January 20, 2016: J-PARC

Toward Kaonic Proton Matter: Double Kaonic Nuclei in Proton and Heavy-Ion Collisions

A possible DARK MATTER candidate:

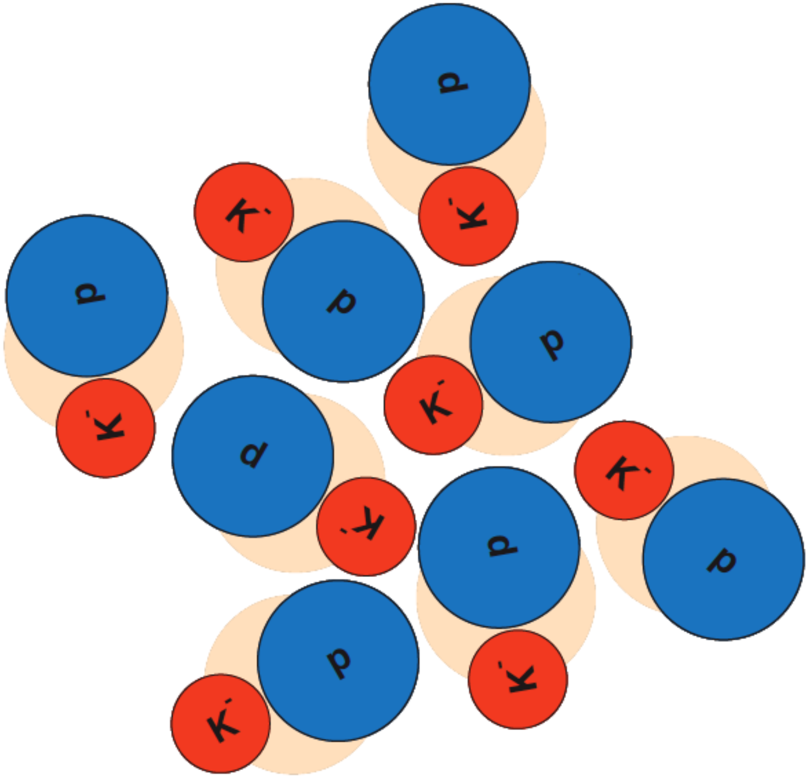
Condensed Kaonic-Proton Matter (KPM)
composed of Lambda* = K^-p

Yoshinori AKAISHI & Toshimitsu Yamazaki

KPM

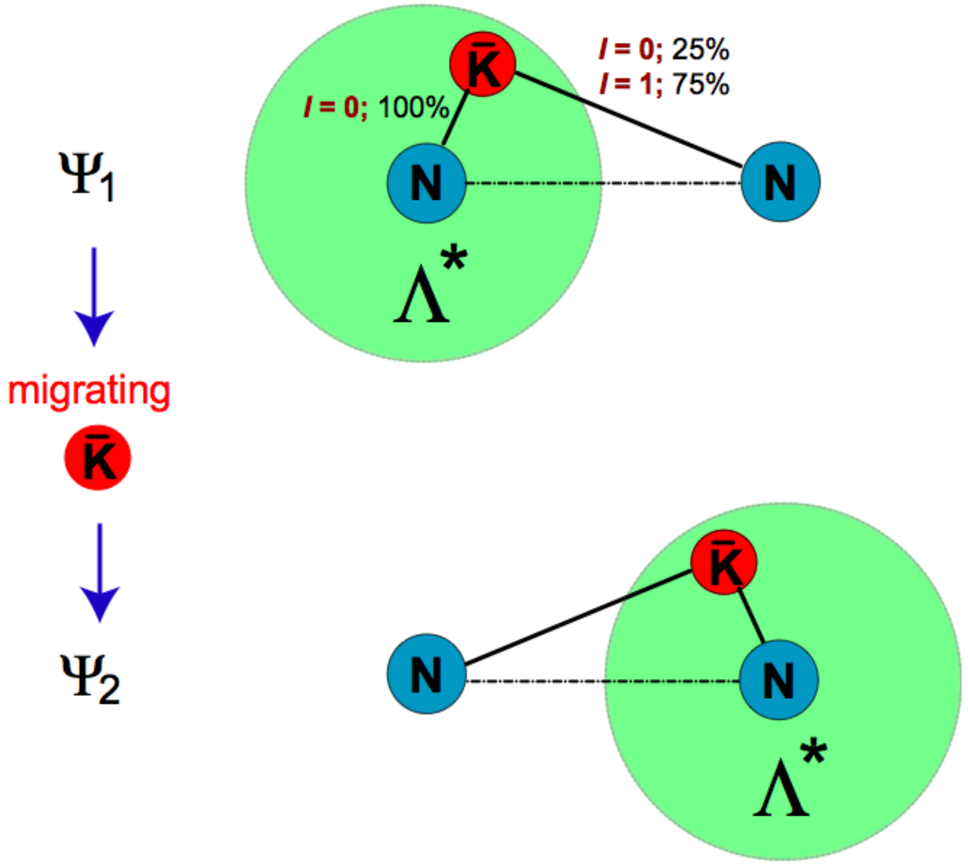
- Strong binding Λ^* = K^- - p (I=0); B=27 MeV
- Stronger inding Λ^*-p; B ~ 100 MeV
- Stronger binding Λ^*-Λ^*; B ~ 200 MeV
- Heitler-London type molecular bonding
- Multi-bonded: Λ^* strangelet -> stable matter?
- Chiral symmetry restoration:
  enhanced binding: furthermore
- Stable, large, heavy, dense, inert, neutral:
  fulfil required properties for DARK MATTER
- How KPM created: Big Bang universe
  right after Big Bang, before hadronization:
  anti-particles are proceeding to annihilation

K^-p (Λ^*) condensed matter



How to prove the high density in Kbar nuclei ?

Extended Heitler-London-Heisenberg



direct Λ^*p sticking

p + p --> K^+ + p + Λ^*

--> K^+ + K^-pp

* Short collision length
* Large momentum transfer
* Dense Λ^*p structure

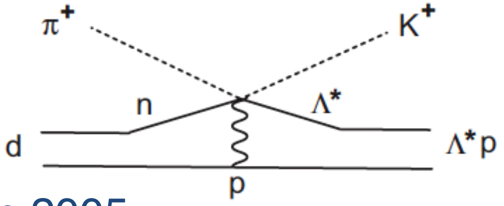
Two different reaction mechanisms to produce $\Lambda^{*}p$ --> $K^{-}pp$

Conventional: $\pi^{+} + n \rightarrow \Lambda^{*} + K^{+}$

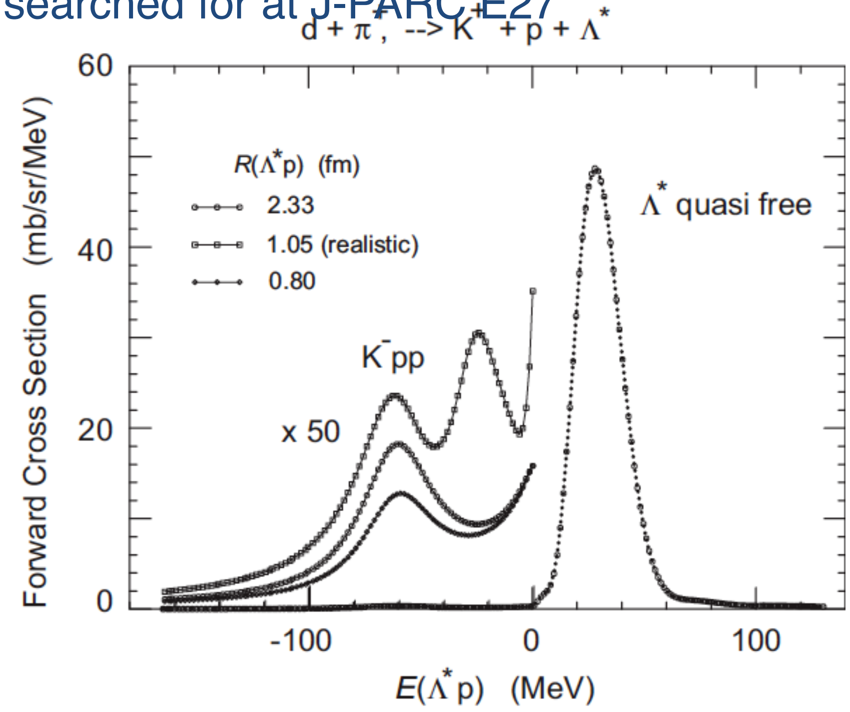
Λ^{*}-p distance at collision ~ 2.2 fm

sticking probability: small ~ 1%

Λ^{*}: mostly in the q. f. region



Predicted in 2005:
searched for at J-PARC E27



New 2007 $p + p \rightarrow \Lambda^{*} + p + K^{+}$

Collision distance $R_{NN} \sim 1/m_{\rho} \sim 0.3$ fm

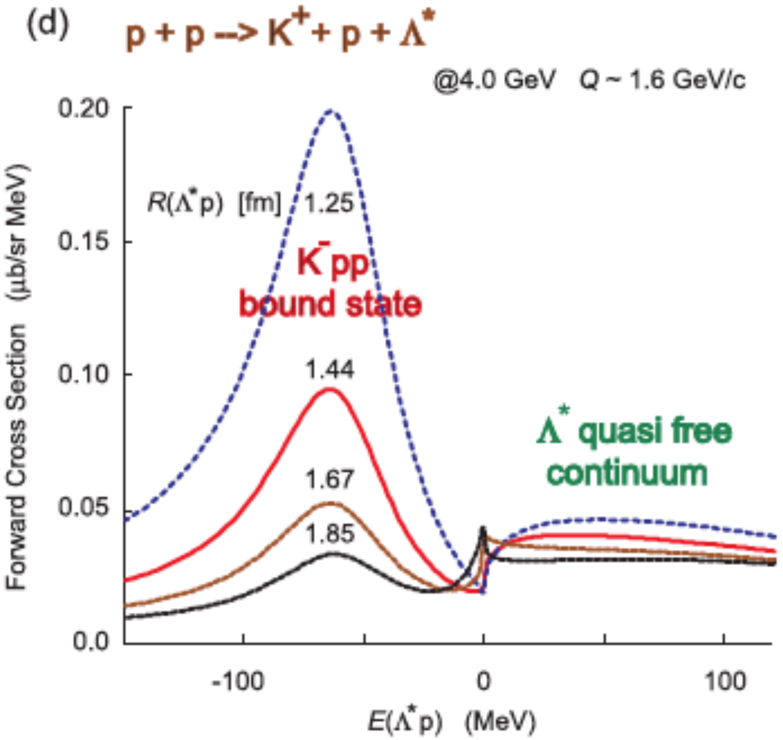
matches the small size ~ 1 fm

of the dense $K^{-}pp$ bound state.

