



Capacitance and Expected Charge for GE2/1 and ME0 Readout Strips

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Motivation & Introduction



- **Purpose:** Inform VFAT3 specifications for GE2/1 and ME0. Help to answer this question:
“Can VFAT3b work for GE2/1 and ME0?”
- Discuss recent strip capacitance measurements on second prototype of GE2/1 M4 readout board at Lappeenranta
- Revisit direct measurements of charges induced on readout strips in CMS GEM detectors when exposed to “mip-like” particles in 2013 beam test



Specific Information Needed



Paul has asked GEM community to fill in this table for GE2/1 and for ME0 to “understand if VFAT3b is suitable ‘as is’ for GE21 and ME0 or if a new design is required”.

Parameter	Value		Notes
	GE2/1	ME0	
Hit rate per channel (at gain ≈ 8000)	< 2.6 kHz	< 46 kHz	Max. GE2/1 hit rate: 700 Hz/cm ² (TDR, Tab. 1.4) Max. ME0 hit rate: 48 kHz/cm ² at inner R (ditto) Strip area estimate: L×W; W=R×Δφ (pitch); at inner R GE2/1: 23.6cm × 137cm × 0.00047 = 1.5 cm ² (TDR) ME0 : 6.7cm × 63cm × 0.00094 = 0.4 cm ² (TDR) Average strip multiplicity : 2.4 strips (at gain 8000)
Signal charge per strip (MPV, Mean, Max)			
Capacitance per channel (min, max)			
Inter-strip capacitance (min, max)			

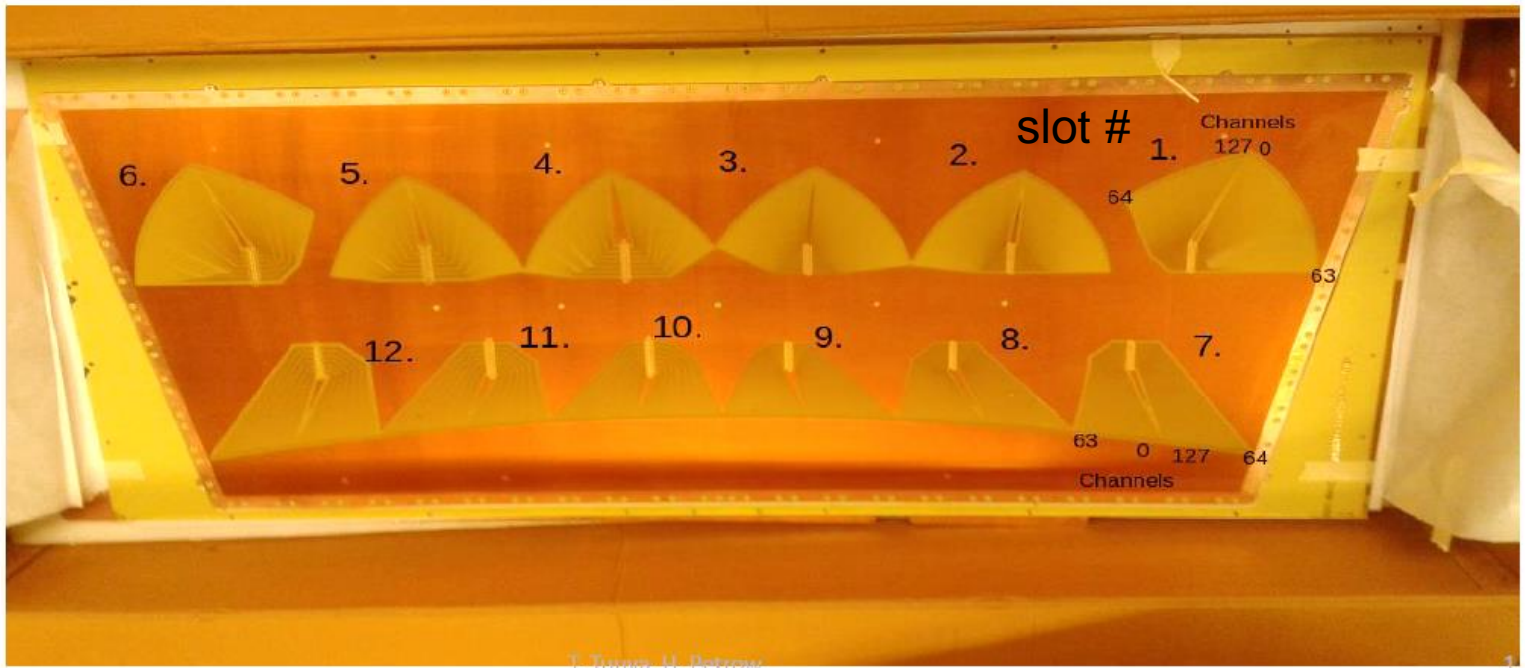


Lappeenranta

GE2/1 READOUT STRIP CAPACITANCE MEASUREMENTS

GE21 RO board capacitance and noise measurements

- 12 different designs, 4, 5, 6, 10, 11, 12 with new connector



T. Tuuva, H. Petrow

[Tuure Tuuva, Henri Petrow, talk at Phase 2 R&D meeting, March 20, 2018](#)



Results for GE2/1 Capacitance



slot		1	2	3	4	5	6	7	8	9	10	11	12	GE11 J19
Total strip interstrip capacitance [pF]	(w/o GEB; meas. #1)	33	35	34	35	39	33	35	37	34	33	35	37	23
Total strip interstrip capacitance new [pF]	(w/o GEB; meas. #2)	35	35	35	38	37	35	36	35	33	36	37	37	
Total strip interstrip capacitance w. GEB [pF]		38	40	36	0	0	0	40	41	35	0	0	0	25
Strip to ground capacitance [pF]	(w/o GEB)	3	4	4	4	4	4	3	4	4	4	4	4	2
Strip to ground capacitance w. GEB [pF]		10	9	10	0	0	0	9	9	8	0	0	0	4

T. Tuuva, H. Petrow

GE1/1 r/o cap. values for comparison



- For details on the measurement technique, see:
 - [Tuure Tuuva, Henri Petrow, talk at Phase 2 R&D meeting, March 20, 2018](#)
- Total strip capacitance
 - Is the **sum of cap. to both neighboring strips plus cap. to GND**
 - Basically scales with strip length (1.5 pF/cm) as expected
- GEB was floating in these measurements
- Grounding the GEB does not change the C values
- New connectors do not change capacitances



Related Noise Measurements



[Tuure Tuuva, Henri Petrow, talk at Phase 2 R&D meeting, March 20, 2018](#)

- Measured noise with VFAT and OH dummy with adapter using one slot at a time. Adapter doesn't add to noise.
- **Observations:**
 - Connector type (new vs. old) does not appear to affect the noise.
 - GEB shielding reduces noise.
 - **Typical noise is 0.6-0.9 fC with max. 1.8 fC (as of 3/20/18).**
 - Strips on edge show higher noise.
 - Currently have small distance between grounded fanout lines on outside of r/o PCB and floating GEB shield, so have large capacitive coupling. Adding paper sheets to increase GEB-r/o distance reduces noise substantially.
- **(My) Conclusion:** Distance GEB to r/o board is a critical parameter for the VFAT noise that we have to control carefully.



