*ELPH*研究会「ハドロン構造における多粒子相関」 @ *ELPH*

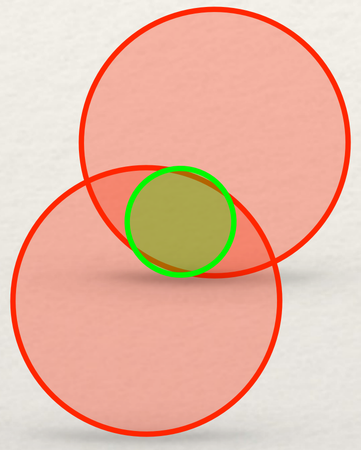
http://www.lns.tohoku.ac.jp/workshop/c024/index.php

反K中間子ビームを用いた反K中間子原子核の研究

Takumi Yamaga, RIKEN
For the E15 collaboration

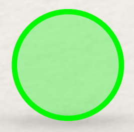
What is interest?

- The simplest kaonic nucleus



=

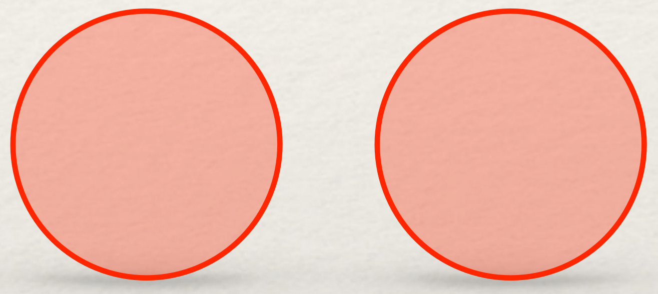
anti-Kaon
$(s\bar{u})$



Meson : $(q\bar{q})$

+

Two protons
(uud)

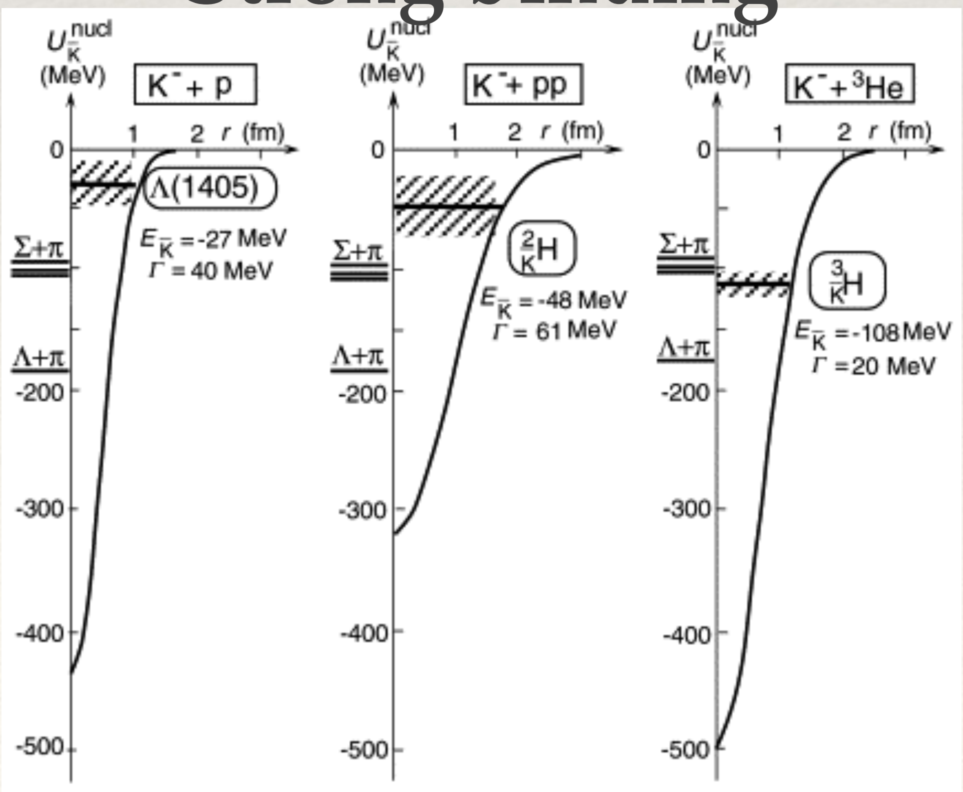


Baryon : (qqq)

<u>Meson could be a building block of matter!</u>

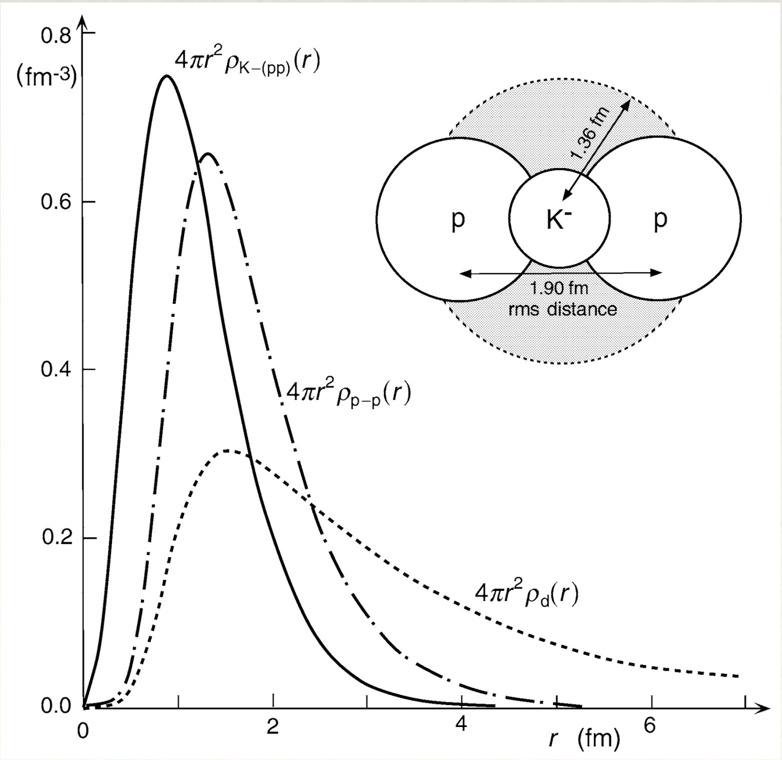
Interesting properties

Strong binding



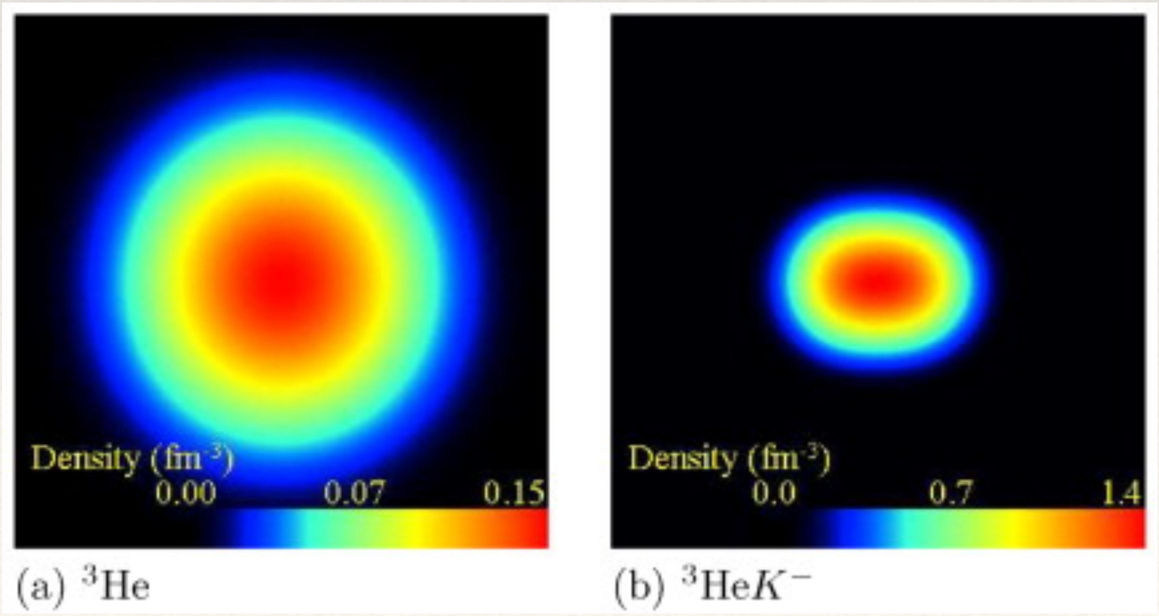
PLB 535 (2002) 70-76

Compact



PLB 535 (2002) 70-76

High-density



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

PLB 590 (2004) 51-56

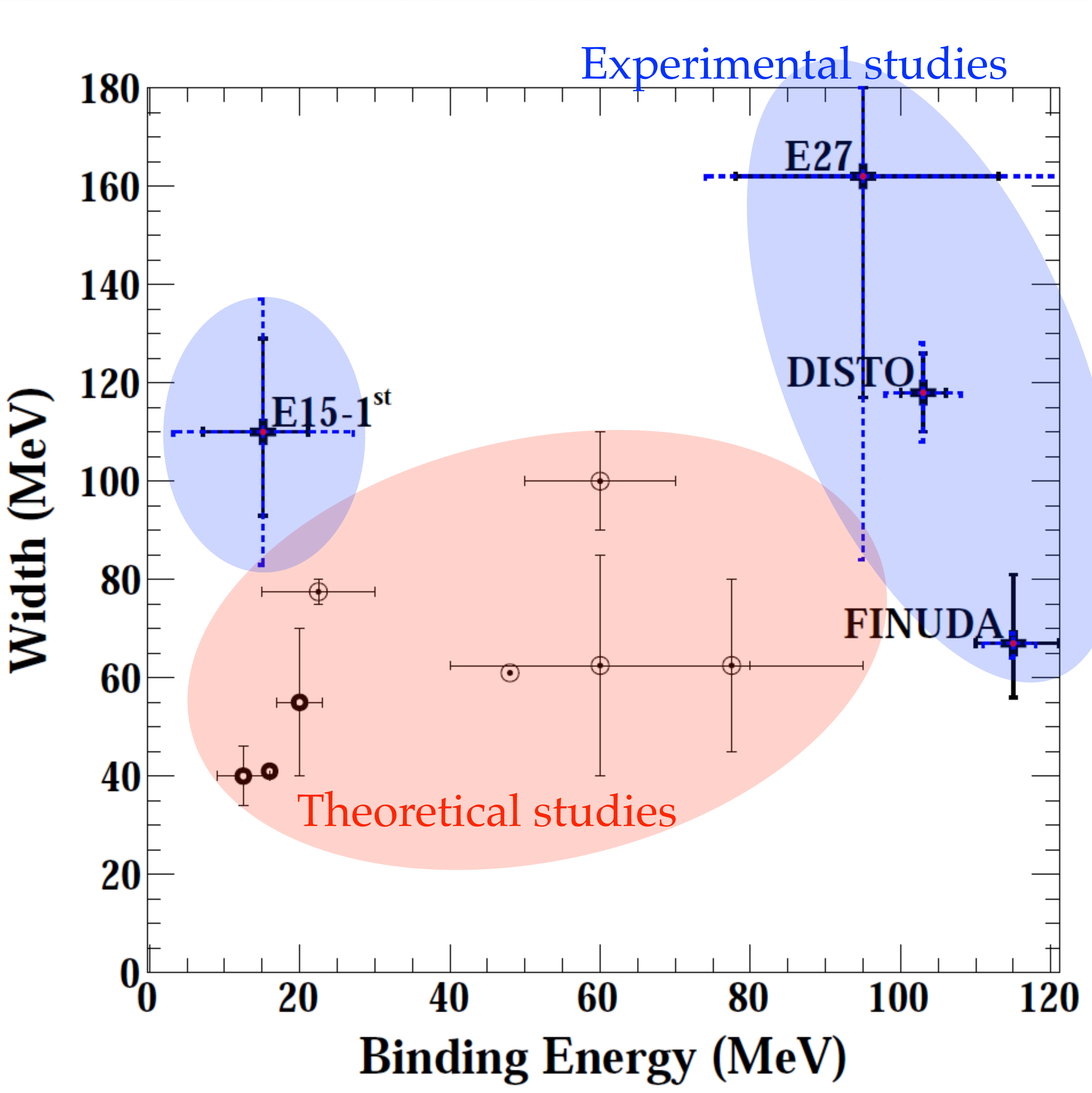
KbarN interaction & Kaonic nuclei

- KbarN interaction is strongly attractive in I = 0 channel.
  - Low energy KbarN scattering
  - X-ray measurement from kaonic atoms
  - Structure of $\Lambda(1405)$

- Bound state of kaon and nucleus ➡ Kaonic nuclei
  - KbarNN : the simplest kaonic nucleus

KbarNN bound state :: Current status

- Many theoretical & experimental studies
  - Theoretical studies
    - B.E and Width strongly depend on KbarN interaction model.
  - Experimental studies
    - Results are different even if we use the same reaction.

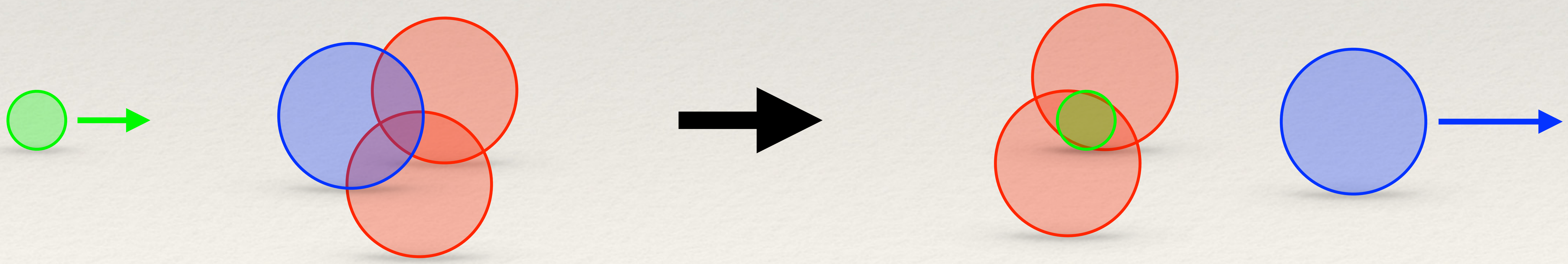


E15 experiment

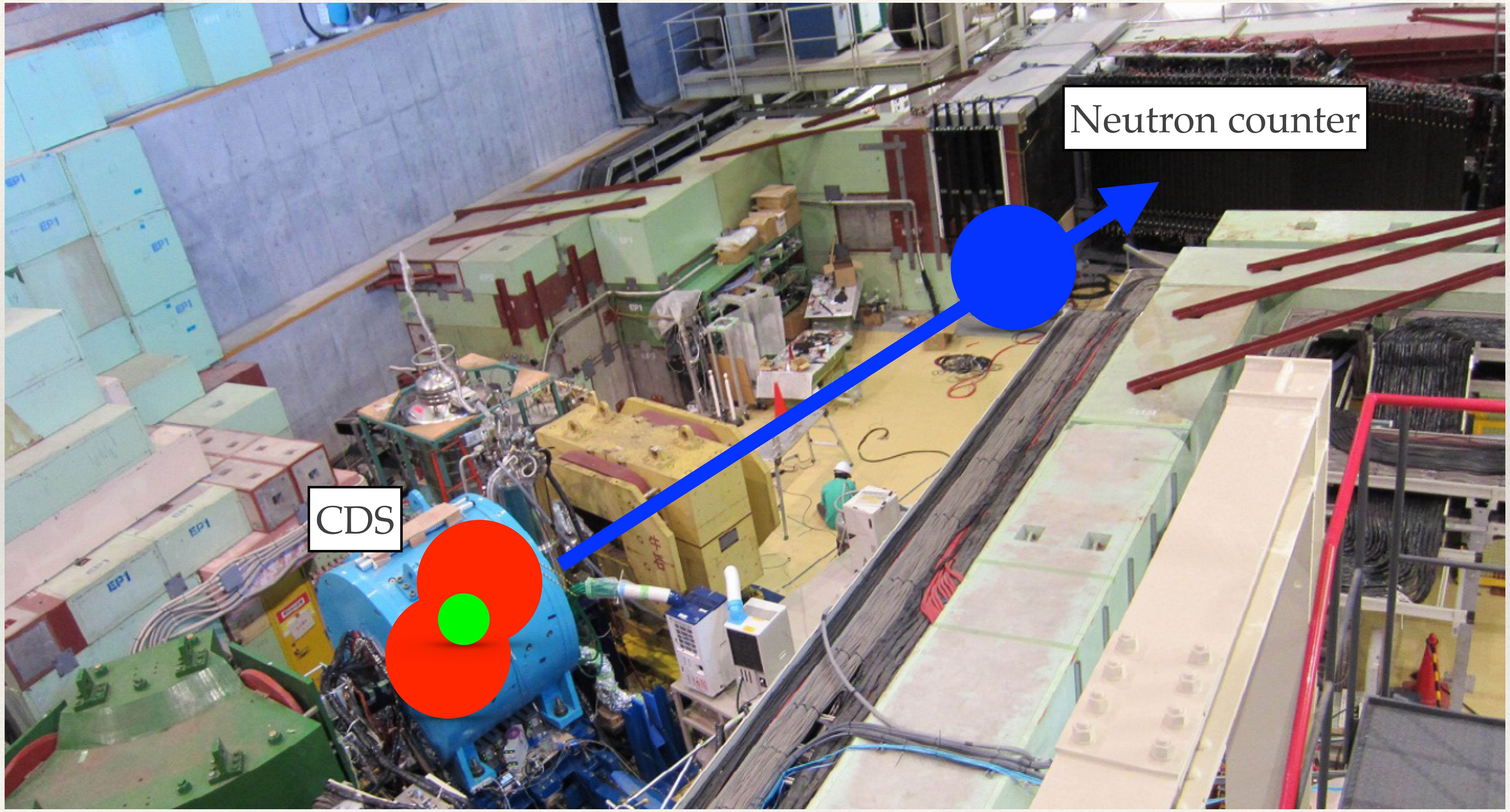
In-flight (K-, n) reaction to generate KbarNN bound state

$$p_K = 1\ \mathrm{GeV}/c$$

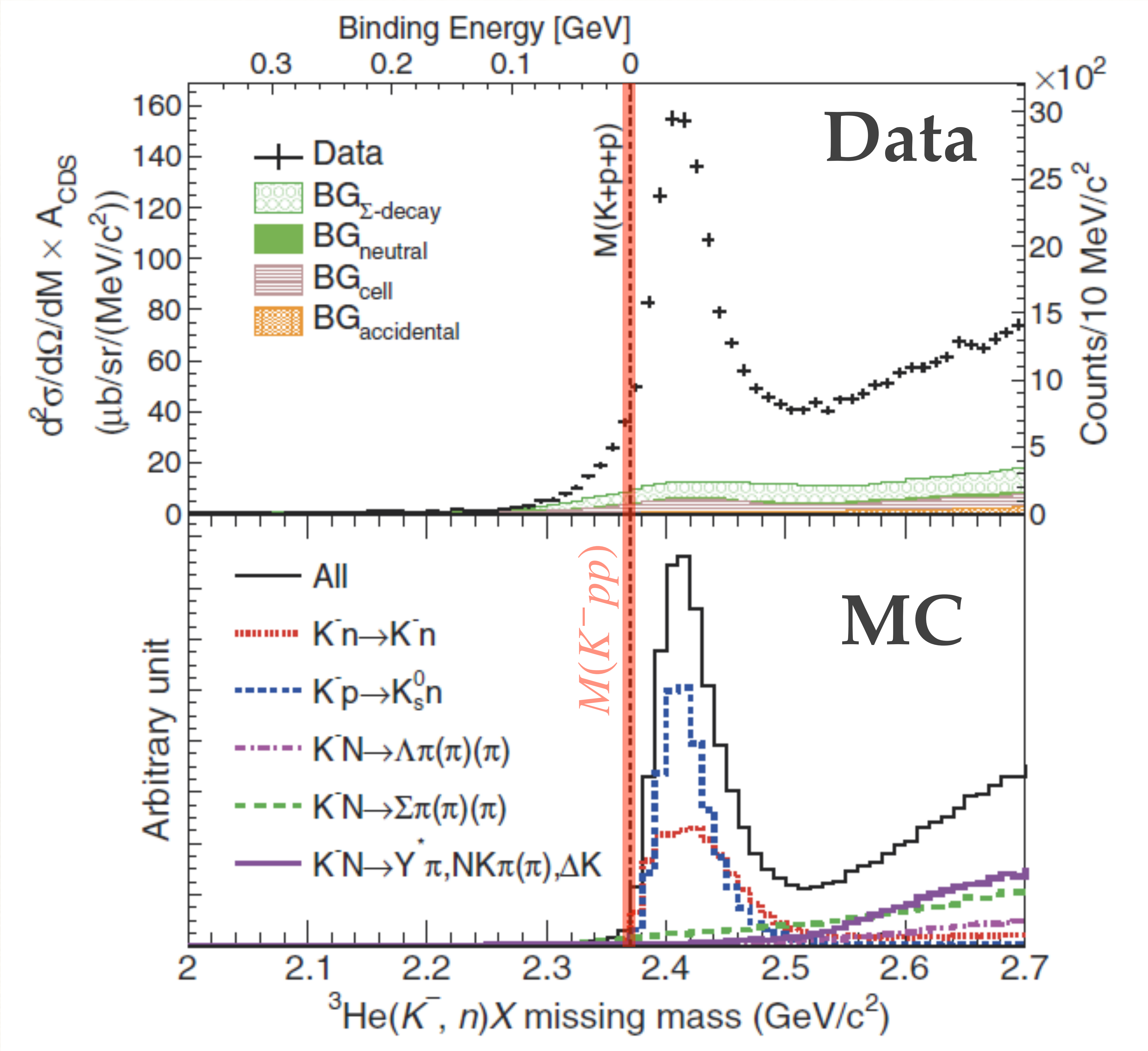
$$K^- \ + \ {}^3\mathrm{He} \ \rightarrow \ K^-pp \ + \ n$$



