Induced signal in RPC, Configuration of the double gap RPC and Grouping of the strips

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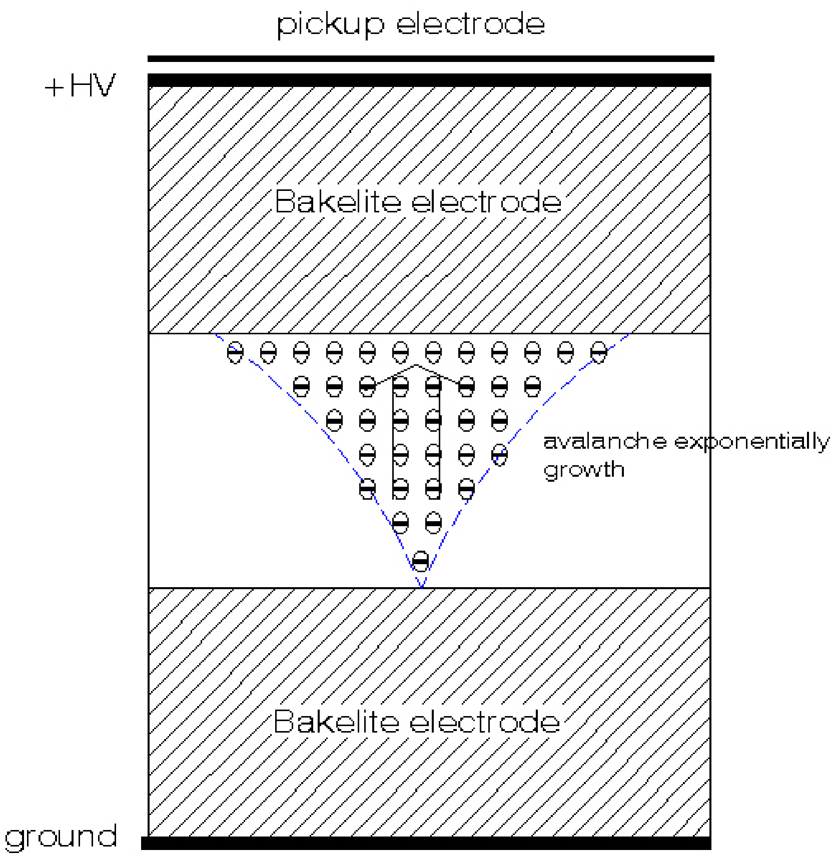
How the induced current formed in an RPC chamber ?



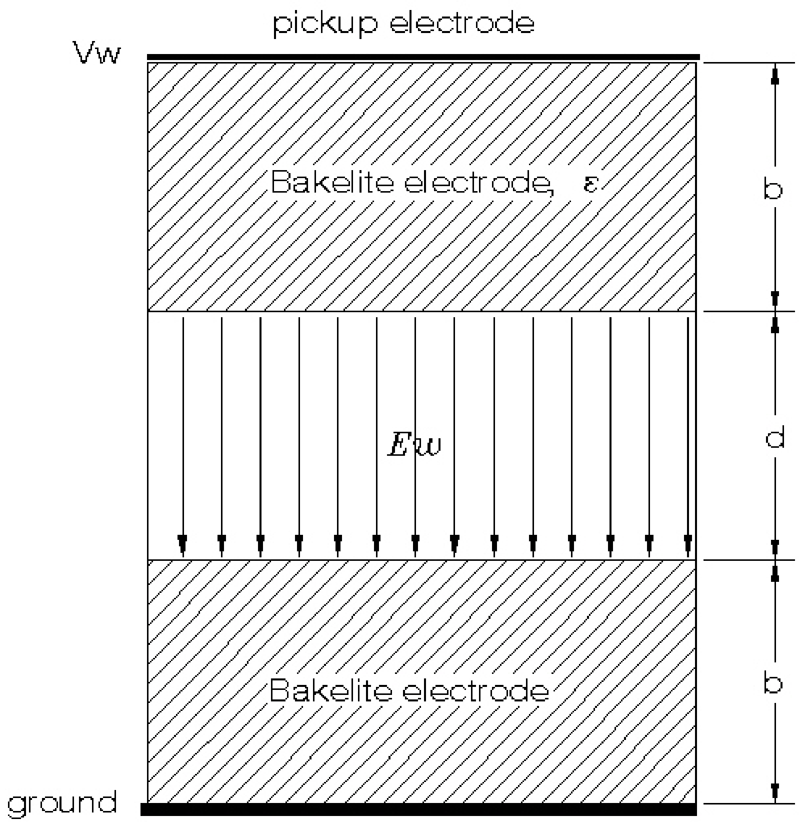
- The movement of the charge in the electric field induces a current signal on the pickup electrode;
- The positive/negative ions are moving very slowly, in the scope of our electronics, we can neglect them;
- According to Ramo's theorem*:

$$i(t) = \frac{E_w}{V_w} v e_0 N(t) \qquad (1)$$

e_0 is the electrons charge, $N(t)$ is the number of electrons presented at time t, v is the electron drift velocity, E_w (weighting field) is the electric field in the gap if we set the pickup electrode to V_w and ground all other electrodes.

