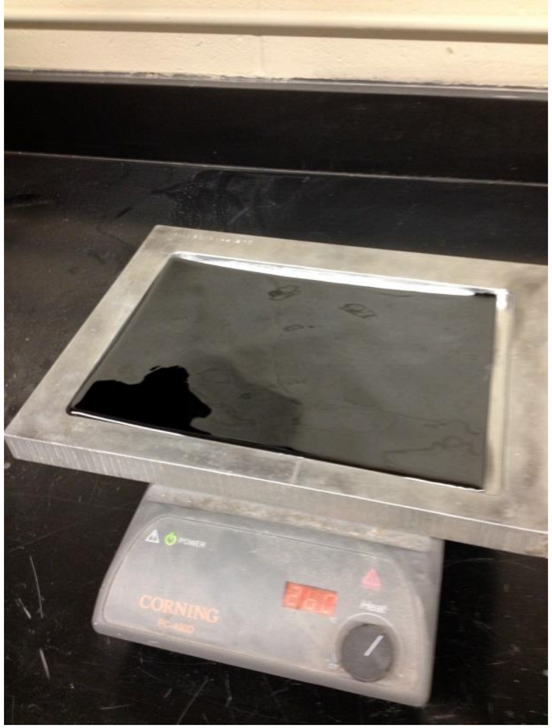
Recent DHCAL Developments

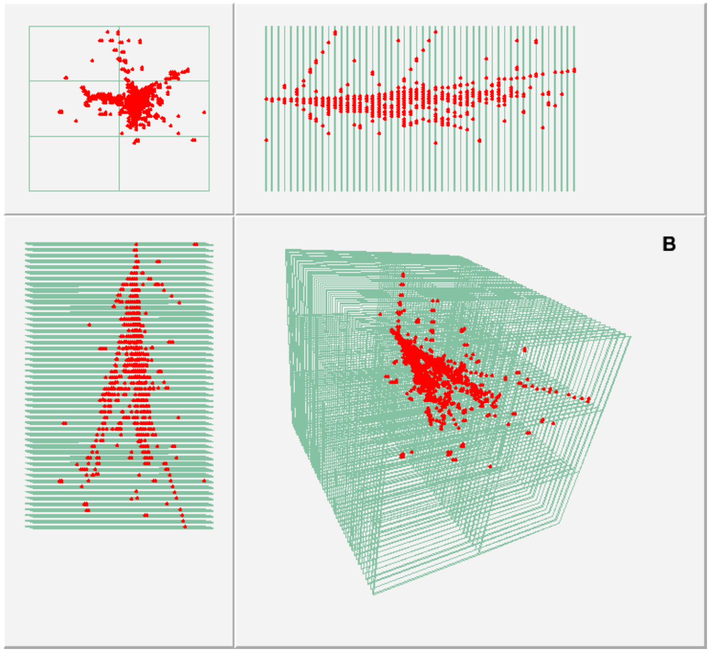


José Repond and Lei Xia

Argonne National Laboratory

Linear Collider Workshop 2013
University of Tokyo
November 11 – 15, 2013

The DHCAL



Description

54 active layers
Resistive Plate Chambers with 1 x 1 cm^2 pads
⟶ ~500,000 readout channels
Main stack and tail catcher (TCMT)

1st time in calorimetry

Electronic readout

1 – bit (digital)
<u>Digitization embedded into calorimeter</u>

Tests at FNAL

with Iron absorber in 2010 - 2011

Tests at CERN

with Tungsten absorber 2012

DHCAL Construction

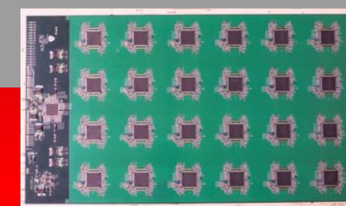
Fall 2008 – Spring 2011

Resistive Plate Chamber

Sprayed 700 glass sheets
Over 200 RPCs assembled
→ Implemented gas and HV connections

Electronic Readout System

10,000 ASICs produced (FNAL)
350 Front-end boards produced
→ glued to pad-boards
35 Data Collectors built
6 Timing and Trigger Modules built



Extensive testing at every step

Assembly of Cassettes

54 cassettes assembled
Each with 3 RPCs
and 9,216 readout channels

350,208 channel system in first test beam
Event displays 10 minutes after closing enclosure

Testing in Beams

Fermilab MT6

October 2010 – November 2011
1 – 120 GeV
Steel absorber (CALICE structure)

CERN PS

May 2012
1 – 10 GeV/c
Tungsten absorber
(structure provided by CERN)

CERN SPS

June, November 2012
10 – 300 GeV/c
Tungsten absorber

RPCs flown to Geneva
All survived transportation

A unique data sample

Test Beam	Muon events	Secondary beam
Fermilab	9.4 M	14.3 M
CERN	4.9 M	22.1 M
TOTAL	**14.3 M**	**36.4 M**

