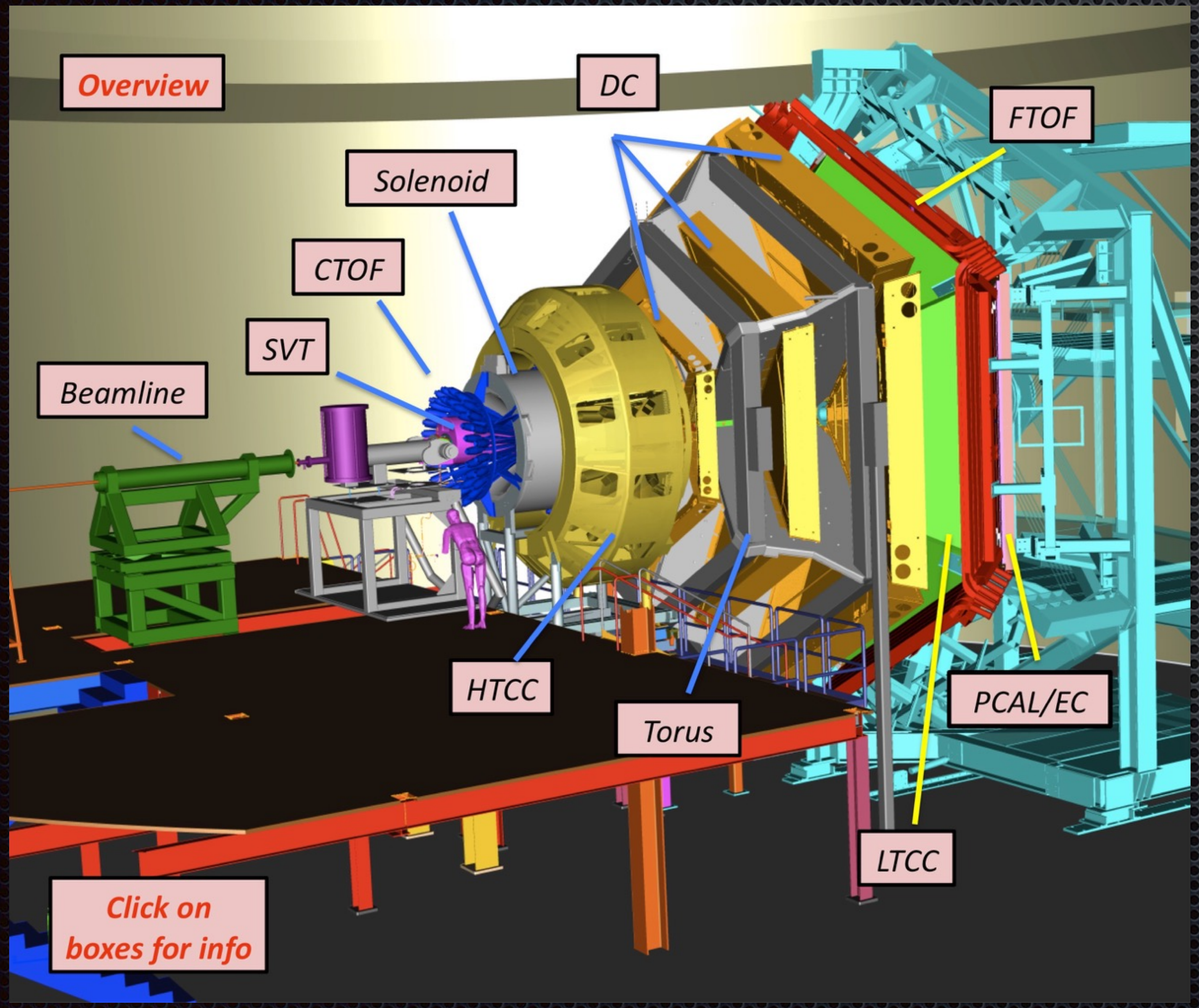
Forward Time of Flight: CLAS12 upgrade

By: Nick Tyler

University Of South Carolina

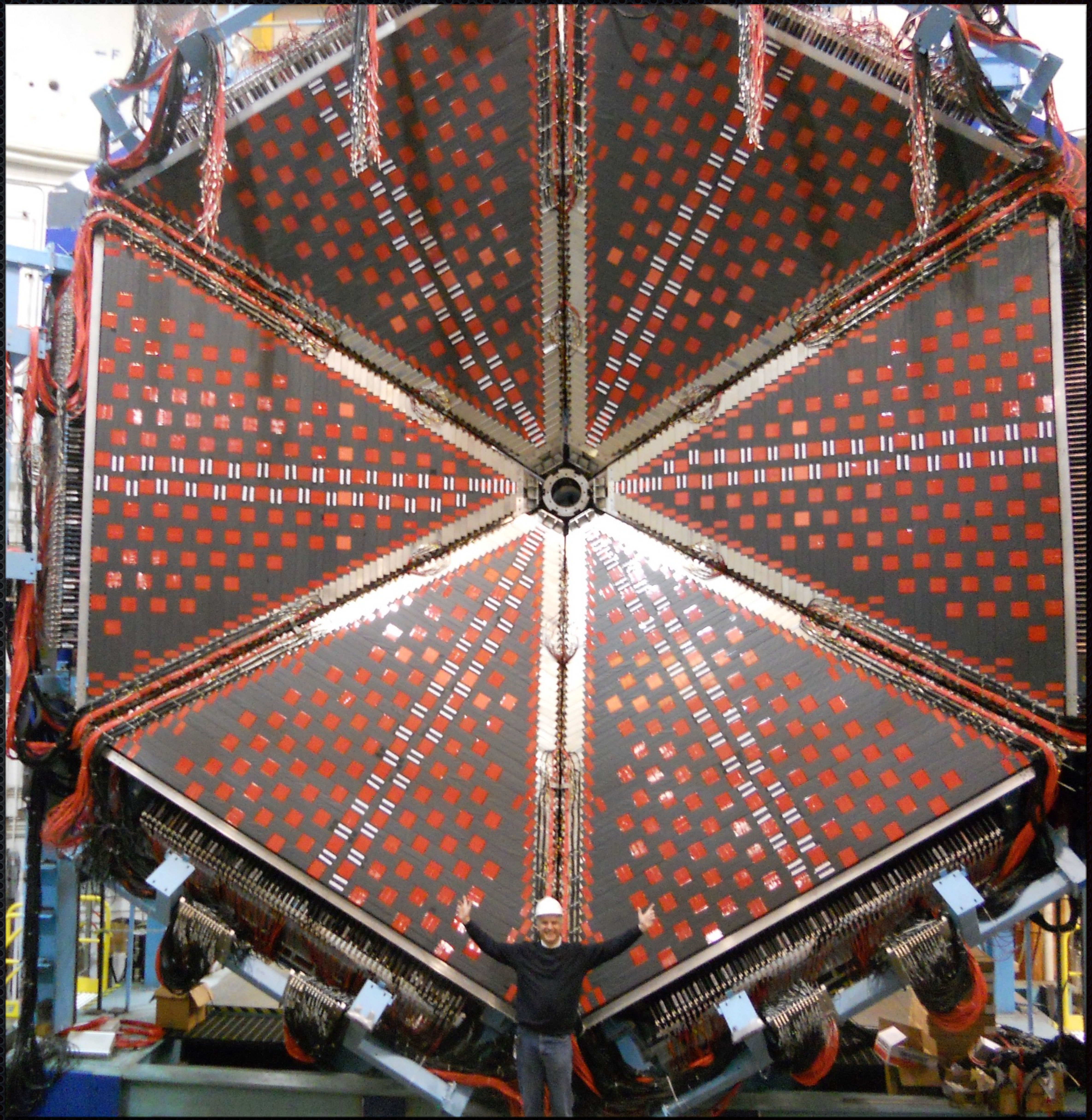


Overview

- What is TOF?
  - What does TOF do?
  - How does it work?

