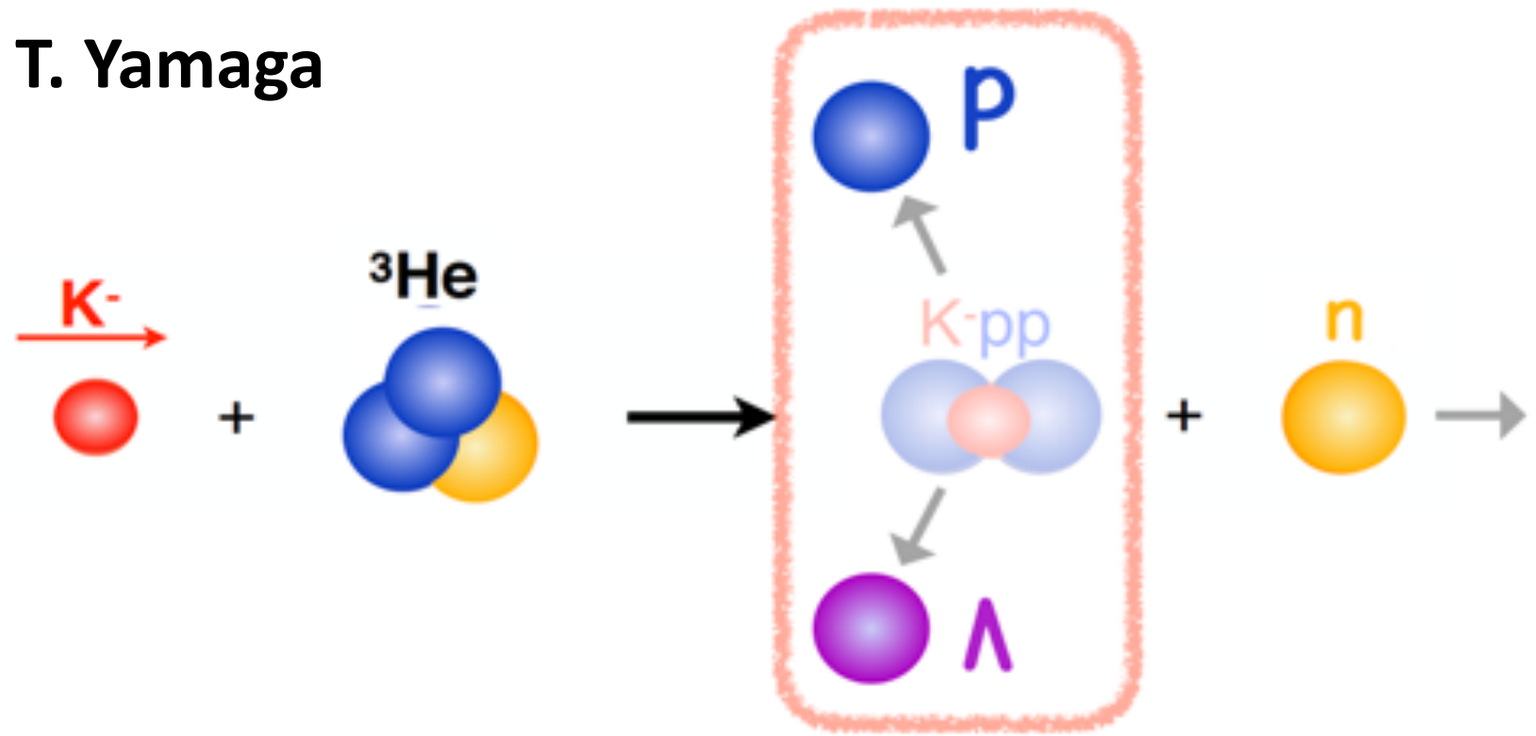
J-PARC E15実験の解析の進展と今後の展望

J-PARC E15 Present & Future

— for J-PARC E15 collaboration —

T. Yamaga



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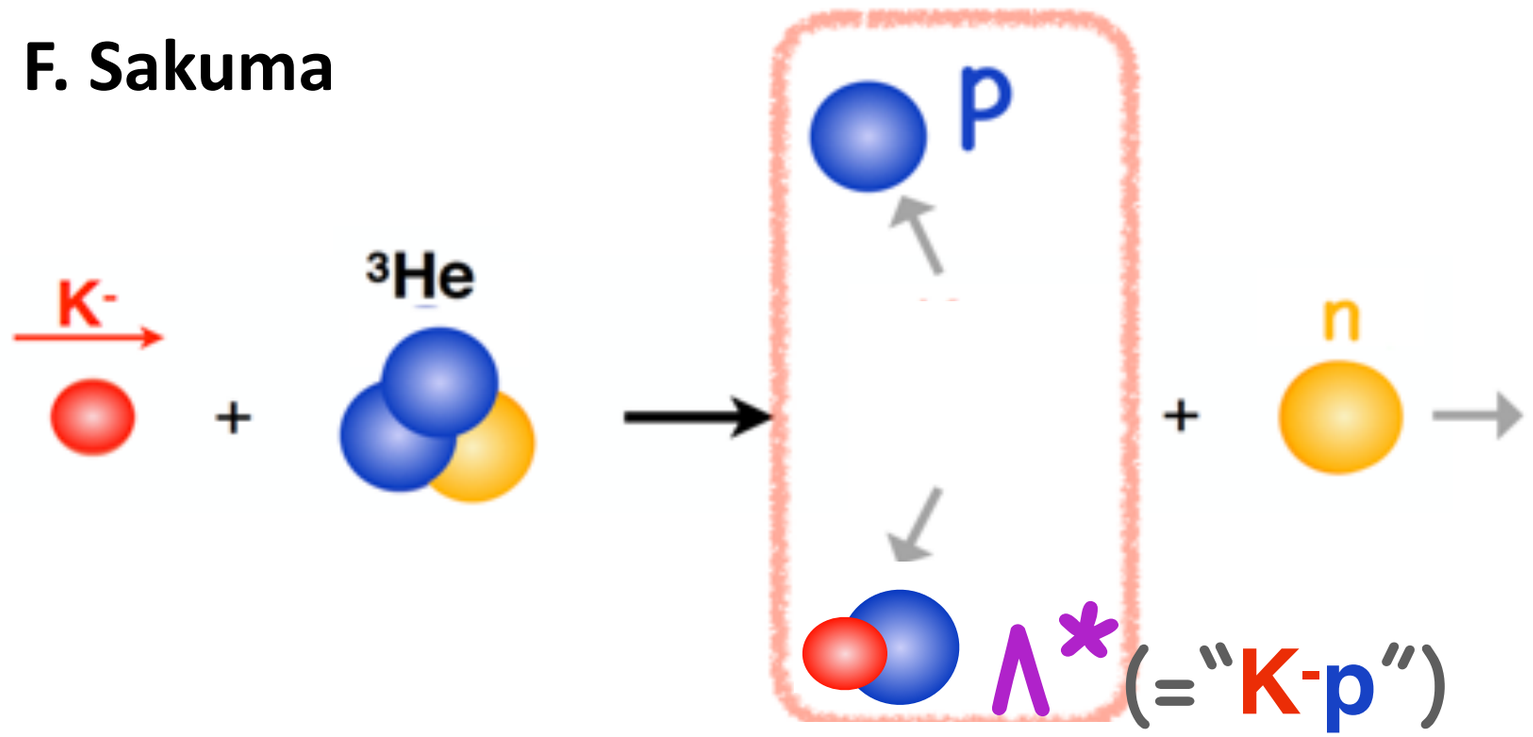

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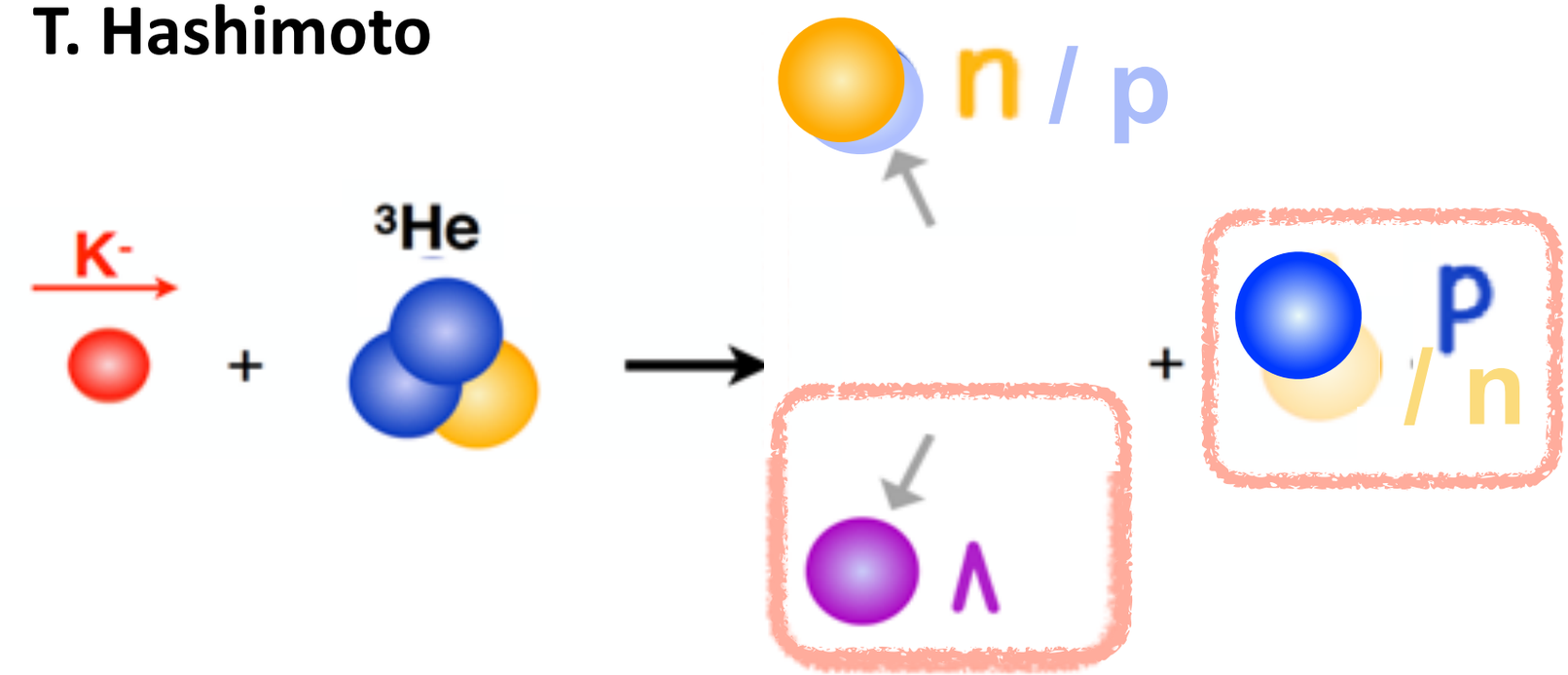


