Measurements of GEM electron and ion transmission using the Cornell/Purdue TPC

Cornell University	Purdue University	Radford University
T. Anous L. Fields R. S. Galik P. Onyisi D. P. Peterson	K. Arndt G. Bolla I. P. J. Shipsey	J. Inman

Information available at the web site:
http://www.lepp.cornell.edu/~dpp/tpc_test_lab_info.html

* presentation at ALCPG Vancouver	18-July-2006
* presentation at Berkeley TPC Workshop	08-April-2006
* presentation at ECFA 2005 Vienna	24-November-2005
* presentation at ALCPG Snowmass	23-August-2005
* presentation at LCWS05, Stanford	21-March-2005
* presentation at TPC mini-workshop, Orsay	12-January-2005

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Topics

Modifications to the TPC since the Vienna meeting

Preparations for ion feedback measurements

- Double layer field cage termination transparency
- Ion feedback demonstration with wire gas-amplification

Measurements of electron and ion transmission

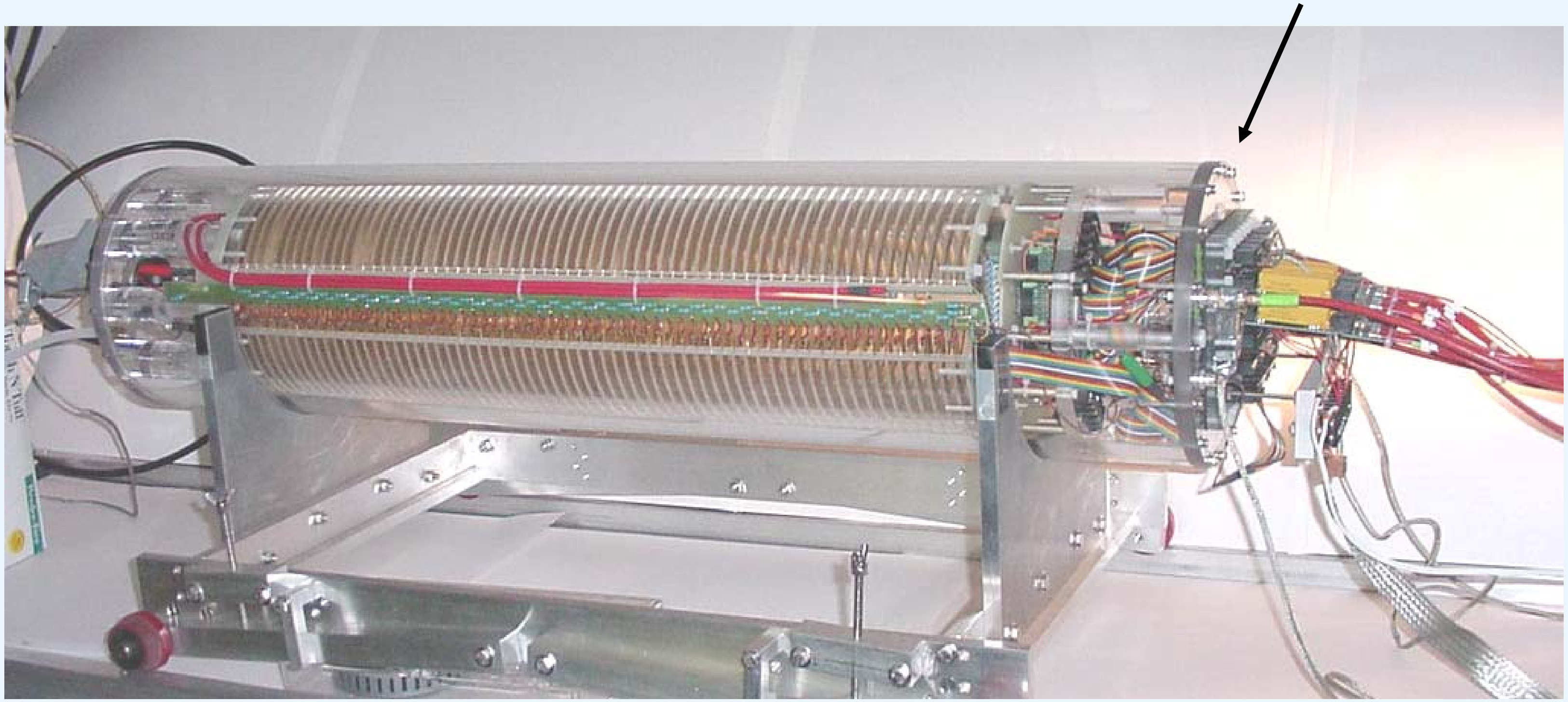
Comments on continued preparations for ion feedback measurements

TPC

14.6 cm ID field cage - accommodates a 10 cm GEM
64 cm drift field length
22.2 cm OD outer structure (8.75 inch)

“field cage termination” and “final” return lines for the field cage HV distribution allow adjustment of the termination bias voltage with an external resistor.

Read-out end:
- field cage termination
- **readout pad and amplification module**
- pad biasing boards
- CLEO II cathode preamps

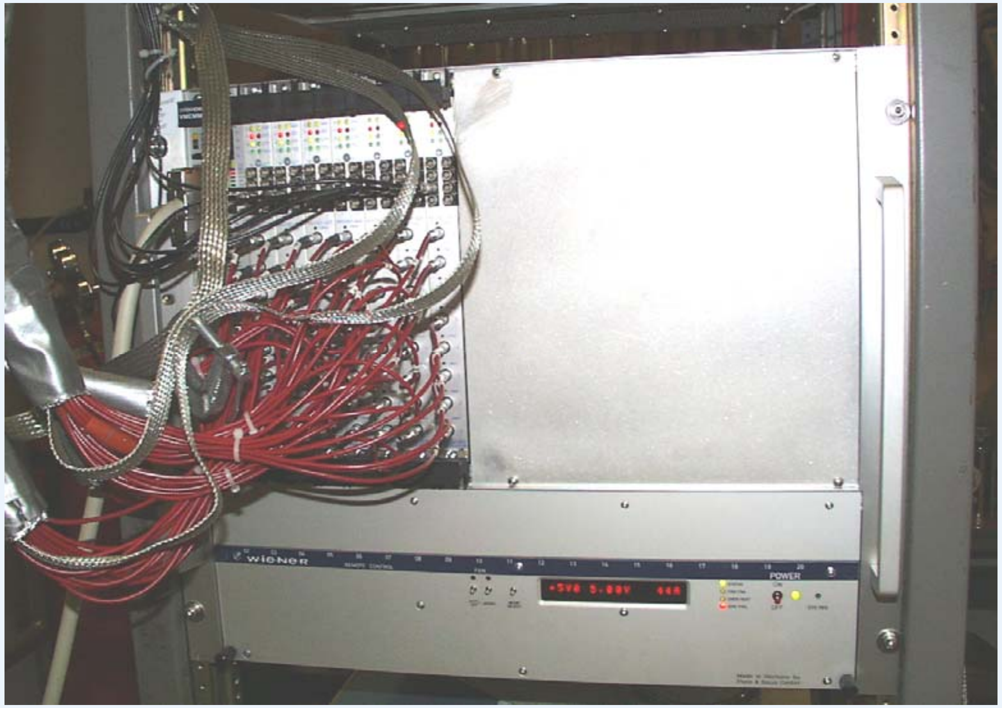


Electronics

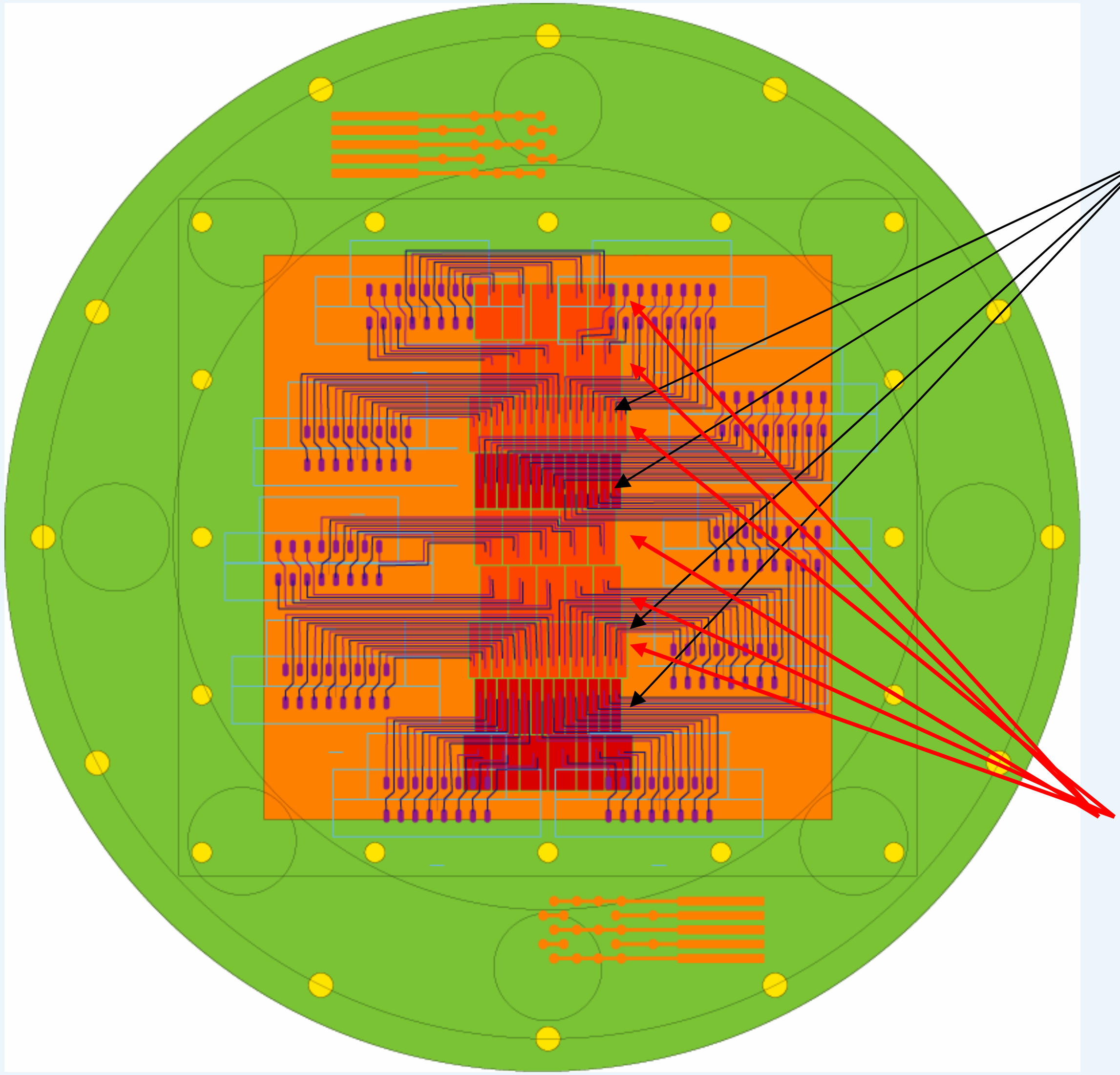
High voltage system:
- -20 kV module
- -2 kV module, 4 channels
- +2 kV module, 4 channels

Readout:
- VME crate
- PC interface card
- LabView

- Struck FADC
  - 56 channels
  - 105 M Hz
  - 14 bit
  - +/- 200 mV input range
  - (least count is 0.025mV)
  - NIM external trigger input
  - circular memory buffer



TPC Improvements:



FADC channels increase from
32 to 56 channels

Pad board with 2 mm pads.

