The ADRIANO3 Calorimetric Technique

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For ADRIANO3 Project

DRD6 Collaboration Meeting

April 9-11, 2024, CERN

Rationale for ADRIANO3

- Neutron fluctuation of a hadronic shower responsible for up-to 20% of the energy measurement uncertainties
  - A triple readout calorimeter extends the event-by-event energy compensation of the dual-readout technique by measuring the neutron component of the shower
- High-granularity helps in disentangling overlapping showers in a high-multiplicity event (e.g. hadron colliders)
  - A small-tile a-la CMS has enough granularity for events with ~10^3 particles
- Fast timing (<50 psec) provides:
  - TOF of slow particles
  - Disentangling of triggers in a high-collision rate accelerator
  - Discriminating low energy electrons vs pions (the showers start at different depths)

The ADRIANO3 Technique

REDTOP

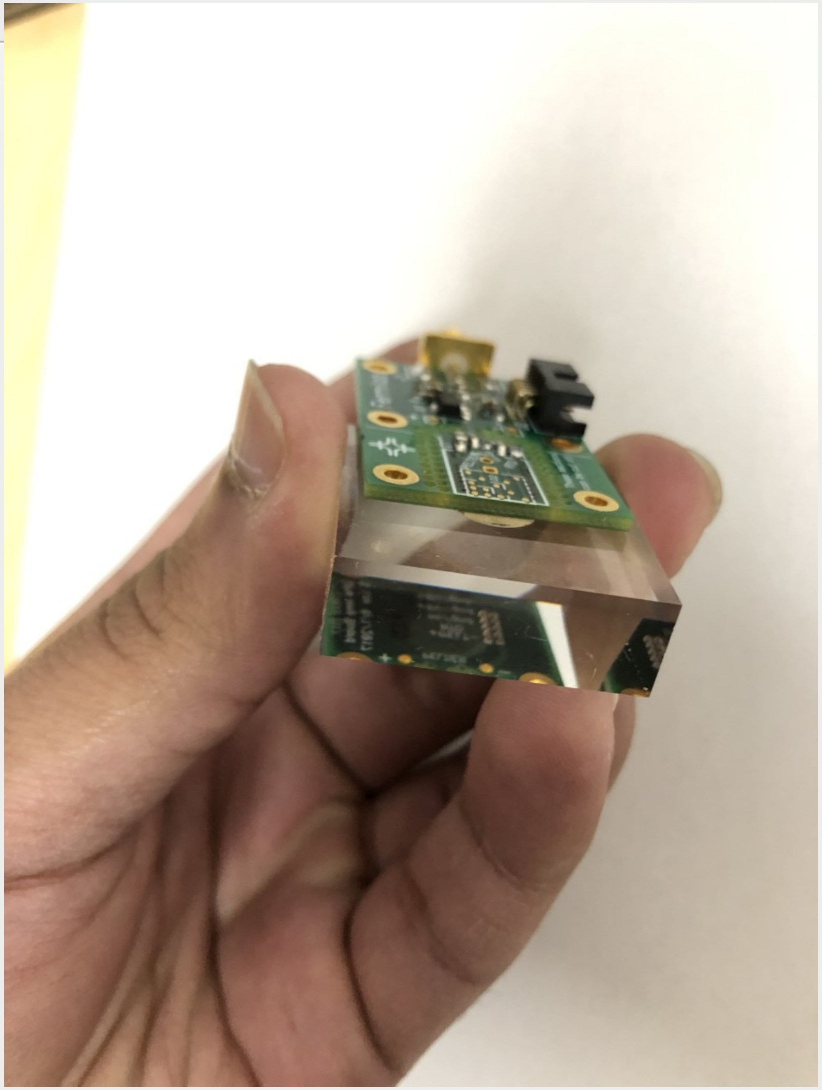
- High-granularity, **triple-readout** electromagnetic **and** hadronic calorimeter with fast timing
- Performance goals:
  - EM energy resolution: $\sigma(E)/E \sim 3\%/\sqrt{E}$
  - Hadronic energy resolution: $\sigma(E)/E < 25\%/\sqrt{E}$
  - Timing resolution: < 50 psec
- Relatively low cost

ADRIANO3 Active Components

- Cerenkov radiator: 3x3x2 cm^3 lead-glass tiles (typical size)
- Scintillator component: 3x3x 0.5 cm^3 scintillating tiles (typical size)
- Neutron component: 10x10x1 cm^3 doped RPC
- Tiles readout: on-tile sipm
- RPC readout: pads

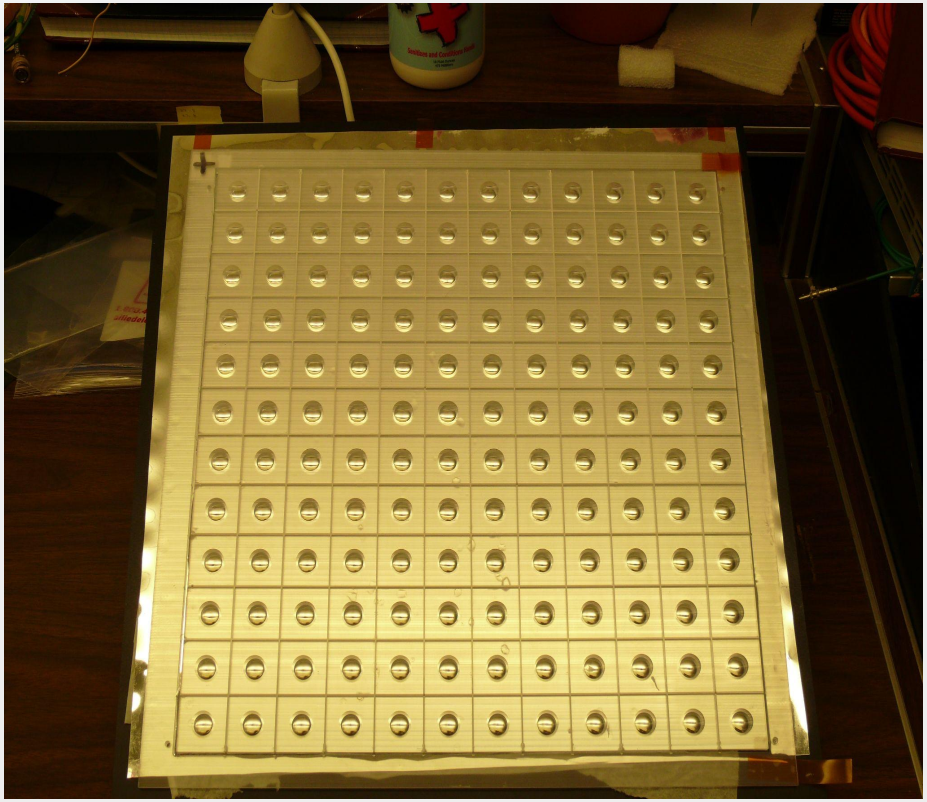
ADRIANO3 Lead Glass Tiles

- Mostly sensitive to the EM component of a hadronic shower
- Prompt Cerenkov signal from small tile has a single-channel timing resolution of 80 ps (for > ~20 pe) – See T1604 test beam
- Active absorber for electromagnetic showers



ADRIANO3 Scintillating Tiles

- Sensitive to all charged component of a hadronic shower
- Also sensitive to neutrons thanks to high-H_2 content (too thin for high efficiency detection)
- Inherits from CMS HGC with SiPM-on-tile readout
- Tile wrapping replaced with tile coating



ADRIANO3 Thin Gd-Doped Glass RPC

- Sensitive to all the ionizing particles of the shower
- Capable of sustaining a particle rate up to 2 kHz/cm^2 (see, high η CMS muon detectors)
- Timing resolution of a few hundred psec per layer is achievable
- Glass doping with Gd would increase the triple-readout capability of ADRIANO3

ADRIANO3 Perspectives

REDTOP

Lead-glass and scintillating components R&D in T1604 Collaboration

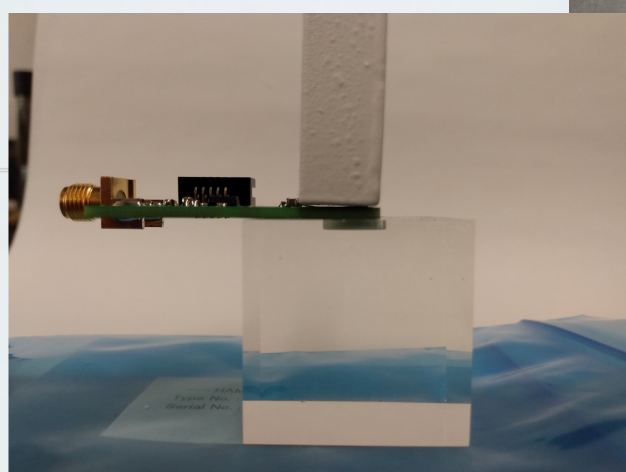
Thin-glass RPC R&D in T1041 Collaboration

