P986: Medium-Energy Antiproton Experiments at Fermilab

Daniel M. Kaplan

Physics Advisory Committee
Fermilab
Batavia, IL
Mar. 5, 2009
Outline

(Varied menu!)

• Antiproton sources
• Hyperon CP violation
• A new experiment
• Issues in charmonium
• Charm mixing
• Summary
Antiproton Sources

- Fermilab Antiproton Source is world’s most intense (and highest-energy)

<table>
<thead>
<tr>
<th>Facility</th>
<th>( \bar{p} ) K.E. (GeV)</th>
<th>Rate ( \times 10^{10} \text{/hr} )</th>
<th>Stacking Duty Factor</th>
<th>Hours /Yr</th>
<th>( \bar{p} )/Yr ( \times 10^{13} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN AD</td>
<td>0.005, 0.047</td>
<td>–</td>
<td>–</td>
<td>3800</td>
<td>0.4</td>
</tr>
<tr>
<td>FNAL (Accumulator)</td>
<td>( \approx 3.5 \sim 8 )</td>
<td>20</td>
<td>15%</td>
<td>5550</td>
<td>17</td>
</tr>
<tr>
<td>FNAL (New Ring)</td>
<td>2 – 20?</td>
<td>20</td>
<td>90%</td>
<td>5550</td>
<td>100</td>
</tr>
<tr>
<td>FAIR ( \geq 2016 )</td>
<td>2 – 15</td>
<td>3.5</td>
<td>90%</td>
<td>2780*</td>
<td>9</td>
</tr>
</tbody>
</table>

* The lower number of operating hours at FAIR compared with that at other facilities arises from medium-energy antiproton operation having to share time with other programs.

...even after GSI FAIR turns on (has yet to break ground; will likely take some time to reach this goal)

D. M. Kaplan, IIT
Hyperon CP Violation

- Differently sensitive to new physics than $B, \varepsilon'/\varepsilon$ (parity-conserving interactions)
  - complementary to mu2e
- B Factories have shown $B$ mixing & CPV dominantly SM
  $\Rightarrow$ worth looking elsewhere!

- Leading potential signals are $A_\Lambda, A_\Xi, A_\Omega, \Delta_\Omega$:

$$A_\Lambda \equiv \frac{\alpha_\Lambda + \bar{\alpha}_\Lambda}{\alpha_\Lambda - \bar{\alpha}_\Lambda}, \quad B_\Lambda \equiv \frac{\beta_\Lambda + \bar{\beta}_\Lambda}{\beta_\Lambda - \bar{\beta}_\Lambda}, \quad \Delta_\Lambda \equiv \frac{\Gamma_{\Lambda \to P\pi} - \bar{\Gamma}_{\Lambda \to P\pi}}{\Gamma_{\Lambda \to P\pi} + \bar{\Gamma}_{\Lambda \to P\pi}}$$

- $\bar{\rho}$ source can produce $\sim 10^8 \Omega^- \bar{\Omega}^+$,
  & maybe $\sim 10^{10} \Xi^- \bar{\Xi}^+$ (transition crossing)
Hyperon CP Violation

- SM predicts small CP asymmetries in hyperon decay
- NP can amplify them by orders of magnitude:

Table 5: Summary of predicted hyperon CP asymmetries.

<table>
<thead>
<tr>
<th>Asymm.</th>
<th>Mode</th>
<th>SM</th>
<th>NP</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_\Lambda$</td>
<td>$\Lambda \rightarrow p\pi$</td>
<td>$\lesssim 10^{-5}$</td>
<td>$\lesssim 6 \times 10^{-4}$</td>
<td>[68]</td>
</tr>
<tr>
<td>$A_{\Xi\Lambda}$</td>
<td>$\Xi^\mp \rightarrow \Lambda\pi$, $\Lambda \rightarrow p\pi$</td>
<td>$\lesssim 0.5 \times 10^{-4}$</td>
<td>$\lesssim 1.9 \times 10^{-3}$</td>
<td>[69]</td>
</tr>
<tr>
<td>$A_{\Omega\Lambda}$</td>
<td>$\Omega \rightarrow \Lambda K$, $\Lambda \rightarrow p\pi$</td>
<td>$\lesssim 4 \times 10^{-5}$</td>
<td>$\lesssim 8 \times 10^{-3}$</td>
<td>[36]</td>
</tr>
<tr>
<td>$\Delta_{\Xi\pi}$</td>
<td>$\Omega \rightarrow \Xi^0\pi$</td>
<td>$2 \times 10^{-5}$</td>
<td>$\leq 2 \times 10^{-4}$</td>
<td>[35]</td>
</tr>
<tr>
<td>$\Delta_{\Lambda K}$</td>
<td>$\Omega \rightarrow \Lambda K$</td>
<td>$\lesssim 1 \times 10^{-5}$</td>
<td>$\leq 1 \times 10^{-3}$</td>
<td>[36]</td>
</tr>
</tbody>
</table>

