TPC Electronics Monitoring System

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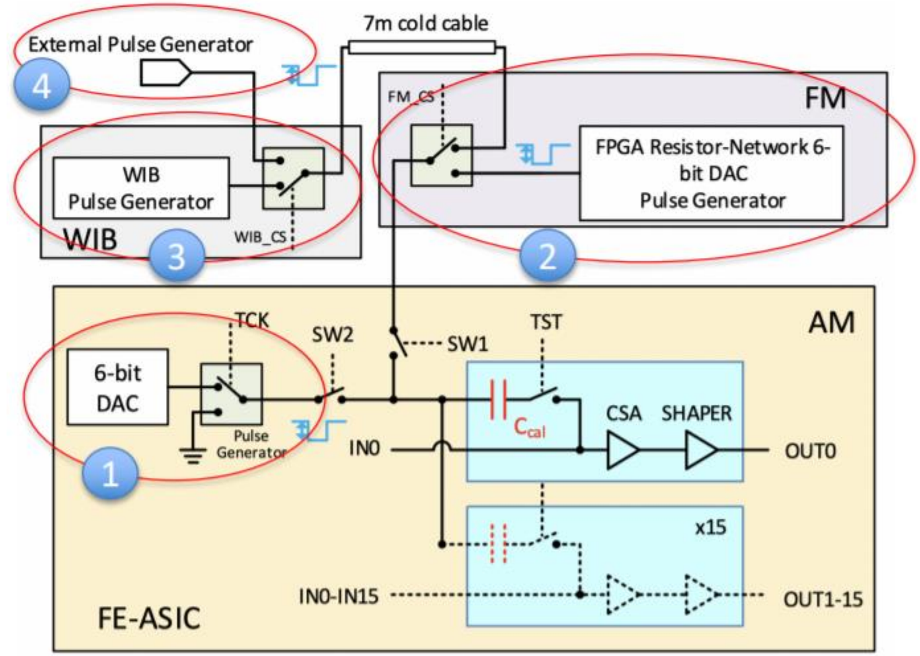
Introduction

- I am going to tell you why this is not a TPC Electronics Calibration System and explain the difference
- I will try to answer the question "Can you get an absolute calibration between ADC counts and charge collected on the wires of the APA ?"
- If you know the recombination, this is what would allow you to get the response of the TPC to the energy deposited in the LAr
- We had a TPC electronics / calibration / physics joint meeting yesterday (agenda in Indico, recording in DocDB-19255)
- Using materials from slides prepared by Shanshan Gao, David Adams, and Tingjun Yang, representing the work of the team that build and operated ProtoDUNE and of the DRA group

ProtoDUNE

- The response of the ProtoDUNE FE electronics has been calibrated / monitored with four different DACs
  - 6 bit DAC internal to LArASIC (limited precision, cannot calibrate range below ~2 MIPs)
  - 6 bit pulse generator driven by FPGA on the FEMB mezzanine
  - 16 bit DAC on Warm Interface Board
  - High precision external pulse generator



- Measurements with LArASIC/FPGA DACs repeated during ProtoDUNE data taking

What have we learnt ? (i)

- Calibration capacitor internal to LArASIC ~188 pF at LN_2 temperature, measurement obtained by comparison with high precision external capacitor
  - This kind of measurement is time consuming, cannot be repeated for every ASIC, some residual uncertainty due to additional capacity of test setup
  - Variation of calibration capacitors is better than 0.2% within one production batch (larger variations observed between MicroBOONE and ProtoDUNE versions of LArASIC, still ~1% level)
- Can calibrate non-linearity of the 6 bits DACs with external high precision DAC
  - Non-linearity of the FE amplifier is very small (<0.1%)
- No variations of the response of the electronics over 15 months period
  - Repeat the pulser measurements once more prior to turning ProtoDUNE off

What have we learnt ? (ii)

