1997

Bemerkungen zu einem Hochenergie-Experimentierspeicherring Projekt bei GSI

Paul Kienle, Physik-Department E12, TU München

Im Zusammenhang mit den Ausbauplänen der GSI wird ein 200 Tm Hochenergie-Experimentierspeicherring HESR vorgeschlagen, der zusammen mit einem 100 Tm Synchrotron SIS 100 eine neue Experimentiereinrichtung ergäbe, die einmalige Experimente zur Untersuchung der Struktur und Dynamik von Hadronen mit schweren Quarks (s,c), verdichteter und erhitzter hadronischer Materie und der Struktur von neutronenarmen und -reichen Kernen erlauben würde.

⋮

Zur Physik am HESR

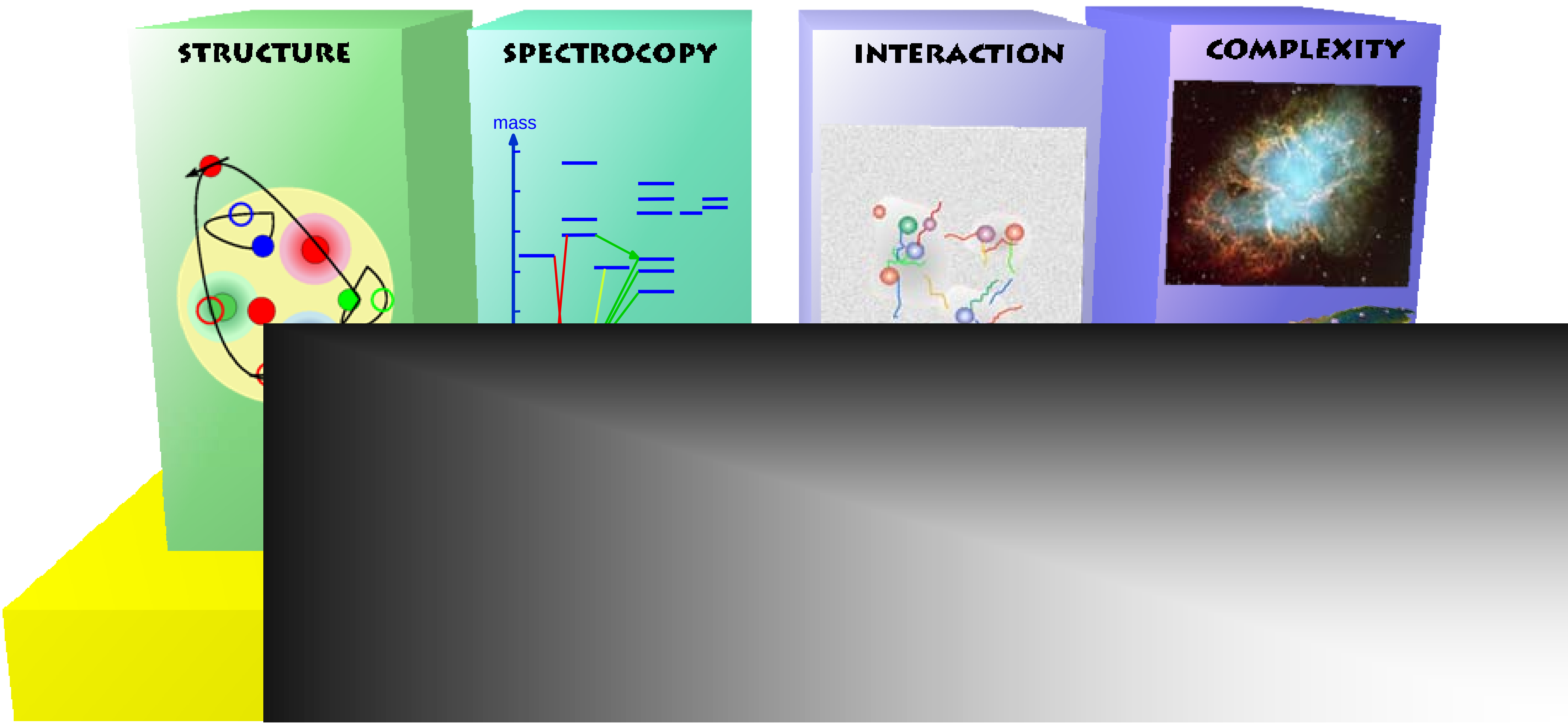
Mögliche Physikprogramme schließen Experimente ein, die im Rahmen des LISS-Projekts und früher für SuperLEAR diskutiert wurden. Die höhere Energie des HESR im Vergleich zu LISS und SuperLEAR, die Hochenergie-Elektronenkühlerausstattung, die Verfügbarkeit von Schwerionenstrahlen und von SIS 100-Sekundärstrahlen lassen darüber hinaus ein wesentlich breiteres Experimentierprogramm zu.

Pillars of QCD

Martin J. Savage:

"The first lattice QCD calculation of the deuteron will be a milestone for nuclear physics."

hep-lat/0509048



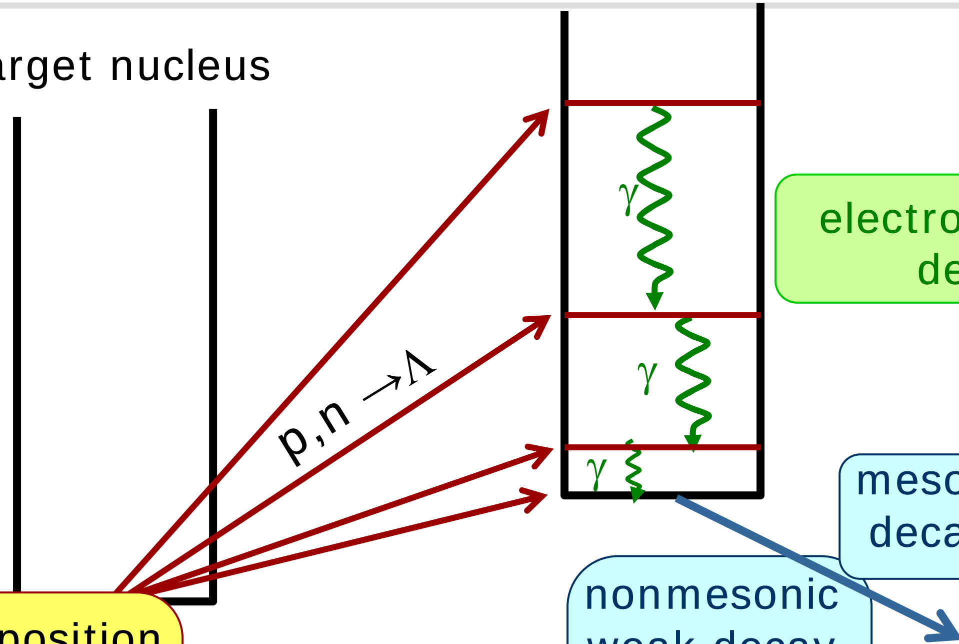
HYPER-NUCLEI IN PANDA

- SHOPPING LIST OF HYPERNUCLEI
- DOUBLE HYPERNUCLEI IN PANDA
- SOME MORE THINGS

Sixth Framework Programme

Bundesministerium für Bildung und Forschung

Birth, life and death of a hypernucleus



electromagnetic decays

mesonic decays
$\Lambda \rightarrow p\pi^-$
$\Lambda \rightarrow n\pi^0$

nonmesonic weak decay
$\Lambda p \rightarrow np$
$\Lambda n \rightarrow nn$
$\Lambda\Lambda \rightarrow YN$

hadronic decay in emulsion

strangeness deposition
$e^+ + e^- \rightarrow \Phi \rightarrow K^+ + K^-$
$K^-_{stopped} + {}^A Z \rightarrow {}^A_\Lambda Z + \pi^-$
FINUDA

strangeness production
(π^+, K^+), (π^-, K^0)
BNL,KEK

strangeness exchange
(K^-, π^-) ,(K^-, π^0)
BNL,KEK,JPARC

electroproduction
$(e,e'K^+)$, (γ,K^+)
Jlab, MAMI-C

energy resolution
- K,π: 1-2 MeV
- $K_{stopped}$: 1 MeV
- e: 0.5 MeV
- γ-transitions: 5 keV

Physics of Hypernuclei

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- specific aspects baryon-baryon weak interactions
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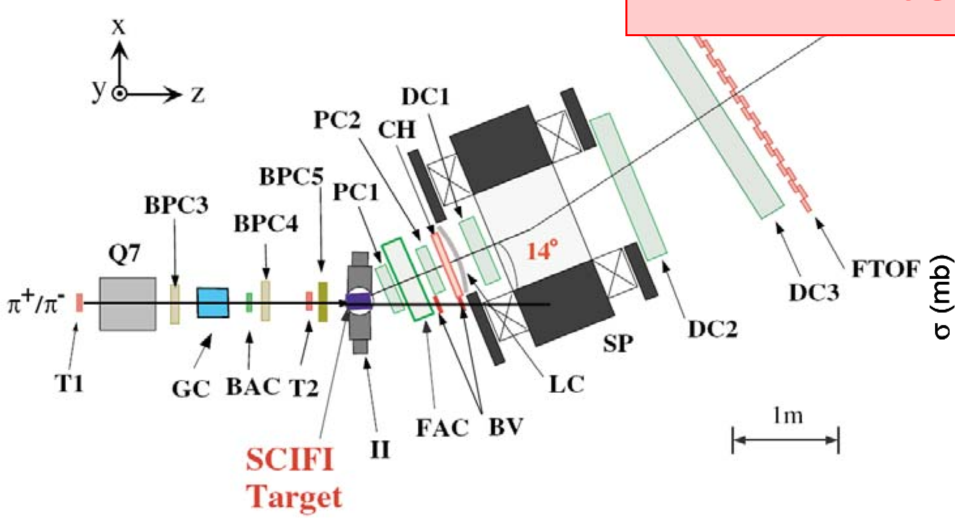
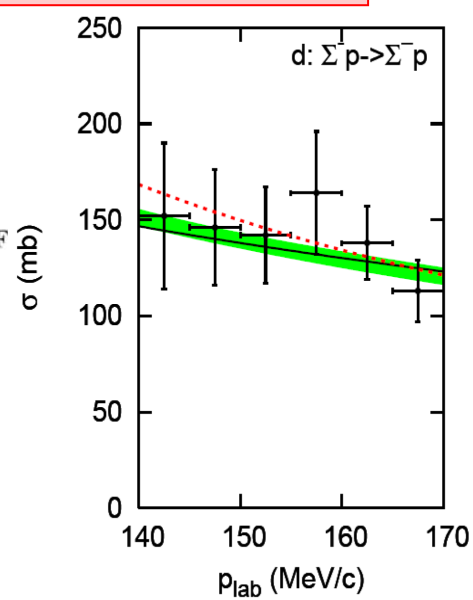
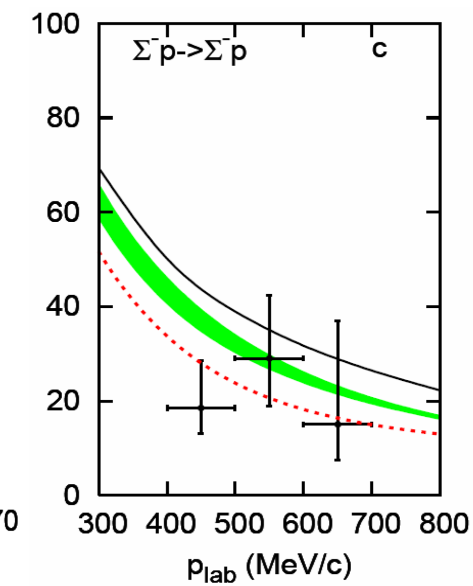
Exp. Approaches to Y-N interactions

- low energy baryon-baryon scattering
  - N-N: ~10^4 data points available
  - for hyperons only very few elastic data ≲(≳)300MeV/c
    - Λ-p→Λ-p: 12 (10) Σ^+-p→ Σ^+-p: 4 Σ^--p→ Σ^--p: 9 (3)
  - spin averaged → can not access LS or SS coupling
  - usually low statistics
    - Σ^-p: KEK-PS E289 (π^-,K^+) ⇒ 30 events
    - Σ^+p: KEK-PS 2 … 31 events each
    - Ξ^- p: (K^-,K^+) … 1 candidate

not practical for Y-Y interaction!





