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STRANEX @ECT*

Possible Modification of a Hyperon in Hypernuclei

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Contents

1. **Magnetic moment of a Λ (g_{Λ}) in medium**

   -- Going to run soon.

2. **Beta decay rate of a Λ (g_{A}^{Λ}) in medium**

   -- Future experiments ?

“Modifications” of baryons in nuclear matter

A problem over ~40 years

- **EMC effect (Change of structure function in DIS)**

  -- Experimentally established but Nnot well understood

- **Various conjectures on**

  Changes of form factors (“Swelling”) ?

  Magnetic moment ? Weak charge (g_A) ? .....

  due to structure change in nuclear medium

-- What is the probe sensitive to “baryon modification” ?

-- How to discriminate between “baryon modification” and hadronic effects (meson exchange current, baryon mixing...) as well as nuclear many-body effects.

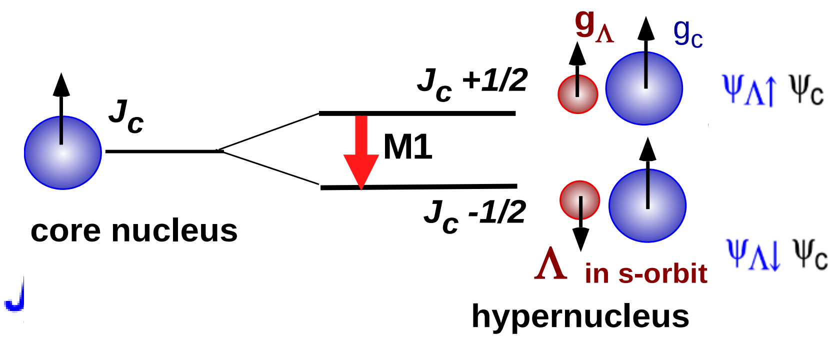
Hyperons are free from Pauli blocking
-> can stay in 0s orbit = can be a suitable probe

1. Magnetic moment of a Λ (g_Λ) in medium

g_Λ in a nucleus

- Measurement of μ_Λ in a hypernucleus is very difficult => possible via HI

- **Λ-spin-flip M1 transition: B(M1) -> g_Λ**



$$B(M1) = (2J_{up}+1)^{-1}\,|\langle\,\Psi_{low}\,\|\,\mu\,\|\,\Psi_{up}\,\rangle|^2$$

$$= (2J_{up}+1)^{-1}\,|\langle\,\psi_{\Lambda\downarrow}\,\psi_c\,\|\,\mu\,\|\,\psi_{\Lambda\uparrow}\,\psi_c\,\rangle|^2$$

$$\mu = g_c J_c + g_\Lambda J_\Lambda = g_c J + (g_\Lambda - g_c) J_\Lambda$$

$$= \frac{3}{8\pi}\,\frac{2J_{low}+1}{2J_c+1}\,(g_\Lambda - g_c)^2 \quad [\mu_N^2]$$

: assuming "weak coupling" between a Λ and the core.

R.H. Dalitz and A. Gal, Annals of Phys. 116 (1978) 167.

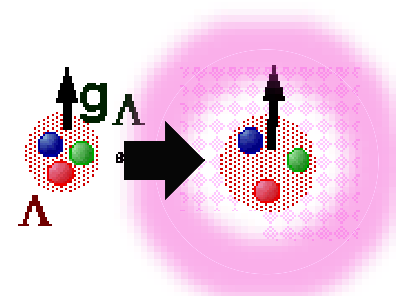
$^{7}_{\Lambda}$Li ~100%

Doppler Shift Attenuation Method: eg) B(E2): Tanida et al. *PRL 86 (2001) 1982*

$$\Gamma = BR\,/\,\tau = \frac{16\pi}{9}\,E_\gamma^3\,B(M1)$$

Modification of g_Λ in nuclear medium?

- Λ–Σ mixing: *C.B. Dover, H. Feshbacj, A. Gal, PRC 51 (1995) 541.*
  +2--5 % for $^{4}_{\Lambda}$He, small for T=0 hypernuclei
- K, 2π exchange current: *K. Saito, M. Oka, T. Suzuki, NPA 625 (1997) 95.*
  -7% for $^{7}_{\Lambda}$Li
- "Quark exchange current" in QCM *T. Takeuchi, K. Shimizu, K. Yazaki, NPA 481 (1988) 693.*



Experiment at J-PARC

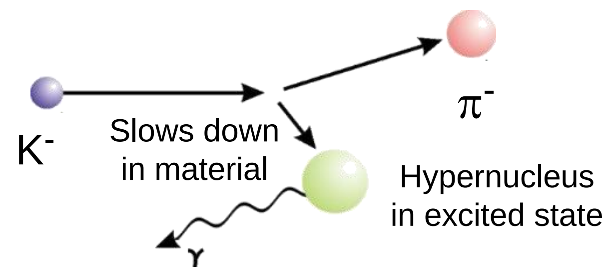
Approved as E13 -> E63

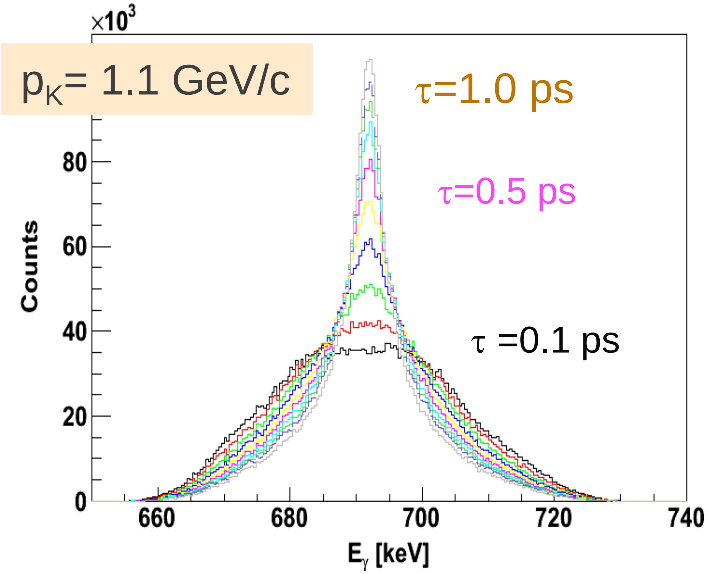
DSAM (Doppler Shift Attenuation Method)

