Int. Sym. on Nuclear Physics in Asia
October 15, 2010, Beihang University, Beijing

Nuclear Physics at J-PARC

famous for 魯迅

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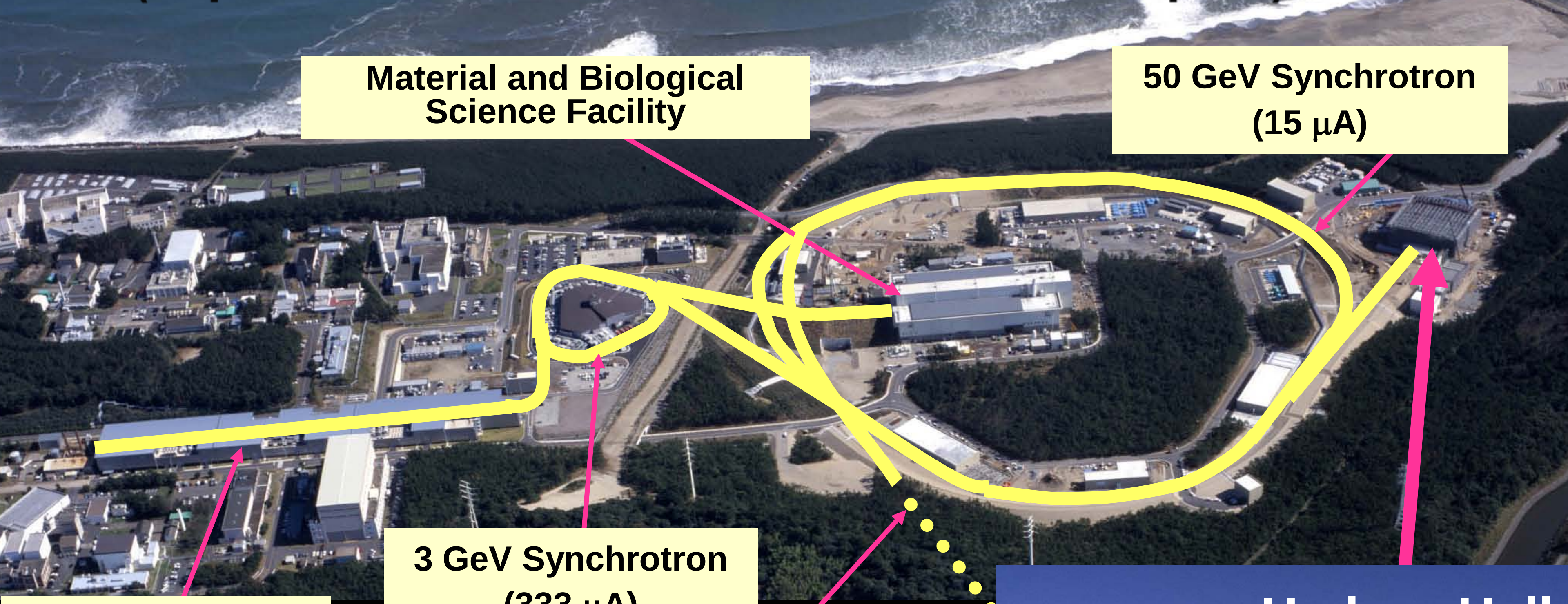
1. Introduction

J-PARC and Hadron Hall

J-PARC

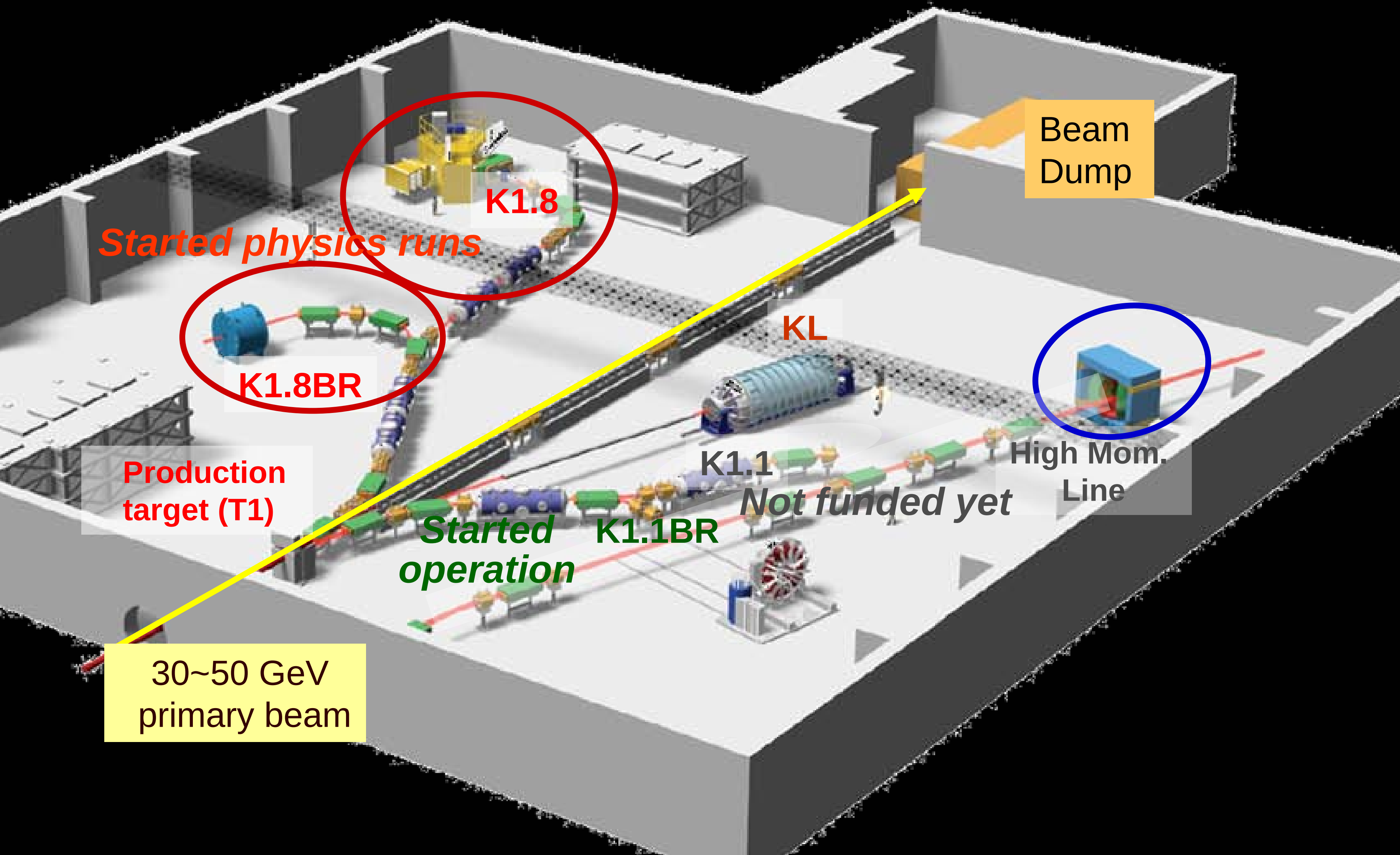
Tokai, Japan

(Japan Proton Accelerator Research Complex)



World-highest beam intensity : ~1 MW
x10 of BNL-AGS, x100 of KEK-PS

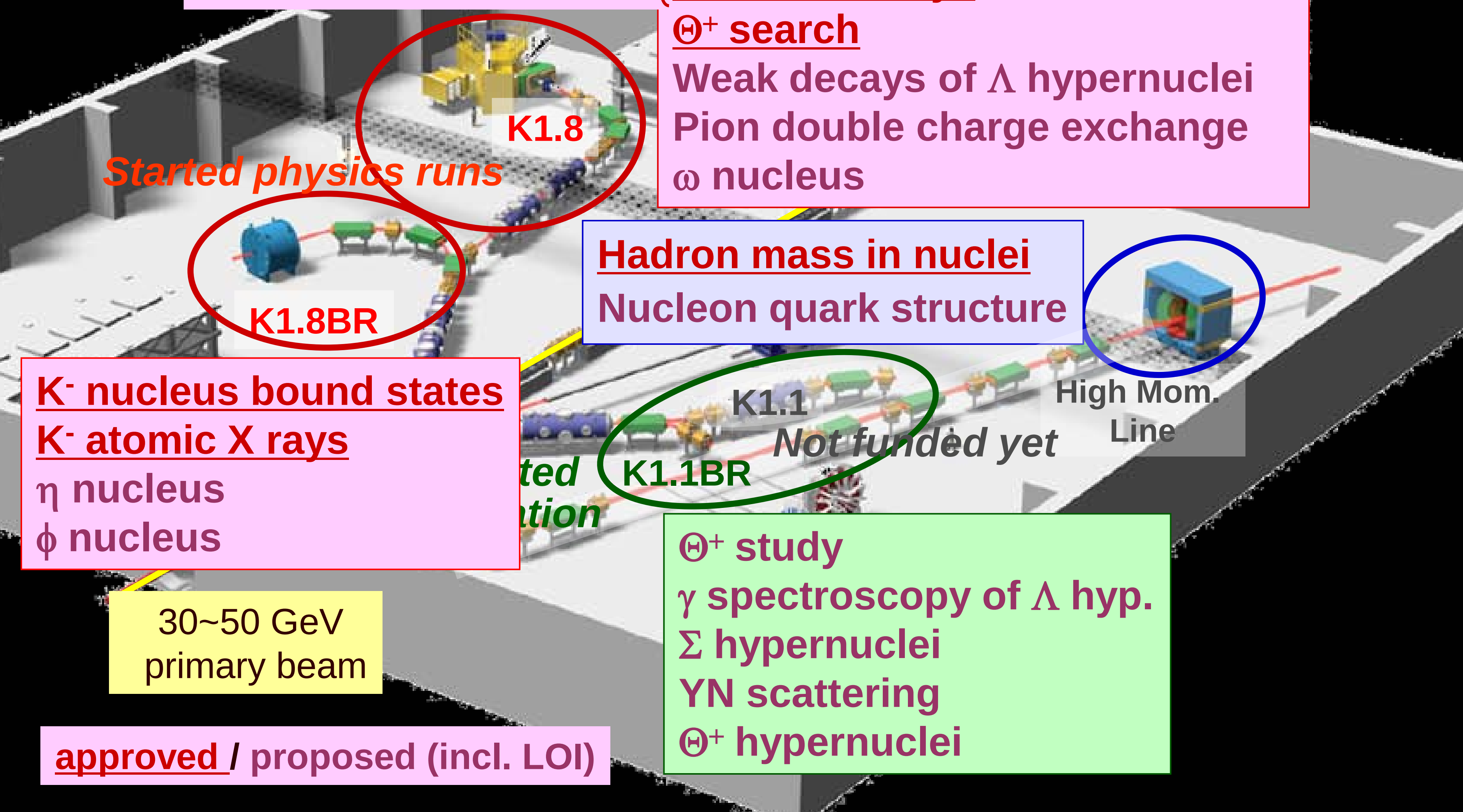
J-PARC Hadron Hall



J-PARC

S=-2 systems
quite unique at J-PARC

- γ spectroscopy of Λ hypernuclei
- n-rich Λ hypernuclei
- Ξ hypernuclei
- ΛΛ hypernuclei
- Ξ-atomic X rays
- Θ+ search
- Weak decays of Λ hypernuclei
- Pion double charge exchange
- ω nucleus



- Hadron mass in nuclei
- Nucleon quark structure

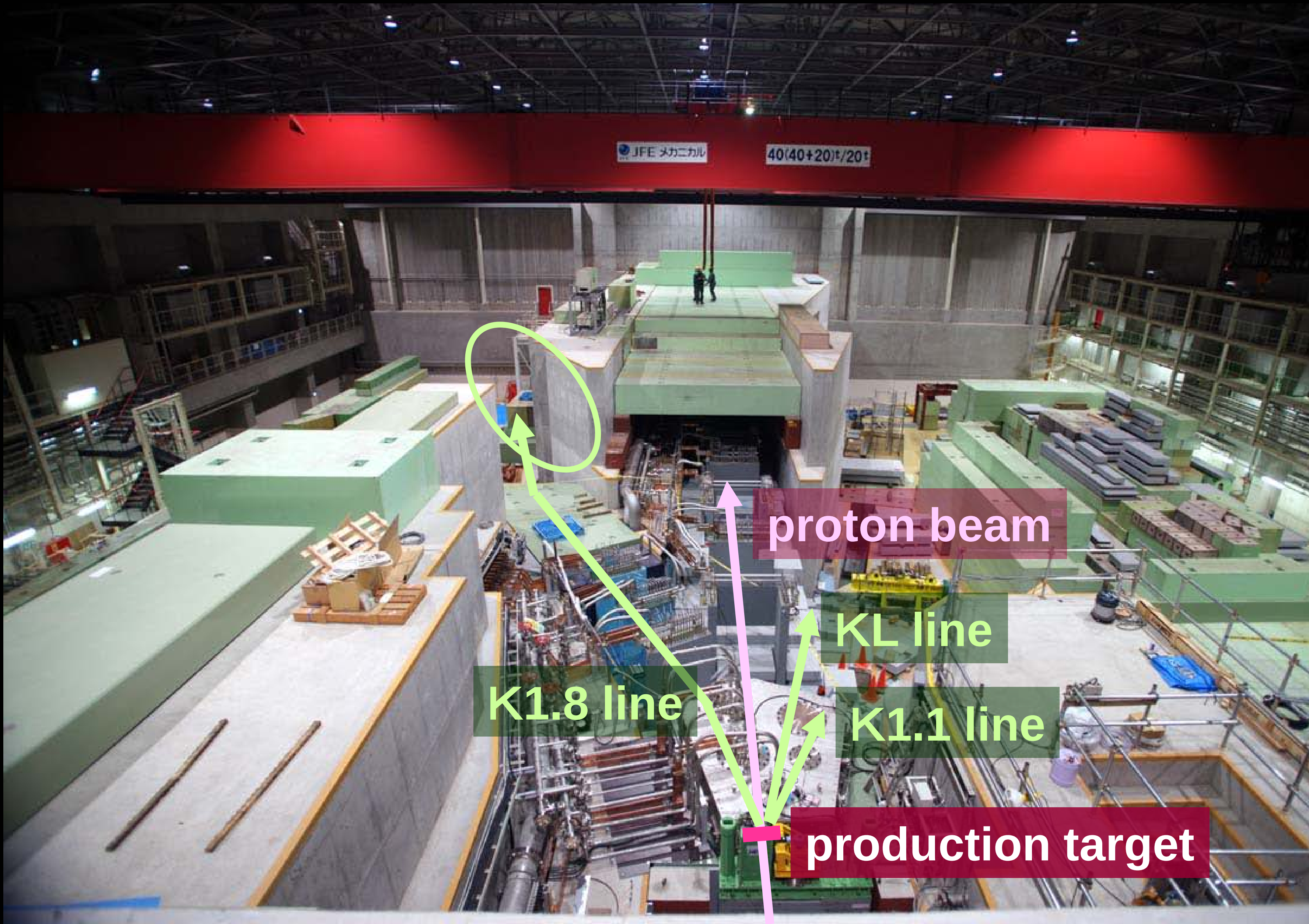
- K- nucleus bound states
- K- atomic X rays
- η nucleus
- ϕ nucleus

