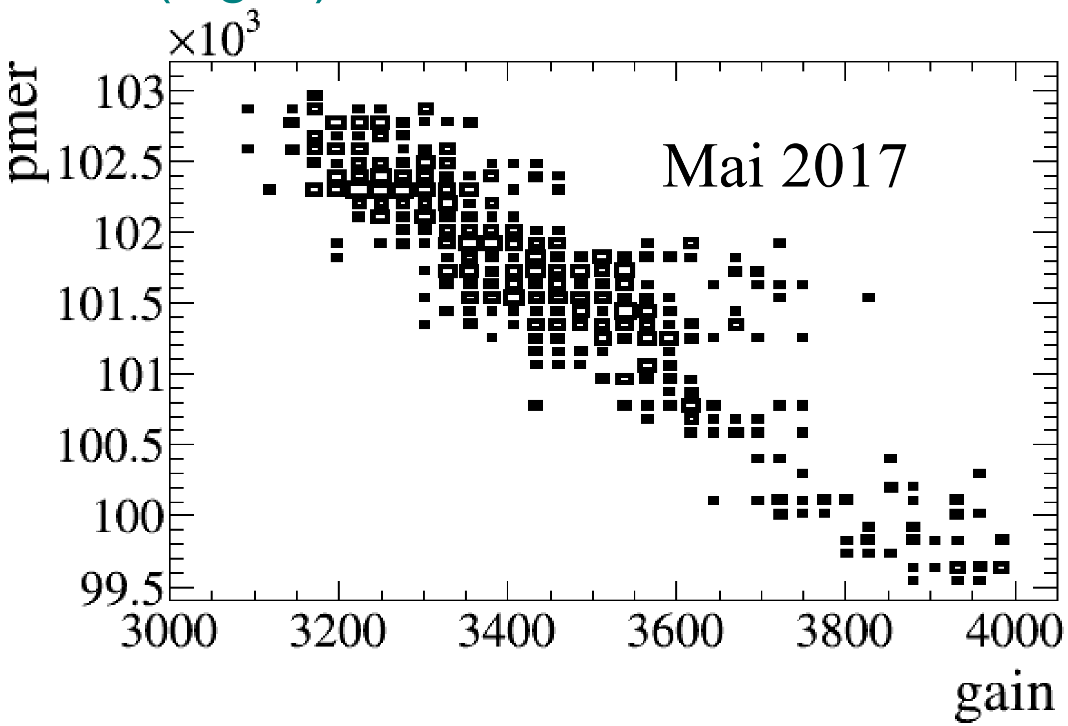
- TPC test-bench at Saclay
  - Project to study ion back flow effects on track reconstruction
  - Small team of people <0.5 FTE
  - Progress could be faster with students or Post-doc
- Test bench working and taking cosmic data for 2 years
  - This is also a good test of TPC module stability over time.
- Several stability issues in the past years.
  - gas leak/purity, gain stability and grounding of detector.
- Track reconstruction not yet as good as expected
  - Pad Response Function only at preliminary level
  - More work on tracking to get better tracking performance
  - Need to understand tracking performance vs time, etc
- Next steps
  - Understand tracking and achieve design performance
  - Turn-on UV light, measure performance, measure space charge
  - Simulate the test-bench.
  - Compare data to simulation

