STRANEX: Recent progress and perspectives in STRANge EXotic atoms studies and related topics

from Monday, 21 October, 2019 - 08:00 to Friday, 25 October, 2019 - 14:00

A novel and peculiar quantum system — K-meson and two protons bound state —

Physics Letters B 789 (2019) 620–625

for J-PARC E15 collaboration

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RIKEN

Cluster for Pioneering Research
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Why a meson bound state is novel and peculiar quantum system?

hadron: <qqq> proton, neutron, … : <q̄q> π meson, K meson, …

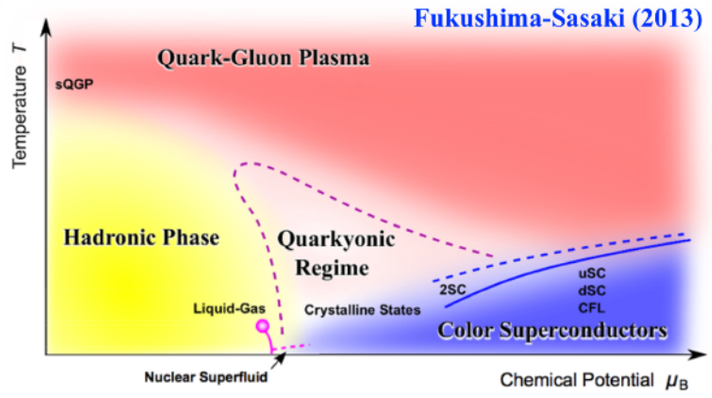
existence form	Fermion one particle per one state Particle consisting matter	Boson as many for a state Particle generating field (nuclear foce)
	exists as particle at anywhere	particle in vacuum or meson field in nuclei (virtual particle)

key question

Can Kaon(meson) be bound in nuclei?

Can <q̄q> be a "real particle" even in nuclei?

What is a role of meson DoF. in nuclei?

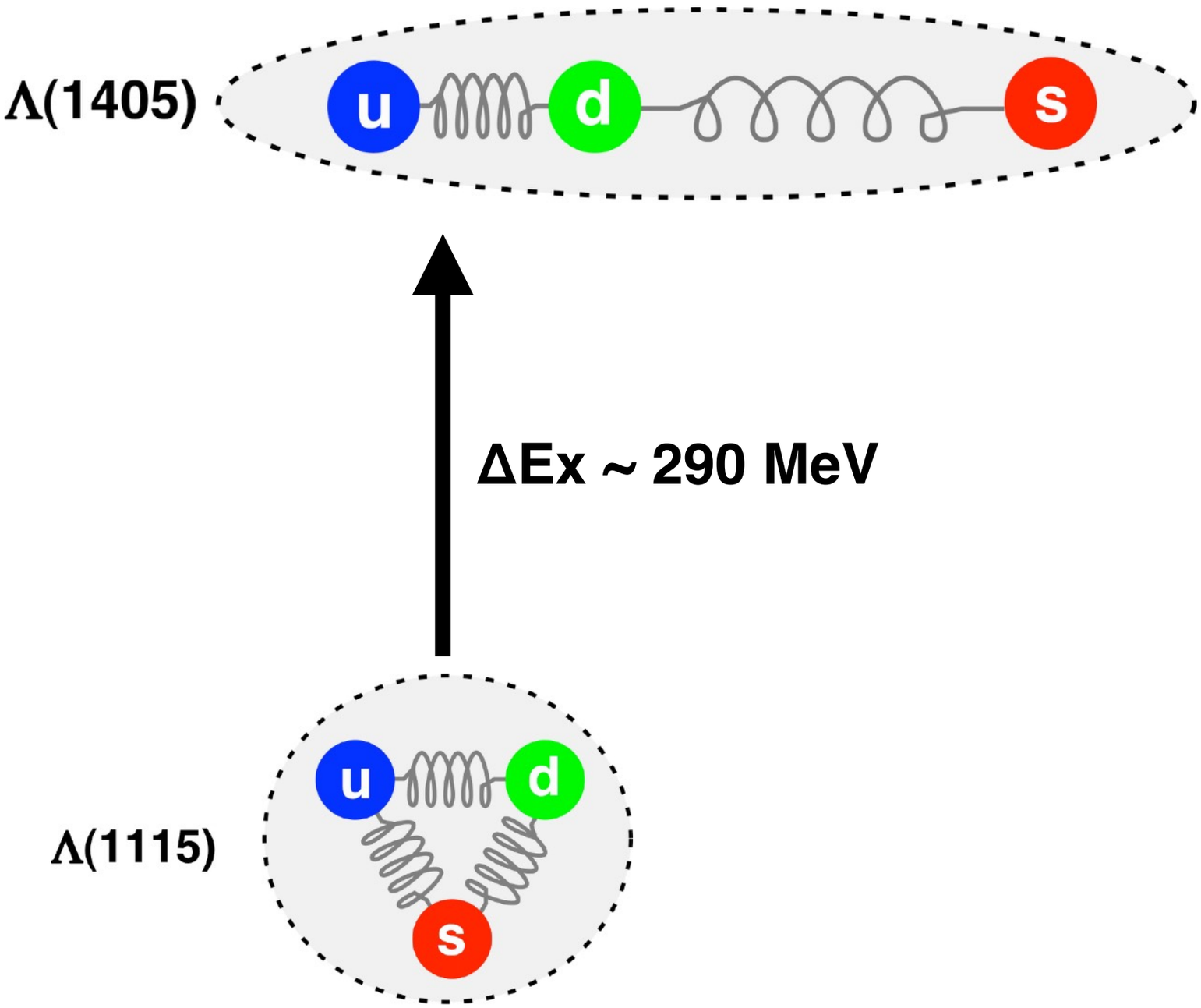


Meson predicted in 1935. Since then, it has been studied for ~80 years to identify <u>mesonic nuclear bound states</u>, but no definitive evidence was made before.

	$\Lambda(1405)$ as $\bar{K}N$ bound state	$\bar{K}NN$ bound state
Prediction	**1959**	**2002 ~**
Discovery	**1961**	**2019 ?**
Spin / parity	$1/2^-$ **(2014)**	$J^P = 0^-$ **???**
Interaction	**Chiral dynamics**	**Two-body** $\bar{K}N$ ***and*** NN **+ Three-body** $\bar{K}NN$ **?**
Component	$\bar{K}N$ **dominant in chiral D (2015 ~)**	$\bar{K}NN$ **dominant ???**
Peak position	**Depends on reaction**	**Depends on reaction**
Pole position	$(1415 - 1435) - (10 - 25)\,i$ MeV	**???**

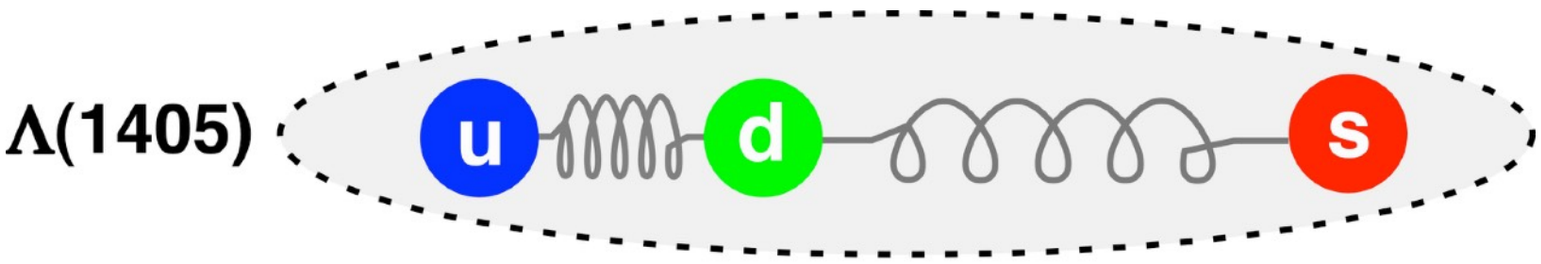
From Λ(1405) to kaonic nuclei

Is Λ(1115) an excited state of *uds*?



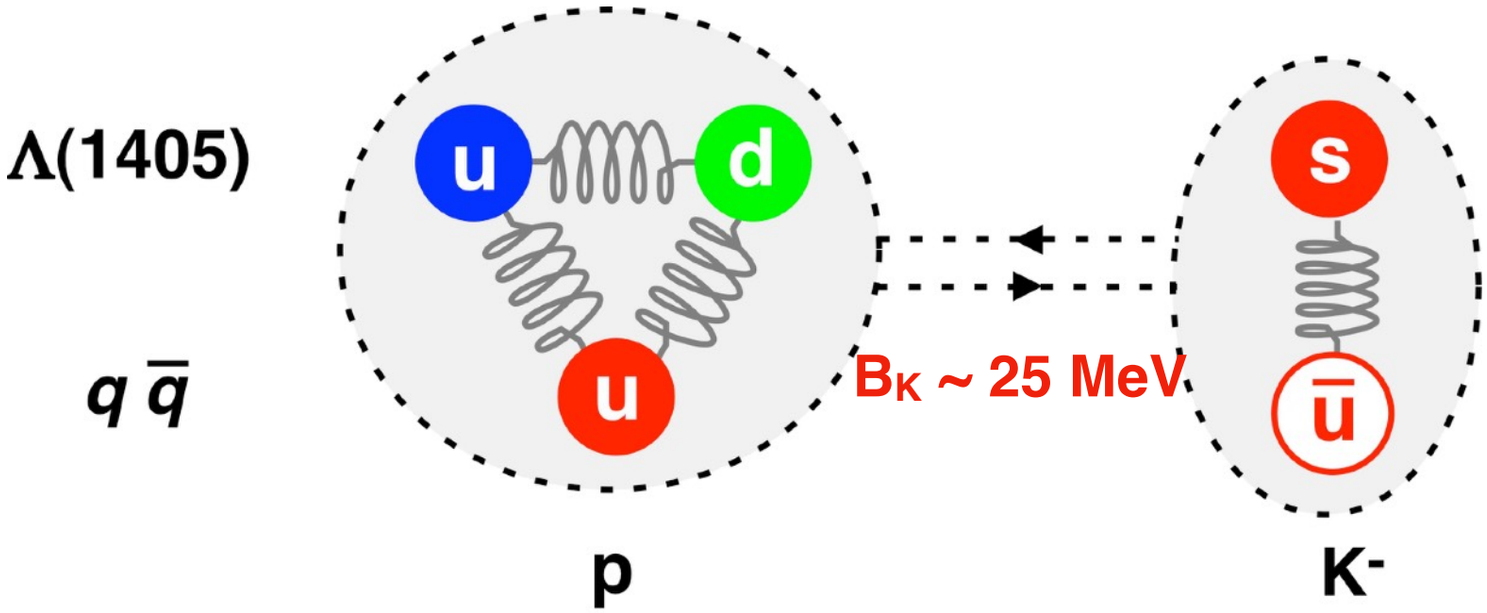
From Λ(1405) to kaonic nuclei

with $\bar{q}q$ (χ-condensate) in vacuum



From Λ(1405) to kaonic nuclei

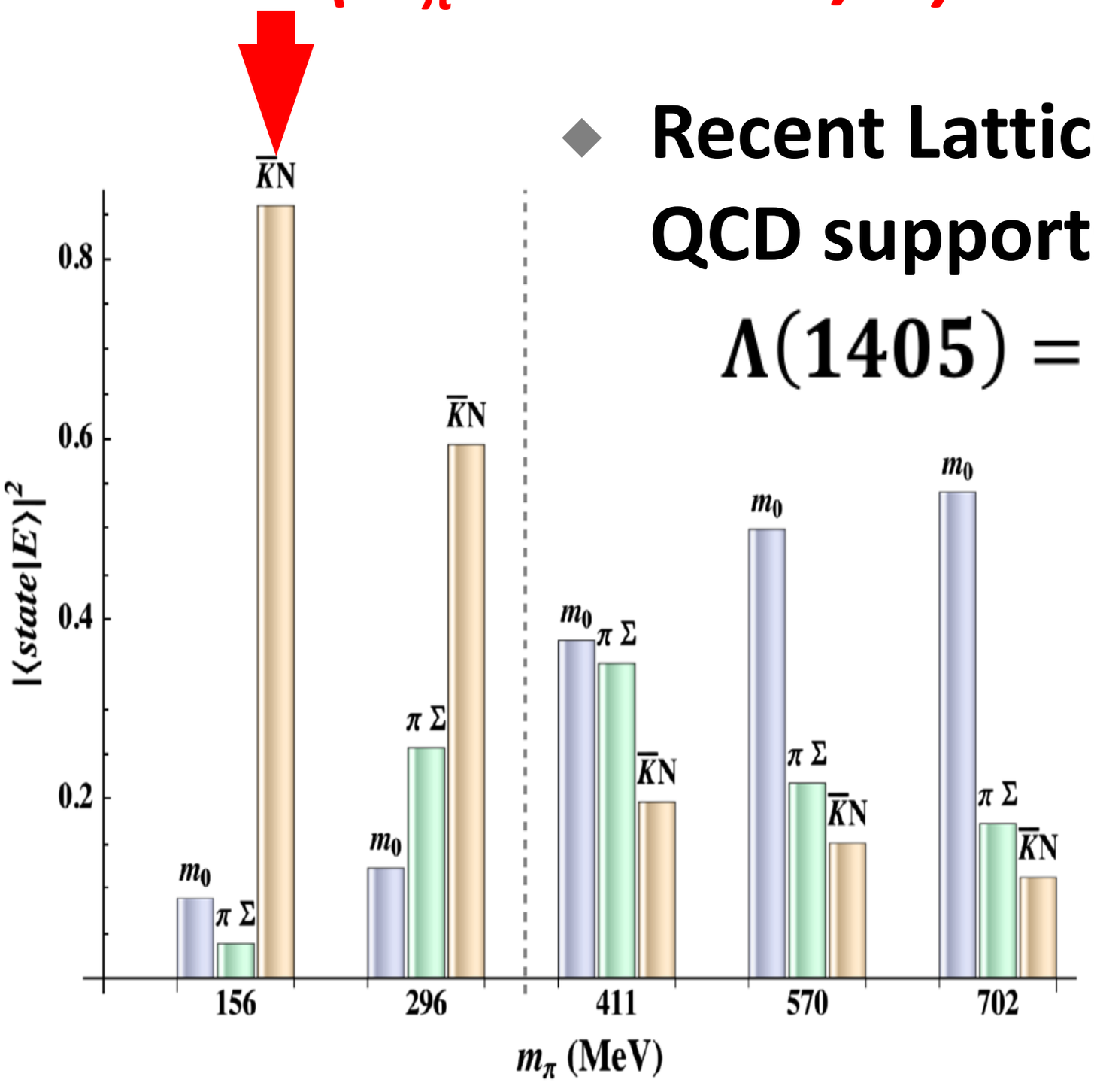
two color-singlet objects bound by meson exchange : p = K^-



$M(pK^-) = 1432\ MeV/c^2$

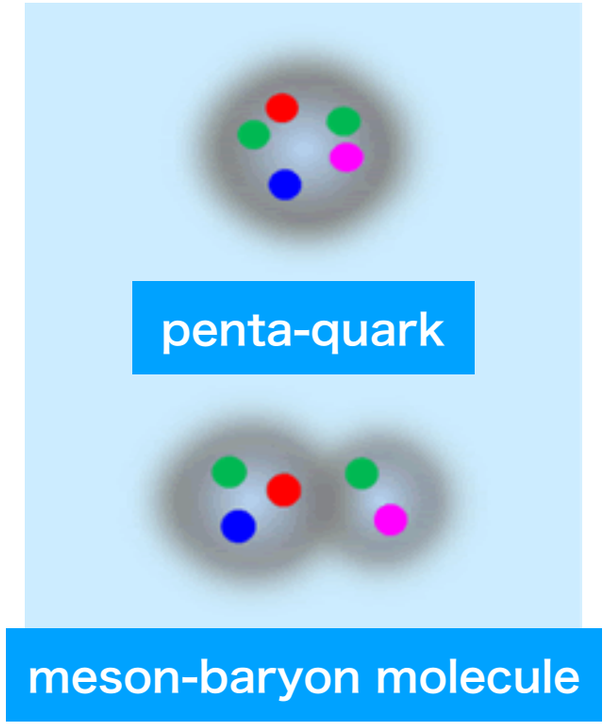
Λ(1405) (Λ*) in Lattice-QCD

~ Real (m_π = 140 MeV/c^2)