- Θ+ study
- γ spectroscopy of Λ hyp.
- Σ hypernuclei
- YN scattering
- Θ+ hypernuclei

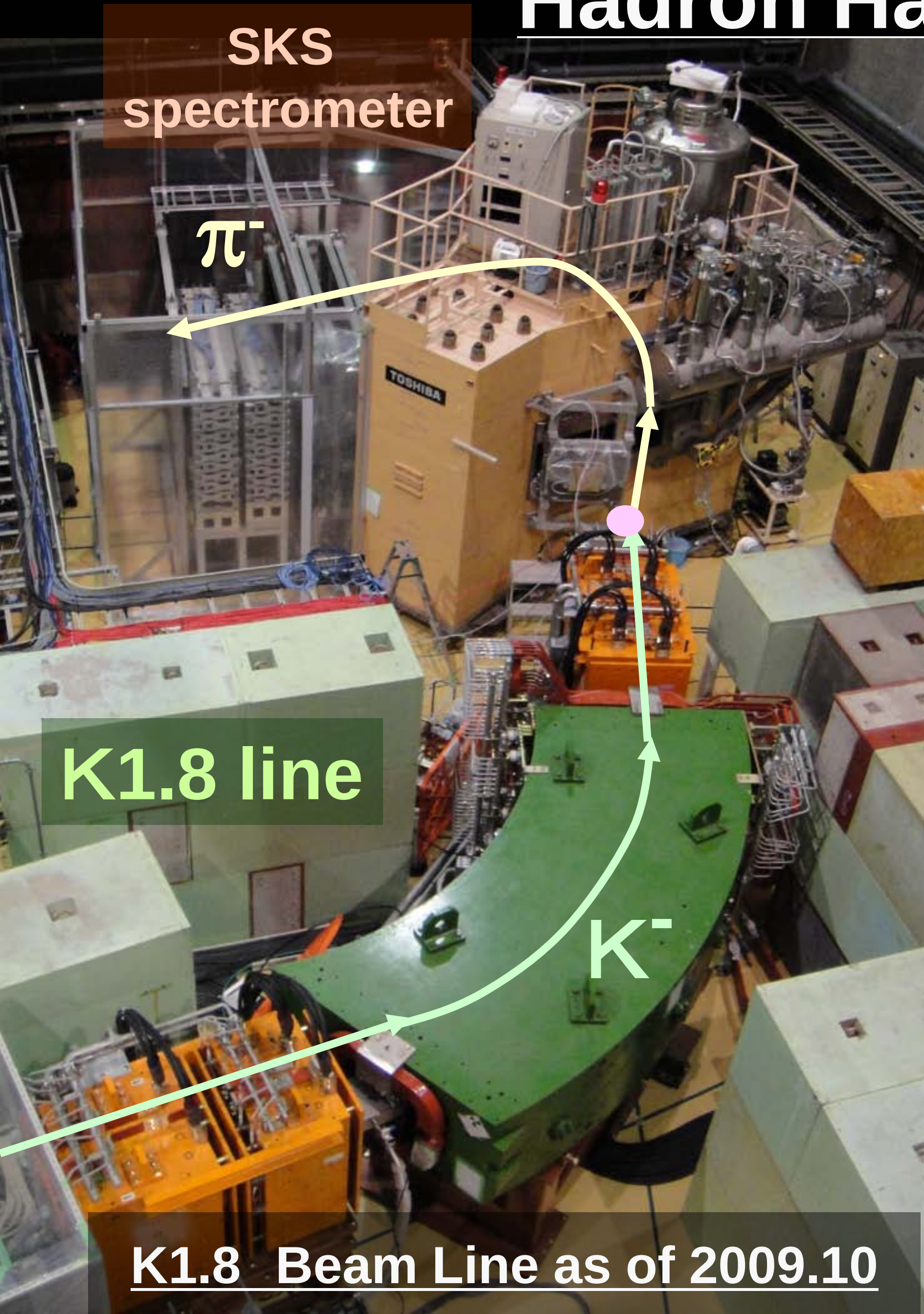
30~50 GeV
primary beam

approved / proposed (incl. LOI)