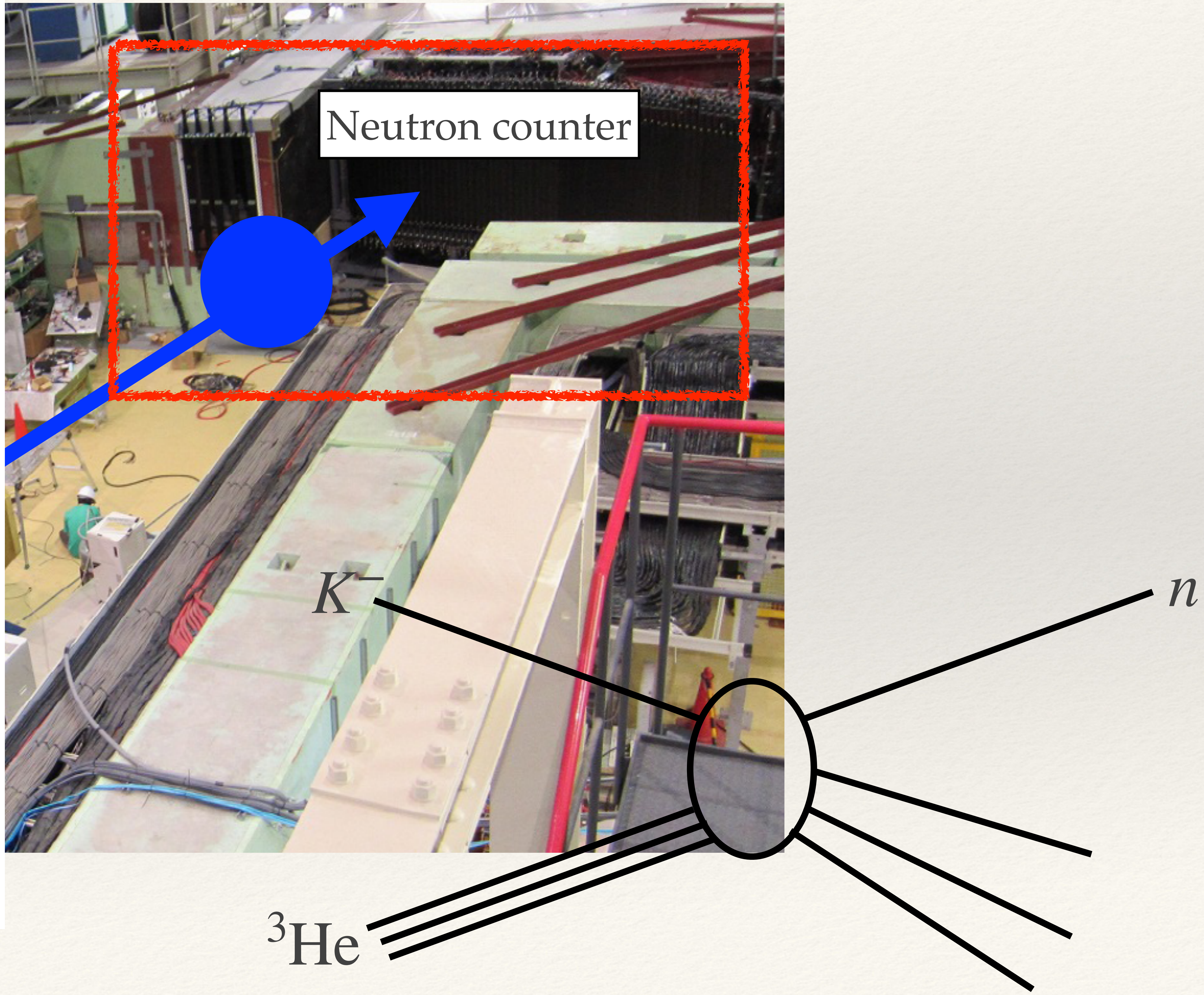
E15 experiment



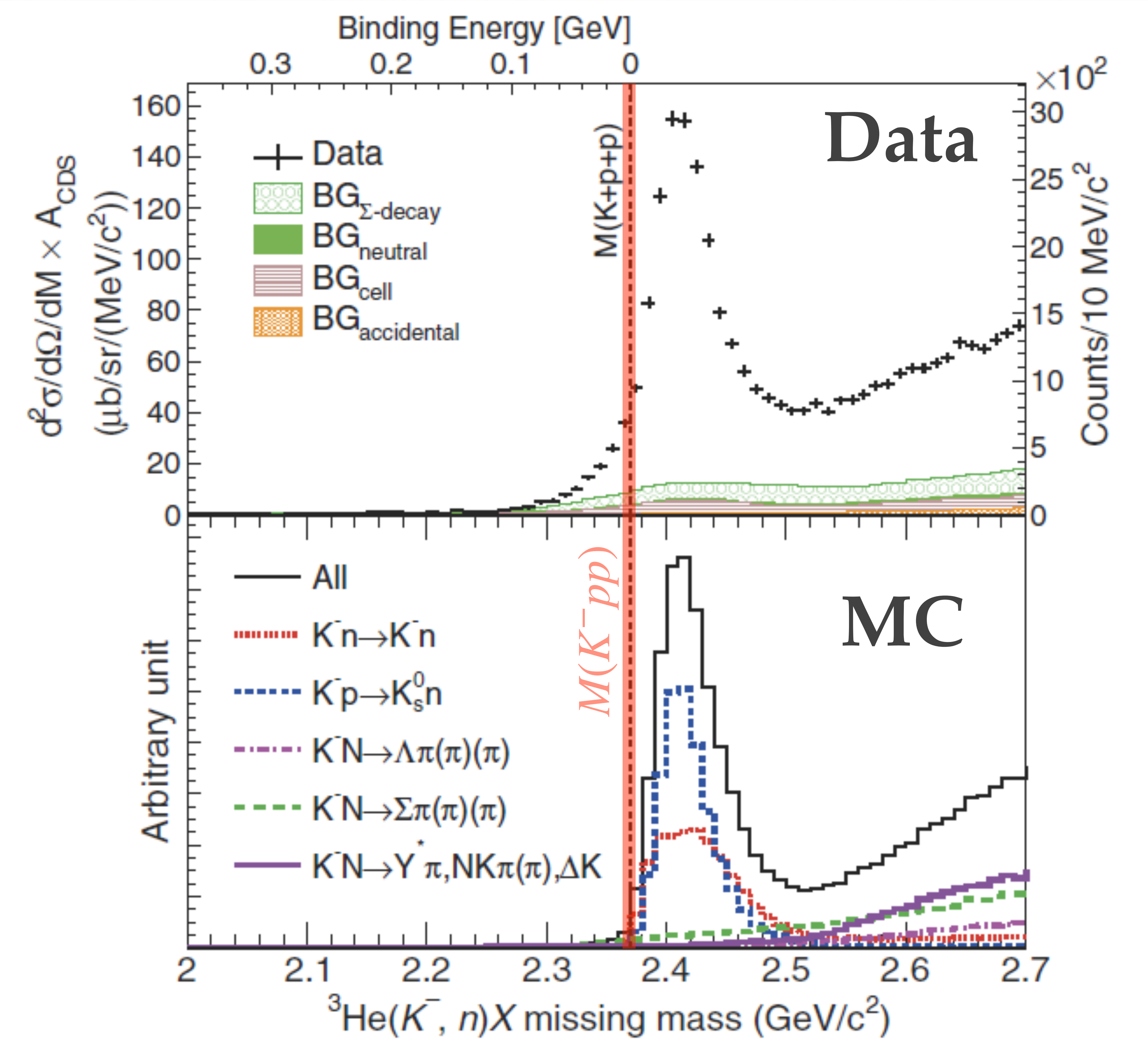
E15 experiment



PTEP (2015) 061D01

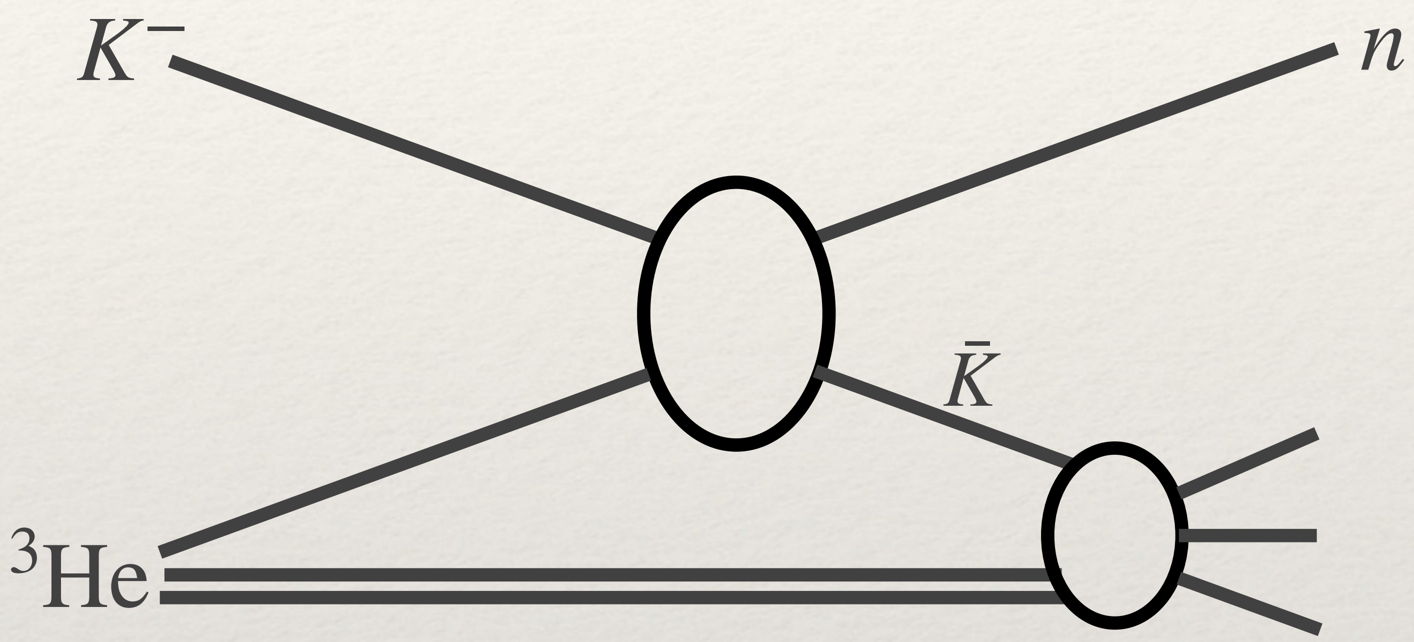


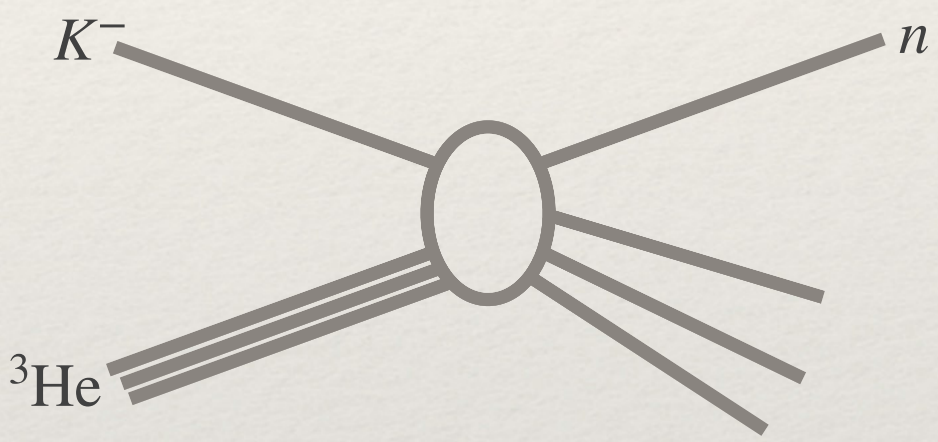
E15 experiment



PTEP (2015) 061D01

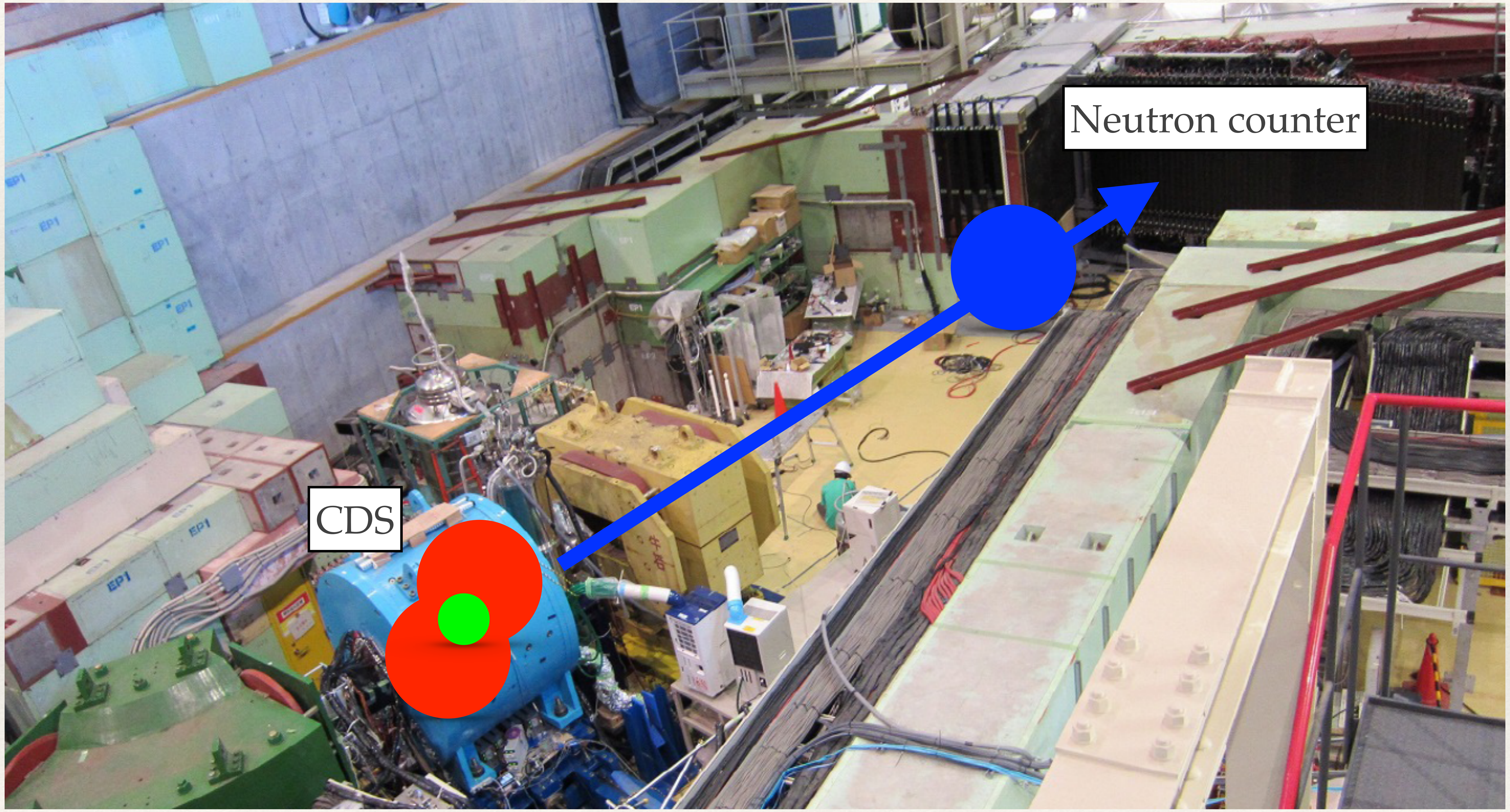
- Clear peak from quasi-free process



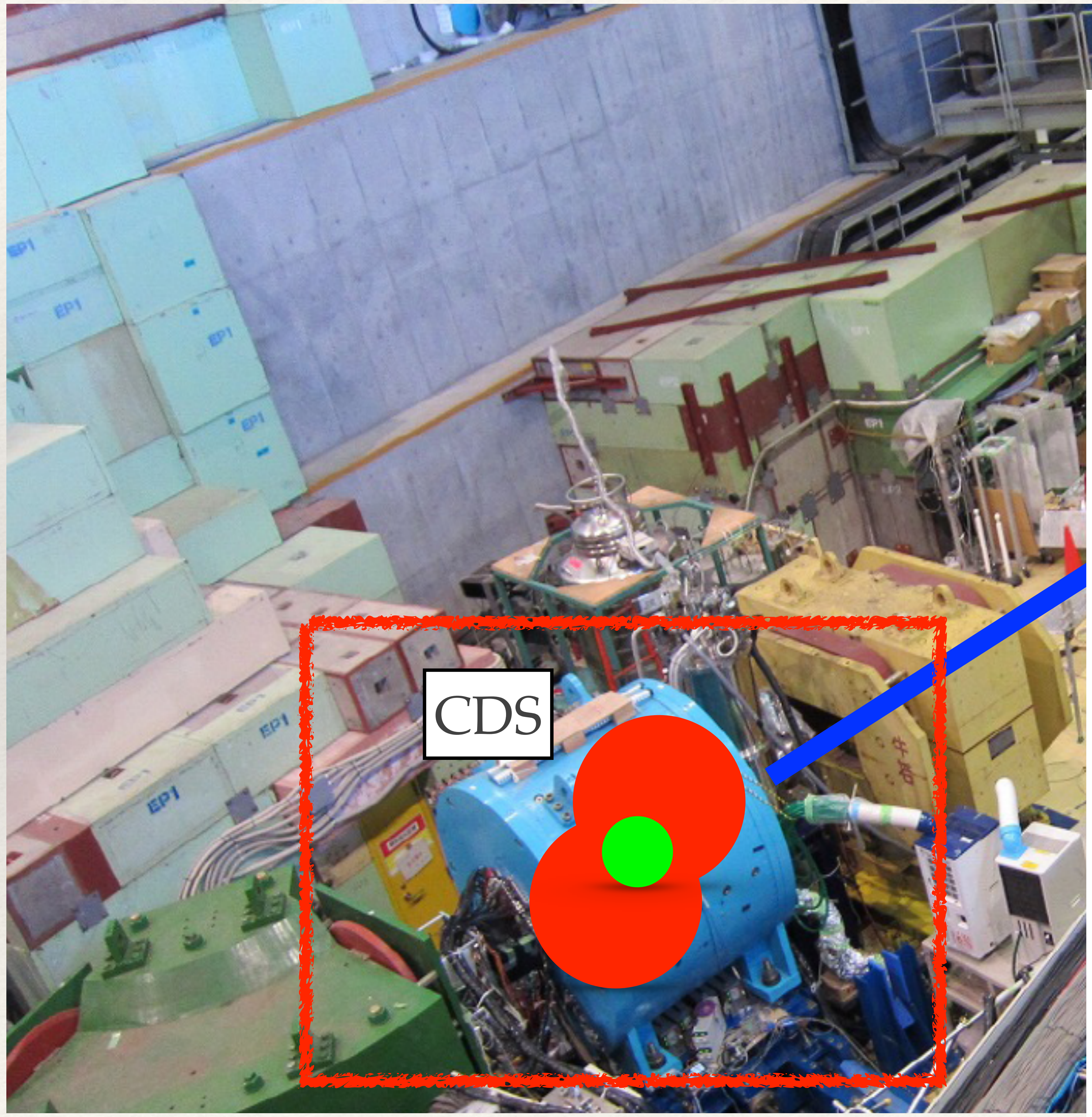


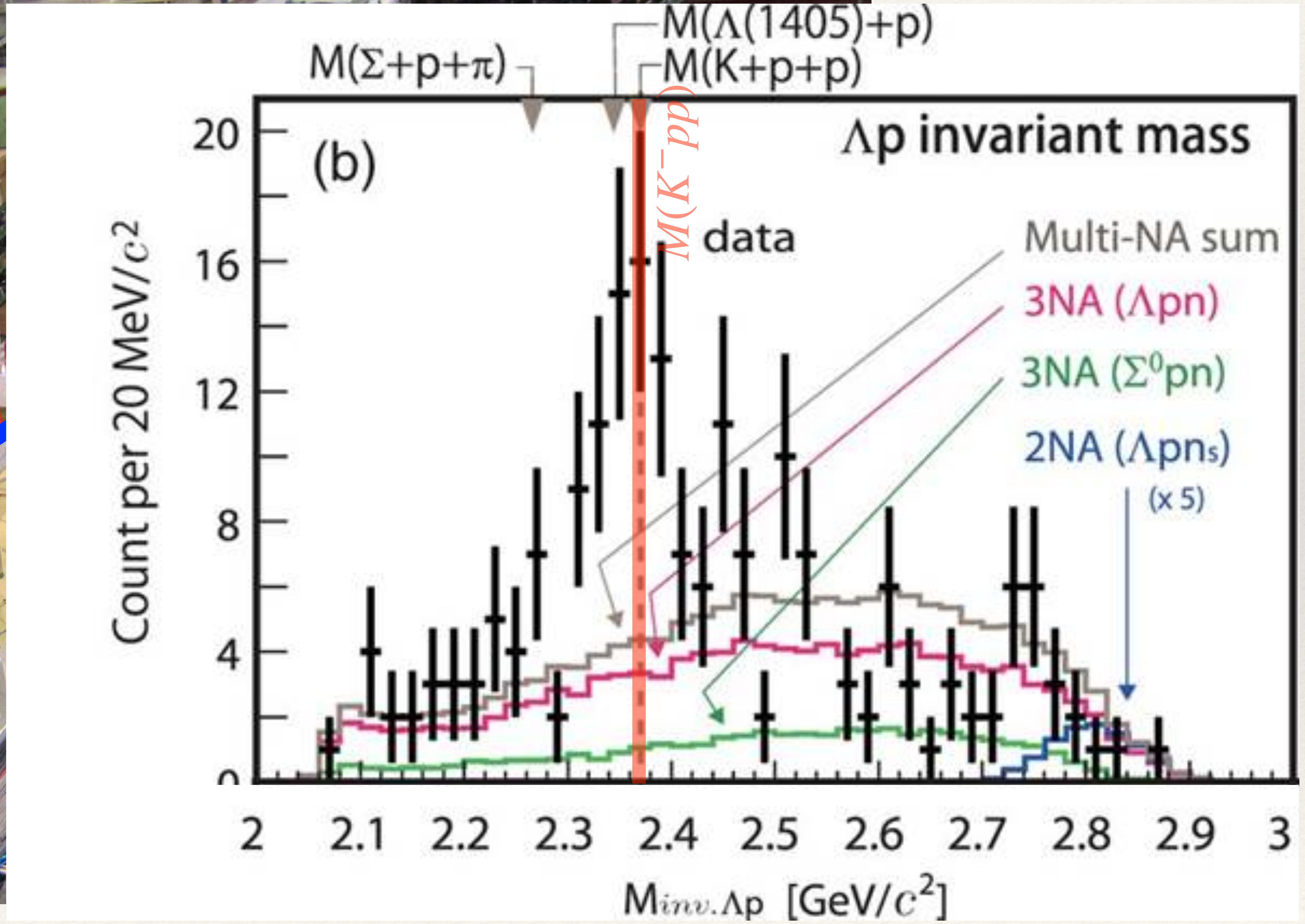
- No clear structure below the threshold
  - Need exclusive analysis

E15 experiment



E15 experiment

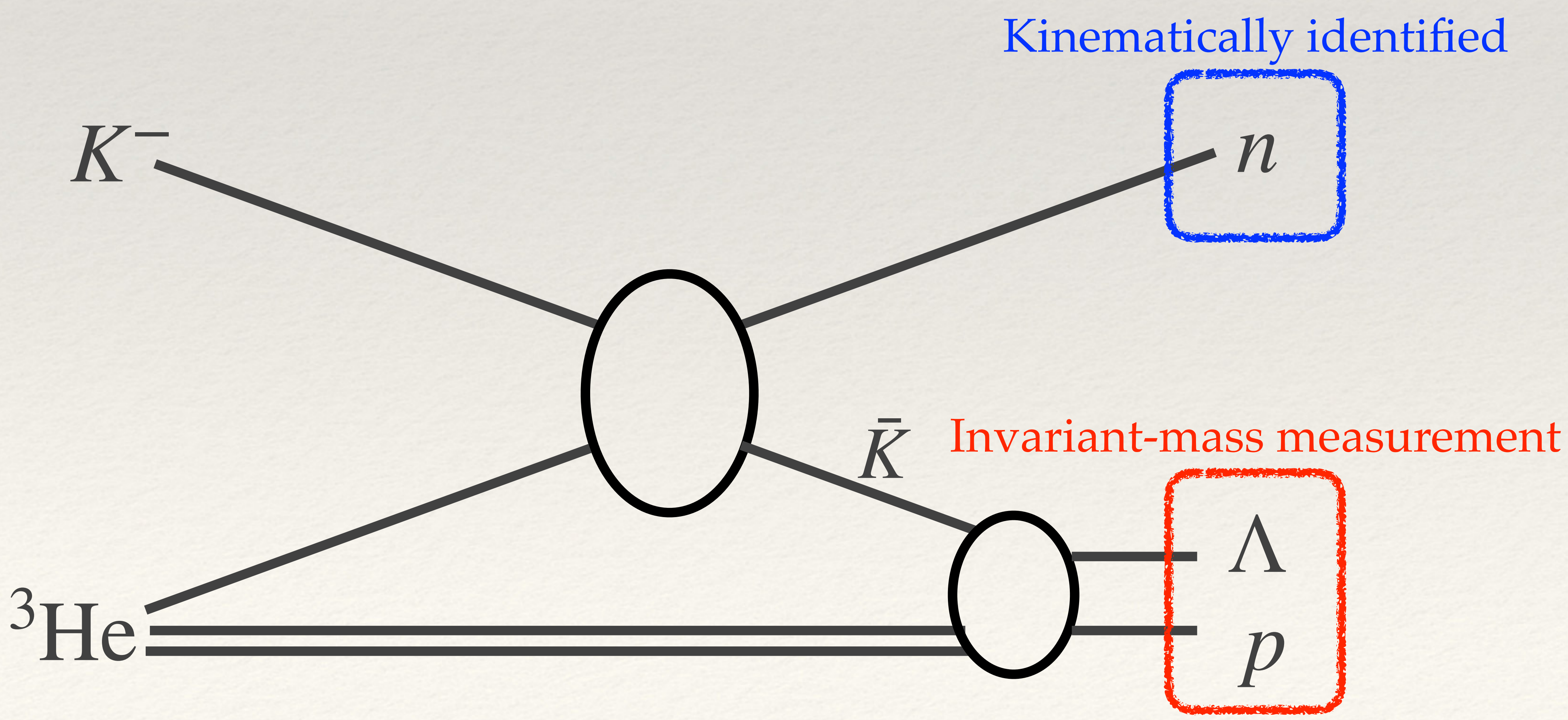


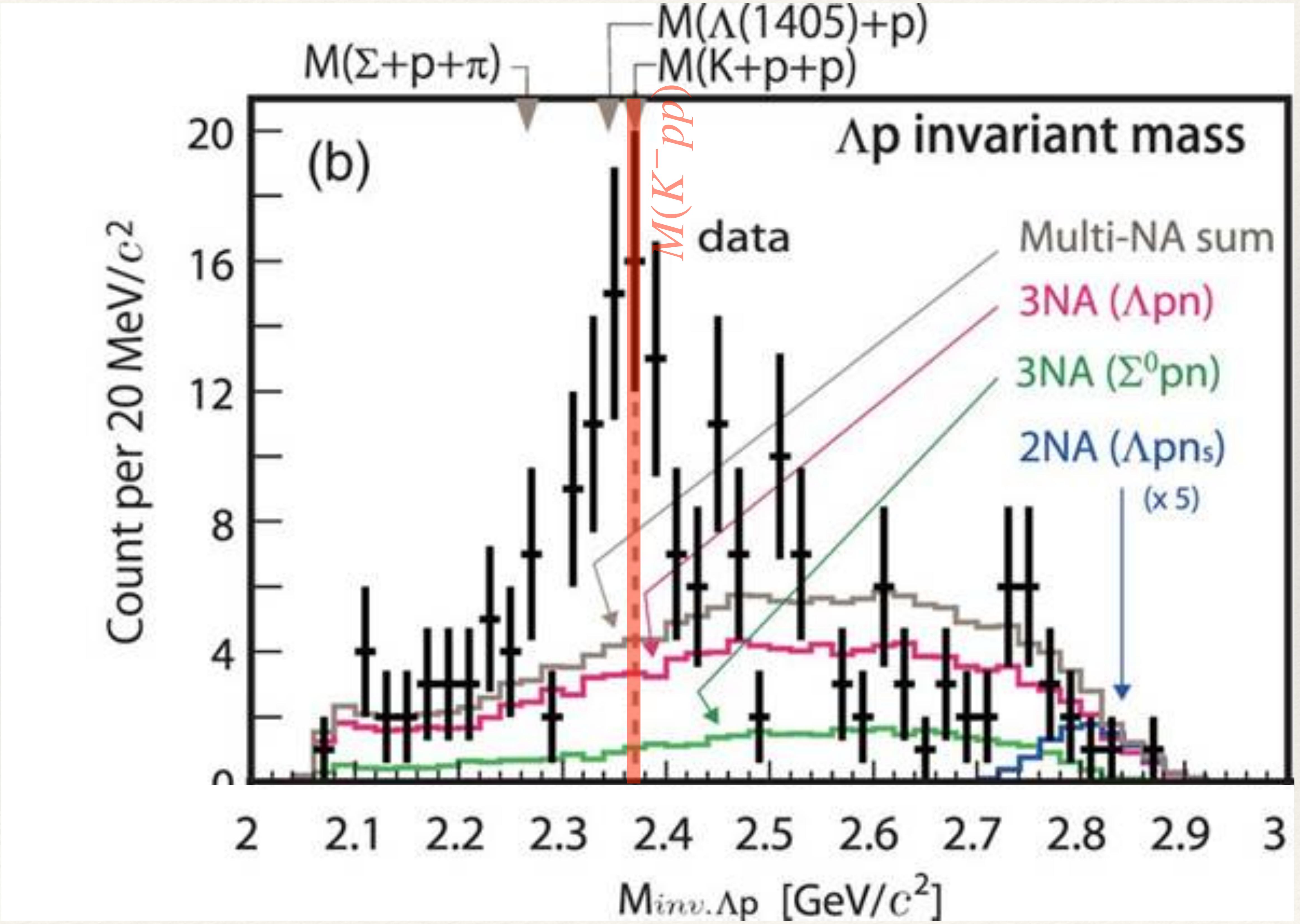


PTEP (2016) 051D01

E15 experiment

- Not consistent with 3NA distribution
- Peak around M(Kpp)
  - Could be Kpp signal
  - Need more statistics

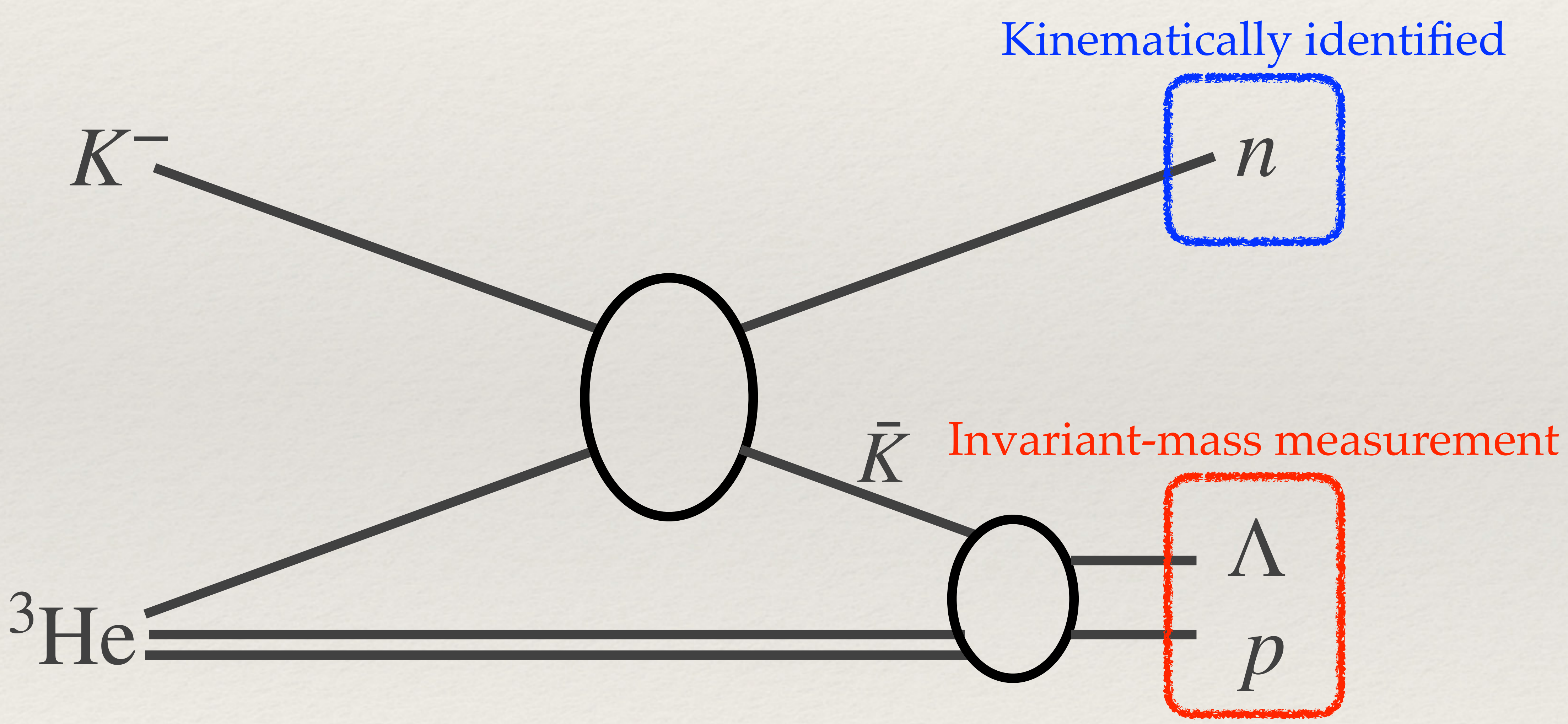


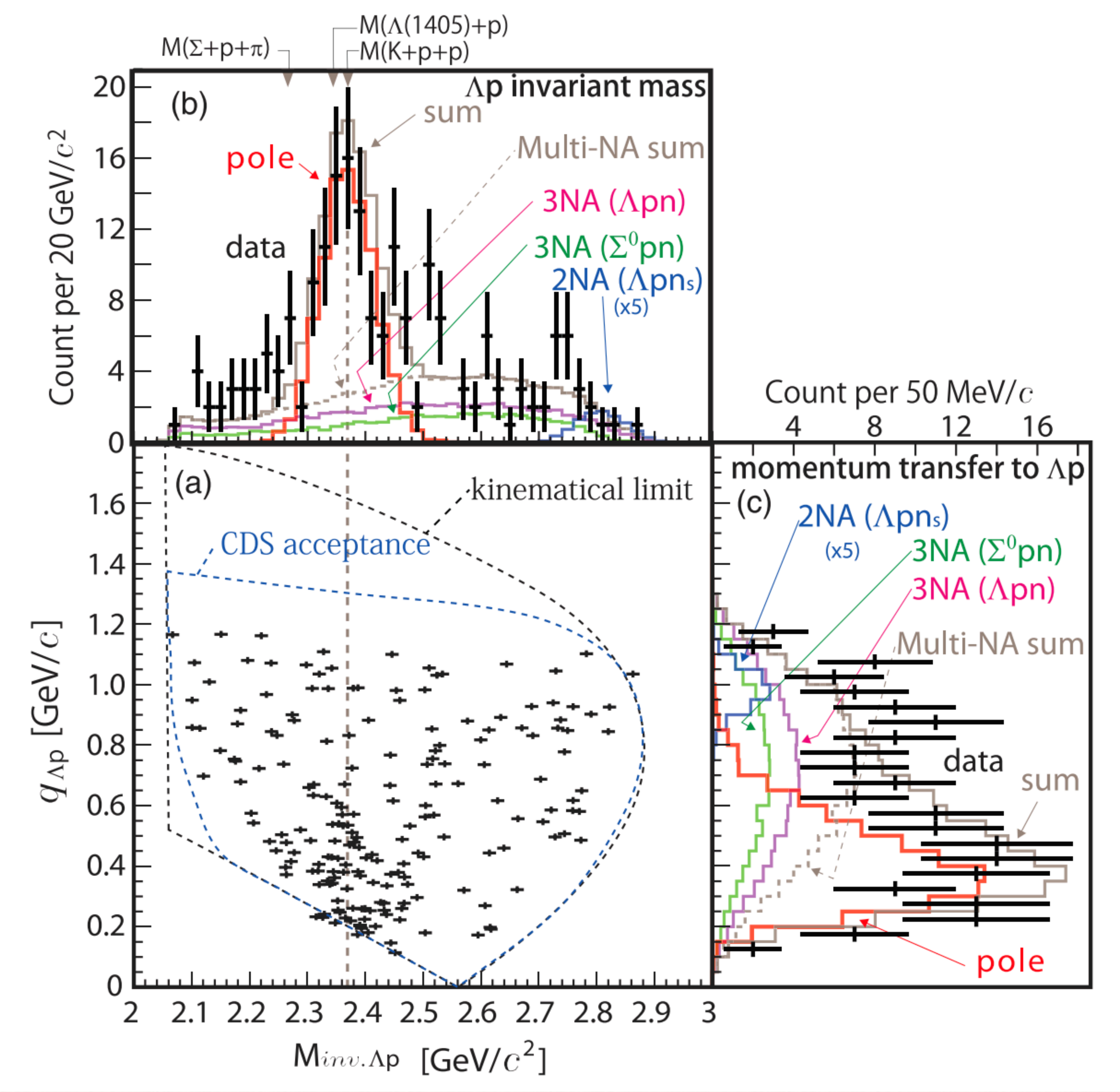


PTEP (2016) 051D01

Summary of E15-1st

- Exclusive Λpn analysis
- More statistics



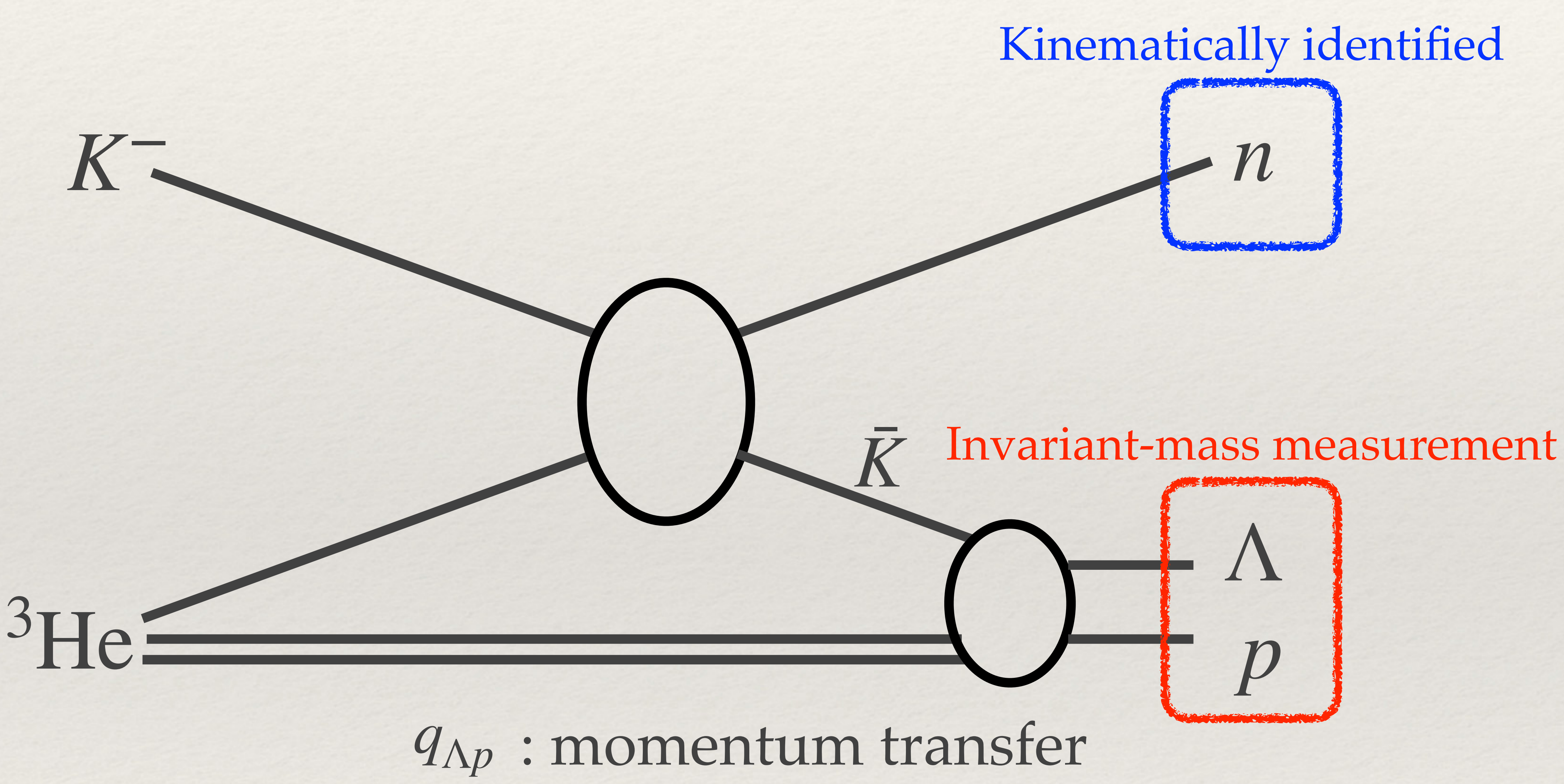


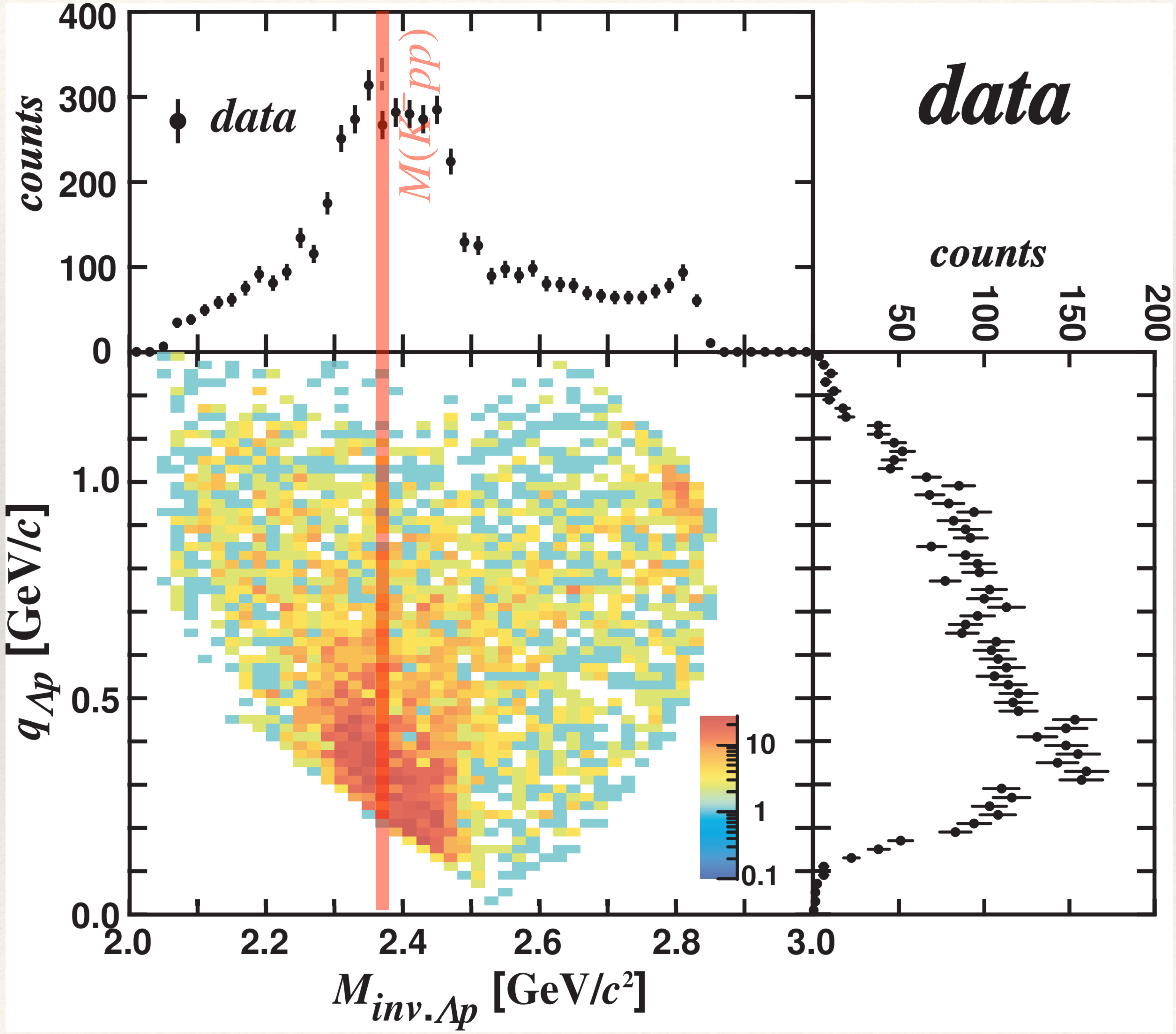
→ E15-2nd

(x30 times larger statistics for Λpn channel)

Result of E15-2nd

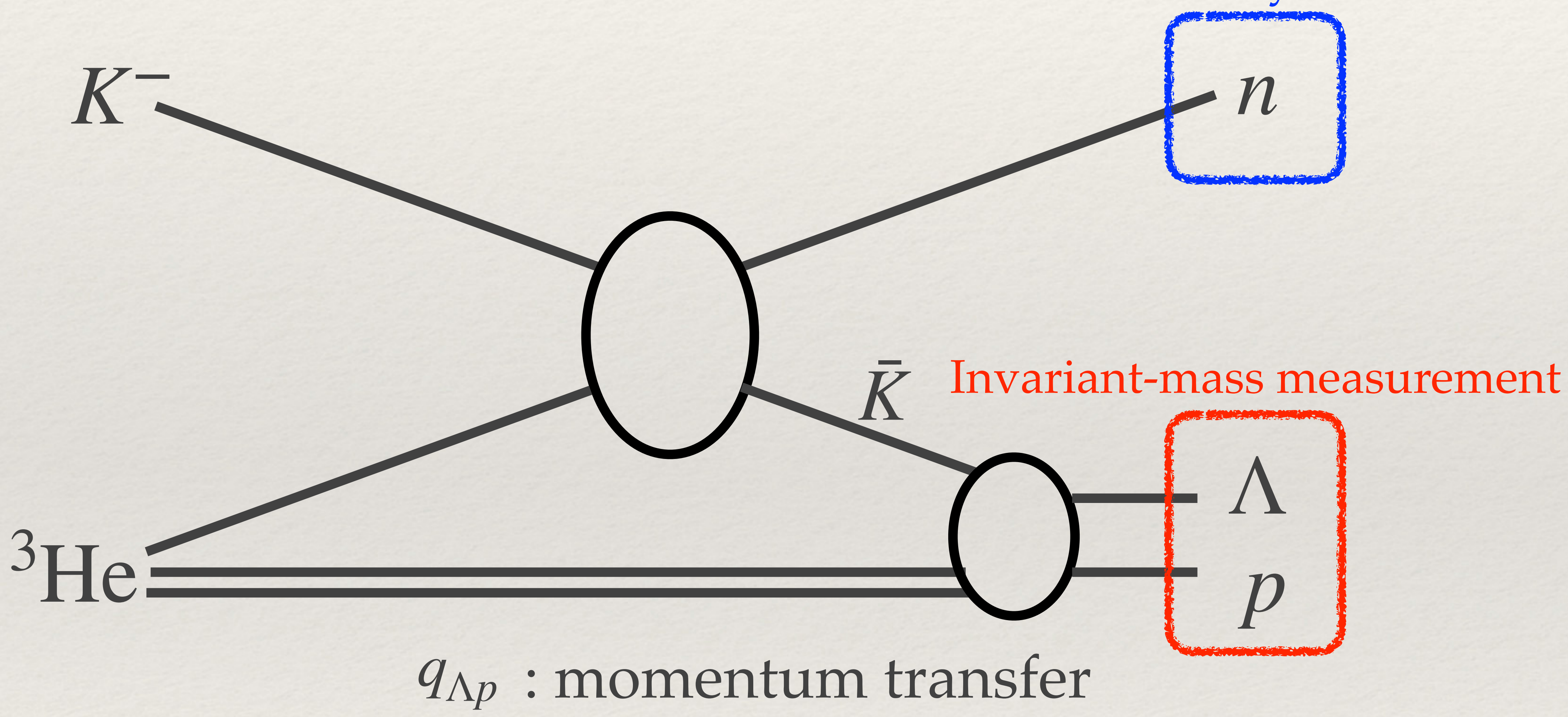
$$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$$

