Mesonic decay of $\bar{K}NN$ & Future projects

Takumi Yamaga (RIKEN)
for the J-PARC E15/E80/P89 collaboration

JPARC Hadron workshop @ J-PARC
2023.3.27–29

$\bar{K}N$ interaction

$I_{\bar{K}N} = 0$	$\frac{1}{\sqrt{2}}\left(-K^- p + \bar{K}^0 n\right)$	**Strong attractive**
$I_{\bar{K}N} = 1$	$\bar{K}^0 p$ $\frac{1}{\sqrt{2}}\left(K^- p + \bar{K}^0 n\right)$ $K^- n$	attractive

↓

Possible to make quasi-bound states with $I_{\bar{K}N} = 0$

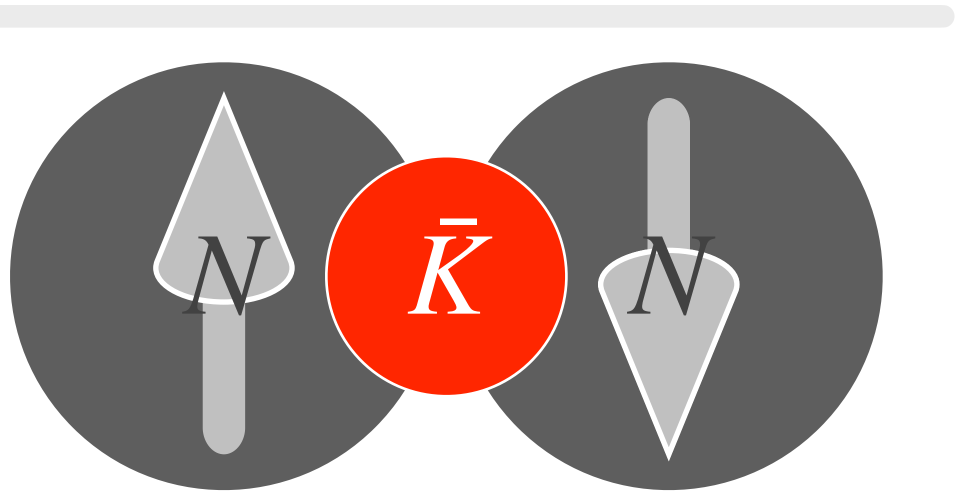
$\Lambda(1405)$

$\bar{K}$-nuclei

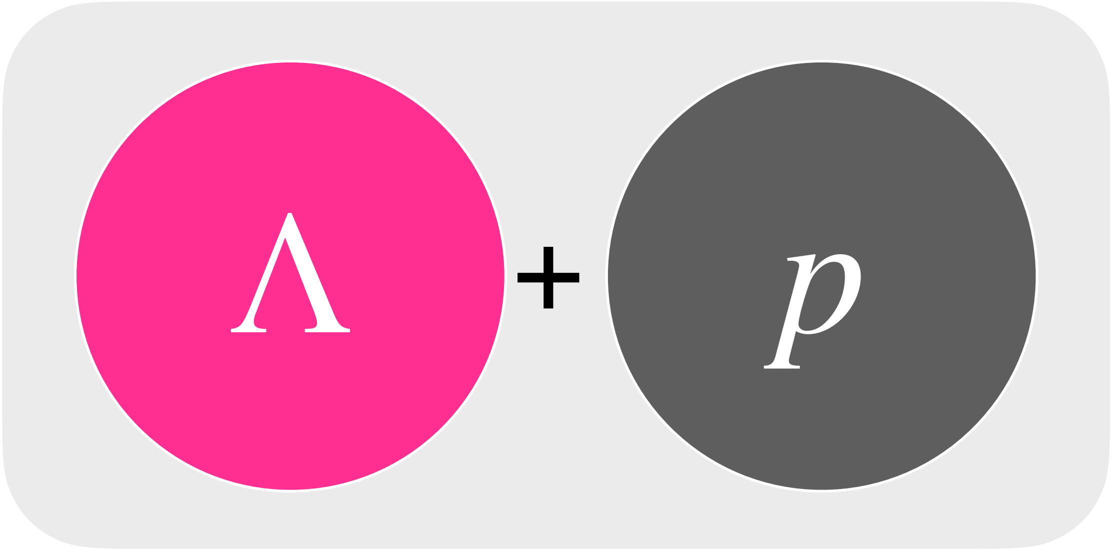
$(\bar{K}NN)^{I=1/2}$

The lightest $\bar{K}$-nucleus

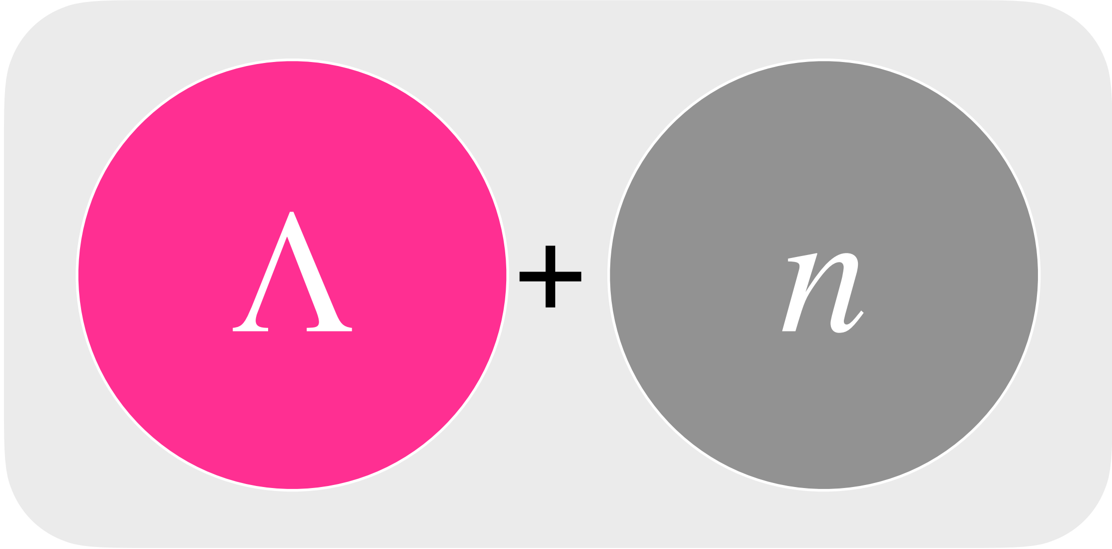
$J^{\pi} = 0^{-}$



$I_z = +1/2$ state — "$K^{-}pp$" — $K^{-}pp$-$\bar{K}^{0}pn$ →



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



Experimental study so far

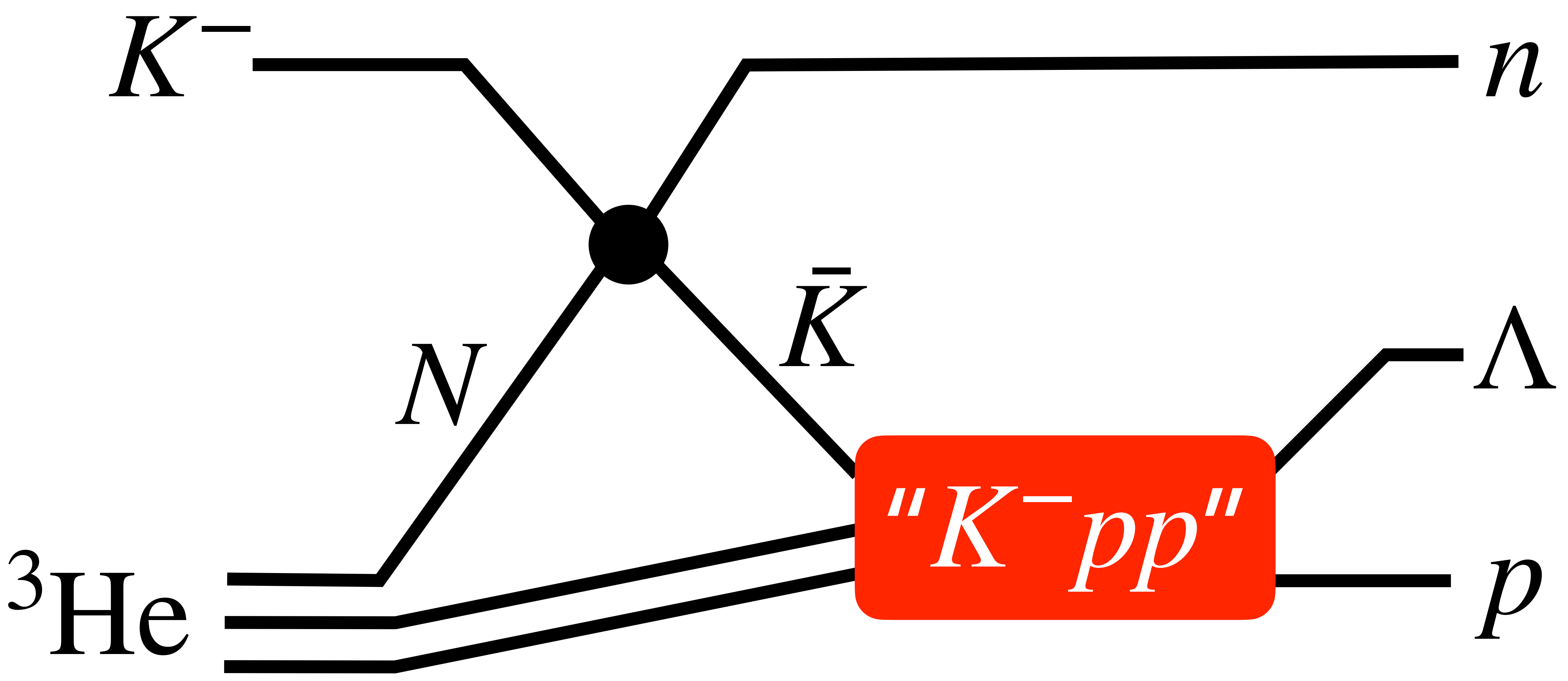
The J-PARC E15 experiment to search for "$K^- pp$"

"$K^- pp$"

$K^- pp$-$\bar{K}^0 pn$

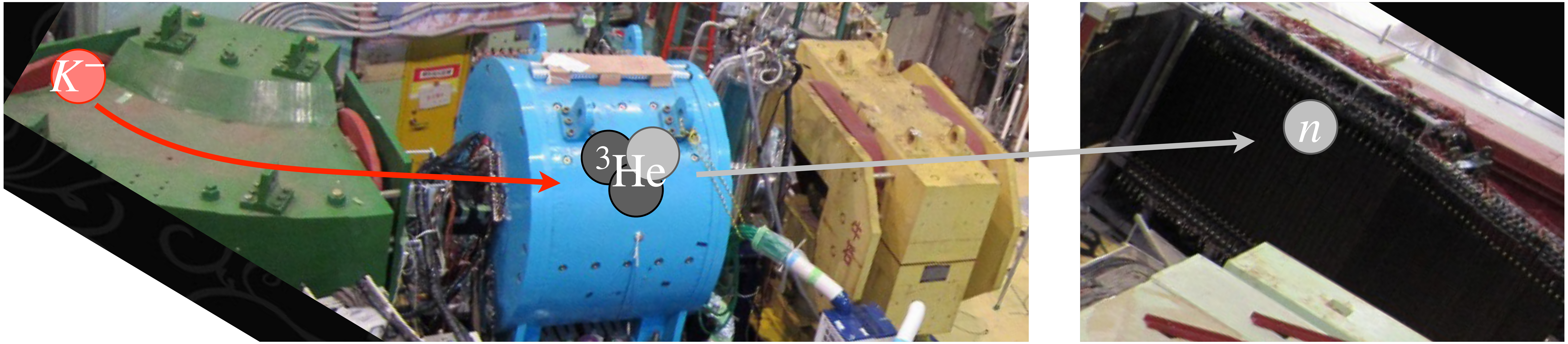
produced by the $^3\mathrm{He}(K^-, n)$ reaction

reconstructed from the Λp decay



Beam spectrometer

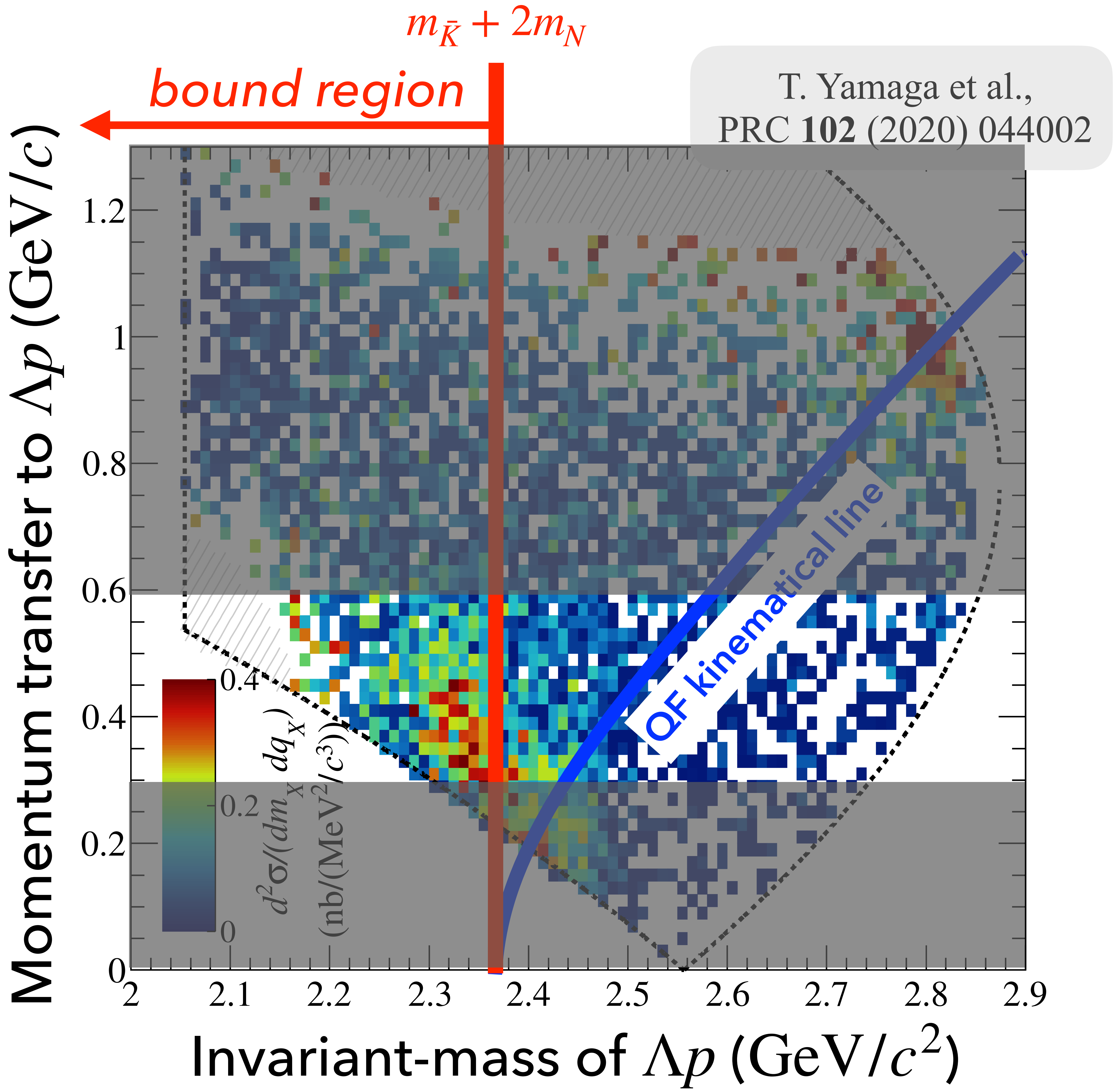
Forward spectrometer



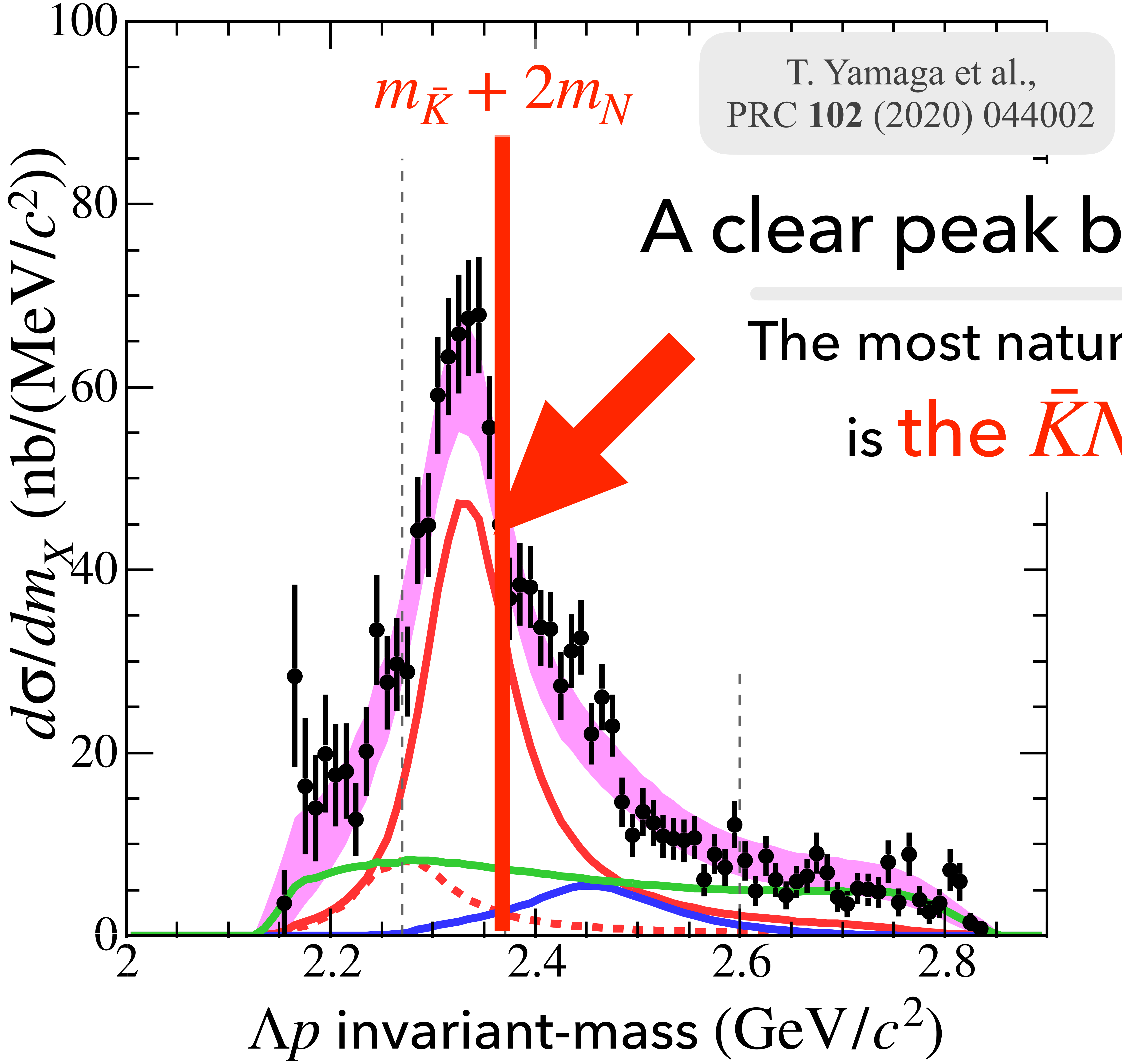
Cylindrical detector system

To detect "K^-pp" $\rightarrow \Lambda p \rightarrow (p\pi^-)p$

Experimental study so far



Experimental study so far



A clear peak below $m_{\bar{K}} + 2m_N$

The most natural interpretation is the $\bar{K}NN$ signal.

