APEX 2025 Proposal 25-03 presentation

Light from Carbon targets

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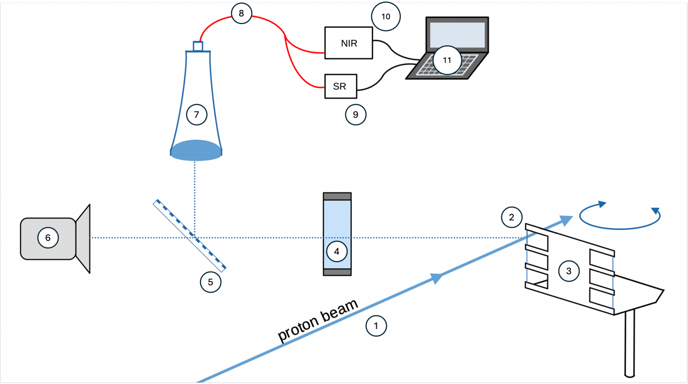
Motivation

Direct measurement of temperature of carbon targets

- Carbon fiber targets of RHIC polarimeters do not reach carbon sublimation temperature of $T_{\mathrm{sub}} = 3915\,\mathrm{K}$: **targets survive proton bombardment**.
  - Observation aligns with energy loss calculations by Peter Thieberger (BNL) using appropriate beam sizes at the interaction point.[a]
- Carbon beam polarimeters were essential for RHIC and will be for EIC, enabling fast beam polarization measurements
  - Targets measure polarization components (p_x, p_y) of $\vec{P} = (p_x, p_y, p_z)$.
  - It is critical to verify the applicability of carbon fibers for polarimetry with increased proton beam currents.
  - Temperature estimates suggest similar target temperatures at IP4 in the HSR (EIC) as at RHIC, due to favorable beam optics despite increased RF heating.
- Direct temperature measurement of carbon targets remains crucial goal
  - Black-body radiation theory [1] offers a method to determine temperature by analyzing the emitted light spectrum.

[a] Thieberger's code is available on SharePoint.

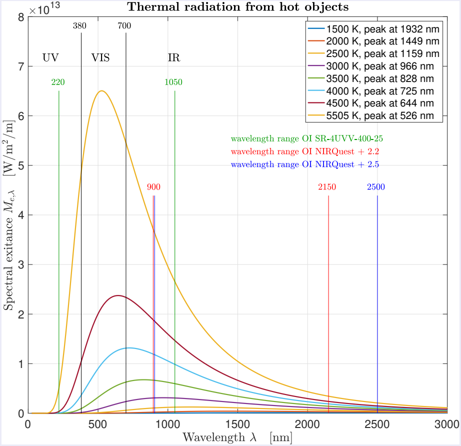
Experimental setup



1. proton beam
2. fiber target
3. target holder
4. fused-silica viewport
5. semi-transparent polka-dot mirror
6. optical camera
7. collimator lens
8. fiber splitter (VIS and IR)
9. spectrometer VIS (SR)
10. spectrometer IR (NIR)
11. spectral analysis ($\lambda = 200 - 2200\,\text{nm}$)

Black body radiation

Ideally, one would measure:

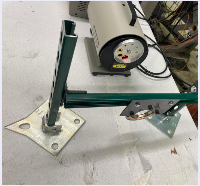


But: wavelength-dependent attenuation in

- fused-silica viewport
- collimator lens
- 100 m glass fibers from IP12 to spectrometers

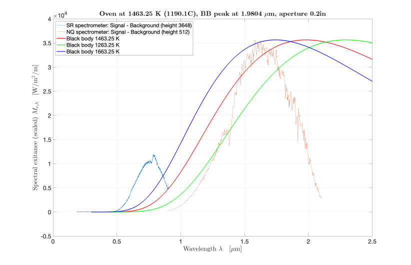
Lab test measurement using IR light source

Experimental setup



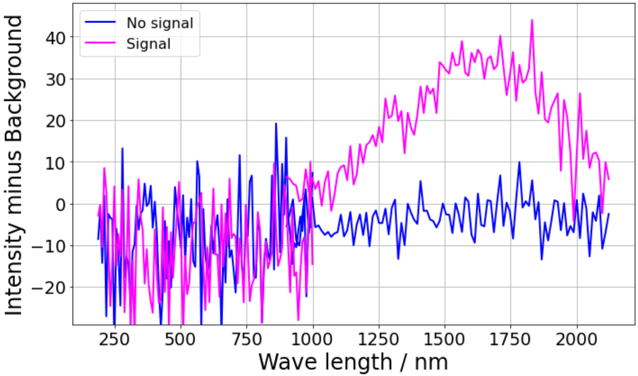
Black body radiation using oven at 1463 K

- SR spectrometer: 200 to 900 nm
- NIR spectrometer: 900 to 2100 nm
- Light path includes fiber splitter and 100 m glass fibers
- Measured spectrum compared to blackbody radiation spectra at 1463 K, 1263 K, and 1663 K