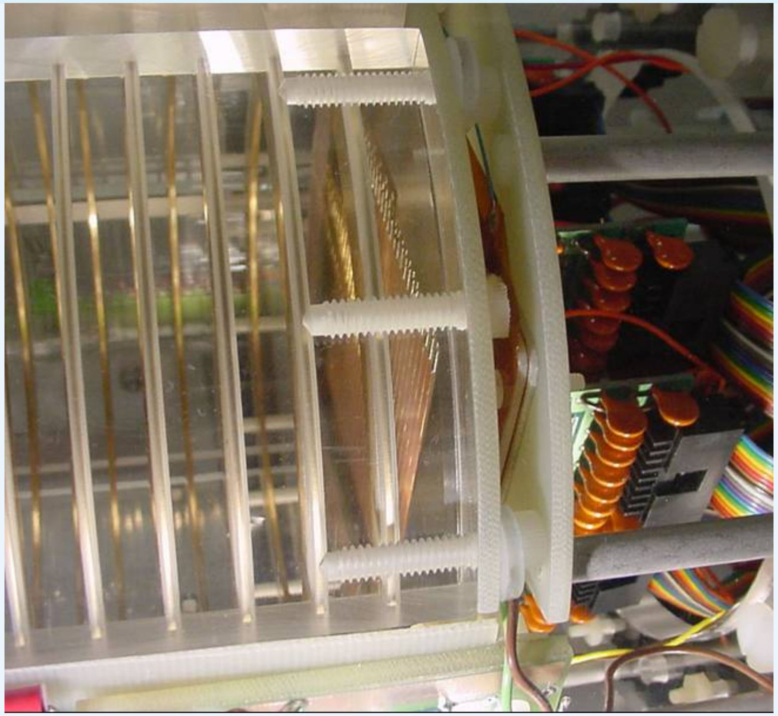
4 layers of 2mm pads
5 layer of 5mm pads
for track definition

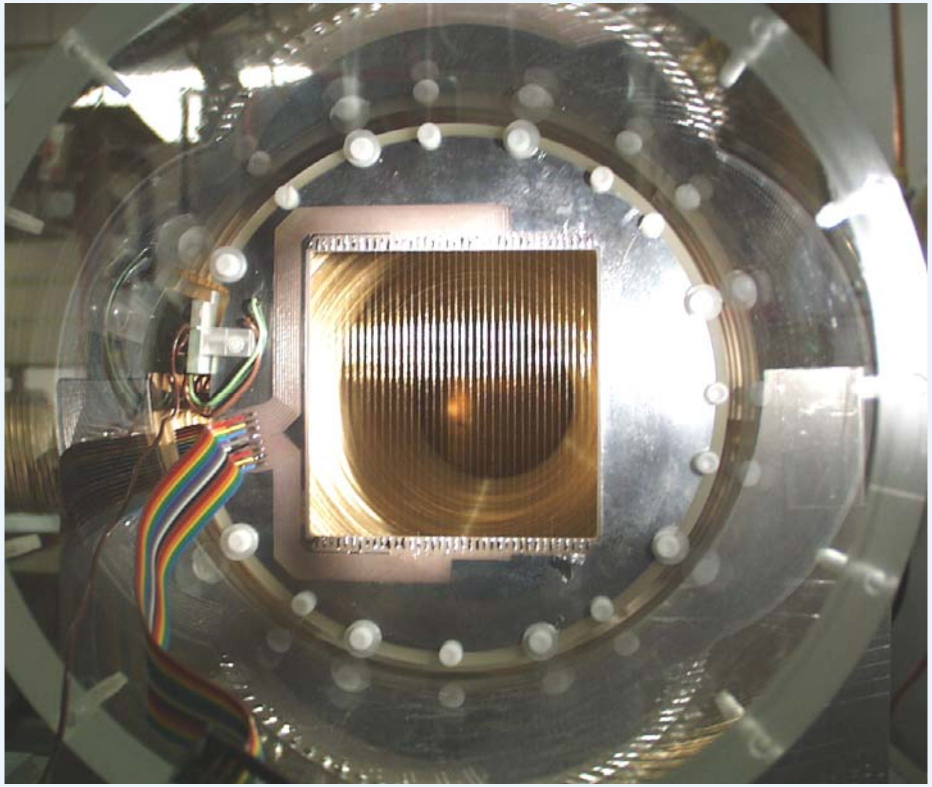
80 pads on the board

For the ion measurements, precision resolution measurements are not necessary; do not use the adjacent 2mm layers.

Use 6 layers, 4 @ 5 mm width
2 @ 2 mm width.

Ion Feedback Detection



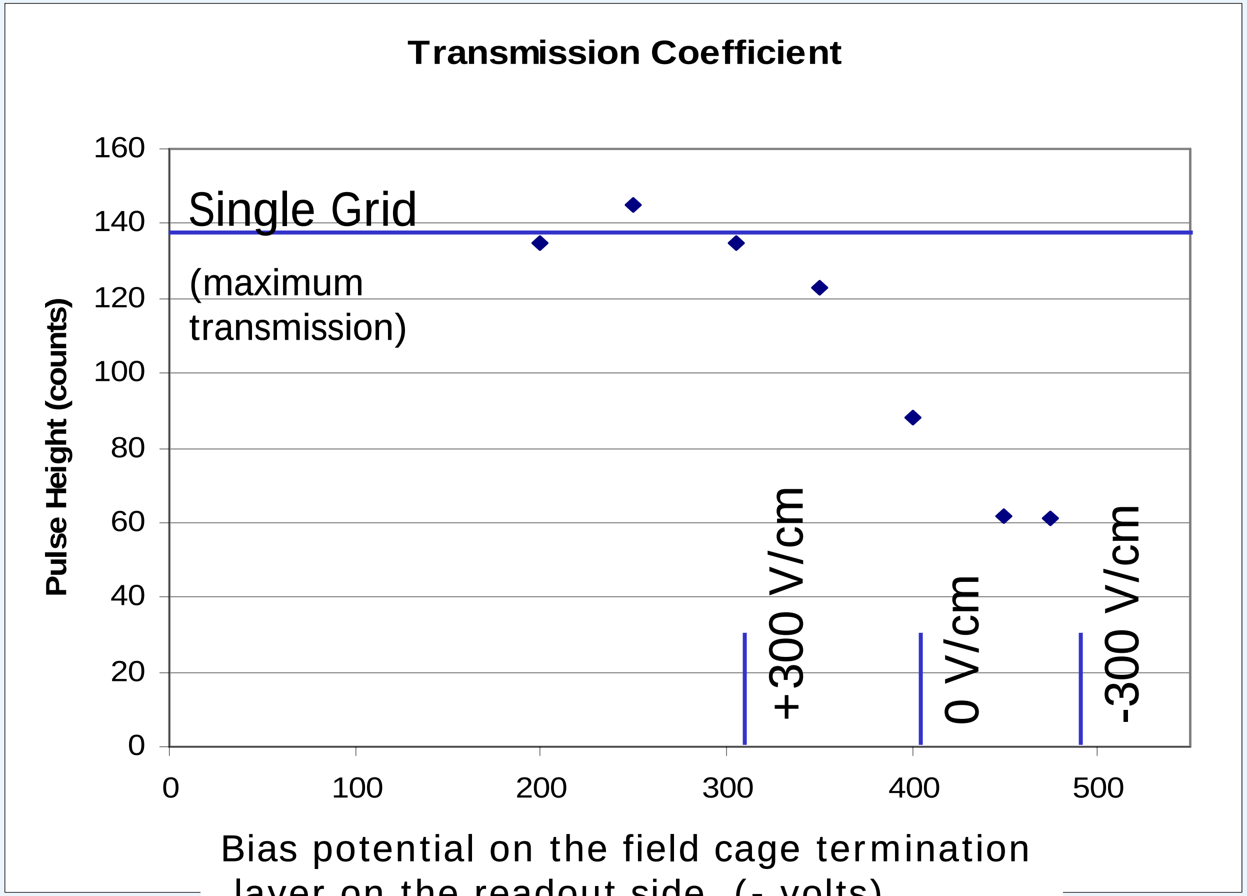


Positive ions are created in the amplification and drift back into the field cage.

Ions on the field cage termination plane, for individual tracks.
- A double-layer field cage termination allows biasing the read-out side to collect ions. (slide)
- The read-out side is segmented with 8 readout channels (5mm each)

The method differs from that used by Saclay/Orsay on MicroMegas and by Aachen on GEM.
For those measurements, a source was used to create ionization. Current was measured on the cathode.

Field cage termination electron transmission



Bias potential on the field cage termination layer on the readout side (- volts) , with the layer on the drift side at -401 V.

Tests were performed with the Purdue-3M Micromegas installed.

Installed double layer field cage termination.

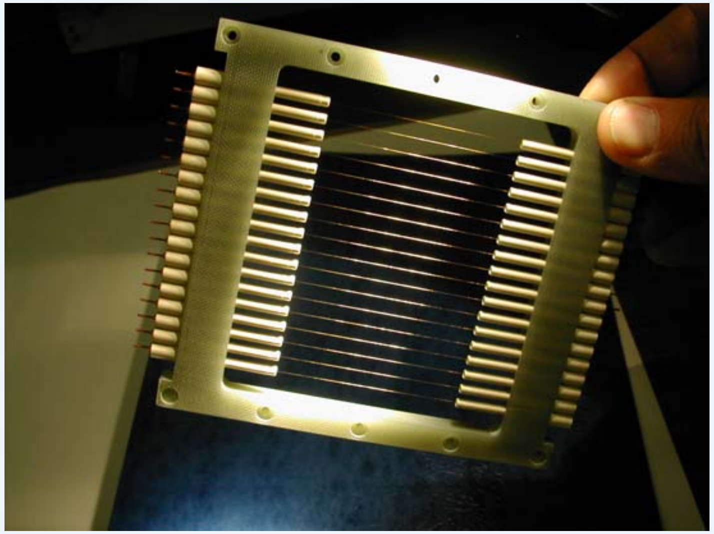
Varied the voltage difference between the layers.