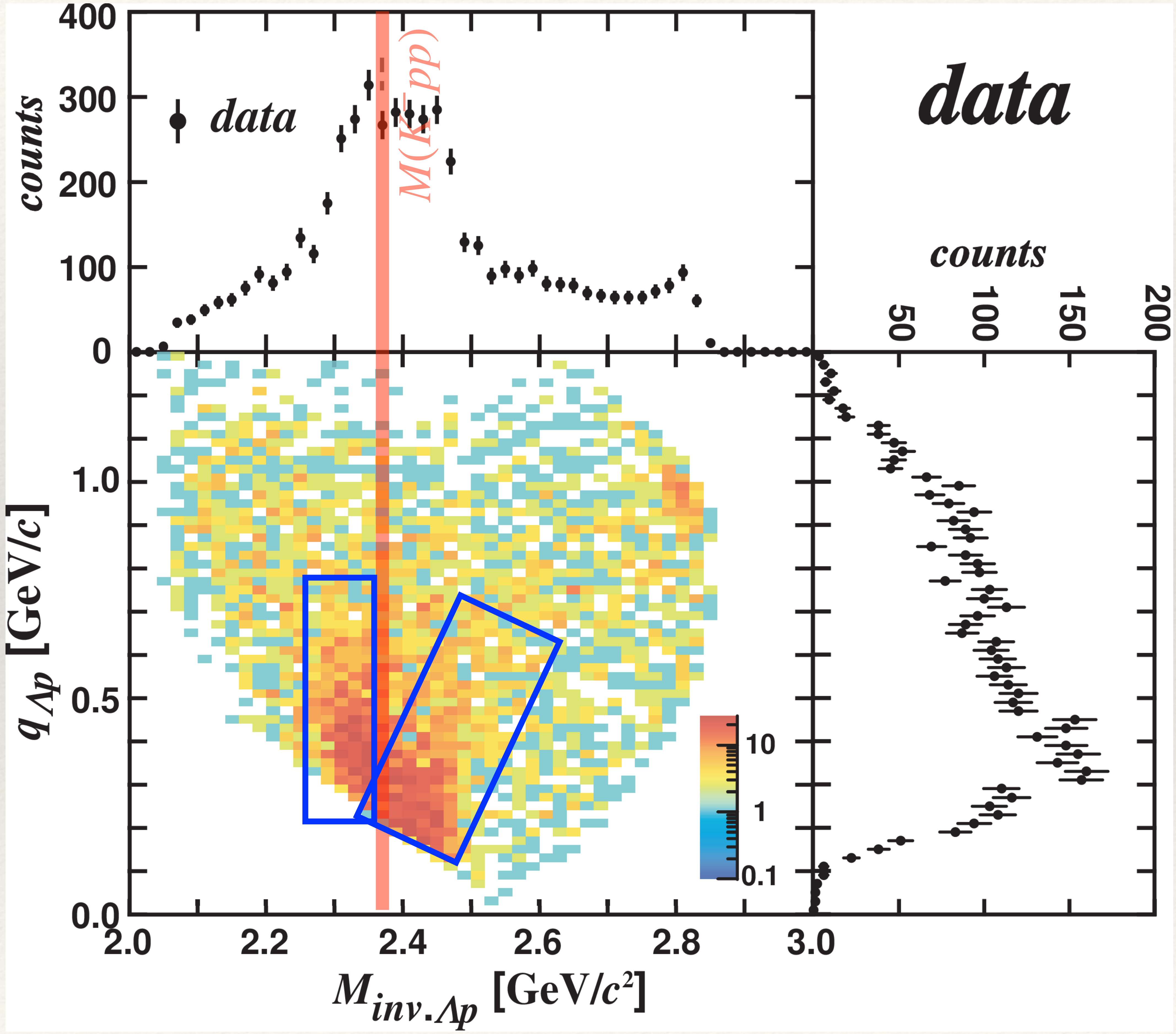




Result of E15-2nd

$$\boxed{K^- + {}^3\text{He} \rightarrow \Lambda p + n}$$

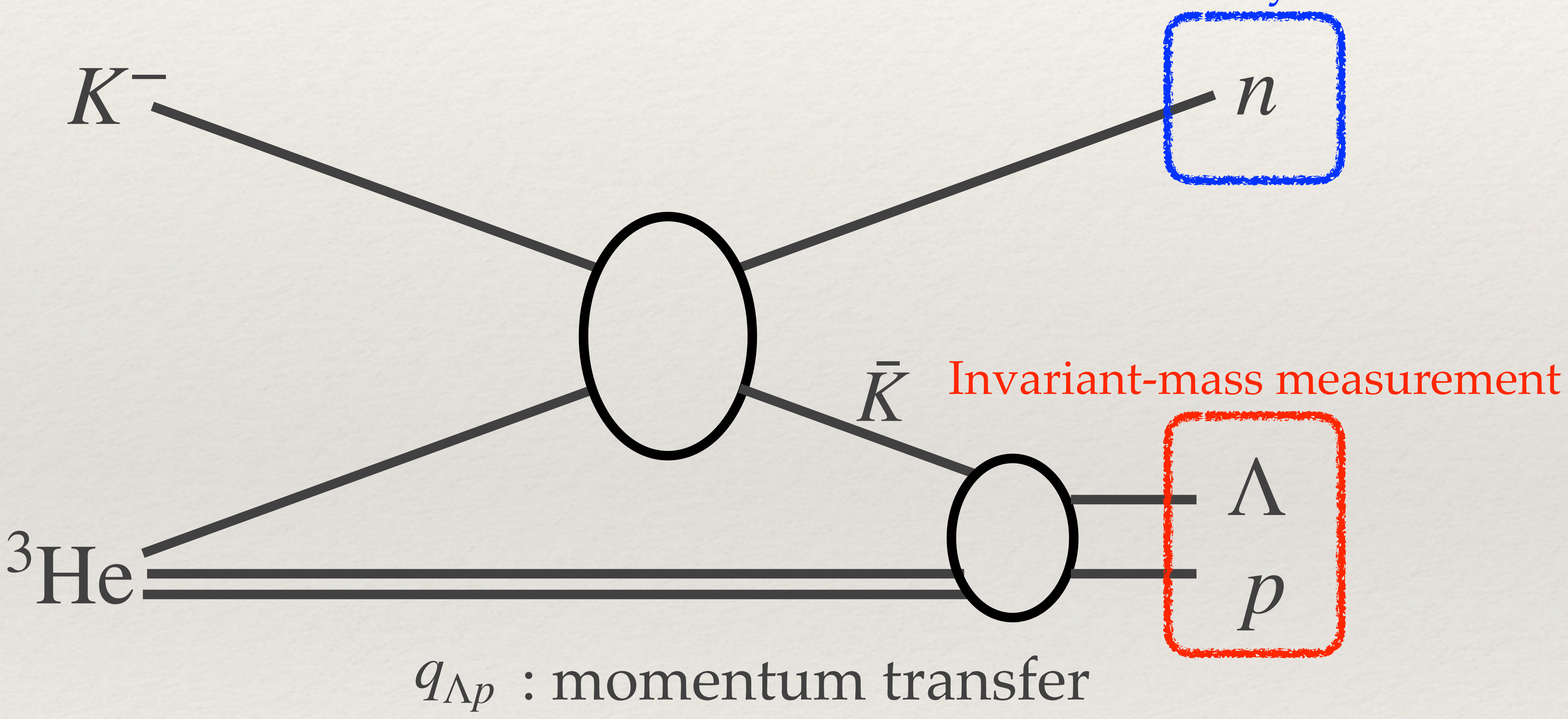


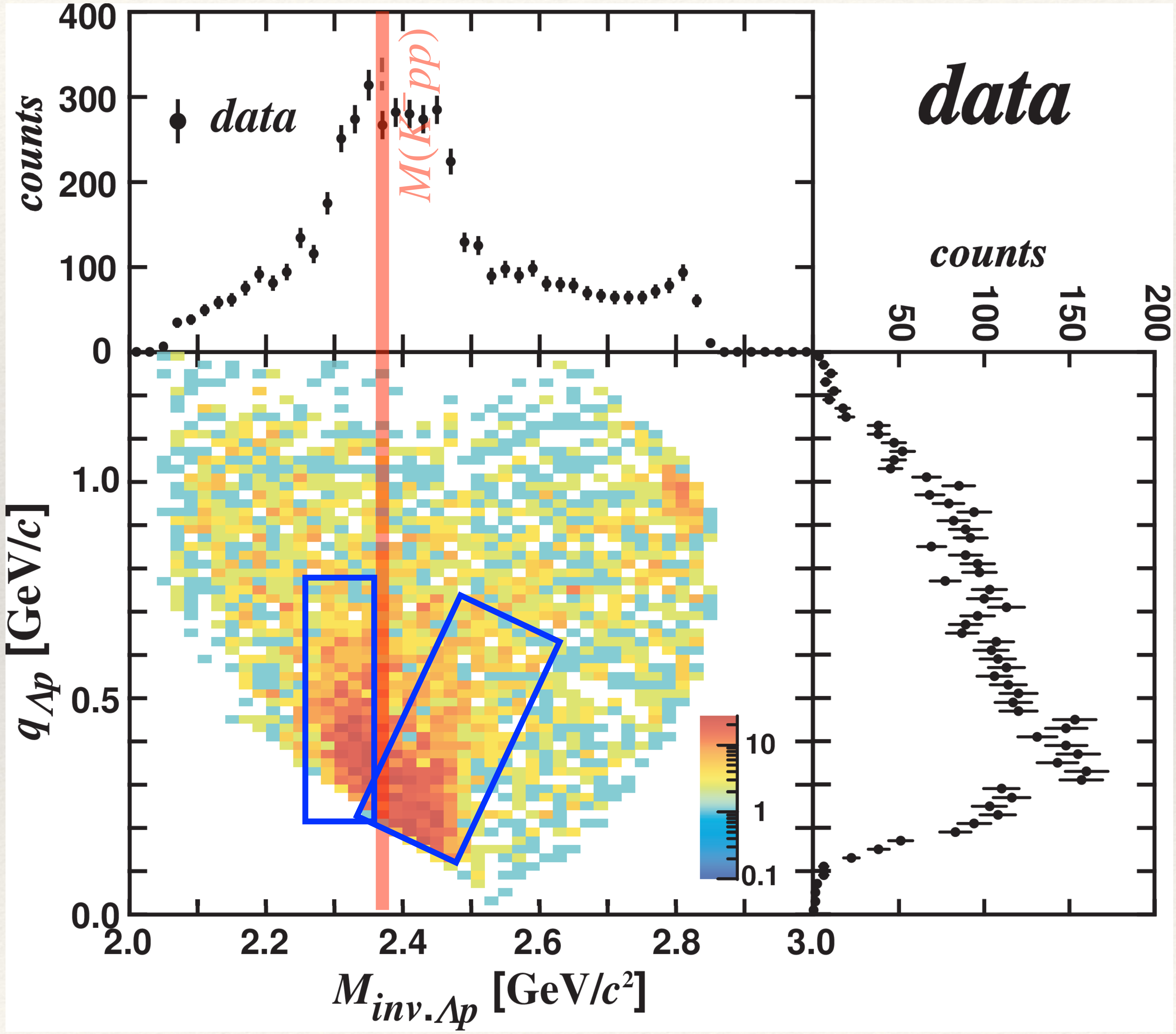


- Clear two components
  - Below & above M(Kpp)

Result of E15-2nd

$$\boxed{K^- + {}^3\text{He} \rightarrow \Lambda p + n}$$

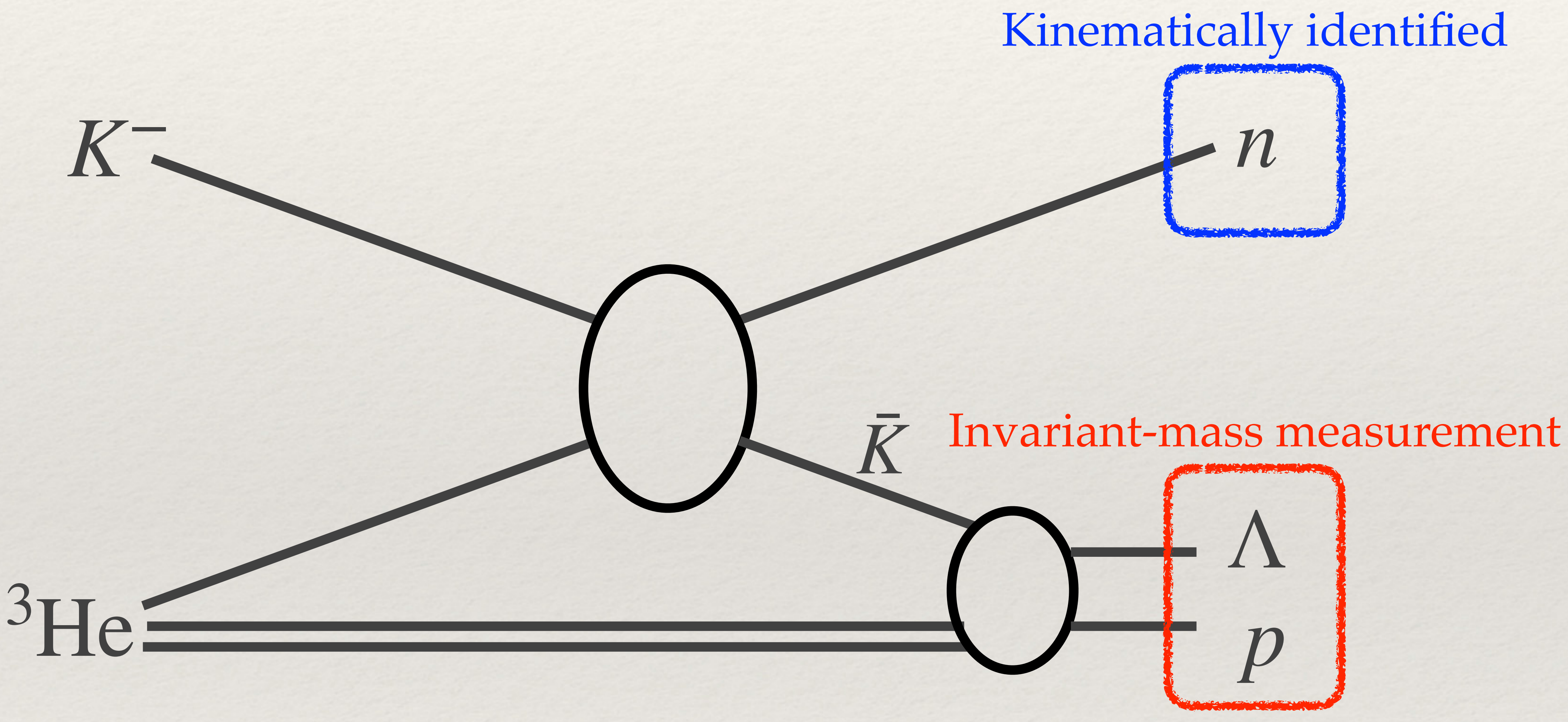


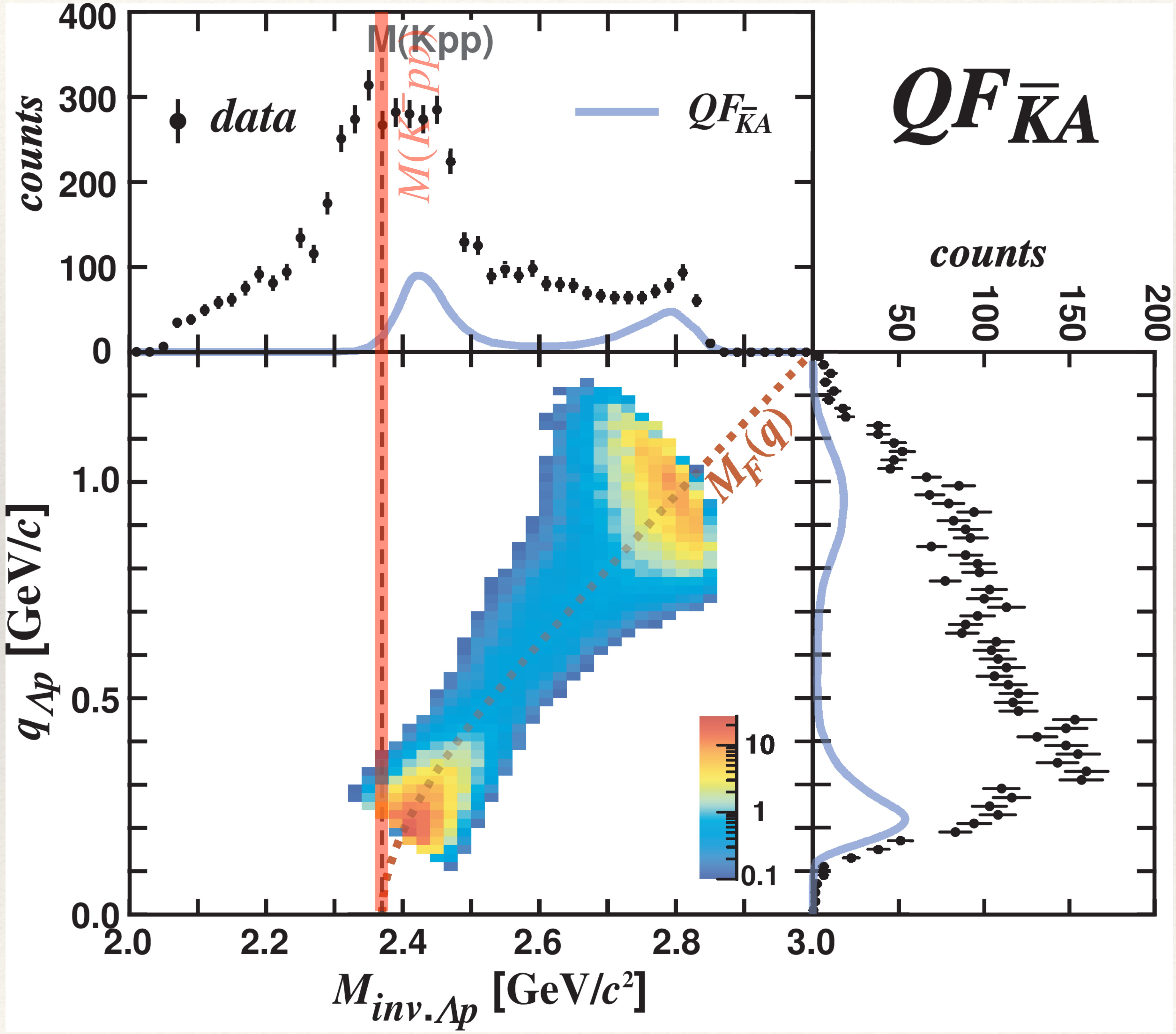


➡ Decomposition into 3 major components

Spectrum decomposition

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$

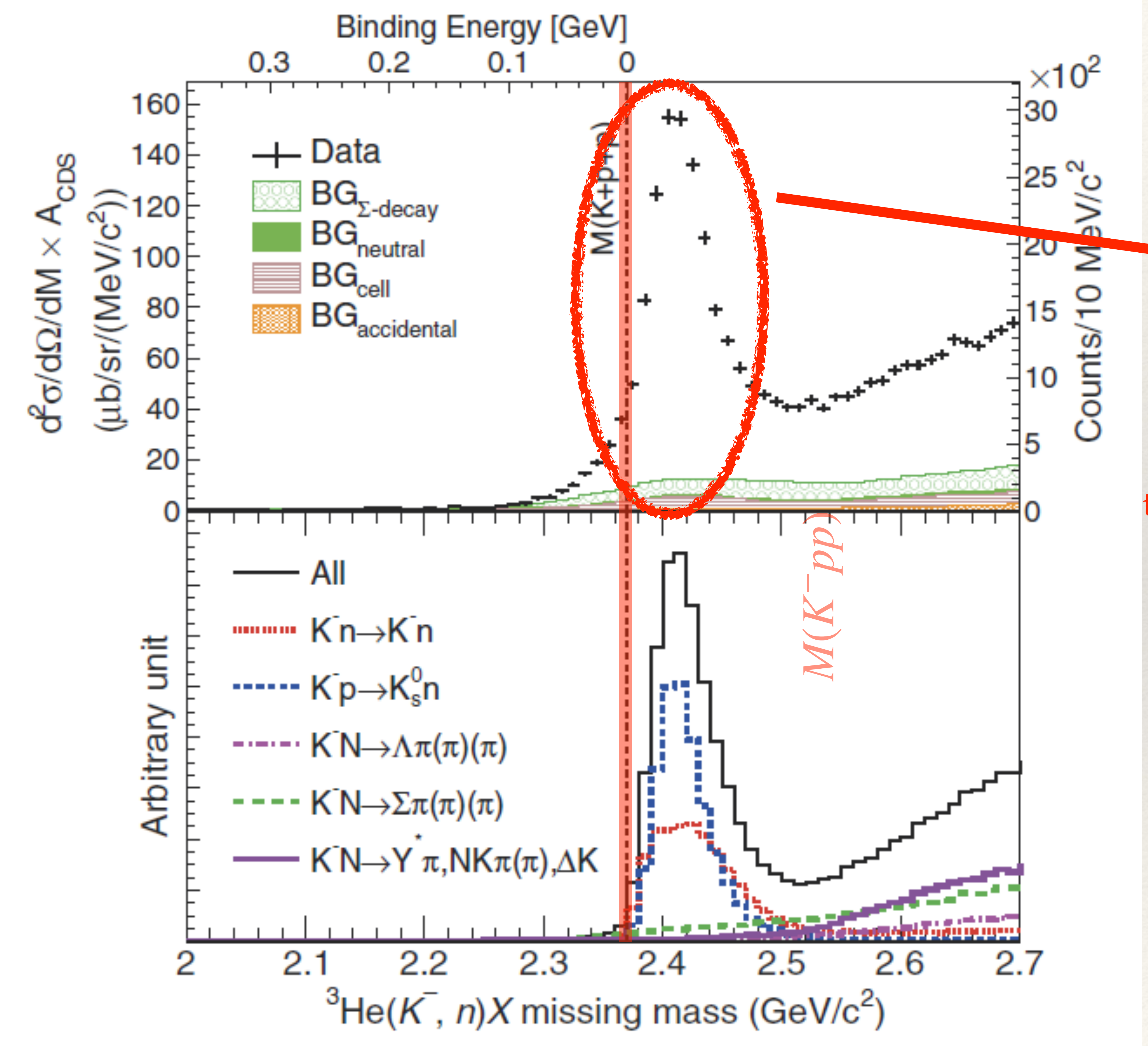


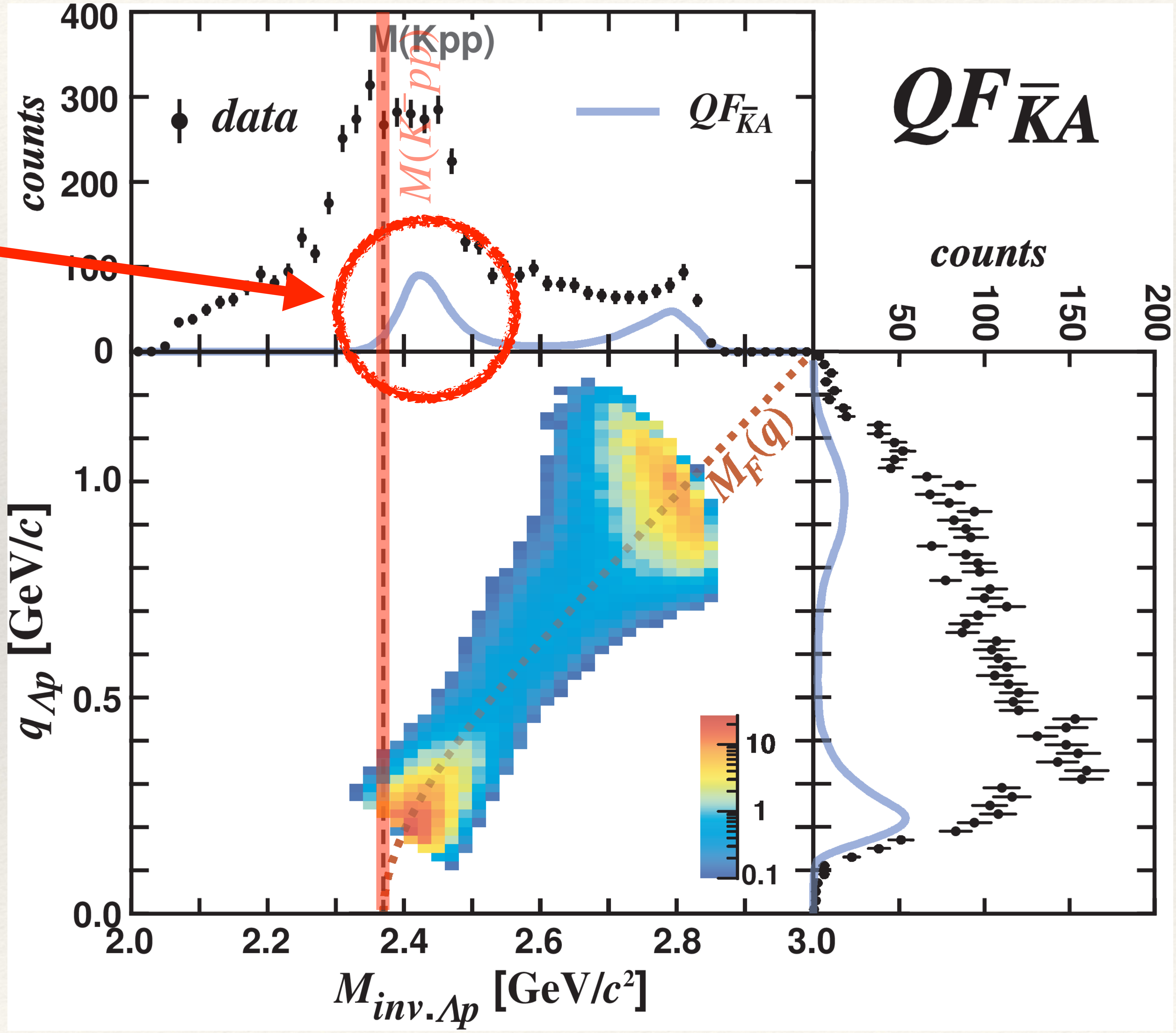


Peak position

$$m(q) = \sqrt{4m_p^2 + m_K^2 + 4m_p\sqrt{m_K^2 + q^2}}$$

Spectrum decomposition

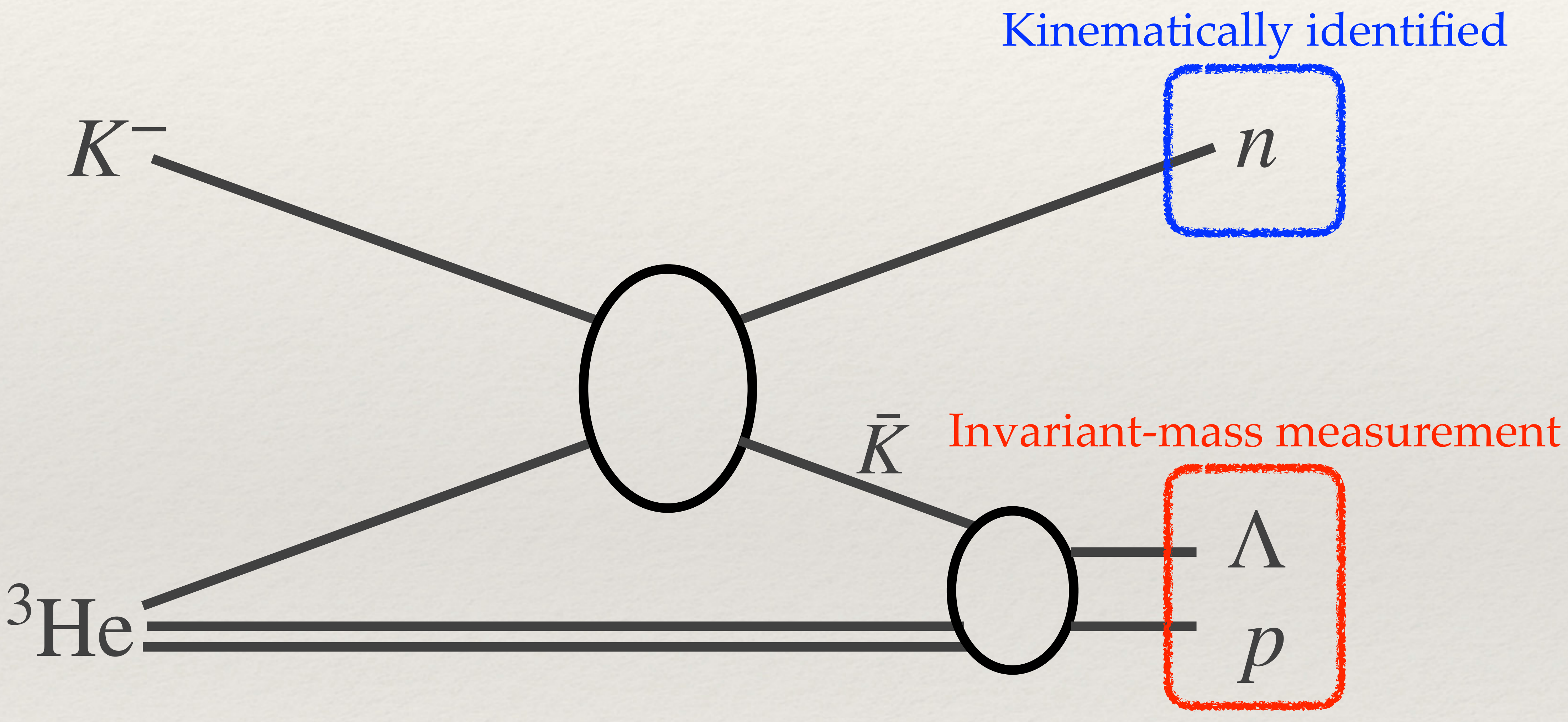


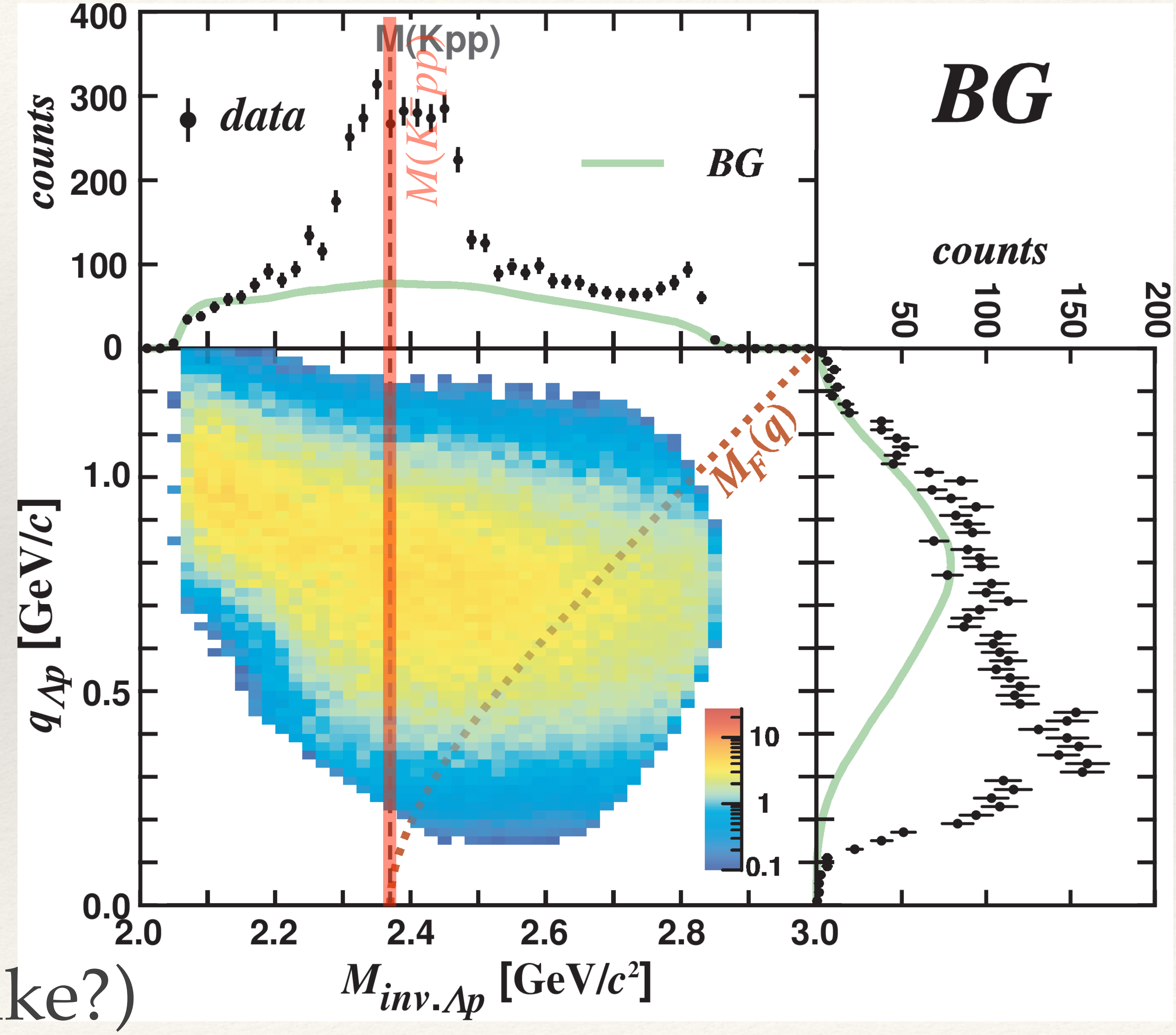


3

Spectrum decomposition

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$



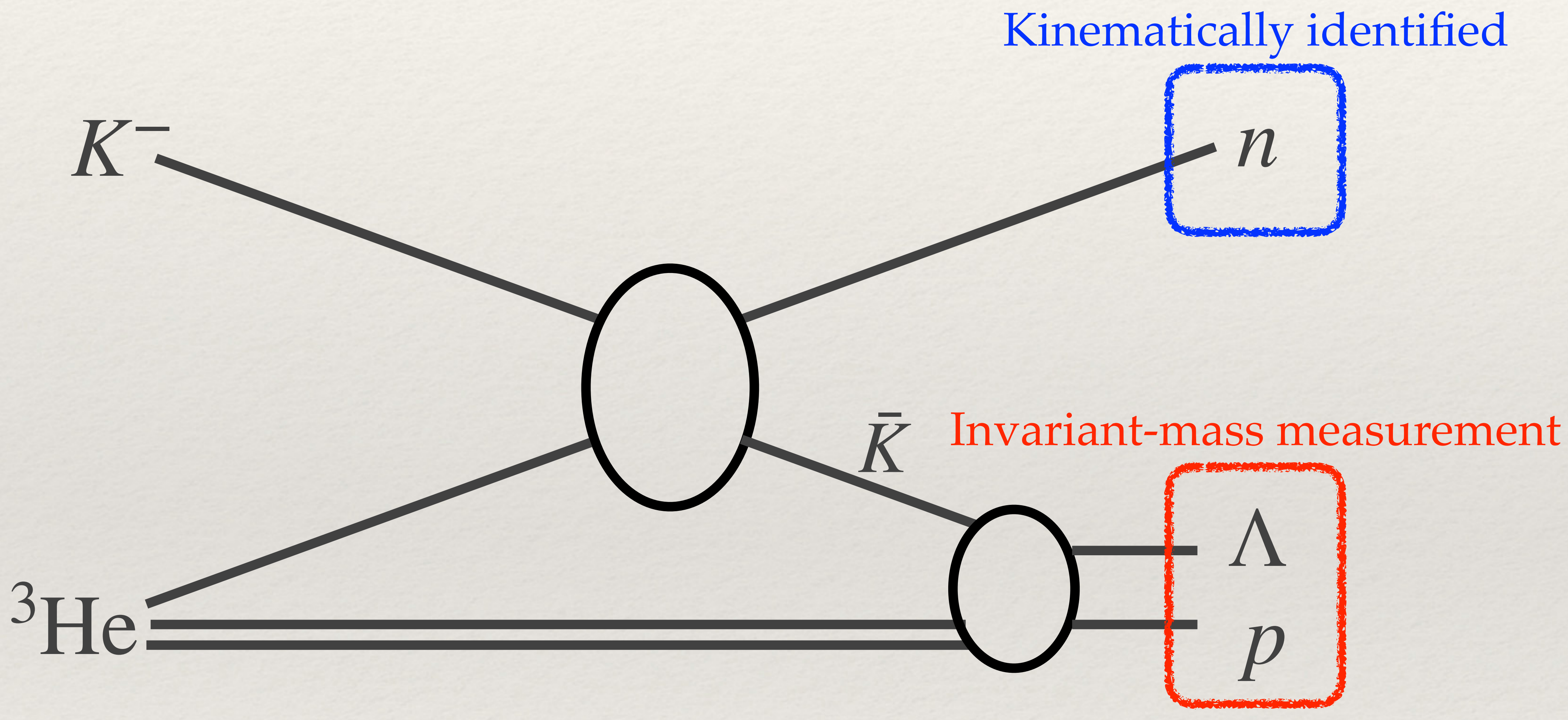


Physics background : $\Sigma^0 pn$ / $\Sigma^- pp$

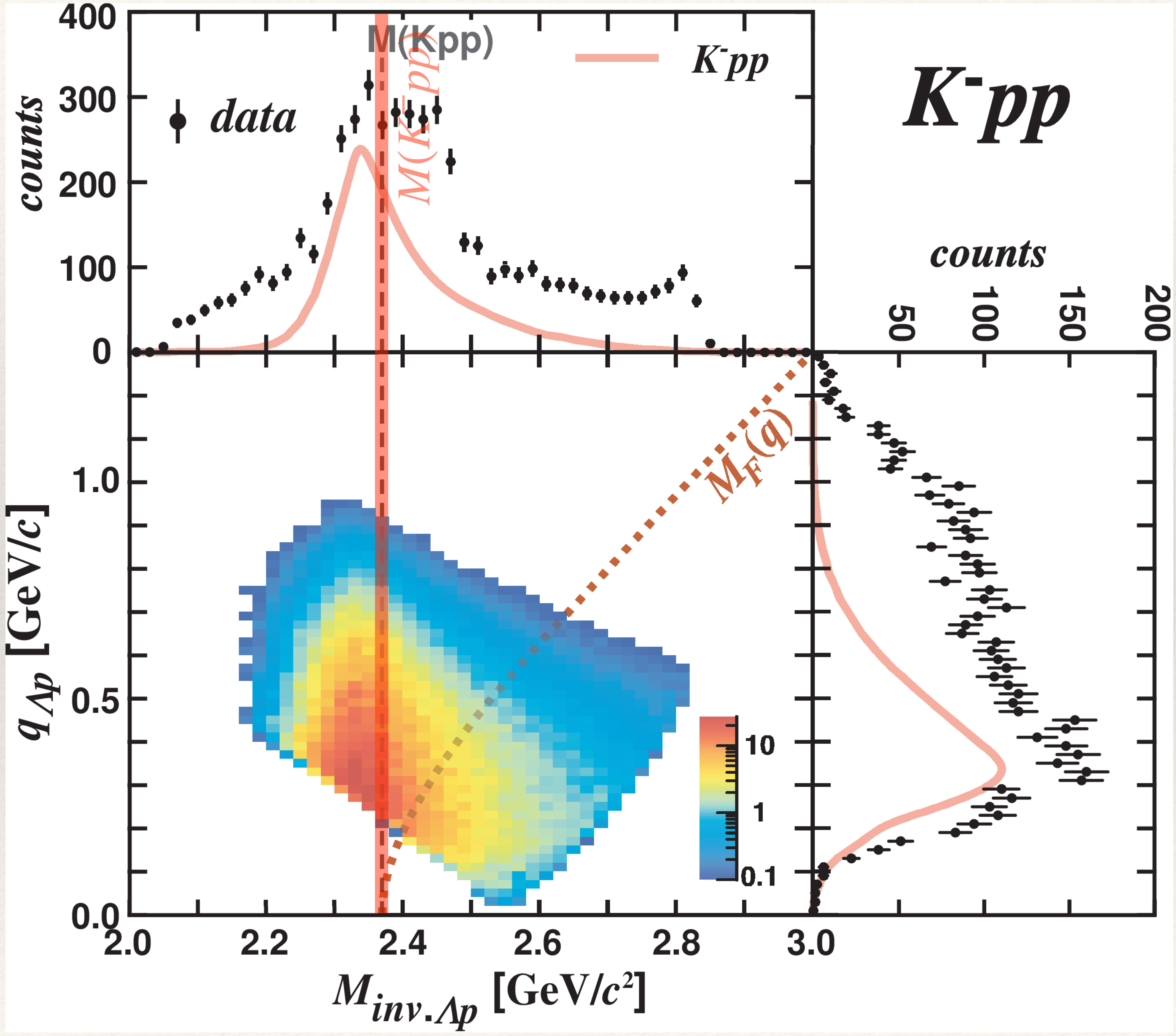
Conversion & FSI processes (or point-like?)

