Update on DHCAL and RPC progress

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Outline

- Summary DHCAL test beam activities
- Progress on test beam data analysis
- RPC R&D progress

DHCAL test beam has finished!

- Last DHCAL test beam period at CERN with W absorber finished in Nov. 2012.
  - Got more hadron data at high momenta, and did another muon run
  - Tried high-gain mode of the DCAL chip, and measured change in rate capability
  - Experienced a sudden gas gain change – understood why

DHCAL Data Summary

Testbeam	Configuration	Muons[3]	Secondary beam[3]	Total[3]
Fermilab[1]	DHCAL	6.9	9.3	16.2
	SiW ECAL + DHCAL	2.5	5.1	7.6
CERN[2]	DHCAL	5.6	23.4	29.1
TOTAL		**15.0**	**37.8**	**52.8**

[1]Contains a significant fraction of 'calibration events'
[2]Contains no 'calibration events'
[3]Numbers in millions

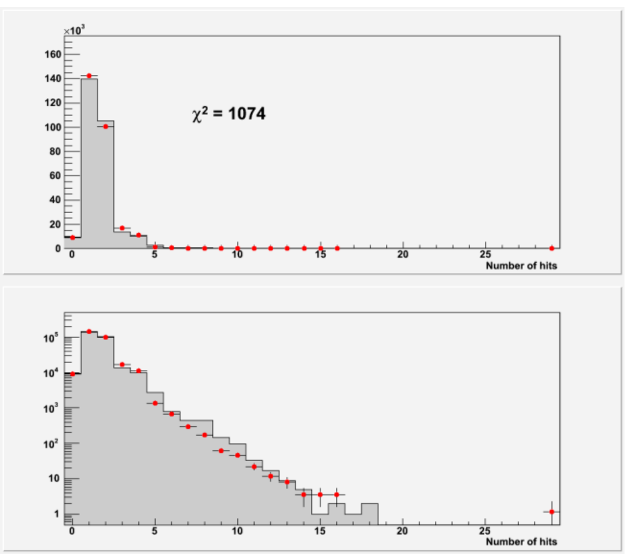
DHCAL prototype has been shipped back to ANL

- What should we do next (with the prototype)?
  - Have a few ideas, but suggestions are very welcome

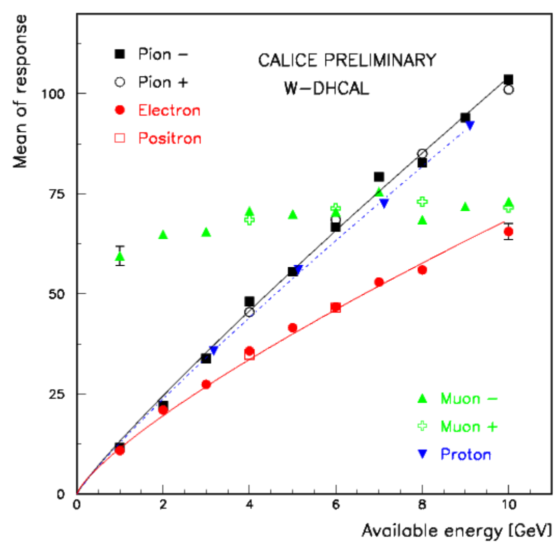
Data analysis

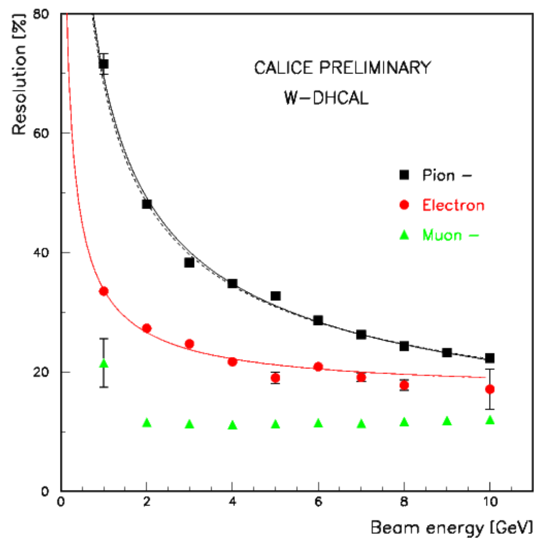
- Results from the first look of the data exist (and were reported at conferences)
- Analysis towards final publications is on-going
  - ANL team is analyzing the data from Fermilab test beam
  - ANL and CERN group will work together on CERN test beam data, with CERN playing a major role
  - We made a lot of progress, but things are not easy
    - Calibration is significantly more complicated than we anticipated
    - Shortage of manpower is slowing us down

