Study of "Kpp" bound state in d(K^-, Λp)π^- reaction at K1.8BR E31 experiment

ＪーＰＡＲＣハドロン研究会　２０２２

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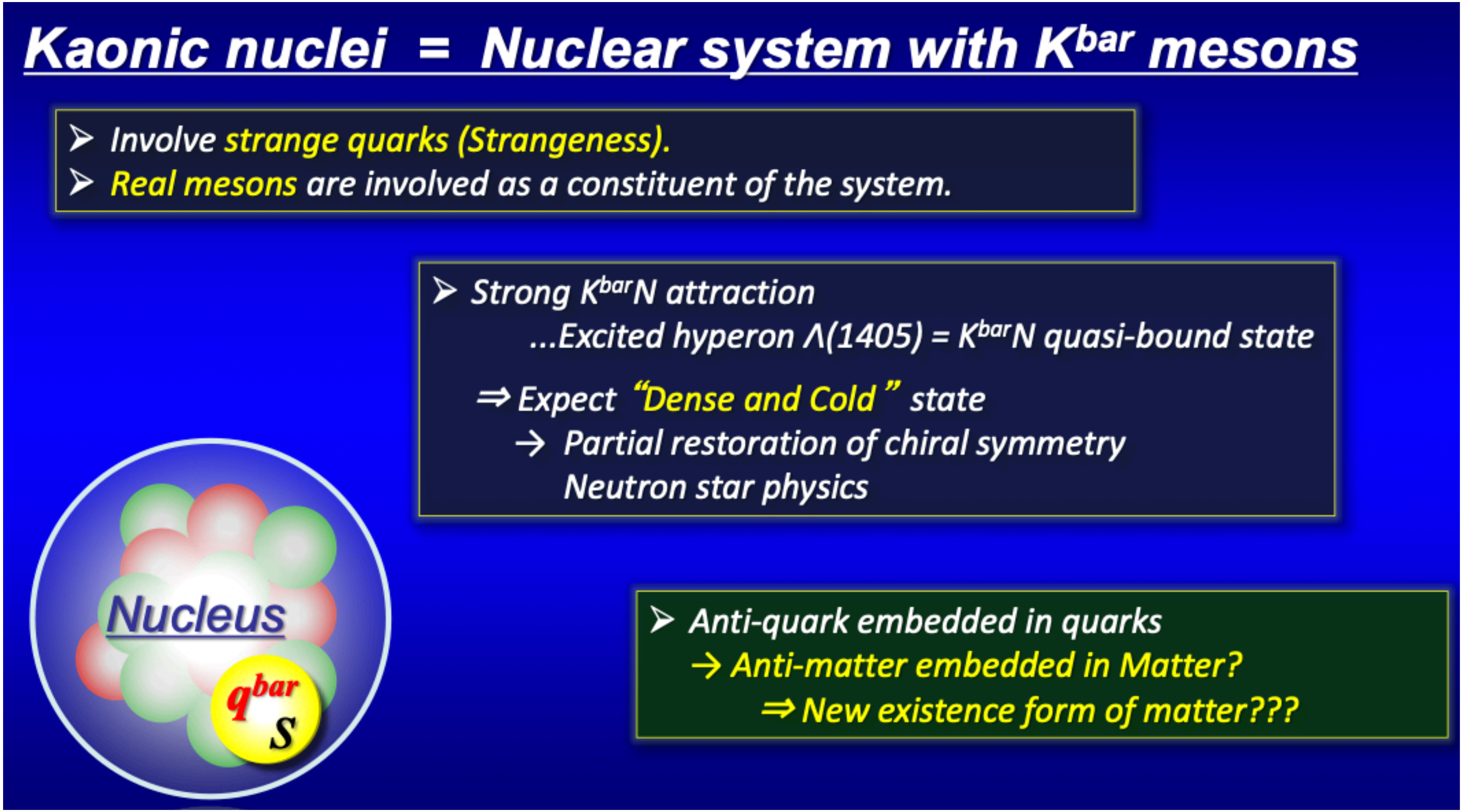
RIKEN

Mar/ 22/ 2022

2022.02.16 HEF-ex workshop 土手さんスライド



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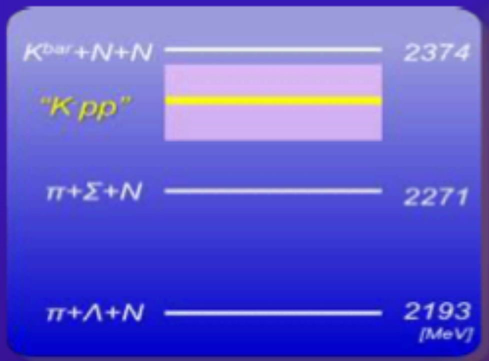
“K^-pp” = the simplest kaonic nucleus

- $K^{bar}N$ potential is so attractive to generate a quasi-bound state, Λ(1405).
- K^{bar} meson can be bound in a nucleus: Kaonic nuclei.
- Among them, the three-body system “K^-pp” is a prototype of kaonic nuclei.

