REIMEI workshop 2019@ Tokai

Results of experimental search for KbarNN bound state at J-PARC

Takumi Yamaga, RIKEN
For the E15 collaboration

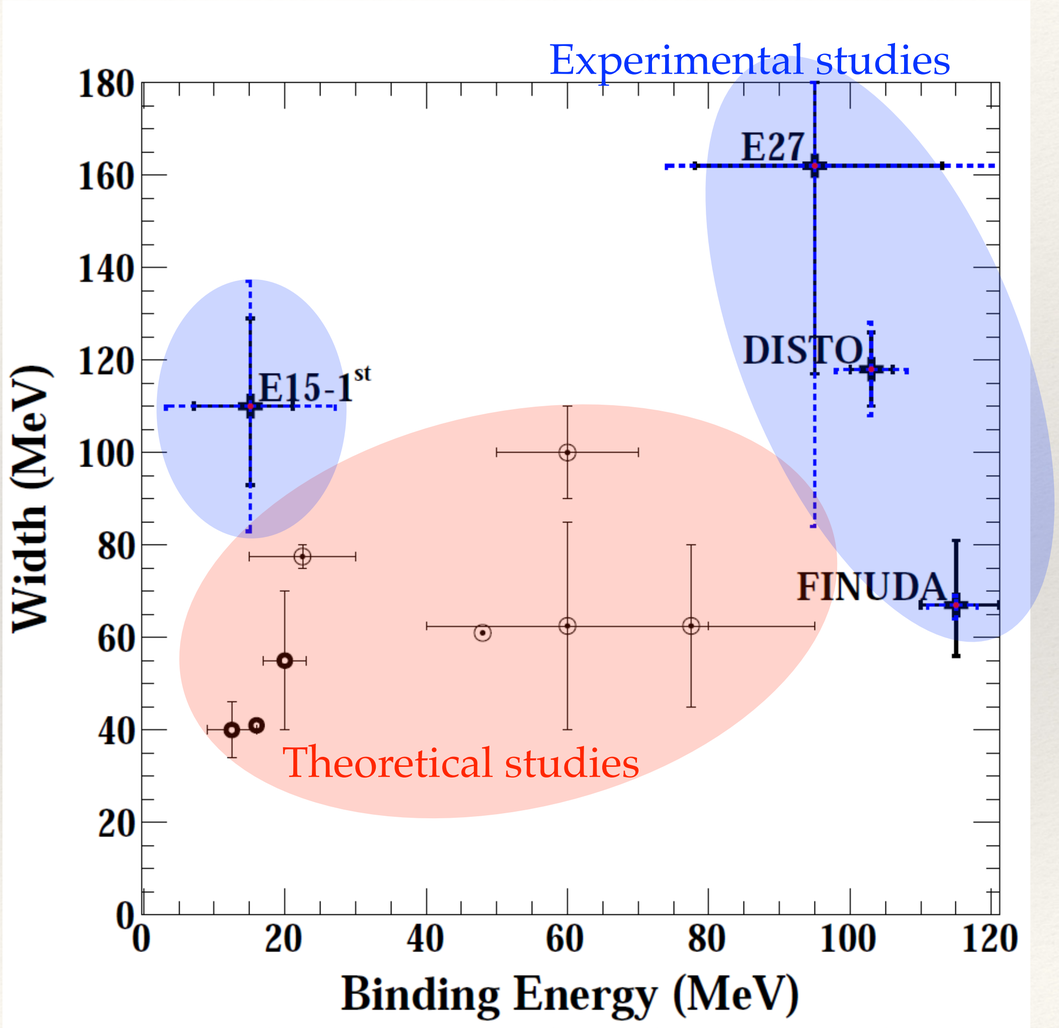
KbarN interaction & Kaonic nuclei

- 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

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.

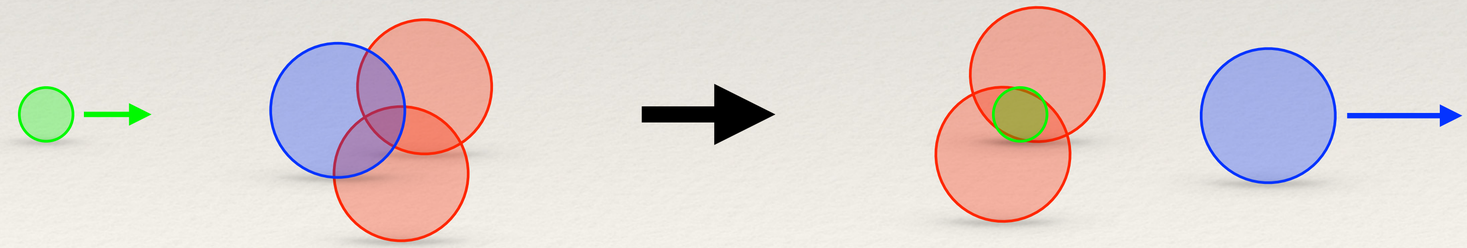


E15 experiment

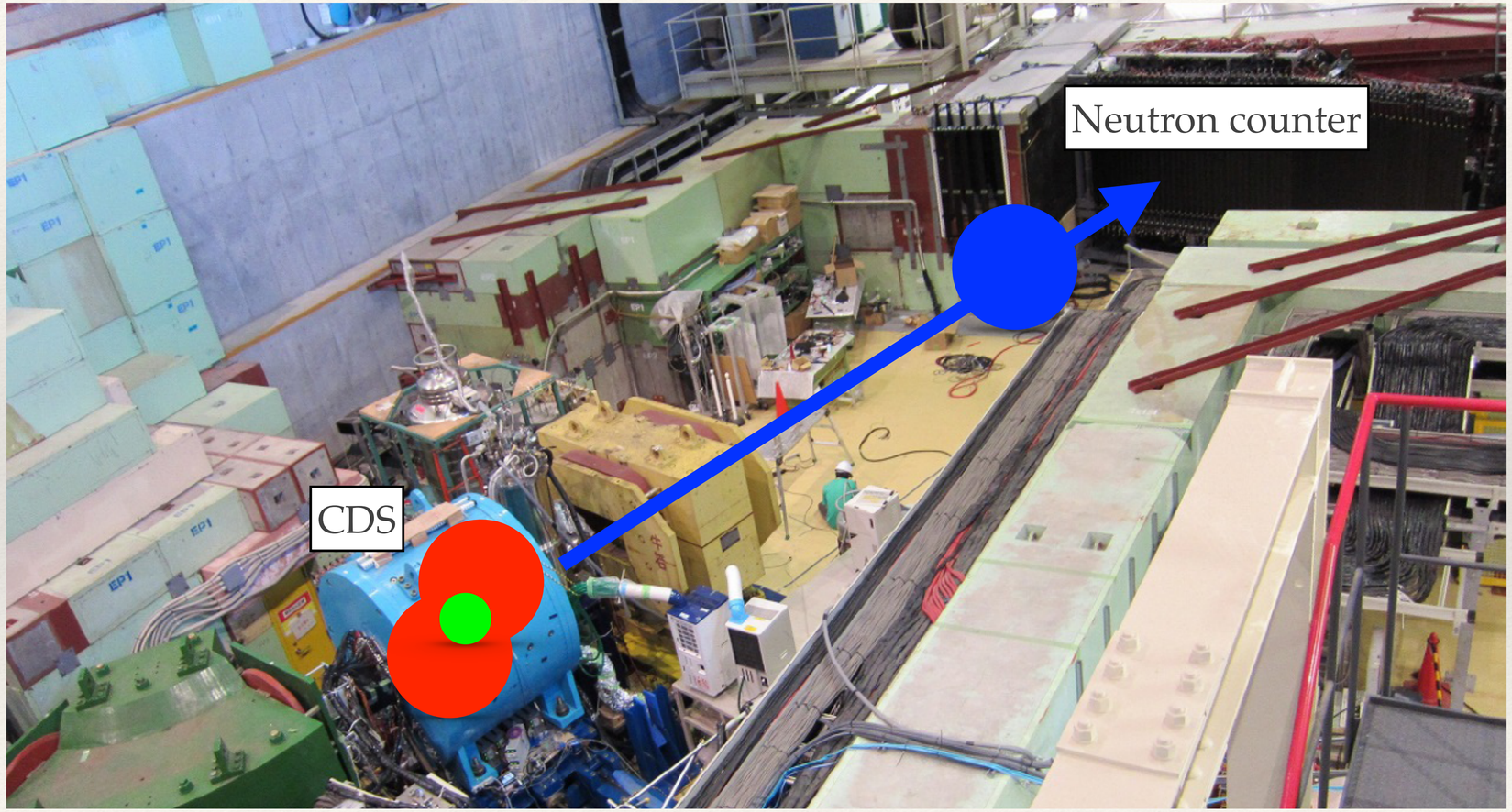
In-flight (K-, n) reaction to generate KbarNN bound state

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

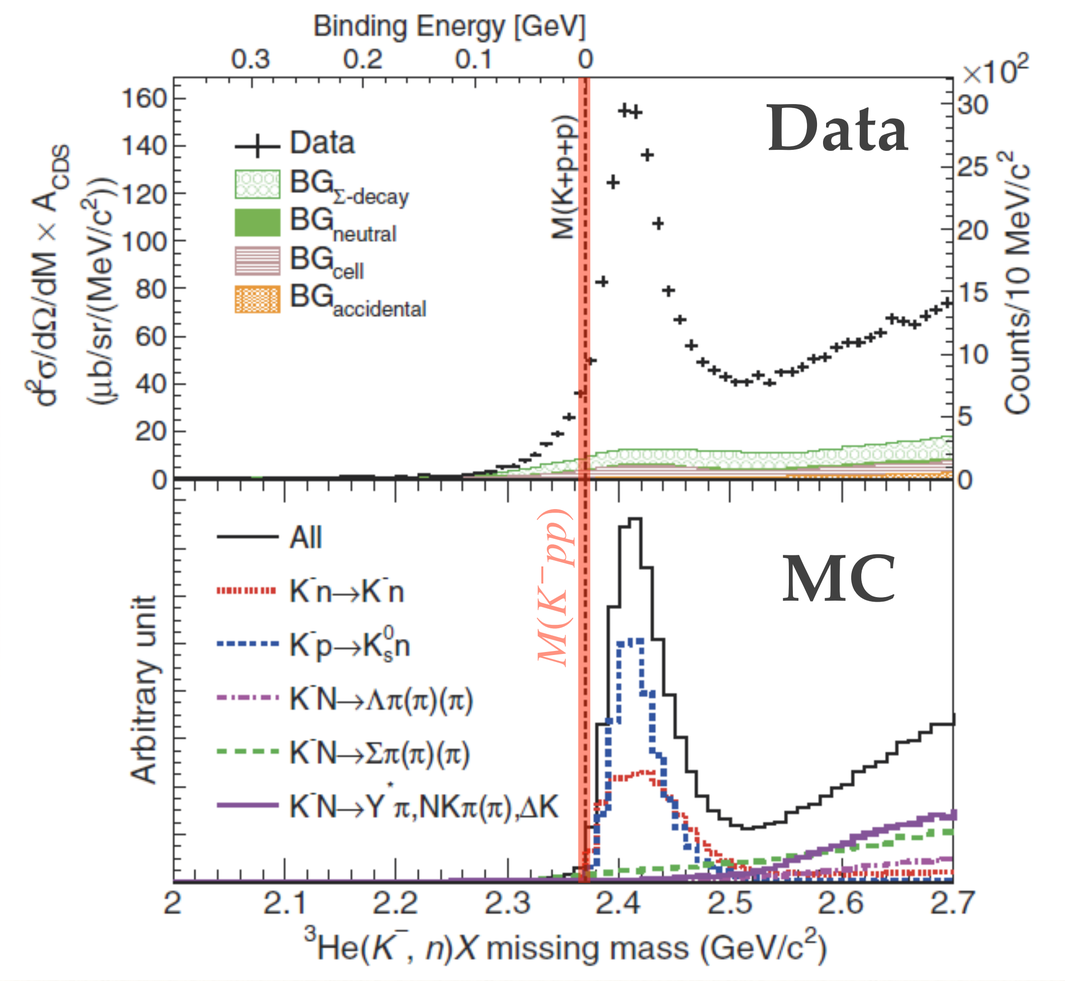
$$K^- + {}^3\text{He} \rightarrow K^- pp + n$$