Muon response/simulation



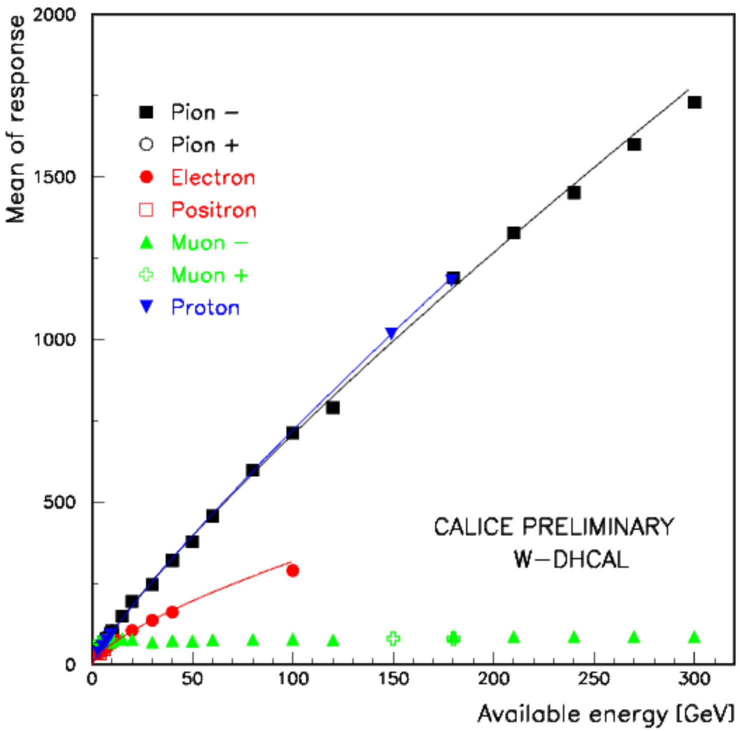
DHCal response/resolution at PS (1 – 10 GeV)