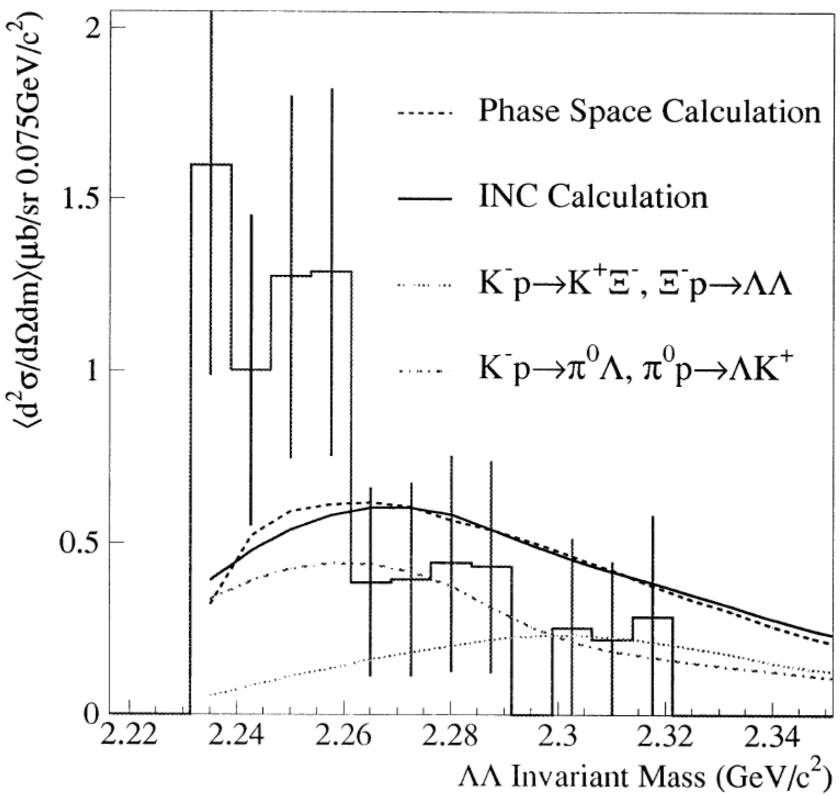


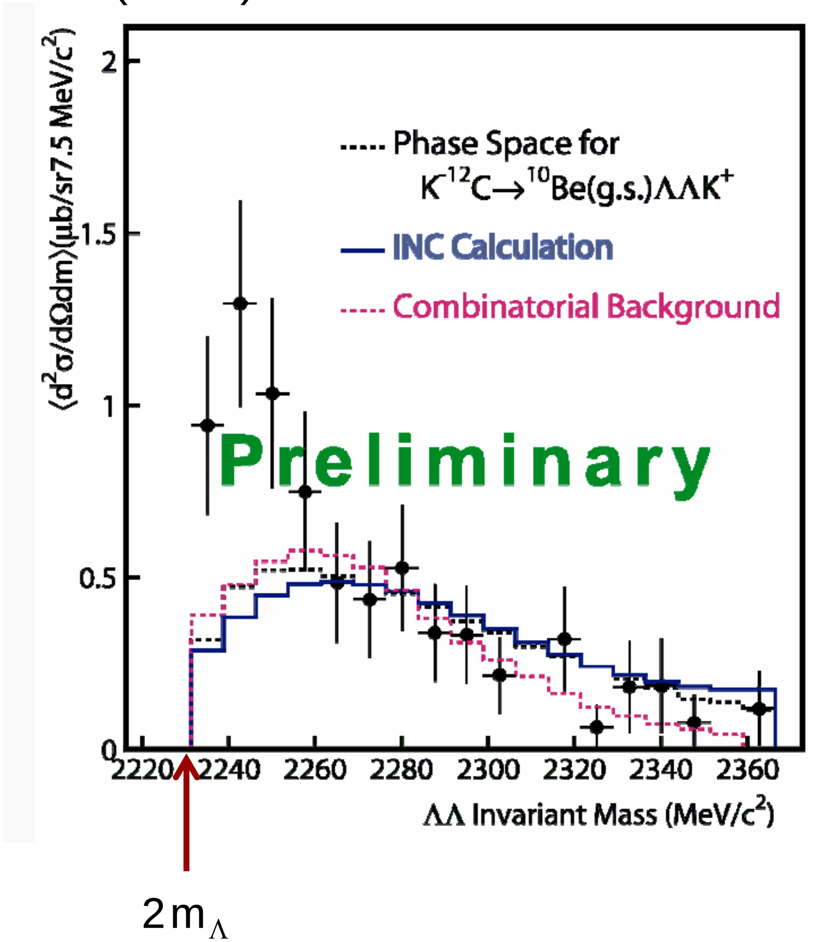
- JPARC: ~1000 events/day

Polinder, Haidenbauer, Meißner 2006

Λ-Λ Final state interaction

- hyperon-hyperon final state interaction via ΛΛ invariant mass
  - KEK-PS E224, Physics Letters B 444, 267 (1998)
  - KEK-PS E522: K.Nakazawa *PS-Review* (2004)

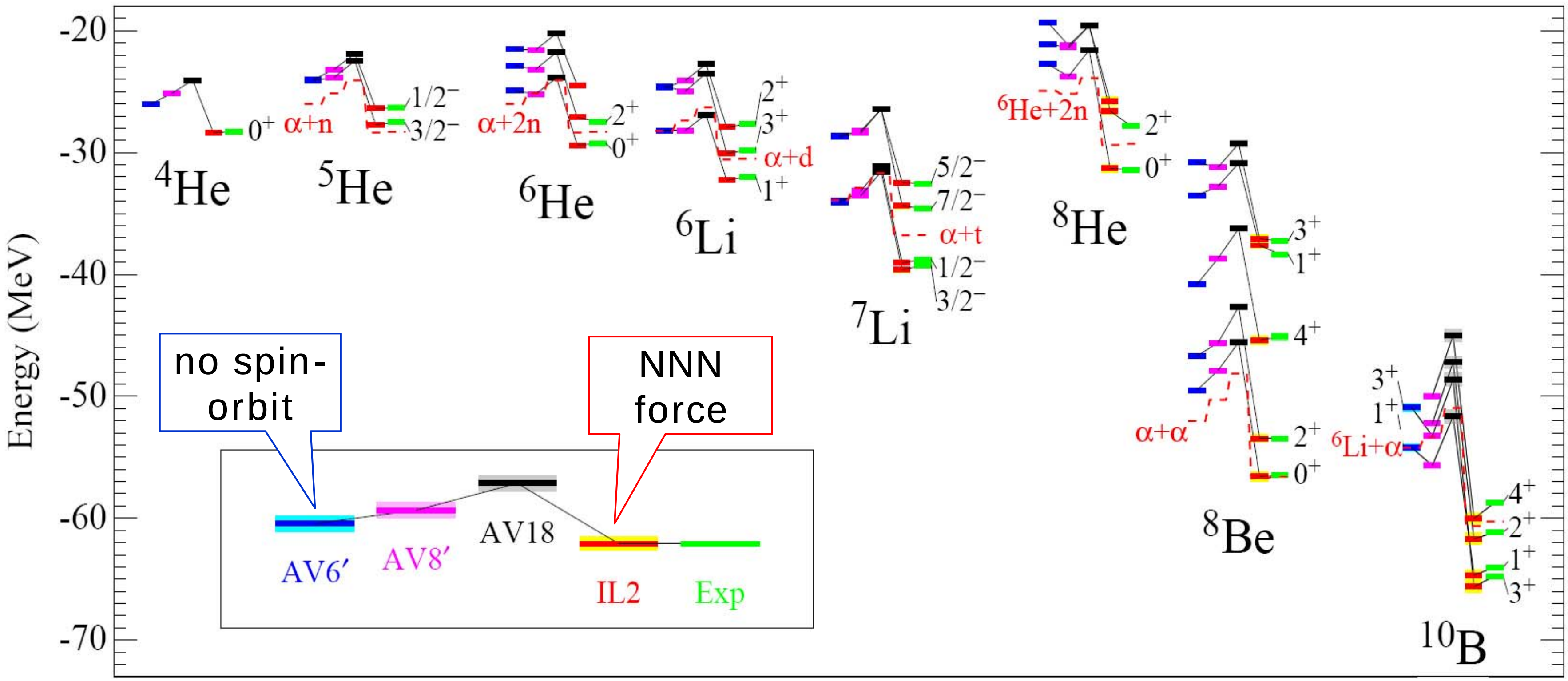




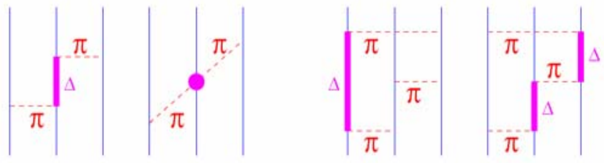
- feasible but difficult to interpret (rescattering, size,...)

