Development of high rate RPCs

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RPC rate capability

- Particle flux through RPC → Signals → Current through detector, in particular through resistive electrode (glass/Bakelite) → Voltage drop on resistive electrode → Reduced voltage on gas volume → Lower gas gain, lower efficiency → limiting factor for rate capability
- For stable particle flux, after transient, the voltage on gas volume u_{1f} is *:

Constant ∝ signal charge

High voltage applied on RPC

Threshold voltage for signal to appear

$$u_{1f} = \frac{u + 2cf\rho d_2 u_0}{1 + 2cf\rho d_2}$$

Particle flux rate

Thickness of resistive electrode

Bulk resistivity of electrode material

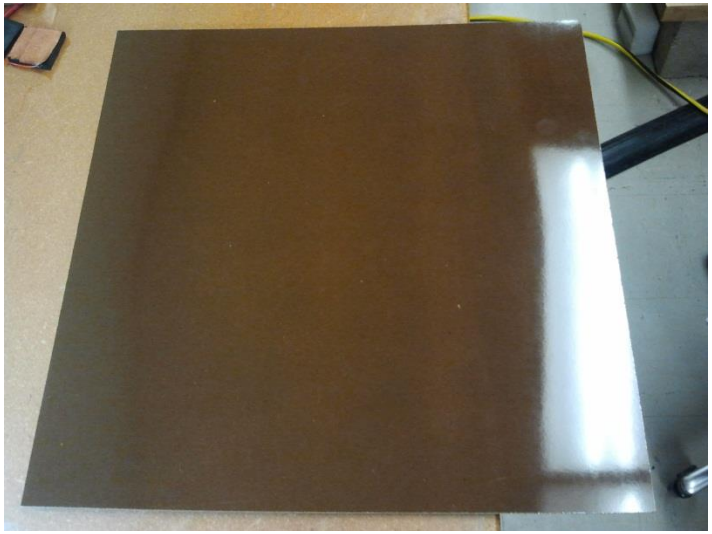
- Ways to improve RPC rate capability
  - $\rho\downarrow$: lower resistivity electrode material
  - $d_2\downarrow$: reduce thickness of electrode
  - $c\downarrow$: operate with lower gas gain, together with more sensitive readout

Focus of this talk

* For details, please see B. Bilki, et al., "Measurement of the Rate Capability of Resistive Plate Chambers" JINST 4 (2009) P06003

Development of low resistivity Bakelite

- USTC (University of Science and Technology of China) engaged Chinese Bakelite manufacturer to work on R&D of low resistivity Bakelite material
- First batch of boards delivered
  - Bulk resistivity 10^8 – 10^{10} Ω·cm
  - Visual inspection suggests good quality

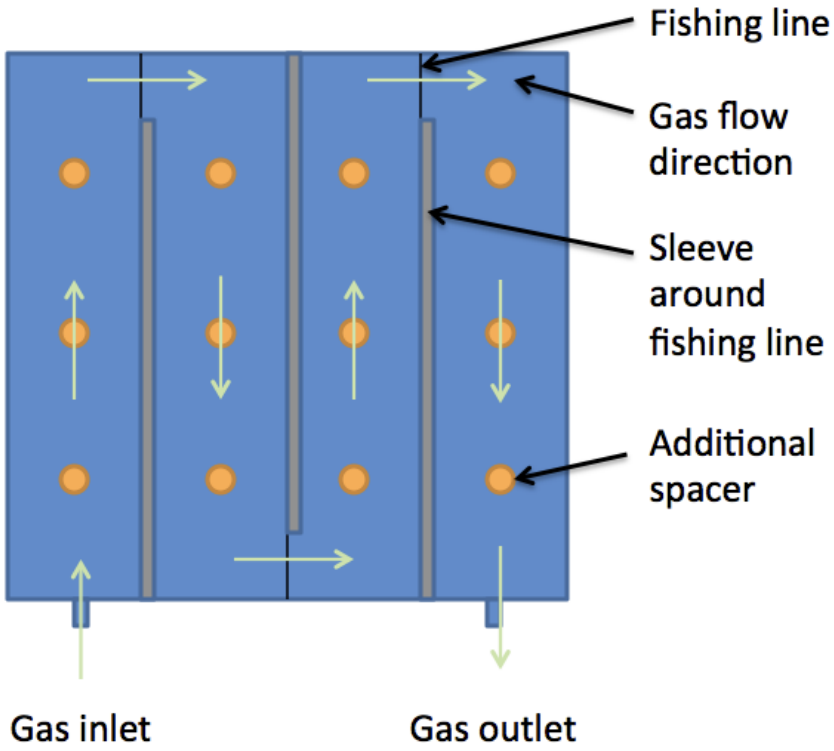


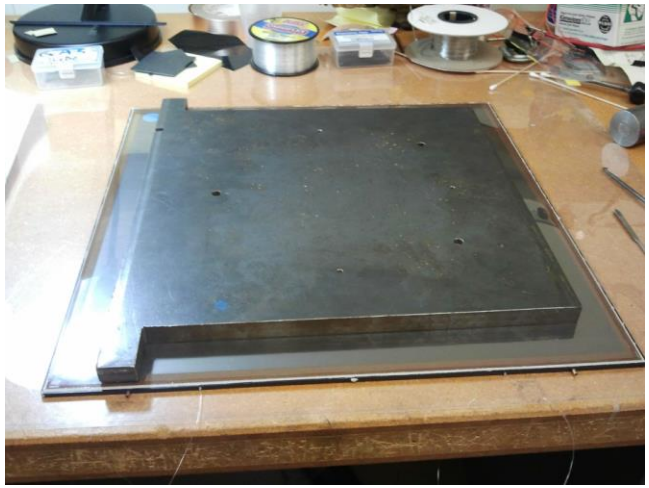
Serial number	Thickness (mm)	Resistivity (Ω•cm)	Temperature (℃)	Humidity (%)
15001	1.567	8.00E+09	26.1	35
15002	1.495	1.45E+10	26.4	35
15003	1.557	2.43E+10	26.8	35
15004	1.549	2.12E+10	26.9	35
15005	1.426	4.79E+10	27.1	35
15006	1.417	5.06E+10	27.1	35
15007	1.423	4.97E+10	27.3	30
15008	1.448	5.06E+10	27.4	30
15009	1.433	1.43E+09	24.2	30
15010	1.422	5.95E+10	24.9	30
20001	2.046	3.61E+10	24.8	30
20002	1.961	8.79E+09	25.1	30
20003	2.074	1.54E+09	25.6	30
20004	2.058	3.92E+09	25.6	30
20005	2.136	1.74E+10	26.2	30
20006	1.876	1.83E+10	26.4	30
20007	2.127	6.17E+08	26.7	30
20008	1.573	9.57E+08	26.7	25

