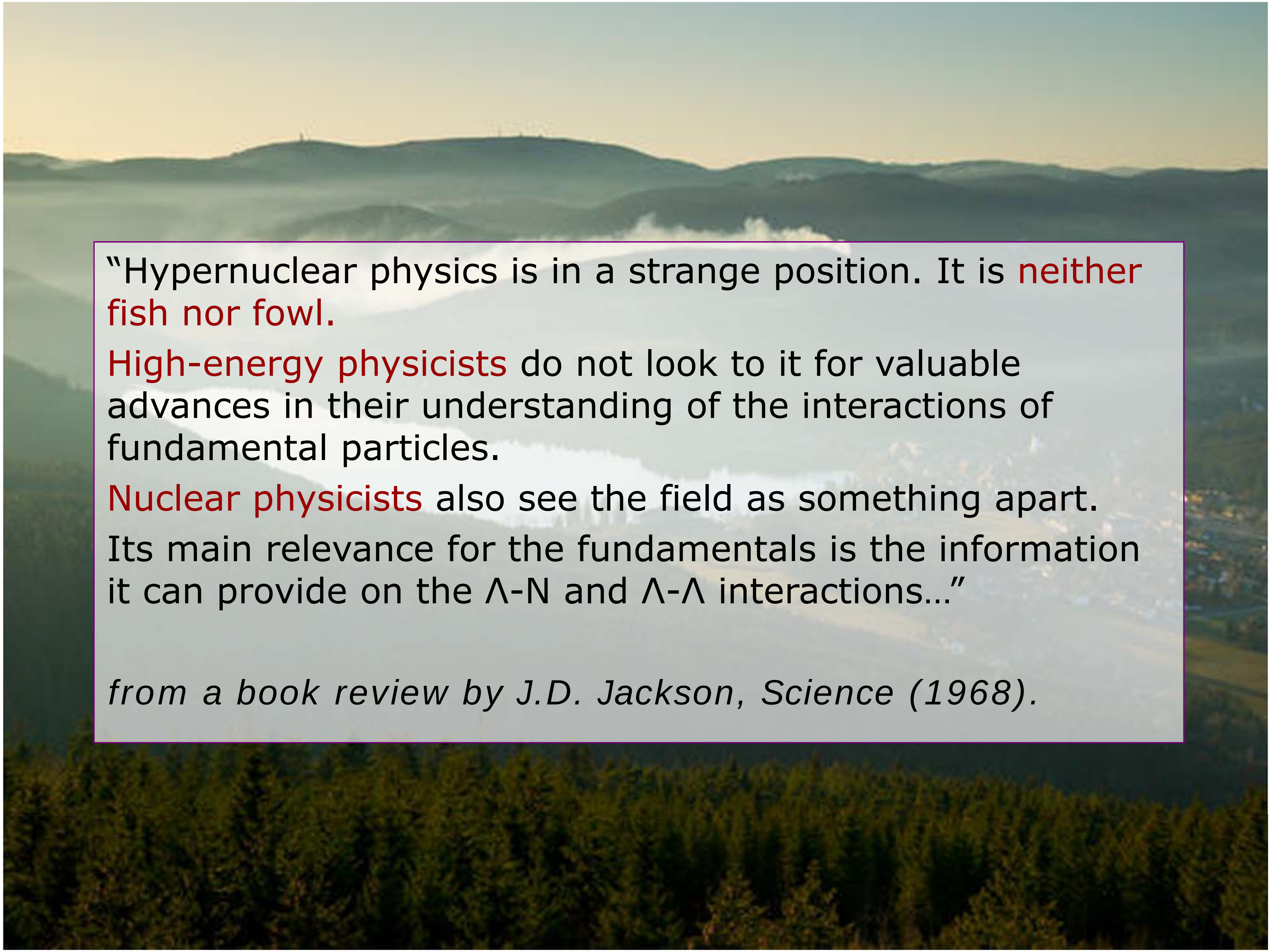
Hypernuclei: Bridging the gap between Quarks and Stars

Josef Pochodzalla TOURS 2012



"Hypernuclear physics is in a strange position. It is neither fish nor fowl.

High-energy physicists do not look to it for valuable advances in their understanding of the interactions of fundamental particles.

Nuclear physicists also see the field as something apart.

Its main relevance for the fundamentals is the information it can provide on the Λ-N and Λ-Λ interactions…"

from a book review by J.D. Jackson, Science (1968).

Hypernuclei…

- How it all began
- Many roads lead to Rome
- Basic properties
- Why bother?
- Recent observations

Hypernuclei…

How it all began

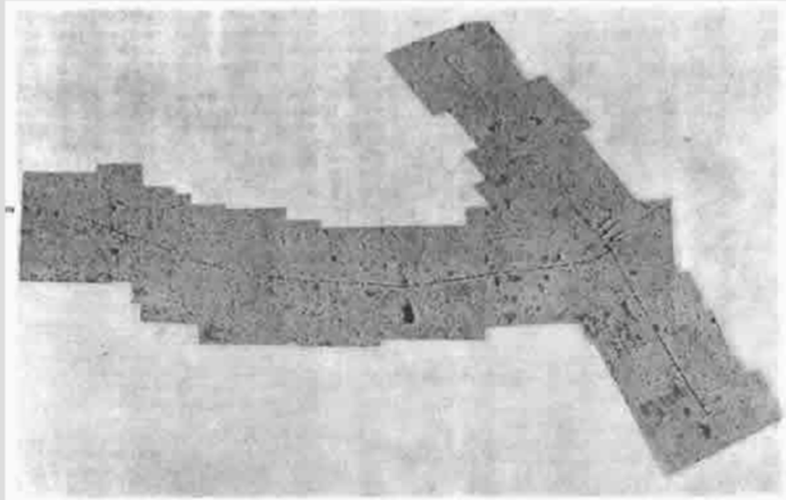
Many roads lead to Rome

Basic properties

Why bother?

Recent observations

Nuclear Emulsion



- Cecil Frank Powell (1903-1969)
  - Nobel Prize in Physics 1950
- Multiple layers of emulsion were historically the first means of visualizing charged particle tracks
  - very high positional precision
  - ionisation density (dE/dx)
  - range
  - 3-dimensional view of the interaction

- An emulsion is made, as for photographic film, of a silver salt, (AgBr), embedded in gelatine and spread thinly on a substrate.
  - grain size 0.2-0.5μm (today: 40nm)
  - during developement excited grains are reduced to elemental silver
  - density 3g/cm^3
- Data acquisition by automated means (e.g. by scanning the film with a CCD camera) is now possible.

Composition of Emulsions

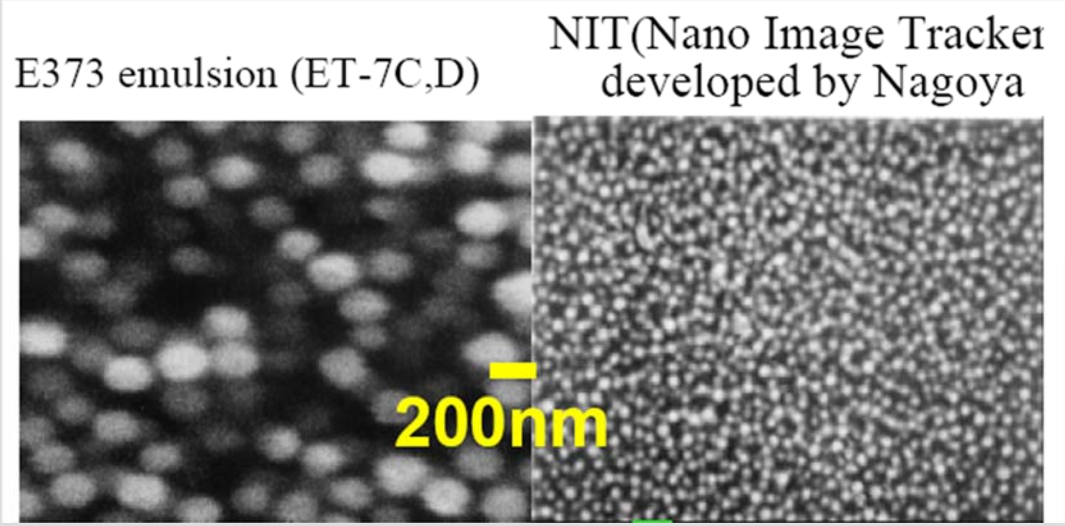


Table 2.6: The composition of the Fuji ET-7C and ET-7D emulsion.

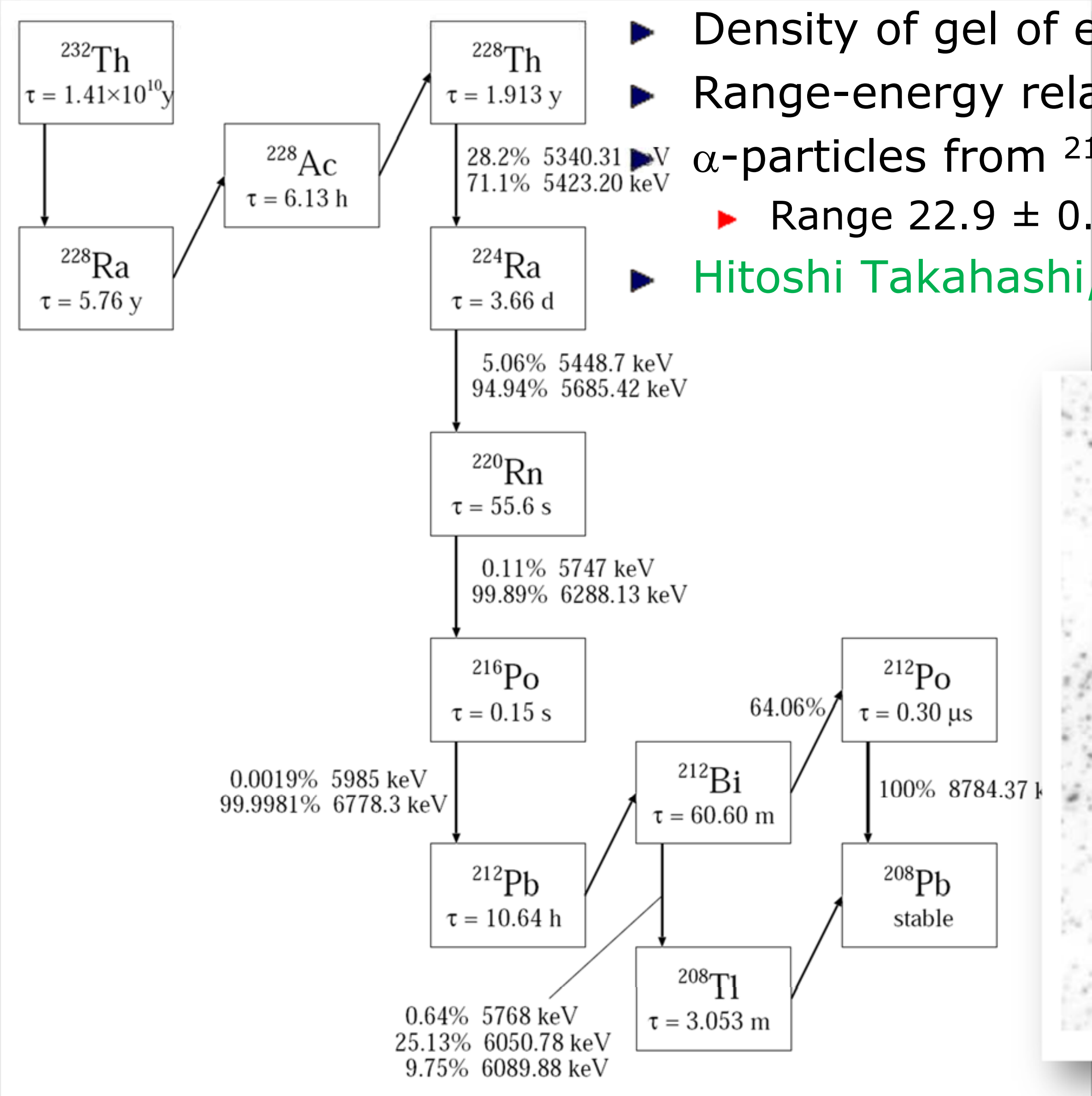
material	weight ratio (%)	mol ratio (%)
I	0.3	0.06
Ag	45.4	11.2
Br	33.4	11.1
S	0.2	0.2
O	6.8	11.3
N	3.1	5.9
C	9.3	20.6
H	1.5	40.0

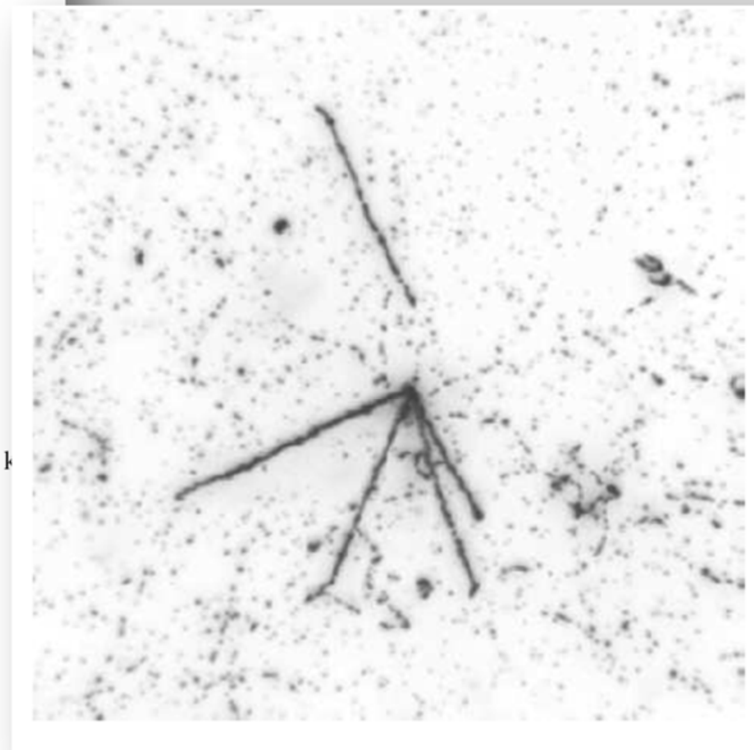
heavy elements (I, Ag, Br)

light elements (O, N, C)

Emulsion - calibration

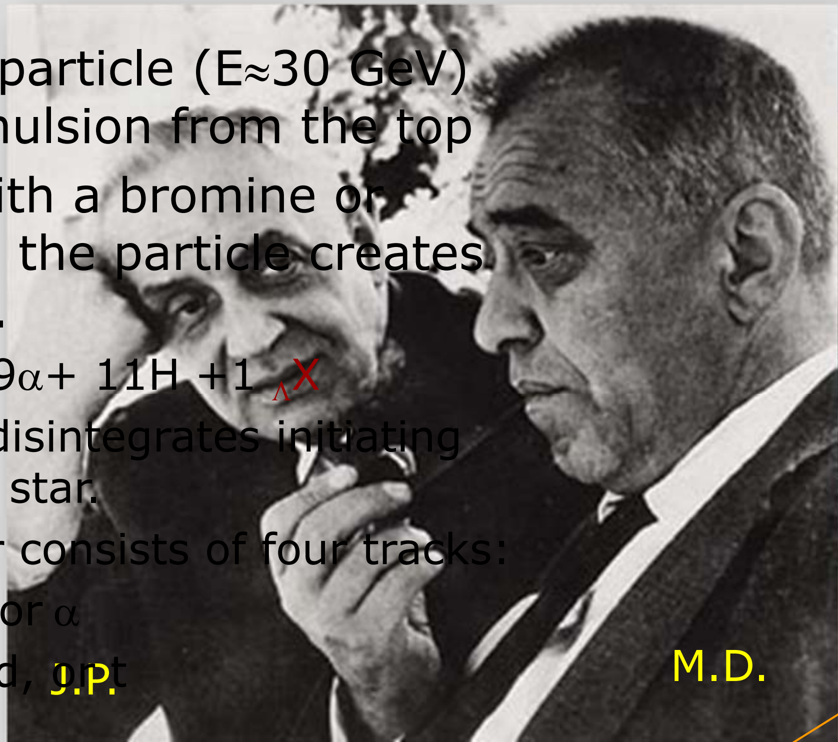
- Density of gel of emulsion may vary
- Range-energy relation needs to be calibrated
- α-particles from ^{212}P and ^{228}Th;
  - Range 22.9 ± 0.3 μm for 5.4MeV α from ^{228}Th
- Hitoshi Takahashi, thesis 2003

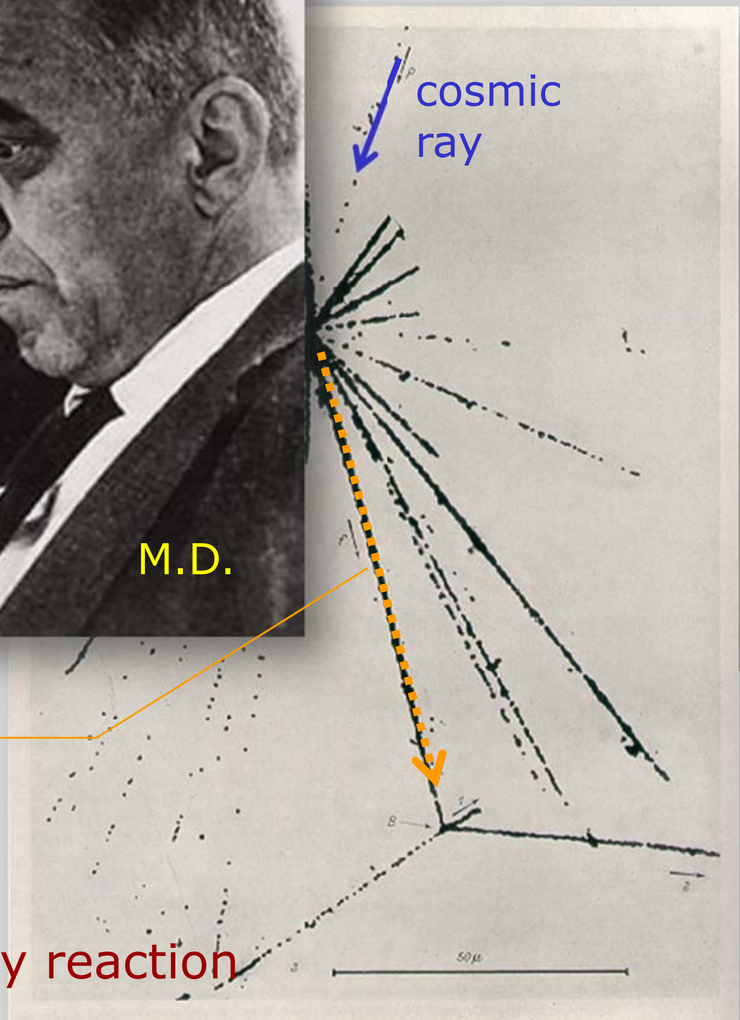




How the Hypernuclei Story began

- Marian Danysz, Jerzy Pniewski, et al. Bull. Acad. Pol. Sci. III **1**, 42 (1953)
- Marian Danysz, Jerzy Pniewski, Phil. Mag. **44**, 348 (1953)





- A cosmic ray particle (E≈30 GeV) enters the emulsion from the top
- Interacting with a bromine or silver nucleus the particle creates an upper star.
  - 21 tracks: 9α+ 11H +1 $_{\Lambda}X$
  - Finally, $_{\Lambda}X$ disintegrates initiating the bottom star.
  - second star consists of four tracks:
    - 2 p,d,t or α
    - 1 π, p, d, or t
    - 1 recoil
  - energy release >140MeV

$$t > \frac{s}{c} \sim \frac{80\mu m}{300000 km/s} \approx 2.6 \cdot 10^{-13} s$$

$$\tau(\Lambda) = 2.6 \cdot 10^{-10} s$$

$\Rightarrow$ typical for weak decay

- many associated particles in primary reaction

The second event

COMPTES RENDUS

HEBDOMADAIRES

DES SÉANCES

DE L'ACADÉMIE DES SCIENCES,

PUBLIÉS,

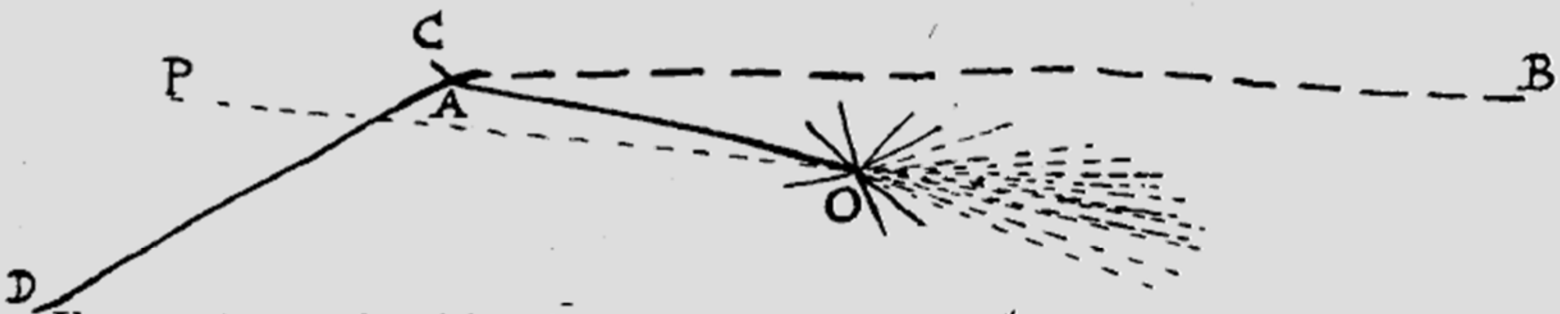
CONFORMÉMENT A UNE DÉCISION DE L'ACADÉMIE

EN DATE DU 13 JUILLET 1835.

PHYSIQUE NUCLÉAIRE. — *Émission probable d'un fragment nucléaire contenant une particule* V°. Note de MM. **Jean Crussard** et **Daniel Morellet**, présentée par M. Louis Leprince-Ringuet.

