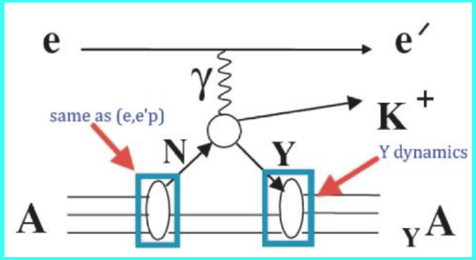
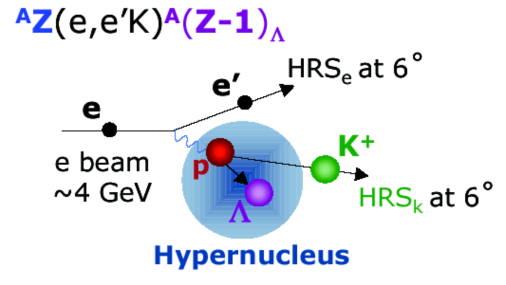
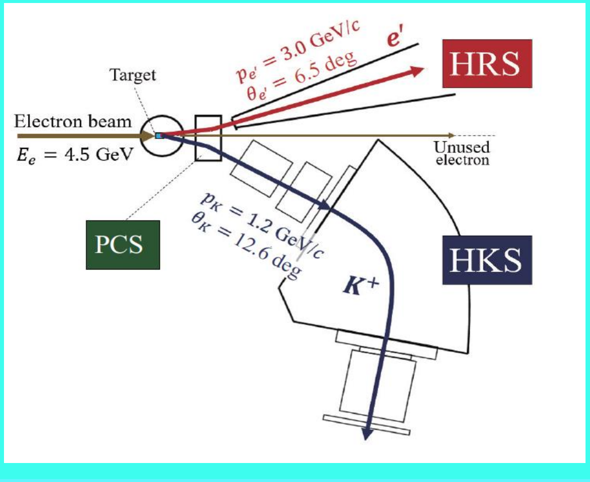
Studying Λ interactions in nuclear matter with the $^{208}Pb(e,e'K^+)^{208}_{\Lambda}Tl$

F. Garibaldi - Joint THEIA-STRONG2020 and JAEA/Mainz REIMEI – October – 21-2020

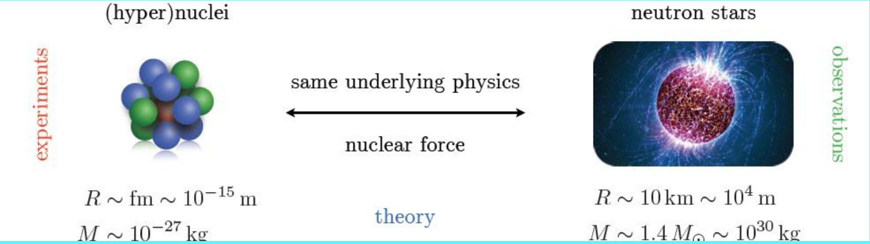
- The physics
- Why $^{208}\mathrm{Pb}(\mathrm{e},\mathrm{e}'\mathrm{K}^+)^{208}_{\Lambda}\mathrm{Tl}$?
  - Hyperon puzzle
  - The experiment
- Summary and conclusions







The hyperon puzzle

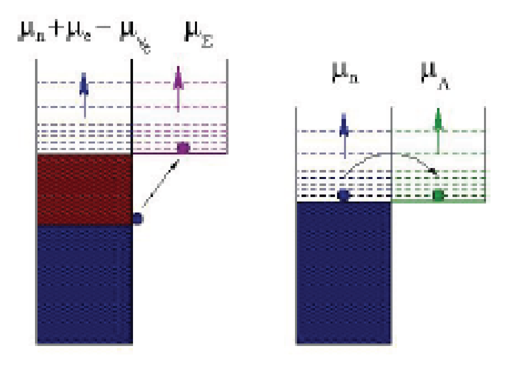


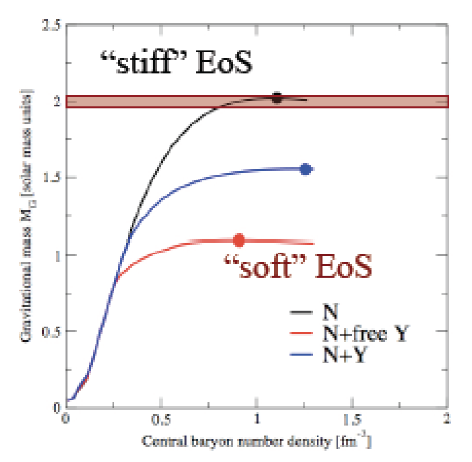
Neutron stars are remnants of the gravitational collapse of massive stars having masses of (1-2 Mo ~ 2 x 10^{33} Kg)

They are excellent observatories to test fundamental properties of nuclear matter under extreme conditions and offer interesting interplay between nuclear processes and astrophysical observables

Hyperons are expected to appear in their core at $\rho \sim (2\text{-}3)\rho_o$ when μ_N is large enough to make conversion of N to Y energetically favorable

but

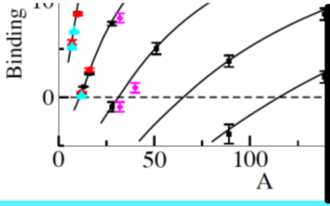




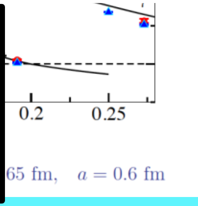
The relief of the Fermi pressure due to its appearance → EoS stiffer → reduction of the mass to values incompatible with observation (~ 2 Mo that requires much stiffer EoS)

Strong softening of the EoS of dense matter due to the appearance of hyperons which leads to maximum masses of compact stars that are not compatible with the observations.

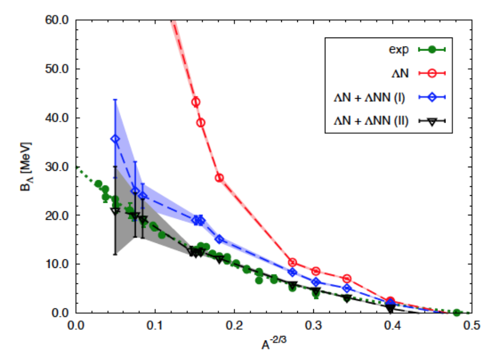
The present understanding of the nuclear interactions involving hyperons is far from being complete. The reason is in a combination of an incomplete knowledge of the forces governing the system (in the hypernuclear case both two- and three-body forces), and in the concurrent use of approximated theoretical many-body techniques.



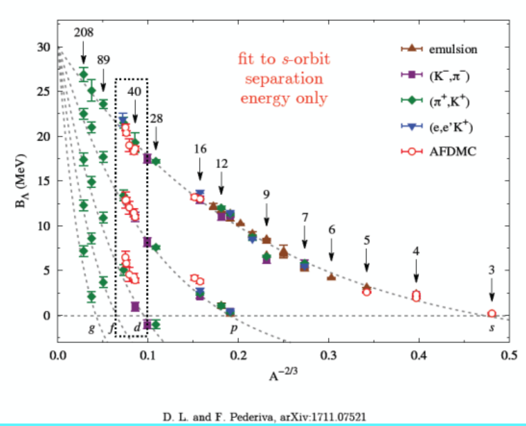
It has been suggested that three body forces could provide additional repulsion making the EOS stiffer enough to help solving the hyperon puzzle.



Lonardoni

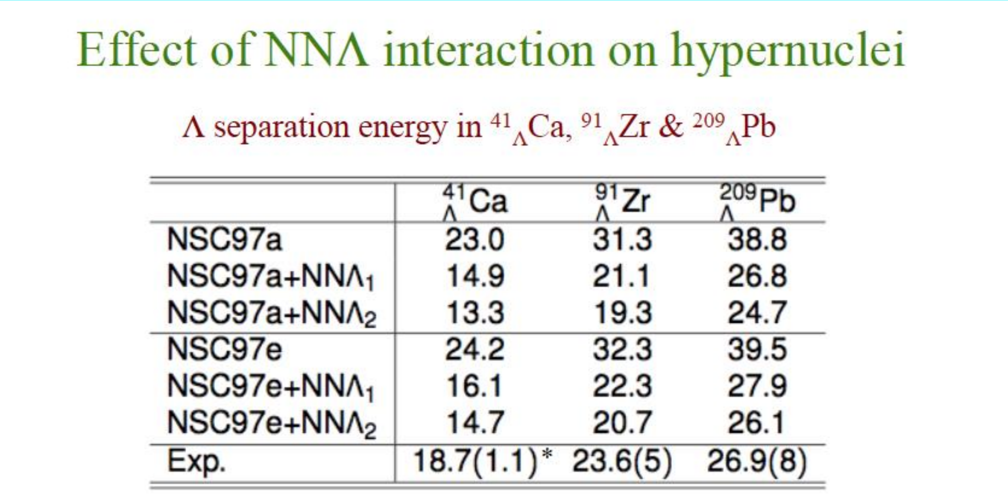


the effect of including the ΛNN termin the Hamiltonian is very strong. It provides the repulsion necessary to realistically reproducethe limiting value of B_{Λ}