*Once they are taken into account, large final-state interactions may increase this prediction [56].
Hyperon CP Violation

- **Theory & experiment:**

  **Theory** [Donoghue, He, Pakvasa, Valencia, et al., e.g., PRL 55, 162 (1985); PRD 34, 833 (1986); PLB 272, 411 (1991)]

  - **SM:**
    \[ A_\Lambda \sim 10^{-5} \]
    \[ |A_{\Xi\Lambda}| < 5 \times 10^{-5} \]

  - **Other models:**
    [e.g. SUSY gluonic dipole: X.-G.He et al., PRD 61, 071701 (2000)]

  \[ O(10^{-3}) \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Decay Mode</th>
<th>( A_\Lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>R608 at ISR</td>
<td>( pp \to \Lambda X, \bar{p}p \to \bar{\Lambda}X )</td>
<td>(-0.02 \pm 0.14)  [P. Chauvat et al., PL 163B (1985) 273]</td>
</tr>
<tr>
<td>DM2 at Orsay</td>
<td>( e^+ e^- \to J/\Psi \to \Lambda \bar{\Lambda} )</td>
<td>(0.01 \pm 0.10)  [M.H. Tixier et al., PL B212 (1988) 523]</td>
</tr>
<tr>
<td>PS185 at LEAR</td>
<td>( p\bar{p} \to \Lambda \bar{\Lambda} )</td>
<td>(0.006 \pm 0.015)  [P.D. Barnes et al., NP B 56A (1997) 46]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Decay Mode</th>
<th>( A_{\Xi} + A_\Lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>E756 at Fermilab</td>
<td>( \Xi \to \Lambda \pi, \Lambda \to p\pi )</td>
<td>(0.012 \pm 0.014)  [K.B. Luk et al., PRL 85, 4860 (2000)]</td>
</tr>
<tr>
<td>E871 at Fermilab</td>
<td>( \Xi \to \Lambda \pi, \Lambda \to p\pi )</td>
<td>((0.0 \pm 6.7) \times 10^{-4})  [T. Holmstrom et al., PRL 93. 262001 (2004)]</td>
</tr>
<tr>
<td>(HyperCP)</td>
<td></td>
<td>((6 \pm 2 \pm 2) \times 10^{-4})  [BEACH08 preliminary]</td>
</tr>
</tbody>
</table>
Hyperon CP Violation

- **Theory & experiment:**

  - **Theory** [Donoghue, He, Pakvasa, Valencia, et al., e.g., PRL 55, 162 (1985); PRD 34, 833 (1986); PLB 272, 411 (1991)]
  
  - **SM:**
    
    \[ |A_{\Xi\Lambda}| < 5 \times 10^{-5} \]
    
  - **Other models:**
    
    [e.g. SUSY gluonic dipole: X.-G.He et al., PRD 61, 071701 (2000)]

<table>
<thead>
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<th>Decay Mode</th>
<th>( \Lambda )</th>
<th>( \Xi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>R608 at ISR</td>
<td>( pp \rightarrow \Lambda X, \bar{p}p \rightarrow \bar{\Lambda}X )</td>
<td>( \Lambda \sim 10^{-5} )</td>
<td>( 0 )</td>
</tr>
<tr>
<td>DM2 at Orsay</td>
<td>( e^+e^- \rightarrow J/\Psi \rightarrow \Lambda\bar{\Lambda} )</td>
<td>( 0 )</td>
<td>( 0 )</td>
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<td>( \Xi \rightarrow \Lambda\pi, \Lambda \rightarrow p\pi )</td>
<td>( \Xi \sim 10^{-3} )</td>
<td>( 0 )</td>
</tr>
</tbody>
</table>

**Hyperon CP Violation**

- **Previous Measurements**
  
  None of the pre-HyperCP experiments had the sensitivity to test theory
  
  HyperCP probes well into regions where BSM theories predict nonzero asymmetries

- **Present Measurement**
  
  \( (6 \pm 2 \pm 2) \times 10^{-4} \) [BEACH08 preliminary]
Made possible by... **Enormous HyperCP Dataset**

- $\bar{p}$ source can produce $\sim 10^8 \Omega^- \bar{\Omega}^+ / \gamma$ & maybe $\sim 10^{10} \Xi^- \bar{\Xi}^+$
Does the HyperCP Evidence for the Decay $\Sigma^+ \rightarrow p\mu^+\mu^-$ Indicate a Light Pseudoscalar Higgs Boson?

