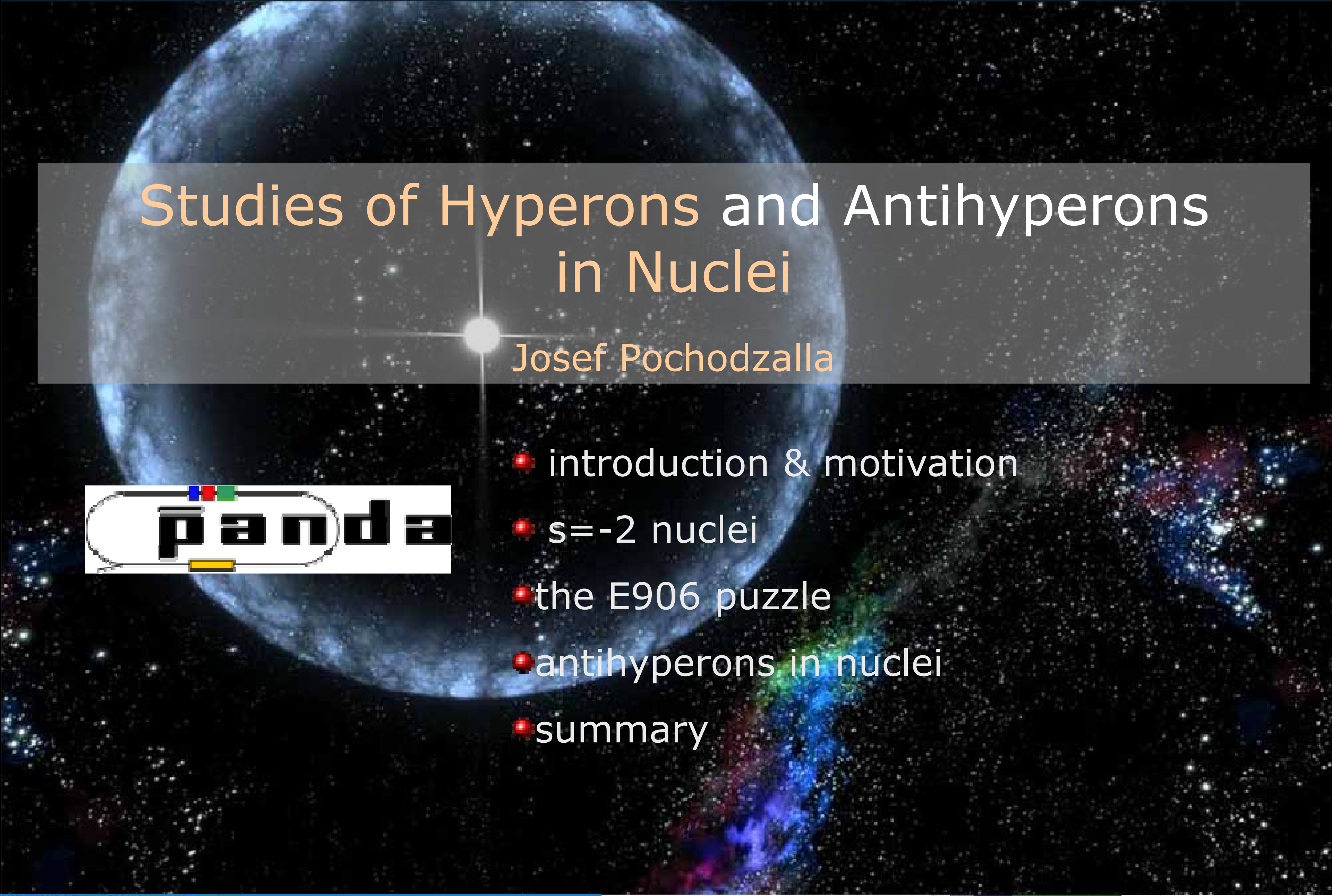


Studies of Hyperons and Antihyperons in Nuclei

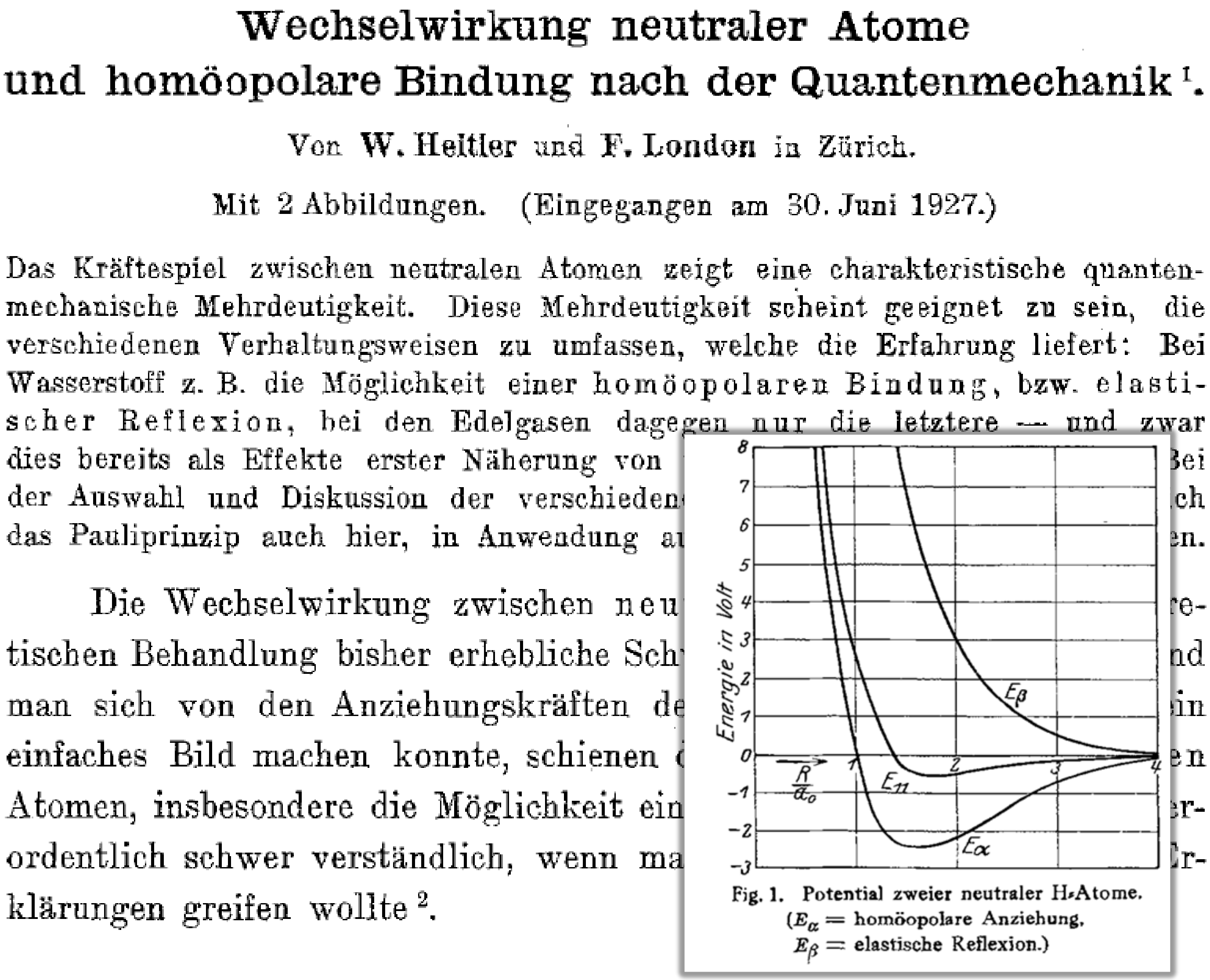
Josef Pochodzalla

panda

- introduction & motivation
- s=-2 nuclei
- the E906 puzzle
- antihyperons in nuclei
- summary

HadronPhysics2
Study of Strongly Interacting Matter
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
MAMI
MAINZER MIKROTRON
Bundesministerium für Bildung und Forschung

Pioneers of Quantum Chemistry



Wechselwirkung neutraler Atome und homöopolare Bindung nach der Quantenmechanik[1].

Von W. Heitler und F. London in Zürich.

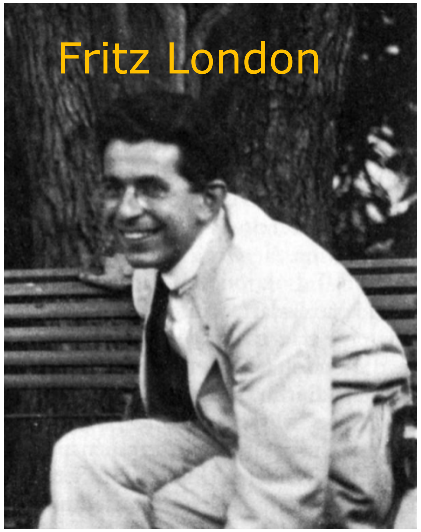
Mit 2 Abbildungen. (Eingegangen am 30. Juni 1927.)

Das Kräftespiel zwischen neutralen Atomen zeigt eine charakteristische quantenmechanische Mehrdeutigkeit. Diese Mehrdeutigkeit scheint geeignet zu sein, die verschiedenen Verhaltungsweisen zu umfassen, welche die Erfahrung liefert: Bei Wasserstoff z. B. die Möglichkeit einer homöopolaren Bindung, bzw. elastischer Reflexion, bei den Edelgasen dagegen nur die letztere — und zwar
dies bereits als Effekte erster Näherung von Bei
der Auswahl und Diskussion der verschieden ch
das Pauliprinzip auch hier, in Anwendung a en.

Die Wechselwirkung zwischen neu re-
tischen Behandlung bisher erhebliche Sch nd
man sich von den Anziehungskräften de in
einfaches Bild machen konnte, schienen en
Atomen, insbesondere die Möglichkeit ein er-
ordentlich schwer verständlich, wenn ma Er-
klärungen greifen wollte[2].

Fig. 1. Potential zweier neutraler H-Atome. (E_α = homöopolare Anziehung. E_β = elastische Reflexion.)

Walter Heitler



Fritz London

Zeitschrift für Physik, **44**, 455—472 (1927).

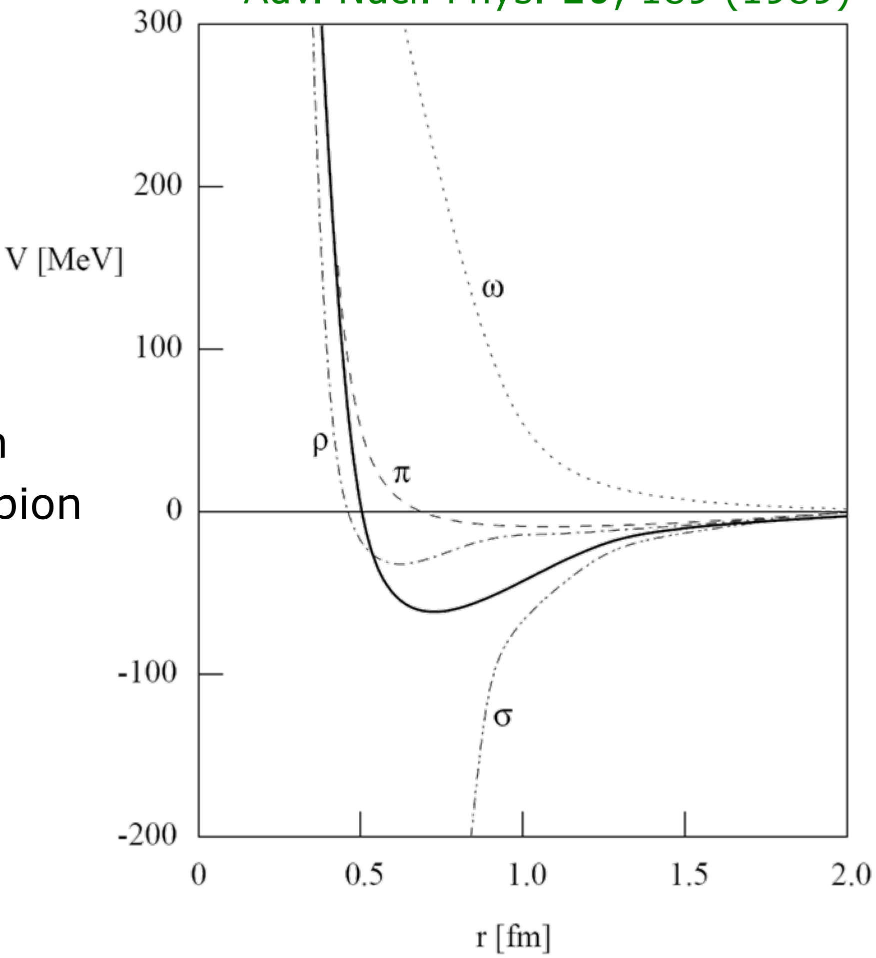
Traditional View of the N-N Interaction

- Experimental observation
  - short range (r<0.5fm) repulsion
  - intermediate (r≈1fm) strong attraction
  - long range (r>1.5fm) attraction
- Boson exchange model
  - Yukawa (1935)
  - Klein-Gordon equation

$$\left(\partial^2 + m^2\right)\varphi(x) = g\bar{\psi}\psi$$

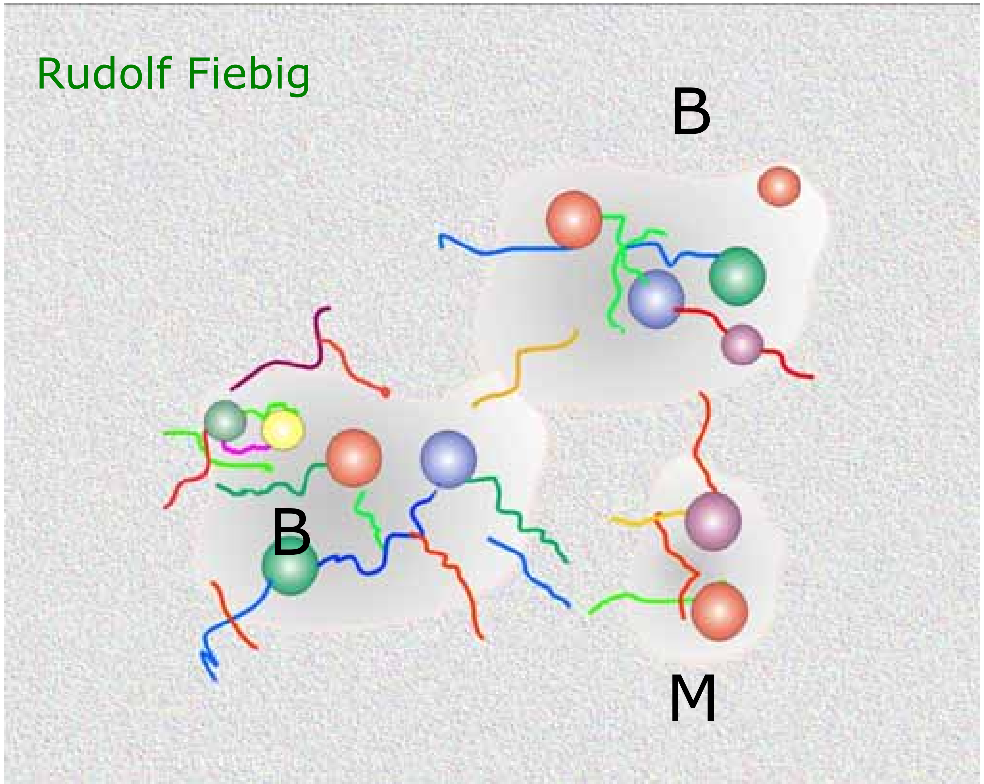
  - range of N-N interaction R≈2fm
  - $R = \hbar c / mc^2 \Rightarrow m \approx 100\,\mathrm{MeV}/c^2 \Rightarrow$ pion

R. Machleidt,
Adv. Nucl. Phys. **19**, 189 (1989)

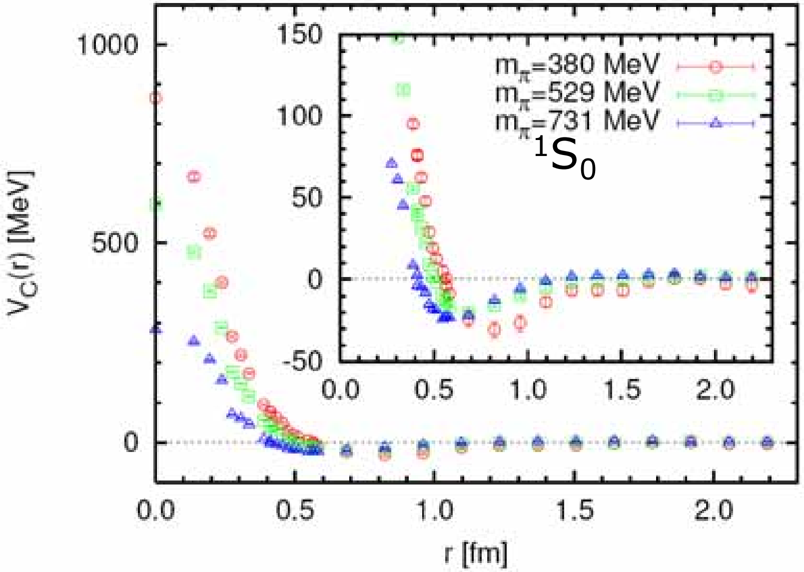


Modern Version of B-B Interaction

- Pauli Principle not essential for repulsive core: Spin ⊗ flavor ⊗ color
- Understanding baryons and their mutual interactions is a complex, quantum-fieldtheoretical, non-perturbative many-body problem


Rudolf Fiebig

arXiv:0909.5585v1



Hadrons to Atomic nuclei HAL from Lattice QCD

„The achievment is both a computational *tour de force* and a triumph for theory“

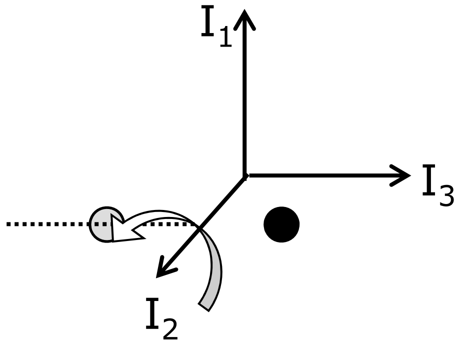
Nature Research Highlights 2007

G-Parität

- strong interaction conserves isospin and C-parity
- *G*=charge conjugation + 180° rotation around 2nd axis in isospin (Lee und Yang 1956, L. Michel 1952 „Isoparität“)

$$G = C \cdot e^{i\pi I_2}$$

$$\left|I, I_3\right\rangle \xrightarrow{C} \left|I, -I_3\right\rangle \xrightarrow{e^{i\pi I_2}} \left|I, I_3\right\rangle$$