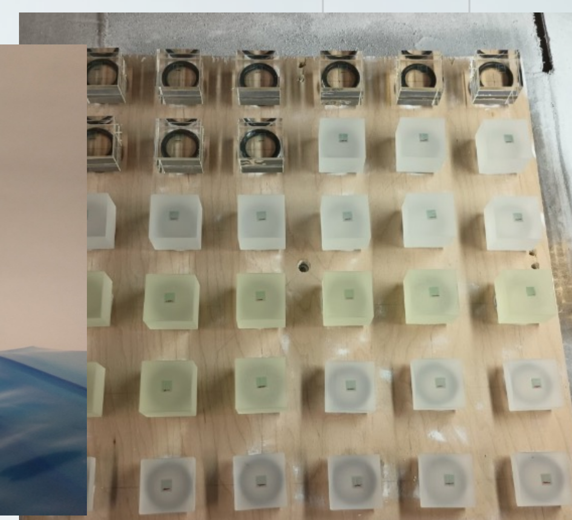
Effort merged in a newly formed collaboration

- Under construction: 12 cm x 12 cm x 13 triple-layer prototype
- Integrate 2-3 hybrid RPCs at the first stage
- Goal is to test it at Fermilab in Winter 2025
- ADRIANO3 project still not funded: piggy-back on 1041 and 1604 activities
- Planning to respond to a DOE solicitation in Fall 2024

ADRIANO2 Highlights

1) Layout: alternating tiles of Pb-glass (Č) and scintillating plastics (S)
2) Tile size: 3x3x1 cm^3 for glass, 3x3x0.7 cm^3 for plastic (same as CMS)
3) SiPM-on-tile readout
4) High-granularity, dual-readout, integrally active, <100 psec/cell timing resolution
5) Č vs S used as PID at low energy experiments and for energy compensation at high energy





Tested Configurations over 3-years

- Three sizes
  - 3x3x1 cm^3, 3x3x2 cm^3, 3x3x3 cm^3
- Six glasses:
  - SF57-HHT, ZF2, ZF6, ZF7, JGS1, HZPK7
- Three surface finish
  - Cut ground, sandblasted, polished
- Ten surface coating
  - $BaSO_4$, Teflon, Kevlar, Al sputtering , Al paint, ESR2000, Ag sputtering , Mo ALD, W ALD
- Two sensor interfaces
  - Dimple, no-dimple
- Three single sensors
  - HamamatsuS13360, S14160 , Broadcom S466P014M (6x6 mm^2)
- Two quadruple-sensors in active ganged mode
  - Hamamatsu S14160 (3x3 mm^2), S14160 (4x4 mm^2) S14160 (6x6 mm^2), Broadcom S466P014M (6x6 mm^2)

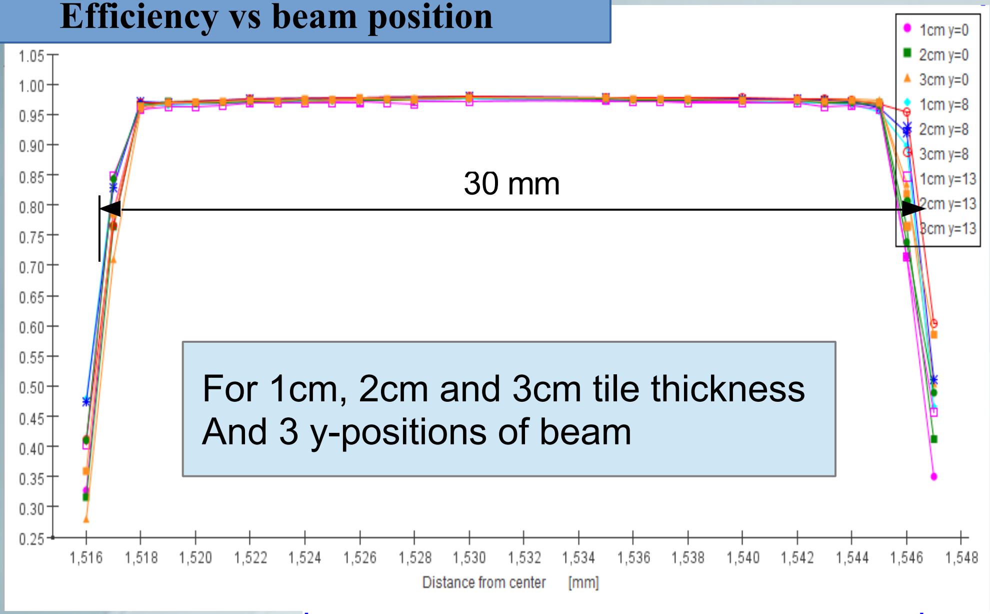
Total: 75 tiles tested

Energy resolution predicted (EM)< 2%/√(E)