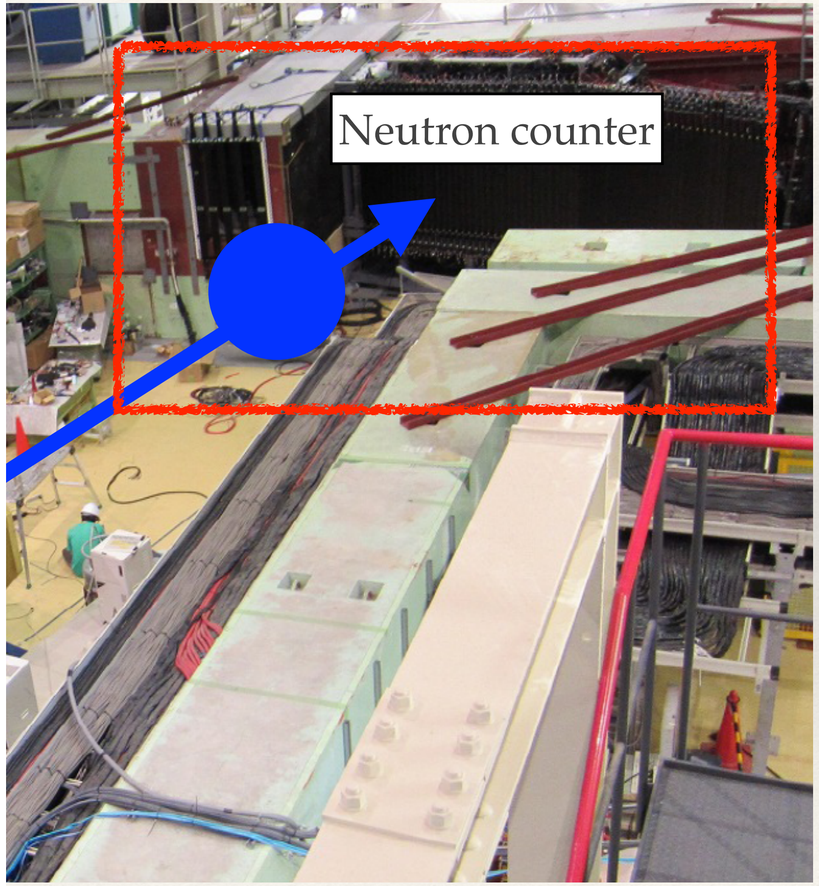
E15 experiment



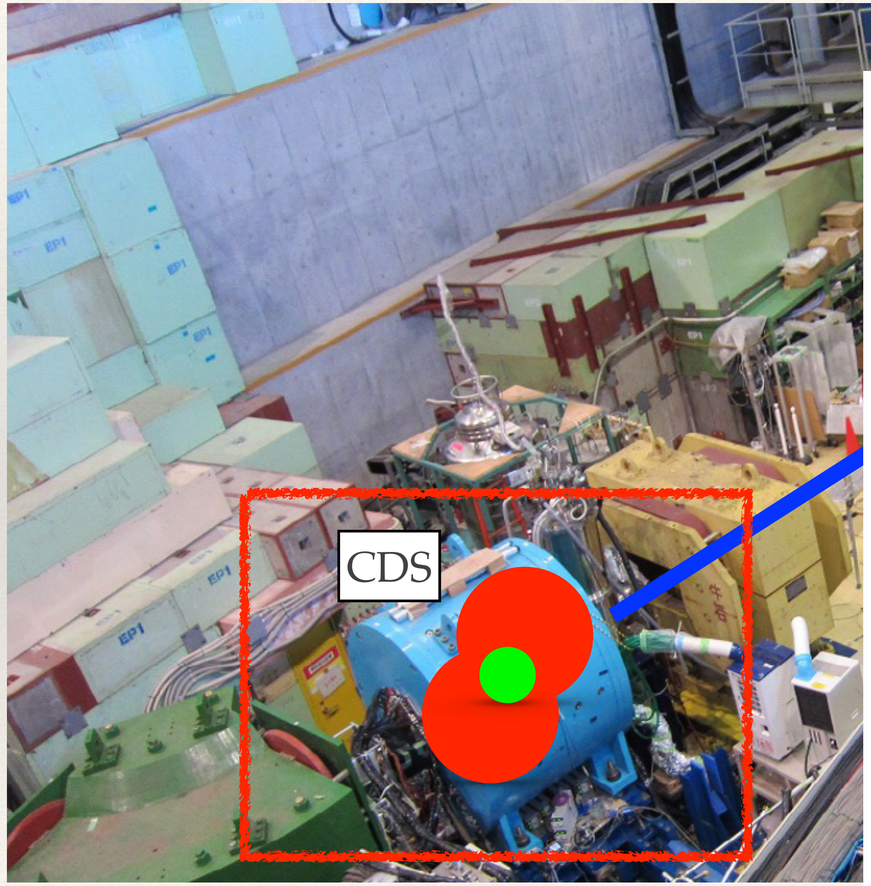
E15 experiment

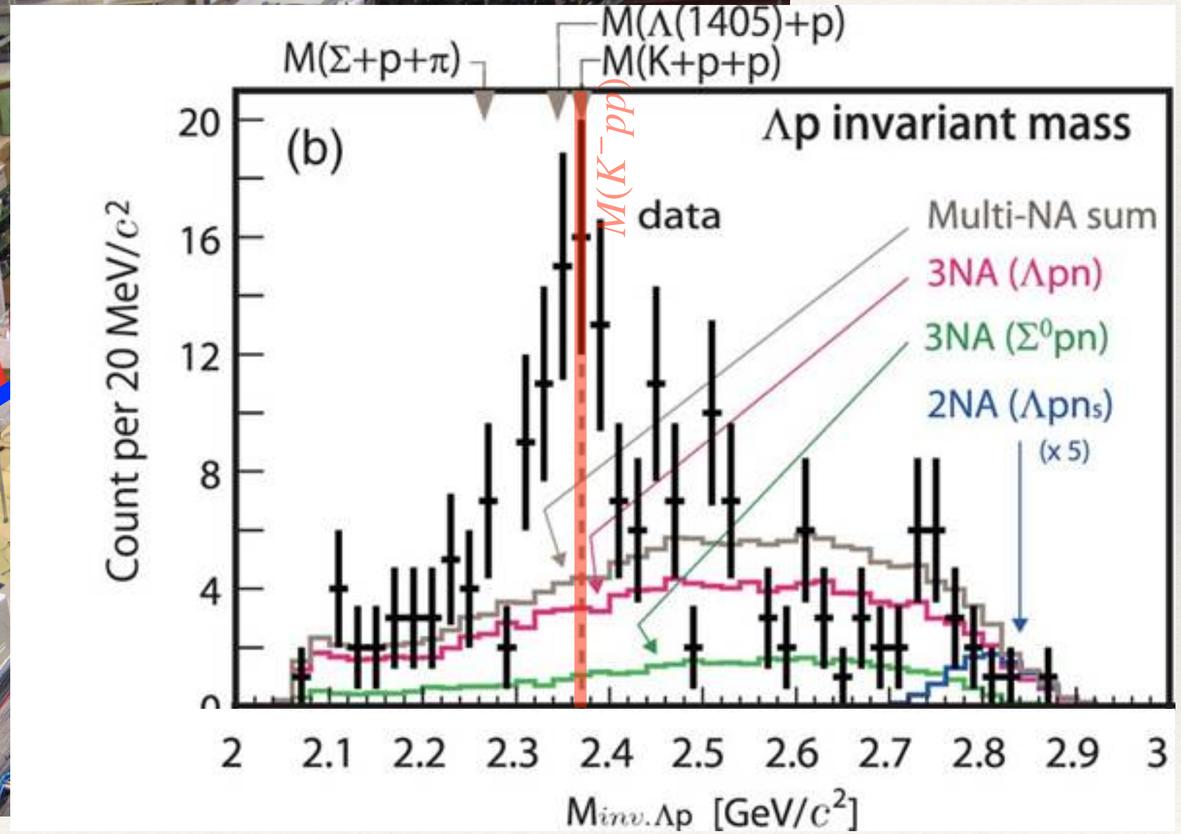


PTEP (2015) 061D01



E15 experiment



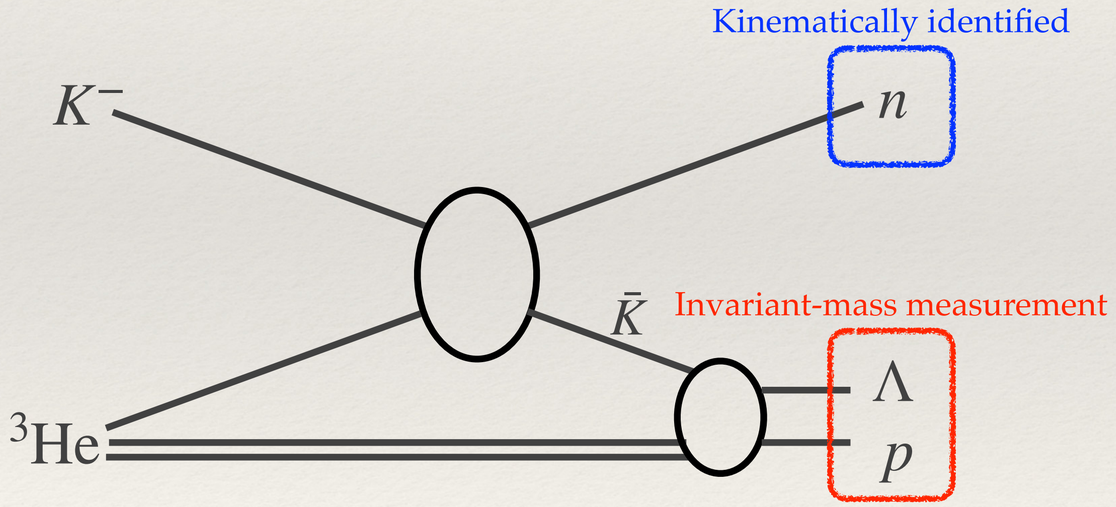


PTEP (2016) 051D01

Analyzed channels

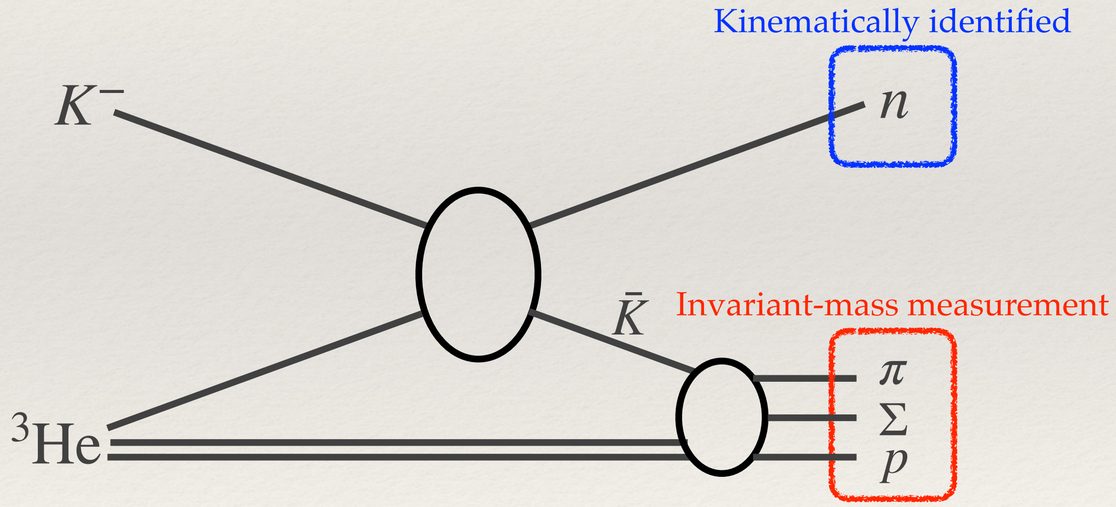
Measured exclusive channels are,,,

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



Detected particles : $pp\pi^-$

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

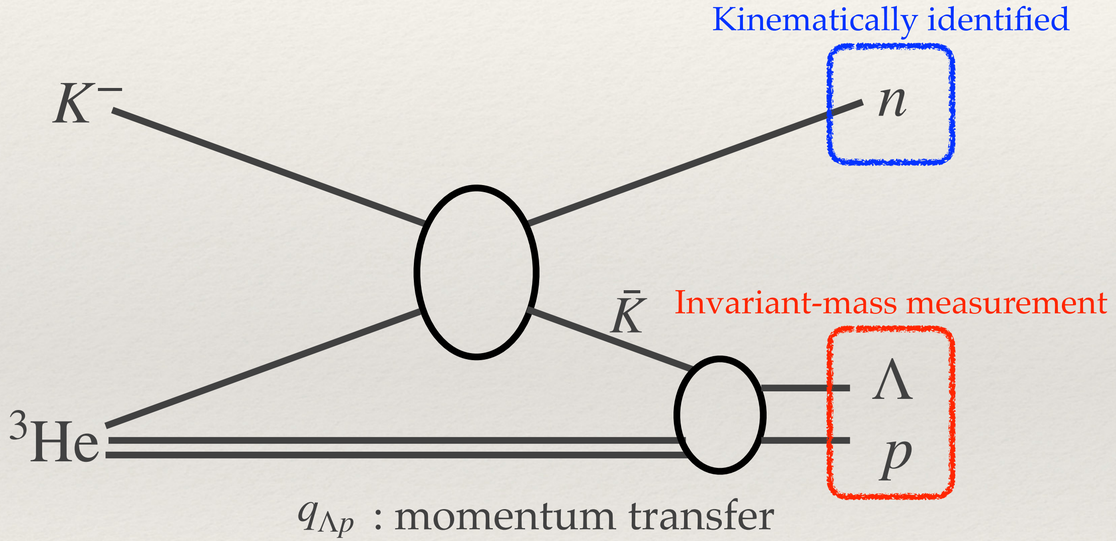


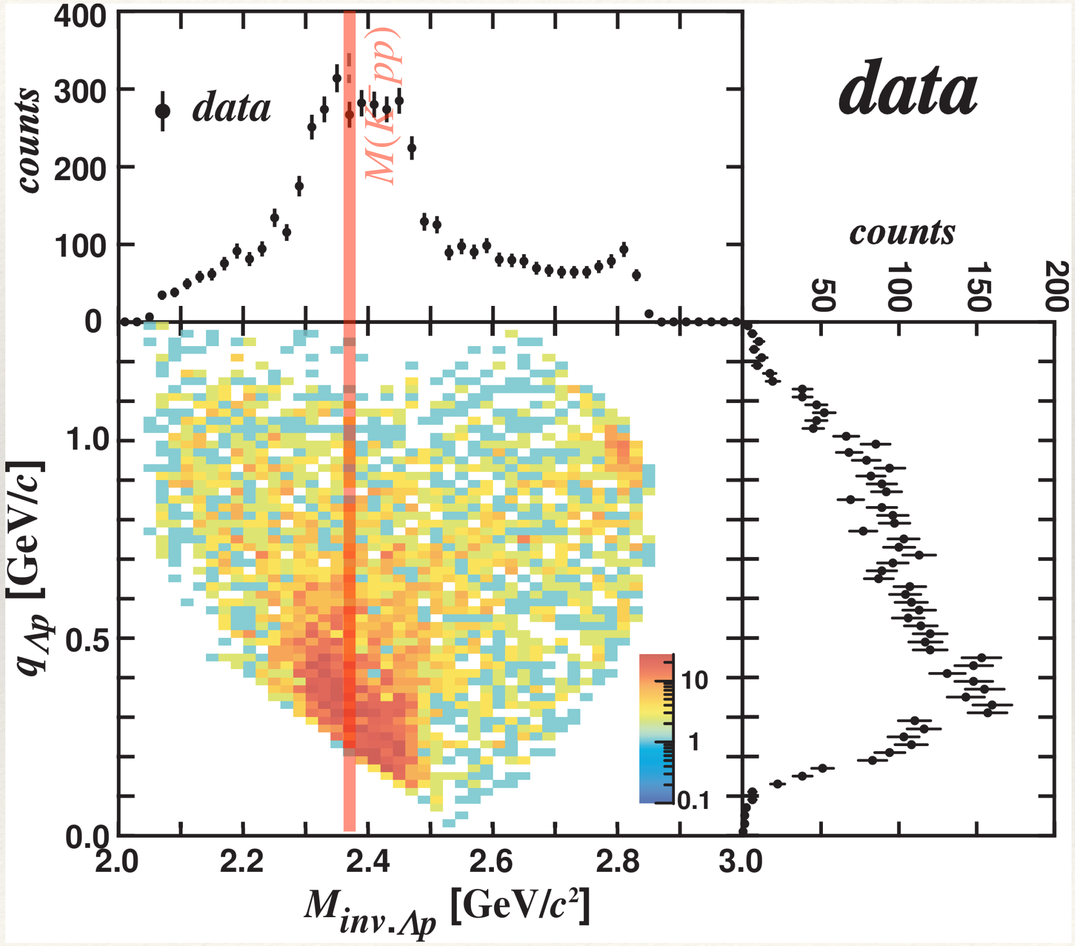
Detected particles : $np\pi^+\pi^-$

! Neutron detection by CDS

Result of Λpn analysis

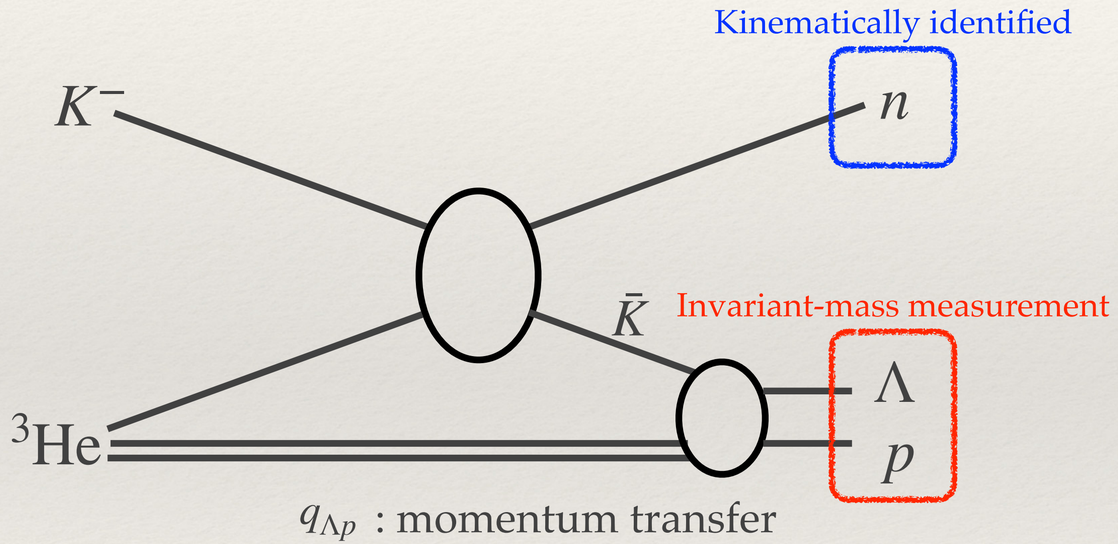
$$K^- + {}^3\mathrm{He} \rightarrow \Lambda p + n$$