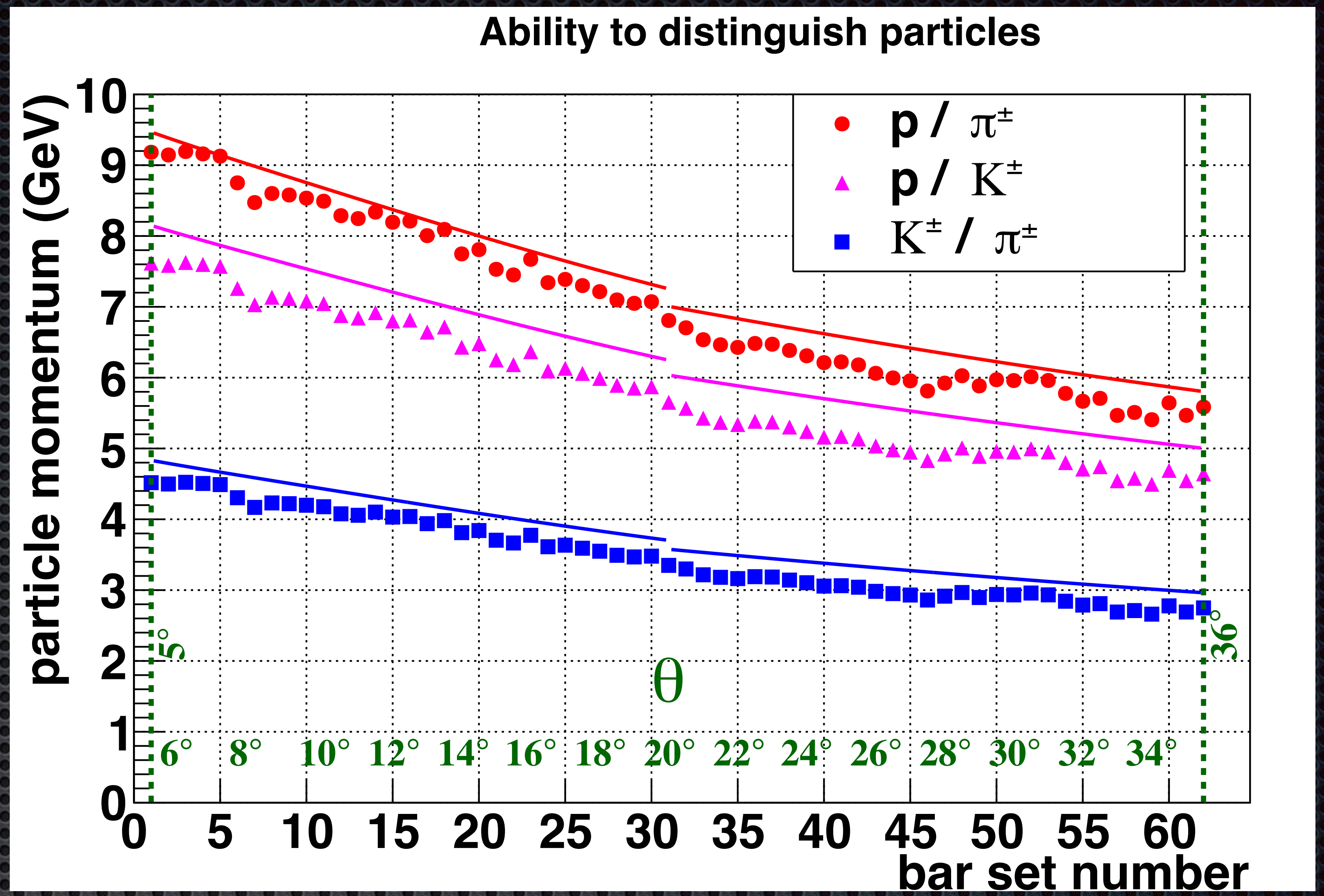
- Complications
  - Attenuation Length
  - Decay Time
  - Calibration

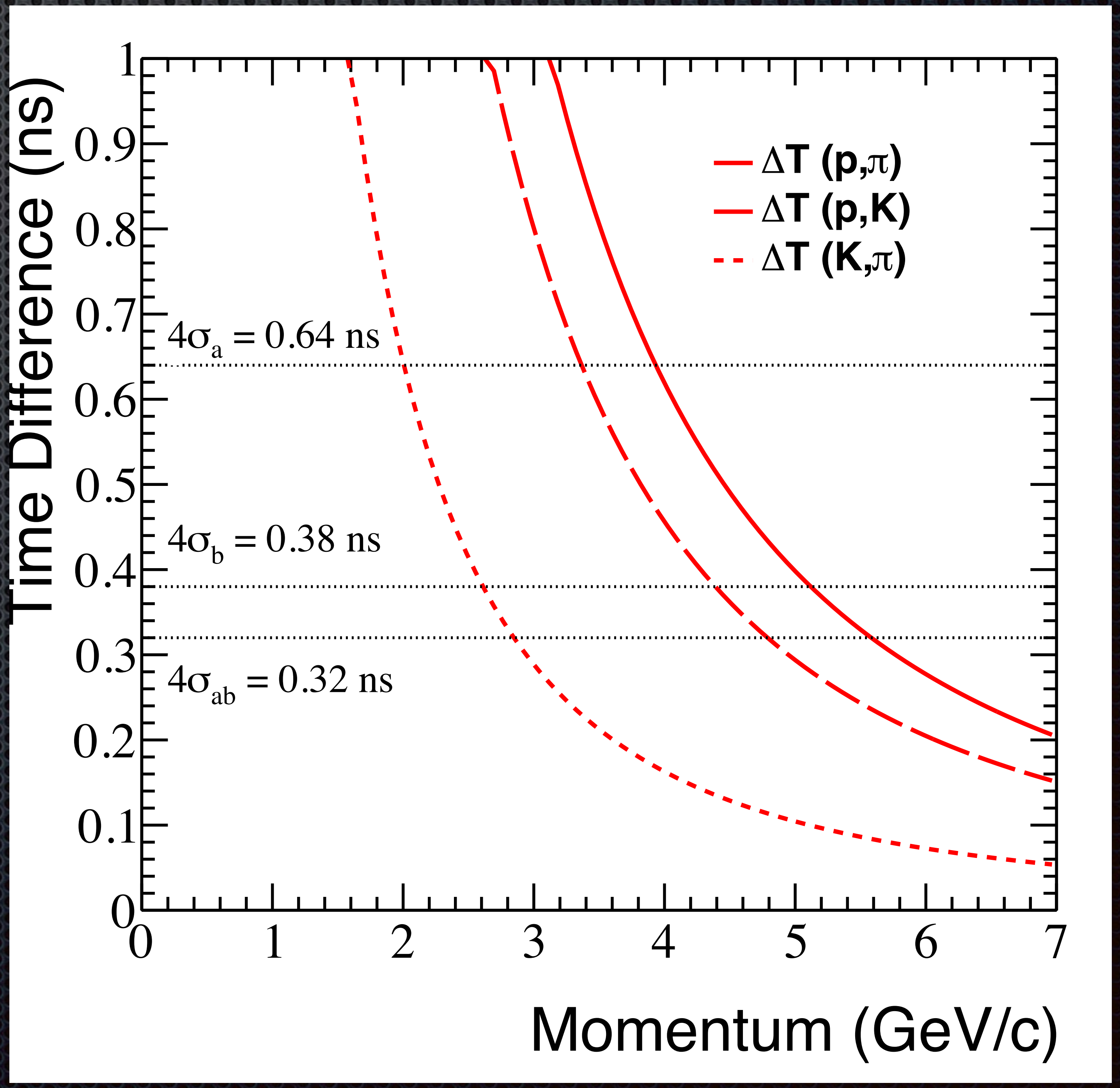
- Performance
  - Why the upgrade?
  - Results



Time Of Flight

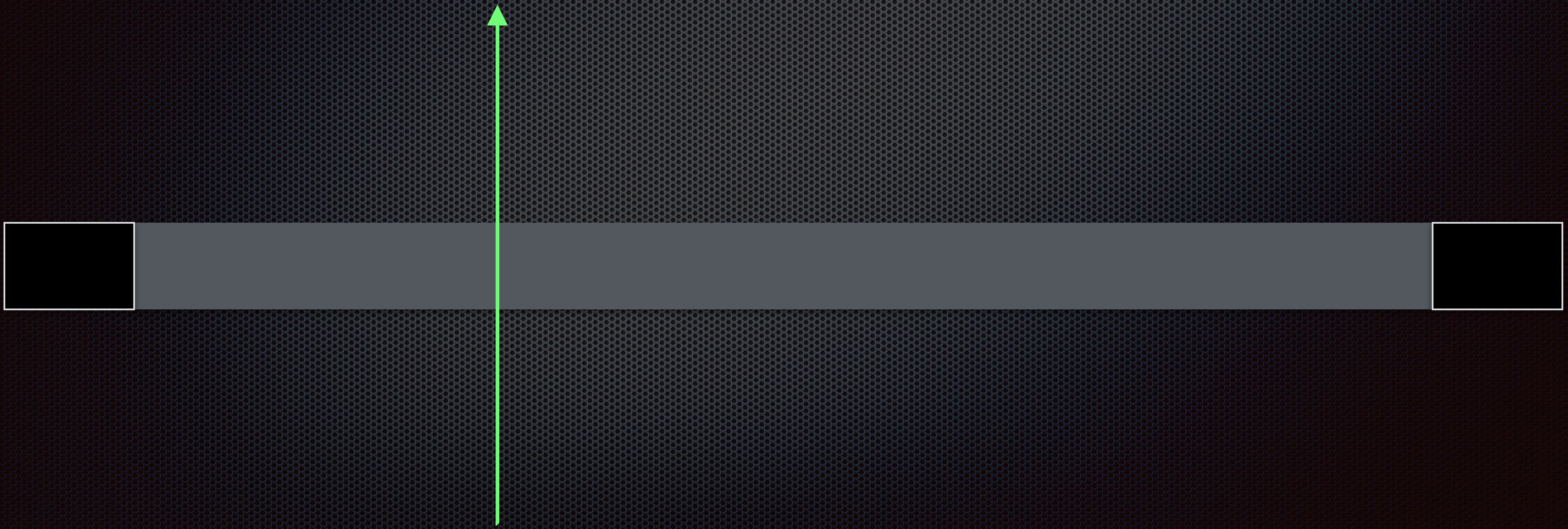
- Useful in particle identification
- Higher momentum particles take less time to reach detector
- High resolution is important to distinguish individual particles





