Development of a detection system to measure low levels of ^{210}Pb using β/γ coincidence

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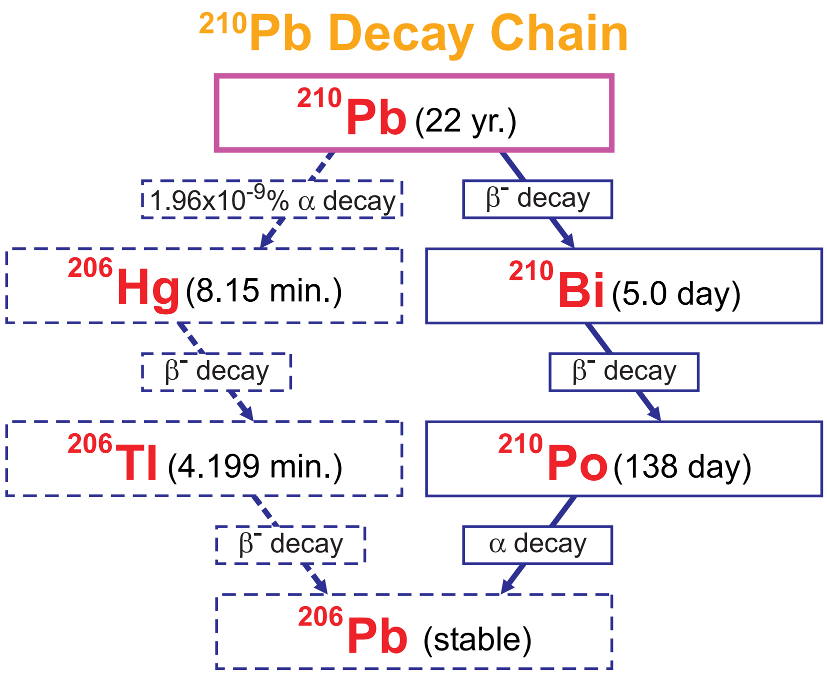
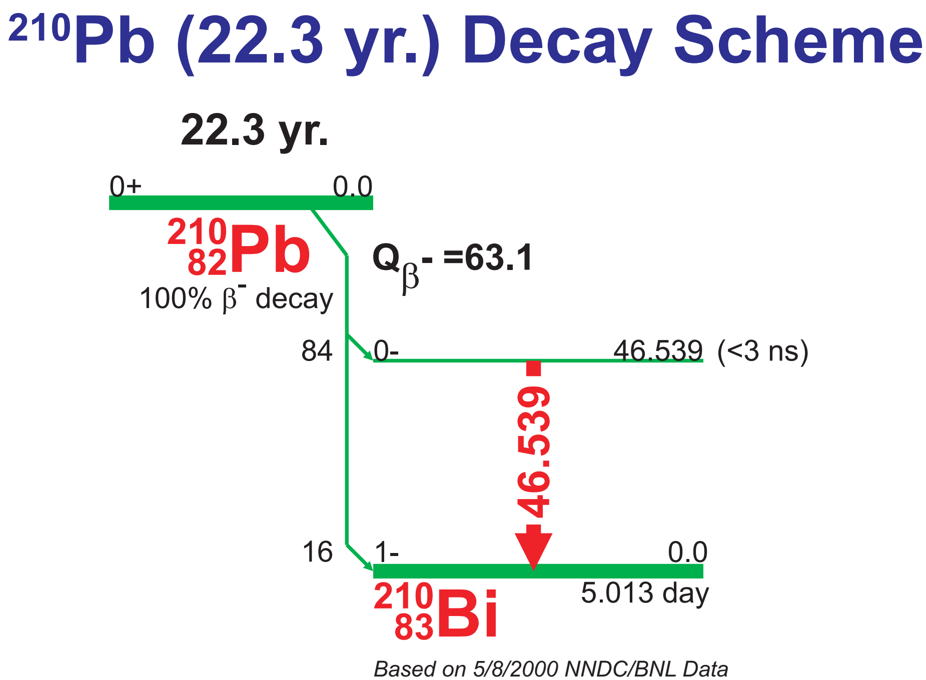
^{210}Pb





Established measurement methods:

- alpha spectroscopy (^{210}Po) – long buildup time, radiochemistry
- beta counting (^{210}Bi) – large background, radiochemistry
- gamma spectroscopy (^{210}Pb) – large background

^{210}Pb in acrylic for DEAP-3600

- Background from residual radioactivity in bulk acrylic from Uranium and Thorium chains.
- Specified limits for ^{210}Pb content in bulk acrylic [B. Cai, 2011]:

  <u>~ 4.7x10^{-7} ppt = 1.33 mBq/kg acrylic (=115 d^{-1}kg^{-1})</u>

- Typical detection limits (sample typically < 5 g):
  - Alpha spectrometry (^{210}Po): 0.1 – 1 mBq/sample
  - Beta counting (^{210}Bi): ~10 mBq/sample
  - Gamma spectrometry (^{210}Pb): 100 – 400 mBq/sample
- Volume reduction of acrylic sample
  - done by vaporization and incineration at Queen's University / SNOLAB (C. Nantais)
    → liquid acid sample matrix with expected 10^{3}-10^{4} reduction in volume

^{210}Pb determination by coincidence measurement

- For low detection limits, low background required: coincidence methods are advantageous, however total efficiency is a critical issue
- ^{210}Pb β-decay: emission of coincident (<3ns) γ at low energy

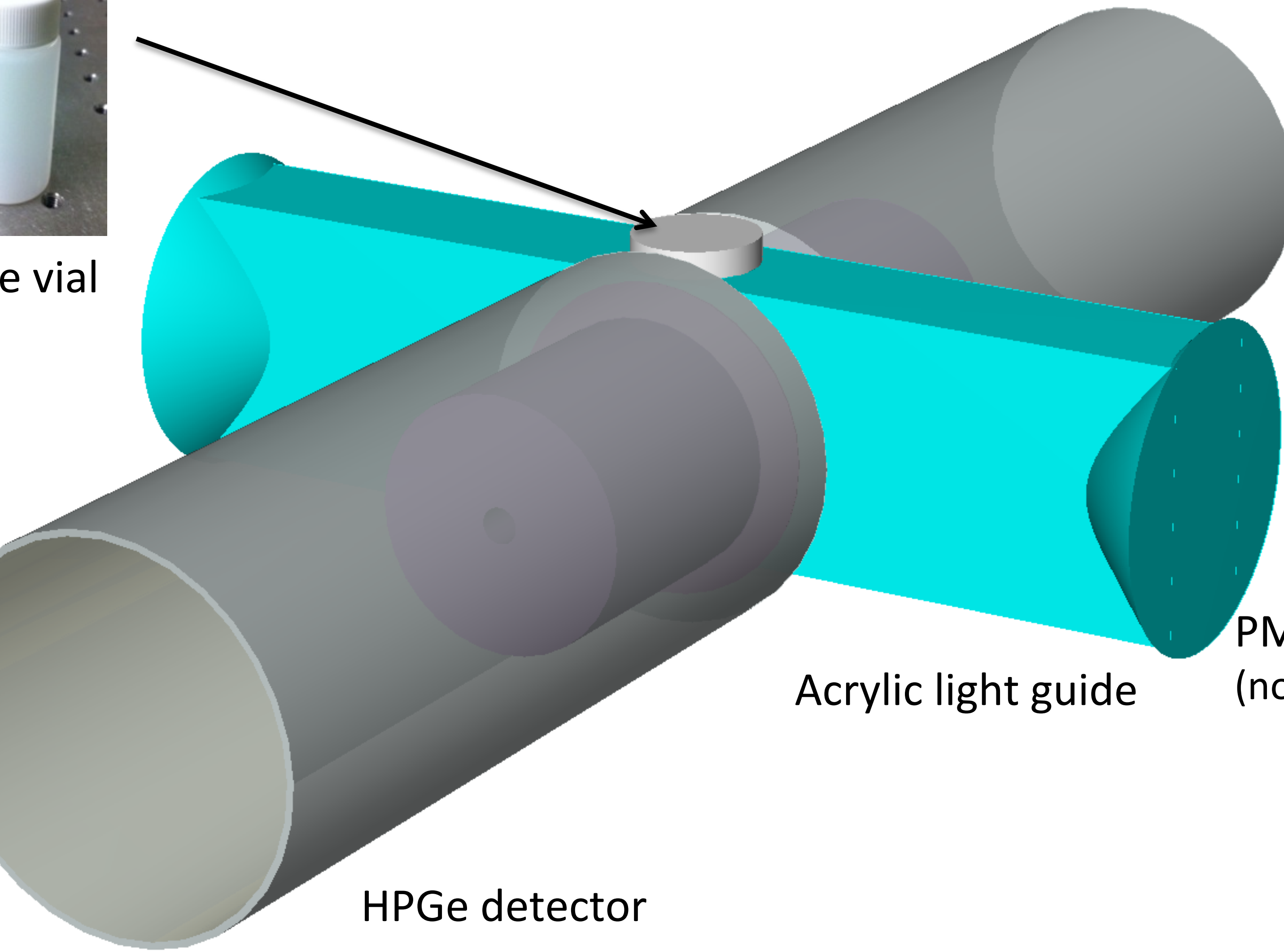
$$E_{\beta,max} = 17 \text{ keV } (I_\beta = 0.86)$$
$$E_\gamma = 46.5 \text{ keV } (I_\gamma = 0.04)$$

