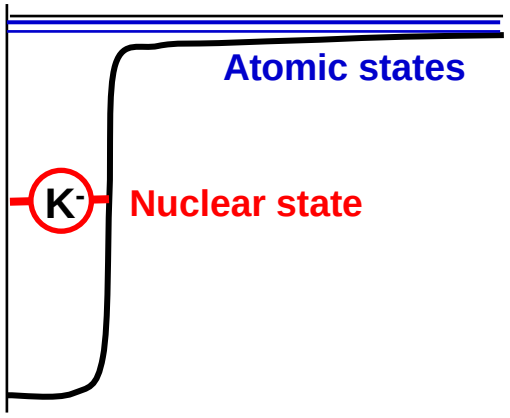
KEK05
Dec. 2, 2005

STRANGE TRIBARYONS
- Theory -

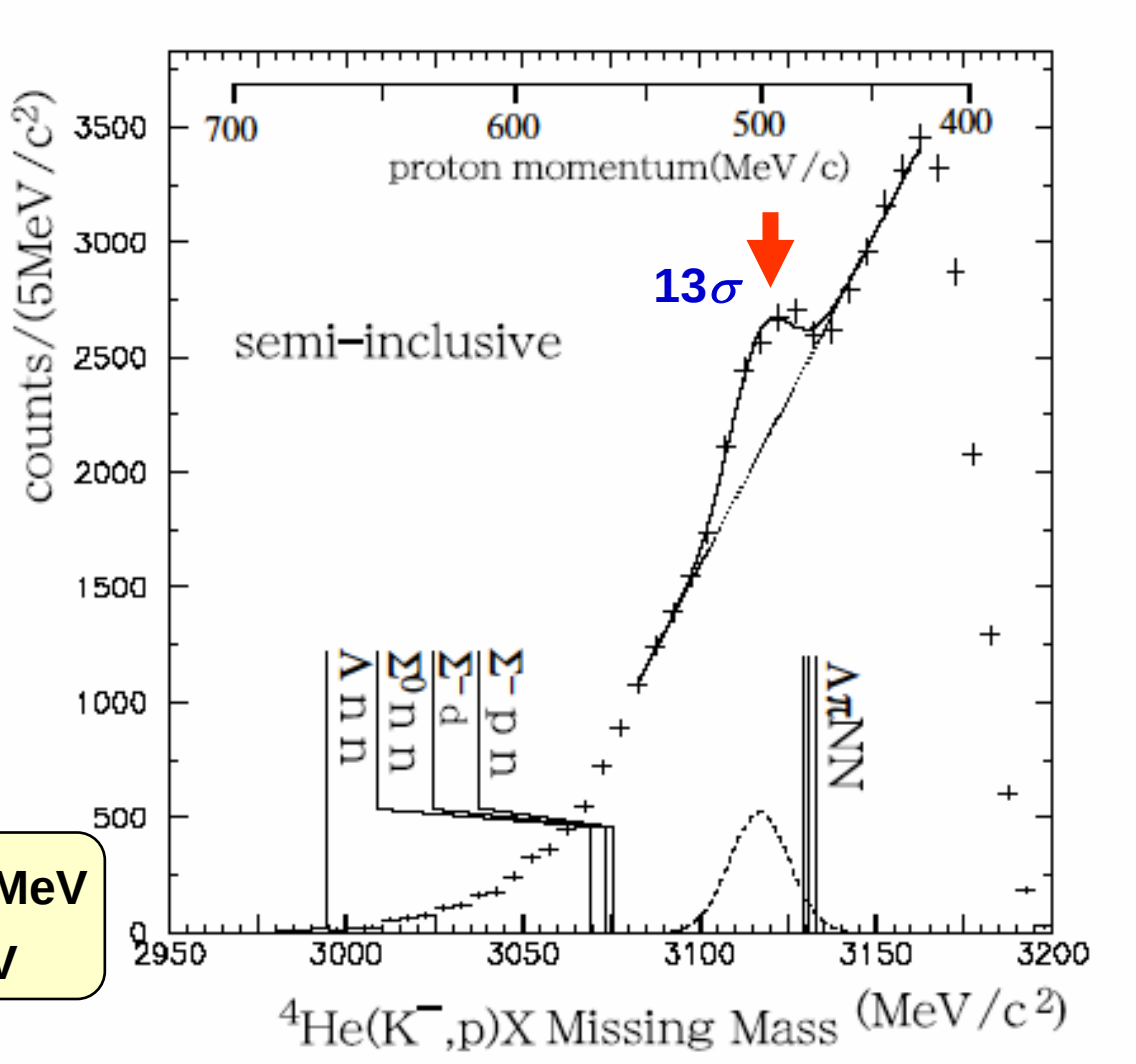


Y. Akaishi, A. Dote, T. Yamazaki

Discovery of $S^0(3115)$

in ^{4}He(stopped K^-,p)K^-pnn

Phys. Lett. B597 (2004) 263

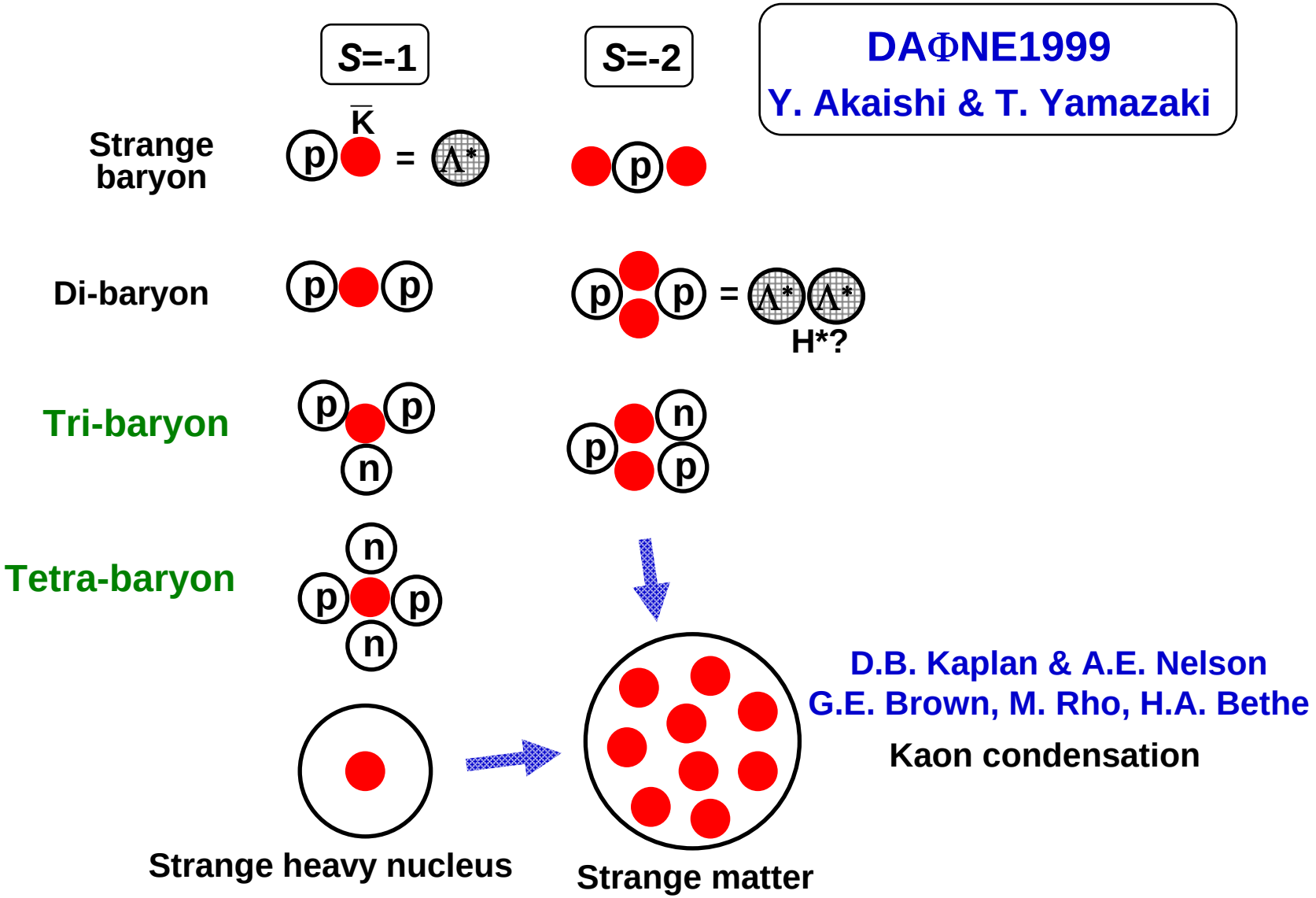


$E = -193^{+1.5}_{-4.4}$ MeV

$\Gamma \leq 21$ MeV

T. Suzuki
H. Bhang
G. Franklin
K. Gomikawa
R.S. Hayano
T. Hayashi
K. Ishikawa
S. Ishimoto
K. Itahashi
M. Iwasaki
T. Katayama
Y. Kondo
Y. Matsuda
T. Nakamura
S. Okada
H. Outa
B. Quinn
M. Sato
M. Shindo
H. So
P. Strasser
T. Sugimoto
K. Suzuki
S. Suzuki
D. Tomono
A.M. Vinodkumar
E. Widmann
T. Yamazaki
T. Yoneyama

Few-Body $\bar{K}N$ Systems



$\bar{K}N$ interaction

$$V^T_{\bar{K}N}(r) = V^T_D \exp(-(r/0.66)^2)$$

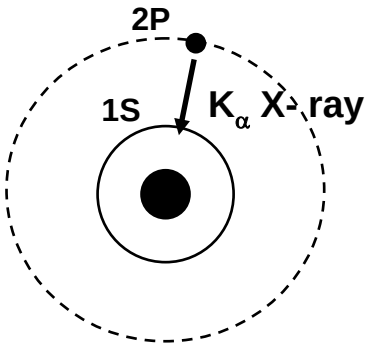
$$V^T_{\bar{K}N,\pi\Sigma}(r) = V^T_{C_1} \exp(-(r/0.66)^2)$$

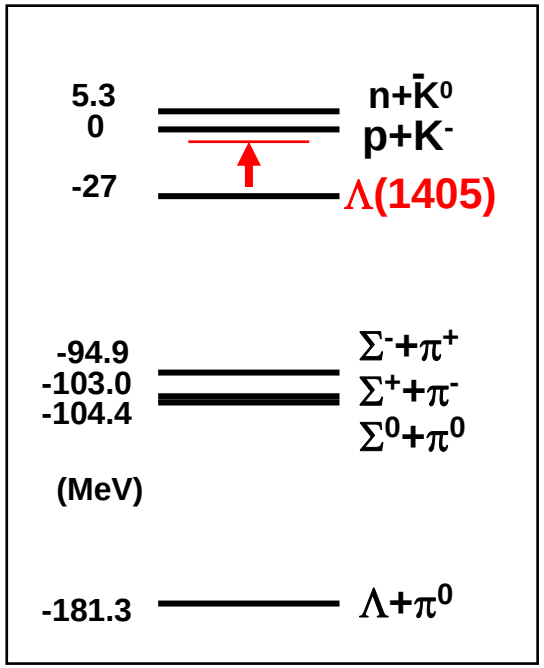
$$V^T_{\bar{K}N,\pi\Lambda}(r) = V^T_{C_2} \exp(-(r/0.66)^2)$$

$$V^T_{\pi\Sigma}(r) = V^T_{\pi\Lambda} = 0$$

$V_D^{T=0}$ = -436 MeV
$V_{C_1}^{T=0}$ = -412 MeV
$V_{C_2}^{T=0}$ = none

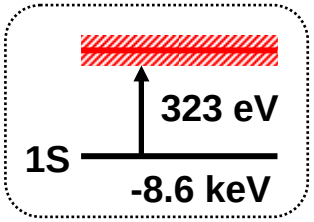
$V_D^{T=1}$ = -62 MeV
$V_{C_1}^{T=1}$ = -285 MeV
$V_{C_2}^{T=1}$ = -285 MeV





KpX Iwasaki et al. (1997)

$a_{K^-p} = (-0.78 \pm 0.15 \pm 0.03) + i(0.49 \pm 0.25 \pm 0.12)$ fm



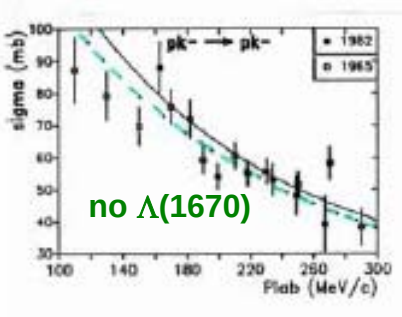
Phys. Rev. Lett. 78 (1997) 3067

$\bar{K}N$ scatt. Martin (1981)