- ANL, U. Michigan and IPAS participate the development as well.

Development of low resistivity Bakelite

- ANL and USTC each built several prototype RPCs, with modified DHCAL design
  - Extruded PVC frame, ~1.2 mm gap
  - Added spacers to deal with board warpage

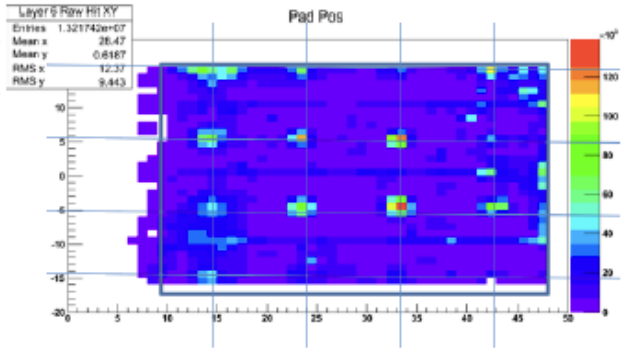




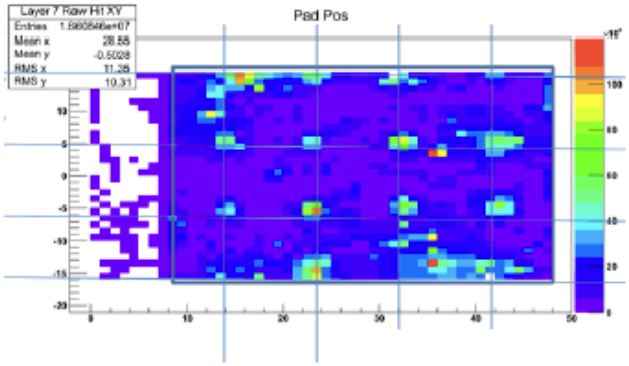
Cosmic ray test at ANL

2 Chambers made with low resistivity bakelite work very well, stabled after running 2 days.

Chamber A



Chamber B



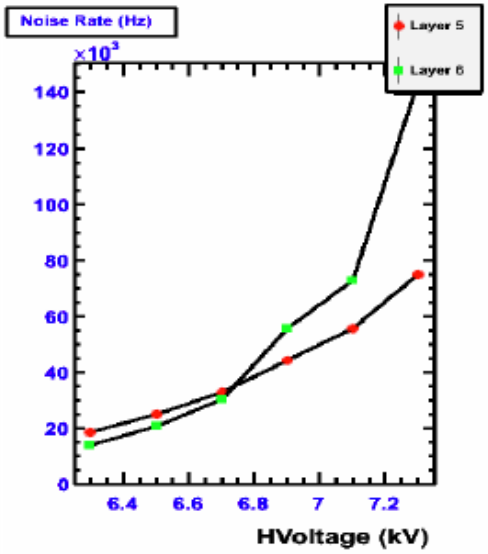
Red Point: Chamber A

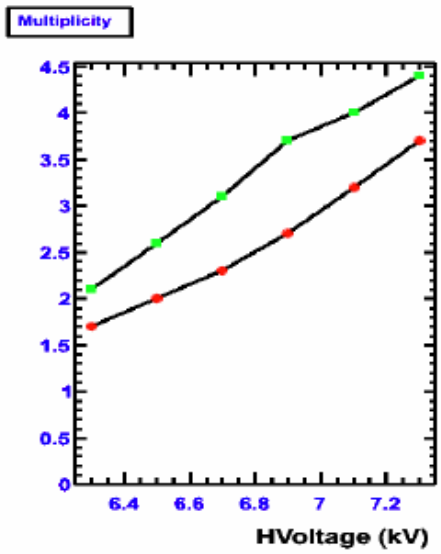