SÉANCE DU 5 JANVIER 1953. 65

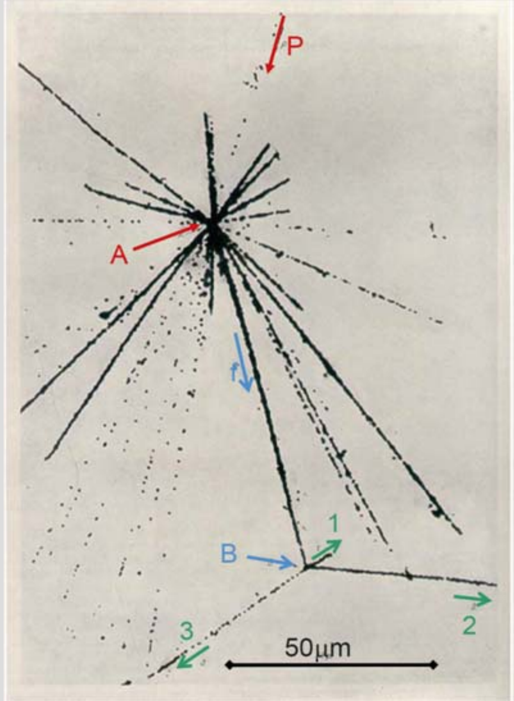
probable. Un méson π est exclu (scattering trop faible). Un noyau lourd plus rapide est impossible (absence de rayons δ). On ne peut affirmer que la particule s'arrête en A, mais sa vitesse résiduelle y est en tous cas très faible.



2° Il paraît préférable de rapprocher ce phénomène d'un cas observé récemment par Danysz ([7]), dans lequel un fragment lourd (Z ≧ 8), émis

Interpretation of the Event (1)

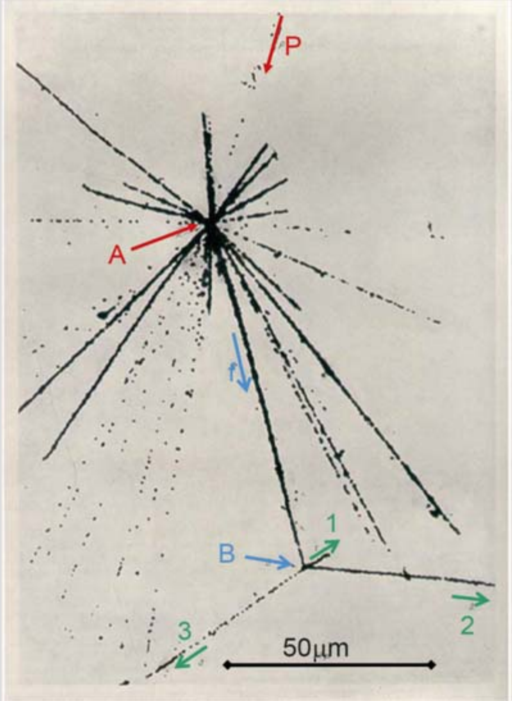
- The event Danysz and Pniewski observed shows a nuclear fragment emerging from a cosmic-ray star was stopped within the emulsion in about 10^{-12}s and subsequently disintegrated with an energy release 140 to 180 MeV
- Since the mean life for the emission of a nucleon from a fragment having an excitation energy around 100 MeV is of the order of 10^{-20}s, a decay of an excited ordinary nucleus was excluded.



- The fact, that the fragment was practically at rest at the moment of its disintegration also excluded the possibility of a secondary collision between f and a nucleus in the emulsion.
- Due to the time-integrating property of emulsion stacks a chance coincidence of two interactions was considered not to be impossible. However Tidman and co-workers discarded this solution because of the extremely small probability of a repeated chance coincidence.

Interpretation of the Event (2)

- Two possible explanations remained still:
  - a subsequent capture of a $\pi-$ meson or some other heavy meson close to the stopping point B from an atomic orbit.
  - a heavy neutral $V^0{}_1$-particle which has been observed only a few years before in a bound state within a nucleus .
- One of the fragments in the event of Crussard and Morellet turned out to be a pion. As a consequence, a pionic atom as the origin of these connected stars could be discarded. Analysing a two-body decay of a secondary star, Bonetti and co-workers also exclude a capture of a heavier meson as the trigger of the secondary decay leaving only the second possibility.
- As suggested by Goldhaber such fragments were called later hyperfragments



Two body decay of a hypernucleus

$$^{9}_{\Lambda}\mathrm{Be} \rightarrow \pi^{-} + {}^{9}\mathrm{B} \quad ({}^{9}\mathrm{B} \rightarrow 2\alpha + \mathrm{p})$$

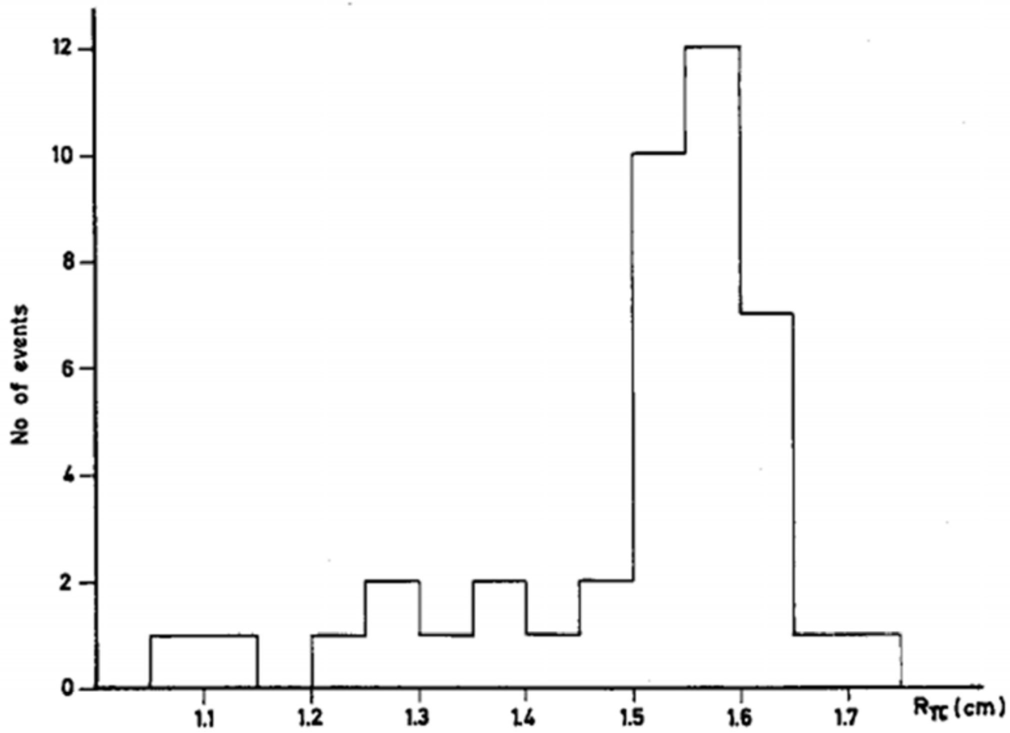
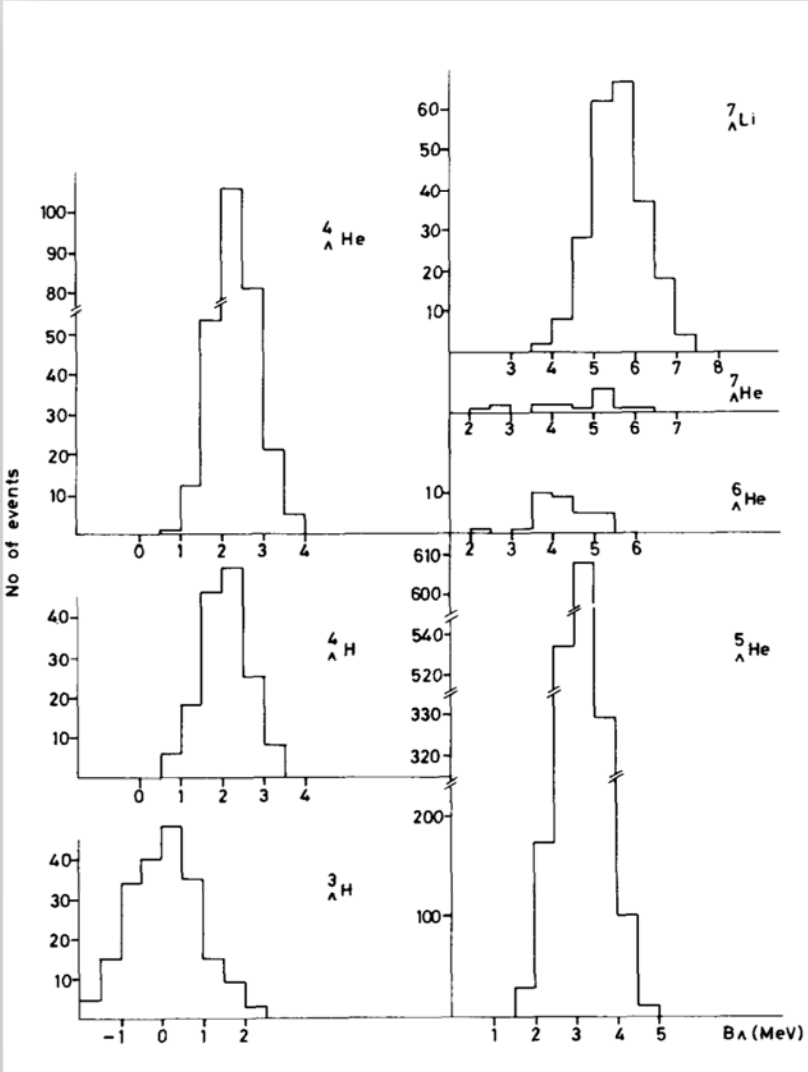


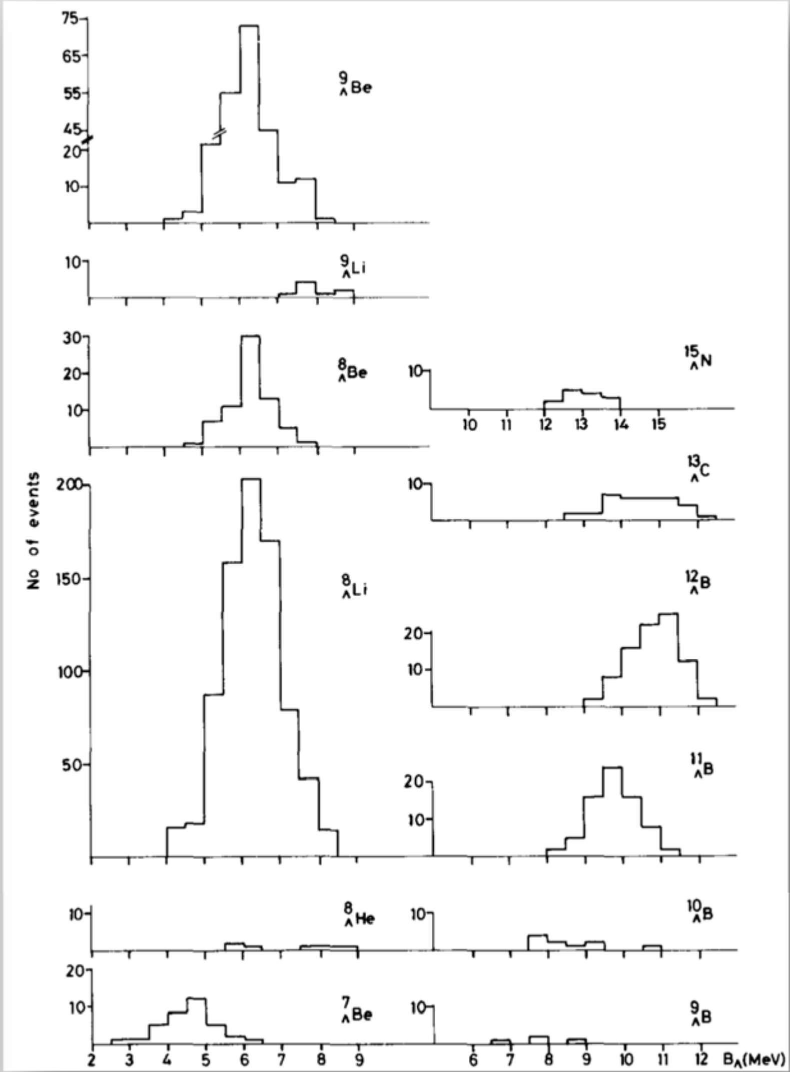
Fig. 1. Range distribution of π^- mesons from the events of the type (π + 2 or 3 stub-like tracks).

Gajewski et al., Nucl. Phys. B1, 105 (1967)

World data from emulsion (1973)

- M. Juric at al, Nucl. Phys. B52, 1 (1973)
  - 4042 uniquely identified events in 1973

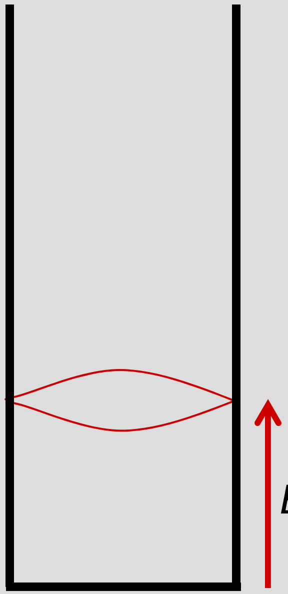




Λ Potential

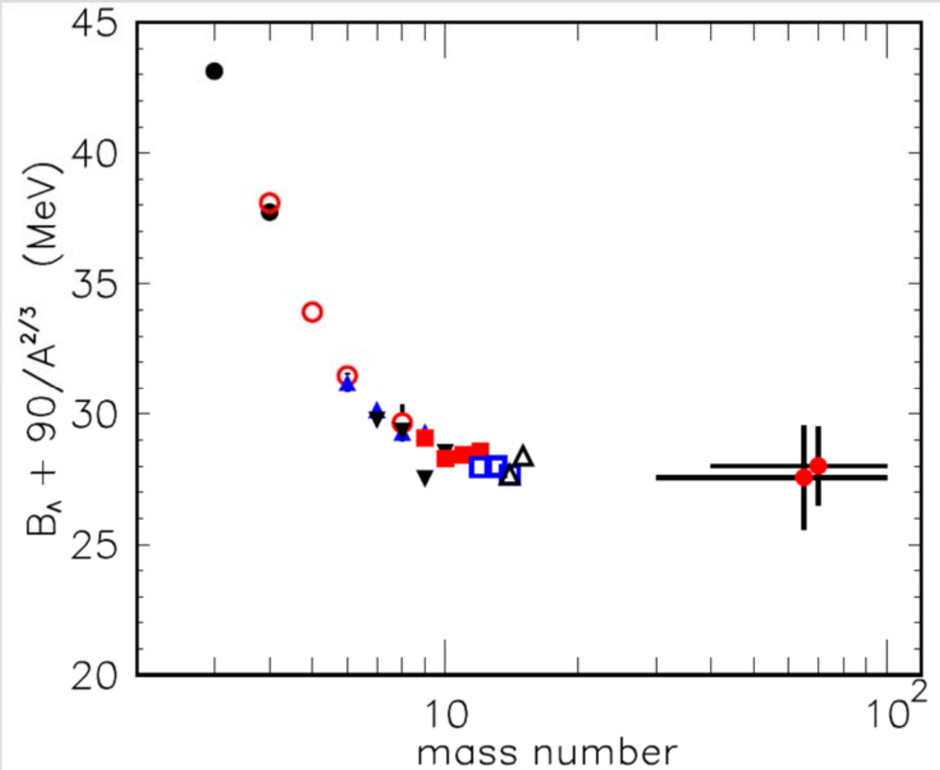
- $B_\Lambda = (M_{core} + M_{Lambda} - M_{hn})c^2$
- The mass of the hypernucleus M_{hn} can be determined from the sum of the masses m_i of all decay products and their summed kinetic energies T_i

$$M_{hn} = \sum m_i c^2 + \sum T_i$$



$$E_{111} = \frac{3\hbar^2\pi^2}{2m_\Lambda \cdot 4r_0^2 A^{2/3}}$$

$$V_\Lambda \sim B_\Lambda + E_{111} = B_\Lambda + \frac{90MeV}{A^{2/3}}$$

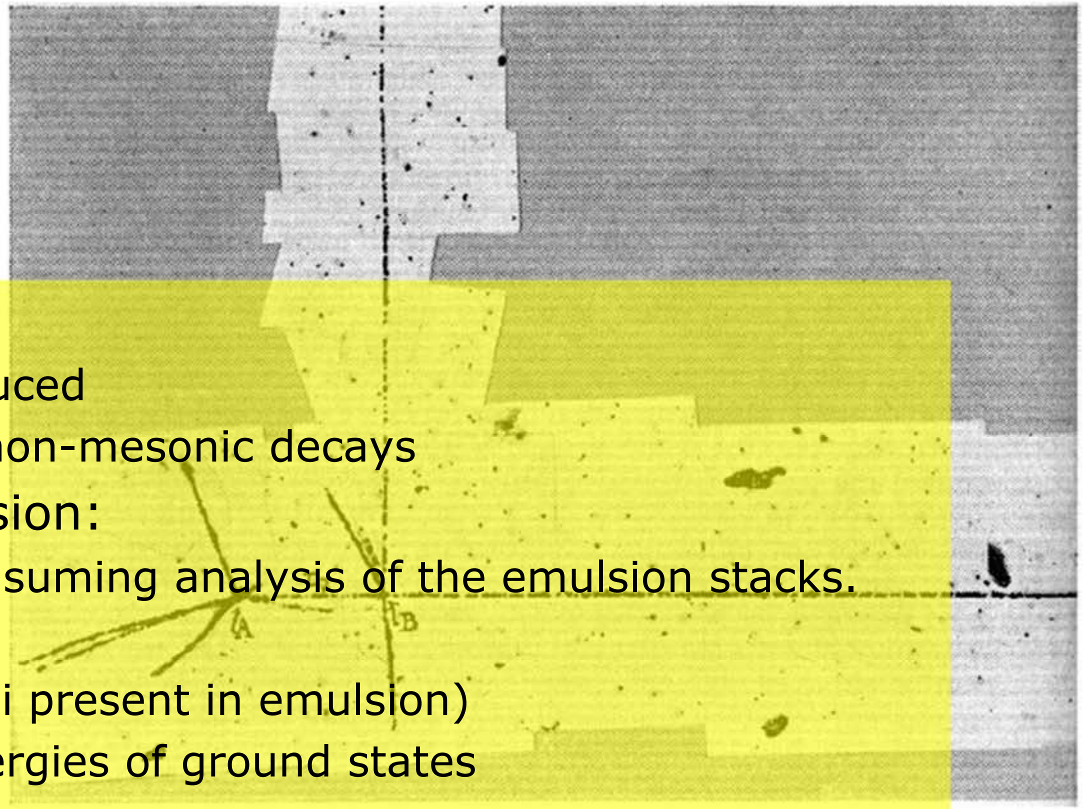


Time Integrating Property of Emulsion

168 NATURE July 31, 1948 Vol. 162

OBSERVATIONS ON THE PRODUCTION OF MESONS BY COSMIC RADIATION

By DR. G. P. S. OCCHIALINI
AND
DR. C. F. POWELL
H. H. Wills Physical Laboratory, University of Bristol



- Measured:
  - binding energies deduced
  - ratios of mesonic to non-mesonic decays
- Drawback of the emulsion:
  - The tedious, time consuming analysis of the emulsion stacks.
  - very limited statistics
  - limited species (nuclei present in emulsion)
  - limited to binding energies of ground states

Fig. 1. Chance juxtaposition of unrelated events

The particle, τ, emitted from the star A, passes by chance within a distance of $2\,\mu$ of the star B. The interpretation depends upon the observation that the two portions of the track τ, on each side of B, are precisely in line; and that they show no significant difference in grain density

Observer Miss P. Dyer Exposure Jungfraujoch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Nomenclature

- a hypernucleus is specified by
  - the number of neutrons N
  - the number of protons Z
  - the number of hyperons Y

number of baryons N+Z+Y

(number of) hyperons Y

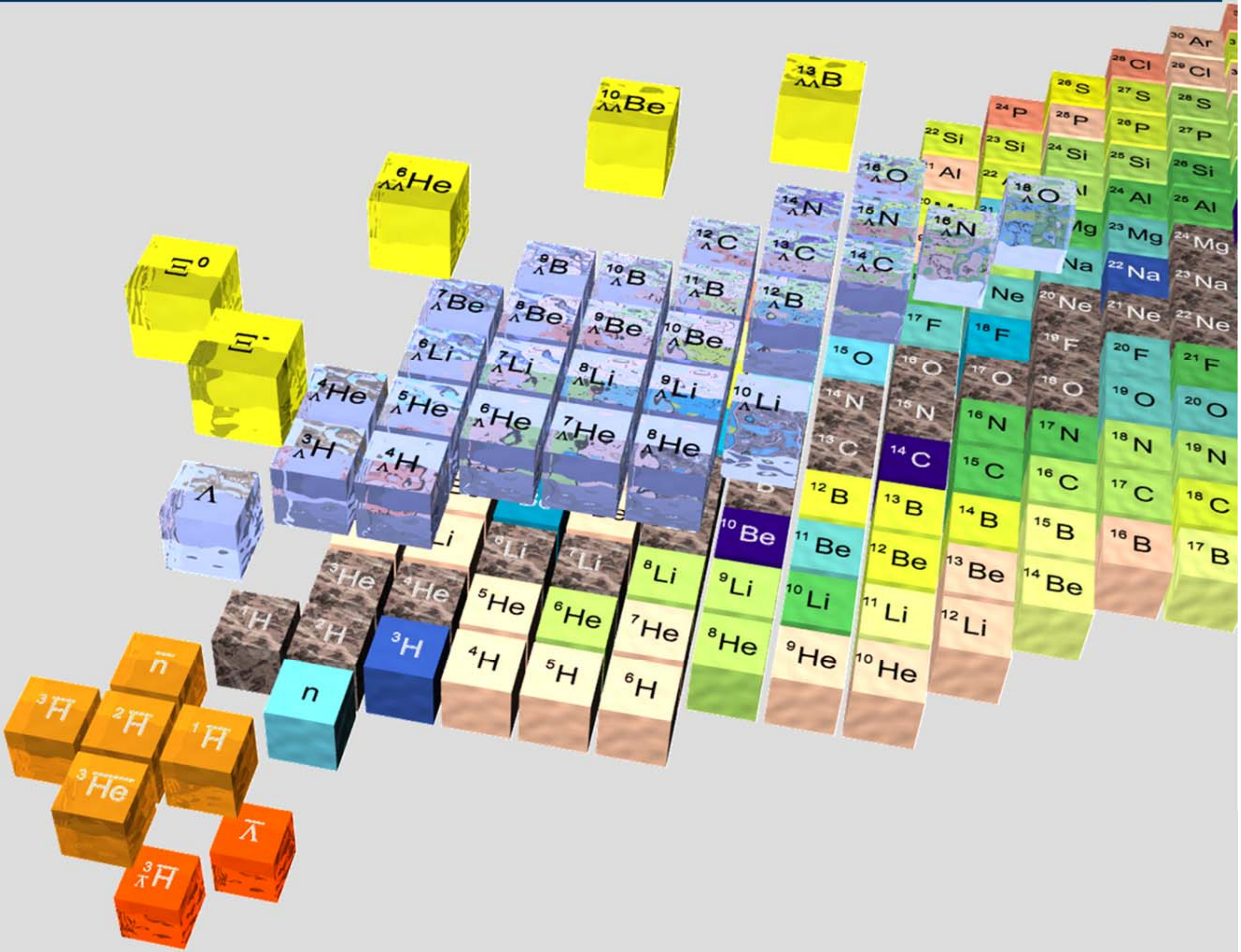
$${}^{B}_{Y}X$$

element = total charge (not number of protons)

