IS THERE AN X^0 AT $214\,\mathrm{MeV}$?

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SUSY 06
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[hep-ph/0509081] Deshpande, Eilam, Jiang

EXPERIMENTAL EVIDENCE

HyperCP collaboration at FermiLab studied the process[a]

$$\Sigma^+ \longrightarrow p + \mu^+ + \mu^-$$

Three events are found, implying

$$\mathrm{BR} = (3.1^{+2.4}_{-1.9} \pm 1.5) \times 10^{-8}$$

More importantly, the $\mu^+\mu^-$ invariant mass is $214.3 \pm 0.5\,\mathrm{MeV}$ for all three events.

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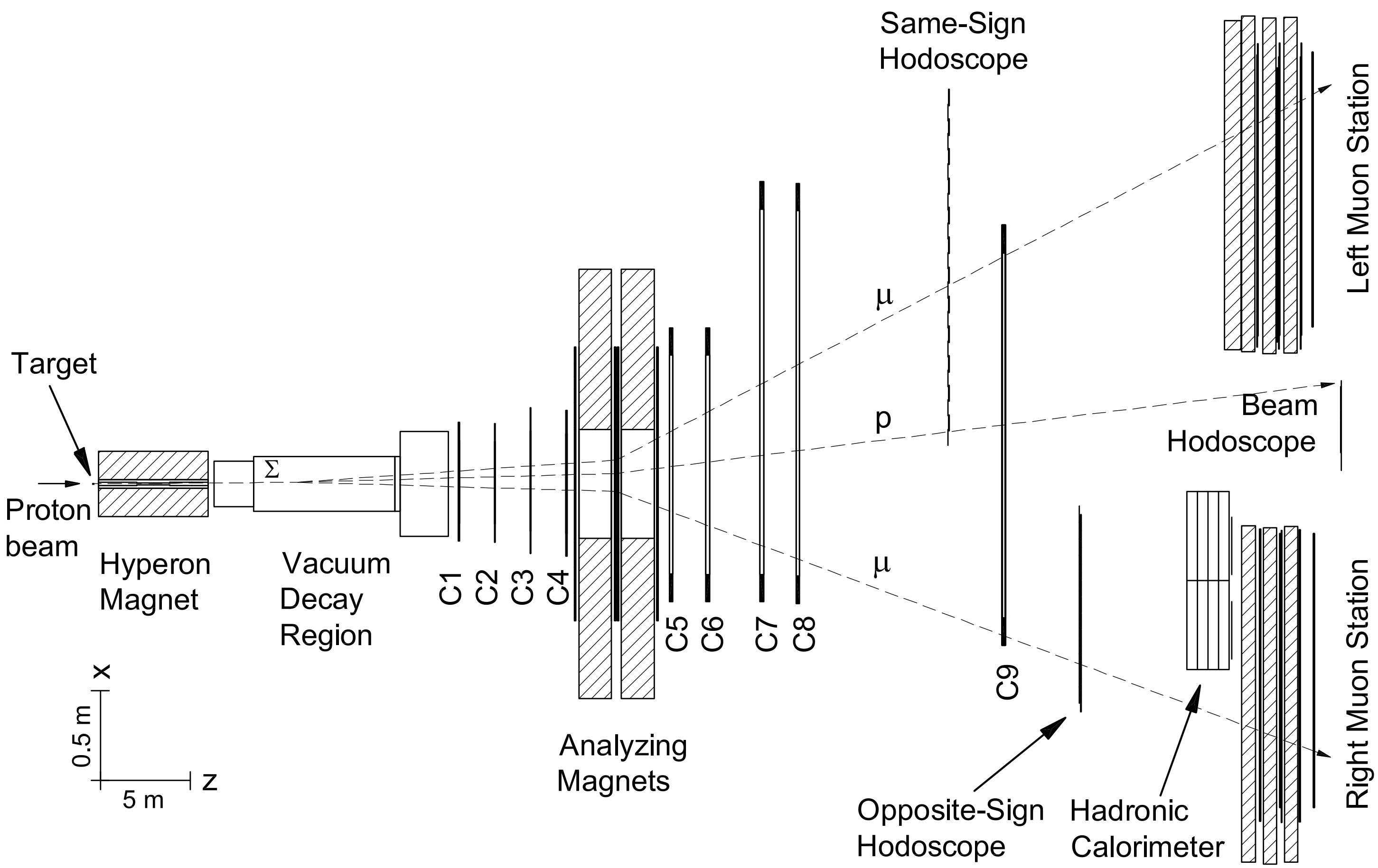
[a] Park *et al.*

