$\Lambda - n$ Scattering Lengths from Radiative K$^-$ Capture by Deuterium at Rest

B. F. Gibson
Nuclear Physics Group, T-16
Theoretical Division
Los Alamos National Laboratory

NP@J-PARC
Tokai, Japan
June 1-2, 2007

In collaboration with: W. R. Gibbs
New Mexico State University

LA-UR-07-3495
Acknowledgment: This work was performed under the auspices of the National Nuclear Security Administration of the U.S. Department of Energy at Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396.

Few-Body Λ Hypernuclei

Hypernuclei are NOT simple extensions of conventional $S = 0$ phenomena. The Λ-separation energies for the s-shell systems are given in the Table along with the measured γ-ray de-excitation energies for the isotopes with excited states. ${}^{3}_{\Lambda}$H is weakly bound, one of the world's largest halo systems. ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He exhibit particle stable excited states, whereas the conventional α particle has none.

Table Hypernuclear Λ-separation energies and excitation energies in MeV

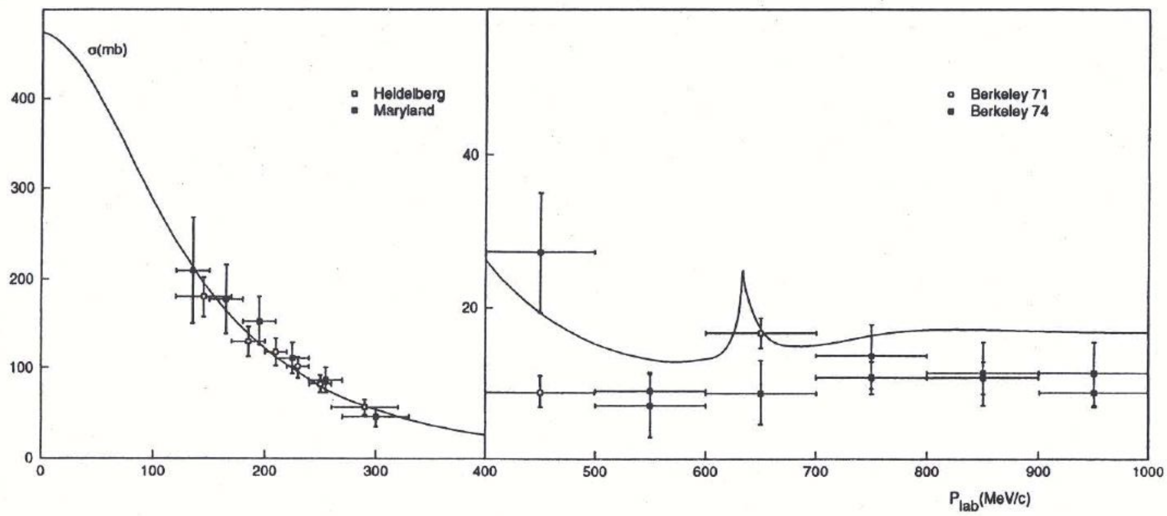
hypernucleus	B_Λ	E_γ
${}^{3}_{\Lambda}$H	0.13±.05	
${}^{4}_{\Lambda}$H	2.04±.04	1.04±.04
${}^{4}_{\Lambda}$He	2.39±.03	1.15±.04
${}^{5}_{\Lambda}$He	3.10±.02	

The binding energy difference in the $A = 4$ isodoublet, $\Delta B_\Lambda = 2.39 - 2.04 \approx 0.35$ MeV = 350 keV, is a direct measure of Charge Symmetry Breaking (**CSB**) in the ΛN interaction ($V_{\Lambda n} \neq V_{\Lambda p}$) and is some 3 times the **CSB** ($\approx$ 120 keV) seen in the ^{3}H - ^{3}He binding energy difference due to $V_{nn} \neq V_{pp}$ after one accounts for the sizeable Coulomb energy ($\approx$ 650 keV) in ^{3}He.

NN & ΛN DATA

- NN data are abundant, including crucial spin observables; one can unravel spin-dependent partial wave amplitudes.
- Deuteron (np bound state) provides additional constraints, in particular for the tensor (S_{12}) interaction.
- **CSB** in the a_{pp} and a_{nn} scattering lengths are consistent with **CSB** in the $A = 3$ binding energy difference.
- Λp scattering data are meager; <600 events below 300 MeV/c and <250 events between 300 and 1500 MeV/c.
- There is no ΛN or ΣN bound state.
- Λp spin-dependent data are few; one has primarily differential and total cross section measurements.
- No Λn scattering data exist.

Λp Data



Λp total cross section data for $p_{\rm lab}$ in the range from 0 to 1000 MeV/c compared with predictions from the Nijmegen soft-core potential model.

See J. J. de Swart, P. M. M. Maessen, and Th. A. Rijken in "Properties and Interactions of Hyperons," edited by B. F. Gibson, P. D. Barnes, and H. Nakai (World Scientific, Singapore, 1994) p. 37 for further discussion.