D. L. and F. Pederiva, arXiv:1711.07521

Vidana



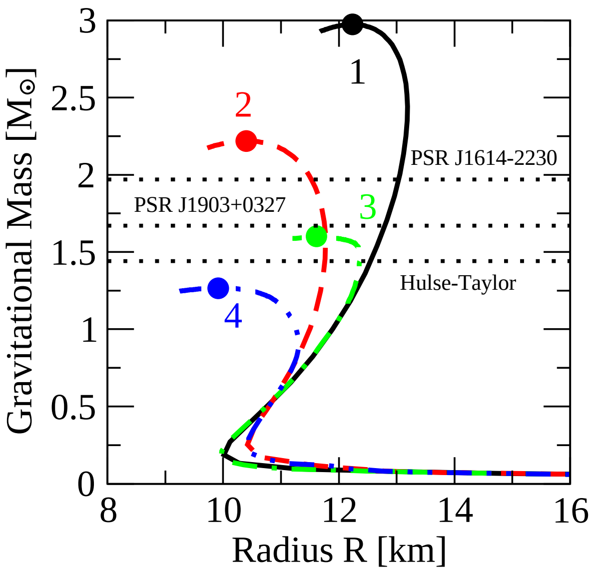
Effect of NNΛ interaction on hypernuclei

Λ separation energy in $^{41}{}_{\Lambda}$Ca, $^{91}{}_{\Lambda}$Zr & $^{209}{}_{\Lambda}$Pb

	$^{41}_{\Lambda}$Ca	$^{91}_{\Lambda}$Zr	$^{209}_{\Lambda}$Pb
NSC97a	23.0	31.3	38.8
NSC97a+NNΛ$_1$	14.9	21.1	26.8
NSC97a+NNΛ$_2$	13.3	19.3	24.7
NSC97e	24.2	32.3	39.5
NSC97e+NNΛ$_1$	16.1	22.3	27.9
NSC97e+NNΛ$_2$	14.7	20.7	26.1
Exp.	18.7(1.1)*	23.6(5)	26.9(8)

Only hypernuclei described as a closed shell nuclear core + a Λ sitting in a s.p. state are considered. Comparison with the closest hypernucleus for which exp. data is available

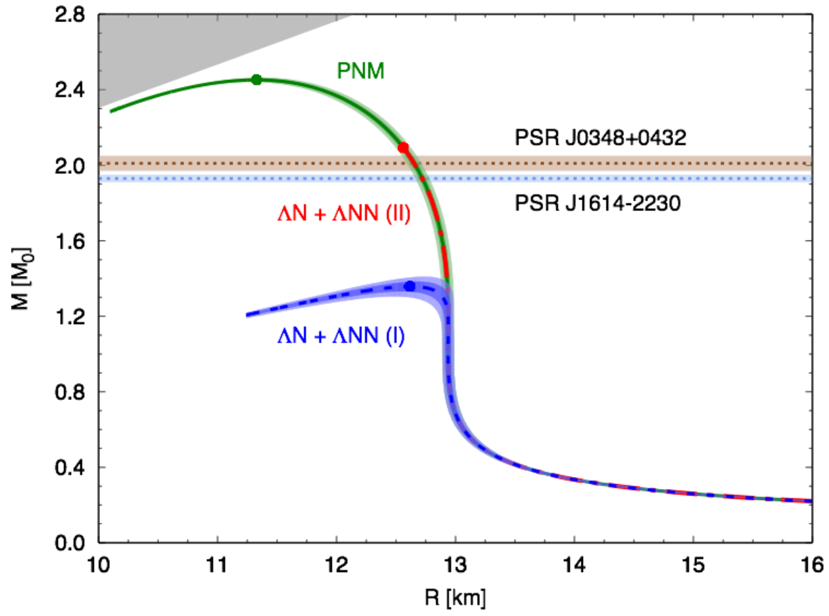
Inclusion of NNΛ improves the agreement with data for $^{91}\Lambda$Zr & $^{209}\Lambda$Pb.



It clearly appears that the inclusion of YNN forces (curve 3) leads to a large increase of the maximum mass, although the resulting value is still below the two solar mass line.

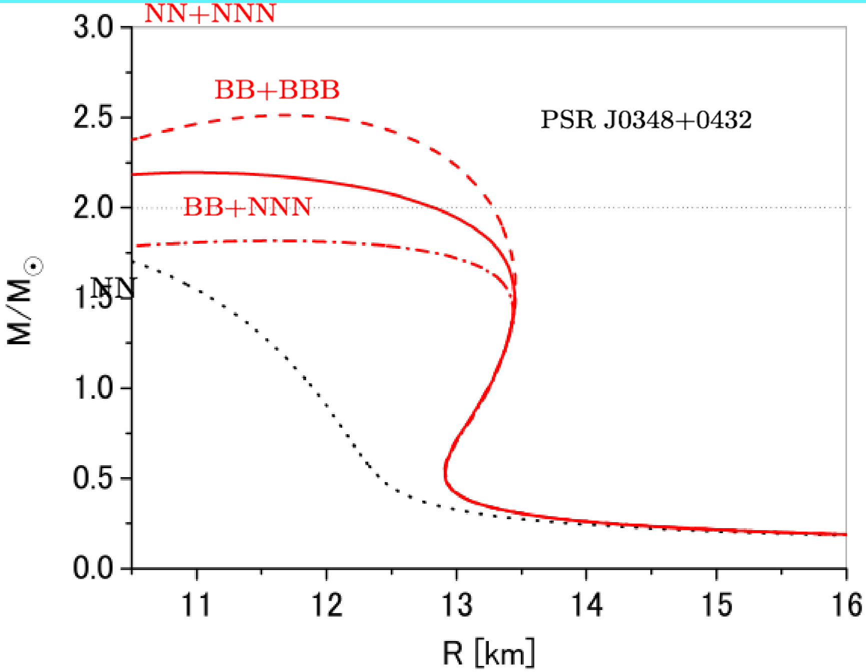
1. Nucleons without 3 body forces
2. Nucleons with 3 body forces
3. Λ and N with 3 body forces(ΛNN)
4. Λ and N without 3 body force

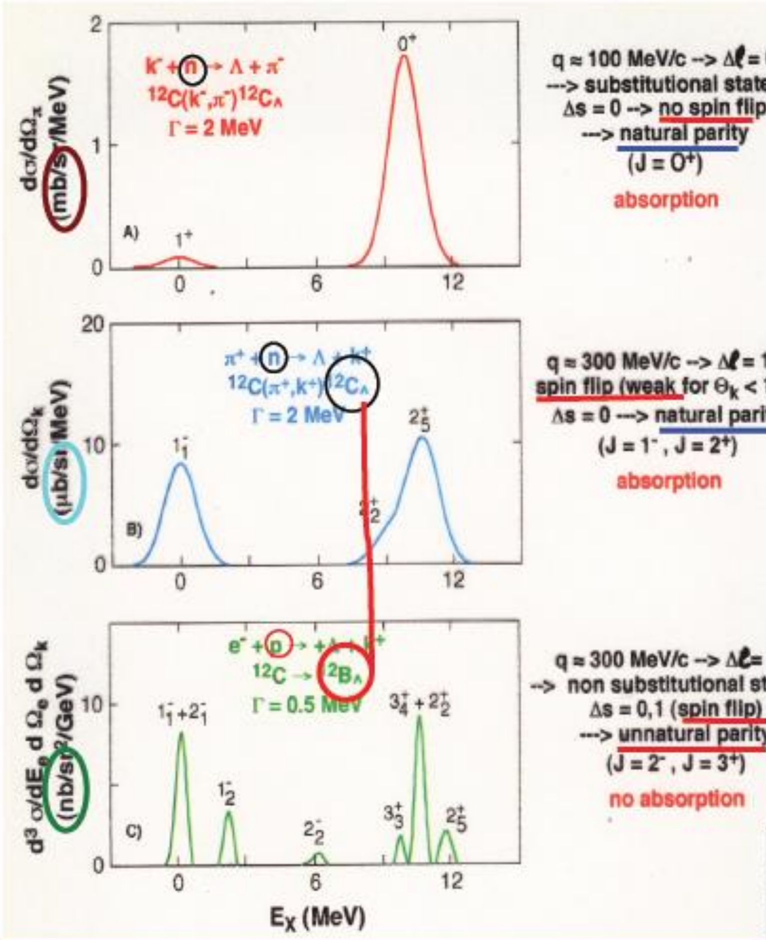
D.Lonardoni *et al.*, Phys. Rev. Lett. 114, 092301 (2015) (AFDMC)



