QNP2018 @ Tsukuba

Results of KbarNN search via the (K^-, n) reaction at J-PARC

Takumi Yamaga, RIKEN
For the E15 collaboration

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

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

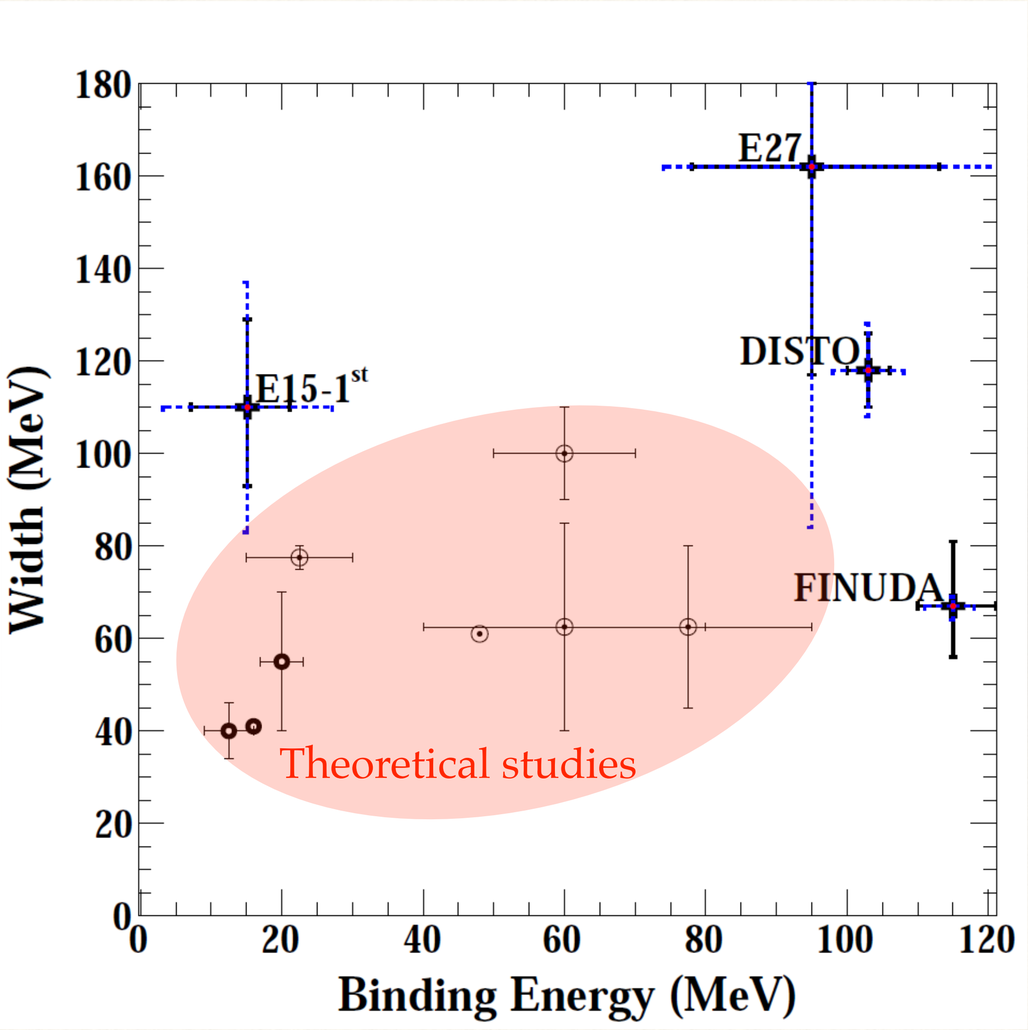
KbarN interaction	Chiral SU(3)			Phenomenological			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B.E. (MeV)	16	17 - 23	9 - 16	48	40 - 80	50 - 70	60 - 95
Width (MeV)	41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

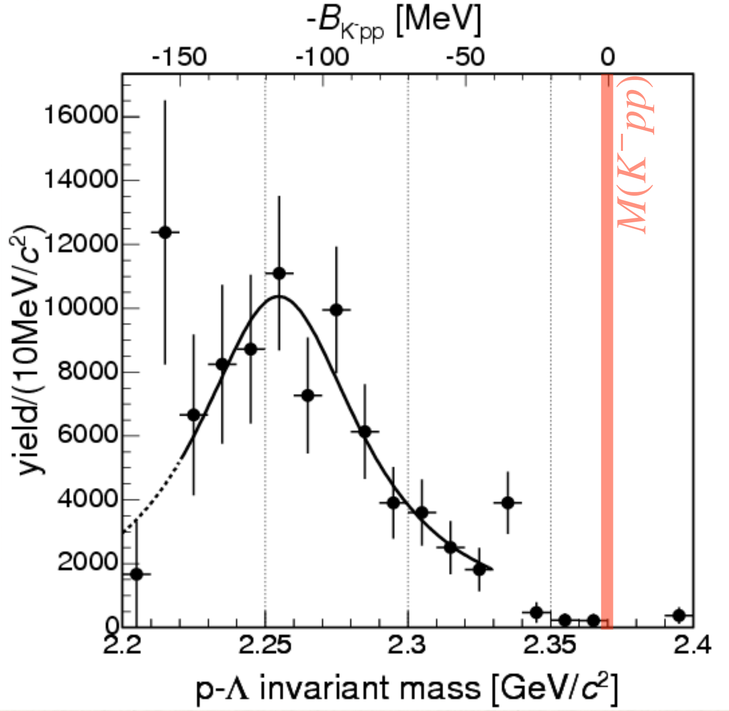
- Many theoretical & experimental studies
  - Theoretical studies
    - KbarNN can be exist.
    - B.E. & Width strongly depend on KbarN interaction model.