$a^{T=0} = (-1.70 \pm 0.07) + i(0.68 \pm 0.04)$ fm

$a^{T=1} = 0.37 + i\,0.60$ fm

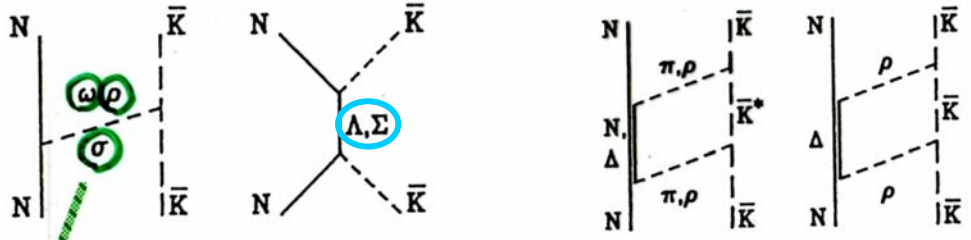
Jülich $\bar{K}N$ Quasi-potential



A. Müller-Groeling, K. Holinde & J. Speth, Nucl. Phys. **A513** (1990) 557.

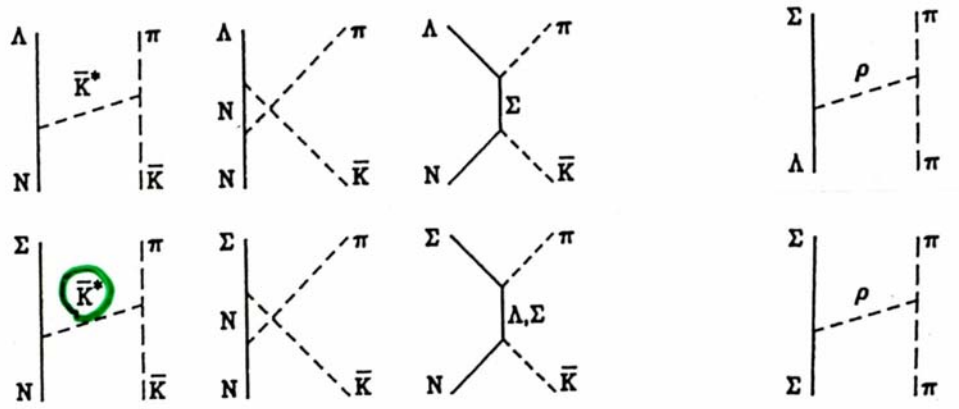
$p_{\bar{K}}^{\text{lab.}} = 60 \sim 300\ \text{MeV}/c$

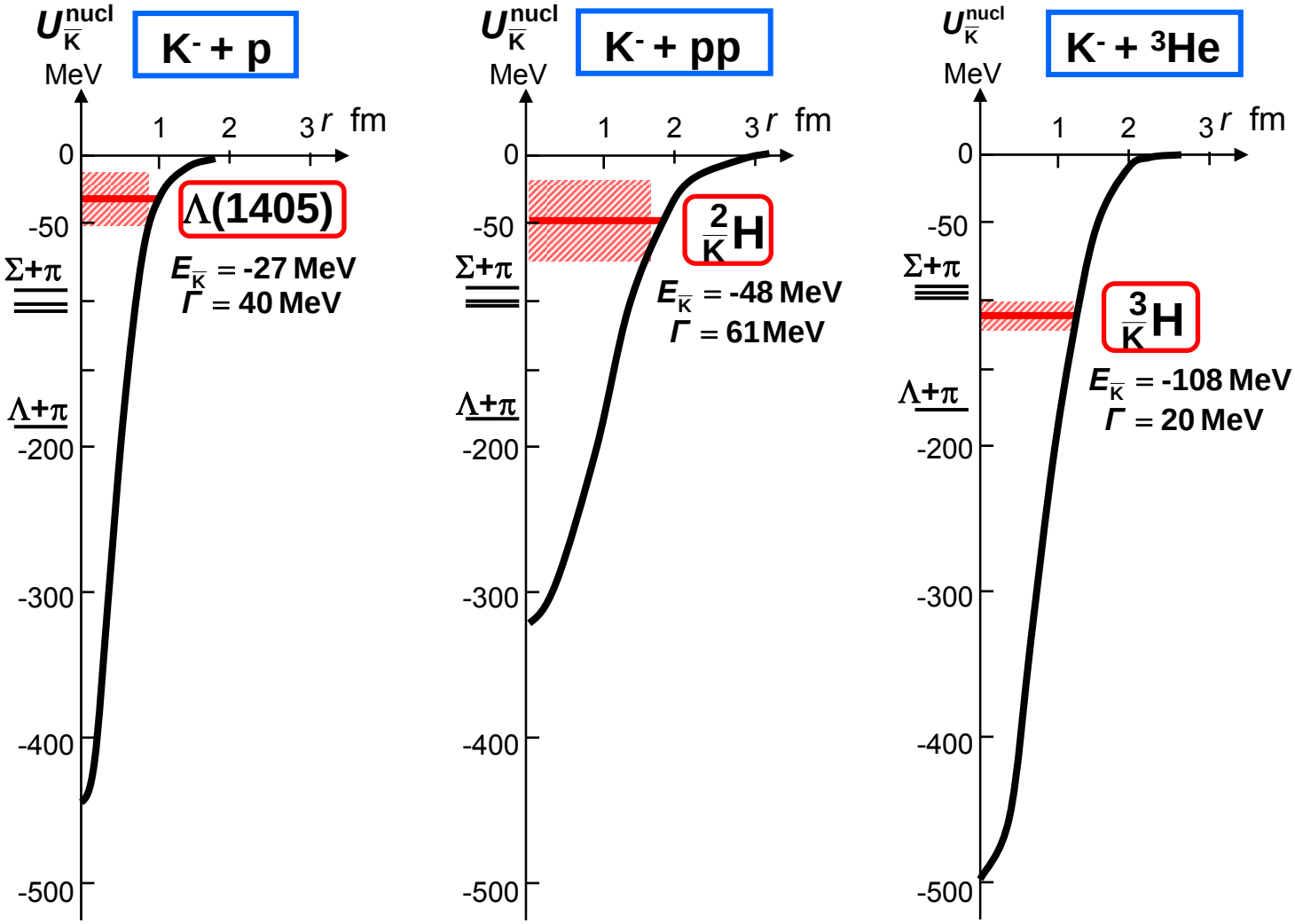
Dominant Minor



G-parity

Coherently added to form Λ(1405).

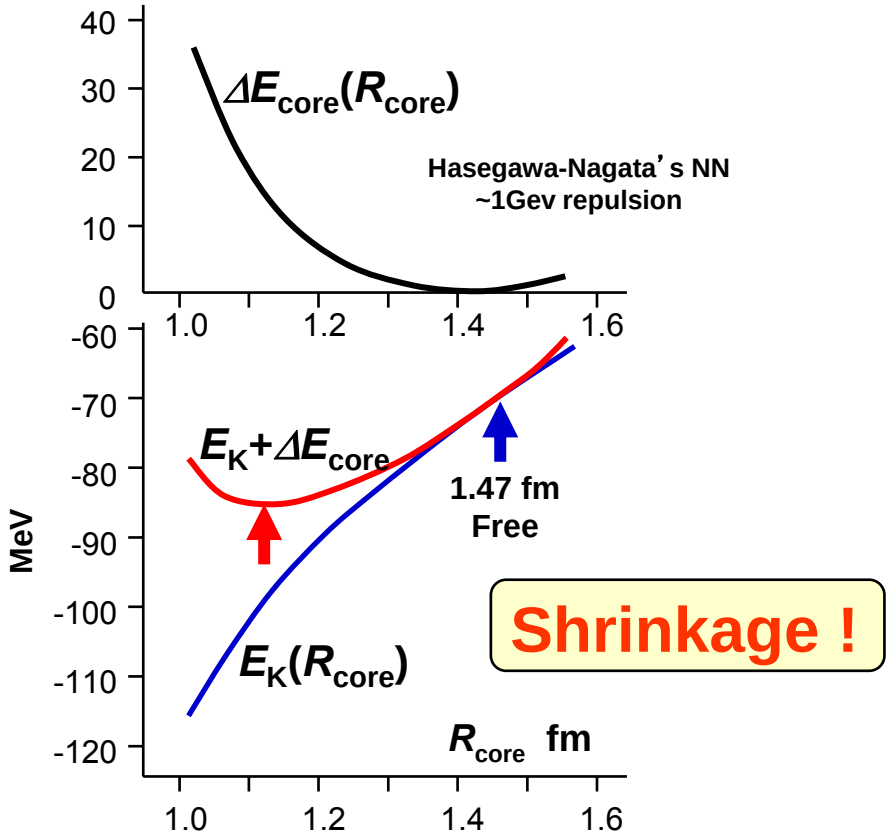




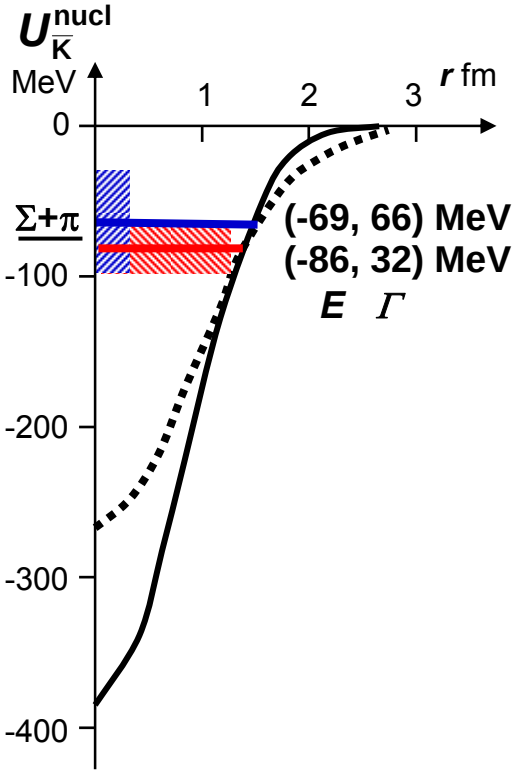
Y. Akaishi & T. Yamazaki, Phys. Rev. C 65 (2002) 044005

Nuclear $^{4}_{\bar{K}}$H bound state

$[K^- \otimes {}^4\mathrm{He}]_{T=1/2}$

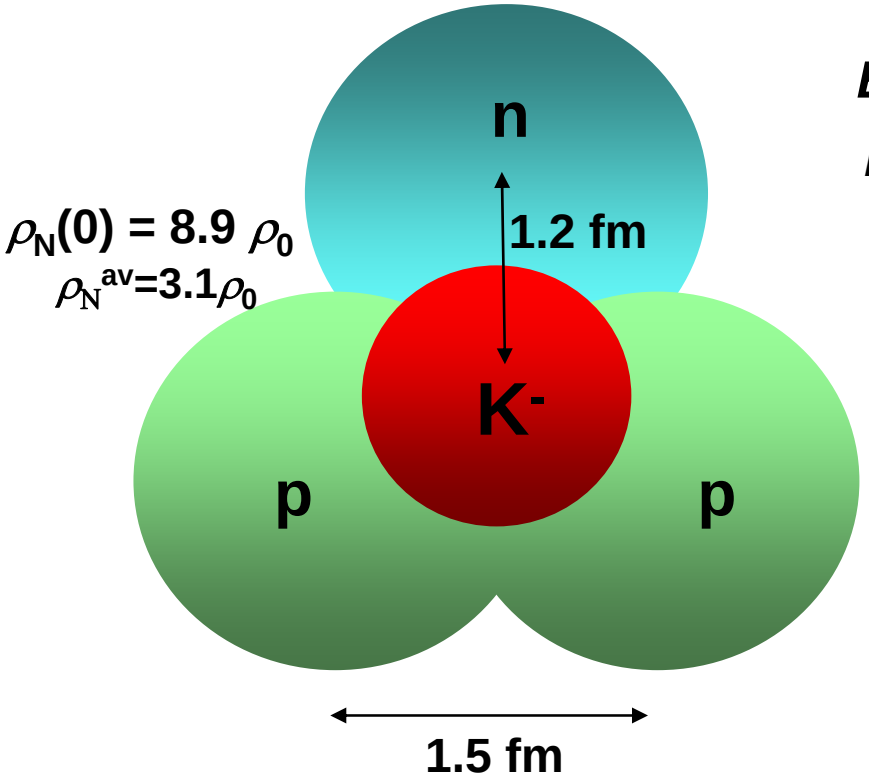


Shrinkage !



