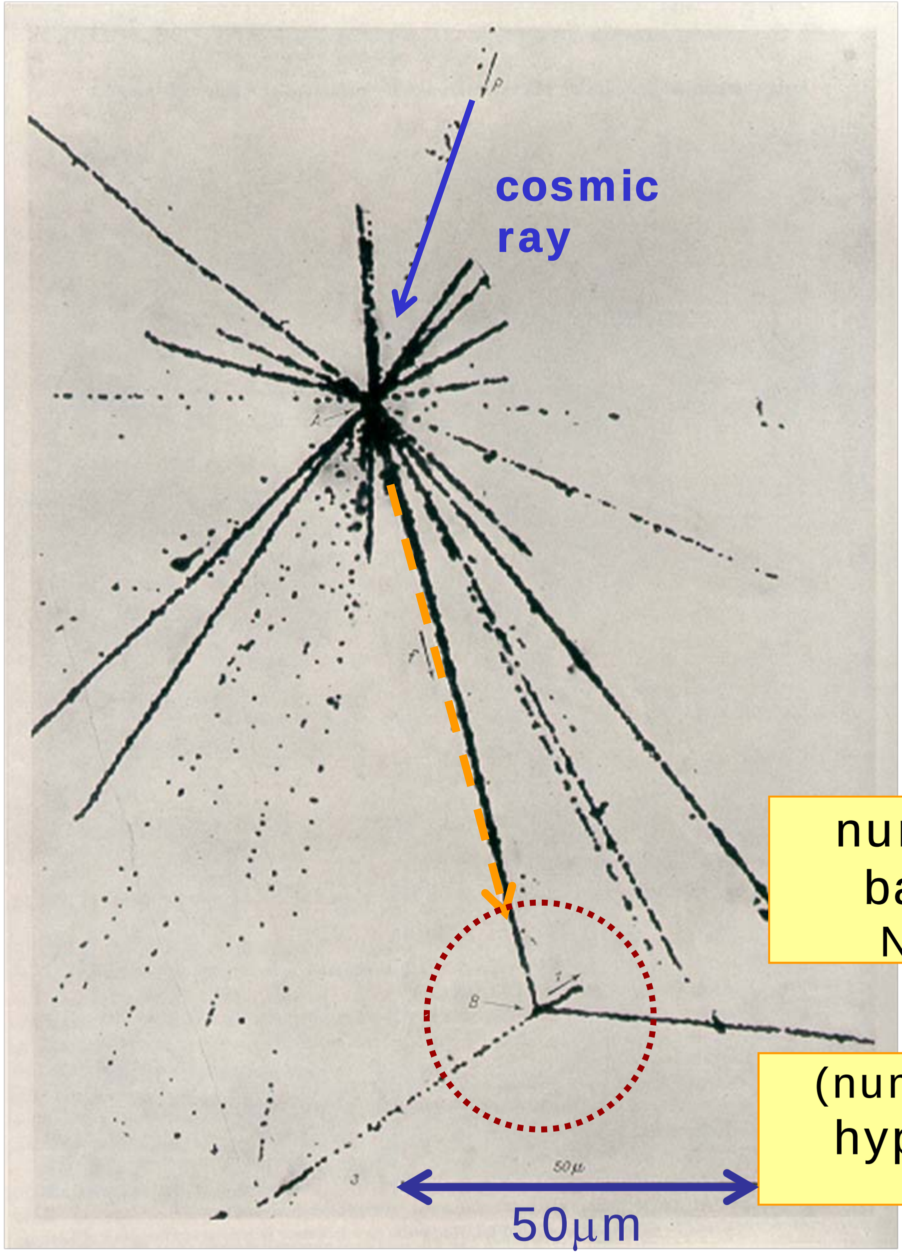
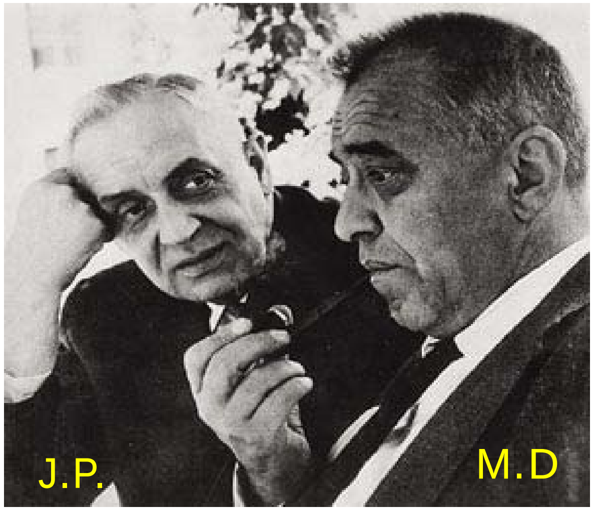
How it began





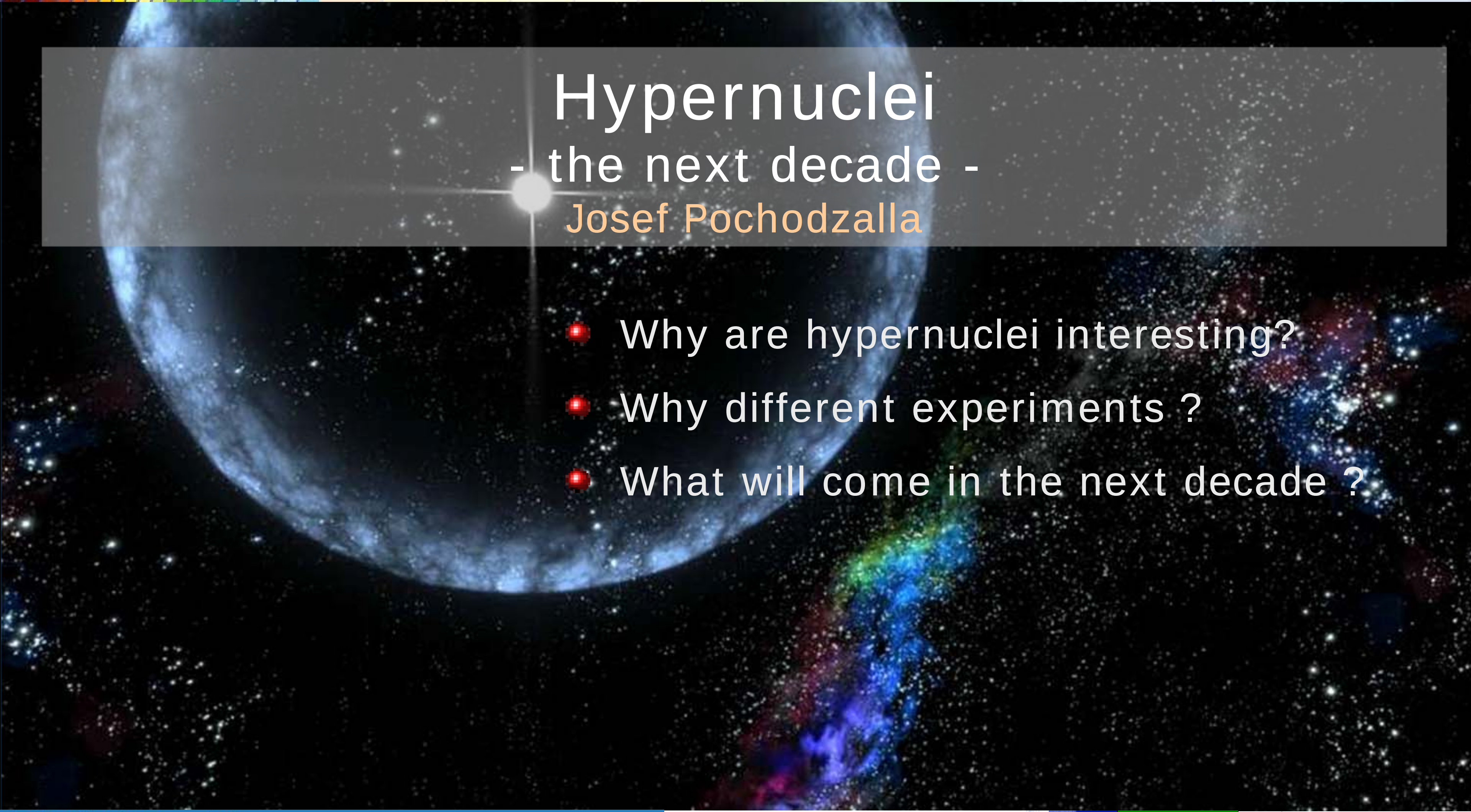
Marian Danysz
Jerzy Pniewski
1953

$^{10}_{\Lambda\Lambda}\mathrm{Be}$

number of baryons
N+Z+Y

(number of) hyperons
Y

element
=
total charge
(not number of protons)



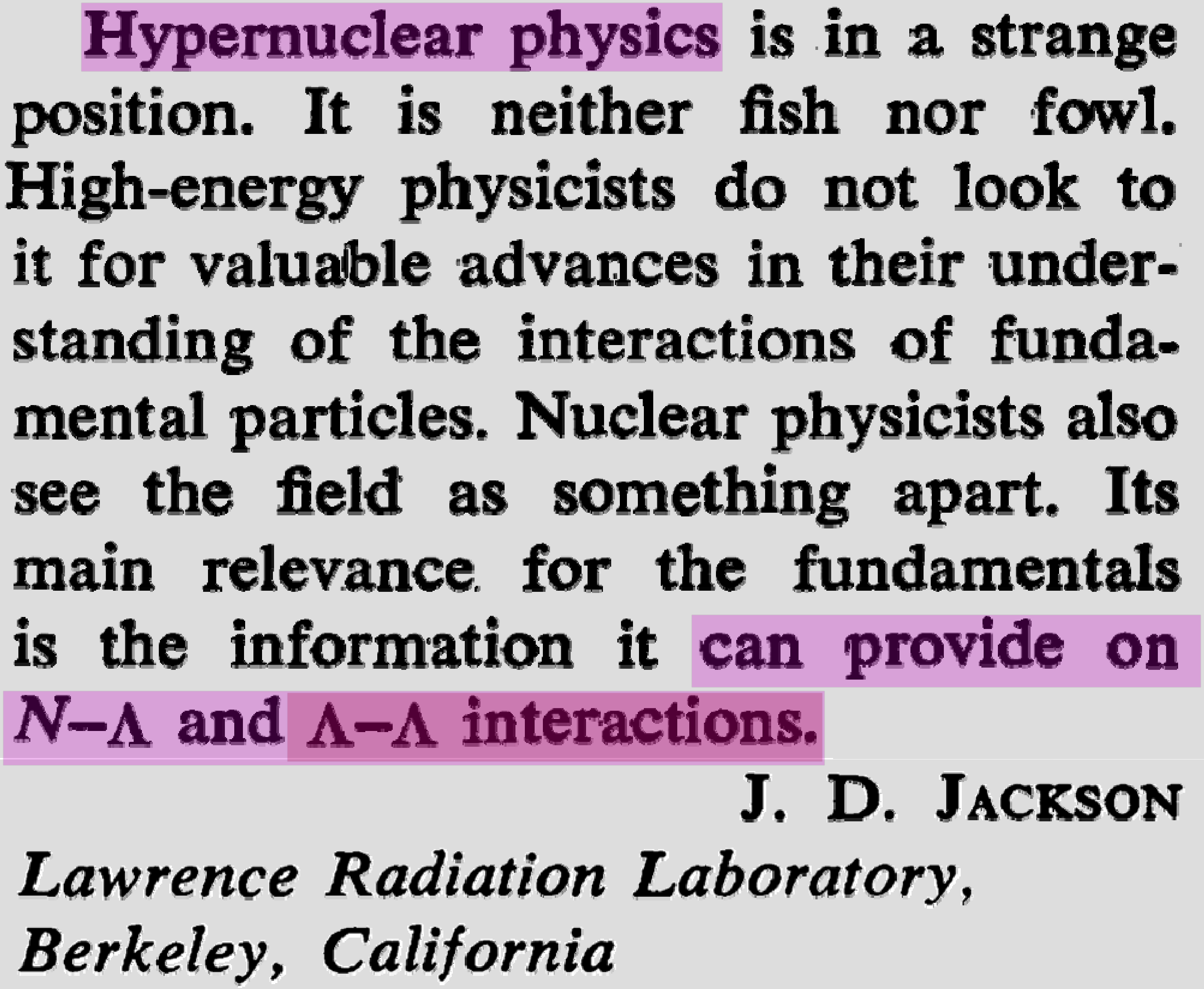
Hypernuclei

- the next decade -

Josef Pochodzalla

- Why are hypernuclei interesting?
- Why different experiments ?
- What will come in the next decade ?

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



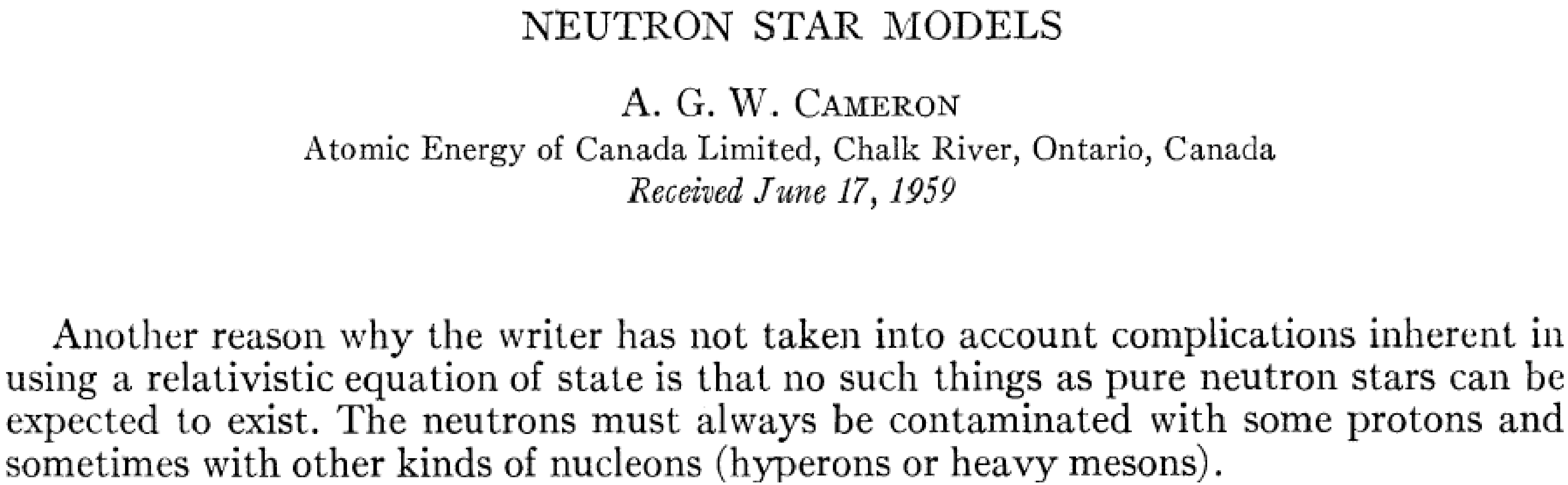
Hypernuclear physics is in a strange position. It is neither fish nor fowl. High-energy physicists do not look to it for valuable advances in their understanding of the interactions of fundamental particles. Nuclear physicists also see the field as something apart. Its main relevance for the fundamentals is the information it can provide on N–Λ and Λ–Λ interactions.

J. D. Jackson

Lawrence Radiation Laboratory,
Berkeley, California

Science, Vol. 159, p. 1346

5 decades of hyperons in neutron stars



NEUTRON STAR MODELS

A. G. W. Cameron

Atomic Energy of Canada Limited, Chalk River, Ontario, Canada

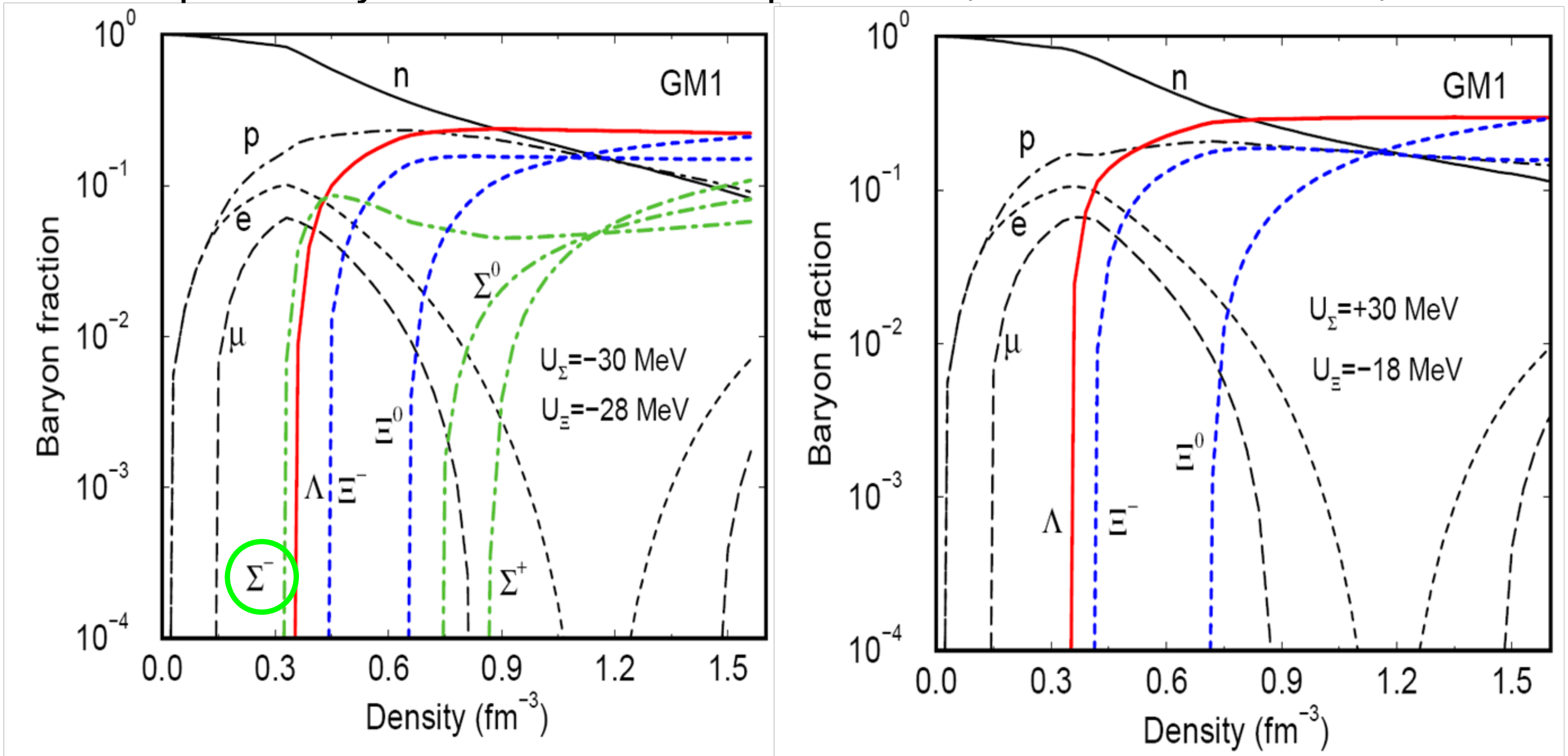
Received June 17, 1959

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)

Baryon stars

- 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

  Wambach 2008:"...it becomes practically impossible to ignore strangeness when considering neutron stars"

- needed: full BB interaction at high density= at small distances

Y-Y Interaction in neutron stars

- MI Ai-Jun and YOU Wie, Commun. Theor. Phys. (Beijing, China) 53 (2010) pp. 133–137

