Developing The Detector Array For Energy Measurements Of Neutrons (DAEMON)

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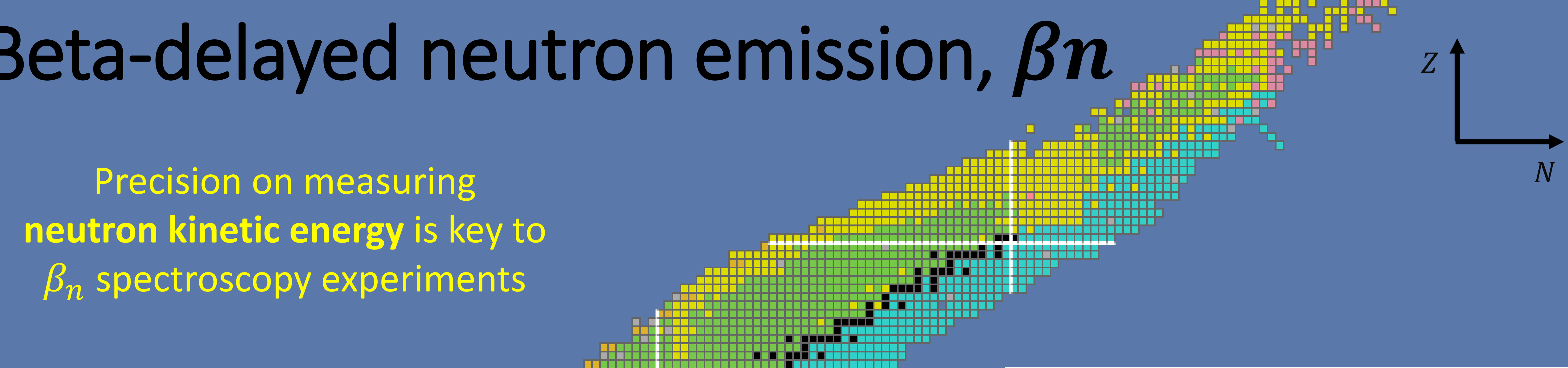
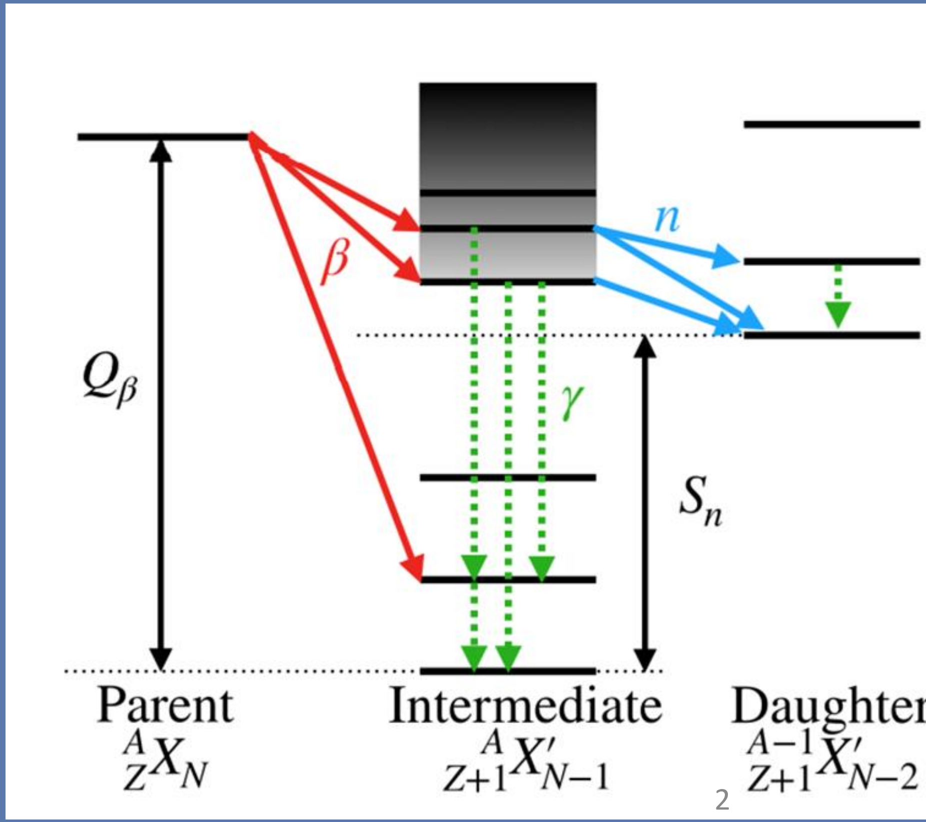
Beta-delayed neutron emission, βn

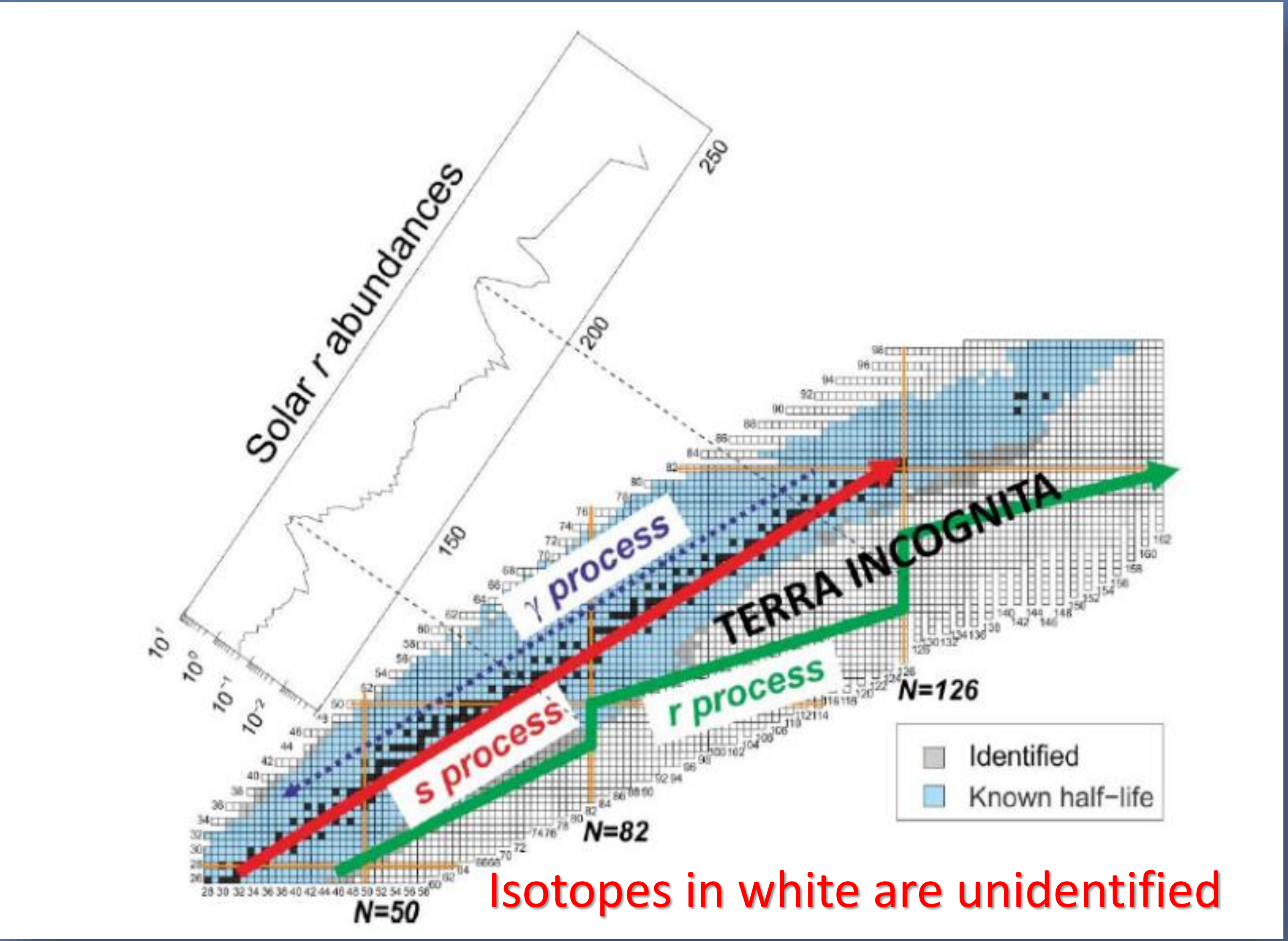
Precision on measuring **neutron kinetic energy** is key to β_n spectroscopy experiments





Bridging the Gap: Neutron-Rich Nuclei & Solar Abundance Models

- **Astrophysical rapid neutron capture**
- **Nuclear structure**
- **Nuclear reactors**



Abriola, B. Singh, and I. Dillman, IAEA Report, INDC(NDS) 0599 (2011).

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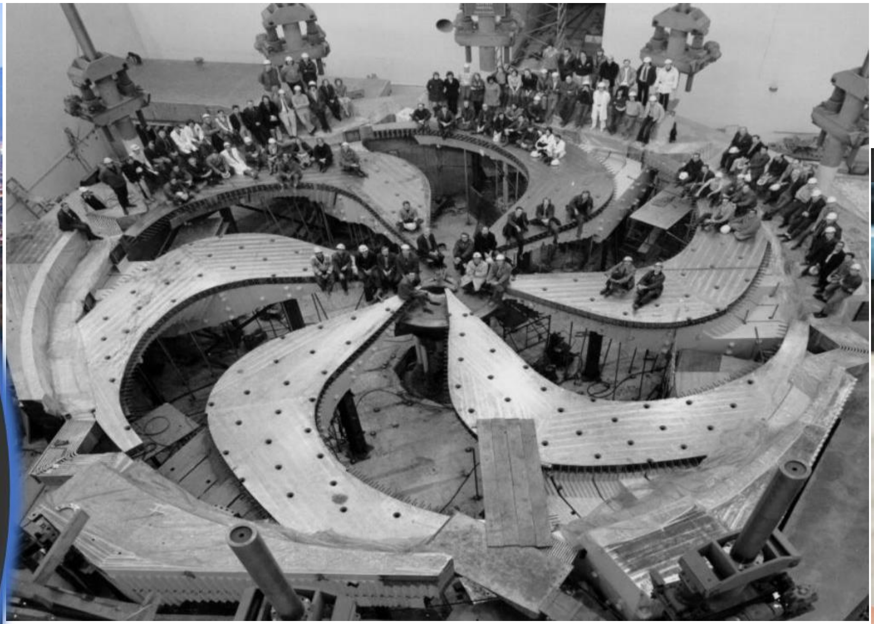
Canada's particle accelerator centre
Centre canadien d'accélération des particules

Vancouver, BC

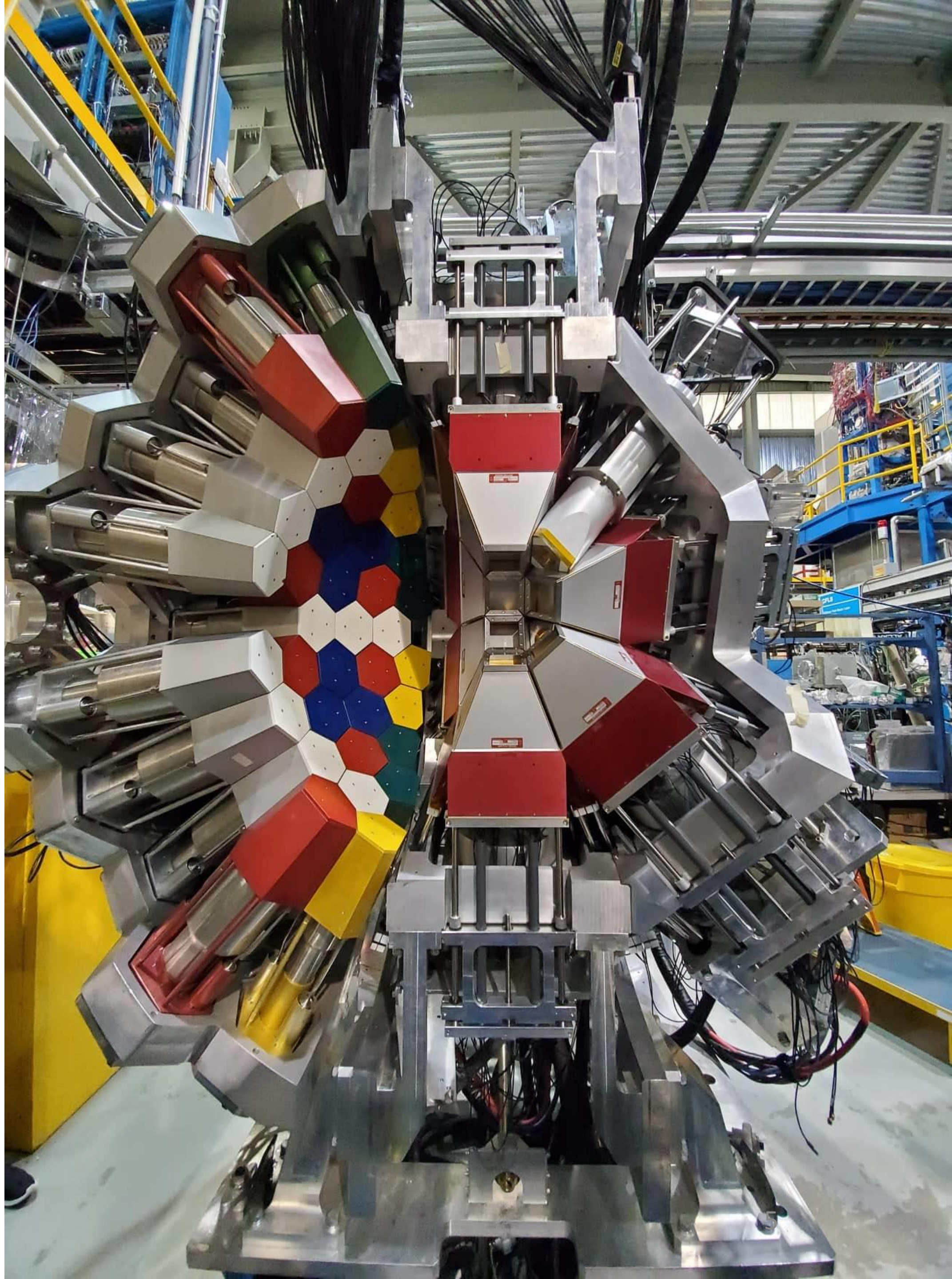


GRIFFIN
Decay Station

Isotope Separator and Accelerator (ISAC-I) facility

GRIFFIN - Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei

- **ZDS - Zero Degree Scintillator**
- **DESCANT - DEuterated SCintillator Array for Neutron Tagging**
- **DAEMON - Detector Array for Energy Measurements Of Neutrons**