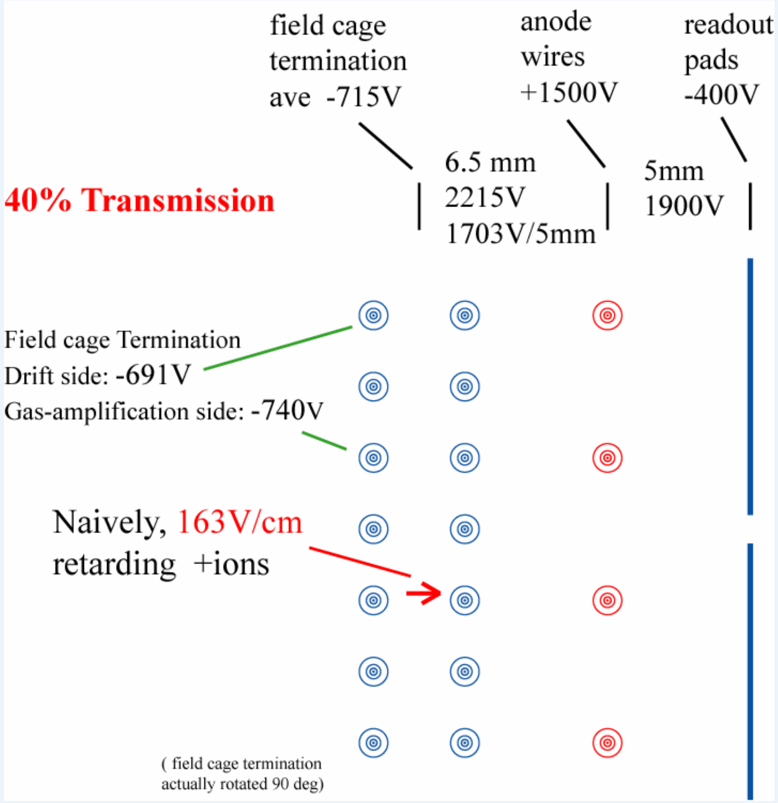
Measure pulse height at the anode pads.

~40% transmission at -450 V
(150V more negative)

~60% of the ion feedback should be captured by the field cage termination wires

Ion feedback, initial tests with wire amplification





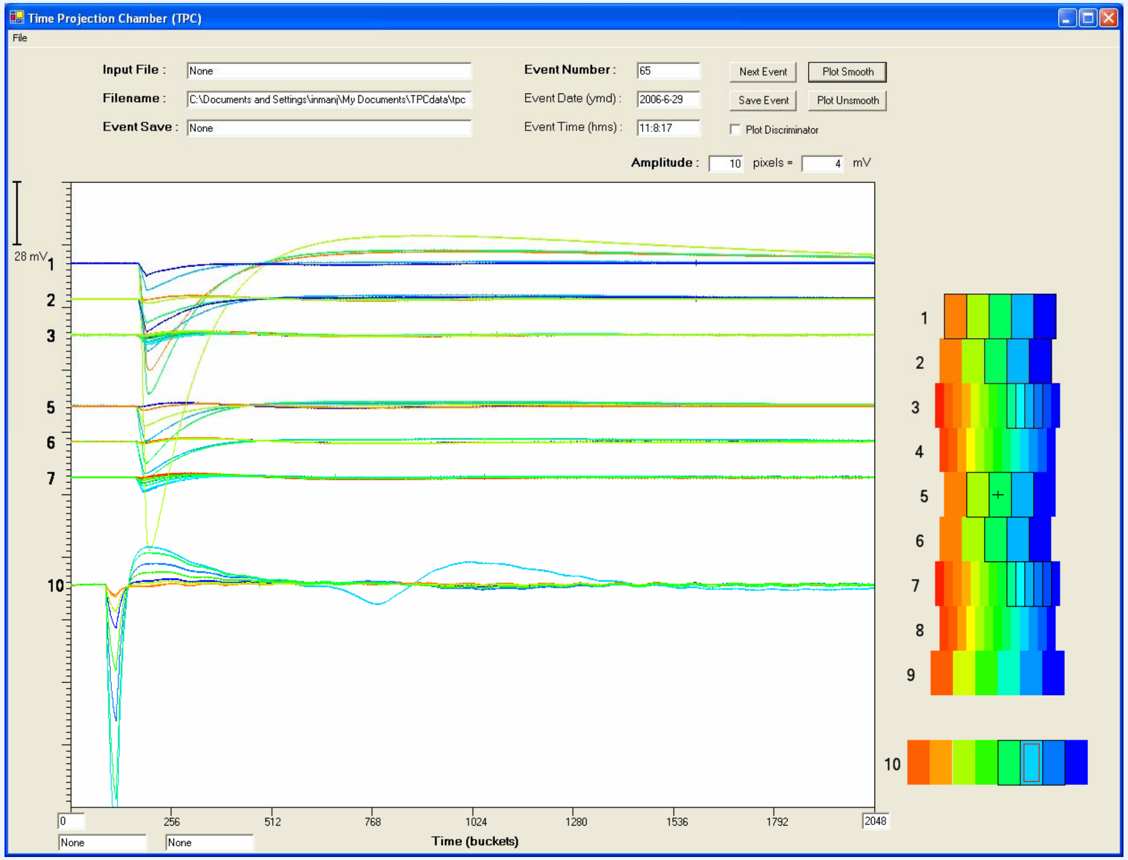
Wire amplification is used for initial tests; it has a predictable, and large, ion feedback fraction.

Partial transmission mode of the field cage termination is used
because a bias pulsing circuit, and gated electronic amplifiers that can tolerate the pulsing, are not ready.

The ion feedback signal will be measured on the instrumented field cage termination layer.

Naively, the ion drift time is $T = (.5\text{cm}) / [1.535\text{cm}^2/(\text{V sec}) \times 3406\ \text{V/cm}] = 124\ \mu\text{s}$,
but this does not account for the potential difference in the radial field regions,
which is necessary to see the signal.

Ion feedback, 40% transmission



Time Projection Chamber (TPC)

File

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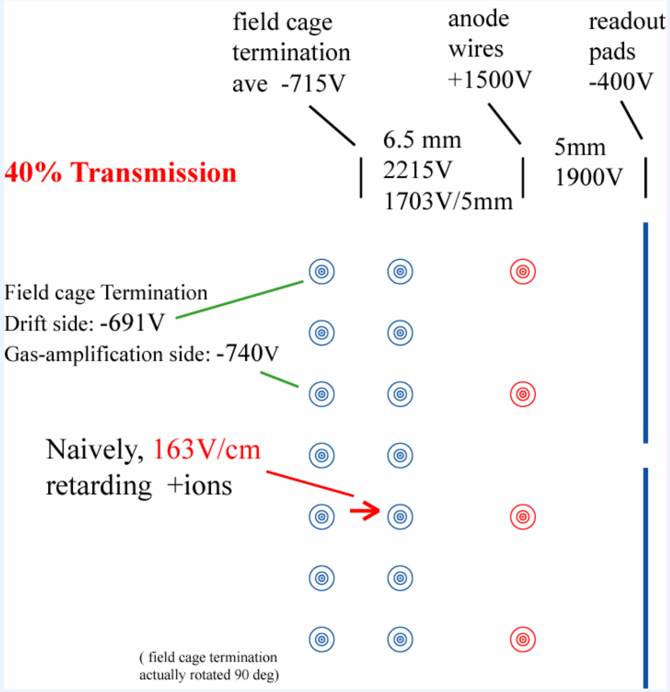
Event Time (hms) : 11:8:17

☐ Plot Discriminator

Amplitude : 10 pixels = 4 mV

None

None



field cage termination ave -715V

anode wires +1500V

readout pads -400V

40% Transmission

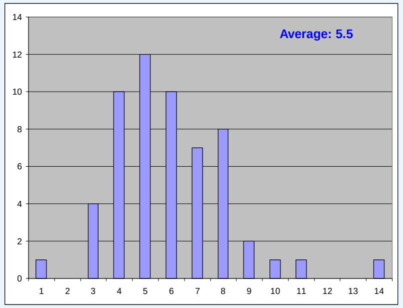
6.5 mm
2215V
1703V/5mm

5mm
1900V

Field cage Termination
Drift side: -691V
Gas-amplification side: -740V

Naively, 163V/cm
retarding +ions

(field cage termination
actually rotated 90 deg)



Upper traces are the cathode pad rows. (25 MHz, 82 µsec full width)

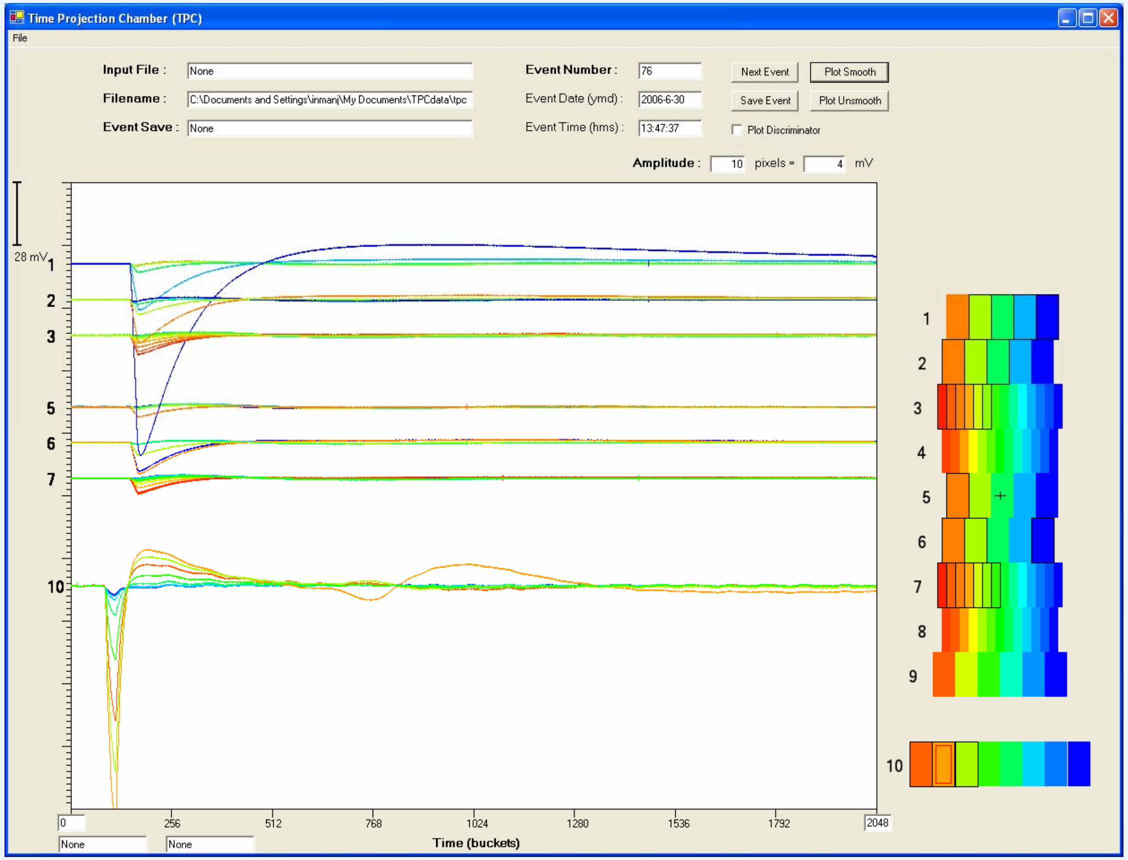
Bottom traces are the instrumented field cage termination cathode wires. (3.125 MHz, 650 µsec)

The fast, in-time, wire signal is on all wires; it is inductive.

There is a second pulse, 203 µsec later, with average relative pulse height of 5.5%.

The delayed pulse is in one channel, typically the peak channel of the inductive pulse.