- reminder: rotation in space

$$Y_l^m(\vartheta,\varphi) \xrightarrow{\exp(i\pi L_y)} Y_l^m(\vartheta+\pi, \pi-\varphi) = (-1)^l\, Y_l^m(\vartheta,\varphi)$$

- isospin rotation

$$\left|I, I_3\right\rangle \xrightarrow{\exp(i\pi I_2)} (-1)^I \left|I, I_3\right\rangle$$

- particle-antiparticle systems

$$G\left|\mathrm{f}\bar{\mathrm{f}}\right\rangle = (-1)^I\, C\left|\mathrm{f}\bar{\mathrm{f}}\right\rangle = (-1)^{I+L+S}\left|\mathrm{f}\bar{\mathrm{f}}\right\rangle$$

$$G\left|\pi^{\pm 0}\right\rangle = (-1)^1 C\left|\pi^{\pm 0}\right\rangle = -\left|\pi^{\pm 0}\right\rangle$$

$$G\left|\rho\right\rangle = (-1)^1 C\left|\rho\right\rangle = +\left|\rho\right\rangle$$

$$G\left|\omega\right\rangle = (-1)^0 C\left|\omega\right\rangle = -\left|\omega\right\rangle$$

$$G\left|\sigma\right\rangle = (-1)^0 C\left|\sigma\right\rangle = +\left|\sigma\right\rangle$$

G-Parity and N$\bar{\text{N}}$ Potential

- G-parity of particle-antiparticle multipletts

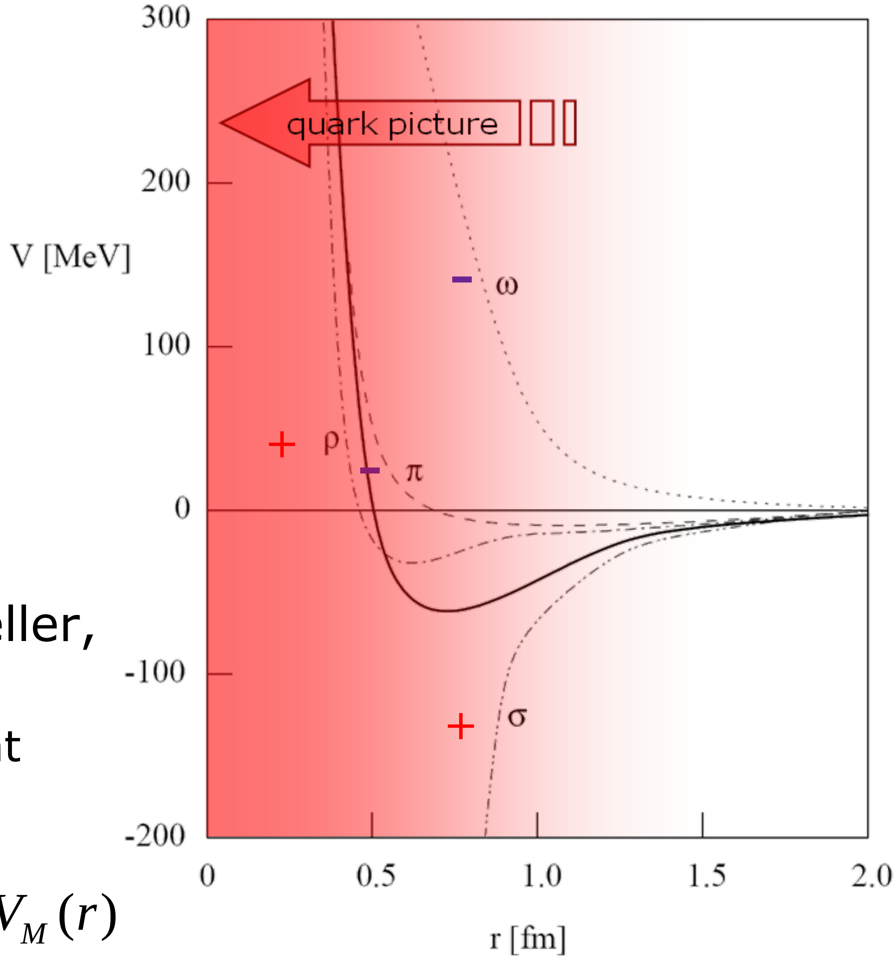
$$G\left|f\bar{f}\right\rangle = (-1)^I C\left|f\bar{f}\right\rangle = (-1)^{I+L+S}\left|f\bar{f}\right\rangle$$

$$G\left|\pi^{\pm 0}\right\rangle = (-1)^1 C\left|\pi^{\pm 0}\right\rangle = -\left|\pi^{\pm 0}\right\rangle$$

$$G\left|\rho\right\rangle = (-1)^1 C\left|\rho\right\rangle = +\left|\rho\right\rangle$$

$$G\left|\omega\right\rangle = (-1)^0 C\left|\omega\right\rangle = -\left|\omega\right\rangle$$

$$G\left|\sigma\right\rangle = (-1)^0 C\left|\sigma\right\rangle = +\left|\sigma\right\rangle$$

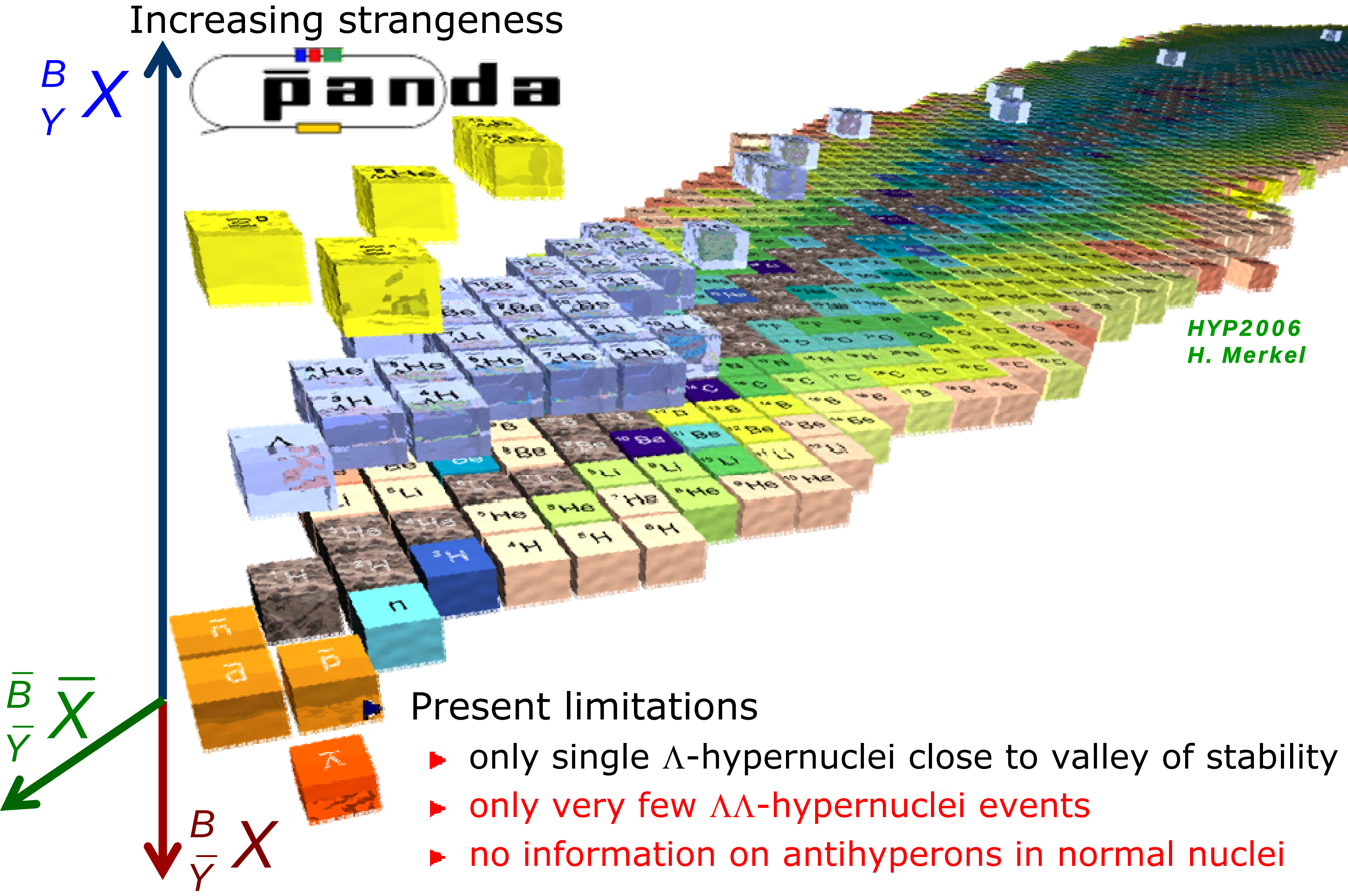


- Hans-Peter Dürr and Edward Teller, Phys. Rev. **101**, 494 (1956)
  - sign change in coupling constant when going from NN to NN

$$V(NN)(r) = \sum_M V_M(r) \rightarrow V(N\bar{N})(r) = \sum_M G_M V_M(r)$$

- Caveat: meson picture will probably not work at small distance
- Chance to study transition from meson to quark-gluon regime

The present nuclear chart

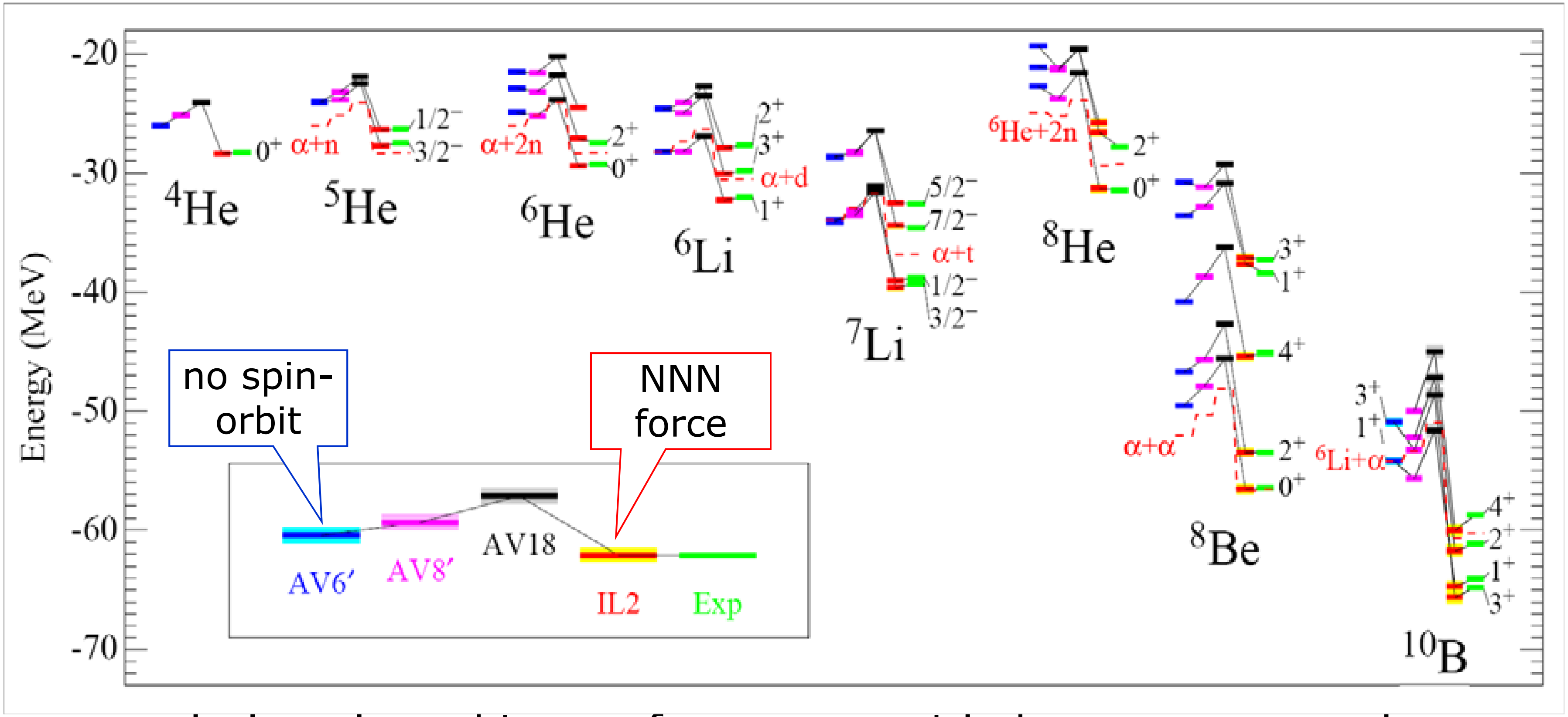


Present limitations

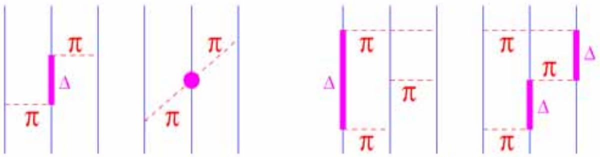
- only single Λ-hypernuclei close to valley of stability
- only very few ΛΛ-hypernuclei events
- no information on antihyperons in normal nuclei

Understanding Nuclear Structure

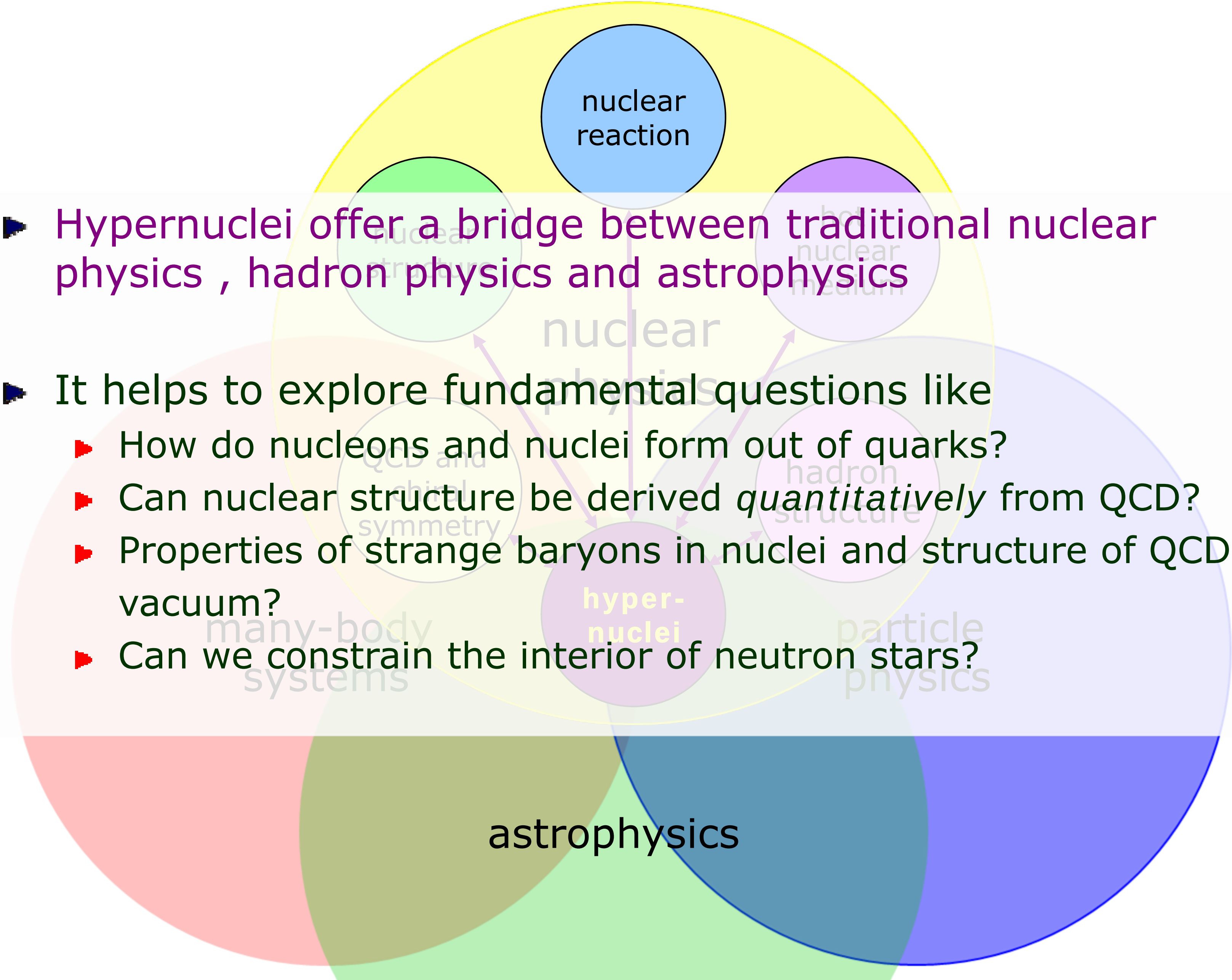
- Steven Stephen C. Pieper *et al.*, 2002
- potentials with increasing complexity



- 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)



Nature of emerging structures



- Hypernuclei offer a bridge between traditional nuclear physics , hadron physics and astrophysics

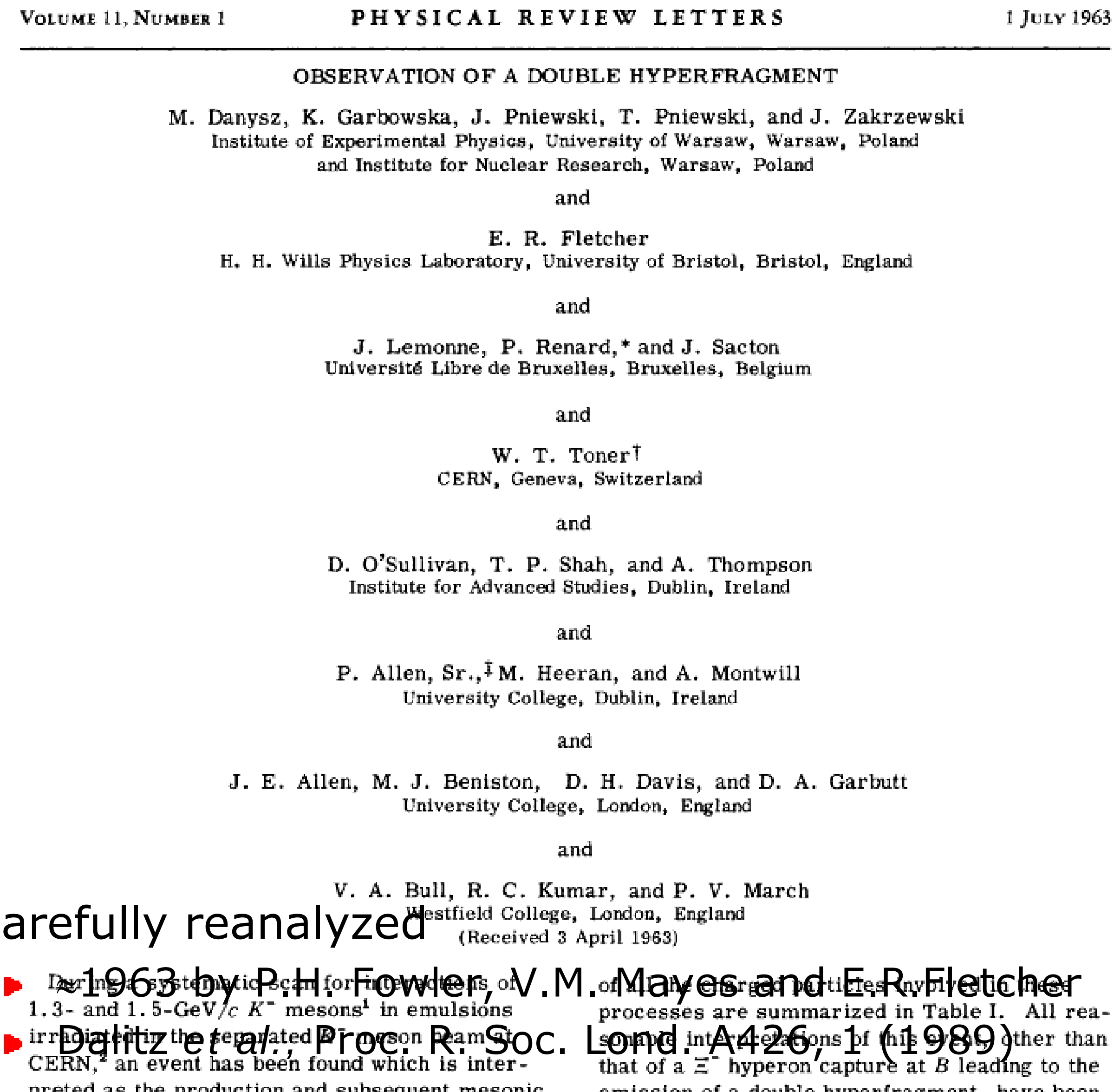
- It helps to explore fundamental questions like
  - How do nucleons and nuclei form out of quarks?
  - Can nuclear structure be derived *quantitatively* from QCD?
  - Properties of strange baryons in nuclei and structure of QCD vacuum?
  - Can we constrain the interior of neutron stars?