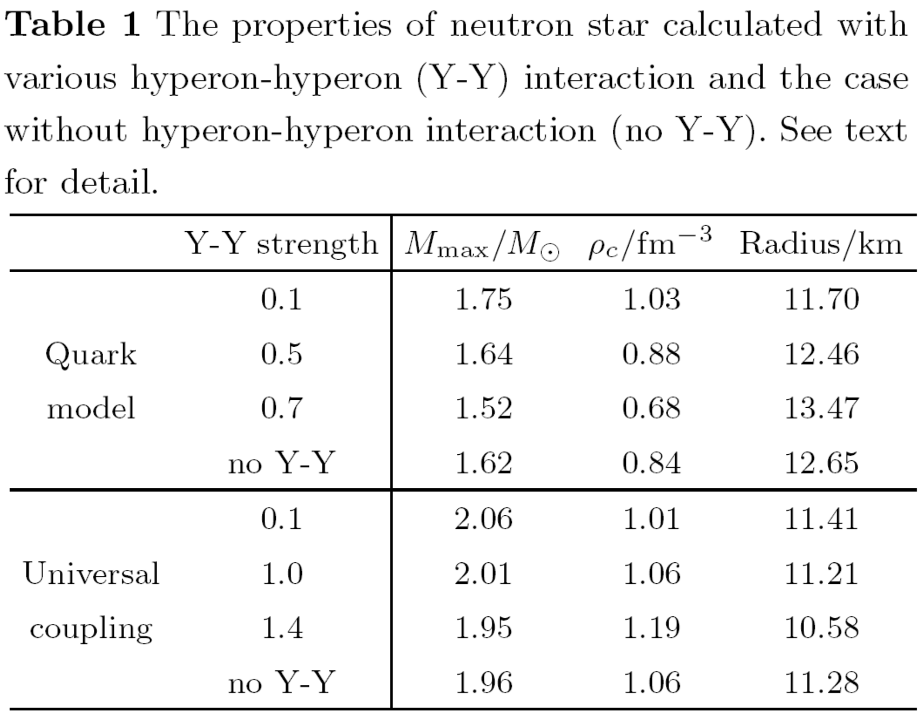
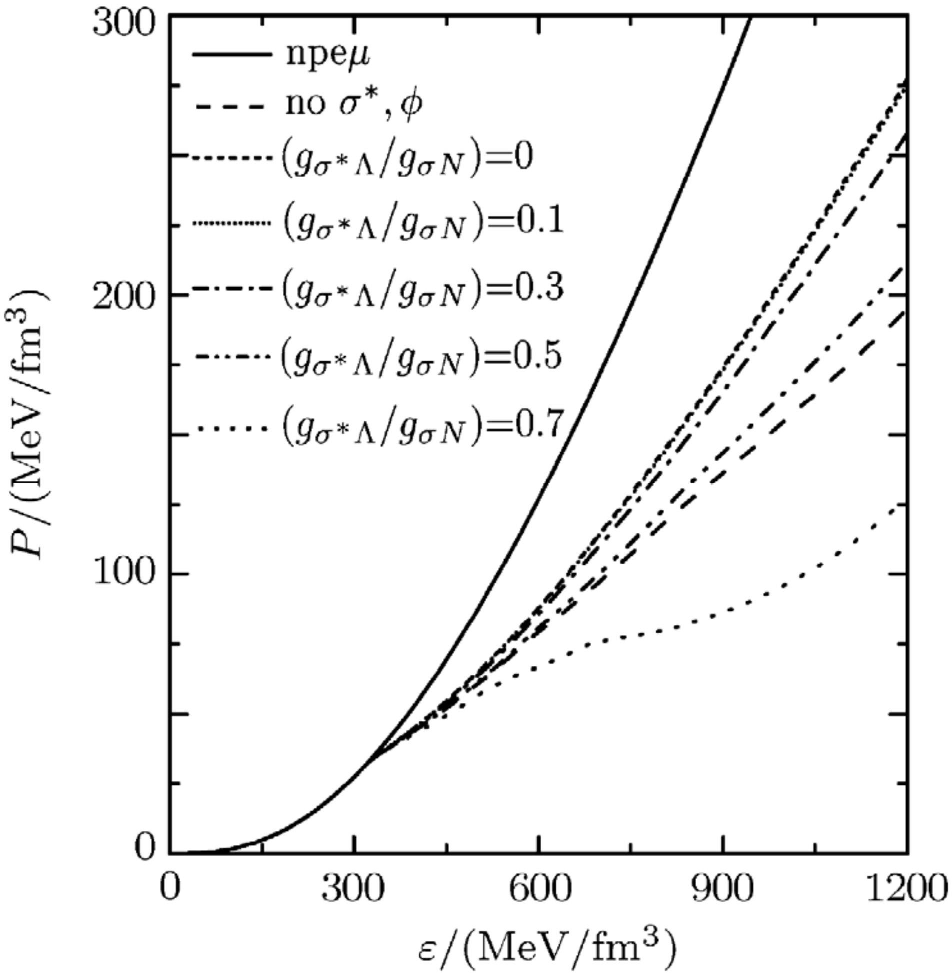


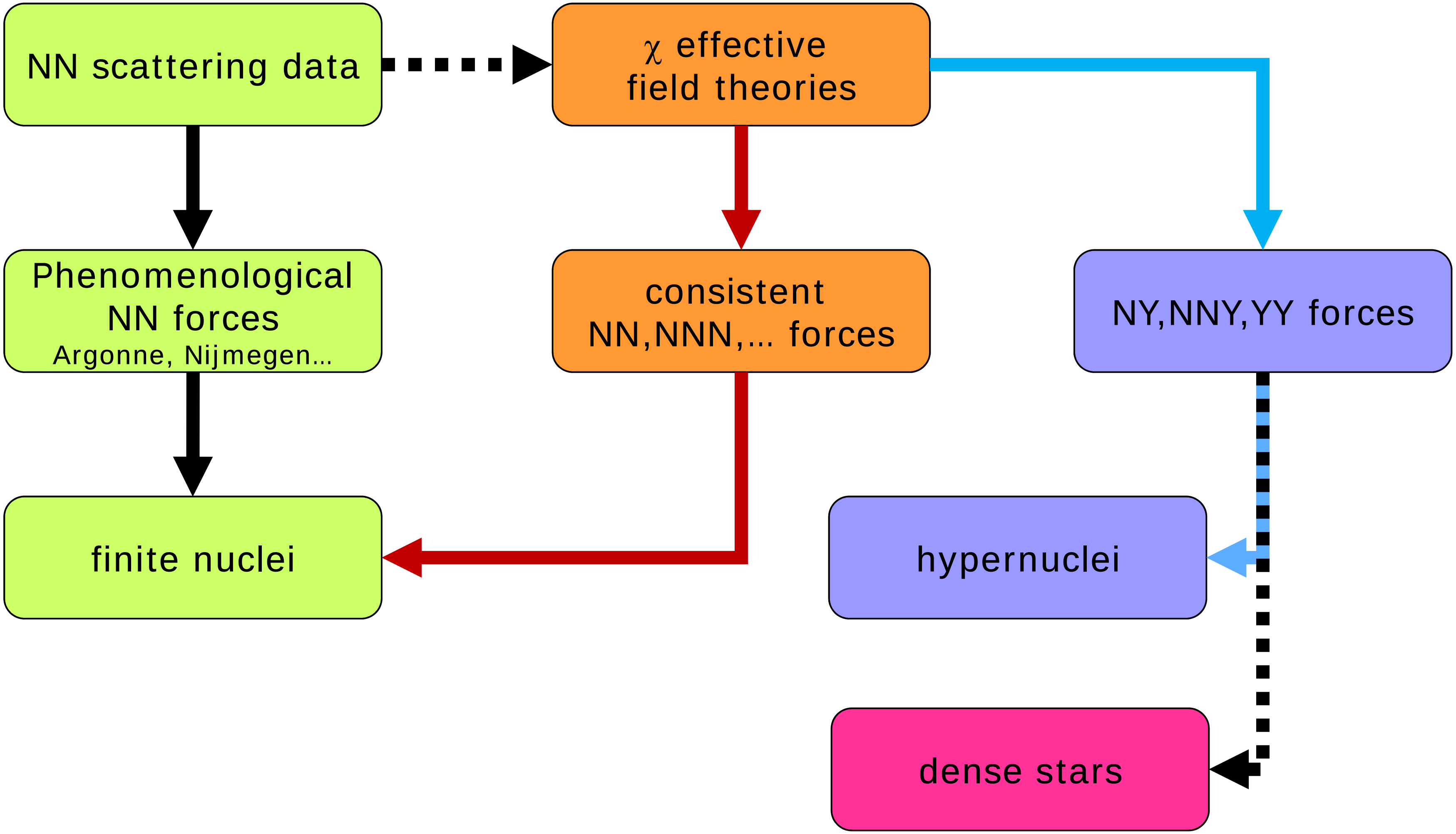
Table 1 The properties of neutron star calculated with various hyperon-hyperon (Y-Y) interaction and the case without hyperon-hyperon interaction (no Y-Y). See text for detail.

	Y-Y strength	$M_{\max}/M_{\odot}$	ρ_c/fm^{-3}	Radius/km
Quark model	0.1	1.75	1.03	11.70
	0.5	1.64	0.88	12.46
	0.7	1.52	0.68	13.47
	no Y-Y	1.62	0.84	12.65
Universal coupling	0.1	2.06	1.01	11.41
	1.0	2.01	1.06	11.21
	1.4	1.95	1.19	10.58
	no Y-Y	1.96	1.06	11.28



Strategy

- → see talk of James Vary: ab initio calculations...



NN scattering data

χ effective field theories

Phenomenological NN forces
Argonne, Nijmegen...

consistent NN,NNN,... forces

NY,NNY,YY forces

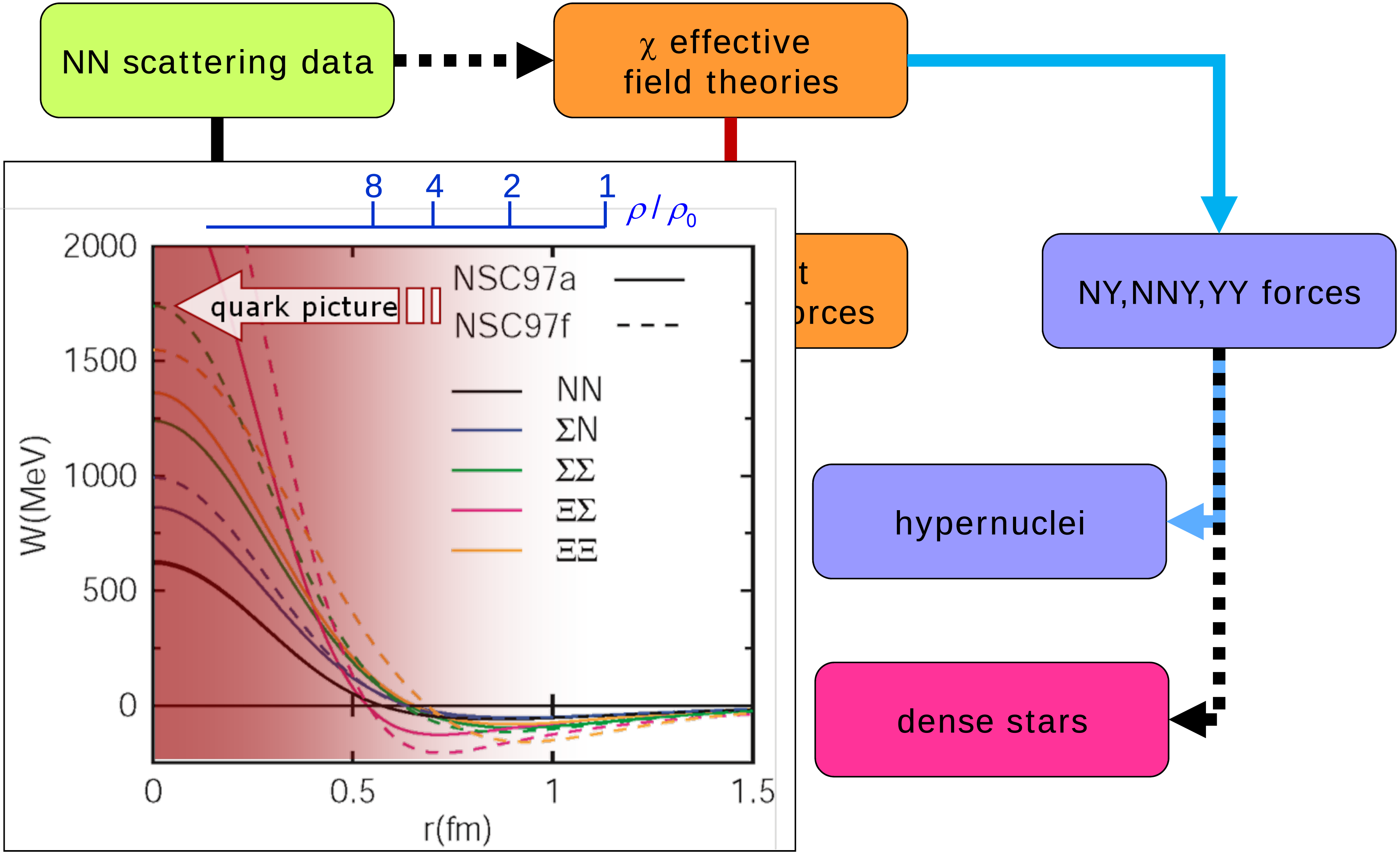
finite nuclei

hypernuclei

dense stars

Strategy

- ...but there is still a long way to go



NN scattering data

χ effective field theories

t
orces

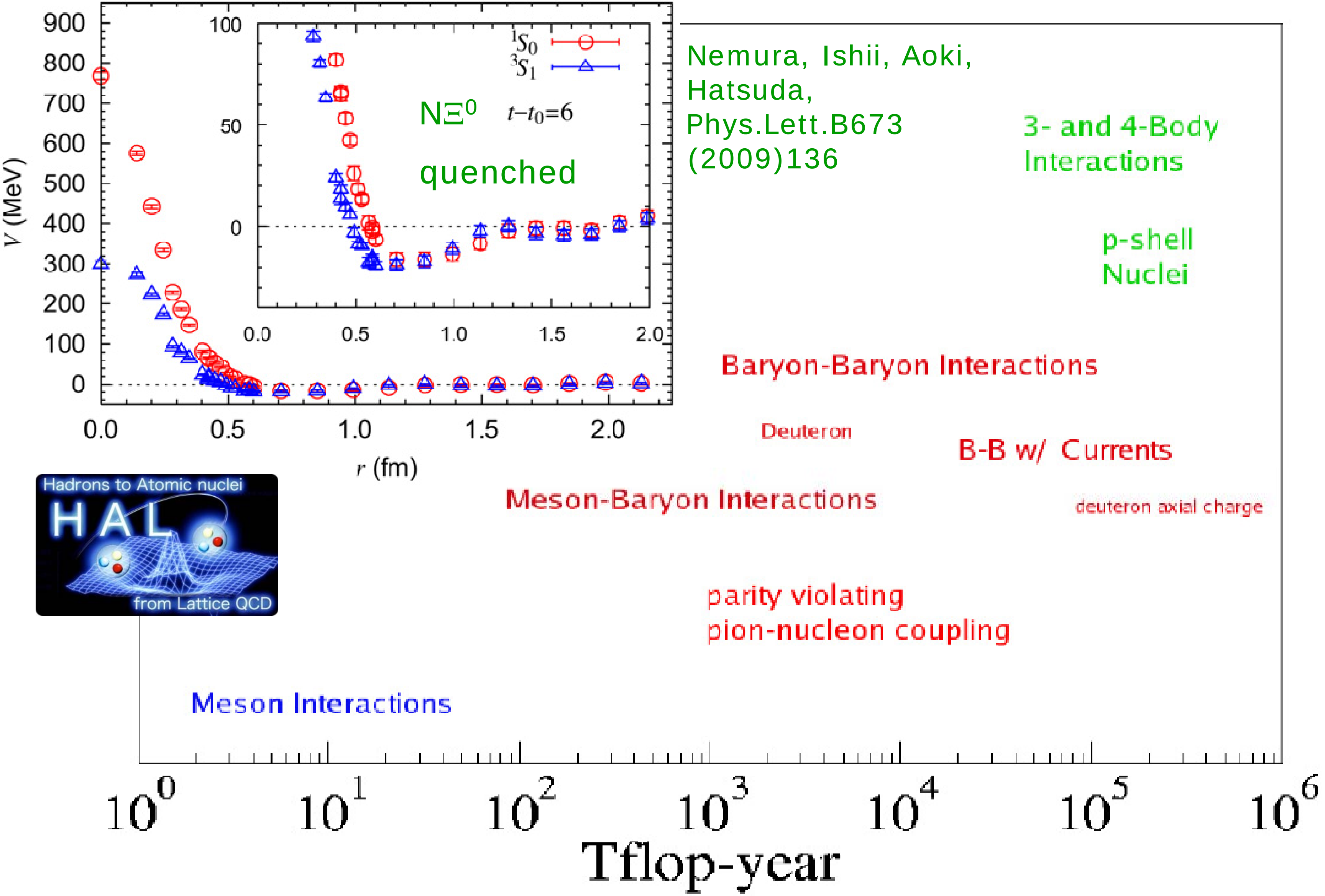
NY,NNY,YY forces

hypernuclei

dense stars

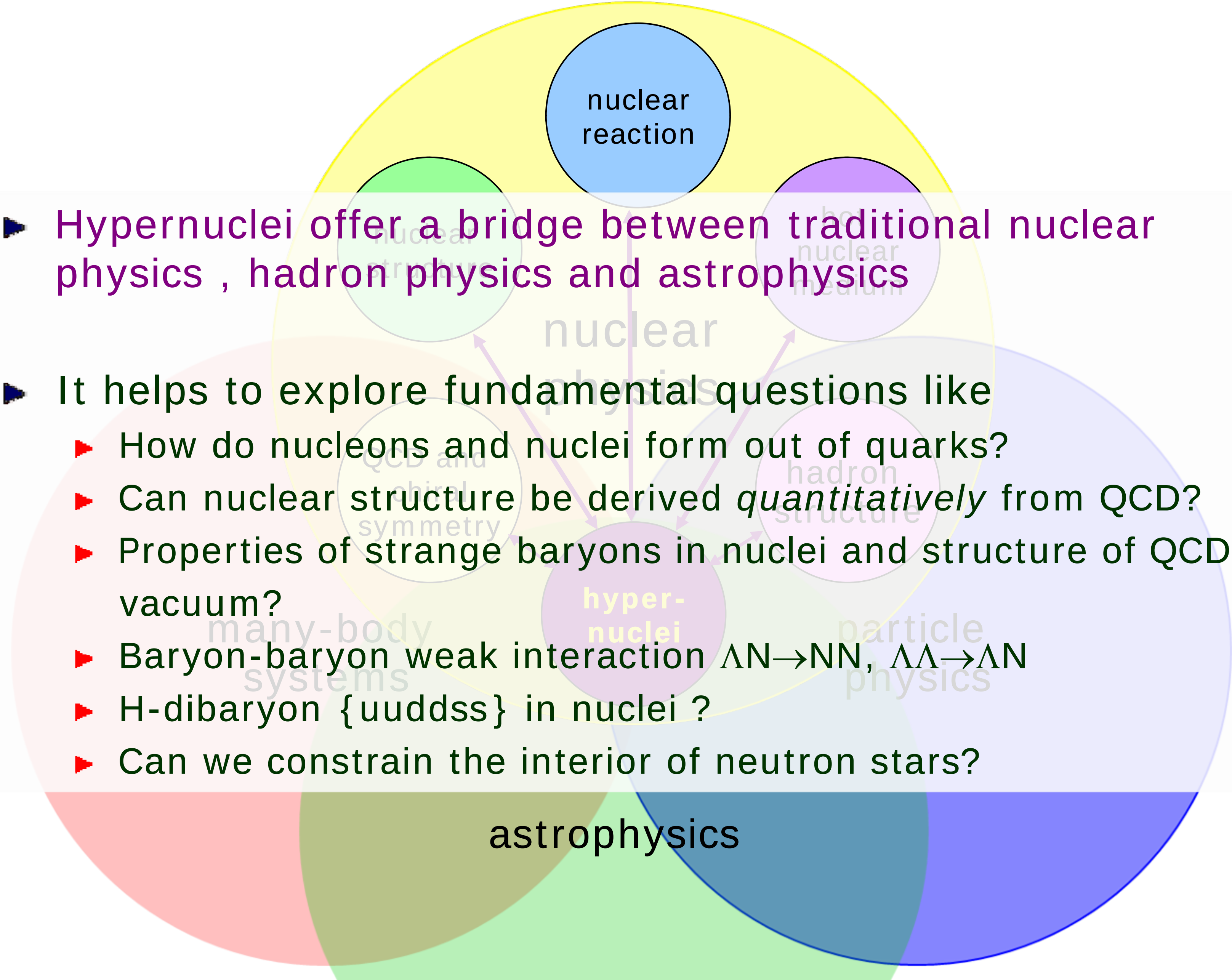
Nuclear Forces from Lattice QCD

- Forefront Questions in Nuclear Science and the Role of HighPerformance Computing, January 26-28, 2009 · Washington D.C.