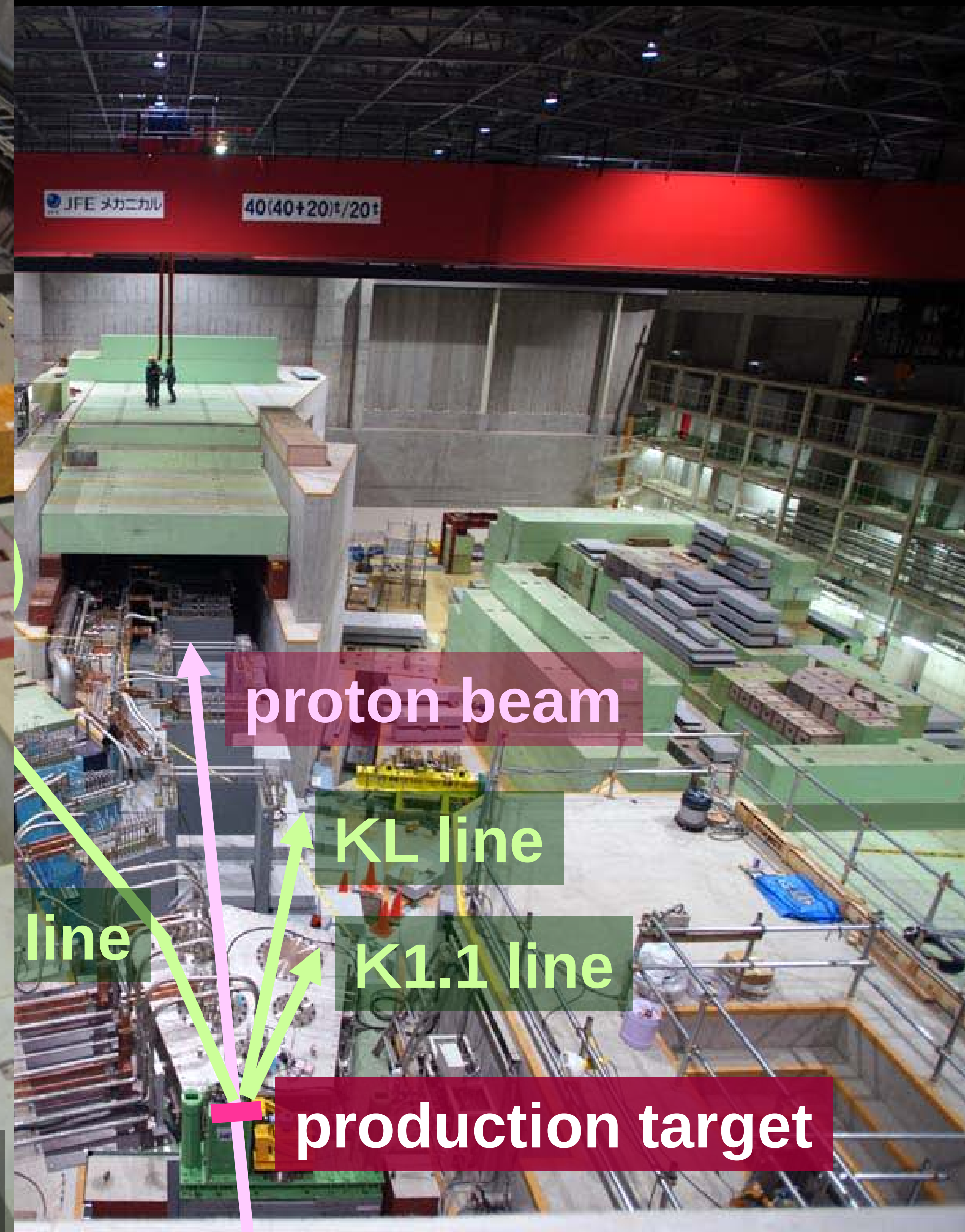
Hadron Hall as of 2008.10



Hadron Hall as of 2008.10



K1.8 Beam Line as of 2009.10

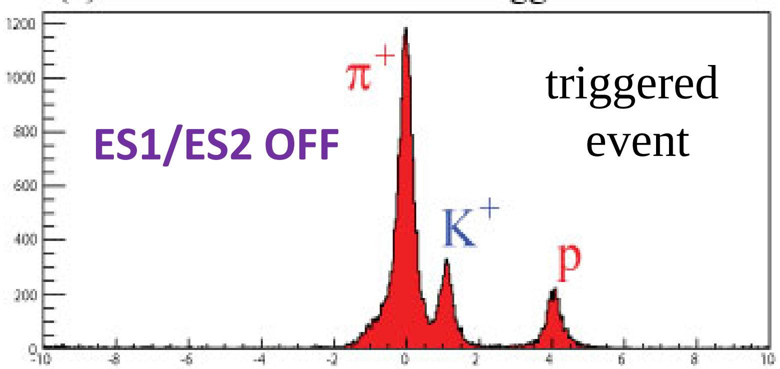


K1.8/SKS Performance

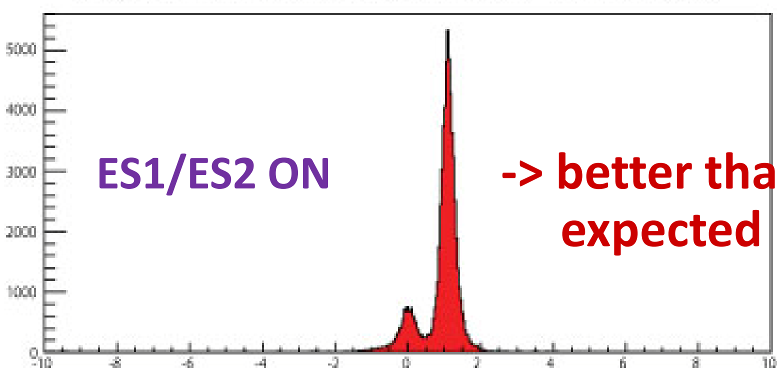
DC Mass Separators

1.25GeV/c

(a) ES1 off / ES2 off / “K” trigger

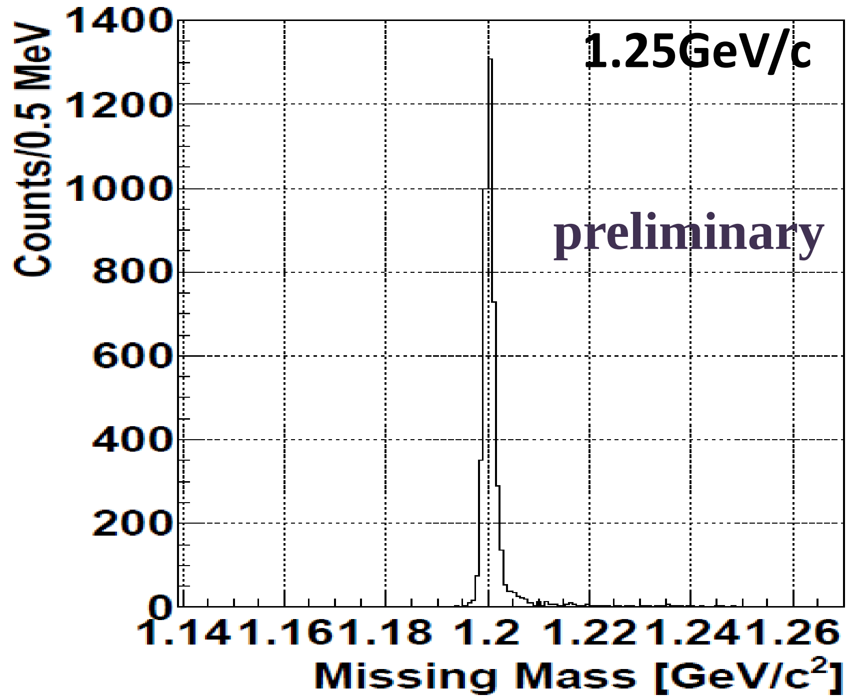


(c) ES1 on (K) / ES2 on (K) / “K” trigger



Missing mass resolution by K1.8/SKS spectrometers

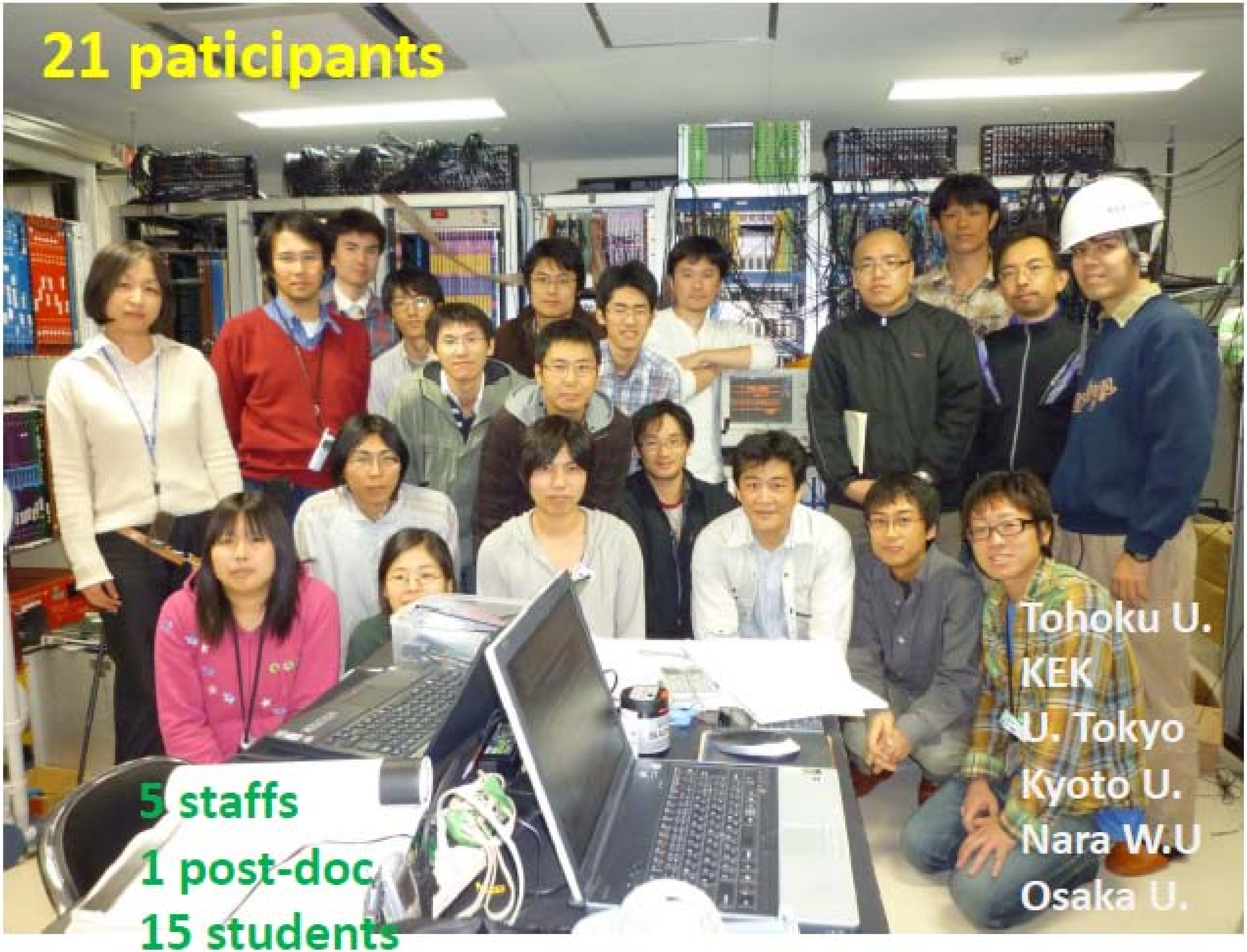
$\pi^- p\ (LH_2) \rightarrow \Sigma^- K^+$



- ΔM = 1.66±0.03 MeV (FWHM)
- M_{Σ^-} = 1.200 GeV/c^2 (1.1974 GeV/c^2)
- Yield consistent with cross section (efficiency OK)

-> Physics run from October, 2010

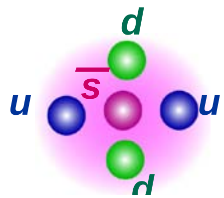
Participants at K1.8: the first beam day



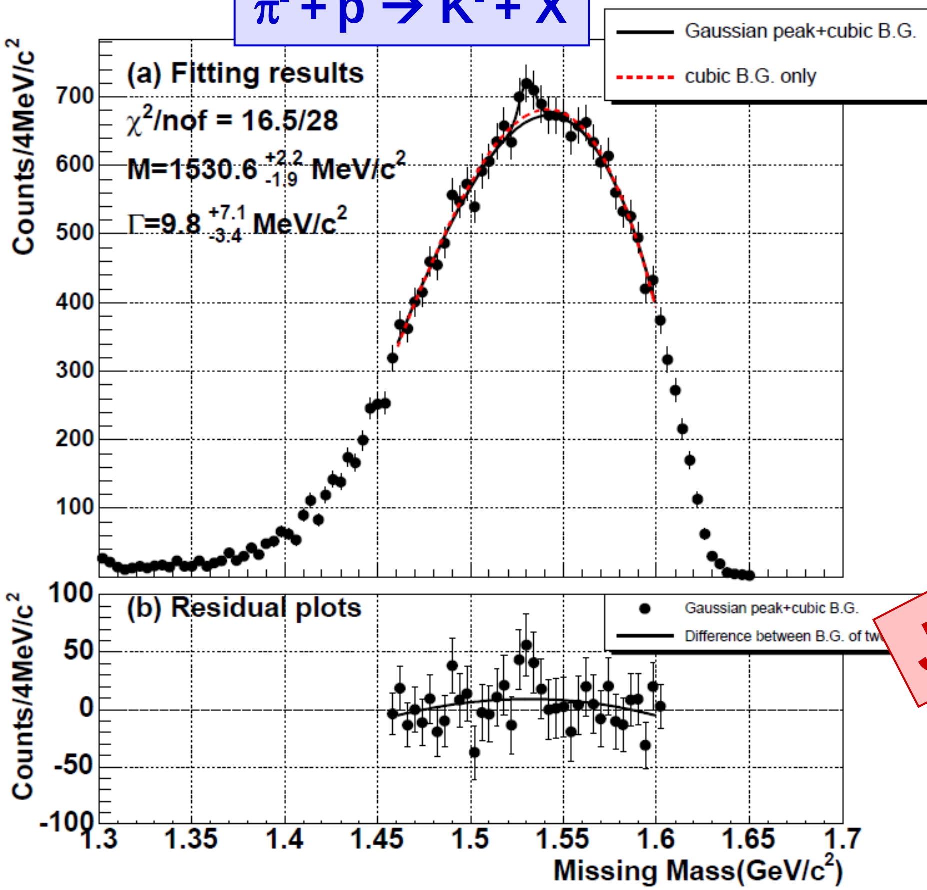
E19 (Naruki et al.)

Search for Pentaquark Θ^+ in $\pi^- p \rightarrow K^- X$ reaction

Physics Motivation



$\pi^- + p \rightarrow K^- + X$



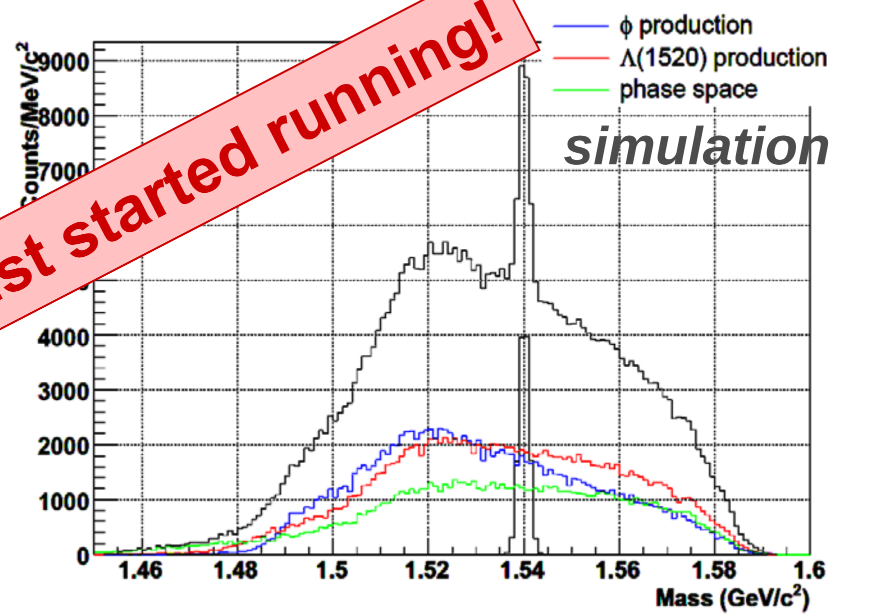
K. Miwa et al., Phys.Lett. B635 (2006) 72.

J-PARC E19

- Hadronic "direct reaction"

  $\pi^- + p \rightarrow K^- + X$
- Previous (π^-,K^-) missing mass spectrum shows a hint of 2.6σ.
- We can determine the width of Θ^+ with SKS spectrometer (Δm=2 MeV)

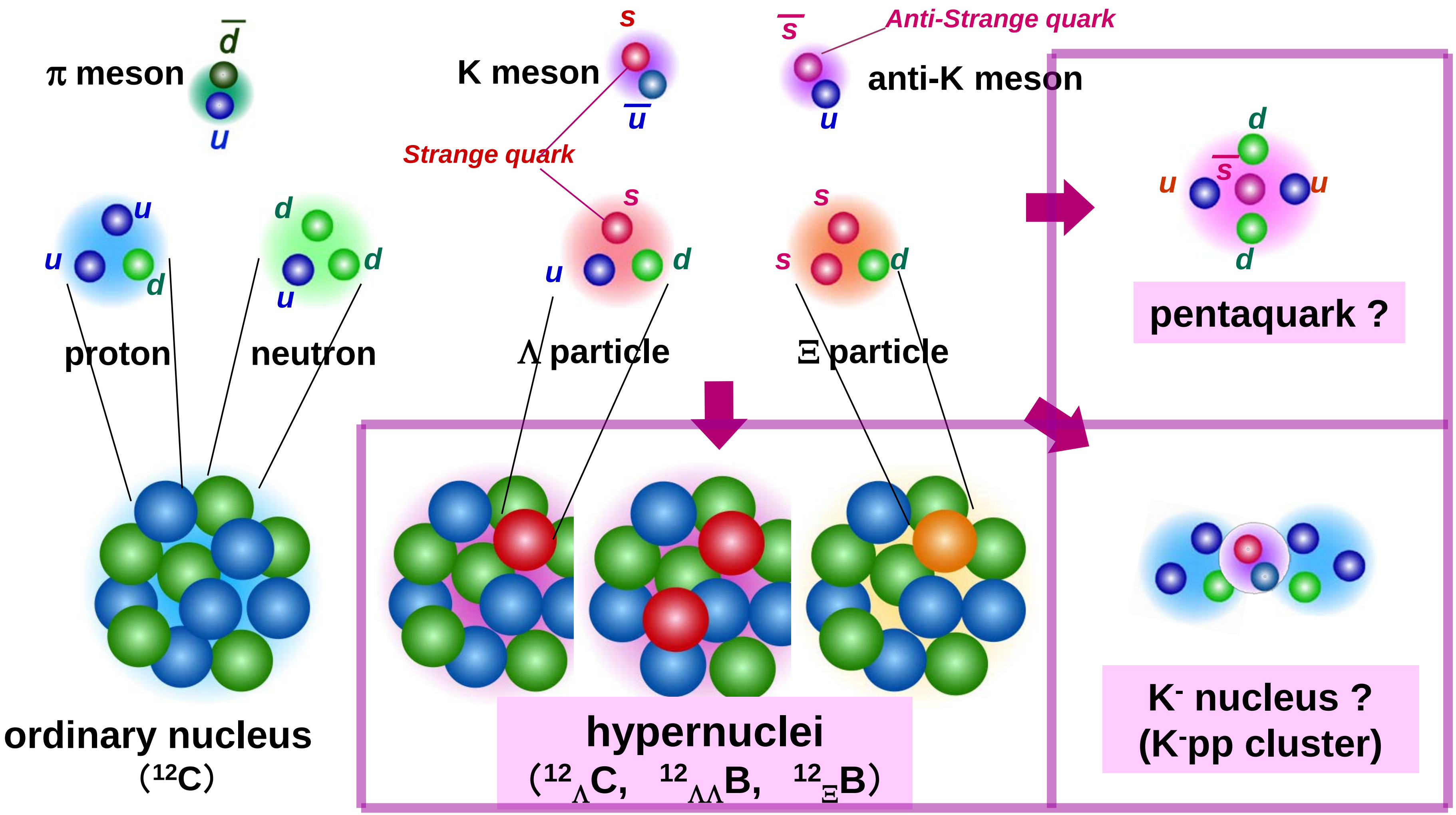
Just started running!



