$\bar{K}NN \to \pi YN$崩壊事象の探索

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for the J-PARC E15 collaboration

2022.9.6 – 8 物理学会 (岡山理科大)

$\bar{K}NN$ bound state

Bound system of anti-kaon and two nucleons

$$\left[\bar{K}_{I=\frac{1}{2}}(NN)_{I=1}\right]_{I=\frac{1}{2}}$$

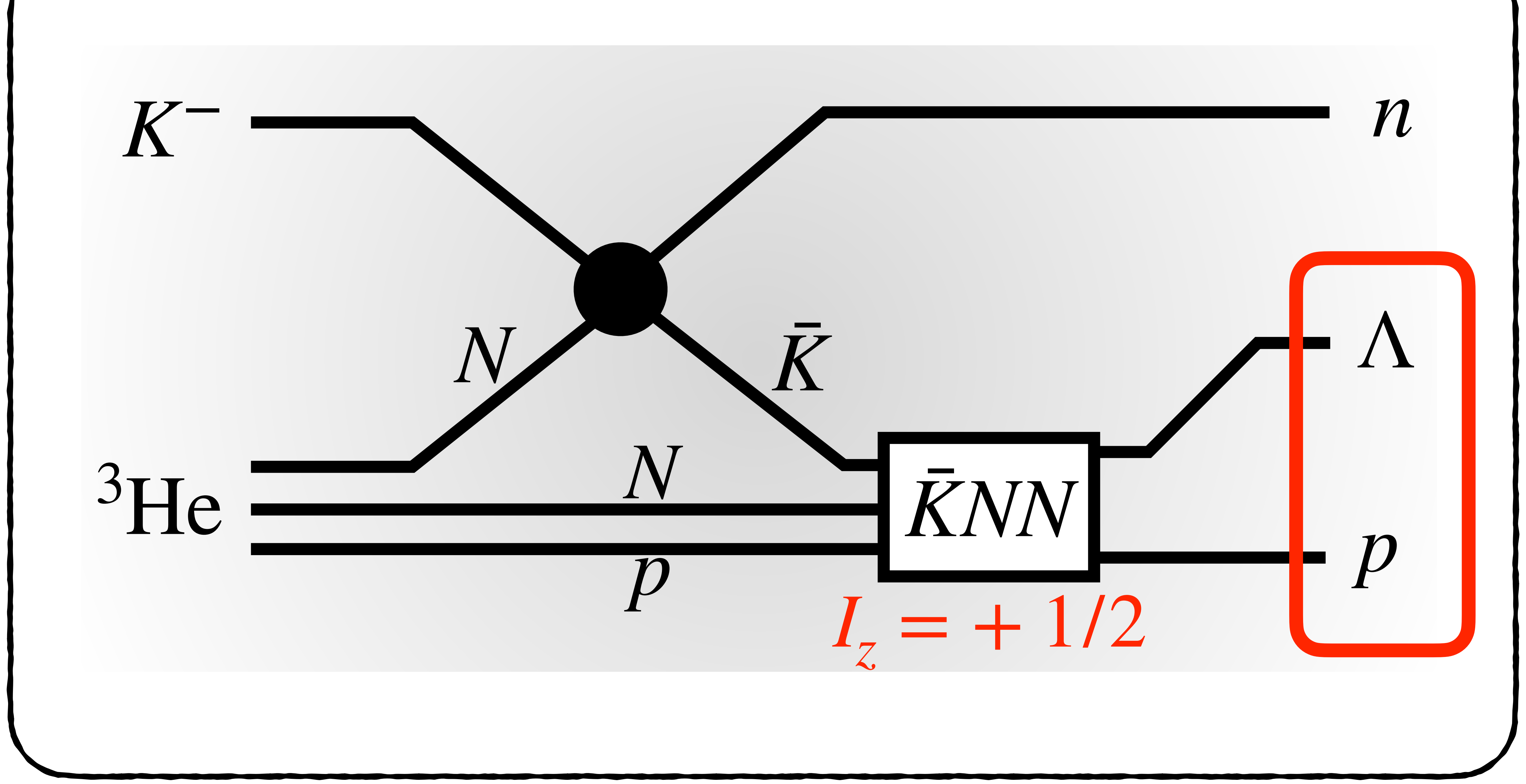
Considered to be $J^{\pi} = 0^{-}$

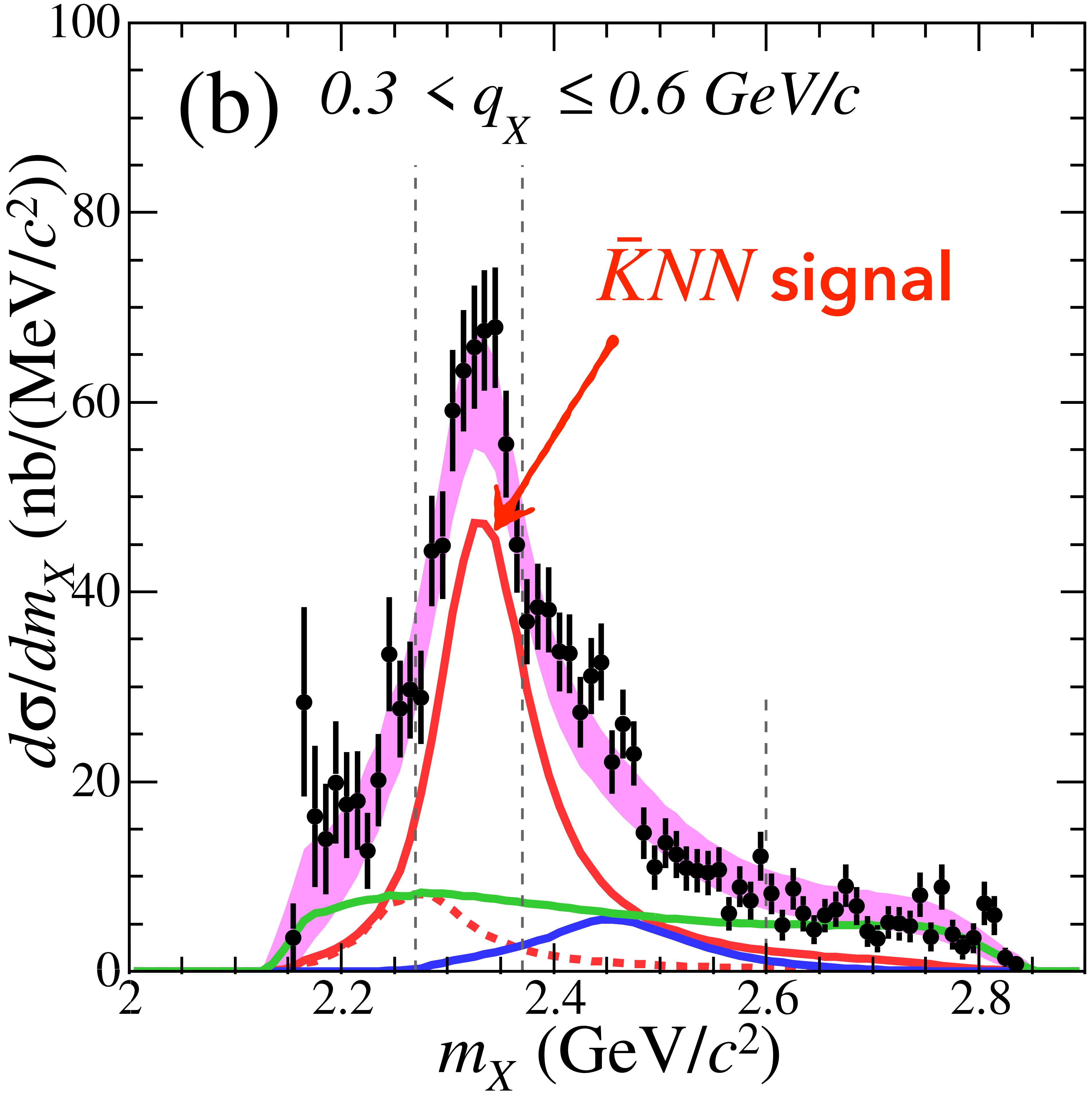
$I_z = +1/2$ $K^{-}pp$ - $\bar{K}^{0}pn$ → We observed signal in J-PARC E15

$I_z = -1/2$ $K^{-}pn$ - $\bar{K}^{0}nn$

What we measured/observed in E15

Production reaction





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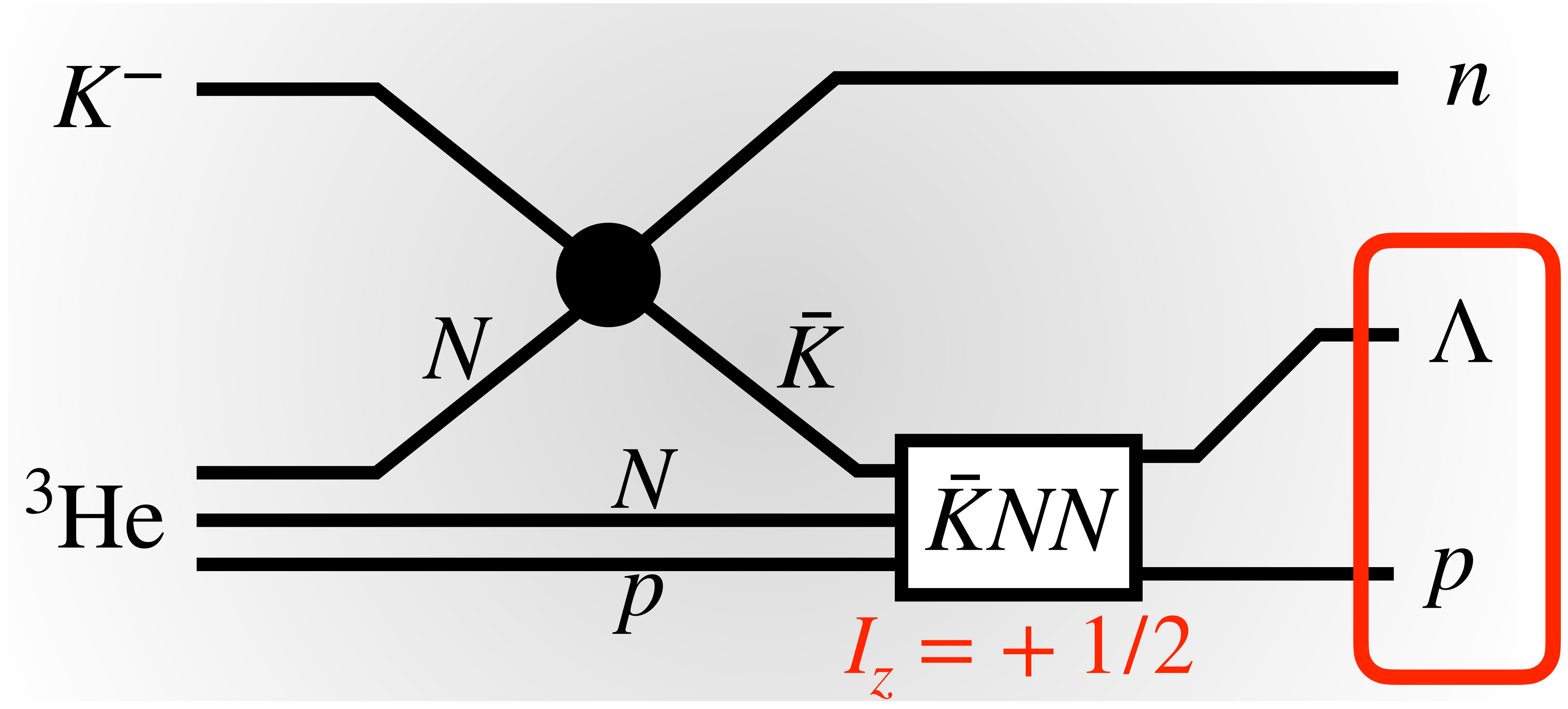