Y. Akaishi & T. Yamazaki, Phys. Rev. C 65 (2002) 044005

$ppnK^-$



$\rho_N(0) = 8.9\ \rho_0$

$\rho_N^{av} = 3.1\rho_0$

Meson-baryon ?

$E = -111\,\text{MeV}, \quad \Gamma = 20\,\text{MeV}$

$E = -169 \pm 6\,\text{MeV}, \quad \Gamma \leq 25\,\text{MeV}$

Exp.

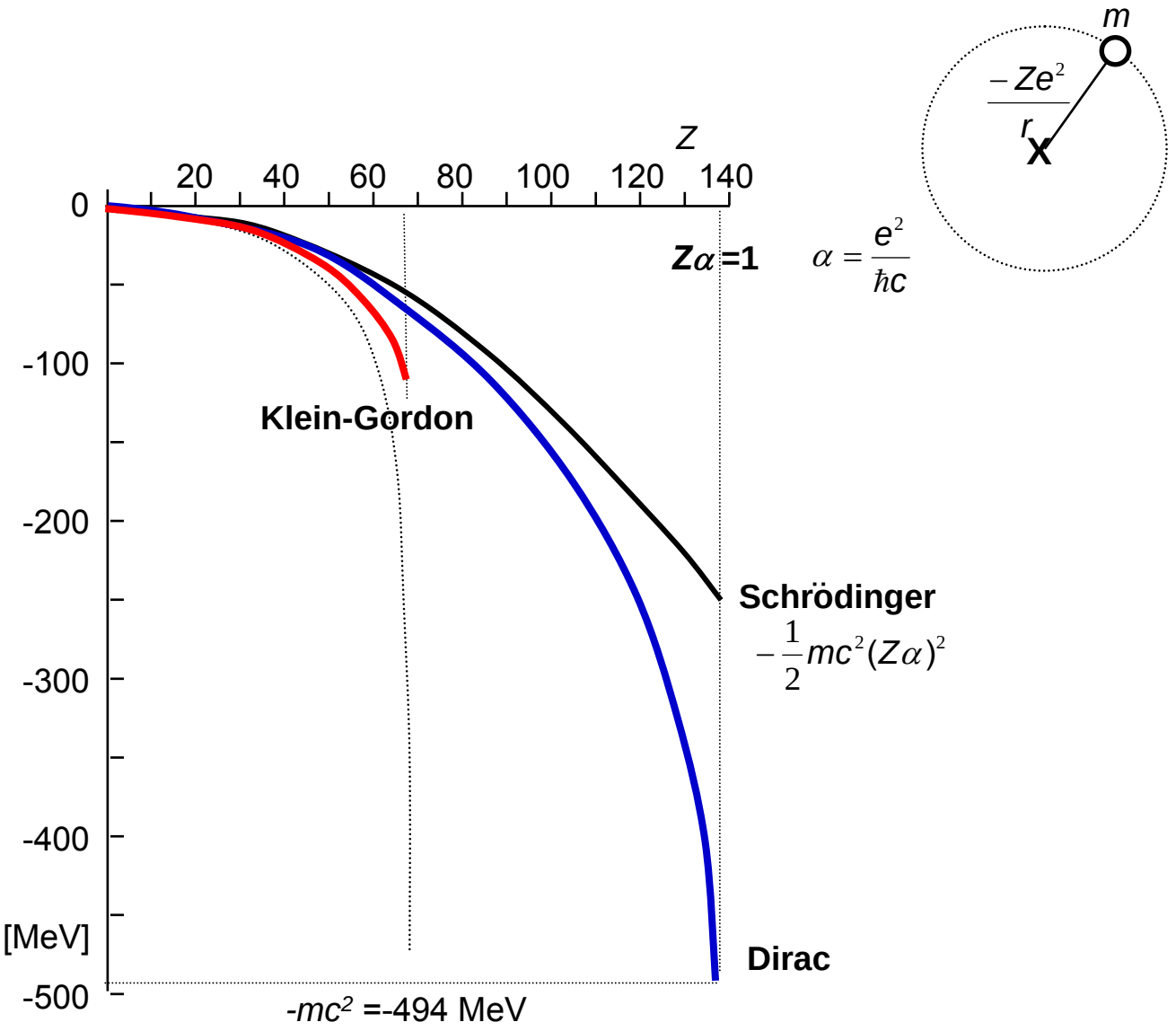
$\Delta B_{\text{th-ex}} \sim 60\,\text{MeV}$

Chiral restoration ?

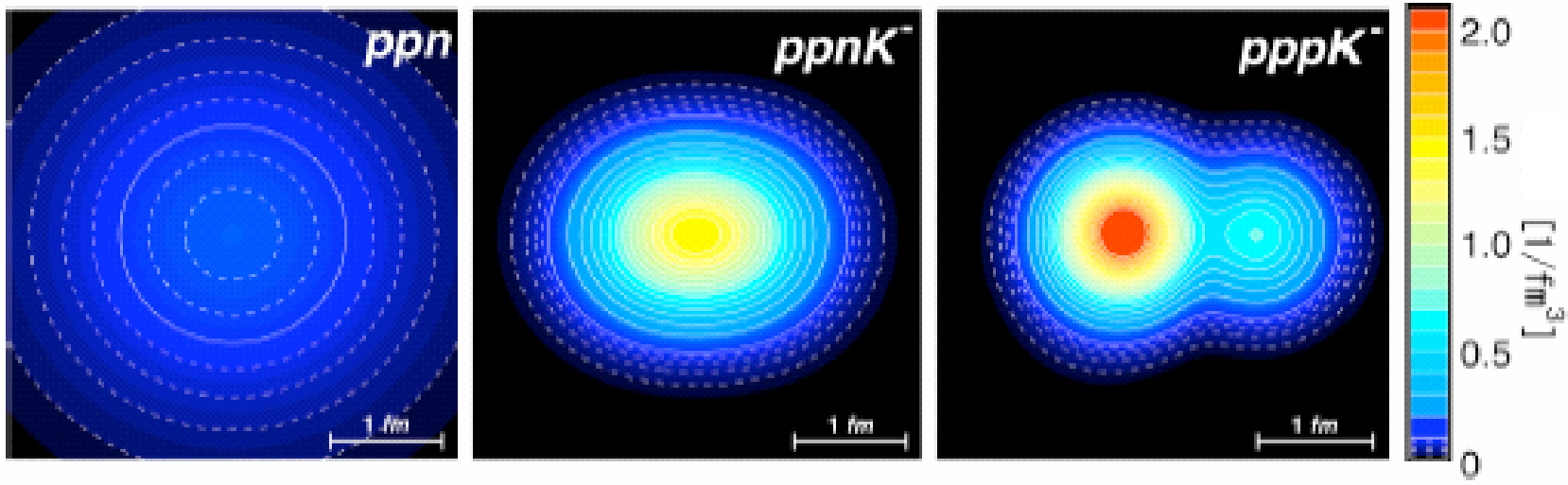
m_K / f^2

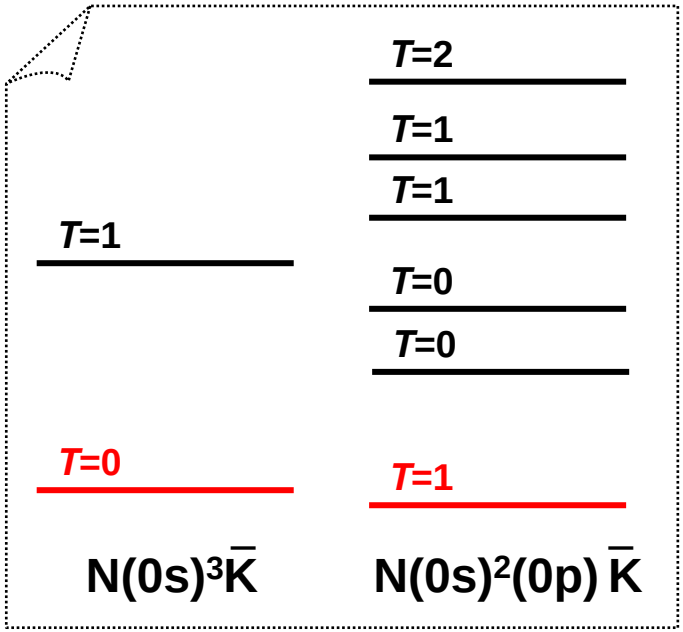
Relativistic effect ?

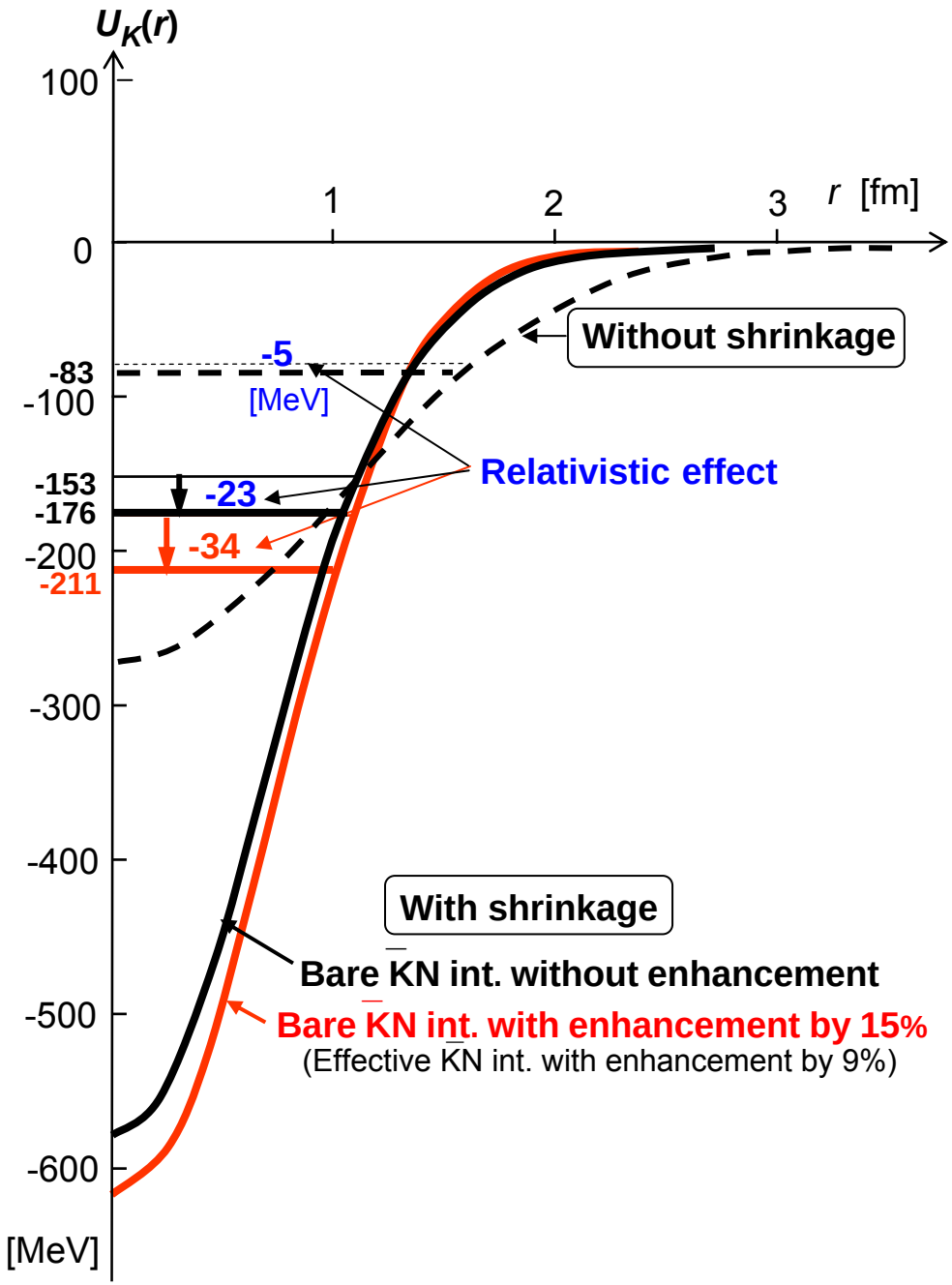
Atomic systems by point-Coulomb interaction



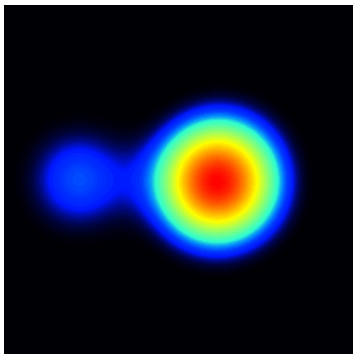
A. Dote et al.,
Phys. Rev. C70 (2004) 044313

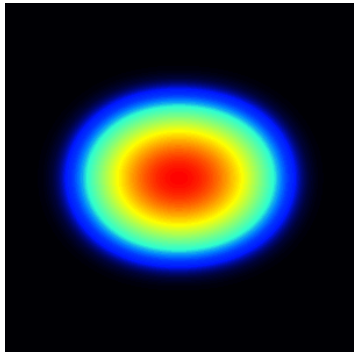





$U_K(r)$
100
0
-100
-200
-300
-400
-500
-600
[MeV]
1
2
3
r [fm]
-83
-153
-176
-211
-5
[MeV]
-23
-34
Without shrinkage
Relativistic effect
With shrinkage
Bare $\bar{K}N$ int. without enhancement
Bare $\bar{K}N$ int. with enhancement by 15%
(Effective $\bar{K}N$ int. with enhancement by 9%)

Y. Akaishi, A. Dote & T. Yamazaki,
Phys. Lett. B 613 (2005) 140





$N(0s)^2(0p)\,\bar{K}$

$N(0s)^3\bar{K}$

-97 MeV

$\frac{2}{3}v^{I=0} + \frac{4}{3}v^{I=0}$

-126 MeV

-111 MeV

$\frac{3}{2}v^{I=0}$

Bare $\bar{K}N$ interaction enhanced by 15%

-135 MeV

$1/2^+$

Relativistic effect

-169 MeV (obs.)

