Search for Bound Θ^{+}-nuclei (Hyponuclei)

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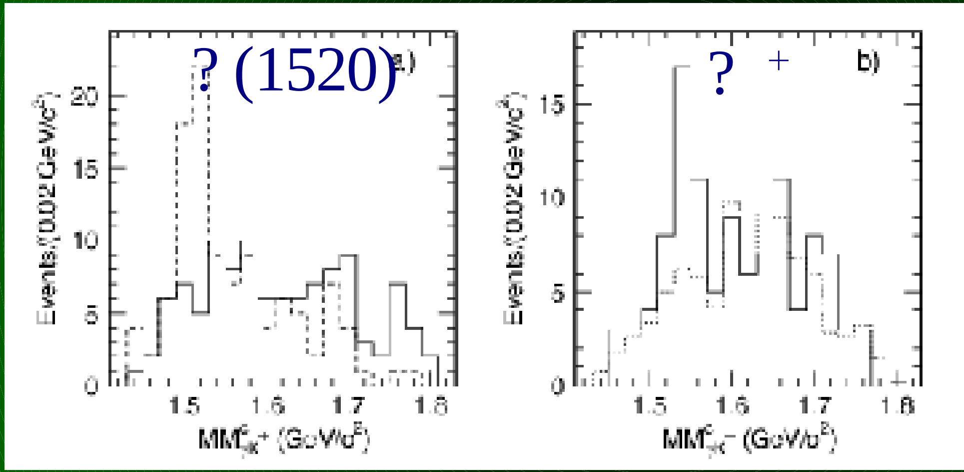
Presentation Format

- Motivation
  - Pentaquark sightings
  - Why look for the Θ^+-bound states now?
  - Theoretical support for hyponuclear formation
- Experimental plan
- Anticipated results
- Beam time request

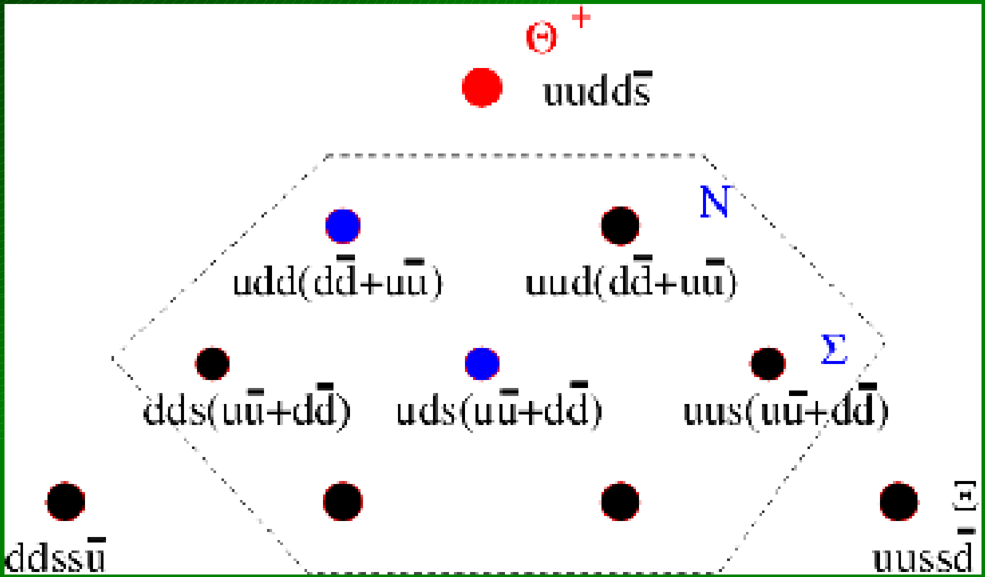
Θ^+-Pentaquark Sightings



Nakano, PRL91, 012002

- Predicted by Diakonov within chiral-soliton model
- First seen on ^{12}C
- Lack of observation of a Θ^{++} suggests I=0

- However, limits from partner search also question the original anti-decuplet description.
- What is the Θ^+?



Different Approach: Θ^+ in Nuclei

- Study the Θ^+ in the environment it was first discovered.
  - Nucleon-meson interactions
  - Coherent excitation of nucleons?
  - Multi-meson coupling
- With a deep enough potential, might produce stable against strong decay pentaquark.
- All models find the pentaquark narrower in medium than in the vacuum.

