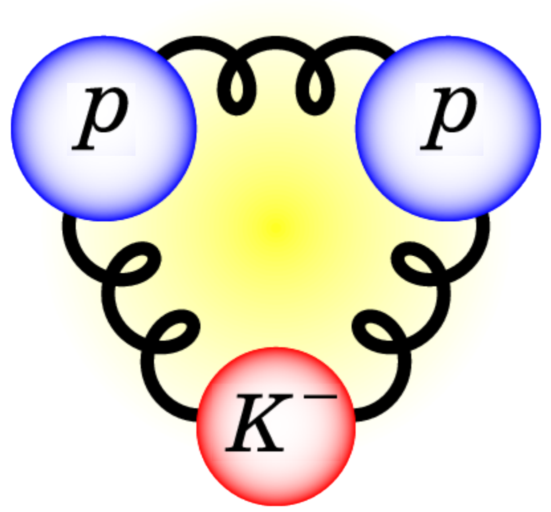

INPC 2022
Cape Town, South Africa

$\bar{K}$ nuclear bound state

Toward revolutionary Nuclear Study via
revealing Internal Structure of Kaonic Nuclei

M. Iwasaki

for the J-PARC E15/E73/T77 collaboration

from **RIKEN**
Cluster of Pioneering Research
Nishina Center

Outline

- **Brief introduction**
- $\bar{K}NN,\ I_3 = +\frac{1}{2}$ **identified in** $\bar{K}NN \to \Lambda p$ **analysis**

  Phys. Lett. B789, 620-625 (2019)

  Phys. Rev. C102, 044002 (2020)
- $\bar{K}NN \to \pi YN$ **decay dominance** $Br_{\pi Yp} > 10 \times Br_{\Lambda p}$

  preliminary analysis … T. Yamaga
- $\bar{K}NNN,\ I = 0$ **identified in** $\bar{K}NNN \to \Lambda d$ **analysis**

  preliminary analysis … T. Hashimoto

Basic understanding of nuclei

- Nuclei consist of nucleons bound by nuclear force

nucleons (N): qqq

Fermion:

Pauli exclusion

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nucleons (*N*): ***qqq***

q* = *u* or *d

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Z [e]	ist	2nd	3rd
$+\frac{2}{3}$	u	c	t
$-\frac{1}{3}$	d	s	b

quark flavor

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Boson:
particles can share a quantum state

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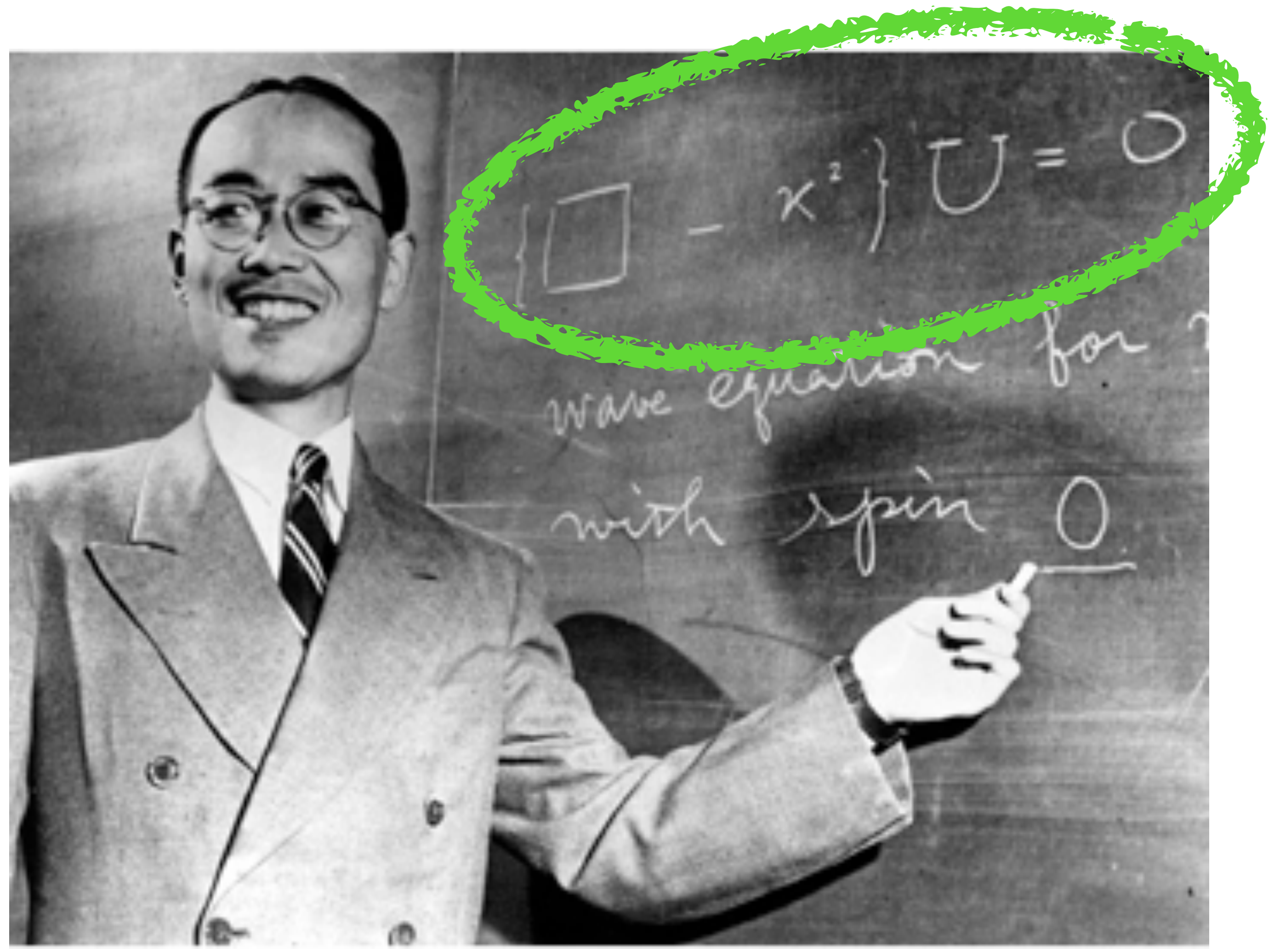

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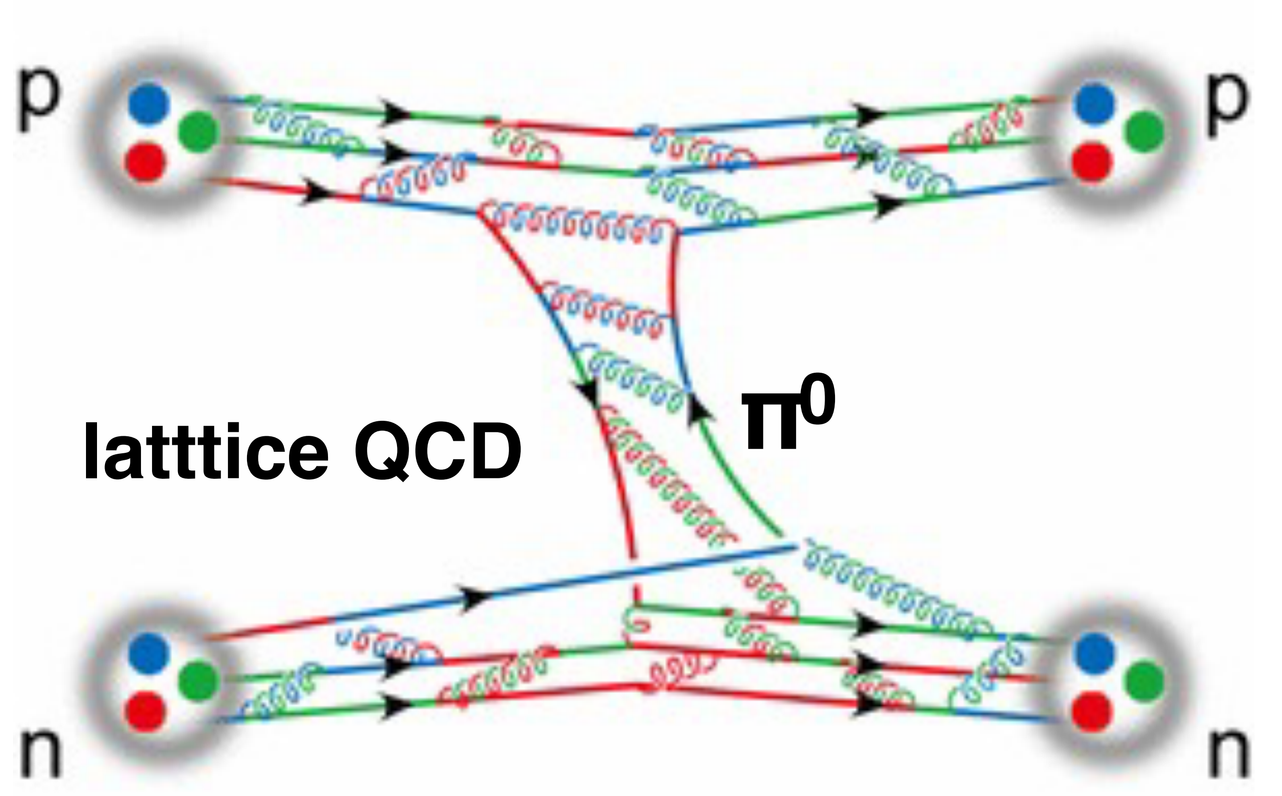
Yukawa Theorem tells：

- **in nuclei, mesons are virtual particle and form nuclear potential**

$$\phi \propto \frac{1}{r} \exp(-mr)$$



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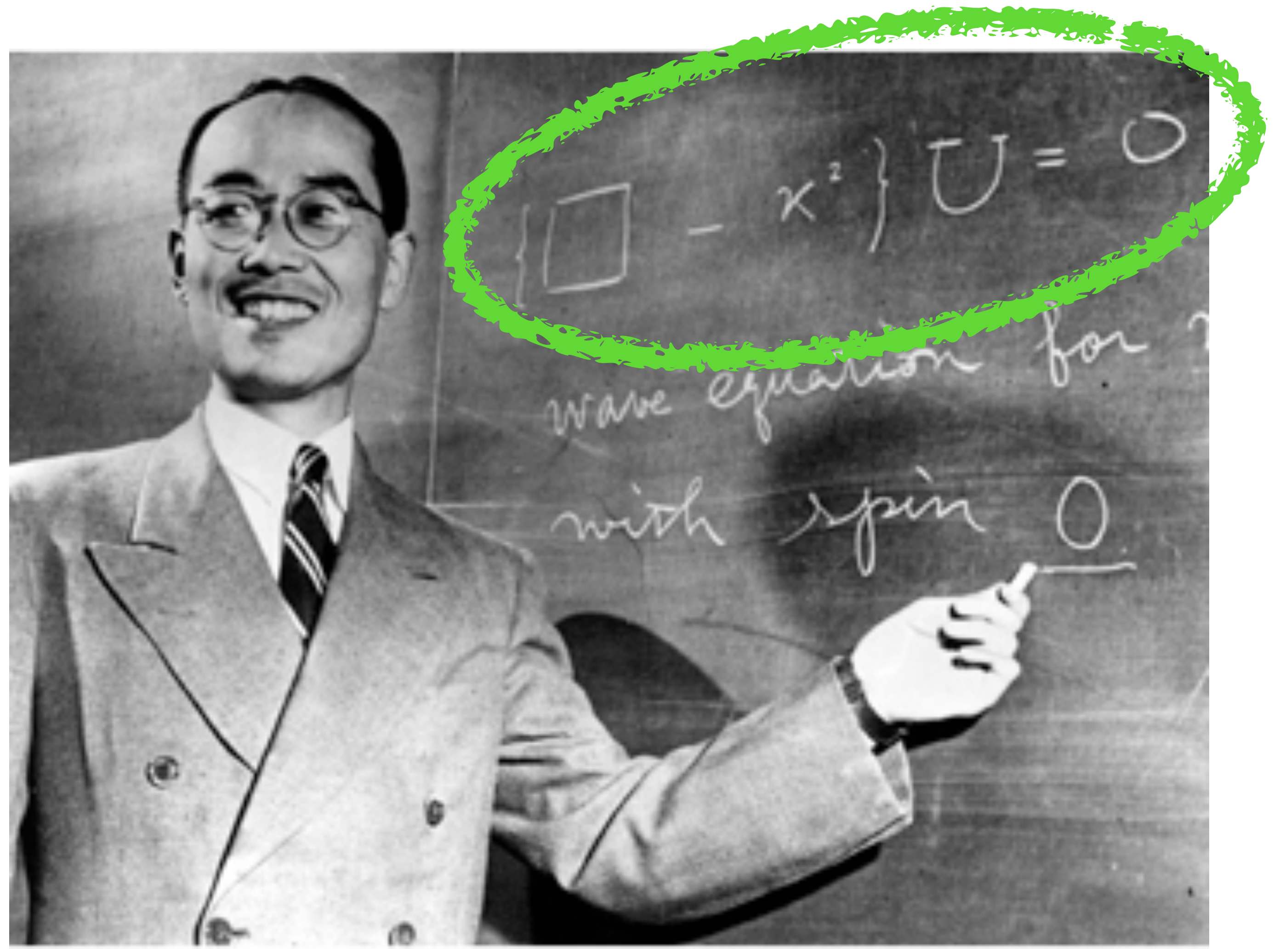

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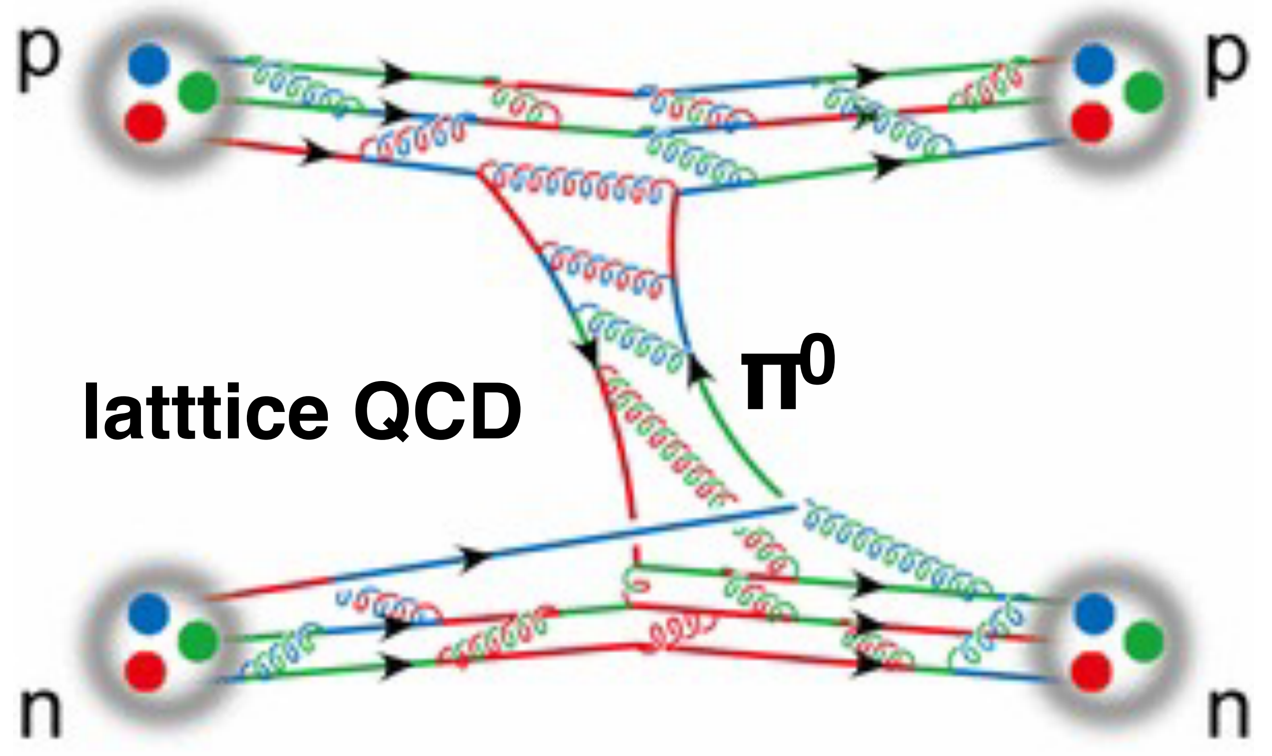

Long standing question：

Can meson be a constituent particle forming nuclei?

— Can meson form a quantum state as a particle ? —

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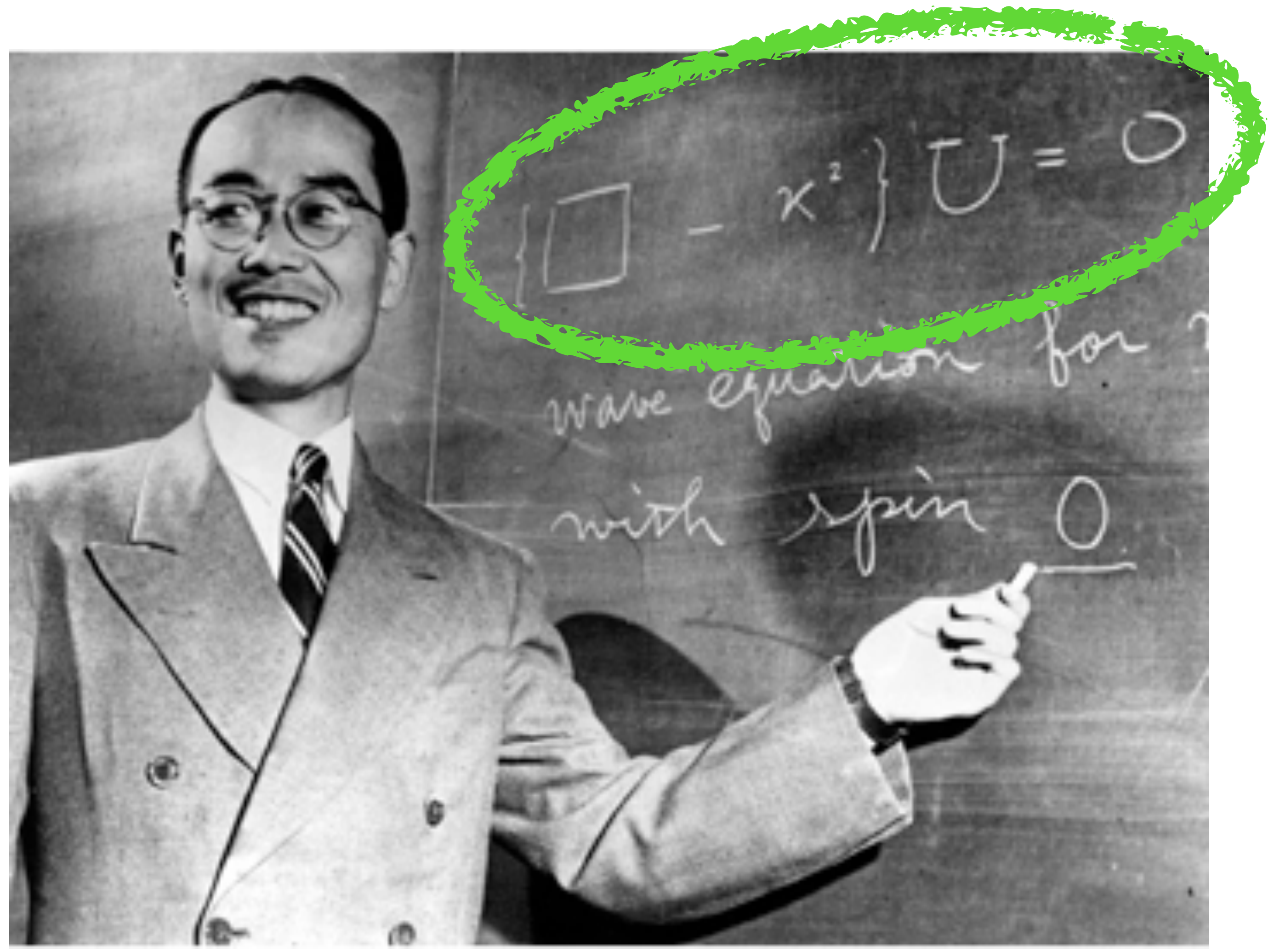

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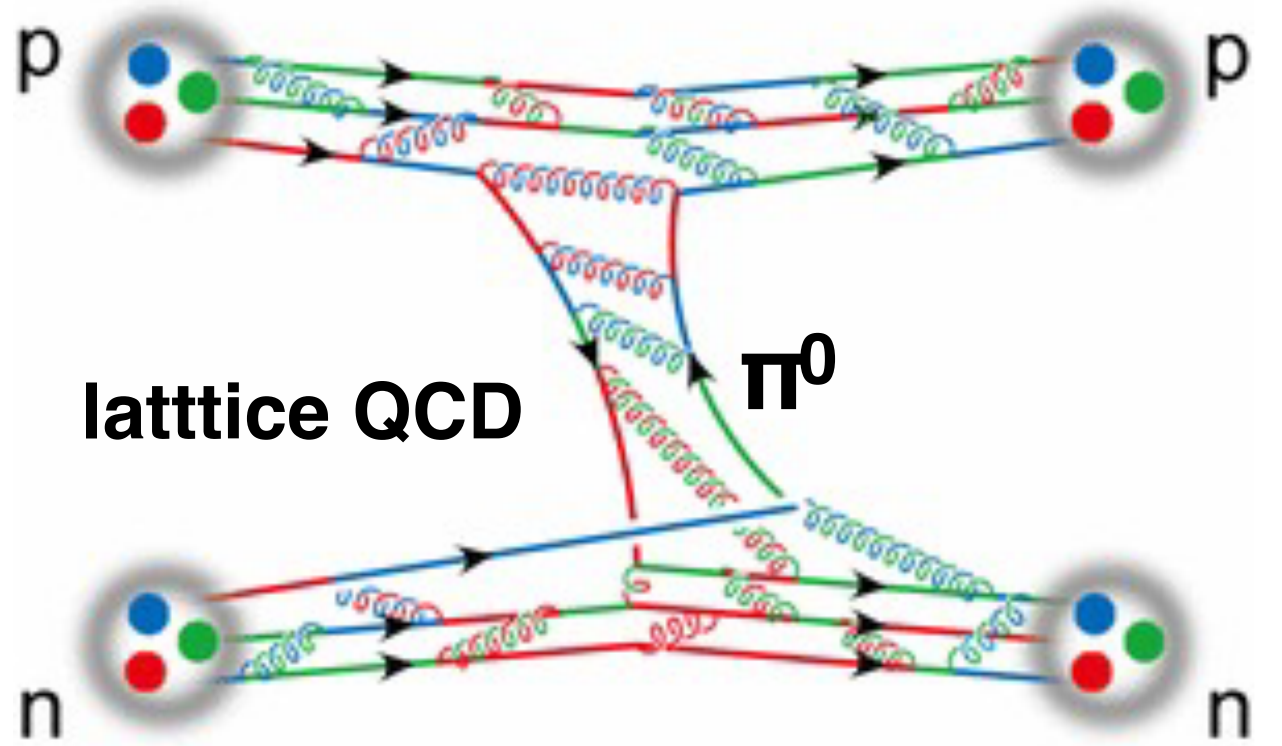

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... what we learned ...

$\bar{K}$ ($\bar{q}s$) forms a bound state with two nulceons

$\bar{K}$ meson (K^- : $\bar{u}s$, $\bar{K}^0$: $\bar{d}s$)

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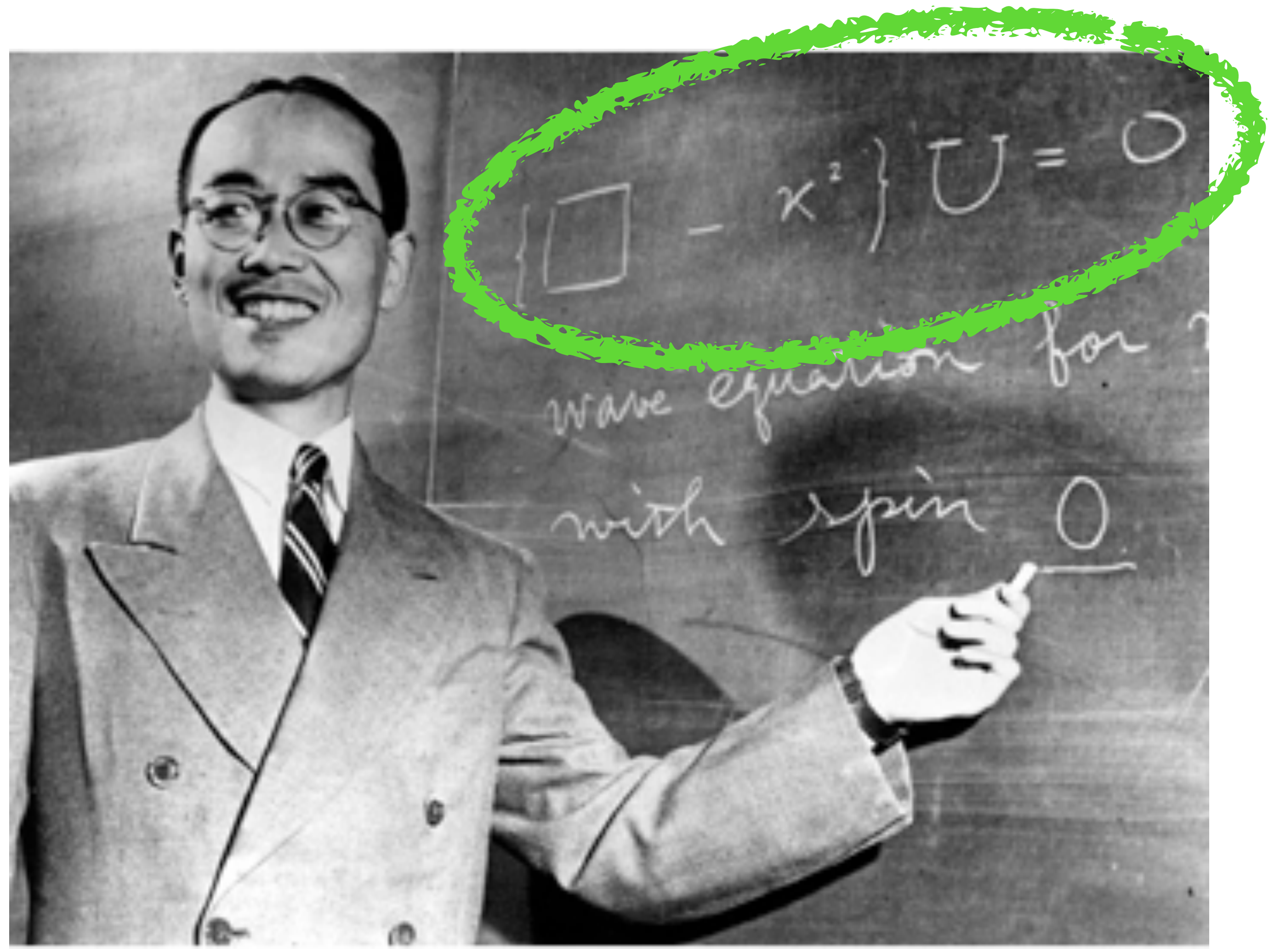

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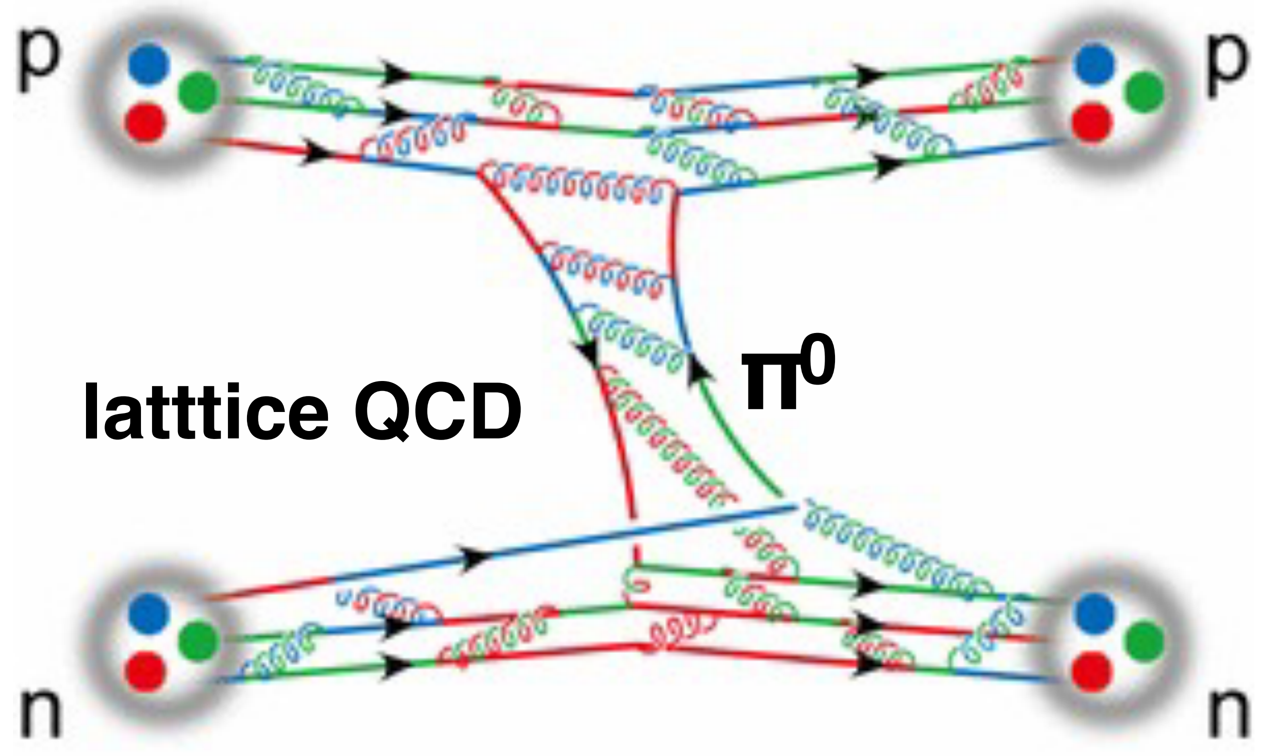

Long standing question：

Can meson be a constituent particle forming nuclei?

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... what we learned ...

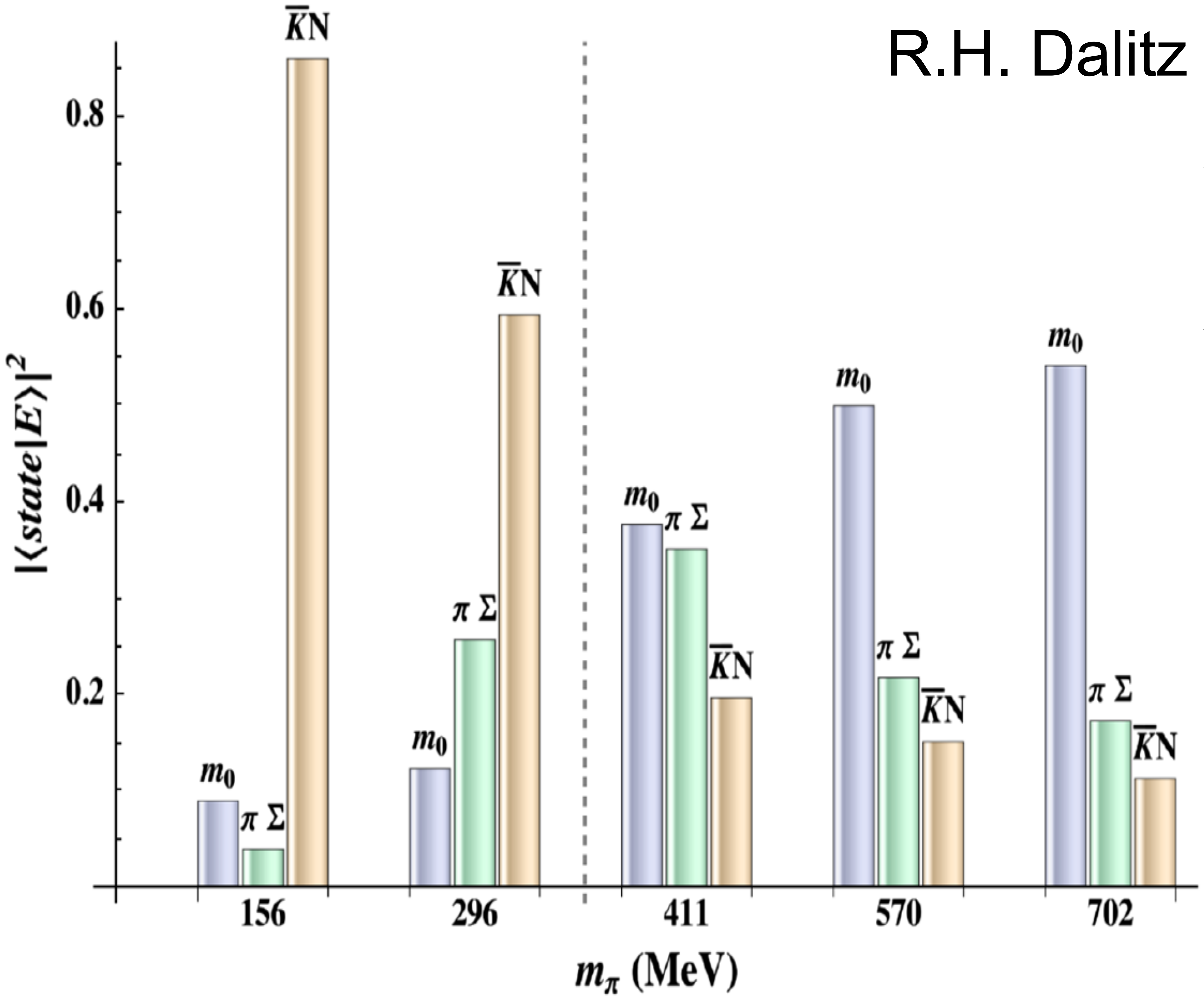
$\bar{K}$ ($\bar{q}s$) forms a bound state with two nulceons → **totally new pobe (impurity) to study inside nuclei**

$\bar{K}$ meson (K^- : $\bar{u}s$, $\bar{K}^0$: $\bar{d}s$)

What is Λ(1405)?

- Is it quark excited state of Λ baryon (*uds*)?

Λ(1405) = $\bar{K}N$ … a "molecule-like hadron composite"



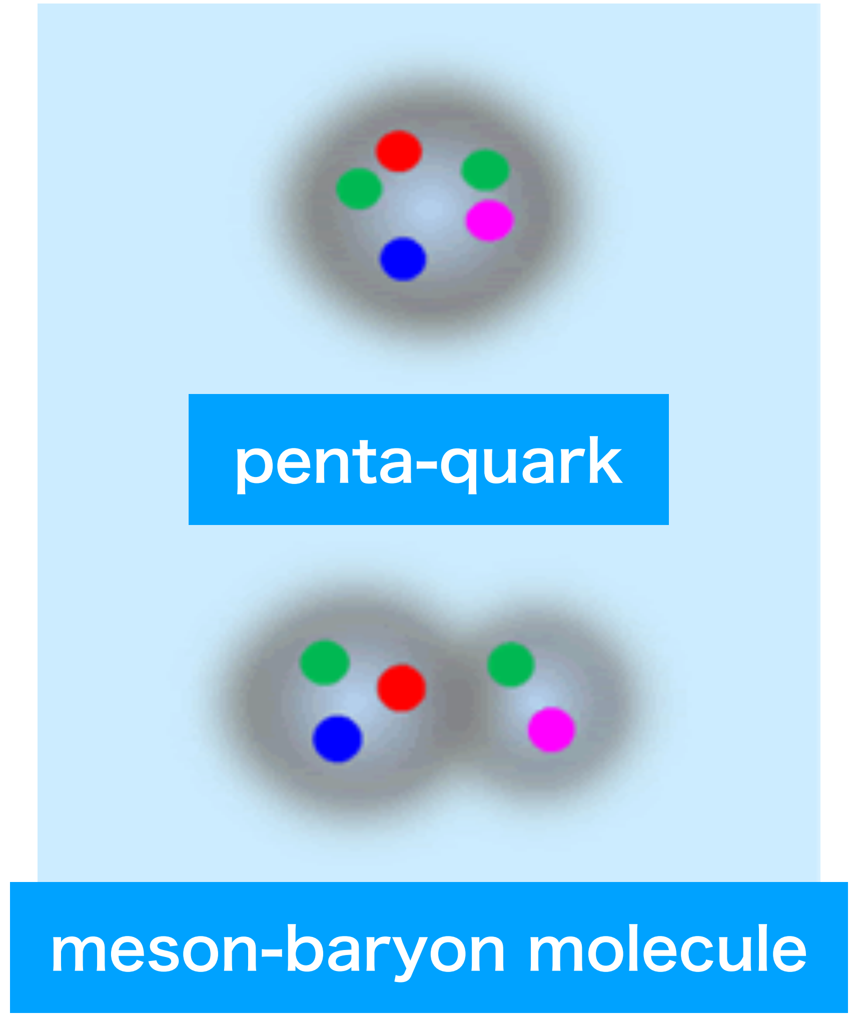
R.H. Dalitz and S.F. Tuan, Ann. Phys., 3, 307 (1960)

- **supported by kaonic hydrogen data**

  Phys. Rev. Lett., 78, 3067 (1997)

- **supported by Lattice QCD**

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



why not $\bar{K}NN$?

forming a nuclear bound state

what we have done …

- $\bar{K}NN,\ I_3 = +\frac{1}{2}$ **identified in $\bar{K}NN \to \Lambda p$ analysis**

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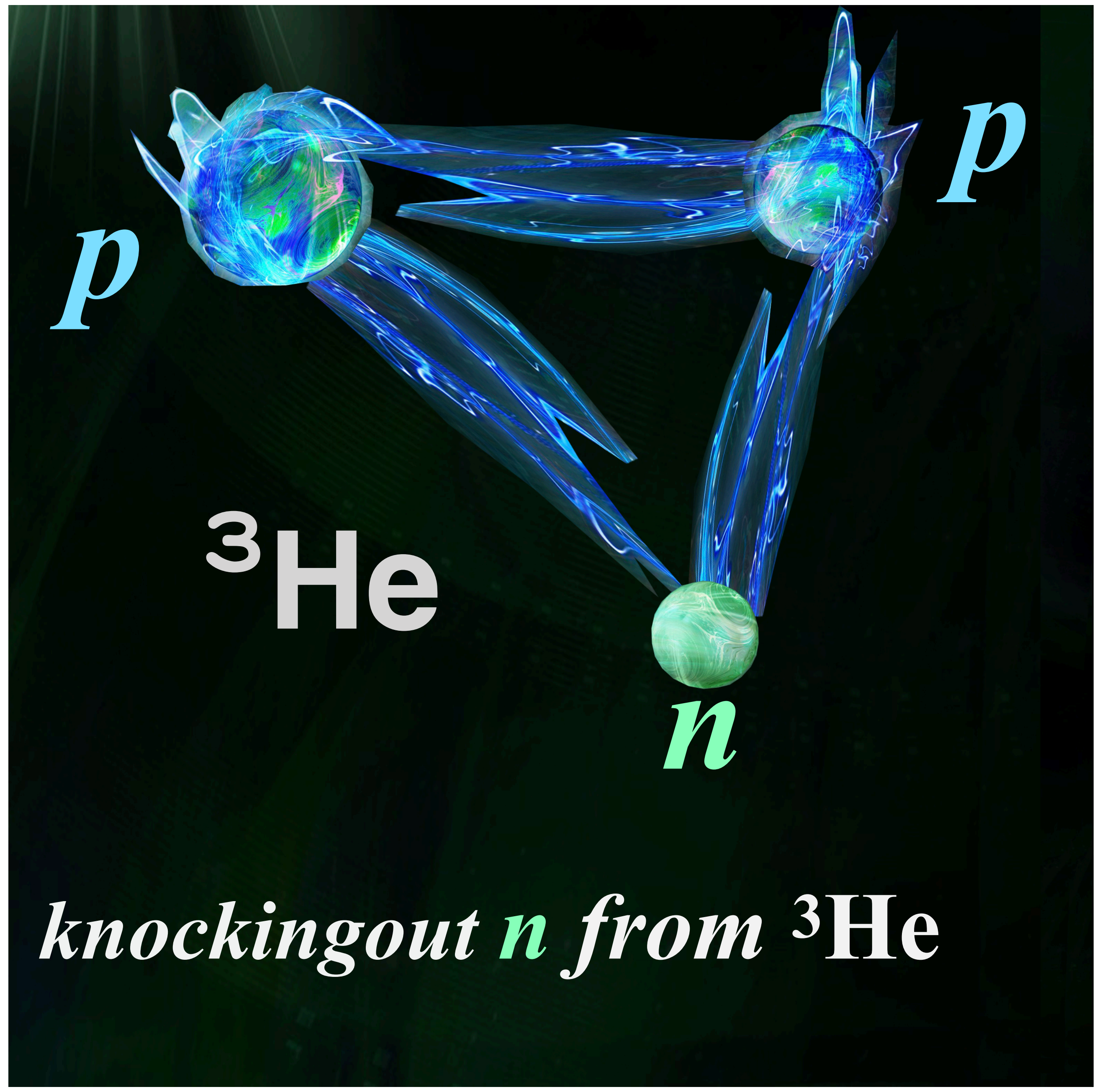
J-PARC E15: “K⁻pp” Exploration Research