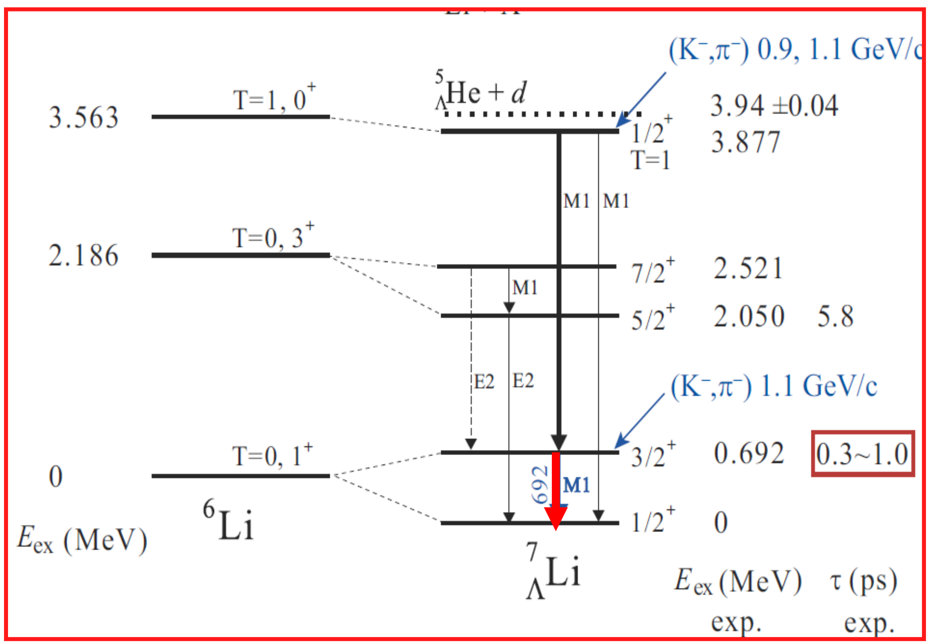
τ **~ 0.5 ps**

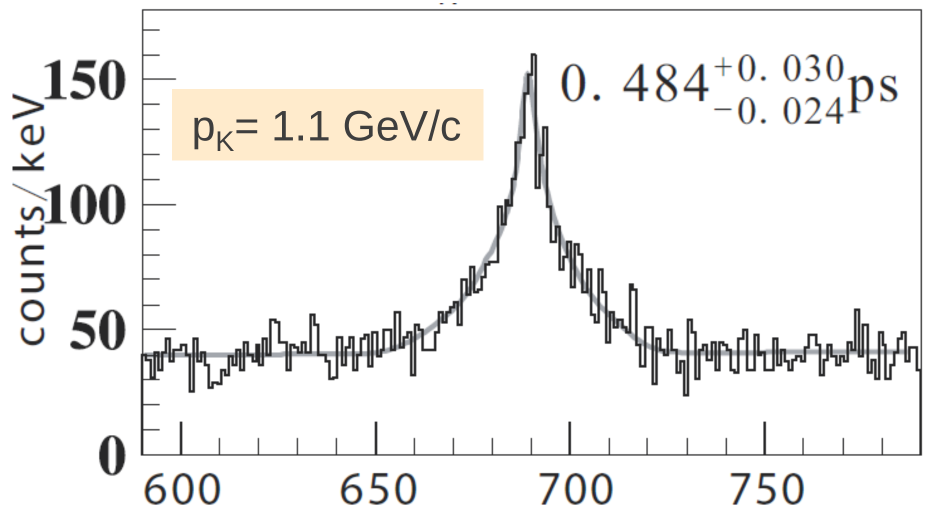
t_{stop} **~ 2 ps**

in Li_2O (2.01 g/cm^3)









H. Tamura et al., Nucl.Phys. A881 (2012) 310

For 35 days for 50kW
Assuming 56k K-/spill for 0.9 GeV/c
176k K-/spill for 1.1 GeV/c

Stat. error
$\Delta\tau/\tau = 6\%$ $\Rightarrow \dfrac{\Delta|g_\Lambda - g_c|}{|g_\Lambda - g_c|} \sim 3\%$

K1.1

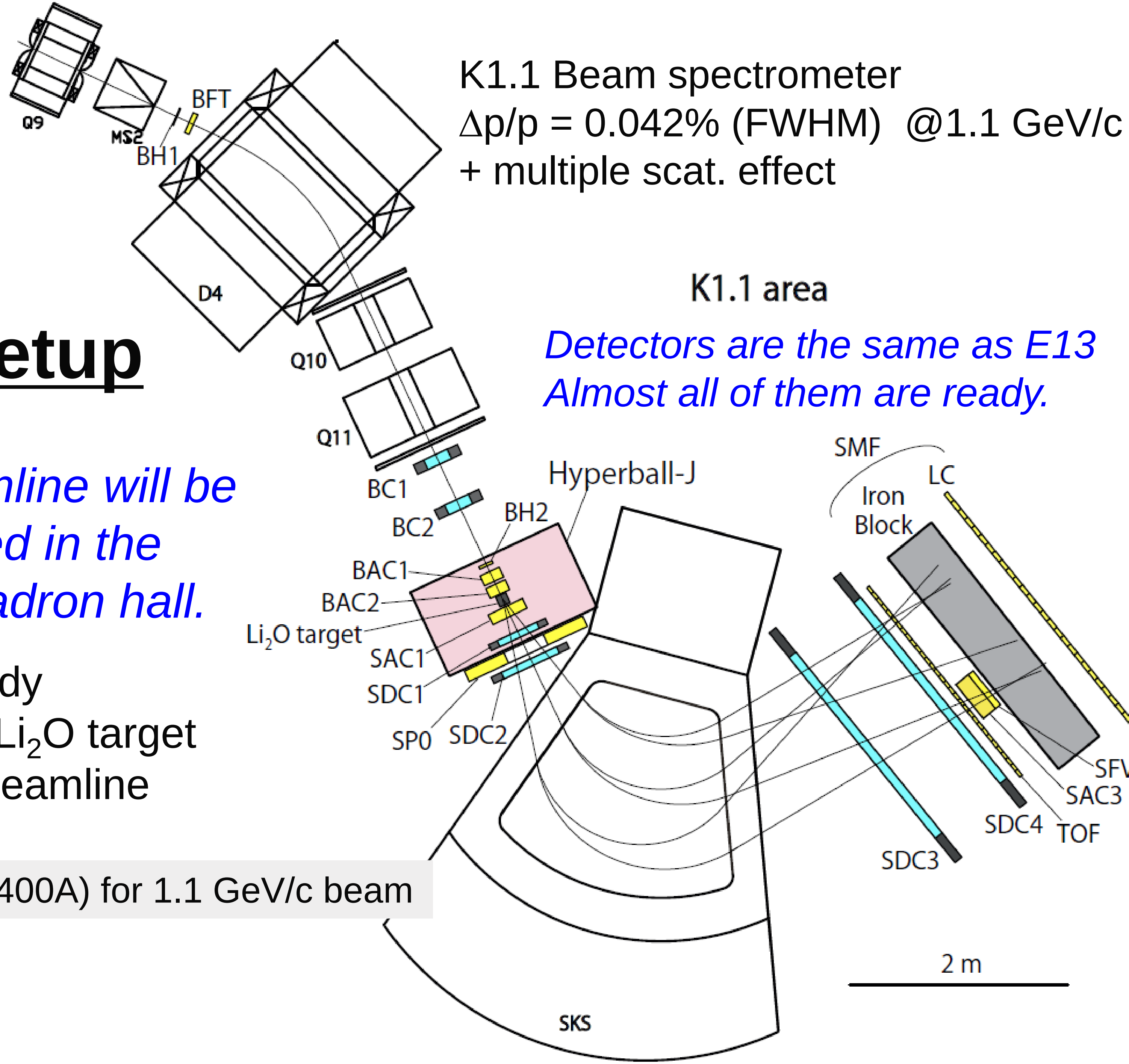
E63 setup

K1.1 Beam spectrometer
$\Delta p/p$ = 0.042% (FWHM) @1.1 GeV/c
+ multiple scat. effect

Detectors are the same as E13
Almost all of them are ready.