Experimental studies :: Stopped K-

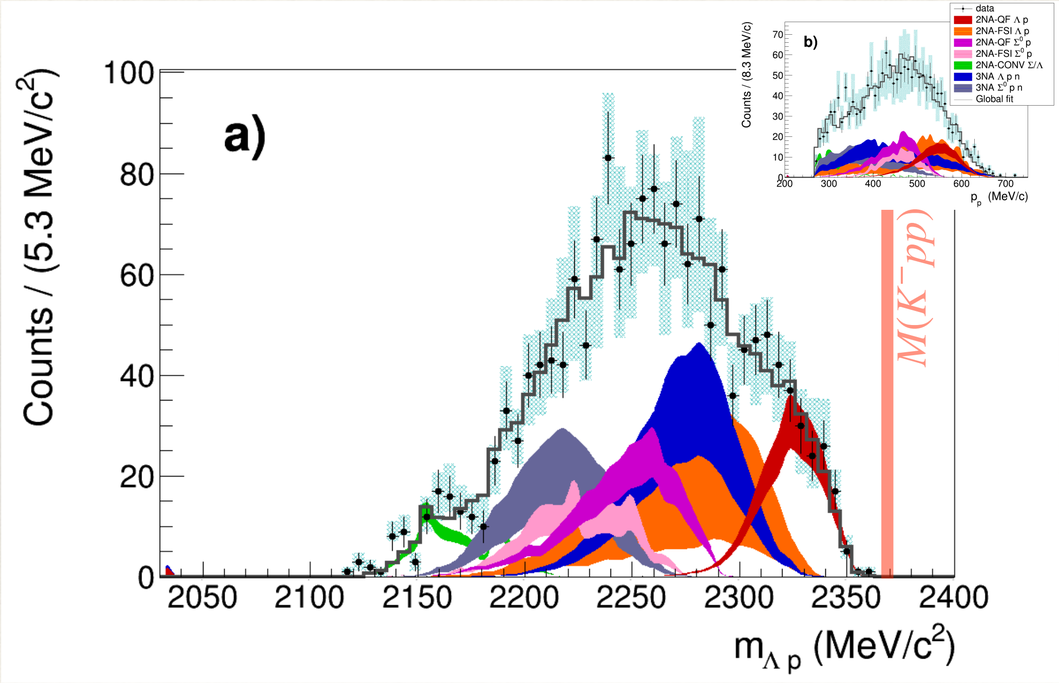
$A(stopped\ K^-, \Lambda p)$

FINUDA@DAΦNE



PRL94(2005) 132502

AMADEUS@DAΦNE

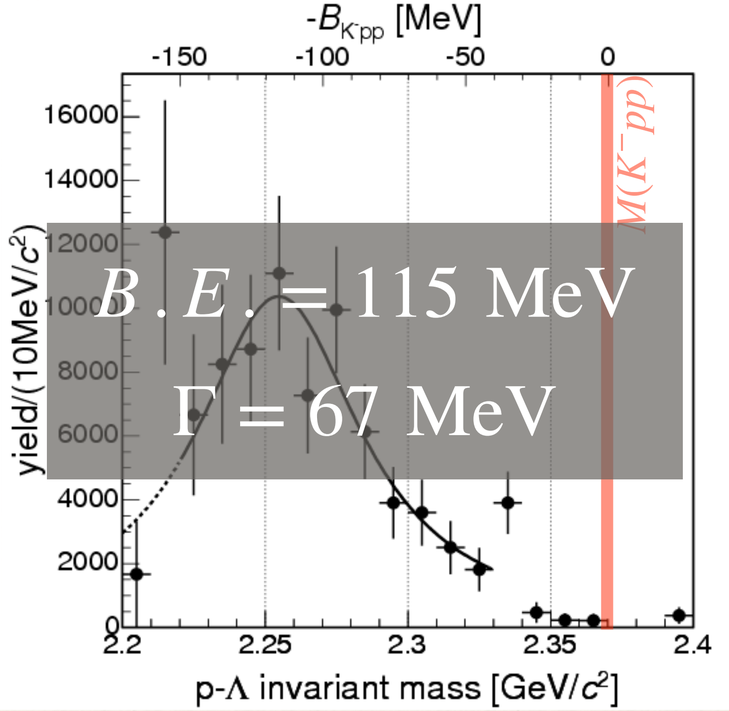


arXiv:1809.07212

Experimental studies :: Stopped K-

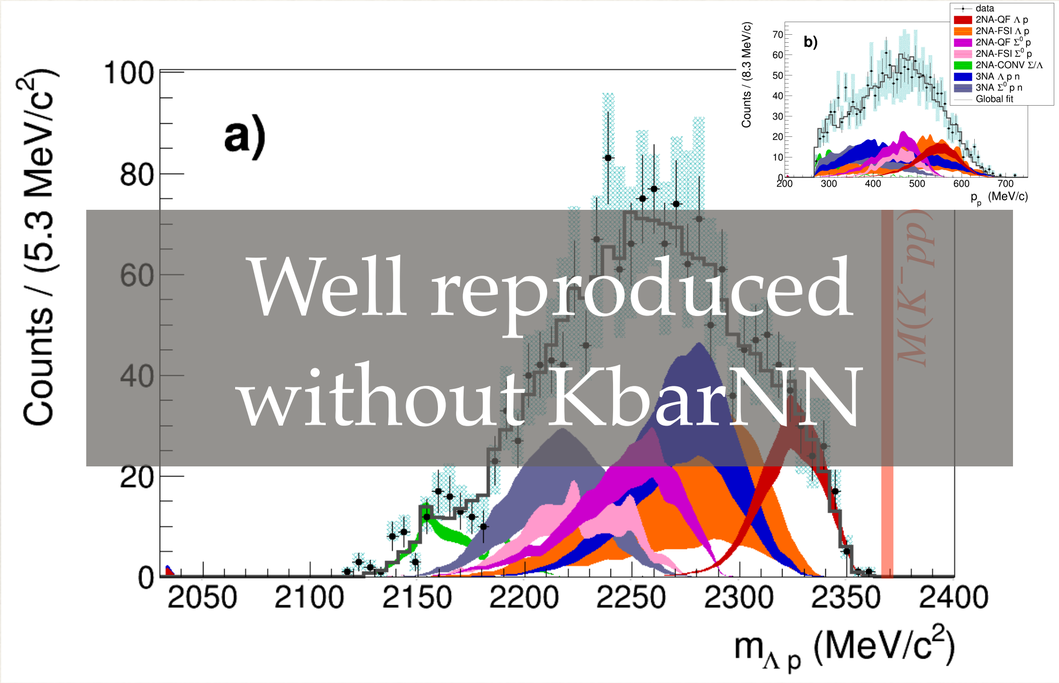
$$A(stopped\ K^-, \Lambda p)$$

FINUDA@DAΦNE



PRL94(2005) 132502

AMADEUS@DAΦNE



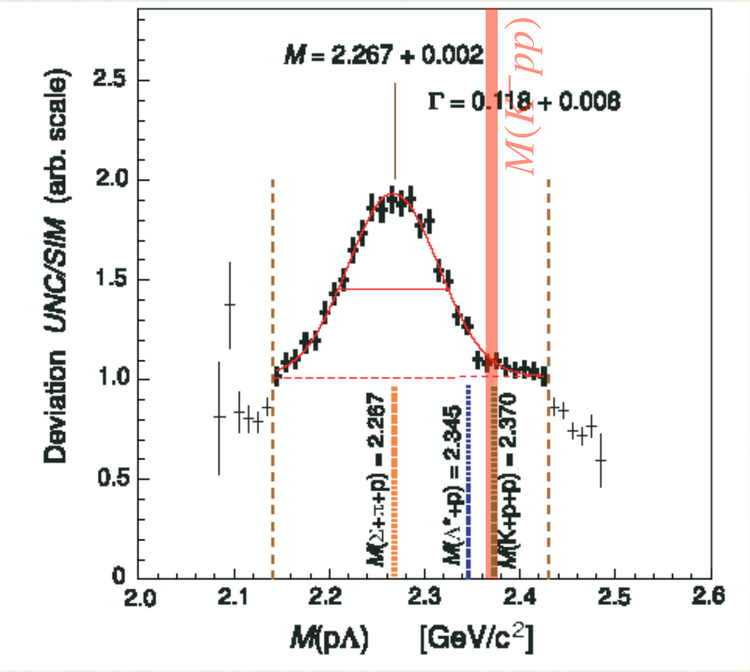
arXiv:1809.07212

Experimental studies :: pp collison

$$p + p \rightarrow \Lambda p + K^+$$

@ 2.85 GeV

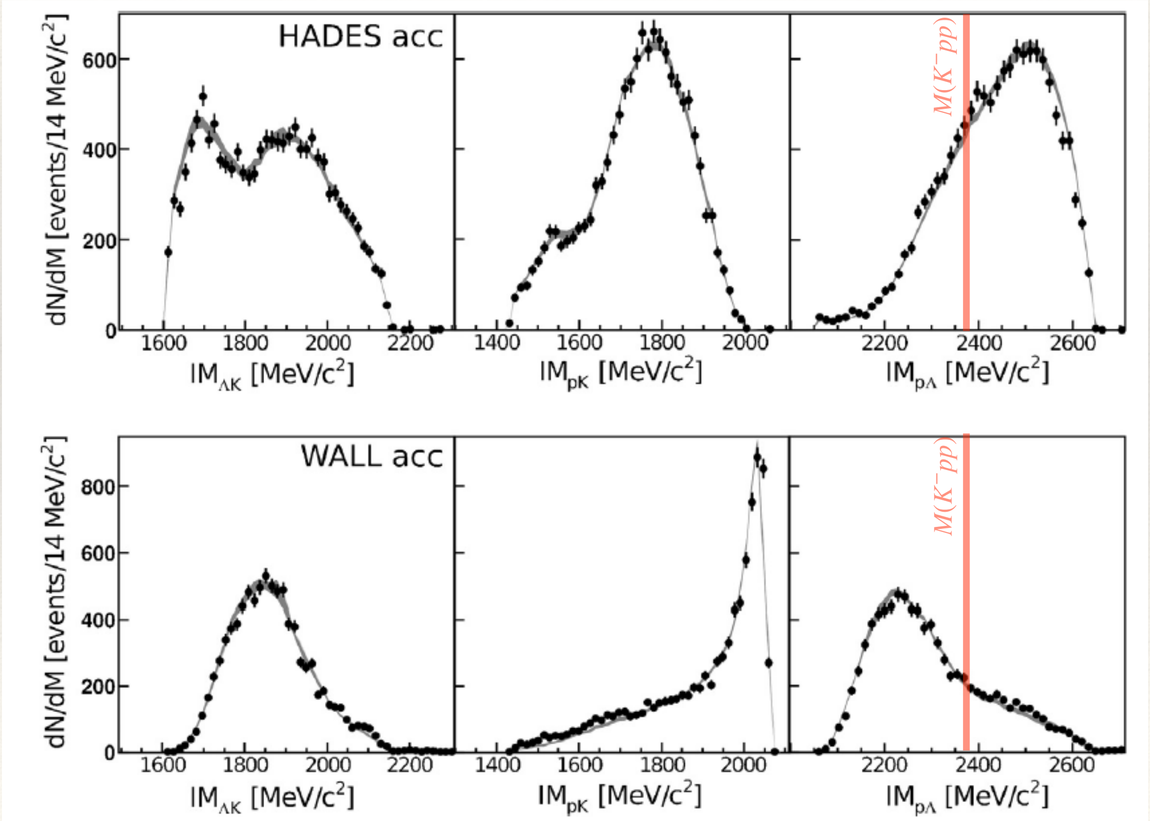
DISTO@SATURNE



PRL104(2010) 132502

@ 3.5 GeV

HADES@GSI



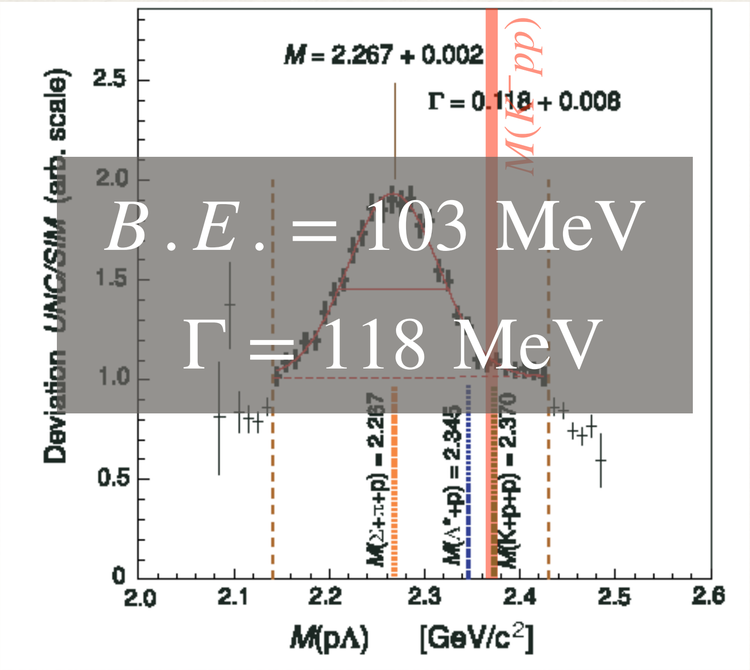
PLB742(2015) 242

Experimental studies :: pp collison

$$p + p \rightarrow \Lambda p + K^+$$

@ 2.85 GeV

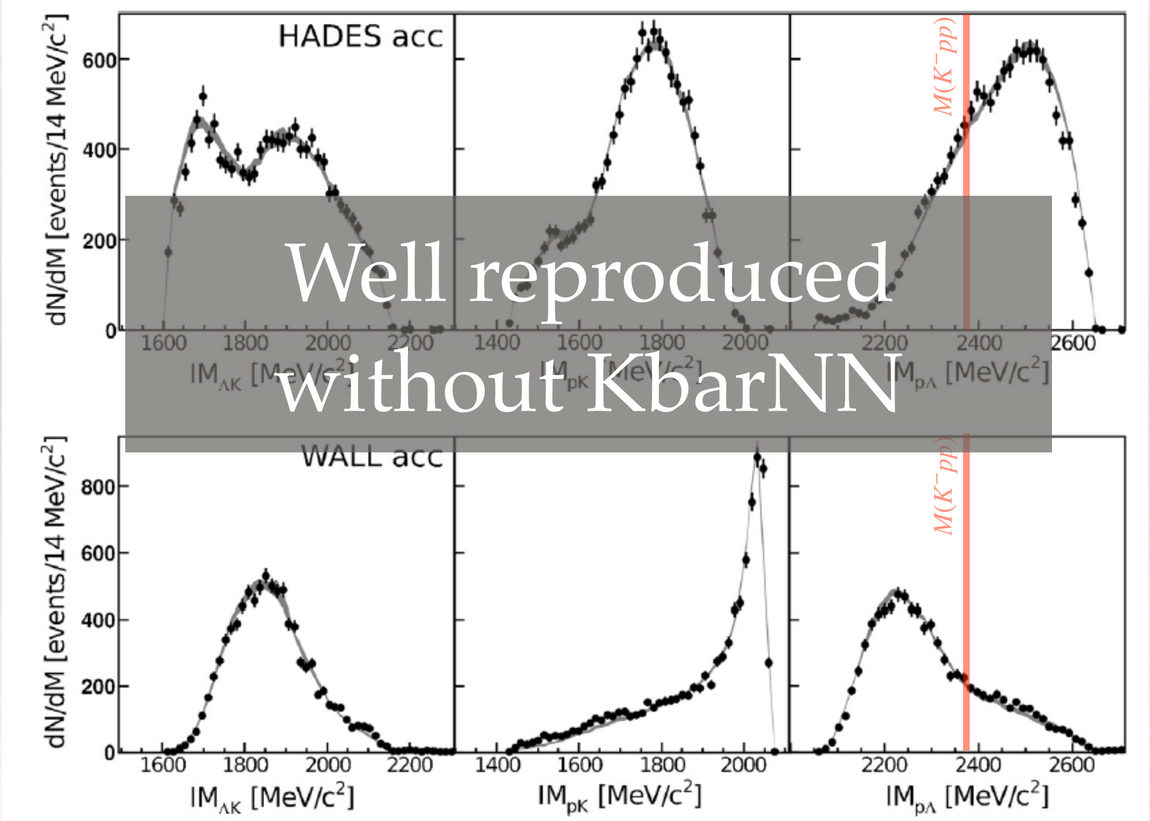
DISTO@SATURNE



PRL104(2010) 132502

@ 3.5 GeV

HADES@GSI

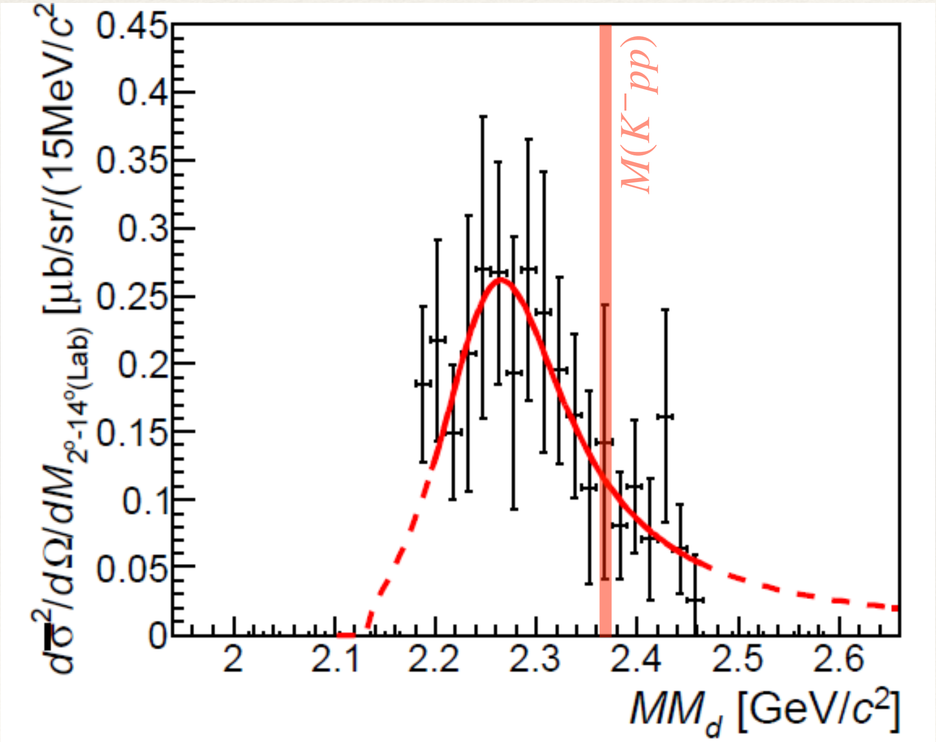


PLB742(2015) 242

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

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

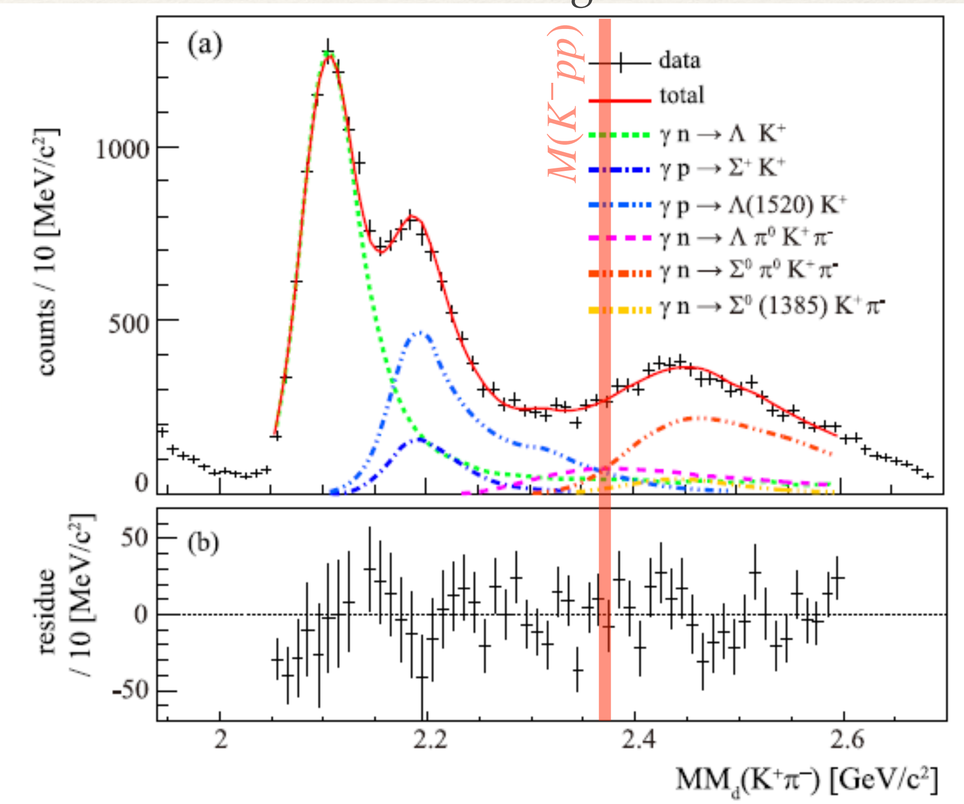
E27@J-PARC



PTEP(2015) 021D01

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

LEPS@SPring-8

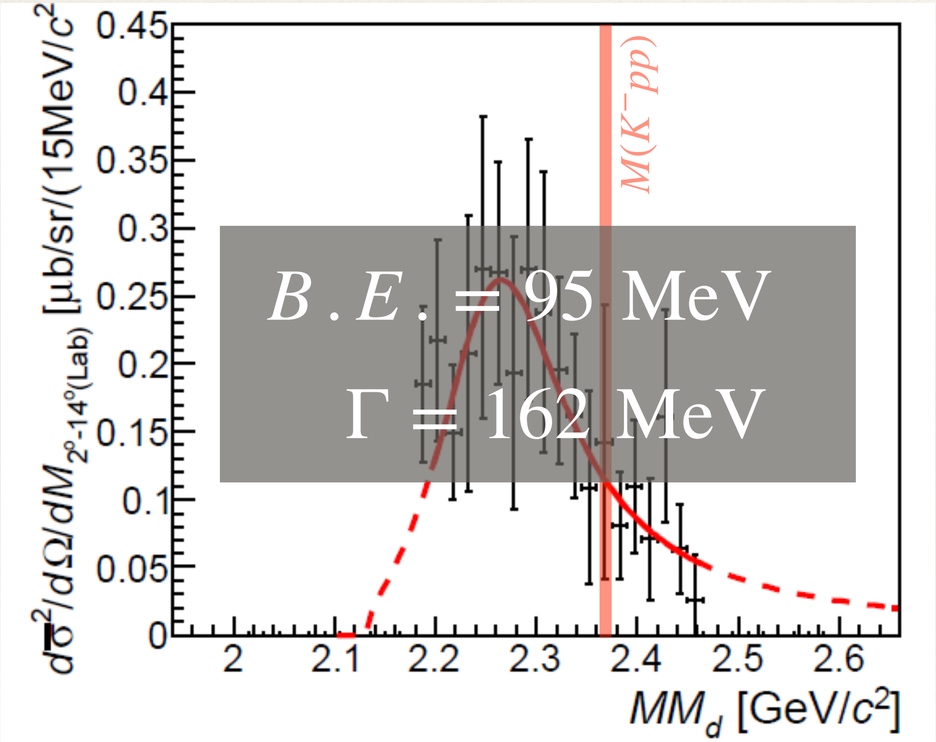


PLB 728 (2014) 616

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

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

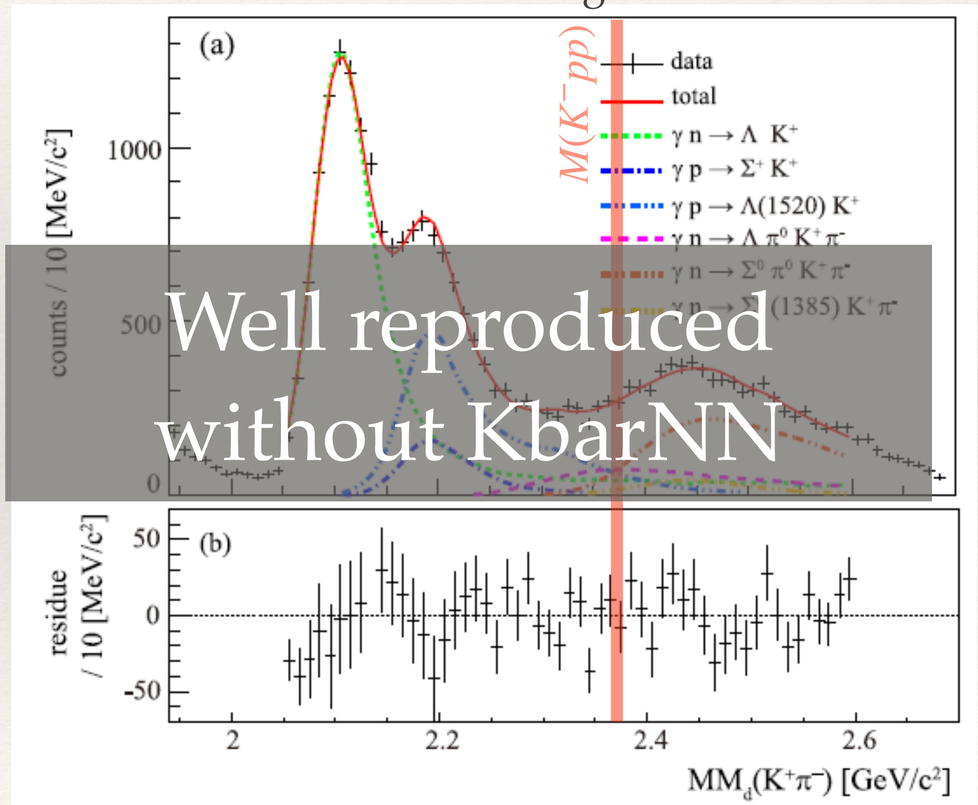
E27@J-PARC



PTEP(2015) 021D01

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

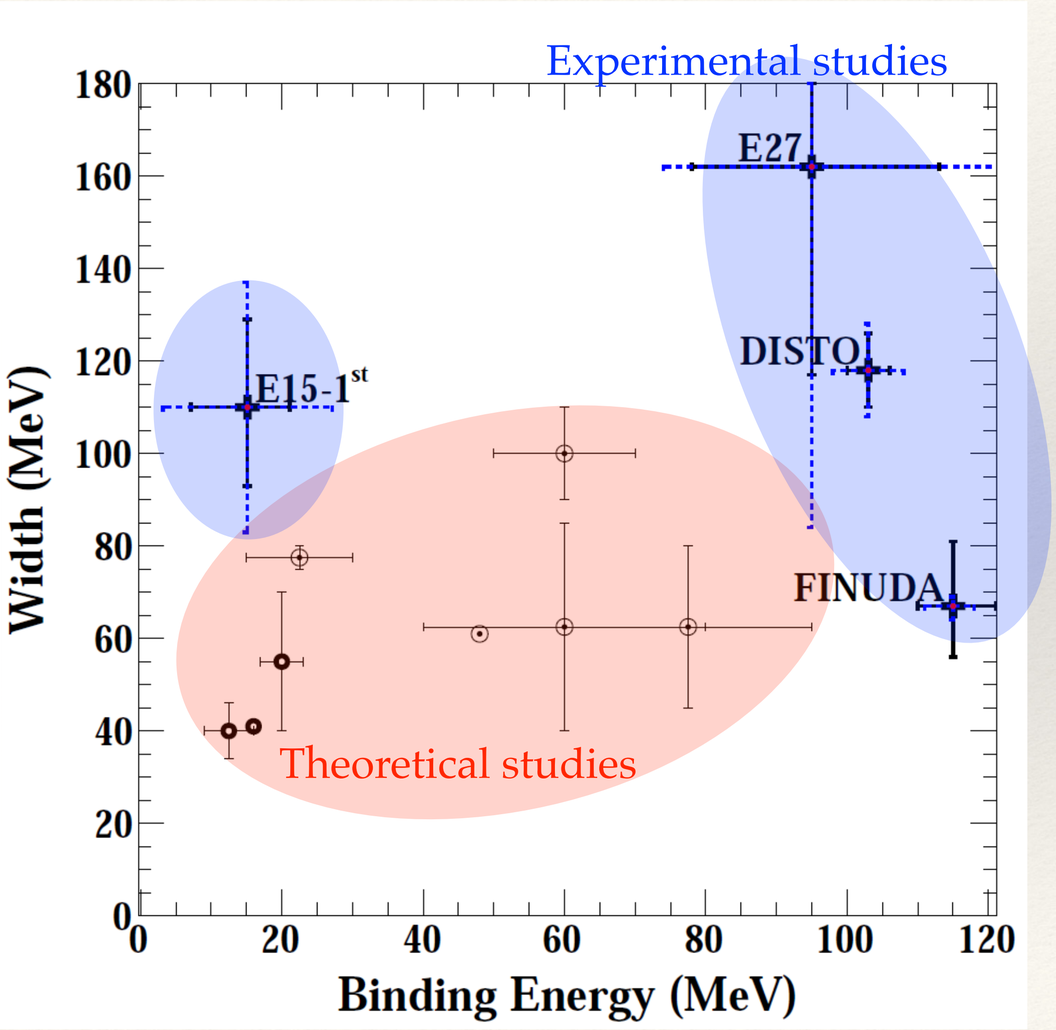
LEPS@SPring-8



PLB 728 (2014) 616

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.
    - More simple reaction is desire to compare to theoretical studies.