FIT

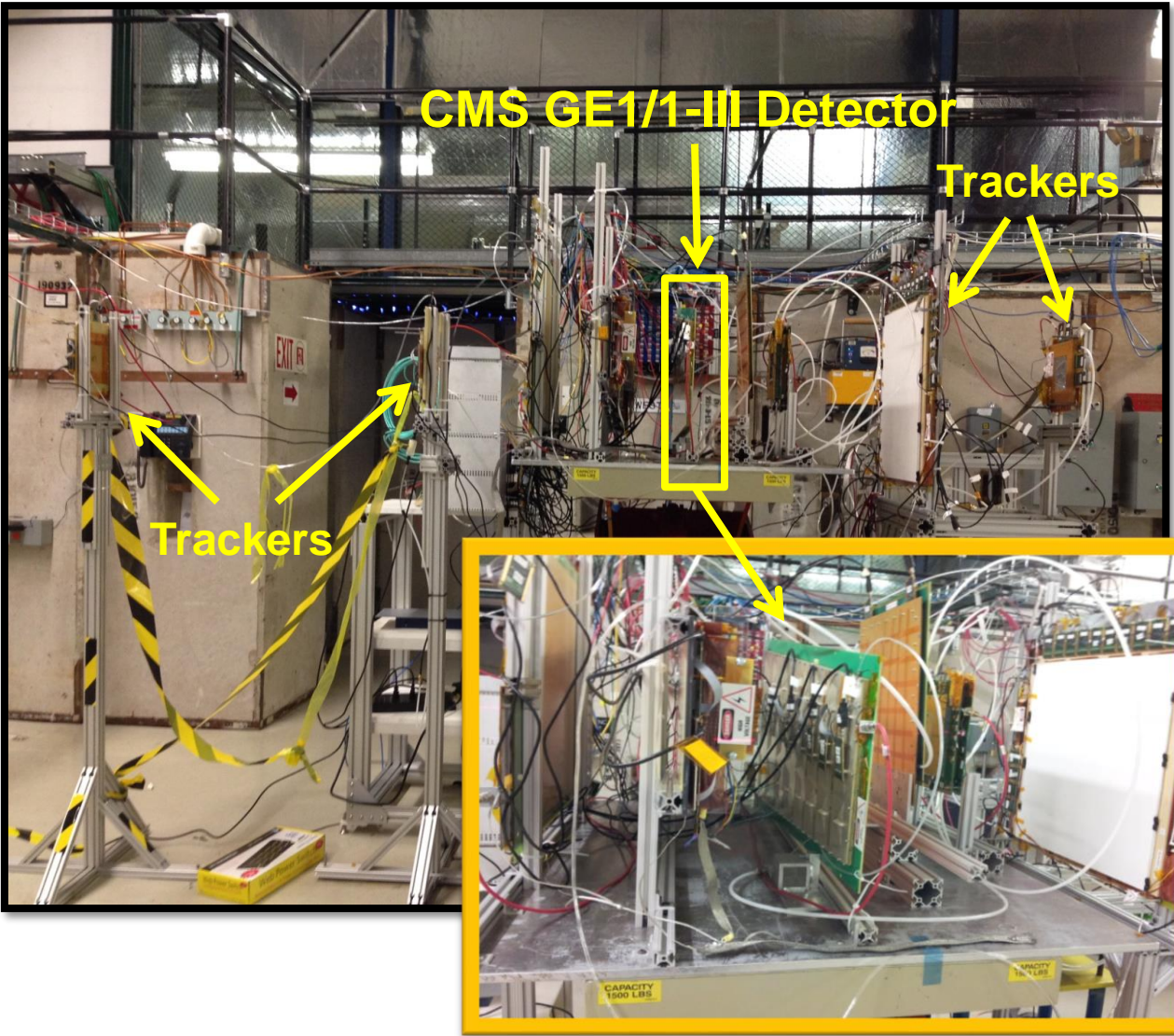
READOUT STRIP CHARGE MEASUREMENTS



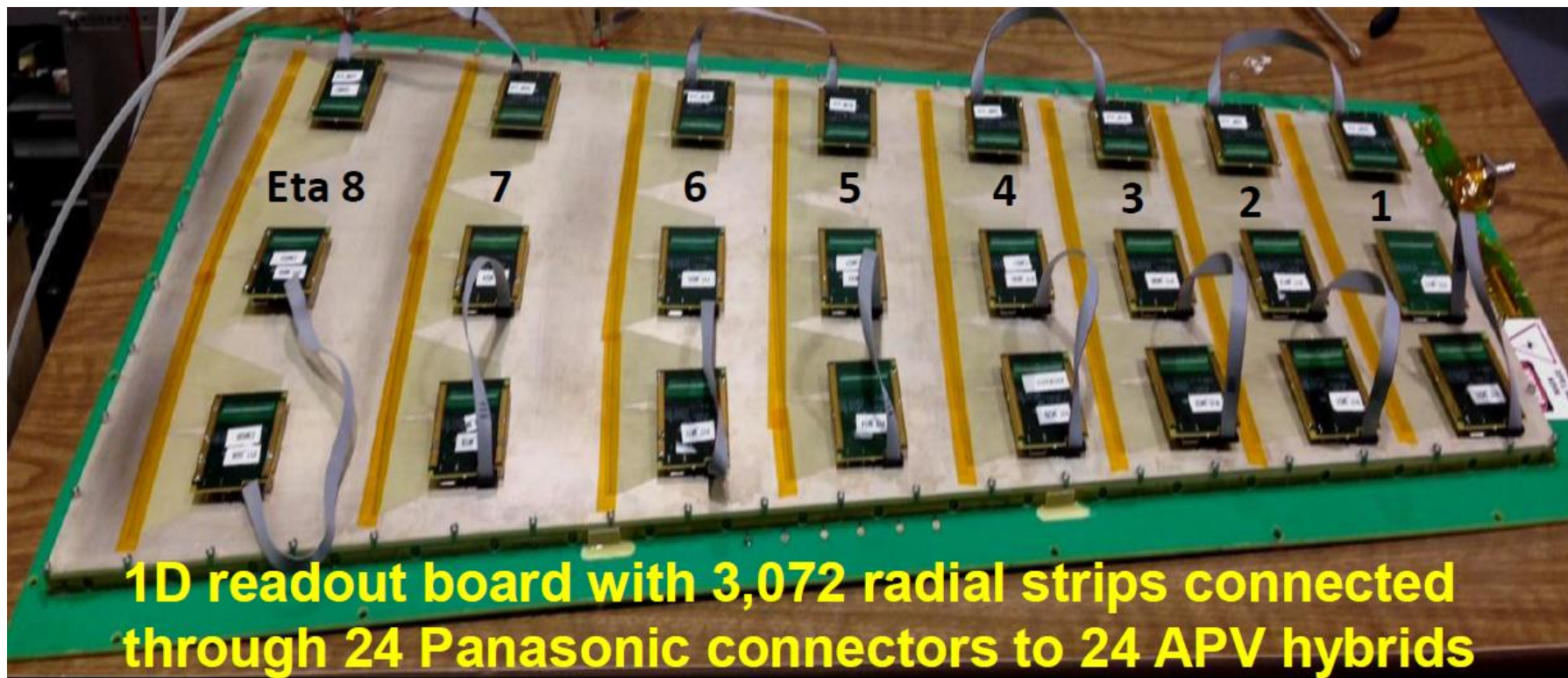
Geometry Reminder



- GE1/1-X prod. chambers, GE1/1-III prototype discussed here, and GE2/1 and ME0 all have the same electrode gap sizes (3/1/2/1 mm)
- GE1/1-X prod. chambers, GE1/1-III prototype discussed here, and GE2/1 have very similar angular readout strip pitches (455 - 474 μ rad)
- **In terms of gain and signal induction process, GE1/1 and GE2/1 should be very similar.**
- The angular pitch of readout strips in ME0 is twice as big (940 μ rad) as in GE1/1, but the linear strip pitch in ME0 is similar to GE1/1 (because ME0 is at half the radial distance to beam as GE1/1)



- Gas mixture used in all detectors: Ar/CO₂ 70:30
- Beam Energy:
32 GeV mixed hadrons (mostly pions)
- Three 10 cm × 10 cm & one 50 cm × 50 cm GEM trackers with 2D readout area @ 4200V
- DAQ with RD51 SRS
- GE1/1-III detector tests:
High voltage scan from 2900V to 3350V
- Operating voltage: 3250V (50V above the start of efficiency plateau of this detector)



- Each η -sector has 384 radial strips and a total of 3072 strips
- Strip pitch = 455 μ rad (standard); **very similar to GE2/1**
- APV-25 chip is used to read signal from readout strips



Results: Old Hat!



- All data reported here were reported previously in GEM workshop XII (Oct 2015) and are documented in CMS note CMS IN-2017/001
- Work done by Vallary Bhopatkar and Aiwu Zhang (FIT).

Available on CMS information server



CMS IN -2017/001

CMS Internal Note

The content of this note is intended for CMS internal use and distribution only

05 April 2017

Measurement of the Charge Induced on the Readout Strips of a GE1/1 Detector Prototype for the CMS Muon Endcap GEM Upgrade

Vallary Bhopatkar, Marcus Hohlmann, Aiwu Zhang

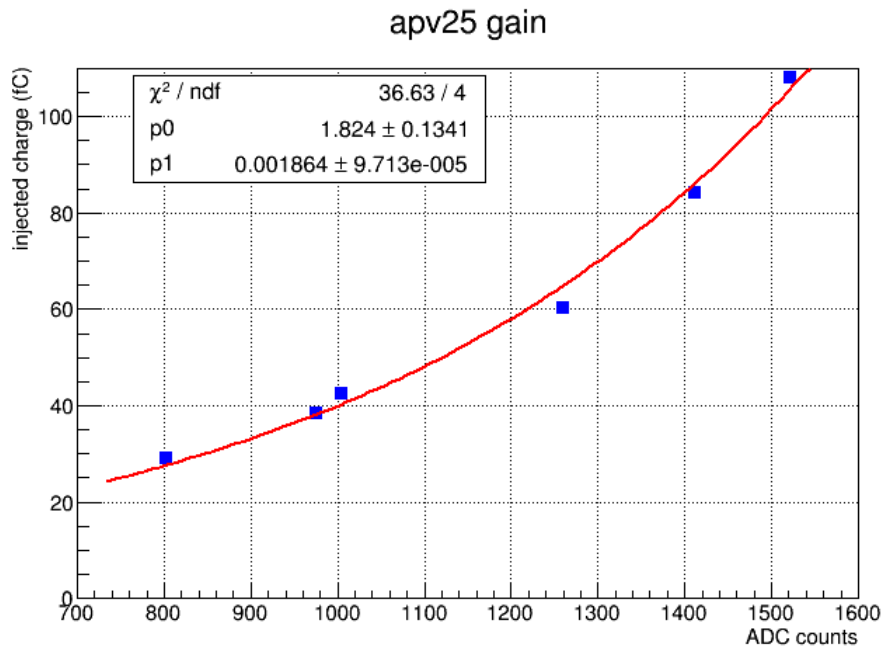
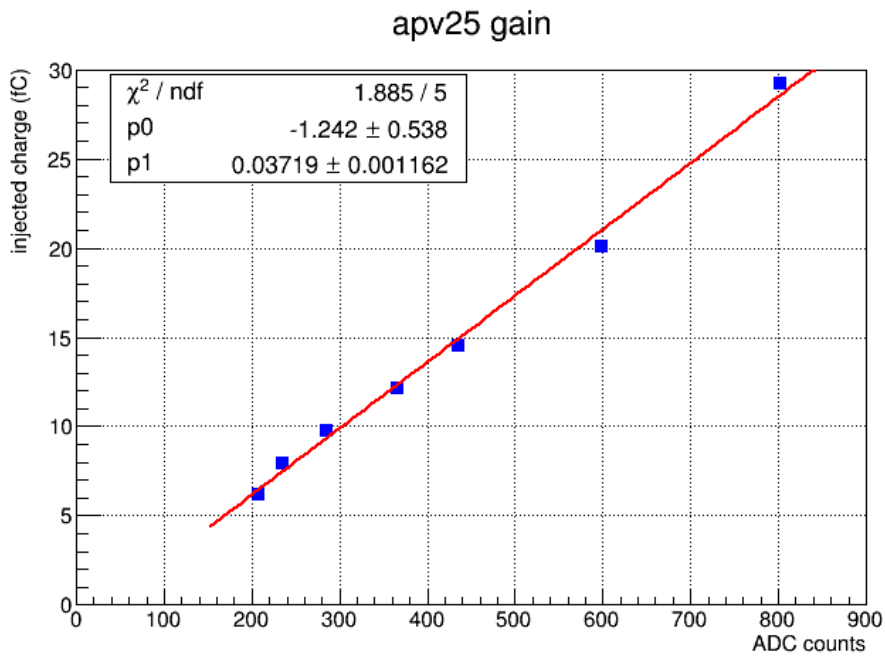
Abstract