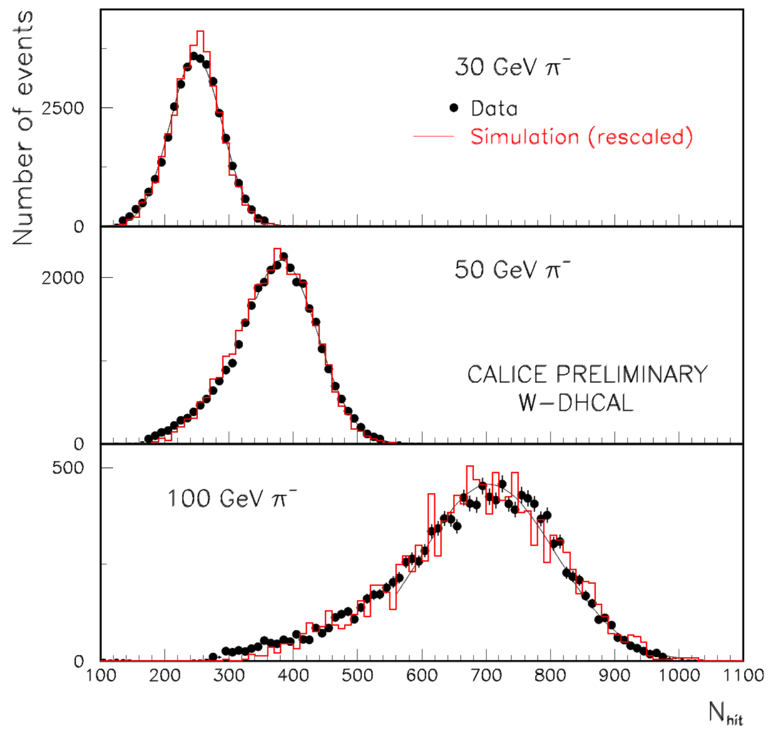


Some preliminary results from CERN data

More preliminary results from CERN data



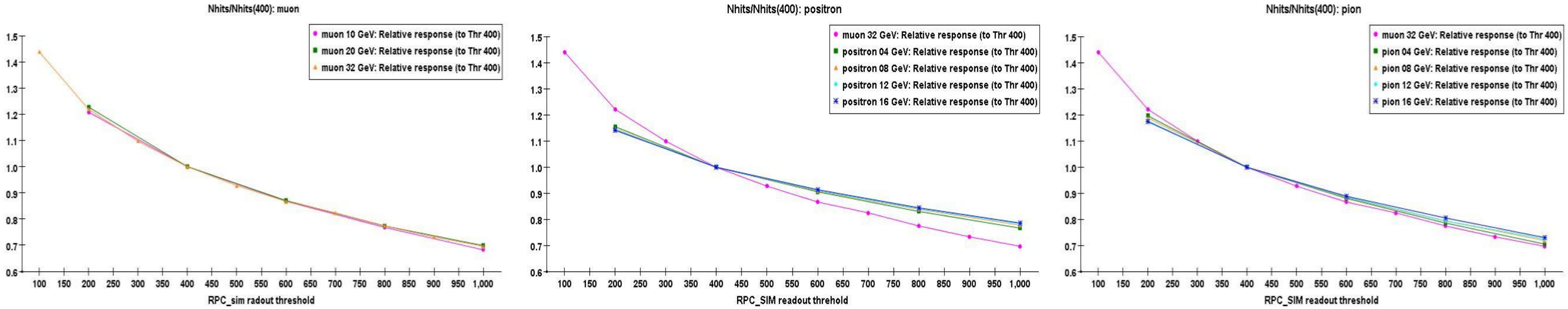
Response at the SPS (12 – 300 GeV)



Comparison with Simulation – SPS energies
(data: not calibrated; simulation: rescaled)