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(Received 2 November 2006; published 22 February 2007)

The HyperCP Collaboration has observed three events for the decay $\Sigma^+ \rightarrow p\mu^+\mu^-$ which may be interpreted as a new particle of mass 214.3 MeV. However, existing data from kaon and $B$-meson decays provide stringent constraints on the construction of models that support this interpretation. In this Letter we show that the “HyperCP particle” can be identified with the light pseudoscalar Higgs boson in the next-to-minimal supersymmetric standard model, the $A_1^0$. In this model there are regions of parameter space where the $A_1^0$ can satisfy all the existing constraints from kaon and $B$-meson decays and mediate $\Sigma^+ \rightarrow p\mu^+\mu^-$ at a level consistent with the HyperCP observation.
How Follow Up?

One possibility:

- Once Tevatron shuts down ($\approx 2010$),
  - Reinstall E835 EM spectrometer
  - Add small magnetic spectrometer
  - Add precision TOF system
  - Add wire or pellet target
  - Add $2^{\text{nd}}$ary-vertex trigger
- Run $p\bar{p} = 5.4$ GeV/$c$ ($2m_\Omega < \sqrt{s} < 2m_\Omega + m_{\Pi^0}$) @ $\mathcal{L} \sim 10^{32}$ cm$^{-2}$ s$^{-1}$ ($10 \times $ E835)
  $\Rightarrow \sim 10^8 \Omega^- \bar{\Omega}^+/\text{yr} + \sim 10^{12}$ inclusive hyperon events!
What Can This Do?

- Observe many more $\Sigma^+ \rightarrow p\mu^+\mu^-$ events and confirm or refute SUSY interpretation

- Discover or limit $\Omega^- \rightarrow \Xi^-\mu^+\mu^-$ and confirm or refute SUSY interpretation

- Discover or limit CP violation in $\Omega^- \rightarrow \Lambda K^-$ and $\Omega^- \rightarrow \Xi^0\pi^-$ via partial-rate asymmetries

Predicted $\mathcal{B} \sim 10^{-6}$ if $P^0$ real

Predicted $\Delta\mathcal{B} \sim 10^{-5}$ in SM, $\leq 10^{-3}$ if NP
Much interest lately in new states observed in charmonium region: \( X(3872) \), \( X(3940) \), \( Y(3940) \), \( Y(4260) \), and \( Z(3930) \)

\( X(3872) \) of particular interest: may be the first meson-antimeson \( (D^0 \overline{D}^{*0} + \text{c.c.}) \) molecule (or tetraquark or what?)

\[ \overrightarrow{pp} \rightarrow X(3872) \text{ formation ideal for this} \]

Also \( h_c \) mass & width, \( \chi_c \) radiative-decay angular distributions, \( \eta_c' \) full and radiative widths,...
Example: precision $\bar{p}p$ mass & width measurements

- The beam is the spectrometer! $\rightarrow$ \begin{align*}
\delta m(\chi_c) &\approx 0.1 \pm 0.02 \text{ MeV}/c^2 \\
\delta \Gamma(\chi_c) &\approx 0.1 \pm 0.01 \text{ MeV}/c^2
\end{align*}
- The experiment is just the detector.
Example: precision $\bar{p}p$ mass & width measurements

- Works even for $\psi'$:
  - E835 measured $\Gamma = (290 \pm 25 \pm 4)$ keV with 2,700 events
  - used “complementary scans” to reduce systematics

$\Rightarrow$ Best technique for $X(3872)$ mass & (sub-MeV?) width measurement

![Cross section plots](Image)

