Studies of the KNN bound state via the exclusive analysis of the in-flight (K^-, n) reaction at J-PARC

T. Yamaga
For the J-PARC E15 collaboration

Contents

- Introduction
- Experimental apparatus
- Results & Discussion

Question of the KbarN interaction

- Can Kaon be building block?
  - We know that KbarN interaction is strongly attractive!

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In “hadron”

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uds **KN**

Question of the KbarN interaction

- Can Kaon be building block?
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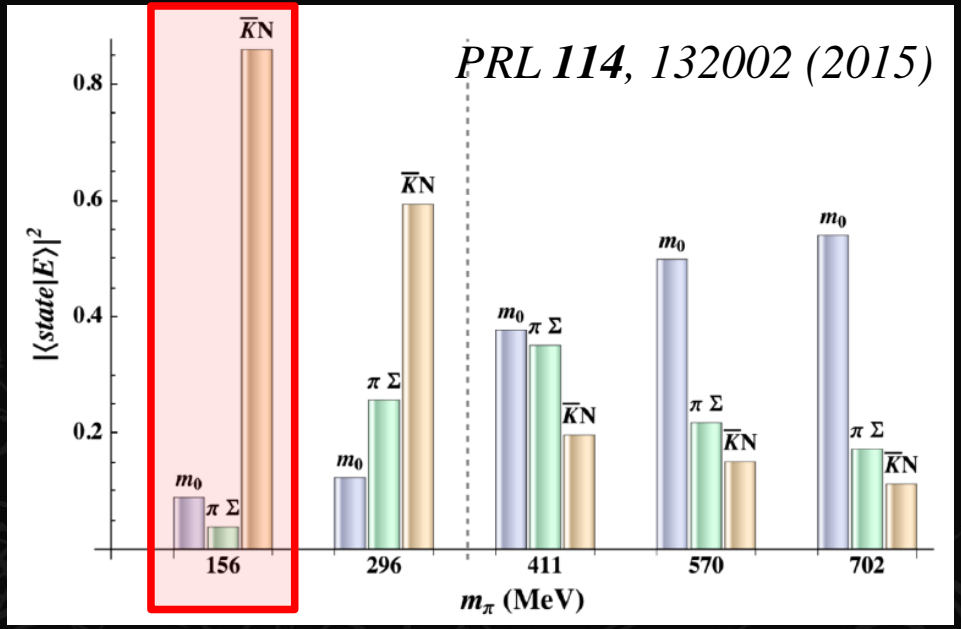
Recent lattice calculation



Question of the KbarN interaction

- Can Kaon be building block?
  - We know that KbarN interaction is strongly attractive!

In “hadron”

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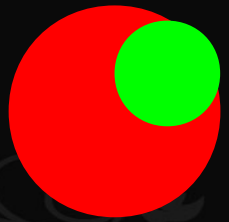
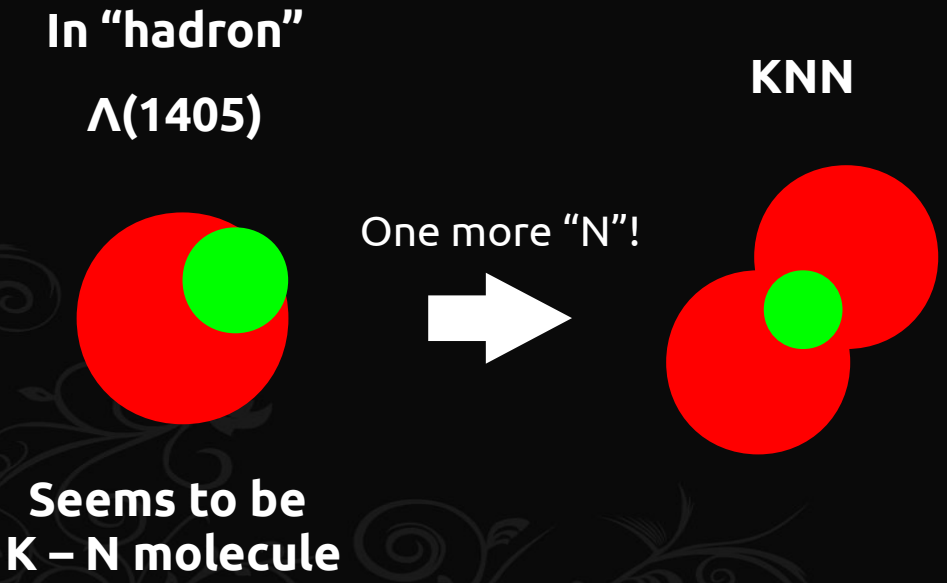


Seems to be
K – N molecule

Question of the KbarN interaction

- Can Kaon be building block?
  - We know that KbarN interaction is strongly attractive!



Question of the KbarN interaction

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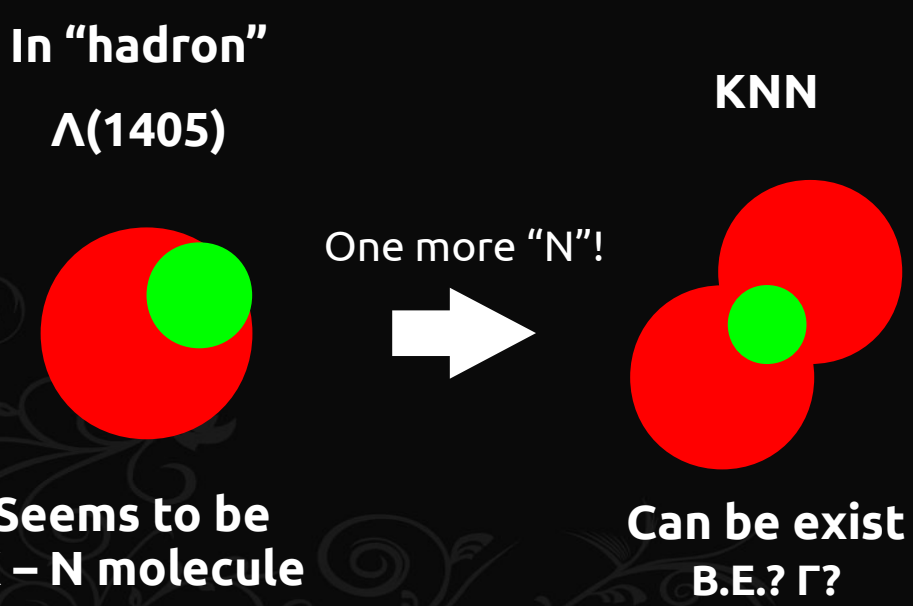
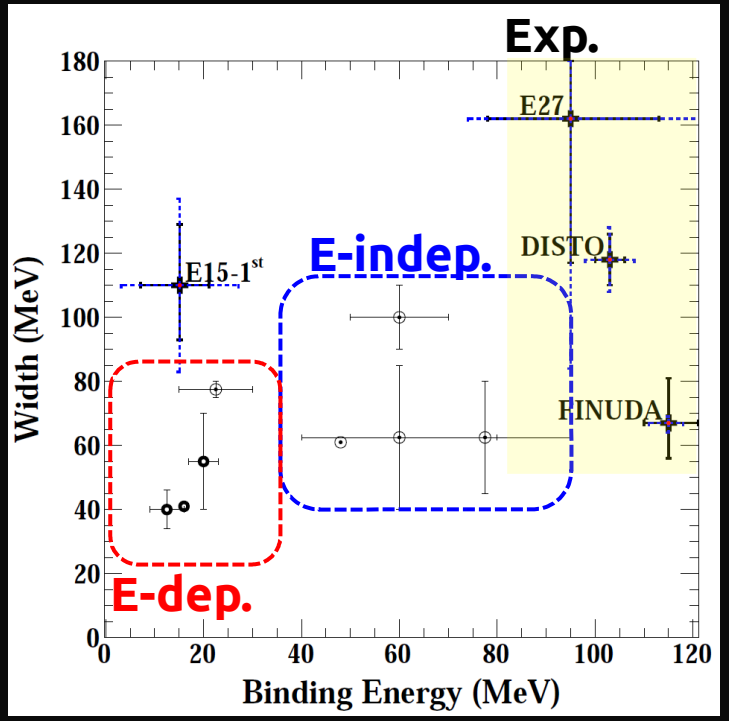
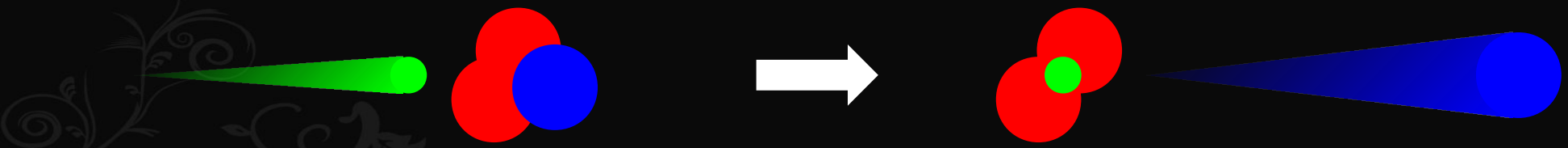




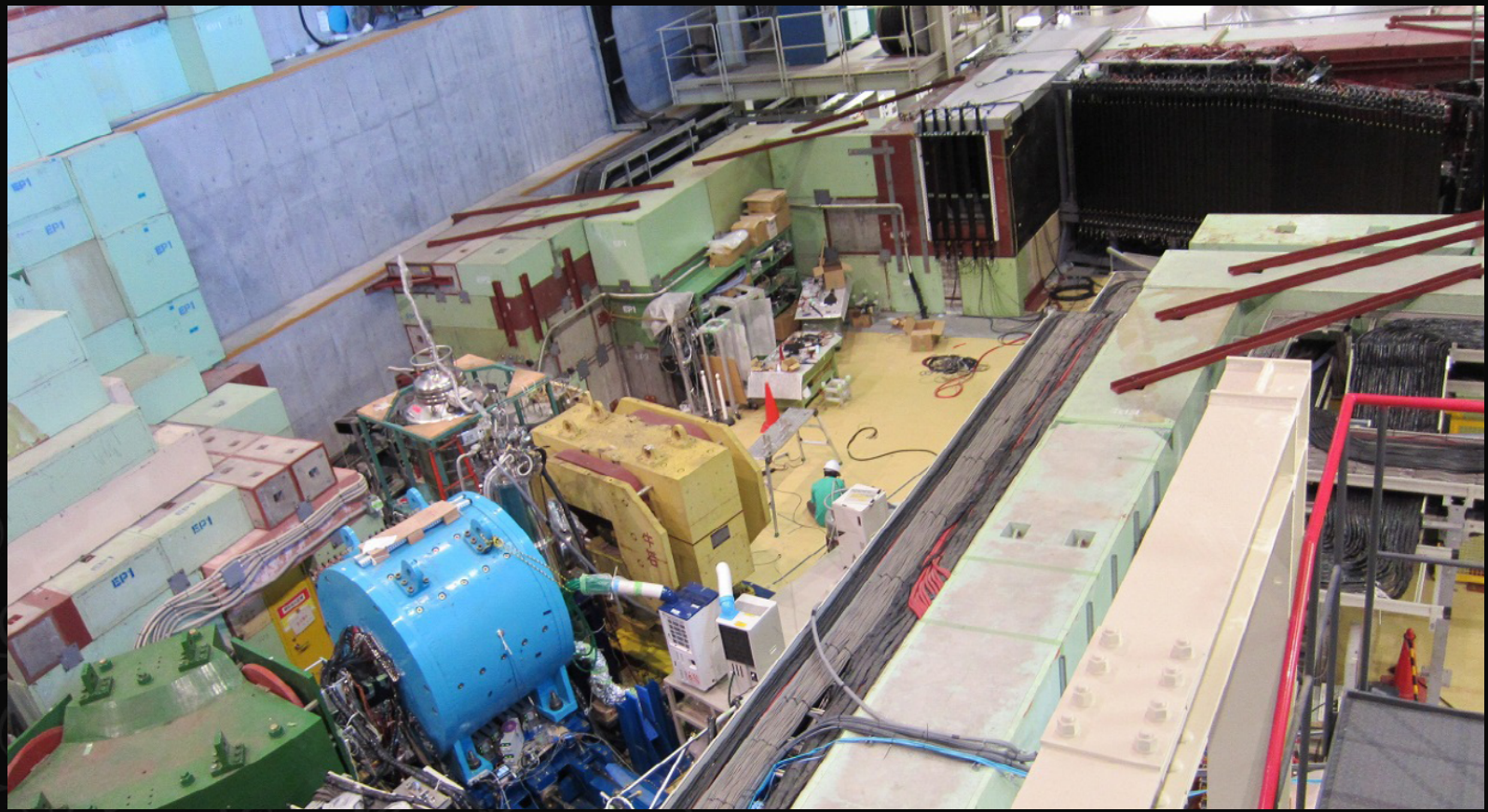
E15 experiment

- Experiment to search for Kpp bound state
  - In-flight (K-, n) reaction to generate Kpp bound state