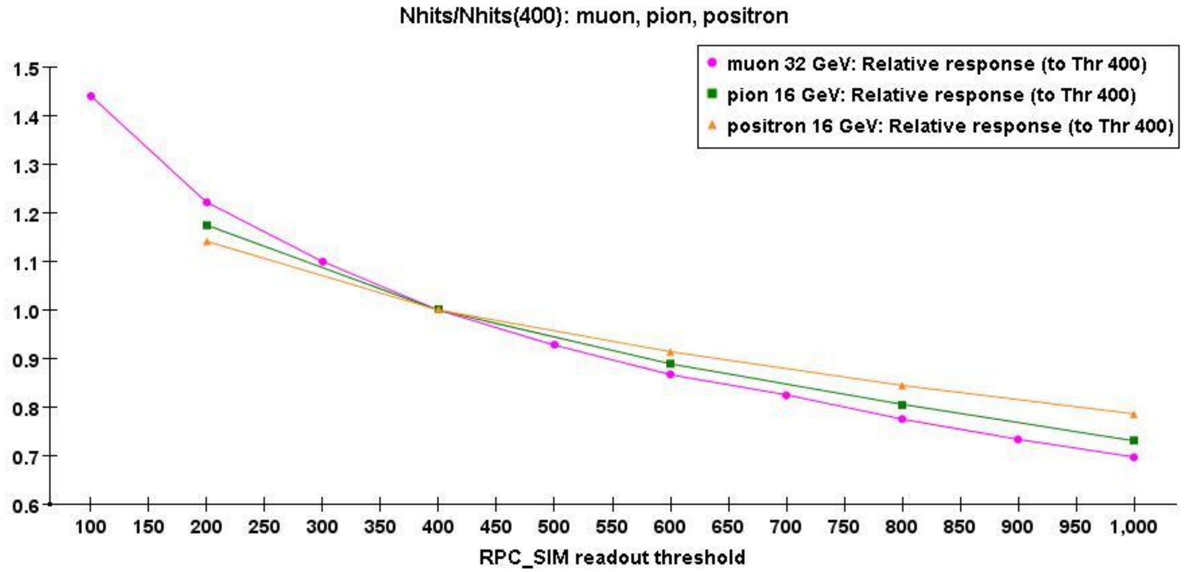
Data analysis: calibration

- DHCAL calibration was though to be simple and painless
  - Control parameters: RPC efficiency (ε), multiplicity (μ)
  - DHCAL response, to first order, should scale with 'calibration factor' = ε x μ
  - In deed, this calibration scheme works to first order, more or less
- To go further, things become complicated
  - Due to the fact that some pads were hit by more than one particle, these hits scale differently from the others
  - Number of particles hitting a pad can be approximated by local hit density, which changes with energy and type of showering particle
  - As a result, calibration may have hit density, energy, particle type dependences
  - Simulation samples were generated at different signal charge thresholds, in order to study the calibration scheme



Average number of hits as a function of readout threshold: scaling is energy dependent
(muon, pion and positron at several energies, all normalized to the number of hits at threshold = 400)

Data analysis: calibration



Scaling of number of hits as a function of readout threshold: particle type dependence (muon, positron, pion: all response are scaled to their own response at threshold of 400)

- Current calibration studies
  - Data driven method
    - 'Full calibration' using 'calibration factor' = ε x μ
    - Try to 'reduce' the full calibration and find new calibration functions based on local hit density
  - MC sample driven method
    - Using MC sample to study the migration of hits in density bins as a function of threshold
    - Bin by bin calibration function for each density bin, using ε and μ as parameters
- Both methods make a lot of progress → hope to solve the problem soon

RPC R&D progress

- R&D on improving RPC rate capability
- Progress on 1-glass RPC

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
  - ρ↓: lower resistivity electrode material
  - d_2↓: reduce thickness of electrode
  - c ↓: operate with lower gas gain, together with more sensitive readout

Low resistivity material

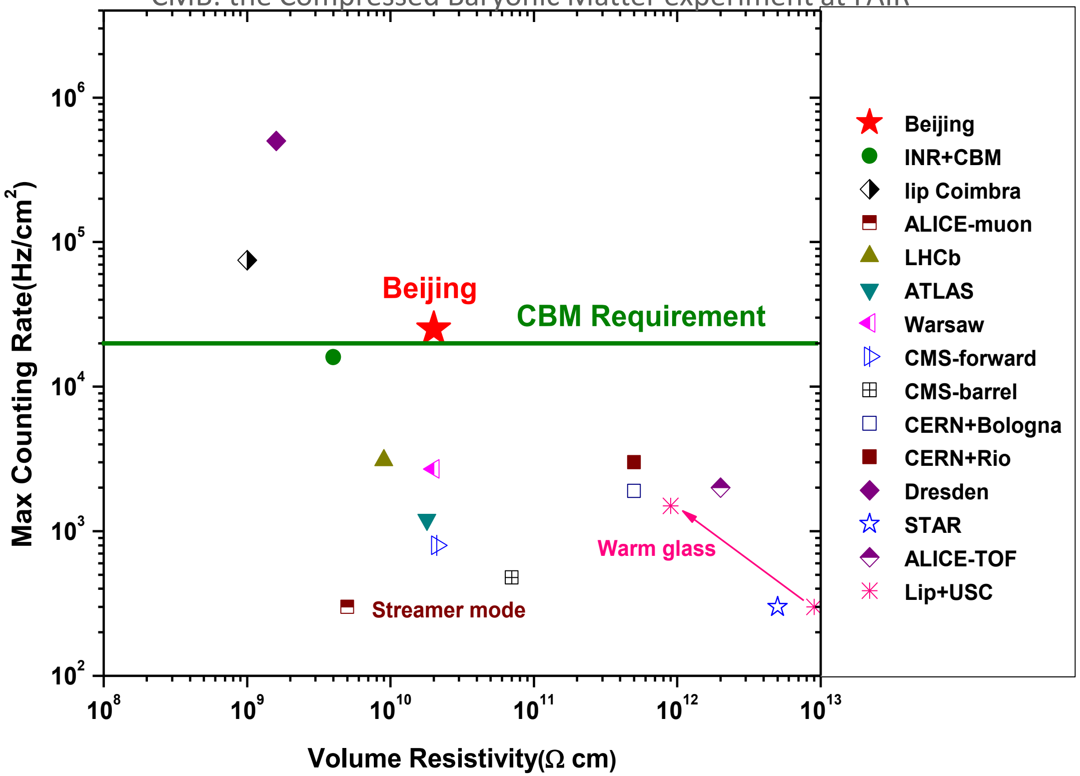
- Electrode material currently available:

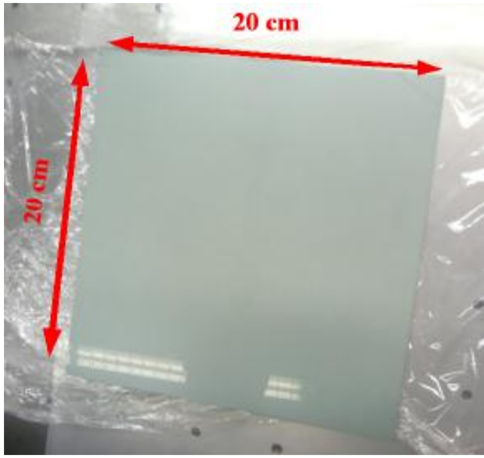
CMB: the Compressed Baryonic Matter experiment at FAIR

Ceramics

Semi-conductive glass

Float glass





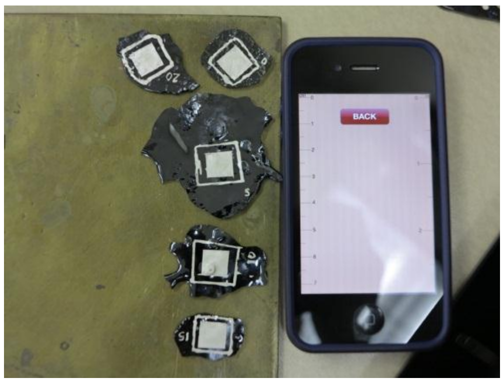
Ceramic electrode

Semi-conductive glass electrode

- Various R&D groups are exploring ways to produce low resistivity electrodes
  - Partially successful, but production cost very high

Finding new electrode material: glass

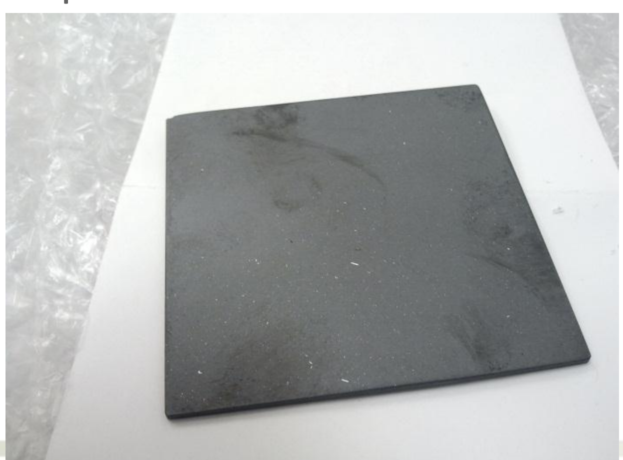
- Argonne, U. Iowa has engaged Coe College [expert in glass research] to develop affordable low resistivity glass
- Lab samples achieved resistivity in very large range:

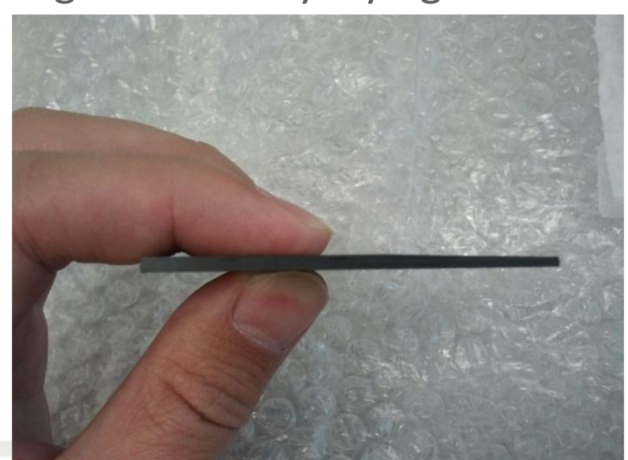


	Conductivity			in S-cm			
	0%	5%	10%	15%	20%	25%	30%
100 V	4.87E-09	2.06E-09	2.01E-09	3.14E-09	5.79E-08	6.19E-08	7.01E-08
200 V	1.06E-08	4.74E-09	6.47E-09	7.80E-09	6.14E-08	6.33E-08	7.16E-08
400 V	1.58E-08	6.70E-09	1.17E-08	1.32E-08	6.89E-08	6.54E-08	7.26E-08
800 V	1.96E-08	8.10E-09	5.24E-08	2.77E-08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

