Hypernuclei- Introduction and historical overview

Tullio Bressani
Dipartimento di Fisica Sperimentale, Universita' di Torino
Istituto Nazionale di Fisica Nucleare, Sezione di Torino

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Summary

1. Introduction

2. 1953÷1971: Visualizing techniques

3. 1972÷1980: First Counter Experiments

4. 1980÷~1990: Dedicated Facilities: Moby-Dick at BNL, K^-_{stop} at KEK

5. 1990÷now: Hypernuclear Factories: SKS at KEK, FINUDA at LNF, TJNAF

6. Other approaches

7. The case of S=-2 systems; counter+ visualizing techniques

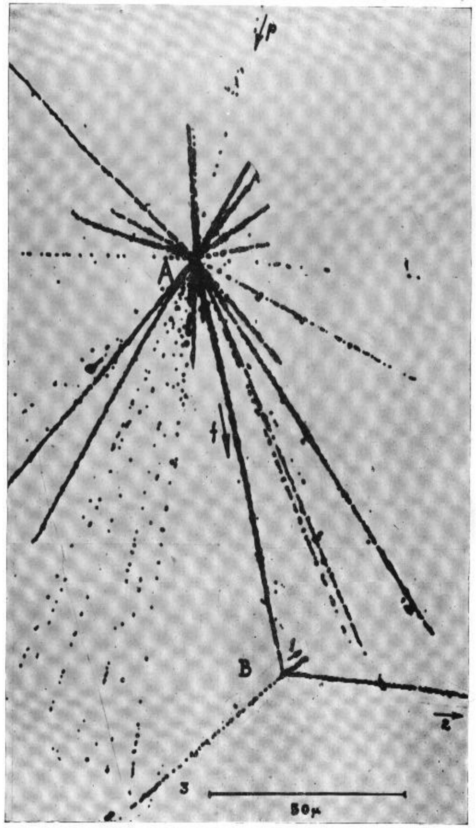
8. Conclusions

1. Introduction

1953: Birth of Hypernuclear Physics
Remember: 1947 first strange particle
1951 associated production
1953 concept of strangeness (Gell-Mann)

Description of the EXPERIMENTAL EFFORT
(no discussion of results, theories, …..)
→ other lecturers will do

Remarks by inside (some unpublished)



2. Visualizing Techniques

No much care of how Hypernuclei were produced

-Enough energy: cosmic rays (hyperfragments)
-K^- beams
-Detectors: emulsions, Bubble chambers (^{4}He, H.L.)

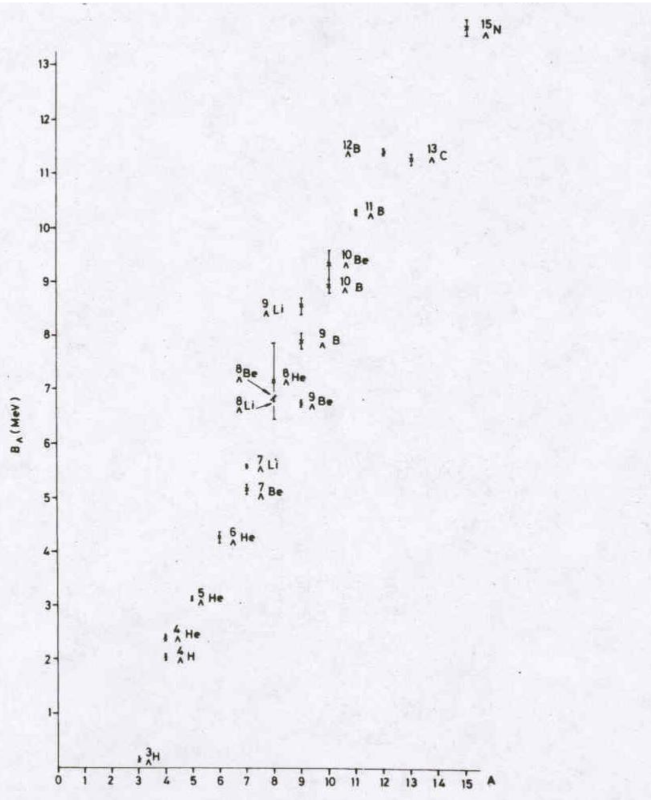
Mostly particle physics approach (I.M.)

A very good wealth of first round information

Very important theoretical support by Dalitz

- Existence of 19 Hypernuclei
- Observation of Mesonic
  and Non Mesonic Decays
- Observation of other related

observables (capt. rates, spectra of particles)