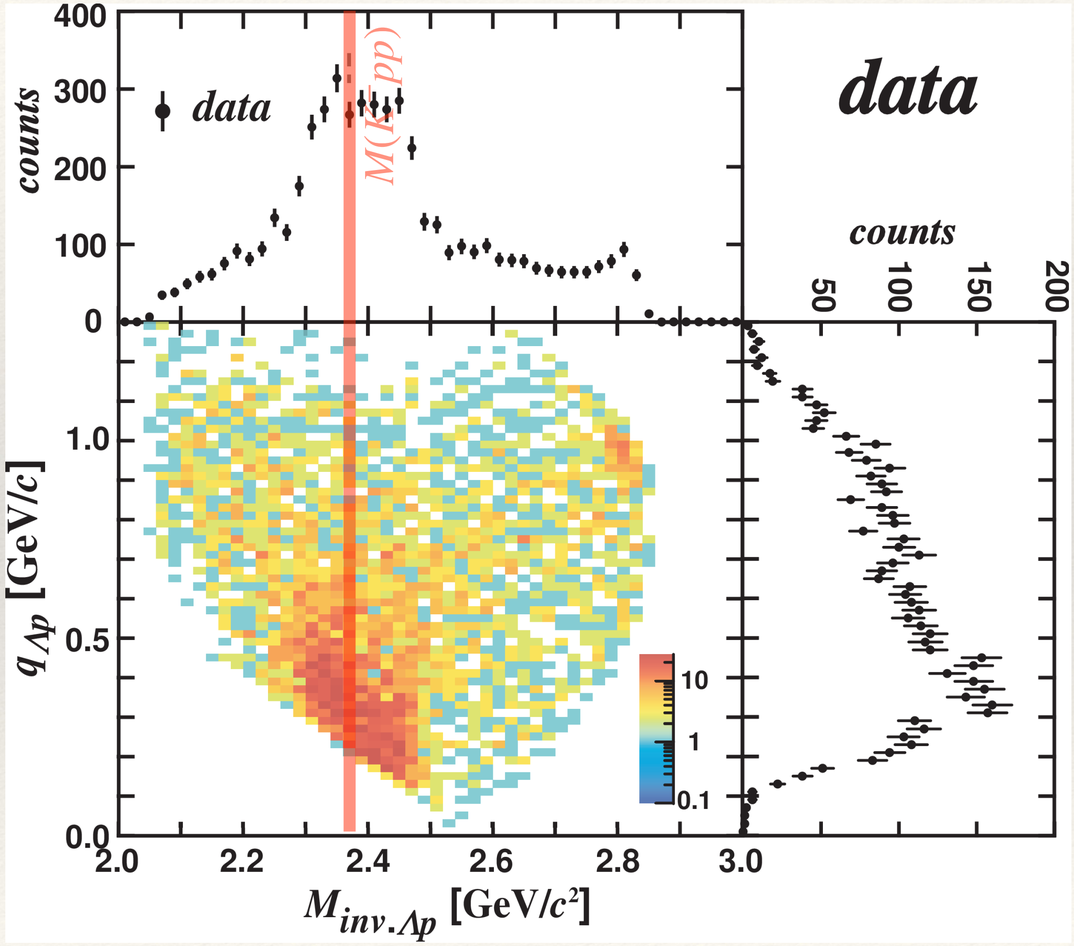




Result of Λpn analysis

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

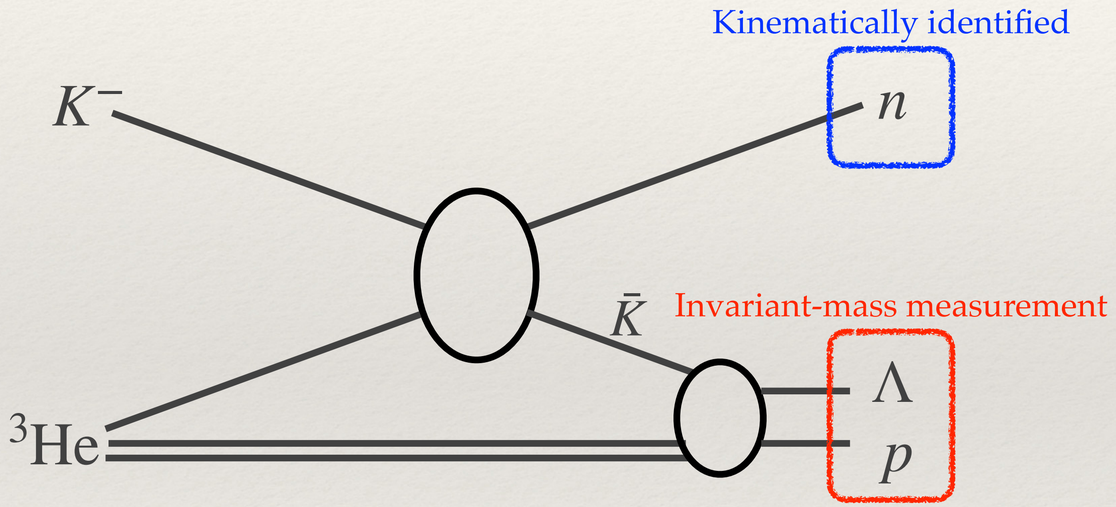




- Decomposition into 3 major components

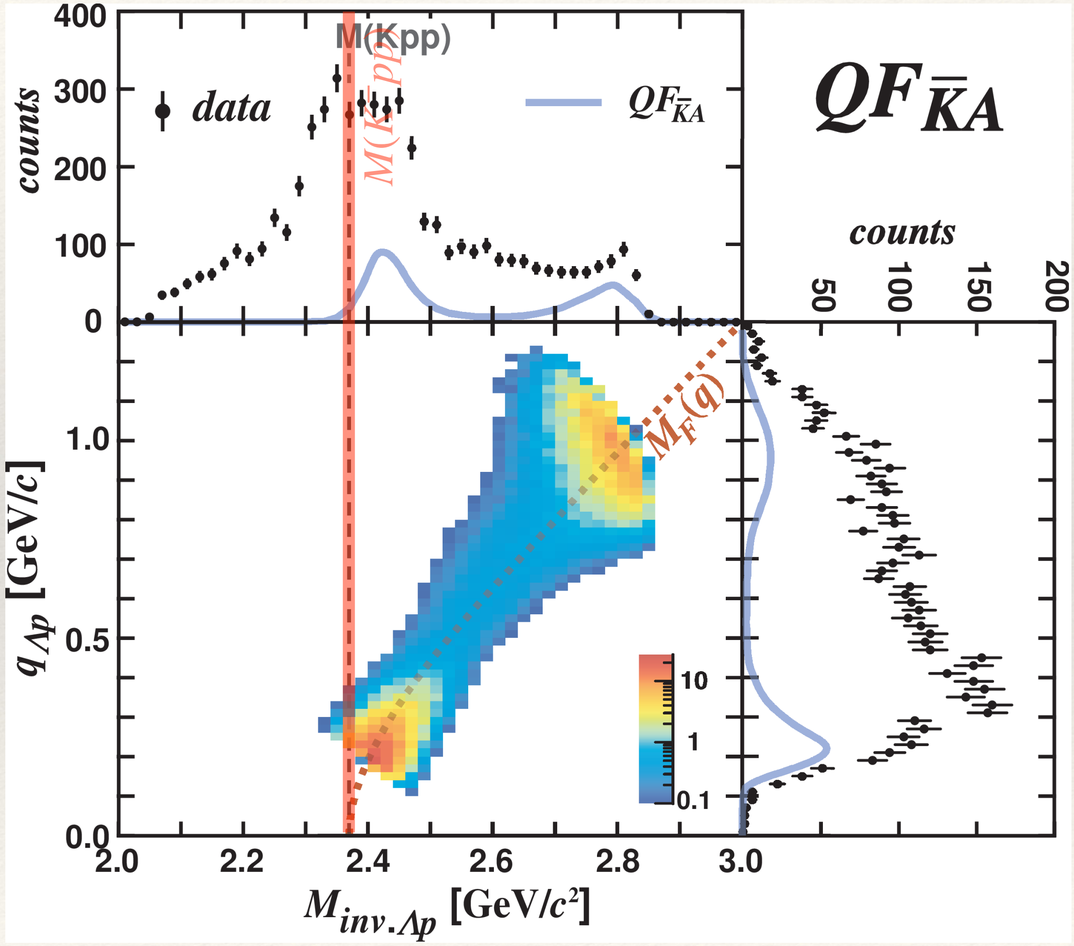
Result of Λpn analysis

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

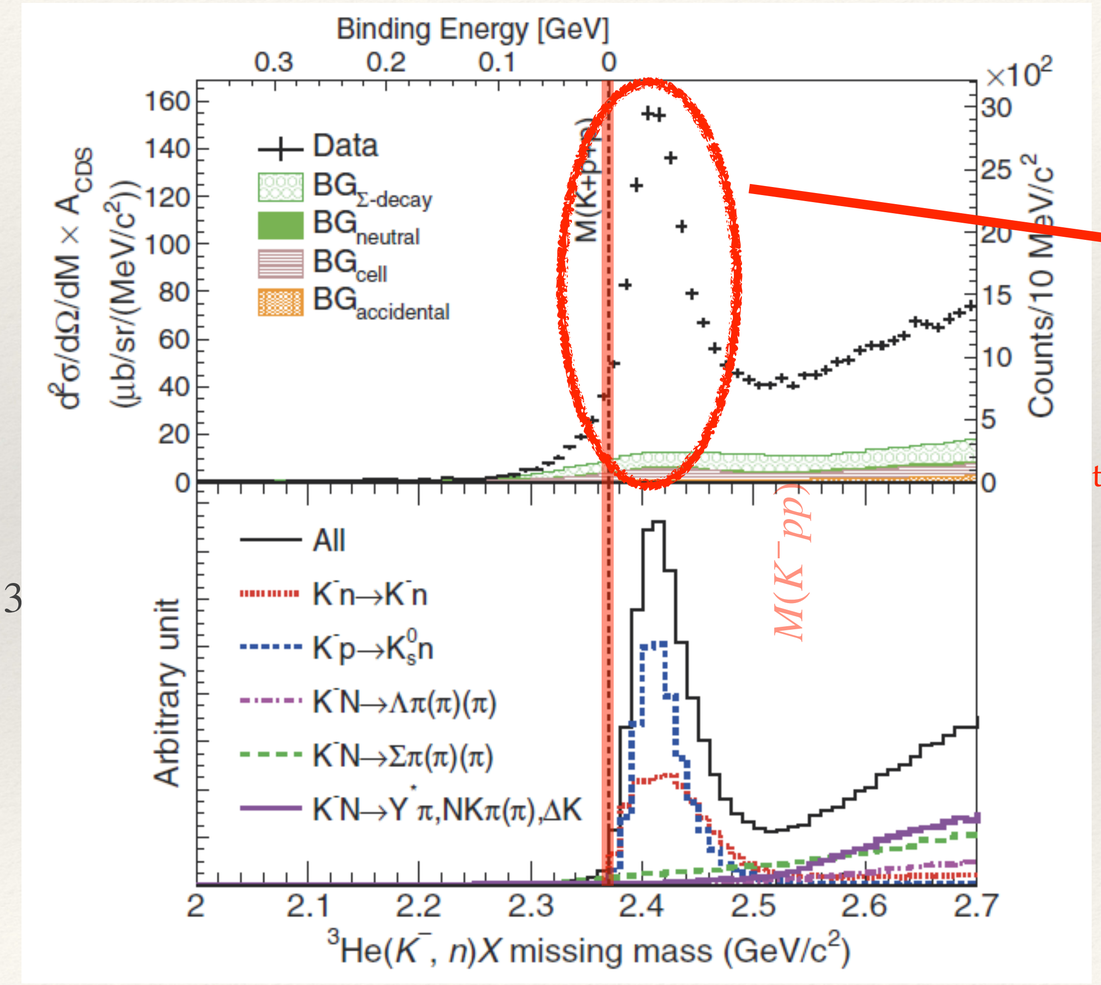


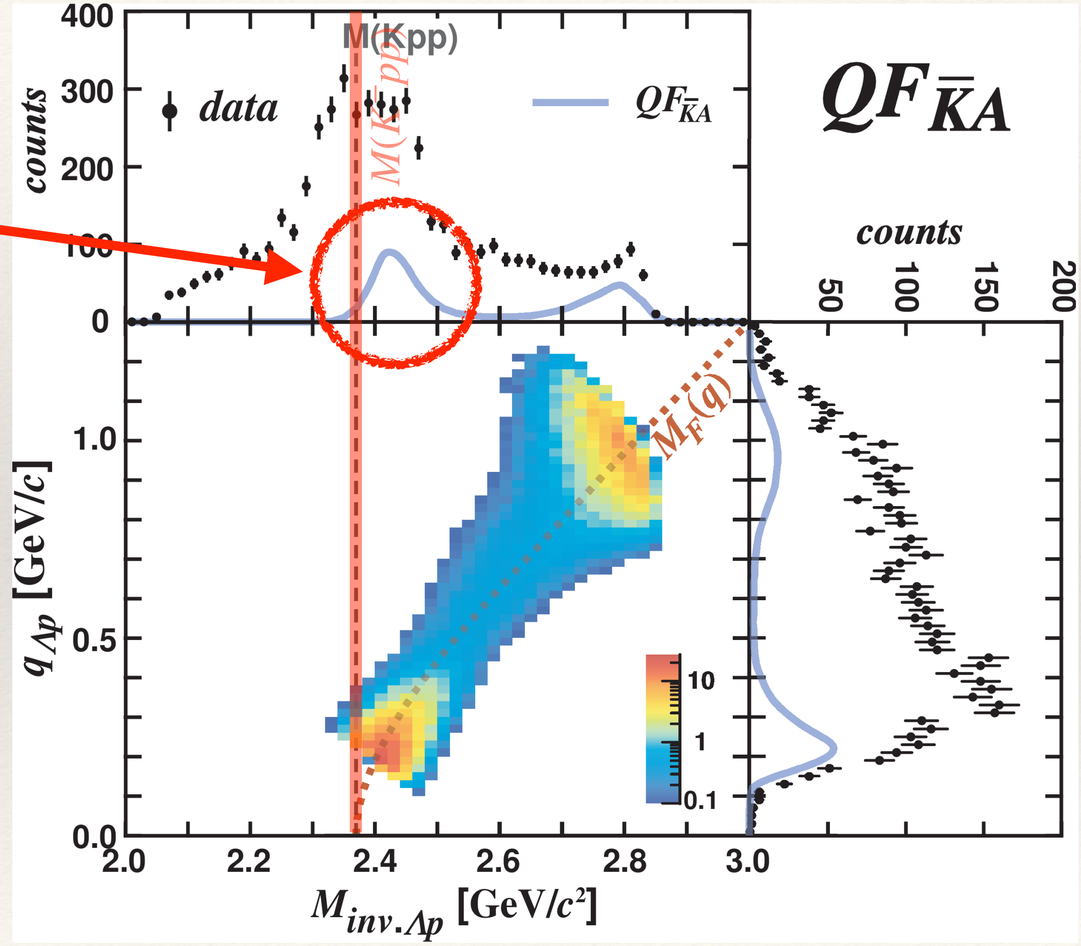
Peak position

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



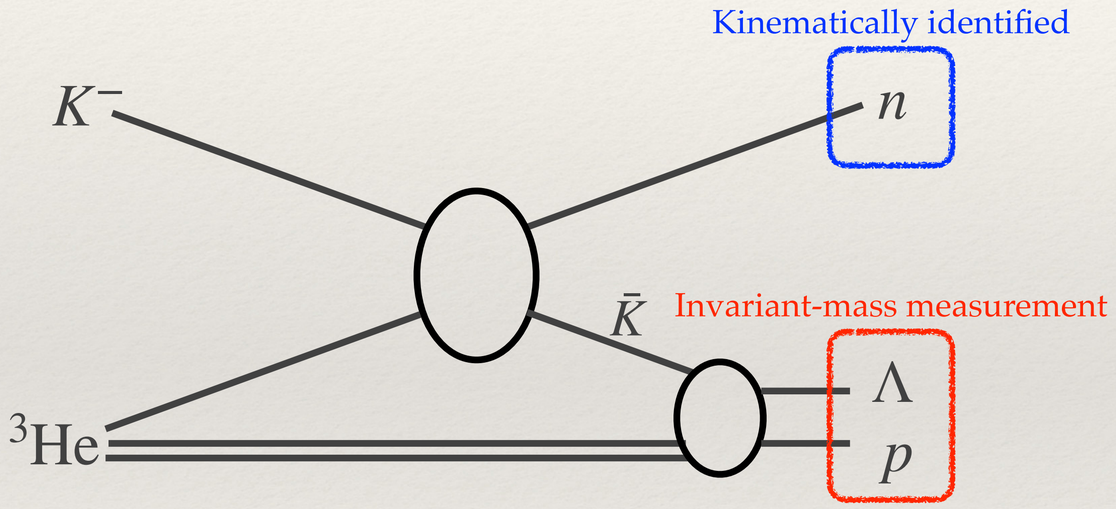
Result of Λpn analysis





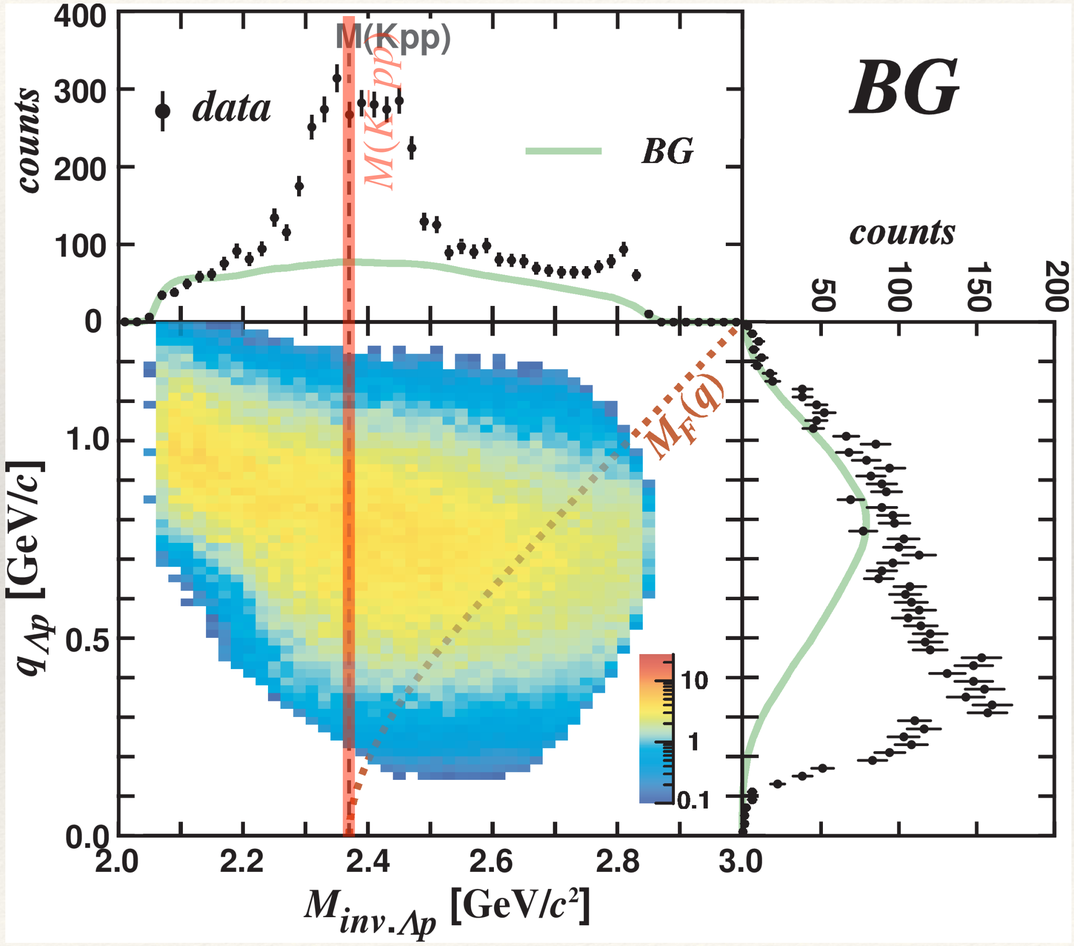
Result of Λpn analysis

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



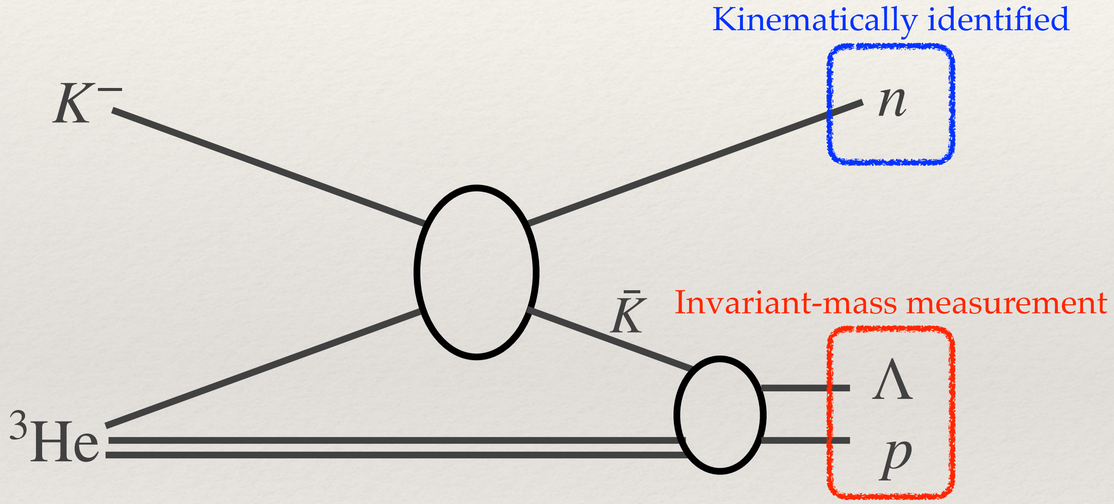
Physics background : $\Sigma^0 pn$ / $\Sigma^- pp$