Understanding Nuclear Structure

- Steven Stephen C. Pieper *et al*., 2002
- potentials with increasing complexity

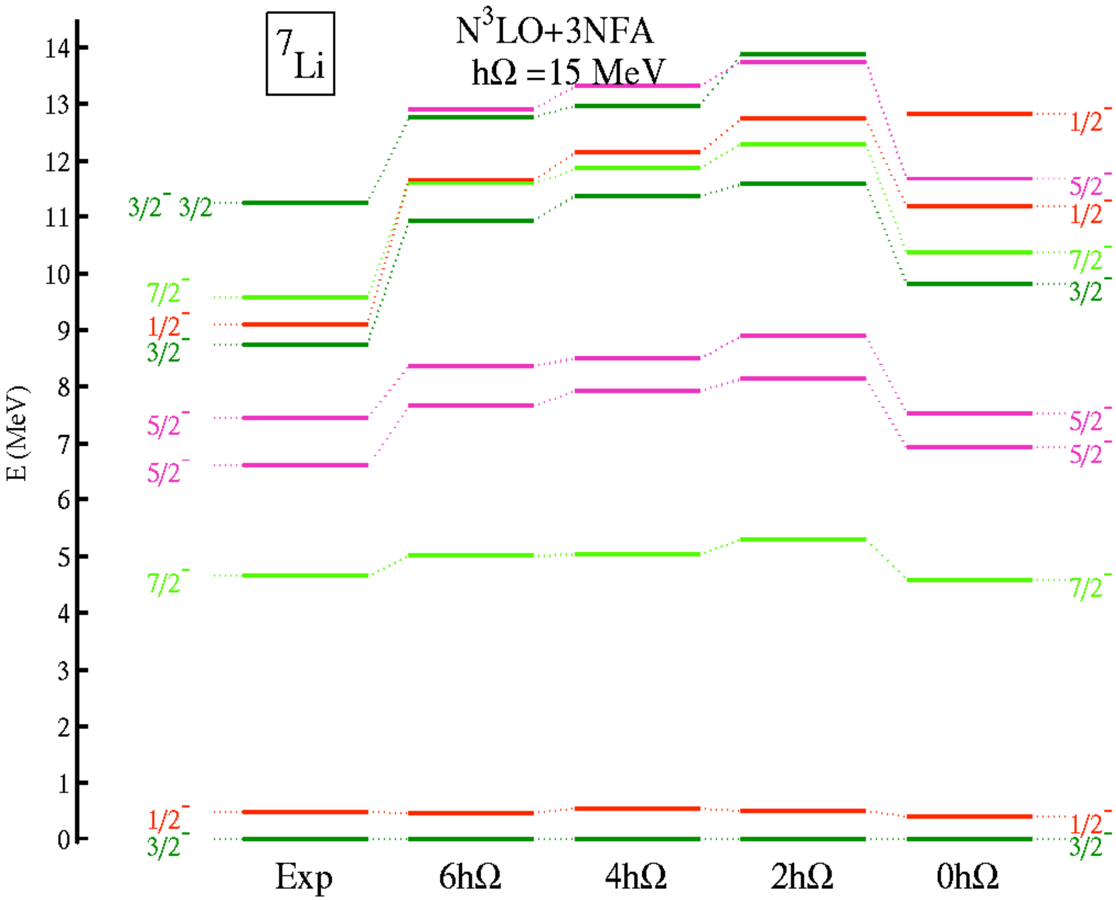


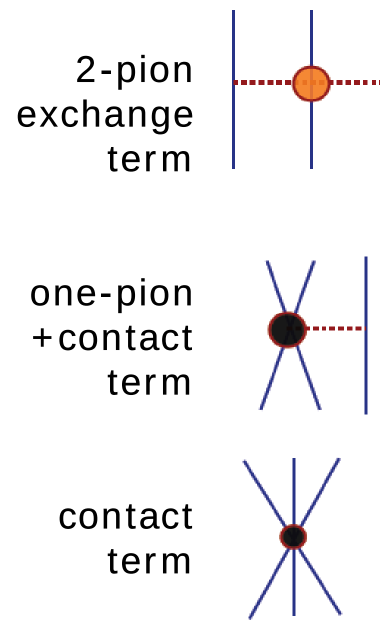
- spin-isospin and tensor forces present in long-range one-pion-exchange are essential
- multi-nucleon forces are vital
- sub-MeV precission (~3 parameters only)



Nuclear spectra in χEFT

- great progress in recent years
  - e.g. Petr Navratil *et al.* (2005)
  - *consistent* (same cutoff parameter Λ) treatment of NN (N^3LO) and NNN force (N^2LO; from fit to ^3H and ^4He binding energies)





- no hypernuclei yet, but work in progress (N. Kaiser, Paolo Finelli...)

Physics of Hypernuclei

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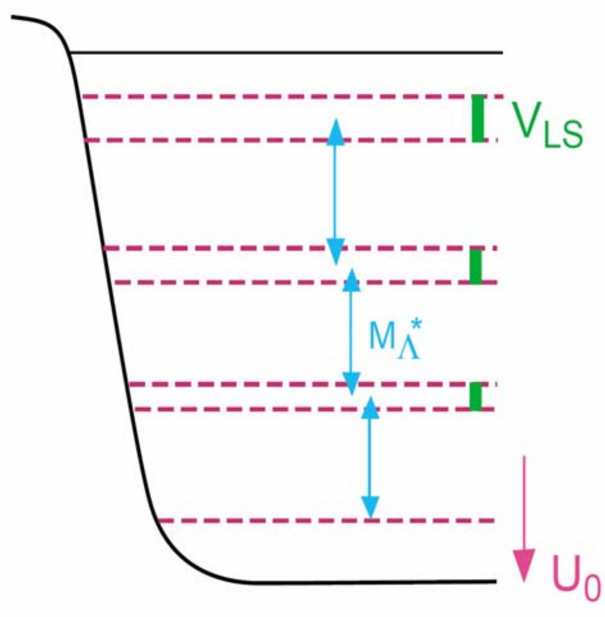
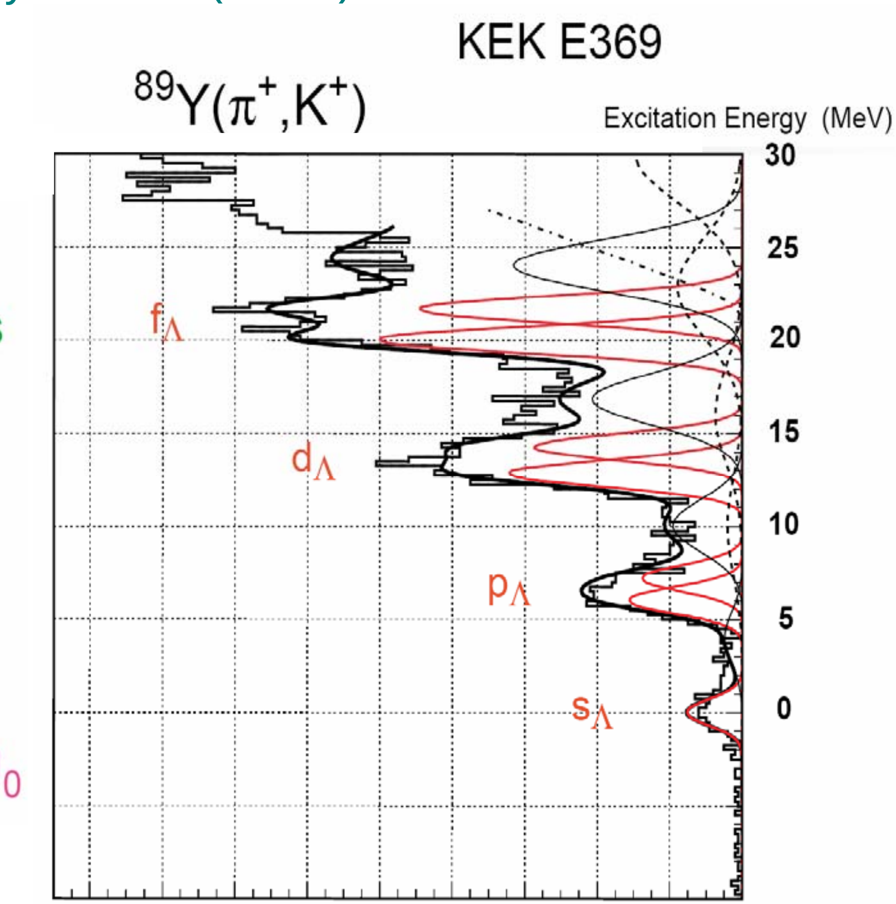
Λ Potential in Nuclei

- in normal nuclei: strong spin-orbit interaction (~5MeV for light nuclei) needed to explain shell structure
  - Haxel, Jensen, Suess and Goeppert-Mayer (1949)
- origin still unclear
  - see e.g. N. Kaiser, Nucl. Phys. A709 (2002) 251

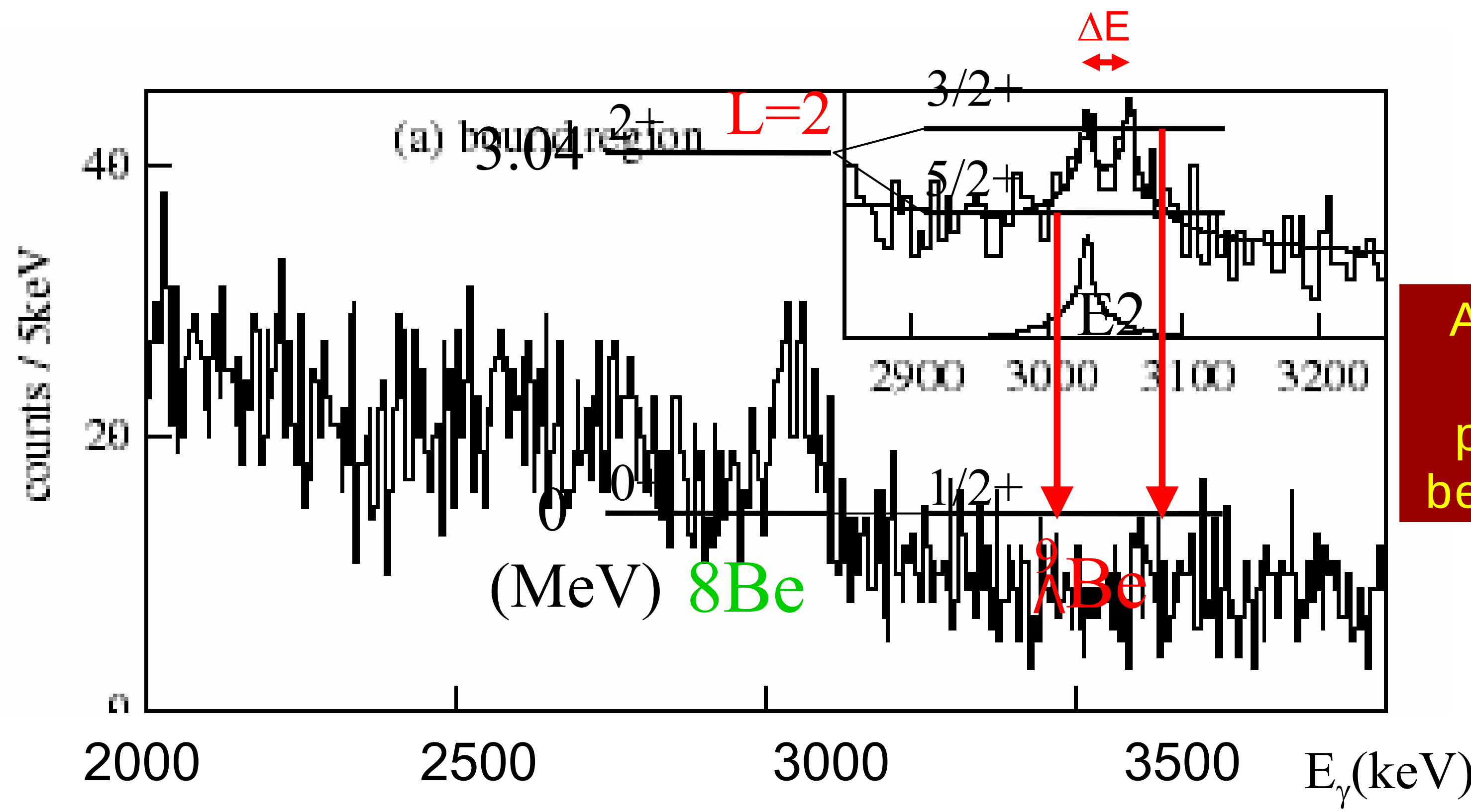




Spin-Orbit Force in Hypernuclei

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- BNL AGS E930; H. Akikawa et al., PRL88(2002)082501
- γ ray from ${}^{9}_{\Lambda}$Be created by ^{9}Be(K^-,π^-) reaction
- ΔE(5/2$^+$,3/2$^+$) $\Rightarrow$ ΛN spin-orbit force, LS
  (core structure: 2α rotating with L=2)