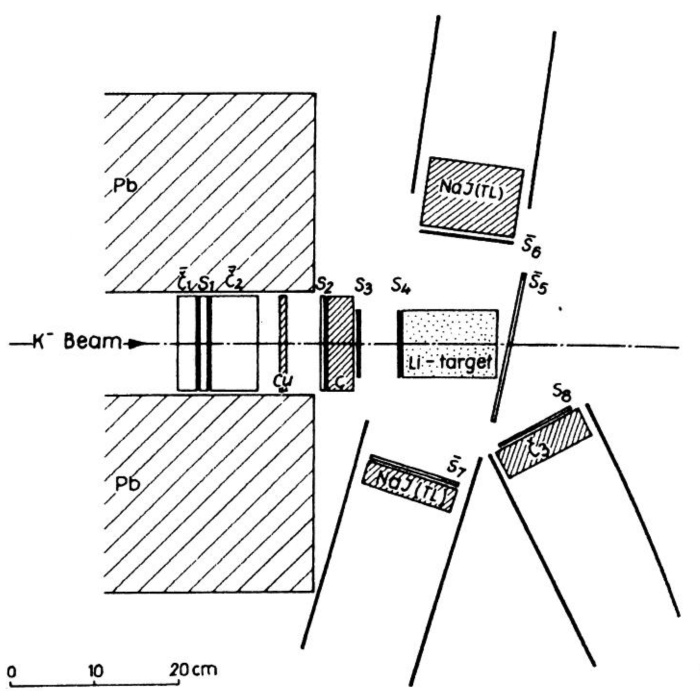
Limitation: statistics

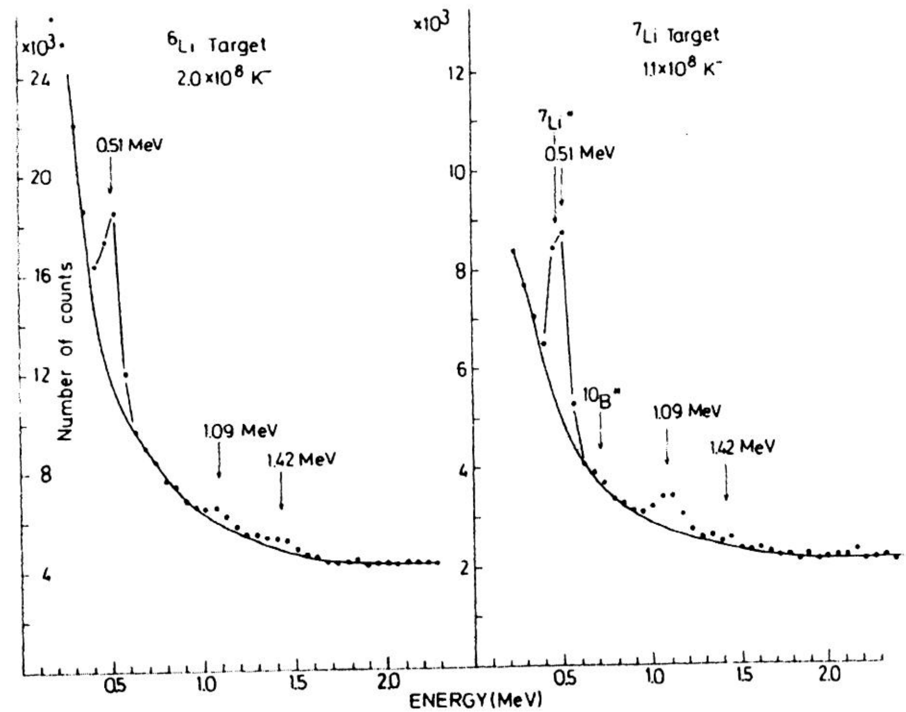
Advantage: fully reconstructed events, no acceptance corrections

Still now these data are important for planning or checking counter experiments

3. 1971-1990 First Counter Experiments

First Experiment with stopped K^-: γ spectroscopy (NaI(Tl))





A. Bamberger et al., PLB 36 (1971) 412

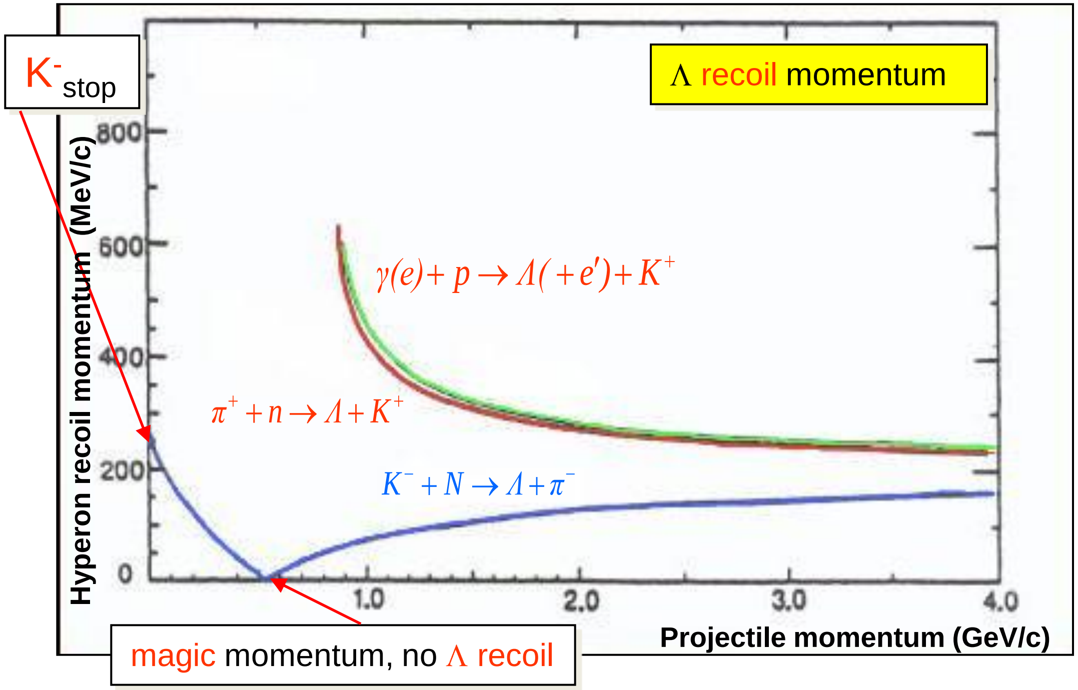
This result allowed the planning of better set-ups (~20 years later)
Curiosity: $^4_\Lambda$H and $^4_\Lambda$He γ –spectroscopy <u>never</u> repeated (planned for J-PARC)

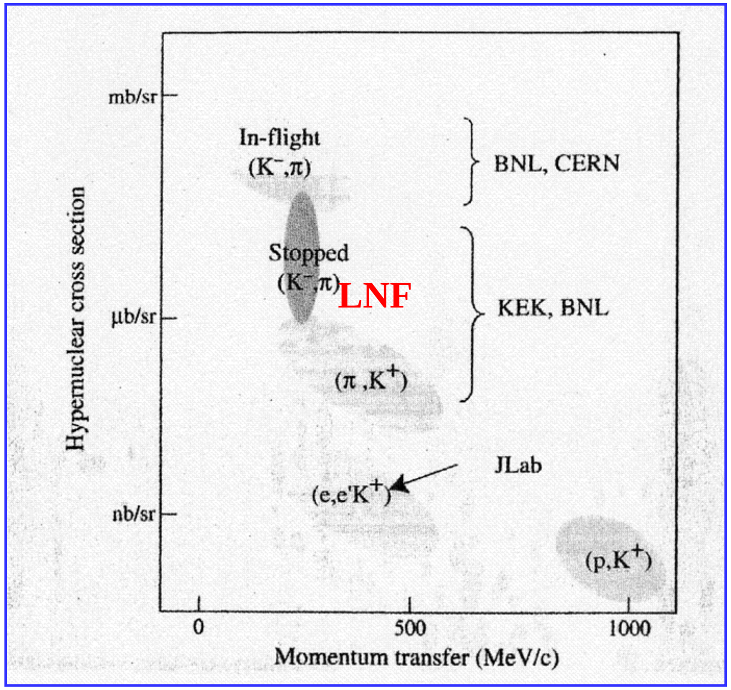
Two body reactions

1) $K^- + n \rightarrow \Lambda + \pi^-$

2) $\pi^+ + n \rightarrow \Lambda + K^+$

3) $\gamma + p \rightarrow \Lambda + K^+$ $(e + p \rightarrow e' + \Lambda + K')$

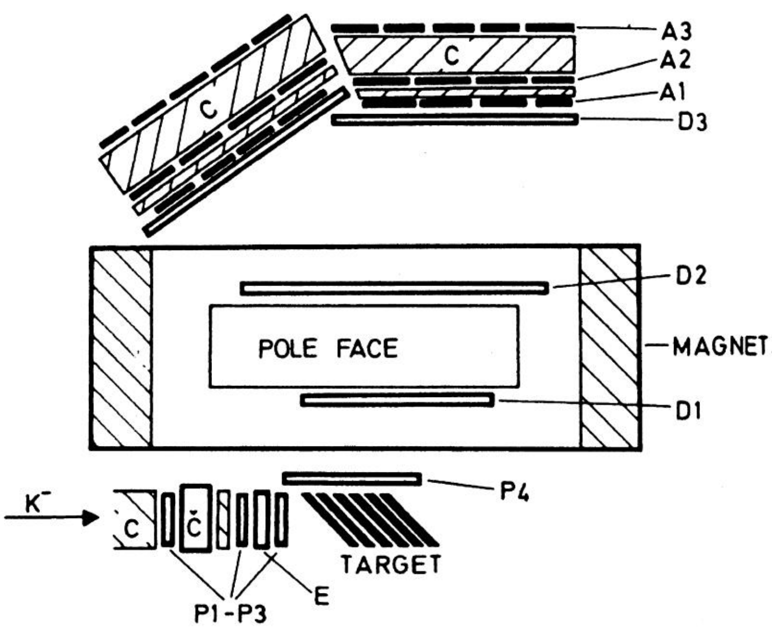




- Exclusive reactions
- Nuclear Physics approach
- Magnetic spectrometers
- First tools: non dedicated experiments/magnets with reaction 1)