K^- + ^{3}He (ppn)



(K^- + pp) + n

substitute n in ^{3}He by K^-

J-PARC E15: “K^-pp” Exploration Research

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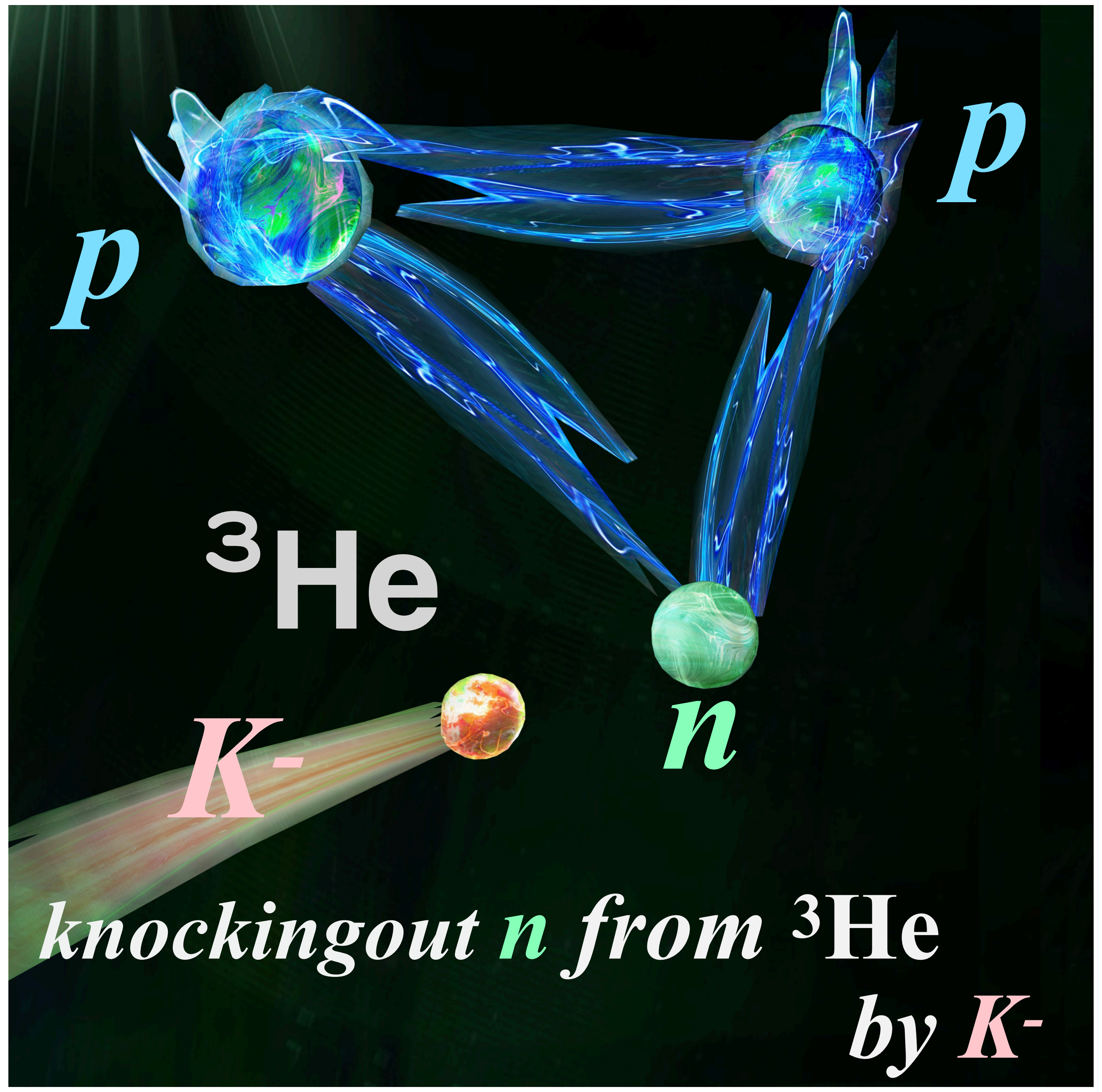

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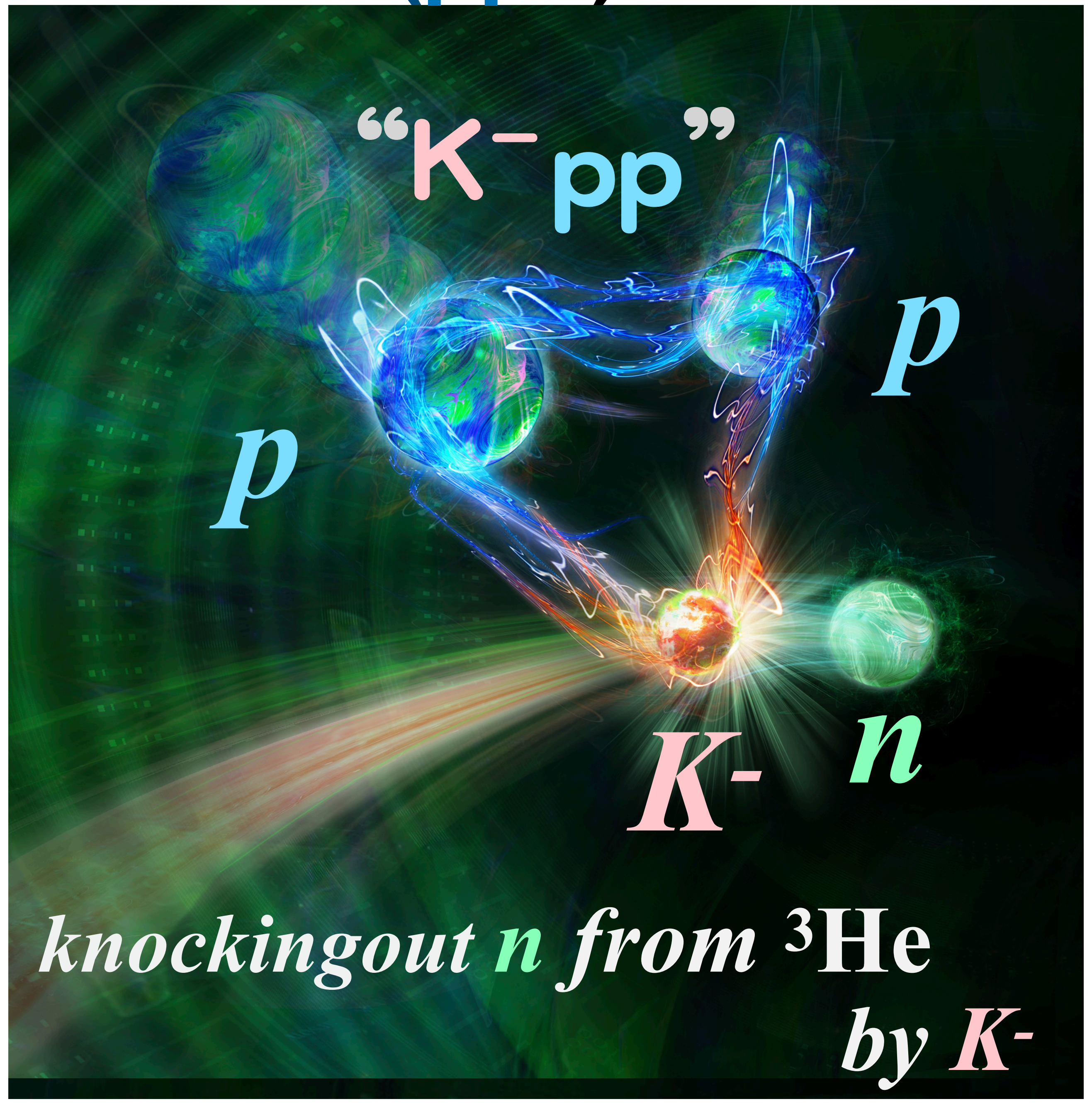

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$$K^- + {}^3\mathrm{He} \rightarrow (K^- + pp) + n$$

: formation

J-PARC E15: “K^-pp” Exploration Research

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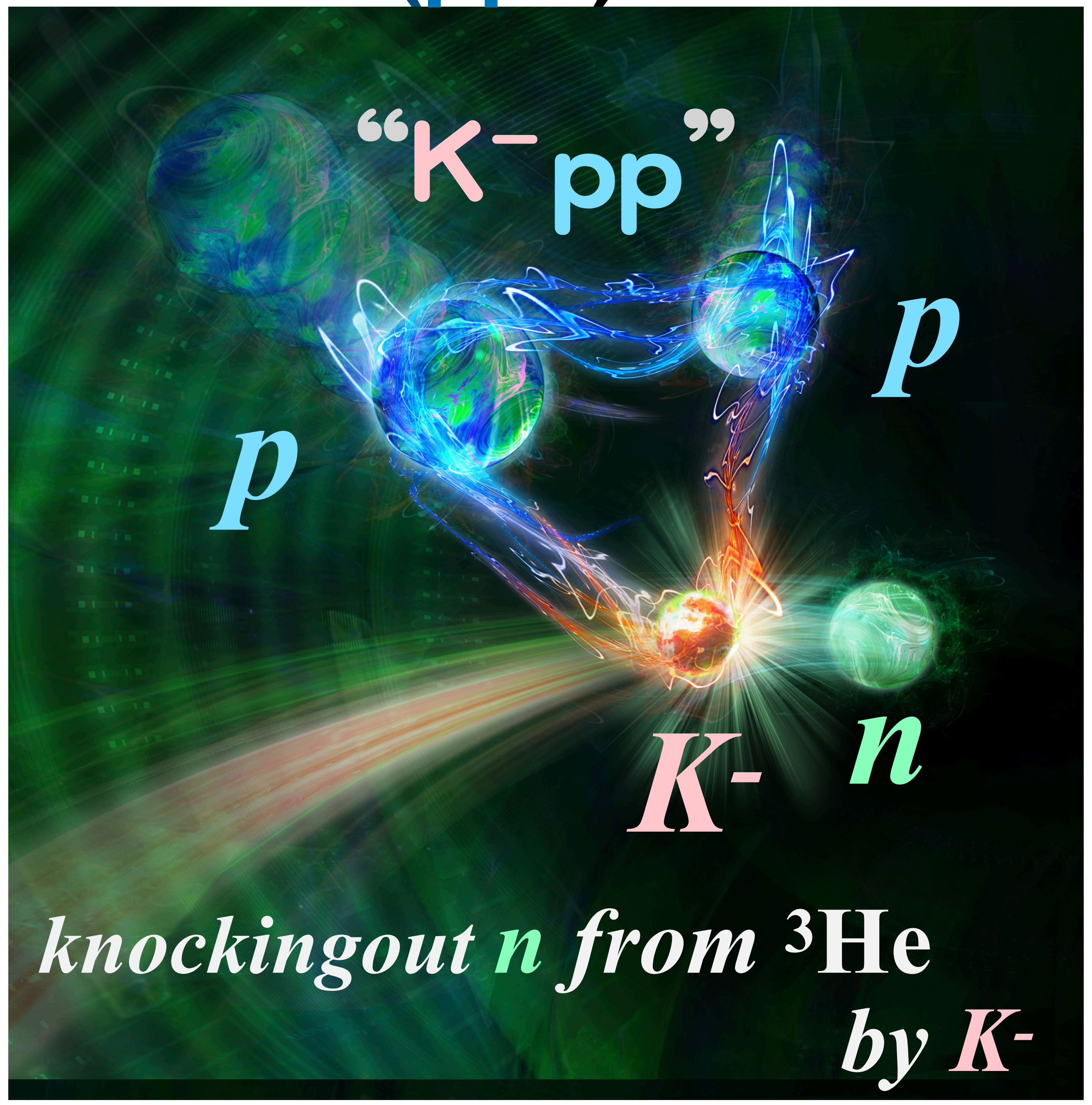

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“K^-pp” bound state? / compact system?

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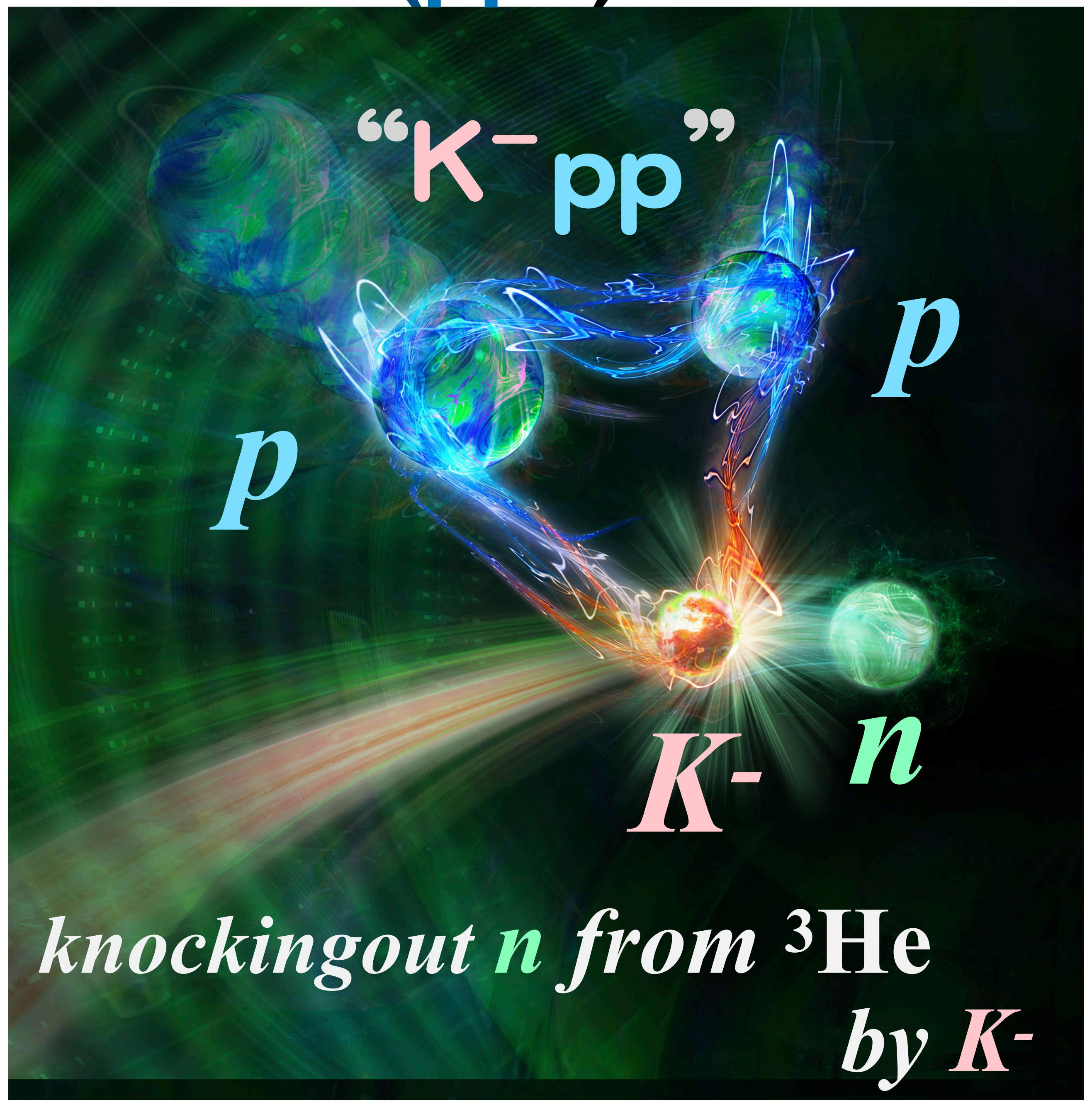

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If "K^-pp" exits, a peak will be formed in invariant mass spectrum below M(K^-pp)

$$M(K^-pp) \equiv m_{K^-} + 2m_p$$

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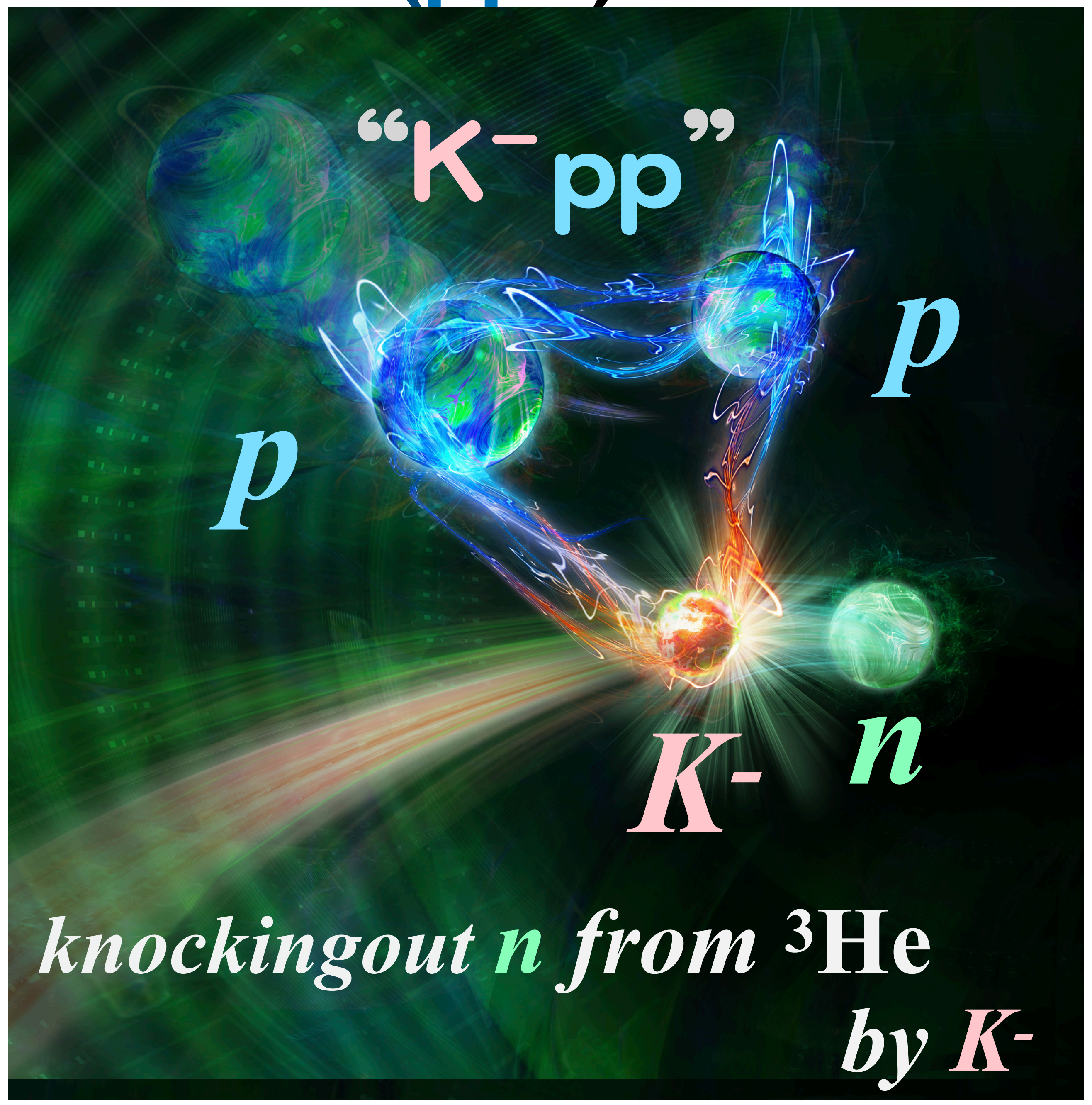

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K^- + ^{3}He → (K^- + pp) + n : formation

(K^- + pp) → Λ + p : decay (*M*, *q*)

strong $\bar{K}$N attraction?

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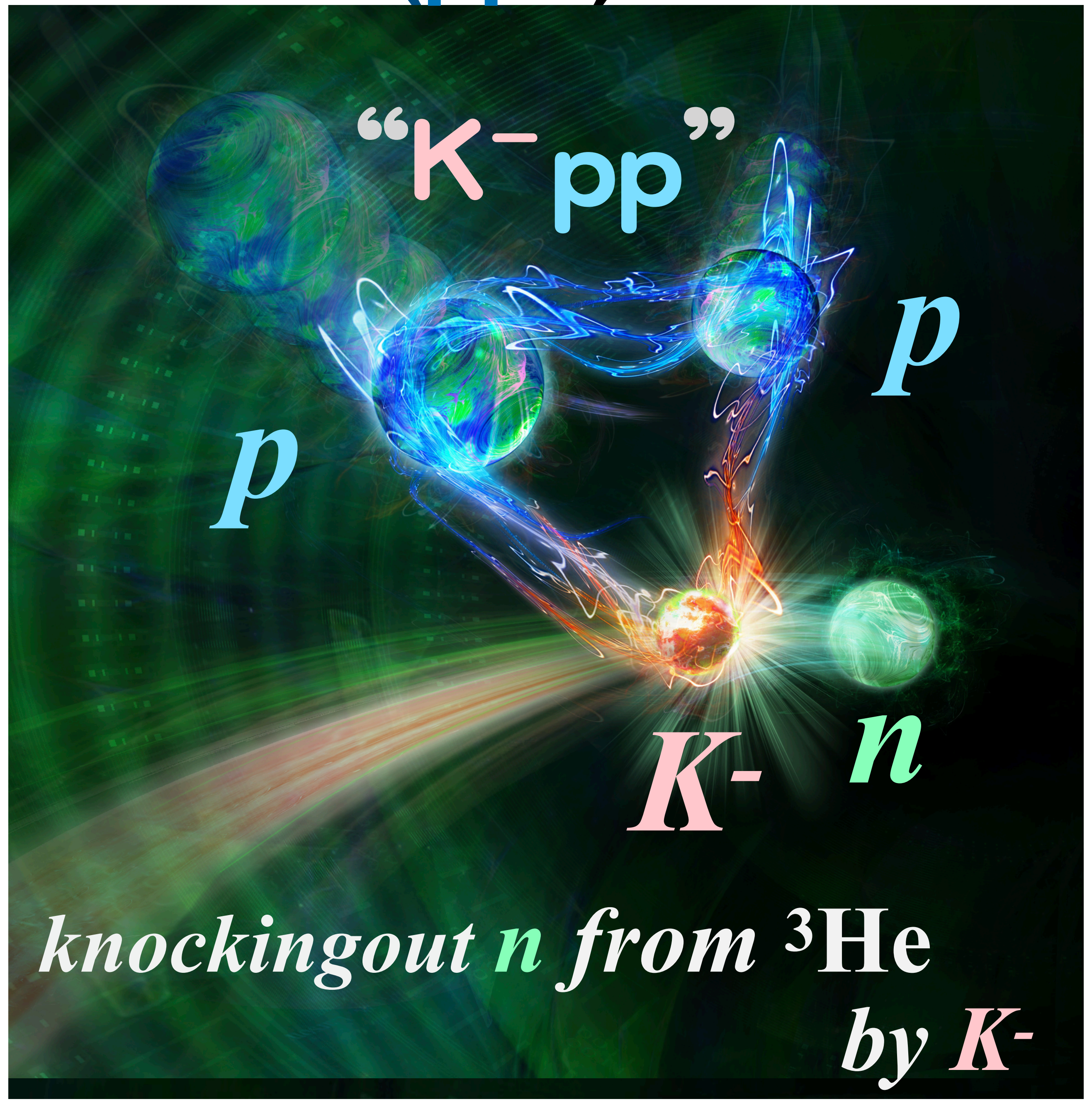
J-PARC E15: "K^-pp" Exploration Research

K^- + ^{3}He (ppn)



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final state particles

K^- + ^{3}He → (K^- + pp) + n : formation

(K^- + pp) → Λ + p : decay (*M*, *q*)

select K^- + ^{3}He → (Λ+p)+n events,

analyze *invariant mass M* of (K^- + pp)-system

and *momentum transfer q* to the system

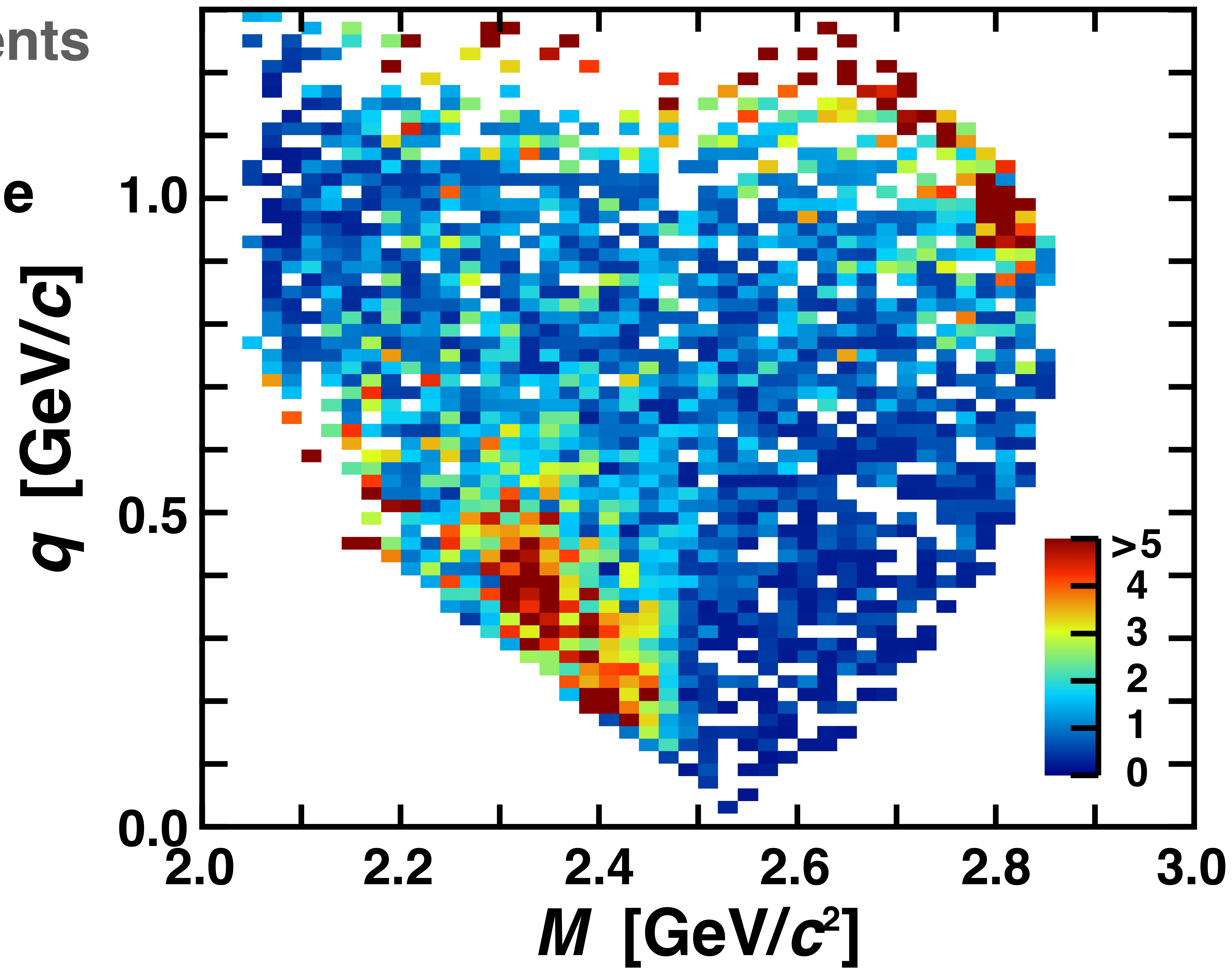
strong $\bar{K}$N attraction?

"K^-pp" bound state? / compact system?

$\Lambda p + n$ events

on (*M*, *q*)-plane

Acceptance corrected event distribution on (*M*, *q*)



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

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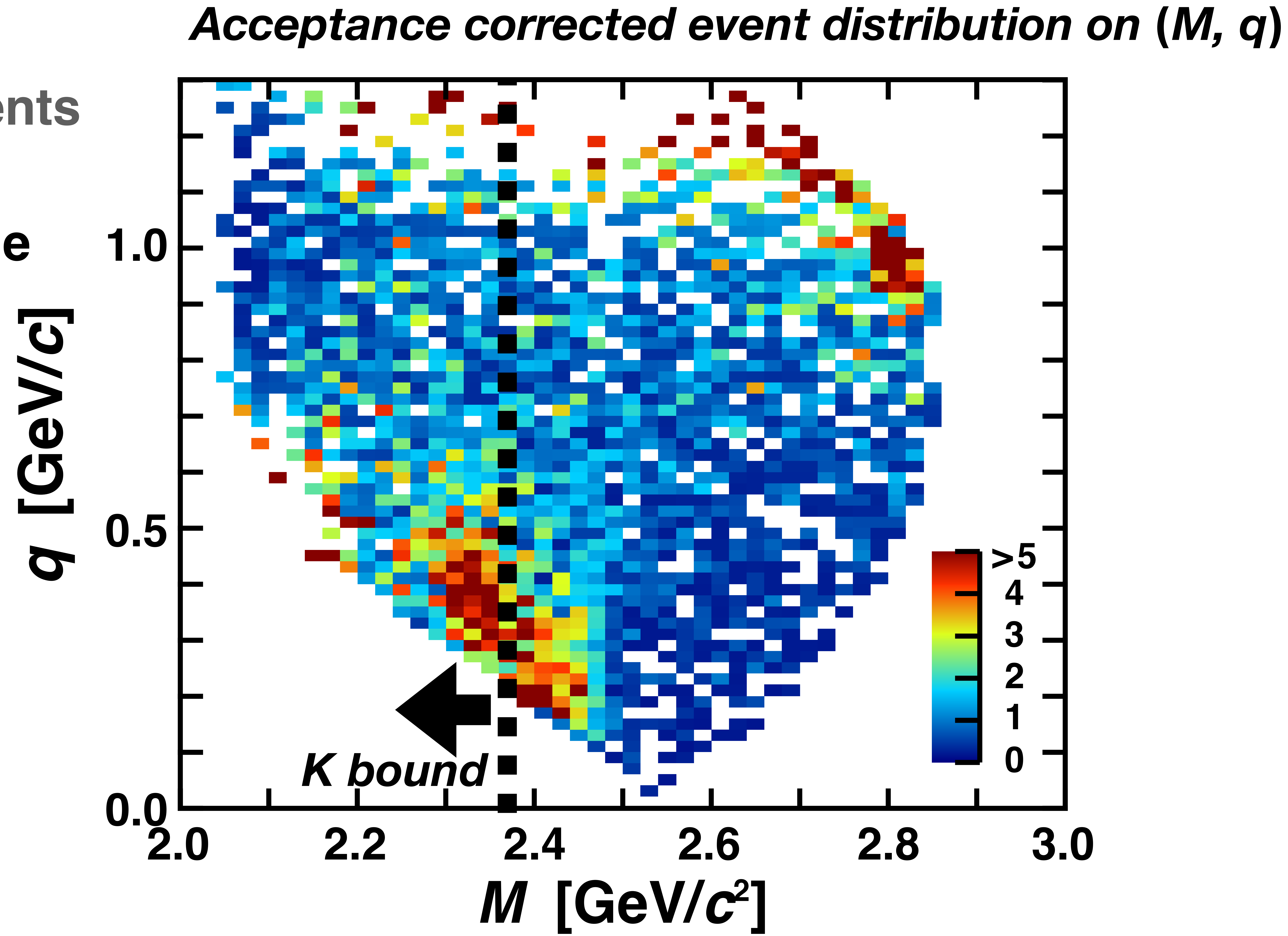
on (M, q)-plane



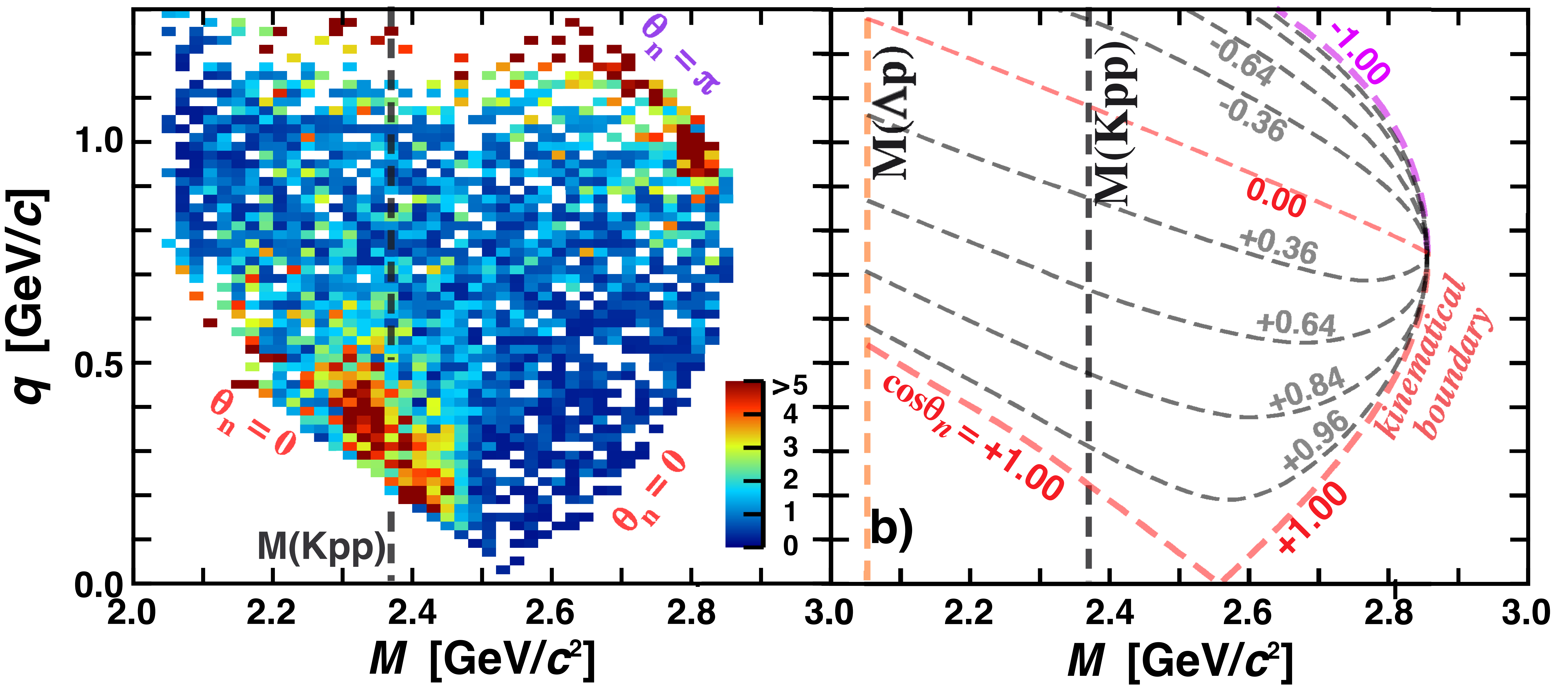
z-axis is in [nb] per (20MeV/c x 20 MeV/c²)

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

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

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

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



cosθ_n in Fig. is in CM (K^- + ^{3}He)

kinematics of Kaon 2N-absorption after $K^- N \to \bar{K} N'$

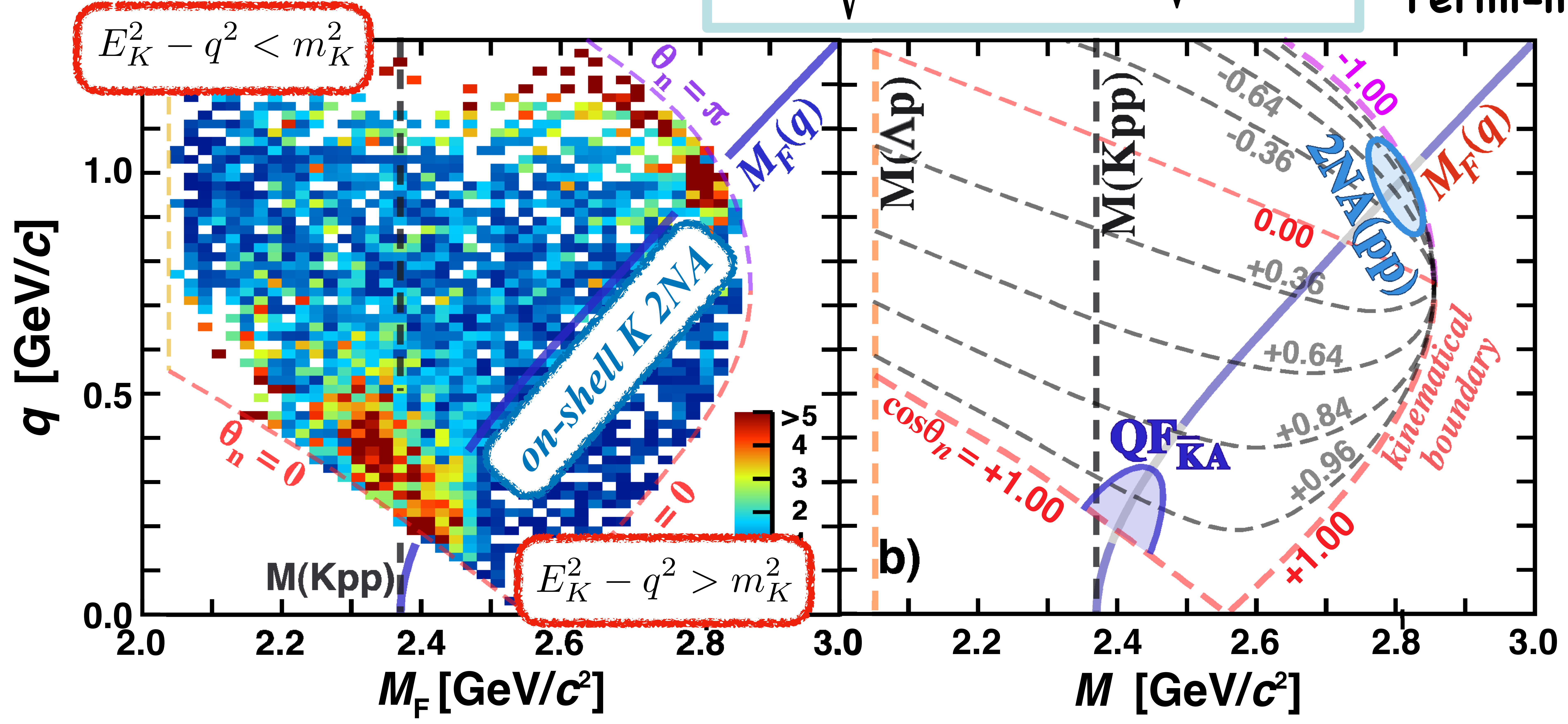
$\bar{K}$ + N_s + N_s → F (→ Λ + p)