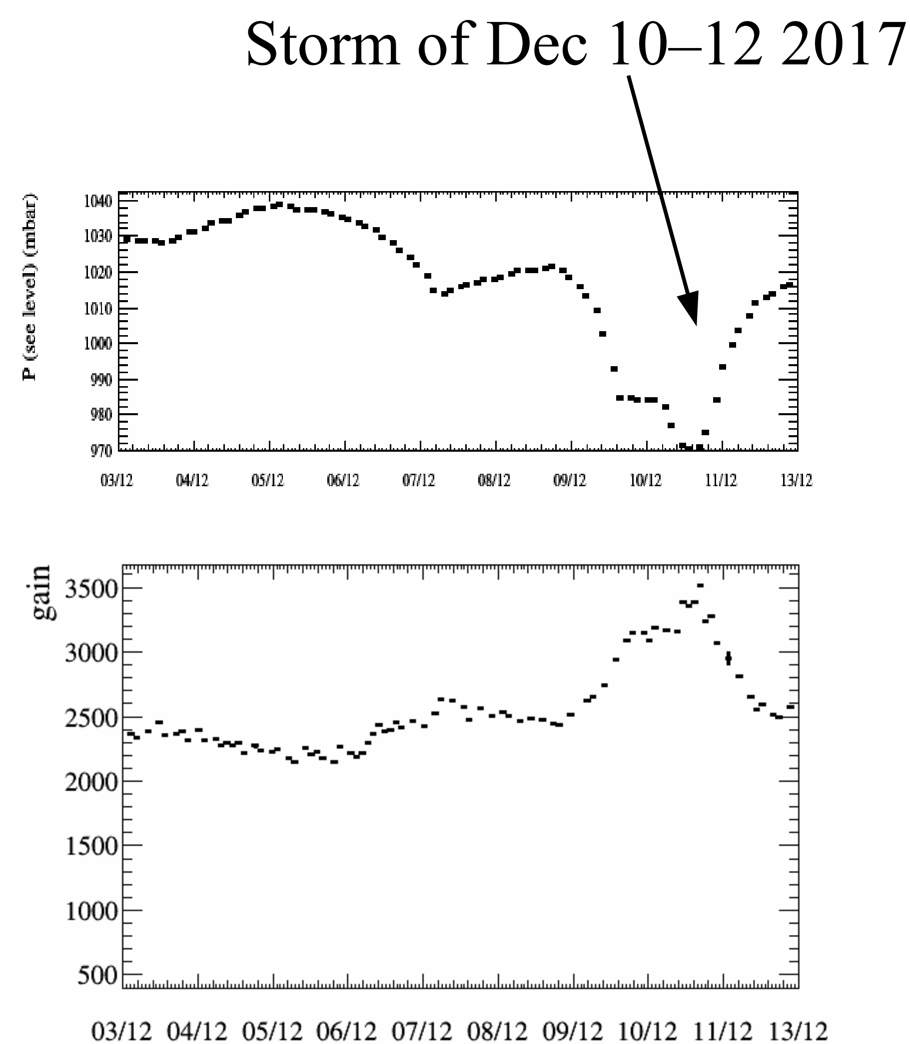
Support

Monitoring data:TPC sensitivity to pressure

- crude estimate of “gain”.
  - Better say charge in “good” events using some not so arbitrary units
- See something like

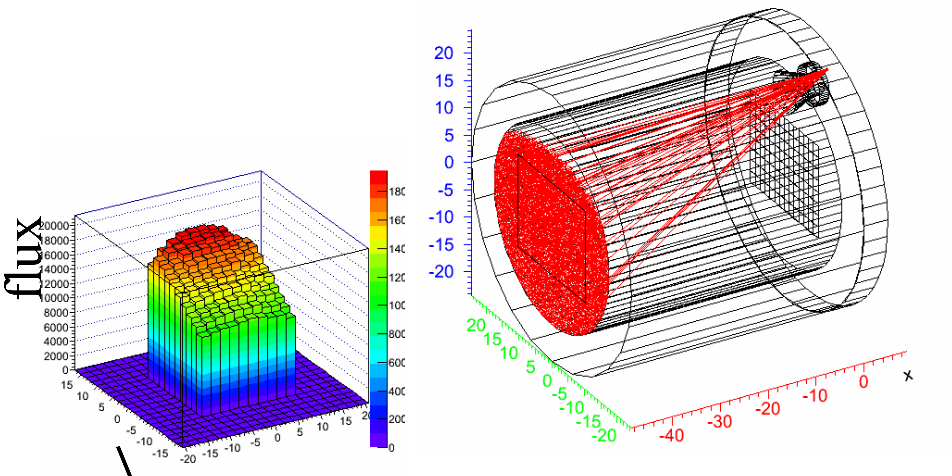
  d(log G) / dP = ~-0.65%/mbar

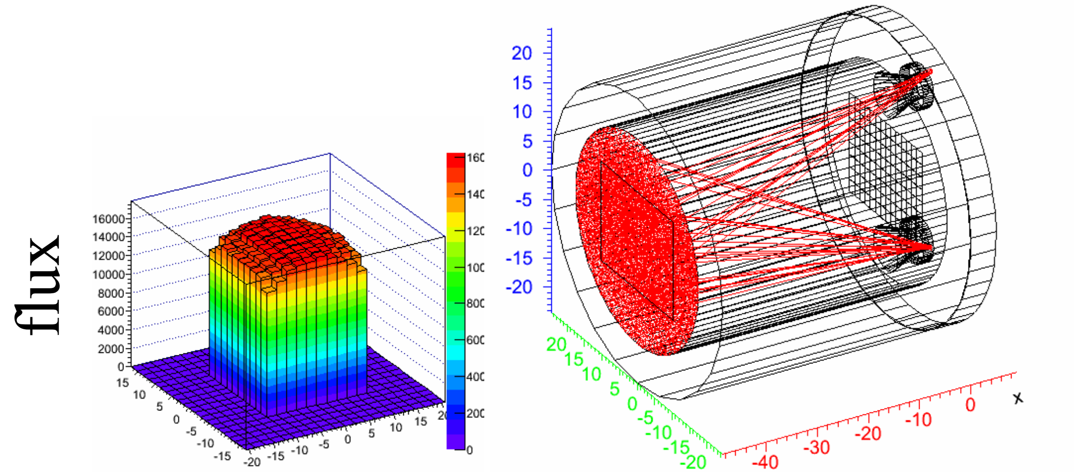




- So far: P and T collected from meteo-France Orly station
- Would be good to have P,T in-situ probes!!