Also for multi-hypernuclei precission will be the key issue

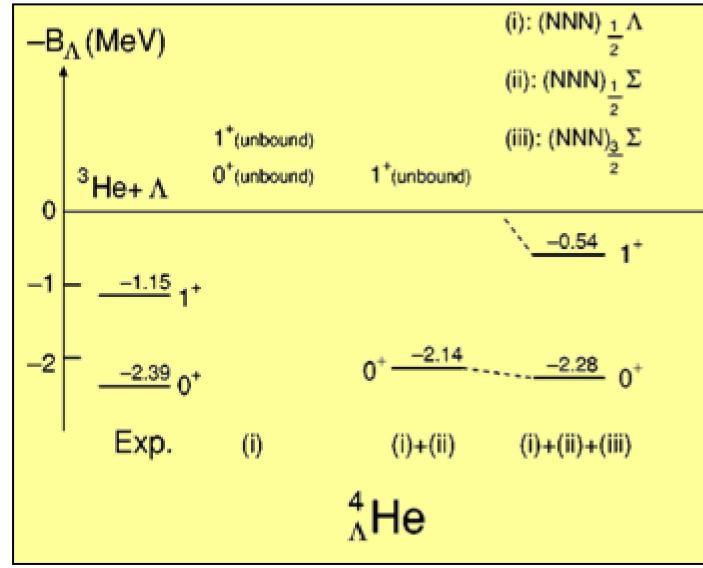
- |ΔE| = 31±3 keV
- surprisingly small spin-orbit force (~few percent of NN case)

Y-N or Y-Y Interaction in Hypernuclei

- Mass difference between Σ and Λ in single hypernuclei and $\Lambda\Lambda$, ΞN, $\Lambda\Sigma$ in double hypernuclei are small
  - $m(\Xi^0 n) - m(\Lambda\Lambda) = 23$MeV $m(\Sigma^0\Lambda) - m(\Lambda\Lambda) = 77$MeV
- $\Rightarrow$ mixing important

  $\Rightarrow$ strong medium dependence

E. Hiyama *et al.*, Phys. Rev. C65, 011301R (2001)



- impact on spin-orbit force

  N. Kaiser, W.Weise, PRC 71, 015203 (2005)

- magnitude of mixing depends strongly on nuclei

  D. E. Lanskoy, Y. Yamamoto, Phys. Rev. C **69**, 014303 (2004)

  Nemura *et al.* (2005)

	${}^{4}_{\Lambda\Lambda}H$ (${}^{3}_{\Lambda}H$)	${}^{5}_{\Lambda\Lambda}H$ (${}^{4}_{\Lambda}H$, ${}^{4}_{\Lambda}H^*$)	${}^{6}_{\Lambda\Lambda}He$ (${}^{5}_{\Lambda}He$)
$P_{N\Xi}$	0.12	4.34	0.27
$P_{\Lambda\Sigma}$ (P_{Σ})	0.35 (0.16)	2.52 (2.17, 0.36)	1.18 (0.55)
$P_{\Sigma\Sigma}$	0.01	0.05	0.04

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Weak Decay of Λ Hypernuclei

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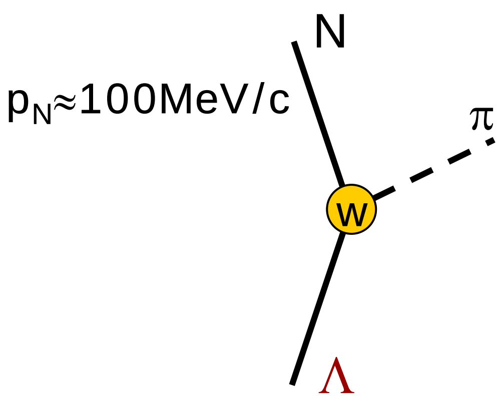
free Λ decay



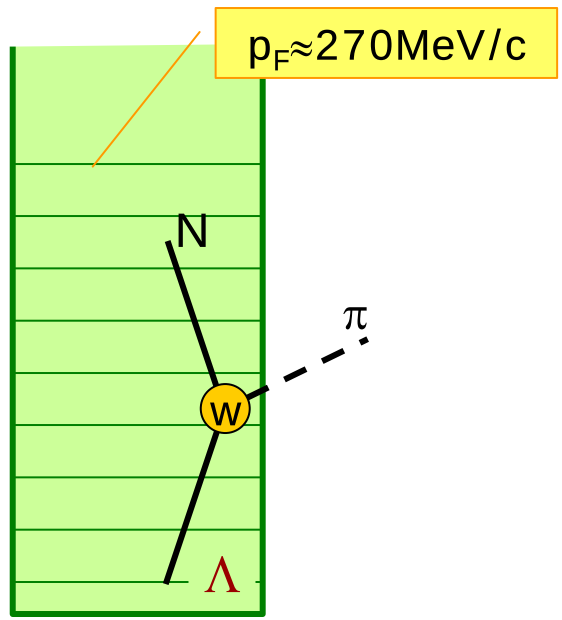
$\Lambda \rightarrow p\pi^- + 38MeV$ (64%)

$\Lambda \rightarrow n\pi^0 + 41MeV$ (36%)