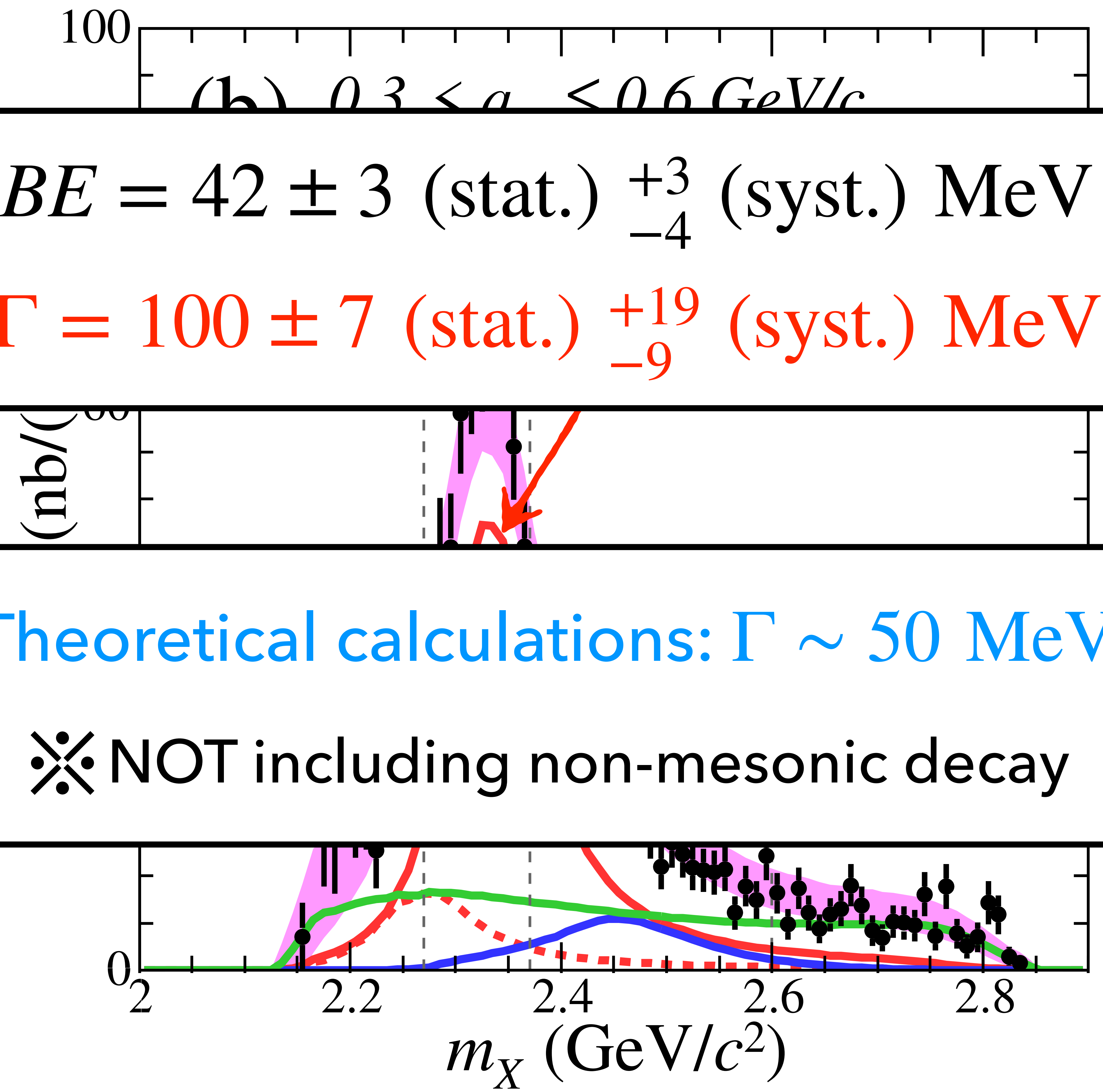

$BE = 42 \pm 3$ (stat.) $^{+3}_{-4}$ (syst.) MeV

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

Theoretical calculations: $\Gamma \sim 50$ MeV

※NOT including non-mesonic decay

Why is Γ so large?

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

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

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※NOT including non-mesonic decay

$$\Gamma_{\text{non-mesonic}} \sim \Gamma_{\text{mesonic}} \sim 50\ \text{MeV?}$$

Today's talk

$$\Gamma_{\text{non-mesonic}} \ll \Gamma_{\text{mesonic}}$$

Γ_{mesonic} would be $\mathcal{O}(10)$ times larger than $\Gamma_{\text{non-mesonic}}$

Analyzed final states

Previous study: (non-mesonic)

$I_z = +1/2$

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

This study: (mesonic)

$I_z = +1/2$

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

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

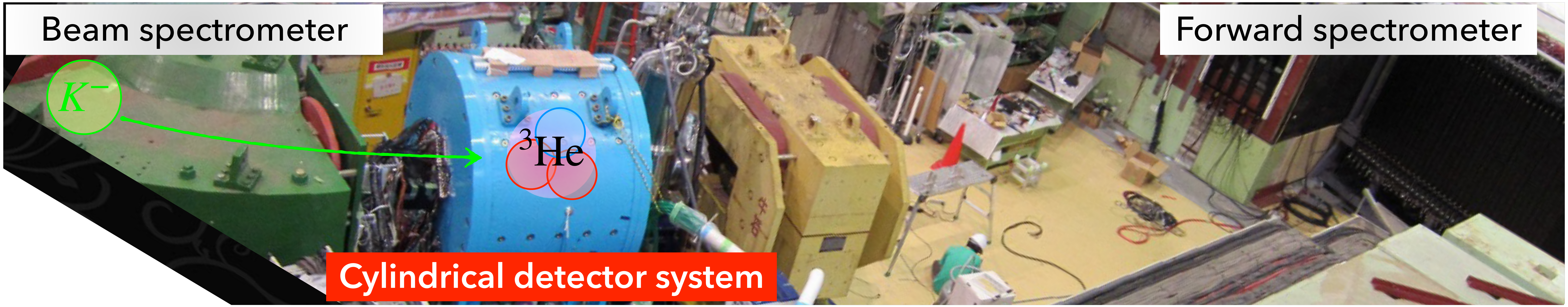
$\boxed{\pi^+\Sigma^- p} + n_{\text{miss}}$

$I_z = -1/2$

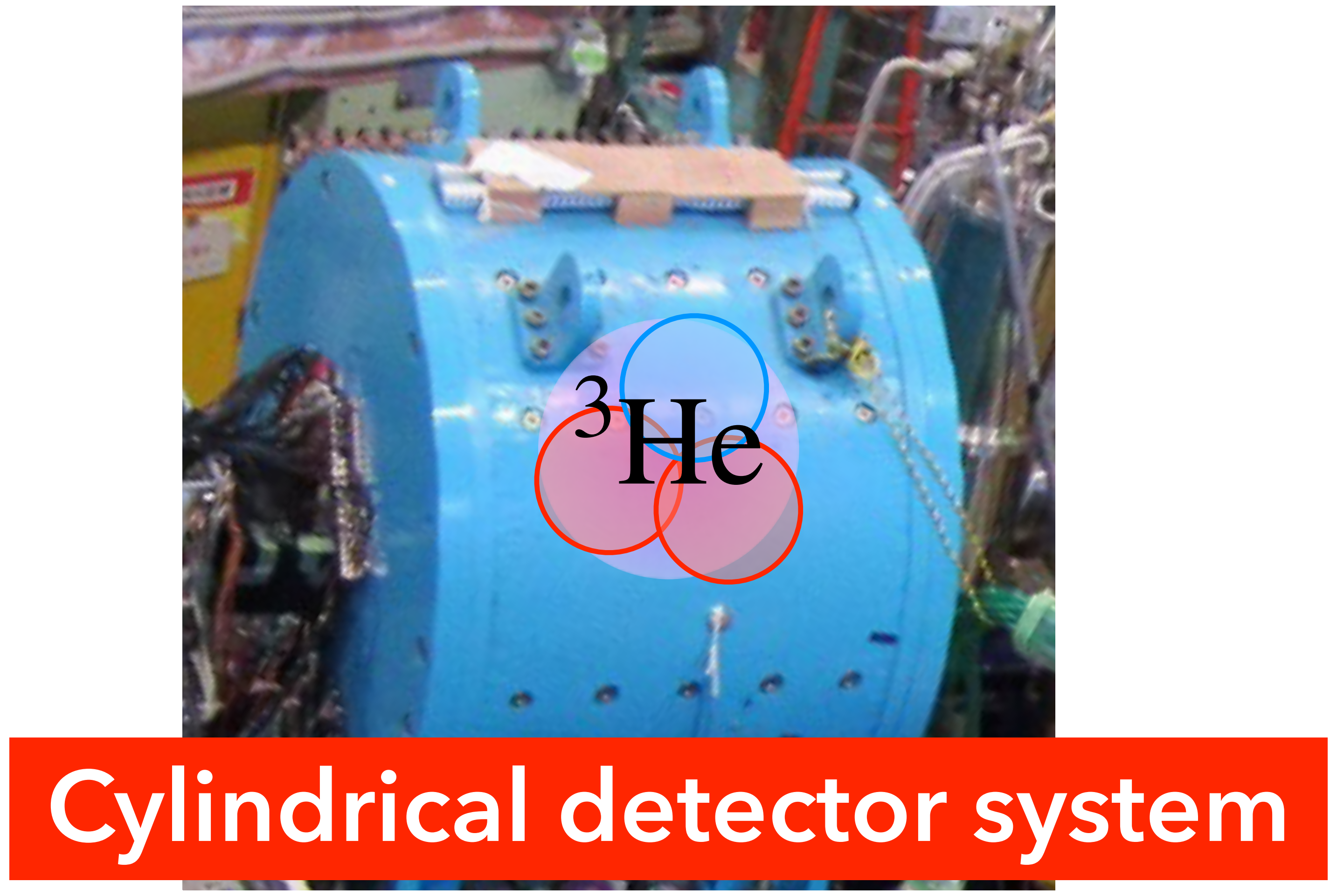
$\boxed{\pi^-\Lambda p} + p_{\text{miss}}$