Early in the second phase of the LHC program, Gas Electron Multiplier (GEM) technology will be implemented in the GE1/1 muon chambers for the region $1.6 < |\eta| < 2.2$ of the CMS muon endcap. A VFAT3 front-end chip is being designed to read out the GE1/1 detector that will provide binary hit output. The charge that is induced on the GE1/1 readout strips by minimum-ionizing particles is an important parameter that informs the design of the amplifier-shaper input stage of the VFAT3 chip. We have measured this charge distribution directly with a GE1/1-III prototype chamber read out with the pulse-height-sensitive APV25 chip and exposed to a mixed-hadron beam at Fermilab. When operating 50 V above the start of the efficiency plateau in an Ar/CO₂ 70:30 gas mixture, i.e. with 3250 V applied to the drift electrode, the most probable value, mean value, and 99th percentile value of the Landau distribution of the charge induced on a single strip are found to be 4 fC, 11 fC, and 115 fC, respectively. Measurements with a more economical readout structure with 128 zigzag strips per η -sector instead of the 384 strips per η -sector in the GE1/1 are also analyzed. When equipping the same GE1/1 chamber with a readout board that features such zigzag strips and operating the chamber in the same way as before, the corresponding measured values for most probable and mean values are 7 fC and 16 fC, respectively.

- Using APV calibration data (courtesy Kondo Gnanvo, U. of Virginia), the charge conversion for SRS ADC counts to fC is

$$Q \text{ (in fC)} = 0.03719 \times \text{ADC} \quad \text{for ADC} < 800$$

$$Q \text{ (in fC)} = \exp [1.8 + (0.0018 \times \text{ADC})] \quad \text{for ADC} \geq 800$$

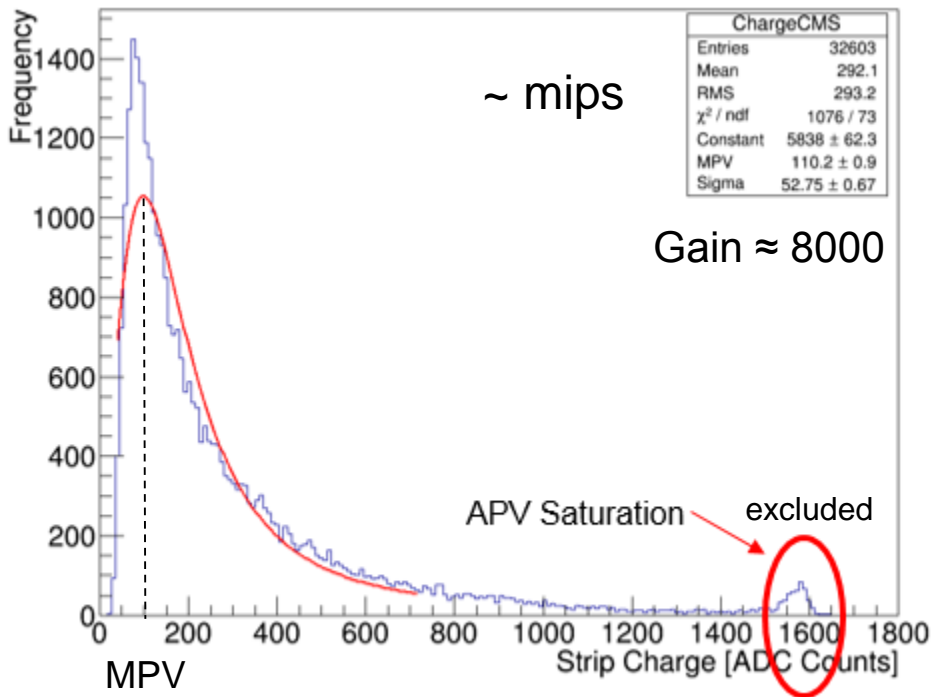




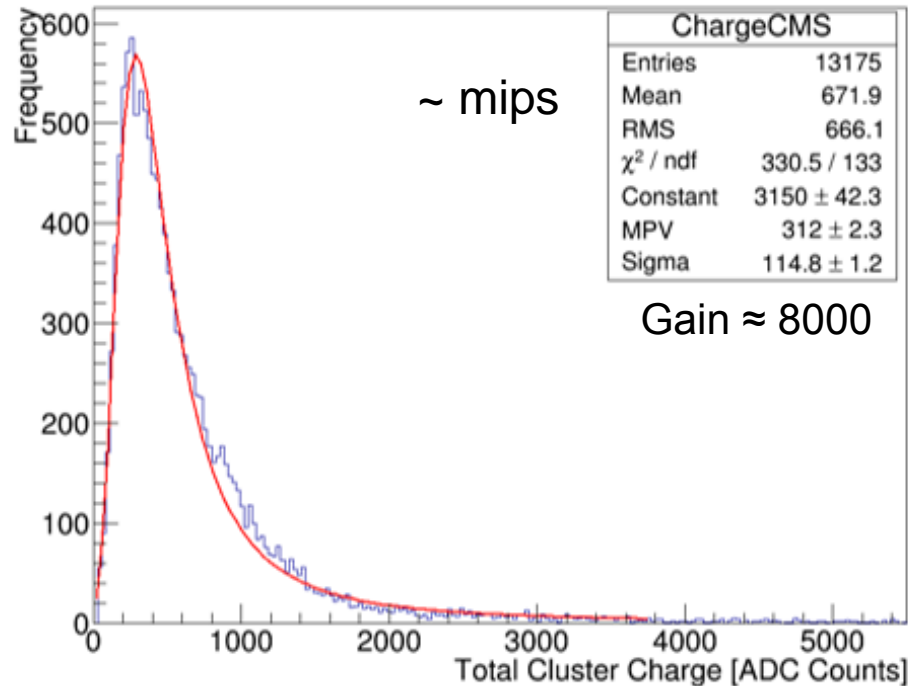
GE1/1-III: Measured Charge Distribution



Strip charge distribution



Strip cluster charge distribution



Measured strip charge at $V_{\text{drift}} = 3250\text{V}$:

Mean charge = 292 ADC $\approx 11 \text{ fC}$

Most Prob. Value = 110 ADC $\approx 4 \text{ fC}$ (fit)