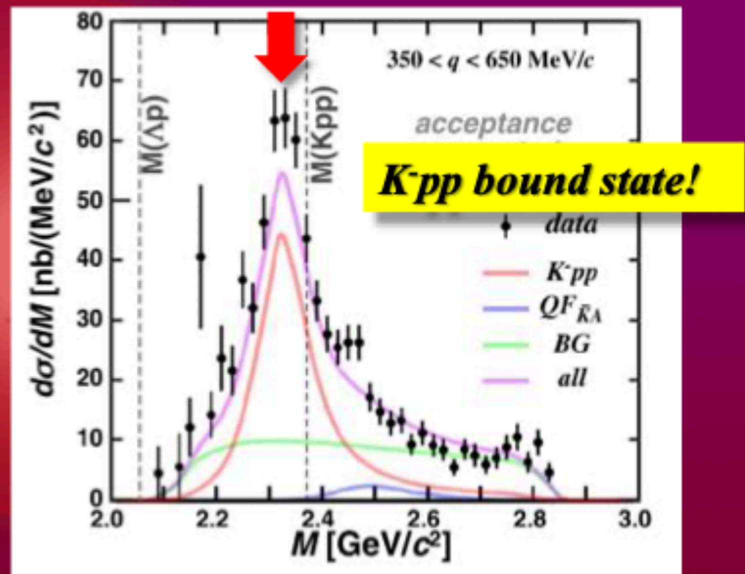
Theoretical studies:
“K^-pp” = $K^{bar}NN$-πΣN-πΛN ($J^\pi=0^-$, T=1/2)



- Akaishi, Yamazaki, PRC76, 045201 (2007)
- Shevchenko, Gal, Mares, PRC76, 044004 (2007)
- Wycech, Green, PRC79, 014001 (2009)
- Doté, Hyodo, Weise, PRC79, 014003 (2009)
- Ikeda, Kamano, Sato, PTP124, 533 (2010)
- Barnea, Gal, Liverts, PLB712, 132 (2012)
- Bayar, Oset, PRC88, 044003 (2013)
- Revai, Shevchenko, PRC90, 034004 (2014)
- Doté, Inoue, Myo, PLB784, 405 (2018)
- ...

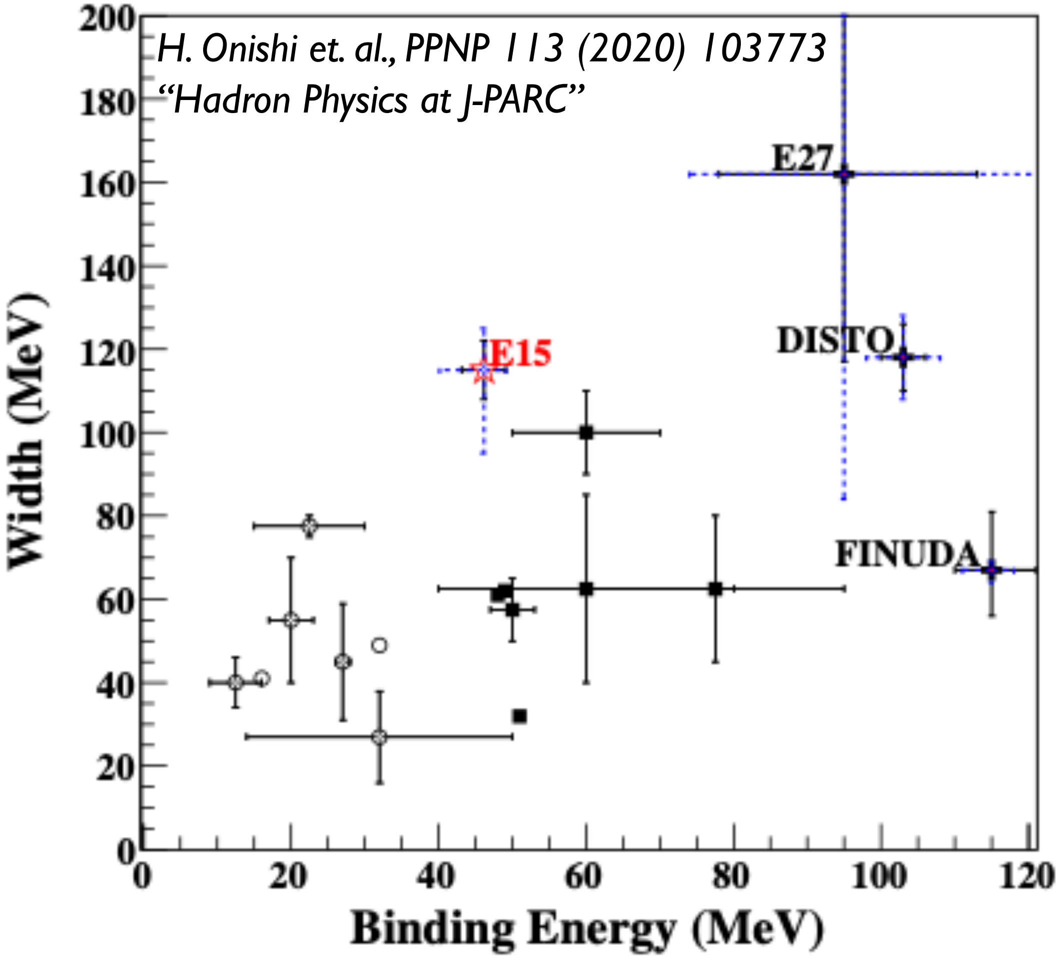
“K^-pp” should exist as a resonant state between $K^{bar}NN$ and πΣN thresholds.