T=0,1/2$^-$

Observe all.
Exciting !

T=1

$3/2^+$

-194 MeV(obs.)

T_3=1

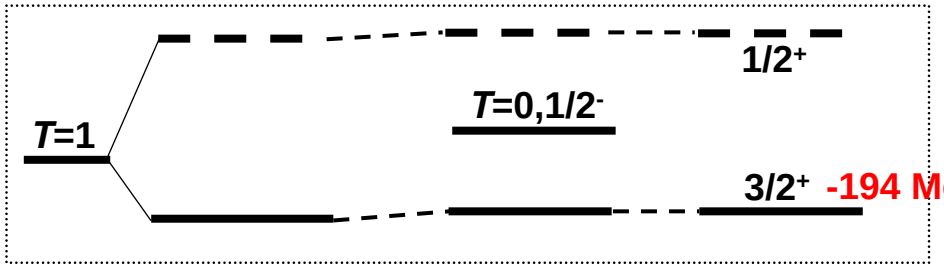
T_3=0

T_3=-1

pppK$^-$

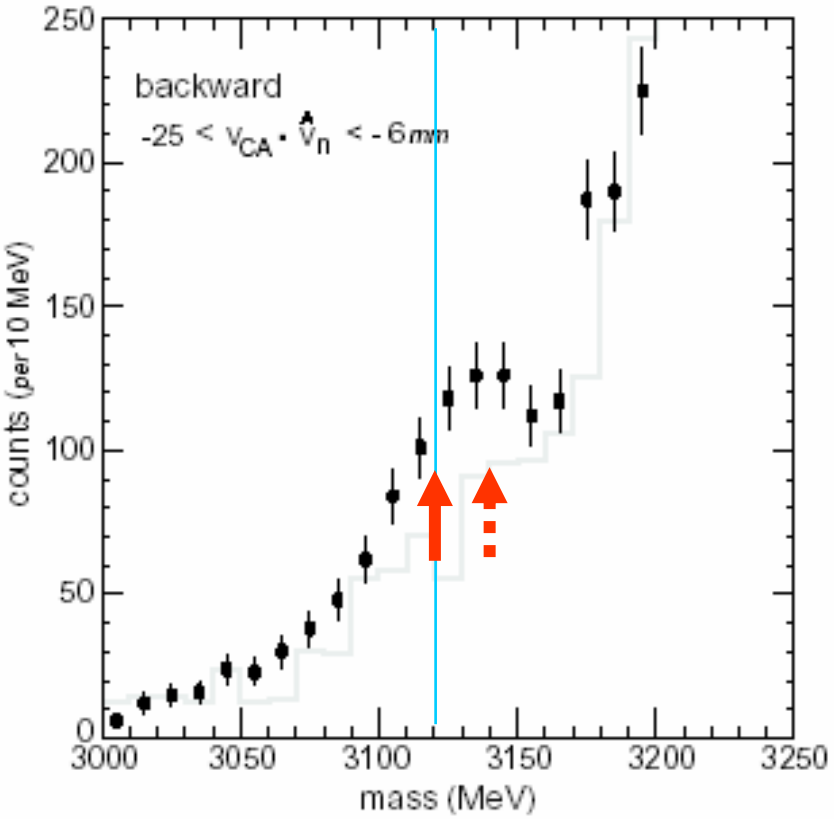
ppnK$^-$

pnnK$^-$



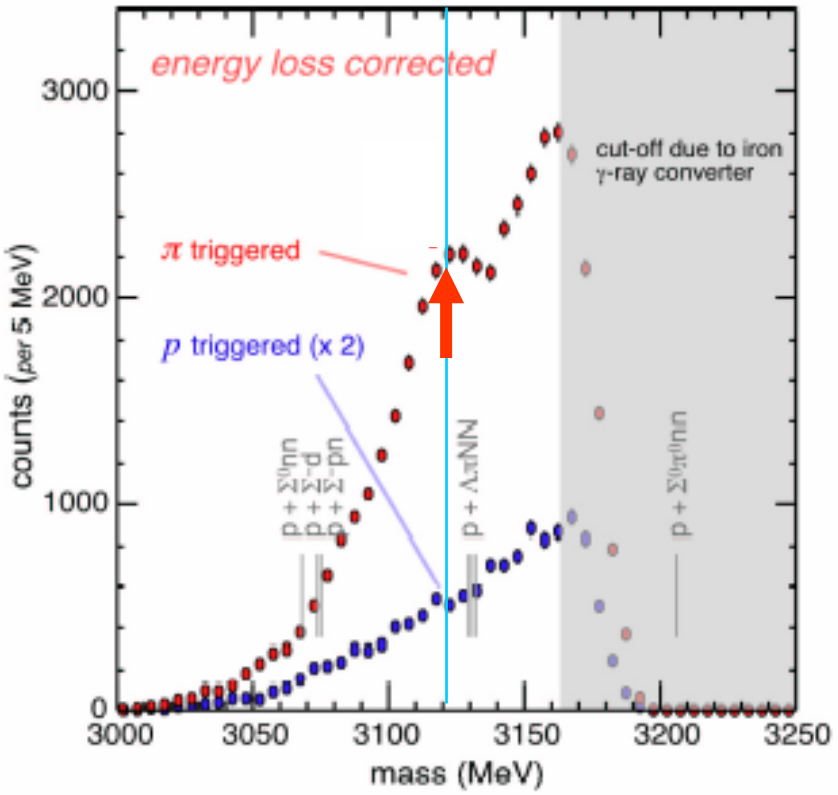
T. Suzuki et al.,
Phys. Lett. B597 (2004) 263

^{4}He(stopped K$^-$, n)

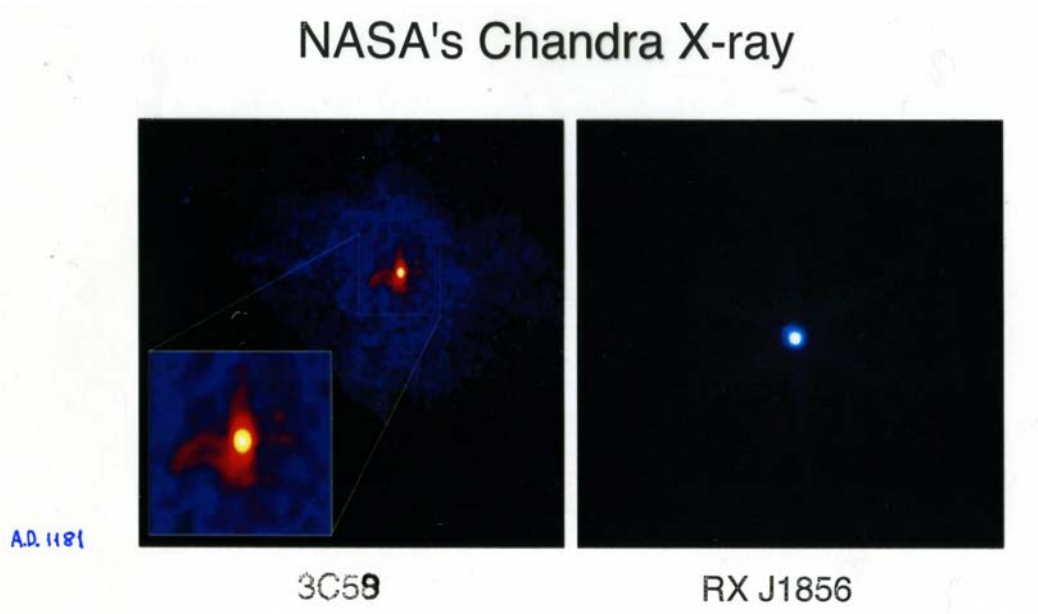


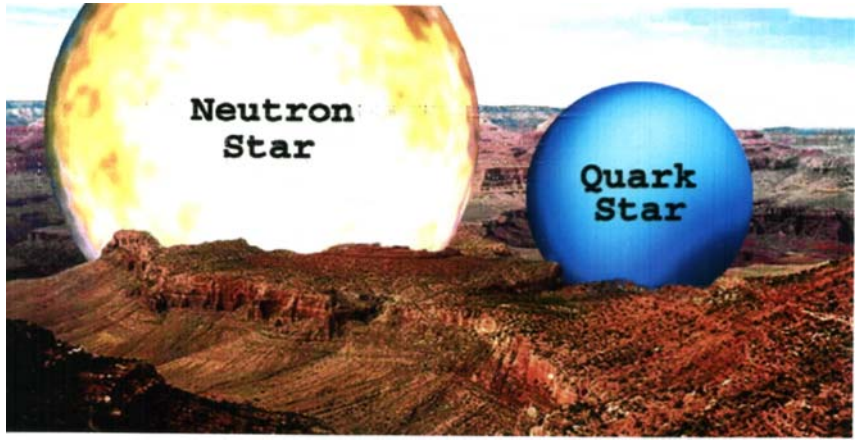
S^0(3115)?
S$^+$(3140)?

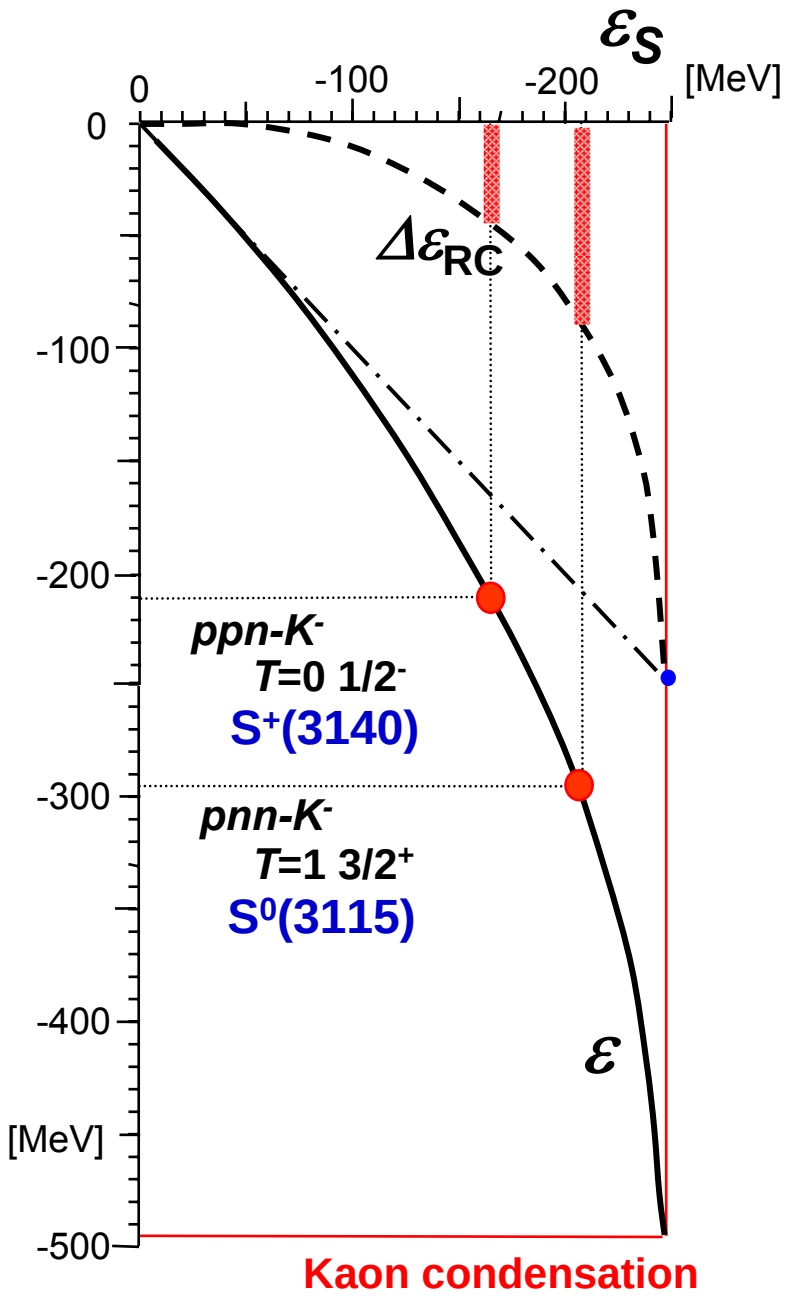
^{4}He(stopped K$^-$, p)