4% of strips have $Q < 50 \text{ ADC} \approx 2 \text{ fC}$

Estimate for expected mean cluster charge (mip):

Primaries: $N_T = 29 \text{ e/ion}$ over 3mm drift

$$Q = N_T \times \text{Gain} = 29 \text{ e} \times (\approx 8000) = 232,000 \text{ e}$$

$$= 37.12 \text{ fC}$$

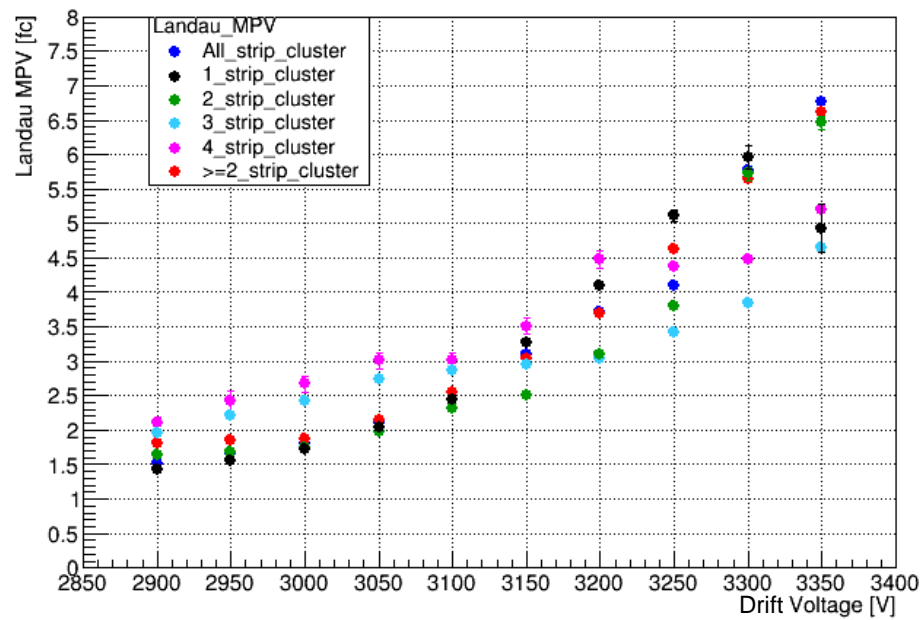
$$= 964 \text{ ADC counts}$$

Note: Slice test chambers run at gain = 10,000; scale Q to actual gain as needed

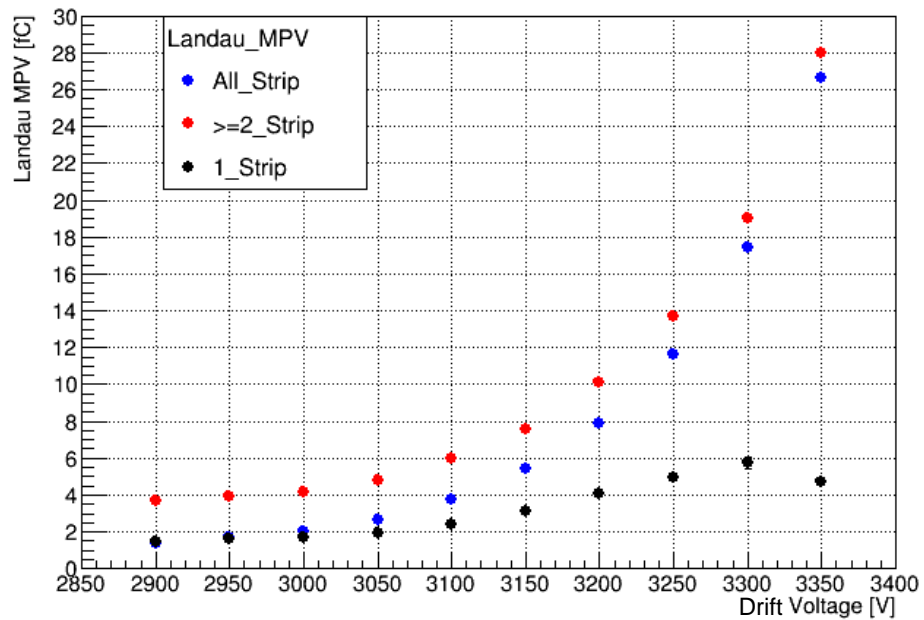
Strip charge (fC)

Total cluster charge (fC)

Landau MPV vs. High Voltage



Landau MPV [fC] vs. High Voltage

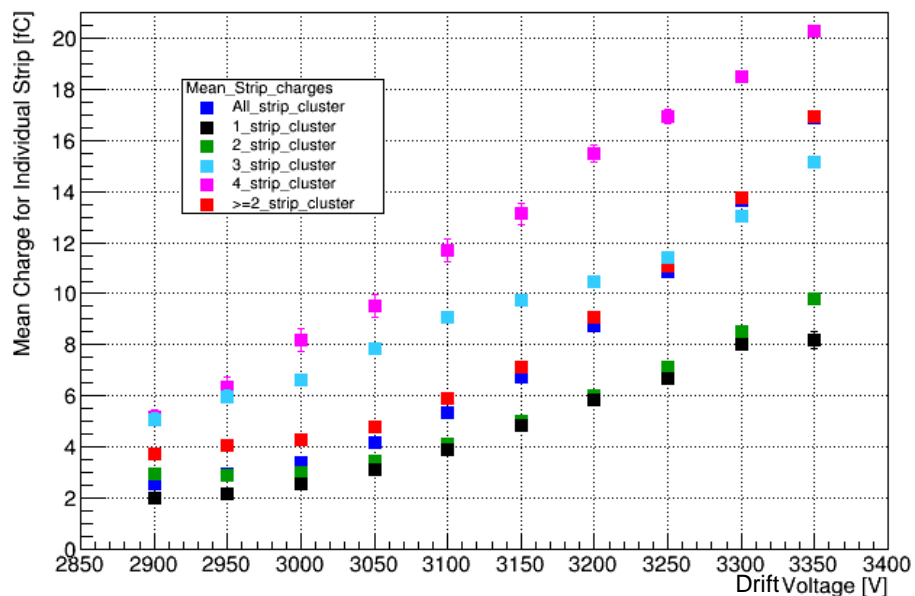


Charges are plotted using different cuts on strip cluster size, i.e. for all strip clusters, for 1-strip, 2-strip and 3-strip clusters and so on.