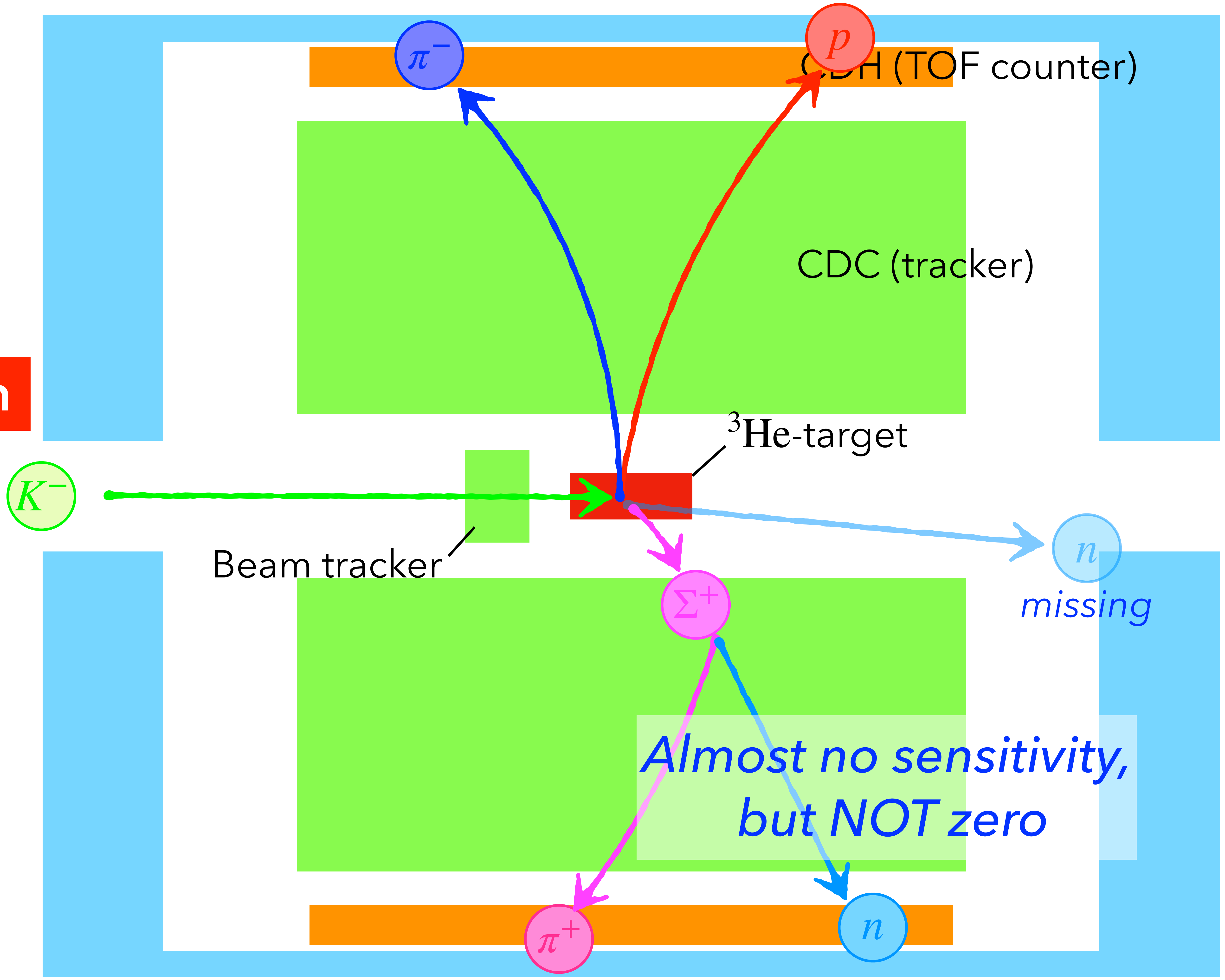
Excluded from this talk

Measurement / Analysis



Measurement / Analysis



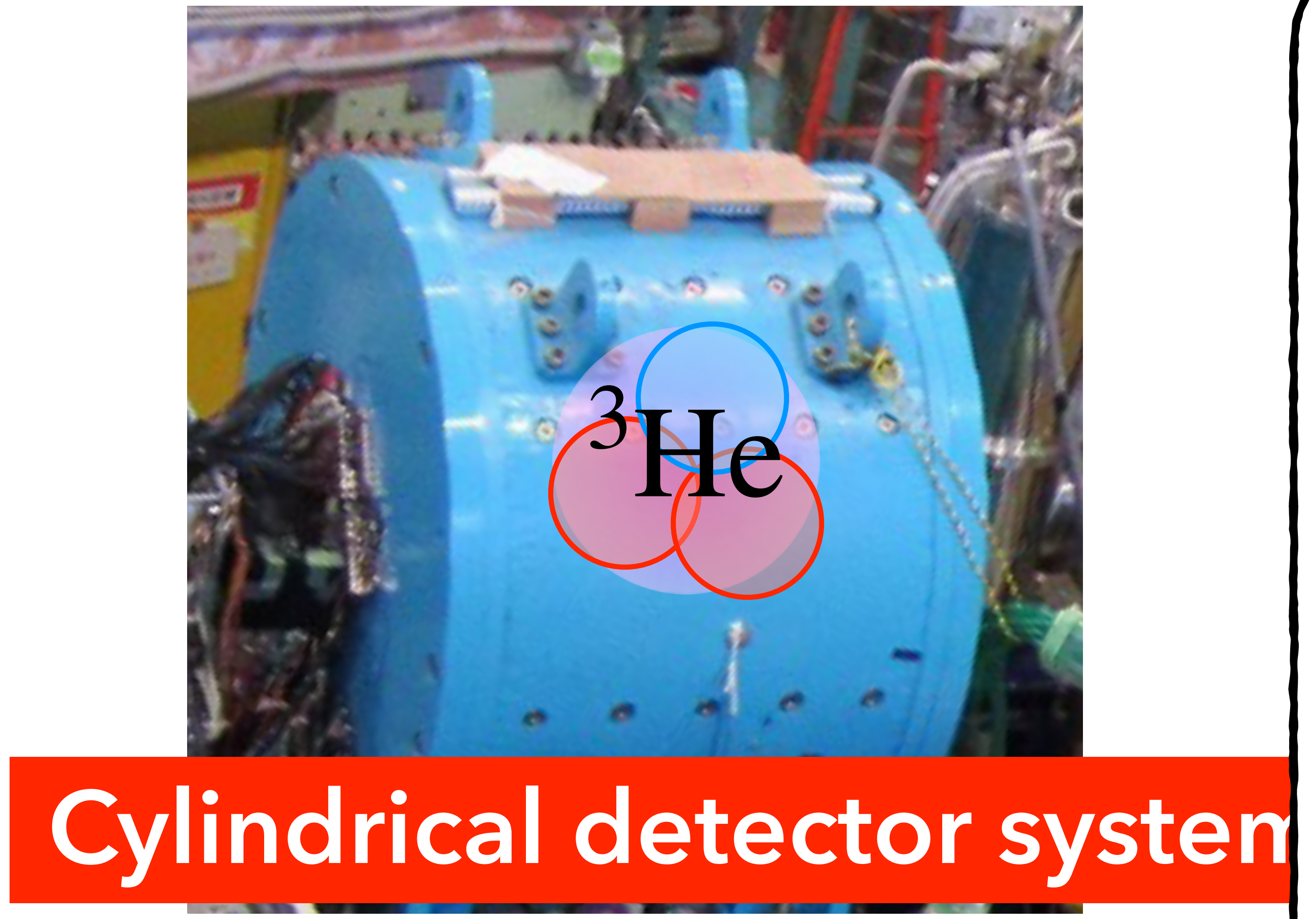


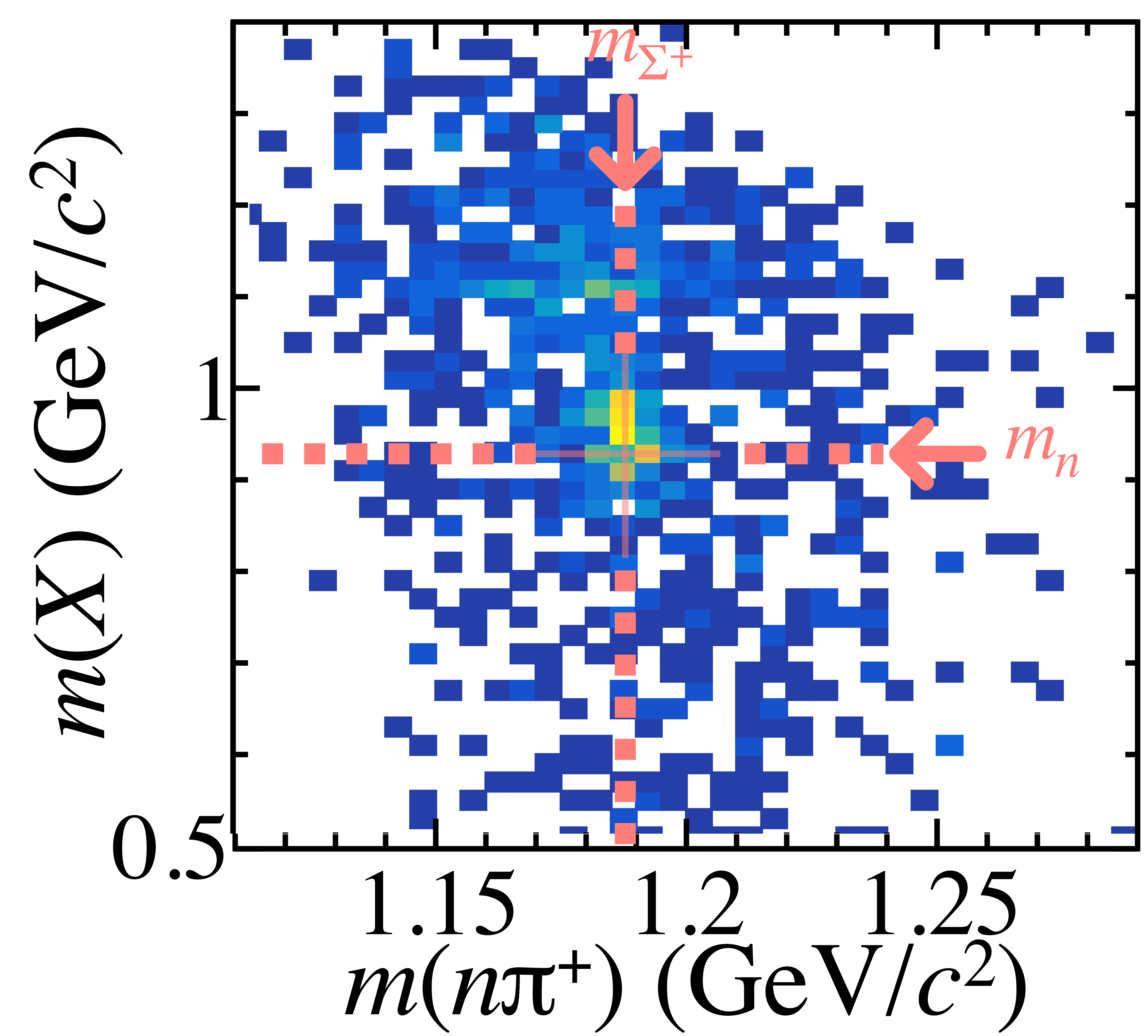
In the case of

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

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

Measurement / Analysis





In the case of

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

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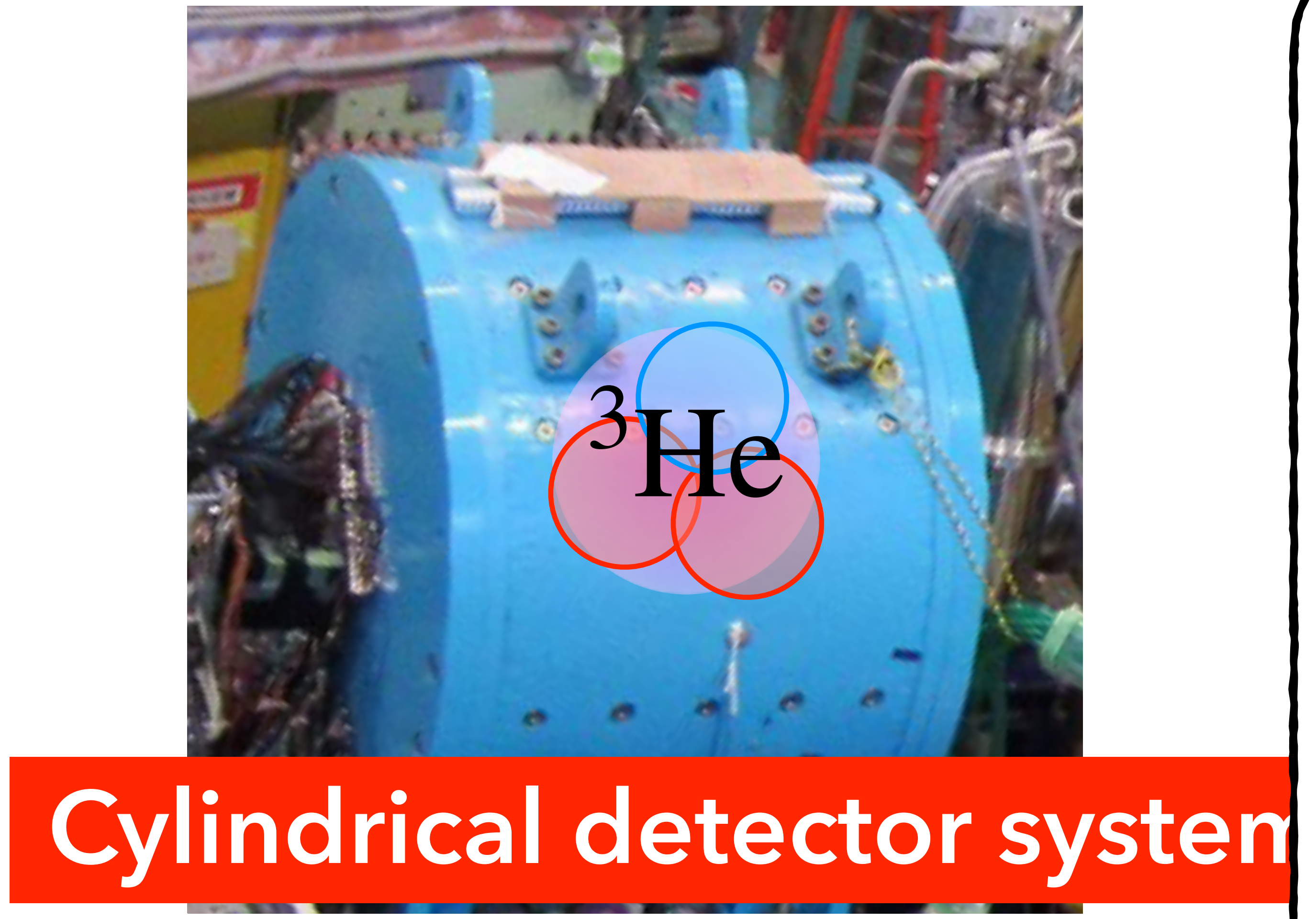
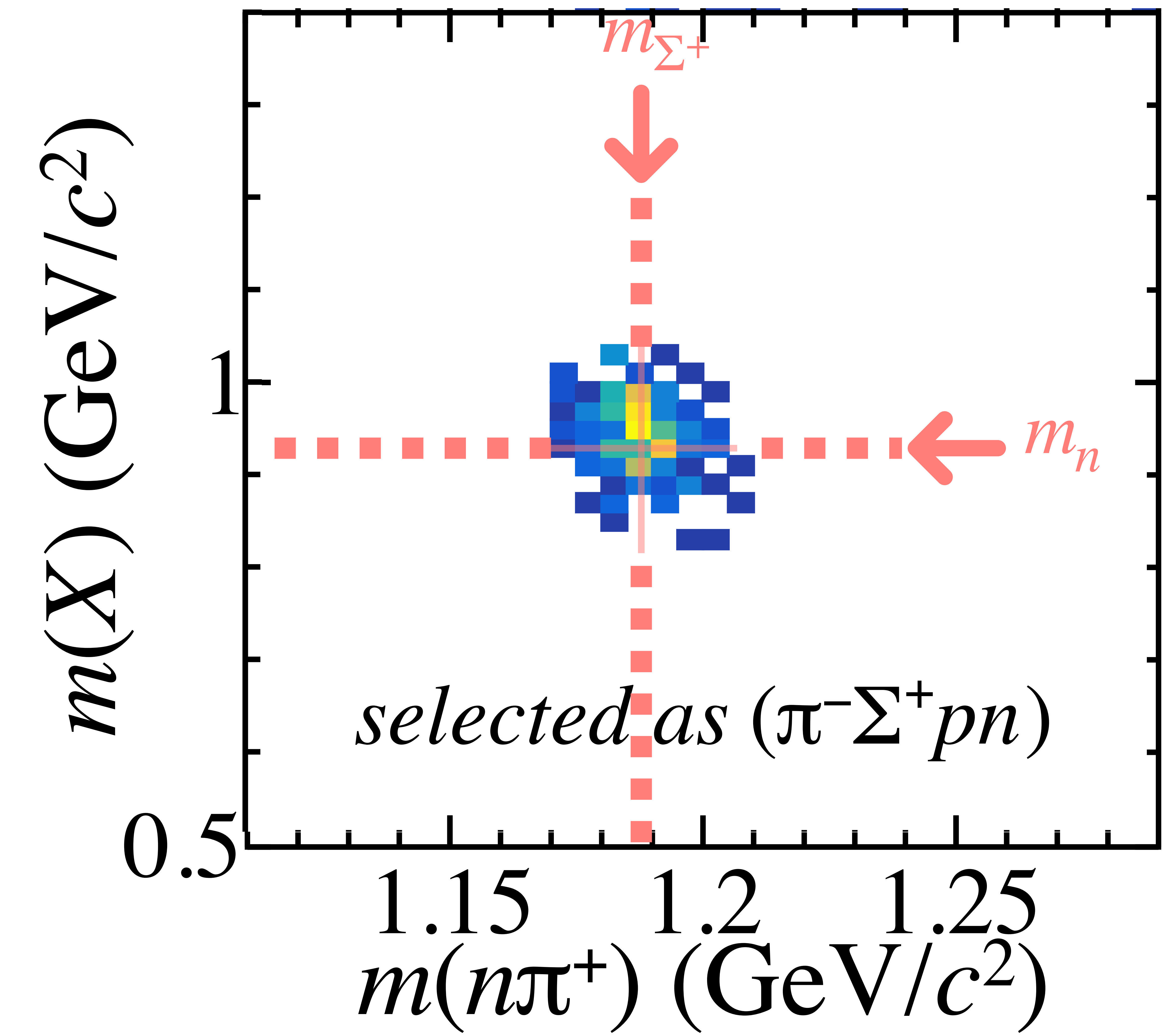
Measurement / Analysis