S^0(3115)


NASA's Chandra X-ray
A.D. 1181
3C58
RX J1856


Neutron Star
Quark Star


ε_S
0
-100
-200
[MeV]
$\Delta\varepsilon_{RC}$
ppn-K⁻
T=0 1/2⁻
S⁺(3140)
pnn-K⁻
T=1 3/2⁺
S⁰(3115)
ε
Kaon condensation

@high densities

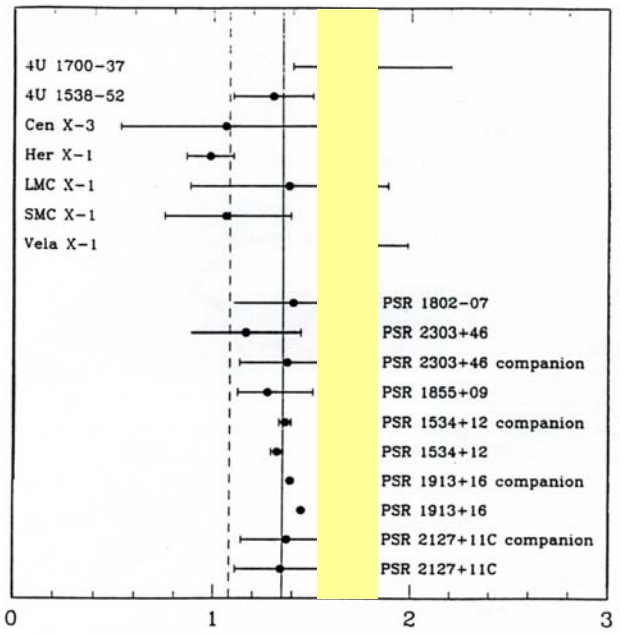
$e^- + p \longrightarrow \nu + n$ “Neutron star”

$\sim 3\rho_0$

$\nu + K^- + p$

Strong attraction

“Nucleon star”
with kaon condensation

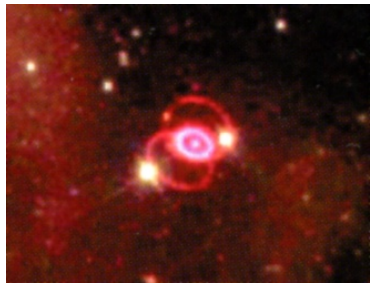


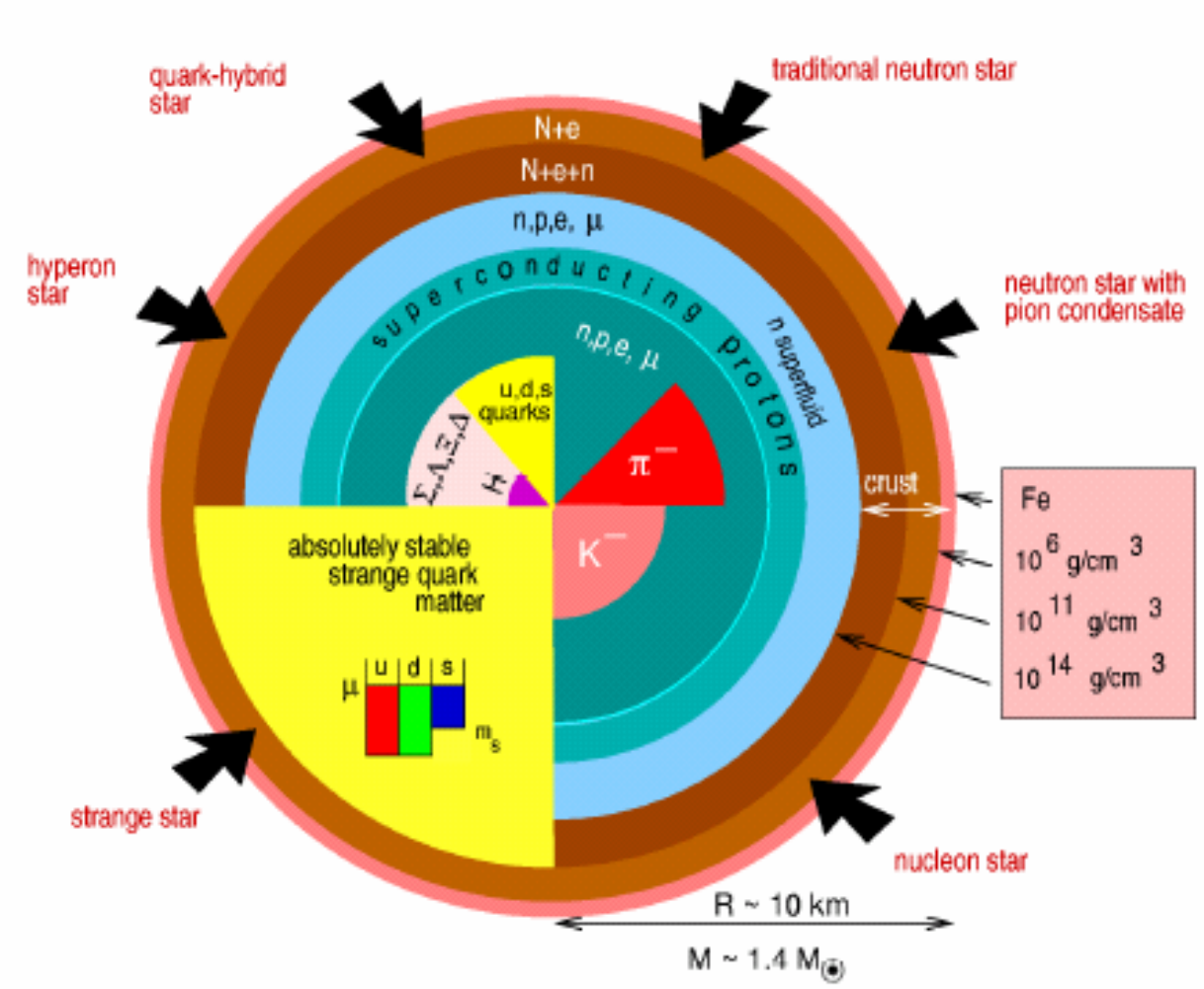
“Low-mass black hole”
$1.5\sim1.8\ M_\odot$

G.E. Brown, Nucl. Phys. A574 (1994) 217c.

G.E. Brown & H.A. Bethe, Astrophys. J. 423 (1994) 659.

SN1987A ?




quark-hybrid star
traditional neutron star
N+e
N+e+n
n,p,e, μ
hyperon star
neutron star with pion condensate
superconducting protons
n superfluid
n,p,e, μ
u,d,s quarks
$\Sigma,\Lambda,\Xi,\Delta$
π^-
K^-
crust
Fe
10^6 g/cm^3
10^{11} g/cm^3
10^{14} g/cm^3
absolutely stable strange quark matter
u d s
μ
m_s
strange star
nucleon star
R ~ 10 km
M ~ 1.4 $M_\odot$

Nona-Quark States

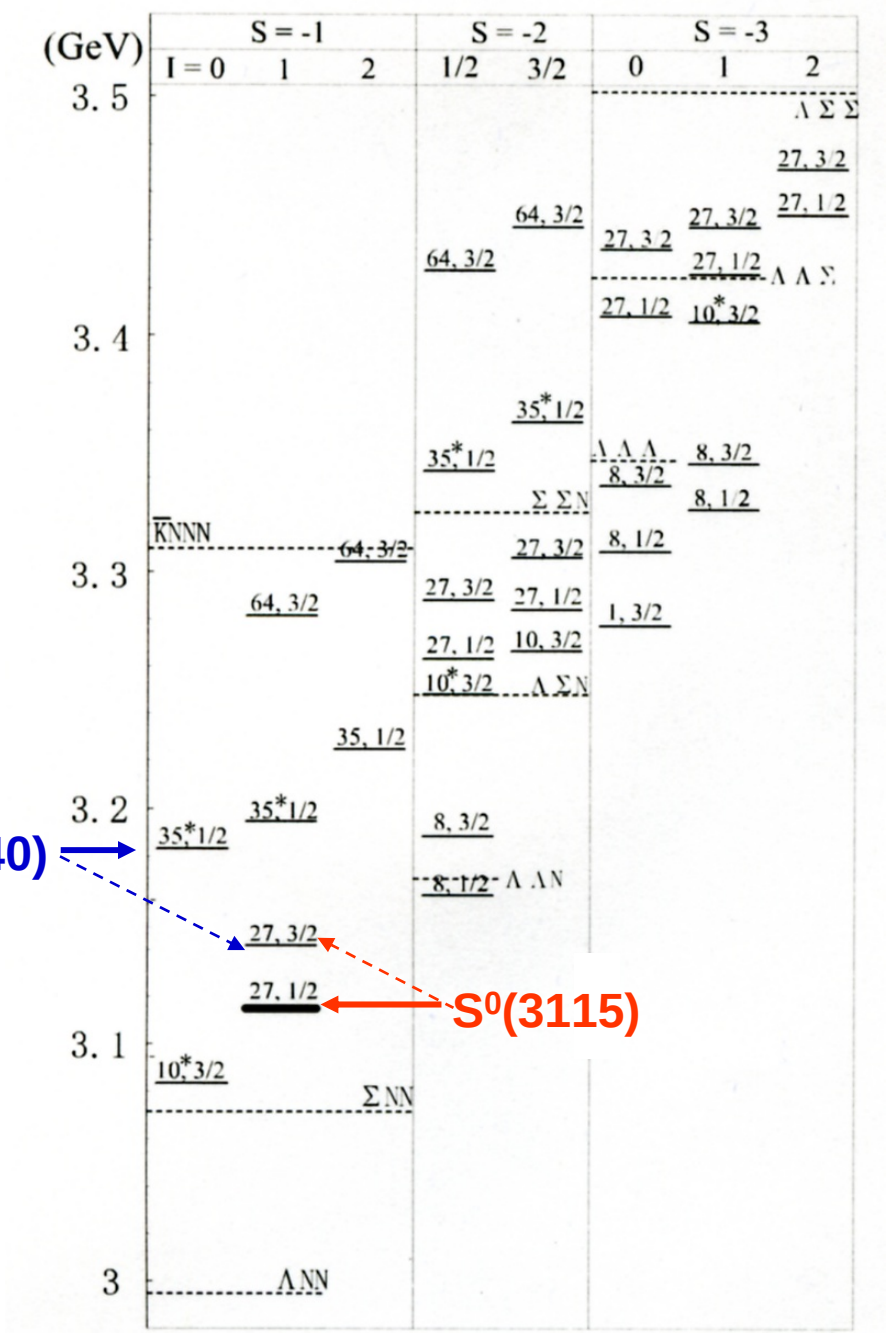
Y. Maezawa, T. Hatsuda & S. Sasaki,
Hep-ph/0412025