$\tau_\Lambda = 263ps$

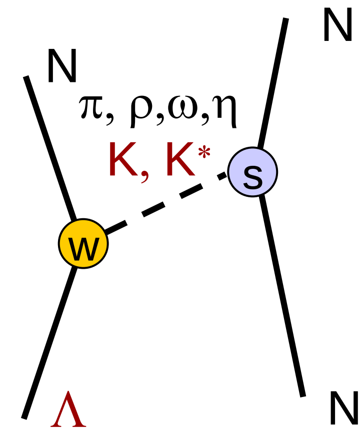
ΔI=1/2 rule

mesonic decay of hypernuclei



suppresed by
Pauli blocking

non-mesonic decay of hypernuclei



$\Lambda p \rightarrow np + 176MeV$

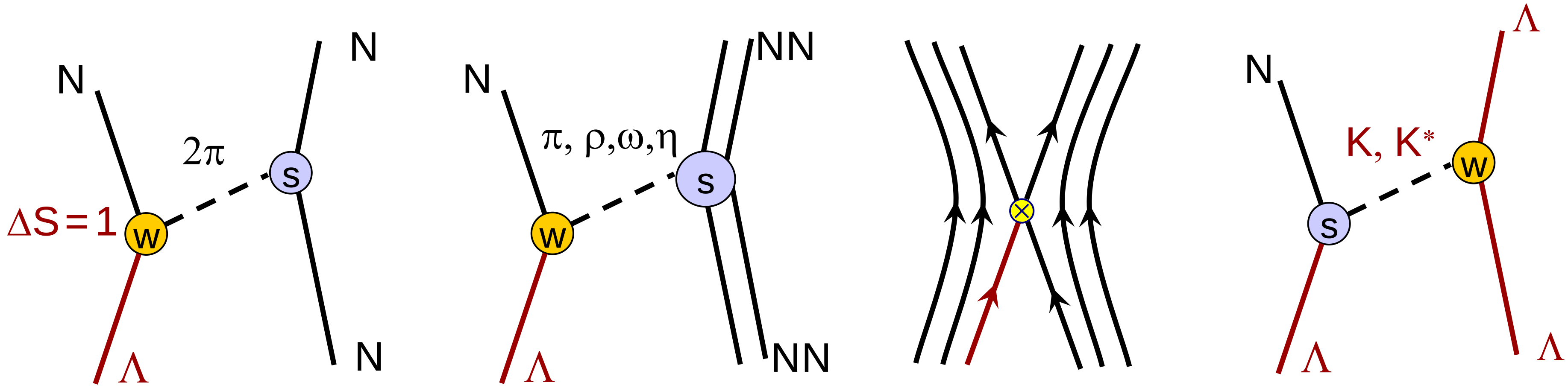
$\Lambda n \rightarrow nn + 176MeV$

dominant in all
but the lightest
hypernuclei

Weak baryon-baryon interaction

ΛN→N N

ΛΛ→Y N

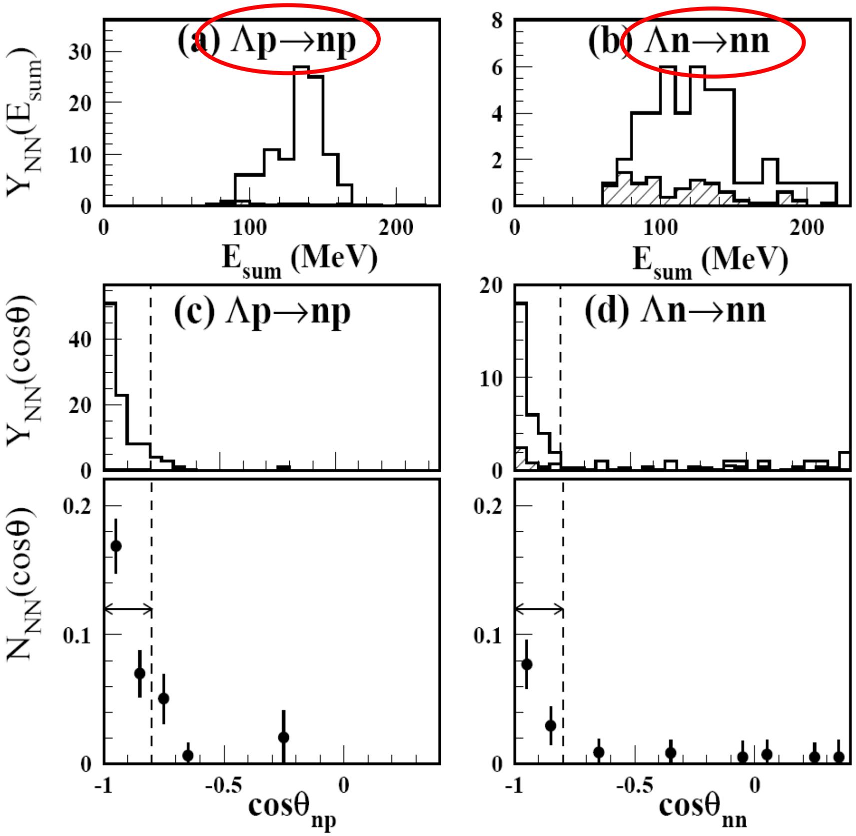


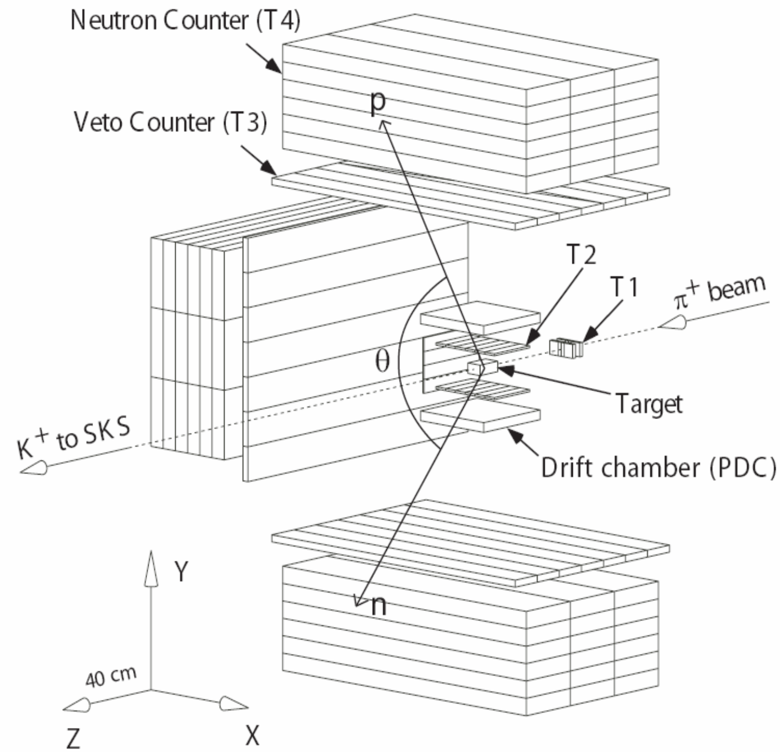
- two-pion exchange
- two-nucleon induced decays ΛNN→NNN
- meson vs. direct quark process
- ${}^{6}_{\Lambda\Lambda}He$: $\Lambda\Lambda \rightarrow \Lambda n$ → access to weak ΛΛK vertex
  - A. Parreno, A. Ramos and C. Bennhold, Phys. Rev C **65**, 015205: 3.6%
  - K. Sasaki, T. Inoue, and M. Oka, Nucl.Phys. A726 (2003) 349-355: 0.2%
  - K. Itonaga, T. Ueda, and T. Motoba, Nucl. Phys. A691 (2001) 197c: 2.5%

High statistics is another key issue

Example: Weak decay of $^5_\Lambda He$

- KEK–E462, B. H. Kang *et al.* Phys. Rev. Lett. 96. 062301 (2006)





$$\frac{\Gamma_n}{\Gamma_p} \approx \frac{N_{nn}}{N_{pn}} = 0.45 \pm 0.11_{stat} \pm 0.03_{sys}$$

- open issues
  - FSI
  - role of two nucleon induced decyas: ΛNN→NNN (→tripple coincidences ?)
- For ΛΛ→Λn: back-to back Λ-n coincidences

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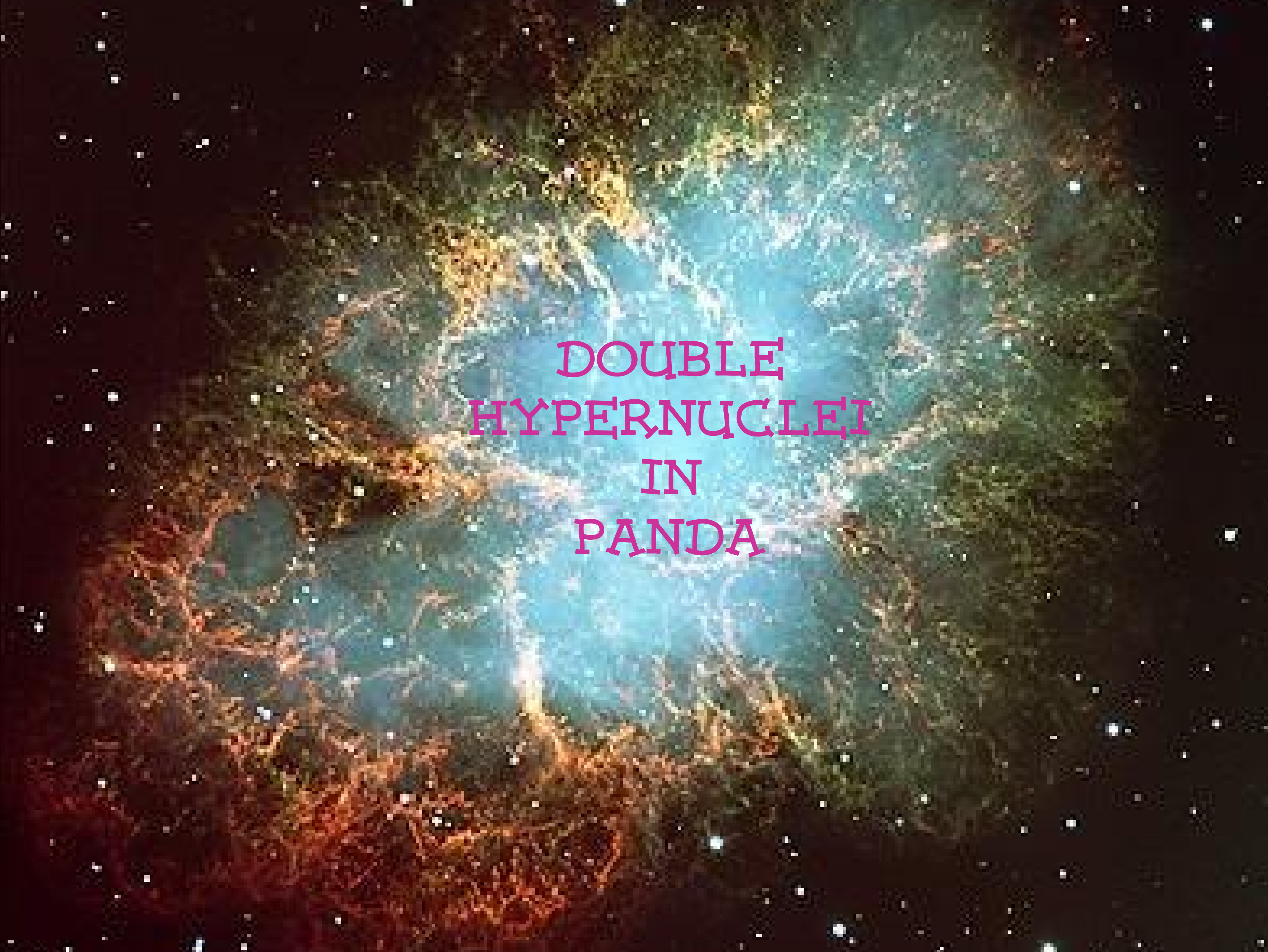

DOUBLE
HYPERNUCLEI
IN
PANDA

Task

High resolution
γ-spectroscopy
and
weak decay studies
of double hypernuclei

The first event (1)

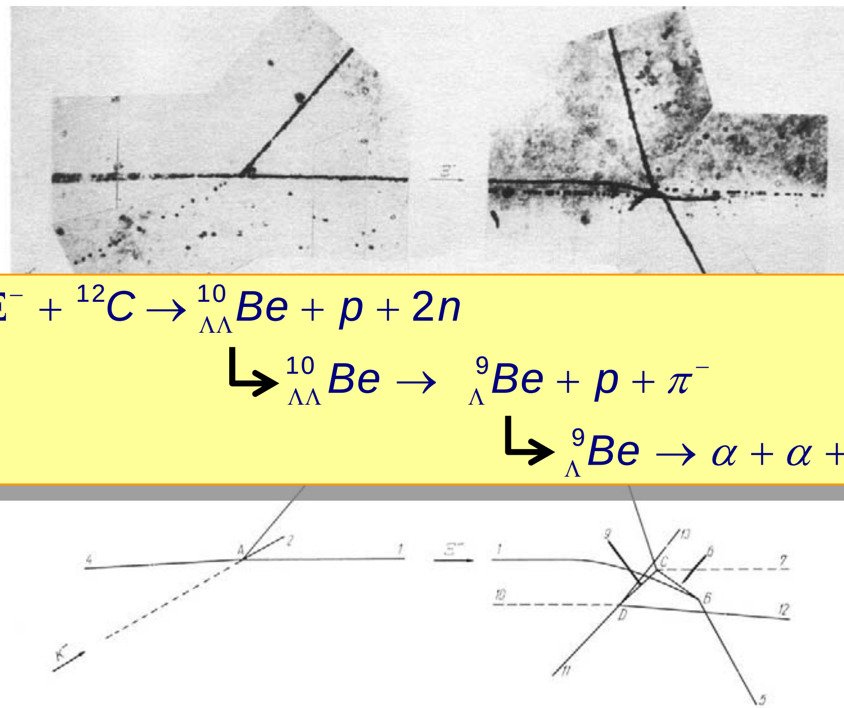
- 1.3-1.5 GeV/c K^-+Emulsion; 31000 K^-

VOLUME 11, NUMBER 1 PHYSICAL REVIEW LETTERS 1 JULY 1963

OBSERVATION OF A DOUBLE HYPERFRAGMENT

M. Danysz, K. Garbowska, J. Pniewski, T. Pniewski, and J. Zakrzewski
Institute of Experimental Physics, University of Warsaw, Warsaw, Poland
and Institute for Nuclear Research, Warsaw, Poland

and



$$\Xi^- + {}^{12}C \rightarrow {}^{10}_{\Lambda\Lambda}Be + p + 2n$$

$$\hookrightarrow {}^{10}_{\Lambda\Lambda}Be \rightarrow {}^{9}_{\Lambda}Be + p + \pi^-$$

$$\hookrightarrow {}^{9}_{\Lambda}Be \rightarrow \alpha + \alpha + p + \pi^-$$

FIG. 1. A photomicro- ... schematic ... the production ... eron in a 1.5- ... meson interac- ... llowed by cap- ... of the Ξ⁻ hy- ... with the emis- ... uble hyperfrag- ment decaying in cascade at C and D.