Recent developments

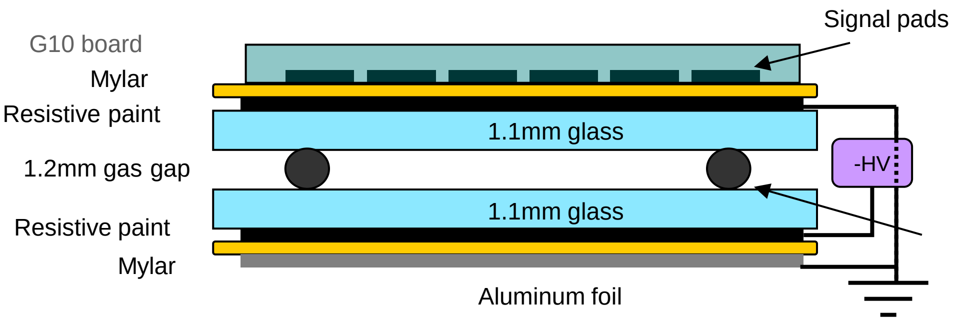
Improved Resistive Plate Chambers

1-glass design
High-rate RPCs

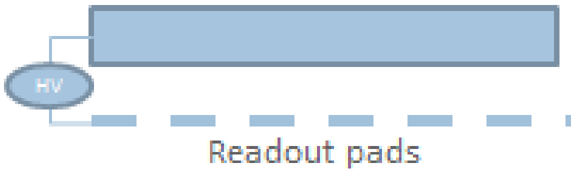
High voltage distribution system

Gas recirculation system

Typical RPC design



1-glass RPCs

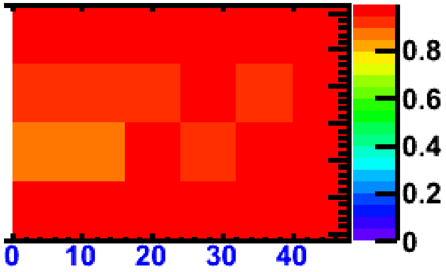


Offers many advantages

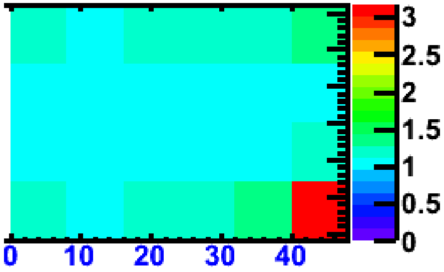
Pad multiplicity close to one
  → easier to calibrate
Better position resolution
  → if smaller pads are desired
Thinner
  → $t = t_{chamber} + t_{readout}$ = 2.4 + ~1.5 mm
  → saves on cost
Higher rate capability
  → roughly a factor of 2

Status

Efficiency



Pad multiplicity



Built several large chambers
Tests with cosmic rays very successful
 → chambers ran for months without problems
Both efficiency and pad multiplicity look good