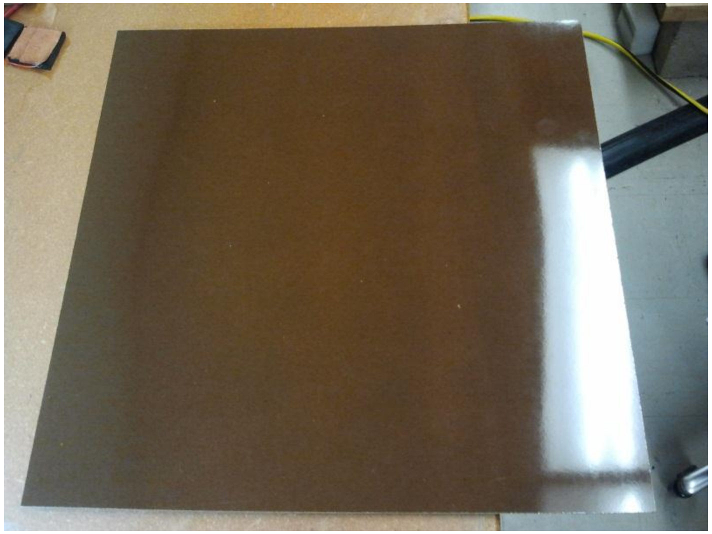
- Small size glass pieces delivered several weeks ago. Currently trying to make RPC with them.





Finding new electrode material: 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



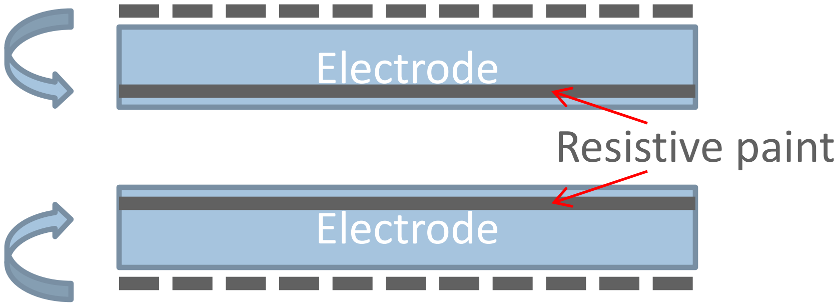
编号	厚度/mm	电阻率 /Ω•cm	室温/℃	湿度/%
15001	1.567	8.00E+09	26.1	35
15002	1.495	1.45E+10	26.4	35
15003	1.557	2.43E+10	26.8	35
15004	1.549	2.12E+10	26.9	35
15005	1.426	4.79E+10	27.1	35
15006	1.417	5.06E+10	27.1	35
15007	1.423	4.97E+10	27.3	30
15008	1.448	5.06E+10	27.4	30
15009	1.433	1.43E+09	24.2	30
15010	1.422	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