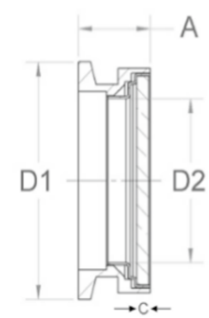
Two Viewports





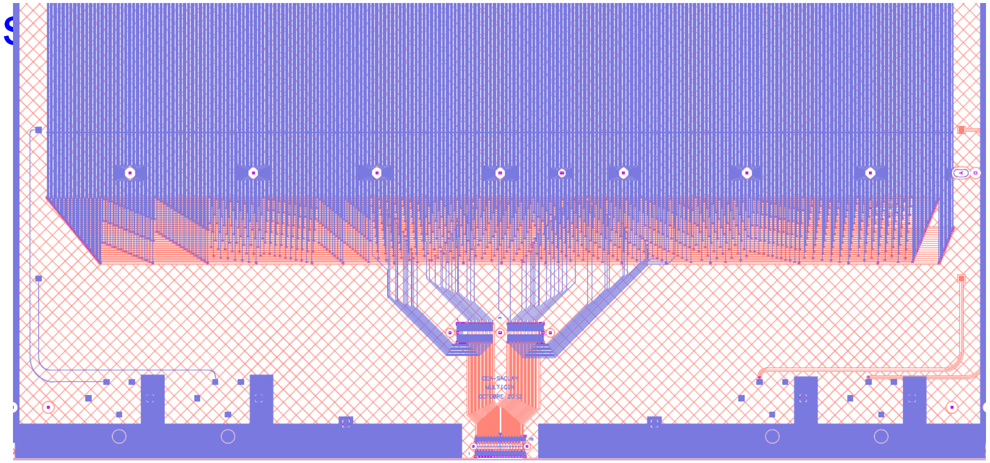
Solid angle effect+UV absorption+ Quantum efficiency= non homogeneous photo-electrons yield

- Two viewports for better control on photon-electron yield homogeneity
- Will use CaF_2 viewport of diameter 3.8cm



Multigen detector

- Genetic “multiplexling”
  - (Procureur et al, NIM A 729 (2013) 888)
  - 1024 strips → 61 readout channels
    - ~17 strips connected together.
    - 50 x 50 cm^2 coverage with 122 channels !



However

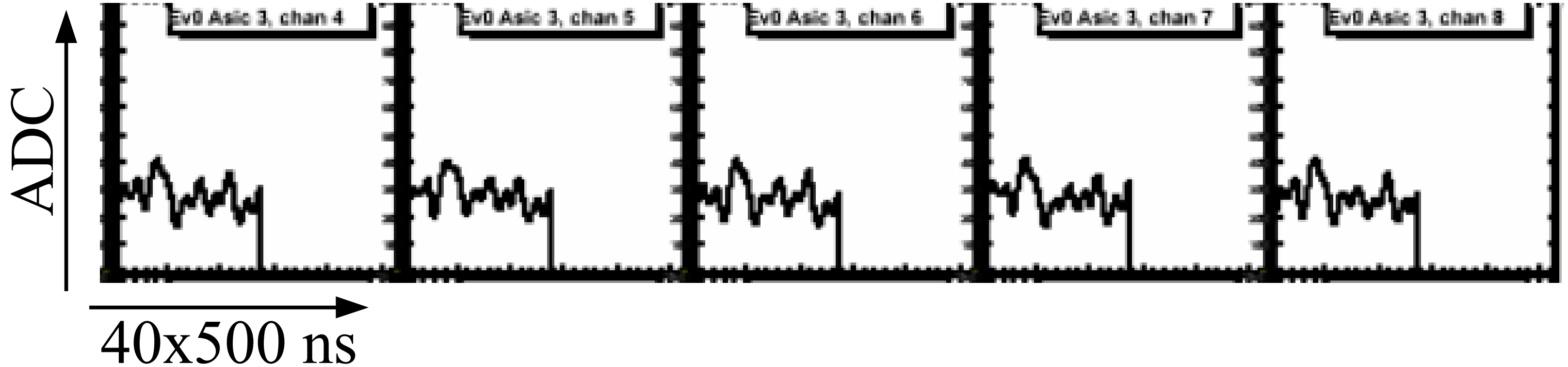
- Very large capacitance
  - Sensitive to outside noise
  - Cross-talks between channels
  - “Common noise subtraction” needed
- Somewhat complicate pattern recognition
  - Connections are optimized so that three fired channels uniquely defines three possible adjacent strips.
  - Need to test all possibilities to find physical clusters of hits
  - Any mistake in channel mapping kills reconstruction

Noise in Hodoscope

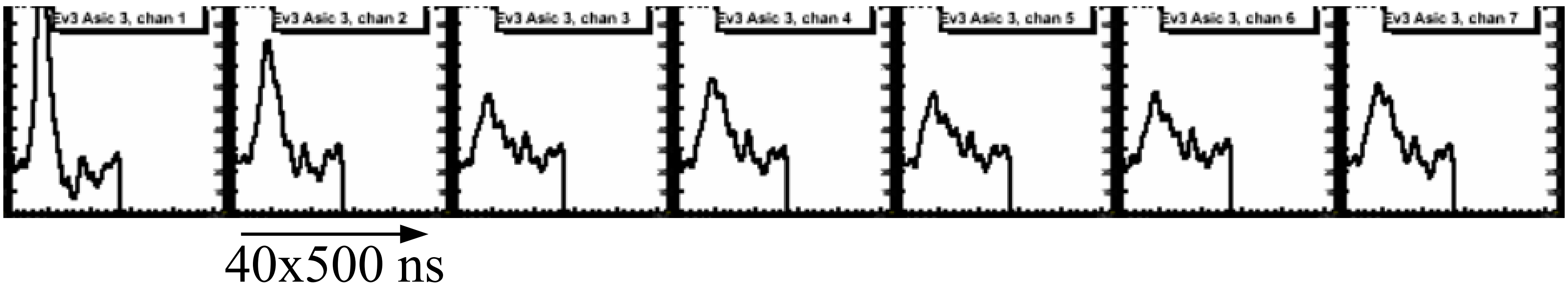
Struggled against noise in Hodoscope for a while