Y. Yamamoto *et al.*, Phys. Rev. C 90, 045805 (2014)

G-Matrix: ESC08 + MPa

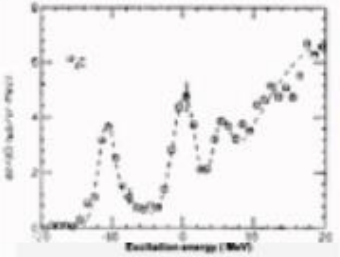




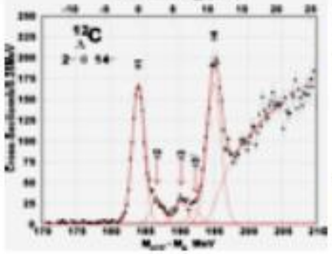
q ≈ 100 MeV/c --> $\Delta\ell = 0$
---> substitutional states
$\Delta s = 0$ --> no spin flip
---> natural parity
($J = 0^+$)
absorption

q ≈ 300 MeV/c --> $\Delta\ell = 1,2$
spin flip (weak for $\Theta_K < 10°$)
$\Delta s = 0$ ---> natural parity
($J = 1^-$, $J = 2^+$)
absorption

q ≈ 300 MeV/c --> $\Delta\ell = 1,2$
--> non substitutional statesd
$\Delta s = 0,1$ (spin flip)
---> unnatural parity
($J = 2^-$, $J = 3^+$)
no absorption

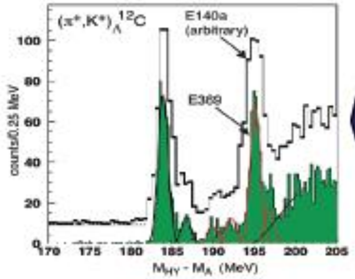


BNL 3 MeV



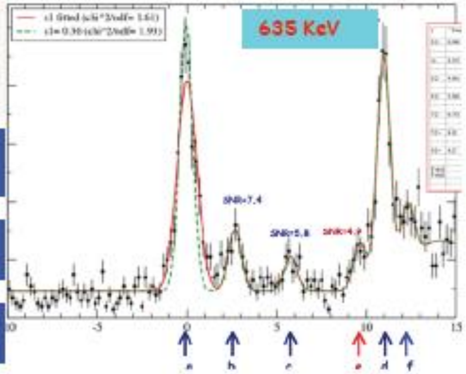
KEK336 2 MeV

Improving energy resolution



~ 1.5 MeV

and



using electromagnetic probe

High resolution, high yield, and systematic study is essential

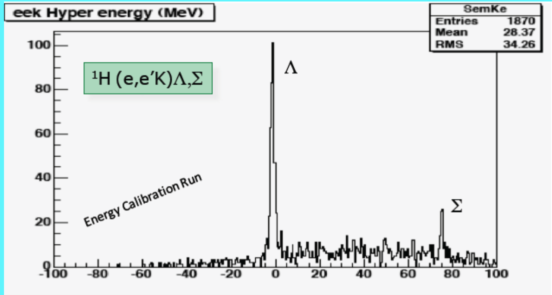
new aspects of hyernuclear structure

production of mirror hypernuclei

energy resolution ~ 500 KeV

(e,e'K+) hypernuclear spectroscopy provides information on the cross section as well as on the binding energy. These information are complementary to the information obtained by decay product studies such as gamma and decay-pion spectroscopies

Hypernuclear spectroscopy is the only method that can measure the absolute binding energy for ground and excited states with an high accuracy (~ 70 KeV)



Energy calibration IS important !

We are proposing to extend the experimental study of kaon electroproduction to the $^{208}Pb(e,e'K^+)^{208}{}_{\Lambda}Tl$ reaction.

It is a complementary (to the $^{40}{}_{\Lambda}K$ and $^{48}{}_{\Lambda}K$ experiment that was approved by PAC 45) way to address the same problem ("hyperon puzzle").
In fact E12-15-008 will allow us to extract isospin dependence of the 3-body ΛNN force

Three-body ΛNN forces are known to be strongly A-dependent, making the ^{208}Pb target uniquely suited to study Λ interaction in a uniform nuclear medium with large neutron excess

The contribution of three-nucleon forces, which is known to be large and repulsive in nuclear matter at equilibrium density, is believed to be much smaller and attractive in ^{40}Ca

Theoretical framework

Exploiting K^+ electroproduction data to constrain the models of hyperon dynamics requires a quantitative understanding of the nucleon sector

A framework has been developed (O.Benhar*, P. Bydzowsky**, I.Vidana***) to carry out calculations of the nuclear (e,e'K^+) cross section within the formalism of nuclear many-body theory, which has been extensively and successfully employed to study the proton knockout, (e,e'p) reaction. In fact, the clear connection between (e,e'p) and (e,e'K^+) processes that naturally emerges from the proposed analysis, shows that the missing energy spectra measured in (e,e'p) experiments provide the baseline for a model-independent determination of the hyperon binding energies

** New Elementary calculations have been performed

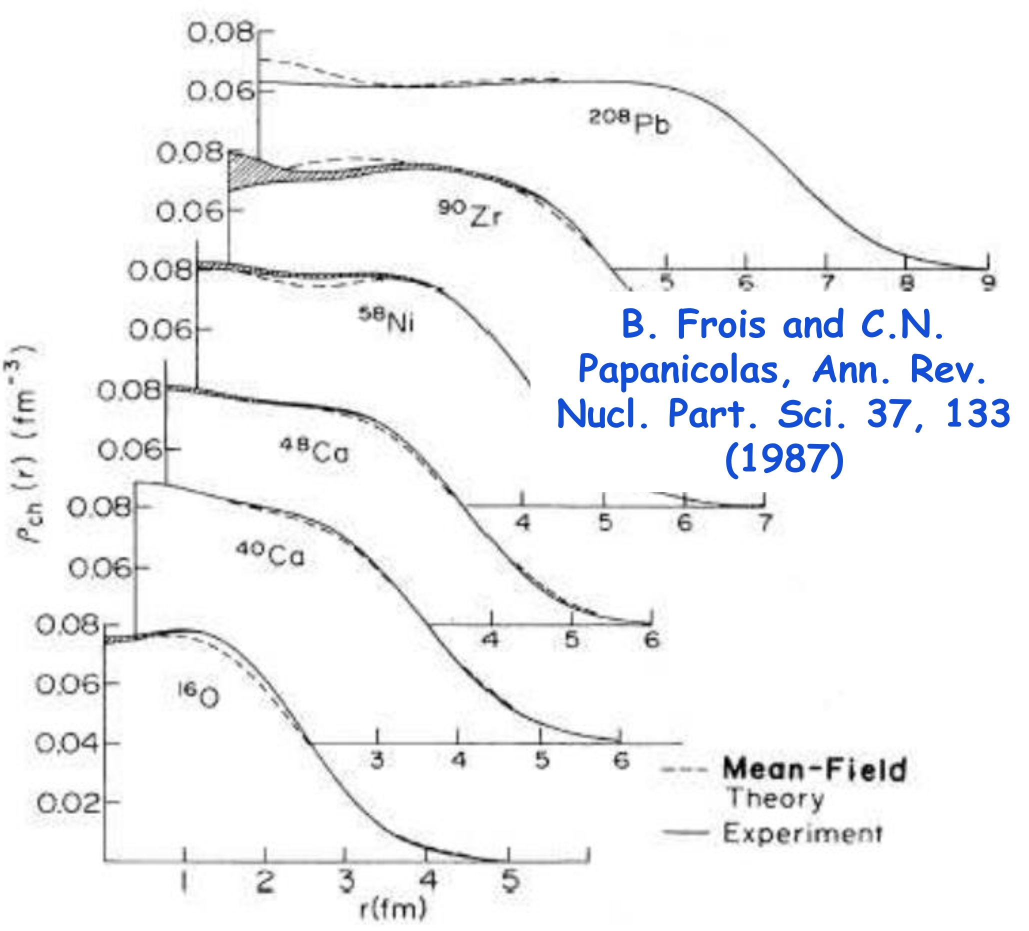
*** Microscopic calculations of the Λ spectral function in a variety of nuclei, ranging from ^{5}He to ^{208}Pb, have been recently carried out (Lonardoni)