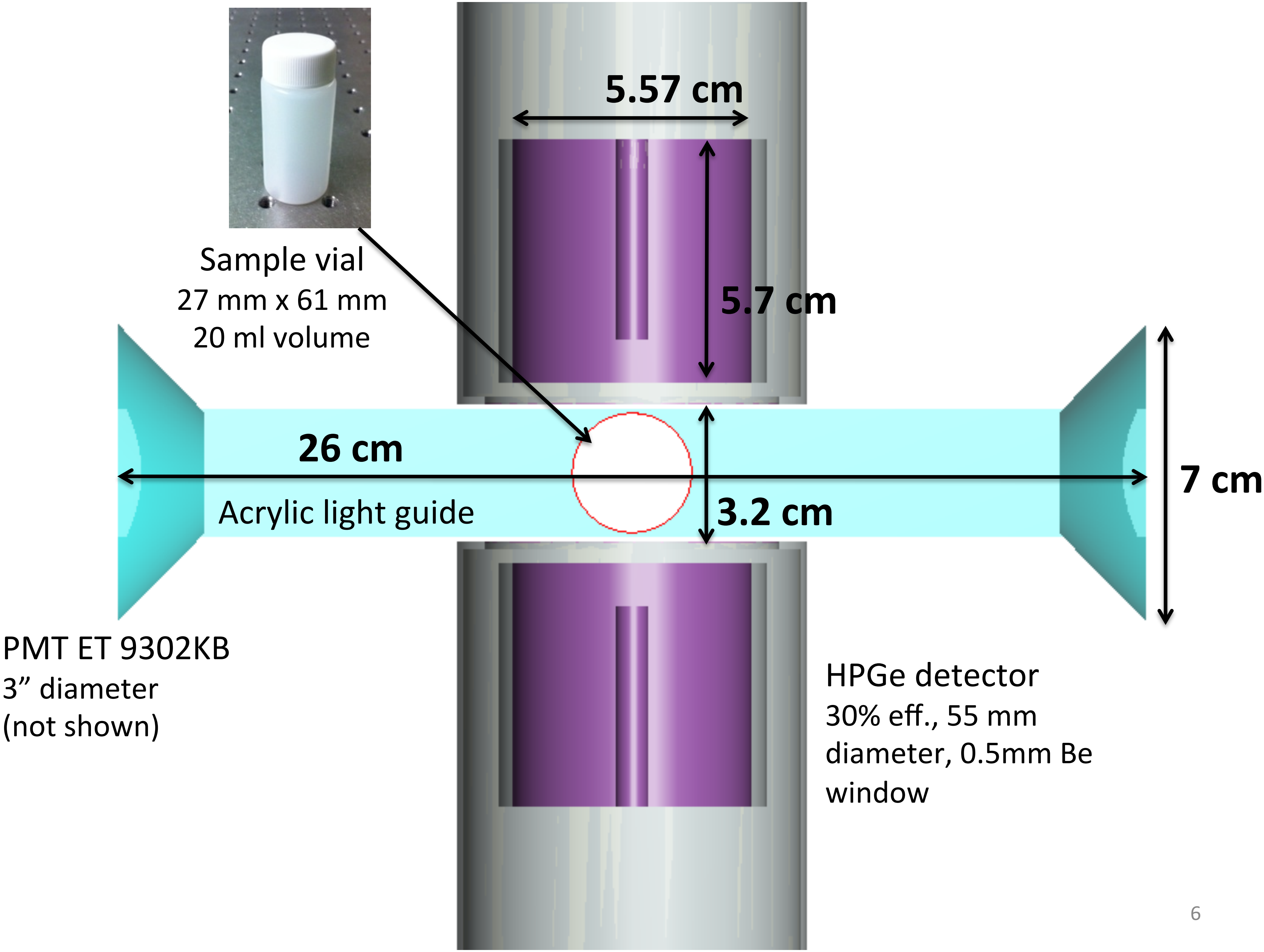
<u>Techniques:</u>

- *Beta*: Liquid scintillation counting, sample immersed into liquid scintillator; light detection by PMT
- *Gamma*: Low-energy sensitive HPGe detector

Measurement setup

Sample vial




5.57 cm
Sample vial
27 mm x 61 mm
20 ml volume
5.7 cm
26 cm
7 cm
Acrylic light guide
3.2 cm
PMT ET 9302KB
3” diameter
(not shown)
HPGe detector
30% eff., 55 mm
diameter, 0.5mm Be
window

Expected performance

- Efficiencies:
  - Double HPGe: 28 % at 46.5 keV peak (simple estimate)
  - Liquid scintillation: ~ 30% (literature)

  → Combined abs. efficiency: 0.3 %
- Background:
  - HPGe: measured ~ 0.015 cps/keV (44-48 keV window)
  - PMT: estimated ~ 6 cps

  → Combined (t_{coinc}=50ns): 1.8E-9 cps (= 0.000155 cpd)*
- Expected signal:
  - 0.259 cpd for 1 mBq/sample

*only chance coincidences …

Samples

- Calibration source: ^{210}Pb (523 +/- 6 Bq)
- Background sample: HNO_3
- Acrylic sample: HNO_3 + remainder from VapID 25
- Pure scintillator -

+ liquid scintillator: Ultima Gold uLLT (PPO / bis-MSB)

BG Acrylic

at 22 °C

BG Acrylic

at ~ 10 °C

BG Acrylic

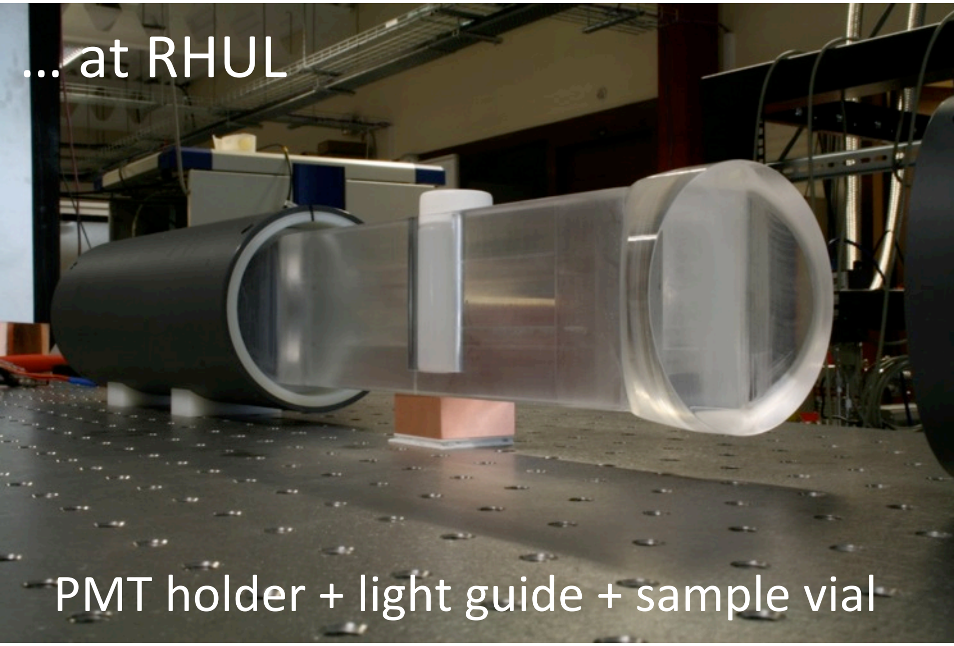
at ~ 15 °C
after 2 months and warm for unknown time

<u>Liquid Scintillator Selection</u>

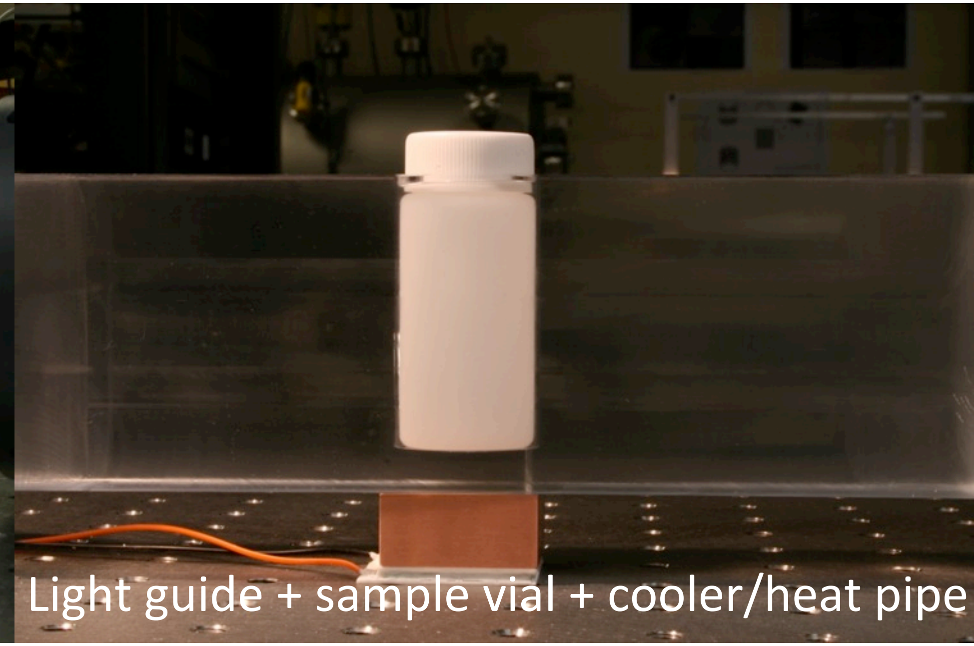
- Sample load and stability
- Quench resistance
- Efficiency
- Chemo + photoluminiscence

→ Cooling required

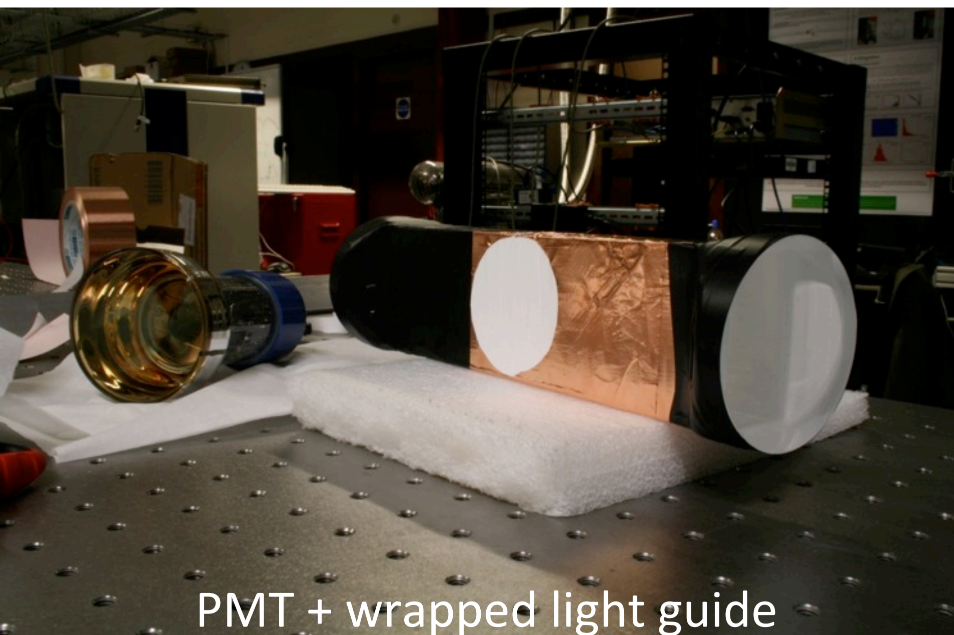
… at RHUL



PMT holder + light guide + sample vial



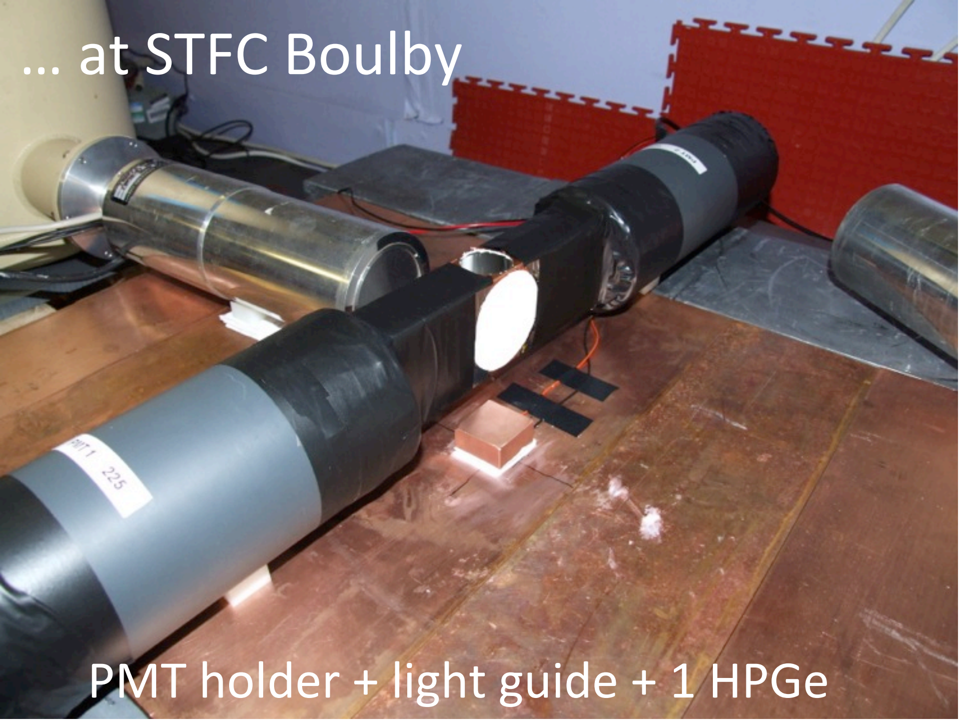
Light guide + sample vial + cooler/heat pipe