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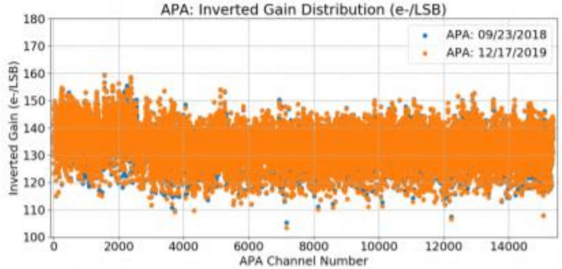
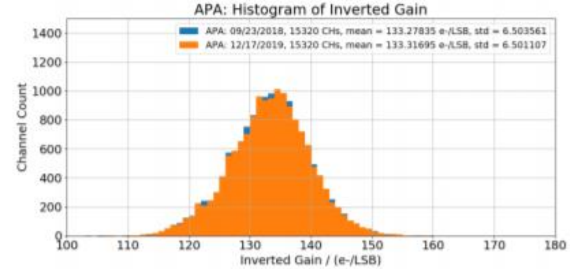
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Stability of CE in ProtoDUNE-SP (P2 FE ASIC)

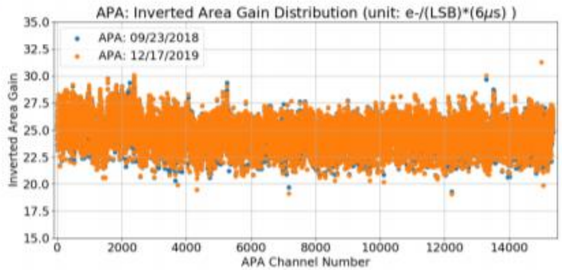
- No measurable degradation is observed over 15 months operation

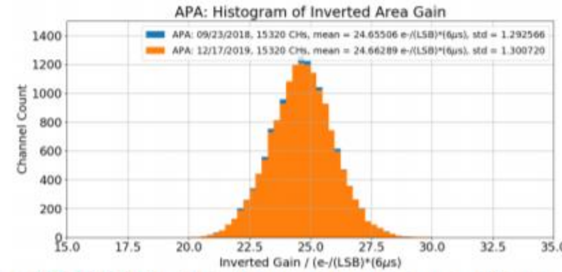




FPGA-DAC Calibration
(only 4-bit DAC is used)

Gain calculated from peaks indicates no degradation (0.03%) in the pulse amplitude





Gain calculated from areas indicates no degradation (0.03%) in the shape of pulse waveform

