The Anticyclotron Project

Dezső Horváth

horvath@rmki.kfki.hu.

RMKI, Budapest and ATOMKI, Debrecen, Hungary
Outline

- Historical Introduction
- Cyclotron Trap I
- Anticyclotron Test at LEAR
- Anticyclotron Tests at PSI
- Cyclotron Trap II
- Extracted Muons at PSI

Who should have given this talk?

Leo Simons (PSI), Franz Kottmann (ETH), John Eades (CERN)
Historical Introduction: LEAR

- ULEAP Workshops at CERN (John Eades): 1989-90

- Proposals for ultra low energy $\bar{p}$ beam:
  - 1981: PS189 proposal with ELENA
  - 1985: PS189 with RFQD
  - 1989-91: Anticyclotron (AC) tests (gravity measurement)

- Both RFQD and AC gave up by 1991 (no LEAR beam below 100 MeV/c)
Historical Introduction: present

- Proposals for ultra low energy $\bar{p}$ beam at AD
  - ASACUSA’s RFQD: it works!
  - ELENA proposed (again?)
- The AC at PSI
  - 1991-94: AC tested for muons
  - 2000: Slow muon beam with new CT-AC
- Maybe AC revives for $\bar{p}$?
Cyclotron Trap

Low pressure (mbar) gas target in SC inverse cyclotron
Inject charged particles at max radius through foil
Cyclotron motion, slowing down in gas
Field shape: stop in middle, detector in bore hole
PS-175 at LEAR

Missing X-ray transitions

Auger transitions of remaining electrons

Naked exotic atoms

L. M. Simons:

K. Heitlinger et al.:
Anticyclotron at LEAR

Inject 61 MeV/c $\bar{p}$ at high radius off median plane
Cyclotron & betatron motion, slowing down in gas
Slow $\bar{p}$ at axis, electrostatic extractor in bore hole
extraction into Penning trap

Anticyclotron test at LEAR

Anticyclotron test at LEAR: P118T, 1990-91
Pisa, Genova, PSI, CERN, Budapest

We could not extract the antiprotons

Mapped $\bar{p}$ trajectories with radially moving scintillator

Simulations (GEANT3): large emittance at injection

Later: stochastic cooling was not set up for $p(\bar{p}) \sim 60 - 70 \text{ MeV}/c$

Success with muon extraction at PSI with much worse injected beam

Muon Anticyclotron at PSI

Muons: continuous beam with large beam spot and emittance

Slowing down in thin Formvar foil (in median plane)

Extraction possible with no vacuum separation

## Anticyclotron I for $\mu^-$ and $\bar{p}$

<table>
<thead>
<tr>
<th>Property</th>
<th>$\mu^-$ at PSI (measured)</th>
<th>$\bar{p}$ at LEAR (expected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam momentum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>— energy</td>
<td>30 MeV/c</td>
<td>61 MeV/c</td>
</tr>
<tr>
<td>— emittance</td>
<td>4 MeV</td>
<td>2 MeV</td>
</tr>
<tr>
<td>— $\frac{\Delta p}{p}$</td>
<td>300 mm mrad</td>
<td>30 mm mrad</td>
</tr>
<tr>
<td>— focus on window</td>
<td>1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>— contamination</td>
<td>$22 \times 9$ mm$^2$</td>
<td>$1 \times 1$ mm$^2$</td>
</tr>
<tr>
<td>— intensity (cont.)</td>
<td>$10^3$ e$^-$/\mu$^-$ (\pi E1)</td>
<td>none</td>
</tr>
<tr>
<td>— — (bunched)</td>
<td>$3 \times 10^6$ $\mu^-$/s</td>
<td>$3 \times 10^6$ $\bar{p}$/s</td>
</tr>
<tr>
<td>— — (bunched)</td>
<td>none</td>
<td>$3 \times 10^8$ $\bar{p}$/100$,\text{ns}$</td>
</tr>
</tbody>
</table>
# Anticyclotron I for $\mu^-$ and $\bar{p}$

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<th>$\mu^-$ at PSI (measured)</th>
<th>$\bar{p}$ at LEAR (expected)</th>
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<tr>
<td>Moderator medium</td>
<td>$4,\mu m$ Mylar foil</td>
<td>$0.3$ mbar $H_2$</td>
</tr>
<tr>
<td>Injection eff.</td>
<td>$15%$</td>
<td>$100%$</td>
</tr>
<tr>
<td>Stopping eff.</td>
<td>$17% \rightarrow 20%$</td>
<td>$20 - 30%$</td>
</tr>
<tr>
<td>Extraction eff.</td>
<td>$2% \rightarrow 5%$</td>
<td>$75%$</td>
</tr>
<tr>
<td>MeV$\rightarrow$keV conv. eff.</td>
<td>$0.05% \rightarrow 0.15%$</td>
<td>$15 - 22%$</td>
</tr>
<tr>
<td>Extracted energies</td>
<td>$5 - 25$ keV</td>
<td>$7 - 10$ keV</td>
</tr>
<tr>
<td>Extracted intensity</td>
<td>$2 \times 10^4 , \mu^-/s ,(\pi E5)$</td>
<td>$6 \times 10^6 , \bar{p}/shot$</td>
</tr>
</tbody>
</table>

Pionic Hydrogen Expt at PSI


Dezső Horváth: The Anticyclotron Project

Workshop on Physics with Ultra Slow Antiproton Beams

RIKEN, 14-16 March 2005 – p.12
Slow Muon Beam at PSI

The new PSI anticyclotron

Axial $\pi^-$ injection

$p(\pi^-) = 100 \text{ MeV}/c$

$2 \times 10^8/s$, $B = 4 \text{ T}$

$\pi^- \rightarrow \mu^-$ in flight

$\mu^-$ MeV $\Rightarrow$ keV in foils

Extraction in $E_{\text{axial}}$

$B_{\text{transport}} = 0.15 \text{ T}$

cleans beam of $e^-$
Slow Muon Beam at PSI

Arrival:

\[ E(\mu^-) = 10 - 50 \text{ keV} \]

\[ \varnothing 3 \text{ cm} \]

\[ \sim 10^4 \text{s} \mu^- \text{ in Be foil} \]

\[ \text{H}_2 \text{ target} \]

in \( B = 5 \text{ T solenoid} \)

\[ 100 \mu^- \text{ stops/s in} \]

\[ p(\text{H}_2) = 2 \text{ mbar H}_2 \]

(limited by laser expt)

Conclusion

- The anticyclotron project failed at LEAR
- ... probably due to poor beam cooling
- It works at PSI with muons
- ... of much worse beam characteristics
- It could be as efficient as an RFQD
- ... but much smaller, cheaper and easier to operate