CALICE Collaboration

Status of ADRIANO2 R&D in T1604 Collaboration

Corrado Gatto

On behalf of T1604 Collaboration

G. 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 Mathieu, J. Marquez, A. Mane, J. Elam

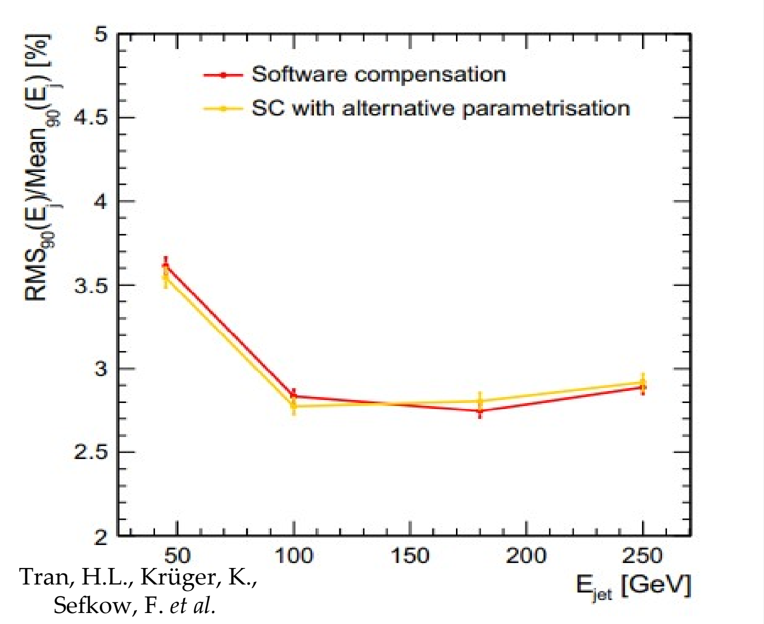
ANL, FNAL, KU, NIU, INFN, ETL

Rationale for High-Granularity Dual-Readout Calorimetry

Energy compensation: most useful for high-energy

PFA

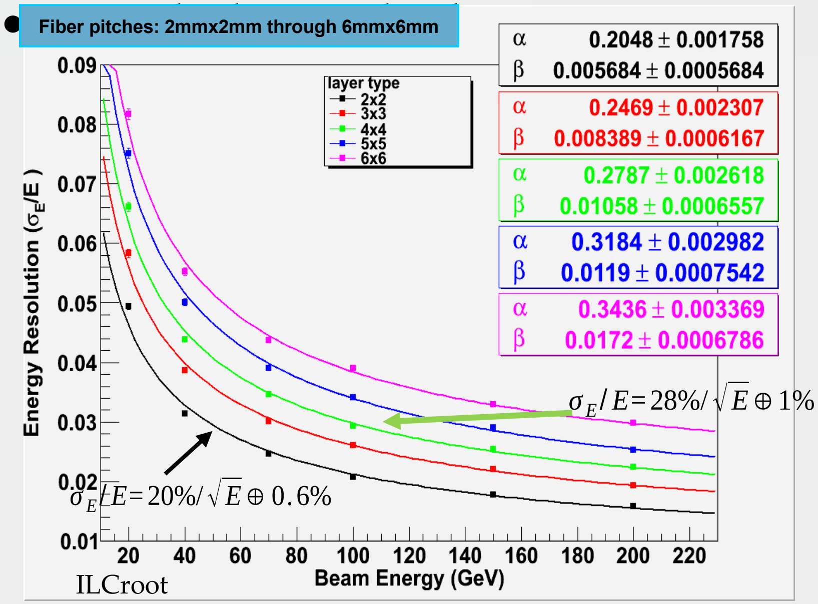
- Combines tracking with calorimetry
- PID from software algorithm
- Fantastic energy resolution with small constant term at low energies



Tran, H.L., Krüger, K., Sefkow, F. *et al.*

Dual-readout

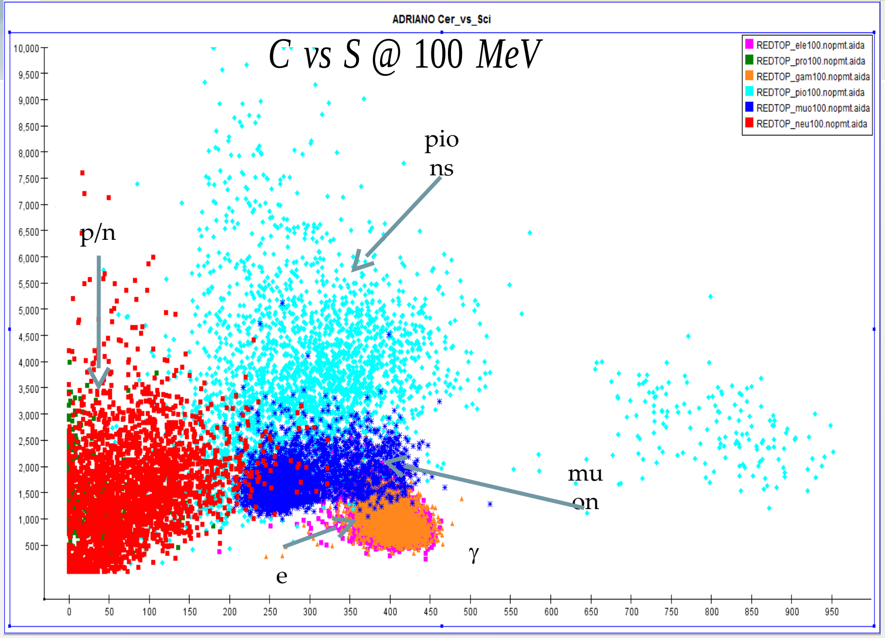
- Exploit the stochastic side only of calorimetry
- PID in hardware (from S/Č)
-

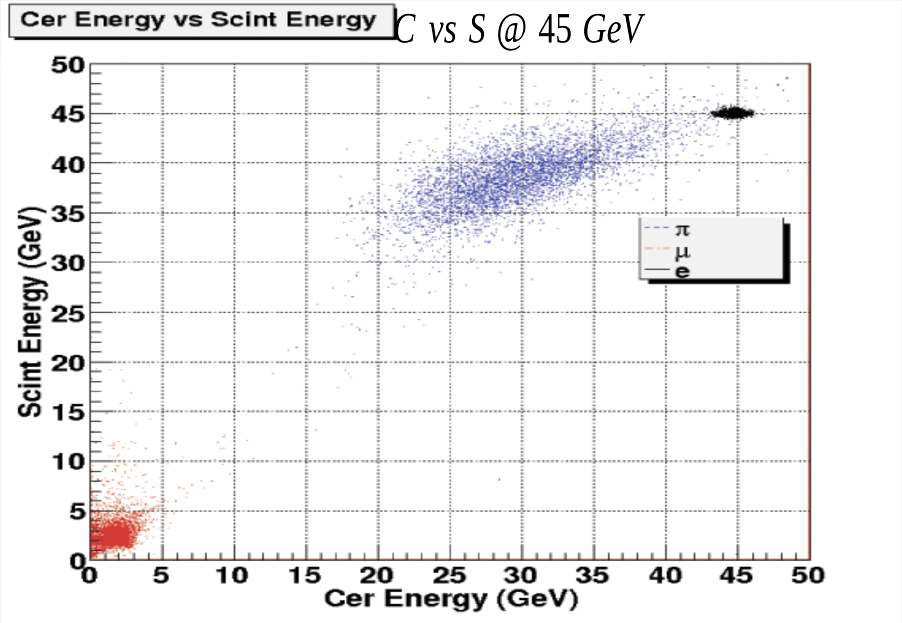


ILCroot simulations

Rationale for High-Granularity Dual-Readout Calorimetry

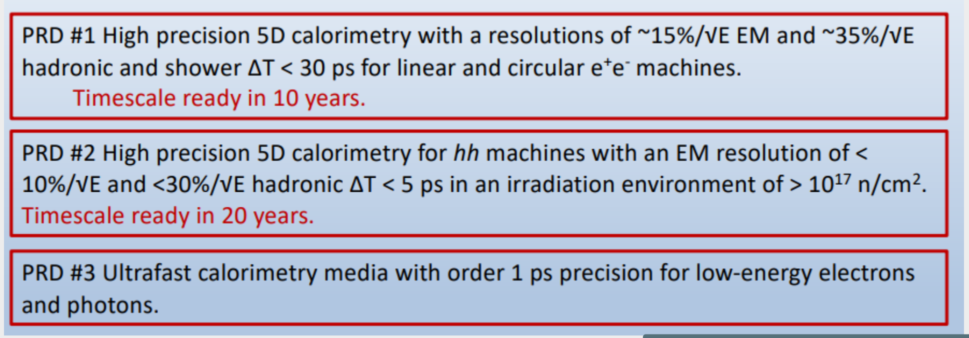
PID: most useful for low-energy, high-intensity experiments





Fast timing

- PID via TOF measurements
- Used in L0 trigger



PRD #1 High precision 5D calorimetry with a resolutions of ~15%/√E EM and ~35%/√E hadronic and shower ΔT < 30 ps for linear and circular e^+e^- machines.
Timescale ready in 10 years.

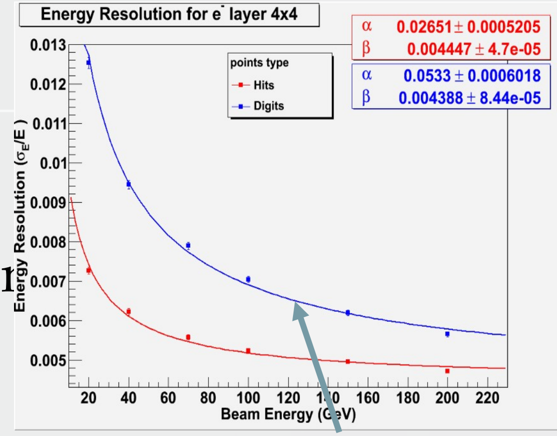
PRD #2 High precision 5D calorimetry for *hh* machines with an EM resolution of < 10%/√E and <30%/√E hadronic ΔT < 5 ps in an irradiation environment of > 10^{17} n/cm^2.
Timescale ready in 20 years.

PRD #3 Ultrafast calorimetry media with order 1 ps precision for low-energy electrons and photons.

From R. Rusack, BRN report

PFA + Dual-readout (with psec timing)= Ultimate calorimetry (6D)

Integrally active HG-Dual-Readout



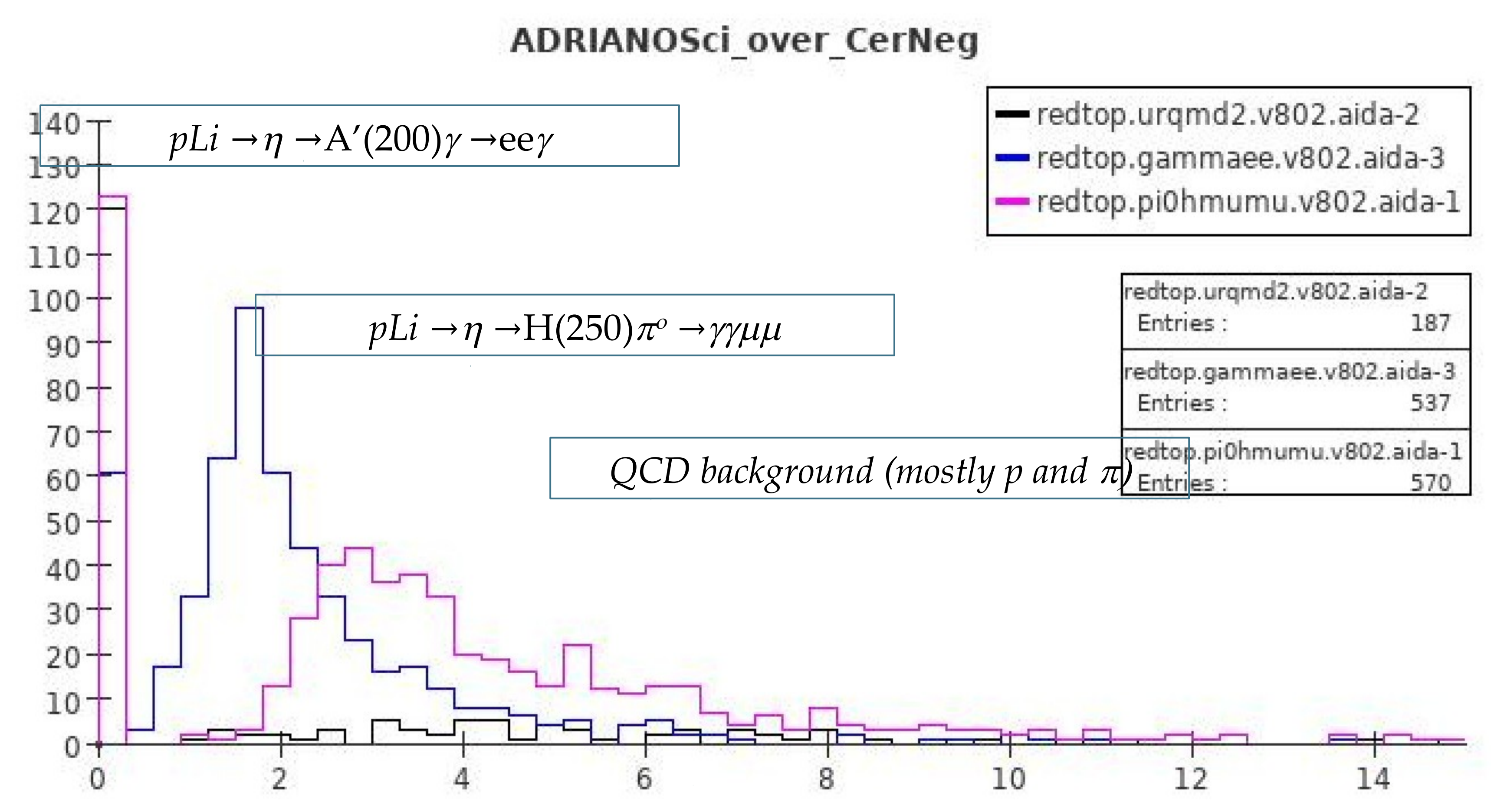
- Typical electromagnetic energy resolution: 5%/ (includes effects from the electronics)
- Particle ID from S vs Č: neutron/gamma separation at 3σ level
- Fine granularity: it can be used as a range stack for muons and/or pions
- Sensitivity > 10 MeV (layout for ORKA and REDTOP experiments)

ADRIANO2 is a semi-homogeneous, integrally active calorimeter

It is, at the same time, an EM and Hadronic calorimeter without change in absorber density