5/26/2020 FE Calibration 12

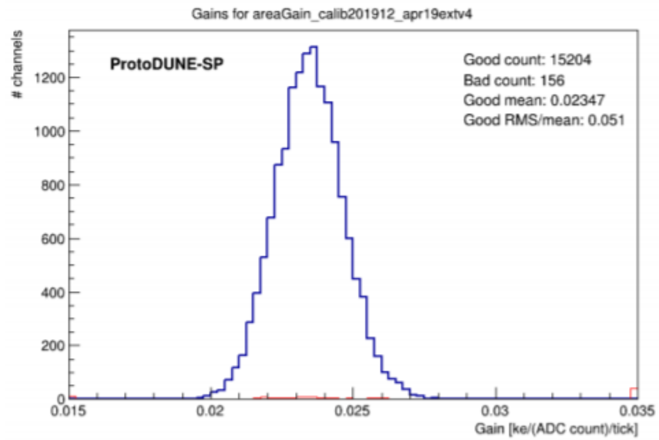
Fermilab DUNE

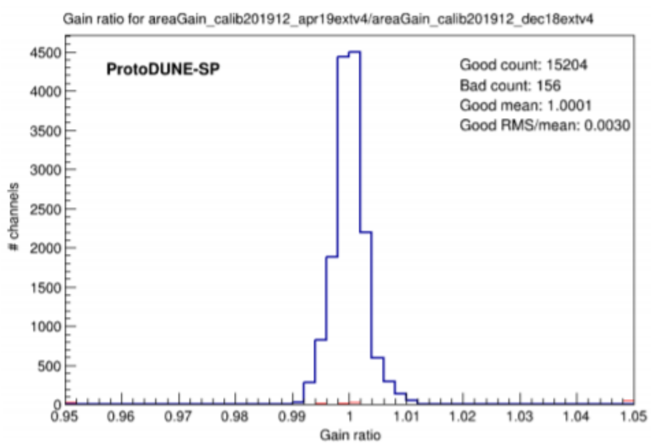
What have we learnt ? (iii)

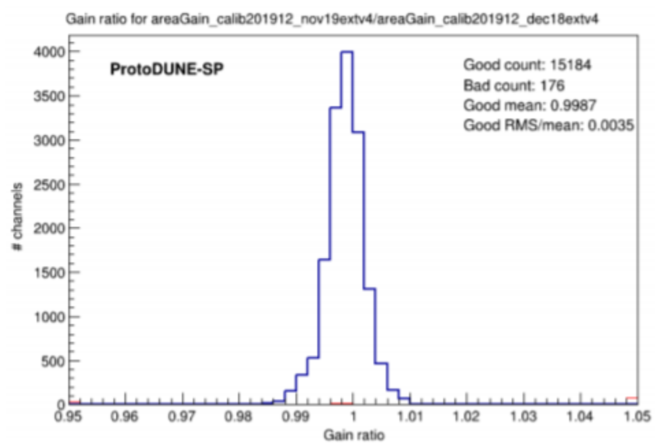
Final protoDUNE gain distributions

Summary plots

- Right is the gain distribution for the final calibration based on the Dec 2018 data
- Bottom are distributions for the gain ratios for the April 2019 and Nov 2019 datasets to the Dec 2018 data







D. Adams, BNL   DUNE charge injection   ProtoDUNE charge calibration   May 26, 2020   17

What have we learnt ? (iv)

- Channel to channel gain variation is significant (5.1%)
  - Mostly due to variation in shaping time

- 6 bit DAC internal to LArASIC does not allow access to ~1 MIP region with desired granularity

- Need to improve data taking procedures in such a way that pulser data can be collected more frequently, with small/no dead time (TPC electronics/DAQ issue)

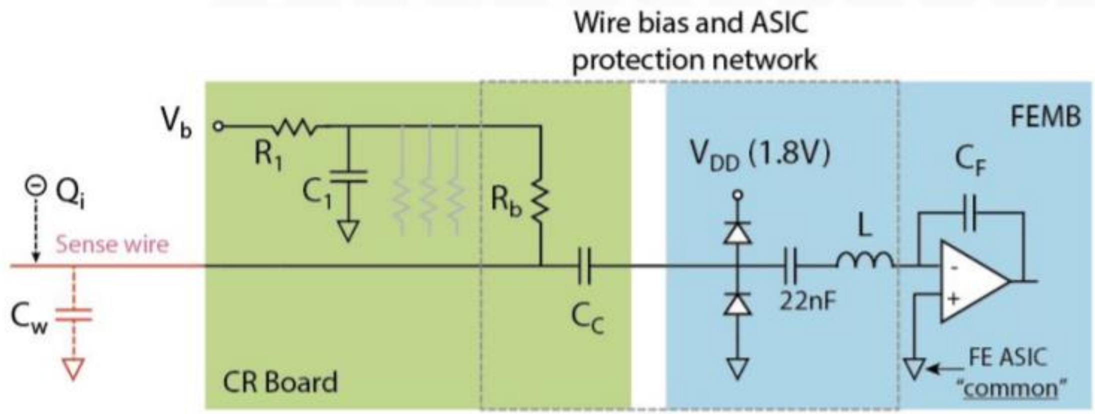
Charge measurement precision ?

