On Λ-$\bar{\Lambda}$ Oscillation

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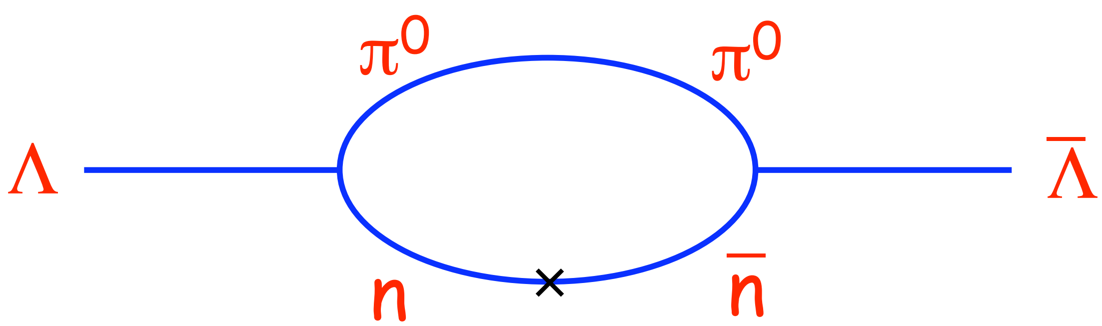
Motivation

- Baryon number may not conserve
- Grand unified theories predict
  - $\Delta B = -1$, $\Delta L = -1$, B-L conserving processes: $p \rightarrow e^+\pi^0$

  or
  - $\Delta B = 2$, $\Delta L = 0$, B-L non-conserving processes: n-$\bar{n}$ oscillation
- If n-$\bar{n}$ oscillation exists, then

Λ-$\bar{\Lambda}$ Oscillation

can take place as well:



Phenomenology

- The equation of motion in a static magnetic field is:

$$\frac{d}{dt}\begin{pmatrix}\Lambda \\ \overline{\Lambda}\end{pmatrix} = -\frac{i}{\hbar}\begin{pmatrix} m_{\Lambda} - \Delta E_{\Lambda} & \delta m_{\Lambda\overline{\Lambda}} \\ \delta m_{\Lambda\overline{\Lambda}} & m_{\overline{\Lambda}} - \Delta E_{\overline{\Lambda}} \end{pmatrix}\begin{pmatrix}\Lambda \\ \overline{\Lambda}\end{pmatrix}$$

where

$$\Delta E = -\vec{\mu}\cdot\vec{B}$$

- The probability of oscillation is then given by

$$P_{\overline{\Lambda}}(t) = \left(\frac{\omega_m^2}{\omega_m^2 + \omega_B^2}\right)\sin^2\sqrt{\omega_m^2 + \omega_B^2}\,t$$

where

$$\omega_m = \frac{\delta m_{\Lambda\overline{\Lambda}}}{\hbar} \qquad \omega_B = \frac{\mu B}{\hbar}$$

- If the magnetic field is absent,

$$P_{\overline{\Lambda}}(t) = \sin^2\omega_m t$$

Inputs

- For free neutron, the mean n-$\bar{n}$ oscillation time is

$$\tau_{n\bar{n}} > 8.6 \times 10^{7}\ \text{sec}\quad \text{(PDG)}$$

Hence, we expect, to the first order,

$$\tau_{\Lambda\bar{\Lambda}} \approx \tau_{n\bar{n}}$$

- As a result, the mass splitting is

$$\delta m_{\Lambda\bar{\Lambda}} < \frac{\hbar}{\tau_{\Lambda\bar{\Lambda}}} \approx 10^{-23}\,\text{eV}$$

- The local magnetic field leads to

$$\Delta E = \mu B = (0.642\mu_N)(0.5 \times 10^{-4}\,\text{T}) \approx 10^{-12}\,\text{eV}$$

Consequences

- The mean life of Λ is τ_Λ = (2.632±0.020) × 10^{-10} s (PDG)
- At the Fermilab fixed-target energies, most Λ's decay in a region of about 30 m; hence the time available for oscillation is

$$t = 10^{-7}\ s$$

- During this time, the effect of the local magnetic field is given by

$$\frac{2\Delta E \cdot t}{\hbar} \approx 3 \times 10^{-4} << 1$$

- To achieve the quasi-free condition, attenuate the local magnetic field. Then the probability of oscillation is

$$P_{\overline{\Lambda}}(t) = \sin^2 \omega_m t \approx \left(\omega_m t\right)^2$$