- **Recent Lattice QCD supports,**

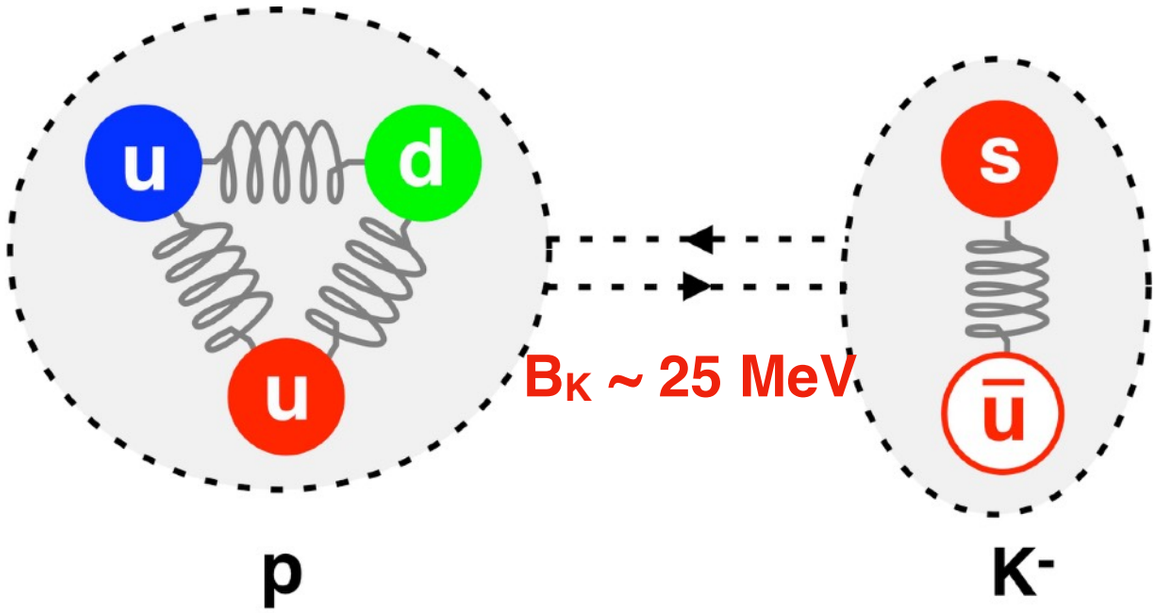
$$\Lambda(1405) = p - K^- = (uud)\text{-}(\bar{u}s)$$



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

From Λ(1405) to kaonic nuclei

two color-singlet objects bound by meson exchange : p = K^-



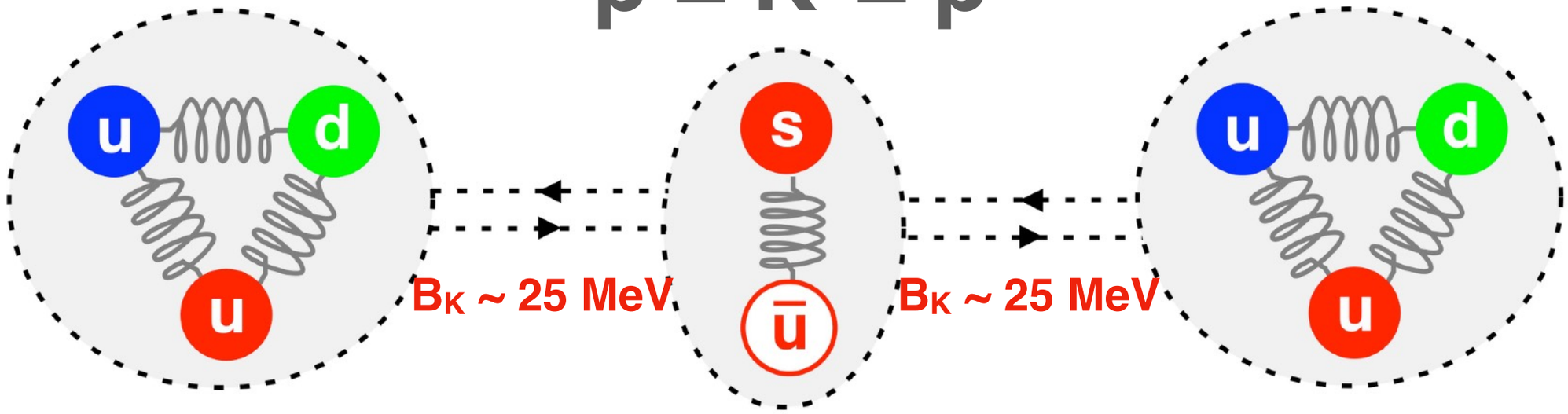
$M(pK^-) = 1432\ MeV/c^2$

then, one can embed K into nucleus

From Λ(1405) to kaonic nuclei

kaonic nucleus “Kpp” (E15)

p = K⁻ = p



p K⁻ p

$M(pK^-) = 1432\ MeV/c^2$

$M(ppK^-) = 2370\ MeV/c^2$

$M_{Kpp} \sim 2320\ MeV/c^2$

$B_{Kpp} \sim 50\ MeV$

$\Gamma_{Kpp} \sim 100\ MeV$

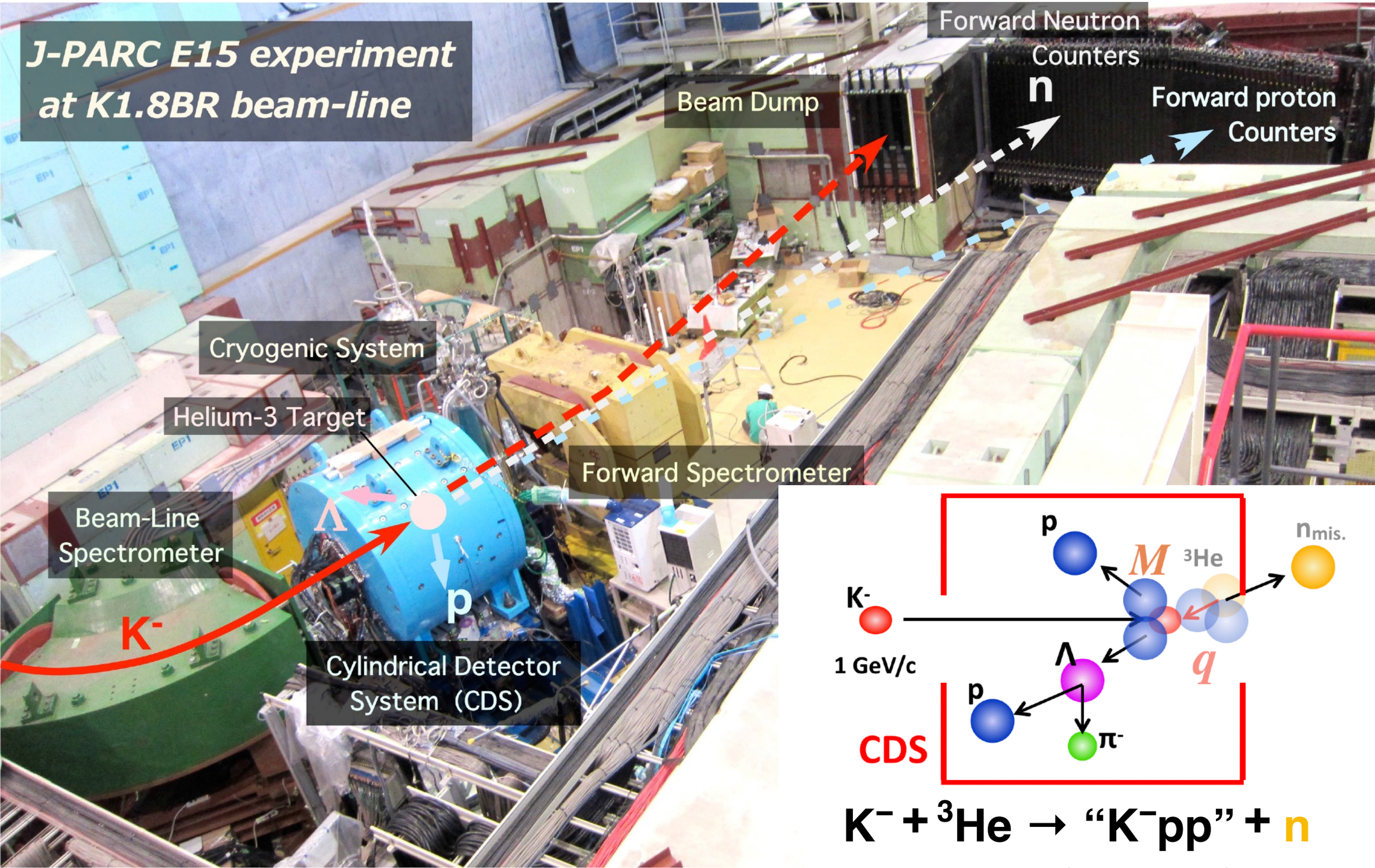
What we have done at J-PARC?

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

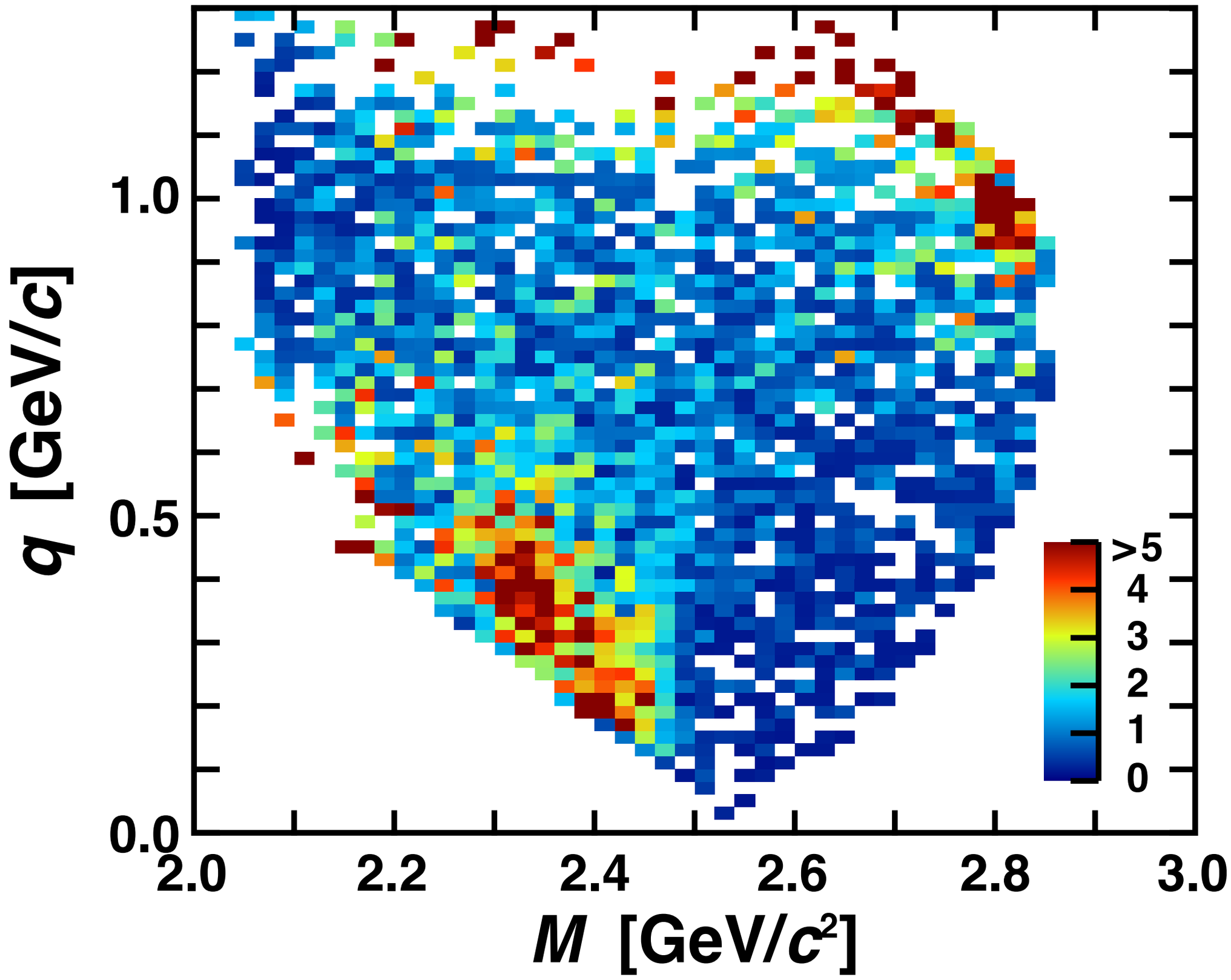
by KN→KN reaction as a doorway

"K^-pp" a tightly bound compact object?

Formation-reaction image illustrated by ÖEW Harald Ritsch


J-PARC E15 experiment
at K1.8BR beam-line
Forward Neutron
Counters
n
Beam Dump
Forward proton
Counters
Cryogenic System
Helium-3 Target
Forward Spectrometer
Beam-Line
Spectrometer
Λ
p
K-
Cylindrical Detector
System (CDS)
p
M
3He
nmis.
K-
1 GeV/c
Λ
q
p
CDS
π-
K⁻ + 3He → “K⁻pp” + n
(Λ + p) + n

Acceptance corrected event distribution on (M, q)



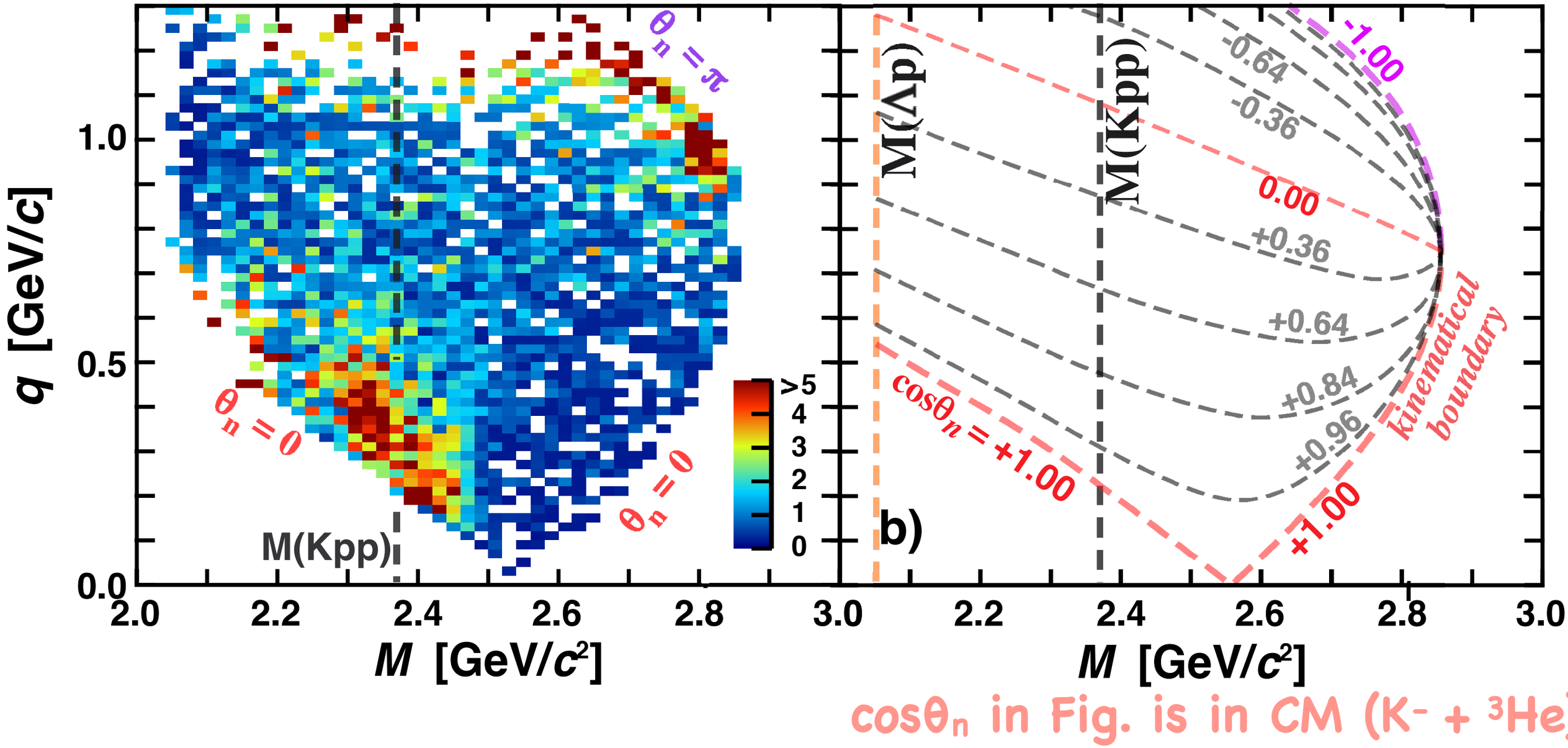
z-axis is in [nb] per (20MeV/c x 20 MeV/c²)

