A Neutron Spectrometer for General Fusion

generalfusion®

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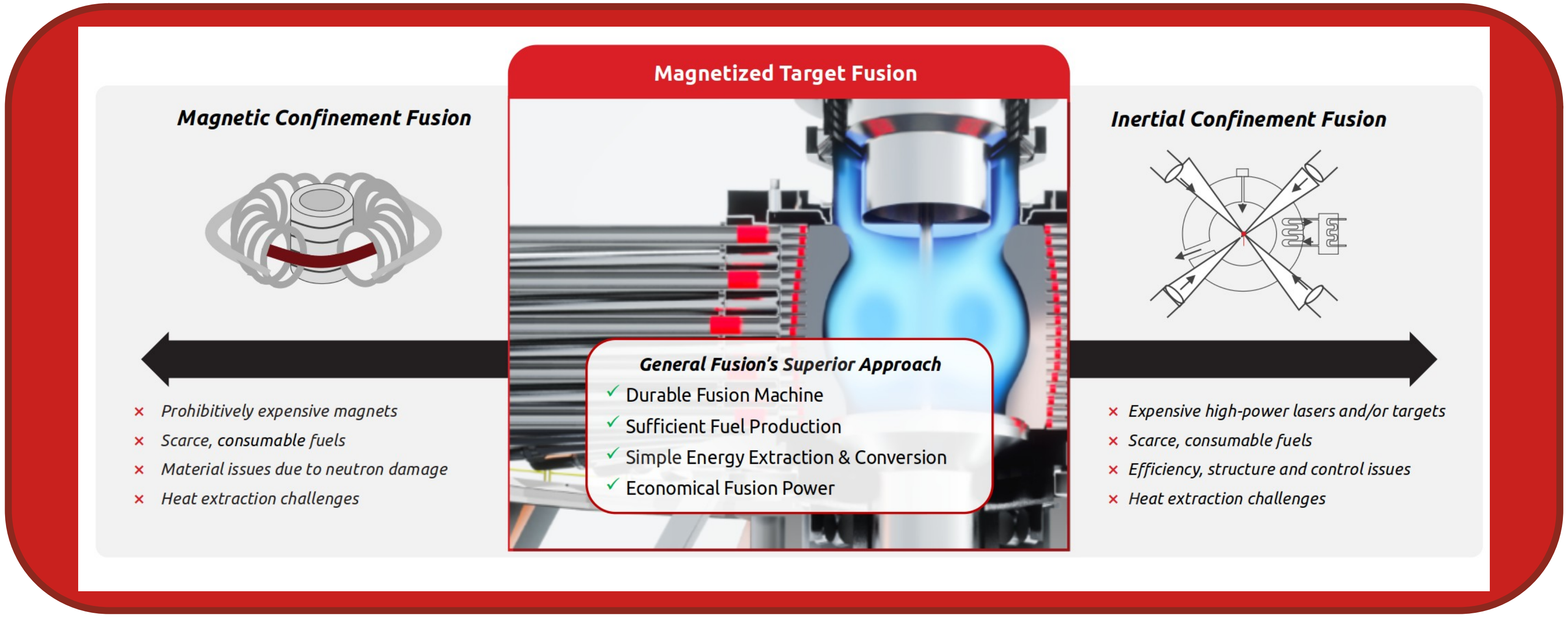
TRIUMF

Outline

- Introduction to General Fusion
- Design of Neutron Spectrometer
- SiPM and Scintillator Testing