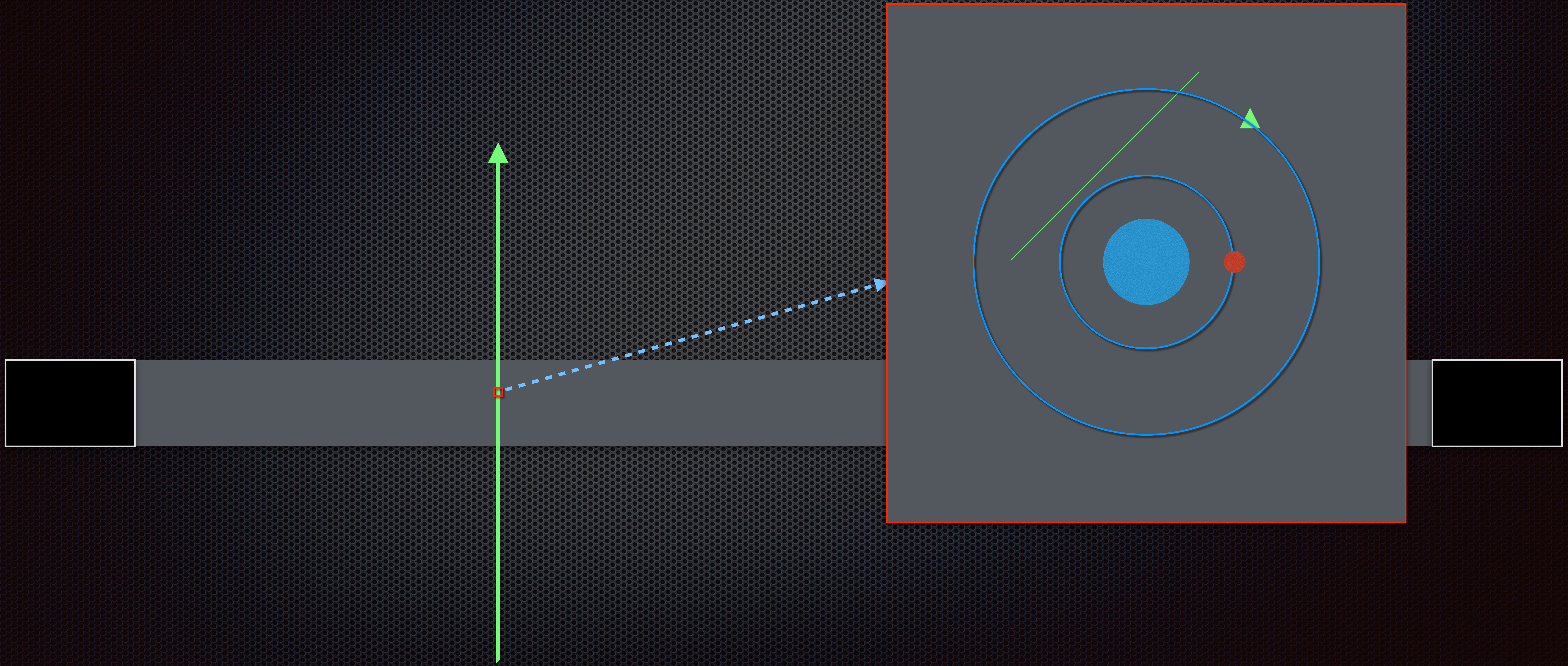
How it works

- Charged particles enter scintillator



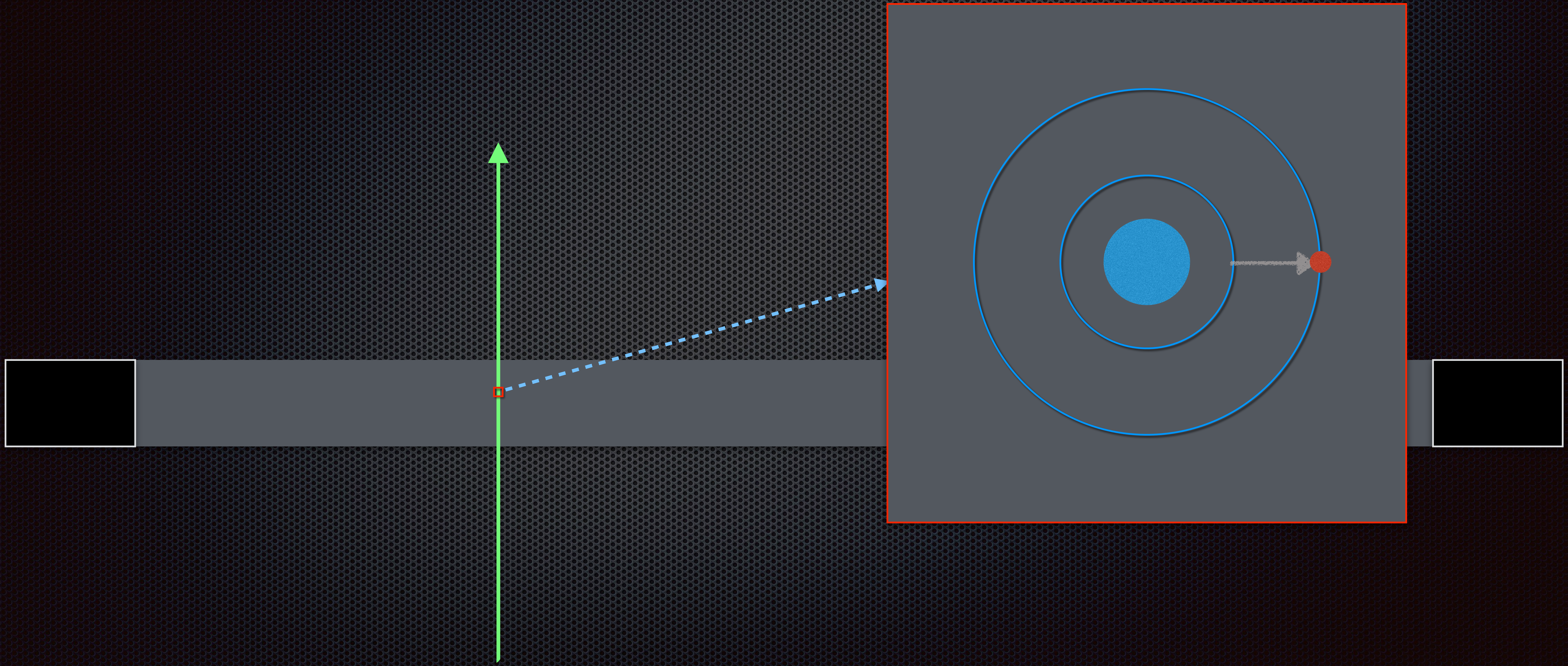
How it works

- The particle excites electrons



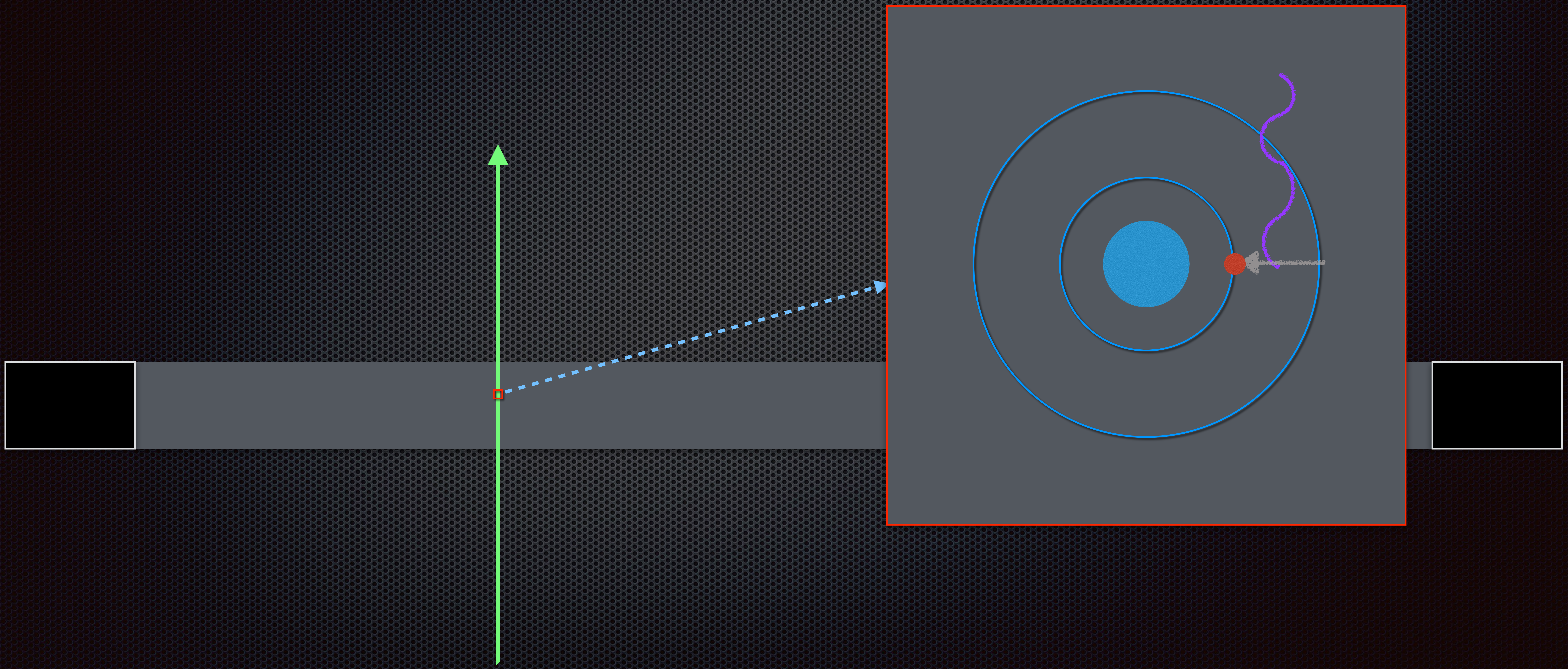
How it works

- Ionizing the material



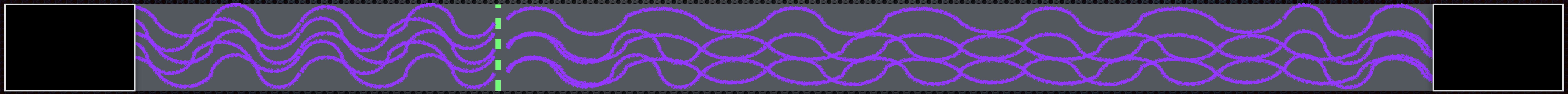
How it works

- Electrons release scintillation light



How it works

- Light travels down scintillator



How it works

- Captured by the photomultiplier tube

- Photoelectric effect frees electrons which can be amplified to create signal

Complications

- In a perfect world:
  - All the light would be captured by the PMT's
  - Photons would emit perpendicular to the particle track
  - Electrons would instantaneously emit light
  - Each PMT would be made identically

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- In a perfect world:
  - All the light would be captured by the PMT's
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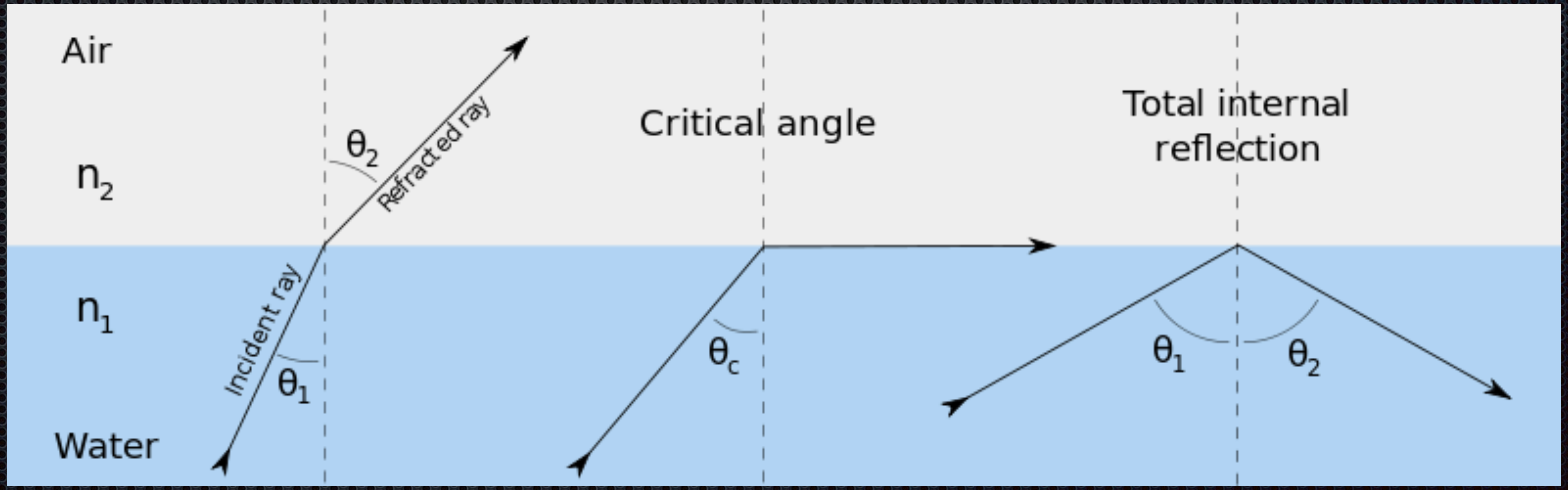
  - Each PMT would be made identically

- Attenuation Length
- Decay Time
- Calibration

Losing Light

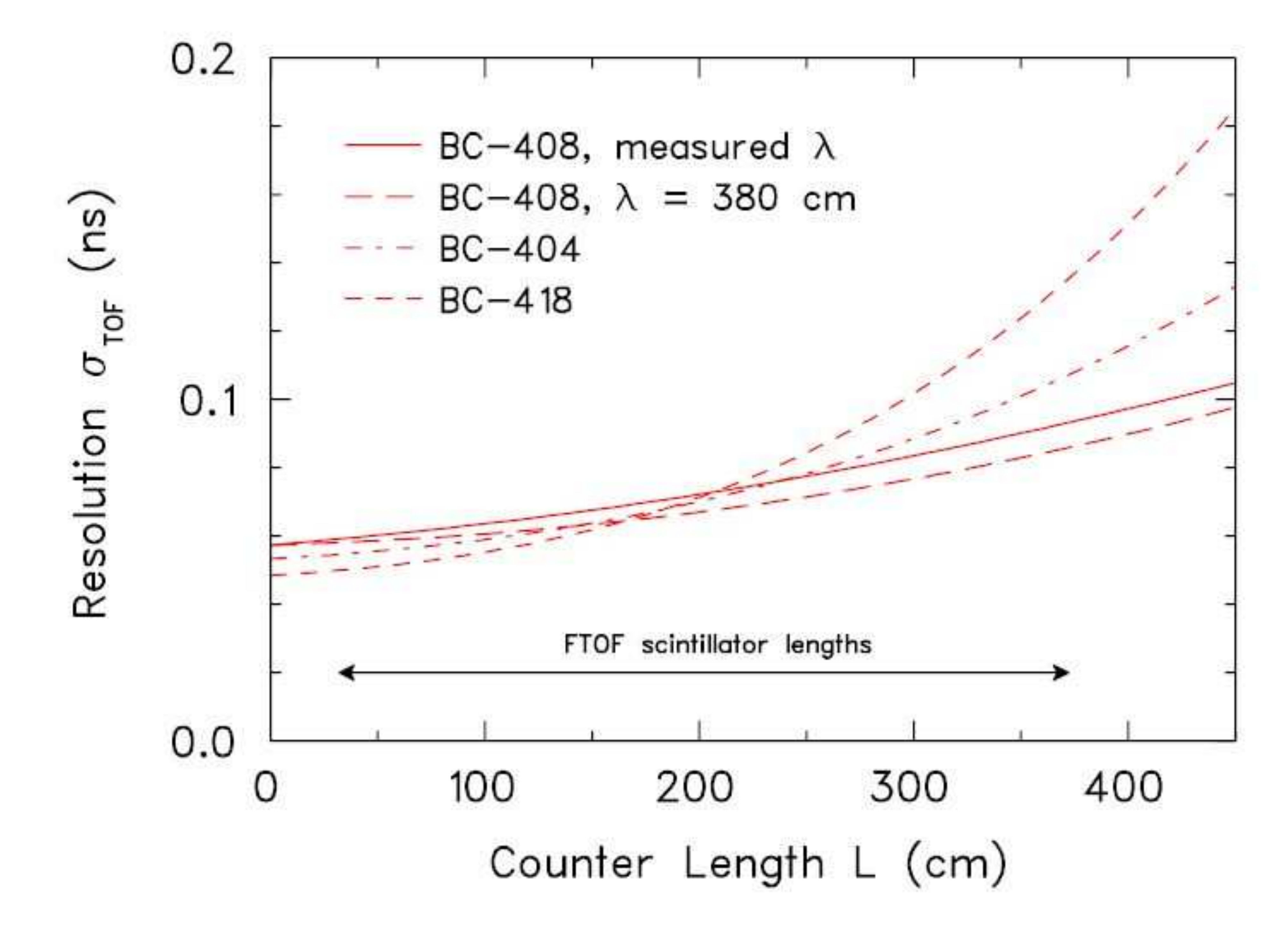
- Attenuation length:

  - Technical attenuation length
    - Photons leaving the material before they reach the PMT
    - Create air gap to facilitate total internal reflection
    - Use aluminized mylar to help reflect light



Losing Light

- Attenuation length:
  - Bulk attenuation length
    - In an infinitely large scintillator how far will light travel
    - Choose material with better time resolution at longer lengths



Decay Time

- The time it takes for ionized atom to emit photon
- Shorter decay times give better time resolutions
- Materials with shorter decay times generally have shorter attenuation lengths
- Not optimal for longer length counters

Decay Time Vs. Attenuation length

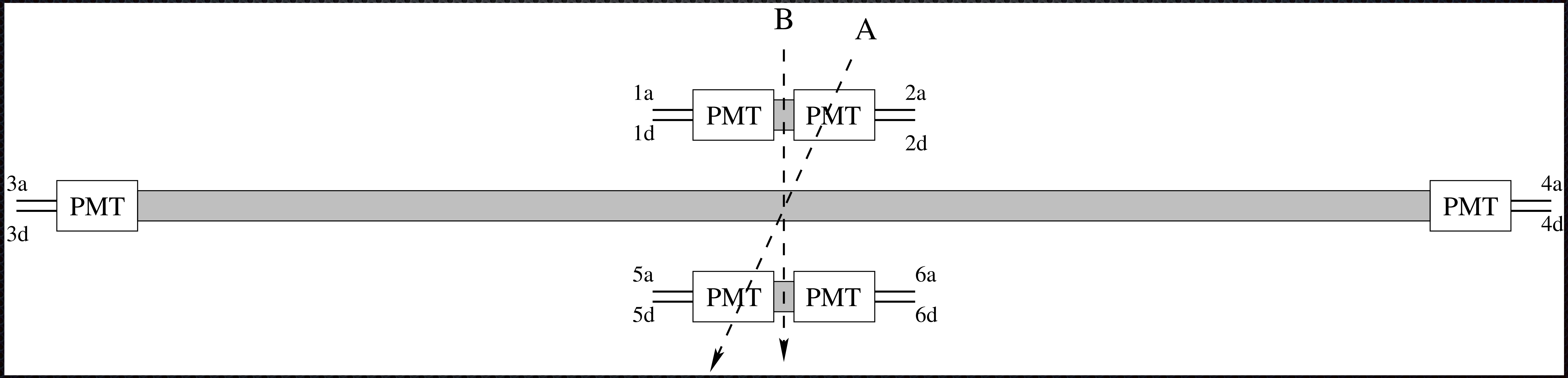
- Compromise by using two different materials
  - Short Bars (BC404)
    - Under 200cm
    - Have fast decay time of 1.8ns
    - Shorter attenuation length
  - Longer bars (BC408)
    - Over 200cm
    - Slower decay time of 2.1ns
    - Longer attenuation length

Calibration

- Each bar must have it's individual time resolution calculated
- Methods:
  - Source method
    - Place radioactive source on scintillator bar
    - Measure the timing differences between left and right PMT's
    - Requires many manual measurements
      - Every 10cm along the bar
    - Only one particle energy based on the radioactive source
      - Sr-90

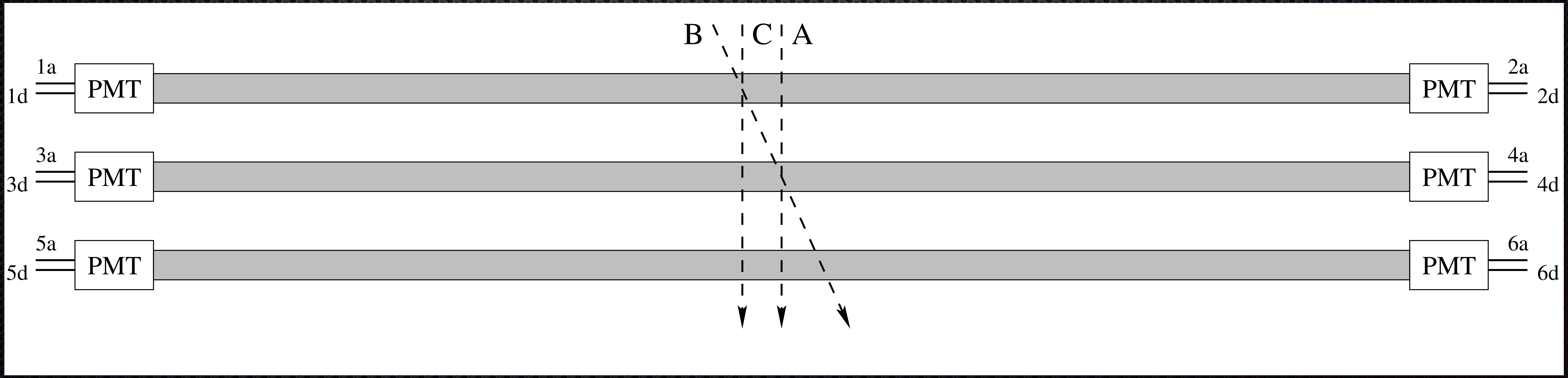
Calibration

- Each bar must have it’s individual time resolution calculated
- Methods:
  - Thin scintillator method
    - Place two thin scintillators on either side of main scintillator
    - Allow cosmic rays to enter the detectors
    - Find time resolution similarly to source method