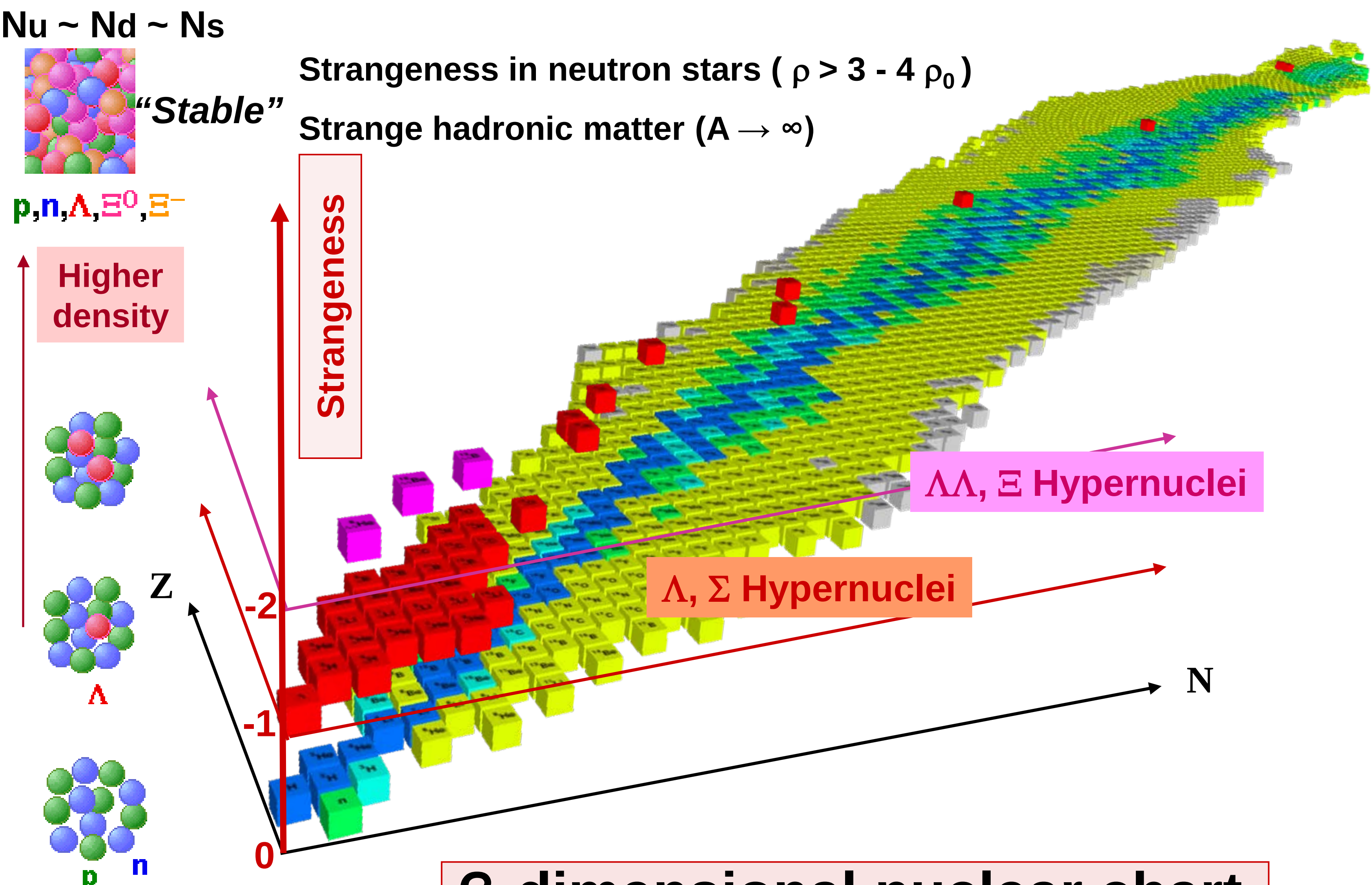
2. YN and YY interactions (Hypernuclei)

γ spectroscopy of Λ hypernuclei, $\Lambda\Lambda$ hypernuclei, Ξ hypernuclei

Objects of nuclear physics at J-PARC
(Strangeness Nuclear Physics)



World of matter made of u, d, s quarks



3-dimensional nuclear chart

by M. Kaneta inspired by HYP06 conference poster

Hyperon mixing in neutron star core

Nucleons only -> EOS too stiff -> Mass of neutron stars much larger than observed.

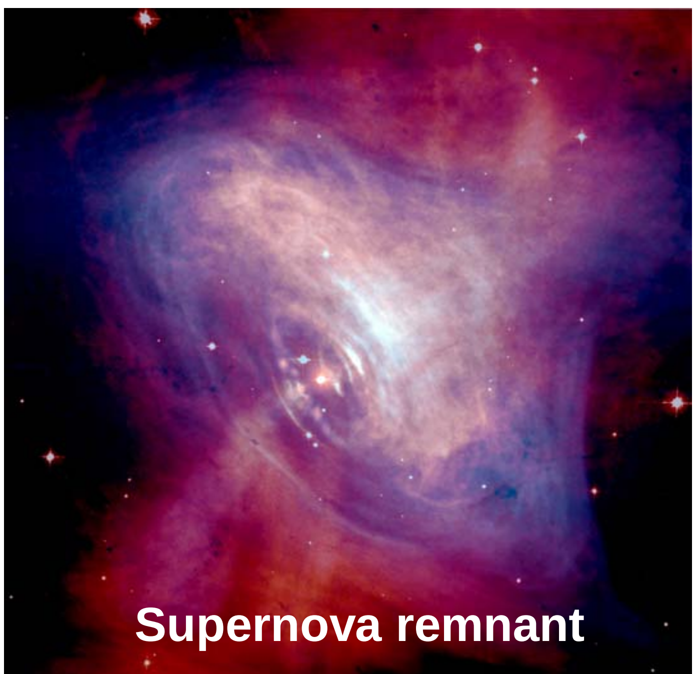
A new degree of freedom necessary – most probably strangeness (hyperons)

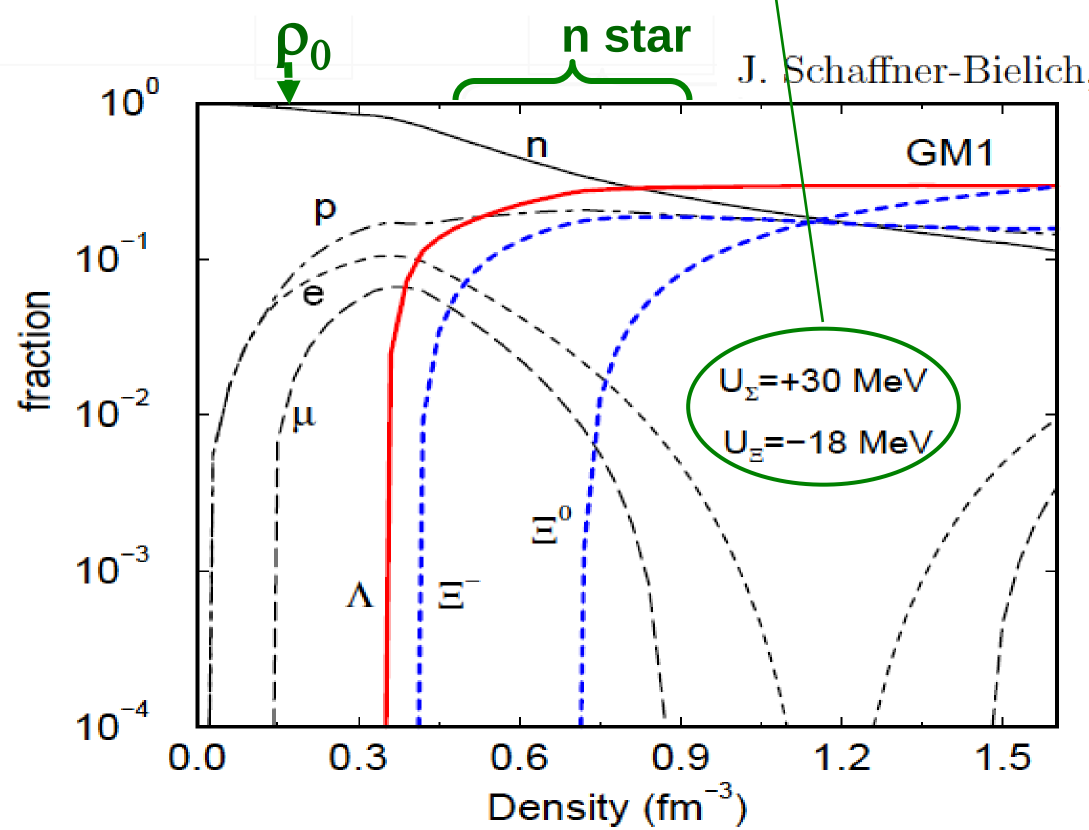
Baryon fraction: very sensitive to YN, YY interactions

-> maximum mass, cooling speed

Hypernuclear data -> realistic calculations possible

One probable assumption but should be determined by exp.





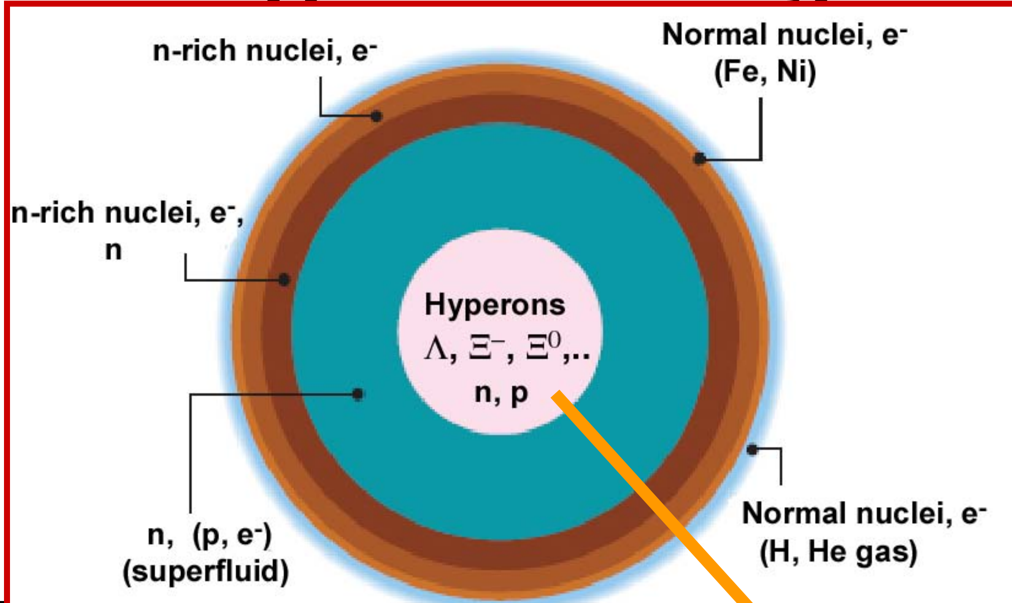
Hyperon mixing in neutron star core

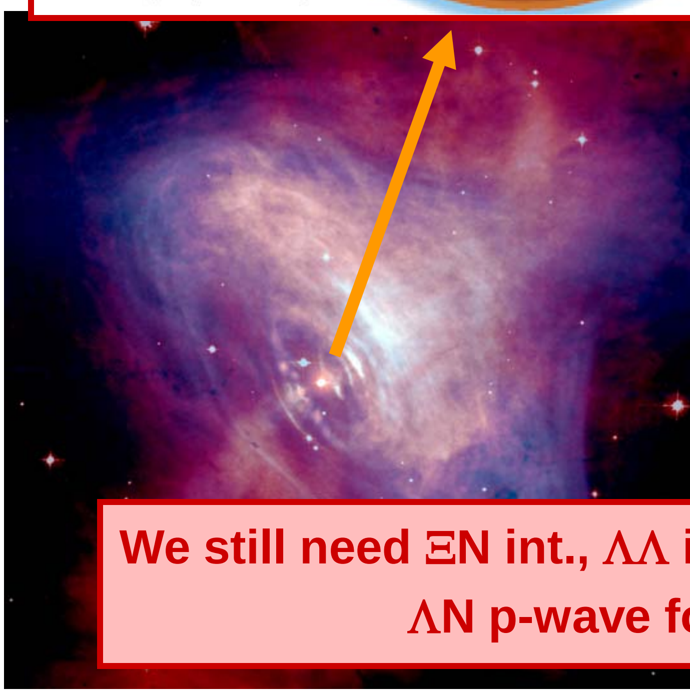
on stars much larger than observed.

ost probably strangeness (hyperons)

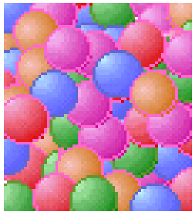
ctions

ossible



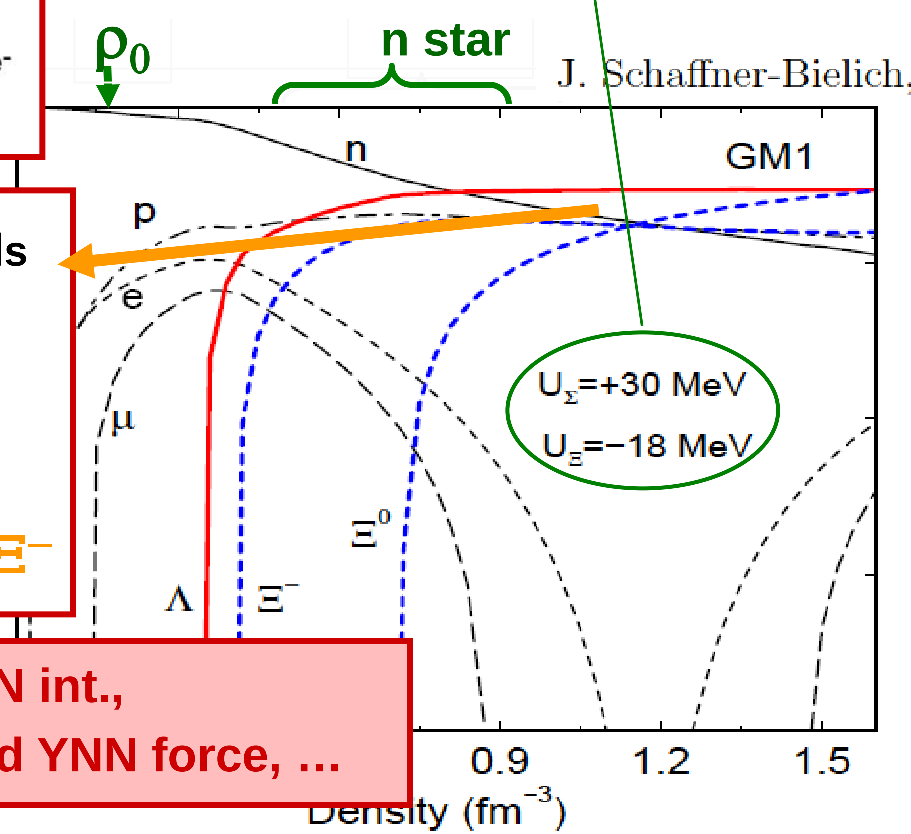


Nu ~ Nd ~ Ns



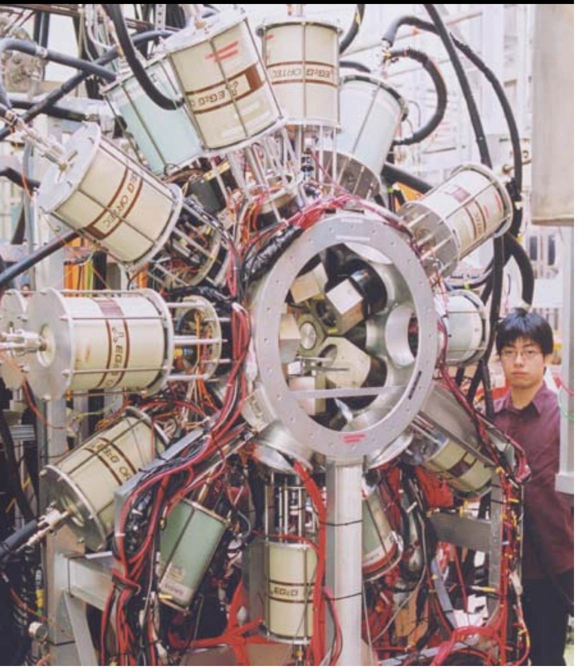
p,n,Λ,Ξ^0,Ξ^-

One probable assumption but should be determined by exp.