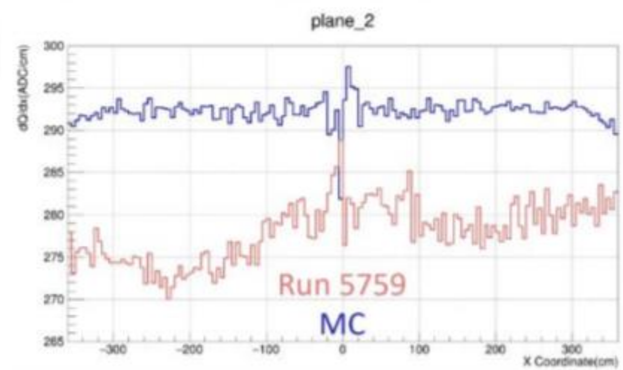
- What limits the precision of the measurement of the collected charge ?
  - Using an external pulser we can calibrate the relative response of different FE channels
    - Inject the same pulse in every channel, measure the amplitude
    - Repeat for different pulses
    - Get the gain for each channel
  - This does not get us the absolute scale
    - The knowledge of the total capacitance in front of the FE amplifier limits our capability of getting an absolute calibration

Some charge is lost

Additional charge loss on wire

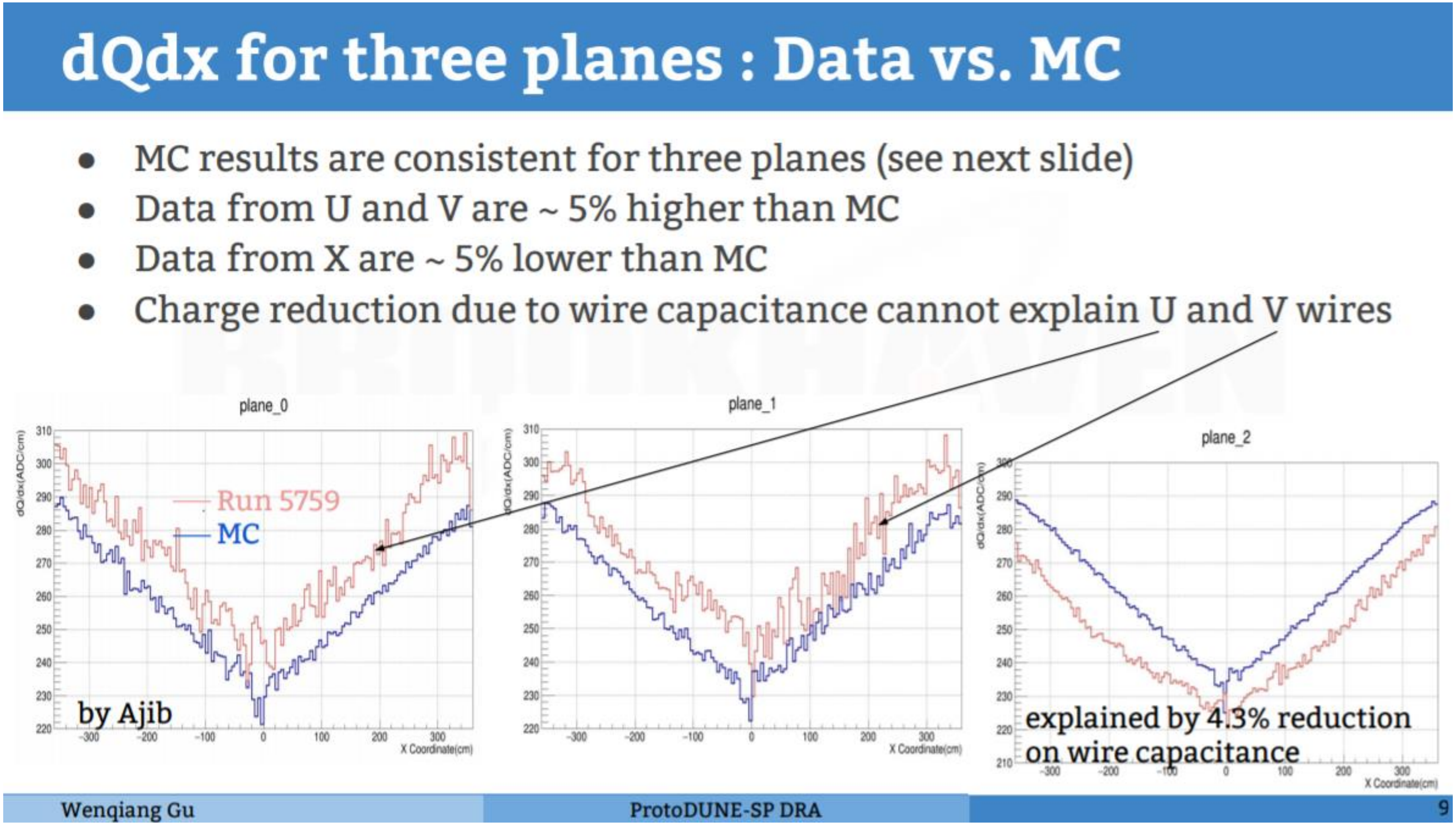
- Capacitance on a wire is about 120pF + 30pF (parasitic)
  - Both are difficult to measure, wire capacitance estimated from COMSOL simulation
- Non-transferred charge is about 150pF/(150pF + 3.31nF) ~ 4.3%
  - Serial connection of Cc (3.9nF) and 22nF = 3.31nF
- Seems to explain the 4% lower dQdx in X plane in data