Time-Of-Flight (TOF) Neutron Detector

- TOF between two clocks to find neutron energy:

$$E_n = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{L^2}{TOF^2}$$

  - L, known flight path
  - $TOF = t_2 - t_1$, time difference between two detectors

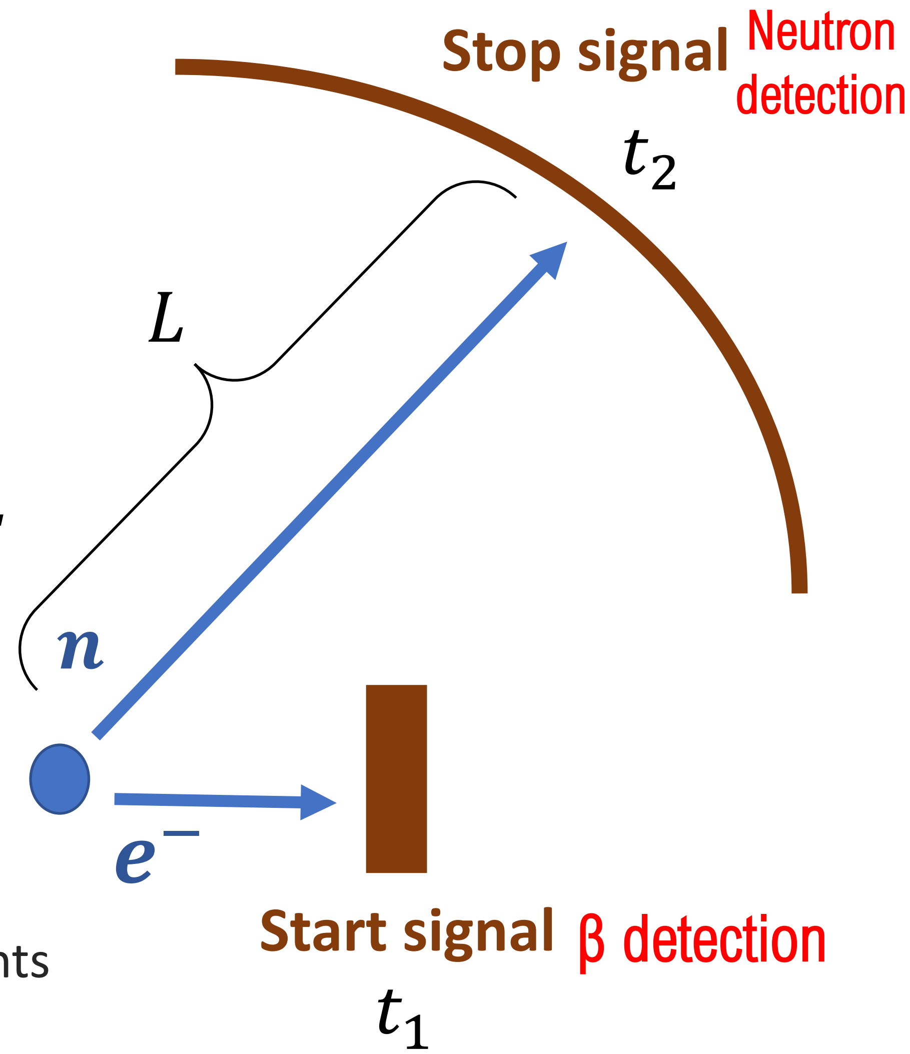
- Energy resolution dependent on flight L and TOF

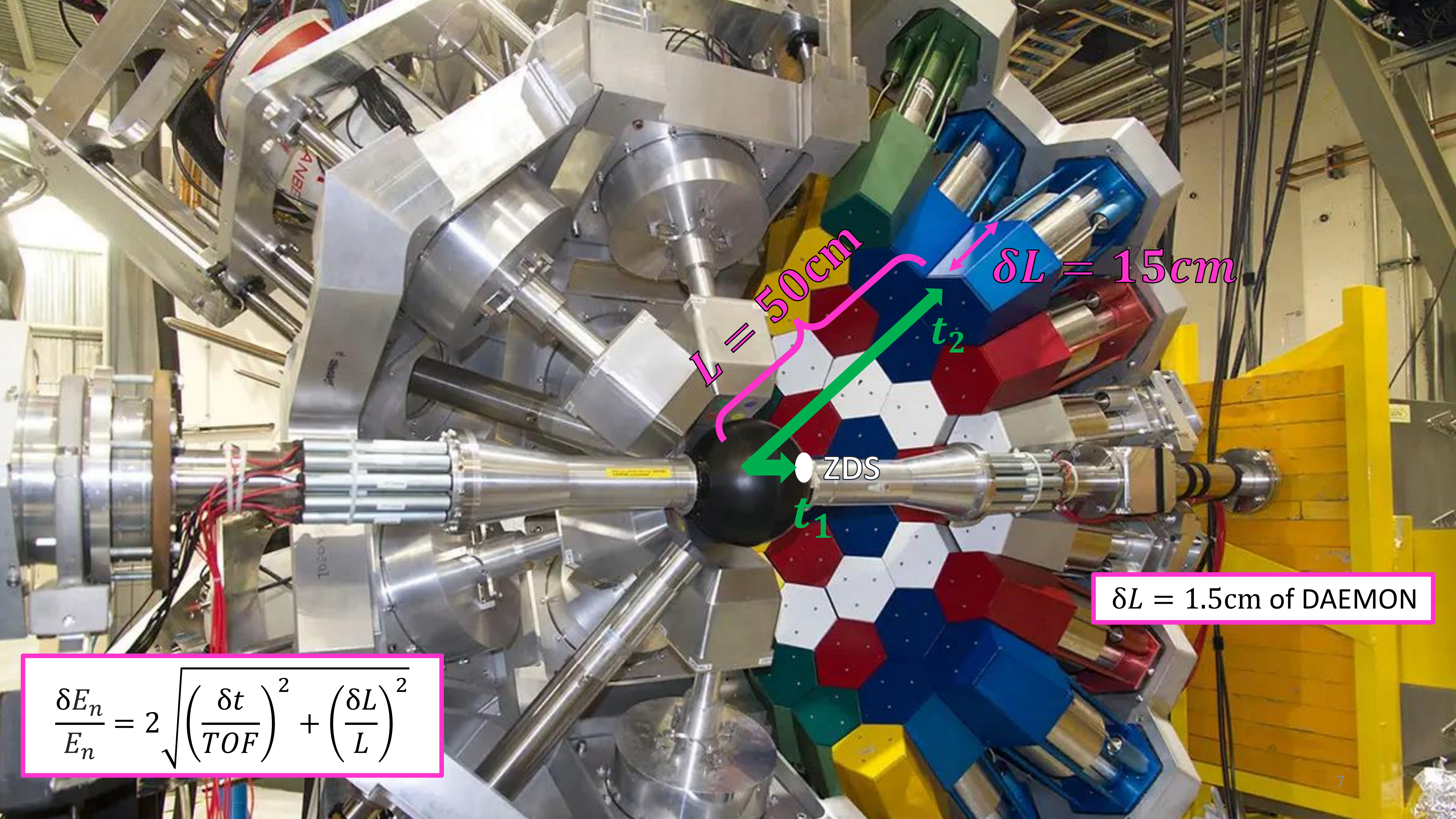
$$\frac{\delta E_n}{E_n} = 2\sqrt{\left(\frac{\delta t}{TOF}\right)^2 + \left(\frac{\delta L}{L}\right)^2}$$

- δL, detector thickness
- δt, time resolution of electronics

Reduced by

Thin detectors
Fast components



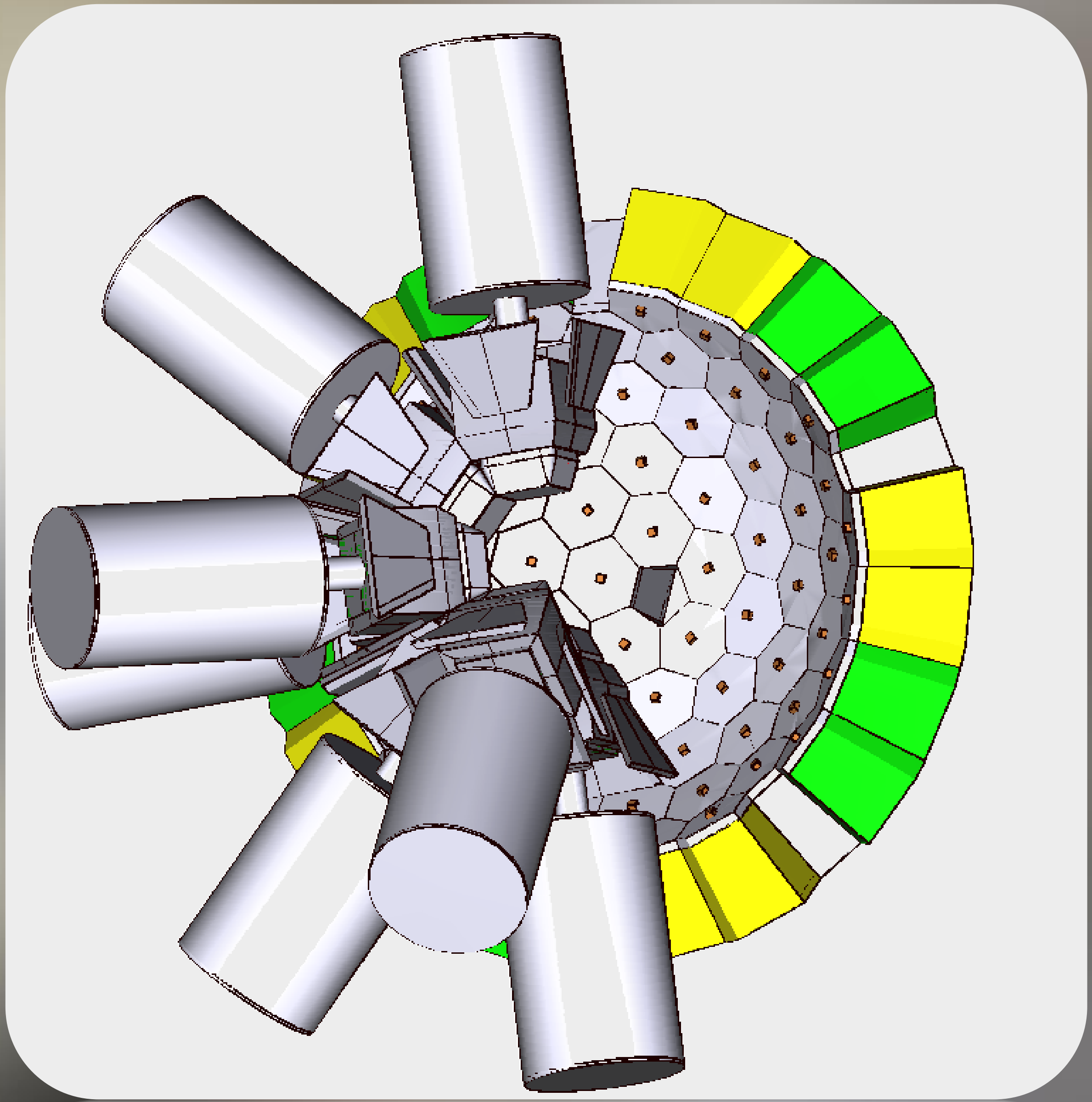


$$\frac{\delta E_n}{E_n} = 2\sqrt{\left(\frac{\delta t}{TOF}\right)^2 + \left(\frac{\delta L}{L}\right)^2}$$

