Collecting Helium Scintillation Light

Investigation of Wavelength Shifting Materials for an Active Helium Target

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A2 Collaboration

- Nuclear Physics collaboration based at Johannes Gutenberg Universität in Mainz, Germany
- Real photon experiments ranging from 40 MeV - 1603 MeV
- Compton scattering of photons off protons and neutrons

Quantum Chromodynamics

- Theory governing the strong nuclear force
- Well understood at high energies (Asymptotic Freedom and pQCD)
- Much harder to test at low energies (confinement, non-pQCD)

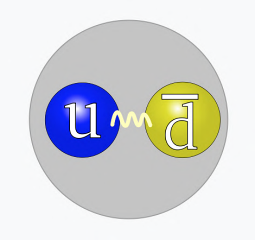


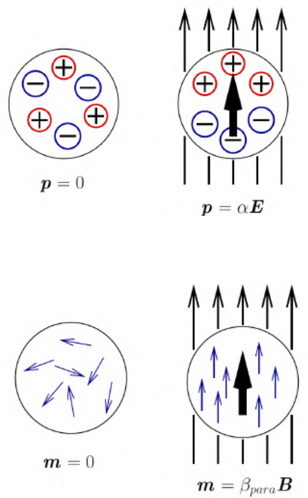
Figure: π^+ meson
https://en.wikipedia.org/wiki/Pion

Scalar Polarizabilities

Where Theory and Experiment Meet

- Fundamental structure constants (mass, charge...)
- Response of internal structure to applied EM fields
- Note: $\beta = \beta_{para} + \beta_{dia}$
- **Photon acts as applied EM field**

Composite system



Neutron Problem

Current Accepted Values

Nucleon	$\alpha(\times 10^{-4} \text{fm}^3)$	$\beta(\times 10^{-4} \text{fm}^3)$
Proton	11.2 ± 0.4	2.5 ± 0.4
Neutron	$11.8 \pm$ **1.1**	$3.8 \pm$ **1.2**

- Direct proton measurments $\rightarrow$ Liquid hydrogen
- No free neutron target available ...
- Must resort to alternate target materials

Measuring Neutron Polarizabilities

Until now...

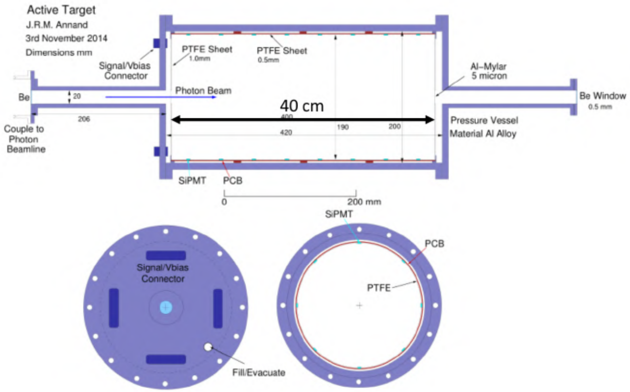
- Low energy neutron scattering $\rightarrow$ **Dependent only on α**
- Compton experiments on deuterium $\rightarrow$ Require Theoretical models $\rightarrow$ **Larger uncertainty**

ChPT for Compton on ^{3}He

- Shukla, Nogga, and Phillips (2009) present methods using chiral pertubation theory to extract neutron polarizabilities
- Larger sensitivity to α and β, less model dependent
- Larger atom $\rightarrow$ larger Compton cross section

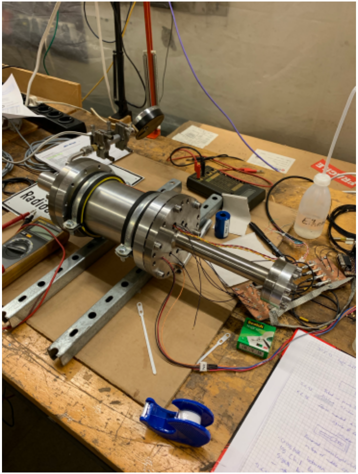
Active Helium Target Theory

- Many background channels: π^0 production, ^{3}He breakup
- **Active: $\mathbf{E}_{miss} = \mathbf{E}_{\gamma}$ - $\mathbf{E}_{\gamma'}$ - $\mathbf{E}_{He'} = 0$**
- Require $\mathbf{E}_{He'}$ to reduce background