- since we have more than one hyperon (Λ, Ξ^-, Σ^{-+0}) one usually writes explicitely the symbols of one (or more) hyperon
- examples:

$${}^{10}_{\Lambda\Lambda}Be \rightarrow \begin{cases} Be & \rightarrow \text{4 protons} \\ \Lambda\Lambda & \rightarrow \text{2 lambdas} \\ 10 & \rightarrow \text{10-4-2=4 neutrons} \end{cases}$$

$${}^{4}_{\Sigma}He \rightarrow \begin{cases} 1p + 2n + 1\Sigma^+ \\ 2p + 1n + 1\Sigma^0 \\ 3p + 0n + 1\Sigma^- \end{cases} \quad \text{indistinguishable}$$



Ξ0
Ξ-
6ΛΛHe
10ΛΛBe
13ΛΛB
Λ
3ΛH
4ΛH
4ΛHe
5ΛHe
6ΛHe
7ΛHe
8ΛHe
6ΛLi
7ΛLi
8ΛLi
9ΛLi
10ΛLi
7ΛBe
8ΛBe
9ΛBe
10ΛBe
9ΛB
10ΛB
11ΛB
12ΛB
12ΛC
13ΛC
14ΛC
14ΛN
15ΛN
16ΛN
16ΛO
18ΛO
n
3H
4H
5H
6H
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6He
7He
8He
9He
10He
8Li
9Li
10Li
11Li
12Li
10Be
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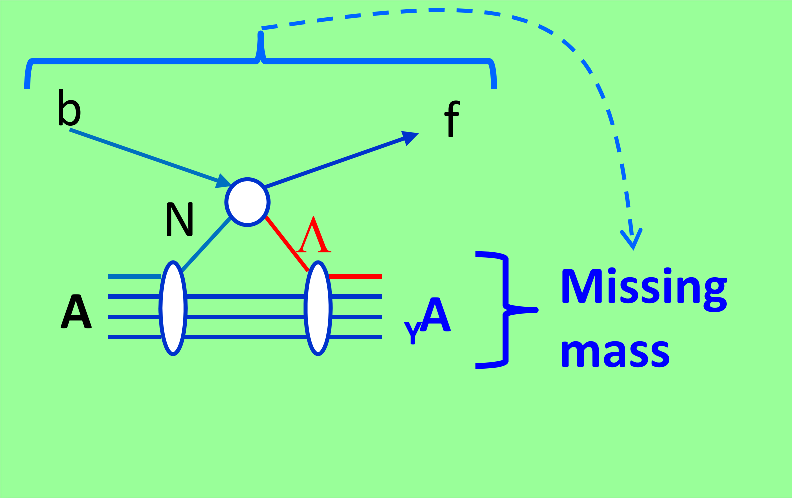
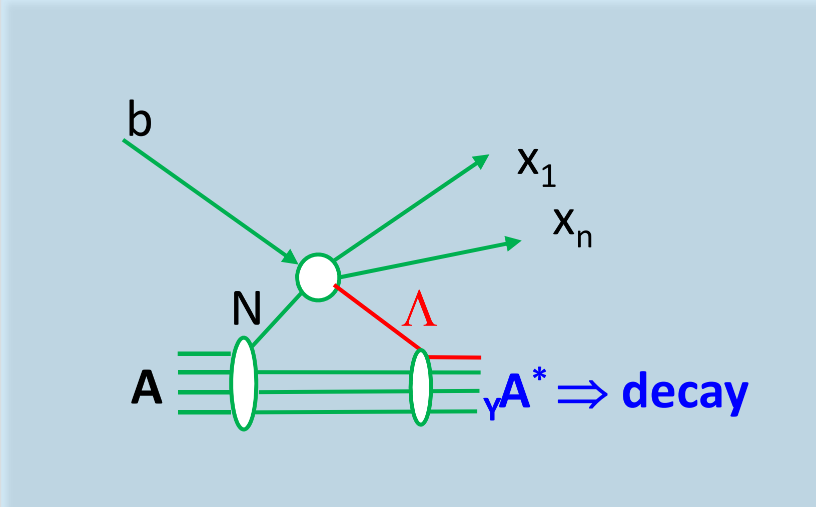
14Be
12B
13B
14B
15B
16B
17B
14C
15C
16C
17C
18C
14N
16N
17N
18N
19N
15O
19O
20O
17F
18F
19F
20F
21F
20Ne
21Ne
22Ne
22Na
23Na
23Mg
24Mg
24Al
25Al
22Si
23Si
24Si
25Si
26Si
24P
25P
26P
27P
26S
27S
28S
28Cl
29Cl
30Ar
n̄
1H̄
2H̄
3H̄
3He̅
Λ̄
3Λ̄H̄

The twofold way



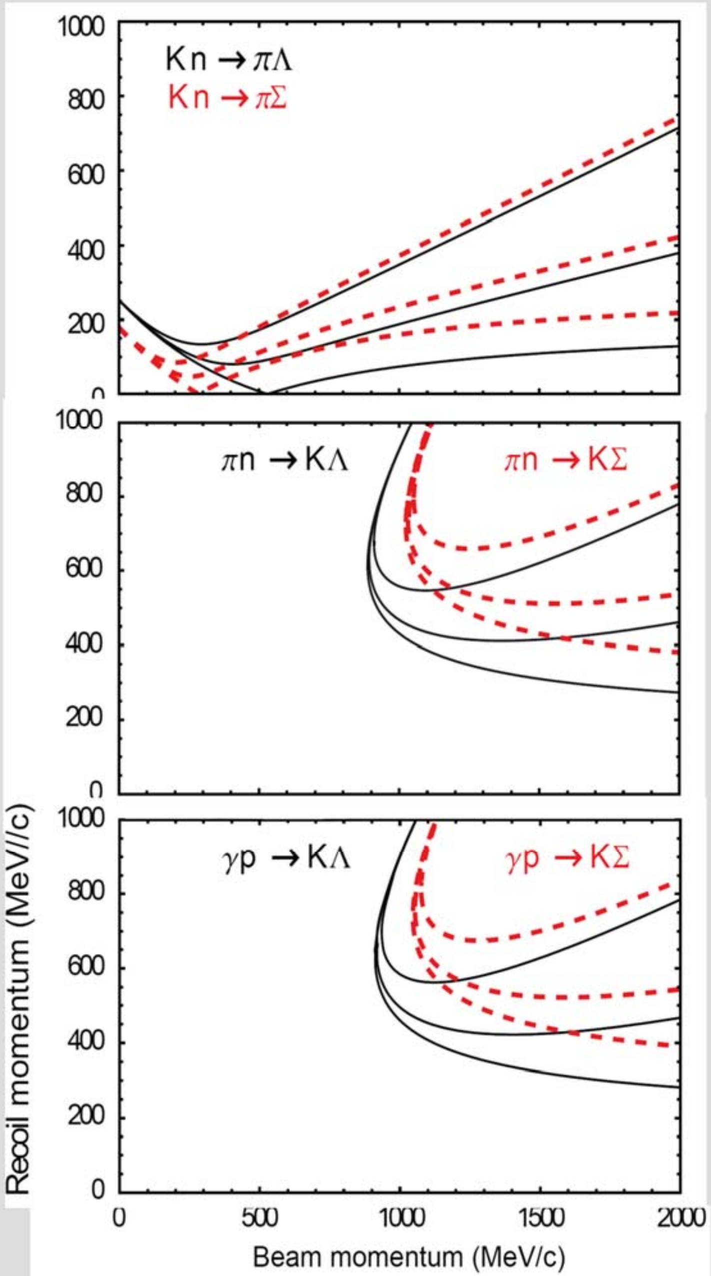


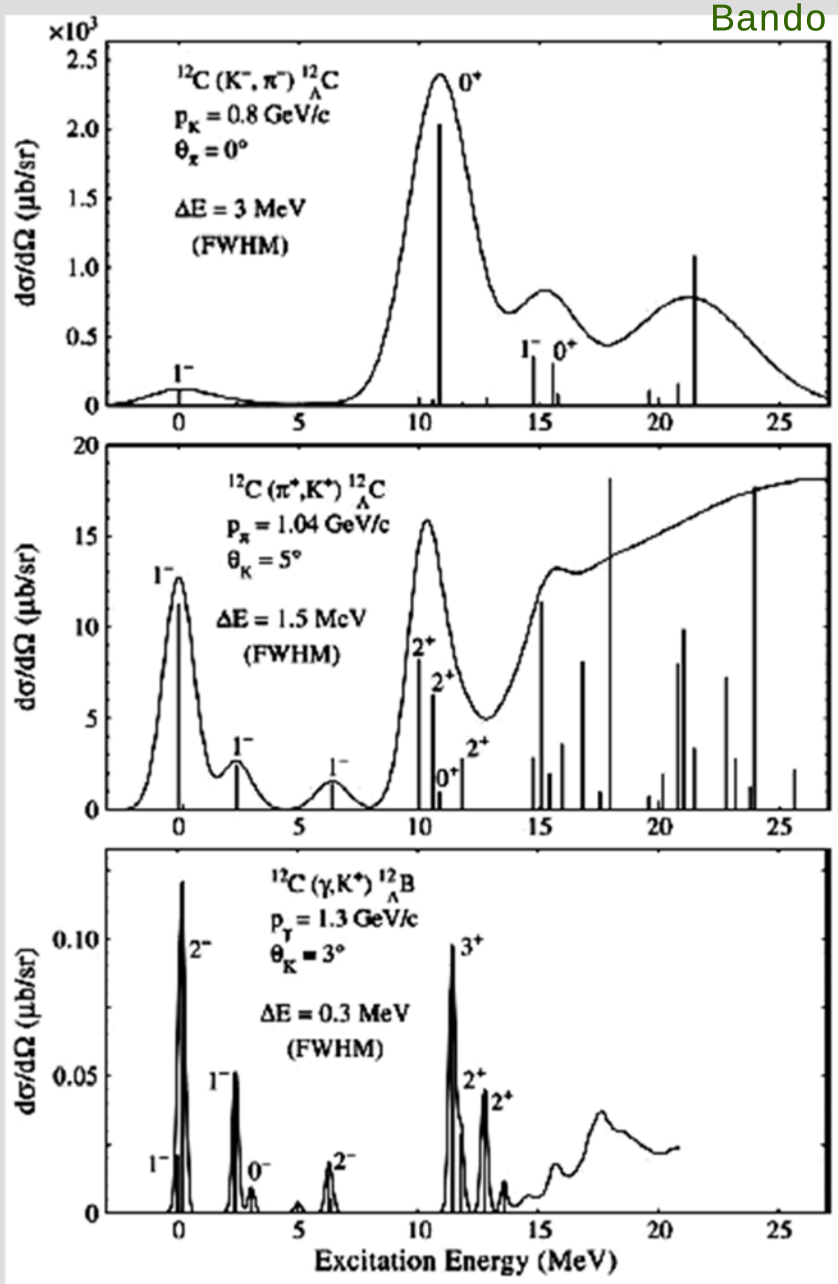
- Direct production spectroscopy
- Examples
  - strangeness production (π^+, K^+), (π^-, K^0)
  - strangeness exchange (K^-, π^-) ,(K^-, π^0), (K^-,K^+)
  - electroproduction (e,e´K^+) , (γ,K^+)

- Decay spectroscopy
  - γ-decay of excited states
  - π from weak decay
  - charged fragments
- Examples
  - nuclear emulsions
  - heavy ion reactions
  - antiproton induced reactions
  - continuum excitation in (e,e´K+)

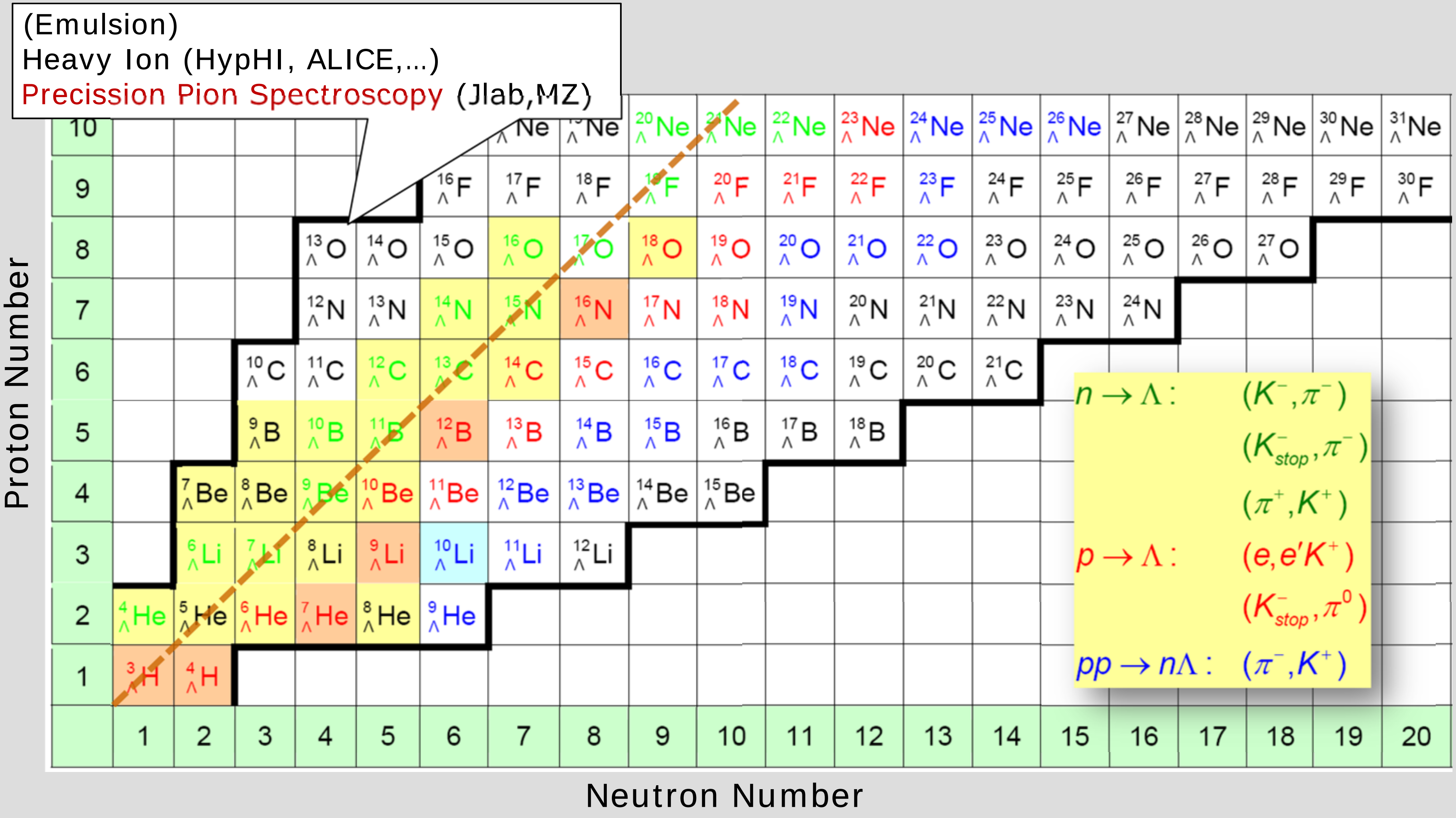
Missing mass experiments

Bando



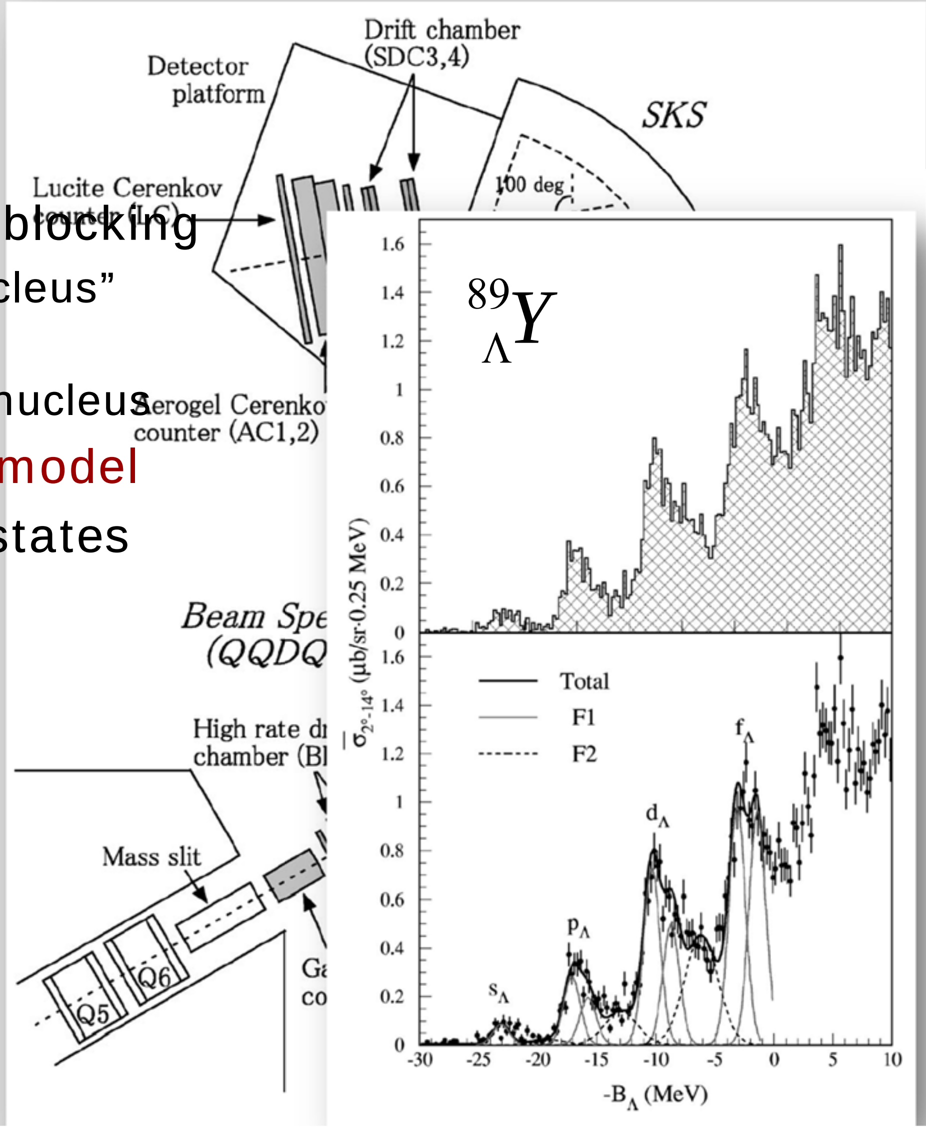


Missing Mass Experiments

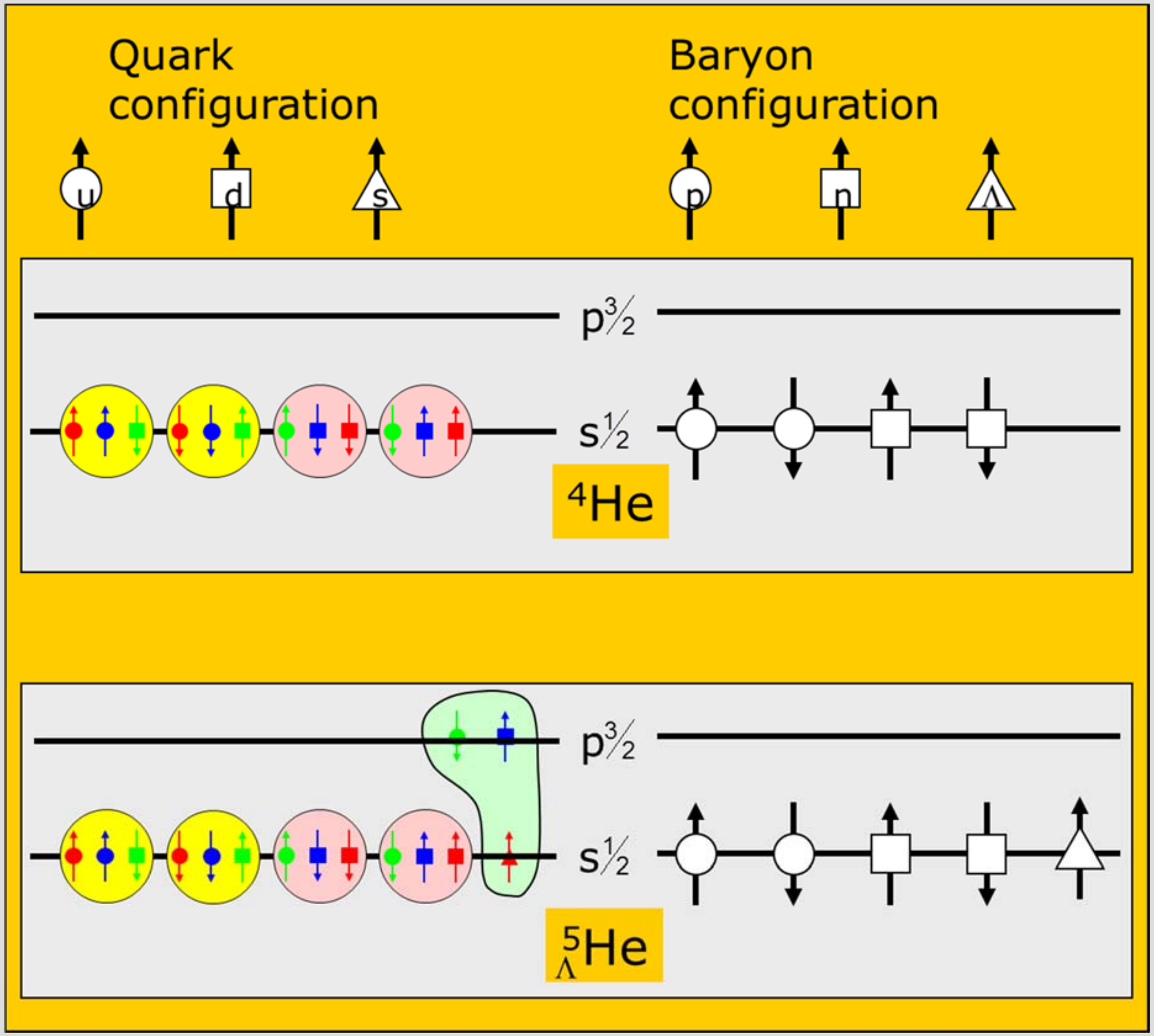


Single Particle States in Nuclei

- H. Hotchi *et al.*, PRC 64, 044302 (2001)
- KEK, Superconduction Kaon Spectromter (SKS)
- P_π=1.05GeV/c, $p_K \approx$0.72GeV/c
- Hyperons are free from Pauli blocking
  - can stay at the "center of nucleus" (especially for Λ)
  - is a good probe for depth of nucleus
- confirmation of nuclear shell model
- deeply bound single particle states
- small spin-orbit interaction