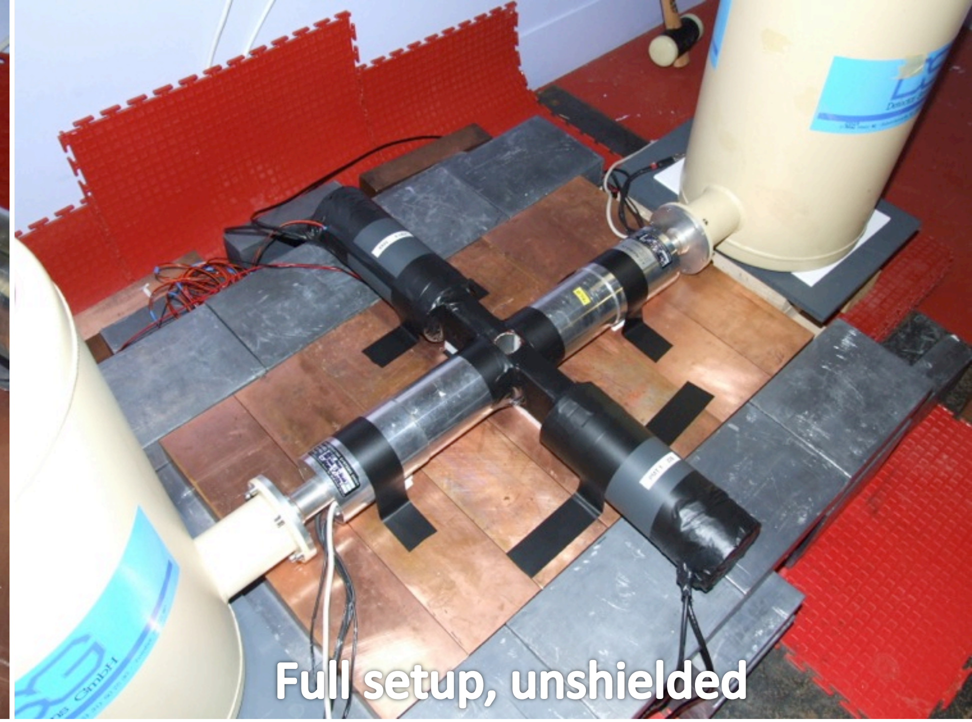


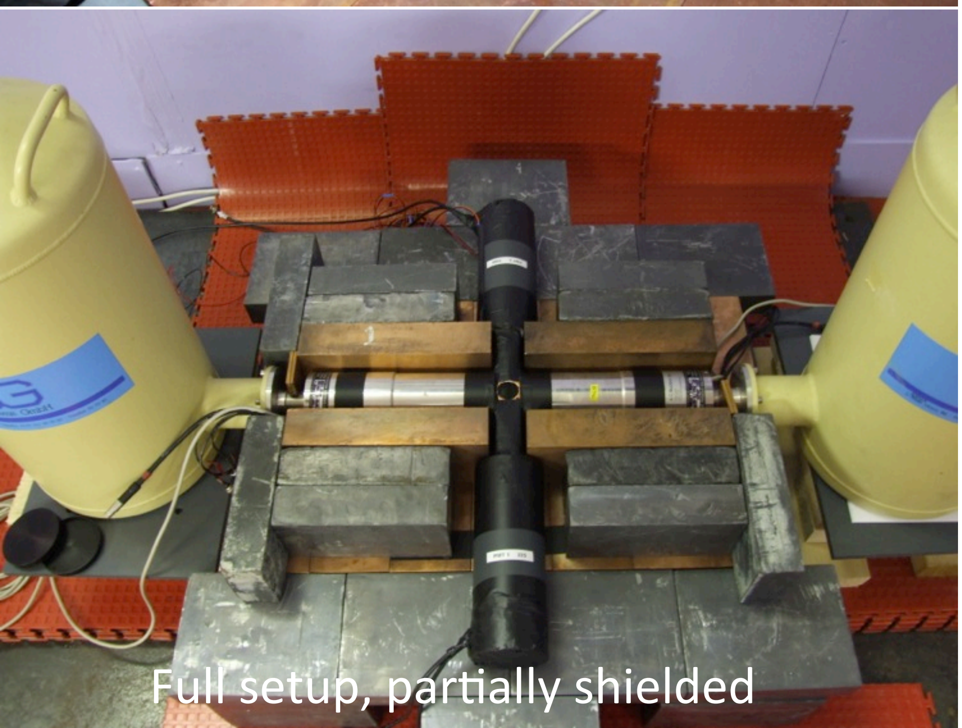
PMT + wrapped light guide

PMT ET 9302KB (w/o base)

… at STFC Boulby

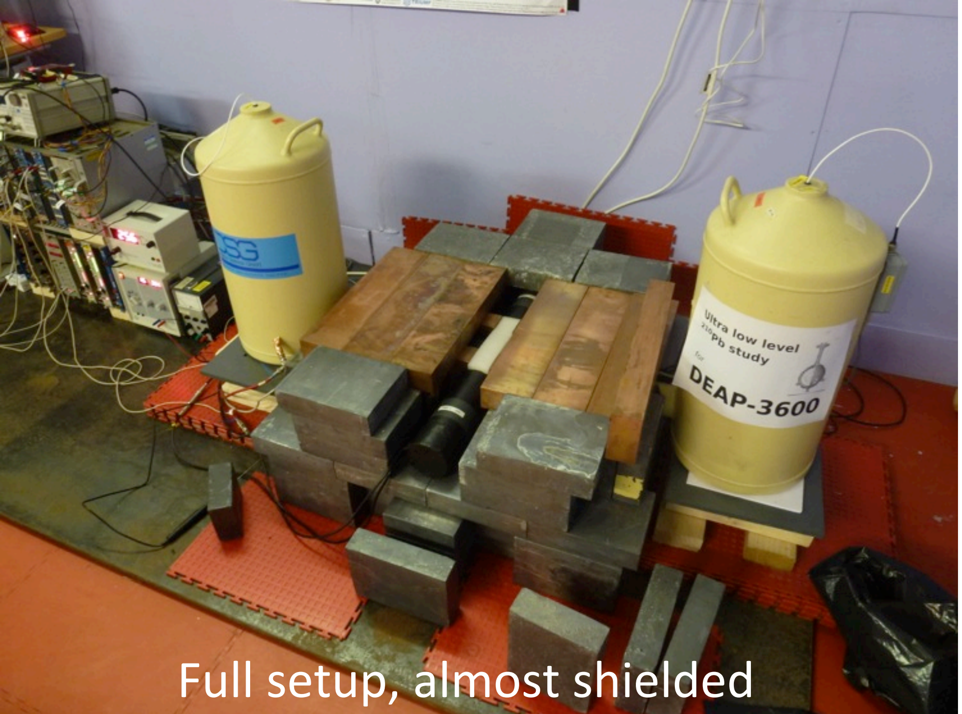






BOULBY UNDERGROUND LABORATORY

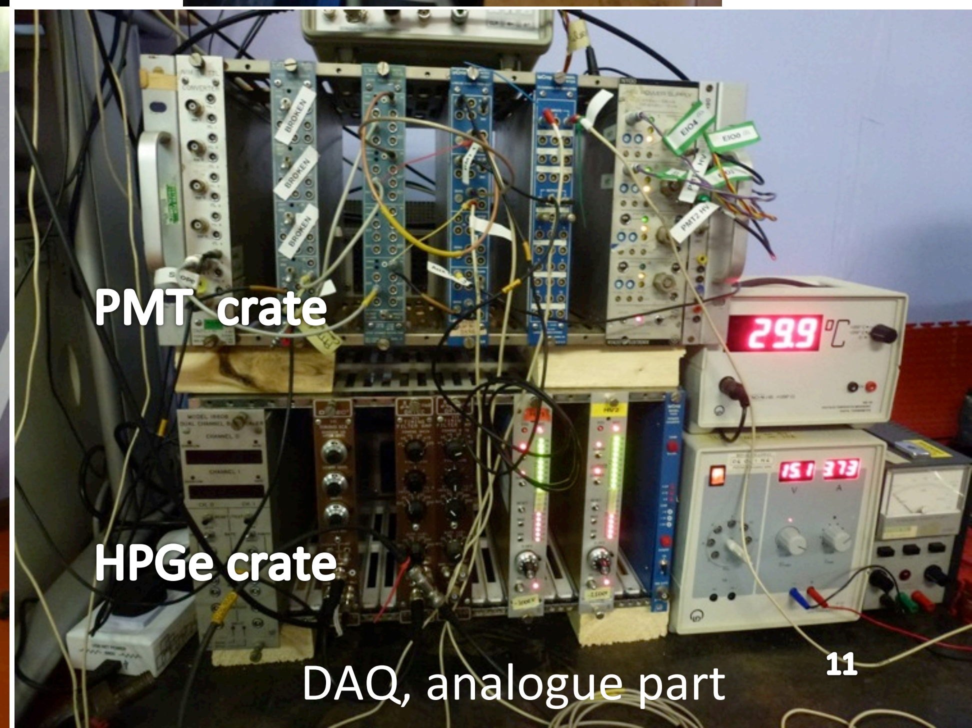
Cleveland Potash Ltd. – Boulby Mine
STFC Underground Laboratory
1100 m deep, 2800 m w.e.
Host to: ZEPLIN and DRIFT DM experiments