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

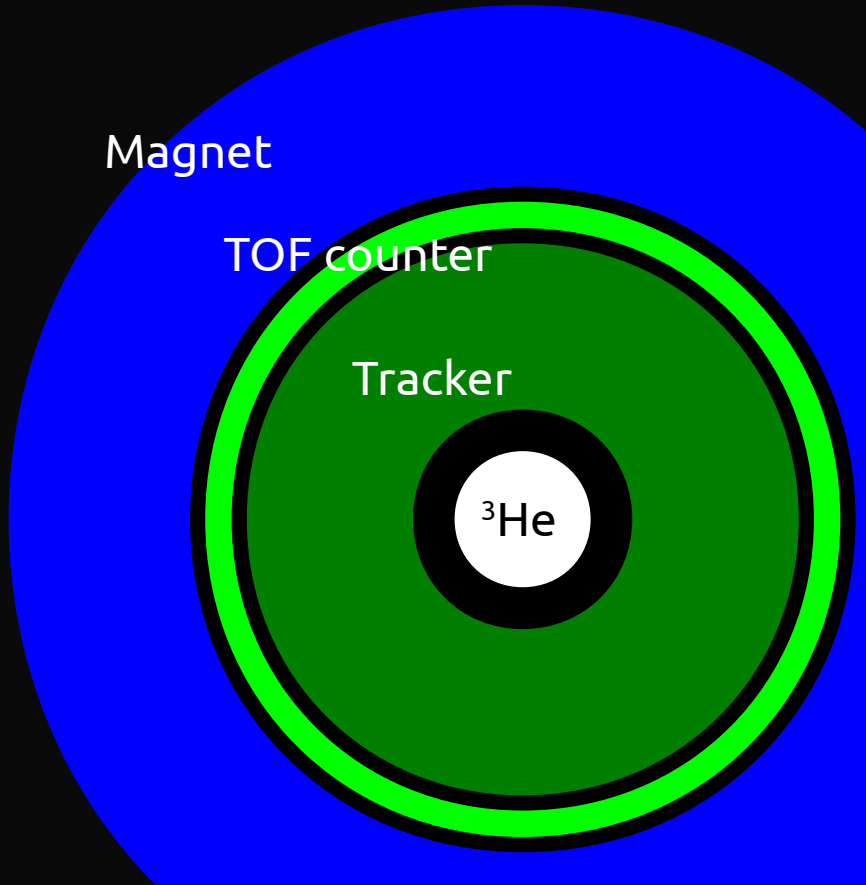


Setup



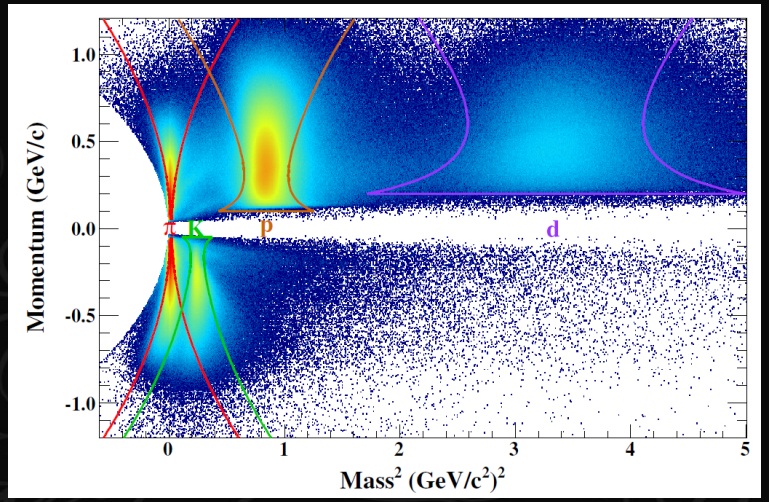
Setup

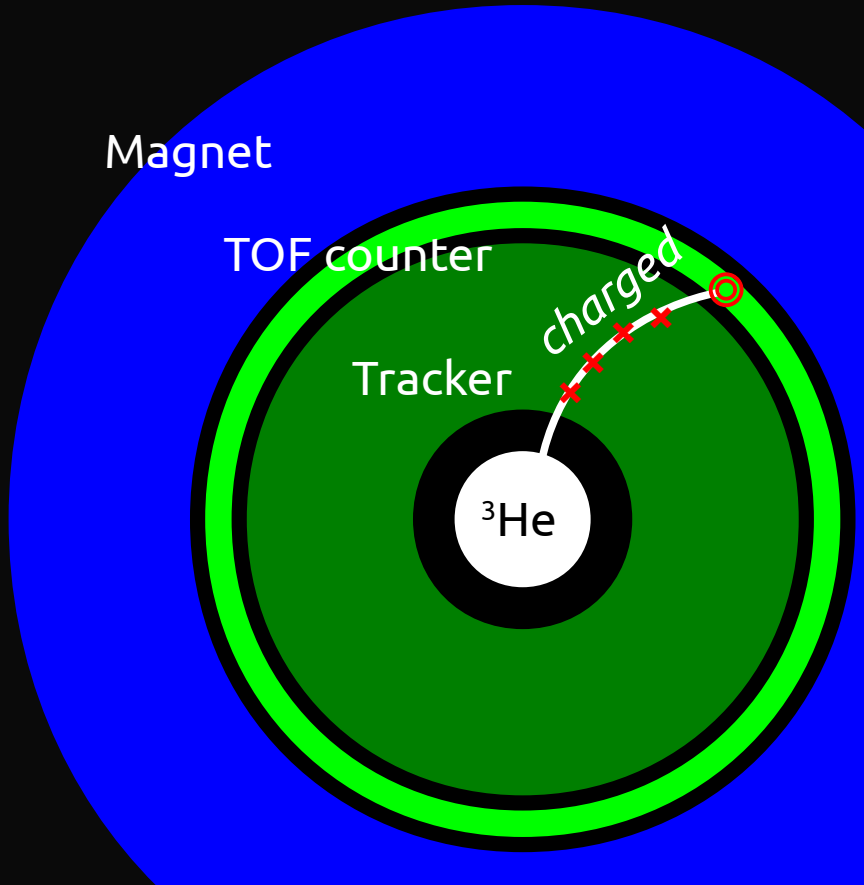
- Cylindrical detector system
  - Surrounding the ^{3}He target
  - Detecting scattering particles



Setup

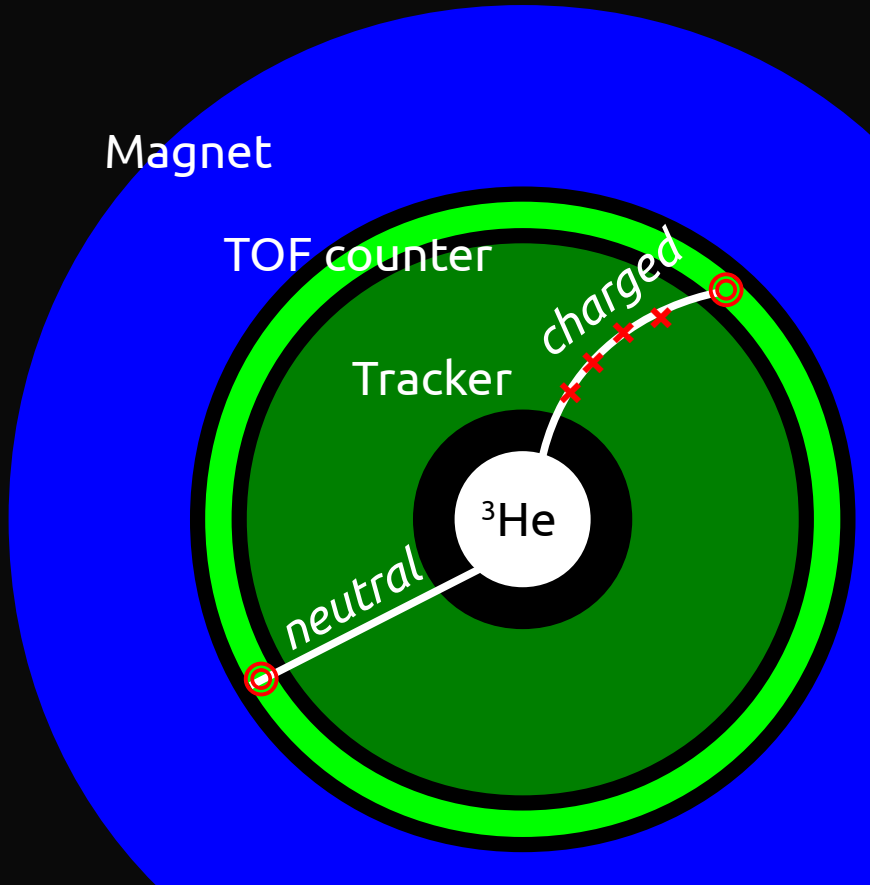
- Cylindrical detector system
  - Surrounding the ^{3}He target
  - Detecting scattering particles
    - Charged
      - Track & TOF information → PID





Setup

- Cylindrical detector system
  - Surrounding the ^{3}He target
  - Detecting scattering particles
    - Charged
      - Track & TOF information → PID
    - Neutral
      - Momentum by TOF
      - Only a few % efficiency...



Setup

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  - Surrounding the ^{3}He target
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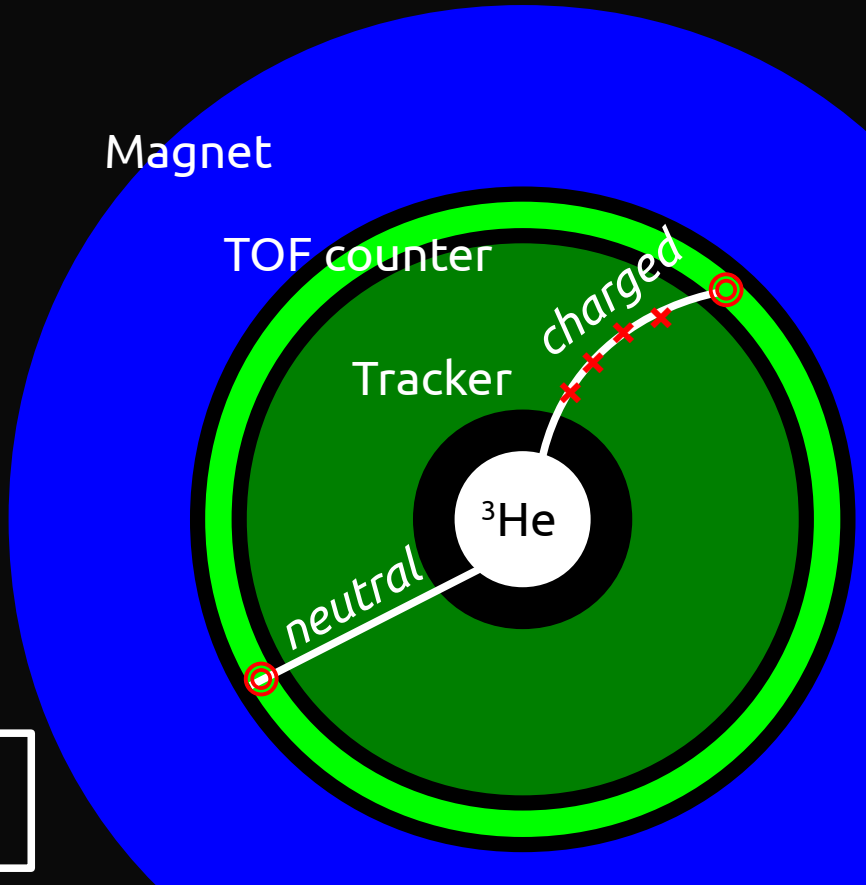
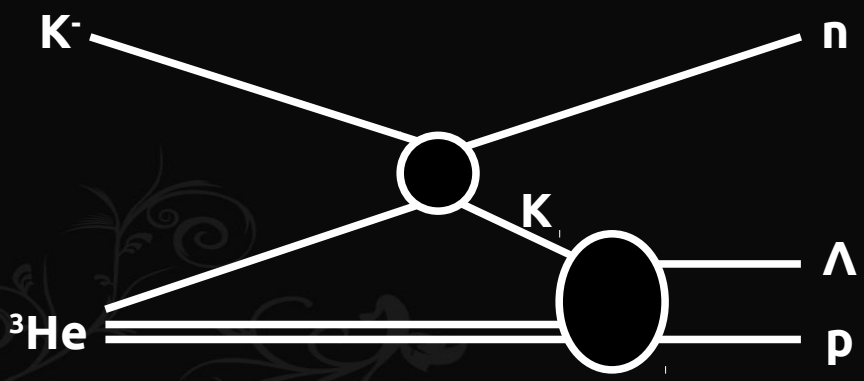
      - Only a few % efficiency...

Final state is identified
by using “kinematic fitting” & “DCA informations”.

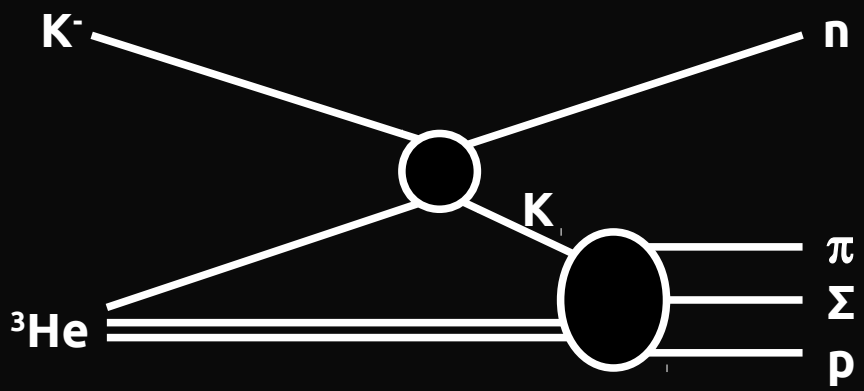


Exclusive channels

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

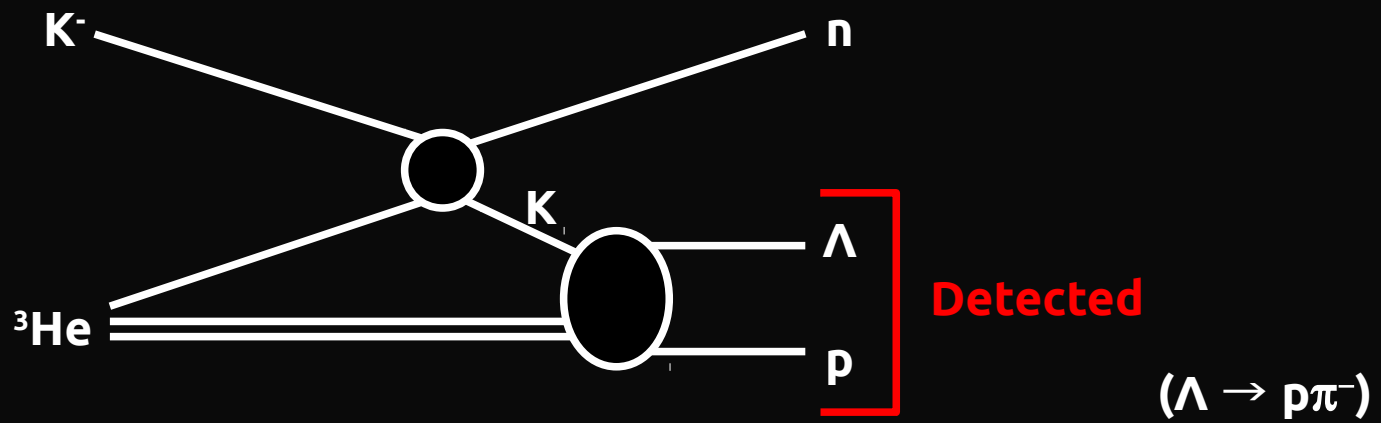


$K^- + {}^3He \rightarrow \pi\Sigma p + n$



Exclusive analysis of„

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



- $K^- + {}^3He \rightarrow \Lambda p + n$ channel
  - Detected : $\pi^- pp$
  - Missing : n

Exclusive analysis of„

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

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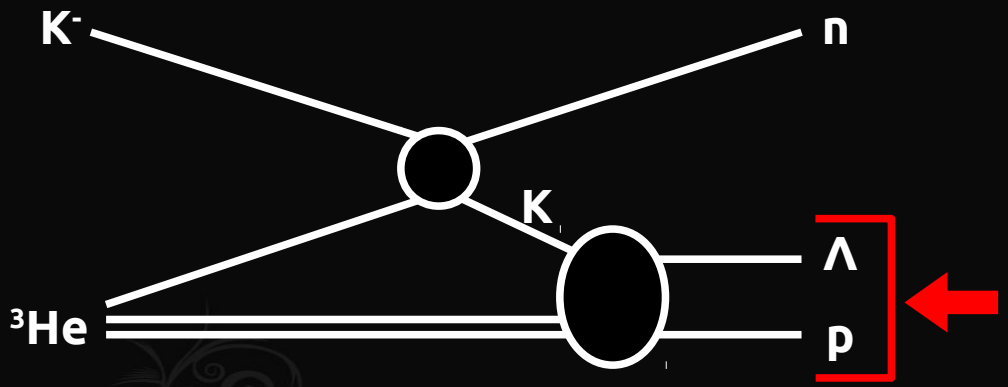
"$K^- pp$", a $\overline{K}$-Meson Nuclear Bound State, Observed in ^{3}He$(K^-, \Lambda p)n$ Reactions