J-PARC E15 (2^{nd} run):
Exclusive exp. $^3He(K^-, \Lambda p)n_{missing}$



S. Ajimura et al., PLB 789, 620 (2019)

Theories and experiments



- E15 at K1.8BR

  $^3He(K^-, \Lambda p)n$

- E27 at K1.8

  $d(\pi^+, K^+)\Lambda p$ / $\Sigma^0 p$

Inverse reaction $dK^- \rightarrow \Lambda p \pi^-$ has be taken at K1.8BR.

- DISTO

  $pp \rightarrow p \Lambda K^+$

- FINUDA

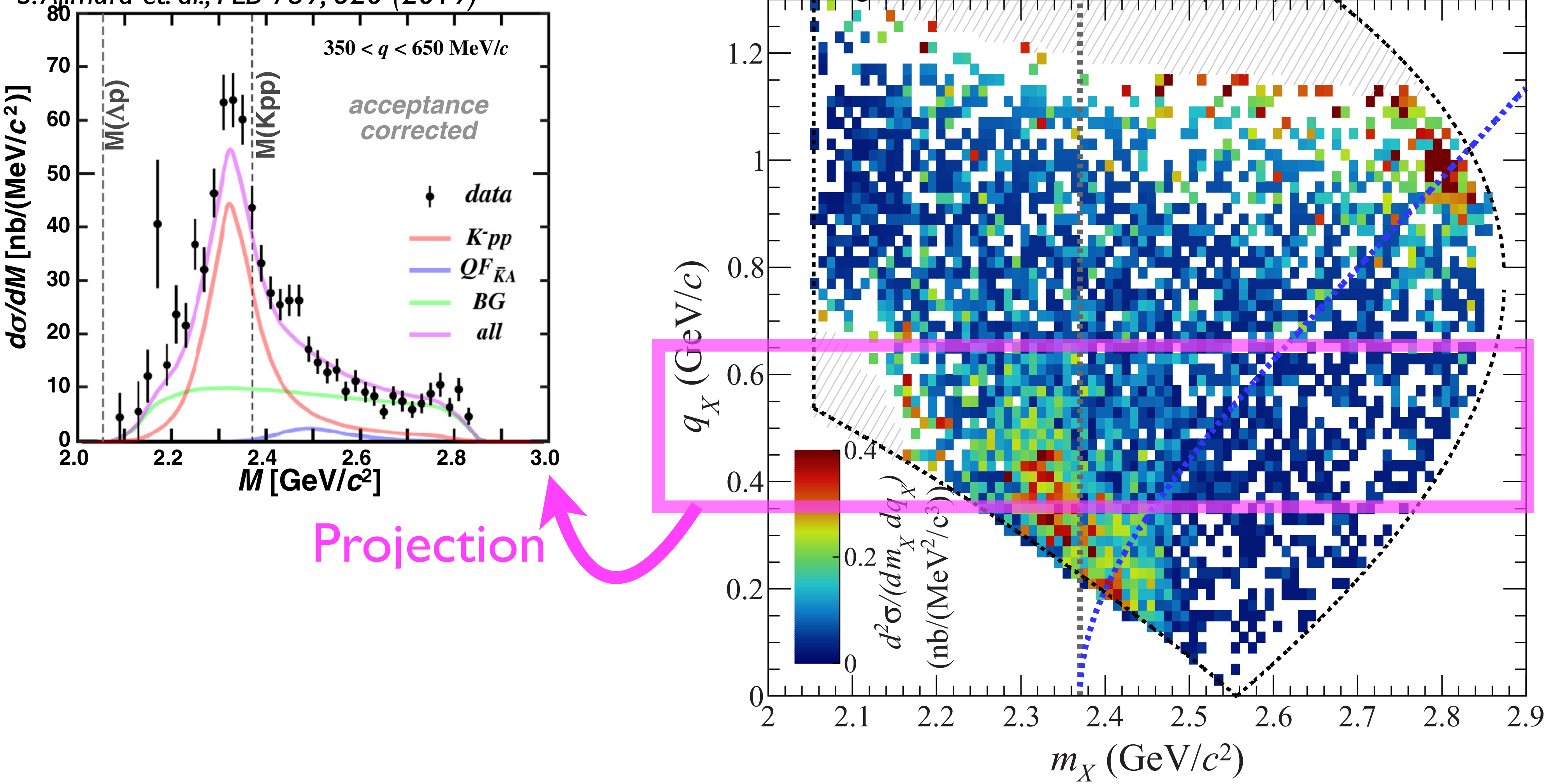