Full setup, almost shielded

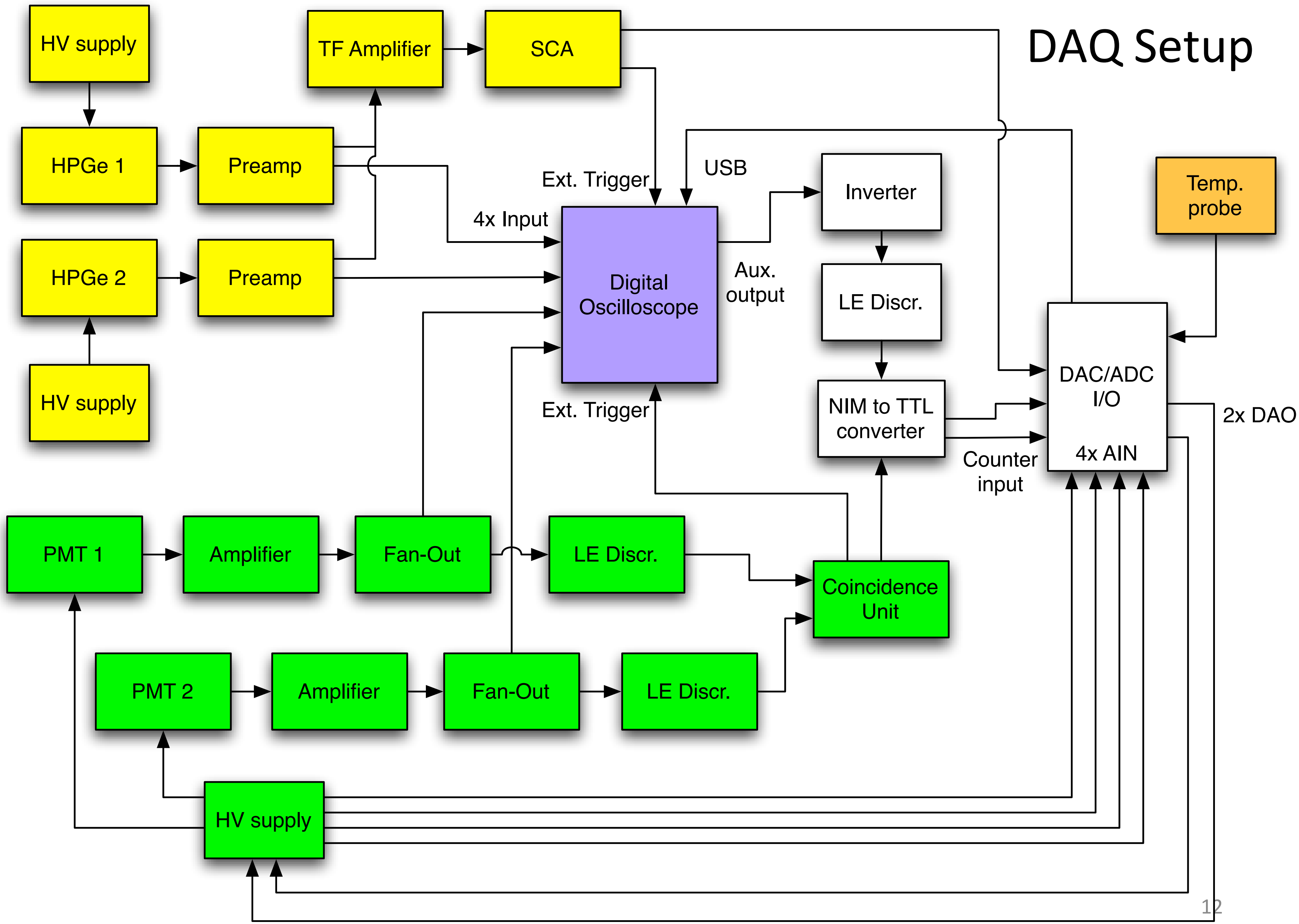

Sample placed

Full setup

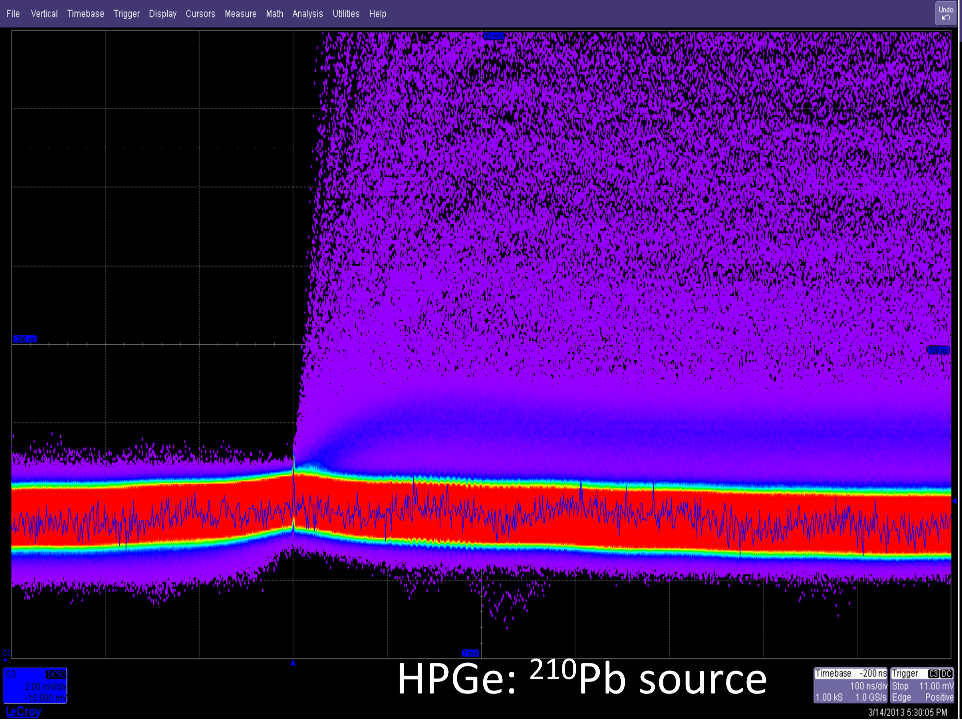


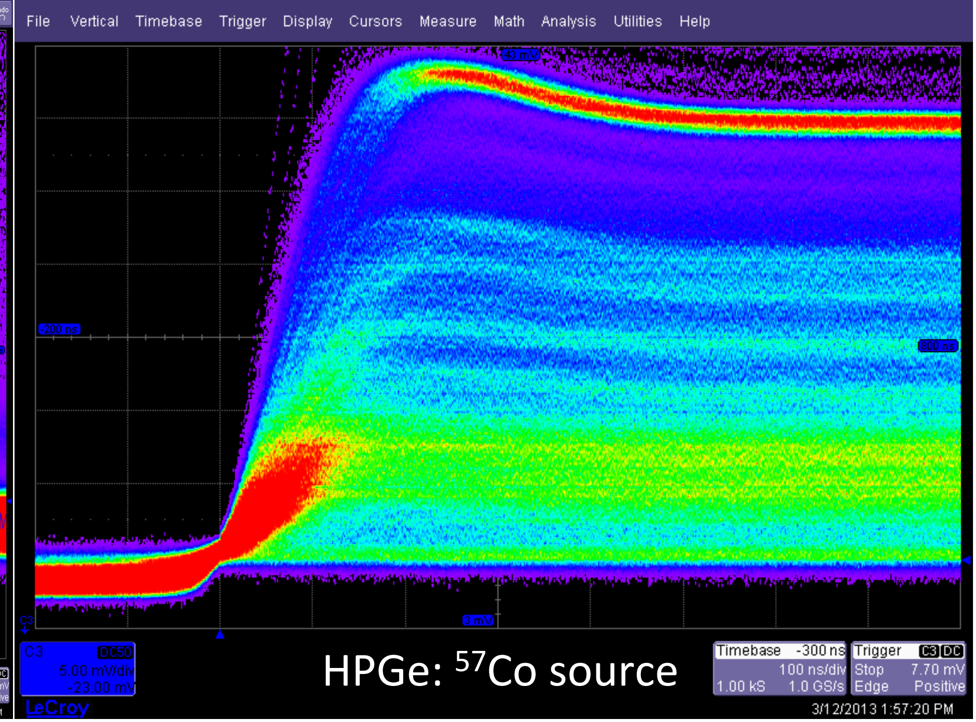
DAQ, analogue part

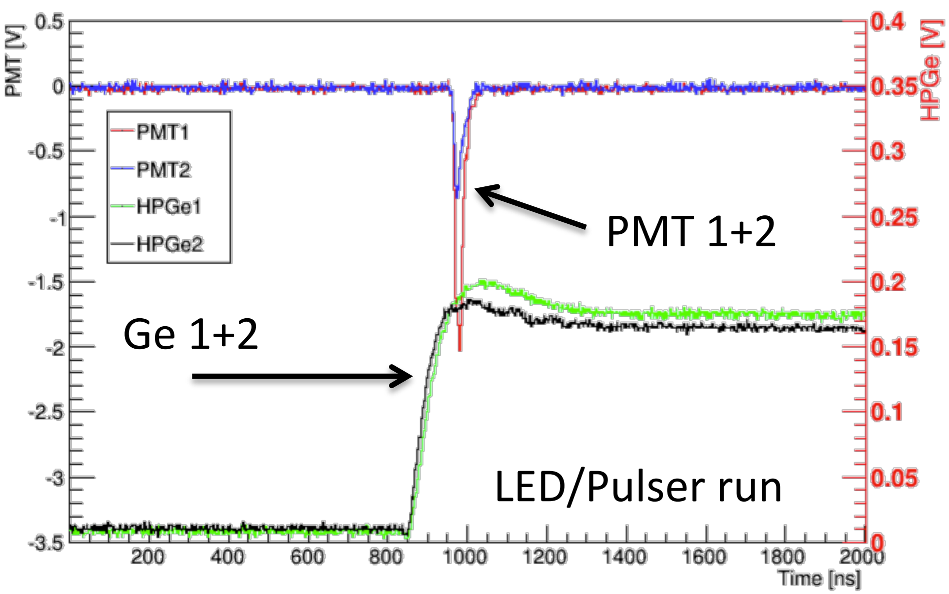
DAQ Setup



HV supply
TF Amplifier
SCA
HPGe 1
Preamp
HPGe 2
Preamp
HV supply
Ext. Trigger
USB
4x Input
Digital Oscilloscope
Aux. output
Inverter
LE Discr.
NIM to TTL converter
Temp. probe
DAC/ADC I/O
4x AIN
2x DAO
Counter input
Ext. Trigger
PMT 1
Amplifier
Fan-Out
LE Discr.
Coincidence Unit
PMT 2
Amplifier
Fan-Out
LE Discr.
HV supply