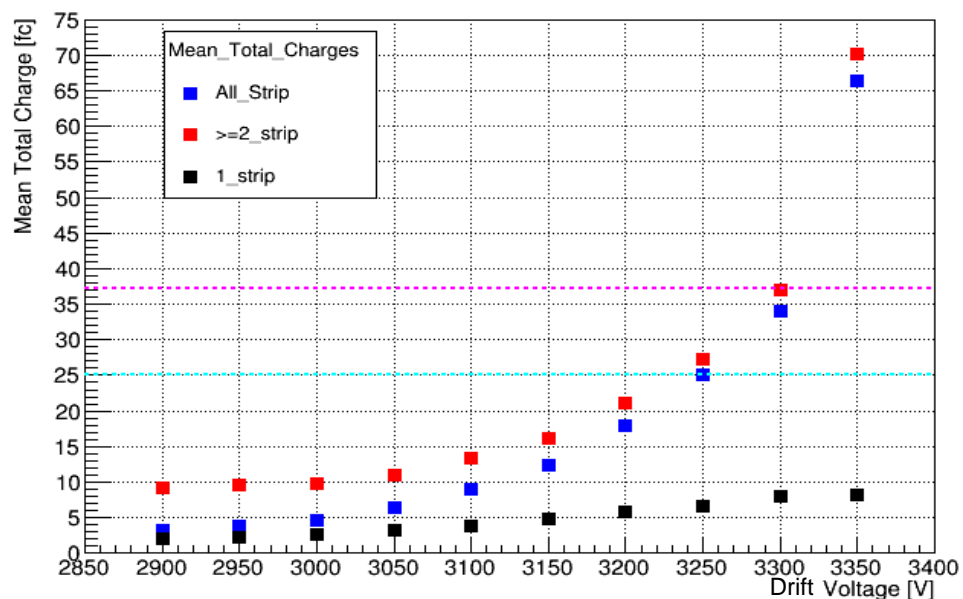
Strip charge (fC)

Total cluster charge (fC)

Mean Strip Charge vs. High Voltage

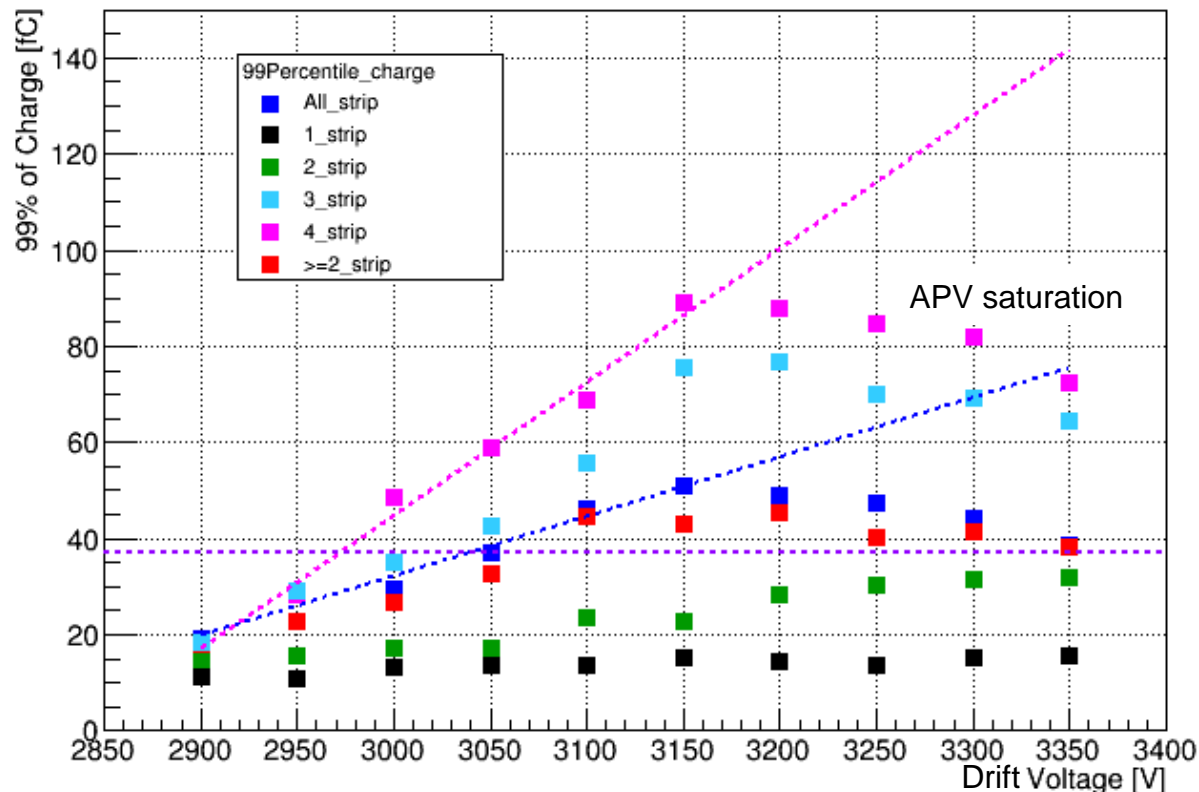


Mean Total Charge vs. High Voltage



99th Percentile of Strip Charge

99% of Charge vs. High Voltage



Largest expected charge by extrapolating strip charges for 4-strip clusters:

99% (at operating voltage) \leq 115 fC
 99% (at max. HV) \lesssim **140 fC**



Information Summary



Paul has asked GEM community to fill in this table for GE2/1 and for ME0 to “*understand if VFAT3b is suitable ‘as is’ for GE21 and ME0 or if a new design is required*”. **Here it is:**

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Signal charge per strip 96% have charge above MPV Mean Max (99 th percentile)	2 fC 4 fC 11 fC 115 fC	Expect similar	For mip-like particles at gain 8000; based on GE1/1-III measurements Note: compare with the 0.6-0.9 fC typical noise measured recently on the GE2/1 r/o board at Lappeenranta
Capacitance to ground per channel (min, max)	3 - 4 pF 8-10 pF	Expect 2 - 4 pF (like GE1/1)	No GEB (GE2/1) With GEB (GE2/1)
Total strip capacitance (min, max)	33-41 pF	Expect 10-20 pF	GE2/1: \approx 1.5 pF/cm; similar to GE1/1 ME0 strip lengths are 6.7-13 cm