Rate capability of RPCs

Measurements of efficiency

With 120 GeV protons
In Fermilab test beam

Rate limitation

NOT a dead time
But a loss of efficiency

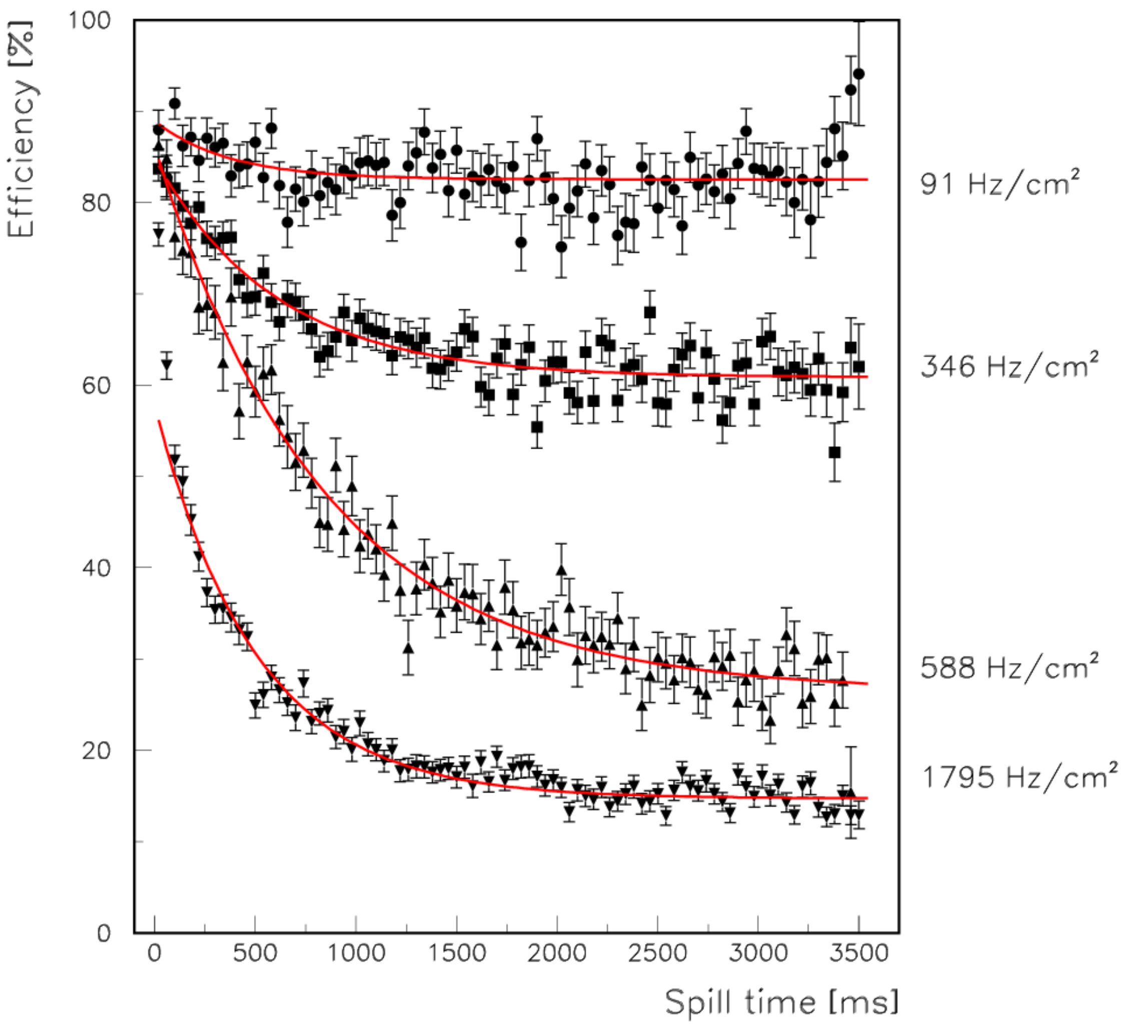
Theoretical curves

Excellent description of effect

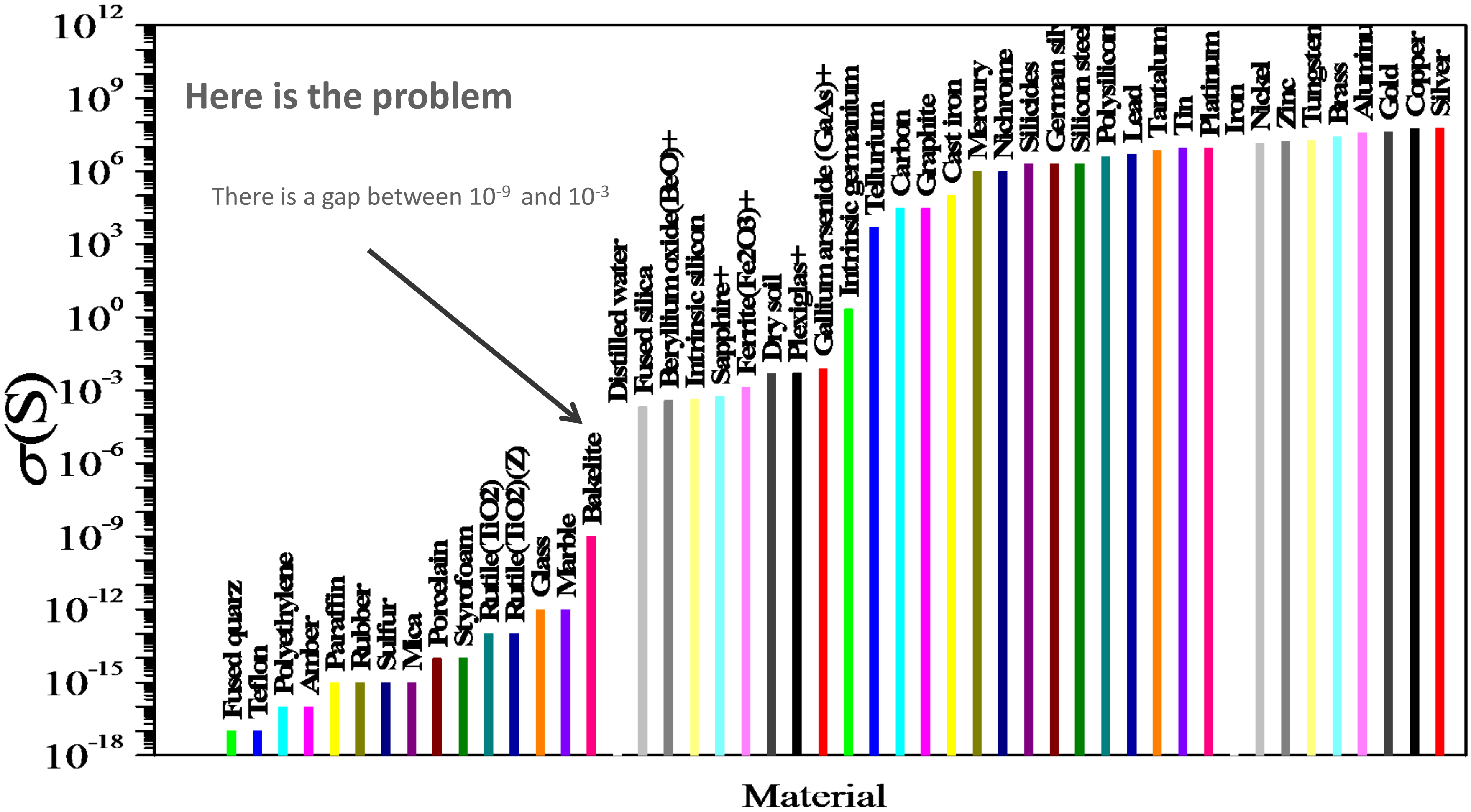
Rate capability depends

Bulk resistivity R_{bulk} of resistive plate
(Resistivity of resistive coat)

Not a problem for an HCAL at the ILC

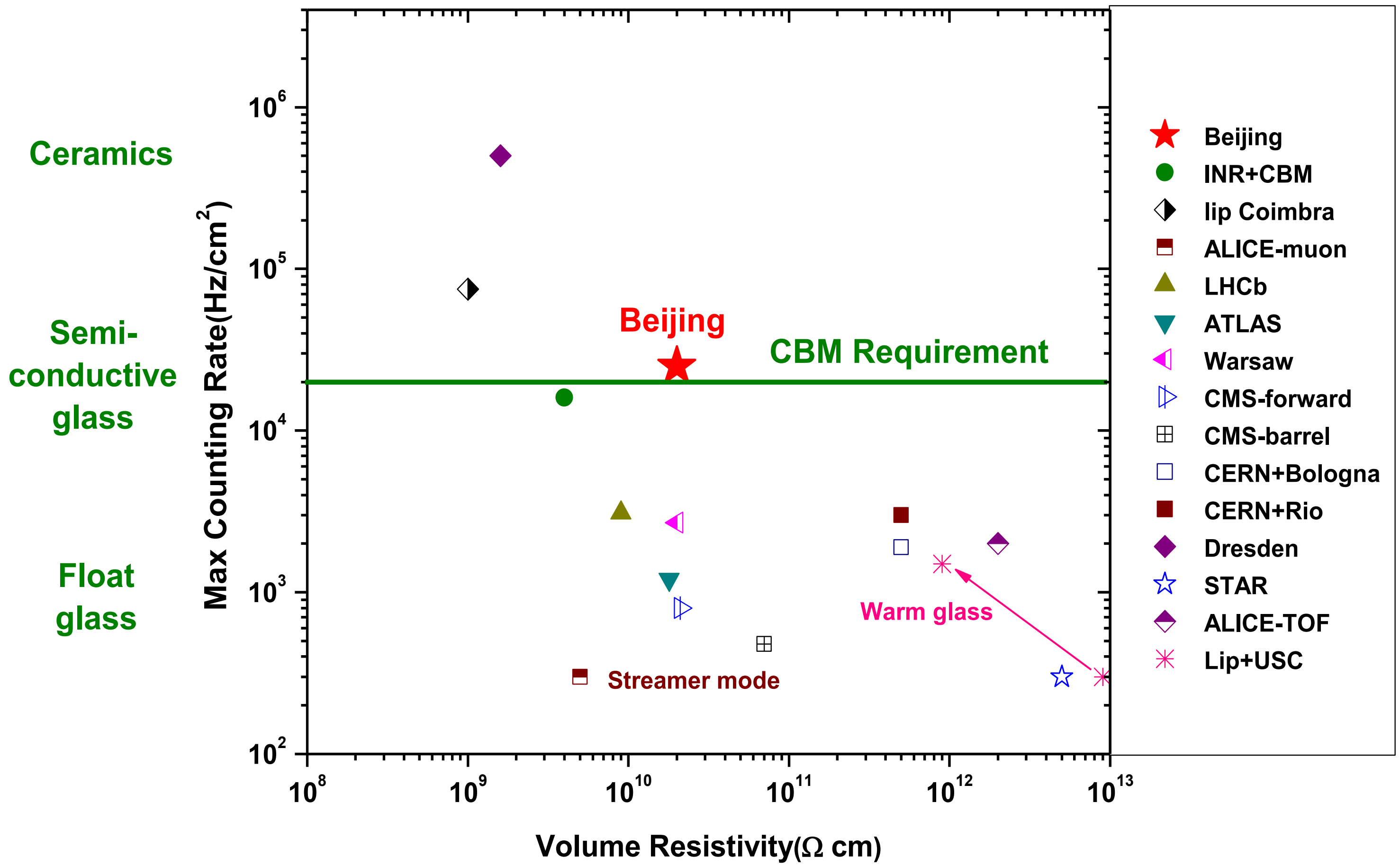


B.Bilki et al., JINST 4 P06003(2009)