**** Cross sections for the new kinematics have been calculated by T. Motoba

***** and J. Millener

******* Calculations by Millener, Vidana, Lonardoni et al for A dependence

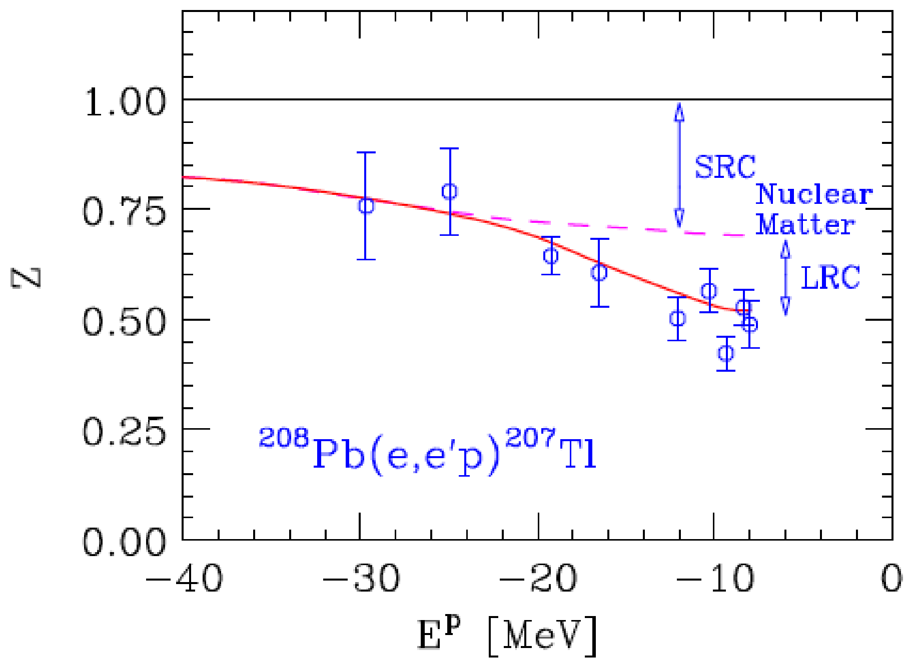
******** G-matrix calulations by Y. Yamamoto *et al.*



B. Frois and C.N. Papanicolas, Ann. Rev. Nucl. Part. Sci. 37, 133 (1987)

The measured charge density distribution of ^{208}Pb clearly shows that the region of nearly constant density accounts for a very large fraction (~70 %) of the nuclear volume, thus suggesting that its properties largely reflect those of uniform nuclear matter in the neutron star

The validity of this conjecture has been long established by a comparison between the results of theoretical calculations and the data extracted from the ^{208}Pb(e,e´p)^{207}Tl cross sections measured at NIKHEF in the 1990s



Short-range correlations appear to be the most important mechanism leading to the observed quenching of the spectroscopic factor, while surface and shell effects only play an important role in the vicinity of the Fermi surface.

Deeply bound protons in the ^{208}Pb ground state largely unaffected by finize size and shell effect

→ behave as if they were in nuclear matter

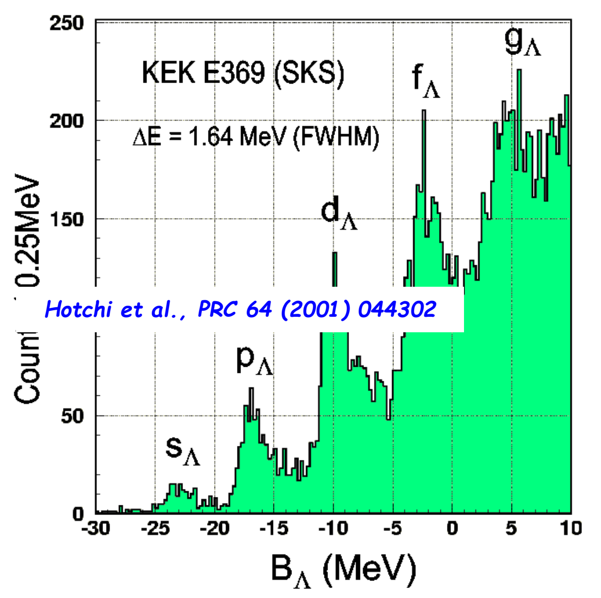
The hyperon binding energies are given by the difference between the missing energies measured in (e,e´K^+) and the proton binding energies obtained from the (e,e´p) cross sections. Hence, (e,e´p) data will provide the baseline needed to extract information, in a model independent way, on hyperon binding energies

→ The use of a ^{208}Pb target appears to be uniquely suited to study Λ interactions in a uniform nuclear medium with large neutron excess
Jlab is the only lab where to make this experiment

Hyperon in heavy nuclei – $^{208}(e,e'K+)^{208}{}_{\Lambda}\mathrm{Ti}$

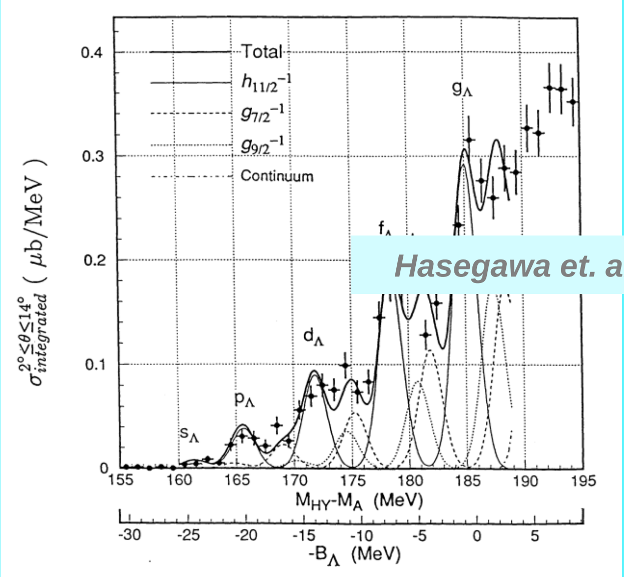
✓ Mass spectroscopy to its extreme

$^{89}\mathrm{Y}\ (\pi^{+},K^{+})\ ^{89}{}_{\Lambda}\mathrm{Y}$

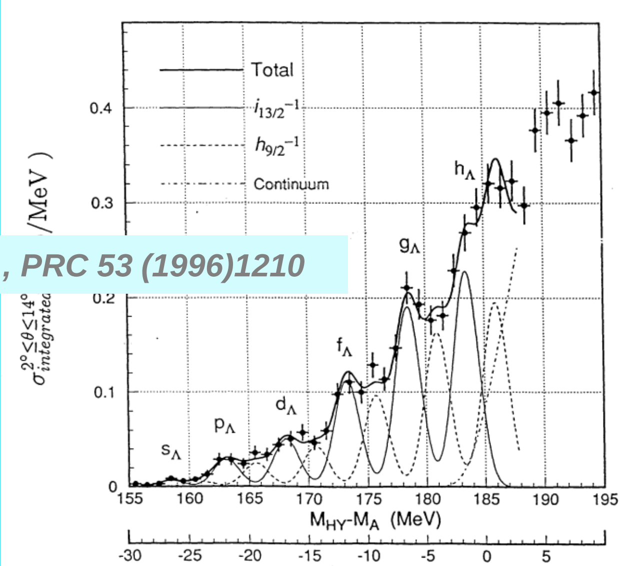


Hotchi et al., PRC 64 (2001) 044302

$^{139}\mathrm{La}(\pi^{+},K^{+})^{139}_{\Lambda}\mathrm{La},\ p_{\pi} = 1.06\ \mathrm{GeV/c}$