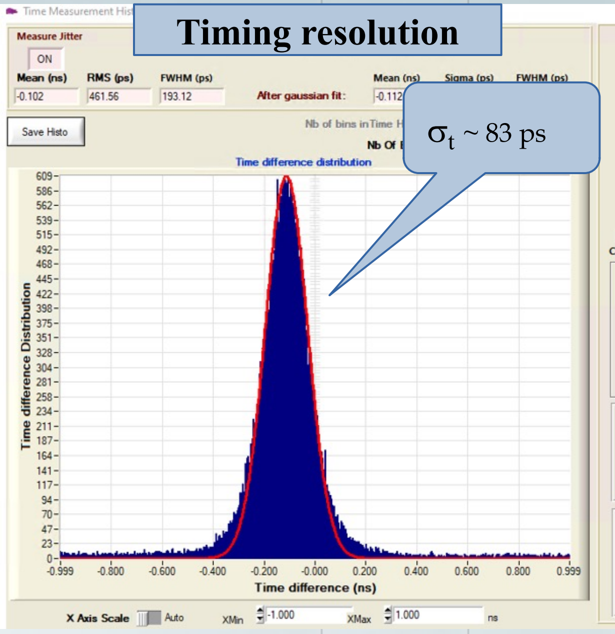
Timing resolution: ~80 psec/cell

ADRIANO2 performance

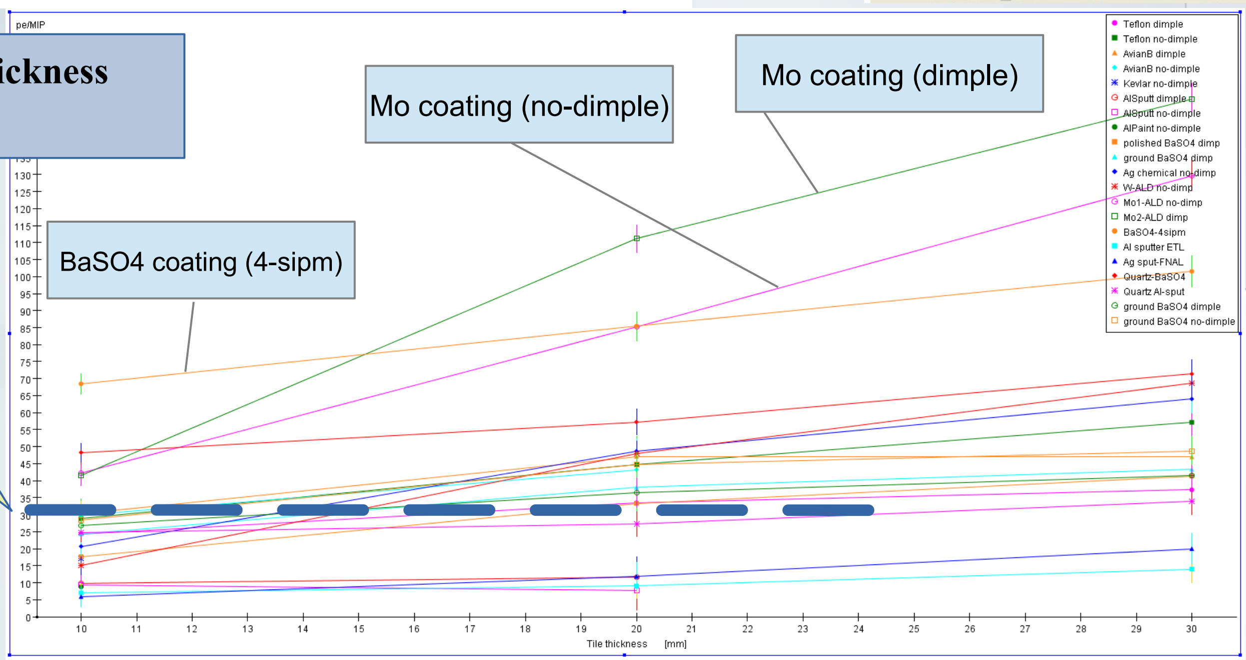
Efficiency vs beam position



Timing resolution



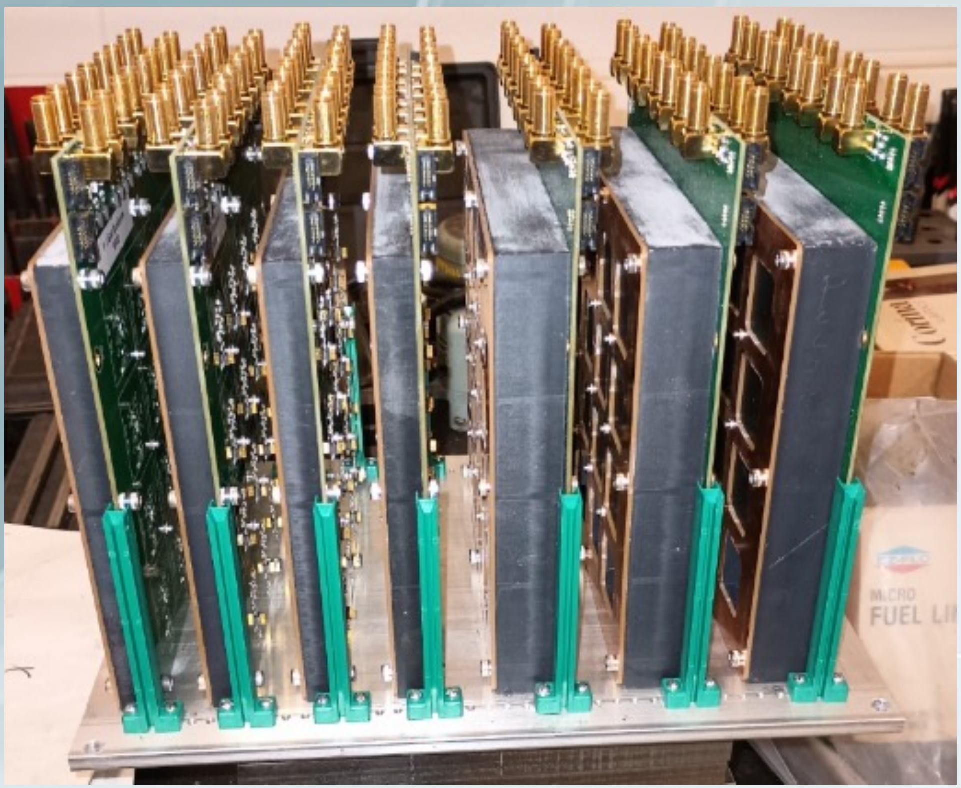
Light Yield vs tile thickness pe/MIP

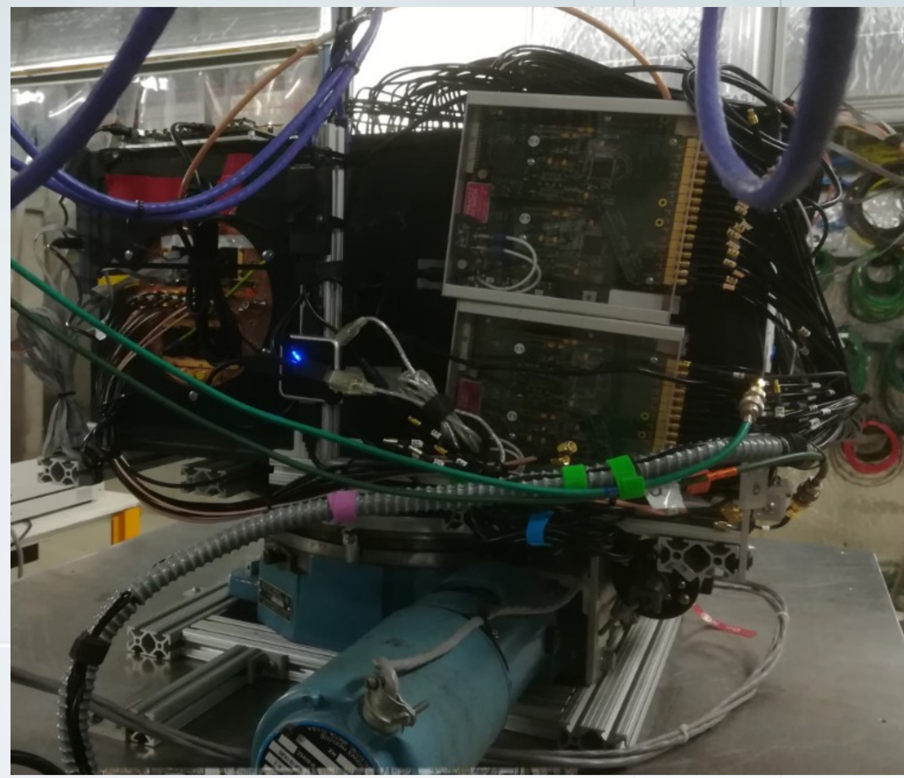


$\sigma_E/E \sim 2\%/\sqrt{E}$ estimated
EM stochastic term

ADRIANO2 R&D in T1604 Collaboration

- Currently in the beam at Fermilab: 7 layer, ~5X_0, 64 cells prototype, with Sampic & petiroc readout (CAEN DT5550W)





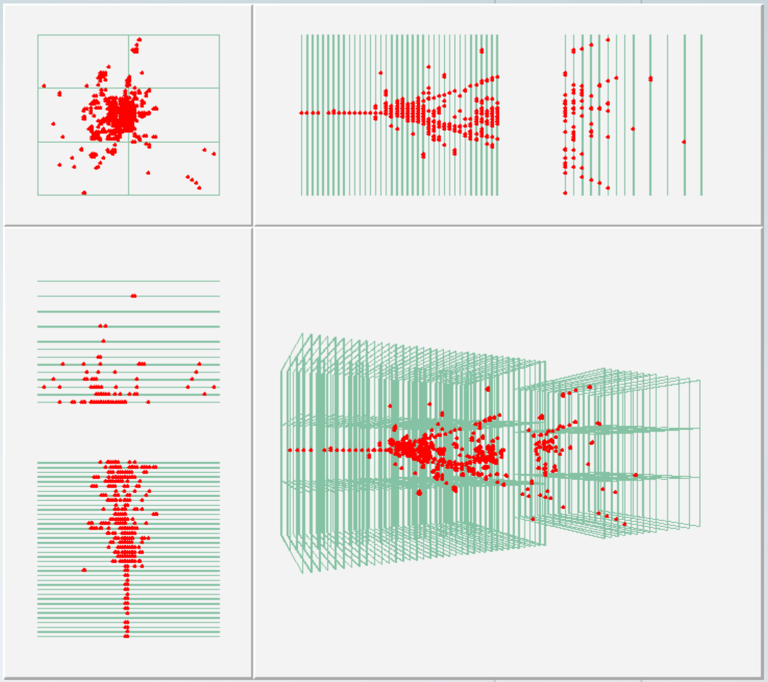
xG. Blazey, A. Dychkant, M. Figora, T. Fletcher, C. Gatto, K. Francis, A. Liu, S. Los, M. Murray, E. Ramberg, C. Royon, M. Syphers, R. Young, V. Zutshi, C. Le Mahieu, J. Marquez, A. Mane, J. Elam, Z. Sheemanto

ANL, FNAL, KU, NIU, INFN, ETL

Thin-glass R&D in T1041 Collaboration

Inherits from the CALICE Digital Hadron Calorimeter

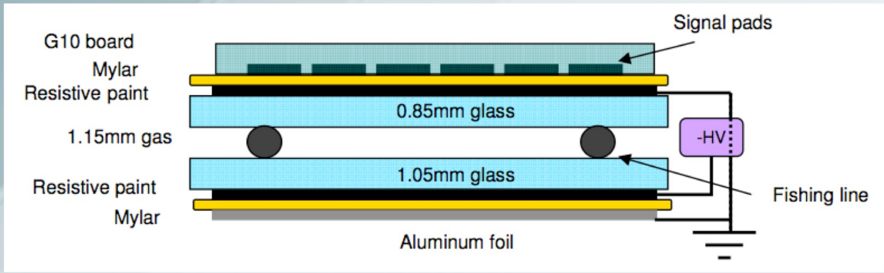
60 GeV π+



The DHCAL prototype

Description

Hadronic sampling calorimeter
Designed for future electron-positron collider (ILC)
54 active layers (~1 m^2)
Resistive Plate Chambers (RPCs) with 1 x 1 cm^2 pads
→ ~500,000 readout channels