The End



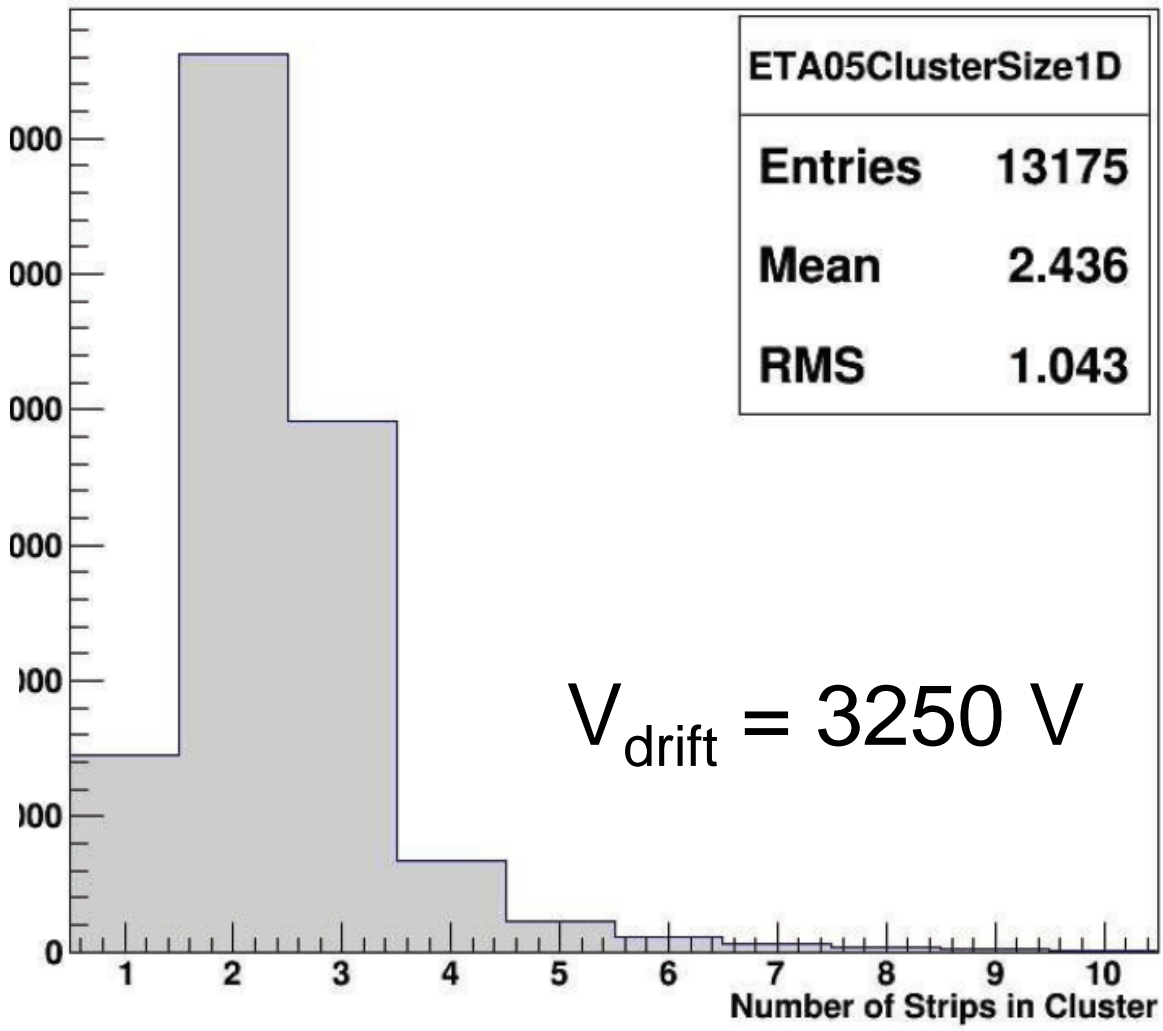
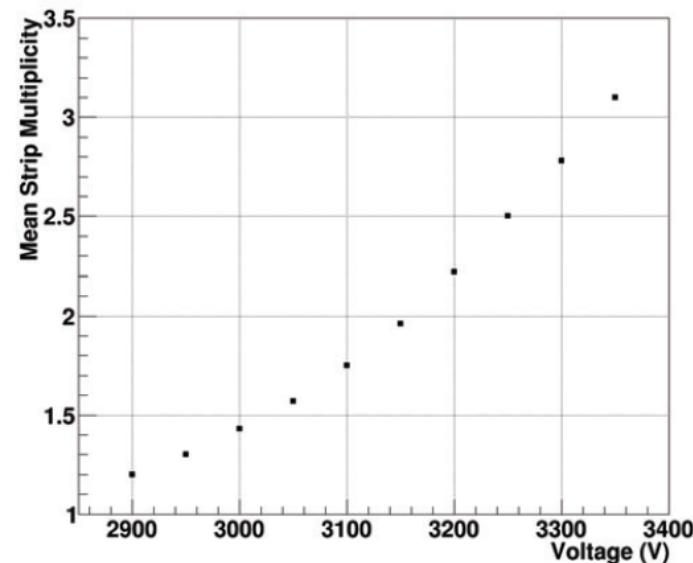
Thank You !