Ion Feedback, “full” transmission



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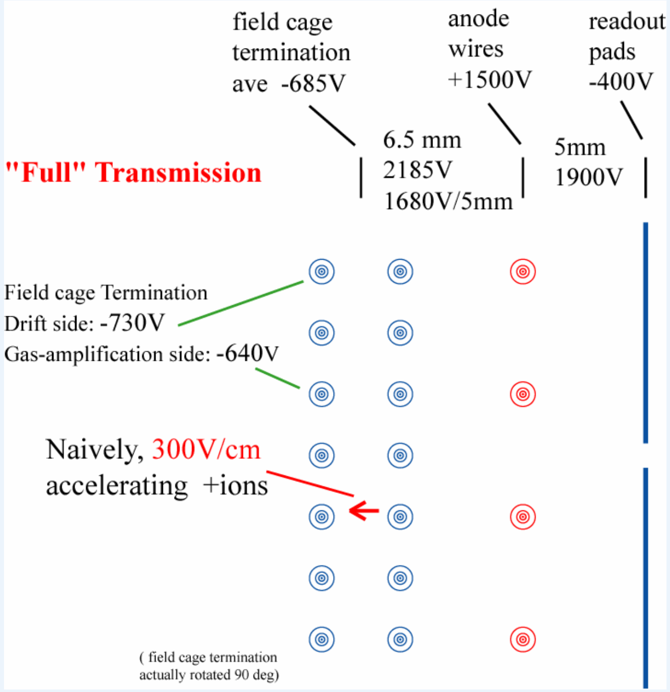
Event Time (hms) : 13:47:37
Amplitude : 10 pixels = 4 mV



"Full" Transmission

field cage termination ave -685V

anode wires +1500V

readout pads -400V

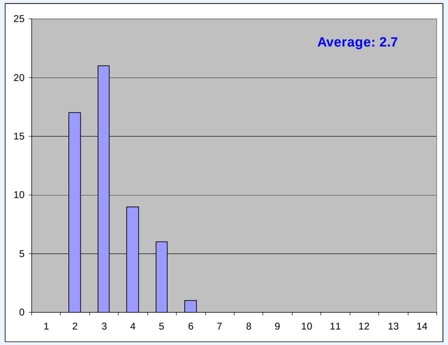
6.5 mm 2185V 1680V/5mm

5mm 1900V

Field cage Termination
Drift side: -730V
Gas-amplification side: -640V

Naively, 300V/cm accelerating +ions

(field cage termination actually rotated 90 deg)



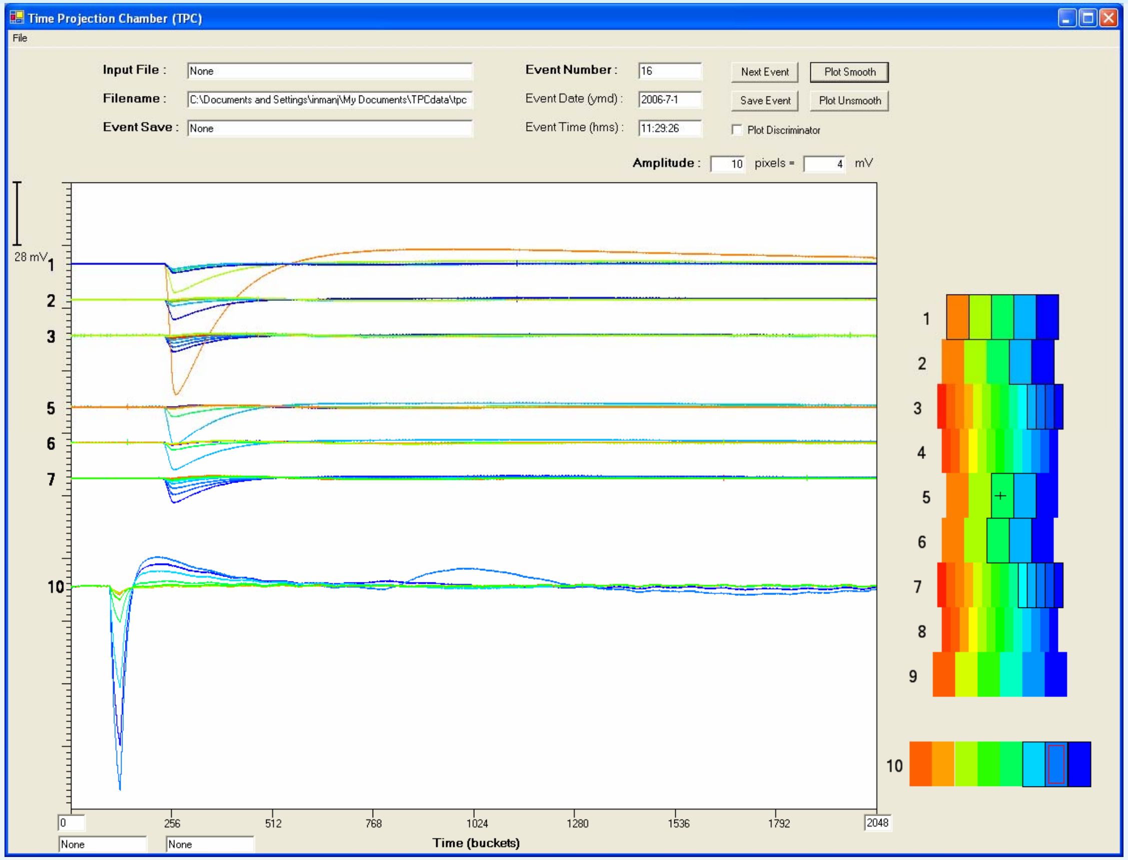
With +300V/cm between the layers of the field cage termination, expect more transmission. (Measured full transmission for electrons.)

The pulse delay is 208 µsec (vs 203).

The relative pulse height is 2.7 % (reduced from 5.5%).

The channel with the delayed pulse is again consistent with the track seen on the pads.

Ion Feedback, “>full” transmission



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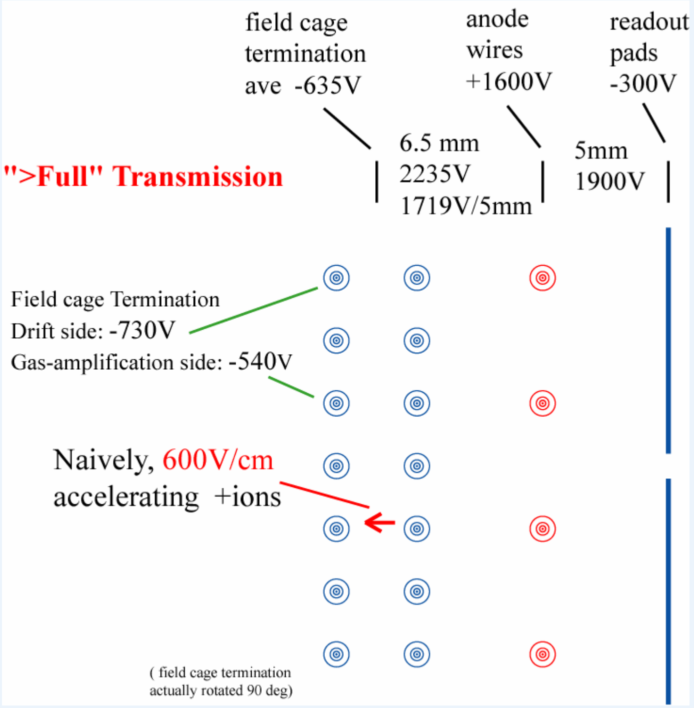
Event Date (ymd) : 2006-7-1

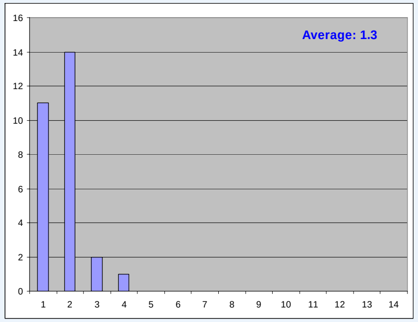
Event Time (hms) : 11:29:26

Amplitude : 10 pixels = 4 mV

None

None



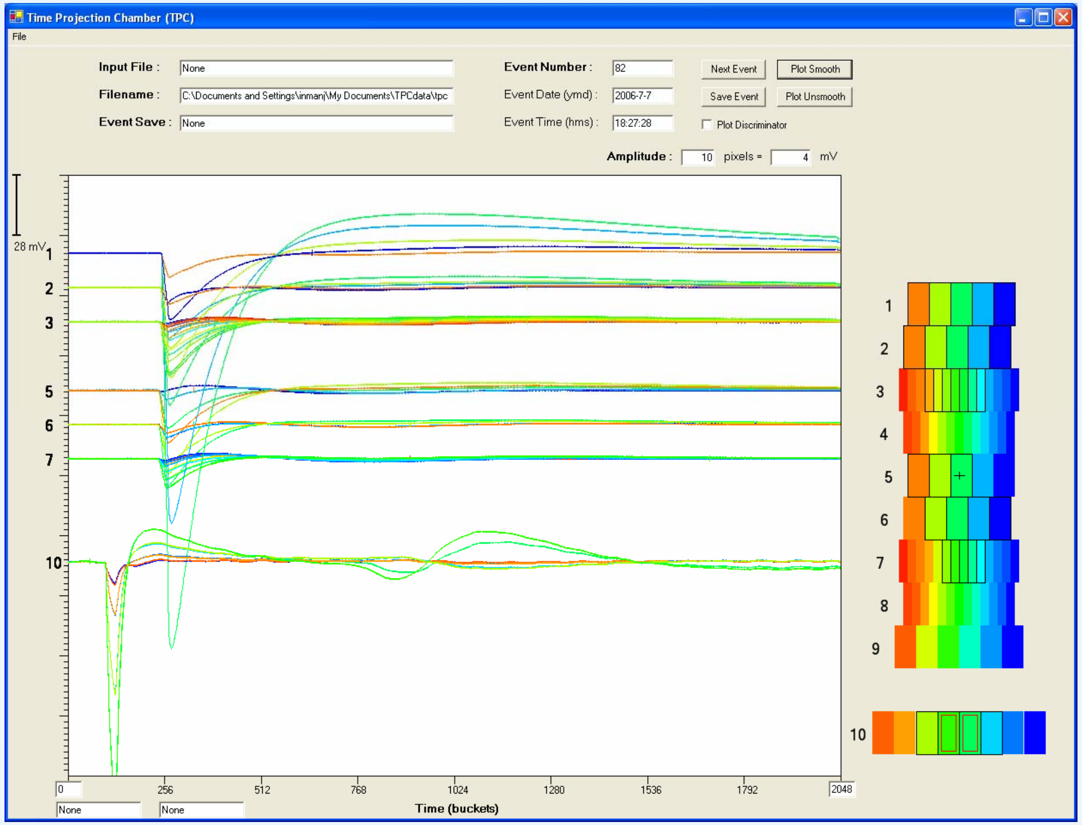


With +600V/cm between the layers of the field cage termination, expect to further increase transmission, and reduce collection.

The pulse delay is 210 µsec (vs 203).

The relative pulse height is 1.3 % (reduced from 5.5%, 2.7%).