Experimental study so far

	BE	Γ
J-PARC E15 PRC **102** (2020) 044002	42 ± 3 (stat.) $^{+3}_{-4}$ (syst.) MeV	100 ± 7 (stat.) $^{+19}_{-9}$ (syst.) MeV

* Obtained as peak position & width of simple Breit-Wigner

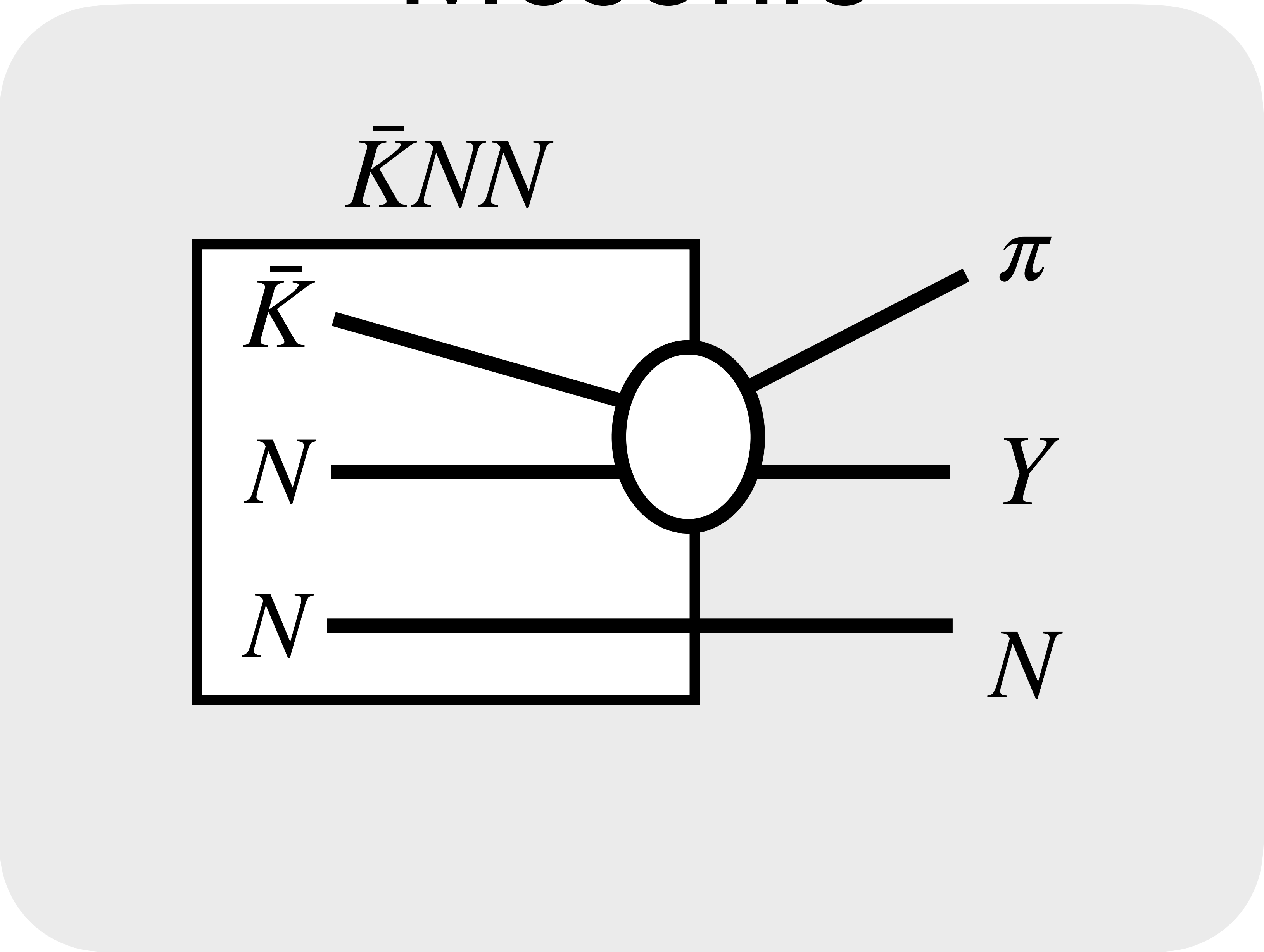
Consistent **Exp > Theor**

S. Ohnishi et al., Phys. Rev. C **95** (2017) 065202	26 – 28 MeV	31 – 59 MeV
N. Shevchenko, Few-Body Syst. **61** (2020) 27	29 – 30 MeV	46 – 47 MeV
A. Dote et al., Phys. Lett. B **784** (2018) 405	14 – 59 MeV	16 – 38 MeV

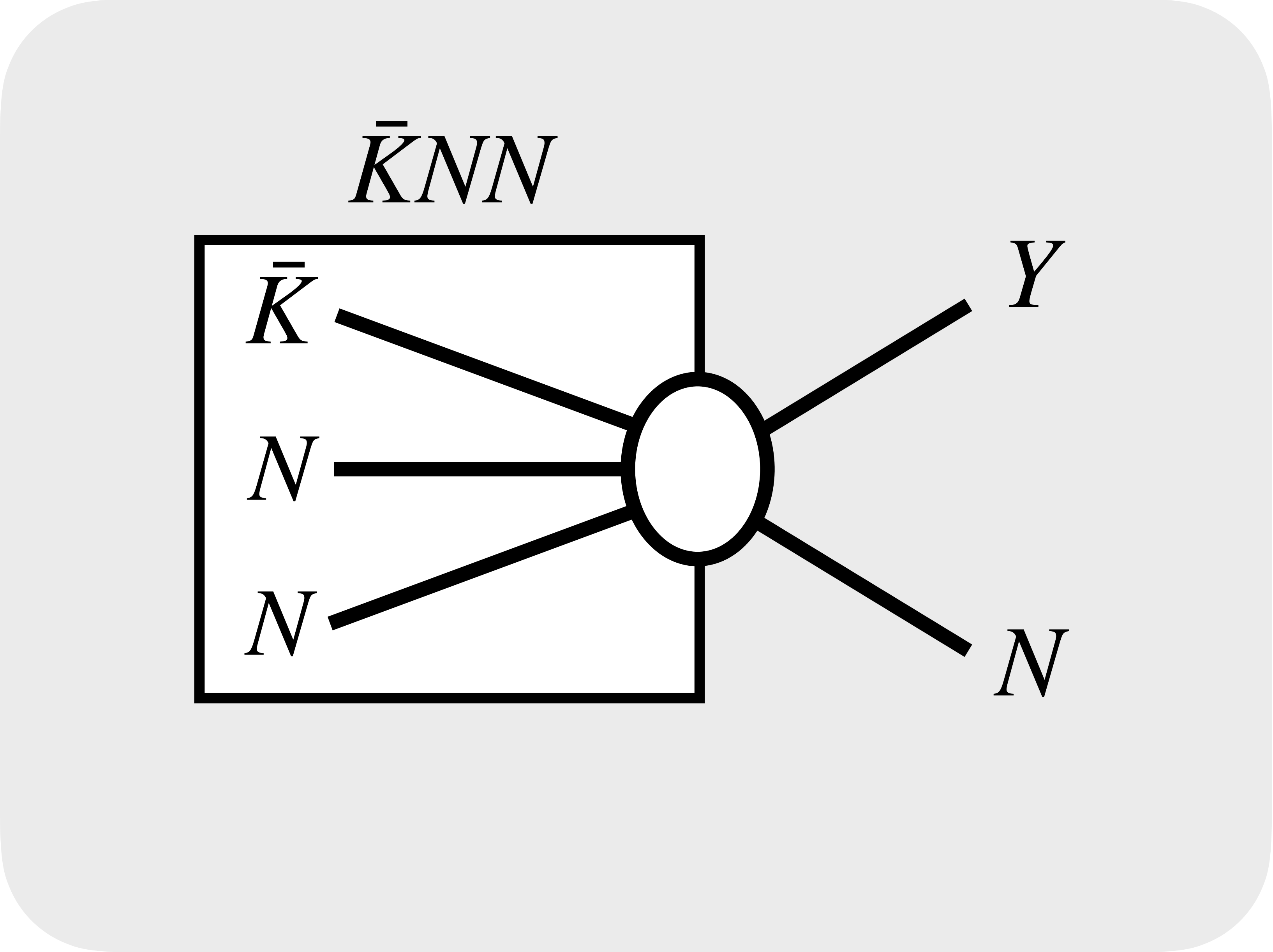
* Mesonic decay width only

$\bar{K}NN$ decay

Mesonic



Non-mesonic



2N absorption

The non-mesonic fraction

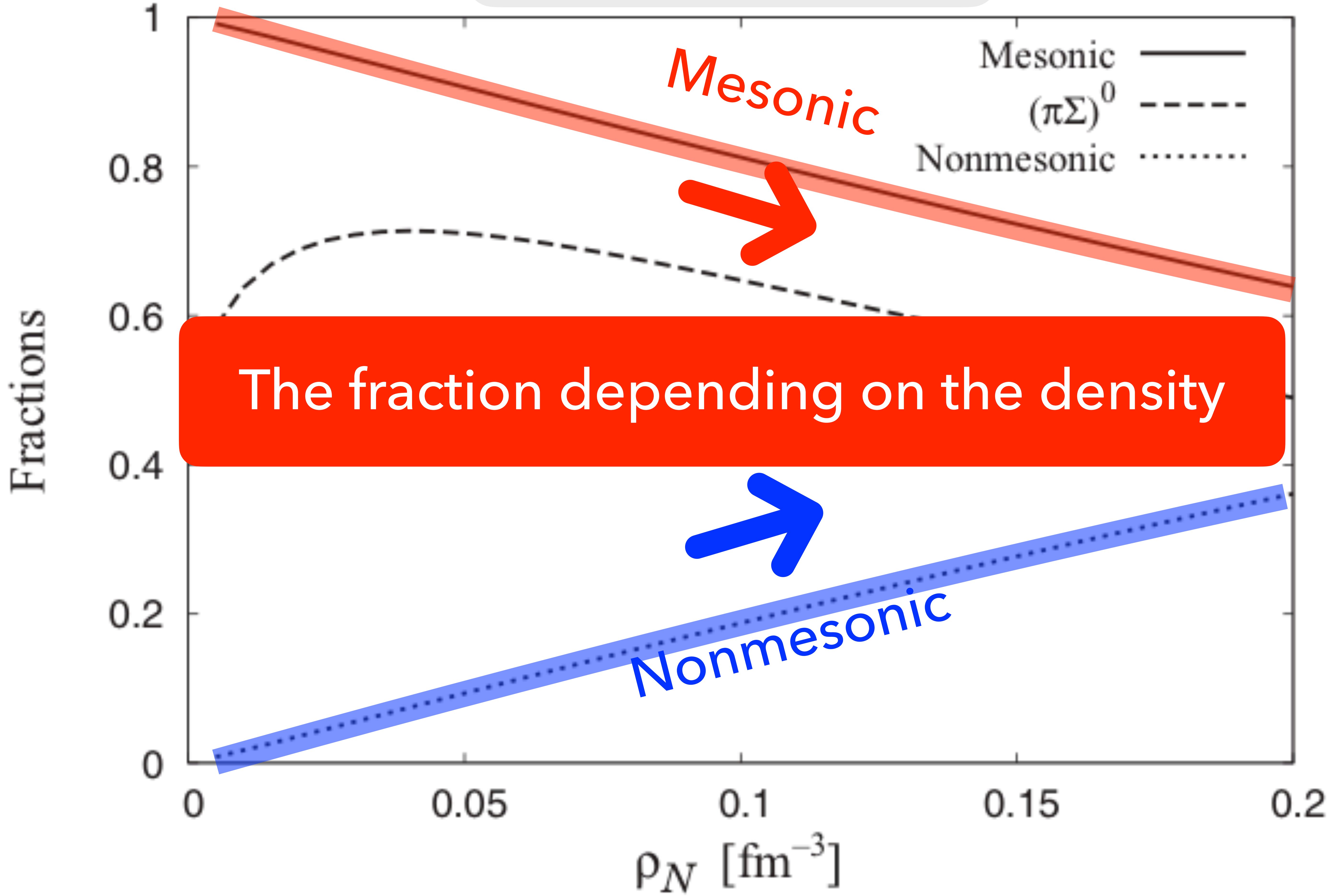
in stopped-K^- experiments

Target	Non-mesonic / mesonic ratio	
p	$100\,\%$ mesonic	Nucl. Phys. B **33**, (1971) 493. Nucl. Phys. B **139**, (1978) 61.
d	$\sim 1\,\%$	Phys.Rev.D**1**, (1970) 1883.
^{4}He	$\sim 20\,\%$	Phys.Rev.D**1**, (1970) 1267.

The non-mesonic fraction

theoretical calculation

T. Sekihara *et al.*,
Phys. Rev. C **86** (2012) 065205



The non-mesonic fraction

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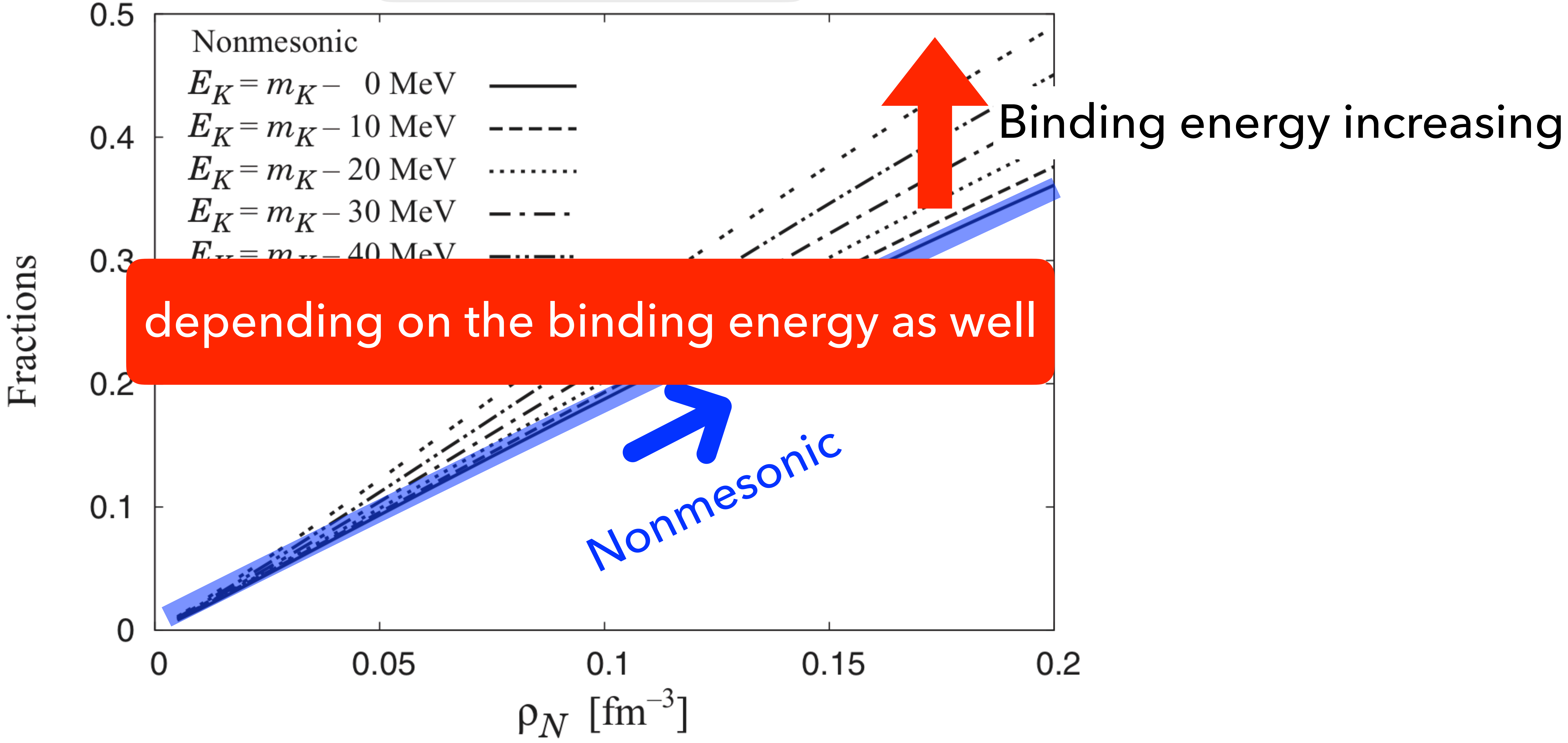
Phys. Rev. C **86** (2012) 065205