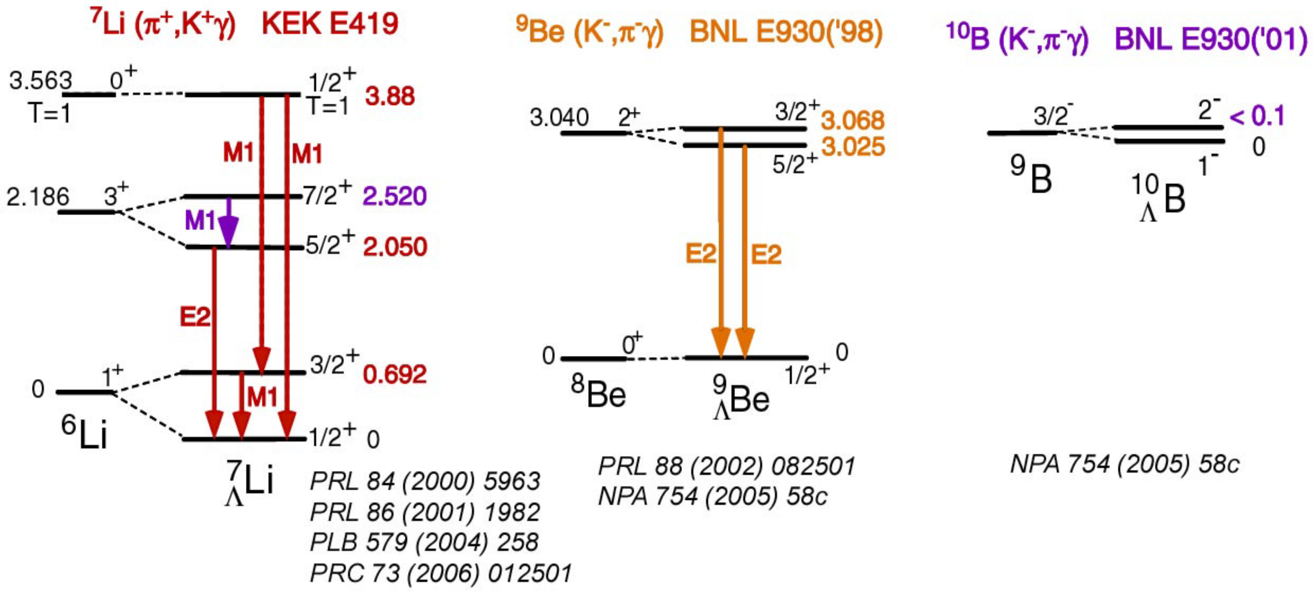


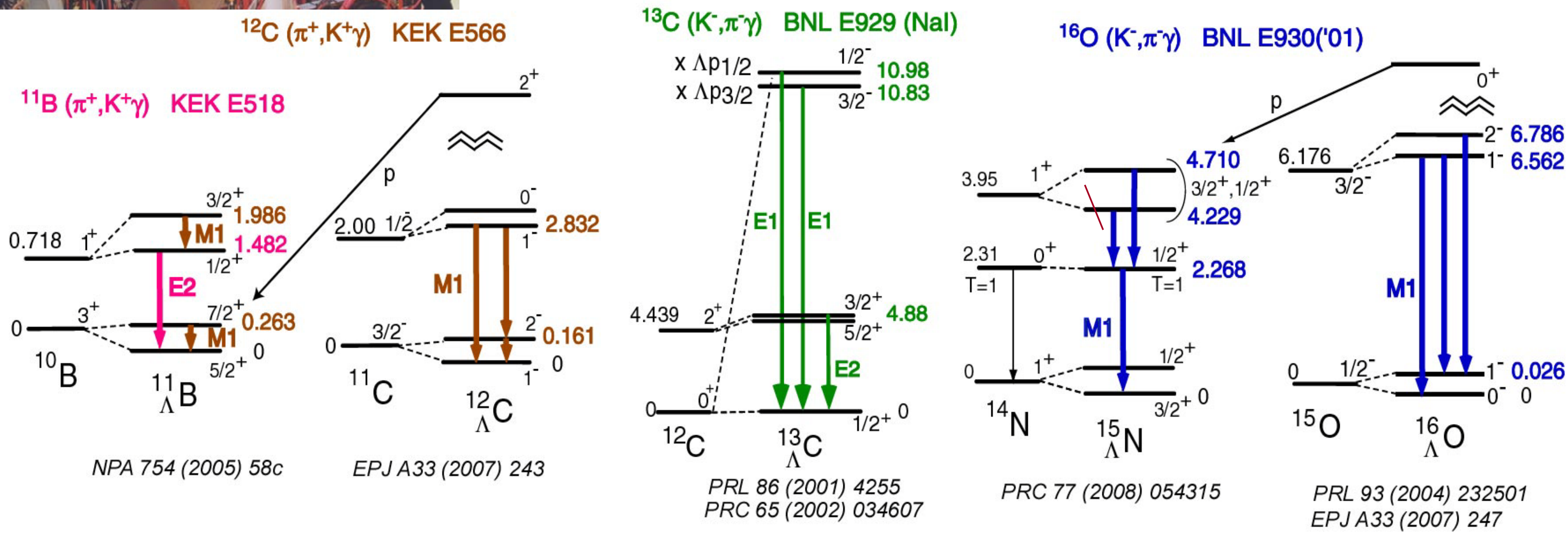
We still need ΞN int., ΛΛ int., ΣN int., KN int., ΛN p-wave force, NNN and YNN force, …

Hyperball



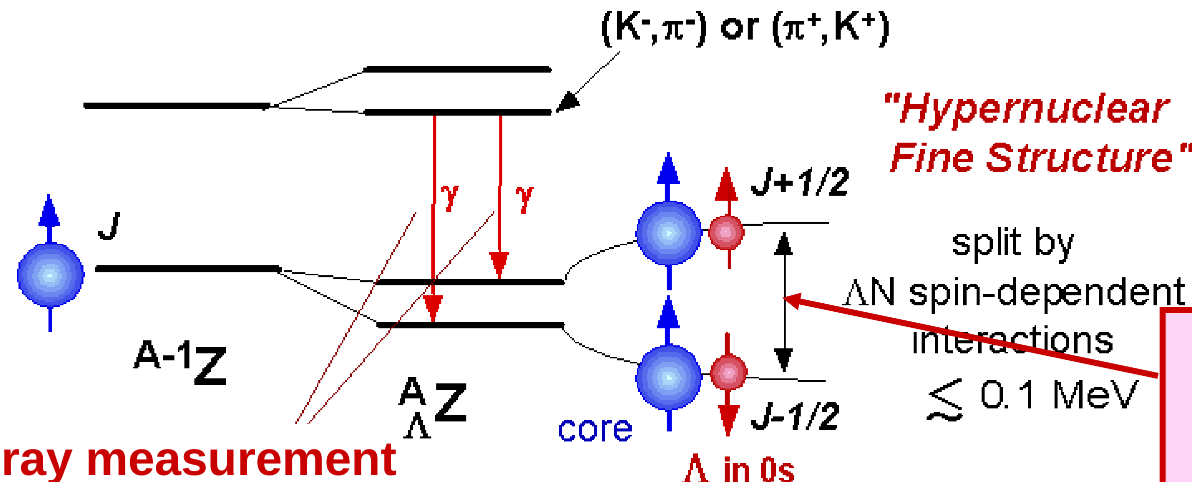
Hypernuclear γ-ray data





ΛN spin-dependent interactions

- **Low-lying levels of Λ hypernuclei**



γ-ray measurement
(ΔE~2 keV) is the only method

Level spacing:
Linear combination of *Δ*, *S*$_Λ$, *S*$_N$, *T*

- **Two-body ΛN effective interaction**

Dalitz and Gal, Ann. Phys. 116 (1978) 167
Millener et al., Phys. Rev. C31 (1985) 499

$$V_{\Lambda N}^{eff} = V_0(r) + V_\sigma(r)\,\vec{s}_\Lambda \vec{s}_N + V_\Lambda(r)\,\vec{l}_{\Lambda N}\vec{s}_\Lambda + V_N(r)\,\vec{l}_{\Lambda N}\vec{s}_N + V_T(r)\,S_{12}$$

$\bar{V}$ — Δ — S_Λ — S_N — T

Well known from U_Λ = - 30 MeV

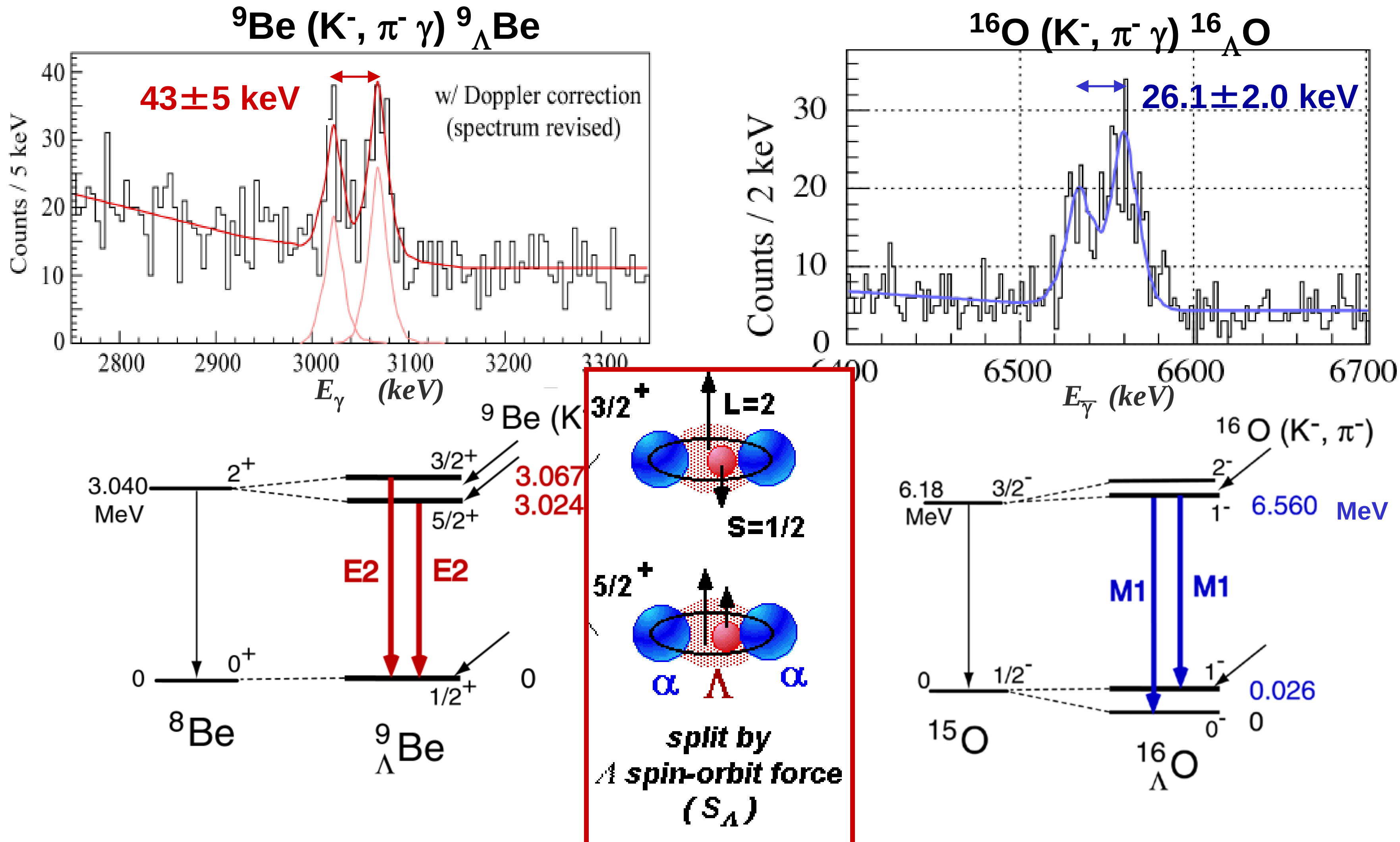
p-shell: 5 radial integrals for $s_\Lambda p_N$ w.f.