K1.1 beamline will be constructed in the present hadron hall.

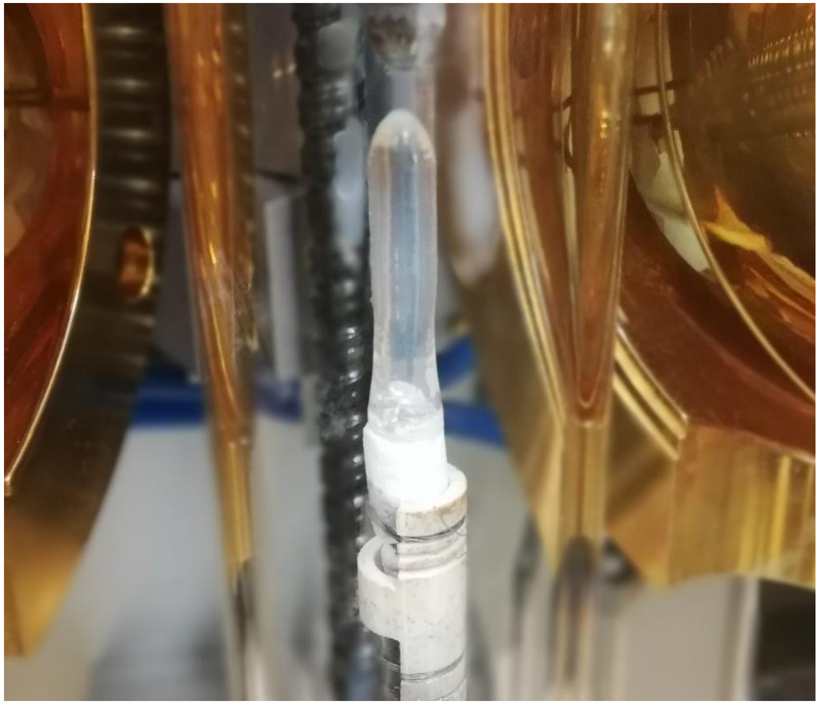
Almost ready
except for Li_2O target
and K1.1 beamline



2.5T (400A) for 1.1 GeV/c beam

Preparation for E63

- Almost all the detectors are ready.
- Target material should be microscopically uniform.
  -> Single crystal of Li_2O



Succeeded in growing a single crystal rod of Li_2O by floating-zone (FZ) method.

To be done:
Check the quality (density, impurity)
Grow a larger crystal
Mass production
Measure the stopping power (dE/dx) with Li ion beam

- **K1.1 beam line should be constructed.**

B(M1) value expected in "ordinary" nuclear physics

Experimental values:

^{6}Li: $g_c = 0.822047 \mu_N$

Λ: g_Λ (free) = $-1.226 \pm 0.008\ \mu_N$

=> If weak coupling is OK, $^{7}_{\Lambda}$Li B(M1) = $0.334 \pm 0.003\ \mu_N^2$

Calculations

	$J_i, T_i \rightarrow J_j, T_f$	$B(M1)\ (\mu_N^2)$	
$^{7}_{\Lambda}$Li	$3/2^+, 0 \rightarrow 1/2^+, 0$	0.322	$^{5}_{\Lambda}$He+p+n cluster (Hiyama et al.) [a]
		0.352	^{4}He+d+Λ cluster (Motoba-Bando-Ikeda) [b]
		0.364	Shell model (Dalitz-Gal) [c]

-3.5% from weak coupling (0.322)

<+5.5% from weak coupling (0.352)

[a] H. Hiyama et al., PRC 59 (1999) 2351.
[b] T. Motoba, H. Bando, K. Ikeda, T. Yamada, PTP Suppl. 81 (1985) 42.
[c] R.H. Dalitz and A. Gal, Annals of Phys. 116 (1978) 167.

- Suggesting that the weak coupling hypothesis holds well.
- Better calculation by Hiyama is going on.
  ^{4}He+p+n+Λ cluster model with and without Λ–Σ coupling
- Ab-initio 7-body calculations in future (if the measurement is done)

2. Beta decay rate of a Λ ($g_A{}^{\Lambda}$) in medium

[Main topic today]

Weak decay of Λ

Λ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^-$		(63.9 ± 0.5) %		101
$n\pi^0$		(35.8 ± 0.5) %		104
$n\gamma$		$(1.75 \pm 0.15) \times 10^{-3}$		162
$p\pi^-\gamma$	[c]	$(8.4 \pm 1.4) \times 10^{-4}$		101
$pe^-\overline{\nu}_e$		$(8.32 \pm 0.14) \times 10^{-4}$		163
$p\mu^-\overline{\nu}_\mu$		$(1.57 \pm 0.35) \times 10^{-4}$		131

$pe^-\overline{\nu}_e$ $\quad g_A/g_V = -0.718 \pm 0.015$ [b]

… measured from $p\ e^-$ angular correlation

Beta decay and axial vector coupling

- g_V (n->p) = 1 [CVC], g_V (Λ->p) ≒ 1 [Ademollo-Gatto theorem]
- g_A/g_V (n->p) = −1.2732±0.0023 [= D+F]
- g_A/g_V (Λ->p) = −0.718 ± 0.015 [= - (D+3F)/√6 for $SU(3)_f$]
- g_A^*(n->p) quenching in nuclear beta decay (GT quenching)

  has been a long standing problem.

  ---- Not clearly understood

  (1) Nuclear many-body effect

  (2) Hadronic effect (meson exchange current, Δ excitation, ..)

  (3) Quark effect (baryon structure change) ??

  => How well can be estimate (1) and (2)?

  How can we separate (3) from (1) and (2)?

<u>But (1) and (2) should be small for light nuclei, say, ${}^{5}_{\Lambda}$He</u>

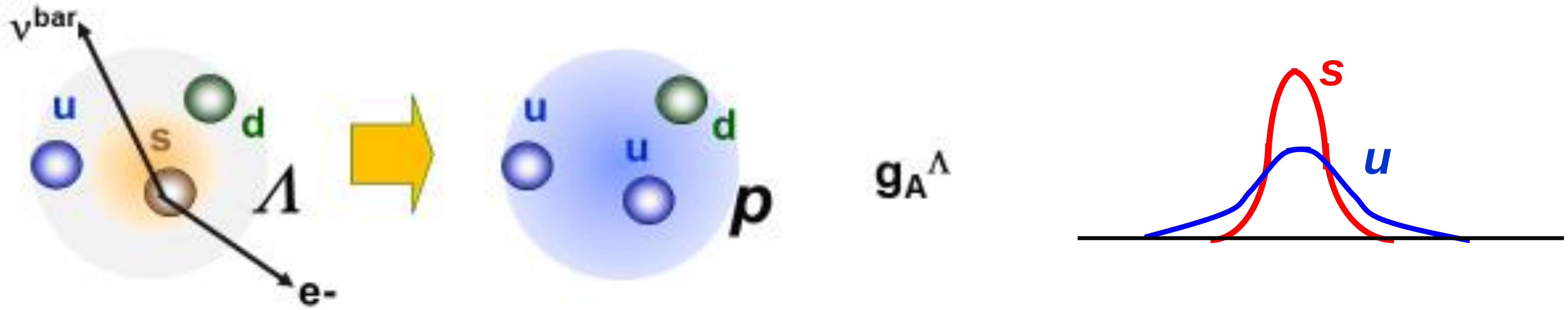
- g_A^* is important for double beta decay -> Majorana neutrino mass