Green Point: Chamber B

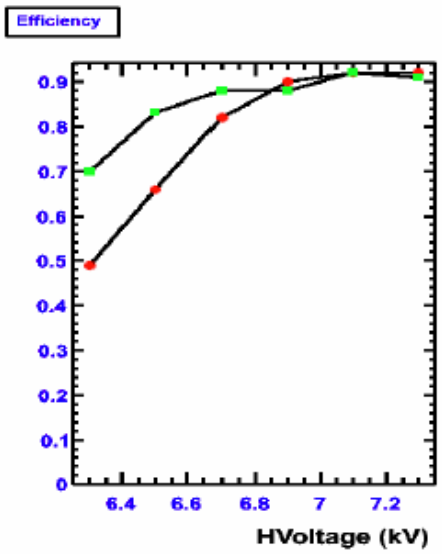
Noise Rate

--Chamber A=34Hz/cm^2

--Chamber B=24Hz/cm^2

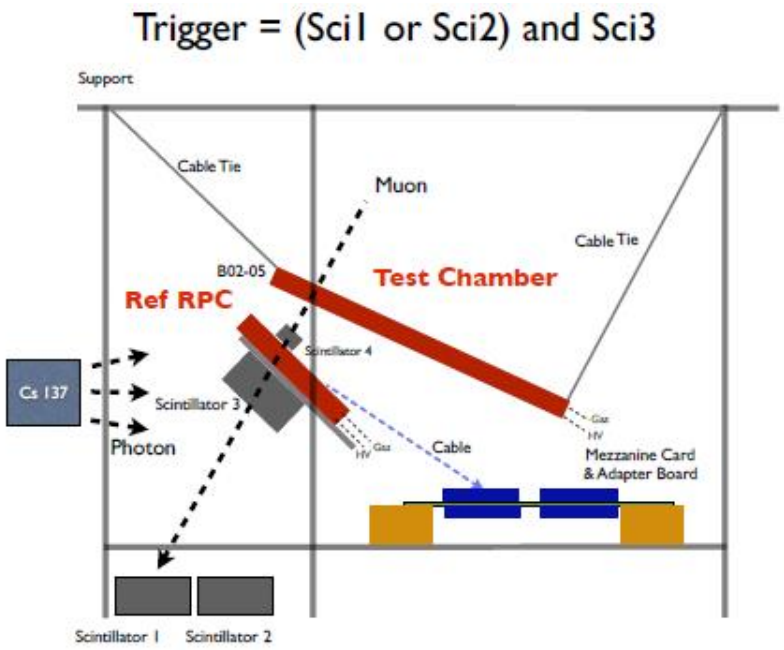


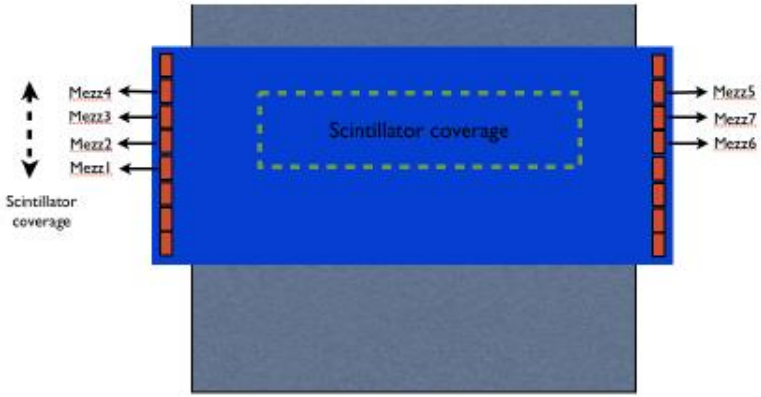


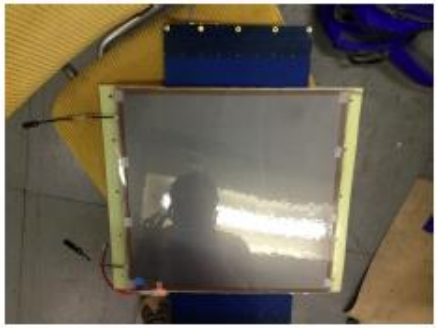


GIF test setup

- Radiation Test (Cs137) at CERN
- Gas: 94.7% $C_2H_2F_4$, 5% C_4H_{10}, 0.3% SF_6
- Signal pick up board: 1 small(for reference chamber), 1 large(for test chamber), strip width=1.2mm, 2-end readout.
- MDT DAQ system, 8 mezzanine cards(7x24 channels, 1 for trigger). The accuracy of TDC is 0.78125ns.