Active Helium Target Prototype

- Tests with ^{4}He at 10 bar, ^{3}He = $$$
- Testing with 5 MeV ^{241}Am α source excite He the same way ^{3}He recoil nuclei would
- SiPMs used to collect scintillation light (200 nm - 900 nm)
- Three active diodes, coincidences



Helium Scintillation

- Helium gas with pressure $>$1 bar scintillates in VUV (10 nm – 200 nm)

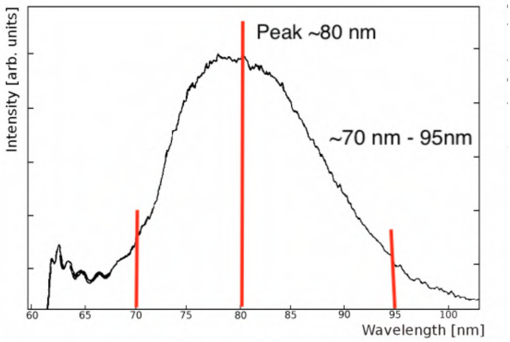
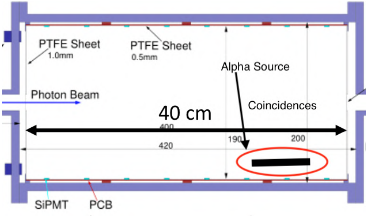


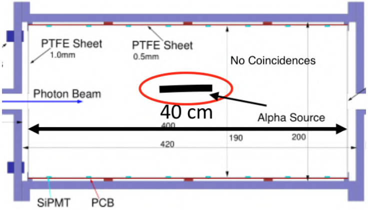
Figure: Helium scintillation spectrum (Jebali 2013)

Original Idea: Helium/Nitrogen Mixture

Add Nitrogen Gas

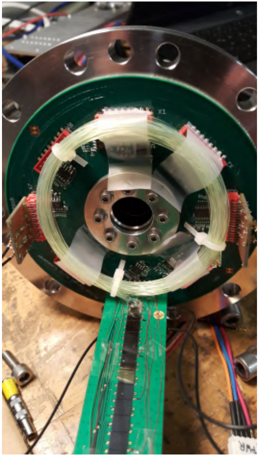
- 500 ppm
- Shifts to ~390 nm
- Worked for close α source
- Not enough for realistic Compton events





Numerous (Unsuccessful) Attempts

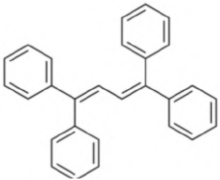
- Wavelength shifting fibres
- Light guides
- Tested in vacuum, helium with & without nitrogen



Tetraphenyl Butadiene

TPB

- Scintillating noble gas experiments (NEXT, DEAP, many more!)
- VUV (as low as 45 nm) to 430 nm (SiPM)
- Ideally applied via vacuum evaporation, dissolved
- Scintillation under α excitation (Pollman, Boulay and Kuźniak 2010)
- **Will scintillation from He be discernible from α excitation?**



Chemically Coated Slides

In the MTA Chemistry lab

- Followed coating procedure from Ignarra 2014
- Dissolve TPB, Polystyrene in Toluene
- 1:3 ratio of TPB to PS
- 1:1 ratio of TPB to PS (layers, END)

Initial Tests

- P. Drexler, MZ Technician, performed tests with various slides
- No coincidences with 1:3 TPB to PS