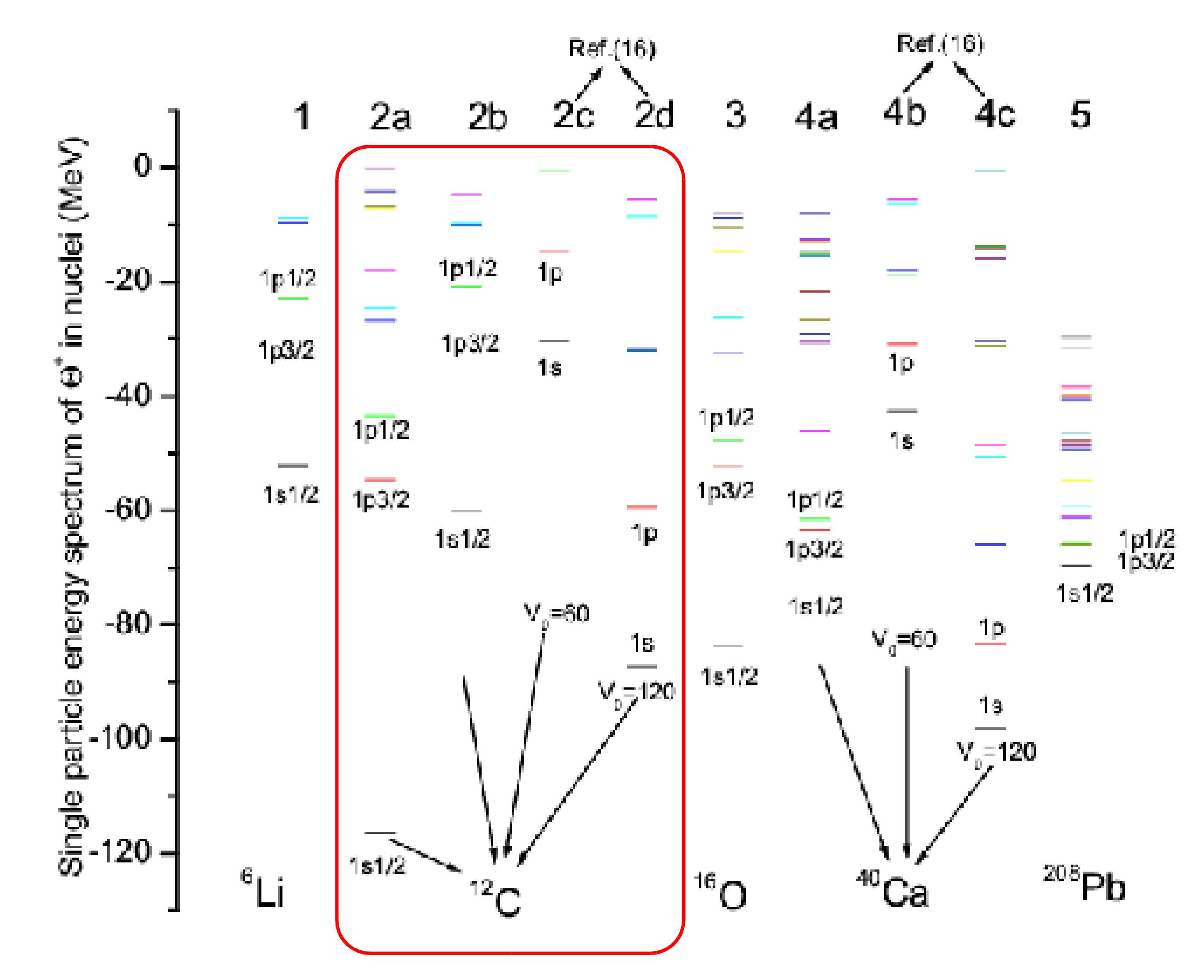
Theoretical Status of Hyponuclei

As coherent excitation of nucleons (Miller)

Two-meson cloud self-energy calculation (Vacas *et al.*)