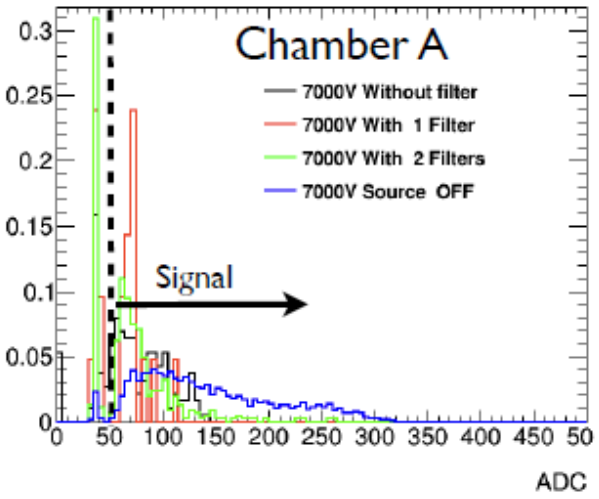


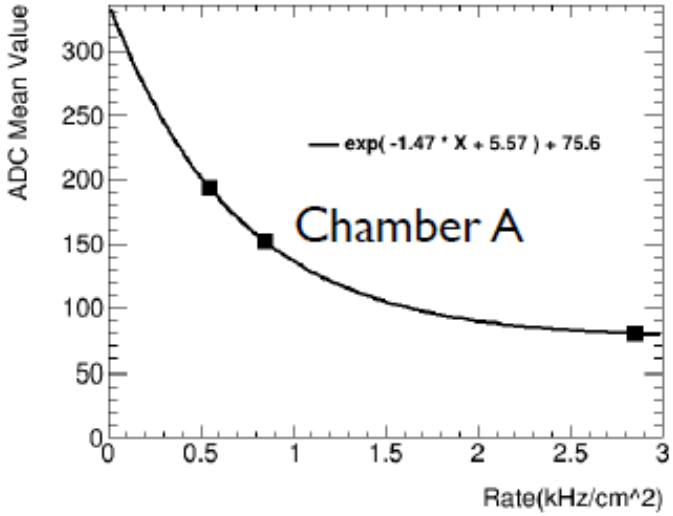


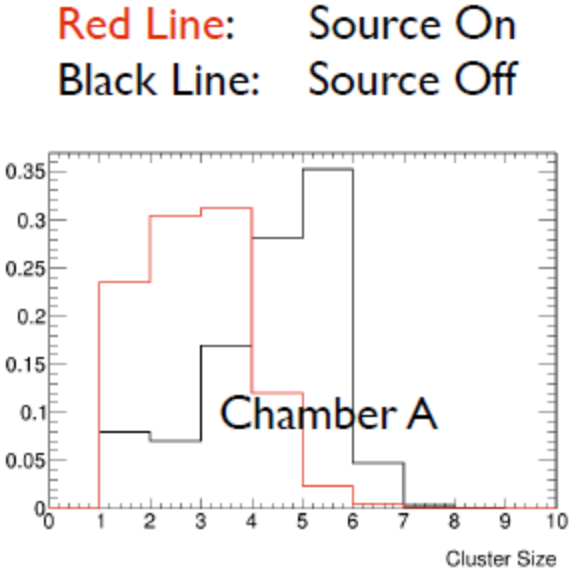


Some GIF test results

- With source ON, signal charge decrease rather rapidly
- Rate capability NOT as high as expected from previously measured resistivity
- Later confirmed that the Bakelite resistivity creeps up over time



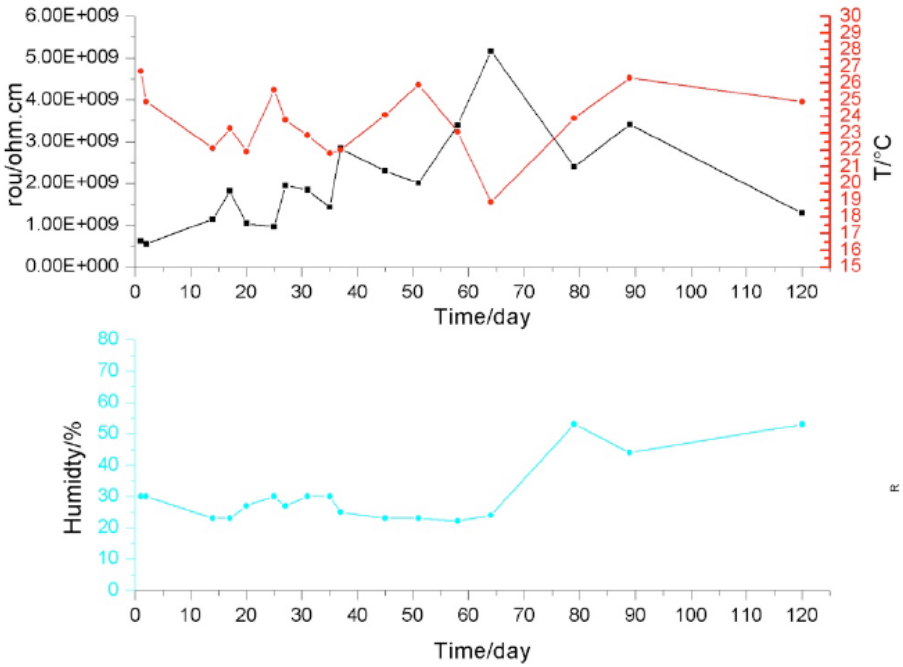




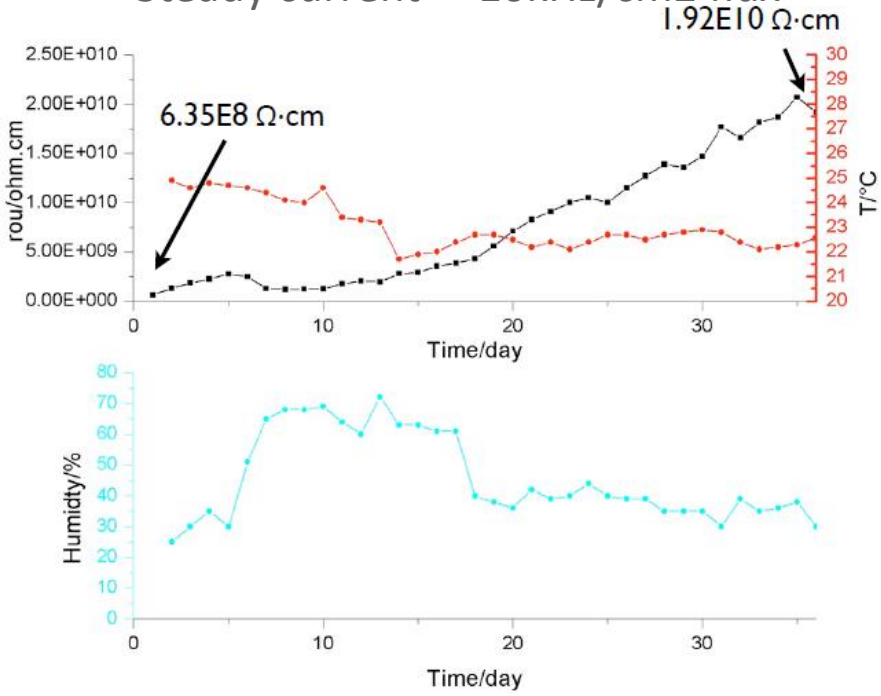
Bakelite aging study

- Bakelite resistivity stable over time, if no current is applied
- When a steady current is maintained through the sample, resistivity go up over time (carrier being drained)
- More R&D is needed