Fast Dual Readout ADRIANO2 in REDTOP

- 1 GHz interaction rate -> Cerenkov process a winner
- 1/200 η mesons produced -> large background



$pLi \rightarrow \eta \rightarrow A'(200)\gamma \rightarrow ee\gamma$

$pLi \rightarrow \eta \rightarrow H(250)\pi^o \rightarrow \gamma\gamma\mu\mu$

QCD background (mostly p and π)

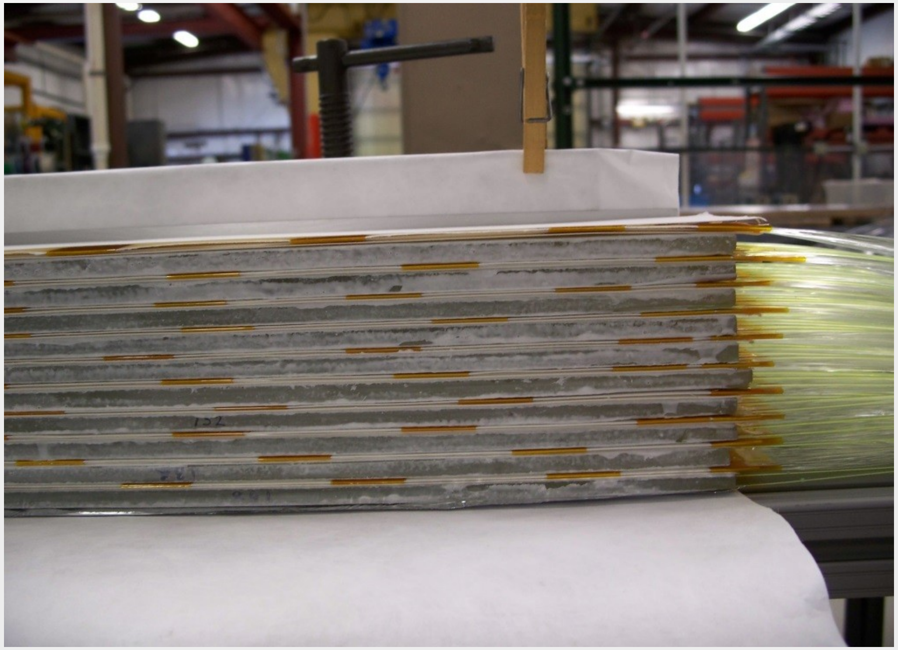
ADRIANO predecessor: Non-Segmented Version

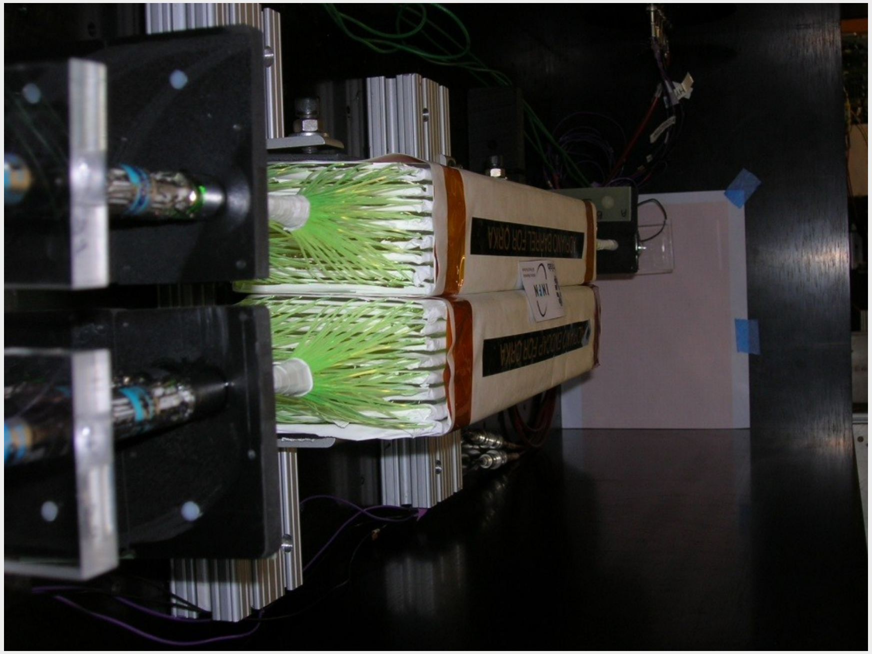
High Energy

- Detection of Hadronic and EM showers with large S and Č light production
- Optimized for maximum shower containment (i.e. max detector density)
  - Thicker glass
  - Thin scintillating fibers or ribbons
  - Fewer WLS fibers

High Intensity

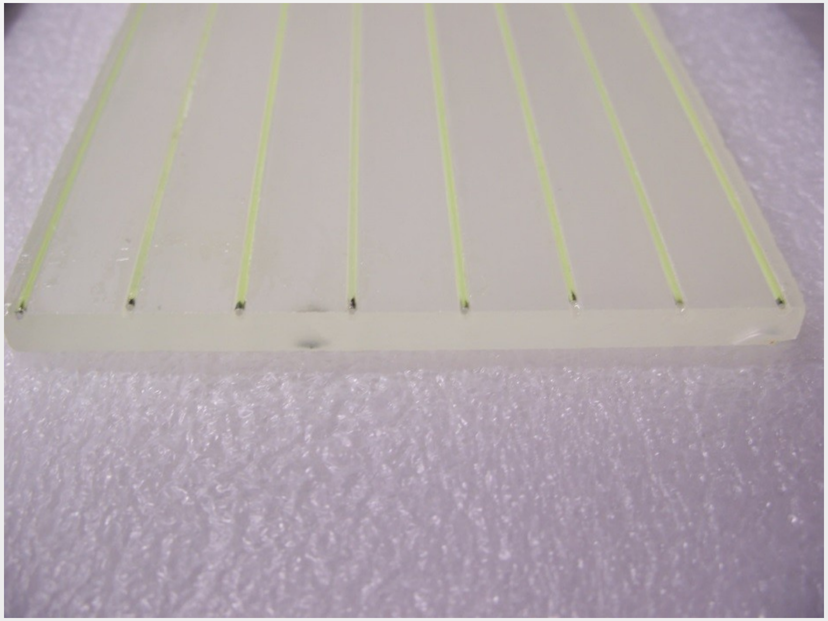
- Detection of EM showers only with small S and Č light production
- Optimized for high sensitivity in the 10 MeV range (i.e. max detector granularity)
  - Thinner glass
  - Thicker scintillator plates
  - More WLS fibers



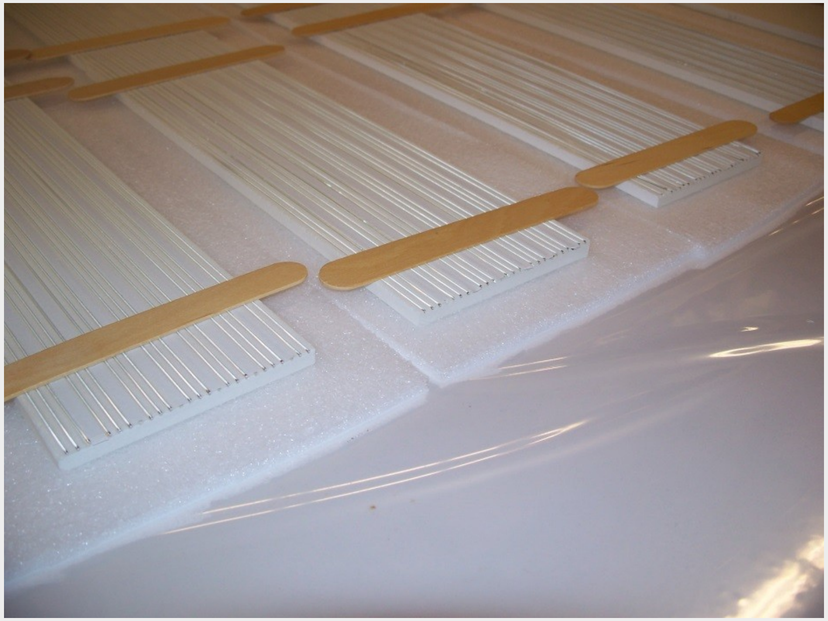


ADRIANO-2014

- Two versions built: scifi and scintillating plates
- 10 x 8 x105 cm3 long prototypes, about 50 Kg each
- 4 cells total, front and back readout
- Hopefully , we will be able to test the dual-readout concept with integrally active detectors



ADRIANO 2014A: 8 grooves



ADRIANO 2014B: 23 grooves

ADRIANO Detector Response

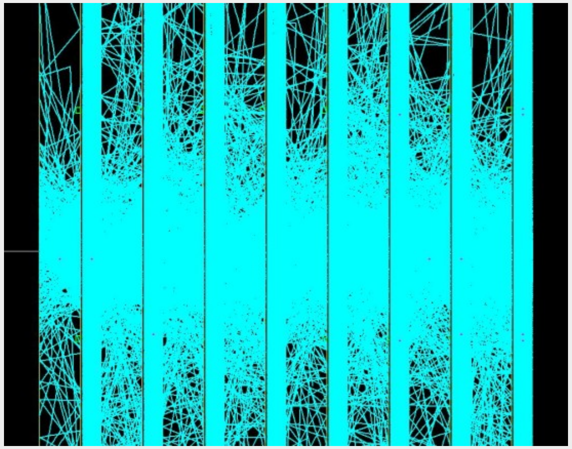
	ADRIANO 2014A	ADRIANO 2014B
Scintillation L.Y.	523 pe/GeV	256 pe/GeV
Čerenkov L.Y.	**354 pe/GeV**	**338 pe/GeV**
% scint. energy	6.0% @ 4 GeV	1.14% @ 4 GeV
% Cher. energy	94% @ 4 GeV	98.86% @ 4 GeV
% visible energy	89.7% @ 4 GeV	89.7% @ 4 GeV
Scint. pe/deposited energy [MeV]	0.215 GeV@ 4gev Or 18 pe/MeV	0.041 GeV@ 4gev or 44 pe/ MeV
Cher. pe/deposited energy [MeV]	3.37 GeV@ 4gev Or 0.36 pe/MeV	3.52 GeV@ 4gev Or 0.4 pe/MeV

16 prototypes tested over 6 yrs

Light yield goals for 30%/√E resolution achieved in 2014 !

ADRIANO2: A Dual-Readout Integrally Active Tile Calorimeter

- Layout: sandwich of small (~cm^3) lead-glass and scintillating plastic tiles
- Tiles are optically separated (wrapped or coated) and individually readout with sipm(s)
- Optional dimple to accommodate the SiPM



Geant4 optical simulation with Al coating

Rationale for ADRIANO2

- Advantages:
  1) Prompt Cerenkov signal for timing resolution and L0-trigger
  2) Small Pb-glass tile unaffected by aging
  3) Good energy resolution
  4) High-granularity
- Disadvantaged
  1) Cost
  2) Large number of readout channels

Tested Configurations

- Three sizes
  - 3x3x1 cm^3, 3x3x2 cm^3, 3x3x3 cm^3
- Two glasses:
  - SF57-HHT, Fused silica
- Three surface finish
  - Cut ground, sandblasted, polished
- Ten coating

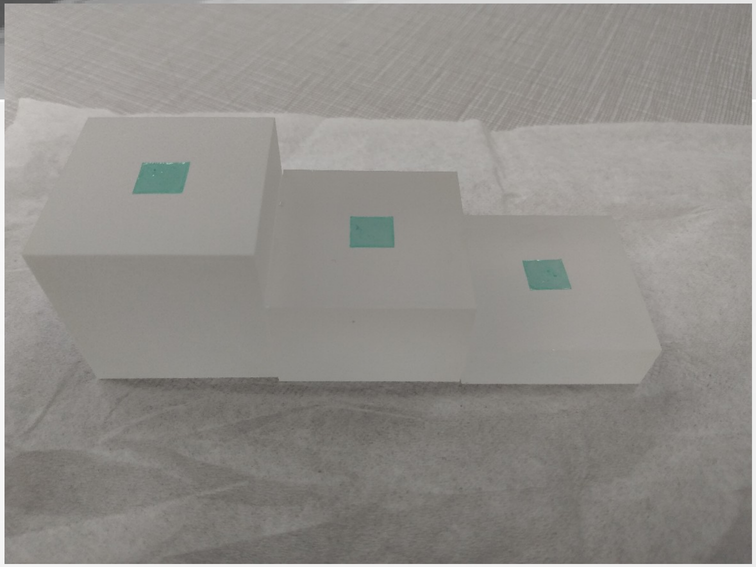
$BaSO_4$, Teflon, Kevlar, Al sputtering (NIU and Euclid Techlabs, LLC)), Al paint, ESR2000, Ag sputtering (FNAL), Mo ALD, W ALD (ANL)

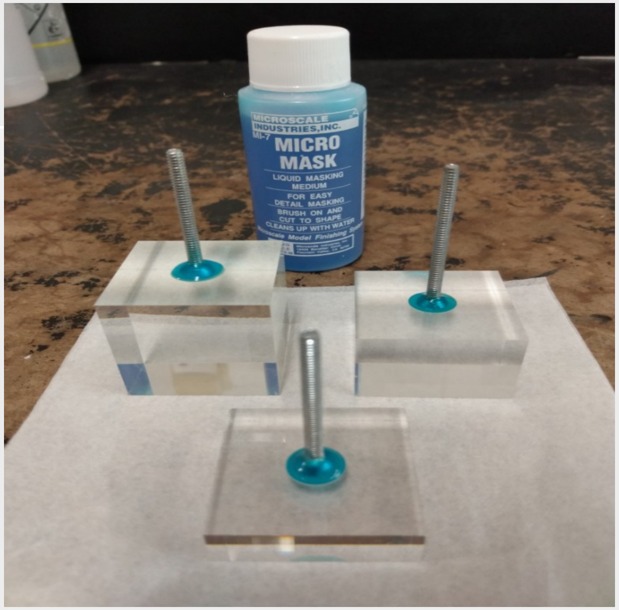
- Two sensor interfaces
  - Dimple, no-dimple
- Two sensors
  - S13360, S14160 (6x6 mm^2)
- One special tile