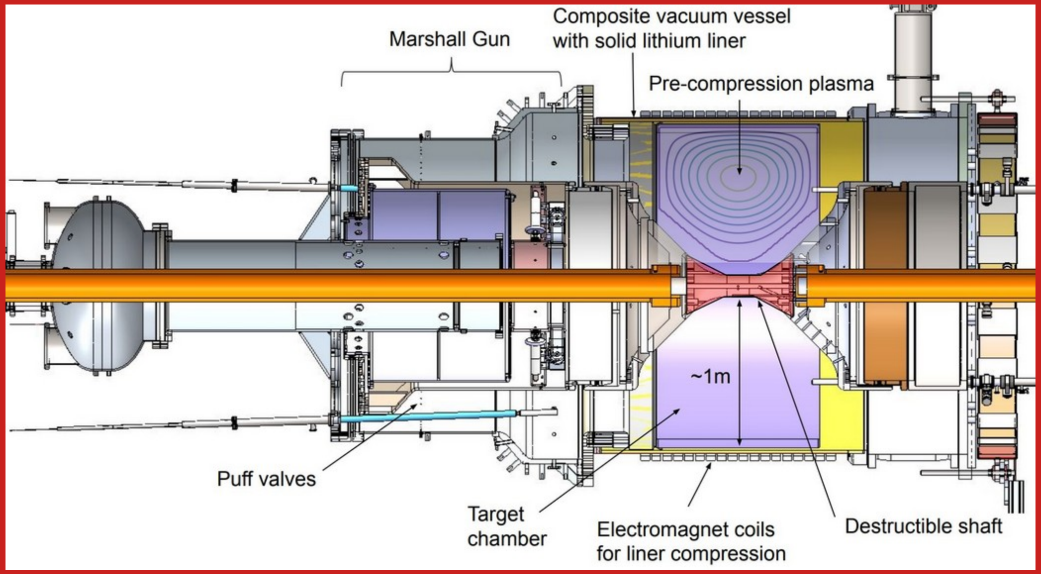
General Fusion

- General Fusion is a private fusion company in Richmond, BC which aims to revolutionize the world's energy production by developing fusion power plants using unique Magnetized Target Fusion (MTF) approach
- Compressing a lithium liner solves many of fusion's challenges:
  - Neutron absorption to prevent structure irradiation
  - Tritium production to maintain fuel
  - Heat exchange to get energy out



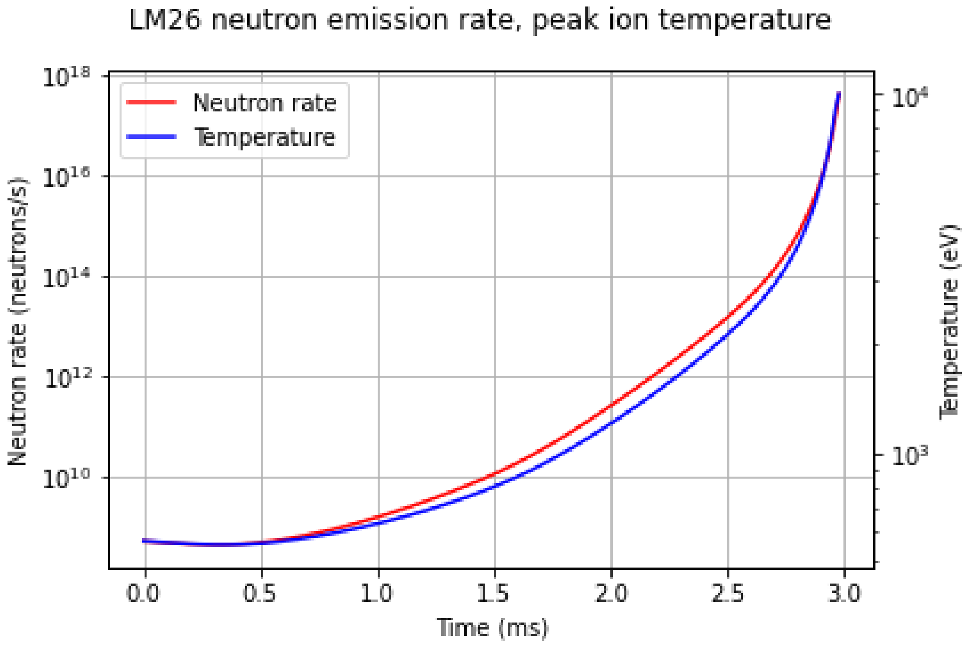
LM26

- Lawson Machine 2026 (LM26) is a prototype machine that aims to demonstrate the feasibility of mechanically compressing plasma
- Goal of reaching temperatures of 10+ keV
- Eventually reach Lawson criteria
- Compressions of D-D fuel with solid lithium liner