  $(K_{stop}^+, \Lambda p)$

J-PARC E15 exp. $^3He(K^-,\Lambda p)n$

S. Ajimura et. al., PLB 789, 620 (2019)

J-PARC E15 exp. $^3He(K^-,\Lambda p)n$

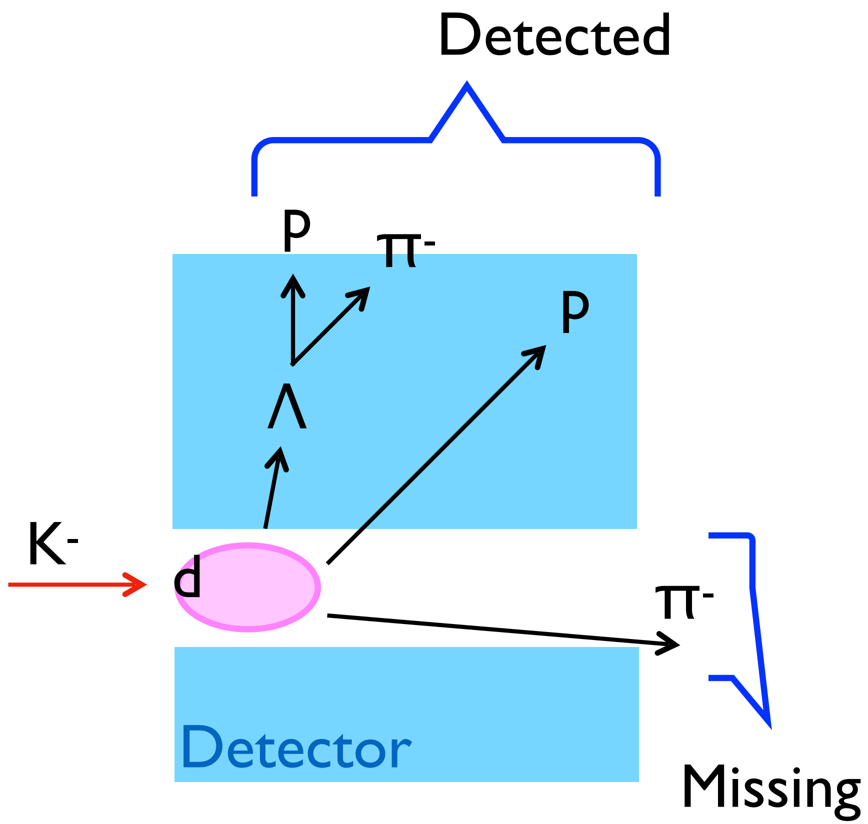
T.Yamaga et. al., PRC 102, 044002 (2020)



- Momentum transfer q
  $q(\Lambda p) = p_k - p_n$

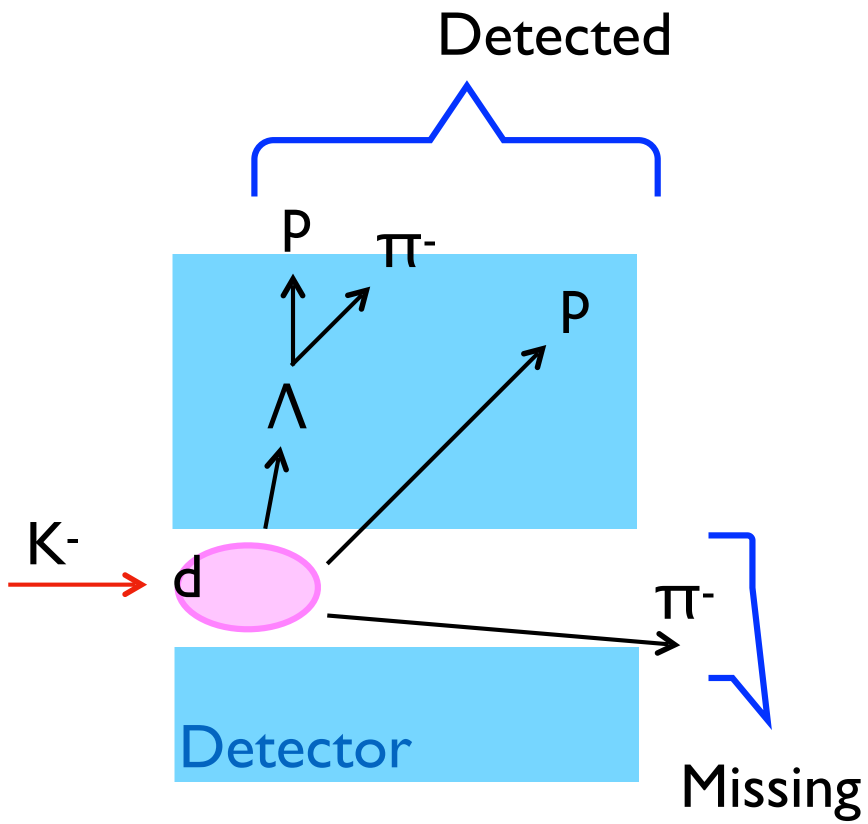
E15 exp. often showed 2D plot of q vs mass.

d(K-, Λp)π- reaction



- Detect Λp .
- π^{-} Missing.