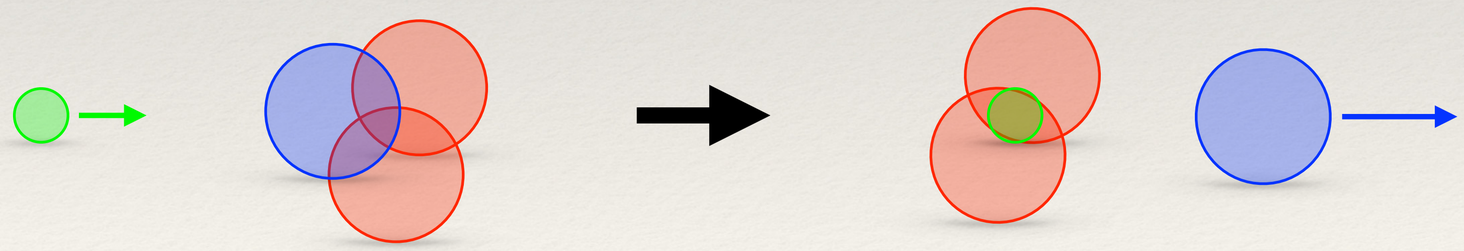


E15 experiment

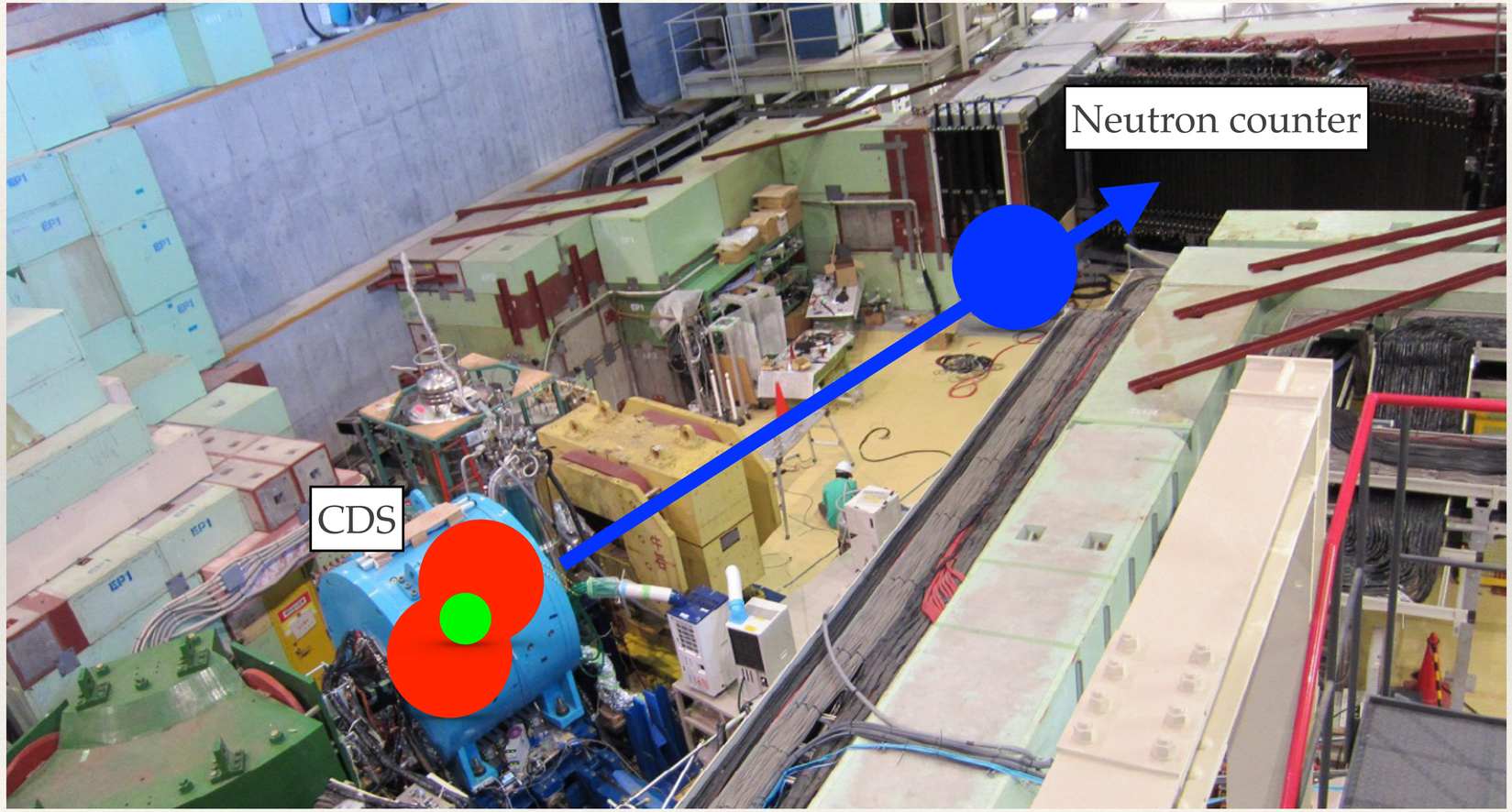
In-flight (K-, n) reaction to generate KbarNN bound state

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

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

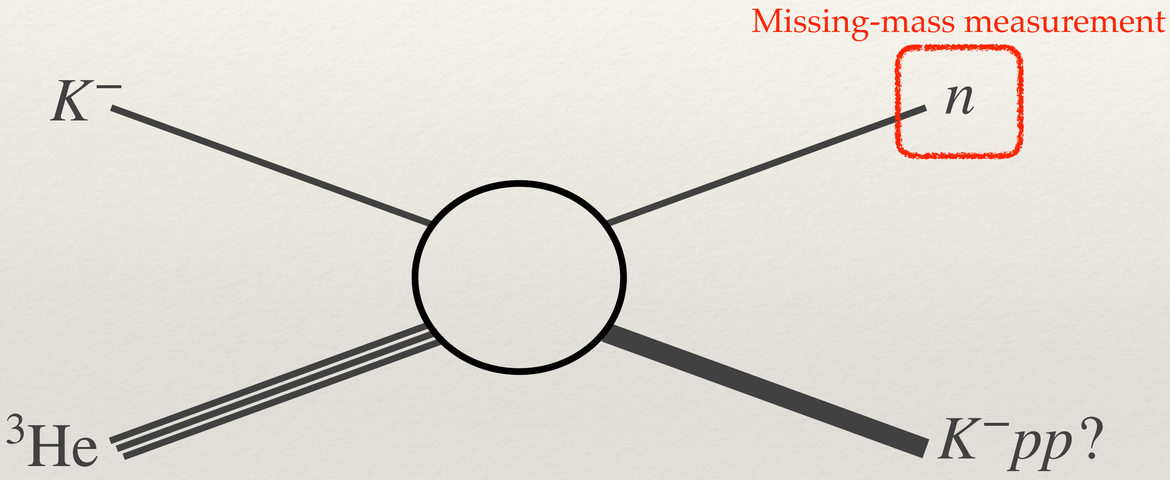


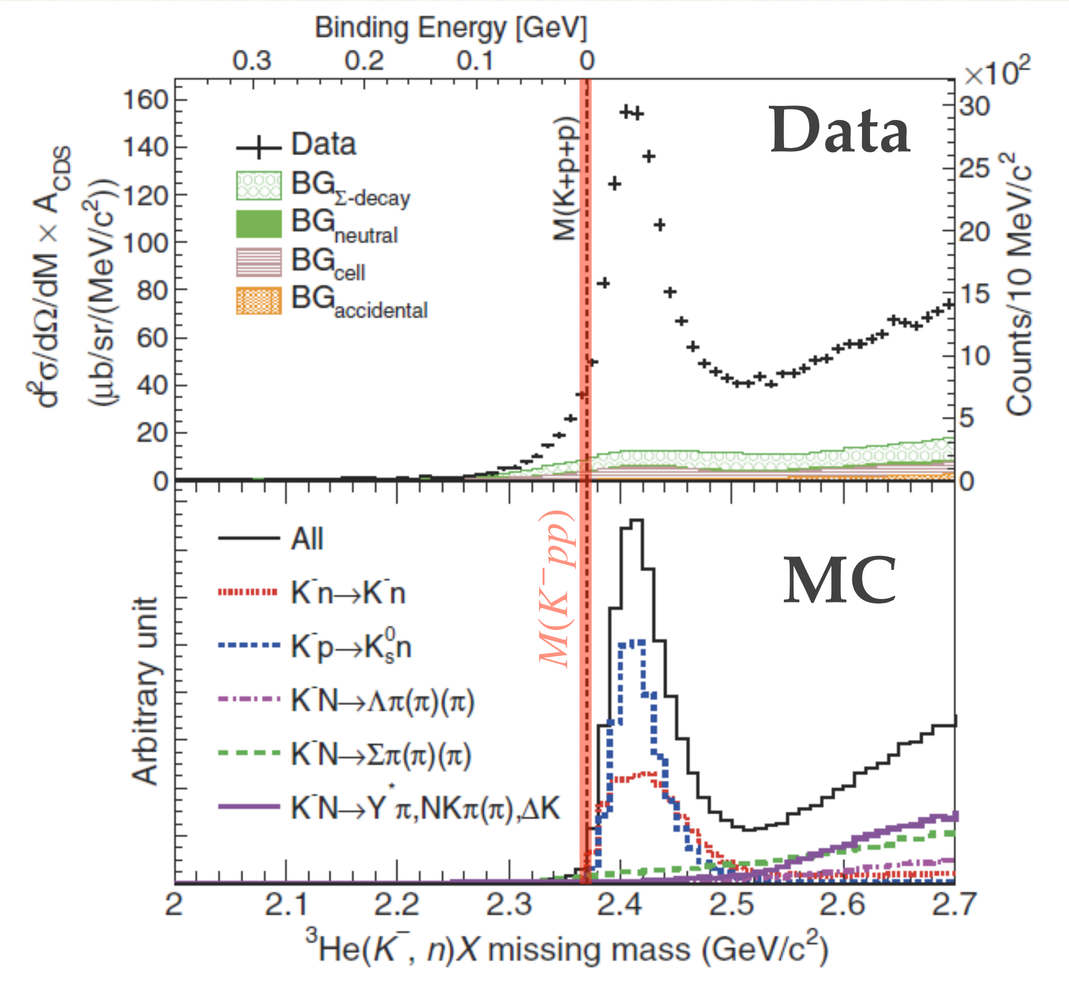
E15 experiment



Results of E15 - 1st

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

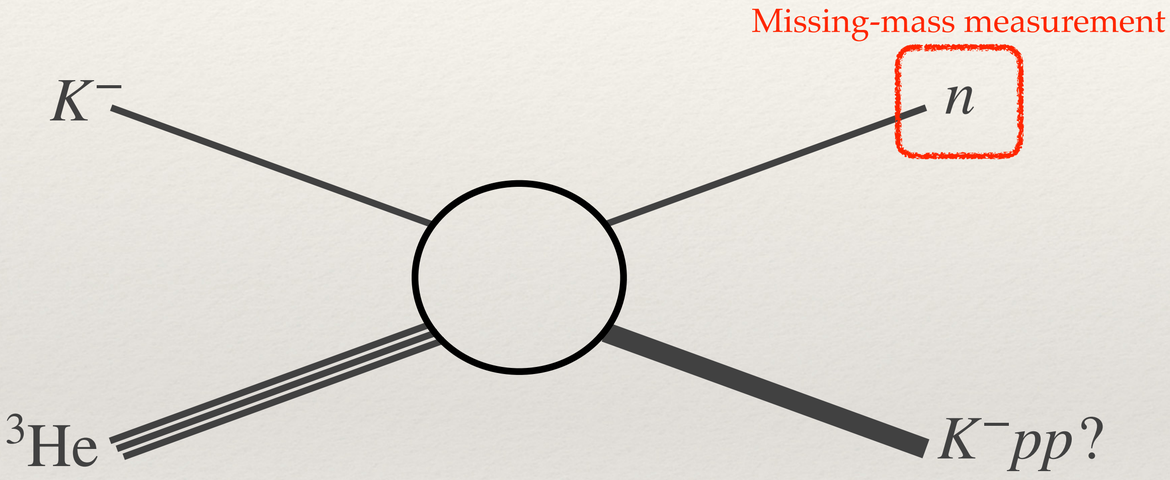




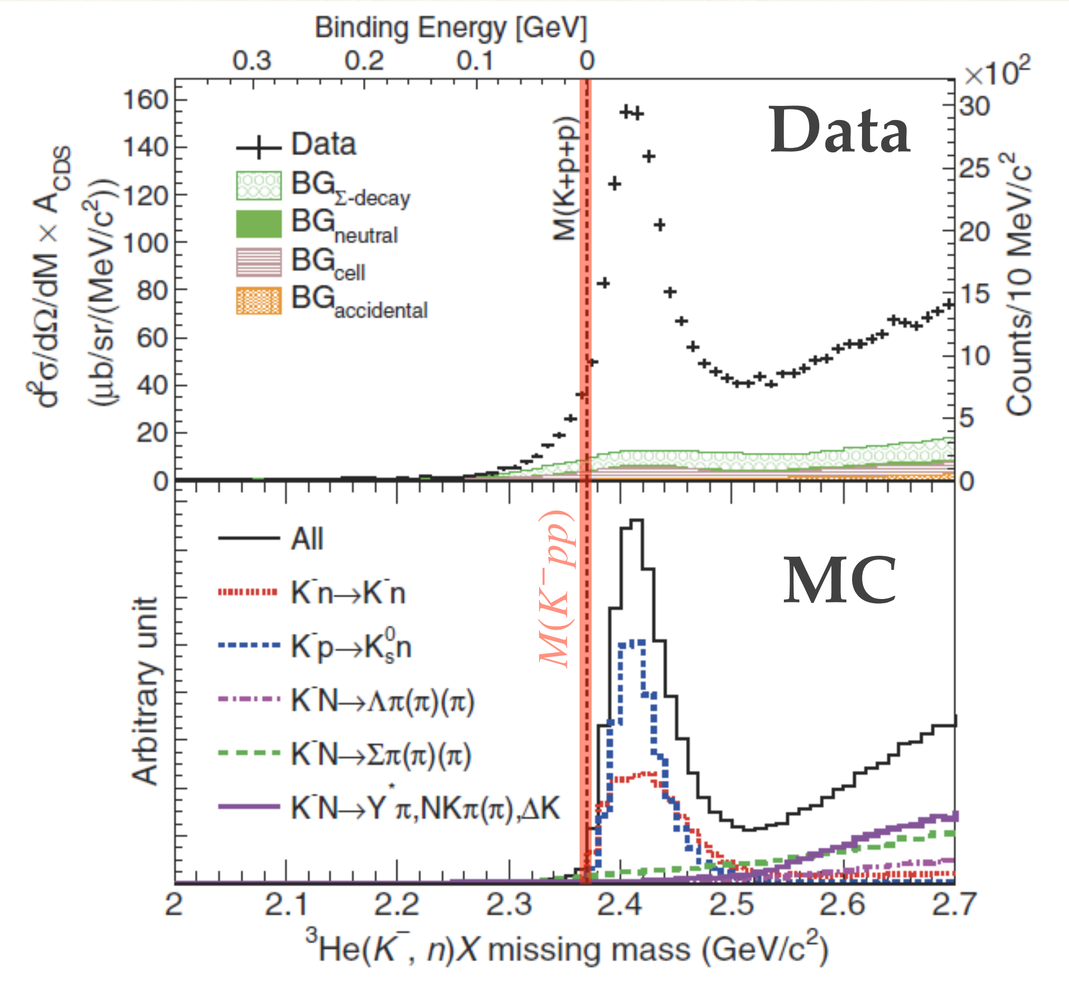
PTEP (2015) 061D01

Results of E15 - 1st

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



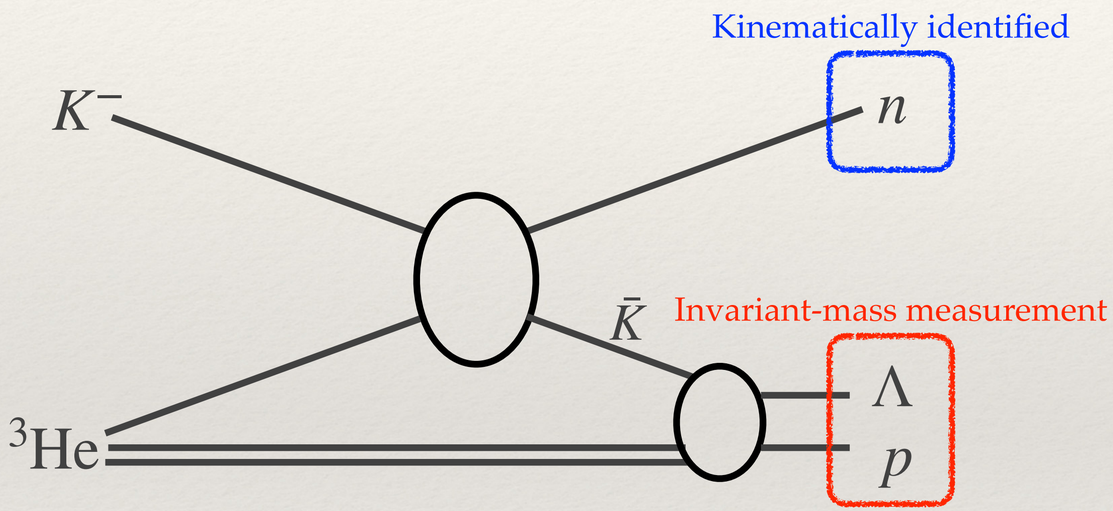
- Strong QF peak above M(Kpp)
- No clear peak below M(Kpp)