Spectrum decomposition

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$

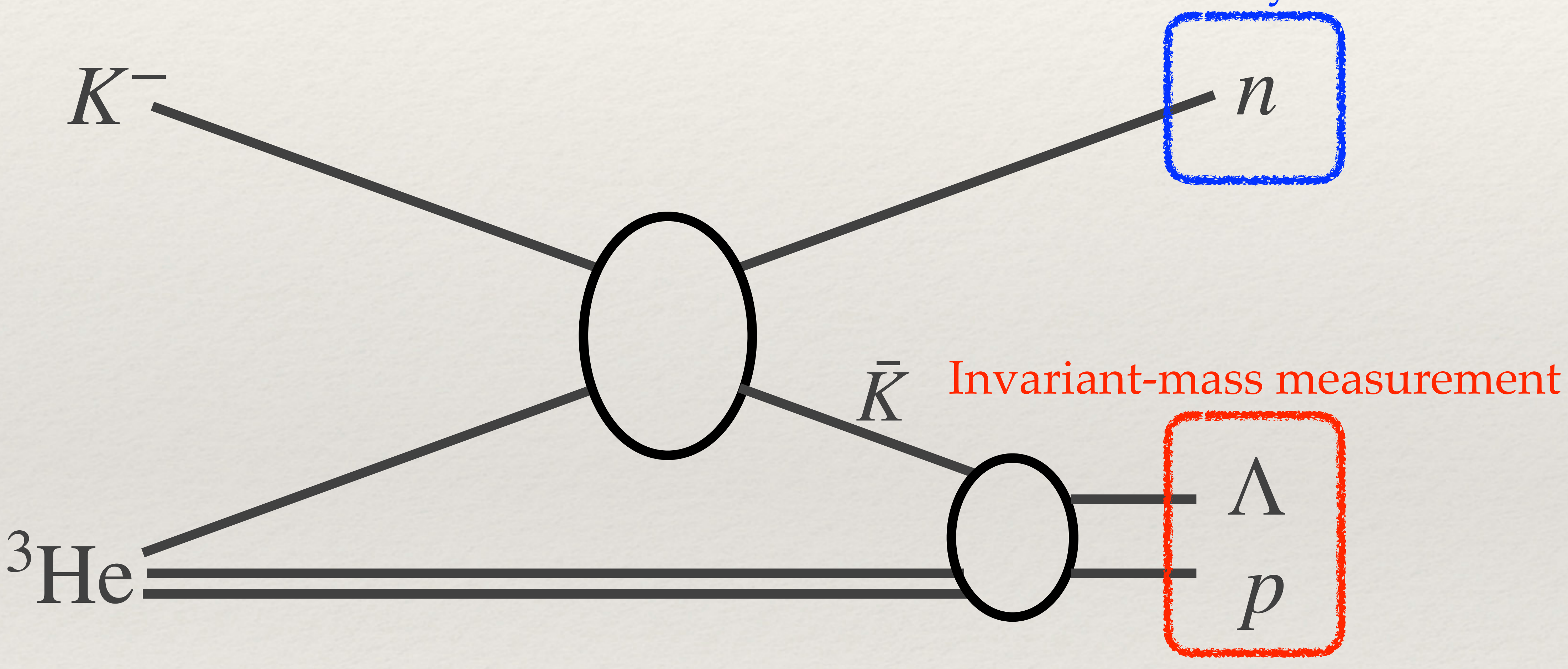


Assuming Breit-Wigner shape

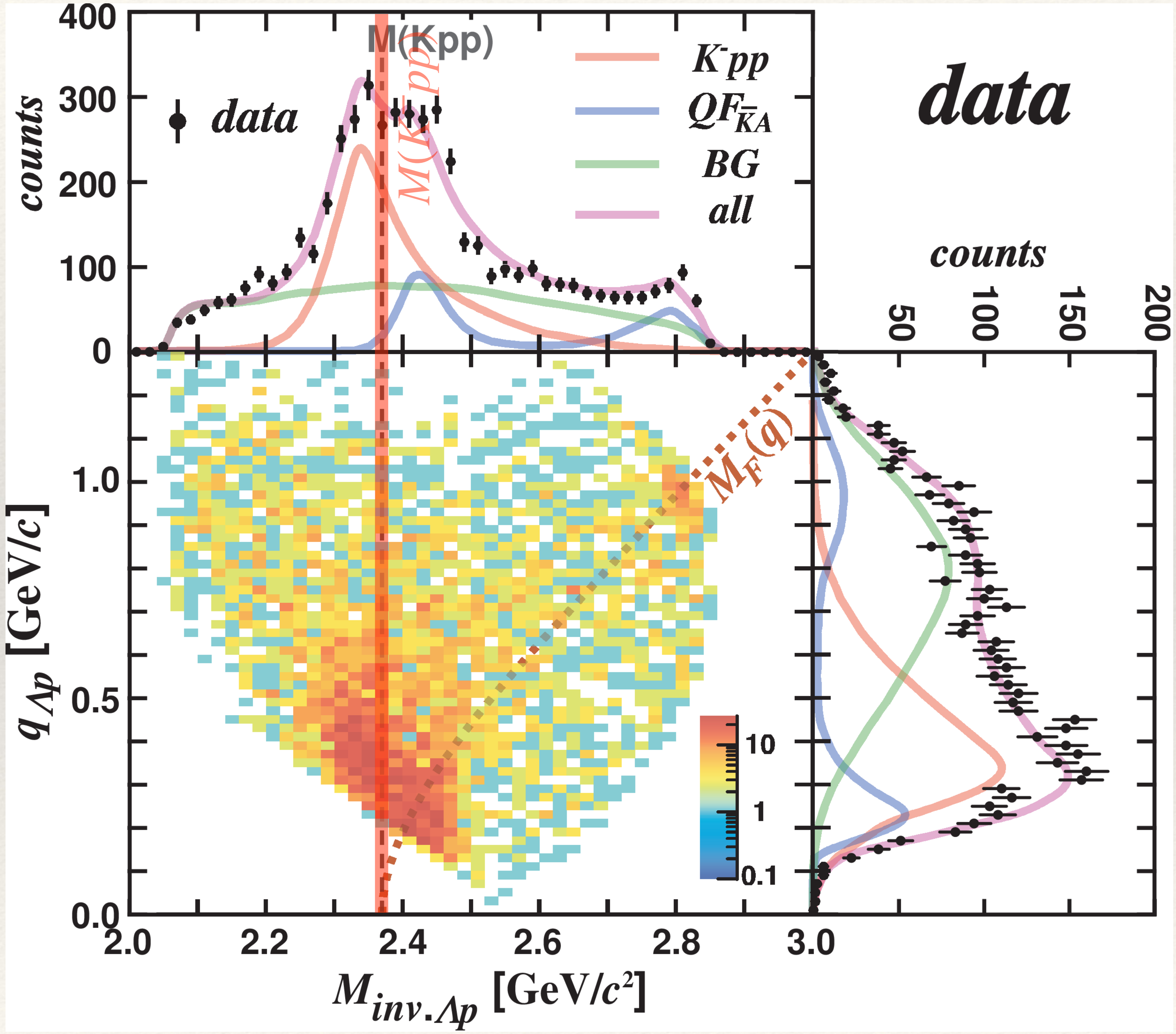


Spectrum decomposition

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$

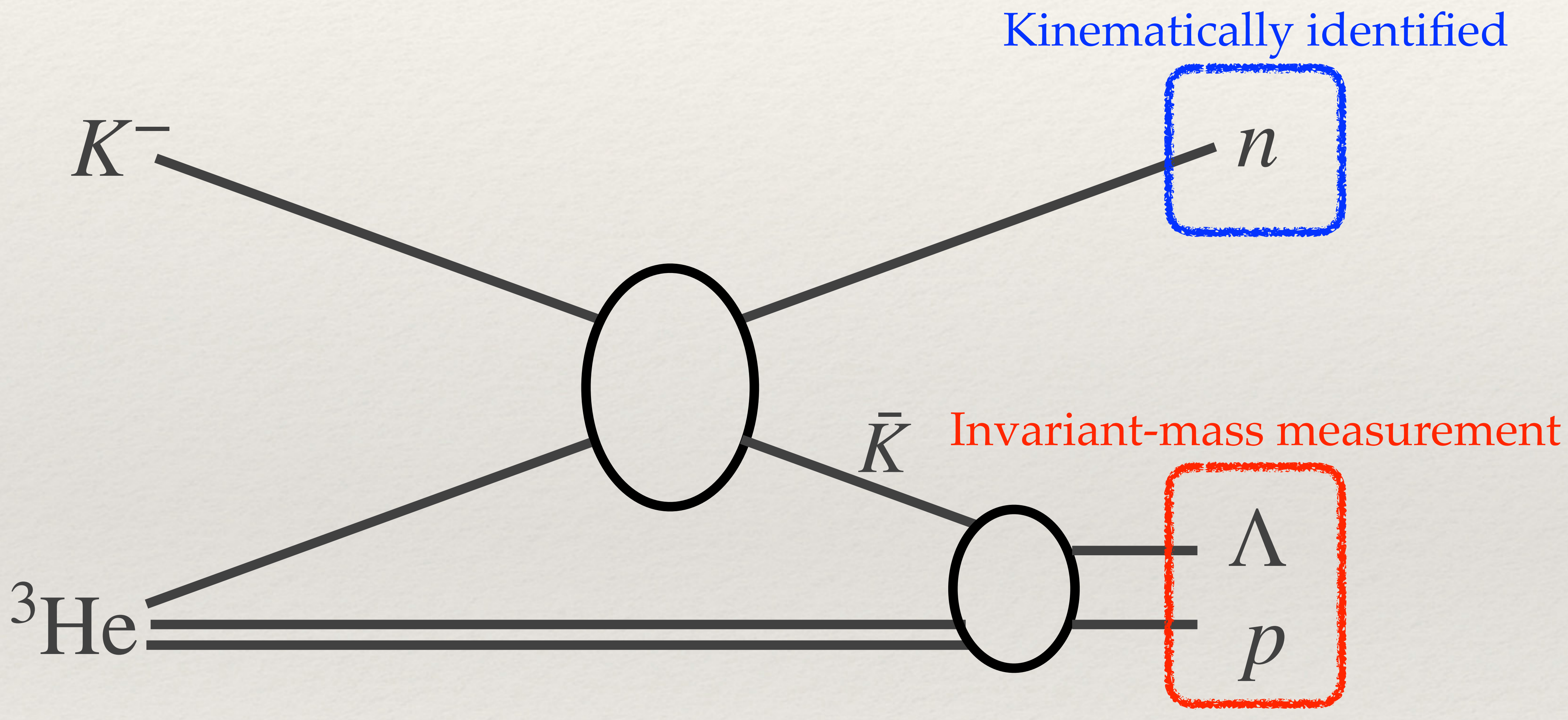


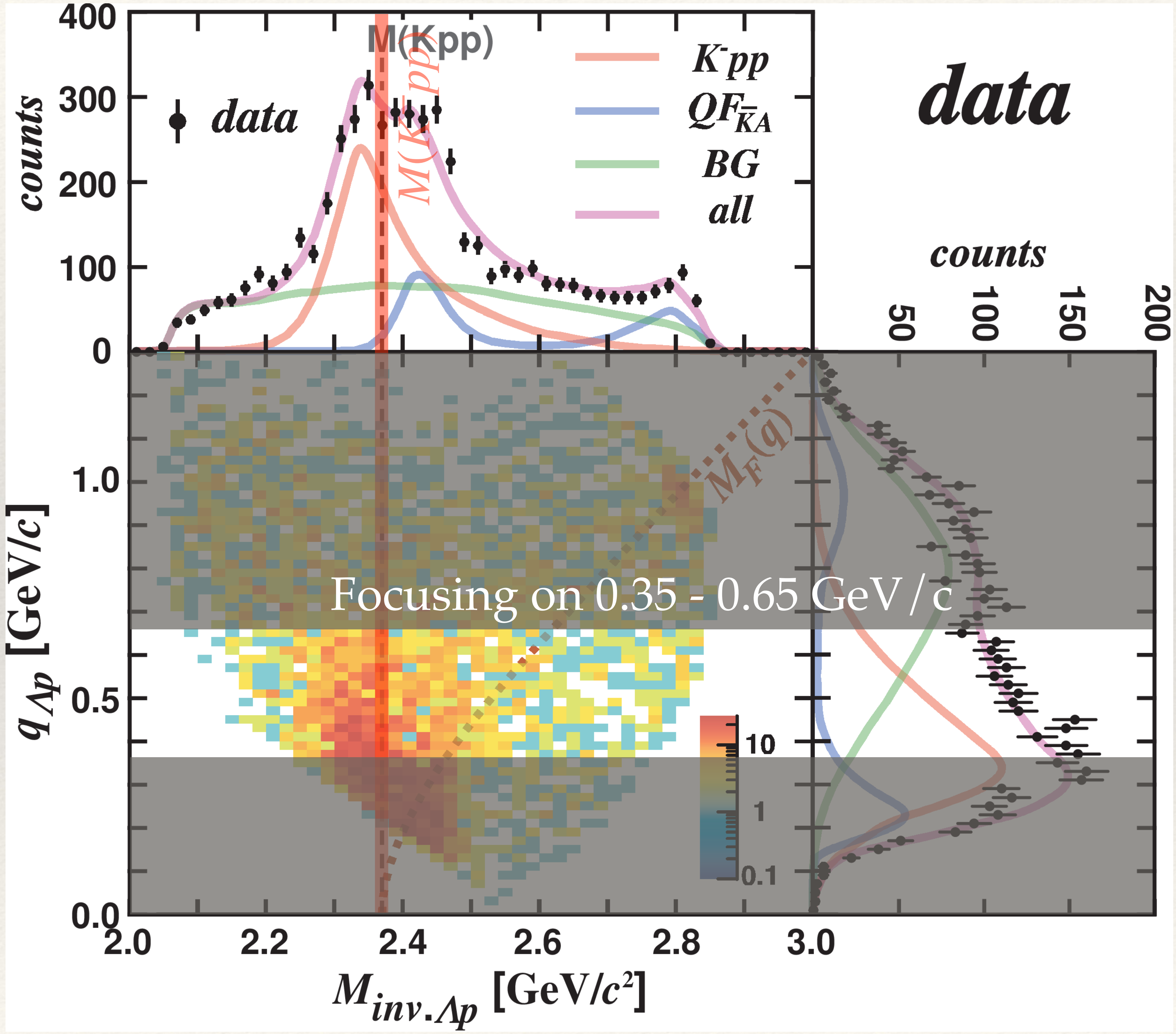
Well reproduced by 3 components



Result of Λpn analysis

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$



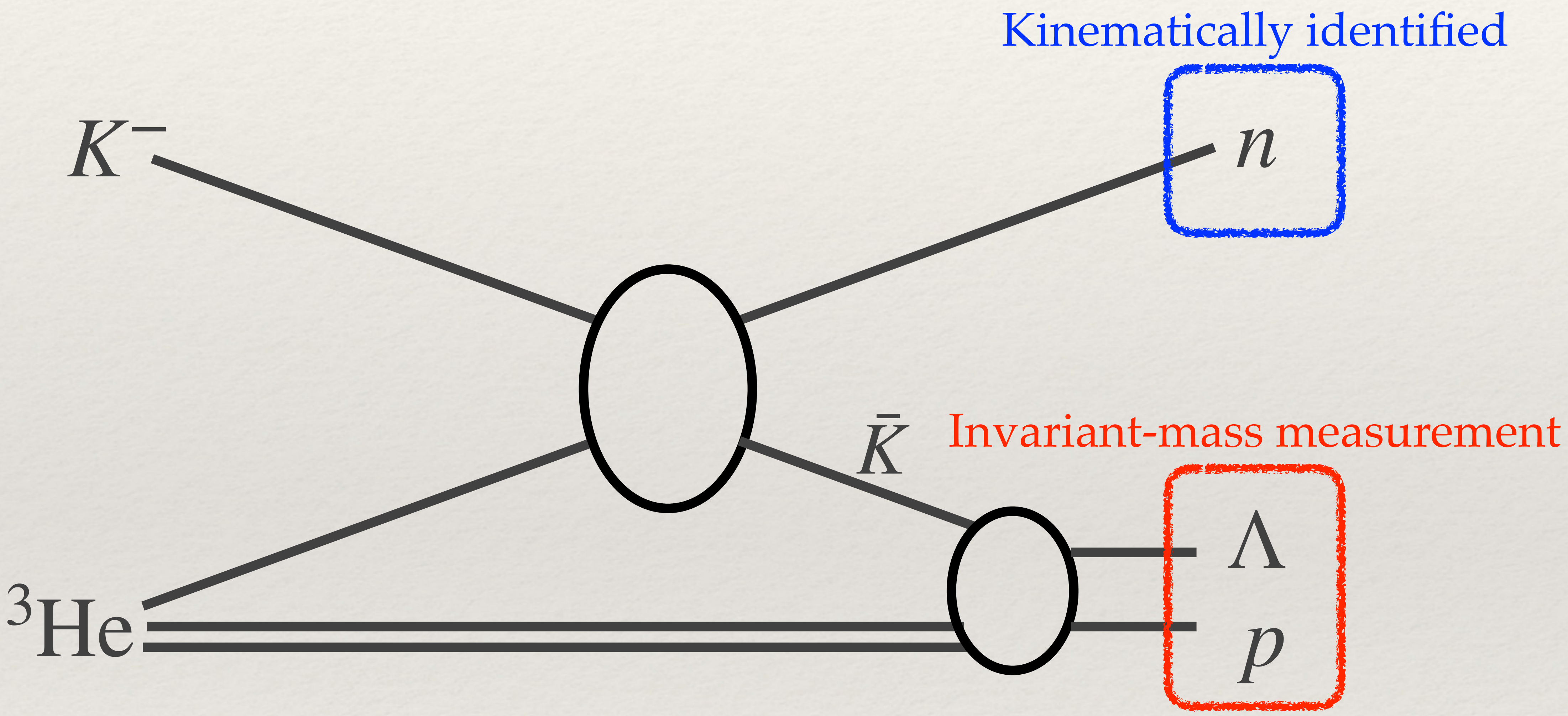


Well reproduced by 3 components

➡ Acceptance correction

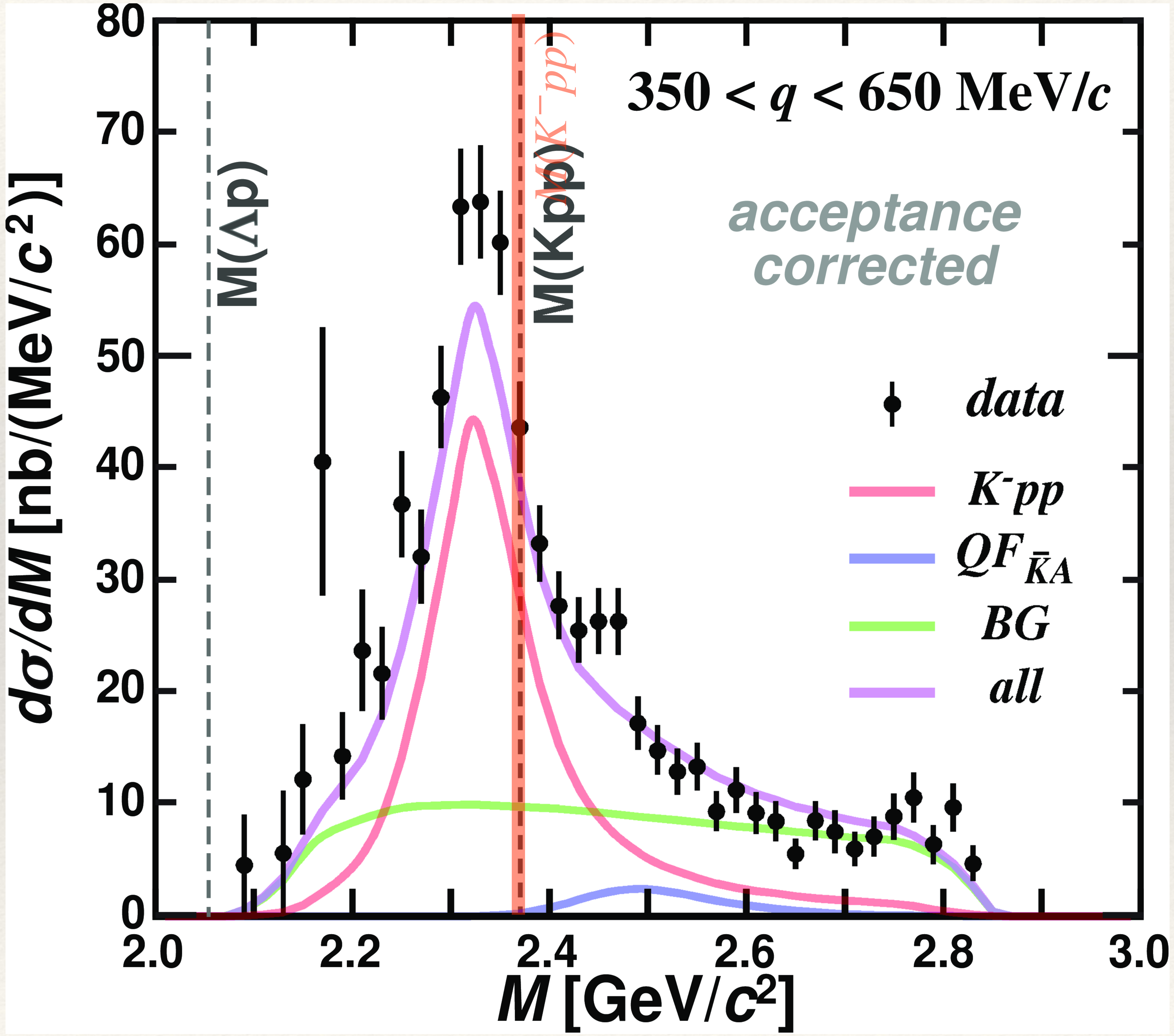
Result of Λpn analysis

$$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$$



$$B.E. = 47 \pm 3(\text{stat.})^{+3}_{-6}(\text{syst.})\ \text{MeV}$$

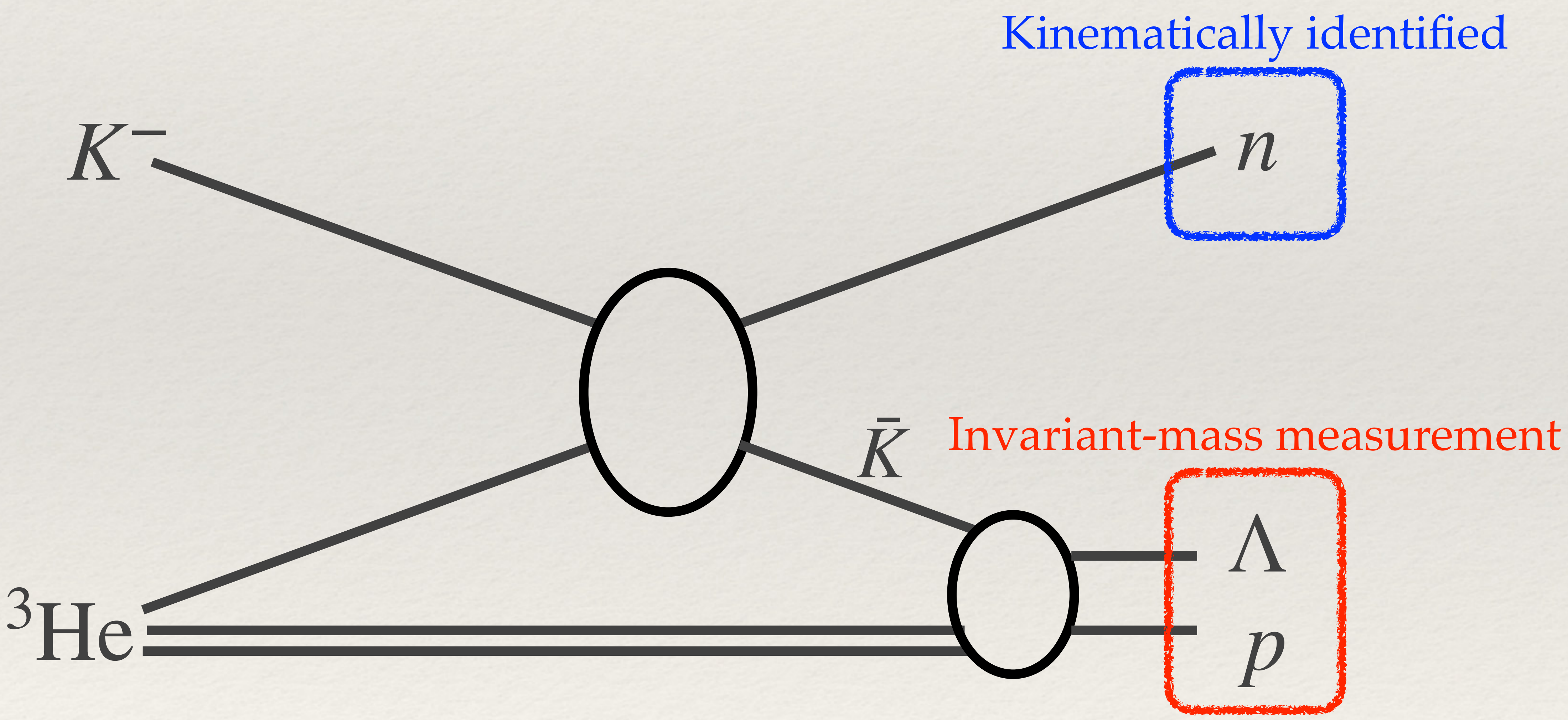
$$\Gamma = 115 \pm 7(\text{stat.})^{+10}_{-20}(\text{syst.})\ \text{MeV}$$



Non-mesonic & mesonic channels

Non-mesonic

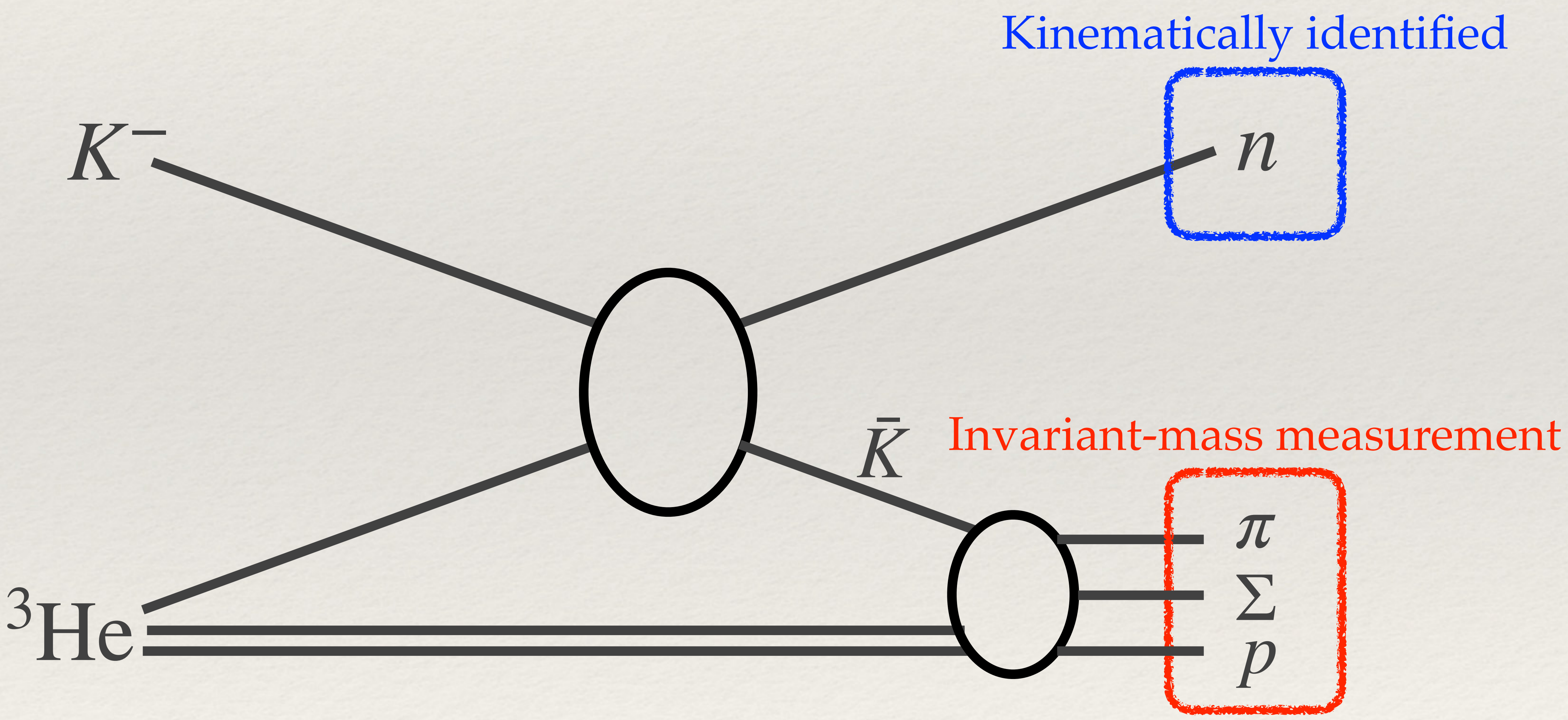
$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$



Detected particles : $pp\pi^-$

Mesonic

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \pi^\pm \Sigma^\mp p + n}$$



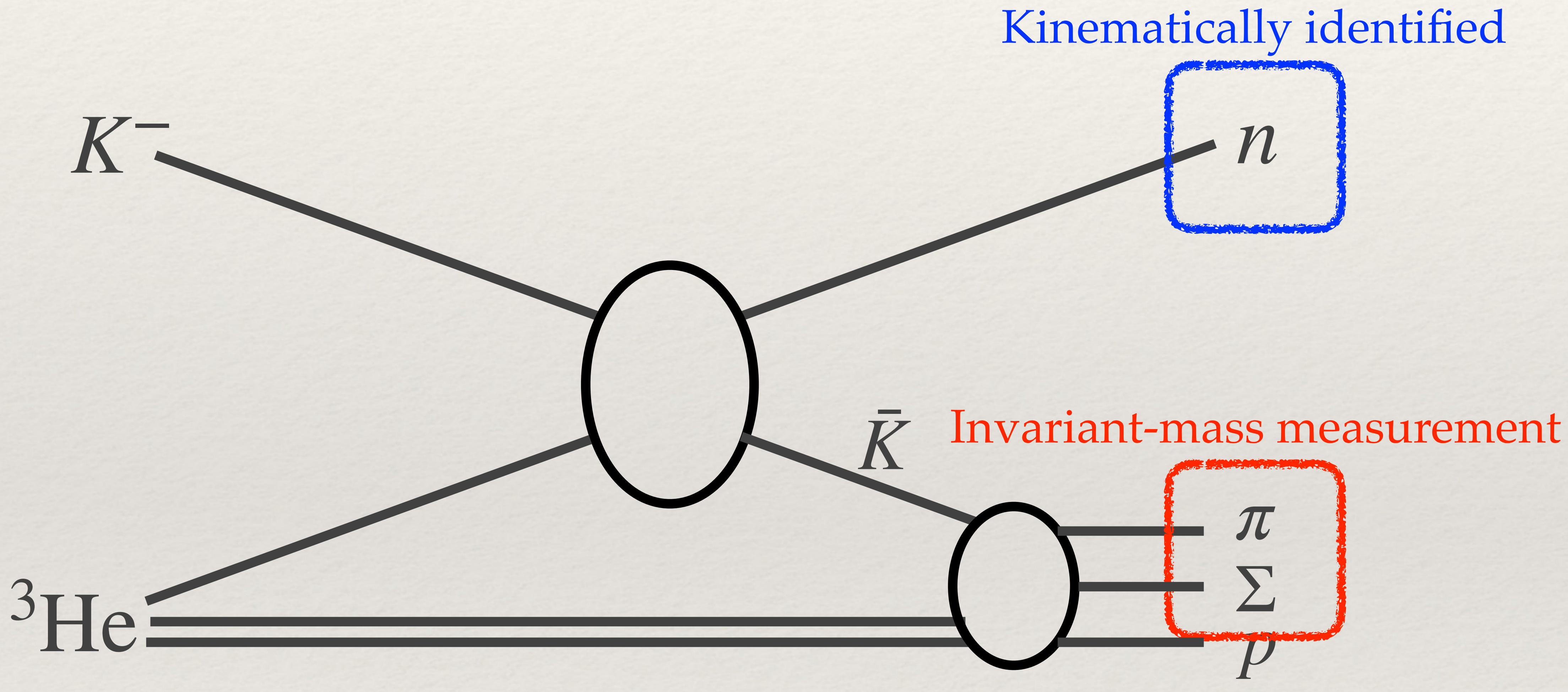
Detected particles : $np\pi^+\pi^-$

! Neutron detection by CDS

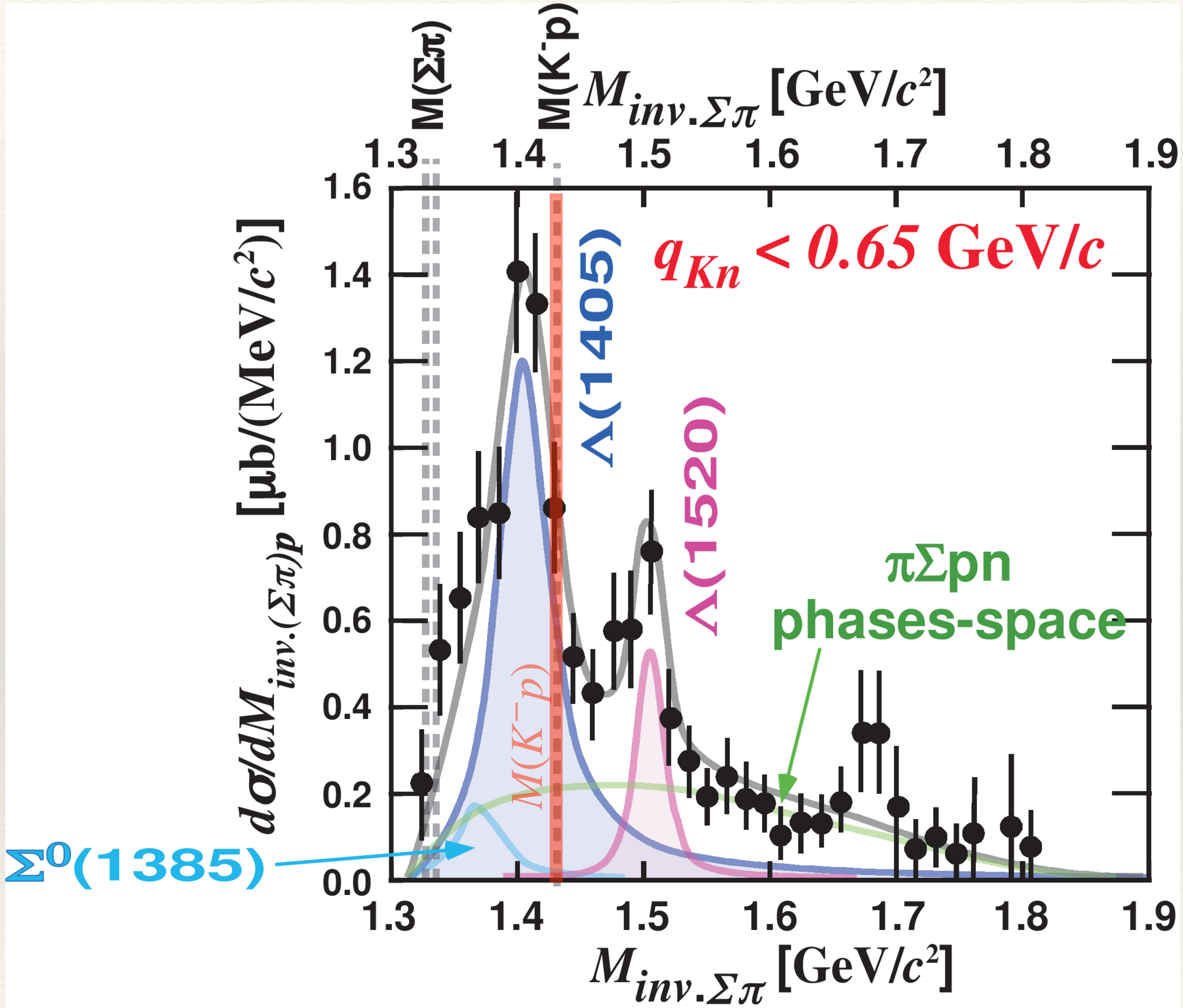
Result of πΣpn analysis

Neutron from Σ-decay is detection by CDS

$$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$$



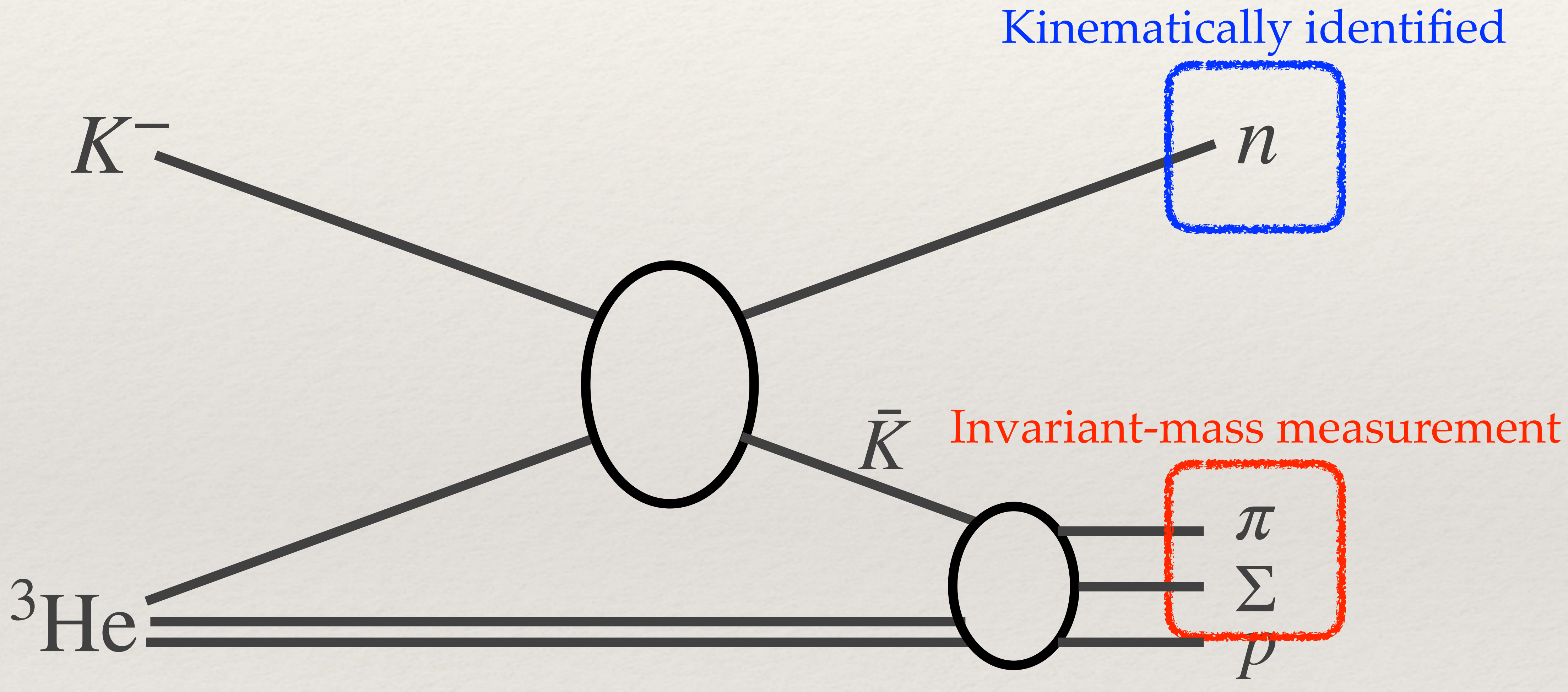
Observation of Y* production



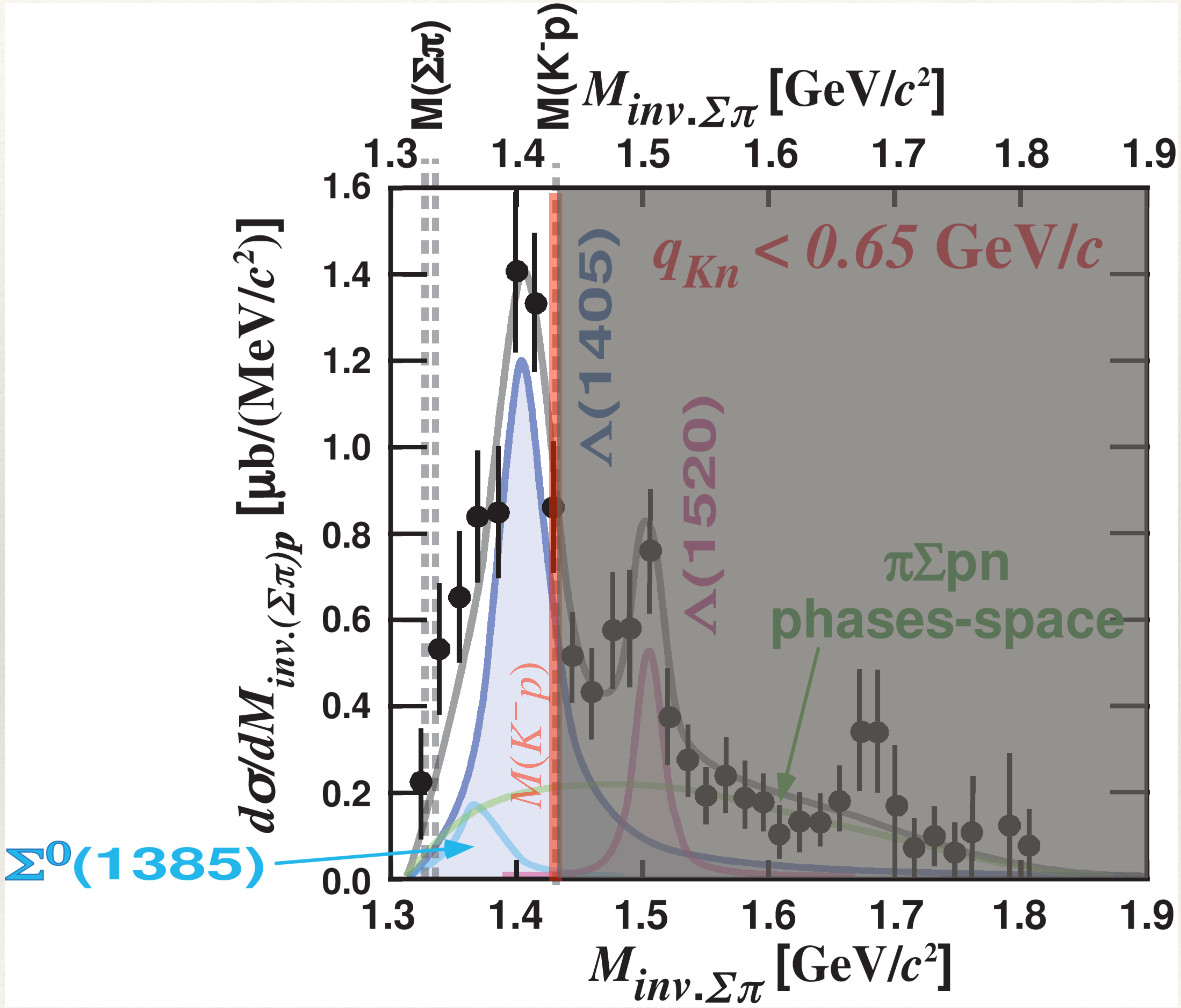
Result of πΣpn analysis

- Neutron from Σ-decay is detection by CDS

$$\boxed{K^{-} + {}^{3}\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n}$$