Electronic readout

1 – bit (digital)

Tests at FNAL

with Iron absorber in 2010 – 2011
with no absorber in 2011

Tests at CERN

with Tungsten absorber in 2012

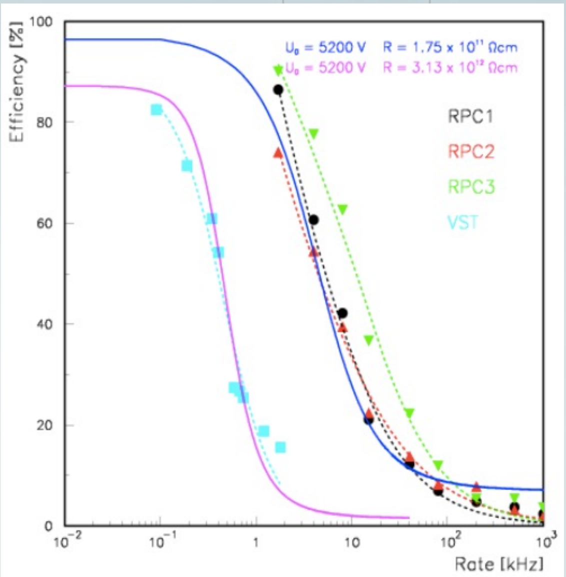
Development of semi-conductive glass

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

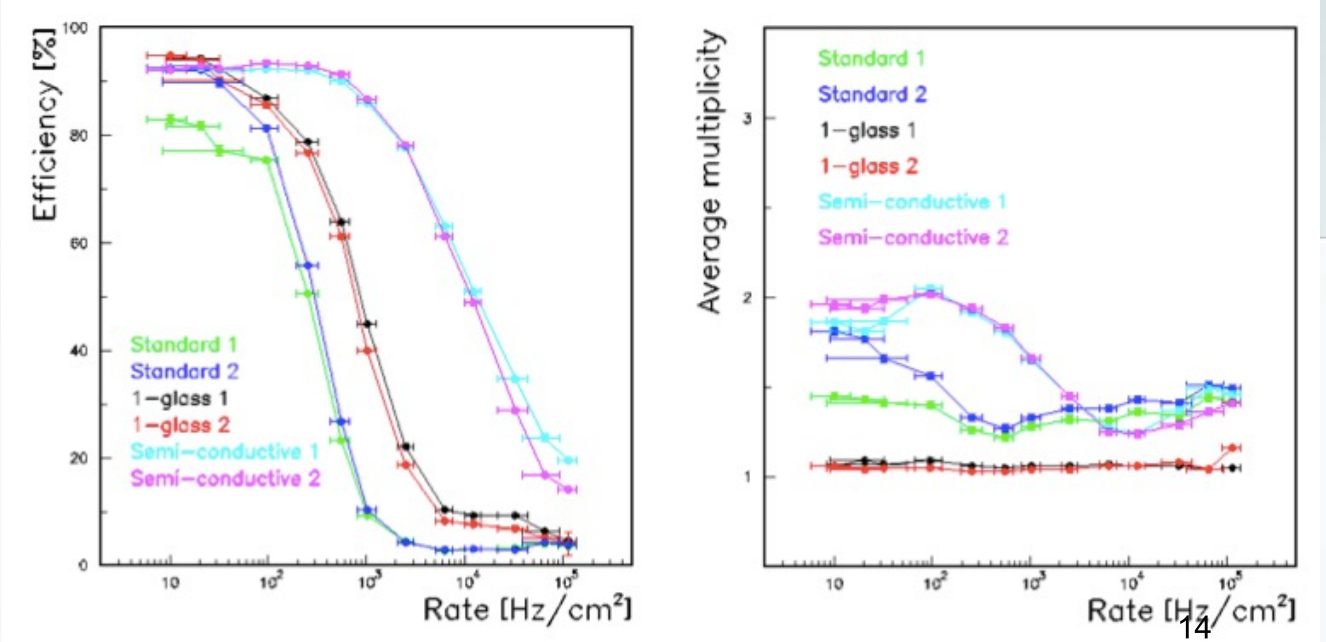
Vanadium based glass

Resistivity tunable!

Procedure aimed at industrial manufacture (not expensive)



Tests were also done with commercial semi-conductive glass



Development of Hybrid RPCs

Probing a hybrid readout where part of the electron multiplication is transferred to a thin film of high secondary emission yield material coated on the readout pad with the purpose of reducing/removing gas flow and enabling the utilization of alternative gases.

➔ RPCs with functional anodes

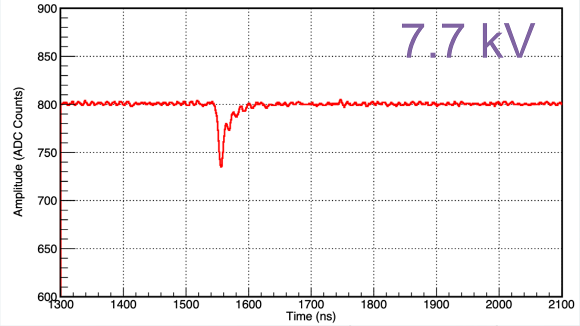
Built several 10 cm x 10 cm chambers with single pad readout.

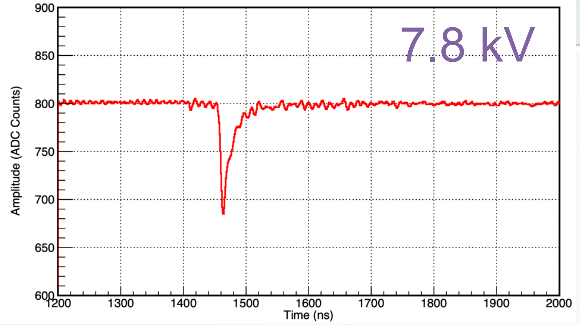
Coating of Al_2O_3 made with magnetron sputtering.

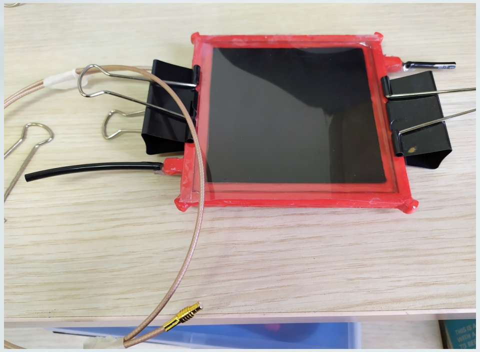
Coating of TiO_2 made with airbrushing after dissolving TiO_2 in ethanol.

RPCs obtain high efficiency at considerably lower high voltage settings.

Cosmic muon response







Next Steps for ADRIANO3

➔ RPCs with functional cathodes

Dope the cathode glass of one-glass RPCs with Gd to introduce the neutron capture functionality.

