Hyperon physics at Supper tau-charm factory

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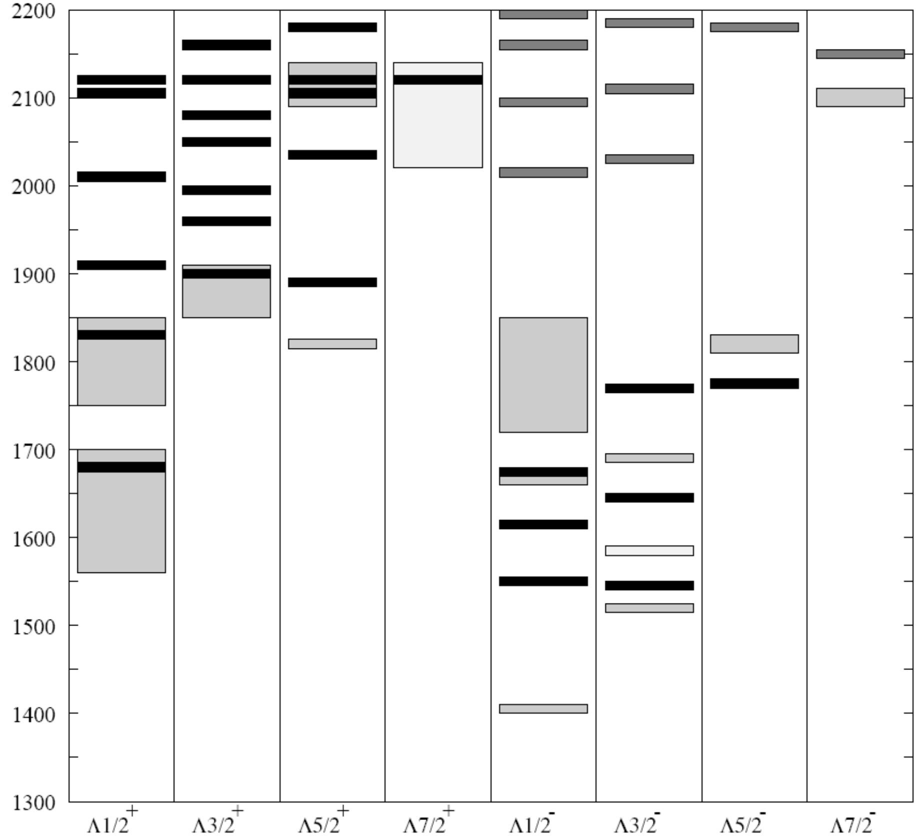
- **Hyperon spectroscopy**
- **Hyperon non-leptonic decays and CP violation**
- **Hyperon semi-leptonic decays**
- **Hyperon radiative decays**
- **Rare decays**