Two kind of noises:

- Common noise due to external source
  - Seen in all strips of a given ASIC
  - Reduced with proper grounding.



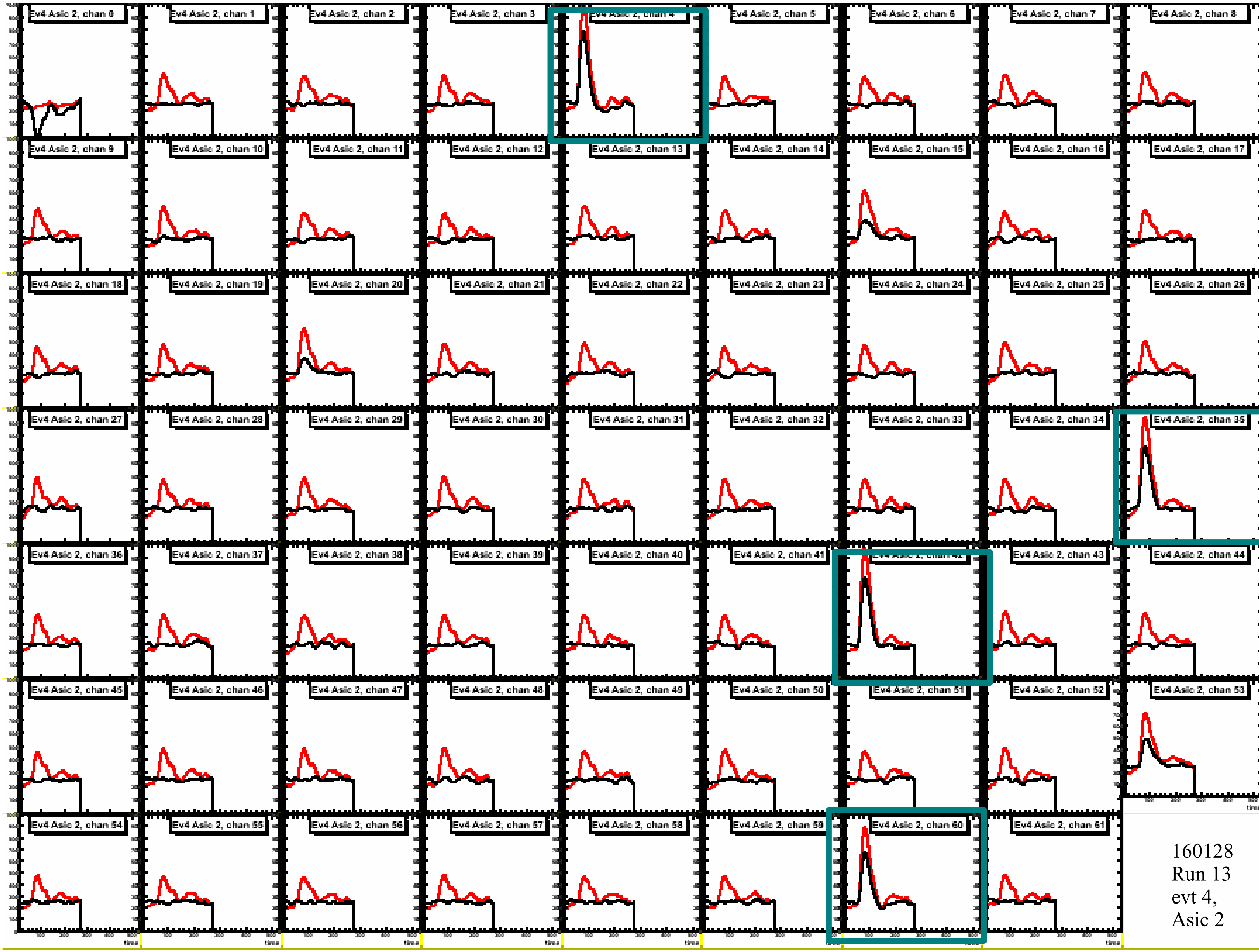
- Auto-correlated noise due to the signal itself = cross-talk
  - Seen in all strips of a given ASIC