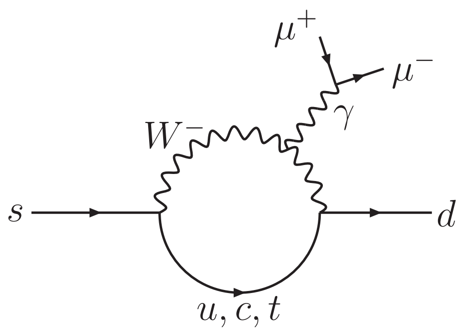
EXPERIMENTAL SETUP



Opposite-sign muons and reconstruct $p\mu^+\mu^-$ invariant mass

STANDARD MODEL PREDICTIONS

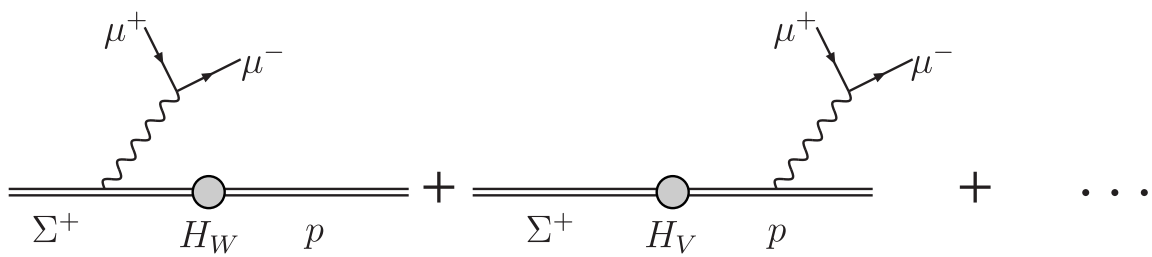
1) Short distance contribution (quark diagrams)



$+ \; Z$ Exchange $+$ Box Diagram

$$\text{BR} \sim 10^{-12}$$

2) Long distance contribution (hadronic transitions)[a]



$$\text{BR} \sim 1.6 \times 10^{-8} - 9.0 \times 10^{-8}$$

But does not explain dimuon invariant mass.

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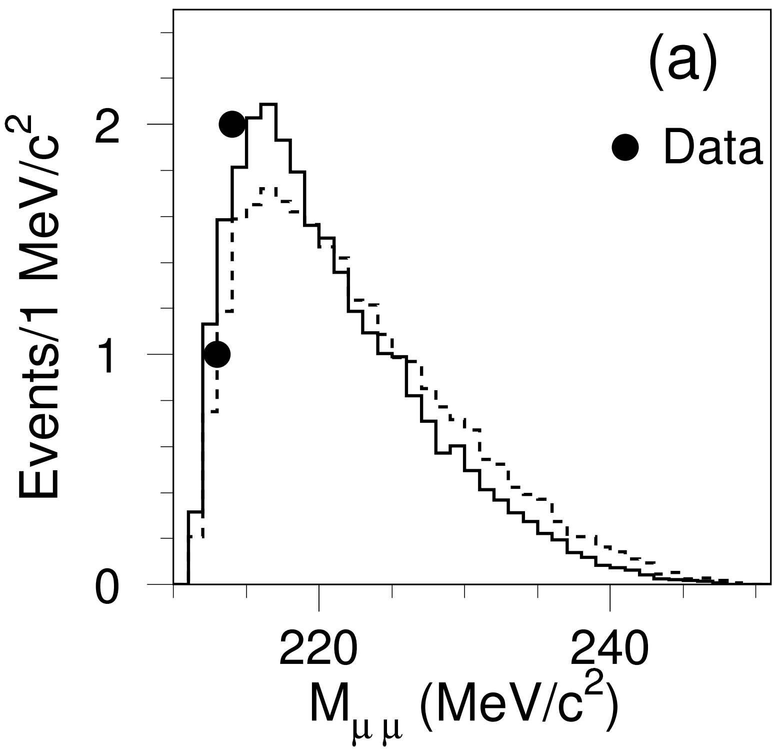
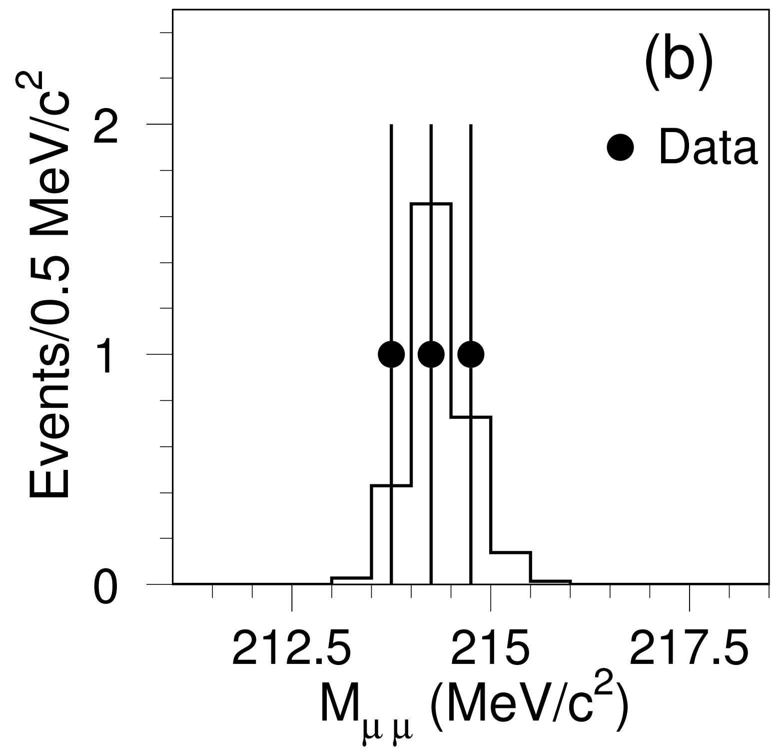
[a] He, Tandean and Valencia.