- carefully reanalyzed
  - ≈1963 by P.H. Fowler, V.M. Mayes and E.R.Fletcher
  - Dalitz *et al.*, Proc. R. Soc. Lond. A426, 1 (1989)

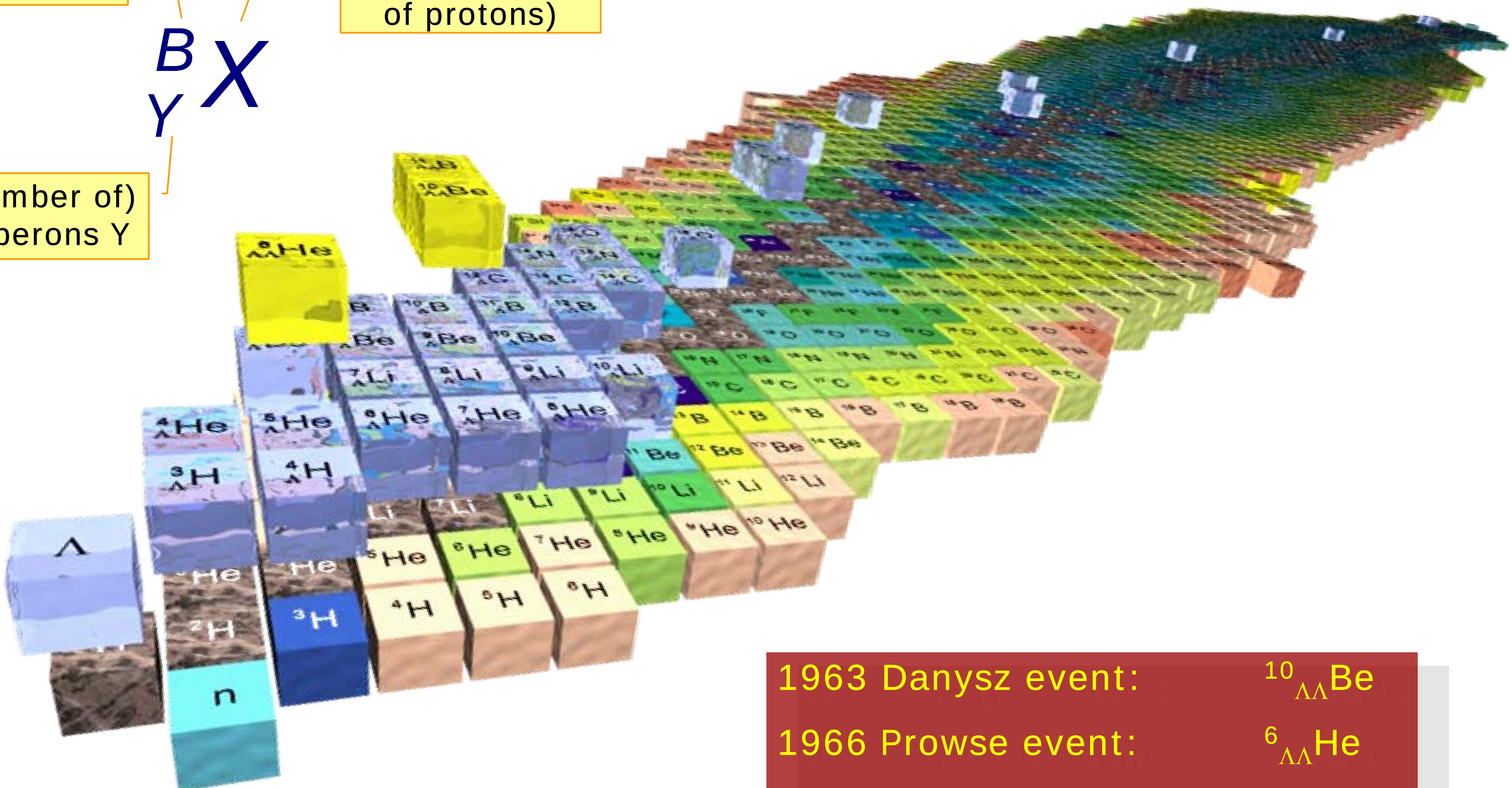
Hypernuclei Chart

number of baryons N+Z+Y

element = total charge (not number of protons)

(number of) hyperons Y

$^{B}_{Y}X$



1963 Danysz event: $^{10}_{\Lambda\Lambda}Be$

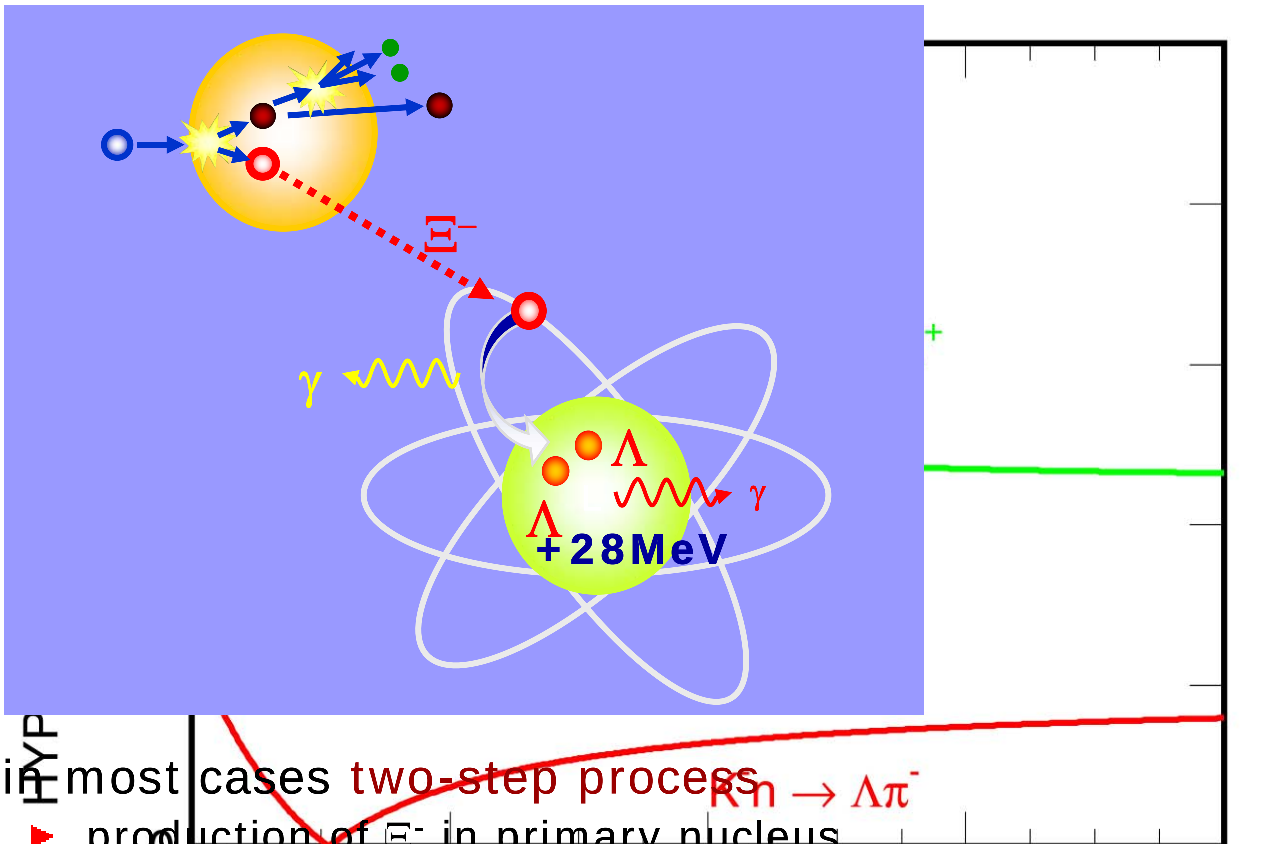
1966 Prowse event: $^{6}_{\Lambda\Lambda}He$

1991 Aoki event: $^{13}_{\Lambda\Lambda}B$

2001 Nagara event: $^{6}_{\Lambda\Lambda}He$

Production of ΛΛ–Hypernuclei

- simultaneous implantation of two Λ is not feasible
- reaction with lowest Q-value: $\Xi^- p \rightarrow \Lambda\Lambda$: 28MeV
- direct implantation of a Ξ^- via a two-body reaction difficult because of large momentum transfer

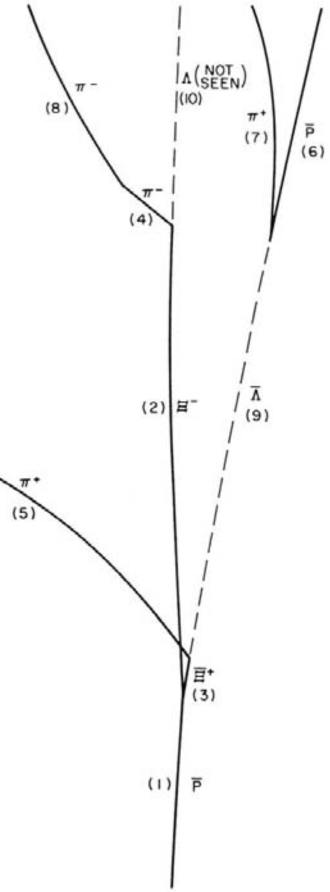


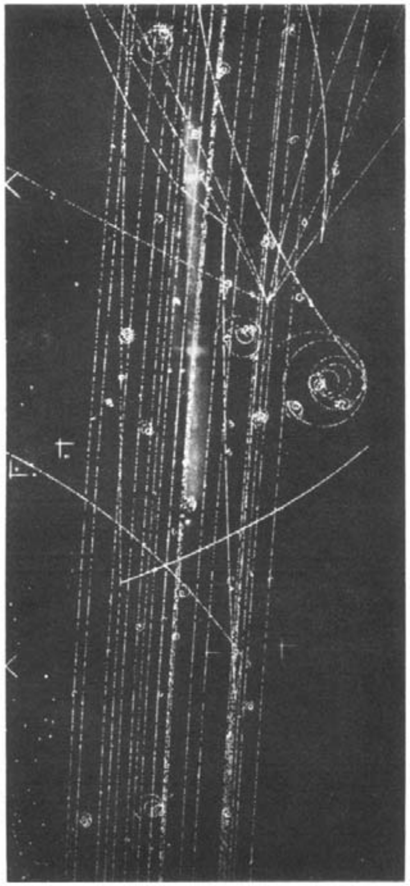
- in most cases two-step process
  - production of Ξ^- in primary nucleus
  - slowing down and capture in a secondary target nucleus
- spectroscopic studies only possible via the decay products

The Discovery of the anti-Xi

- discovered simultaneously at CERN and SLAC

$$\bar{p} + p \rightarrow \Xi^- + \bar{\Xi}^+$$





VOLUME 8, NUMBER 6 PHYSICAL REVIEW LETTERS MARCH 15, 1962

OBSERVATION OF PRODUCTION OF A $\Xi^- + \bar{\Xi}^+$ PAIR†

H. N. Brown, B. B. Culwick, W. B. Fowler, M. Gailloud,† T. E. Kalogeropoulos, J. K. Kopp, R. M. Lea, R. I. Louttit, T. W. Morris, R. P. Shutt, A. M. Thorndike, and M. S. Webster
Brookhaven National Laboratory, Upton, New York
and
C. Baltay, E. C. Fowler, J. Sandweiss,‡ J. R. Sanford, and H. D. Taft
Yale University, New Haven, Connecticut
(Received February 15, 1962)

VOLUME 8, NUMBER 6 PHYSICAL REVIEW LETTERS MARCH 15, 1962

EXAMPLE OF ANTICASCADE ($\bar{\Xi}^+$) PARTICLE PRODUCTION IN $\bar{p}$-p INTERACTIONS AT 3.0 Gev/c

CERN, Geneva, Switzerland *
Laboratoire de Physique, Ecole Polytechnique, Paris, France
and
Centre d' Etudes Nucléaires, Département Saturne, Saclay, France
(Received February 19, 1962)

An experiment is in progress at the CERN proton synchrotron to study the interactions of fast antiprotons with protons. A high-energy separated beam[1] has been installed and optimized to provide, in the first instance, a high-purity beam of 3.0-Gev/c antiprotons. The interactions are being produced and observed in the Saclay 81-cm hydrogen bubble chamber.[2]

In the methodical scanning of the first ten thousand photographs (with an average of seven antiprotons per photograph) an event has been found showing the production of an anticascade particle ($\bar{\Xi}^+$). The object of this Letter is to present the data and the analysis leading to this conclusion.