non-mesonic reaction channel @ $\theta_N = 0$?

Yukawa's theorem

relativistic scalar boson field (Klein-Gordon Eq.)

$$\left\{\Box - \kappa^2\right\} U = 0 \quad \text{or} \quad \left\{\left(\hat{E}^2 - \hat{\mathbf{p}}^2\right) - m^2\right\}\phi = 0$$

(ħ = c = 1)

$$\phi \propto \frac{\exp(-mr)}{r} \quad \text{for} \quad E = 0 \qquad \phi \propto \exp(i(Et - \mathbf{p}\cdot\mathbf{x})) \quad \text{for} \quad E \geq m$$

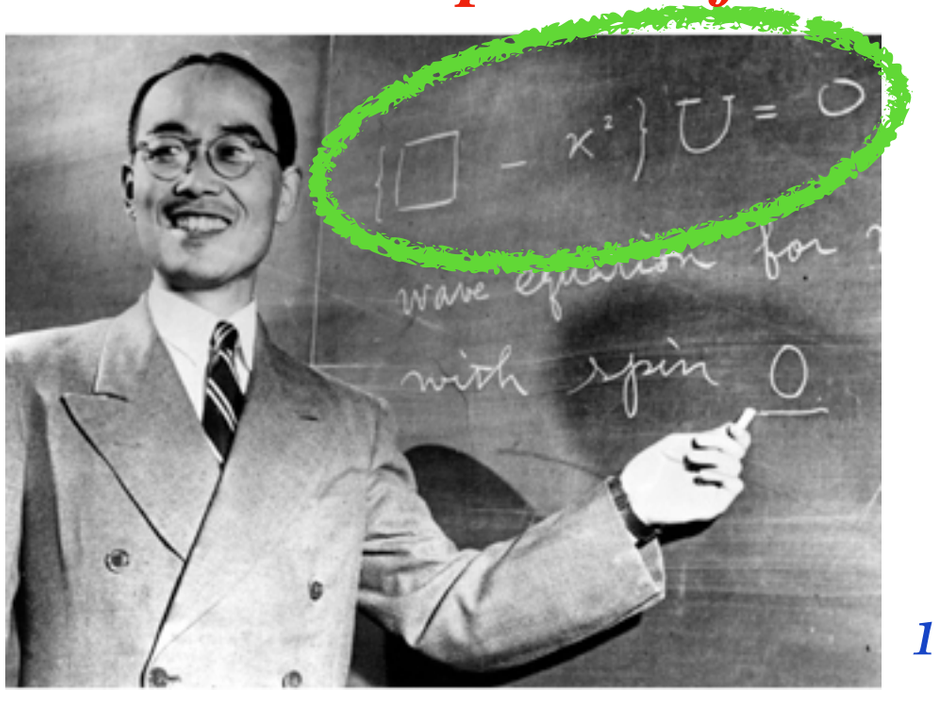
Yukawa potential

Static point source wave function of total energy Zero

plane-wave

Similar to Schrödinger but energy shifted by m

virtual pion as for nucleon glue (m-0 gives Coulomb!)



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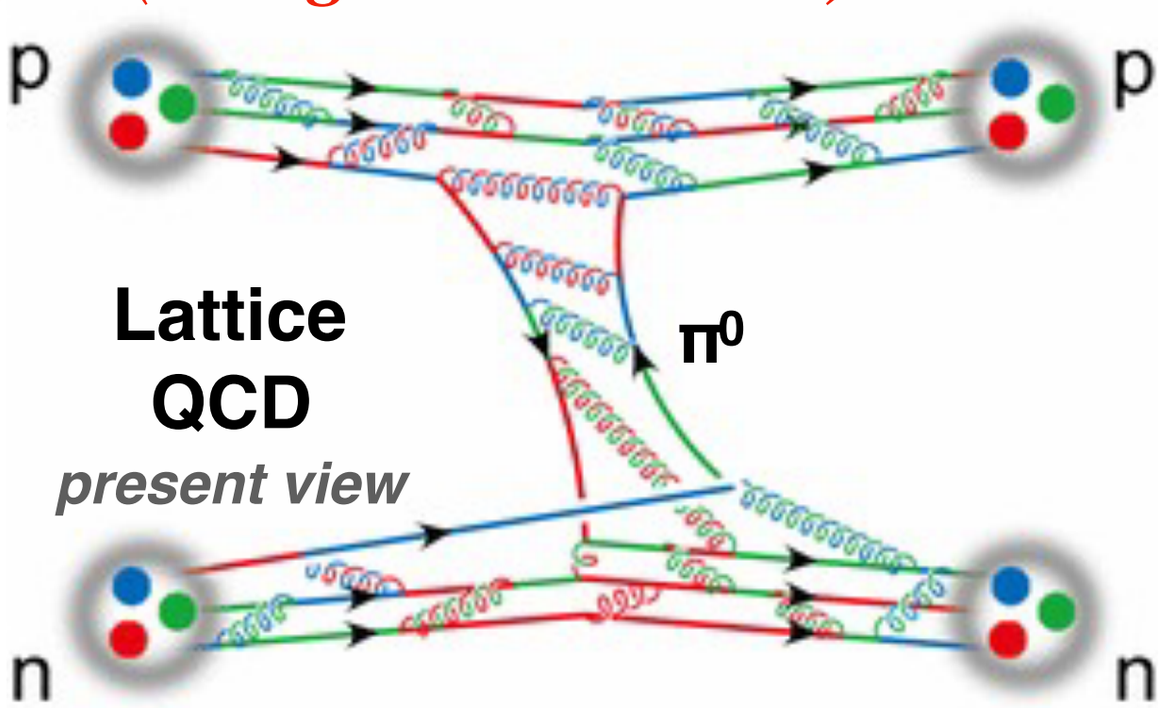


Meson in vacuum

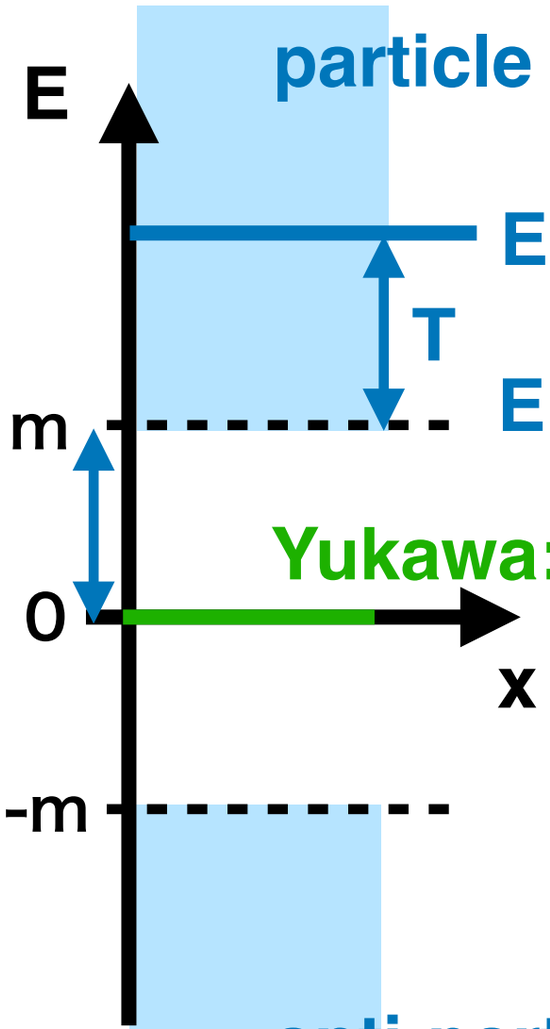
Particular solution having point-source

$$\phi \propto \frac{\exp(-mr)}{r} \quad \text{for} \quad E = 0$$

Yukawa potential
= Coulomb for *m* = 0

$$\phi \propto \exp(i(Et - \mathbf{p} \cdot \mathbf{x})) \quad \text{for} \quad E \geq m$$

plane-wave solution



$E = mc^2$

virtual pion as for nucleon glue

absolute zero-point for E?

absolute zero-point for T = –273.15 °C

Meson in Atom (exotic)

$m \sim 100$ MeV/c^2

E(keV)

E

$E = m - \frac{C}{r} + T$

T

T

Coulomb scattering

$m \sim 100$ MeV/c^2

bound states

$V_C \sim$ keV

$E = m - \frac{C}{r}$

$= V_C$

Coulomb potential

0

r (pm)

different hierarchy

Meson in Nucleus?