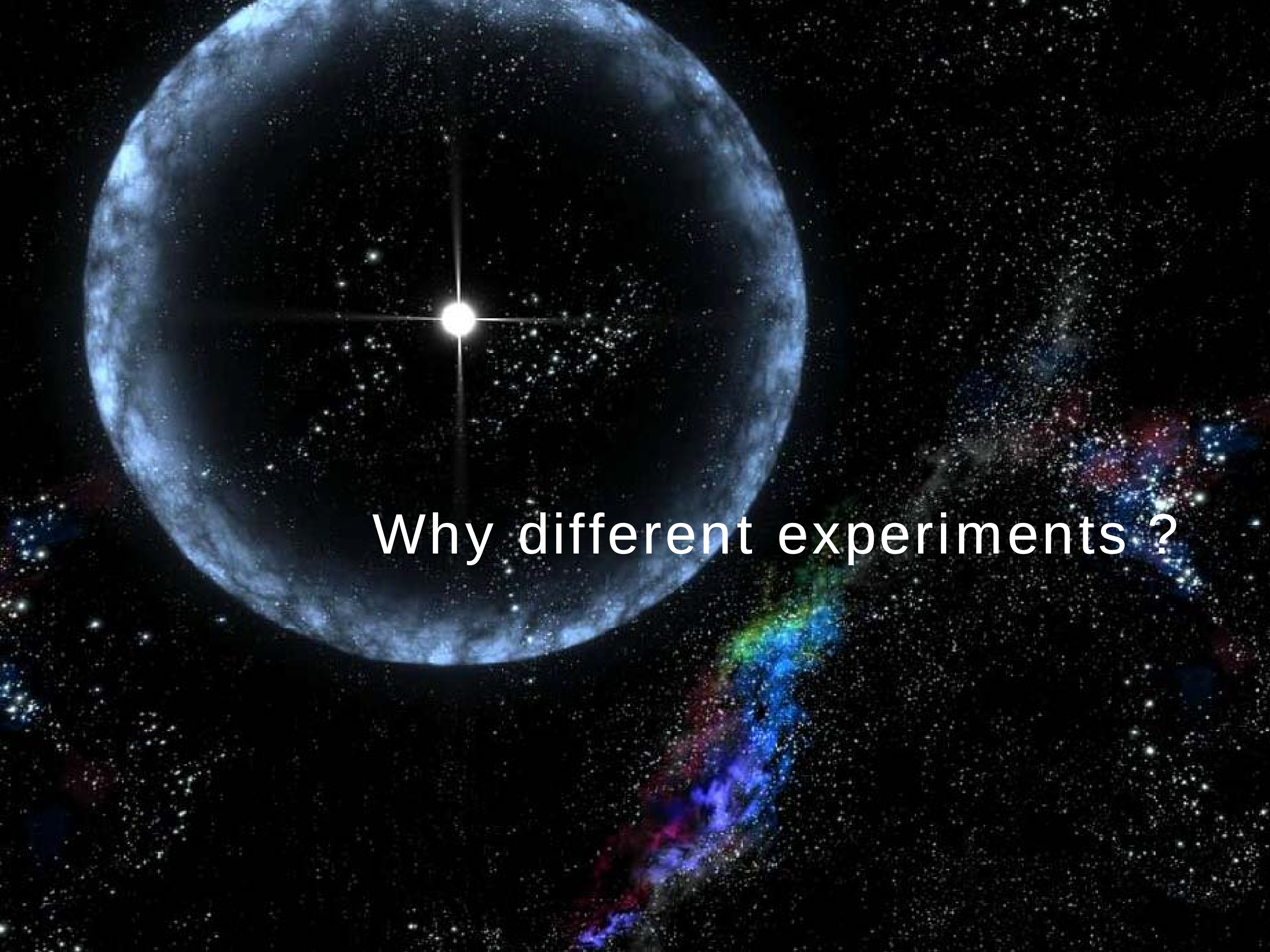
Nemura, Ishii, Aoki, Hatsuda, Phys.Lett.B673 (2009)136

Hypernuclear physics: a multicultural activity



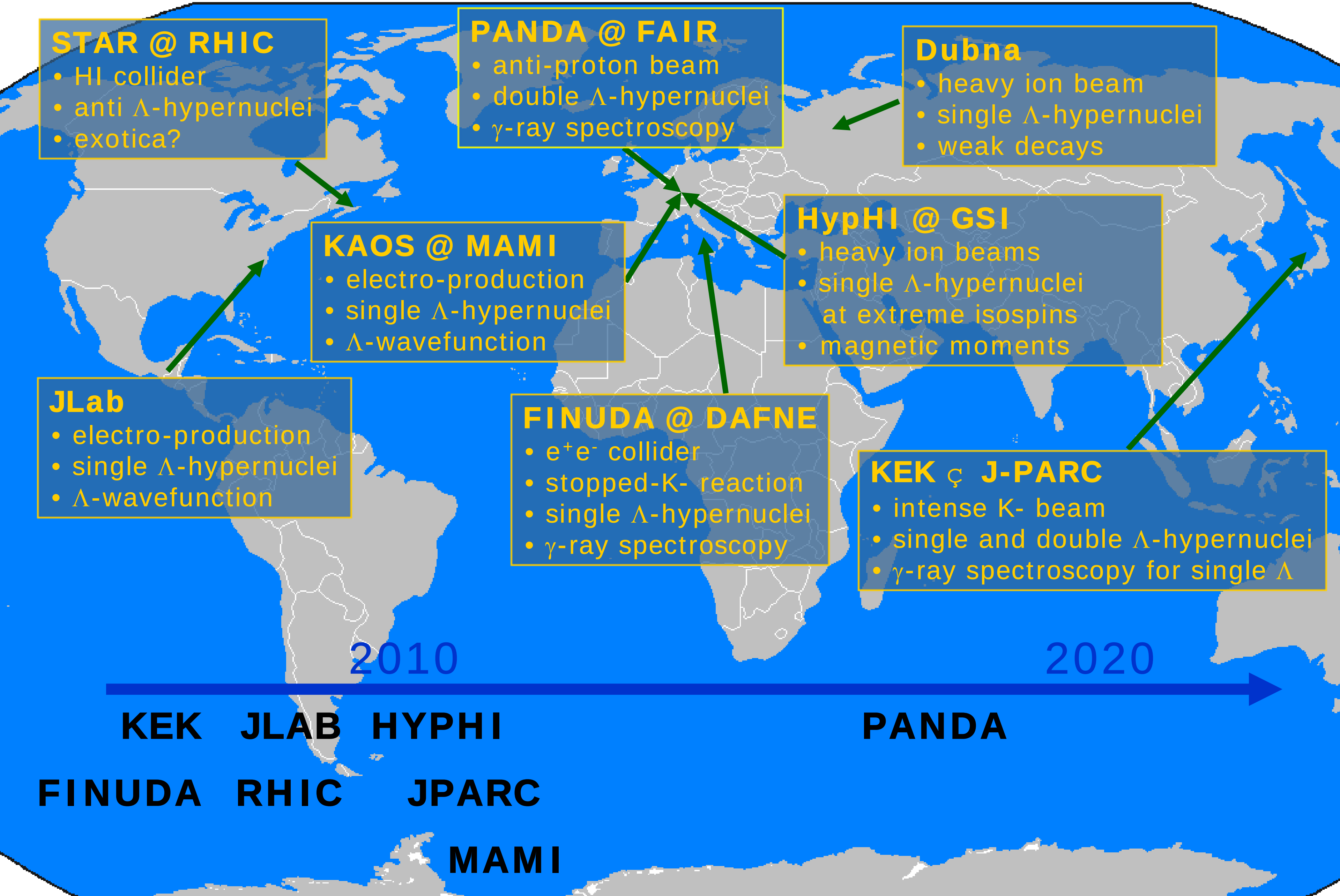
- Hypernuclei offer a bridge between traditional nuclear physics , hadron physics and astrophysics

- 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?
  - Baryon-baryon weak interaction $\Lambda N \rightarrow NN$, $\Lambda\Lambda \rightarrow \Lambda N$
  - H-dibaryon {uuddss} in nuclei ?
  - Can we constrain the interior of neutron stars?



Why different experiments ?

International Hypernuclear Network



STAR @ RHIC
- HI collider
- anti Λ-hypernuclei
- exotica?

PANDA @ FAIR
- anti-proton beam
- double Λ-hypernuclei
- γ-ray spectroscopy

Dubna
- heavy ion beam
- single Λ-hypernuclei
- weak decays

KAOS @ MAMI
- electro-production
- single Λ-hypernuclei
- Λ-wavefunction

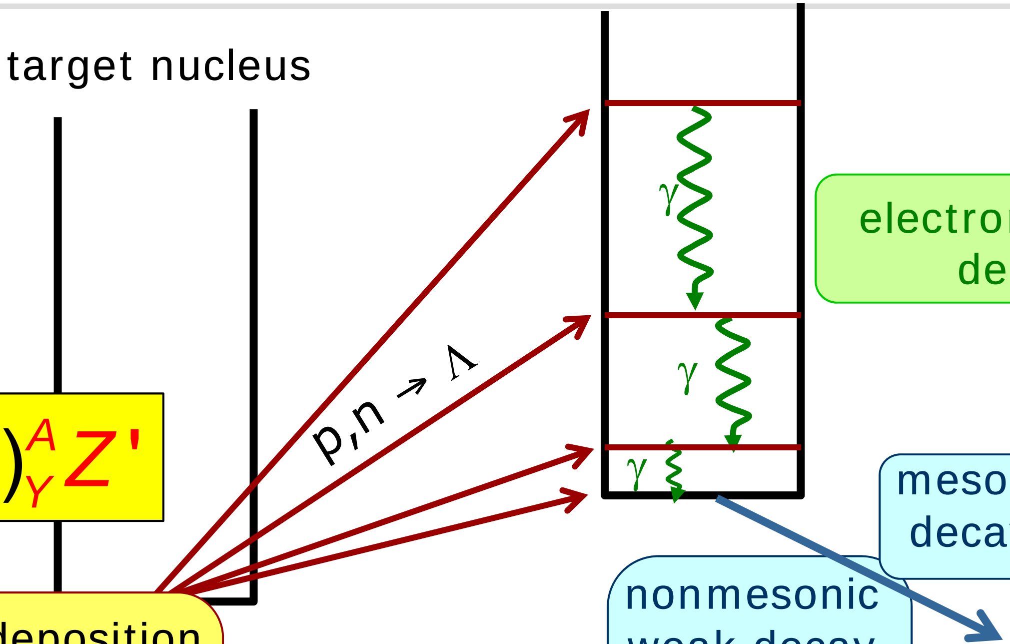
HypHI @ GSI
- heavy ion beams
- single Λ-hypernuclei at extreme isospins
- magnetic moments

JLab
- electro-production
- single Λ-hypernuclei
- Λ-wavefunction

FINUDA @ DAFNE
- e^+e^- collider
- stopped-K- reaction
- single Λ-hypernuclei
- γ-ray spectroscopy

KEK ç J-PARC
- intense K- beam
- single and double Λ-hypernuclei
- γ-ray spectroscopy for single Λ

Birth, life and death of a hypernucleus



$$^{A}Z(a,b)^{A}_{Y}Z'$$

strangeness deposition

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

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

FINUDA

strangeness production

(π^+, K^+), (π^-, K^0)

BNL,KEK,(GSI)

strangeness exchange

(K^-, π^-) ,(K^-, π^0)

BNL,KEK,JPARC

electroproduction

$(e,e^\prime K^+)$, (γ,K^+)