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

on-shell K　　2N ~ at-rest

$$M_F = \sqrt{4m_N^2 + m_K^2 + 4m_N\sqrt{m_K^2 + q^2}}$$

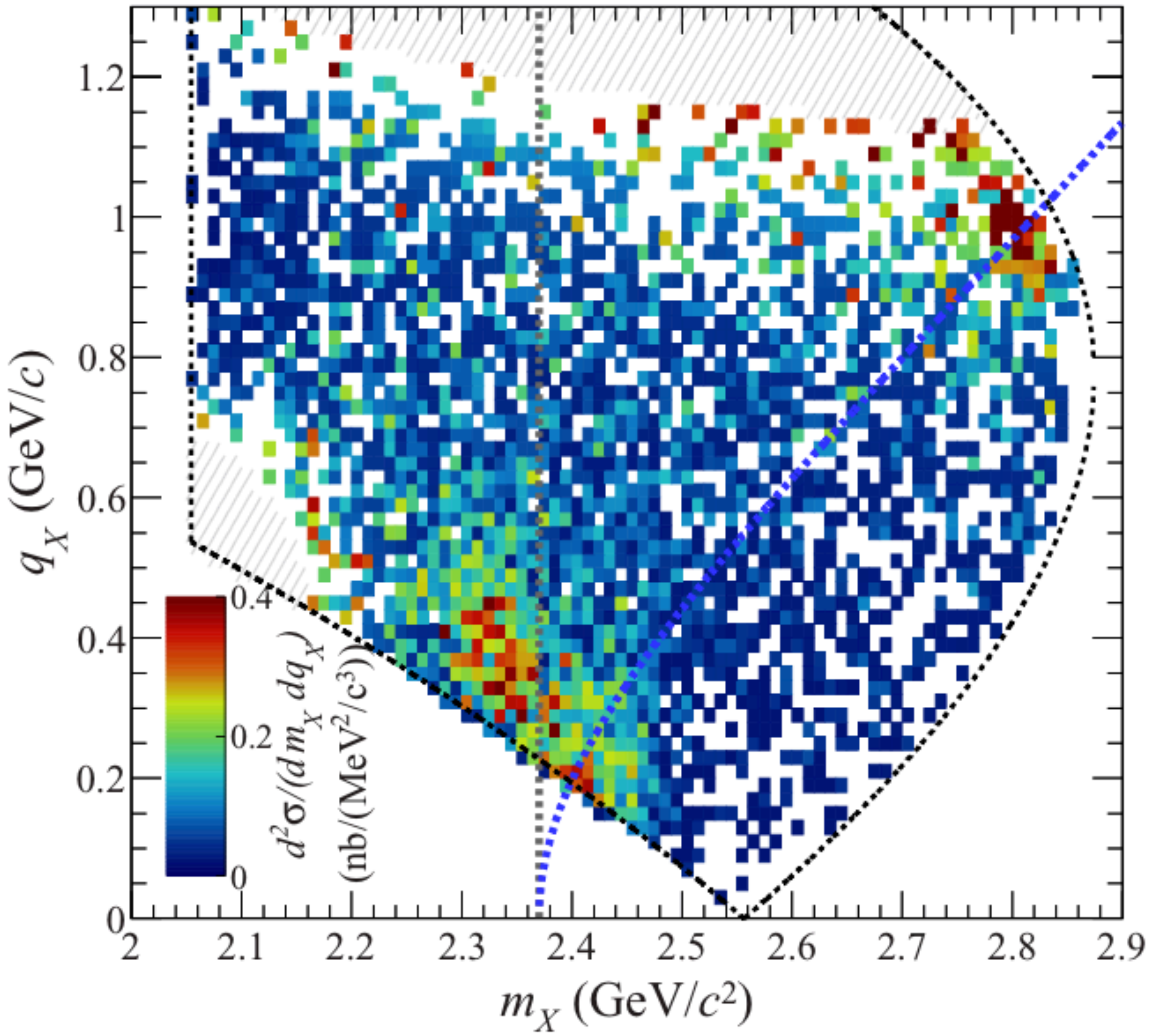
smeared by Fermi-motion



$\Lambda p + n_{miss}$ model fitting function in (m, q)-plane

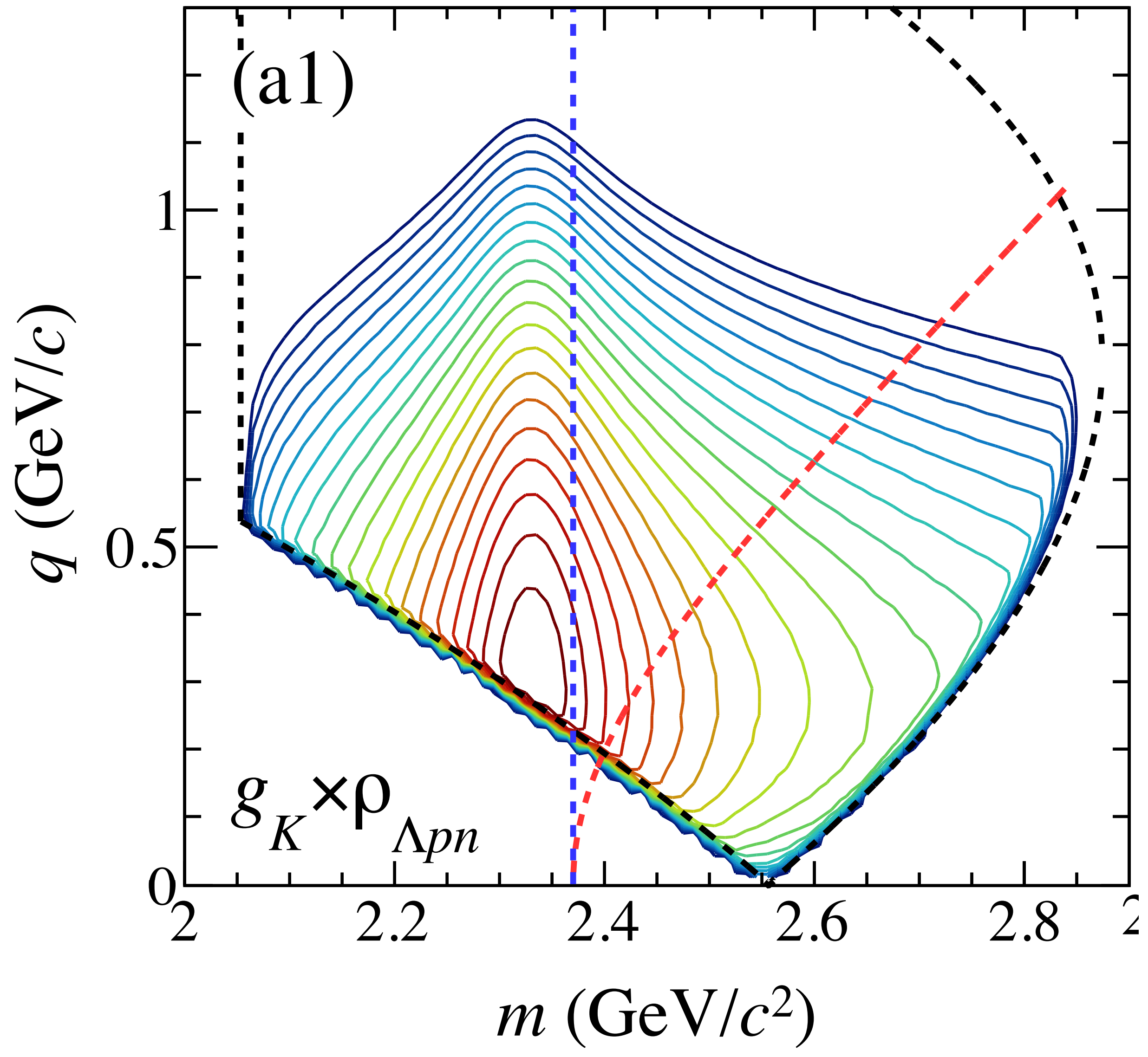
ρ : Lorentz-invariant phase-space

$$f_{\bar{K}NN}(m,q) \times \rho_{\{\Lambda pn\}}(m,q) \quad f_{QF\text{-}\bar{K}}(m,q) \times \rho_{\{\Lambda pn\}}(m,q)$$



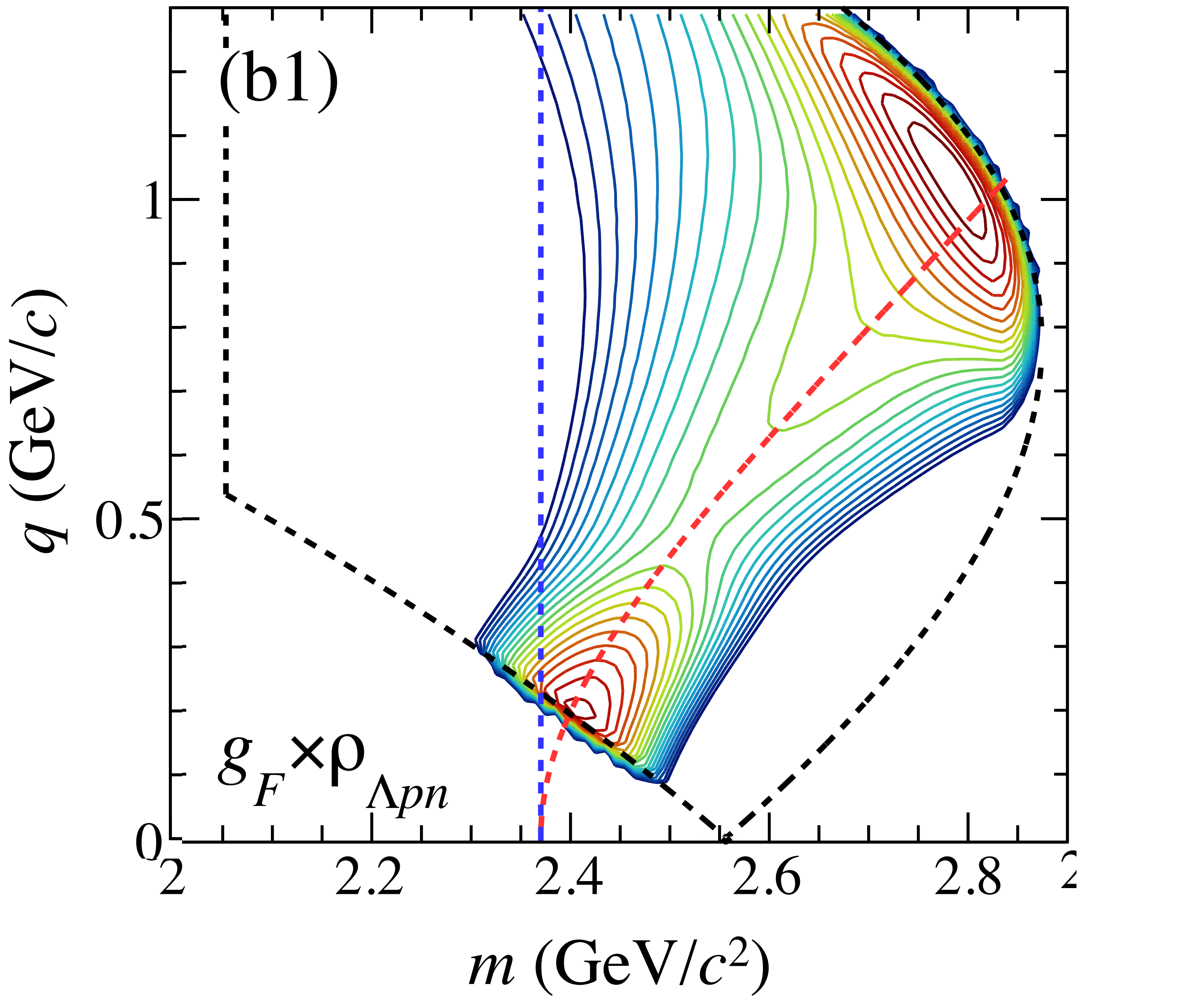
~

$\bar{K}NN$ production



+

QF-$\bar{K}$ absorption



$f_{\bar{K}NN}(m,q)$: $B.W.(m) \times$ form factor(q)

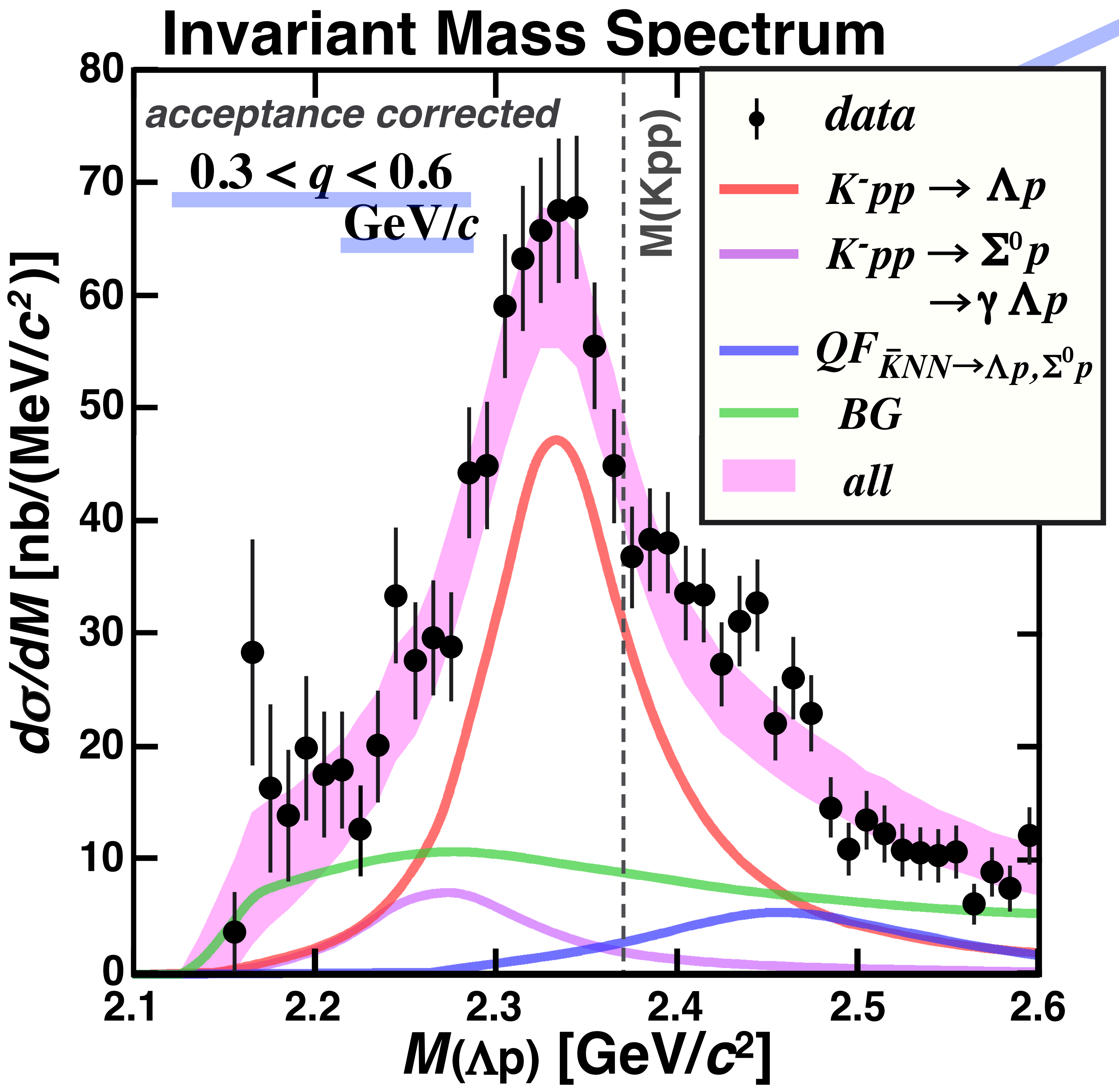
$f_{QF\text{-}\bar{K}}(m,q)$: quasi-free (on mass-shell) K abs.

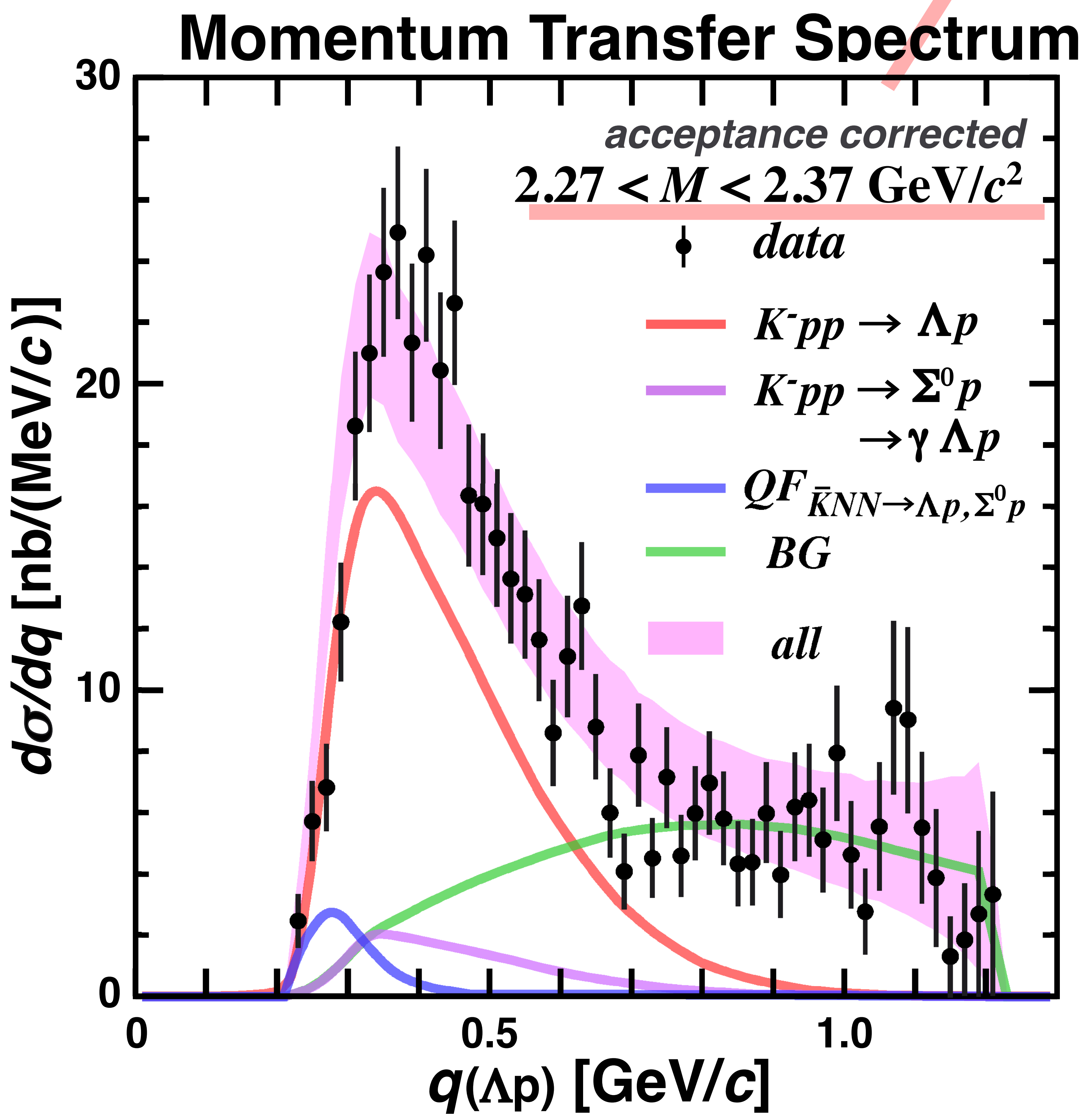
PWIA based interpretation

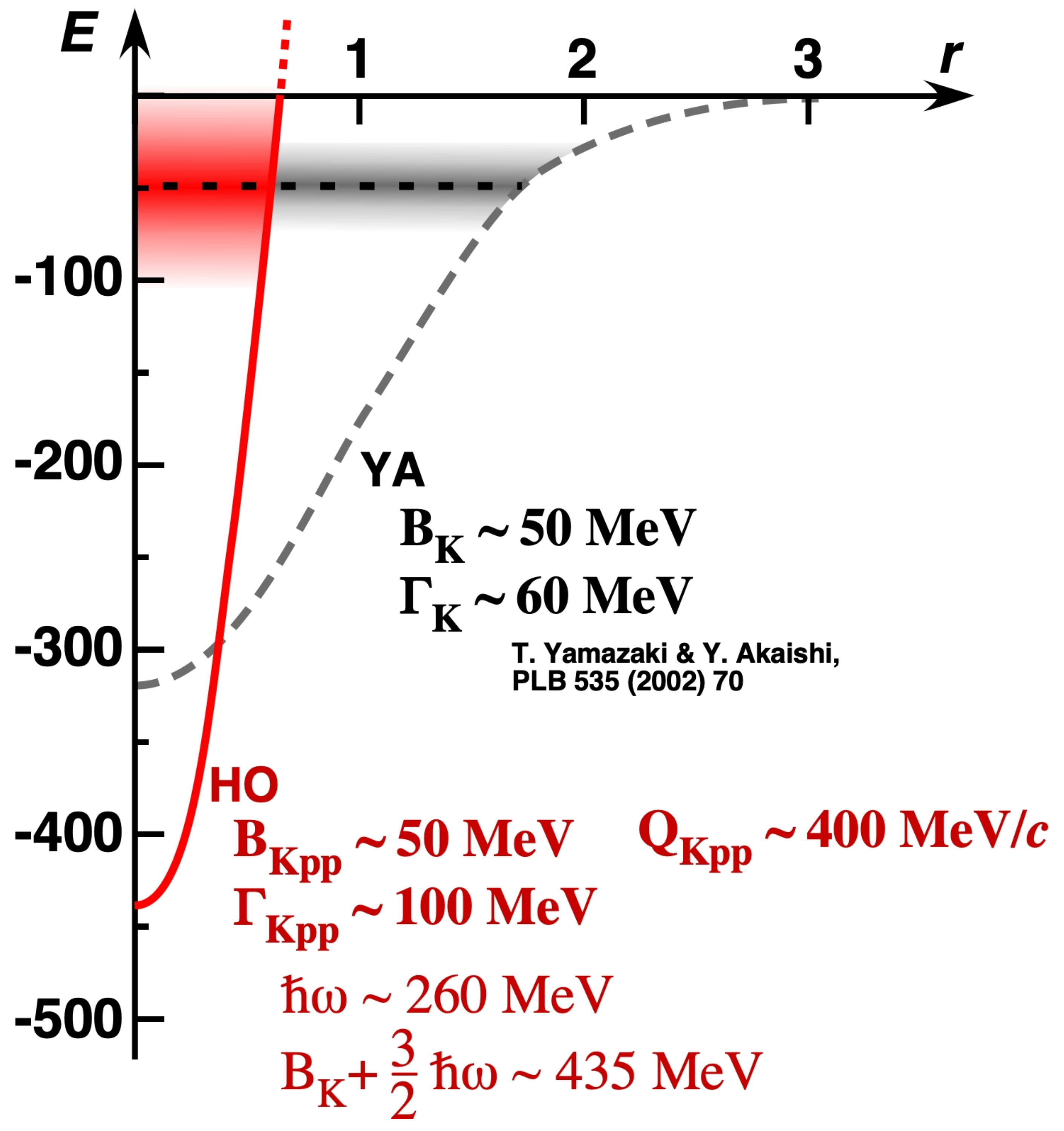
(plane wave impulse approximation)

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

- $\sigma(M, q)$: Differential cross section
- $\rho_{3B}(M,q)$: Lorentz invariant phase space (Λpn)
- B.W. / Lorentzian
- form factor / structure factor







strong binding ($\bar{K}N$ attraction)

$B_{Kpp} \sim 40$ MeV, $\Gamma_{Kpp} \sim 100$ MeV

wide momentum width

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

... could be quite compact ...

($R_{Kpp} \sim 0.6$ fm (H.O.))

Mesonic decay of $\bar{K}NN$

$$\bar{K}NN \to \pi YN$$

… T. Yamaga

Why Γ is so large?

observation in non-mesonic channel:

$BE = 42 \pm 3\ (\text{stat.})\ {}^{+3}_{-4}\ (\text{syst.})\ \text{MeV}$

$\Gamma = 100 \pm 7\ (\text{stat.})\ {}^{+19}_{-9}\ (\text{syst.})\ \text{MeV}$

$\sigma \cdot Br_{\Lambda p} = 9.3 \pm 0.8^{+1.4}_{-1.0}\ \mu\text{b}$

Theoretical calculations: $\Gamma \sim 50\ \text{MeV}$

※ **mesonic decay channel only**

$\Gamma^{\text{theor.}}_{\text{mesonic}} \approx 50\ \text{MeV?}$ $\approx \Gamma_{\Lambda(1405)}$

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~ twice wider than theory ~

~ relatively weak in cross-section~

$$\Gamma_{\text{mesonic}} \sim \Gamma_{\text{non-mesonic}}\ ?$$

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note:

$$\Lambda(1405) \rightarrow \pi\Sigma \quad 100\%$$

$$\bar{K}NN \rightarrow \pi\Sigma N \text{ or } \pi\Lambda N$$

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mesonic decay branch should be measured!

$\Gamma_{\text{mesonic}} \gg \Gamma_{\text{none-mesonic}}$

Study on mesonic decay of "$\bar{K}NN$"

$I_3 = +1/2$

Study on non-mesonic decay mode: $\Lambda p + n_{\text{miss}}$

$I_3 = +1/2$

$\pi^+ \Lambda n + n_{\text{miss}}$

$\pi^- \Sigma^+ p + n_{\text{miss}}$

$\pi^+ \Sigma^- p + n_{\text{miss}}$

$I_3 = -1/2$

$\pi^- \Lambda p + p_{\text{miss}}$

Excluded from this talk

$(\pi^-\Sigma^+)\,p$ $+n_{\text{miss}}$

$(\pi^+\Sigma^-)\,p$ $+n_{\text{miss}}$

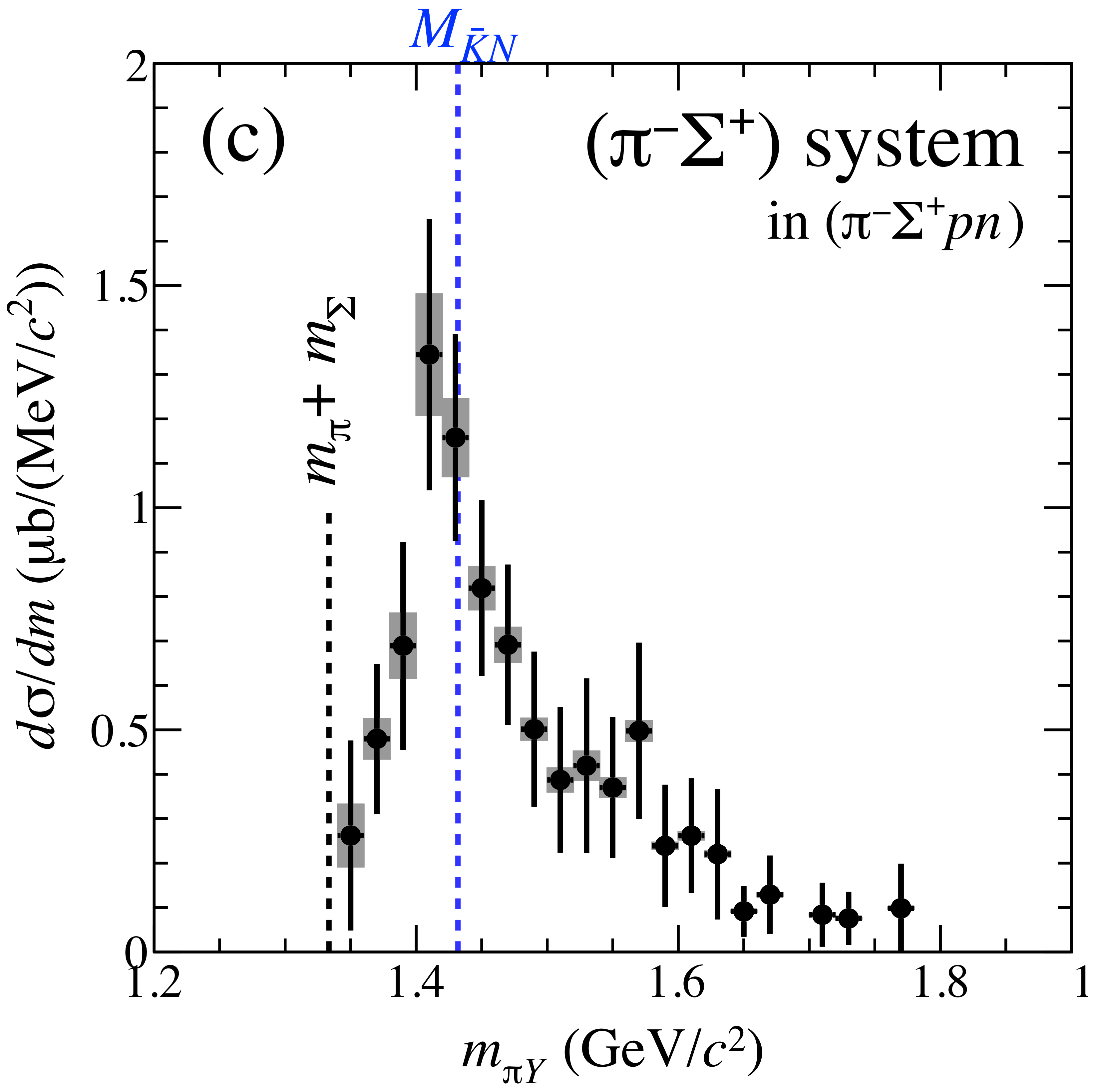
$(\pi^+\Lambda)\,n$ $+n_{\text{miss}}$

$(\pi^- \Sigma^+)\, p$

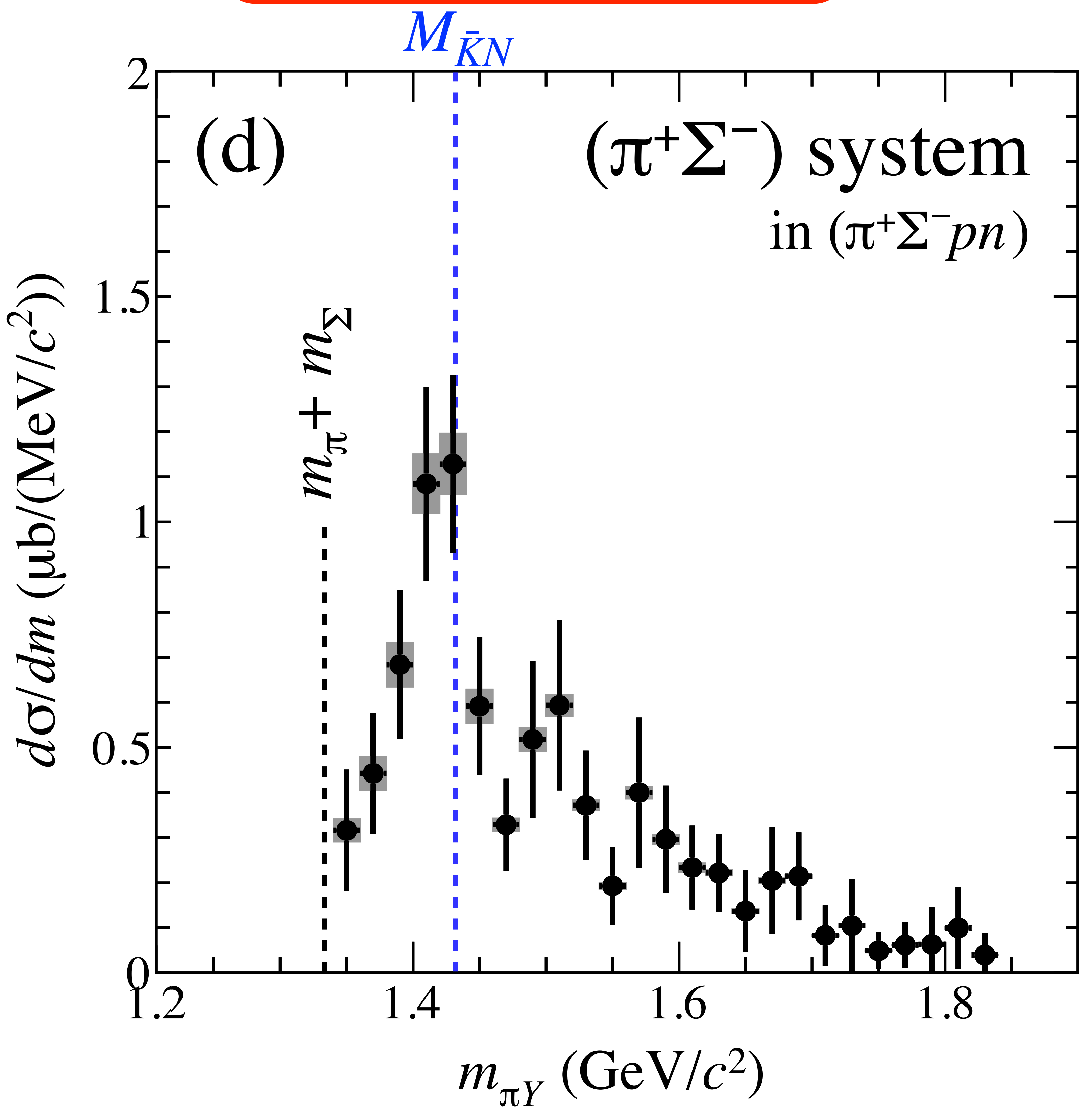
$(\pi^+ \Sigma^-)\, p$

$(\pi^+ \Lambda)\, n$

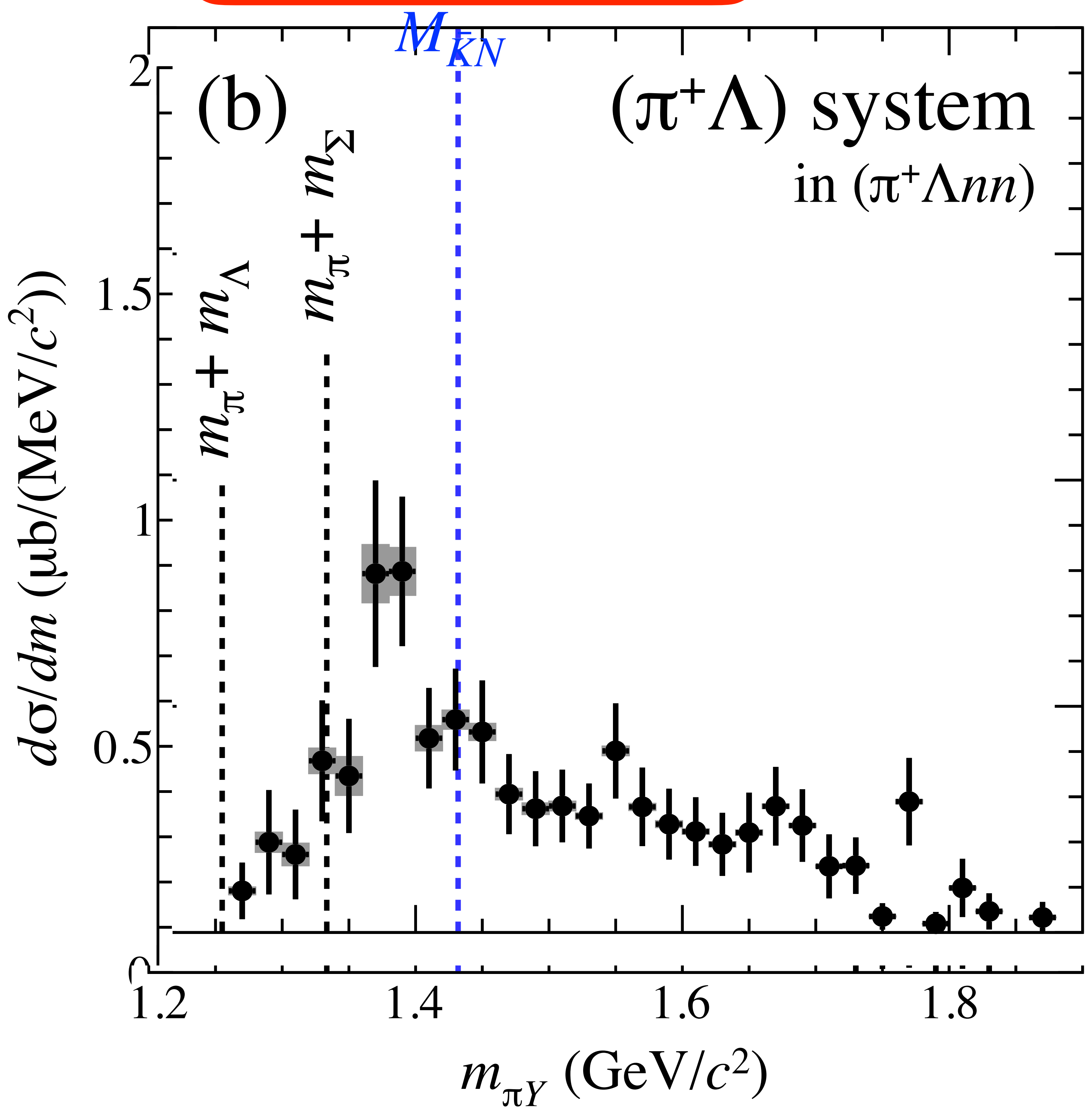
$(\pi^-\Sigma^+)\,p$



$(\pi^+\Sigma^-)\,p$



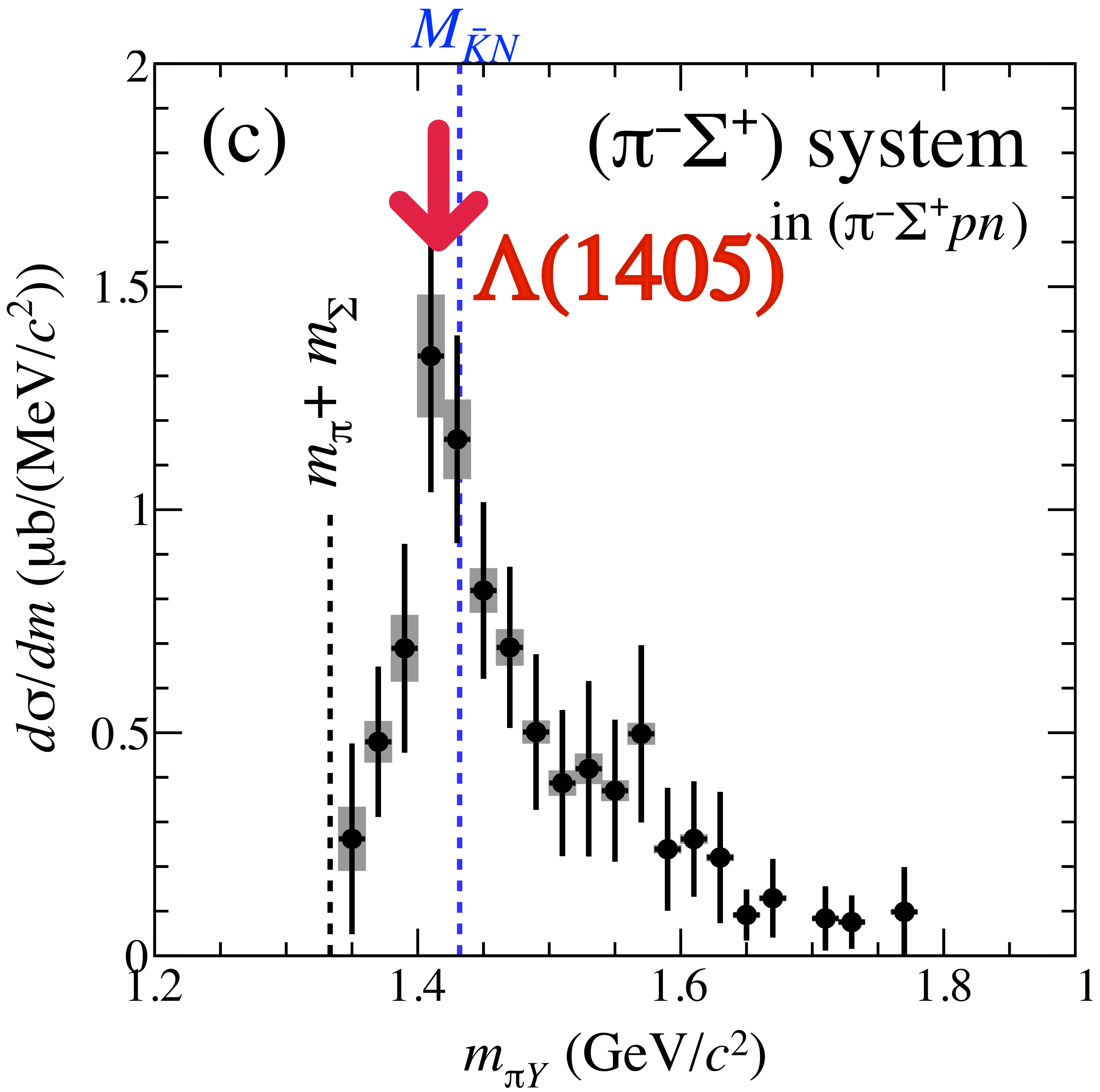
$(\pi^+\Lambda)\,n$

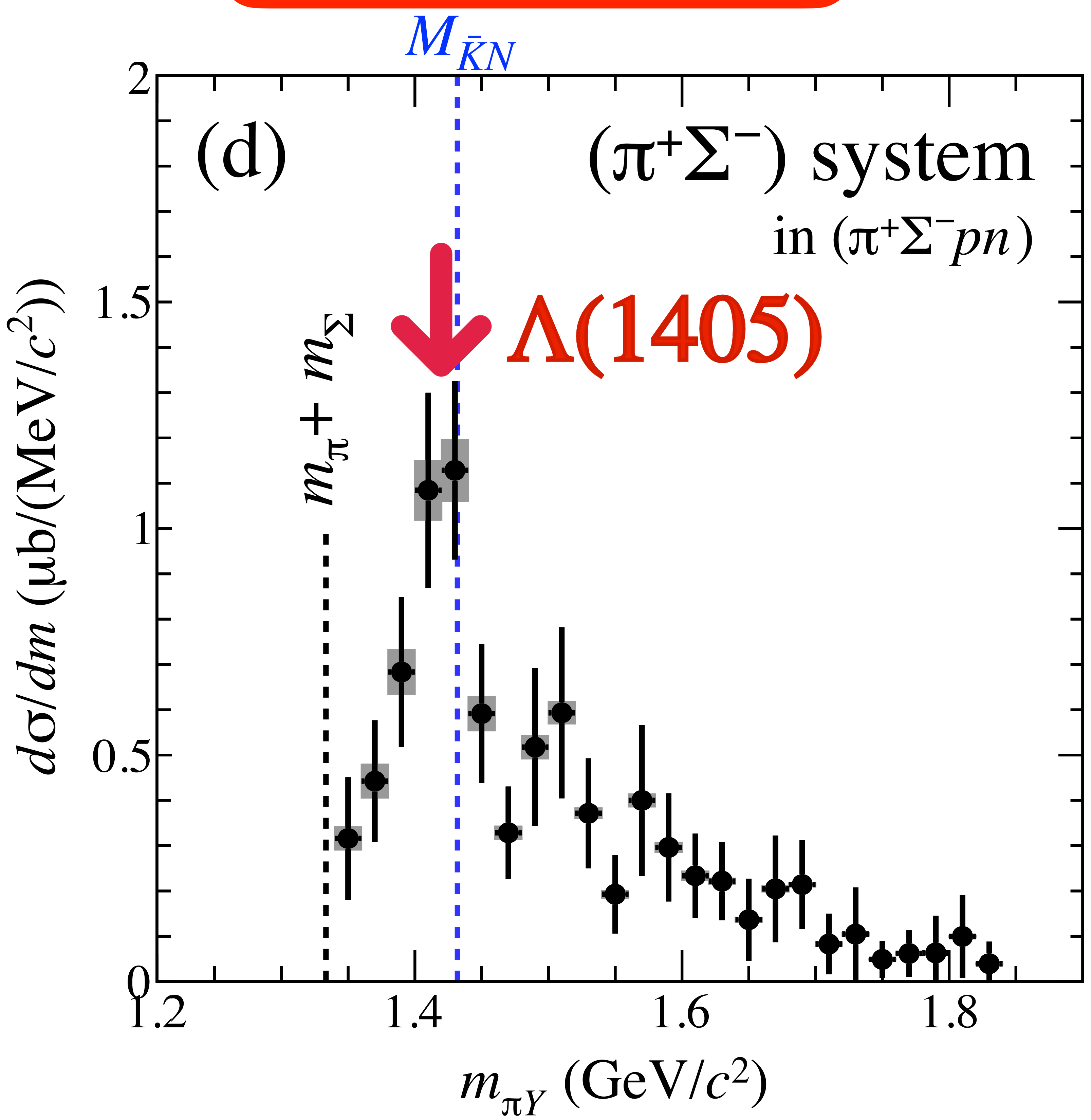


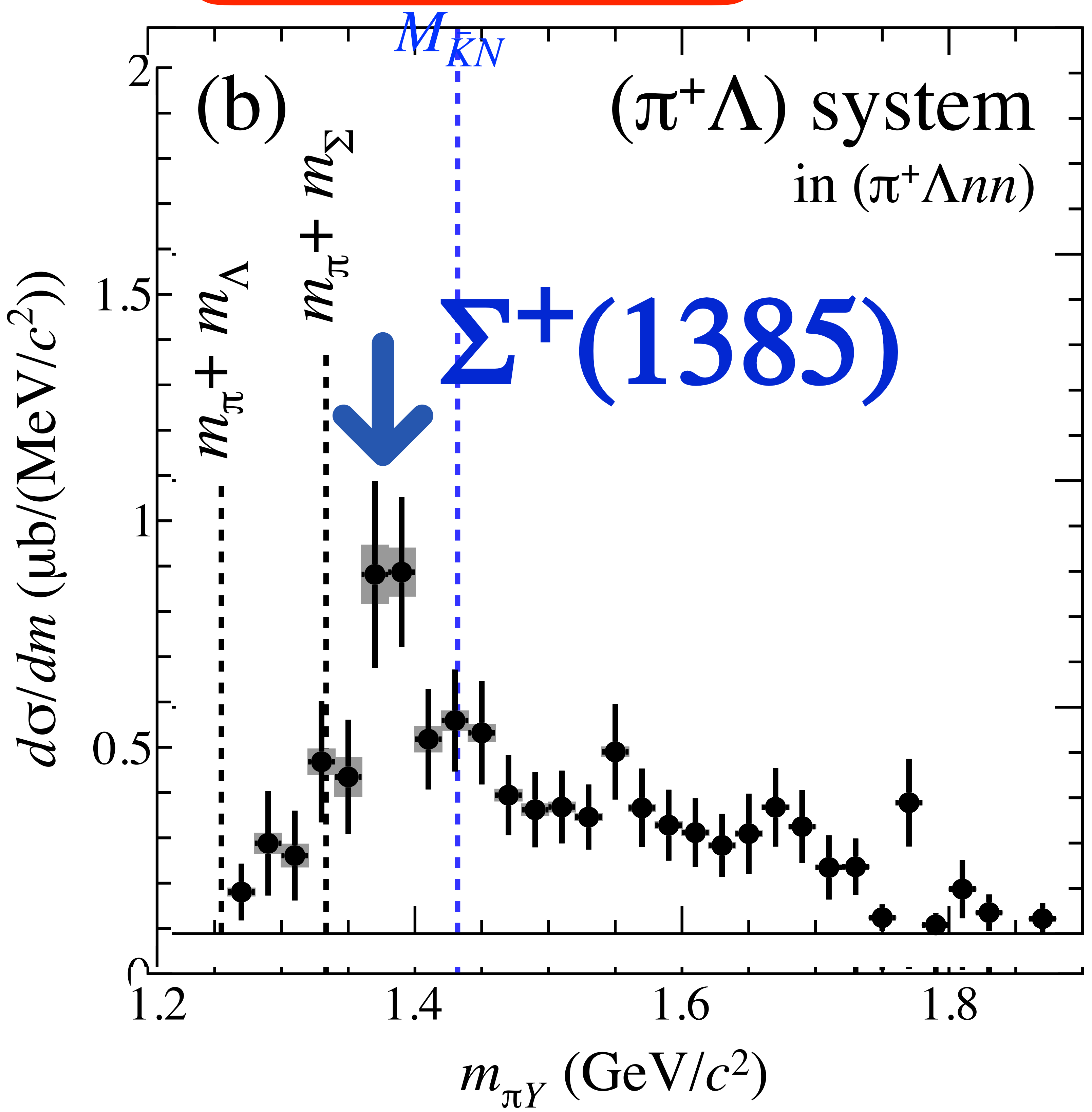
$(\pi^-\Sigma^+)\,p$ $(\pi^+\Sigma^-)\,p$ $(\pi^+\Lambda)\,n$