S=-2 Nuclei

Alicia Sachez Lorente, PhD Thesis, Mainz 2010
J.P., Nucl. Instr. and Methods in Physics Research B **214**, 149-152 (2004).
A. Sanchez Lorente, A. Botvina, J.P.

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

E. R. Fletcher
H. H. Wills Physics Laboratory, University of Bristol, Bristol, England

and

J. Lemonne, P. Renard,* and J. Sacton
Université Libre de Bruxelles, Bruxelles, Belgium

and

W. T. Toner†
CERN, Geneva, Switzerland

and

D. O'Sullivan, T. P. Shah, and A. Thompson
Institute for Advanced Studies, Dublin, Ireland

and

P. Allen, Sr.,‡ M. Heeran, and A. Montwill
University College, Dublin, Ireland

and

J. E. Allen, M. J. Beniston, D. H. Davis, and D. A. Garbutt
University College, London, England

and

V. A. Bull, R. C. Kumar, and P. V. March
Westfield College, London, England

(Received 3 April 1963)

During a systematic scan for interactions of 1.3- and 1.5-GeV/c K^- mesons[1] in emulsions irradiated in the separated K^- meson beam at CERN,[2] an event has been found which is interpreted as the production and subsequent mesonic

of all the charged particles involved in these processes are summarized in Table I. All reasonable interpretations of this event other than that of a Ξ^- hyperon capture at B leading to the emission of a double hyperfragment, have been

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

The observed first event

$$\Xi^- + p \rightarrow \Lambda + \Lambda + 28.5\text{MeV}$$

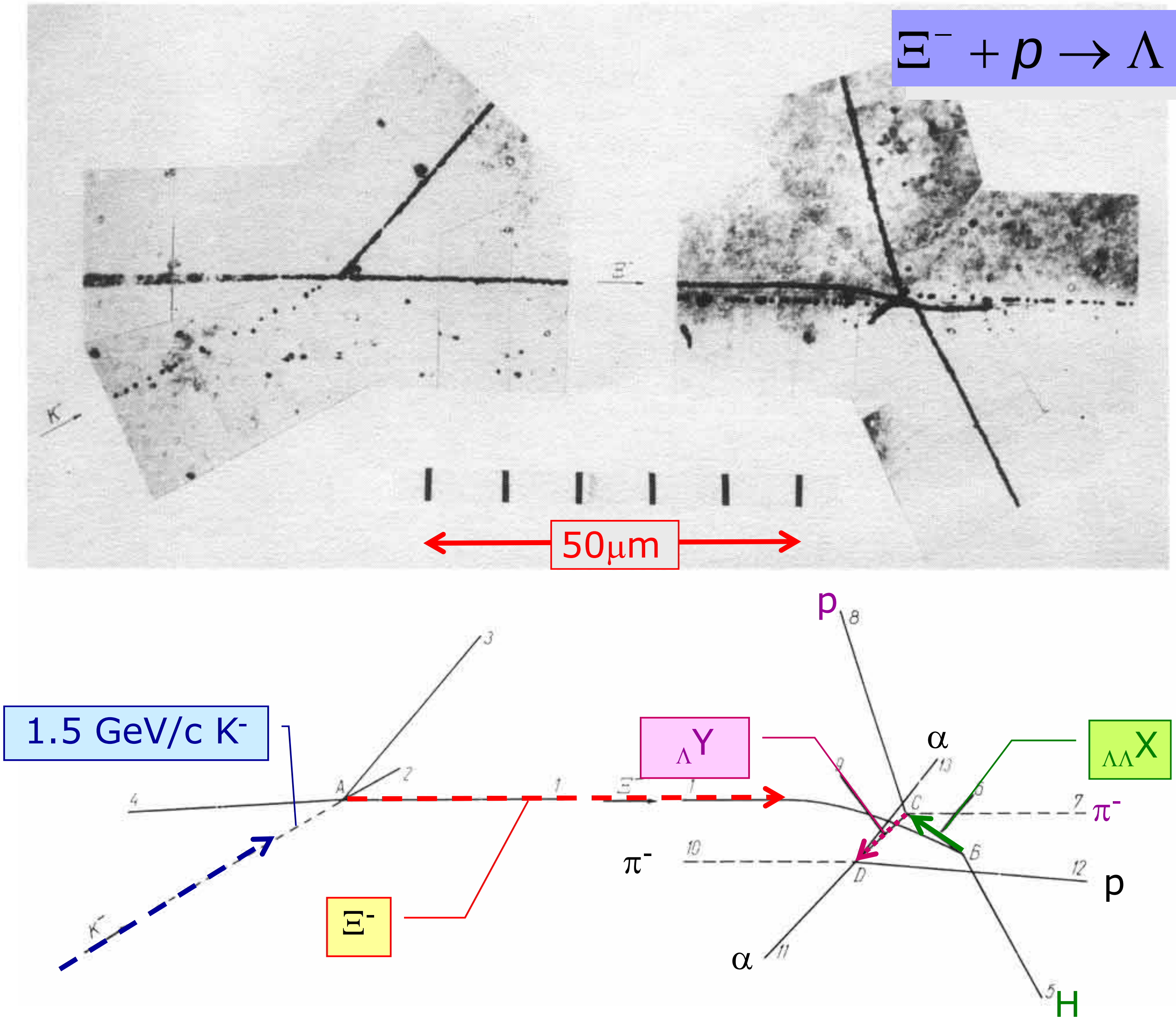
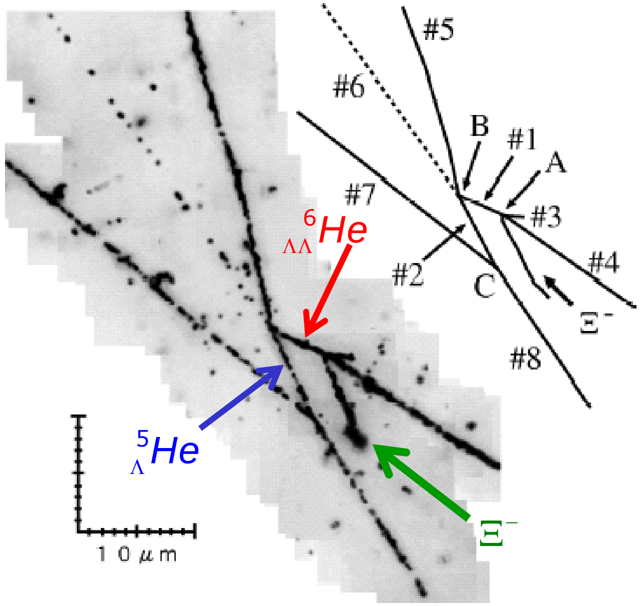
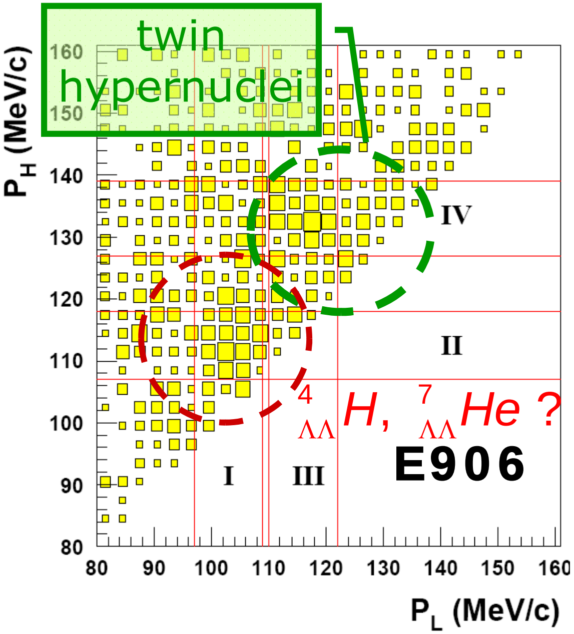


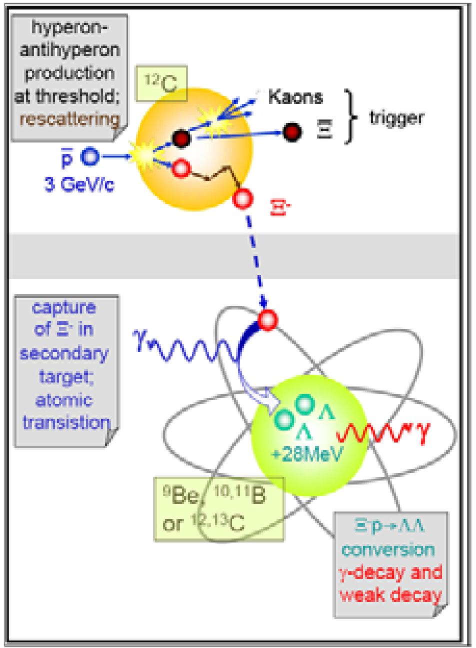
FIG. 1. A photomicrograph and a schematic drawing of the production of a Ξ^- hyperon in a 1.5-GeV/c K^--meson interaction at A followed by capture at rest of the Ξ^- hyperon at B with the emission of a double hyperfragment decaying in cascade at C and D.

Decay Products of ΛΛ Hypernuclei

- nuclear fragments ⇒ emulsion hadron+nucleus
  - detection of charged products only
  - limited to light nuclei
- weak decay products ⇒ BNL-AGS E906 ^{9}Be(K$^-$,K$^+$)X
  - resolution limited
  - no information on excited states
  - interpretation not unique because π momenta are similar
- γ- spectroscopy ⇒ PANDA p+A
  - no excited states observed yet, but theoretically predicted
  - How to identify the nucleus ?

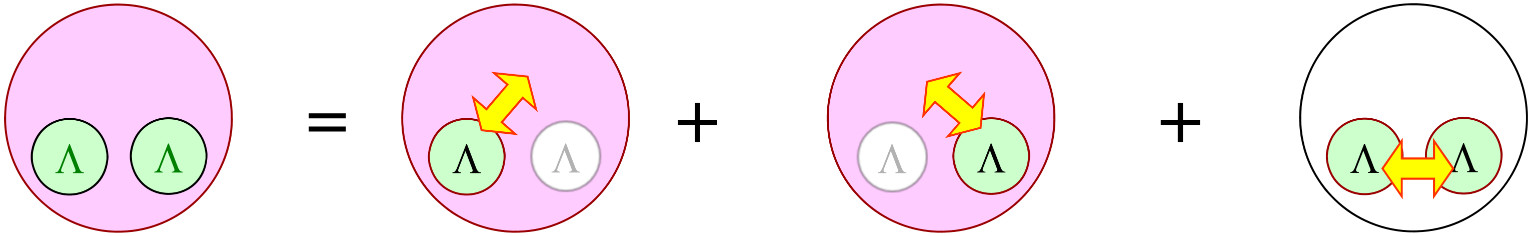






First approach to the ΛΛ interaction

- We are mainly interested in the additinal binding energy *between* the two Λs



$$\boxed{B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) \qquad -B_{\Lambda}({}^{A-1}_{\Lambda}Z) \qquad -B_{\Lambda}({}^{A-1}_{\Lambda}Z) \quad = \quad \Lambda B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z)}$$

- in the case of the Danysz-event one obtains

$$B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) + B_{\Lambda}({}^{A-1}_{\Lambda}Z) = (17.7 \pm 0.4)\,\mathrm{MeV}$$

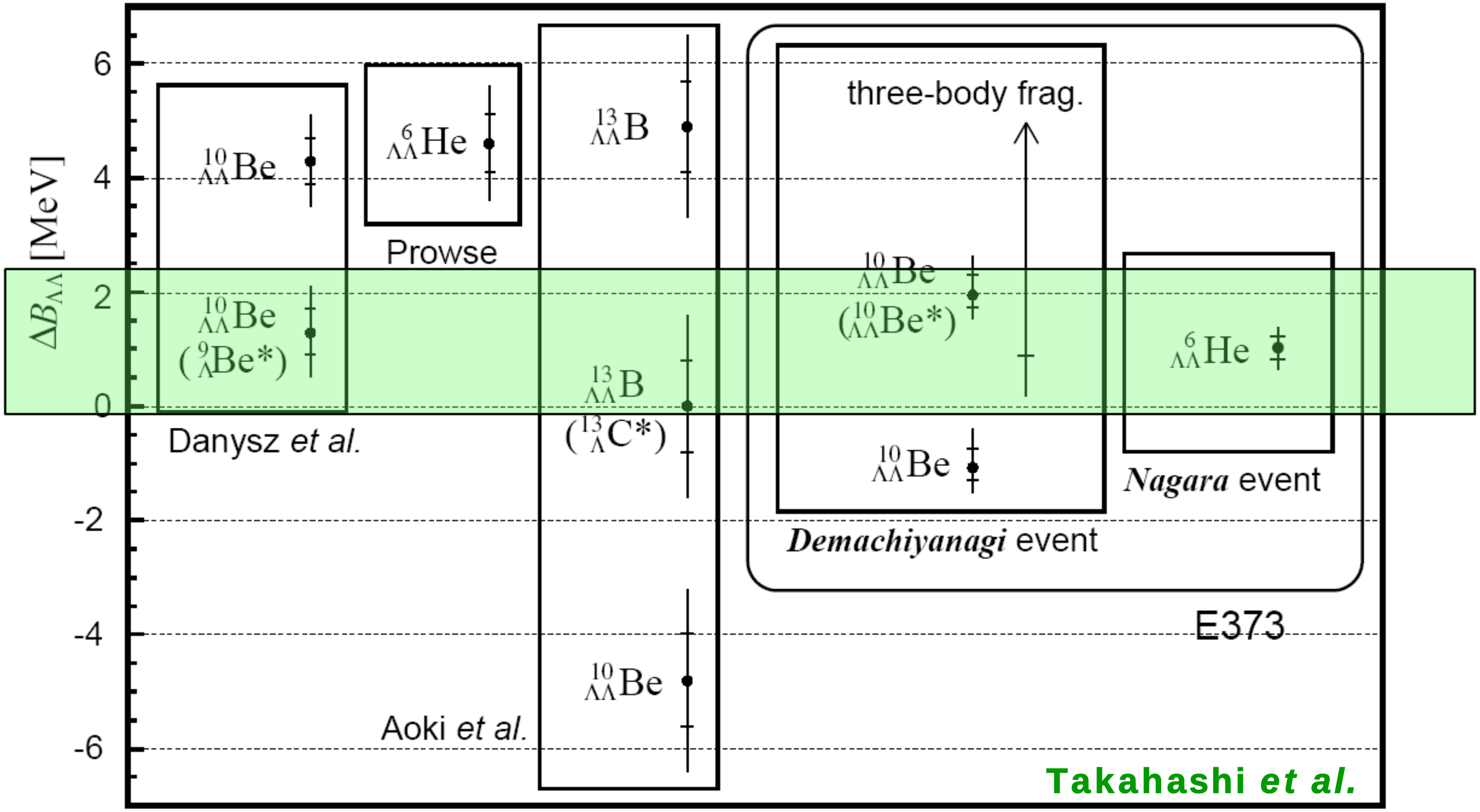
$$\Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) - B_{\Lambda}({}^{A-1}_{\Lambda}Z) = (4.3 \pm 0.4)\,\mathrm{MeV}$$

- positive ⇒ attractive interaction
- this is the net ΛΛ binding provided that
  - the core is not distorted by adding one Λ after the other
  - the core spin is zero
  - no γ-unstable excited states are produced

note:

$\Delta B_{\Lambda\Lambda}$ is proportional to the kinetic energy of the produced pions

Double Hypernuclei – Status <2009



- Interpreting $\Delta B_{\Lambda\Lambda}$ as $\Lambda\Lambda$ bond energy one has to consider e.g.
  - dynamical change of the core nucleus
  - ΛN spin-spin interaction for non-zero spin of core
  - $\Lambda\Lambda$-ΞN-$\Sigma\Sigma$ coupling
  - excited states possible, but have not been clearly identified so far

Double-Λ Hypernuclei via Capture Reaction of Ξ^- hyperon at rest in Hybrid-Emulsion Experiments