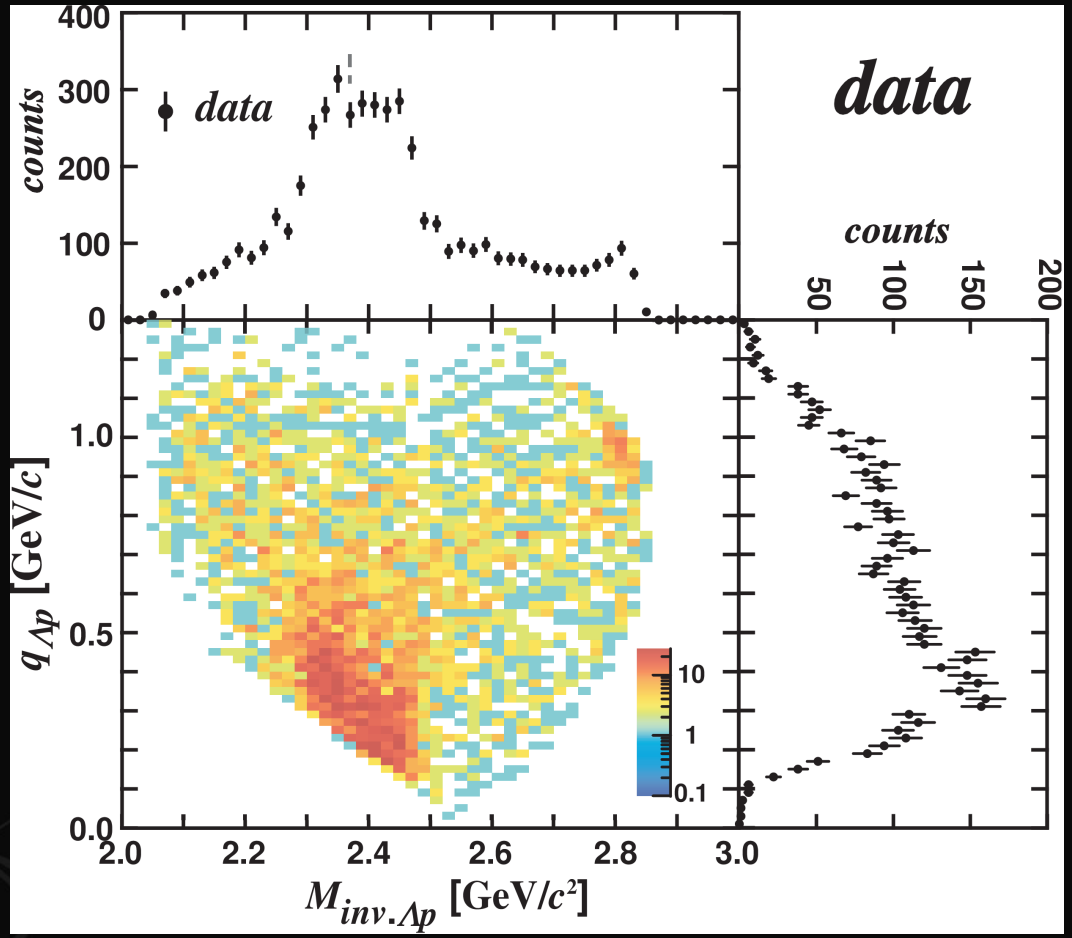
S. Ajimura[1], H. Asano[2], G. Beer[3], C. Berucci[4], H. Bhang[5], M. Bragadireanu[6], P. Buehler[4], L. Busso[7,8], M. Cargnelli[4], S. Choi[5], C. Curceanu[9], S. Enomoto[10], H. Fujioka[11], Y. Fujiwara[12], T. Fukuda[13], C. Guaraldo[9], T. Hashimoto[14], R. S. Hayano[12], T. Hiraiwa[1], M. Iio[10], 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]

Λp invariant-mass spectrum

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



$q_{\Lambda p}$: momentum transfer by virtual kaon



Fitting the spectrum

Fitting functions

1) Quasi-elastic Kaon

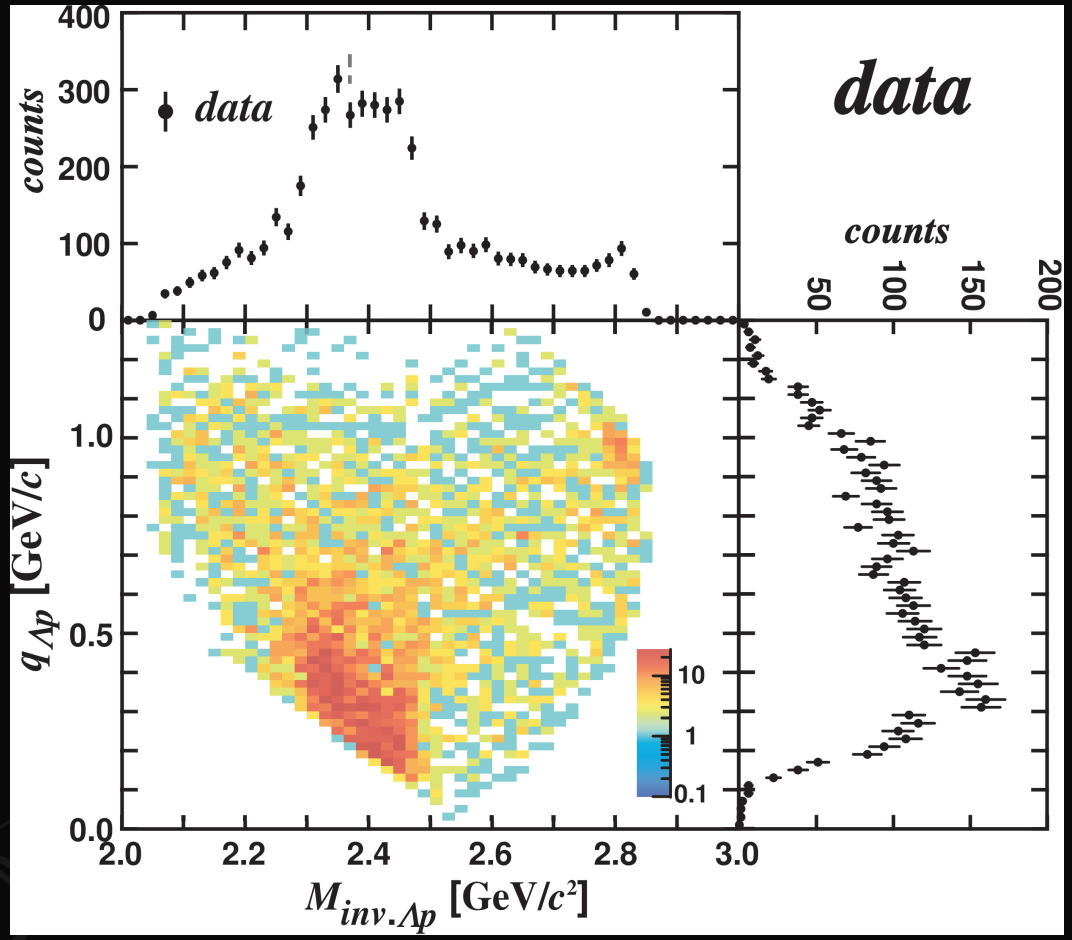
- Gaussian peak
- Moving with q

2) Kpp bound state

- Breit-Wigner peak
- Independent on q

3) Broad background

- Small m dependence
- distribute in higher q region



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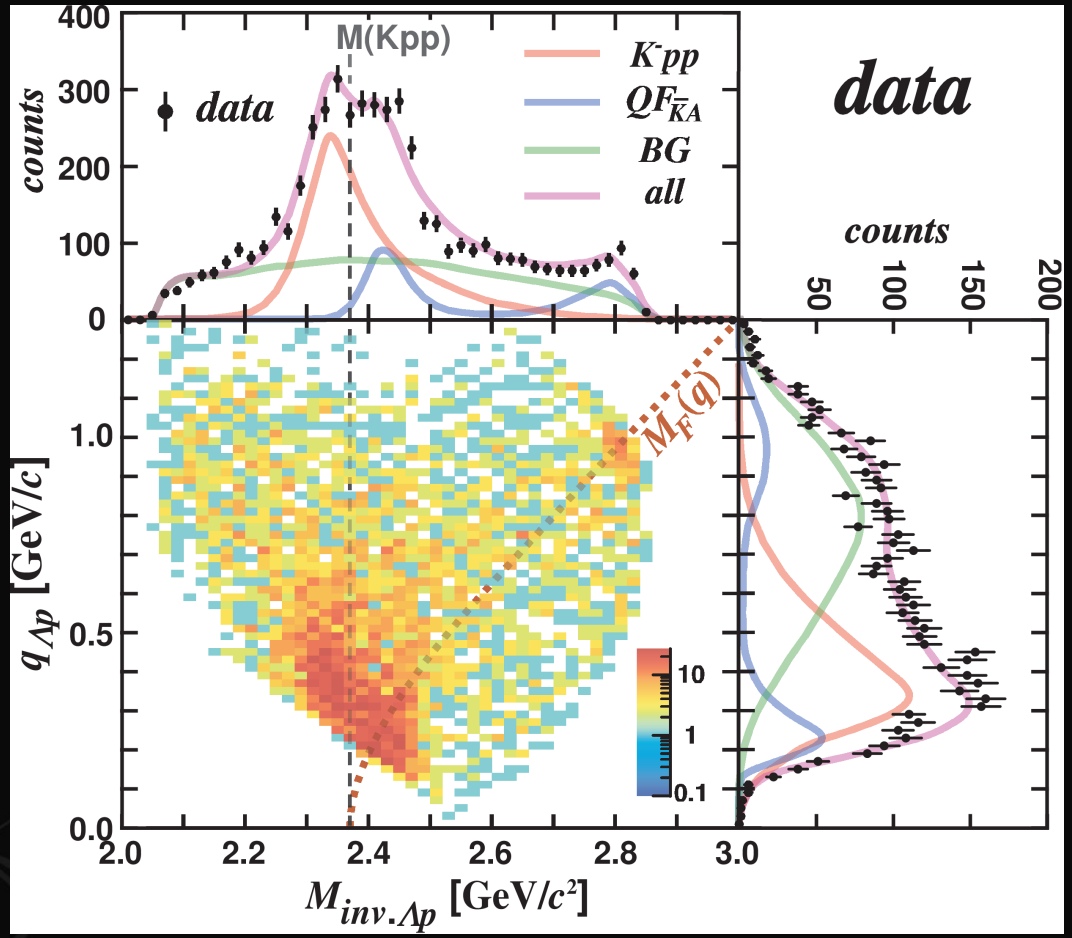

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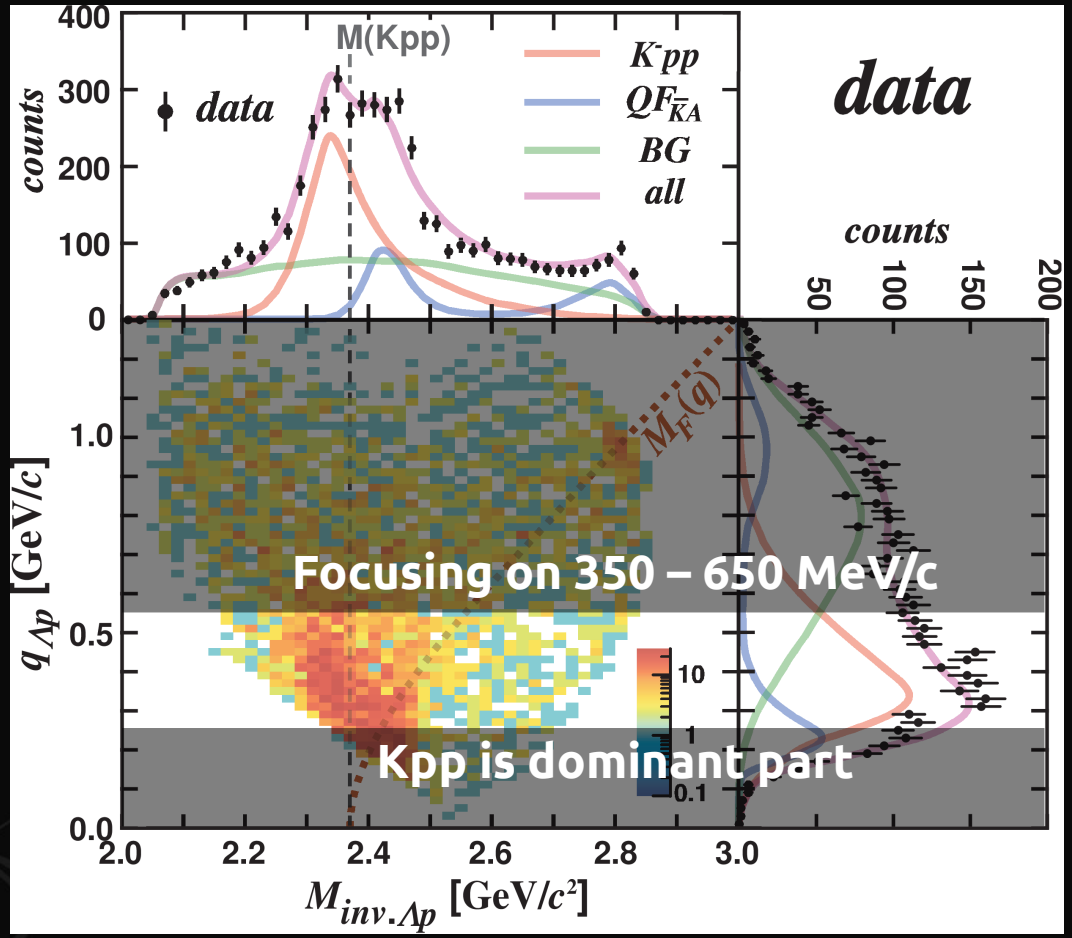