Λ(1405) + Phase space

$(\pi^-\Sigma^+)\,p$ $(\pi^+\Sigma^-)\,p$ $(\pi^+\Lambda)\,n$



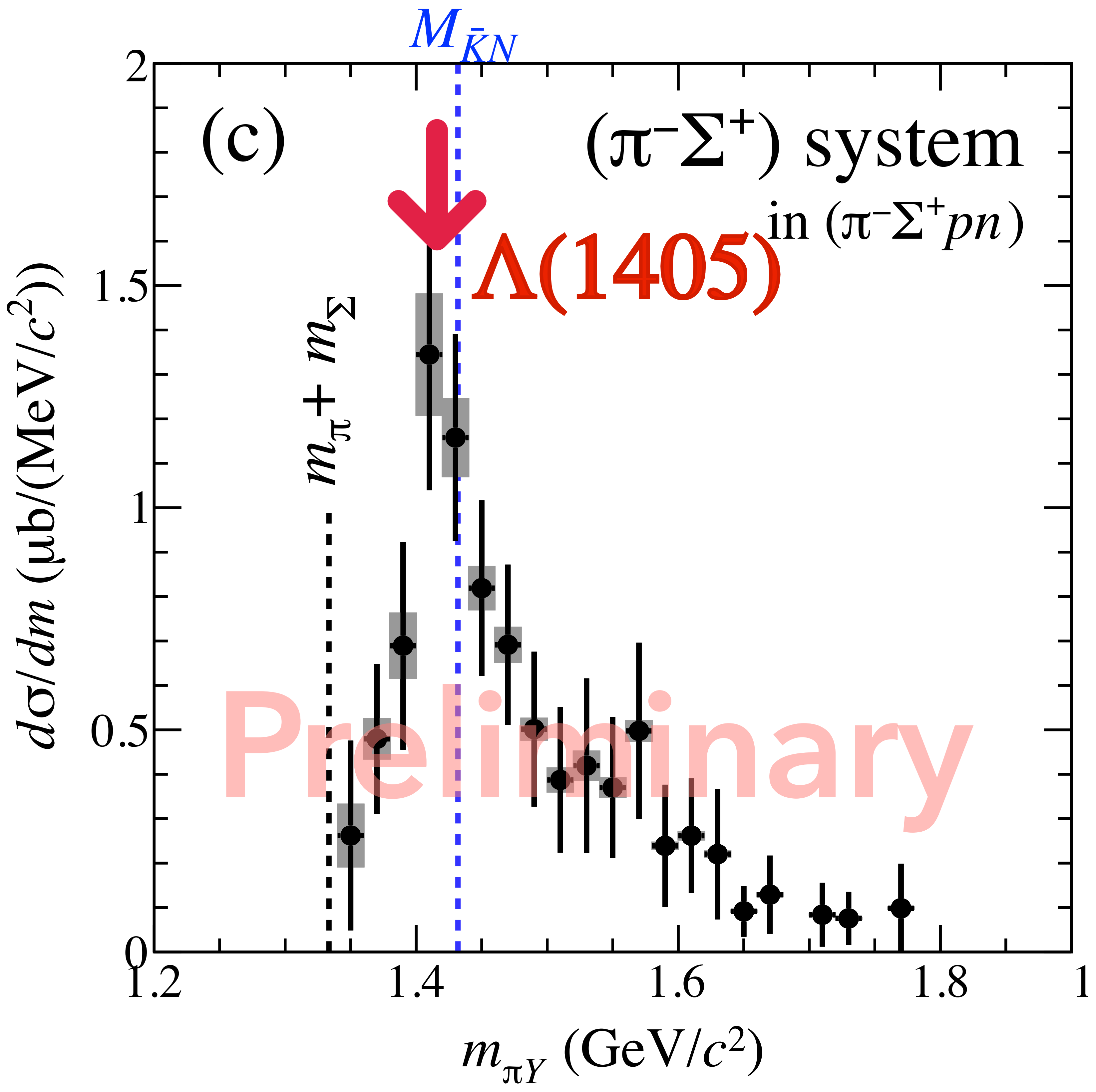




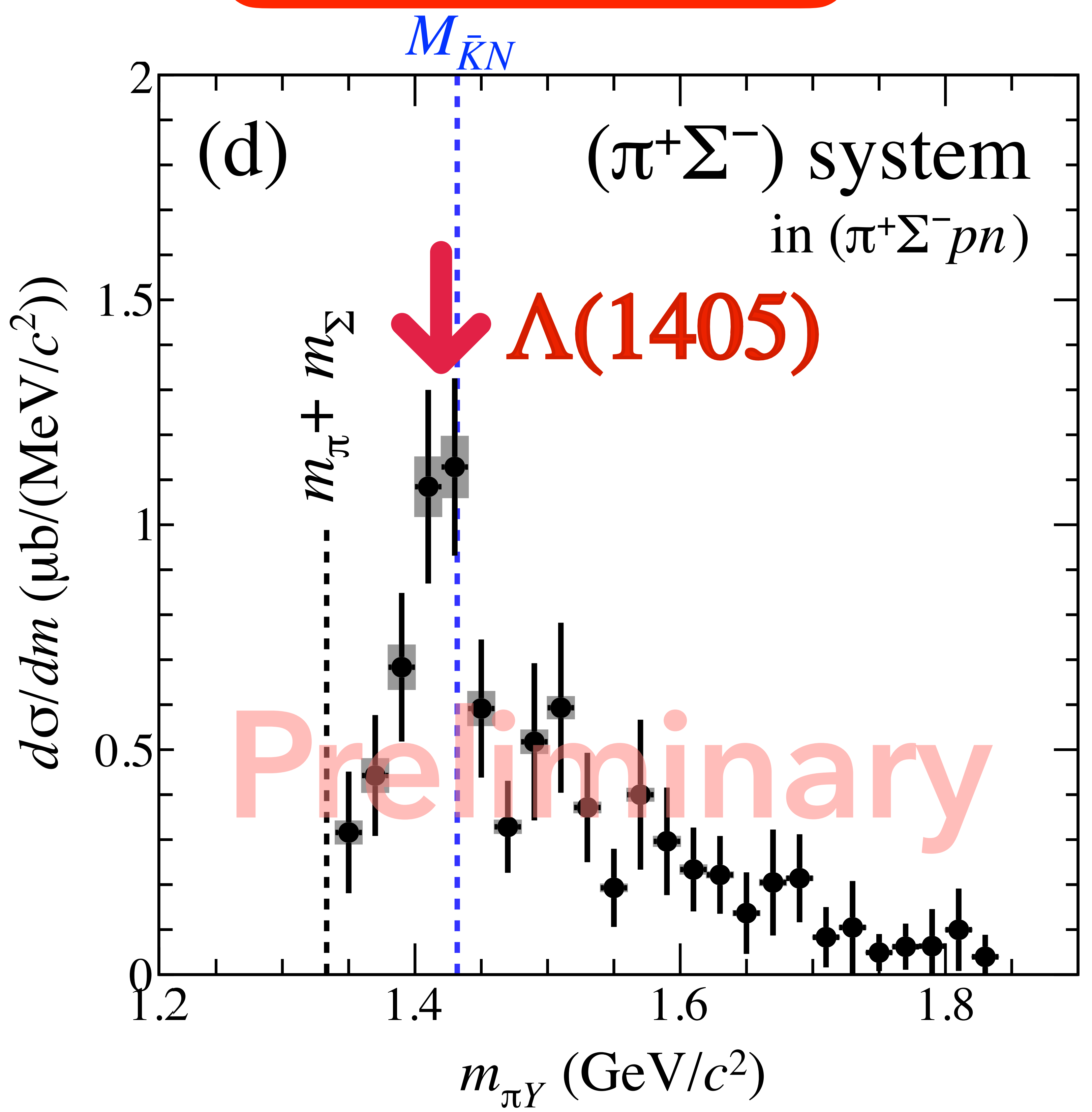
Λ(1405) + Phase space

Σ(1385)$^+$ + Phase space

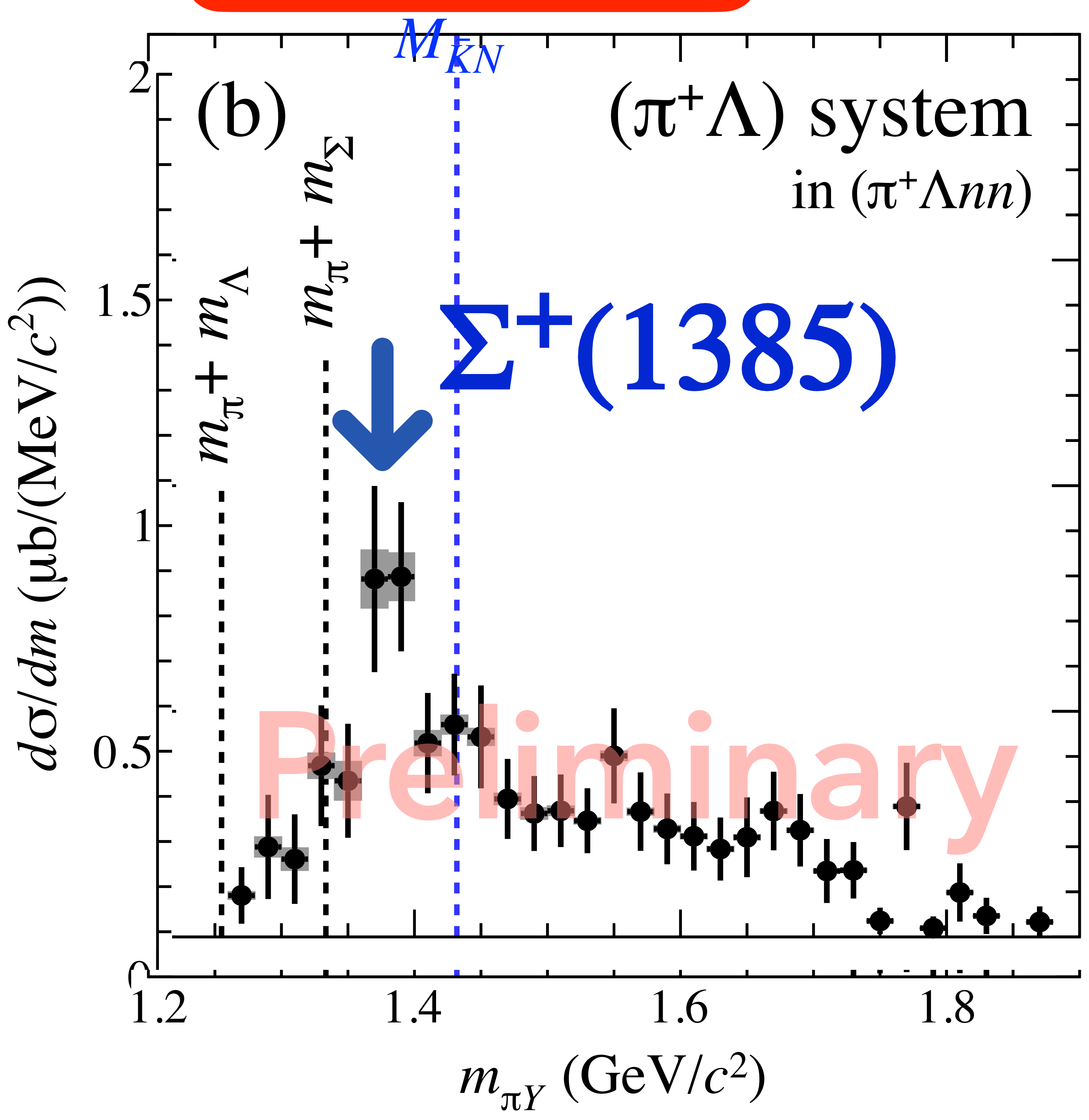
$(\pi^-\Sigma^+)\,p$



$(\pi^+\Sigma^-)\,p$



$(\pi^+\Lambda)\,n$



Λ(1405) + Phase space

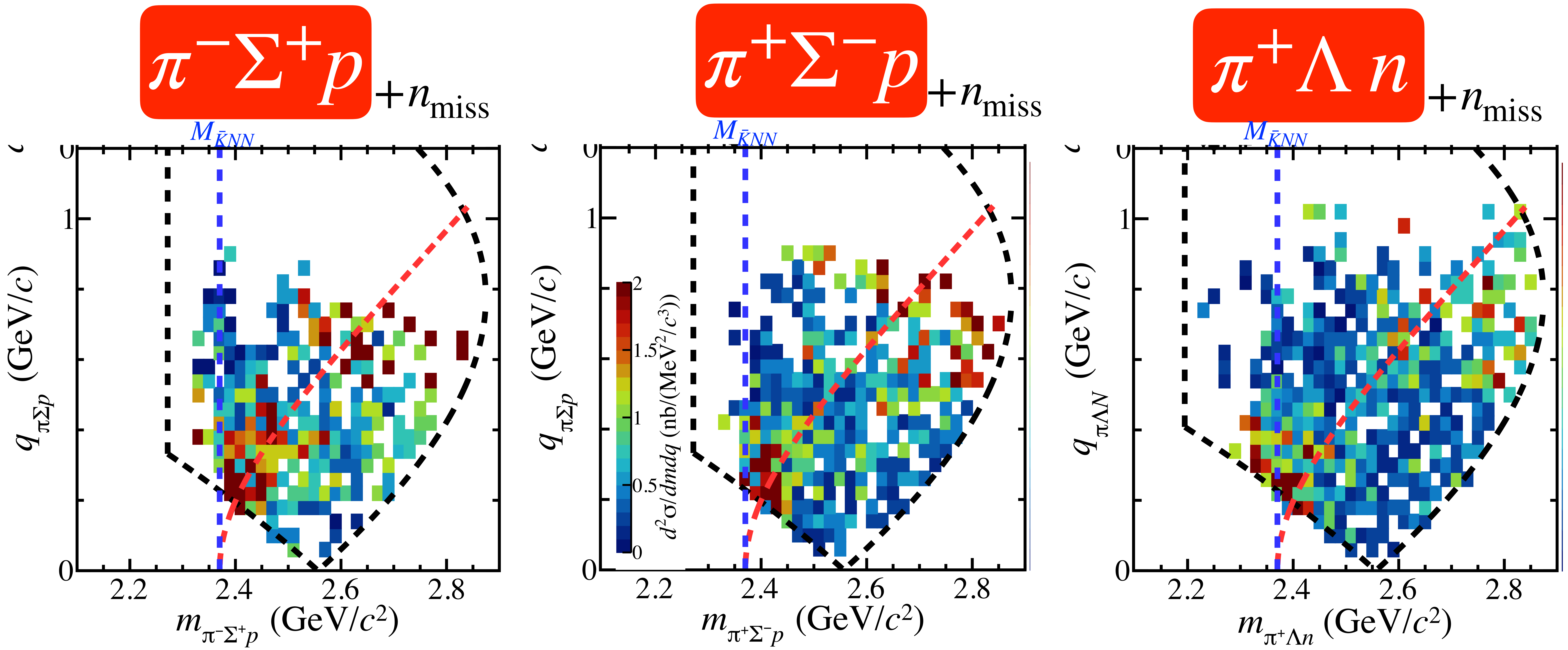
Σ(1385)$^+$+ Phase space

No heavier Y^* productions → scattered-$\bar{K}$ is low in momentum

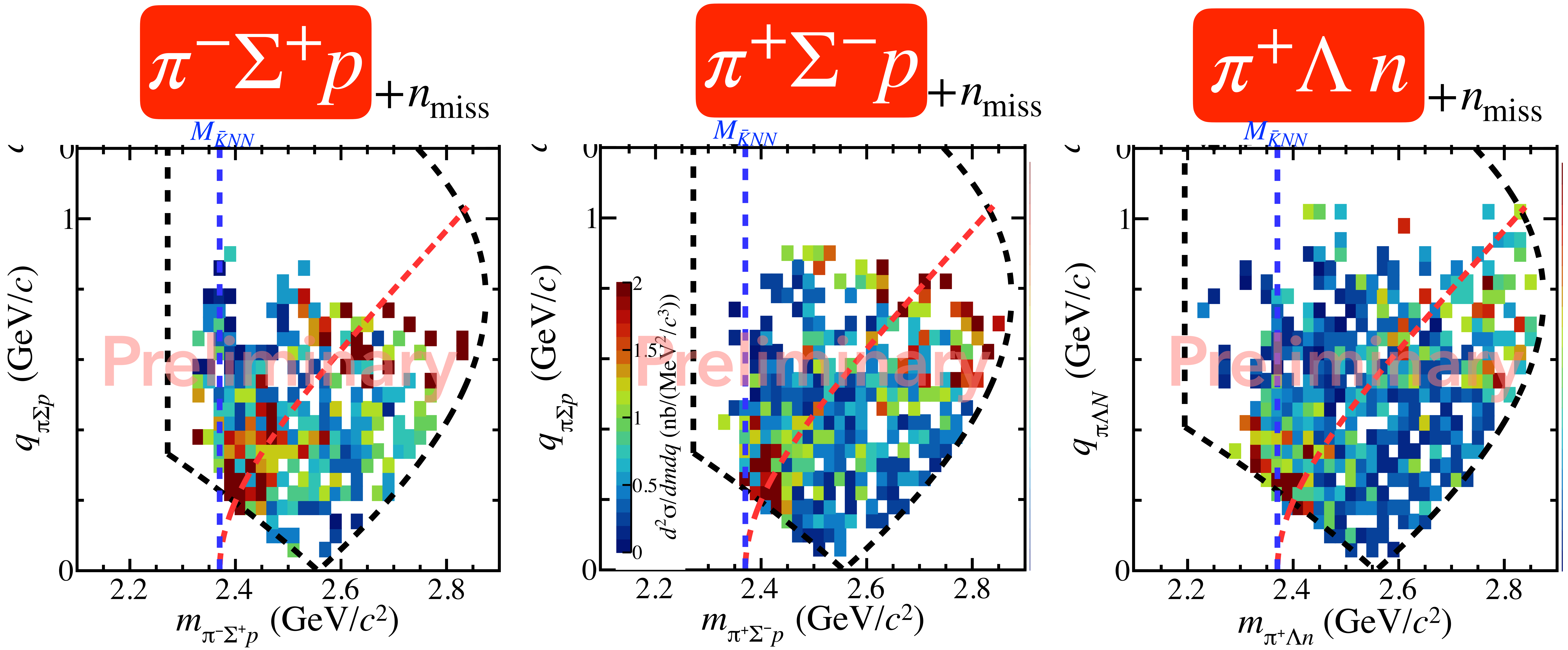
$\pi^-\Sigma^+p$ $+n_{\text{miss}}$

$\pi^+\Sigma^-p$ $+n_{\text{miss}}$

$\pi^+\Lambda\, n$ $+n_{\text{miss}}$



$\pi^-\Sigma^+p$ +$n_{\rm miss}$
$\pi^+\Sigma^-p$ +$n_{\rm miss}$
$\pi^+\Lambda n$ +$n_{\rm miss}$
$M_{\bar{K}NN}$
$q_{\pi\Sigma p}$ (GeV/c)
$q_{\pi\Lambda N}$ (GeV/c)
$m_{\pi^-\Sigma^+p}$ (GeV/c^2)
$m_{\pi^+\Sigma^-p}$ (GeV/c^2)
$m_{\pi^+\Lambda n}$ (GeV/c^2)
$d^2\sigma/dmdq$ (nb/(MeV^2/c^3))
2.2
2.4
2.6
2.8
0
1
0.5
1.5
2



Similar to Λp $+n_{\mathrm{miss}}$, but

clear for QF-$\bar{K}$ absorption, not significant for $\bar{K}NN$ production

Why $\bar{K}NN$ signal is not THAT clear?

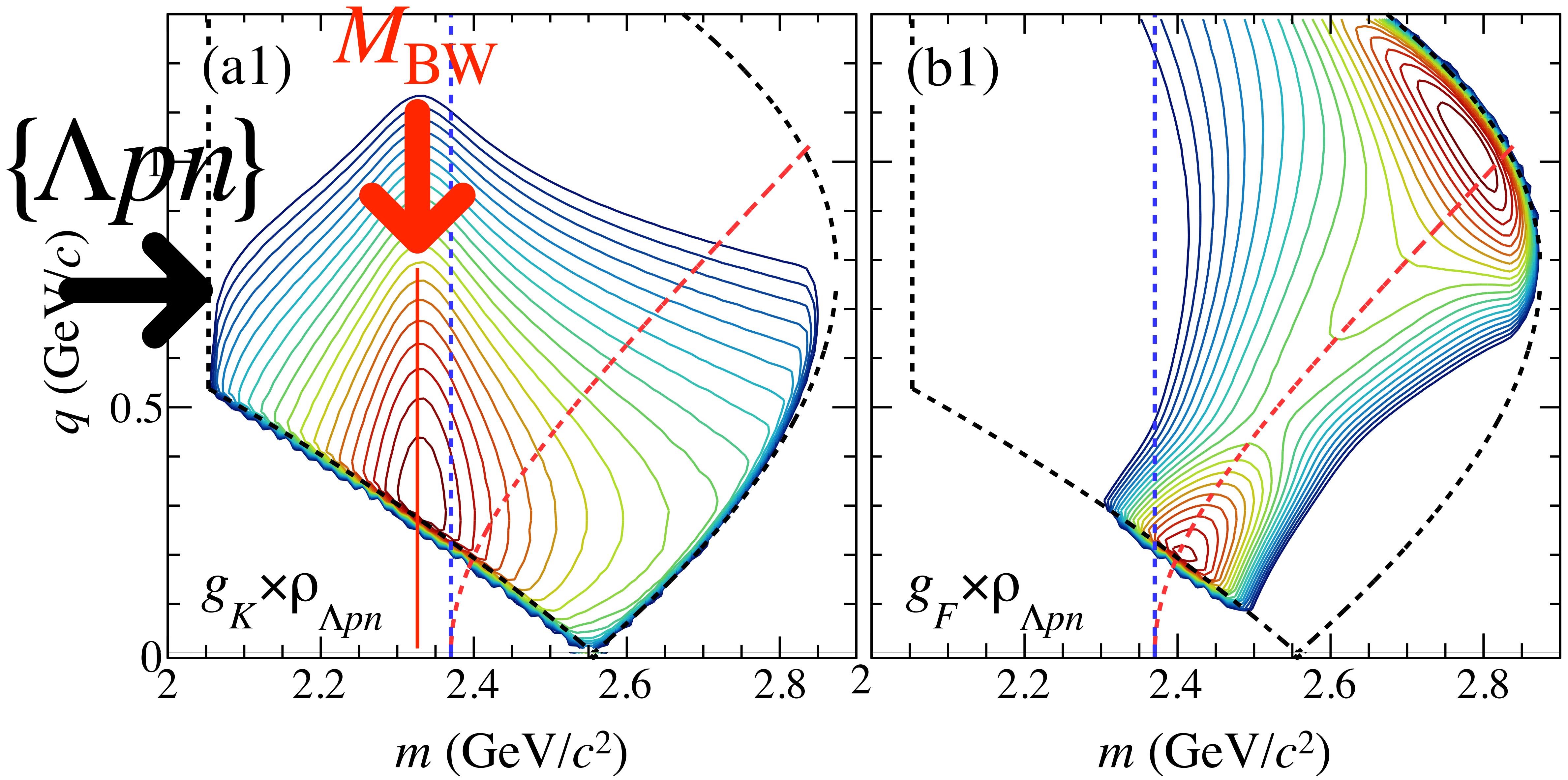
final state density

→ Due to phase volume reduction below $M_{\bar{K}NN}$ toward $M_{\pi\Sigma N}$

$f_{\bar{K}NN}(m,q) \times \rho_{\{\Lambda pn\}}(m,q)$ $f_{QF\text{-}\bar{K}}(m,q) \times \rho_{\{\Lambda pn\}}(m,q)$ $f_{\bar{K}NN}(m,q) \times \rho_{\{\pi\Sigma pn\}}(m,q)$ $f_{QF\text{-}\bar{K}}(m,q) \times \rho_{\{\pi\Sigma pn\}}(m,q)$

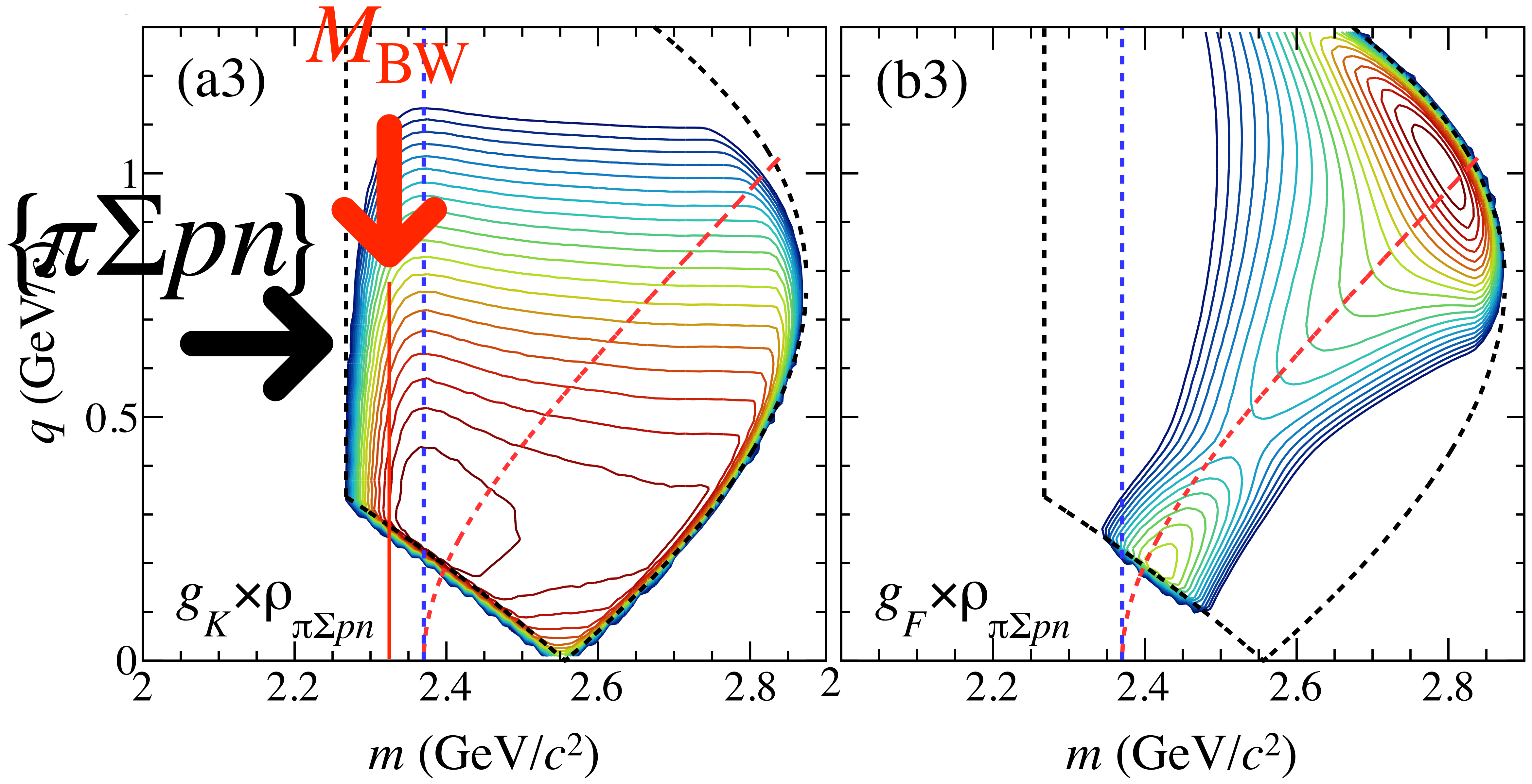
$\Lambda p + n_{\text{miss}}$

$\bar{K}NN$ production | QF-$\bar{K}$ absorption



$\pi^-\Sigma^+ p + n_{\text{miss}}$

$\bar{K}NN$ production | QF-$\bar{K}$ absorption

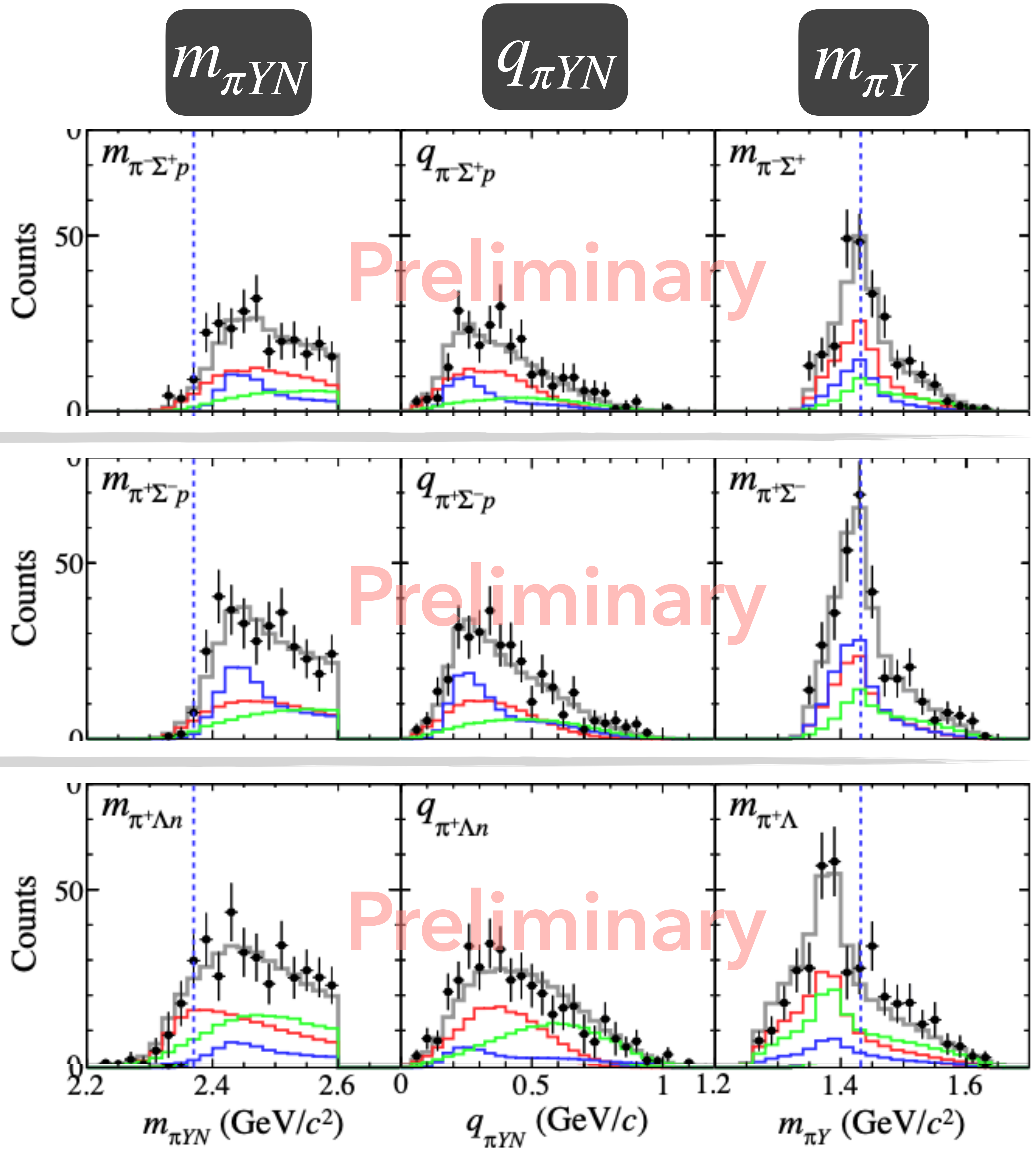


Fit result assuming $f_{\bar{K}NN}$ and $f_{QF-\bar{K}}$ are common with what observed in Λp

$\pi^-\Sigma^+ p$ $+n_{mis}$

$\pi^+\Sigma^- p$ $+n_{mis}$

$\pi^+\Lambda n$ $+n_{mis}$

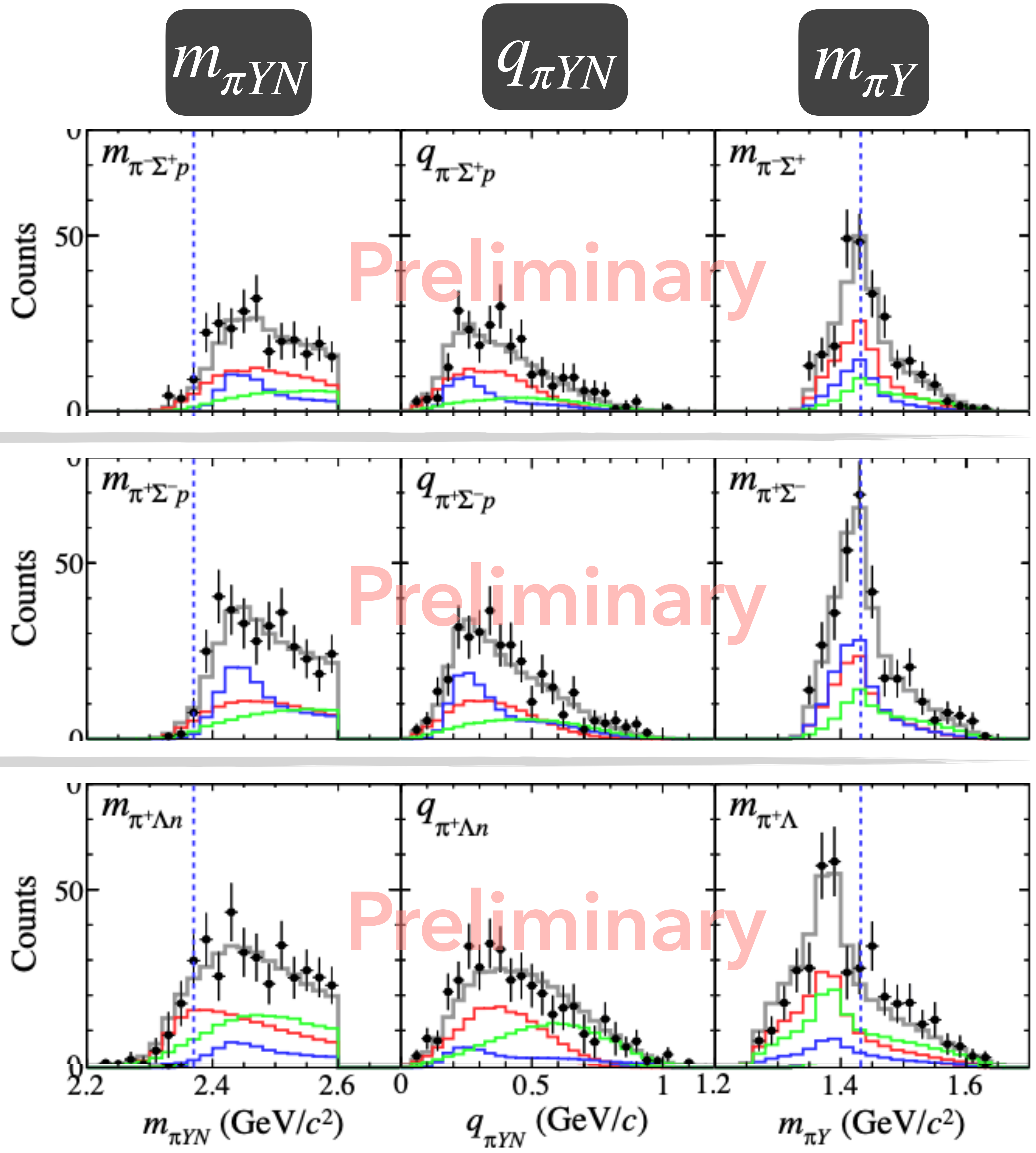


Fit result assuming $f_{\bar{K}NN}$ and $f_{QF-\bar{K}}$ are common with what observed in Λp

$\pi^-\Sigma^+p + n_{mis}$

$\pi^+\Sigma^-p + n_{mis}$

$\pi^+\Lambda n + n_{mis}$



All distributions are well fitted with $\bar{K}NN$, QF, and BG.