M & *q* defines kinematics ⟷ (or *M* & θ_n)

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

$$\tan\theta_n^{Lab.} = \frac{-q\sin\theta}{p_K - q\cos\theta}$$

$$\begin{pmatrix}\sqrt{m_K^2+p_K^2}\\ p_K\\ 0\end{pmatrix} + \begin{pmatrix}M_{^3\mathrm{He}}\\ 0\\ 0\end{pmatrix} = \begin{pmatrix}\sqrt{M^2+q^2}\\ q\cos\theta\\ q\sin\theta\end{pmatrix} + \begin{pmatrix}\sqrt{m_n^2+p_K^2-2p_Kq\cos\theta+q^2}\\ p_K - q\cos\theta\\ -q\sin\theta\end{pmatrix}$$

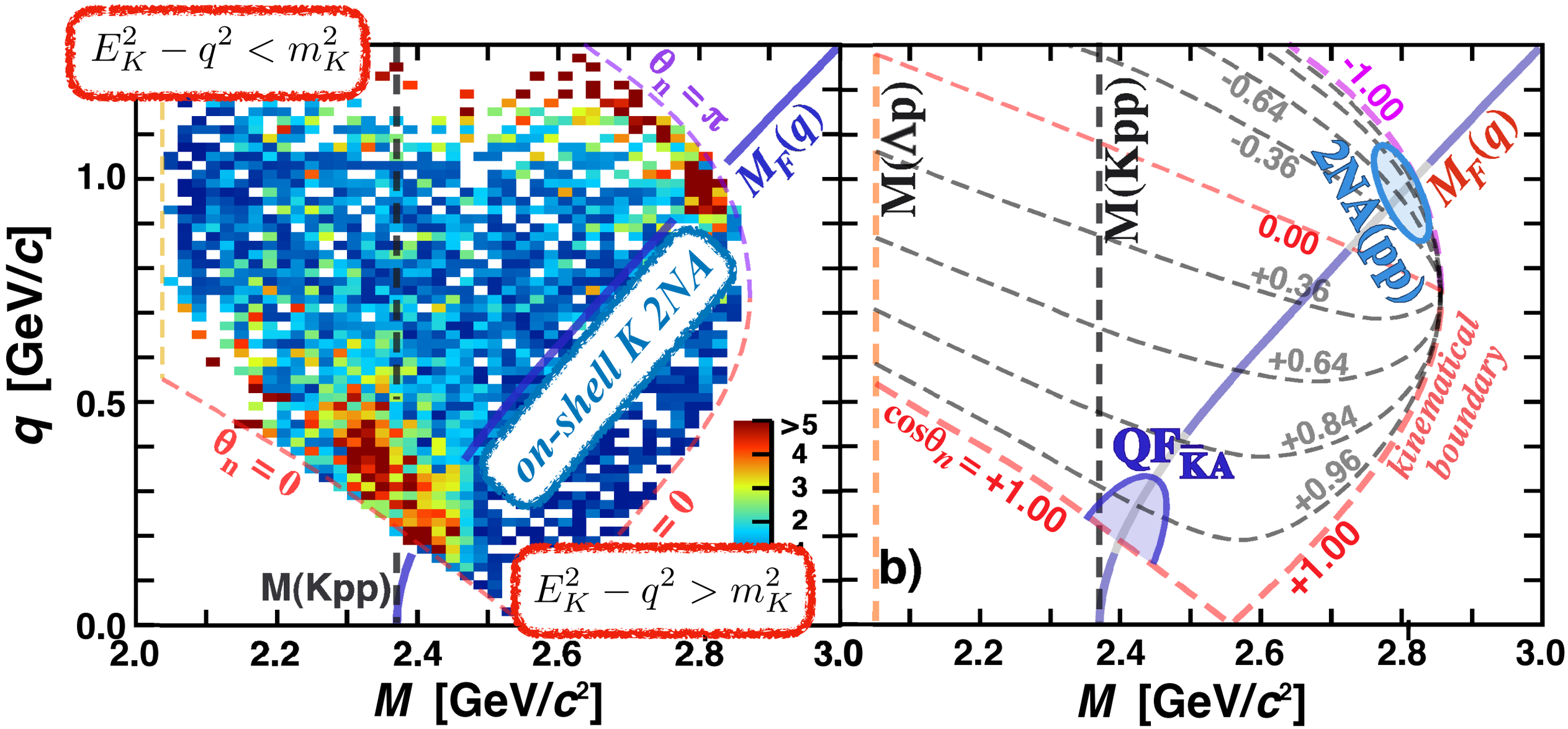


cosθn in Fig. is in CM (K^- + ^{3}He)

kinematics of Kaon 2N-absorption (on-shell)

$\bar{K} + N_s + N_s \rightarrow F\ (= \Lambda + p)$

$$\begin{pmatrix} \sqrt{m_K^2 + q^2} \\ q \end{pmatrix} + \begin{pmatrix} m_N \\ 0 \end{pmatrix} + \begin{pmatrix} m_N \\ 0 \end{pmatrix} = \begin{pmatrix} \sqrt{M_F^2 + q^2} \\ q \end{pmatrix}$$

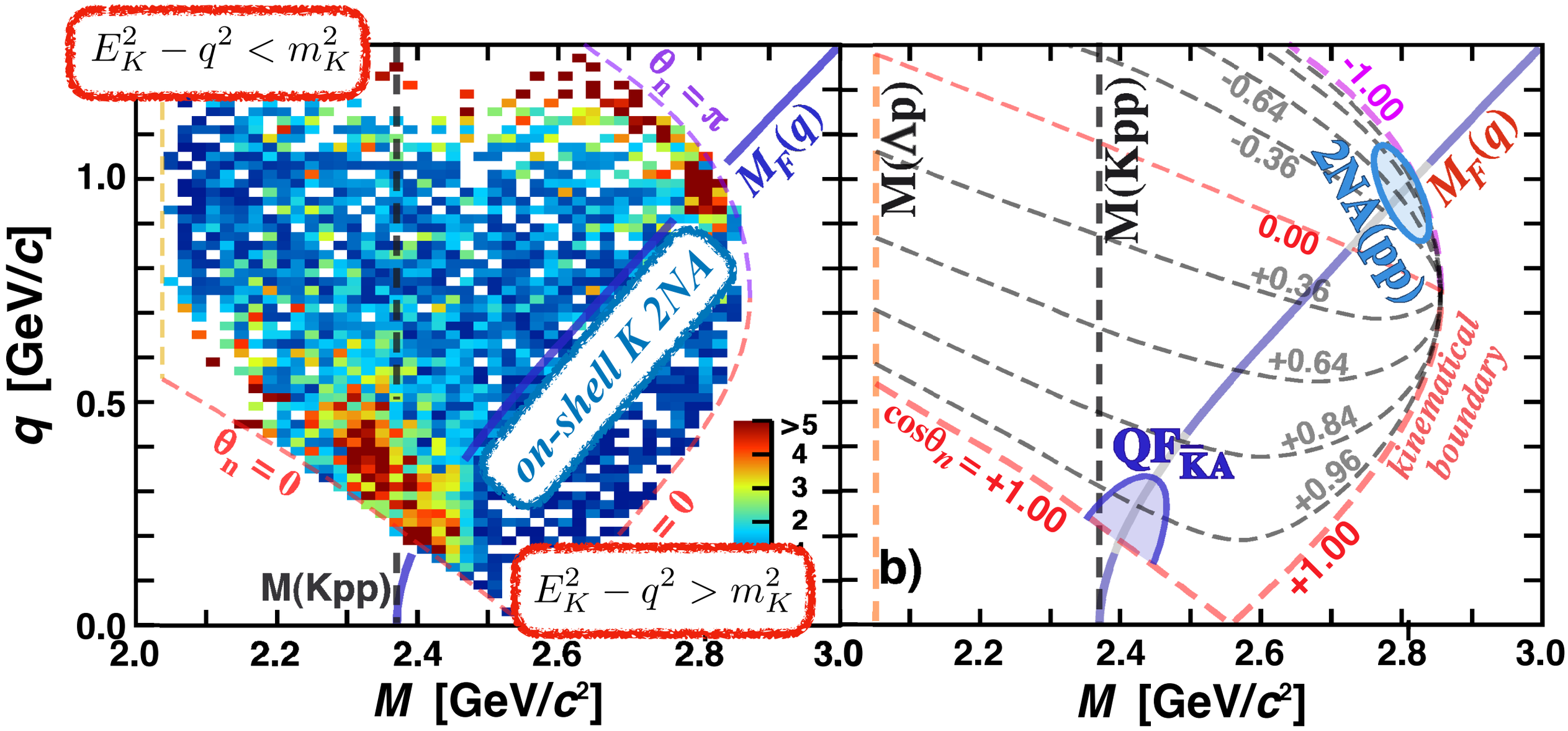


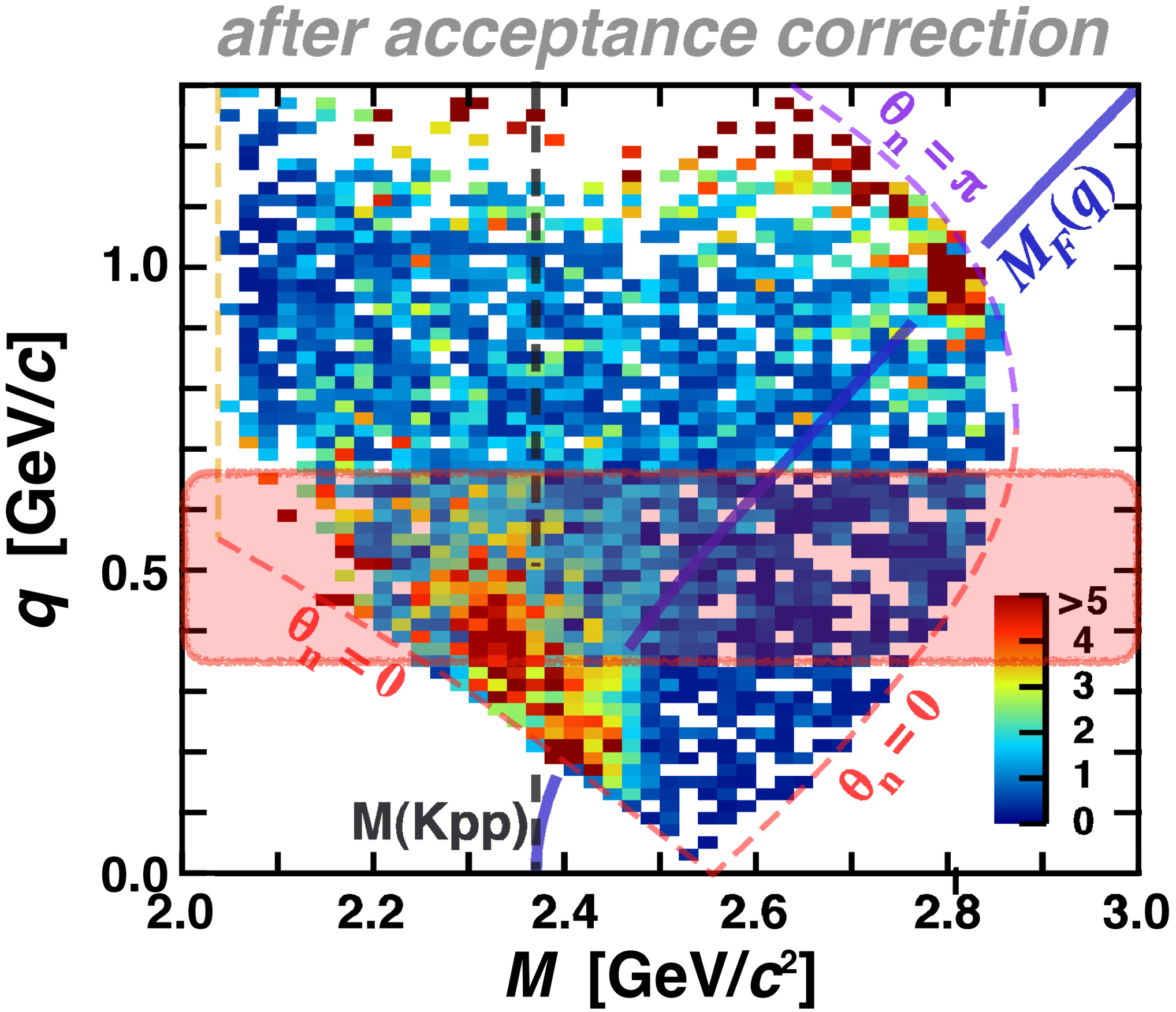
$QF_{\bar{K}A}$: $K^- + N \rightarrow \bar{K} + n$

back-scattered K ~ 200MeV/c

$\bar{K} + N_s + N_s \rightarrow F\ (= \Lambda + p)$

$$\begin{pmatrix} \sqrt{m_K^2 + q^2} \\ q \end{pmatrix} + \begin{pmatrix} m_N \\ 0 \end{pmatrix} + \begin{pmatrix} m_N \\ 0 \end{pmatrix} = \begin{pmatrix} \sqrt{M_F^2 + q^2} \\ q \end{pmatrix}$$



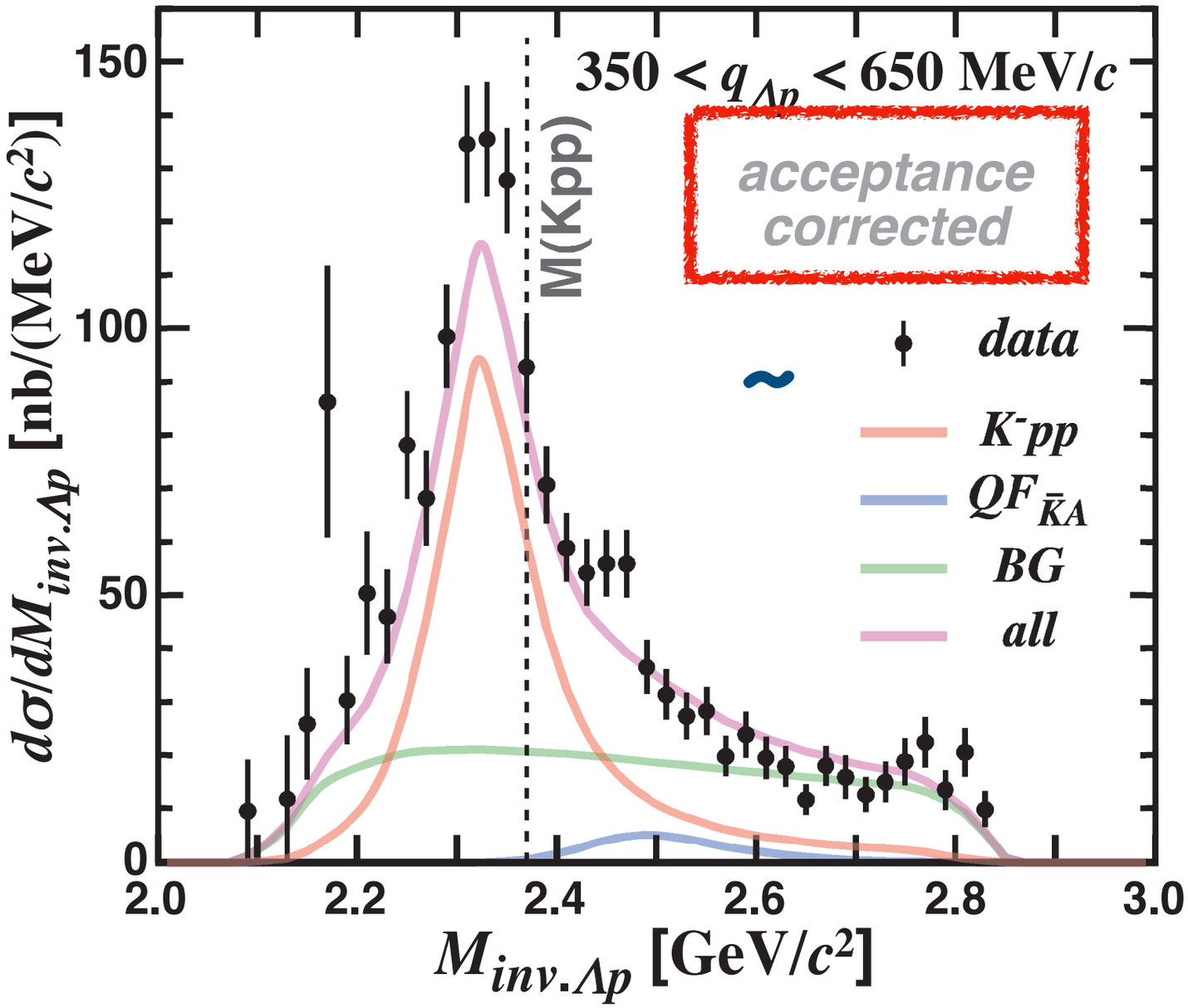

after acceptance correction
$\theta_n = \pi$
$M_F(q)$
$\theta_n = 0$
$\theta_n = 0$
M(Kpp)
>5
4
3
2
1
0
1.0
0.5
0.0
2.0
2.2
2.4
2.6
2.8
3.0
q [GeV/c]
M [GeV/c^2]