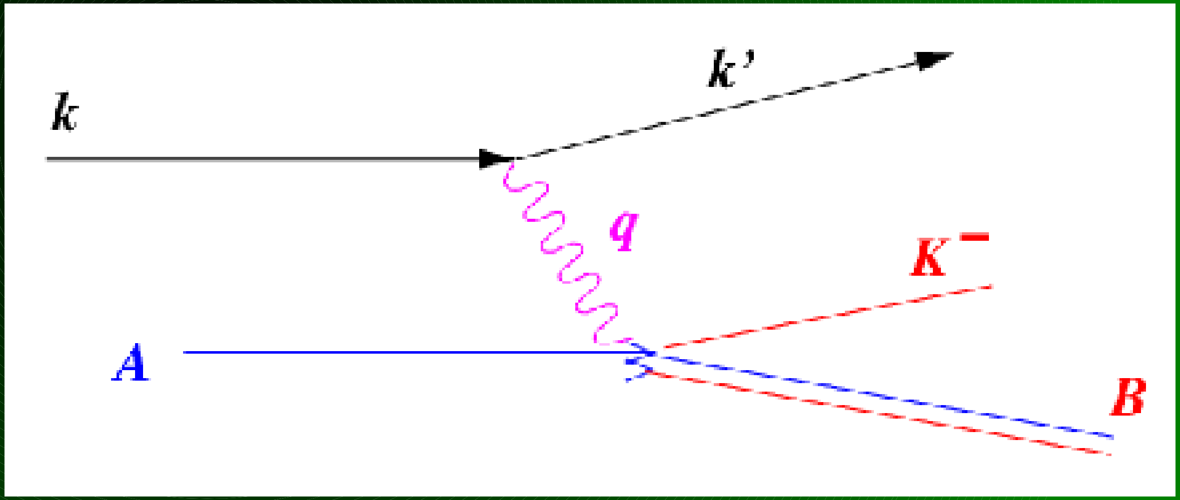
Meson-couplings within QMF ($g^{\omega}_{u/d}$) and RMF ($g^{\sigma}_{u/d}$) models.

Chiral soliton (P=-1) calculation.



Relativistic Mean Field
Zhong *et al.*, nucl-th/0408046

Reaction



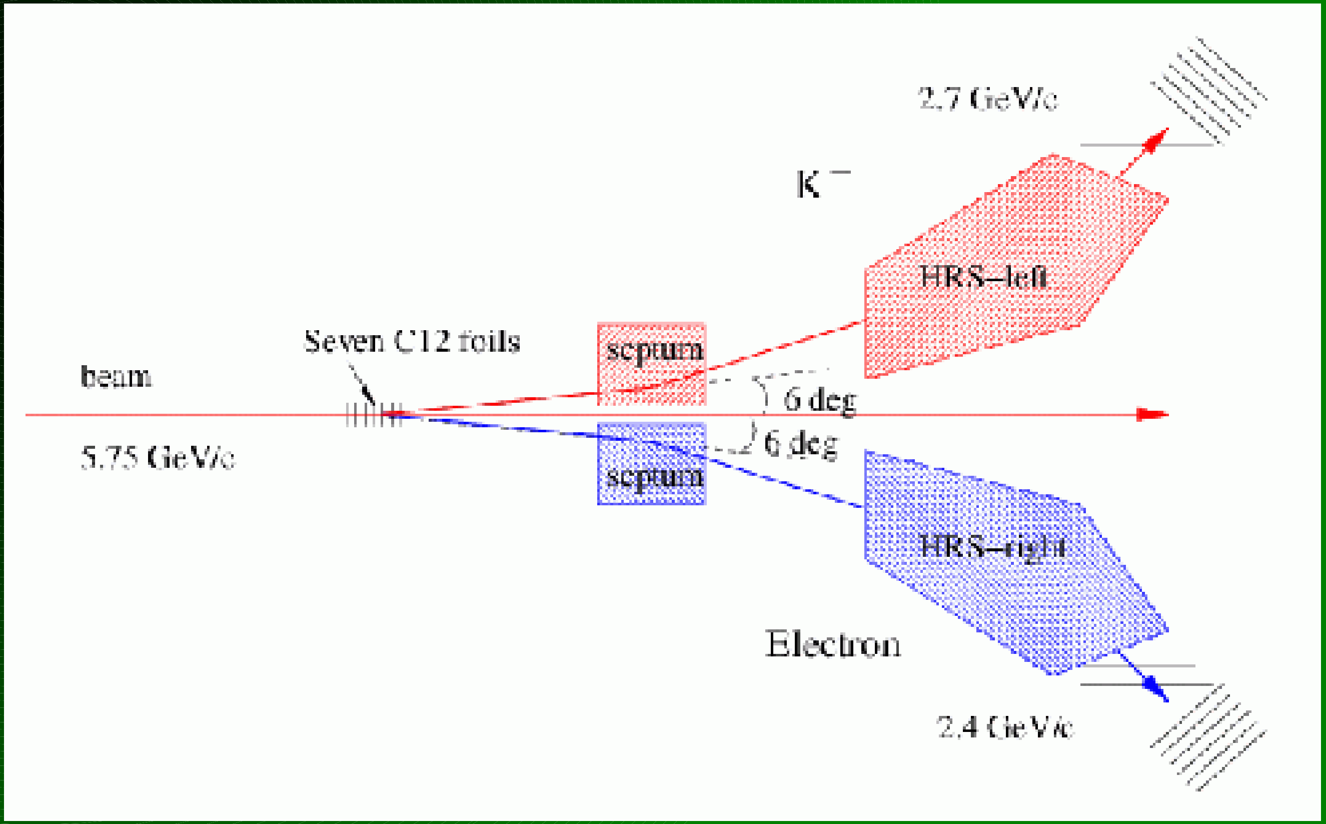
Look for the hyponuclei recoiling against the e K^-.