$$H = a_0 + a_2 Y + a_1\left[C_3(F) + \tfrac{1}{3}\vec{J}^2\right] + \ldots$$

Color-magnetic interaction

$\alpha_s^{\text{eff}} = 2.0 \rightarrow 1.0$ ⇨

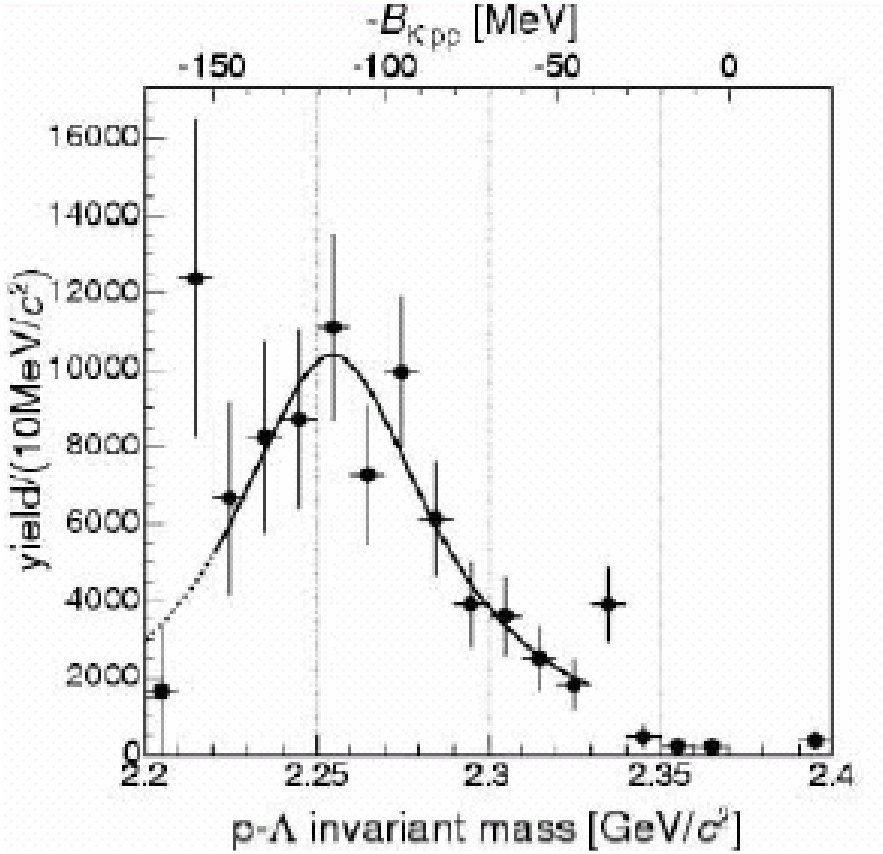
MIT bag: R_9=1.3 fm



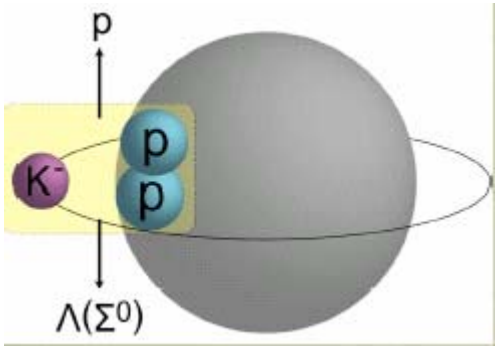
$M_\Delta - M_N \approx 300\ \text{MeV}/c^2$

Observation of ppK$^-$

M. Agnello, H. Fujioka, T. Nagae et al.,
Phys. Rev. Lett. 94 (2005) 212303



FINUDA
@DAΦNE



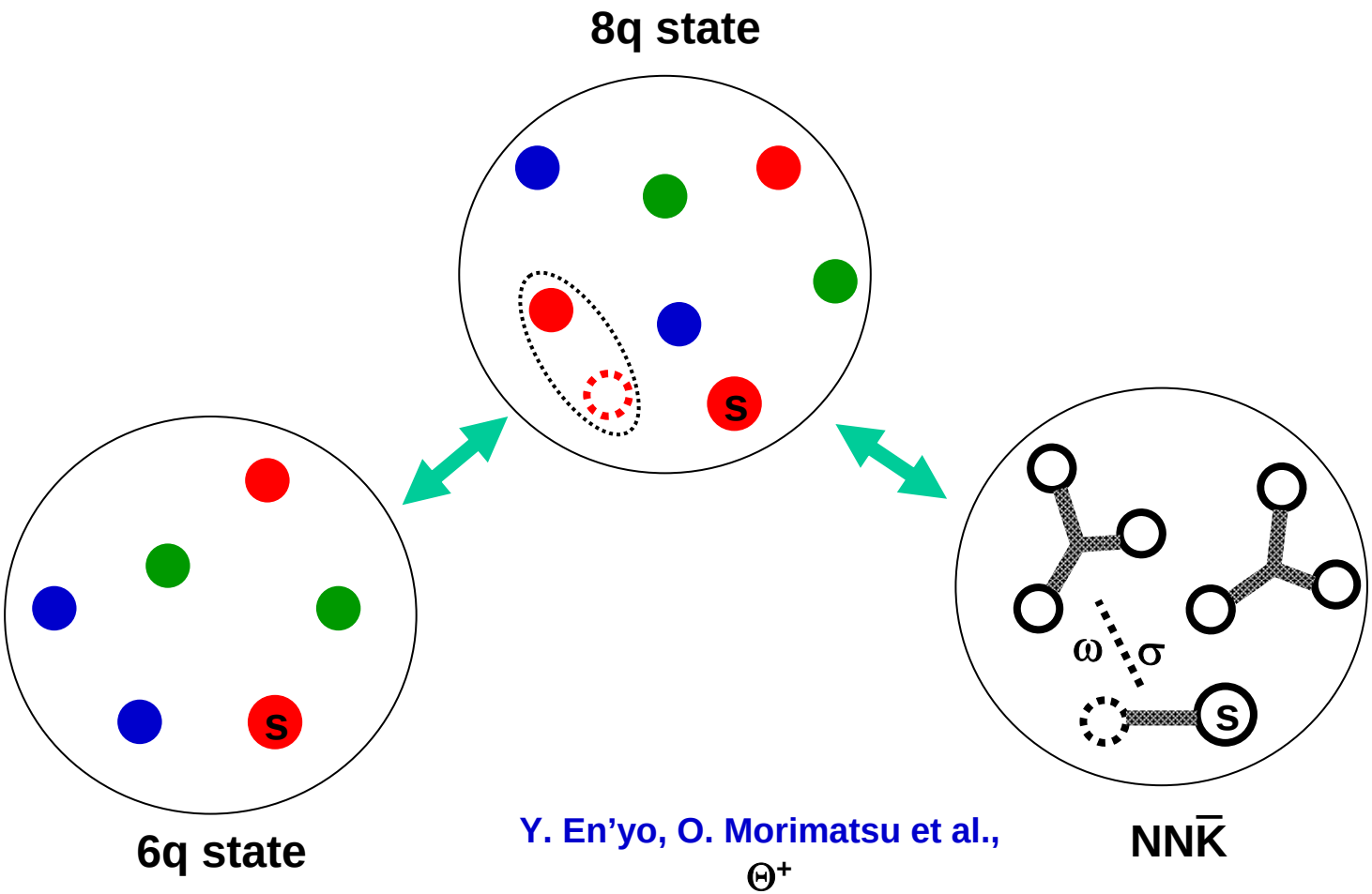
$$B = 115\,^{+6}_{-5}\,^{+3}_{-4}\ \text{MeV}$$

$$\Gamma = 67\,^{+14}_{-11}\,^{+2}_{-3}\ \text{MeV}$$

15% enhanced $\bar{K}$N interaction

***B* = 48 MeV → 86 MeV**

Phase transition of ppK$^-$



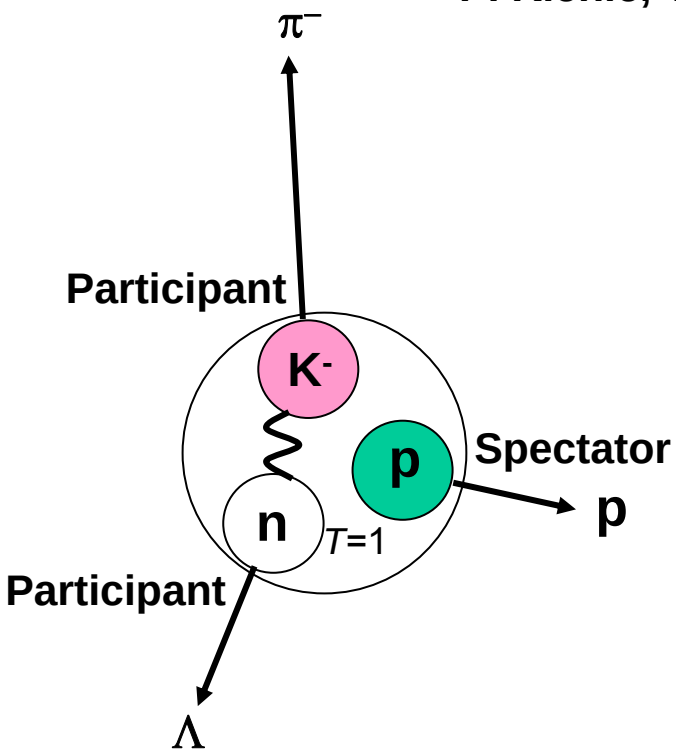
Y. En'yo, O. Morimatsu et al.,

Θ^+

Challenging problem !

Invariant masses of pnK$^-$ decay

P. Kienle, Y. Akaishi & T. Yamazaki, PLB



All are detectable !

Invariant mass

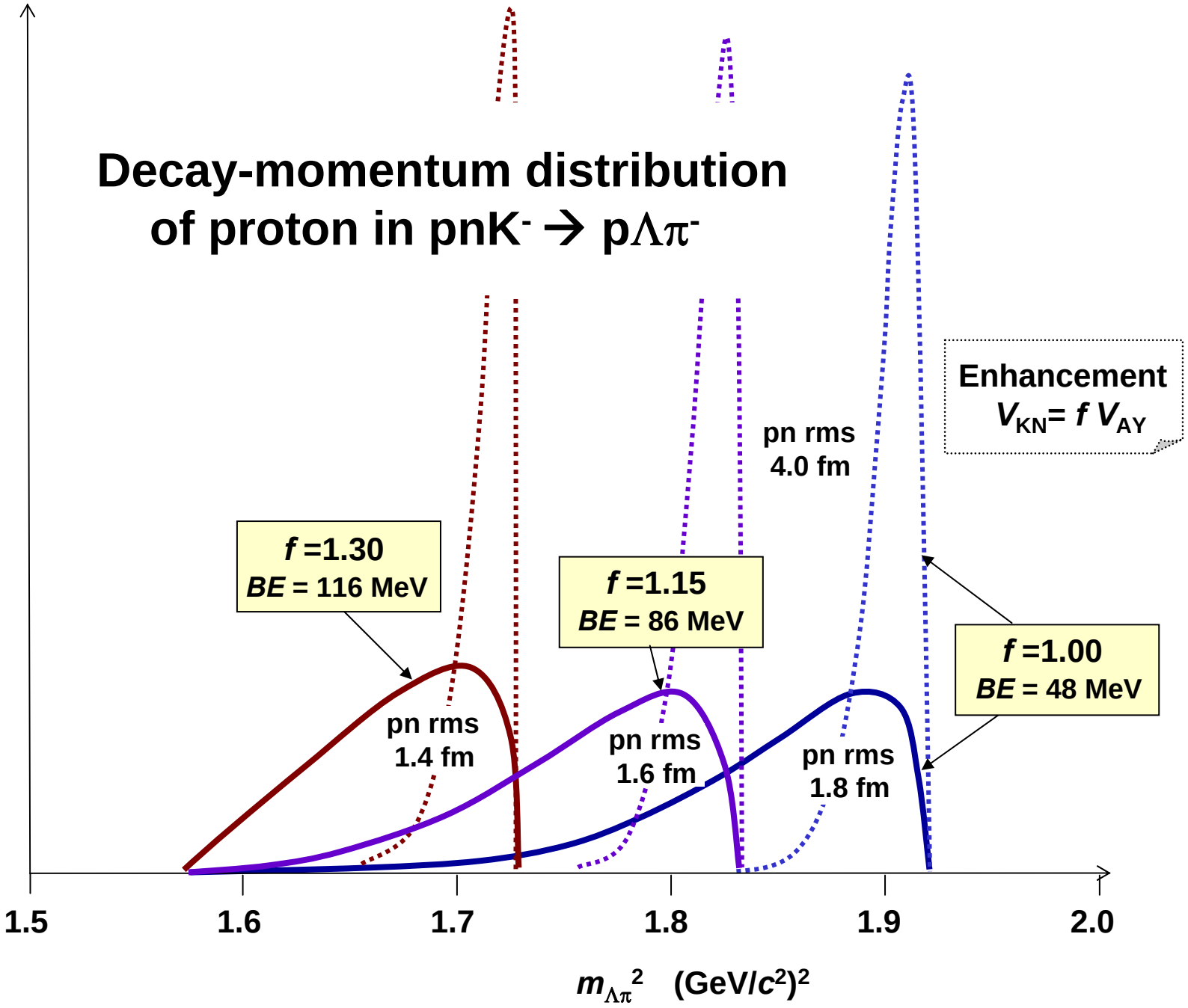
$$M_{pnK}^2=(E_p+E_\pi+E_\Lambda)^2-(\boldsymbol{p}_p+\boldsymbol{p}_\pi+\boldsymbol{p}_\Lambda)^2$$