Four sensors in active ganged mode – $BaSO_4$ coated

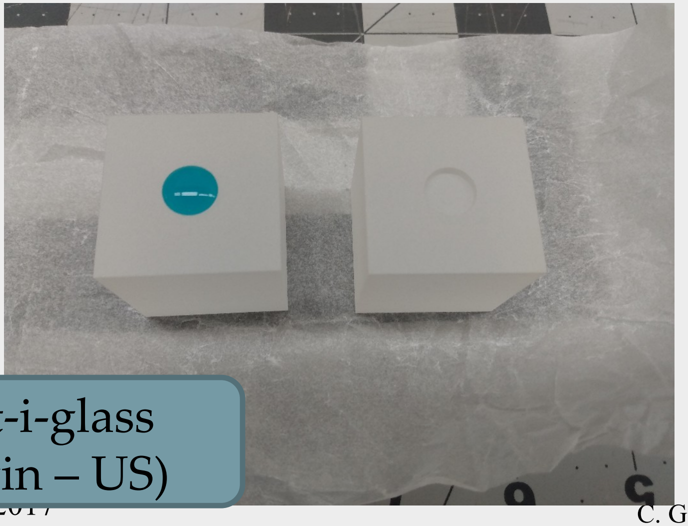
Total: 48 tiles tested

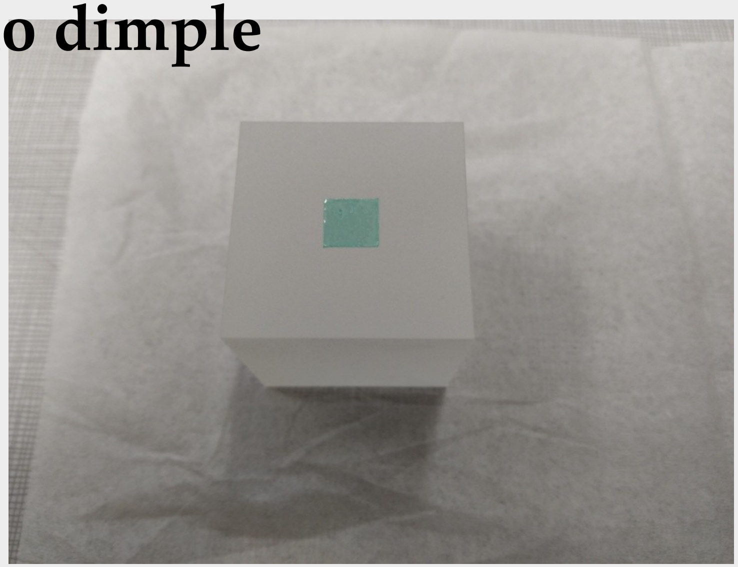
Polished vs unpolished Tiles





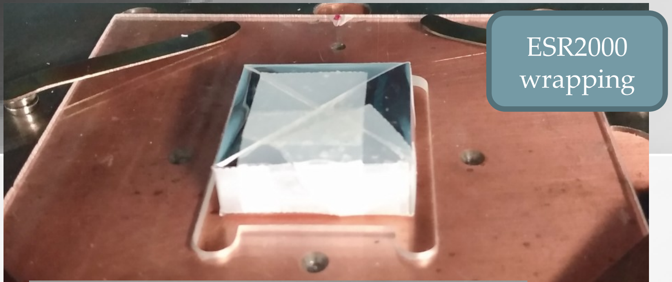
Dimple vs no dimple





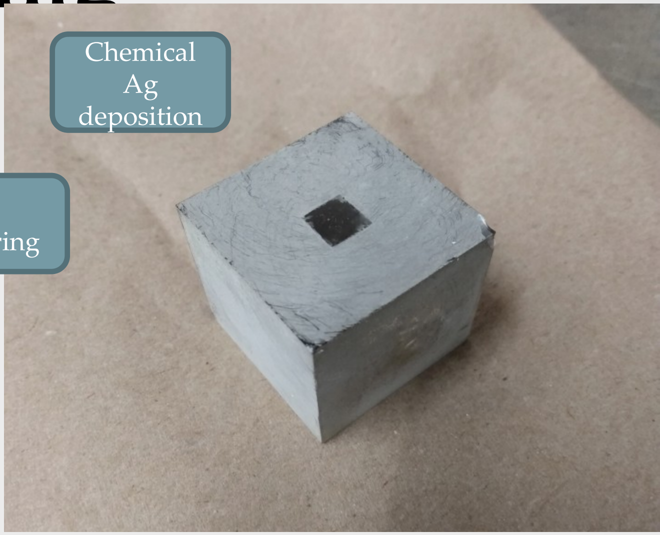
Cat-i-glass
(Elgin – US)

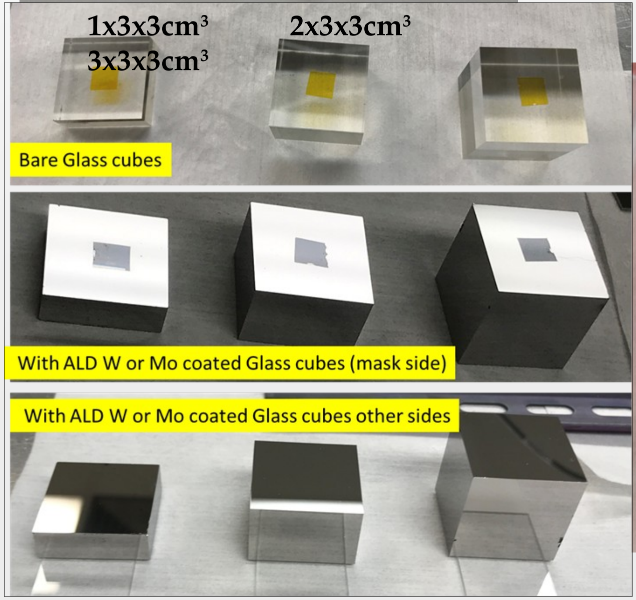
Coating vs wrapping

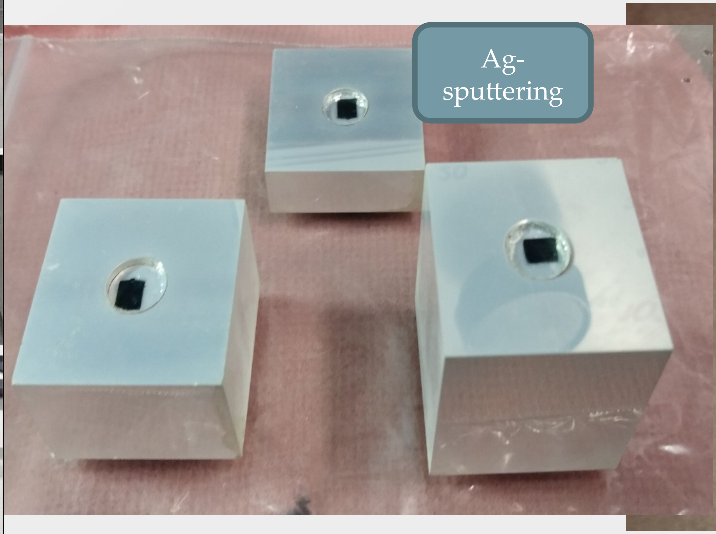

ESR2000 wrapping


Avian-B spray


Al-sputtering


Chemical Ag deposition




Ag-sputtering


Avian-B dipping

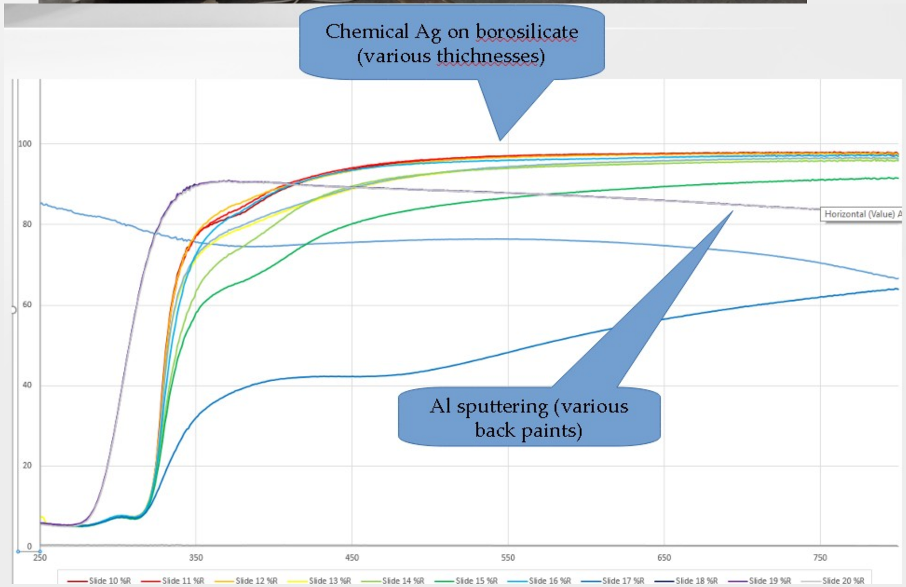
Quartz Tiles for REDTOP TOF and hadronic Calorimeter

- Much less dense than SF57, but inexpensive and highly transparent
- Two coating tested: BaSO4 and Al sputtered

Construction Facilities

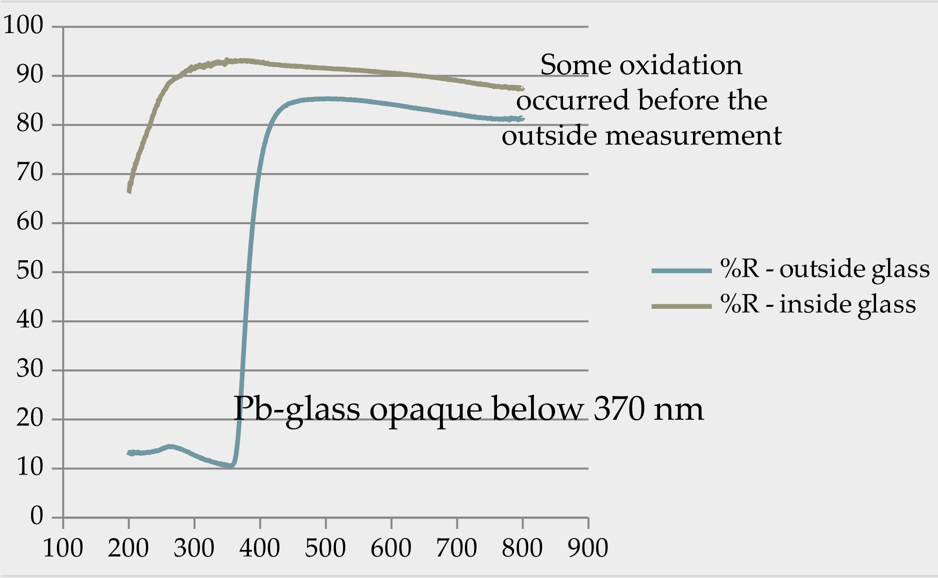
- ALD: ANL (A. Mane, J. Elam)
- Al sputtering: NIU and Euclid Techlabs, LLC (A. Liu, T. Fletcher, M. Figora)
- Ag sputtering: Fermilab (E. Hahn)
- All diffuse coatings: NIU
- All wrappings: NIU
- Mechanics: NIU (M. Figora)
- FEE Electronics: Fermilab (S. Los)
- DAQ – ASIC: KU (R. Young)

T. Fletcher



Chemical Ag on borosilicate (various thichnesses)

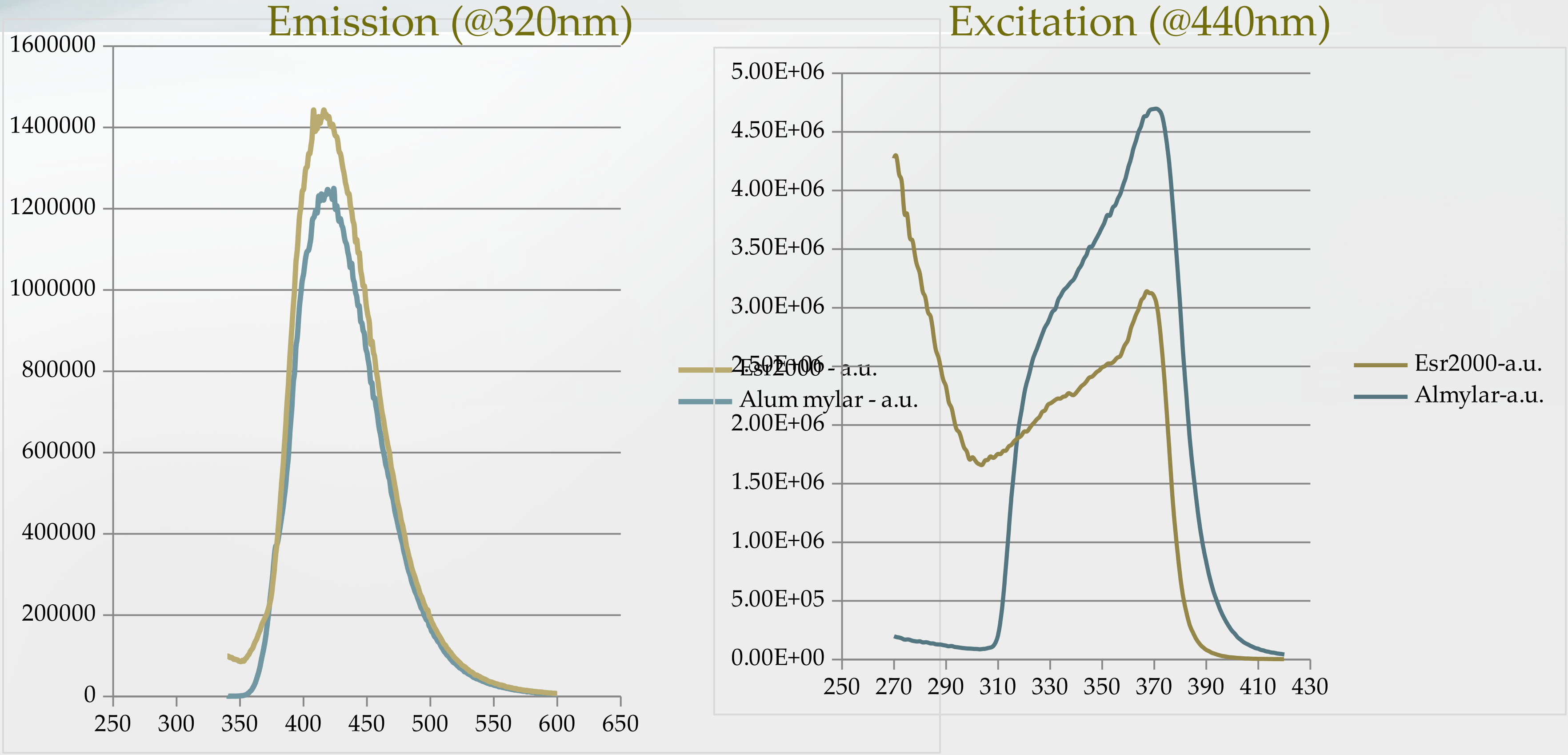
Al sputtering (various back paints)