The non-mesonic fraction

Calculated decay width of $\bar{K}NN$

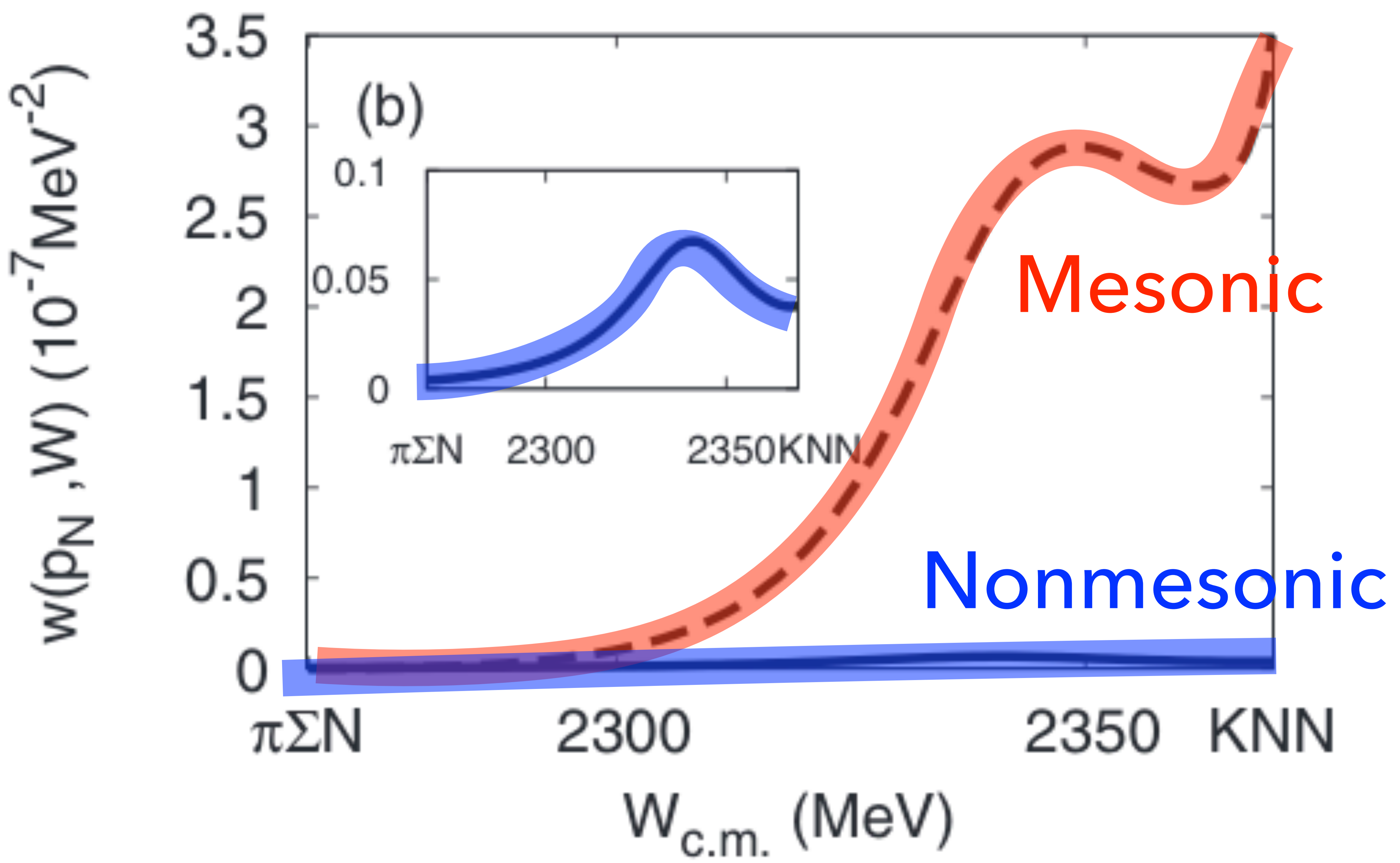
M. Bayar and E. Oset,
Phys. Rev. C 88 (2013) 044003

$$\Gamma_{YN} \sim 30 \text{ MeV}$$

$$\Gamma_{\pi YN} \sim 40 - 50 \text{ MeV}$$

S. Ohnishi, et al.,
Phys. Rev. C 88 (2013) 025204.

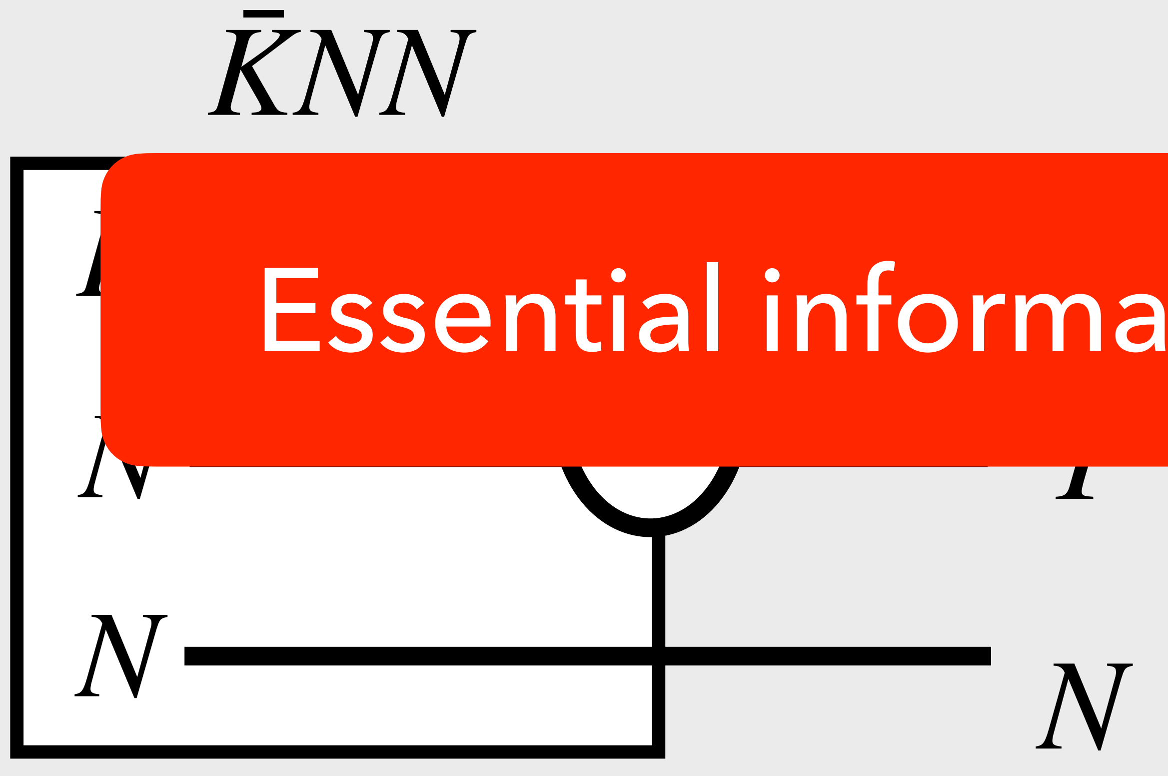
$$\Gamma_{YN} \ll \Gamma_{\pi YN}$$



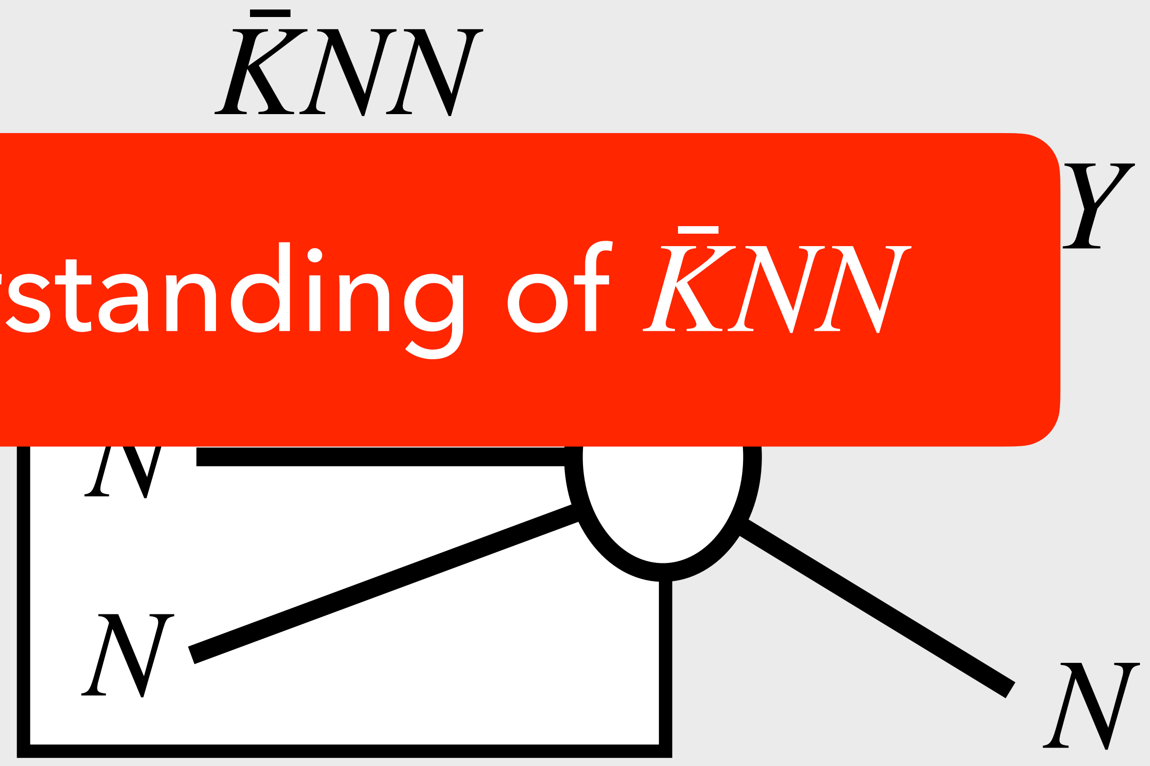
$\bar{K}NN$ decay

Fraction ~ (Internal structure) ⊗ ($\bar{K}N$ interaction)

Mesonic



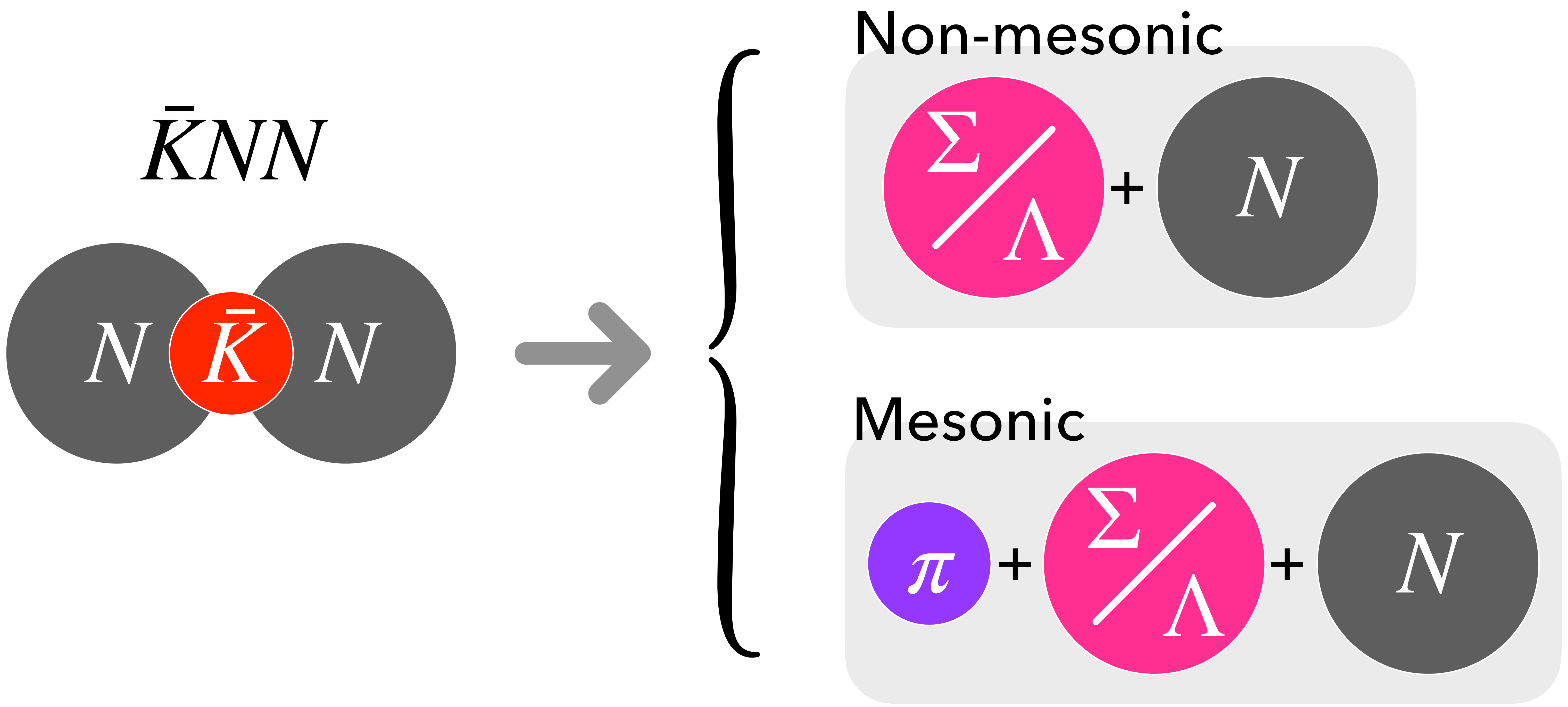
Non-mesonic



2N absorption

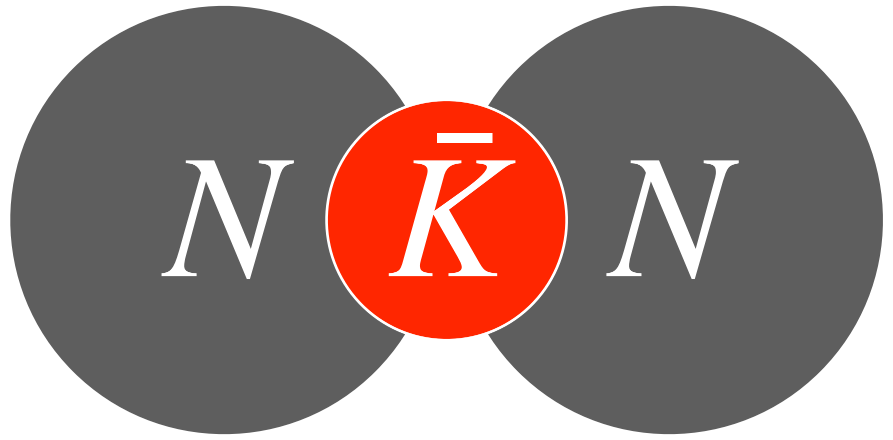
Essential information for further understanding of $\bar{K}NN$

Decay channels of $\bar{K}NN$



Decay channels of $\bar{K}NN$

"$K^- pp$"



Non-mesonic

Need γ/n detectors

Λp | $\Sigma^0 p$ | $\Sigma^+ n$

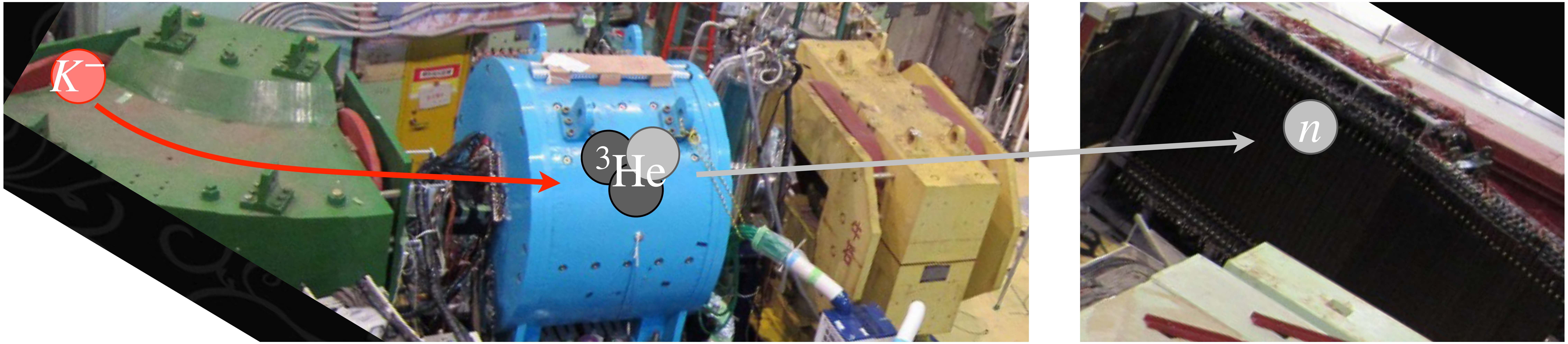
Mesonic

$\pi^0 \Lambda p$	$\pi^+ \Lambda n$
$\pi^0 \Sigma^0 p$	$\pi^- \Sigma^+ p$
$\pi^0 \Sigma^+ n$	$\pi^+ \Sigma^- p$