Modification of g_A? : A naïve picture

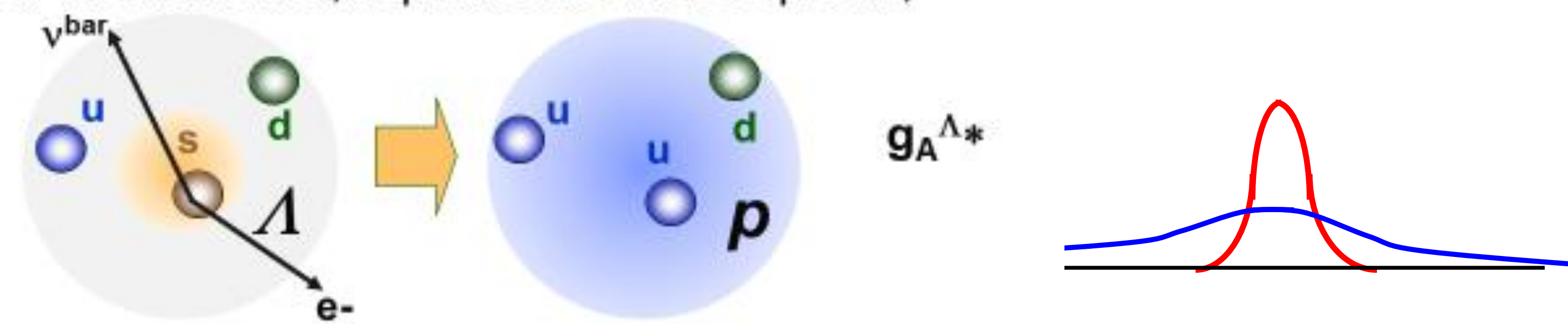
$\Lambda \to p\, e^- \nu^{bar}$ $\quad$ $BR = (8.32 \pm 0.14) \times 10^{-4}$

Sensitive to overlap of u and s quark w.f.

In free space



In nuclear medium if u,d quarks are more spread,



Prediction by Quark Meson Coupling Model

Lambda beta-decay in-medium

P.A.M. Guichon, A.W. Thomas / Physics Letters B 773 (2017) 332–335

- $m^* = m - g_{q\sigma}\sigma$ and w,f. of u,d quarks in a baryon change due to scalar field σ.
- m^* and w.f. of s quark do not change.

- For $n \to p$, $g_V - 1 \propto (m^*_d - m^*_u)^2$
- For $\Lambda \to p$, $g_V - 1 \propto (m^*_s - m^*_u)^2 = (m_s - m_u + g_{q\sigma}\sigma)^2$

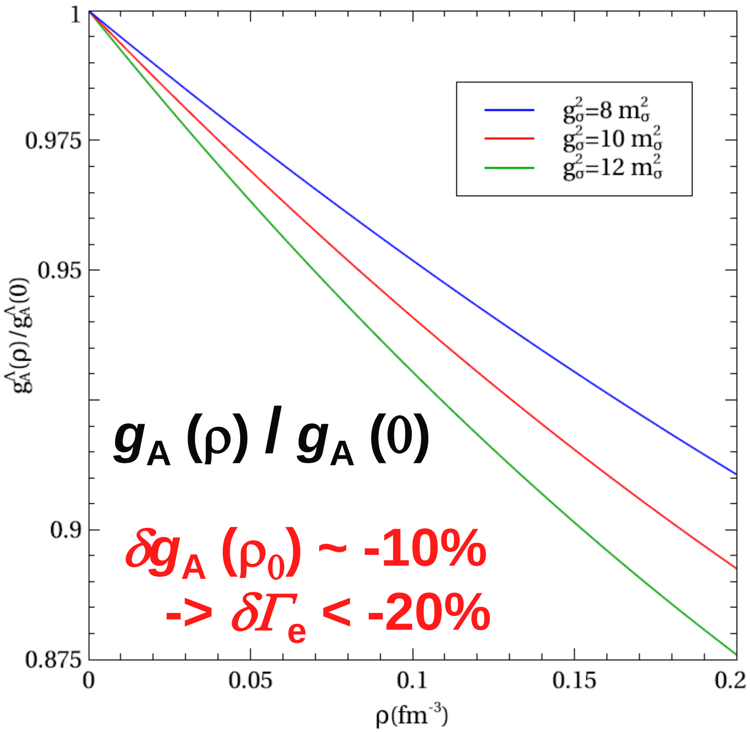


Fig. 1. Relative variation of the axial coupling as a function of density.

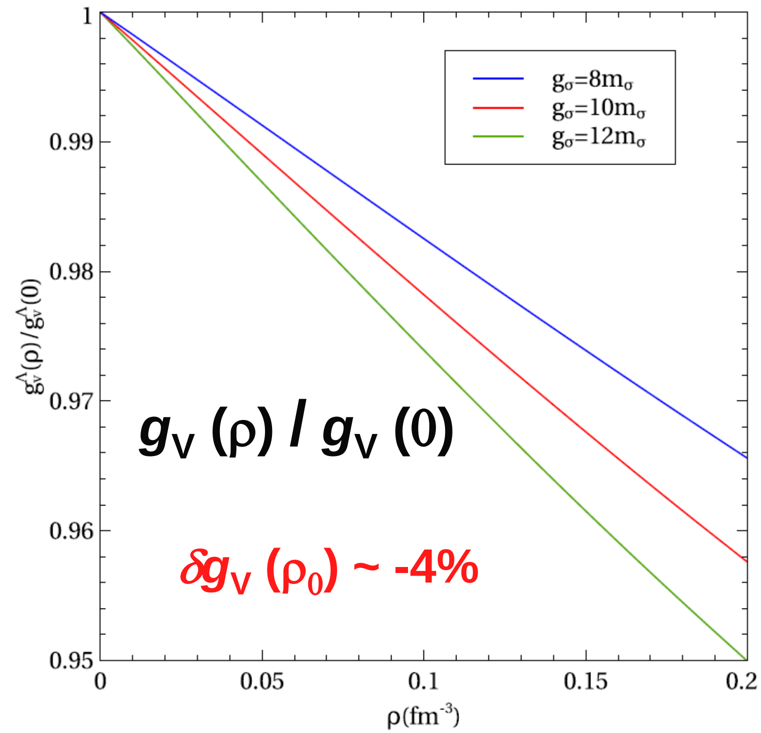
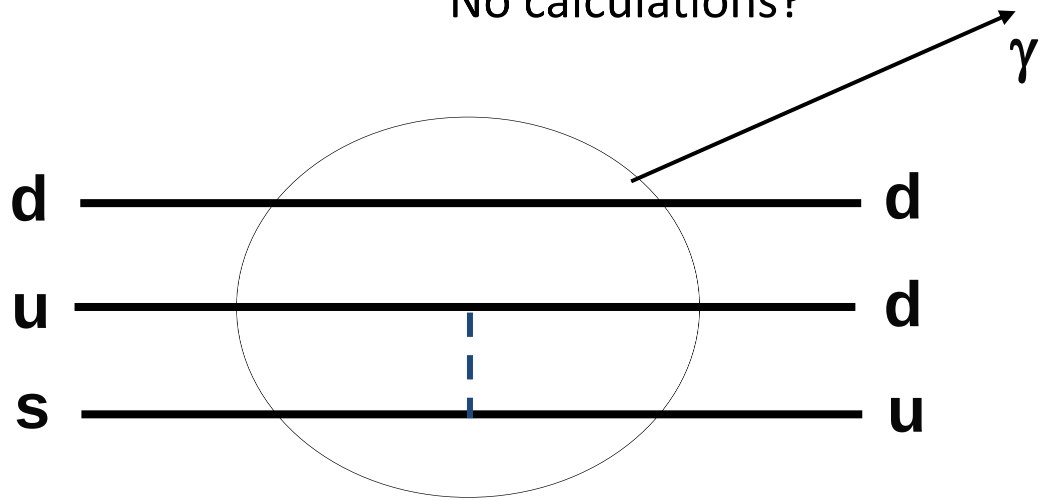


