Experimental Nuclear Physics at UMass

Faculty: D. Kawall, K. Kumar, and R. Miskimen

- Our activities span energies from 100 MeV to 500 GeV
- From photon-nucleon scattering, electron-electron scattering, electron-nucleon scattering, proton-proton collisions, storage rings…
- Address fundamental questions involving the strong nuclear force, weak interactions, searches for new physics
Probing Mysteries in the Spin Structure of the Proton
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http://www.phenix.bnl.gov

- Simple non-relativistic quark model of proton suggests \( J_z = \frac{1}{2} = S_z^{\text{quarks}} \)
- Measurements around 1988 showed \( S_z^{\text{quarks}} = (12 \pm 17)\% \)
- Quark contribution to proton spin consistent with zero! Spin Crisis was born.
- Today, \( S_z^{\text{quarks}} \approx 25\% \pm 5\% \) - so where does 3/4 of proton spin come from ???
- Nucleon spin can be decomposed as: \( J_z = \frac{1}{2} = S_z^{\text{quarks}} + S_z^{\text{gluons}} + L_z^{q+g} \)

⇒ To measure gluon contribution, \( S_z^{\text{gluons}} \), need strongly interacting probe

UMass, January 28th, 2011
Probing Mysteries in the Spin Structure of the Proton

- RHIC: collides polarized protons with center of mass energies from 200 to 500 GeV
- Measure how number of jets, direct photons, pions, produced depends on colliding proton spin directions
- Work backwards from asymmetry measurements to extract gluons contribution to proton spin
- 2009 results suggest gluon contribution $S^\text{gluons}_z$ to proton spin is small, $\leq 20\%$
- 2009-2011: Use parity violation in $W$ production $\Rightarrow$ for clean measurement of $\bar{u}$ and $\bar{d}$ contributions to proton spin: First results in PRL soon
- 1000s of papers on proton spin - efforts have deepened our understanding of QCD tremendously
- Physics beyond SM: measure muon g-2 to 0.14 ppm, just approved January 2011 !!!
- In development: proposals to improve limits on $p$, $d$ EDMs by factor 1000 to $\leq 10^{-29}$ e·cm !!!

Good Student Needed!
Elastic Electron Scattering (Kumar)

Measure $\sigma$ as a function of $Q^2$

Neglecting recoil and spin:
Obtain Fourier transform of charge distribution

We now know that electrons interact with nuclei also via the weak force

This is a rare process; tough to isolate: sophisticated measurement technique

\[ Q^2 = -(p - p')^2 \]

\[ Q \approx \frac{hc}{\lambda} \]

\[ \rho (r) \]

\[ 4\pi r^2 dr \]

\[ 2 \text{fm} \quad 4 \text{fm} \]

\[ N \quad N \]

\[ e^- \gamma \]

\[ e^- \]

\[ 4\text{-momentum transfer} \]

\[ Q^2 = 4EE' \sin^2 \frac{\theta}{2} \]

\[ A_{PV} = \frac{\sigma}{\sigma^0} \]

\[ \sim \frac{A_{\text{weak}}}{A_{\text{EM}}} \sim \frac{G_F Q^2}{4\pi \alpha} \]

\[ A_{PV} \sim 10^{-4} \times Q^2 \left( \text{GeV}^2 \right) \]
The PREX Experiment  

- Neutron star has solid crust over liquid core.
- Heavy spinless nucleus has neutron skin.

$R_p \sim 5.5 \text{ fm}$

$R_n - R_p \sim 0.1 \text{ to } 0.3 \text{ fm}$?

- First data taken in summer '10
- Analysis in progress
- Followup runs being designed
- Work towards new data in '13

Faculty: Krishna Kumar
Postdocs: Juliette Mammei, Seamus Riordan
Graduate Students: Luis Mercado, Jon Wexler, Sereres Johnston, Adam Blomberg
Undergraduates: Patrick Rogan, Vireak Yim

Next Project: The MOLLER Experiment
- Precision test of the weak force to search for clues about the early universe
- Complementary to Large Hadron Collider experiments
Nuclear physics with polarized photons and protons at the Mainz Microtron, Germany

Faculty: R. Miskimen
Postdoc: A. Mushkarenkov
Ph.D. students: B. Barnes, C. Harris, P. Martel
Undergraduates: Eric Lee, Fabian

Physics

• Use the Crystal Ball detector to measure nucleon polarizabilities by polarized Compton scattering \( \gamma p \rightarrow \gamma p \)
• Polarizabilities are fundamental properties of strongly interacting particles, as fundamental as the mass or magnetic moment
• Threshold pion photoproduction, \( \gamma p \rightarrow p\pi^0 \) as a test of low-energy QCD

Measuring the dielectric constant of the proton
Crystal Ball detector

Phil Martel working on the Crystal Ball

Polarized proton target