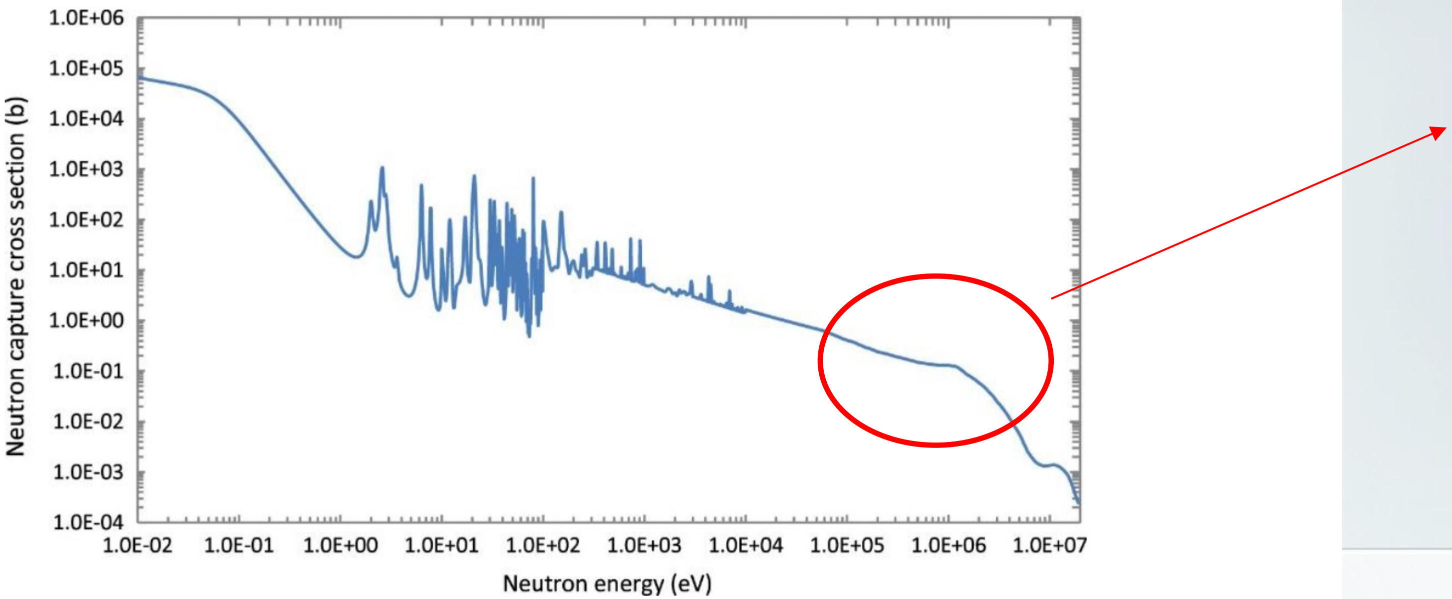


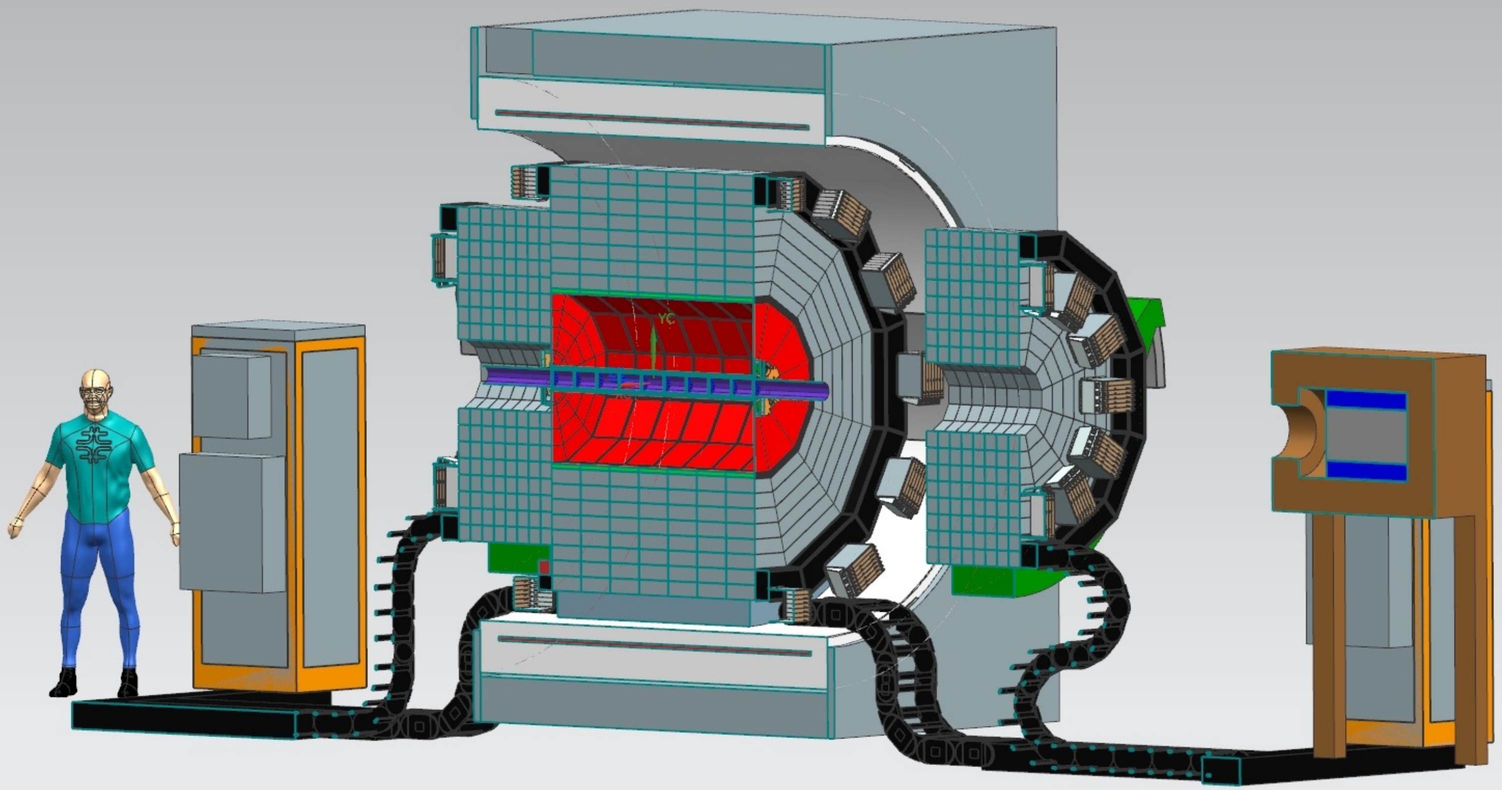
Fig. 2. Capture cross section as a function of neutron energy for natural Gd (IRDFF-1.0).

Region of interest for hadron calorimetry

J. Dumazert et. al., “Gadolinium for neutron detection in current nuclear instrumentation research: A review“, Nucl. Instrum. And Meth. A 882, 53, 2018.

Several R&D points to probe

ADRIANO3 first customer: the REDTOP Experiment



https://redtop.fnal.gov* and *https://arxiv.org/abs/2203.07651
also https://redtop.fnal.gov/wp-content/uploads/2023/09/REDTOP_LOI_2023-4.pdf

Conclusions

- The ADRIANO3 **triple-readout** calorimeter technique has been proposed **for the first time**
- High-granularity, triple-readout, and fast timing will benefit High-energy (e.g. FCC) as well as High-Intensity (e.g. REDTOP) experiments
- Experience and know-how of T1041 and T1604 are being merged, but new funds are necessary
- Gd-doped RPC glass is going to be explored
- Plan to apply for DOE funds in 2024

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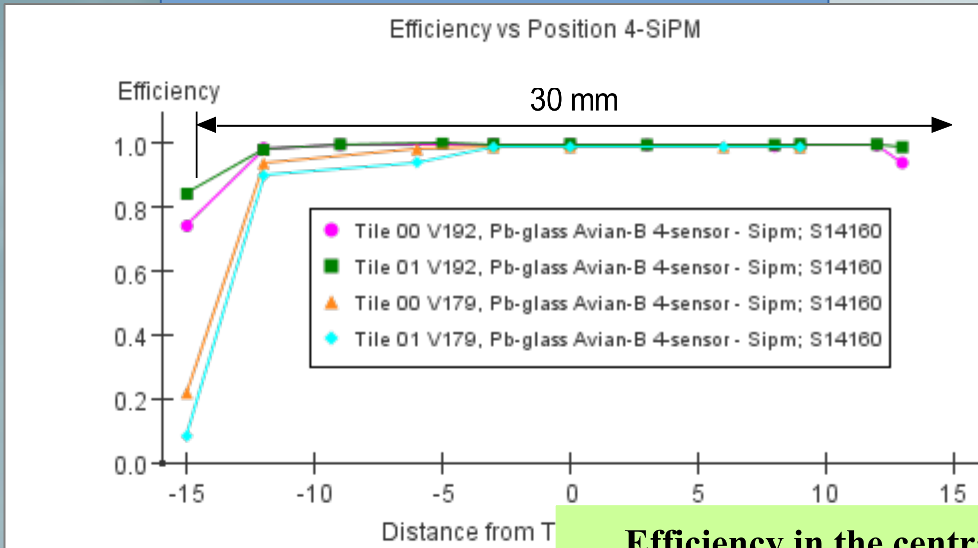
- C. Adams, et.al., Design, construction and commissioning of the Digital Hadron Calorimeter — DHCAL, JINST 11, P07007, 2016.
- M. Chefdeville, et.al., Analysis of testbeam data of the highly granular RPC-steel CALICE digital hadron calorimeter and validation of Geant4 Monte Carlo models, Nucl. Instr. And Meth. A 939, 89, 2019.
- C. Gatto et al, Preliminary Results from ADRIANO2 Test Beams Instruments 6 (2022) 4, 49
- C. Gatto et al, Status of Dual-readout R&D for a Linear Collider in T1015 Collaboration, Proceedings, International Workshop on Future Linear Colliders (LCWS15) : Whistler, B.C., Canada, November 02-06, 2015
- REDTOP Collaboration, The REDTOP experiment: a low energy meson factory to explore dark matter and physics beyond the Standard model. PoS CD2021 (2024) 043