K.NAKAZAWA and KEK-E176 & E373 collaborators
Phys. Dept., Gifu Univ., JAPAN

Outline

1. Motivation of our experiment
2. Introduce recent data of double-Λ hypernuclei
    - 2-1. from KEK-E176
        - **13B$_{\Lambda\Lambda}$** nucleus ==> **S.Aoki et al., NP. A828 (2009) 191-232**
    - 2-2. from KEK-E373
        - / **NAGARA** event **6He$_{\Lambda\Lambda}$** nucleus
        - / **MIKAGE** event **6He$_{\Lambda\Lambda}$** nucleus
        - / **DEMACHI-YANAGI** event **10Be$_{\Lambda\Lambda}$** (Excited) nucleus
        - / **HIDA** event **11Be$_{\Lambda\Lambda}$** (**12Be$_{\Lambda\Lambda}$**) nucleus
3. Summary and near-future perspective

Summary and perspective (1)

By checking consistency of $\Delta B_{\Lambda\Lambda}$ (NAGARA) within 3 STD. errors,

	$^{A}_{\Lambda\Lambda}Z$	Ξ^- Captured	$B_{\Lambda\Lambda} - B_{\Xi^-}$ [MeV]	$\Delta B_{\Lambda\Lambda} - B_{\Xi^-}$ [MeV]	Assumed level	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
NAGARA	$^{6}_{\Lambda\Lambda}\mathrm{He}$	$^{12}\mathrm{C}$	$B_{\Lambda\Lambda} = 6.79 + 0.91 B_{\Xi^-}$ (+/- 0.16) $\Delta B_{\Lambda\Lambda} = 0.55 + 0.91 B_{\Xi^-}$ (+/- 0.17) $B_{\Xi^-} < 1.86$		3D	6.91 +/- 0.16	0.67 +/- 0.17
MIKAGE	$^{6}_{\Lambda\Lambda}\mathrm{He}$	$^{12}\mathrm{C}$	9.93 +/- 1.72	3.69 +/- 1.72	3D	10.06 +/- 1.72	3.82 +/- 1.72
DEMACHI-YANAGI	$^{10}_{\Lambda\Lambda}\mathrm{Be}^*$	$^{12}\mathrm{C}$	11.77 +/- 0.13	-1.65 +/- 0.15 *cf.* *Ex* = 3.0	3D	11.90 +/- 0.13	-1.52 +/- 0.15 *cf.* *Ex* = 3.0
HIDA	$^{11}_{\Lambda\Lambda}\mathrm{Be}$	$^{16}\mathrm{O}$	20.26 +/- 1.15	2.04 +/- 1.23	3D	20.49 +/- 1.15	2.27 +/- 1.23
	$^{12}_{\Lambda\Lambda}\mathrm{Be}$	$^{14}\mathrm{N}$	22.06 +/- 1.15	------	3D	22.23 +/- 1.15	------
E176	$^{13}_{\Lambda\Lambda}\mathrm{B} \to {}^{13}_{\Lambda}\mathrm{C}^*$		------ *Ex* = 4.9	-------	3D	23.3 +/- 0.7	0.6 +/- 0.8
	$^{10}_{\Lambda\Lambda}\mathrm{Be} \to {}^{9}_{\Lambda}\mathrm{Be}^*$		------ *Ex* = 3.0	-------	not checked, yet.	14.7 +/- 0.4	1.3 +/- 0.4

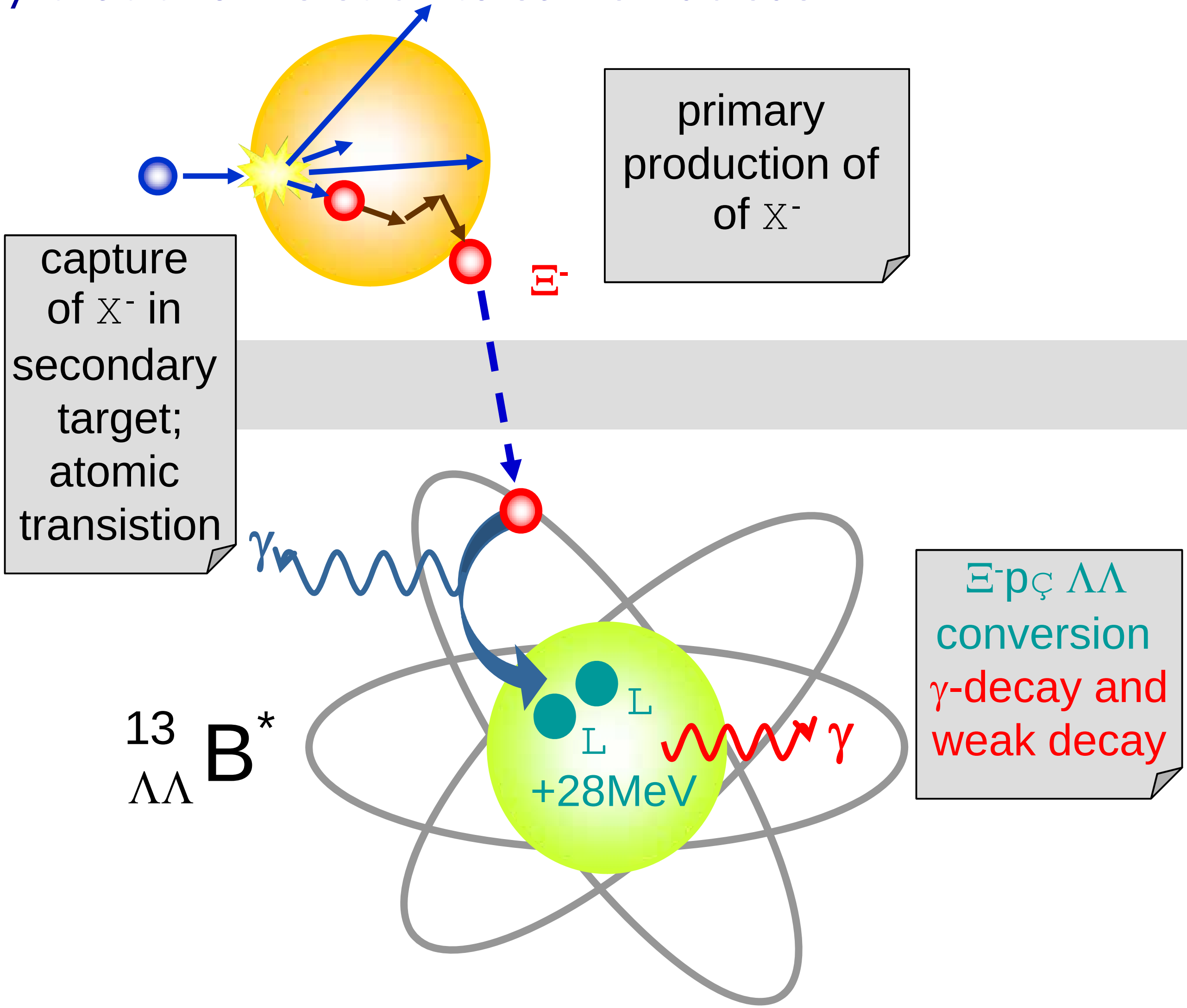
M.Danysz et al., PRL.11(1963)29;
R.H.Dalitz et al., Proc. R.S.Lond.A436(1989)1

B_{Ξ^-} (atomic 3D) = 0.13 MeV [^{12}C- Ξ^-], 0.17 MeV [^{14}N- Ξ^-], 0.23 MeV [^{16}O- Ξ^-].

Production of ΛΛ Hypernuclei

- simultaneous implantation of two Λ's impossible
- Ξ^- conversion in 2Λ: $\Xi^- + p \rightarrow \Lambda + \Lambda$ + 28MeV

⇒large probability that two Λ's stick to same nucleus

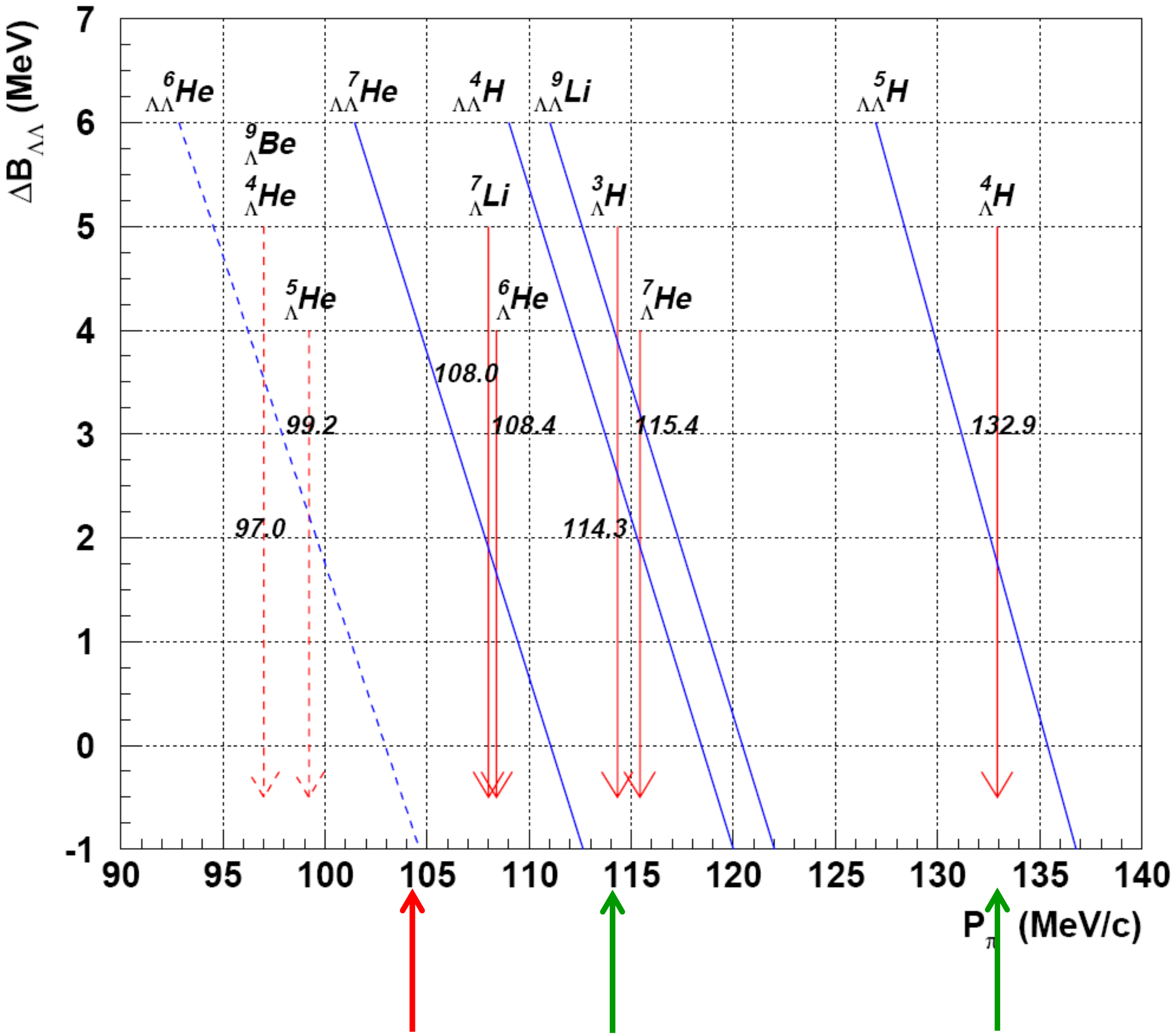


primary production of of X^-

capture of X^- in secondary target; atomic transition

Ξ^-pç ΛΛ conversion γ-decay and weak decay

Pion momenta



104 MeV/c

114 MeV/c

133 MeV/c

- …is not straight forward

Questions

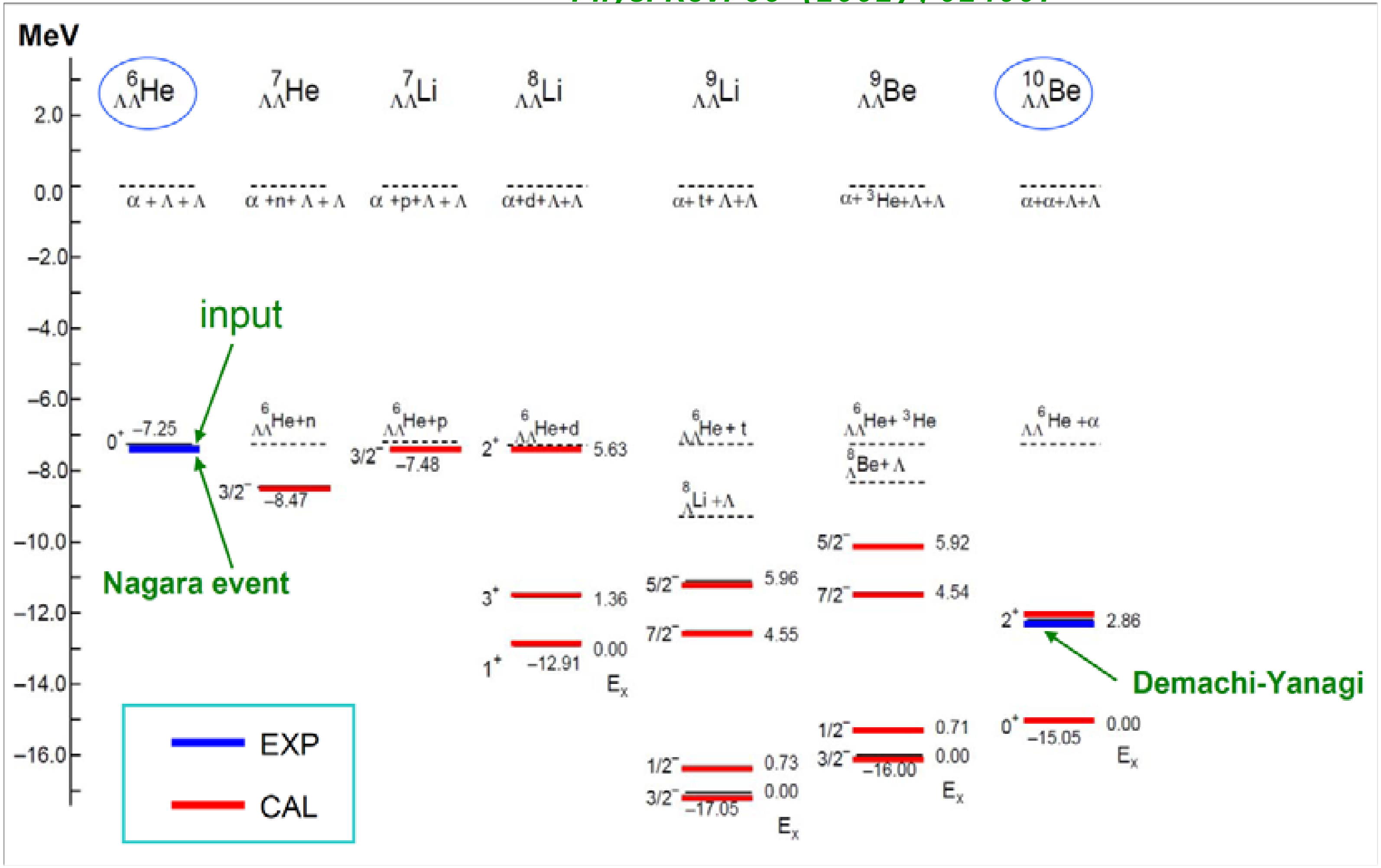
- Do excited states exist ?

- What is the chance that individual excited, particle stable states of double hypernuclei are produced ?

- Can we develop a strategy to identify and assign possible γ-transitions?

Spectroscopy of ΛΛ-hypernuclei

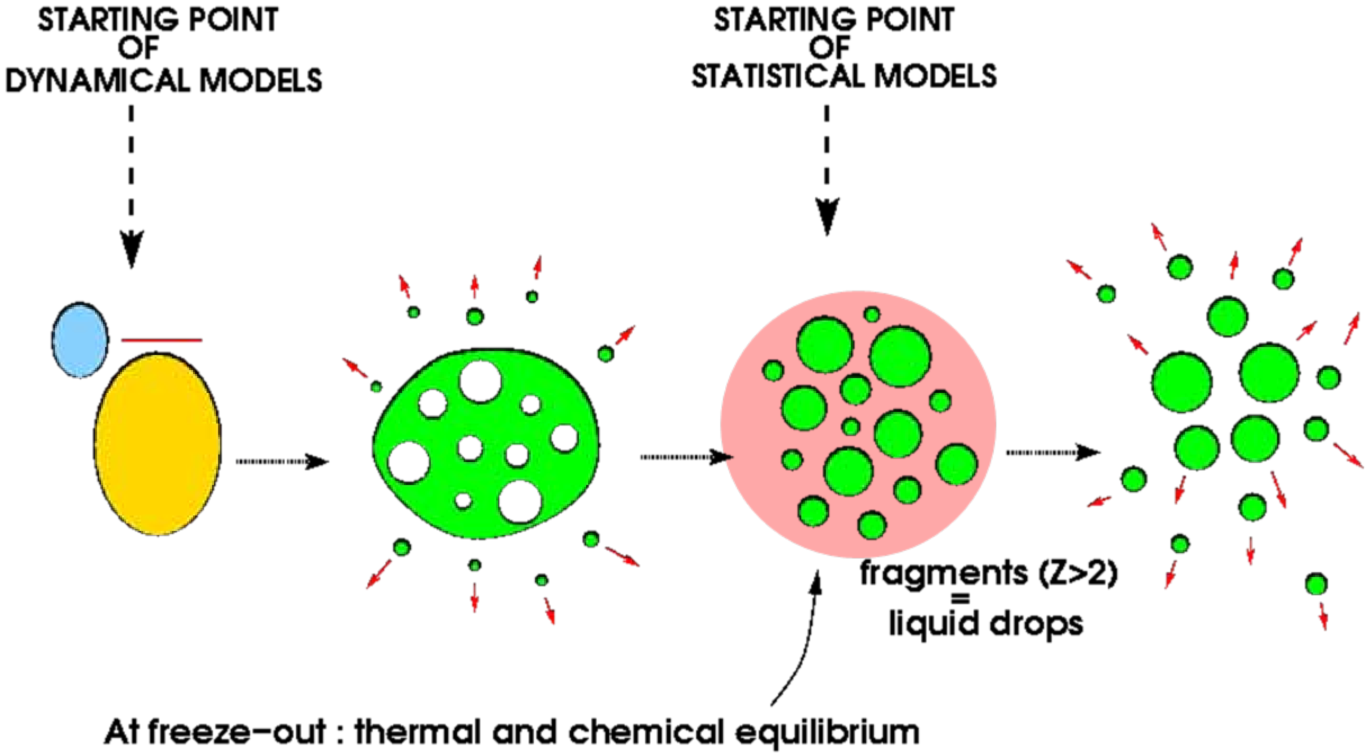
E. Hiyama, M. Kamimura, T.Motoba, T. Yamada and Y. Yamamoto
Phys. Rev. 66 (2002) , 024007