$$\Delta = \int V_\sigma(r)\,|u(r)|^2\, r^2 dr, \quad \mathbf{r} = \mathbf{r}_{s_\Lambda} - \mathbf{r}_{p_N}$$

can be determined form γ-ray data

Observation of Hypernuclear Fine Structure

BNL E930 (AGS D6 line + Hyperball)



Akikawa et al., PRL 88 (2002) 082501
Tamura et al., NPA 754 (2005) 58c

Ukai et al., PRL 93 (2004) 232501

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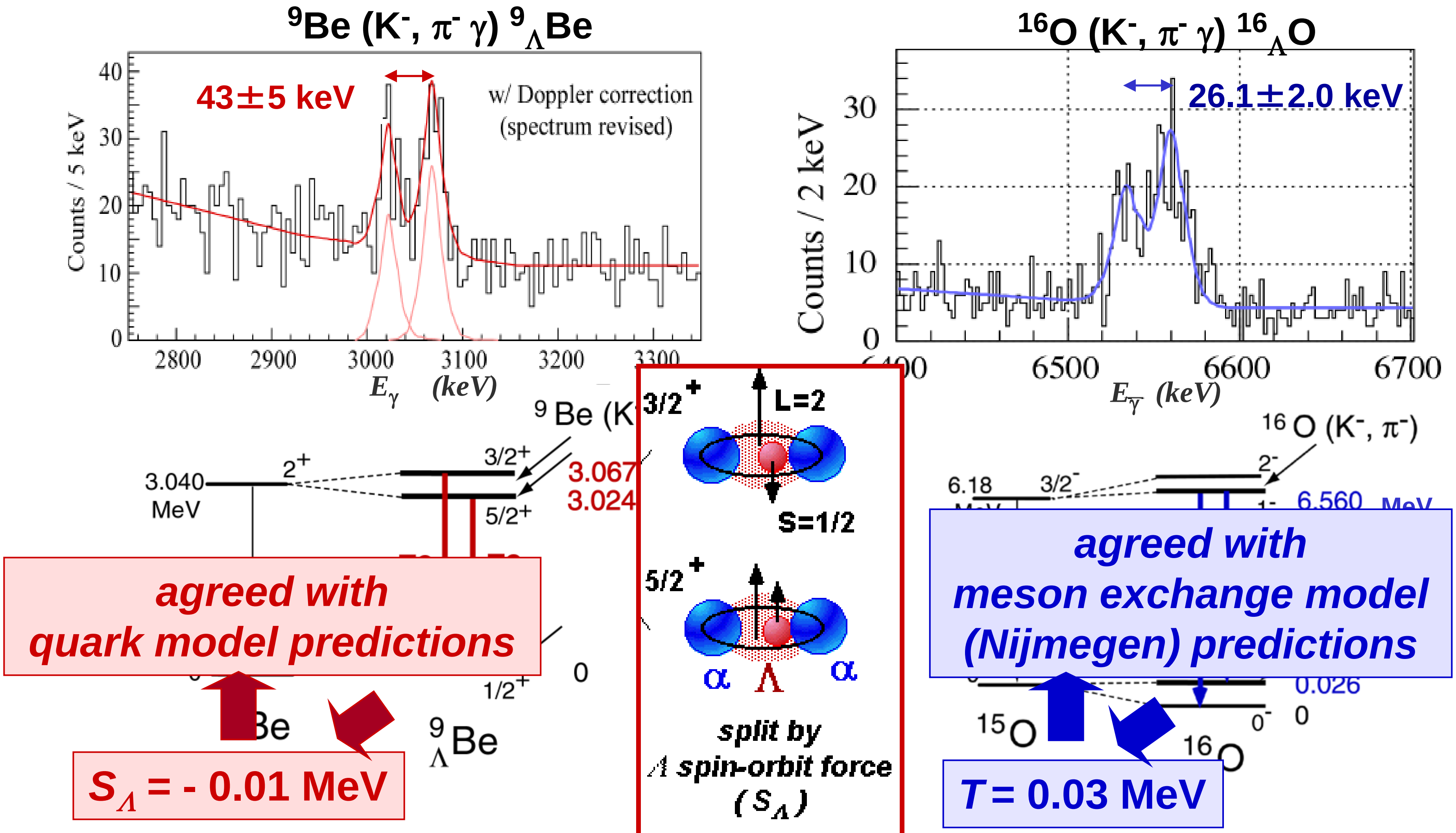

Akikawa et al., PRL 88 (2002) 082501
Tamura et al., NPA 754 (2005) 58c

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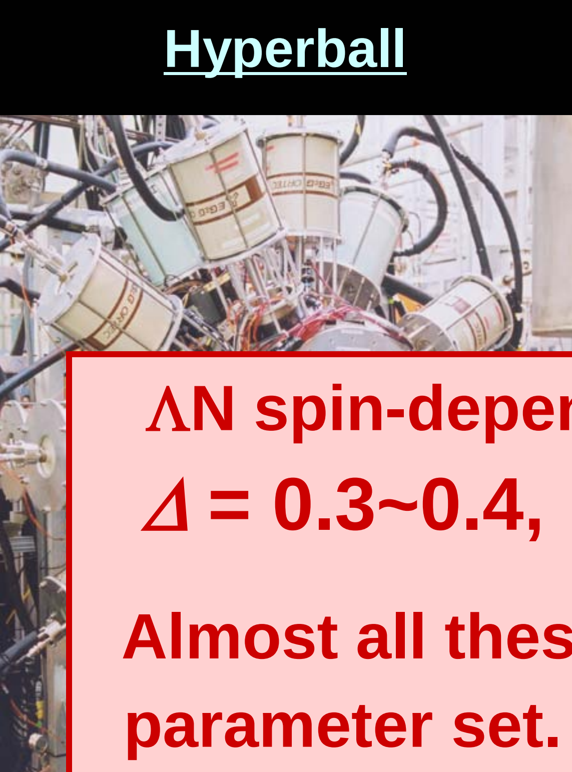
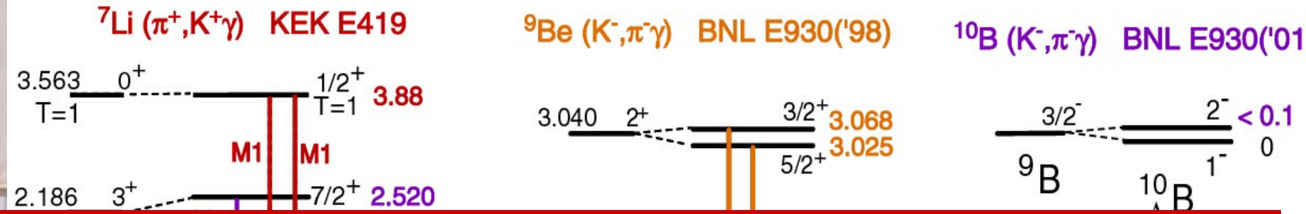


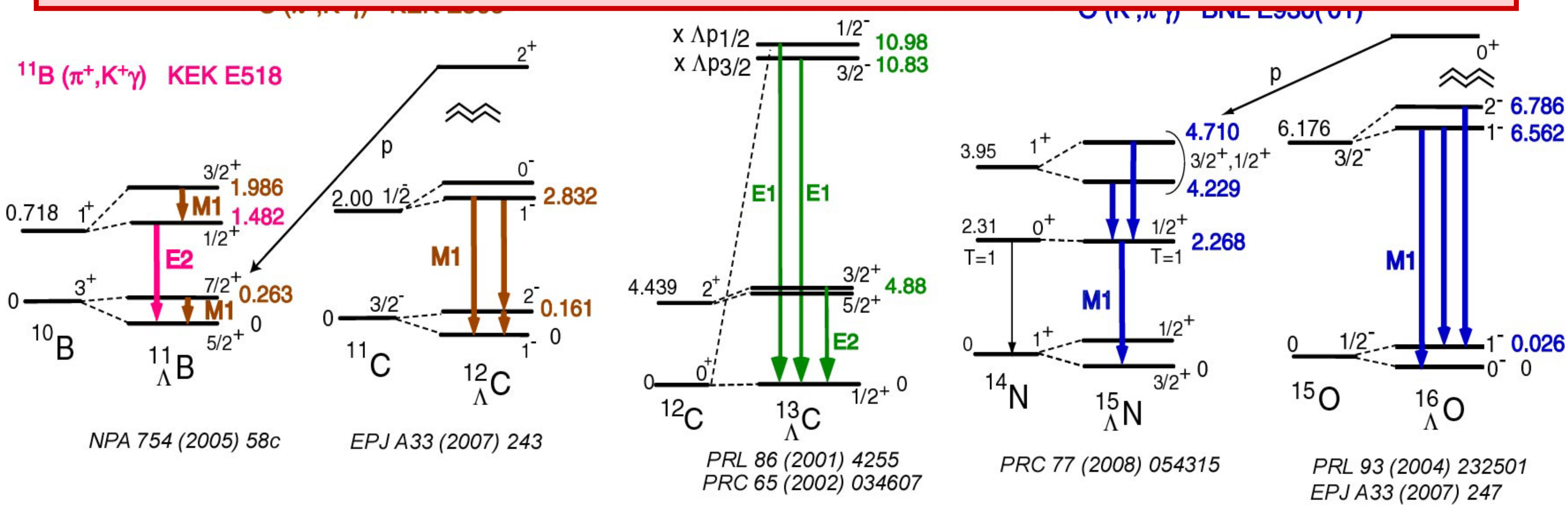
Hypernuclear γ-ray data



ΛN spin-dependent interaction strengths determined:

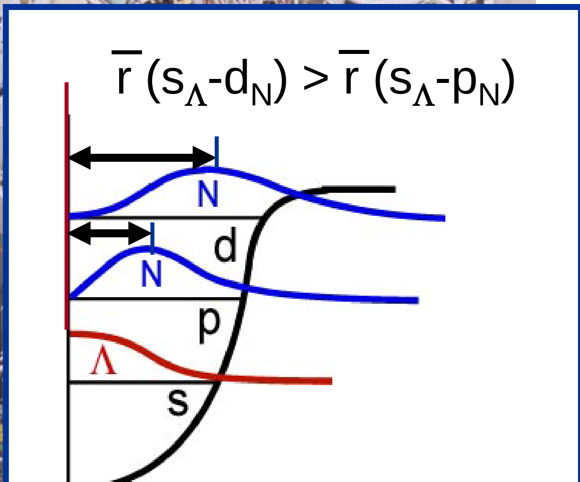
Δ = 0.3~0.4, S_Λ = -0.01, S_N = -0.4, T =0.03 MeV

Almost all these p-shell levels are reproduced by this parameter set. (D.J. Millener)

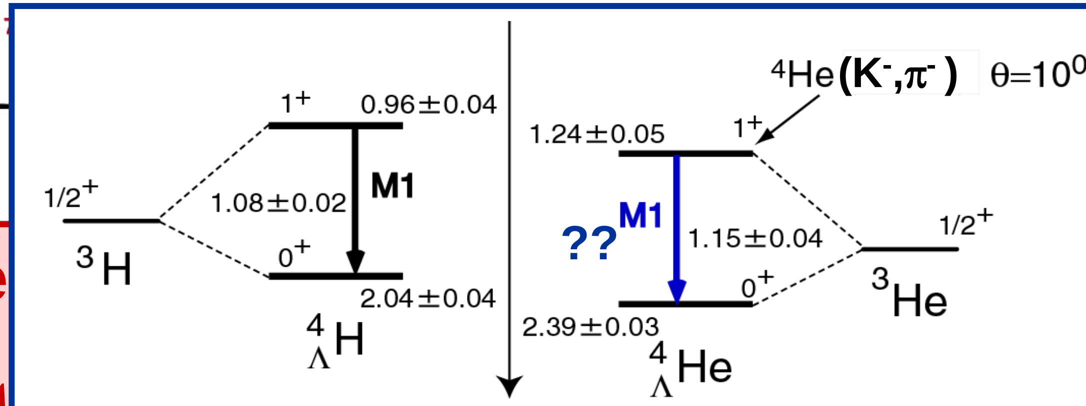


Hypernuclear γ-ray data

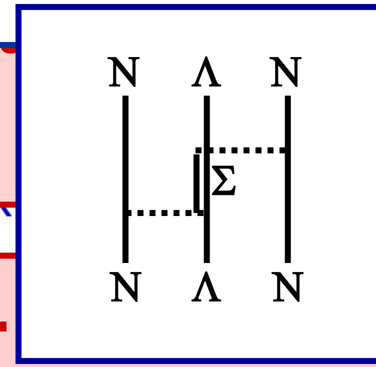
Hyperball



sensitive to interaction range
and exchanging meson mass



Very large CSB !?
Not theoretically understood.



p-shell levels are reprod... (D.J. Millener)

Further: ΛN-ΣN and ΛNN force: $^{10}{}_\Lambda B$, $^{11}{}_\Lambda B$,..

r-dependence via sd-shell hypernuclei: $^{19}{}_\Lambda F$

Charge symmetry breaking (Λp ≠ Λn?): $^{4}{}_\Lambda He$ …

J-PARC E13 (Tamura et al.)