One of the three views of the event is reproduced in Fig. 1. Briefly, the event is as follows: After travelling 20 cm in the chamber, a beam particle interacts at point A, producing two charged particles. The positive particle decays at point B (distant 6 cm from A) and the negative at point D (4 cm from A). Both decay secondaries are light particles, as we will see. At C—about 20 cm downstream from B—there appears a V^0, which will be identified later as the decay of a $\bar{\Lambda}^0$ particle. Near point B another two-prong interaction can be seen at point I: Stereoscopic reconstruction shows that there is no direct link between this interaction and the $\bar{\Lambda}^0$ decay.

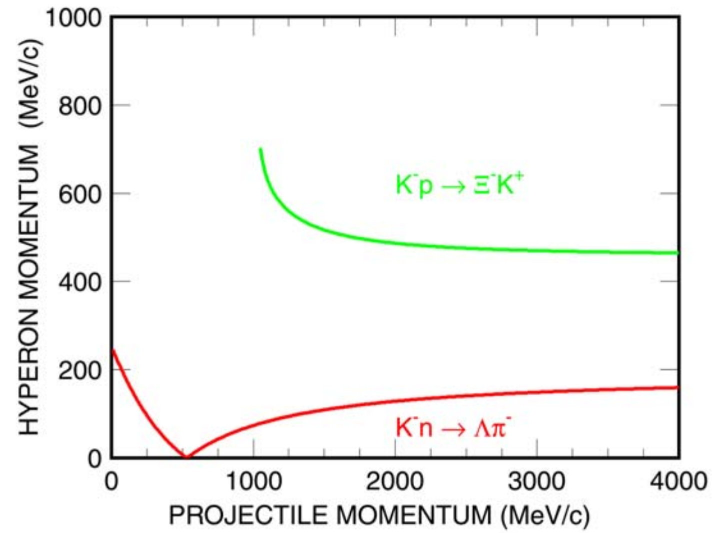
The event can be analyzed in several ways. We have chosen to proceed in two steps: We first analyze the event connected with the positive particle from apex A, and then with the improved knowledge thus derived we analyze the complete interaction at the same apex.

Production of Ξ^-

- Ξ^- conversion in 2 Λ: $\Xi^- + p \rightarrow \Lambda + \Lambda + 28.5\text{MeV}$

- Ξ- production
  - p(K⁻,K⁺)Ξ⁻
    - needs K⁻ beam ($c \cdot \tau = 3.7$cm)
    - recoil momentum >460 MeV/c
  - KEK-E176: 10^2 stopped Ξ
  - KEK- E373: 10^3 stopped Ξ
  - AGS-E885: 10^4 stopped Ξ

  } per week(s)



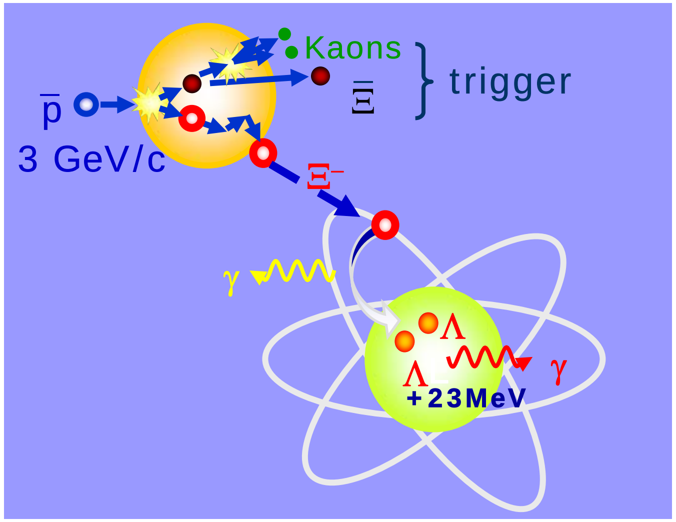
- antiproton storage ring HESR

$$p + \bar{p} \rightarrow \Xi^- + \bar{\Xi}^+$$

$$p + \bar{p} \rightarrow \Omega^- + \bar{\Omega}^+$$

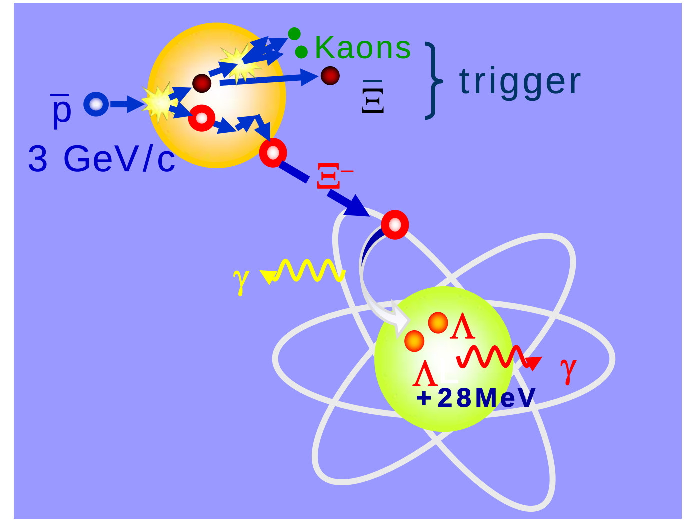
- few times 10^5 stopped Ξ per day

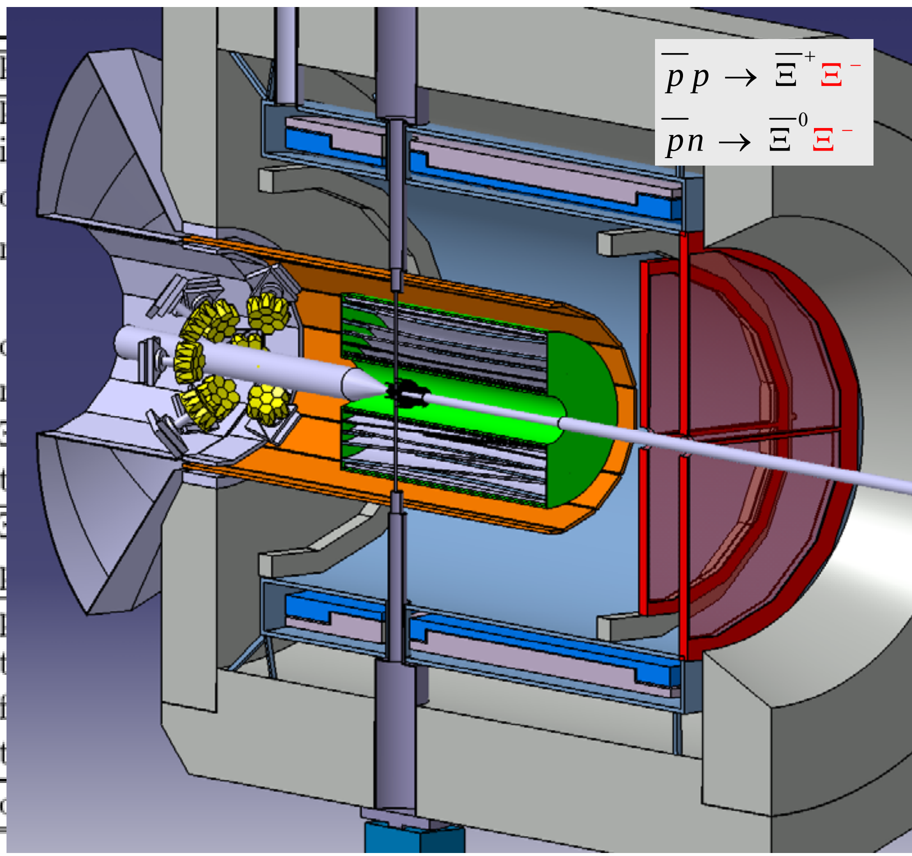
$\Rightarrow \gamma$-spectroscopy feasible

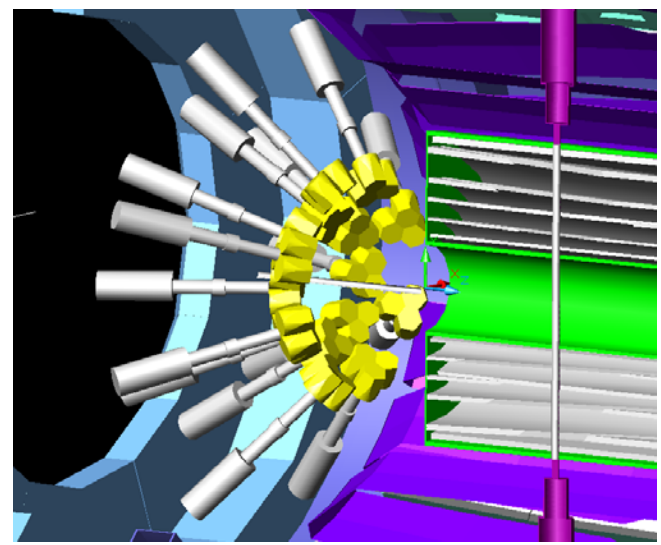


PANDA setup

- $\theta_{lab} < 45°$: Ξ-bar, K trigger (PANDA)
- $\theta_{lab} = 45°\text{-}90°$: Ξ^--capture, hypernucleus formation
- $\theta_{lab} > 90°$: γ-detection (Euroball)
  - neutron background (4000n $cm^{-2}s^{-1}$)








WHAT
ELSE ?

What we (probably) can't do

- triple hypernuclei via $p\bar{p} \to \Omega\bar{\Omega}$ $\quad \Omega pn \to \Lambda\Lambda\Lambda + 203MeV$?
  - lower cross section
  - large momenta $\Rightarrow$ lower stopping probability
  - large Q-value $\Rightarrow$ low probability for triple Λ nuclei
  - γ-spectroscopy most likely not practical at the beginning

- Λ_c hypernuclei
  - production via primary + secondary target not possible because of short lifetime of $\tau_{\Lambda c}$ =0.2ps which exceeds stopping time
  - direkt production via pp $\to \Lambda_c \Lambda_c$bar or $\pi^- p \to \Lambda_c D^-$ difficult because of high momenta involved (very low sticking probability)
  - does a two-step process *within one nucleus* work?