$m \sim 100$ MeV/c^2

E(100MeV)

$E = m - V + T$

elastic scattering

T

T

$m \sim 100$ MeV/c^2

B

V ~100 MeV

bound states?

T

$E = m - V$

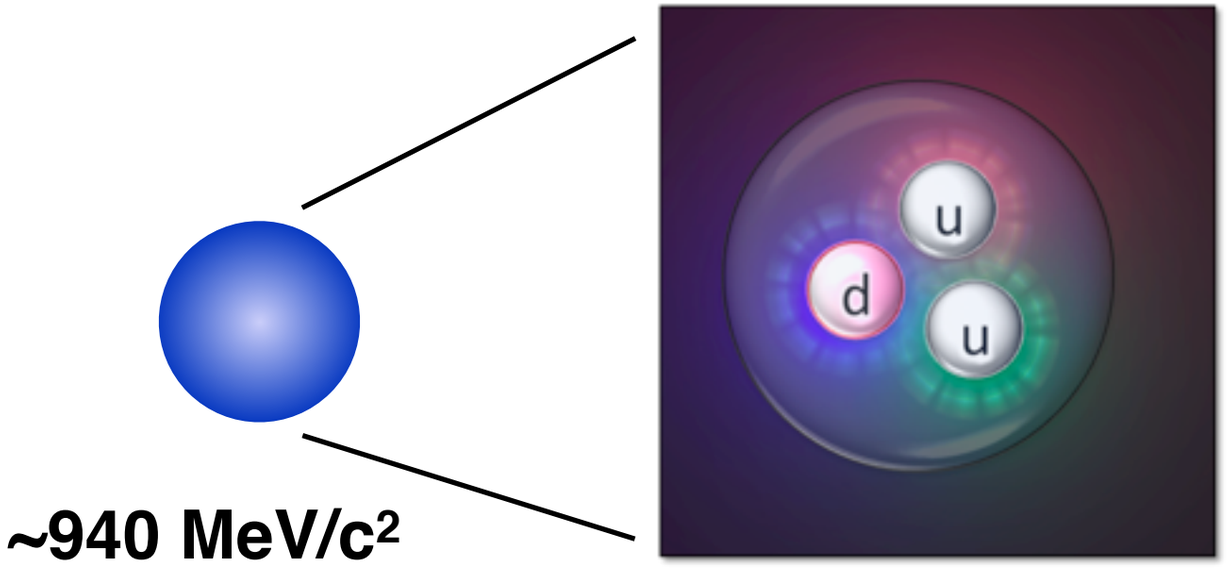
Lighter effective mass in nuclear media?

0

r (fm)

Subjects of global objective are …

Nucleon (hadron) internal structure



~3 MeV/c^2 each

3 x 3 = ~10 MeV/c^2 in total

Why dose not lose energy (or mass) to 10 MeV/c^2?

What is the nature of confinement?

Hadron (composite particle made of q or $\bar{q}$) is heavy, because …

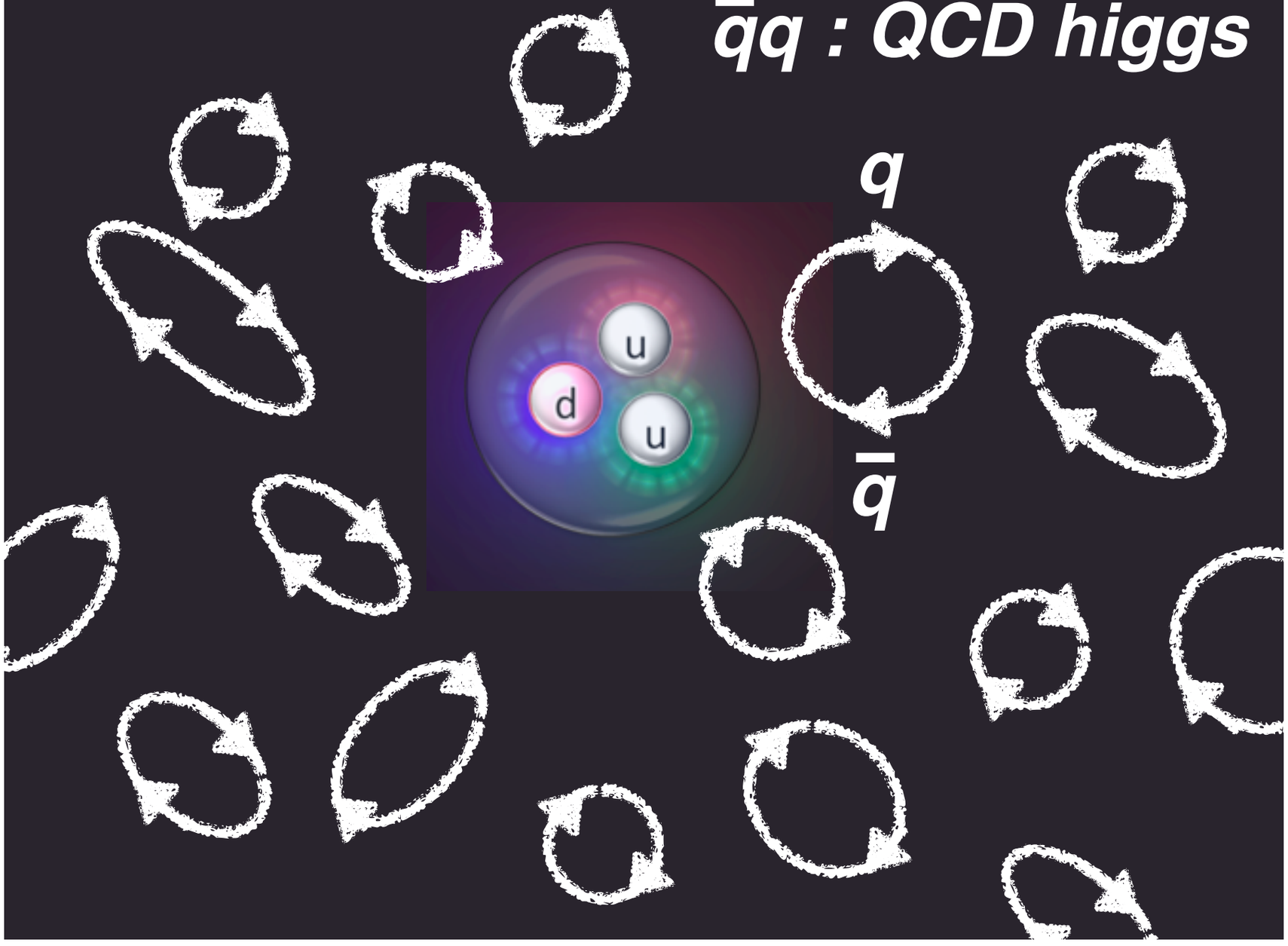
Nambu

…

Vacuum is filled with scalar bosons

spontaneous chiral symmetry braking introduce

$\bar{q}q$: QCD higgs



In fact, hadrons are mass-less, if no condensation occurs

Hadrons looks to be heavy, because vacuum is in $\bar{q}q$ "superconducting phase", and hadrons partially break the condensation.

Subject for discussion: J-PARC E15

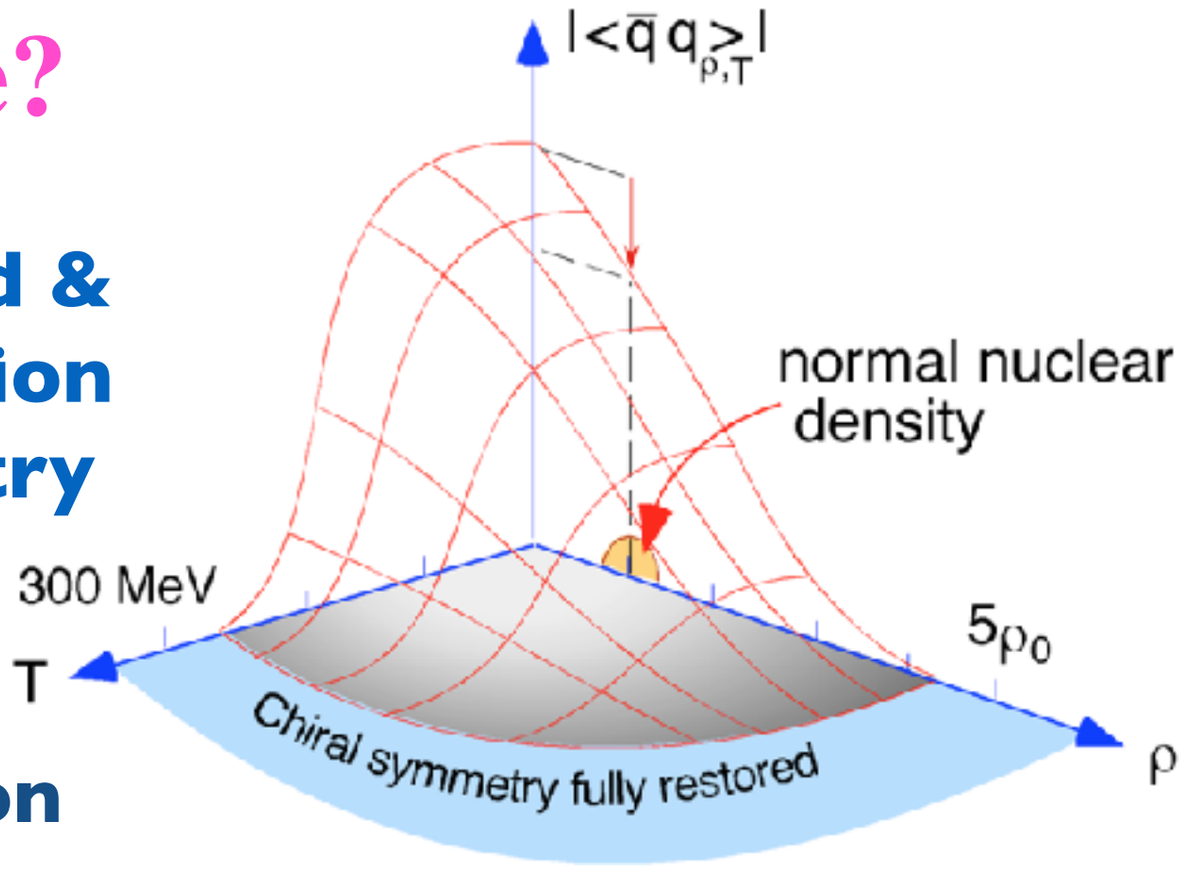
Strong $\bar{K}N$ attraction! $\Lambda(1405)$ = K^-p bound state?