↓

misconceiving of QF

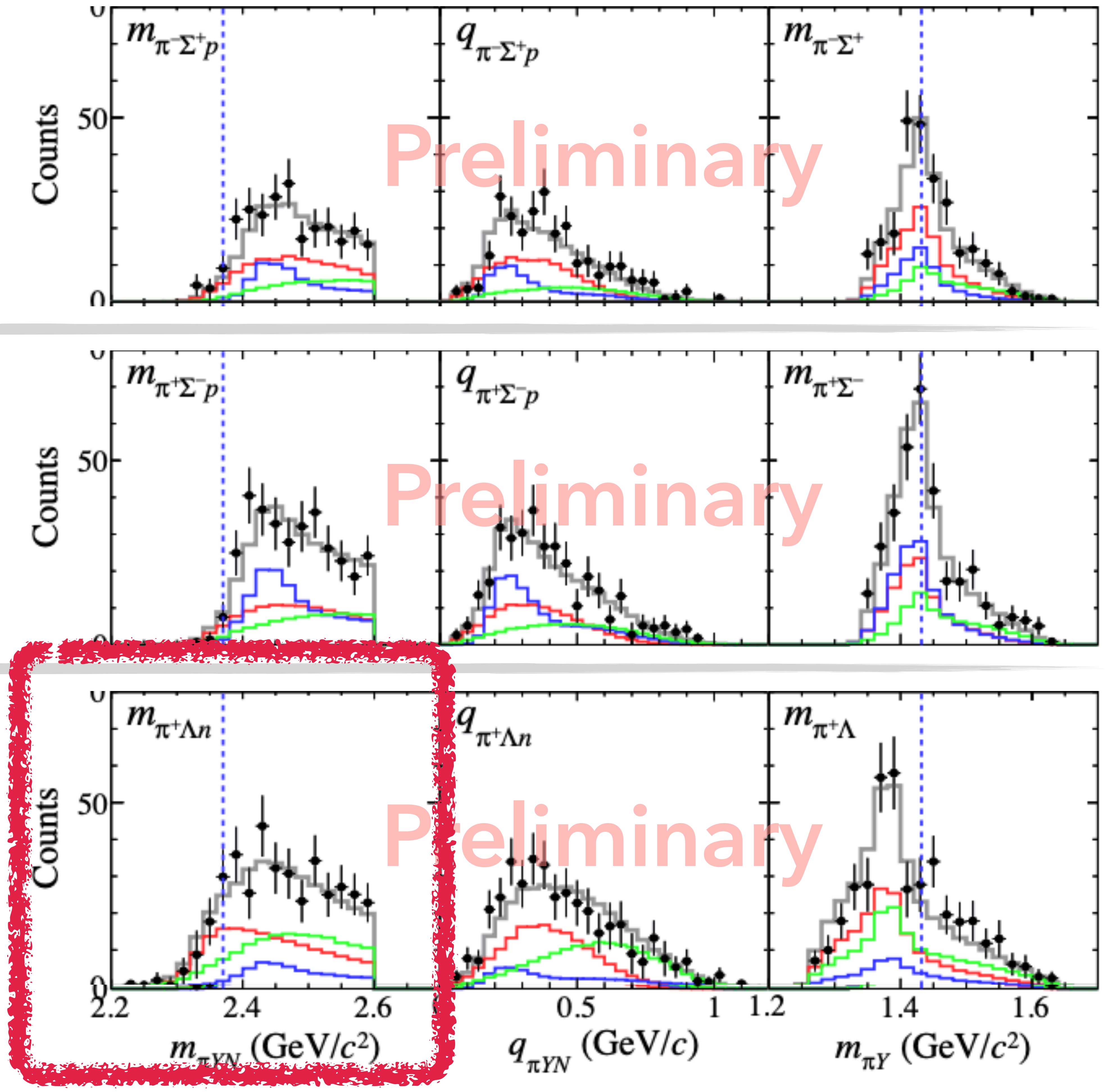
Fit result assuming $f_{\bar{K}NN}$ and $f_{QF-\bar{K}}$ are common with what observed in Λp

$m_{\pi YN}$ | $q_{\pi YN}$ | $m_{\pi Y}$

$\pi^-\Sigma^+ p + n_{mis}$

$\pi^+\Sigma^- p + n_{mis}$

$\pi^+\Lambda n + n_{mis}$



All distributions are well fitted with $\bar{K}NN$, QF, and BG.

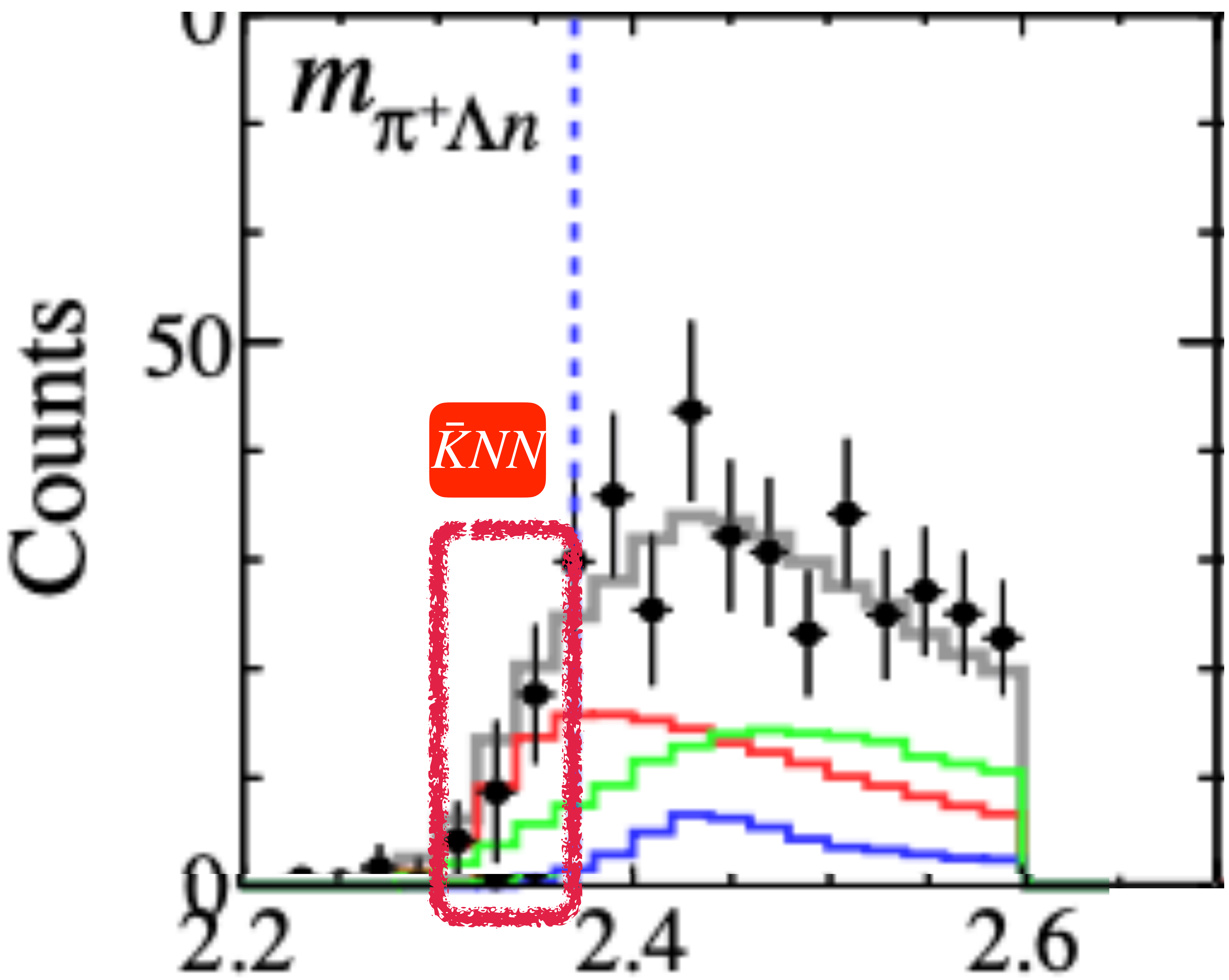
↓

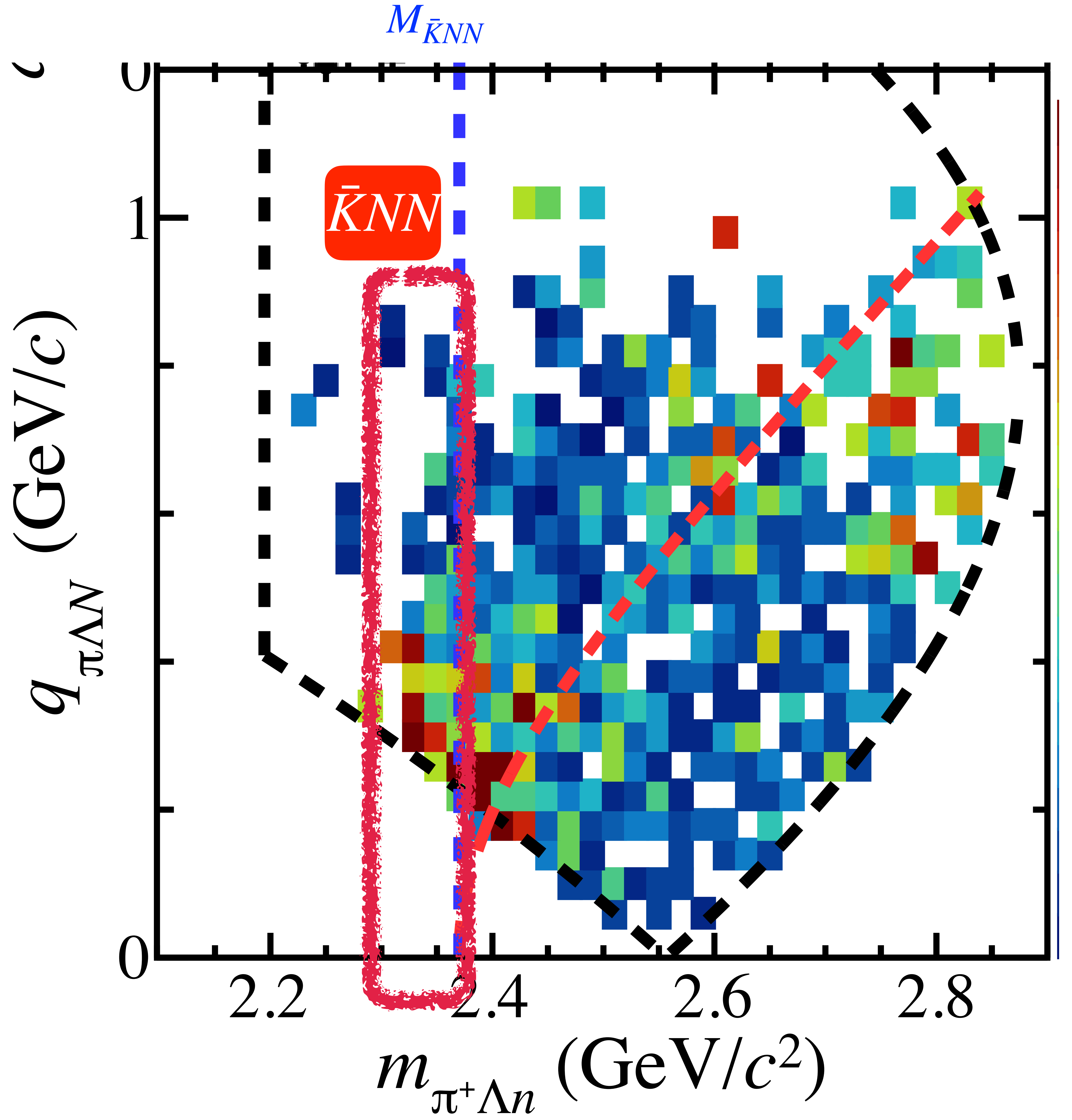
misconceiving of QF

Can only be fitted by assuming the presence of $\bar{K}NN$

An example of the fit

$\pi^+\Lambda n$ $+n_{miss}$





Cross section x Br$_{\pi YN}$ from the fit

Cross section of $\bar{K}NN$ x Br.

※Statistical error only

$I_{\bar{K}N} = 0, 1$

$\pi^-\Sigma^+ p$ $+n_{\mathrm{miss}}$

Preliminary

$85.4 \pm 21.2\ \mu\mathrm{b}$

$I_{\bar{K}N} = 0, 1$

$\pi^+\Sigma^- p$ $+n_{\mathrm{miss}}$

Preliminary

$43.8 \pm 9.6\ \mu\mathrm{b}$

$I_{\bar{K}N} = 1$

$\pi^+\Lambda\, n$ $+n_{\mathrm{miss}}$

Preliminary

$83.6 \pm 12.0\ \mu\mathrm{b}$

c.f. Λp $+n_{\mathrm{miss}}$ $9.3 \pm 0.8^{+1.4}_{-1.0}\ \mu\mathrm{b}$

mesonic decay channel is more difficult to identify $\bar{K}NN$ signal in invariant mass due to $\rho_{\{\pi Ypn\}}(m, q)$

$\Gamma_{\mathrm{mesonic}}$ *is more than* $\mathcal{O}(10)$ ***larger*** *compared to* $\Gamma_{\mathrm{non-mesonic}}$

$\Gamma_{\mathrm{mesonic}} \gg \Gamma_{\mathrm{non-mesonic}}$

what we are working on … II

Signal of $\bar{K}NNN$

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

$(K^- + pp) \rightarrow \Lambda + p$

➡

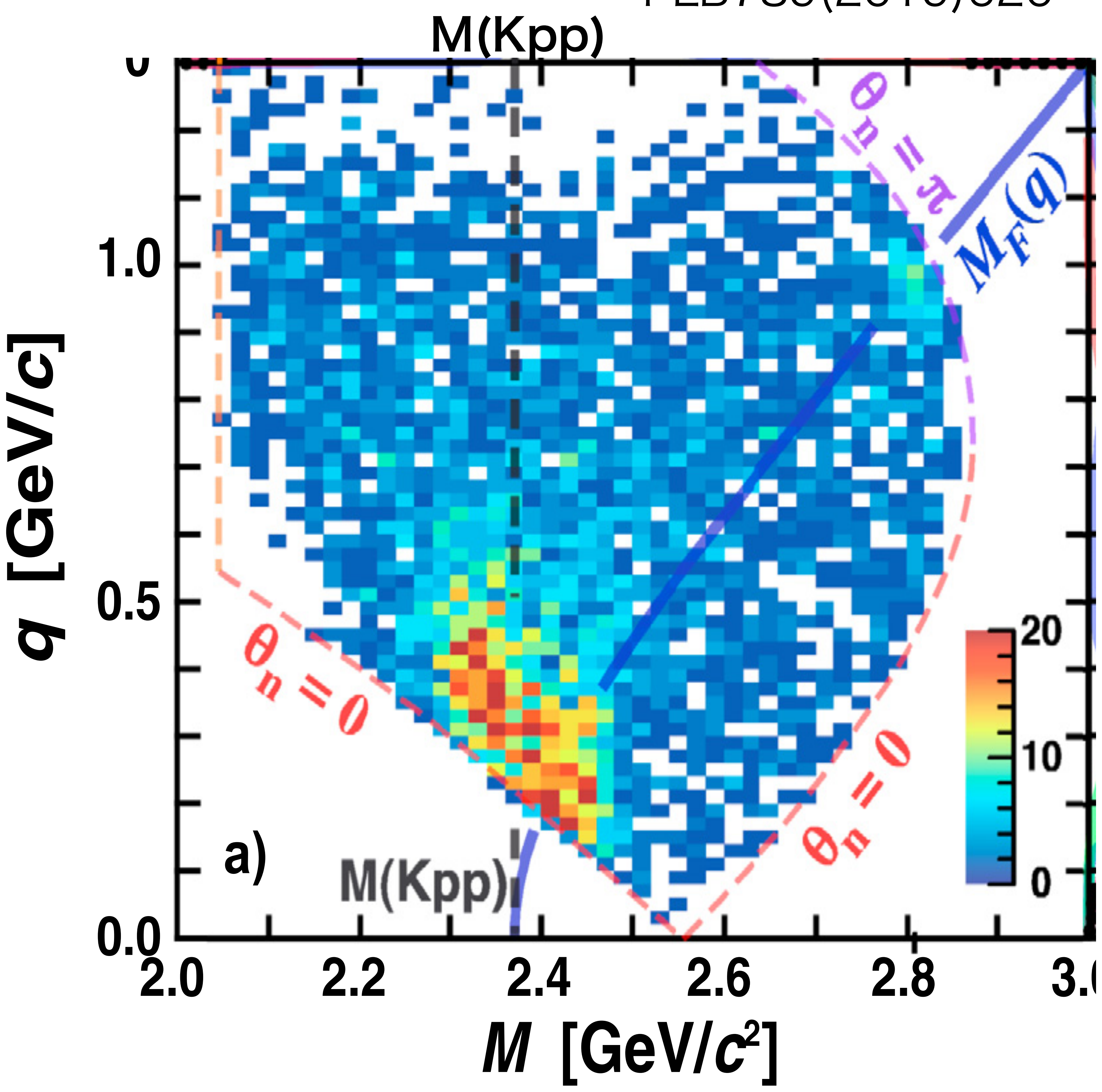
$K^- + {}^4He \rightarrow (K^- + ppn) + n$

$(K^- + ppn) \rightarrow \Lambda + d$

… T. Hashimoto

E15: Λp

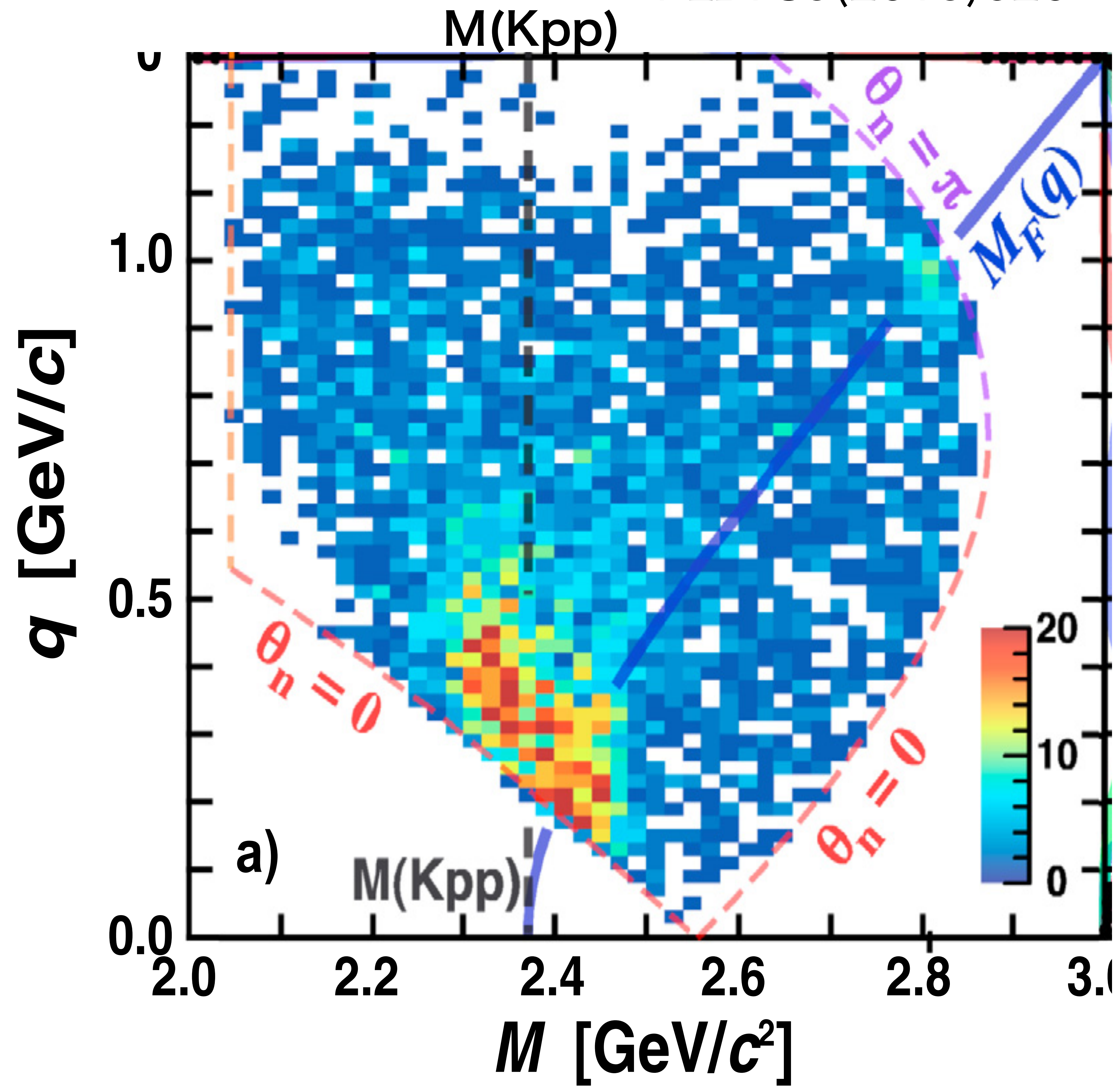
PLB789(2019)620



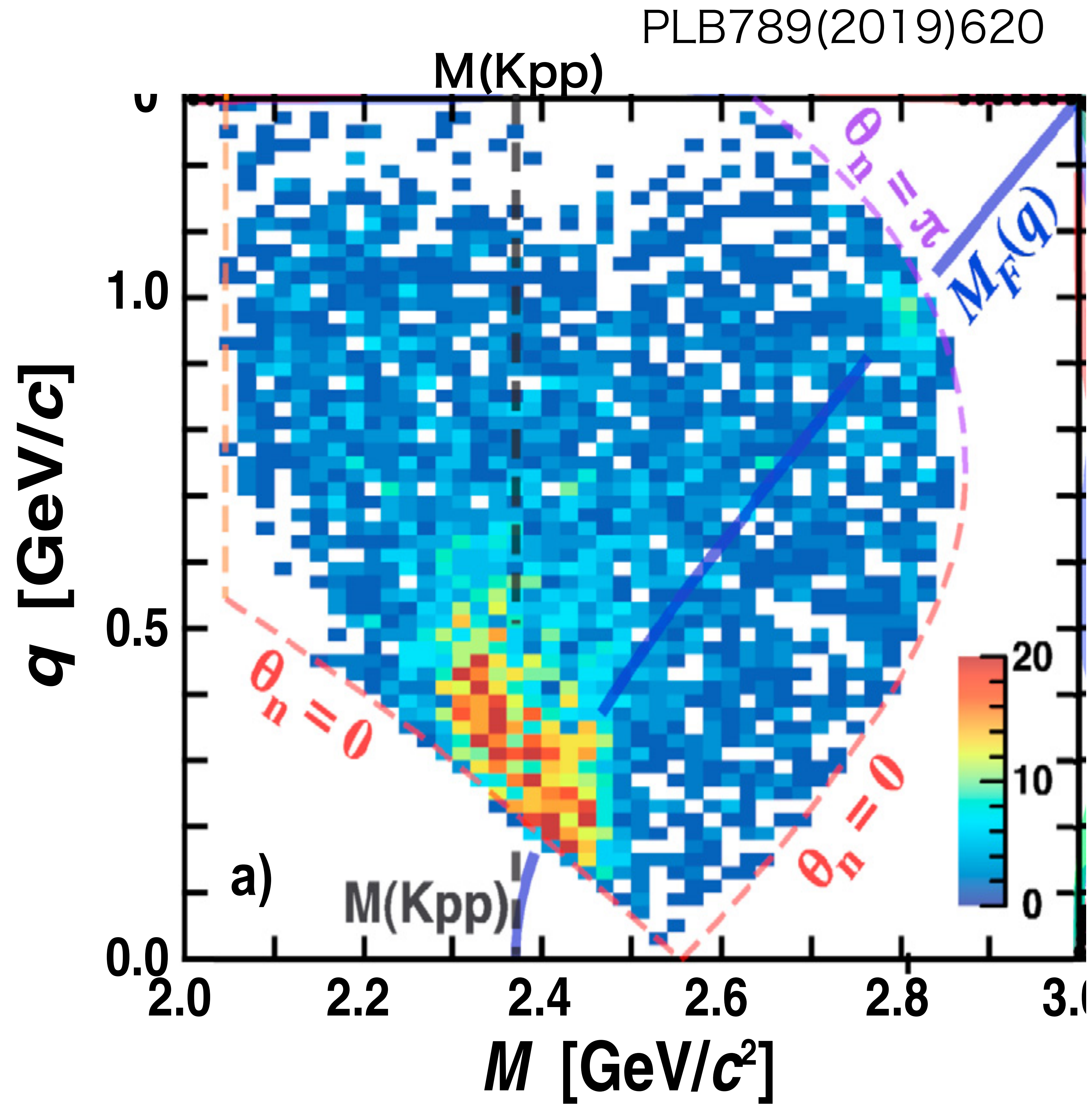
E15: Λp

Preliminary Λd result

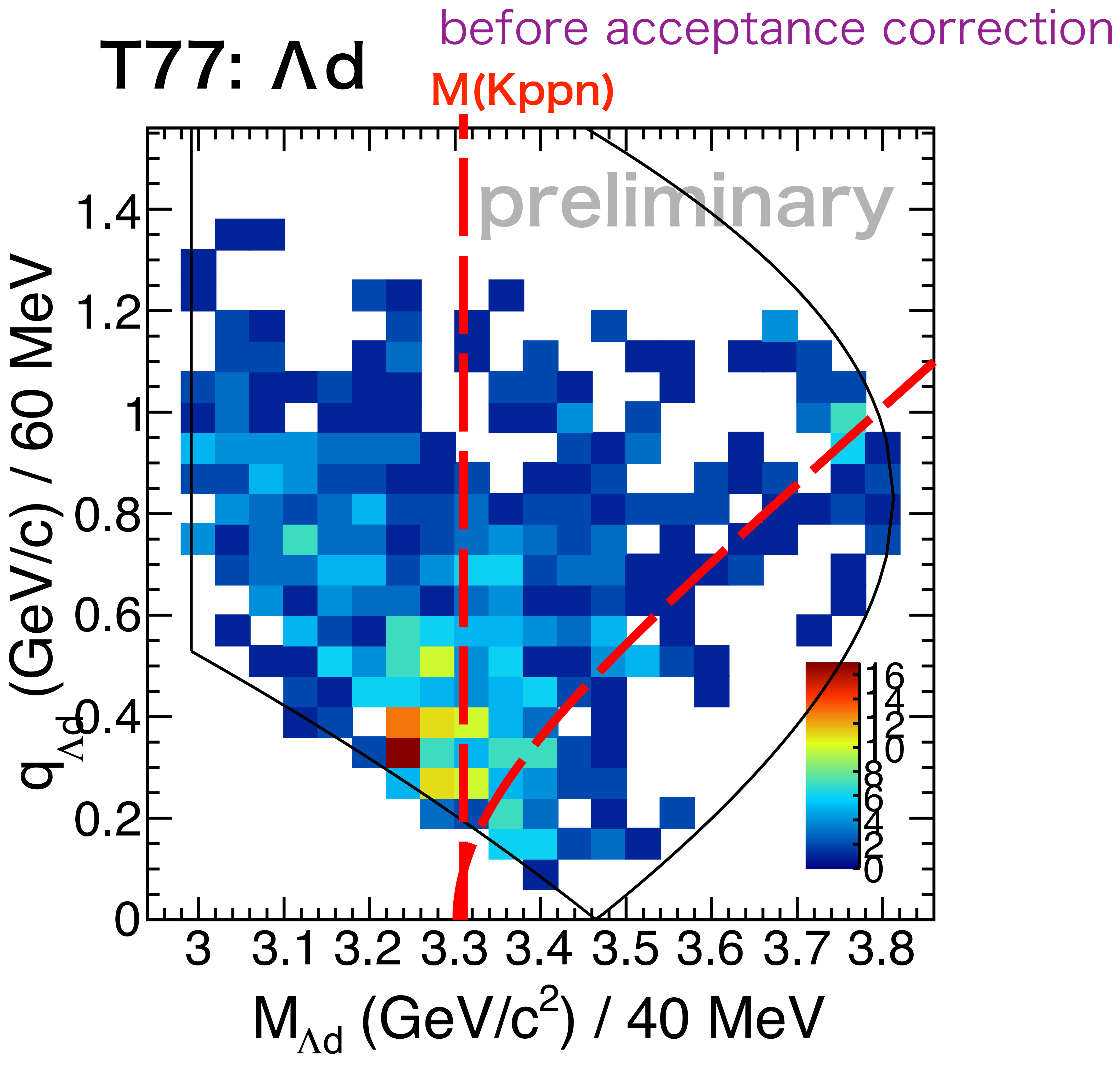
PLB789(2019)620



E15: Λp

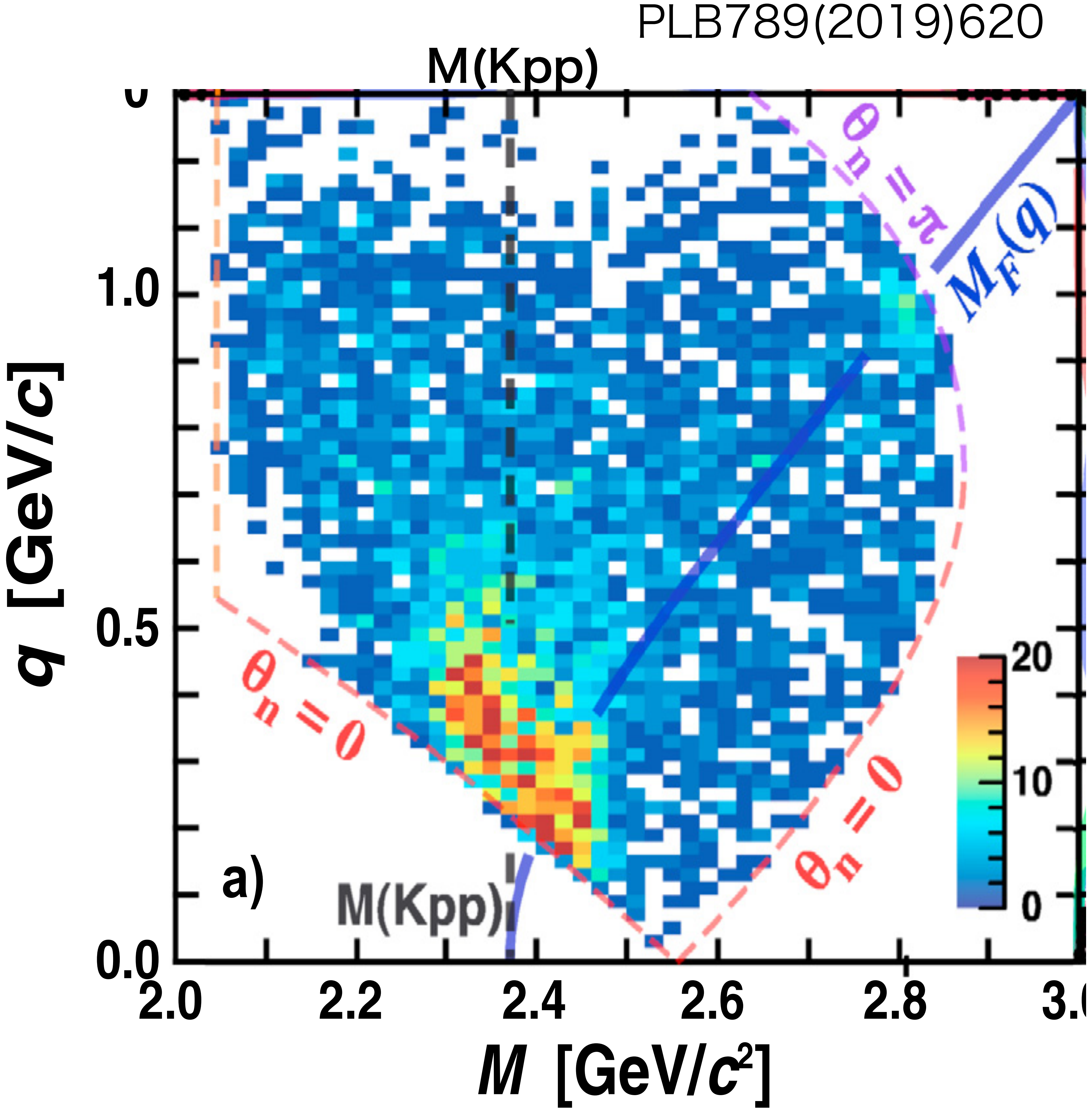


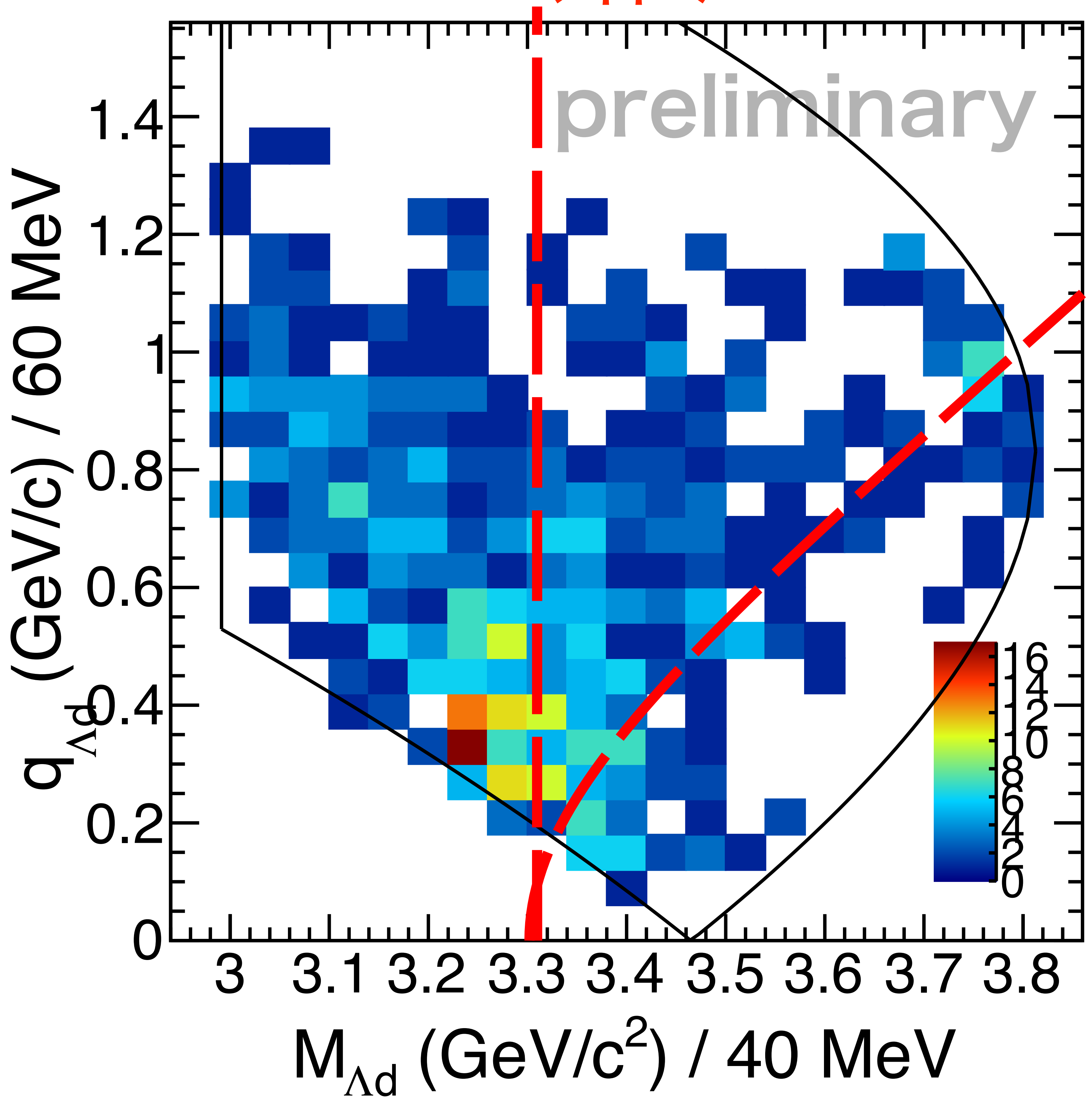
Preliminary Λd result



E15: Λp

Preliminary Λd result



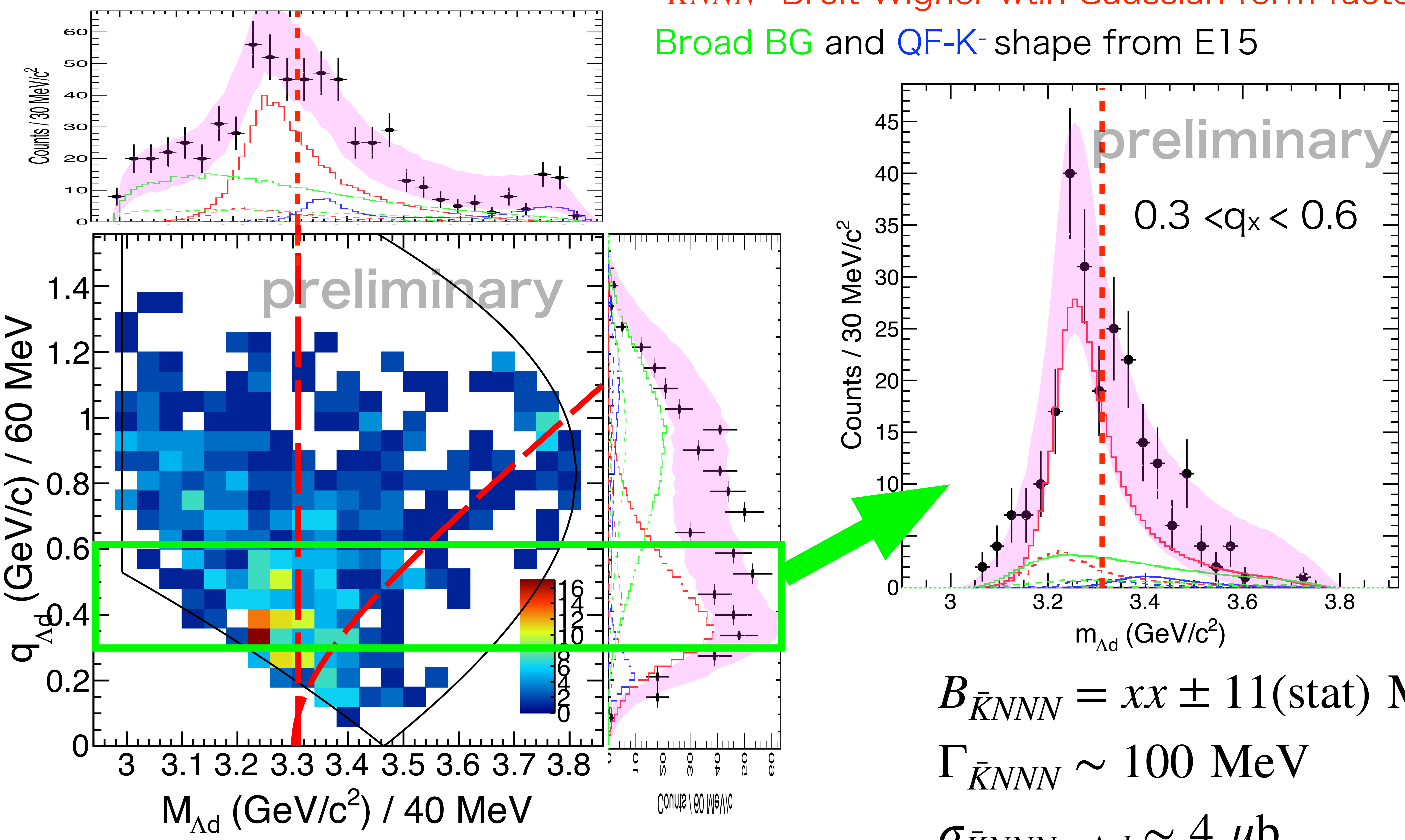


- Two disributions are quite similar
- structure below the threshold, QF-K, and broad background

Preliminary result

"$\bar{K}NNN$" Breit-Wigner wtih Gaussian form factor

Broad BG and QF-K- shape from E15



$$B_{\bar{K}NNN} = xx \pm 11(\text{stat})\ \text{MeV}$$

$$\Gamma_{\bar{K}NNN} \sim 100\ \text{MeV}$$

$$\sigma_{\bar{K}NNN \to \Lambda d} \sim 4\ \mu\text{b}$$

Summary:

- $\bar{K}NN,\ I_3 = +\frac{1}{2}$ **identified in $\bar{K}NN \rightarrow \Lambda p$ analysis**

Phys. Lett. B789, 620-625 (2019)
Phys. Rev. C102, 044002 (2020)

- $\bar{K}NN \rightarrow \pi Y p$ **decay dominance** $Br_{\pi Y p} > 10 \times Br_{\Lambda p}$