Common noise subtraction

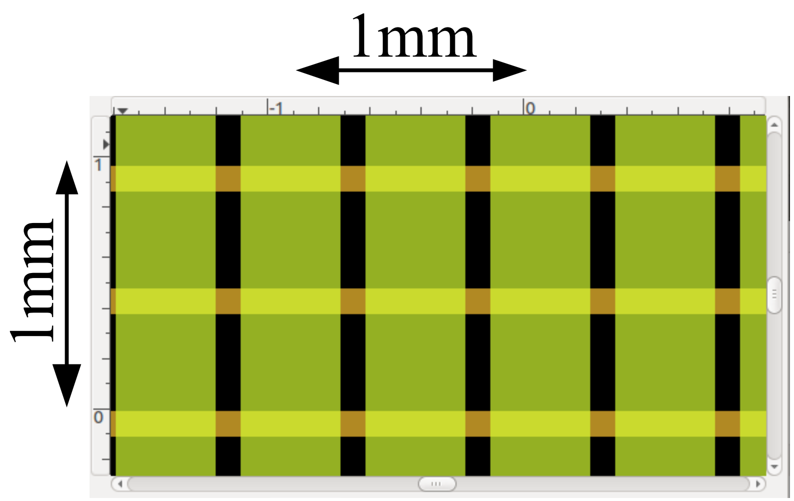
- Common noise subtraction technique seems to work to remove signal-induced noise. X-layer

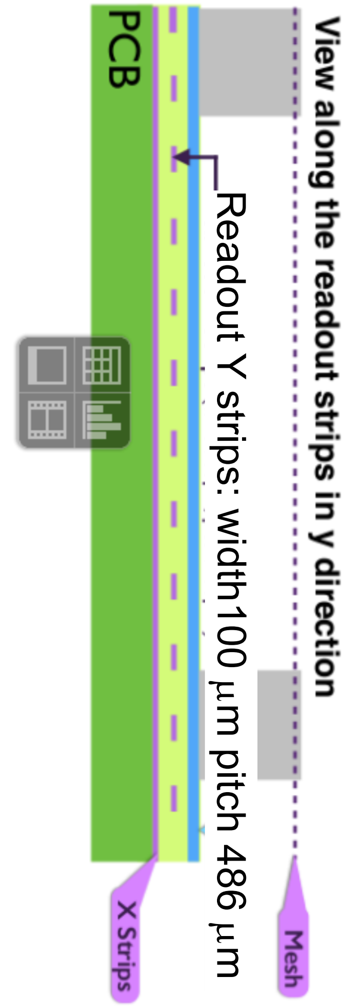
before subtraction
after



Geometry

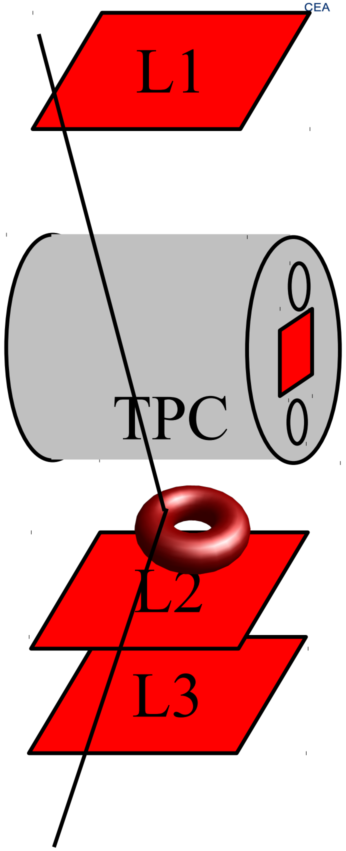
- 386 μm wide resistive strips (1MΩ/□) along Y