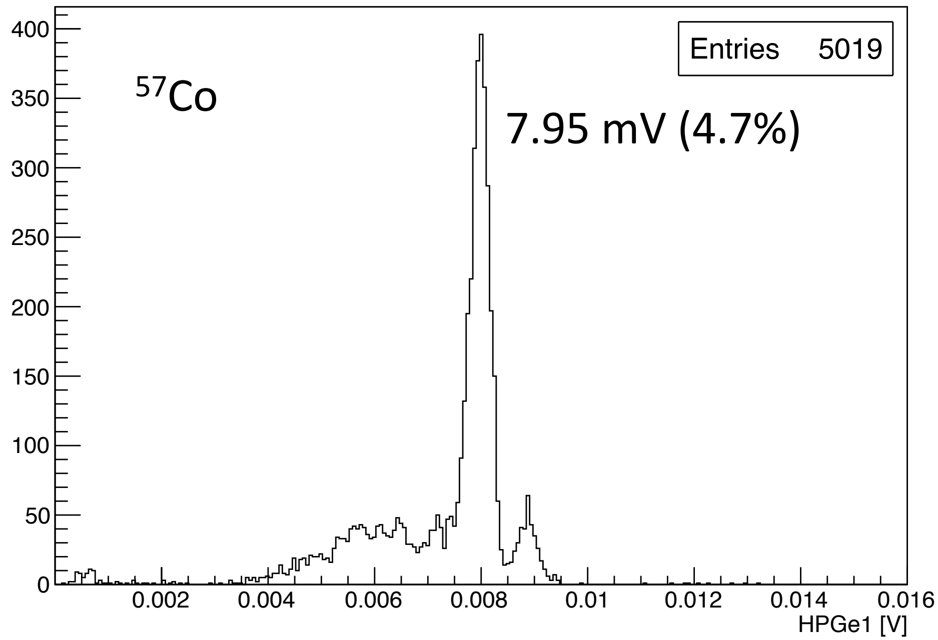
LeCroy waveSurfer Digital Oscilloscope

<u>Waveform acquisition</u>

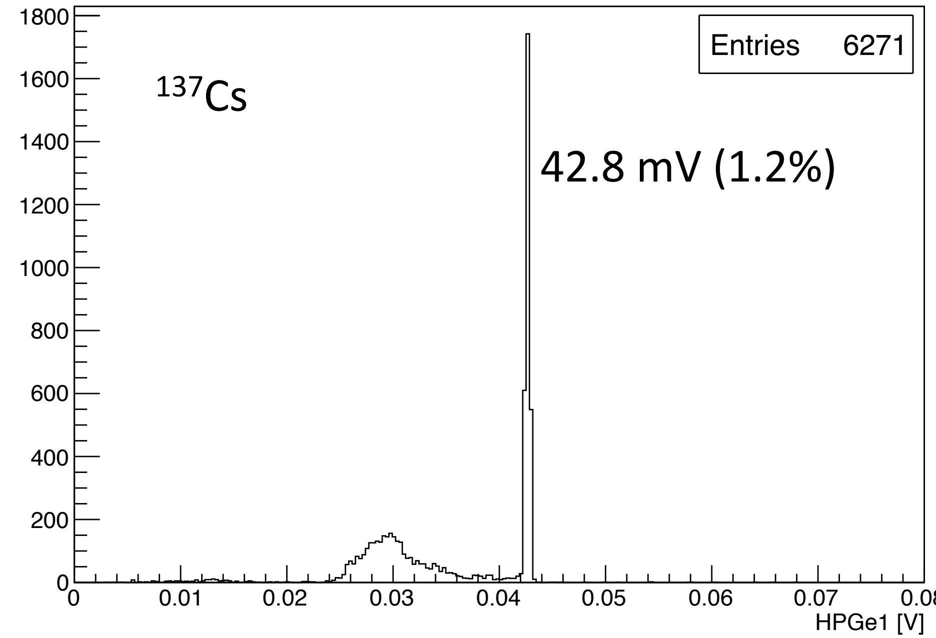
- Max. recording rate 10 Hz (4 channels)
- Trigger rate (BG): 0.6 Hz
- Classical troublemakers present: HF/LF noise, microphonics, etc.

<u>Data analysis</u>

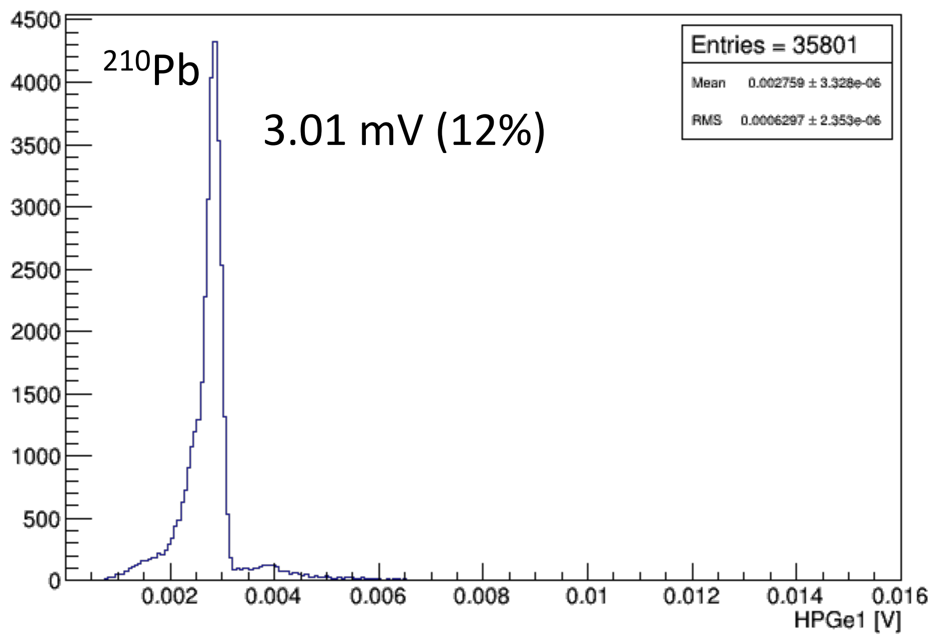
Based on ROOT analysis scripts for MIT NeutronVeto system



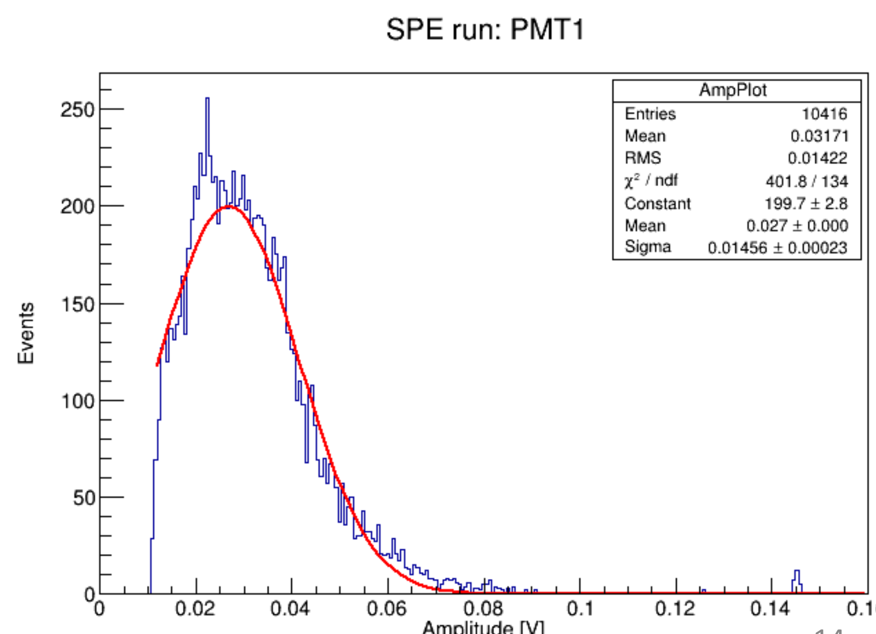
^{57}Co
7.95 mV (4.7%)
Entries 5019
HPGe1 [V]



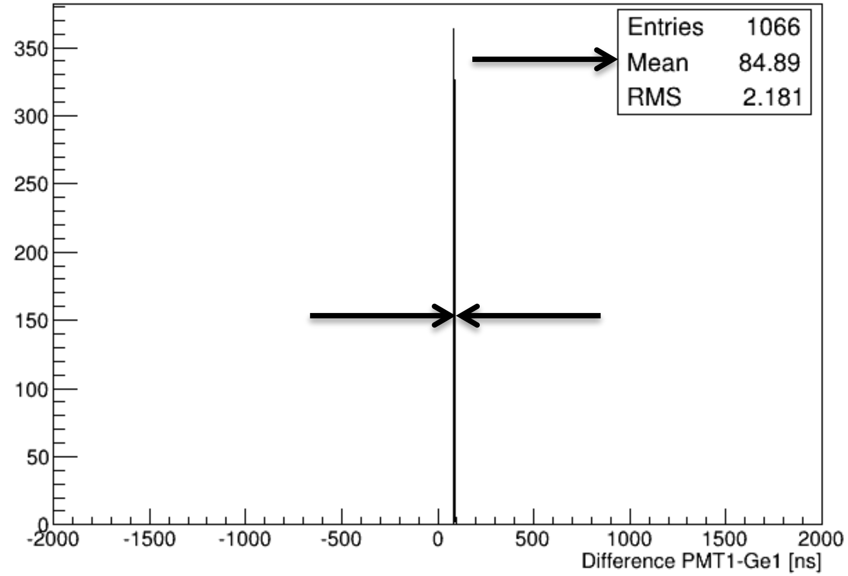
^{137}Cs
42.8 mV (1.2%)
Entries 6271
HPGe1 [V]



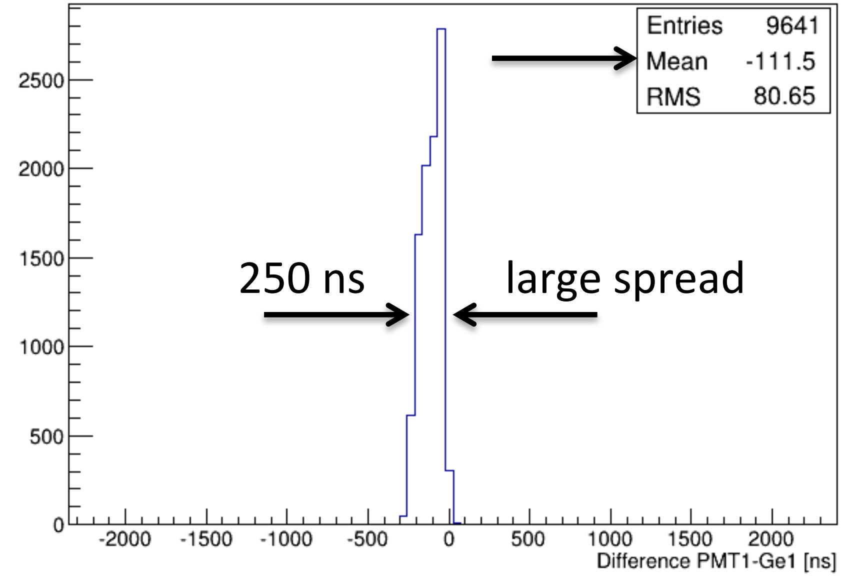
^{210}Pb
3.01 mV (12%)
Entries = 35801
Mean 0.002759 ± 3.328e-06
RMS 0.0006297 ± 2.353e-06
HPGe1 [V]



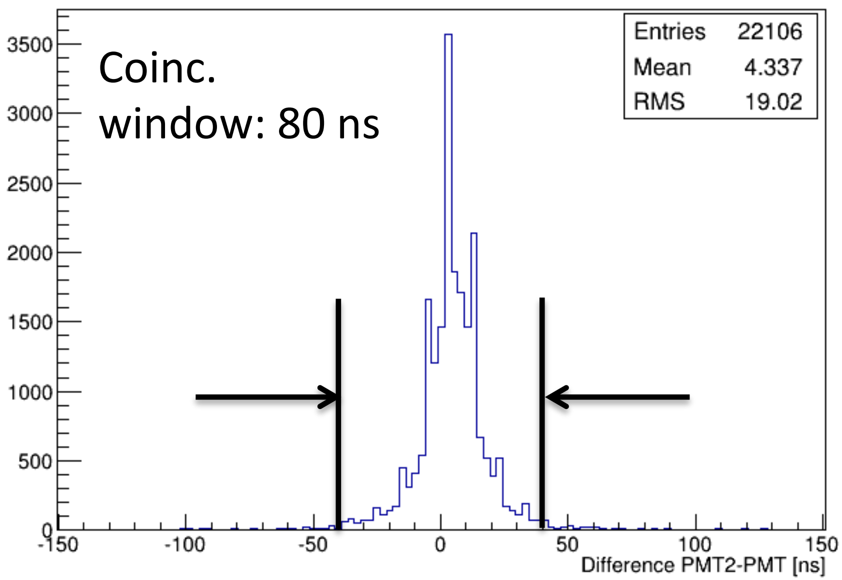
SPE run: PMT1
AmpPlot
Entries 10416
Mean 0.03171
RMS 0.01422
χ² / ndf 401.8 / 134
Constant 199.7 ± 2.8
Mean 0.027 ± 0.000
Sigma 0.01456 ± 0.00023
Events
Amplitude [V]