Conversion & FSI processes

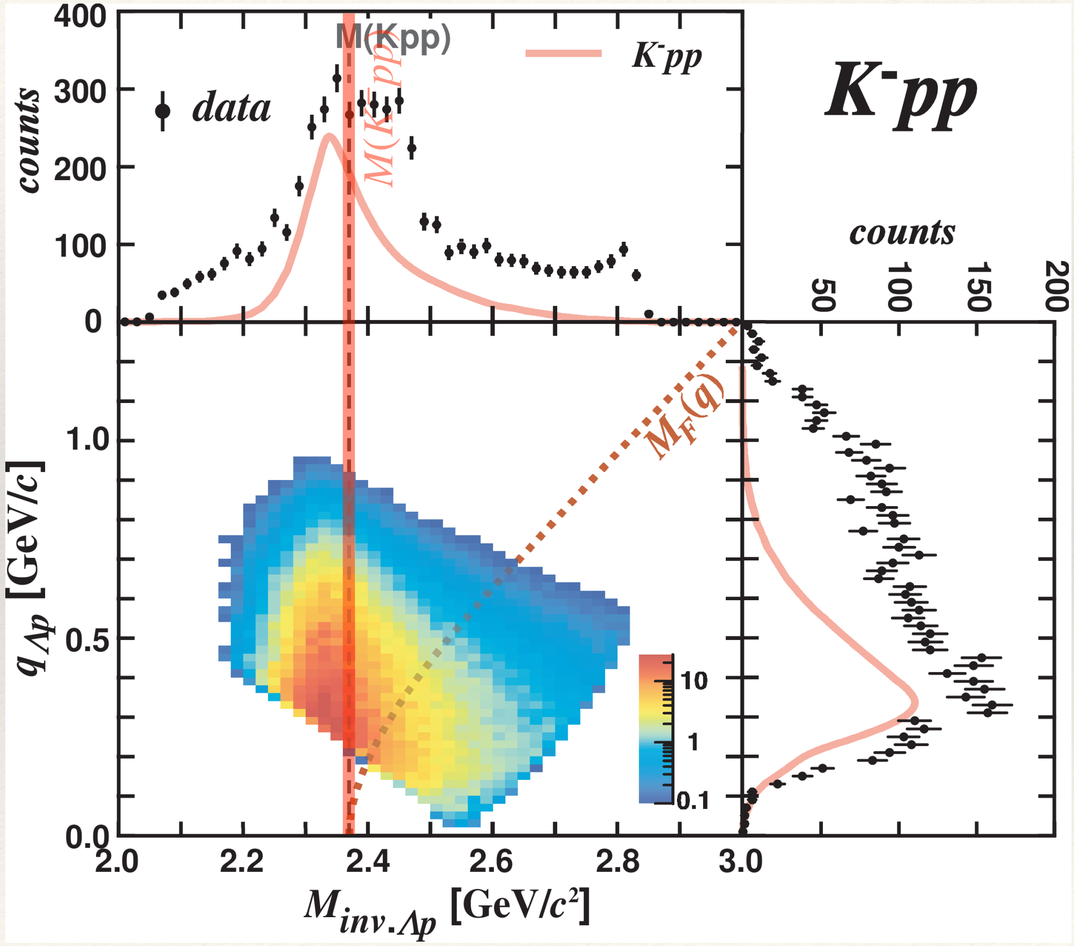


Result of Λpn analysis

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

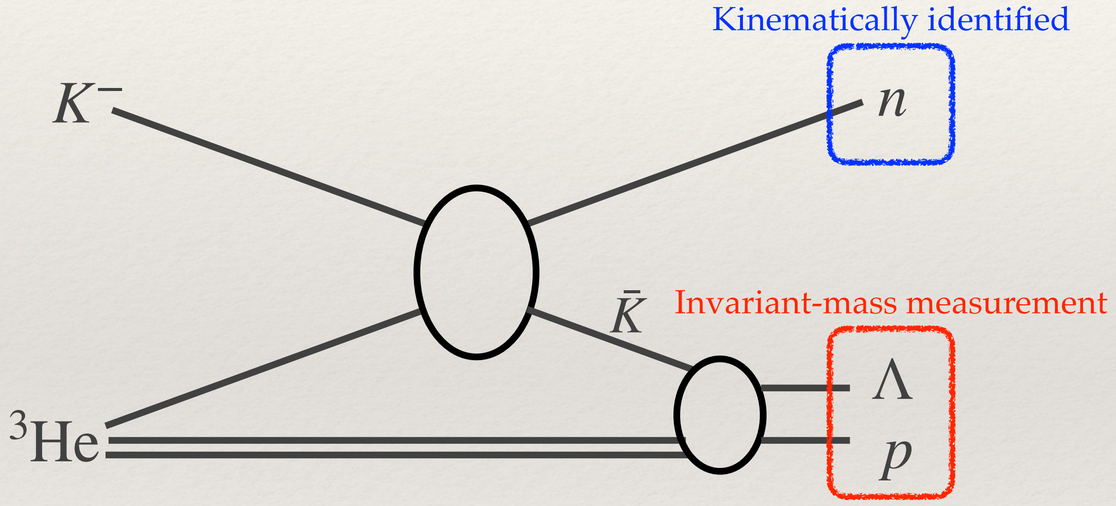


Breit-Wigner shape



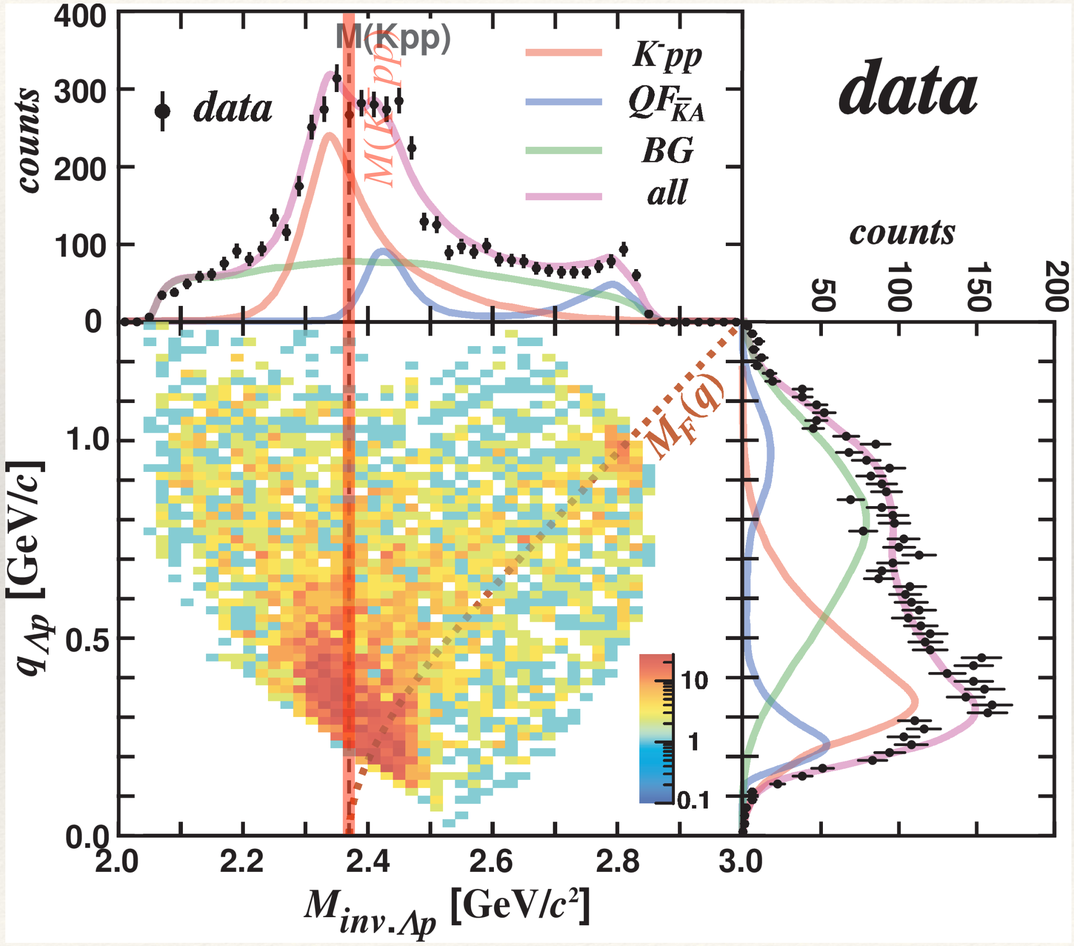
Result of Λpn analysis

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



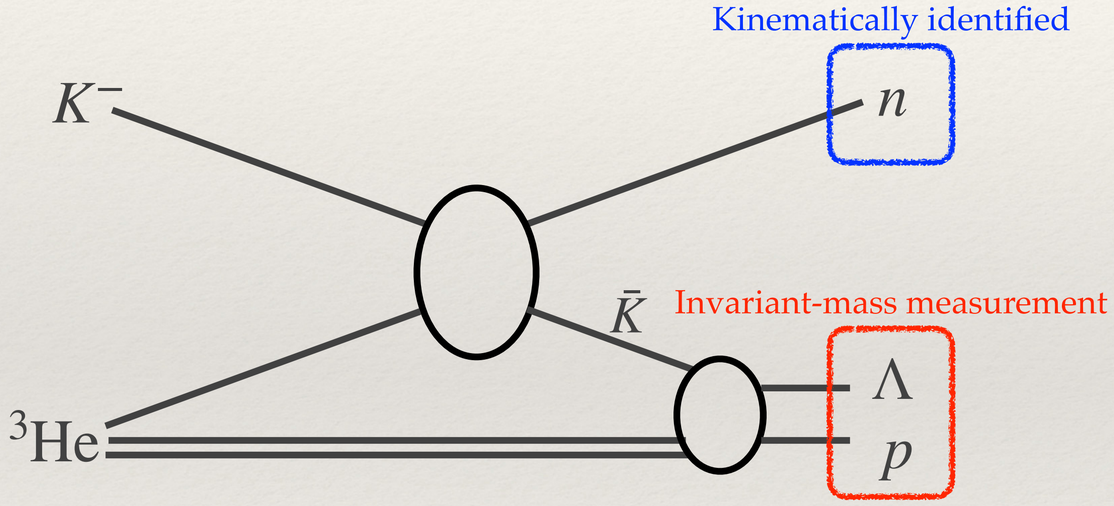
Well reproduced by 3 components

➡ Acceptance correction



Result of Λpn analysis

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



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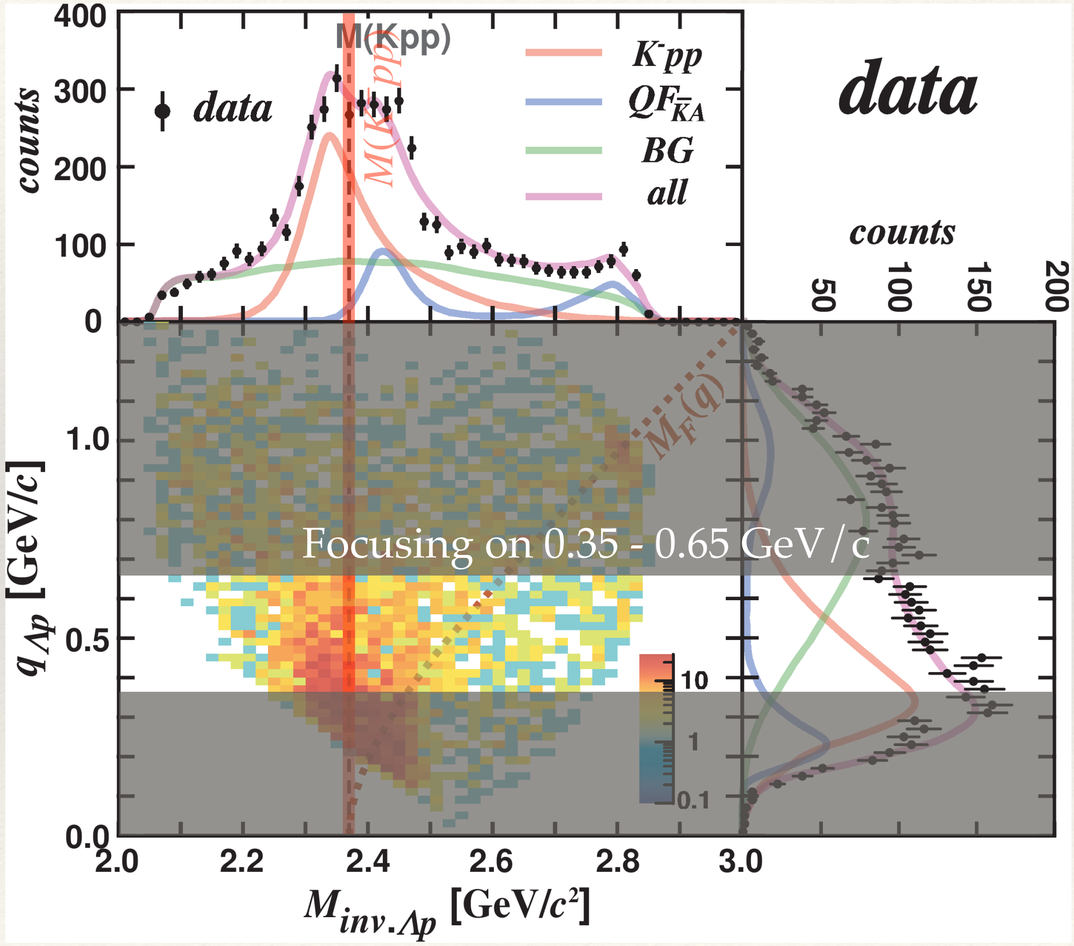

Result of Λpn analysis

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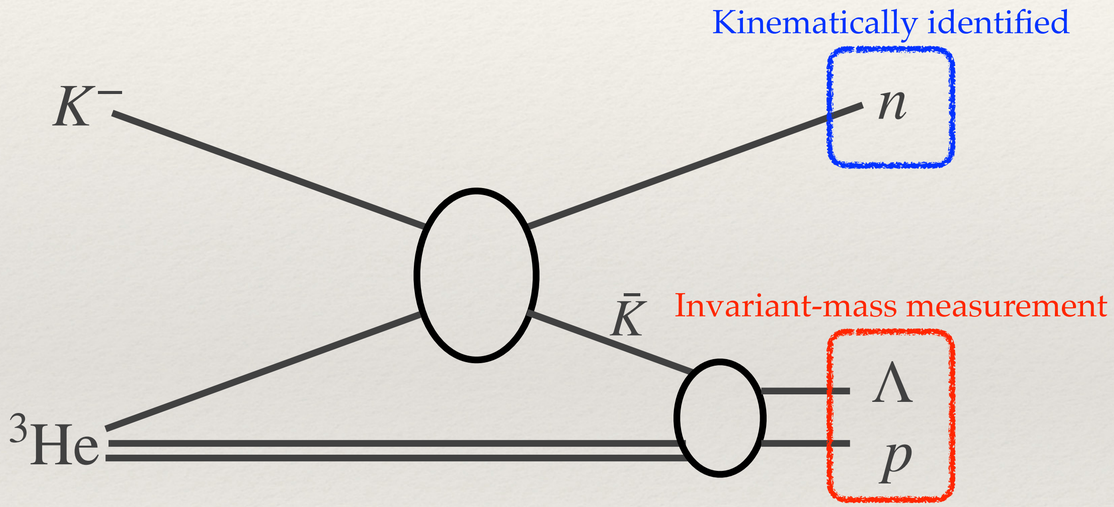
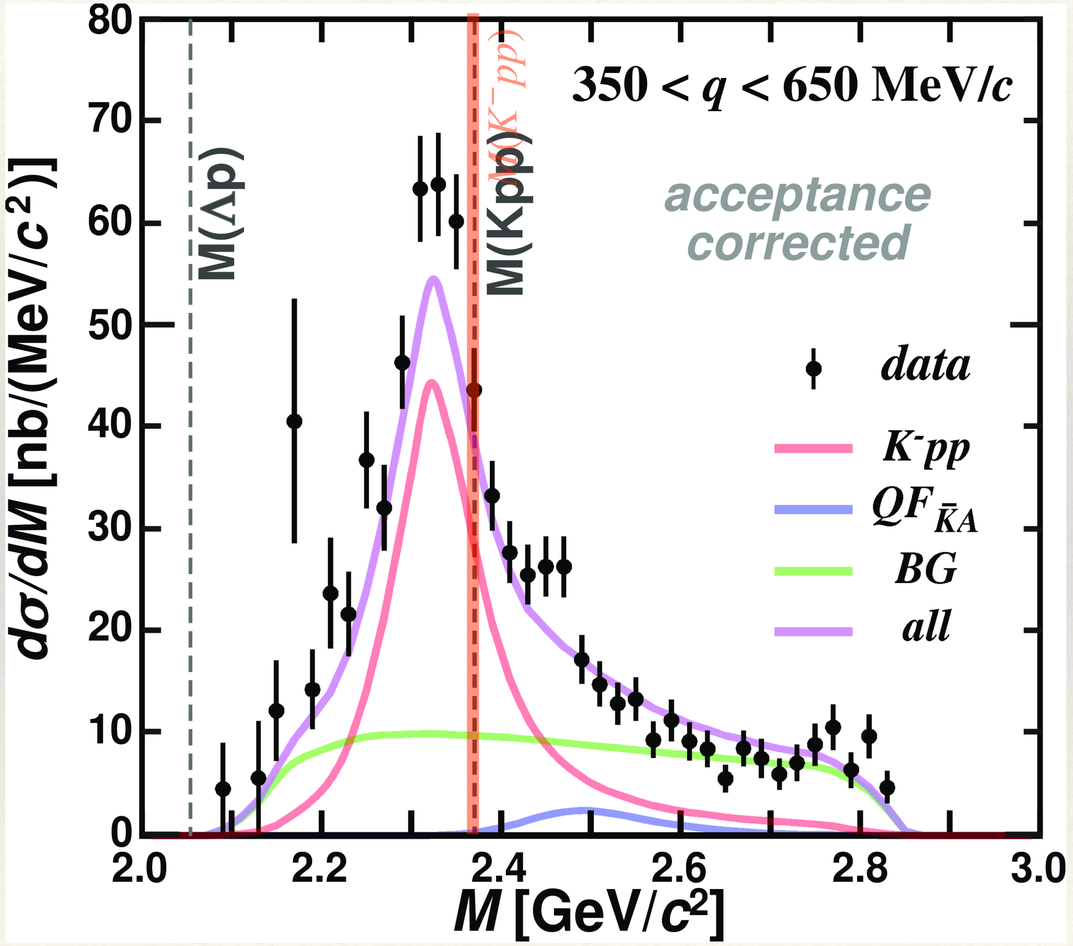


$B.E. = 47 \pm 3(\mathrm{stat.})^{+3}_{-6}(\mathrm{syst.})$ MeV

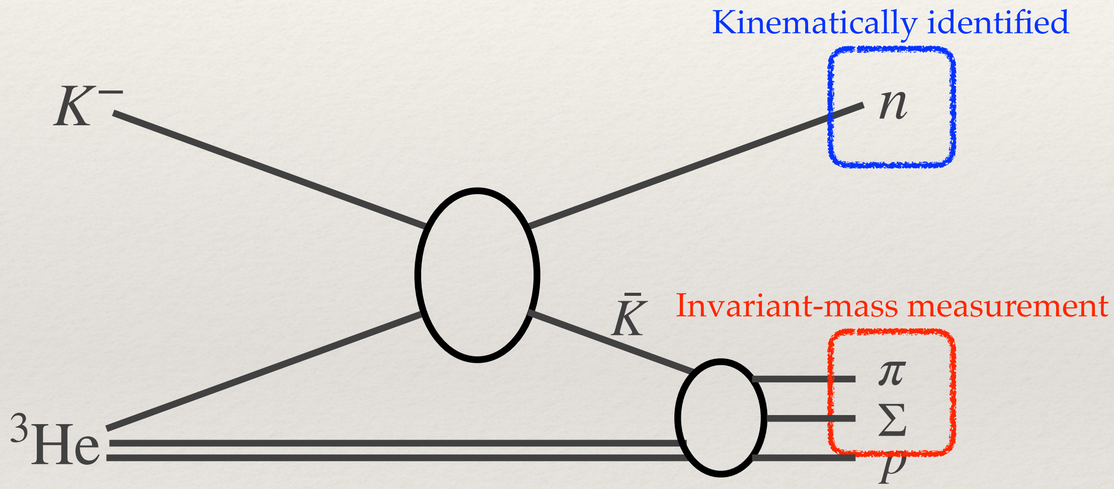
$\Gamma = 115 \pm 7(\mathrm{stat.})^{+10}_{-20}(\mathrm{syst.})$ MeV