Experiment Setup

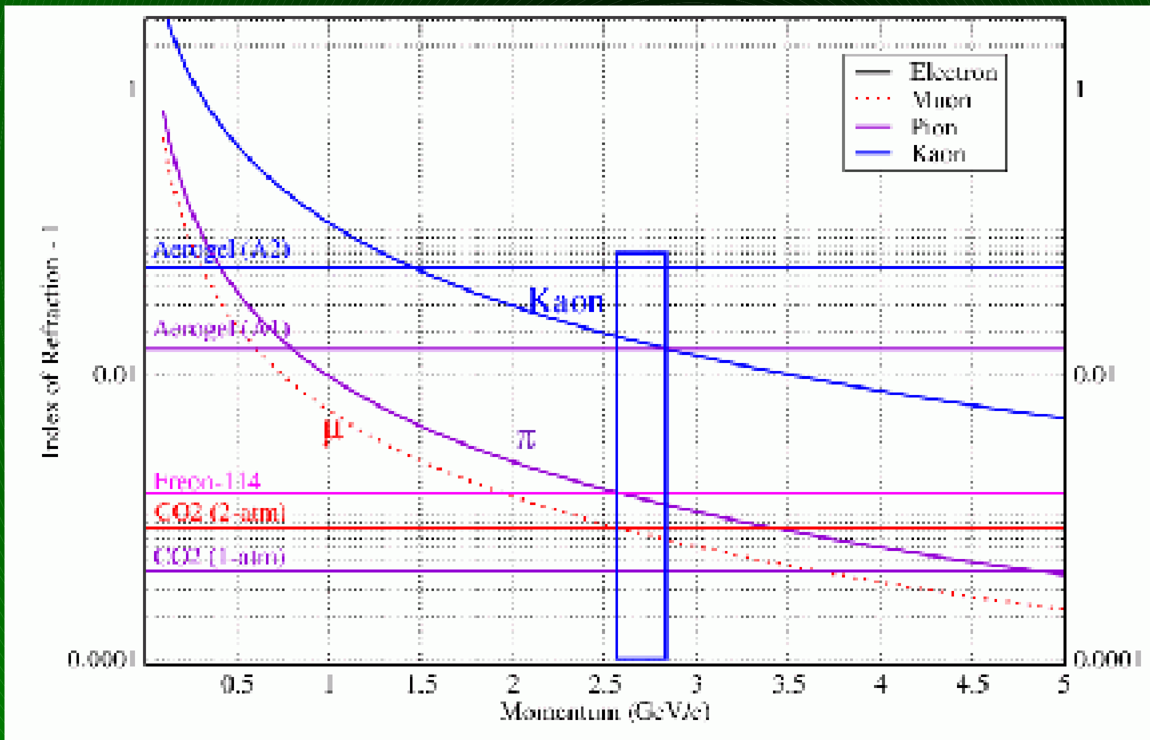
40 μA on 700mg/cm^2 multi-foil ^{12}C target