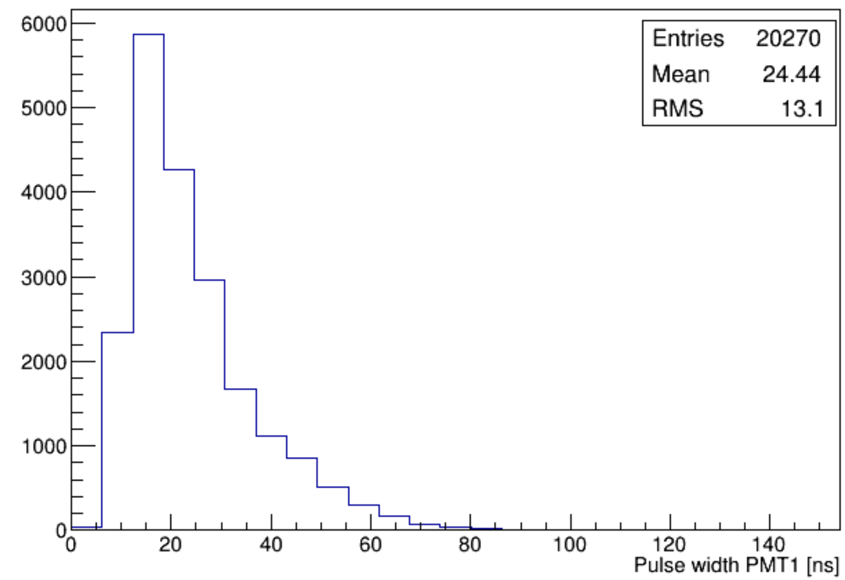
Δt between PMT1 and Ge1
- LED pulse -



Δt between PMT1 and Ge1
- Cal Source -

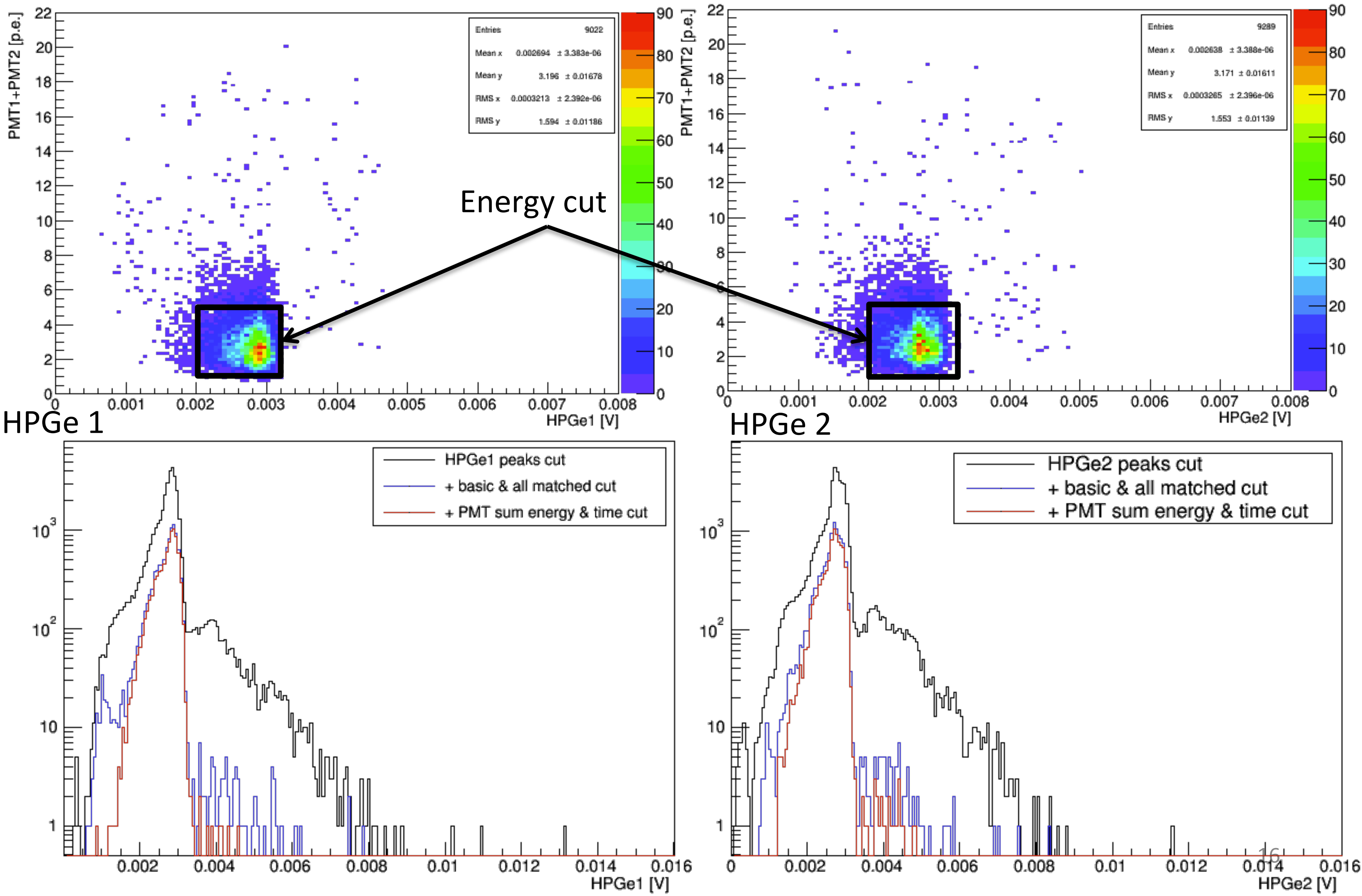


Δt between PMT1 and PMT2
- Cal Source -

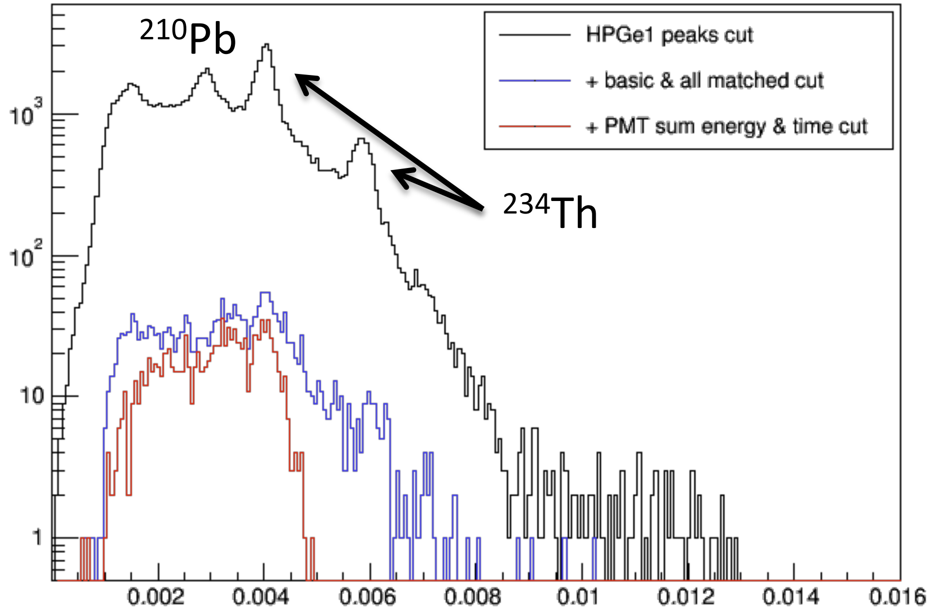


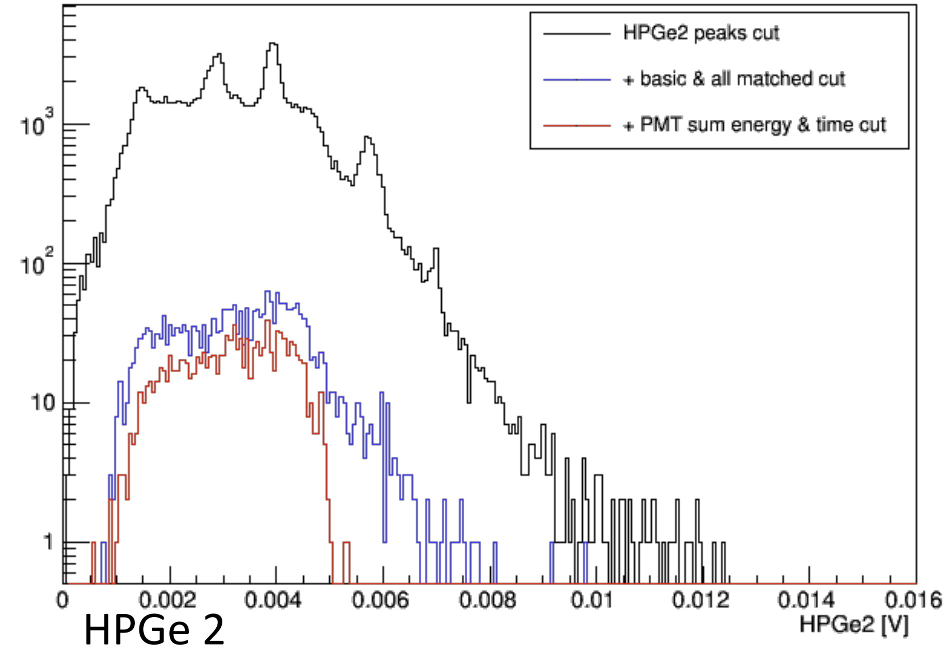
Pulse widths PMT1
- Cal Source -

Calibration results (^{210}Pb source)



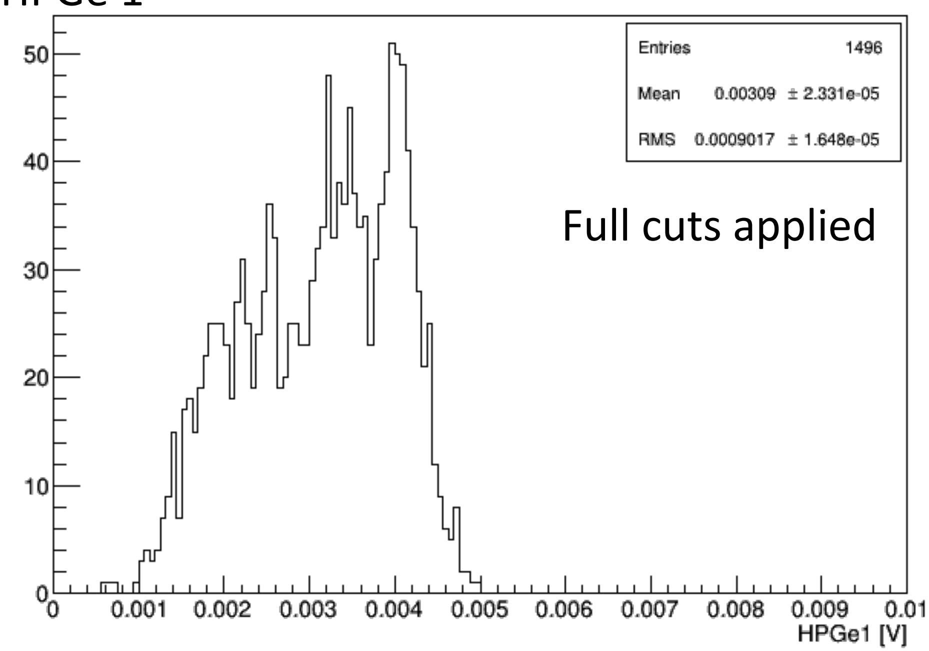
Background sample HNO_3 (Apr/May'13)