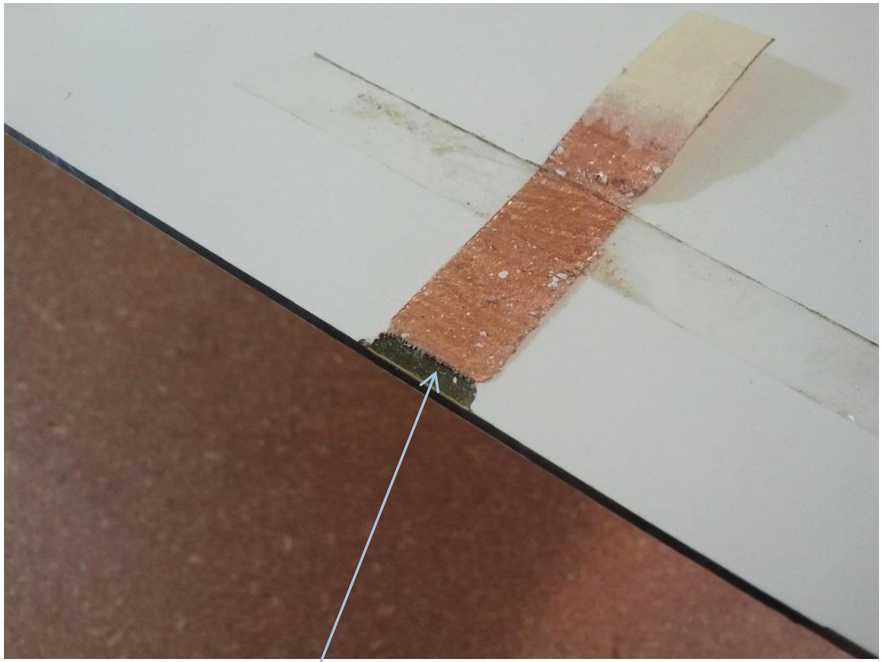
- ANL agreed to evaluate the new boards. We are trying to build RPCs with this batch of Bakelite boards

Other approaches

- Reducing the 'effective' electrode thickness
  - Practical electrode thickness is limited by mechanical strength: ~ 1 – 2 mm
  - However, one can try to embed the resistive coating into the electrode → reduce effective thickness that limits the rate capability
  - Bakelite boards are built layer by layer → perfect candidate to try this idea
  - USTC + Chinese Bakelite producer delivered the 1st batch of samples recently
  - Again, ANL will evaluate the new boards

- Using more sensitive readout
  - Running RPC with smallest possible signal → smaller signal current → smaller voltage drop on electrodes
  - Idea and test results reported in recent RPC conference*
  - Recent DHCAL test beam verified the idea with two different gain settings



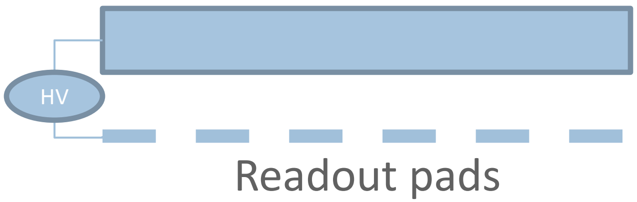


Embedded graphite layer

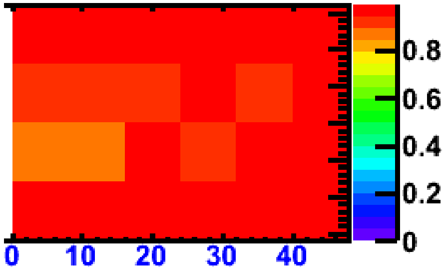
* R. Santonico, Keynote talk at RPC 2012

1-glass RPC development

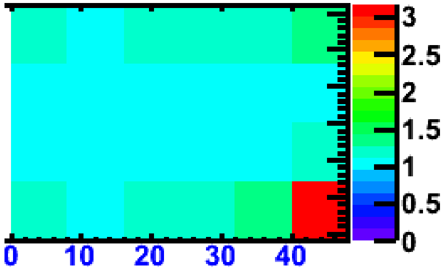
- 1-glass design has many advantages for DHCAL, and as a new type of RPC
  - ~1mm thinner than normal 1-gap RPC → significant cost saving for magnet
  - Can significantly simplify DHCAL calibration
  - Avoids several production difficulties: gap size control, resistive coating, coating uniformity
  - Potential better tracking resolution



- Finally, got to build 2 large (32x48 cm^2) 1-glass RPC prototypes
  - Built with DHCAL prototype FEB's
  - 1 RPC leaks, but can be avoided
  - Has been running (more or less) continuously for ~2 months
  - Test results looks good



Efficiency



Hit multiplicity

Summary

- DHCAL test beam has been successfully finished
- Data analysis is the current focus
  - First look of the data is pretty good
  - Calibration of DHCAL is taking shape
  - Hope to have final results soon
- More RPC R&D is on-going
  - Improve RPC rate capability
  - 1-glass RPC
  - Will have some results in the near future