Fig. 2. Relative variation of the vector coupling as a function of density for $m_s =$ 300 MeV.

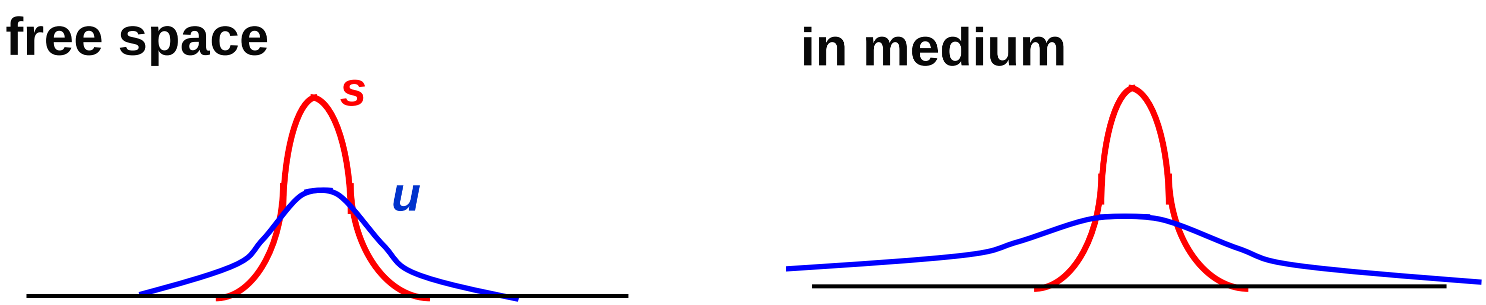
Modification of Λ –> n γ : A naïve picture

$\Lambda \to n\,\gamma$ BR = $(1.75 \pm 0.15) \times 10^{-3}$

No calculations?



Sensitive to overlap of u and s quark w.f.



Gamov-Teller matrix elements for beta decays of light nuclei

W.T. Chou et al., PRC 47 (1993) 163

Reaction	$2J_k^\pi,2T$ (i)	(f)	$\log f_A t$	M(GT) (exp)	M(GT) th(free)	$M(GT)_{exp}$ / $M(GT)_{th(free)}$
$^1n(\beta^-)^1H$	$1^+,1$	$1_1^+,1$	3.024(1)	3.100(7)	3.096	1.00
$^3H(\beta^-)^3He$	$1^+,1$	$1_1^+,1$	3.058(1)	2.929(5)	3.096	0.946
$^6He(\beta^-)^6Li$	$0^+,2$	$2_1^+,0$	2.910(1)	2.748(4)	3.031	0.907
$^7Be(EC)^7Li$	$3^-,1$	$3_1^-,1$	3.300(1)	2.882(4)	3.187	0.904
$^{11}C(\beta^+)^{11}B$	$3^-,1$	$3_1^-,1$	3.598(2)	1.480(9)	2.084	0.710
$^{13}N(\beta^+)^{13}C$	$1^-,1$	$1_1^-,1$	3.671(2)	0.788(8)	0.891	0.884

↑ g_A^{exp} / g_A

Change of g_A* is ~5% for s-shell

Estimated change of g_A by meson exchange current

4.A

Nuclear Physics A305 (1978) 349–356; © *North-Holland Publishing Co., Amsterdam*

QUENCHING OF AXIAL-VECTOR COUPLING CONSTANT IN THE β-DECAY OF FINITE NUCLEI

F. C. KHANNA, I. S. TOWNER and H. C. LEE

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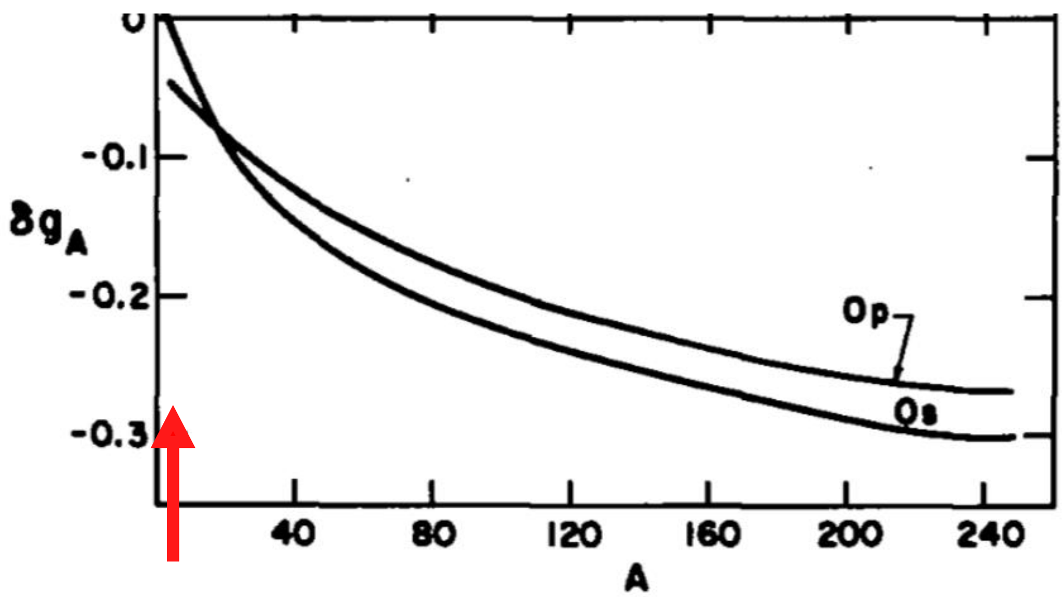


Fig. 3. Variation of Γ_p for the lowest p-state and variation of δg_A for the lowest s- and p-states with mass number A.