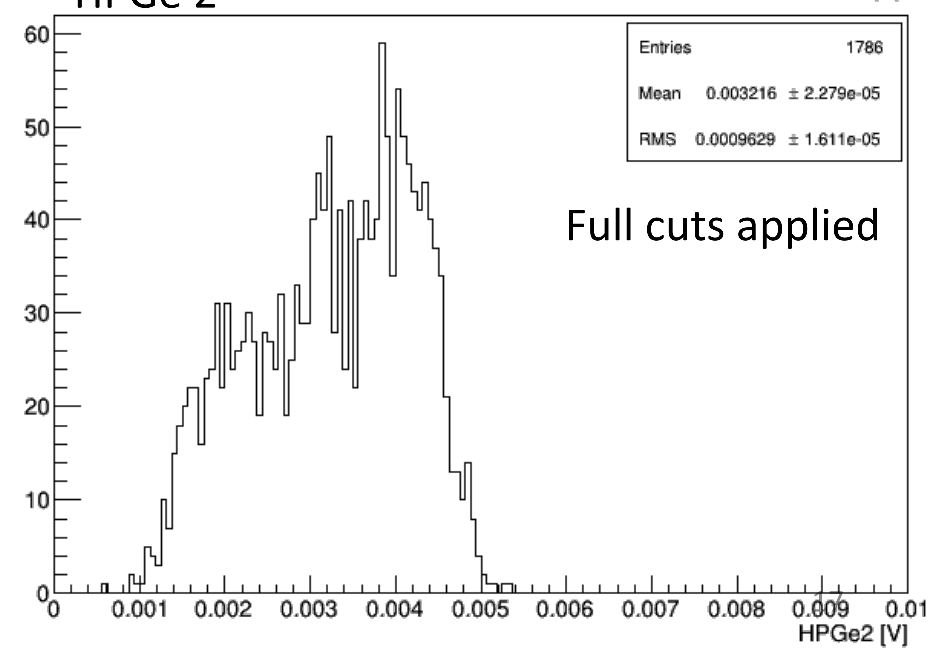




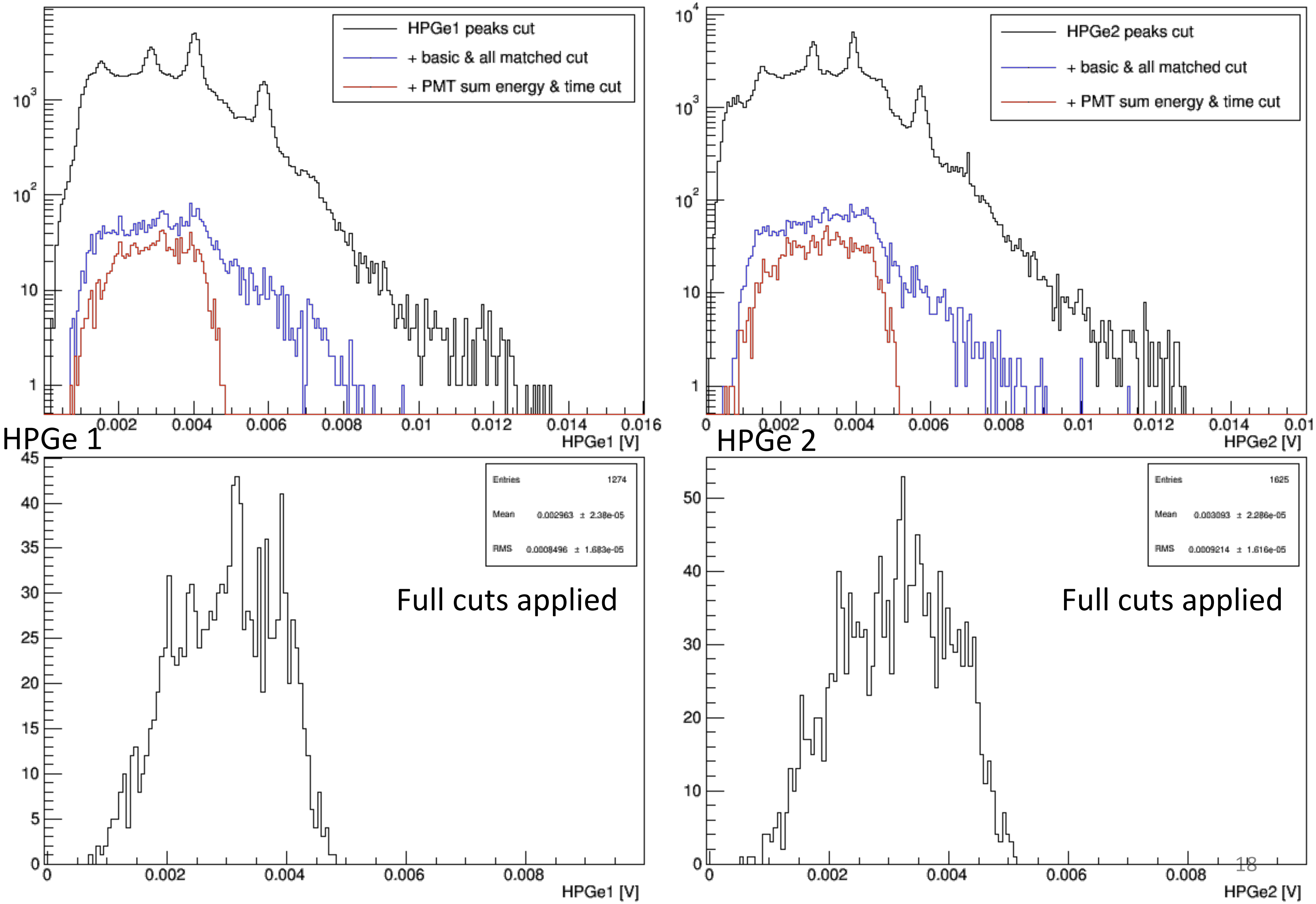
HPGe 1

HPGe 2





Background UG only (June'13)



Results in numbers

Calibration

Applying all cuts on energy and timing (250 ns time window) results in an absolute ^{210}Pb detection efficiency: 0.395±0.016%

Background (HNO_3 sample, April/May'13)

Live time: 5.9 d

^{210}Pb equivalent activity: 356 mBq

Background (UG sample, June'13)

Live time: 10.5 d

^{210}Pb equivalent activity: 320 mBq

Remaining questions …

- HPGe resolution
- Compton background influence
- Coincidence peak width
- Scintillator timing
- Sample contamination

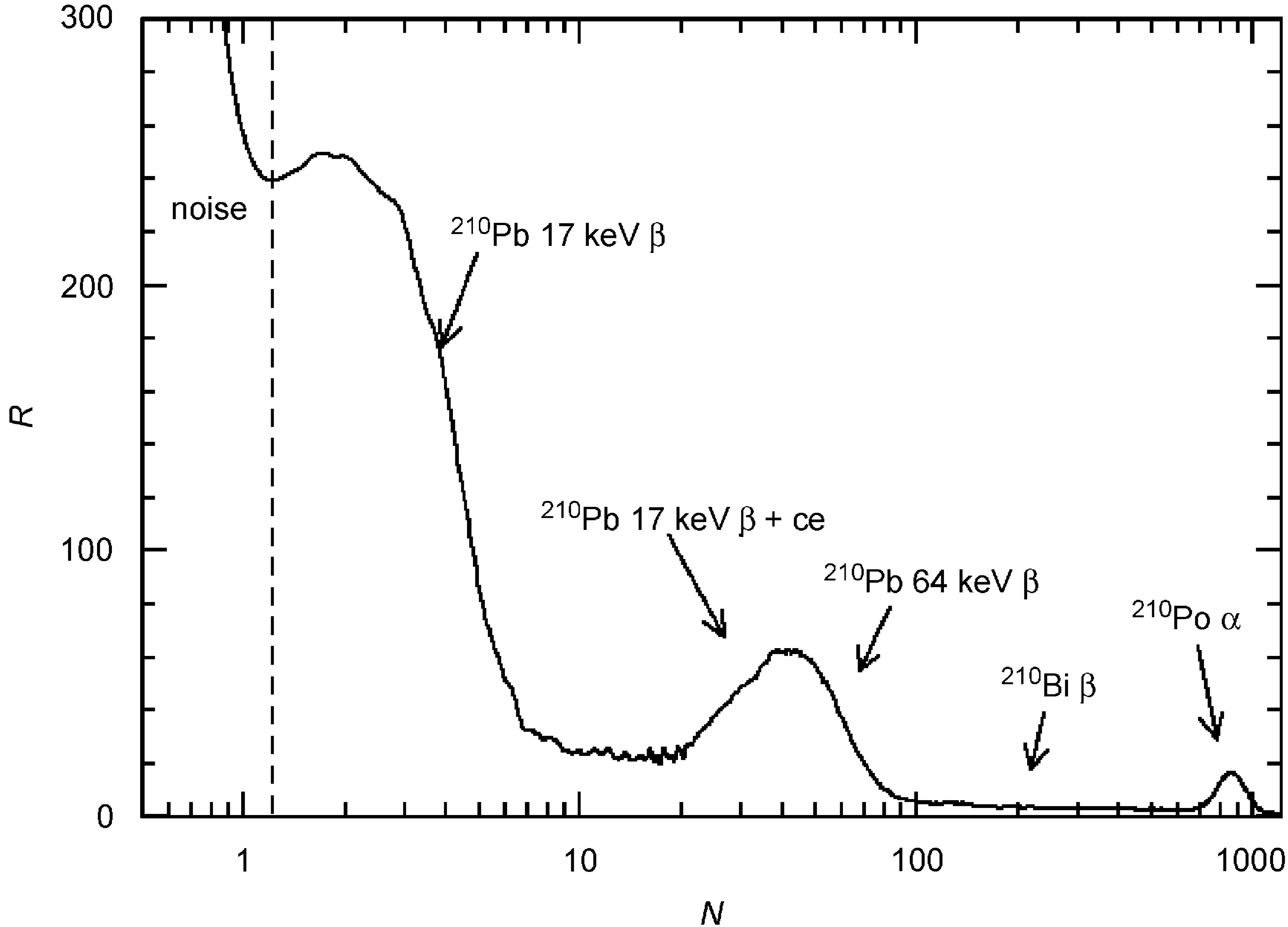
Possible improvements

- DAQ: dynamic range, dead time, trigger
- Scintillator and sample chemistry
- Setup: sample vial, light transmission, PMT
- Cooling system

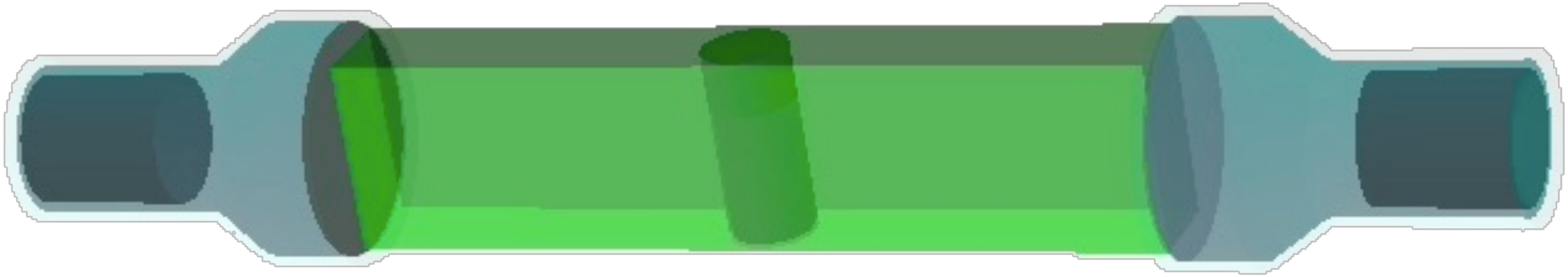
Thank You !