Some oxidation occurred before the outside measurement

Pb-glass opaque below 370 nm

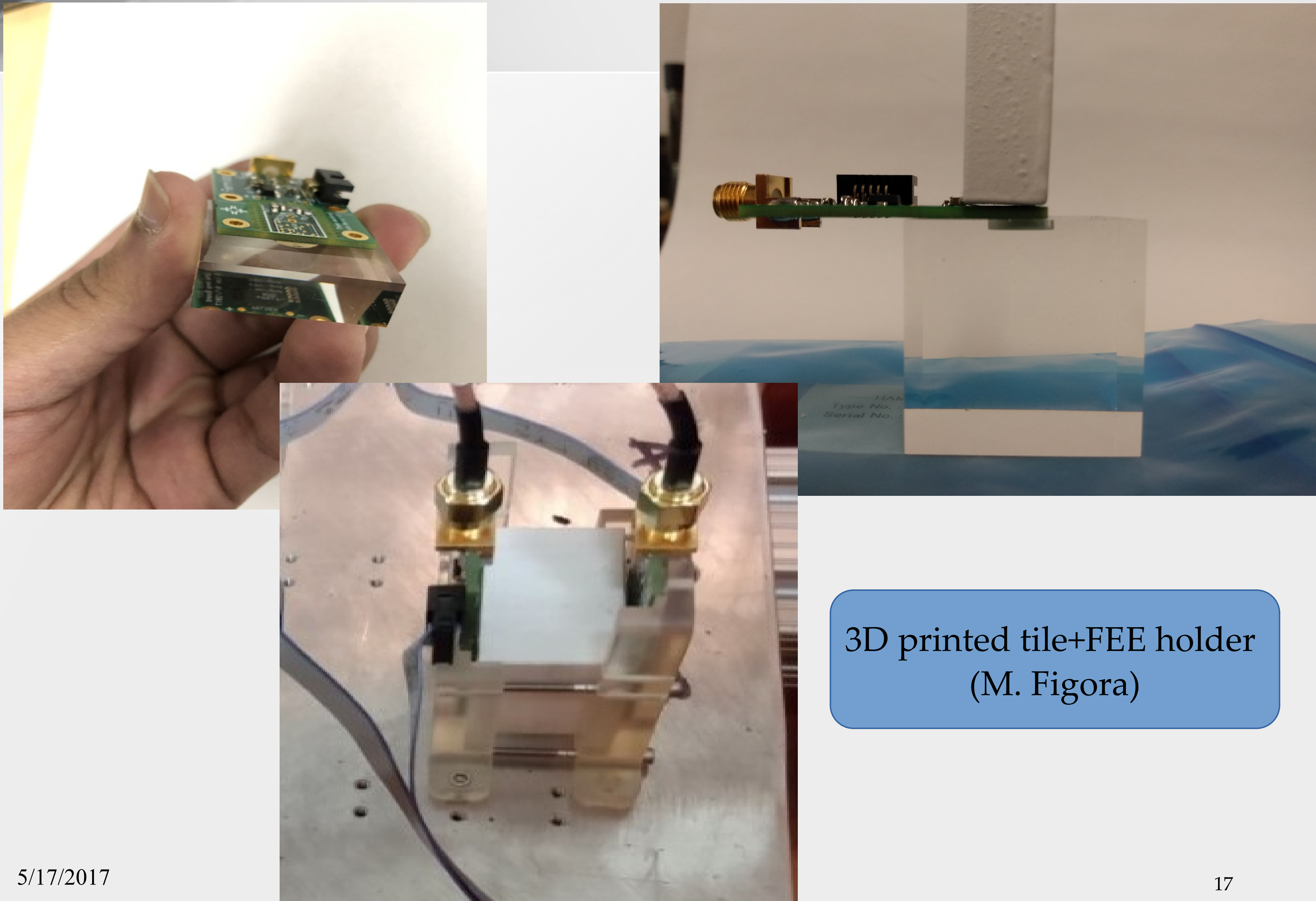
Fluorescence spectra of wrapping


Emission (@320nm)

Excitation (@440nm)

- Measurement performed with an PTI QuantaMaster4/2006SE spectrofluorimeter (E. Nesterov lab. – NIU Chem. Dept.)
- The excitation and emission spectra were acquired at the right-angle configuration
- Results in M. Janecek paper are fully confirmed (brilliant fluorescence with τ=14nsec)

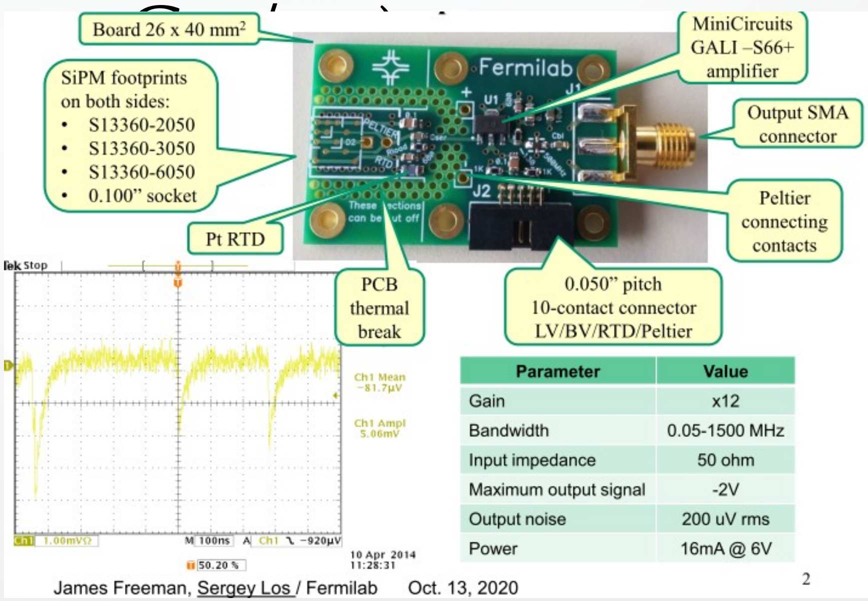
FEE + Tiles with dimple



3D printed tile+FEE holder
(M. Figora)

FEE and DAQ: Test beam #1: June 2021

- Porka boards (S. Los) with Sampic digitizer (10/8



Board 26 x 40 mm²

SiPM footprints on both sides:
- S13360-2050
- S13360-3050
- S13360-6050
- 0.100” socket

Pt RTD

PCB thermal break

MiniCircuits GALI –S66+ amplifier

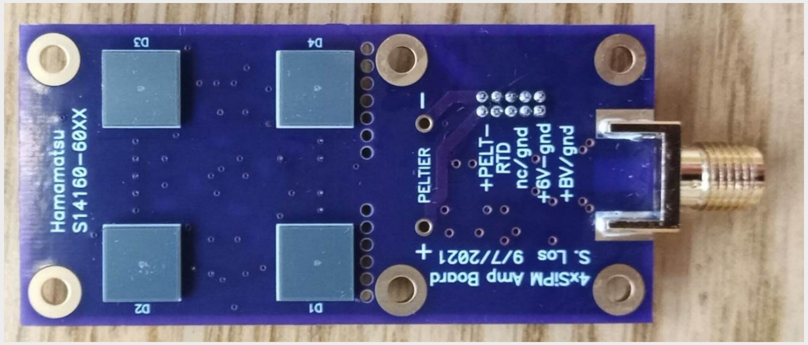
Output SMA connector

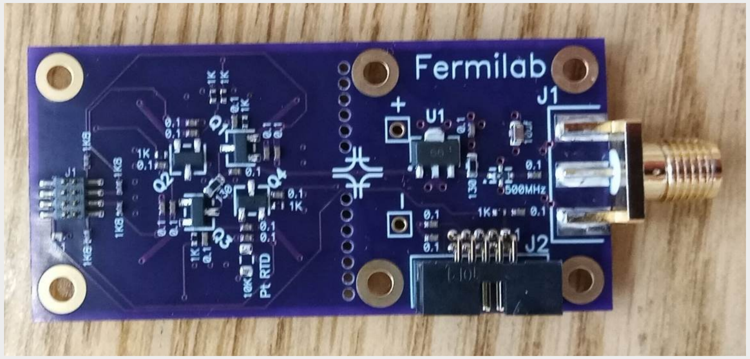
Peltier connecting contacts

0.050” pitch 10-contact connector LV/BV/RTD/Peltier

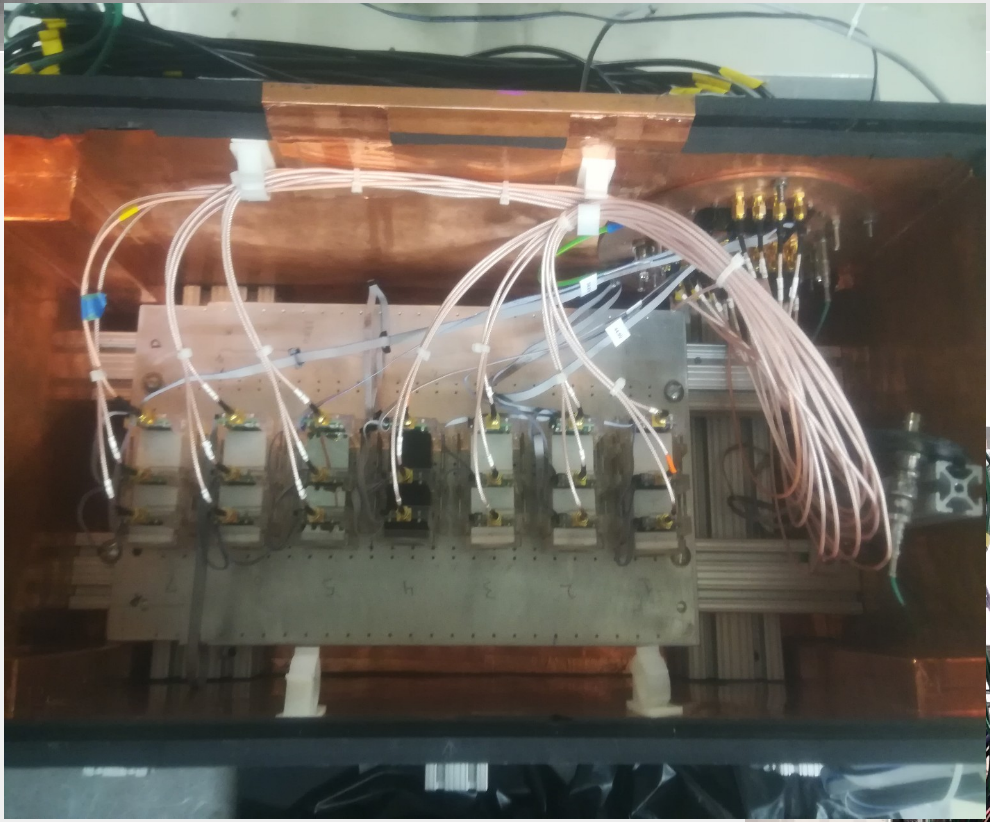
Parameter	Value
Gain	x12
Bandwidth	0.05-1500 MHz
Input impedance	50 ohm
Maximum output signal	-2V
Output noise	200 uV rms
Power	16mA @ 6V