→ excellent introduction by Dr. Laura Tolós

Key questions :

- Can kaon (boson) be a member of nuclei?
- Kaon properties change in nuclear media?
- Size of kaon bound state?

Could be a good probe for cold & dense QCD, to study the relation of hadron mass and χ-symmetry

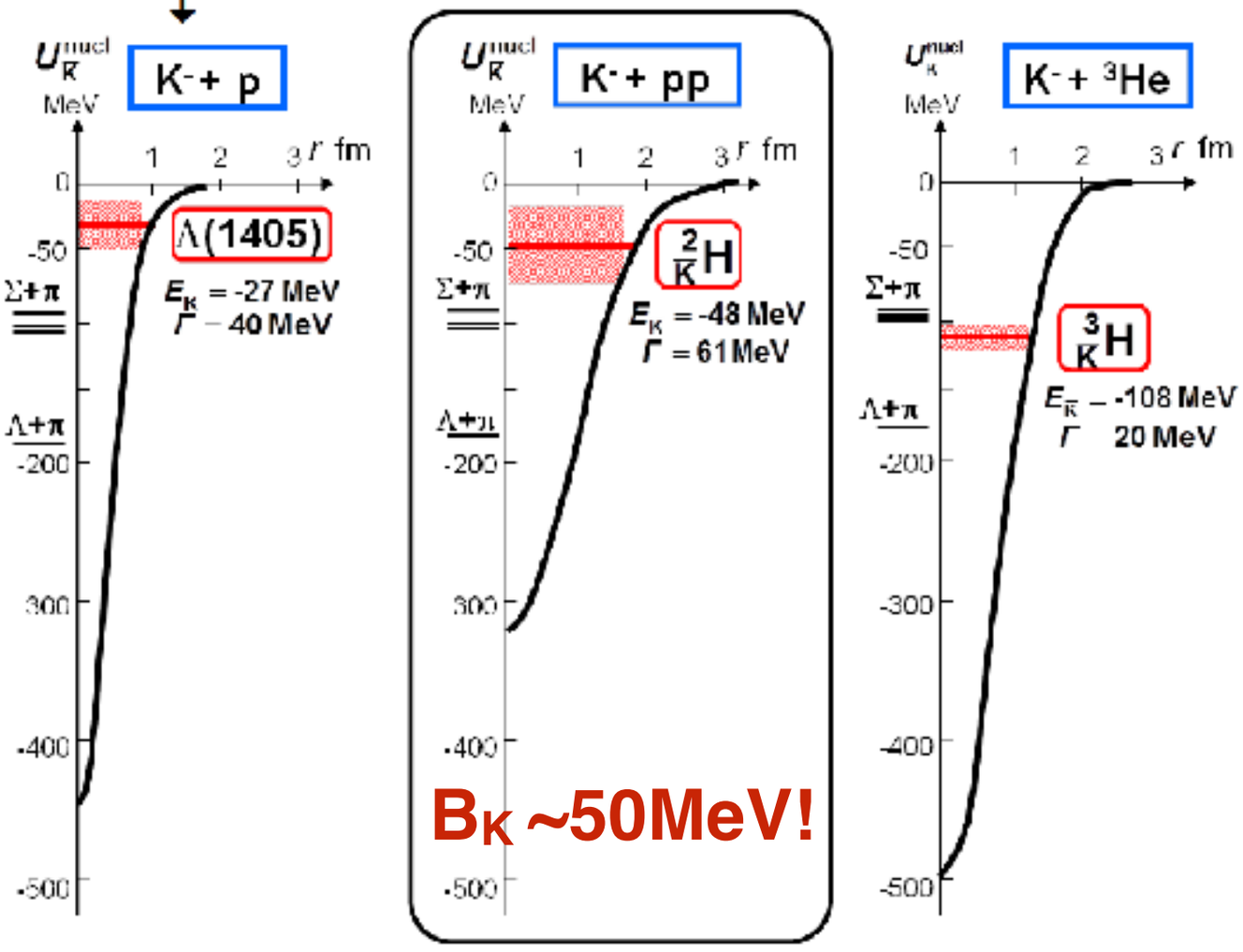


<q̄q> as QCD-Higgs condensation

Kaonic nuclear bound state

Could be a good probe for dense & cold QCD

Assumption



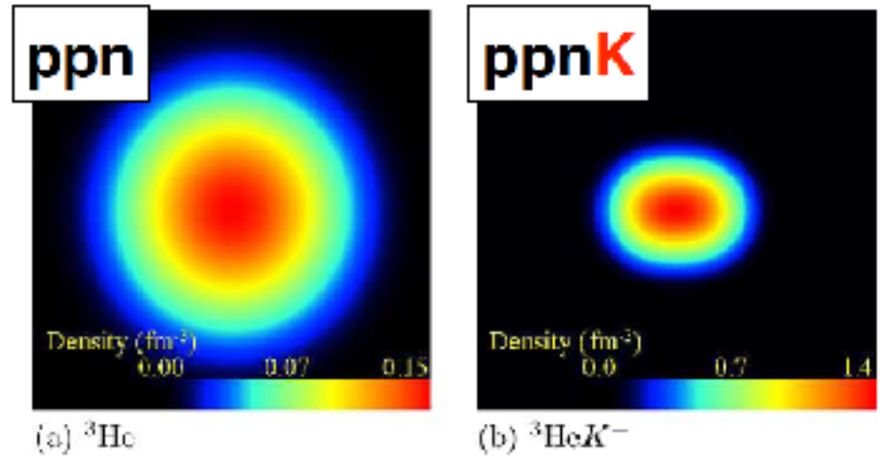
1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).

B_K ~50MeV!

the lightest kaonic nucleus

"K-pp" : $[K^{bar}(NN)_{I=1,S=0}]_{I=1/2}$, $J^\pi=0^-$

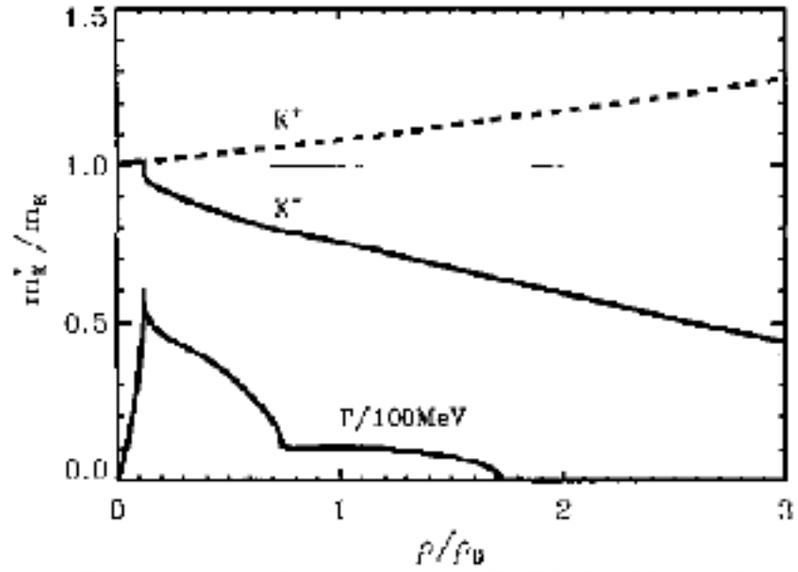
dense nuclei are predicted



(a) ^{3}He (b) ^{3}HeK^-

A. Dote, H. Horiuchi, Y. Akaishi and T. Yamazaki, Phys. Lett. B 590 (2004) 51

Kaon mass in nuclear medium?