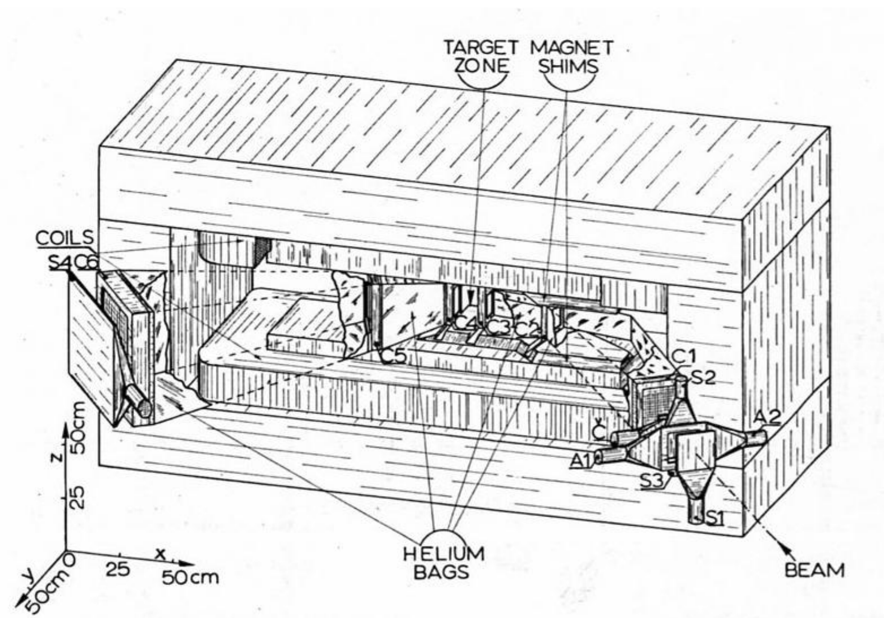
K^- stopped (CERN-Heidelberg-Wasaw)

Resolution: 6 MeV



K^- in flight (Torino)

Resolution: 6 MeV



Proof of the possibility of performing experiments (counting rates)

Experimentalist’s comment:

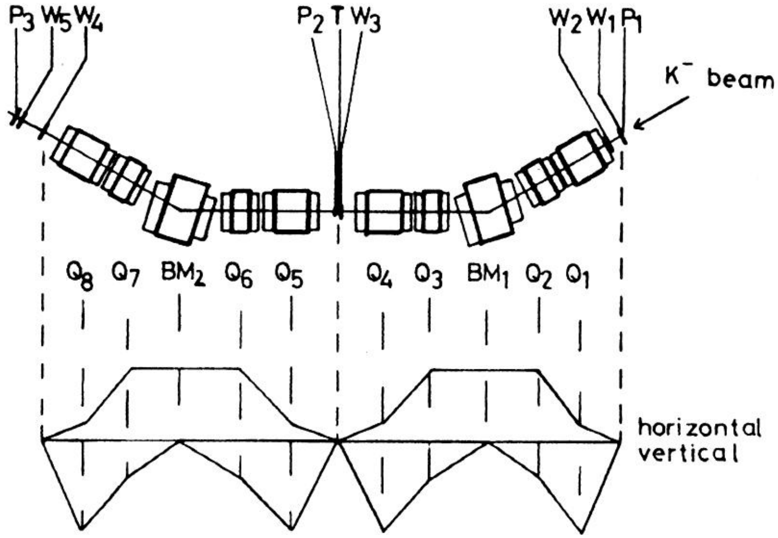
Detector/Electronics: performances at same level or sometimes better than now, but

Few channels: cost → Decrease of the cost/channel by 2-3 order of magnitude today

DAQ: poor…only a few channels

Beams: bad, very scarce enrichment in K^-

CERN-Heidelberg (K^-,π^-) in flight



"Focusing" spectrometer for both K^-, π^- built with existing elements of beam transport (not dedicated)

Better beam, low $\Delta\Omega$ (5 msr), low Δp

Resolution 5 MeV , low background, first systematics with first interesting results on <u>spectroscopy</u> of hypernuclei

-SPES2: first dedicated spectrometer for Hypernuclear Physics, large $\Delta\Omega$(~1 order of magnitude) (Saclay speciality), large Δp
Very clever device: magnets used till now at J-PARC!

First experiment at Saturne failed:
(p,p', K^+) due to overwhelming background and very low signal (not seen)

TOO MUCH CREDIT TO THEORETICIANS!

-Combination of K^- beam at CERN
and SPES2 (Heidelberg-Saclay-Strasburg Coll.)

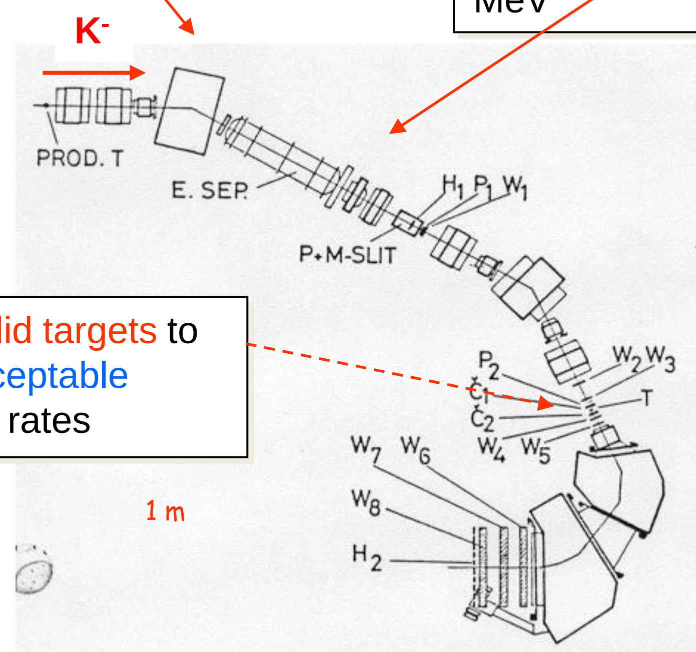
Very good compromise (reasonable Beam (El.Separator), reasonable $\Delta\Omega$, good Δp)