M: q-selected Λp + $n_{mis.}$

PWIA w/ HO

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

energy (mass) *momentum*

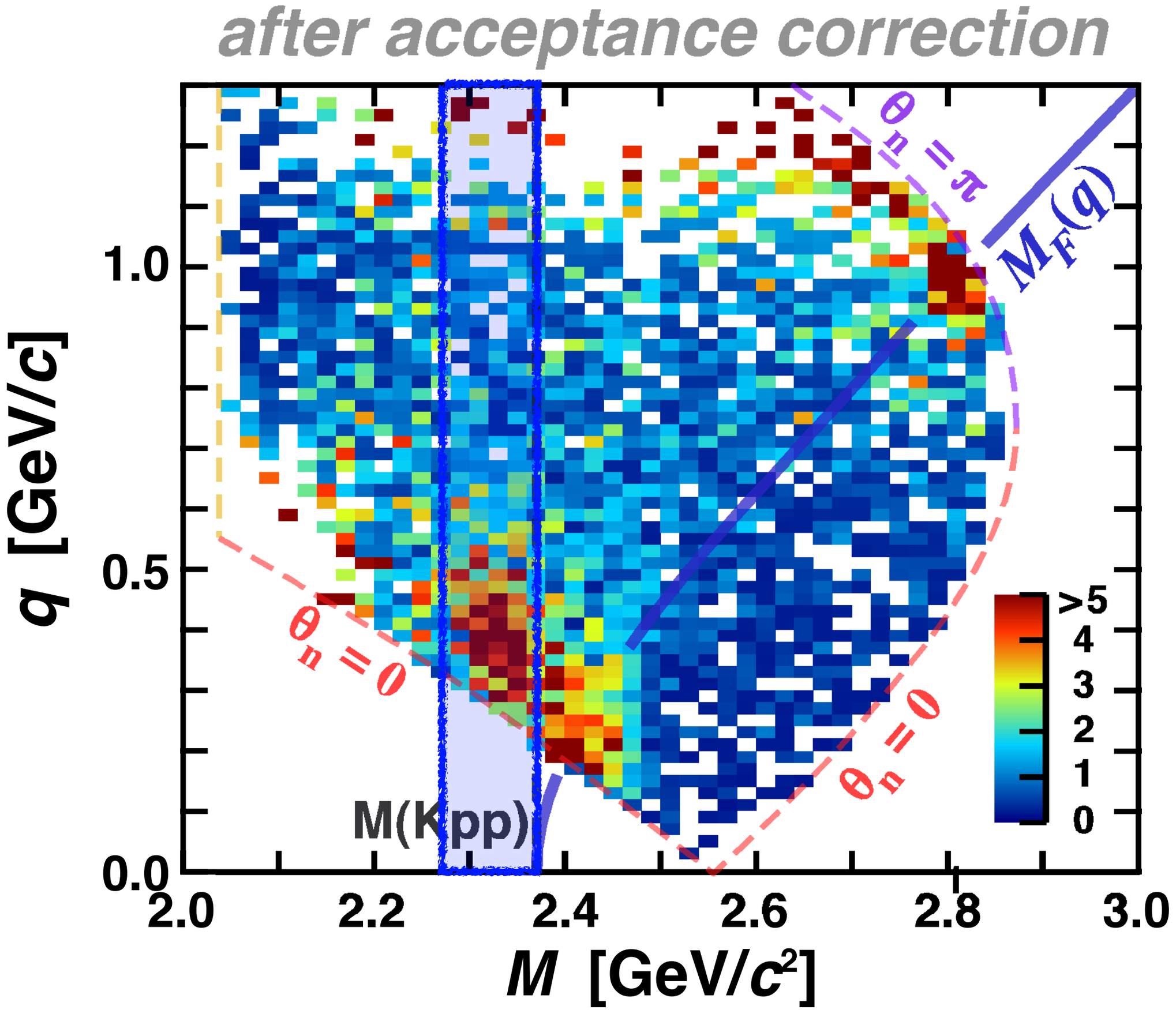


$\sigma_{Kpp} * Br_{\Lambda p} \sim 12$ μb

$B_{Kpp} \sim 50$ MeV
(B.W. pole)

$\Gamma_{Kpp} \sim 100$ MeV

$\sigma_M(\Lambda p) \sim 10$ MeV/c²


after acceptance correction
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$M_F(q)$
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M(Kpp)
>5
4
3
2
1
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0.0
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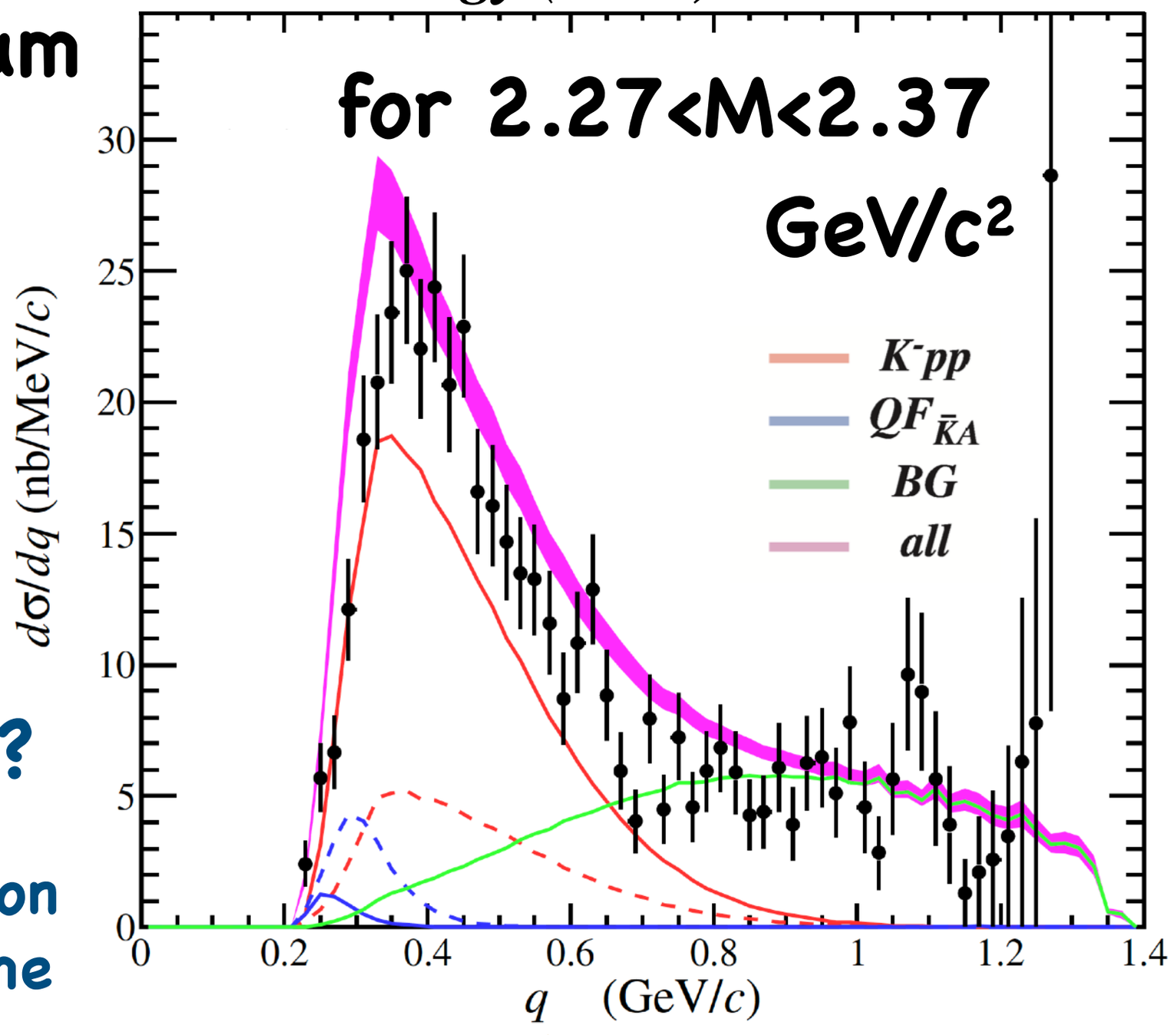
2.2
2.4
2.6
2.8
3.0
q [GeV/c]
M [GeV/c^2]

q: M-selected Λ p + $n_{mis.}$

PWIA w/ HO $\rho_{3B}(M,q) \times \dfrac{\left(\Gamma_{Kpp}/2\right)^2}{\left(M-M_{Kpp}\right)^2+\left(\Gamma_{Kpp}/2\right)^2} \times \exp\left(-\dfrac{q^2}{Q_{Kpp}^2}\right)$

energy (mass) *momentum*

q spectrum



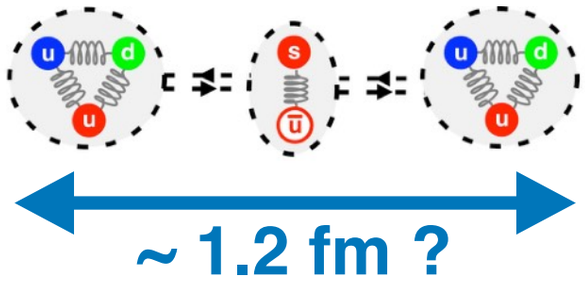
$Q_{Kpp} \sim 400$ MeV/c

$R_{Kpp} \sim \dfrac{\hbar c}{Q_{Kpp}} \sim 0.5$ fm?

~0.6 fm relative K motion in Kpp CM-frame

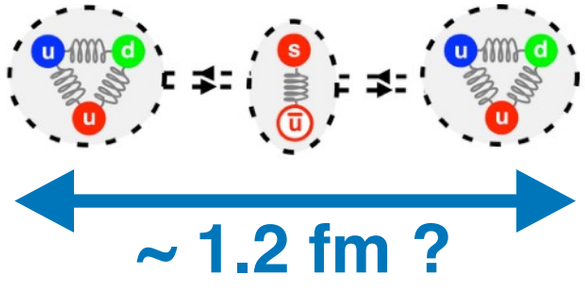
Hierarchy inside nucleon

kaonic nucleus “Kpp”

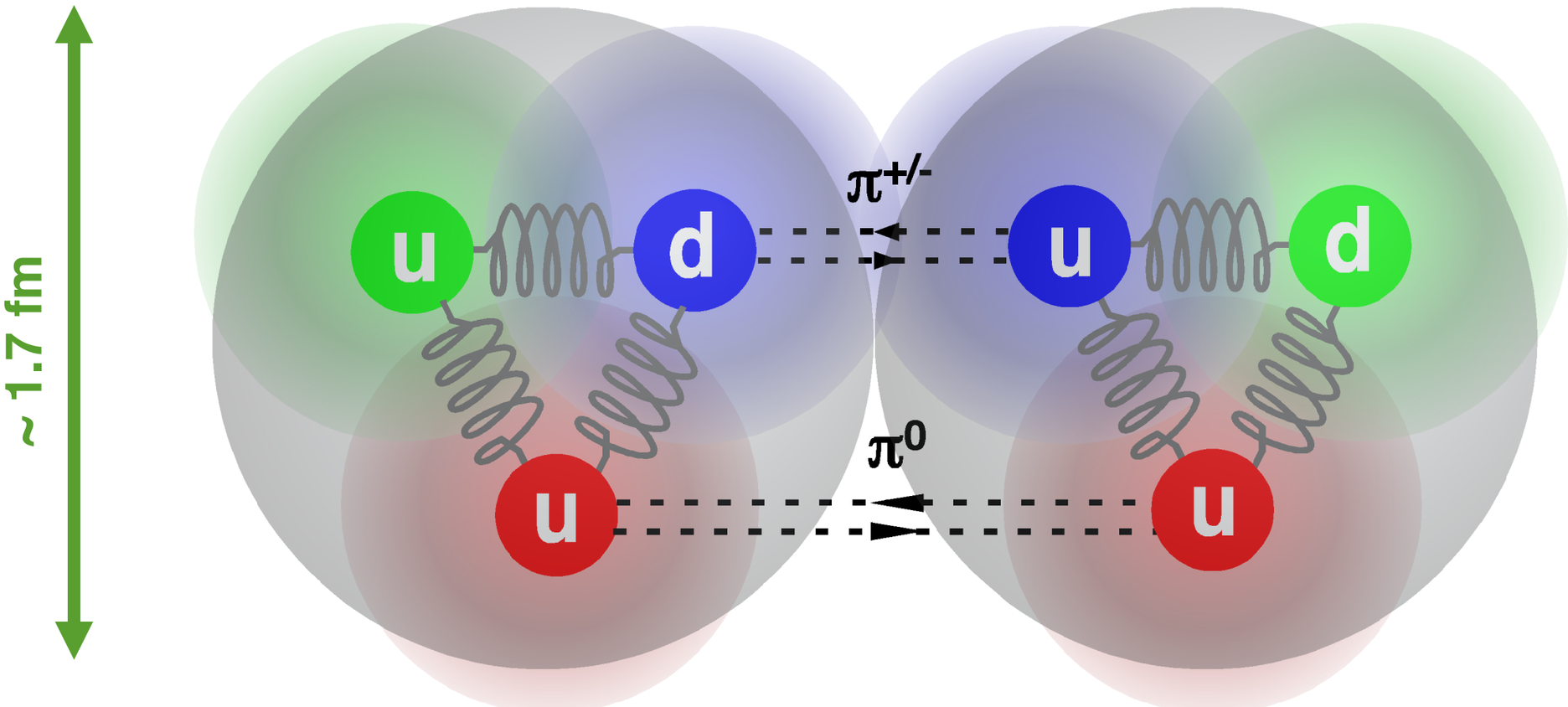


Hierarchy inside nucleon

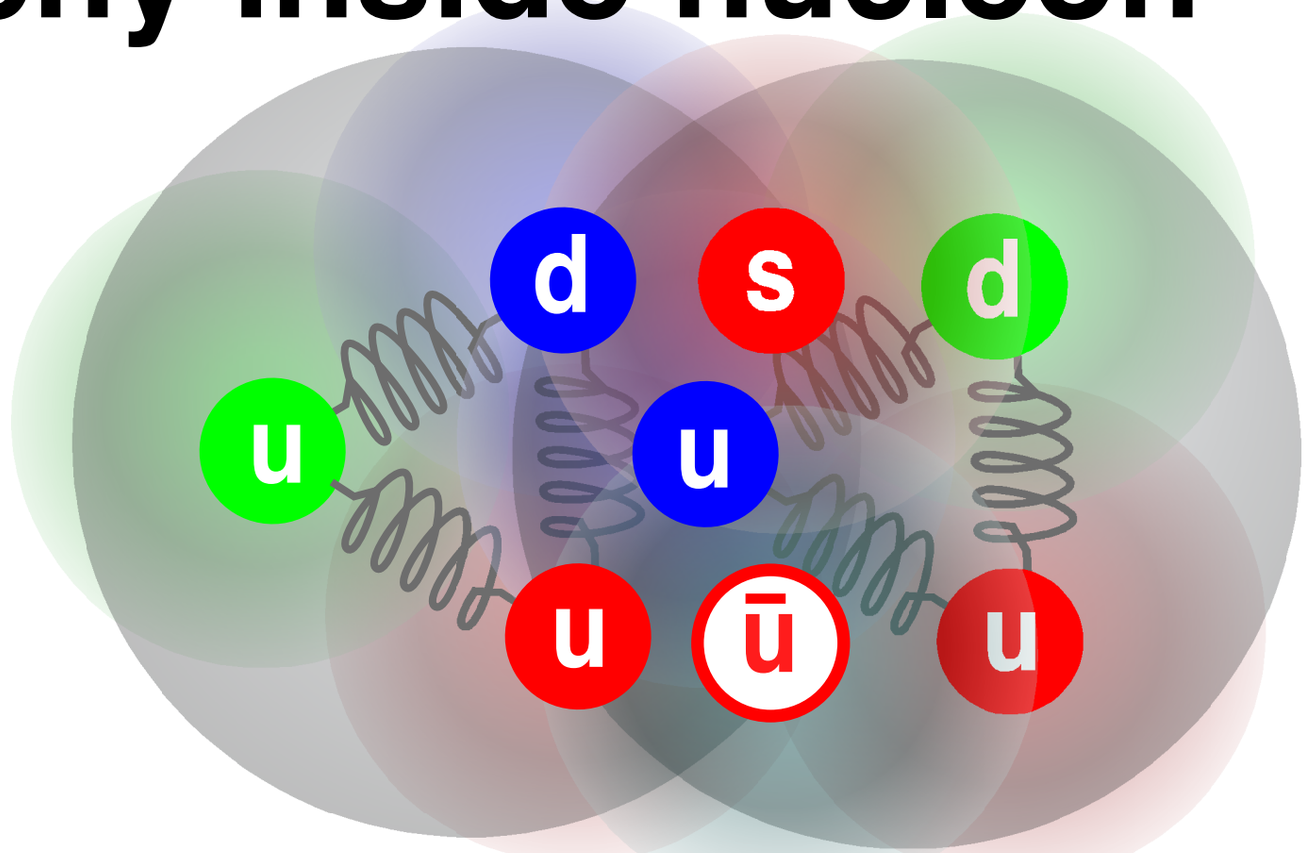
kaonic nucleus “Kpp”