Λp distribution



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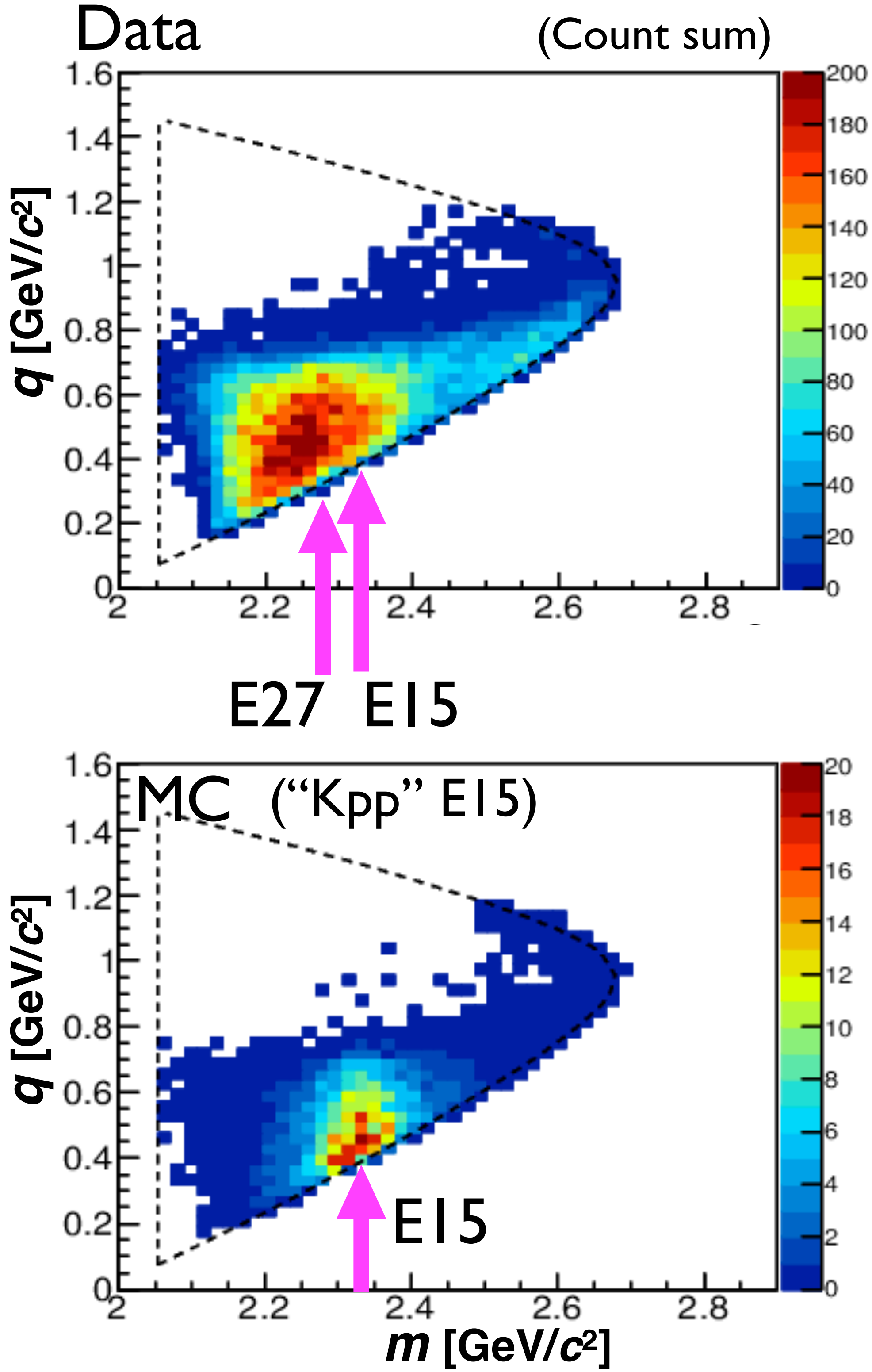
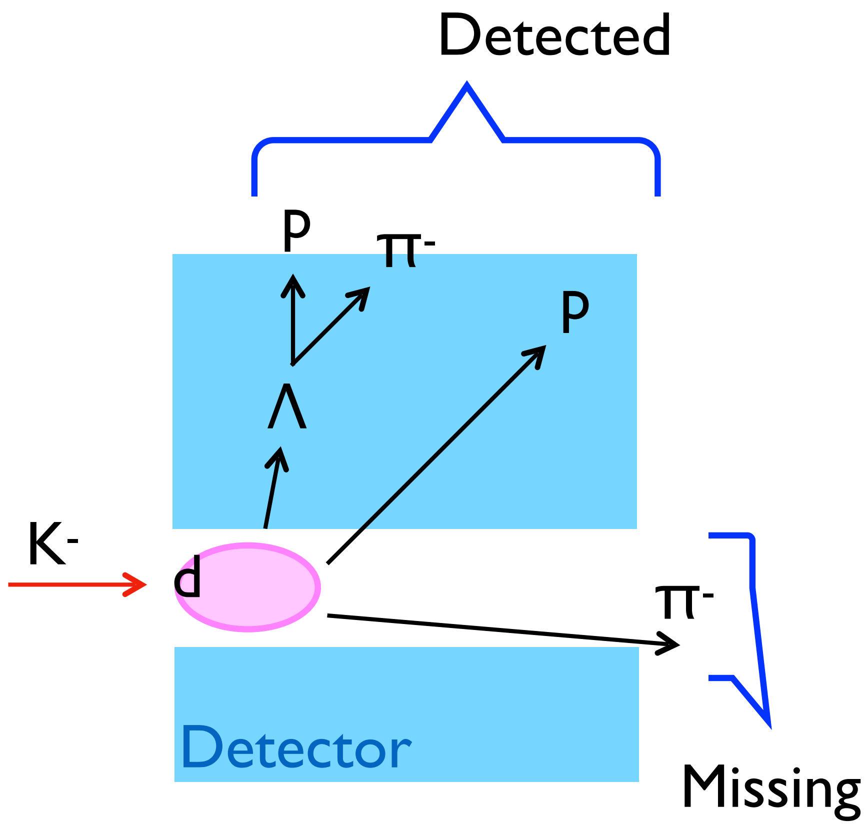
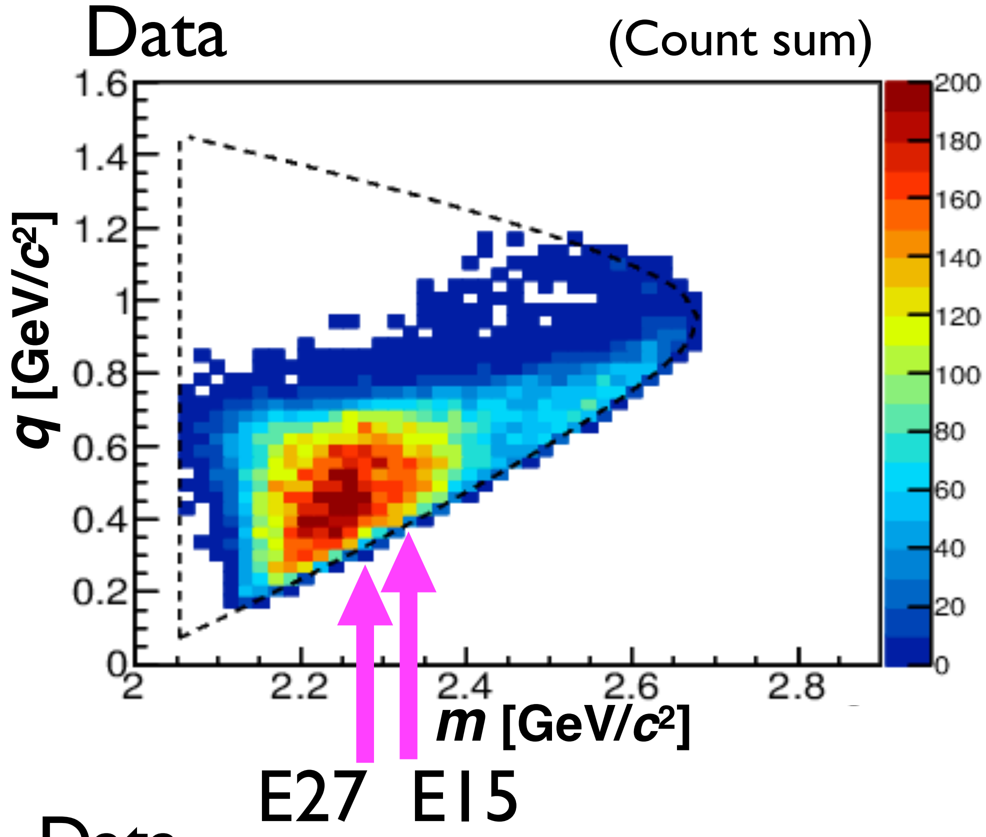