Fig. 2. $\psi(2S)$ resonance scans: the observed cross section for each channel (filled dots); the expected cross section from the fit (open diamonds); the ‘bare’ resonance curves $\sigma_{BW}$ from the fit (solid lines). The two bottom plots show the normalized energy distributions $B_i$. 
What Else Can This Do?
We present an estimate of the partial width of \( X(3872) \) into \( pp \) under the assumption that it is a weakly bound hadronic molecule whose constituents are a superposition of the charm mesons \( D^{*0}\bar{D}^{0} \) and \( D^0\bar{D}^0 \). The \( pp \) partial width of \( X \) is therefore related to the cross section for \( pp \to D^{*0}\bar{D}^{0} \) near the threshold. That cross section at an energy well above the threshold is estimated by scaling the measured cross section for \( p\bar{p} \to K^+K^- \). It is extrapolated to the \( D^{*0}\bar{D}^{0} \) threshold by taking into account the threshold resonance in the \( 1^{++} \) channel. The resulting prediction for the \( pp \) partial width of \( X(3872) \) is proportional to the square root of its binding energy. For the current central value of the binding energy, the estimated partial width into \( pp \) is comparable to that of the P-wave charmonium state \( X_{c1} \).
Charm?

- Braaten estimate of $\bar{p}p$ $X(3872)$ coupling assuming $D^*D$ molecule
  - extrapolates from $K^*K$ data
- By-product is $D^{*0}\bar{D}^0$ cross section
  - $1.3 \mu b \rightarrow 5 \times 10^9$/year
- Expect efficiency as at $B$ factories
**Charm?**

- *D^0*’s mix! (c is only up-type quark that can)

- **Big question:** New Physics or old?
Charm?

- **$D^0$’s mix!** ($c$ is only up-type quark that can)

  Singly Cabibbo-suppressed (CS) $D$ decays have 2 competing diagrams:

  a)
  
  $D^0$  
  \[ \begin{array}{c}
  c \\
  u \\
  \end{array} \rightarrow \begin{array}{c}
  s \\
  u \\
  \end{array} \rightarrow \begin{array}{c}
  W^+ \\
  \end{array} \rightarrow \begin{array}{c}
  K^+ \\
  s \\
  u \\
  \end{array} \]

  b)
  
  $D^0$  
  \[ \begin{array}{c}
  c \\
  u \\
  \end{array} \rightarrow \begin{array}{c}
  d, s, b \\
  g, \gamma, Z \\
  \end{array} \rightarrow \begin{array}{c}
  W^+ \\
  \end{array} \rightarrow \begin{array}{c}
  K^+ \\
  s \\
  u \\
  \end{array} \]

- **Big question:** New Physics or old?
  
  \[ \rightarrow \text{key is } CP \text{ Violation!} \]
  Possible in CF, DCS only if New Physics

- **$B$ factories have } \sim 10^9\text{ open-charm events}

- **$\bar{p}p$ can produce } \sim 10^{10}/y\text{**

\[ \rightarrow \text{world’s best sensitivity to charm CPV} \]
Charm?

- Ballpark sensitivity estimate using cross section based on Braaten $\bar{p}p \to D^{*0}\bar{D}^0$ formula and assuming $\sigma \propto A^{1.0}$:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running time</td>
<td>$2 \times 10^7$</td>
<td>s/y</td>
</tr>
<tr>
<td>Duty factor</td>
<td>0.8*</td>
<td></td>
</tr>
<tr>
<td>$L$</td>
<td>$2 \times 10^{32}$</td>
<td>cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Target $A$</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>$A^{0.29}$</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>$\sigma(\bar{p}p \to D^{*+}X)$</td>
<td>1.25</td>
<td>$\mu$b</td>
</tr>
<tr>
<td>$# D^{*\pm}$ produced</td>
<td>$2.1 \times 10^{10}$</td>
<td>events/y</td>
</tr>
<tr>
<td>$B(D^{*+} \to D^0\pi^+)$</td>
<td>0.677</td>
<td></td>
</tr>
<tr>
<td>$B(D^0 \to K^-\pi^+)$</td>
<td>0.0389</td>
<td></td>
</tr>
<tr>
<td>Acceptance</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$2.7 \times 10^7$</td>
<td>events/y</td>
</tr>
</tbody>
</table>

(known from H.E. fixed-target)

- Compare with $1.22 \times 10^6$ tagged events at Belle [M. Staric et al., PRL 98, 211803 (2007)]

- LHCb will have comparable statistics but diff’r systematics

D. M. Kaplan, IIT

P986 Letter of Intent

FNAL PAC 3/5/09
Charm?

• Another possibility (E. Braaten): use the $X(3872)$ as a pure source of $D^*\bar{D}^0$ events

  - the $\bar{p}p$ equivalent of the $\psi(3770)$!?  