sticking probability ~ 1

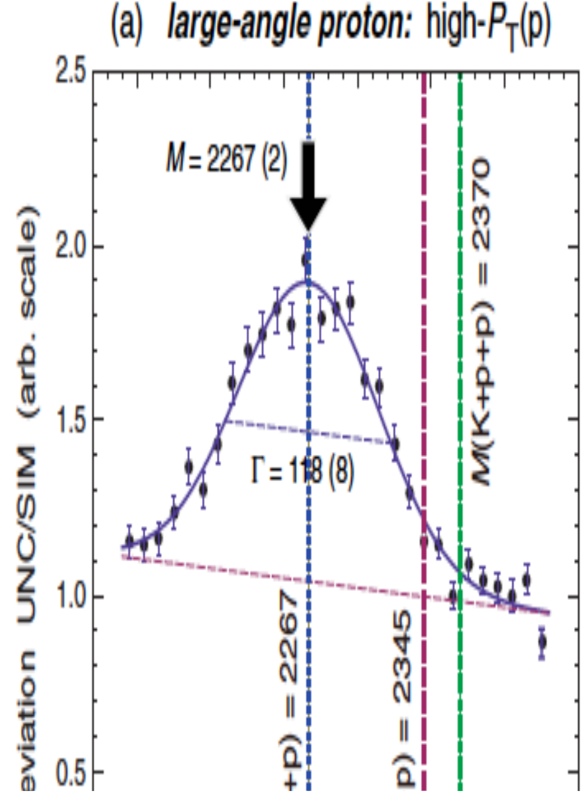
Dominance of Λ_{1405}-p sticking

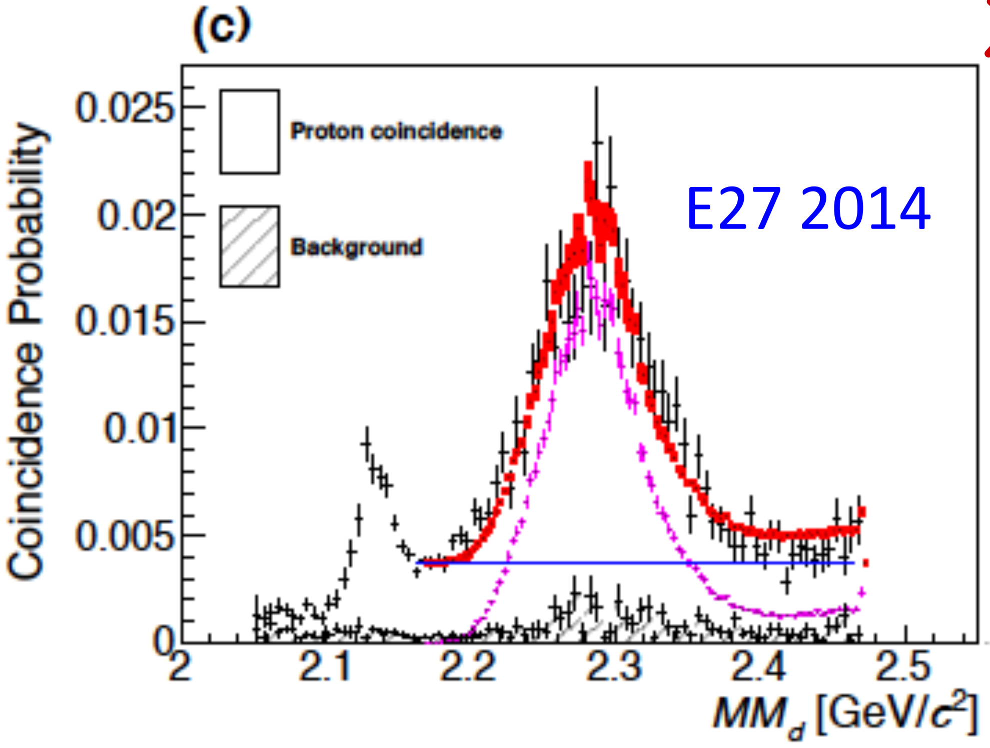
in NN collisions: **Λ^{*}-p doorway**



Experimental evidences

DISTO 2010





E27 2014

X2265 -> p+Λ population

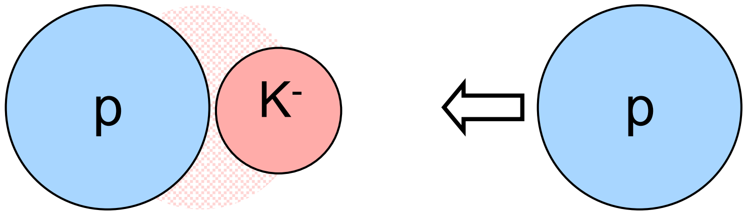
~ 100% in p + p -> X + K^+
q = 1.6 GeV/c

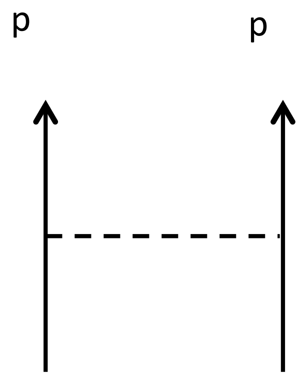
Indicating:

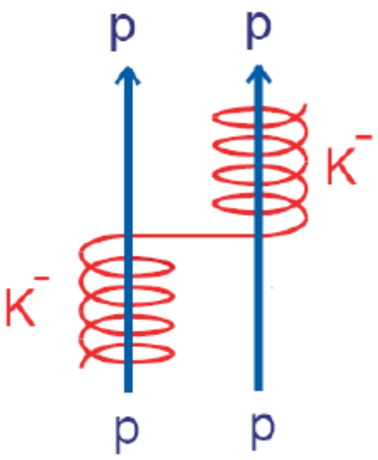
X2265 = dense K^-pp
B.E. ~ 100 MeV

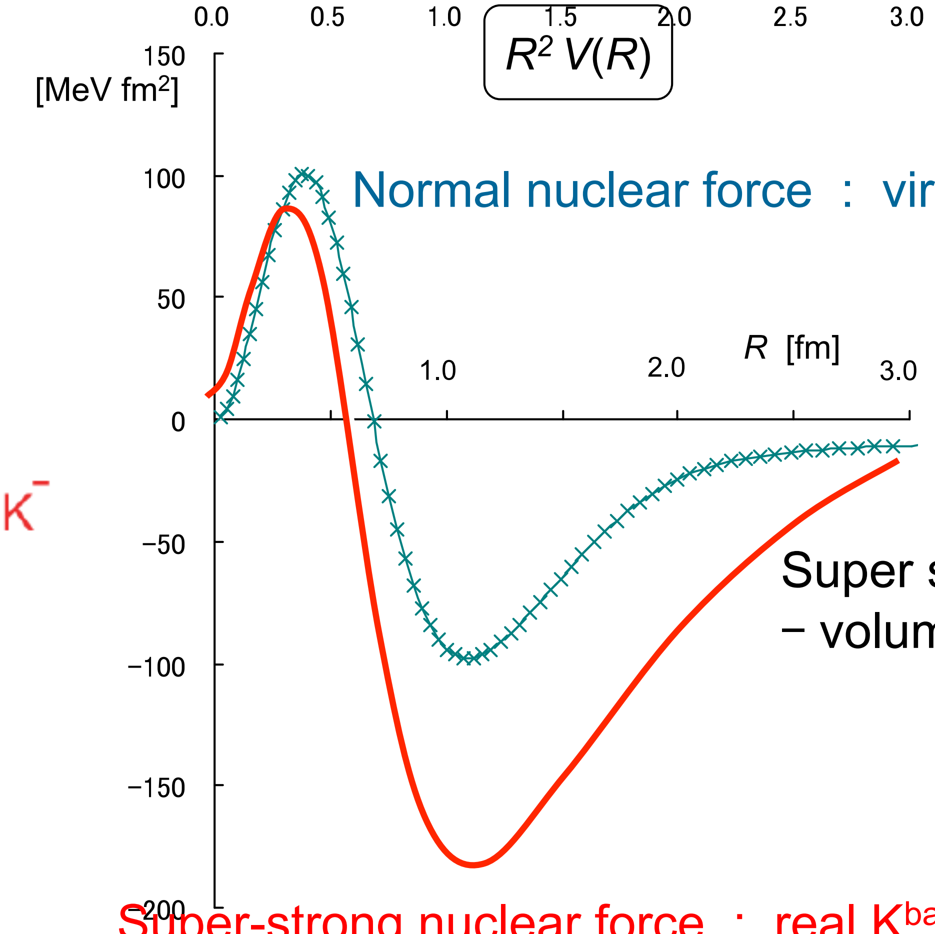
J-PARC E27
Ichikawa et al. 2014
~ 2% in π^+ + d -> X + K^+
q = 0.3 GeV/c

Adiabatic p-p potential in K^-pp









Normal nuclear force : virtual meson exchange

Super strong / Normal ~ 4.1

− volume integral ratio −

Super-strong nuclear force : real K^{bar} migration

* Impacts of the observed K^-pp:

Enormous cross section of $p + p \to K^-pp + K^+$

Low cross section at $d(\pi^+,K^+)\ K^-pp$

→ indicate a dense system

Binding energy by a factor of 2 larger than theory

→ indicates 20% enhanced K^{bar}-N attraction

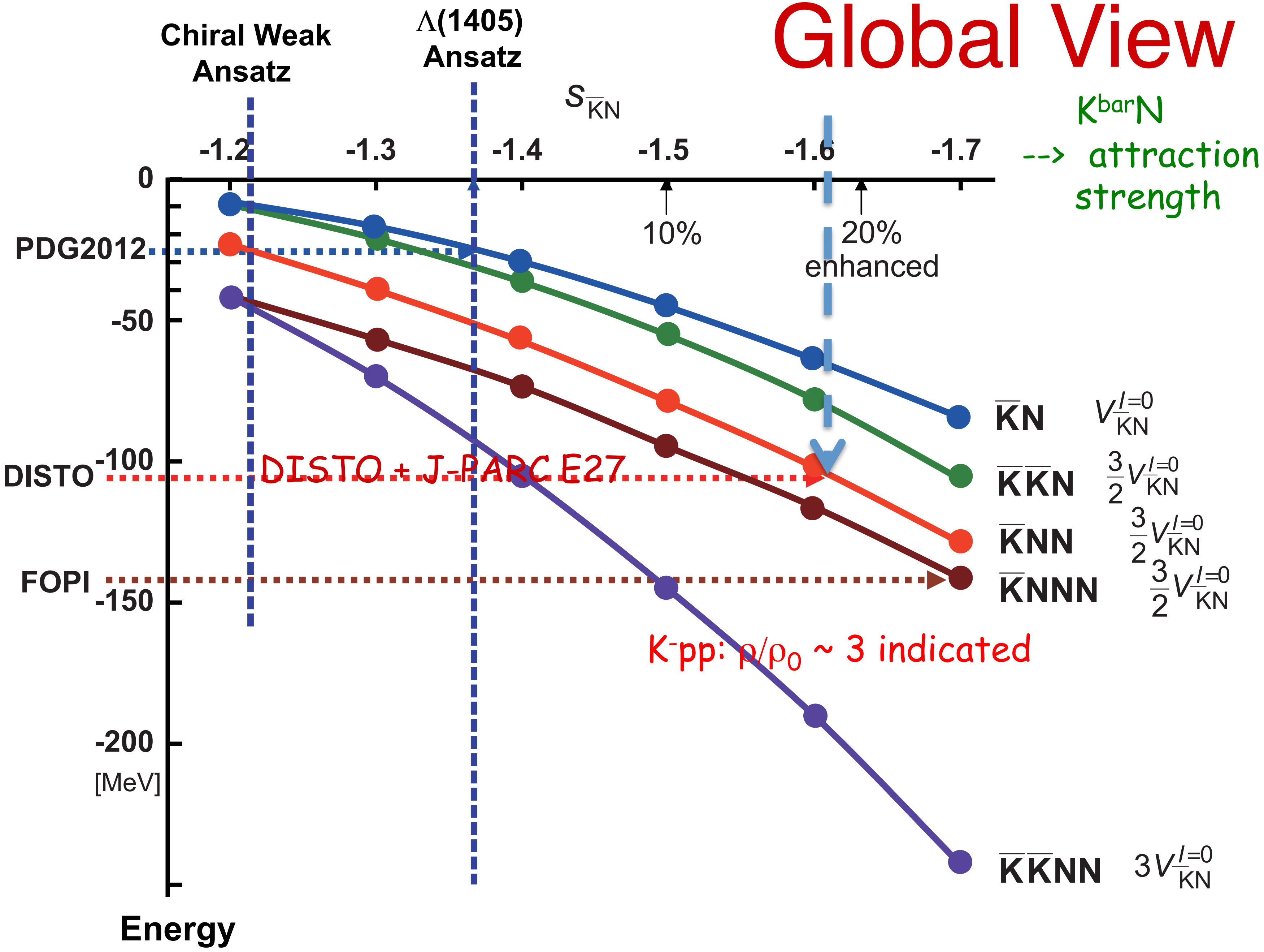
→ suggesting chiral symmetry restoration;

increasing attraction, densities

Hadronic phase to quark-gluon phase !?

Maeda et al., Proc. Jpn. Acad. **B 89** (2013) 418 Faddeev-Yakubovsky

Global View



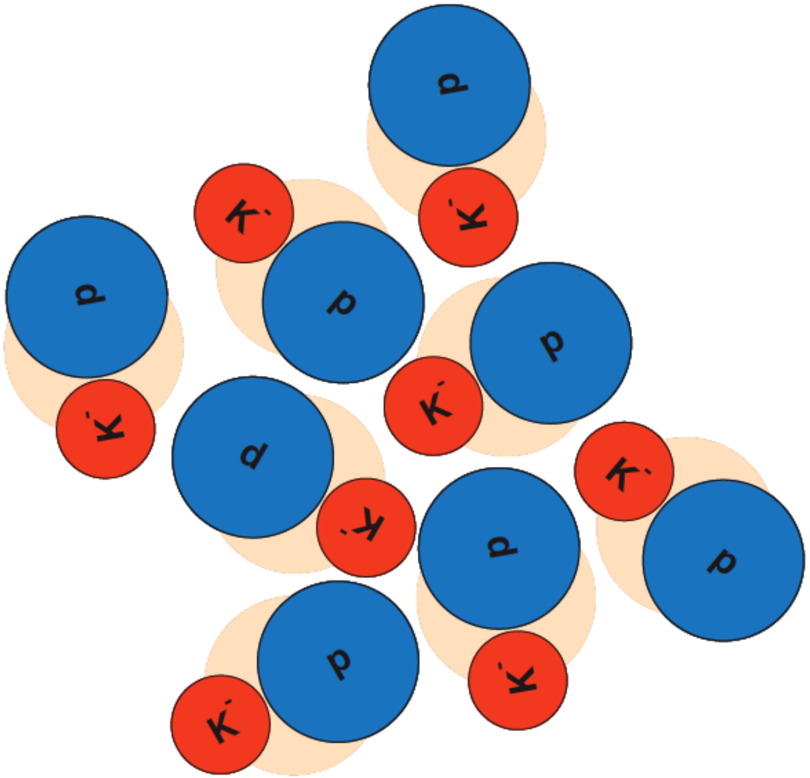
S. Maeda, Y. Akaishi & T. Yamazaki, Proc. Jpn. Acad. 89 (2013) 418

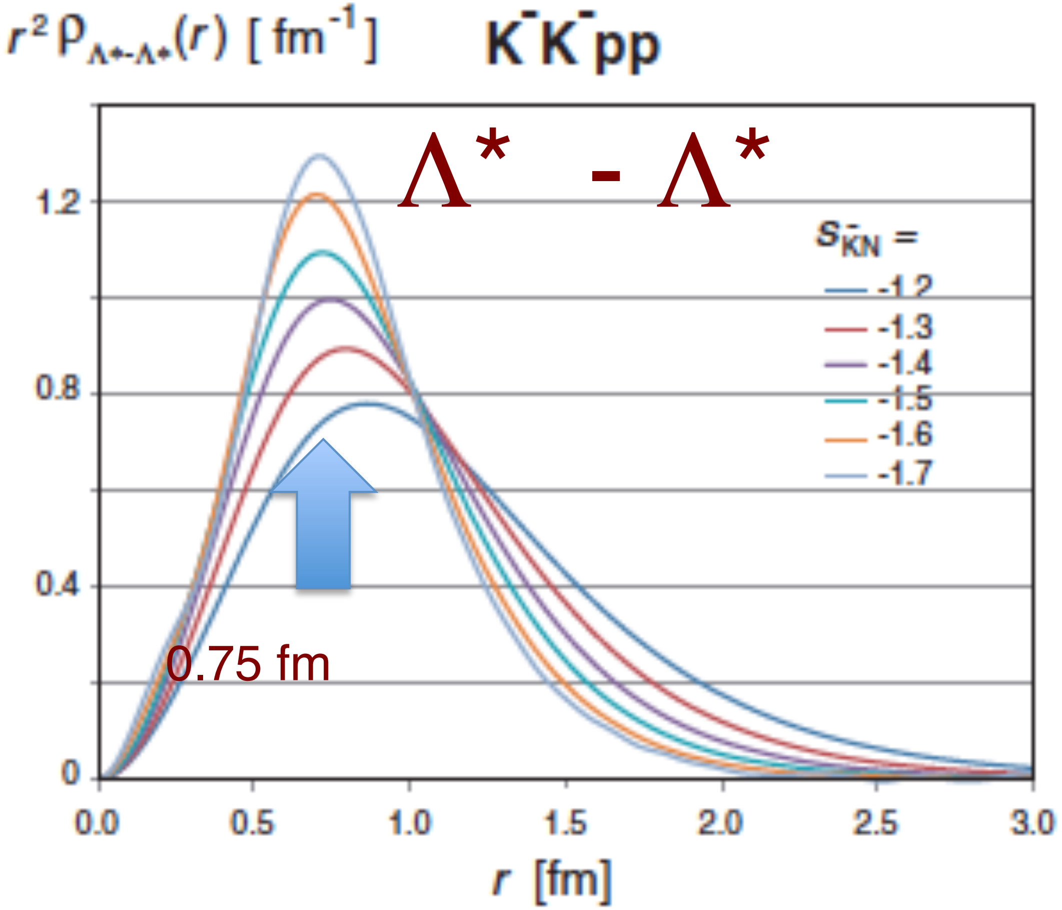
Dynamical formation of Λ^*=K^-p clusters in K^-K^-pp → Λ^* condensed matter

No repulsion among K^-'s

Strong attraction among Λ^*'s

K^-p (Λ^*) condensed matter





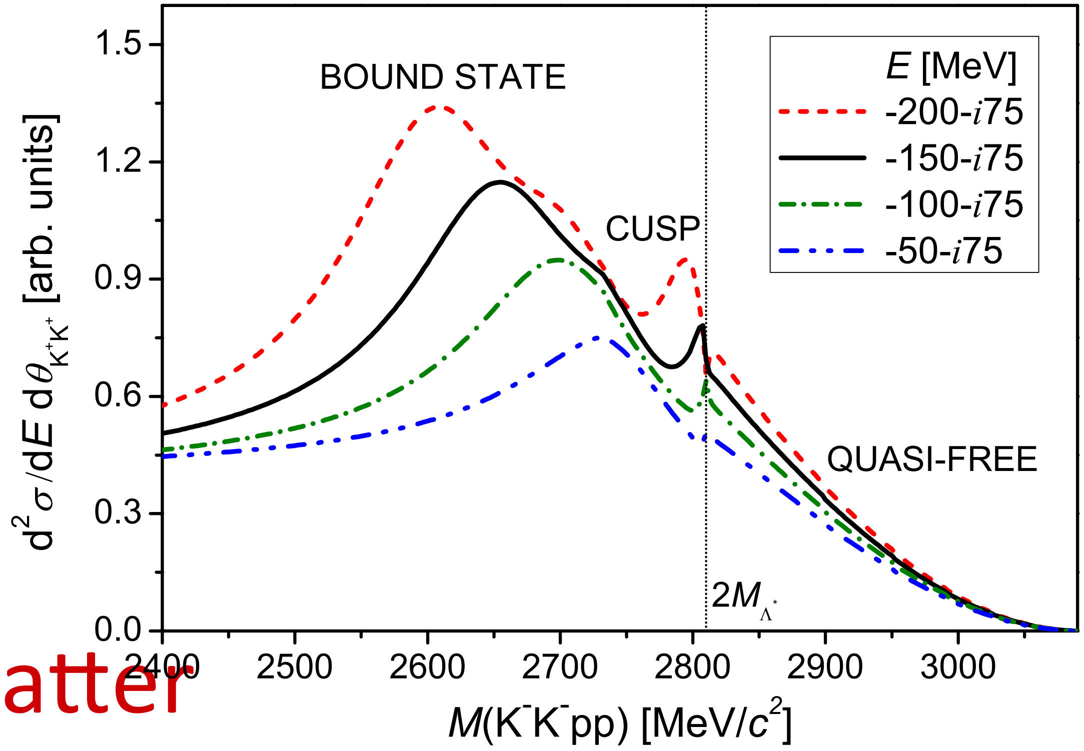
NEW EXPERIMENTAL PROPOSAL (conceptual)