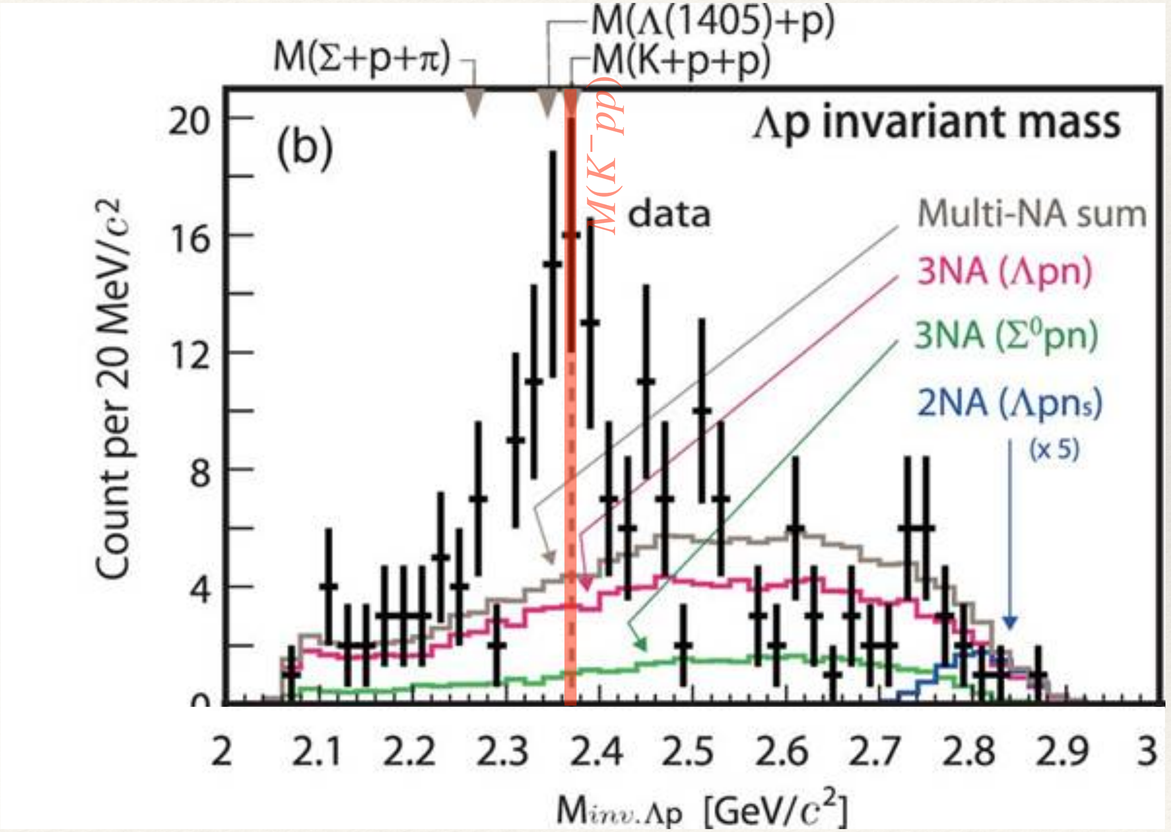


PTEP (2015) 061D01

Results of E15 - 1st

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

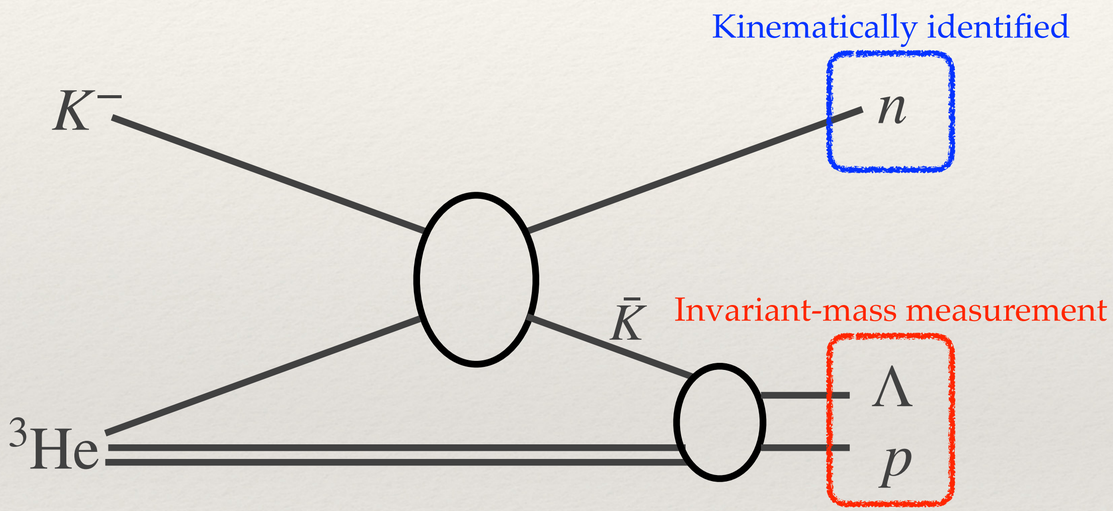




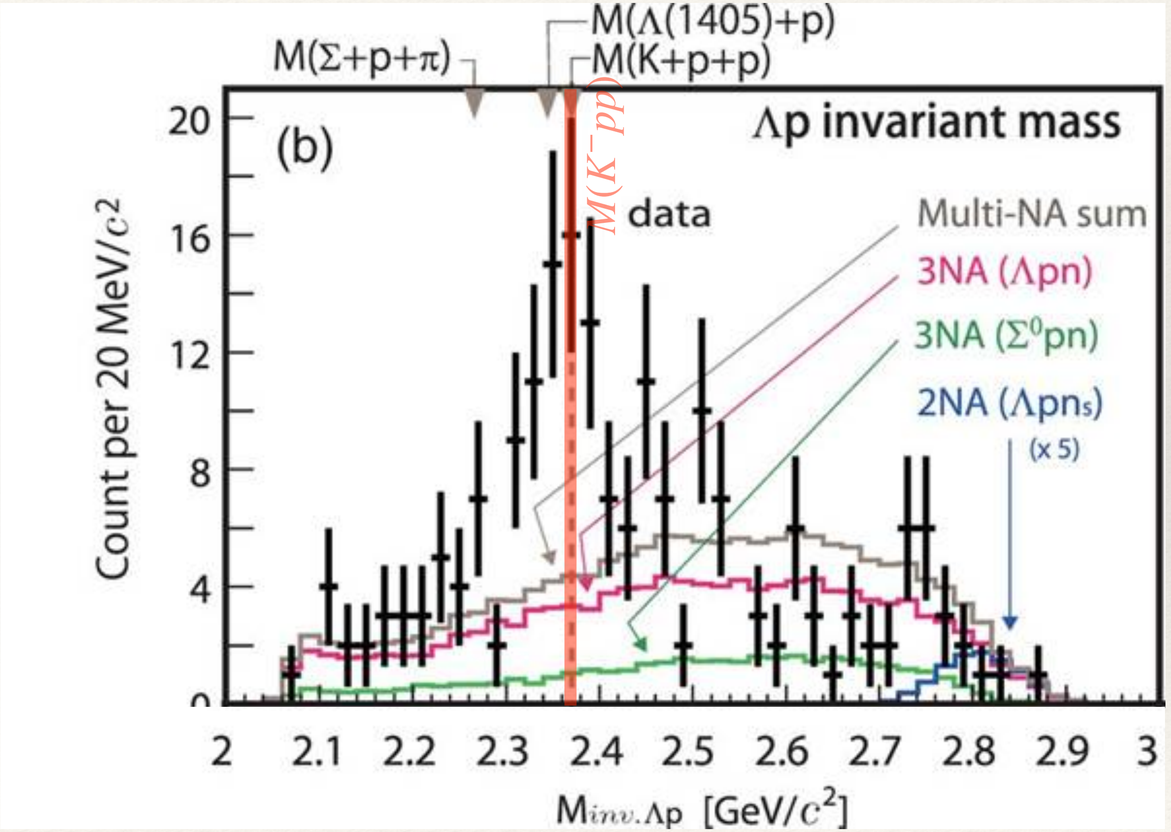
PTEP (2016) 051D01

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



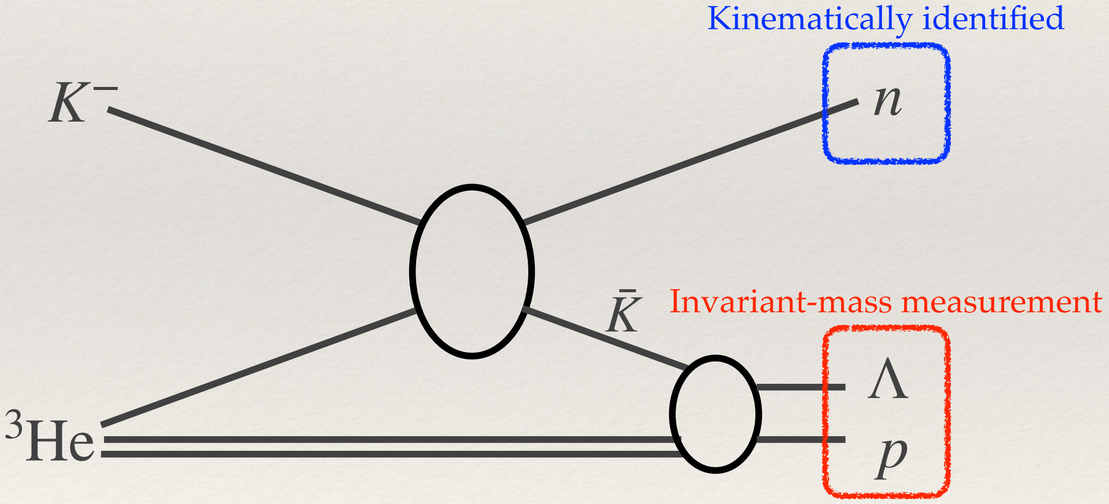
PTEP (2016) 051D01

Result of E15 - 2nd

Results of E15 - 2nd

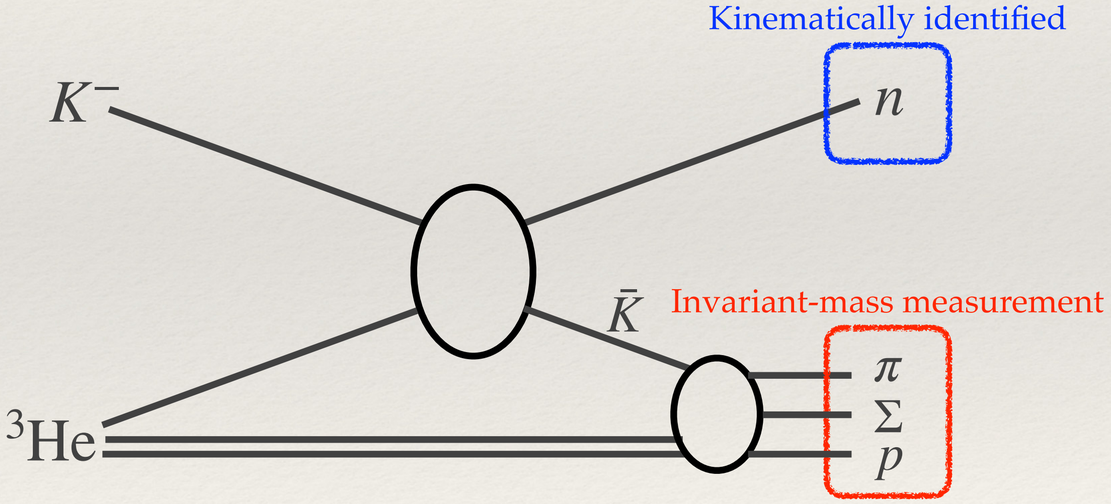
Measured exclusive channels

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



Detected particles : $pp\pi^-$

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

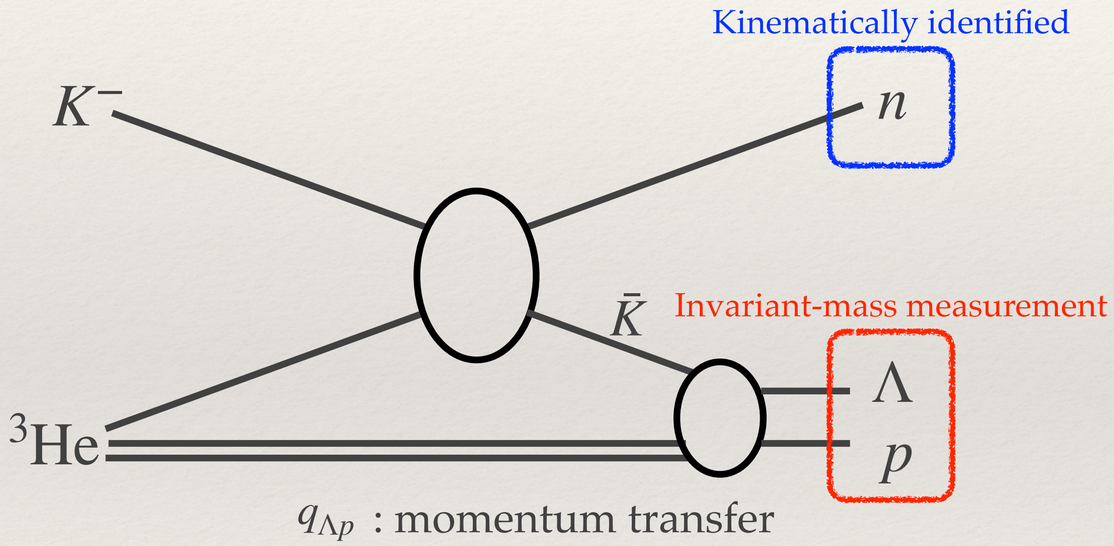


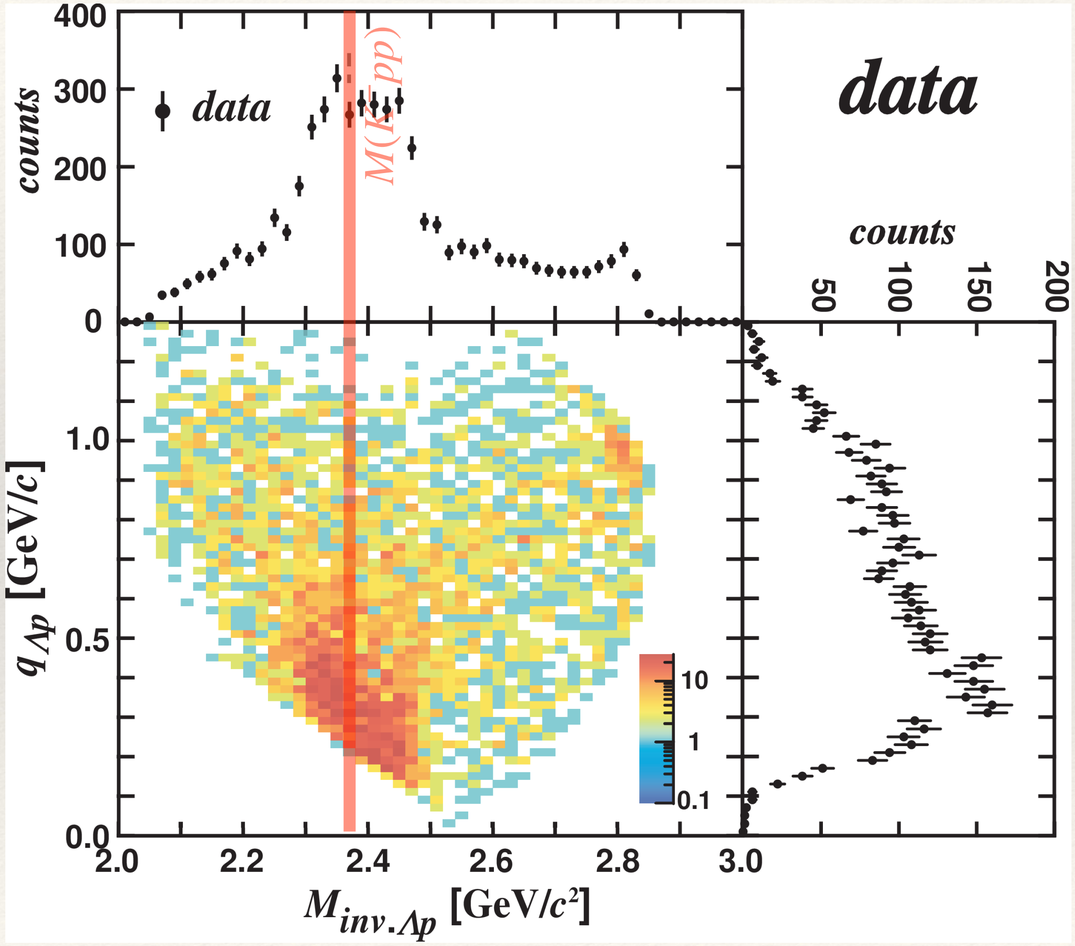
Detected particles : $np\pi^+\pi^-$

! Neutral particle detection by CDS

Result of Λpn analysis

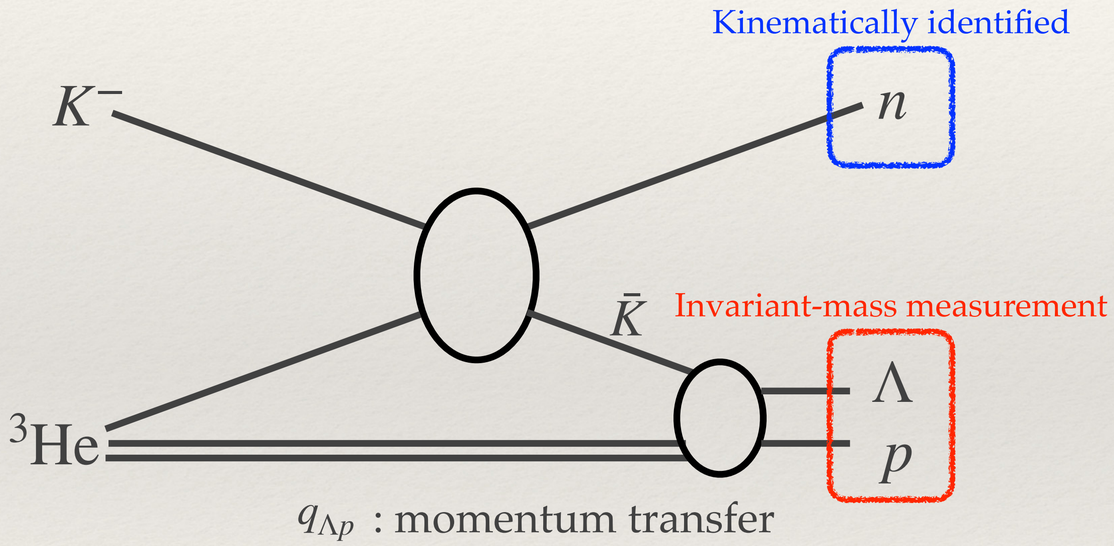
$$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$$