Resolution: 4MeV

Several meters from production target to the experimental area

High energy kaon beam 370 MeV

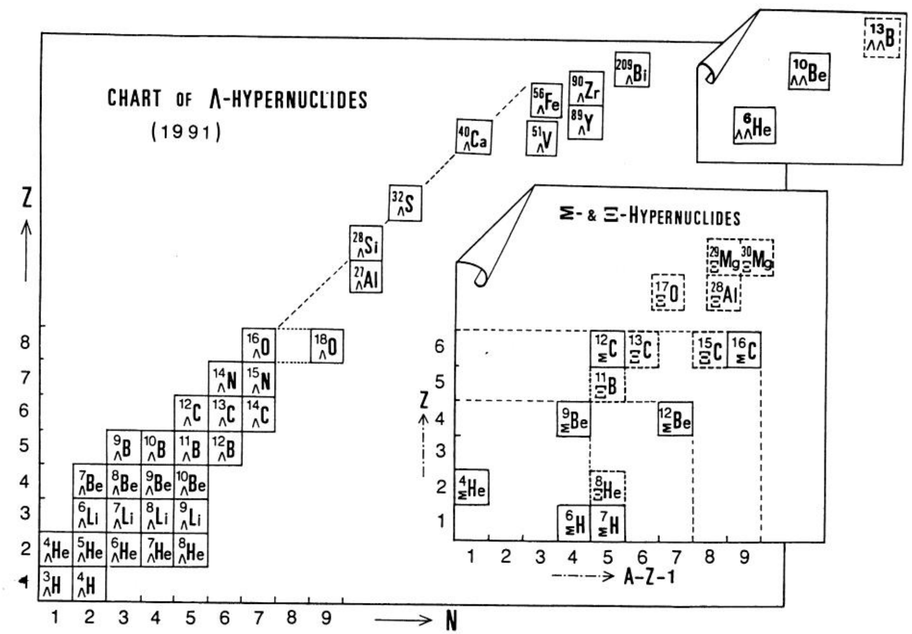
Thick solid targets to have acceptable counting rates



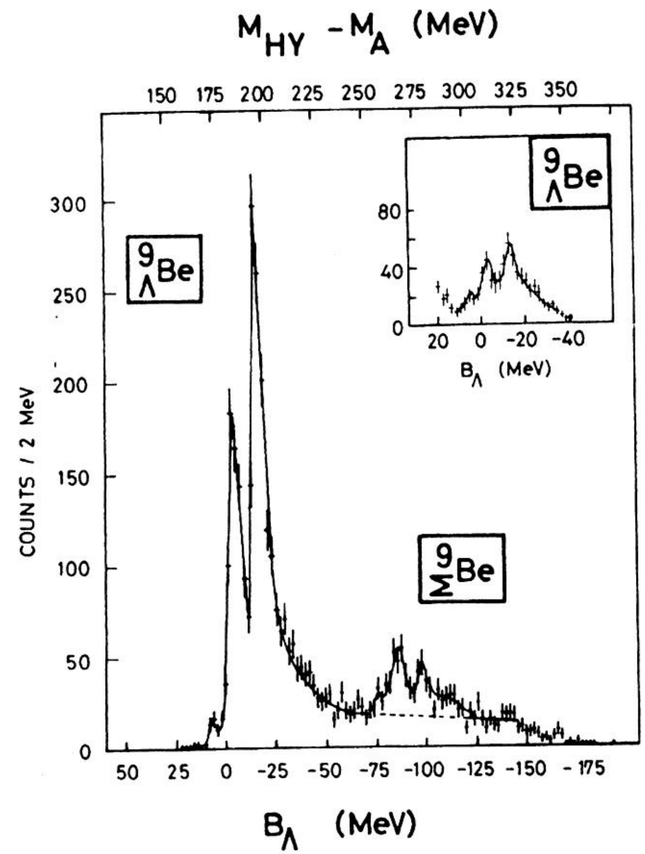
Very interesting results, improving the interest for Hypernuclear Physics

Unfortunately, at the end, a bad experimental artifact: Σ Hypernuclei

TOO MUCH CREDIT TO EXPERIMENTALISTS!



H. Bandō, T. Motoba and J. Žofka in Perspectives of Meson Science(1992)



R. Bertini et al., PLB 90 (1980) 375

4. 1980-~1990 Dedicated Facilities: Moby-Dick at BNL, K^-_{stop} at KEK

Moby-Dick at BNL: Fully dedicated set-up (Beam, Spectrometer, Detectors)

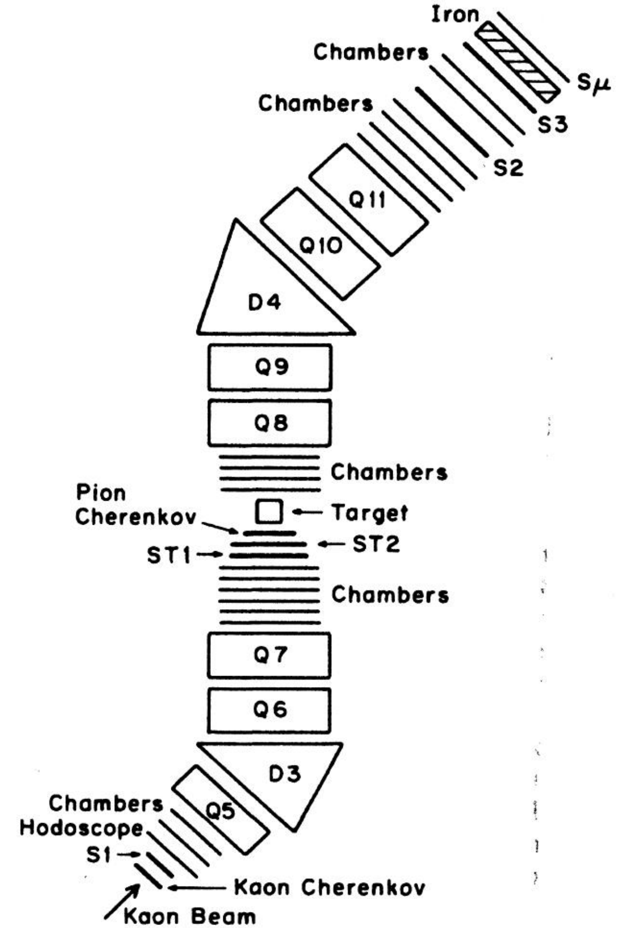
Resolution: 3 MeV

Pionereed all the experimental tecniques adopted by the following factories (SKS)

-first assessement of the usefulness of the (π^+,K^+) reaction to produce Hypernuclei in ground state

-first measurement of Weak Decay Products in coincidence

-no existence of Σ–Hypernuclei (with the exception of $^4_\Sigma$He)



Weak points:

-not enough machine time (BNL management)→no systematics

-$\Delta\Omega$ not enough large for statistics in coincidence measurement

-Δp limited

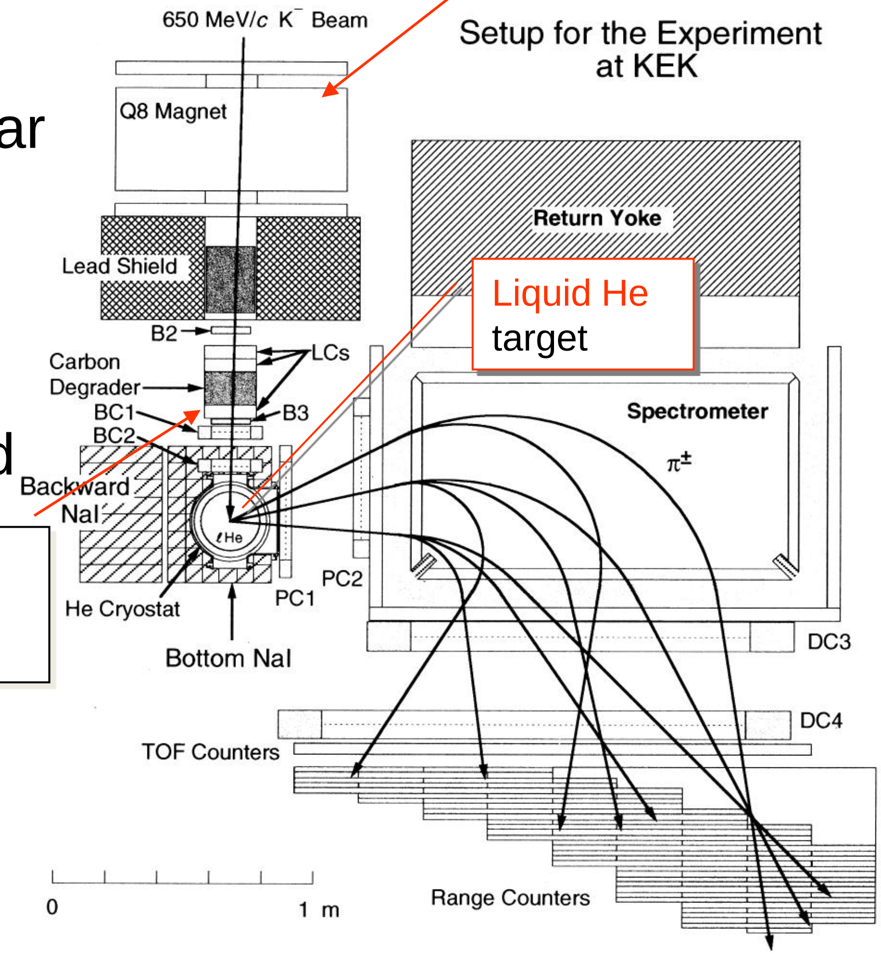
K^-_{stop} at KEK

Revival of experiments with stopped K^-

Spectroscopy:
Importance of formation of hypernuclear ground states

Pionereed the experimental tecniques adopted by subsequent factories (FINUDA), mainly physical background subtraction $K^-(np) \rightarrow \Sigma^- p$

High energy kaon beam 280 MeV



Liquid He target

Thick degraders to stop high energy kaons

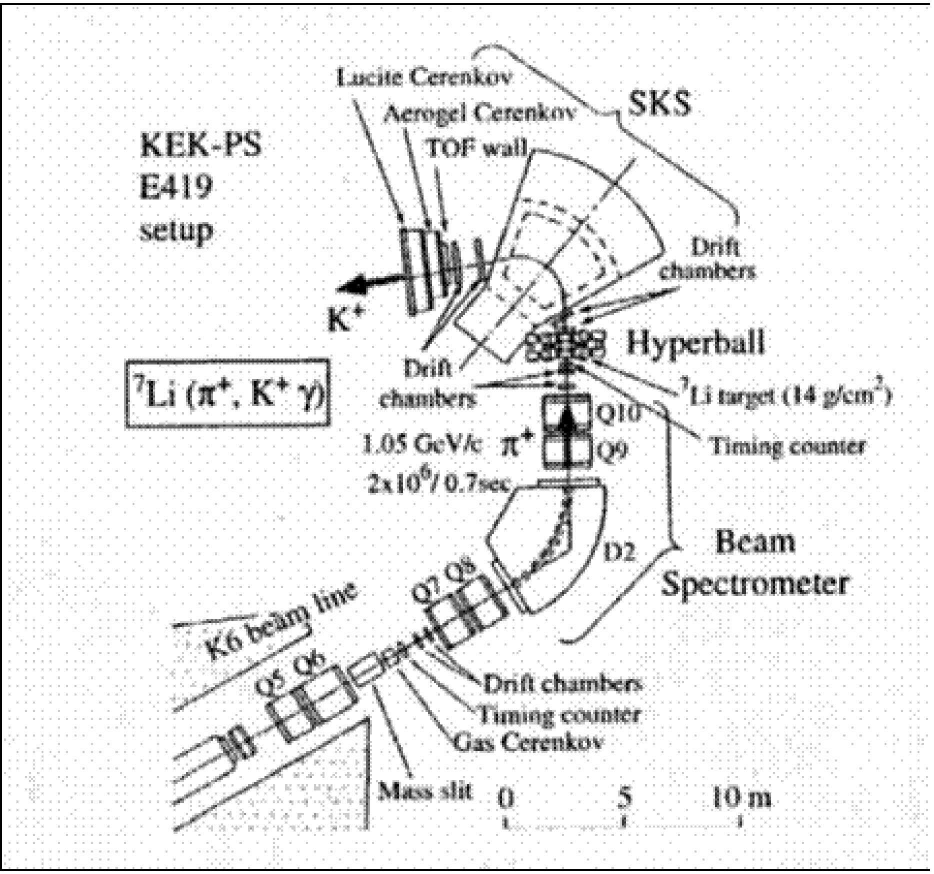
Boosted the interested of the Japanese community for Hypernuclear Physics

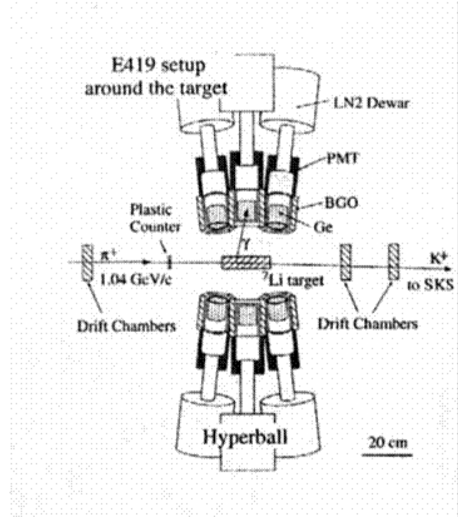
-Weak points:

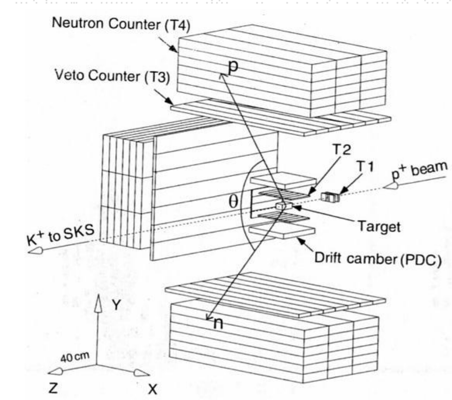
Stopped K^- source

Capture rates (good only for p-shell Hypernuclei)