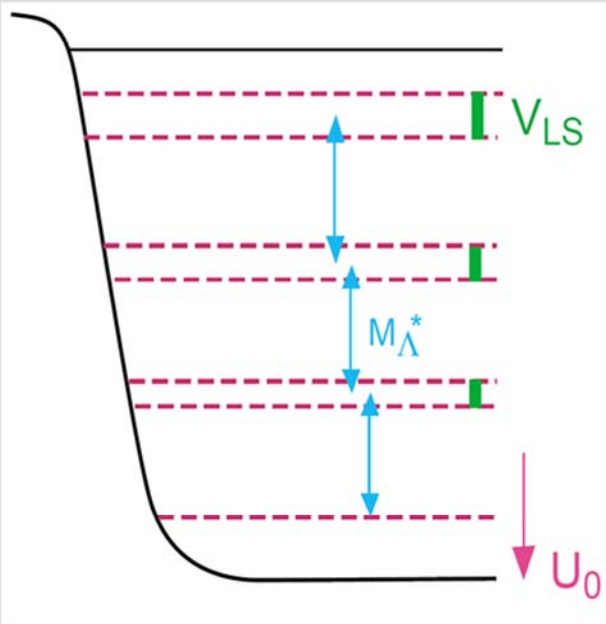


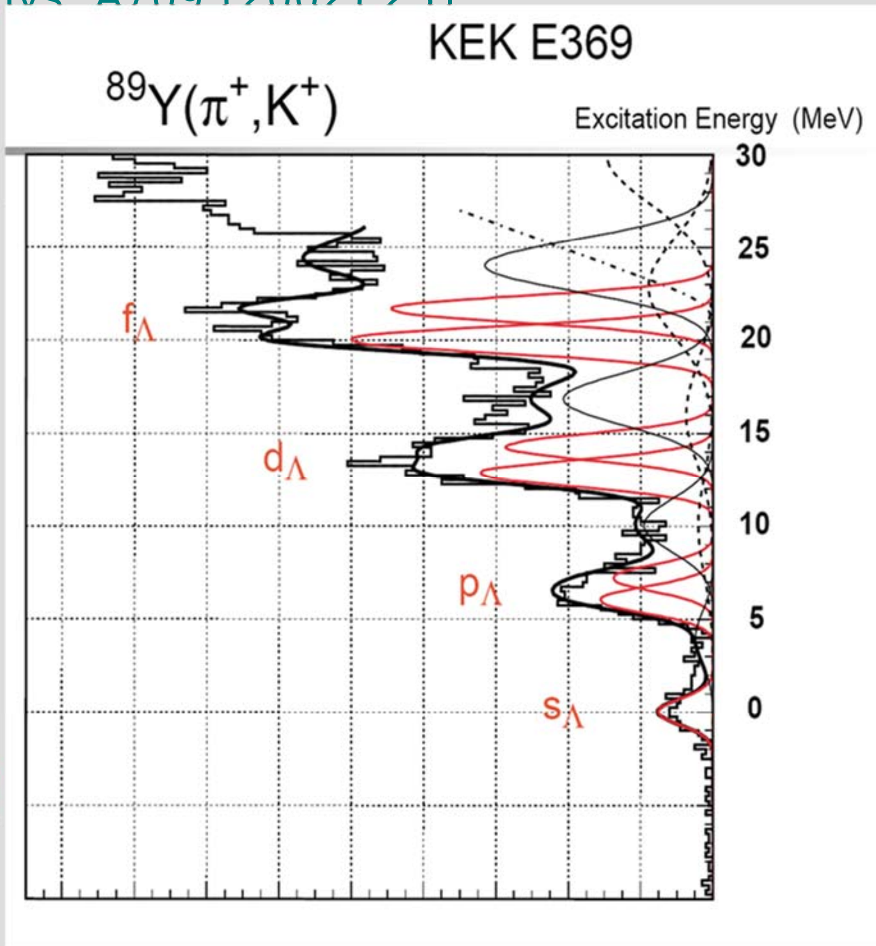
Λ in nuclei – to be or not to be?



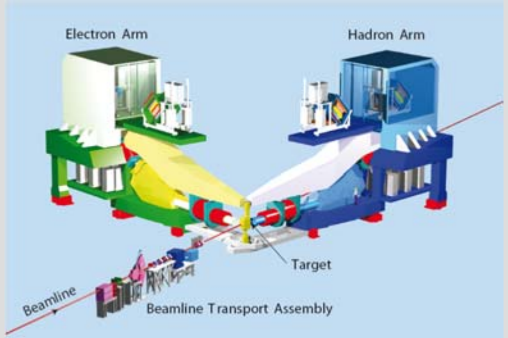
Spin-Orbit Force

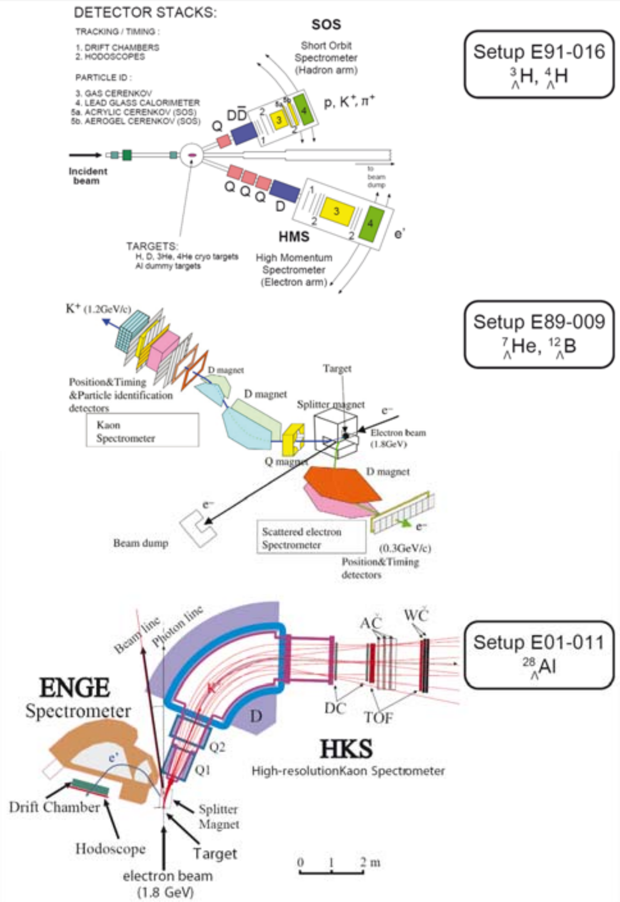
- in normal nuclei: strong spin-orbit interaction (~5MeV for light nuclei) needed to explain shell structure
  - Haxel, Jensen, Suess and Goeppert-Mayer (1949)
- origin still unclear
  - see e.g. N. Kaiser, Nucl. Phys. A709 (2002) 251

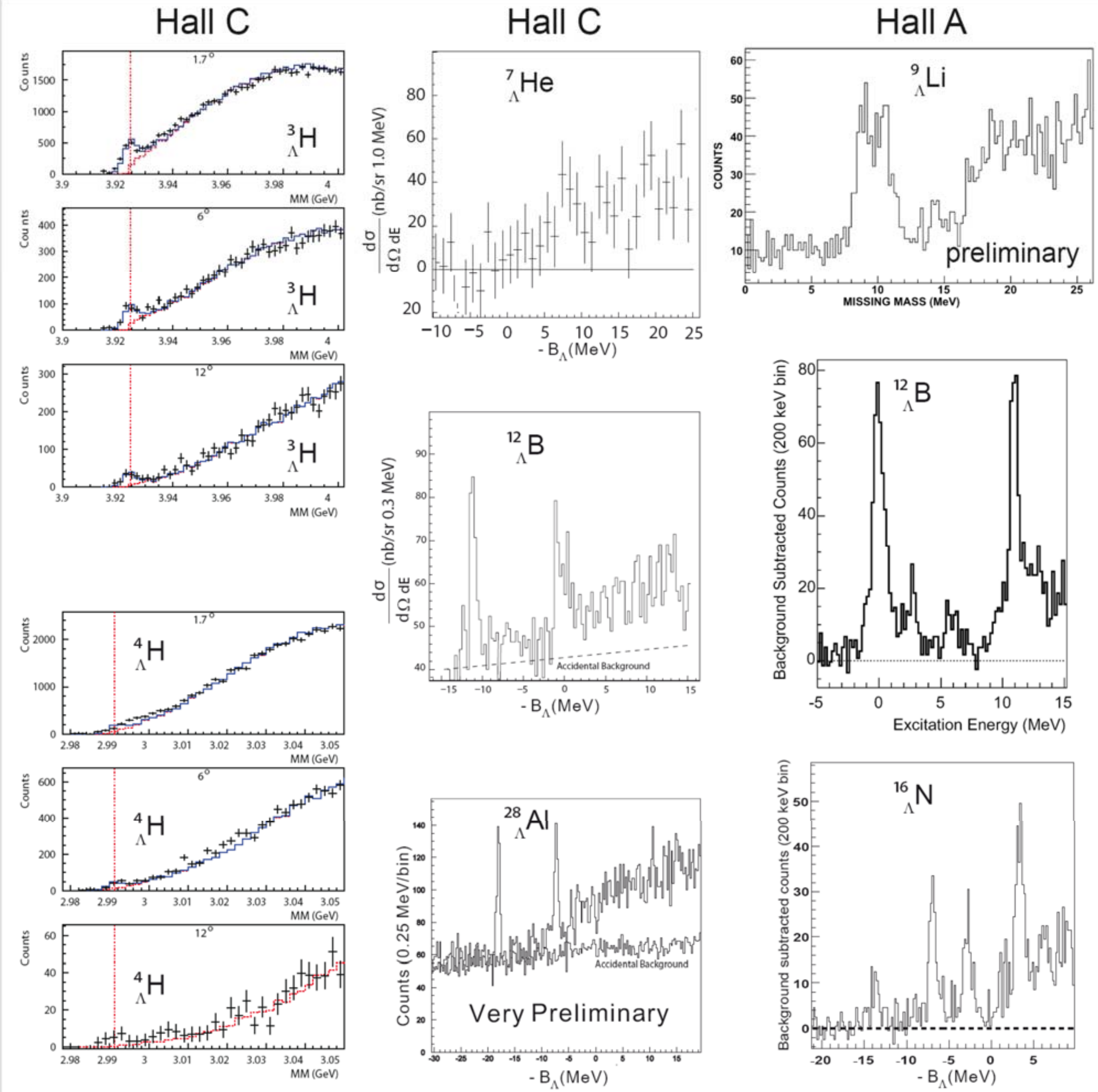




J-Lab Experiments (e,e‘K+)

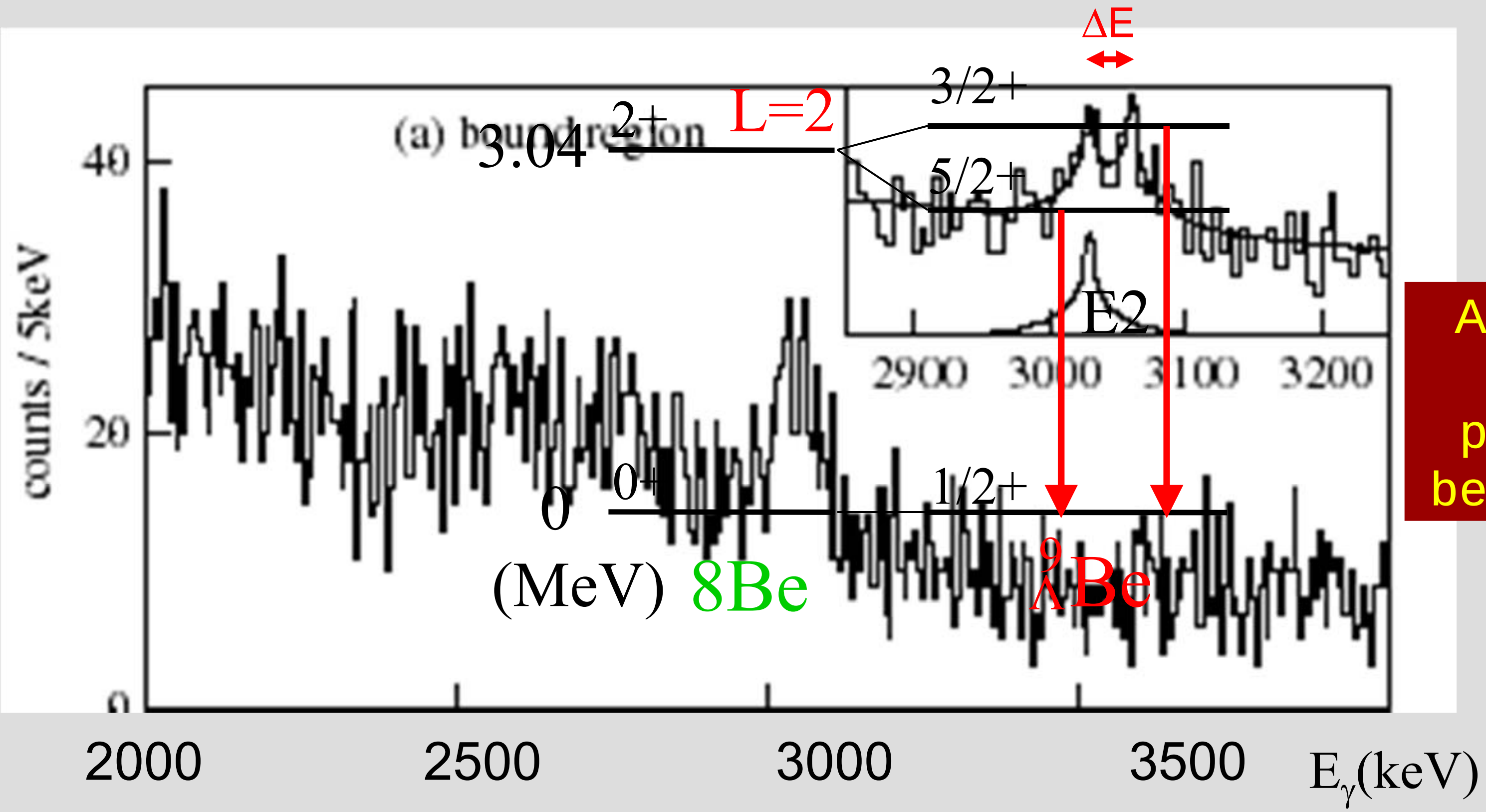






Spin-Orbit Force in Hypernuclei

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

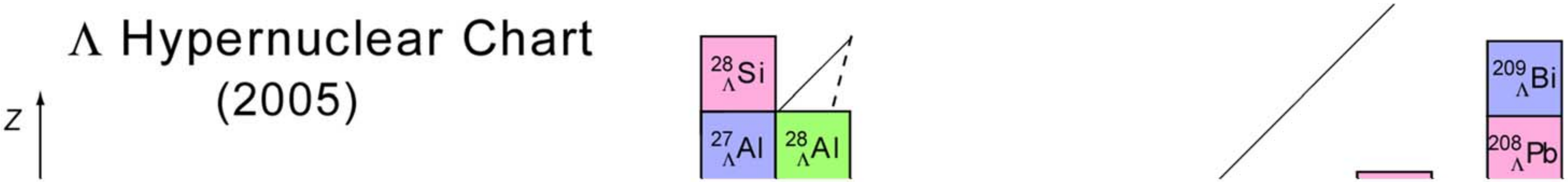


Also for multi-hypernuclei precission will be the key issue

- |ΔE| = 31±3 keV
- surprisingly small spin-orbit force (~few percent of NN case)
- N. Kaiser, W.Weise, PRC 71, 015203 (2005)

International Hypernuclear Network

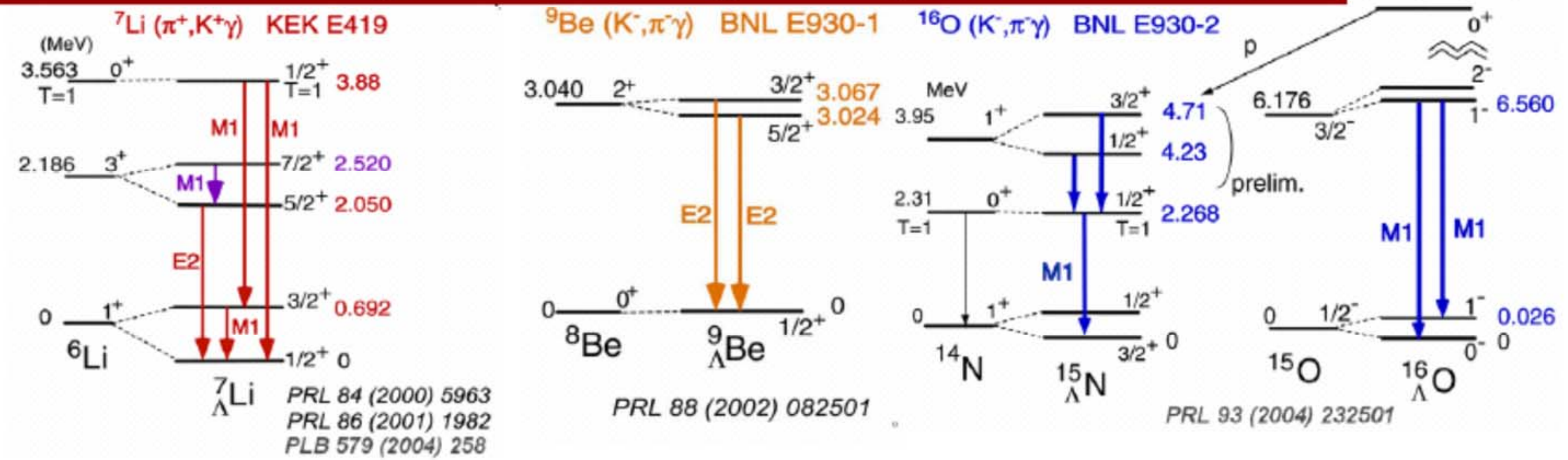
High Resolution γ-Spectroscopy at KEK



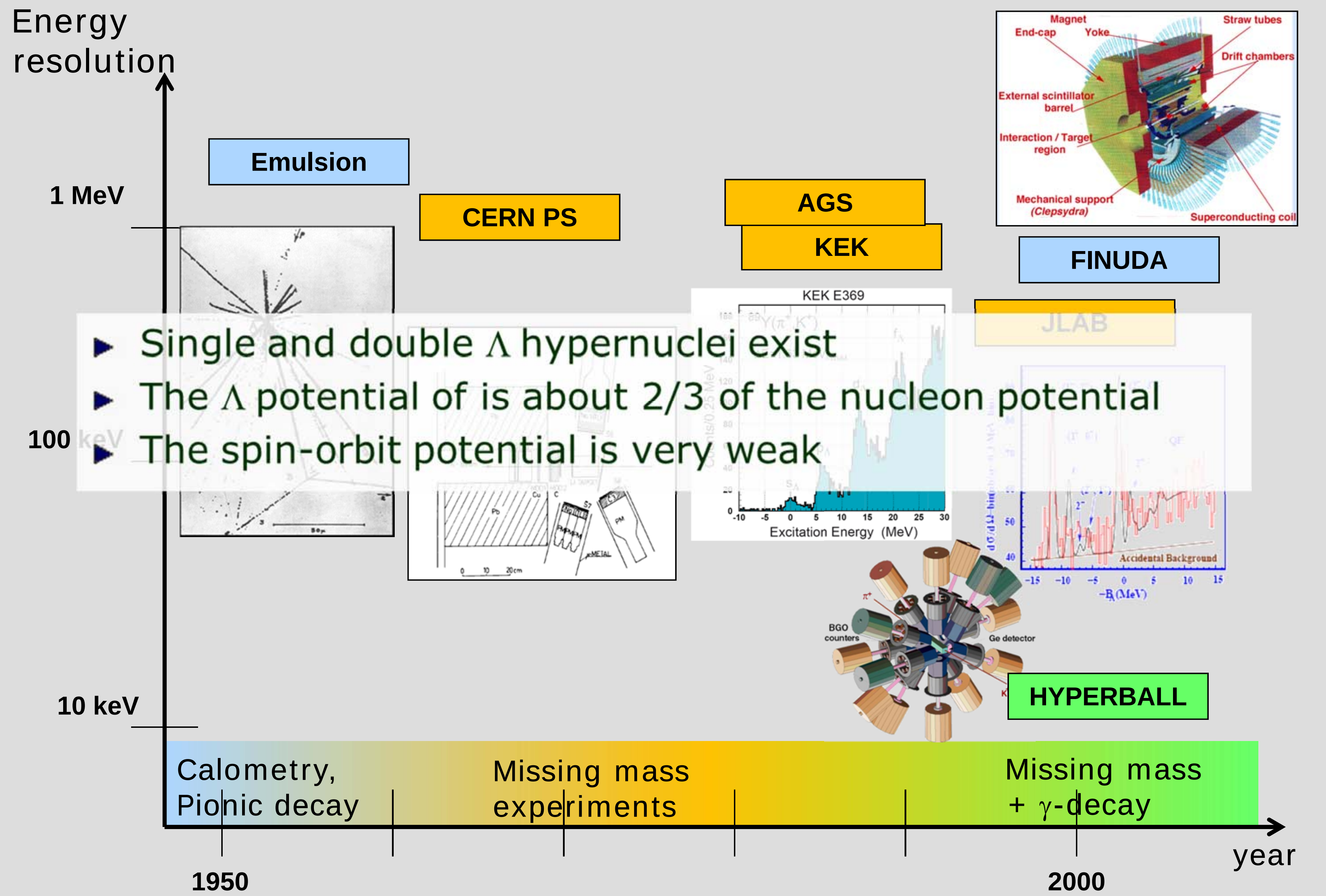
$$V_{\Lambda N}^{eff} = V_0 + \Delta(\vec{s}_\Lambda \cdot \vec{s}_N) + S_N(\vec{l}_{\Lambda N} \cdot \vec{s}_N) + S_\Lambda(\vec{l}_{\Lambda N} \cdot \vec{s}_\Lambda) + T(s_{12})$$