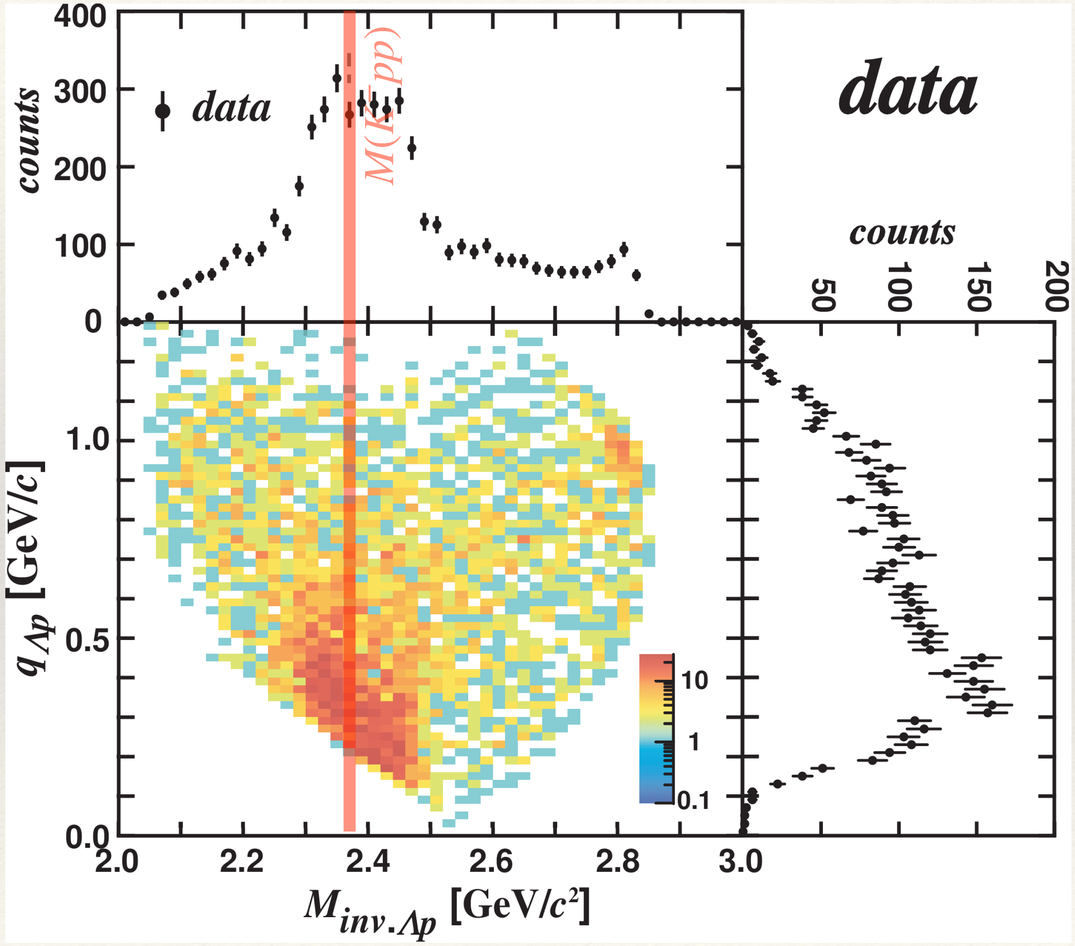




Result of Λpn analysis

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

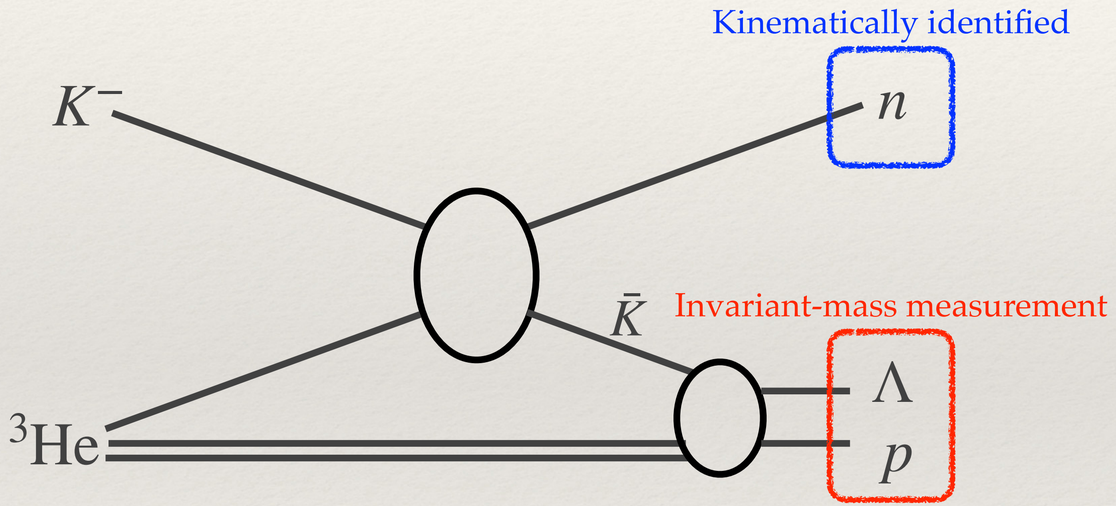




Decomposition into 3 major components

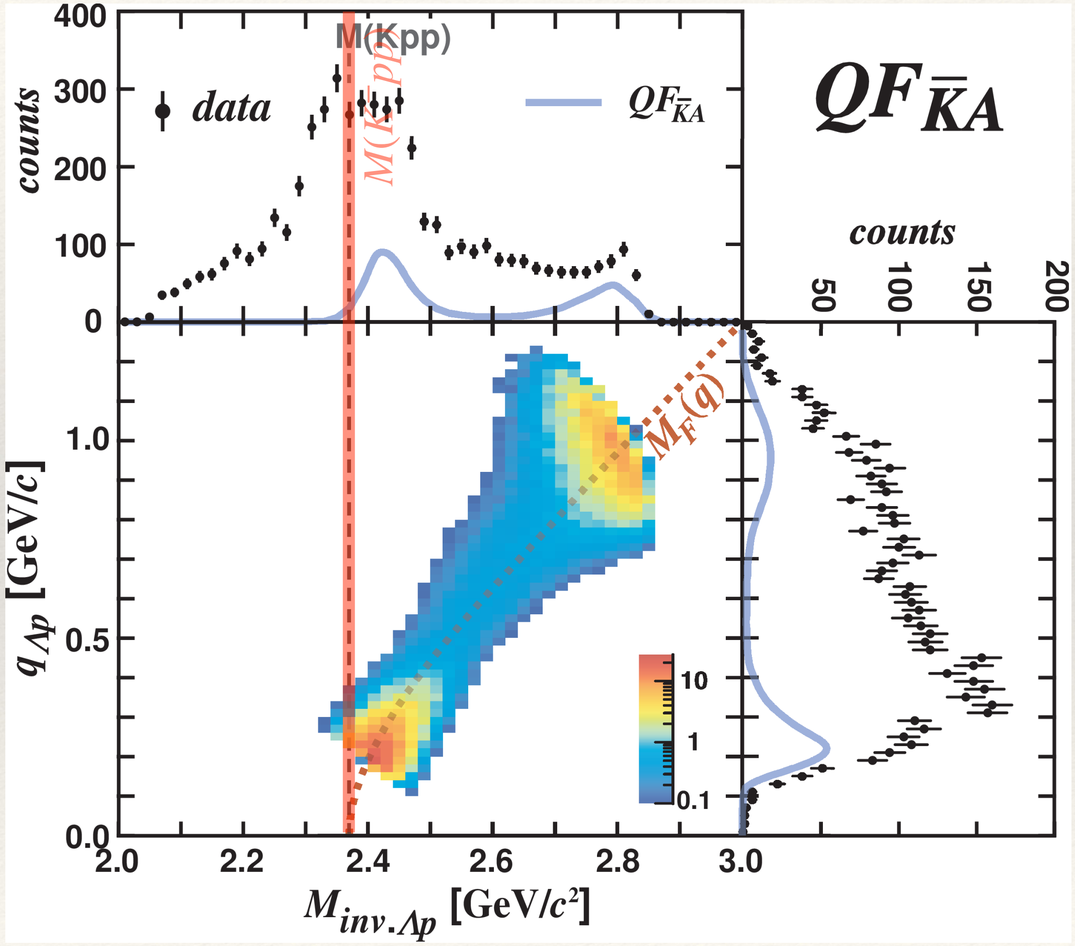
Result of Λpn analysis

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

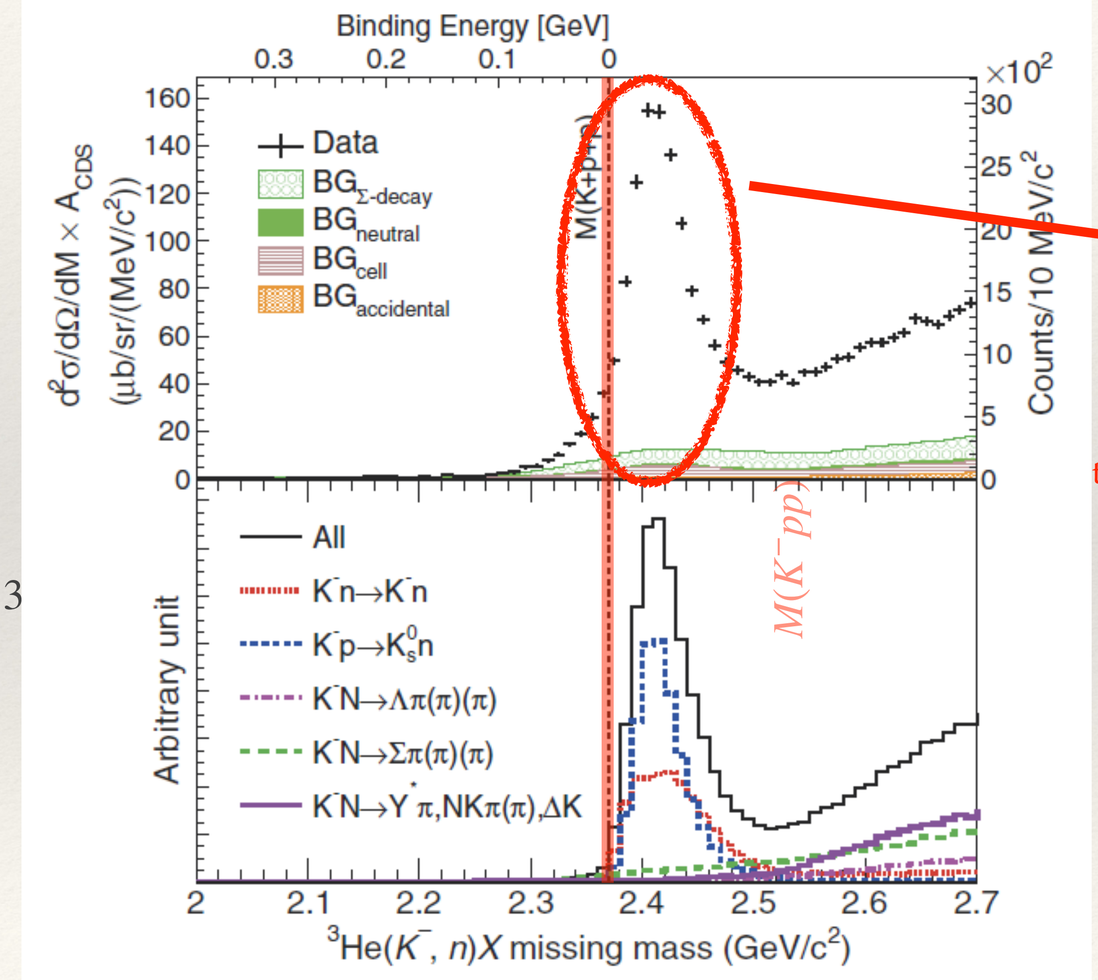


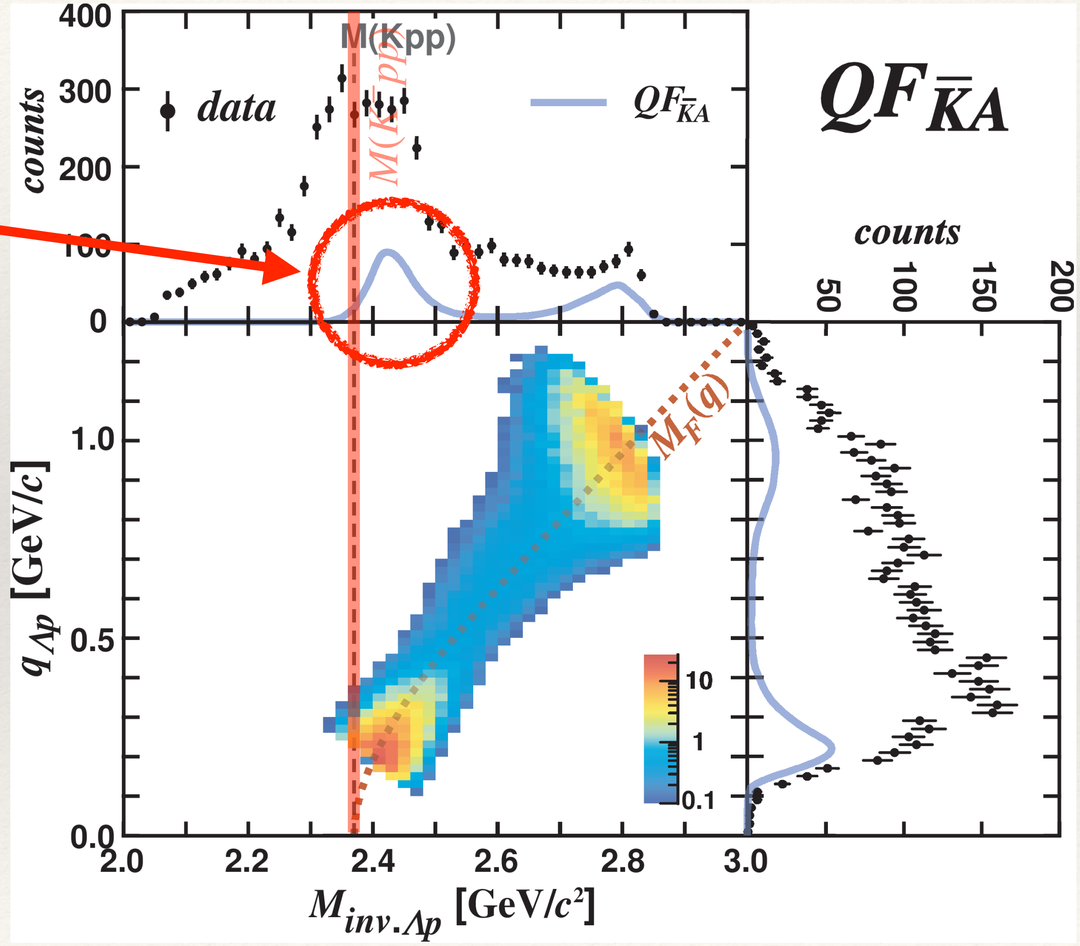
Peak position

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



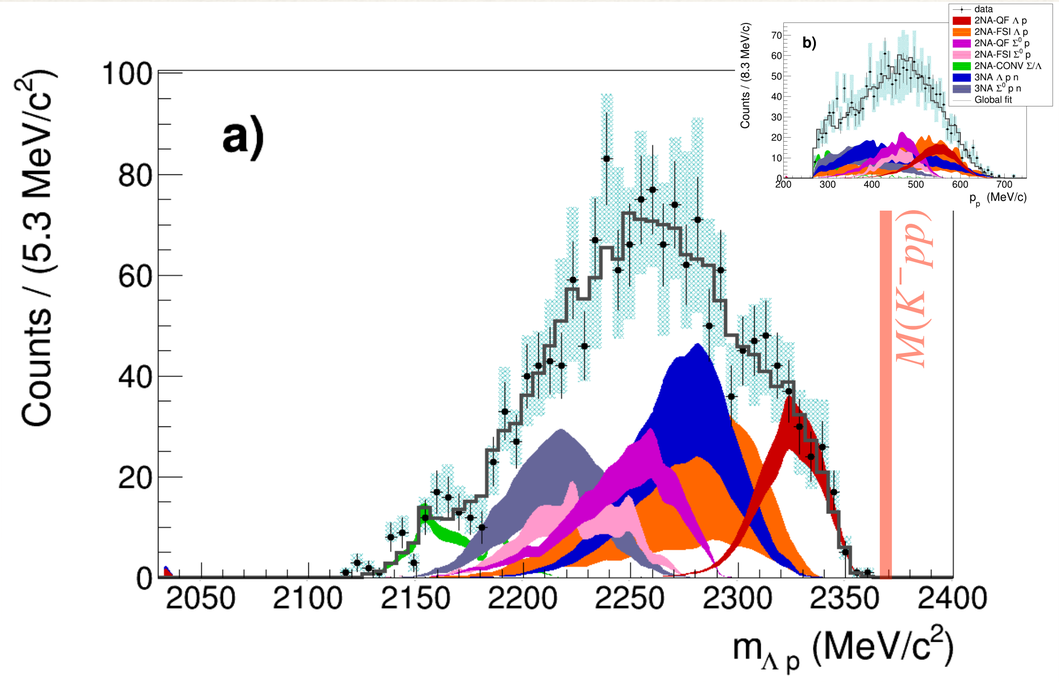
Result of Λpn analysis





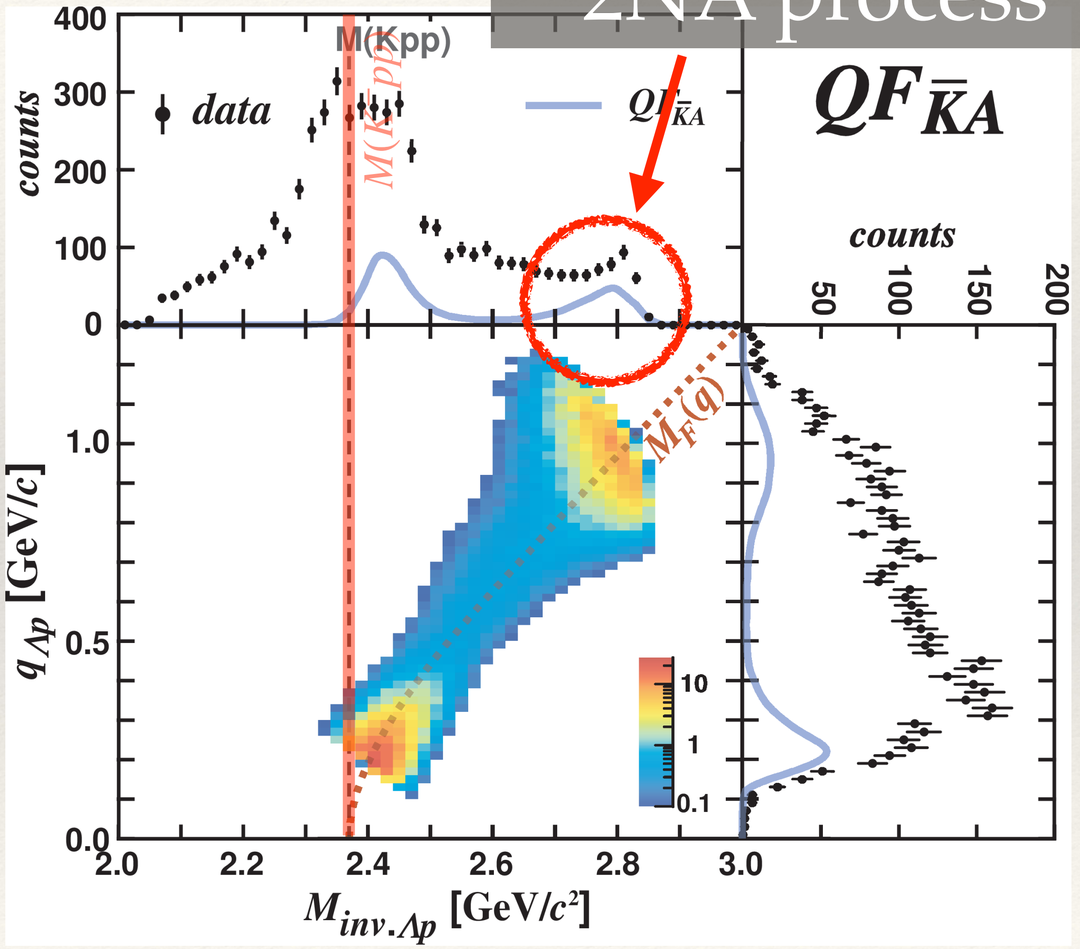
Result of Λpn analysis