D-D Fusion and the Need for a Neutron Spectrometer

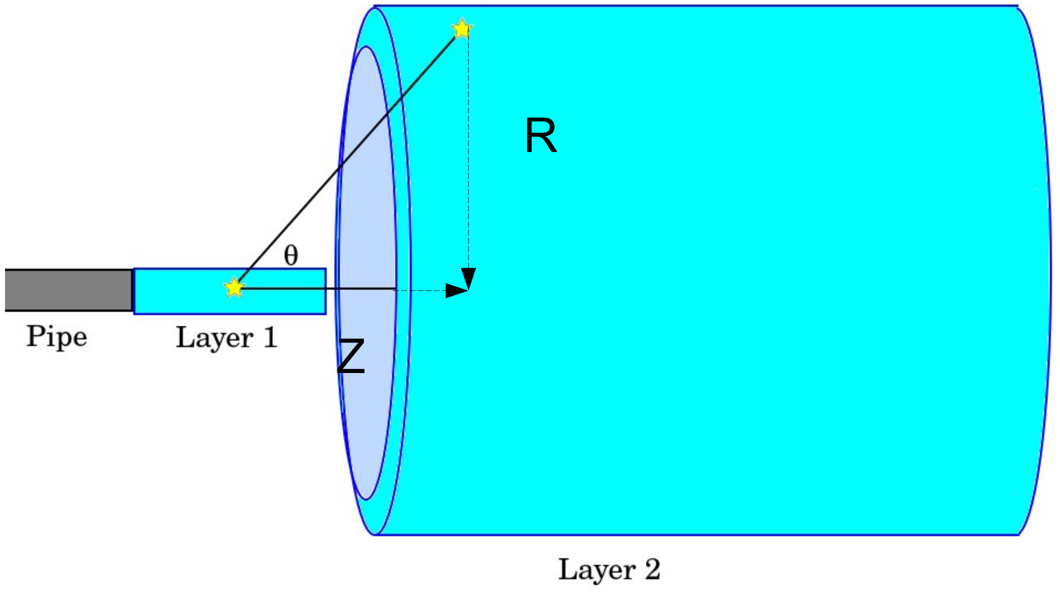
- D-D Fusion creates 2.45 MeV neutrons
- Temperature of the plasma is key metric in determining LM26 success- goal of 10+ keV
- Thermal motion of plasma causes apparent broadening of 2.45 MeV neutron energy peak
- At 10 keV plasma, this corresponds to 99.9% of the neutrons having energies from ~2-3 MeV
- Collimate the neutrons coming from the plasma, and they can be used to measure the temperature
- Neutron energy can be measured with a time-of-flight neutron spectrometer