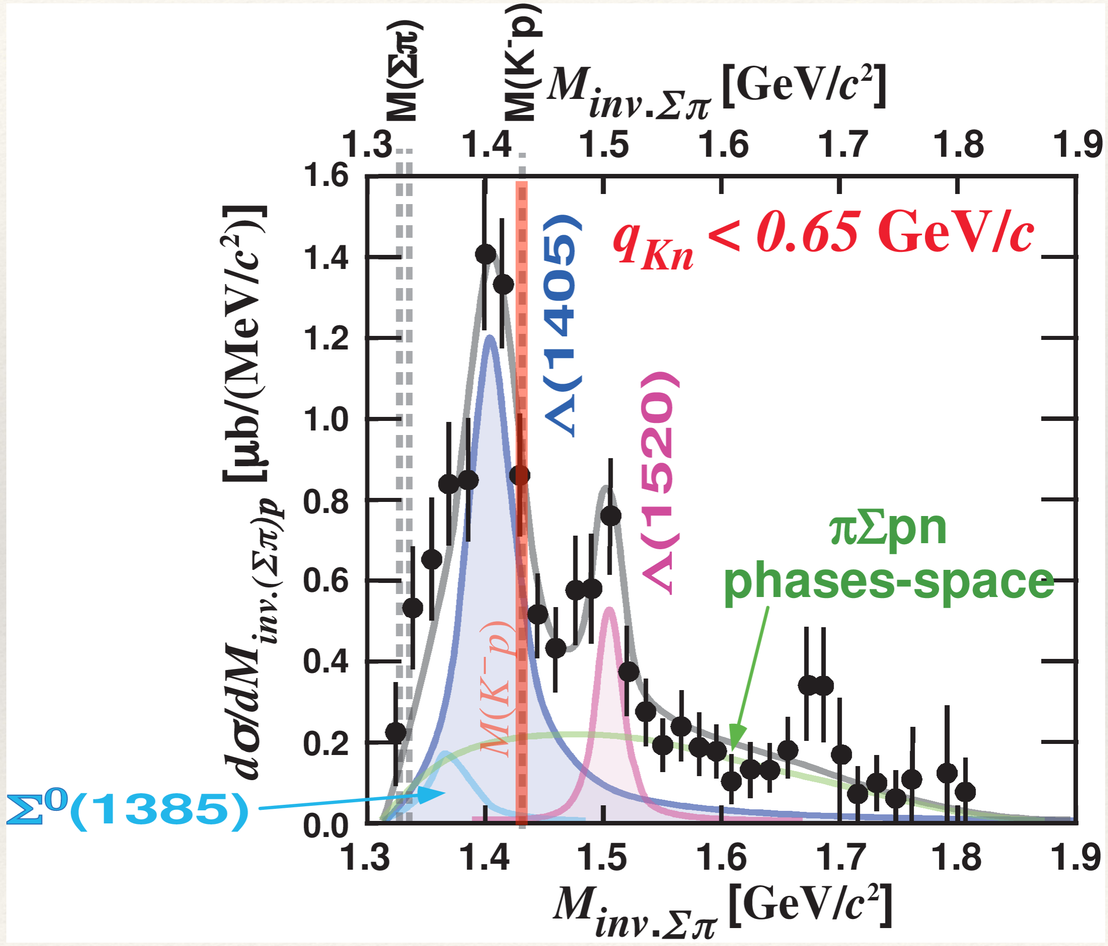
Result of πΣpn analysis

! Neutron from Σ-decay is detection by CDS

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



Observation of Y* production



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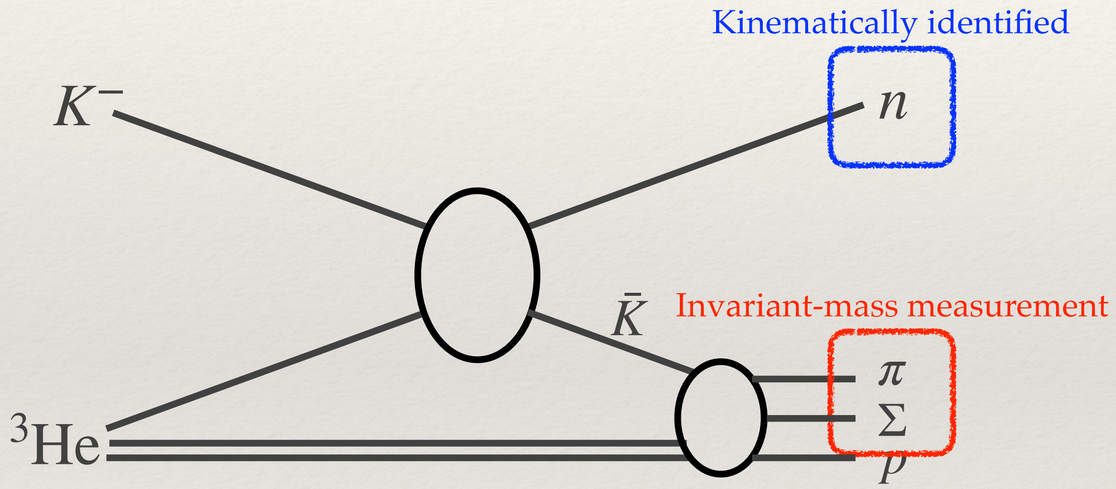
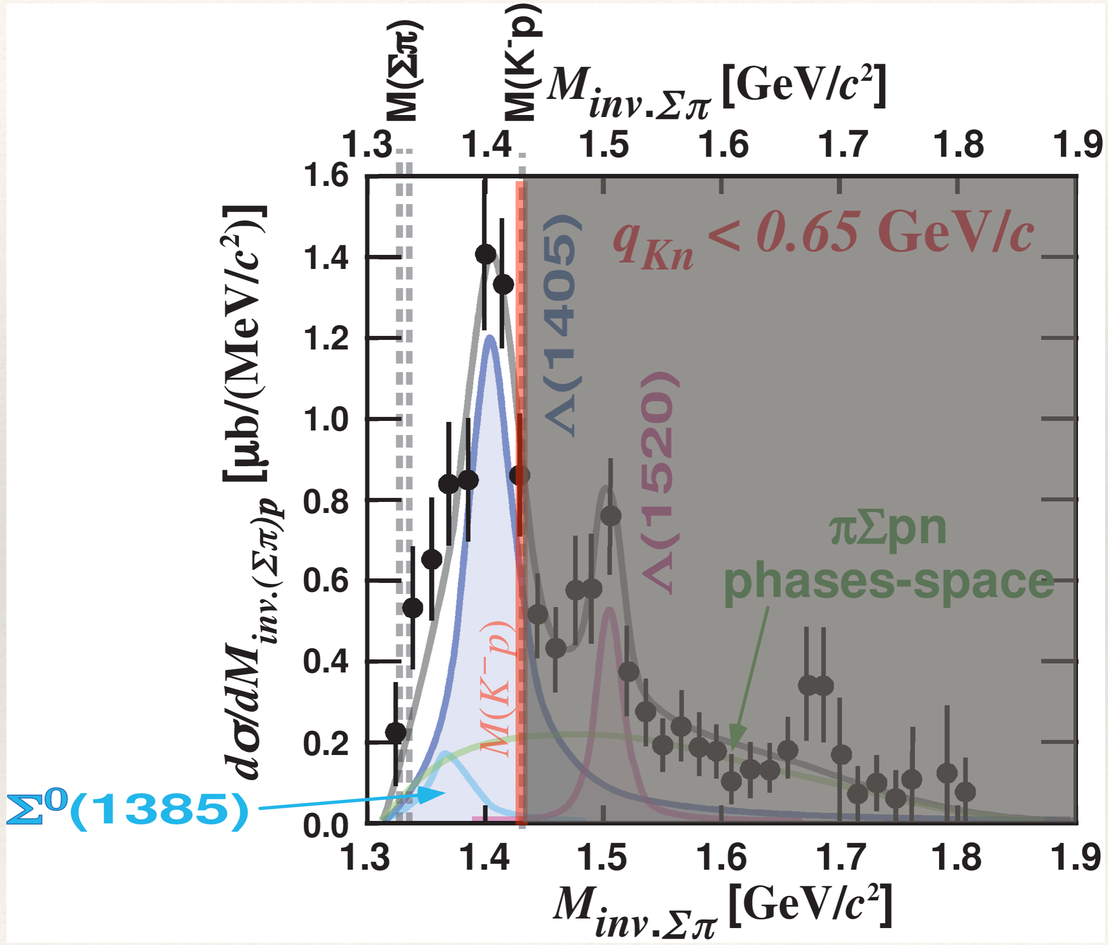
$$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$$



Observation of Y* production



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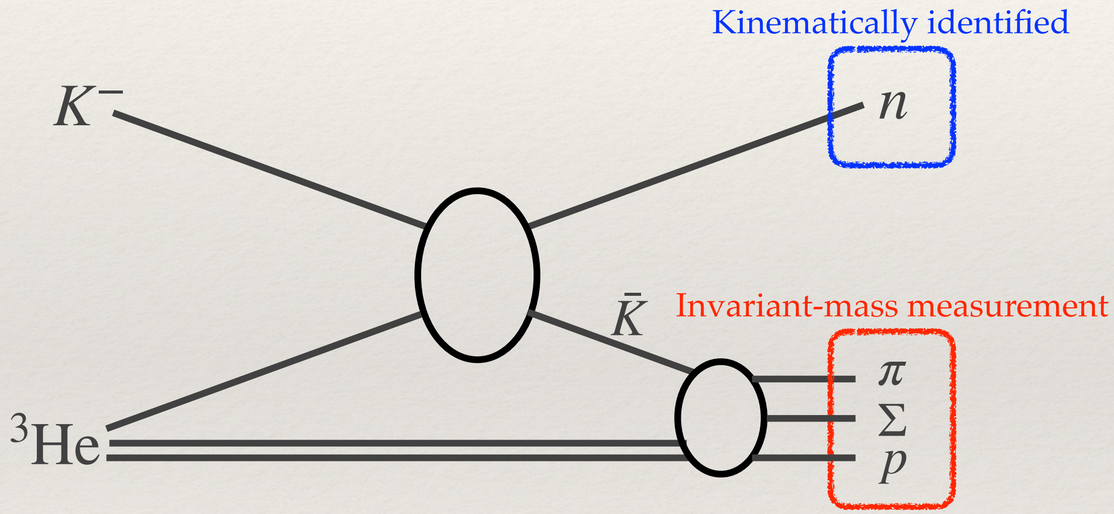
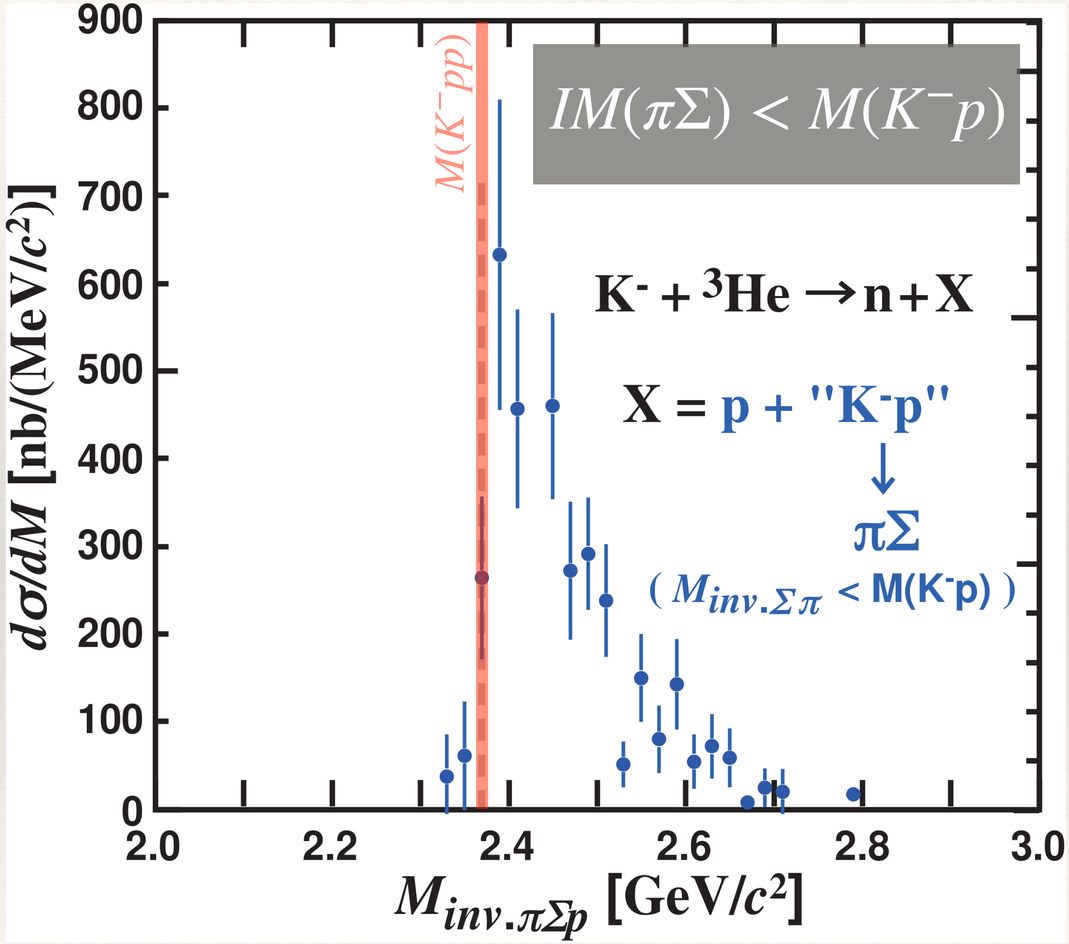


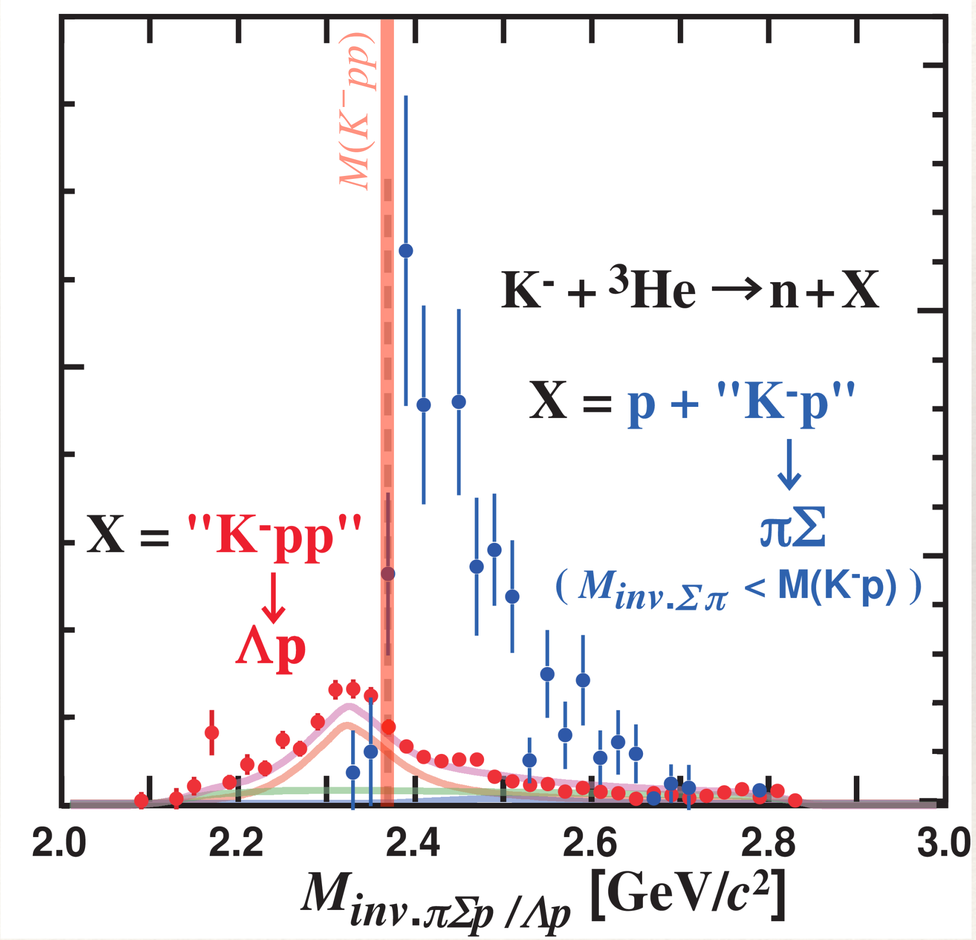
Structure is similar to QF.

➡ Compare to Λpn analysis



Comparison between Λpn & πΣpn

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



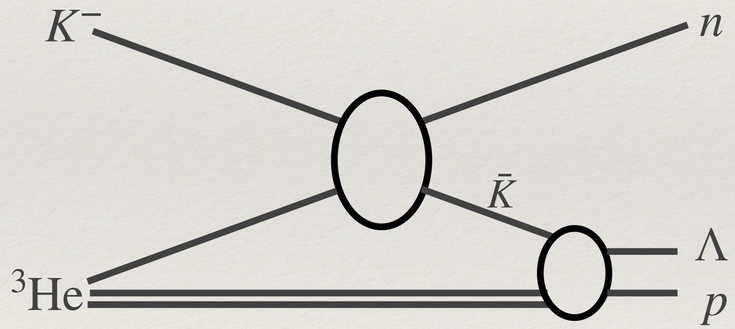
$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$