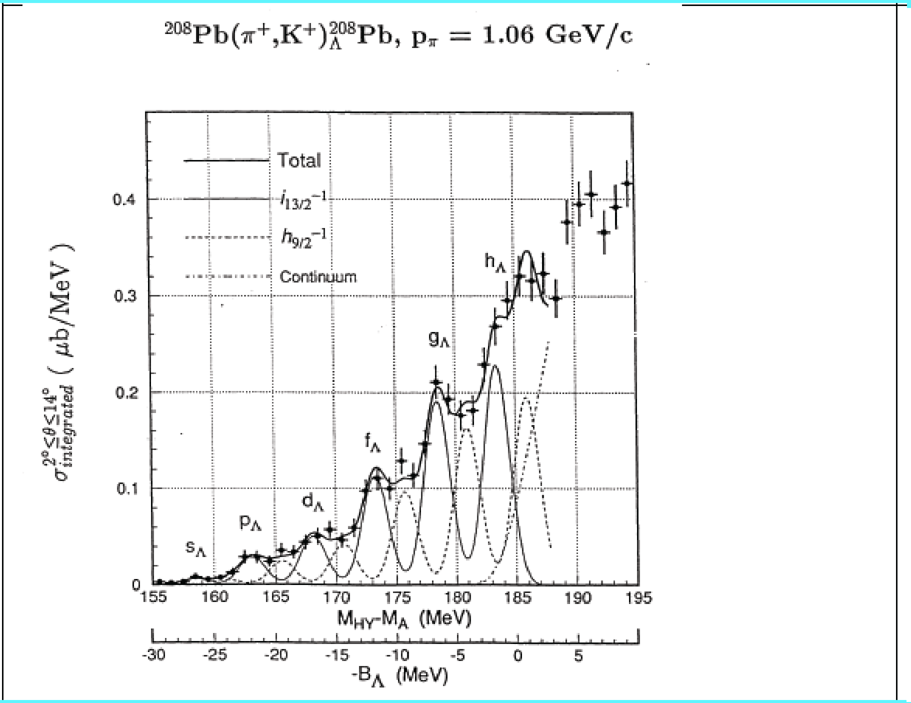


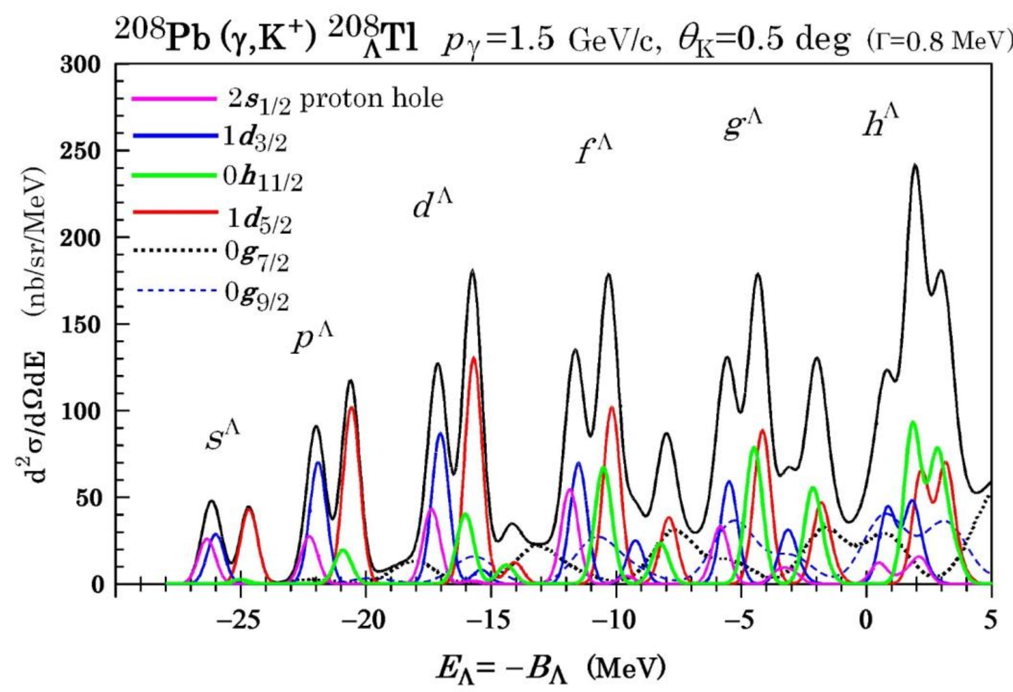
$^{208}\mathrm{Pb}(\pi^{+},K^{+})^{208}_{\Lambda}\mathrm{Pb},\ p_{\pi} = 1.06\ \mathrm{GeV/c}$



Hasegawa et. al., PRC 53 (1996)1210

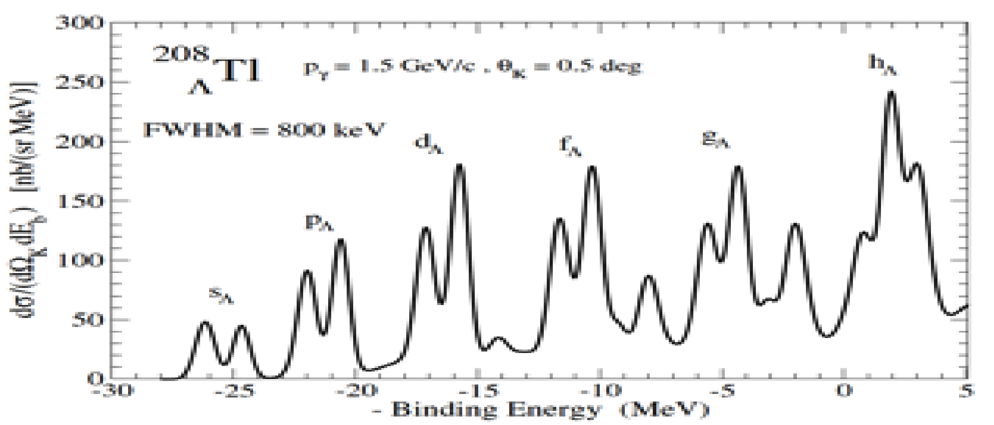
“Therefore is of vital importance to perform precision spectroscopy of heavy Λ hypenuclei with mass resolution comparable to or better than the energy differences of core excited states, in order to further investigate the structure of the Λ hyperon deeply bound states in heavier nuclei. (e,e'K) spectroscopy is a promising approach to this problem

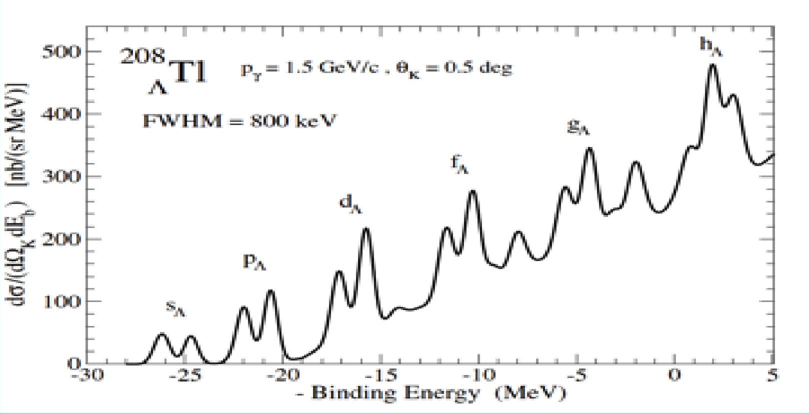


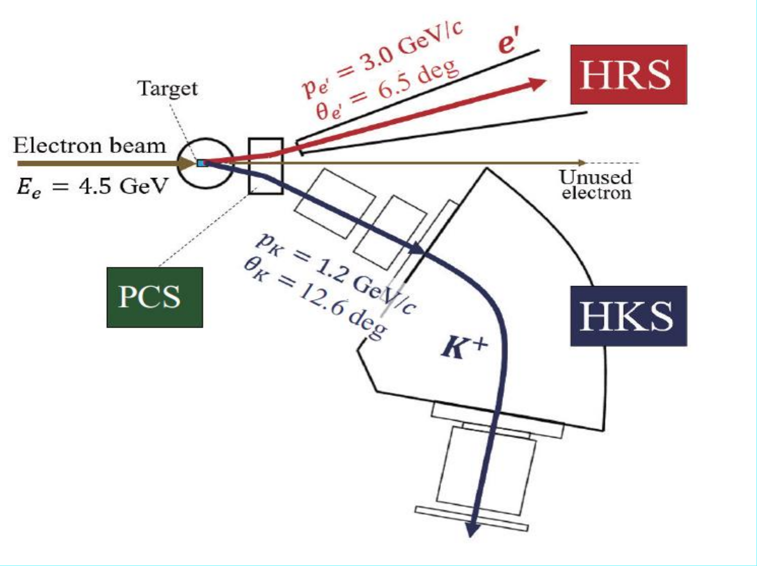


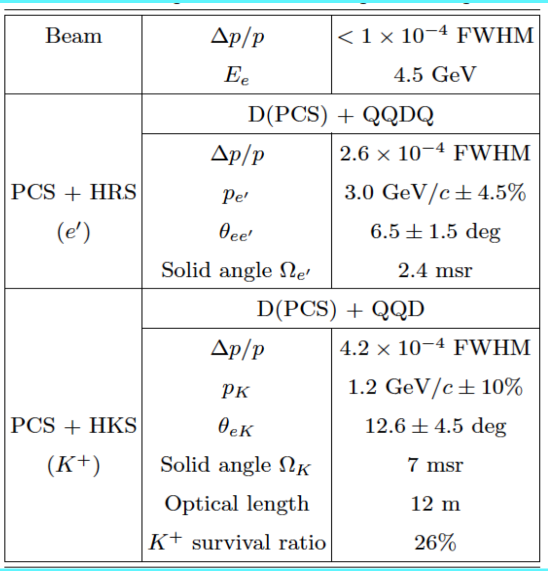
Millener-Motoba calculations

- Particle hole calculation, weak-coupling of the Λ hyperon to the hole states of the core (i.e. no residual Λ-N interaction). One can extract Λ single-particle energies from each of the observed peaks. **Each peak does correspond to several levels** based on two closely-spaced proton-hole states