$^{7}_{\Lambda}$Li (3/2$^+$,1/2$^+$) | **$^{7}_{\Lambda}$Li (5/2$^+$,1/2$^+$)** | **$^{9}_{\Lambda}$Be (3/2$^+$,5/2$^+$)** | **$^{16}_{\Lambda}$O (1$^-$,0$^-$)**

Δ = 0.4 MeV ***S_N = - 0.4 MeV*** ***S_Λ = - 0.01 MeV*** ***T = 0.03 MeV***



Past and Presence of Hypernuclei



- Single and double Λ hypernuclei exist
- The Λ potential of is about 2/3 of the nucleon potential
- The spin-orbit potential is very weak

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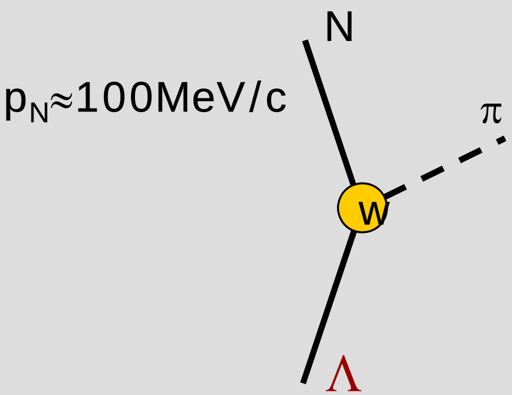
- **Basic properties**
- Why bother?
- Recent observations

Weak Decay of Λ Hypernuclei

free Λ decay



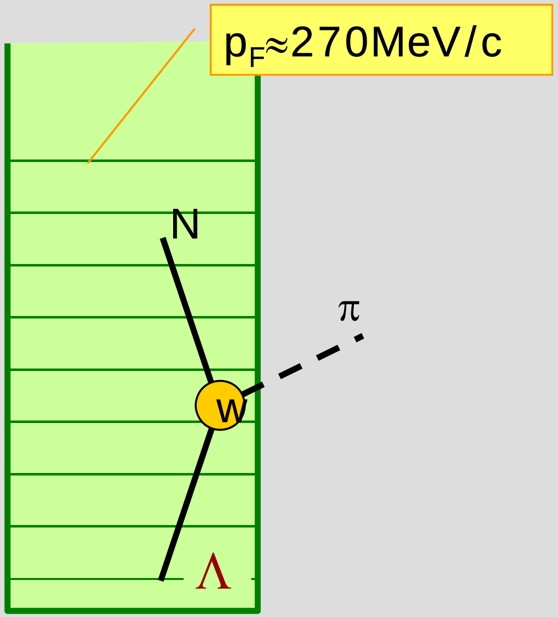
$\Lambda \to p\pi^- + 38MeV \ (64\%)$

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

$\tau_\Lambda = 263 ps$

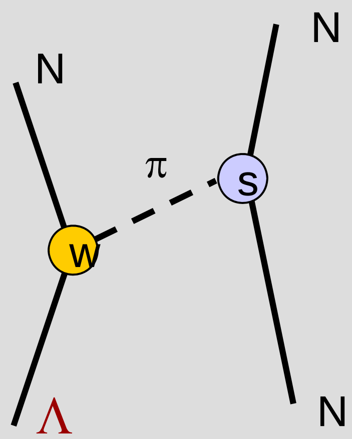
ΔI=1/2 rule

mesonic decay of hypernuclei



suppresed by Pauli blocking

non-mesonic decay of hypernuclei

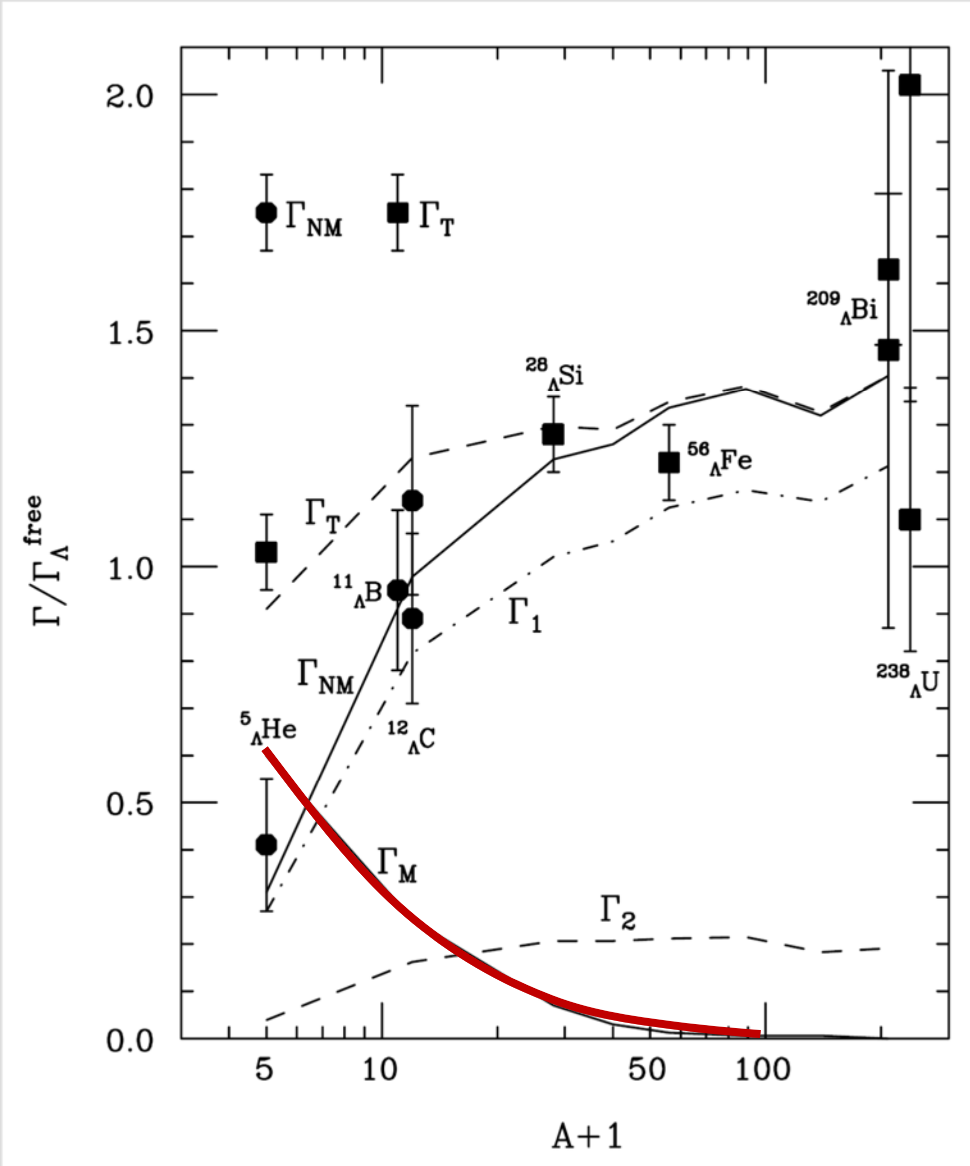


$\Lambda p \to np + 176 MeV$

$\Lambda n \to nn + 176 MeV$

dominant in all but the lightest hypernuclei

Mesonic vs. Non-mesonic Decay



W.M. Alberico and G. Garbarino, Phys. Rep. **369** (2002) 1

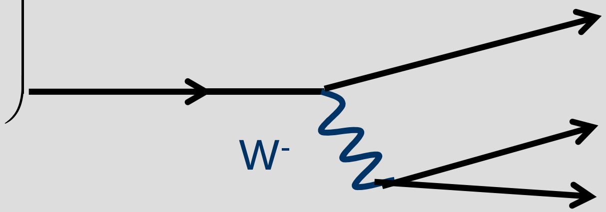
ΔI=1/2 rule for ΔS=1 weak transitions

- standard theory: no neutral current for flavor changing transition

$$s \to u + W^- \qquad W^- \to d + \bar{u}$$

I=0, I_3=0

$$\Lambda = \begin{pmatrix} u \\ d \\ s \end{pmatrix}$$



$$\begin{pmatrix} u \\ d \\ u \end{pmatrix} = p \qquad \begin{pmatrix} \bar{u} \\ d \end{pmatrix} = \pi^-$$

I=1/2, I_3=1/2

I=1, I_3=-1

ΔI=1/2 or 3/2

$$\Delta I = \frac{1}{2} \qquad \left\langle \frac{1}{2}\frac{1}{2} 1 -1 \middle| \frac{1}{2} -\frac{1}{2} \right\rangle = \sqrt{\frac{2}{3}}$$

$$\Delta I = \frac{3}{2} \qquad \left\langle \frac{1}{2}\frac{1}{2} 1 -1 \middle| \frac{3}{2} -\frac{1}{2} \right\rangle = \sqrt{\frac{1}{3}}$$

$$\Rightarrow \quad \text{ratio} = 2:1$$

- Λ→N+π:

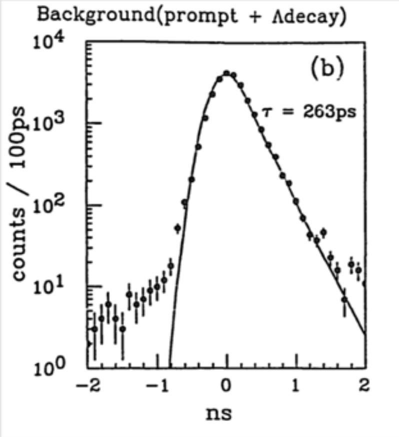
$$\Gamma(\Lambda \to p + \pi^-) : \Gamma(\Lambda \to n + \pi^0) = \begin{cases} 2:1 & \text{for } \Delta I = 1/2 \\ 1:2 & \text{for } \Delta I = 3/2 \end{cases} \quad \text{dominance}$$

- Experiment:

$$\Gamma(\Lambda \to p + \pi^-) : \Gamma(\Lambda \to n + \pi^0) = 0.639 : 0.358 = 1.78$$

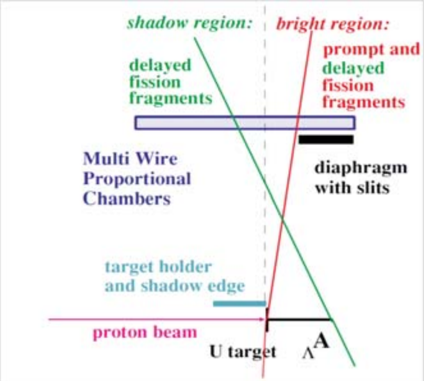
Lifetime of Hypernuclei

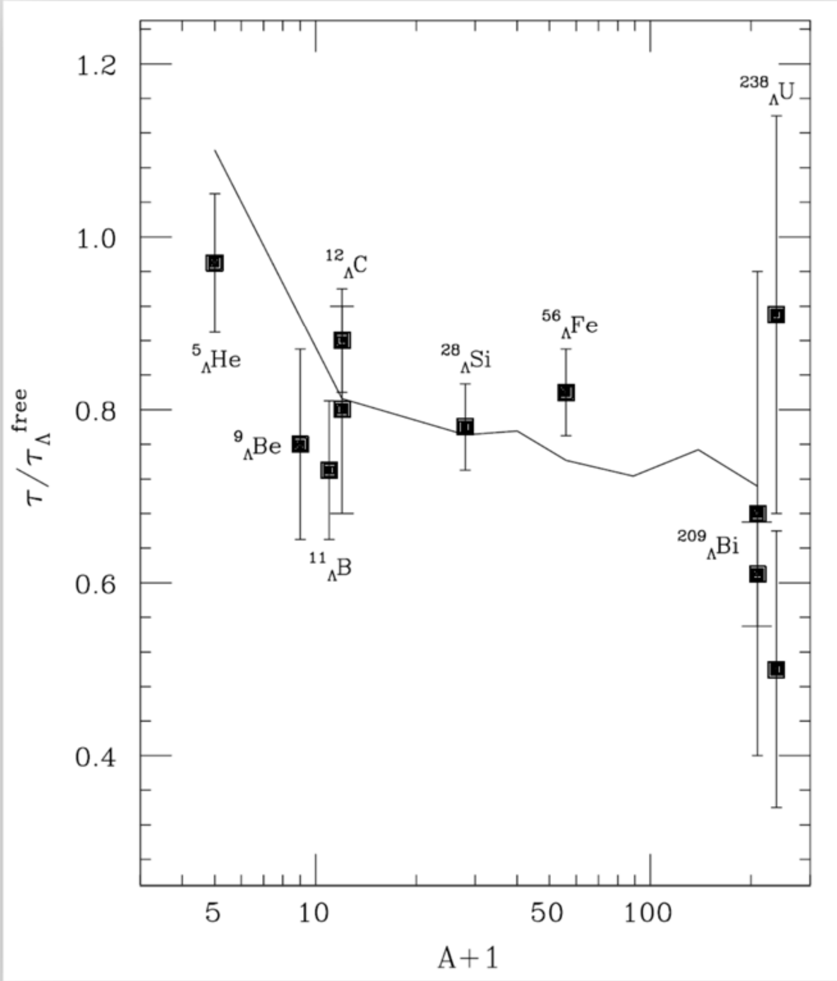
- Light hypernuclei
  - Decay in flight (→ HYPHI, STAR)
  - Direct time measurements



H. Outa *et al.*, Nucl. Phys. A**547** (1992) 109c

- Heavy Nuclei
  - Shadow method (→Jülich)





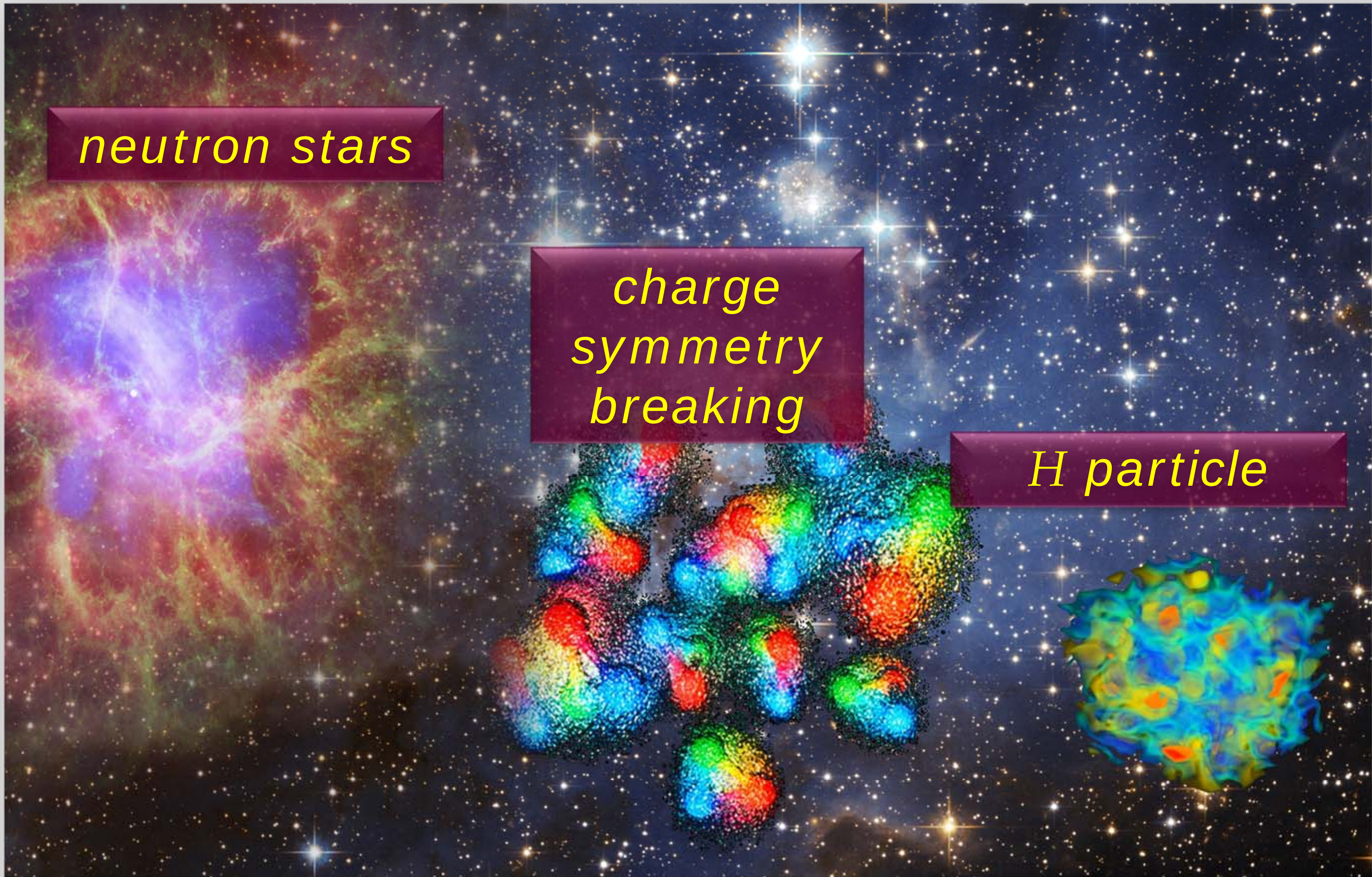
Kulessa et al., J. Phys. G **28** (2002) 1715

Hypernuclei…

- How it all began
- Many roads lead to Rome
- Basic properties
- Why bother?
- Recent observations

Bridging the gap between Quarks and Stars

Comprehensive description of Nuclei in terms of basic principles (QCD)...



...to allow quantitative predictions in regions not accessible by experiments

5 decades of hyperons in neutron stars

NEUTRON STAR MODELS

A. G. W. Cameron
Atomic Energy of Canada Limited, Chalk River, Ontario, Canada
Received June 17, 1959

Another reason why the writer has not taken into account complications inherent in using a relativistic equation of state is that no such things as pure neutron stars can be expected to exist. The neutrons must always be contaminated with some protons and sometimes with other kinds of nucleons (hyperons or heavy mesons).

Alastair G.W. Cameron, Astrophysical Journal, vol. 130, p.884 (1959)

Rather than being a surprise to find hyperons it would stretch our understanding of fundamental strong and weak interaction processes to breaking point if they were not to appear. It is certainly inconceivable that a nucleon-only EoS could be realistic at such large densities.

J. R. Stone, P. A. M. Guichon, A. W. Thomas, arXiv:1012.2919v1

Hyperons in neutron stars (2008)

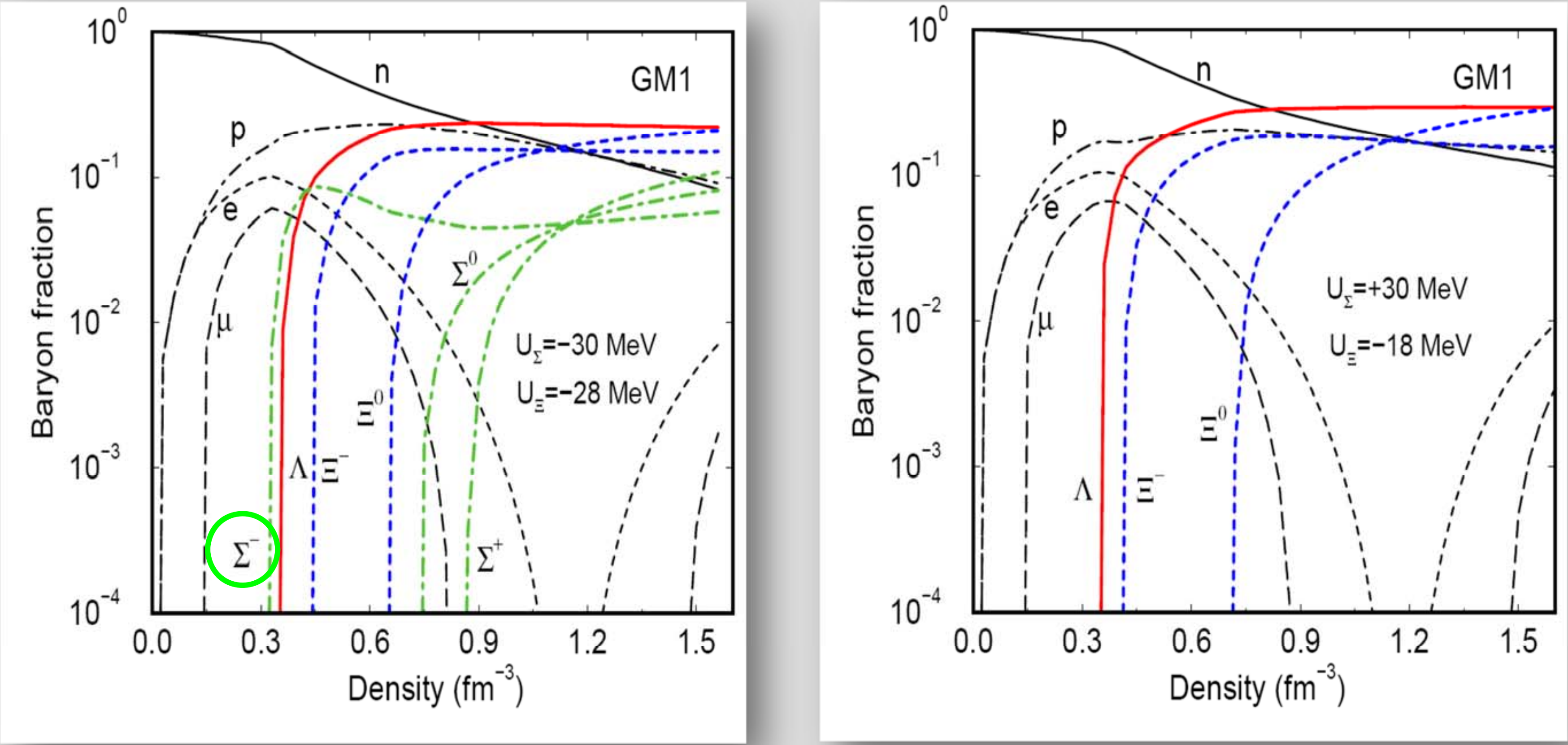
- Haris Djapo, Bern-Jochen Schäfer and Jochen Wambach
  arXiv:0811.2939v1 [nucl-th] 18 Nov 2008

In conclusion, irrespective of the YN interactions, incompressibility and symmetry parameter used, hyperons will appear in dense nuclear matter at densities around $\sim 2\rho_0$. This immediately leads to a softening of the EoS which in turn results in a smaller maximum mass of a neutron star.

With the prediction of a low onset of hyperon appearance it becomes practically impossible to ignore strangeness when considering neutron stars. Even though the prediction for the maximum masses of neutron stars are too low, the appearance of hyperons in neutron stars is necessary and any approach to dense matter must address this issue.