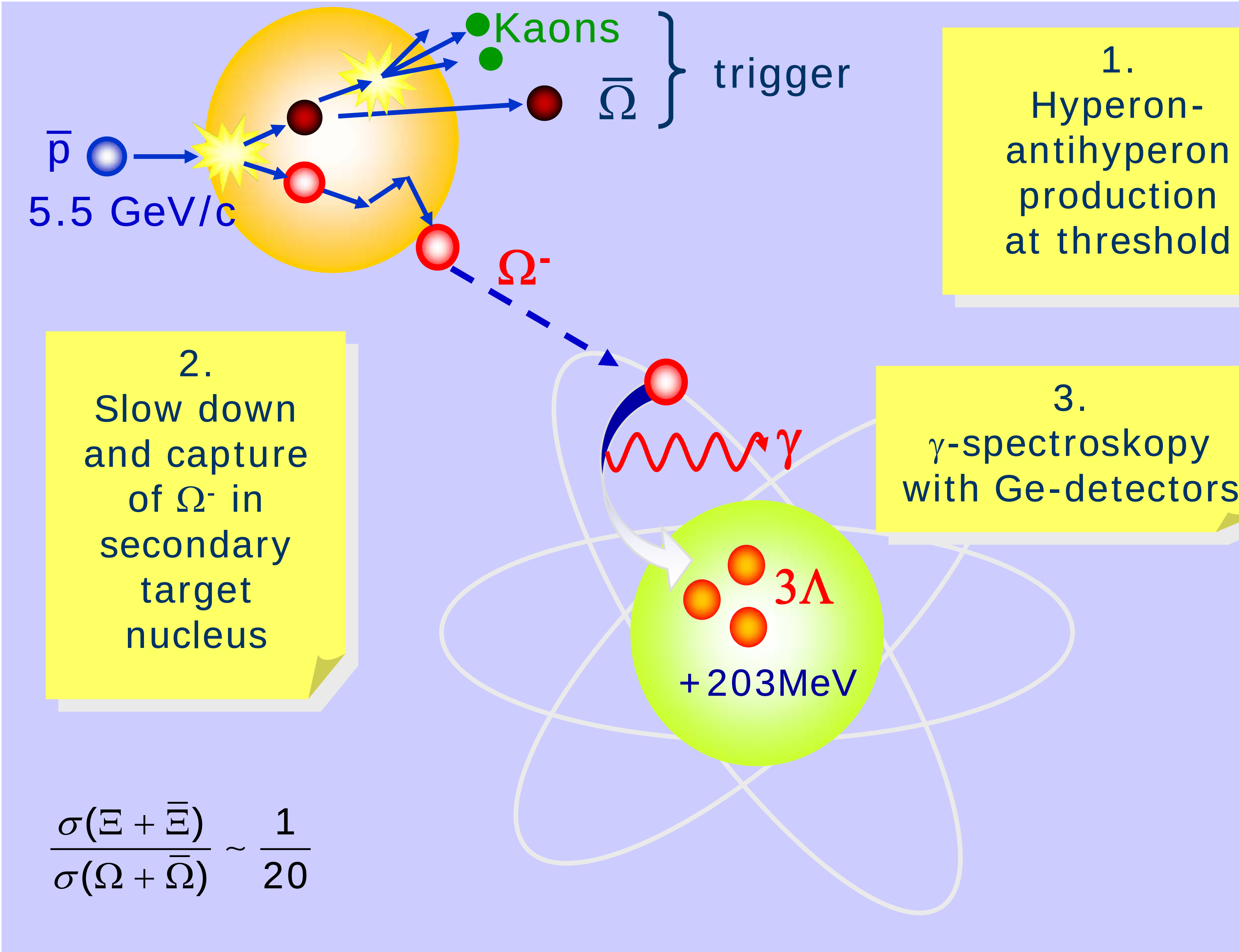
$$\bar{p} + p \to D^+ + D^-$$
$$D^+ + p \to \Lambda_c^+ + \pi^+$$

detected (D^-, π^+)

captured in the nucleus A-2 (Λ_c^+)

  - determination of the Λ_c hypernucleus mass via missing mass
    - needs good knowledge of beam momentum (10^{-4})
    - excellent momentum resolution for π^+ and D^- (resp. decay products)
  - expected rate ~0.01 day^{-1} (??? rescattering → 1day^{-1} ???)

Production of Ω-Atoms



Deformation of a Baryon

- J=1/2 baryons have no *spectroscopic* quadrupole moment

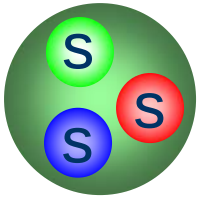
$$Q_i = \int d^3r\, \rho(r)(3z^2 - r^2)$$

$$Q_s \propto (3J_z^2 - J(J+1)) \xrightarrow[J_z=1/2]{J=1/2} 0$$

- **The Ω^- Baryon is the only „elementary“ particle whose quadrupole moment can be measured**
  - J=3/2
  - long mean lifetime $0.82 \cdot 10^{-10}$ s

- Contributions to *intrinsic* quadrupole moment of baryons
  - General: One-gluon exchange and meson exchange
  - Ω: only one-gluon contributions to quadrupole moment

A.J. Buchmann Z. Naturforsch. **52** (1997) 877-940



  - e.g. within SU(3) limit $m_u/m_s=1$

$$Q_\Omega = Q_\Delta(gluon)$$

A very strange Atom

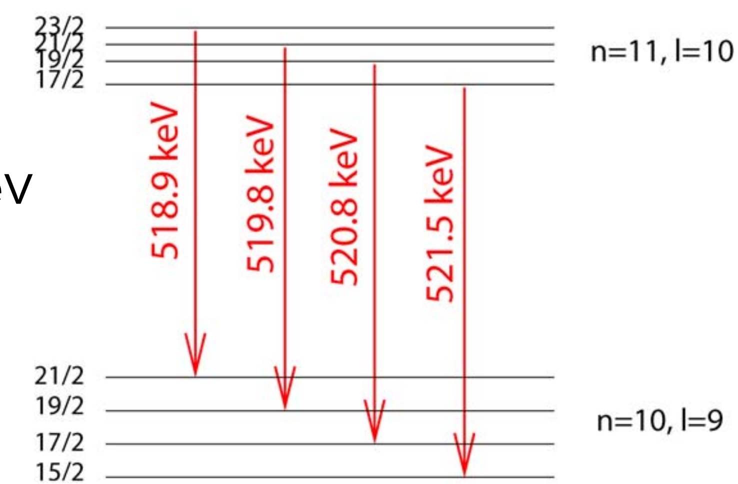
- hyperfine splitting in Ω-atom
  ⇒ electric quadrupole moment of Ω

spin-orbit	$\Delta E_{ls} \sim (aZ)^4\, l \cdot m_\Omega$
quadrupole	$\Delta E_\Theta \sim (aZ)^4 Q m^3_\Omega$

R.M. Sternheimer, M. Goldhaber, Phys. Rev. A 8, 2207 (1973)

M.M. Giannini, M.I. Krivoruchenko, Phys. Lett. B 291, 329 (1992)

- prediction Q_Ω = (0 - 3.1) 10^{-2} fm^2
  - E(n=11, l=10 → n=10, l=9) ~ 520 keV
    - calibration with 511keV line!
  - ΔE_Θ ~ few tenth of keV for Pb



$Q_\Omega = 0.02 fm^2$

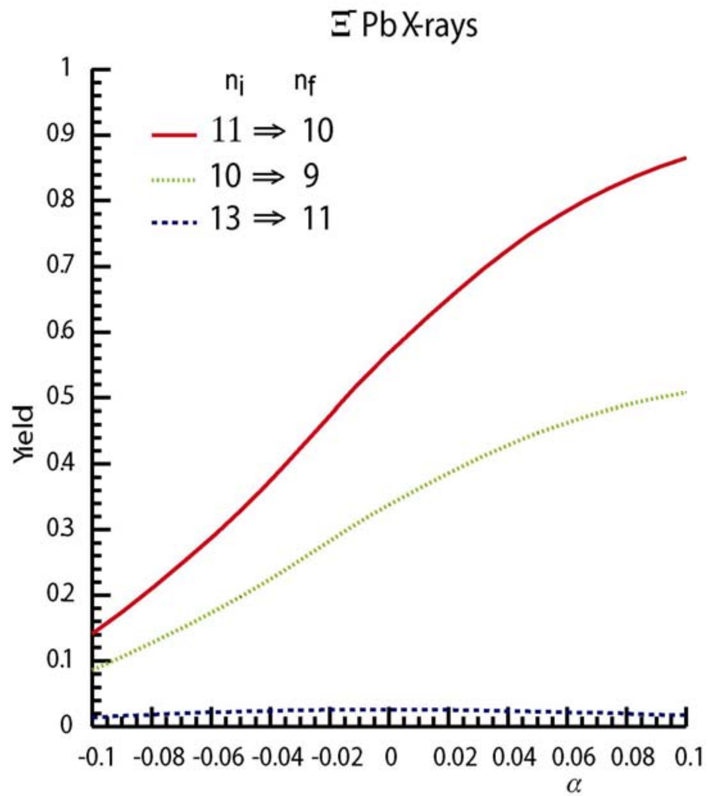
Experimental details

- 10 $\Omega\underline{\Omega}$ pairs/s
- few 100 stopped Ω per day
- Yield(Σ-Pb)≈Yield(Ξ-Pb)

  C.J.Batty, E. Friedman, A. Gal, PRC 59, 295 (1999)
- capture probability ~10%
- X-ray detection efficiency ~5%
- trigger efficiency
- ...

~10 observed X-rays/month

- antiprotonic atoms at FLAIR could be an ideal testground!



$$p_{initial}(l) = (2l+1)\cdot e^{\alpha l}$$

CONCLUSION

Conclusion

- Antiproton collisions with nuclei offer many opportunities to study strange baryons in cold nuclei
  - baryon-baryon interaction
  - weak decay
  - spectroscopy of baryonic atoms
  - ...

- These studies are made possible by a unique combination of experimental facilities at FAIR
  - γ-spectroscopy with Ge detectors ⊕ PANDA ⊕ antiproton beams

IX International Conference on
Hypernuclear and Strange Particle Physics

HYP 2006

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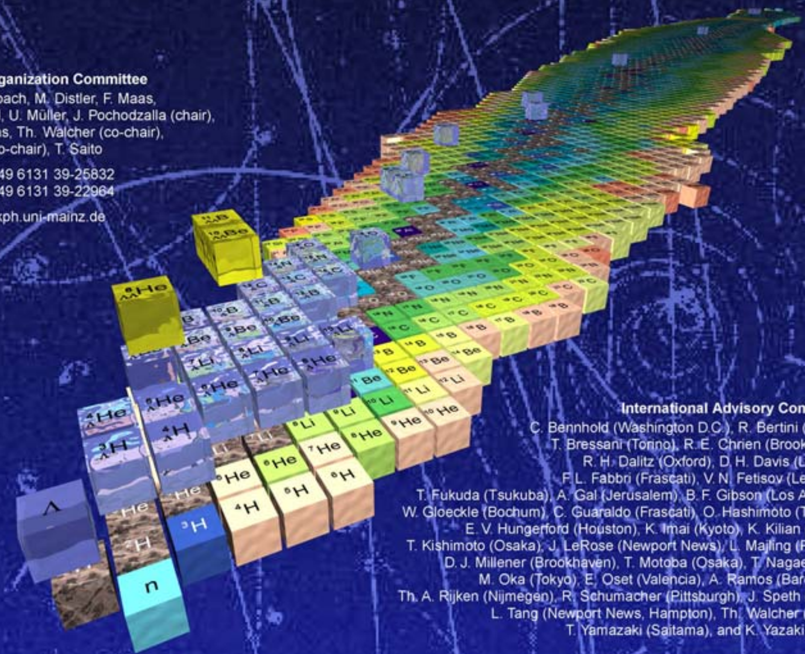
http://wwwa1.kph.uni-mainz.de/Hyp2006



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TOPICS

- **Production of Hypernuclei**
- **Structure of Lambda Hypernuclei**
- **$S = -2$ Hypernuclear States**
- **Decay of Hypernuclei**
- **Electromagnetic Production of Strangeness**
- **Strange Hadron Structure**
- **Low Energy Strange Hadron Interactions and Exotic Matter**
- **Present and Future Facilities**

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