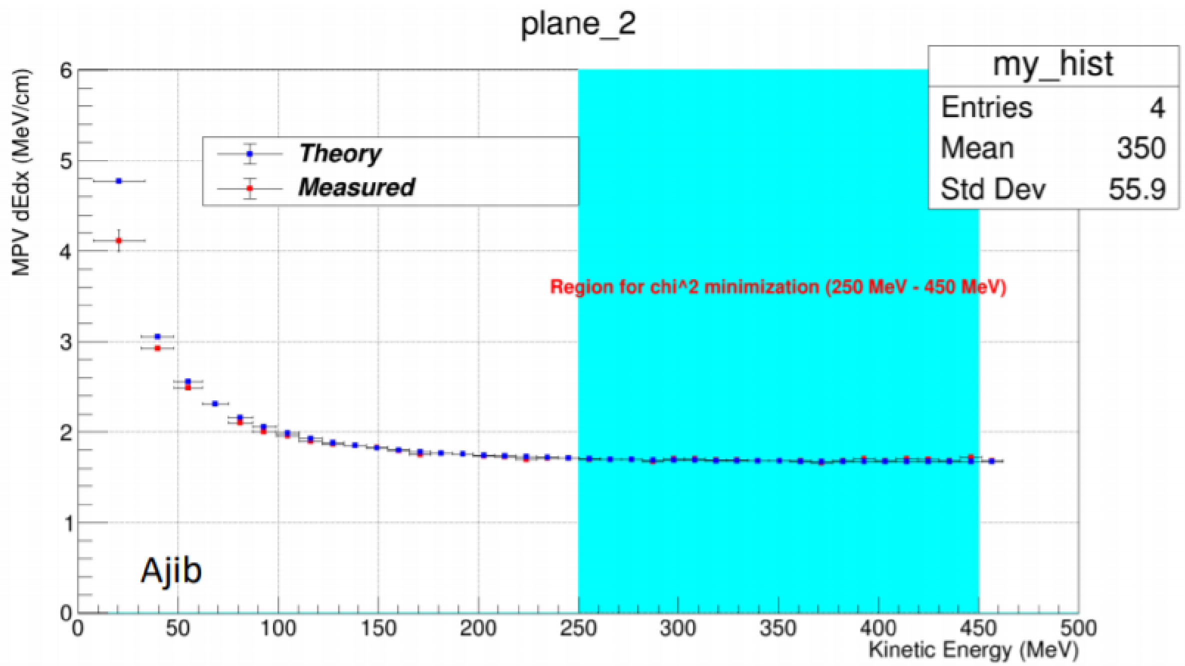
Wenqiang Gu ProtoDUNE-SP DRA 7

Not everything is fully understood



Closure test

Determine dE/dx scale using stopping muons



- Use stopping muons to determine/validate the dE/dx scale.
- If all the effects are measured and calibrated out, dE/dx should just match the prediction.
  - E.g. recombination effect needs to be well understood.

12 5/26/20 T. Yang I ProroDUNE-SP TPC Calibration

Charge measurement precision ?

- Physics analysis results are very recent
- Some aspects are not fully understood (induction wires, impact of differences between calibration pulses and physics signals)
- Important to continue these investigations and not to be satisfied with the (possibly accidental) agreement seen for collection wires

- In the future the knowledge of the capacitance of the wires and of the traces on the boards will be the limiting factor
- This is a few % correction, needs to be know to a relative ~15% level in order to claim that we know the charge deposited on the wires at the % level

Measuring the capacitance

- Wire capacitance extracted from COMSOL simulation
- Some estimate of parasitic capacitance (boards)
- Can they be measured ?
  - Very complicated and long process
    - For the wires:
      - Can this be a byproduct of the electronics wire tension measurement setup ? Don't need to do this on every APA, it would be nice to measure a couple of APAs and understand the measurements and spread
    - For the boards:
      - Same considerations, but at least the boards should be more manageable
      - How much is the capacitance of traces related to the board thickness ?
  - Other suggestions made
    - Relation to FE noise
    - Have some boards where the 3.9 nF capacitance is replaced with different one and try to understand the trend
- No, you cannot inject a signal on the wire….

Toward DUNE

1. We will continue to have the 6 bit (10 bit in CRYO) DAC in the FE amplifier
2. We will <u>consider</u> the addition of a 16-18 bit DAC on the WIB that will allow us to perform calibrations in situ (i.e. when the APAs are in the LAr)
3. We will keep having the possibility of using an external DAC