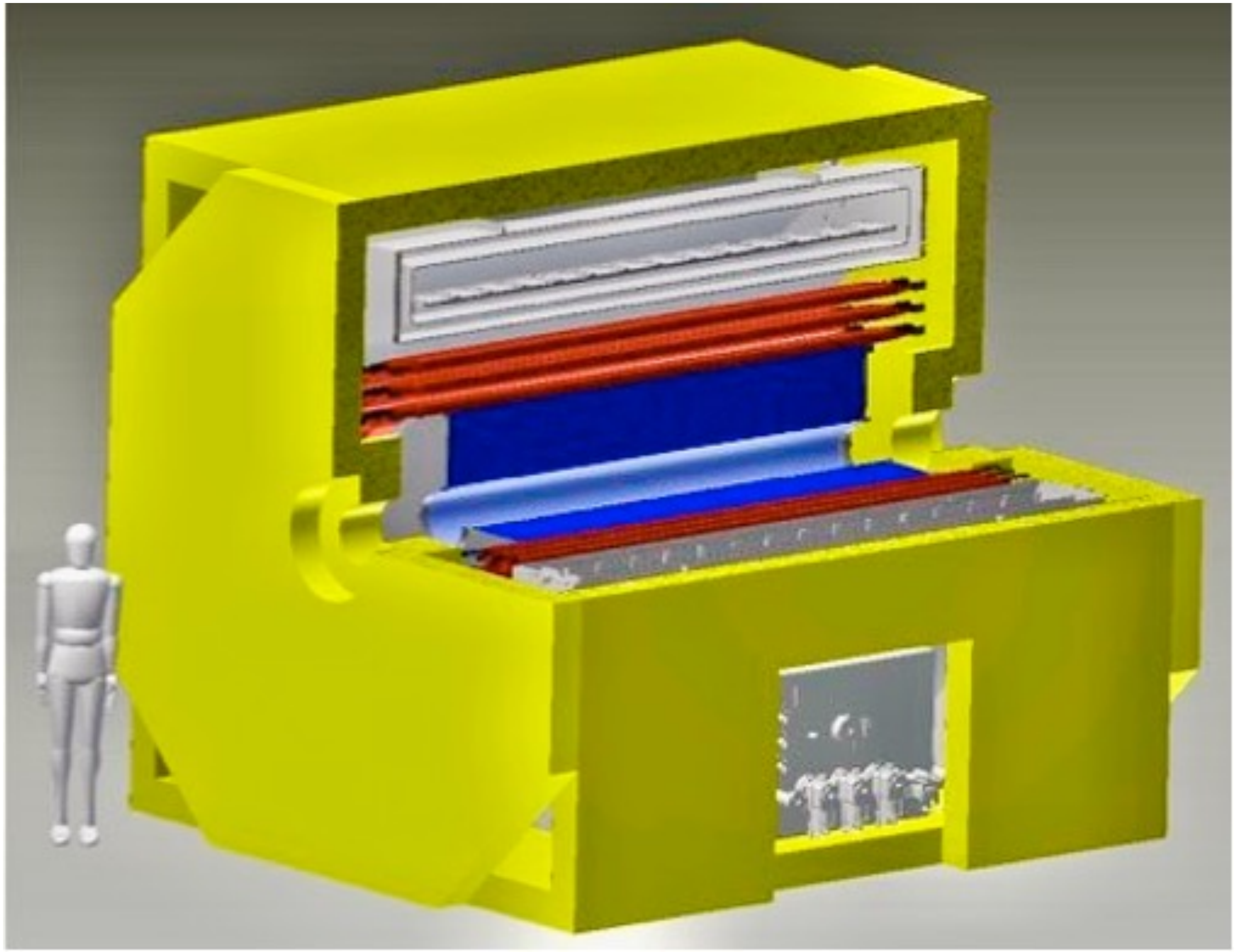
preliminary analysis ***K absorption in $I_{\bar{K}N} = 1$ as well***

- $\bar{K}NNN,\ I = 0$ **identified in $\bar{K}NNN \rightarrow \Lambda d$ analysis**

preliminary analysis ***Three nucleon bound state!***

$\bar{K}$ nuclear bound state becomes more solid

Toward J^P (spin・parity) study

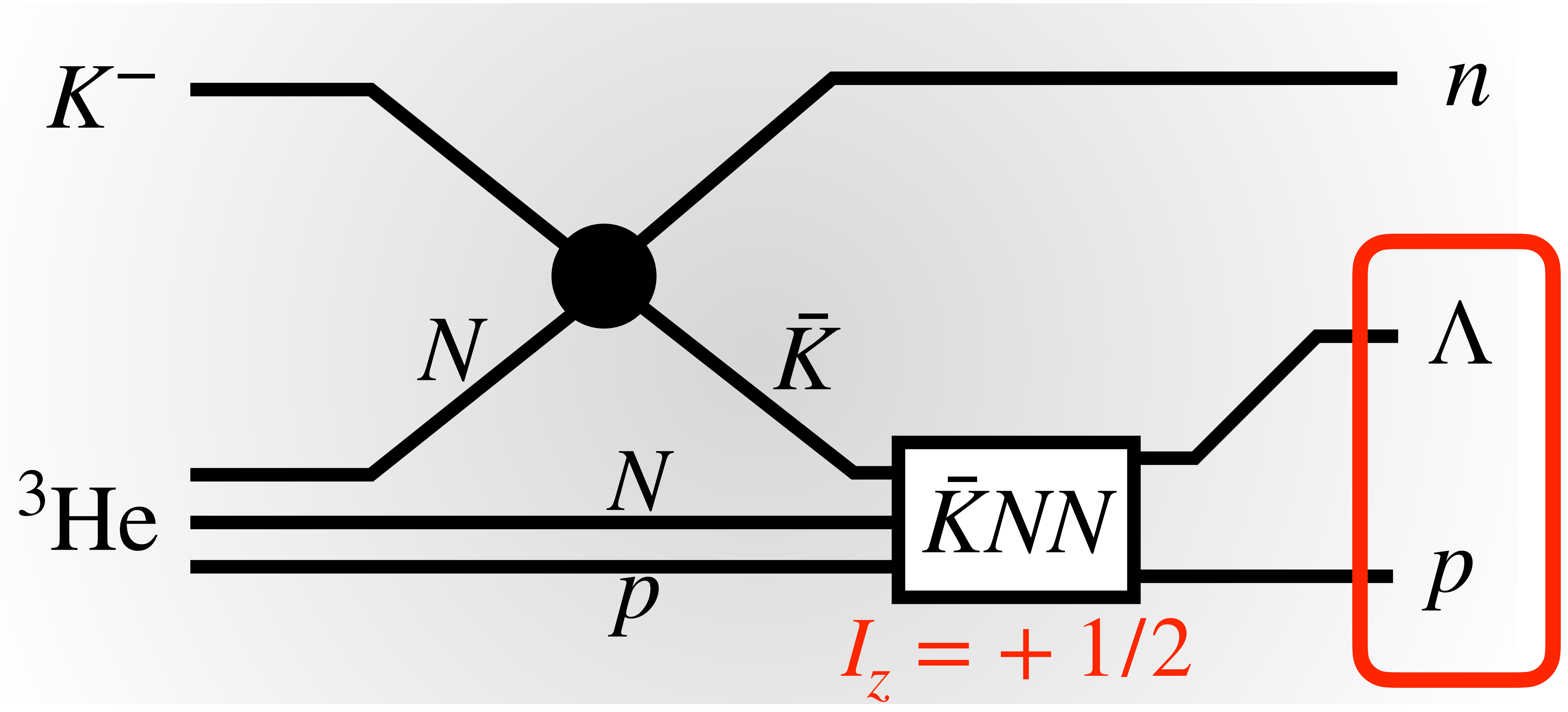


we welcome you if you can join !!!

Thank you for your attention!

What we measured/observed in E15

Production reaction

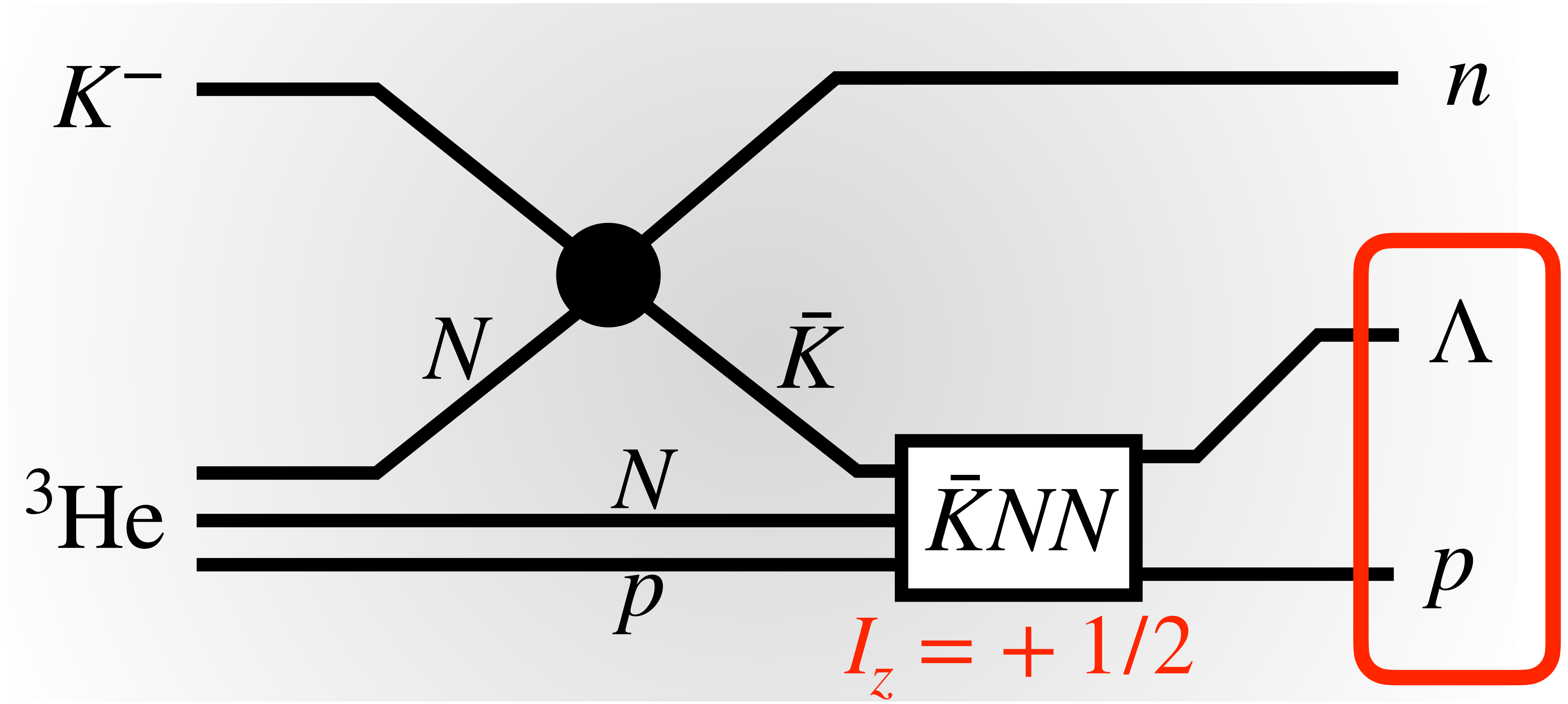


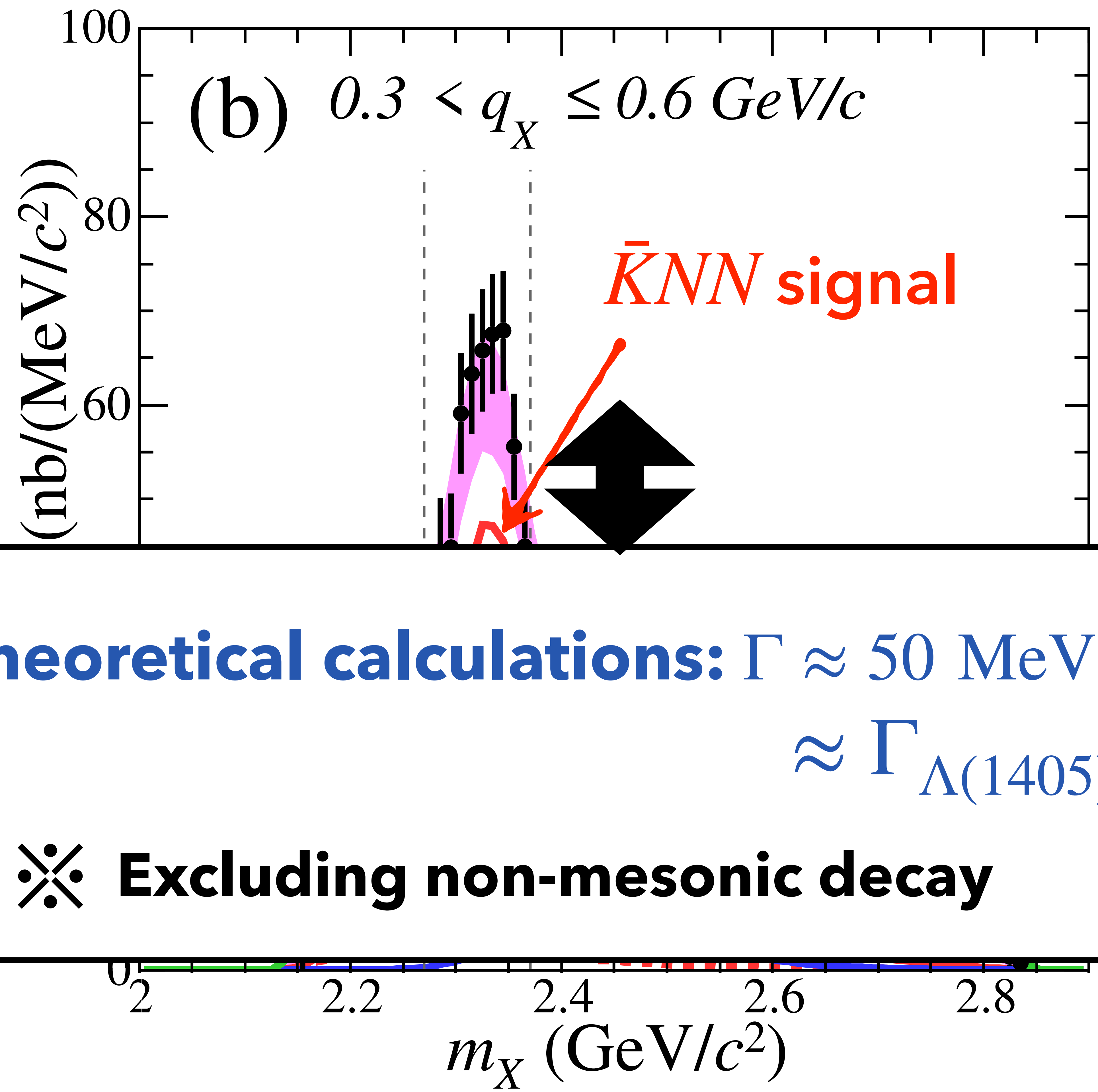
Theoretical calculations: $\Gamma \approx 50$ MeV $\approx \Gamma_{\Lambda(1405)}$

※ **Excluding non-mesonic decay**

What we measured/observed in E15

Production reaction





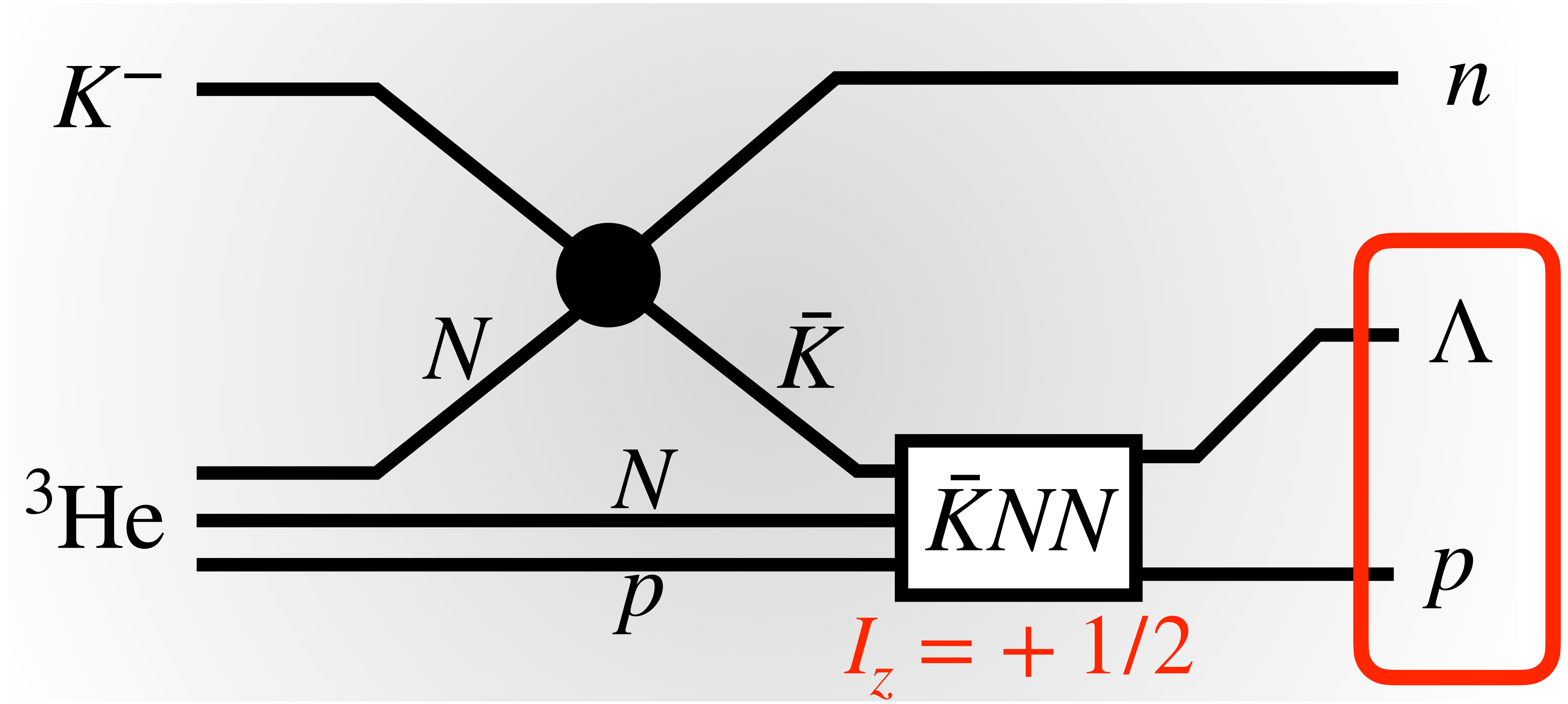
Theoretical calculations: $\Gamma \approx 50$ MeV

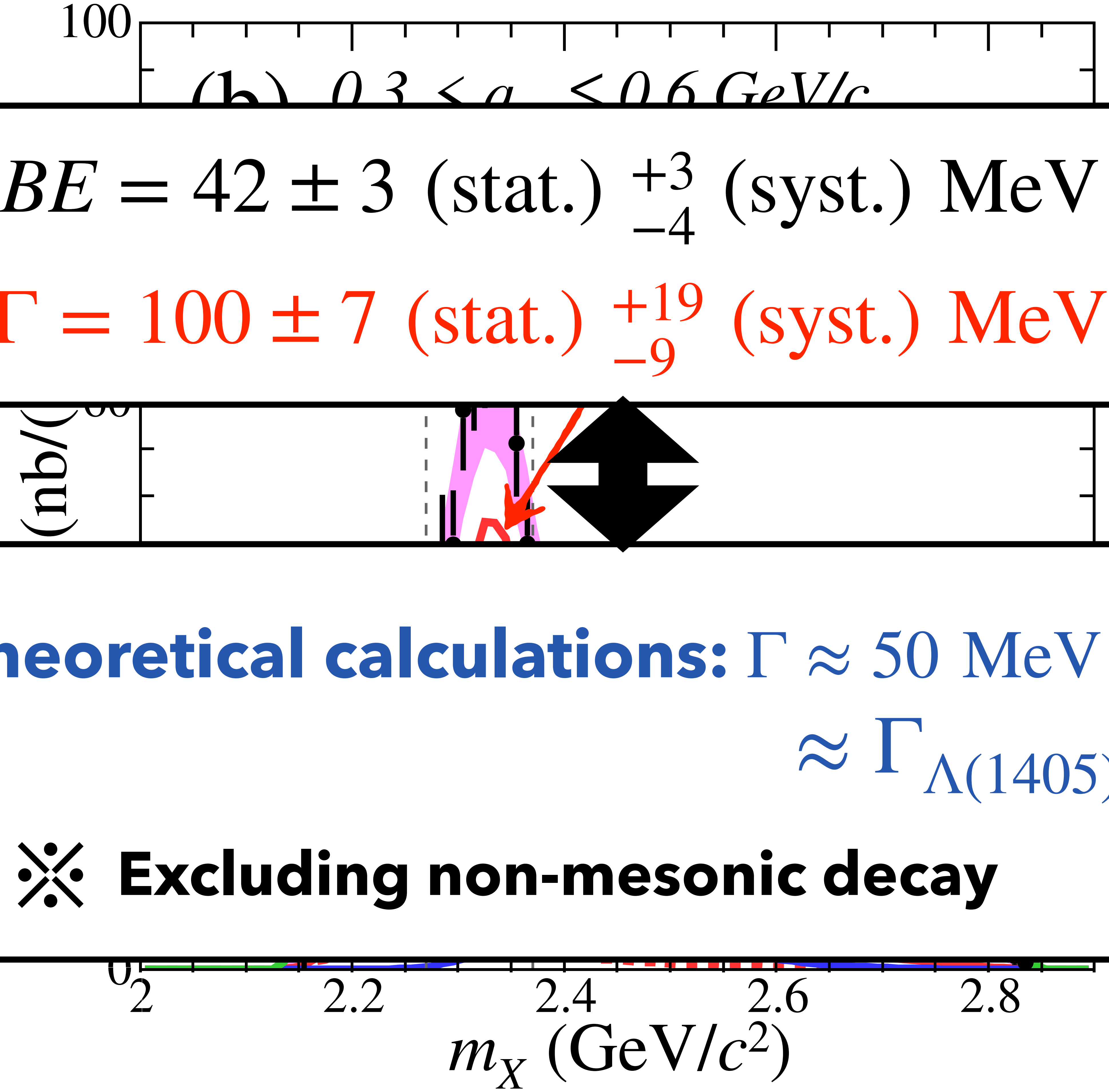
$\approx \Gamma_{\Lambda(1405)}$

※ **Excluding non-mesonic decay**

What we measured/observed in E15

Production reaction





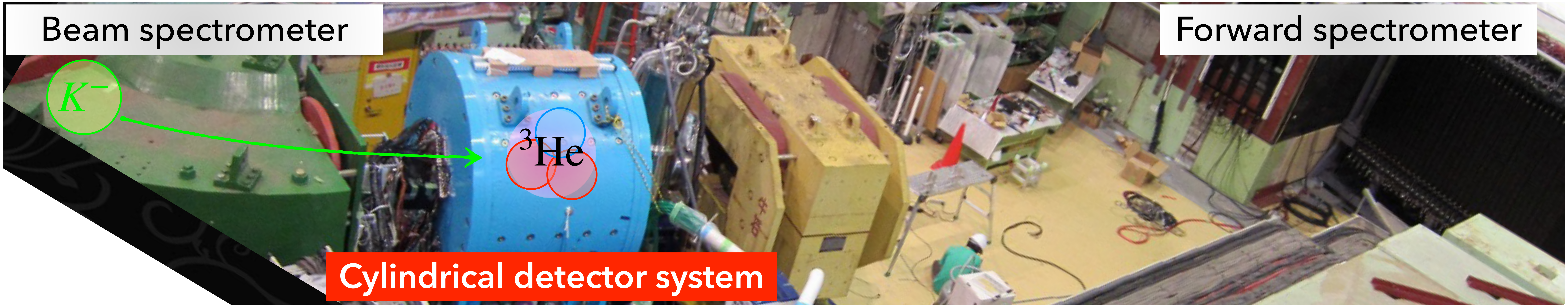
$$BE = 42 \pm 3 \text{ (stat.) } {}^{+3}_{-4} \text{ (syst.) MeV}$$

$$\Gamma = 100 \pm 7 \text{ (stat.) } {}^{+19}_{-9} \text{ (syst.) MeV}$$

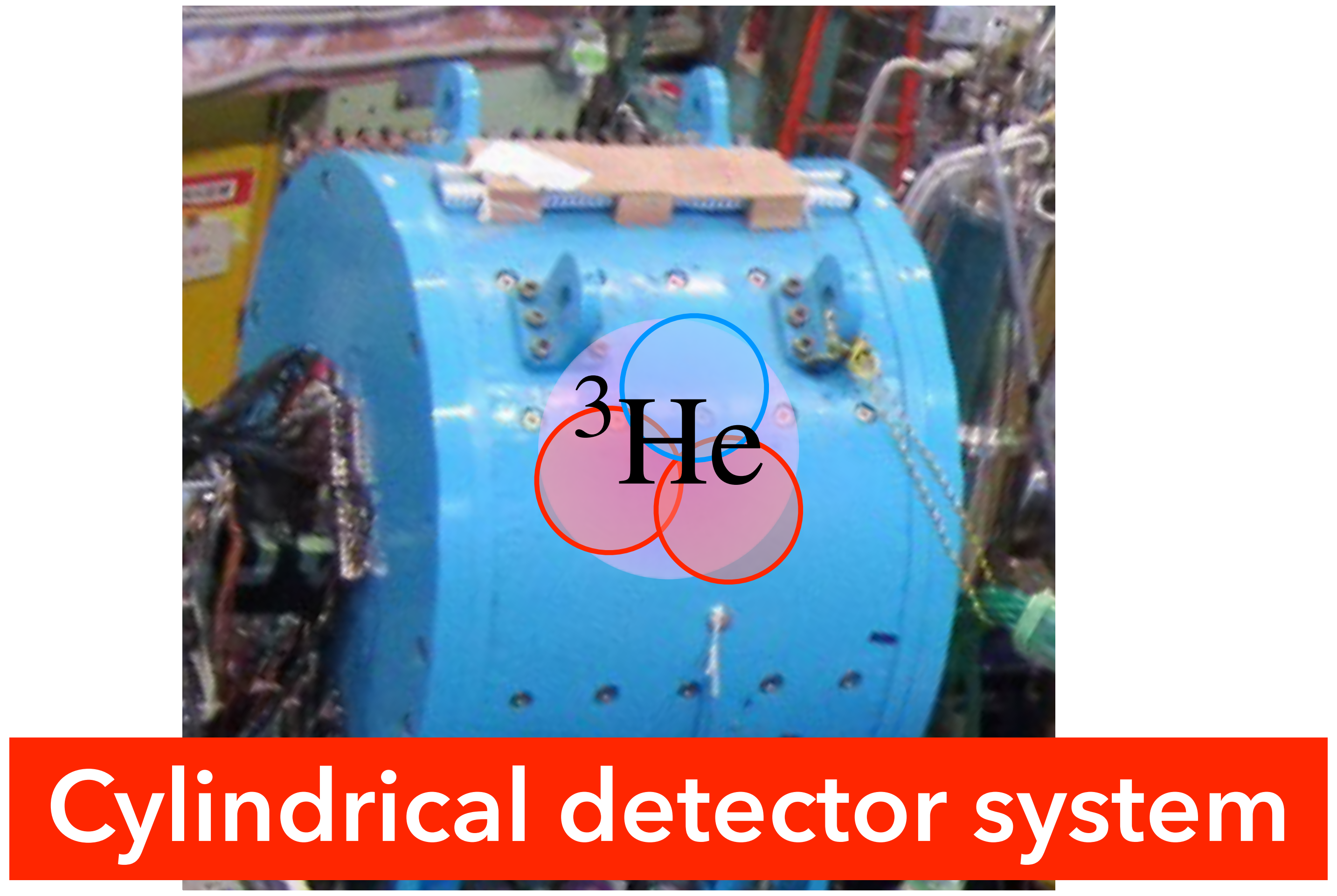
Theoretical calculations: $\Gamma \approx 50$ MeV $\approx \Gamma_{\Lambda(1405)}$