Can be reconstructed with single-n

Beam spectrometer

Forward spectrometer



Cylindrical detector system

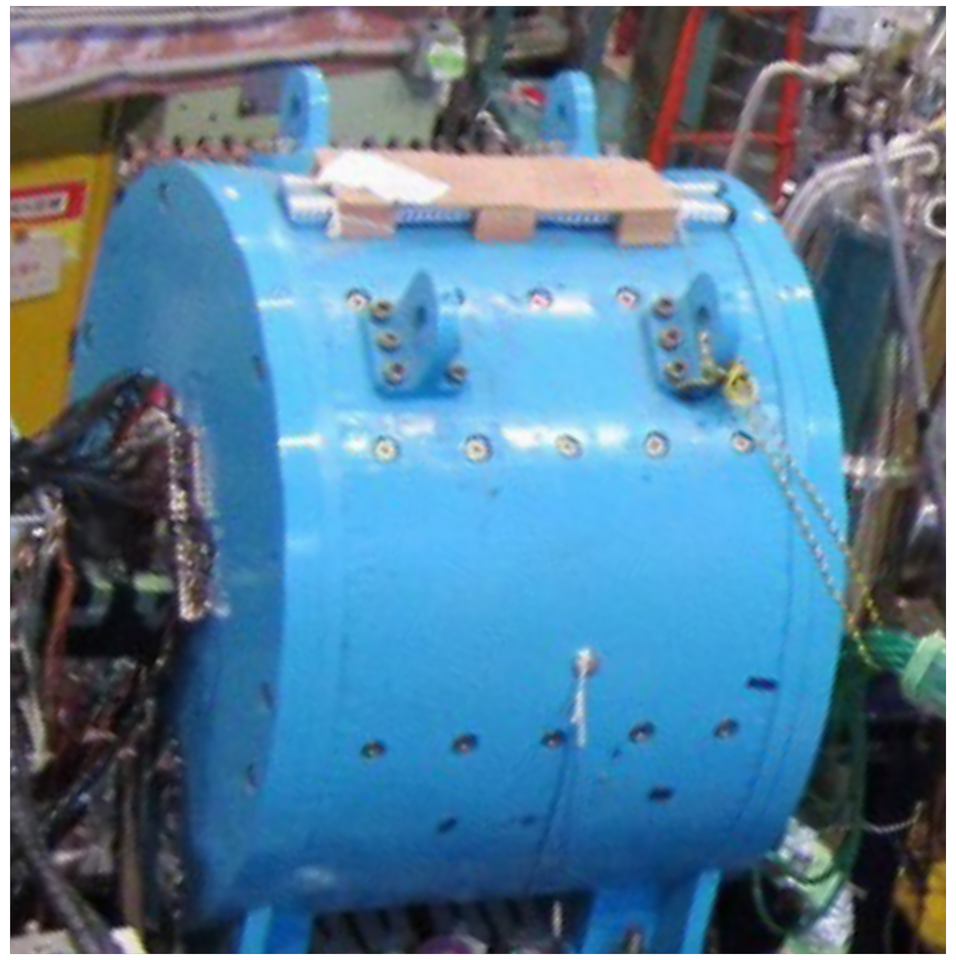
To detect "K^-pp" $\rightarrow \Lambda p \rightarrow (p\pi^-)p$

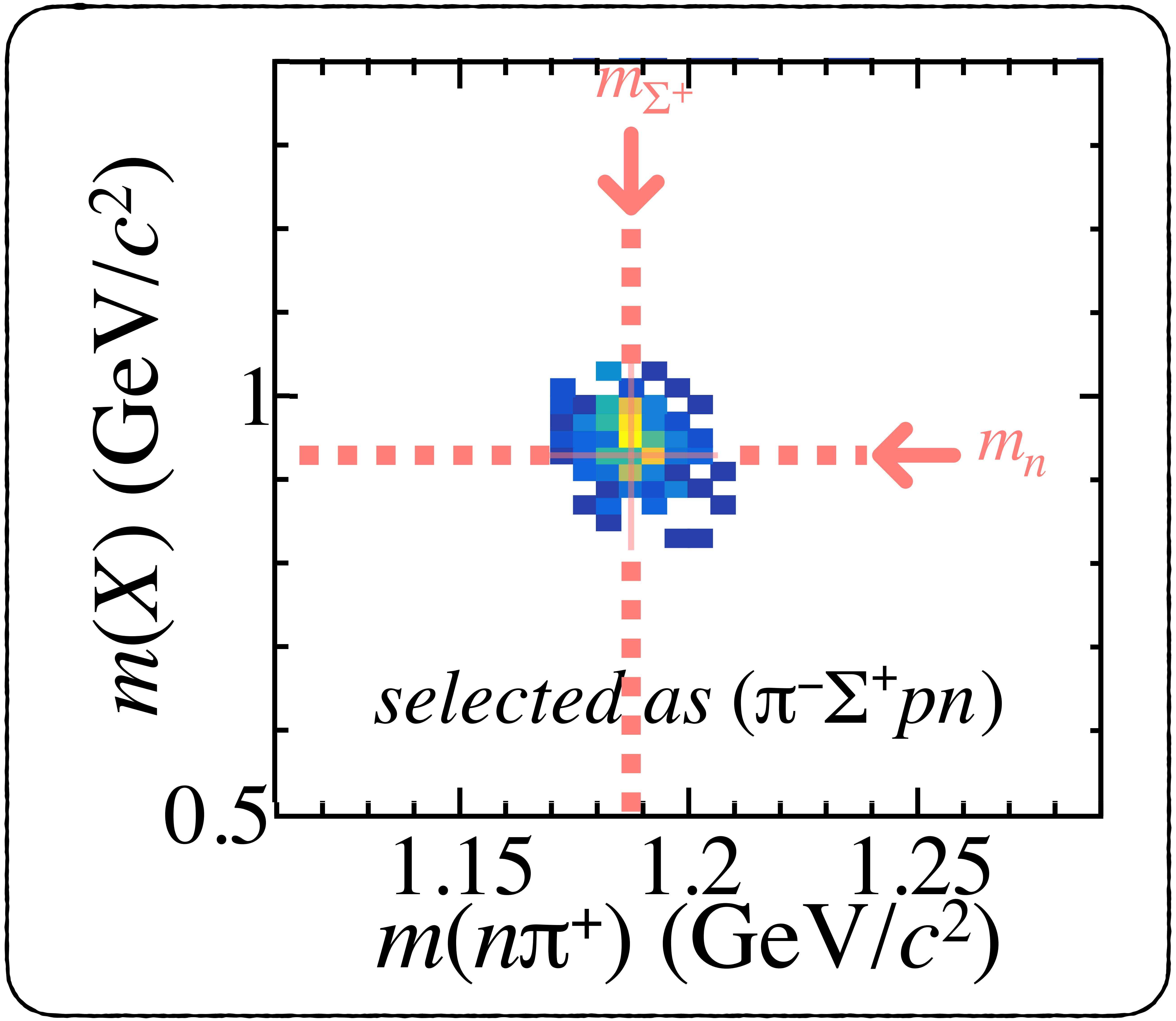
Selection of the $\pi^-\Sigma^+ pn$ final state events

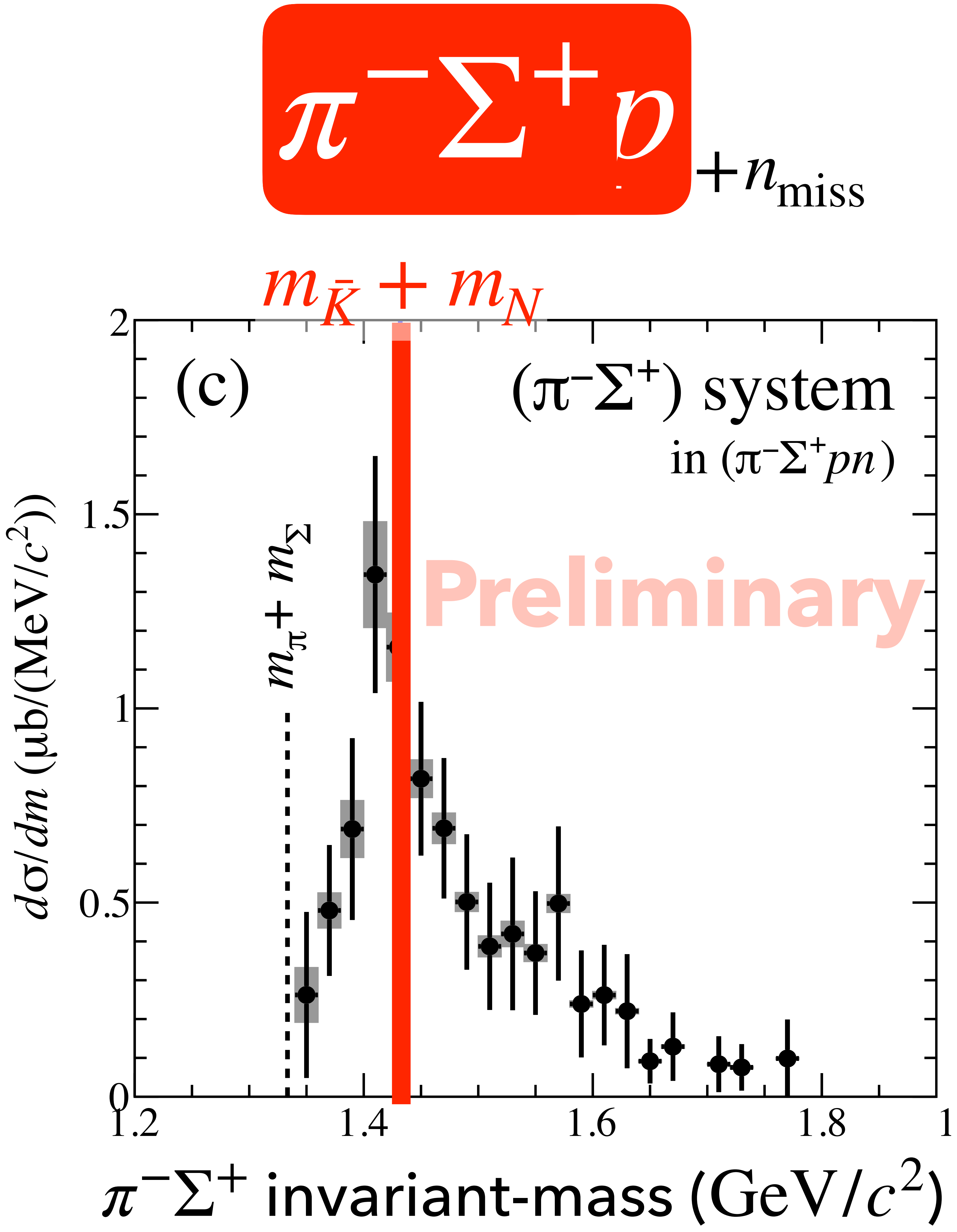
In the case of

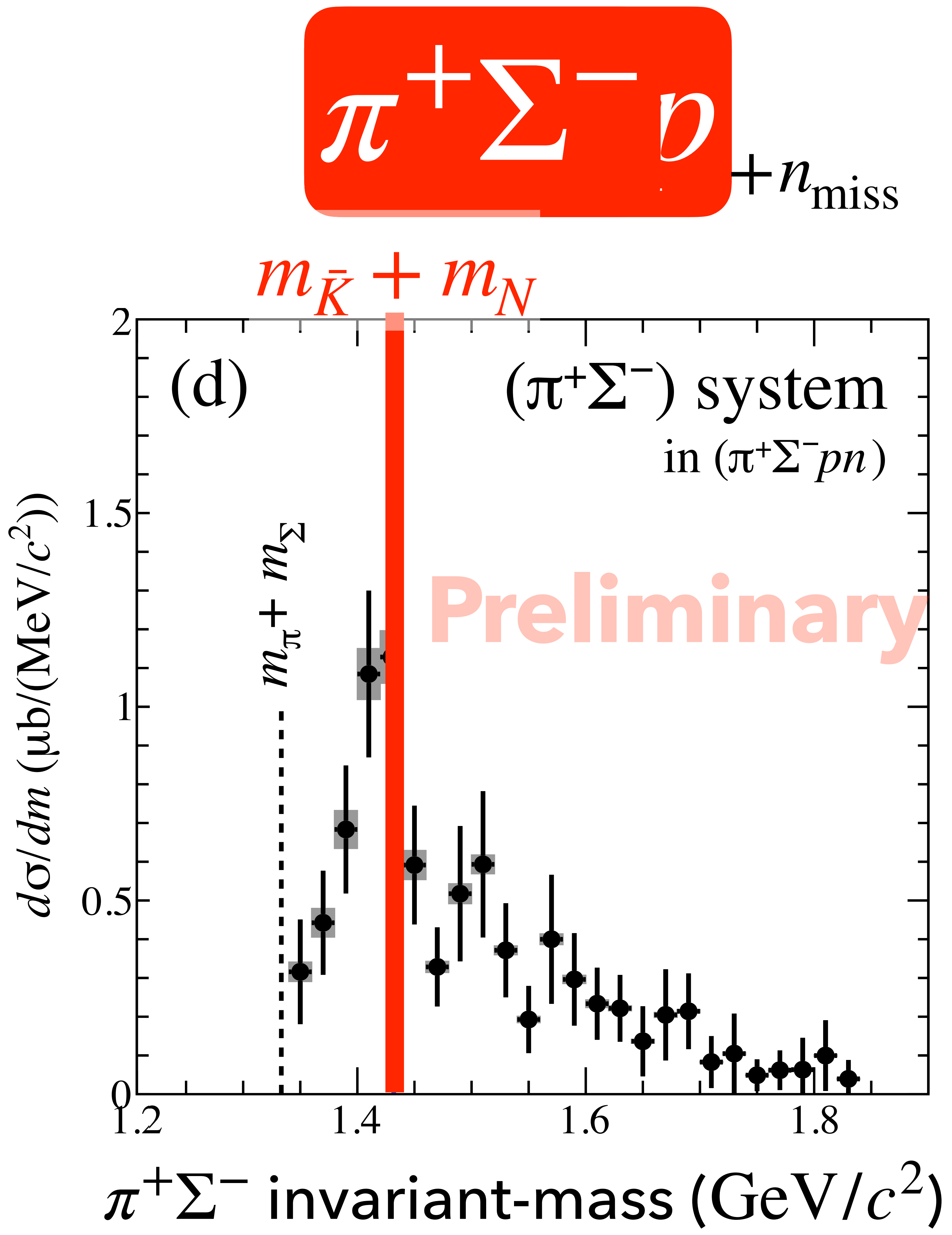
$$\boxed{\pi^-\Sigma^+ p} + n_{\text{miss}}$$

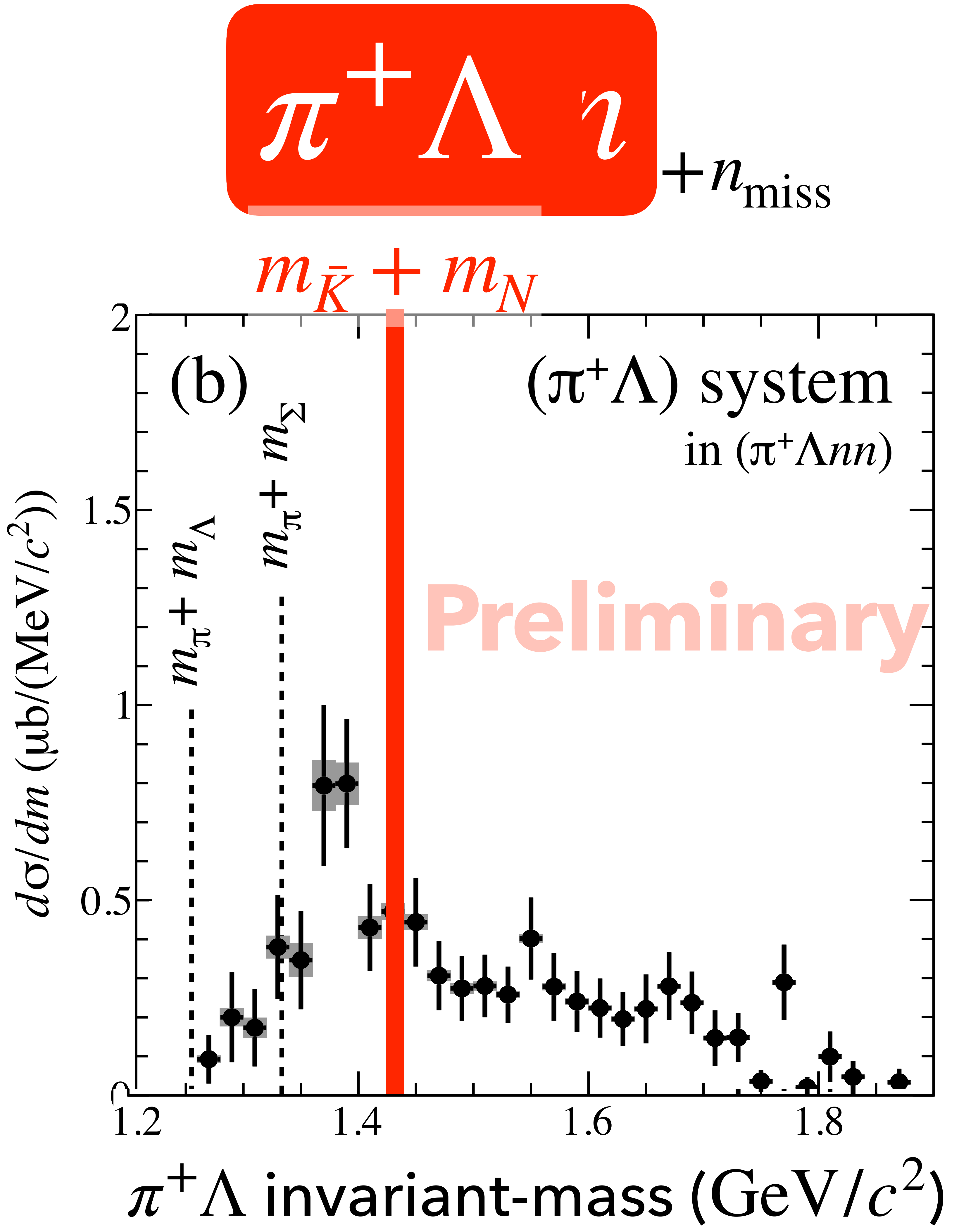
$$\rightarrow \underbrace{\pi^-(\pi^+ n)p}_{\text{Detected with CDS}}$$