- many excited, particle stable states in double hypernuclei predicted
- level structure reflects levels of core nucleus

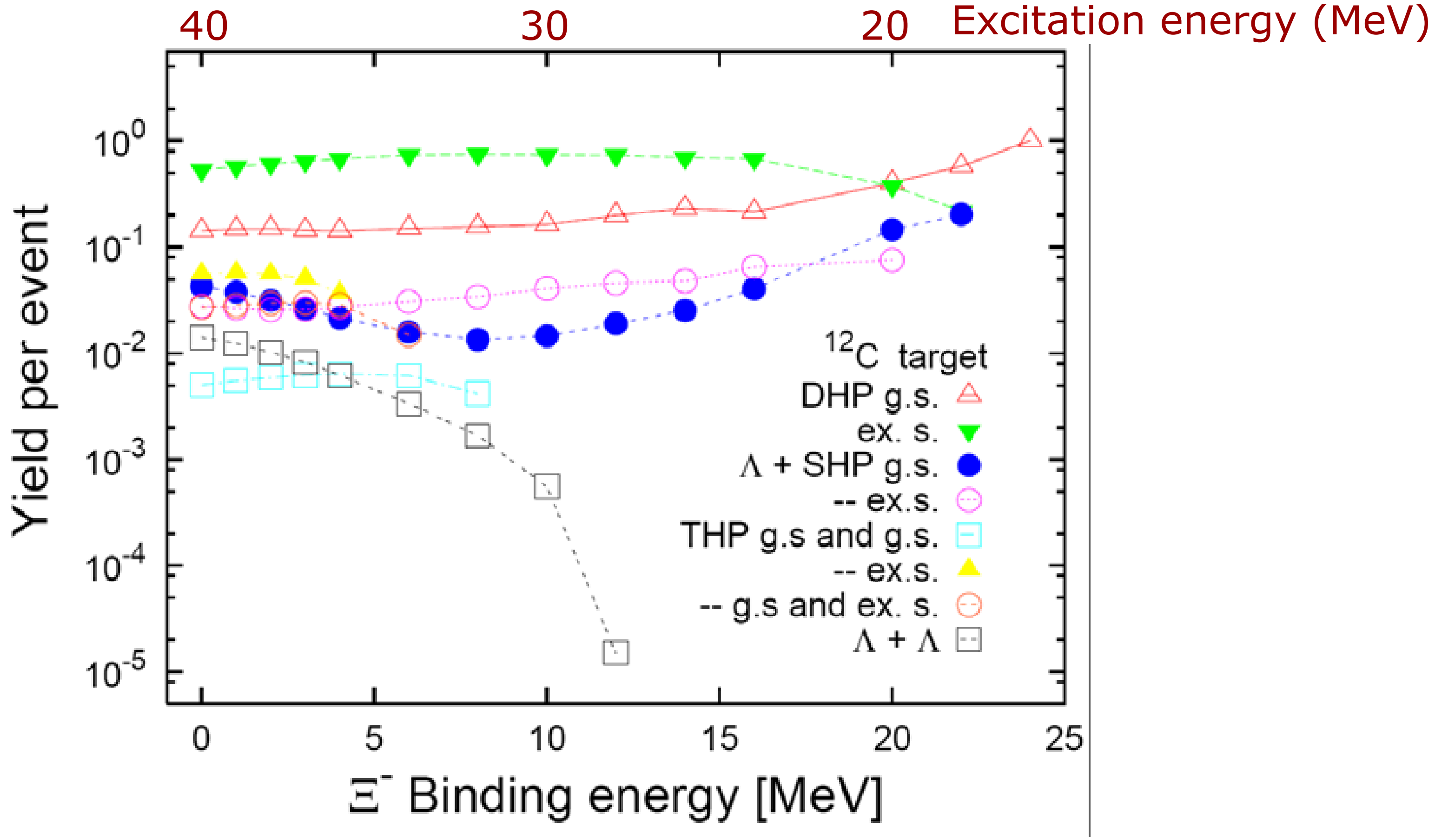
Multifragmentation

- conversion width Ξ+pç $\Lambda\Lambda$ around Γ=1MeV
- excitation energy ~ 40MeV/12≈ 3MeV/nucleon
  - fragmentation of excited projectile remnants are well understood in that regime
- ⇒ Statistical decay models may work ***(E. Fermi; J.P. Bondorf et al.)***
  - De-excitation of light nuclei via Fermi break-up process
  - Conservation of A, Z, H, Energy and momentum



Excitation Function for $^{13}_{\Lambda\Lambda}B^*$ decays

- DHP ▼△: double hypernuclei dominates
- SHP ●○ : single hypernuclei below B_Ξ=-12MeV only $^{12}{}_\Lambda B$ states
- THP □▲○: twin hypernuclei ~10%



- note: relevant range probably B_Ξ≈-5…0MeV

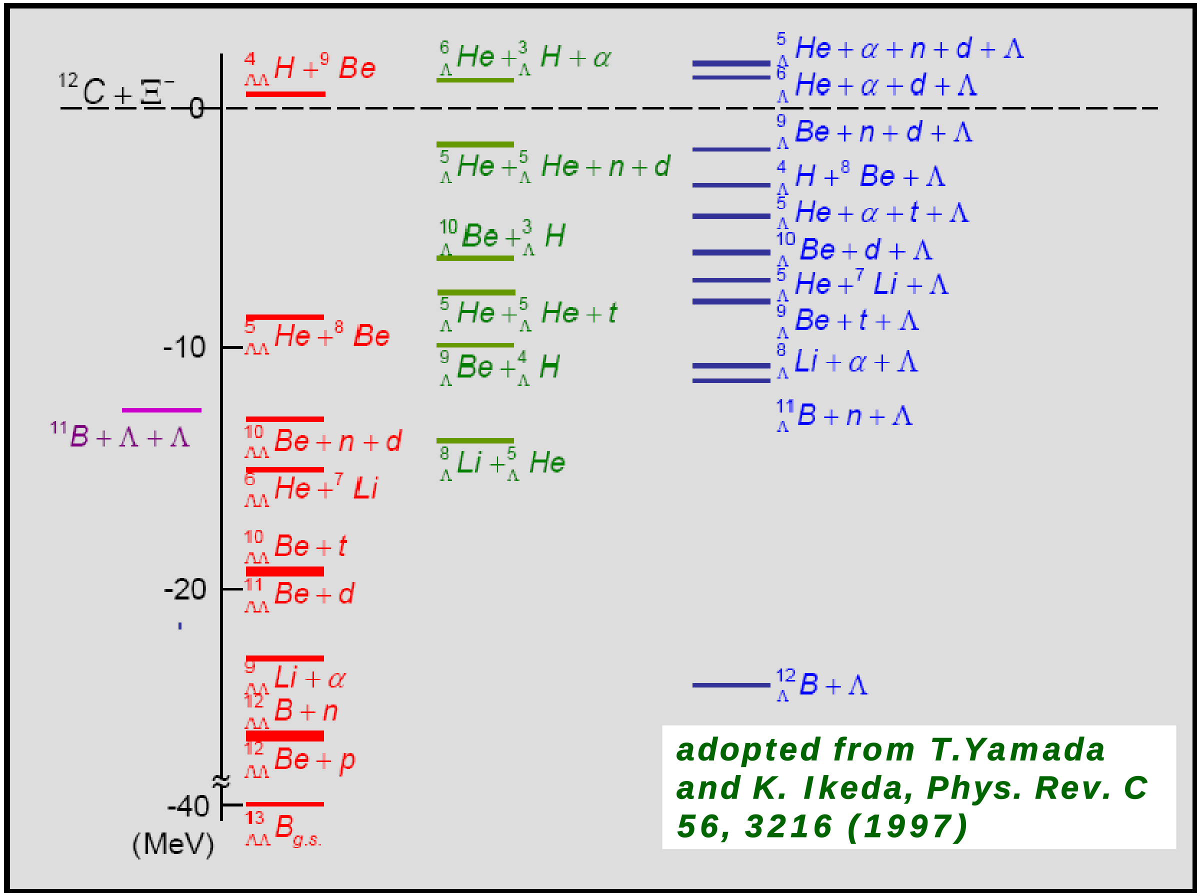
Energy Balance for Ξ conversion

- Maximum energy available with respect to $^{13}_{\Lambda\Lambda}\mathrm{B}_{g.s.}$ ≈40 MeV

$$E_x = m(^{12}C) + m(\Xi^-) + B_\Xi - m(^{13}_{\Lambda\Lambda}B)$$

- Ξ^- binding energy unknown
  - Theoreticals calculations on Ξ nuclear potential leads to 0.6 – 3.7 MeV

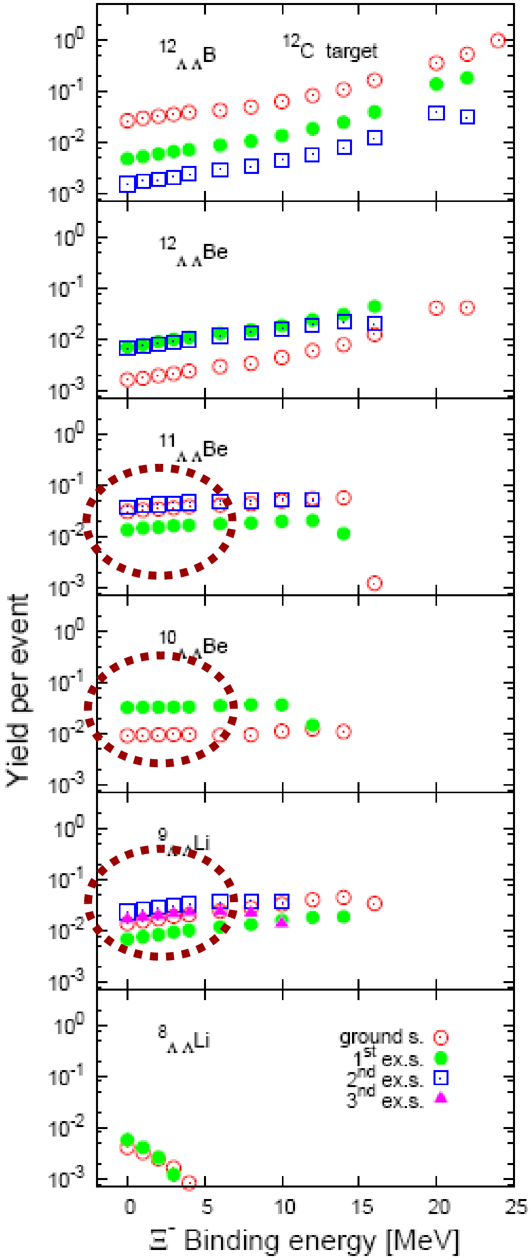
    (C.J Batty et al, Aoki et al.,…)



adopted from T.Yamada and K. Ikeda, Phys. Rev. C 56, 3216 (1997)

Population of individual states for ^{12}C

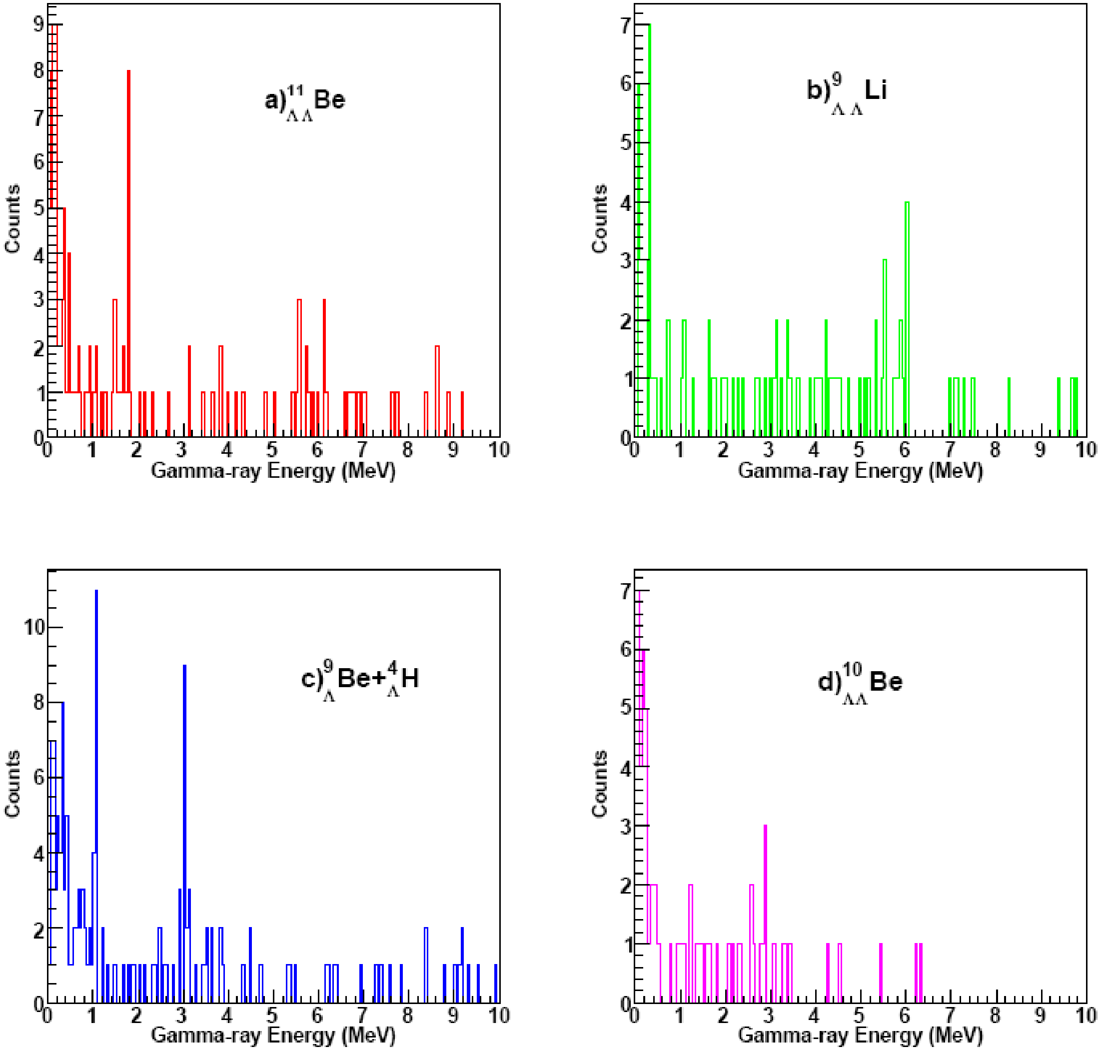
- ${}^{9}_{\Lambda\Lambda}$Li, ${}^{10}_{\Lambda\Lambda}$Be, ${}^{11}_{\Lambda\Lambda}$Be dominate (few percent)
- excited state in ${}^{10}_{\Lambda\Lambda}$Be more likely than ground state ⇒ c.f. E. Hiyama
- relative large probability (~5%) for individual *excited* states ● □



Simulation within PANDA_ROOT

- Example: secondary ^{12}C target (~2 weeks$^{*)}$)

Alicia Sanchez (Mainz)

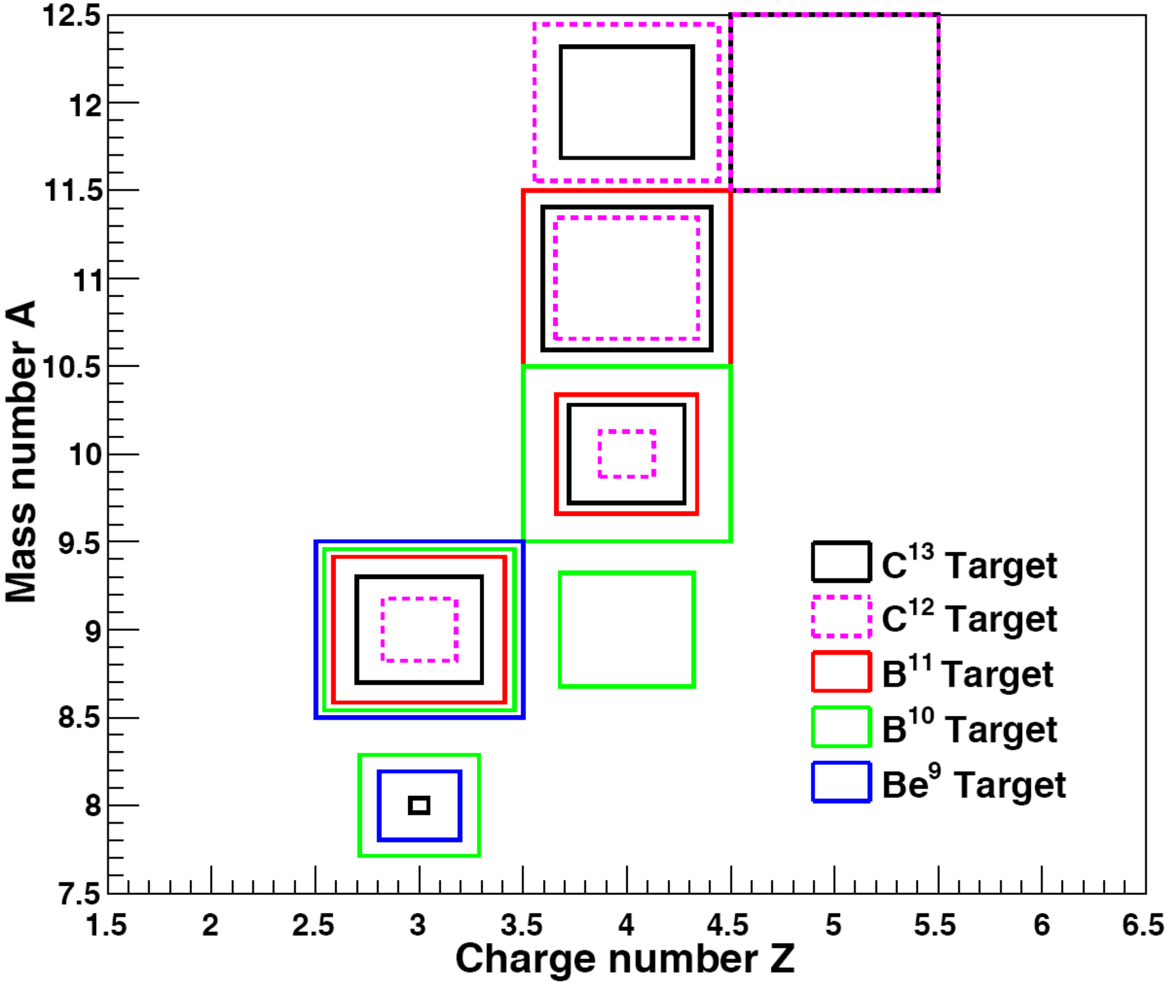


$^{*)}$In these simulations we assume a Ξ capture and conversion probability of 5%