In the case of

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

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

$\pi^-\Sigma^+p$ | $\pi^+\Sigma^-p$ | $\pi^+\Lambda n$

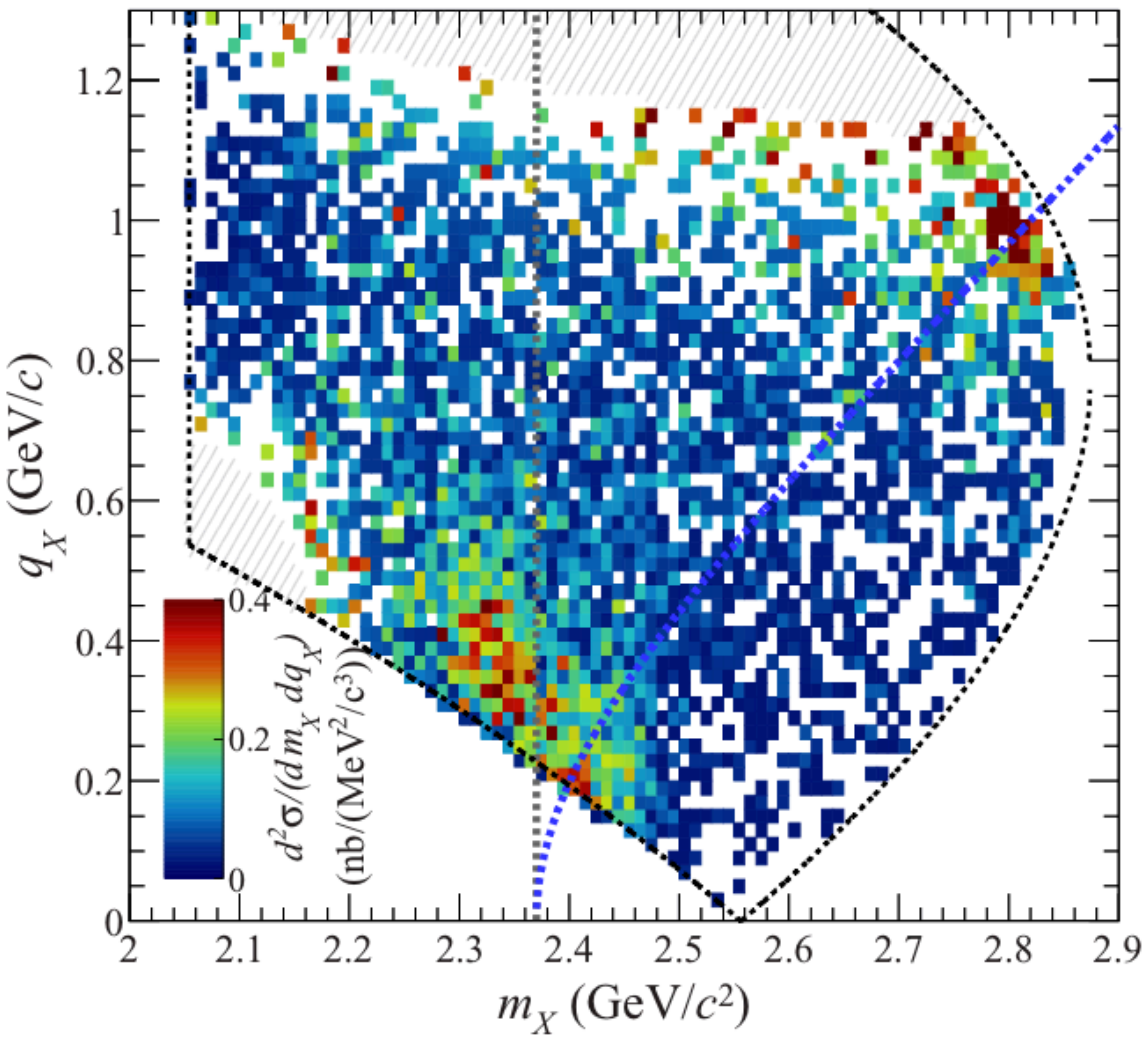
$\Lambda(1405)$ + Phase space

$\Sigma(1385)^+$ + Phase space

No other heavier Y^* productions → Due to recoiling-$\bar{K}$ having small momentum