AMADEUS@DAΦNE



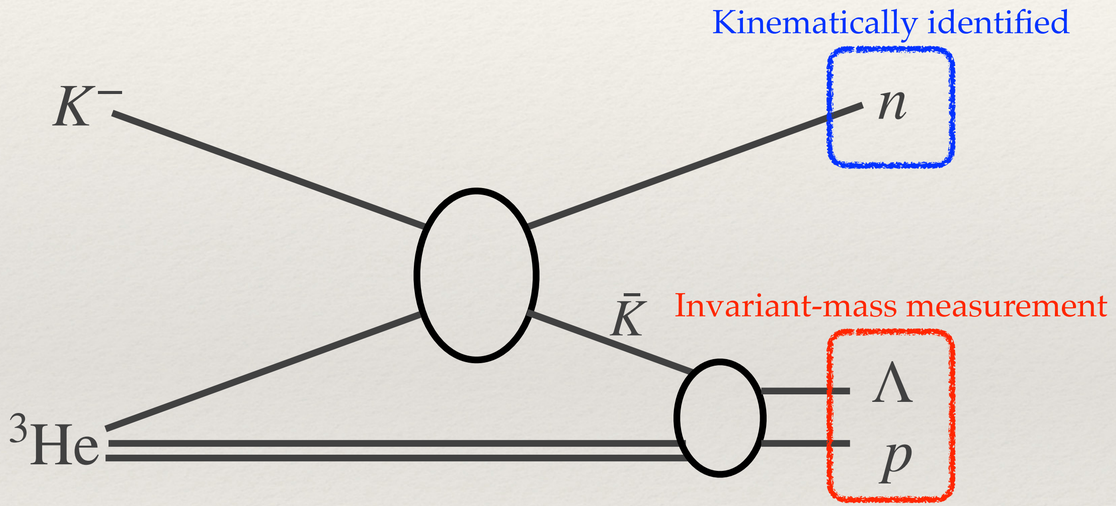
arXiv:1809.07212

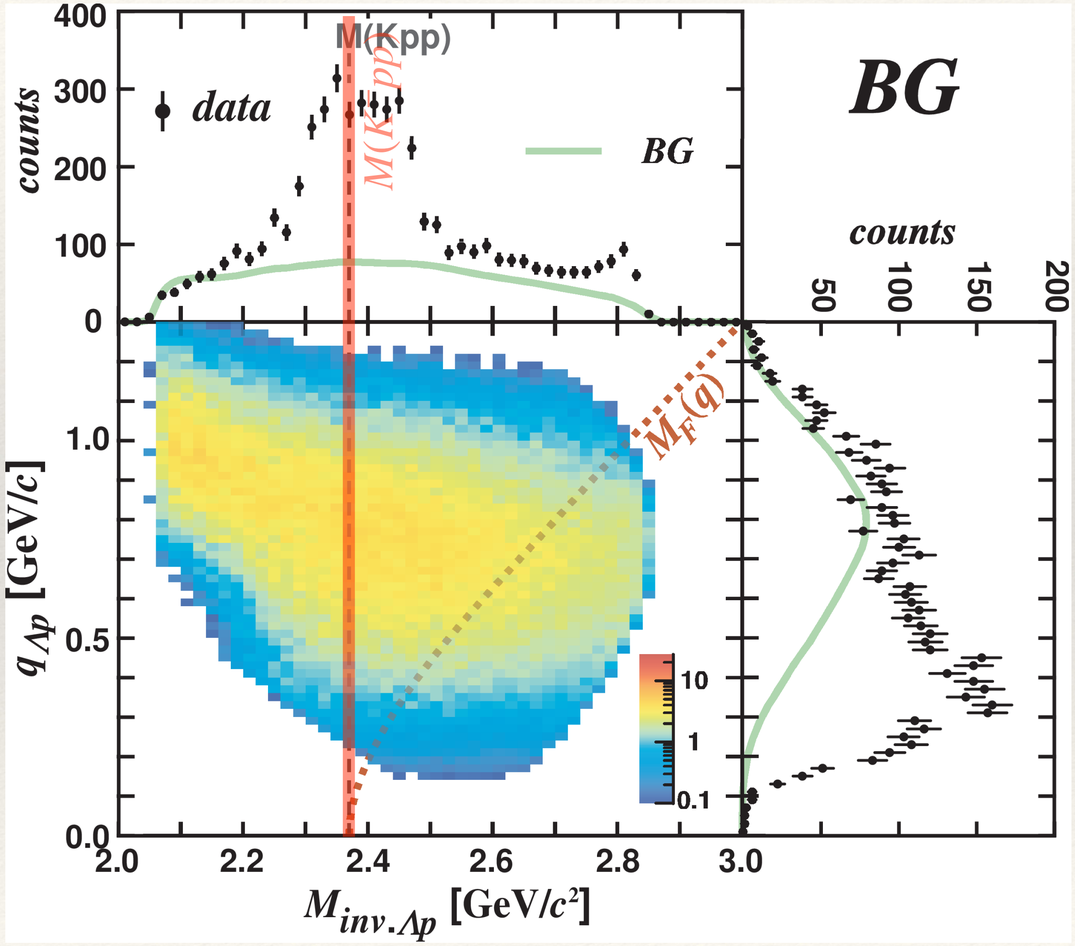
2NA process



Result of Λpn analysis

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



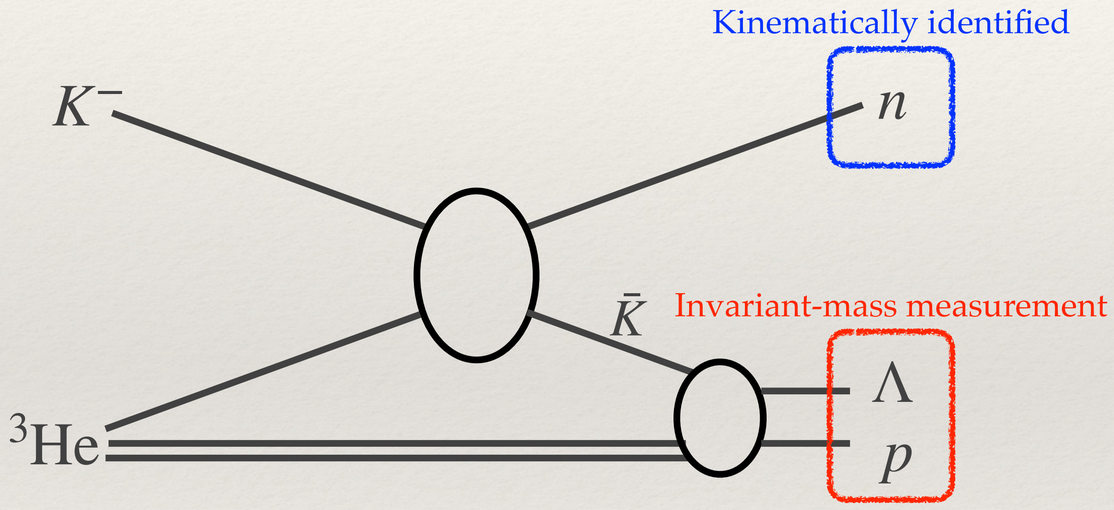


Physics background : $\Sigma^0 pn$ / $\Sigma^- pp$

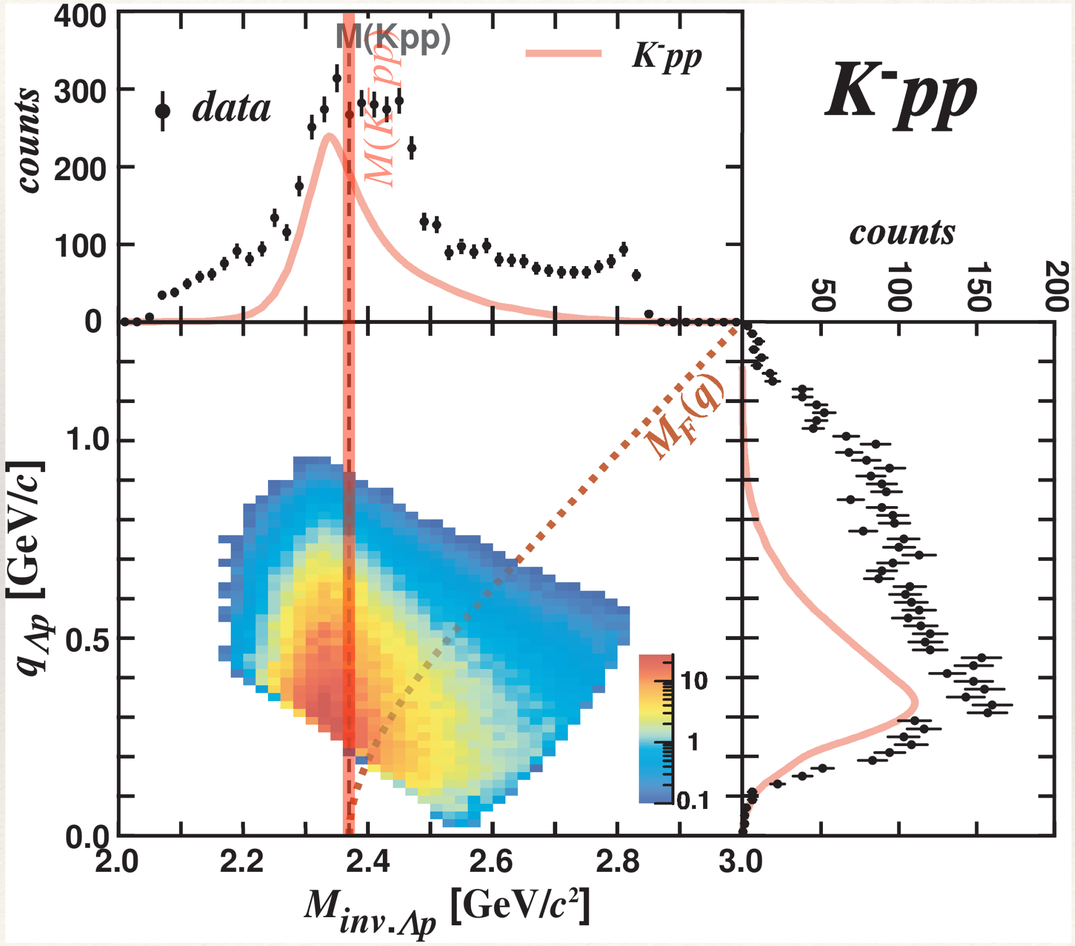
Conversion & FSI processes

Result of Λpn analysis

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

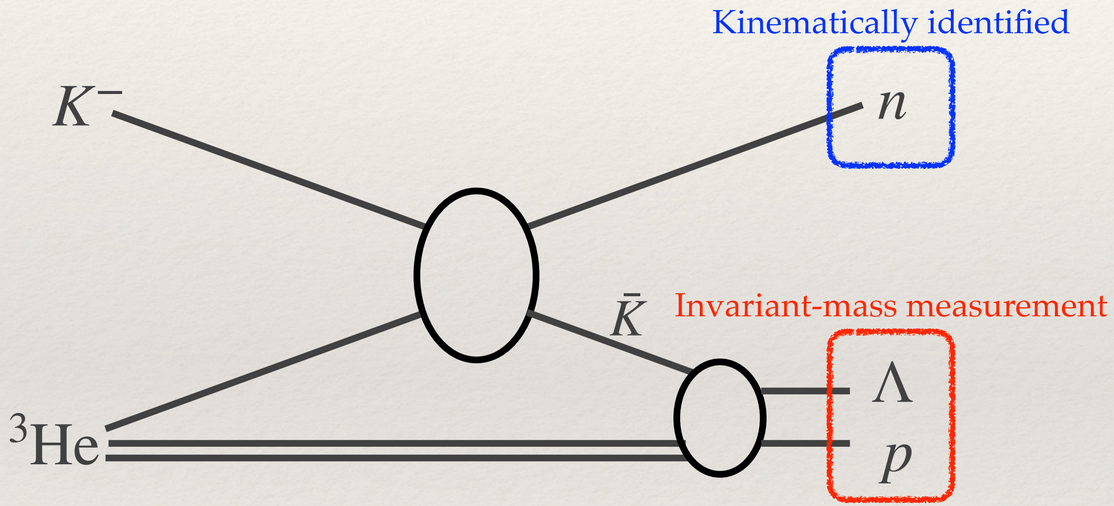


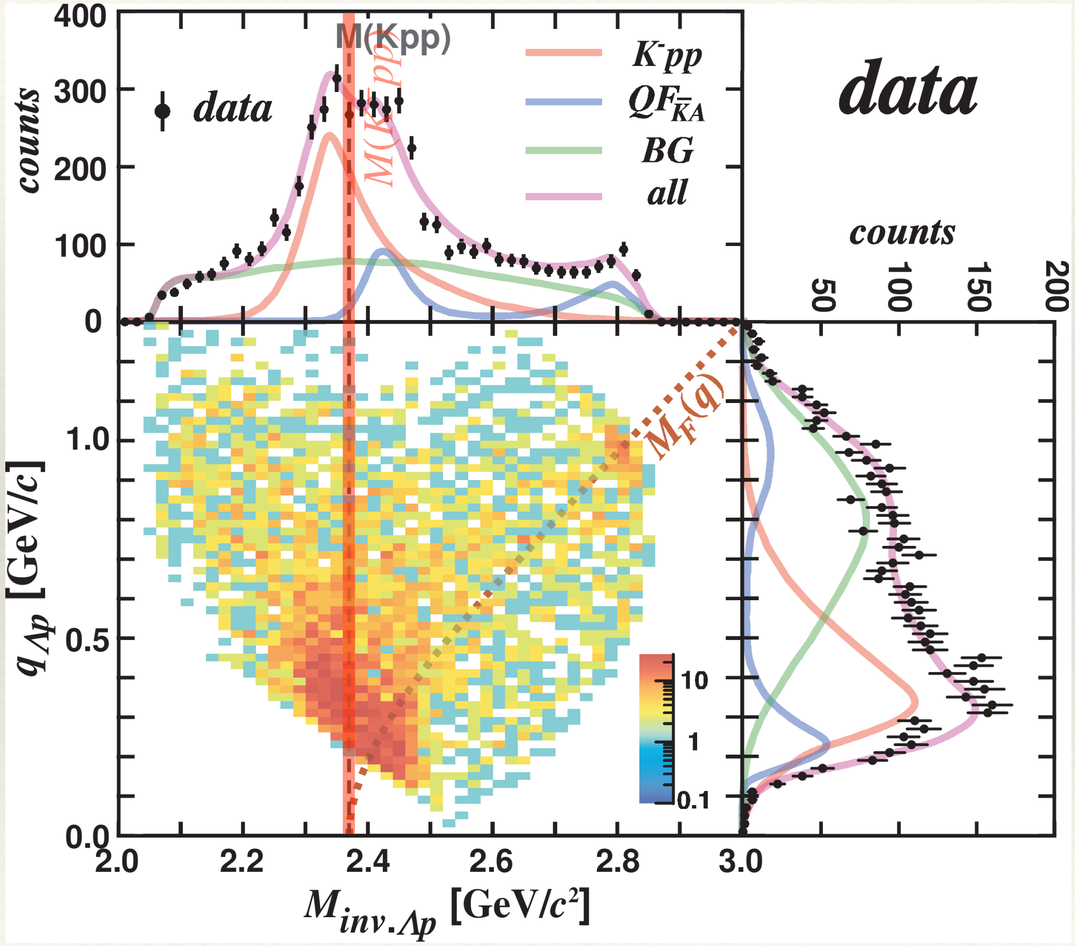
Breit-Wigner shape



Result of Λpn analysis