Appereance of Hyperons

- hyperons appear, when its in-medium energy equals its chemical potential
- Input: Baryons in chemical Equilibrium, conservation laws, interaction



N. K. Glendenning, Phys. Rev. C **64**, 025801 (2001)

- beyond $2\rho_0$ hyperons may play a significant role in neutron stars
- in the core hyperons may even be more abundant than neutrons

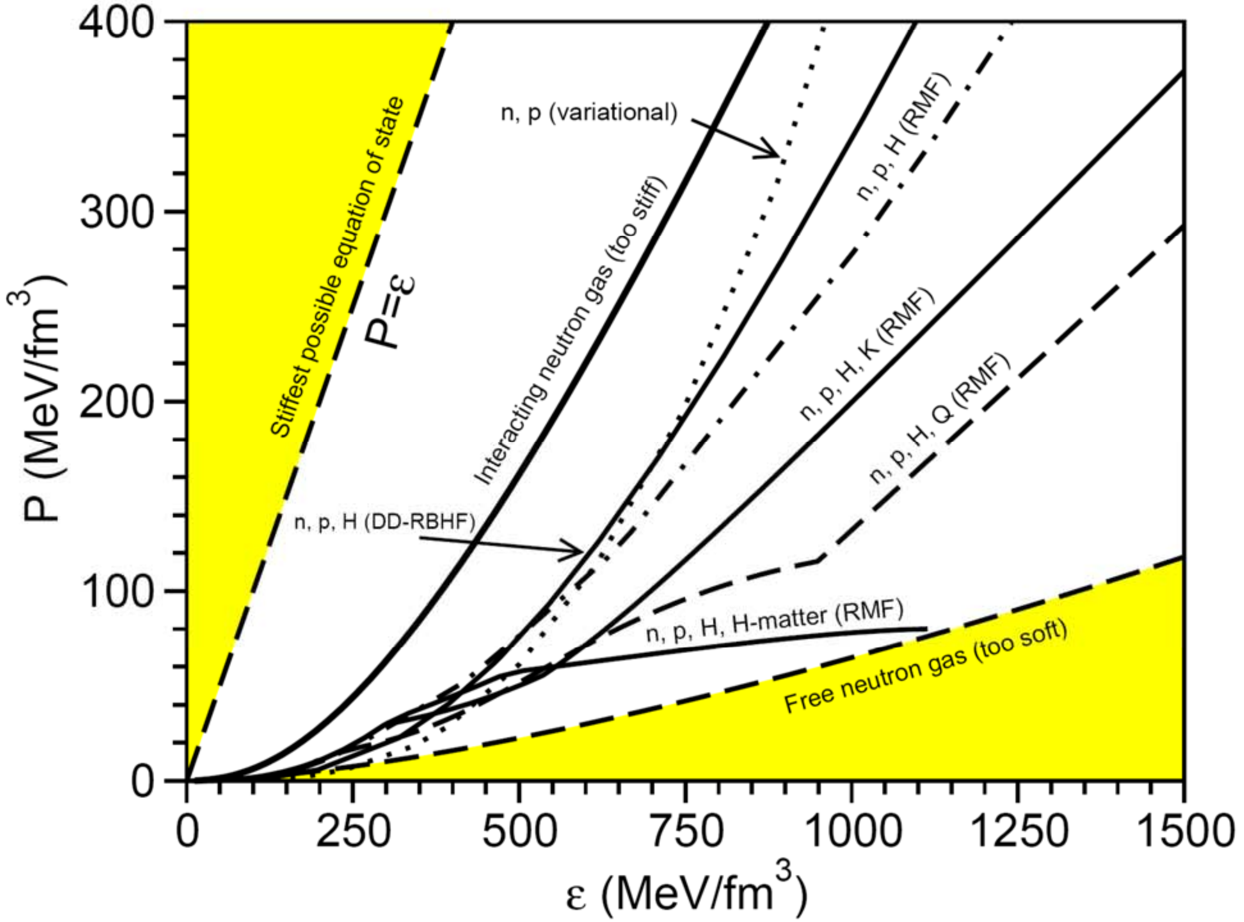
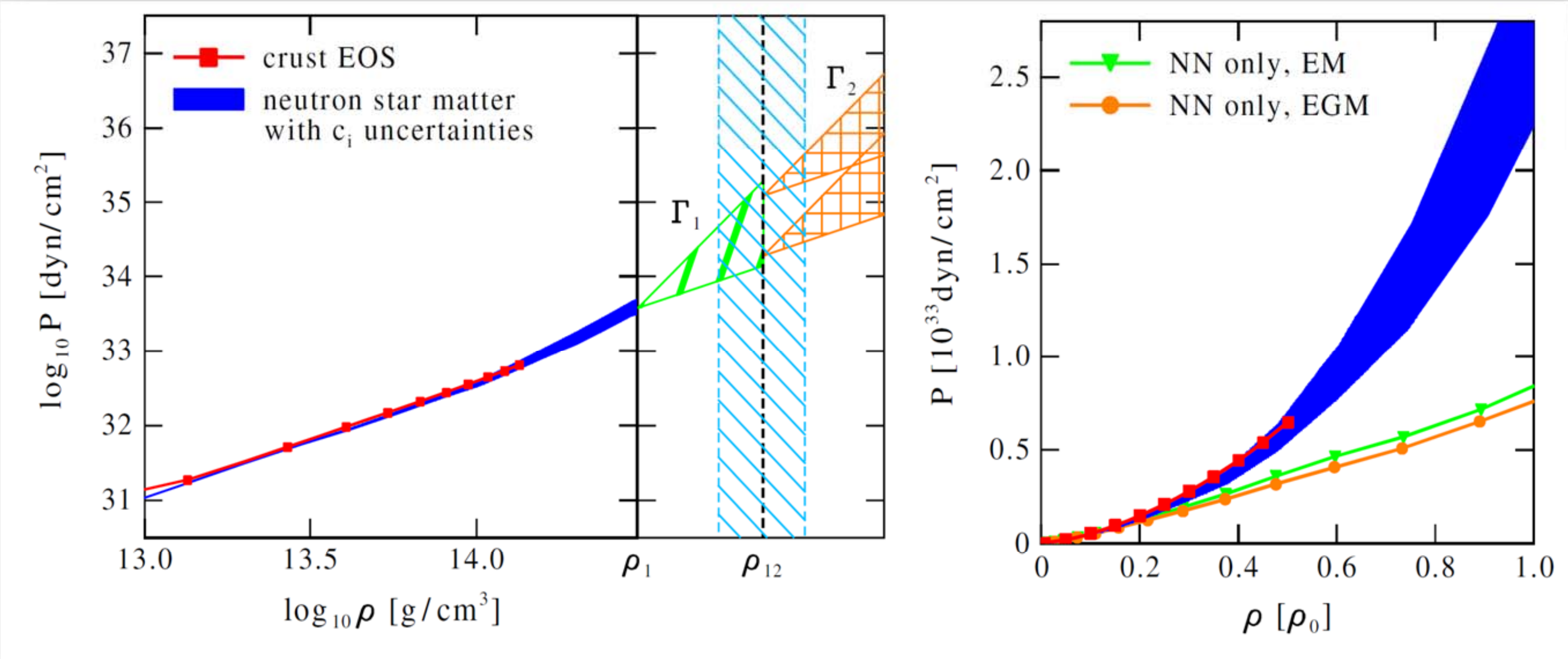


Fig. 2. Models for the equation of state (pressure versus energy density) of neutron star matter [11]. The notation is as follows: RMF=relativistic mean-field model; DD-RBHF=density dependent relativistic Brueckner-Hartree-Fock model; n=neutrons; p=protons; H=hyperons, K=$K^-[u,\bar{s}]$ meson condensate; Q=u, d, s quarks; H-matter=H-dibaryon condensate.

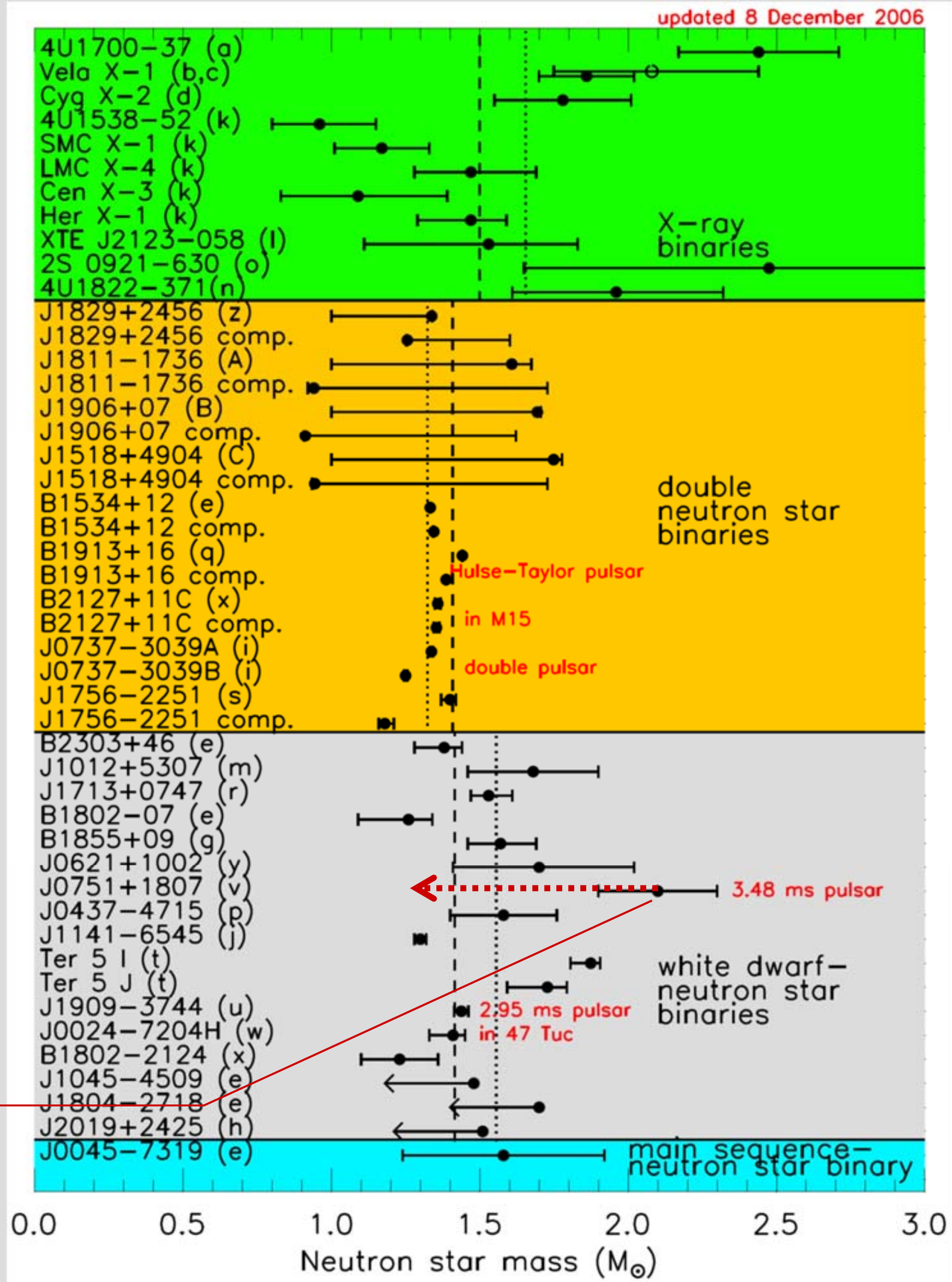
3-body Forces in Neutron Stars

- K. Hebeler et al., PRL 105, 161102 (2010)