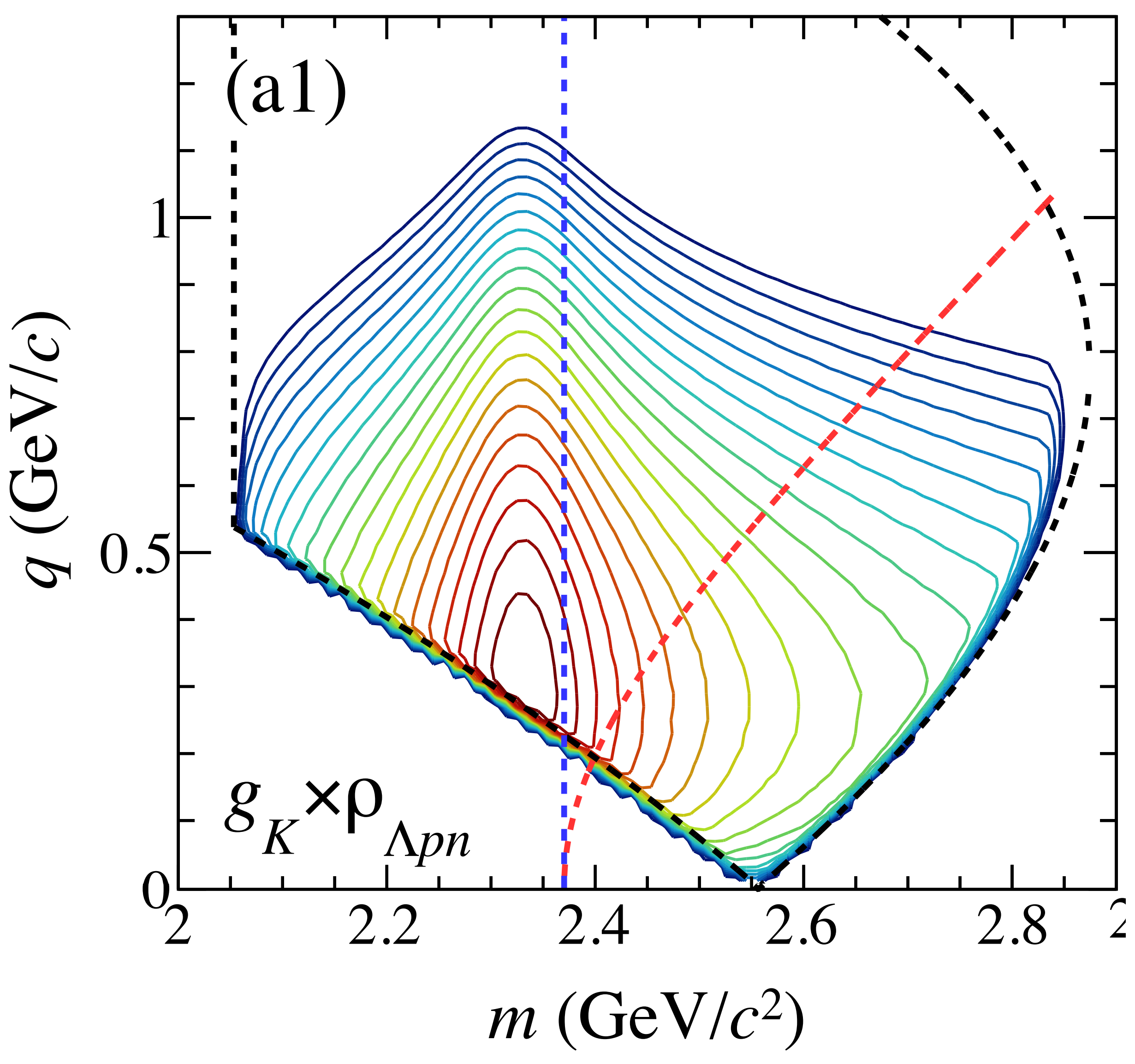
Before going result,

let's review Λp $+n_{\mathrm{miss}}$ *result.*



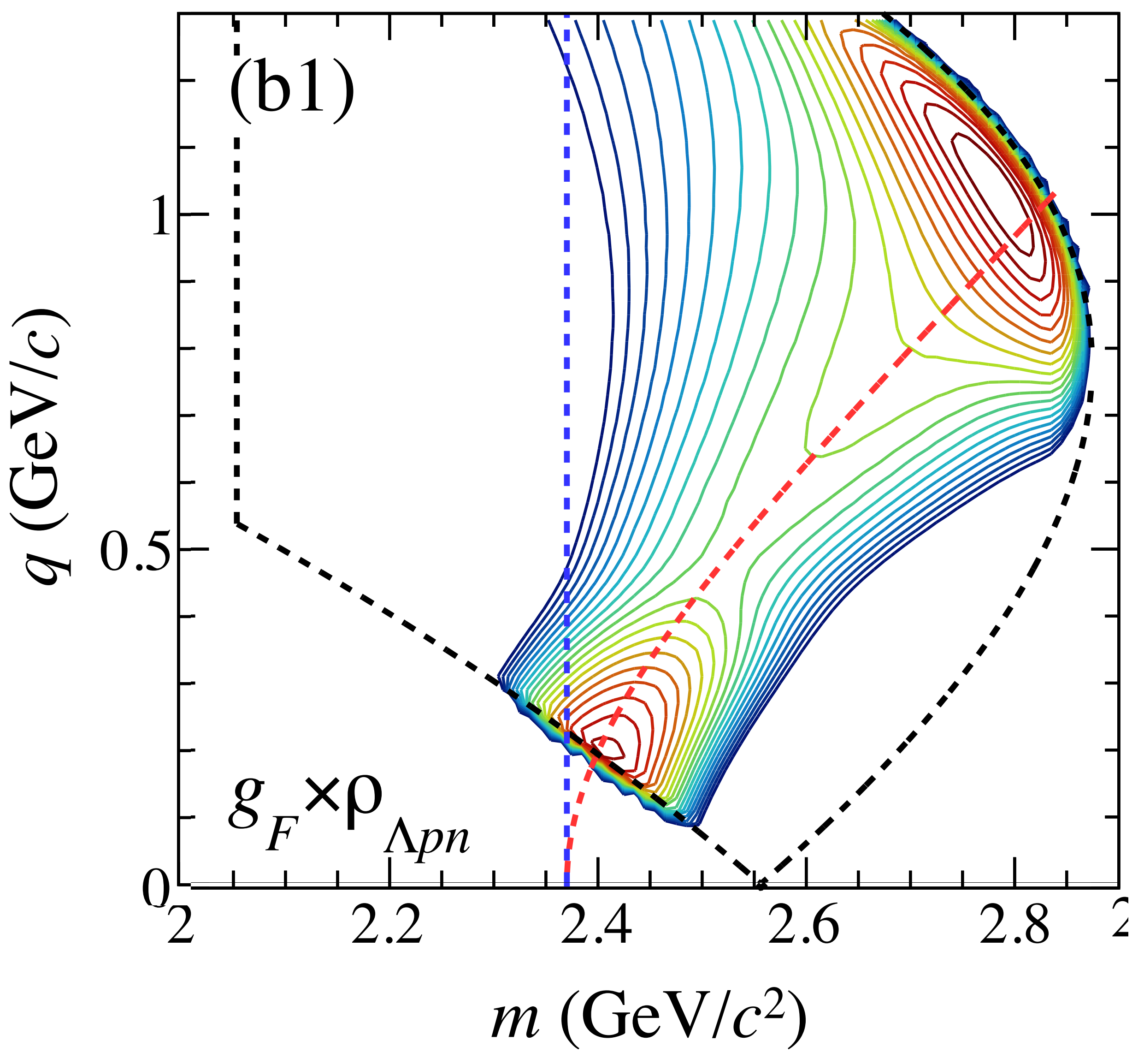
$\sim$

$\bar{K}NN$ production

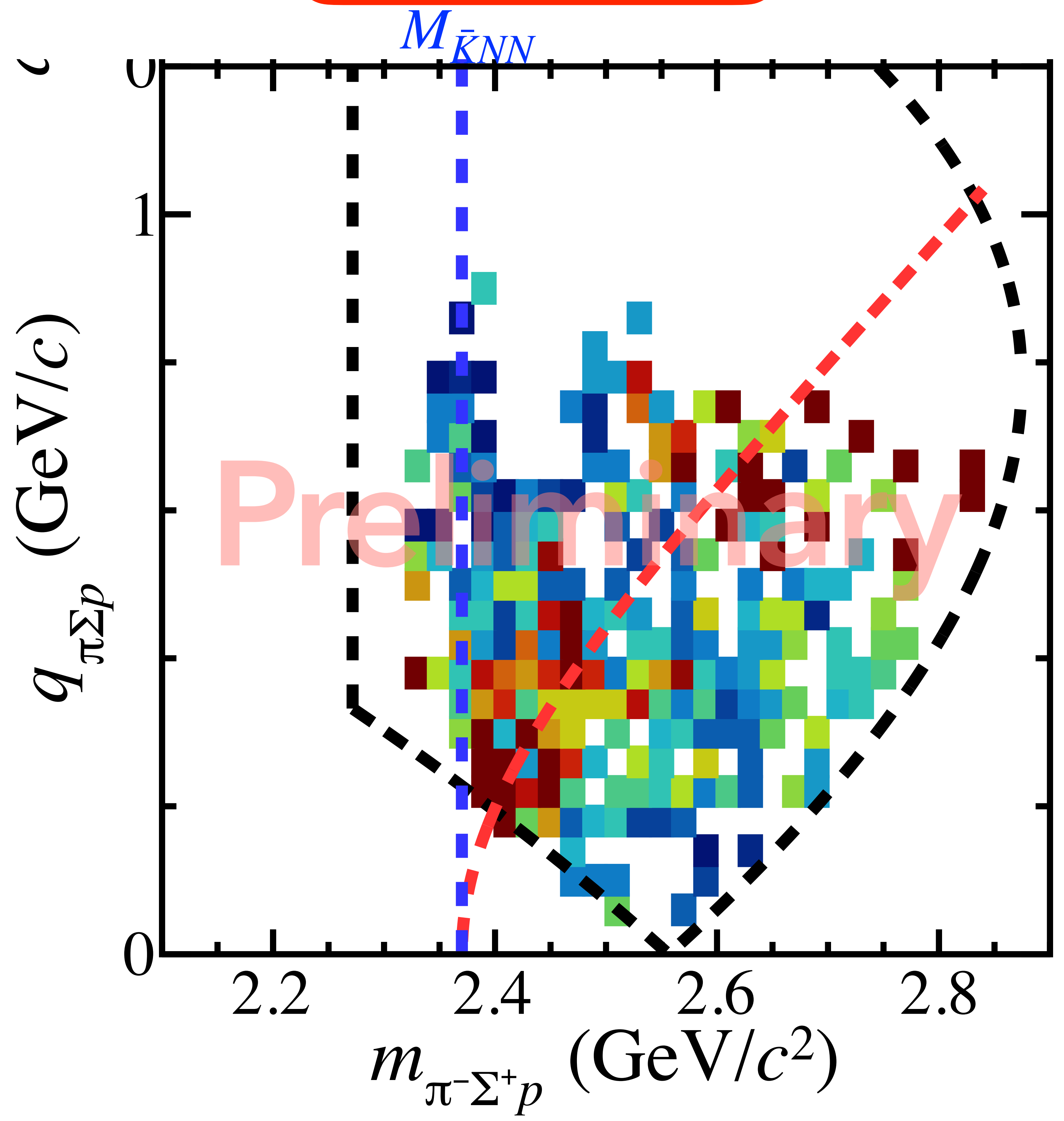


$+$

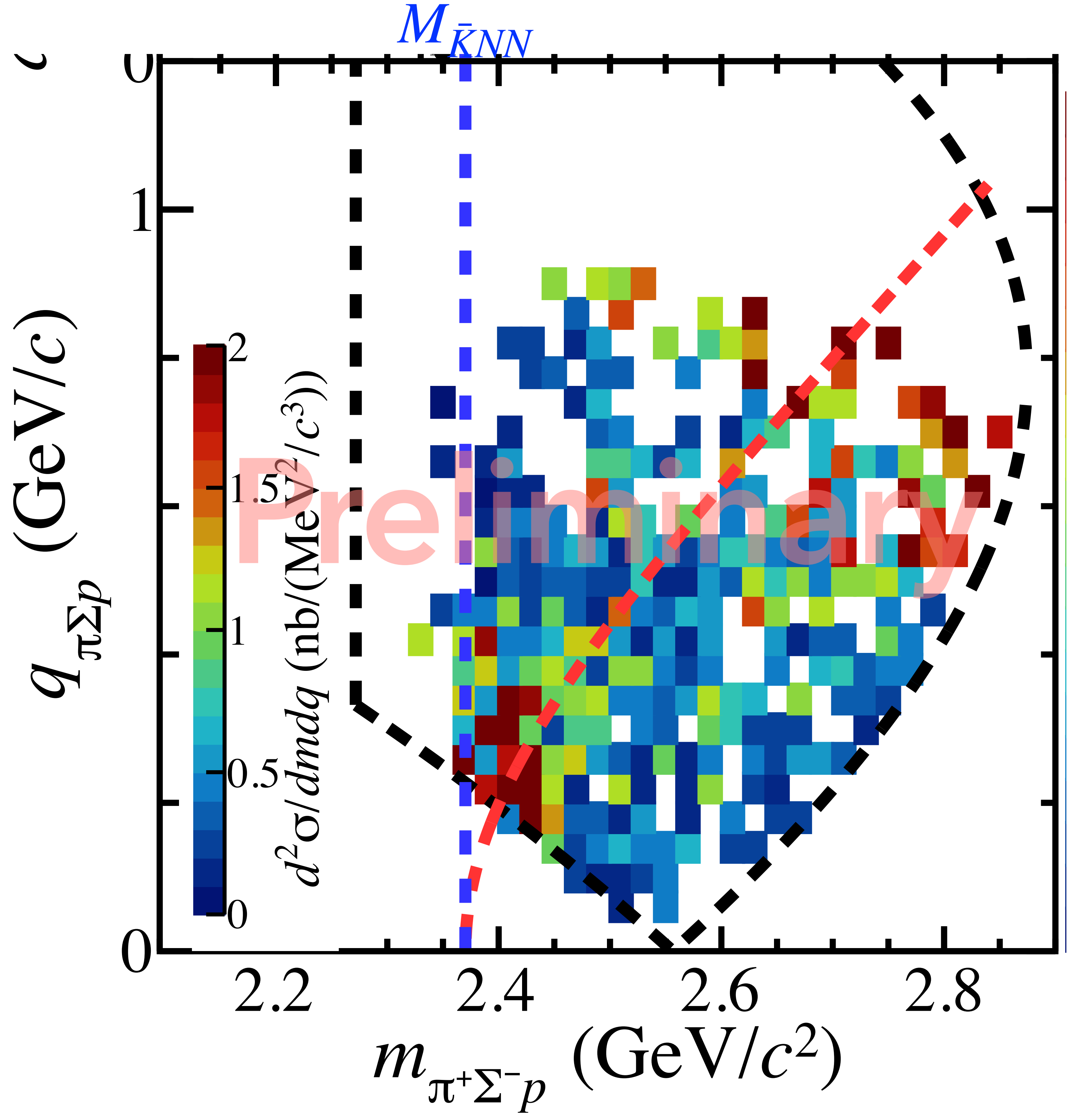
QF-$\bar{K}$ absorption



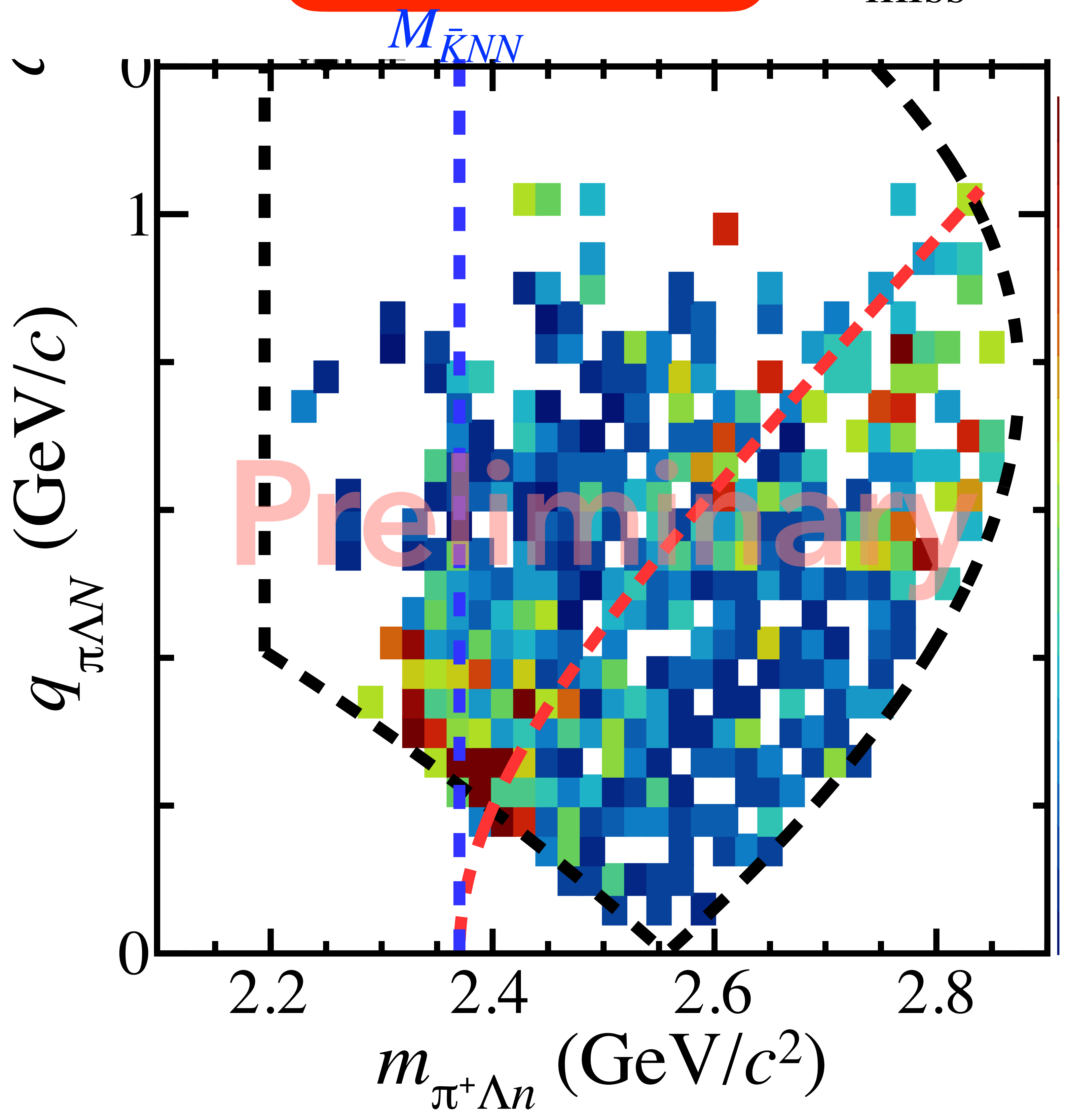
$\pi^-\Sigma^+ p$ $+n_{\mathrm{miss}}$



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



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



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

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

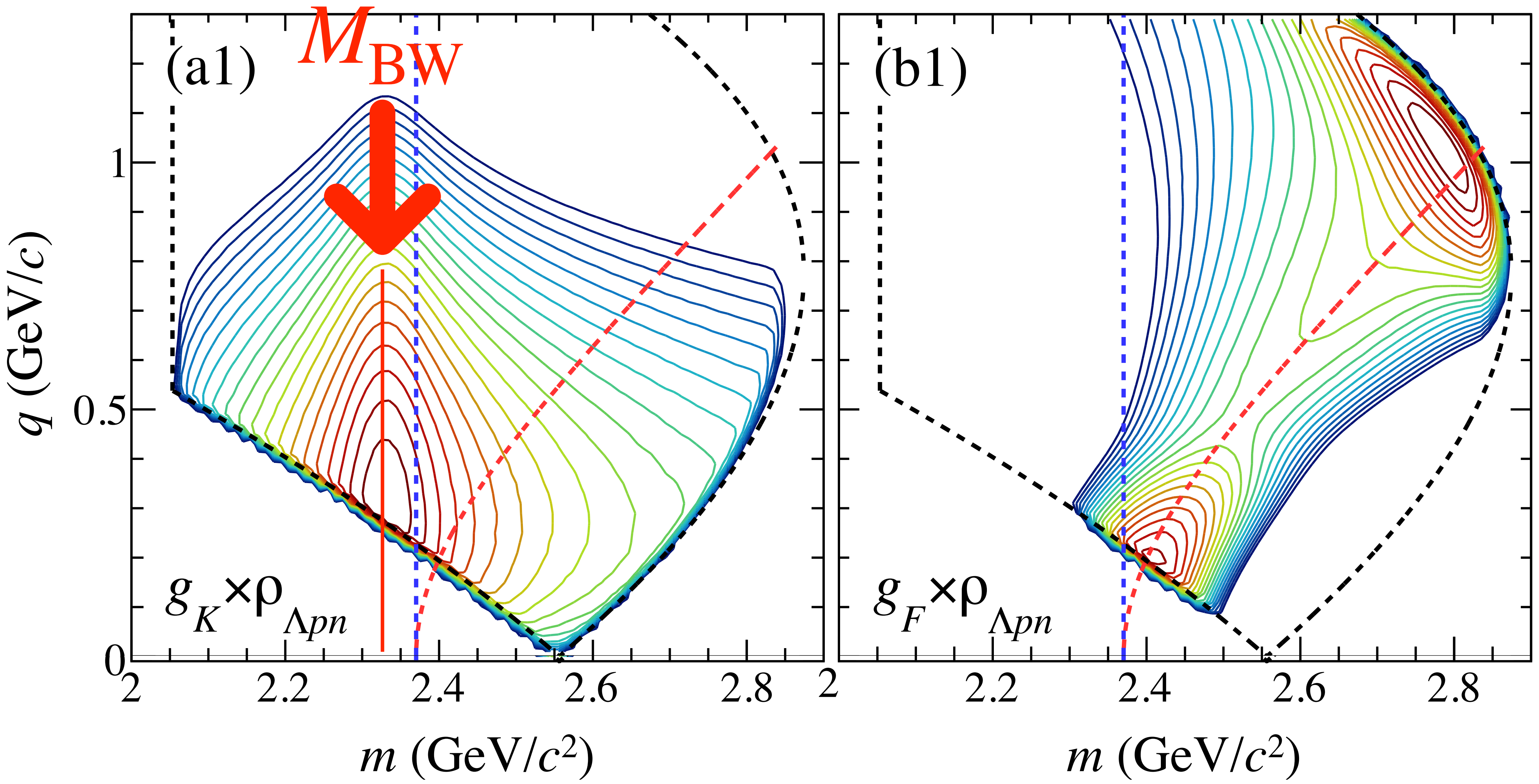
Why is $\bar{K}NN$ production not clear?