C. Pecharromán *X. Workshop on RPC and related Detectors* (Darmstadt)

Available resistive plates



Where to use high-rate RPCs

ILC – Hadron calorimeter (close to beam pipe)

CLIC – Hadron calorimeter (forward direction – 2γ background)

CMS – Hadron calorimeter (forward direction)

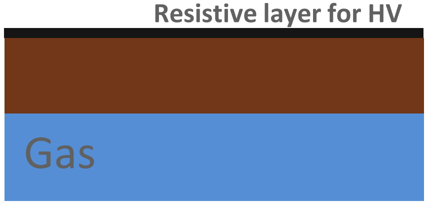
Current forward calorimeters inadequate for high-luminosity running

$PbWO_4$ Crystals
Scintillator/Brass + Quartz fibers/Steel

To start in year ~2023
Luminosity of 5 x 10^{34} cm^{-2}
(> x10 higher than now)

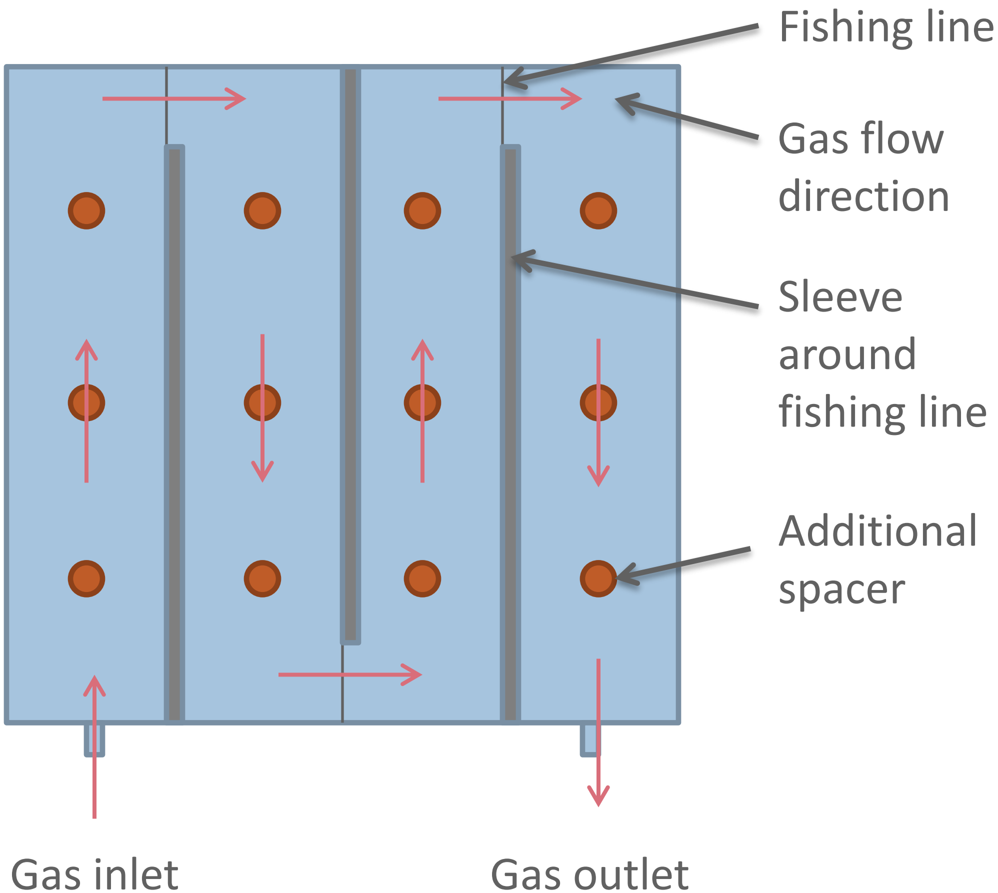
High-rate Bakelite RPCs

Bakelite does not break like glass,
is laminated
but changes R_{bulk} depending on humidity
but needs to be coated with linseed oil

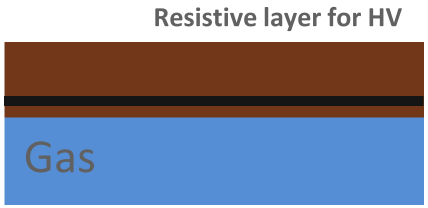


Use of low R_{bulk} Bakelite with $R_{bulk} \sim 10^8 - 10^{10}$ and/or Bakelite with resistive layer close to gas gap