* Detailed information on the induced signal mechanism see the following paper:
Werner Riegler*, Christian Lippmann, Rob Veenhof, NIM A500(2003)144
"Detector physics and simulation of resistive plate chambers"

Weighting field for RPC chamber



Apply V_w to the pickup electrode, assume:

d_1=b, d_2=d, d_3=b,

$\varepsilon_1 = \varepsilon_3 = \varepsilon$, $\varepsilon_2 = 1$,

to satisfy the following conditions:

$$\sum_{i=1}^{3} E_i d_i = V_w, \varepsilon_i E_i = \varepsilon_j E_j$$

we derive the weighting field:

$$\frac{E_w}{V_w} = \frac{\varepsilon}{2b + d\varepsilon} \qquad (2)$$

Starting from a single electron

Assume:

- A single electron initially is at distance x from the cathode;
- Ideal Townsend avalanche – exponential growth with the drift path length;

The induced current: $$i(t,x) = \frac{E_w}{V_w} e_0 v e^{(\alpha-\eta)vt} \Theta\left(\frac{d-x}{v} - t\right)$$

When the electrons reach Bakelite surface, the induced current suddenly stopped.

where $\Theta(x)$ is the step function, the induced charge is:

$$Q^{ind}(d-x) = \int_0^\infty i(t,x)dt = \left[\frac{E_w}{V_w(\alpha-\eta)}\right] e_0 (e^{(\alpha-\eta)(d-x)} - 1) \qquad (3)$$

We already know the weighting potential: $\frac{E_w}{V_w} = \frac{\varepsilon}{2b + d\varepsilon}$

The total charge reaches anode Q^{total}: $e_0(e^{(\alpha-\eta)(d-x)} - 1)$

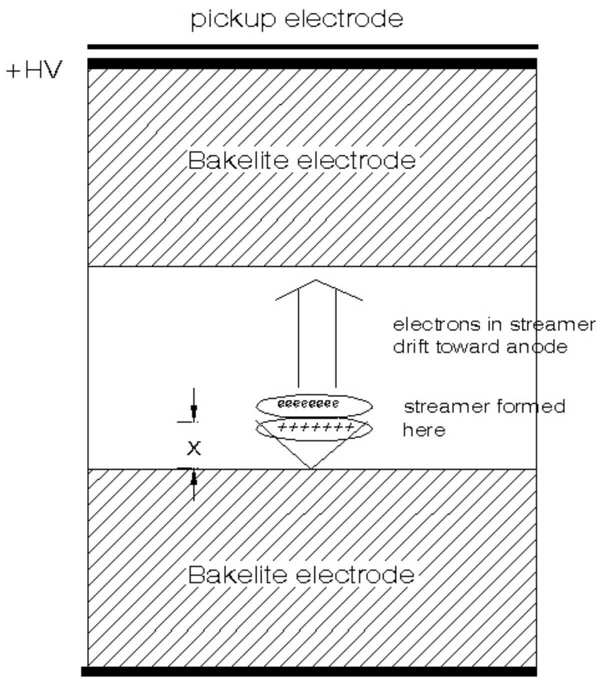
$$Q^{ind}/Q^{total} : \frac{\varepsilon}{(2b+d\varepsilon)(\alpha-\eta)} \qquad (4)$$

Typical values: $\varepsilon \sim 8$, $b = d = 0.2cm$, $\alpha - \eta \sim 100$

$Q^{ind}/Q^{total} = 0.04$

In avalanche mode the induced charge is only 4% of total created charge in an avalanche, quite wasteful !!!

Induced charge in streamer mode



Assume the streamer is formed at distance x from the cathode, ignore the induced charge during the streamer forming period, the total charge in the streamer is $e_0 N_0$, the induced current:

$$i(t) = \frac{E_w}{V_w} v e_0 N_0 \Theta\left(\frac{d-x}{v} - t\right) \quad (1)$$

$$Q^{ind}(d-x) = \int_0^{\infty} i(t,x)dt = \left[\frac{E_w}{V_w}\right] e_0 N_0 (d-x) \quad (2)$$

$$\frac{E_w}{V_w} = \frac{\varepsilon}{2b + d\varepsilon} \qquad Q^{ind}(d-x) = \frac{(d-x)\varepsilon}{2b+d\varepsilon} e_0 N_0 \quad (3)$$

Typical values: d=0.2cm, x=0.05cm, b=0.2cm, ε=8

$$\Rightarrow Q^{ind}/Q^{total} = \frac{(d-x)\varepsilon}{2b+d\varepsilon} \approx 0.6 \quad (4)$$

In streamer mode the induced charge is ~ 60% of the total charge, much more effective than avalanche mode.