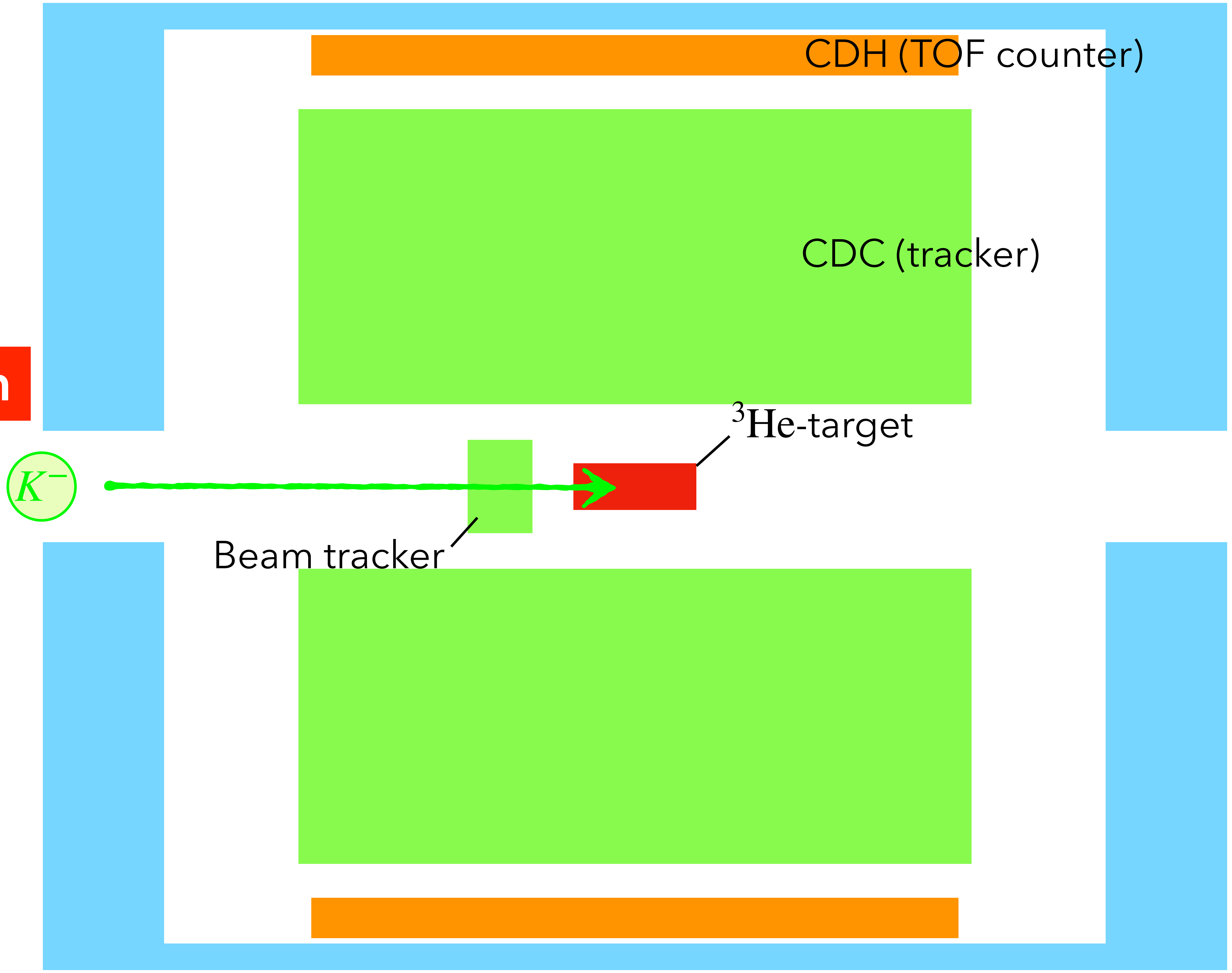
※ **Excluding non-mesonic decay**

Measurement / Analysis

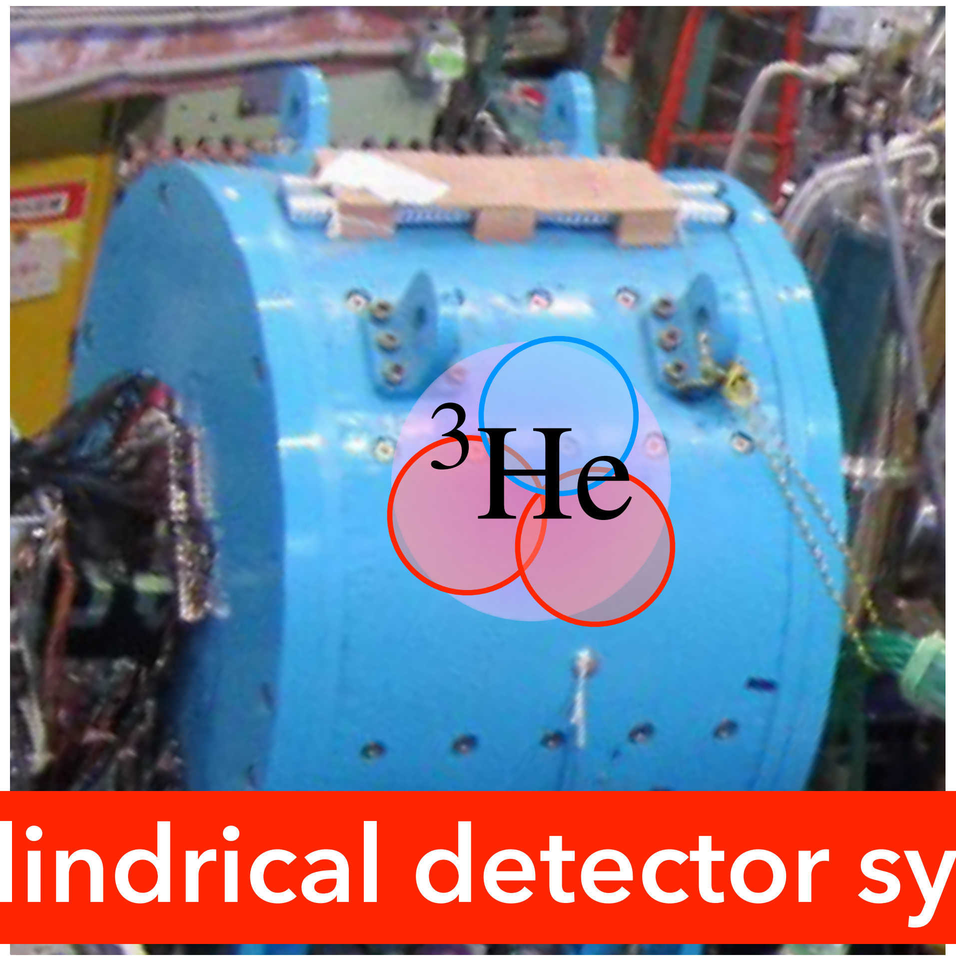


Measurement / Analysis

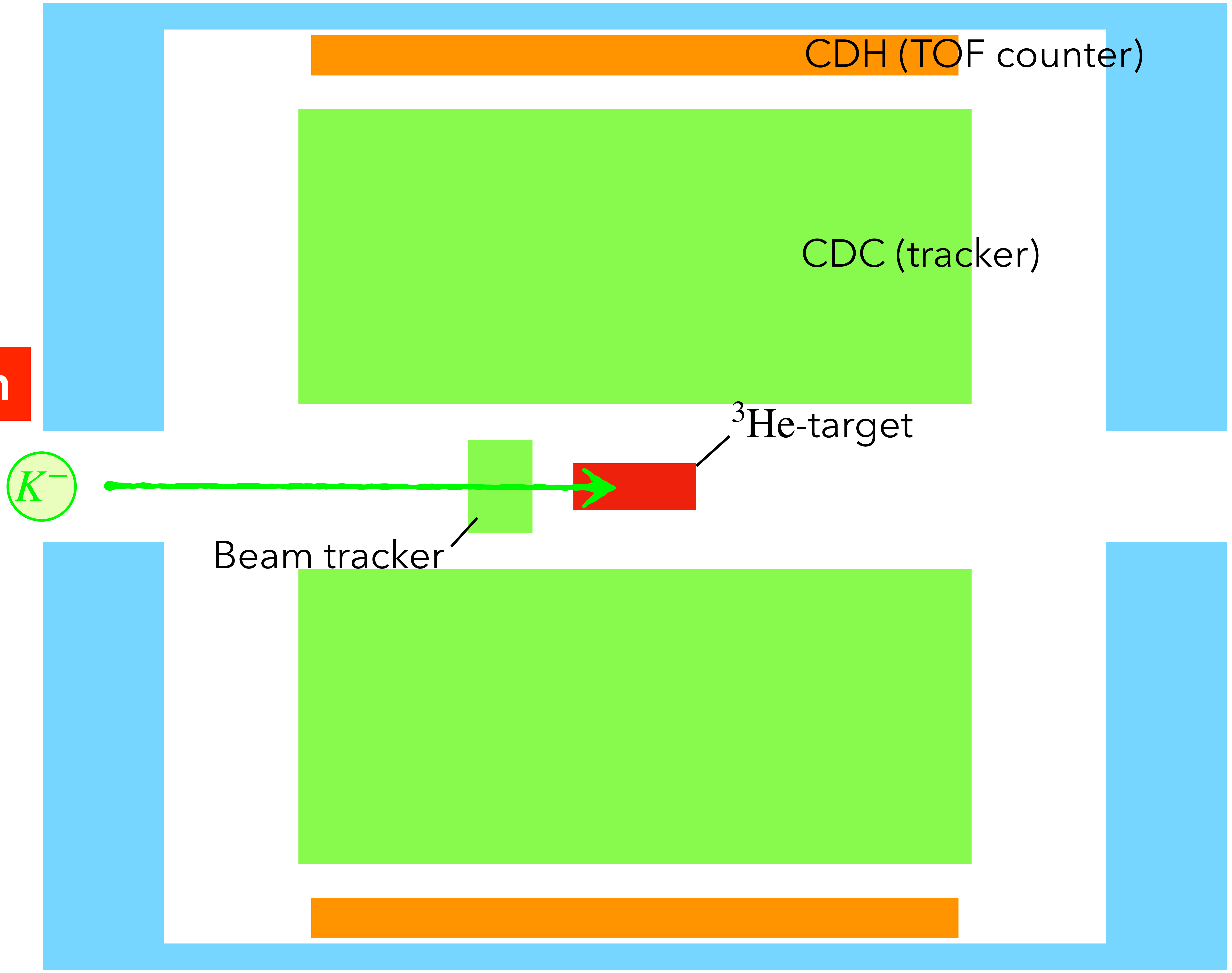




Measurement / Analysis



Cylindrical detector system

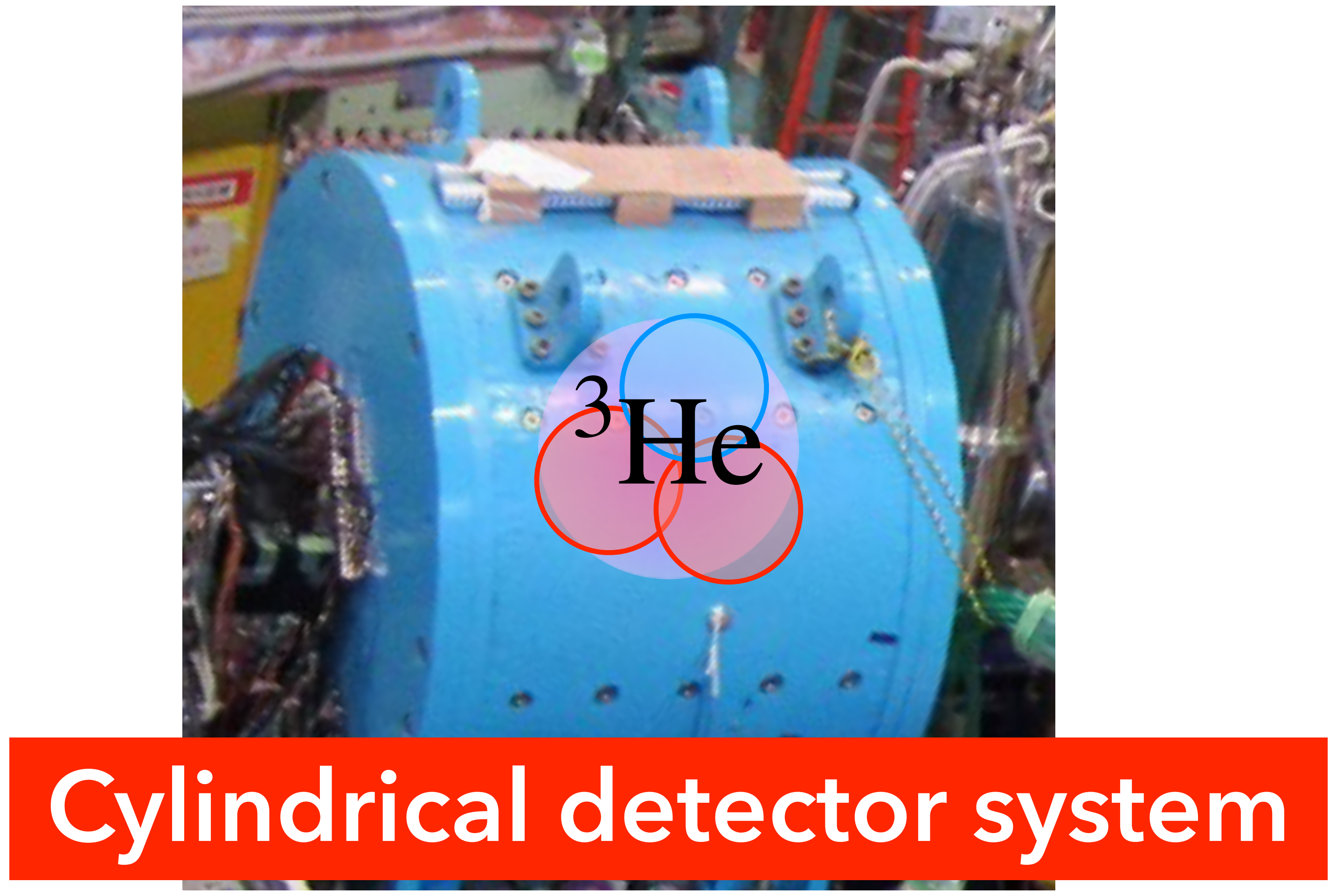


In the case of

$$\pi^-\Sigma^+p + X_{\text{miss}}$$

$$\rightarrow \underbrace{\pi^-(\pi^+n)p}_{\text{Detected with CDS}}$$

Measurement / Analysis

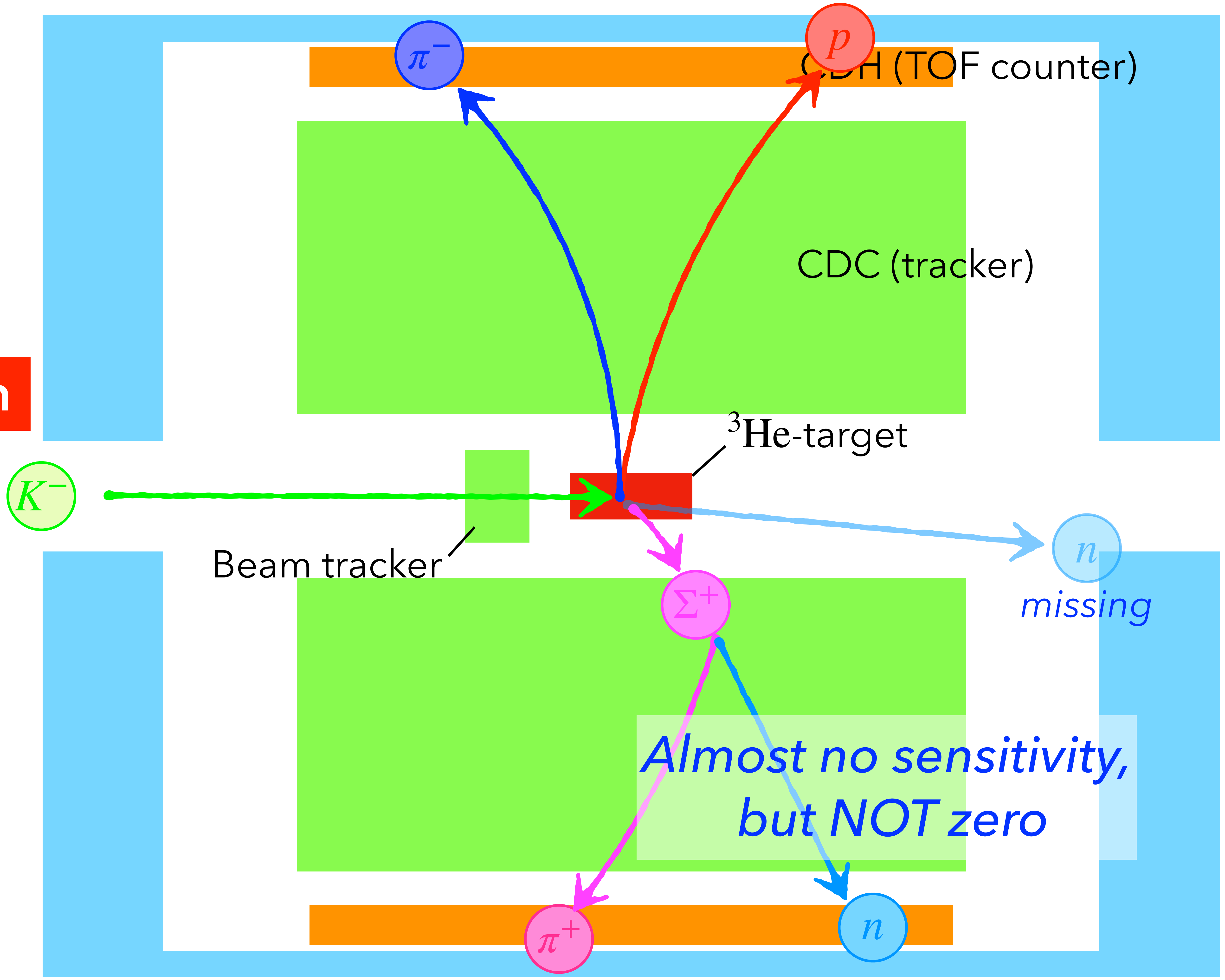


In the case of

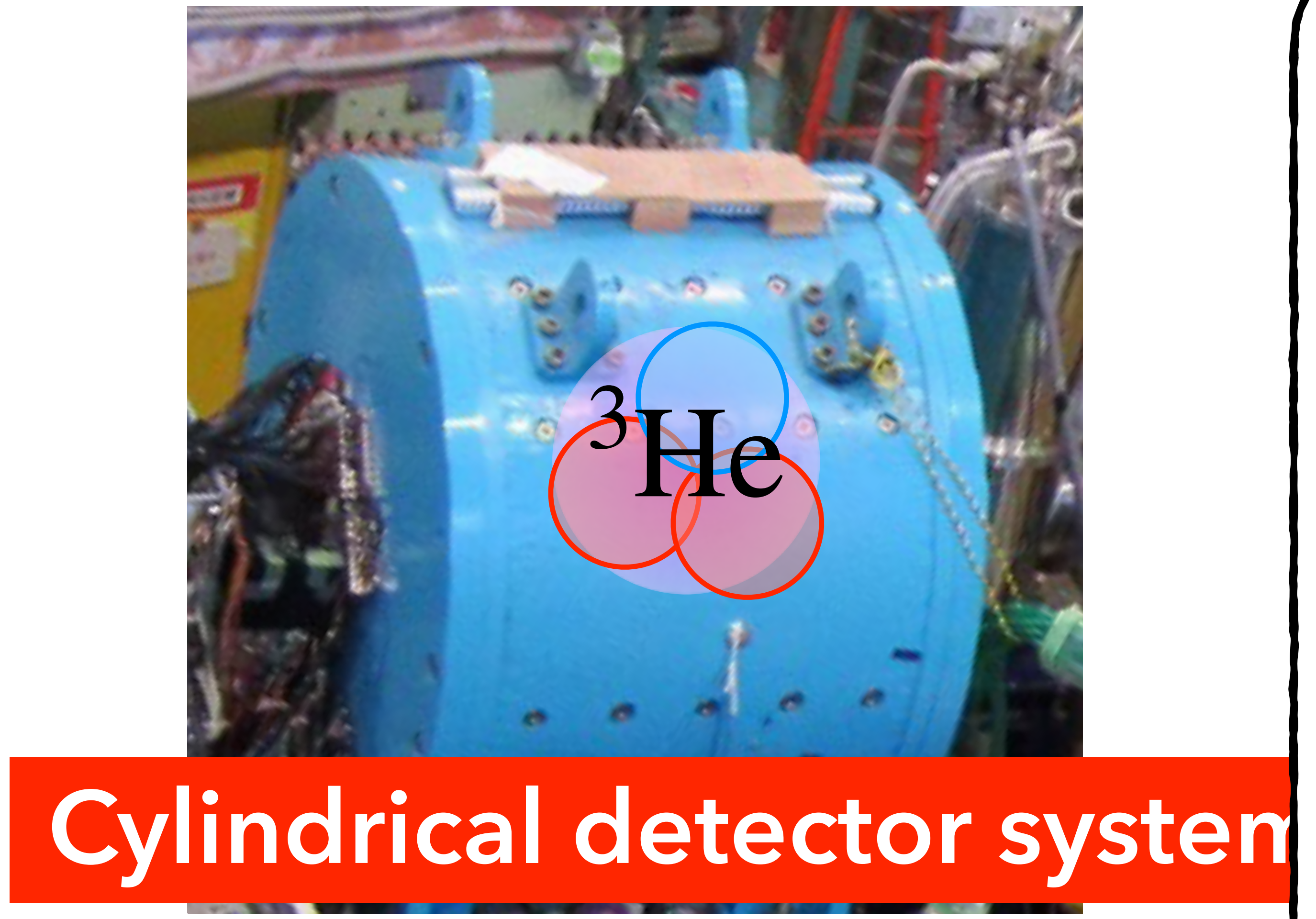
$$\pi^-\Sigma^+p + X_{\text{miss}}$$

$$\rightarrow \underbrace{\pi^-(\pi^+n)p}_{}$$

Detected with CDS



Measurement / Analysis

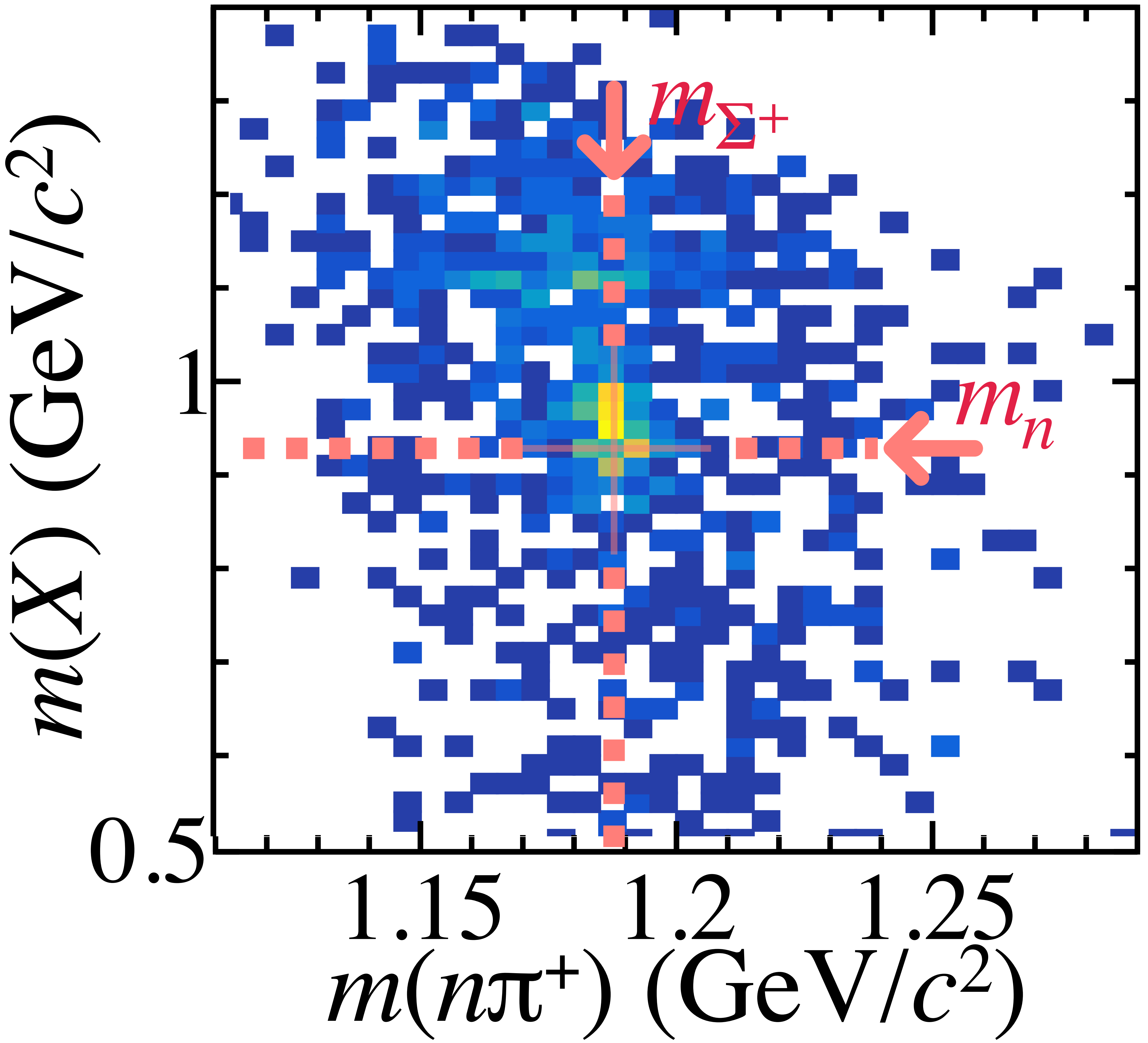


In the case of

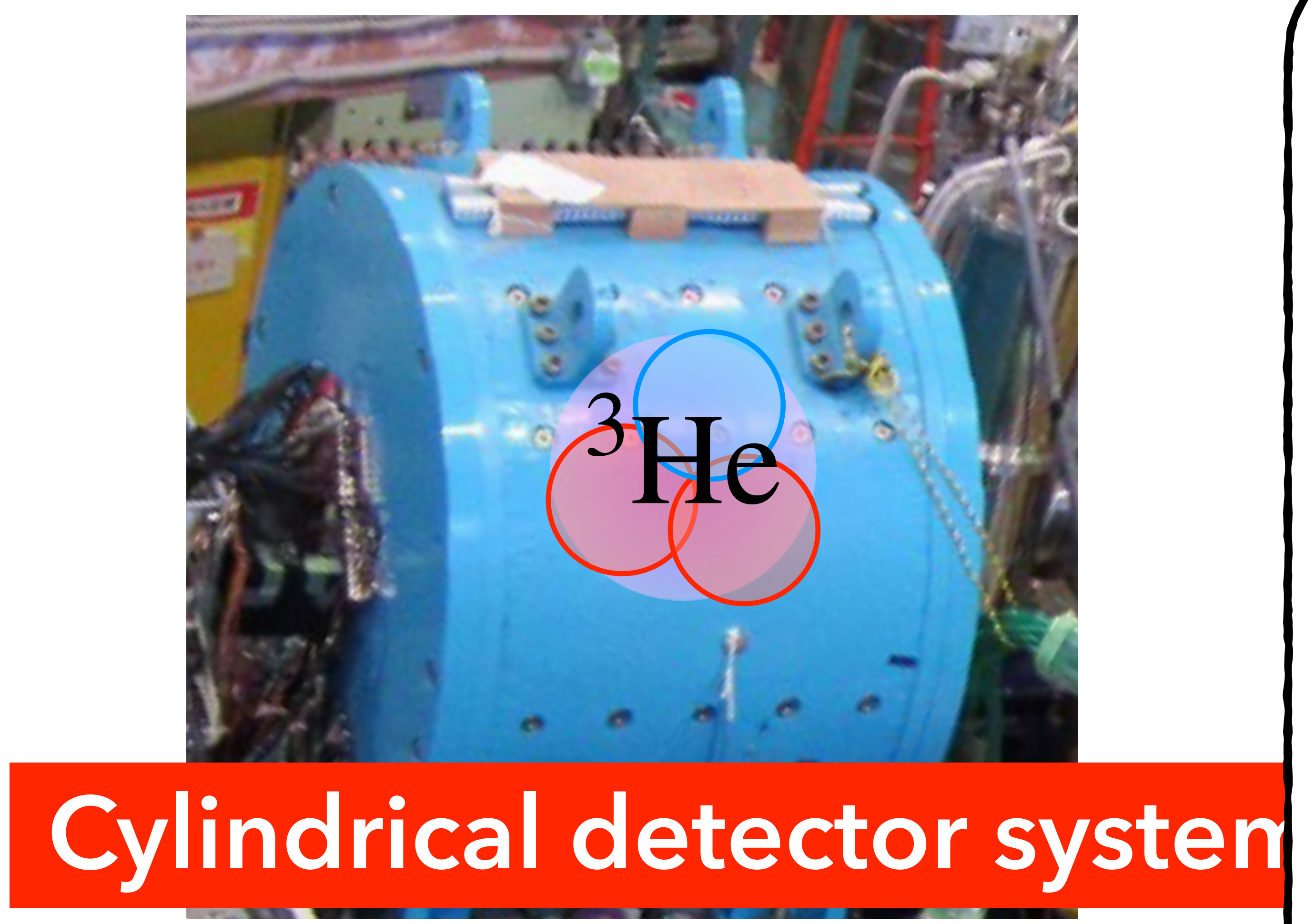
$$\pi^-\Sigma^+p + X_{miss}$$

$$\rightarrow \pi^-(\pi^+n)p$$

Detected with CDS



Measurement / Analysis

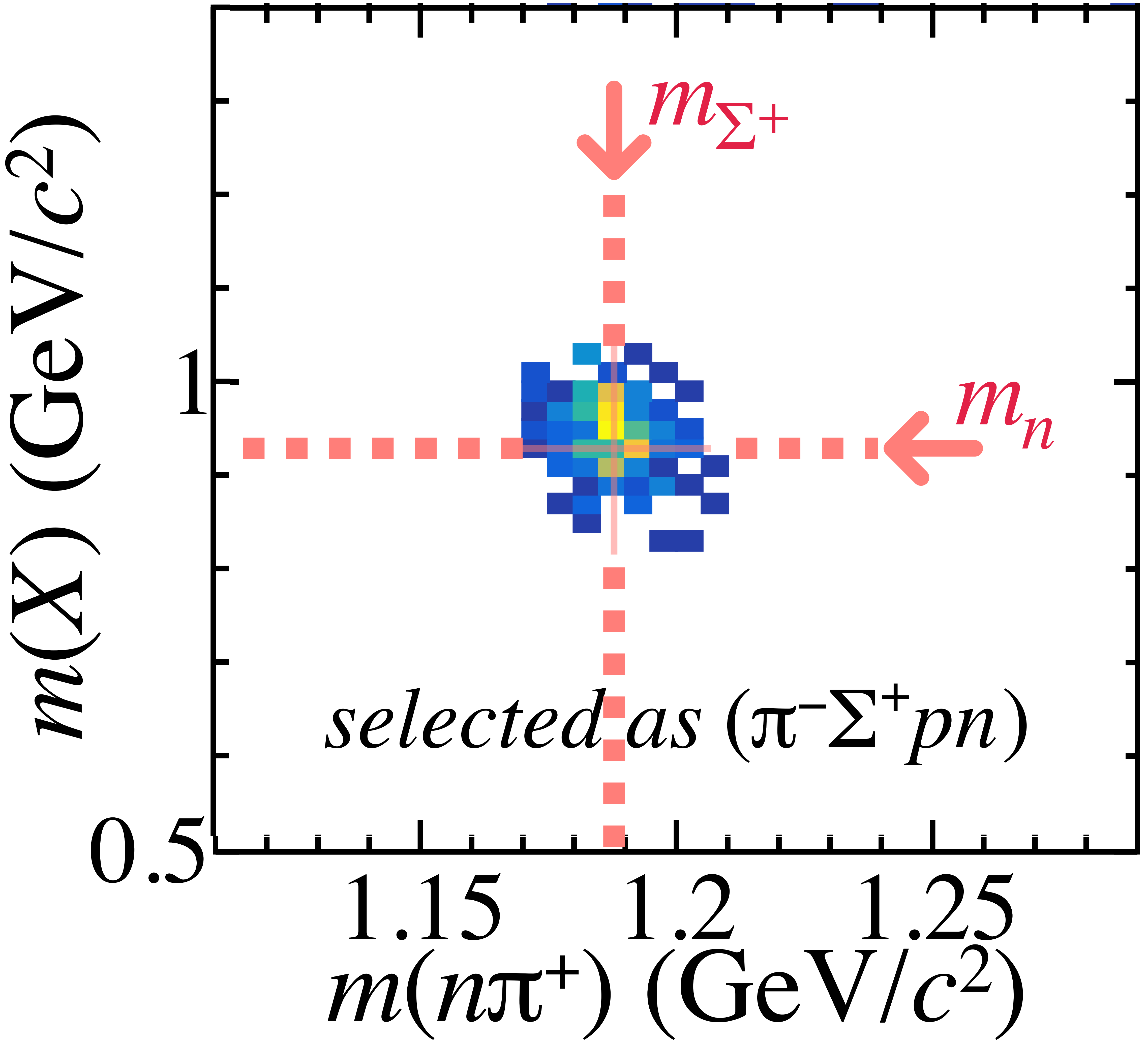


In the case of

$$\pi^-\Sigma^+p + X_{\text{miss}}$$

$$\rightarrow \underbrace{\pi^-(\pi^+n)p}_{\text{Detected with CDS}}$$

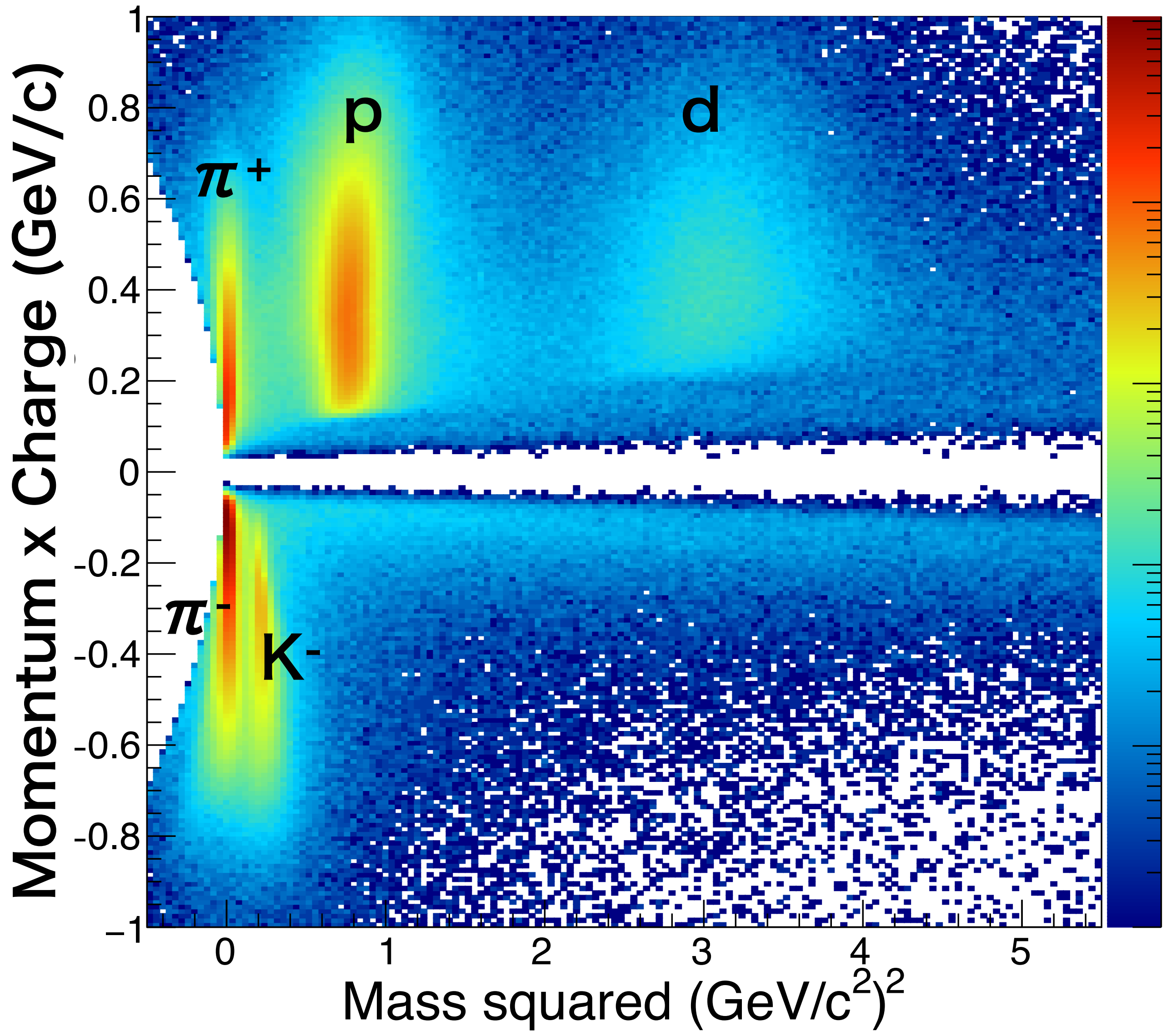
Detected with CDS



Λd+n event selection

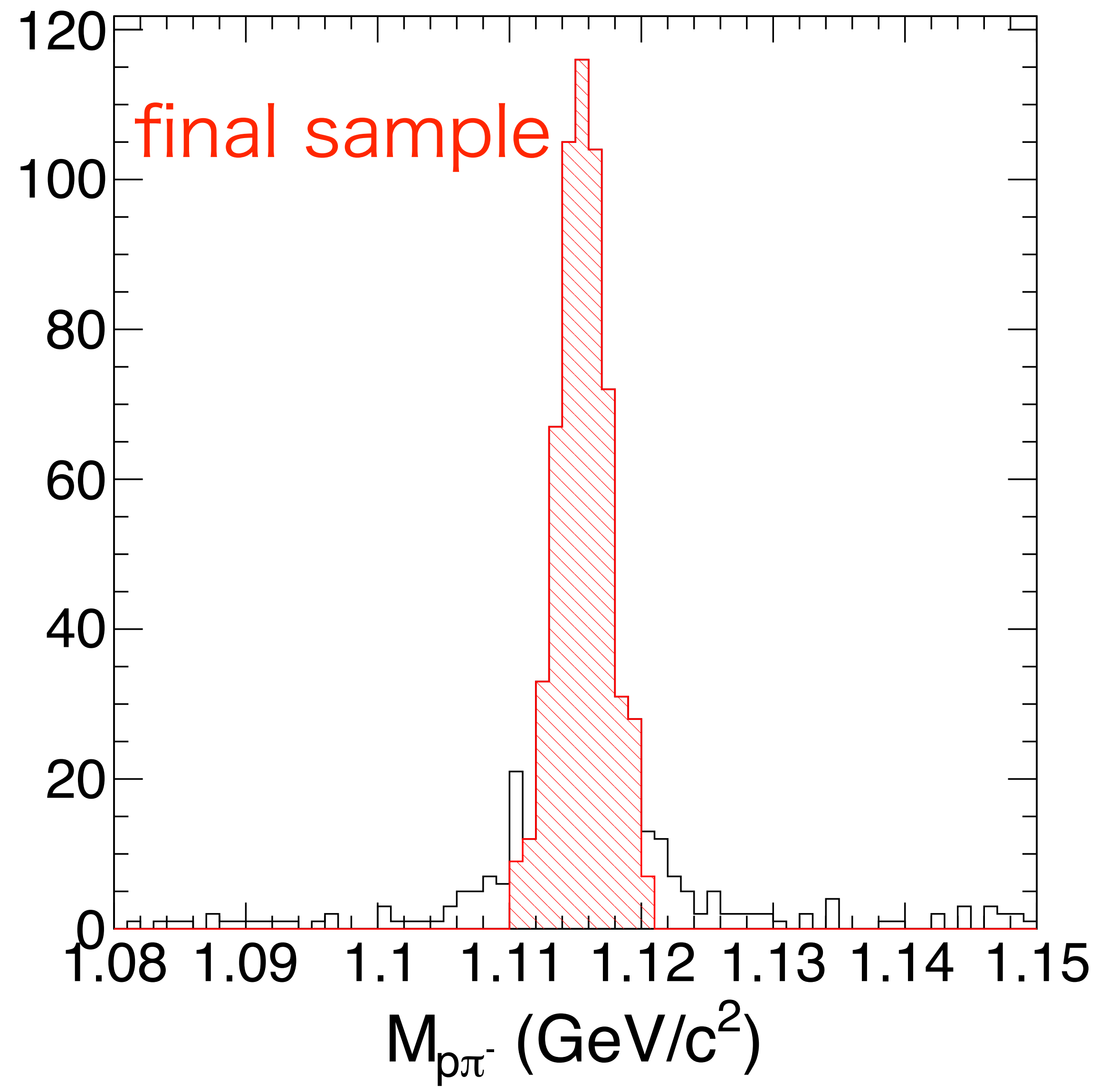
deuteron ID

CDC track curvature &
CDH time of flight



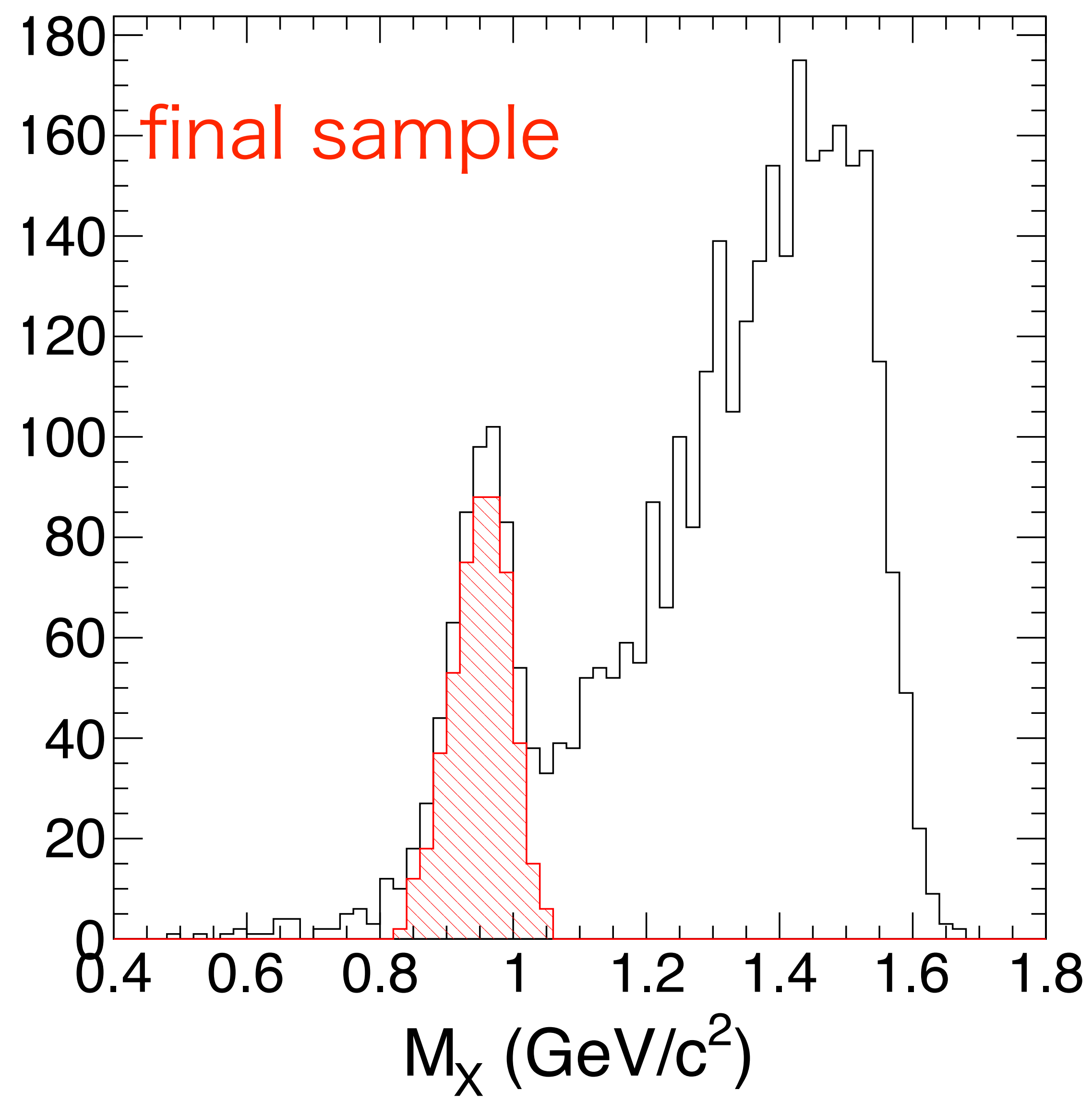
Λ reconstruction

w/ vertex consistency cut
w/ pipd missing mass cut



Missing neutron ID

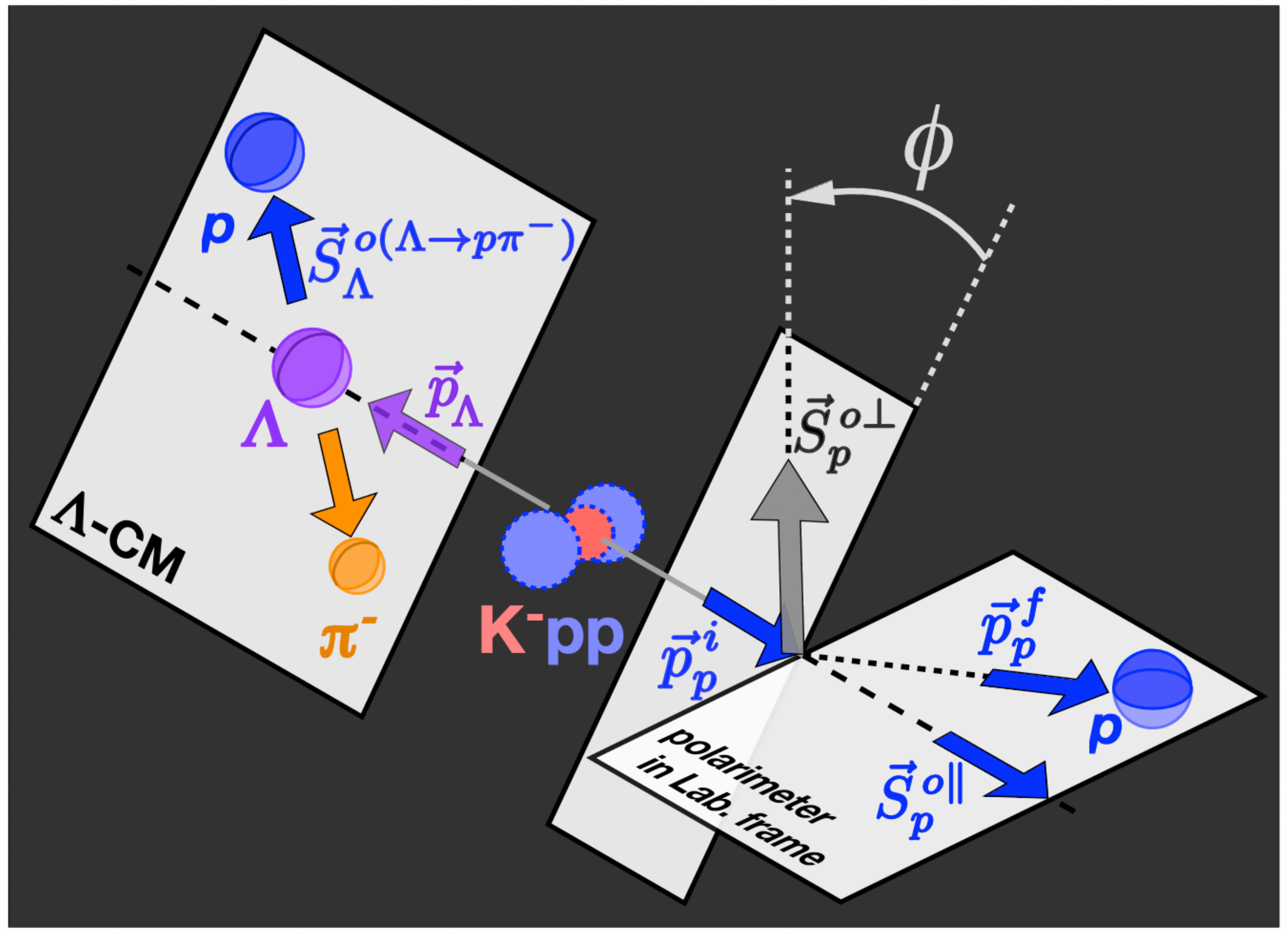
w/ vertex consistency cut
w/ lambda mass cut



- Λdn final states are identified with a good purity by considering kinematical & topological consistensies
- ~20% contamination from Σ^0dn/Σ^-dp