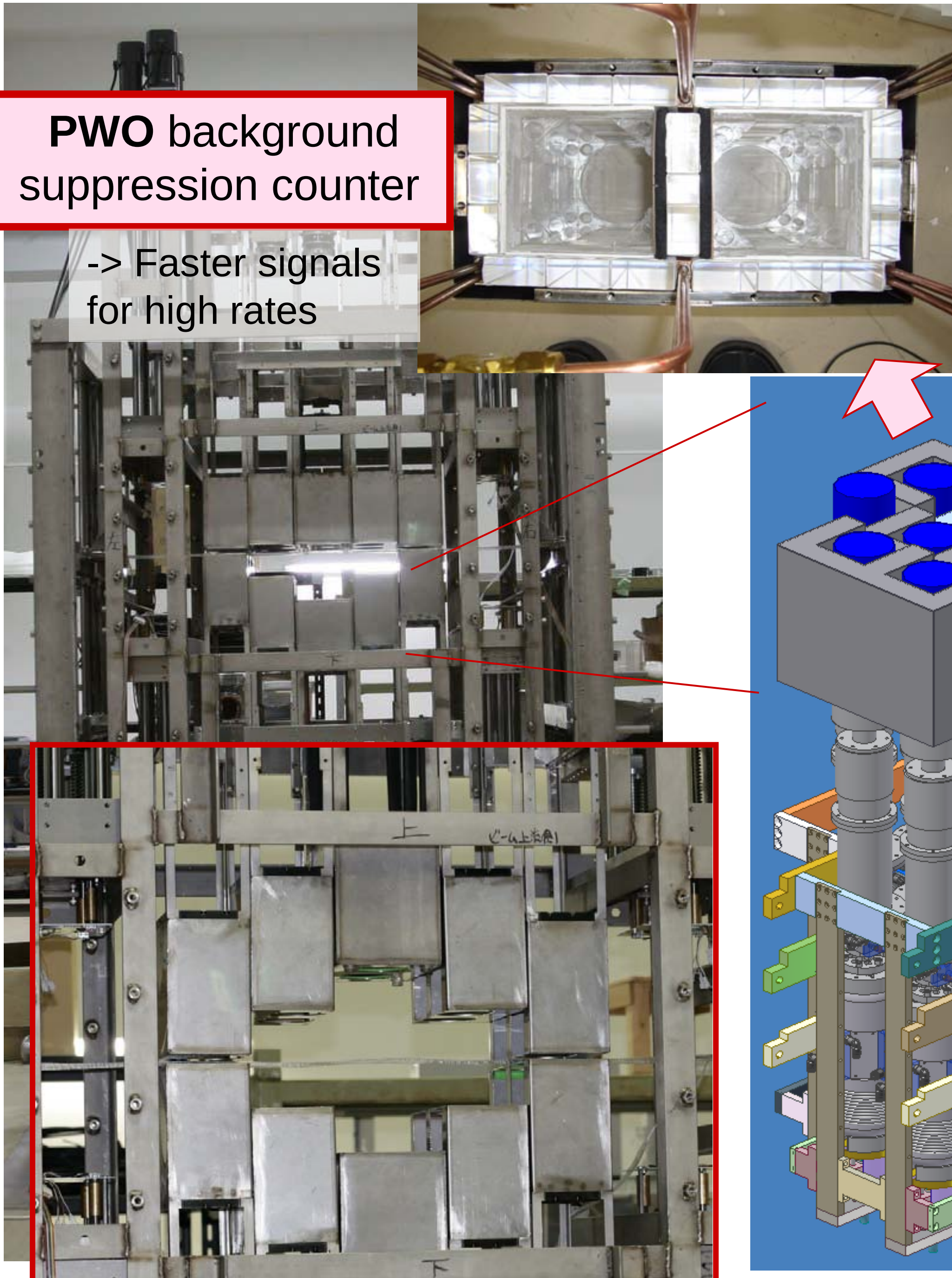
=> 10~100 times faster data collection -> Table of Hyper Isotopes

Hyperball-J

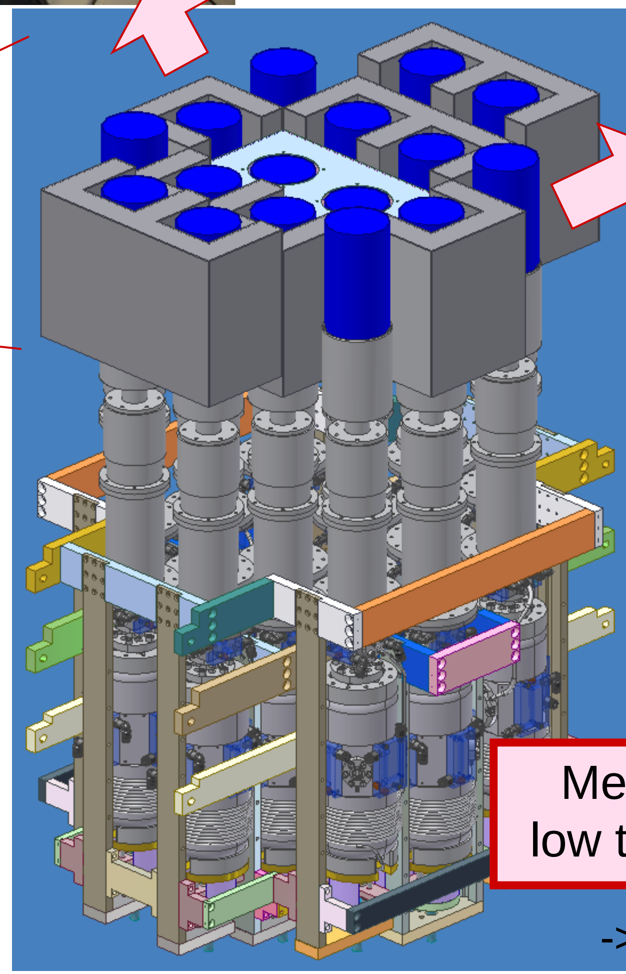
New generation Ge array

PWO background suppression counter

-> Faster signals for high rates



Lower half



Mechanically-cooled low temp. **Ge detector**

-> Suppress effects from radiation damage

J-PARC E05 (Nagae et al.)

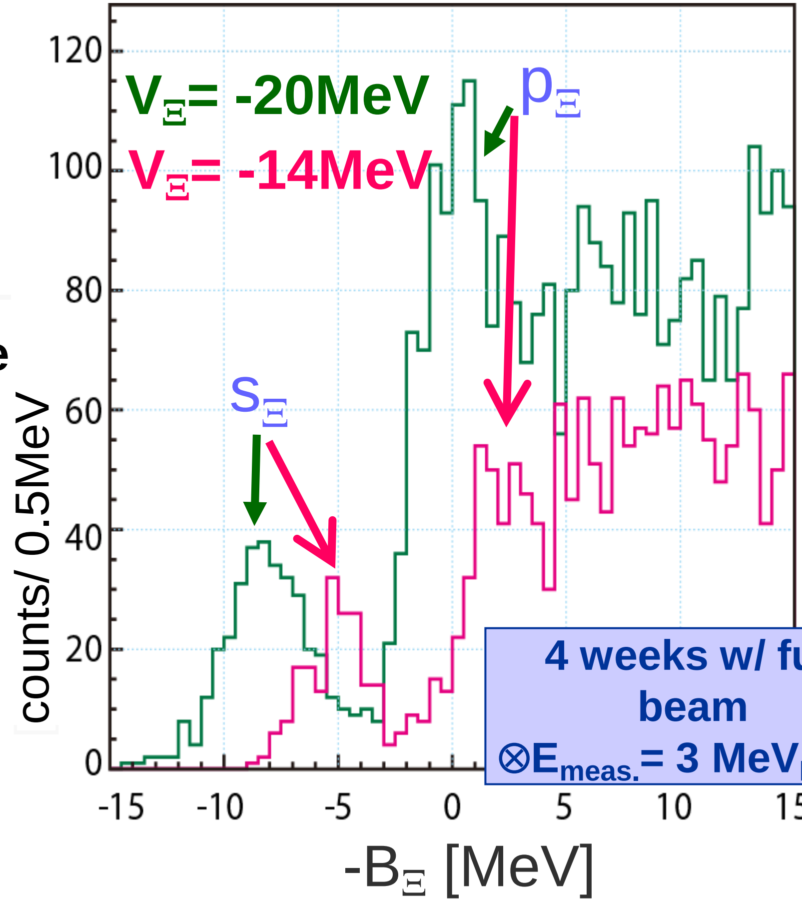
$K^- p \rightarrow \Xi^- K^+$

Ξ-hypernuclear spectroscopy by (K^-, K^+)

- **First spectroscopic study of S=-2 systems in (K^-, K^+) reaction**
  - First step to multi-strangeness baryon systems

- **Properties of ΞN Interaction**
  - Attractive or repulsive? How large
    <- Ξ-nuclear potential depth
  - Isospin dependence ?
    <- Different targets
  - ΞN-ΛΛ coupling force ?
    <- Ξp→ΛΛ conversion width
    <- Ξ and ΛΛ hypernuclear mixing

Expected $^{12}C\ (K^-, K^+)\ ^{12}_{\Xi}Be$ Spectrum

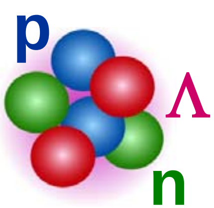


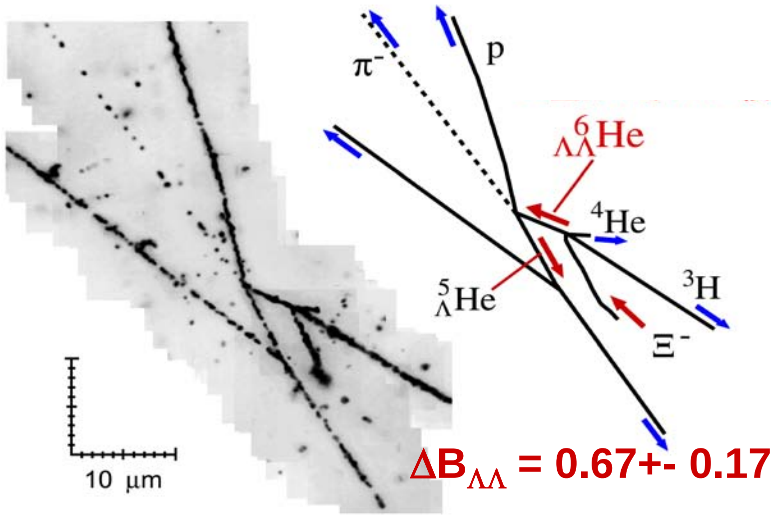
4 weeks w/ full beam
$\otimes E_{meas.}$ = 3 MeV$_{FWHM}$

J-PARC E07 (Nakazawa, Imai, Tamura et al.)
S=-2 Systems with Emulsion-Counter Hybrid Method

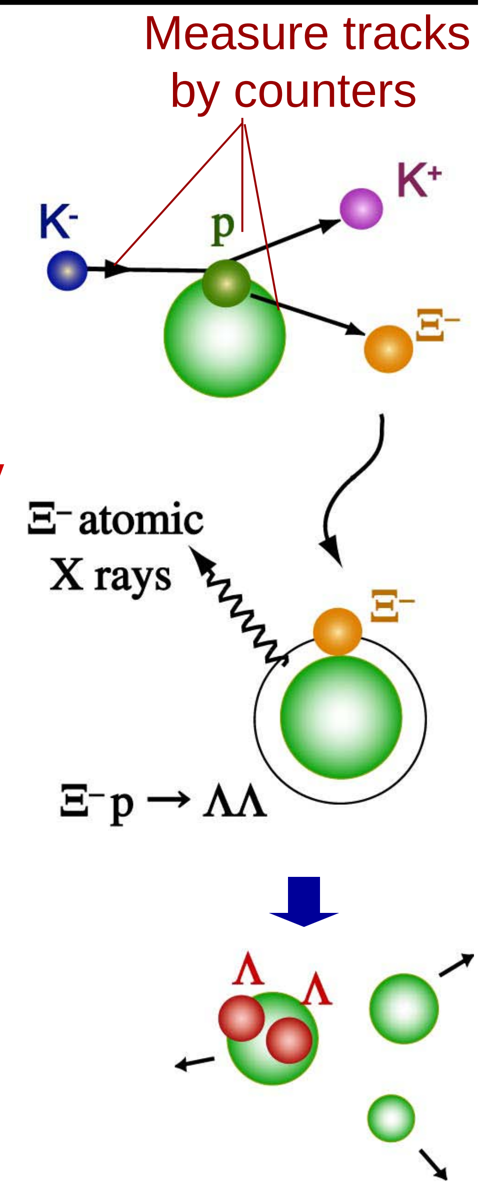
Nagara event

PRL 87 (2001) 212502





$\Delta B_{\Lambda\Lambda}$ = 0.67+- 0.17 MeV



- **Ten times more events of ΛΛ hypernuclei**
  $>10^4$ stopped Ξ^-, $\sim10^2$ ΛΛ hypernuclei
  - Details of ΛΛ interaction strength
  - Λ–Λ correlation (H dibaryon-like state) in nucleus from “ΛΛ” -> Σ^-p decay
- **Measure Ξ^- -atomic X-rays with Hyperball-J**
  - Shift and width of X-rays -> Ξ-nuclear potential
  - Stopped Ξ^- events identified from emulsion

3. Hadrons in Nuclei

Magnetic moment of Λ in a nucleus

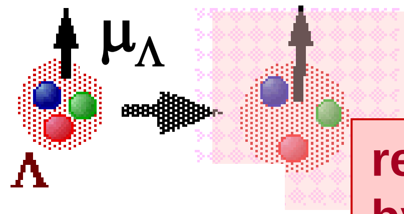
$\bar{K}$-Nucleus bound states

(Vector meson mass in nuclei)

J-PARC E13 (Tamura et al.)
Baryon's magnetic moment in a nucleus using gamma-ray spectroscopy technique

How the magnetic moment of baryons changes in a nucleus?