Jlab, MAMI-C

electromagnetic decays

mesonic decays

$\Lambda \to p\pi^-$

$\Lambda \to n\pi^0$

nonmesonic weak decay

$\Lambda p \to np$

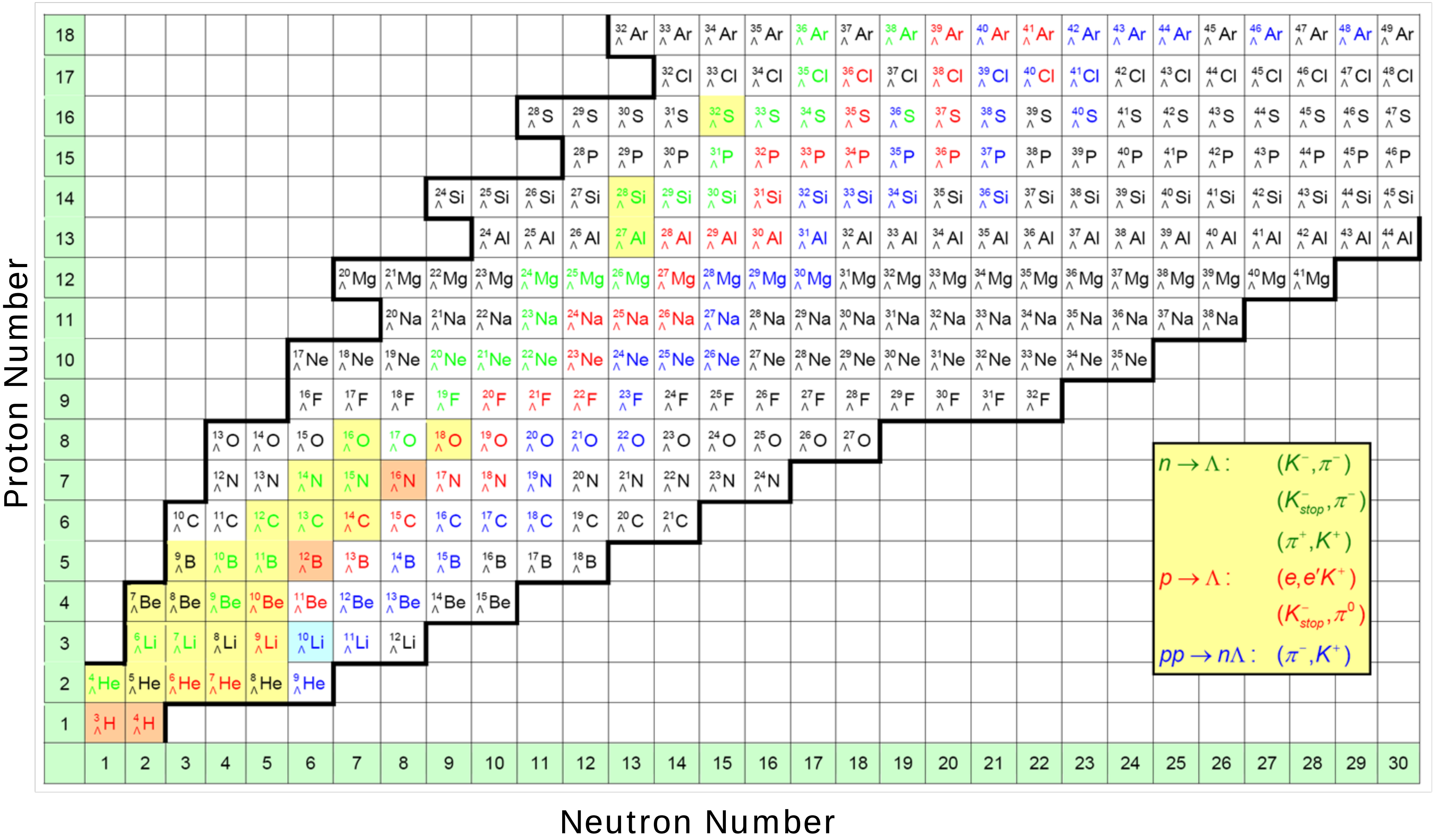
$\Lambda n \to nn$

$\Lambda\Lambda \to YN$

hadronic decay in emulsion, heavy ion recations

$$^{A}_{Y}Z \to \pi^- + {}^{A}(Z+1)$$

Single Hypernuclei - Two-body Reactions



18													$^{32}_{\Lambda}$Ar	$^{33}_{\Lambda}$Ar	$^{34}_{\Lambda}$Ar	$^{35}_{\Lambda}$Ar	$^{36}_{\Lambda}$Ar	$^{37}_{\Lambda}$Ar	$^{38}_{\Lambda}$Ar	$^{39}_{\Lambda}$Ar	$^{40}_{\Lambda}$Ar	$^{41}_{\Lambda}$Ar	$^{42}_{\Lambda}$Ar	$^{43}_{\Lambda}$Ar	$^{44}_{\Lambda}$Ar	$^{45}_{\Lambda}$Ar	$^{46}_{\Lambda}$Ar	$^{47}_{\Lambda}$Ar	$^{48}_{\Lambda}$Ar	$^{49}_{\Lambda}$Ar
17														$^{32}_{\Lambda}$Cl	$^{33}_{\Lambda}$Cl	$^{34}_{\Lambda}$Cl	$^{35}_{\Lambda}$Cl	$^{36}_{\Lambda}$Cl	$^{37}_{\Lambda}$Cl	$^{38}_{\Lambda}$Cl	$^{39}_{\Lambda}$Cl	$^{40}_{\Lambda}$Cl	$^{41}_{\Lambda}$Cl	$^{42}_{\Lambda}$Cl	$^{43}_{\Lambda}$Cl	$^{44}_{\Lambda}$Cl	$^{45}_{\Lambda}$Cl	$^{46}_{\Lambda}$Cl	$^{47}_{\Lambda}$Cl	$^{48}_{\Lambda}$Cl
16											$^{28}_{\Lambda}$S	$^{29}_{\Lambda}$S	$^{30}_{\Lambda}$S	$^{31}_{\Lambda}$S	$^{32}_{\Lambda}$S	$^{33}_{\Lambda}$S	$^{34}_{\Lambda}$S	$^{35}_{\Lambda}$S	$^{36}_{\Lambda}$S	$^{37}_{\Lambda}$S	$^{38}_{\Lambda}$S	$^{39}_{\Lambda}$S	$^{40}_{\Lambda}$S	$^{41}_{\Lambda}$S	$^{42}_{\Lambda}$S	$^{43}_{\Lambda}$S	$^{44}_{\Lambda}$S	$^{45}_{\Lambda}$S	$^{46}_{\Lambda}$S	$^{47}_{\Lambda}$S
15												$^{28}_{\Lambda}$P	$^{29}_{\Lambda}$P	$^{30}_{\Lambda}$P	$^{31}_{\Lambda}$P	$^{32}_{\Lambda}$P	$^{33}_{\Lambda}$P	$^{34}_{\Lambda}$P	$^{35}_{\Lambda}$P	$^{36}_{\Lambda}$P	$^{37}_{\Lambda}$P	$^{38}_{\Lambda}$P	$^{39}_{\Lambda}$P	$^{40}_{\Lambda}$P	$^{41}_{\Lambda}$P	$^{42}_{\Lambda}$P	$^{43}_{\Lambda}$P	$^{44}_{\Lambda}$P	$^{45}_{\Lambda}$P	$^{46}_{\Lambda}$P
14									$^{24}_{\Lambda}$Si	$^{25}_{\Lambda}$Si	$^{26}_{\Lambda}$Si	$^{27}_{\Lambda}$Si	$^{28}_{\Lambda}$Si	$^{29}_{\Lambda}$Si	$^{30}_{\Lambda}$Si	$^{31}_{\Lambda}$Si	$^{32}_{\Lambda}$Si	$^{33}_{\Lambda}$Si	$^{34}_{\Lambda}$Si	$^{35}_{\Lambda}$Si	$^{36}_{\Lambda}$Si	$^{37}_{\Lambda}$Si	$^{38}_{\Lambda}$Si	$^{39}_{\Lambda}$Si	$^{40}_{\Lambda}$Si	$^{41}_{\Lambda}$Si	$^{42}_{\Lambda}$Si	$^{43}_{\Lambda}$Si	$^{44}_{\Lambda}$Si	$^{45}_{\Lambda}$Si
13										$^{24}_{\Lambda}$Al	$^{25}_{\Lambda}$Al	$^{26}_{\Lambda}$Al	$^{27}_{\Lambda}$Al	$^{28}_{\Lambda}$Al	$^{29}_{\Lambda}$Al	$^{30}_{\Lambda}$Al	$^{31}_{\Lambda}$Al	$^{32}_{\Lambda}$Al	$^{33}_{\Lambda}$Al	$^{34}_{\Lambda}$Al	$^{35}_{\Lambda}$Al	$^{36}_{\Lambda}$Al	$^{37}_{\Lambda}$Al	$^{38}_{\Lambda}$Al	$^{39}_{\Lambda}$Al	$^{40}_{\Lambda}$Al	$^{41}_{\Lambda}$Al	$^{42}_{\Lambda}$Al	$^{43}_{\Lambda}$Al	$^{44}_{\Lambda}$Al
12							$^{20}_{\Lambda}$Mg	$^{21}_{\Lambda}$Mg	$^{22}_{\Lambda}$Mg	$^{23}_{\Lambda}$Mg	$^{24}_{\Lambda}$Mg	$^{25}_{\Lambda}$Mg	$^{26}_{\Lambda}$Mg	$^{27}_{\Lambda}$Mg	$^{28}_{\Lambda}$Mg	$^{29}_{\Lambda}$Mg	$^{30}_{\Lambda}$Mg	$^{31}_{\Lambda}$Mg	$^{32}_{\Lambda}$Mg	$^{33}_{\Lambda}$Mg	$^{34}_{\Lambda}$Mg	$^{35}_{\Lambda}$Mg	$^{36}_{\Lambda}$Mg	$^{37}_{\Lambda}$Mg	$^{38}_{\Lambda}$Mg	$^{39}_{\Lambda}$Mg	$^{40}_{\Lambda}$Mg	$^{41}_{\Lambda}$Mg		
11								$^{20}_{\Lambda}$Na	$^{21}_{\Lambda}$Na	$^{22}_{\Lambda}$Na	$^{23}_{\Lambda}$Na	$^{24}_{\Lambda}$Na	$^{25}_{\Lambda}$Na	$^{26}_{\Lambda}$Na	$^{27}_{\Lambda}$Na	$^{28}_{\Lambda}$Na	$^{29}_{\Lambda}$Na	$^{30}_{\Lambda}$Na	$^{31}_{\Lambda}$Na	$^{32}_{\Lambda}$Na	$^{33}_{\Lambda}$Na	$^{34}_{\Lambda}$Na	$^{35}_{\Lambda}$Na	$^{36}_{\Lambda}$Na	$^{37}_{\Lambda}$Na	$^{38}_{\Lambda}$Na				
10						$^{17}_{\Lambda}$Ne	$^{18}_{\Lambda}$Ne	$^{19}_{\Lambda}$Ne	$^{20}_{\Lambda}$Ne	$^{21}_{\Lambda}$Ne	$^{22}_{\Lambda}$Ne	$^{23}_{\Lambda}$Ne	$^{24}_{\Lambda}$Ne	$^{25}_{\Lambda}$Ne	$^{26}_{\Lambda}$Ne	$^{27}_{\Lambda}$Ne	$^{28}_{\Lambda}$Ne	$^{29}_{\Lambda}$Ne	$^{30}_{\Lambda}$Ne	$^{31}_{\Lambda}$Ne	$^{32}_{\Lambda}$Ne	$^{33}_{\Lambda}$Ne	$^{34}_{\Lambda}$Ne	$^{35}_{\Lambda}$Ne						
9						$^{16}_{\Lambda}$F	$^{17}_{\Lambda}$F	$^{18}_{\Lambda}$F	$^{19}_{\Lambda}$F	$^{20}_{\Lambda}$F	$^{21}_{\Lambda}$F	$^{22}_{\Lambda}$F	$^{23}_{\Lambda}$F	$^{24}_{\Lambda}$F	$^{25}_{\Lambda}$F	$^{26}_{\Lambda}$F	$^{27}_{\Lambda}$F	$^{28}_{\Lambda}$F	$^{29}_{\Lambda}$F	$^{30}_{\Lambda}$F	$^{31}_{\Lambda}$F	$^{32}_{\Lambda}$F								
8				$^{13}_{\Lambda}$O	$^{14}_{\Lambda}$O	$^{15}_{\Lambda}$O	$^{16}_{\Lambda}$O	$^{17}_{\Lambda}$O	$^{18}_{\Lambda}$O	$^{19}_{\Lambda}$O	$^{20}_{\Lambda}$O	$^{21}_{\Lambda}$O	$^{22}_{\Lambda}$O	$^{23}_{\Lambda}$O	$^{24}_{\Lambda}$O	$^{25}_{\Lambda}$O	$^{26}_{\Lambda}$O	$^{27}_{\Lambda}$O												
7				$^{12}_{\Lambda}$N	$^{13}_{\Lambda}$N	$^{14}_{\Lambda}$N	$^{15}_{\Lambda}$N	$^{16}_{\Lambda}$N	$^{17}_{\Lambda}$N	$^{18}_{\Lambda}$N	$^{19}_{\Lambda}$N	$^{20}_{\Lambda}$N	$^{21}_{\Lambda}$N	$^{22}_{\Lambda}$N	$^{23}_{\Lambda}$N	$^{24}_{\Lambda}$N														
6			$^{10}_{\Lambda}$C	$^{11}_{\Lambda}$C	$^{12}_{\Lambda}$C	$^{13}_{\Lambda}$C	$^{14}_{\Lambda}$C	$^{15}_{\Lambda}$C	$^{16}_{\Lambda}$C	$^{17}_{\Lambda}$C	$^{18}_{\Lambda}$C	$^{19}_{\Lambda}$C	$^{20}_{\Lambda}$C	$^{21}_{\Lambda}$C																
5			$^{9}_{\Lambda}$B	$^{10}_{\Lambda}$B	$^{11}_{\Lambda}$B	$^{12}_{\Lambda}$B	$^{13}_{\Lambda}$B	$^{14}_{\Lambda}$B	$^{15}_{\Lambda}$B	$^{16}_{\Lambda}$B	$^{17}_{\Lambda}$B	$^{18}_{\Lambda}$B																		
4		$^{7}_{\Lambda}$Be	$^{8}_{\Lambda}$Be	$^{9}_{\Lambda}$Be	$^{10}_{\Lambda}$Be	$^{11}_{\Lambda}$Be	$^{12}_{\Lambda}$Be	$^{13}_{\Lambda}$Be	$^{14}_{\Lambda}$Be	$^{15}_{\Lambda}$Be																				
3		$^{6}_{\Lambda}$Li	$^{7}_{\Lambda}$Li	$^{8}_{\Lambda}$Li	$^{9}_{\Lambda}$Li	$^{10}_{\Lambda}$Li	$^{11}_{\Lambda}$Li	$^{12}_{\Lambda}$Li																						
2	$^{4}_{\Lambda}$He	$^{5}_{\Lambda}$He	$^{6}_{\Lambda}$He	$^{7}_{\Lambda}$He	$^{8}_{\Lambda}$He	$^{9}_{\Lambda}$He																								
1	$^{3}_{\Lambda}$H	$^{4}_{\Lambda}$H																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

$n \to \Lambda$: (K^-,π^-)
(K^-_{stop},π^-)
(π^+,K^+)
$p \to \Lambda$: $(e,e'K^+)$
(K^-_{stop},π^0)
$pp \to n\Lambda$: (π^-,K^+)

Past and Presence of Hypernuclei

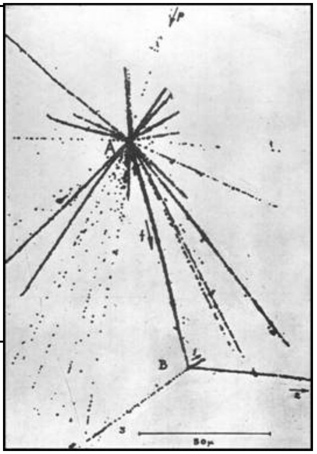
Energy resolution

1 MeV

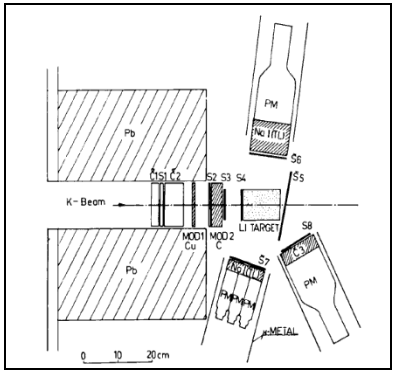
100 keV

10 keV

Emulsion

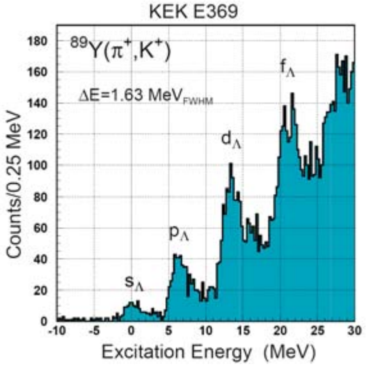


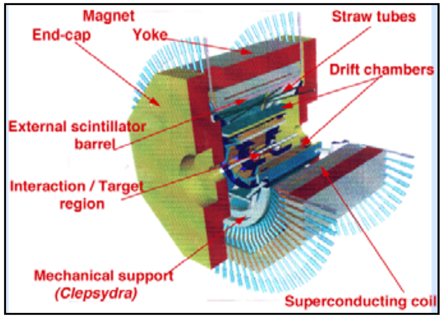
CERN PS



AGS

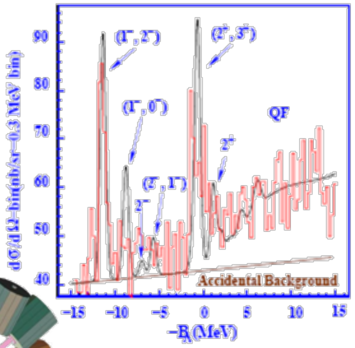
KEK

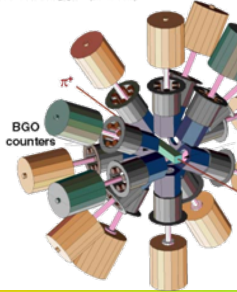




FINUDA

JLAB





HYPERBALL

Calometry,
Pionic decay

Missing mass
experiments

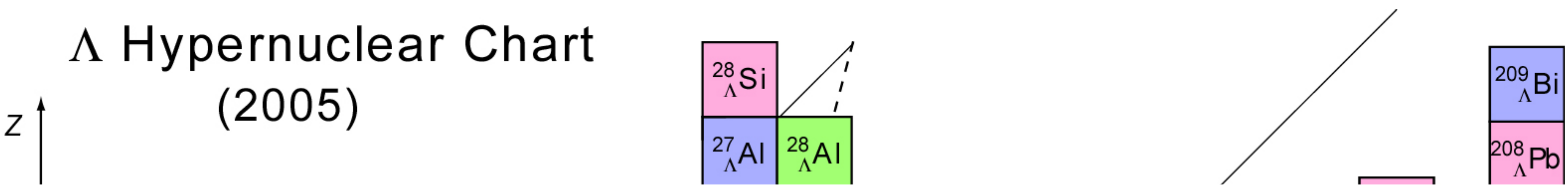
Missing mass
+ γ-decay

year

1950

2000

High Resolution γ-Spectroscopy at KEK

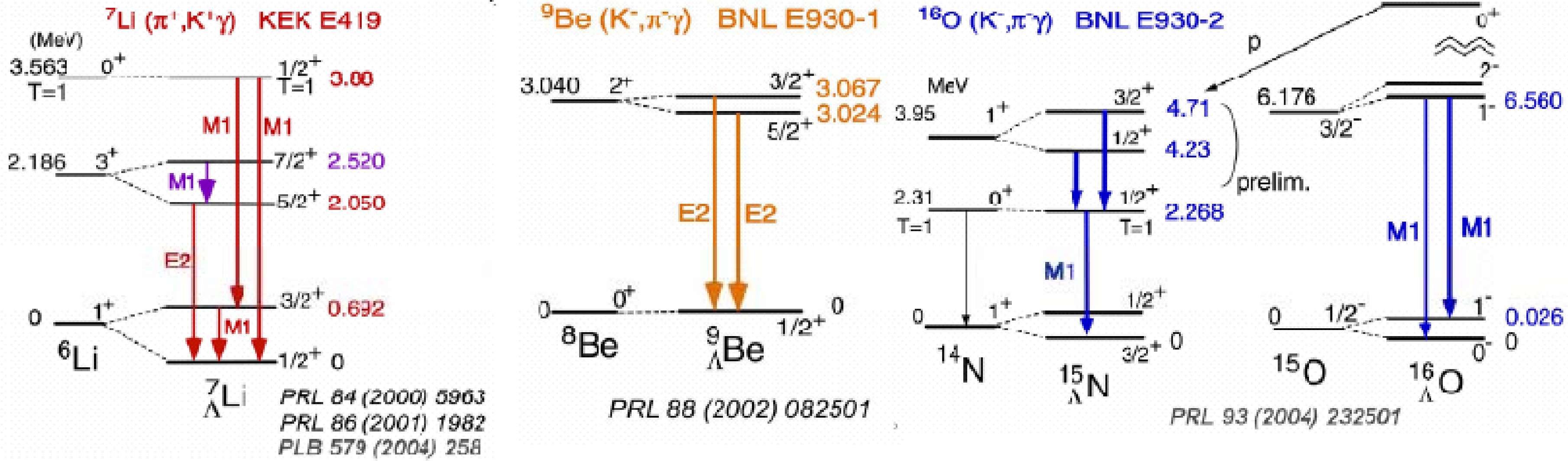


Λ Hypernuclear Chart (2005)

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

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

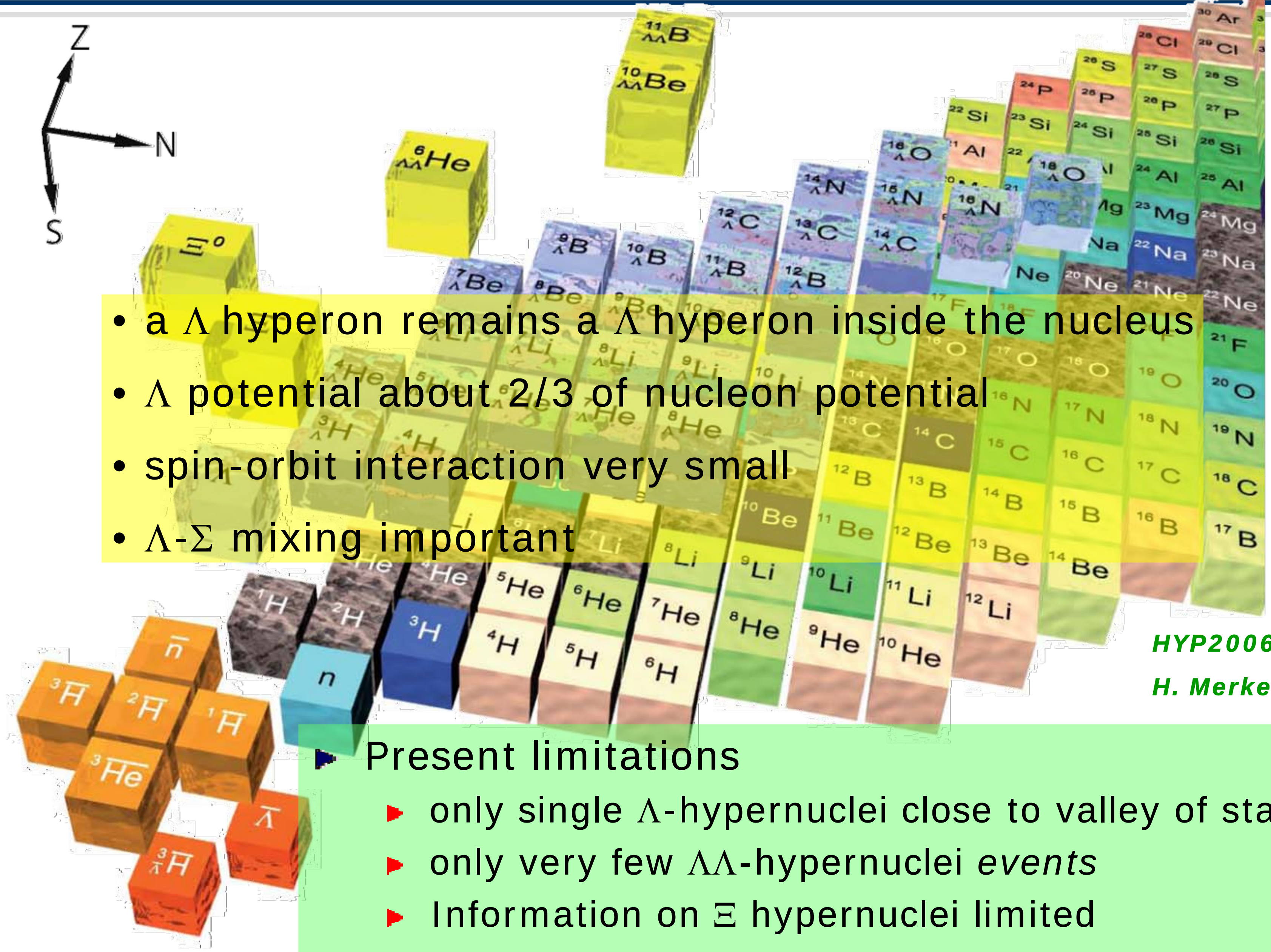


PRL 84 (2000) 5963
PRL 86 (2001) 1982
PLB 579 (2004) 258

PRL 88 (2002) 082501

PRL 93 (2004) 232501

The present nuclear chart



- a Λ hyperon remains a Λ hyperon inside the nucleus
- Λ potential about 2/3 of nucleon potential
- spin-orbit interaction very small
- Λ-Σ mixing important

HYP2006

H. Merkel

- Present limitations
  - only single Λ-hypernuclei close to valley of stability
  - only very few ΛΛ-hypernuclei *events*
  - Information on Ξ hypernuclei limited
  - no information on antihyperons in normal nuclei

What will come in the next decade?