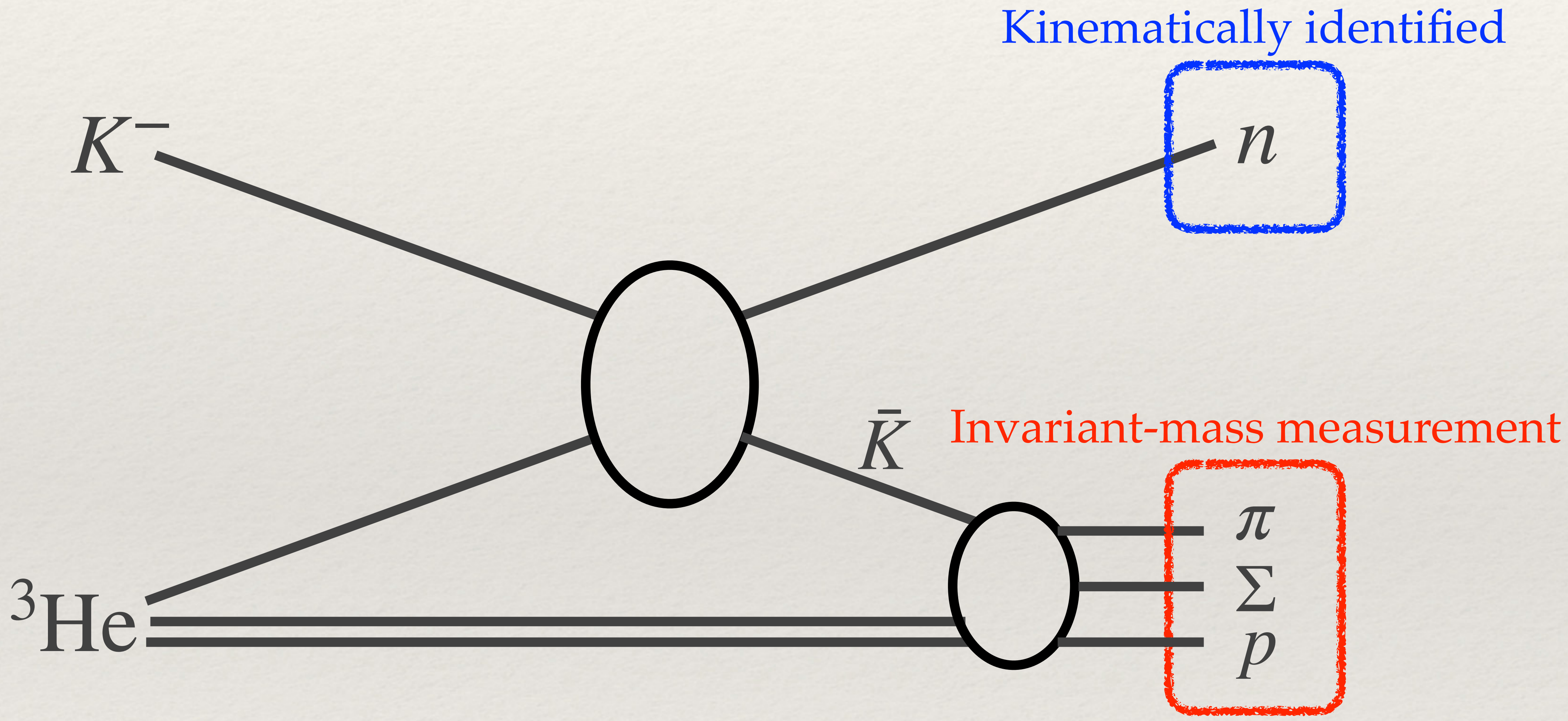
Observation of Y* production



Result of πΣpn analysis

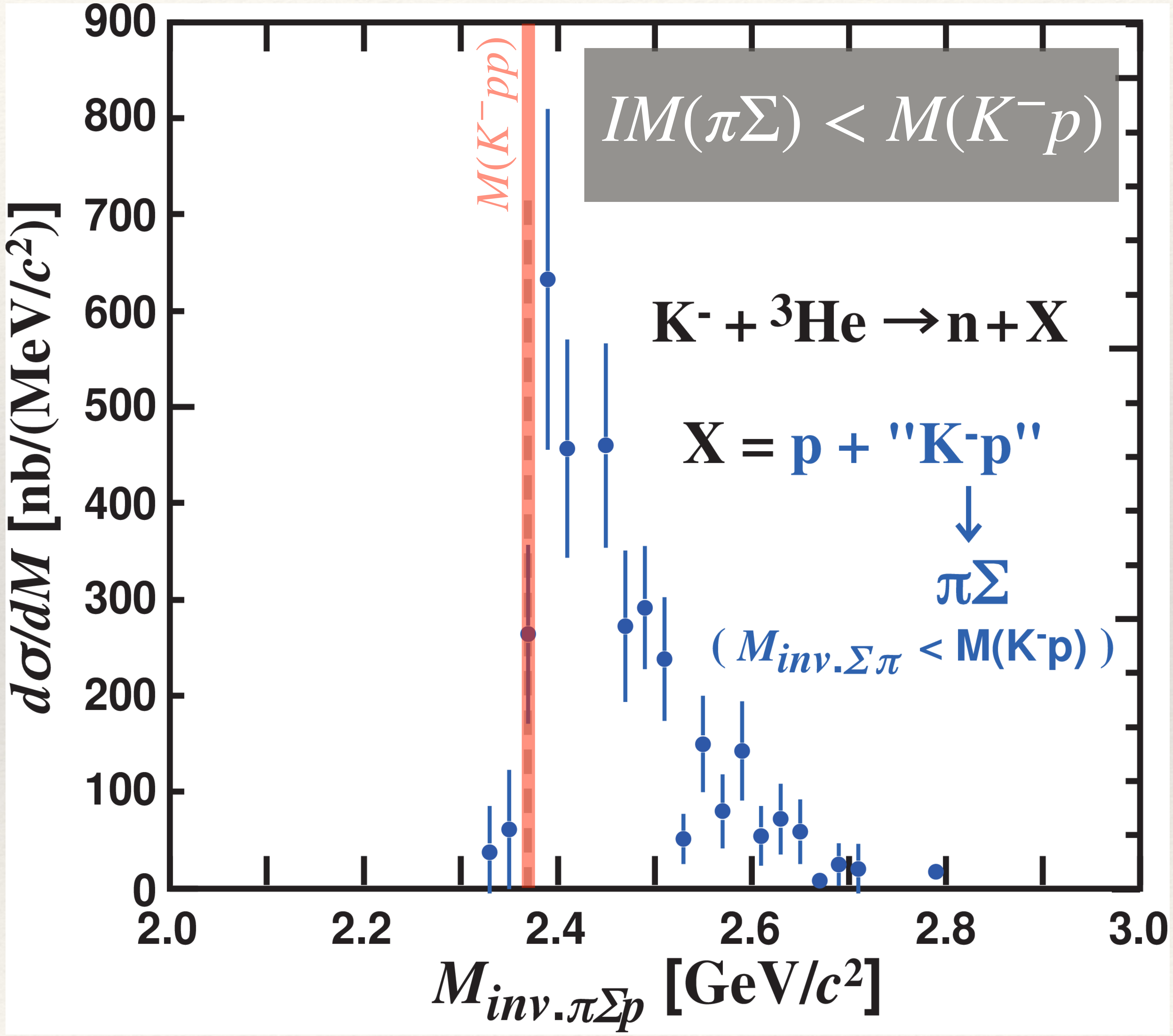
Neutron from Σ-decay is detection by CDS

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \pi^\pm\Sigma^\mp p + n}$$



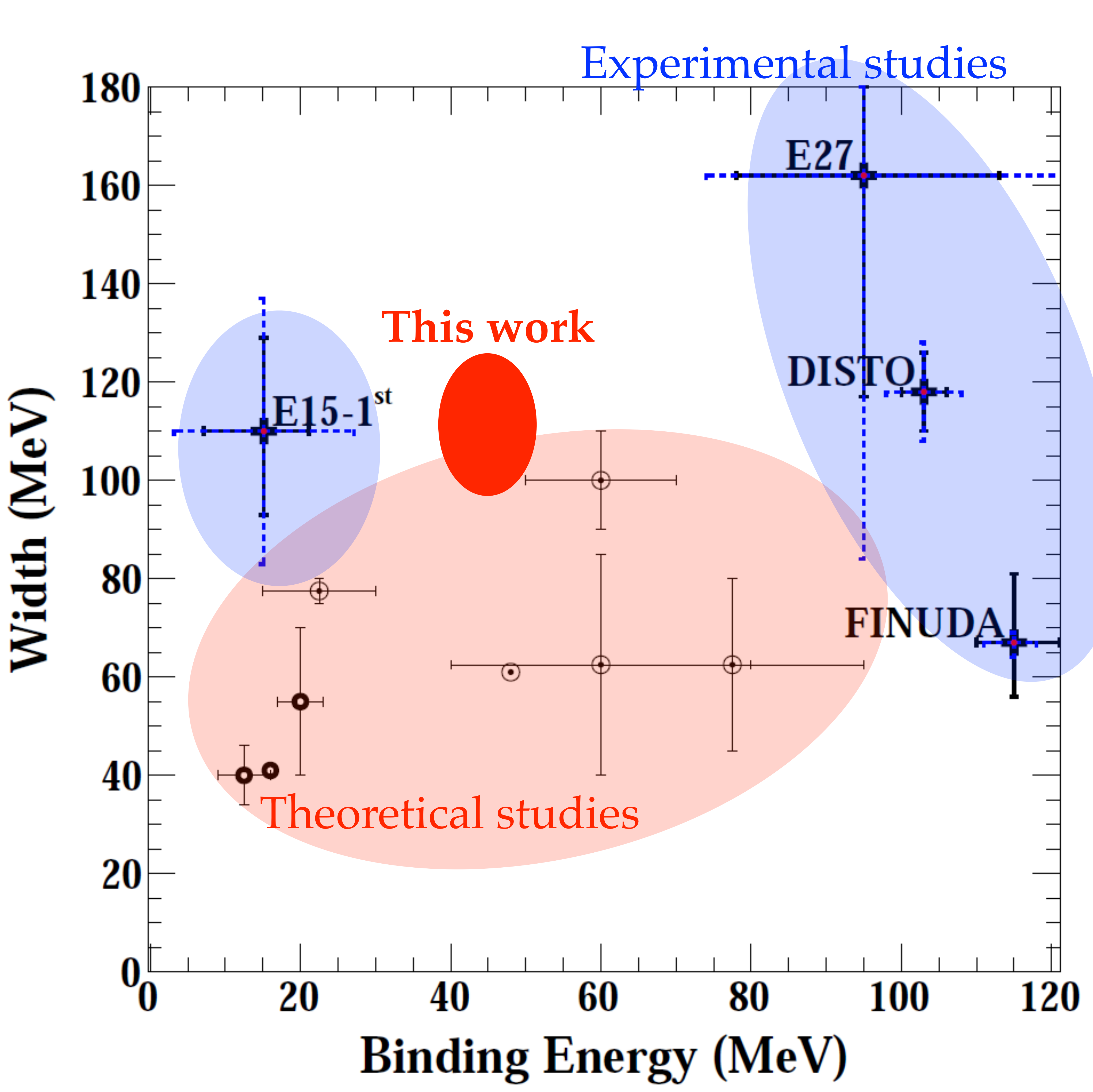
Not contributing below M(Kpp)

Need more statistics to study mesonic decay mode of KbarNN



Conclusion1

- There are many studies of KbarNN bound state.
- We have been performed experiment with (K-, n) reaction.
  - We successfully measured exclusive Λpn & πΣpn channels.
    - In Λpn channel
      - We observed Clear peak below the M(Kpp).
        - Assuming Breit-Wigner shape, B.E. and Width are found to be,
          - $B.E. = 47 \pm 3(\text{stat.})^{+3}_{-6}(\text{syst.})\ \text{MeV}$
          - $\Gamma = 115 \pm 7(\text{stat.})^{+10}_{-20}(\text{syst.})\ \text{MeV}$
    - In πΣpn channel
      - We observed Y* production in 3He(K-, n) reaction at first time in IM(πΣ) spectrum.
      - No structure was observed below the M(Kpp) in IM(πΣp) spectrum
        - More statistics is desired to understand the mesonic decay mode of KbarNN

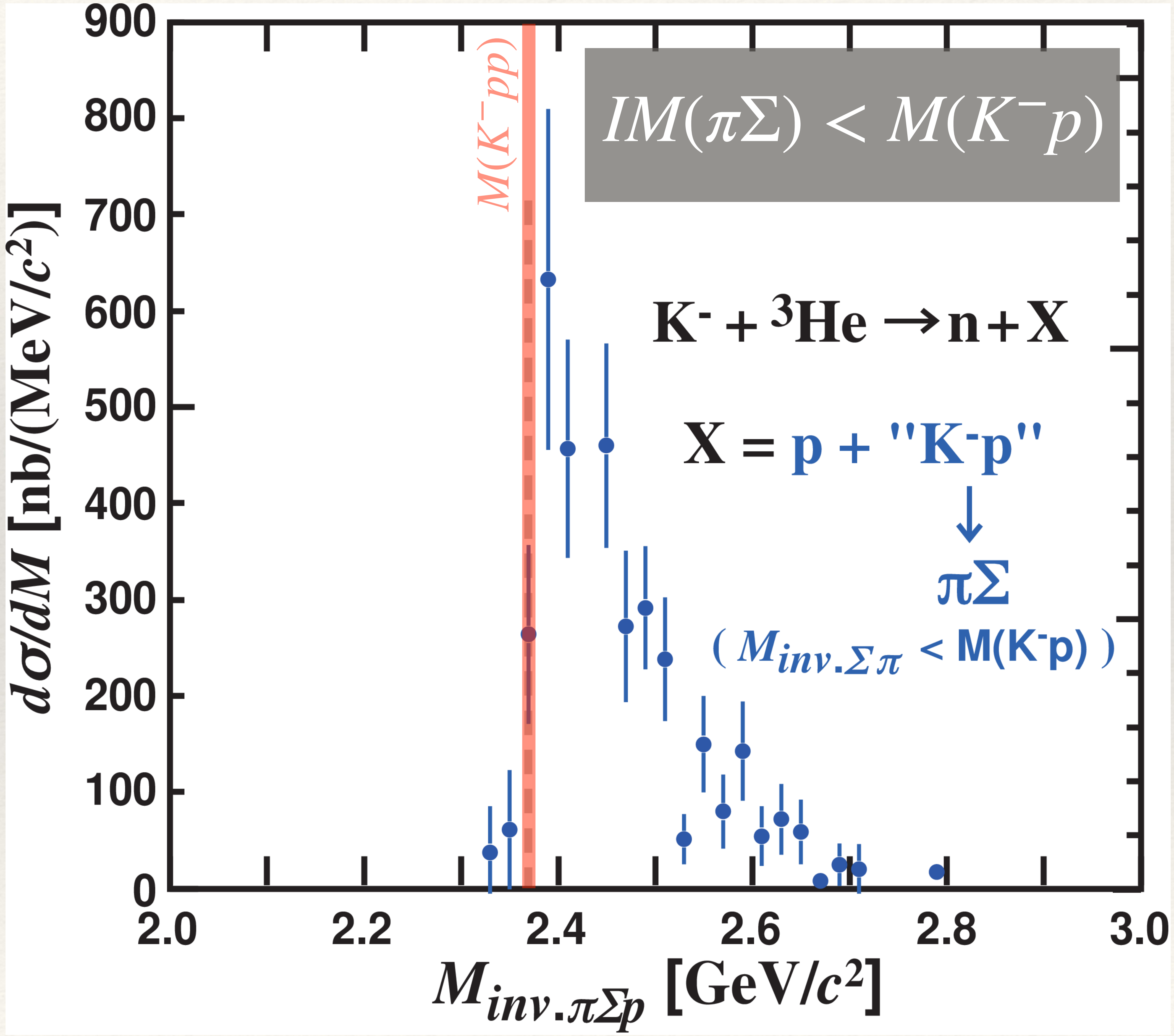


Further investigation

To establish KbarNN

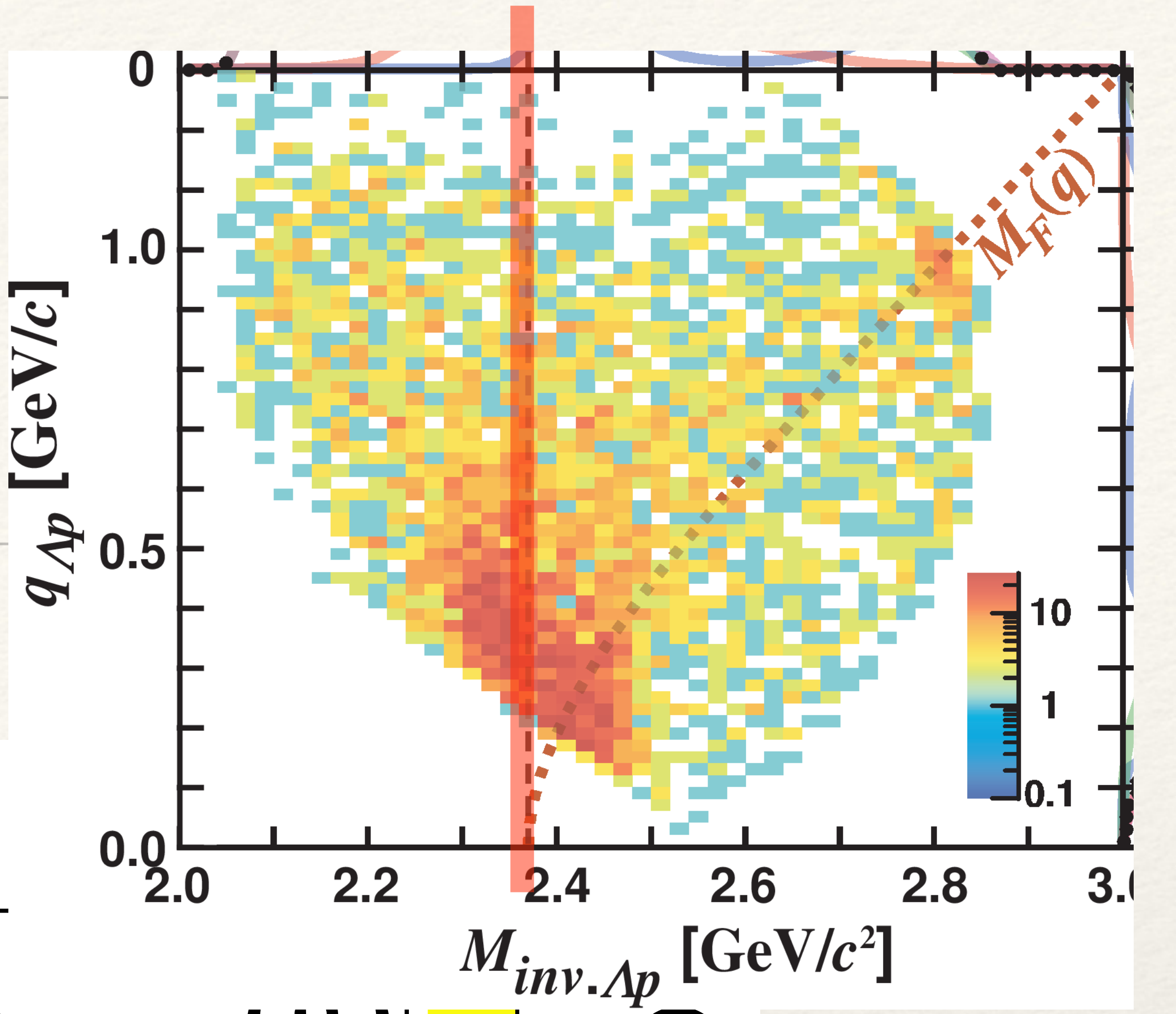
- Measuring other decay modes
  - $\pi^{\pm}\Sigma^{\mp}p \rightarrow \pi^{\pm}\pi^{\mp}np$
    - More statistics
    - Need neutron detector
  - $\Sigma^0 p \rightarrow \gamma\Lambda p$
    - Need gamma detector

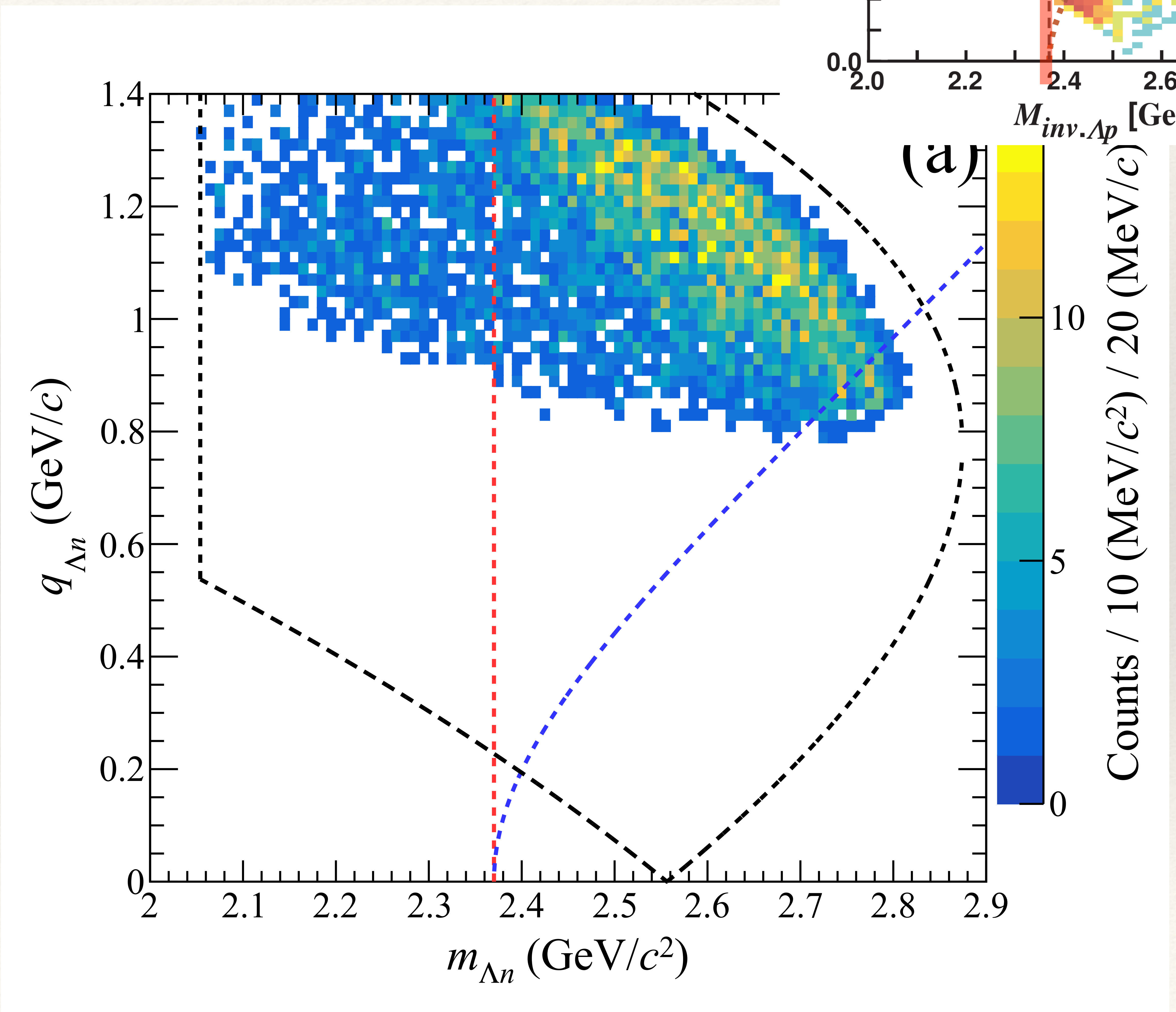
Need more statistics!



To establish KbarNN

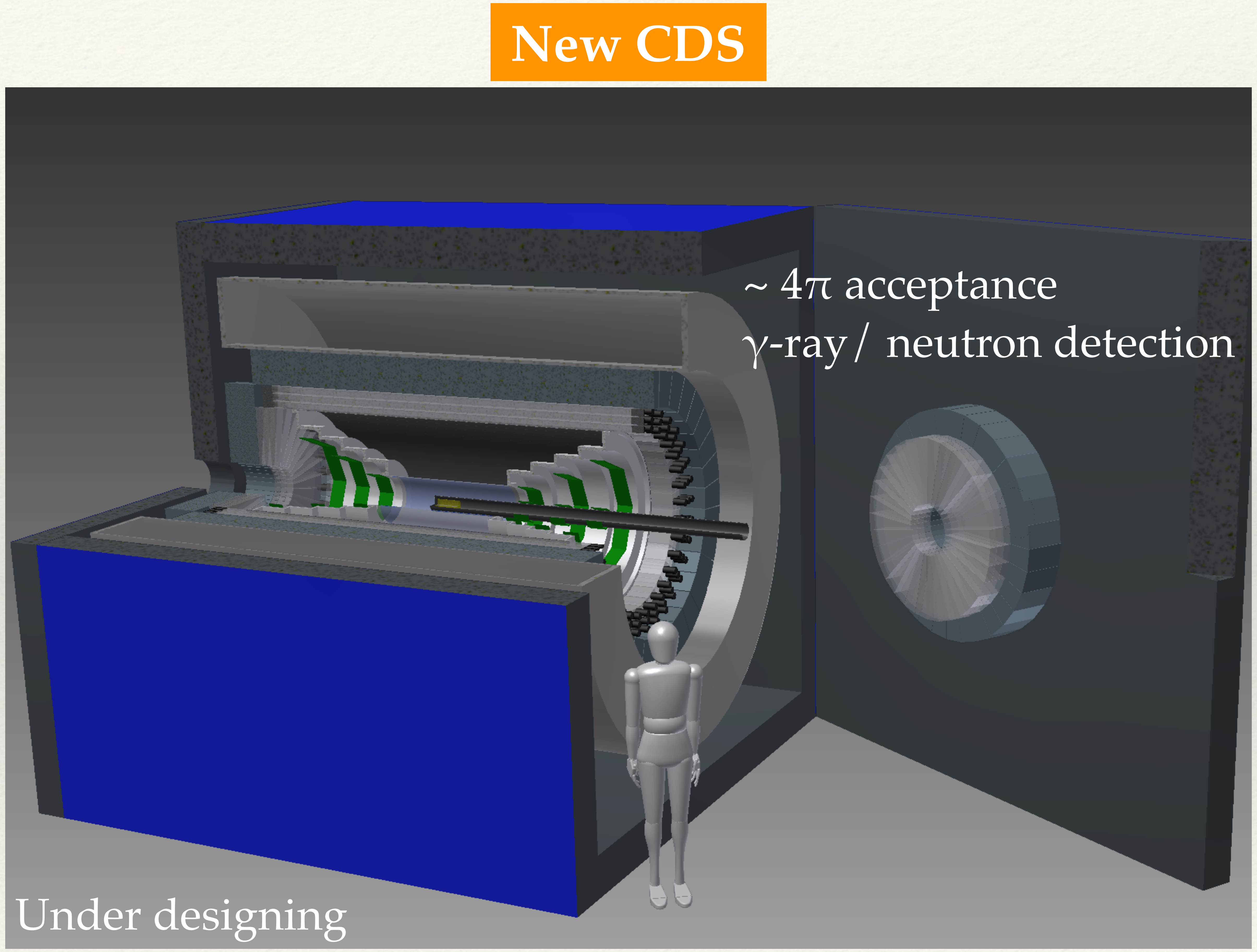
- Measure isospin partner
  - $K^- pp \to \Lambda p$ (done)
  - $K^- pn \to \Lambda n$
    - Need neutron detection
- Spin & parity
  - Decay angle measurement
  - Need more discussion





Further investigation

- To establish KbarNN,
  - Σp decay mode
    - Need γ-ray detection
  - $\pi\Sigma p$ decay mode
    - Need n detection
  - Isospin partner by Λn measurement
    - Need n detection
  - Spin-Parity
    - Need more careful discussion…

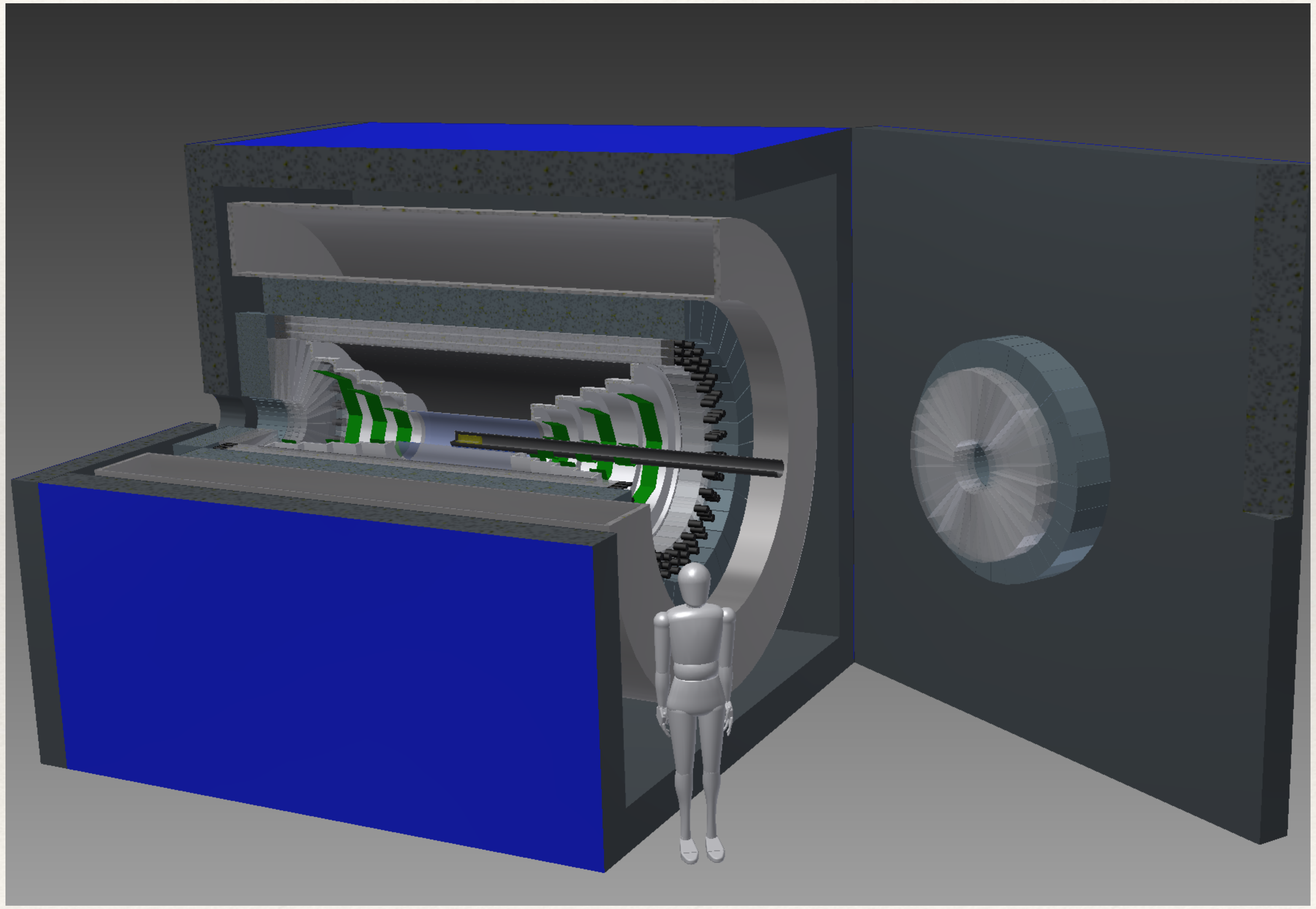


Future experiments

System	Reaction
KbarN (Λ(1405))	$d(K^-, n)$
KbarNN	$^3He(K^-, n)$ $^3He(K^-, p)$
KbarNNN	$^4He(K^-, n)$ $^4He(K^-, p)$
KbarNNNN	$^6Li(K^-, d)$

Conclusion2

- We are planning construct new spectrometer system
  - n/γ detection
  - 4π coverage
- To establish KbarNN
- To search for other kaonic nucleus



Thank you for your attention

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]

[1] *Osaka University, Osaka, 567-0047, Japan*
[2] *RIKEN, Wako, 351-0198, Japan*
[3] *University of Victoria, Victoria BC V8W 3P6, Canada*
[4] *Stefan-Meyer-Institut für subatomare Physik, A-1090 Vienna, Austria*
[5] *Seoul National University, Seoul, 151-742, South Korea*
[6] *National Institute of Physics and Nuclear Engineering - IFIN HH, Bucharest - Magurele, Romania*
[7] *INFN Sezione di Torino, 10125 Torino, Italy*
[8] *Universita' di Torino, Torino, Italy*
[9] *Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy*
[10] *High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan*
[11] *Tokyo Institute of Technology, Tokyo, 152-8551, Japan*
[12] *The University of Tokyo, Tokyo, 113-0033, Japan*
[13] *Osaka Electro-Communication University, Osaka, 572-8530, Japan*
[14] *Japan Atomic Energy Agency, Ibaraki 319-1195, Japan*
[15] *Kyoto University, Kyoto, 606-8502, Japan*
[16] *Technische Universität München, D-85748, Garching, Germany*
[17] *Tohoku University, Sendai, 982-0826, Japan and*
[18] *Lund University, Lund, 221 00, Sweden*

Backup

Theoretical studies

From F. Sakuma NFQCD2018 slide

KbarN interaction	**Chiral SU(3)**			**Phenomenological**			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B.E. (MeV)	16	17 - 23	9 - 16	48	40 - 80	50 - 70	60 - 95
Width (MeV)	41	40 - 70	34 - 46	61	40 - 85	90 - 110	45 - 80

Theoretical studies

From F. Sakuma NFQCD2018 slide

KbarN interaction	Chiral SU(3)			Phenomenological			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B.E. (MeV)	16	17 - 23	9 - 16	48	40 - 80	50 - 70	60 - 95
Width (MeV)	41	40 - 70	34 - 46	61	40 - 85	90 - 110	45 - 80

Theoretical studies

From F. Sakuma NFQCD2018 slide

KbarN interaction	Chiral SU(3)			Phenomenological			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B.E. (MeV)	16	17 - 23	9 - 16	48	40 - 80	50 - 70	60 - 95
Width (MeV)	41	40 - 70	34 - 46	61	40 - 85	90 - 110	45 - 80

Theoretical studies

From F. Sakuma NFQCD2018 slide

KbarN interaction	Chiral SU(3)			Phenomenological			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B.E. (MeV)	16	17 - 23	9 - 16	48	40 - 80	50 - 70	60 - 95
Width (MeV)	41	40 - 70	34 - 46	61	40 - 85	90 - 110	45 - 80

Theoretical studies

From F. Sakuma NFQCD2018 slide

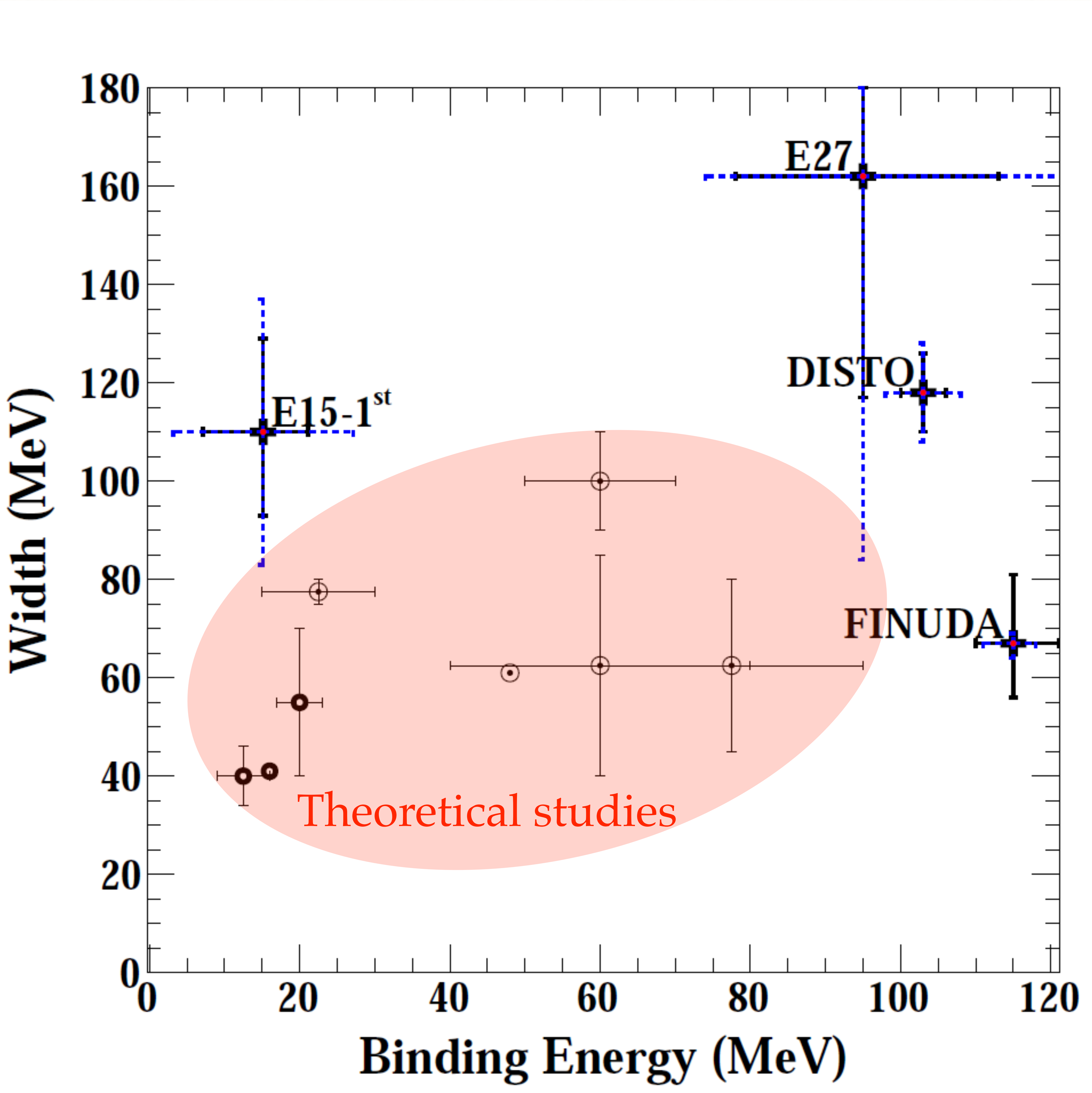
KbarN interaction	**Chiral SU(3)**			**Phenomenological**			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B.E. (MeV)	16	17 - 23	9 - 16	48	40 - 80	50 - 70	60 - 95
Width (MeV)	41	40 - 70	34 - 46	61	40 - 85	90 - 110	45 - 80

Variational vs. Faddeev : Not so changed

Chral SU(3) vs. Phenomenological : large difference in B.E.