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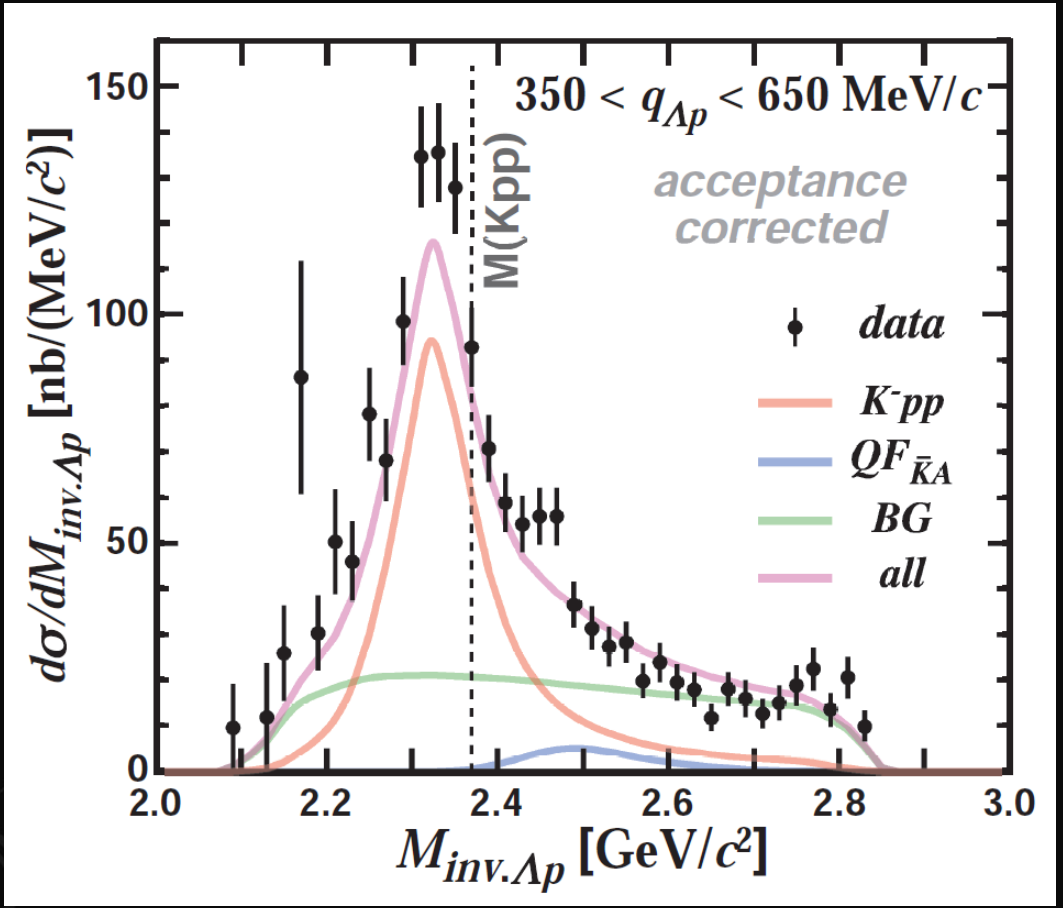


Summary of Λpn analysis

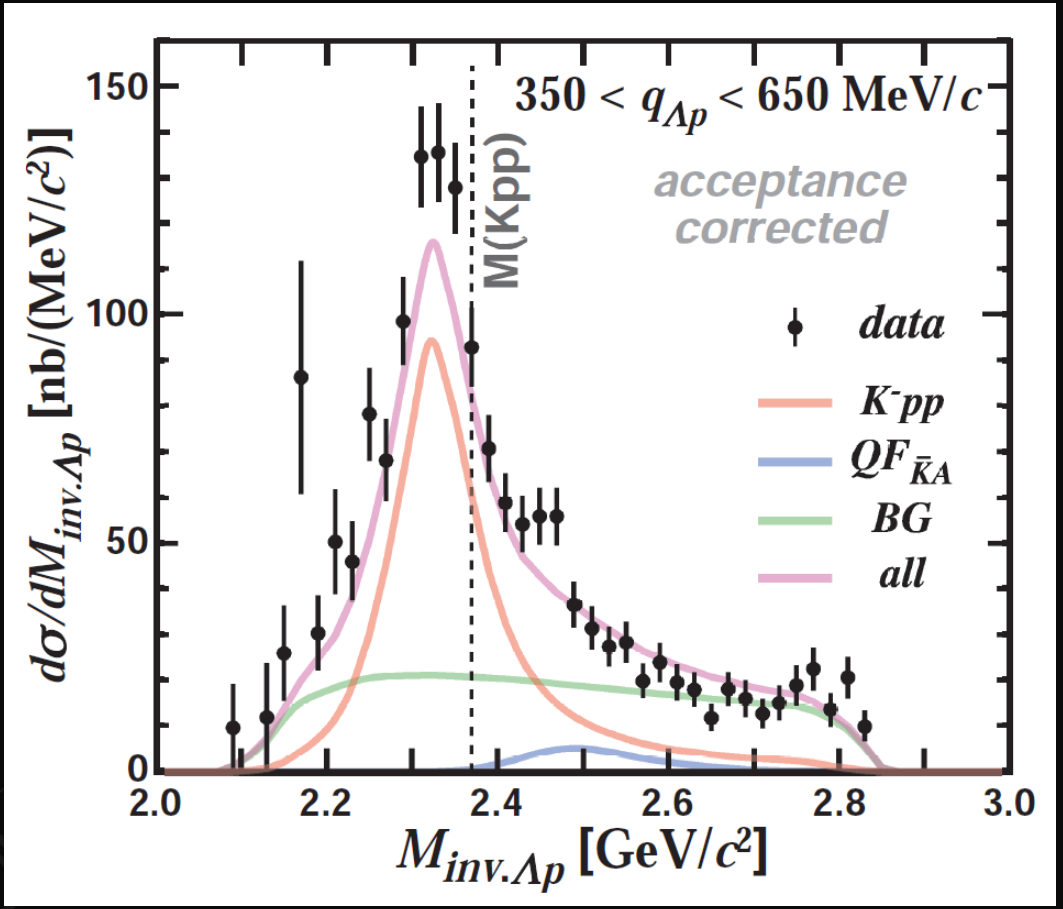
Observed spectrum can be reproduced by three components.

Parameters of Kpp are,

B.E. ~ 50 MeV

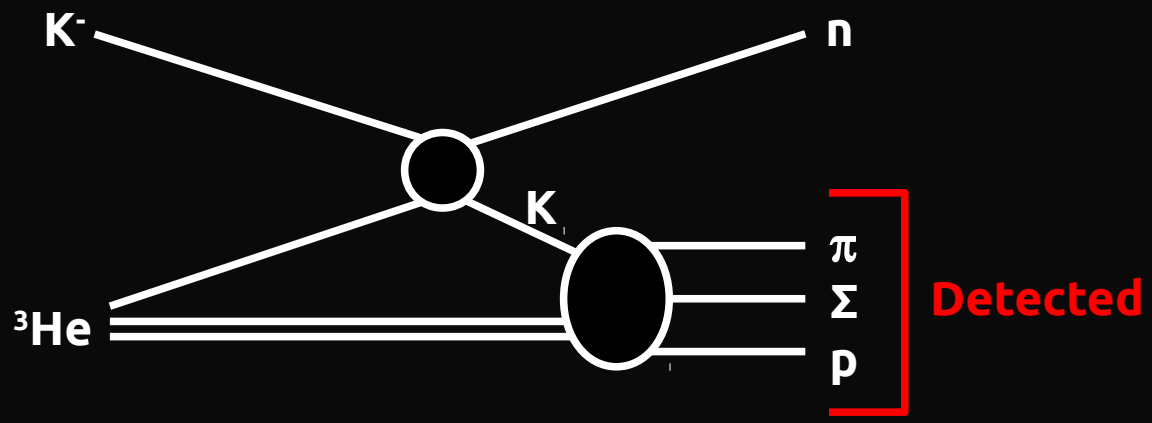
Γ ~ 100 MeV

Q ~ 400 MeV



Exclusive analysis of„

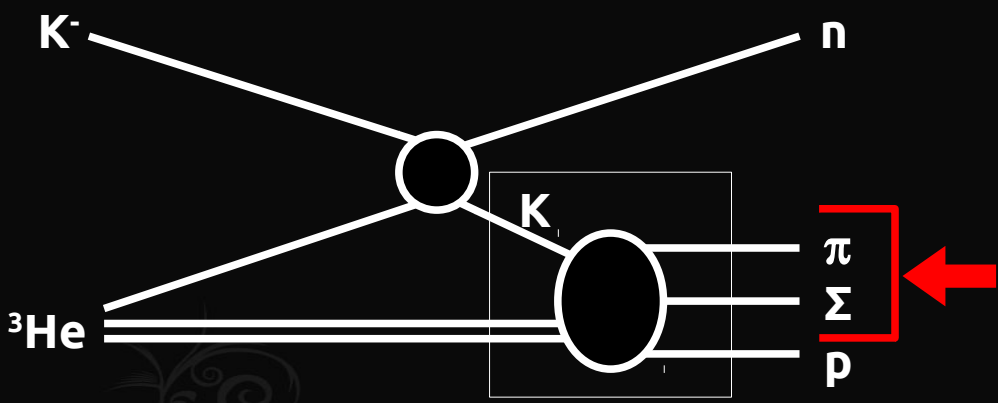
$$K^- + {}^3He \longrightarrow \pi\Sigma p + n$$



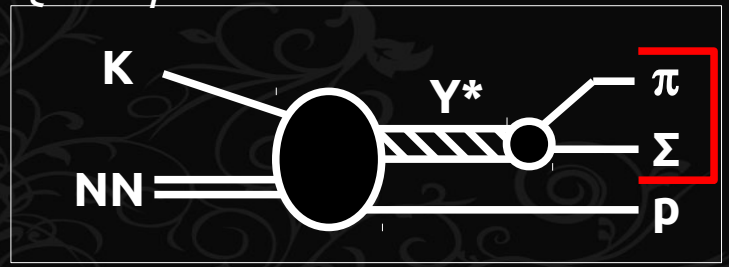
- $K^- + {}^3He \rightarrow \pi\Sigma p + n$ channel
  - Detected : $\pi^+\pi^-np$ ← *Neutron from Σ-decay must be detected!*
  - Missing : n