No current through sample

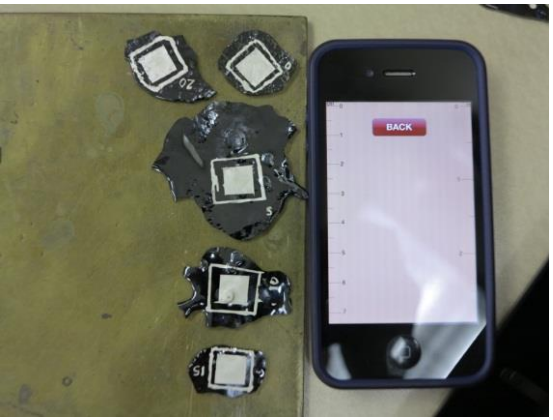


Steady current ≈ 10kHz/cm2 flux



Development of low resistivity glass

- Glass electrode has distinct advantages over Bakelite
  - More stable material properties
  - Better surface quality and flatness
  - However, low resistivity glass currently available is quite expensive
- ANL engaged Iowa University and COE College to develop low resistivity glass
  - COE College (Cedar Rapids, Iowa) is the expert in glass related research
  - Small samples made/tested at COE college in 2012 → 'any resistivity is achievable'
  - First 'large' samples made at COE college, tested at ANL in 2012 – 2013
  - Second 'large' samples made at COE college late 2013, being tested at ANL

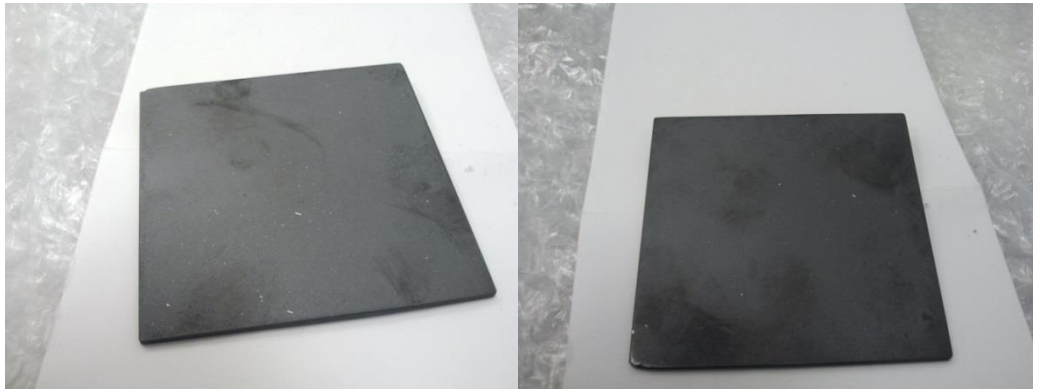


Conductivity							in S-cm
	0%	5%	10%	15%	20%	25%	30%
100 V	4.87E-09	2.06E-09	2.01E-09	3.14E-09	5.79E-08	6.19E-08	7.01E-08
200 V	1.06E-08	4.74E-09	6.47E-09	7.80E-09	6.14E-08	6.33E-08	7.16E-08
400 V	1.58E-08	6.70E-09	1.17E-08	1.32E-08	6.89E-08	6.54E-08	7.26E-08
800 V	1.96E-08	8.10E-09	5.24E-08	2.77E-08	9.85E-08	6.97E-08	7.52E-08

	5%	10%	20%	30
100	2.87E-04	1.16E-05	2.38E-04	1.48E-03
200	1.38E-05	1.05E-05	1.14E-05	1.56E-03
400	7.02E-06	5.44E-06	5.83E-06	1.55E-03
800	3.61E-06	2.79E-06	2.97E-06	2.97E-06

First batch of ‘large’ glass samples

- 6 glass samples were produced at COE college and were sent to vender for polishing
- Only 2 (partially) survived polishing, and were cut to 6 cm x 6 cm squares
- Resistivity measurement reveals that
  - Bulk resistivity is around 10^8 -10^9 Ω·cm, exactly what we requested
  - However, some impurity creates low resistance path through glass
- Went ahead to made RPC prototype