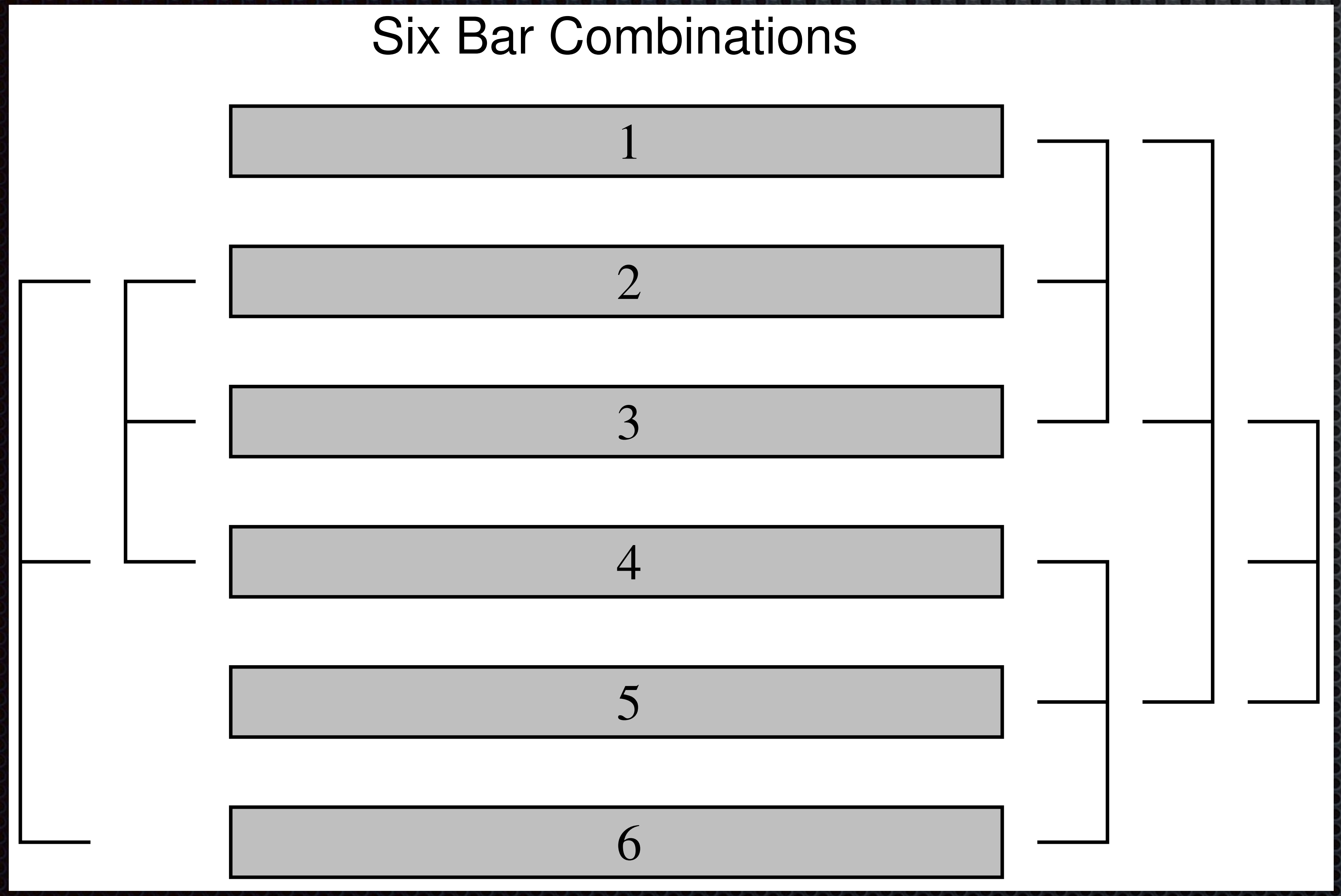
Calibration

- Each bar must have it's individual time resolution calculated
- Methods:
  - Three bar method
    - Similar to thin scintillator method
    - The time resolution can be found for the center bar



Calibration

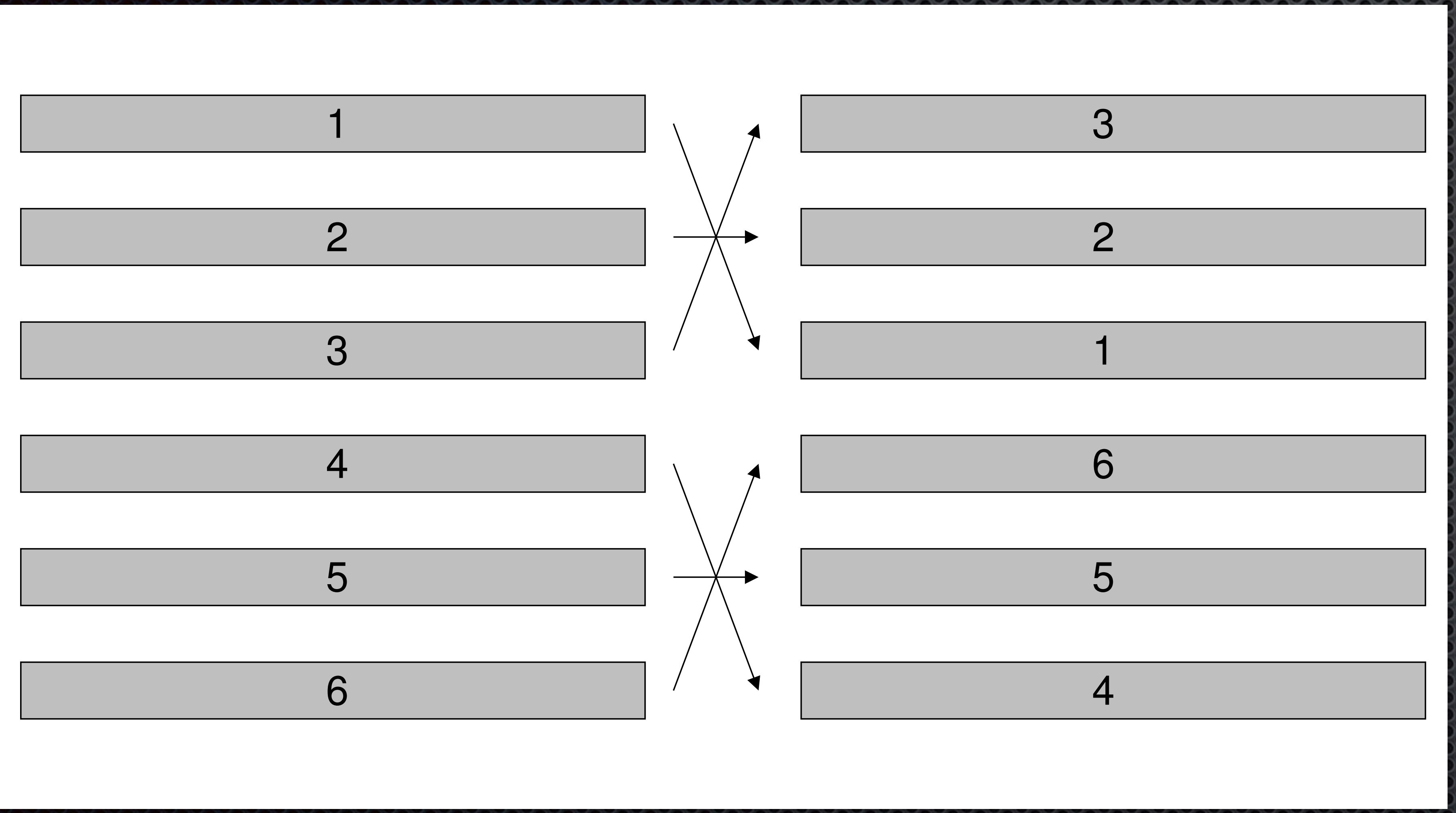
- Each bar must have it's individual time resolution calculated
- Methods:
    - Six bar method
        - Six simultaneous three bar measurements
        - Can be reordered to get timing resolution for every bar



$$\begin{bmatrix} \sigma^2_{T(1,2,3)} \\ \sigma^2_{T(2,3,4)} \\ \sigma^2_{T(3,4,5)} \\ \sigma^2_{T(4,5,6)} \\ \sigma^2_{T(1,3,5)} \\ \sigma^2_{T(2,4,6)} \end{bmatrix} = \begin{bmatrix} \frac{1}{4} & 1 & \frac{1}{4} & 0 & 0 & 0 \\ 0 & \frac{1}{4} & 1 & \frac{1}{4} & 0 & 0 \\ 0 & 0 & \frac{1}{4} & 1 & \frac{1}{4} & 0 \\ 0 & 0 & 0 & \frac{1}{4} & 1 & \frac{1}{4} \\ \frac{1}{4} & 0 & 1 & 0 & \frac{1}{4} & 0 \\ 0 & \frac{1}{4} & 0 & 1 & 0 & \frac{1}{4} \end{bmatrix} \begin{bmatrix} \sigma^2_1 \\ \sigma^2_2 \\ \sigma^2_3 \\ \sigma^2_4 \\ \sigma^2_5 \\ \sigma^2_6 \end{bmatrix}$$