$\delta L = 1.5$cm of DAEMON

Building a powerful all-in-one capability

for broad investigation of neutron-rich species



Step 1:

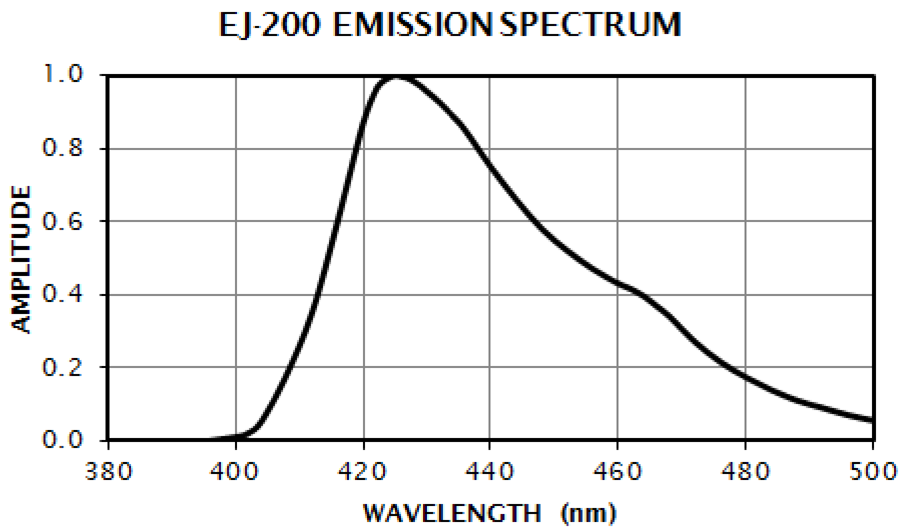
Prototyping DAEMON

Step 2:

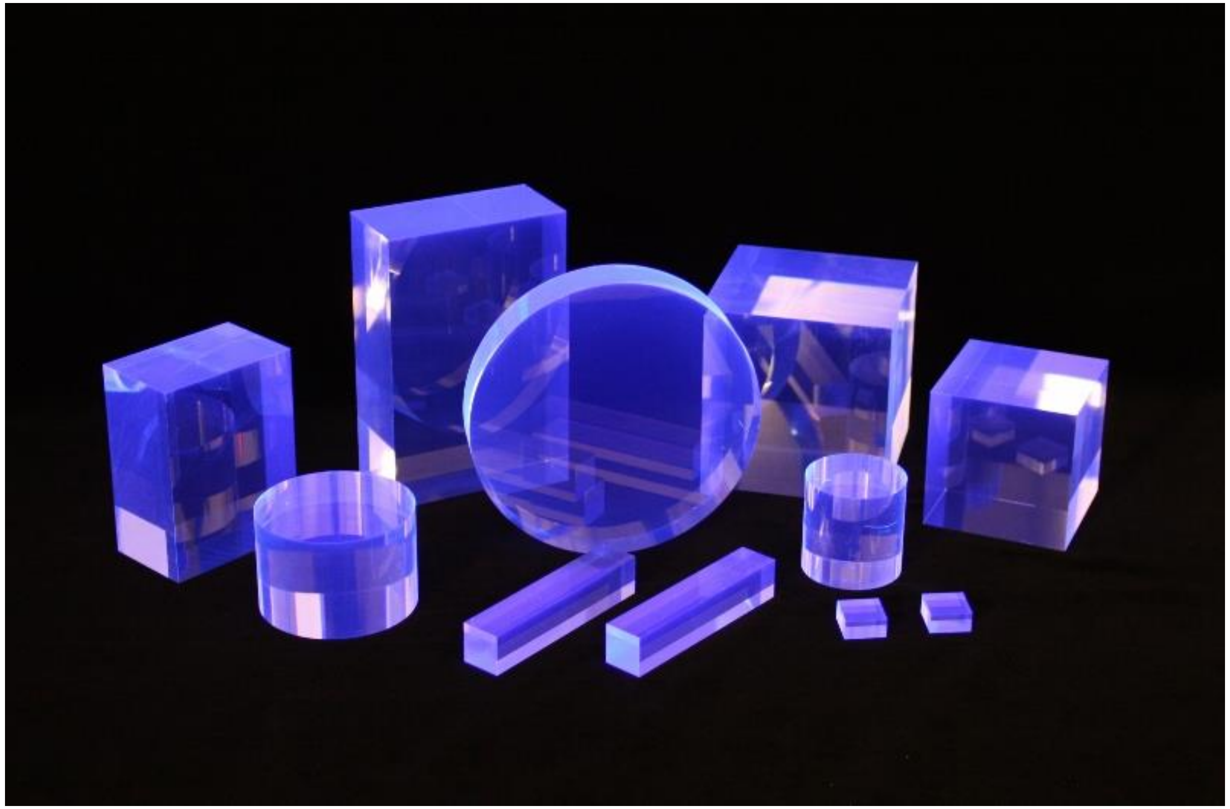
Building the full array

Plastic Scintillators

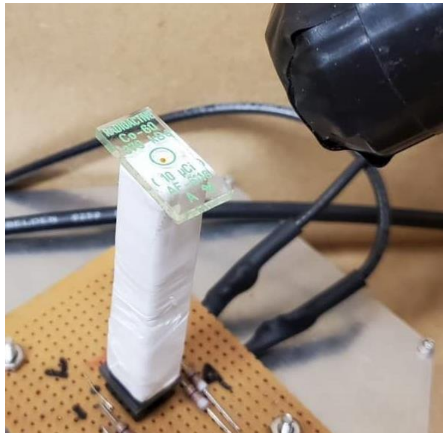
- Well-suited for fast-timing measurements
- Large light attenuation length (380 cm)
- Can be machined to different shapes



EJ-204 and EJ-200 (Eljen Technologies)



$1cm \times 1cm \times 1cm$

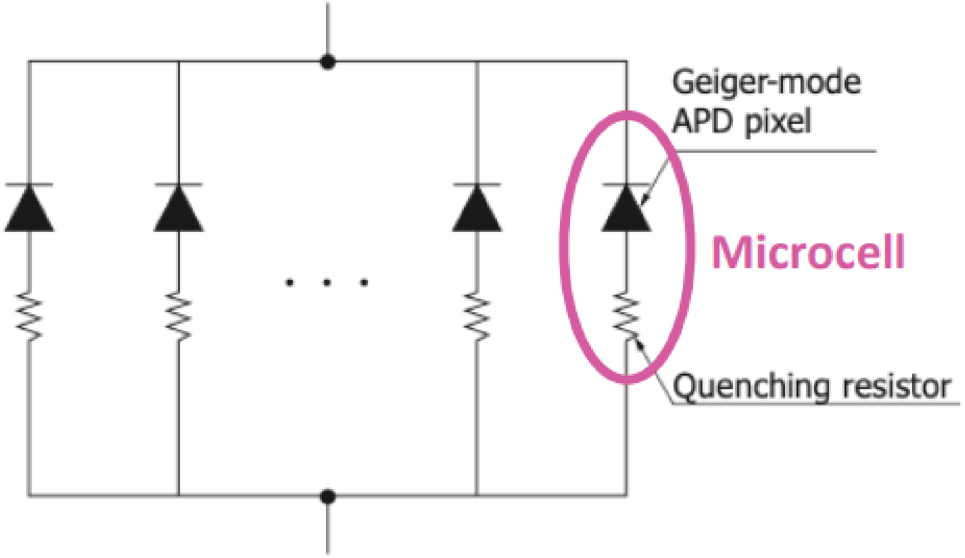


$1cm \times 1cm \times 6cm$

$1.5cm\ thick\ hexagon$

Silicon Photomultipliers (SiPMs)

- Dense array of single photon avalanche diode
- Alternative to PMT (but requires much less bias voltage!) Low profile, robust, large are coverage,



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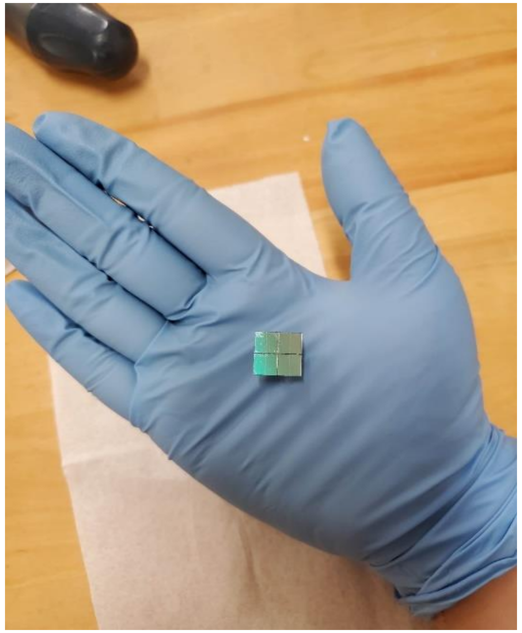
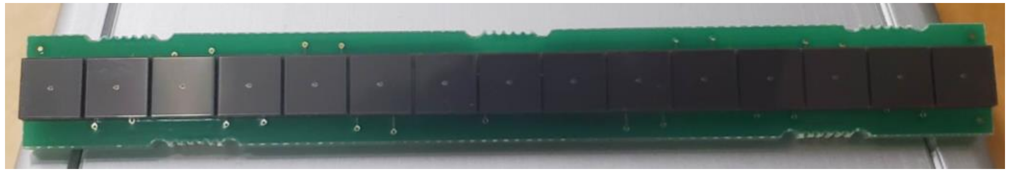
$4mm \times 4mm$



2x2 array of $6mm \times 6mm$

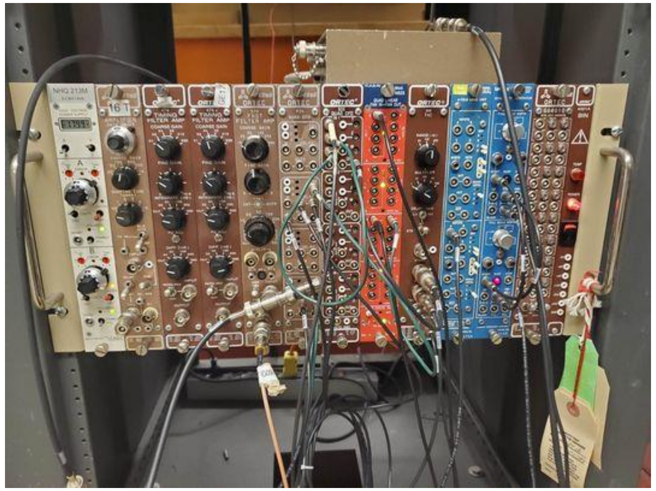


1x15 array of $6mm \times 6mm$

Data AcQuisition System (DAQ)

- Convert physical signal into data that can be analysed
- DAQ considerations are need when designing an experiment
- Output that is sufficient for the physics goals

Data AcQuisition System (DAQ)



- Analog DAQ → To understand SiPM signals
- Digital DAQ → Customizable parameters & event selection

  - ➢Stage 1 : **CAEN VX1730 digitizer**

    → Customizable threshold, pulse polarity, has dynamic range and waveform collection option

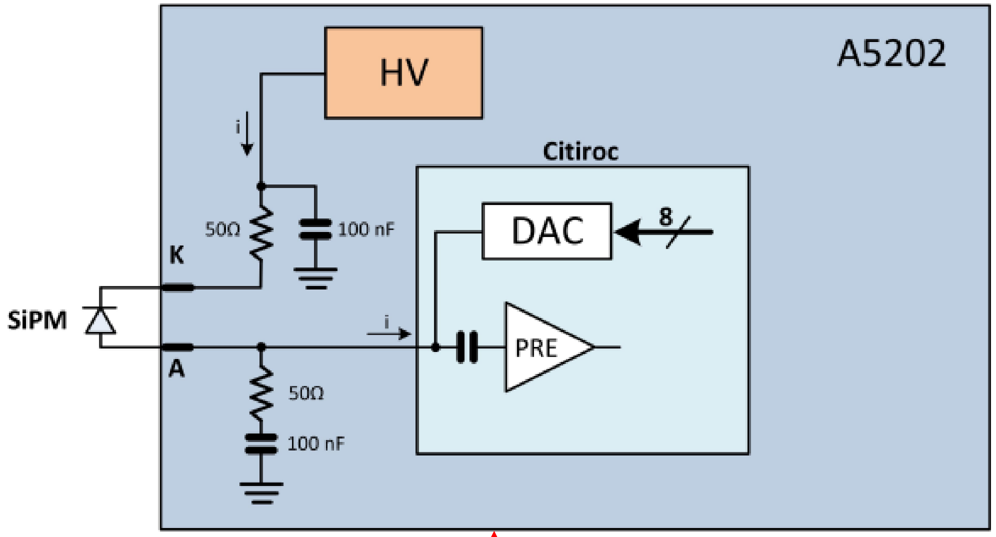
    → Each comes with 16 readout channels