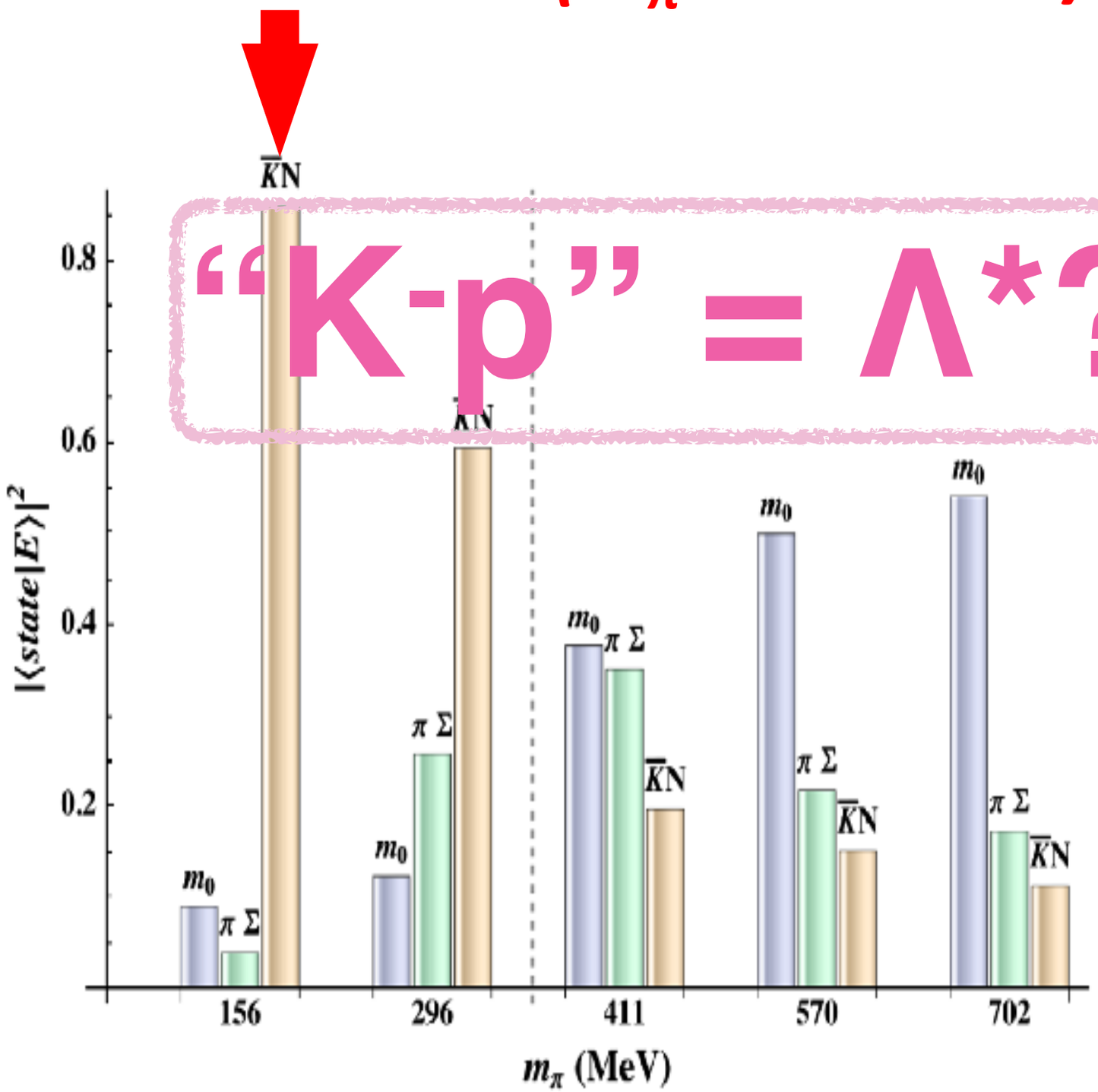


1.T. Waas *et al. Physics Letters B* **379,** 34–38 (1996).

***cf.*: $^3_\Lambda$H = "Λpn", $B_\Lambda \lesssim$ MeV**

Λ(1405) (Λ*) in Lattice-QCD

~Real world (m_π = 140 MeV/c²)



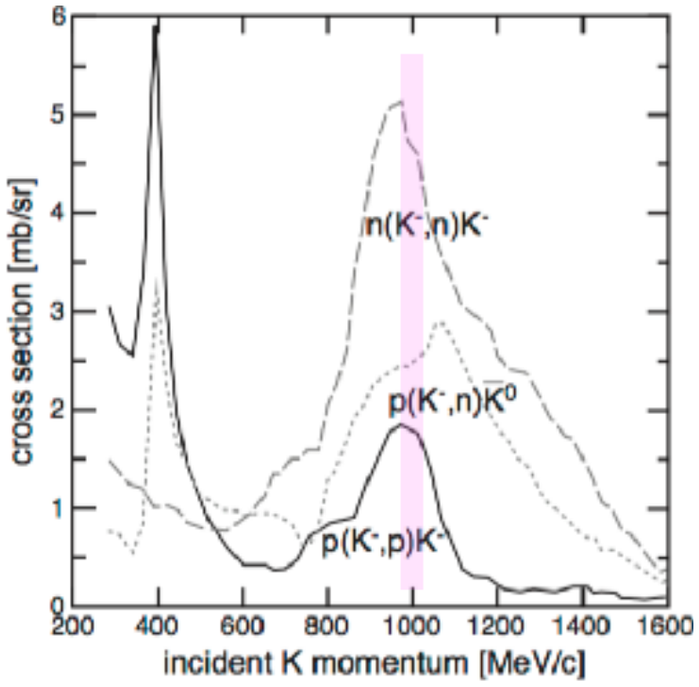
"K-p" = Λ*?

- **Recent Lattice QCD supports,**

$$\Lambda(1405) = p - K^-$$
$$= (uud)\text{-}(\bar{u}s)$$

then, one can embed K into nucleus

J.M.M. Hall et al., Phys. Rev. Lett. 114(2015)132002.



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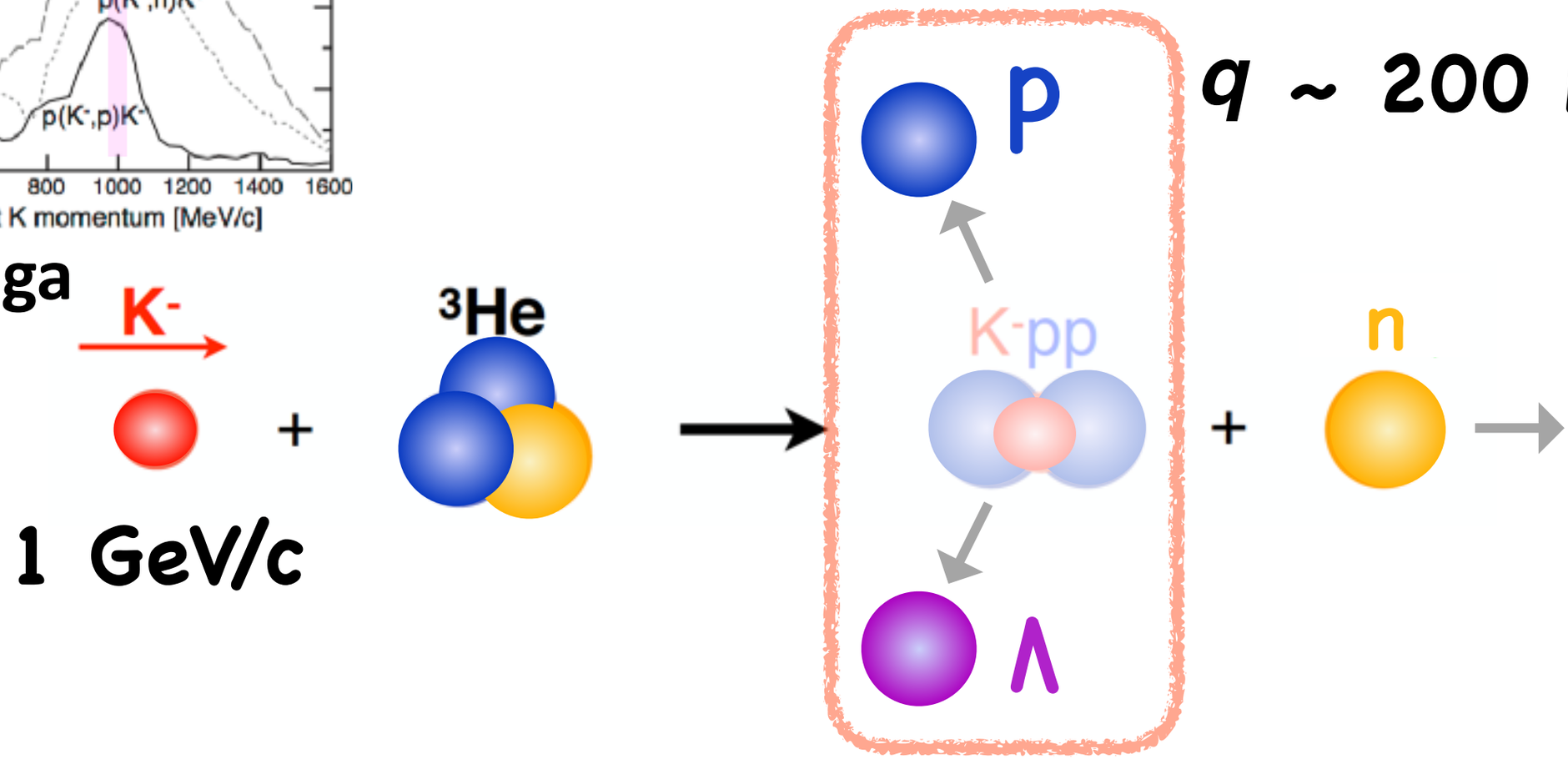
- large KN→KN knockout @ 1GeV/c
- *q* is as small as~ 200 MeV/c