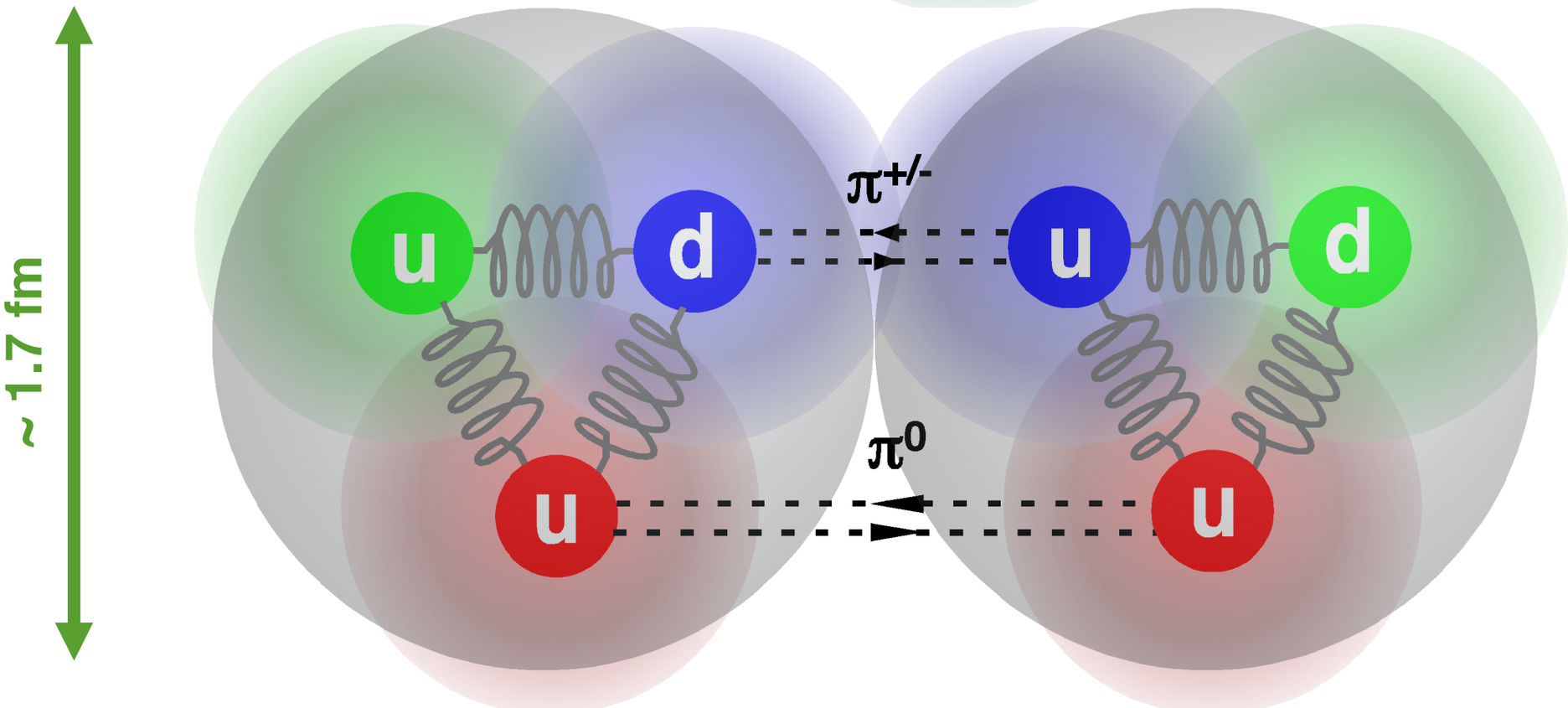


nucleon in nuclei / incompressibile

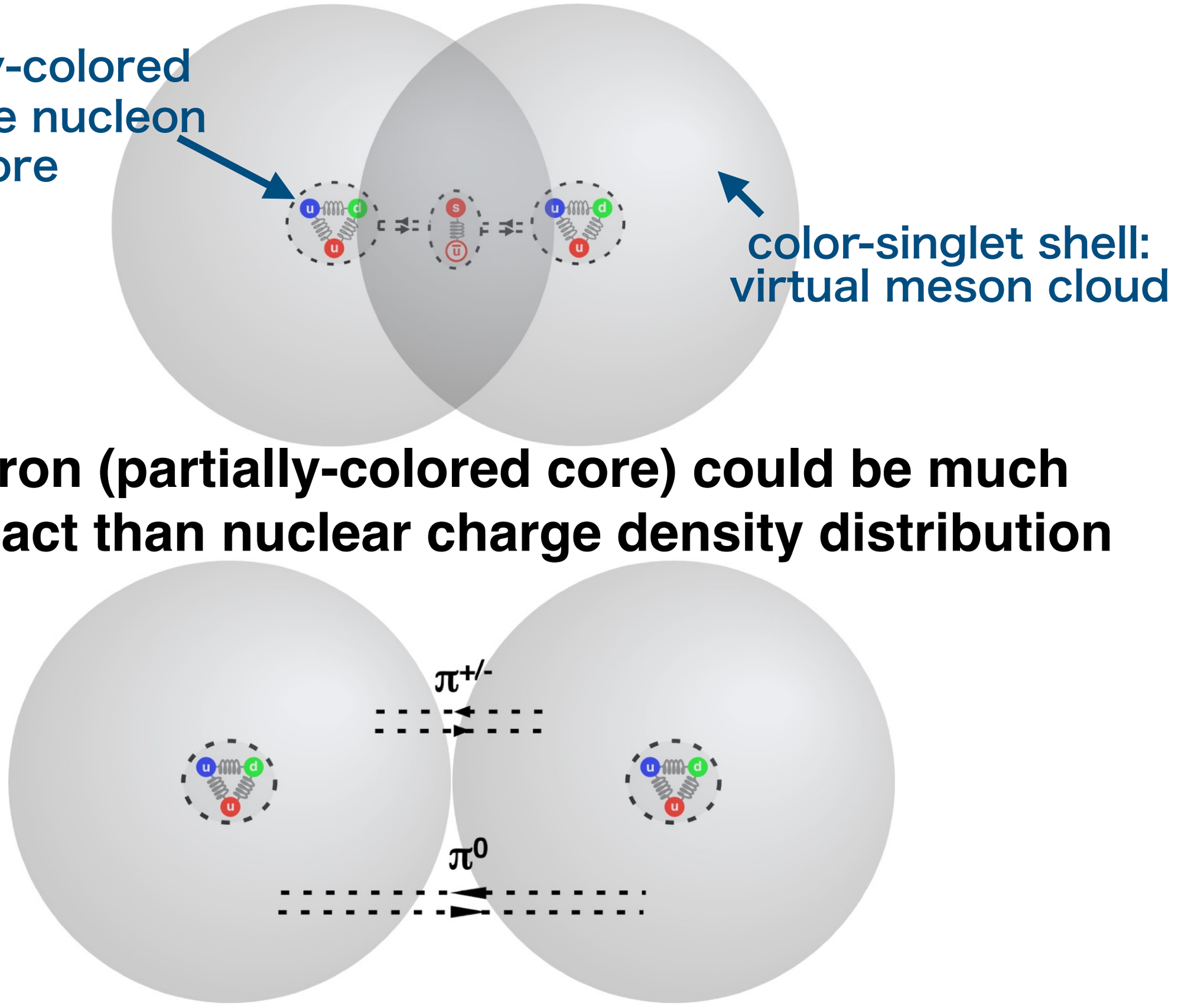


Hierarchy inside nucleon





There could be a hierarchy inside nucleon



hadron (partially-colored core) could be much compact than nuclear charge density distribution

Summary

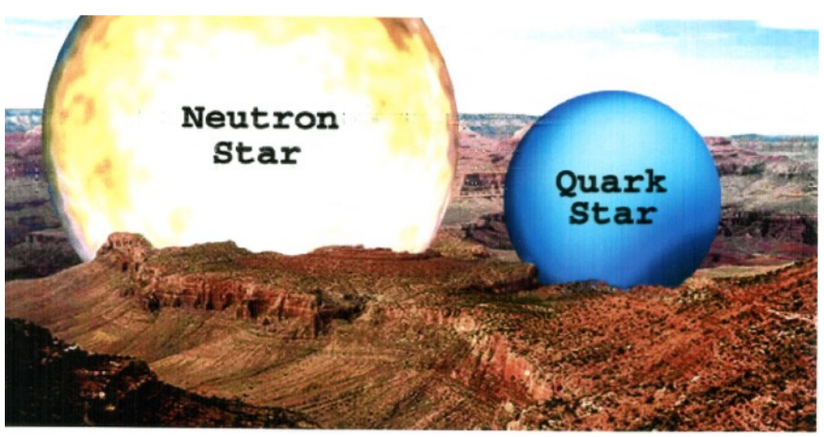
future to go

E15: $K^- + {}^3He \rightarrow (\Lambda + p) + n$

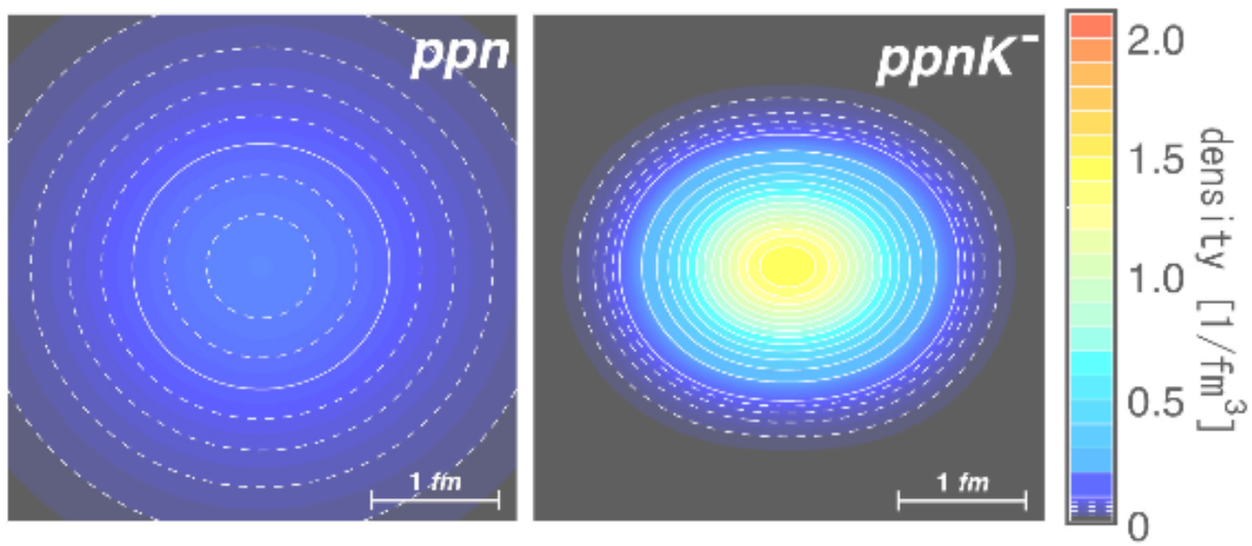
convincing Kpp signal obtained

systematic study on light kaonic nuclei

compact deep nuclear bound system ?



Dote et al., PLB 590 (2004) 51



Renewed key questions:

- Dose K-meson change mass in nuclei?

➡ **Atomic number (A) dependence = *n* detector**

“K⁻p”(=Λ(1405)), “K⁻pp”, “$\bar{K}^0$nn”, “K⁻ppn”, “K⁻ppnn”, …

- Spatial size?

➡ **precise angular dependence = *full coverage***

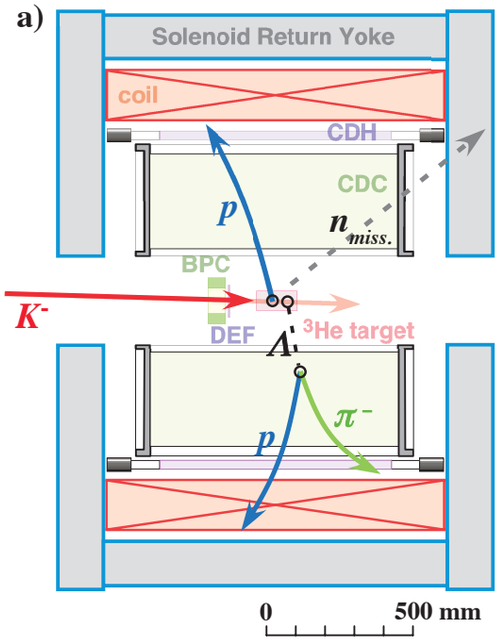
- Quantum state & decay?