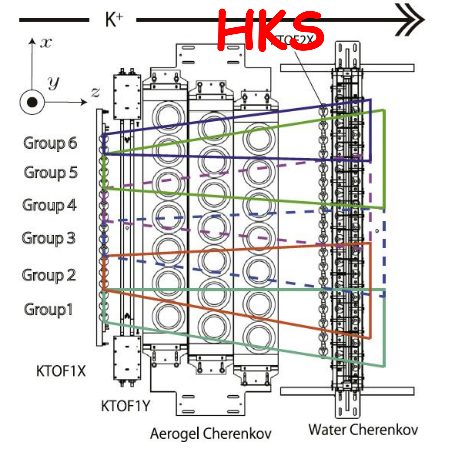


Beam	$\Delta p/p$ E_e	$< 1 \times 10^{-4}$ FWHM 4.5 GeV
PCS + HRS (e')	D(PCS) + QQDQ	
	$\Delta p/p$ $p_{e'}$ $\theta_{ee'}$ Solid angle $\Omega_{e'}$	2.6×10^{-4} FWHM 3.0 GeV/$c \pm 4.5\%$ 6.5 ± 1.5 deg 2.4 msr
PCS + HKS (K^+)	D(PCS) + QQD	
	$\Delta p/p$ p_K θ_{eK} Solid angle Ω_K Optical length K^+ survival ratio	4.2×10^{-4} FWHM 1.2 GeV/$c \pm 10\%$ 12.6 ± 4.5 deg 7 msr 12 m 26%

	Momentum/Energy Resolution (%)	Angle resolution (mrad)	Contribution to the missing mass resolution (keV)
PCS + HKS	4.2 x10^{-4}	0.6	500
PCS + HRS	2x10^{-4}	1.5	600
Beam	5x10^{-5}	-	250
Missing Mass Resolution			850

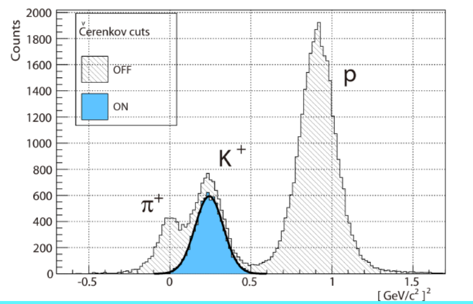
Target and objective hypernucleus	Beam current (μA)	Target thickness (mg/cm²)	Assumed cross section (nb/sr)	Expected Yield (/hour)	Num. of events	Req. beamtime (hours)	B.G. Rate (/MeV/h)	S/N (±4 σ)	Comments
CH_2	2	500	200	19	1000	54	0.05	252	Calibration
^{6,7}Li	50	100	10	5.4	150	28	1.3	4.9	Calibration
^{9}Be	100	100	10	36	300	9	4.7	8.8	Calibration
^{10,11}B	25	100	10	16	150	19	0.29	33	Calibration
^{12}C	100	100	100	54	2000	37	4.4	17	Calibration
Subtotal for calibration						147			
^{208}Pb	**25**	**100**	**80(g.s.)**	**0.3**	**145**	**480**	**0.1**	**21**	**Production**

PID



3 TOF, 2 water Cherenkov, three aerogel Cerenkov

pK=1.2 GeV/c)

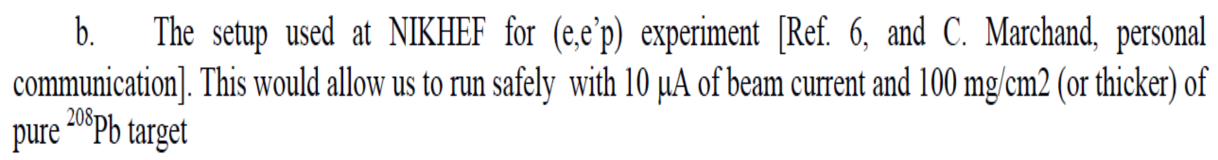


(π/k rejection ratio: 4.7 x 10^{-4})

(T. Gogami et al, NIM (2018) 69-83)

We will add up the RICH detector if needed

Target



b. The setup used at NIKHEF for (e,e'p) experiment [Ref. 6, and C. Marchand, personal communication]. This would allow us to run safely with 10 μA of beam current and 100 mg/cm2 (or thicker) of pure ^{208}Pb target

Water - 15° - 60—70 l/h

Heath transfer calculation show that the conduction cooling becomes competitve as compared to increase radiation cooling by rotating the target for thick target

$$< i_{max}> = 2\pi k\ (T_{\text{melting}} - T_0)/\{[\ln(r_1/r_0) + ½]\ \rho\, dE/dx\}$$

Using the right K for cryocooling brings to the conclusion that we will be able to run safely at 25 μA

Summary and conclusions

We propose to extend the experimental study of kaon electroproduction to the ^{208}Pb(e,e'K)$^{208}_{\Lambda}$Tl reaction to study the hyperon puzzle in a complementary way with respect to the approved proposal $^{40}_{\Lambda}$K and $^{48}_{\Lambda}$K on isospin dependence of ΛNN

ΛNN could provide additional repulsion making the EOS stiffer enough to help solving the hyperon puzzle. Moreover they rapidly increase with A, making the ^{208}Pb target uniquely suited to study Λ interaction in a uniform nuclear medium with large neutron excess

In fact, the contribution of three-nucleon forces, which is known to be large and repulsive in nuclear matter at equilibrium density, is believed to be much smaller and attractive in ^{40}Ca

The availability of accurate ^{208}Pb(e,e'p)^{207}Tl data may be exploited to achieve a largely model-independent analysis of the measured cross section, based on the well established formalism of nuclear many-body theory

In conclusion, even if the typical baryon density inside a neutron star is much higher than in a hypernucleus a precise knowledge of the ^{208}Pb level structure can, by constraining the hyperon-nucleon potential, contribute to more reliable predictions regarding the internal structure of neutrons stars, and in particular their maximum mass

The recent progresses in the treatment of both the elementary $e + p \rightarrow e' + \Lambda + K^+$ reaction and the transition amplitues of heavy nuclei, will allow the generalisation of the approach based on factorization, successfully employed to analyse (e,e'p) data, to the description of the ^{208}Pb(e,e'K+)^{208}Tl cross section. The results of this analysis, combined with the availability of model independent information on the hyperon binding energies, will allow to constrain and improve the available models of YN and YNN potentials.

→ The use of a ^{208}Pb target appears to be the best suited to obtain information on Λ interactions in a uniform nuclear medium with large neutron excess

The collaboration is particularly suitable for this proposal

In fact an ambitious and challenging experimental program, aimed at obtaining high-resolution hypernuclear spectroscopy via the (e,e'K+) reaction, was started successfully at Jefferson Lab 15 years ago. The data, taken in both Hall A and Hall C using p-shell and medium-mass nuclear targets, have provided clear spectra with 0.5~0.8-MeV energy resolution.

We published 10 or more physics papers on physics and few tents of tehcnical ones.

The extremely good Jlab beam and all the detetors to be used, as well as the anlaisys's tools, are very well known to the collaboration

Thank you!

References

*Omar Benhar, "Extracting Hypernuclear Properties from the (e, e'K+) Cross Section", submitted at Phys Rev C, available at arXiv:2006.12084
O Benhar, A Fabrocini, S Fantoni , Occupation Probabilities and Hole-State Strengths in Nuclear Matter, Phys. Rev. C 41, R24 (1990)
O. Benhar, Exploring Nuclear Dynamics with (e, e'p) Reactions: From LNF to JLab*Nucl.Phys.News* 26 (2016) 2, 15-20

** D. Skoupil and P. Bydžovský Phys. Rev. C 97, 025202 (1918)

*** I. Vidana"Impact of chiral hyperonic three-body forces on neutron stars", Eur. Phys. J. A (2019) 55: 207
I. Vidana, "Single-particle spectral function of the Λ hyperon in finite nuclei", Nuclear Physics A 958 (2017) 48–70

**** T. Motoba. Photoproduction of typical hypernculei - JPS Conf. Proc. , 011003 (2017) – https://doi.org/10.7566/JPSCP.17.011003 (and peronal communication

***** Gal, Hugenford and Millener, "Strangeness in Nuclear Physics", Rev of Mod. Phyisics 88 July 2016

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D. Lonardoni, F. Pederiva, and S. Gandolfi, Phys. Rev. C 89, 014314 (2014).
D. Lonardoni, A. Lovato, S. Gandolfi, and F. Pederiva, Phys. Rev. Lett. 114, 092301 (2015).
D. Lonardoni *et al*, Phys. Rev. C 96, 024326 (2017)

******* Y. Yamamoto *et al.*, Phys. Rev. C 90, 045805 (2014)

PAC issues and the proposal "answers"

1.The PAC is not convinced that this is the appropriate nucleus in which to extract this physics.