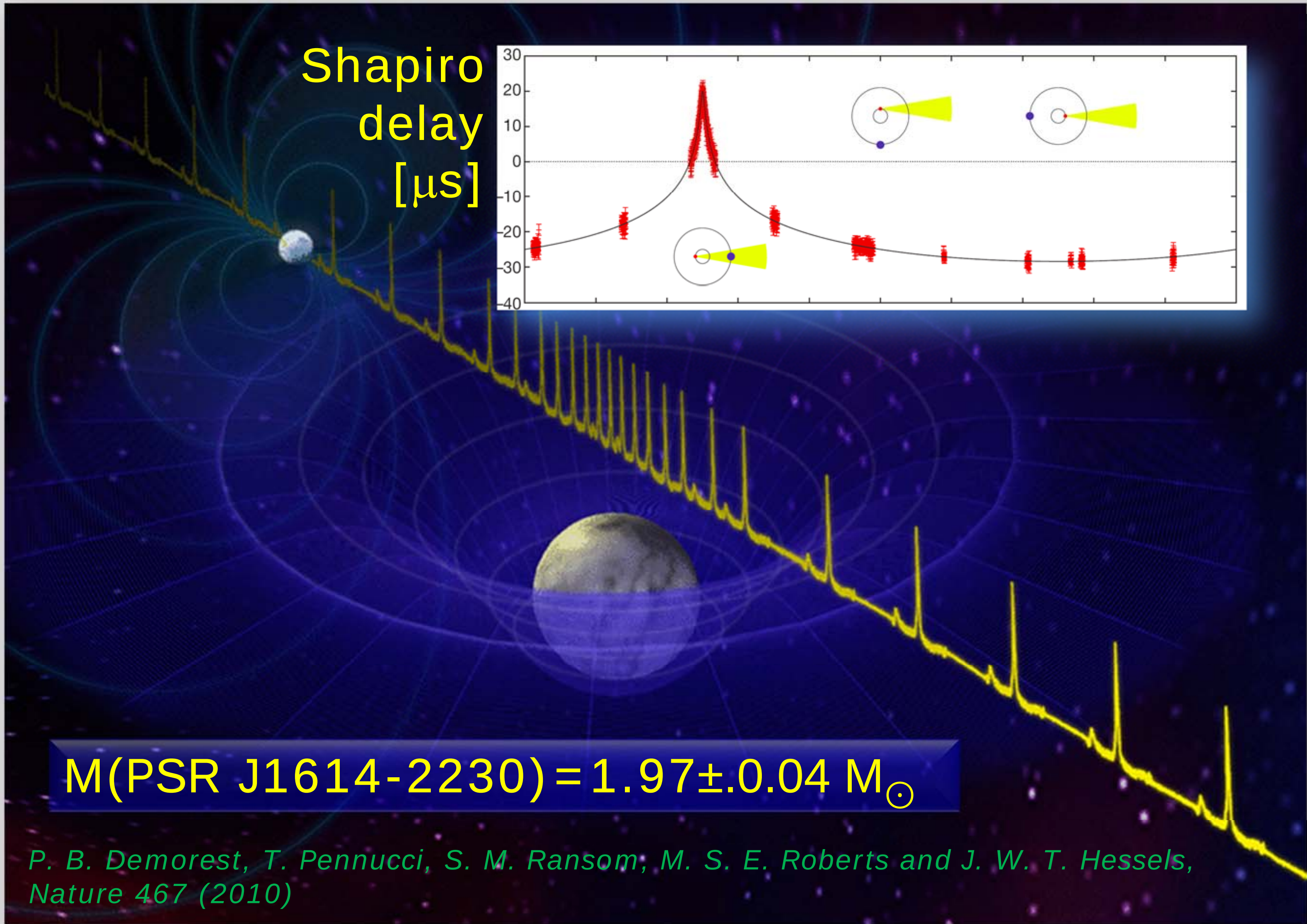
Masses of neutron stars

- J.M. Lattimer and M. Prakash
  astro-ph/0612440v1



D. J. Nice, I. H. Stairs and L. E. Kasian, AIP Conference Proceedings 983, 453 (2008).
M(J0751)=1.26±0.14 $M_\odot$

Masses of Neutron Stars

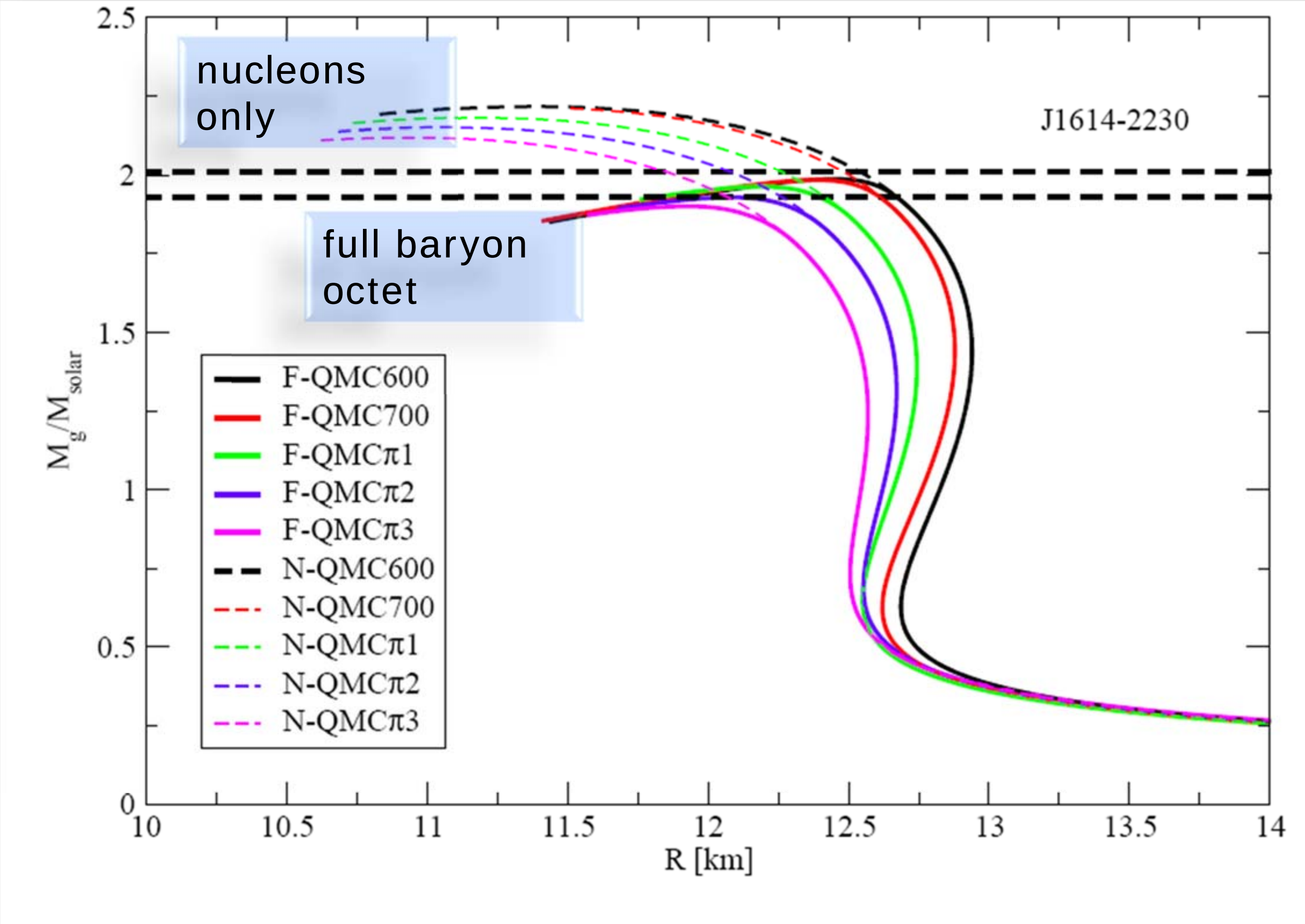


M(PSR J1614-2230) = 1.97±.0.04 $M_\odot$

P. B. Demorest, T. Pennucci, S. M. Ransom, M. S. E. Roberts and J. W. T. Hessels, Nature 467 (2010)

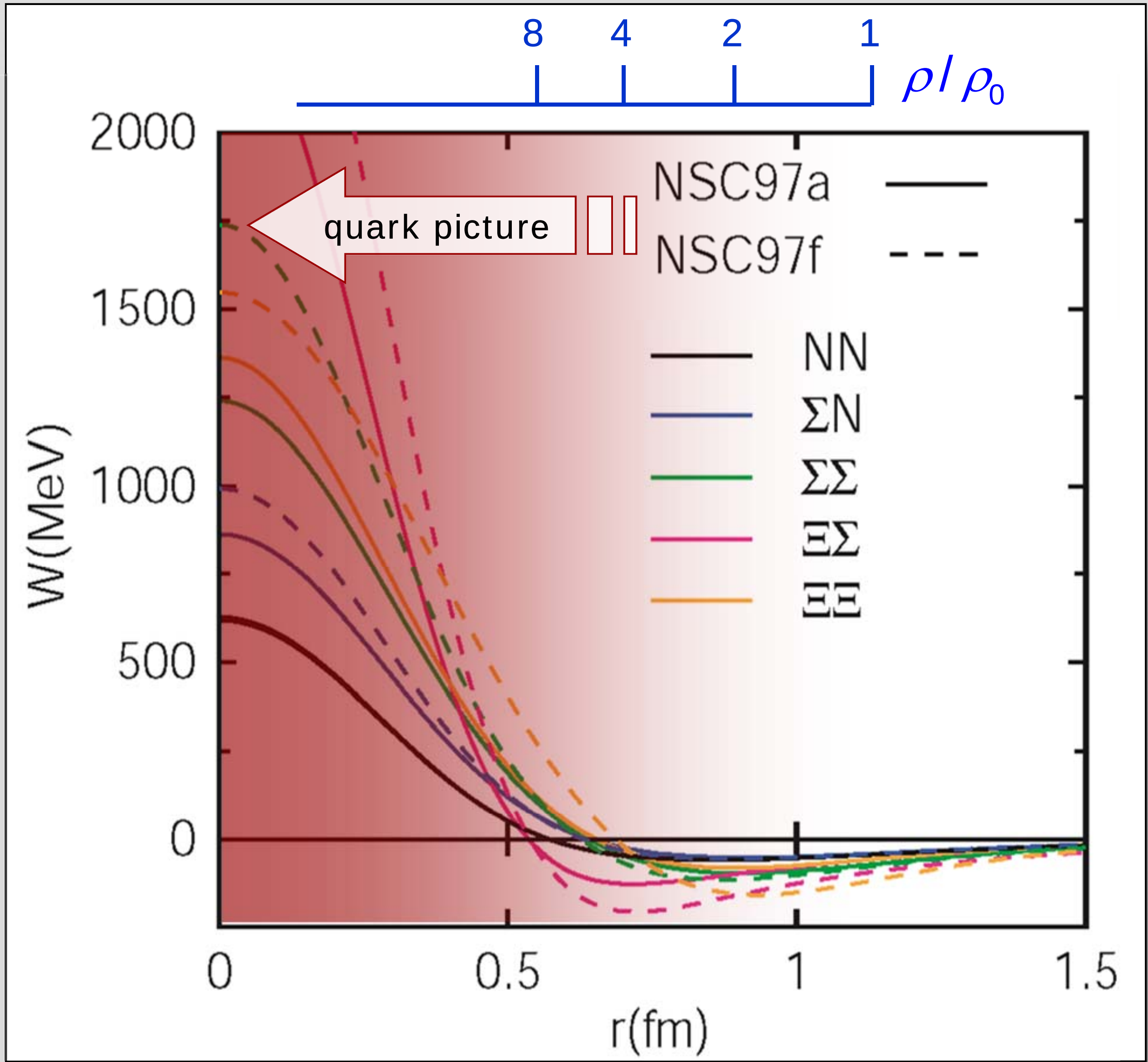
Masses of Neutron Stars

- EOS predicted within Quark-Meson-Coupling model

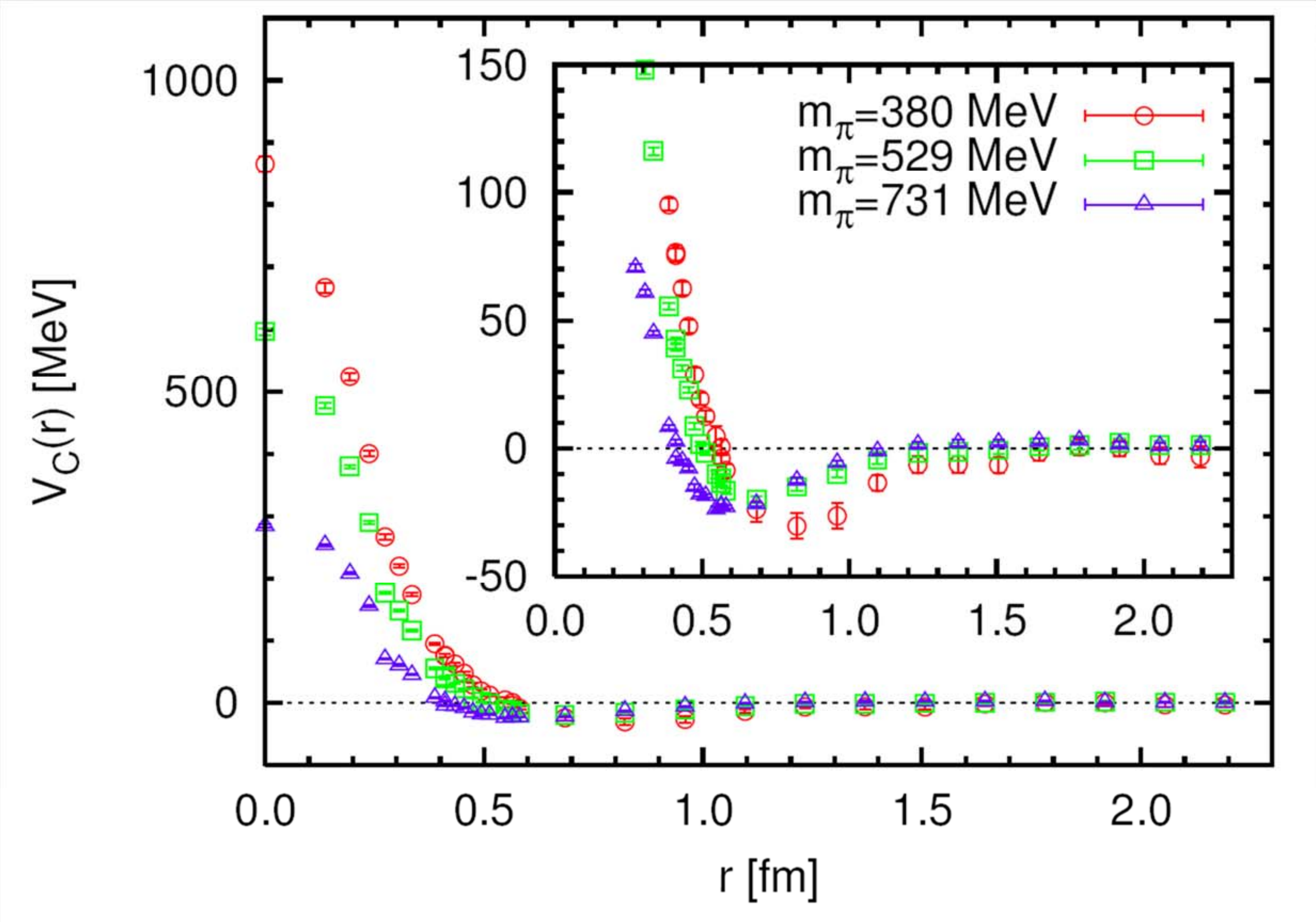


J. R. Stone, P. A. M. Guichon, A. W. Thomas, arXiv:1012.2919v1

Interpolation vs. extrapolation



Nuclear Forces from Lattice QCD



S. Aoki, T. Hatsuda and N. Ishii, Prog. Theor. Phys. 123 (2010) 89

Charge Symmetry Breaking

- Protons and neutrons are the two isospin states of the nucleon
- Protons and neutrons have different masses
- Coulomb interaction would make p (uud) heavier than n (udd)
- Mass difference between up and down quarks is the *only* strong-interaction effect that breaks charge symmetry.

u $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 1.5$ to 3.0 MeV [a] Charge $= \frac{2}{3}\,e$ $I_z = +\frac{1}{2}$

$m_u/m_d = 0.3$ to 0.6

d $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 3$ to 7 MeV [a] Charge $= -\frac{1}{3}\,e$ $I_z = -\frac{1}{2}$

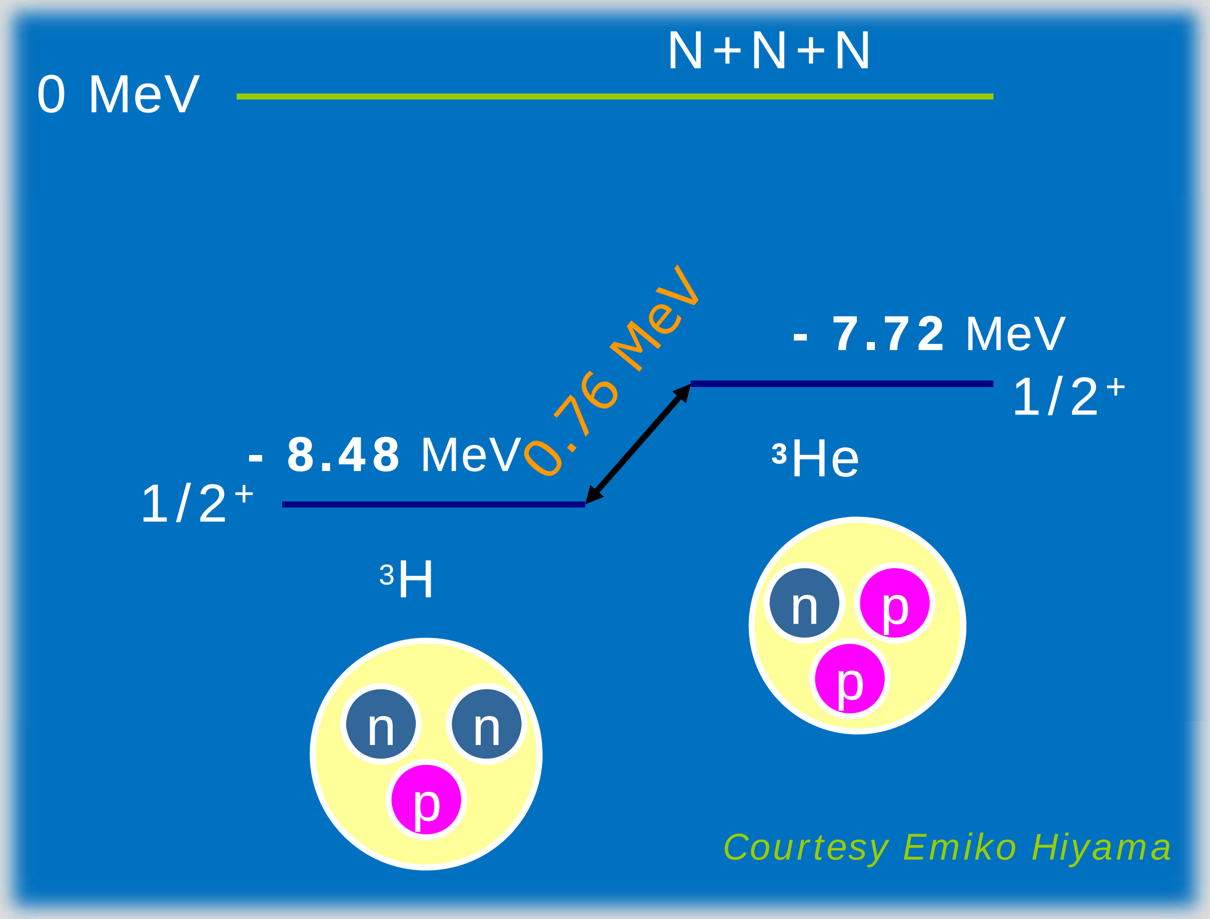
$m_s/m_d = 17$ to 22

$\overline{m} = (m_u + m_d)/2 = 2.5$ to 5.5 MeV

- Strong CSB in S=0 sector makes neutrons decay into protons and is therefore decisive for the structure of our universe
- Reminder: one has to distinguish between
  - Isospin invariance: $[H_{strong}, T] = 0$
  - Charge independence
  - Charge symmetry: $[H_{strong}, e^{i\pi T_2}] = 0 \quad \leftrightarrow \quad |u\rangle \xrightarrow{CS} -|d\rangle, \; |d\rangle \xrightarrow{CS} +|u\rangle$
    - Example: π^0-π^0 and π^0-π^+ scattering
      - Hamiltonian isospin invariant
      - Clebsch Gordan coefficients are different $\quad |10\rangle|10\rangle \neq |10\rangle|11\rangle$

        $\Rightarrow$ interaction is charge dependent

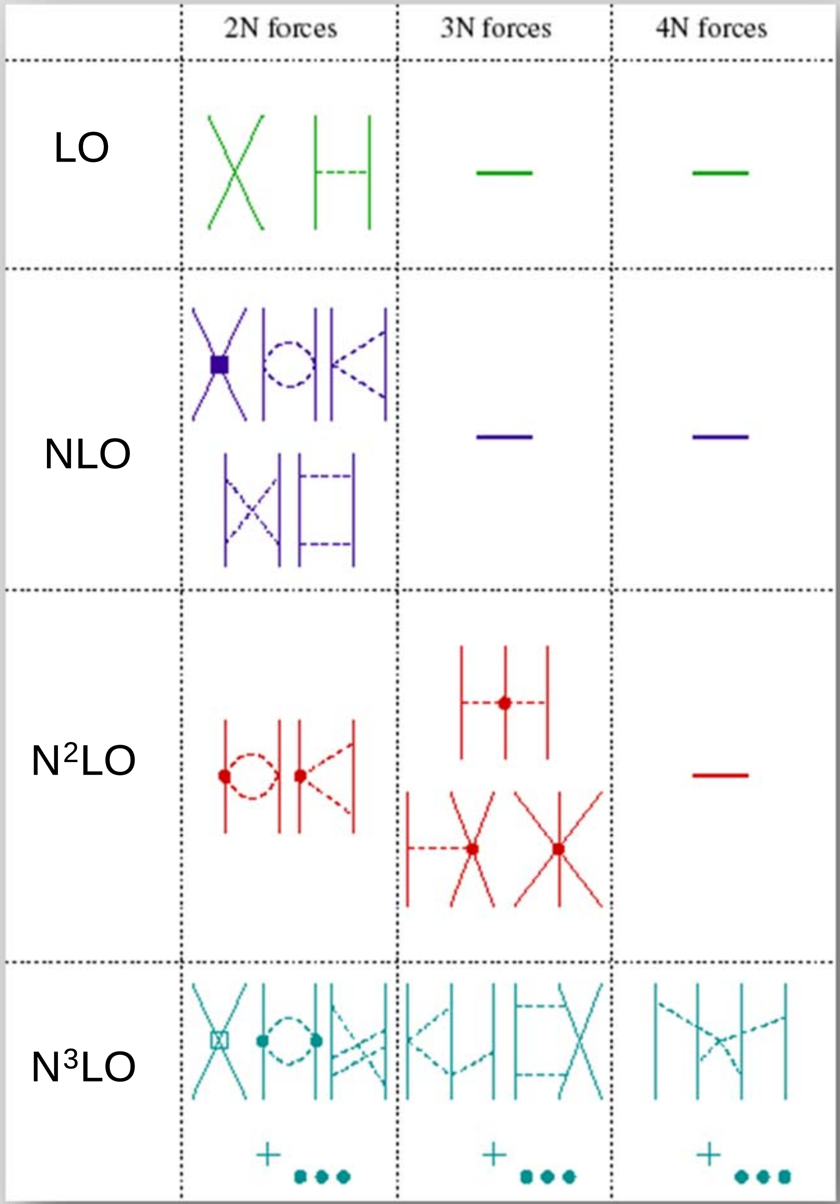
Charge Symmetry Breaking in Mirror Nuclei



- Coulomb interaction and modifications of nuclear structure due to Coulomb interaction may mask the effect of the strong CSB!

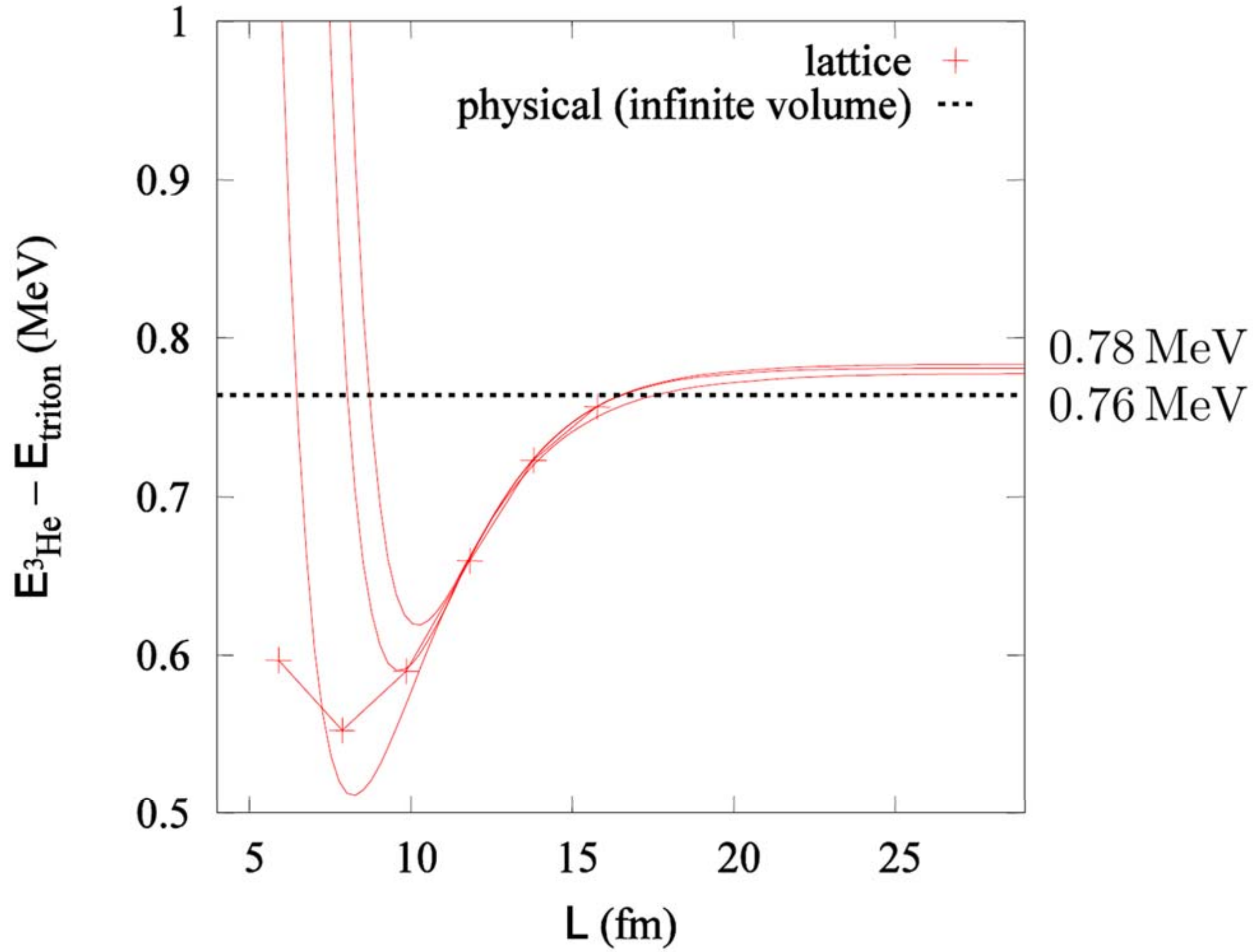
Effective Field Theories are getting mature

- EFT for relevant degrees of freedom based on symmetries of QCD
- Long range pion dynamics treated explicitely
- Short-range physics absorbed in contact terms
- Low energy constants fitted to experimental data
- Hierarchy of *consistent* NN, 3N, 4N,… interactions



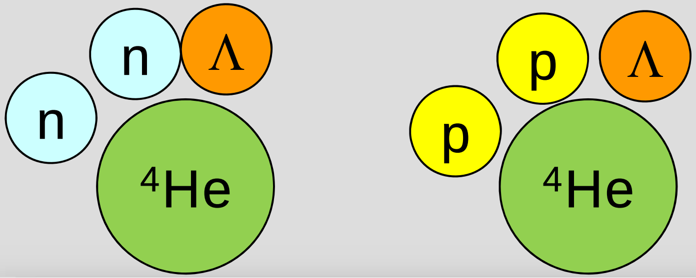
CSB and EFT

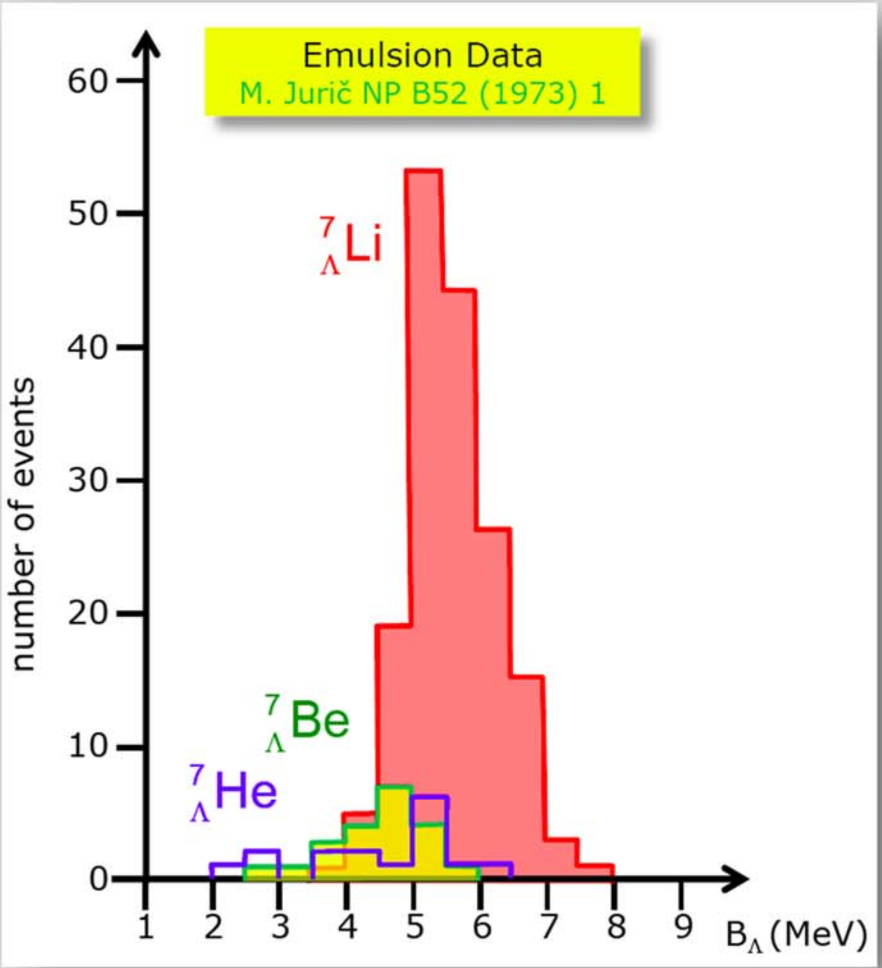
$$E_{^3\mathrm{He}} - E_{\mathrm{triton}} = 0.78(5)\ \mathrm{MeV}$$