Ion Feedback, variation with ion drift distance



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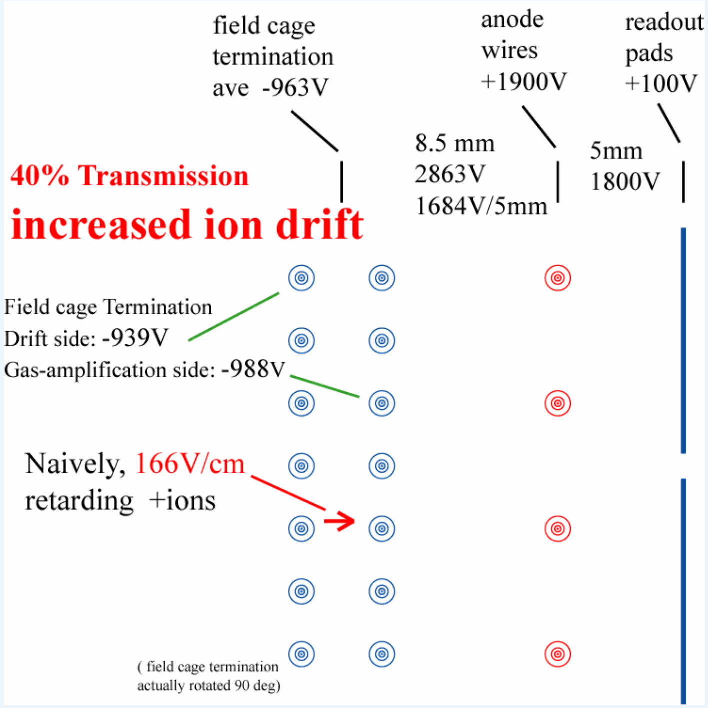
Event Number : 82

Event Date (ymd) : 2006-7-7

Event Time (hms) : 18:27:28

Amplitude : 10 pixels = 4 mV

None None



field cage
termination
ave -963V

anode
wires
+1900V

readout
pads
+100V

8.5 mm
2863V
1684V/5mm

5mm
1800V

40% Transmission

increased ion drift

Field cage Termination
Drift side: -939V
Gas-amplification side: -988V

Naively, 166V/cm
retarding +ions

(field cage termination
actually rotated 90 deg)

Determine if the delay time increases with ion drift distance;
any electronic source for this signal will have a constant time.

Again, with ~40% transmission, -166V/cm, in the field cage termination,
but the field cage termination-to-anode spacing is increased to 7mm (from 5 mm), (x 1.4) .

Pulse delay increases to 246 μsec , σ=6 μsec , (from 203 μsec), (x 1.2) .

Conclude that the signal is ion feedback

We observe an ion signal on the segmented field cage termination plane

Electrons pass through the field cage termination.
Ions are produced during the gas amplification.
Ions drift back to the field cage termination.
Some of the ions are collected.

The signal amplitude varies with the transparency of the field cage termination to the initial drift of electrons.

The signal delay is consistent with the calculated ion drift.

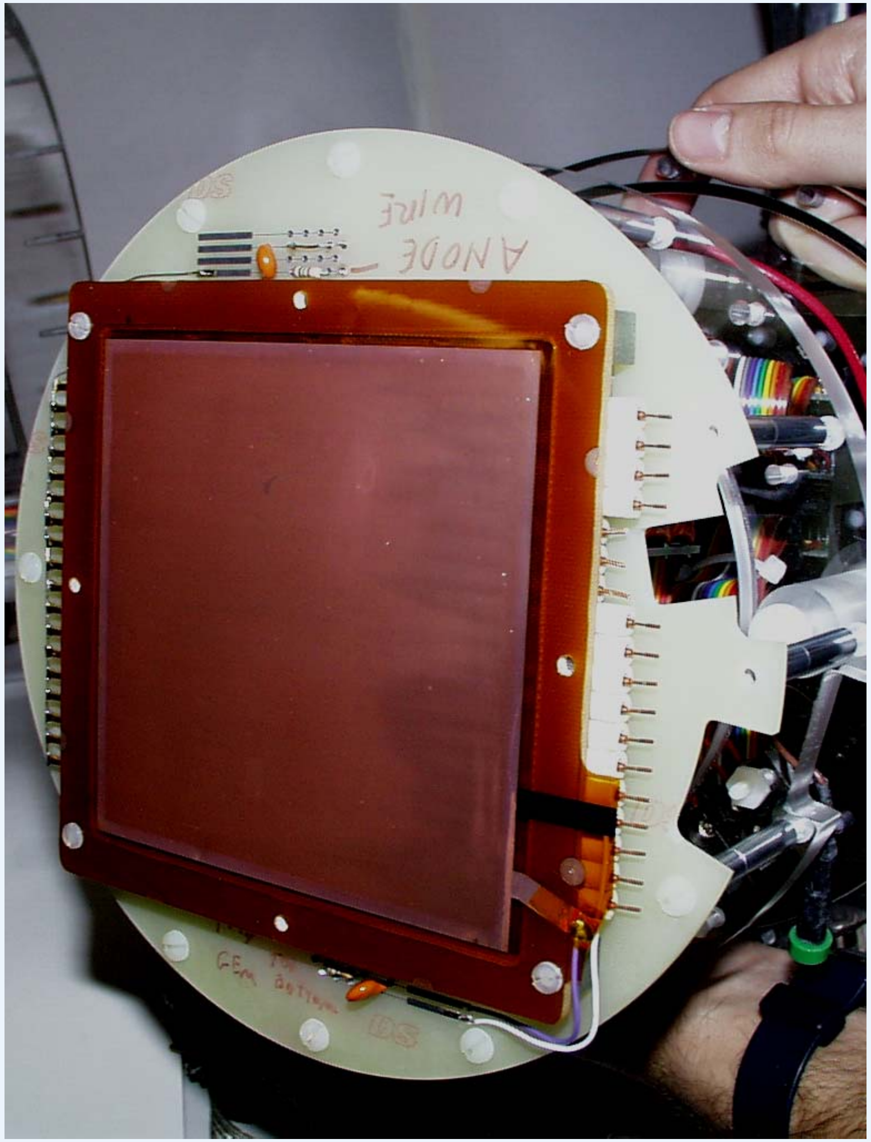
The signal delay increases with the ion drift distance.

The ion signal correlates with the pad signal in horizontal position.

GEM transmission measurements

We will use this tool to measure the ion transparency, along with the electron transparency, of a GEM.

The GEM is placed in front of a MWPC gas-amplification.



MWPC gas-amplification is used to

measure the relative electron transmission through the GEM

and as a source of positive ions.

GEM transmission measurements

The GEM is positioned between the field cage termination and the readout.

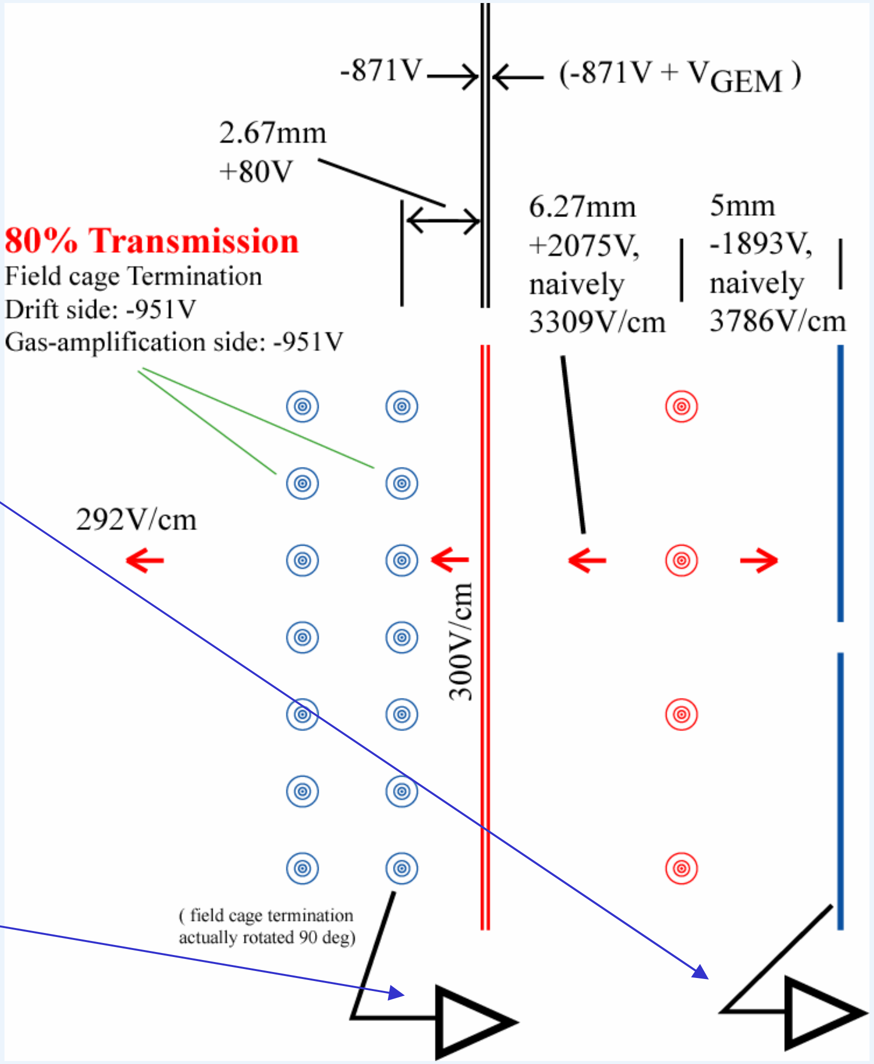
Most of the electrons pass through the field cage termination and the GEM.

The average pulse height of pads on the track gives the relative electron yield.

Positive ions crated in the avalanche pass through the GEM. A fraction is collected on the field cage termination.