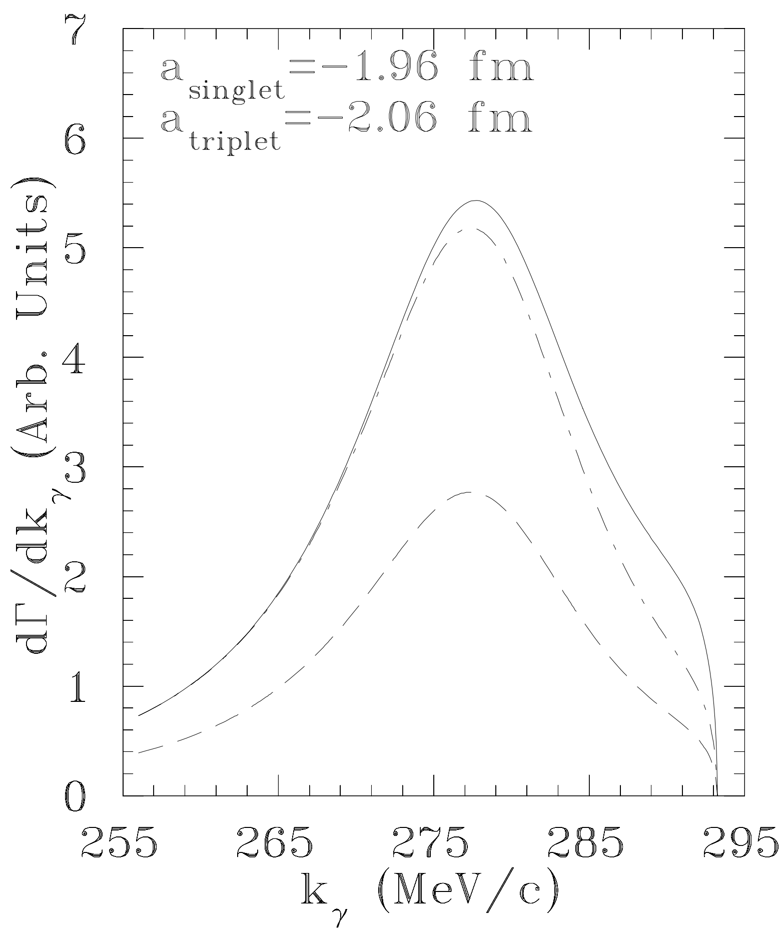
Background

Radiative K^- capture at rest by deuterium ($K^- d \rightarrow n\Lambda\gamma$) was first suggested in 1973 by Gibson *et al.* as a means to measure the Λn scattering lengths. [BNL Report 18335]. Due to Stark mixing, the capture takes place from an atomic S-state, so that the angular momentum analysis is straightforward.

Workman and Fearing [PRC **41**, 1688 (1990) concluded that different hadronic routes considered by Akhiezer *et al.* [SJNP **27**, 115 (1978)] had little impact on a possible measurement.

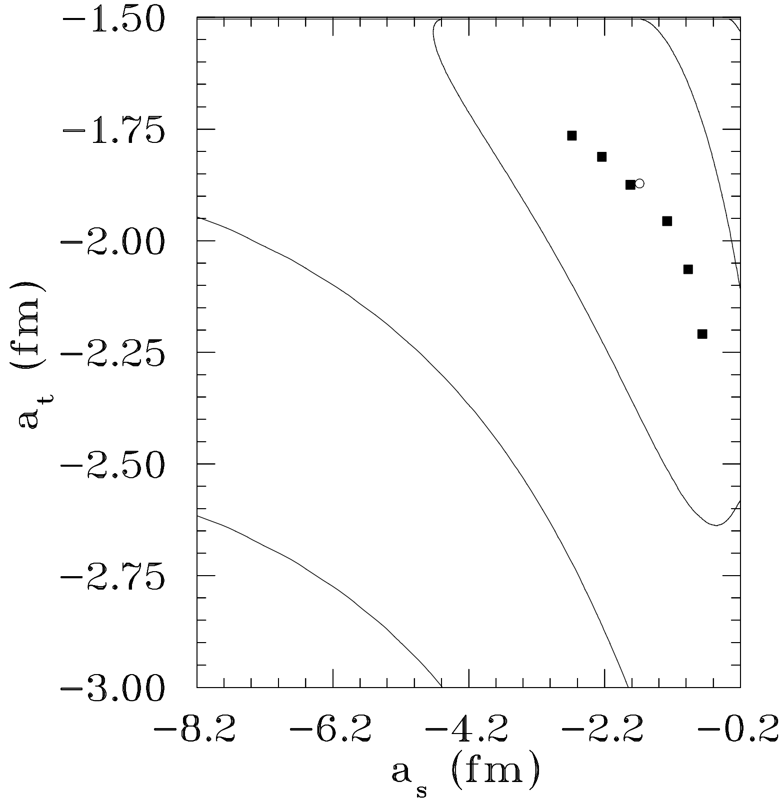
In an analogous analysis of radiative π^- capture by deuterium ($\pi^- d \rightarrow nn\gamma$) Gibbs *et al.* [PRC **11**, 90 (1975)] found the unknown short range nature of the final-state wave function provided the dominant uncertainty in an extraction of a_{nn}.