PRODUCTION OF

K^-K^-pp

Gateway toward

Kaon Condensed Matter



by p + p -> $\Lambda^* + \Lambda^* + K^+ + K^+$

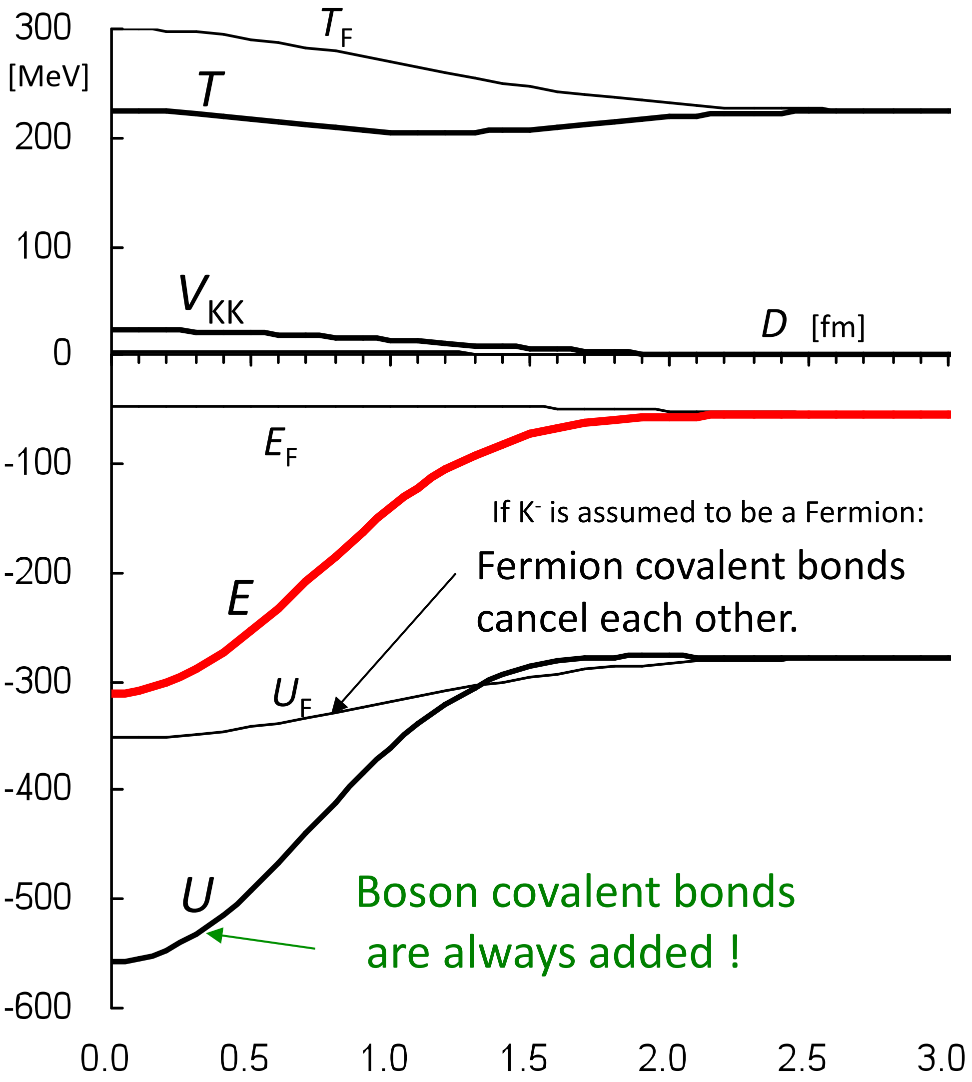
-> $K^-K^-pp + K^+ + K^+$

A denser state more favored in short-range collision

$\Lambda^*\Lambda^*$ model for K^-K^-pp

Y. Akaishi

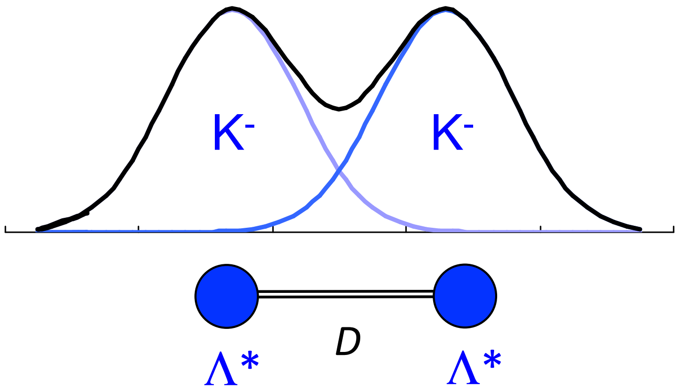
$$\Phi(\vec{r}_1,\vec{r}_2) = N\{\phi_a(\vec{r}_1)\phi_b(\vec{r}_2) \pm \phi_b(\vec{r}_1)\phi_a(\vec{r}_2)\}$$

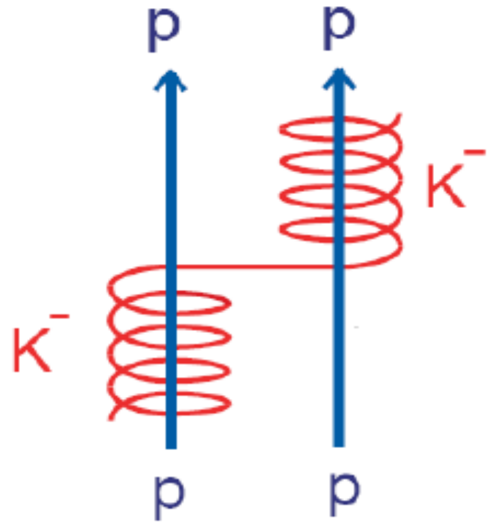


If K^- is assumed to be a Fermion:

Fermion covalent bonds cancel each other.

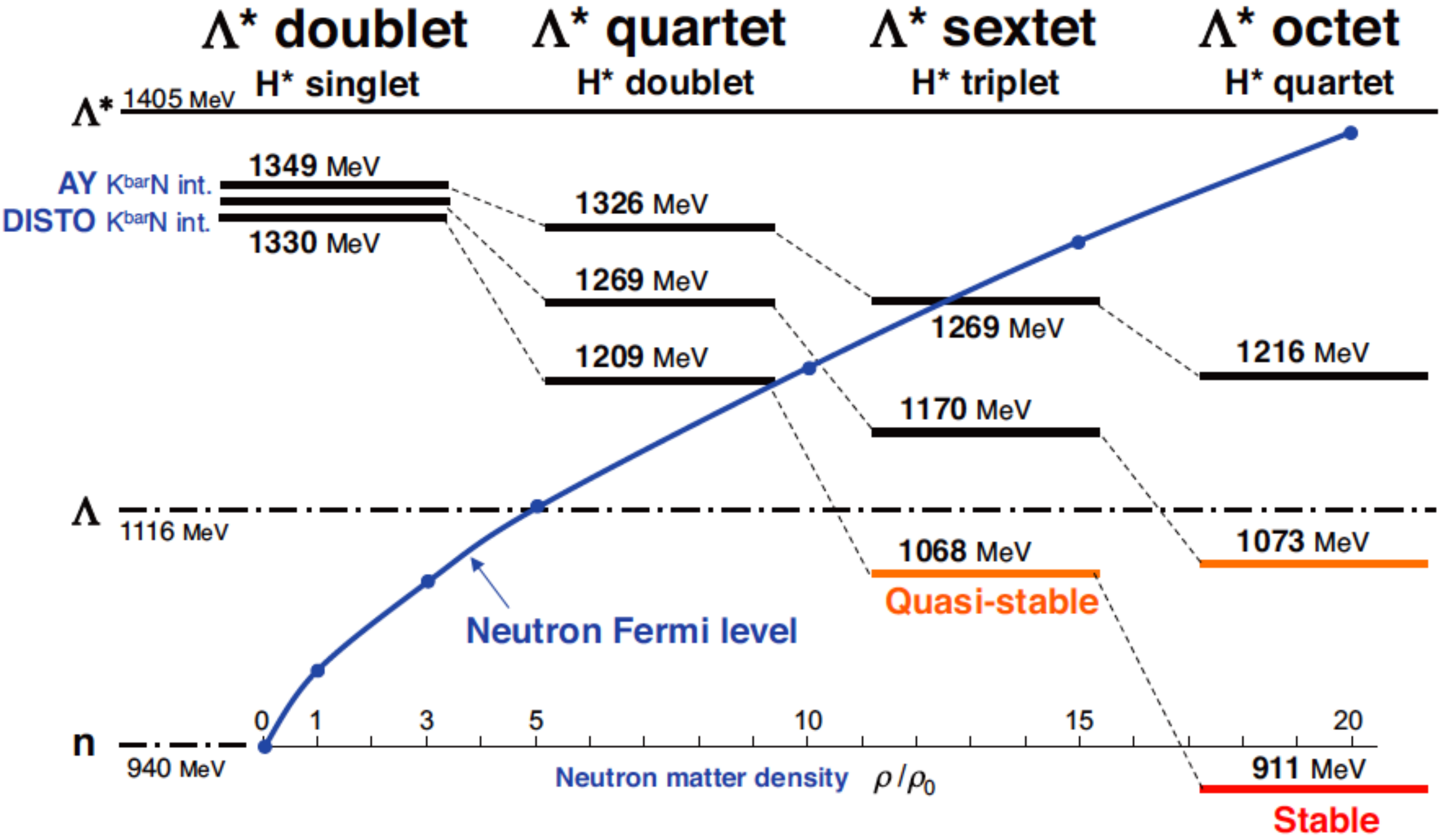
Boson covalent bonds are always added !