Several chambers built at ANL



High-rate Bakelite RPCs



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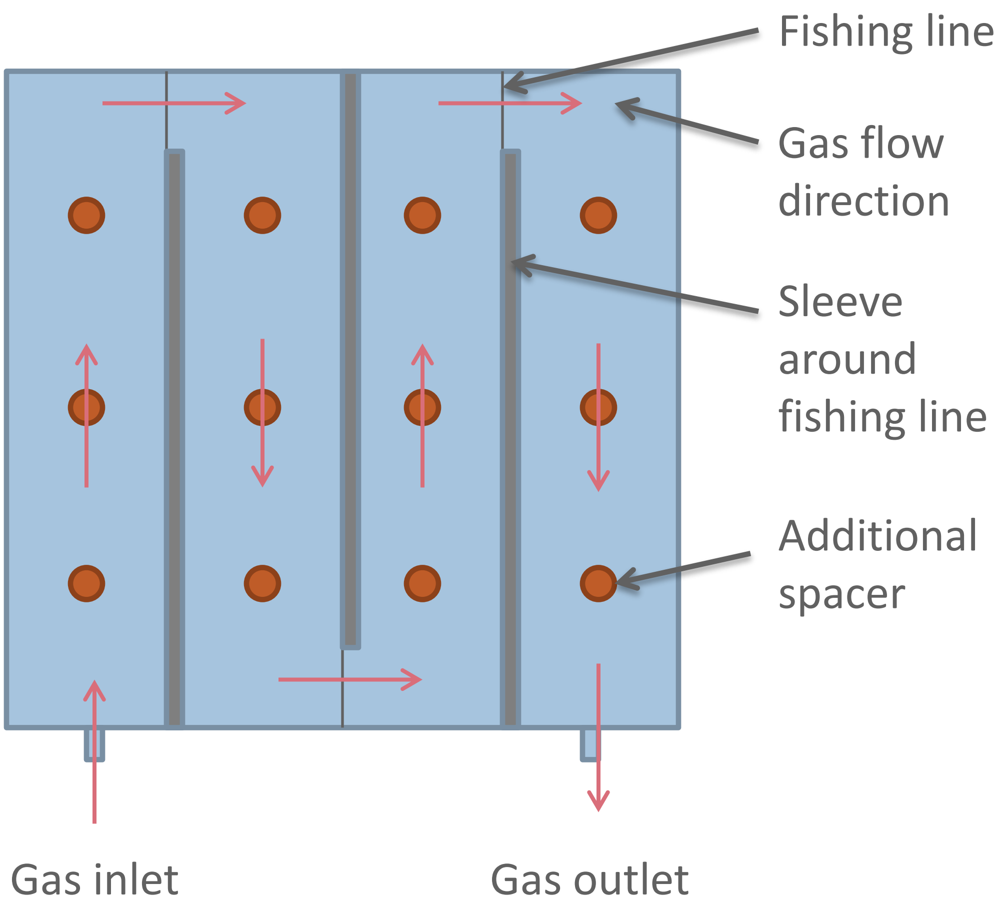
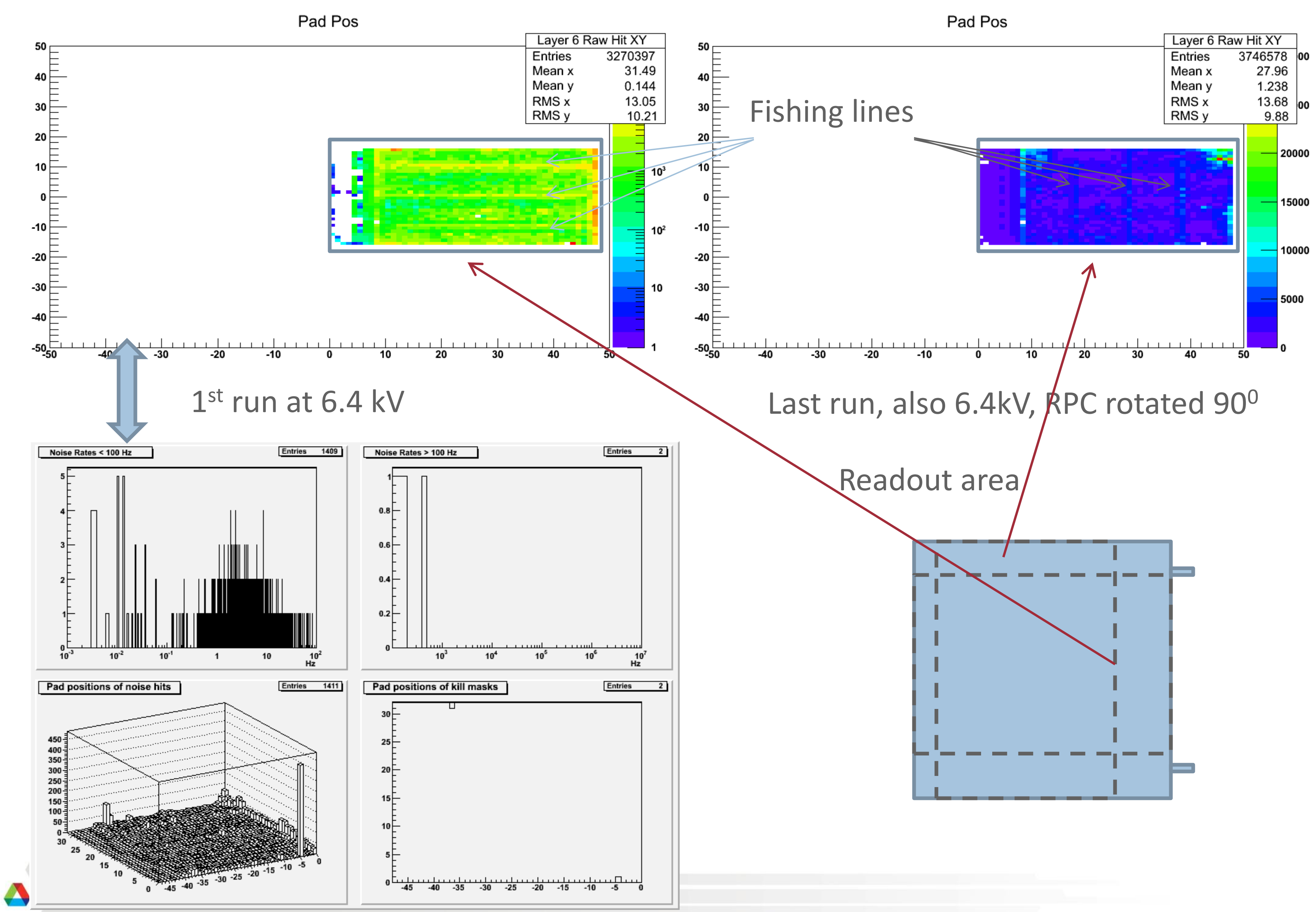


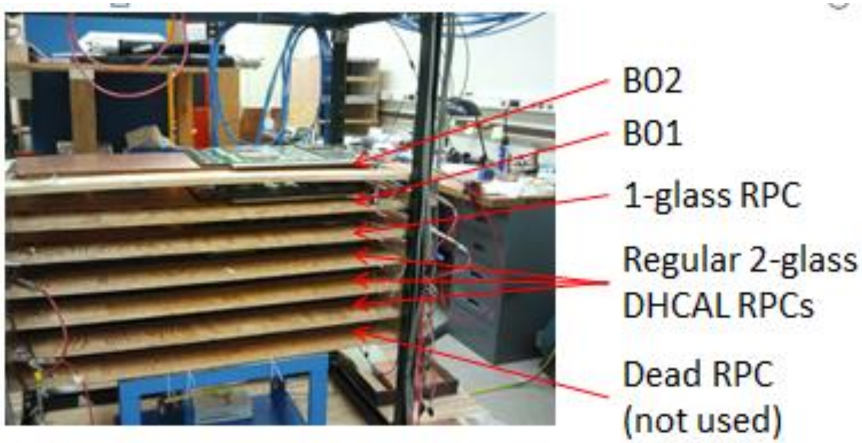
Noise measurement: B01

(incorporated resistive layers)