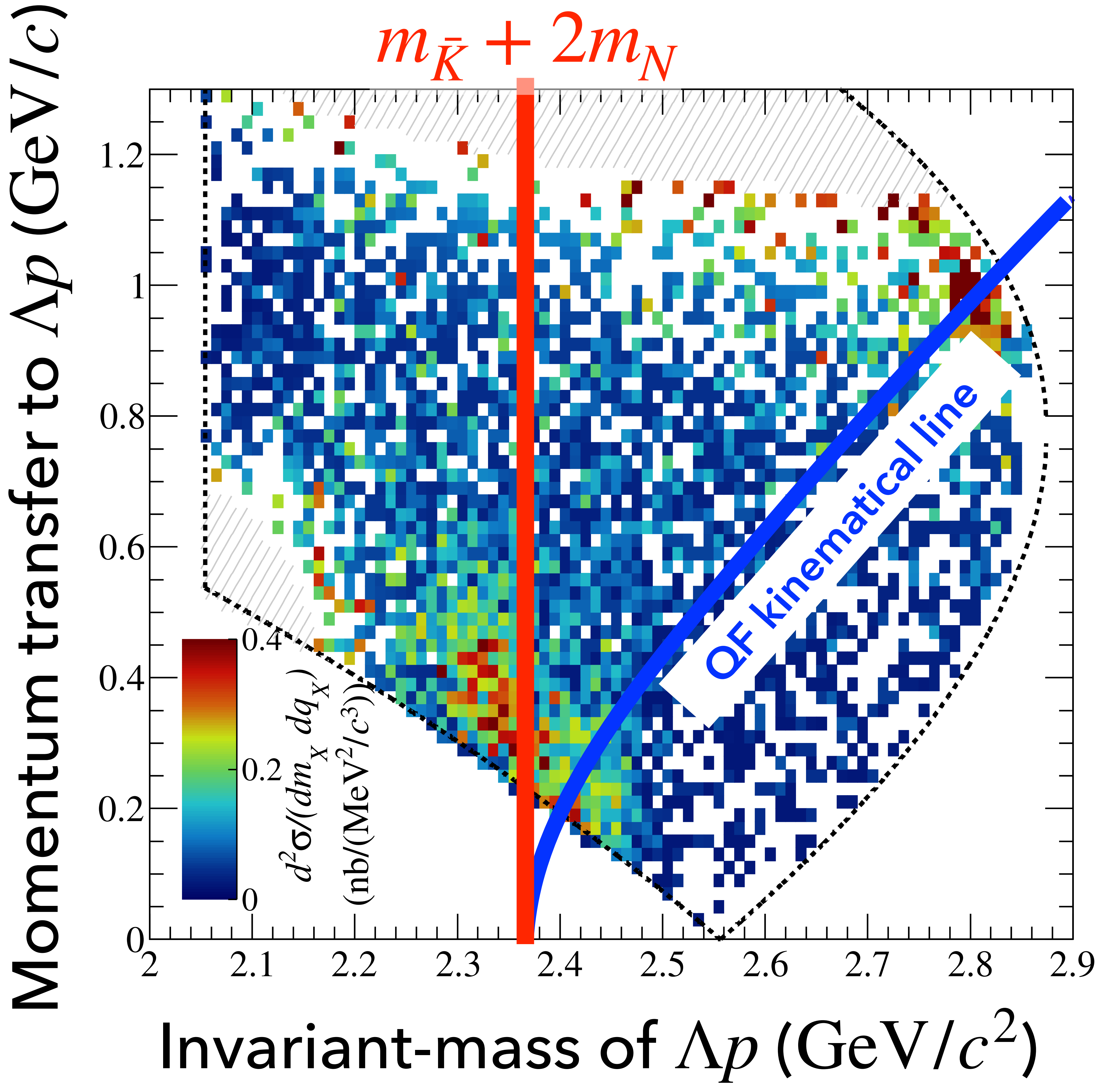




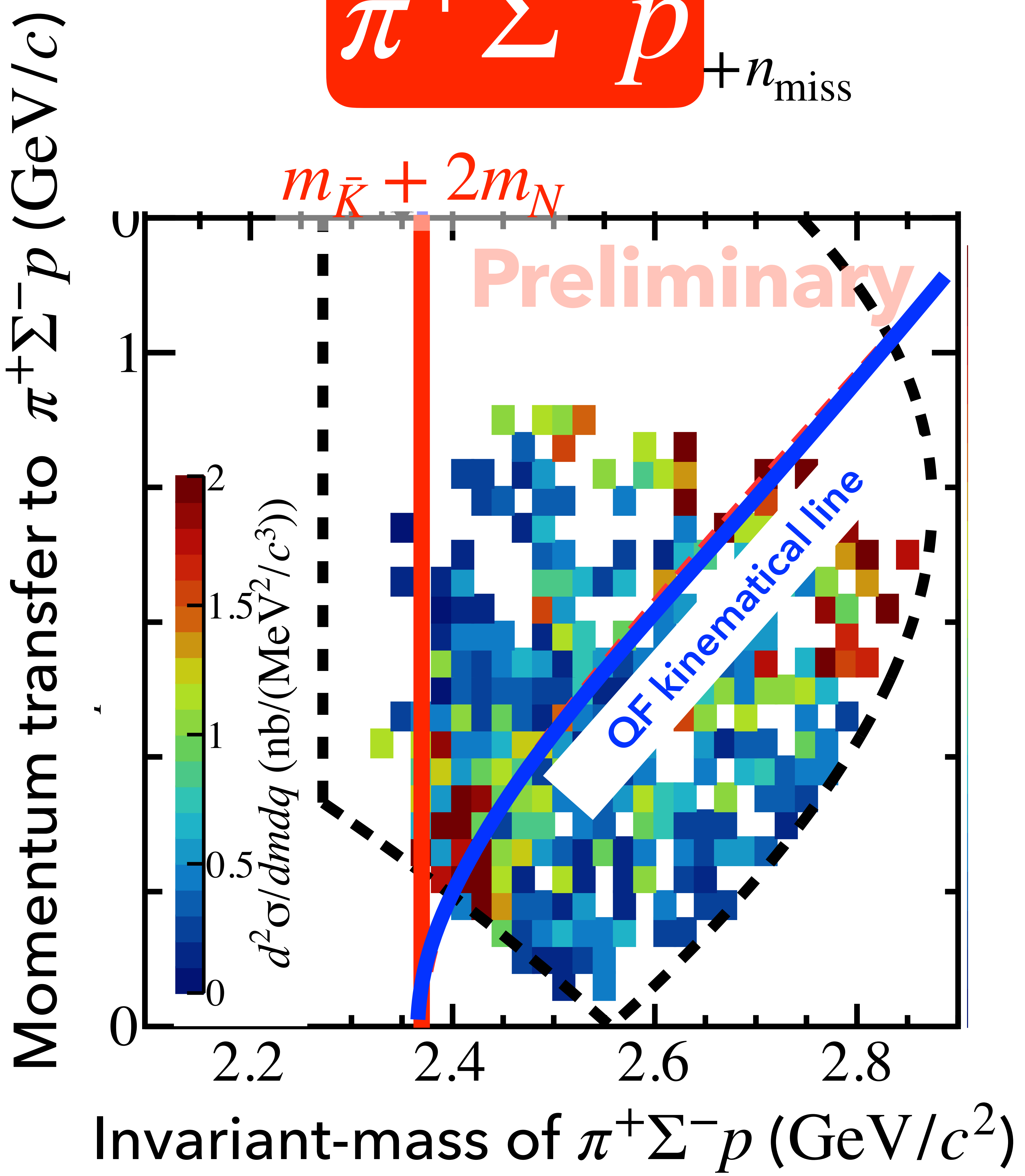


Λ(1405) & Σ(1385) peaks were clearly observed.

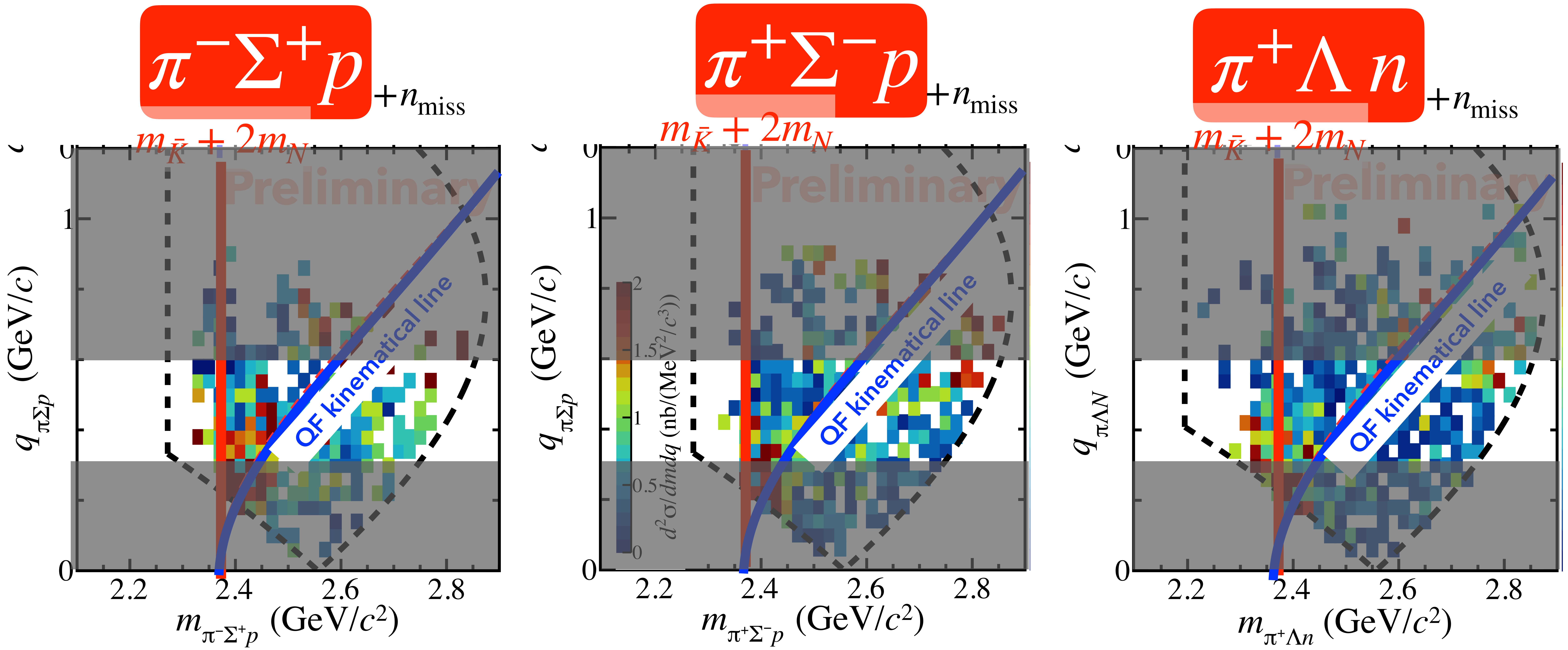
Λp $+n_{\text{miss}}$



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

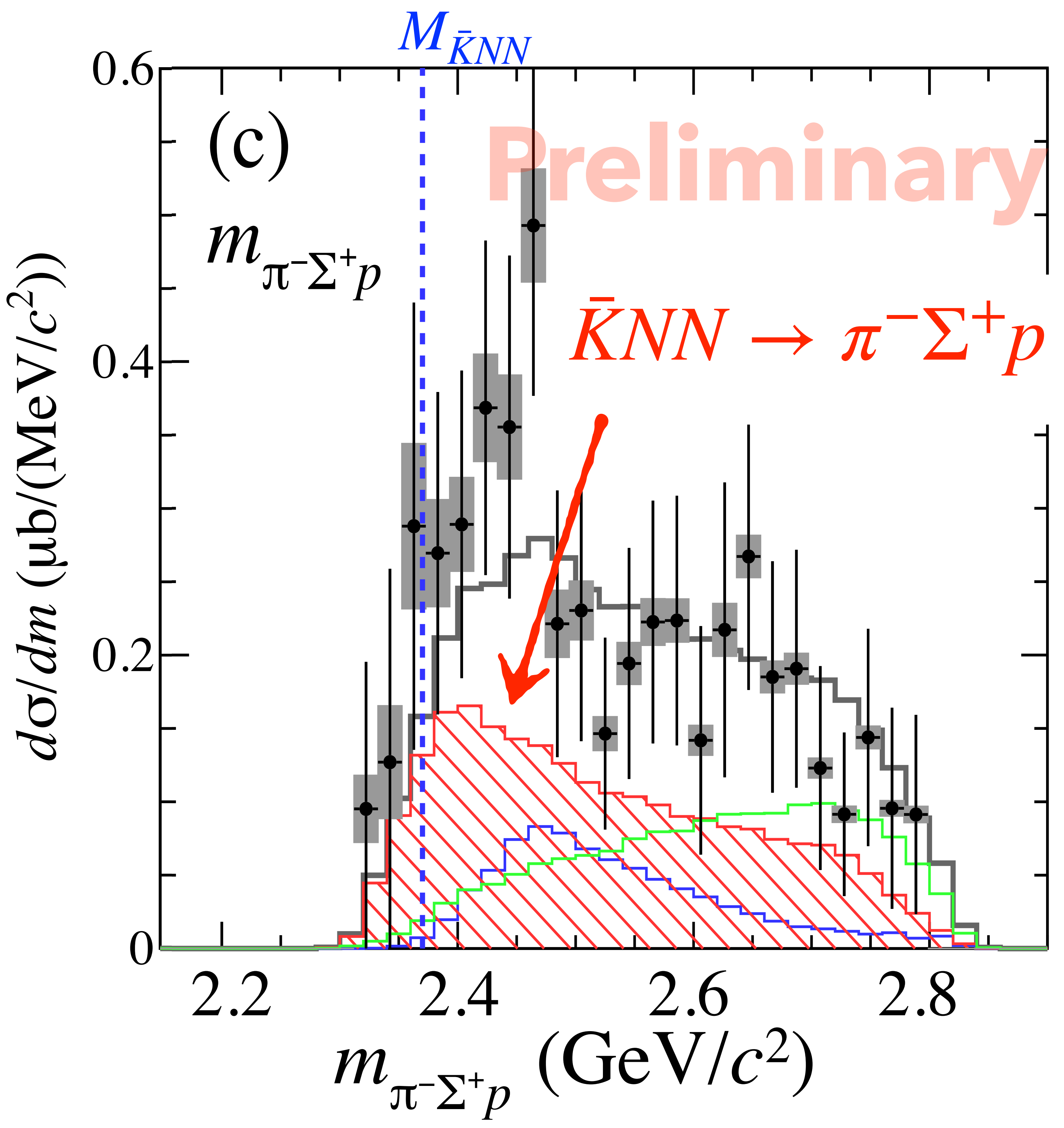


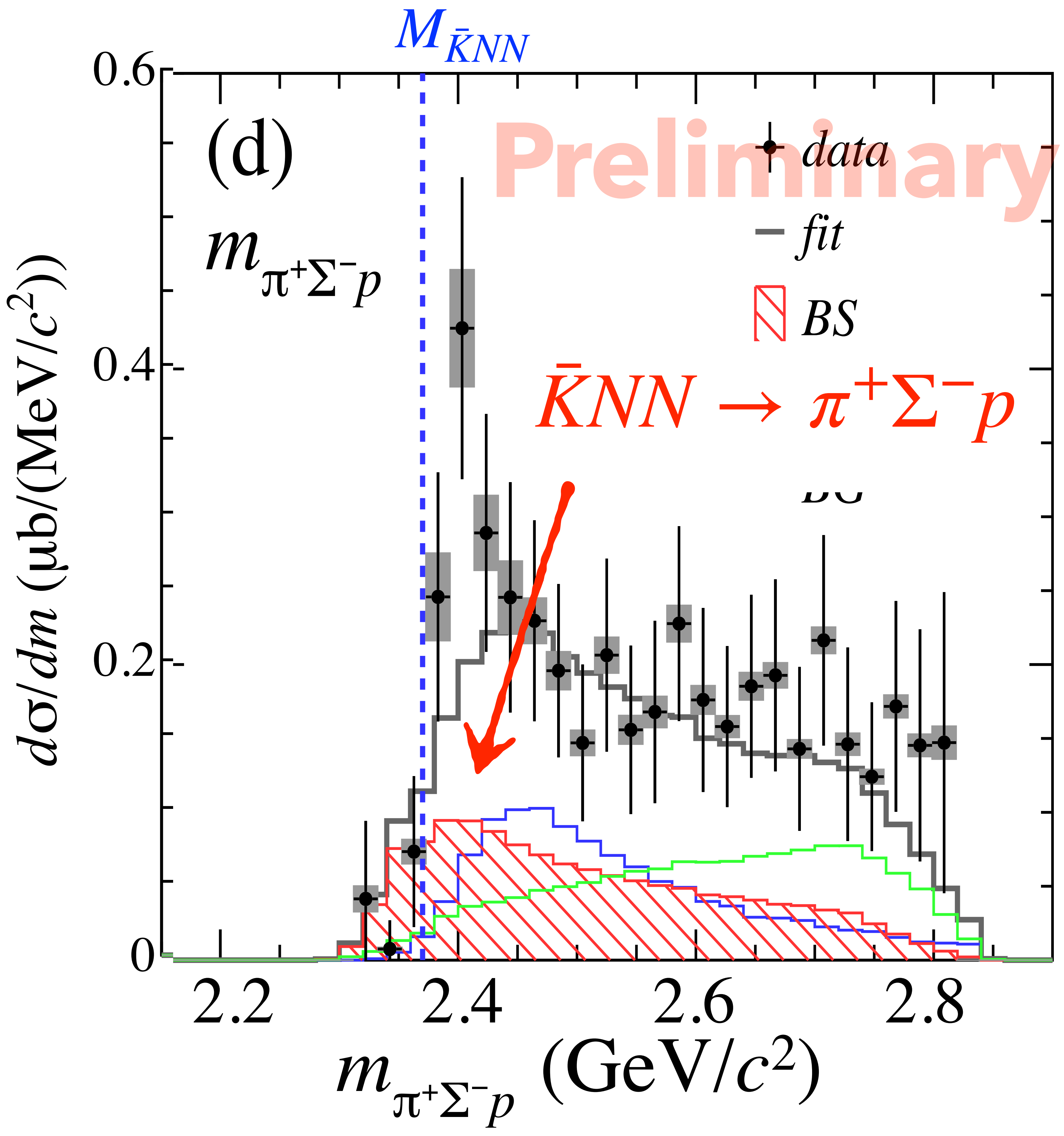
Similar but not clear peak below $m_{\bar{K}} + 2m_N$ due to the phase space