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

(low efficiency as well)

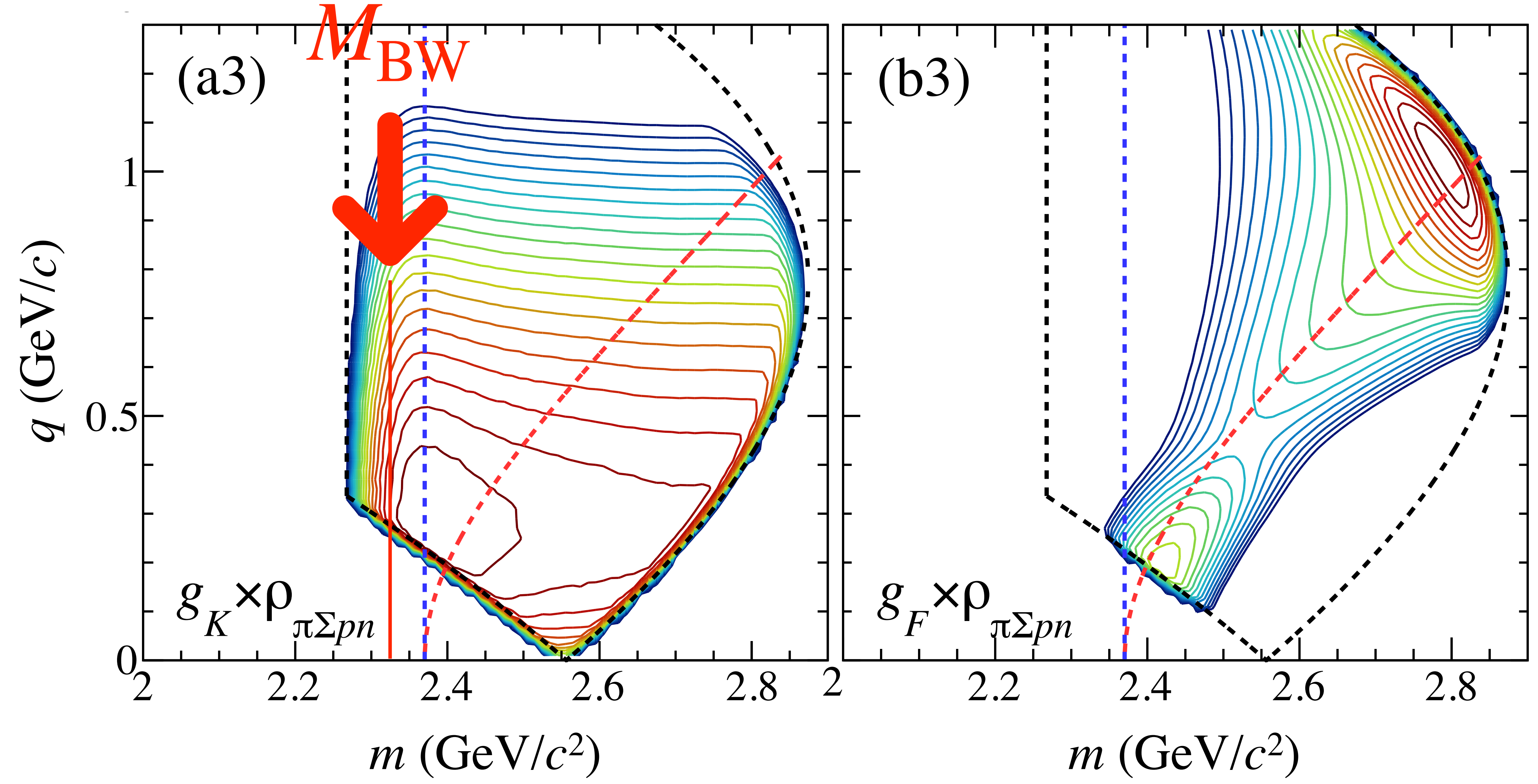
$\Lambda p + n_{\mathrm{miss}}$

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



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

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



Model functions in the fit

Λp $+n_{\mathrm{miss}}$

$m_{\Lambda p}$ $q_{\Lambda p}$

$\bar{K}NN$ production

$+$

QF-$\bar{K}$ absorption

→ See PRC**102**, 044002 (2020)

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

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

$\bar{K}NN$ production

$+$

QF-$\bar{K}$ absorption

→ Same function as PRC

Only strengths are free

Due to a lack of statistics,
other parameters are fixed.

$\times$

$m_{\pi Y}$

$\Lambda(1405)$ + Phase space

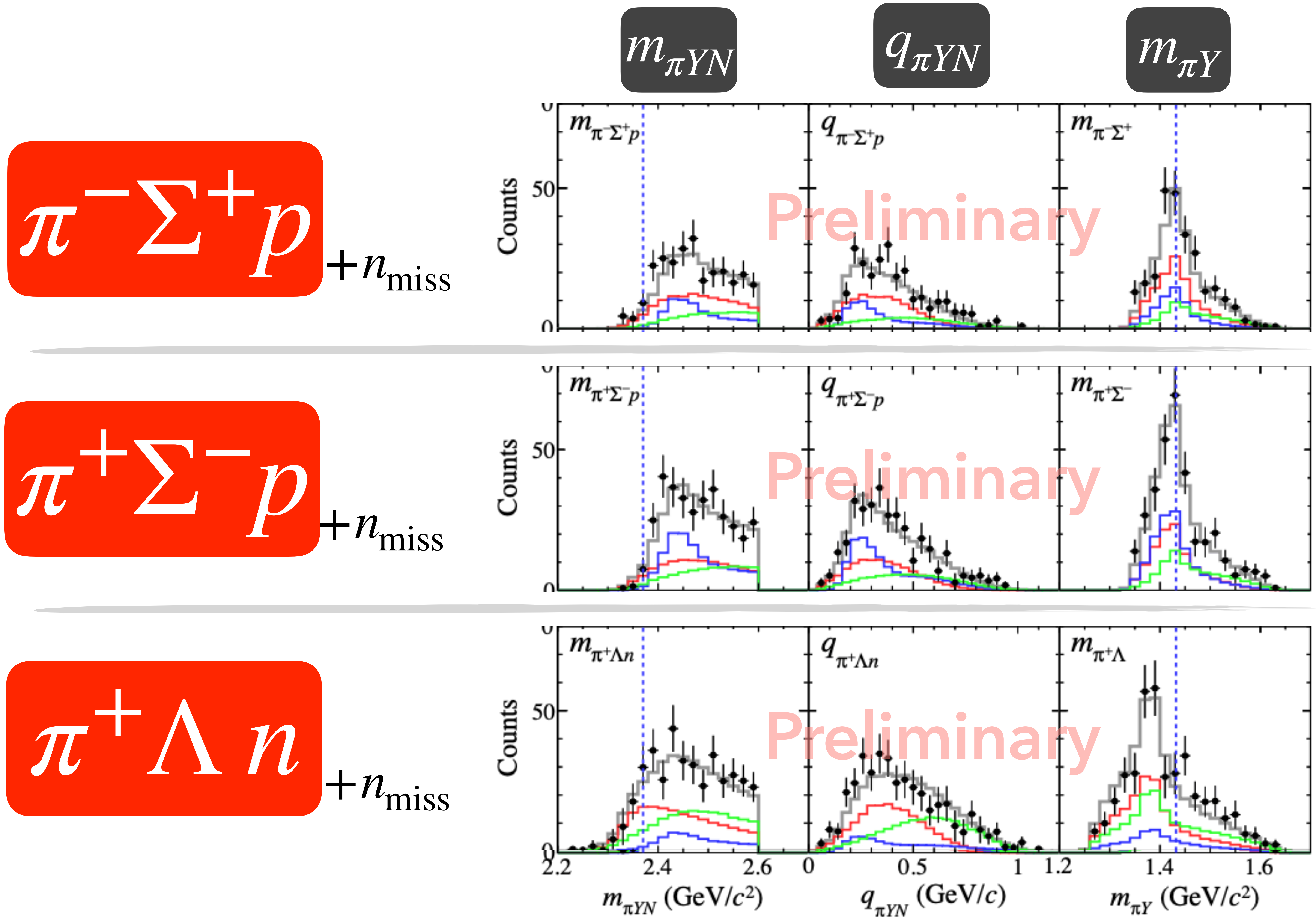
or

$\Sigma(1385)^{+}$+ Phase space

→ simple Breite-Wigner

Free M & Γ

Fit result



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

misconceiving of QF

It could NOT be reproduced without $\bar{K}NN$.

Fit result

Cross section of $\bar{K}NN$

※Statistical error only

$\pi^-\Sigma^+ p$ $+n_{\mathrm{miss}}$	Preliminary $85.4 \pm 21.2\ \mu\mathrm{b}$
$\pi^+\Sigma^- p$ $+n_{\mathrm{miss}}$	Preliminary $43.8 \pm 9.6\ \mu\mathrm{b}$
$\pi^+\Lambda n$ $+n_{\mathrm{miss}}$	Preliminary $83.6 \pm 12.0\ \mu\mathrm{b}$
c.f. Λp $+n_{\mathrm{miss}}$	$9.3 \pm 0.8^{+1.4}_{-1.0}\ \mu\mathrm{b}$

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

$\Gamma_{\mathrm{mesonic}}$ would be $\mathcal{O}(10)$ times larger than $\Gamma_{\mathrm{non-mesonic}}$.

But, other mesonic channels should be measured to conclude the exact ratio.

Theoretical works

T. Sekihara et. al., PRC **86**, 065205 (2012).

$\Gamma_{\mathrm{non-mesonic}} \sim \Gamma_{\mathrm{mesonic}}/2$ @ nuclear dens.

(depending on density)

→ *To be compared in more detailed*

Summary

$(m_{\pi YN},\ q_{\pi YN})$ distributions are similar to the $(m_{\Lambda p},\ q_{\Lambda p})$ distribution.

All distributions of $\pi YN + N_{\text{miss}}$ channels are well explained with $\bar{K}NN$, QF, and BG.

$$\Gamma_{\text{non-mesonic}} \ll \Gamma_{\text{mesonic}}$$

Γ_{mesonic} would be $\mathcal{O}(10)$ times larger than $\Gamma_{\text{non-mesonic}}$.

But, other mesonic channels should be measured to conclude the exact ratio.

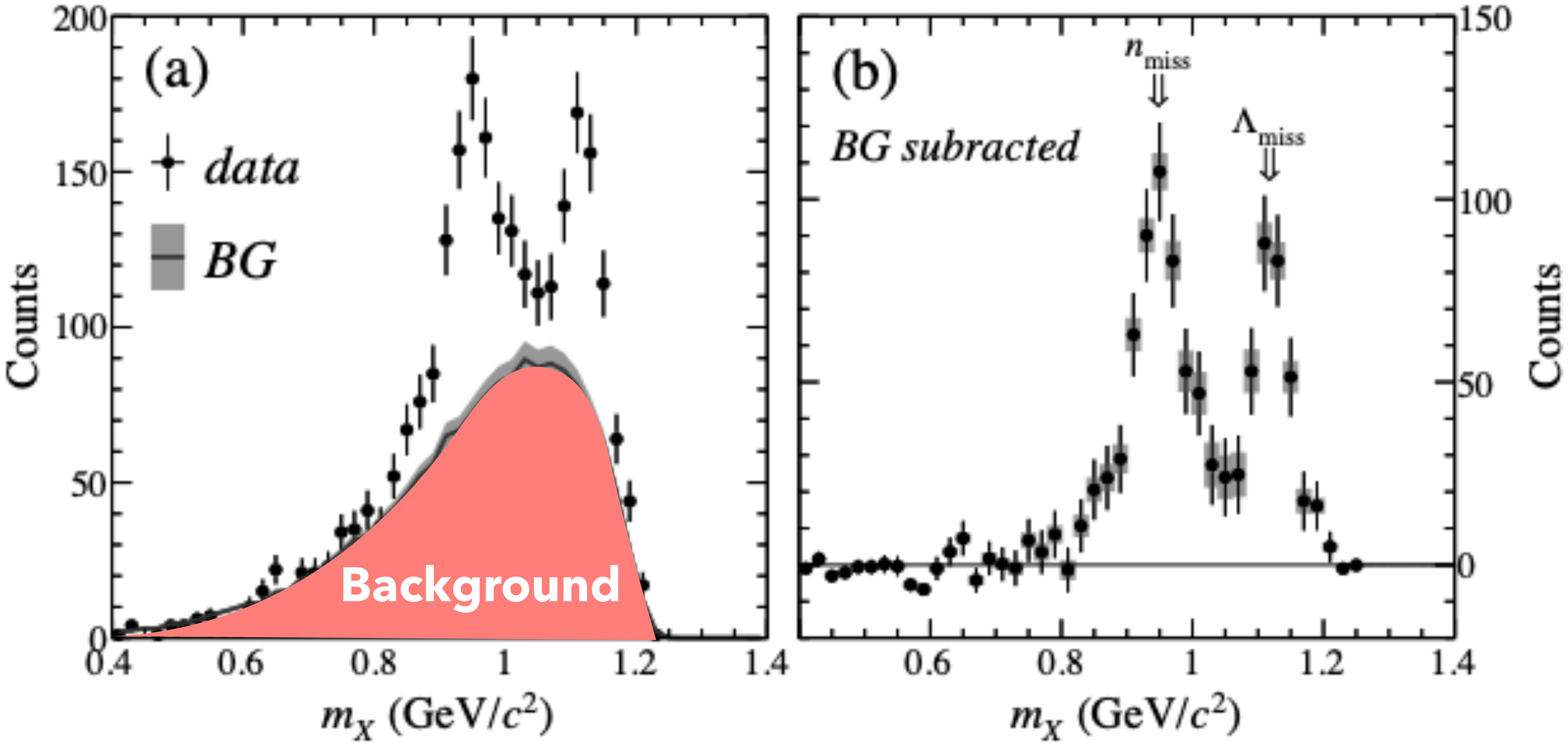
→ J-PARC P89 *with larger acceptance & higher neutron detection efficiency*