Partial invariant mass

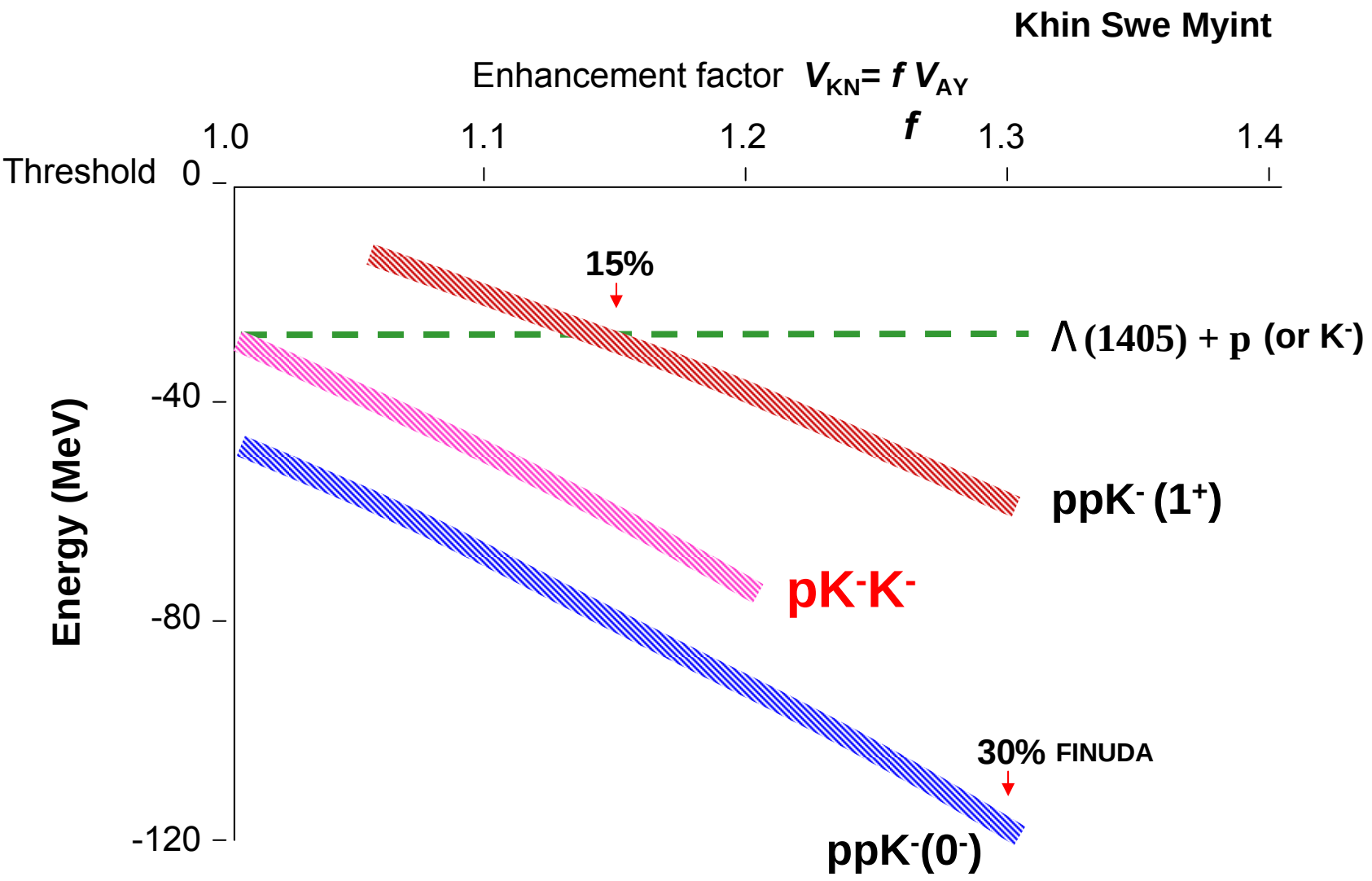
Dalitz's variable:

$$m_{\Lambda\pi}^2=(E_\pi+E_\Lambda)^2-(\boldsymbol{p}_\pi+\boldsymbol{p}_\Lambda)^2$$ **: Any frame**

$$=(M_{pnK}-E_p)^2-\boldsymbol{p}_p^2$$ **: Rest frame of pnK$^-$**


Decay-momentum distribution
of proton in pnK- → pΛπ-
Enhancement
VKN= f VAY
pn rms
4.0 fm
f =1.30
BE = 116 MeV
f =1.15
BE = 86 MeV
f =1.00
BE = 48 MeV
pn rms
1.4 fm
pn rms
1.6 fm
pn rms
1.8 fm
1.5
1.6
1.7
1.8
1.9
2.0
mΛπ2 (GeV/c2)2

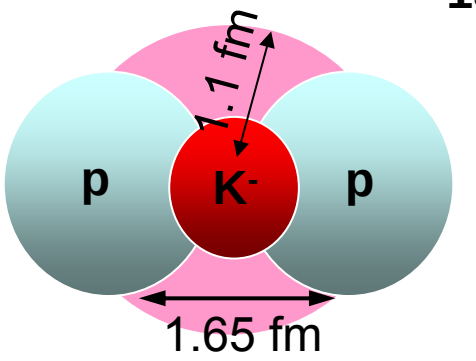
Energy of three-body kaonic nuclei

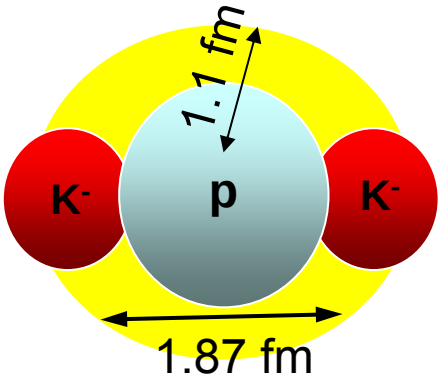


ppK^-

pK^-K^-

15% enhancement





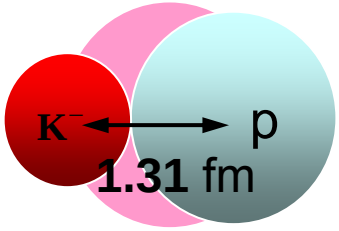
rms d (fm)

p-p = 1.65

K^--p = 1.37

K^--(pp) = 1.10

⇦



⇨

rms d (fm)

K^-- K^- = 1.87

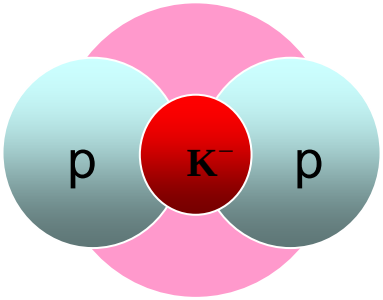
K^--p = 1.42

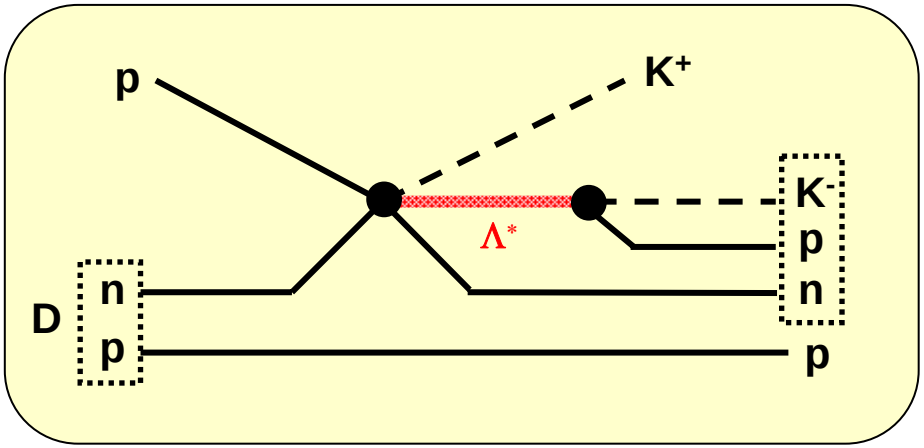
p-(K^-K^-) = 1.10

$\Lambda(1405)$

Λ(1405)-Doorway Process

T. Yamazaki & Y. Akaishi, Phys. Lett. B535 (2002) 70.





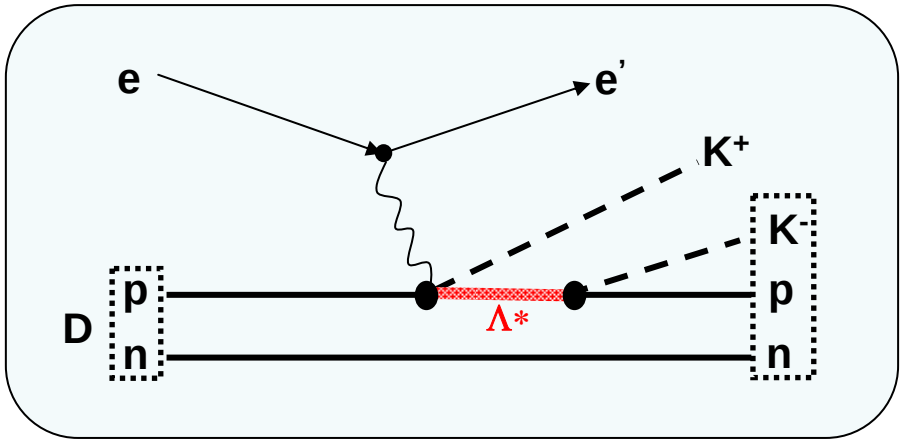
Iso-doublet

T=1

D(p,p'K⁺)pnK⁻

(p,K⁺) S⁺(3140)

Missing mass spectroscopy



T=1

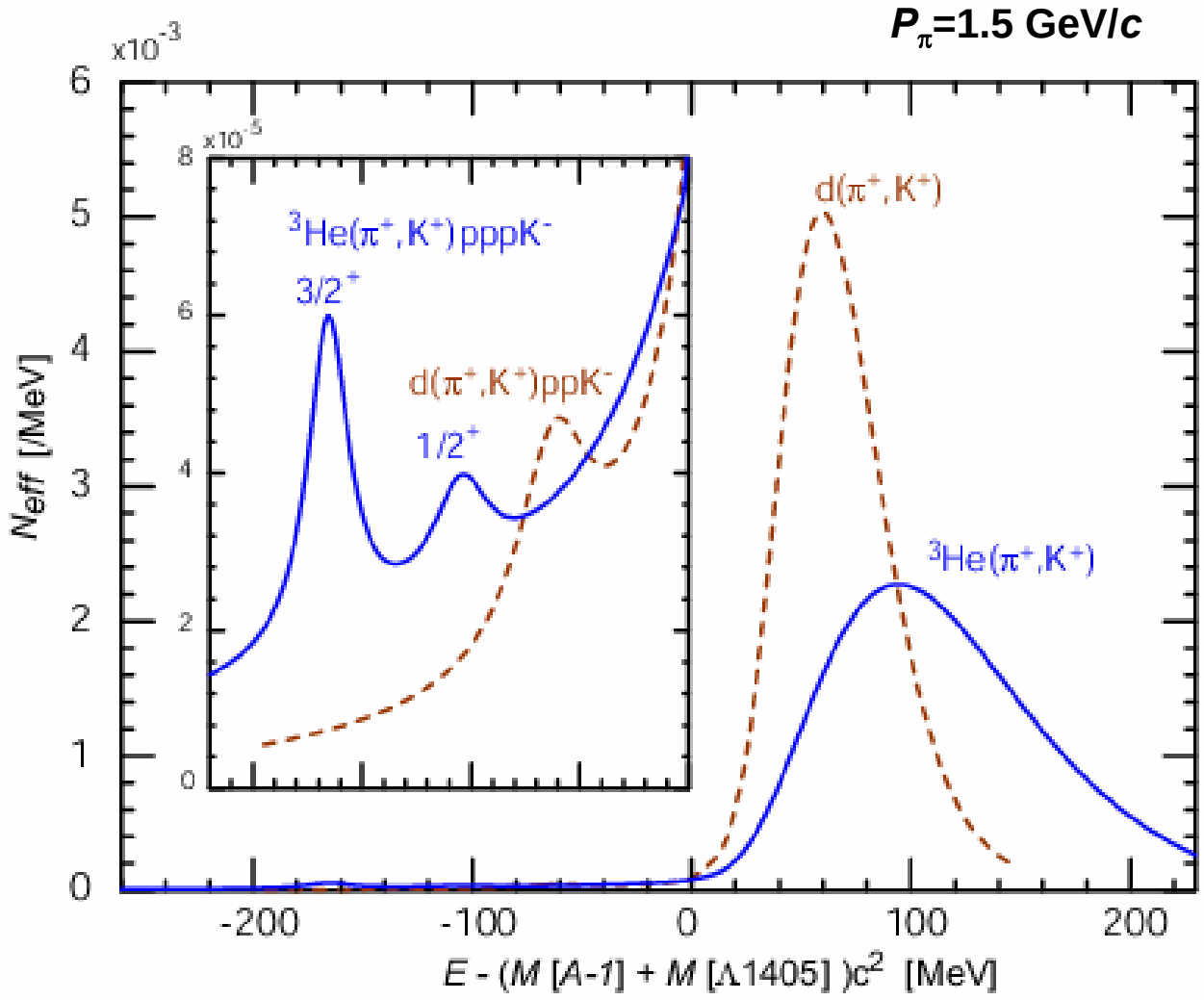
D(e,e'K⁺)pnK⁻

(γ,K⁺)