International Hypernuclear Network

RHIC
- HI colli
- anti Λ-
- exotica

JLab
- electro-
- single Λ
- Λ-wave

日本物理学会誌

BUTSURI

■ 日本における核融合研究開発の歴史
■ 分子計算とその物理的基礎
■ 三次元素粒子飛跡の並列画像処理

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KEK/JPARC

Dubna
- heavy ion beam
- single Λ-hypernuclei
- weak decays

HypHI @ GSI
- heavy ion beams
- single Λ-hypernuclei at extreme isospins
- magnetic moments

E
n
ei

KEK ç J-PARC
- intense K- beam
- single and double Λ-hypernuclei
- γ-ray spectroscopy for single Λ

2020

KE

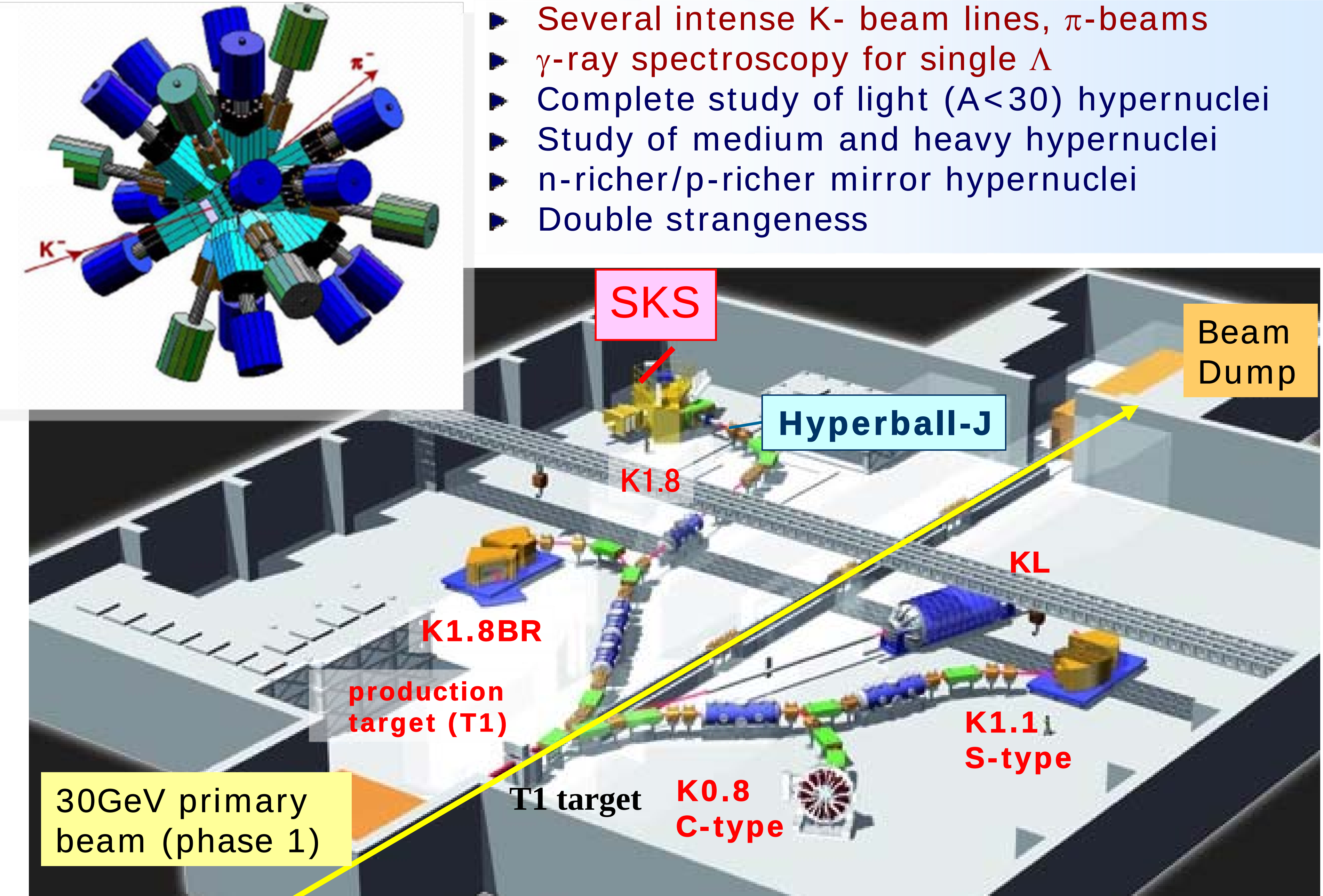
FINUD

PANDA

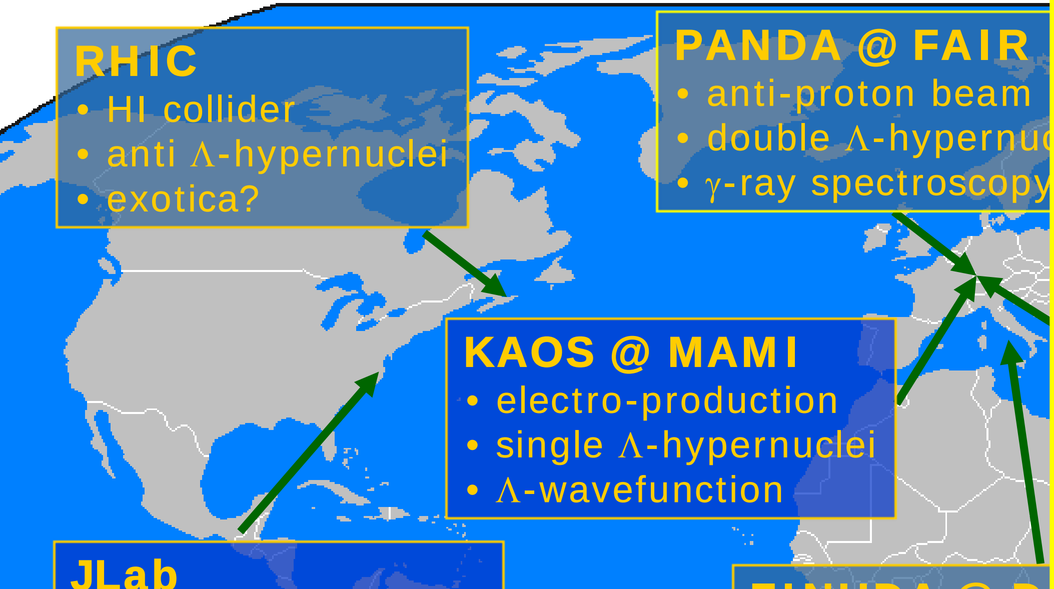
MAMI

J-PARC beyond 2010

- Several intense K- beam lines, π-beams
- γ-ray spectroscopy for single Λ
- Complete study of light (A<30) hypernuclei
- Study of medium and heavy hypernuclei
- n-richer/p-richer mirror hypernuclei
- Double strangeness



Electroproduction of Hypernuclei



RHIC
- HI collider
- anti Λ-hypernuclei
- exotica?

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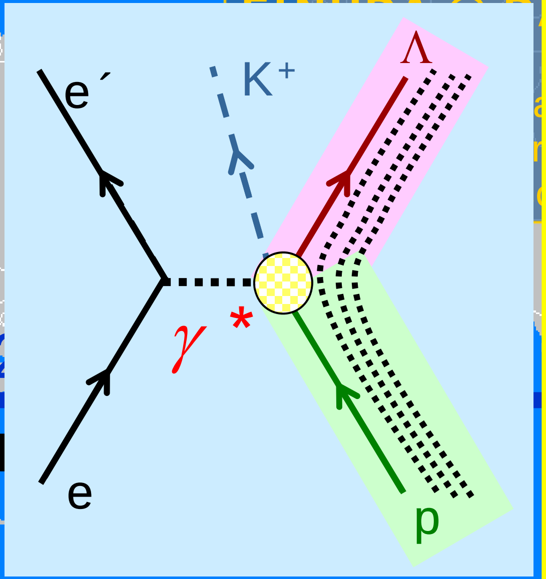
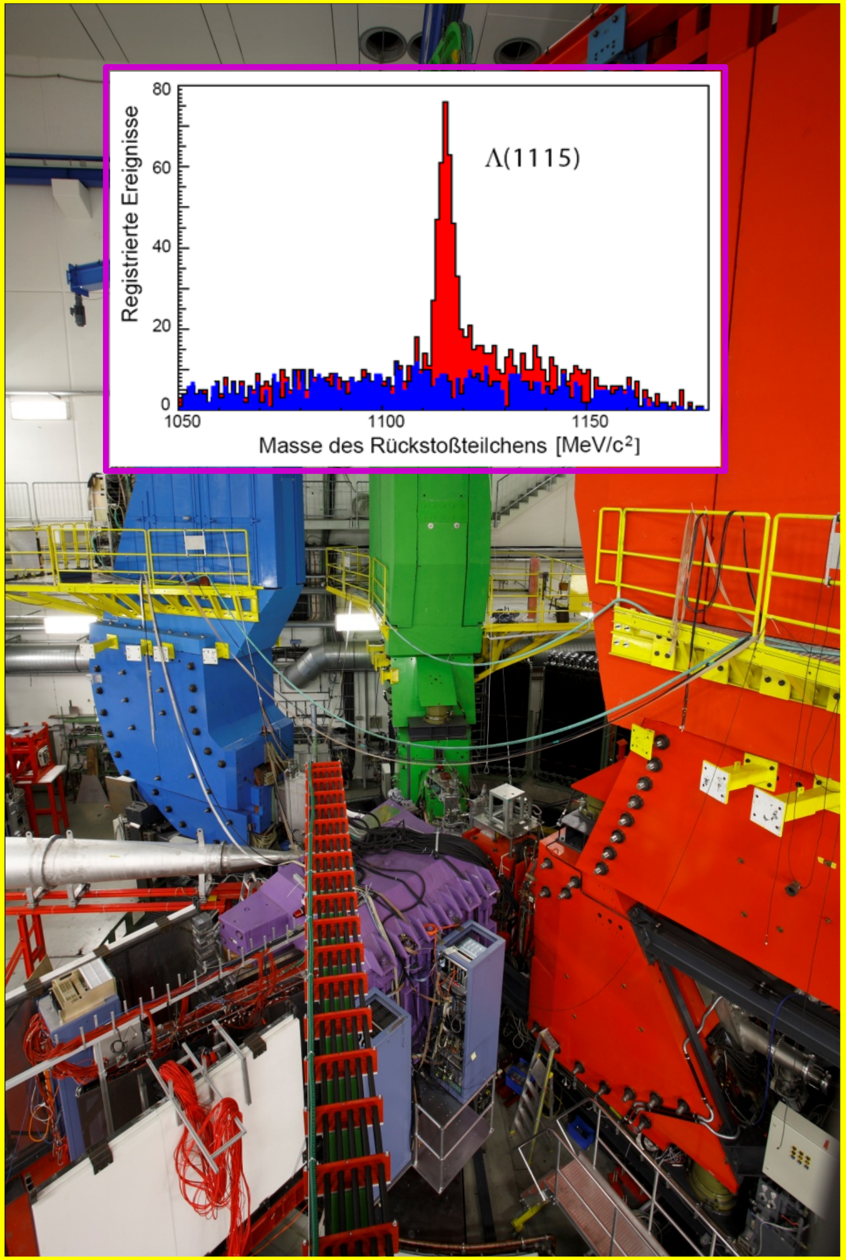
JLab
- electro-production
- single Λ-hypernuclei
- Λ-wavefunction



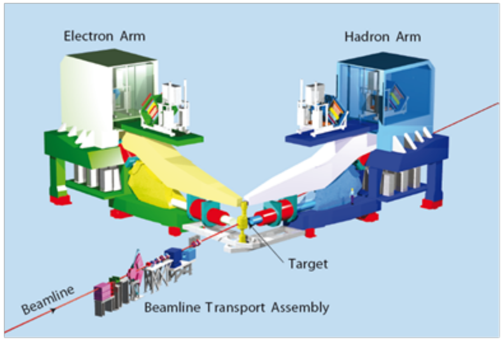
KEK **JLAB**

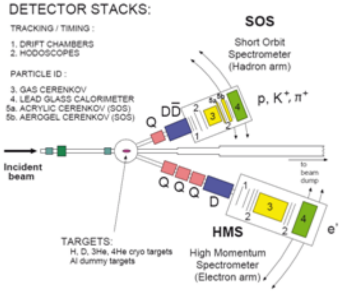
FINUDA **RHIC**

MAMI

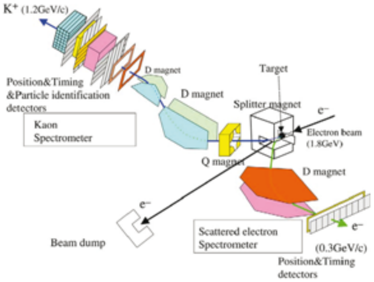


J-Lab Experiments

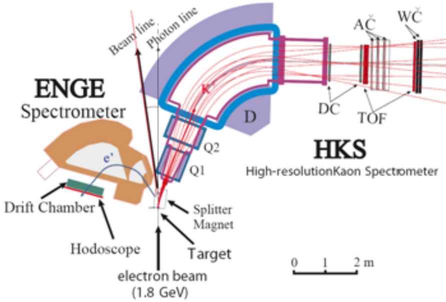




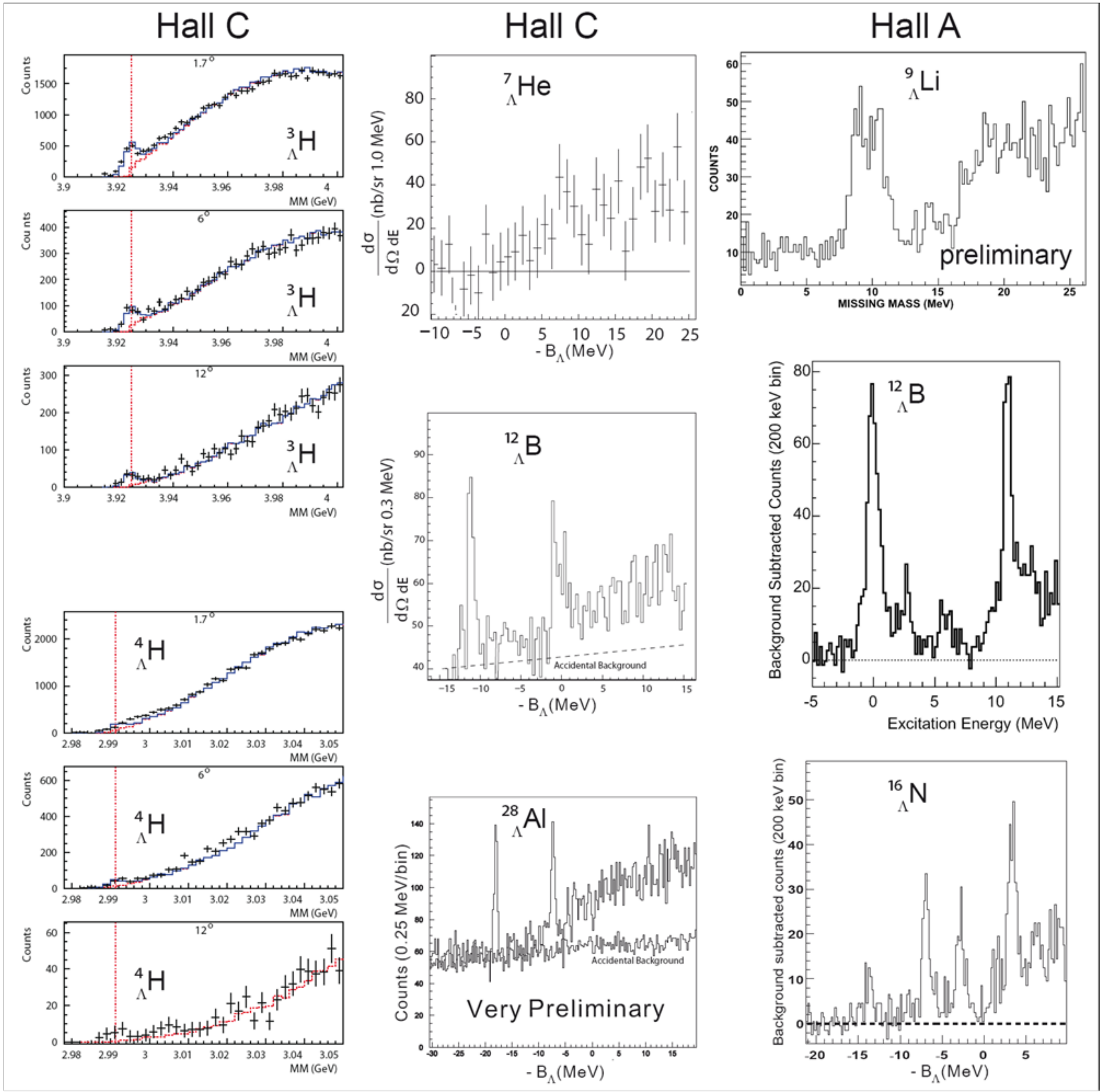
Setup E91-016
$^3_\Lambda$H, $^4_\Lambda$H



Setup E89-009
$^7_\Lambda$He, $^{12}_\Lambda$B

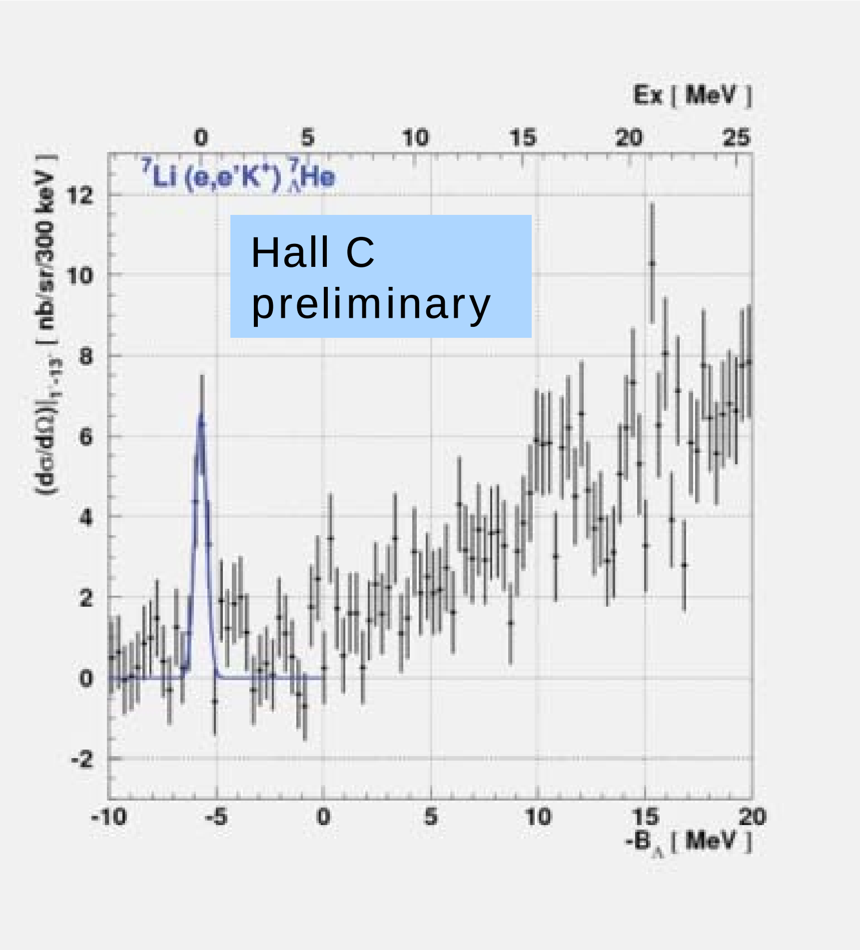


Setup E01-011
$^{28}_\Lambda$Al



Λ Binding Energy in Mirror Hypernuclei

- If isospin is an exact symmetry and therefore also no ΛN charge symmetry breaking ⇒ B_Λ of mirror nuclei identical



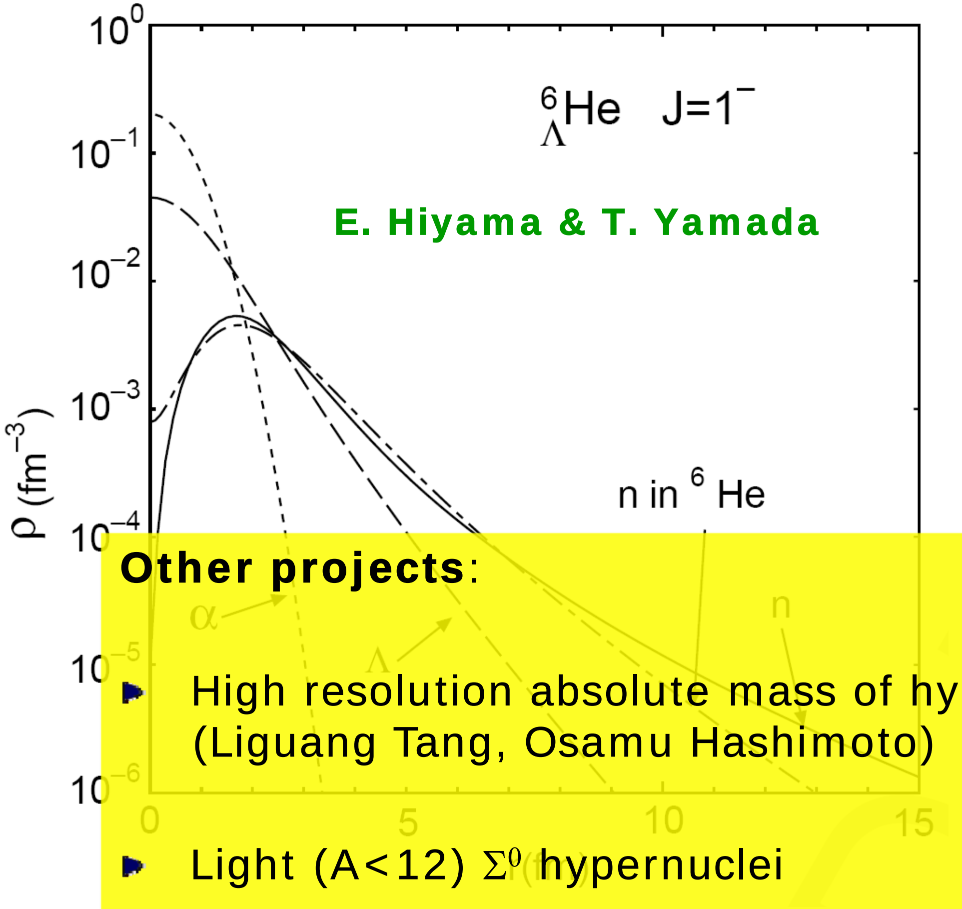
${}^{4}_{\Lambda}H$	2.04 ± 0.04	${}^{4}_{\Lambda}He$	2.39 ± 0.03
${}^{6}_{\Lambda}He$	4.18 ± 0.10	${}^{6}_{\Lambda}Li$	3.92 ± 0.37
	4.42 ± 0.13		
${}^{7}_{\Lambda}He$	3.69 ± 0.90	${}^{7}_{\Lambda}Be$	5.16 ± 0.08
${}^{8}_{\Lambda}Li$	6.80 ± 0.03	${}^{8}_{\Lambda}Be$	6.84 ± 0.05
${}^{9}_{\Lambda}Li$	8.53 ± 0.15	${}^{9}_{\Lambda}B$	7.88 ± 0.15
${}^{10}_{\Lambda}Be$	9.11 ± 0.22	${}^{10}_{\Lambda}B$	8.89 ± 0.12
${}^{12}_{\Lambda}B$	11.37 ± 0.06	${}^{12}_{\Lambda}C$	10.76 ± 0.19
			11.38 ± 0.09
${}^{16}_{\Lambda}N$	13.76 ± 0.16	${}^{16}_{\Lambda}O$	12.42 ± 0.05
			13.28 ± 0.36
			13.40 ± 0.40