Luminosity = 10^{38} cm^{-2} s^{-1}

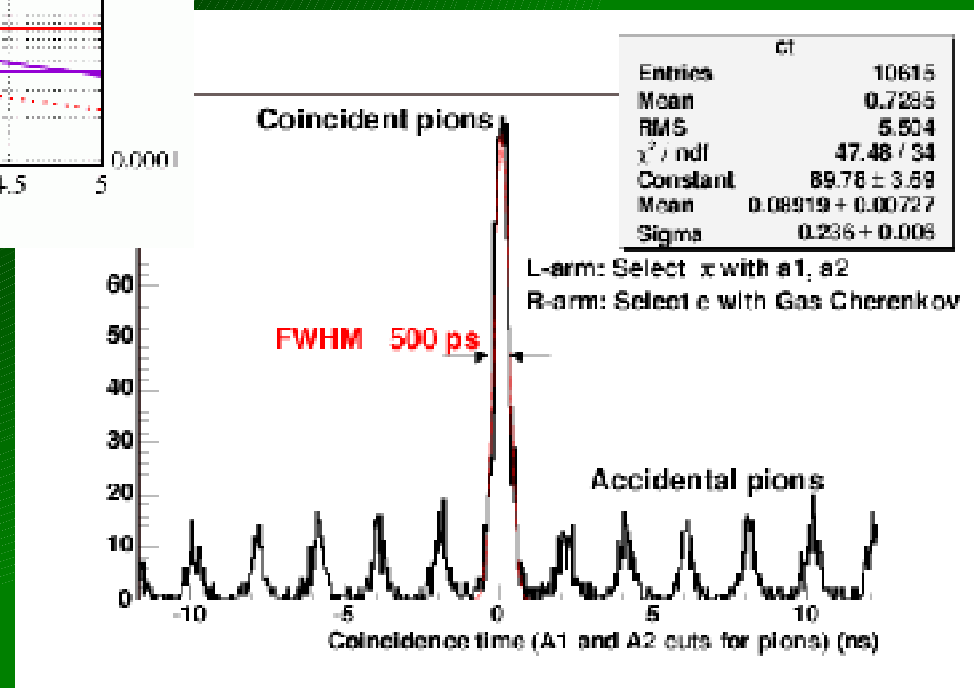
Foils spaced to by 3cm to be able to identify them in HRS's, to reduce random coincidences.



Particle Identification



- Online: e/pi rejection from K^- with factor of 10 (A1)
- Offline: additional factor of 10(A1) *ToF (5σ)=10000 total e/pi rejection factor.



Expected Rates

Electron rate was calculated with in a Quark-Fragmentation (QFS) framework and checked against the total photon-deuteron cross-section. Hadronic rates were calculated using Wiser's parameterization. Decay along the 27m flight-path to S2m was taken in account.

Singles Rates:

	P_0 [GeV/c]	e^- [kHz]	π^- [kHz]	K^- [kHz]	Total [kHz]	Scaled Exp. [kHz]
R-HRS	2.41	230	176	1.4	410	425
L-HRS	2.67	280	145	1.3	430	365

Accidental coincidence rate (50ns window):

Rates (cont'd)

Accidental coincidence rate (50ns window):

R-HRS/L-HRS	Rate	w/ on-line e^-/K^- PID
e^-/e^-	3.2 kHz	322 Hz
e^-/pi^-	1.7 kHz	170 Hz
e^-/K^-	15 Hz	15 Hz
Total	4.9 kHz	507 Hz

Offline: With a 2ns time-window and vertex cut (from the same foil), the accidental rate from Kaon is reduced to 0.086 Hz.

True coincidence rate (background):

L-HRS PID	x_F	$p_\perp$ [GeV/c]	$E\frac{d^3\sigma}{d^3p}$ [$\mu b/GeV^2$]	Coinc. Rate [Hz]
π^-	> 0.78	0.23	29.9	66
K^-	> 0.93	0.23	0.225	0.19

Estimated from inclusive hadronic photoproduction on deuterium.

Burfeindt *et al.* Nucl.Phys. **B**74:189 (1974); Boyarski *et al.* Phys.Rev. **D**14:1733 (1976)

Signal Rate

$$\nu_S = \mathcal{L}_{\gamma^* n} \cdot \sigma^{\Theta^-}_{\gamma n} \cdot f^{L-HRS}_{\gamma^*,K^-} \cdot f^{decay}_{K} \lambda_S$$

$\sigma^{\Theta^+}_{\gamma n}$ shape	$f^{L-HRS}_{\gamma^*,K^-}$
Uniform in γn C.o.M.	0.0024
exp(3t) (selected)	0.033
exp(5t)	0.052

Acceptance with R-functions and various angular distributions: 0.033 selected

$L_{\gamma^* n} = 5.8\ 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

$f_K^{decay} = 0.27$

λ_S=sticking probability for the transition S

Rate for observing transition S $\quad \nu_S = 5.2\ \lambda_S\ \sigma^{\Theta+}_{\gamma n}/\mu\mathrm{b}$ Hz

λ_S depends upon the kinematics, most importantly the momentum transfer.