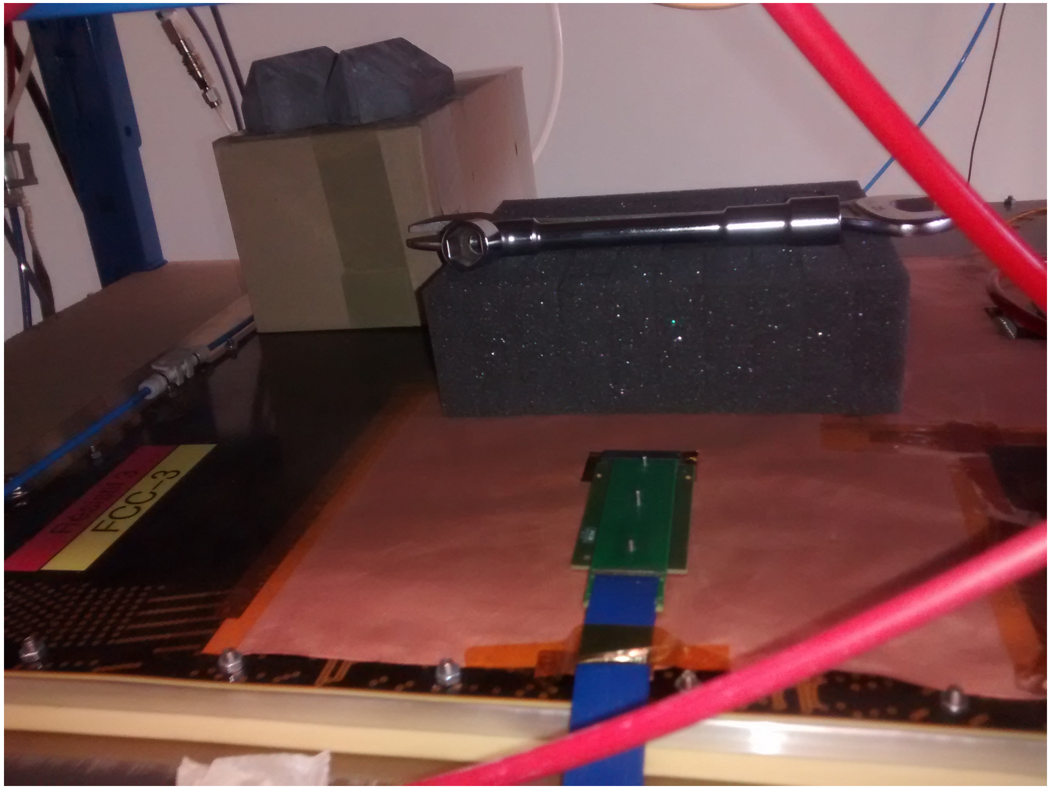




Tomography tests

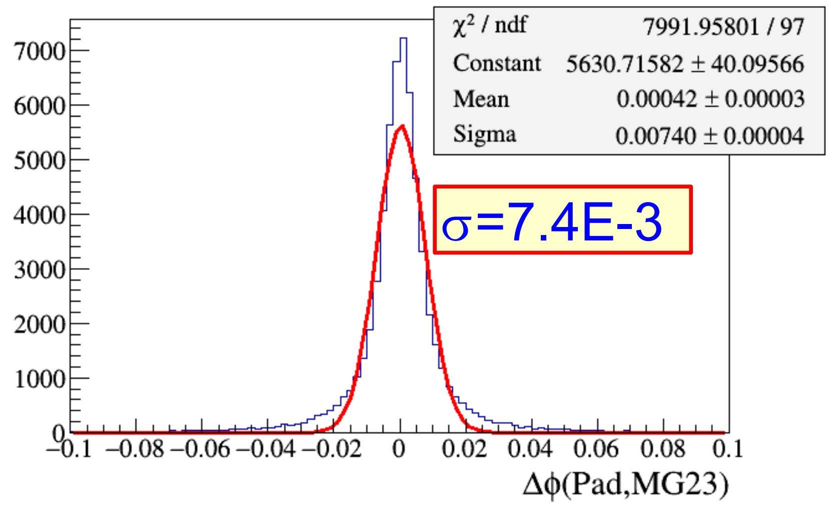
- Insert object between L2 and TPC
  - Try to observe overdensities by looking at deviation due to multiple scattering
  - Roy inserted wrenches on 06/04
    - ~ 0.5 cm thickness of iron
  - I added chevron-shapped lead tile on 06/05
    - ~ 3.5 cm thickness of lead at max

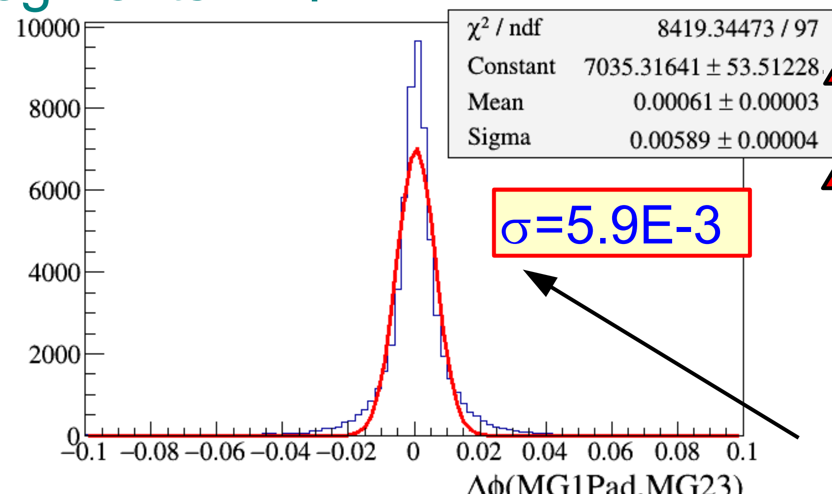


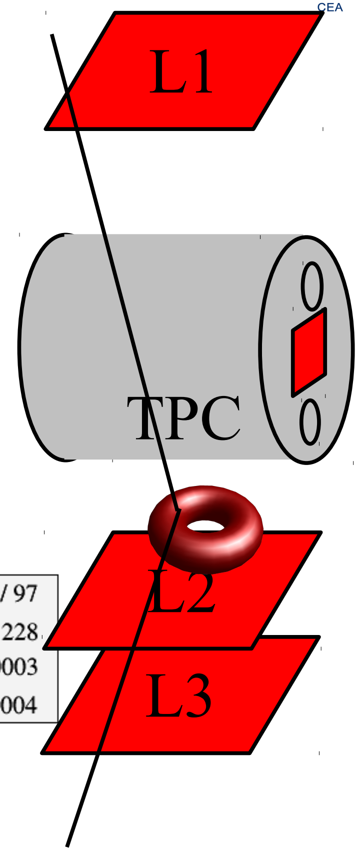


Tomography tests

- Multiple scattering expectations $\sigma(\theta) = \frac{0.0136}{\beta p}\sqrt{\frac{L}{X_0}}\left[1 + 0.038\ln\left(\frac{L}{X_0}\right)\right]$
    - 2d RMS angle for 1 GeV muon in 0.5cm iron: 7 E-3 rad
    - 2d RMS angle for 1 GeV muon in 3.5cm lead: 3 E-2 rad
- 3 ways to reconstruct cosmic muon track segments
    - use Multigen L2L3
    - use TPC only (no PRF)
    - use TPC+Multigen L1
- "Resolution" between track segments in Φ