Calibration

- Each bar must have it's individual time resolution calculated
- Methods:
  - Six bar method
    - Complimentary ordering gives time resolution for each bar



$$
\begin{bmatrix} \sigma^2_{T(1,2,3)} \\ \sigma^2_{T(2,3,4)} \\ \sigma^2_{T(3,4,5)} \\ \sigma^2_{T(4,5,6)} \\ \sigma^2_{T(1,3,5)} \\ \sigma^2_{T(2,4,6)} \\ \sigma^2_{T(3,2,1)} \\ \sigma^2_{T(2,1,6)} \\ \sigma^2_{T(1,6,5)} \\ \sigma^2_{T(6,5,4)} \\ \sigma^2_{T(3,1,5)} \\ \sigma^2_{T(2,6,4)} \end{bmatrix}
=
\begin{bmatrix}
\frac{1}{4} & 1 & \frac{1}{4} & 0 & 0 & 0 \\
0 & \frac{1}{4} & 1 & \frac{1}{4} & 0 & 0 \\
0 & 0 & \frac{1}{4} & 1 & \frac{1}{4} & 0 \\
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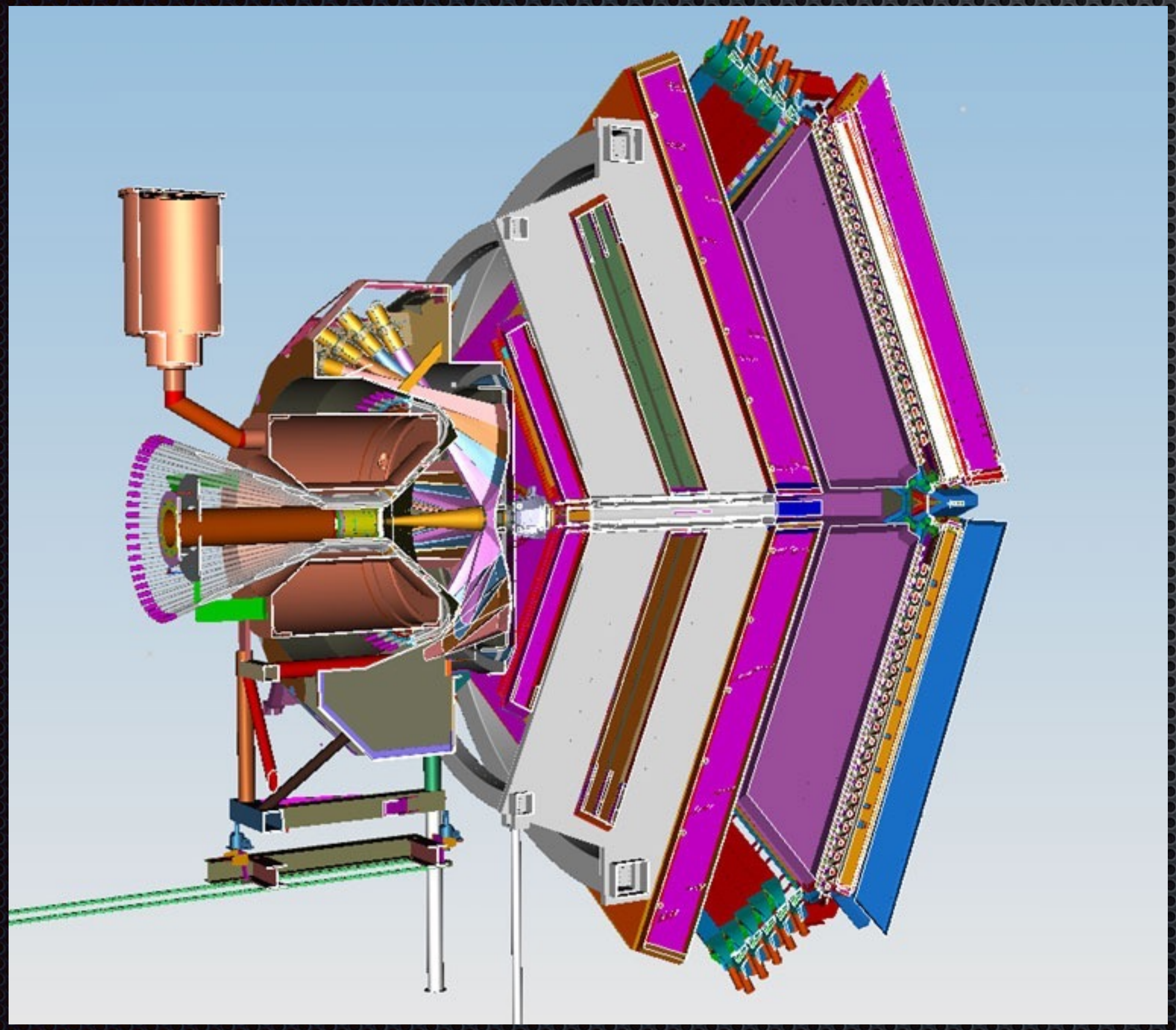
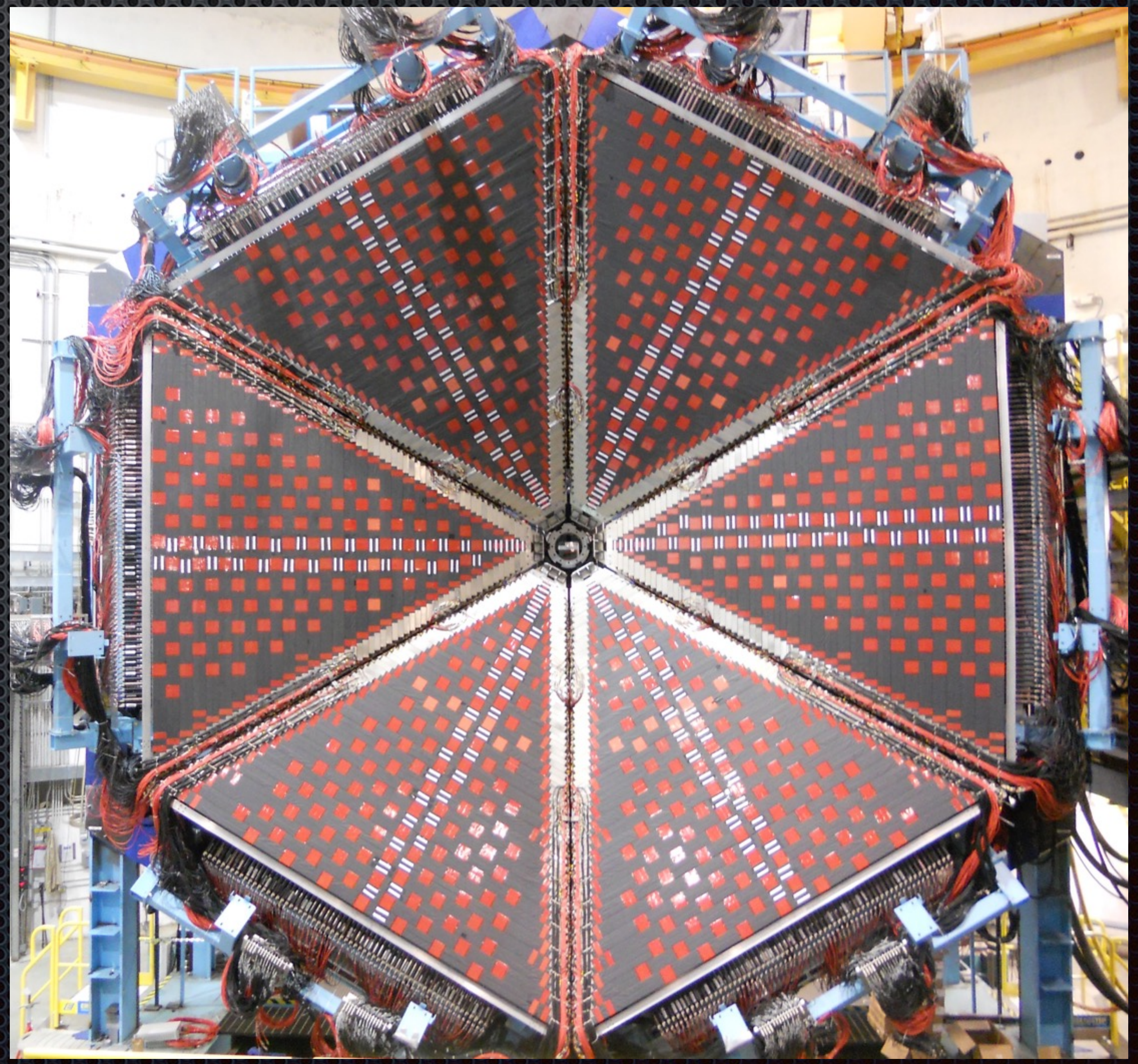
\frac{1}{4} & 0 & 1 & 0 & \frac{1}{4} & 0 \\
0 & \frac{1}{4} & 0 & 1 & 0 & \frac{1}{4} \\
\frac{1}{4} & 1 & \frac{1}{4} & 0 & 0 & 0 \\
1 & \frac{1}{4} & 0 & 0 & 0 & \frac{1}{4} \\
\frac{1}{4} & 0 & 0 & 0 & \frac{1}{4} & 1 \\
0 & 0 & 0 & \frac{1}{4} & 1 & \frac{1}{4} \\
1 & 0 & \frac{1}{4} & 0 & \frac{1}{4} & 0 \\
0 & \frac{1}{4} & 0 & \frac{1}{4} & 0 & 1
\end{bmatrix}
\begin{bmatrix} \sigma^2_1 \\ \sigma^2_2 \\ \sigma^2_3 \\ \sigma^2_4 \\ \sigma^2_5 \\ \sigma^2_6 \end{bmatrix}
$$

Why the upgrade?