It is a fact that, owing to the extended region of constant density and the large neutron excess, 208Pb is the best available proxy for neutron star matter. Using a heavy target is all the more important in view of the results of advanced many-body calculations in the non strange sector, showing that the effects of three-nucleon forces in uniform matter and Calcium are qualitatively different.

2.Furthermore, the experimental technique is not sufficiently described for us to be convinced that thenecessary resolution can be achieved.

In par. 5.1 we have quoted the parameters affecting the energy resolution and described the Monte Carlocalculations made for evaluating the expected missing mass resolution (~ 800 kev) good enough for thepurpose of the experiment (see Figs, 2.7 and 2.9)

3. Thirdly, the theoretical tools that would be used to extract ΛNN forces have since been replaced by more modern techniques that are more suited to determine the necessary fine detail required

We are aware that modern computational approaches, mostly based on the Monte Carlo method, have been very successful in obtaining ground-state expectation values of Hamiltonians involving nucleons and hyperons. Unfortunately, however, the present development of these techniques does not allow the calculation of either (e,e'p) or (e,e'K) cross sections. On the other hand, the approach based on factorization and the Green's function formalism has proved very effective for the interpretation of the available (e,e'p) data, and its extension to the (e,e'K) process appears to be feasible

4.First, it does not present in a convincing way the feasibility of the measurement.

We have shown in par. 5.2 that the experiment is feasible. In fact, the SNR for the smallest peak in the binding energy spectrum, corresponding to a Λ in the s shell, is 21! Moreover in par. 3.5 (and Appendix 1) we describe in great detail the Pb target showing that is it is safe, with no risk of melting. In par. 5. And Appendix 2 we describe the Particle IDentifcation (PID) system showing that there is no problem at all in identifying kaons

5. Second, while motivating the physics case with a need of better pinning down the ΛNN force, the extraction of this information from the measurements was not convincingly laid out. Thus, the impact on the solution of the “hyperon puzzle” is not at all clear and cannot justify the approval of this proposal. In addition, it will be highly valuable to see the results of the approved 40Ca and 48Ca measurements and their impact on ΛN and ΛNN forces to better understand the need of studying even heavier targets

The solution of the “hyperon puzzle" will require a great deal of theoretical and experimental work, for many years to come. The extension of the JLab kaon electroproduction program to 208Pb will allow to collect new unbiased information, useful to understand the effects of three-body forces in a regime in which—based in the present understanding of the non-strange sector---they are expected to be large. This information will be complementary to that obtainable from the approved Calcium experiments

Questions raised by the TAC report

Technical Comments:

1. Except for target, the apparatus for this proposal is the same as for experiment E12-15-008 (hypernuclear spectroscopy with 40Ca and 48Ca targets.) and the proponents assume that this proposal would be scheduled to run with that experiment. If this experiment were scheduled to run standalone, it would require installation time (months), commissioning time (weeks?) and about 6 days for calibration measurements.

The Pb experiment is non supposed to run standalone

2. Information on the lead target is not clear in the proposal. Nevertheless, given the 3x3 mm raster size to mitigate melting, a lead target is feasible. In order to avoid extra setup and calibration time it will be necessary to design a target system that can accommodate the calcium targets for E12-15-008, the calibration targets and the lead target. Care will be needed to ensure that the optics are understood well enough with the larger raster size.

The setup for the Pb experiment has been discussed several times with Dave Meekins, even very recently. The setup for Pb experiment is just the PREX system but the Pb target not sandwiched between diamond foils. In fact, the beam current requested by PREX was more than 3 times our requested current and the PREX target thickness was several times bigger than the proposed experiment target. The solid target ladder will have to host the Ca targets and calibration targets. The optics are understood thanks to the experience accumulated during the 94-107 experiment. Similar raster sizes were employed during the experiment E06-007 without compromising the missing mass resolution.

3. Some lead data was taken during E05-115. If analyzable, does that data provide any useful information for this proposal? (Backgrounds, single rates)

We have not data with a Pb target from E05-115. This experiment was performed with nuclei as heavy as Cr. E05-115 data as well as the data taken in Hall A during the experiment 94-107 have provided information for background, single rates etc.

4. The experiment requests a beam energy of 4.5238 GeV. The current achievable two pass energy is 4.24 GeV. Event when the accelerator reaches full 12 GeV performance, the two pass energy will be 4.48 GeV. Does this experiment need three pass operations (with a non-standard energy) to reach 4.5238, or is a lower beam energy acceptable? What is the impact on estimated event rate and backgrounds from a lower beam energy?

Running with the lower incident energy quoted is not an issue and there is in practice no impact on estimated event rate and background

5. A beam energy spread and stability of 5 x10-5 is requested? Is this RMS or FWHM? Accelerator setup time will be needed achieve and measure this.

The request is 5 x 10^-5 FWHM ~~(This was the stability obtained during the 6 Gev running time)~~
However, a 225 keV sigma energy spread, the present CEBAF limit during 12 GeV era, can be tolerated bringing an overall resolution of 950 keV - 1000 keV. A request of smaller energy spread/stability seems to be feasible at the cost of a couple of days of data taking to restore the needed energy spread given gradual drifts. This data taking loose is still affordable because of the high Signal to Noise ratio expected. The collaboration reserves the possibility of analyzing the possibility to ask for smaller but sill feasible beam energy spread/stability. If this option will be pursued, synchrotron light monitors will have to be installed in arcs 3 and 4 to allow Ops to see gross changes real time
The 225 KeV energy spread evaluation comes form an exchange of e-mails we had with Jay Benesh. We include it to the present e-mail

7. It is not clear if the RICH detector is required for this experiment. The detector uses liquid C6F14 as the Cherenkov medium. Is sufficient quantity of this material on hand or budget available to purchase it? The RICH detector may require a pressure system analysis to satisfy current codes. The effort to integrate the electronics/DAQ for this detector should not be underestimated.

As written in the proposal and quoted in papers the HKS hadron PID system is expected to be excellent and adequate for Pb experiment. However, kaon identification on top of the expected background is one of the key, challenging, aspect in the Pb experiment and minimizing risks of PID under-performance is desirable and can actually be done including the existing, powerful Hall-A Proximity RICH detector in HKS. The Proximity RICH ran twice, for 94-107 experiment and, upgraded in the 3He transversity experiment E06-010 (this upgrade is particularly "effective" in the Pb kinematics as described in the Appendix of the Pb proposal). Therefore we would like to consider the possibility to install it, after veryfying what is needed for its refurbishing.

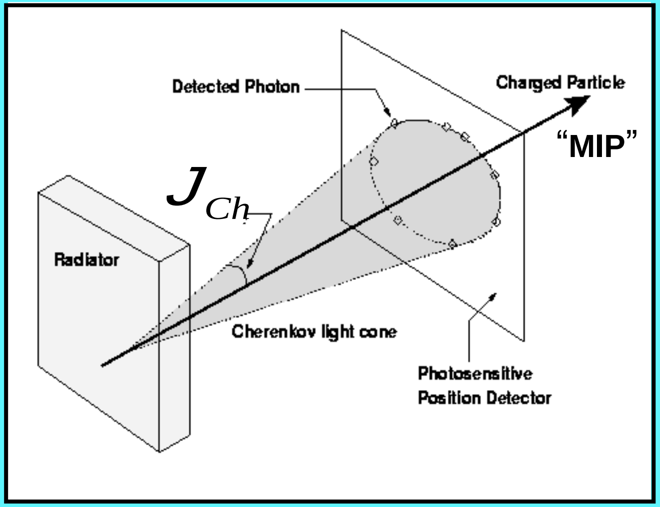
About the availability of the liquid Freon, Brian Kross, who built the Freon system told me that the Freon we used for 94-107 experiment is still vailable at the company that provided it last time. The money needed to be run for ~ 3 months would be ~10 KUSD, so no problems