Λ* effective mass in Λ* strangelet

$K^-K^-pp = \Lambda^*\Lambda^* = H^*$



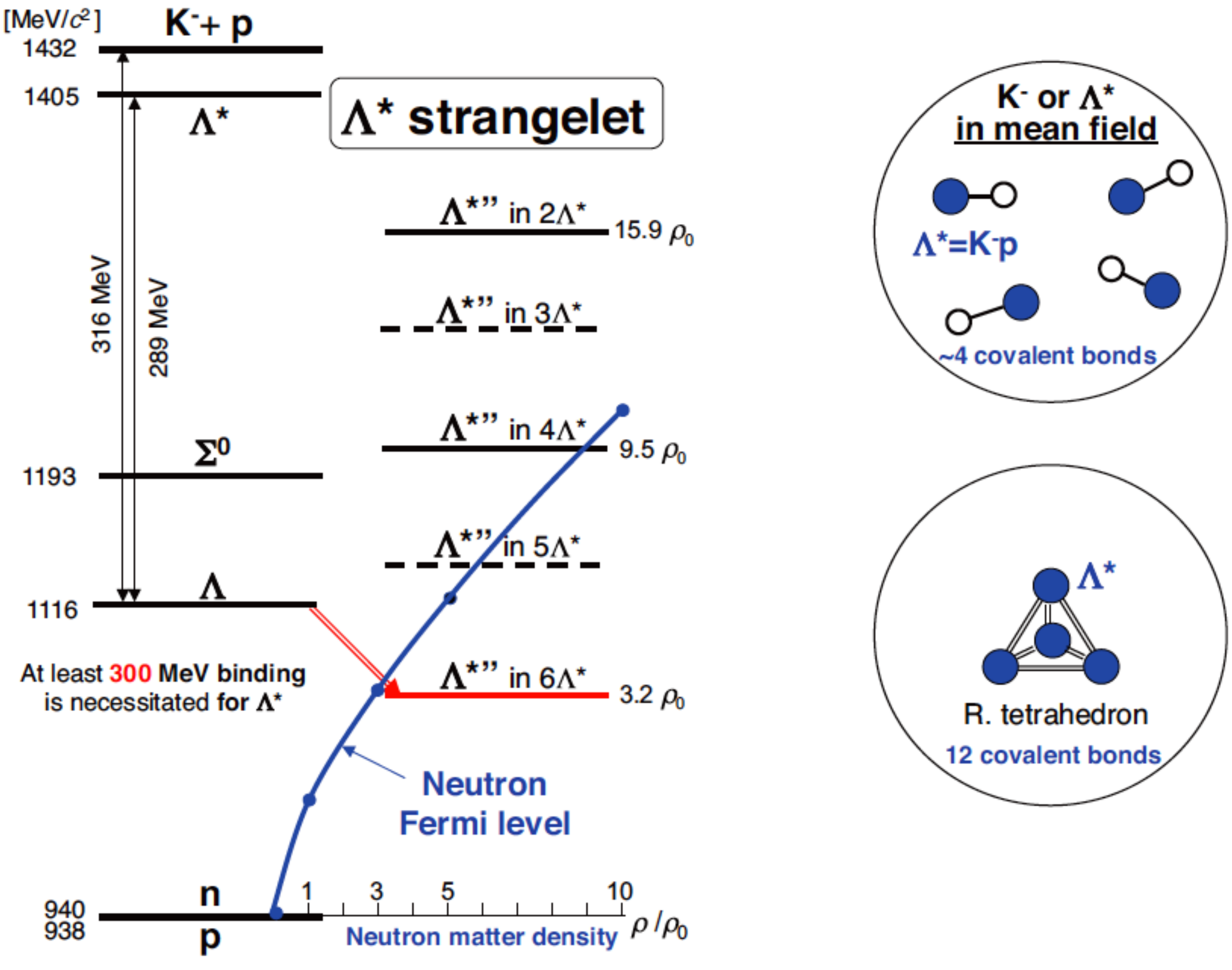
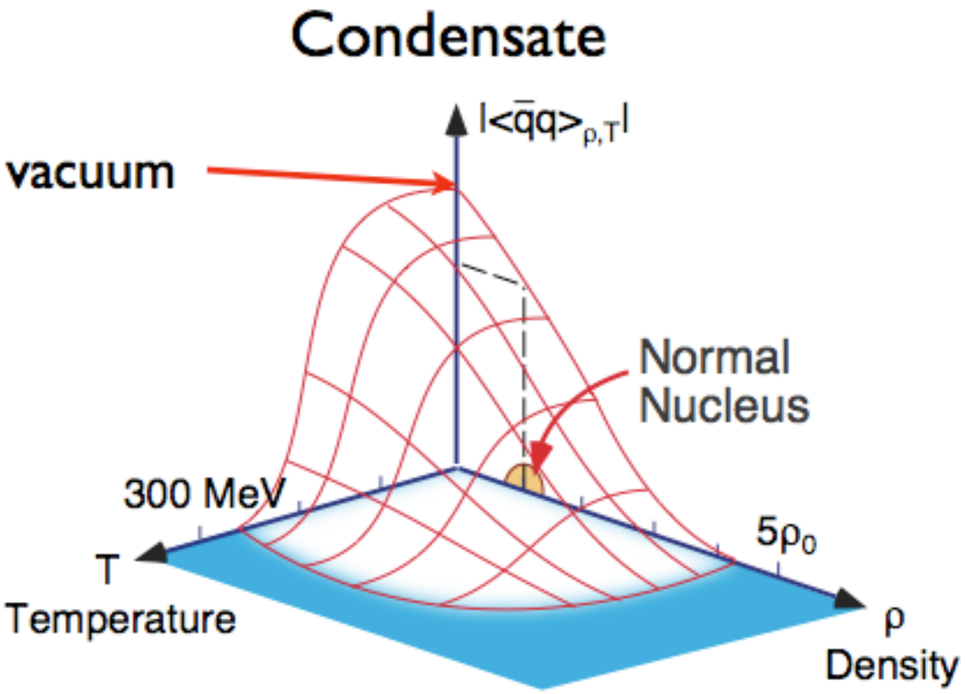


FIG. 4: **Fig-v3-2-L*strangelet-levels.eps** Predicted energy levels of $\Lambda^* = K^-p$ in Λ^* multiplets. The corresponding nuclear densities and neutron Fermi levels are also shown, indicating that the Λ^* in the Λ^* sextet cannot decay to neutron.



T. Hatsuda and T. Kunihiro, Phys. Rev. Lett. 55 (1985) 158.
W. Weise, Nucl. Phys. A443 (1993) 59c.

$$\frac{<\bar{q}q>_\rho}{<\bar{q}q>_0} \approx 1 - \frac{v_N}{v_\rho}\frac{\rho}{\rho_0} \approx 1 - \frac{1}{3}\frac{\rho}{\rho_0}$$

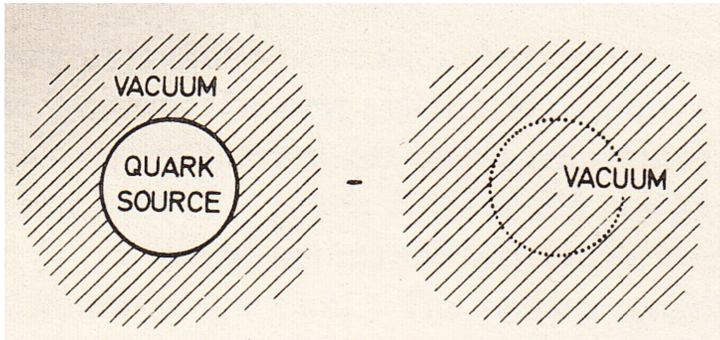
For ρ -> 3 ρ_0,
Chiral restoration,

Isovector πN:
increased repulsion
GSI (2005) and RIKEN (2015) experiments
confirmed
in π^- 1s states in Sn

I = 0 KbarN:
increased attraction
→ shrinkage

Chiral symmetry restoration of KbarN interaction in dense nuclear medium

Clearing QCD vacuum model



Brown, G.E., Kubodera, K. and Rho, M. (1987) Strangeness condensation and "clearing" of the vacuum. Phys. Lett. B **192**, 273–278.

QCD vacuum expressed by the quark condensate is reduced by the amount of clearing of the QCD vacuum by the presence of nucleons.