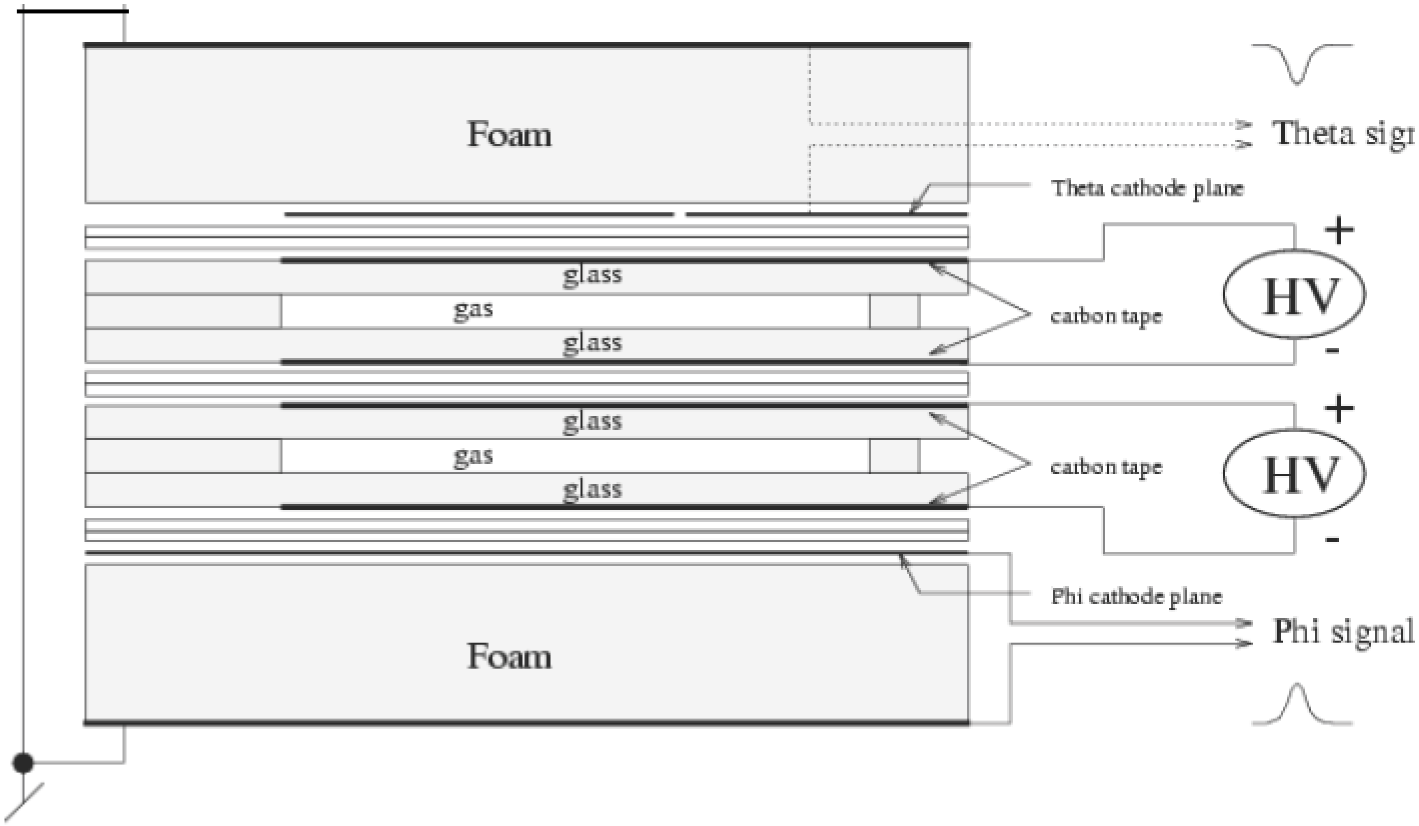
In the case of x~0.0cm, Ratio will reach the maximum: $Q^{ind}/Q^{total} \rightarrow \frac{d\varepsilon}{2b+d\varepsilon} = 0.8$

Possible configurations of the double gap RPC

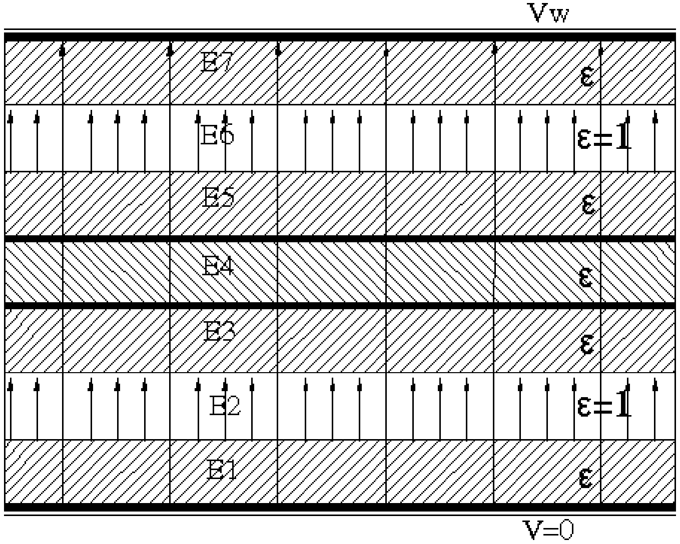
- Belle
- CMS and IHEP
- Back-to-back RPC
- Middle strip plane + top/bottom readout plane

Belle Double gap RPC

If we use BELLE's double gap configuration, two dimensions are readout from top and bottom sides:



Calculate the weighting field of the double gap RPC



Apply V_w to the top pickup electrode, assume Bakelite and gas gap thickness as b and the thickness of the insulator between two RPCs is b as well, besides the gas gap ε=1, all other layers have same ε

To satisfy the following conditions:

$$\sum_{i=1}^{7} E_i b = V_w, \varepsilon_i E_i = \varepsilon_j E_j$$

we derive the weighting field in the gas gap:

$$\varepsilon E_1 = E_2 = \varepsilon E_3 = \varepsilon E_4 = \varepsilon E_5 = E_6 = \varepsilon E_7, E = E_1 = E_3 = E_4 = E_5 = E_7$$

$$E_w = E_2 = E_6, \varepsilon E = E_w, 5E + 2E_w = V_w / b, 5E_w / \varepsilon + 2E_w = V_w / b$$

$$\frac{E_w}{V_w} = \frac{\varepsilon}{b(5+2\varepsilon)},$$ Compare to single gap case: $$\frac{E_w}{V_w} = \frac{\varepsilon}{b(2+\varepsilon)}$$

$$E_w(DG)/E_w(SG) = \frac{2+\varepsilon}{5+2\varepsilon},$$ Assume ε=4, $$\frac{E_w(DG)}{E_w(SG)} = \frac{6}{13} = 0.46$$