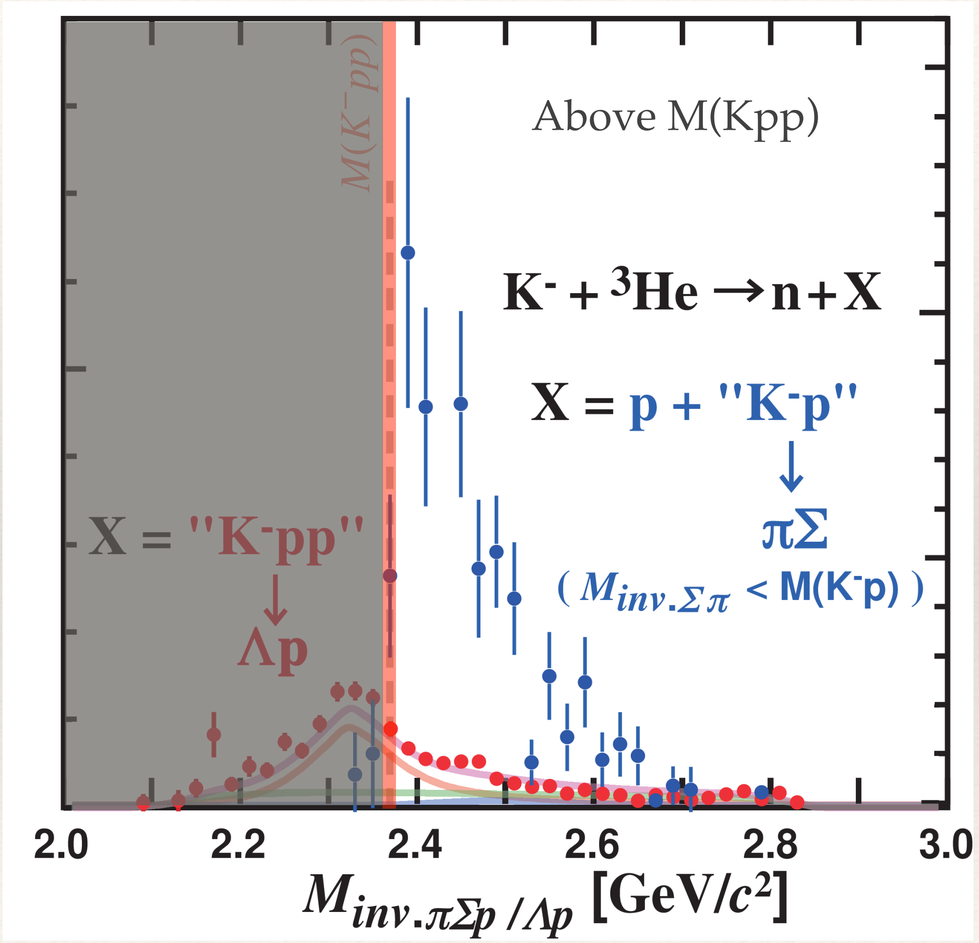
Comparison between Λpn & πΣpn

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

QF-K

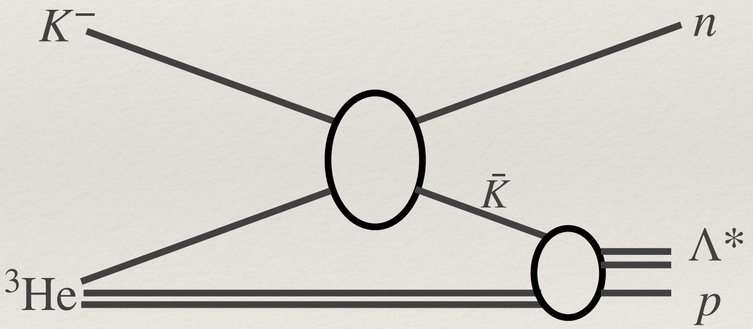
QF-Y*





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

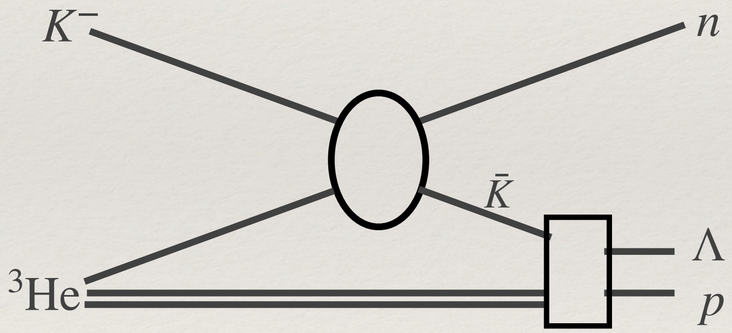
QF-Y*

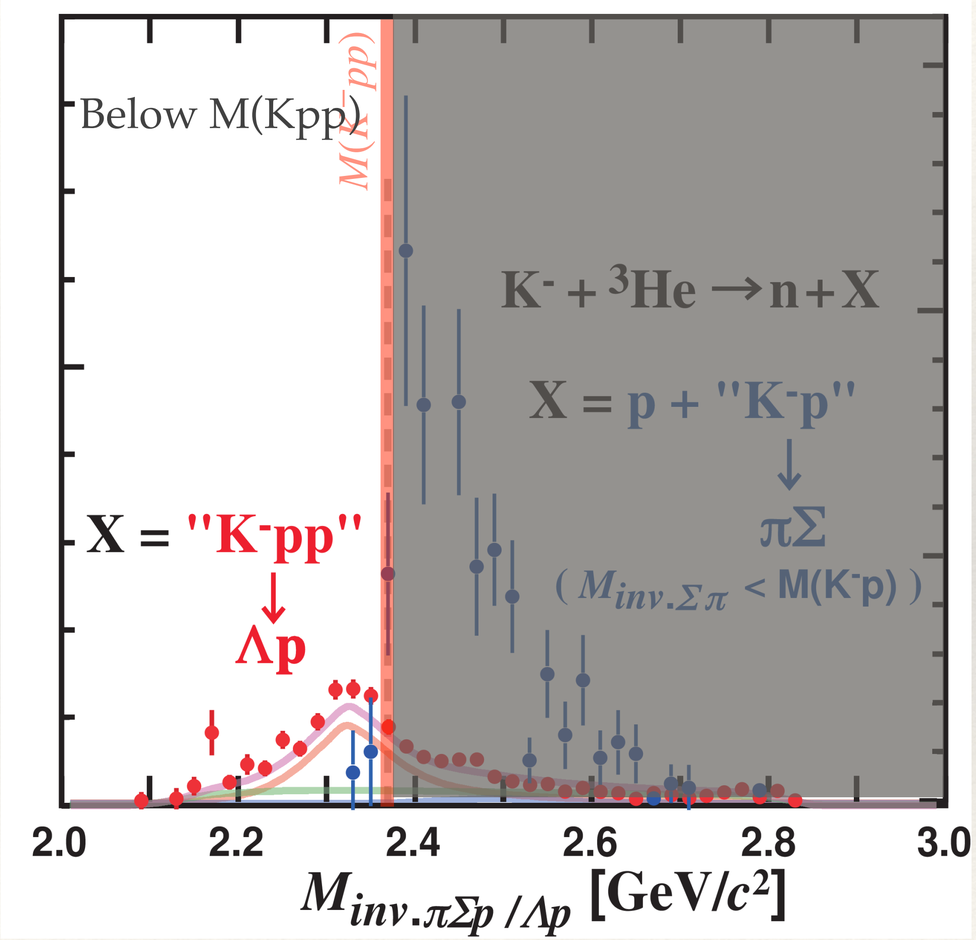


Comparison between Λpn & πΣpn

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

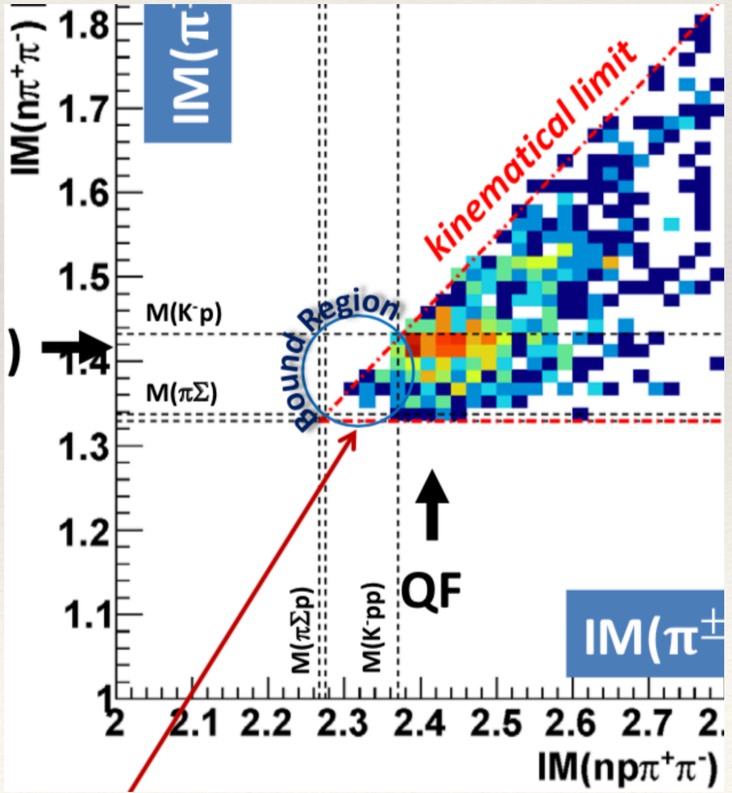
Kpp production





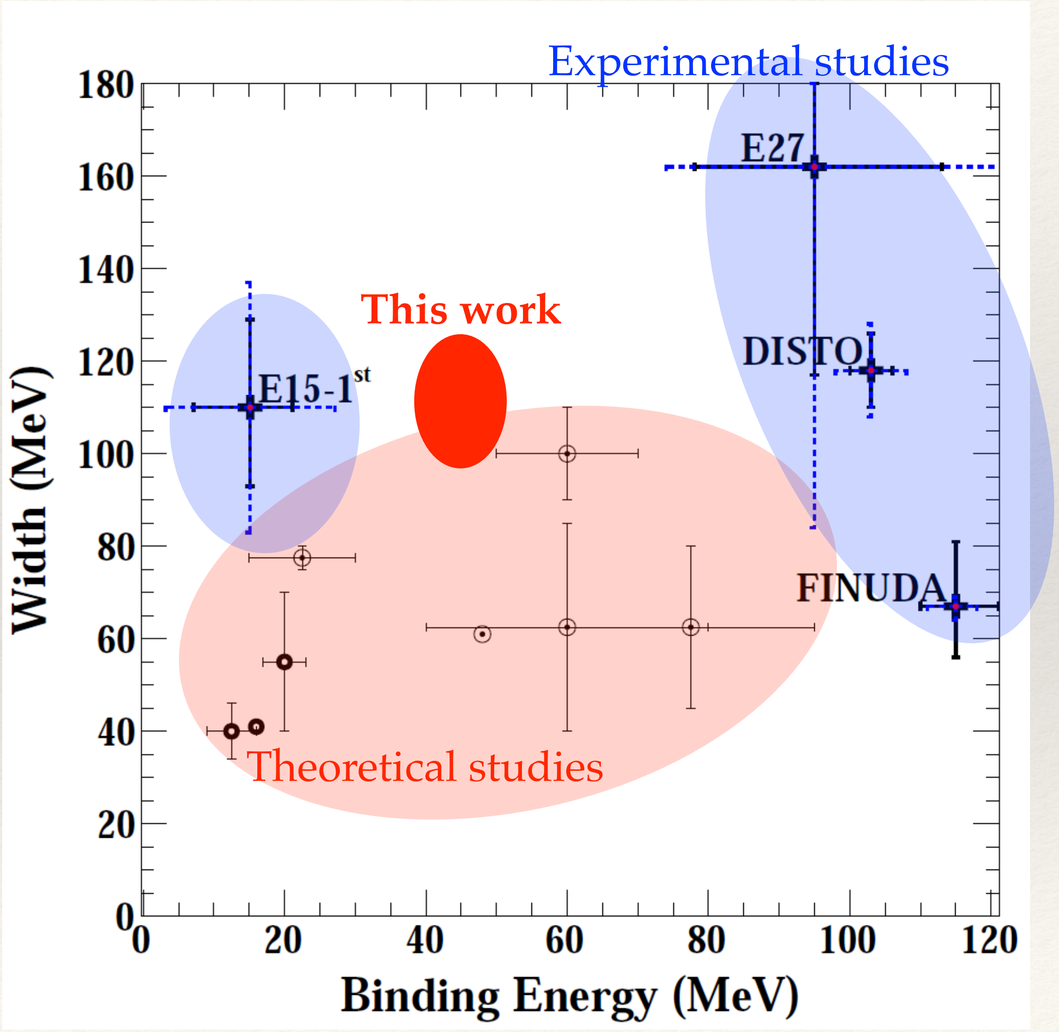
$K^- + {}^3\mathrm{He} \rightarrow \pi^{\pm}\Sigma^{\mp}p + n$

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

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[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

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Theoretical studies

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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

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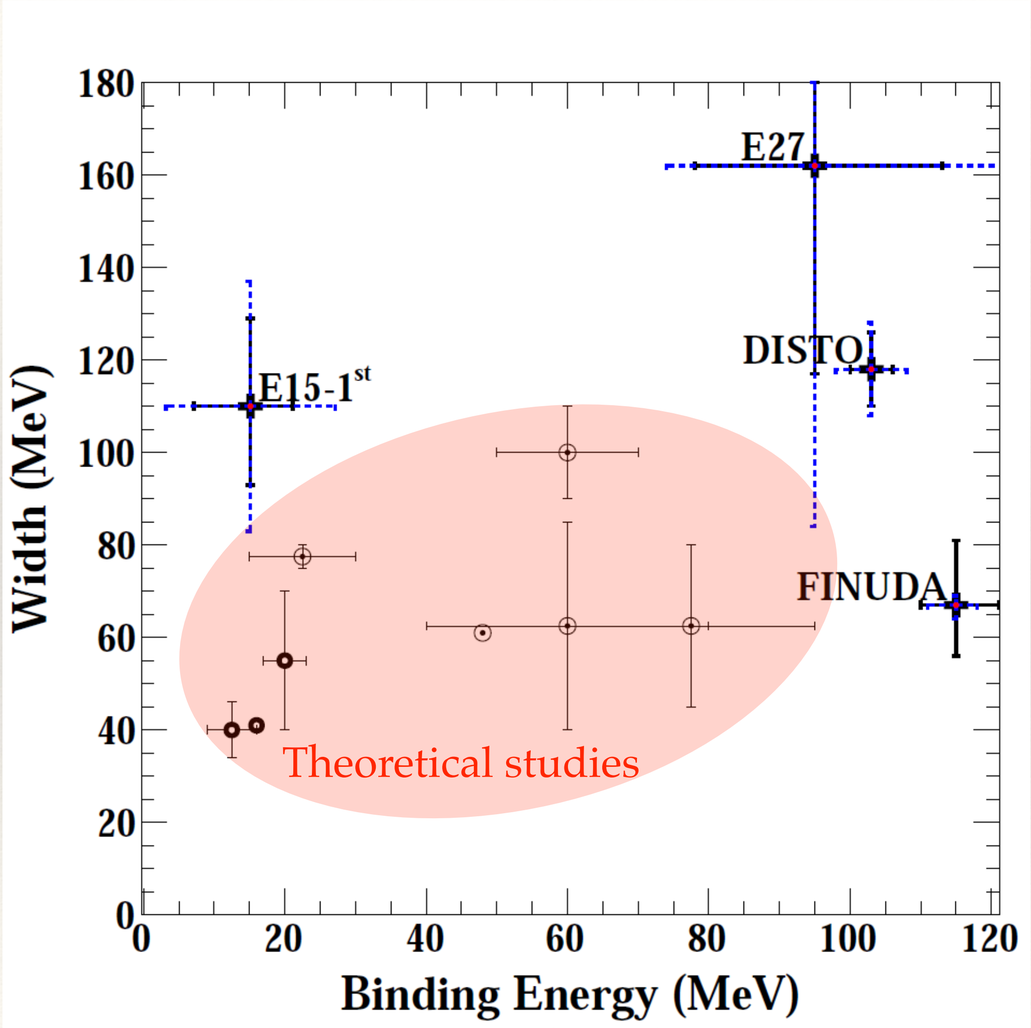
Variational vs. Faddeev : Not so changed

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

KbarNN bound state :: Current status

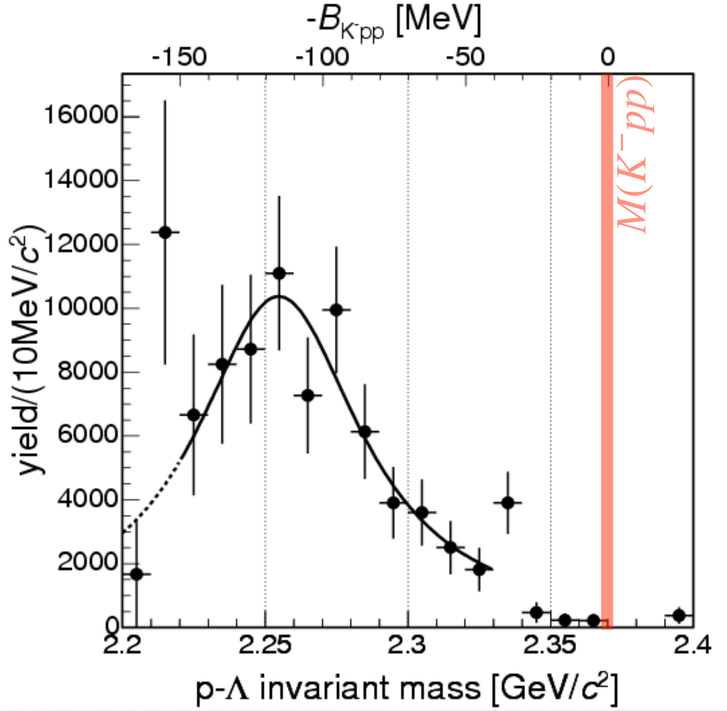
- Many theoretical & experimental studies
  - Theoretical studies
    - KbarNN can be exist.
    - B.E. & Width strongly depend on KbarN interaction model.