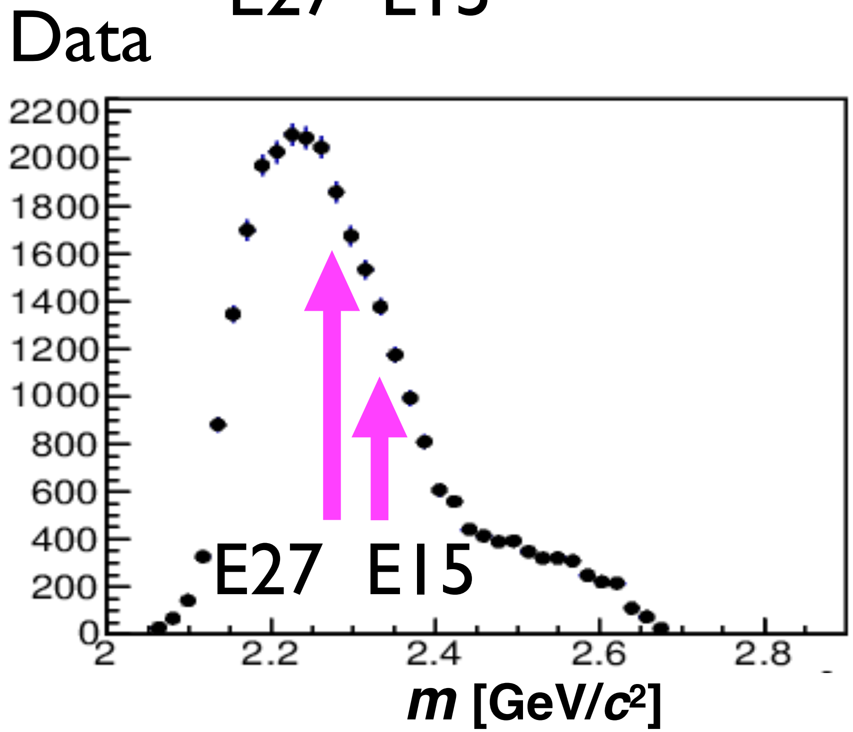
Λp distribution



- Detect Λp .
- π^- Missing.

“Kpp” signals could not be seen.
What are the seen events ?





Separation from background processes (≠ other reaction) is needed.

Example of the many diagrams.