…can be measured using a Λ



$$\mu_q = \frac{e\hbar}{2m_q c}$$

m_q : Const. quark mass

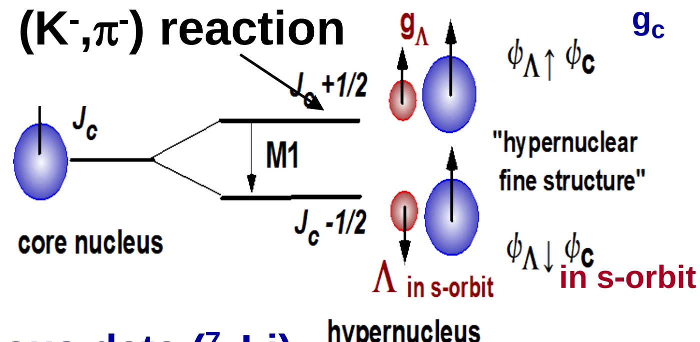
reduction of mass by chiral symm. restoration -> enhancement of μ??

Direct measurement of μ : extremely difficult

-> B(M1) gives g_Λ value

$$B(M1) = (2J_{up}+1)^{-1} \left| \langle \Psi_{low} \| \mu \| \Psi_{up} \rangle \right|^2 = \frac{3}{8\pi}\frac{2J_{low}+1}{2J_c+1}(g_\Lambda - g_c)^2 \quad [\mu_N^2]$$

(K⁻,π⁻) reaction



Lifetime of $^7_\Lambda$Li(3/2⁺)

via Doppler shift attenuation method

-> Transition rate (accuracy ~5%)

-> g_Λ

Previous data ($^7_\Lambda$Li)

- $g_\Lambda = 1.1^{+0.4}_{-0.6}\ \mu_N$

⬌ - g_Λ(free) = 1.226 μ_N

$\overline{K}$-Nuclear Bound Systems

- **Suggestions:**

Strongly attractive $\overline{K}$-Nuclear potential (← K^- atomic and scattering data)

Freedmann-Gal

Λ(1405) as a $\overline{K}$-N bound state

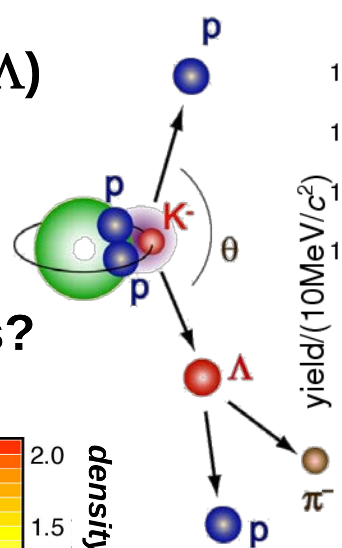
-> Suggests an extremely deep state (BE ~ 110 MeV for K^-ppn)

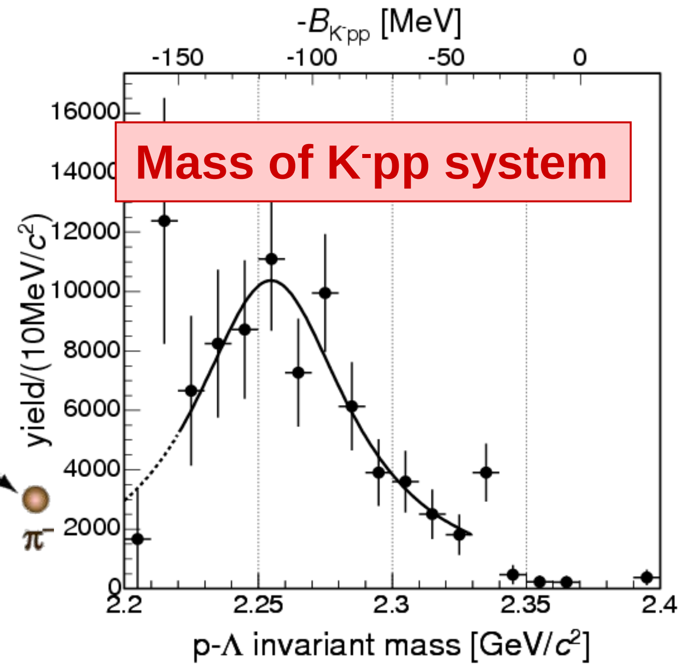
Akaishi-Yamazaki **c.f. m_K = 494 MeV**

- **Experimental Hints:**

FUNIDA@DAFNE, stopped K^-, $m(p\Lambda)$

KEK, $^{16}O(K^-, n)$ reaction @ 1 GeV/c



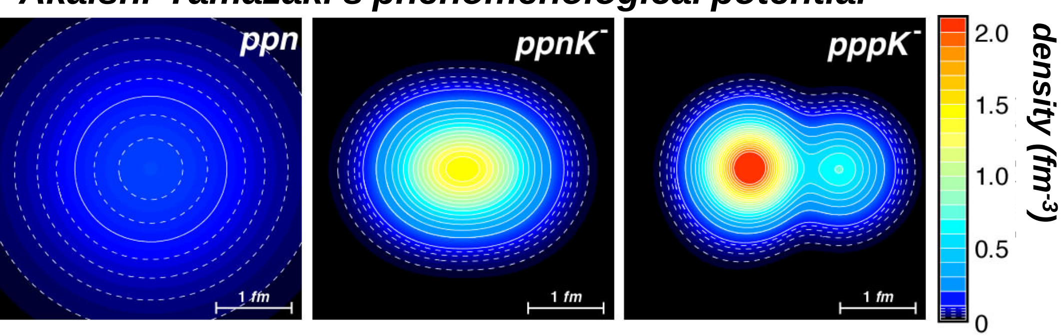


M. Agnello et al., PRL 94 (2005) 212303.

How deep? Width? Density?

Kaon condensation in neutron stars?

Akaishi-Yamazaki's phenomenological potential



A. Dote et al. : PLB590 (2004) 51, etc.

$\rho > \rho_0$ x10

Neutron/quark star on the earth ??

Present Status – exciting but puzzling

- **Under a big debate by theorists**

  Deep (150~200 MeV, phem. models) or shallow (~50 MeV chiral model)?

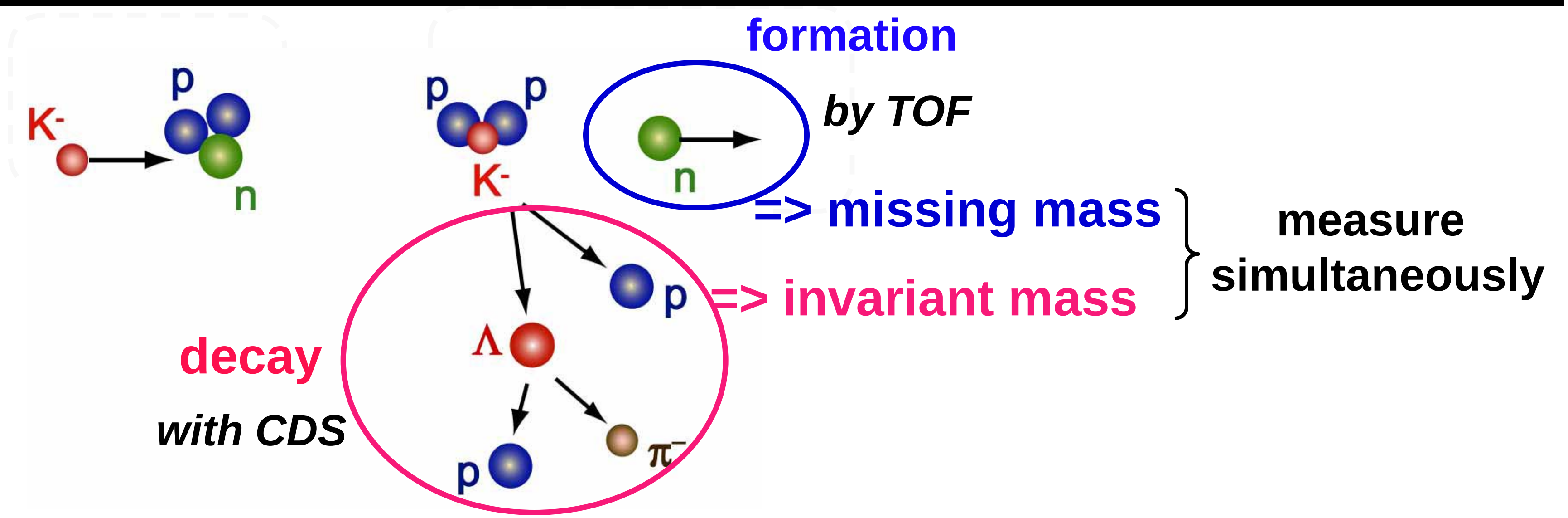
  Two nucleon absorption?

- **More experimental data**
  - E471 @KEK $^4He(K^-_{stop},n)$ [K^-ppn]
  - FOPI @GSI Ni+Ni
  - OBELIX K^-_{stop} on ^4He, Li
  - DISTO p p -> K^+ [ppK^-]

  Seem to be inconsistent with each other

=> Decisive experiments strongly required

J-PARC E15 (Iwasaki, Nagae et al.) Kaonic Nuclei via $^3He(K^-,n)$



Summary

approved / proposed (incl. LOI)

PARC

Strang

S=-2 systems
quite unique at J-PARC

γ spectroscopy of Λ hypernuclei

n-rich Λ hypernuc

Ξ hypernuclei

$\Lambda\Lambda$ hypernuclei

Ξ-atomic X rays

YN,YY interactions

Θ^+ search

Weak decays

Exotic hadrons

Pion double charge exchange

ω nucleus

Hadron mass in nuclei

ucleon quark structure

Hadrons in nuclei

K^- nucleus bound states

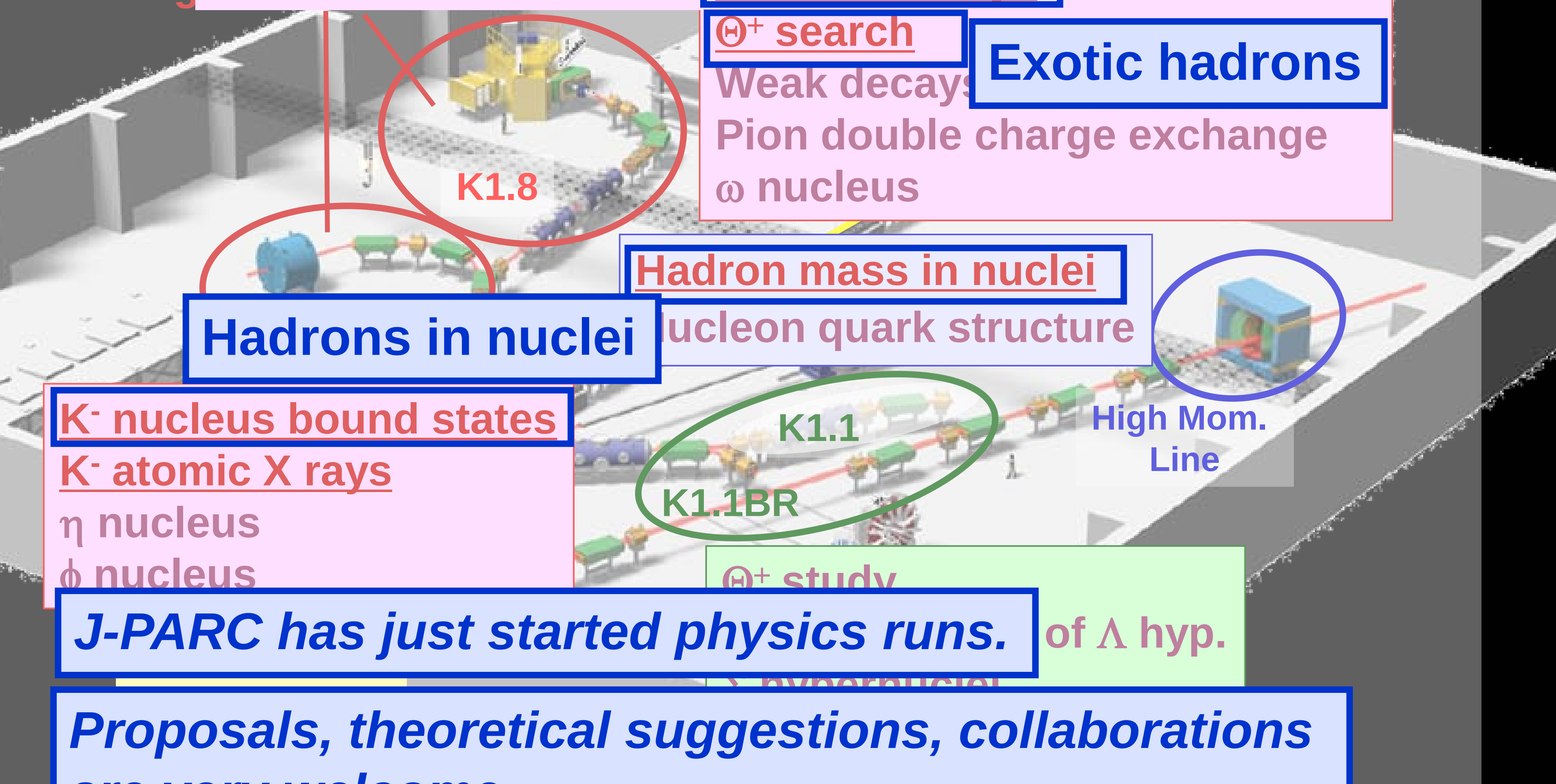
K^- atomic X rays

η nucleus

ϕ nucleus

Θ^+ study

of Λ hyp.



J-PARC has just started physics runs.

Proposals, theoretical suggestions, collaborations are very welcome.