  - assuming current Antiproton Accumulator parameters ($\Delta p/p$) & Braaten estimate, produce $\sim 10^8$ events/year

  - comparable to BES-III statistics

  - could gain factor $\sim 5$ via AA $e^-$ cooling?

• Proposed expt will establish feasibility & reach
Background Study

• How efficiently can we identify $D^* \rightarrow D^0$ decays while adequately suppressing background?

• Study via MIPP 20 GeV $\bar{p}p$ data:

- MIPP 20 GeV $\bar{p}p$ (h$^+h^-h^+$ and h$^-h^+h^-$ comb’s w/ $p_t1 < p_t2,p_t3$)

- $D^*,$ $D$ mass window

1st-order correction for higher beam energy:

$p_z \rightarrow 0.65 p_z$

(conservative)
Background Study

- Cut on $D^*$ and $D$ masses and $D^* - D$ mass difference:

  - Leaves only ~1 background event – with no kaon ID!
Background Study

- MIPP normalization @ 20 GeV not yet worked through in detail, but sample sensitivity $\sim 1$ evt/$\mu$b

- Suppose total inclusive $\sigma(D^*) \sim 10 \ \mu$b (incl. A-dep.)
  
  \[ x \ B \cdot 0.67 \times 0.039 \rightarrow \sim \frac{1}{4} \text{evt signal} \]

  $\Rightarrow$ sig/bkg $\sim 0.1$ (with above $D^*$–$D$ cuts)

- Kaon ID $\rightarrow \sim x$ 10

- Lifetime cuts $\rightarrow \sim x$ 10 –100

  $\Rightarrow$ Clean sample can likely be obtained with reasonable ($\sim 0.1$) efficiency
Summary

• Best experiment ever on hyperons, charm, and charmonia may soon be feasible at Fermilab
  - including world’s most sensitive charm CPV study?
• Mix of speculative and established physics goals
  - for some, feasibility depends on poorly known cross sections
  - we can measure them quickly and cost-effectively
  - no modification of accelerator complex required
• World’s best $\bar{p}$ source → simple way to broad physics program in (pre-)Project X era
### 0\textsuperscript{th}-order run-plan example:

<table>
<thead>
<tr>
<th>Task</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>install/debug</td>
<td>~3 mo</td>
</tr>
<tr>
<td>find $X(3872)$</td>
<td>~1 mo</td>
</tr>
<tr>
<td>measure $\sigma(D^*)$</td>
<td>~1 mo</td>
</tr>
<tr>
<td>measure $\sigma(\Omega\overline{\Omega})$</td>
<td>~1 mo</td>
</tr>
<tr>
<td>charmonium</td>
<td>~3 mo</td>
</tr>
<tr>
<td>$X(3872)$ run</td>
<td>~12 mo</td>
</tr>
<tr>
<td>hyperon CP run</td>
<td>~12 mo</td>
</tr>
<tr>
<td>install/debug hadron-ID upgrade</td>
<td>~3 mo</td>
</tr>
<tr>
<td>charm CP run</td>
<td>~12 mo</td>
</tr>
</tbody>
</table>

\{ if $\sigma$'s favorable \}

- **Our request:**
  - encouragement from Directorate to continue simulation, design, & planning studies & develop proposal
International Aspect

• Potential European interest (e.g. PANDA)
  - opportunity for early data & experience
• Could significantly reduce needed US resources
• But recent US HEP events cautionary

➡ need indication of US interest to begin negotiation
The answer is, for 20,000 D0 decays where Ebeam=8.937, the pi+K+pi are all 0.1<atan(theta)<1.0, and the vertex resolution is taken as 100 microns for both the D and the 20,000 background events that have D->Kpi kinematics but z=0.:

<table>
<thead>
<tr>
<th>vtx cut</th>
<th>#bkg</th>
<th>#sig</th>
<th>sig/bkg</th>
<th>D accept.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cut on z</td>
<td>10,000</td>
<td>10,000</td>
<td>1</td>
<td>50%</td>
</tr>
<tr>
<td>z&gt;100 microns</td>
<td>1,589</td>
<td>7,106</td>
<td>4.5</td>
<td>35%</td>
</tr>
<tr>
<td>z&gt;200 microns</td>
<td>238</td>
<td>5,168</td>
<td>22</td>
<td>25%</td>
</tr>
<tr>
<td>z&gt;300 microns</td>
<td>14</td>
<td>3,679</td>
<td>250</td>
<td>18%</td>
</tr>
<tr>
<td>z&gt;400 microns</td>
<td>0</td>
<td>2,669</td>
<td>&gt;1000</td>
<td>13%</td>
</tr>
</tbody>
</table>

- ChuckB

-----Original Message-----
From: Daniel Kaplan [kaplan@iit.edu]
Sent: Tuesday, March 03, 2009 7:52 AM
To: Chuck Brown
Subject: Re: Easy simulation?