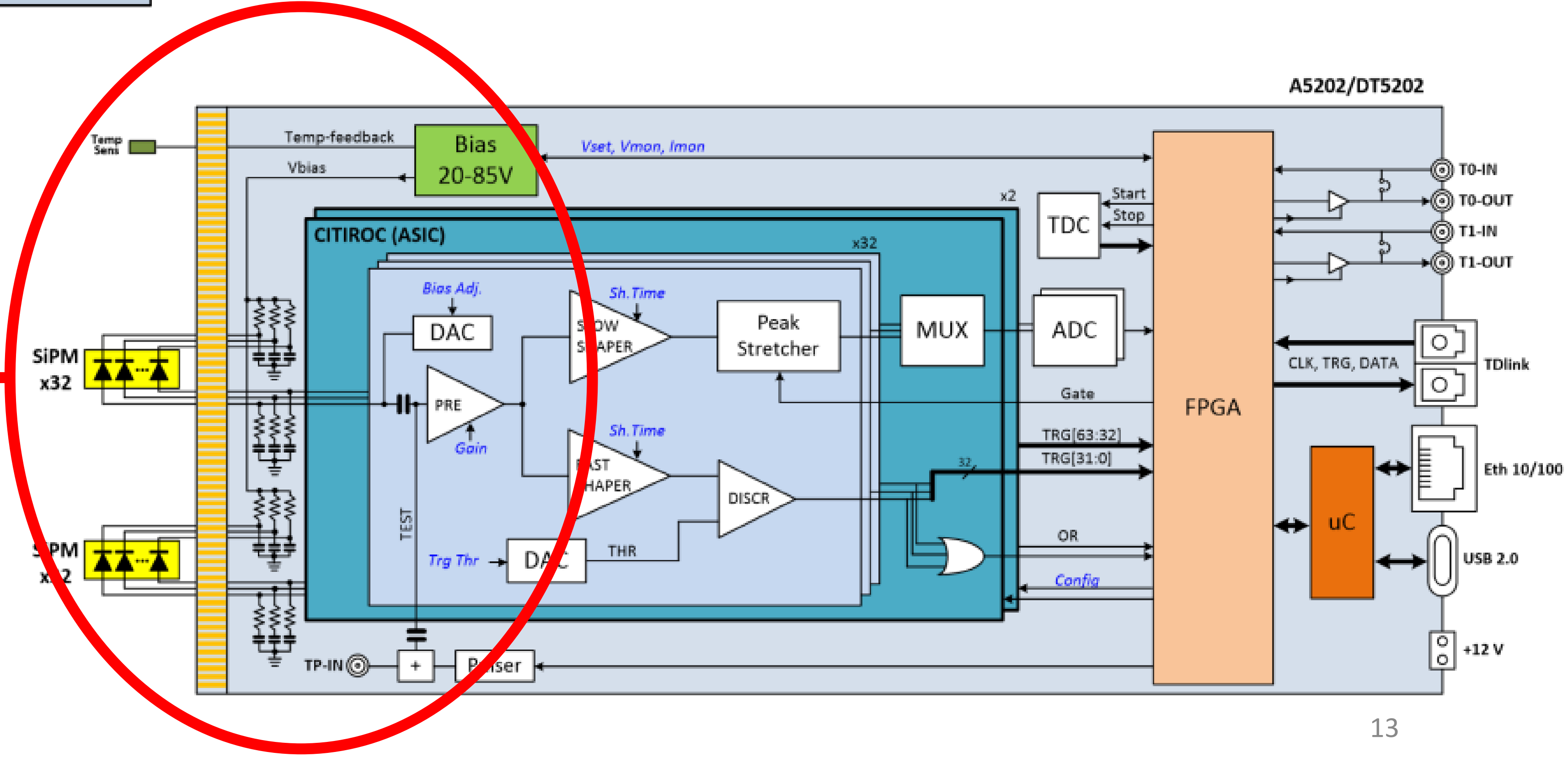
  - ➢Stage 2: **CAEN FERS-5200 A5202 board**

    → ASIC based front-end with multichannel readout

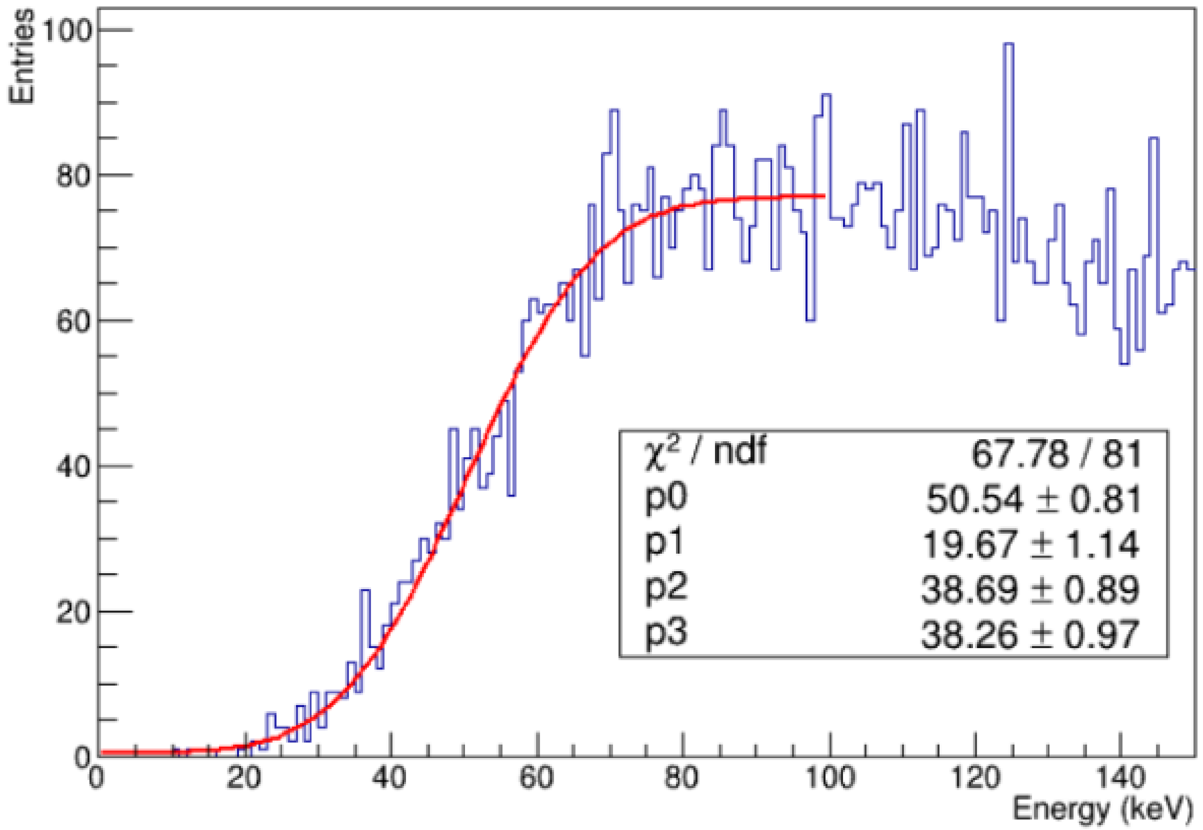
    → Each unit houses 64 or 128 readout channels