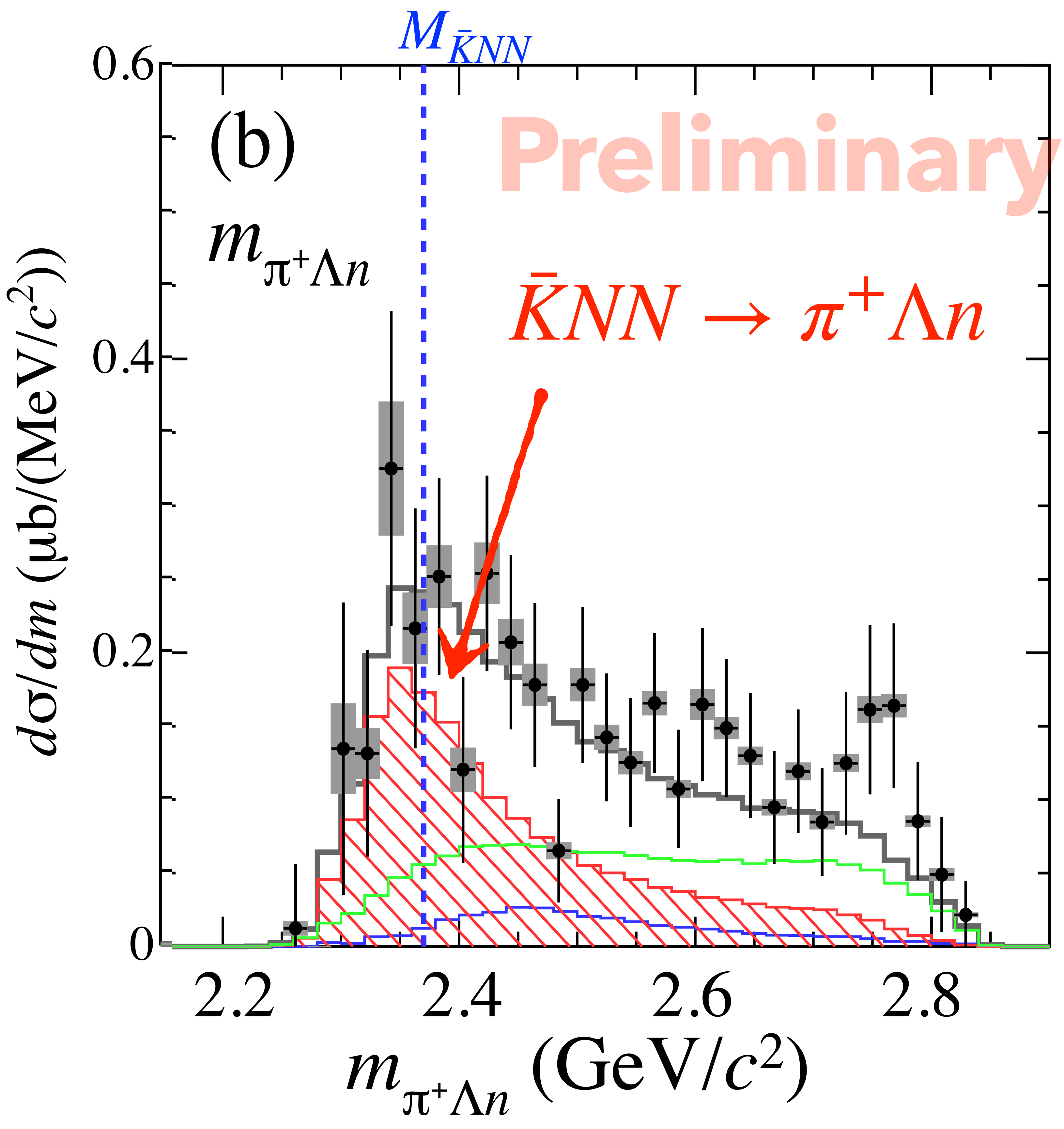


The same fitting procedure is applied for the mesonic channels.

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







Well reproduced but data error is rather large…

Cross section of $\bar{K}NN$

※Statistical error only

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

Preliminary

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

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

Preliminary

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

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

Preliminary

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

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

$$\Gamma_{YN} \ll \Gamma_{\pi YN}$$

$\Gamma_{\pi YN}$ would be $\mathcal{O}(10)$ times larger than Γ_{YN}.

$$\Gamma_{\pi^+\Lambda n} \sim \Gamma_{\pi^\mp\Sigma^\pm p}$$

$$\Gamma_{YN} \ll \Gamma_{\pi YN}$$

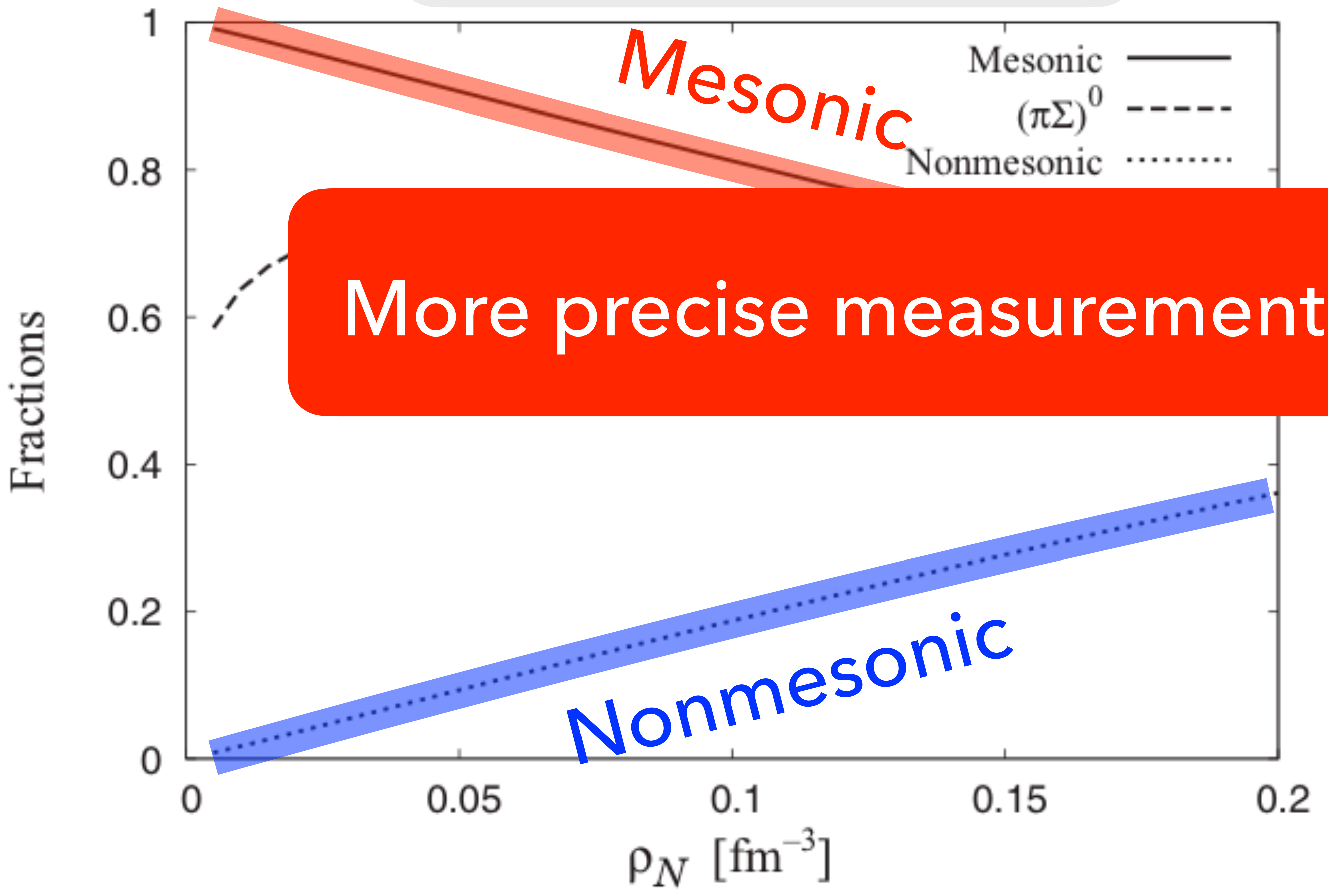
Non-mesonic fraction seems to be smaller than calc.

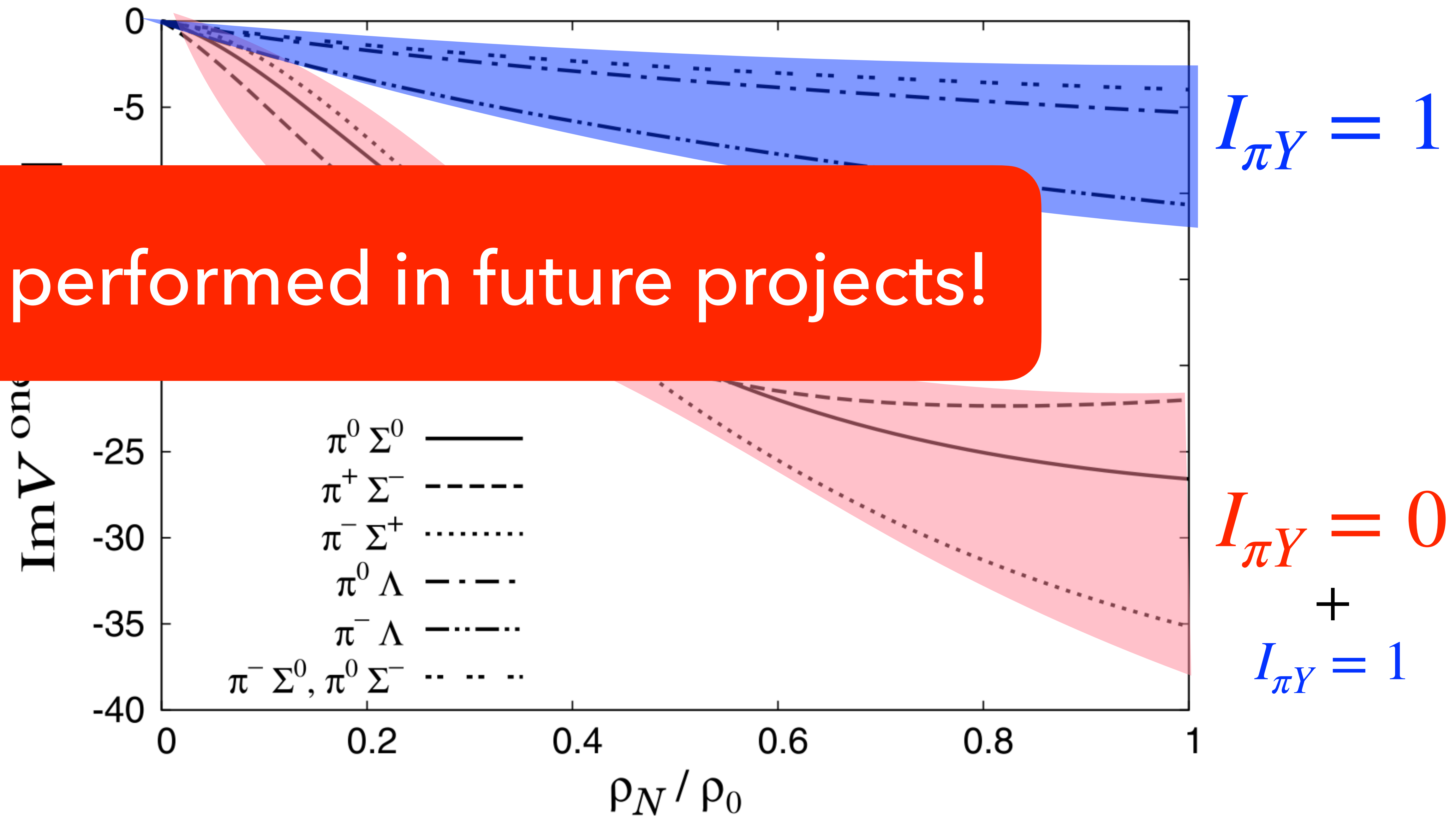
T. Sekihara *et al.*,
Phys. Rev. C **86** (2012) 065205

$$\Gamma_{\pi^+\Lambda n} \sim \Gamma_{\pi^\mp\Sigma^\pm p}$$

$I_{\pi Y} = 1$ fraction seems to be larger than calc.