$$\sigma_T = \frac{82.5\sqrt{T}}{2\sqrt{2ln(2)}} = 110.79(T = 10keV)$$

Multilayer Coaxial Time-of-Flight Neutron Spectrometer Design

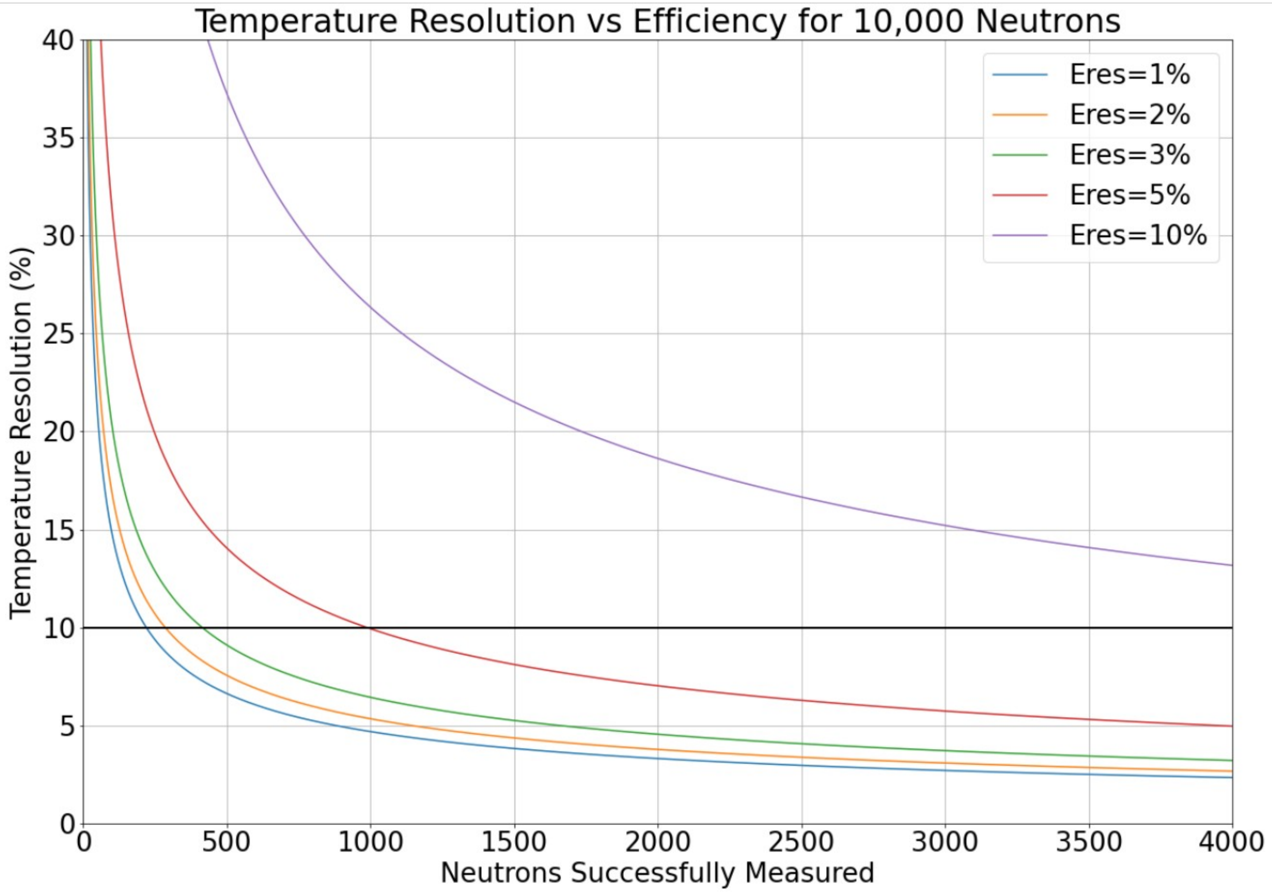
- Principle: Can reconstruct energy of a particle if you have two interaction points and the time of flight and scattering angle between them
- Use plastic scintillator in two layers:
  - A first block called Layer 1 at the end of a 1.5 cm diameter collimator
  - A hollow cylindrical shape Layer 2 that is positioned to be at the most common scattering angles of the neutrons off of Layer 1
  - In cylindrical coordinates, where Z is the axial distance travelled between an interaction point in Layer 1 and Layer 2, R is the radial distance travelled, and t_{TOF} is the time of flight:



$$E_n = \frac{m_n(R^2 + Z^2)^2}{2Z^2 t_{TOF}^2}$$

Spectrometer Requirements

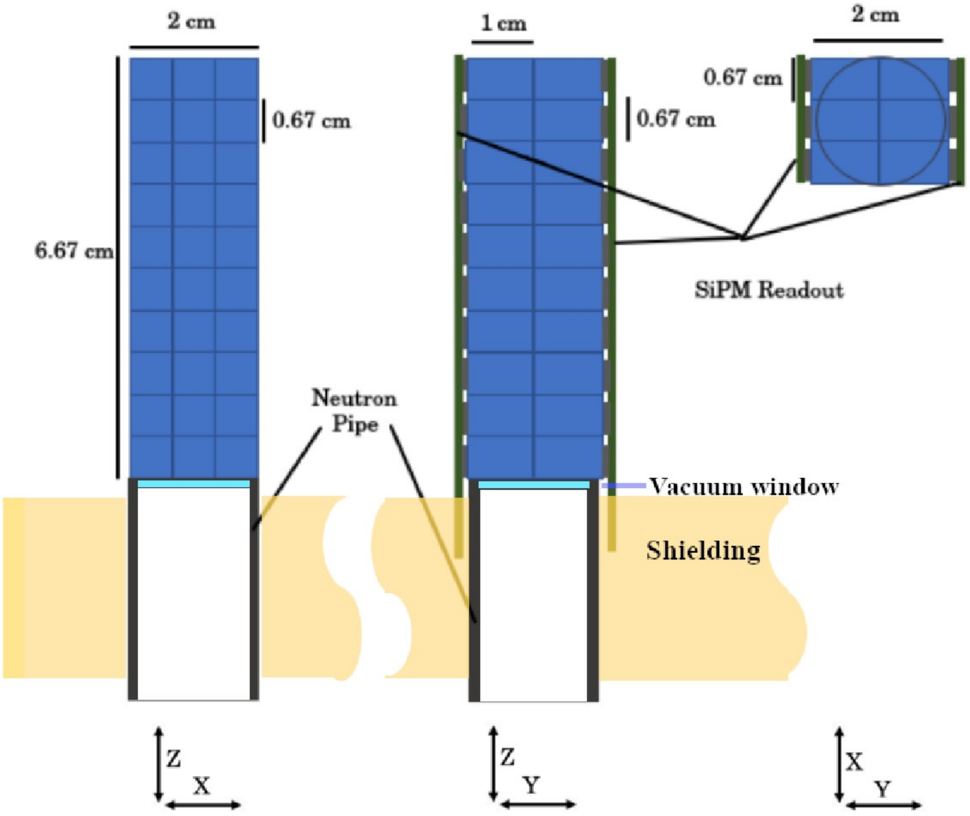
- Need to measure a few hundred neutrons at better than 3% uncertainty in energy
- Must be fast ~better than 150 ps resolution
- Must be precise in z dimension ~1 cm
- Must be able to distinguish between interactions coming ~1 ns apart



Layer 1 Design

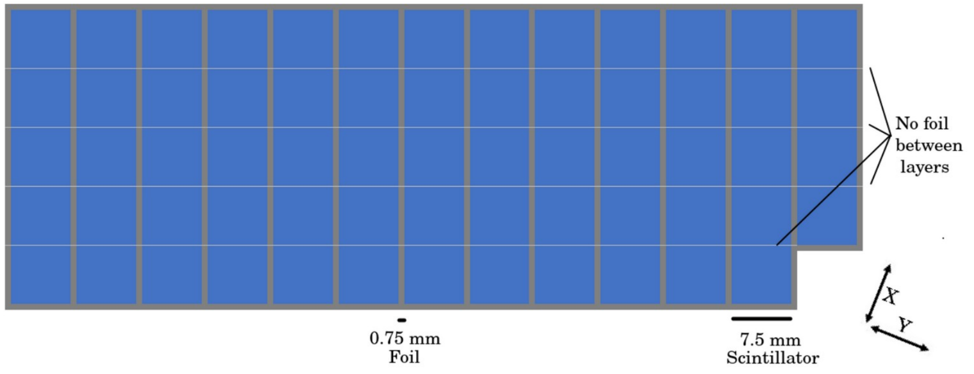
- Layer 1 must be finely segmented to prevent pileup
- Use Eljen EJ232Q plastic scintillator
    - Chosen for fast rise and fall time
- Layer 1 chosen to be about 7 cm long, between 1.5-2 cm wide to optimize number of interactions
- 60 bars of 1x0.67x0.67 cm^3
- Fully light isolate bars with reflective coating

Property	EJ-232Q (0.5% Doped)	EJ-230
Neutron Spectrometer Usage	Layer 1	Layer 2
Scintillation Efficiency (γ/1 MeV e-)	2,900	9,700
Rise Time (ps)	110	500
Decay Time (ps)	700	1500
Pulse Width, FWHM (ps)	360	1300



Layer 2 Design

- Layer 2 is made of long skinny bars of Eljen EJ230, chosen for its large light yield and good attenuation of light, necessary for long skinny bars
- Eight segments of 64 bars, arranged in groups 13x5 (with 1 gap, since readout electronics built for 64 channels)
- Light isolation in vertical segments (improves total light collection and potentially R information