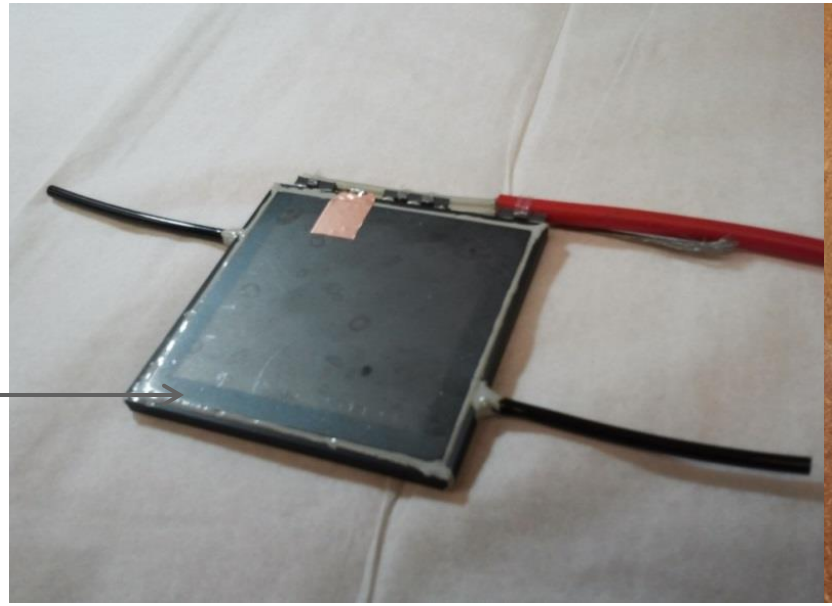
Two sides of sample 1

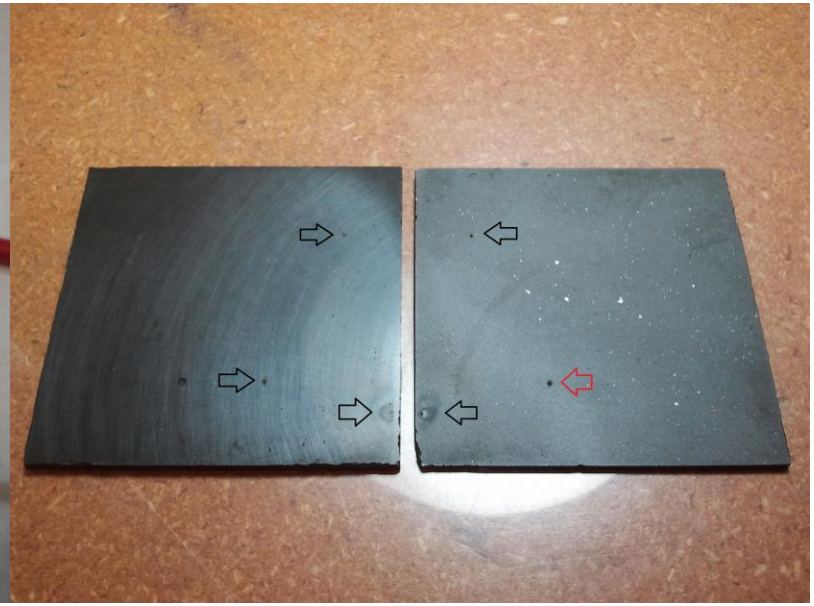
Two sides of sample 2

RPC prototype

- The chamber construction went smoothly
- HV test shows large dark current starting at ~ 4 kV: seems to have trouble controlling discharge in the gas volume
- Took apart the RPC, the marks on the inside surfaces verified the assumption

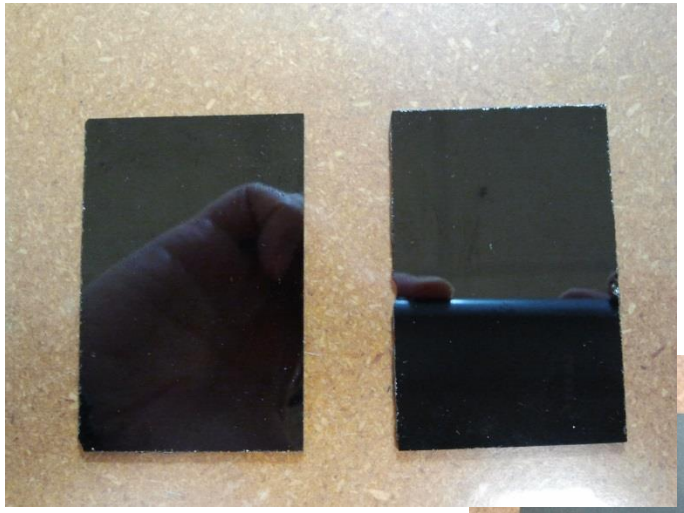
Graphite coating

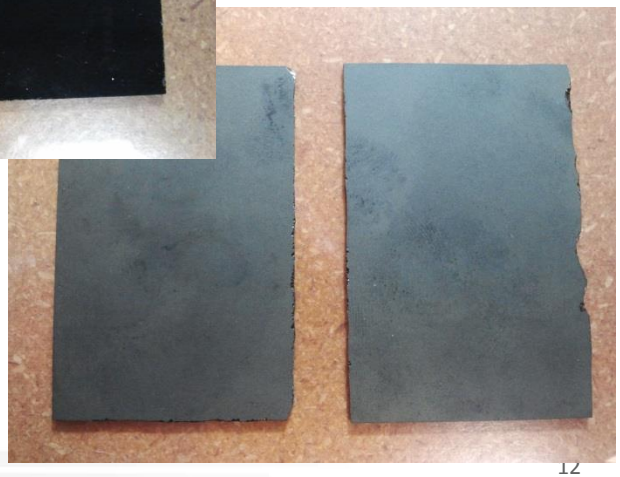




Second batch of ‘large’ samples

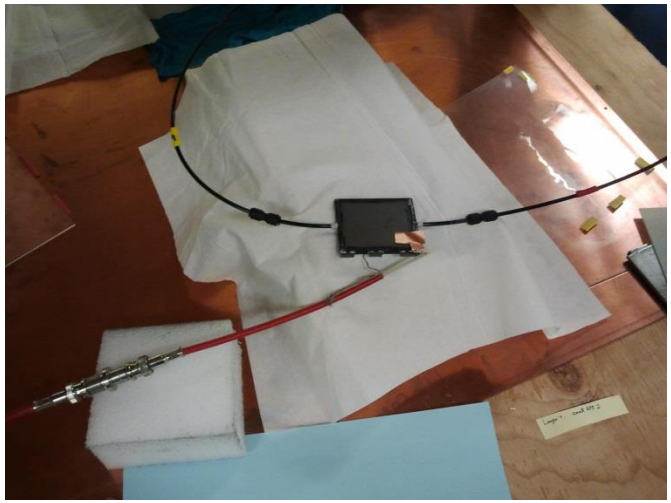
- Based on the results of first batch, we requested the second batch to have better uniformity and the target resistivity was said to be 10^{10} – 10^{12} Ω·cm
- 4 large samples (~ 12 cm x 24 cm) were made at COE college, with very much improved quality
- Unfortunately, all 4 samples were broken in the polishing process. But we managed to recover some relatively large fragments