Experimental studies :: Stopped K-

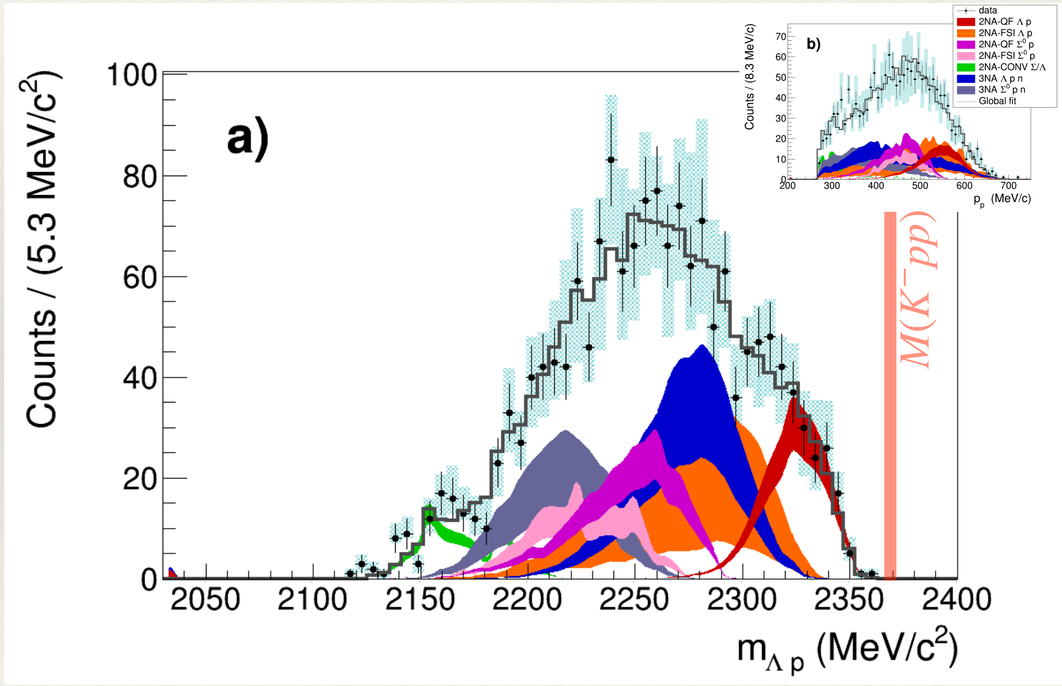
$A(\textit{stopped}\ K^-, \Lambda p)$

FINUDA@DAΦNE



PRL94(2005) 132502

AMADEUS@DAΦNE

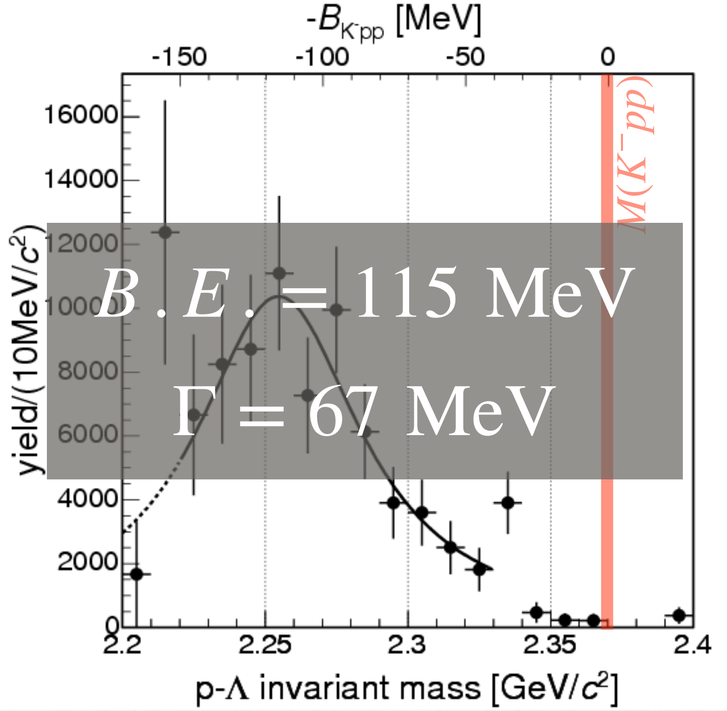


arXiv:1809.07212

Experimental studies :: Stopped K-

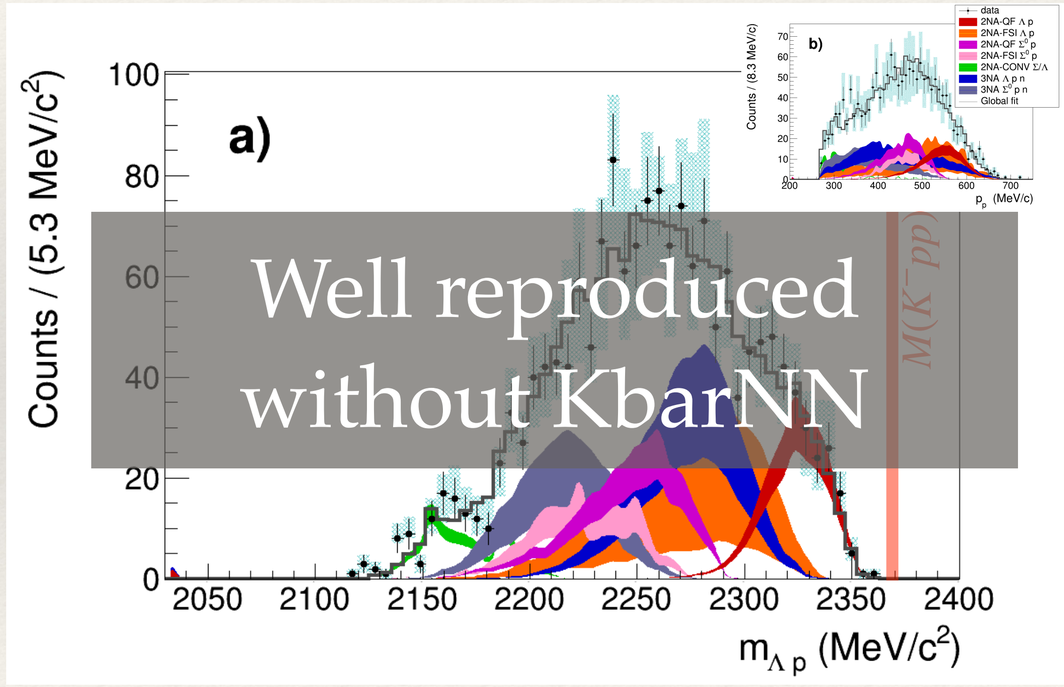
$A(\mathit{stopped}\ K^-, \Lambda p)$

FINUDA@DAΦNE



PRL94(2005) 212303

AMADEUS@DAΦNE



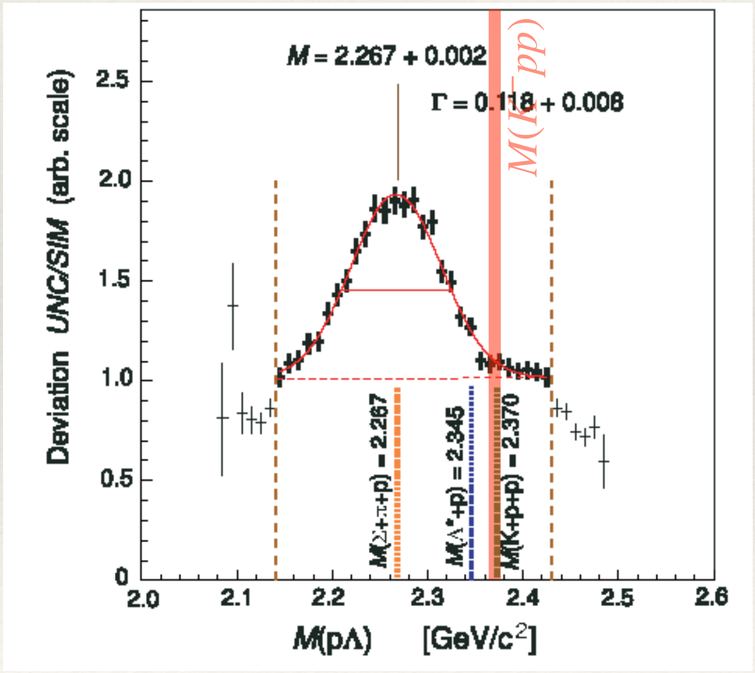
arXiv:1809.07212

Experimental studies :: pp collison

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

@ 2.85 GeV

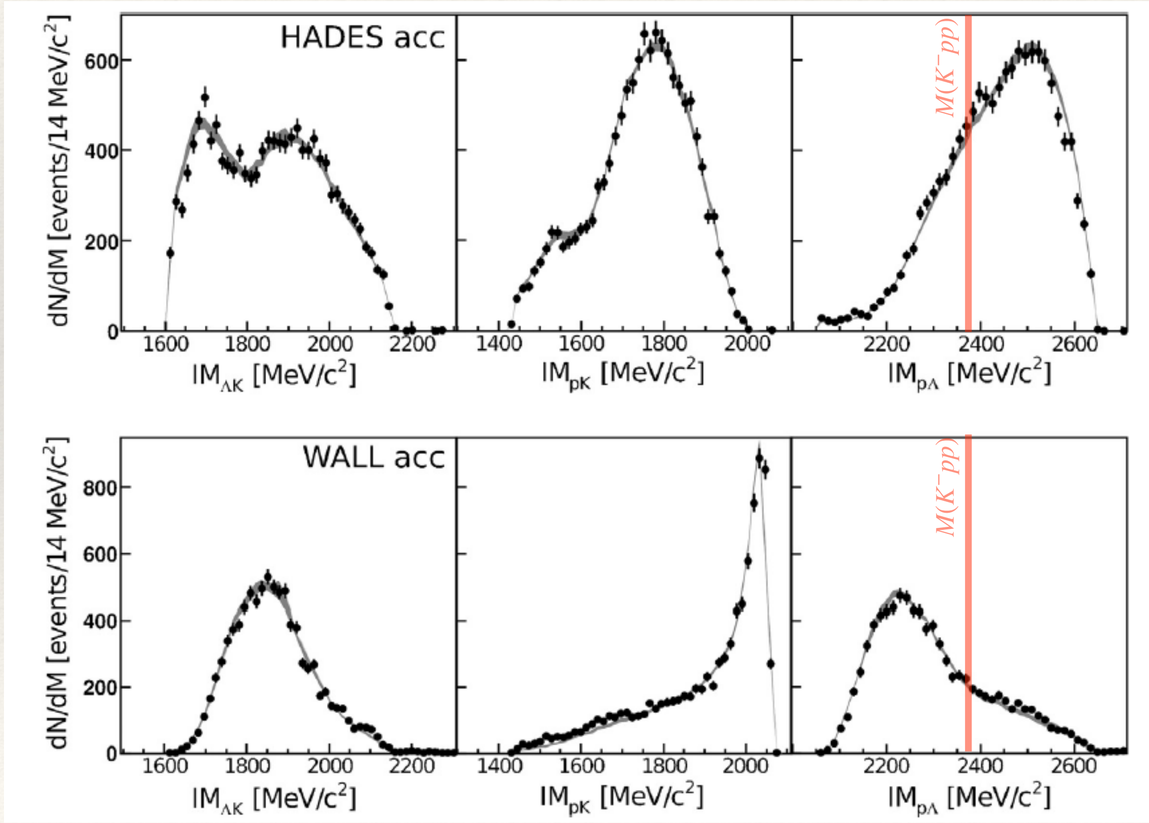
DISTO@SATURNE



PRL104(2010) 132502

@ 3.5 GeV

HADES@GSI



PLB742(2015) 242

Experimental studies :: pp collison

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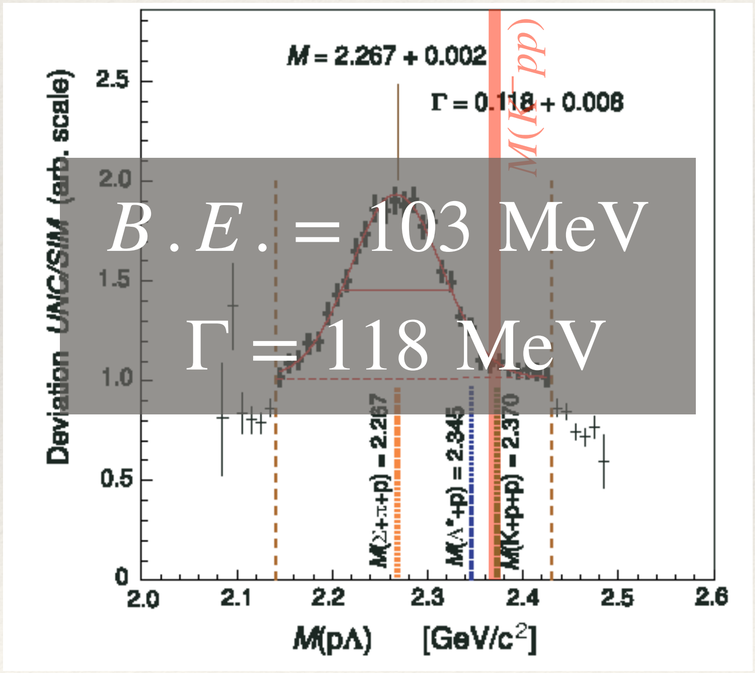
DISTO@SATURNE



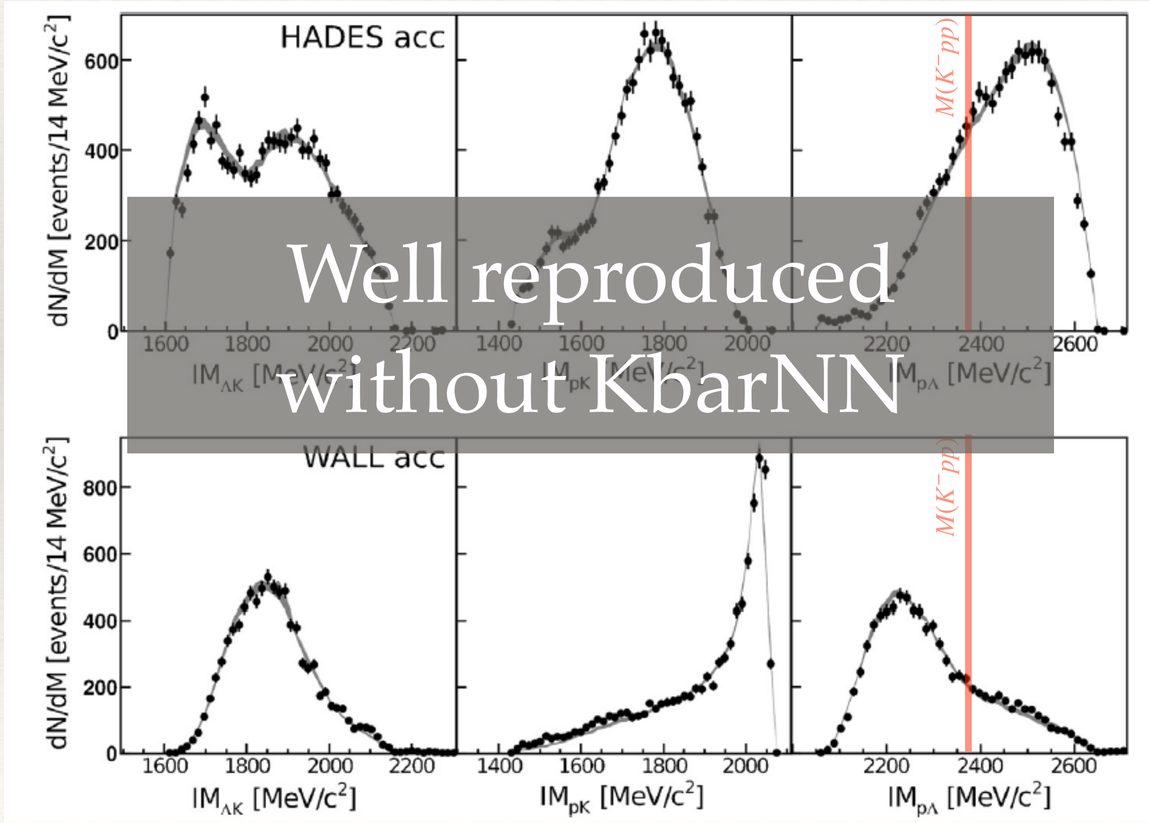
$B.E. = 103$ MeV

$\Gamma = 118$ MeV

PRL104(2010) 132502

@ 3.5 GeV

HADES@GSI



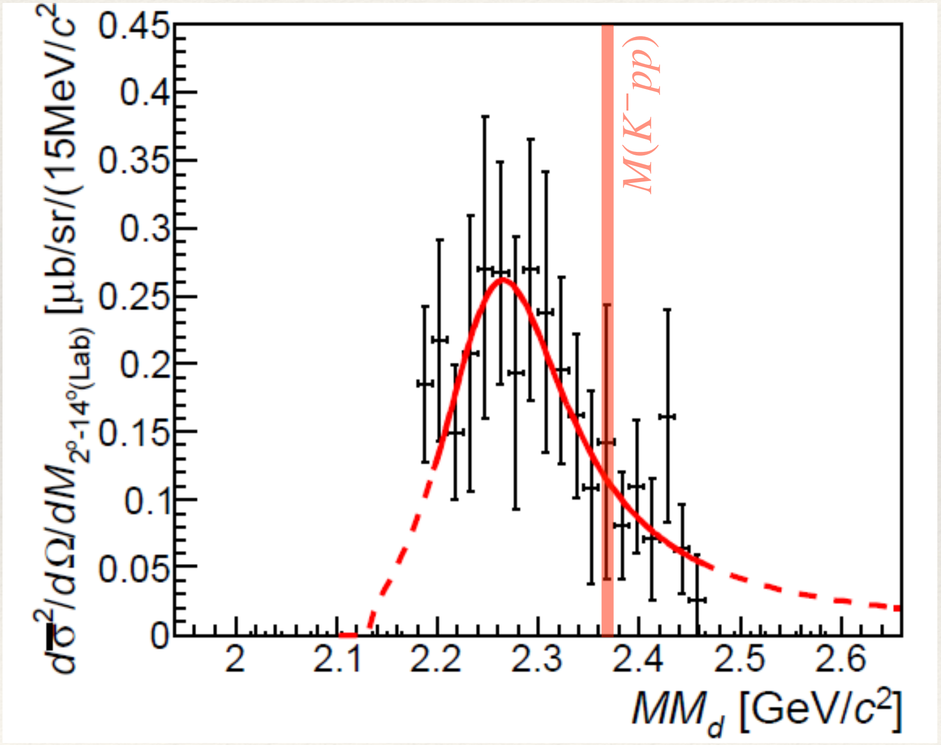
Well reproduced without KbarNN

PLB742(2015) 242

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

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

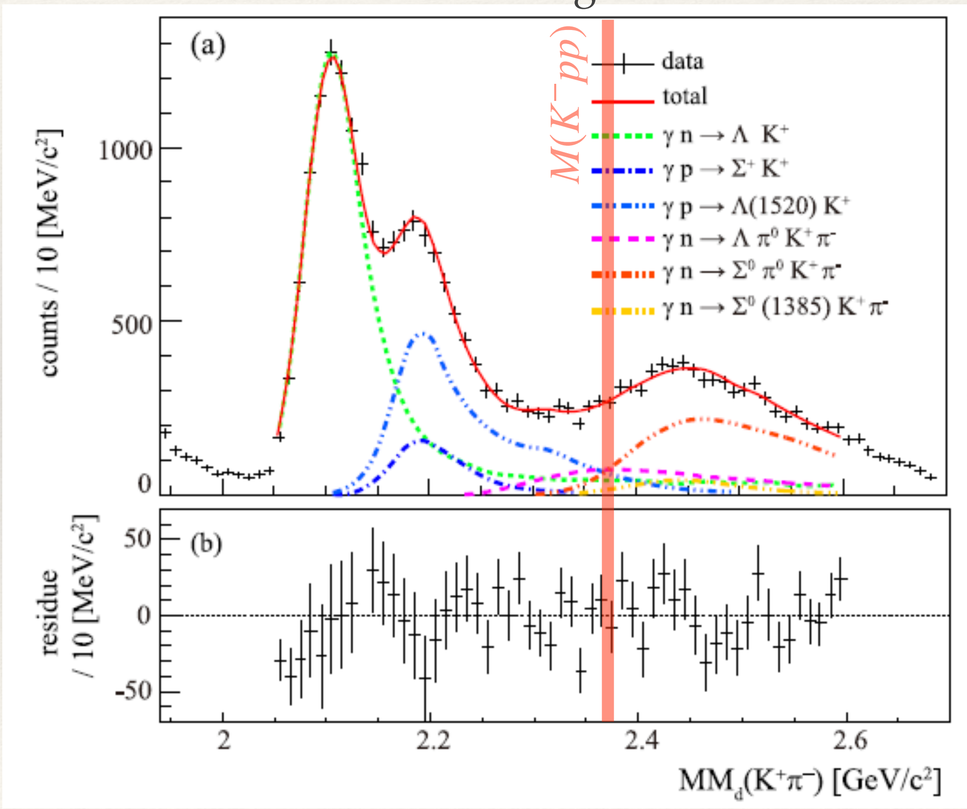
E27@J-PARC



PTEP(2015) 021D01

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

LEPS@SPring-8



PLB 728 (2014) 616

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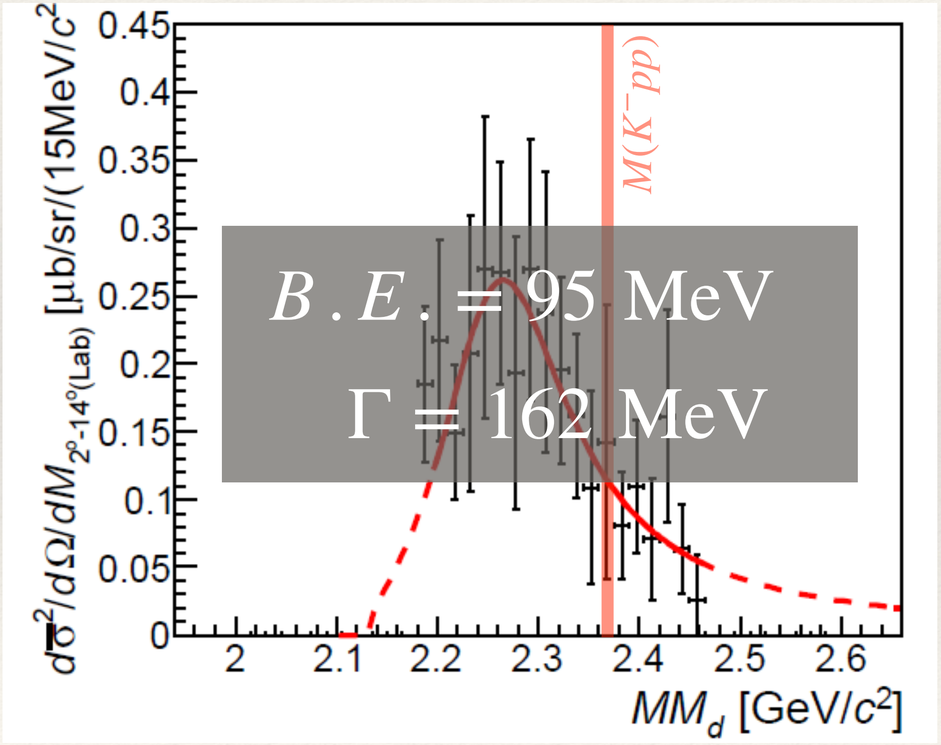
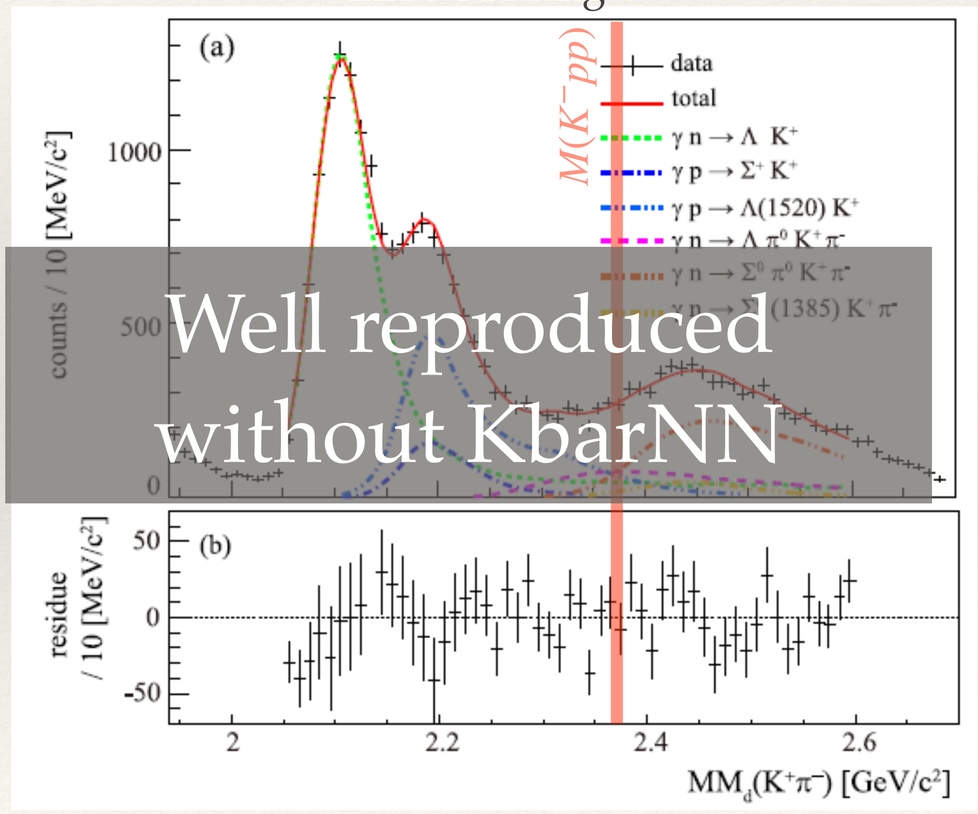
E27@J-PARC