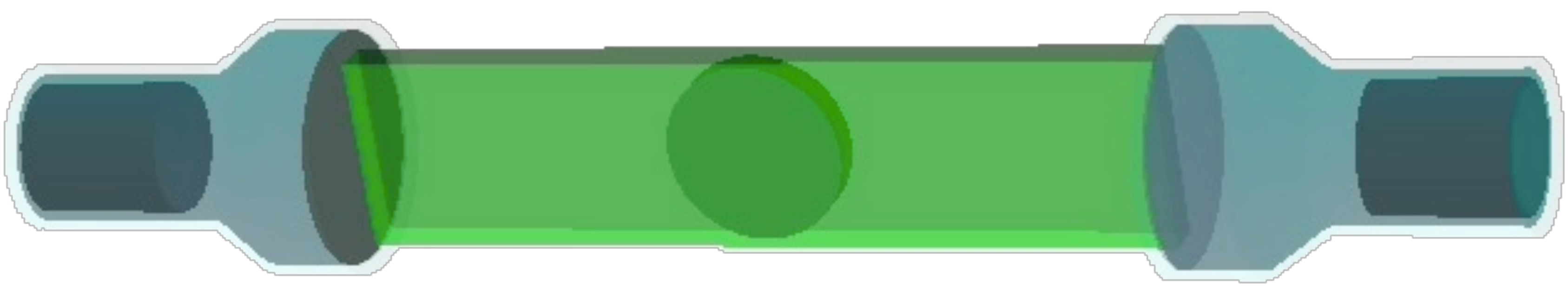
- HPGe detectors provided by the University of Edinburgh
- Calibration source from SUERC Glasgow
- Technical and infrastructure support by STFC Boulby Underground Laboratory
- Technical support by Royal Holloway University of London

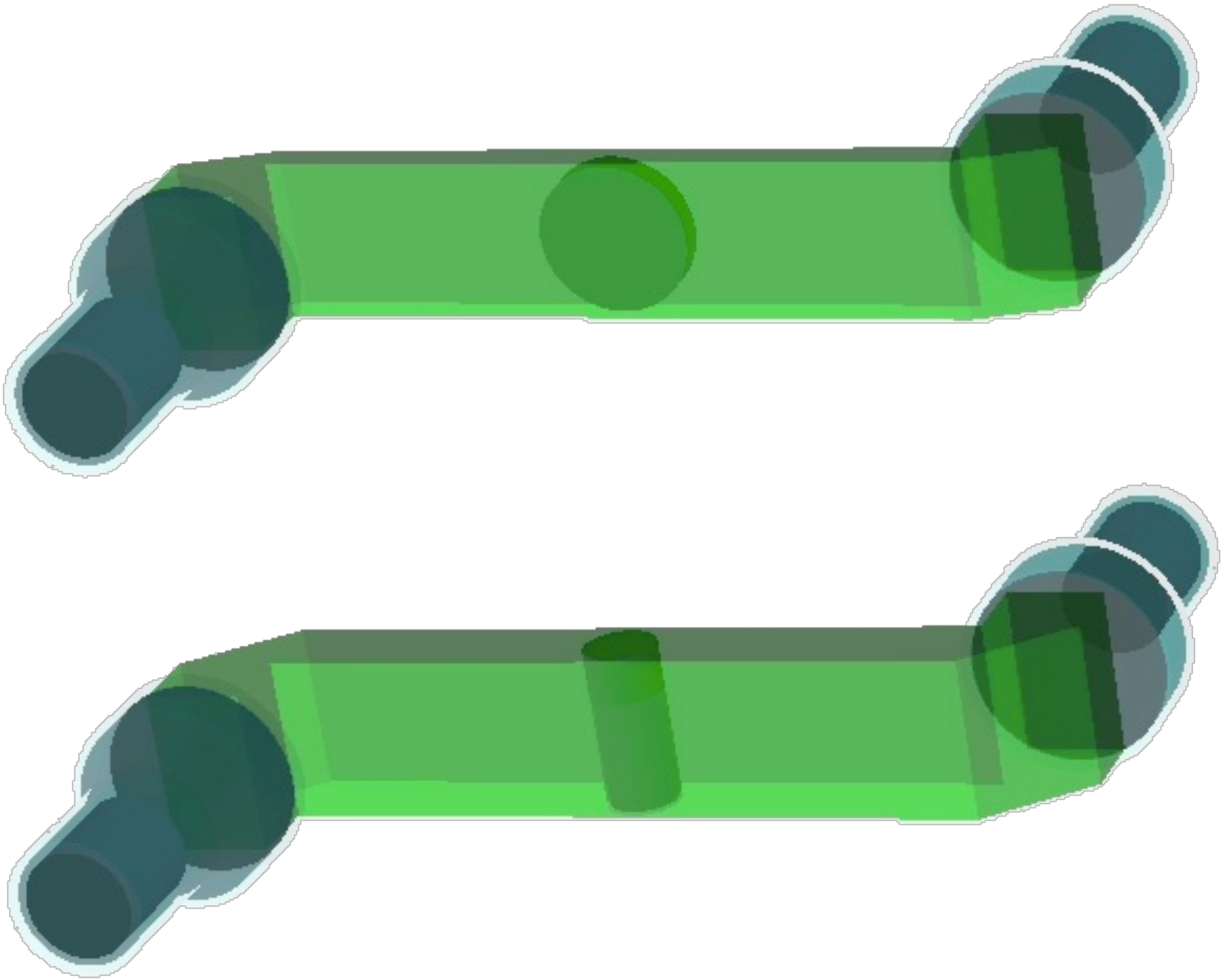
ADDITIONAL SLIDES

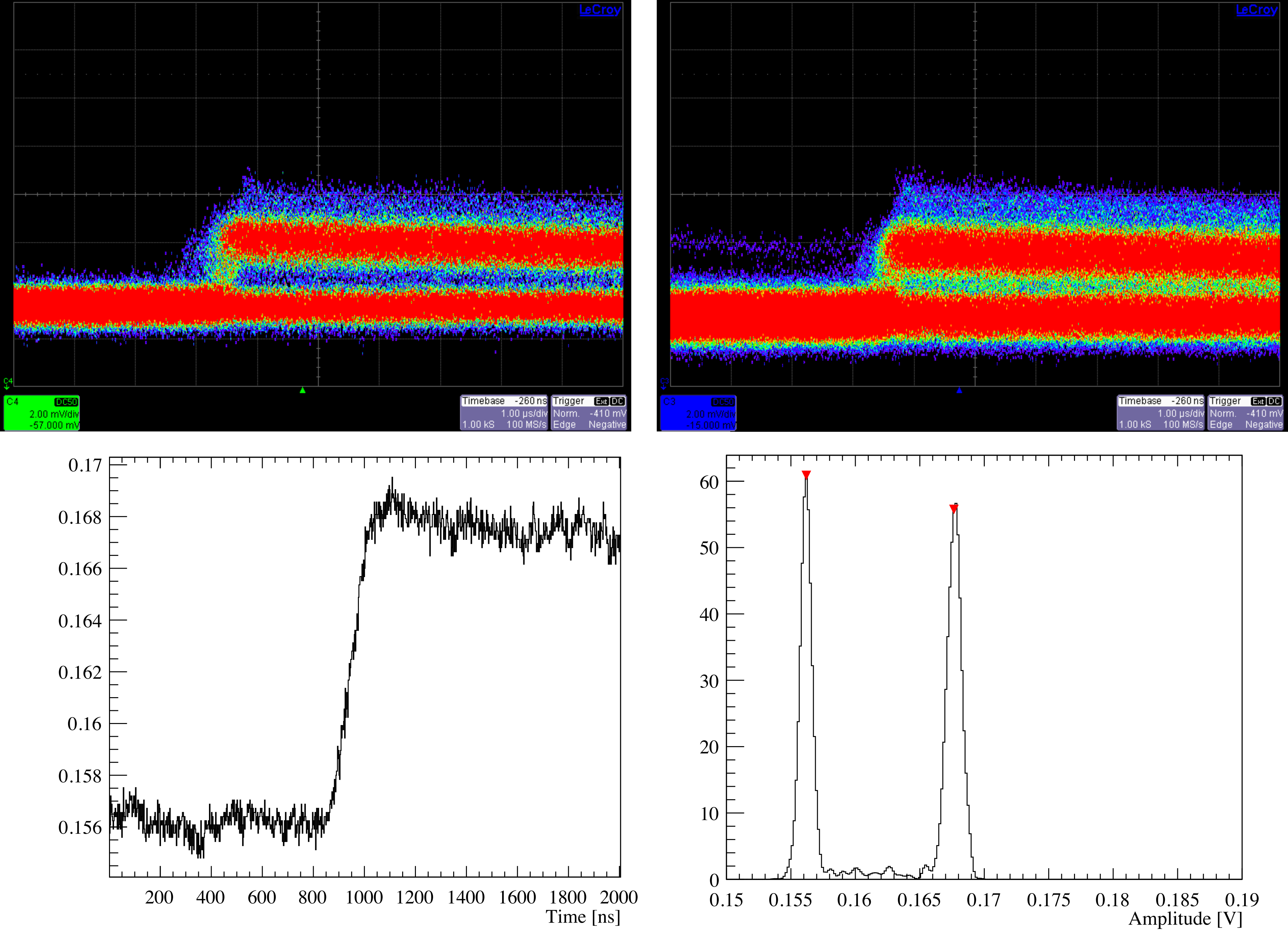


300
200
100
0
R
noise
^{210}Pb 17 keV β
^{210}Pb 17 keV β + ce
^{210}Pb 64 keV β
^{210}Po α
^{210}Bi β
1
10
100
1000
N








LeCroy
C4 DC50
2.00 mV/div
-57.000 mV
Timebase -260 ns
1.00 µs/div
1.00 kS 100 MS/s
Trigger Ext DC
Norm. -410 mV
Edge Negative
LeCroy
C3 DC50
2.00 mV/div
-15.000 mV
Timebase -260 ns
1.00 µs/div
1.00 kS 100 MS/s
Trigger Ext DC
Norm. -410 mV
Edge Negative
0.17
0.168
0.166
0.164
0.162
0.16
0.158
0.156
200 400 600 800 1000 1200 1400 1600 1800 2000
Time [ns]
60
50
40
30
20
10
0
0.15 0.155 0.16 0.165 0.17 0.175 0.18 0.185 0.19
Amplitude [V]