F.C Khanna et al, NPA305 (1978) 349.

Variation of δg_A and Γ_P with the single-particle orbit and with A [a])

	$A = 4$		$A = 16$		$A = 40$		$A = 80$		$A = 140$		$A = 224$	
	δg_A	Γ_P	δg_A	Γ_P	δg_A	Γ_P	δg_A	Γ_P	δg_A	Γ_P	δg_A	Γ_P
0s	0.007		−0.068		−0.143		−0.206		−0.256		−0.294	
	0.046		−0.001		−0.054		−0.100		−0.136		−0.165	
0p	−0.044	0.181	−0.071	0.116	−0.124	0.074	−0.176	0.049	−0.222	0.034	−0.260	0.025
	−0.023	0.114	−0.023	0.068	−0.053	0.039	−0.088	0.023	−0.119	0.013	−0.146	0.008
0d			−0.080	0.139	−0.112	0.096	−0.154	0.066	−0.194	0.047	−0.229	0.035
			−0.047	0.085	−0.058	0.054	−0.081	0.033	−0.106	0.020	−0.130	0.012
1s			−0.101		−0.129		−0.165		−0.202		−0.235	
			−0.066		−0.072		−0.091		−0.113		−0.135	
0f					−0.106	0.110	−0.137	0.080	−0.171	0.058	−0.203	0.043
					−0.065	0.065	−0.079	0.042	−0.097	0.026	−0.117	0.016
1p					−0.131	0.105	−0.156	0.080	−0.185	0.060	−0.213	0.045
					−0.087	0.057	−0.095	0.040	−0.109	0.026	−0.125	0.017
0g							−0.123	0.090	−0.151	0.068	−0.180	0.052
							−0.077	0.050	−0.091	0.033	−0.107	0.021
1d							−0.150	0.088	−0.172	0.069	−0.195	0.054
							−0.100	0.045	−0.108	0.032	−0.119	0.021
2s							−0.161		−0.180		−0.202	
							−0.109		−0.115		−0.125	
0h									−0.134	0.075	−0.160	0.058
									−0.086	0.039	−0.098	0.026
1f									−0.161	0.079	−0.180	0.060
									−0.107	0.036	−0.116	0.025

g_A change is < 5% for s-shell

First line: PCAC; second line: phenomenological Lagrangian.

[a]) The PCAC results quoted in ref. [8]) have an opposite sign (due to the definition of the effective operator) and are smaller in magnitude (due to a smaller value for $\hbar\omega$ and for the pion-Compton wavelength) than the results quoted here.

What to measure?

- **Branching ratio BR(e) and lifetime τ for $^{5}_{\Lambda}$He**

$$\Gamma_e = BR(e)/\tau \propto (g_V^{\Lambda})^2\, |\int 1|^2 + (g_A^{\Lambda})^2\, |\int \sigma|^2 = (g_V^{\Lambda})^2 + 3\,(g_A^{\Lambda})^2$$

~ 1 + 1.5

Statistical accuracy of
ΔBR(e) ~4% and $\Delta\tau$ ~ 2% => $\Delta\Gamma_e$ ~ 4.5% assuming g_V^{Λ} ($^{5}_{\Lambda}$He) = 1.0
=> Δg_A^{Λ} ($^{5}_{\Lambda}$He) ~3.7% is possible.

- **Branching ratio BR(Λ ->nγ) and lifetime τ for $^{5}_{\Lambda}$He**

as well as BR(Λ ->nγ)^{free} [$(1.75\pm0.15) \times 10^{-3}$ at present]

ΔBR(γ) ~2.8%, $\Delta\tau$ ~ 2%, ΔBR(γ)^{free} ~2%

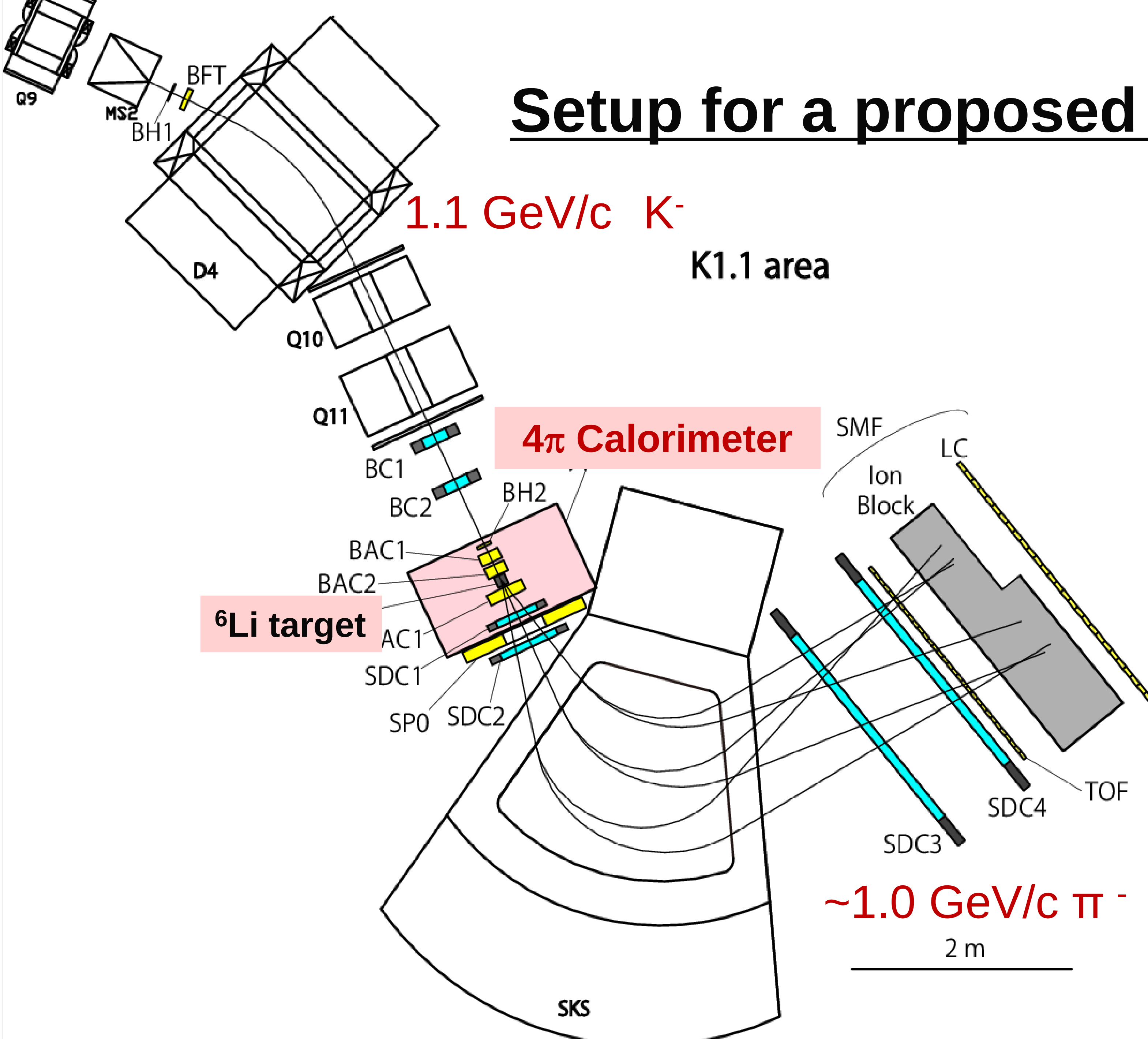
=> $\Delta\Gamma_\gamma$ ($^{5}_{\Lambda}$He) ~4% is possible.