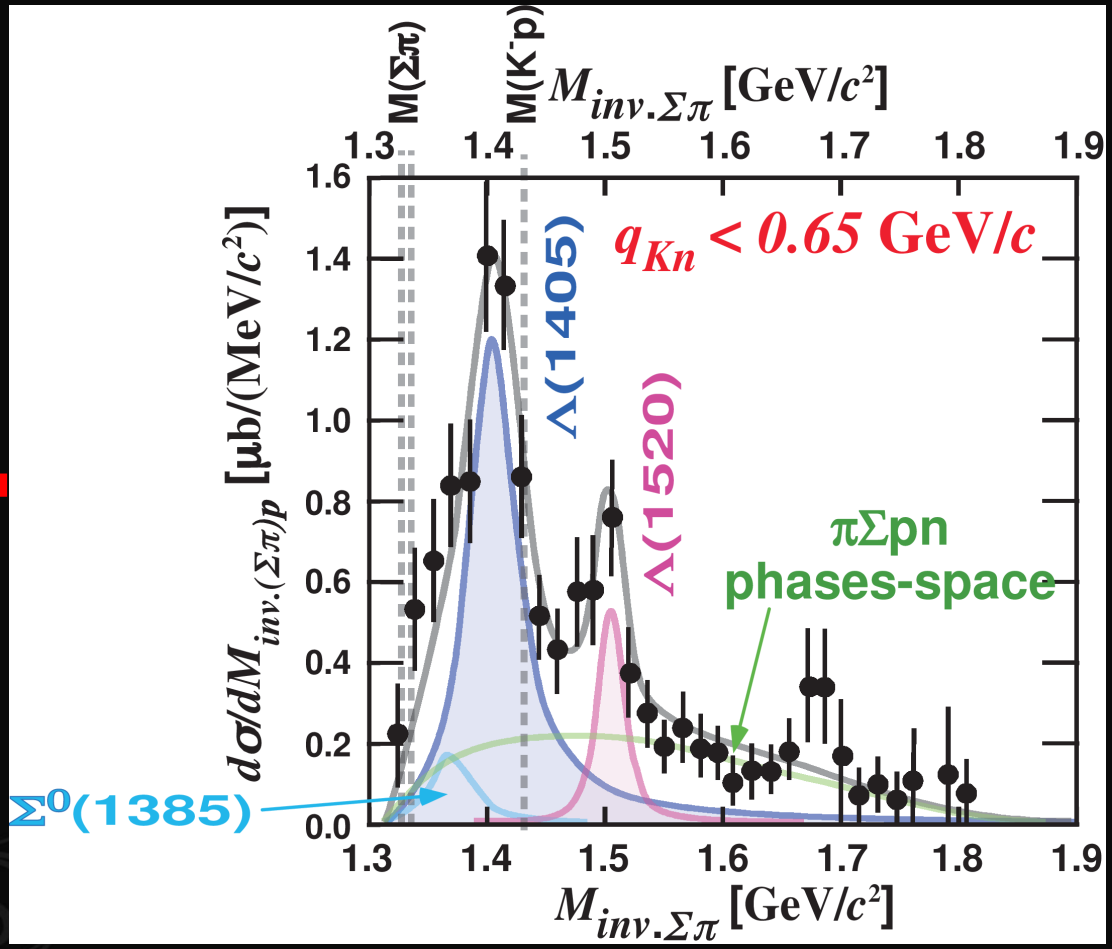
πΣ invariant-mass spectrum

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



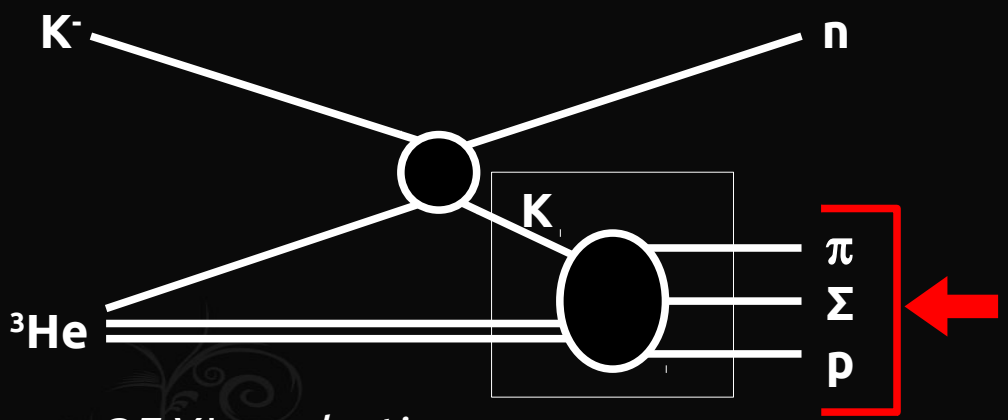
QF-Y production*



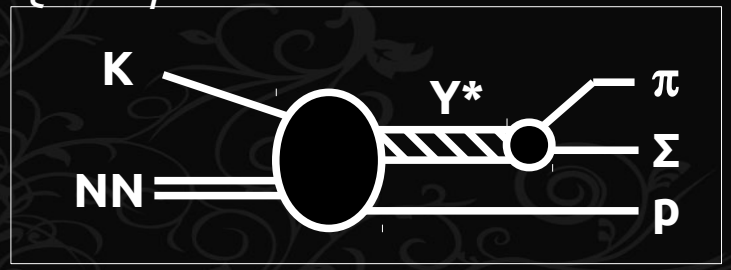


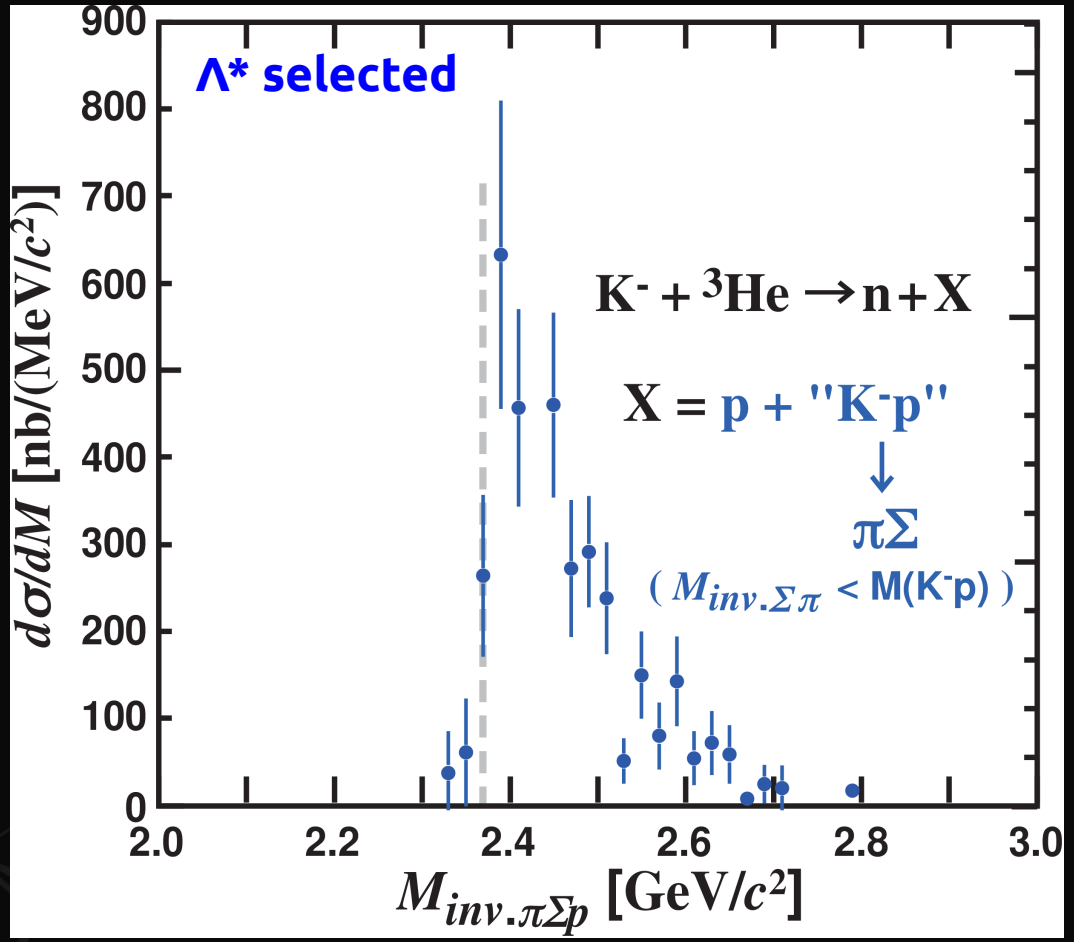
πΣp invariant-mass spectrum

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



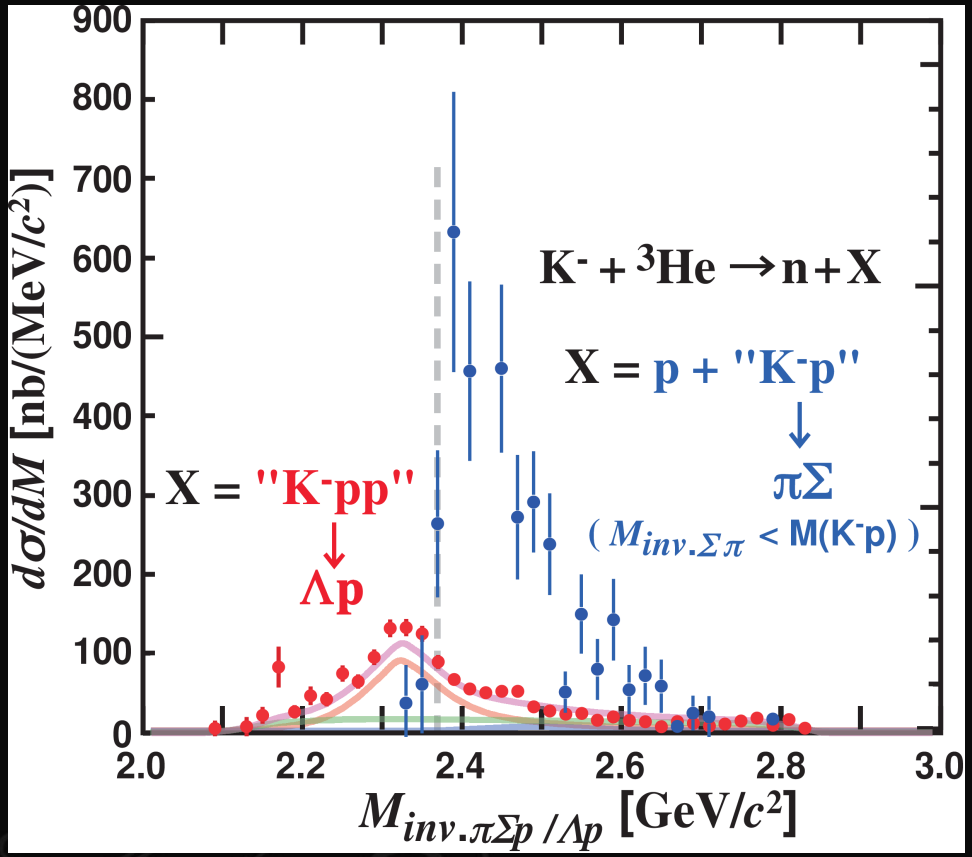
QF-Y production*





Comparison btw. Λp & πΣp

→ Λp + n

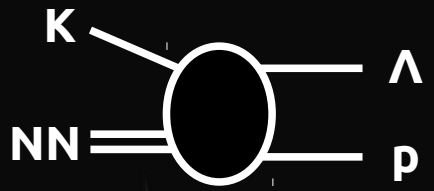


→ πΣp + n

Comparison btw. Λp & πΣp

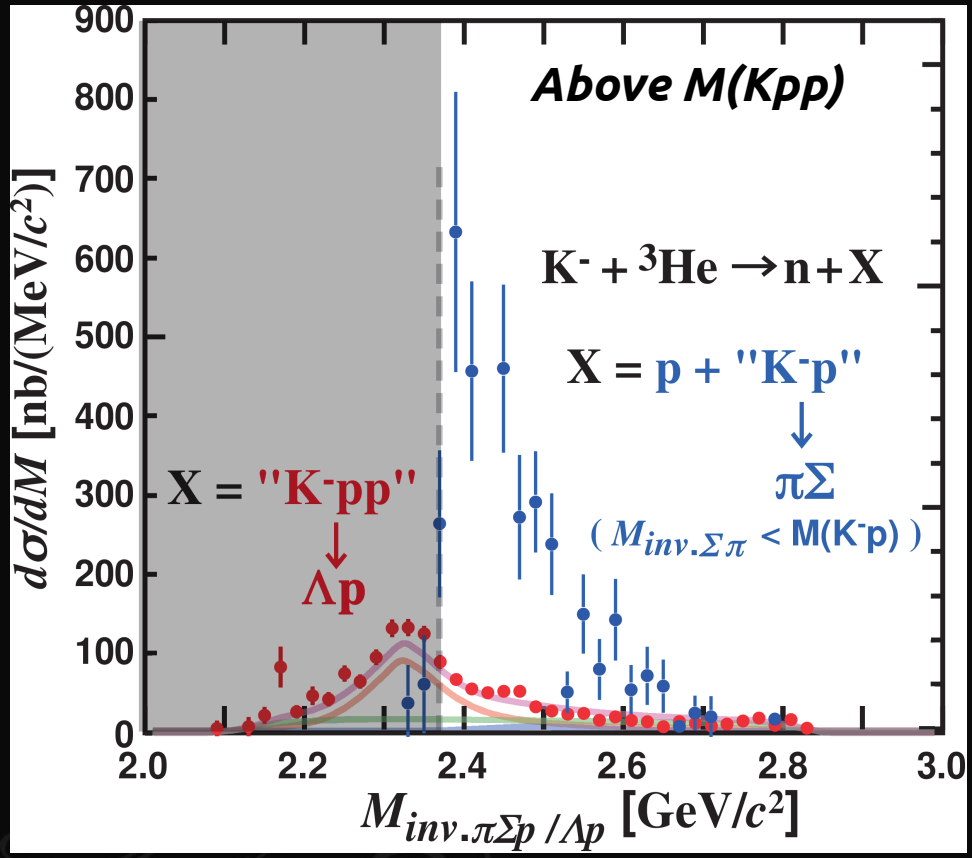
→ Λp + n

*QE-K w/o Y**



QF Y production*

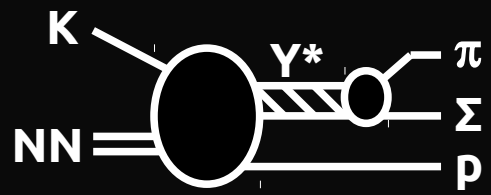
Need conversion



→ πΣp + n

Dominant!

QF Y production*



Comparison btw. Λp & πΣp

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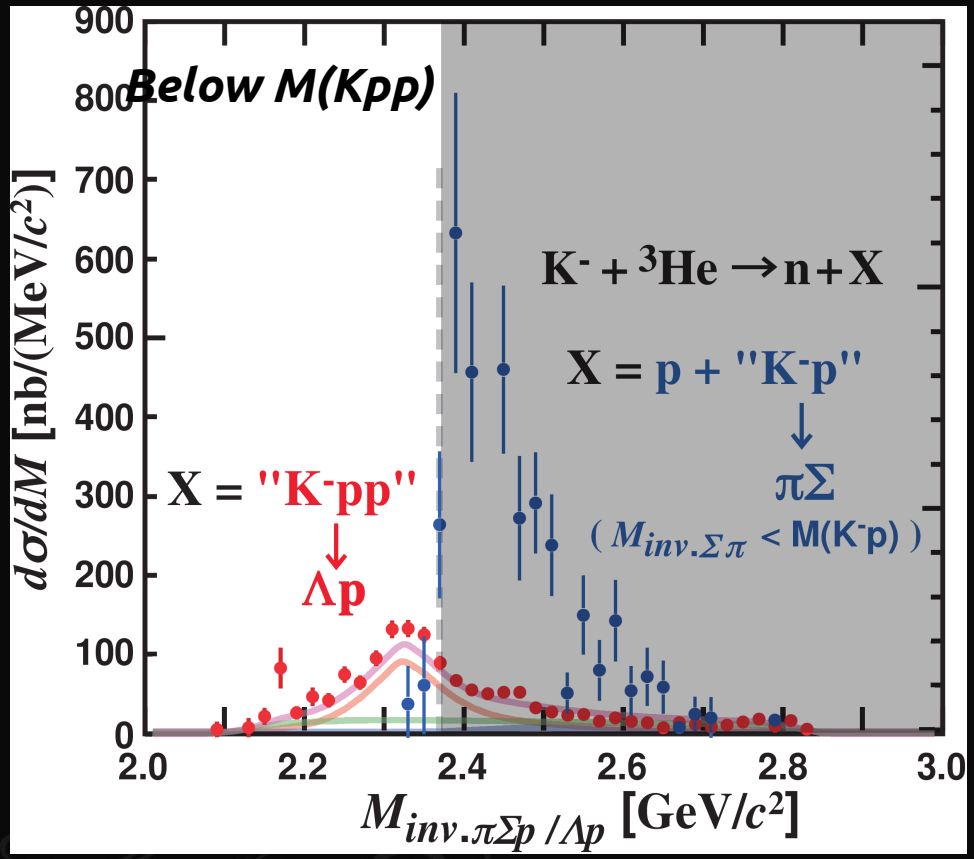
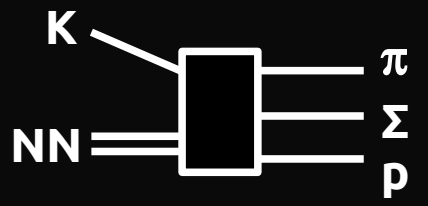
Dominant!

Kpp production



→ πΣp + n

Kpp production



Small phasespace

Conclusion

- Exclusive channel of in-flight (K^-, n) reaction has been studied.
  - Λpn channel
    - Spectrum is reproduced by three components.
    - Kpp production has been observed.
      - B.E. ~ 50 MeV
      - Γ ~ 100 MeV

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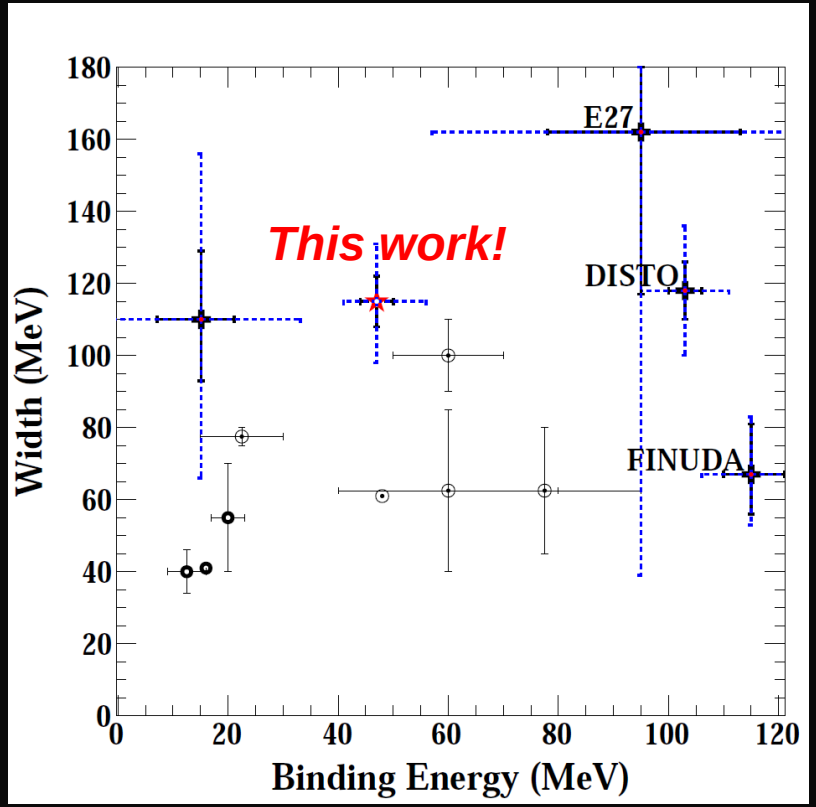
  - πΣp channel
    - QF - Y* production is dominant.
    - Kpp signal is not clearly seen.
      - Due to small phasespace?
      - Need more statistics



Thank you for your attention

J-PARC E15 collaboration

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[17] *Tohoku University, Sendai, 982-0826, Japan and*
[18] *Lund University, Lund, 221 00, Sweden*

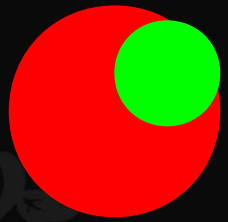
Backup

Question of the KbarN interaction

- Can Kaon be building block?
  - We know that KbarN interaction is strongly attractive!