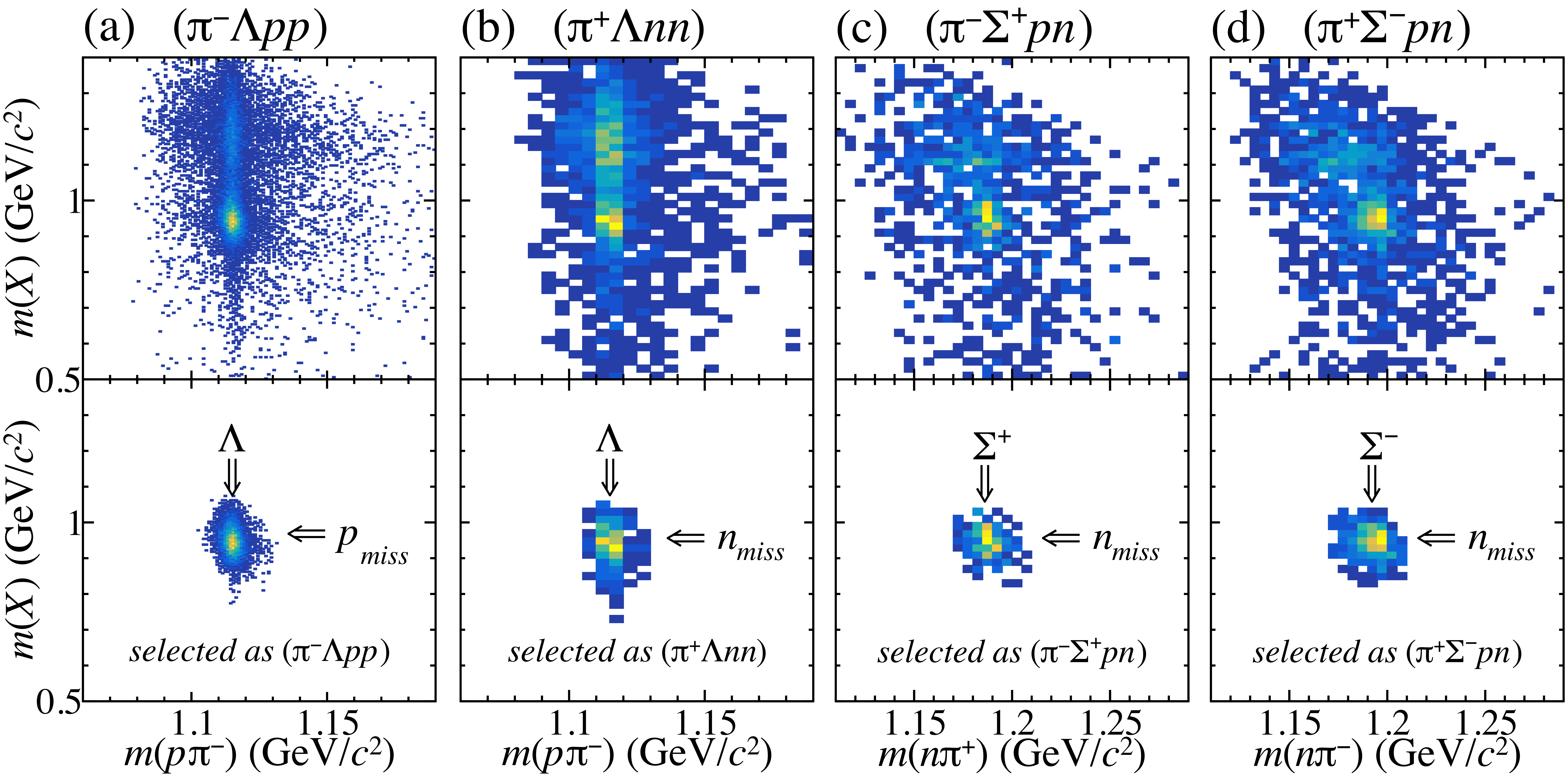
Thank you for your attention!