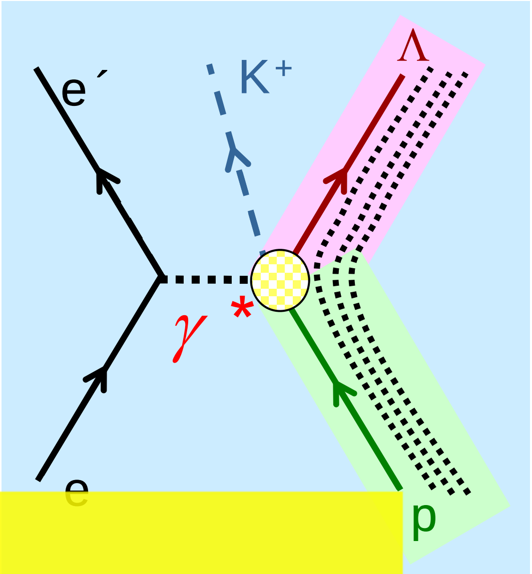
d by

lectromagnetic effects

  - nuclear CSB
  - ΛN CSB

KAOS @ MAMI

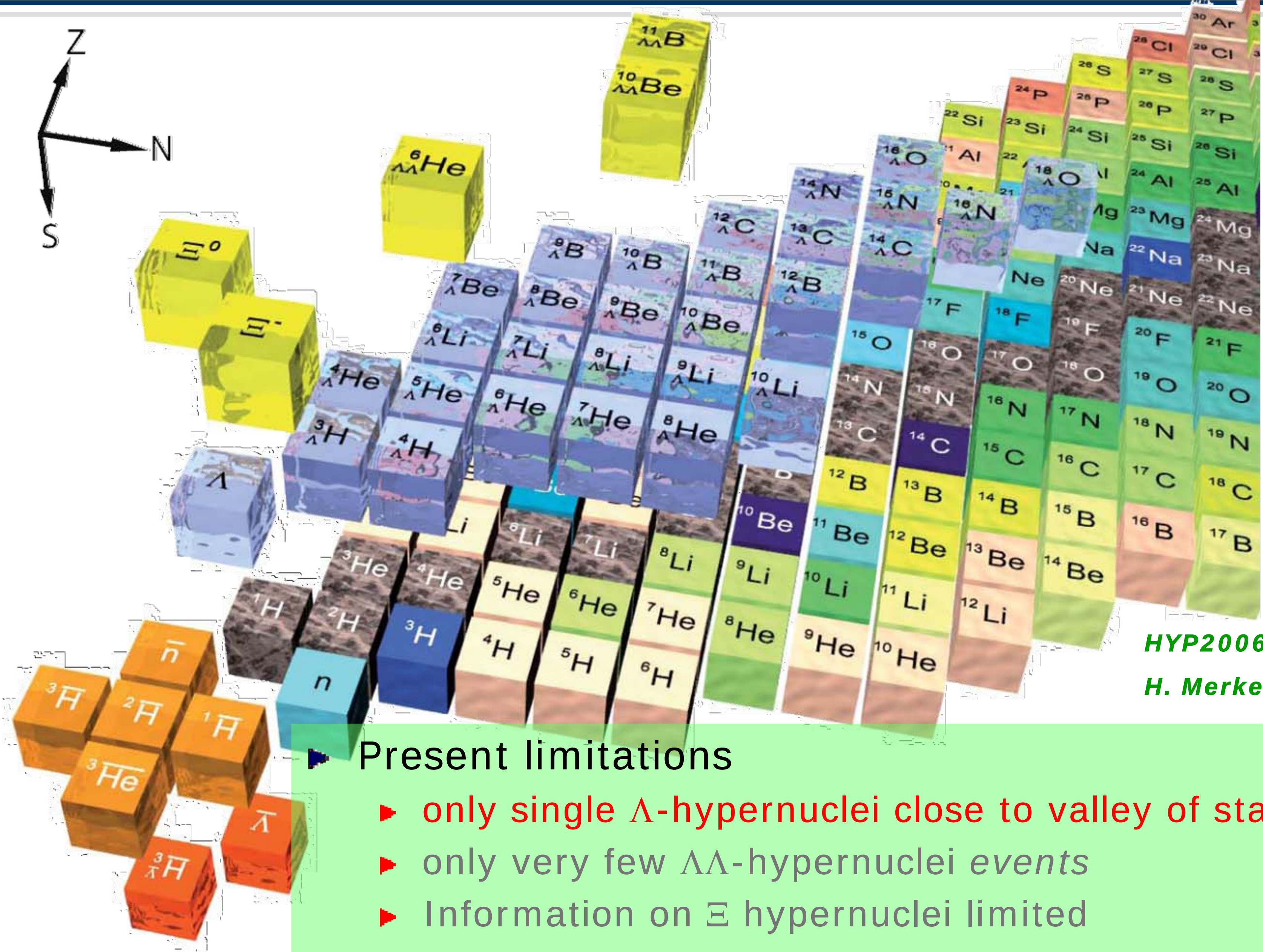




Other projects:

- High resolution absolute mass of hypernuclei by pionic decay (Liguang Tang, Osamu Hashimoto)
- Light (A<12) Σ^0 hypernuclei
- Coulomb assisted bound Σ^- states
- Deformation of hypernuclei

The present nuclear chart

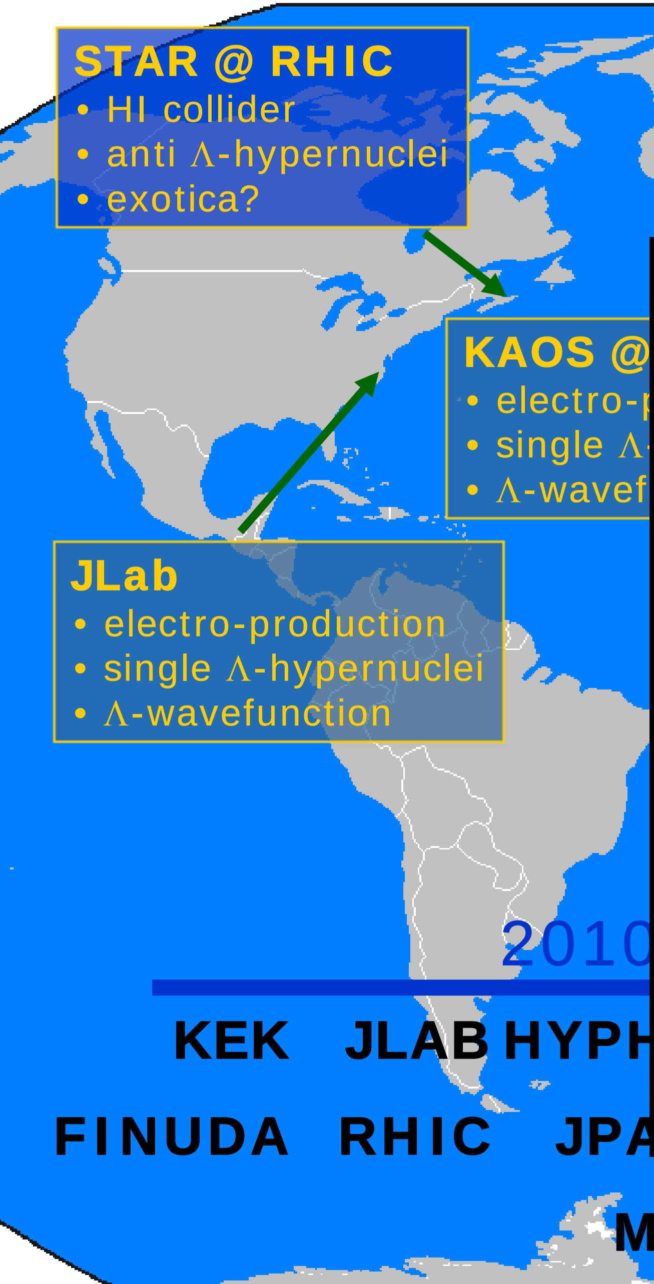


HYP2006

H. Merkel

- Present limitations
  - only single Λ-hypernuclei close to valley of stability
  - only very few ΛΛ-hypernuclei *events*
  - Information on Ξ hypernuclei limited
  - no information on antihyperons in normal nuclei

International Hypernuclear Network



STAR @ RHIC
- HI collider
- anti Λ-hypernuclei
- exotica?

PANDA @ FAIR
- anti-proton beam
- double Λ-hypernuclei
- γ-ray spectroscopy

Dubna
- heavy ion beam
- single Λ-hypernuclei
- weak decays

KAOS @
- electro-p
- single Λ-
- Λ-wavef

JLab
- electro-production
- single Λ-hypernuclei
- Λ-wavefunction

lei

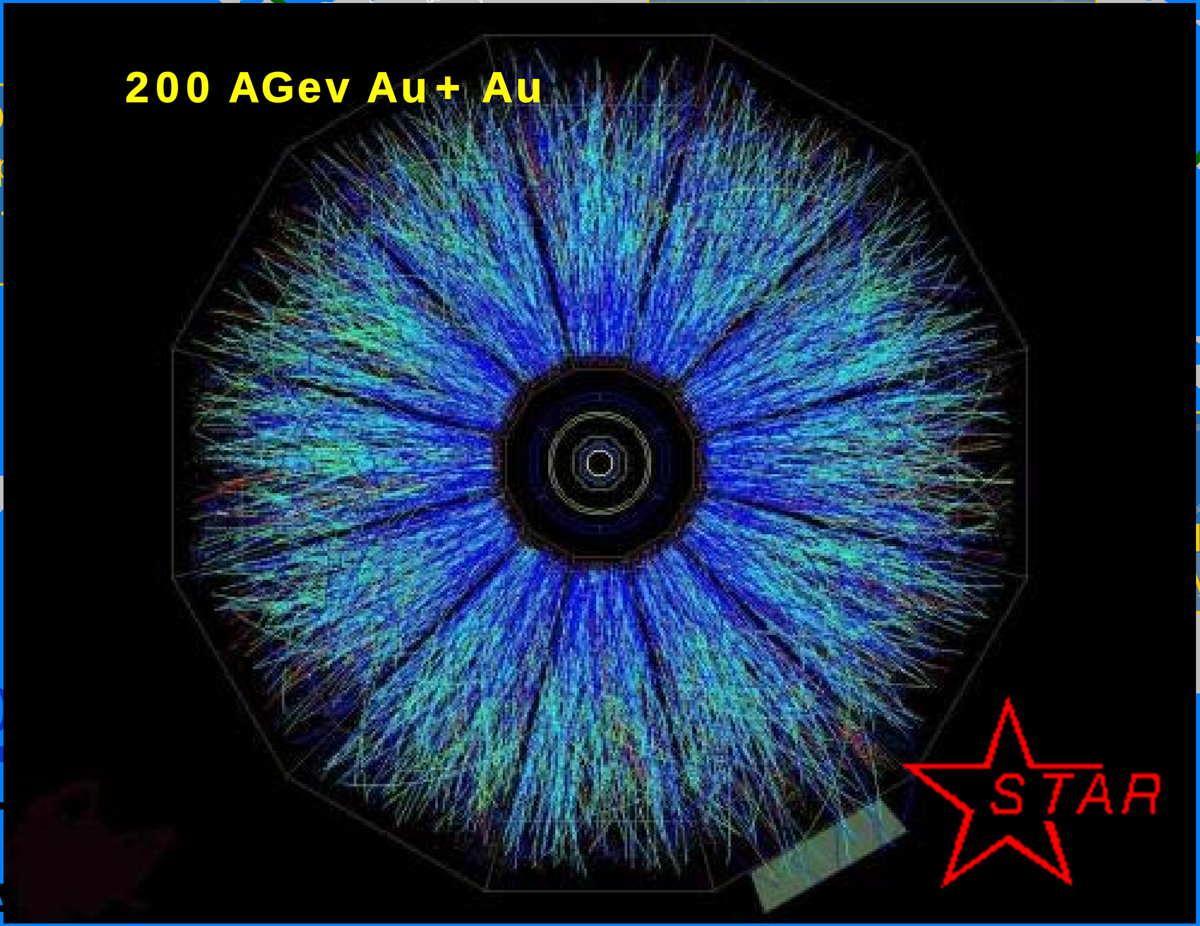
Λ

2010

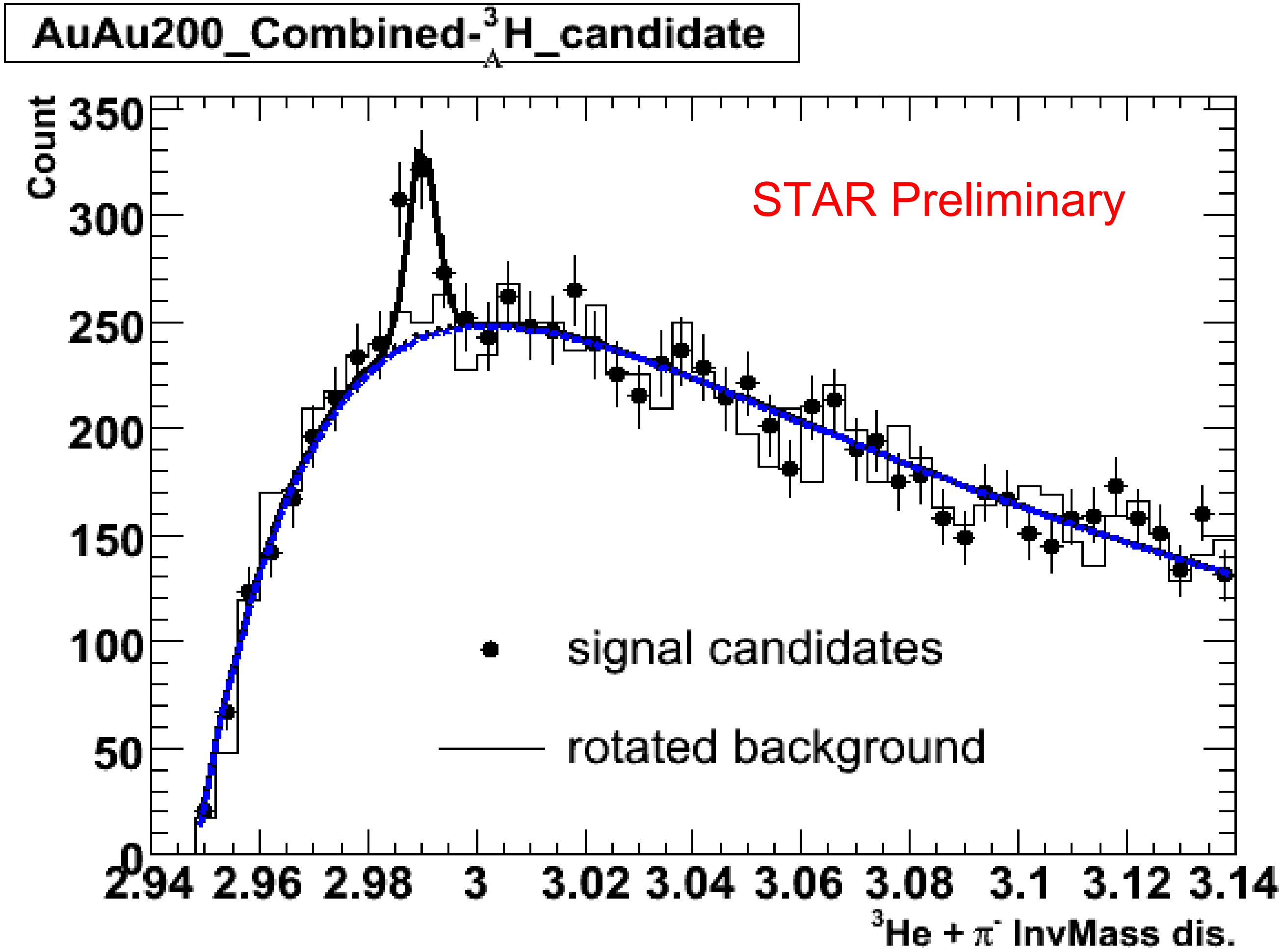
KEK **JLAB** **HYPH**

FINUDA **RHIC** **JPA**

MAMI

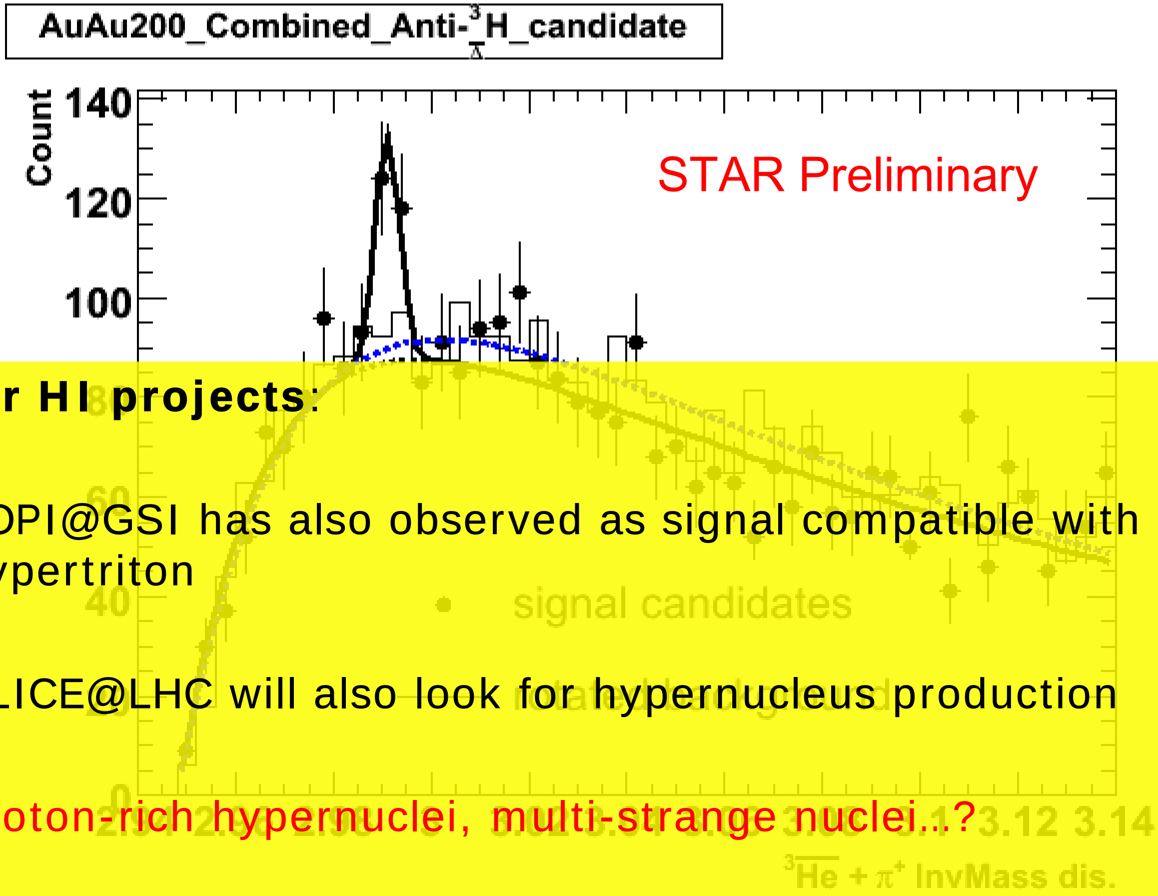


${}^{3}_{\Lambda}H$ at STAR



- background shape determined from rotated background analysis
- Signal observed from the data (bin-by-bin counting): 177 ± 30
- Mass: 2.990 ± 0.001 GeV; Width (fixed): 0.0025 GeV.