q ~ 200 MeV/c

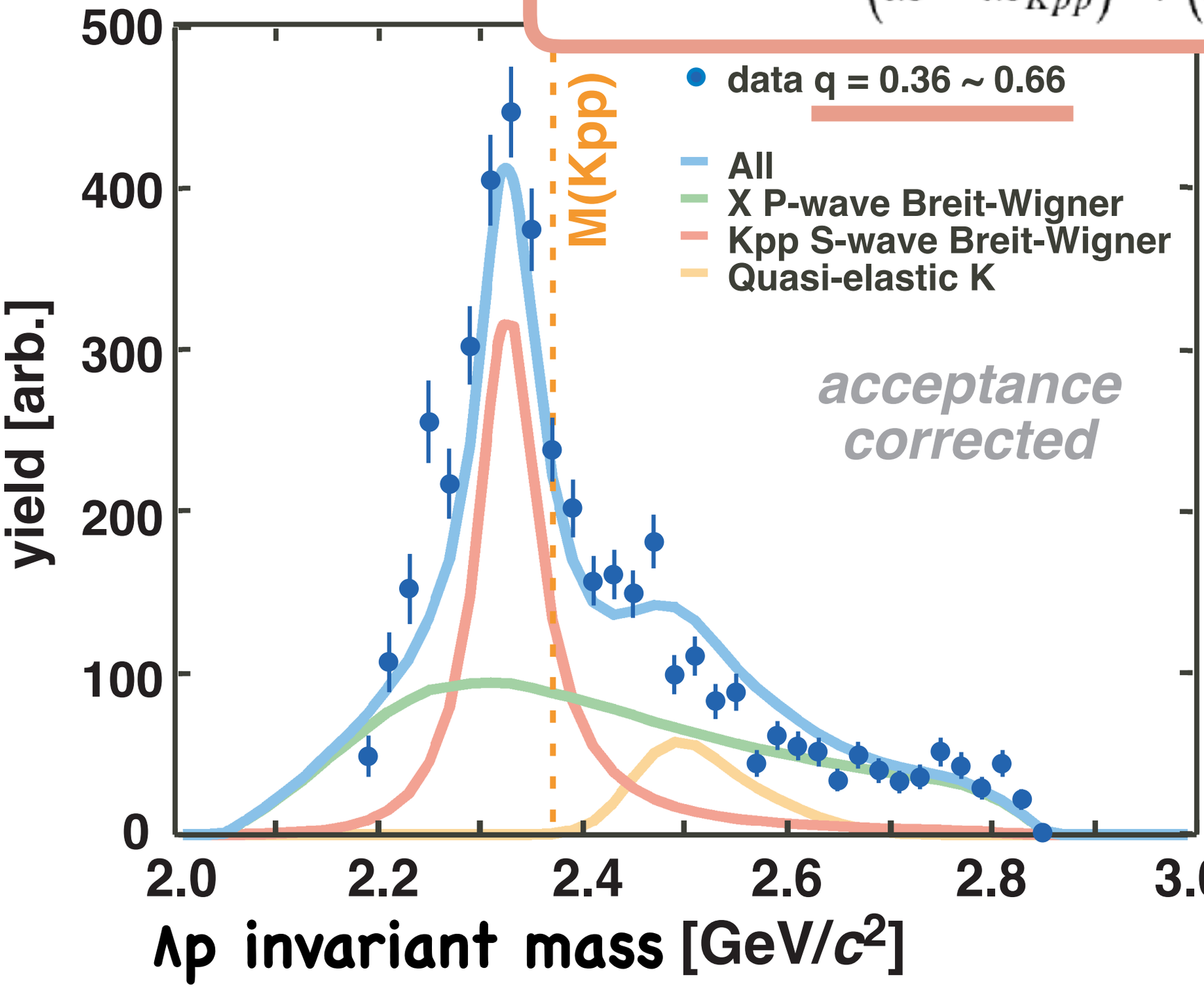


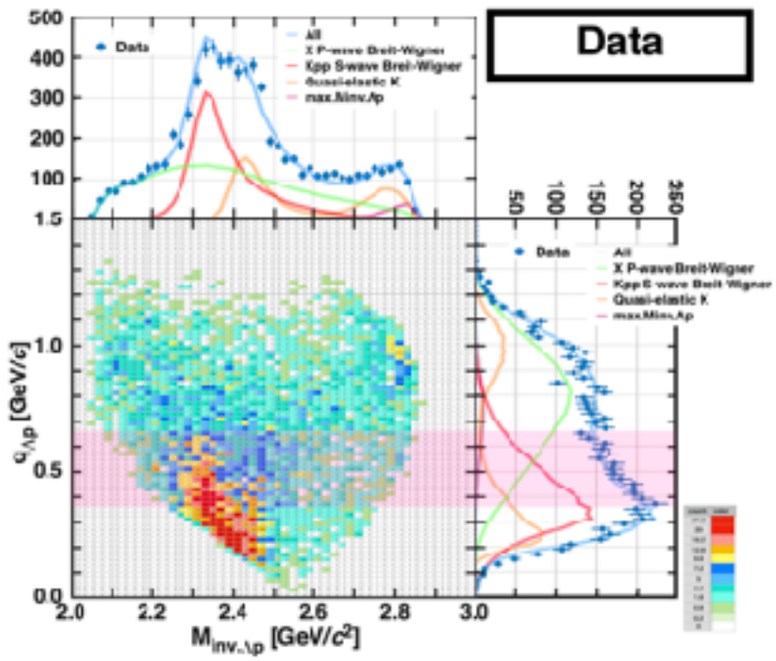
$K^- + {}^3He \rightarrow$ "K^-pp" + n

$\rightarrow$ (Λ + p) + n

"Kpp" observed in Λpn final state

$$\rho_{3B}(M,q) \times \frac{\left(\Gamma_{Kpp}/2\right)^2}{\left(M - M_{Kpp}\right)^2 + \left(\Gamma_{Kpp}/2\right)^2} \times \exp\left(-\frac{q^2}{Q^2_{Kpp}}\right)$$





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“Kpp” formation is clearly seen below M(Kpp)

by **IM(Λp)** via **$K^- {}^3He \rightarrow \Lambda p + n$ channel**

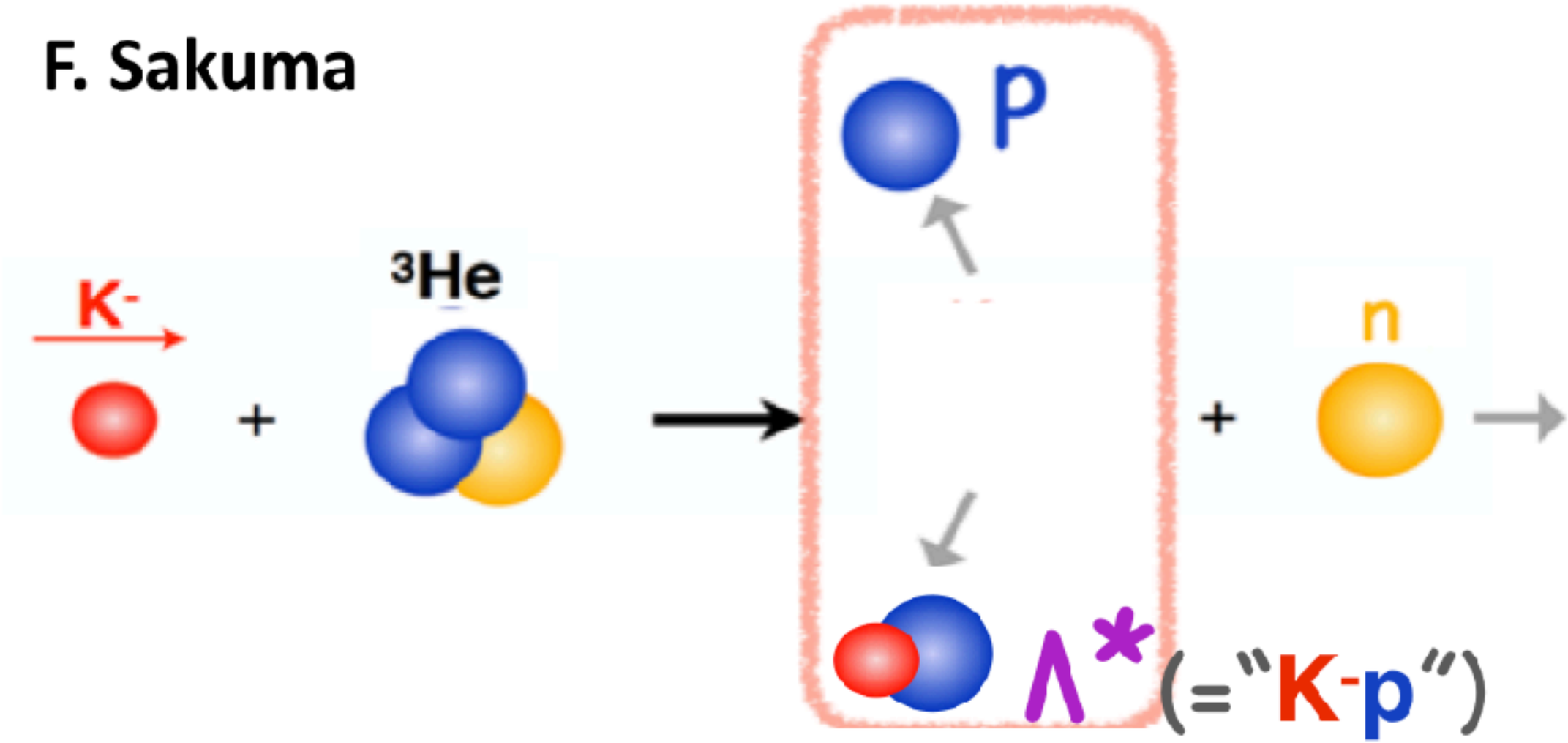
***i.e.*, $K^- + {}^3He \rightarrow$ “Kpp” $+ n \rightarrow \Lambda p + n$**