KbarNN bound state :: Current status

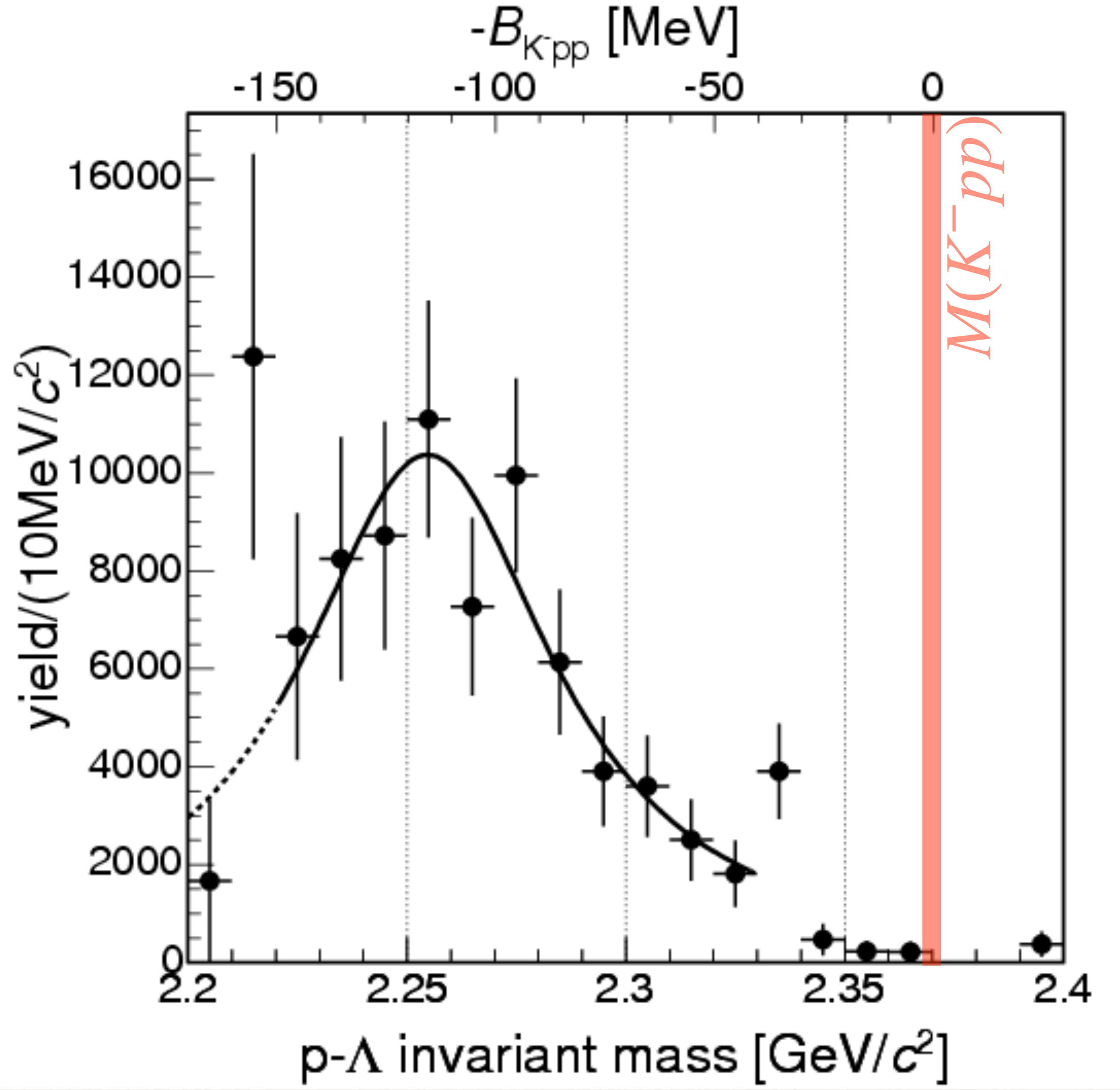
- Many theoretical & experimental studies
  - Theoretical studies
    - KbarNN can be exist.
    - B.E. & Width strongly depend on KbarN interaction model.