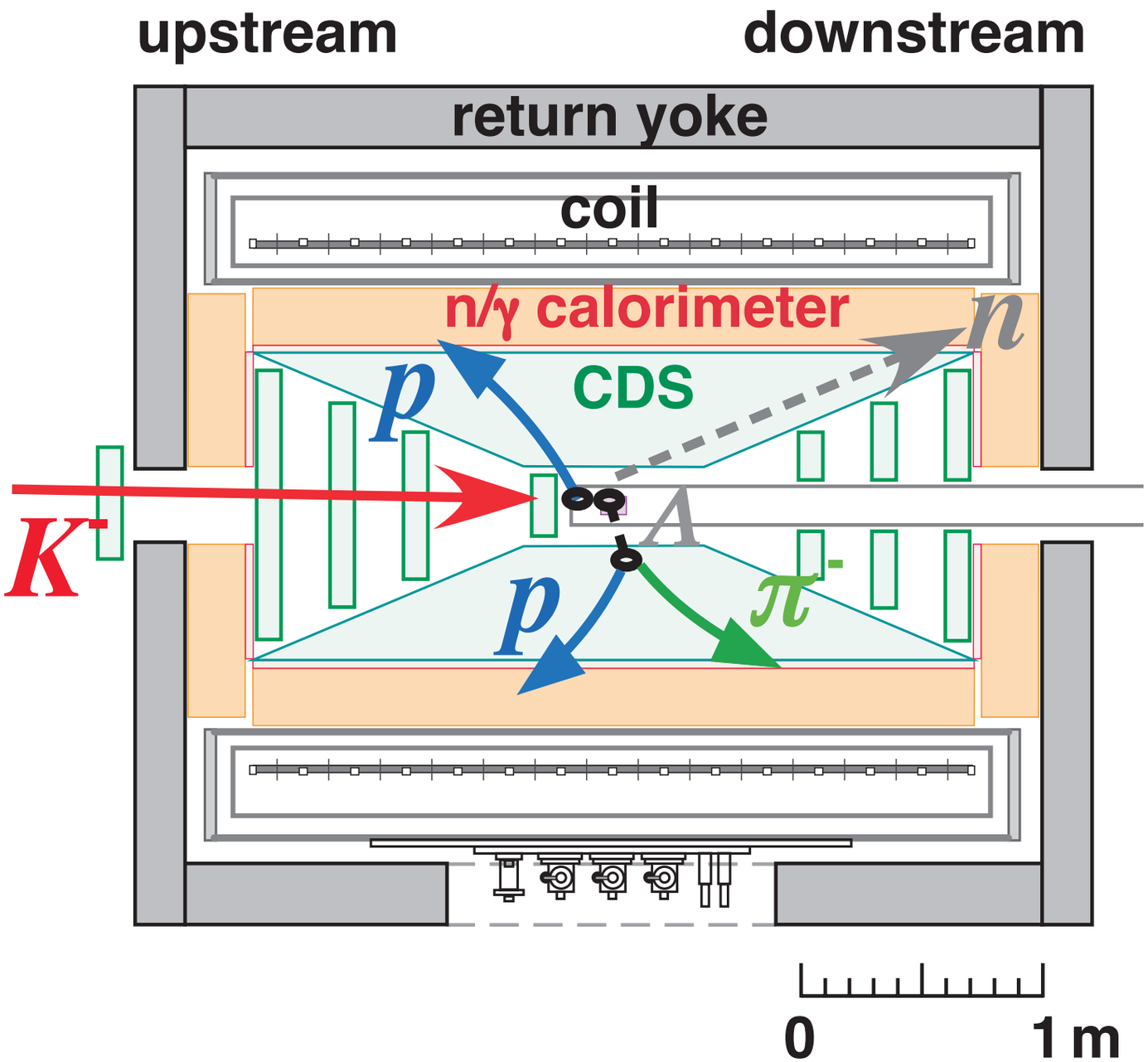
➡ **Λp / Σ⁰p / π⁰Σ⁰p = γ detector**

(γ if budget-wise feasible: maybe too expensive)

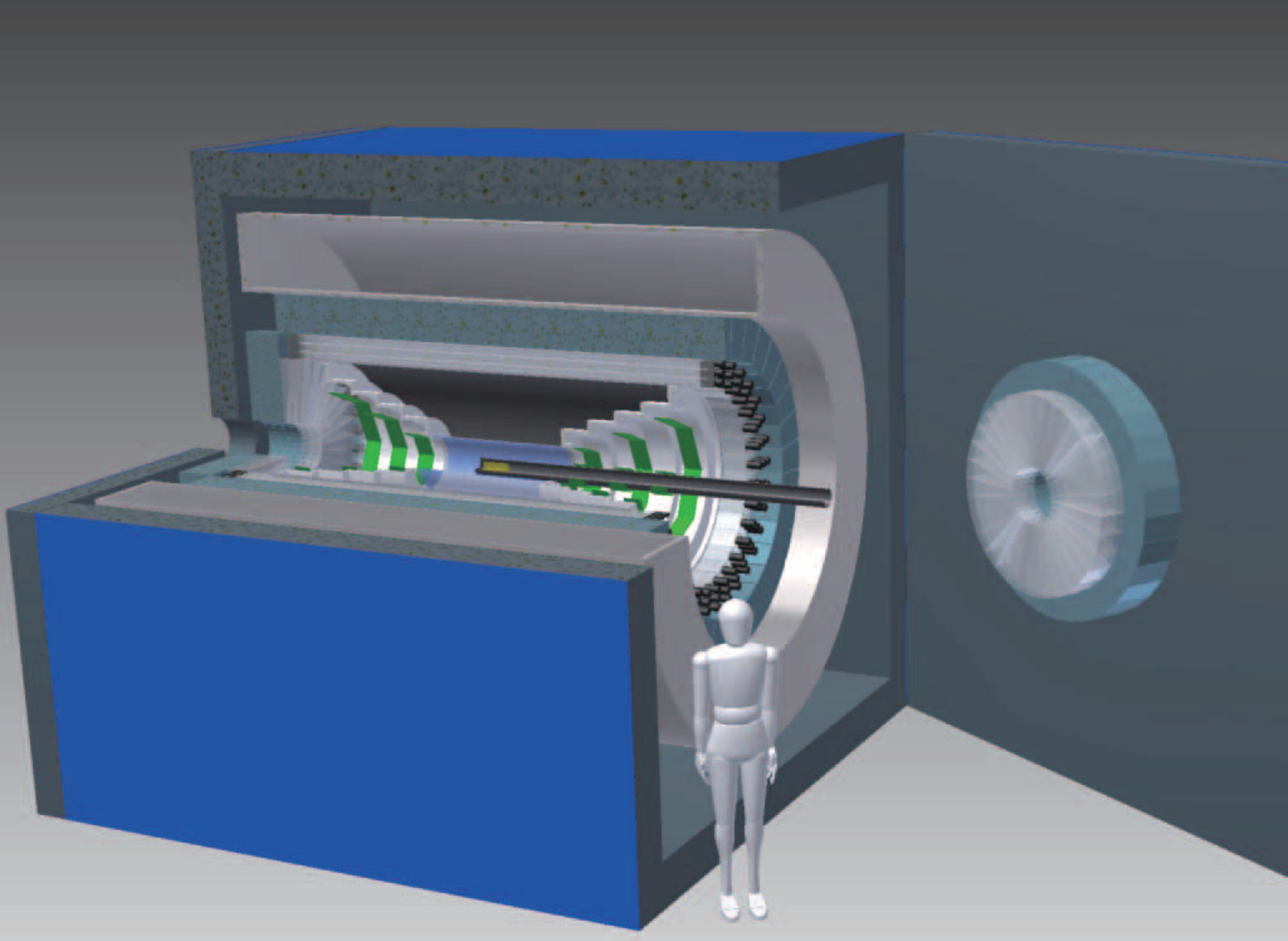
Upgrade Plan

E15 setup





cf. $\Sigma^0 \rightarrow \Lambda + \gamma$!



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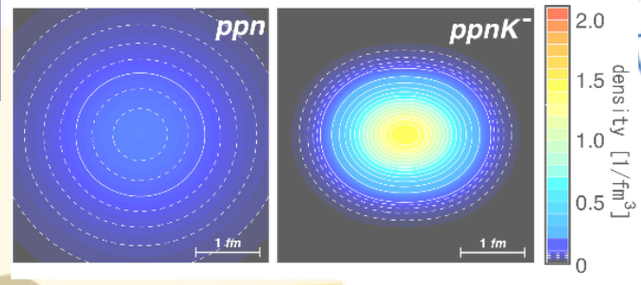
University of Victoria



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INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

KEK-JAPAN

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Tokyo Tech

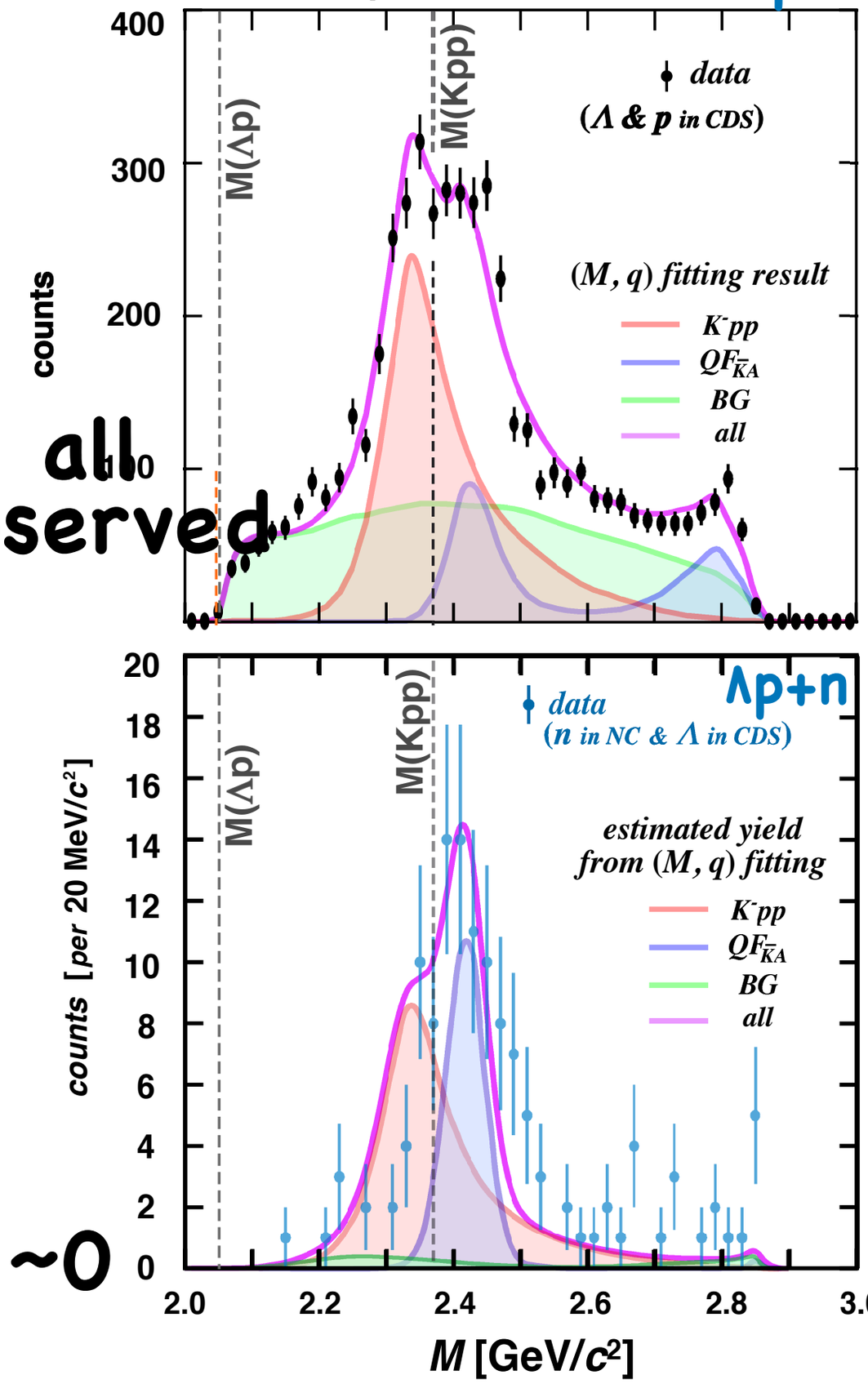
OECU

Thank you for attention!

note: M Spectrum depend on how detected

all observed

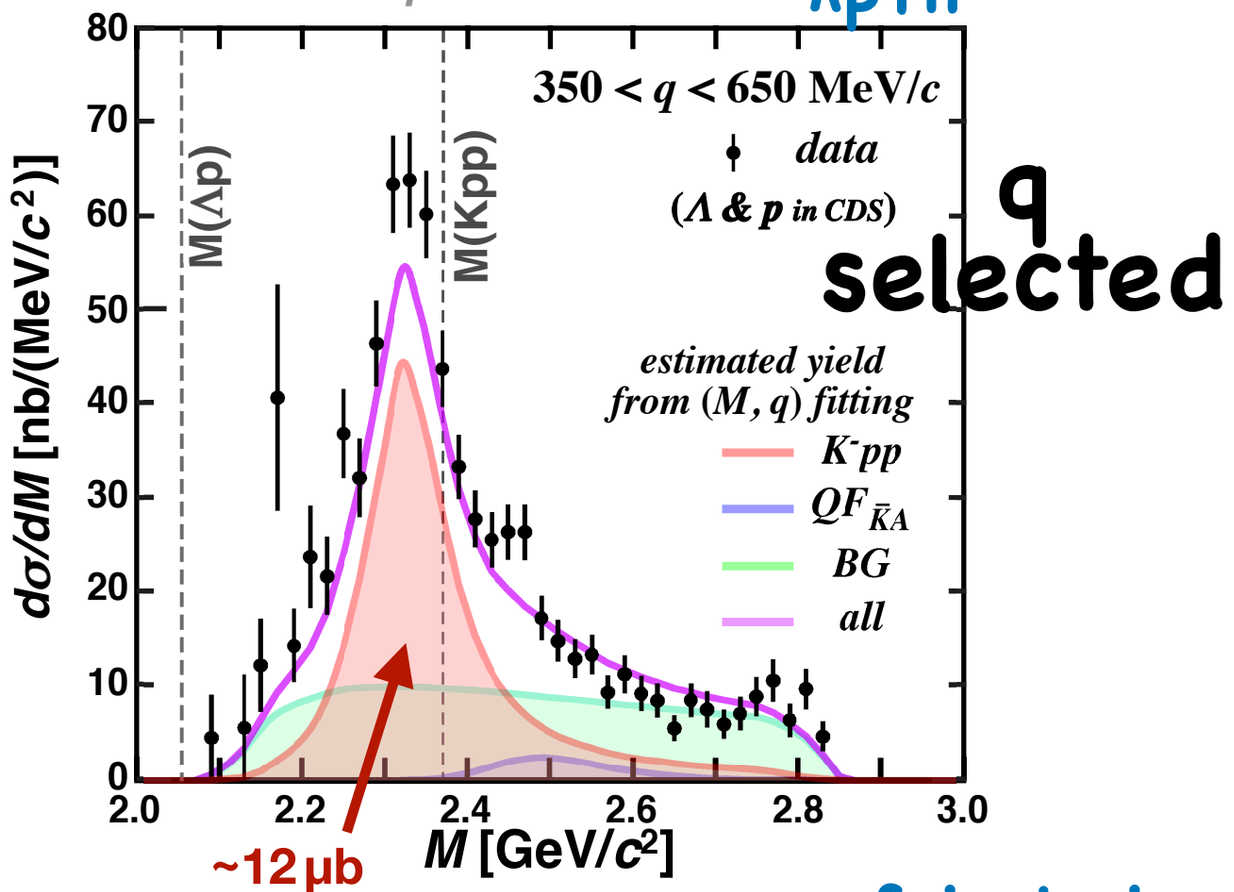
acceptance uncorrected Λp+n



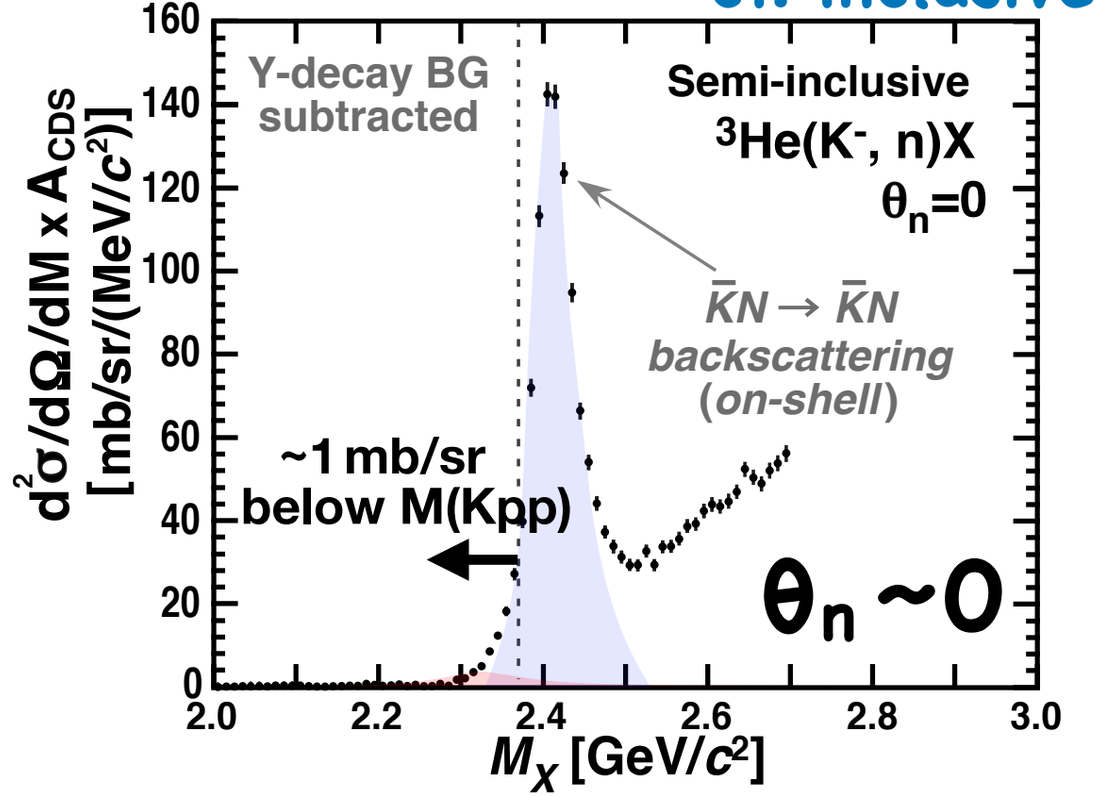
θn ~0

acceptance corrected Λp+n

q selected



cf. inclusive



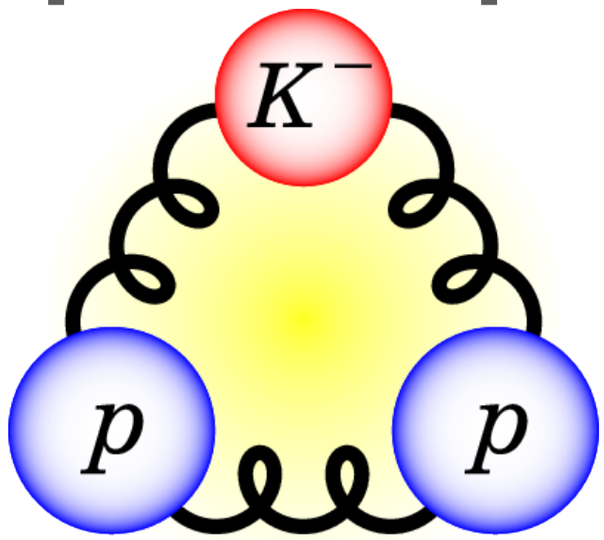
Key question (research motivation):

- Can Kaon(mason) be bound in nuclei?