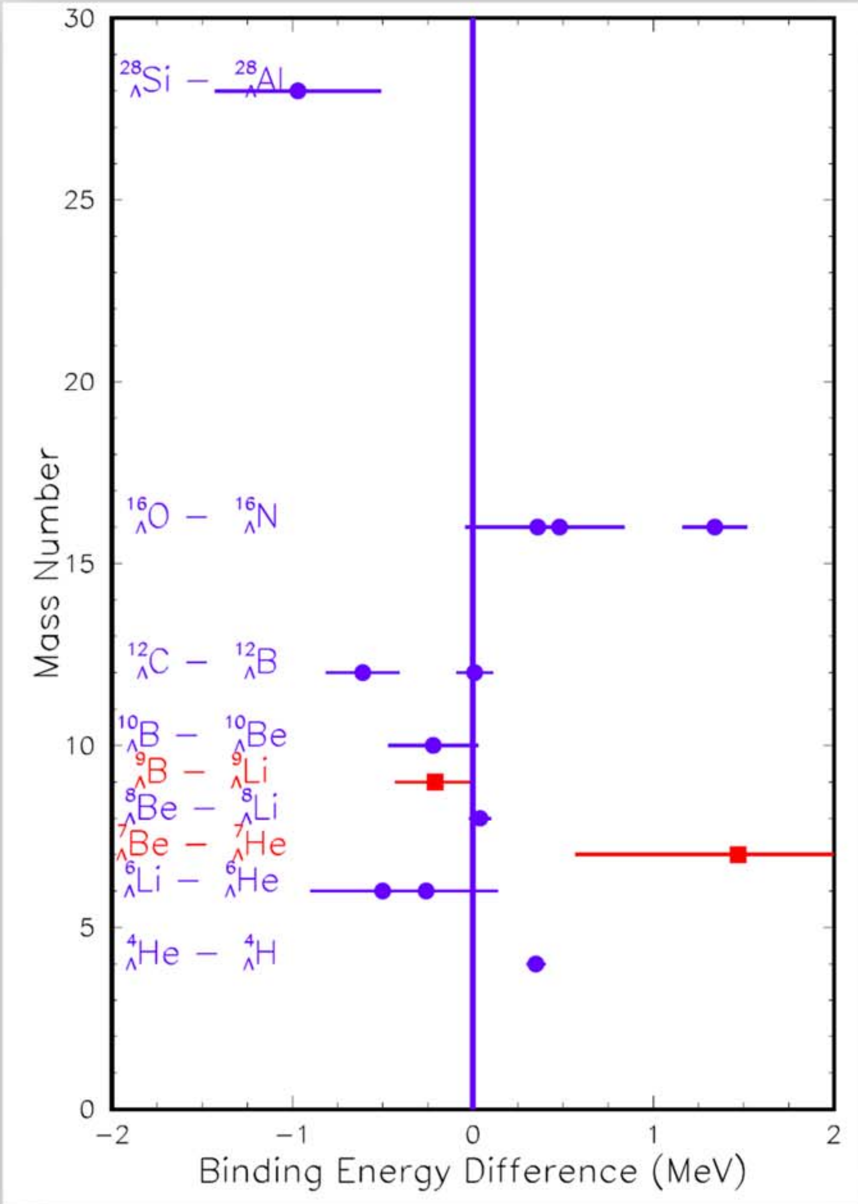


Evgeny Epelbauma, Hermann Krebs, Dean Lee, Ulf-G. Meißner

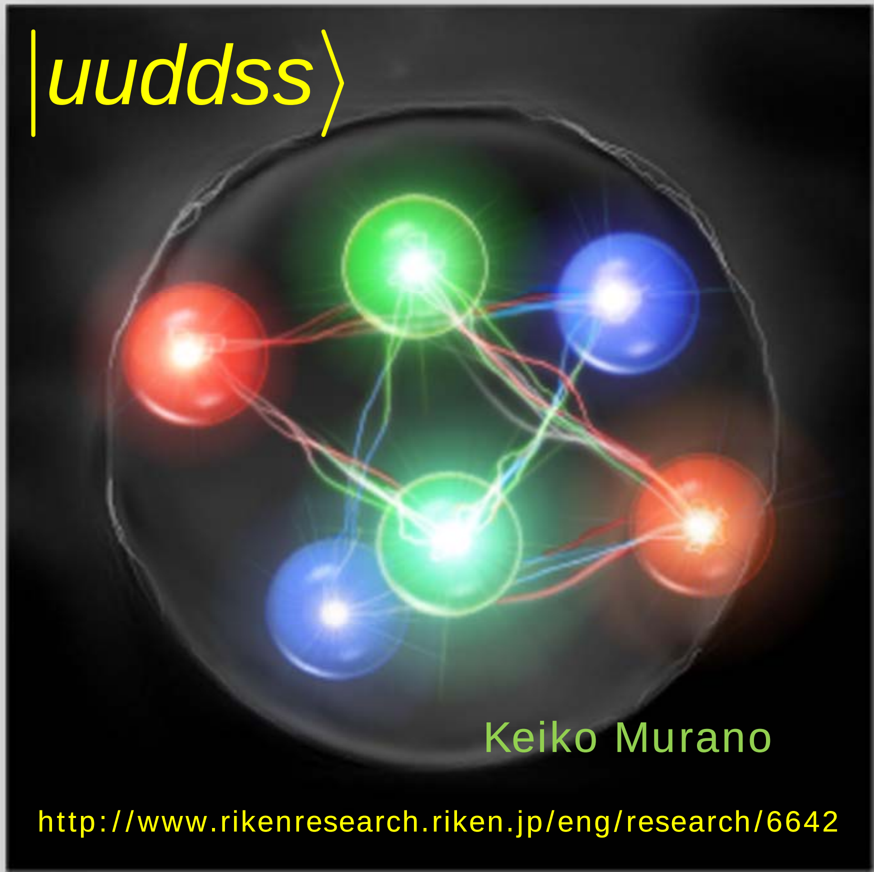
Strange Mirror Nuclei





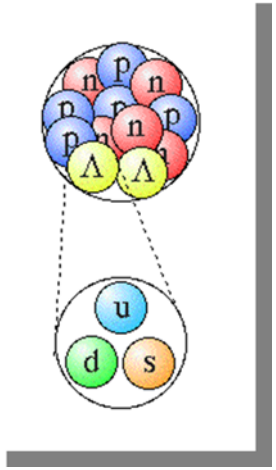


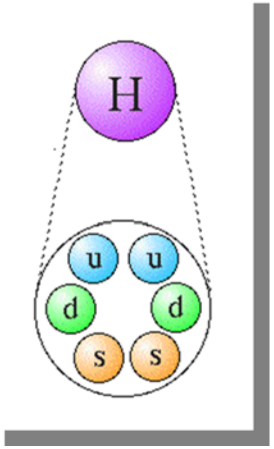
The H-Particle

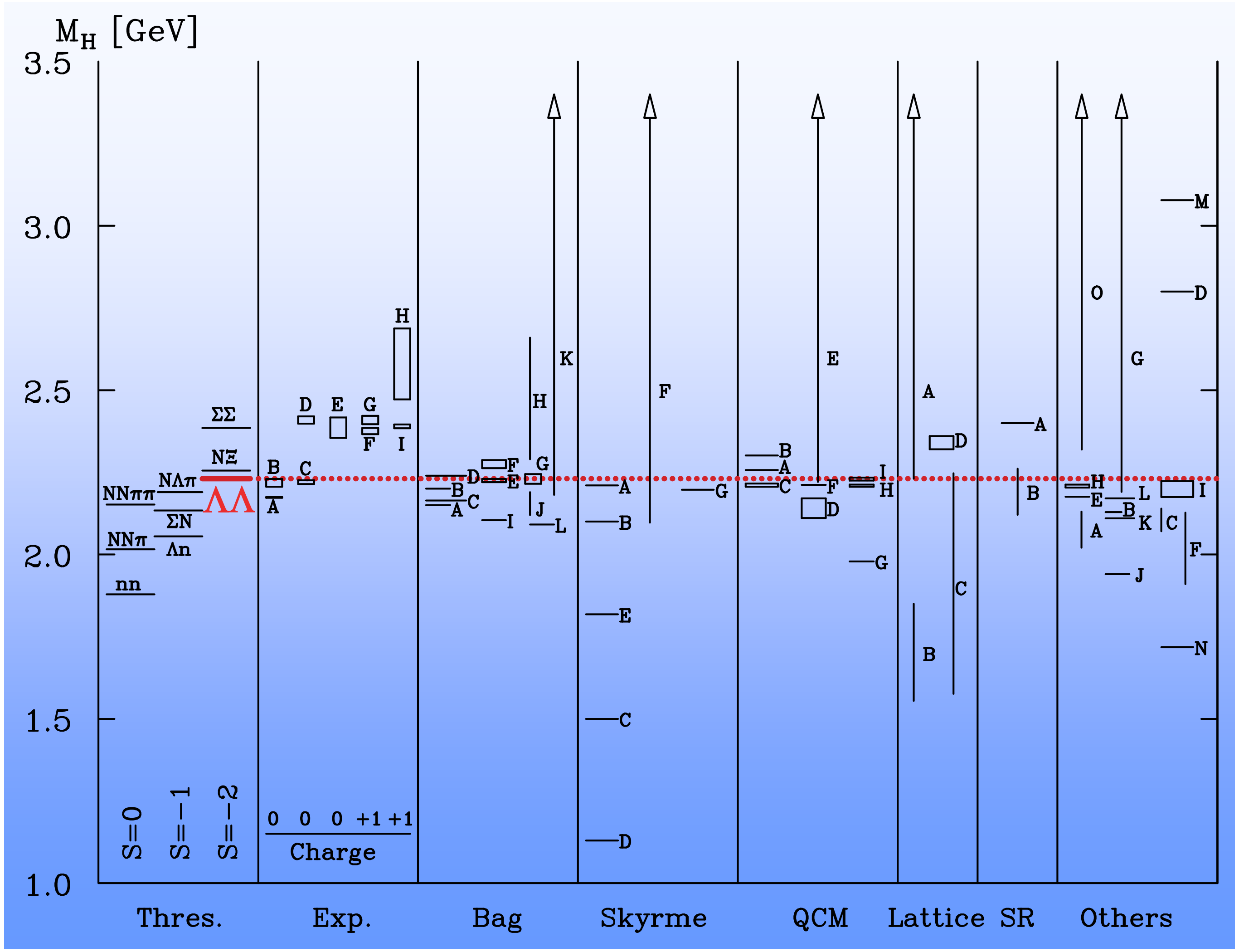


ΛΛ Nuclei as Femto-Laboratory

- *H*-Particle R.L. Jaffe (1977)







T. Sakai, K. Shimizu, K. Yazaki
Prog.Theor.Phys.Suppl. 137 (2000) 121-145

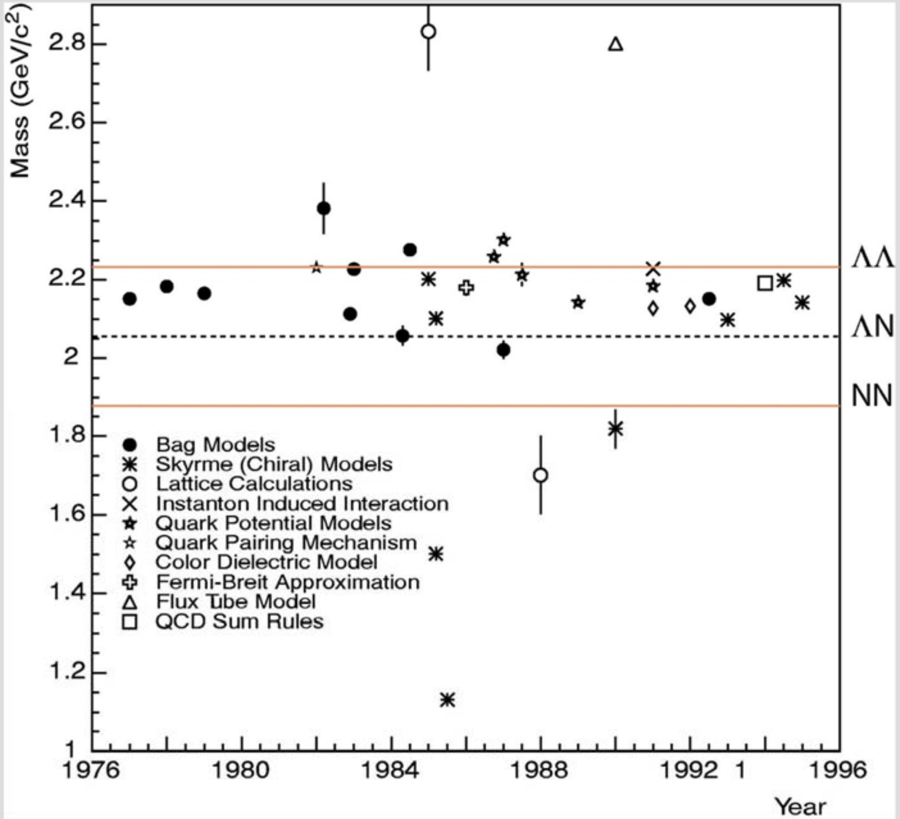
Bound or not bound?

- No experimental evidence yet in production experiments
- Observation of weak decay of double hypernuclei seems to contradict the existence of an H-particle below $2m_\Lambda$
- but
  - H-particle may be rather compact: R~0.5fm

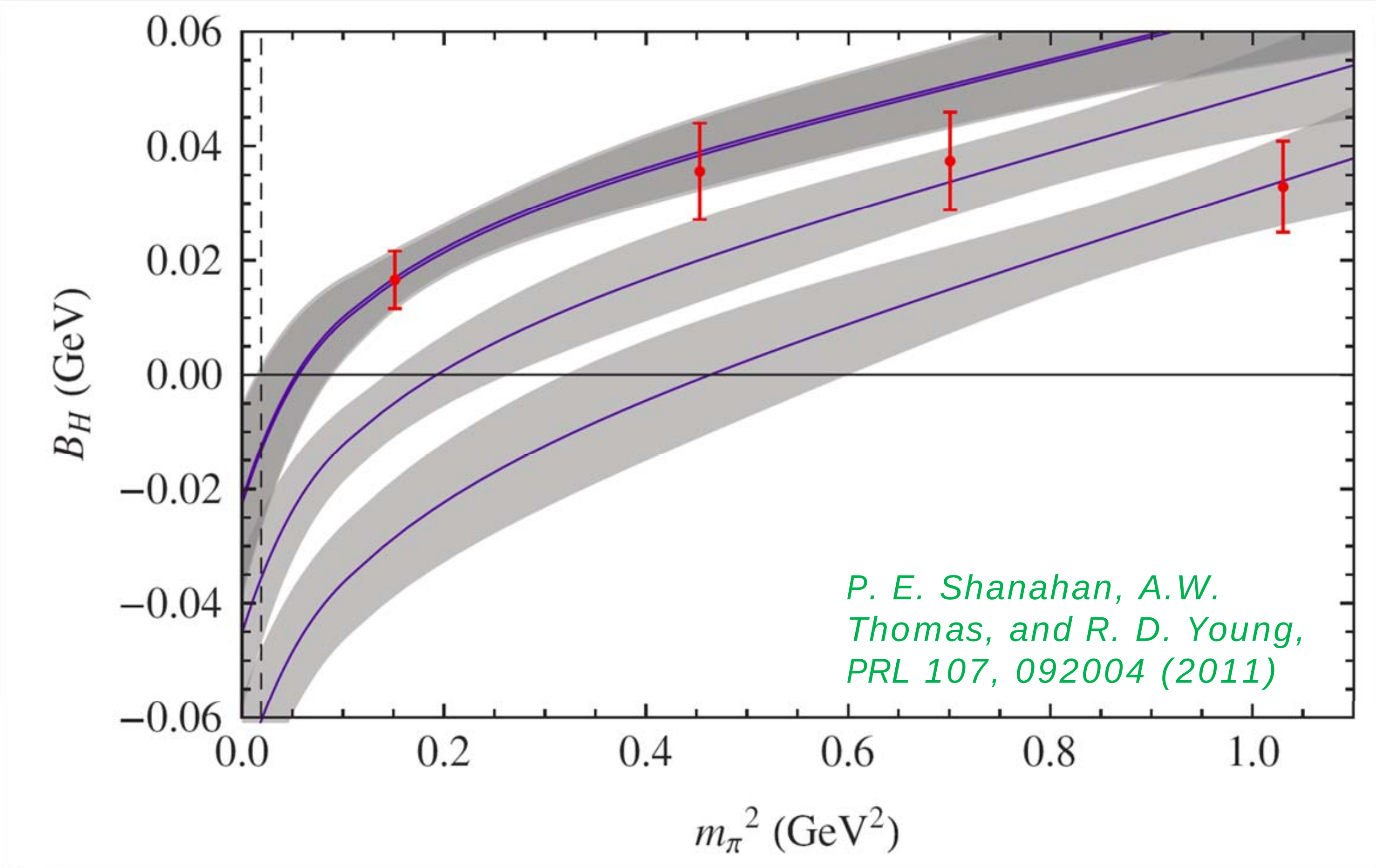
    F.G. Scholtz *et al*. (1993)
  - and formation probability may be therefore reduced

    D.E. Kahana & S.H. Kahana (1999)

    G.R. Farrar et al. (2003)

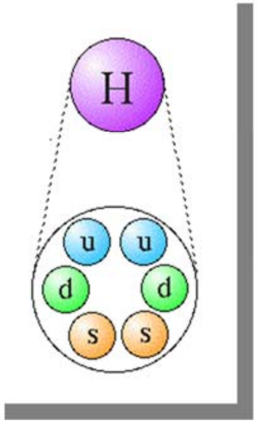


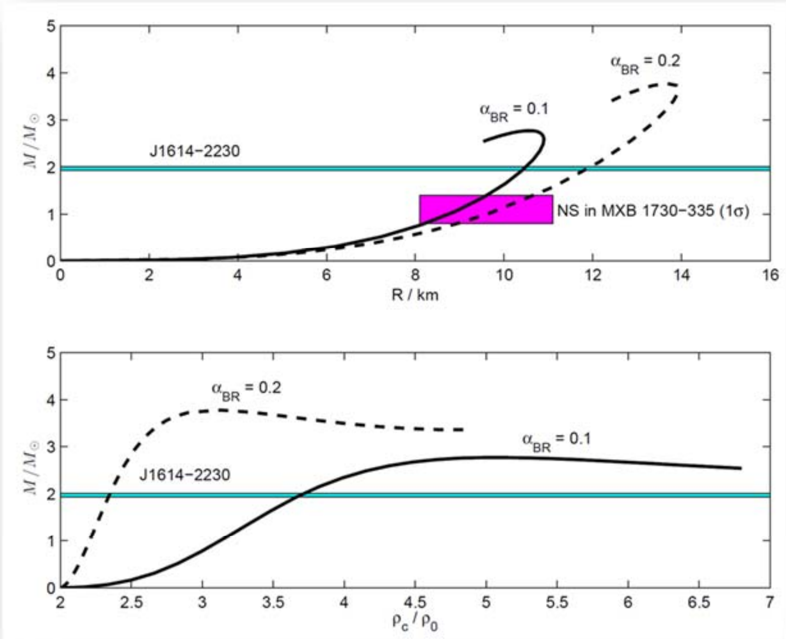
H-Particle on the Lattice



- Recent lattice calculations predict a slightly unbound H with B_H=13±14MeV
- That this is so close to the threshold will undoubtedly spur investigations into the consequences for doubly strange hypernuclei as well as the equation of state of dense matter.

How can we produce the H?



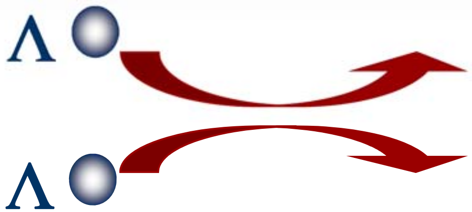


neutron stars

⇒ H-cluster stars

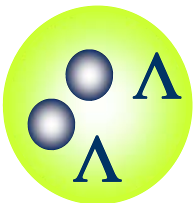
X. Y. Lai, C. Y. Gao and R. X. Xu, arXiv:1107.0834v3

$$m_M^* \simeq m_M \left(1 - \alpha_{BR} \frac{\rho}{\rho_0}\right)$$



free coalescence in energetic HI collisions

$\tau \sim 10^{-23}$s

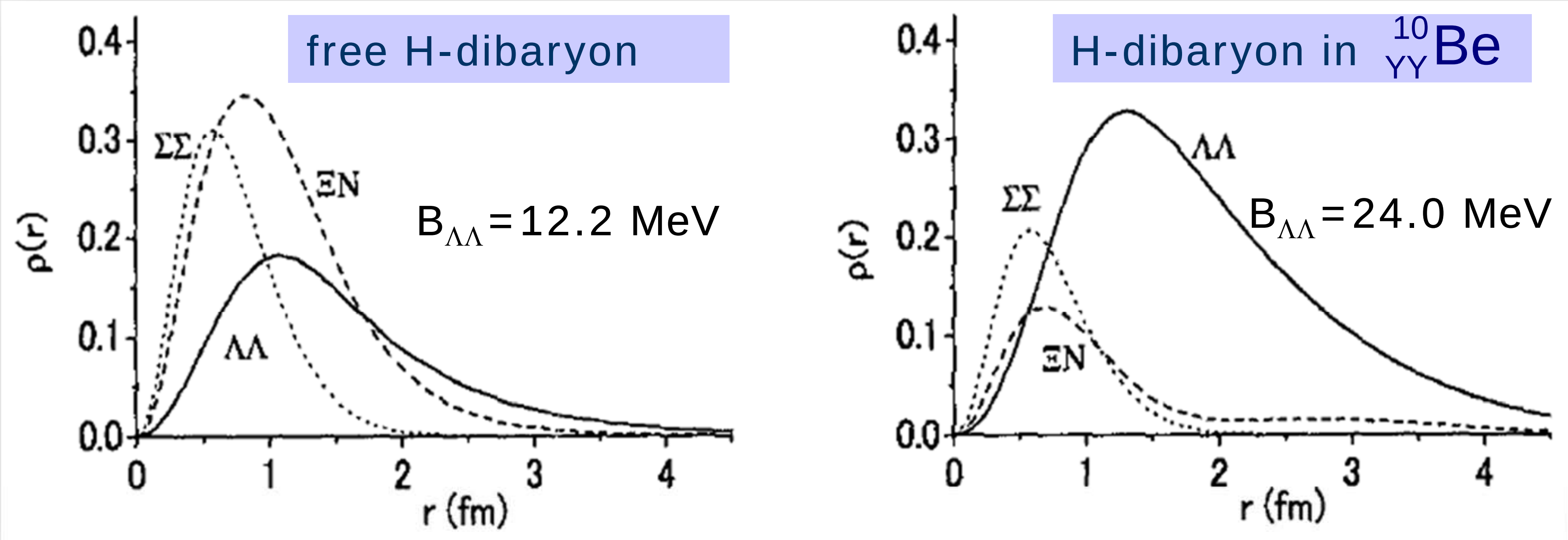


Hypernuclei as doorway state

$\tau \sim 10^{-10}$s

H-dibaryon in nuclei

- ΛΛ-ΞN-(ΣΣ) coupling important (ΔE=22-28MeV)
- Consequences
  - *H*-particle and „ΛΛ“ state will mix
  - *H*-particle in a nucleus ≠ free *H*



- level structure may be modified ⇒ γ-spectroscopy mandatory

T. Yamada, Phys. Rev. C62, 034319-1 (2000)


Hypernuclei…
How it all began
Many roads lead to Rome
Basic properties
Why bother?
Recent observations

Individual Strengths

Experiment @Facility	Experimental tool & status	Methods & topics
JPARC	low mometum meson beams (π,K) setup ready, K beam intensity still limited	• Λ hypernuclei excited states (Δm~few keV) by γ-spectroscopy • Ξ-hypernuclei by missing mass • ground state masses of light double hypernuclei by hybrid emulsion (Δm~ few 10keV)
JLAB	electro production until 20xx upgrade of CEBAF	• Precission ground state masses by π^--spectroscopy (after 2012) • medium-heavy Λ-hypernuclei (after 2012)
A1@MAMI	electro production	• Precission ground state masses by π^--spectroscopy (Δm~10keV) • Λ-wave function by K angular distribution • Σ hyperon in light nuclei
HypHI@GSI&FAIR	projectile fragmentation 2AGeV - 15AGeV two experiments performed, data analysis ongoing	• ground state masses (Δm~few MeV) • lifetimes • exotic hypernuclei by radioactive beams
FOPI@GSI **STAR@AGS** **ALICE@LHC**	(symmetric) heavy ion collisions Signal seen by FOPI and STAR, analysis ongoing; ALICE started	• antihypernuclei and hypernuclei yields and ground state masses (Δm~few MeV) of S=-2 nuclei • lifetimes
PANDA@FAIR	antiproton beam in design and R&D stage; run after 2017	• level scheme of double $\Lambda\Lambda$ hypernuclei by γ-spectroscopy (Δm<10keV)


Thank you