- **e- asymmetry (angular distribution) *A* -> $g_A^{\Lambda} / g_V^{\Lambda}$**

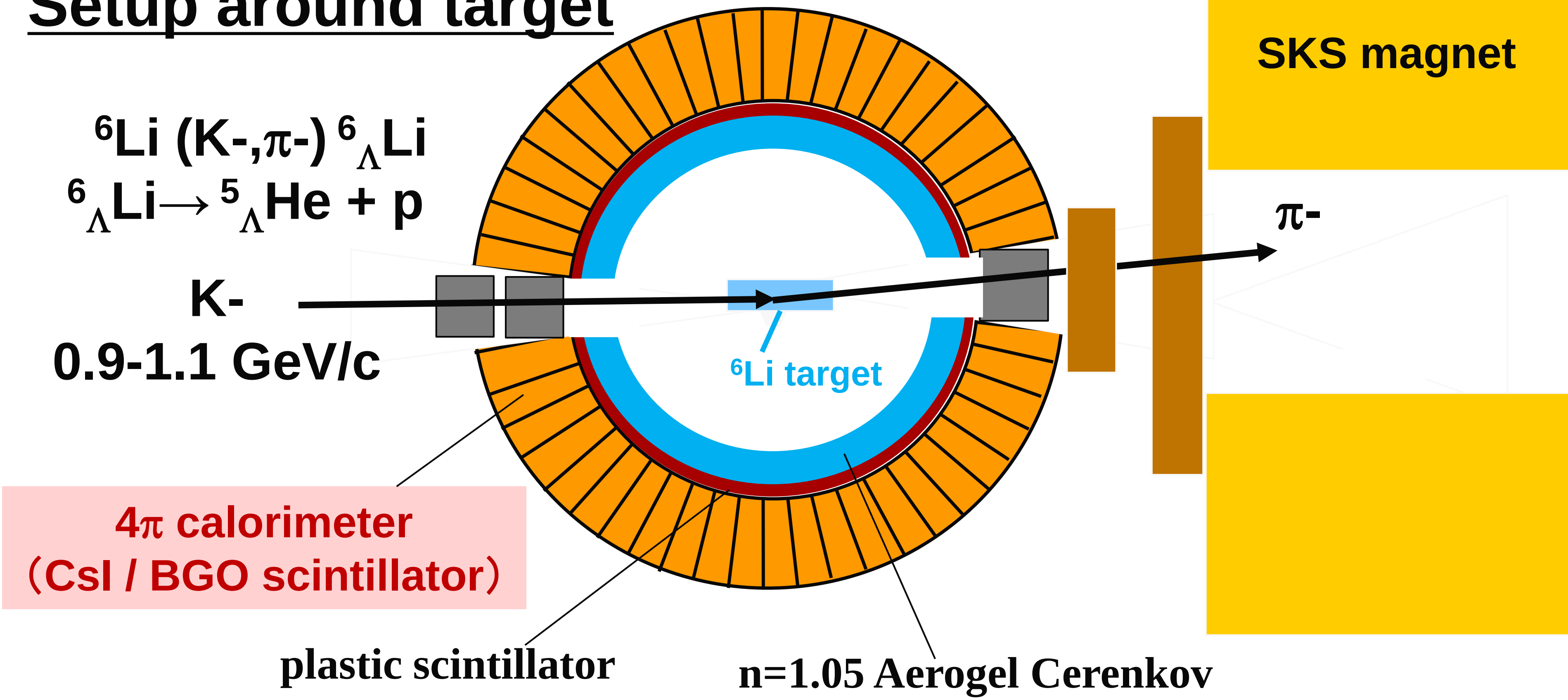
(K-,π-)@1.1 GeV/c *Pol* ~ 90% for Λ $^{12}_{\Lambda}$C(1- gs)

Measure *A*($^{5}_{\Lambda}$He) / *A*(free Λ) to cancel Polarization.
But depolarization of Λ in ^{4}He should be estimated, and effects of the spin-slip state $^{12}_{\Lambda}$C(2-) should be estimated

Setup for a proposed exp.

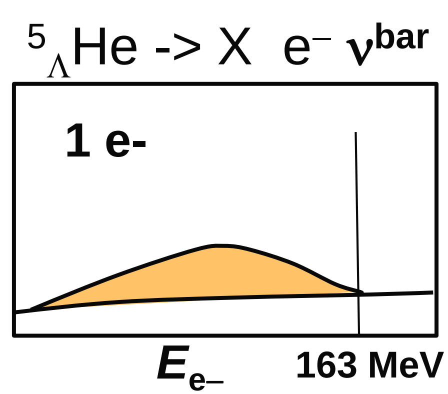


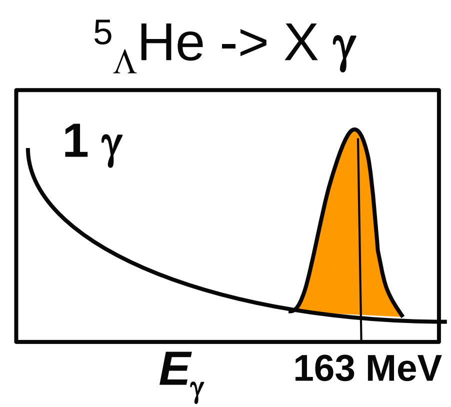
Setup around target



e⁻ /π$^\pm$ / p separation is essential

γ / n discrimination is favorable





Yield and statistical error

$d\sigma/d\Omega \sim$ 20 μb/sr at 1.1 GeV/c 10^o for ^{6}Li (K-,π-) $^6{}_\Lambda$Li$_{gs}$ (-> $^5{}_\Lambda$He)
$d\sigma/d\Omega \sim$ 150 μb/sr at 1.1 GeV/c 10^o for ^{12}C (K-,π-) $^{12}{}_\Lambda$C$_{gs}$

$\Delta\Omega(\pi)$ = 100 msr, ε(K-,π-) ~ 0.7
Target: 20g/cm^2 /6 x 6x10^{23}, 20g/cm^2 /12 x 6x10^{23}
K- beam at 1.1 GeV/c 0.5M/spill(4s)
=> $^5{}_\Lambda$He yield: 1300/hour,
=> $^{12}{}_\Lambda$C yield: 4900/hour,