2核子系 - 反K中間子原子核の J^P の決定

“K^-pp” → Λ + p

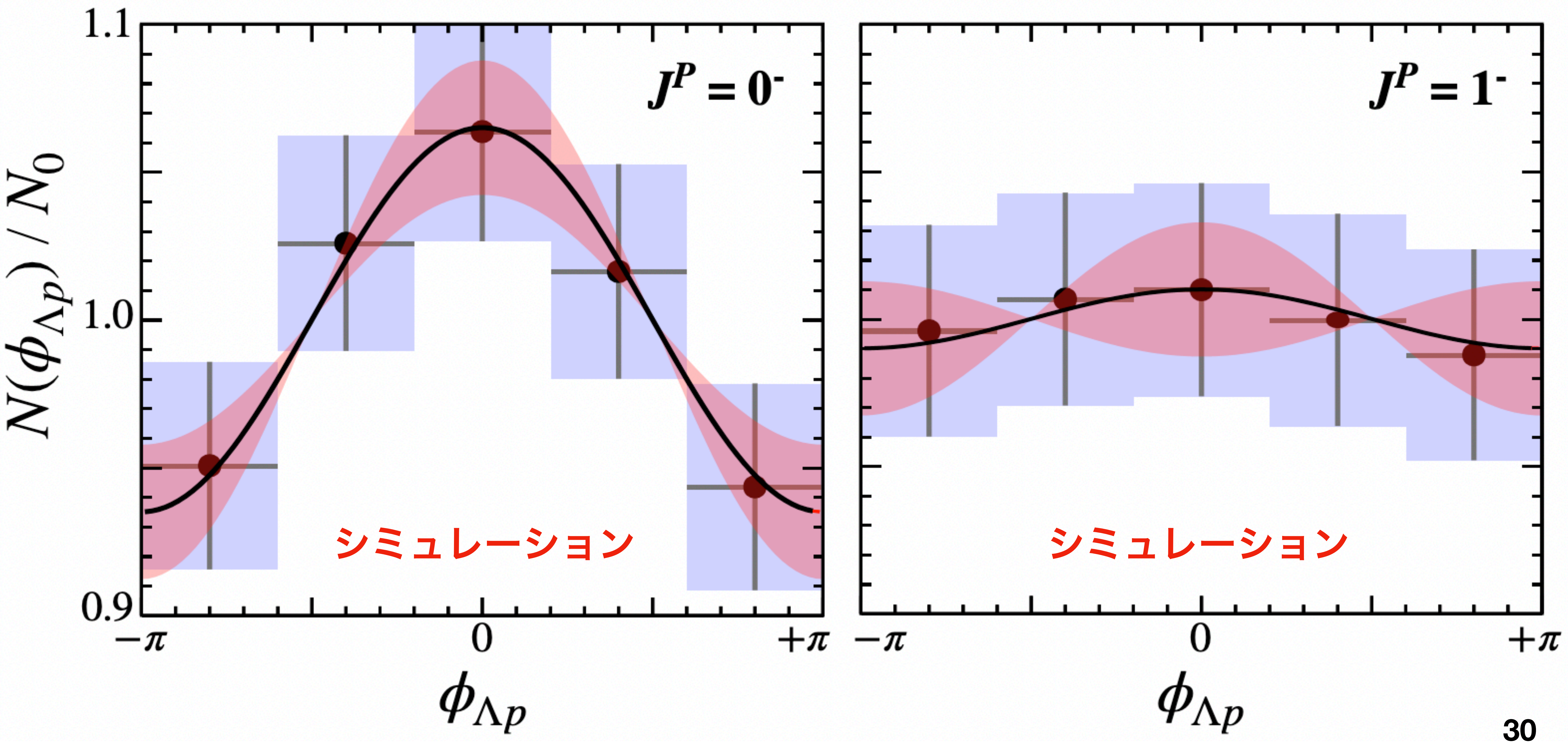


偏向角 ϕ の定義の説明図

シミュレーション(疑似データ)により
「実測すれば十分な精度で物理量を決定できる」
ことを事前確認

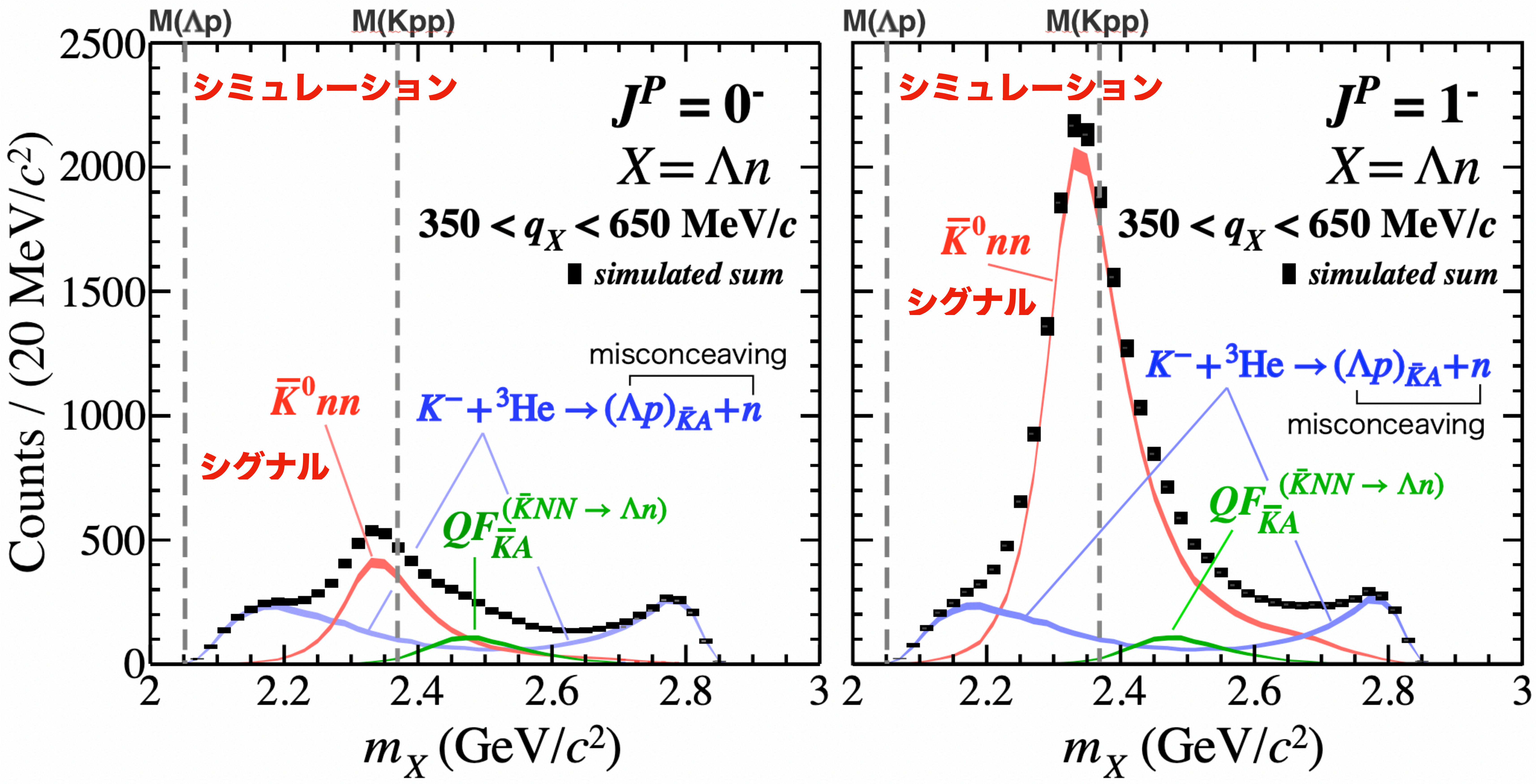
スピンスピン相関により J^P 直接確定が可能

J^P の違いで ϕ 依存性は大きく異る



荷電対称状態 “$\bar{K}^0$nn” の同定

+ J^P 決定の補助データ: J^P の違いで “$\bar{K}^0$nn” の収量は大きく異る



荷電対称状態の同定

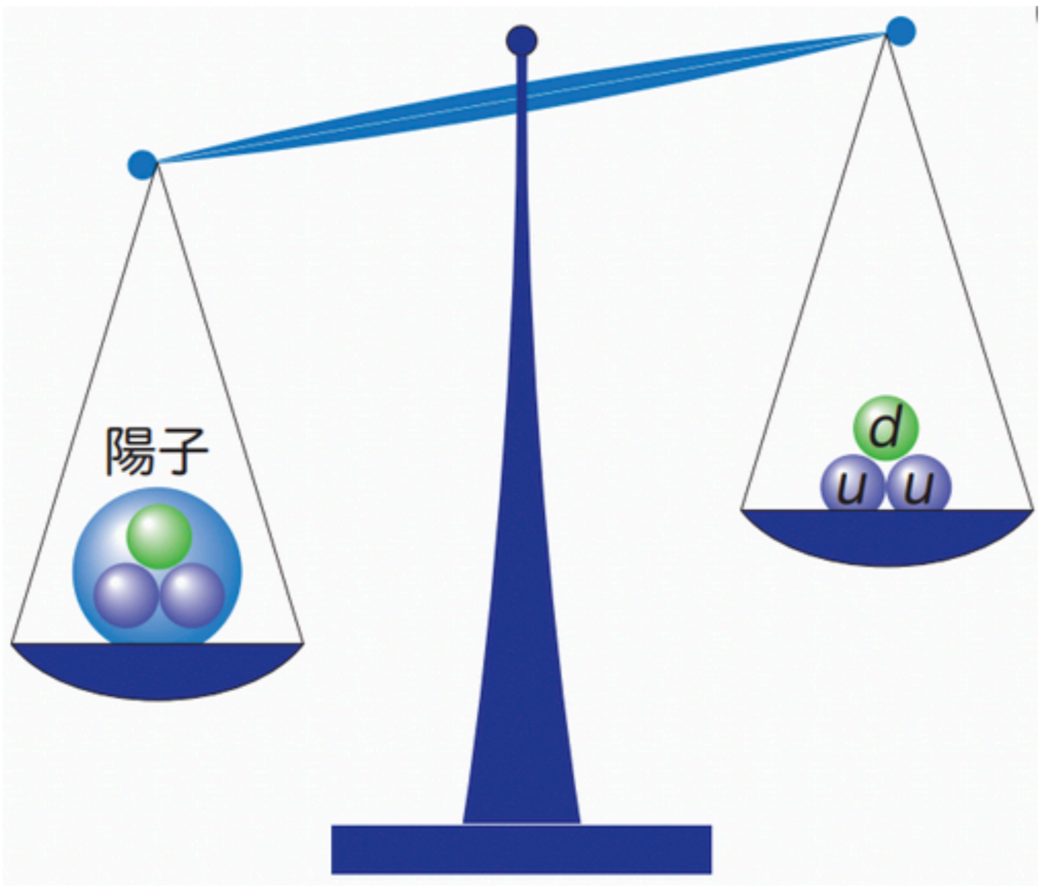
⬇

普遍性の確定
荷電対称性の破れの検証

十分な統計量で 荷電鏡像状態 “$\bar{K}^0$nn” の同定が可能
荷電対称性の検証も可能

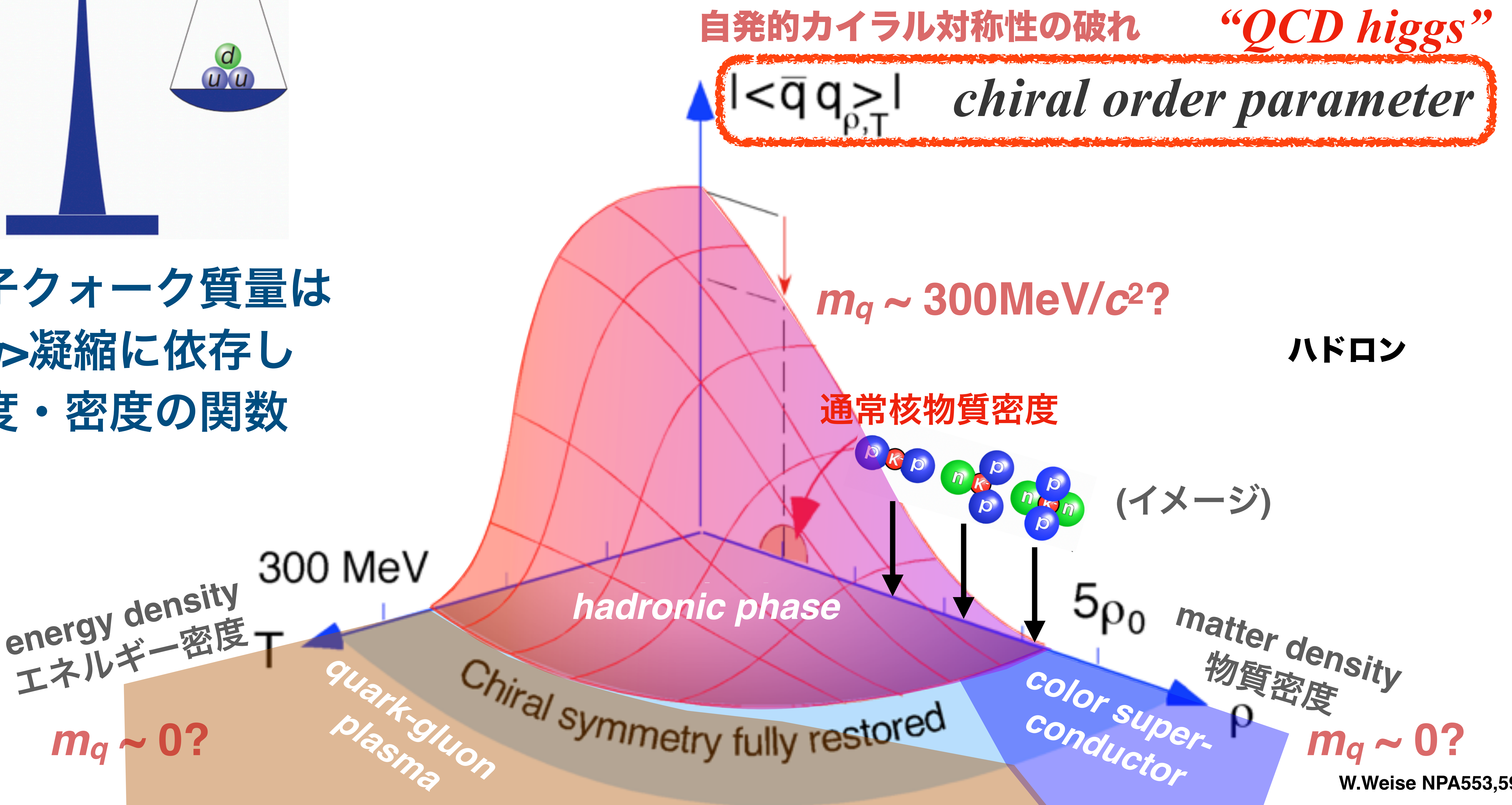
ハドロン質量の起源

真空の自発的対称性の破れ: ⟨$\bar{q}q$⟩ 凝縮？



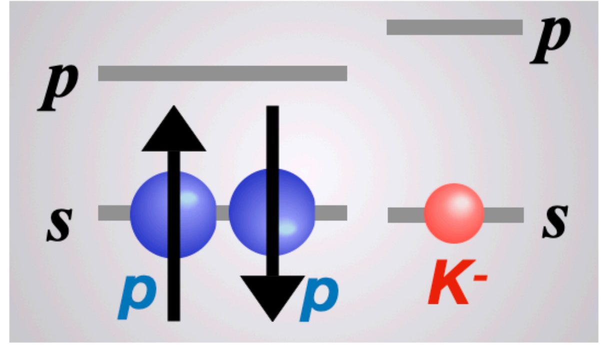
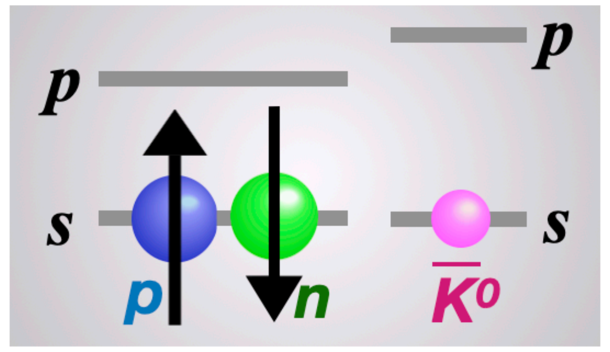
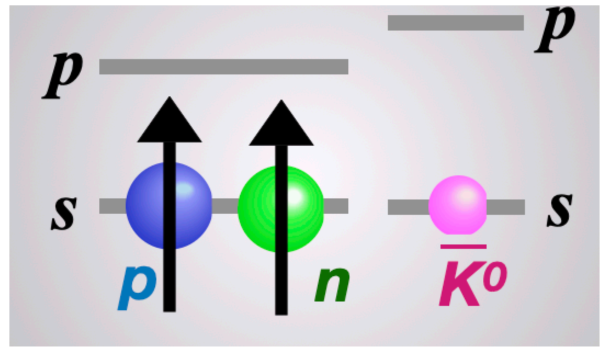
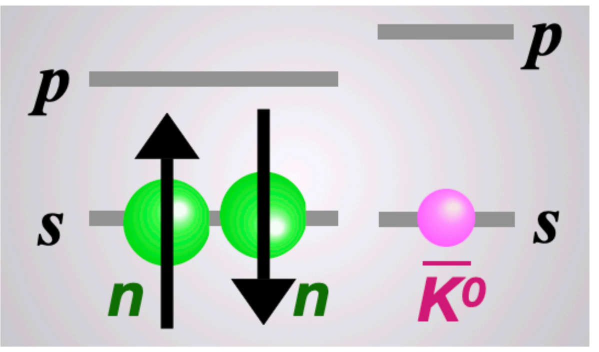
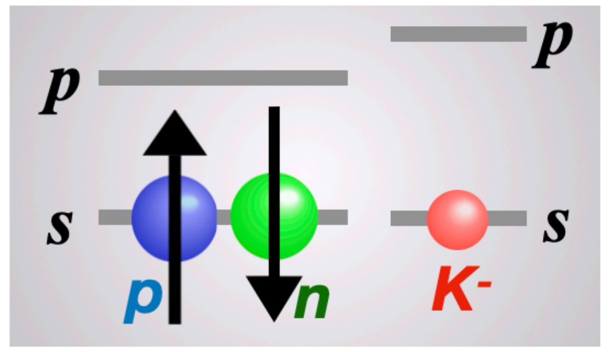
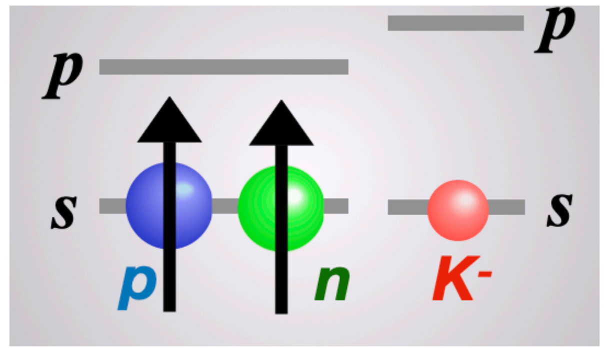
構成子クォーク質量は
<$\bar{q}q$>凝縮に依存し
温度・密度の関数

QCD真空相図と<$\bar{q}q$>凝縮の鳥瞰図



W.Weise NPA553,59 (1993)

2核子系 - 反K中間子原子核の J^P と内部構造

	通常核では有り得ない “荷電対称なNN” に反Kが結合した系	通常核 “重水素 d” に $\bar{K}^0$ が結合した系
$I(\bar{K}NN)$ / $J^P(\bar{K}NN)$	(1/2) / (0^-)	(1/2) / (1^-)
NN symmetry	$I(NN)=1,\ S(NN)=0$	$I(NN)=0,\ S(NN)=1$
“K^-pp” $I_3(\bar{K}NN)=+\frac{1}{2}$	 +  $-\sqrt{\frac{1}{3}}\left(\sqrt{2}K^-pp+\bar{K}^0\frac{pn+np}{\sqrt{2}}\right)\otimes\left(\frac{\uparrow\downarrow-\downarrow\uparrow}{\sqrt{2}}\right)$	 $\bar{K}^0\frac{(pn-np)}{\sqrt{2}}\otimes\left(\uparrow\uparrow,\ \frac{\uparrow\downarrow+\downarrow\uparrow}{\sqrt{2}},\ \downarrow\downarrow\right)$
“$\bar{K}^0nn$” $I_3(\bar{K}NN)=-\frac{1}{2}$	 +  $-\sqrt{\frac{1}{3}}\left(\sqrt{2}\bar{K}^0nn+K^-\frac{pn+np}{\sqrt{2}}\right)\otimes\left(\frac{\uparrow\downarrow-\downarrow\uparrow}{\sqrt{2}}\right)$	 $-K^-\frac{(pn-np)}{\sqrt{2}}\otimes\left(\uparrow\uparrow,\ \frac{\uparrow\downarrow+\downarrow\uparrow}{\sqrt{2}},\ \downarrow\downarrow\right)$
$\bar{K}N$ coupling	$\frac{\lvert I_{\bar{K}N}=0\rvert^2}{\lvert I_{\bar{K}N}=1\rvert^2}=\frac{3}{1}$	$\frac{\lvert I_{\bar{K}N}=0\rvert^2}{\lvert I_{\bar{K}N}=1\rvert^2}=\frac{1}{3}$
$\frac{\sigma_{\bar{K}^0nn}}{\sigma_{K^-pp}}$	$0.13\sim0.15$	~0.75

可能なアイソスピン・スピン対称性

すべてs波のときは $J^P=0^-, 1^-$ だけ

p波励起 $J^P=0^+, 1^+$ の可能性は除外

荷電(アイソスピン)鏡像状態

$\bar{K}N$ I = 0 が強い引力

$J^P=0^-$ の方が 強く $\bar{K}N$ I = 0 と結合

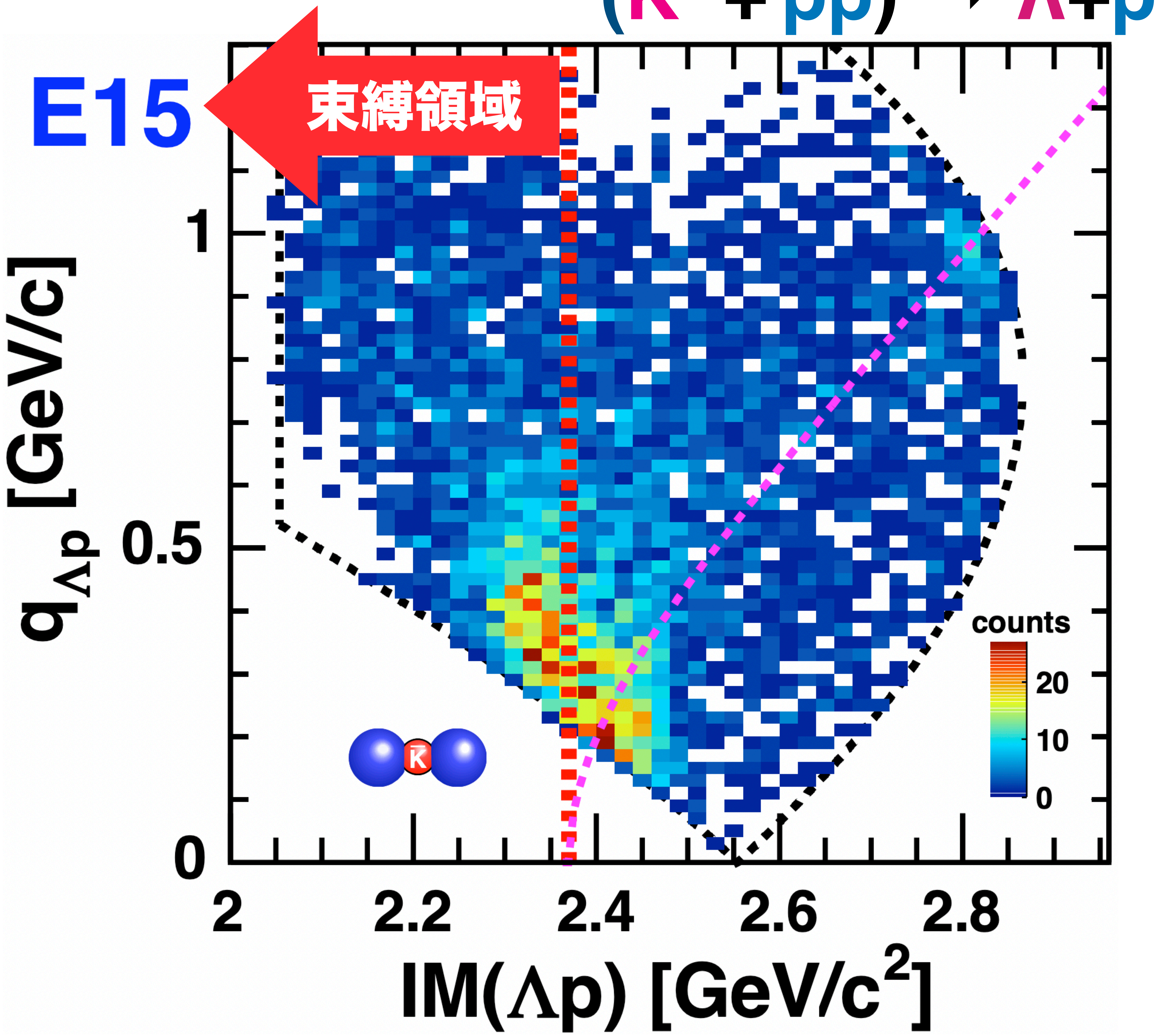
“$\bar{K}^0$nn” の収量は J^P に大きく依存

別実験 (テストデータ) が示した"K⁻ppn"

取り扱い注意

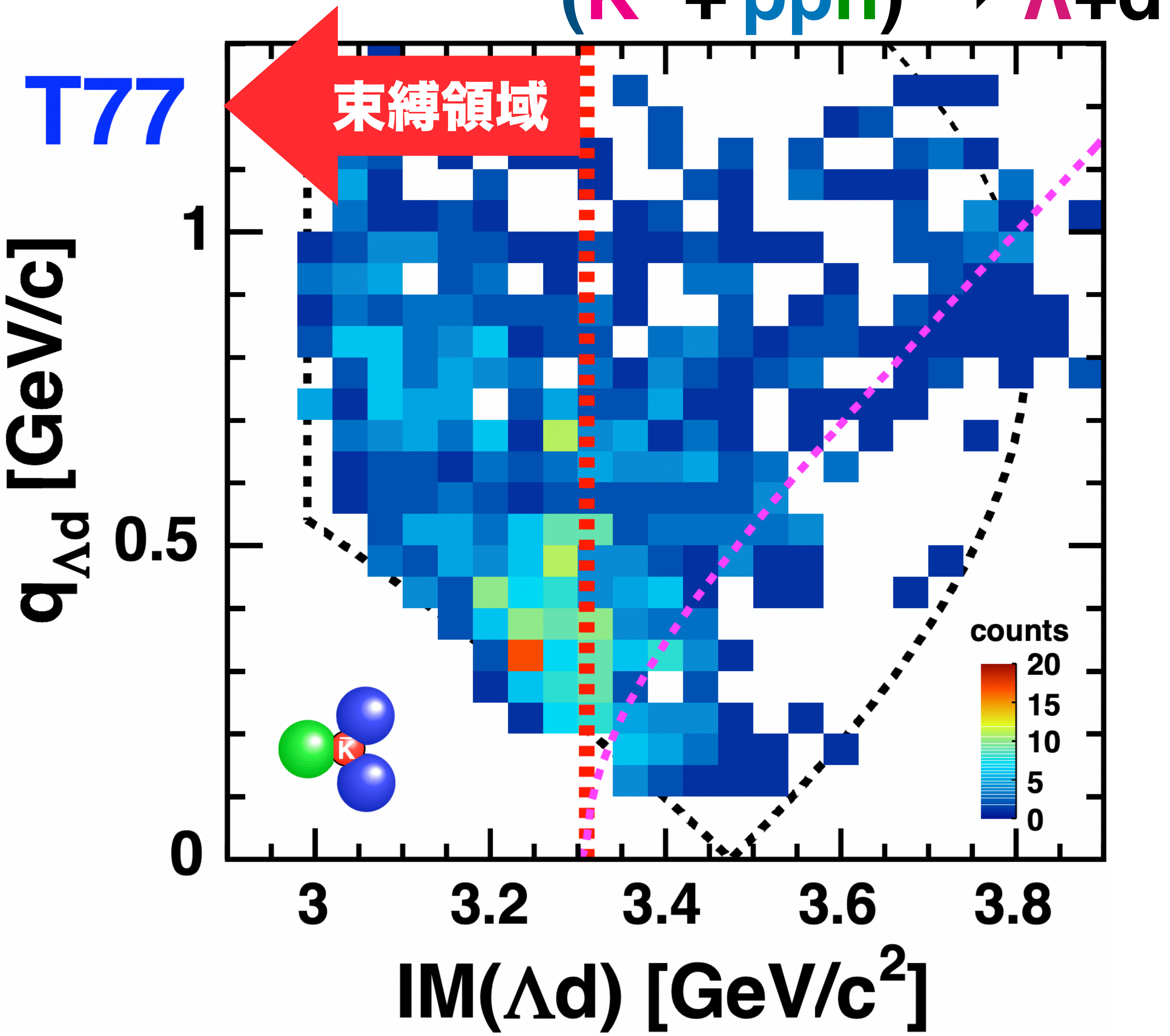
$K^- + {}^3He \rightarrow (K^- + pp) + n$

$(K^- + pp) \rightarrow \Lambda + p$



$K^- + {}^4He \rightarrow (K^- + ppn) + n$

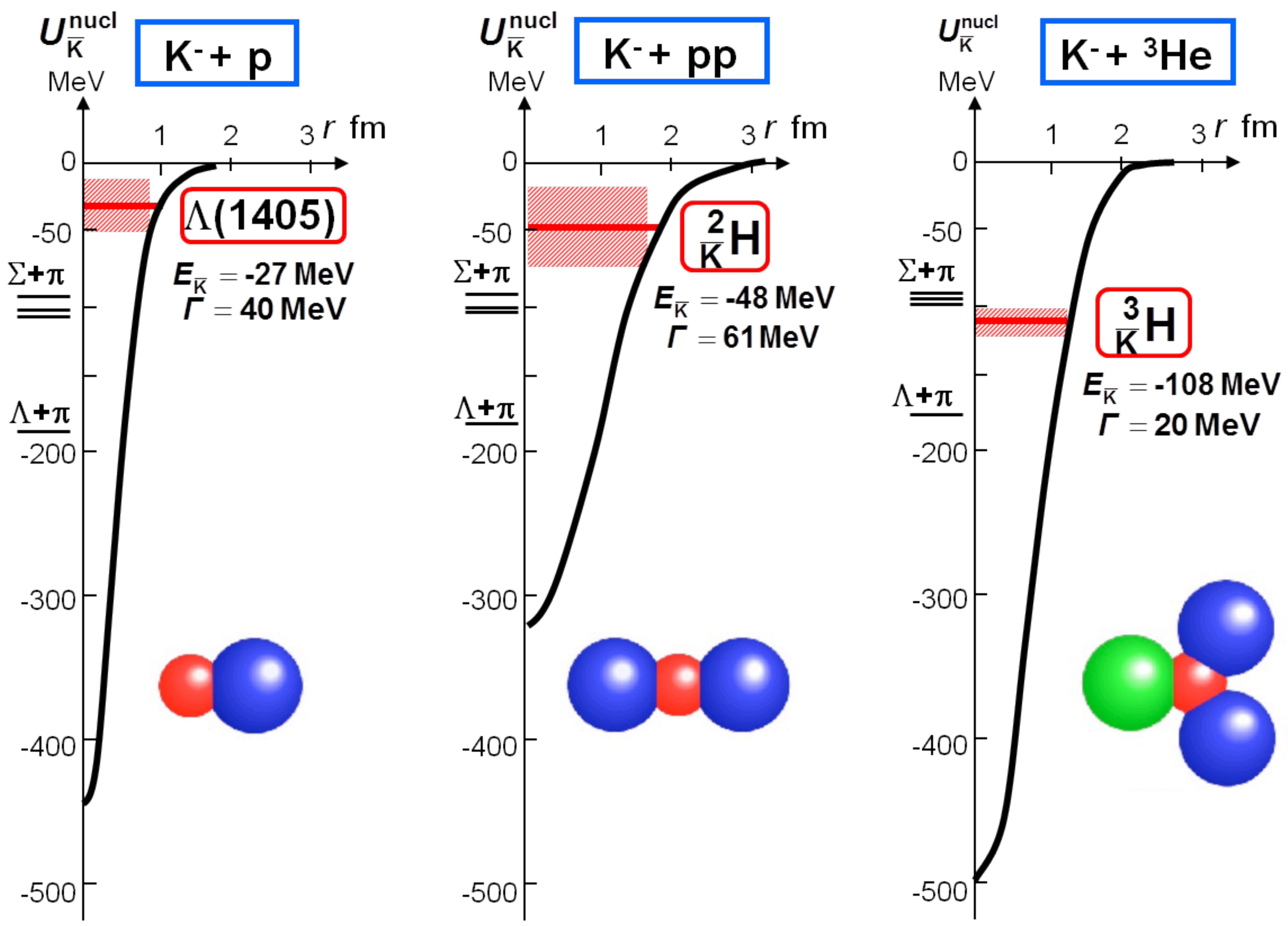
$(K^- + ppn) \rightarrow \Lambda + d$



束縛状態シグナルは閾値 M(K⁻pp) 以下。　束縛状態なら分布中心は q に依存しない

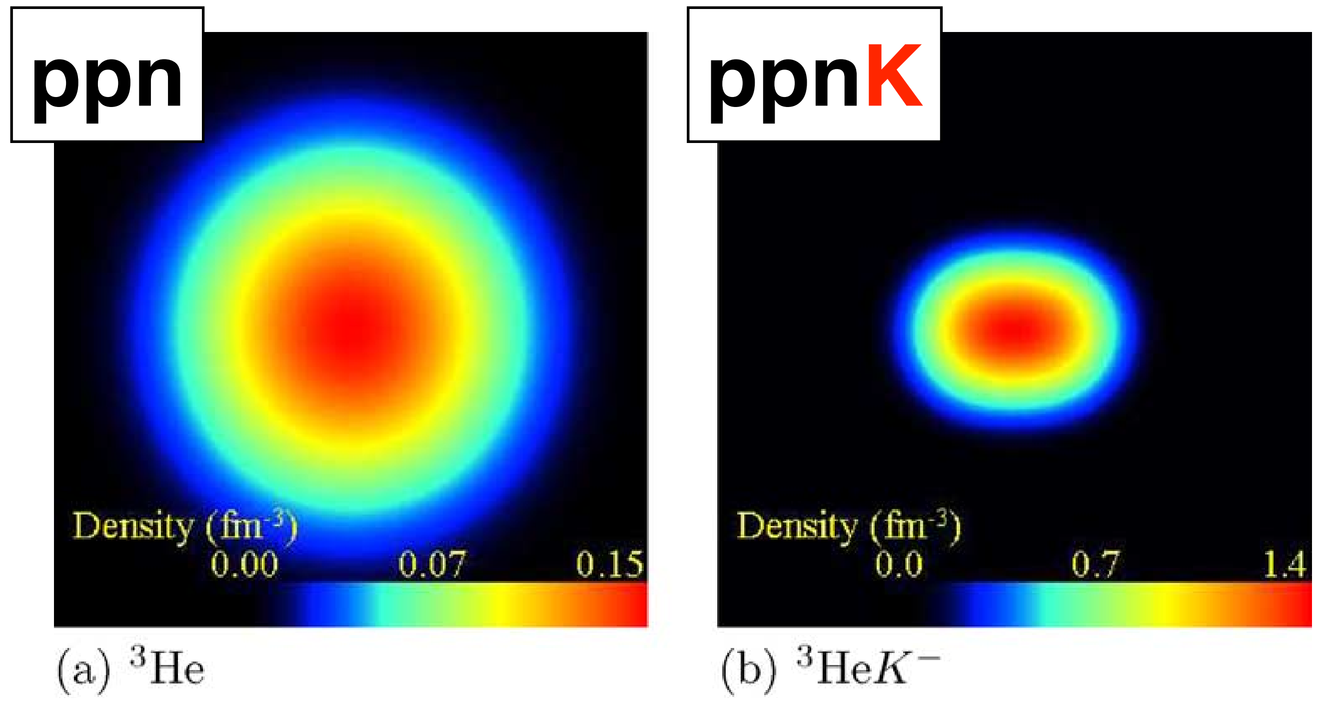
Kaonic nuclei

predicted from
attractive K^bar N interaction in I=0



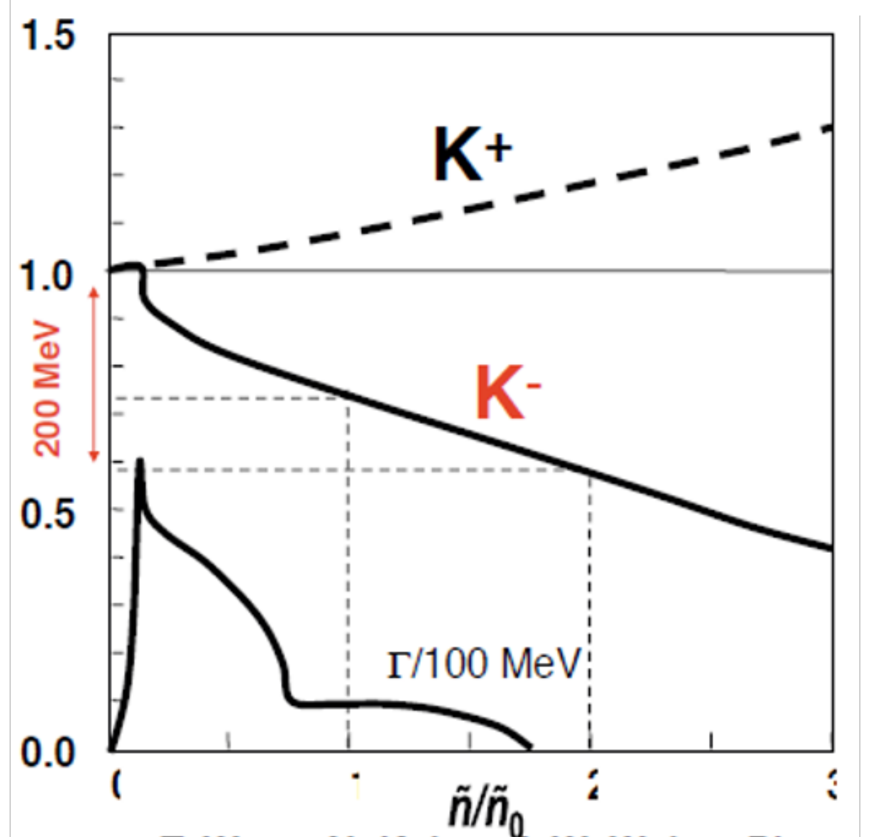
1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).

dense nuclei are predicted



Phys. Lett. B 590 (2004) 51

Kaon mass changes in nuclear medium?



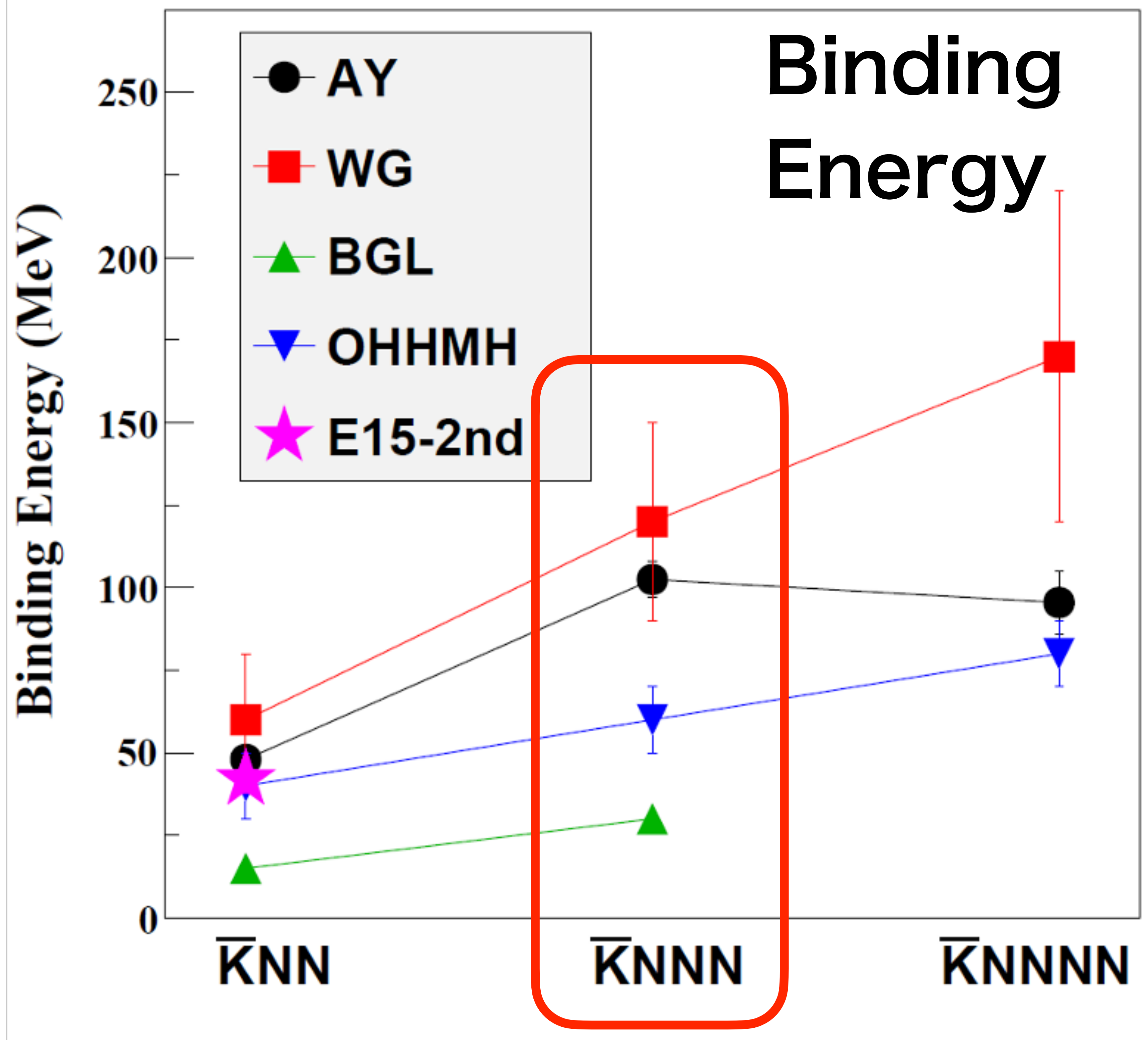
T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

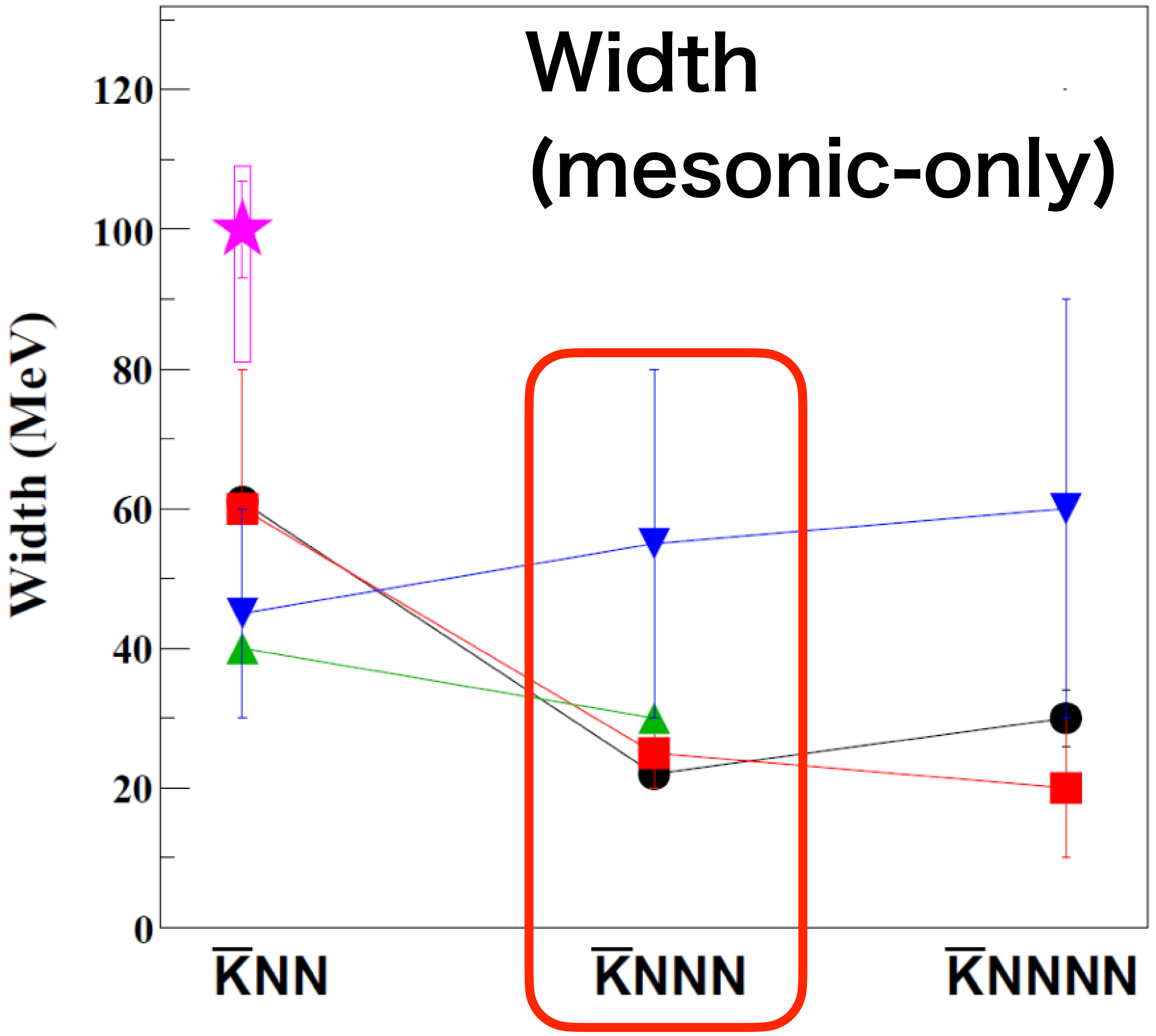
Anti-Kaon could be a unique probe for hadron/nuclear physics

$\bar{K}NNN$: Theoretical situaion

$$I(J^p) = 0(\frac{1}{2}^-)$$

AY: PRC65(2002)044005, PLB535(2002)70.
WG: PRC79(2009)014001.
BGL: PLB712(2012)132.
OHHMH: PRC95(2017)065202.





Larger binding than $\bar{K}NN$ and similar width are predicted.

Acceptance for $K^{-4}He$ reaction