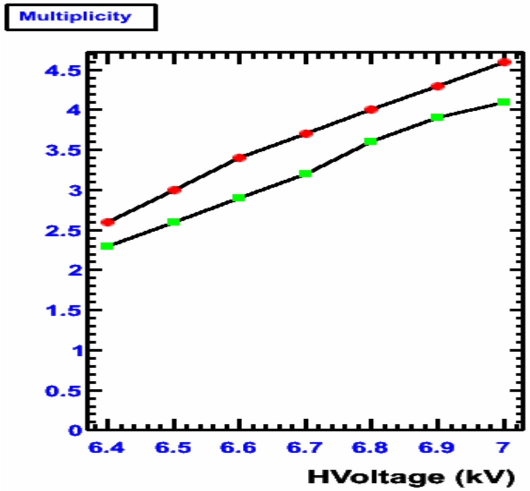
Noise measurements

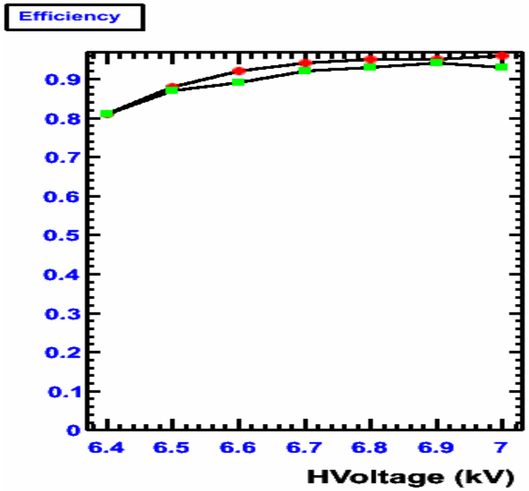
Applied additional insulation
Rate 1 – 10 Hz/cm^2 (acceptable)
Fishing lines clearly visible
Some hot channels (probably on readout board)
No hot regions



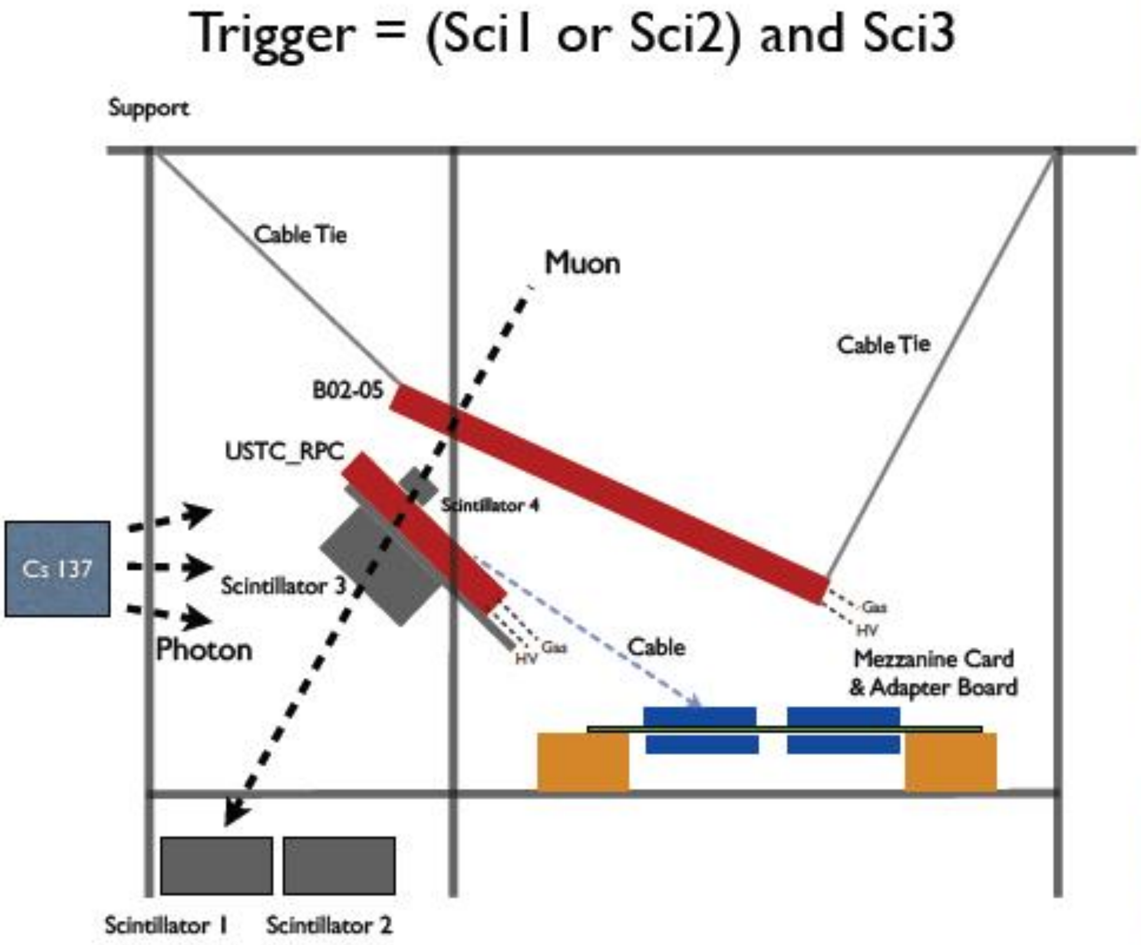
Cosmic ray tests

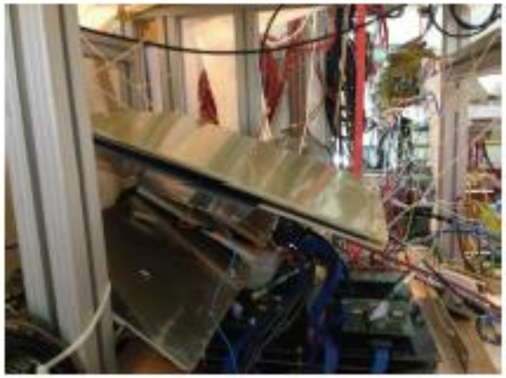
Stack including DHCAL chambers for tracking
Efficiency, multiplicity measured as function of HV
High multiplicity due to Bakelite thickness (2 mm)