- Here, data taken in runs without object
- See non-Gaussian tail
    - Multiple scattering of low momentum muons ?
    - Tail of resolution in detectors

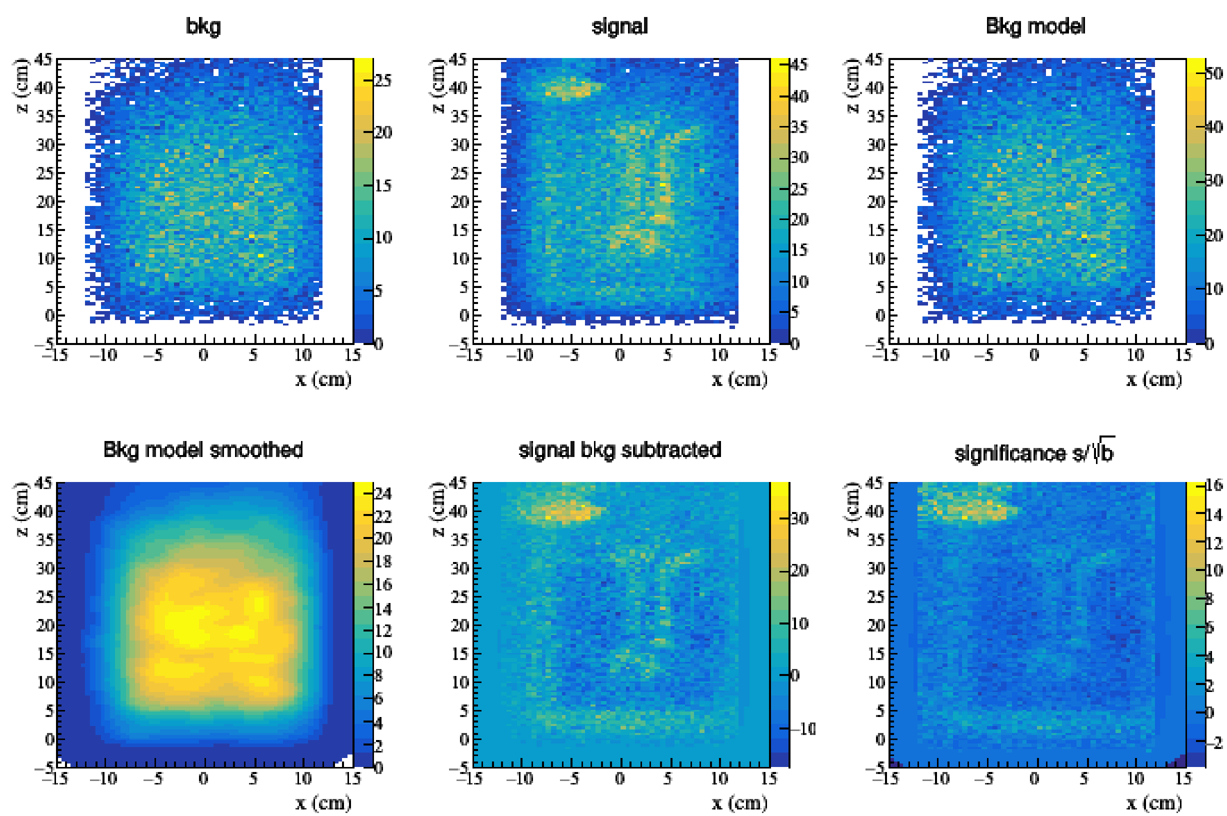
(NB I see ~ same resolution in θ)

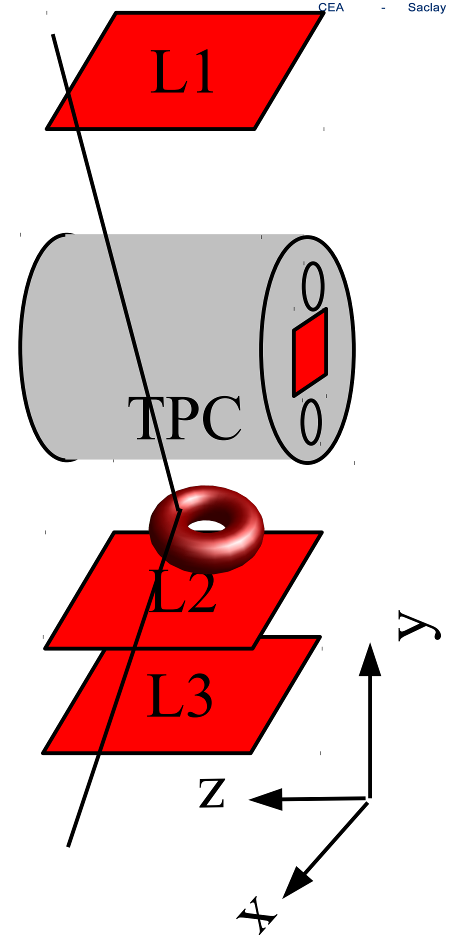
Numbers here are comparable to multiple scattering angle
However :
-lots of muon below 1 GeV
-non-gaussian tail of resolution