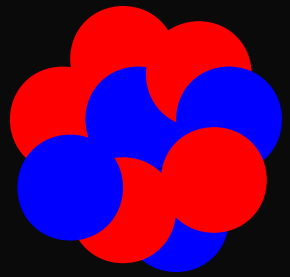
In “hadron”

Λ(1405)

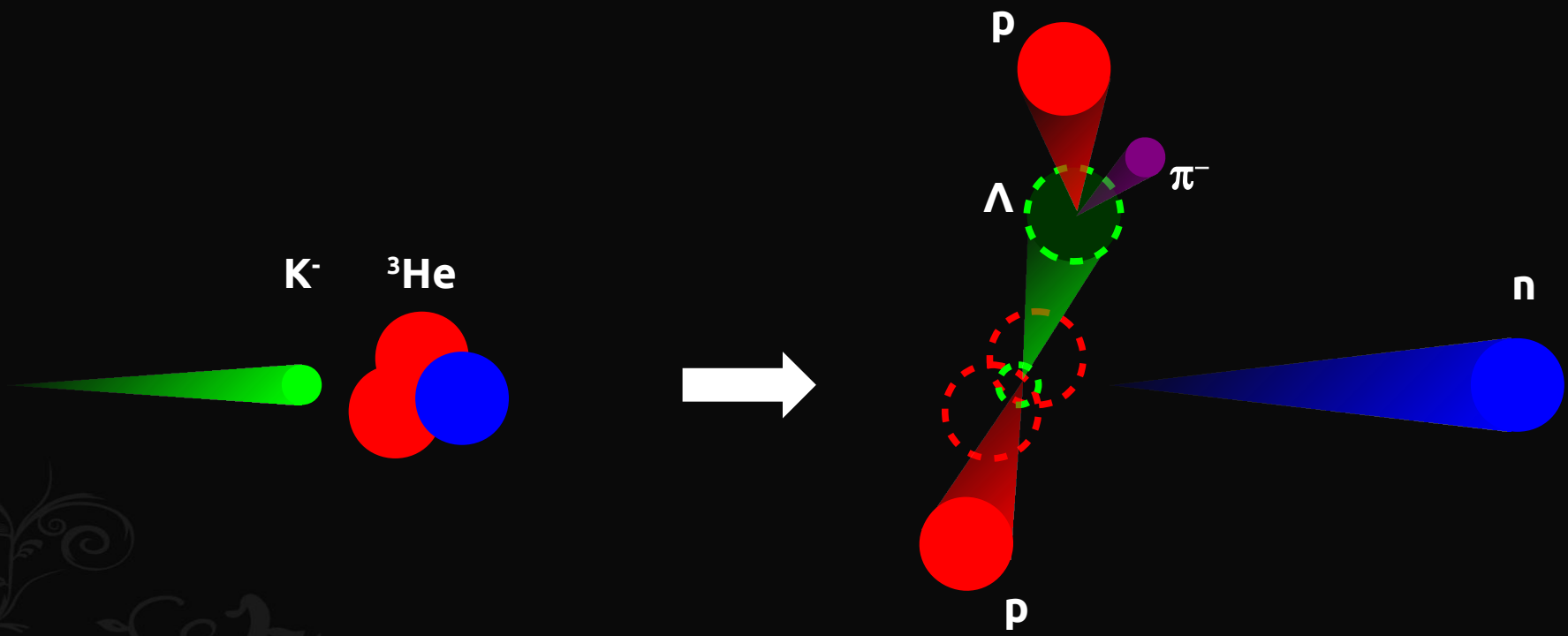


Seems to be
K – N molecule

In “necleus”



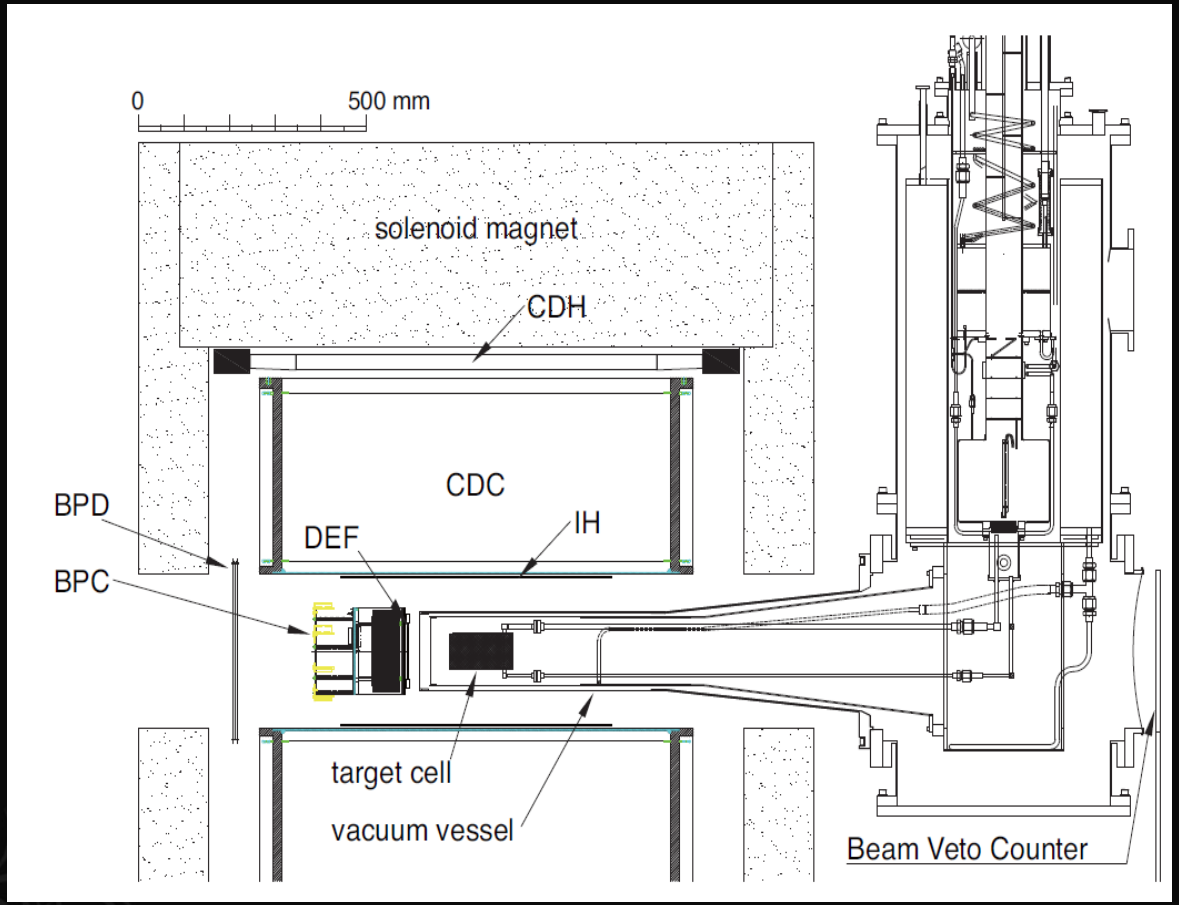
Exclusive analysis



CDS analysis

- Momentum analysis
  - Solenoid magnet & CDC
- PID
  - TOF & momentum
- Demonstration
  - Λ and K^0 reconstruction

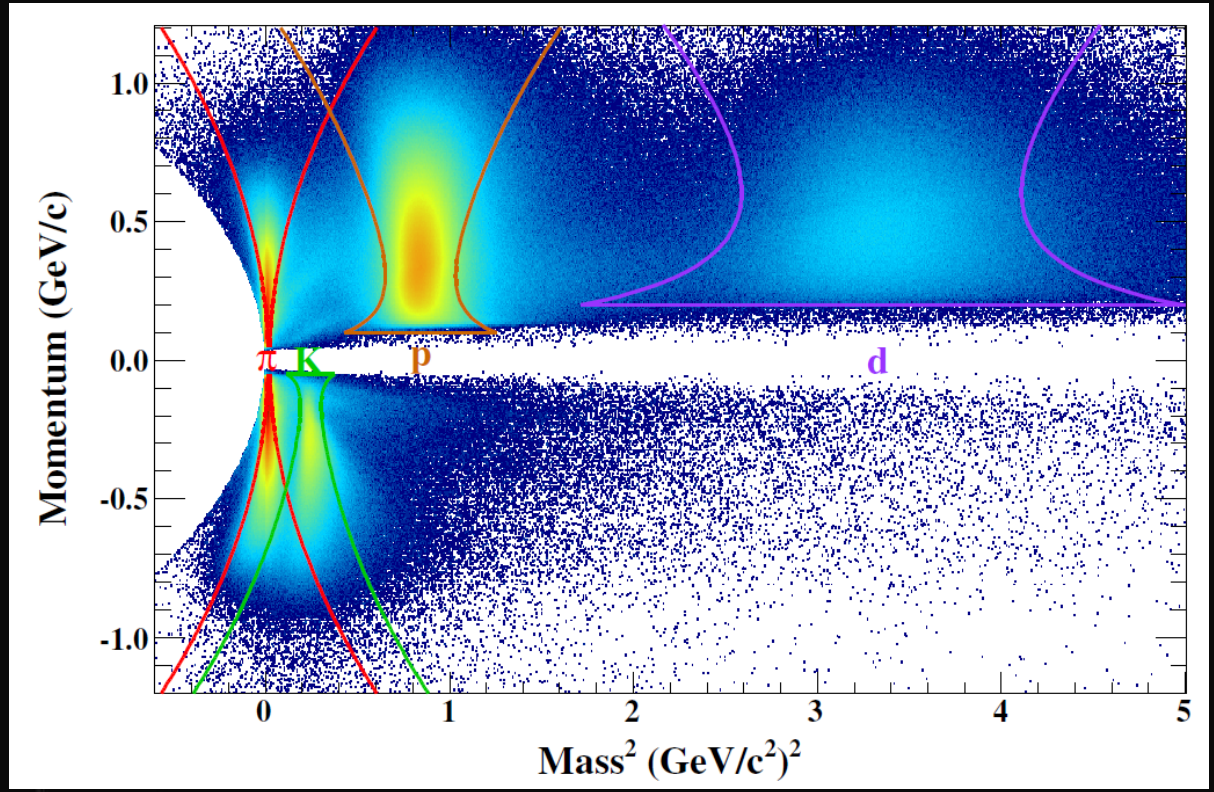
Cylindrical detector system



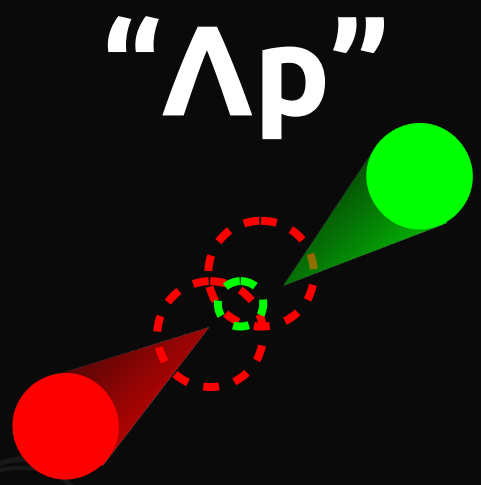
CDS analysis

- Momentum analysis
  - Solenoid magnet & CDC
- PID
  - TOF & momentum
- Demonstration
  - Λ and K^0 reconstruction

Momentum vs. mass



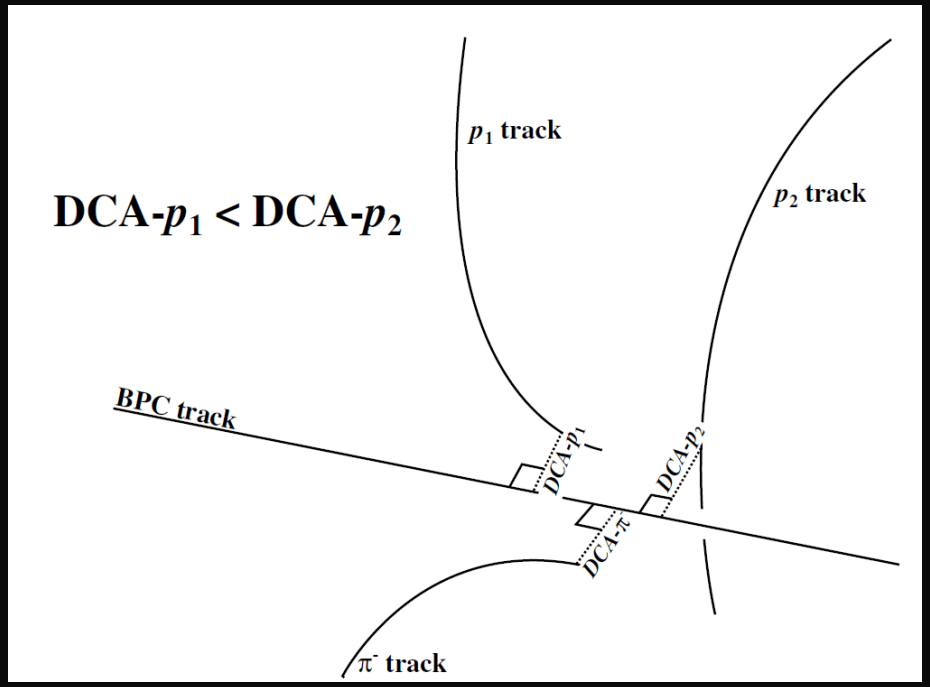
How to find the Kpp?



- Catch **Λ** and **p**
  - PID and momentum measurement
- Select the reaction
  - Λpn final state with missing-mass method
- Look at Λp spectrum
  - Is there peak?

Λ identification

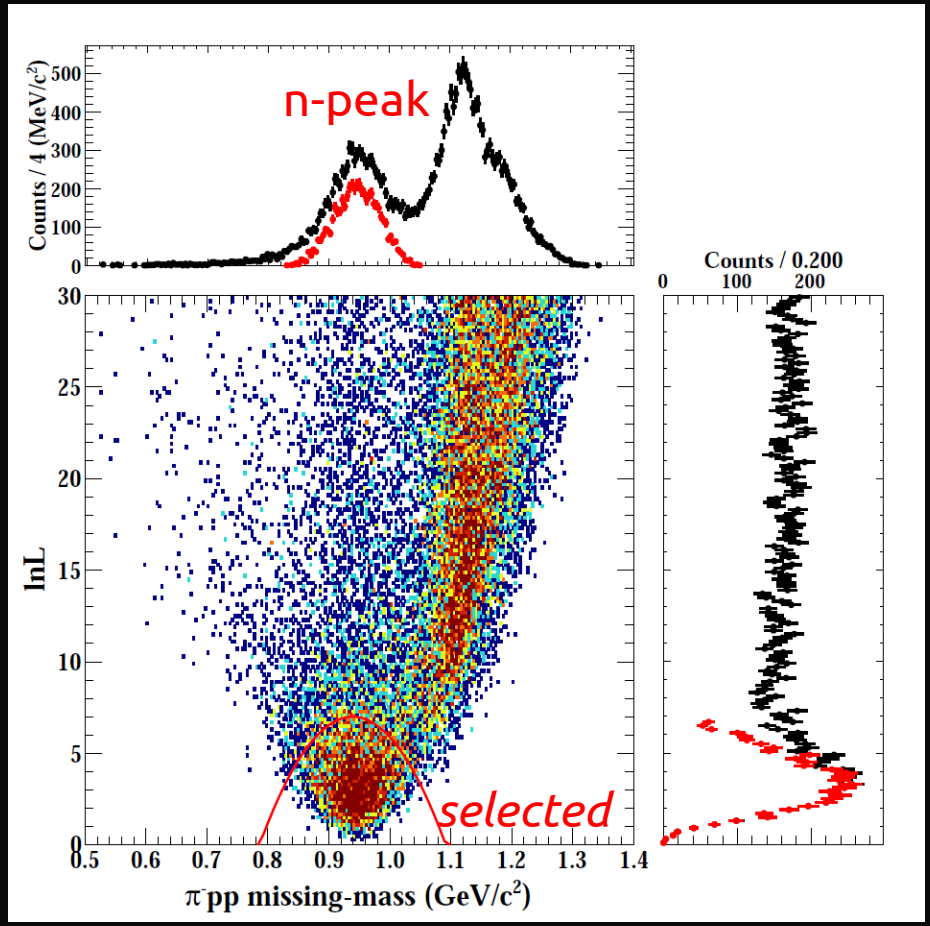
- Identify the proton from Λ-decay
  - πp invariant-mass
  - DCA informations



Λ identification

- Identify the proton from Λ-decay
  - πp invariant-mass
  - DCA informations
- $K^- + {}^3He \rightarrow \Lambda p + n$ event selection
  - Using log-likelihood function
    - DCA informations
    - p-value of the kinematical fit
- Purity?