QCD-vacuum clearing factor

$$\Omega = \frac{n \cdot v_N}{V_{\rm nucl}}$$

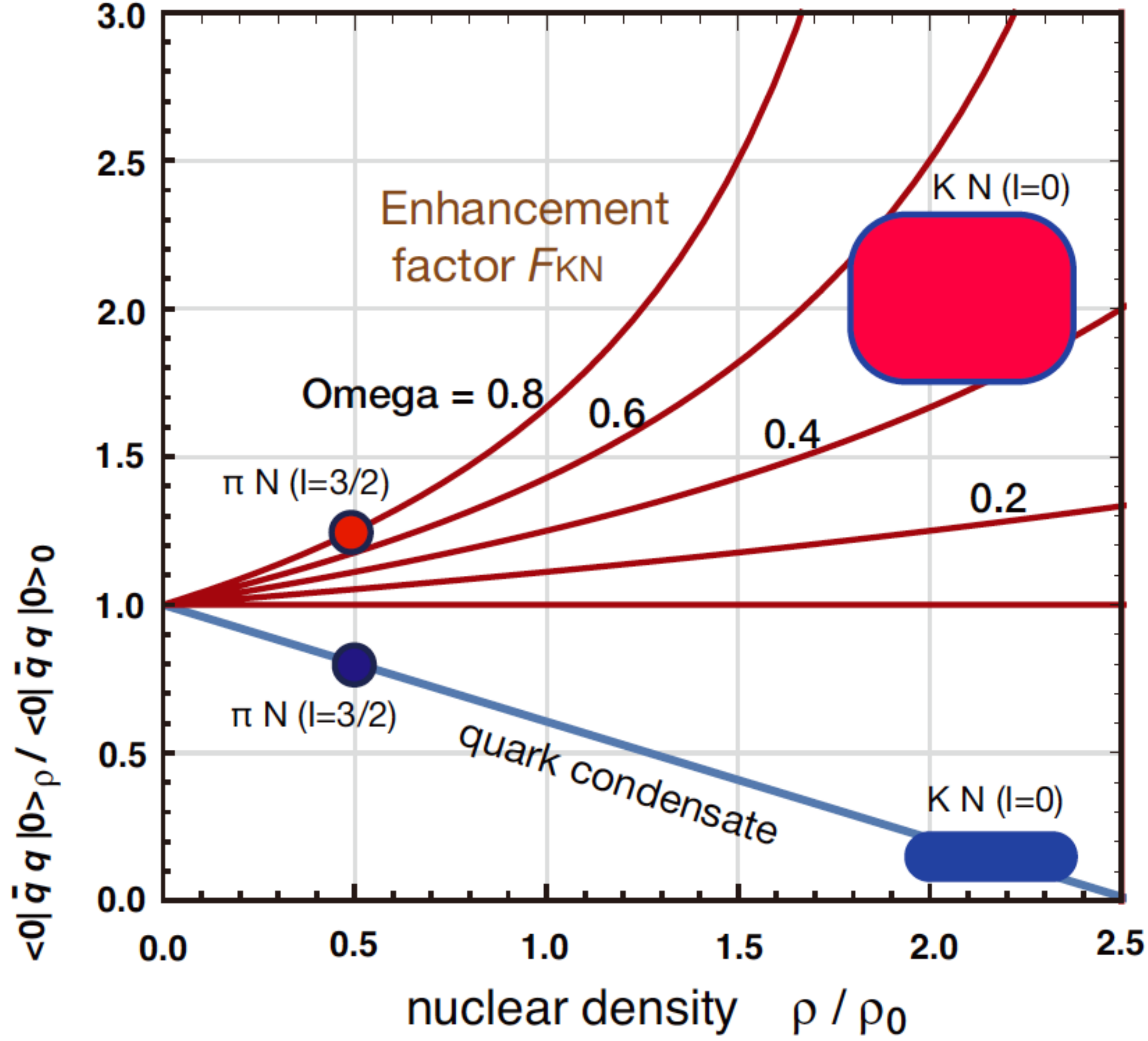
→

Attraction enhancement factor

$$F_{\pi N} = \frac{|\langle 0|\bar{q}q|0\rangle_0|}{|\langle 0|\bar{q}q|0\rangle_\rho|} \approx \frac{1}{1-\Omega},$$

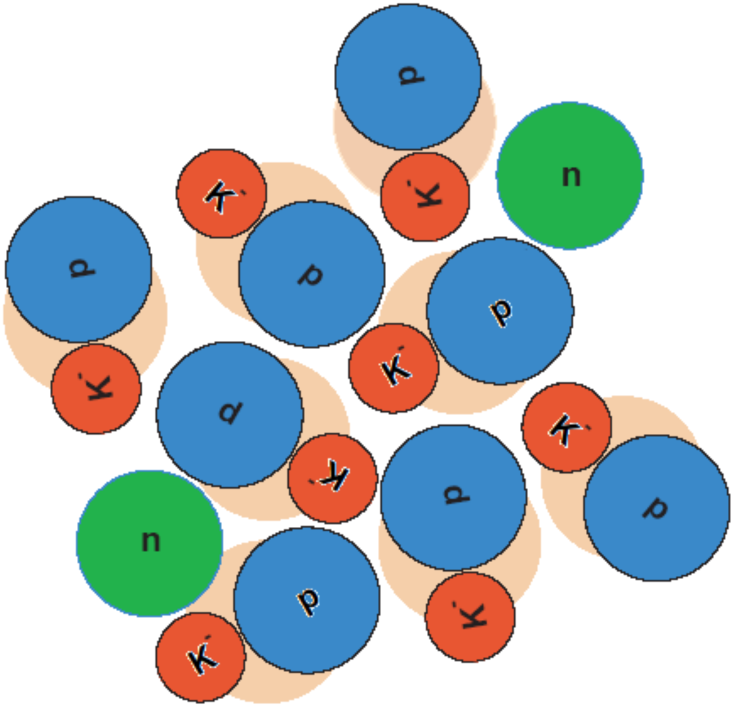
$$F_{\bar{K}N} = \frac{|\langle 0|\bar{q}q|0\rangle_0|}{|\langle 0|\bar{q}q|0\rangle_\rho|} \approx \frac{1}{1-0.5\,\Omega}$$

Chiral Symmetry Restoration in πN and $K^{bar}N$



Kaonic Proton Matter conceived

K^-K^-pp is almost identical to Λ^*-Λ^* in structure, indicating that a large number of K^-p units constitute a large Λ^* system, which can be lighter than dense neutron system; no exit to decay: thus stable



$$M[\Lambda^* = (K^-p)] < M[n]$$

So, we expect stable Λ^* (K^-p) matter may exist as strange dusts, namely, a kind of DARK MATTER.

$$K^-p = s\,(u^{bar}\text{-}u)\,ud$$

The KPM is stabilized by quark-anti-quark hybrids.

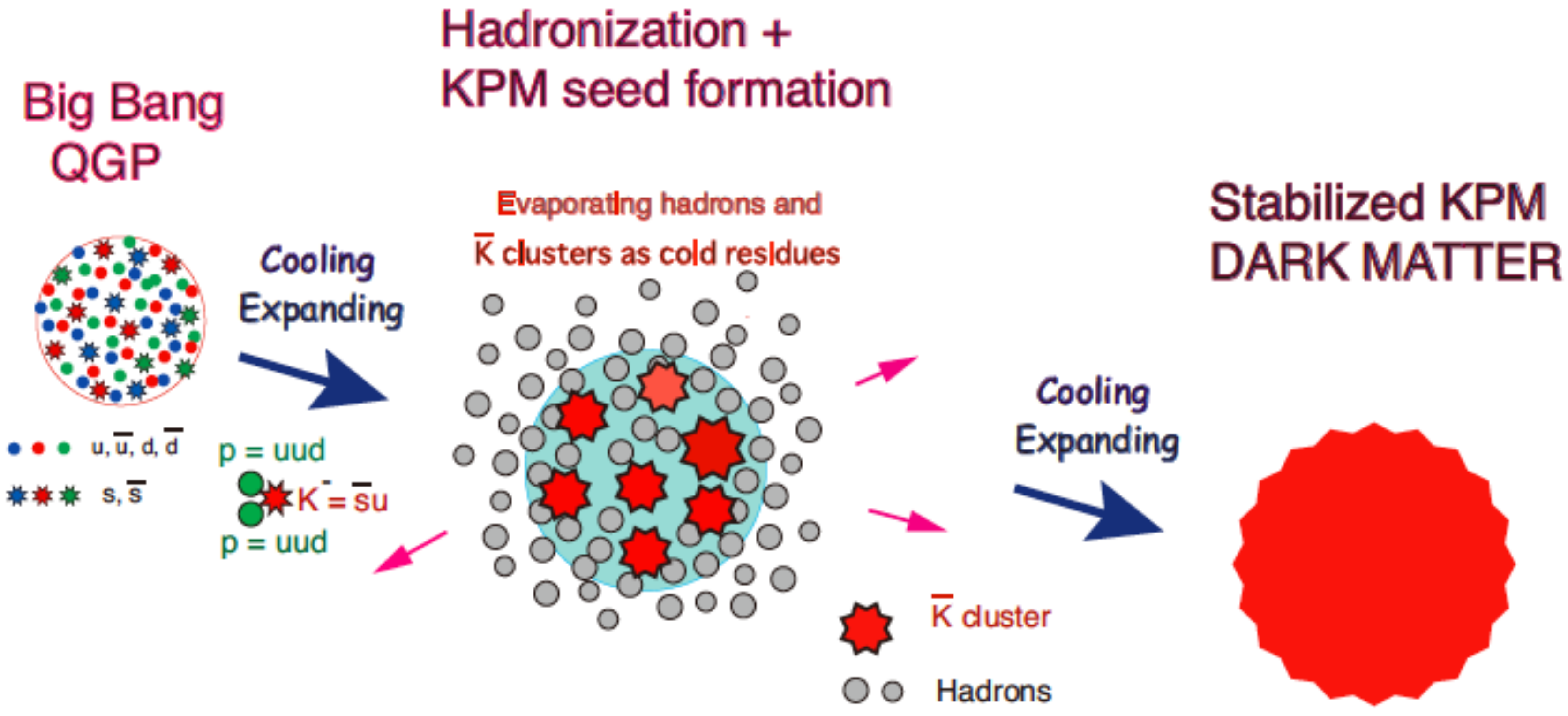
Its existence depends on chiral symmetry restoration.

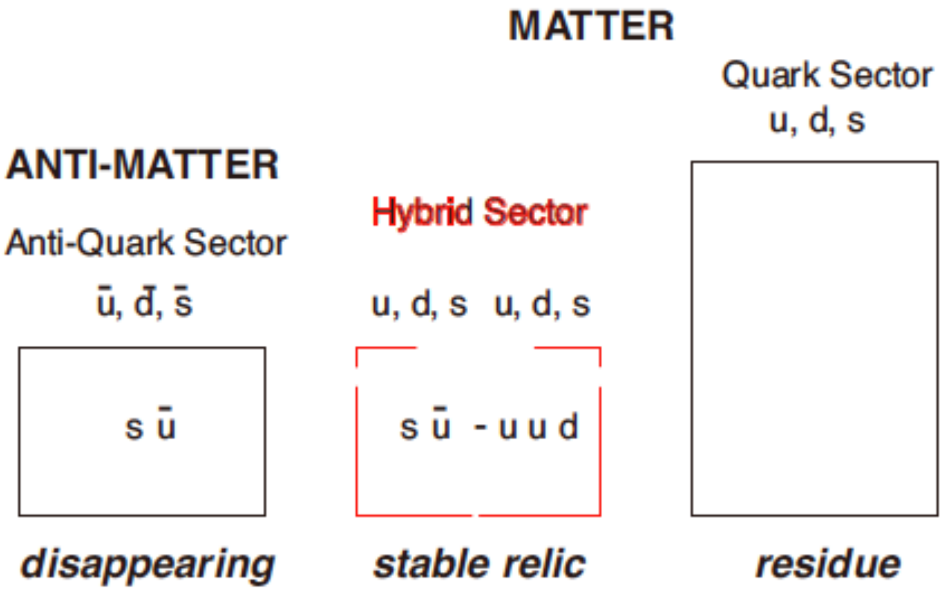
KPM produced only in Big Bang

K-p, K-pp, K-K-pp,,, deep but short lived: Γ ~ 100 MeV
So, short-lived multi-Λ* ($j<j_{crit}$) cannot survive during cascade collisions of hadrons K- and p !
How can KPM be created?