Sticking factor estimate

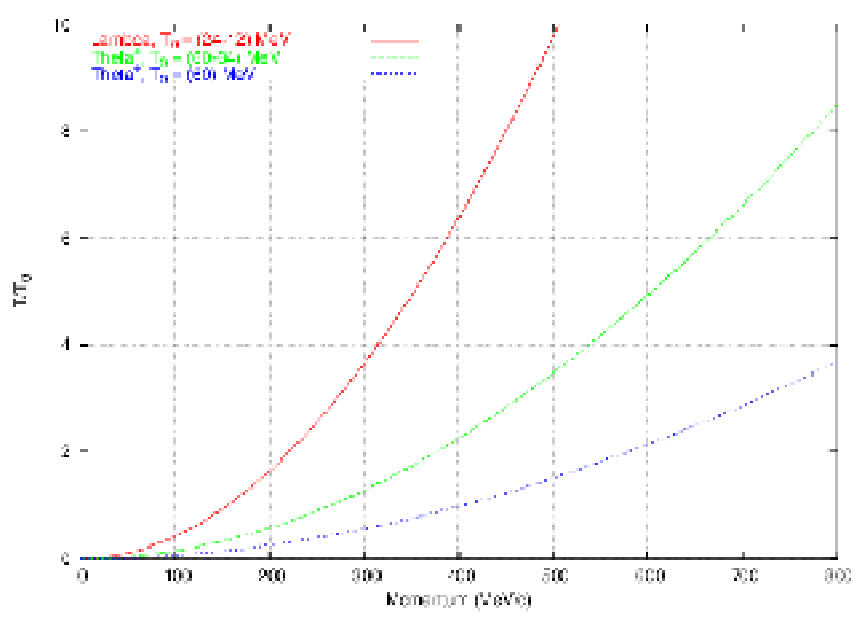
$$\lambda_{(N-1,\Lambda)} \propto \left[C'(l_\Lambda\ l\ l_N, j_\Lambda\ j_B\ j_N)\ I_l\right]^2$$

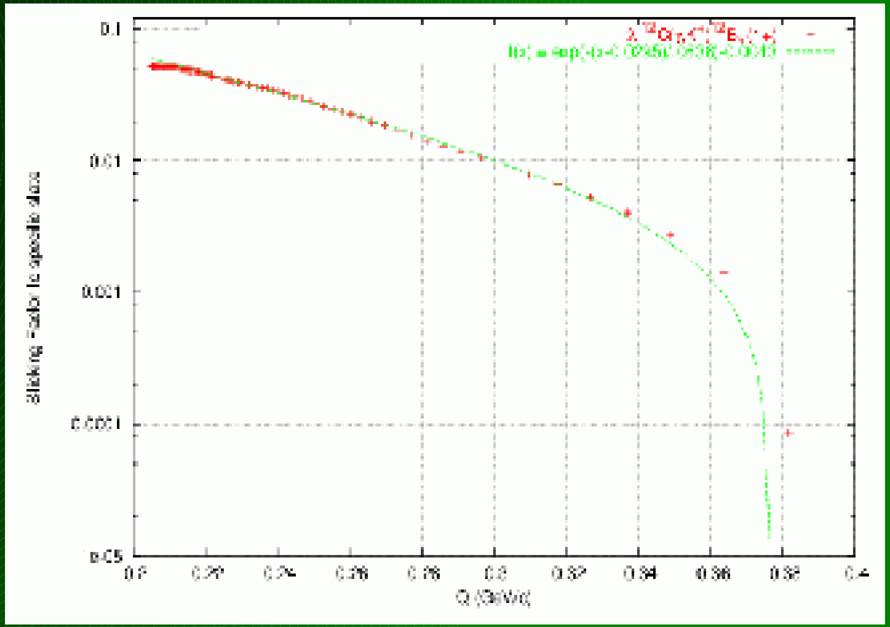
$$I_l = \int_0^\infty u_\Lambda^*(r) j_l(qr) u_N(r) dr$$

$V = -60$ MeV ρ/ρ_0		$V = -120$ MeV ρ/ρ_0	
E_i (MeV), ^{12}C	E_i (MeV), ^{40}Ca	E_i (MeV), ^{12}C	E_i (MeV), ^{40}Ca
-34.0 (1s)	-42.6 (1s)	-87.3 (1s)	-98.2 (1s)
-14.6 (1p)	-30.9 (1p)	-59.5 (1p)	-83.3 (1p)
-0.3 (2s)	-18.7 (1d)	-32.0 (2s)	-67.5 (1d)
	-17.9 (2s)	-31.9 (1d)	-65.9 (2s)
	-6.3 (1f)	-8.6 (2p)	-50.8 (1f)
	-5.6 (2p)	-5.6 (1f)	-48.5 (2p)
			-33.5 (1g)
			-31.1 (2d)
			-30.4 (3s)
			-15.9 (1h)
			-14.2 (2f)
			-13.8 (3p)
			-0.5 (4s)

With SHO w-f, we have crudely calculated the sticking factors for the initial proton states 1s1/2 and 1p3/2 (using binding energies from Vacas).