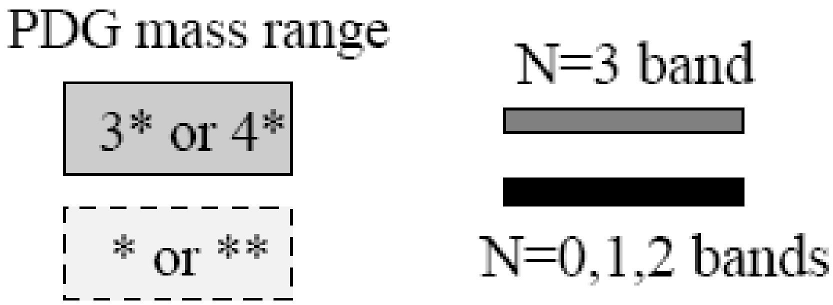
Hyperon spectroscopy

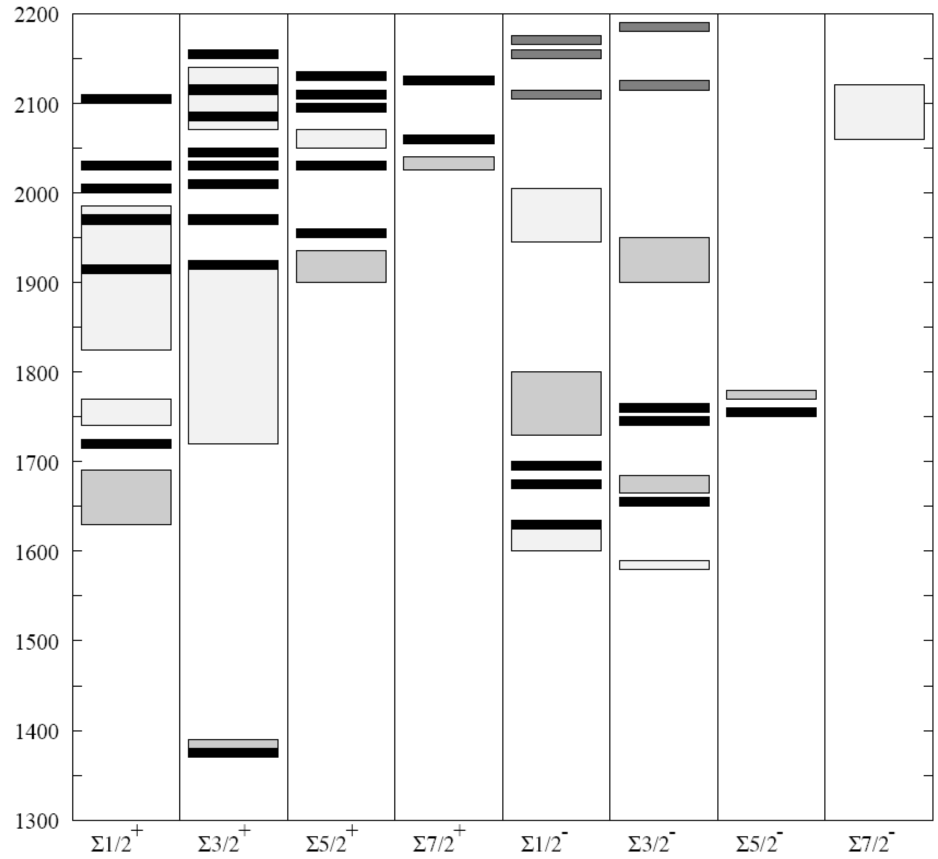
Status of the Λ and Σ resonances (PDG2012)

Particle	J^P	Overall status	Status as seen in — $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2+$	****		F		$N\pi$(weakly)
$\Lambda(1405)$	$1/2-$	****	****	o	****	
$\Lambda(1520)$	$3/2-$	****	****	r	****	$\Lambda\pi\pi, \Lambda\gamma$
$\Lambda(1600)$	$1/2+$	***	***	b	**	
$\Lambda(1670)$	$1/2-$	****	****	i	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2-$	****	****	d	****	$\Lambda\pi\pi, \Sigma\pi\pi$
$\Lambda(1800)$	$1/2-$	***	***	d	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(1810)$	$1/2+$	***	***	e	**	$N\overline{K}^*$
$\Lambda(1820)$	$5/2+$	****	****	n	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2-$	****	***	F	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2+$	****	****	o	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(2000)$		*		r	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2020)$	$7/2+$	*	*	b	*	
$\Lambda(2100)$	$7/2-$	****	****	i	***	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2110)$	$5/2+$	***	**	d	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2325)$	$3/2-$	*	*	d		$\Lambda\omega$
$\Lambda(2350)$		***	***	e	*	
$\Lambda(2585)$		**	**	n		