One can select “Kpp” by *q*

separating from

Quasi-elastic KN→KN & KNN→ΛN

F. Sakuma

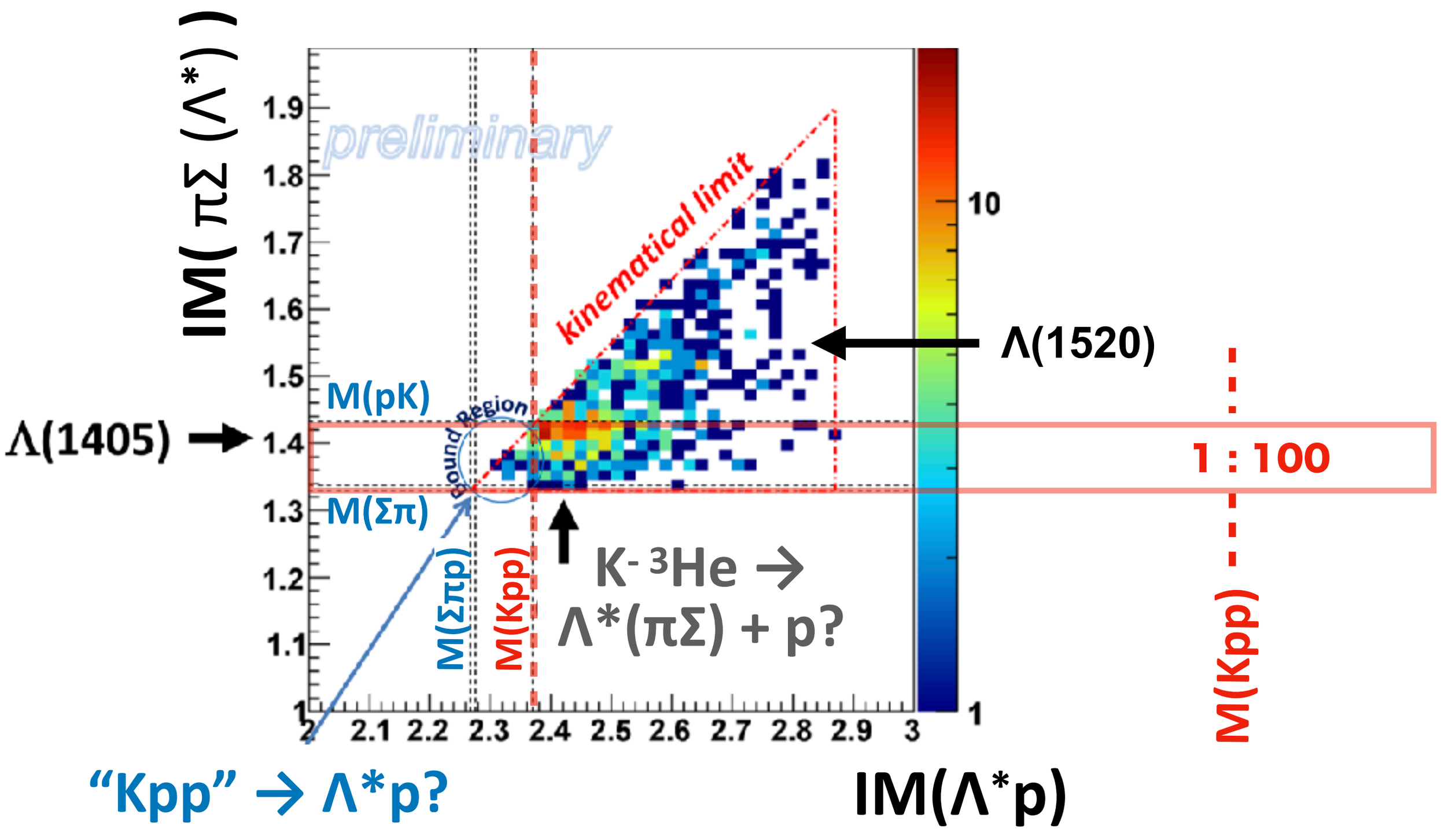


$$K^- + {}^3He \rightarrow (K^- p) + p + n$$

$$\rightarrow (\Sigma\pi) + p + n$$

F. Sakuma

$K^- {}^3He \rightarrow \pi \Sigma p n (\Lambda^* p n)$



"Kpp" → Λ*p?

IM(Λ*p)

“Kp” & “Kpp” seems to be rather exclusive

$$\frac{\text{Br}(\text{“Kpp”} \rightarrow \Lambda p)}{\text{Br}(\text{“Kpp”} \rightarrow \pi \Sigma p)} > 1 \text{ (few times)}$$

“Kpp” decay more strongly to non-mesonic channel

“Kp” and p separated

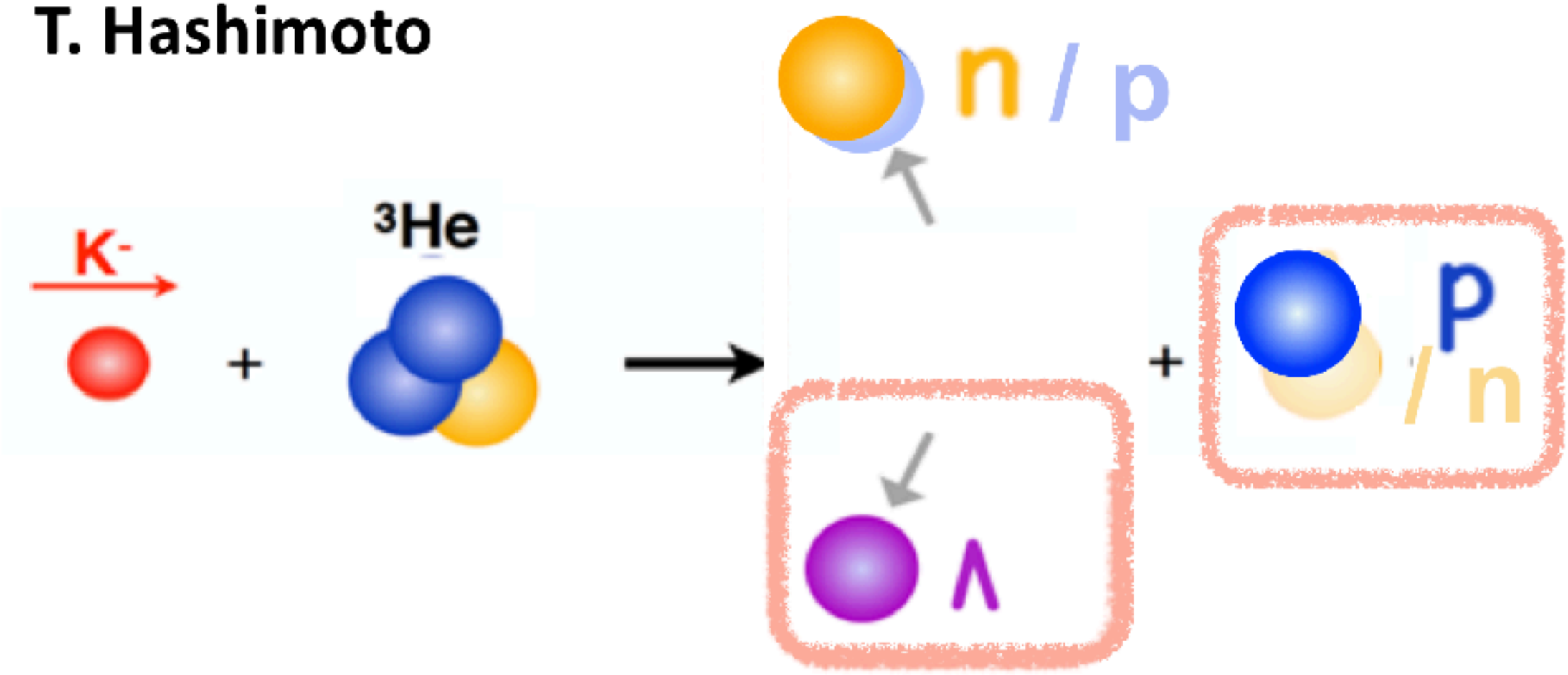
$$\frac{\text{Yield(IM(“Kp”+p) > M(Kpp))}}{\text{Yield(IM(“Kp”+p) < M(Kpp))}} \sim 100 \text{ (order)}$$

can be “Kpp” (“Kp” and p bound)

“Kp”(Λ) is alternative to “Kpp” formation*

“Kpp” formed efficiently (few % of “Kp”(Λ) yield)*

T. Hashimoto



non-mesonic reaction channel @ $\theta_N = 0$?