Sticking factor cross-check



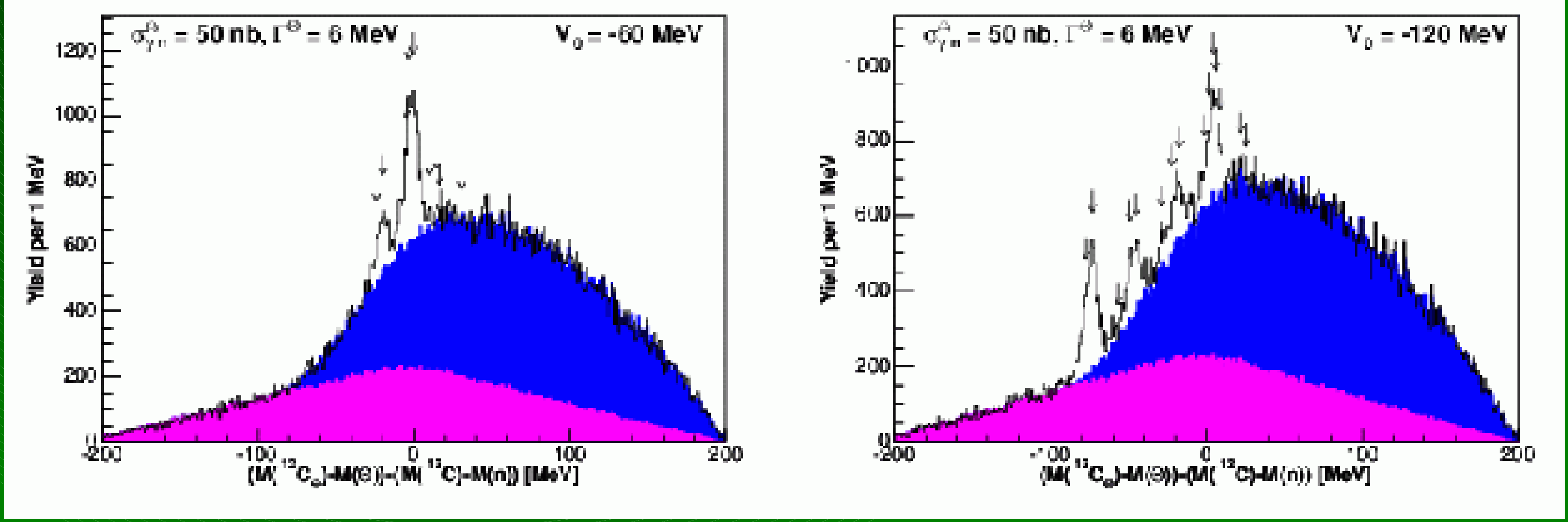


- As a check, came up with empirical estimate, relating the kinetic energy of the Theta+ to the Lambda (with known sticking factors).