Particle	J^P	Overall status	Status as seen in — $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Sigma(1193)$	$1/2+$	****				$N\pi$(weakly)
$\Sigma(1385)$	$3/2+$	****		****	****	
$\Sigma(1480)$		*	*	*	*	
$\Sigma(1560)$		**		**	**	
$\Sigma(1580)$	$3/2-$	*	*	*		
$\Sigma(1620)$	$1/2-$	**	**	*	*	
$\Sigma(1660)$	$1/2+$	***	***	*	**	
$\Sigma(1670)$	$3/2-$	****	****	****	****	several others
$\Sigma(1690)$		**	*	**	*	$\Lambda\pi\pi$
$\Sigma(1750)$	$1/2-$	***	***	**	*	$\Sigma\eta$
$\Sigma(1770)$	$1/2+$	*				
$\Sigma(1775)$	$5/2-$	****	****	****	***	several others
$\Sigma(1840)$	$3/2+$	*	*	**	*	
$\Sigma(1880)$	$1/2+$	**	**	**		$N\overline{K}^*$
$\Sigma(1915)$	$5/2+$	****	***	****	***	$\Sigma(1385)\pi$
$\Sigma(1940)$	$3/2-$	***	*	***	**	quasi-2-body
$\Sigma(2000)$	$1/2-$	*		*		$N\overline{K}^*, \Lambda(1520)\pi$
$\Sigma(2030)$	$7/2+$	****	****	****	**	several others
$\Sigma(2070)$	$5/2+$	*	*		*	
$\Sigma(2080)$	$3/2+$	**		**		
$\Sigma(2100)$	$7/2-$	*		*	*	
$\Sigma(2250)$		***	***	*	*	
$\Sigma(2455)$		**	*			
$\Sigma(2620)$		**	*			
$\Sigma(3000)$		*	*	*		
$\Sigma(3170)$		*				multi-body



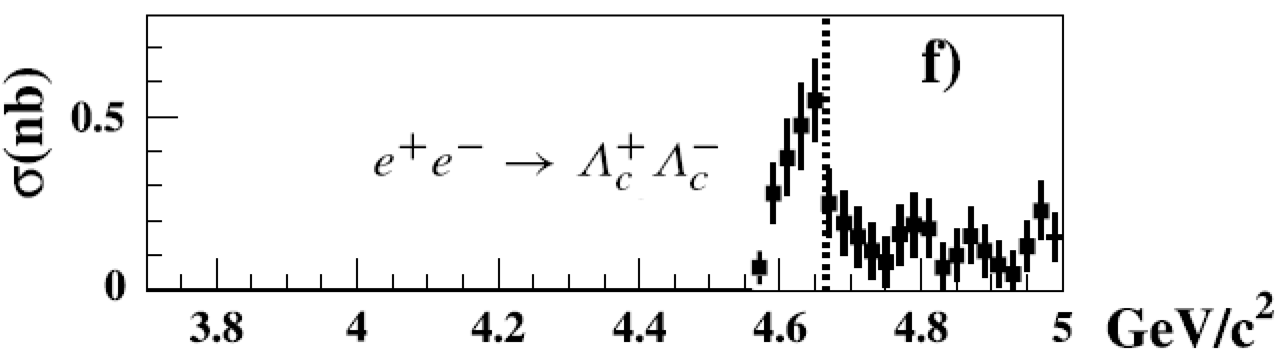




Comparison of hyperon spectrosopy between PDG and quark models.

Status and comments:

1. Evidence for most hyperon resonances, esp. Σ, is poor.
2. The field remains at a standstill (PDG comment)
3. Most hyperon resonaces are established from production experiments; Tau-charm experiments make a little contributions.
4. Establised hyperon spectroscopy is confront with the “missing state problem” as raised in quark model.
5. J/ψ or ψ’ decays don’t allow to access most of the excited hyperon resonaces due to the limited phase space.
6. Do we need to go higher energy to produce $\Lambda_c^+ \underline{\Lambda}_c^+$, $\Sigma_c \underline{\Sigma}_c$,… ?



Hyperon non-leptonic decays and CP violation

Hyperon(1/2+)→ Baryon(1/2+)+P(0-)

Partial waves: S (parity violating), P (parity conserving)

Helicity amplitudes: $F_+ \neq F_-$ (± : ±1/2)

$$S = \frac{1}{\sqrt{2}}(F_+ + F_-), \quad P = \frac{1}{\sqrt{2}}(F_+ - F_-)$$

The transition rate is proportional to

$$R(\hat{\omega}_Y, \hat{\omega}_B) = 1 + \gamma \hat{\omega}_Y \cdot \hat{\omega}_B + (1-\gamma)(\hat{\omega}_Y \cdot \hat{B})(\hat{\omega}_B \cdot \hat{B}) + \alpha(\hat{\omega}_Y + \hat{\omega}_B) \cdot \hat{B} + \beta(\hat{\omega}_Y \times \hat{\omega}_B) \cdot \hat{B}$$

$$\alpha^2 + \beta^2 + \gamma^2 = 1$$

$$\alpha = \frac{|F_+|^2 - |F_+|^2}{|F_+|^2 + |F_+|^2} = \frac{2\Re(S^* P)}{|S|^2 + |P|^2},$$

$$\beta = \frac{2\Im(F_+^* F_-)}{|F_+|^2 + |F_+|^2} = \frac{2\Im(S^* P)}{|S|^2 + |P|^2}$$

$$\gamma = \frac{2\Re(F_+^* F_-)}{|F_+|^2 + |F_+|^2} = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