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



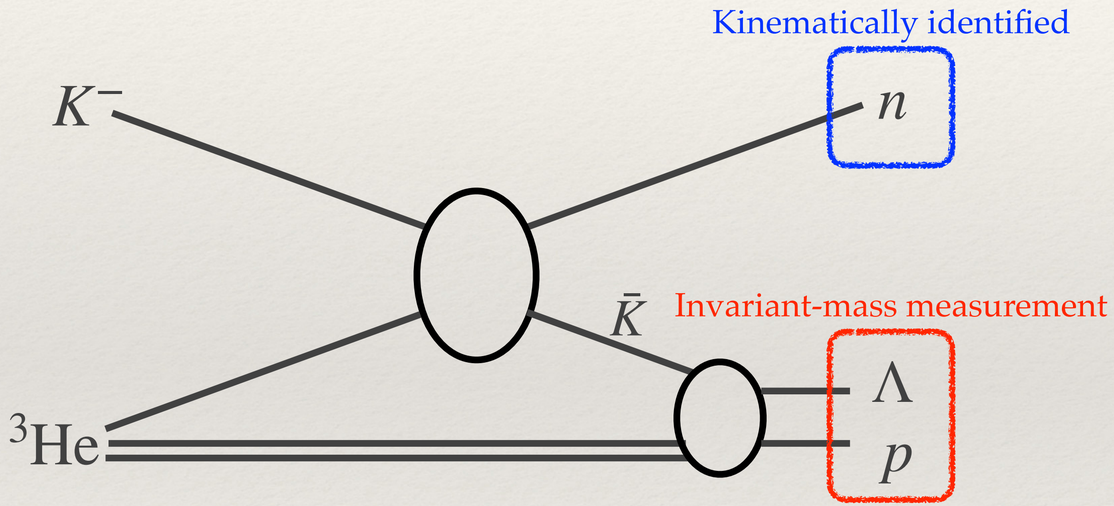


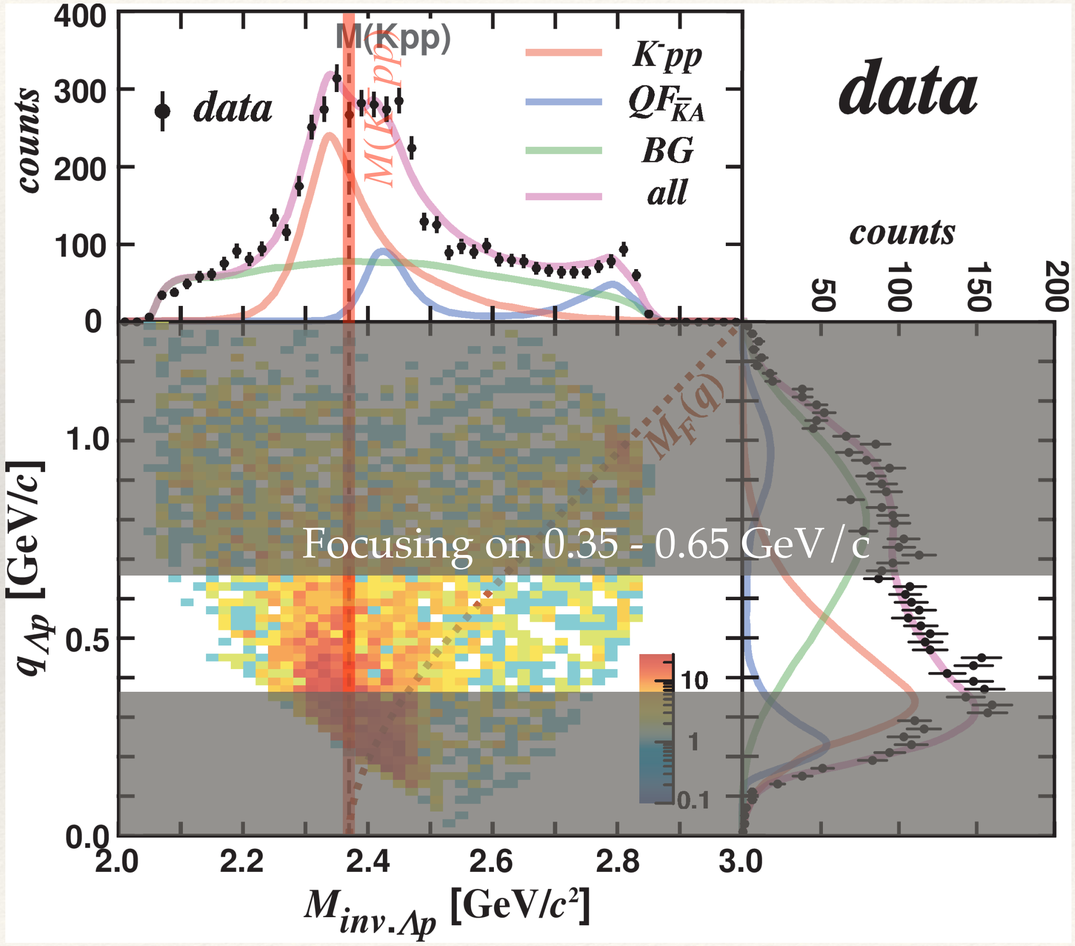
Well reproduced by 3 components

➡ Acceptance correction

Result of Λpn analysis

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



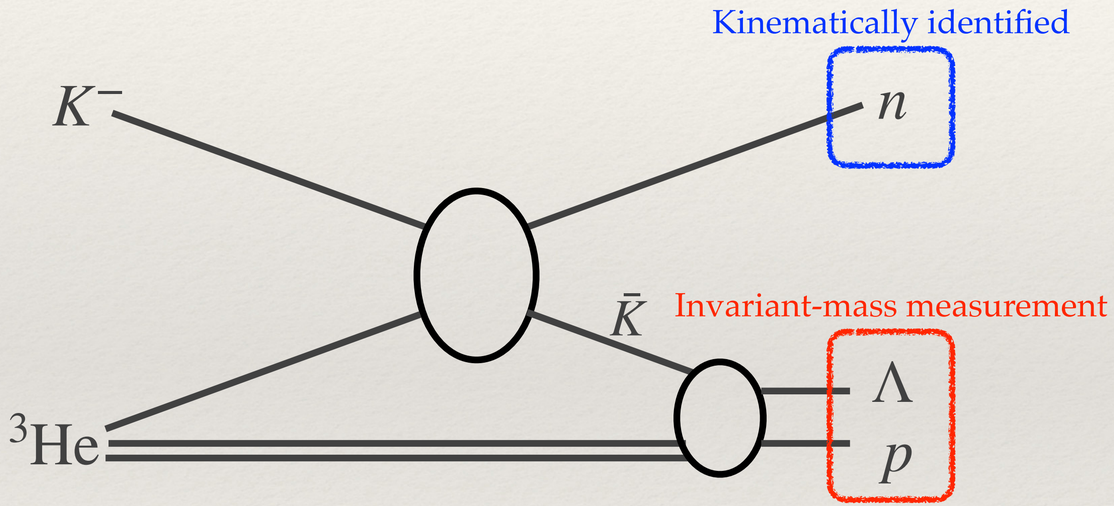


Well reproduced by 3 components

➡ Acceptance correction

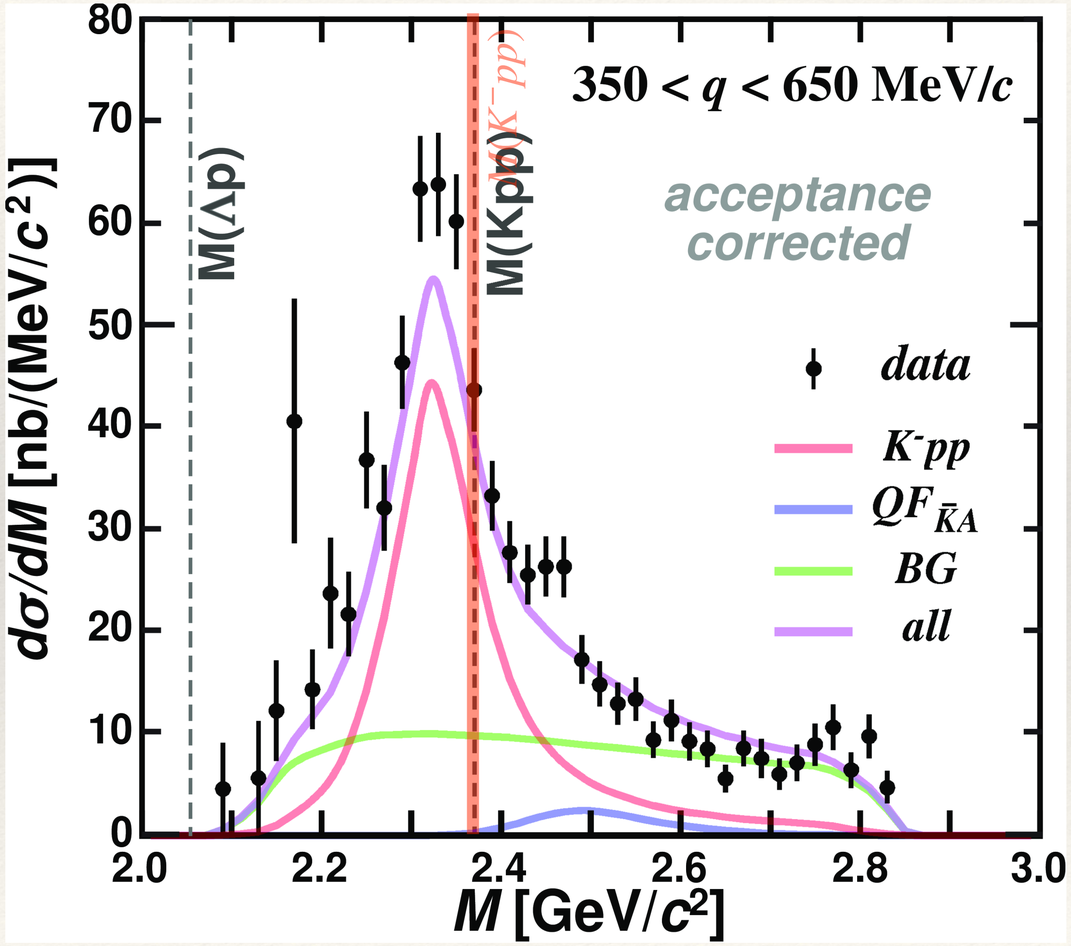
Result of Λpn analysis

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



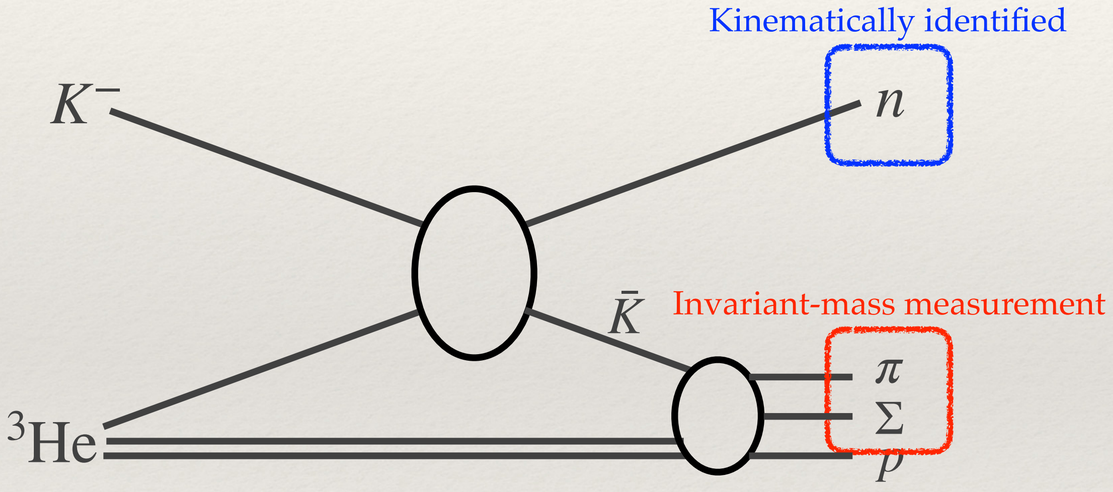
$$B.E. = 47 \pm 3(\mathrm{stat.})^{+3}_{-6}(\mathrm{syst.})\ \mathrm{MeV}$$