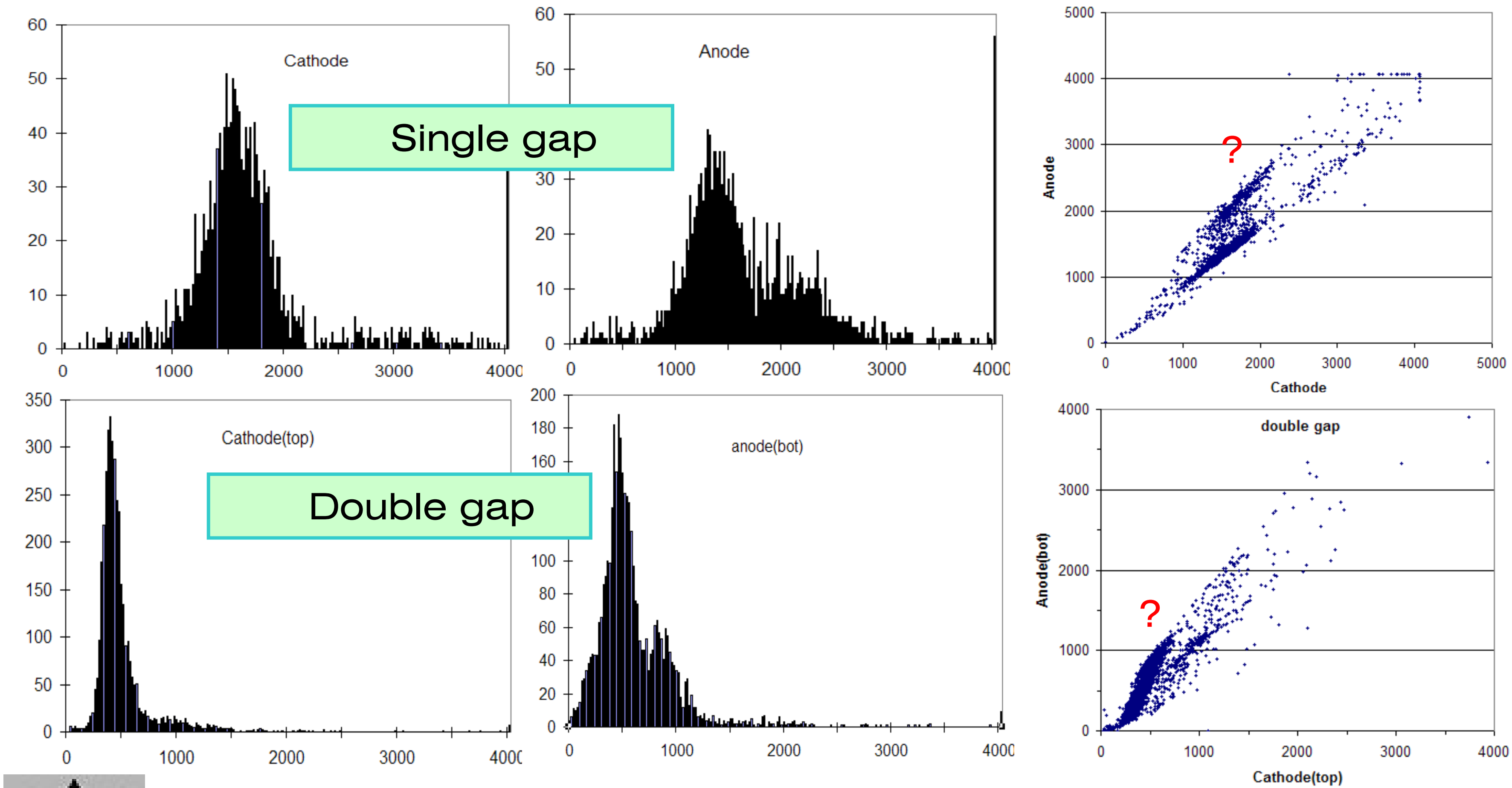
Induced signal would be half for the double gap RPC relative to the single gap RPC, but for the double gap RPC, V_w also doubled, so the ratio should be 0.92, close to 1.

... Calculate the weighting field of the double gap RPC

The conclusion is: in double gap RPC (with an extra 2mm Bakelite gap between two RPCs) the induced signal on the strip would be 92% of the signal from single gap RPC. Without the extra 2mm Bakelite gap between two RPCs the fraction would increase to near 100%.