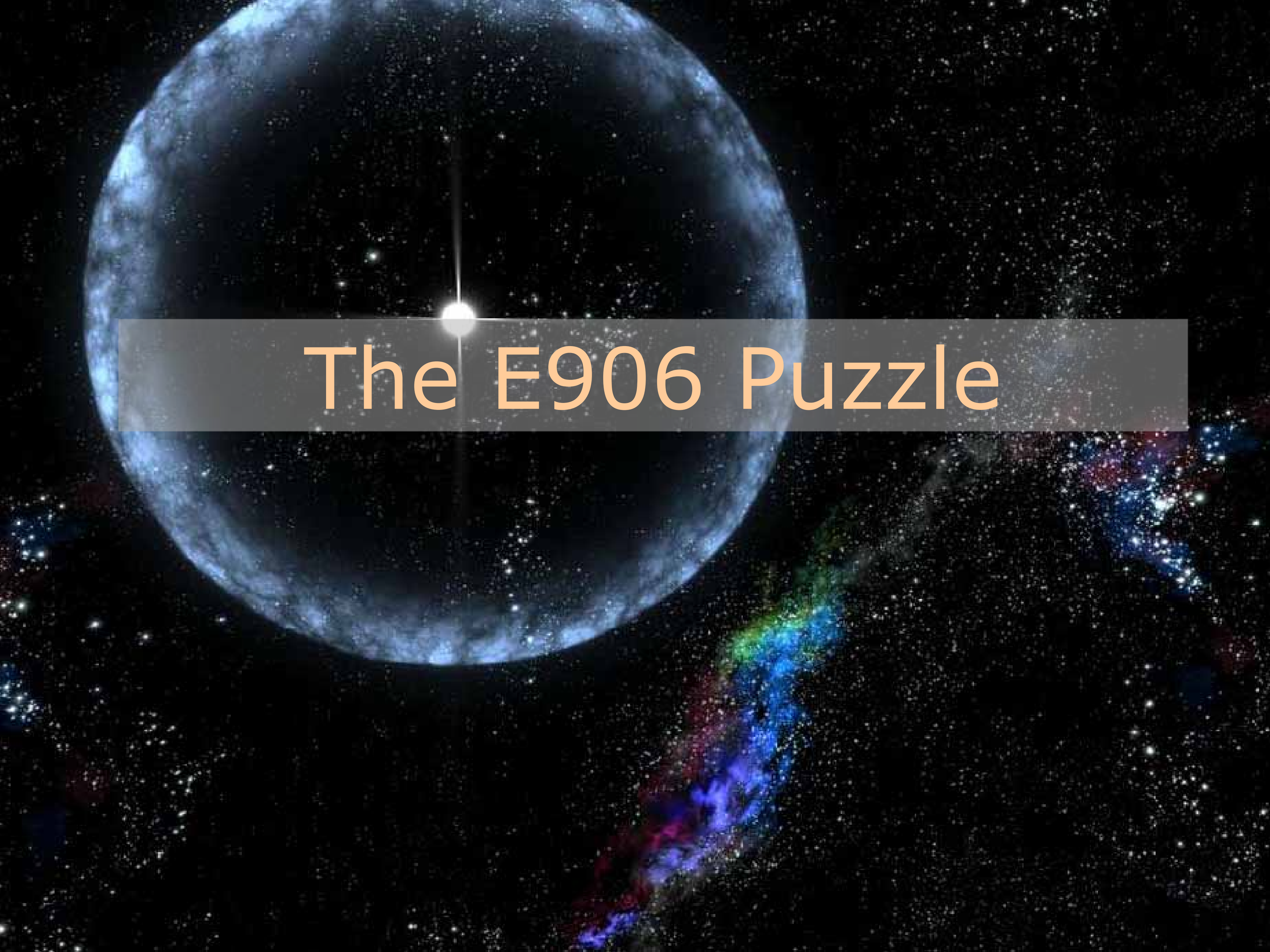
(arXiv:0903.3905)

Identification of double hypernuclei

- PANDA will explore several targets: ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C
- Sum of dominating first and second excited state



- caveat: probabilities need to be folded with efficiency



The E906 Puzzle

DIE WELT 4. September 2001

AGS-E906

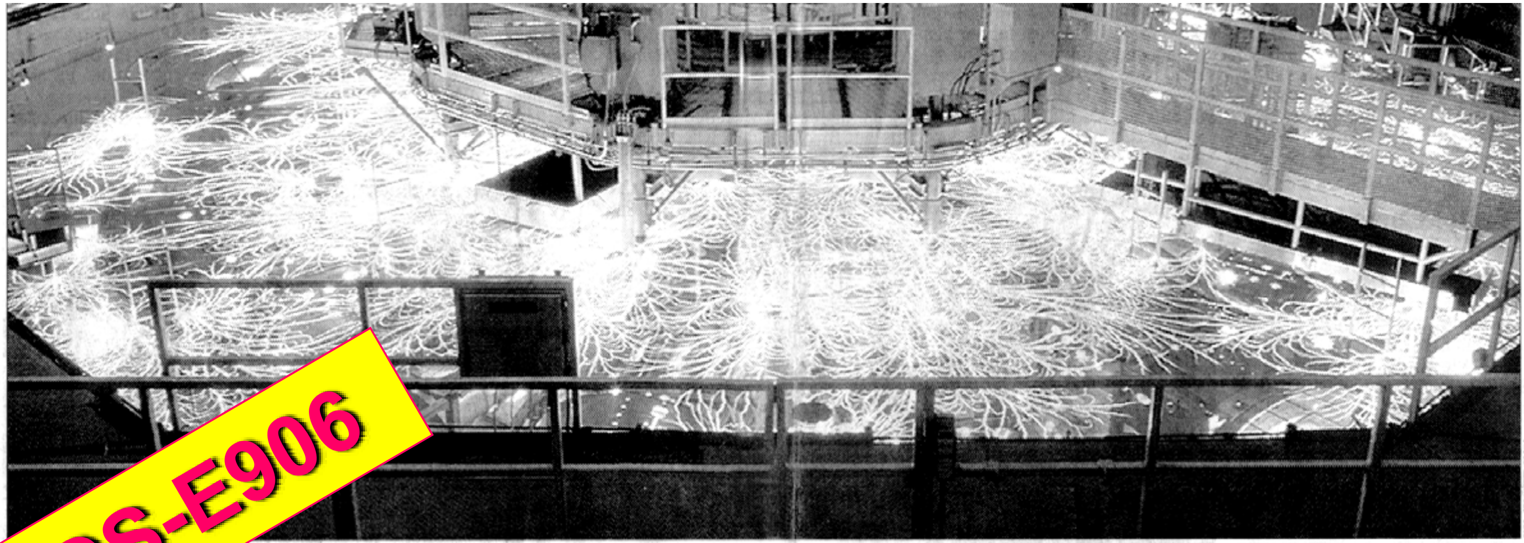


FOTO: STEINMETZ/FOCUS

n die modernen Alchimisten Materie ineinander um oder erzeugen gar Materieformen, die es auf der Erde überhaupt nicht gibt. Das Foto zeigt eine Kernfusionsanlage in Neu-Mexiko

Doppelt seltsame Atomkerne synthetisiert

Nach 40 Jahren gelingt Physikern in den USA die Herstellung von exotischer Neutronenstern-Materie

VON BRIGITTE RÖTHLEIN

Brookhaven – Drei Jahre nach Abschluss einer Serie von Experimenten konnten Forscher im Brookhaven National Lab auf Long Island bei der Auswertung der Ergebnisse eine bisher nicht bekannte Art von Materie nachweisen. Sie entstand 1998 bei Zusammenstößen von Wolframatomen mit superschnellen Protonen.

Die Physiker sprechen von „doppelt seltsamen Kernen" und bringen damit zum Ausdruck, dass sich bei den Kollisionen im Beschleuniger ein Komplex aus mehreren Teilchen gebildet hat, der normalen Atomkernen nicht unähnlich ist. Das Besondere daran ist jedoch, dass diese Gebilde je zwei „seltsame" Teilchen enthalten.

Die Experimente von Teilchenforschern laufen in Sekundenbruchteilen ab. Man lässt dabei beschleunigte Elementarteilchen auf Ziele prallen und untersucht mit Hilfe großer Detektoren, welche Bruchstücke dabei entstehen. Die Vielzahl der in den letzten Jahrzehnten auf diese Weise entdeckten Teilchen hat gezeigt, dass sich unsere „normale" Materie auf zwei so genannte Quarks (mit den Namen „up" und „down") und Elektronen zurückführen lässt.

Daneben gib es aber auch noch exotische Arten von Materie, die aus schwereren Teilchen bestehen und auf der Erde üblicherweise nicht vorkommen. Zur Unterscheidung erhielten die Quarks dieser Materie die willkürlich gewählten Namen „strange" (seltsam) und „charme".

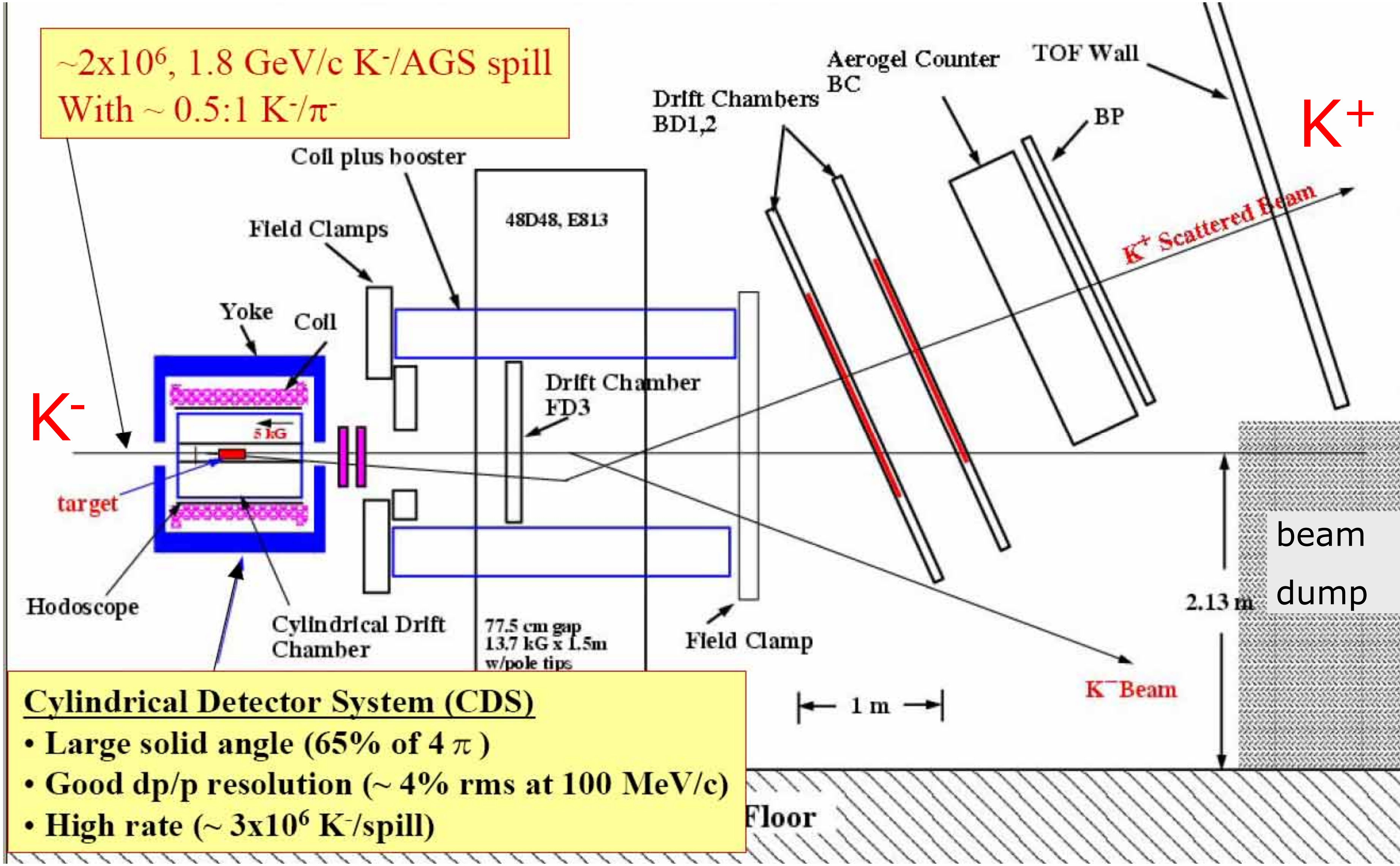
Aus den Millionen von Daten, die während einer Messkampagne entstehen, müssen die Physiker am Ende die wirklich relevanten „Ereignisse" herausfinden, die sprichwörtliche Nadel im Heuhaufen. In Brookhaven hat sich die Mühe offenbar gelohnt; aus 100 Millionen infrage kommenden Ereignissen filterten Computer zunächst 100 000 heraus, unter denen man dann 30 bis 40 mit den gesuchten Eigenschaften fand. „Hier wurde zum ersten Mal eine größere Anzahl von seltsamen Atomkernen erzeugt", erklärt Adam Rusek, der stellvertretende Sprecher der 50 beteiligten Physiker aus sechs Ländern.

40 Jahre lang hatte man in den USA, Europa und Japan nach den Gebilden gesucht, aber nur je eines davon gefunden, zum Teil mit zweifelhafter Sicherheit. Nun gelang es nachzuweisen, dass über einen mehrstufigen Zerfallsprozess Strukturen entstanden waren, die aus einem Neutron, einem Proton und zwei Lambda-Teilchen bestanden. Diese enthalten je ein up- und ein down-Quark und ein seltsames (strange) Quark. Die Lambda-Paare sind nun die bejubelten „doppelt seltsamen Kerne". Es ist allerdings sehr schwierig, sie näher zu untersuchen, da sie bereits nach weniger als einer Milliardstel Sekunde wieder zerfallen.

Die Forscher erhoffen sich vom Studium der seltsamen Kerne Erkenntnisse über jene Kräfte, die zwischen den Teilchen wirken. Daraus wollen sie Rückschlüsse auf die Prozesse in so genannten Neutronensternen ziehen. Diese Himmelskörper entstehen, wenn heiße Sterne am Ende ihres Lebens ausgebrannt sind und in sich zusammenstürzen. Man vermutet, dass sie große Mengen seltsamer Teilchen enthalten und dass sie der einzige Ort im All sind, wo seltsame Materie stabil existiert.

Weitere Informationen im Web:
www.bnl.gov

The E906 experiment



~2×10^6, 1.8 GeV/c K^-/AGS spill
With ~ 0.5:1 K^-/π^-

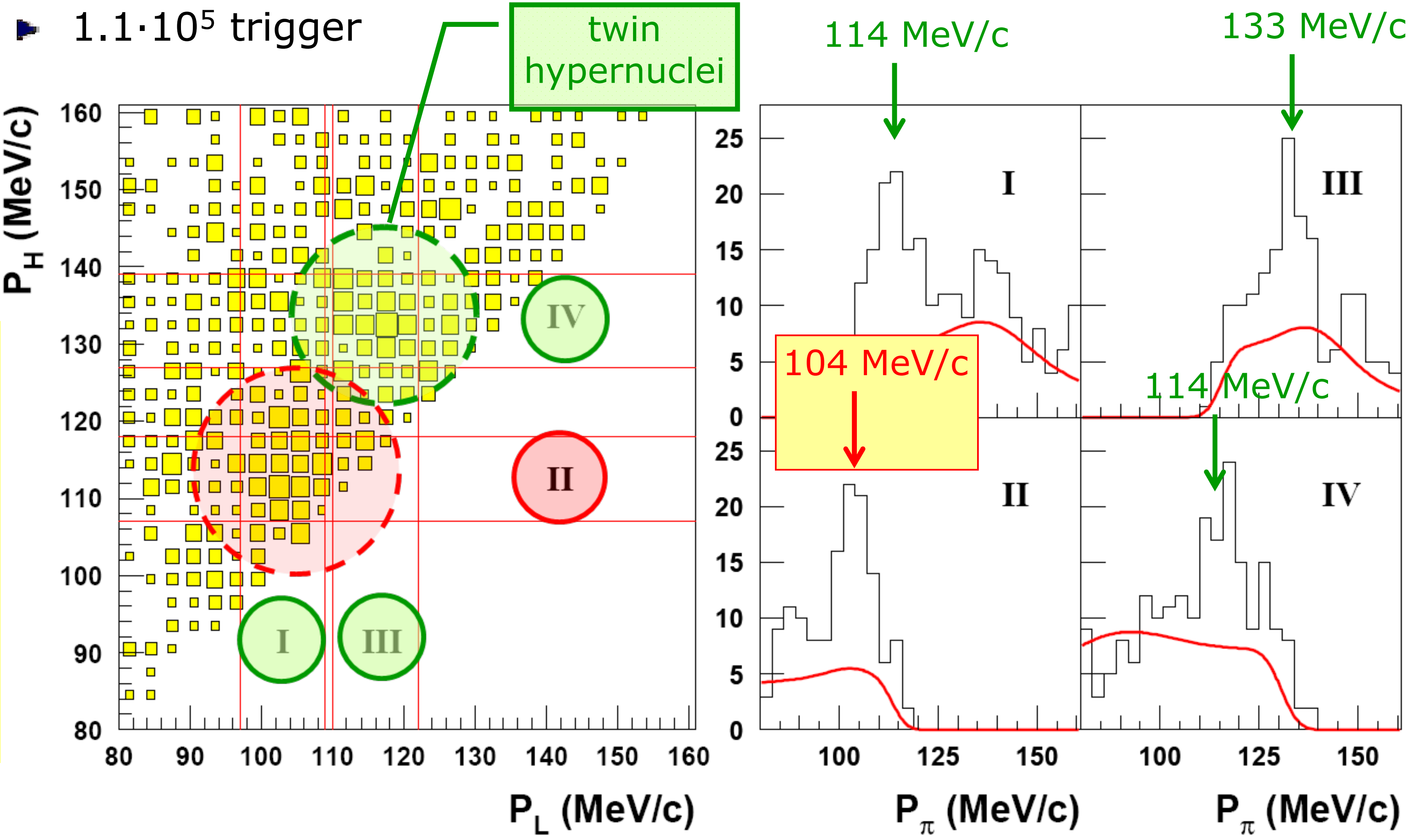
Cylindrical Detector System (CDS)

- Large solid angle (65% of 4 π)
- Good dp/p resolution (~ 4% rms at 100 MeV/c)
- High rate (~ 3×10^6 K^-/spill)

E906

- $9 \cdot 10^{11}$ K^- on Be target
- $1.1 \cdot 10^5$ trigger

consistent with single Λ hypernuclei



twin hypernuclei

114 MeV/c

133 MeV/c

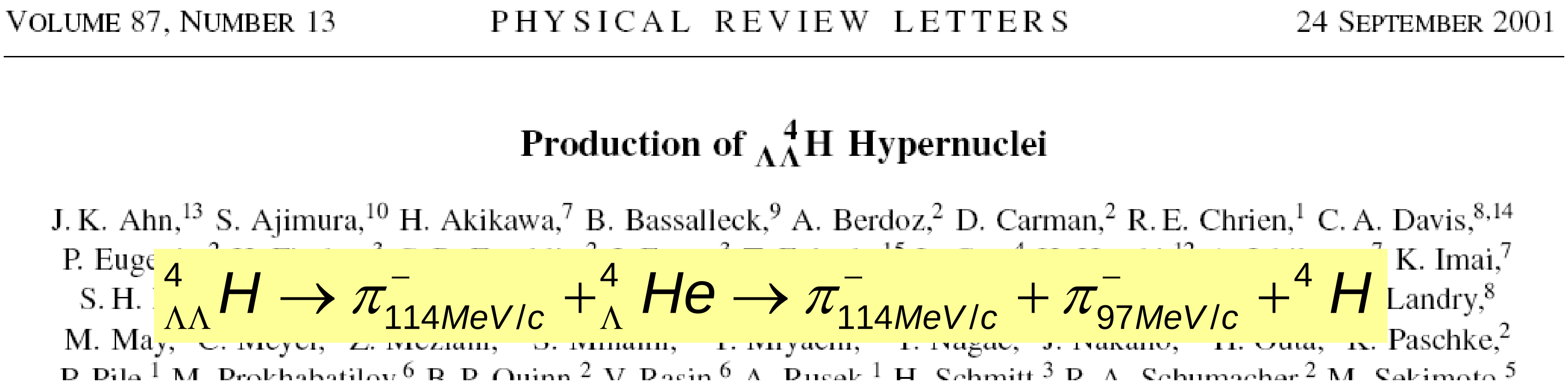
104 MeV/c

114 MeV/c

momentum of the pion with lower momentum

momentum of the pion with lower momentum

E906 – What is it?