The pulse height on the field cage termination gives the relative (*ion transmission x electron transmission*)

Using $ArCO_2$ 90:10 gas.
(well, actually 87:13 based on velocity)



Event with V_{GEM} =163 V

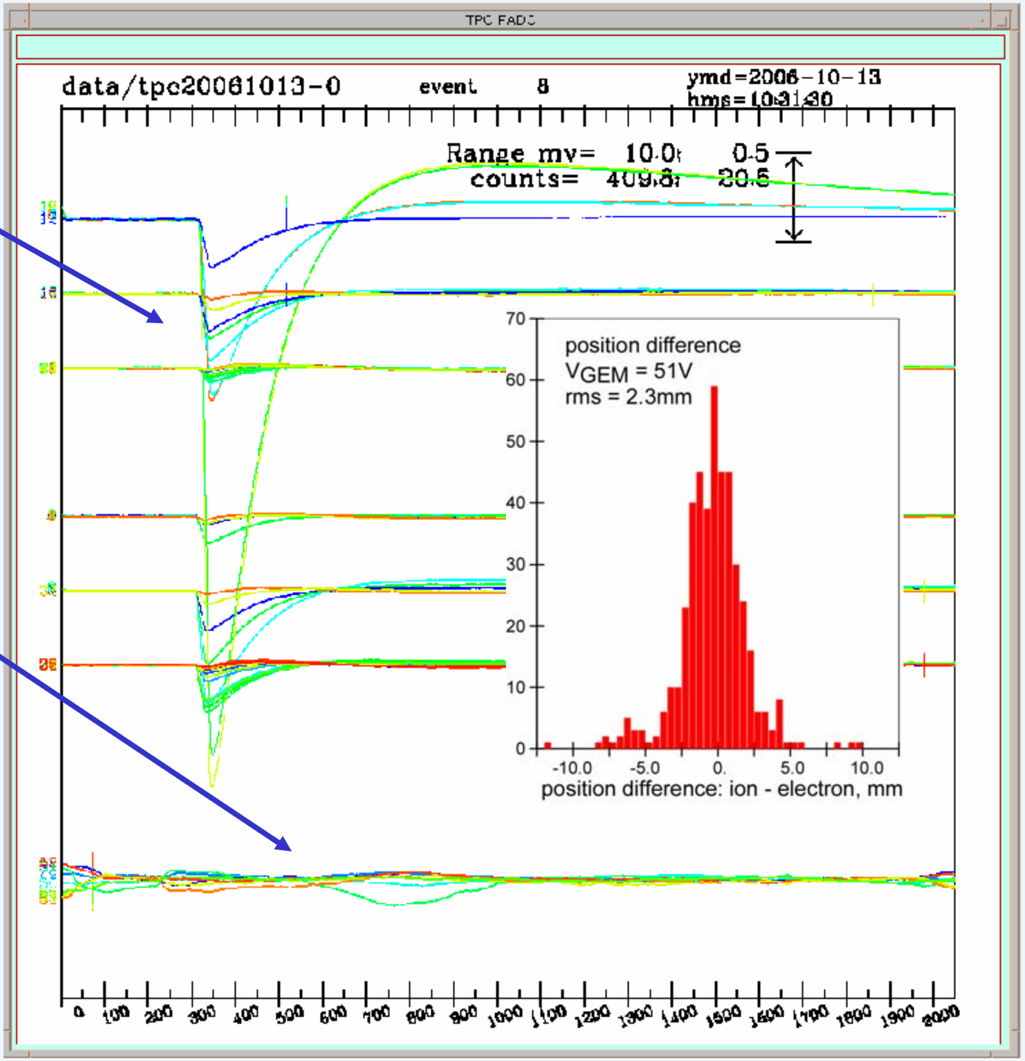
Note:
the electron signal scale is 10mv ,
the ion signal scale is 0.5mv .

Shown is an event with V_{GEM}=163V.

The track is observed on the pads starting at time bin 320.
T_0 is bin 84, 25MHz, 40ns/bin
drift is 9.4 µs, 21cm.

The ion signal is observed on the field cage termination wires centered at time bin 780.
T_0 is bin 84, 3.125MHz, 320ns/bin
ion drift time is (223 – 9.4) µs .

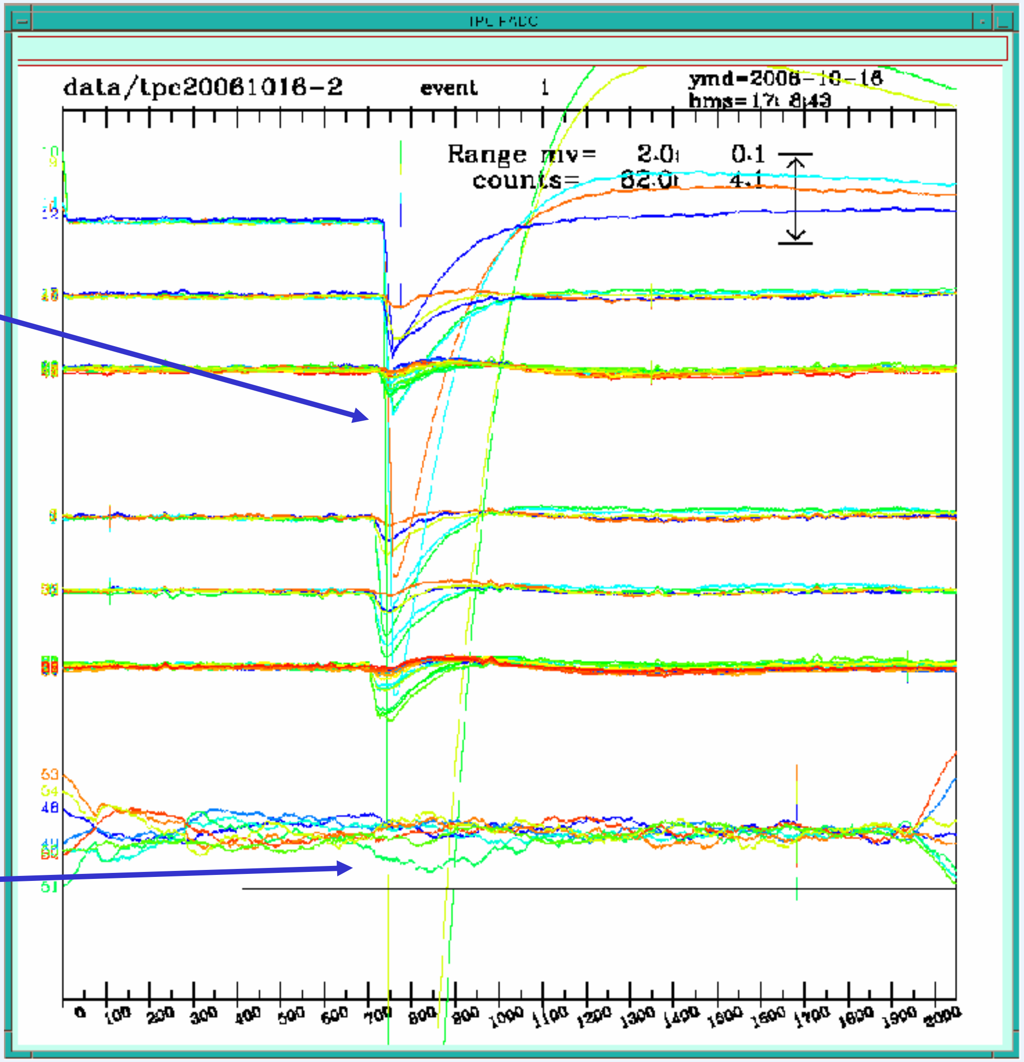
The measured positions of the electrons and ions are correlated. However, the ion signal in narrow because it is due to charge collection.



Event with V_{GEM} = 21 V

Note:
the electron signal scale is 2mv ,
the ion signal scale is 0.1mv .

Shown is an event with V_{GEM}=21V.



pad signals at 25 μs

The ion signal is observed on the field cage termination wires centered at time bin 850.

T_0 is bin 84, 3.125MHz, 320ns/bin

ion drift time is (245 – 25) μs .

Normalization of the relative measurements

Measurements of pulse heights on the pad readout
provide the relative electron yield at the anode.

To extract the transmission, we require the pad pulse heights
without the GEM mounted in the chamber for the normalization.

$$\text{pad PH (with GEM)} = \text{Trans.}(e^-) \times \text{pad PH (no GEM)}$$

Measurements of pulse height on the field cage termination
provide the relative (ion transmission x electron transmission).

$$\text{term PH (with GEM)} = \text{Trans.(ion)} \times \text{Trans.(e-)} \times \text{term PH (no GEM)}$$

or,

$$\text{Trans.(ion)} = \frac{\text{term PH (with GEM)} \;/\; \text{term PH (no GEM)}}{\text{pad PH (with GEM)} \;/\; \text{pad PH (no GEM)}} \;.$$

Require normalization data with no GEM,
with the electric field at the anode wires held constant.

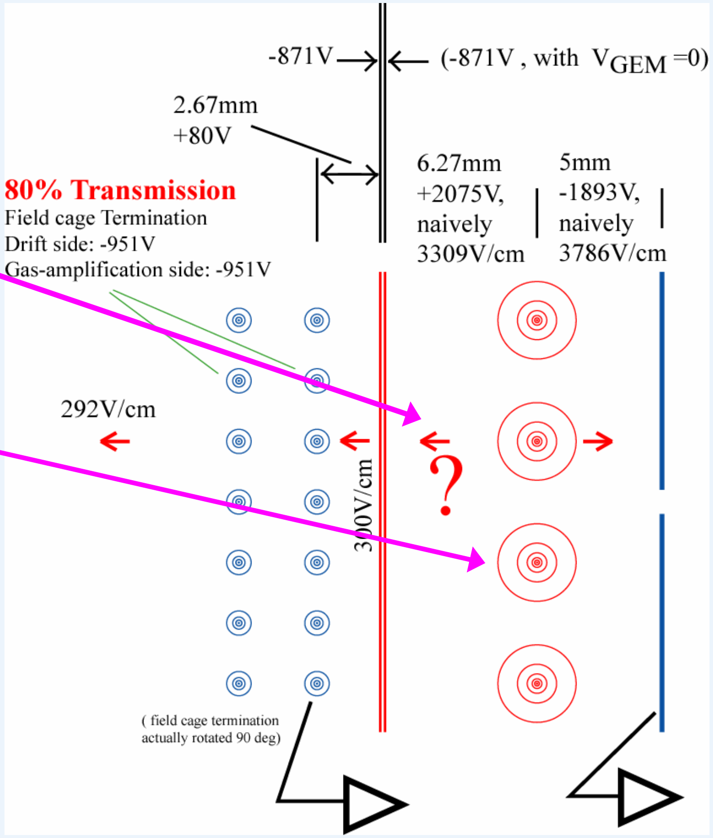
Biasing for the normalization

The field between the GEM and the anode is not the naïve value of 3309 V/cm.

Much of the potential difference is in the radial field region near the anode wire.

Estimate that the radial region extends 1/3 of the wire spacing (as shown).
Then solve for a constant field region and a radial field region matched at the interface.

(Yes, it would be better to do a FEA.)



Measurements of GEM transmission

Result:

996 V potential difference in the radial region (1.67 mm)
(while 1.67/6.27 x 2075V = 553V)

2345 V/cm in the “constant” field region (4.60 mm).

Biasing for the normalization

Estimate that the field, in the “constant” field region between the GEM and the anode, is 2345 V/cm.

The anode must be biased to maintain this field with the GEM removed.

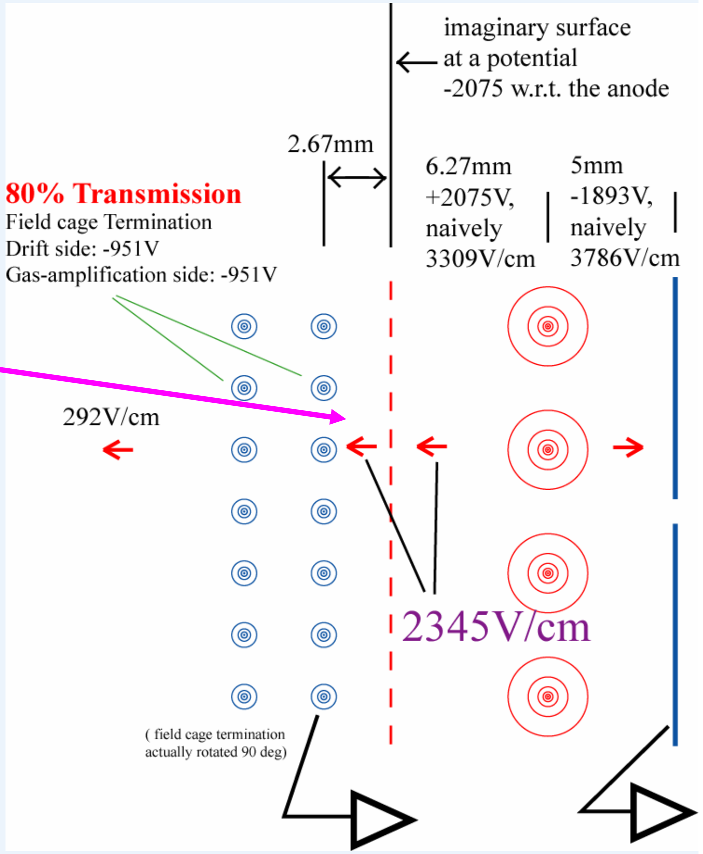
The same field must be established between the field cage termination and the imaginary surface.