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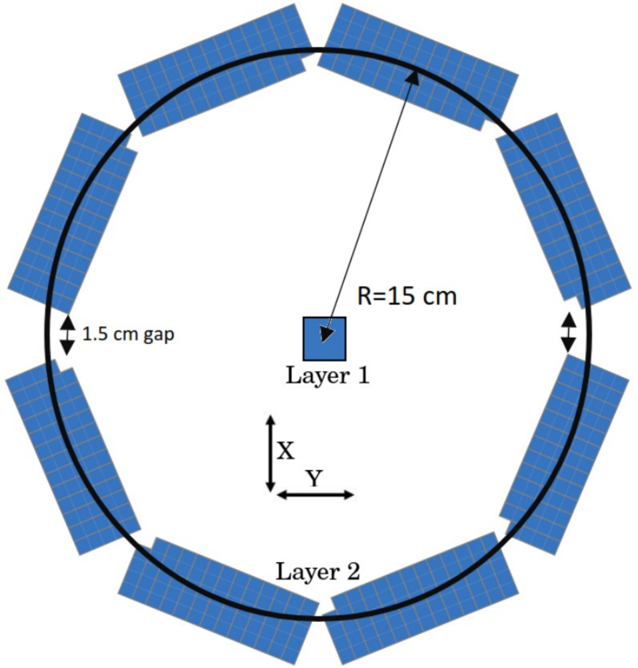
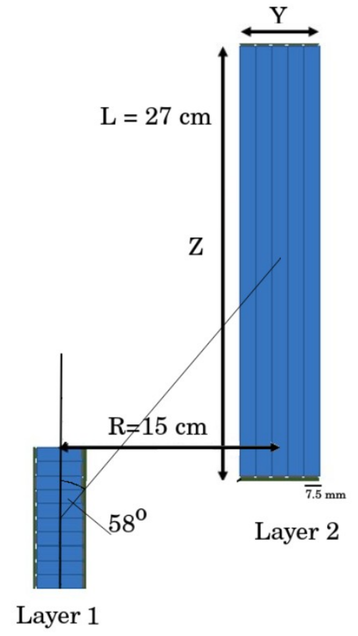




Risks

- Spectrometer Risks:

  - Poor Z-Resolution prevents us from reaching temperature resolution goal
    - Measure light sharing in Layer 2 bars, ensure we can measure to within ~1 cm

  - Poor tof-Resolution prevents us from reaching temperature resolution goal
    - Measure properties of SiPMs, electronics, and scintillator to ensure we reach goals
    - Future version use 3D Photon-to-Digital Converters (PDCs)

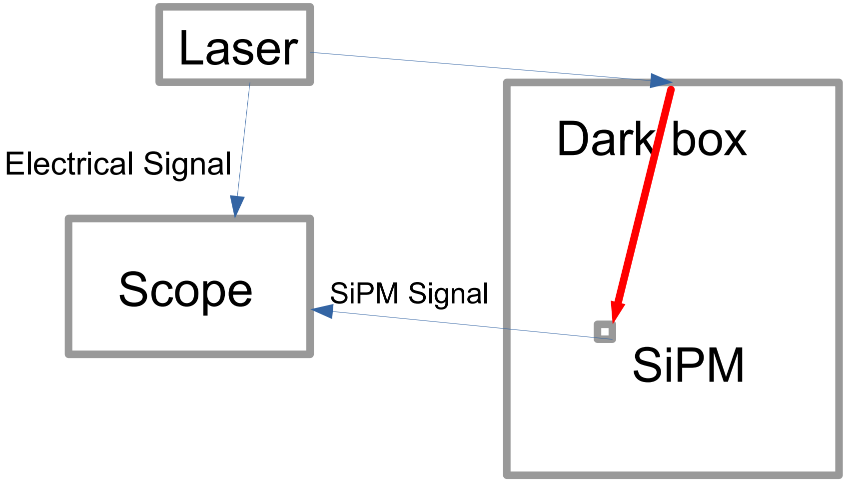
  - Events occurring during small time windows in Layer 1 lead to un-resolvable coincidences
    - Measure photons produced as a function of energy deposited in Layer 1 to maximize the number of events that can be distinguished. If necessary, adjust collimator to lower the rate through Layer 1