James Freeman, Sergey Los / Fermilab Oct. 13, 2020 2



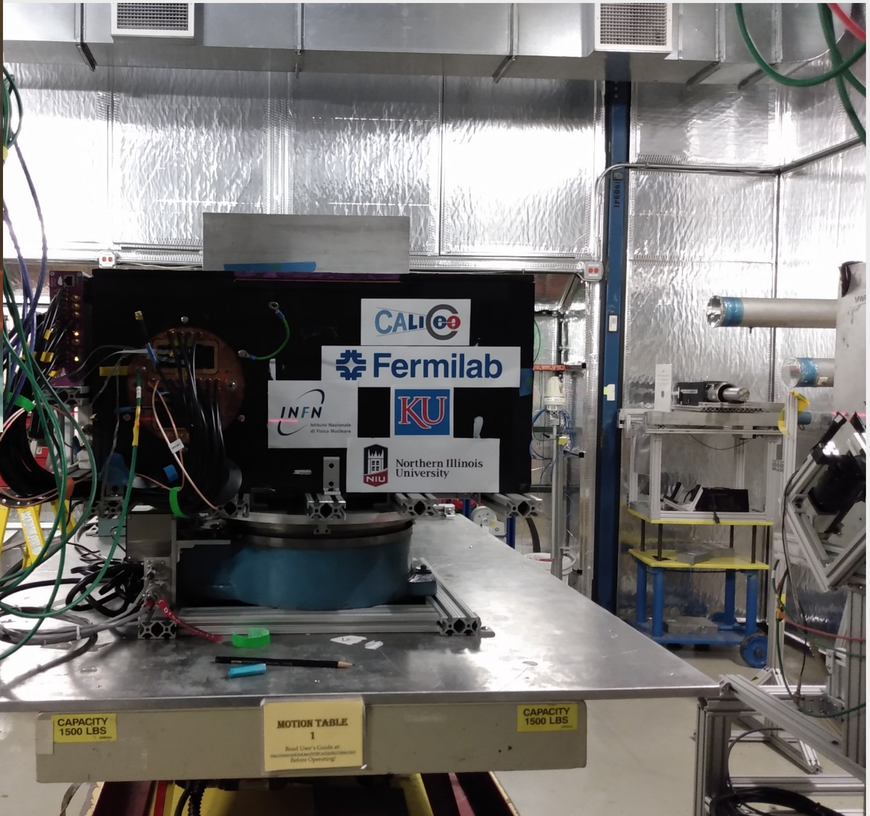


ADRIANO2 at FTBF

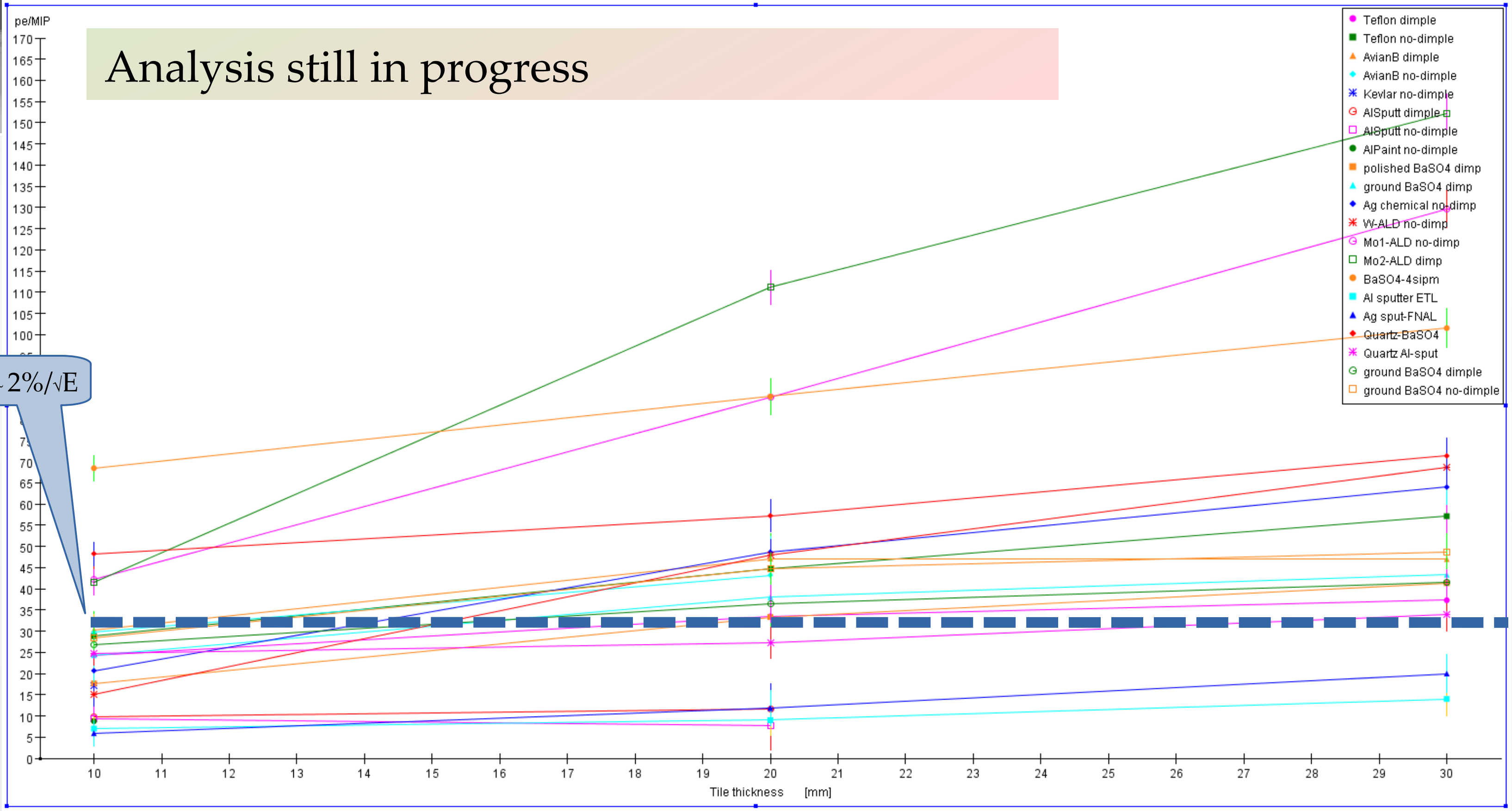


- Three test beam completed
- Tiles organized in triplet of three sizes
- Final test beam planned for Winter 2023
- Final test beam with 64 channels and ASIC DAQ : CAEN 5500 with petiroc-2

(University of Kansas)



Summary LY/MIP Analysis


Analysis still in progress

σ

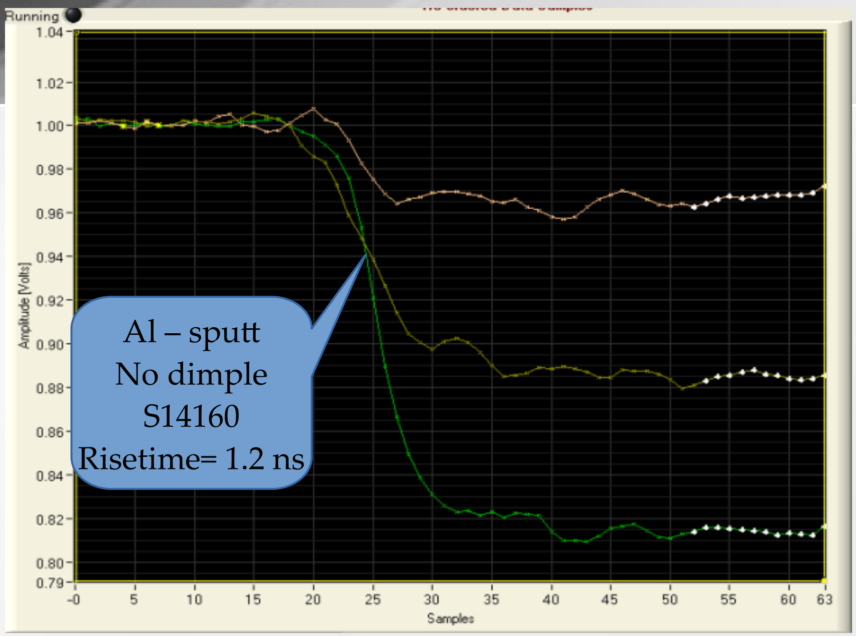
$\sigma_E/E \sim 2\%/\sqrt{E}$

- 1 MIP in SF57 ~ 9 MeV/cm
- 1 MIP in Quartz ~ 3.3 MeV/cm
- 4 configurations exceed a stocastic resolution of 2%/√(E)
- Quarzt tiles have 1/3 of the density of SF57, but large LY
- Analysis still in progress: need to study efficiency, angular and position response

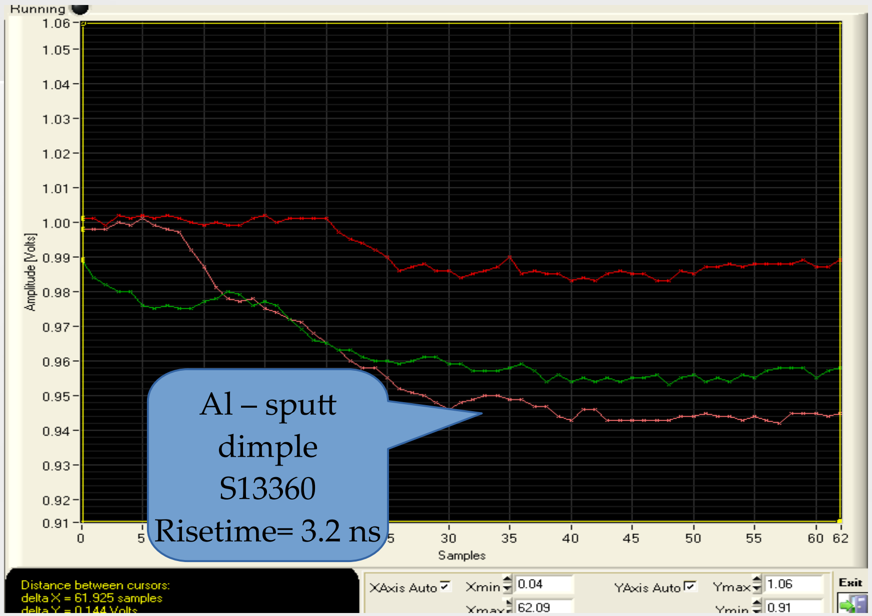
Some Observations on LY of Various Tiles

- LY scales linearly with thickness with a factor of about 2/3
- Mirror coating (Al and Ag) has consistently lower LY, except for the three sets with W and Mo ALD
- Response of diffuse coated and metal sputtered tiles is Landau-like. Mirror coated tiles have very long tails.
- Quartz tiles have much larger LY
- Tiles with dimple have about 20% less LY than similar tiles with no-dimple
- Al-sputtered, Ag-sputtered and Al-paint have 1/3 the LY vs diffuse coating
- Sputter Ag has similar behaviour as Al (oxidation of metal-Pb glass surface ?)
- 3 cm thick sandblasted, $BaSO_4$ tile has 15% lower-than-expected LY
- 4-sensor board with active ganging (16% vs 4% of tile surface coverage) shows ~3x the LY vs single-sensor board

Waveform with SAMPIC @ 6.4 GSa/s



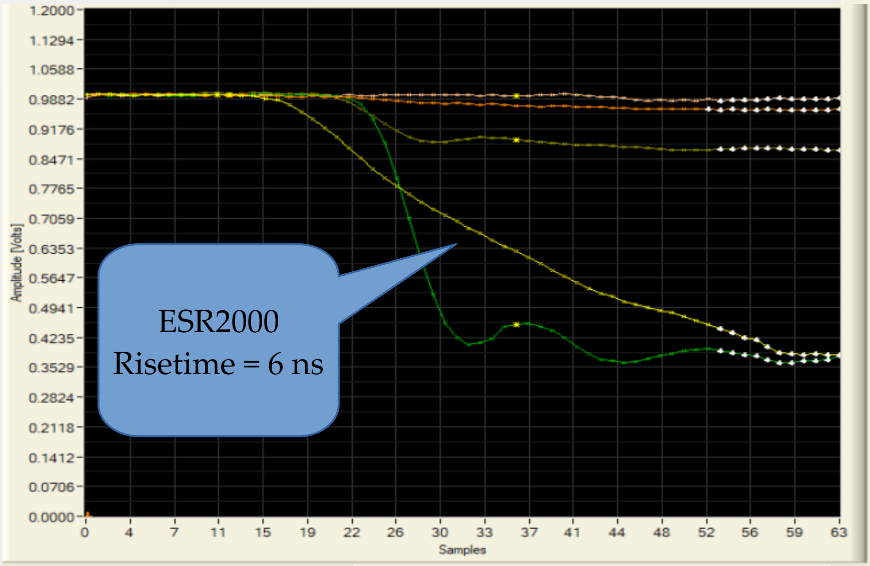
Al – sputt
No dimple
S14160
Risetime= 1.2 ns



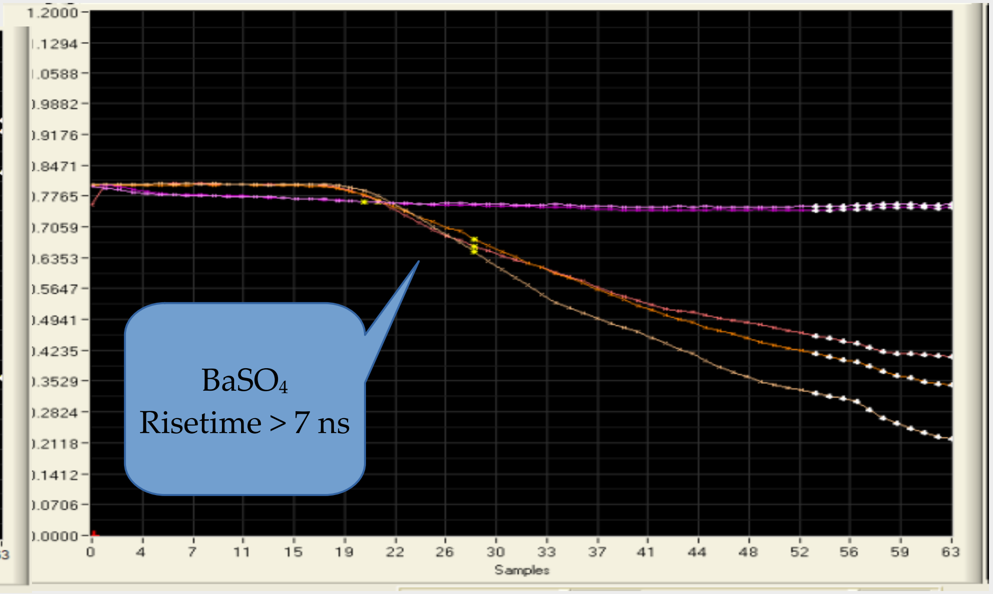
Distance between cursors:
delta X = 61.925 samples
delta Y = 0.144 Volts