CP conserving:

$$\alpha_Y = -\alpha_{\bar{Y}},$$

$$\beta_Y = -\beta_{\bar{Y}},$$

$$\gamma_Y = \gamma_{\bar{Y}},$$

$$\Gamma_Y = \Gamma_{\bar{Y}}.$$

CP violation in Standard model (via higher order penguin diagram)

$$|A_Y| \equiv \left|\frac{\alpha_Y + \alpha_{\bar{Y}}}{\alpha_Y - \alpha_{\bar{Y}}}\right| \sim 10^{-5} - 5\times 10^{-4}$$

$$|B'_Y| \equiv \left|\frac{\beta_Y + \beta_{\bar{Y}}}{\alpha_Y - \alpha_{\bar{Y}}}\right| \sim 10|A_Y| \sim 10^{-4} - 5\times 10^{-3}$$

$$|B_Y| \equiv \left|\frac{\beta_Y + \beta_{\bar{Y}}}{\beta_Y - \beta_{\bar{Y}}}\right| \sim 100|A_Y| \sim 10^{-3} - 5\times 10^{-2}$$

$$|\Delta_Y| \equiv \left|\frac{\Gamma_Y - \Gamma_{\bar{Y}}}{\Gamma_Y + \Gamma_{\bar{Y}}}\right| \sim 0.1|A_Y| \sim 10^{-6} - 5\times 10^{-5}$$

J/ψ event scale: @BESII: 1.5 month ~ 1 billion

8*100 billion/year with luminosity 100*BESII

ψ' events: ~120 Billion / year

Modes	$J/\psi\to\Lambda\underline{\Lambda}$	$J/\psi\to\Sigma\underline{\Sigma}$	$J/\psi\to\Xi\underline{\Xi}$	$\psi'\to\Omega\underline{\Omega}$
Events/year	1.3 billion	~1billion	0.7billion	6 million

Do we need polarized beam?

J/Ψ Decay channel	Beam polar.	Measured parameter combinations	Measured parameters	CP odd observables
$\Lambda\bar{\Lambda}$	**NO**	$\alpha_\Lambda \alpha_{\bar{\Lambda}}$	$\alpha_\Lambda \alpha_{\bar{\Lambda}}$	A_Λ (requires ext. data)
$\Lambda\bar{\Lambda}$	**YES**	α_Λ, $\alpha_{\bar{\Lambda}}$, $\alpha_\Lambda \alpha_{\bar{\Lambda}}$	α_Λ, $\alpha_{\bar{\Lambda}}$	A_Λ
$\Xi^-\bar{\Xi}^+$	**NO**	$\alpha_\Xi \alpha_{\bar{\Xi}}$, $\alpha_\Xi \alpha_\Lambda$, $\alpha_{\bar{\Xi}} \alpha_{\bar{\Lambda}}$, $\alpha_\Lambda \alpha_{\bar{\Lambda}}$ $\alpha_\Xi \alpha_{\bar{\Lambda}}$, $\alpha_{\bar{\Xi}} \alpha_\Lambda$, $\alpha_\Lambda \alpha_{\bar{\Lambda}} \beta_{\bar{\Xi}}$, $\alpha_\Lambda \alpha_{\bar{\Lambda}} \beta_\Xi$, $\alpha_\Lambda \alpha_{\bar{\Lambda}} \gamma_{\bar{\Xi}}$, $\alpha_\Lambda \alpha_{\bar{\Lambda}} \gamma_\Xi$, $\alpha_\Xi \alpha_{\bar{\Lambda}} \beta_{\bar{\Xi}}$, $\alpha_\Xi \alpha_{\bar{\Lambda}} \gamma_{\bar{\Xi}}$, $\cdots$ $\alpha_\Xi \alpha_{\bar{\Xi}} \alpha_\Lambda \alpha_{\bar{\Lambda}}$, $\alpha_\Lambda \alpha_{\bar{\Lambda}} \beta_\Xi \beta_{\bar{\Xi}}, \cdots$	α_Λ, $\alpha_{\bar{\Lambda}}$ α_Ξ, $\alpha_{\bar{\Xi}}$ β_Ξ, $\beta_{\bar{\Xi}}$	A_Ξ A_Λ B'_Ξ
$\Xi^-\bar{\Xi}^+$	**YES**	**As without polarisation plus** α_Ξ, $\alpha_{\bar{\Xi}}$, α_Λ, $\alpha_{\bar{\Lambda}}$, $\alpha_\Lambda \beta_\Xi$, $\alpha_{\bar{\Lambda}} \beta_{\bar{\Xi}}$, $\alpha_\Lambda \gamma_\Xi$, $\alpha_{\bar{\Lambda}} \gamma_{\bar{\Xi}}$, $\alpha_\Xi \alpha_{\bar{\Xi}} \alpha_\Lambda$, $\alpha_\Xi \alpha_{\bar{\Xi}} \alpha_{\bar{\Lambda}}$, $\alpha_\Xi \alpha_\Lambda \alpha_{\bar{\Lambda}}$, $\cdots$ $\alpha_\Xi \alpha_\Lambda \alpha_{\bar{\Lambda}} \beta_\Xi, \cdots$	α_Λ, $\alpha_{\bar{\Lambda}}$ α_Ξ, $\alpha_{\bar{\Xi}}$ β_Ξ, $\beta_{\bar{\Xi}}$	A_Ξ A_Λ B'_Ξ