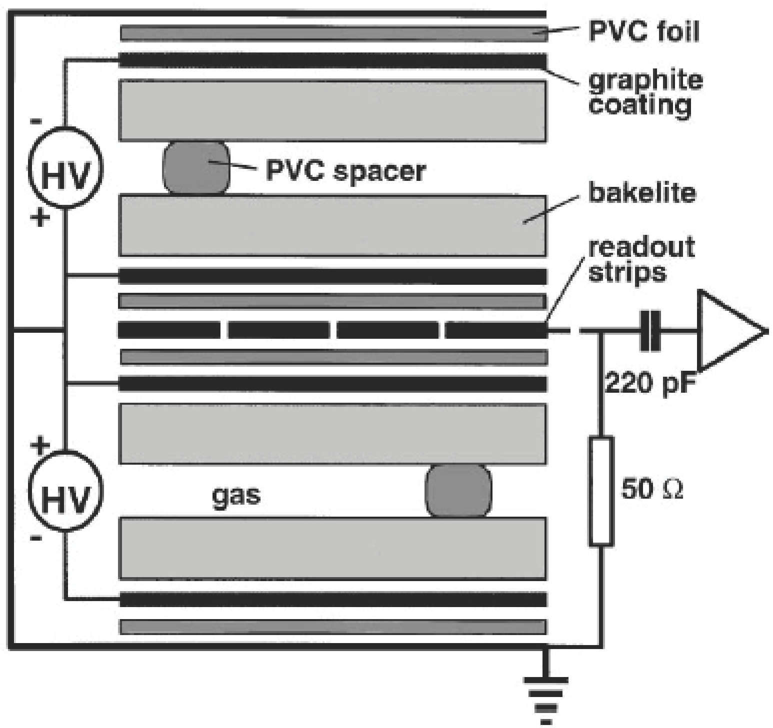
Test results are shown in the next slide. We can see that the signal size is more than fact of 2 less in double gap RPC. The reason is due to the strip arrangement. In single gap case the readout transmission line is formed on both sides of the RPC gap, the induced signal should be doubled the previous calculated number. In double gap case the readout strip only pick up the induced signal from one side. The additional reduction could be due to the absorption on the graphite coatings of the second RPC (when we calculate the weighting field we didn't consider the graphite coating at all).

Test results for single gap and double gap RPC



CMS (same as IHEP) double gap RPC

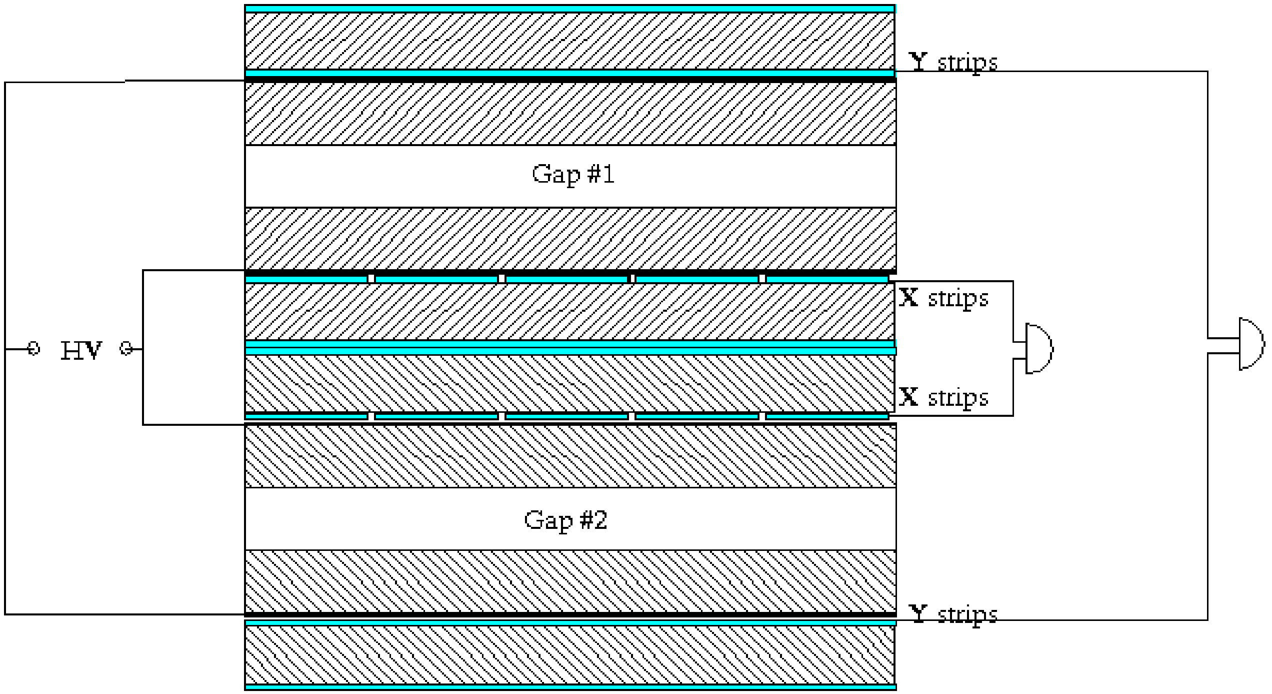
Each double gap RPC only readout one dimension aimed increasing efficiency



Only one dimensional readout for one double gap RPC, the middle strip plane can get double sized signal from two RPCs.