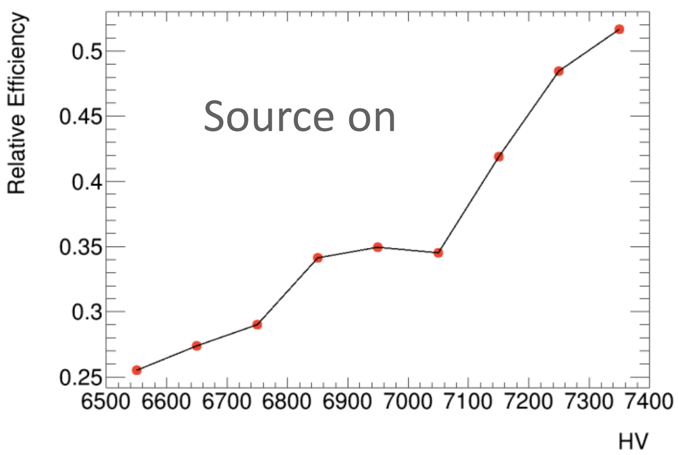
GIF Setup at CERN

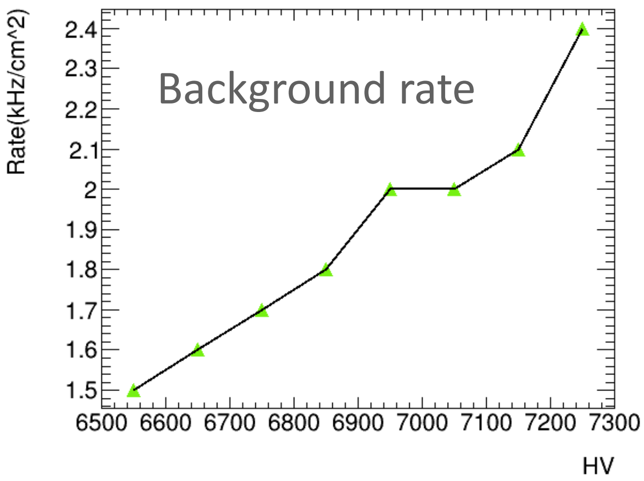


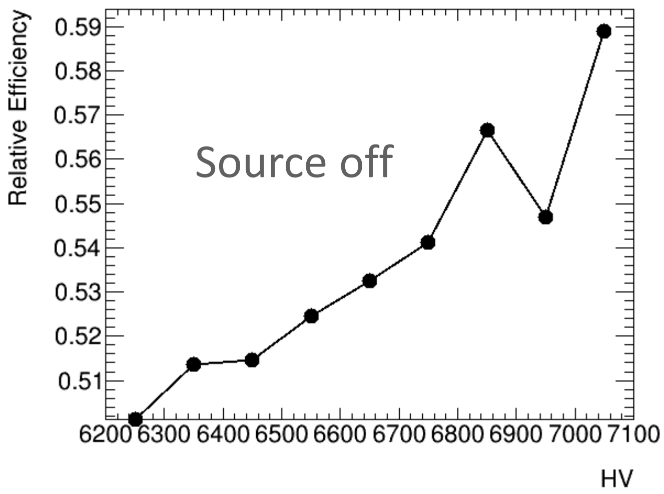


Tests carried out by University of Michigan, USTC, Academia Sinica

First results from GIF







Absolute efficiency not yet determined

Clear drop seen with source on

Background rates not corrected for efficiency drop

Irradiation levels still to be determined (calculated)

Development of semi-conductive glass

Co-operation with **COE college** (Iowa) and University of Iowa

World leaders in glass studies and development

Vanadium based glass

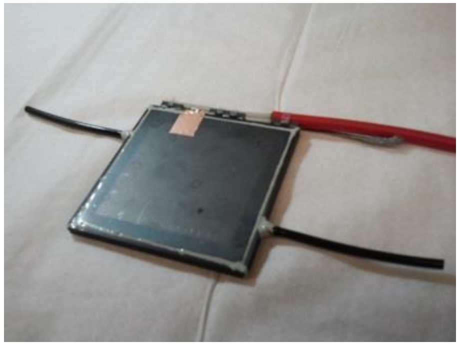
Resistivity tunable
Procedure aimed at industrial manufacture (not expensive)

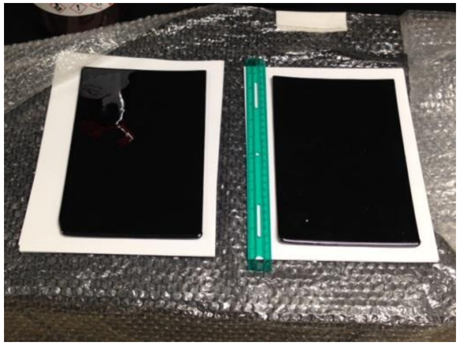
First samples

Very low resistivity $R_{bulk} \sim 10^8\ \Omega\text{cm}$

New glass plates

$R_{bulk} \sim 10^{10}\ \Omega\text{cm}$ produced
Plates still need to be polished
Production still being optimized





High Voltage Distribution System

Generally

Any large scale imaging calorimeter will need to distribute power in a safe and cost-effective way

HV needs

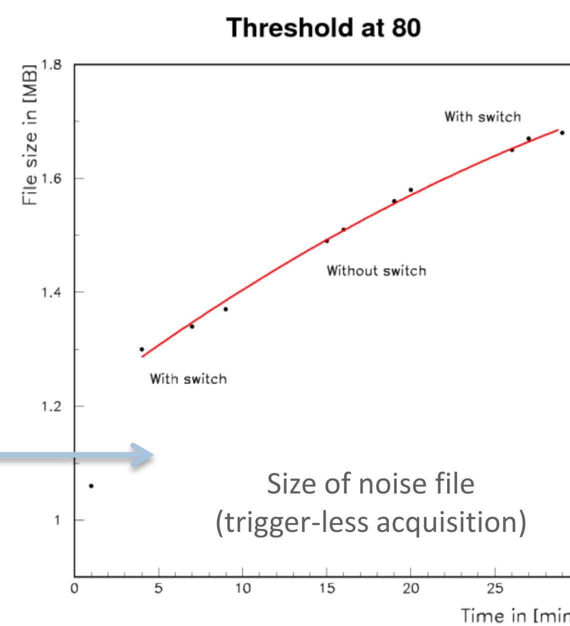
RPCs need of the order of 6 – 7 kV

Specification of distribution system

Turn on/off individual channels
Tune HV value within restricted range (few 100 V)
Monitor voltage and current of each channel

Status

Iowa started development
First test with RPCs encouraging
Work stopped due to lack of funding