5. 1990÷now Hypernuclear Factories: SKS at KEK, FINUDA at LNF, TJNAF







SKS (KEK)

Very good combination of beam (π^+,K^+) and Spectrometer:
$\Delta\Omega \cong 100$ msr
Resolution: 1.5 MeV

Large unbstructed space for installation of detectors (Hyperball for γ-spectroscopy, range counters for protons and neutron counters (T.O.F.) for WD studies)

Achievement

-systematics of Hypernuclei over the full Periodic Table (clear evidence of the hypernuclear single particle states)

γ–spectroscopy in coincidence with the formation of low-lying hypernuclear states

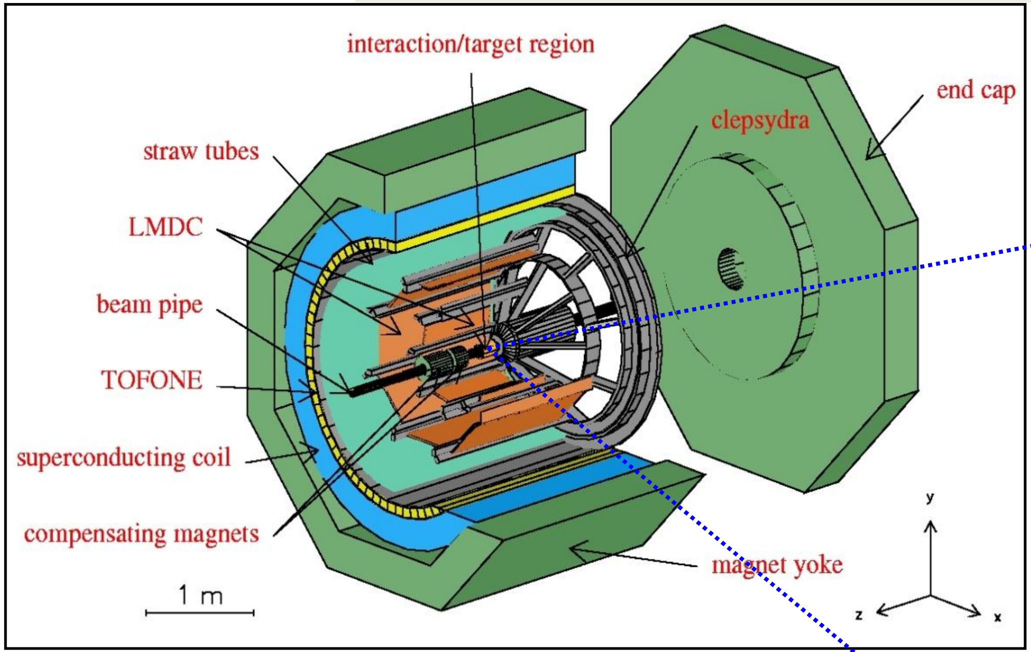
Very interesting results from the p-shell

- selected cases for NMWD studies

Γ_n/Γ_p puzzle solution

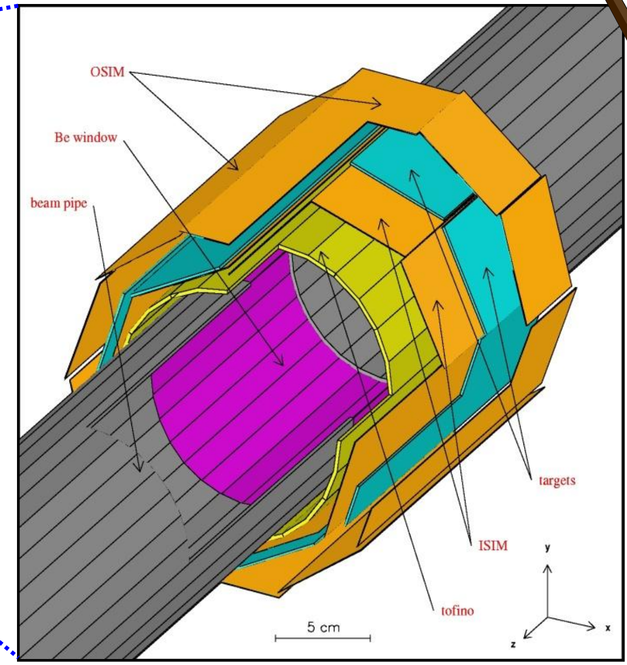
-No strong drawbacks

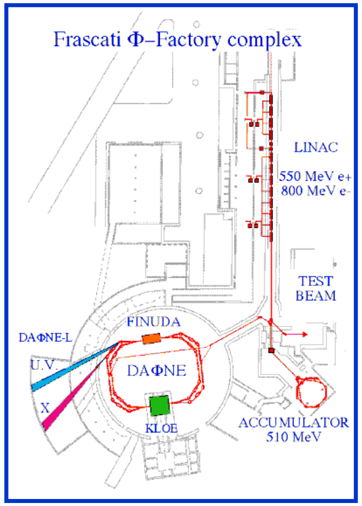
FINUDA @ DAΦNE



$$e^- + e^+ \to \phi \to K^- K^+$$

$$K^-_{stop} + {}^{A}Z \to {}^{A}_{\Lambda}Z + \pi^-$$



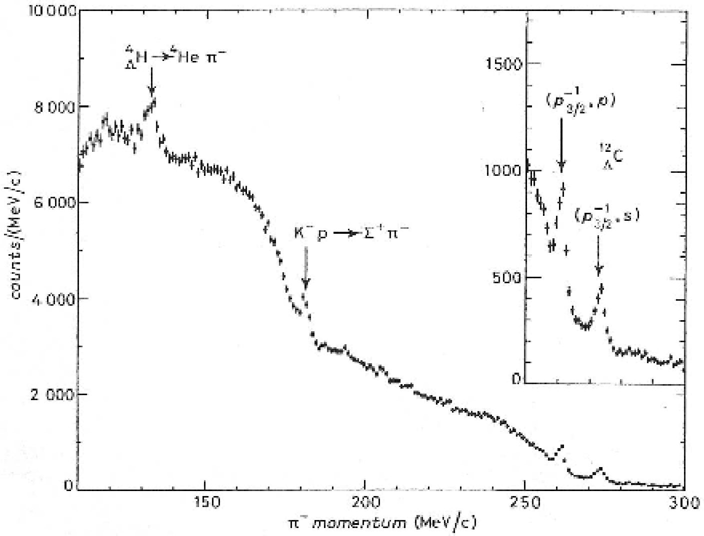


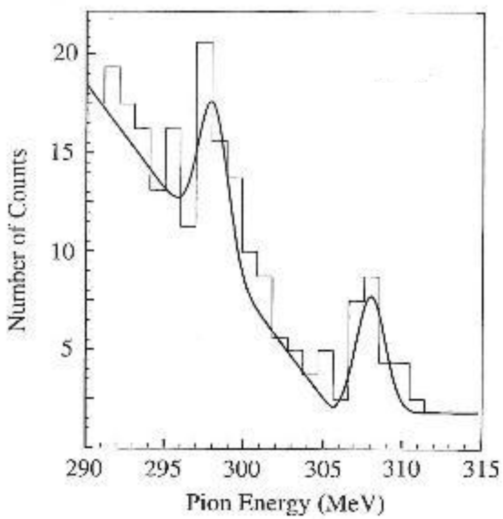
energy	510 MeV
luminosity	5 10^{32} cm^{-2} s^{-1}
σ_x (rms)	2.11 mm
σ_y (rms)	0.021 mm
σ_z (rms)	35 mm
bunch length	30 mm
crossing angle	12.5 mrad
frequency (max)	368.25 MHz
bunch/ring	up to 120
part./bunch	8.9 10^{10}
current/ring	5.2 A (max)