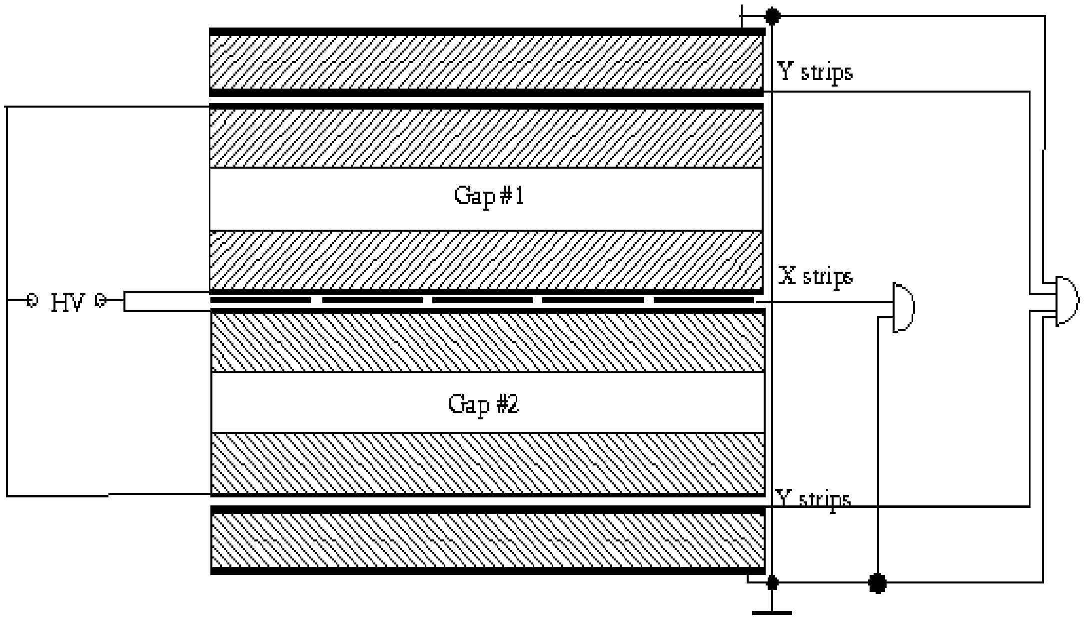
Two back-to-back single gap RPCs with x-y readout

Just like two back-to-back independent RPCs, OR their readout strips together to save electronics channels. Can get two dimensional readout.



Just like two independent RPCs, signal is big, cost little bit more due to an additional readout strip plane.

Middle Y strip plane + top/bottom X strip plane



For x strip the transmission line is not so easy to analyze: the x strip and the shielding plane is separated by the y strip plane. The advantage for this configuration is larger signal. It is worth to do R&D to understand the mechanism.

Pulse shape for different strip grouping configurations

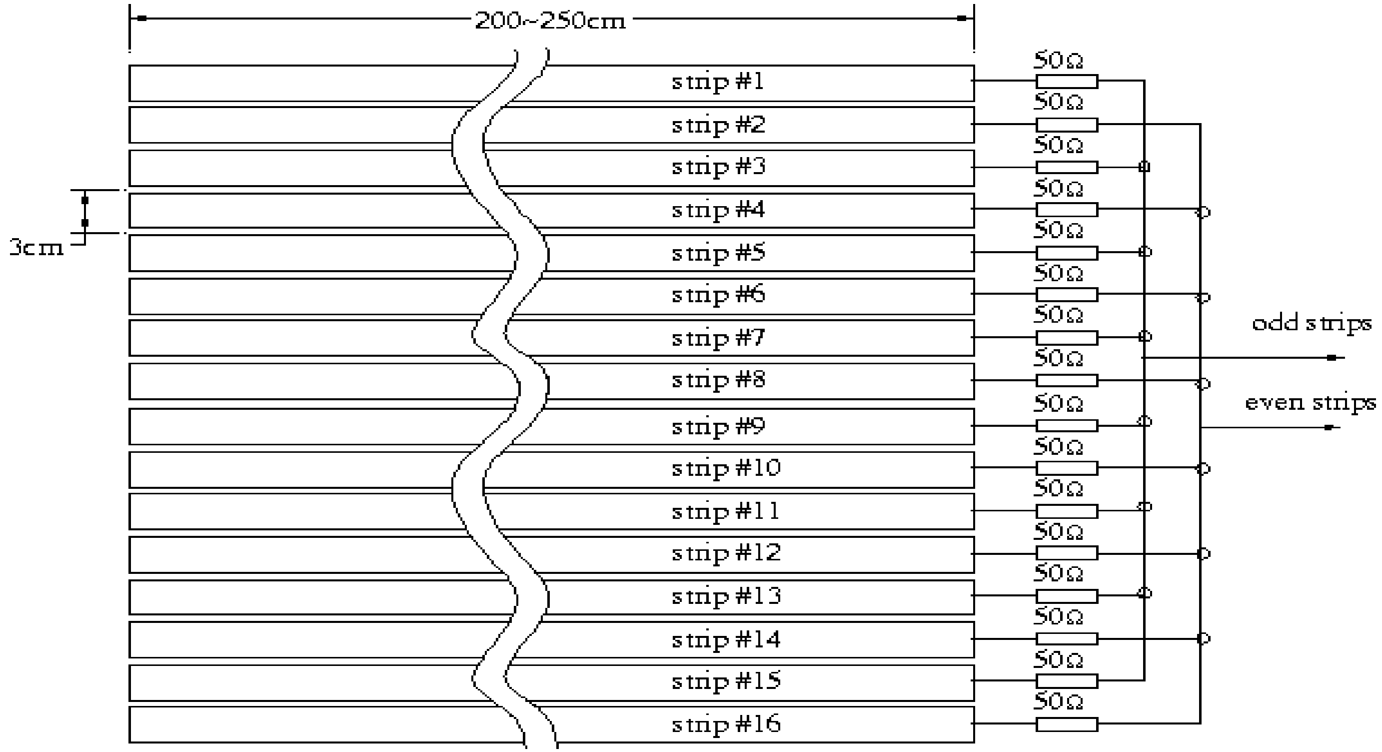
Group 8 strips, time scale 1000ns. Trace #1 and #2 represent the groups of 8 odd strips and 8 even strips, respectively.

