Outline

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The Relativistic Heavy Ion Collider (RHIC)

- 3.83 km circumference
- (polarized) proton, heavy ion, light ion

**Aim:**
1) produce and study Quark Gluon Plasma (QGP) (~ 250,000 X hotter than sun, few µs after big-bang)
2) measure the spin structure of the nucleon. (the only polarized proton collider in the world)
Basis for Compton polarimetry

• The scattering of a photon off an electron

• The cross section for this interaction depends on the relative alignment of the spins of the two interacting particles
Kinematics

• Individual electrons, moving along the z-axis with an energy $E$, $p = (E; 0, 0, p)$
• incoming photon, denoted by $k = (k; -k \sin \alpha, 0, -k \cos \alpha)$, where $\alpha$ is the angle of the incoming photon with respect to the beam axis.
• The photon source is a high-power **green laser**.
• The electron imparts some of its energy to the photon, and is deflected from the main beam line by an angle $\theta_e$
• The recoil electron thus has 4-momentum $p' = (E'; -p' \sin \theta_e, 0, p' \cos \theta_e)$.
• The photon scatters at an angle $\theta_\gamma$; $K' = (k'; k' \sin \theta_\gamma, 0, k' \cos \theta_\gamma)$.
Applying conservation of 4-momentum,

\[ p^\mu + k^\mu = p'^\mu + k'^\mu \]

• The energy of the scattered photon can be found in terms of the incident photon and electron parameters as;

\[ k' = k \frac{E + p \cos \alpha}{E + k - p \cos \theta_{\gamma} + k \cos(\theta_{\gamma} - \alpha)} \]

• The energy of the recoil electron is;

\[ E' = E + k - k' \]
Compton Asymmetry

- The **theoretical** longitudinal asymmetry, $A_{\ell}$, for the Compton scattering of electrons and photons with spins parallel, $\sigma^+$, and spins anti-parallel, $\sigma^-$, is given by:

$$A_{\ell} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}.$$
The experimentally measured asymmetry, \( A_{\text{exp}} \)

\[
A_{\text{exp}} = \frac{n^+ - n^-}{n^+ + n^-}
\]

\( n^+ \) is the number of Compton scattering events with electron and photon spins parallel, and \( n^- \) with the spins anti-parallel.
• The experimentally measured asymmetry $A_{\text{exp}}$ is related to the theoretical asymmetry $A_l$ through the polarizations of the electron beam, $P_e$, and the scattering photons in the laser beam $P_\gamma$, by

$$A_{\text{exp}} = \frac{n^+ - n^-}{n^+ + n^-} = P_e P_\gamma A_l ,$$

• The longitudinal polarization of the electron beam is therefore

$$P_e = \frac{A_{\text{exp}}}{P_\gamma A_l} .$$
Compton scattering from proton (RHIC)

- The cross-section for Compton scattering from protons is small.
- smaller than the analogous electron cross section by a factor of \((m_e/m_p)^3\)
- Modern lasers, with their high power densities and pulse energies, stand a chance of making up this difference in rate.
Summary

- Given the polarization of laser ($P_\gamma$) the polarization of the electron beam ($P_e$) can be measured by
  - Calculating the cross section (theoretical) $\rightarrow A_I$
  - Counting the number of Compton events (experimental) $\rightarrow A_{exp}$

\[ P_e = \frac{A_{exp}}{P_\gamma A_\ell}, \]


*LASER COMPTON POLARIMETRY OF PROTON BEAMS*
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The Compton scattering cross section

\[ \rho = \frac{k'}{k} \simeq \frac{4\gamma^2}{1 + \frac{4k\gamma}{m_e} + \theta_{\gamma}^2\gamma^2} = \frac{4a\gamma^2}{1 + a\theta_{\gamma}^2\gamma^2}, \]

\[ a = \frac{1}{1 + \frac{4k\gamma}{m_e}}. \]

\[ \frac{d\sigma}{d\rho} = 2\pi r_0^2 a \left[ \frac{\rho^2(1-a)^2}{1 - \rho(1-a)} + 1 + \left( \frac{1 - \rho(1+a)}{1 - \rho(1-a)} \right)^2 \right] \]

\[ A_\ell = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}, \]

\[ A_\ell = \frac{2\pi r_0^2 a}{d\sigma/d\rho} (1 - \rho(1+a)) \left( \frac{1}{1 - \rho(1-a)} \right) \frac{1}{(1 - \rho(1-a))^2}. \]