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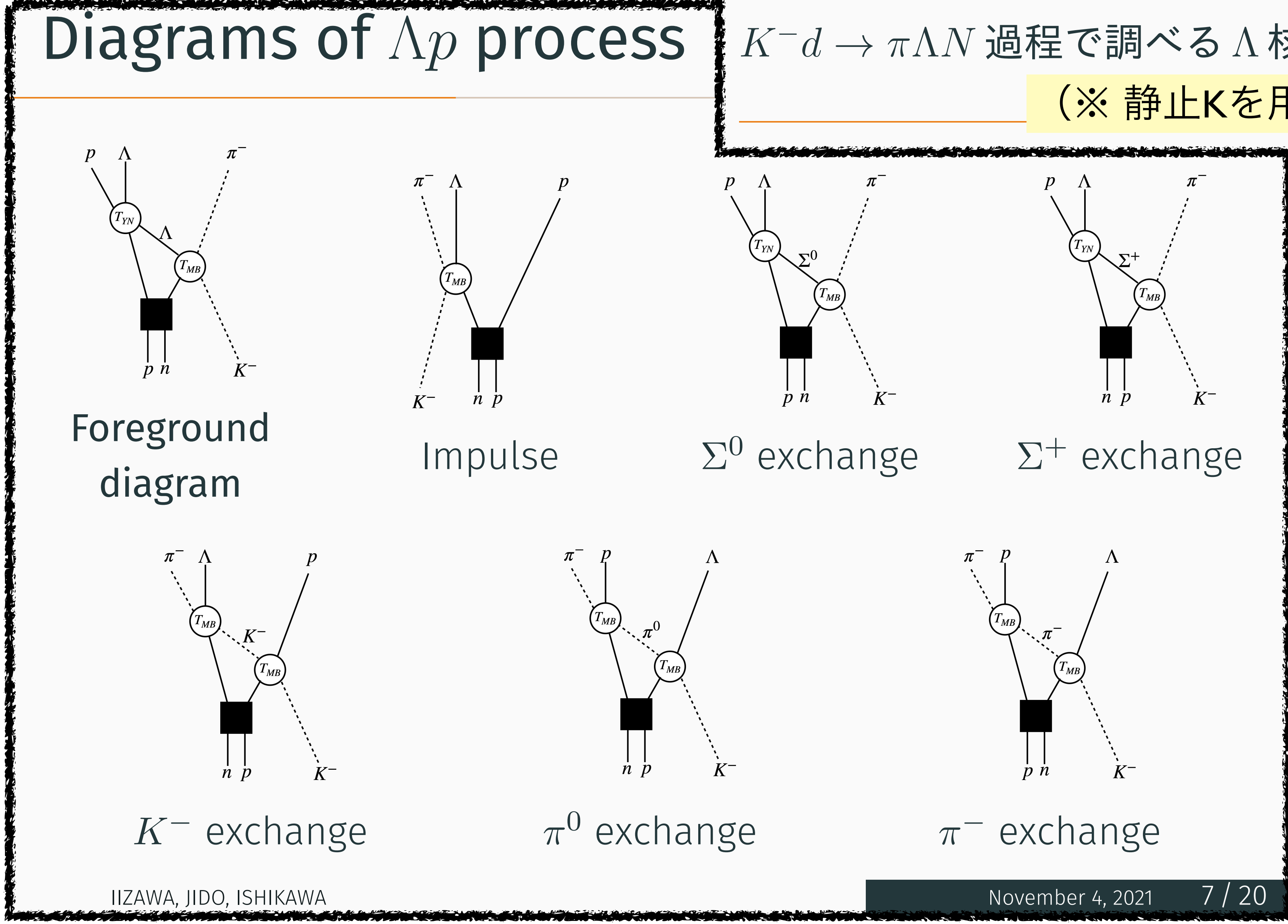
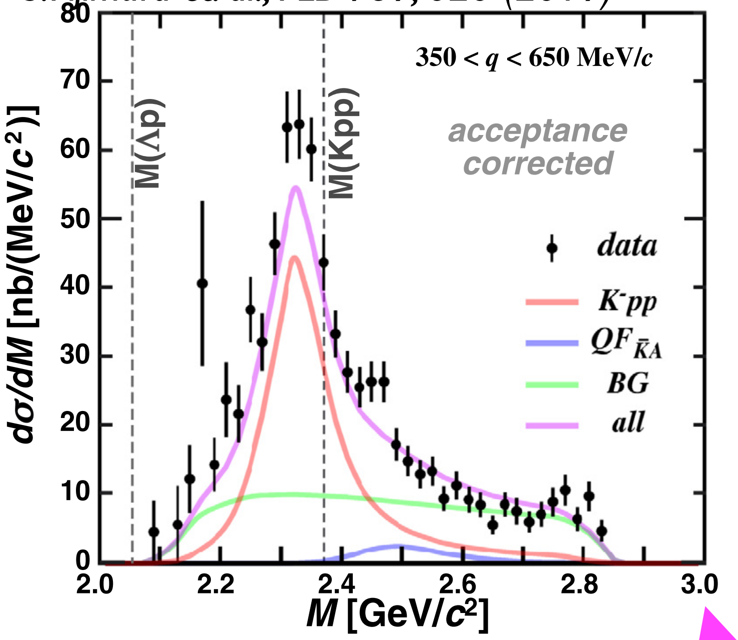
$K^- d \to \pi \Lambda N$ 過程で調べる Λ 核子散乱長