Three Events





Data points vs. Monte Carlo (histogram) dimuon mass distribution[a] for (a) BG MC events with a form-factor decay (solid) and uniform phase-space (dashed) model, and (b) Signal MC assuming an intermediate P.

[a]Park *et al.*

Hypothesis

Let us assume a state X^0 with mass 214 MeV

General interaction with d, s quarks and μ

$$\mathcal{L}_{int} = [\bar{d}(h_1 + h_2\gamma_5)sX^0 + H.C.] + \bar{\mu}(l_1 + il_2\gamma_5)\mu X^0 + \cdots$$

Σ^+ DECAY

For process $\Sigma^+ \to pX^0$,

$$\langle p|\, \bar{d}s \left|\Sigma^+\right\rangle = \;? \qquad \langle p|\, \bar{d}\gamma_5 s \left|\Sigma^+\right\rangle = \;?$$

From semi-leptonic decay $\Sigma^- \to n + e^- + \overline{\nu}_e$, we know

$$\langle n|\, \bar{u}\gamma_\mu s \left|\Sigma^-\right\rangle = f_1 \overline{u}_n \gamma_\mu u_{\Sigma^-}$$

with

$$|f_1| = 1 \qquad g_1 = 0.33$$

Invoking $SU(2)$ isospin symmetry

$$\langle p|\, \bar{d}\gamma_\mu s \left|\Sigma^+\right\rangle = f_1 \overline{u}_p \gamma_\mu u_{\Sigma^+}$$

Divergence of Currents

Taking divergence of the currents

$$i\partial^{\mu} \langle p| \bar{d}\gamma_{\mu}s \left|\Sigma^{+}\right\rangle = f_1(m_{\Sigma^+} - m_p)\overline{u}_p u_{\Sigma^+}$$

and

$$i\partial^{\mu}(\bar{d}\gamma_{\mu}s) \ = \ (m_s - m_d)\bar{d}s$$

Hence

$$\langle p| \bar{d}s \left|\Sigma^{+}\right\rangle \ = \ f_1 \frac{m_{\Sigma^+} - m_p}{m_s - m_d}\overline{u}_p u_{\Sigma^+}$$

Similar for matrix element $\langle p| \bar{d}\gamma_5 s \left|\Sigma^{+}\right\rangle$

Constraining the Couplings

Assuming $\mathrm{BR}(X^0 \to \mu^+\mu^-) \approx 1$ and BR quoted by experimentalists:

$$\mathrm{BR}(\Sigma^+ \to p + X^0) = (3.1^{+2.4}_{-1.9} \pm 1.5) \times 10^{-8}$$

We use only the central values

$$|h_1|^2 + 0.19|h_2|^2 \approx 9.1 \times 10^{-21}$$

Charged Kaon Decay

The scalar operator induced by X^0 contribute to $K^+ \to \pi^+ \mu^+ \mu^-$

The measured branching ratio

$$\mathrm{BR}(K^+ \to \pi^+ \mu^+ \mu^-) = 8.1 \times 10^{-8}$$

means $|h_1| < 7.4 \times 10^{-12}$

Using the dimuon mass distribution, this limit can be improved by a factor of 5 or 6.