Thus, the potential difference from the field cage termination to the imaginary surface is 2345 V/cm x .267cm = 626V.

The potential difference from the imaginary surface to the anode is still 2075.

The anode is biased at -951 + 626 + 2075 = +1750.

Uncertainty in the calculation of the bias potential leads to a systematic error in the electron transmission measurements.
Error bars will reflect a change of 50 V at the anode, corresponding to a change of 85V in the potential difference in the radial region.



Normalization with no GEM

Normalization event

Note: the electron signal scale is 40mv ,
the ion signal scale is 20mv .

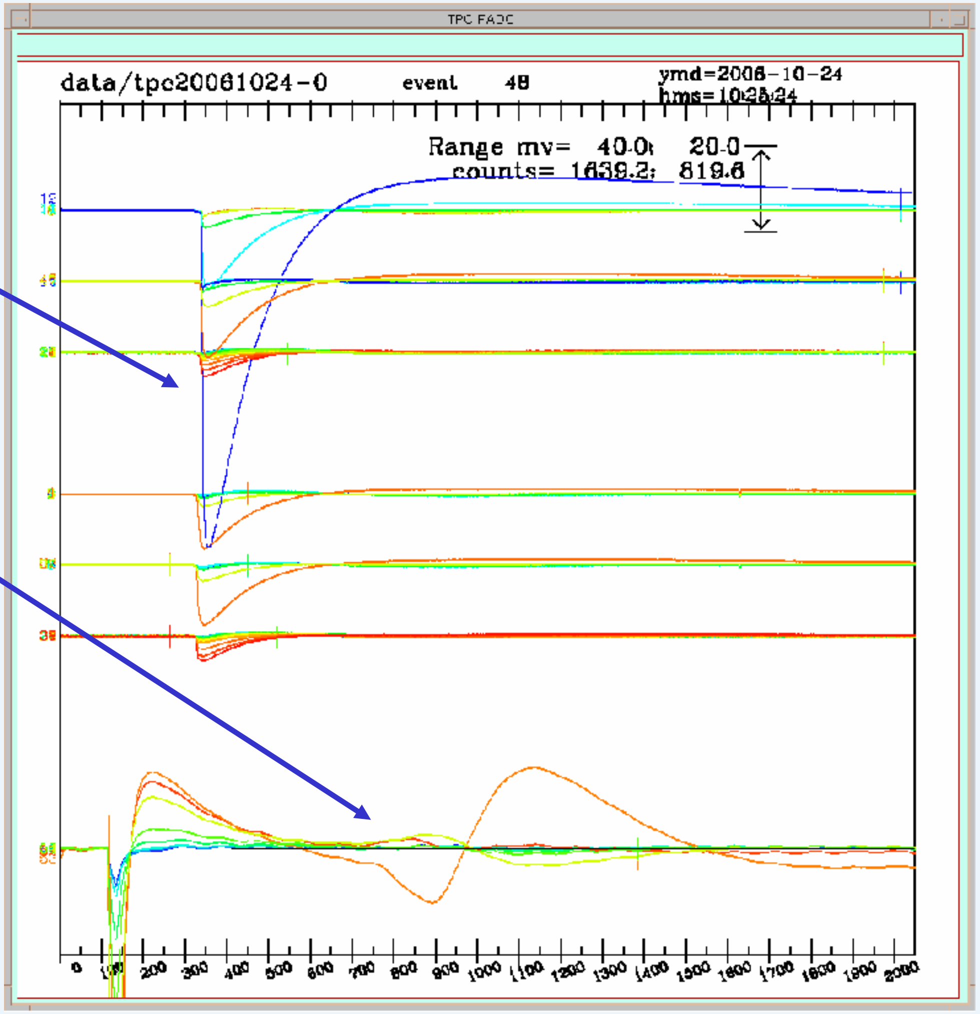
An event with the GEM removed

The ion signal is observed on the field cage termination wires centered at time bin 900.

The inductive signal is observed at time bin 100. With the GEM removed, the field cage termination is part of the MWPC field cage.

The inductive signal is wide, observed on all channels.

The ion collection signal is isolated to one channel of width 5mm.

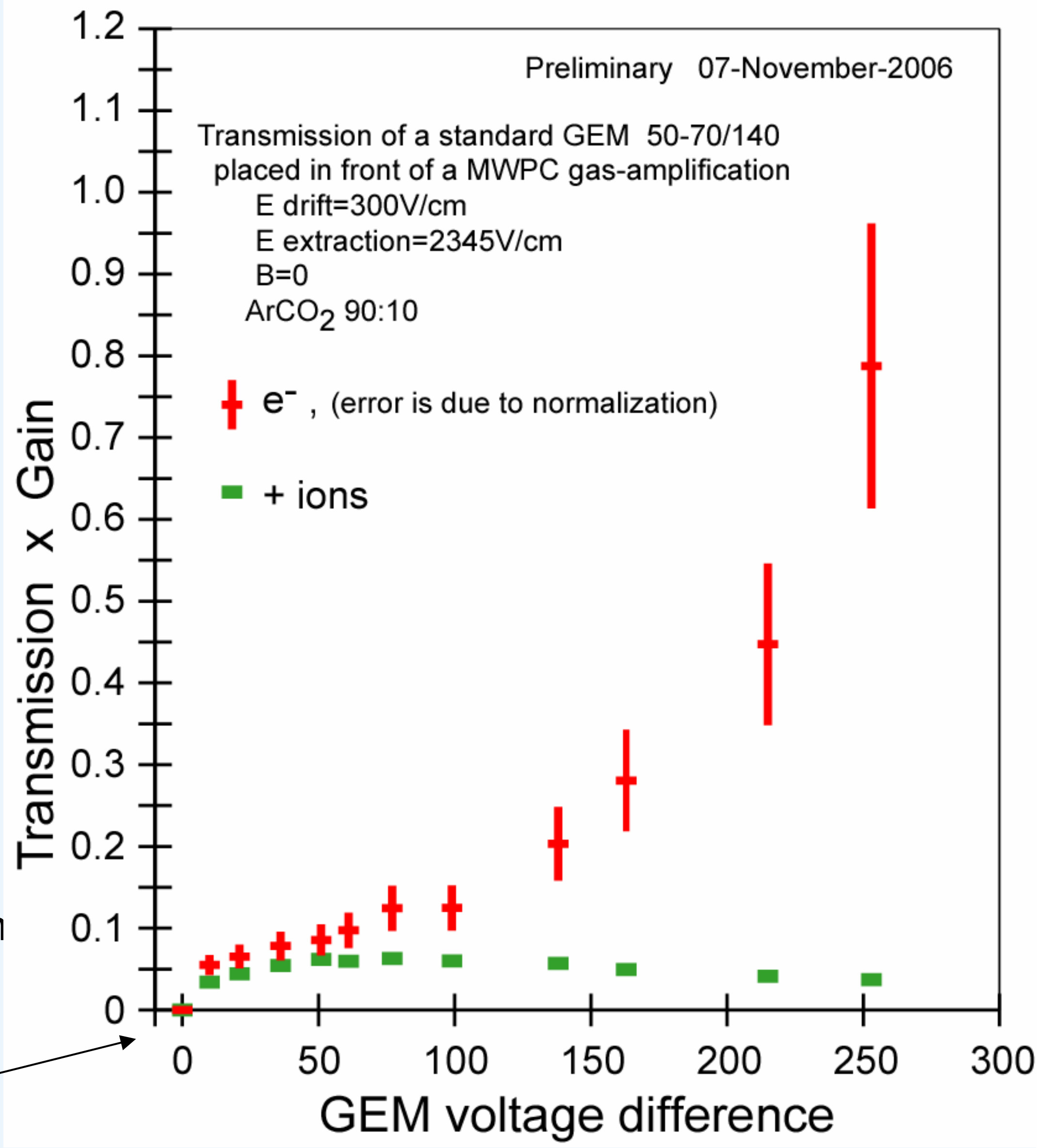


The result

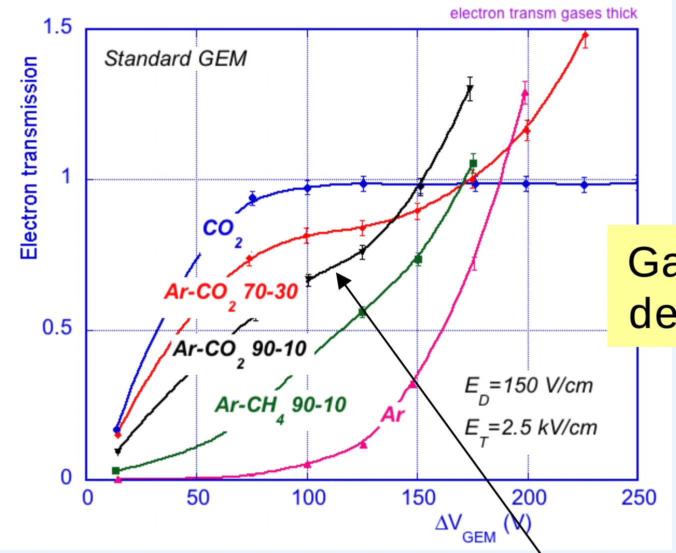
Electron transmission measurements have a systematic uncertainty as described earlier.

Ion transmission measurements are not affected by the uncertainty in the bias voltage calculation because changes in the bias voltage result in only small changes in the ratio of the termination signals to the pad signals.

The measurement of ion transmission for V_{GEM} = 0 is made with a small sample of tracks with drift distance < 11mm (between the GEM and the pads).