Electronics and Readout

- Broadcom AFBR-S4N44(66)P014M NUV-MT 4x4 or 6x6 mm^2
  Silicon PhotoMultipliers (SiPMs)
  - Chosen for fast Single Photon Timing Resolution (SPTR) and rapid re-arming
  - Two 6x6 mm^2 for each end of Layer 2 bars
  - One for each Layer 1 bar
- Tested custom readout electronics amplifier circuits
- Caen PicoTDC Time-to-Digital Converter
  - Time of threshold measurement for some energy discrimination

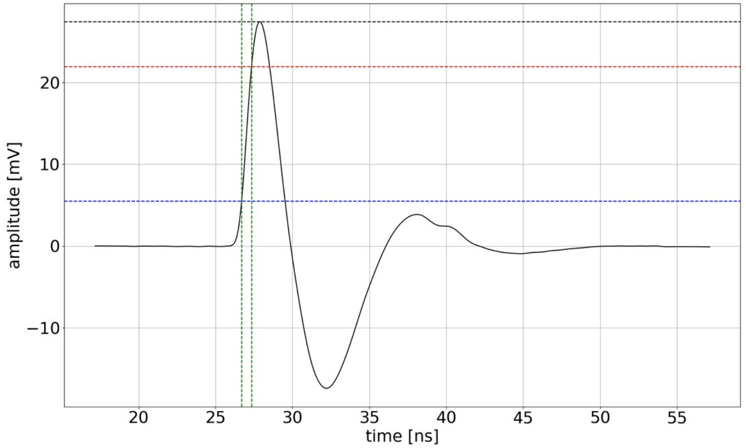
Amplifier Design

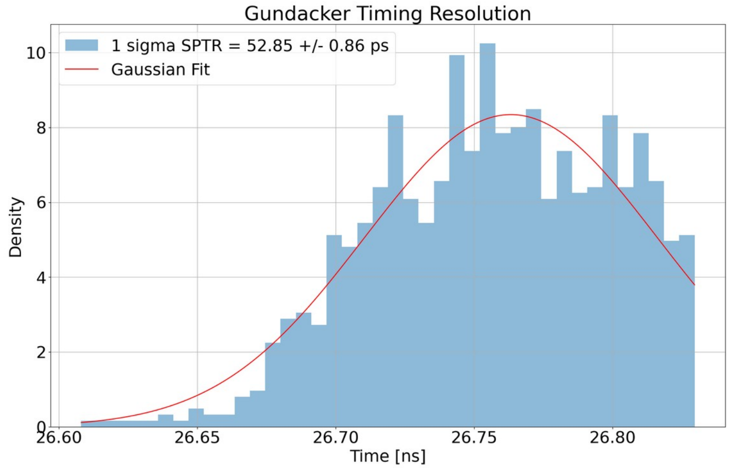
- Choose to minimize SPTR, noise, heat, must be linear in response to high number of photo-electrons
- Test SPTR by shining pulsed single photon laser on SiPM
- Time difference between laser trigger and measured pulse used to calibrate SiPM+amplifier SPTR

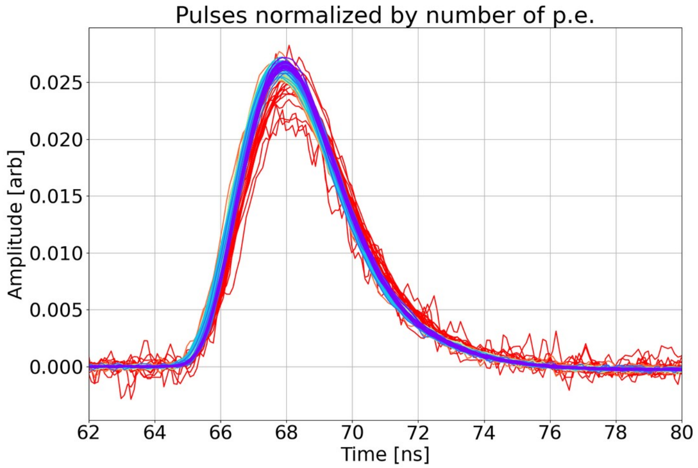


Amplifier Test Results

- Tested in house amplifier setup used for Darklite experiment- timing too slow
- Literature search showed Gundacker had obtained ~50 ps resolution, followed his design, achieved similar results, but pulse shape problematic for time-over threshold
- Two BGA729 amplifiers used, achieved ~70 ps resolution, consistent shape up to 220 pe
- Other configurations were too slow, too hot, or produced pulse shapes incompatible with using time over threshold