Only one conceivable environment is QGP after Big Bang; Both quarks and anti-quarks are diminishing by annihilation to the level of +- 2 x 10^{-8}, where the quark-sector dominates and the anti-quark sector remains as a hybrid sector with stable mixture of quarks and anti-quarks: eventually going as multiple

[s u^{bar} - u ub] -> K^{bar}-proton





MATTER

ANTI-MATTER

Anti-Quark Sector

$\bar{u}, \bar{d}, \bar{s}$

$s\,\bar{u}$

disappearing

Hybrid Sector

u, d, s u, d, s

$s\,\bar{u}$ - u u d

stable relic

Quark Sector

u, d, s

residue

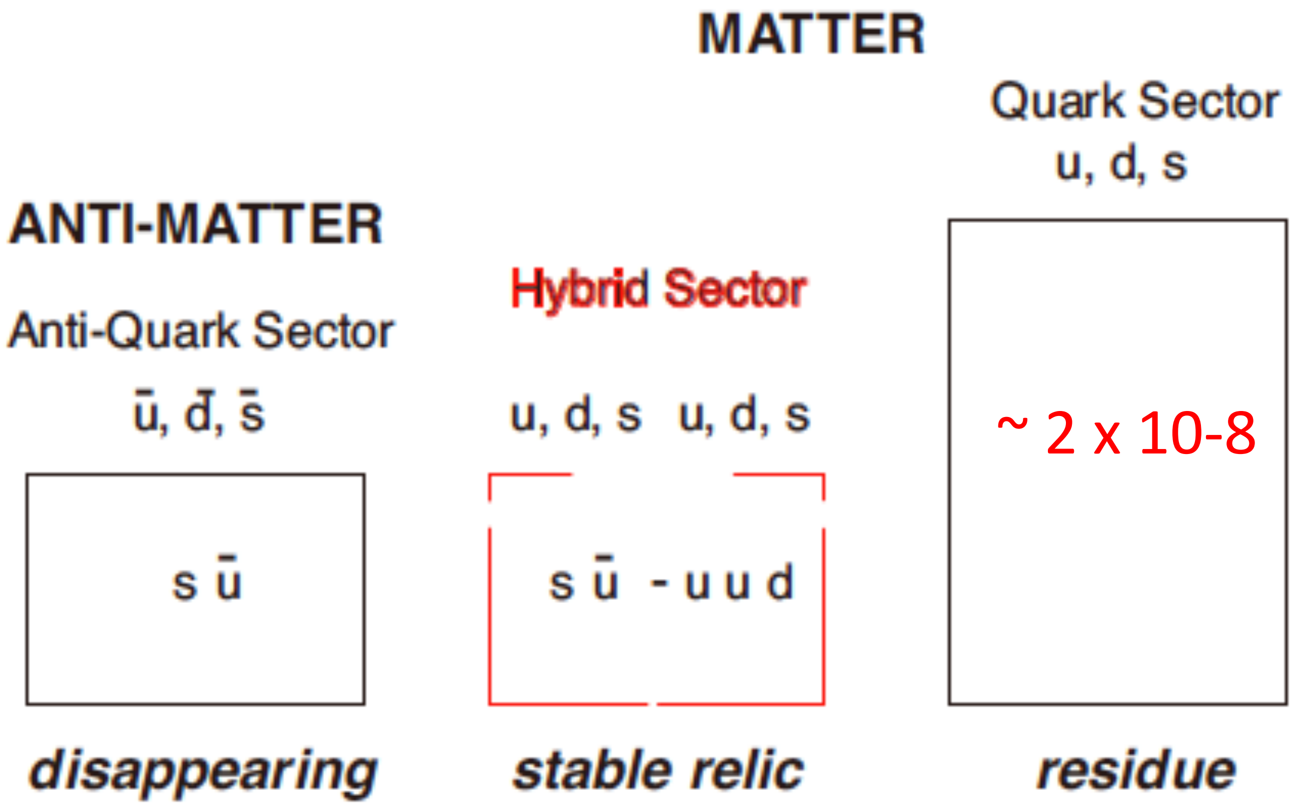
Kaonic Proton Matter

s u^{bar} - u u d

Strong attraction

No short-range repulsion

Related Problems:
Where and when anti-matter disappeared ?



MATTER

ANTI-MATTER

Anti-Quark Sector

$\bar{u}, \bar{d}, \bar{s}$

$s\bar{u}$

disappearing

Hybrid Sector

u, d, s   u, d, s

$s\bar{u}$ - uud

stable relic

Quark Sector

u, d, s

~ 2 x 10-8

residue

Primordial anti-quarks

Primordial quarks

Recent experiments @ HI collisions at LHC-ALICE

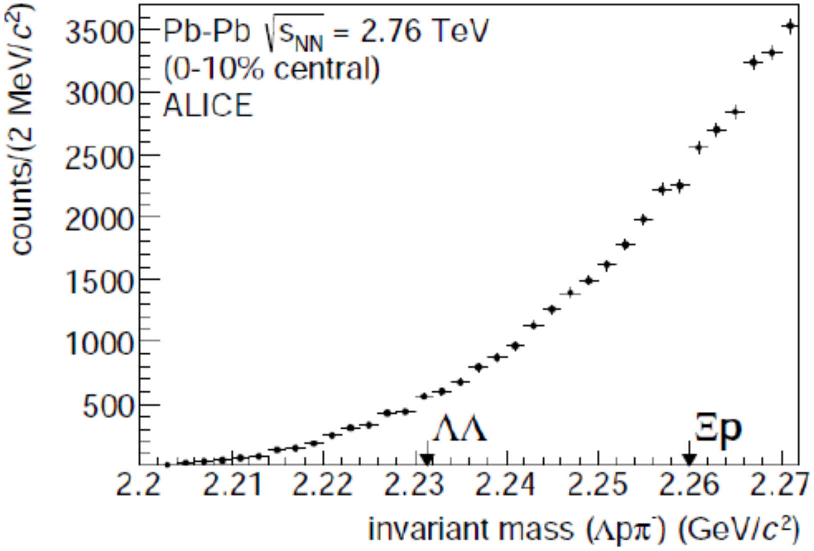
theoretical analyses
by P. Braun-Munzinger's group

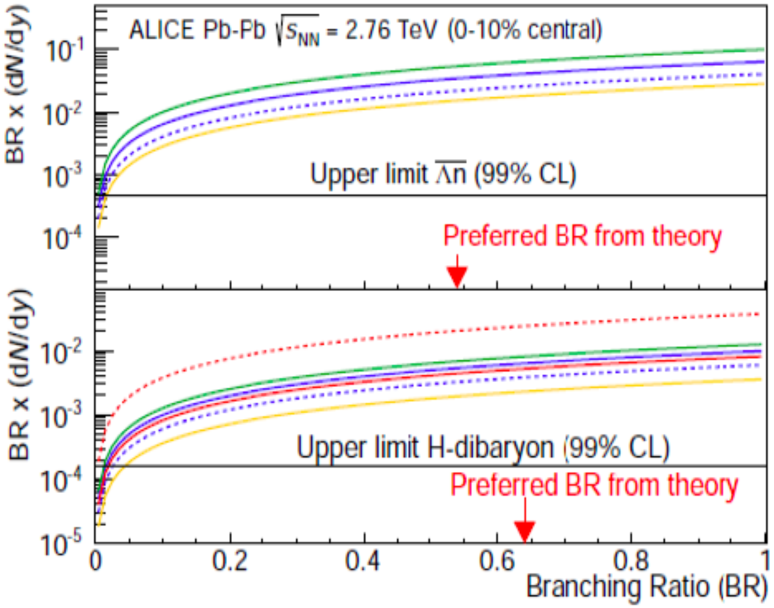
HYP2015, Sendai

Next 3 pages taken from this talk

searches for exotic bound states

Nicole Martin and Benjamin Doenigus, ALICE





no H, Lambda-n bound states

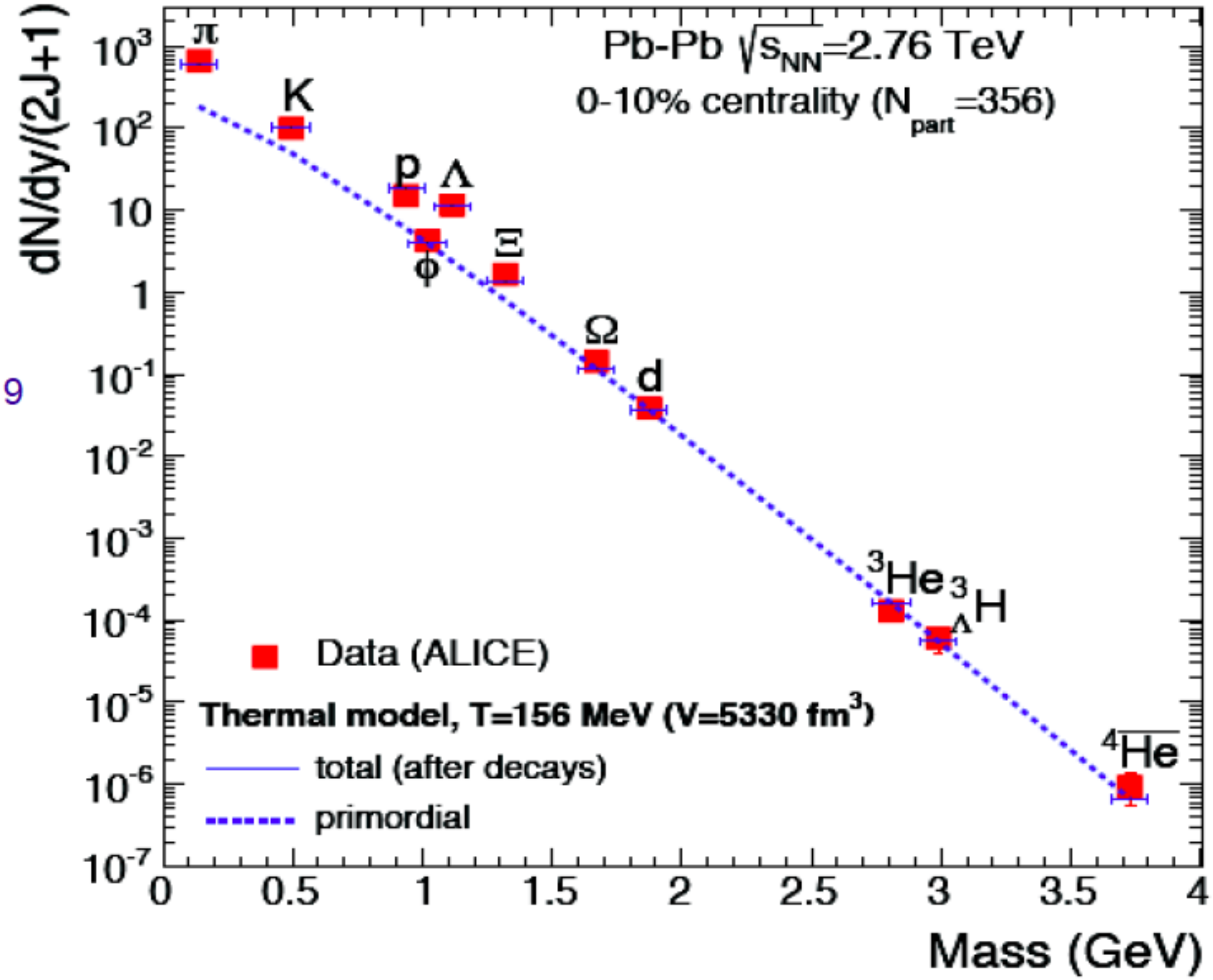
arXiv:1506.07499

No exotic bound states yet found: such as $K^-K^-pp \rightarrow \Lambda + \Lambda$