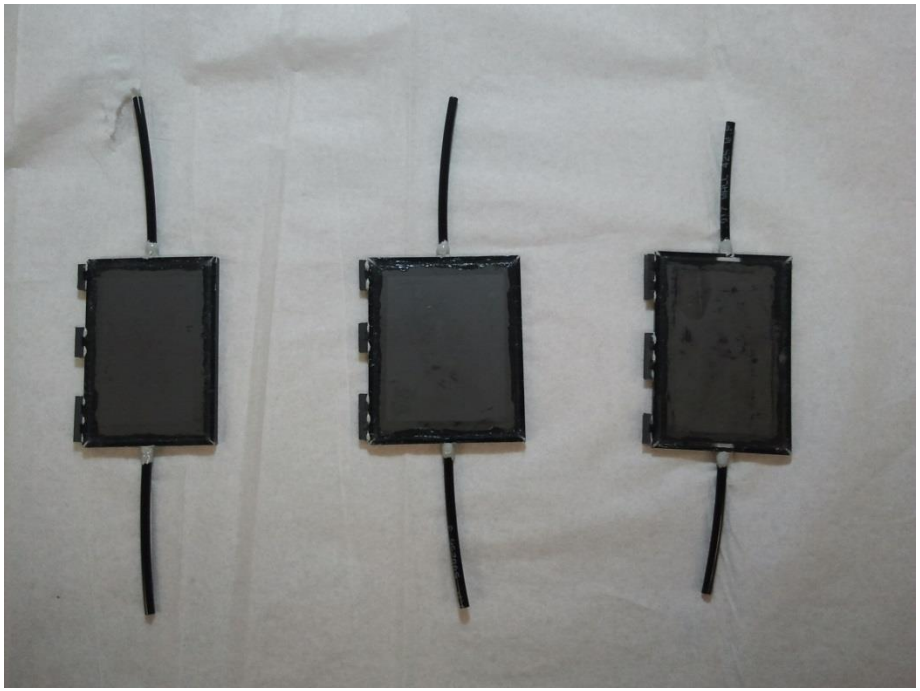


RPC prototype

- Resistivity is measured to be 1.5/2.0 x 10^{11} Ω·cm (only measured two samples out of many), again exactly what we requested
- 3 small prototype RPCs were built and HV tested – all of them can hold > 7 kV with minimum dark current. No sign of any break down / spark.
- The gap size is ~1.1 to 1.2 mm, a decent avalanche signal should show up at ~ 6.3 kV, with ~90% efficiency using DHCAL readout
- Due to the small size of these RPCs, we plan to skip cosmic ray tests and go directly to test beam at Fermilab.

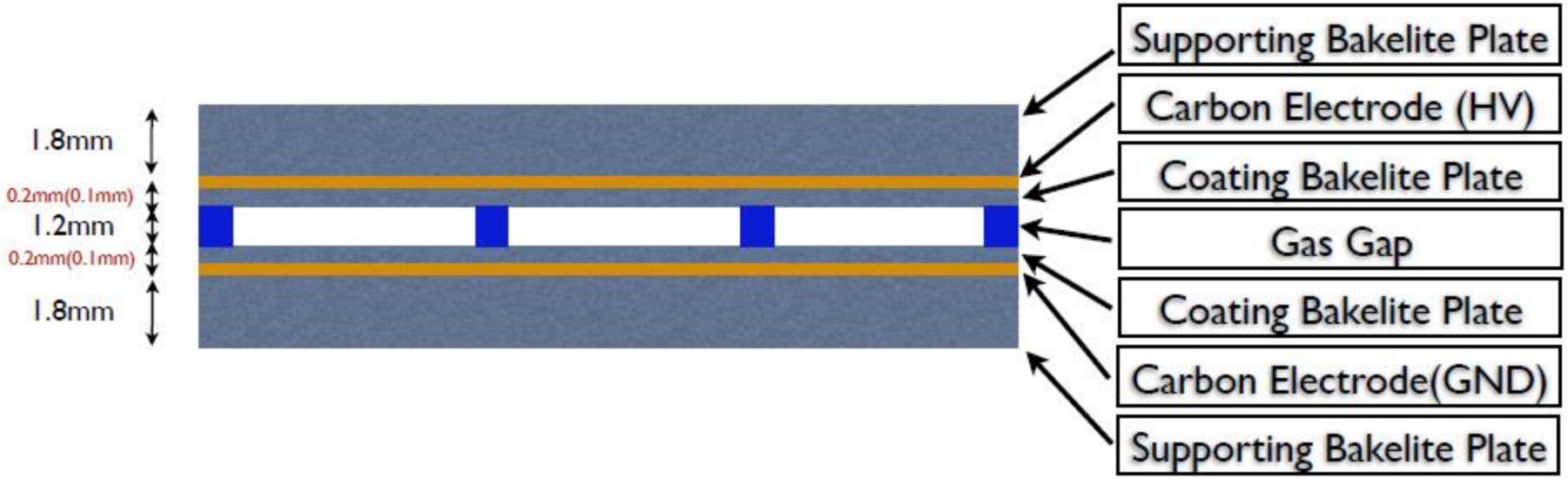


HV test



Development of new electrode structure

- New type of Bakelite board was made with embedded resistive coating, under collaboration with USTC, U. Michigan, IPAC
- Effective electrode thickness is reduced by a factor of ~10 → expect ~10 time higher rate capability
- Two prototype RPCs were constructed at ANL
- Prototype RPCs were tested at ANL and CERN (GIF)