Combined with $|h_1|^2 + 0.19|h_2|^2 \approx 9.1 \times 10^{-21}$

$$|h_2| \gtrsim 3.6 \times 10^{-10}$$

Pseudoscalar coupling dominates

Neutral Kaon Three Body Decay

The processes sensitive to pseudoscalar coupling are:

$$K_L^0 \to \pi^+\pi^- X^0 \qquad K_L^0 \to \pi^0\pi^0 X^0$$

Starting from $K^+ \to \pi^+ + \pi^- + e^+ + \nu_e$ semi-leptonic decay

$$m_K \left\langle \pi^+\pi^- \right| A^\mu \left| K^+ \right\rangle = F(p_{\pi^+} + p_{\pi^-})^\mu + G(p_{\pi^+} - p_{\pi^-})^\mu + R P^\mu_{X^0}$$

with $F = 5.83$ and $G = 4.7$ given from experiments and R derived from Soft Pion Theorem[a], and using $SU(2)$ symmetry we find:

$$\mathrm{BR}(K_L \to \pi^+\pi^- X^0) = 1.5 \times 10^{-9}$$
$$\mathrm{BR}(K_L \to \pi^0\pi^0 X^0) = 8.0 \times 10^{-9}$$

Both are in the measurable ranges.

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[a]Weinberg.

OMEGA DECAY

Consider flavor changing hyperon decay, $\Omega^- \to \Xi^- + \mu^+ + \mu^-$, induced by X^0. The matrix element is

$$\mathcal{M} = \frac{C_A h_2}{m_s + m_d} \overline{u}_\Xi (k_{X^0})_\mu u^\mu_{\Omega^-}$$

with $C_A = -2.08$ determined from $\Omega^- \to \Xi^0 + e^- + \overline{\nu}_e$ decay[a]

Using the spin-3/2 projection operator

$$\Lambda_{\mu\nu} = (\not{p} + m) \left(-g_{\mu\nu} + \frac{1}{3}\gamma_\mu\gamma_\nu + \frac{2}{3}\frac{p_\mu p_\nu}{M^2} - \frac{p_\mu\gamma_\nu - p_\nu\gamma_\mu}{3M} \right)$$

we find

$$\mathrm{BR}(\Omega^- \to \Xi^- X^0) = 2.1 \times 10^{-6}$$

HyperCP has data on this process.

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[a] Finjord and Gaillard.

MUON MAGNETIC MOMENT

By constraining the contribution to $(g-2)_\mu$ to be less then the difference between theory and experiment

$$\Delta a_\mu < 250 \times 10^{-11}$$

we can put limits on $X^0\mu^+\mu^-$ couplings

$$\text{Scalar}: l_1 < 8.6 \times 10^{-4} \qquad \text{Pseudoscalar}: l_2 < 1.0 \times 10^{-3}$$

These imply

$$\Gamma_S(X^0 \to \mu^+\mu^-) < 1.6 \times 10^{-11}\,\text{GeV} \Rightarrow c\tau_S > 12\mu m$$
$$\Gamma_P(X^0 \to \mu^+\mu^-) < 1.3 \times 10^{-9}\,\text{GeV} \Rightarrow c\tau_P > 0.16\mu m$$

At the limits, the lifetimes are not long enough for X^0 to be seen as displaced vertices

Sgoldstino?

Sgoldstino[a]:

Goldstino is the goldstone boson that gives gravitino mass

Sgoldstino is the spin-0 superpartner of goldstino

In models with superlight gravitino, there could be very light sgoldstino

[a] Ellis, Enqvist, and Nanopoulos; Giudice and Rattazzi; Bhattacharya and Roy; Gorbunov; Gorbunov and Rubakov.

FAMILON?

Familons[a]:

Global and continuous family symetry spontaneously broken implies pseudo Goldstone boson

$$\mathcal{L} = \frac{1}{F}\partial_\mu f J^\mu$$

Potential to explain X^0 decays mainly to $\mu^+\mu^-$, but not e^+e^-

F is the scale associated with symmetry breaking

$$\frac{m_s}{F} = h_2 \approx 10^{-10} \Rightarrow F \approx 10^9\,\mathrm{GeV}$$

[a]Wilczek; Reiss; Gelmini, Nussinov and Yanagida; Chang and Senjanovic; Feng, Moroi, Murayama and Schnapka; ...