Tomography results

Compute angle α(L2L3, TPC)

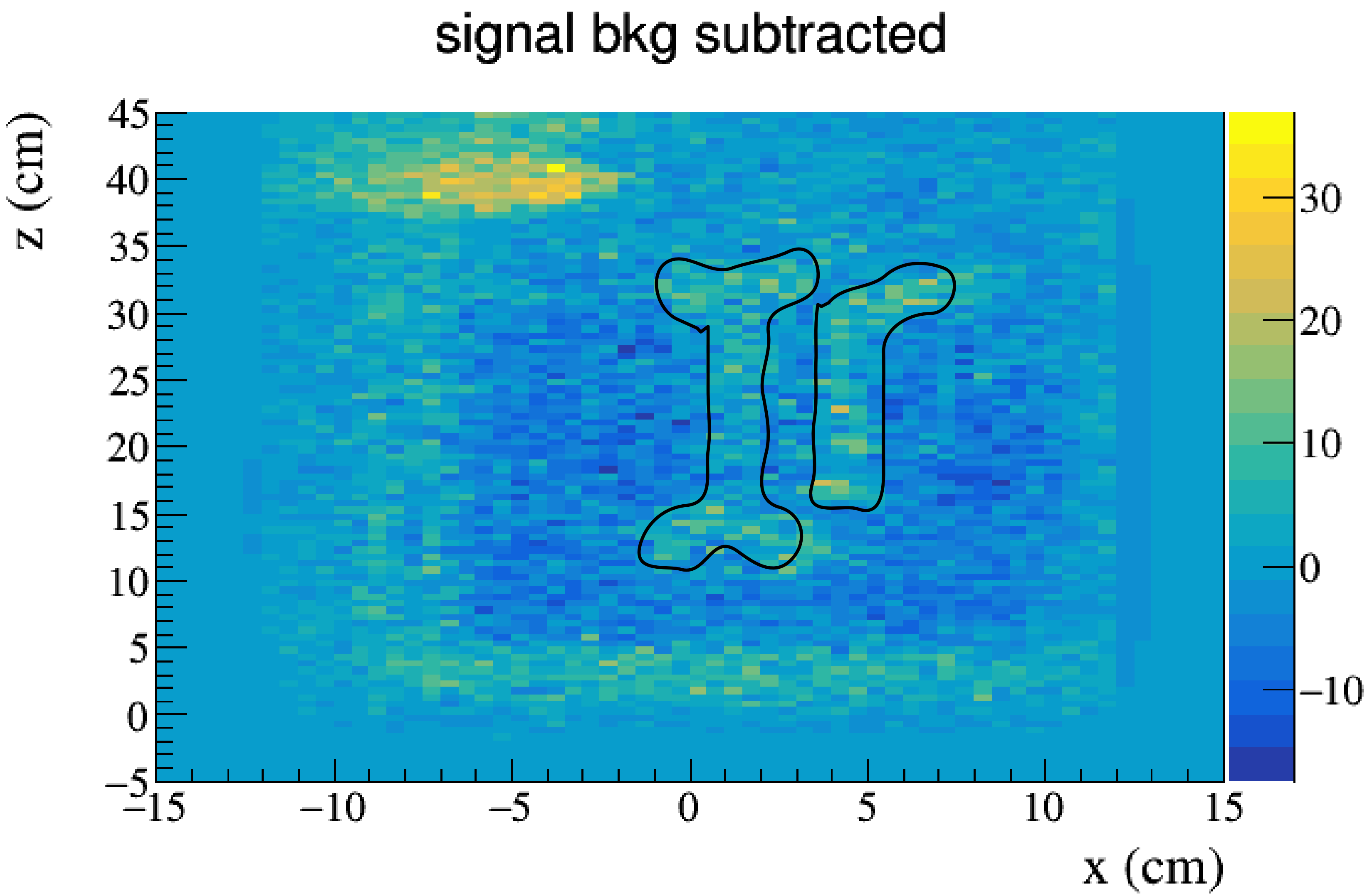
- Signal
  - Require large deviation angle between segments
    - $\alpha=\mathrm{sqrt}(\Delta\theta^2+\Delta\Phi^2)>0.02$
  - Require segments to point to same vertex in x,z ~1cm
- Background= blank image
  - Reverse angle cut $\alpha=\mathrm{sqrt}(\Delta\theta^2+\Delta\Phi^2)<0.01$





Wrenches

-



signal bkg subtracted
z (cm)
45
40
35
30
25
20
15
10
5
0
−5
−15
−10
−5
0
5
10
15
x (cm)
30
20
10
0
−10