Experimental studies :: Stopped K-

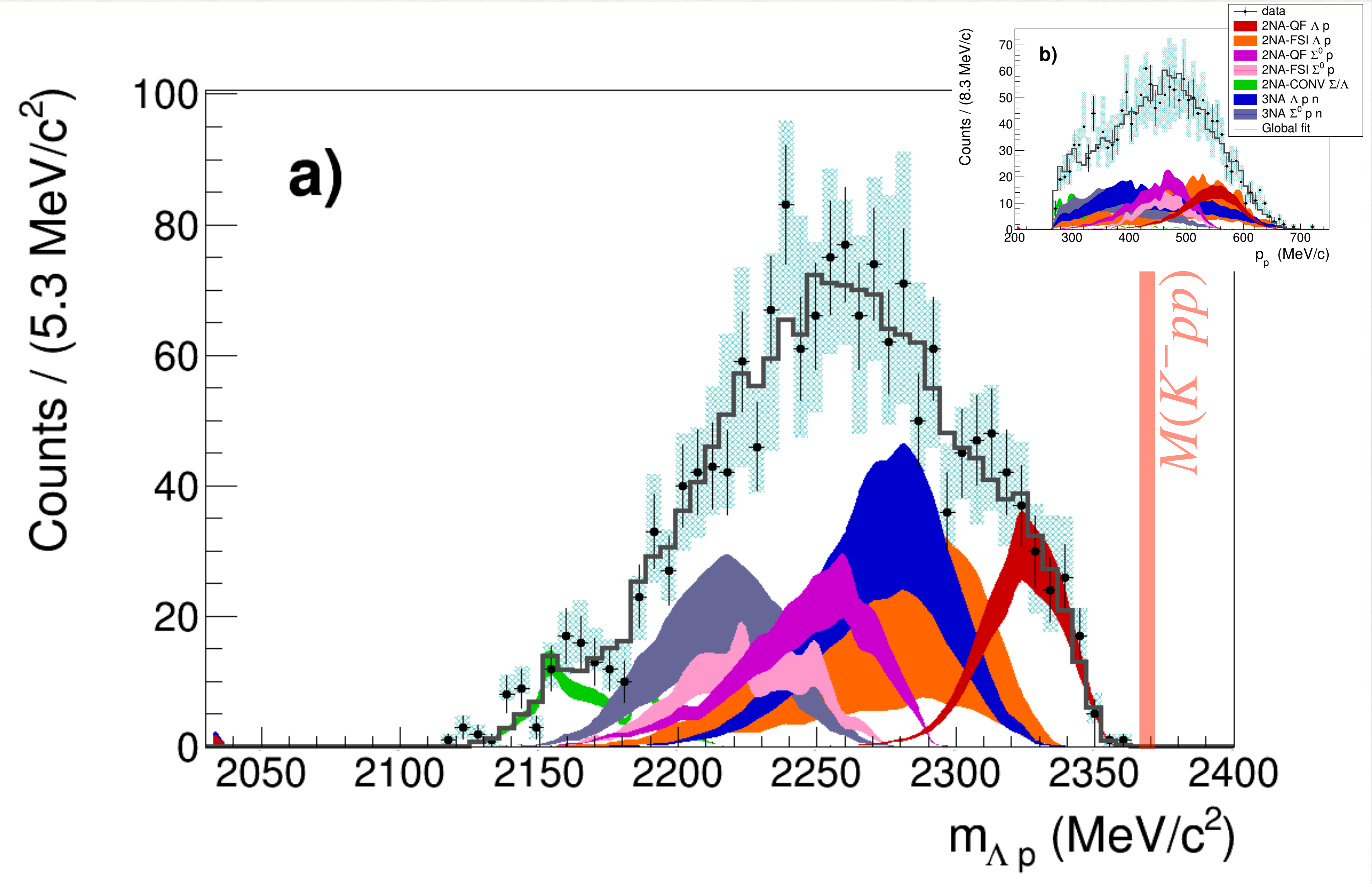
$$A(stopped\ K^{-}, \Lambda p)$$

FINUDA@DAΦNE



PRL94(2005) 132502

AMADEUS@DAΦNE

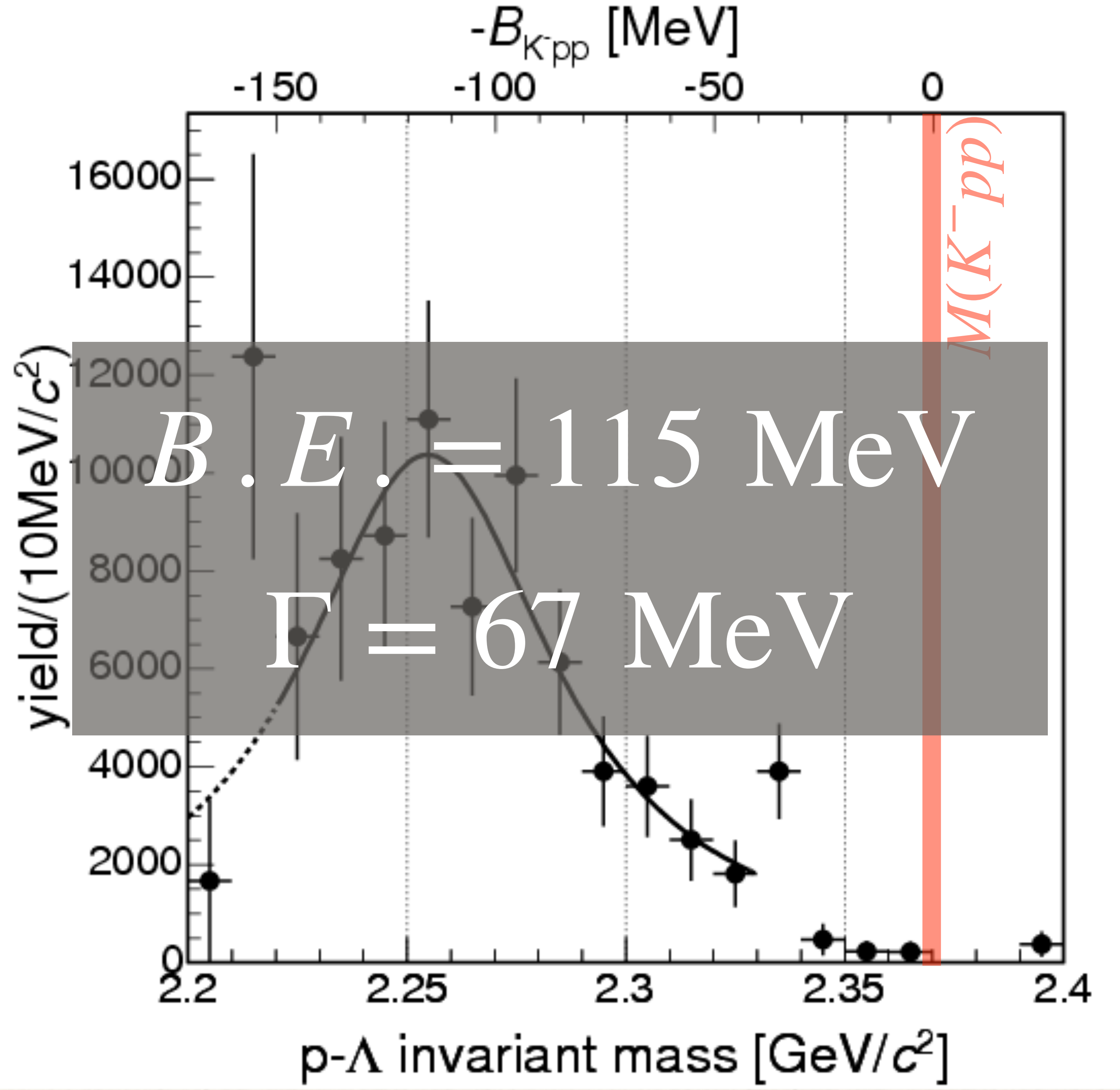


arXiv:1809.07212

Experimental studies :: Stopped K-

$$A(stopped\ K^-, \Lambda p)$$

FINUDA@DAΦNE

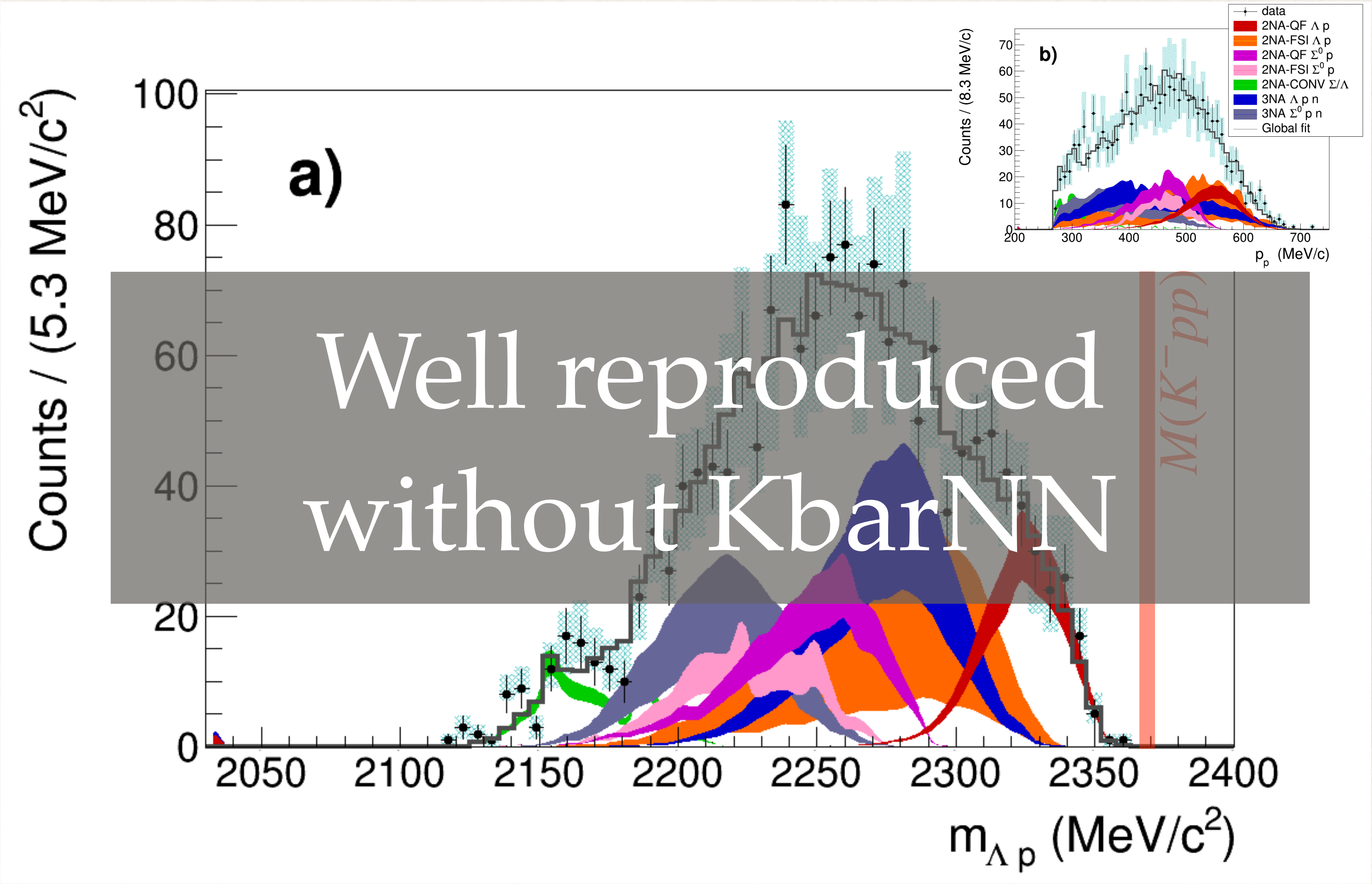


$B.E. = 115$ MeV

$\Gamma = 67$ MeV

PRL94(2005) 212303

AMADEUS@DAΦNE



Well reproduced without KbarNN

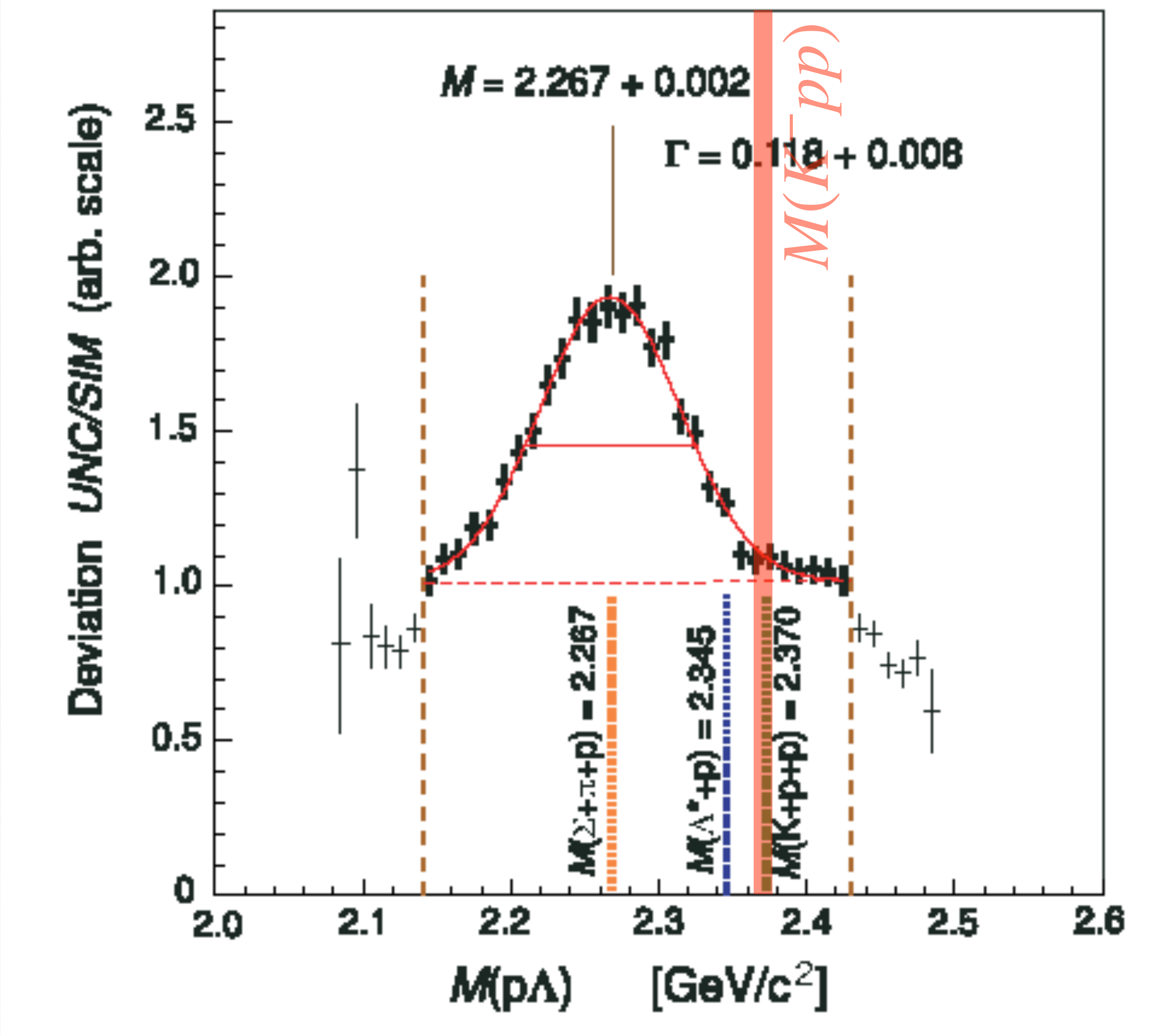
arXiv:1809.07212

Experimental studies :: pp collison

$$p + p \to \Lambda p + K^+$$

@ 2.85 GeV

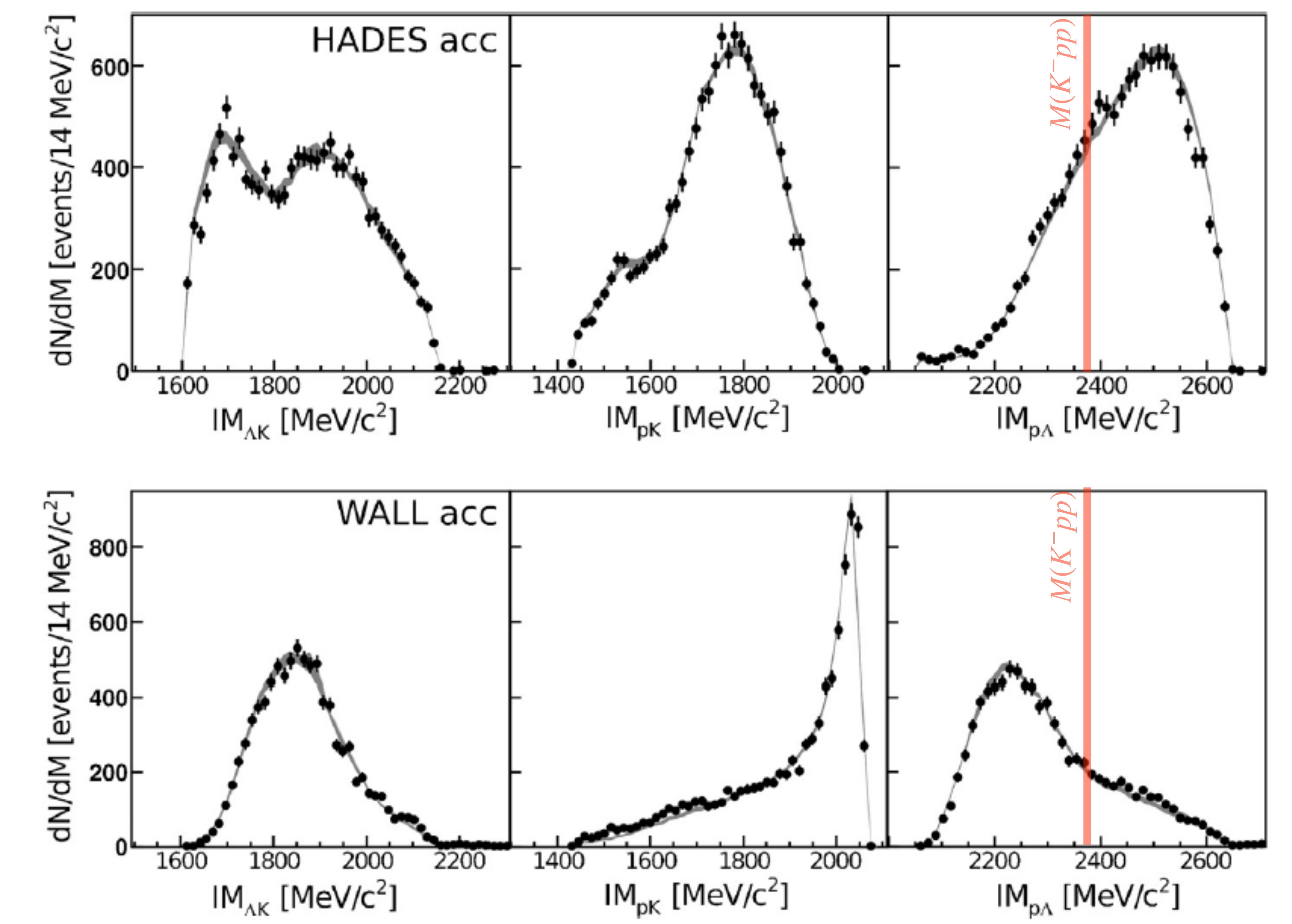
DISTO@SATURNE



PRL104(2010) 132502

@ 3.5 GeV

HADES@GSI



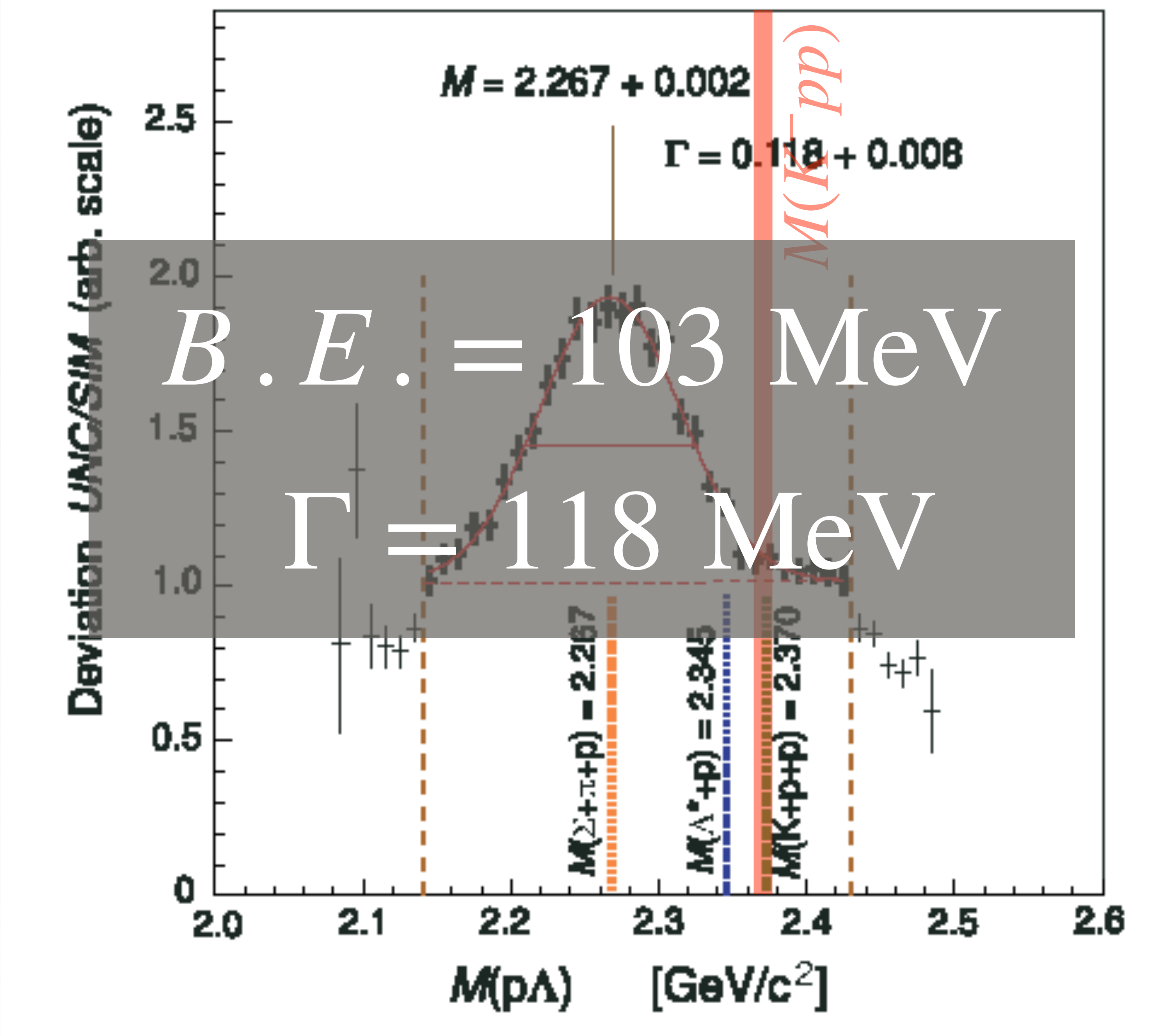
PLB742(2015) 242

Experimental studies :: pp collison

$$p + p \to \Lambda p + K^+$$

@ 2.85 GeV

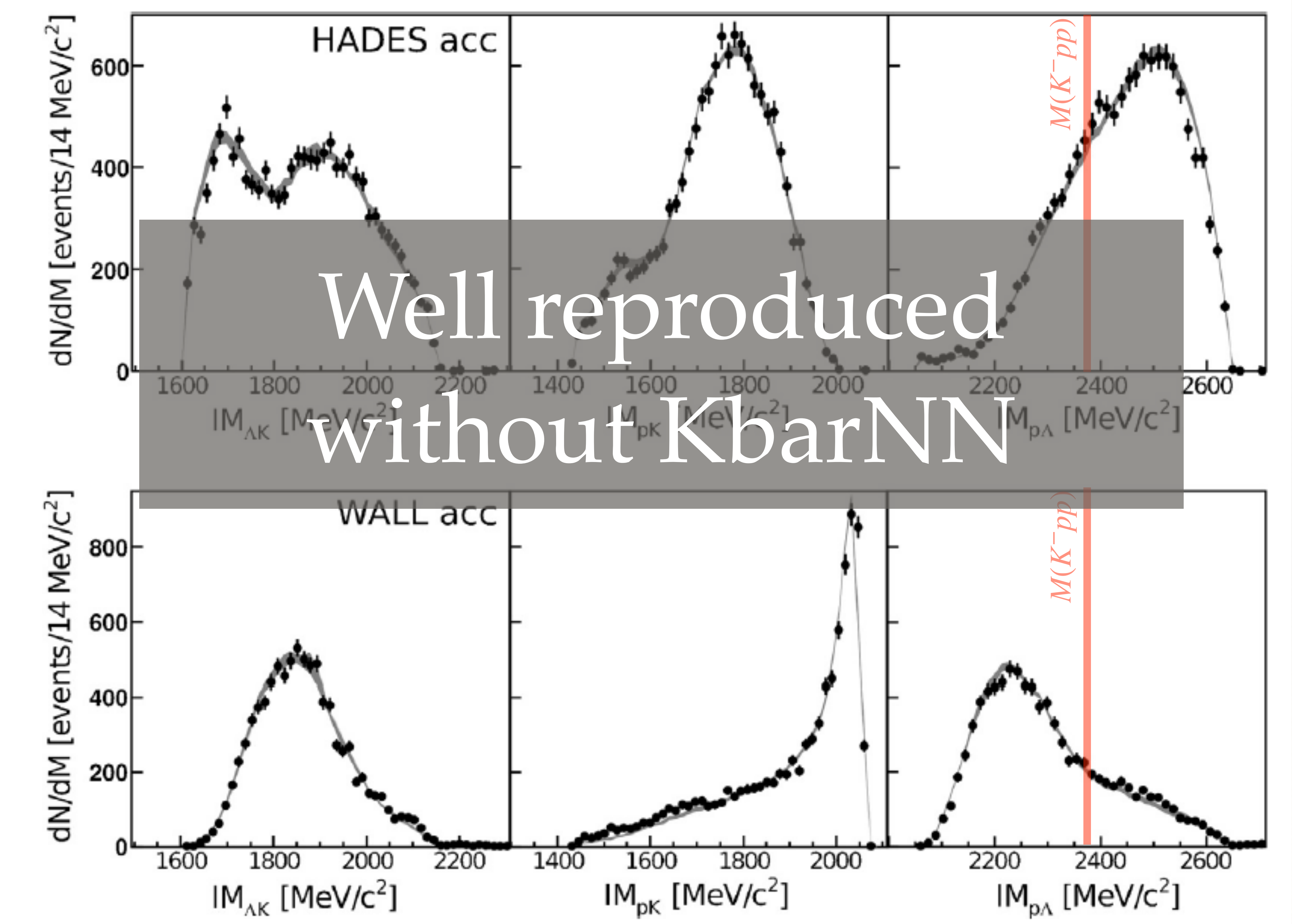
DISTO@SATURNE



PRL104(2010) 132502

@ 3.5 GeV

HADES@GSI



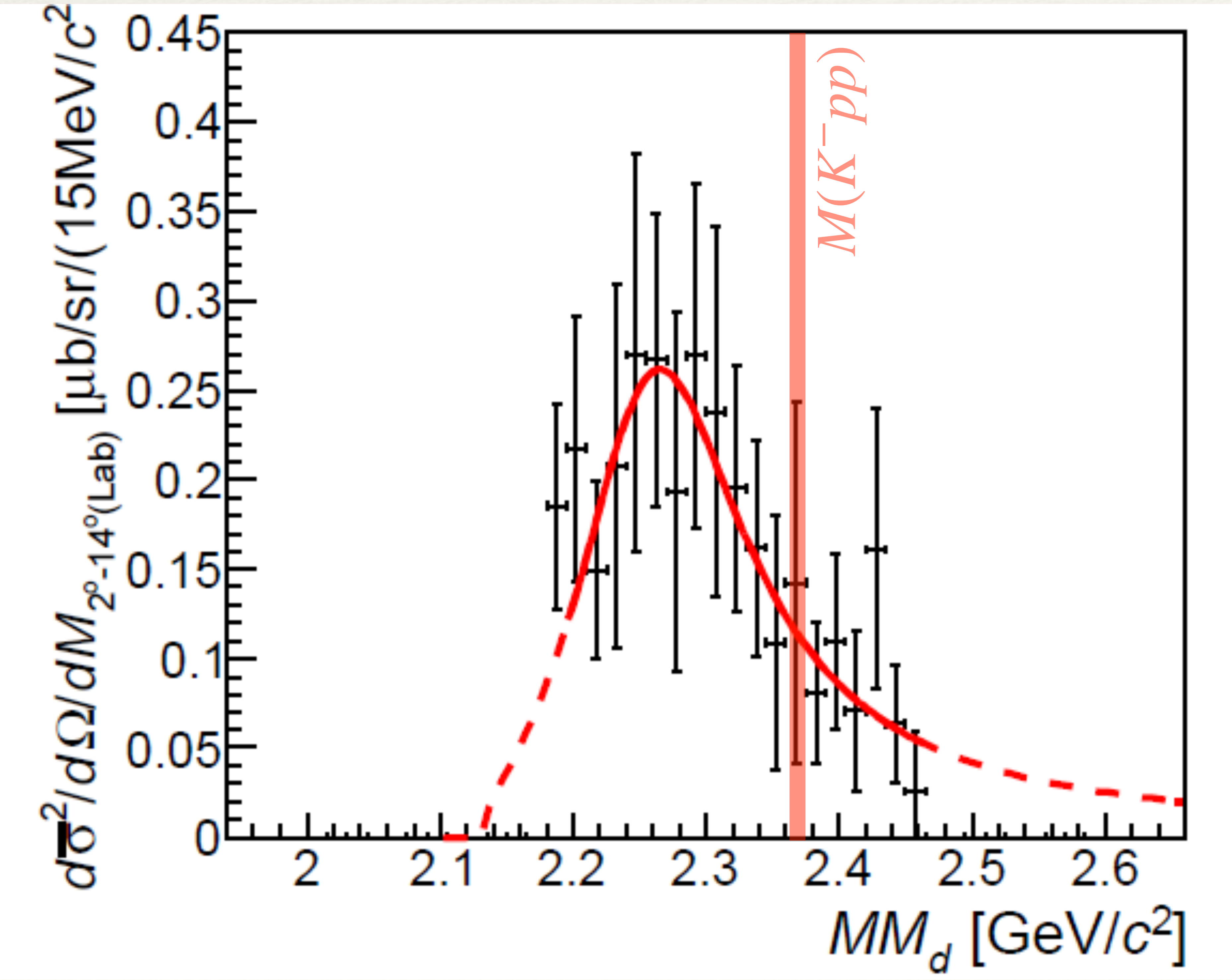
PLB742(2015) 242

Experimental studies :: (π^-, K^-) & (γ, $K^+\pi^-$) reactions

$d(\pi^-, K^-)Yp$

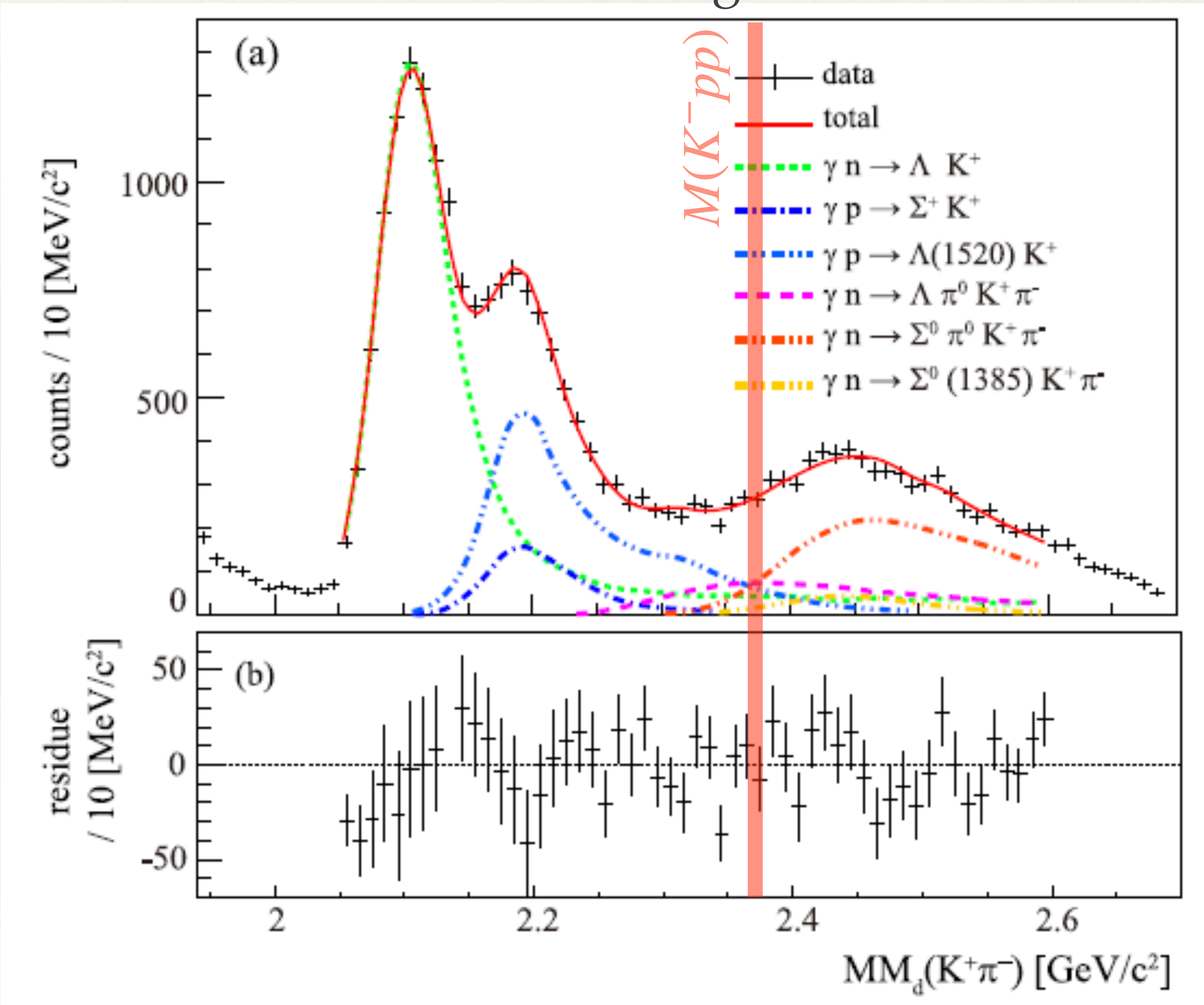
$d(\gamma, \pi^- K^+)X$

E27@J-PARC



PTEP(2015) 021D01

LEPS@SPring-8



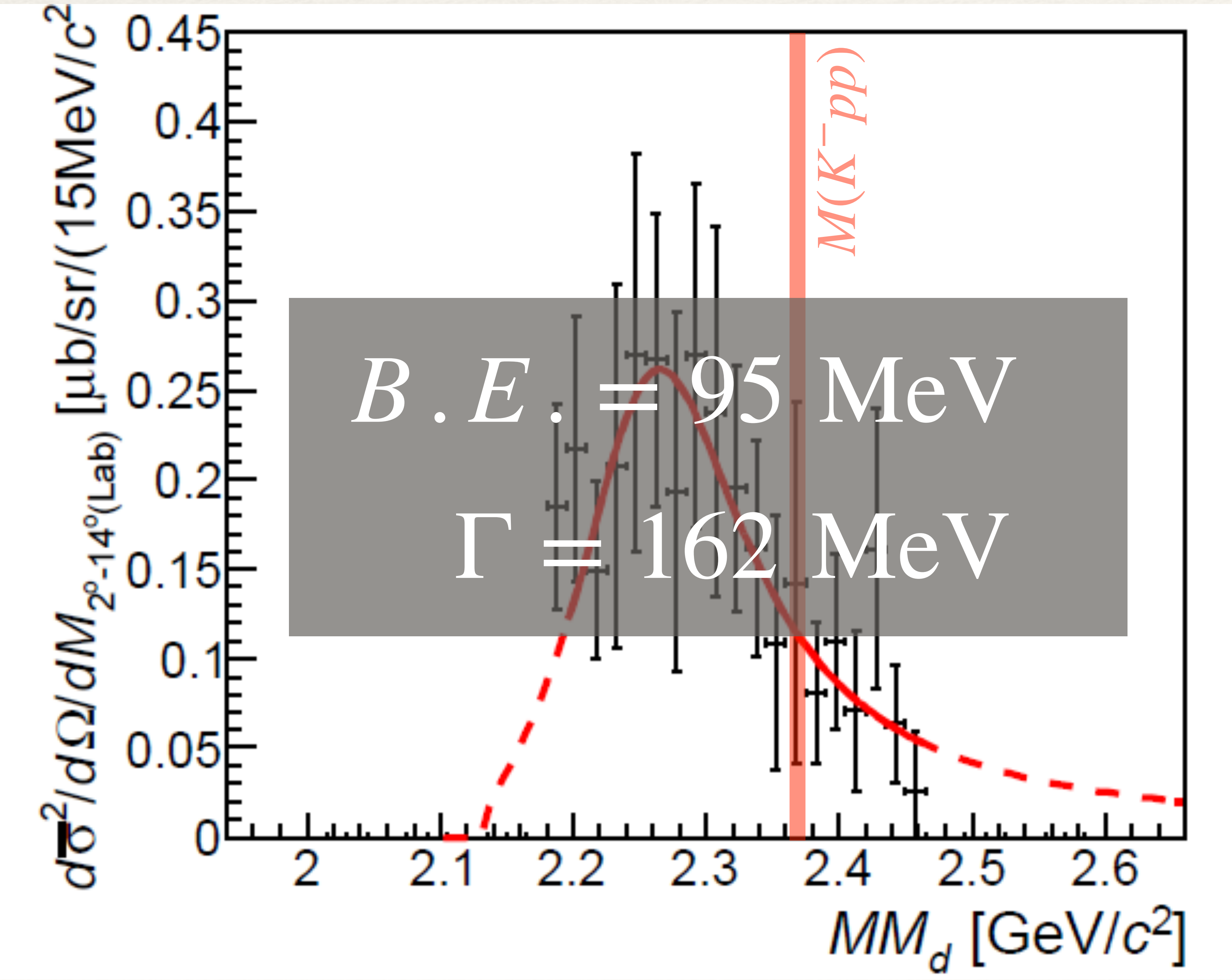
PLB 728 (2014) 616

Experimental studies :: (π^-, K^+) & (γ, $K^+\pi^-$) reactions

$$d(\pi^-, K^+)Yp$$

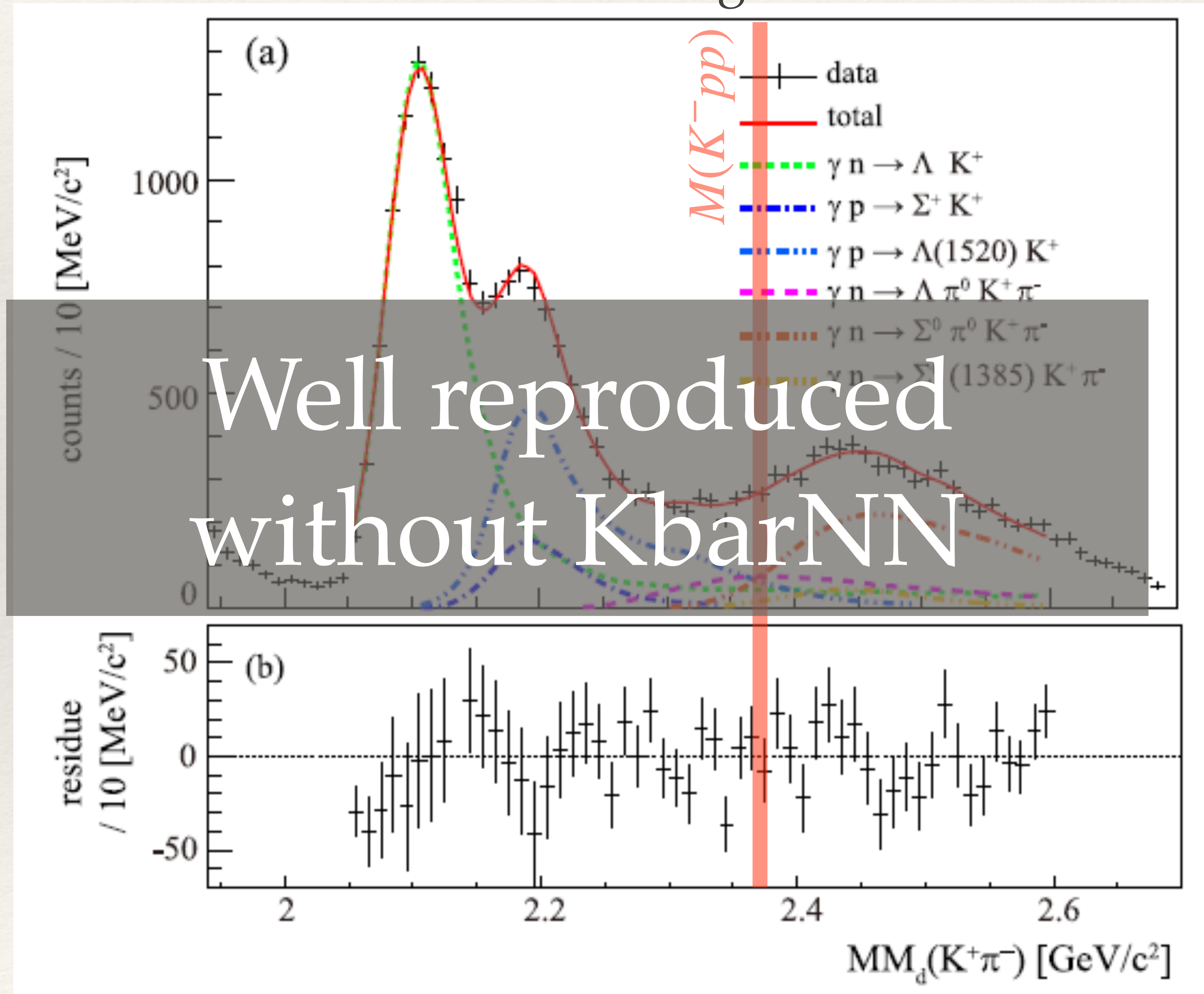
$$d(\gamma, \pi^- K^+)X$$

E27@J-PARC



PTEP(2015) 021D01

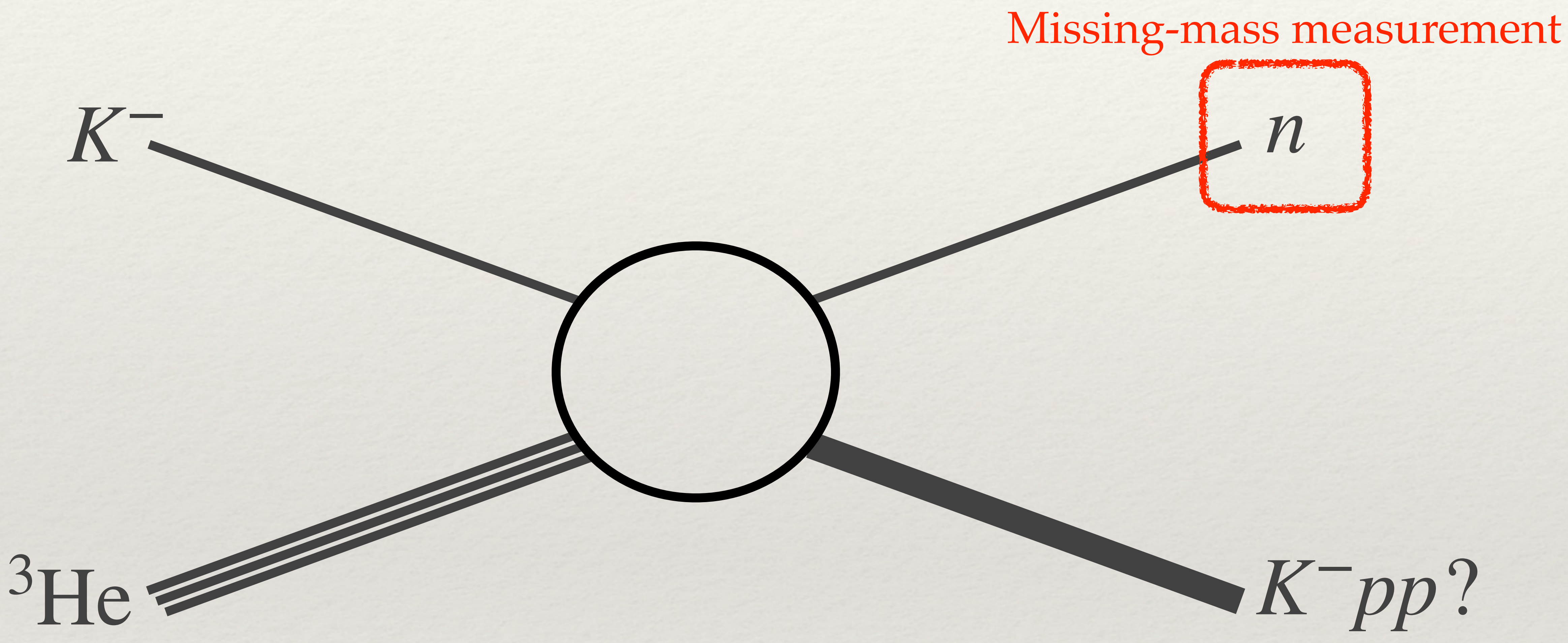
LEPS@SPring-8

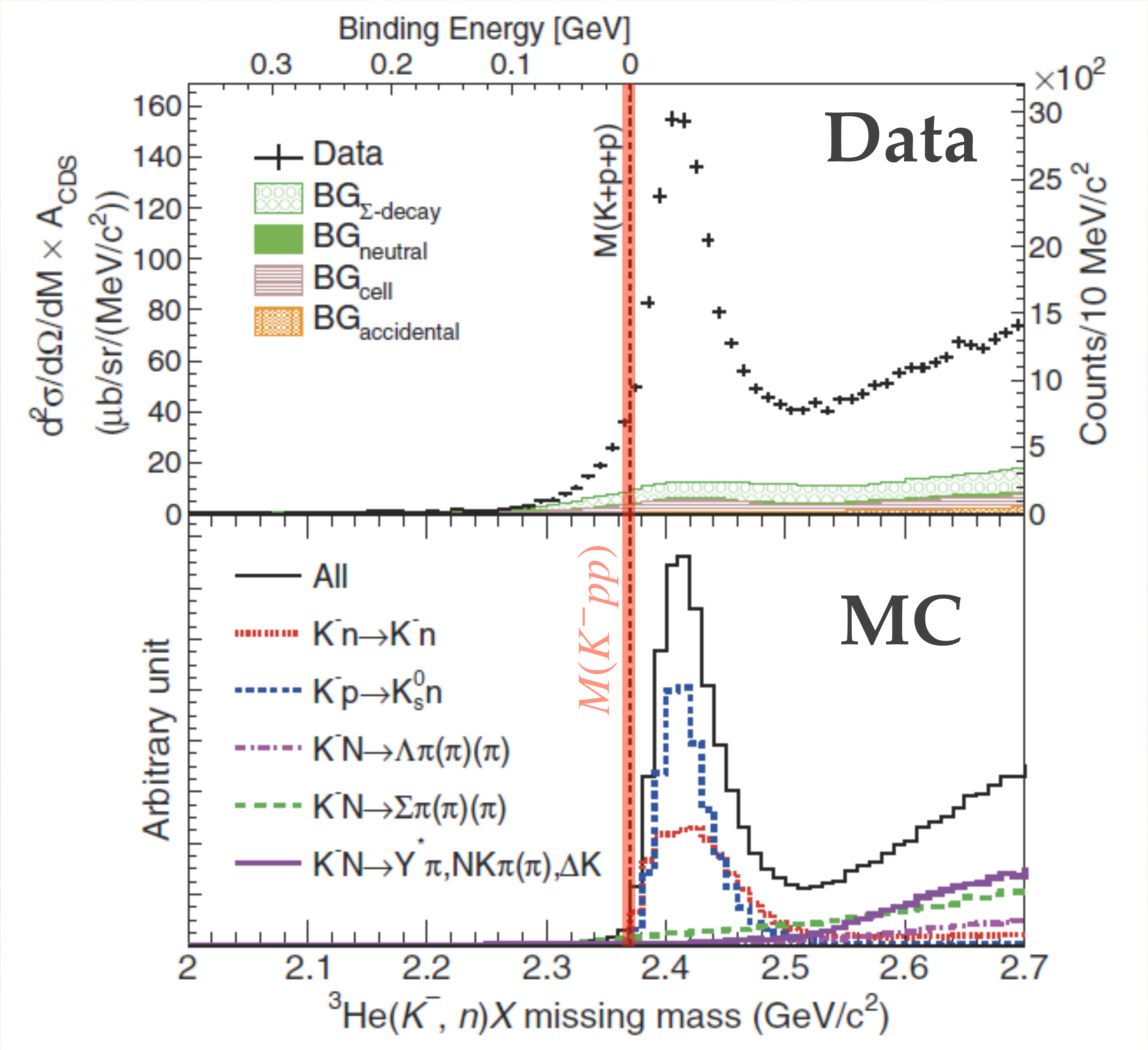


PLB 728 (2014) 616

Results of E15 - 1st

Semi-inclusive analysis of $^3\mathrm{He}(K^-, n)$

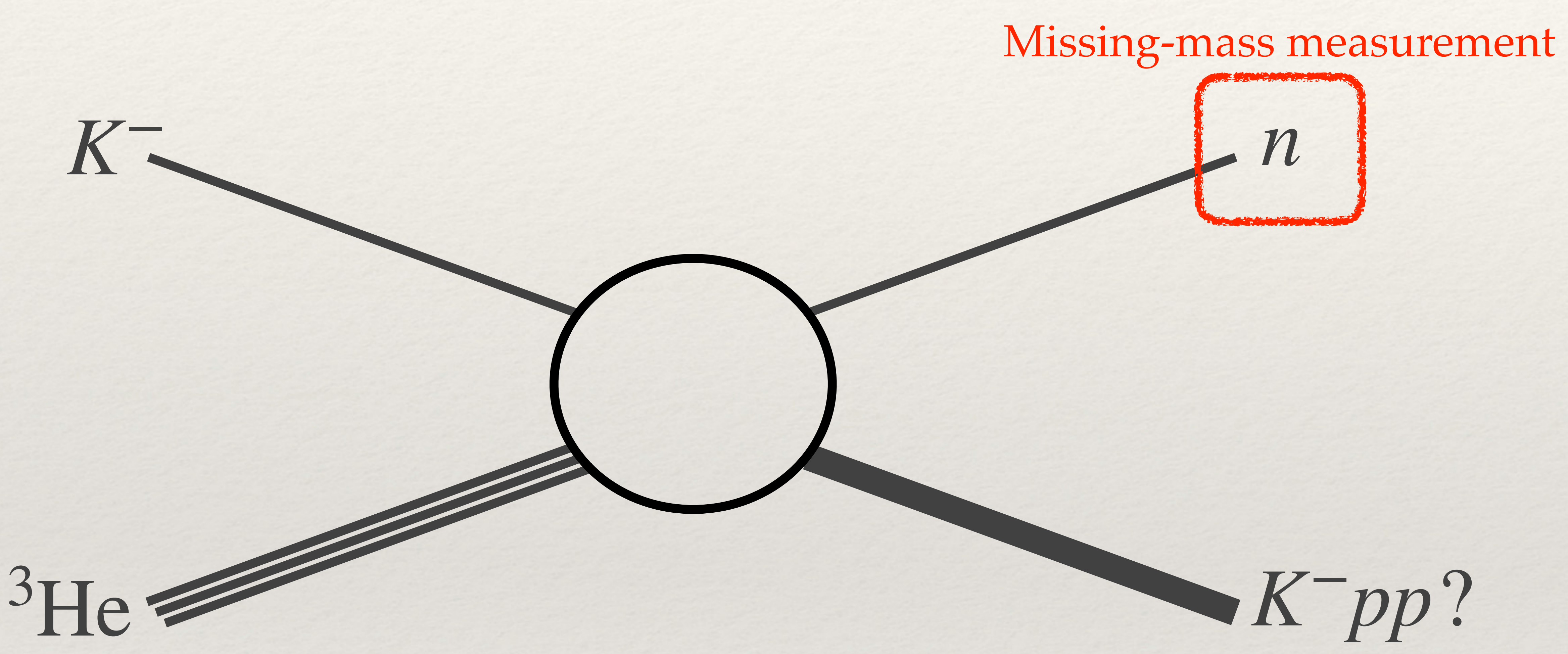




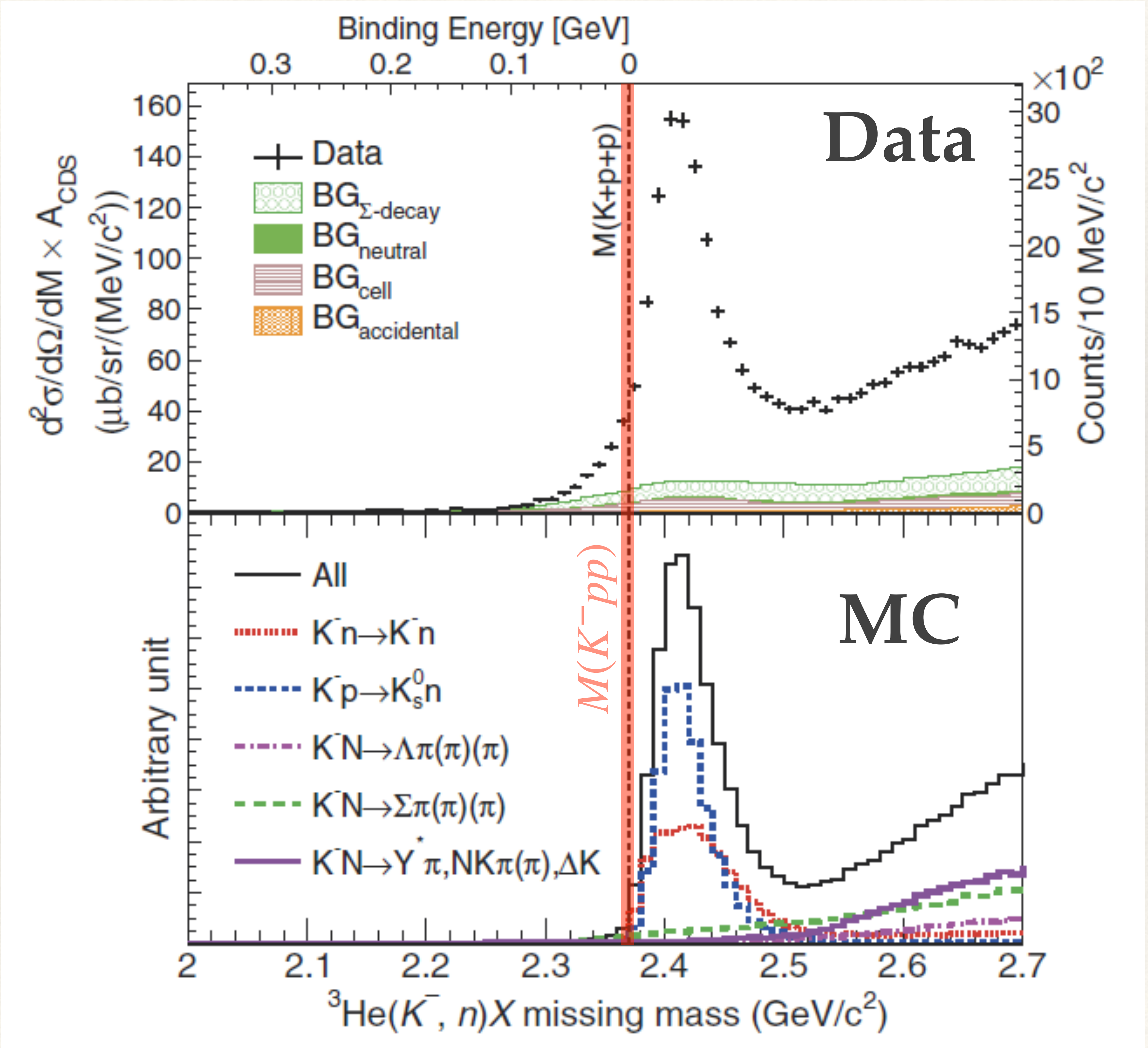
PTEP (2015) 061D01

Results of E15 - 1st

Semi-inclusive analysis of $^3\mathrm{He}(K^-, n)$



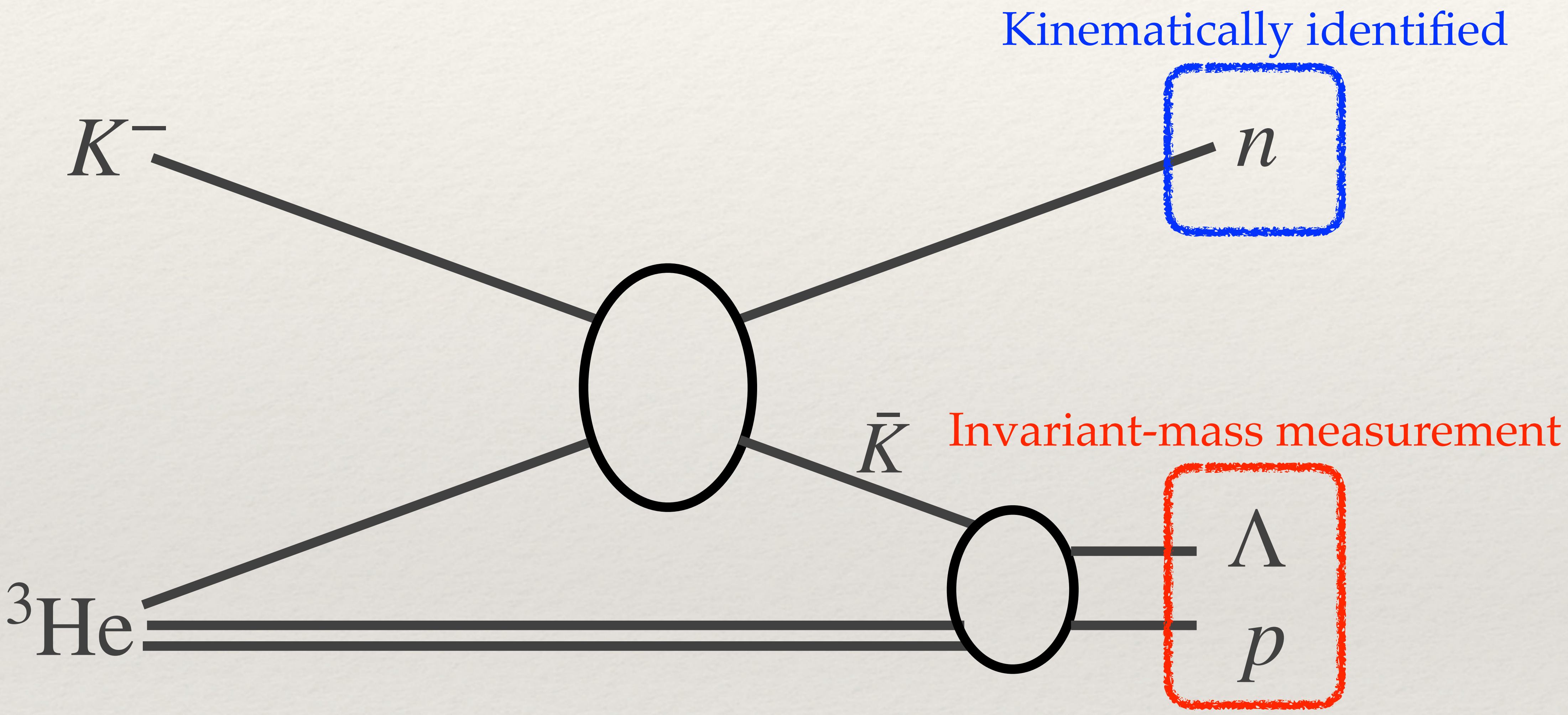
- Strong QF peak above M(Kpp)
- No clear peak below M(Kpp)