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

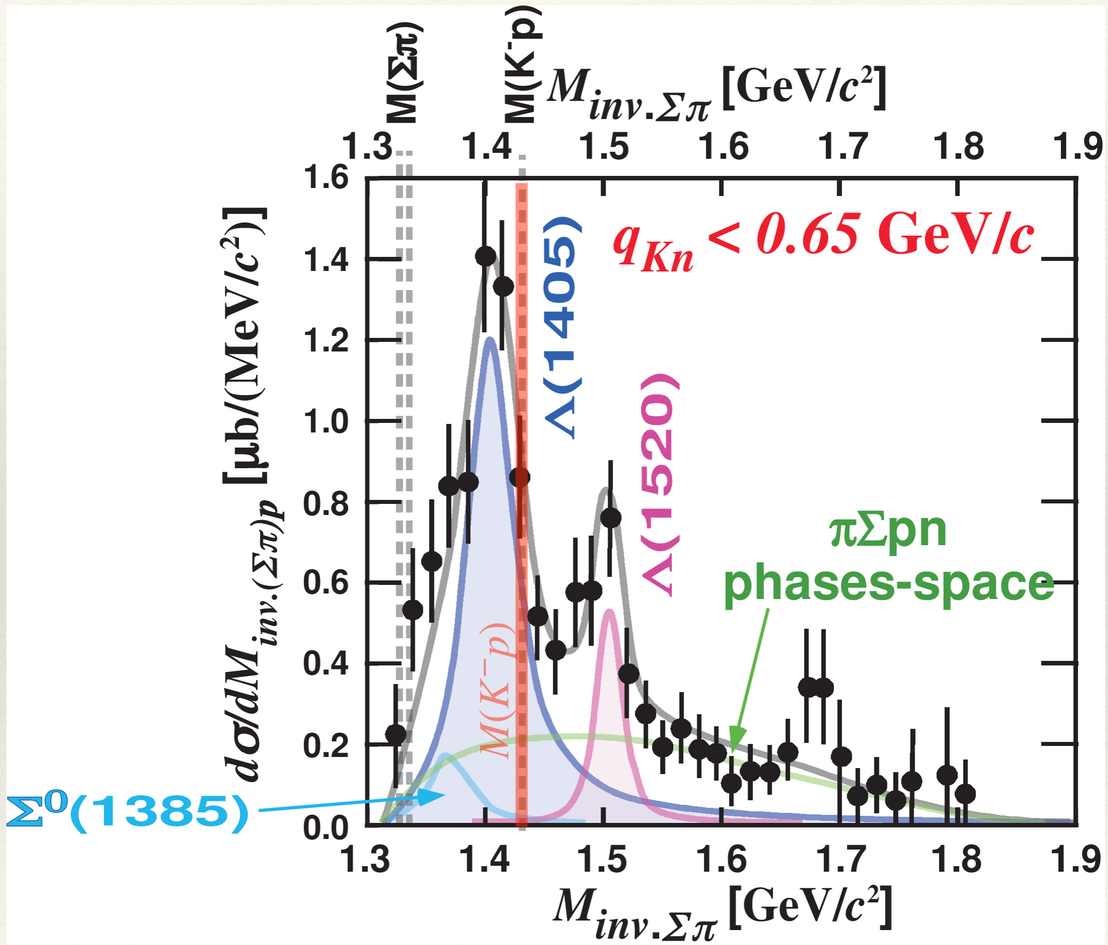


Result of πΣpn analysis

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

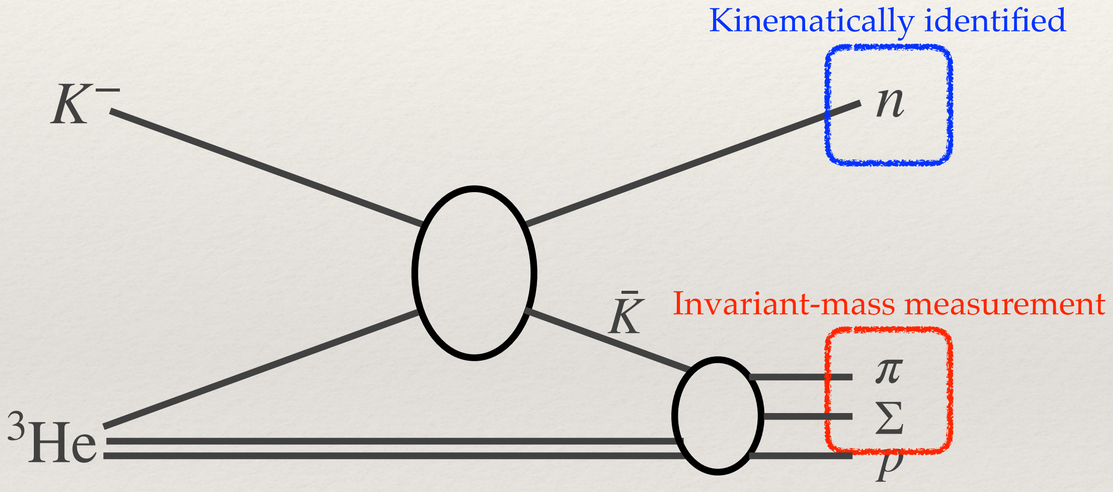


Observation of Y* production

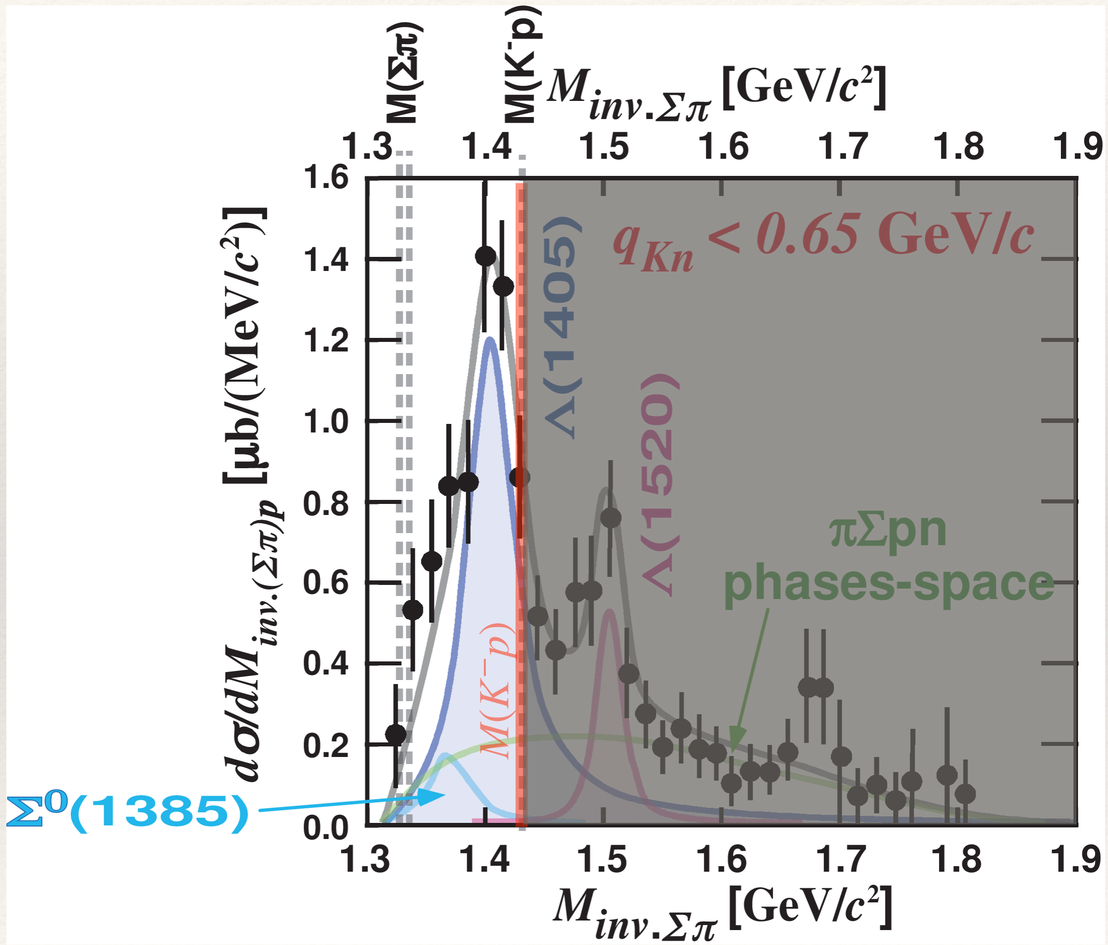


Result of πΣpn analysis

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

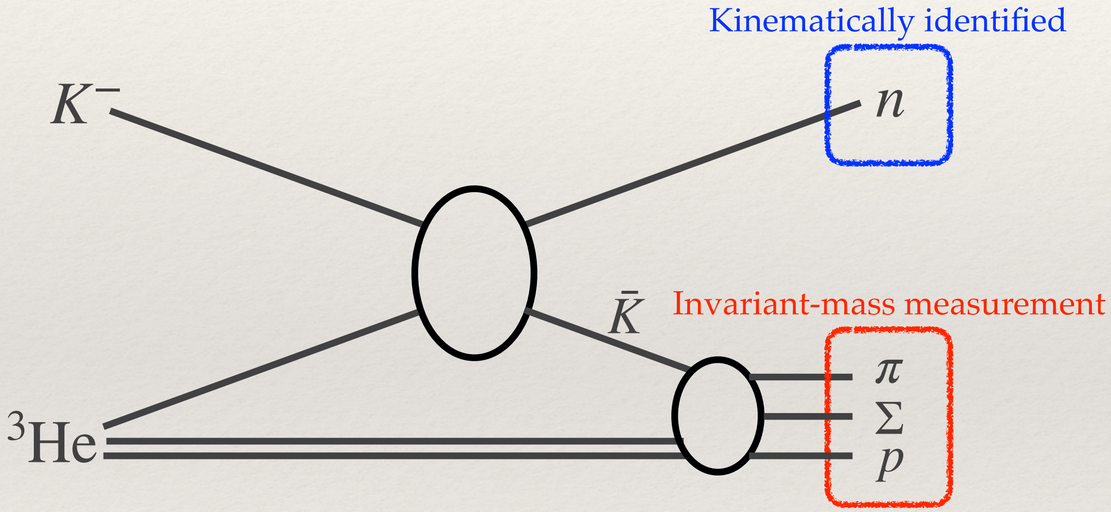


Observation of Y* production



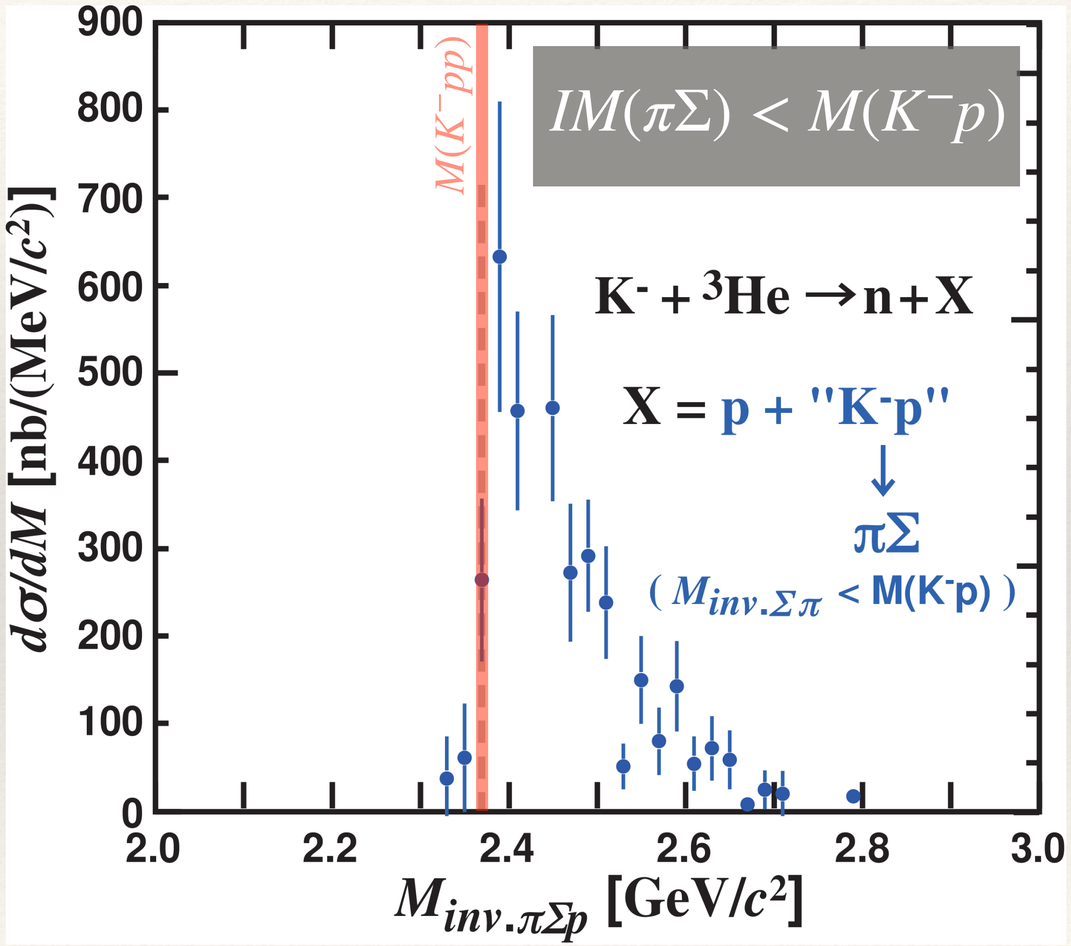
Result of πΣpn analysis

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



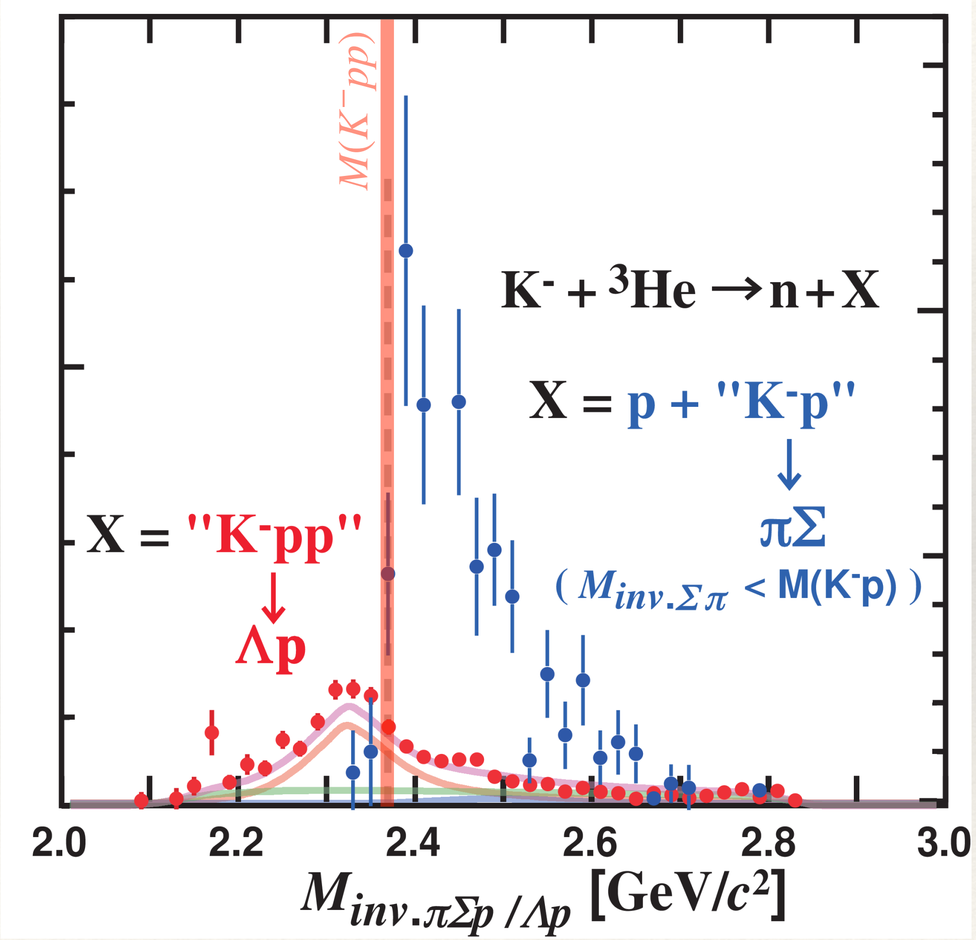
Structure is similar to QF.

➡ Compare to Λpn analysis



Comparison between Λpn & πΣpn

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



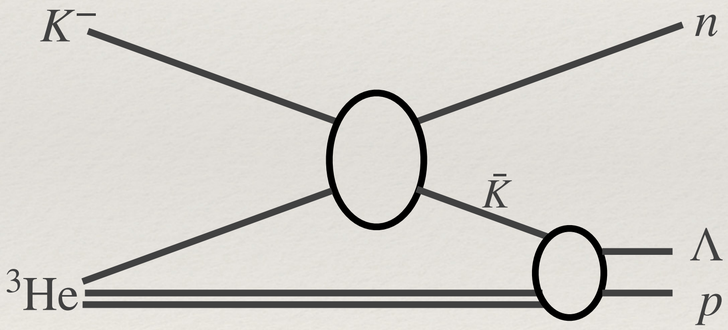
$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$

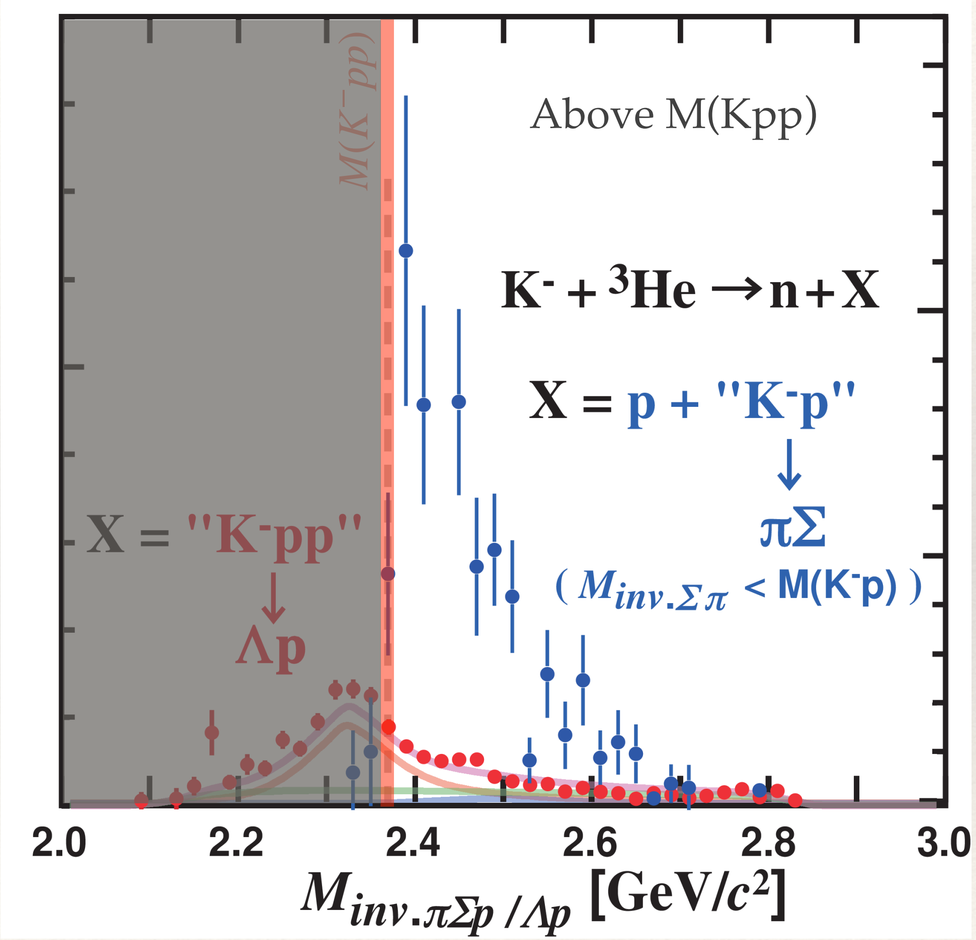
Comparison between Λpn & πΣpn

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

QF-K

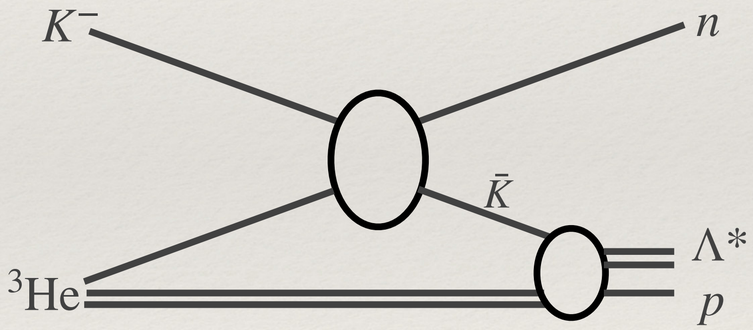
QF-Y*





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

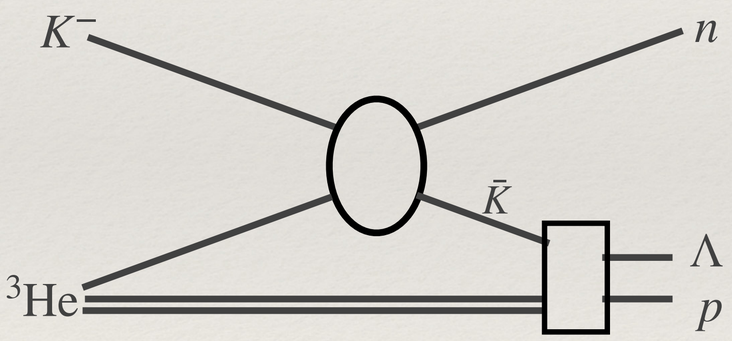
QF-Y*

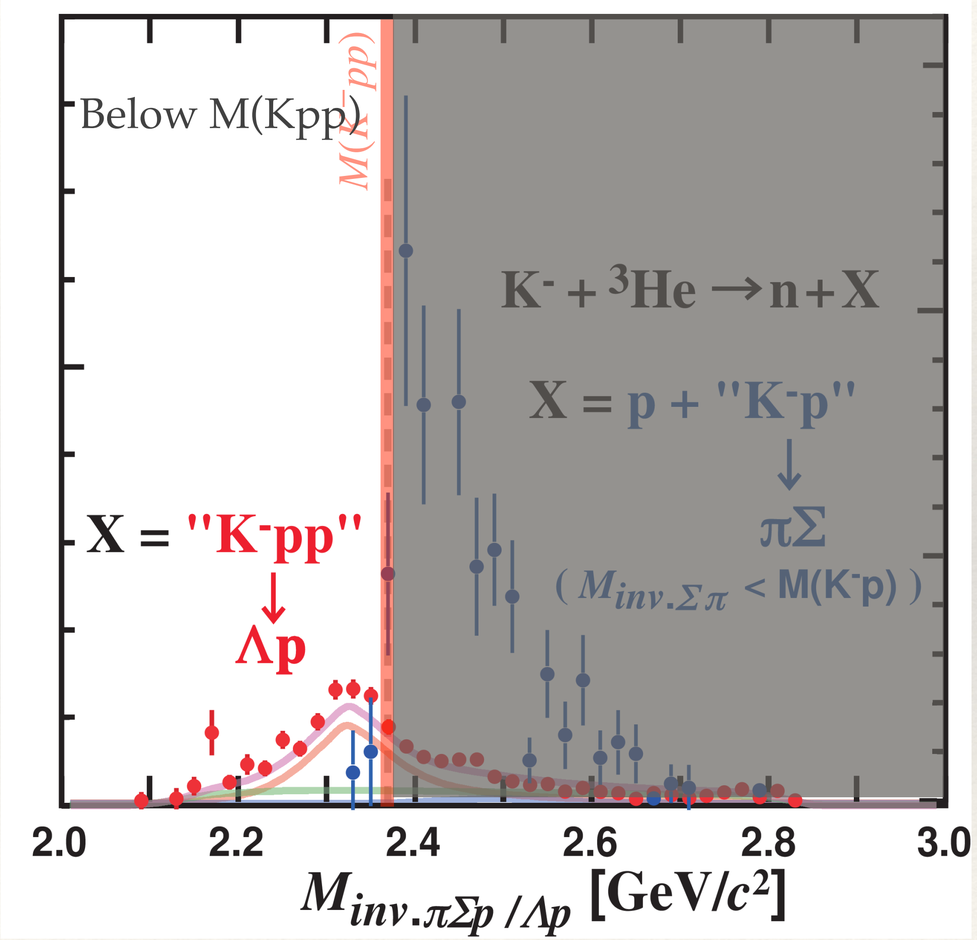


Comparison between Λpn & πΣpn

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

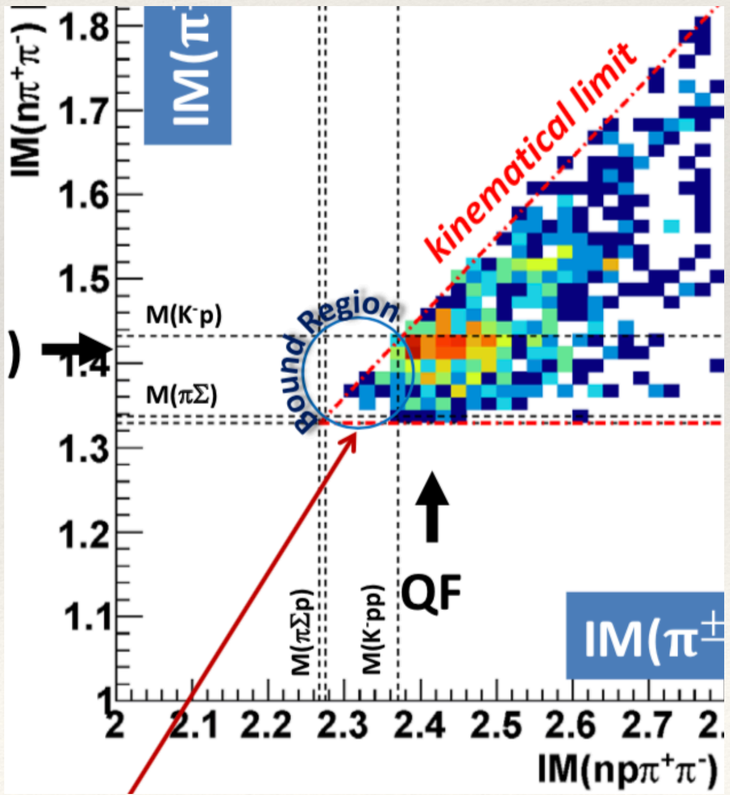
Kpp production





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

Kpp production?



Conclusion

- 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,
          - $B.E. = 47 \pm 3(\text{stat.})^{+3}_{-6}(\text{syst.})$ MeV
          - $\Gamma = 115 \pm 7(\text{stat.})^{+10}_{-20}(\text{syst.})$ 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

Thank you for your attention

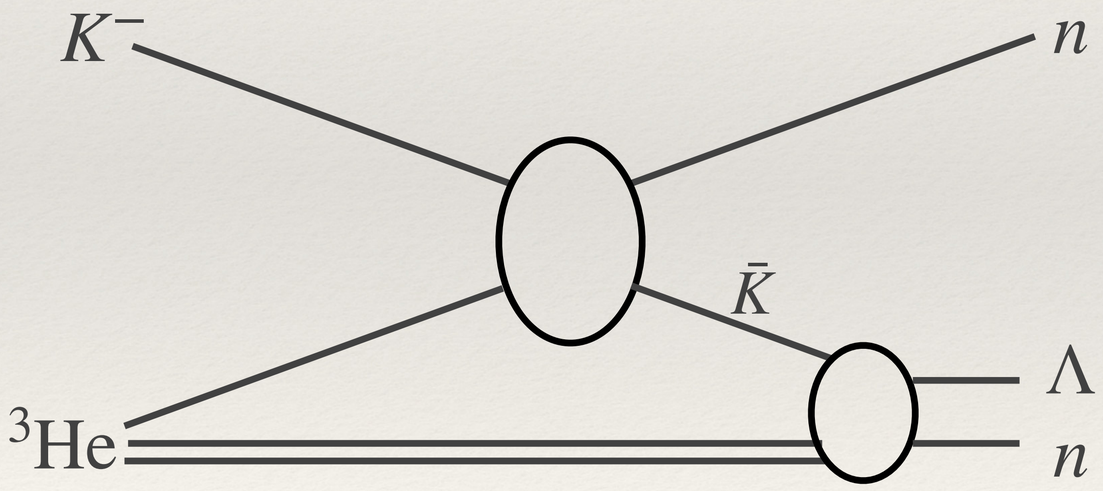
J-PARC E15 collaboration

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

E15 experiment



Test

- Test