J-Lab

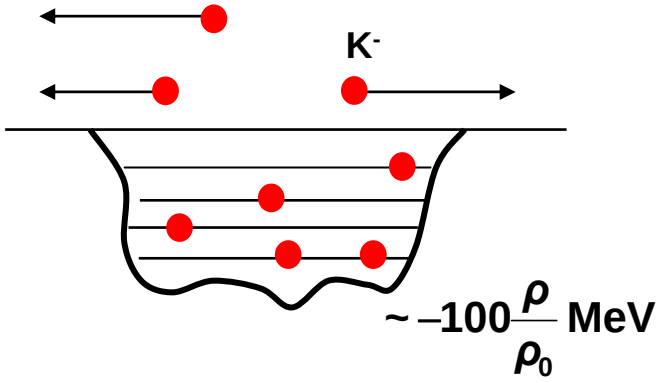
Green's function method
O. Morimatsu & K. Yazaki, Nucl. Phys. A435 (1985) 727

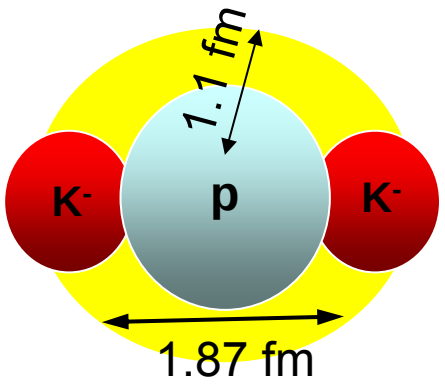
Spectra from (π^+,K^+) Reaction

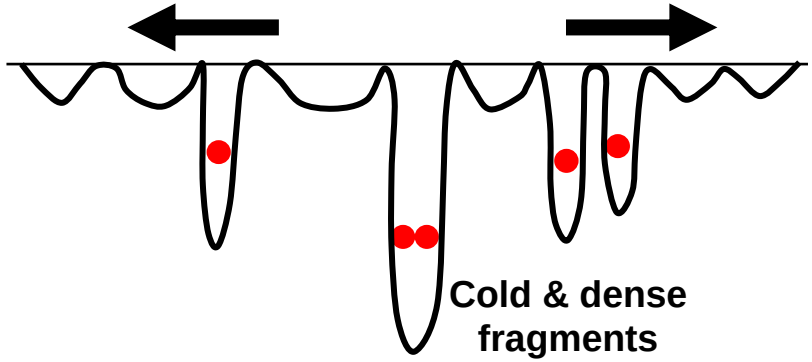


Heavy-Ion Reaction ~10*A* GeV

N. Herrmann , T. Yamazaki







Invariant mass spectroscopy

$ppnK^- \rightarrow \Lambda + d$

$ppK^- \rightarrow \Lambda + p$

$pK^-K^- \rightarrow \Lambda + K^-$

Remarks

Nuclear $\bar{K}$ bound state

Mini strange matter

$\bar{K}$ plays a role of "contractor".

A new means to investigate
hadron dynamics in dense&cold matter

Chiral restoration?
Color superconductivity?
Kaon condensation?
Strange hadronic/quark matter?

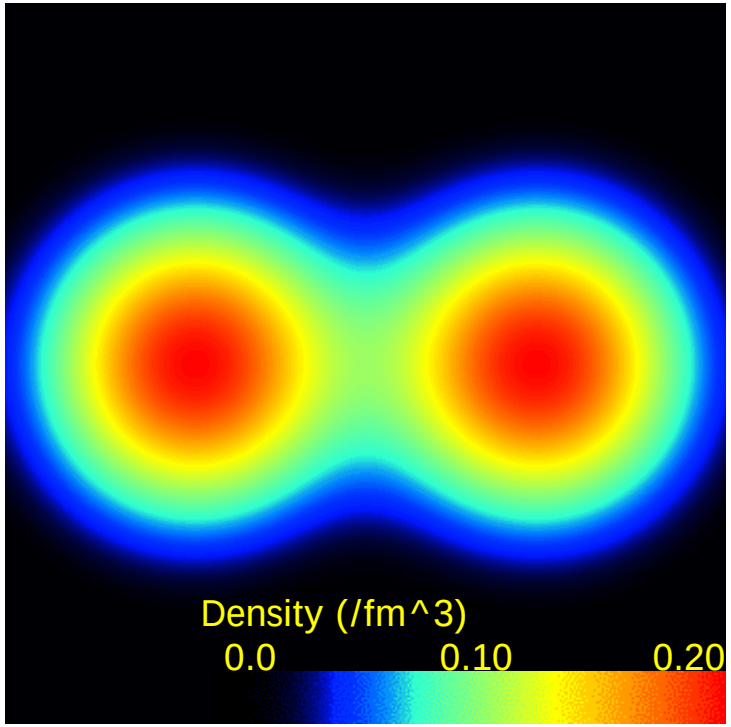
Production-/Decay-channel spectroscopies

Missing-mass/Invariant-mass
Ψ/J

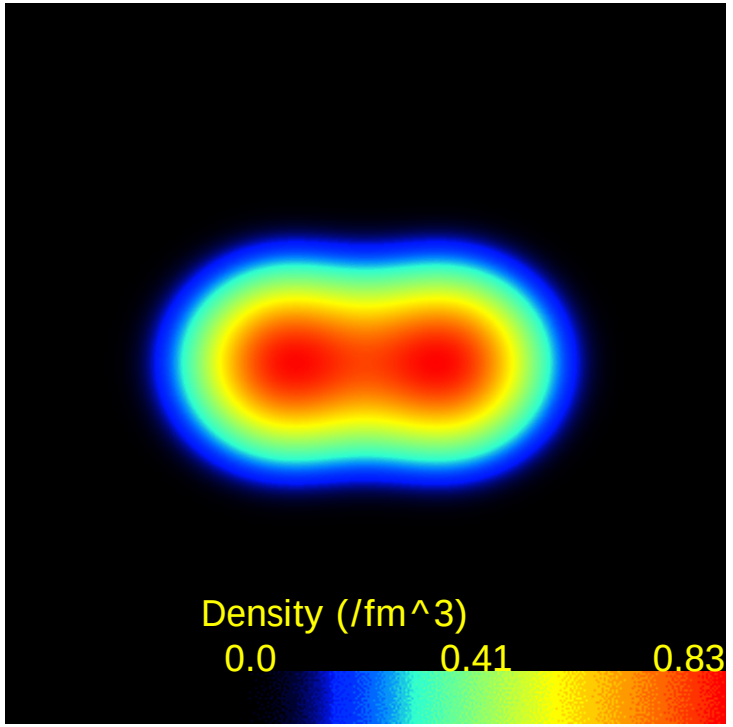
Few-body $\bar{K}$ nuclear systems would provide experimental data of fundamental importance for hadron physics with strangeness.

KEK
DAΦNE
SPring-8
GSI
J-Lab
J-PARC

^{8}Be



^{8}BeK^{-}



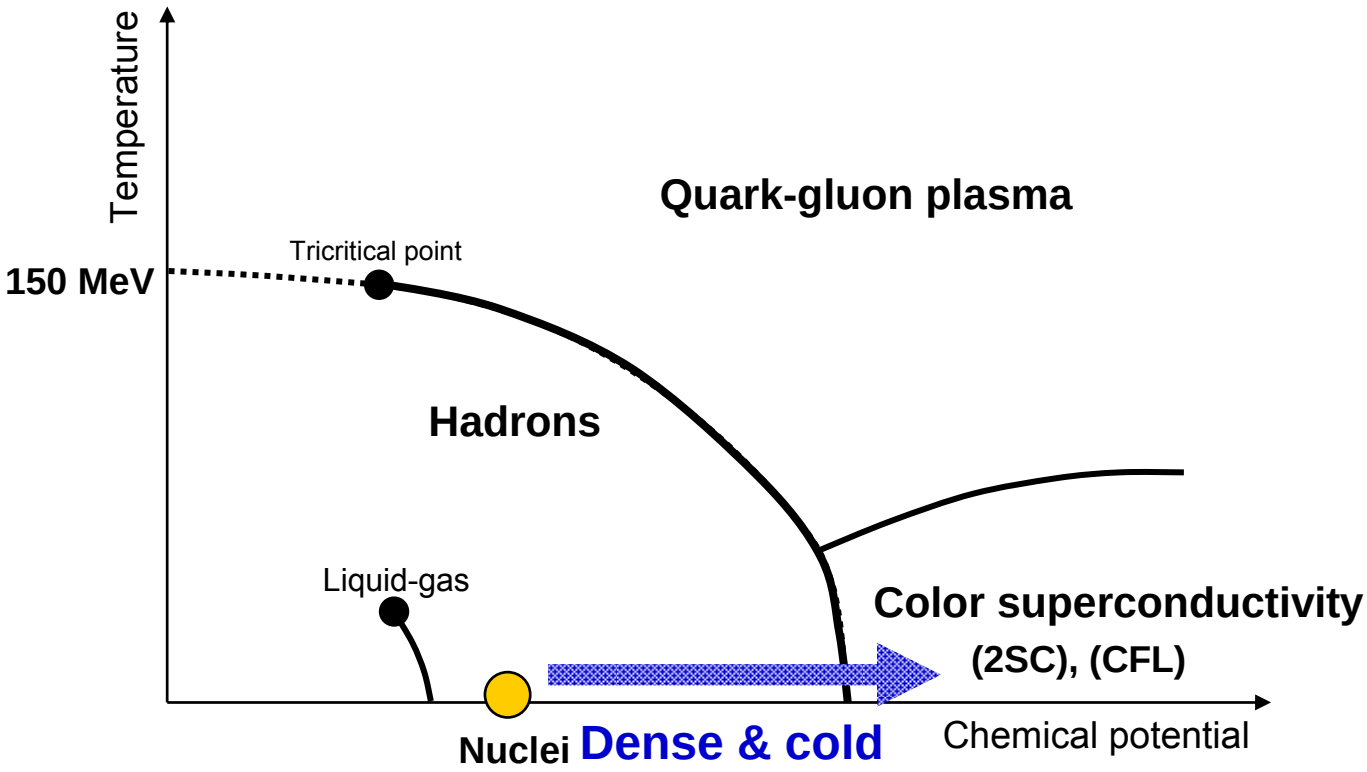
7 fm

Dense & Cold

AntisymmetrizedMolecularDynamics calculation

A. Dote, H. Horiuchi, Y. Akaishi & T. Yamazaki, Phys. Lett. B590 (2004) 51.

Nuclear Phase Diagram



T. Hatsuda & T. Kunihiro,
Phys. Rev. Lett. 55 (1985) 158.

An epoch-making milestone has been obtained by T. Suzuki, M. Iwasaki et al.

A new paradigm of Nuclear Physics

Nuclei of 2nd generation

The $s\bar{u}$ quark plays a leading role in forming a dense and cold nucleus.