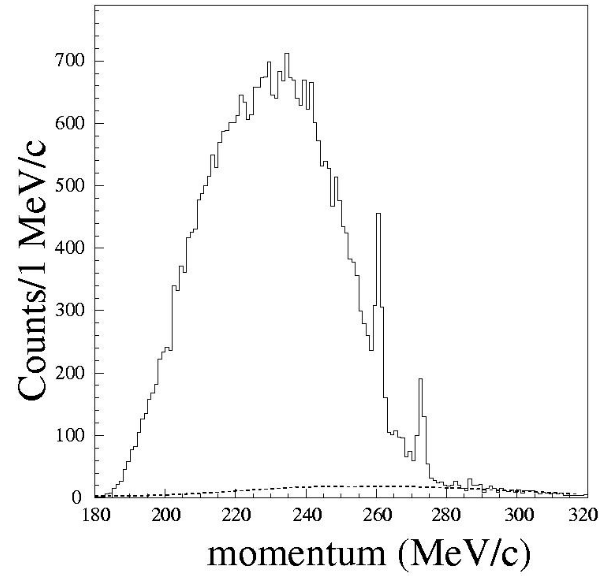
$${}^{A}_{\Lambda}Z \to \begin{cases} {}^{A}(Z+1) + \pi^- \\ {}^{(A-2)}(Z-1) + p + n \\ {}^{(A-2)}Z + n + n \end{cases}$$