T. Sekihara *et al.*,
Nucl. Phys. A **914** (2013) 338

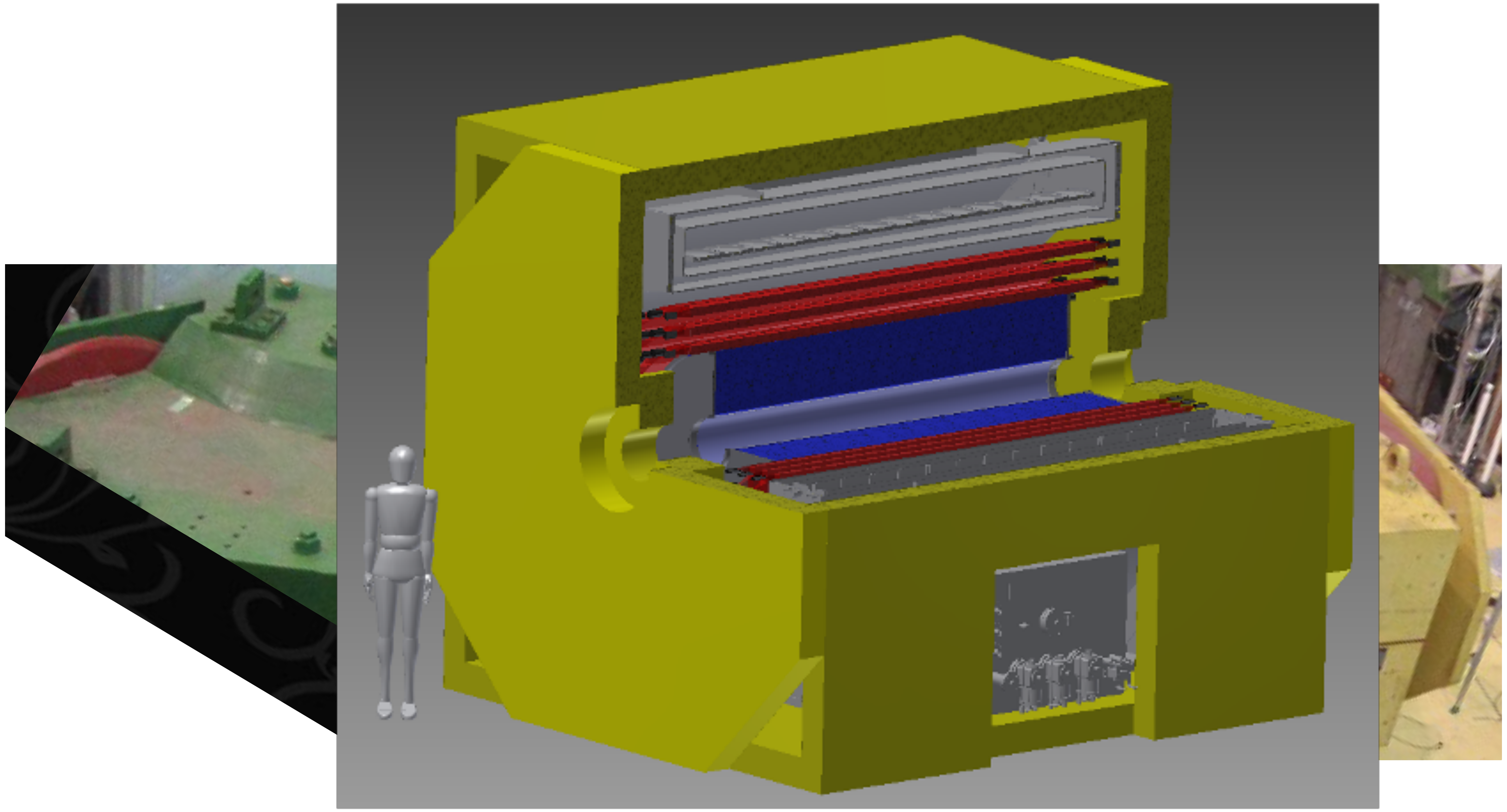


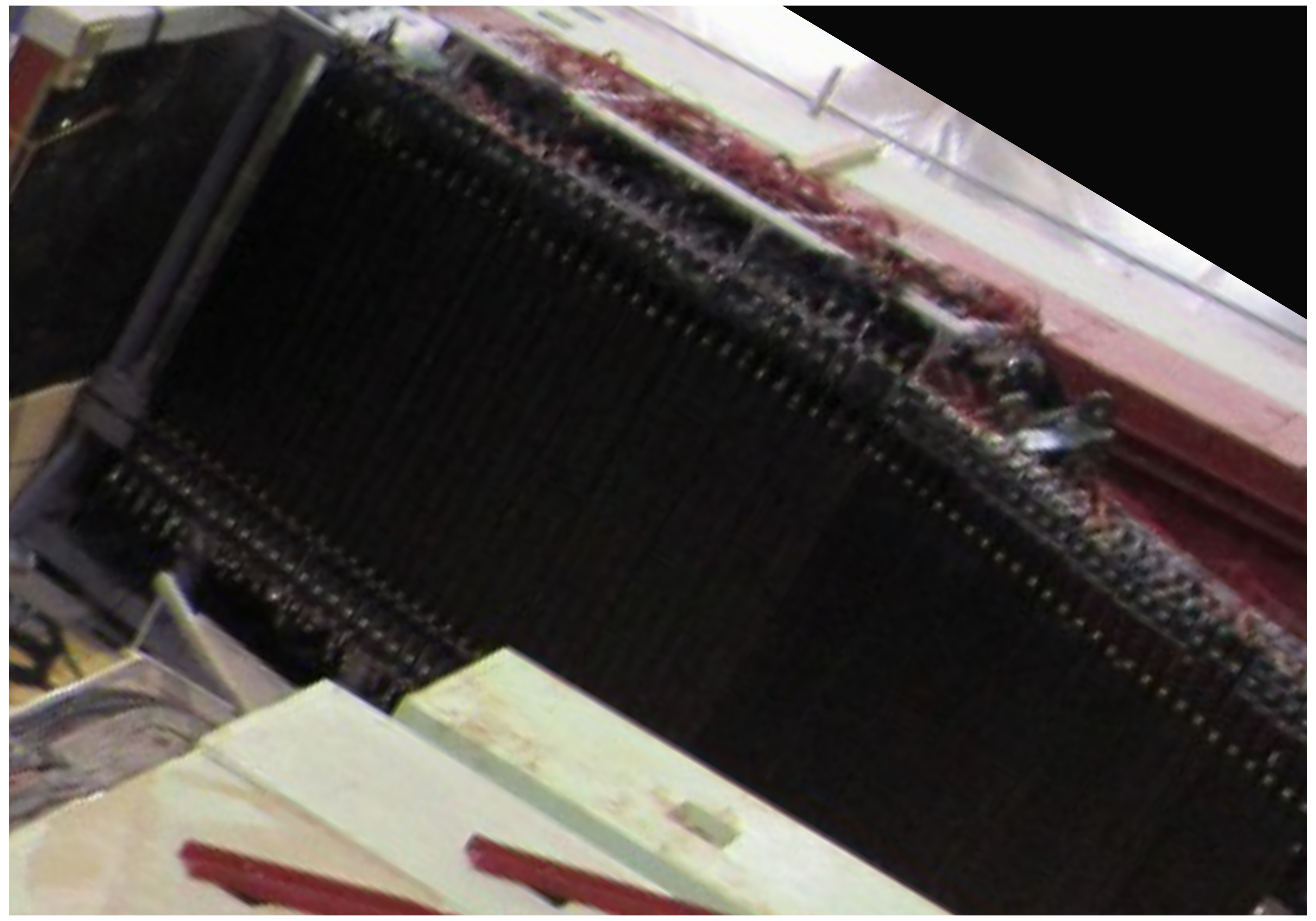


More precise measurement will be performed in future projects!

Future project

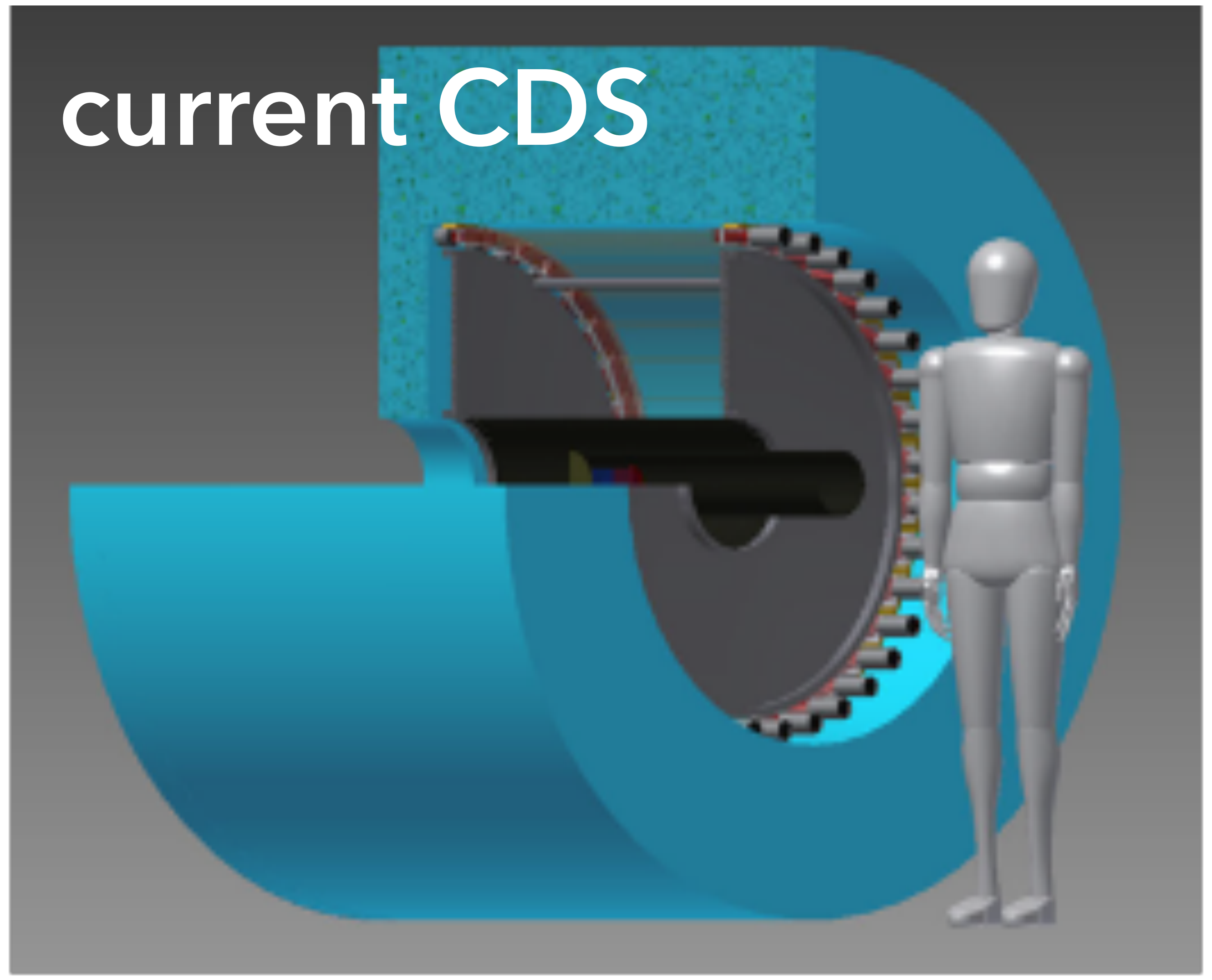
== Systematic measurement for kaonic nuclei ==

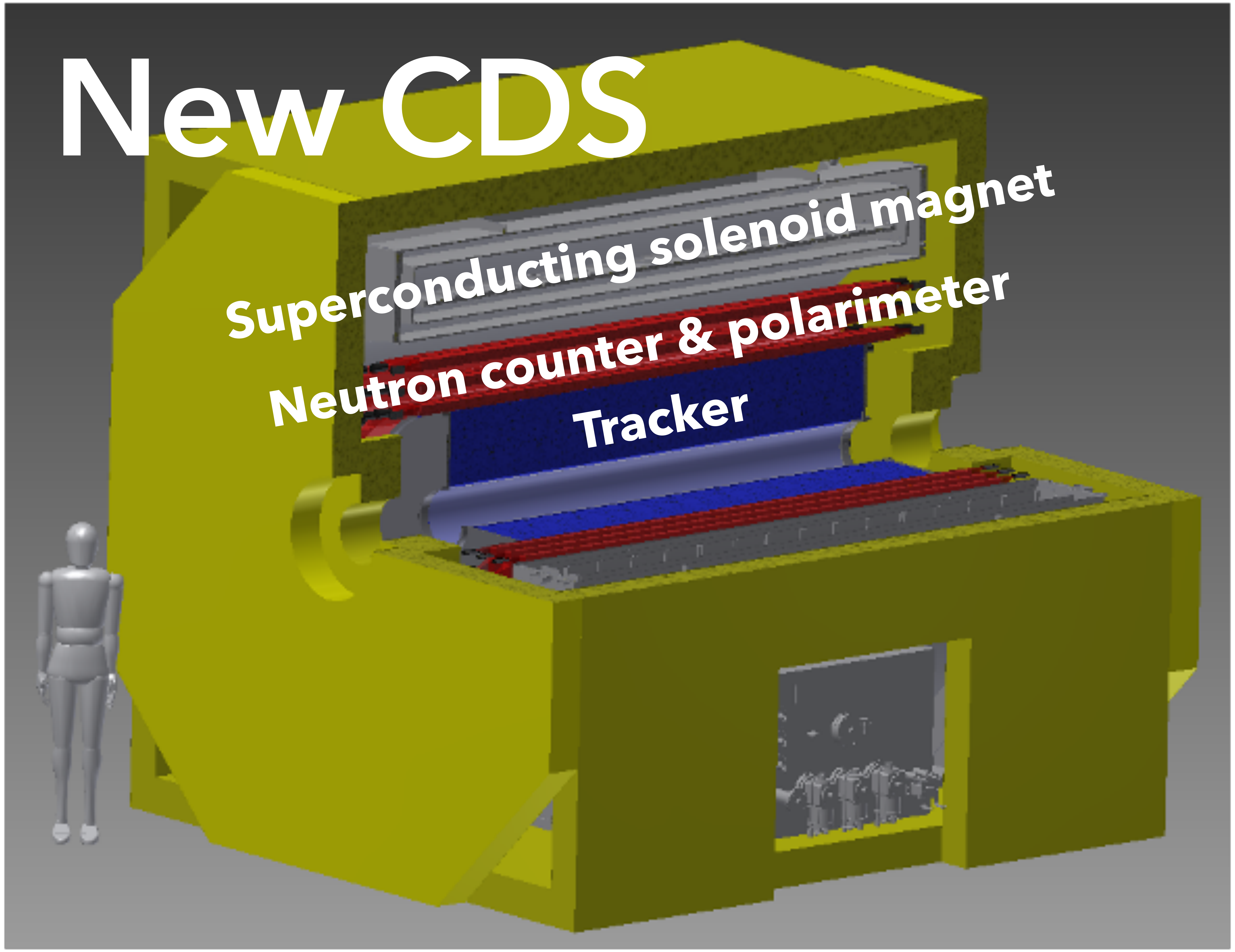




Cylindrical detector system

To detect "$K^{-}pp$" $\rightarrow \Lambda p \rightarrow (p\pi^{-})p$


current CDS


New CDS
Superconducting solenoid magnet
Neutron counter & polarimeter
Tracker


Construction has been started
(Completed in 2025)

Programs for $\bar{K}$-nuclei

Lighter system

$\Lambda(1405)$

with wider q-region

$d(K^-, n)$ reaction

$\pi^\pm\Sigma^\mp$ decay

&

$\pi^0\Sigma^0$ decay as well

$\bar{K}NN$ system

J^π determination

To confirm the existence more robustly

Measuring $d\sigma/dq$ & $\alpha_{\Lambda p}$

Search for $(\bar{K}NN)^{I_z=-1/2}$

Isospin partner of observed $\bar{K}NN$

$\bar{K}NN \to \Lambda n$ decay

Decay branch

Non-mesonic	Mesonic
Λp, $\Sigma^0 p$, $\Sigma^+ n$	$\pi\Lambda N$, $\pi\Sigma N$

Heavier system

$\bar{K}NNN$ system

Door to heavier system

$^4\mathrm{He}(K^-, N)$ reaction

$K^-ppn - \bar{K}^0pnn$ (I=0)