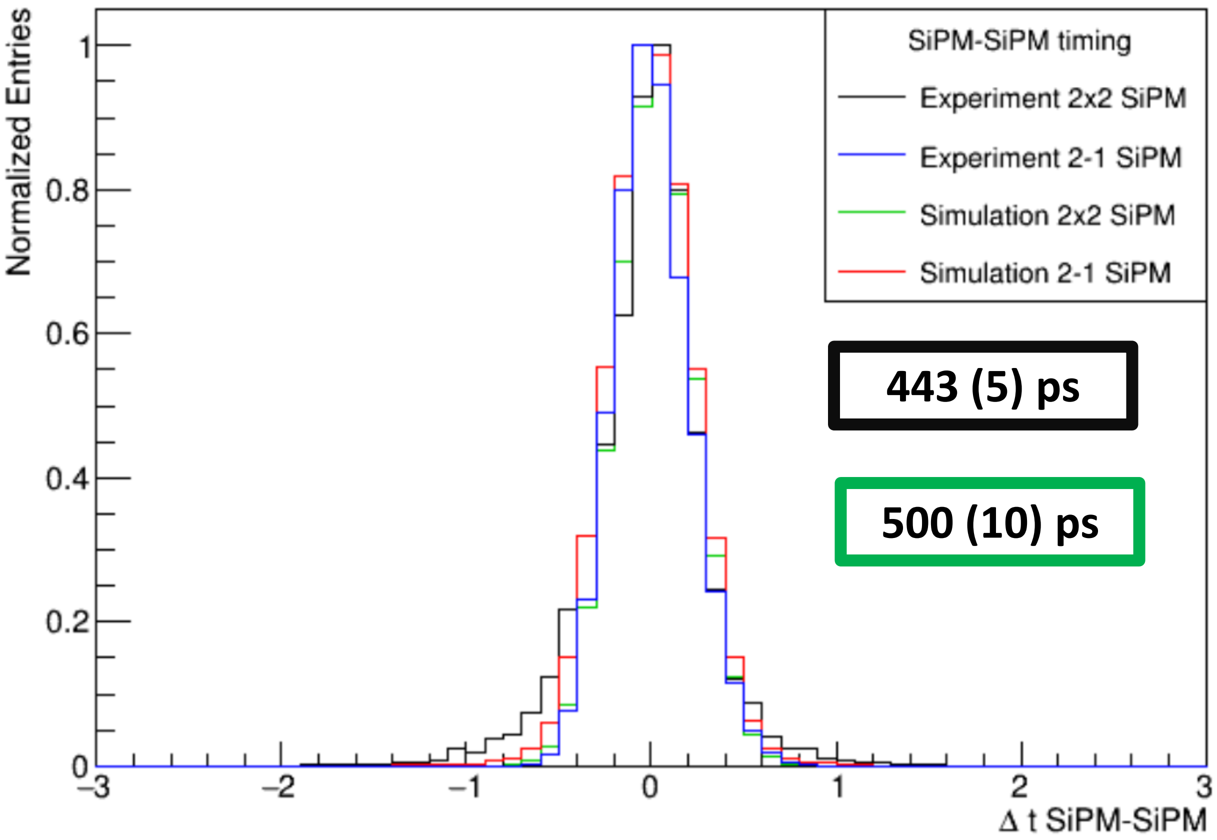
Inside FERS-5200 A5202





Detection threshold & Timing resolution

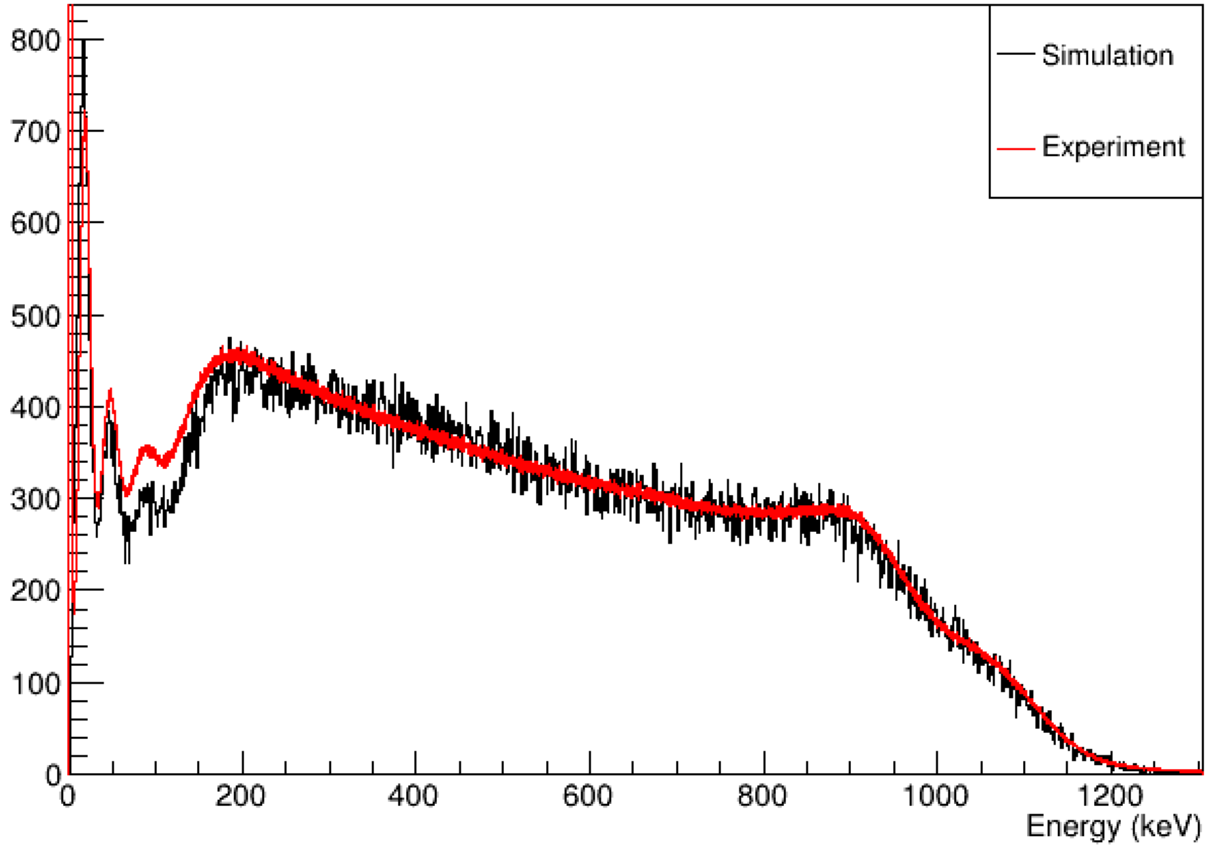


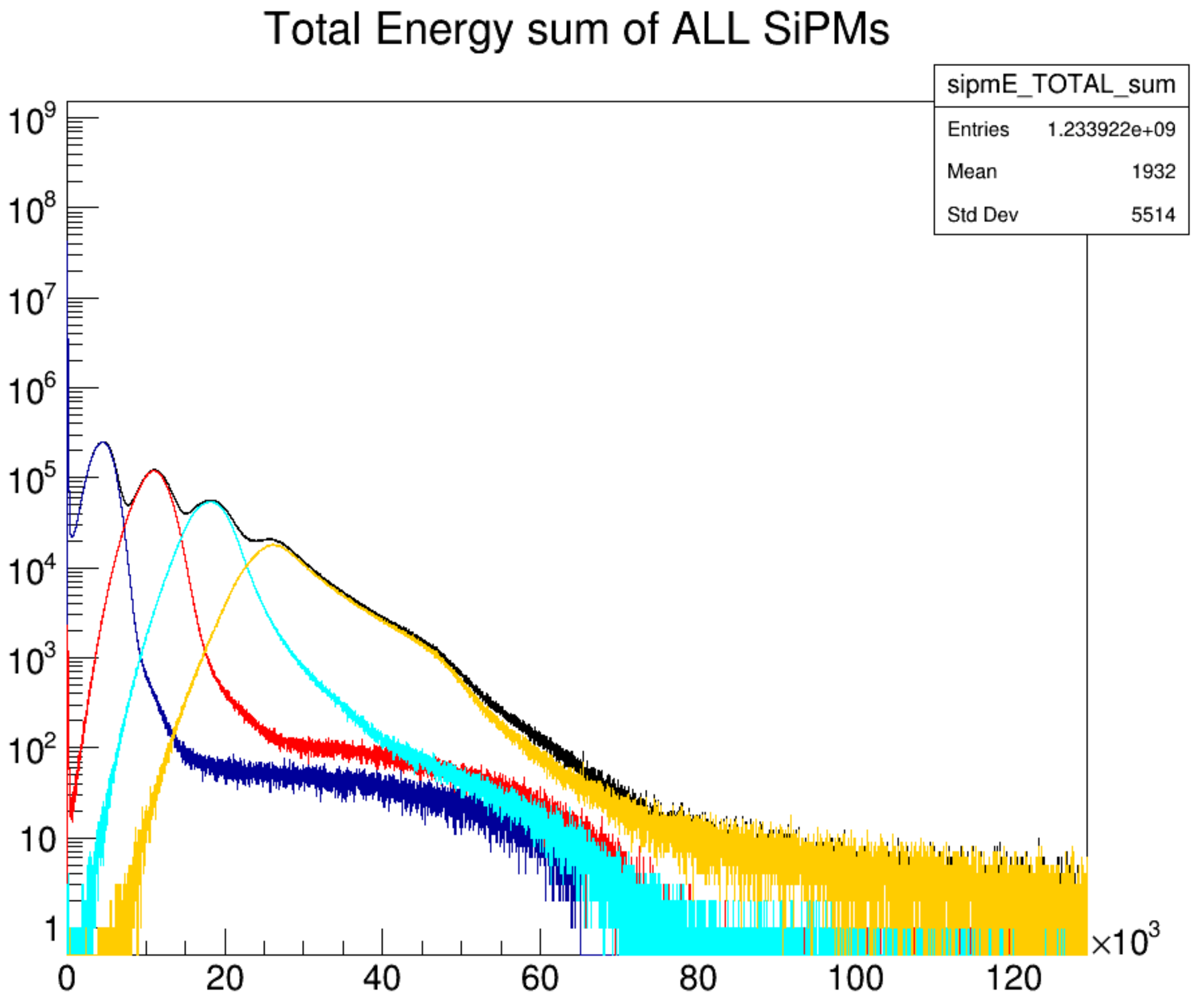


Tests performed using available γ-ray sources: ^{60}Co, ^{137}Cs, ^{133}Ba and ^{241}Am

2x2 SiPM array

- Simulation *(Bidaman, H., PhD dissertation)* versus experimental tests





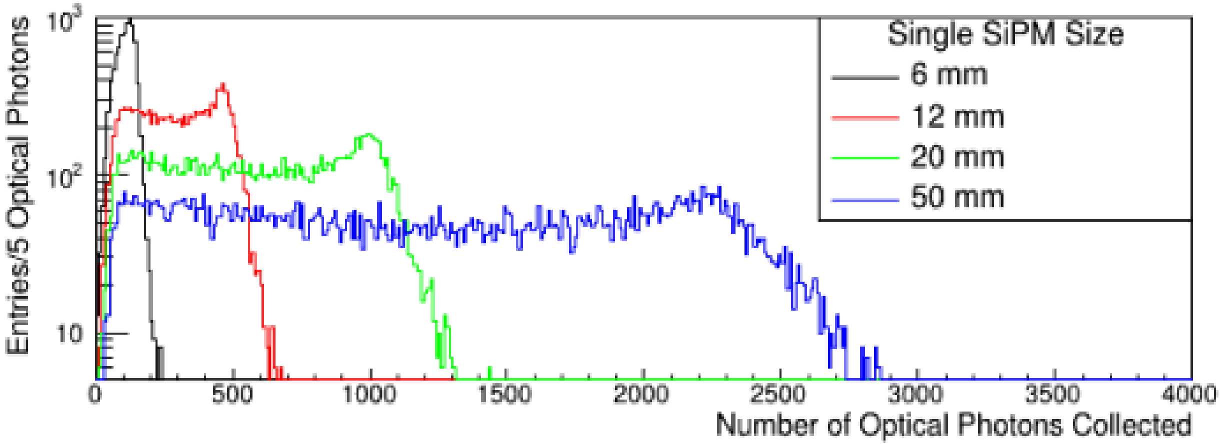
Software summing between four independently read channels

DAEMON Prototyping

- Single SiPM with analog and digital DAQ (Radich, A.J., PhD Dissertation)

- Intensive complementary investigation of experiment and simulations (Bidaman, H., PhD dissertation)

- (Unfortunately), no neutrons were harmed in this work



THANK YOU

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Paul Garrett

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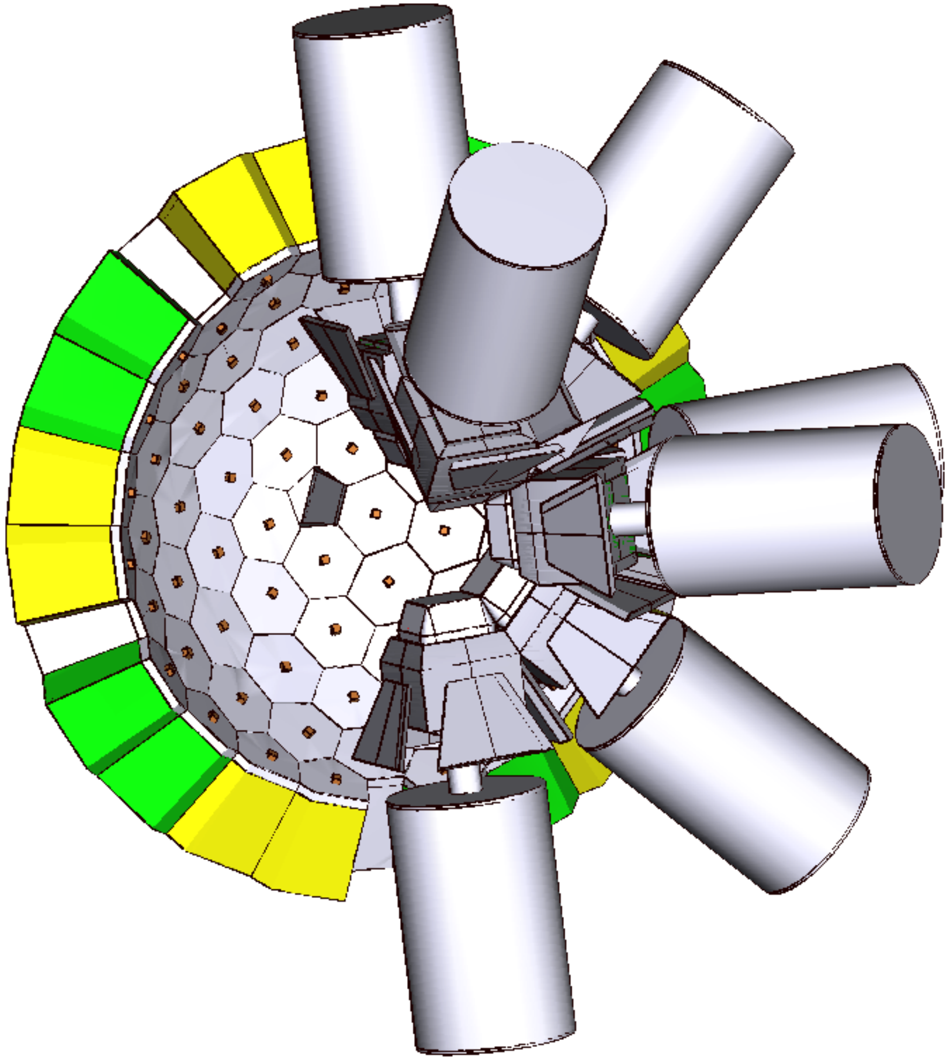
TRIUMF

Iris Dillmann

Adam Garnsworthy



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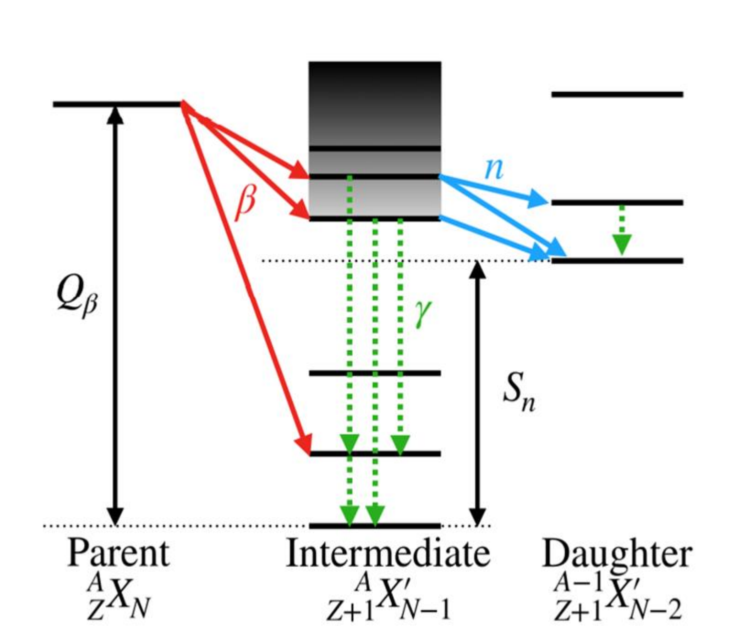
Back-up slides

$\boldsymbol{\beta}$-decay strength function & neutron-rich nuclei

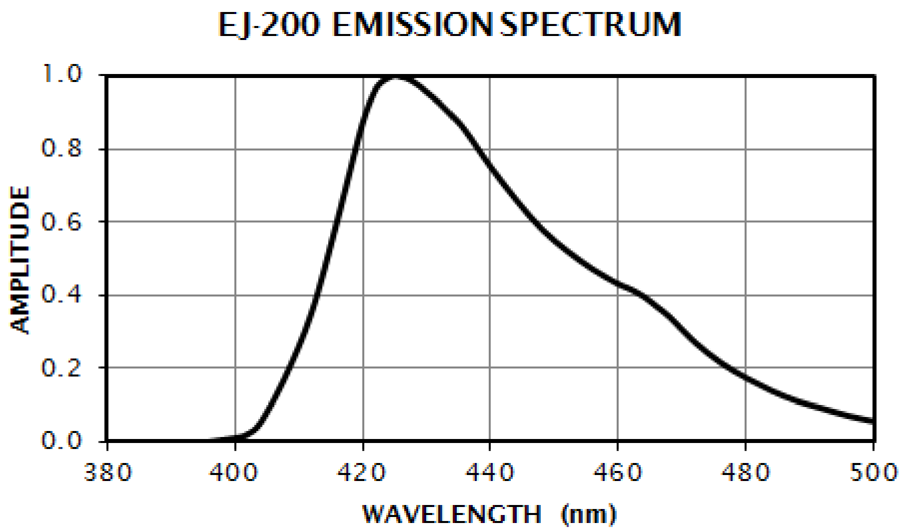
$$T_{1/2}^{-1} = \sum_{E_i \geq Q_\beta}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i)$$