The first antihypernucleus: $^{3}_{\bar{\Lambda}}\bar{H}$ @ STAR

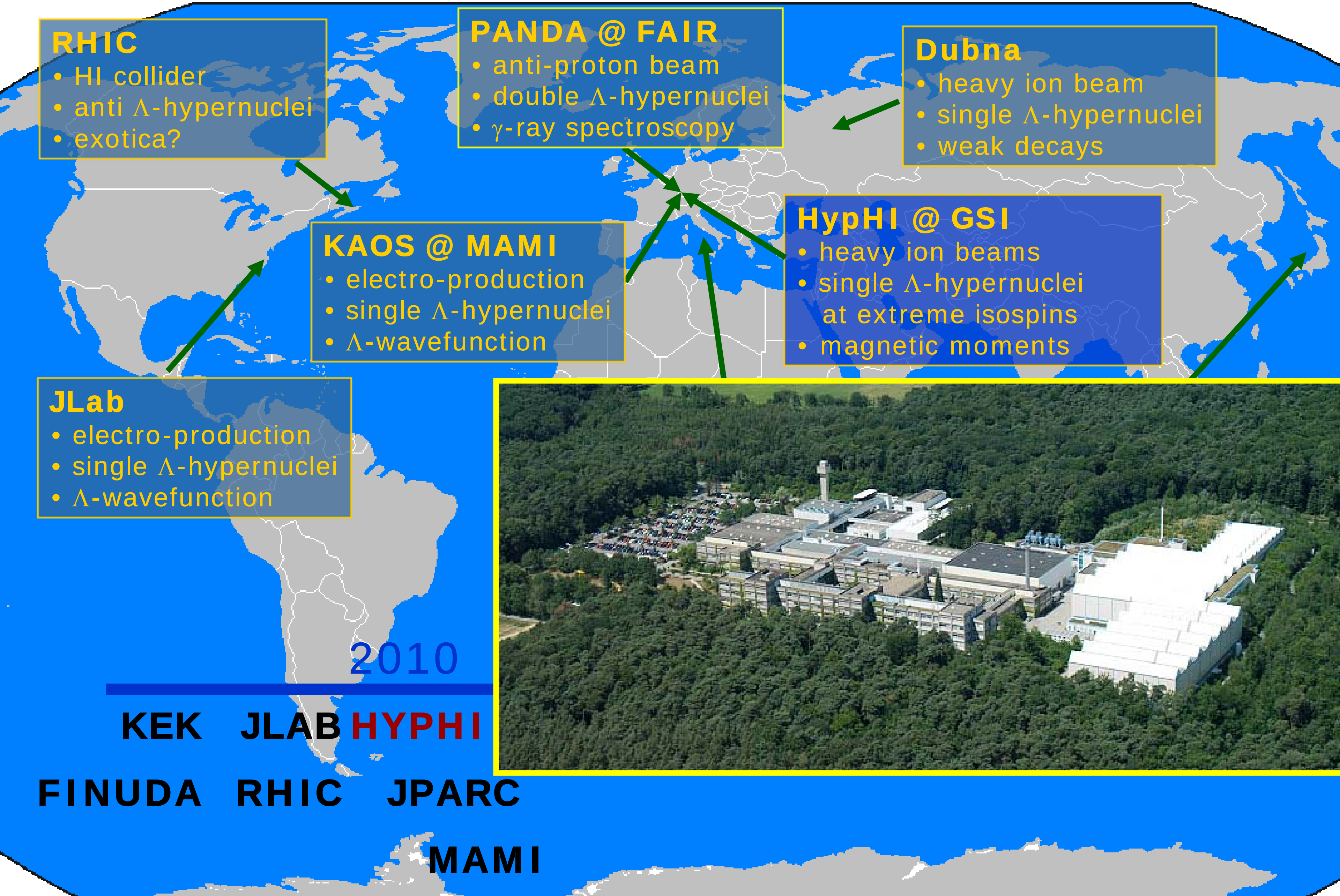


Other HI projects:

- FOPI@GSI has also observed as signal compatible with hypertriton
- ALICE@LHC will also look for hypernucleus production
- Proton-rich hypernuclei, multi-strange nuclei..?

- Signal observed from the data (bin-by-bin counting): 68±18
- Mass: 2.991±0.001 GeV; Width (fixed): 0.0025 GeV

International Hypernuclear Network



RHIC
- HI collider
- anti Λ-hypernuclei
- exotica?

PANDA @ FAIR
- anti-proton beam
- double Λ-hypernuclei
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Dubna
- heavy ion beam
- single Λ-hypernuclei
- weak decays

KAOS @ MAMI
- electro-production
- single Λ-hypernuclei
- Λ-wavefunction

HypHI @ GSI
- heavy ion beams
- single Λ-hypernuclei at extreme isospins
- magnetic moments

JLab
- electro-production
- single Λ-hypernuclei
- Λ-wavefunction

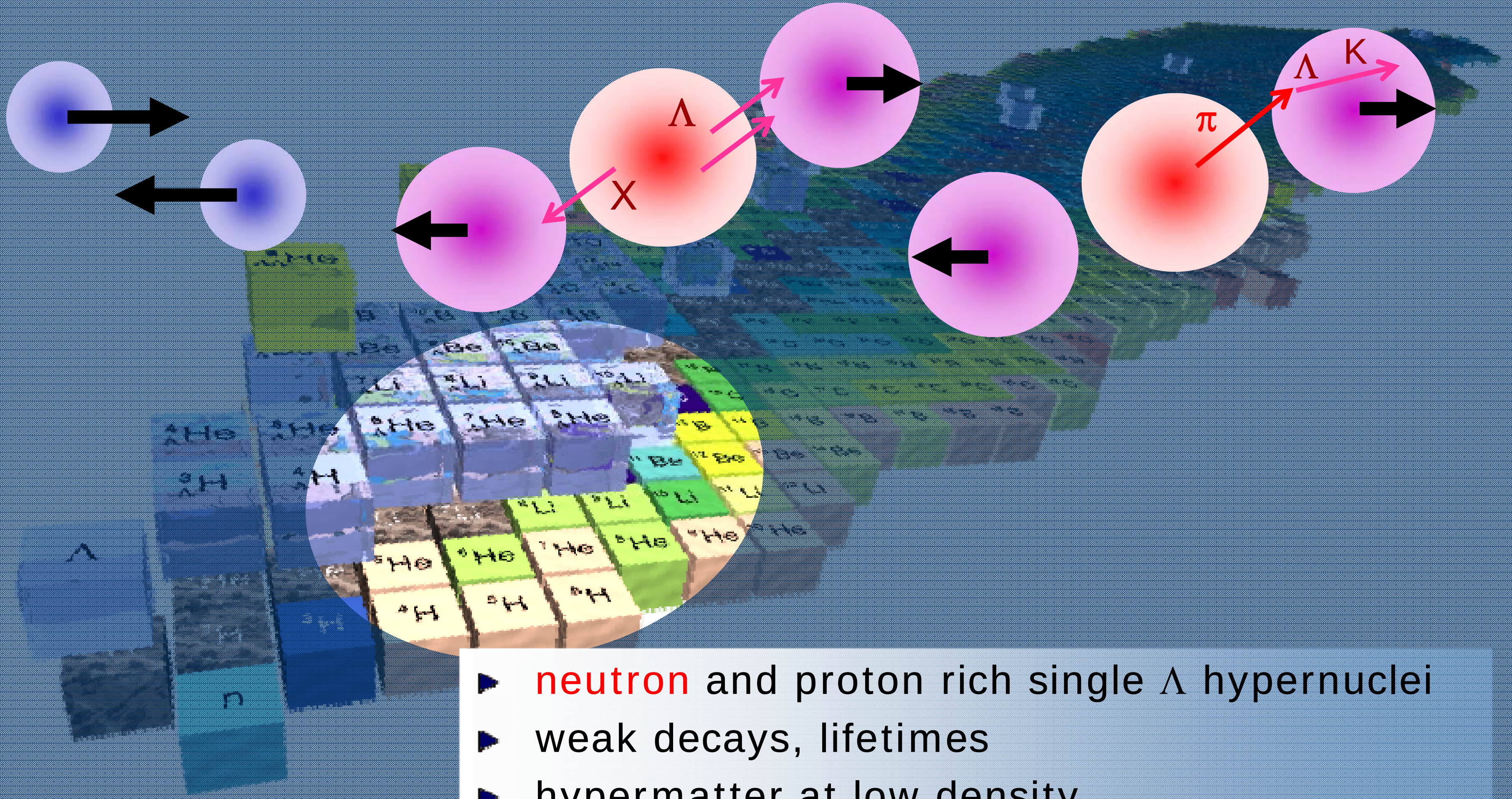
2010

KEK JLAB HYPHI

FINUDA RHIC JPARC

MAMI

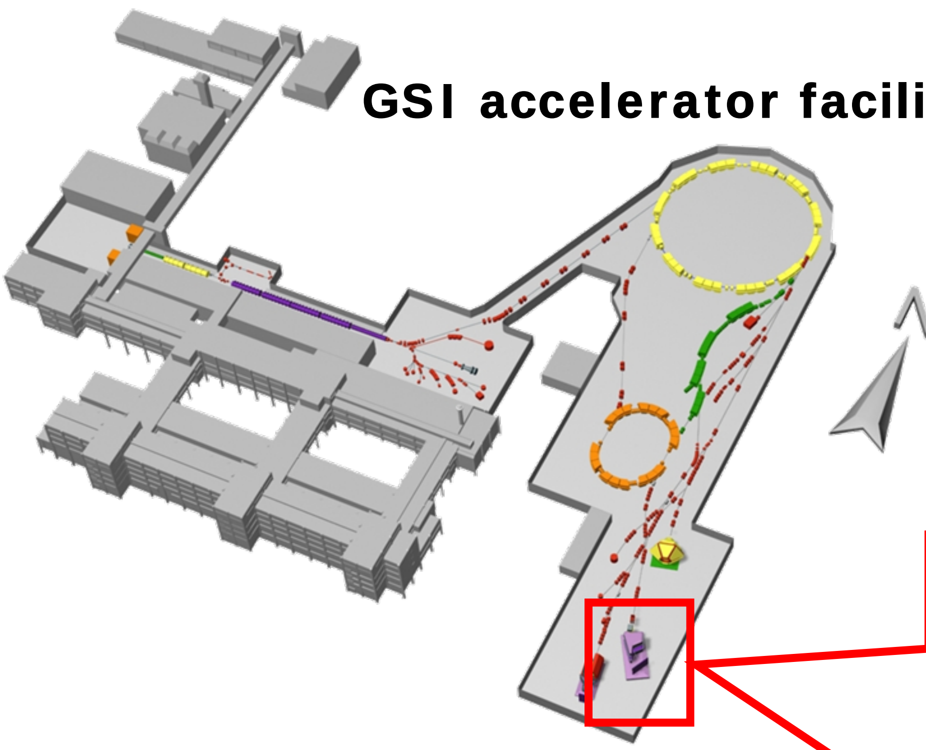
HYPHI @ GSI/FAIR



- **neutron** and proton rich single Λ hypernuclei
- weak decays, lifetimes
- hypermatter at low density
- magnetic moment of Λ inside nucleus

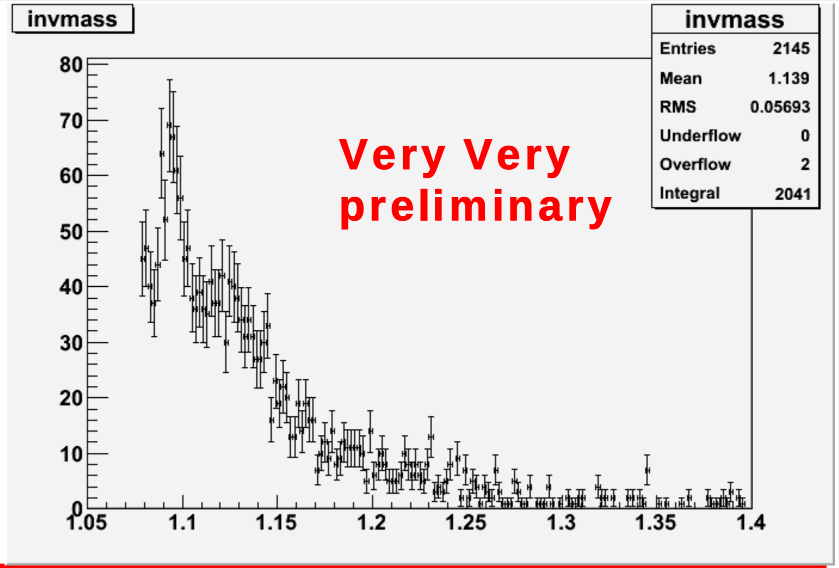
Take Saito (GSI,Mainz)

Phase 0 experiment at GSI, in 2009/2010

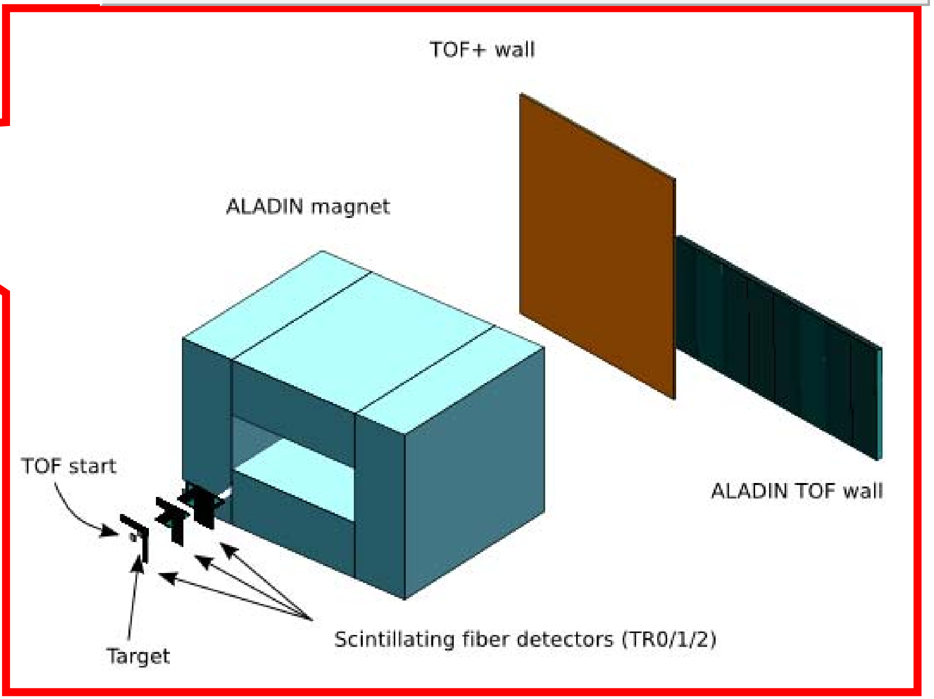


GSI accelerator facility

Cave C



Very Very preliminary

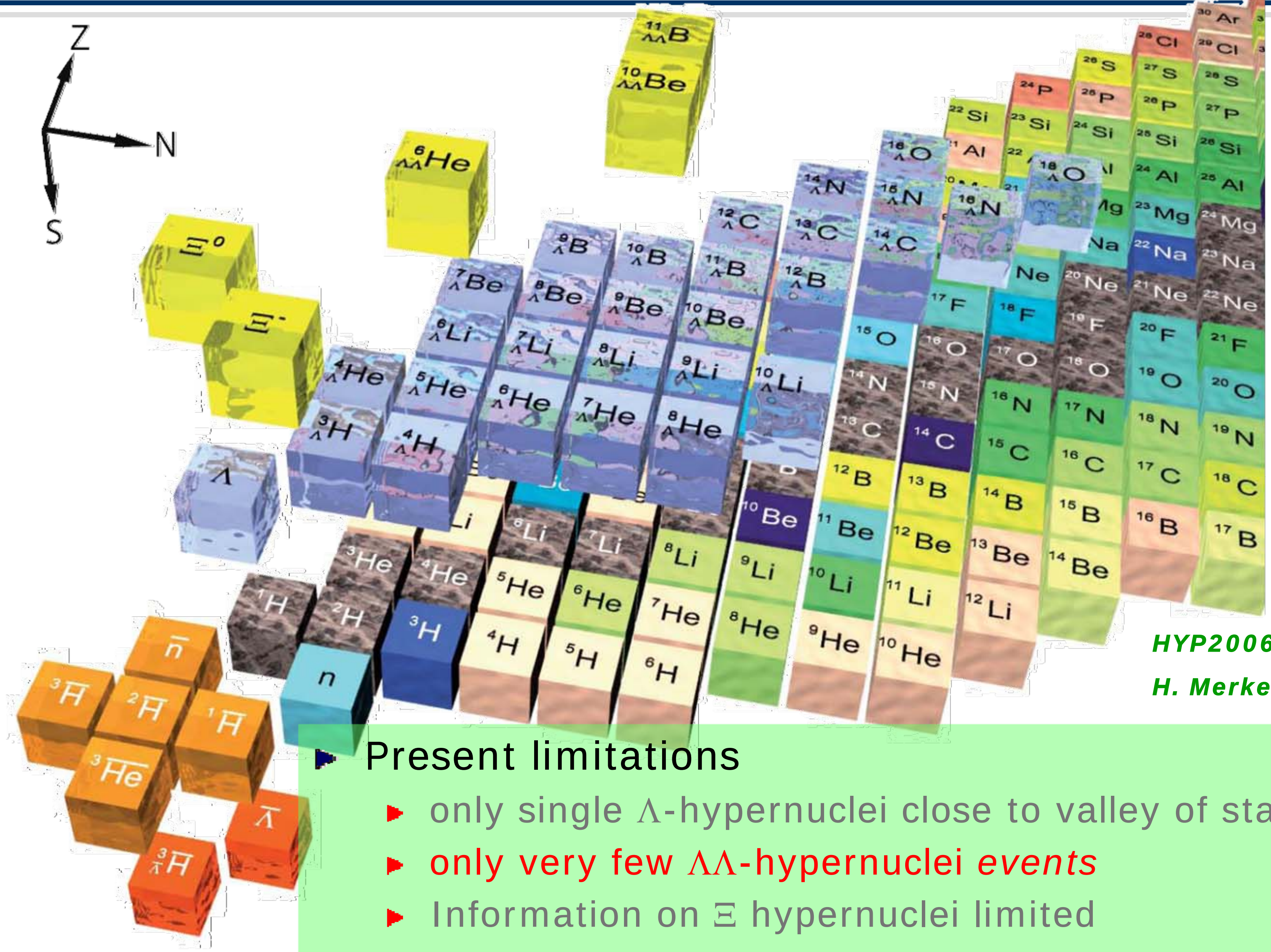


October 2009: 2AGeV ^{6}Li+^{12}C

$$ {}^{5}_{\Lambda}He \rightarrow p + \alpha + \pi^{-} $$

March 2010: 2AGeV ^{20}Ne+^{12}C

The present nuclear chart



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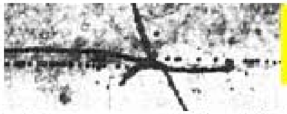
Summary and perspective (1)

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	$^{6}_{\Lambda\Lambda}$He	^{12}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	$^{6}_{\Lambda\Lambda}$He	^{12}C	9.93 +/- 1.72	3.69 +/- 1.72	3D	10.06 +/- 1.72	3.82 +/- 1.72
DEMACHI-YANAGI	$^{10}_{\Lambda\Lambda}$Be*	^{12}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	$^{11}_{\Lambda\Lambda}$Be	^{16}O	20.26 +/- 1.15	2.04 +/- 1.23	3D	20.49 +/- 1.15	2.27 +/- 1.23
	$^{12}_{\Lambda\Lambda}$Be	^{14}N	22.06 +/- 1.15	------	3D	22.23 +/- 1.15	------
E176	$^{13}_{\Lambda\Lambda}$B -> $^{13}_{\Lambda}$C*		------ Ex = 4.9	-------	3D	23.3 +/- 0.7	0.6 +/- 0.8
	$^{10}_{\Lambda\Lambda}$Be -> $^{9}_{\Lambda}$Be*		------ Ex = 3.0	-------	not checked, yet.	14.7 +/- 0.4	1.3 +/- 0.4