XAxis Auto ☑ Xmin 0.04 Xmax 62.09
YAxis Auto ☑ Ymax 1.06 Ymin 0.91

Al – sputt
dimple
S13360
Risetime= 3.2 ns



ESR2000
Risetime = 6 ns

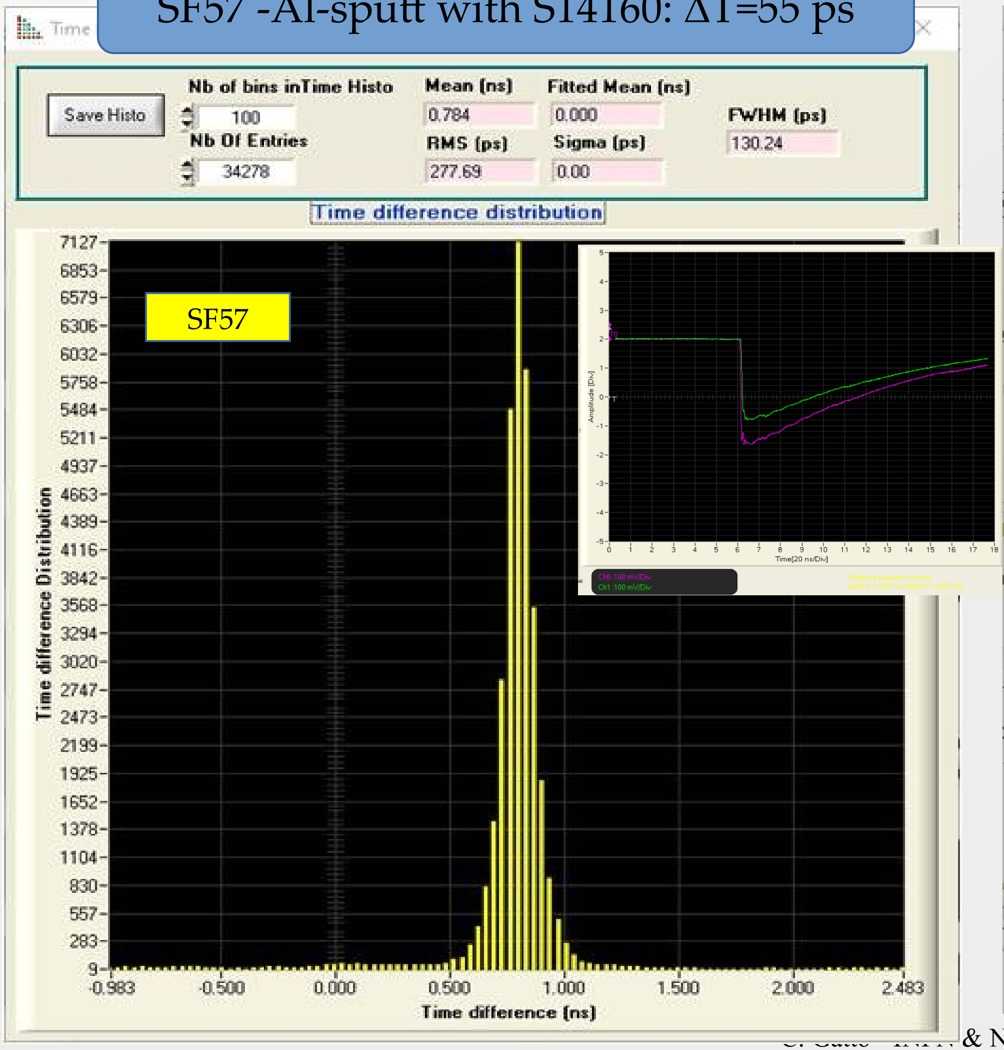


$BaSO_4$
Risetime > 7 ns

ΔT measurement

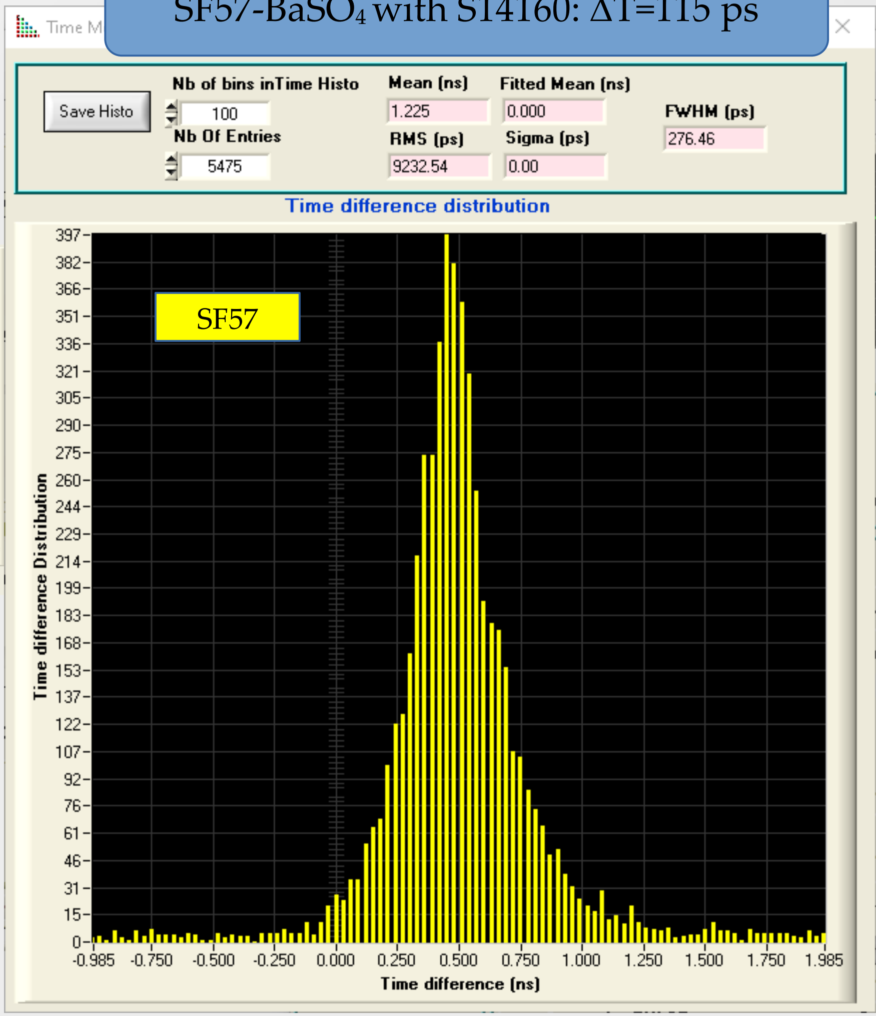
Time difference between two waveforms from 2 cells determined with a CF discriminator

SF57 -Al-sputt with S14160: ΔT=55 ps



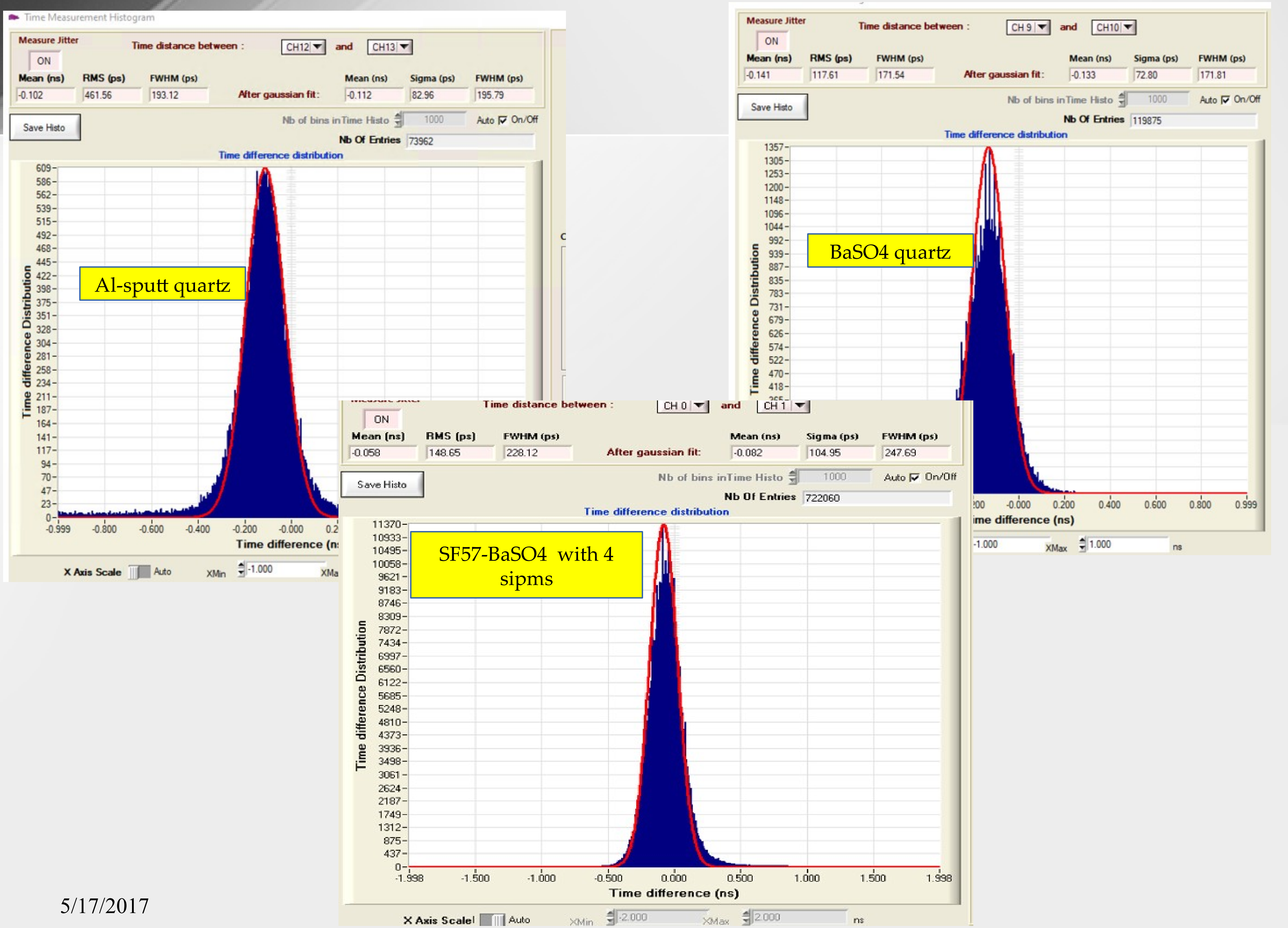
Nb of bins inTime Histo: 100
Nb Of Entries: 34278
Mean (ns): 0.784
RMS (ps): 277.69
Fitted Mean (ns): 0.000
Sigma (ps): 0.00
FWHM (ps): 130.24

SF57-BaSO$_4$ with S14160: ΔT=115 ps



Nb of bins inTime Histo: 100
Nb Of Entries: 5475
Mean (ns): 1.225
RMS (ps): 9232.54
Fitted Mean (ns): 0.000
Sigma (ps): 0.00
FWHM (ps): 276.46

More ΔT measuremens



Al-sputt quartz

Time distance between : CH12 and CH13

Mean (ns)	RMS (ps)	FWHM (ps)	After gaussian fit:	Mean (ns)	Sigma (ps)	FWHM (ps)
-0.102	461.56	193.12		-0.112	82.96	195.79

Nb of bins in Time Histo: 1000

Nb Of Entries: 73962

XMin: -1.000

BaSO4 quartz

Time distance between : CH 9 and CH10

Mean (ns)	RMS (ps)	FWHM (ps)	After gaussian fit:	Mean (ns)	Sigma (ps)	FWHM (ps)
-0.141	117.61	171.54		-0.133	72.80	171.81

Nb of bins in Time Histo: 1000

Nb Of Entries: 119875

-1.000 XMax 1.000 ns

SF57-BaSO4 with 4 sipms

Time distance between : CH 0 and CH 1

Mean (ns)	RMS (ps)	FWHM (ps)	After gaussian fit:	Mean (ns)	Sigma (ps)	FWHM (ps)
-0.058	148.65	228.12		-0.082	104.95	247.69

Nb of bins in Time Histo: 1000

Nb Of Entries: 722060

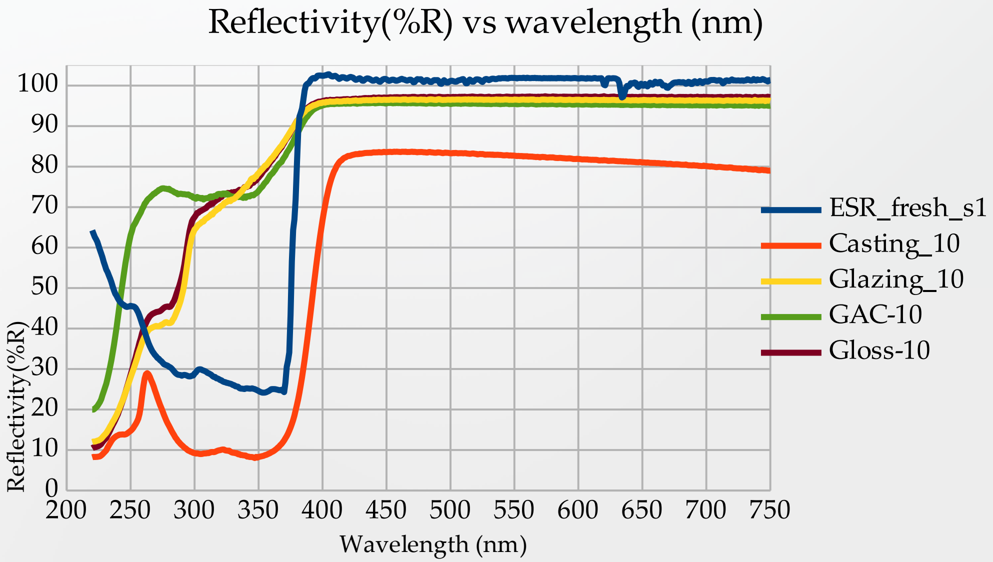
XMin -2.000 XMax 2.000 ns

Some Observations on Timing Resolution of Various Tiles

- Metal-coated tiles have consistently a timing resolution ~60-80/√2 psec
- Diffuse-coated tiles have consistently a timing resolution ~110-200/√2 psec
- Four-sensor tiles and quartz tiles with diffuse coating time resolution: ~100/√2 psec.
- Signals with ESR2000 and Aluminized Mylar have slow components and are unsuitable for fast timing measurements.

Large-tile ADRIANO2 with Diffuse Coatings

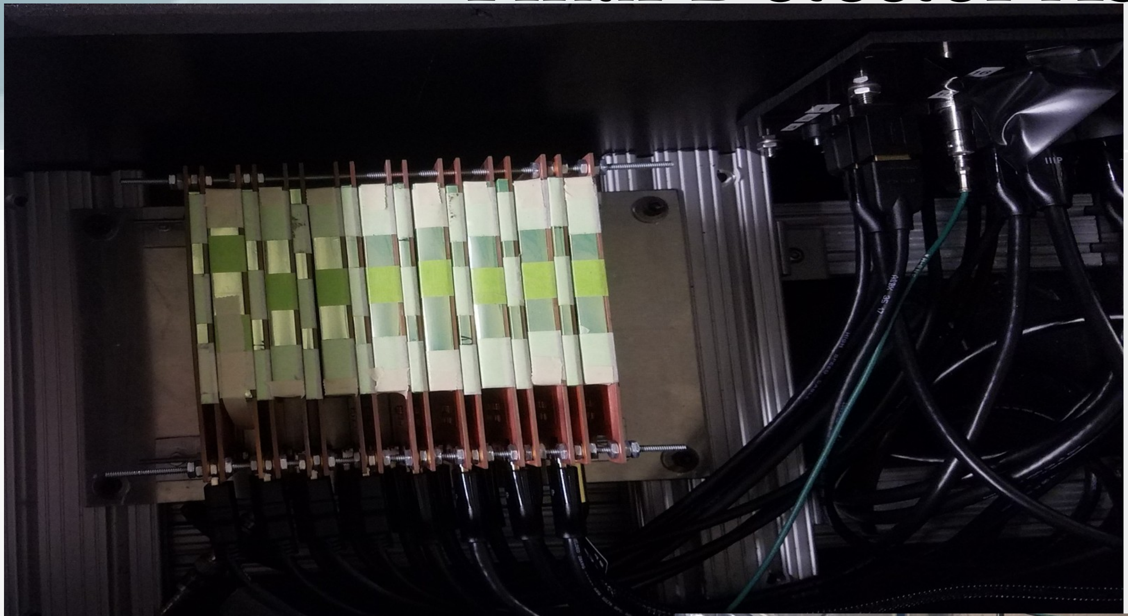
ESR-2000 &Barium sulfate paint
(in oil & water-based binders)