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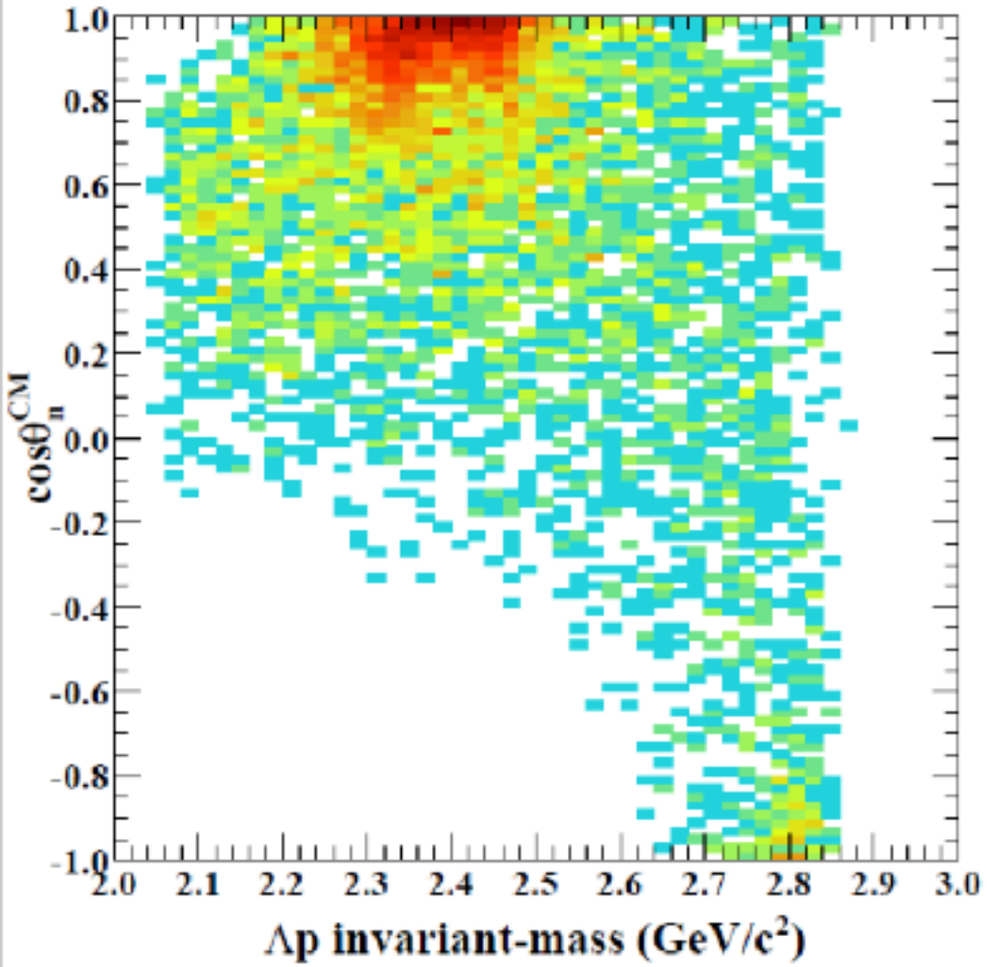
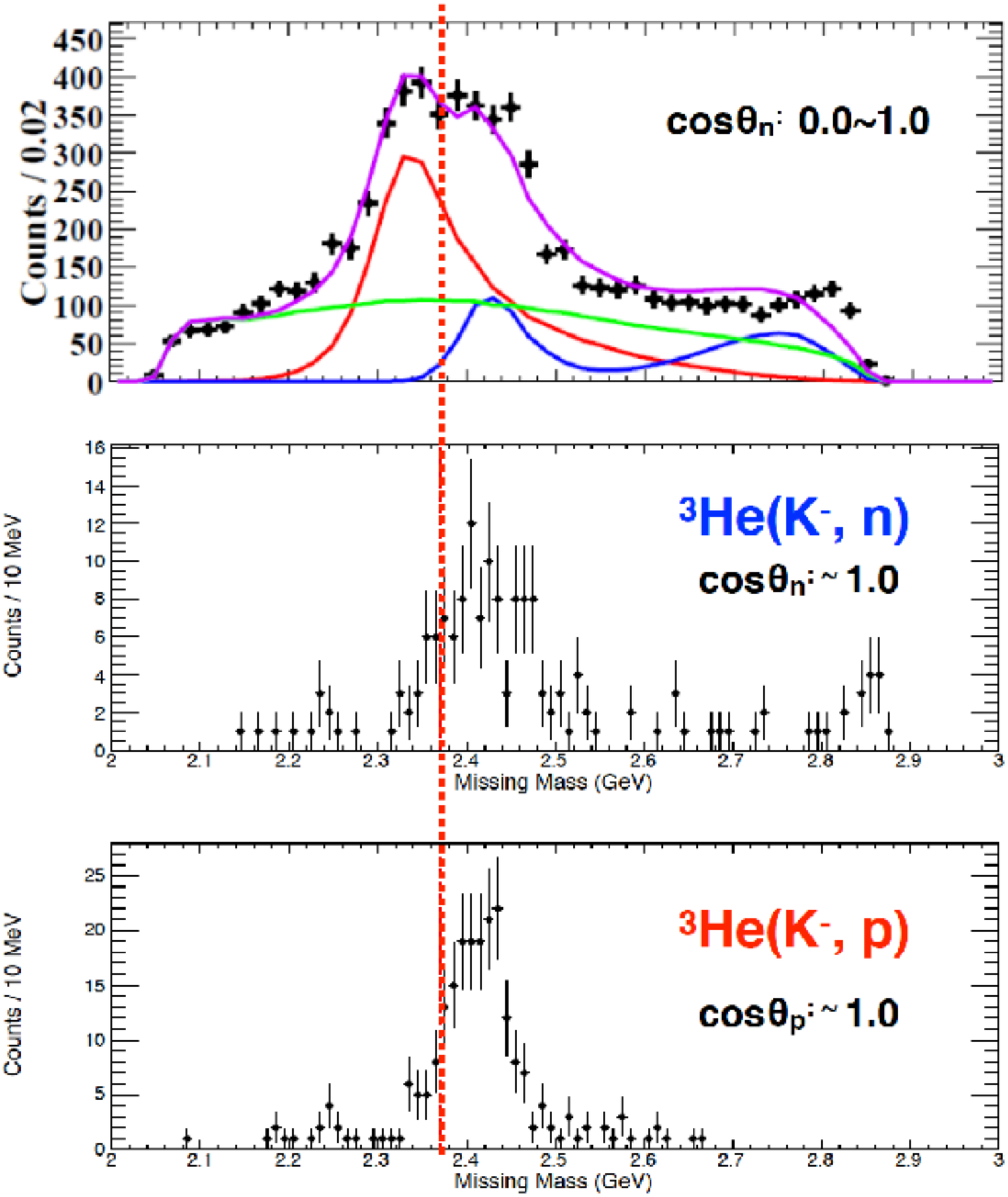
Angular dependence



QE+2NA is much enhanced at very forward angle



Very forward N is consistent with ($\theta_N = 0$)

Quasi-Elastic KN→KN & KNN→ΛN

for forward N = *n or p* (*both*)

unlike to "Kpp" formation ,
QE channel (KN→KN & KNN→ΛN) is very forward peaking

confirmation of QE channel → *confirmation of "KNN"*

@ very forward → *@ ambient q (larger ϑ_N)*

first mesonic bound state “Kpp” identified

“Kpp” is seems to be deep and compact

“Kpp” is more like “Kpp” rather than “Λ*p”

→ Λ(1405) is more like “Kp” rather than “Λ*”

Appendix

Is it mesonic nuclear bound state?

	Kaonic nuclei Kpp		Λ* p resonance Λ* hypernucleus		Hypernuclei: hyperon bound system	
below threshold	M(K+p+p)	yes	slightly below M(Λ*+p)	maybe?	M(Λ+#p+#n)	yes
Theoretical support for existence of pole	Chi.U + Phenomenological	yes	none?	not yet	phenomenological	yes
B.W. pole well separated from threshold	similar to Σ hypernucleus	yes	slightly below M(Λ*+p)	maybe not	weak decay only for Λ while $\Gamma_\Sigma \gg \Gamma_\Lambda$	yes
decay channel open only in nuclei	none-mesonic: Kpp → Λ+p	yes & strong	none-mesonic: Λ*N→ NN	yes but relatively weak	none-mesonic-weak: ΛN→ NN	strong for heavy nuclei
branch suppression of mesonic decay as in vacuum	mesonic: Kpp → Σ π p	yes much weaker	mesonic-weak-decay: Λ* → Σ π	no	mesonic-weak-decay: Λ → p π	yes / weak in heavy nuclei
none-resonant reaction channel above threshold	quasi-elastic K: KN → KN & Kpp → Λ+p	yes	KNN → Λ*N & Λ*p → Λ+p	N.A.	quasi-free : KN → Λ π	yes
Reaction form factor	~ 400 MeV/c :	compact?	N.A.	N.A.	~ 200 MeV/c :	~ nuclei size
variety	Kpp the first	1	N.A.	N.A.	from A = 3 ~	many

most likely, it is.

The other channels of interest

$K^- {}^4He \rightarrow$ "Kppn" + n $\rightarrow \Lambda pn + n$

$K^- {}^6Li \rightarrow$ "Kpα" + n $\rightarrow \Lambda\alpha + n$

need to improve efficiency substantially, especially for n & γ