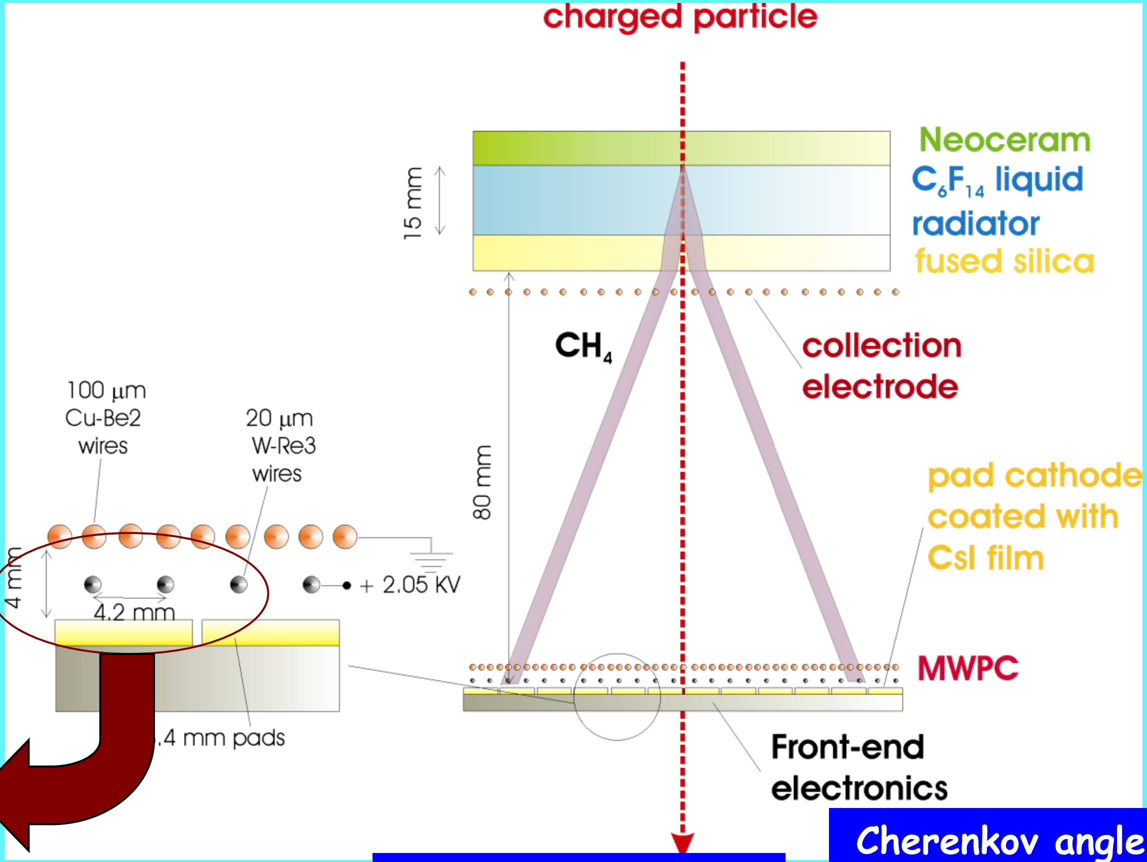
The existing RICH readout electronics is based on back-end VME modules which should facilitate the integration into the DAQ of the experiment (ha sbeen done also in the past transversity experiment).

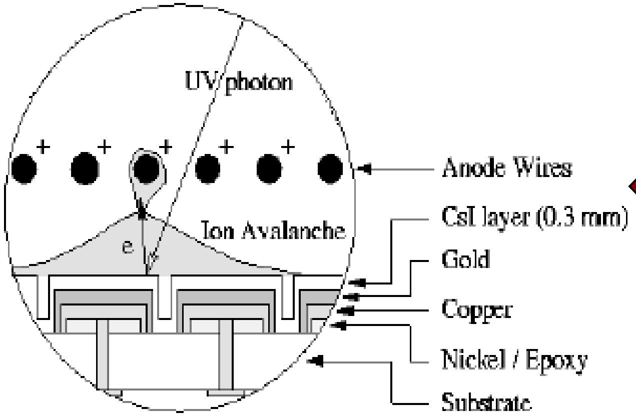
8. Backup lead targets will be needed in case of beam steering, raster or cooling problems.

We agree, we don't think this is an issue; we will contact Dave Meekins about that

RICH detector –C_6F_{14}/CsI proximity focusing RICH







Separation Power

$$n_\sigma \sim \sqrt{\frac{m_A^2 - m_B^2}{2\tan\theta_c\, p\, \sigma_\theta^r}}$$

$$- J_1 = n_s S_{J_c}$$

Cherenkov angle resolution

$$\sigma_{\vartheta_c} = \frac{\sigma_\vartheta^{p.e.}}{\sqrt{N_{p.e}}}$$

N. of detected photoelectrons

$$N_{p.e.} = 370 L \sin^2 \bar{J}_c \prod_i e_i DE \approx 20 - 50$$

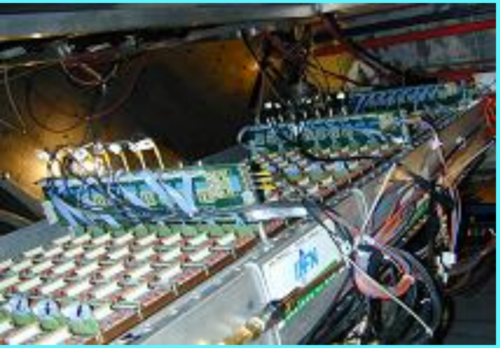
Performances

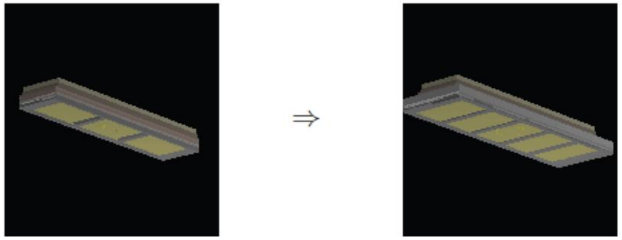
- $N_{p.e.}$ # of detected photons(p.e.) ← maximize
- and σ_θ (angular resolution) ← minimize

The RICH

RICH Detector

The RICH detector has been upgraded for the neutron Transversity experiment. Easy calculation show that the new layout would allow us to get an added factor of 10^6 as π/K rejection factor





Radiator	15 mm thick Liquid Freon (C_6F_{14}, n=1.28)
Proximity Gap	100→175 mm, filled with Methane at STP
Photon converter	300 nm CsI film coated on Pad Planes
Position Detector	3→5 × pad planes = 1940 × 403→2015 × 646 mm^2 Multi Wire/Pad Proportional Chamber, HV= 1050 ÷ 1100 V
Pad Plane	403.2 × 640 mm^2 (single pad: 8.4 × 8 mm^2)
FE Electronics	11520→19200 analog chs. multiplexed S&H

Fig. A1. Old and new upgrated RICH layout

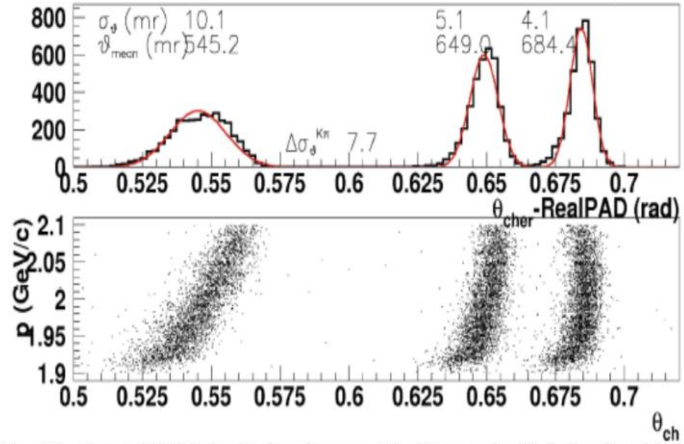


Fig. A3. Upgrated RICH simulated performance. Pion/Kaon angle distribution (equal hadrons populations) at 2 GeV/c momentum, in the HRS acceptance. The Mcarlo is tuned on Hall A hypernuclear experimental data.

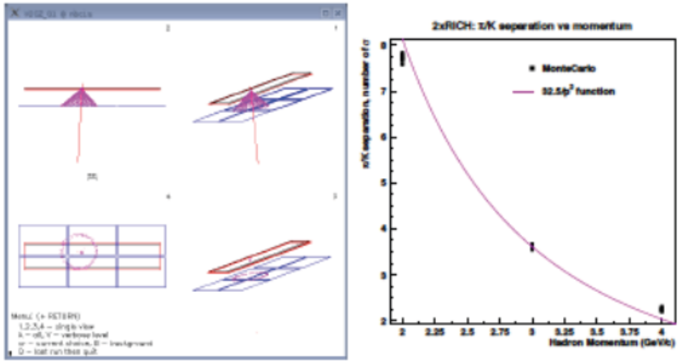


Fig. A2 Upgraded RICH simulation events (left panel) and expected performance (right panel): pion-kaon separation (number of sigmas) at different hadron momenta. The simulation is tuned to the E-94-107 hypernuclear experimental data.