- Gamow-Teller (GT) transitions dominate β strength distribution $S_\beta(E_i)$ for neutron-rich nuclei
- $B(GT)$ within Q_β value has direct influence of β decay half-life
- Theoretical models have high success in $B(GT)$ calculations in limited areas
- Neutron spectroscopy will allow deriving $B(GT)$ for neutron-unbound states
  - Evidence of single-particle states influencing $B(GT)$ (M. Madurga et al. 2016)



Eljen EJ-200 plastic scintillator

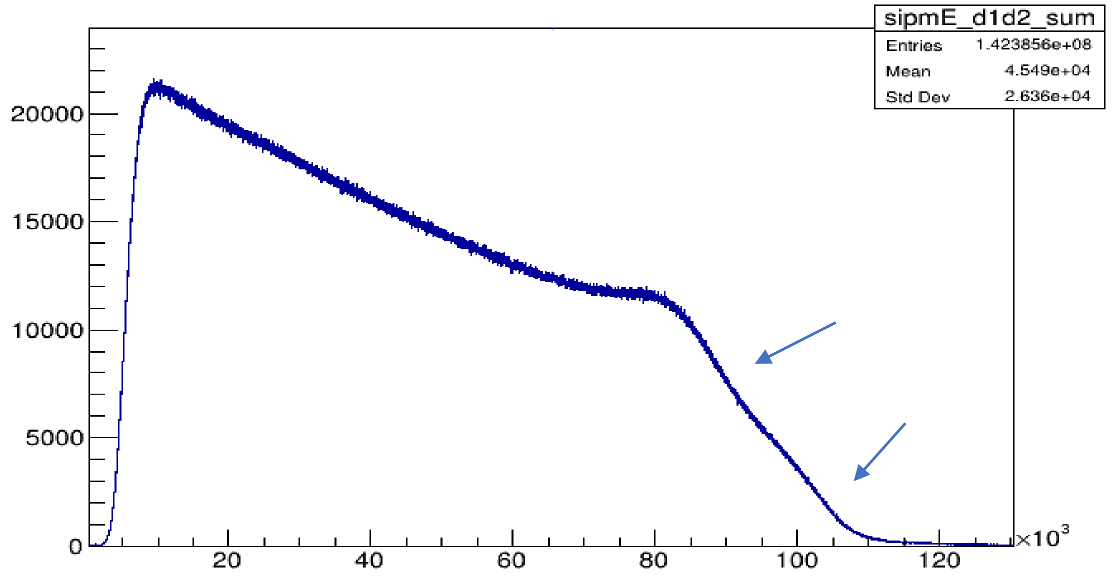
- Scintillation emission wavelengths in the violet-indigo visible region
- Well-suited for fast-timing measurements
- Sensitive to X-rays, γ rays, charged particles and fast neutrons
- Can be machined to different shapes and sizes
- Large light attenuation length (380 cm)
- For critical operating requirements such as high sensitivity and signal uniformity

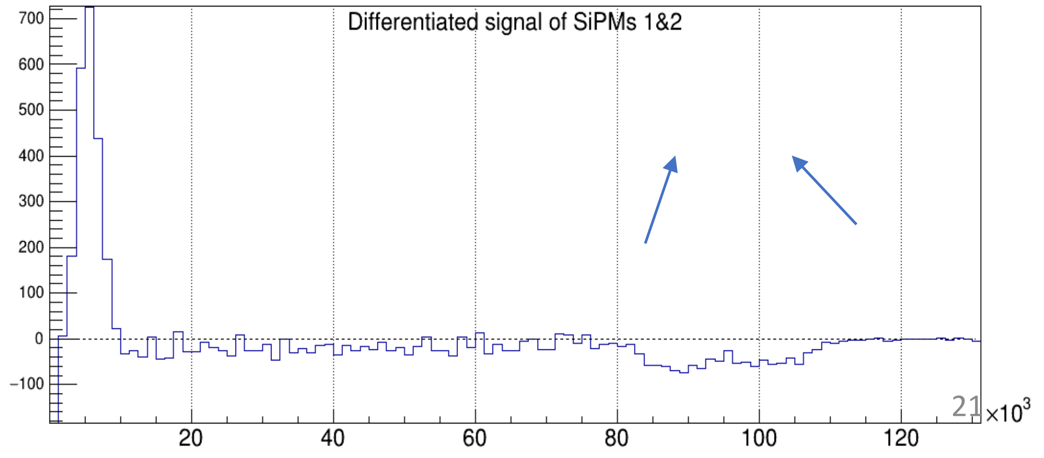


DAEMON Experimental Testing

- Single SiPM with analog and digital DAQ (Radich, A.J., Phd Dissertation)

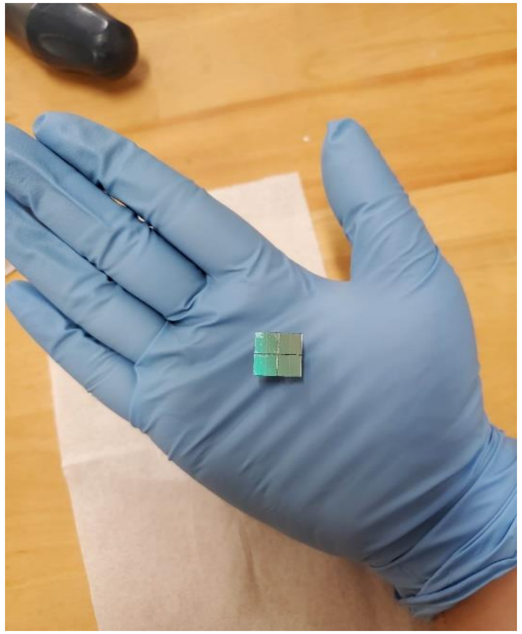
- 2x2 SiPM array
  - ➢ZDS-SiPM Coincidence Timing Resolution
  - ➢SiPM Energy Measures – γ sources
  - ➢Energy calibration with γ sources
  - ➢Low energy threshold measurement
  - ➢Summing at software & hardware level





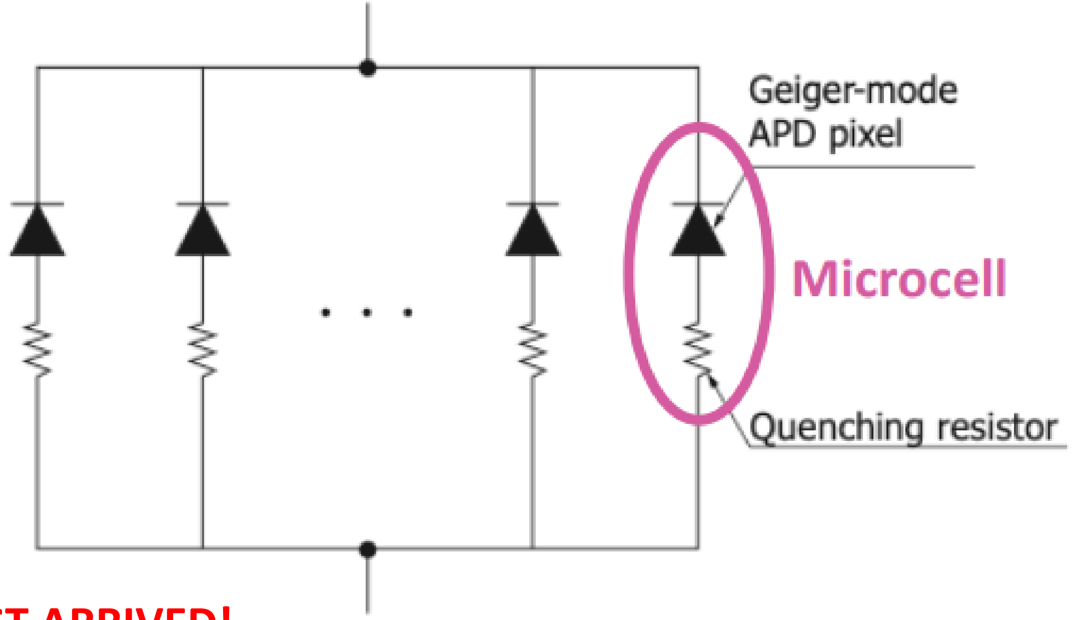
Silicon Photomultipliers (SiPMs)

$4mm \times 4mm$



2x2 array of $6mm \times 6mm$

- Dense array of single photon avalanche diode (SPAD)
- Photon detection efficiency, single photon time resolution, SiPM signal response, gain fluctuation, prompt and delayed cross talk, etc.



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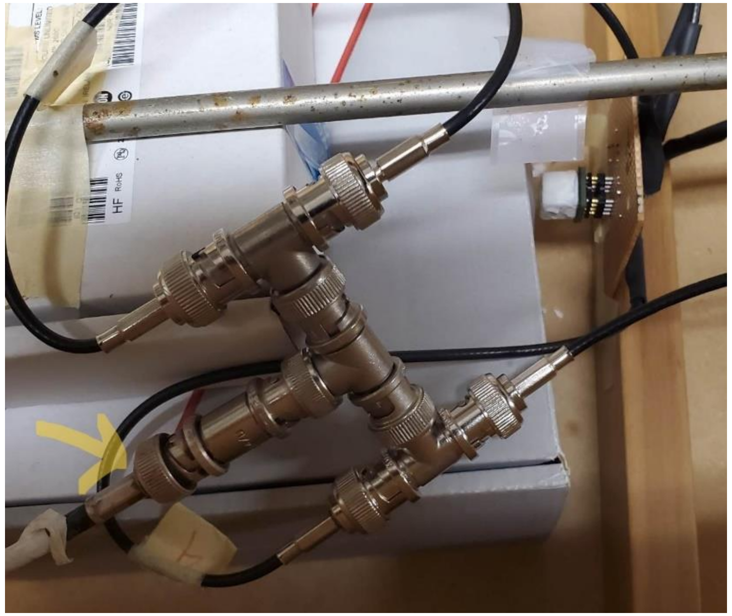
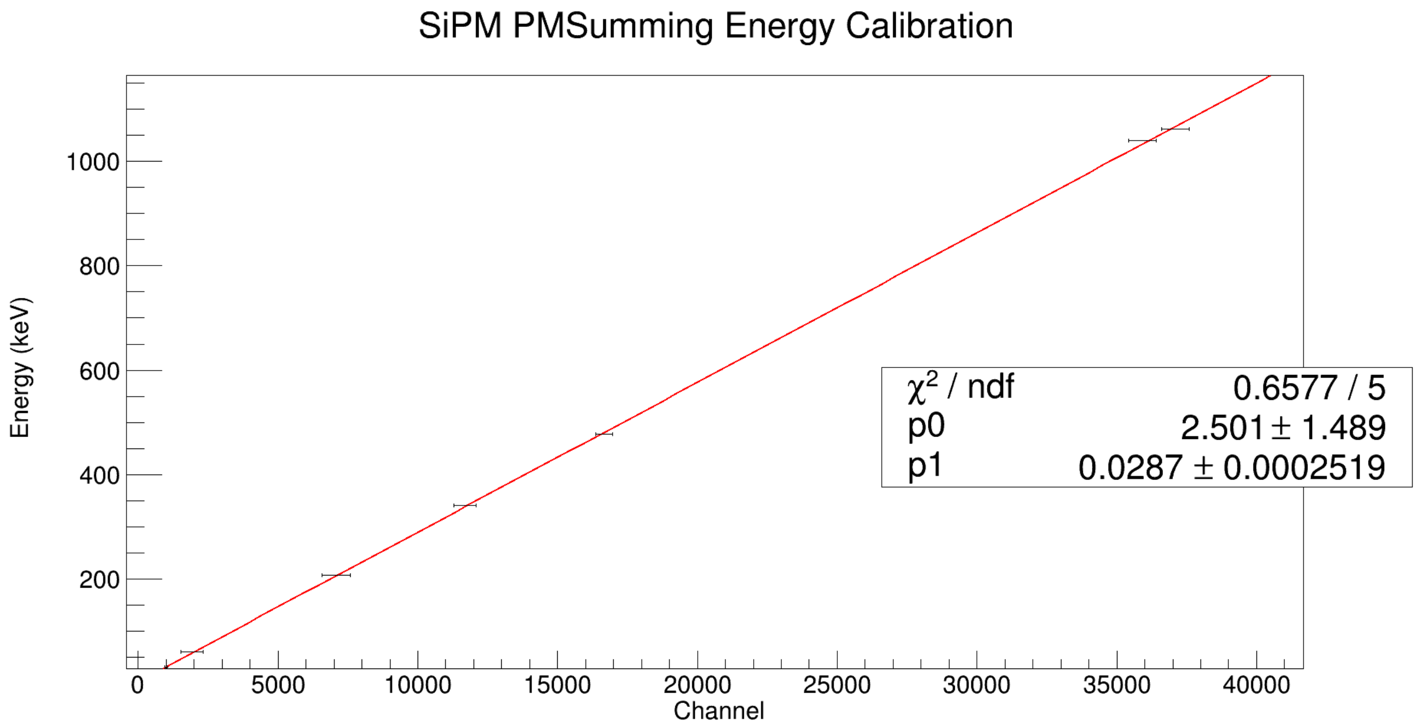
- *MicroFJ-SMA-40035-GEVB (OnSemi)*
- *2x2 Array of ArrayJ-60035-4P-PCB (OnSemi)*
- *1x15 Array of S14161-0686 (Hamamatsu)*
- *4x4 Array of S14161-6050HS-04 (Hamamatsu)* **JUST ARRIVED!**