Summary

Observation of three $\Sigma^+ \to p\mu^+\mu^-$ event clustered around 214 MeV hints at a new state at that mass

From K^+ decay, we can determine the state to be mostly pseudoscalor

The existence can be confirmed in K^0 and Ω^- decays

Possible models include sgoldstino and familon

Appendix

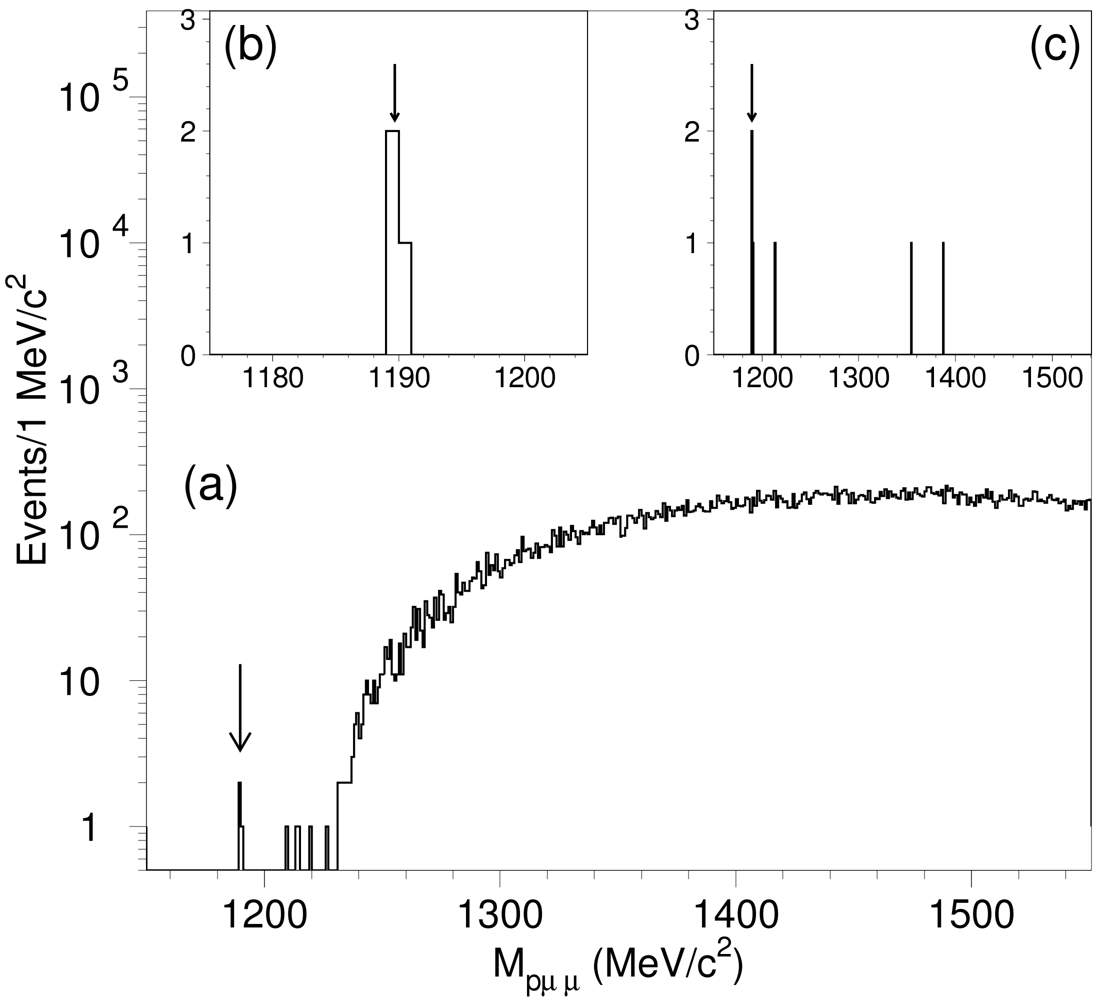
Other Studies

He, Tandean and Valencia `[hep-ph/0509041]`: also consider X^0 as vector and axial vector

Gorbunov and Rubakov `[hep-ph/0509147]`: focus on sgoldstino, consider $e^+e^- \to \gamma P$

Geng and Hsiao `[hep-ph/0509175]`: also consider interference between S and P

Appendix



$p\mu^+\mu^-$ invariant mass distribution

HyperCP Physics Program

- high-precision search for CP violation in Ξ and Λ decay
- measurement of branching ratio of $K^+ \to \pi^+\mu^+\mu^-$ and $K^- \to \pi^-\mu^+\mu^-$
- search for pentaquark
- search for the decay $\Sigma^+ \to p\mu^+\mu^-$
- search for the decay $\Xi^- \to p\mu^-\mu^-$
- search for the decays $\Omega^- \to \Lambda\pi^-$ and $\Xi^0 \to p\pi^-$
- ...
- search for $\Omega^- \to \Xi^-\mu^+\mu^-$