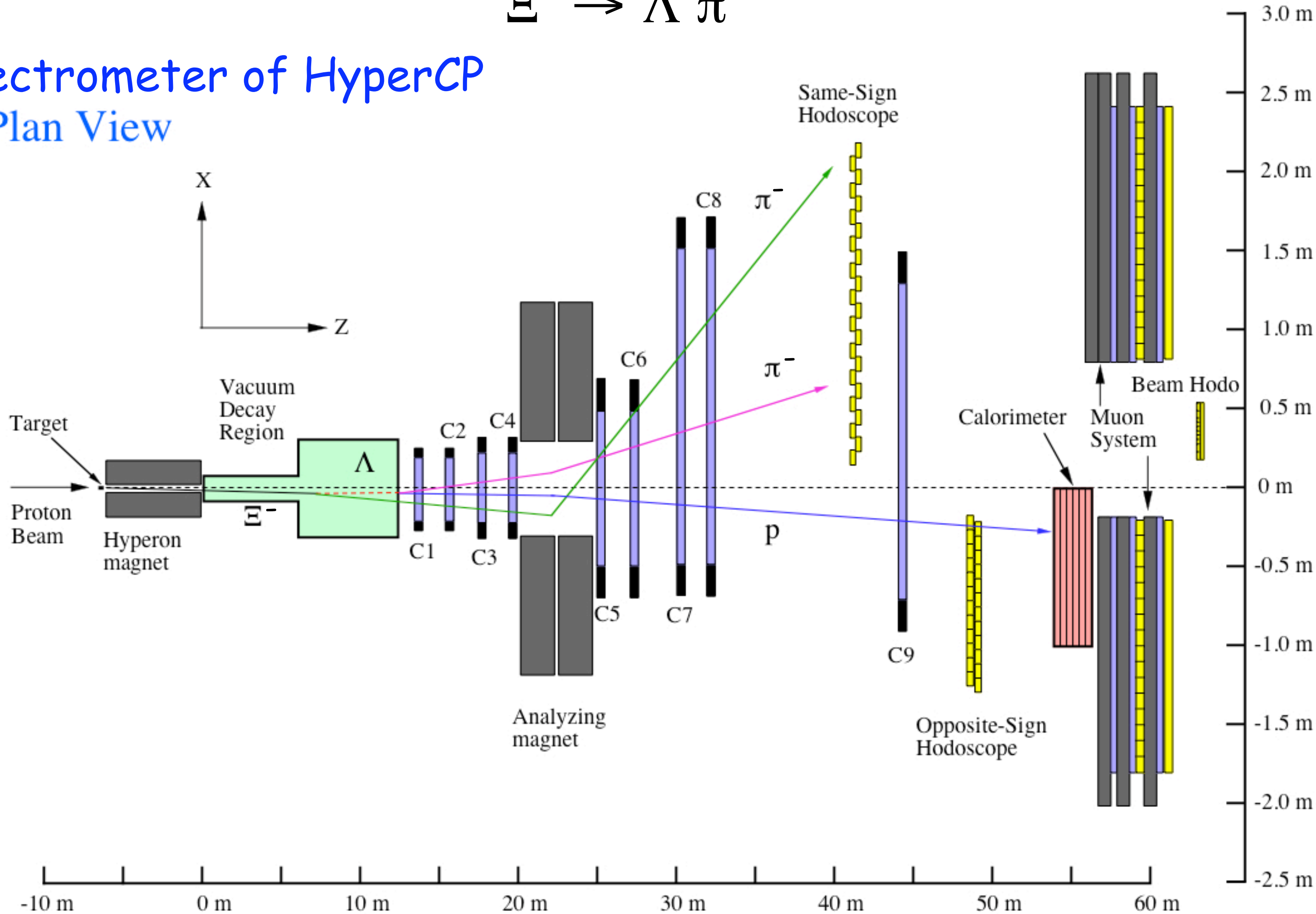
Experimental Considerations

- Need a pure sample of Λ hyperons:

$$\Xi^- \rightarrow \Lambda\,\pi^-$$

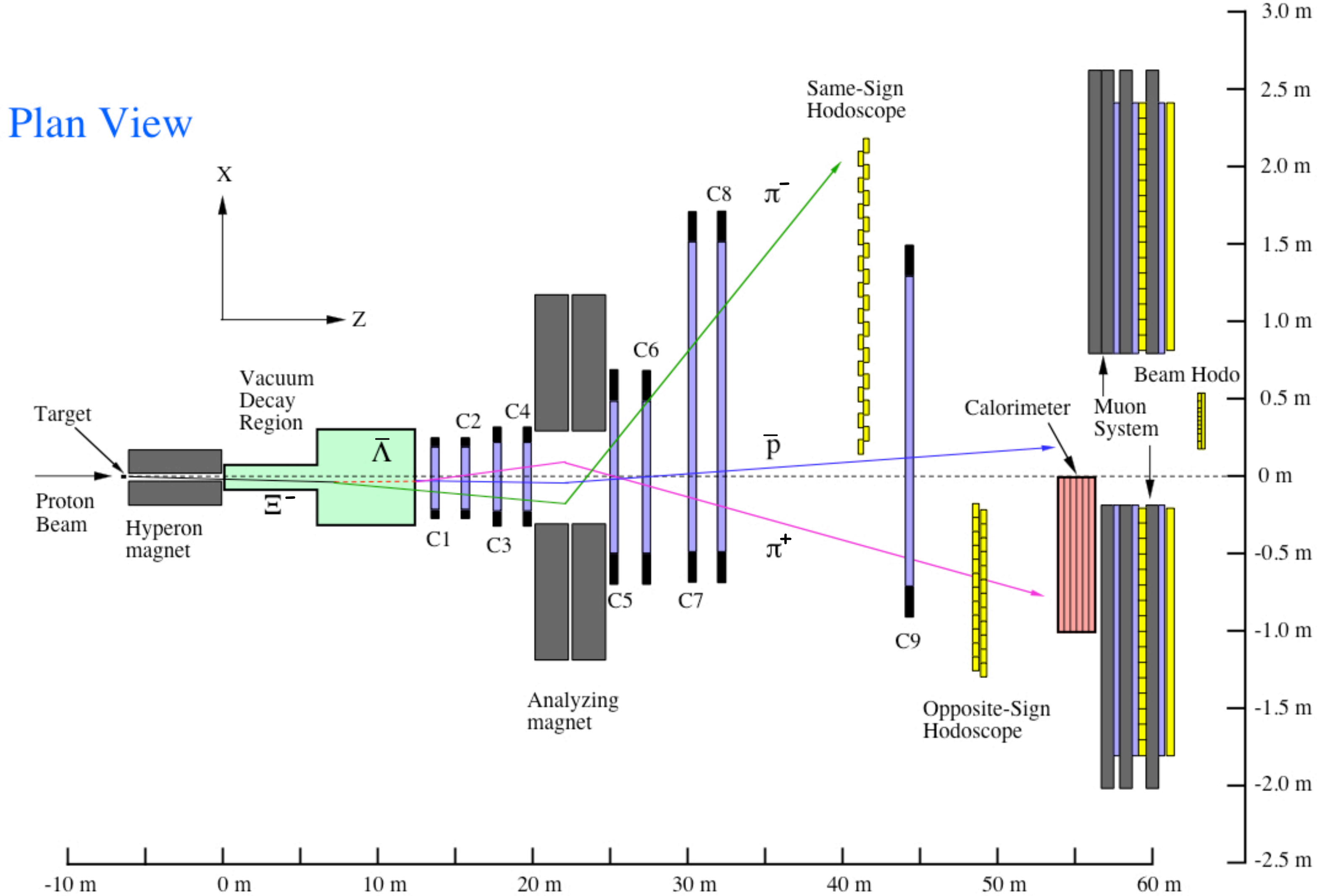
Spectrometer of HyperCP

Plan View



Look For Anomaly

$$\Xi^- \to \bar{\Lambda}\,\pi^-$$



Sensitivity

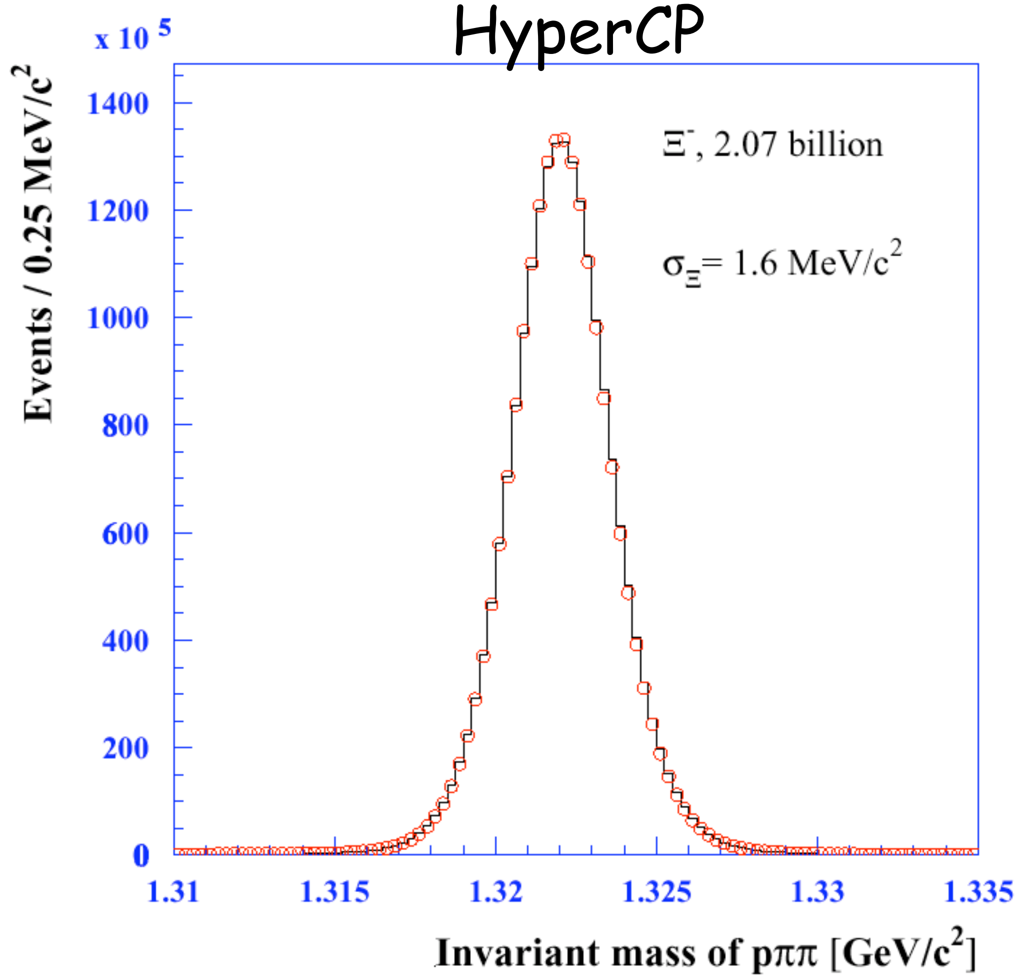
- Single-event sensitivity of observing $\Xi^- \to \bar{\Lambda}\,\pi^-$ in one year of running that can be achieved is

$$\frac{Br(\Xi^- \to \bar{\Lambda}\,\pi^-)}{Br(\Xi^- \to \Lambda\,\pi^-)} < 1 \times 10^{-9}$$

- This would imply

$$\tau_{\Lambda\bar{\Lambda}} > t\sqrt{\frac{N_\Lambda}{N_{\bar{\Lambda}}}} = 10^{-7}\sqrt{\frac{2\times 10^9}{2.3}}\,s \approx 10^{-3}\,s$$

HyperCP



Conclusions

- If n-n oscillation exists, then it would be possible to induce Λ-$\bar{\Lambda}$ oscillation.
- It is possible to produce a clean tagged Λ beam for studying the Λ-$\bar{\Lambda}$ oscillation. However, the significantly shorter mean life of Λ hampers a sensitive search for such oscillation.
- The current data samples can only establish a mixing time $\tau_{\Lambda\bar{\Lambda}}$ to about 10^{-3} s.