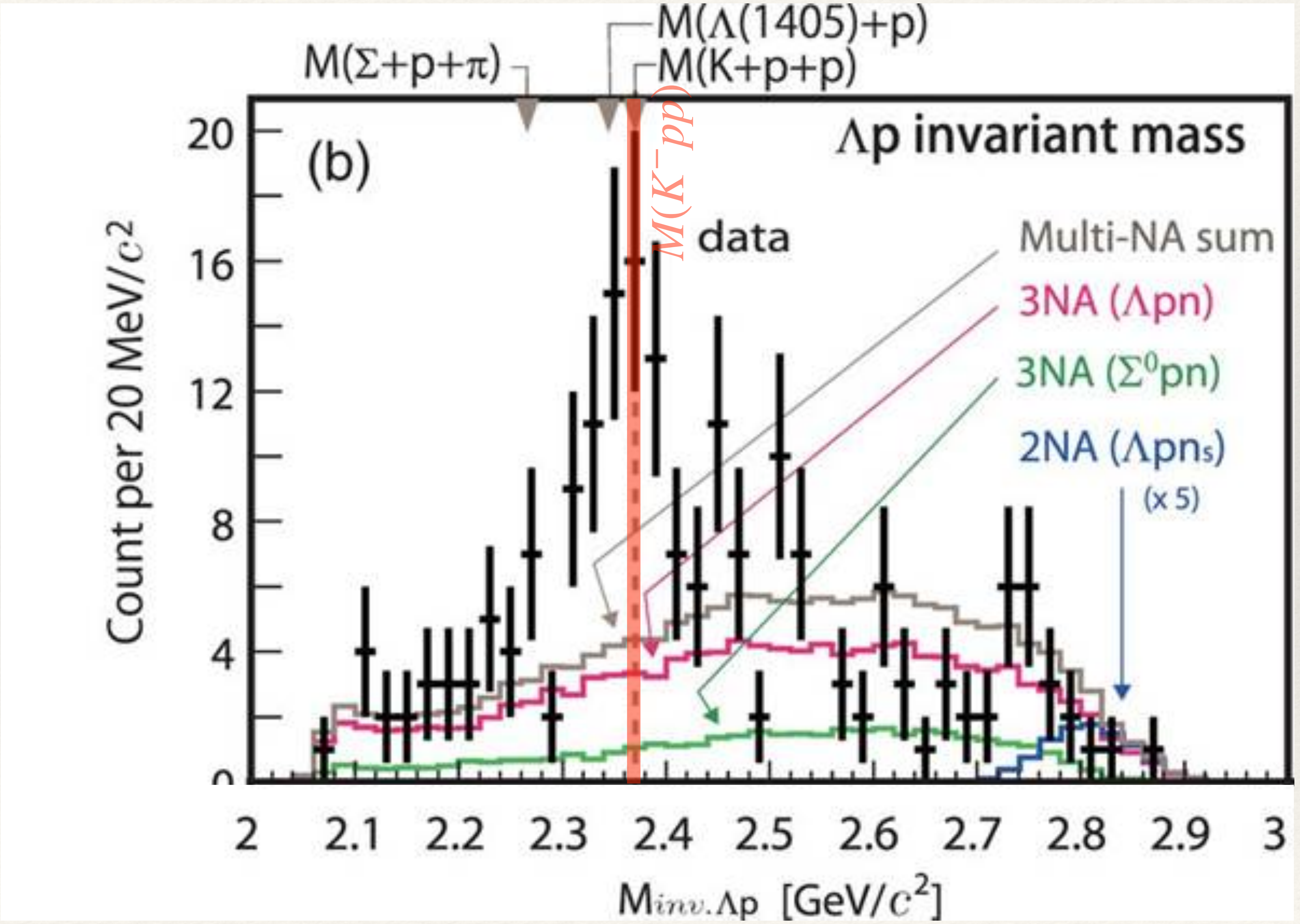


PTEP (2015) 061D01

Results of E15 - 1st

Exclusive analysis of $^{3}\mathrm{He}(K^{-}, \Lambda p)n$

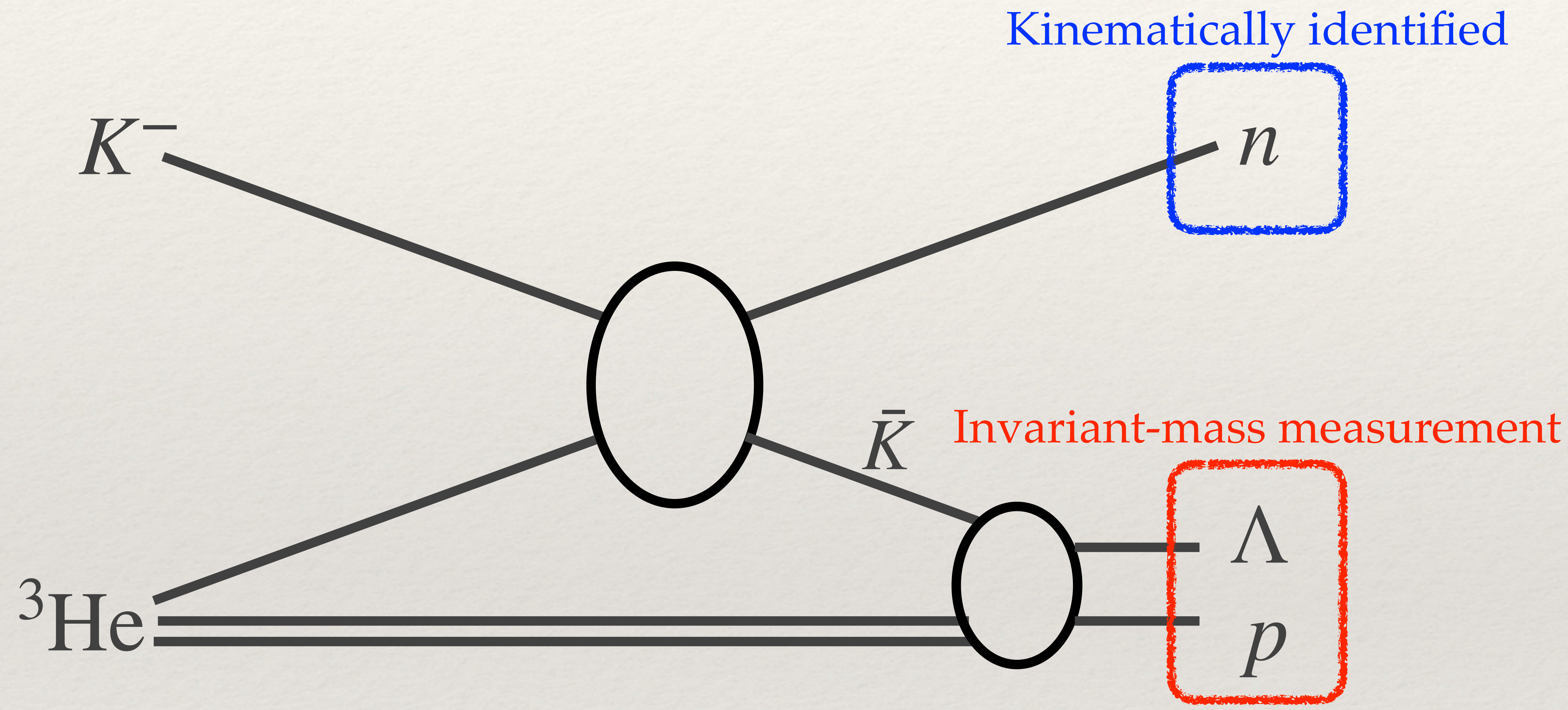




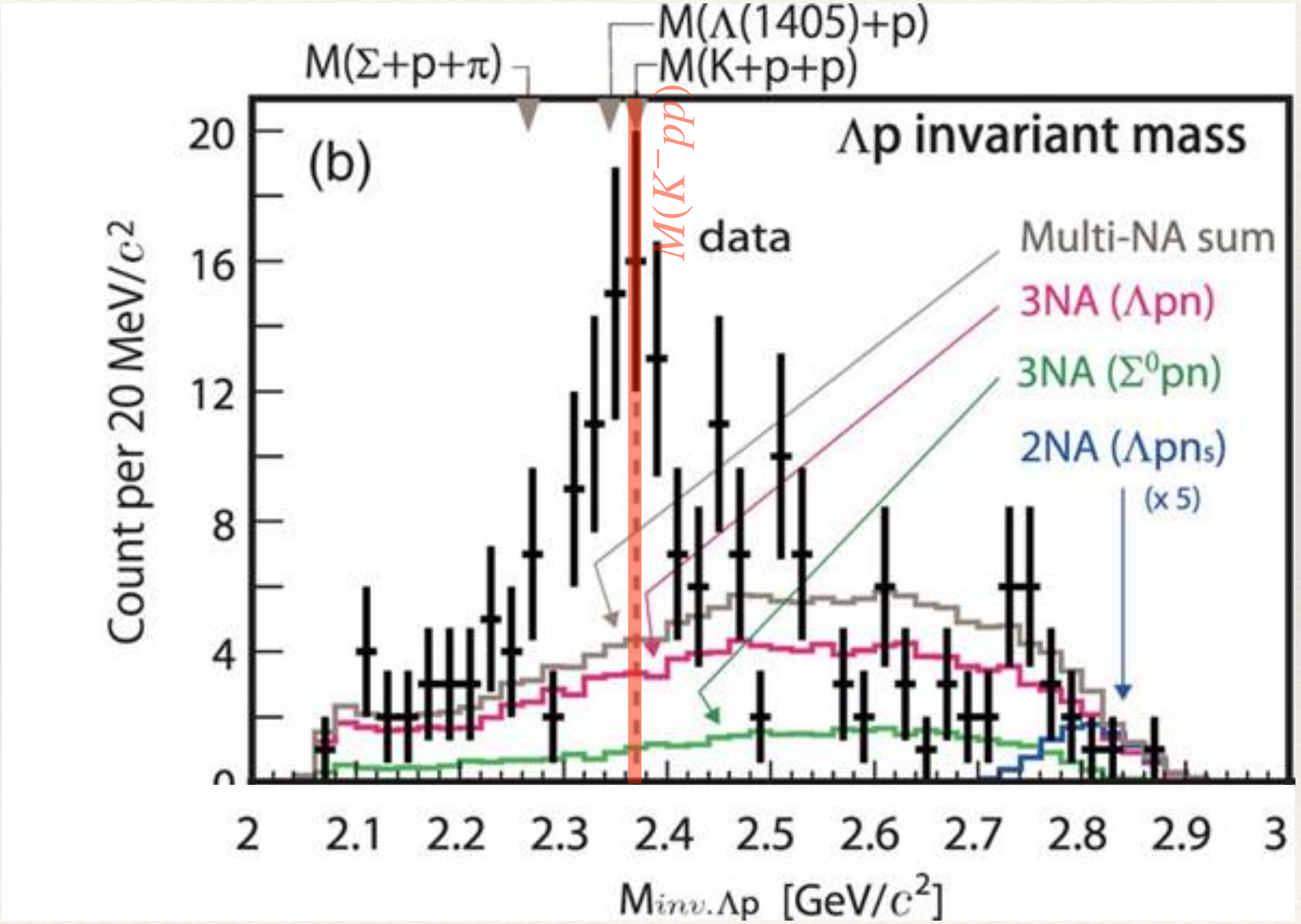
PTEP (2016) 051D01

Results of E15 - 1st

Exclusive analysis of $^3\mathrm{He}(K^-, \Lambda p)n$



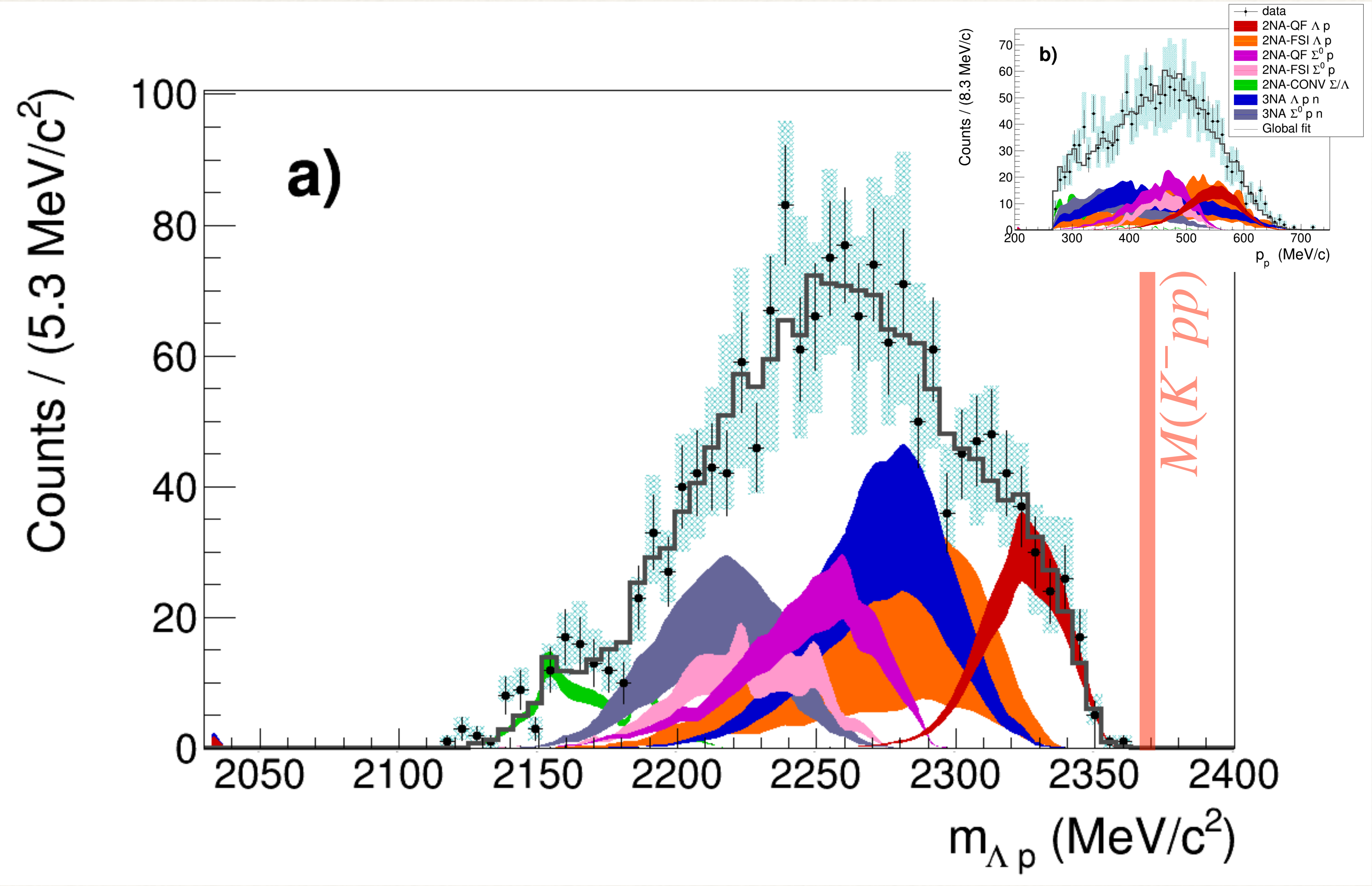
- Peak around M(Kpp)
  - B.E. ~ 15 MeV
  - Width ~ 110 MeV



PTEP (2016) 051D01

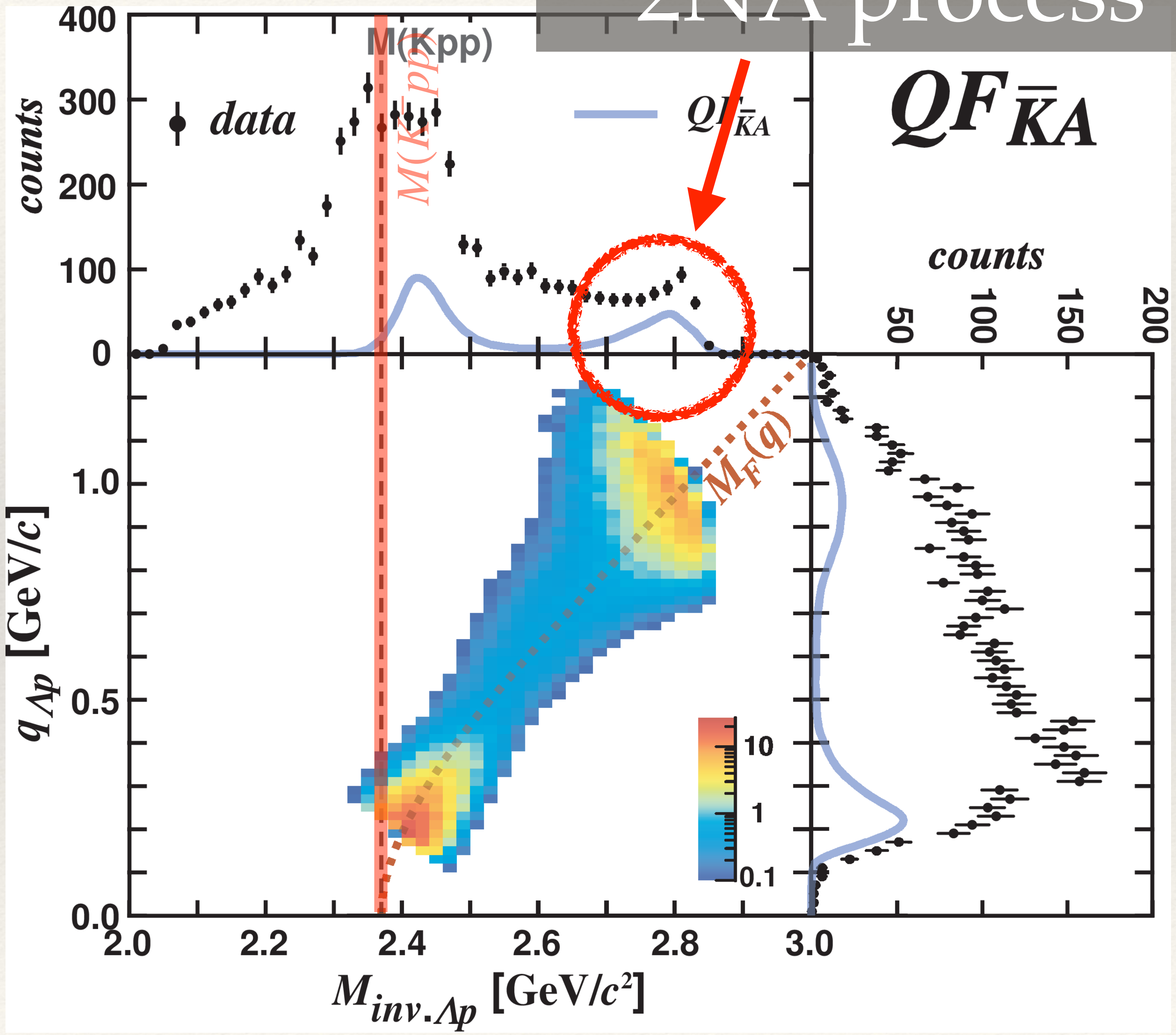
Result of Λpn analysis

AMADEUS@DAΦNE



arXiv:1809.07212

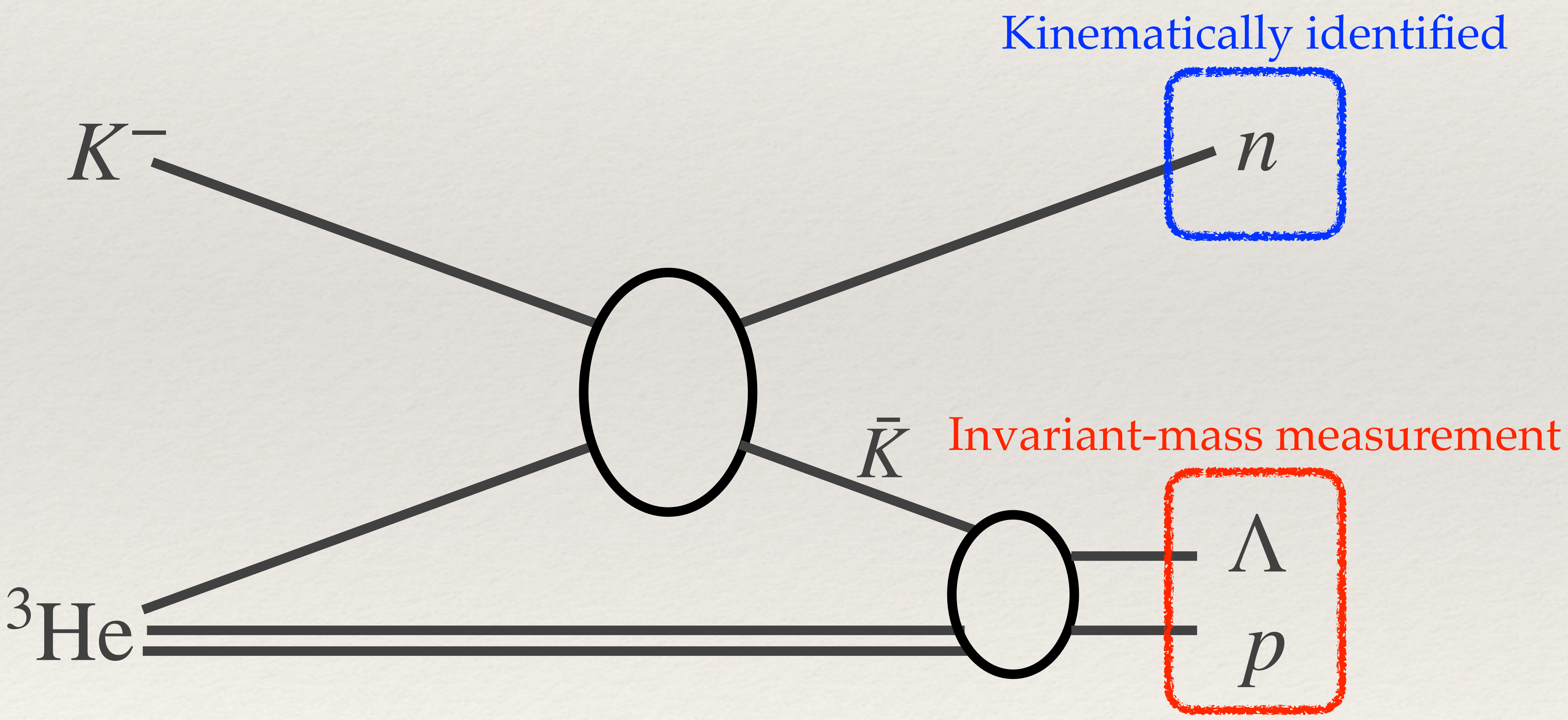
2NA process



Analyzed channels

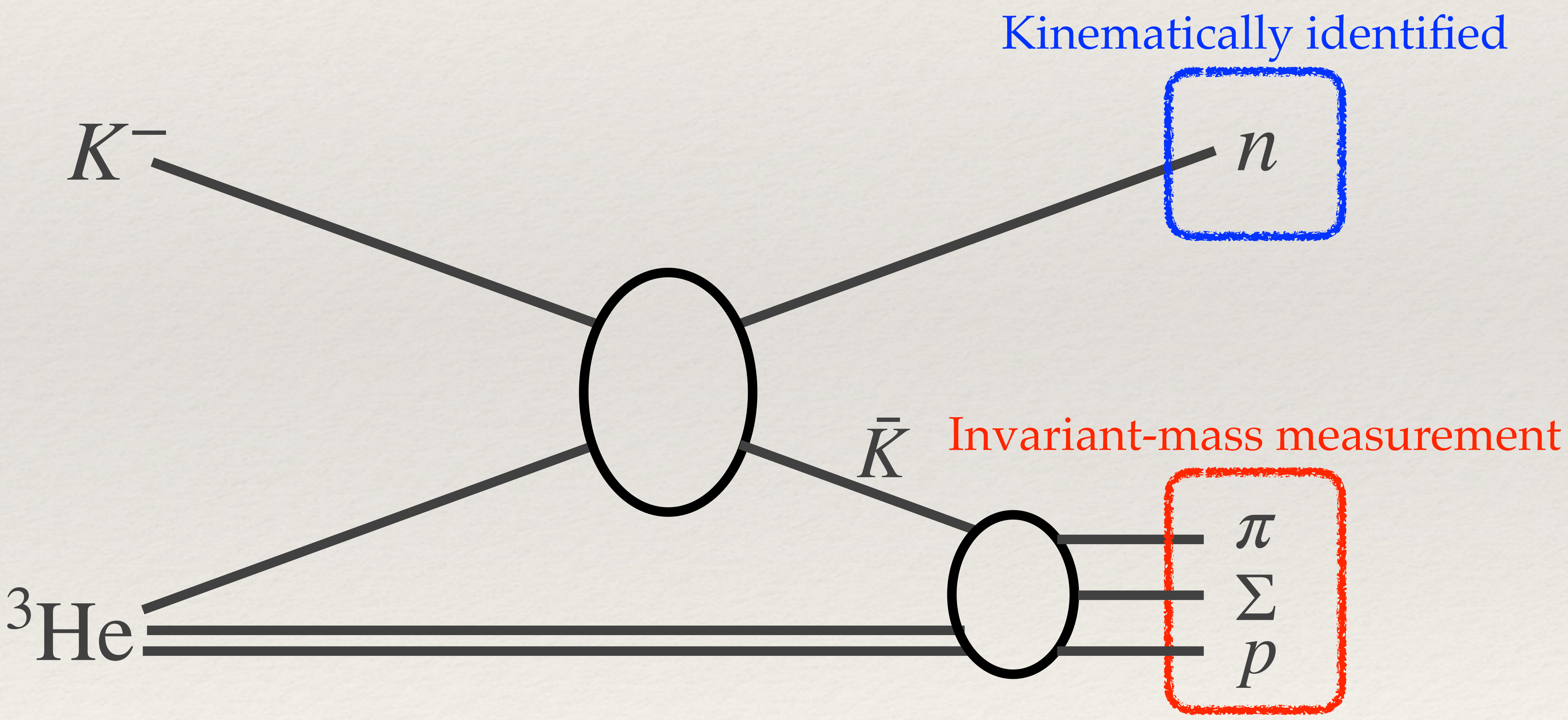
Measured exclusive channels are,,,

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n}$$



Detected particles : $pp\pi^-$

$$\boxed{K^- + {}^3\mathrm{He} \rightarrow \pi^\pm \Sigma^\mp p + n}$$

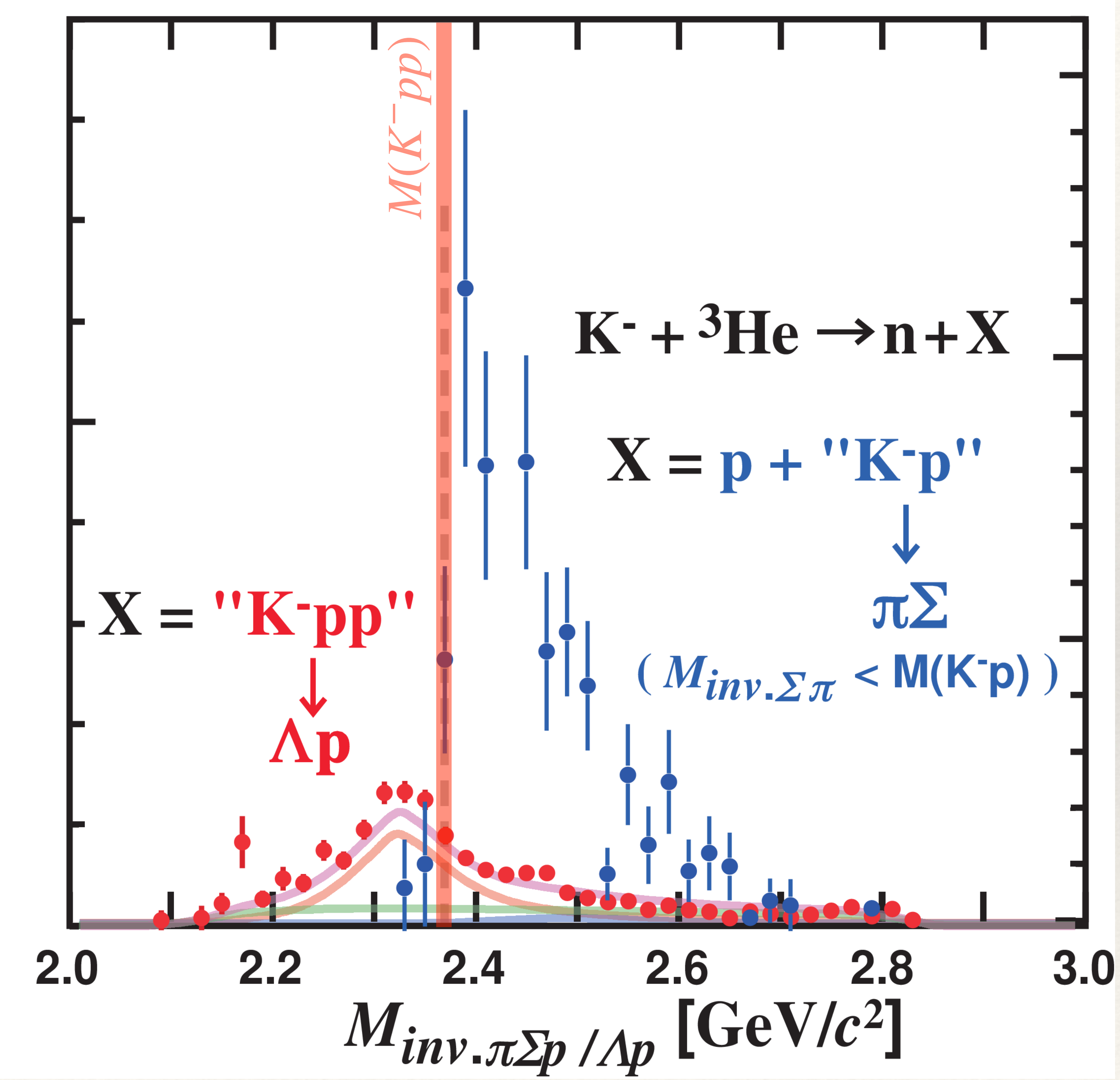


Detected particles : $np\pi^+\pi^-$

! Neutron detection by CDS

Comparison between Λpn & πΣpn

$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$



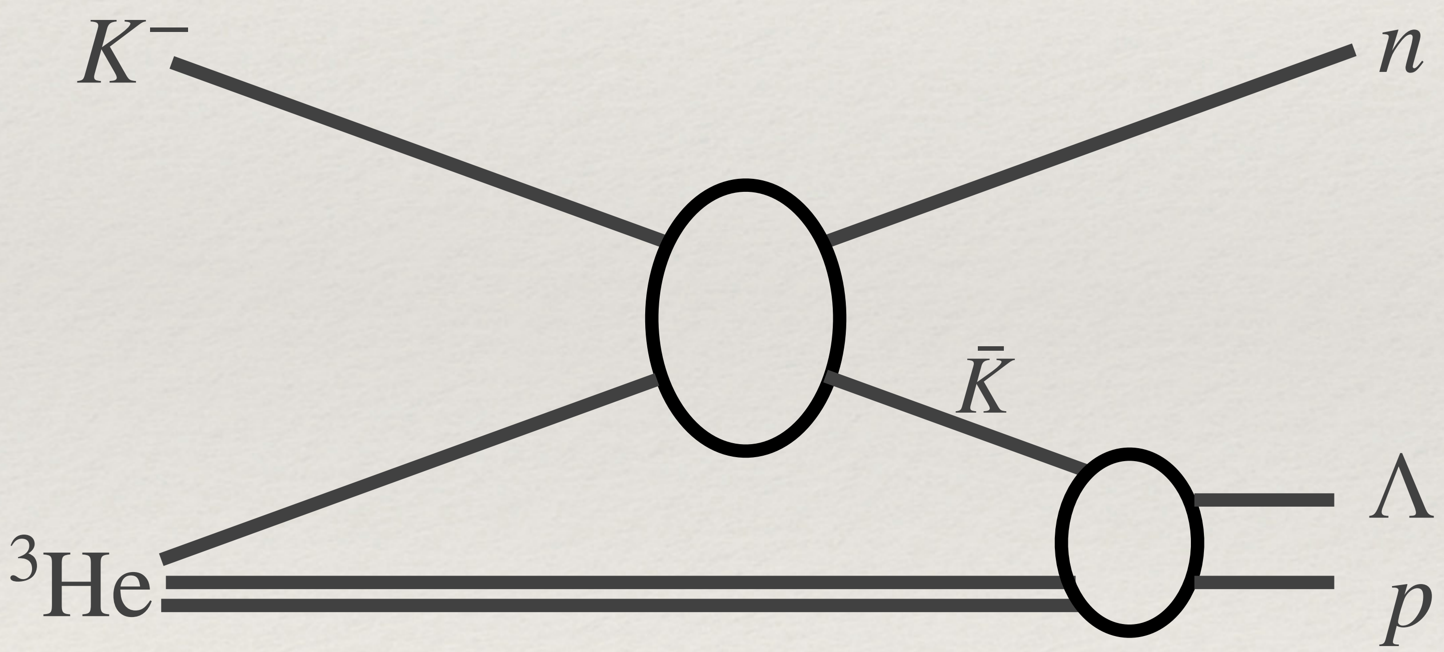
$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$

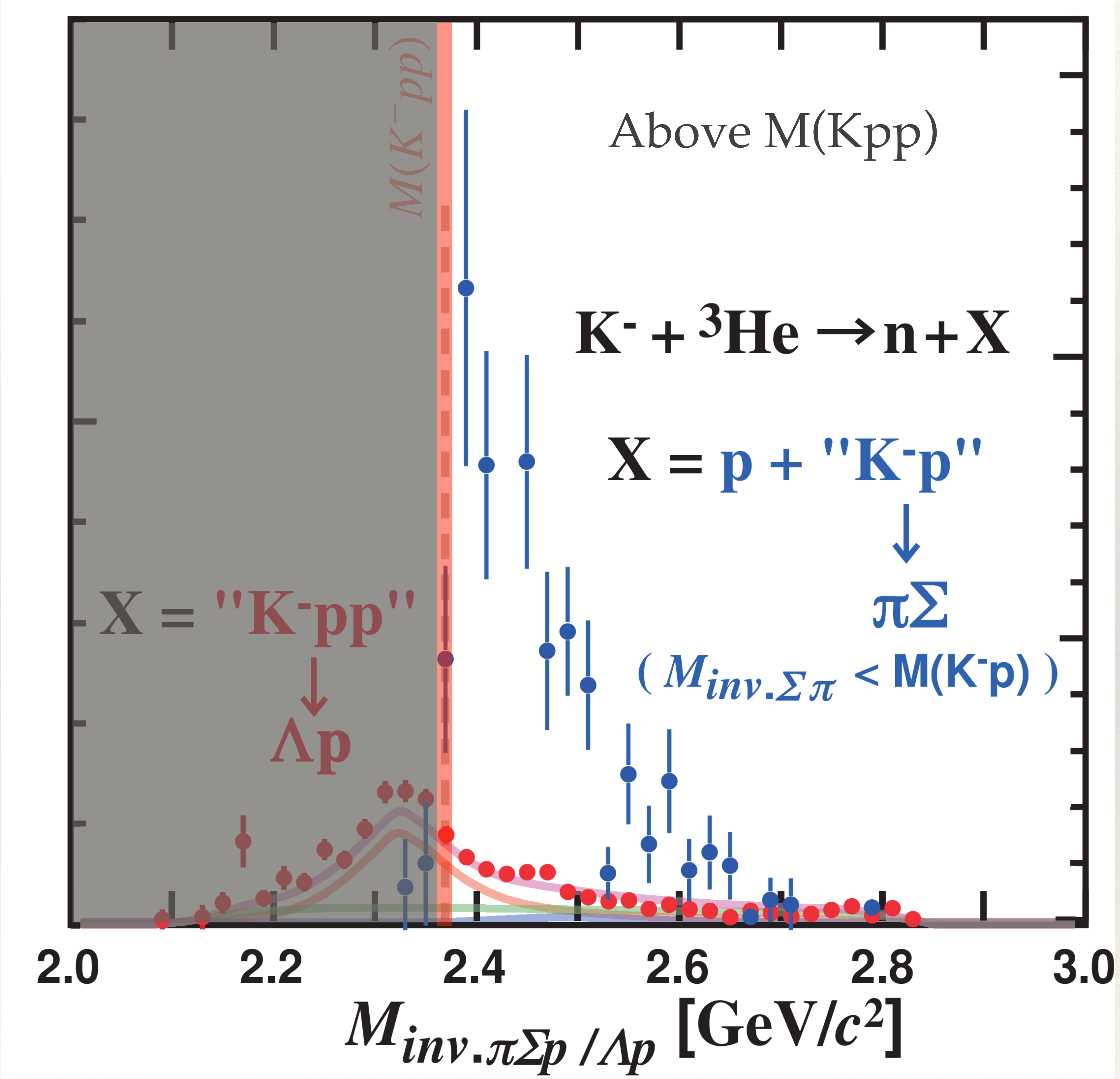
Comparison between Λpn & πΣpn

$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$

QF-K

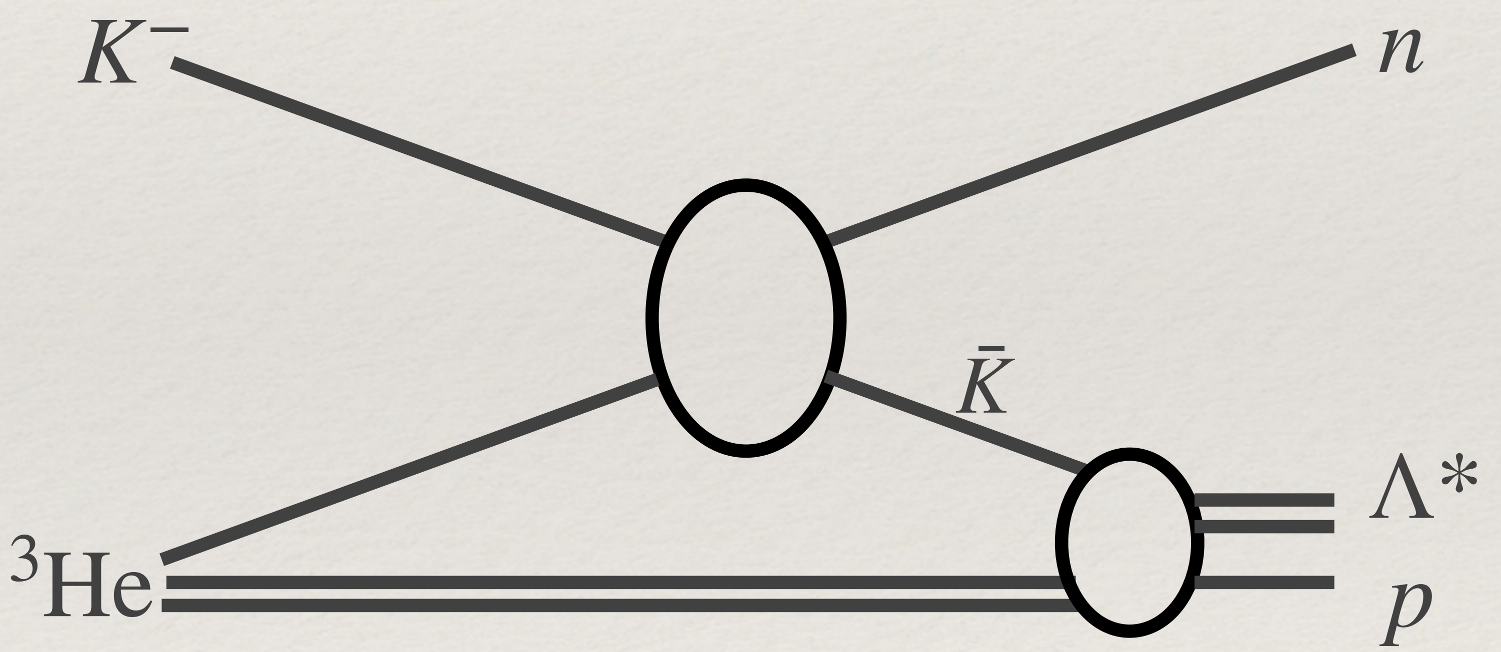
QF-Y*





$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp} p + n$

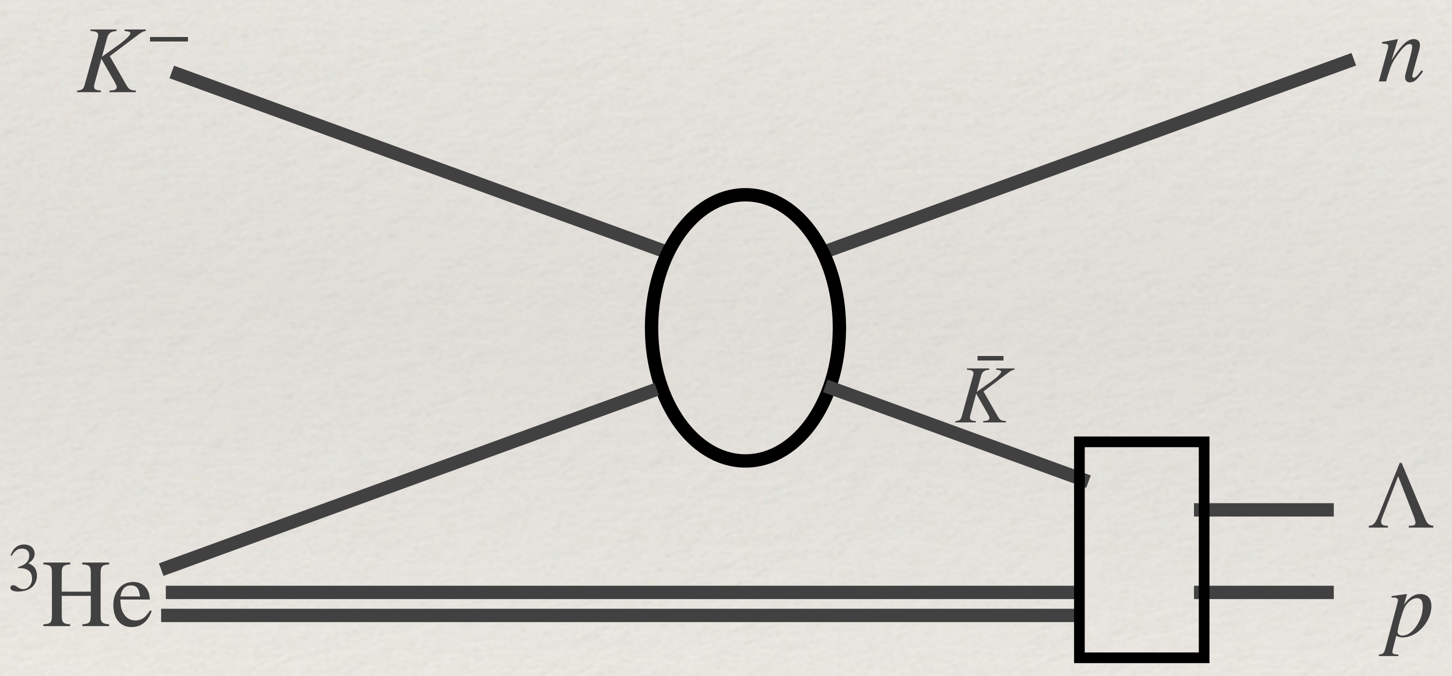
QF-Y*

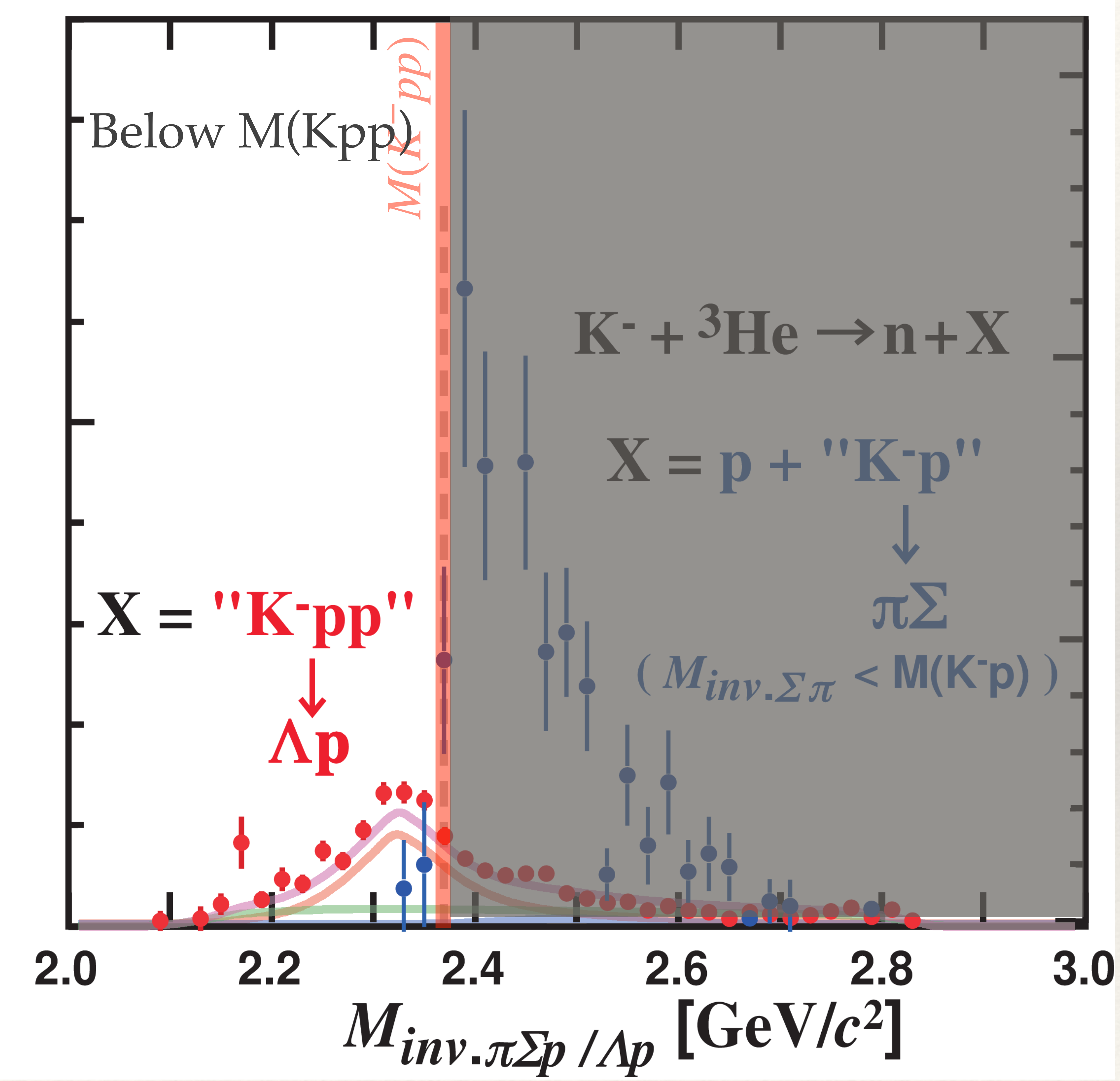


Comparison between Λpn & πΣpn

$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$

Kpp production





$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$

Kpp production?