Coincidences 1:1 TPB to PS

- Coincidences indicate TPB is effective

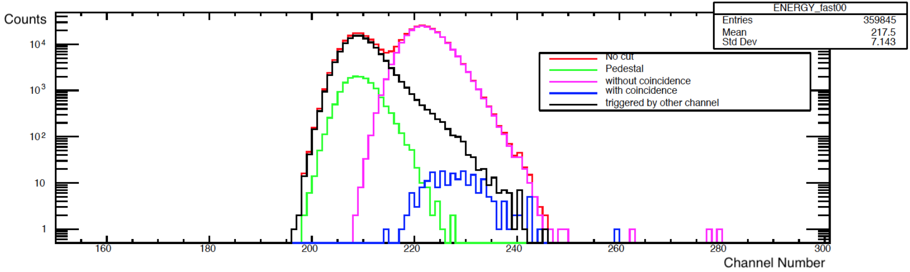
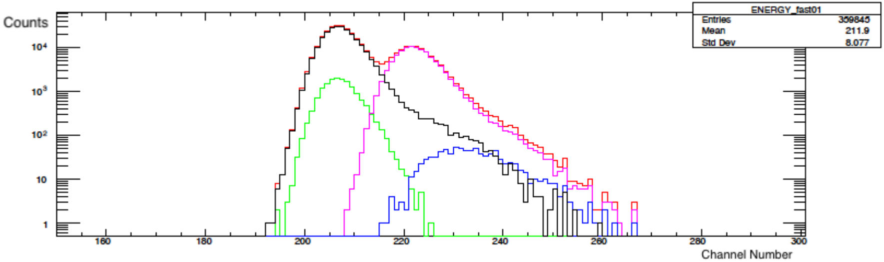
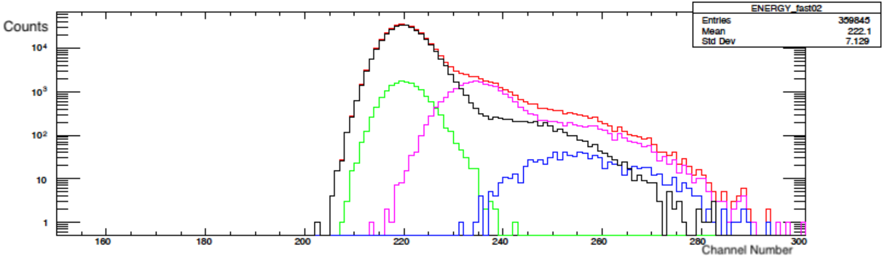


Figure: Blue line indicates coincidences made between SiPM diodes, a signature of how Helium scintillates after a Compton event.

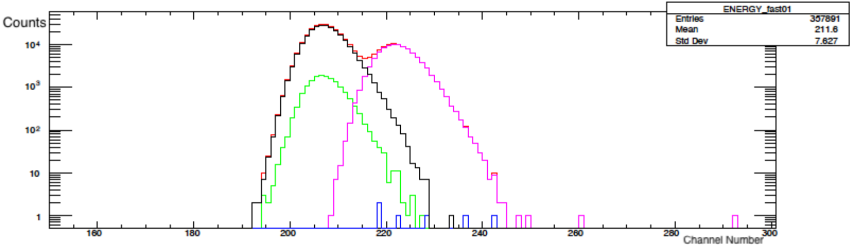
fast01 and fast02

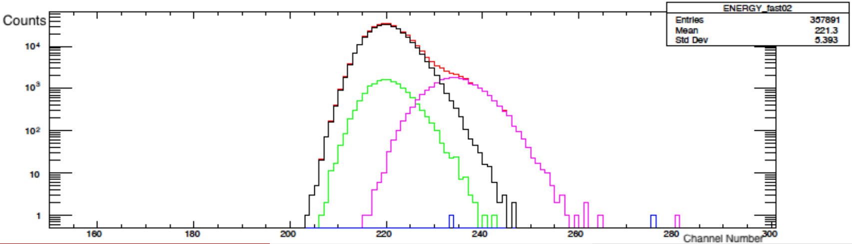




Scintillation under α?

Trial in vacuum: Helium events may be separated from α!





Outlook

TPB

- Tests with other slides
- Tests with α source in realistic setting
- Possible coupling to light guides
- Vacuum Evaporation

Timeline

- Wavelength shifting issues fixed this summer
- Implementation, data taking and analysis over the next 4–5 years

Thank You!

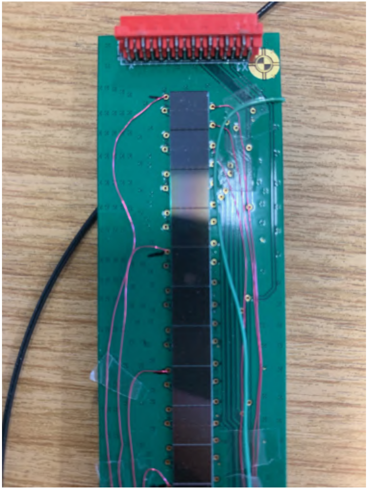
Thanks to ...