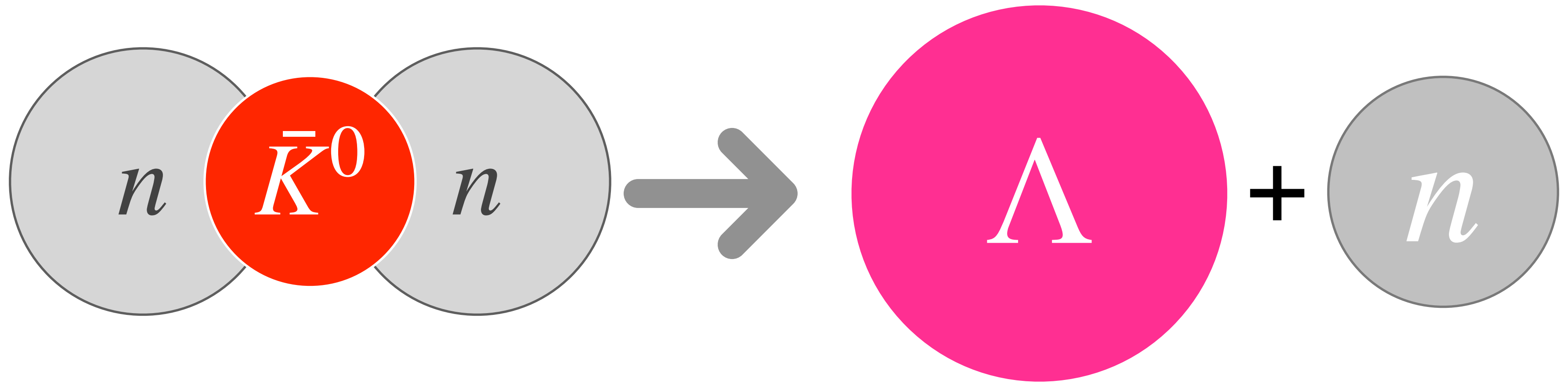
$\bar{K}NNNN$ system

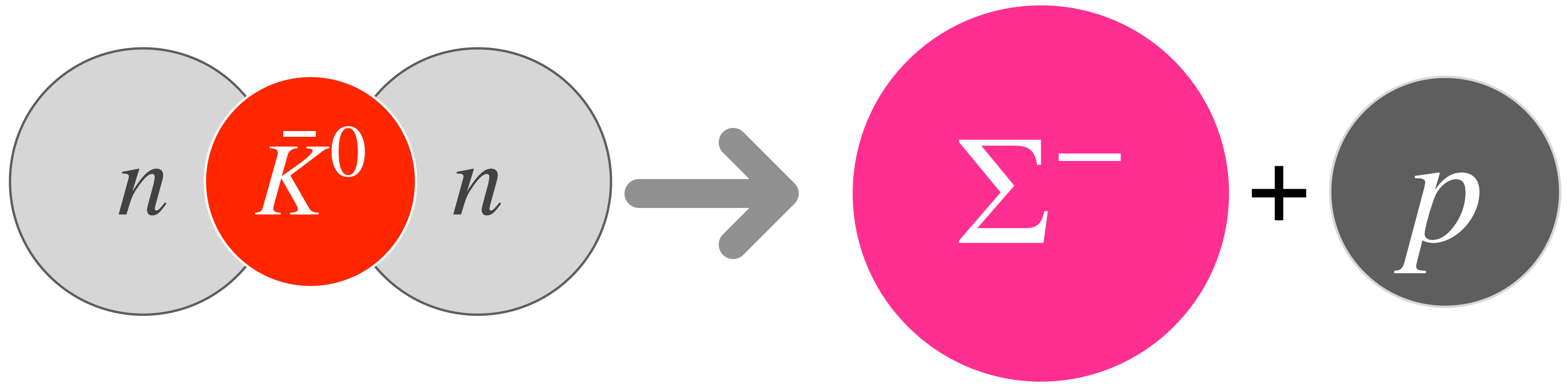
Expected large B.E. & high density

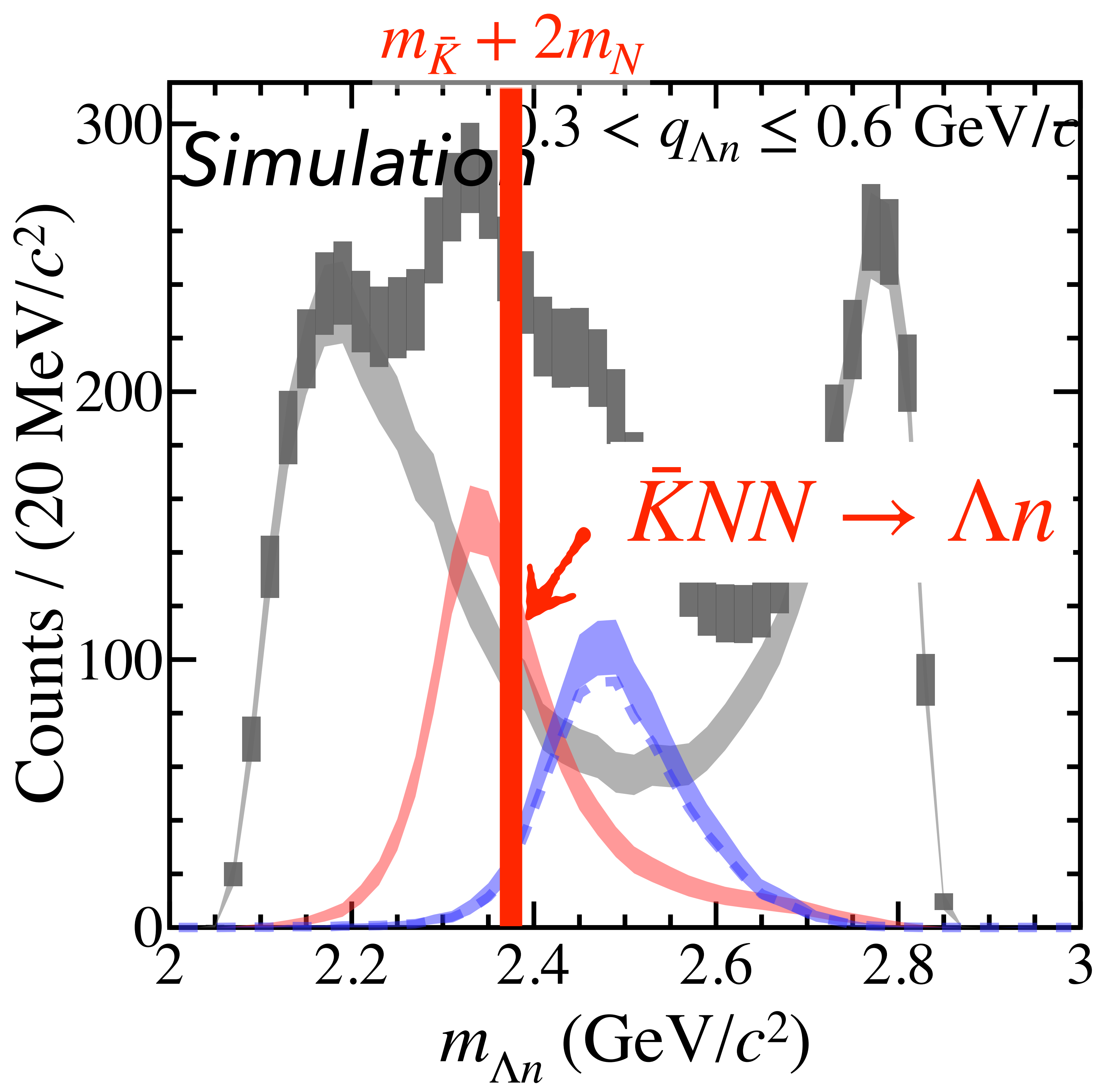
$^6\mathrm{Li}(K^-, d)$ reaction

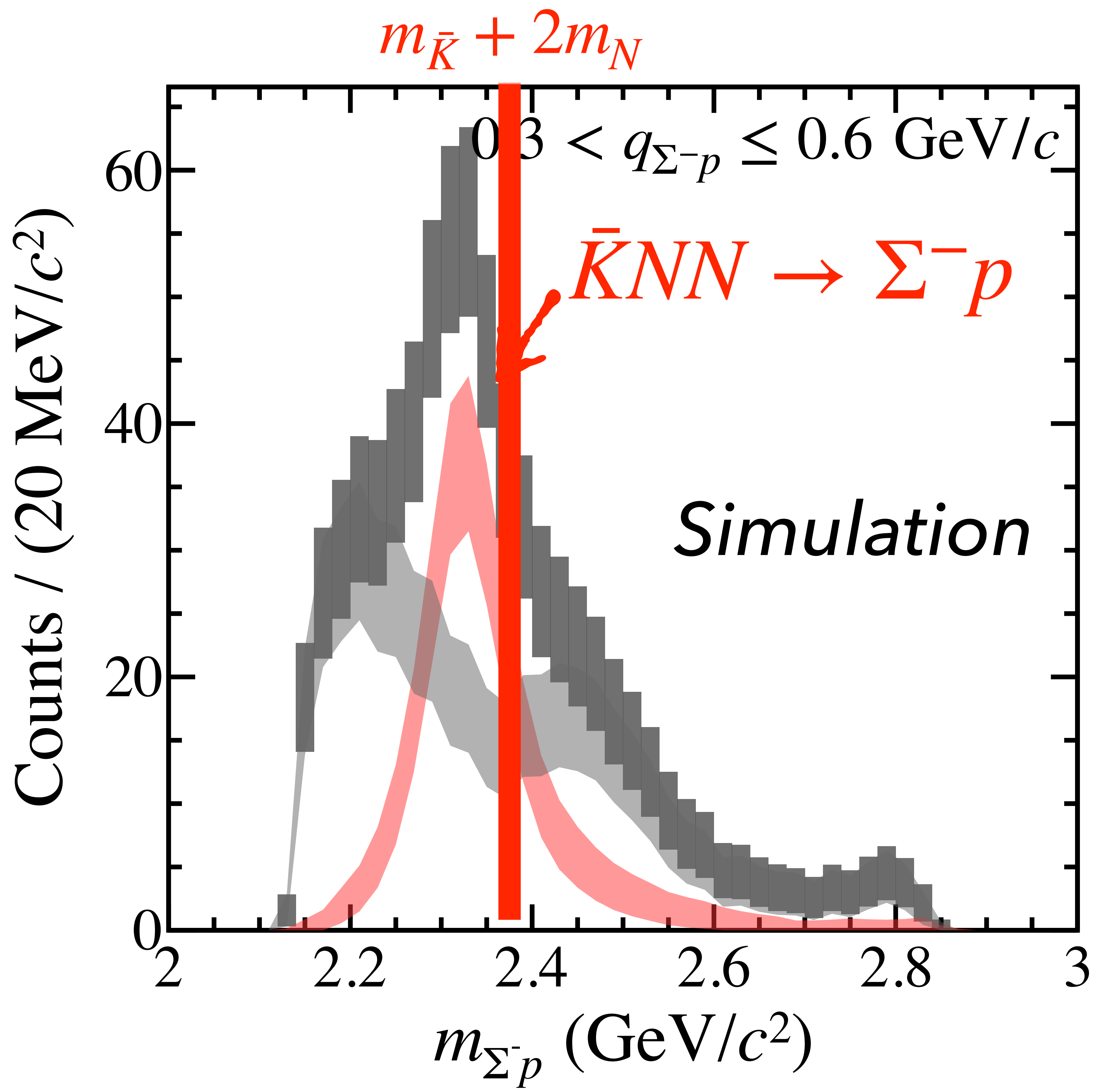
K^--α $\bar{K}^0$-α

Expected results









Programs for $\bar{K}$-nuclei

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with wider q-region

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&

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J-PARC P89

Heavier system

J-PARC E80

$\bar{K}NNN$ system

Door to heavier system

$^4\mathrm{He}(K^-, N)$ reaction

$K^-ppn - \bar{K}^0pnn$ (I=0)

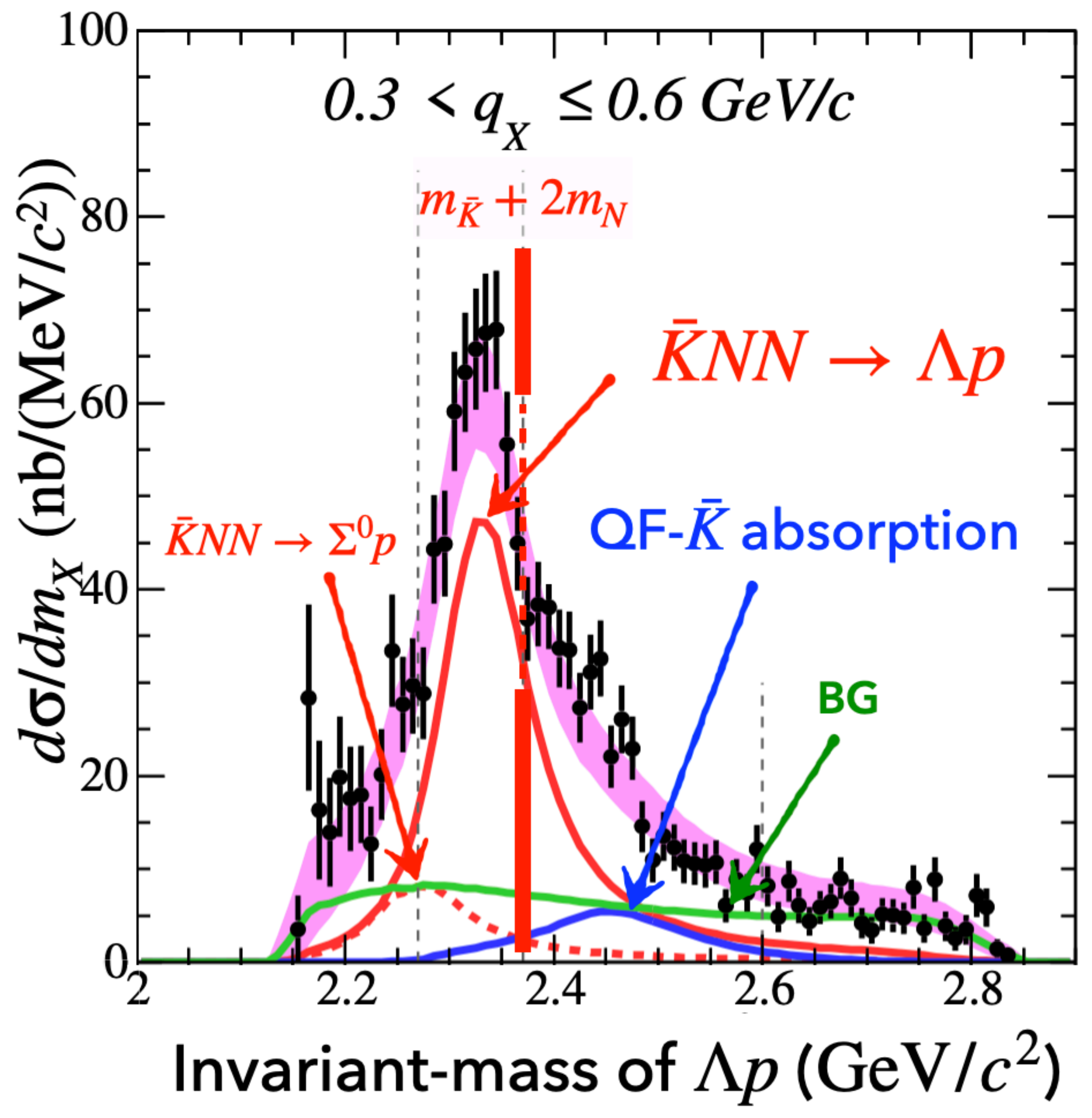
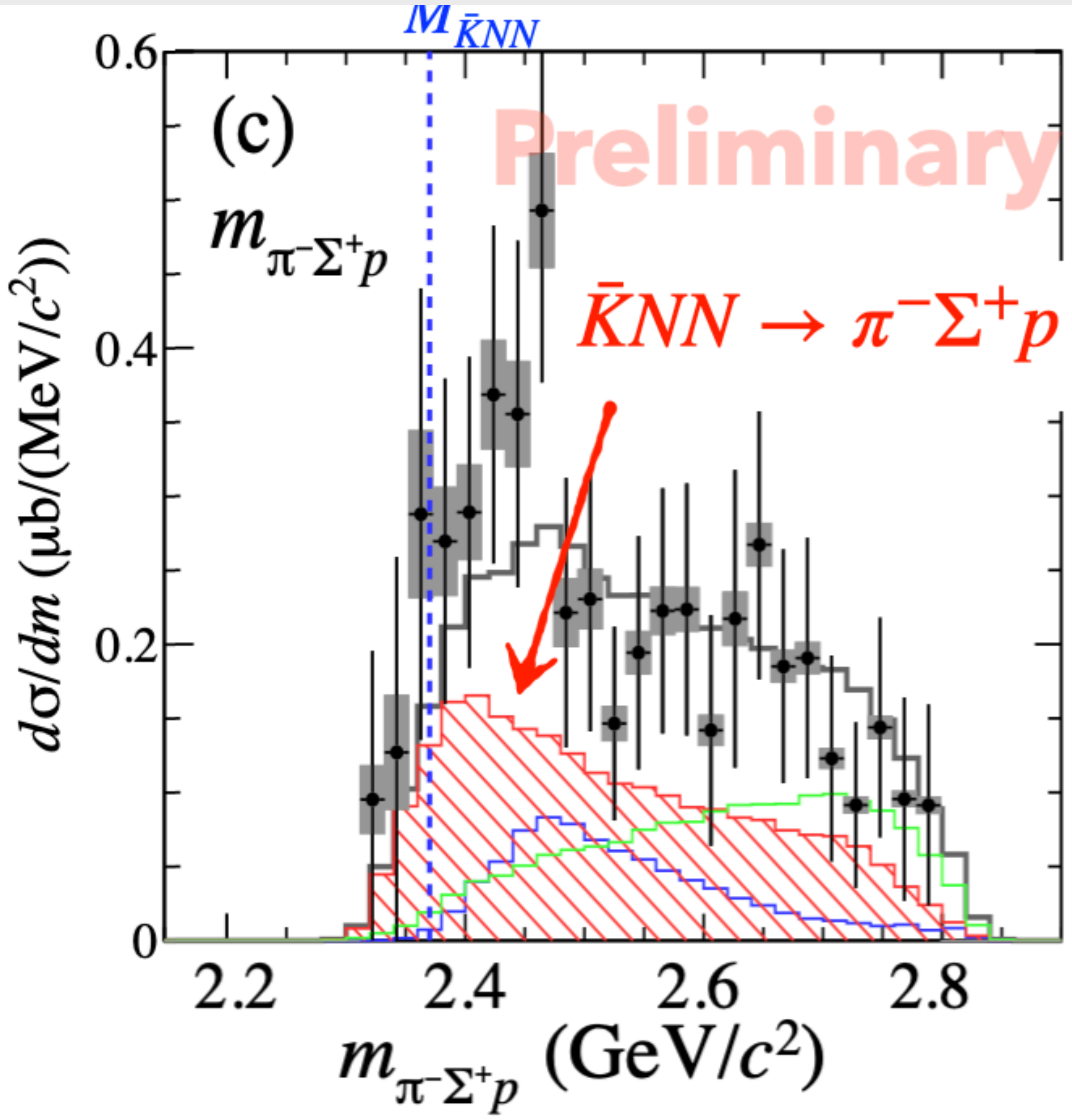
$\bar{K}NNNN$ system

Expected large B.E. & high density

$^6\mathrm{Li}(K^-, d)$ reaction

K^--α $\bar{K}^0$-α

Summary

$K^{-}+{}^{3}\mathrm{He}\to\Lambda p+n$	$K^{-}+{}^{3}\mathrm{He}\to\pi YN+n$	Future projects
		
First clear signal of $\bar{K}NN$	$\Gamma_{\pi YN} \gg \Gamma_{YN}$	Systematic study for kaonic nuclei

Thank you for your attention!

= The J-PARC E15 collaboration =

S. Ajimura[1], H. Asano[2], G. Beer[3], C. Berucci[4], H. Bhang[5], M. Bragadireanu[6], P. Buehler[4], L. Busso[7,8], M. Cargnelli[4], S. Choi[5], C. Curceanu[9], S. Enomoto[10], H. Fujioka[11], Y. Fujiwara[12], T. Fukuda[13], C. Guaraldo[9], T. Hashimoto[14], R. S. Hayano[12], T. Hiraiwa[1], M. Iio[10], M. Iliescu[9], K. Inoue[1], Y. Ishiguro[15], T. Ishikawa[12], S. Ishimoto[10], K. Itahashi[2], M. Iwasaki[2,11],[*] K. Kanno[12], K. Kato[15], Y. Kato[2], S. Kawasaki[1], P. Kienle[16],[†] H. Kou[11], Y. Ma[2], J. Marton[4], Y. Matsuda[12], Y. Mizoi[13], O. Morra[7], T. Nagae[15], H. Noumi[1], H. Ohnishi[17,2], S. Okada[2], H. Outa[2], K. Piscicchia[9], Y. Sada[1], A. Sakaguchi[1], F. Sakuma[2],[‡] M. Sato[10], A. Scordo[9], M. Sekimoto[10], H. Shi[9], K. Shirotori[1], D. Sirghi[9,6], F. Sirghi[9,6], K. Suzuki[4], S. Suzuki[10], T. Suzuki[12], K. Tanida[14], H. Tatsuno[18], M. Tokuda[11], D. Tomono[1], A. Toyoda[10], K. Tsukada[17], O. Vazquez Doce[9,16], E. Widmann[4], T. Yamaga[2,1],[§] T. Yamazaki[12,2], Q. Zhang[2], and J. Zmeskal[4]

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Thank you for your attention!

= The J-PARC E80/P89 collaboration =

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Theorists

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