Sensitivity estimation on the CP violation

$$\delta A_Y = \frac{1}{\alpha |P|}\sqrt{\frac{3}{N} + \frac{3}{\bar{N}}}$$

Assuming 40% polar.

1 year events

modes	**W/o polarization**	**CP-odd parameter**	**SM prediction**	**sensitivity**
$J/\psi \to \Lambda\underline{\Lambda}$	No	A_Λ	$10^{-5} \sim 5\times10^{-4}$	1.5×10^{-3}
	Yes	A_Λ	$10^{-5} \sim 5\times10^{-4}$	$<1.5\times10^{-3}$
$J/\psi \to \Sigma\underline{\Sigma}$	No	A_Σ		$\sim 10^{-3}$
	Yes	A_Σ		$< 10^{-3}$
$J/\psi \to \Xi\underline{\Xi}$	No	$A_{\Xi,}$ $A_{\Lambda,}$ A'_{Ξ}	$10^{-5} \sim 5\times10^{-4}$ $10^{-4} \sim 5\times10^{-3}$	$\sim 3\times10^{-4}$
	Yes	$A_{\Xi,}$ $A_{\Lambda,}$ A'_{Ξ}		$<3\times10^{-4}$
$\psi' \to \Omega\underline{\Omega}$	No	A_Ω		$> 10^{-2}$
	Yes	A_Ω		$\sim 10^{-2}$

Hyperon semi-leptonic decays

For B→be$^-\nu_e$ decay:

$$\mathcal{M} = \frac{G_S}{\sqrt{2}} \bar{u}_b \left(O_\alpha^V + O_\alpha^A\right) u_B \, \bar{u}_e \, \gamma^\alpha \, (1+\gamma_5) \, v_\nu$$

$$O_\alpha^V = f_1(q^2)\gamma^\alpha + \frac{f_2(q^2)}{M_B}\sigma_{\alpha\beta} q^\beta + \frac{f_3(q^2)}{M_B} q_\alpha$$

$$O_\alpha^A = \left(g_1(q^2)\gamma^\alpha + \frac{g_2(q^2)}{M_B}\sigma_{\alpha\beta} q^\beta + \frac{g_3(q^2)}{M_B} q_\alpha \right) \gamma_5$$

$$G_S = G_F V_{us} \text{ for } |\Delta S| = 1$$

- To extract the element Vus of the CKM matrix independently from kaon decays
- To extract the ratio of form factor between axial-vector and vector components.