Summing

"Poor man's summing" at hardware level

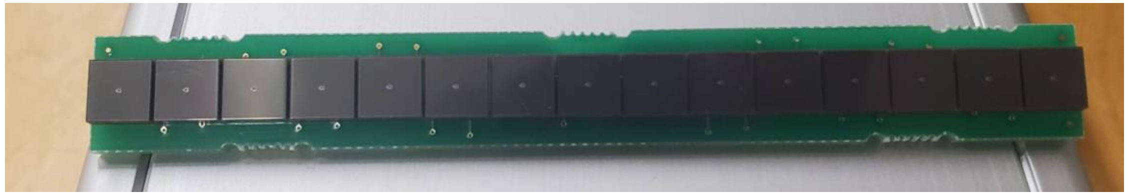




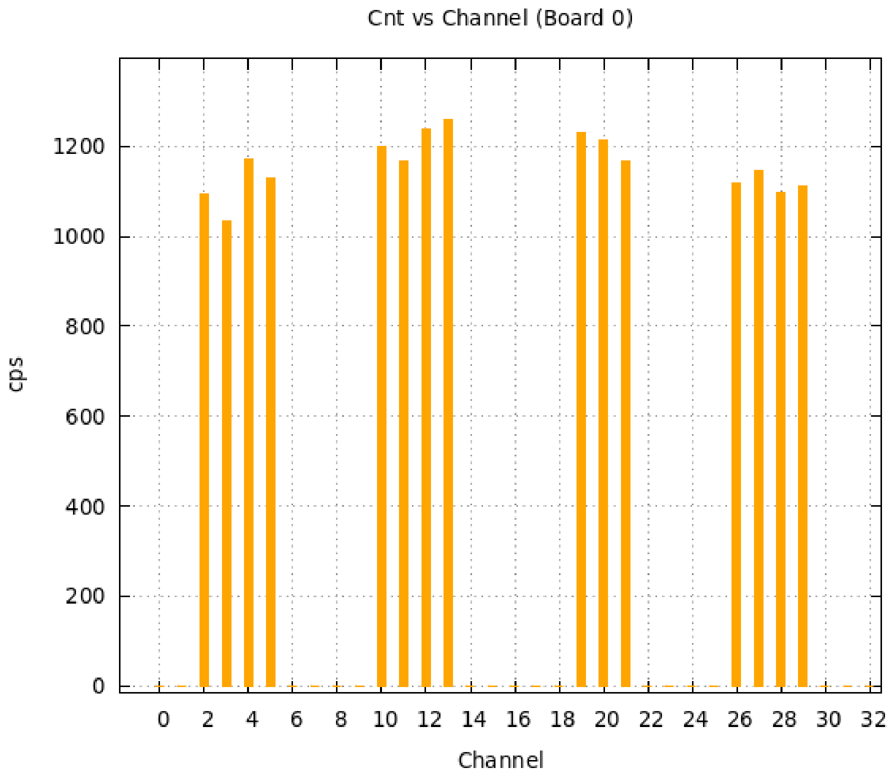
- ➢Reduced noise/event rate allowed to go low threshold settings
- ➢Impedance mismatch

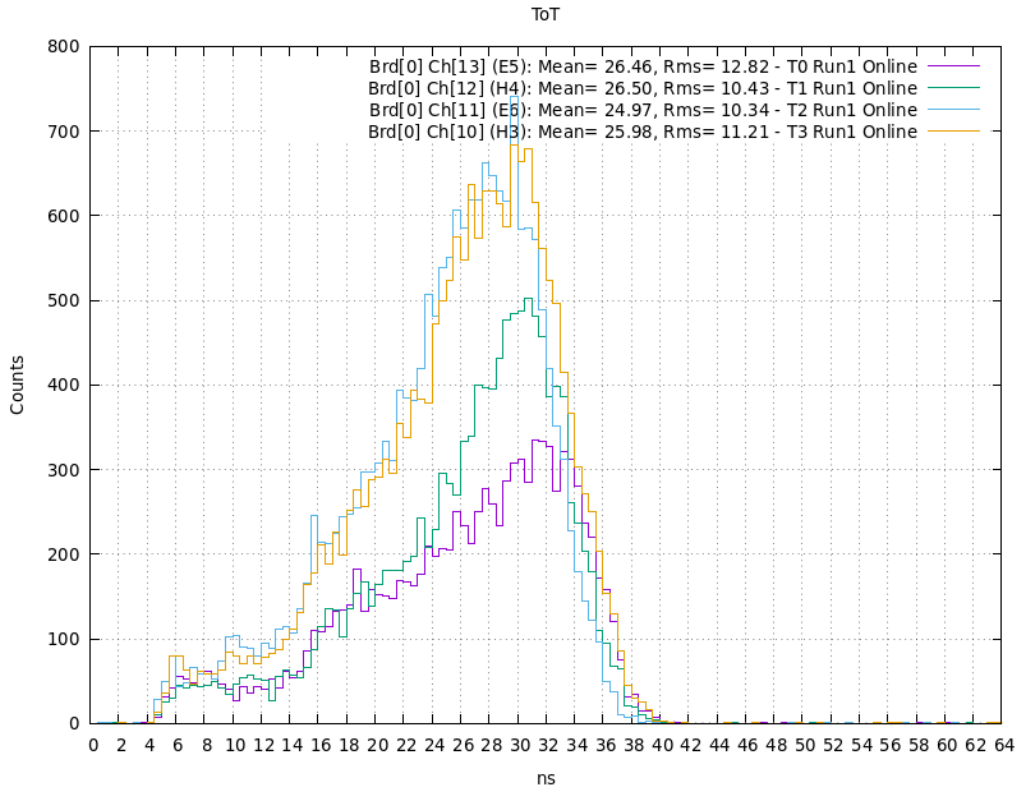
Need to test on industrial summing boards (readily available for 8x8 arrays)

1x15 SiPM with ASIC

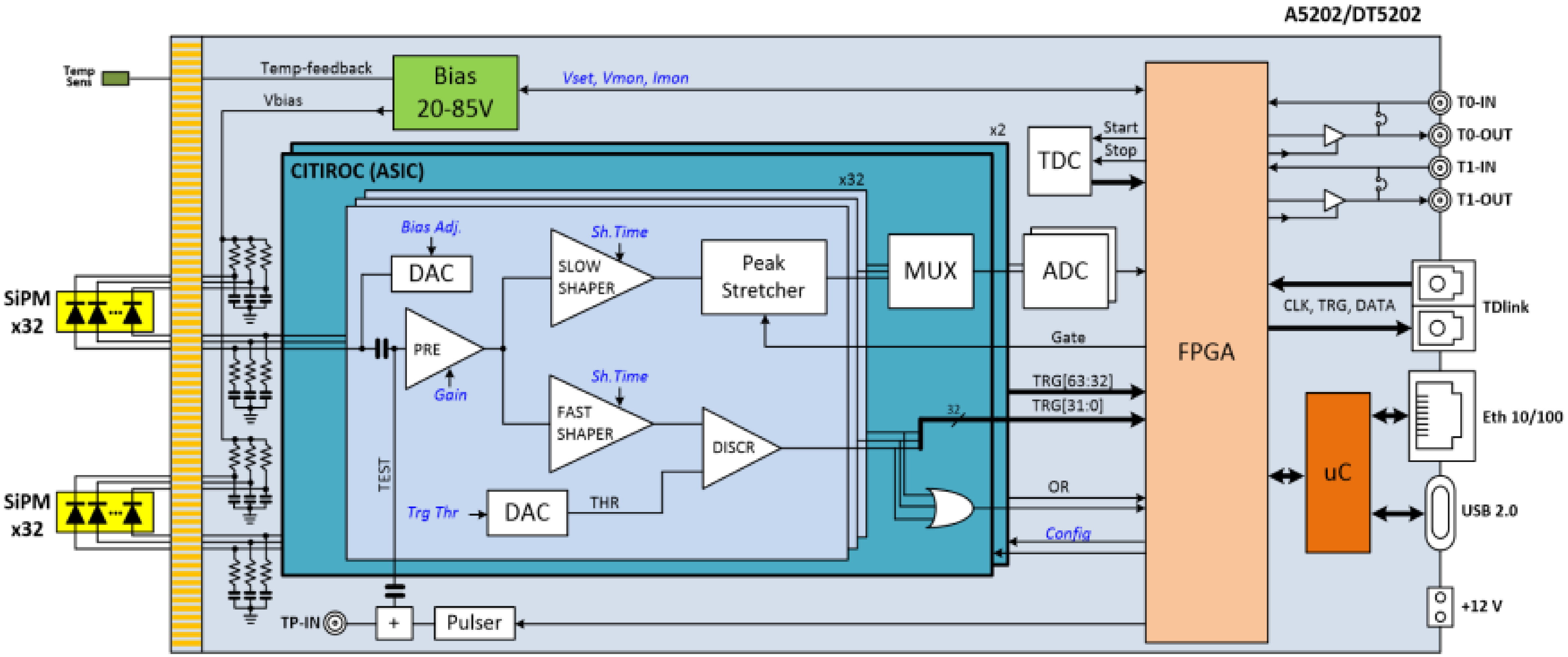


Live feedback during acquisition





FERS-5200 A5202



Emitter Excited States

- Neutron emission is a two-body process: daughter nucleus & emitted neutron
- Conservation of energy:

$$m\left({}_{Z}^{A}Y_{N}\right)c^2 = m\left({}_{Z}^{A-1}Y_{N-1}\right)c^2 + E_x' + T_R + m_n c^2 + T_n$$

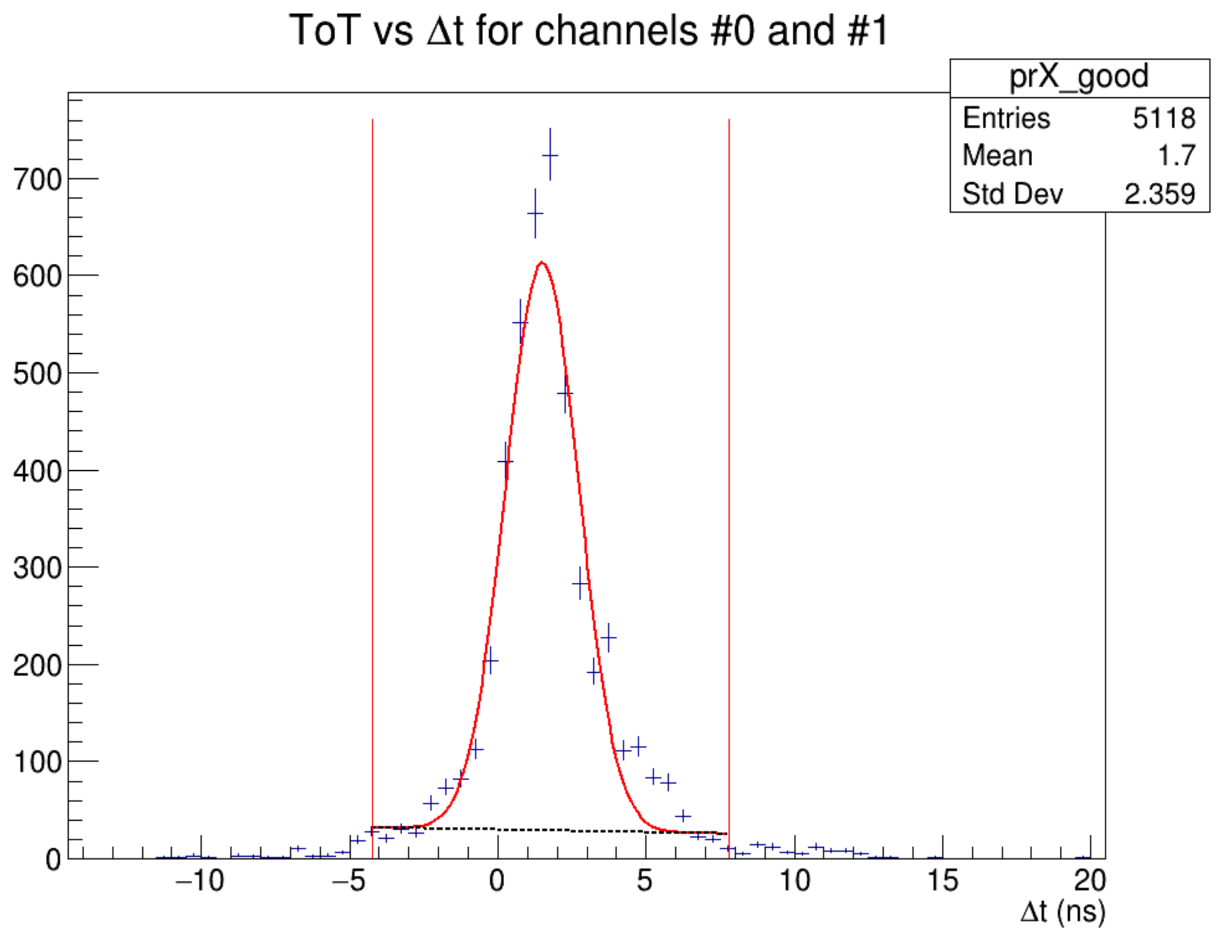
- Rewrite in terms of neutron separation energy:

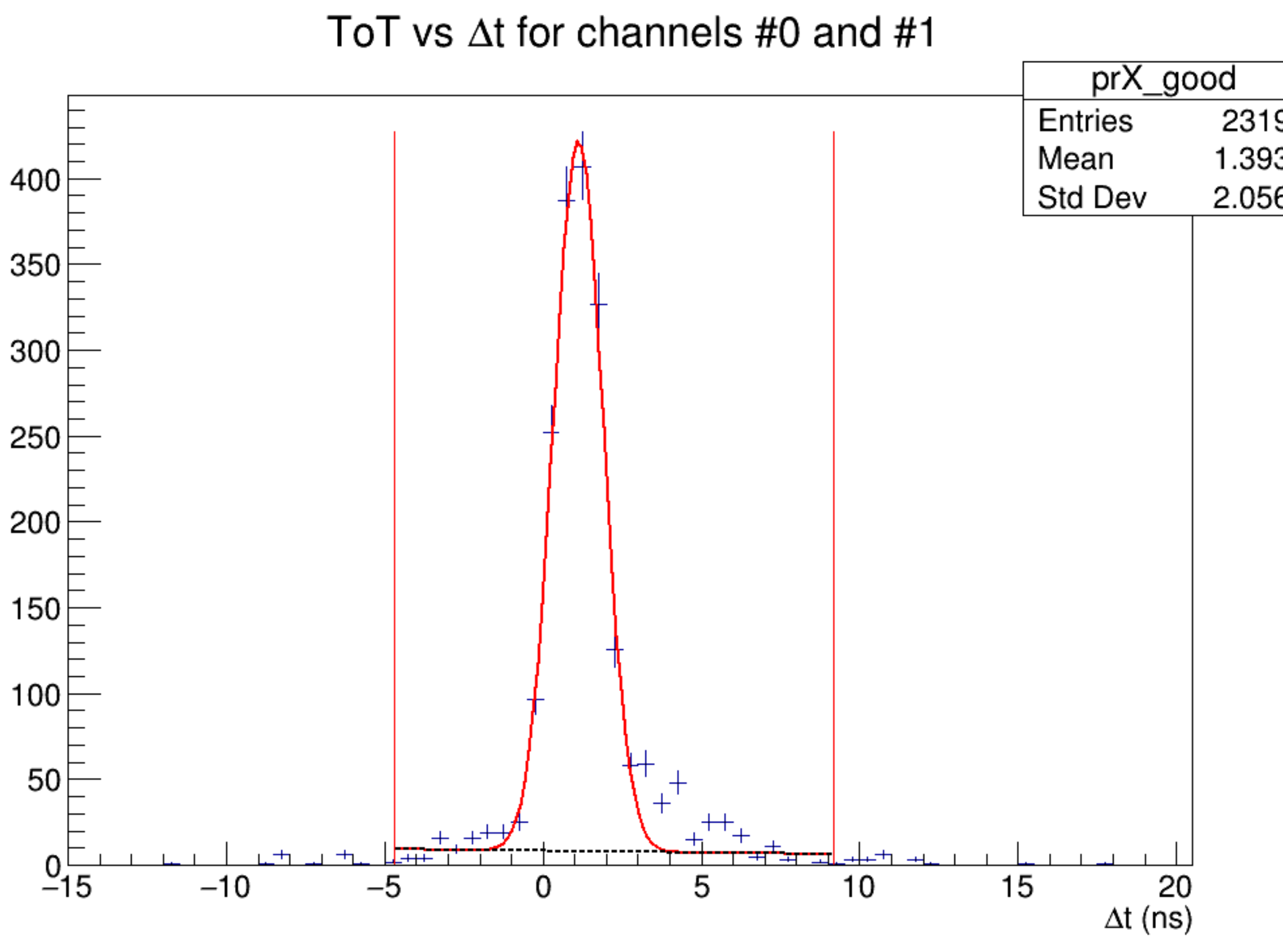
$$S_n = \left(m\left({}_{Z}^{A-1}Y_{N-1}\right) - m\left({}_{Z}^{A}Y_{N}\right) + m_n\right)c^2$$

$$T_R = T_n\left(\frac{m_n}{m_R}\right) \approx \frac{T_n}{A-1}$$

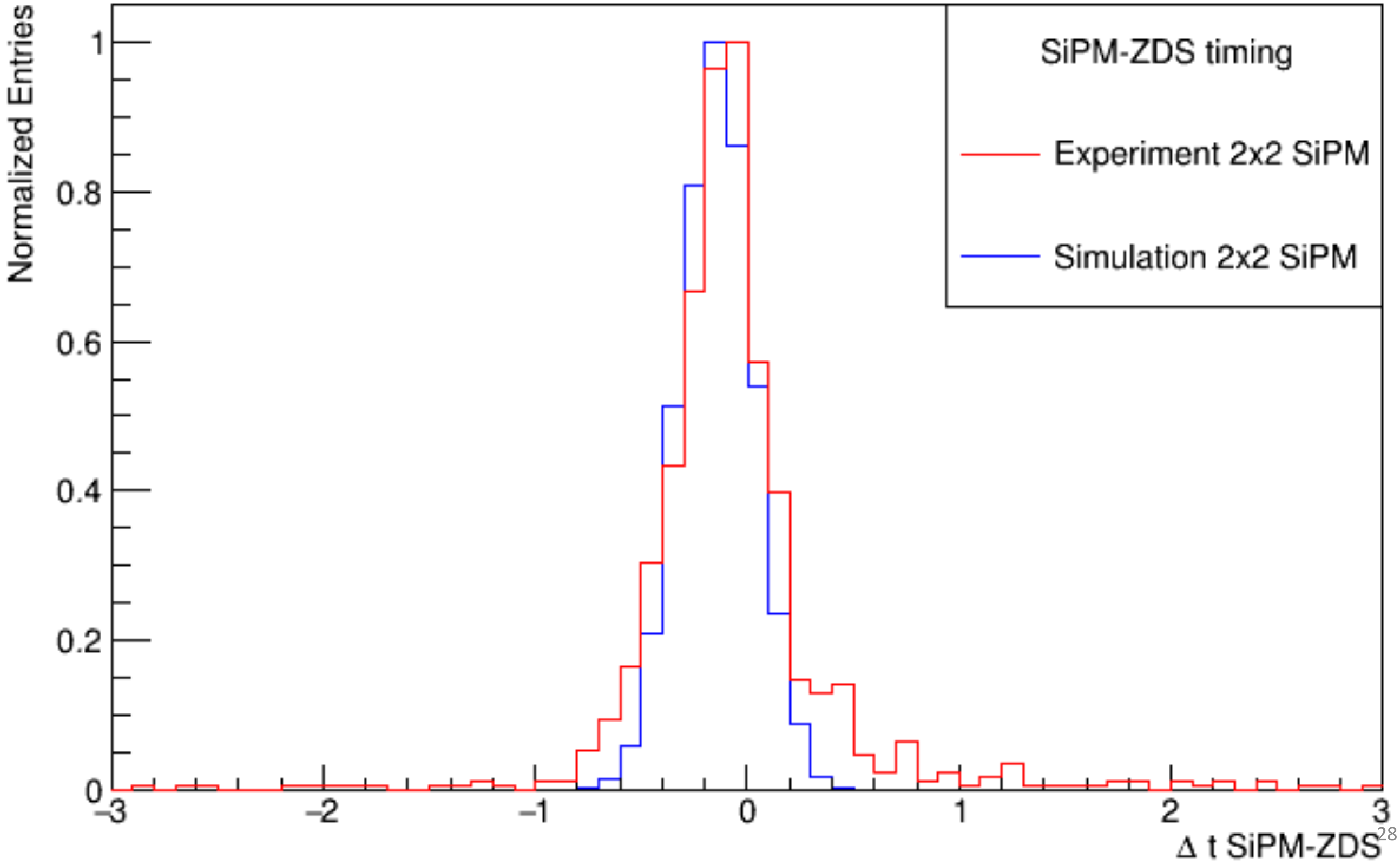
- Obtaining a more simplified form:

$$E_x = E_x' + S_n + \frac{A}{A-1}T_n$$

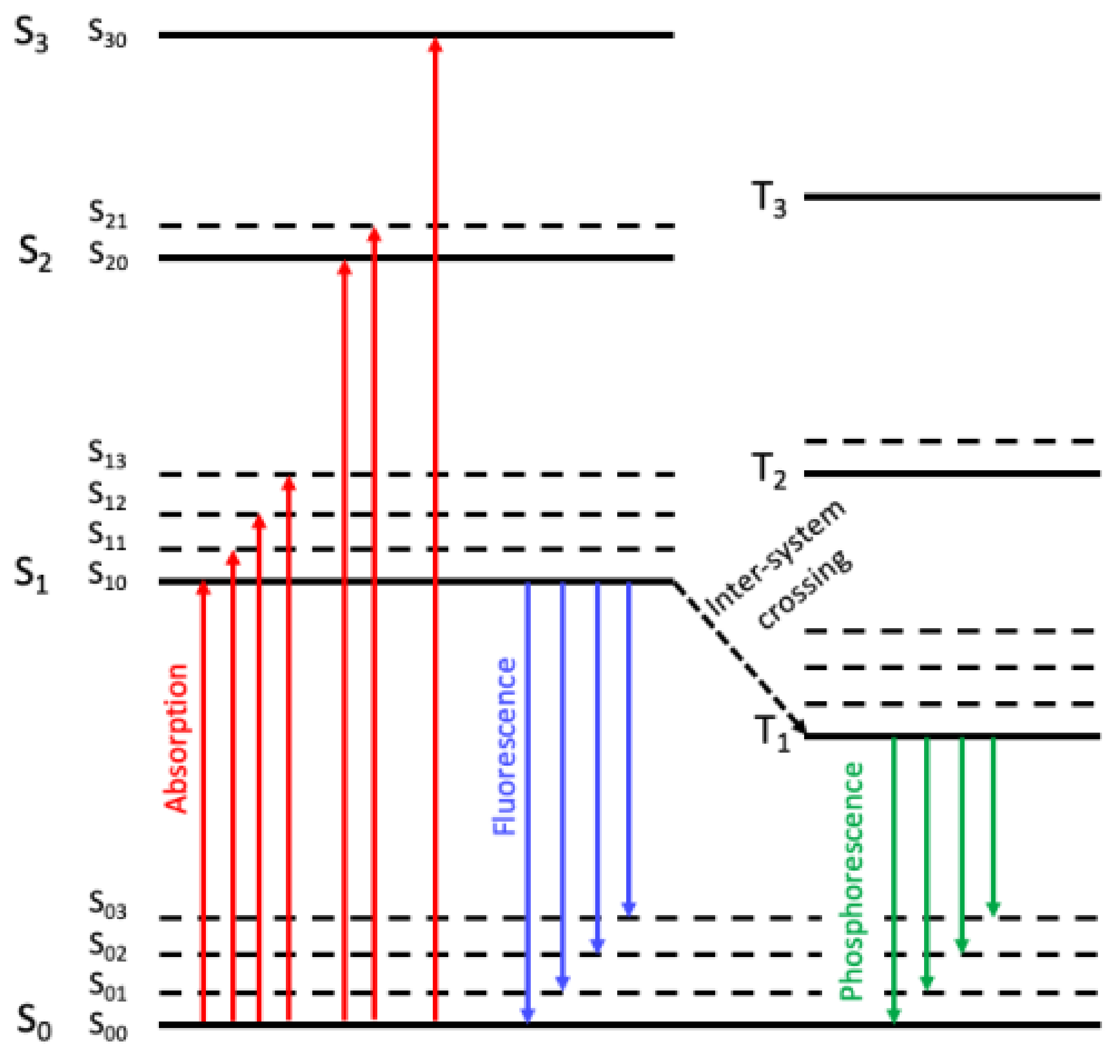




Operating Voltage:	**41.3 V**	**43.3 V**
SiPM0-SiPM1 dT FWHM w/ high ToA cut	2.07(3) ns	1.69(2) ns
SiPM0-SiPM1 dT FWHM w/ high ToT cut	2.92(7) ns	1.85(4) ns
ZDS-SiPM1 dT FWHM w/ 10 ns ToT cut	5.44(44) ns	2.73(17) ns



Normalized Entries
1
0.8
0.6
0.4
0.2
0
−3
−2
−1
0
1
2
3
SiPM-ZDS timing
Experiment 2x2 SiPM
Simulation 2x2 SiPM
Δ t SiPM-ZDS



S3
S30
S21
S2
S20
T3
S13
T2
S12
S11
Inter-system crossing
S1
S10
Absorption
Fluorescence
T1
Phosphorescence
S03
S02
S01
S0
S00