...or maybe it's a back-of-the-envelope theorem and no MC needed? I'll try to find time to work on this.

Dan

On Mar 3, 2009, at 6:56 AM, Daniel Kaplan wrote:

Hi Chuck,

Are you able to attend today's noon phone conference? Your input would be valuable!

It occurs to me that it would be good to have a backup slide about the vertex cut efficiency and rejection. To first order, this is two very simple Monte Carlo calculations - generate a signal with an exponential lifetime distribution, folded with a 100-micron Gaussian resolution, and generate a background with a 100-micron Gaussian, then see what fractions survive various (1-sigma, 2-sigma, etc.) cuts.

D. M. Kaplan, IIT

P986 Letter of Intent

FNAL PAC 3/5/09
FAIR-ESAC/Pbar/Technical Progress Report, January 17, 2005

The TPC is the technically more challenging time projection chamber (TPC) with continuous readout. The baseline technology chosen for the pixel detector is the microstrip technology, which allows for high precision tracking. The outer layers are composed of microstrip detectors, and the inner layers are composed of pixel detectors. The readout can be either done by internal reflection of Cherenkov light or by a ray of photon detectors in the backward direction.

An electromagnetic calorimeter is placed outside the solenoid. It consists of quartz rods in which internally reflected light similar as for the bar calorimeter. The readout is done by a gas Čerenkov counter with quartz radiator and detectors for internally reflected light.

In the forward direction circular or octagonal crystals and a backward end cap with wurtzite crystals are significant but not dominant, and are suppressed by several LHC experiments. The electronics for the TPC is being developed by INFN, Scuola Normale Superiore, and University of Chicago. The readout can be either done by internal reflection of Cherenkov light or by a ray of photon detectors in the backwards direction.

The study of charmonium states of all quantum numbers in contrast to the study of pentaquark states is of great interest for QCD calculations. The bound states are significant but not dominant, and are suppressed by several LHC experiments. The detector is being developed by INFN, Scuola Normale Superiore, and University of Chicago. The readout can be either done by internal reflection of Cherenkov light or by a ray of photon detectors in the backwards direction.

The unique precision of the hadron calorimeter is achieved by using a combination of gas Čerenkov and plastic scintillation detectors. The hadron calorimeter is placed outside the solenoid. It consists of quartz rods in which internally reflected light similar as for the bar calorimeter. The readout is done by a gas Čerenkov counter with quartz radiator and detectors for internally reflected light.

A unique feature of the detector is the combined target spectrometer and forward spectrometer. The target spectrometer is placed outside the solenoid and is used for high energy physics (HEP) experiments. The forward spectrometer is placed outside the solenoid and is used for forward spectrometer experiments.

The detector is being developed by INFN, Scuola Normale Superiore, and University of Chicago. The readout can be either done by internal reflection of Cherenkov light or by a ray of photon detectors in the backwards direction.

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PANDA Physics Topics

• Charmonium ($c\bar{c}$) spectroscopy (mass, widths, branching ratios)

• Establishment of the QCD-predicted gluonic excitations (charmed hybrids, glueballs) in the 3–5 GeV/$c^2$ mass range

• Search for modifications of meson properties in the nuclear medium

• Precision $\gamma$-ray spectroscopy of single and double hypernuclei

• Extraction of generalized parton distributions from $\bar{p}p$ annihilation

• $D$ meson decay spectroscopy (rare decays)

• Search for CP violation in the charm and strangeness sector
• Some Hyperon CP references:


Some HyperCP Publications:

- M. Huang et al., “New Measurement of $\Xi^- \rightarrow \Lambda\pi^-$ Decay Parameters,” Phys. Rev. Lett. 93, 011802 (2004);
- T. Holmstrom et al., “Search for CP Violation in Charged-$\Xi$ and $\Lambda$ Hyperon Decays,” Phys. Rev. Lett. 93, 262001 (2005);
- Y. C. Chen et al., “Measurement of the Alpha Asymmetry Parameter for the $\Omega^- \rightarrow \Lambda K^-$ Decay,” Phys. Rev. D 71, 051102(R) (2005);