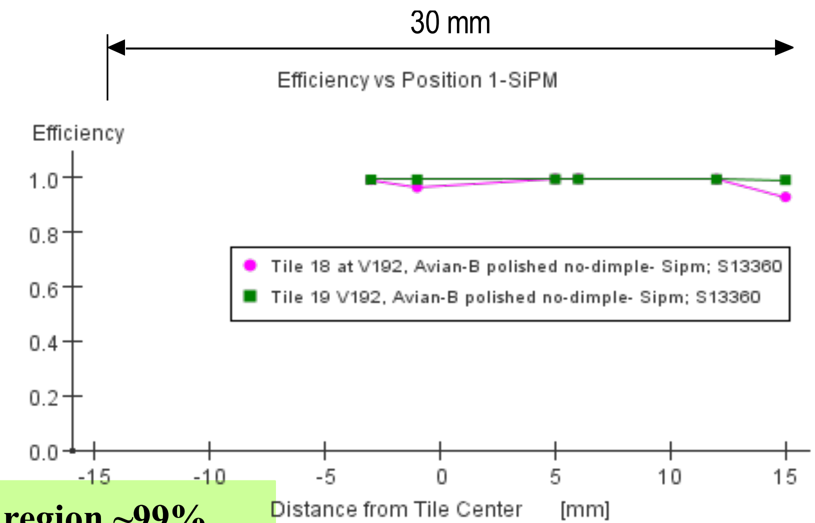
Backup

4-sipm/tile vs 1-sipm/tile performance

Efficiency vs position 4-sipm

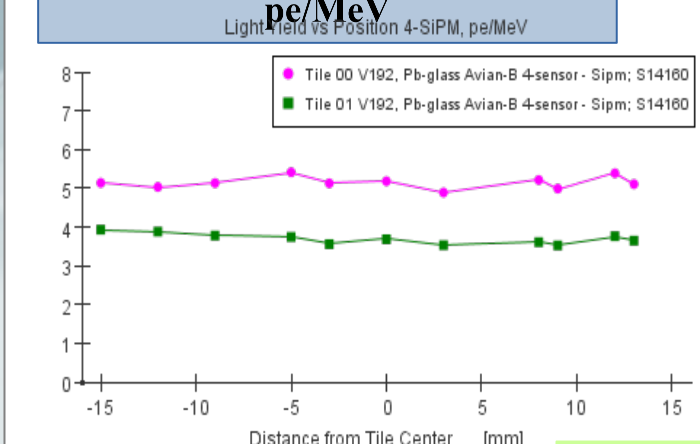


Efficiency vs position 1-sipm

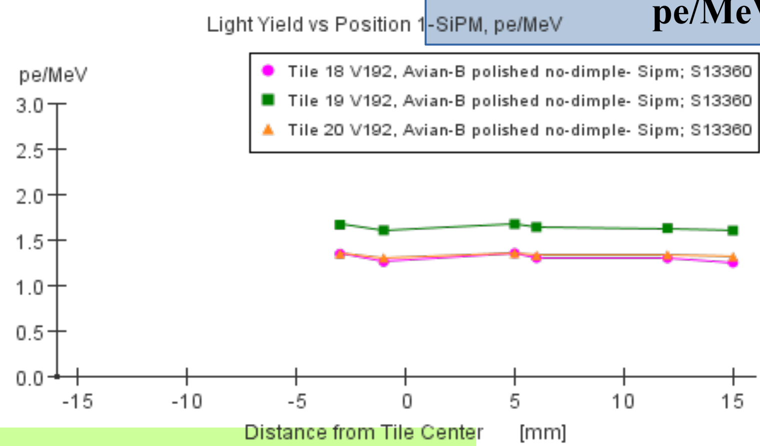


Efficiency in the central region ~99%
It starts dropping ~ 2 mm from tile edge

Light Yield vs position 4-sipm pe/MeV



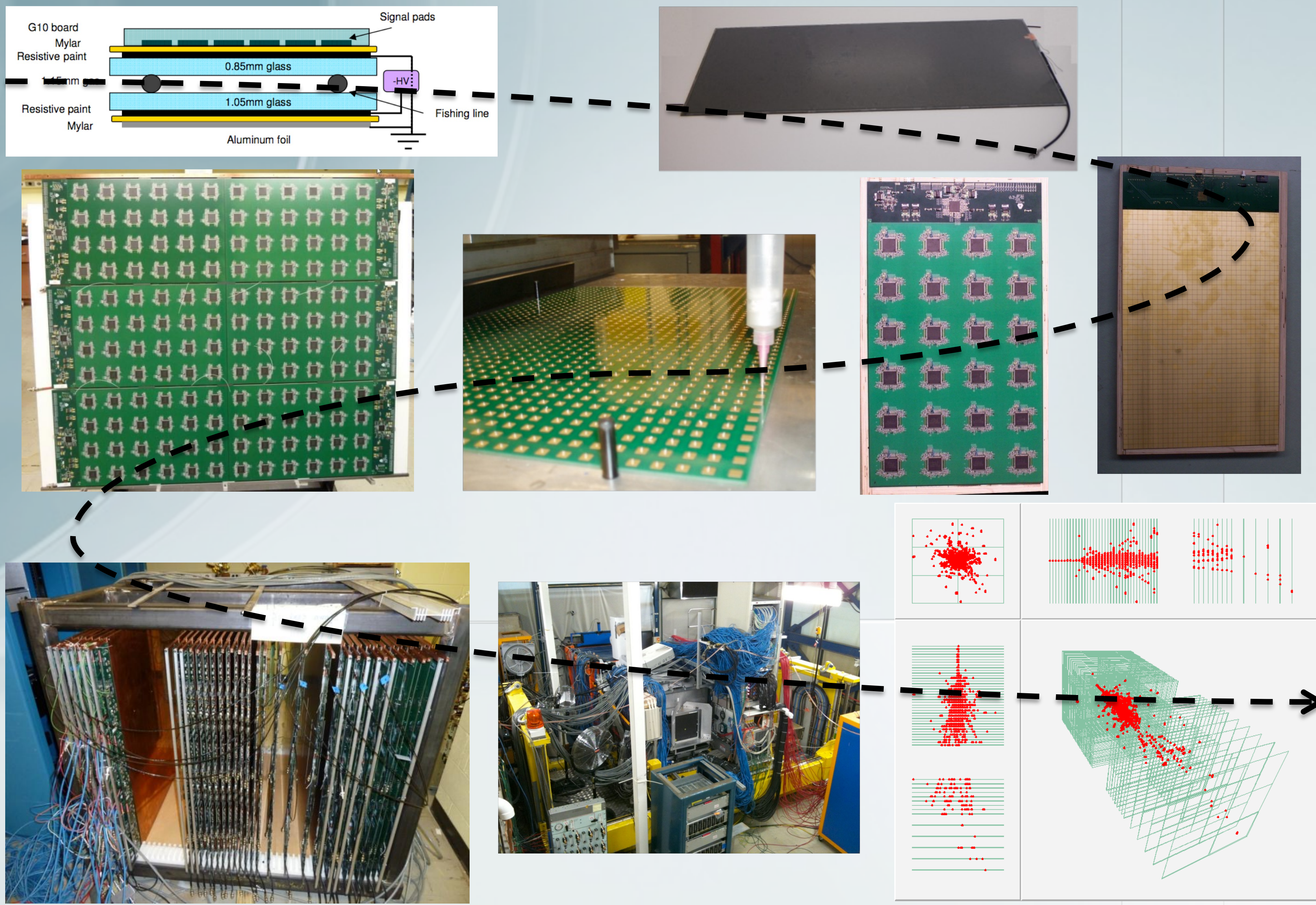
Light Yield vs position 1-sipm pe/MeV



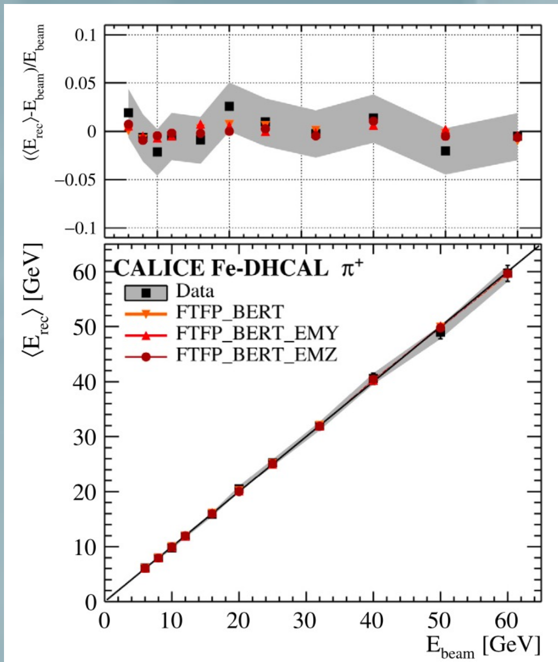
4-sipm L.Y. ~ 3x 1-sipm