Gas Recycling System

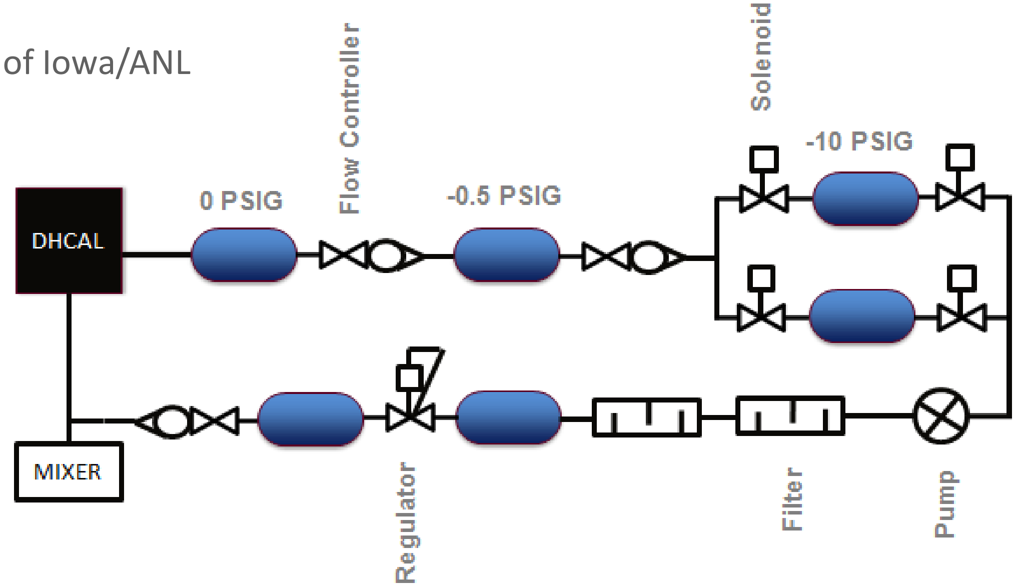
DHCAL's preferred gas

Gas	Fraction [%]	Global warming potential (100 years, CO_2 = 1)	Fraction * GWP
Freon R134a	94.5	**1430**	1351
Isobutan	5.0	3	0.15
SF_6	0.5	**22,800**	114

Recycling mandatory for larger RPC systems

Development of 'Zero Pressure Containment' System

Work done by University of Iowa/ANL



Status

First parts assembled…

Summary

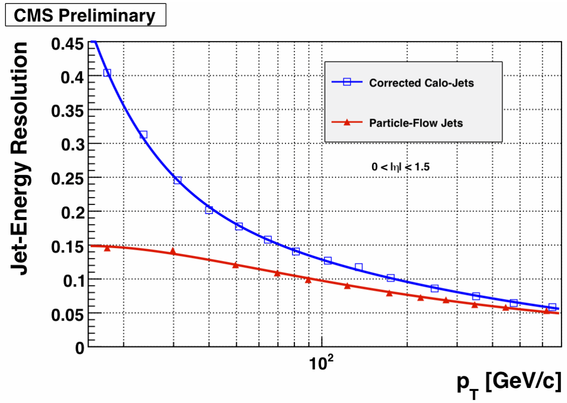
After successful testing of the DHCAL at Fermi and CERN

Further improvements to the active medium and its supplies

Development of **1-glass RPCs** (design validated!)
Development of **low-resistivity bakelite/glass** (ongoing, but encouraging)
Development of a **high-voltage distribution system** (stalled)
Development of **a gas recirculation system** (new concept, being assembled)

Backup

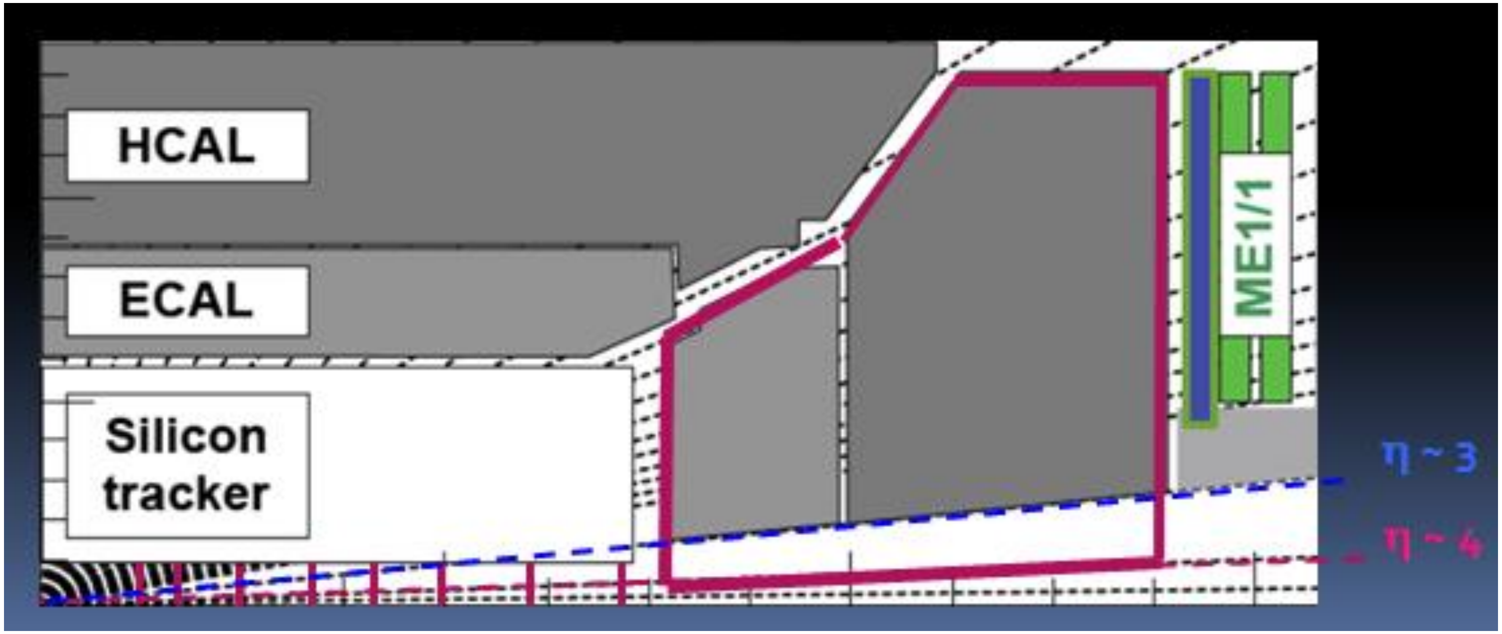
CMS forward calorimeter



Driven by successful application of PFAs to CMS analysis

Proposal to replace forward calorimeters with an **IMAGING CALORIMETER**

Several members of CALICE have been contacted by CMS



Formidable challenge

Charged particle flux

In calorimeter volume up to 50 MHz/cm^2 at shower maximum

Total dose

Fluences of 10^{16} neutrons