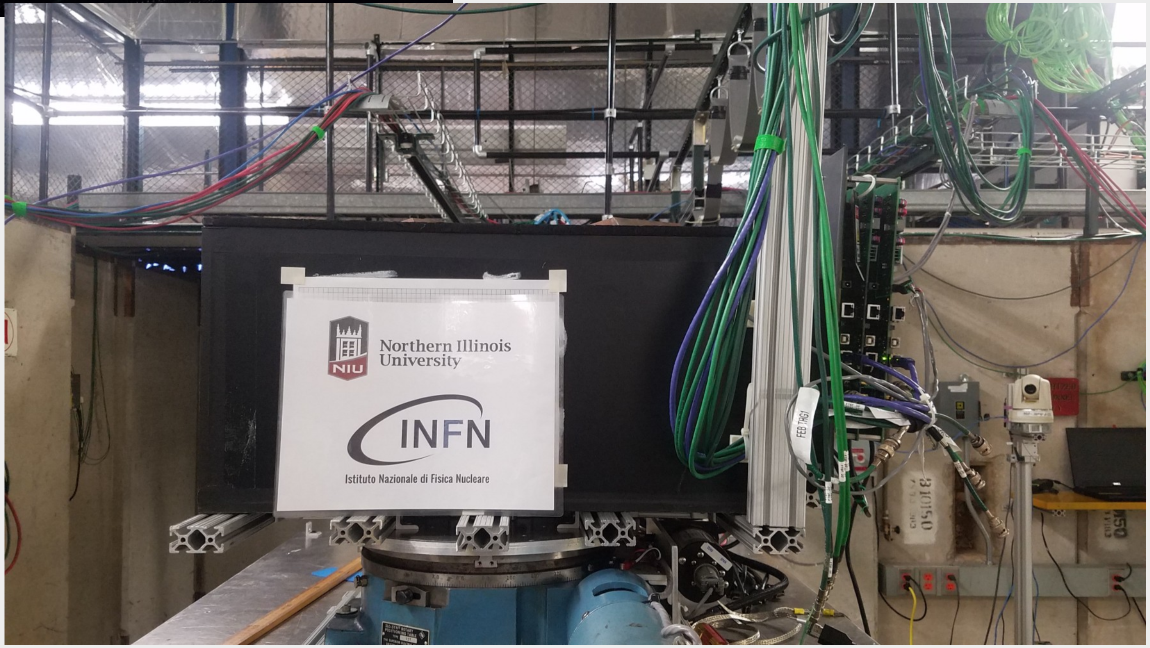
ADRIANO2 large tile

- Four on-tile Sipm's (1.3x1.3 cm^2) in polished dimples
- FEE on tile
- No time measurement

Final Detector Assembly



- 8 glass + 8 plastic tiles
- Total 64 channel
- FEB readout (mu2e)

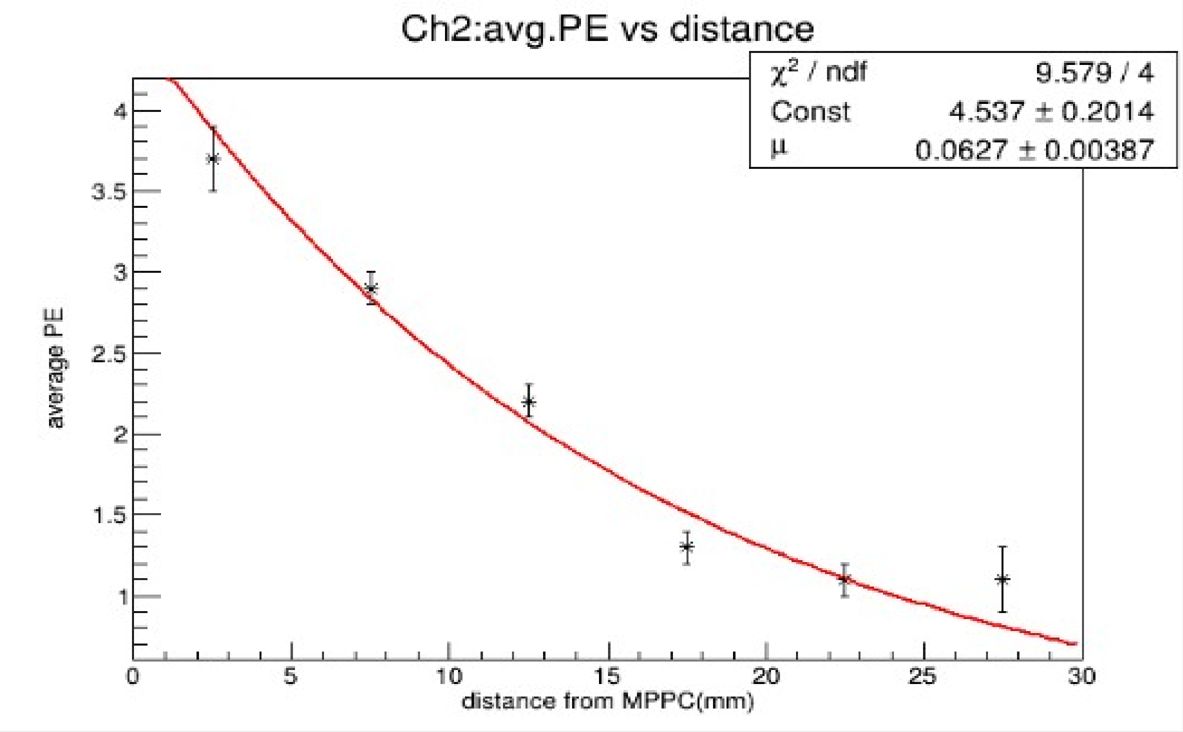


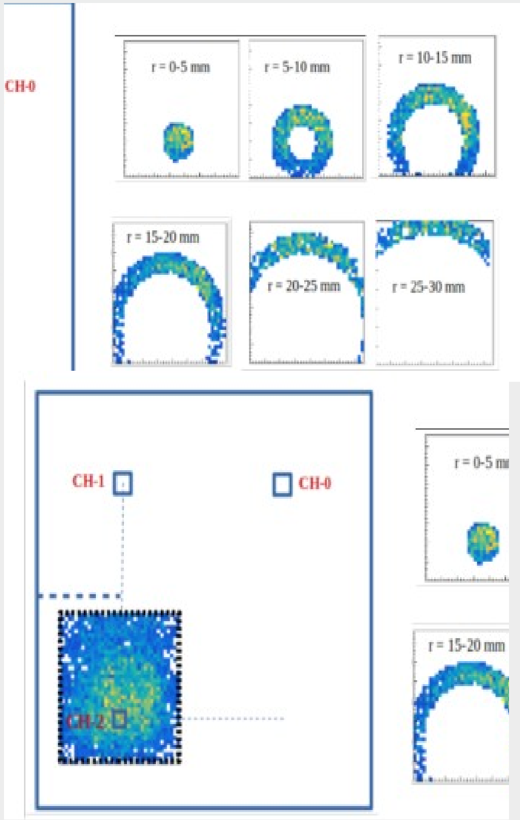
January 2020 Test Beam at Fermilab

Position Analysis

Data Analysis: <pe> vs distance(mm) of slices

$f(x) = 4.5e^{-0.06x}$, which gives 1/e of initial value at x = 1/0.06 =16.67mm





Summary

- Intense R&D is in progress within T1604 to exploit High-granularity, PFA+dual-readout calorimetry
- R&D is well funded and benefits by the participation in CALICE Collaboration: first phase will conclude in about 1 year
- Many configuration tested: Cerenkov light in Pb-glass tiles shows peculiarities not found in traditional large blcks
- Picture for ADRIANO2 response is becoming more clear while the analysis progresses
- Two methodologies stand above the others: metallic ALD and multi-sensors $BaSO_4$. More studies are needed to confirm uniformity of response and efficiency
- One more test beam of a larger prototype with 4x4 tiles/layer. Total layers=4.
- ASIC readout will also indicate viability of the technique for large calorimeters

Backup Slides

Foreseable Applications

REDTOP

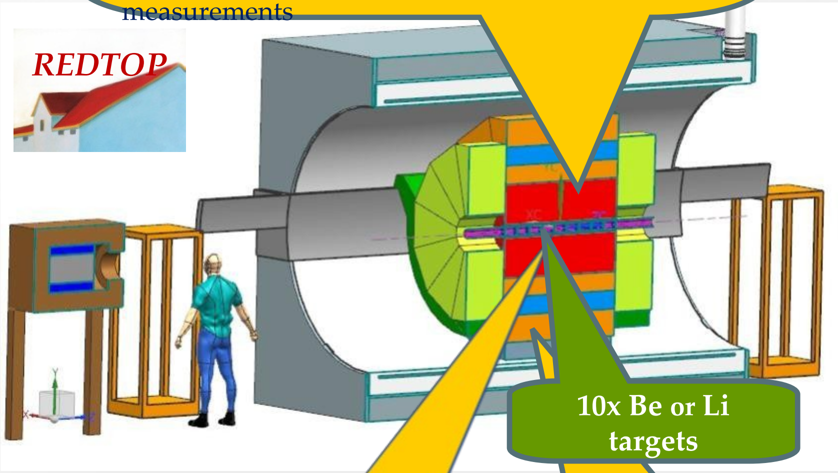
Optical-TPC

For slow background rejection

or

LGAD Tracker surrounded by Quartz cells

For 4D track reconstruction and TOF measurements

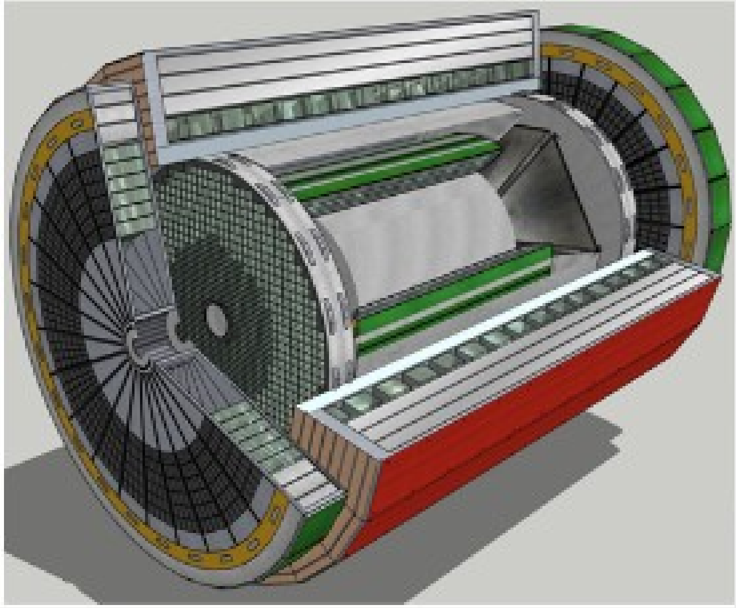


10x Be or Li targets

Vertex Fiber tracker
for rejection of γ-conversion and identifying displaced vertices from long lived particles

5D- Calorimeter: ADRIANO2
(Dual-readout +PFA)
Sci and Cer light read by SiPM or SPAD
For excellent energy , position resolution and PID

EIC (Photon Project)



Pulse Shape and Input Impedance for the 4xSiPM Board

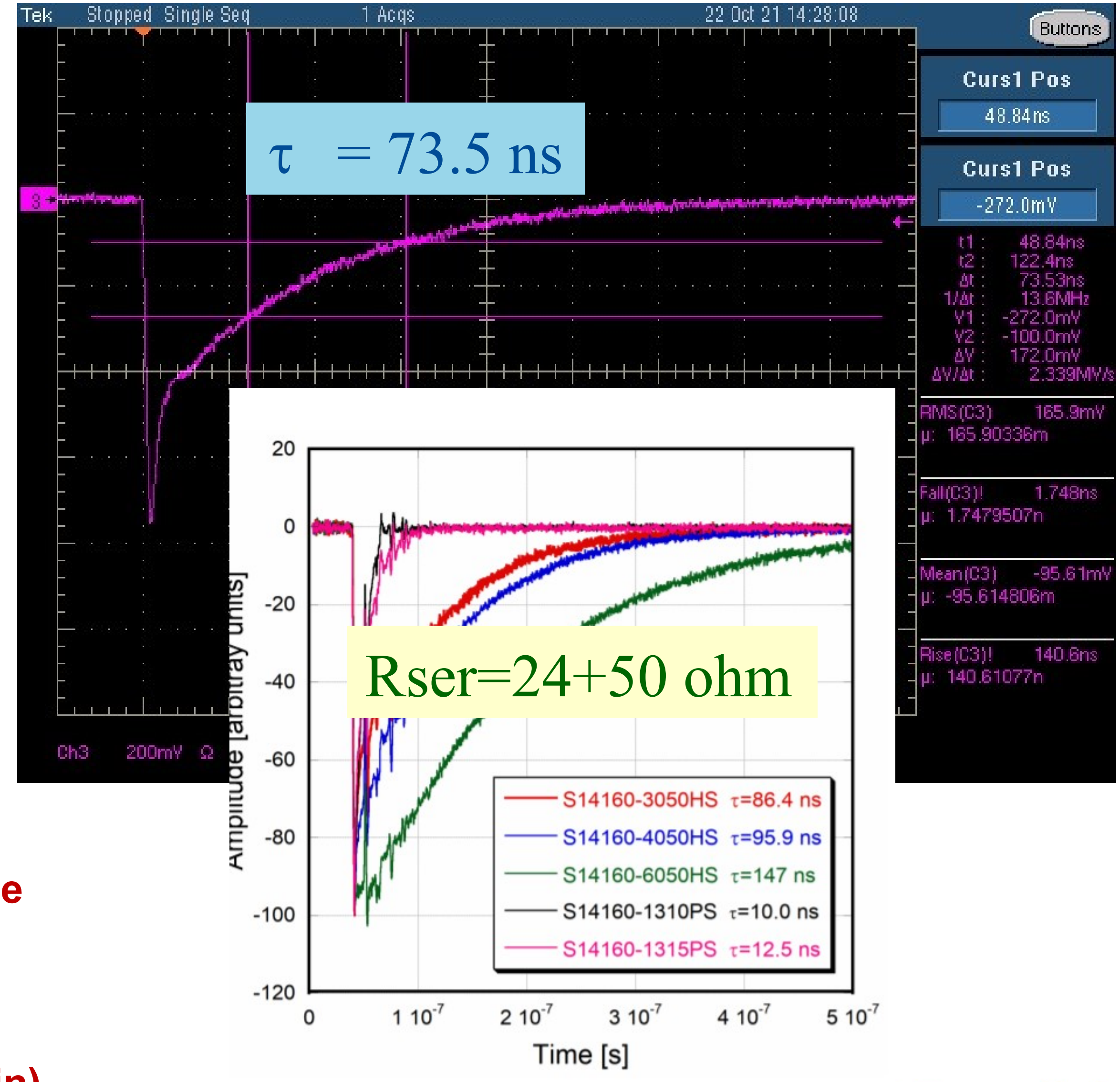
- Signal decay time constant
  - 73.5ns
- SiPM terminal capacitance
  - 2nf
- Total series resistance
  - 37ohm