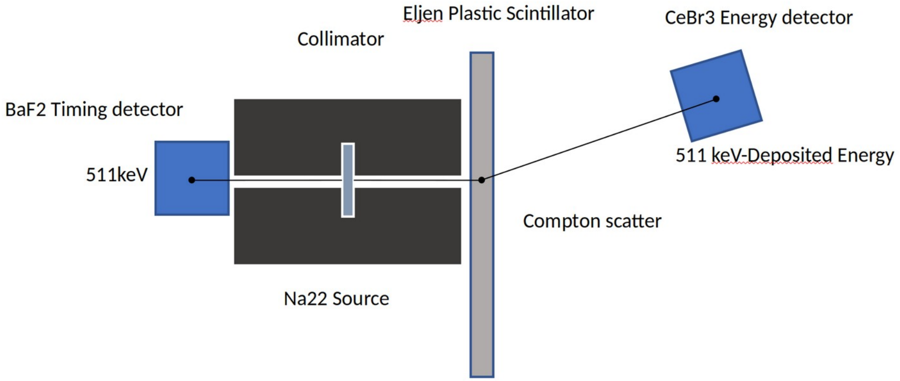


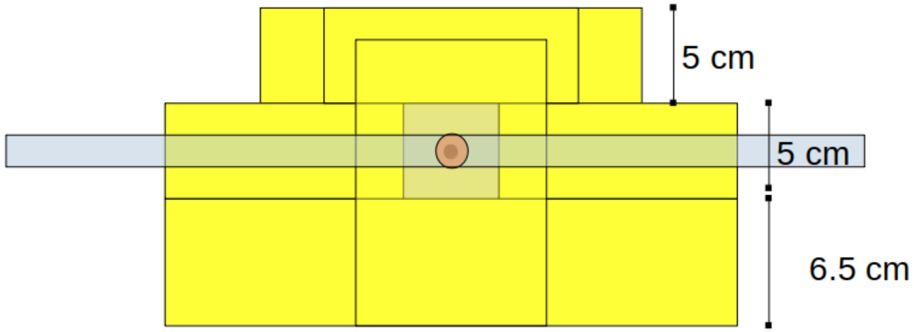


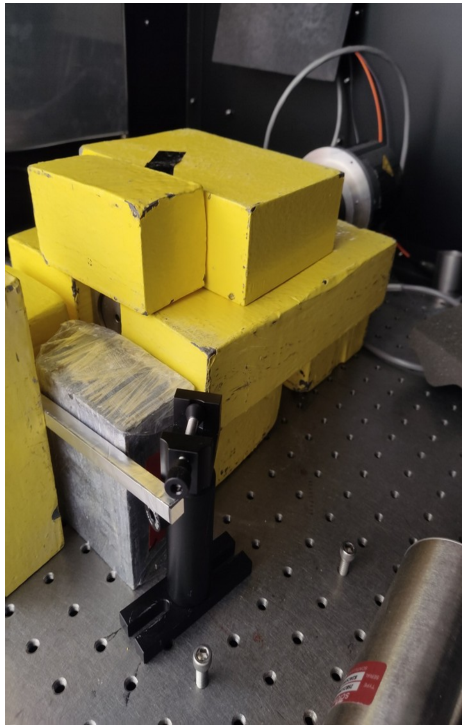


Gamma Test Setup

- Measure energy resolution and time resolution as a function of position in scintillator
- ^{22}Na source emits positrons- annihilate and emit back to back 511 kev gammas
- Use gammas to measure timing resolution of scintillator bars
- Use gammas to measure position resolution of Layer 2 bars
- BaF_2 detector to time stamp gamma
- $CeBr_3$ to measure energy of scattered gamma







Summary

- General Fusion wants to demonstrate the feasibility of MTF and revolutionize the way we produce energy
- To prove the approach is working, need to measure temperature: Use a neutron spectrometer
- Parts testing is underway at TRIUMF to ensure the requirements of the neutron spectrometer can be met, assembly next year
- Challenging measurement with analog SiPMs, pursue PDCs