VOLUME 87, NUMBER 13 PHYSICAL REVIEW LETTERS 24 SEPTEMBER 2001

Production of $^{4}_{\Lambda\Lambda}$H Hypernuclei

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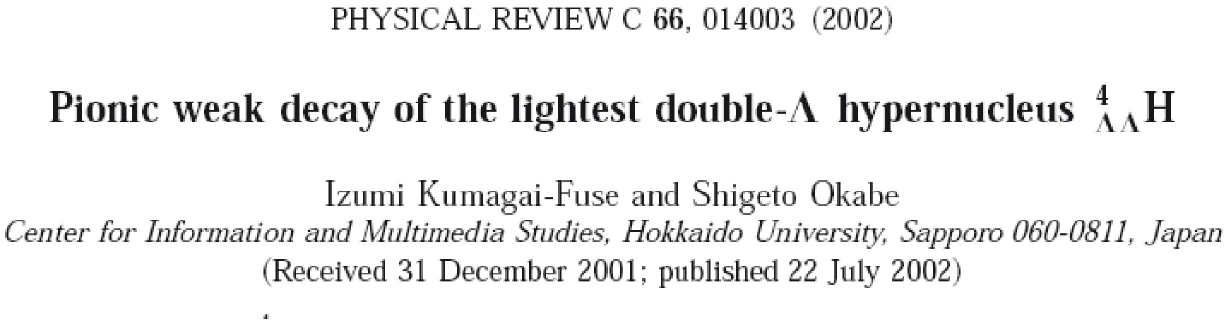
P. Pile,[1] M. Prokhabatilov,[6] R. P. Quinn,[2] V. Rasin,[6] A. Rusek,[1] H. Schmitt,[3] R. A. Schumacher,[2] M. Sekimoto,[5]

$$^{4}_{\Lambda\Lambda}H \rightarrow \pi^{-}_{114MeV/c} + {}^{4}_{\Lambda}He \rightarrow \pi^{-}_{114MeV/c} + \pi^{-}_{97MeV/c} + {}^{4}H$$



PHYSICAL REVIEW C 66, 014003 (2002)

Pionic weak decay of the lightest double-Λ hypernucleus $^{4}_{\Lambda\Lambda}$H

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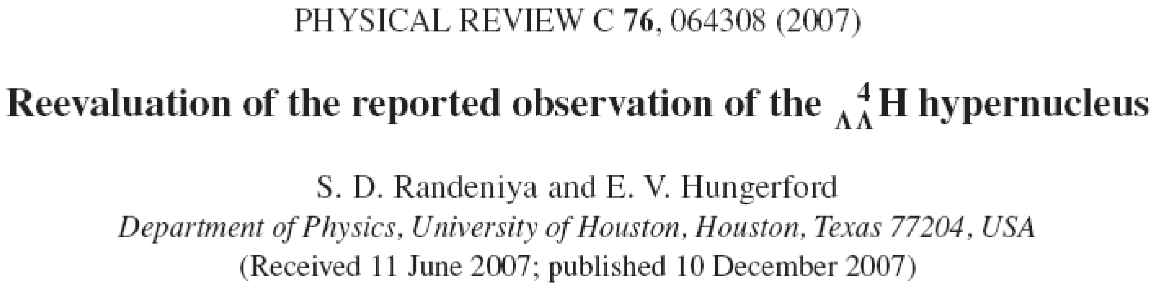
(Received 31 December 2001; published 22 July 2002)

$$^{3}_{\Lambda}H + {}^{6}_{\Lambda}He$$

$$^{7}_{\Lambda\Lambda}He$$



PHYSICAL REVIEW C 76, 064308 (2007)

Reevaluation of the reported observation of the $^{4}_{\Lambda\Lambda}$H hypernucleus

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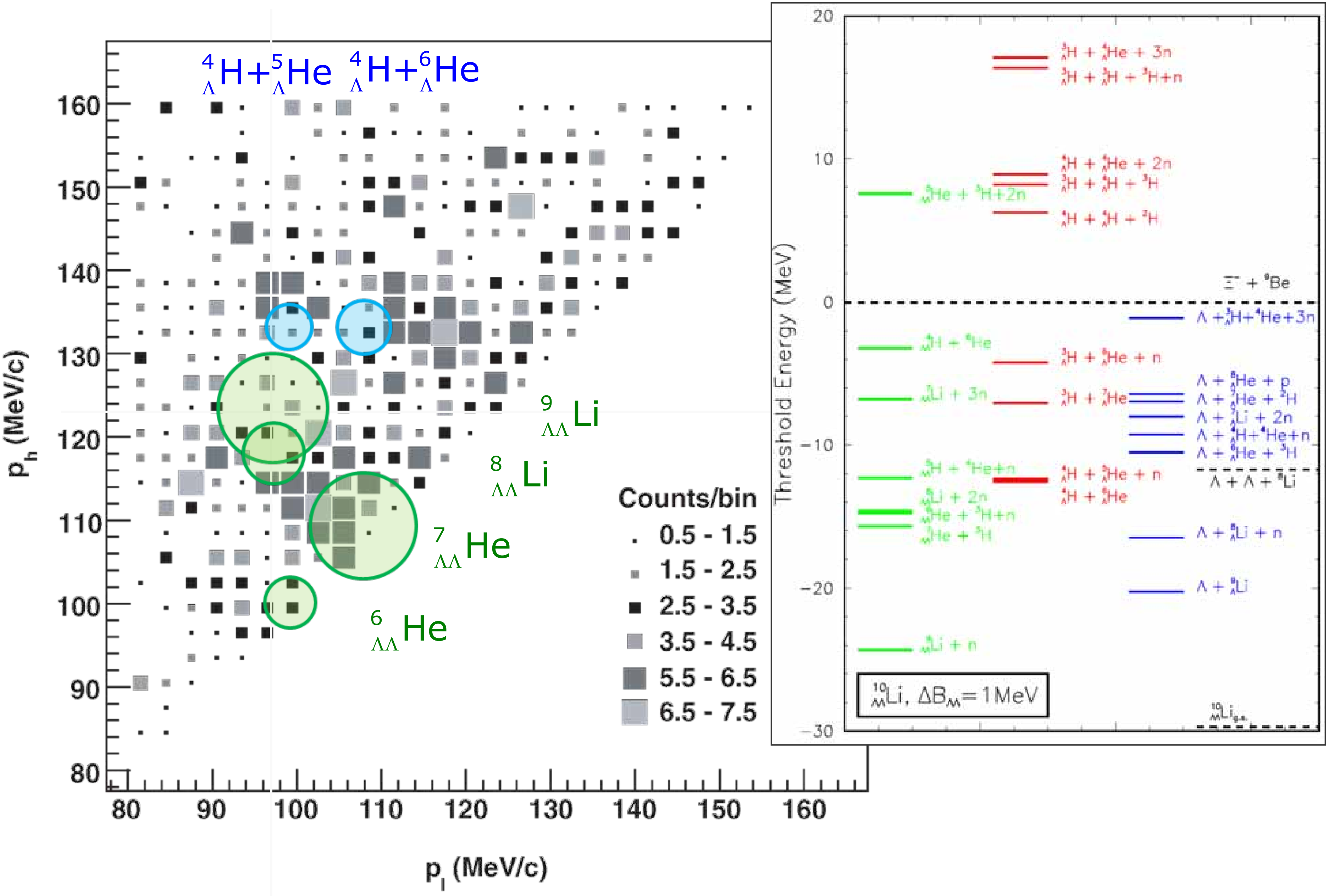
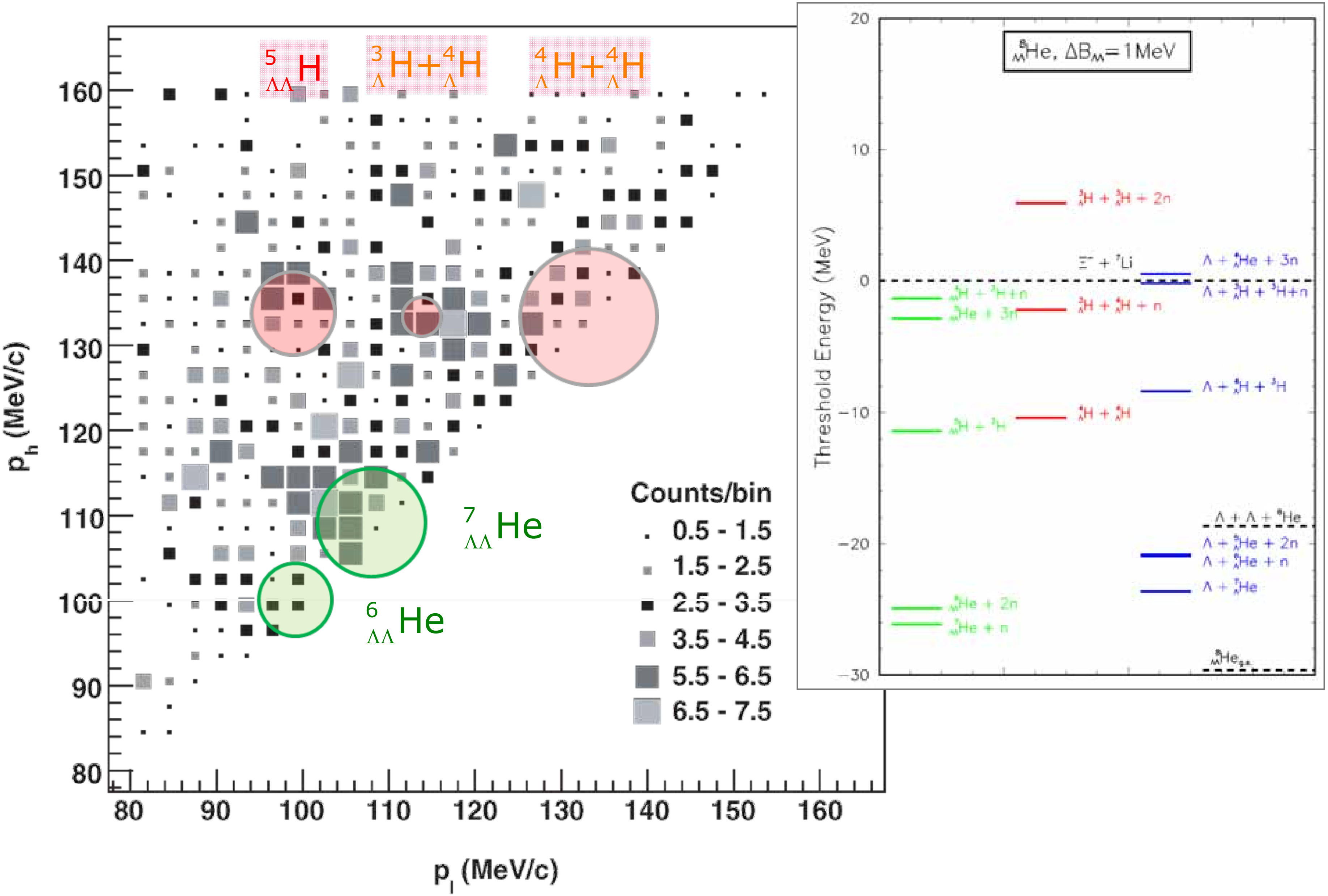
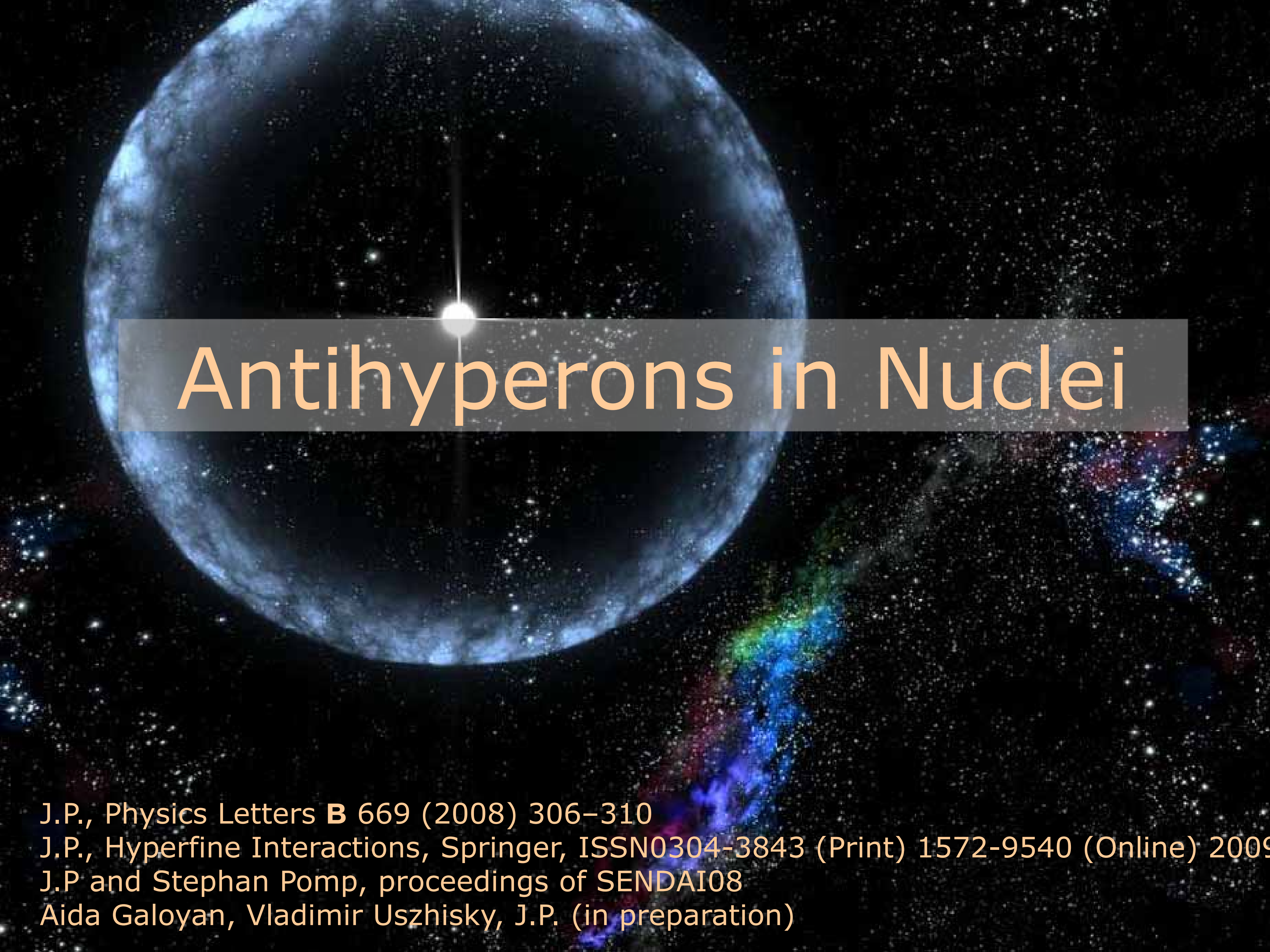
(Received 11 June 2007; published 10 December 2007)

Ξ^- Stopping & Fusion: $\Xi^- + {}^9Be \rightarrow {}^{10}_{\Lambda\Lambda}Li^*$



$p(K^-,K^+)\Xi^-$ & N kickout $\Rightarrow {}^{8}_{\Lambda\Lambda}He^*$ or ${}^{8}_{\Lambda\Lambda}H^*$





Antihyperons in Nuclei

J.P., Physics Letters **B** 669 (2008) 306–310
J.P., Hyperfine Interactions, Springer, ISSN0304-3843 (Print) 1572-9540 (Online) 200
J.P and Stephan Pomp, proceedings of SENDAI08
Aida Galoyan, Vladimir Uszhisky, J.P. (in preparation)