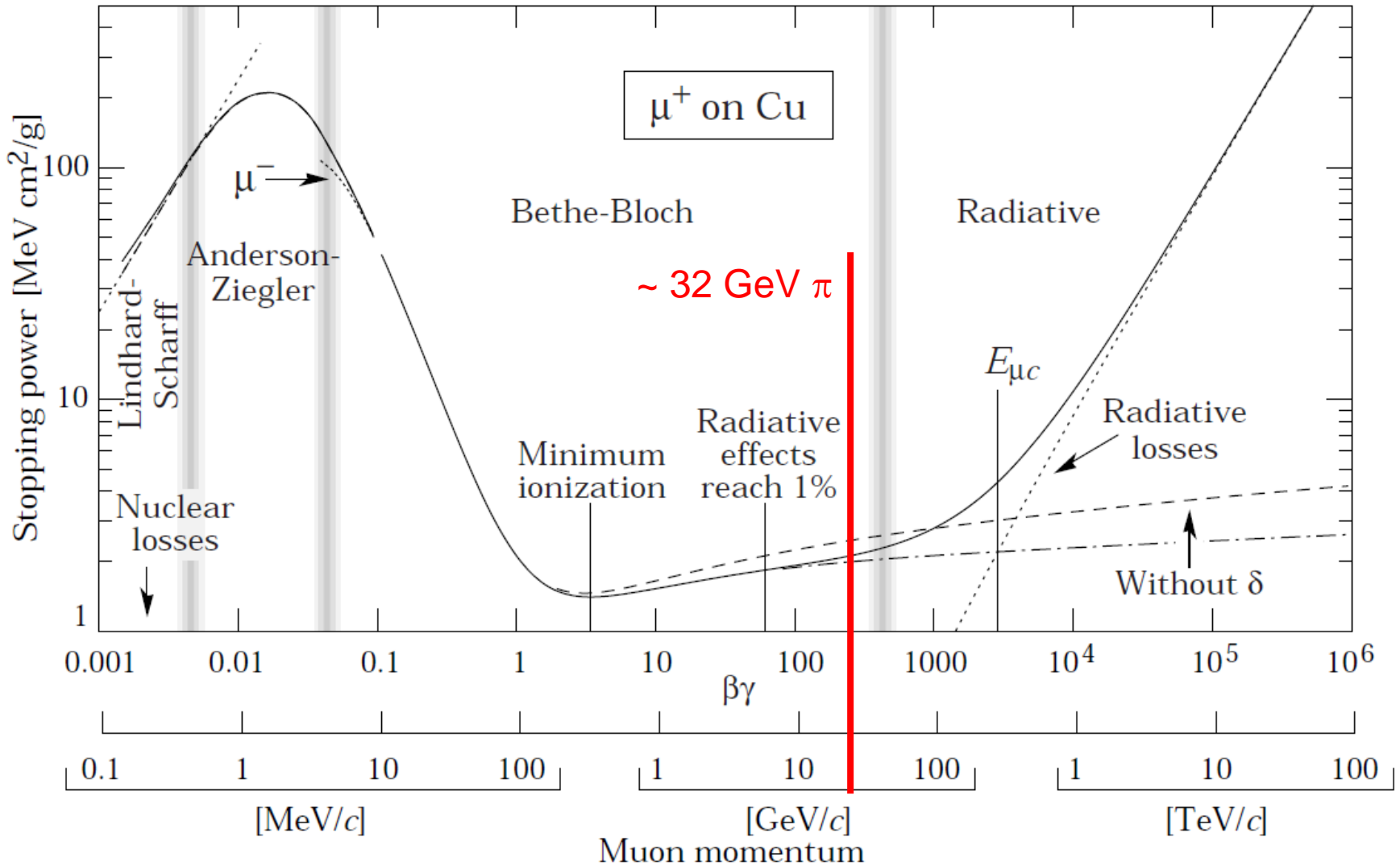
BACKUP



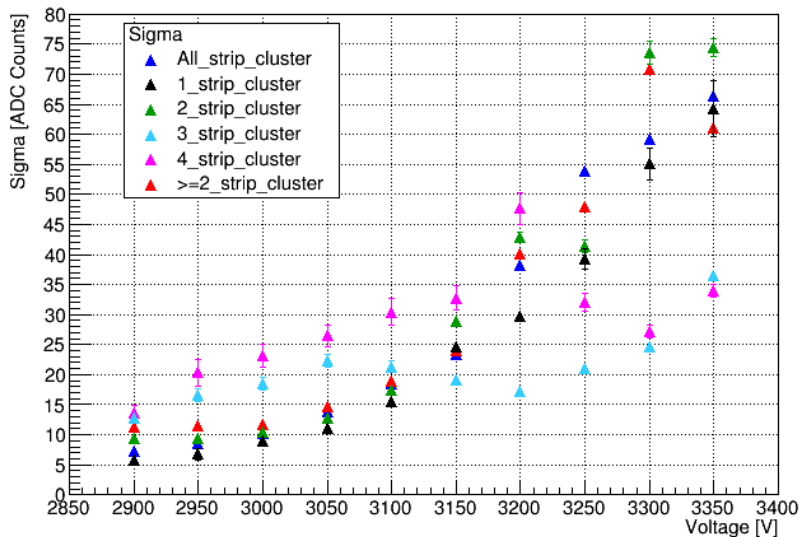
Strip Multiplicity in Clusters



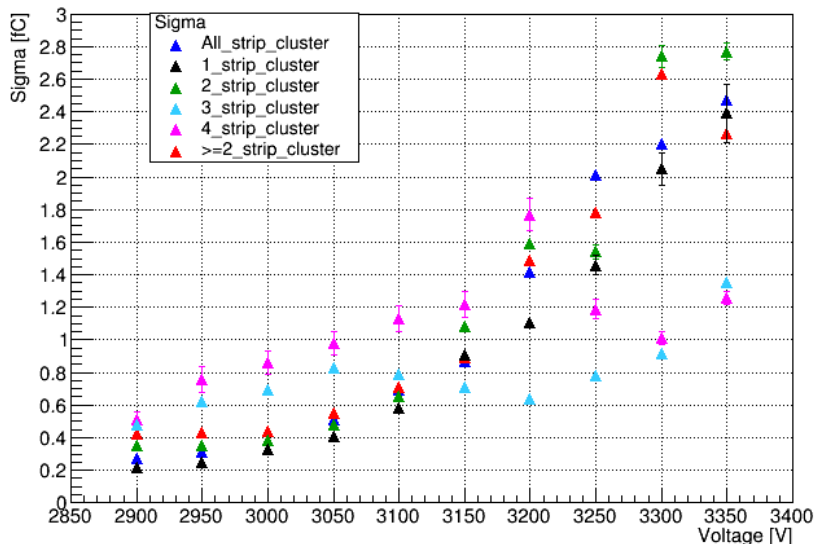
Bethe-Bloch dE/dx Curve



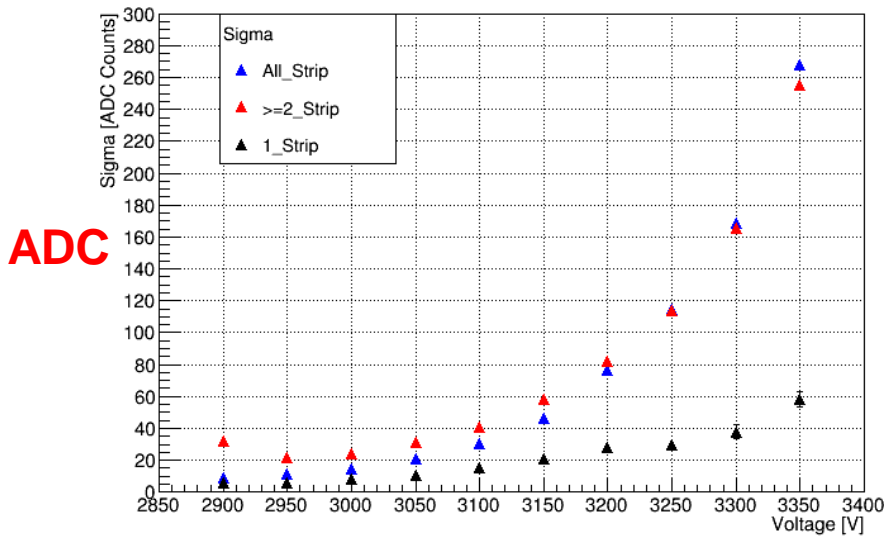
Strip charge
Sigma vs. High Voltage



Sigma vs. High Voltage



Total cluster charge
Sigma vs. High Voltage



Sigma vs. High Voltage