PTEP(2015) 021D01

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

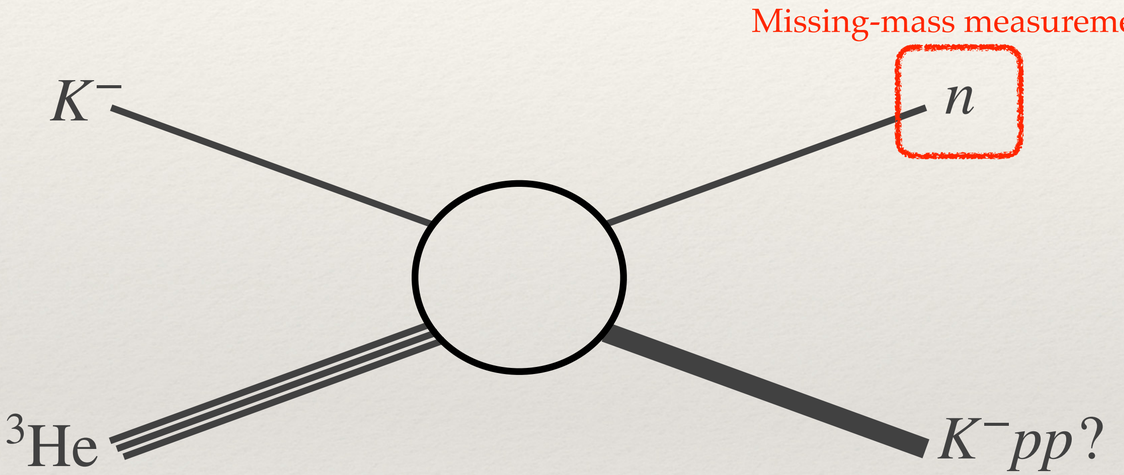
LEPS@SPring-8

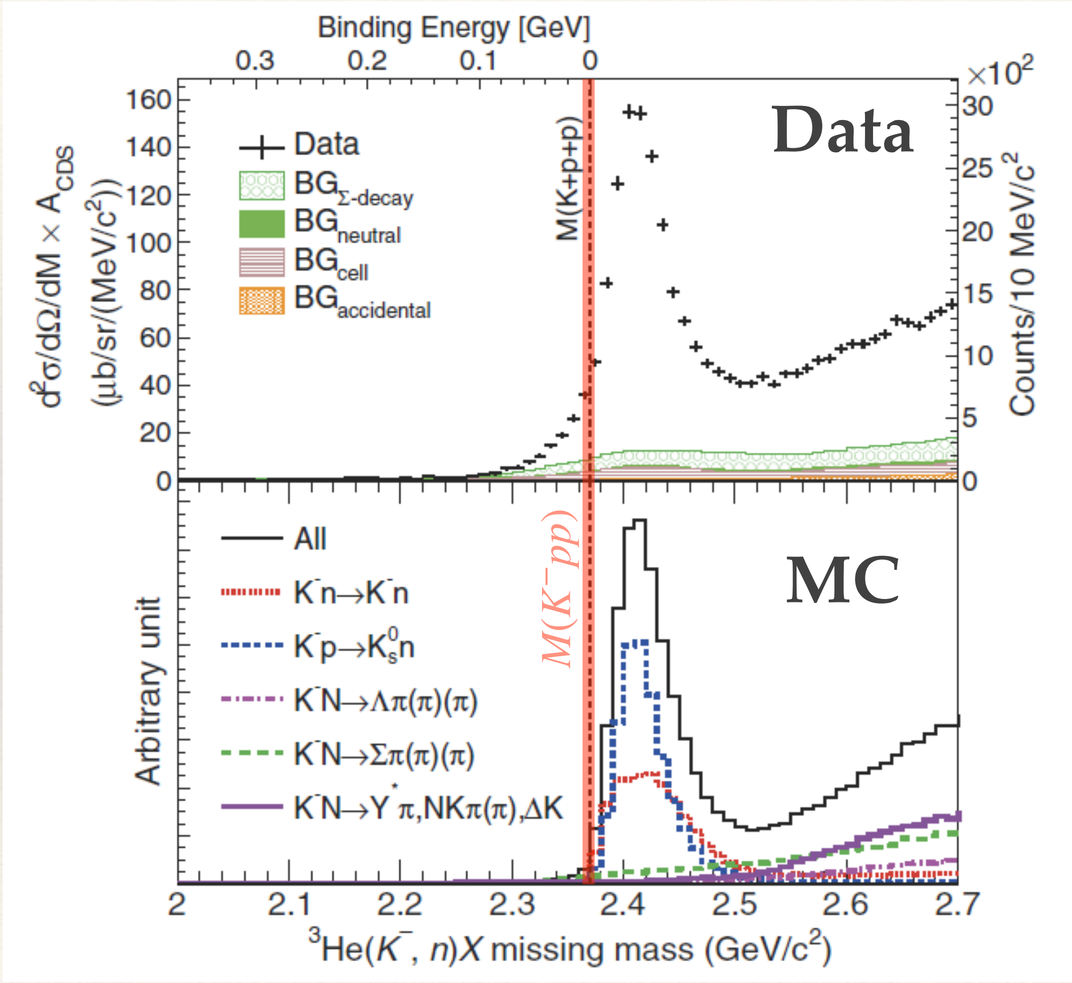


PLB 728 (2014) 616

Results of E15 - 1st

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

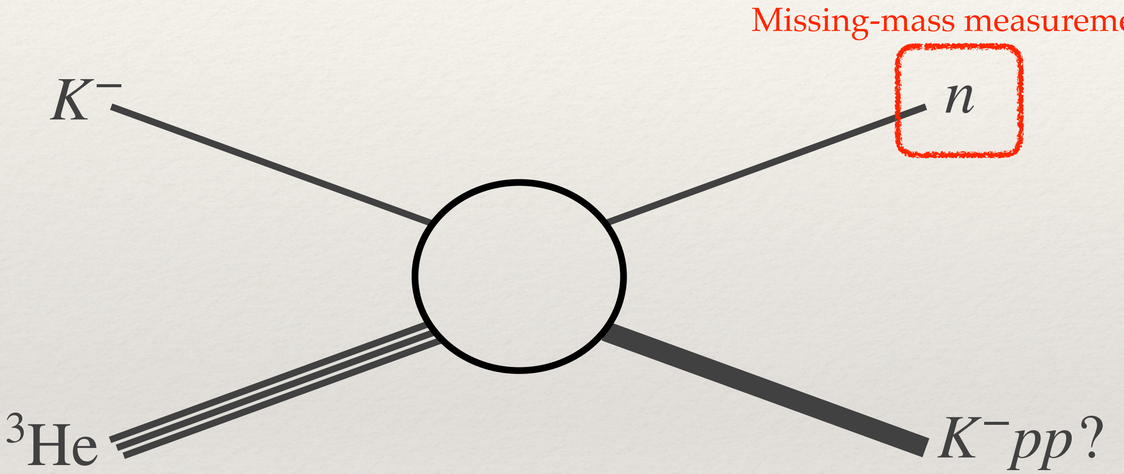




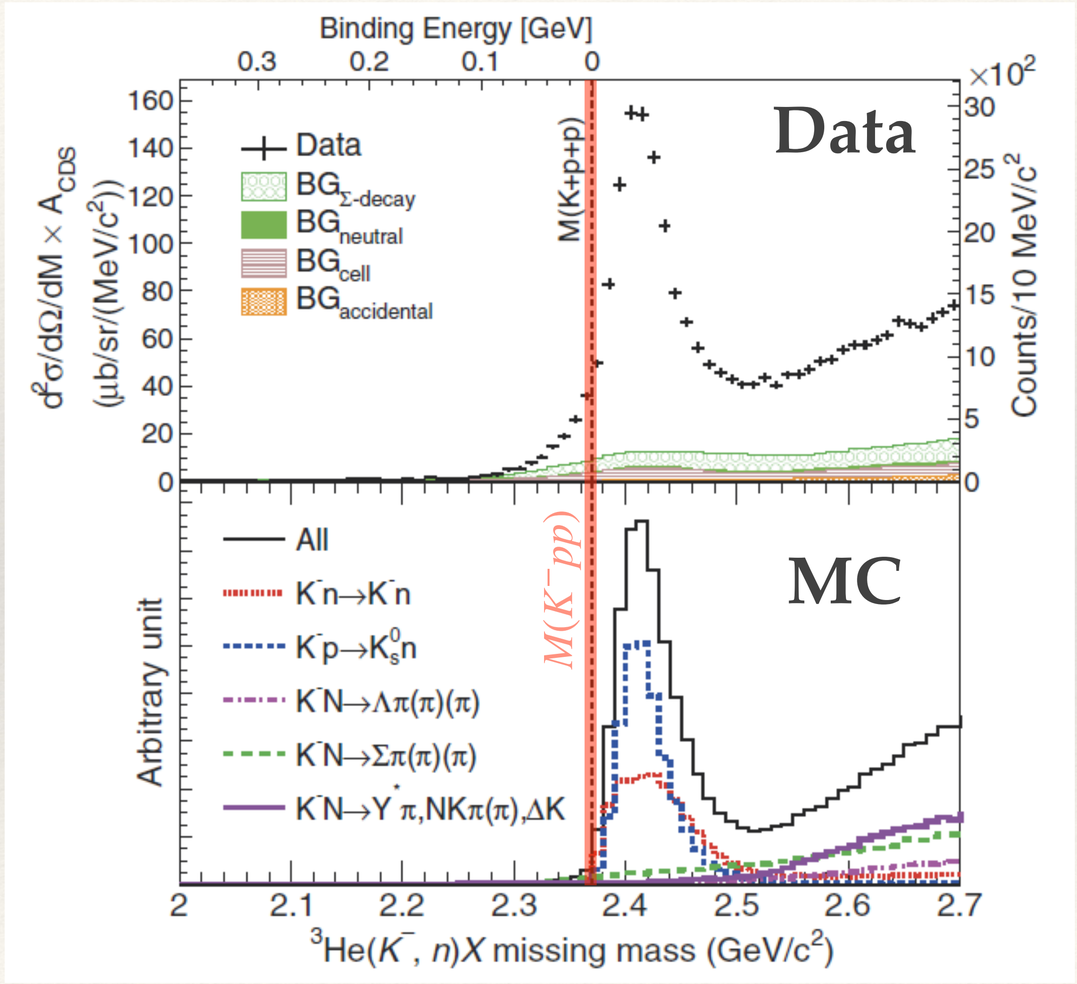
PTEP (2015) 061D01

Results of E15 - 1st

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



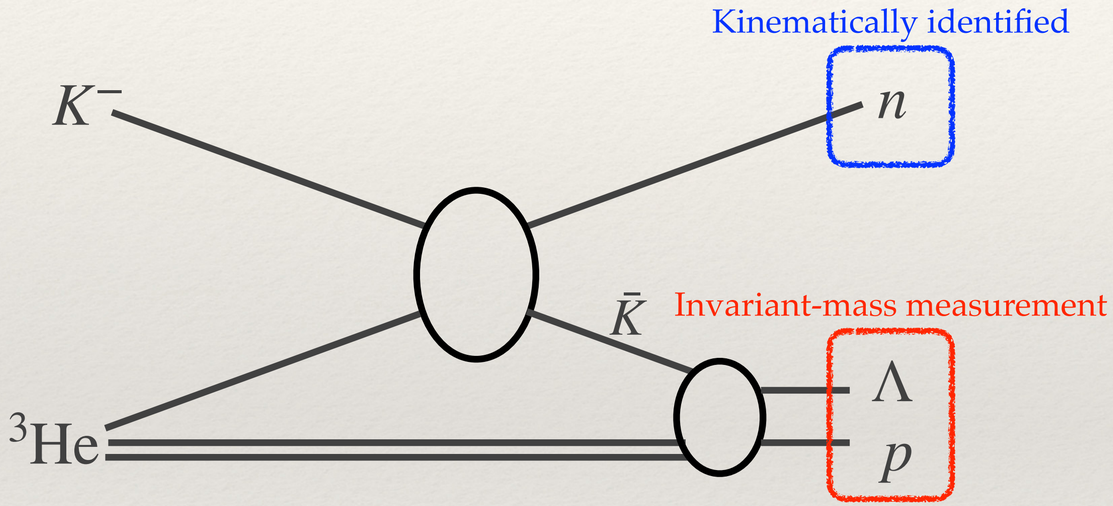
- Strong QF peak above M(Kpp)
- No clear peak below M(Kpp)

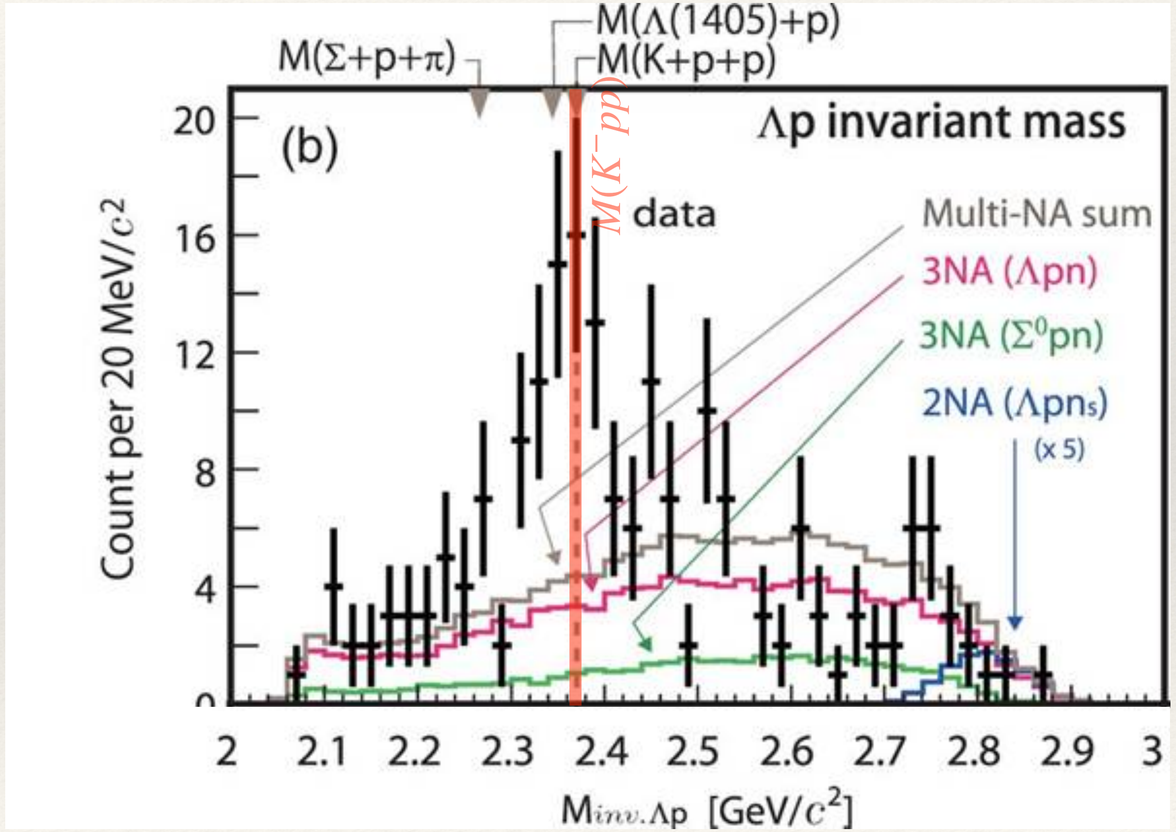


PTEP (2015) 061D01

Results of E15 - 1st

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

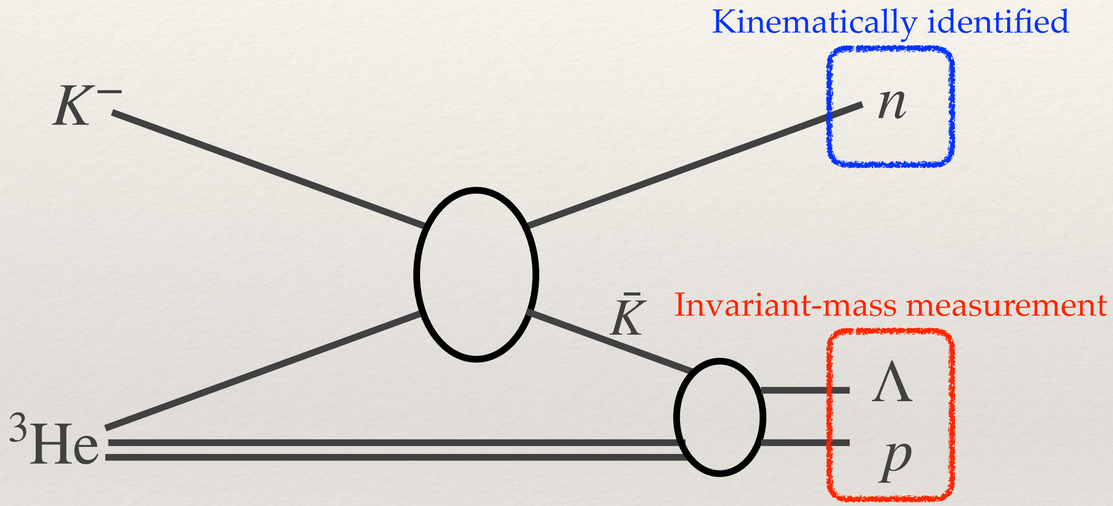




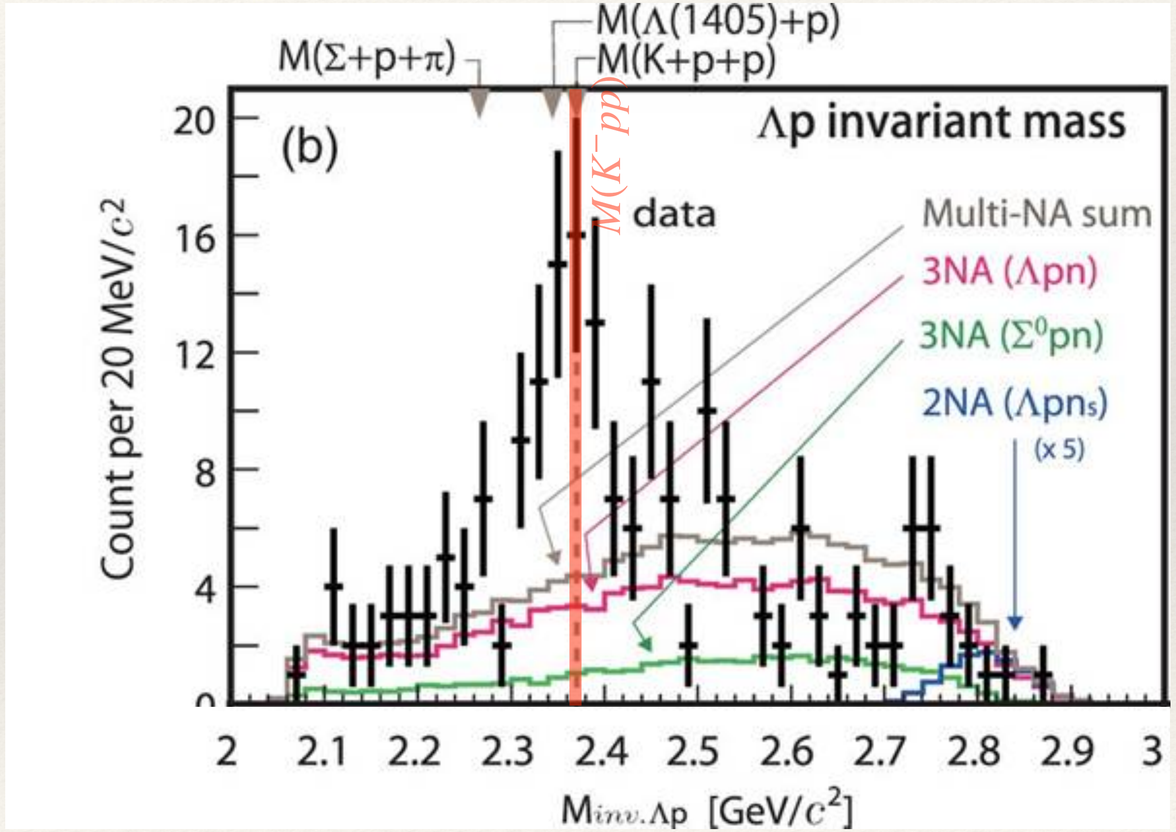
PTEP (2016) 051D01

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

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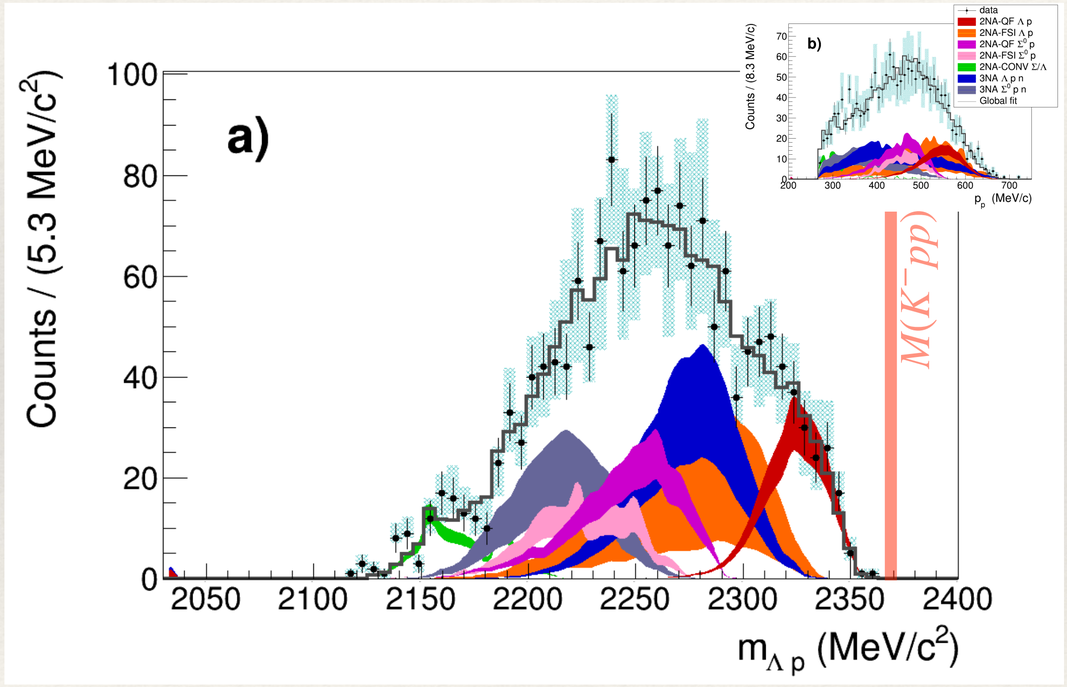

arXiv:1809.07212

2NA process