- Anti-quark $\bar{q}$ and quark q co-exist in nuclei

if so,
- Extremely new quantum states not previously known
- Gateway to ultra-high density physics

p = K^- = p



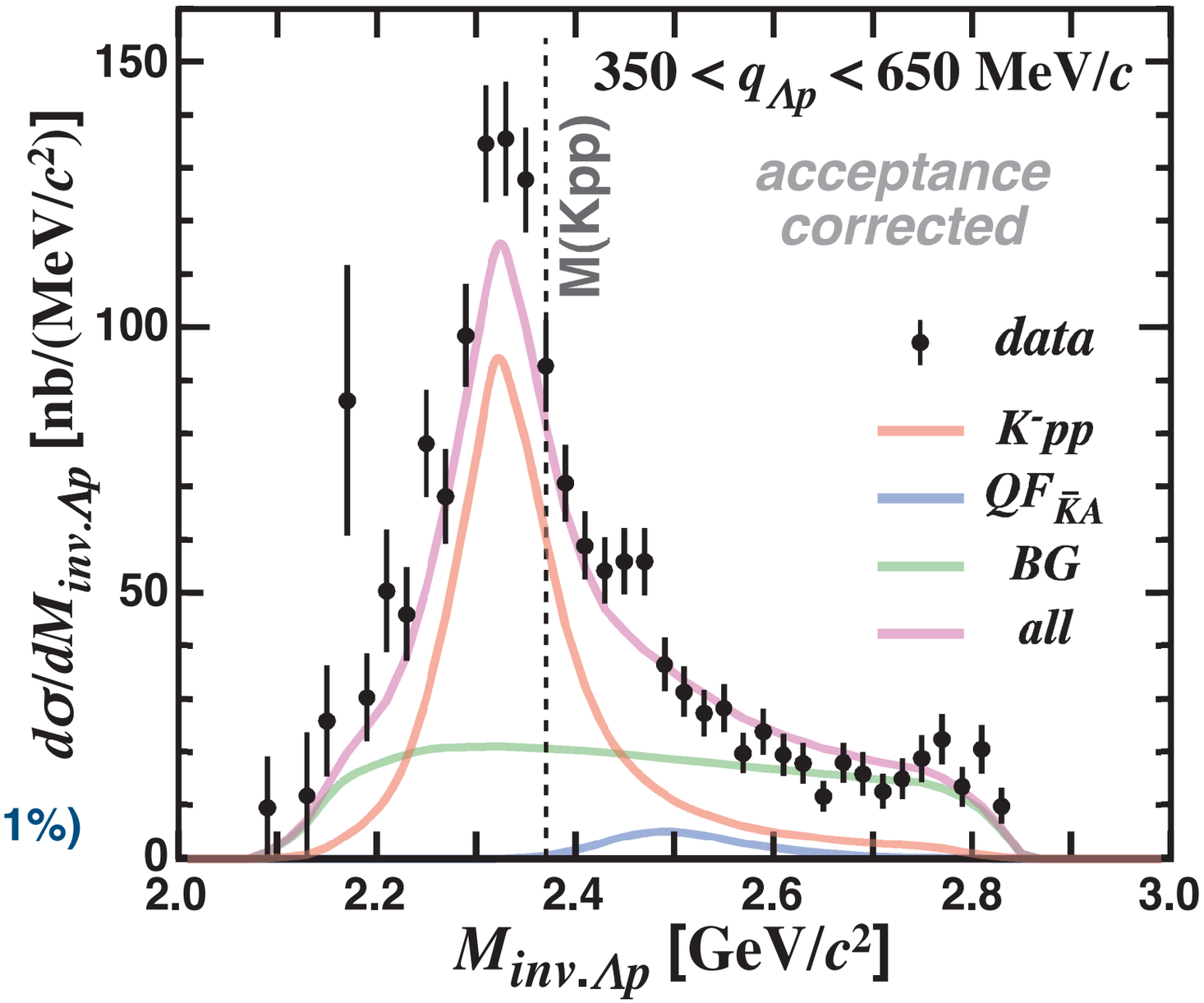
deeply bound

B_{Kpp} ~ 50 MeV (B.W.)

10% mass reduction? (nucleon ~ 1%)

extremely compact?

R_{Kpp} ~0.6 fm ?



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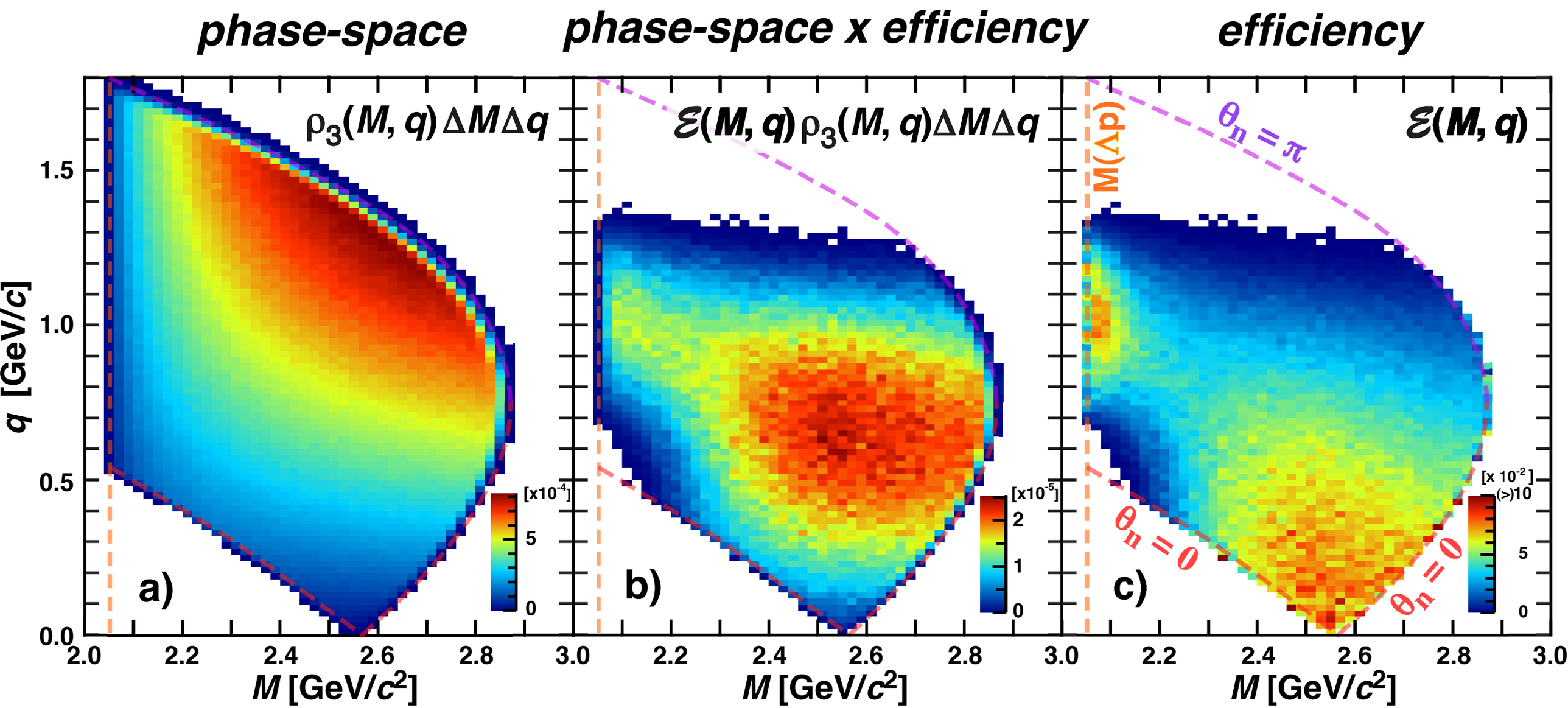
What happens when one observe

point-like $K^- + {}^3He \rightarrow \Lambda + p + n$ reaction

$\propto$ *phase-space*

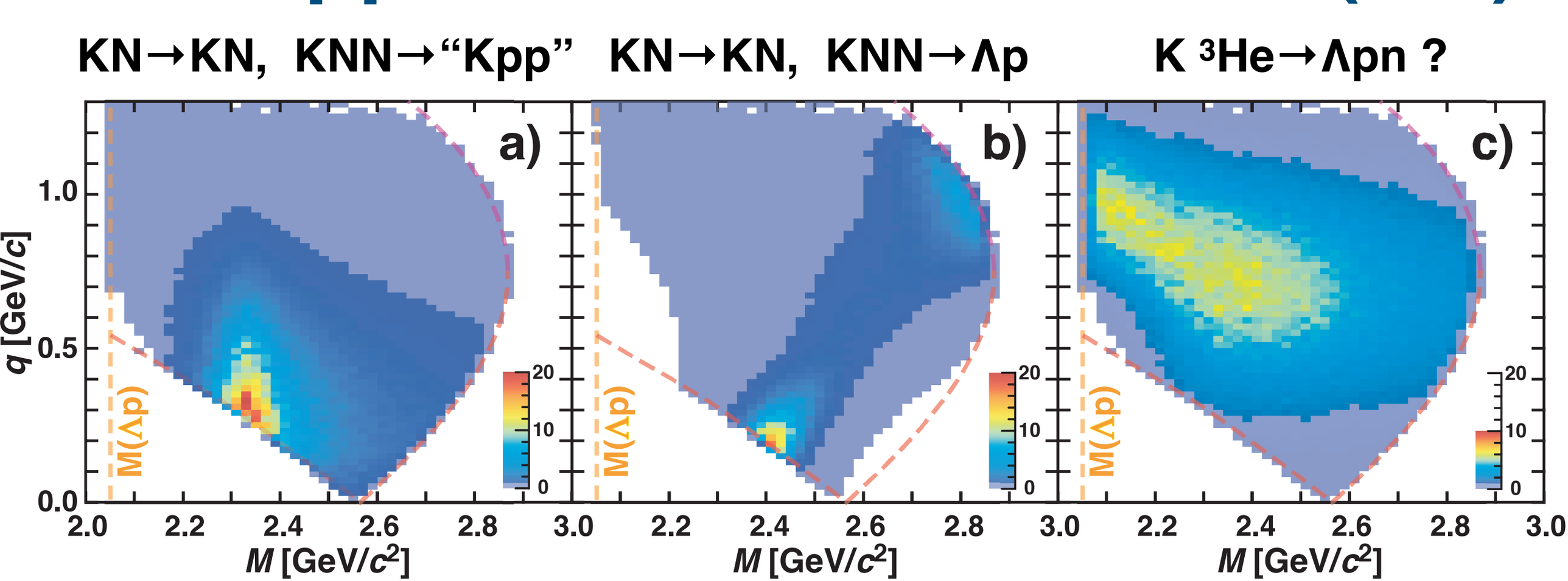


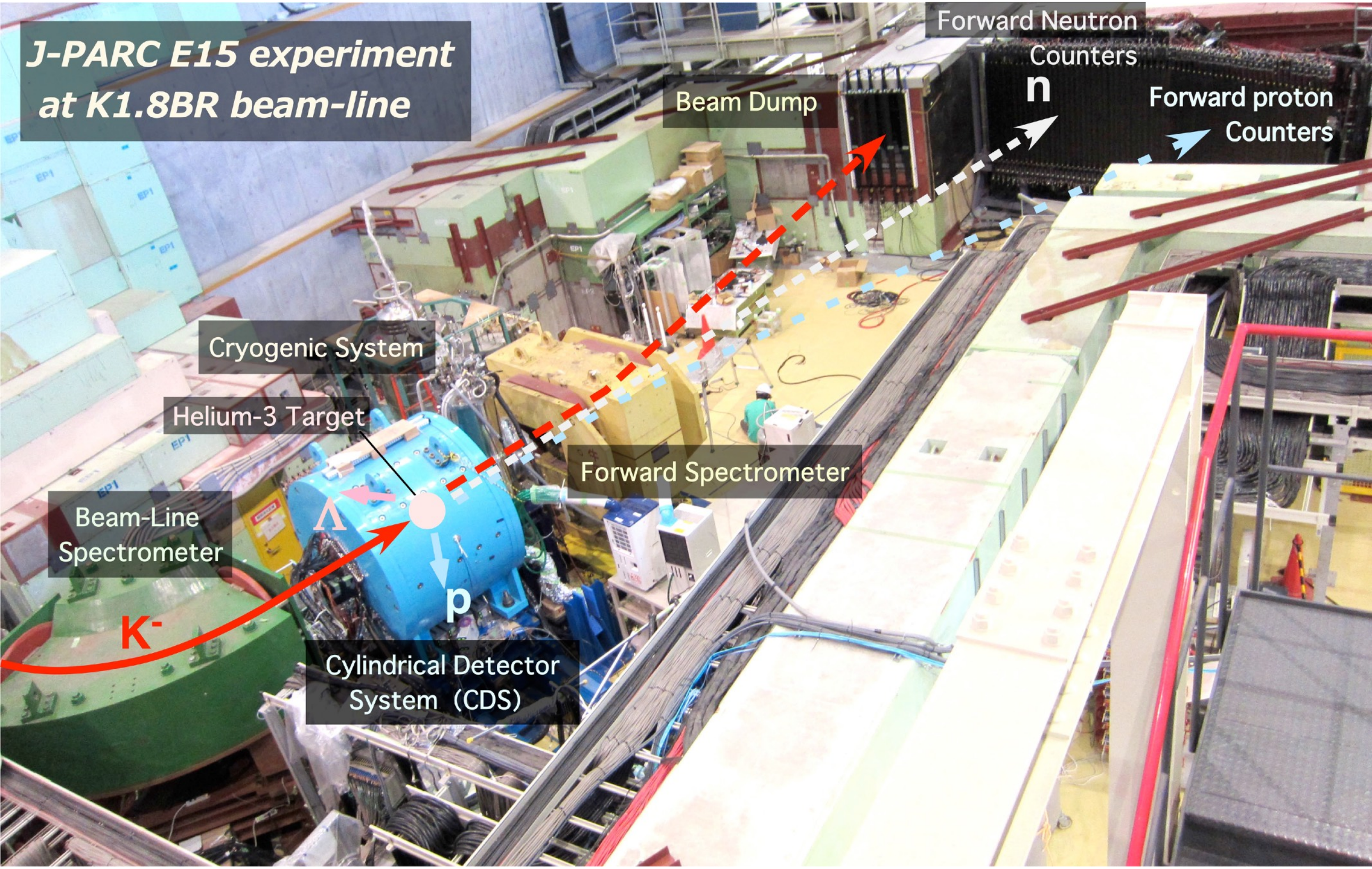
not easy to apply efficiency correction!