- SiPM series resistance
  - (74 – 50) = 24ohm

- **Amplifier input impedance**
  - **(37-24) = 13 ohm**

- **Common base input impedance**
  - **25mV/2.3mA = 11ohm + rbb**

- **Buffer transistor gain (total gain)**
  - **36/13 = x2.8 (x25)**



τ = 73.5 ns

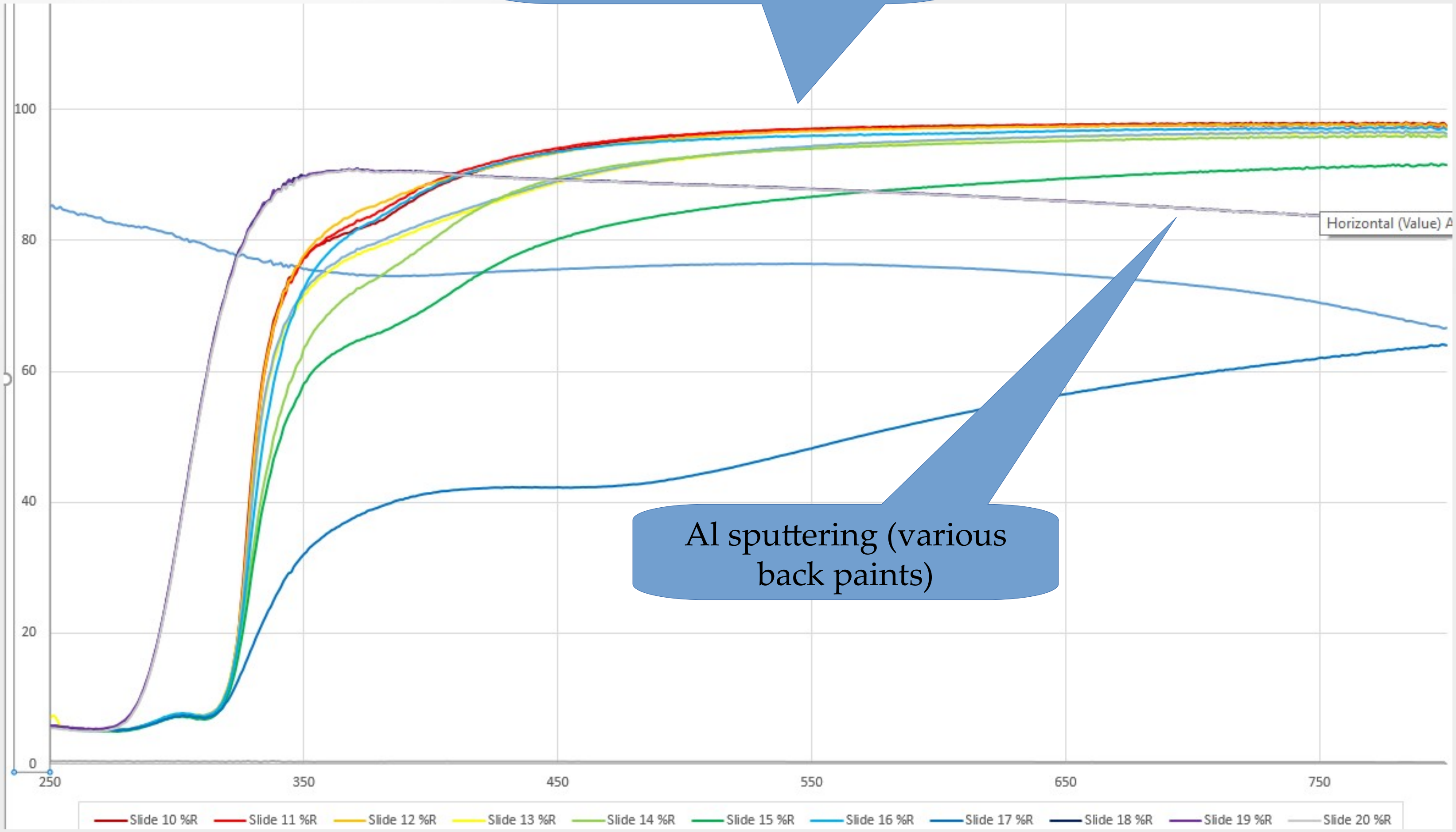
Rser=24+50 ohm

```
Tek   Stopped Single Seq        1 Acqs            22 Oct 21 14:28:08

Curs1 Pos
48.84ns
Curs1 Pos
-272.0mV

    t1 :    48.84ns
    t2 :    122.4ns
    Δt :    73.53ns
  1/Δt :    13.6MHz
    V1 :   -272.0mV
    V2 :   -100.0mV
    ΔV :    172.0mV
 ΔV/Δt :  2.339MV/s

RMS(C3)      165.9mV
μ:  165.90336m

Fall(C3)!    1.748ns
μ:  1.7479507n

Mean(C3)     -95.61mV
μ:  -95.614806m

Rise(C3)!    140.6ns
μ:  140.61077n

Ch3    200mV   Ω
```

New Sipm Control Board (S. Los -Fermilab)

- 4 independent channels
- USB operated
- Temperature and current readout

Ag and Al Reflectivity

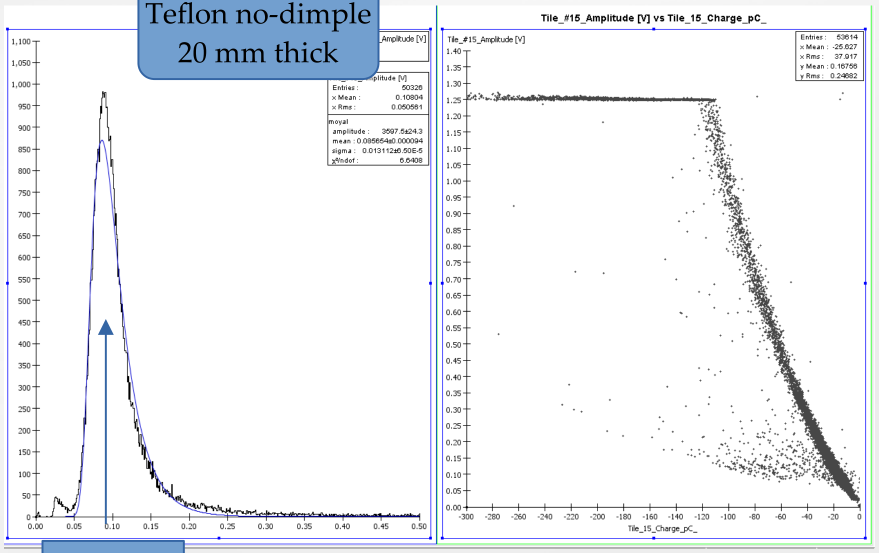


Chemical Ag on borosilicate (various thichnesses)

Al sputtering (various back paints)

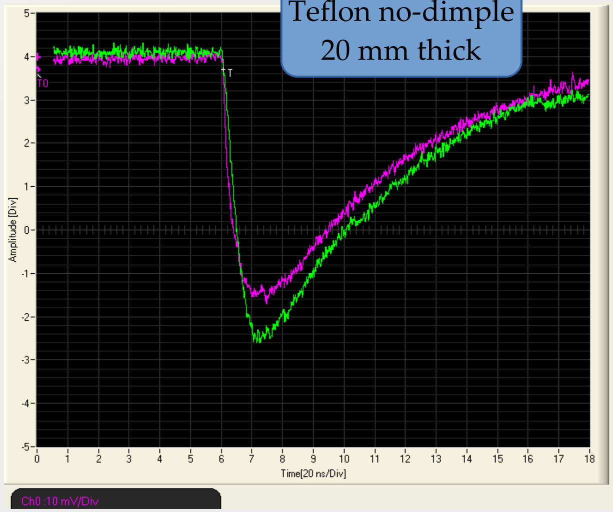
MIP Amplitude Analysis (Wavecatcher)

Diffuse coating

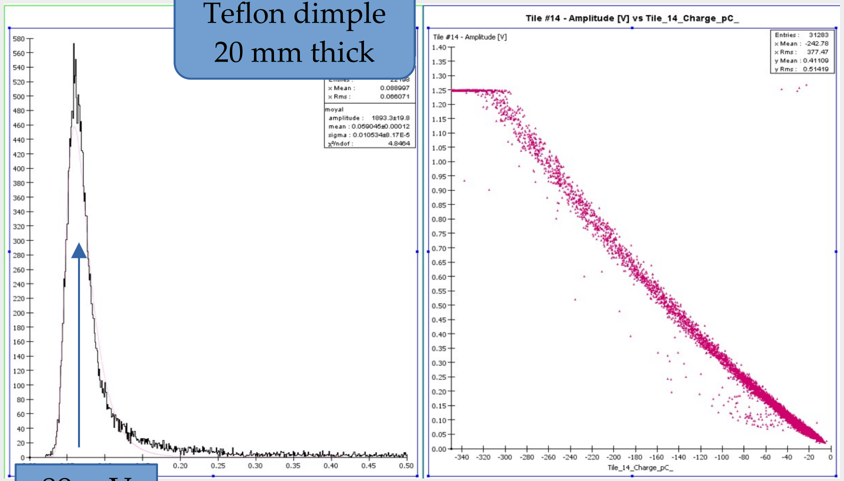


Teflon no-dimple
20 mm thick

86 mV

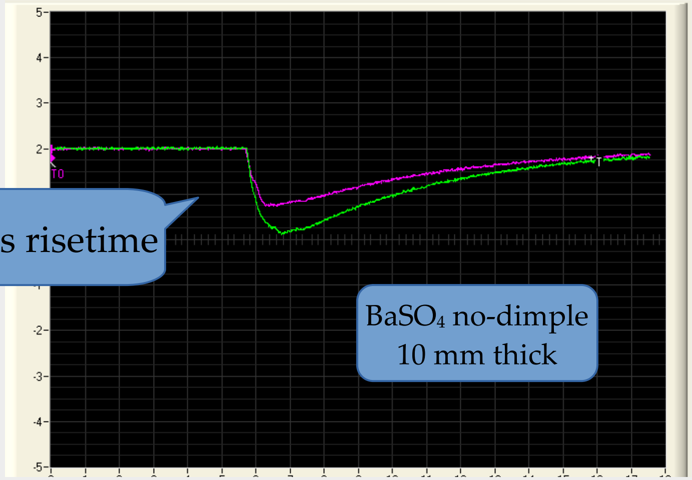


Teflon no-dimple
20 mm thick



Teflon dimple
20 mm thick

89 mV

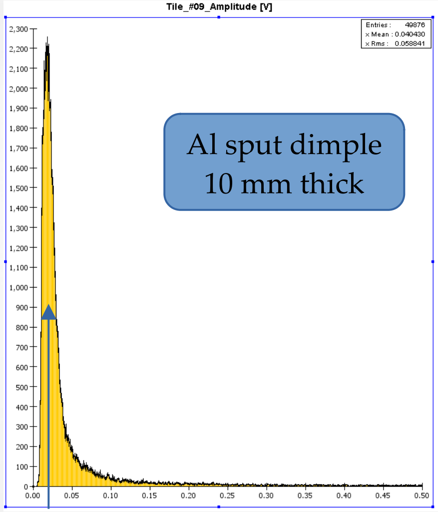


~8 ns risetime

BaSO$_4$ no-dimple
10 mm thick

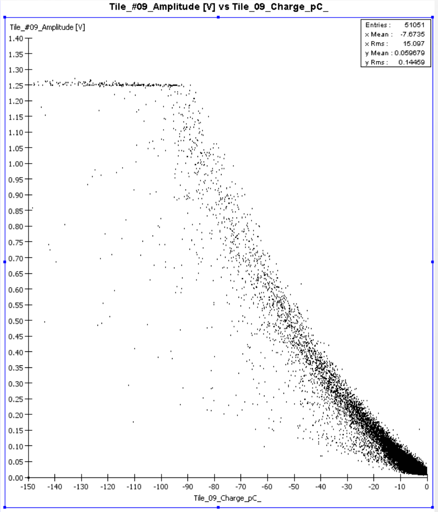
MIP Amplitude Analysis (Wavecatcher)

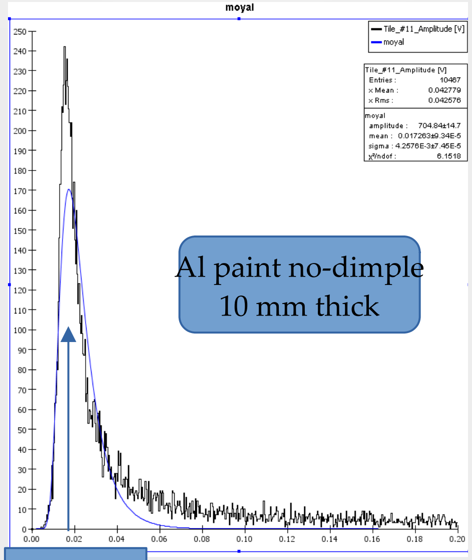
Mirror coating



Al sput dimple
10 mm thick

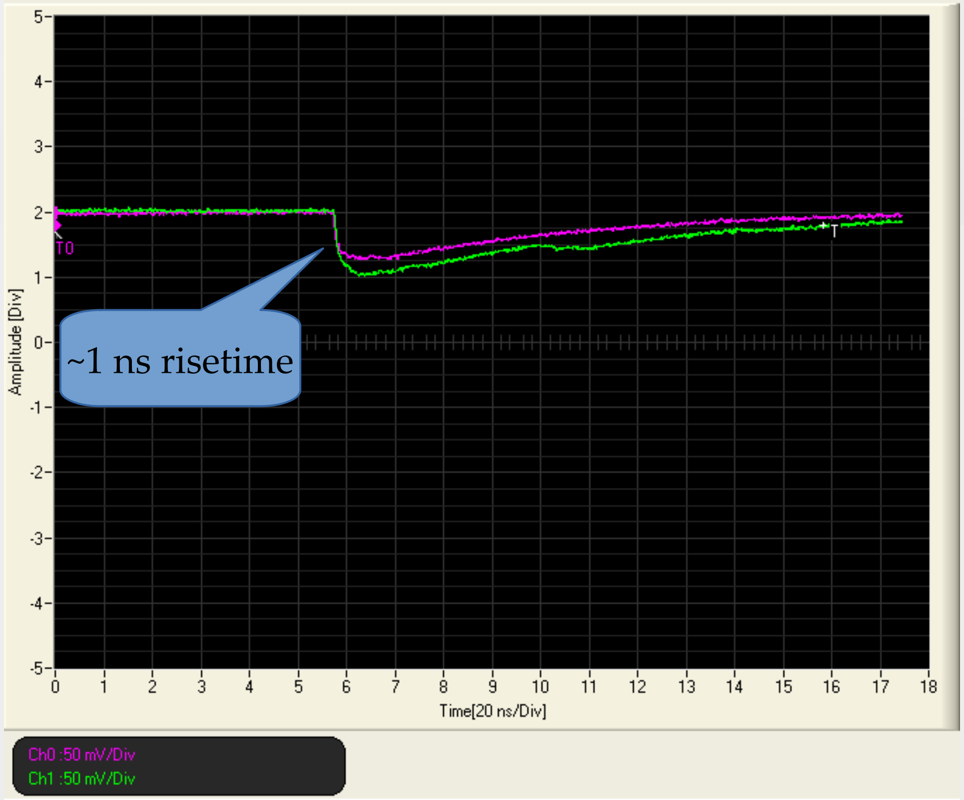
21 mV





Al paint no-dimple
10 mm thick

17 mV



~1 ns risetime