Comparison



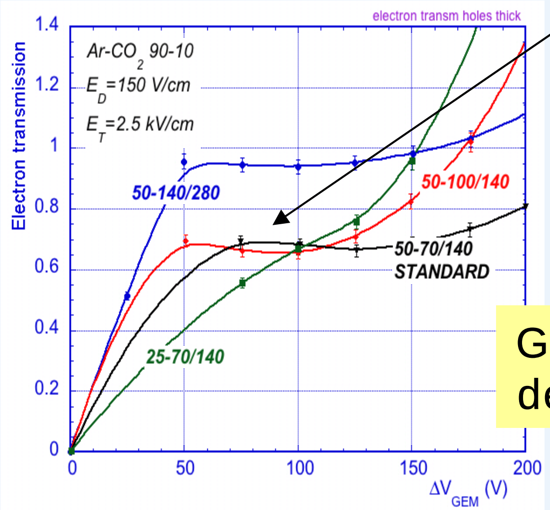
From F. Sauli, Berkeley workshop, April 2006

Gas dependence

F. Sauli showed electron transmission dependence at the Berkeley workshop, April 2006.

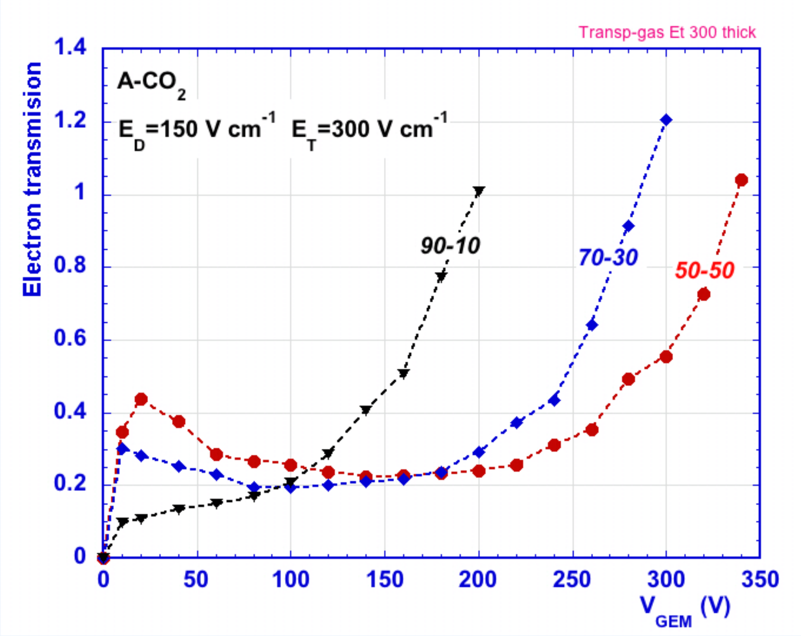
Present results show a much lower electron transmission at ~similar electric fields.

$ArCO_2$ 90:10
Standard GEM
E_D = 150V/cm
E_T = 2500V/cm



GEM geometry dependence

From F. Sauli, Berkeley workshop, April 2006



From F. Sauli, Berkeley workshop, April 2006

Summary / Outlook

Demonstrated a method for measuring ion feedback in the Cornell/Purdue TPC.

Measured electron and ion transmission through a GEM as a function of voltage.
Results for electrons are lower than observed by Sauli’s group.
Systematic uncertainties could be improved with a proper field calculation.

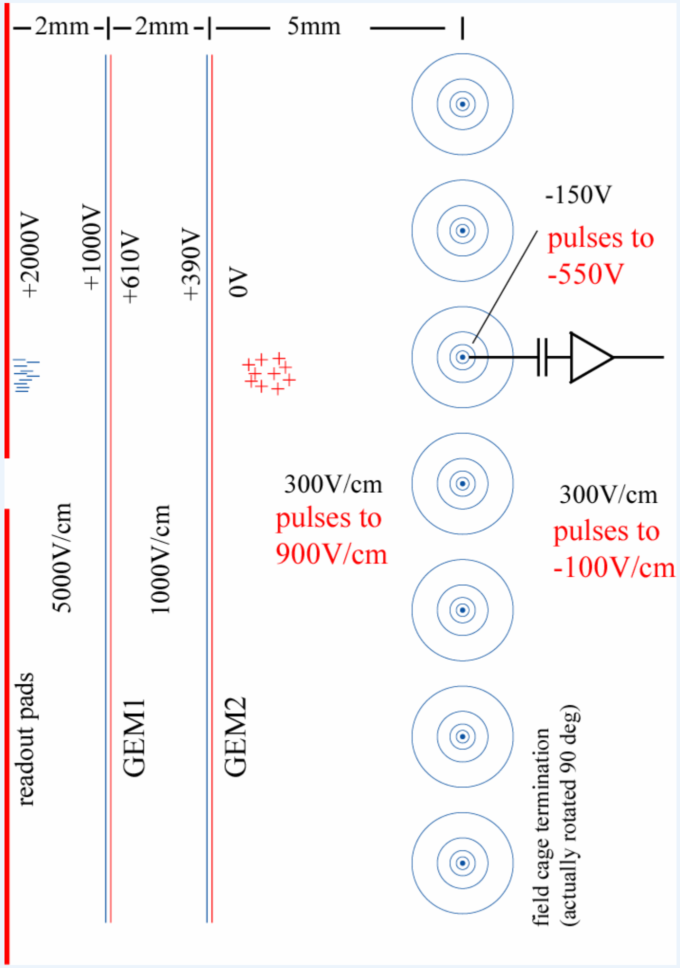
Good signal sensitivity with

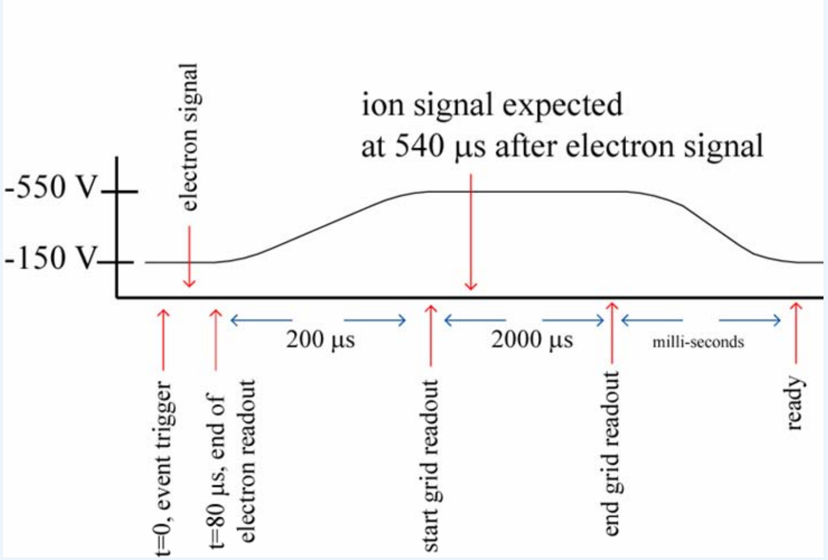
electron transmission	.07	
ion transmission	.04	
ion collection	.20	
ion feedback	.50	
gain	~ 10^4	(product = 3)

We are preparing for measurements of ion feedback fraction
using pulsed biasing on the field cage termination. (slide)
with full transmission and collection, should have
sensitivity for (ion feedback x gain) > 3

A “bulk Micromegas” has been prepared on one of our pad boards by Paul Colas.
Operation will be compared to the Purdue-3M Micromegas. (slide)

Ion Feedback measurement, with pulsed field cage termination



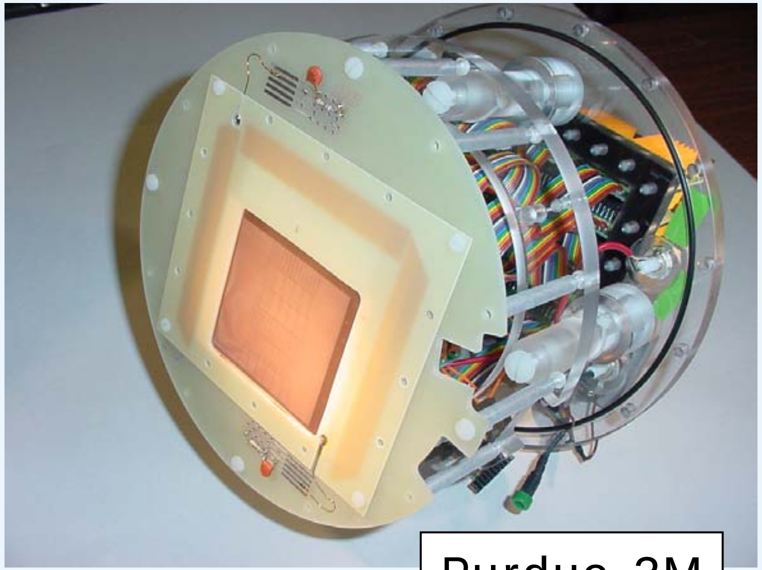


The pulsed biasing will switch from full transmission to full collection.

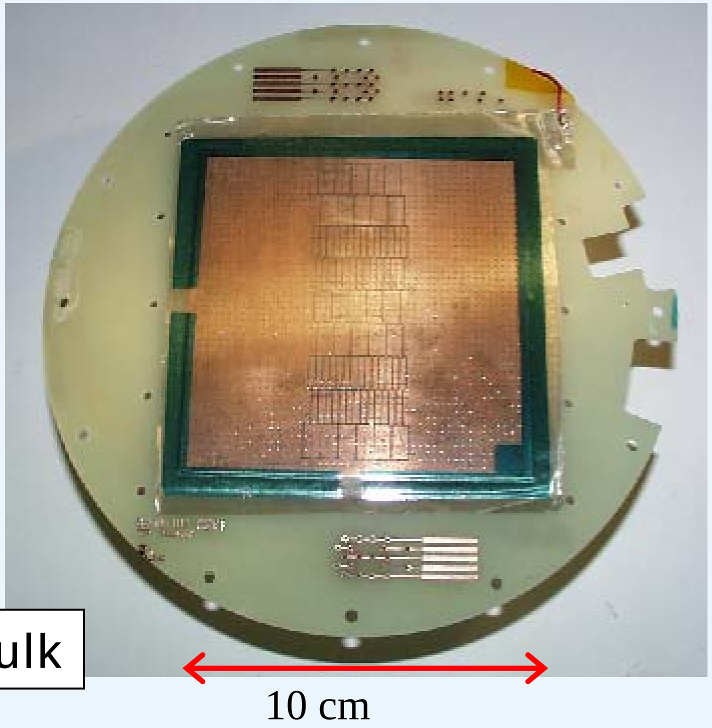
Require small ion drift time to reduce diffusion.
(Expect ~7 μs diffusion at 540 ms drift.)

Require large ion drift time because
the amplifiers saturate during the voltage ramp.
New amplifiers will be switch during the ramp.

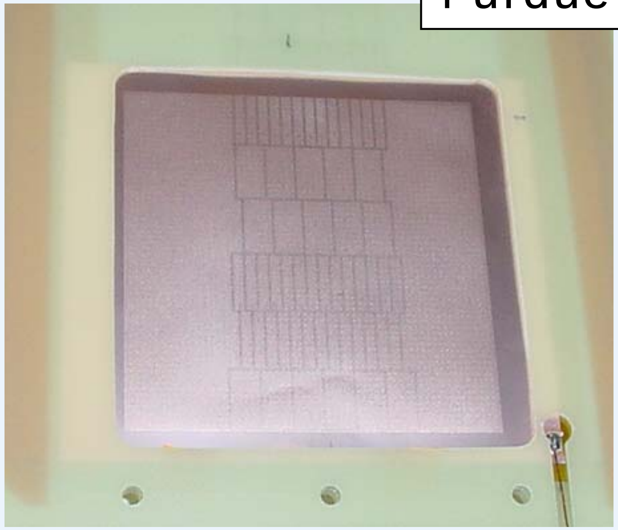
Micromegas amplification



Purdue-3M



bulk



We have received a “bulk Micromaegas”, prepared on one of our pad boards by Paul Colas.

Measurements with the Purdue-3M Micromegas were shown at Vancuover.

We will start measurements with the bulk Micromegas in December.