Last evolution of the K^-_{stop} approach

Φ-Factory → Source of Low Energy K^- (~16 MeV) – Thin targets





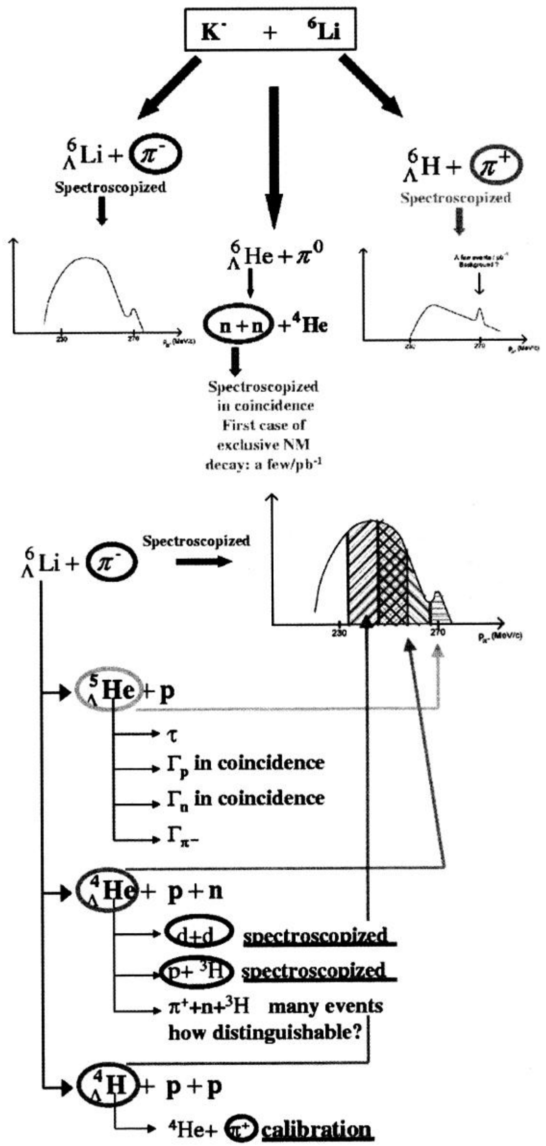


Resolution: 1.3 MeV

Large ΔΩ: 2π sr for formation $K^-_{stop} + {}^AZ \to {}^A_\Lambda Z + \pi^-$

and decay……. $\to \pi^-$, p, ……

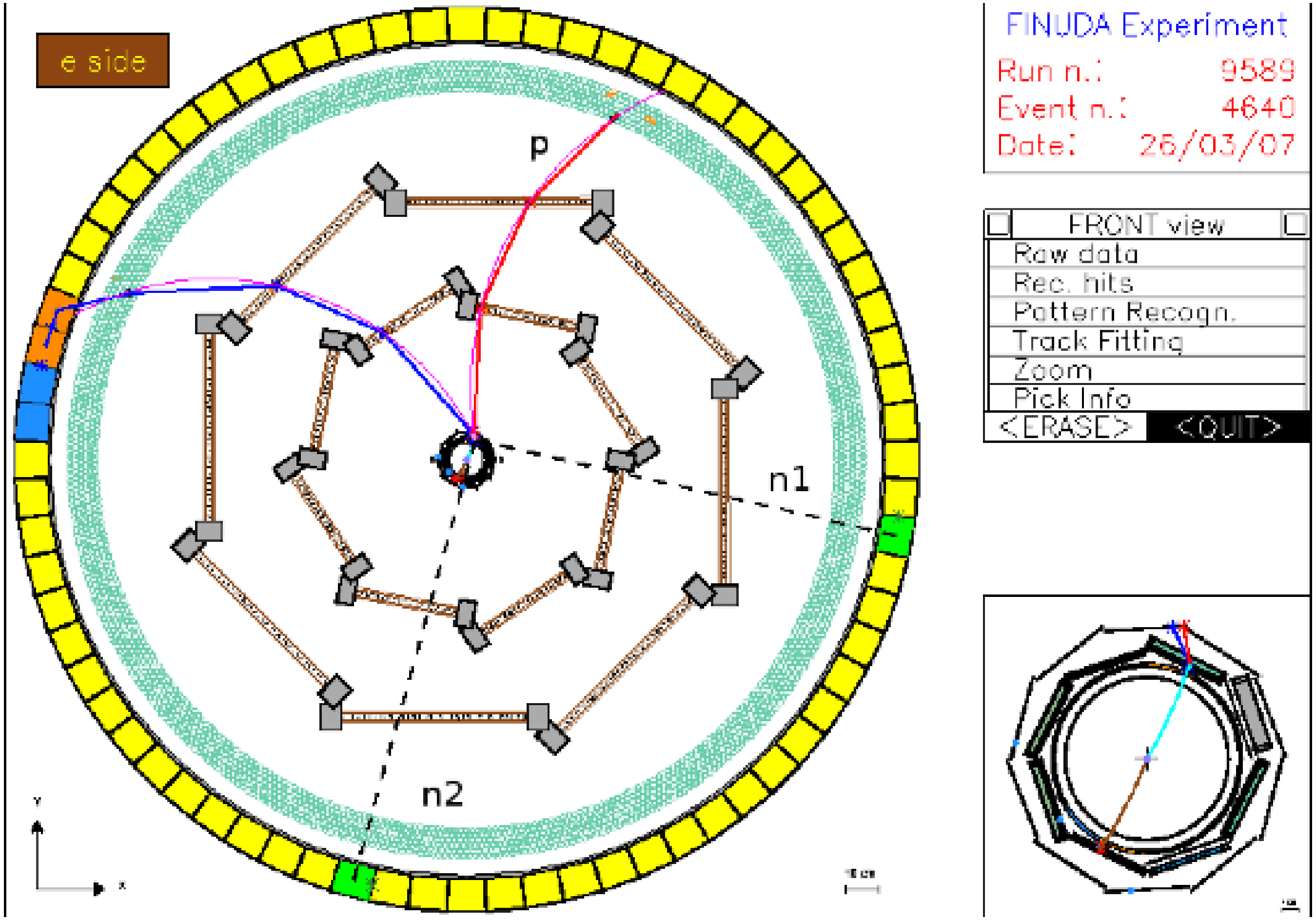
Large Δp



With many charged and neutral particles in coincidence

Up to 8 targets at the same time

Detector more close to visualizing tecniques



$p_{\pi-}$ = 276.93 MeV/c
E_{tot} = 178.3 MeV
Q-value = 167 MeV
p miss = 216.6 MeV/c

E(n1) = 110.2 MeV
E(n2) = 16.9 MeV
E(p) = 51.0 MeV

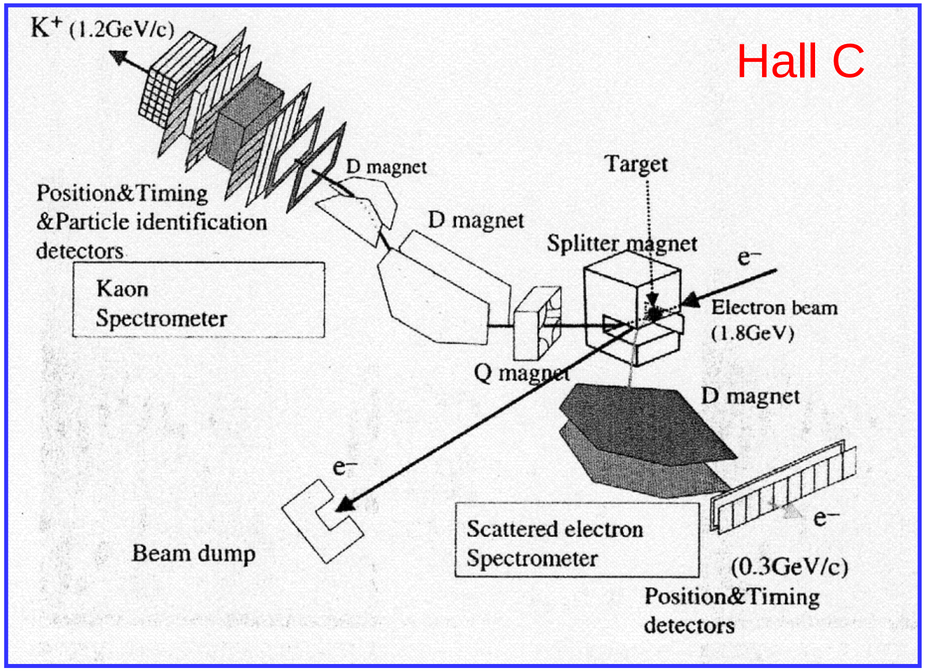
θ(n1 n2) = 95°
θ(n1 p) = 102°
θ(n2 p) = 154°
no n-n scattering

Achievements: Spectroscopy of π^- from MWD in the p-shell
: Spectroscopy of p from NMWD in the p shell
:2N-induced NMWD
:K^- nuclear clusters

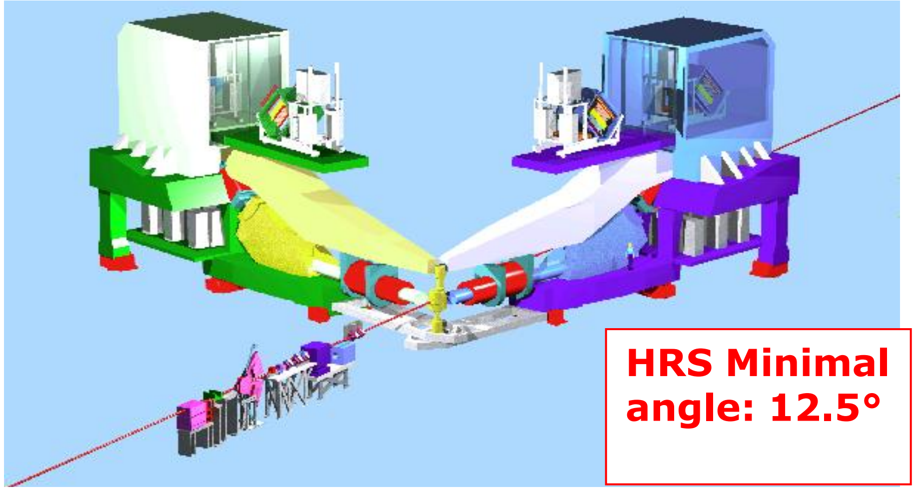
Drawback: Beam time (LNF management)

Electroproduction at TJNAF

Two large two-arm spectrometers in Hall A and Hall C
Experiments with electron beams and coincidence requirements
only possible at machines with high D.C. (CEBAF)
Cross section: low
Incident beam: excellent (ΔE, intensity)
$\Delta\Omega$ of the spectrometer: adequate for spectroscopy, not so much for MD studies



Hall A



HRS Minimal angle: 12.5°

Best resolution achieved with magnetic spectrometers: 0.6 MeV

6. Other approaches

$\bar{p}$ (CERN): delayed fission (lifetime of heavy hypernuclei)
p (COSY): same
Light ions (Dubna Nuclotron): lifetime of light hypernuclei
: search for neutron rich hypernuclei

Dedicated specific experiment: no systematics

(K^-_{stop}, π^0) at BNL
Considerable hopes: mirror hypernuclei in p-shell
Modest result: only $K^-_{stop} + {}^{12}C \rightarrow {}^{12}_{\Lambda}B + \pi^0$
Resolution: ~3 MeV
Rate: very low
Thick stopping target: huge physical background
Difficult to operate a herited spectrometer without some of the builders!

7. The case of S=-2 system

2(?) Events found in emulsion, ~10 years later than Λ-hypernuclei

Very strong interest: $\Lambda-\Lambda$ interaction, H-particle

First Counter experiments: failed, due to overwhelming background

Hybrid experiments: counter + emulsions: successfull in finding some "clean" events (5÷8)?

1 event in principle contains all information

8. Conclusion

Good luck to younger fellows