要らないかも

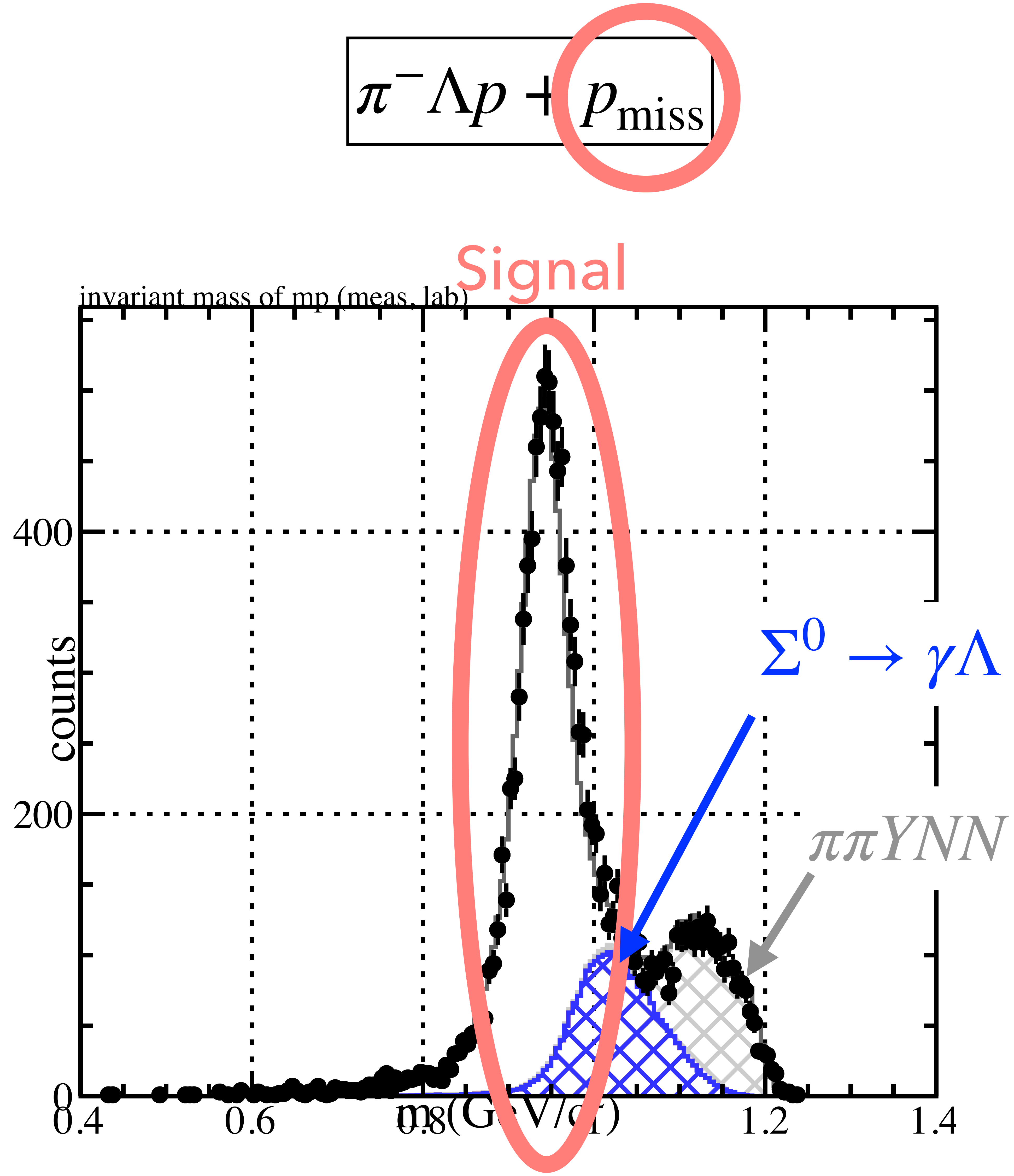
Background from neutron contamination

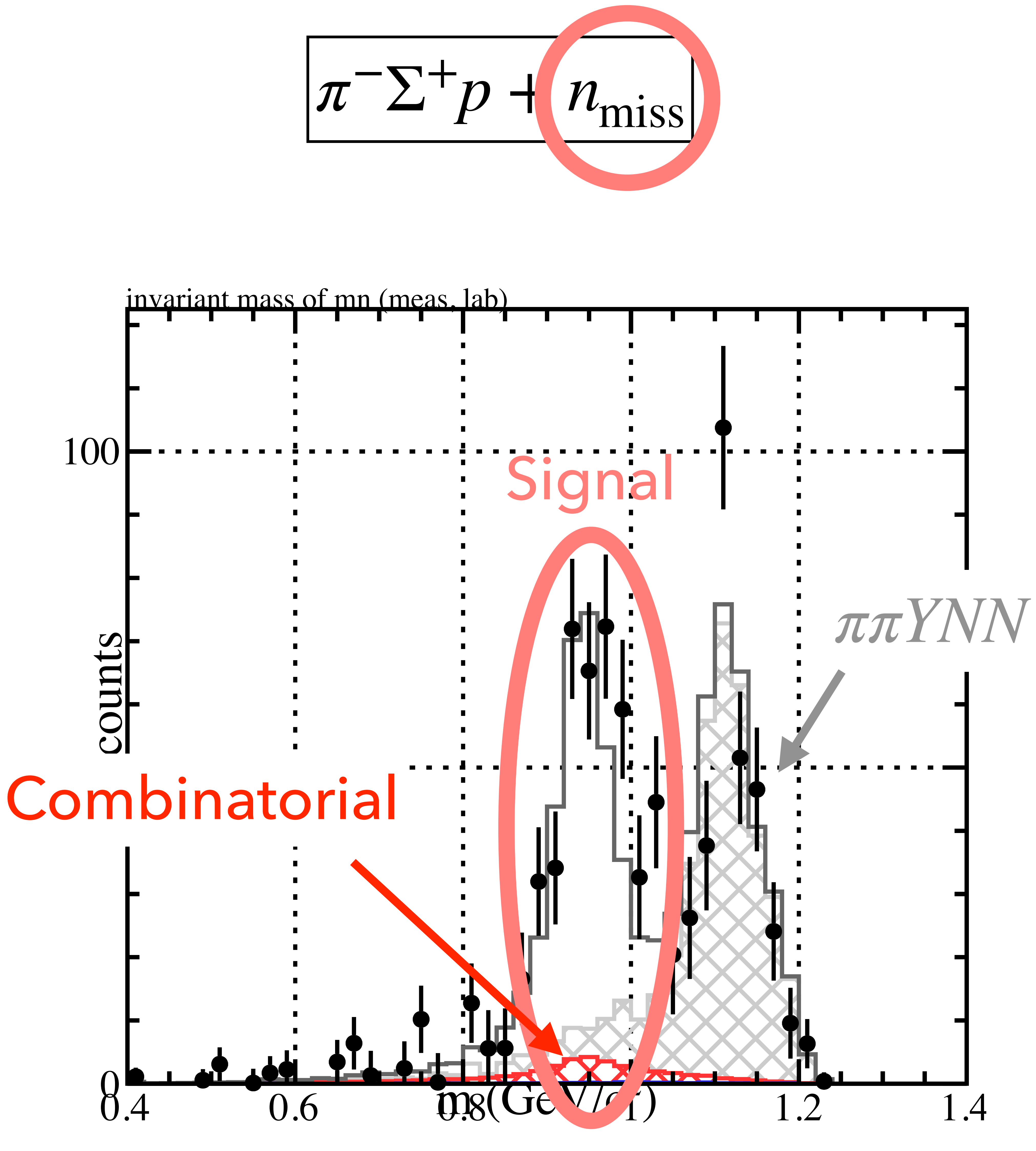
Subtracting neutron contamination



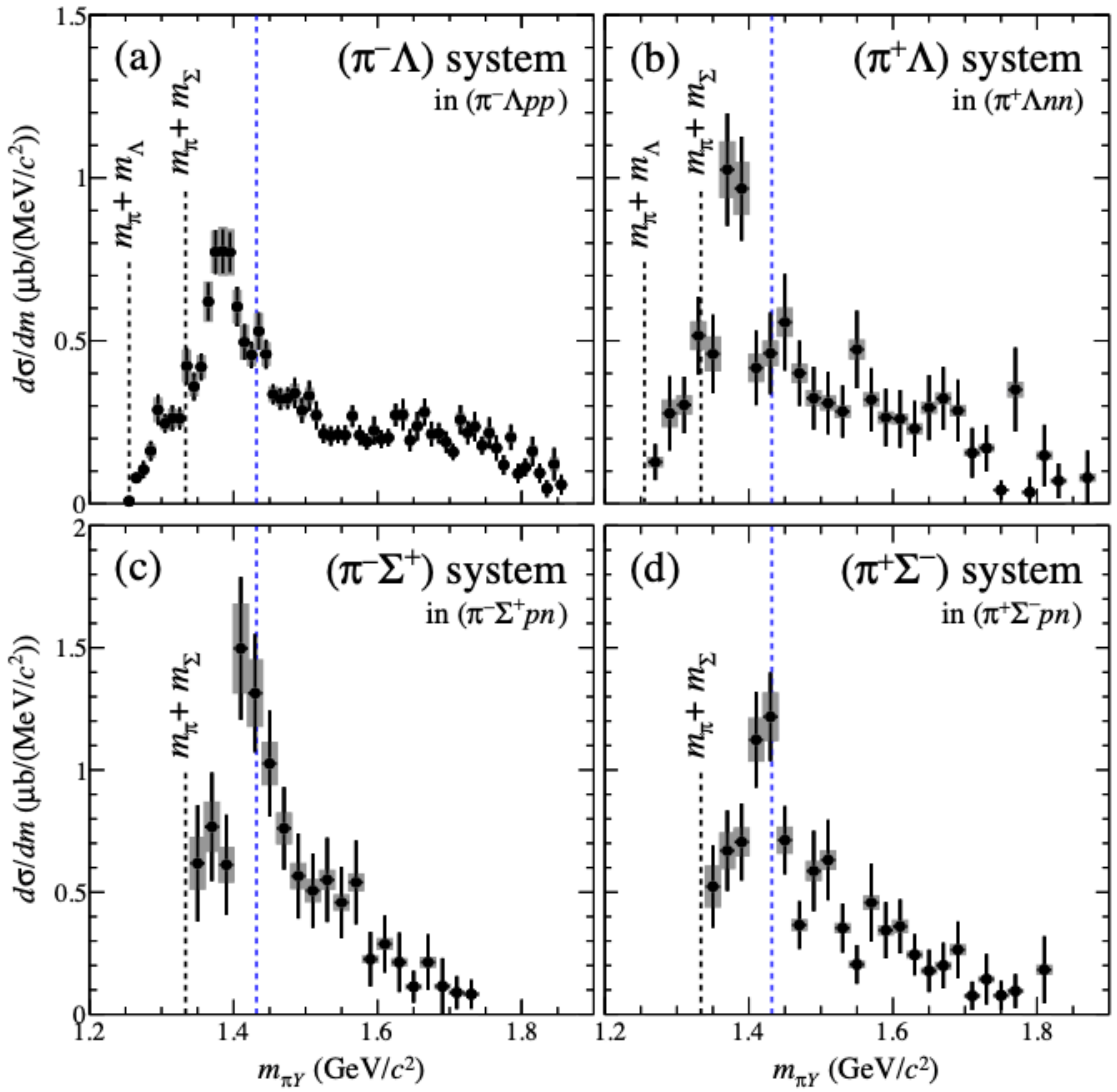

(a) (π⁻Λpp)
(b) (π⁺Λnn)
(c) (π⁻Σ⁺pn)
(d) (π⁺Σ⁻pn)
m(X) (GeV/c²)
1
0.5
Λ
⇐ p miss
selected as (π⁻Λpp)
⇐ n miss
selected as (π⁺Λnn)
Σ⁺
selected as (π⁻Σ⁺pn)
Σ⁻
selected as (π⁺Σ⁻pn)
1.1
1.15
1.2
1.25
m(pπ⁻) (GeV/c²)
m(nπ⁺) (GeV/c²)
m(nπ⁻) (GeV/c²)

Background from other final states





Invariant mass of πY



Σ(1385) & Λ(1405) are seen.

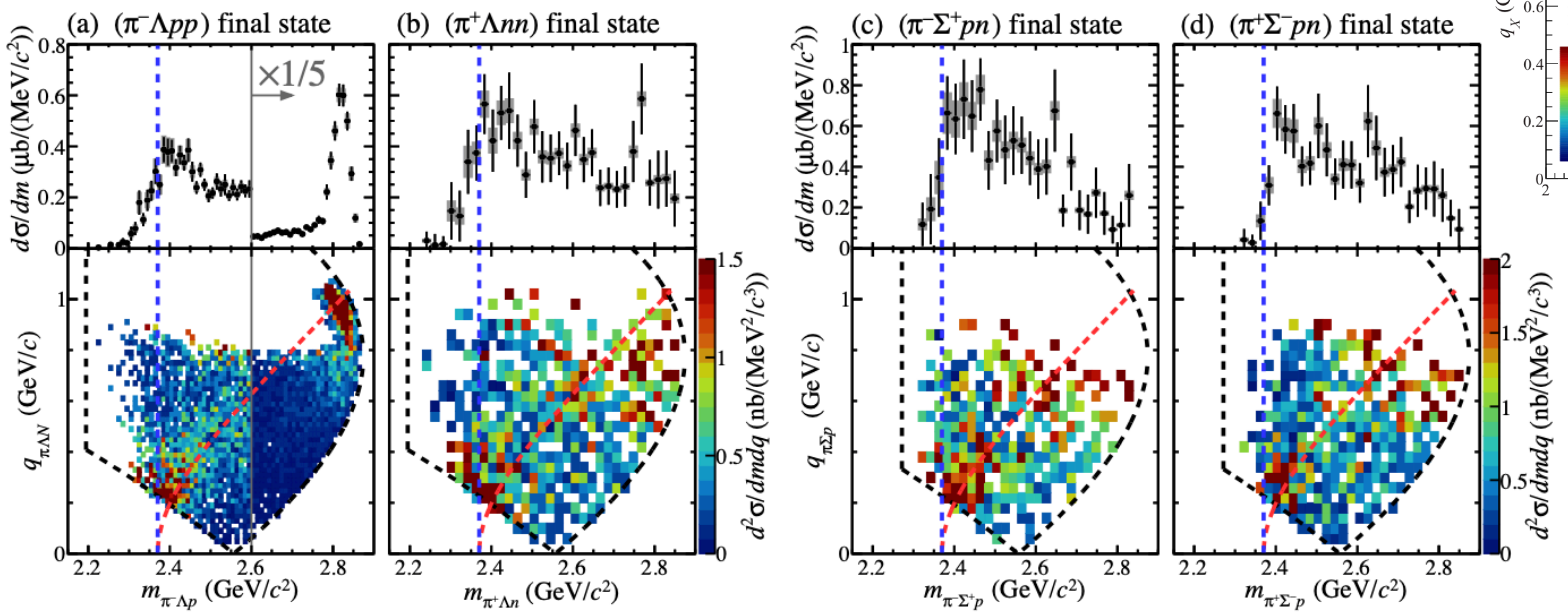
No other higher resonances

Broad distribution (phase space?)

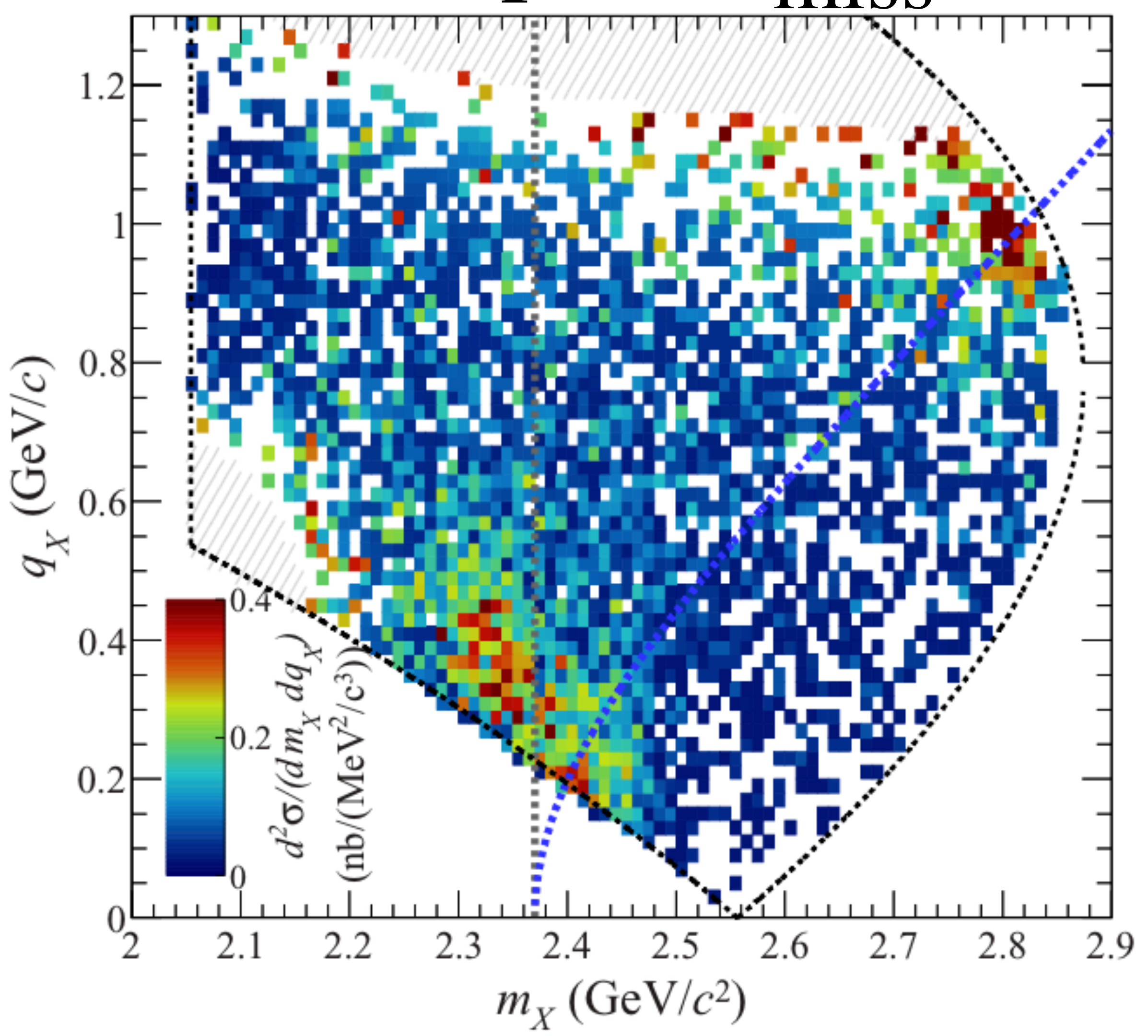
$m_{\pi YN}$ vs. $q_{\pi YN}$

2D distributions in mesonic-channels are quite similar to Λpn channel

Mesonic channels have $\mathcal{O}(10)$ times larger CS than non-mesonic.



c.f. $\Lambda p + n_{\text{miss}}$



Fit function

Similar fitting functions used in the Λpn analysis are used for the present analysis

Extended to three-dimensional functions to include $m_{\pi Y}$

- Three dimensional function, F

$$F(m_{\pi YN},\ q_{\pi YN},\ m_{\pi Y}) = \rho(m_{\pi YN},\ q_{\pi YN},\ m_{\pi Y}) \times f(m_{\pi YN},\ q_{\pi YN},\ m_{\pi Y}),$$

  - ρ : Phase space volume

- Spectral function, f

$$f(m_{\pi YN},\ q_{\pi YN},\ m_{\pi Y}) = g(m_{\pi YN},\ q_{\pi YN}) \cdot h(m_{\pi Y}).$$

$$= \underbrace{(A_K g_K + A_F g_F)}_{m_{\pi Y} \text{ is phase space}} + \underbrace{(A_K g_K + A_F g_F) \cdot A_{Y*} h_{Y*}}_{m_{\pi Y} \text{ is Breit-Wigner}}$$

- For KNN, g_K (same as PRC)

$$g_K(m_{\pi YN},\ q_{\pi YN}) = \frac{(\Gamma_K/2)^2}{(m_{\pi YN} - M_K)^2 + (\Gamma_K/2)^2} \times A_0^K \exp\left(-\frac{q_{\pi YN}^2}{Q_K^2}\right),$$

- For Quasi-free, g_F (same as PRC)

$$g_F(m_{\pi YN},\ q_{\pi YN}) = \exp\left[-\frac{(m_{\pi YN} - M_F(q_{\pi YN}))^2}{\sigma^2(q_{\pi YN})}\right] \times \left[A_0^F \exp\left(-\frac{q_{\pi YN}^2}{Q_F^2}\right) + A_1^F + A_2^F \exp\left(\frac{m_{\pi YN}}{m_0} + \frac{q_{\pi YN}}{q_0}\right)\right],$$

- For Y^*

$$h_{Y^*}(m_{\pi Y}) = \frac{(\Gamma_{Y^*}/2)^2}{(m_{\pi Y} - M_{Y^*})^2 + (\Gamma_{Y^*}/2)^2}.$$

Why is Γ so large?

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

※NOT including non-mesonic decay

$\Gamma_{\text{non-mesonic}} \sim \Gamma_{\text{mesonic}} \sim 50\ \text{MeV?}$

Are there sub-structures?

Such as QF-Y^*, or perhaps $\bar{K}NN$ with $J^\pi = 1^-$

→ **J-PARC P89** *~ x20 statistics for* $\Lambda p + n_{\text{miss}}$