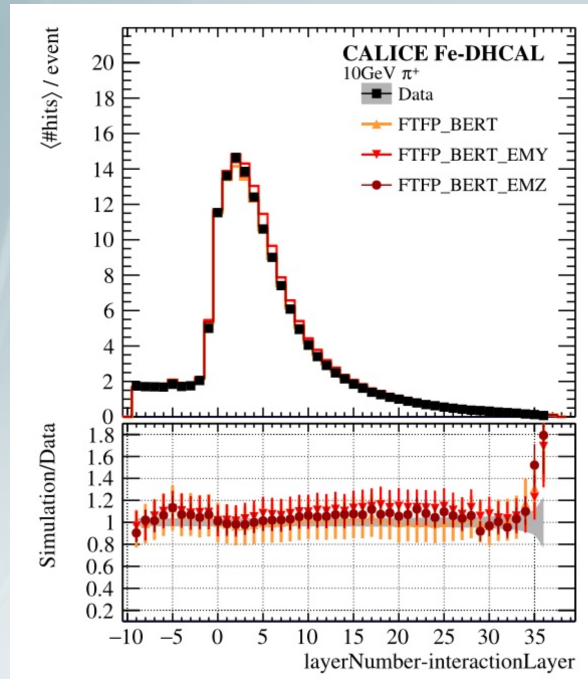
Z. Sheemanto

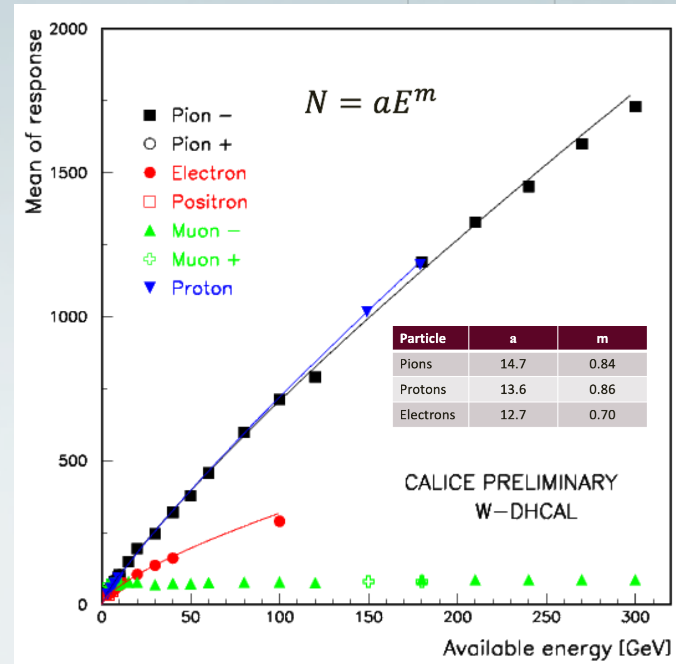
DHCAL Construction

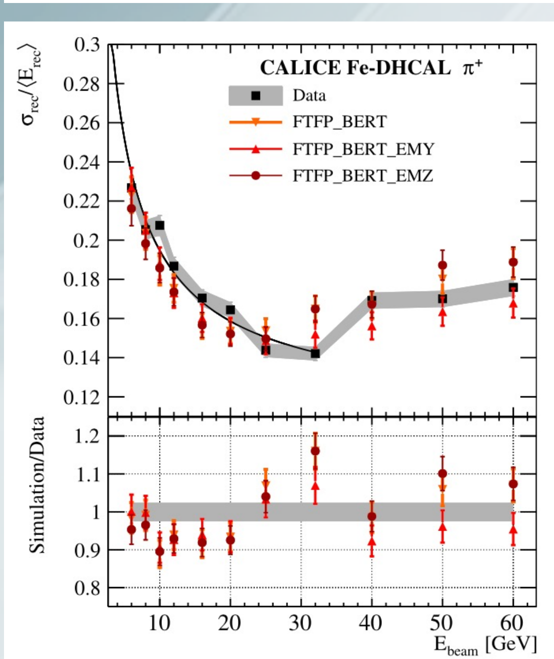


A Few Highlights From DHCAL Performance



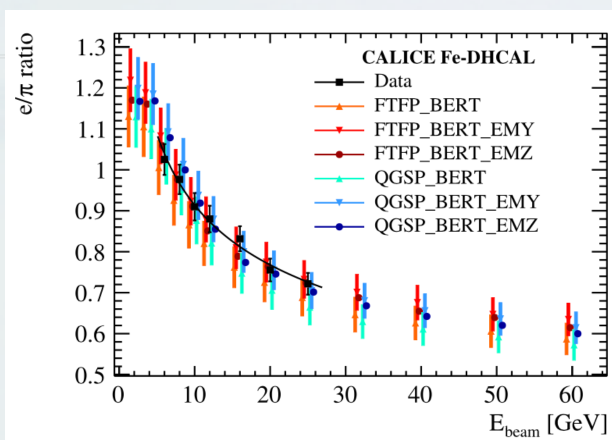


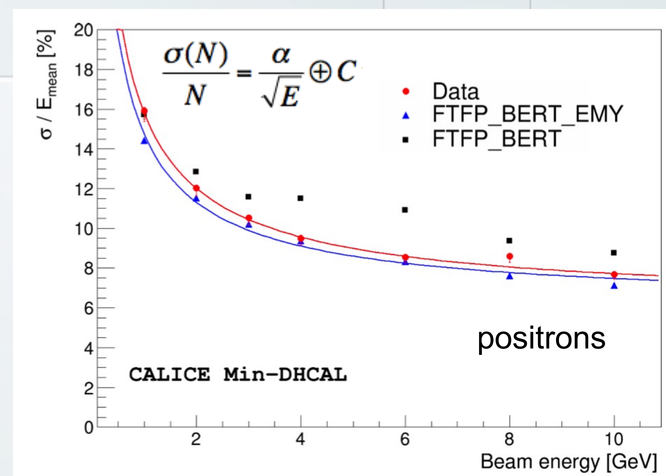




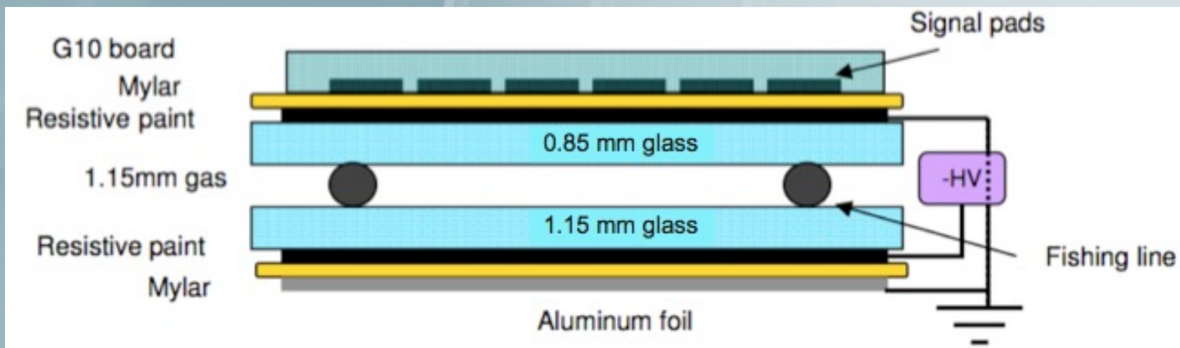
$$\frac{\sigma}{E} = \frac{(51.5 \pm 1.5)\%}{\sqrt{E}} \oplus (10.6 \pm 0.5)\%$$

Fit	c[%]	α [%]
Unweighted	5.7 ± 0.2	14.8 ± 0.4
Weighted (linearized)	6.2 ± 0.2	13.0 ± 0.4