Results from V_{us} analysis using measured g_1/f_1 values

Decay Process	Rate (μsec^{-1})	g_1/f_1	V_{us}
$\Lambda \to pe^-\overline{\nu}$	3.161(58)	0.718(15)	0.2224 ± 0.0034
$\Sigma^- \to ne^-\overline{\nu}$	6.88(24)	−0.340(17)	0.2282 ± 0.0049
$\Xi^- \to \Lambda e^-\overline{\nu}$	3.44(19)	0.25(5)	0.2367 ± 0.0099
$\Xi^0 \to \Sigma^+ e^-\overline{\nu}$	0.876(71)	$1.32(+.22/-.18)$	0.209 ± 0.027
Combined	—	—	0.2250 ± 0.0027

SU(3) breaking effects, exp. uncertaintis

Table 1: $|V_{us}|f_+(0)$ from $K_{\ell 3}$.

Decay Mode	$\|V_{us}\|f_+(0)$
$K^\pm e3$	0.2173 ± 0.0008
$K^\pm \mu 3$	0.2176 ± 0.0011
$K_L e3$	0.2163 ± 0.0006
$K_L \mu 3$	0.2168 ± 0.0007
$K_S e3$	0.2154 ± 0.0013
Average	0.2166 ± 0.0005

PDG2012

Opportunity?

Need vertex detector!

Hyperon radiative decays

- involve radiative and weak interactions
- Hara's theorem violation:

asymmetry parameter :

Hara's theorem:

$$|\alpha(\Sigma^{+} \to p\gamma)| \approx 0.2$$

exp. :

$$\alpha(\Sigma^{+} \to p\gamma) = -0.76 \pm 0.08$$

- The key issue is SU(3) breaking effects
  - VDM+SU(6)
  - Soft-pion approximation

Rare decays

PDG2012

Σ^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 1$ weak neutral current ($S1$) modes				
$n e^+ \nu_e$	SQ	$< 5 \times 10^{-6}$	90%	224
$n \mu^+ \nu_\mu$	SQ	$< 3.0 \times 10^{-5}$	90%	202
$p e^+ e^-$	$S1$	$< 7 \times 10^{-6}$		225
$p \mu^+ \mu^-$	$S1$	$(9 ^{+9}_{-8}) \times 10^{-8}$		121

1 billion evts /year

Upper limits: <10^{-8} @STCF

Ξ^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Delta S = 2$ forbidden ($S2$) modes				
$n \pi^-$	$S2$	$< 1.9 \times 10^{-5}$	90%	304
$n e^- \overline{\nu}_e$	$S2$	$< 3.2 \times 10^{-3}$	90%	327
$n \mu^- \overline{\nu}_\mu$	$S2$	< 1.5 %	90%	314
$p \pi^- \pi^-$	$S2$	$< 4 \times 10^{-4}$	90%	223
$p \pi^- e^- \overline{\nu}_e$	$S2$	$< 4 \times 10^{-4}$	90%	305
$p \pi^- \mu^- \overline{\nu}_\mu$	$S2$	$< 4 \times 10^{-4}$	90%	251
$p \mu^- \mu^-$	L	$< 4 \times 10^{-8}$	90%	272

0.7 billion evts /year

Upper limits: ~10^{-7} @STCF

Summary

- **Search for excited hyperons is limited from charmonium decays. Production forom Λc decays is an alternative.**

- **The sensitivity to search for CP violation in hyperon decays at STCF can reach the limit predicted by SM.**

- **Large statistics of hyperon at STCF can get a better precision of Vus than that from K decays, and allow a better understand the SU(3) breaking effects.**

- **A better upper limits for Δ_s=1 or 2 rare decays**

Basic ideas about generator supper-tau-charm factory

- Good news: the beam polarization option has been implimented in KKMC as author informed

- generation of charmonium produced from polarized beams can be realized by setting the spin matrix for the charmonium in EvtGen.

decay modes	branching fractions
$\Sigma^- \to n e^- \bar{\nu}$	$(1.017 \pm 0.034) \times 10^{-3}$
$\Lambda \to p e^- \bar{\nu}$	$(8.32 \pm 0.14) \times 10^{-4}$
$\Xi^0 \to \Sigma^+ e^- \bar{\nu}$	$(2.53 \pm 0.08) \times 10^{-4}$