4. Even if COLDATA in principle could allow us to have a second 6-bit pulser on the FEMB
   - we may not pursue this if we add the DAC on the WIB (see 2.)
5. Together with the APA consortium we should investigate whether it is possible to get better estimates of the capacitances of wires and boards and to asses an uncertainty on them
6. Together with the DAQ consortium we will develop procedures that will allow us to collect this data more quickly and frequently, without significant down time

Why did I say consider ?

- "We will consider the addition of a 16-18 bit DAC on the WIB that will allow us to perform calibrations in situ (i.e. when the APAs are in the LAr)"
  - This is something that can be done relatively cheaply ($20-25k per detector), if 1 DAC can be used to drive all five FEMBs
- We have not yet understood what the physics group is asking for….. (lower precision may be sufficient)
- Need to consider overall impact on FEMB/WIB/cable plant

Personal opinion (1)

- At this point I do not think that anybody can guarantee that we will be able to obtain an absolute calibration of the charge measurement in DUNE at the ~1% level
- I think we can safely claim that we can reach the 1.5-2% range
- It may well be that we will know the calibration up to few scale factors (upper/lower APA ? Different scale factors for different wires ?) to be determined with data in DUNE

Personal opinion (2)

- Some of this work has also highlighted the lack of proper communication between people working on analysis and people working on detector
  - Need to give serious thought on how to improve on this
  - If you want to calibrate a detector at the % level you need to know the details of every single measurement that has a role in reaching that precision
  - If you want the detector groups to deliver this precision, your requirements must be spelled out very clearly
  - It is not enough to say “something is a critical component in achieving this level of precision”, it is much better to say “we need that component to be known at this level so that we can reach that precision overall”
  - Dissemination of test results outside of the TPC electronics group is also poor