Expected at M=2.8 GeV/c2

… and also including anti-alphas

agreement over 9 orders of magnitude with QCD statistical operator prediction



yield of light nuclei predicted in: pbm, J. Stachel, J.Phys. G28 (2002) 1971-1976,
J.Phys. G21 (1995) L17-L20

Thermal model of particle production and QCD

Partition function Z(T,V) contains sum over the full hadronic mass spectrum and is fully calculable in QCD

For each particle i, the statistical operator is:

P. Braun-Munzinger

$$\ln Z_i = \frac{V g_i}{2\pi^2} \int_0^\infty \pm p^2 \mathrm{d}p \ln[1 \pm \exp(-(E_i - \mu_i)/T)]$$

Particle densities are then calculated according to:

$$n_i = N_i/V = -\frac{T}{V}\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 \mathrm{d}p}{\exp[(E_i - \mu_i)/T] \pm 1}$$

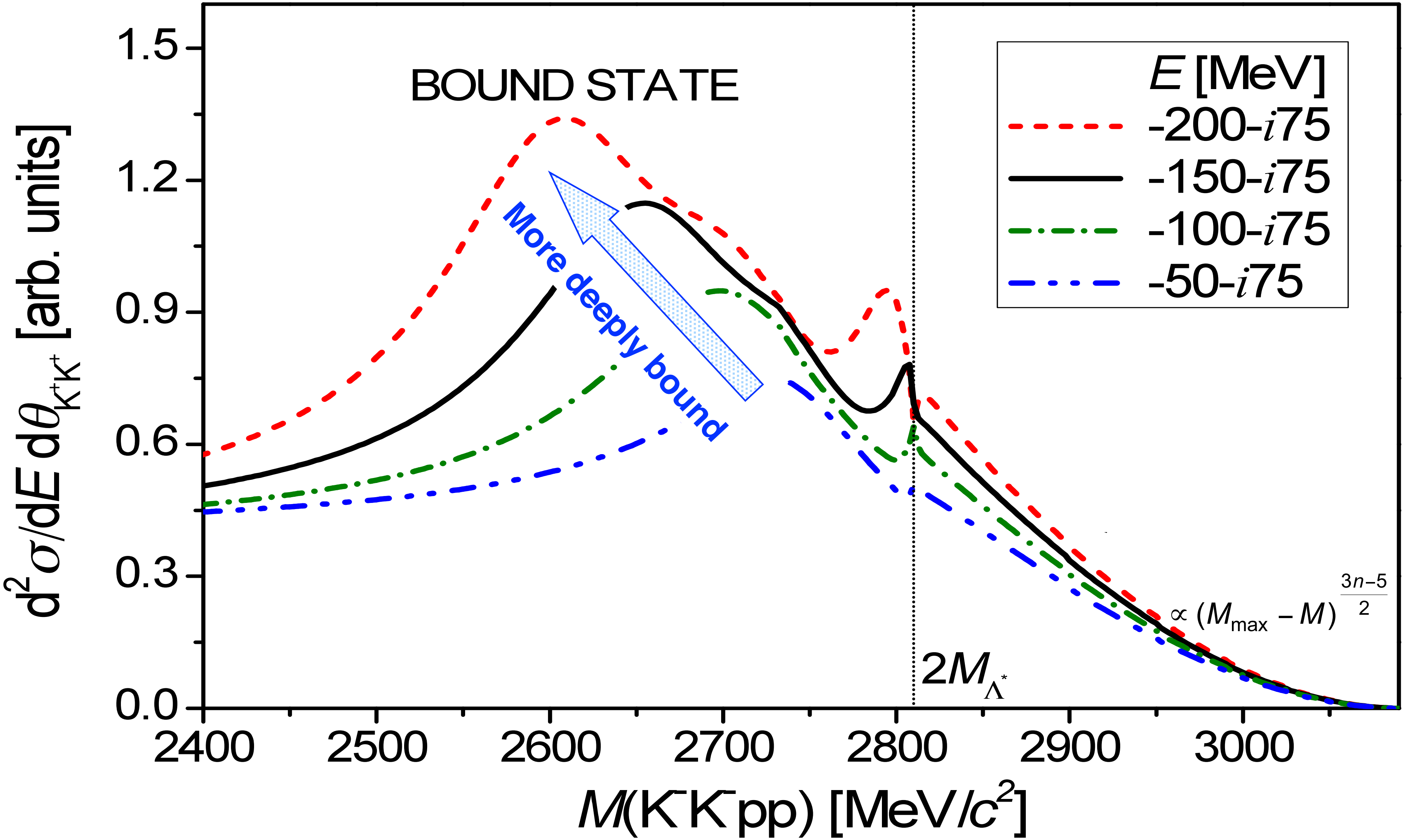
From analysis of all available nuclear collision data we now know the energy dependence of the parameters T, mu_b, and V over an energy range from threshold to LHC energy and can confidently extrapolate to even higher energies

In practice, we use the full experimental hadronic mass spectrum from the PDG compilation to compute the 'primordial yield'

Comparison with measured hadron yields needs evaluation of all strong decays

Production cross section of K^-K^-pp

M. Hassanvand, Y. Akaishi & T. Yamazaki, Phys. Rev. C 84 (2011) 015207



"Hard formation process" different from **Coalescence model and statistical model**

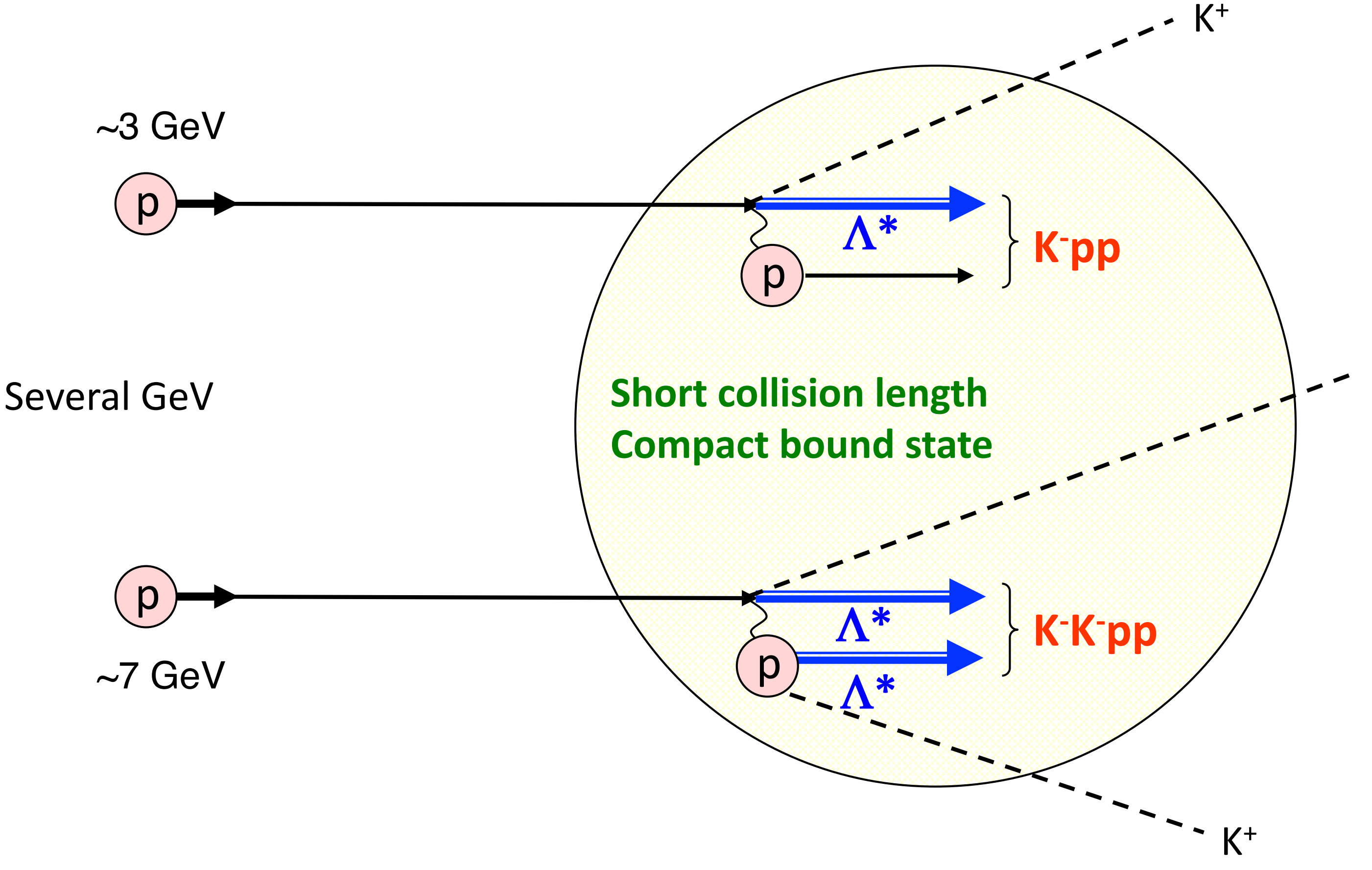
(S. Cho et al., Phys. Rev. Lett. 106 (2011) 212001)

The late Prof. Nishijima

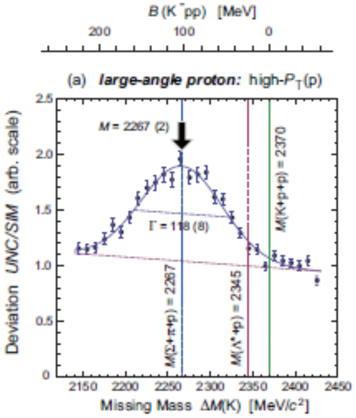
Gateway to "Swan Nuclear Physics"

T. Yamazaki, Y. Akaishi & M. Hassanvand, Proc. Jpn. Acad. B 87 (2011) 362

Bright future is expected at J-PARC



Short collision length
Compact bound state



DISTO