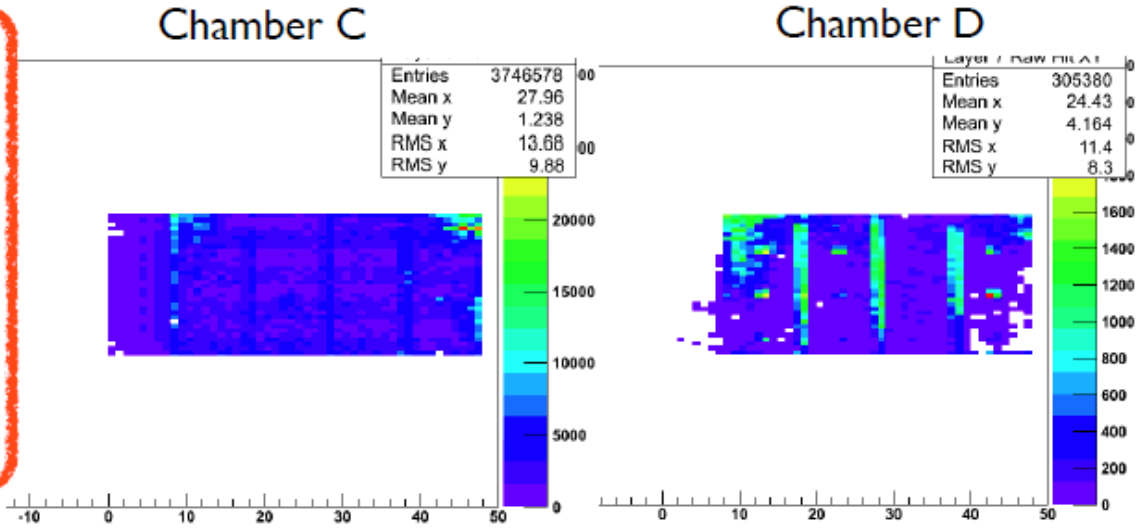


Cosmic ray test at Argonne

--Two Chambers made carbon electrode embedded bakelite work well as normal RPC.

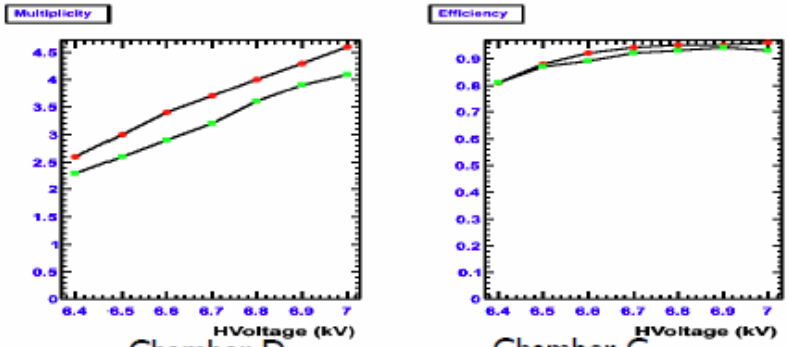
-- Efficiency is pretty high

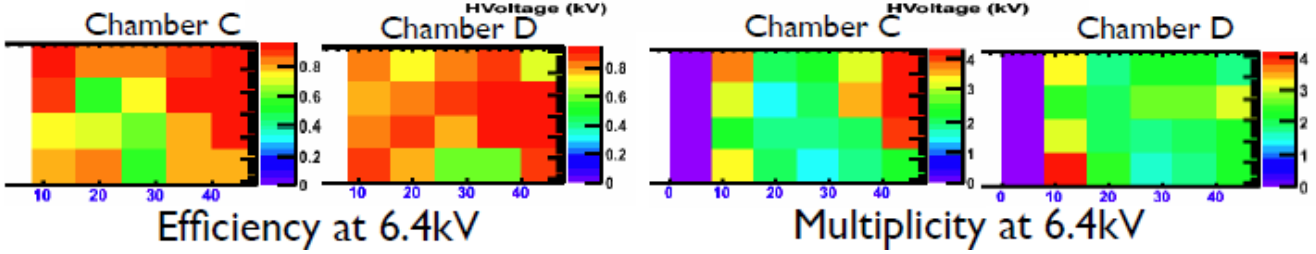
-- Hit Multiplicity doesn't increase obviously.



Red Line: Chamber C

Green Line: Chamber D



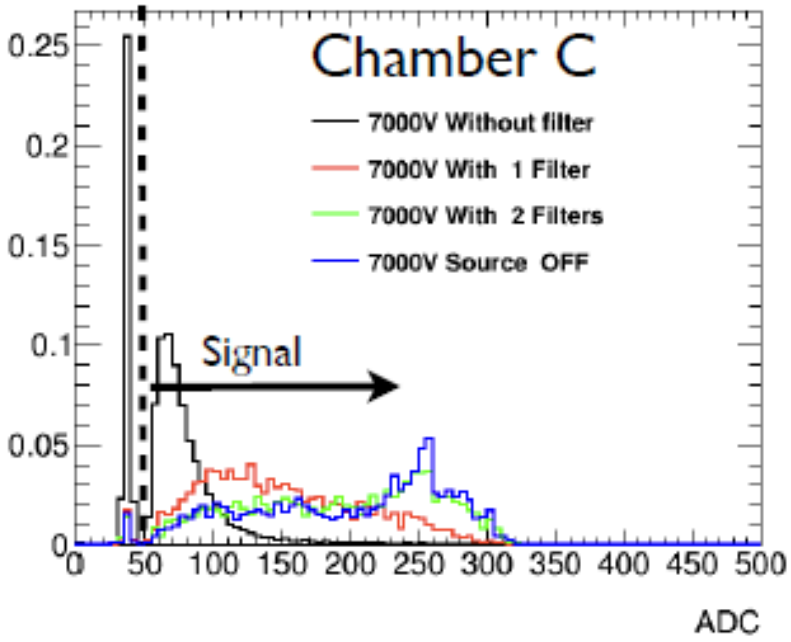


CERN GIF test

- One prototype RPC with the new Bakelite structure was tested at GIF
- Rate capability is better than the 'low resistivity' Bakelite RPC prototypes
- Later Argon measurements confirmed a factor of ~10 reduction in effective R
- Further development has been agreed upon among collaborators

Important message:

The new structure works!



Summary

- ANL group has engaged collaborators to develop RPC with higher rate capability with several different approaches
  - Low resistivity Bakelite:
    - sample/prototype produced/tested, long term stability is still an issue.
  - Low resistivity glass:
    - Sample/prototype produced
    - Test beam coming up in two weeks
  - New Bakelite structure:
    - Concept proved
    - More development on the way

- We have a lot of progress on all fronts, more is coming