The Quest for Polarized Antiprotons

Spin Physics, Medieval Warfare, and Medical Applications

May 03, 2010   Frank Rathmann

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What do we mean by „polarized“?

Most particles possess a magnetic moment, → they behave like little magnets

**Unpolarized** ensemble of particles (e.g. protons)

\[
\begin{align*}
\Delta E &= 2\mu_p B \\
m_1 &= -\frac{1}{2} \\
m_1 &= +\frac{1}{2}
\end{align*}
\]

\[
P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} \\
\approx \frac{\mu_p \cdot B}{k_B \cdot T} \\
\approx 5 \cdot 10^{-6}
\]

**Polarized** ensemble of particles

\[
P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = \frac{7 - 0}{7 + 0} = 1
\]
Picture polarized particles (stored in a ring or in a target)
Outline

- Basics
- Medieval Warfare
  - Storage Rings and Internal Targets
- Quest for Polarized Antiprotons
- Medical Application of Polarized Targets
Medieval Warfare, Storage Rings, and Internal Targets

South of France, between Toulouse and the Mediterranean
Carcassonne
Fortress built by Philippe III (the Strong) (1270-1285)
Medieval Warfare

Multiple use of a projectile oscillating in a potential well.

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Internal Target in a Storage Ring

H, D, etc.  
\( ^{\textbf{\textit{H}}}, ^{\textbf{\textit{D}}}, ^{\textbf{\textit{3\ He}}} \)

Target

orbiting beam of projectiles

Storage Ring: Re-usable Projectiles
Application of the Carcassonne principle (type I)
After each wall collisions, atoms can intercept beam again.

**Storage cell Target:** Re-usable target atoms

Carcassonne principle (type II)
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The basic concept

We have proposed a method to polarize antiprotons by „spin-filtering“.
New initiative, driven by the FAIR-project at GSI

(How) is it possible to provide polarized antiproton beams in HESR?

High Energy Storage Ring (HESR) for a beam of antiprotons
"Transversity" in polarized proton - polarized antiproton Drell-Yan collisions:

\[
A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\downarrow\downarrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\downarrow\uparrow}} = \hat{a}_{TT} \sum_q \frac{e_q^2 h_1^q(x_1, M^2) \bar{h}_1^q(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}
\]
Hadron Physics „Dream Machine“ for FAIR

… an asymmetric (double-polarized) proton (15 GeV/c) – antiproton (3.5 GeV/c) collider using HESR, CSR and APR

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Production of polarization in a stored beam

For an ensemble of spin $\frac{1}{2}$ particles with projections $+$ (↑) and $-$ (↓)

![Diagram showing selective loss and selective flip]

selective loss

discard (one) substrate
(more than the other)

selective flip

reverse (one) substrate
(more than the other)

→Selective flip preferred (no loss in intensity)!
Polarization build-up

repeated passage through a polarized target in a storage ring:
Polarization Buildup

Unpolarized anti-p beam

Polarized target

Polarized anti-p beam

Polarized target
Spin-filtering studies at COSY

Experimental setup:

- low-ß section
- Atomic Beam Source
- Breit-Rabi polarimeter
- Openable storage cell
- Si tracking telescopes
PAX at the AD (the only place worldwide)

Siberian snake

Electron cooler

PAX target section
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Polarized $^3$He for NMR’s of the human lung (Werner Heil)

Spin-Off of Polarized Gas Target Technology

Human Lung with 0.7 bar $\times$ liter of polarized $^3$He

$P_H \sim m \cdot B/kT$
$\sim 5 \cdot 10^{-6}$

$P_{He} \sim 1$

$\rho_H/\rho_{He} \sim 2500$

signal $P \cdot \mu \cdot \rho$
$S/S_H > 10$

amount of gas: 1 bar $\cdot$ liter

Proton - MRI ($^1$H)

DKFZ, HD Nov. 1995;

Helium - MRI ($^3$He)

Lancet 1996
Gas delivery to partners

Research & Training Network (RTN)
Marie Curie Actions
FP 6 (2007-2011)

PHeLINet
Polarized Helium Lung Imaging Network

Feasibility of functional magnetic resonance lung imaging in Australia with long distance transport of hyperpolarized helium from Germany


≈ 100 shipments / year @ 500 bar·litres
Hyperpolarized $^3$He administration

- volume-control: $\Delta V/V = 3\%$

- gas administration at predefined times during inspiration

- on-line polarimetry

- use of gas mixtures ($^3$He, $^{129}$Xe), ($^3$He, SF$_6$)

- gas recovery !!!

(shortage of $^3$He)
Techniques and practices for HP gas production and delivery

Central $^3$He gas production facility

$^3$He recovery

$^3$He administration

3He storage, transport, and polarimetry
Functional NMR using $^3$He

Dynamic Radial Projection MRI of Inhaled $^3$Helium Gas – Emphysema patient

Images courtesy of Jim Wild
“Man muß etwas Neues machen, um etwas Neues zu sehen.”
“You have to make (create) something new, if you want to see something new”
Polarized Antiprotons receive ERC Grant

a nice Xmas present

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1584 ERC AdvG Proposals submitted
• 236 selected (15% success rate)
  – Life Science (89)
  – Social Sciences & Humanities (42)
  – Physical science & Engineering (105)
    o PE2-Fundamental constituents of Matter (11)
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