Odd strips

Even strips

Trigger

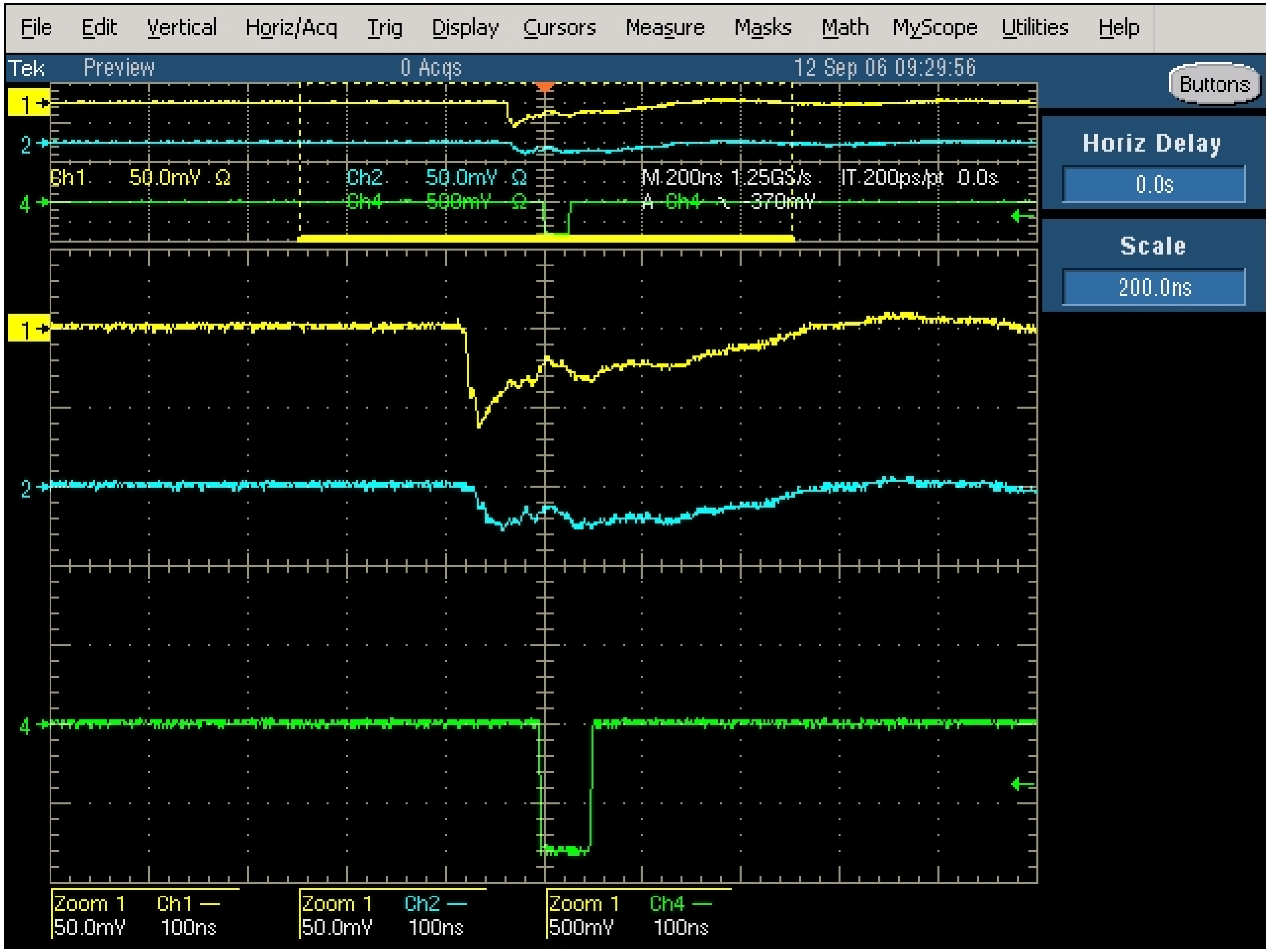
How to group the strips?



Group 8 strips together through 50Ω. Same way to group 4 and 2 strips.

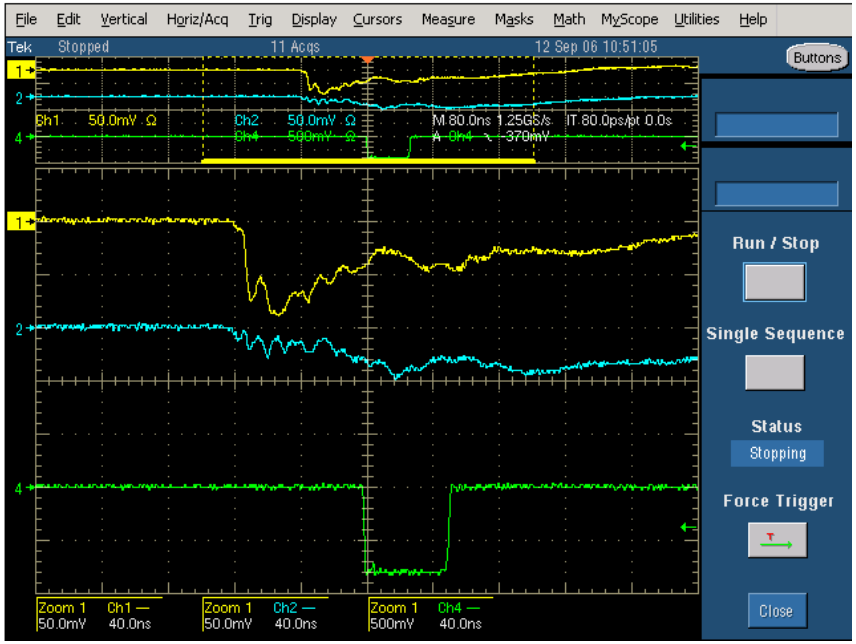
… Pulse shape for different strip grouping configurations