In a recent analysis by Gibbs *et al.* [PRC **61**, 064003] the $K^- d \rightarrow n\Lambda\gamma$ reaction was investigated in detail. It was shown that data from the feasibility study by Gall *et al.* [PRC **42**, R475 (1990)] can be used to infer values for both the spin-singlet and spin-triplet Λn scattering lengths without explicit spin polarization of the target.



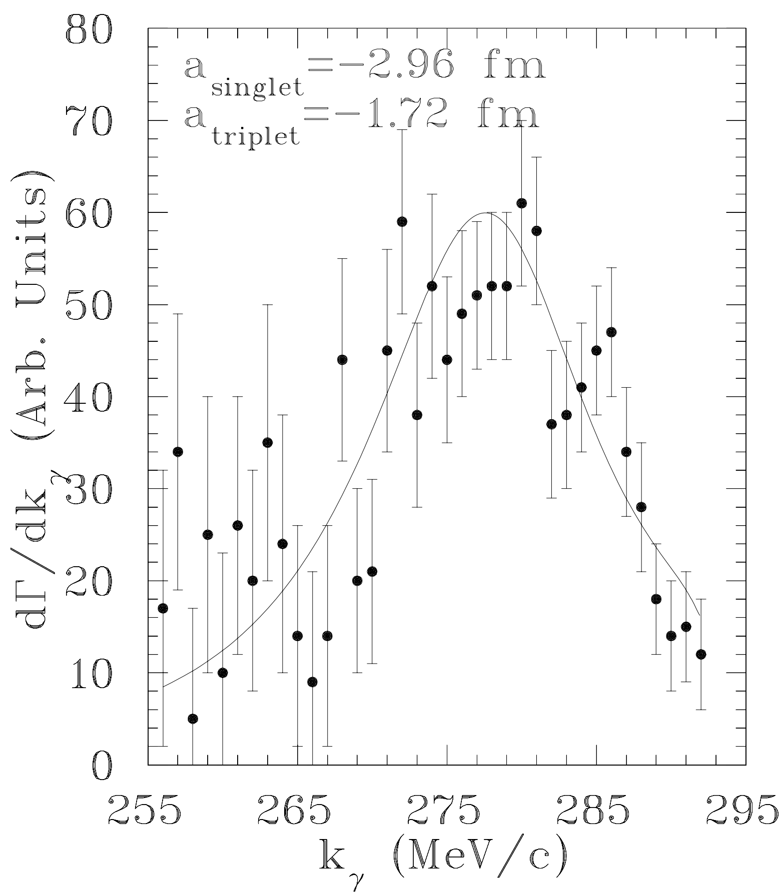
Comparison of the spin-singlet (dashed curve) and spin-triplet (solid curve) photon spectra for model calculations with realistic wave functions. The dashed-dotted curve depicts the spin-singlet spectrum renormalized to the spin-triplet spectrum at the lowest energy.

As in the data of Gall *et al.* [PRC **42**, R475 (1990)], when NO spin is measured then the spin-singlet and spin-triplet states contribute incoherently. However, because their interference with the deuteron s and d states depends upon the initial spin projection, the spectra shapes differ. [Because the triplet contribution is greater, the sensitivity to the triplet scattering is greater.]



An analysis of the data from Gall *et al.* The contour lines correspond to constant χ^2. The inner contour represents one standard deviation, while the next is two, *etc.*

Here we see an analysis of the data from the study of Gall *et al.* [PRC **42**, R475 (1990)]. The open circle marks the point of minimum χ^2. The black squares correspond to the values from the models of Rijken *et al.* [PRC **59**, 21 (1999)]. The one standard deviation limits are: -1.3 fm $\leq a^t \leq$ -2.6 fm and -0.2 fm $\leq a^s \leq$ 6.3 fm. Analysis from Gibbs *et al.* [PRC **61**, 064003] suggests model errors of $\pm$0.28 fm for a^s and $\pm$0.15 fm for a^t.



Estimates for Λn spin-singlet and spin-triplet scattering lengths using the differing shapes of the spin-singlet and spin-triplet spectra.

The spectra shape analysis by Gibbs *et al.* [PRC **61**, 064003] for the data in the feasibility study by Gall *et al.* [PRC **42**, R475 (1990)] does permit one to separate the Λn spin-singlet and spin-triplet scattering lengths. However, a pure vector polarized deuteron target would permit one to measure directly the difference between the spin-singlet and spin-triplet scattering lengths.

J-PARC will provide the needed K^- intensity for a precision measurement.