- NSERC for funding
- Dr. David Hornidge
- Peter, Phil, Lena, and everyone at A2

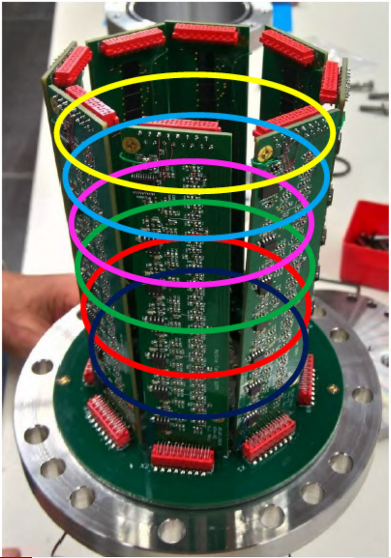
Silicon Photomultipliers

SiPMs

- Used as scintillation detector
- Functions on p-n junction
- PDE at 420 nm, functional 200 nm - 900 nm
- Tests currently only on 3 channels



Geometry of SiPMs



The p-n junction

- The p-n junction is how PV cells generate electricity
- n-doped material into contact with the p-doped material
- Depletion region is formed, $E_{gap} = e\phi$
- $E_{gap} = 1.1$ eV in silicon

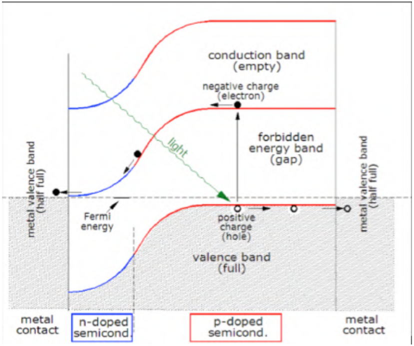
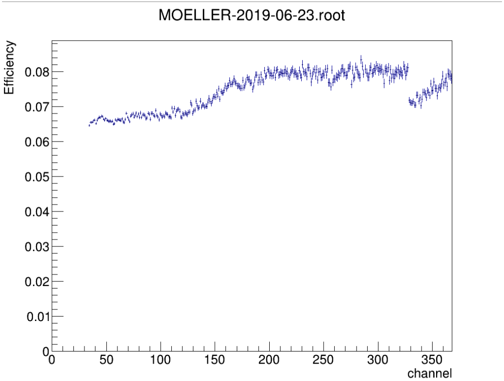


Figure: A schematic of a p-n junction being struck by a photon (Wikipedia)

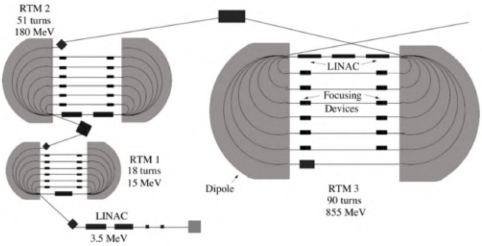
Tagging Efficiencies For June 2019

- $\epsilon_{Tagg}(i) = \frac{N_{Tagg}(i)}{N_{e-}(i)}$, where $N_{e-}(i)$ is the total number of electrons detected, $N_{Tagg}(i)$ is the number of electrons that produced a photon detected in the Pb glass, i is the tagger channel.
- Funny tail where Yoke detectors begins



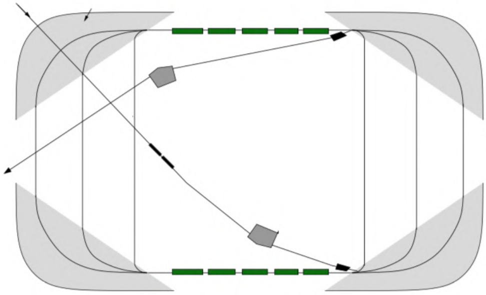
RTMs

- Electrons accelerated via LINAC
- Enter RTM, bent 180°
- Exit at 855 MeV



HDSM

- RTMs become impractical
- Harmonic Double Sided Microtron, bends 90°
- Capable of 1.6 GeV



Electrons to Photons

- Photons via Bremsstrahlung
- Produced in cone, collimated out
- $E_\gamma = E_{e^-} - E'_{e^-}$