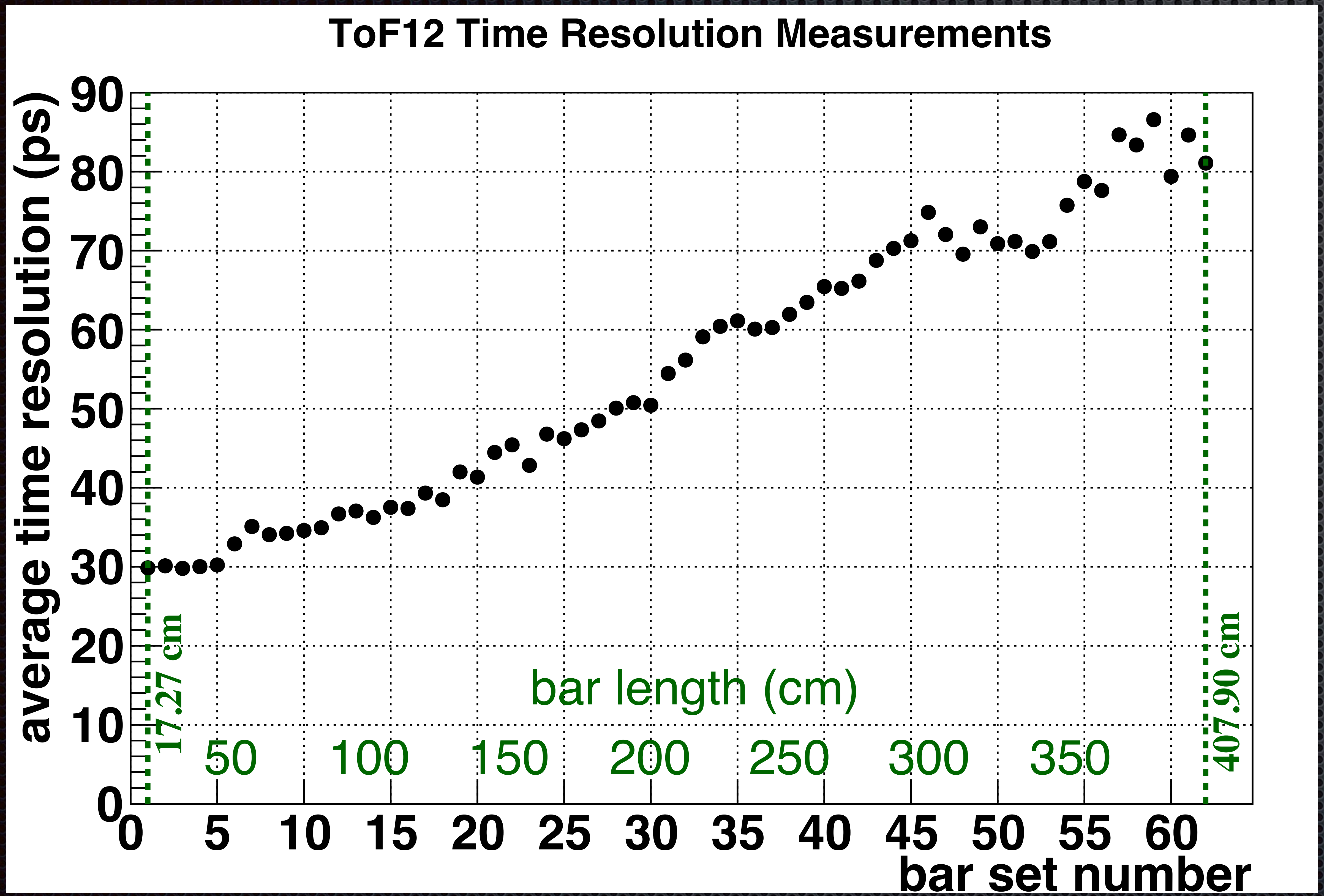
- 12GeV upgrade means higher momentum particles
- Need higher resolution to distinguish between particles
  - Will reuse the existing panel 1a
  - Add new panels to increase time resolutions

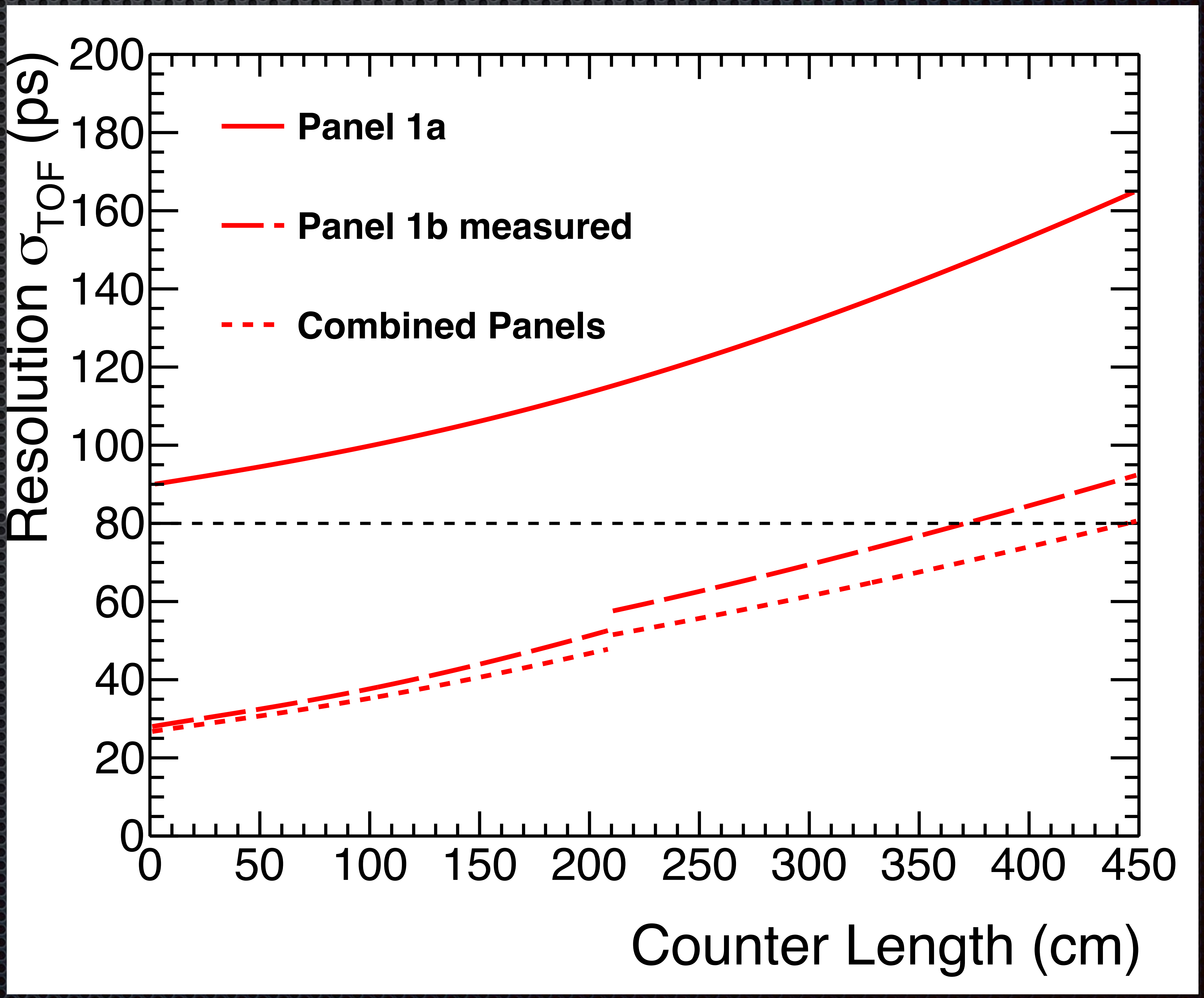




Results

- Resolution measurements for upgraded panel 1b, existing panel 1a, and combination





Conclusion

- TOF detectors are useful in deterring particle identification
- Designing a detector system has many complications
  - Can optimize the system to increase resolution
  - Created new way to calibrate detector system
- Achieved the goals of the design requirements
- World record time resolution for CLAS12 FTOF detector