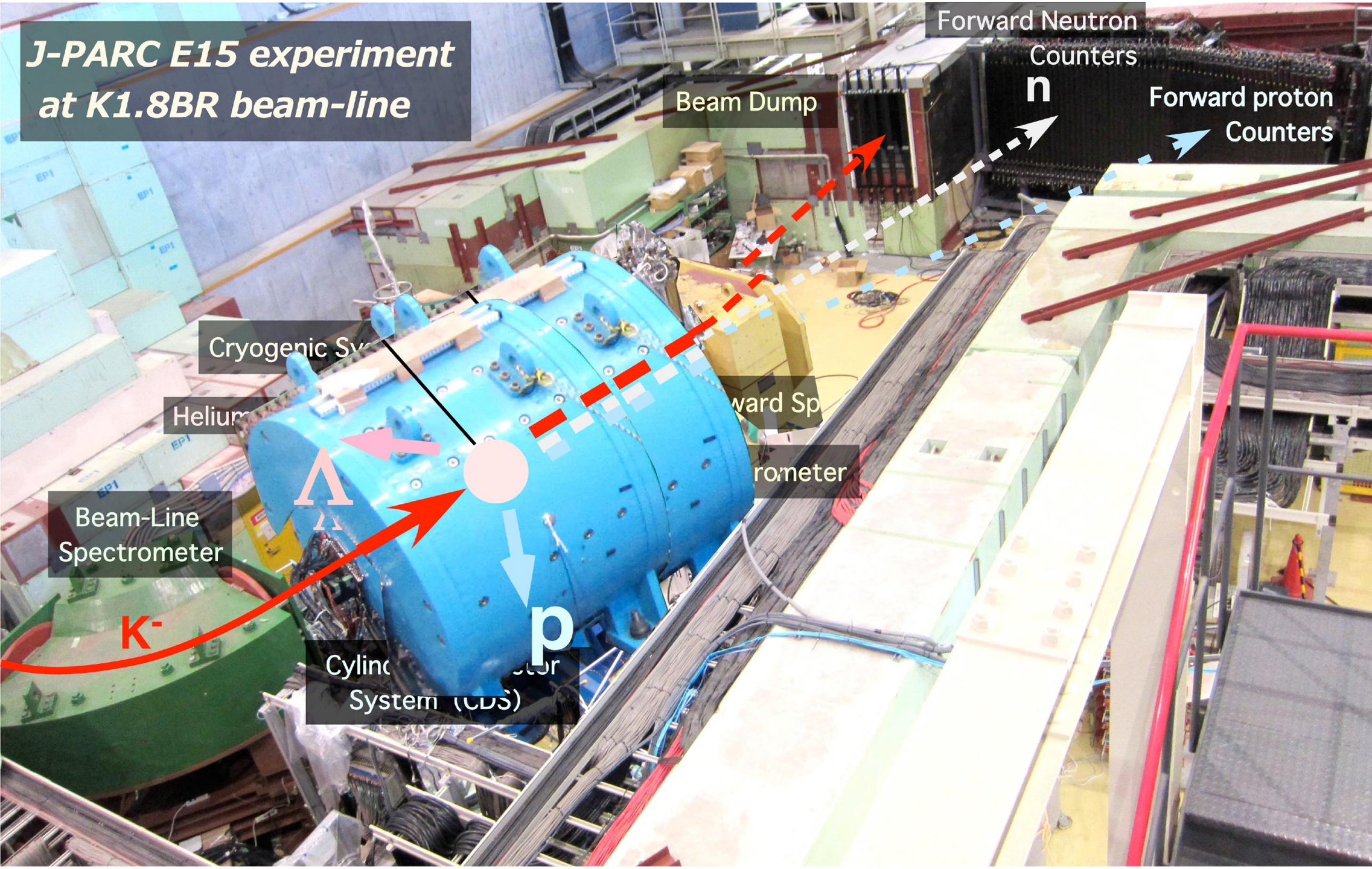
We introduced three model functions to fit data on (M, q) plane 2-dimensionally

$$\mathcal{E}(M,q) \times \rho_3(M,q) \times phys_X(M,q)$$

detector efficiency	Λpn 3-body phase space	physics process
"Kpp"	**$QF_{\bar{K}A}$**	**broad(BG)**




J-PARC E15 experiment
at K1.8BR beam-line
Forward Neutron
Counters
n
Forward proton
Counters
Beam Dump
Cryogenic System
Helium-3 Target
Forward Spectrometer
Beam-Line
Spectrometer
Λ
p
K-
Cylindrical Detector
System (CDS)


J-PARC E15 experiment
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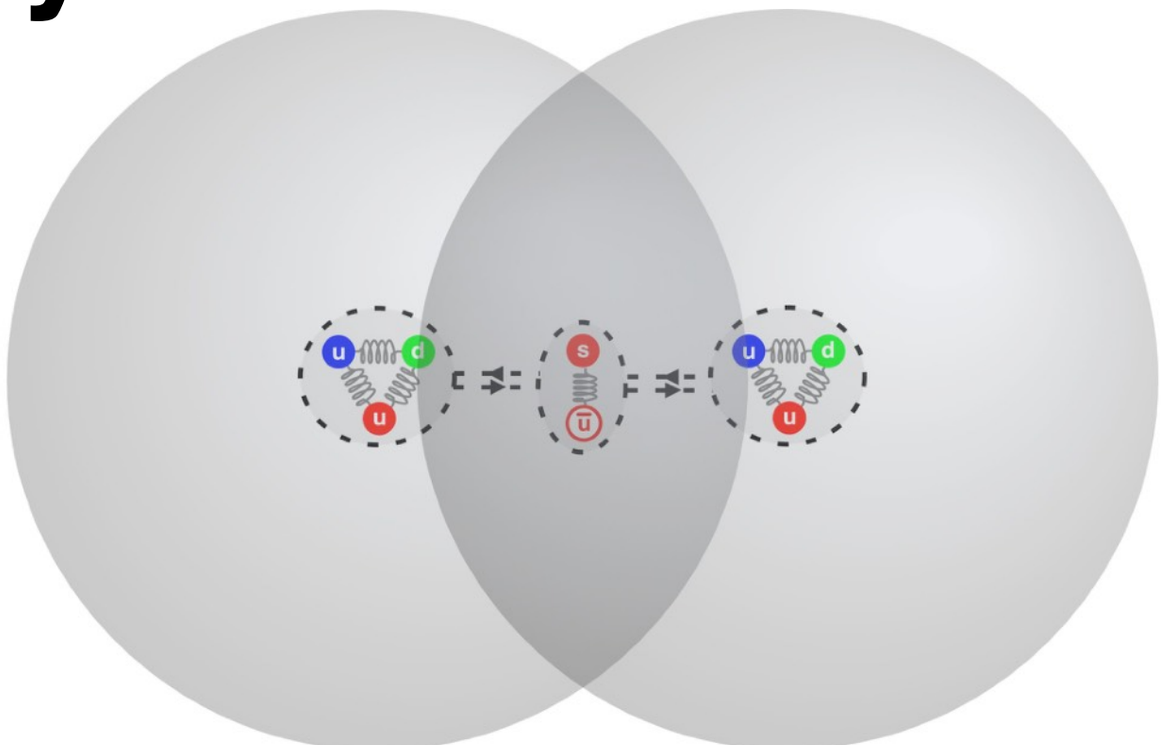
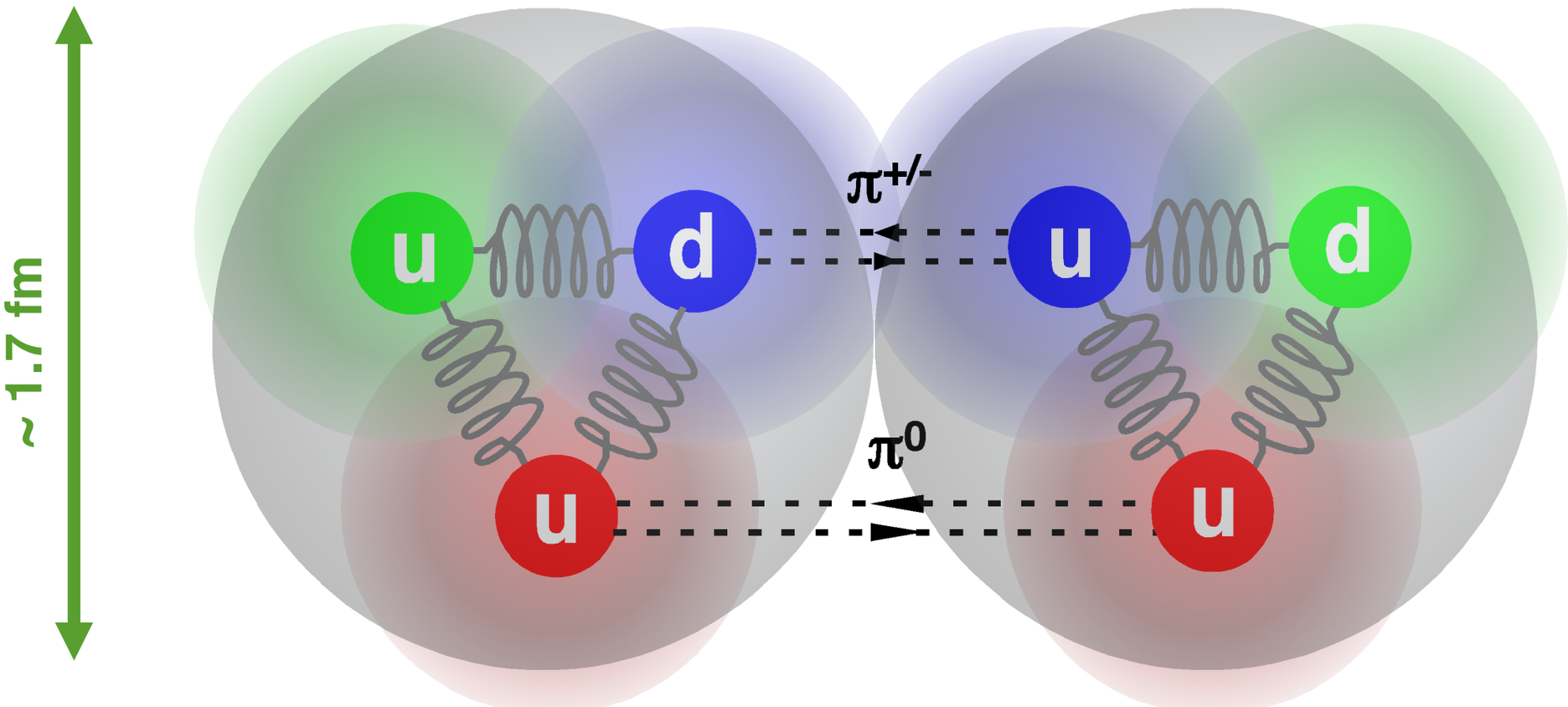
Cylinc
System (CDS)

Hierarchy inside nucleon





Press over the world

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参考資料配布

PRESS RELEASE

2019 年 1 月 24 日
理化学研究所
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日本原子力研究開発機構
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K⁻中間子と二つの陽子からなる原子核の発見
ークォークと反クォークが共存する“奇妙な”結合状態ー

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Italy, tech economy ：2019/03/13

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Home › Visions › Scoperta una nuova forma di materia “strana”: a cosa servirà?

Visions

Scoperta una nuova forma di materia “strana”: a cosa servirà?

By **Catalina Curceanu** - 12/03/2019

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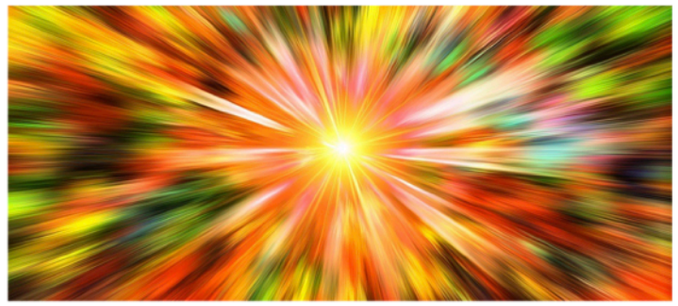

Insieme a un gruppo di ricerca di cui faccio parte abbiamo scoperto una nuova forma di materia “strana” in un esperimento effettuato all’acceleratore J-PARC, in Giappone. Questa scoperta ci aiuterà a capire meglio l’origine della massa immediatamente dopo il Big Bang, ma anche il cuore delle stelle di neutroni.

Sull’autore

Catalina Curceanu
Primo Ricercatore dei Laboratori Nazionali di Frascati dell’Istituto Nazionale di Fisica Nucleare e membro...

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Austrian Academy of Sciences, 29.01.2019

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29.01.2019

PHYSIKER ERZEUGEN NEUE MATERIEFORM

Unter Mitwirkung der Österreichischen Akademie der Wissenschaften gelang es am japanischen Teilchenbeschleunigerzentrum J-PARC erstmals eine neue Form von Materie mit Anti-Kaonen nachzuweisen. Das berichtet das internationale Forschungsteam nun im Fachjournal „Physics Letters B“.

Visualisierung der neuen Materieform (blau: Protonen): Das beschleunigte Anti-Kaon (rot) ersetzt das Neutron (grün) und sorgt damit für eine enorme Bindungsenergie im neu entstandenen Kerncluster. © ÖAW/Harald Ritsch

INFORMATIONEN

Die Publikation:

“K−pp”, a K-meson nuclear bound state, observed in 3He(K−,Λp)n reactions, J-PARC E15 collaboration et al., Physics Letters B, 2019
DOI:
https://doi.org/10.1016/j.physletb.2018

ÖAW-PRESSEMELDUNG

STEFAN-MEYER-INSTITUT FÜR SUBATOMARE PHYSIK DER ÖAW

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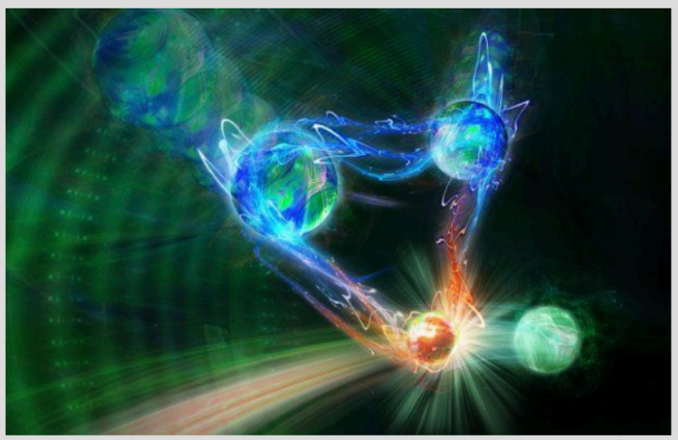
Atentatele UM 0544R si Tradarea fantomelor SIE

O nouă formă de materie NUCLEARĂ STRANIE descoperită în Japonia! Toată omenirea într-un DEGETAR?



Autor: Cătălina Curceanu | duminică, 10 februarie 2019 | 11 Comentarii | 7231 Vizualizari
Distribuie　いいね！　Salvează acest articol

Stiri calde

05:14 USR mai tare decât Nicolae Ceaușescu. Regimul comunist nu a fost niciodată instaurat în România
01:49 Lovitură uriașă în mass media. Apare o nouă televiziune care promite să spulbere concurența
01:47 Final cu deznodământ așteptat pentru Brexit. Anunț de ultim moment făcut în Marea Britanie
01:46 Acuzații grele la adresa lui Dragnea. „Ia droguri!”. Noaptea din Istanbul care a schimbat viitorul PSD. „A avut cuvinte urâte”
01:45 Hackerii care au speriat America, deconspirați de o pizza și de Facebook. Cum i-au prins agenții Secret Service pe Eveline Cismaru și Alexandru Isvanca
01:05 NEWS ALERT. Simona Halep a eliminat-o pe Venus Williams și a făcut pasul către sferturile de finală de la Miami
00:58 Românii dau peste victimele

Stiri calde

- E15^{2nd}

b)

I I(Kpp)

data

K^-pp

$QF_{\bar{K}A}$

BG

all

before acceptance correction

counts

M(Λp)

counts

50 100 150 200

c)

$M_F(q)$

$\theta_n = 0$

$\theta_n = 0$

$\theta_n = 0$

a)

M(Kpp)

20 10 0

q [GeV/*c*]

0.0 0.5 1.0

2.0 2.2 2.4 2.6 2.8 3.0

M [GeV/c^2]