Nuclei with hyperons

Increasing strangeness

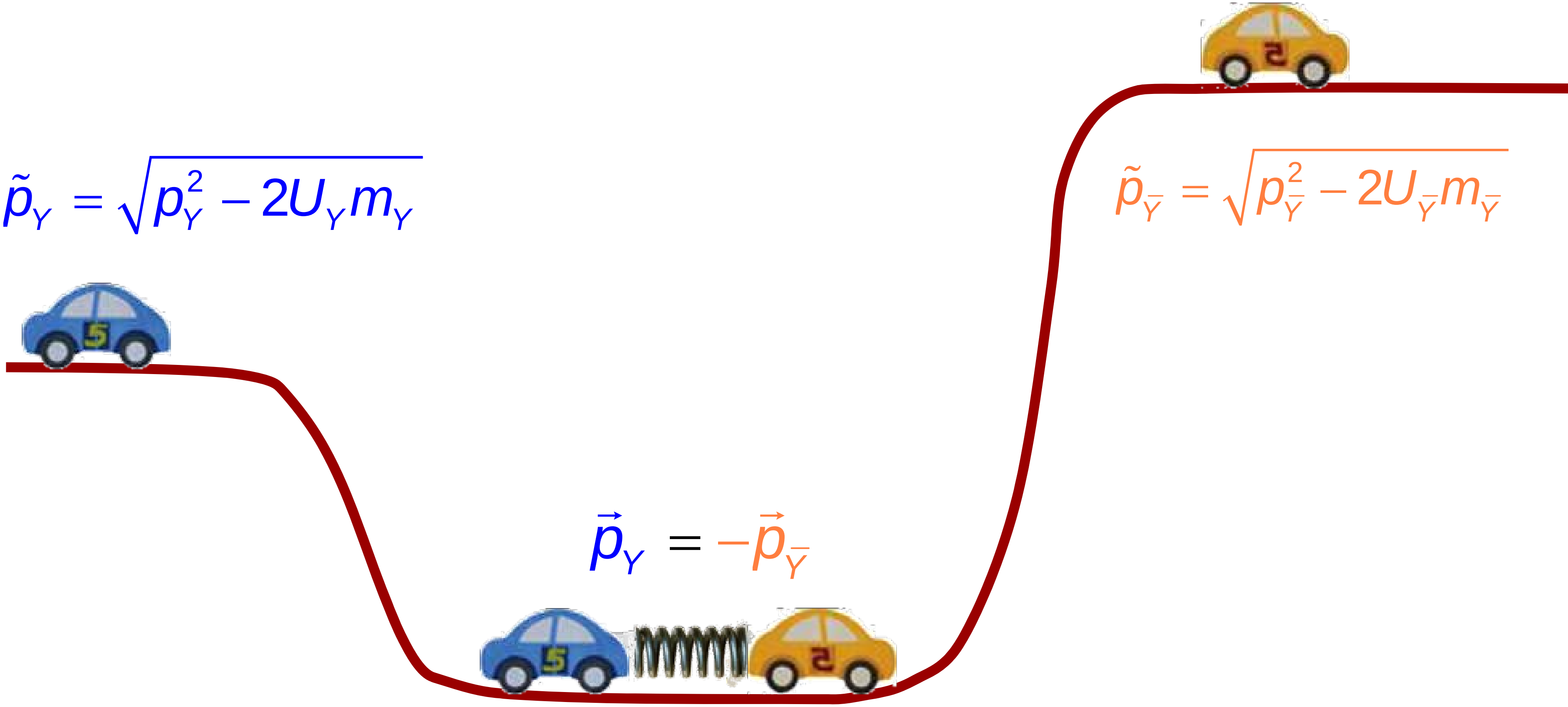
Nucleon	≈ -40MeV
Lambda	≈ -27MeV
Cascade	~ -15MeV
Antinucleon	~ -150MeV
Antilambda	?
Anticascade	?

Can we do a scattering experiment with low momentum antihyperons?

In principle Yes !

HESR + ЯƧƎH

How to measure a potential (difference)



$$\tilde{p}_Y = \sqrt{p_Y^2 - 2U_Y m_Y}$$

$$\tilde{p}_{\bar{Y}} = \sqrt{p_{\bar{Y}}^2 - 2U_{\bar{Y}} m_{\bar{Y}}}$$

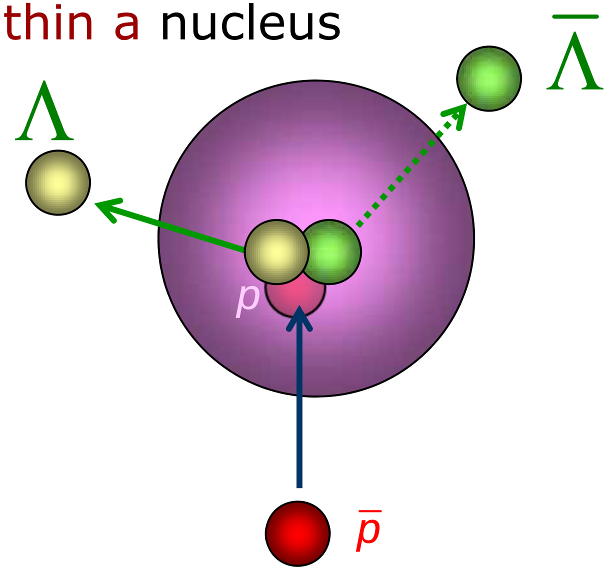
$$\vec{p}_Y = -\vec{p}_{\bar{Y}}$$

- If $m_Y \approx m_Y \approx m$ and $U_Y \approx U_Y \approx U \Rightarrow$

$$\alpha = \frac{\tilde{p}_Y - \tilde{p}_{\bar{Y}}}{\tilde{p}_Y + \tilde{p}_{\bar{Y}}} = \frac{\sqrt{p_0^2 - 2m_Y U_Y} - \sqrt{p_0^2 - 2m_{\bar{Y}} U_{\bar{Y}}}}{\sqrt{p_0^2 - 2m_Y U_Y} + \sqrt{p_0^2 - 2m_{\bar{Y}} U_{\bar{Y}}}} \approx \frac{U_{\bar{Y}} - U_Y}{4\left(\frac{p_0^2}{2m} - U\right)} \approx \frac{U_{\bar{Y}} - U_Y}{4E_{kin}}$$

Can we measure the potential for $\overline{Y}$?

- antiprotons are optimal for the production of mass without large momenta
- consider p+p ç Y+Y close to threshold within a nucleus
- Λ and L that leave the nucleus will have different asymptotic momenta depending on the respective potential

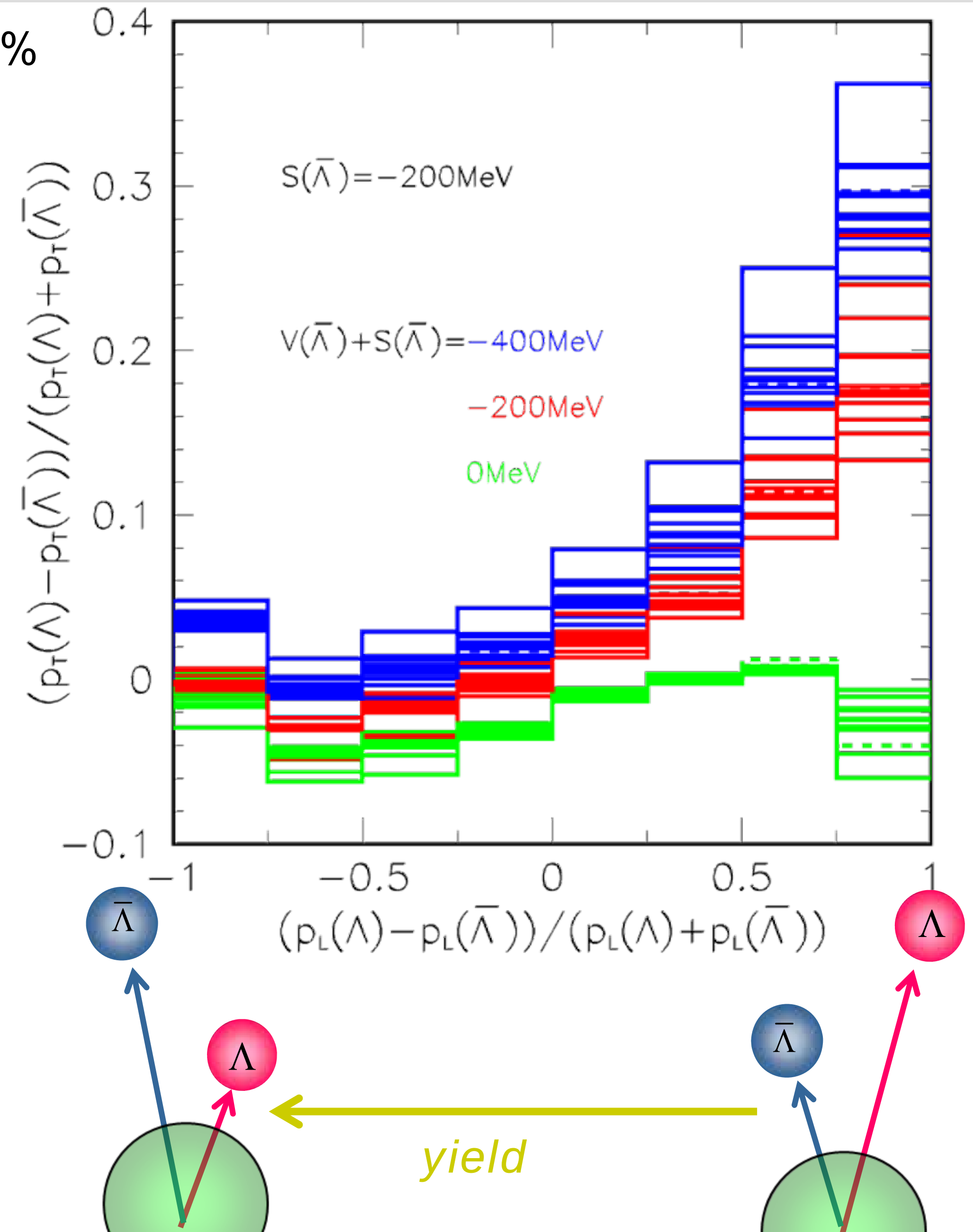


- experimental complications
  - Fermi motion of struck proton
  - Non-isotropic production
  - Density distribution U(ρ)
  - Exclusiveness

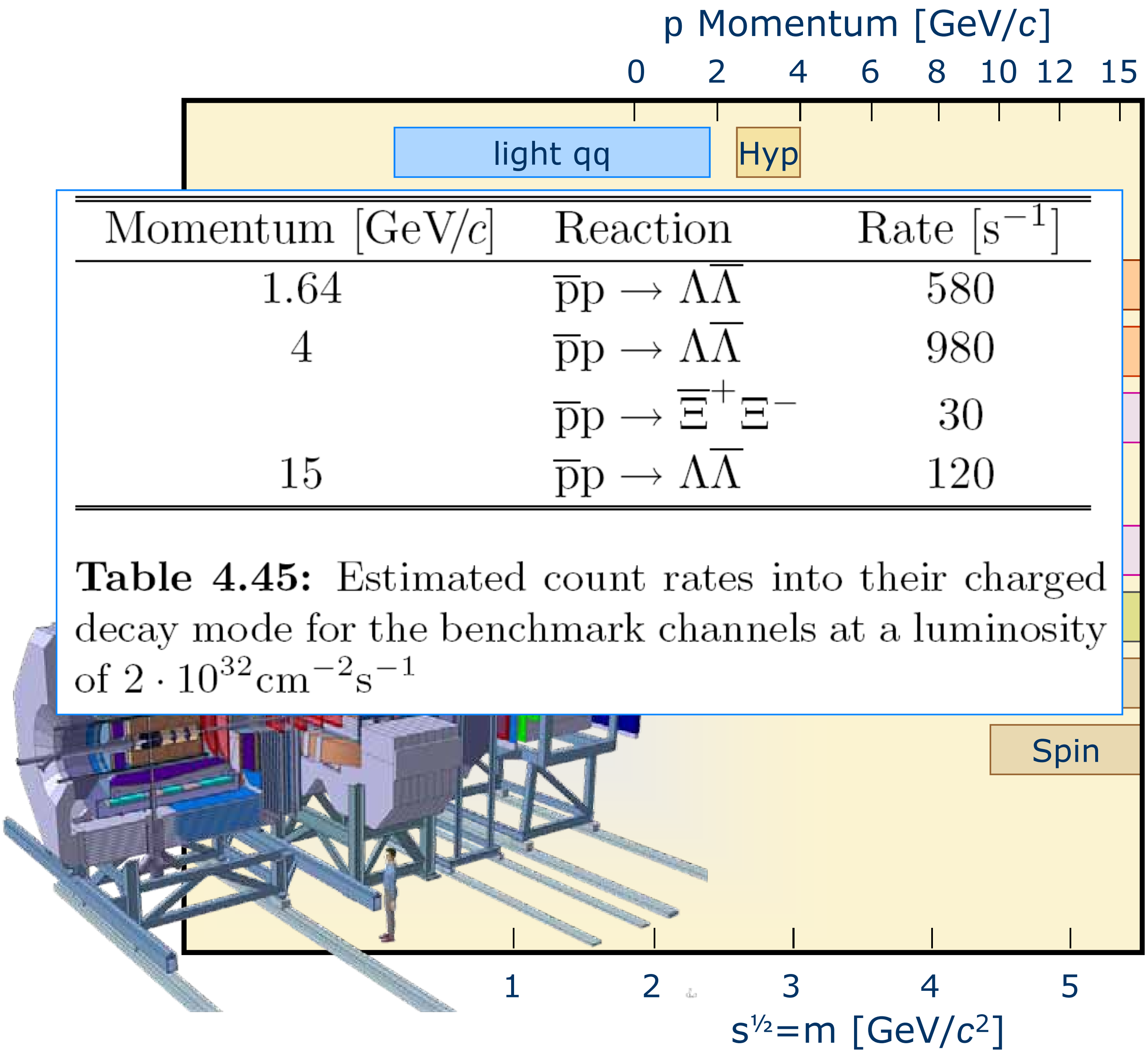
⇒ need to look at average *transverse* momentum close to threshold of *coincident Y Y* pairs

Parameter Scan

- Parameter variation by ±50%
  - Other potentials (p,p,Λ)
  - absorption cross sections
  - angular distribution
  - diffuseness
- Transverse asymmetry mainly determined by total potential
- Effect largest for backward emitted L
- a_T non-zero even if V+S=0



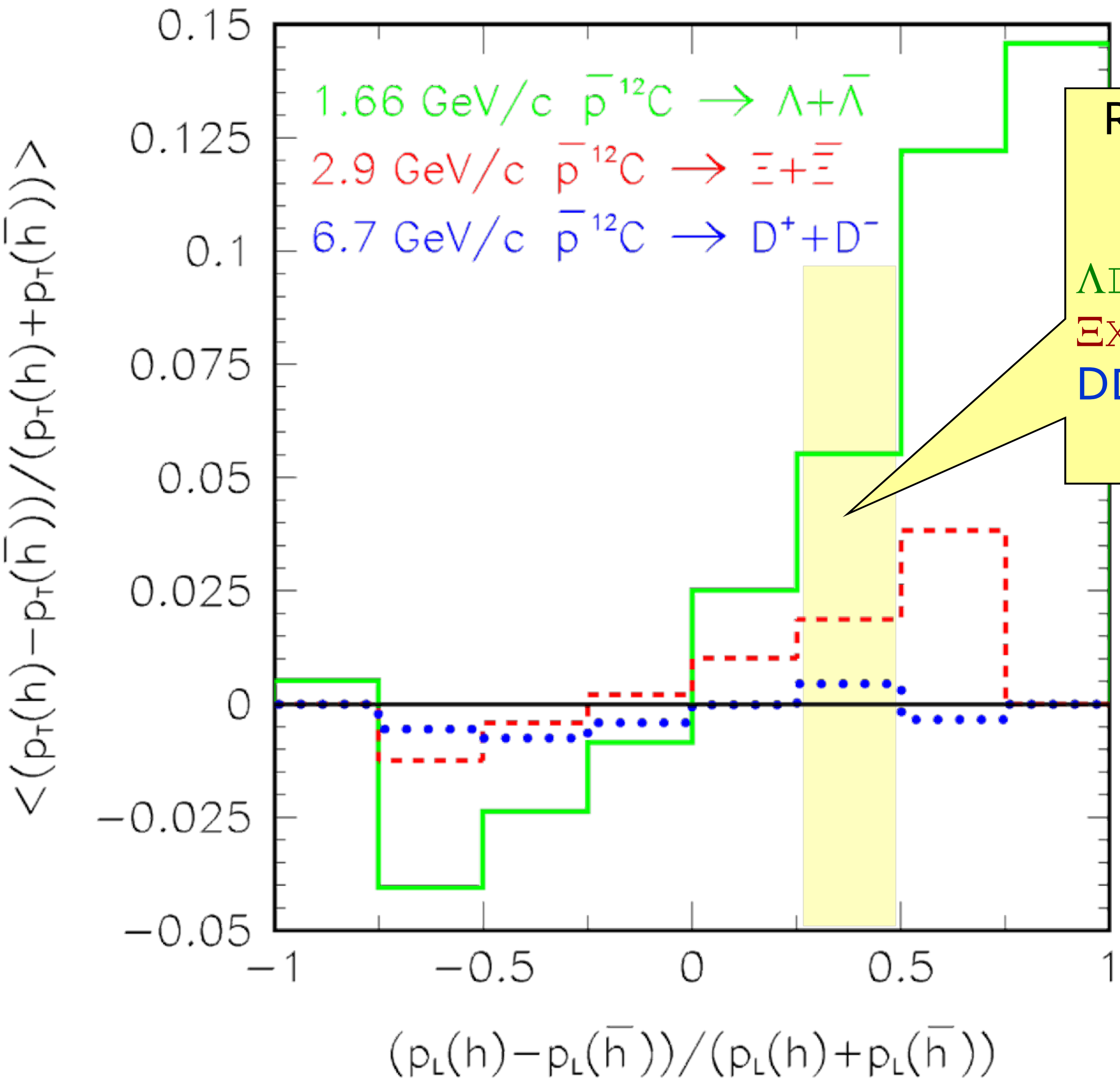
YY at PANDA



Momentum [GeV/c]	Reaction	Rate [s^{-1}]
1.64	$\bar{\mathrm{p}}\mathrm{p} \rightarrow \Lambda\bar{\Lambda}$	580
4	$\bar{\mathrm{p}}\mathrm{p} \rightarrow \Lambda\bar{\Lambda}$	980
	$\bar{\mathrm{p}}\mathrm{p} \rightarrow \bar{\Xi}^{+}\Xi^{-}$	30
15	$\bar{\mathrm{p}}\mathrm{p} \rightarrow \Lambda\bar{\Lambda}$	120

Table 4.45: Estimated count rates into their charged decay mode for the benchmark channels at a luminosity of $2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Other hadron-antihadron pairs



Required running time
for δa/a=10%:

ΛL: few minutes
ΞX: several h
DD: several months
at PANDA

Summary

- Modern theoretical approaches offer the chance to extract Y-N and Y-Y interaction from hypernuclei

- Gamma spectroscopy of double hypernuclei will be feasible at PANDA

- Antiproton collisions with nuclei are the ideal tool to produce exclusively hyperon-antihyperon pairs in nuclei at momenta close to threshold

- Transverse momentum correlations of hyperon-antihyperon pairs produced close to threshold offer a unique opportunity to explore the potential of antihyperons *relative* to that of hyperons

THANK YOU