$^3He(K^-, \pi pp)"X"$ vs. lnL



Purity of final sample

- Evaluated by using MC simulation
  - Signal
    - $\Lambda pn \rightarrow \pi^- ppn$
  - Background
    - $\Sigma^0 pn \rightarrow \gamma \Lambda pn \rightarrow \gamma \pi^- ppn$
    - $\Sigma^- pp \rightarrow \pi^- npp$
    - $\Lambda \pi^0 pn \rightarrow \pi^0 \pi^- ppn$
    - ...

Neutral particles are invisible.

All of them looks the same final state, $\pi^- ppn$

Purity of final sample

- Evaluated by using MC simulation
  - Fitting the spectra

- Signal : 72 %
- Background : 28 %
  - Acceptable S/N ratio

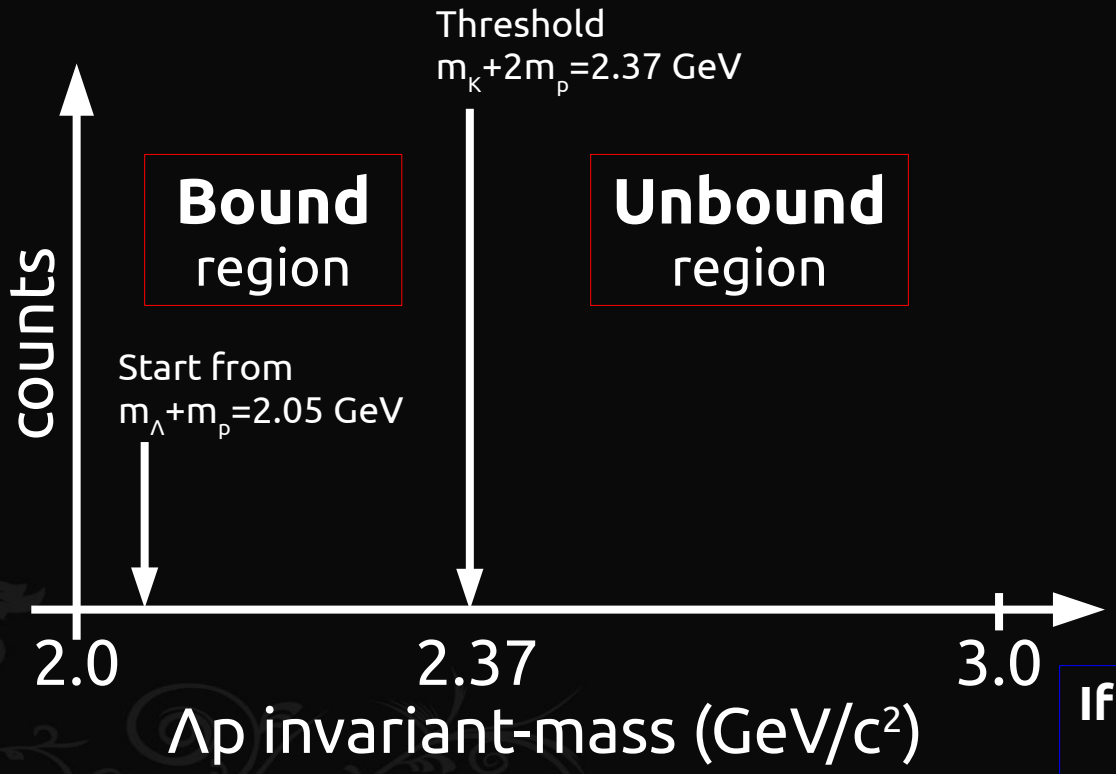
Next

Lets see Λp invariant-mass!

name	ratio
Λpn	72%
Σ^-pp	8.4%
Σ^0pn	18%
ΛNN + π	1.1%
ΣNN + π	0.3%

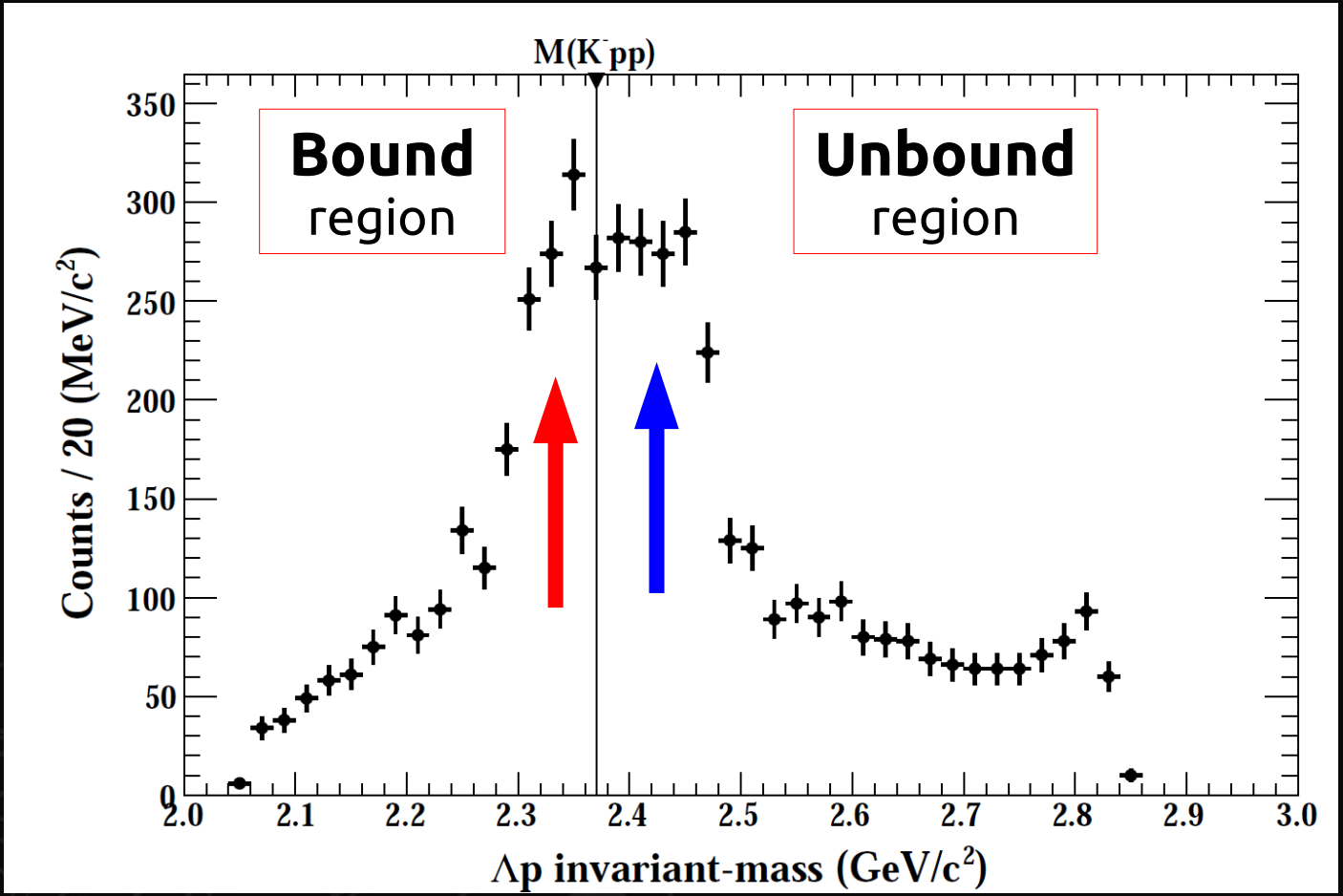
Before showing Λp invariant-mass...

- How does it look? **Peak in bound region?**



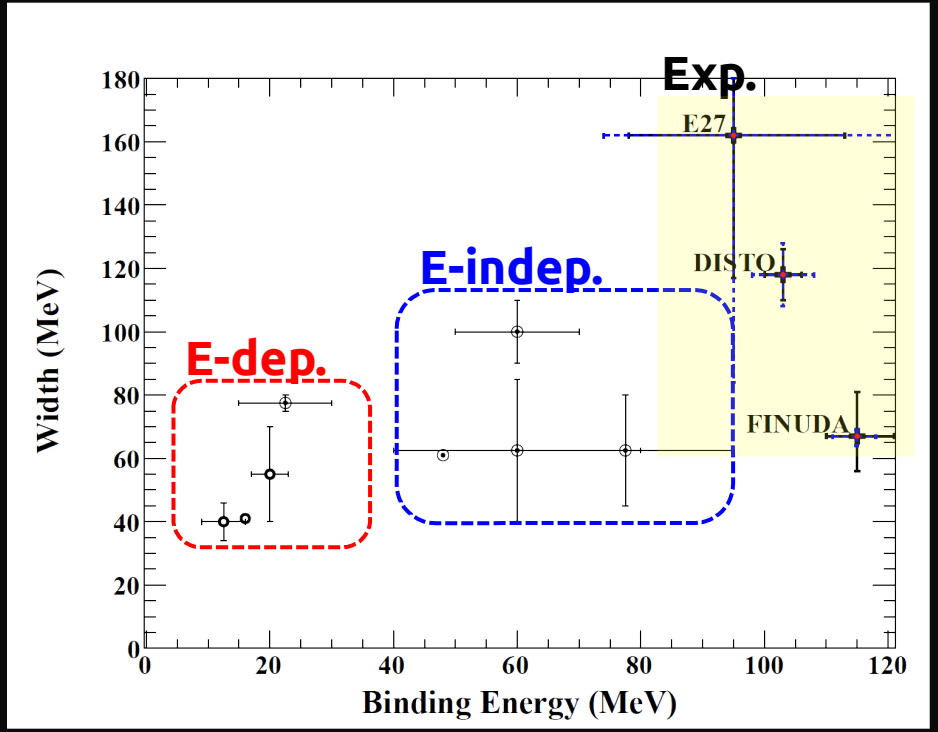
If Kpp formed,
$m_{Kpp} = m_K+2m_p$-B.E.

Λp invariant-mass spectrum



Situation of Kpp

- Theoretical studies
  - Exist!
  - But, B.E. & Γ widely distribute
- Experimental studies
  - Larger B.E.?
  - Really Kpp signal?