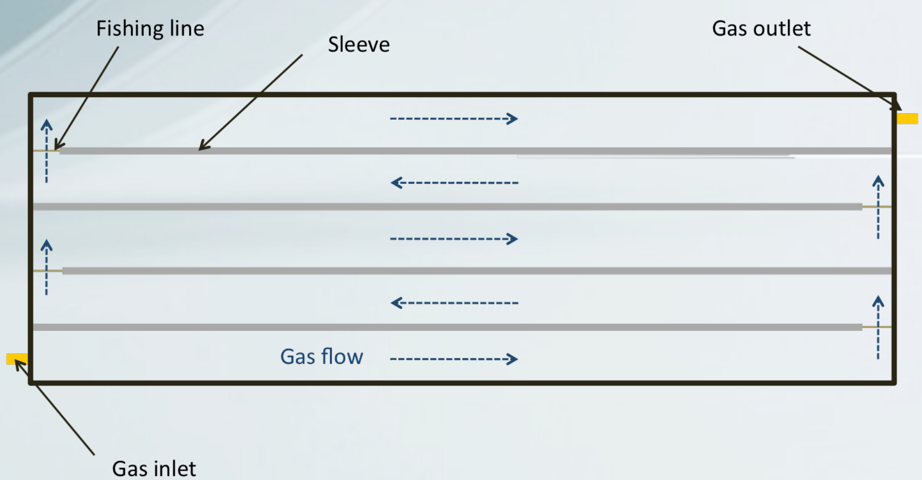




RPCs of the DHCAL



Gap size and gas flow uniformity is maintained via fishing line channels



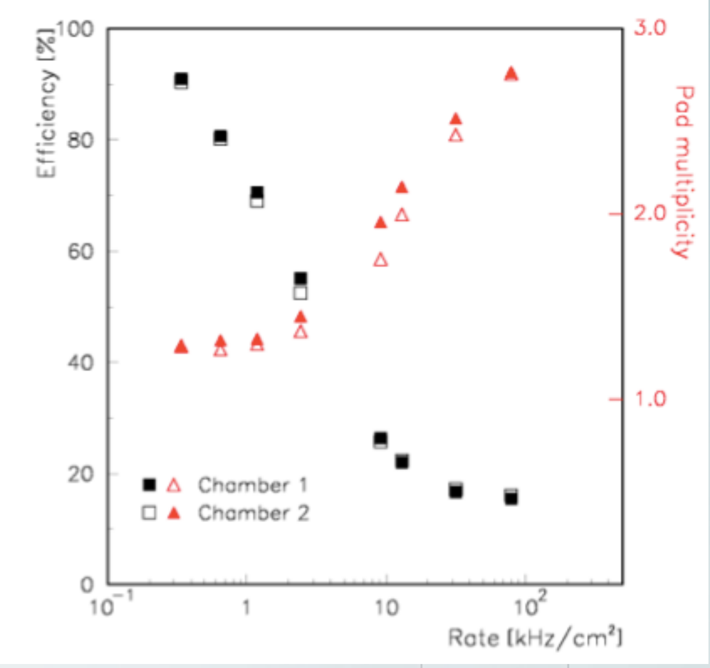
Gas: Tetrafluorethane (R134A) : Isobutane : Sulfurhexafluoride (SF_6) with the following ratios 94.5 : 5.0 : 0.5

High Voltage: 6.3 kV (nominal)

Average efficiency: 96 %

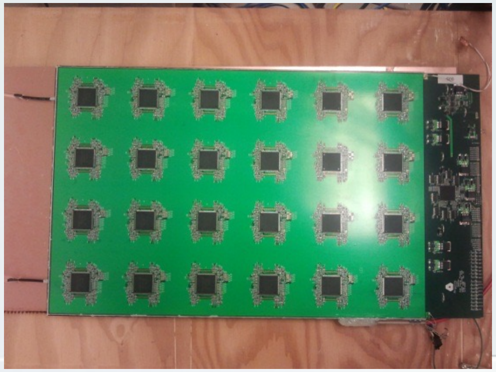
Average pad multiplicity: 1.6

1-glass RPCs



Offers many advantages

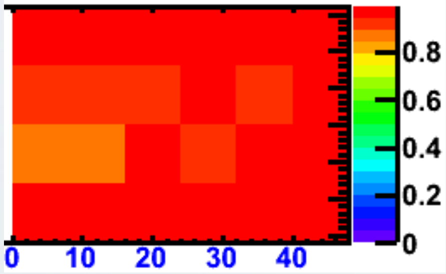
Pad multiplicity close to one
→ easier to calibrate
Better position resolution
→ if smaller pads are desired
Thinner
→ $t = t_{chamber} + t_{readout} = 2.4 + {\sim}1.5$ mm
→ saves on cost
Higher rate capability
→ roughly a factor of 2



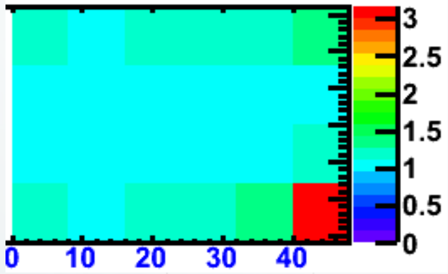
Status

Built several large chambers
Tests with cosmic rays very successful
→ chambers ran for months without problems
Both efficiency and pad multiplicity look good
Good performance in the test beam

Efficiency



Pad multiplicity

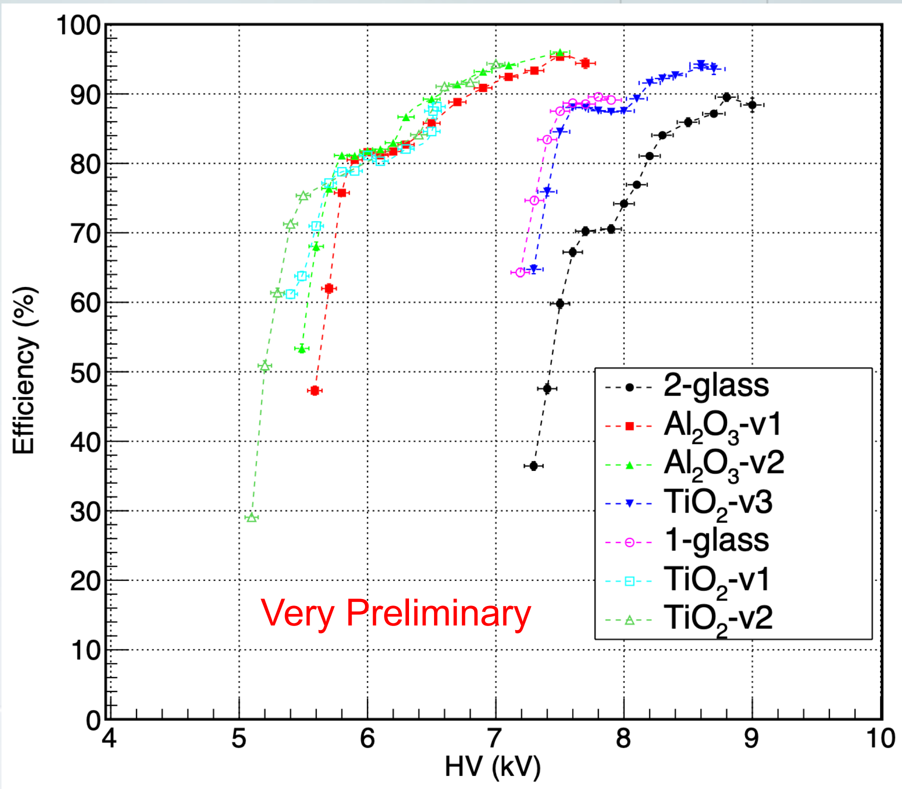


Tests of the First-Generation Hybrid RPCs

We tested the first-generation hybrid RPCs as well as the standard 1-glass and 2-glass RPCs at Fermilab test beam. The lateral size of the chambers was 10 cm x 10 cm, the gas gap was 1.3 mm and the gas mixture was the DHCAL RPC gas mixture R134A : Isobutane : SF_6 ; 94.5 : 5.0 : 0.5 at 2-3 cc/min flow rate (lower than the nominal 5 cc/min).

Chambers tested and their 90% efficiency crossing HV:

1. 2-glass RPC (8.5 kV)
2. 1-glass RPC (7.5 kV)
3. 500 nm Al_2O_3 (v1) (6.5 kV)
4. 350 nm Al_2O_3 (v2) (6.5 kV)
5. 1 mg/cm^2 TiO_2 (v1) (6.5 kV)
6. 0.5 mg/cm^2 TiO_2 (v2) (6.5 kV)
7. 0.15 mg/cm^2 TiO_2 (v3) (7.5 kV)



Efficient if charge > 300 fC

The charge multiplication in the secondary emission layer is qualitatively validated.

LOI Signatories

- **ANL**
  - J. Elam, A. Mane
- **Beykent University**
  - B. Bilki, M. Tosun
- **Fairfield University**
  - D. Winn
- **International Center for Elementary Particle Physics (ICEPP), The University of Tokyo**
  - W. Ootani
- **NIU**
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- **Fermilab**
  - V. Di Benedetto, J. Freeman, S. Los, A. Mazzacane
- **Shinshu University**
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- **University of Iowa**
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- **University of Kansas**
  - M. Murray