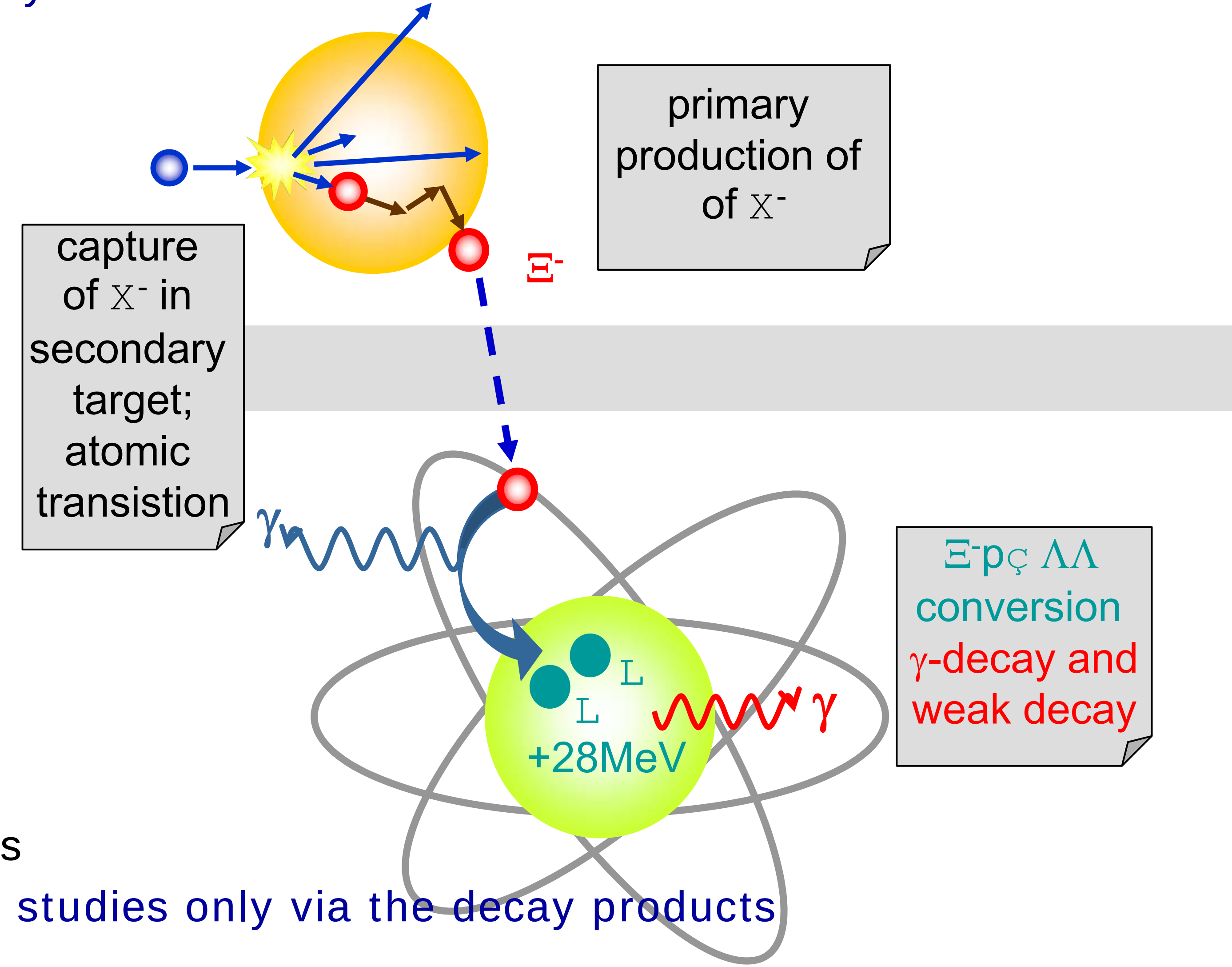
M.Danysz et al., PRL.11(1963)29;
R.H.Dalitz et al., Proc. R.S.Lond.A436(1989)1

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

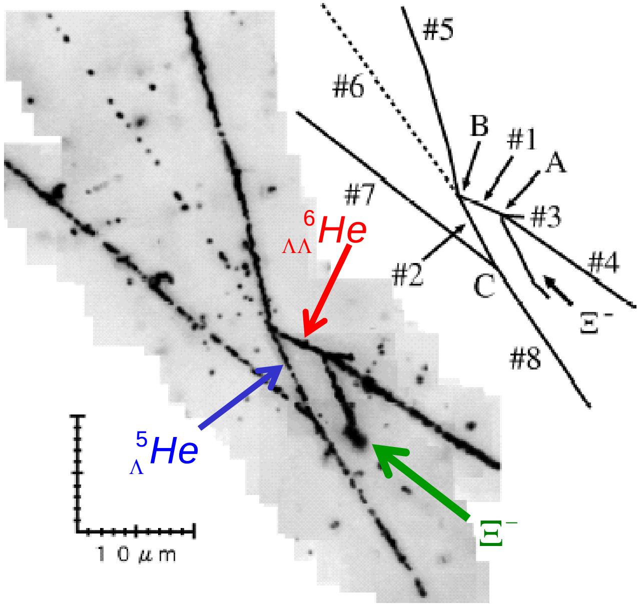
Ξ^-pç ΛΛ conversion γ-decay and weak decay

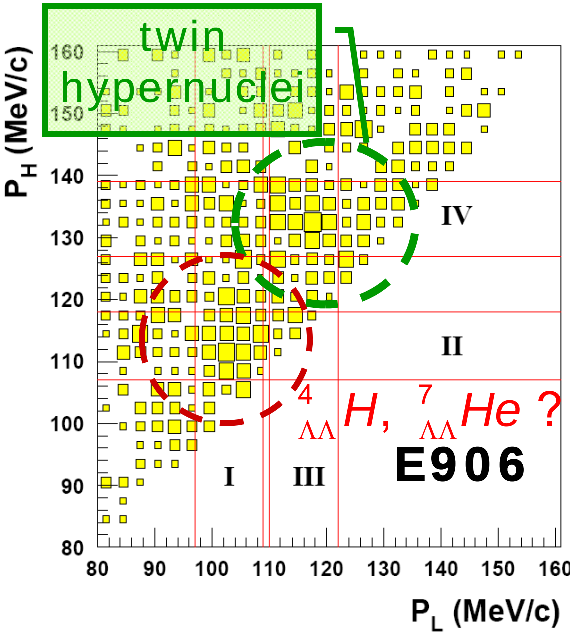
- two-step process

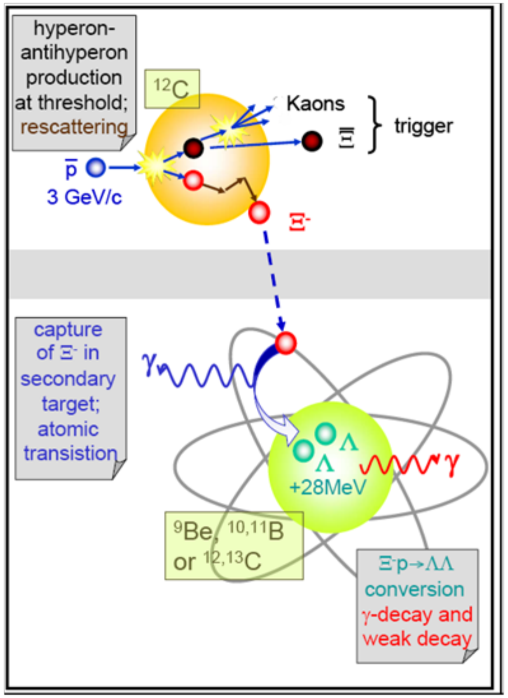
⇒ spectroscopic studies only via the decay products

Decay Products of ΛΛ Hypernuclei

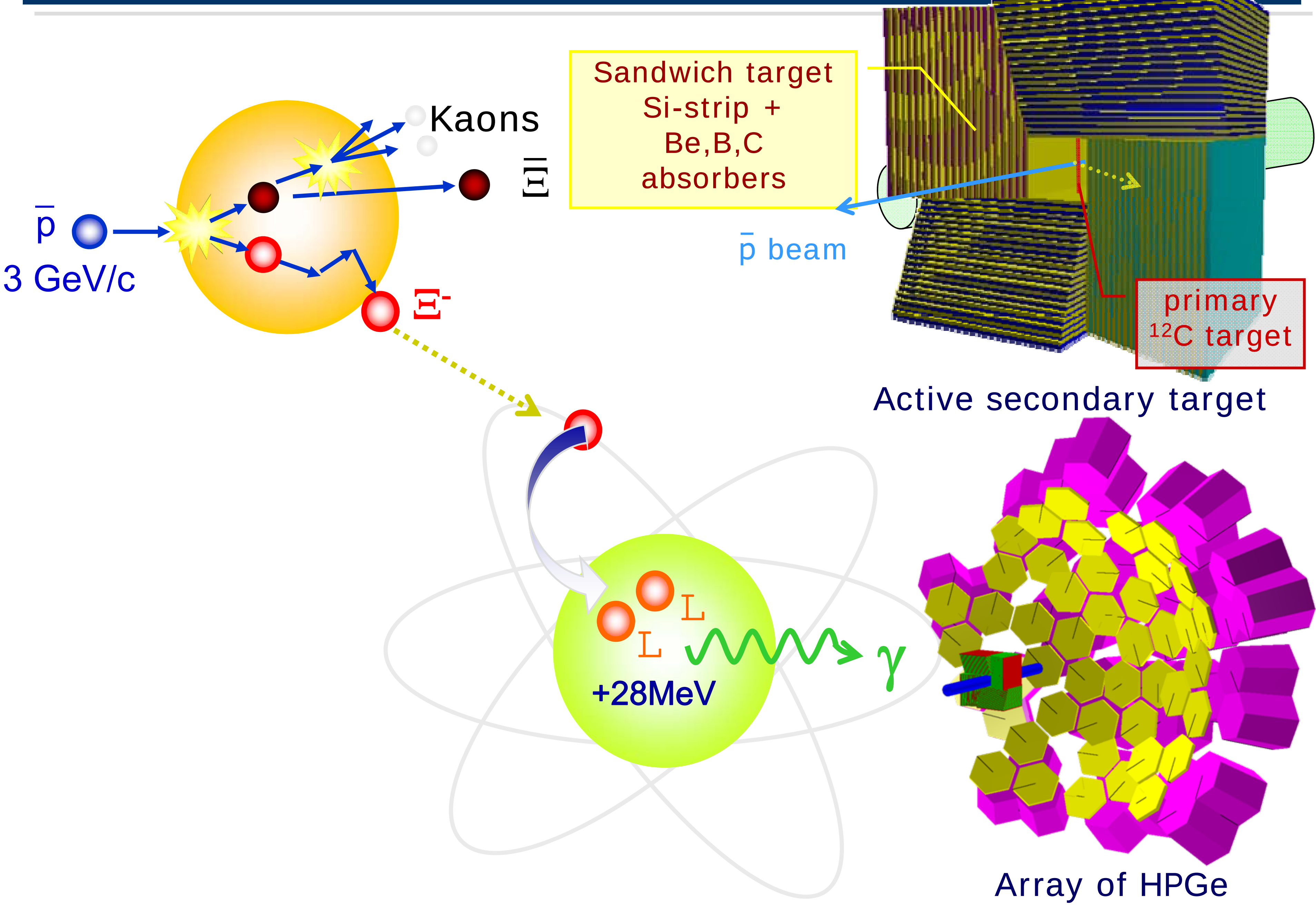
- nuclear fragments ⇒ emulsion hadron+nucleus
  - detection of charged products only
  - limited to light nuclei
- weak decay products ⇒ BNL-AGS E906 ^{9}Be(K^{-},K^{+})X
  - resolution limited
  - no information on excited states
  - interpretion not unique because π momenta are similar
- γ- spectroscopy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







Production of $\Lambda\Lambda$ Hypernuclei at PANDA



Sandwich target
Si-strip +
Be,B,C
absorbers

$\bar{p}$ beam

primary
^{12}C target

Active secondary target

Array of HPGe

PANDA Setup

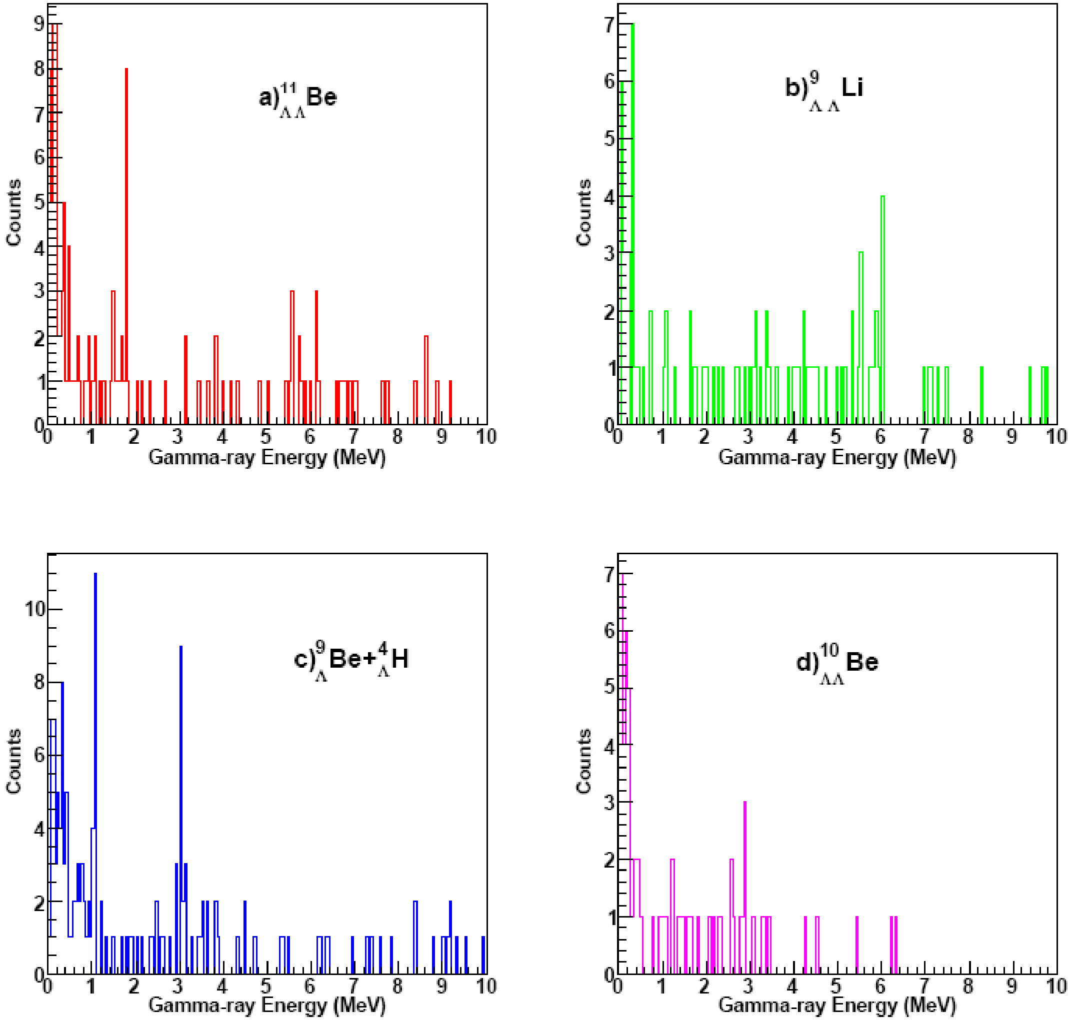
- θ_{lab} < 45°: $\bar{\Xi}$–, K- trigger (PANDA)
- θ_{lab} = 45°-90°: Ξ-capture, hypernucleus formation
- θ_{lab} > 90°: γ-detection Euroball (?) at backward angles

Milestones:

- Full Monte Carlo chain including event generator, new statistical model to simulate the population of excited states
- hardware projects: Ge-detectors, secondary target, primary target...

Simulation within PANDA_ROOT

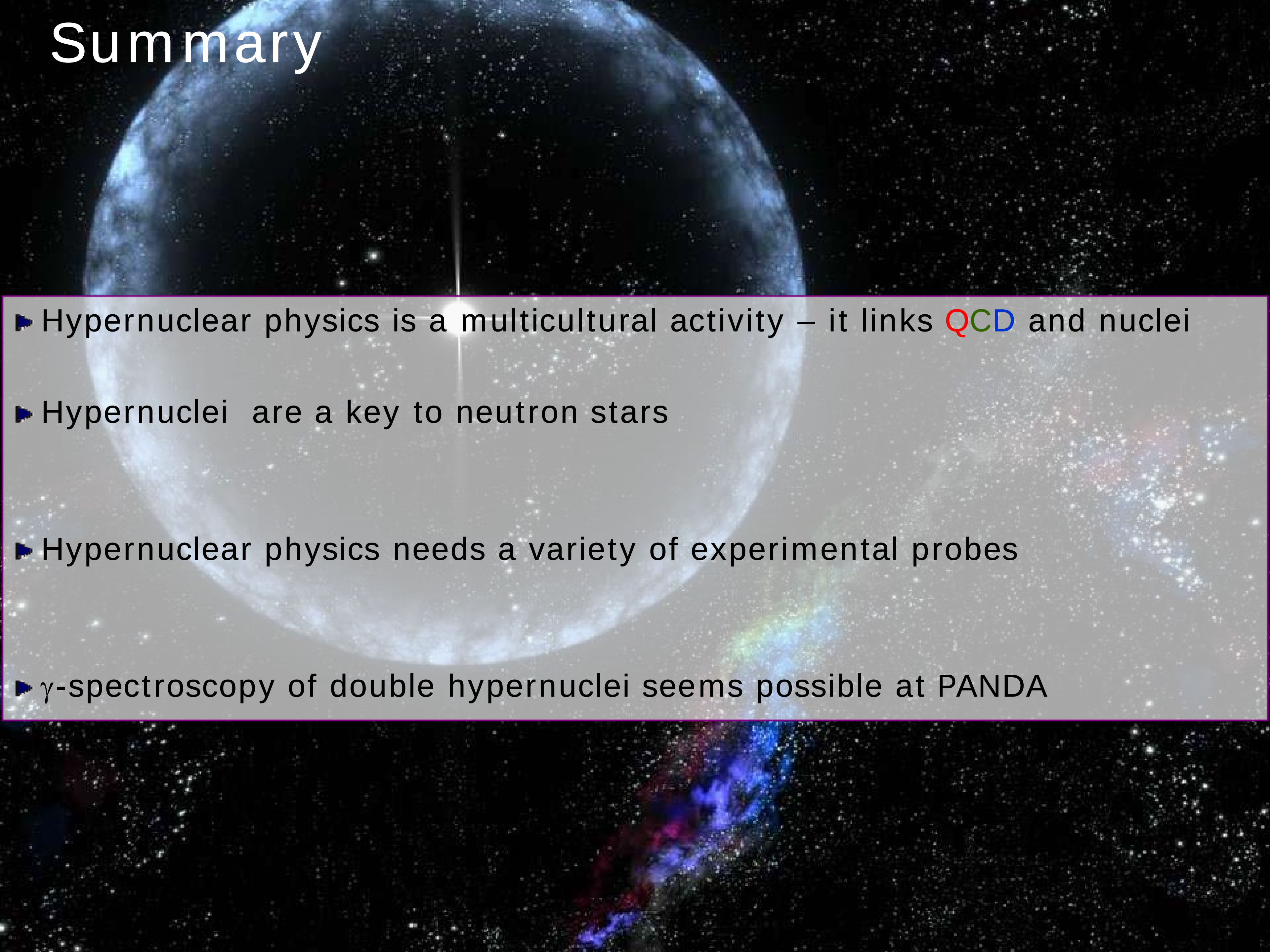
- Example: secondary ^{12}C target (~2 weeks$^{*)}$)
- Bin width 100keV



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

(arXiv:0903.3905)

Summary



- Hypernuclear physics is a multicultural activity – it links QCD and nuclei

- Hypernuclei are a key to neutron stars

- Hypernuclear physics needs a variety of experimental probes

- γ-spectroscopy of double hypernuclei seems possible at PANDA

THANK YOU