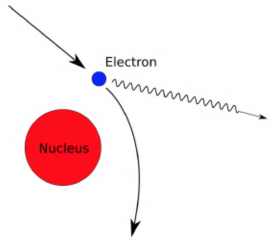
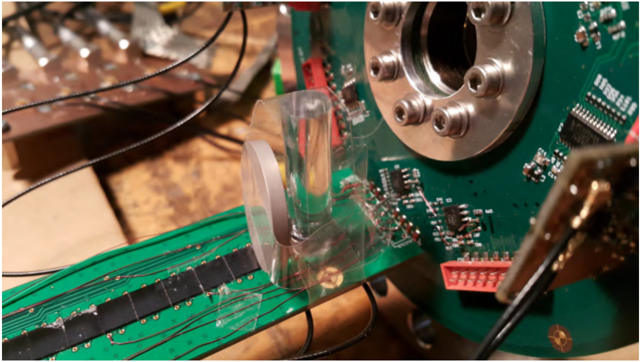


Figure: The Bremsstrahlung Process, image courtesy of thephysicsbehind.com

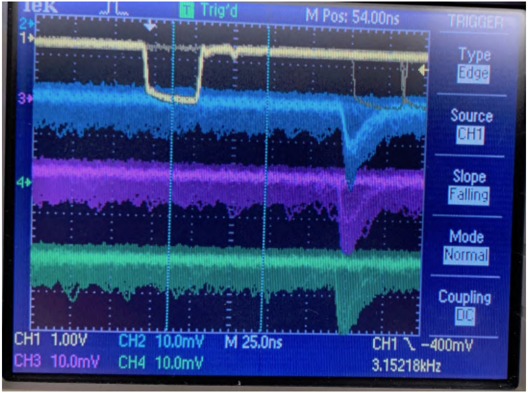
Other tests

- Tried a β source
- Fibres once more, other light guides
- Nothing



Measurements

- Coincidences on oscilloscope
- Also readout to computer
- Signal inverted, QDC can interpret



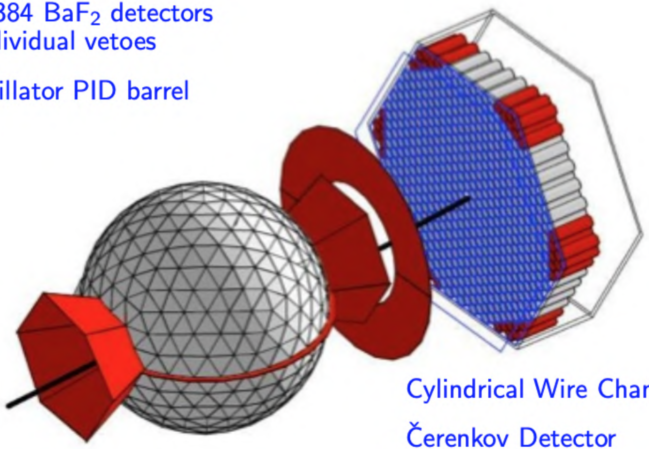
CB-TAPS

GEANT4 View

CB: 672 NaI detectors

TAPS: 384 BaF_2 detectors
with individual vetoes

24-scintillator PID barrel



Cylindrical Wire Chamber

Čerenkov Detector

Tagger Hall

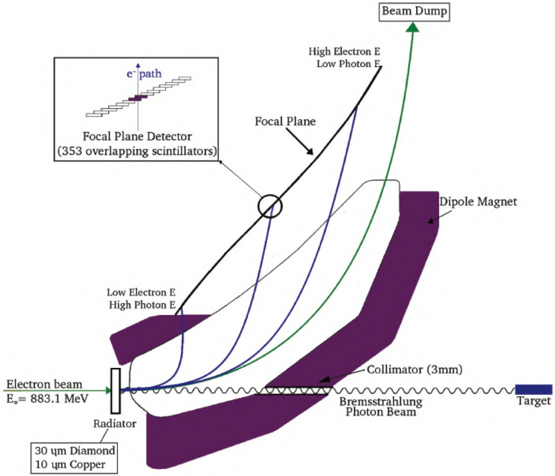


Figure: The A2 Tagger Hall