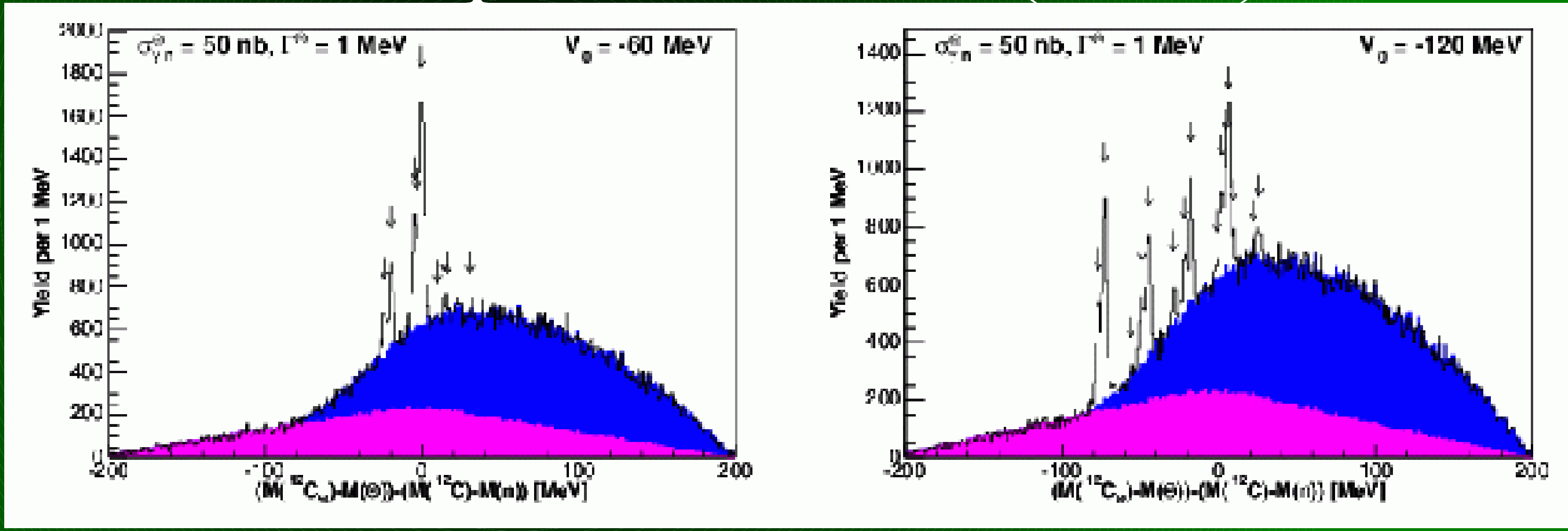
λ_S is up to a few tenths of a percent. However, many states!

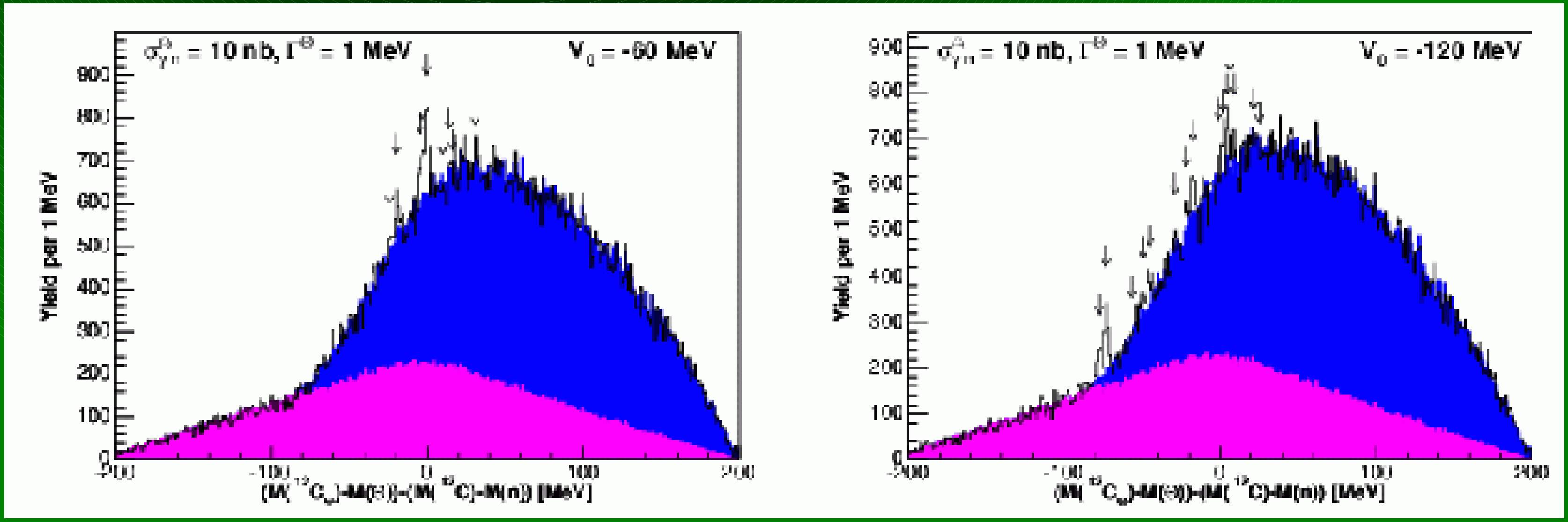
Expected Results

- 200 hours of beamtime.
- Different widths of the states, cross-section, and potential depth.



Expected Results (contd)





Conclusion

- Will be able to identify hyponuclei for a cross-section down to 10nb at the >6σ level with 200hrs of beam time.
- Can measure the energy levels to 1MeV
- Uses existing and proven equipment in Hall A.
- Searches for the Theta+ in the environment it was first observed.