Γ_e = BR(Λ->e) / τ(Λ) x R_{Pauli}
BR = Γ_e / Γ_{tot} = τ ($^5{}_\Lambda$He) / τ(Λ) BR(Λ->e) R_{Pauli}
BR(Λ->e) = (8.32±0.14) × 10^{-4}
R_{Pauli} ~ R_{Pauli}($^5{}_\Lambda$He->π) = Γ_π($^5{}_\Lambda$He) /Γ_Λ ~ 0.6
R_{Pauli} ~ R_{Pauli}($^{12}{}_\Lambda$C->π) = Γ_π($^{12}{}_\Lambda$C) /Γ_Λ = 0.31
ε(e-) = 0.7, 1500 hours run
=> N_e for $^5{}_\Lambda$He = 640 => $\sqrt{N_e}/N_e$ = 4.0% ($\sqrt{N_\gamma}/N_\gamma$ = 2.8%)
=> N_e for $^{12}{}_\Lambda$C = 1200 => $\sqrt{N_e}/N_e$ = 2.8% ($\sqrt{N_\gamma}/N_\gamma$ = 1.0%)

Background suppression

- $\Lambda \to p\,\pi^-$, $\pi^-\,pn \to nn$; $\Lambda p \to np$

  e / π,p separation with n=1.05 Aerogel Cerenkov (~98%)

  & a large cluster size from EM shower

  & n/γ (p/e) separation

- $\Lambda \to n\,\pi^0$, $\pi^0 \to \gamma\,\gamma$

  => select "single charged-cluster" events with 4π detector

Remaining background:

- $\Lambda \to p\,\pi^-$, $\pi^- \to \pi^0$ (50~100μb/sr =>5×10^{-3}) -> γ γ at calorimeter

  => look like a single cluster ~ 0.02 x 5×10^{-3} = 1×10^{-4}

  Any other?

- A full simulation will be done

  => Optimize thickness and segmentation of the calorimeter

  Optimize beam momentum

  => Estimate possible systematic errors

Further plans with the EM calorimeter

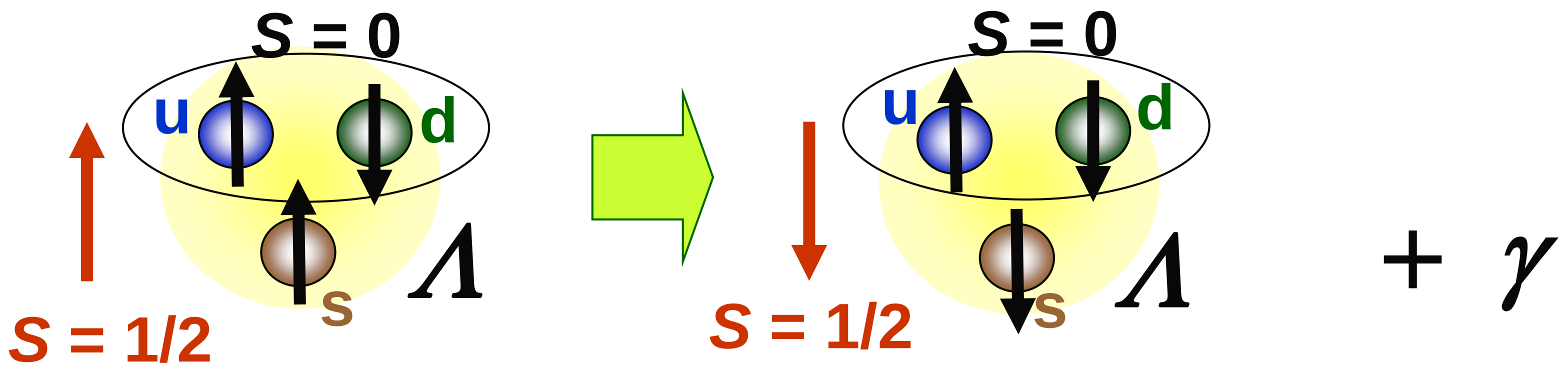
- $\Sigma^0 \rightarrow \Lambda\gamma$ **B(M1) in nuclear matter**

  => Measure *BR*($^4_\Sigma$He(0^+) -> $\Lambda\gamma$)

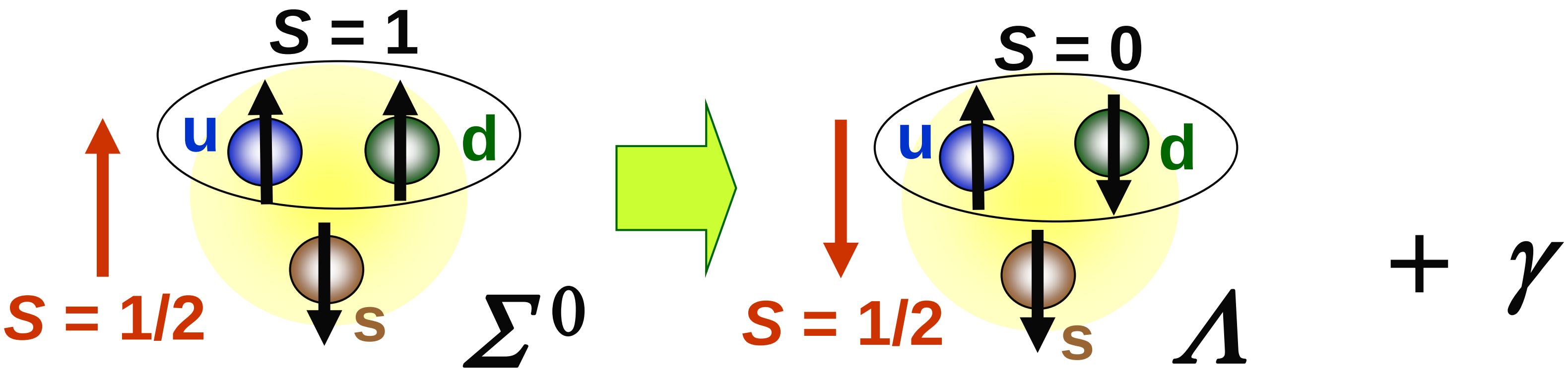
- Λ**-n interaction from K^- d -> Λ n γ (Gibson)**

Spin-flip M1 transition in quark level

$\Gamma \propto B(M1) \propto |\langle \downarrow | \, \mu \, | \uparrow \rangle|^2$ is sensitive to w.f.



Spin-flip of s quark – small medium effect ?



Spin-flip of u/d quarks – large medium effect ?

Takeuchi et al., NPA481(1988) 639 $\delta\mu/\mu$: $^{4}_{\Lambda}$He(1^+) -1% ~ -2%; $^{4}_{\Sigma}$+Li(1^+) -40% ~ -100%

Summary

- Hyperons in hypernuclei are good probes to investigate modification of baryons in nuclear matter.

- Λ's spin-flip B(M1) measurement for g_Λ in matter

  --- J-PARC E63 for ${}^{7}_{\Lambda}$Li is under preparation

- Λ's beta decay and Λ -> nγ decay rates in matter.

  Experimentally, measurement with ~ 4% statistical accuracy is possible for ${}^{5}_{\Lambda}$He.

  To theorists:

  - Please give me theoretical supports on Pauli effect, nuclear many-body effect, and hadronic effect
  - Calculation on Λ -> n γ process (experimentally easier)
  - Is this experiment worth doing? (because it is a bit expensive)

- The EM calorimeter for < 300 MeV γ / e- is also used for $\Sigma^0 \to \Lambda \gamma$ and K^- d -> Λ n γ experiments