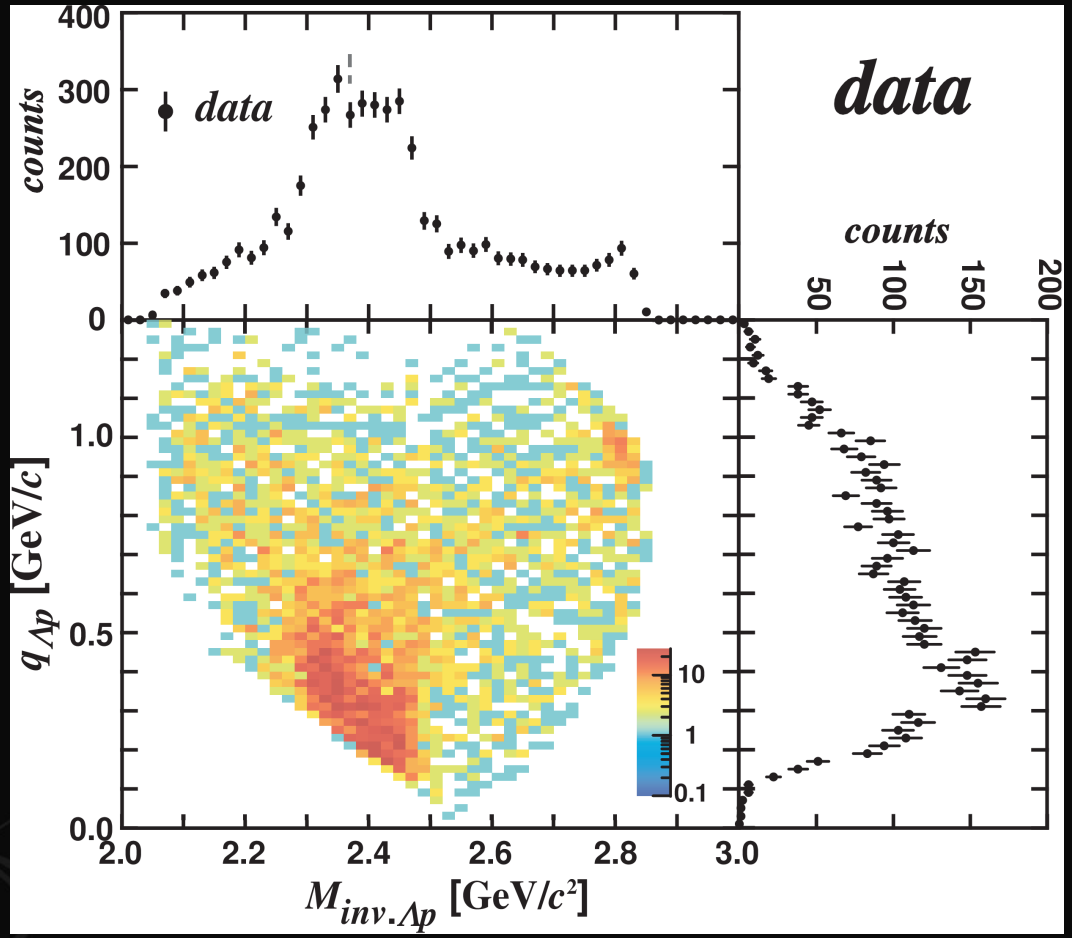
Fitting the spectrum

Fitting functions

1) Quasi-elastic Kaon

2) Kpp bound state

3) Broad background

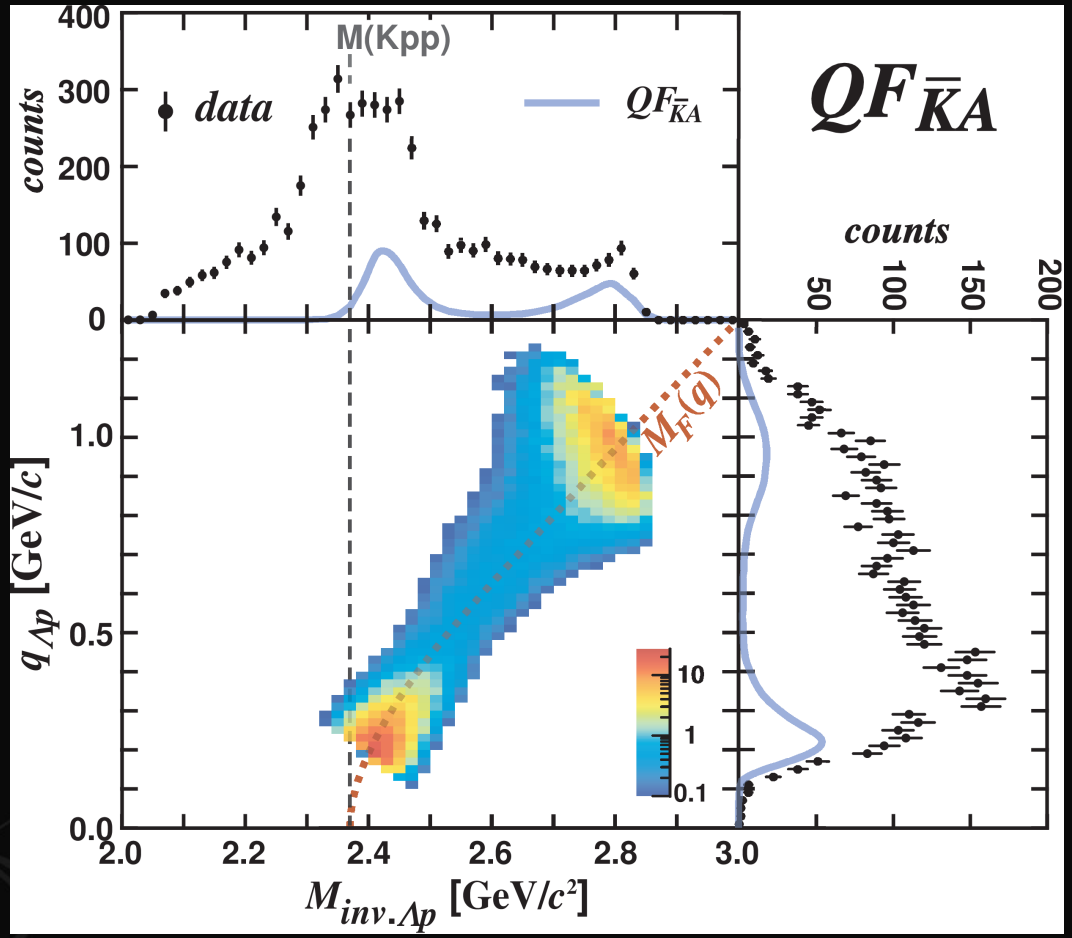


Fitting the spectrum

Fitting functions

1) Quasi-elastic Kaon

- Gaussian peak
- Moving with q



Fitting the spectrum

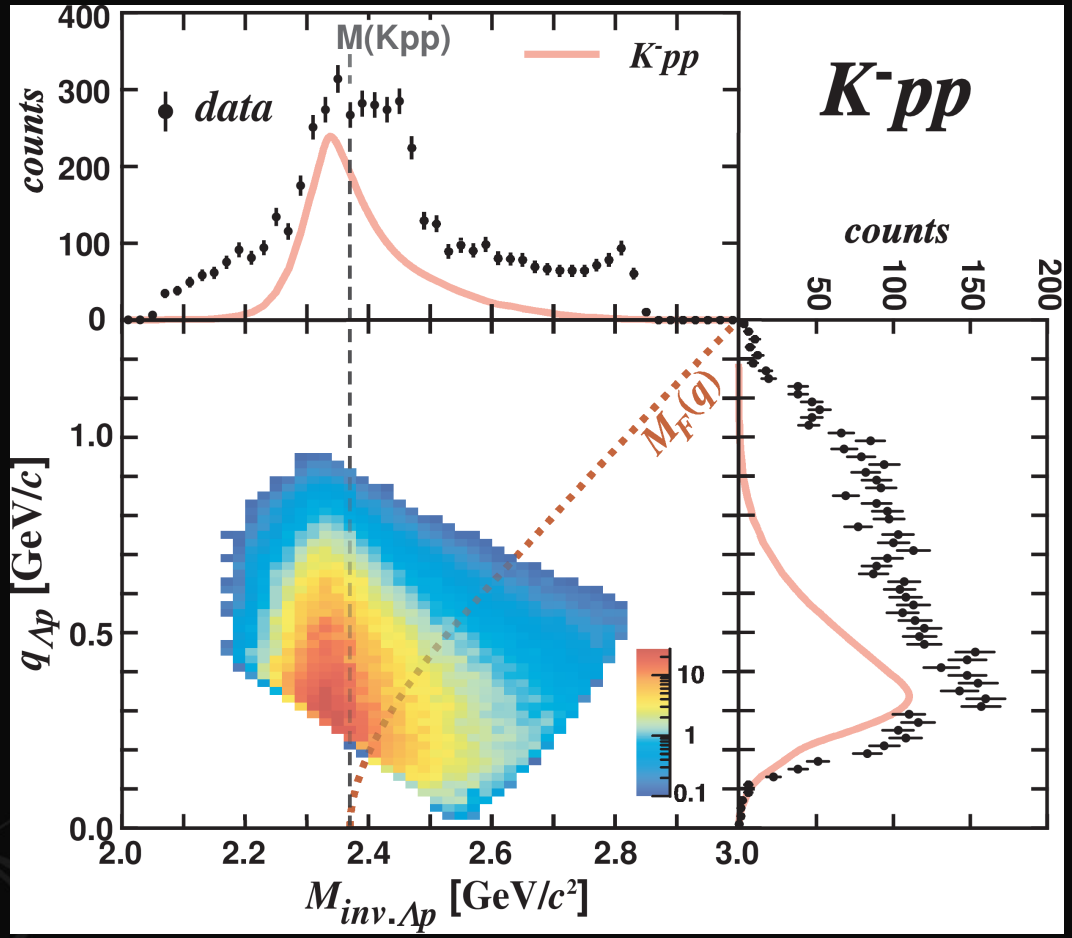
Fitting functions

1) Quasi-elastic Kaon

- Gaussian peak
- Moving with q

2) Kpp bound state

- Breit-Wigner peak
- Independent on q



Fitting the spectrum

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1) Quasi-elastic Kaon

- Gaussian peak
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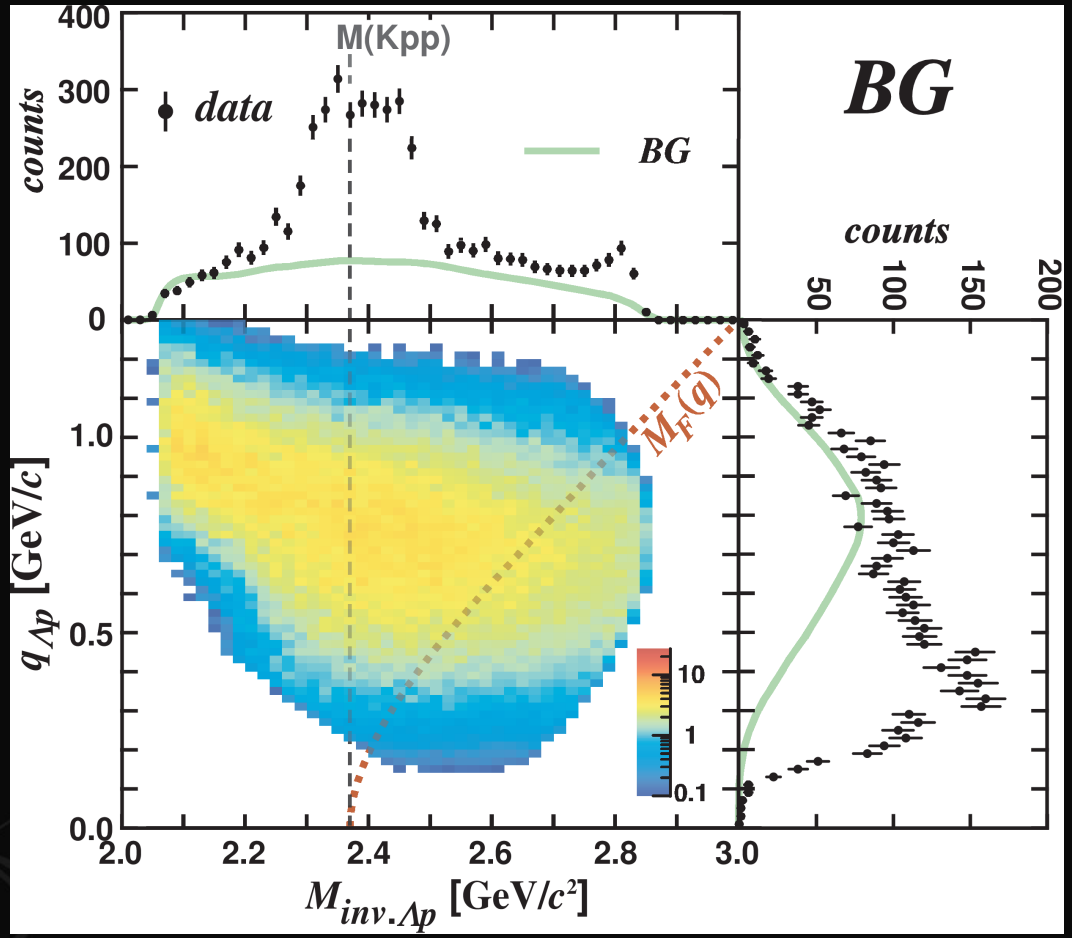
- Breit-Wigner peak
- Independent on q

3) Broad background

- Small m dependence
- distribute in higher q region



Fitting the spectrum

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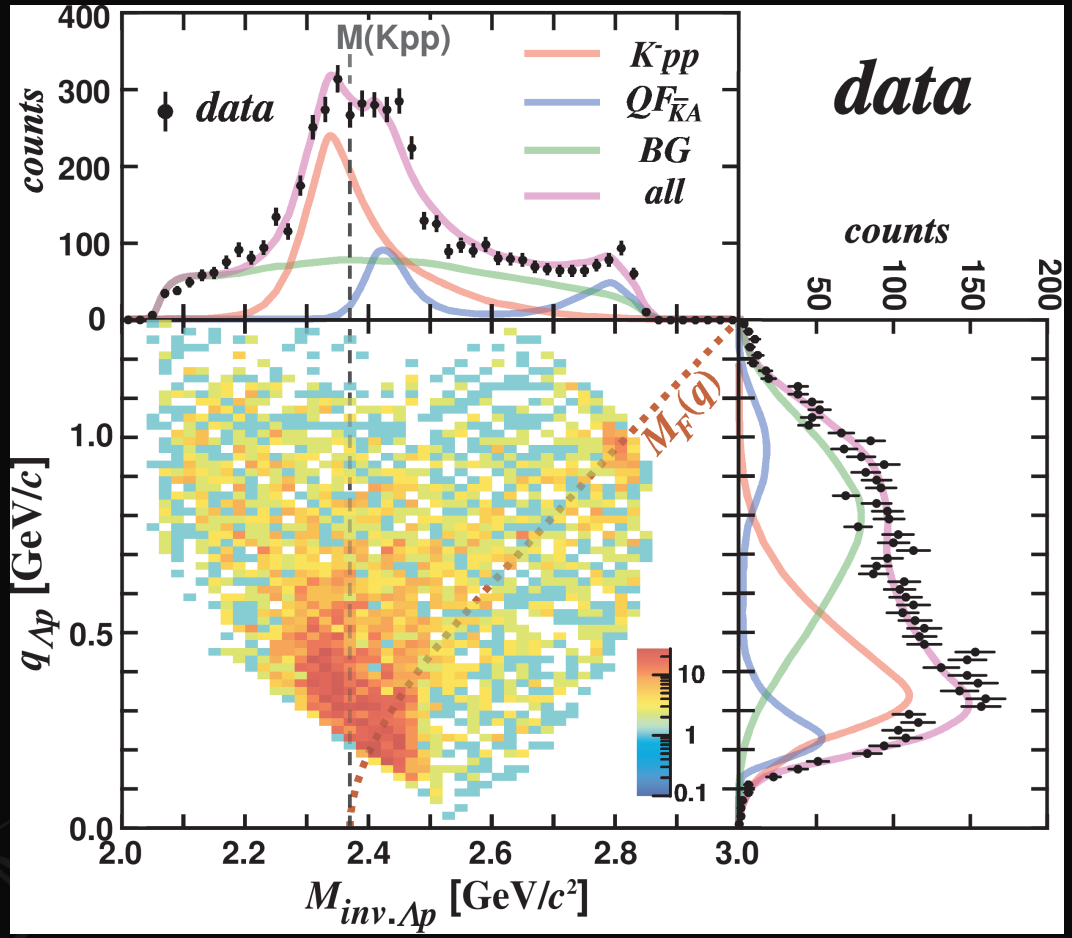
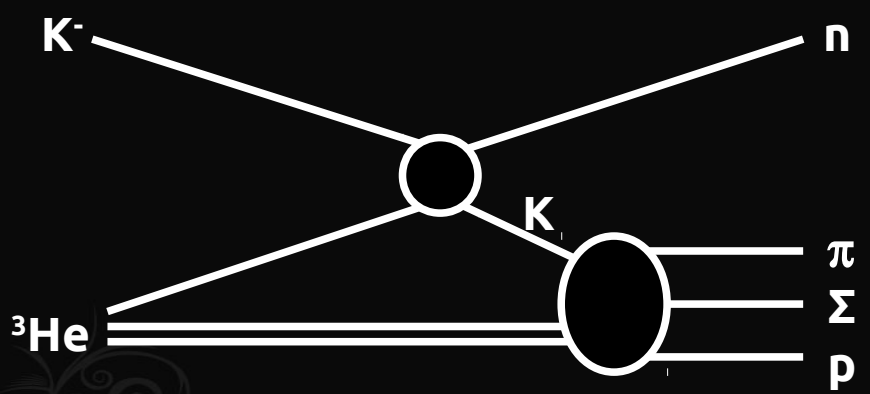


Λ* door-way?

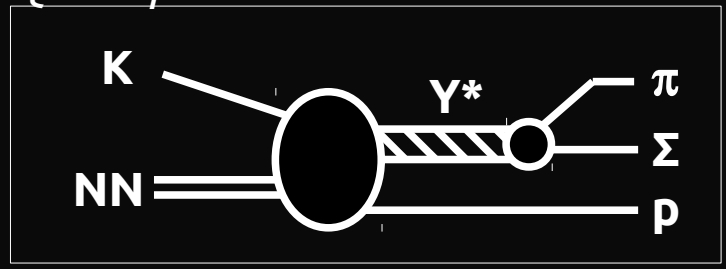
$$K^- + {}^3He \longrightarrow \pi\Sigma p + n$$



Results from M(πΣ) spectrum

- I=0 dominant
- ~100 μb Λ(1405) production

QF-Y production*



Part of Y production*

Kpp production