Test measurements using C targets at IP4

- In 2024, equipment/components arrived late, thus optimal alignment of light collection system at IP4 was not possible.
- We observe a clear signal, however, the light intensity is low because we don't aim at the brightest spot on the target
- For the same reason, the temperature we observe is only around 1400 K, about half of what we would expect



Summary

Goal for run 25

- **Ensure full understanding of energy loss/heating of carbon polarimetry fiber targets by high energy proton beam, in particular for EIC**
- Light collection system was installed and operated already during run 24
  - As CNI chamber was already sealed off/pumped down when all components were available, light collection system could not be properly aligned
- **Improve alignment before ring closes, repeat measurement in run 25**
  1. Our APEX requires dedicated time only in case no proton beam available in run 25. With 100 GeV stored protons, we can run parasitically.
  2. Need 100 GeV protons in blue with max. number of bunches stored
  3. With beam on flattop, a single fill of the machine should be sufficient:
     - Sweep one target back and forth through the beam, then do another one, and so on. No need to wait for target cool down.
     - Will use four targets in blue, two horizontal ones and two vertical ones.
  4. 2h sweeping targets back and forth sufficient to achieve goals
  5. In case something goes wrong with 3. and 4., we need a 2^{nd} fill

References

[1] M. Planck, *The Theory of Heat Radiation* (P. Blakiston's Son & Co., 1914).

[2] W. R. Leo, *Techniques for nuclear and particle physics experiments: a how-to approach; 2nd ed.* (Springer, Berlin, 1994), URL https://cds.cern.ch/record/302344.

Spare slides

Energy loss in C targets I

Bethe-Bloch formalism

Bethe-Bloch formula [2] for energy loss given by

$$-\frac{dE}{dx} = 2\pi N_A r_e^2 m_e c^2 \frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\left(\frac{2m_e\gamma^2 v^2 W_{\max}}{I^2}\right) - 2\beta^2\right] \quad (1)$$

Symbol	Description
N_A	Avogadro's number (6.022×10^{23} mol^{-1})
r_e	Classical electron radius (2.817×10^{-13} cm)
m_e	Electron mass
c	Speed of light
Z	Atomic number of absorbing material
A	Atomic weight of absorbing material
ρ	Density of absorbing material
z	Charge of incident particle in units of e
$\beta = \frac{v}{c}$	Velocity of the incident particle relative to c
$\gamma = \frac{1}{\sqrt{1-\beta^2}}$	Lorentz factor
I	Mean excitation potential
$W_{\max}$	Maximum energy transfer in a single collision

Energy loss in C targets II

Conversion of stopping power $\frac{dE}{dx}$ from MeV/cm to MeV/(g/cm^2),

- also known as *mass stopping power*

$$\left(\frac{dE}{dx}\right)_{\text{mass}} = \frac{1}{\rho}\left(\frac{dE}{dx}\right), \tag{2}$$

  where $\frac{dE}{dx}$ is stopping power in MeV/cm, ρ is density of material in g/cm^3, and $\left(\frac{dE}{dx}\right)_{\text{mass}}$ is mass stopping power in MeV/(g/cm^2).

- Total energy loss ΔE over path length expressed in integral form as

$$\Delta E = \int_{x_1}^{x_2} \frac{dE}{dx}\, dx, \tag{3}$$

  where x_1 and x_2 are the starting and ending points of the path, $\frac{dE}{dx}$ is the stopping power, which may depend on x or other variables like particle energy.

- Using mass stopping power $\left(\frac{dE}{dx}\right)_{\text{mass}}$ with material density ρ, then

$$\Delta E = \int_{x_1}^{x_2} \left(\frac{dE}{dx}\right)_{\text{mass}} \cdot \rho\, dx \tag{4}$$

Energy loss in C targets III

Comparison of proton and Au beams

- Assumed that each of the impinging protons contained in a Au nucleus hitting the C target has *same* kinetic energy of 100 GeV per nucleon as corresponding proton beam.
  - Kinematic parameters β and Lorentz factor γ are the same in the two cases.
- p+C scattering
  - For proton beams impinging on carbon, the relevant factor is

$$\frac{Z(\mathrm{C})}{A(\mathrm{C})} \cdot z(p)^2 = \frac{6}{12} \cdot 1^2 = 0.5 \qquad (5)$$

- Au+C scattering
  - For Au beams, situation given by

$$\frac{Z(\mathrm{C})}{A(\mathrm{C})} \cdot z(\mathrm{Au})^2 = \frac{6}{12} \cdot 79^2 = 3120.5 \qquad (6)$$

With number of Au nuclei in RHIC bunch 100× smaller than for p's:

Total energy loss for Au in a C target will be still ≈ 60 times larger than for protons → **C targets will not survive the Au beam**