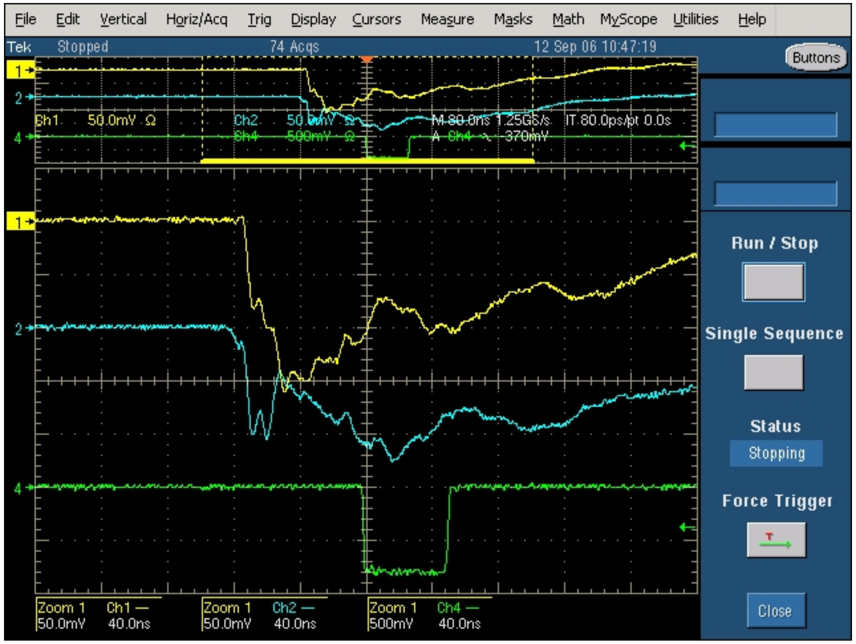
8 strips group, same as before but the time scale is 200ns



... Pulse shape for different strip grouping configurations

Group 4 strips, time scale 80ns.



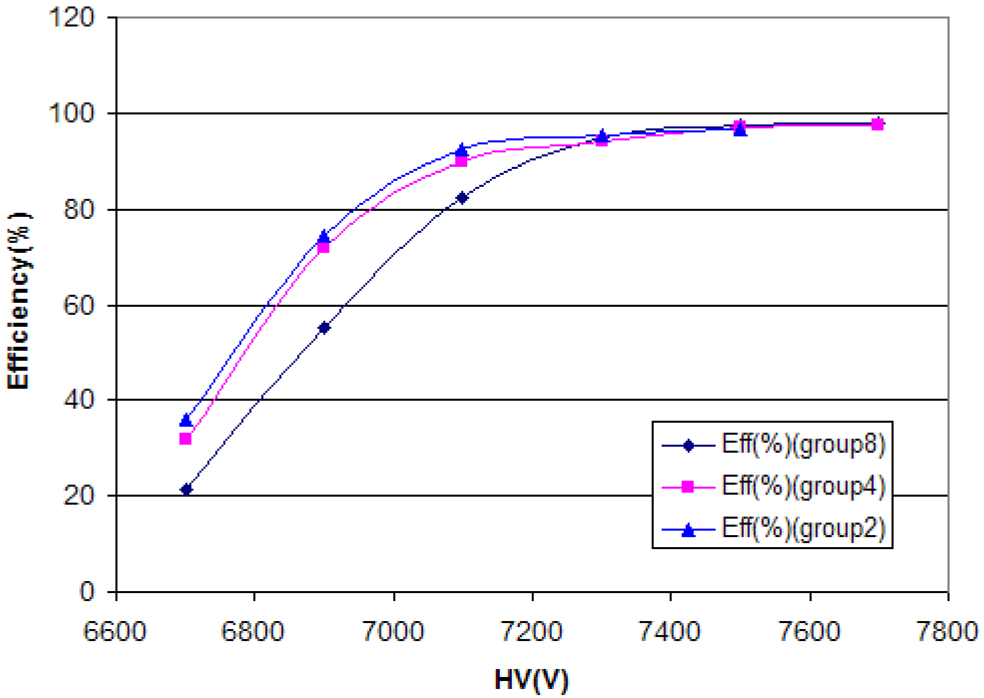


... Pulse shape for different strip grouping configurations

Single strip,
time scale 80ns.

Effect of different grouping scheme on the efficiency plateau

From the screen capture of the induced signal for different grouping schemes we can see that more strips being grouped, less the output signal amplitude will be. Test the efficiency plateau curve will be able to reveal this quantitatively.



Group 8, 4 and 2 strips together, then test the efficiency curve, we found in 8 strips case the efficiency curve shifted towards right for ~200V, group 4 and 2 strips actually make no difference.