（※ 静止Kを用いた研究）



J-PARC E15 exp. ^{3}He(K^{-},Λp)n

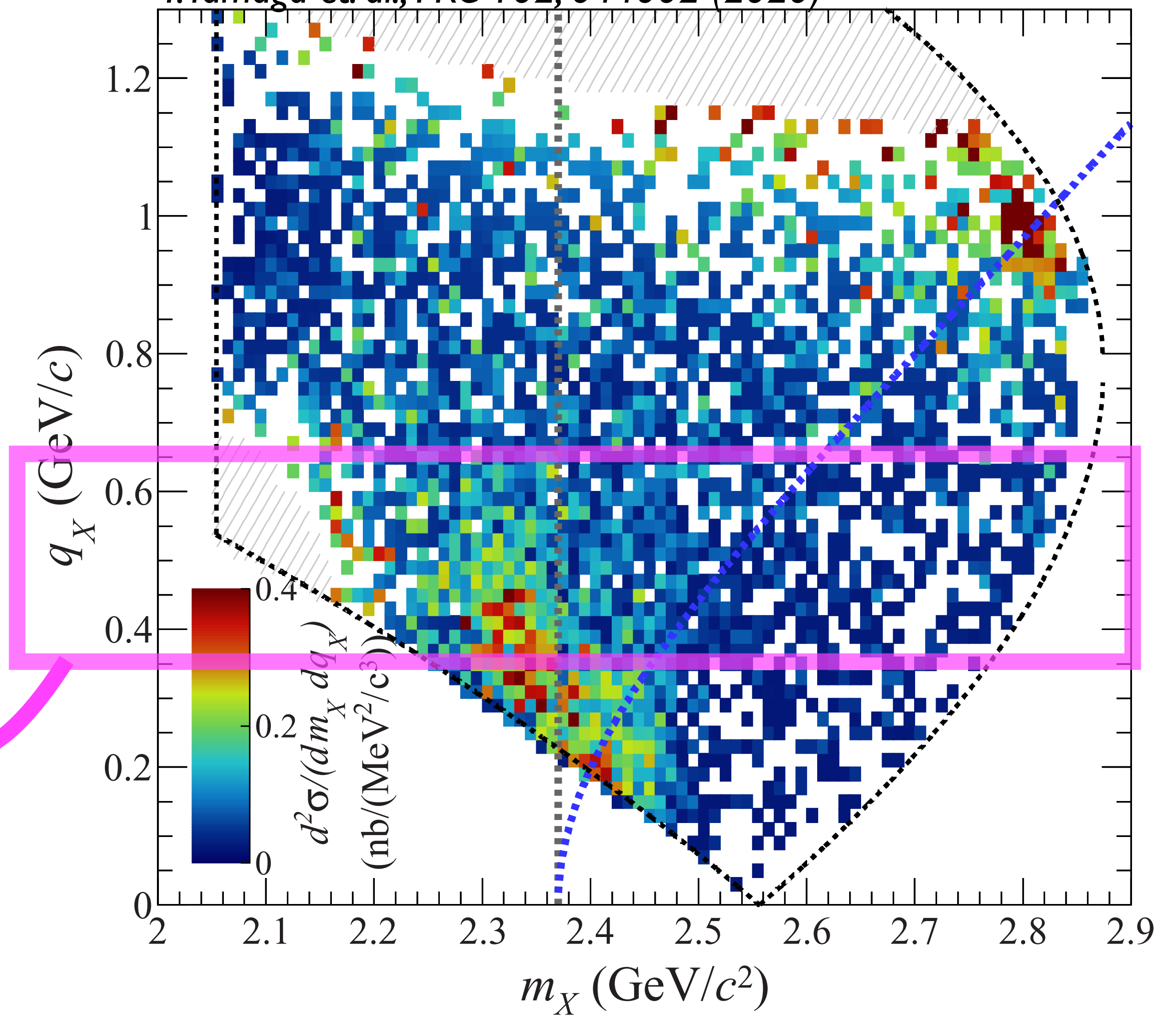
S. Ajimura et. al., PLB 789, 620 (2019)



Projection

J-PARC E15 exp. ^{3}He(K^{-},Λp)n

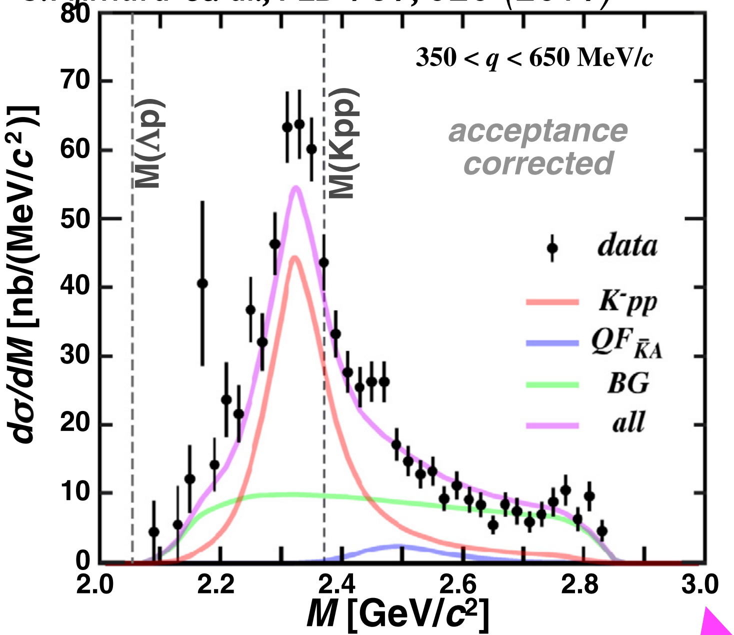
T.Yamaga et. al., PRC 102, 044002 (2020)



- Momentum transfer q
  $q(\Lambda p) = p_k - p_n$

J-PARC E15 exp. ^{3}He(K$^-$,Λp)n

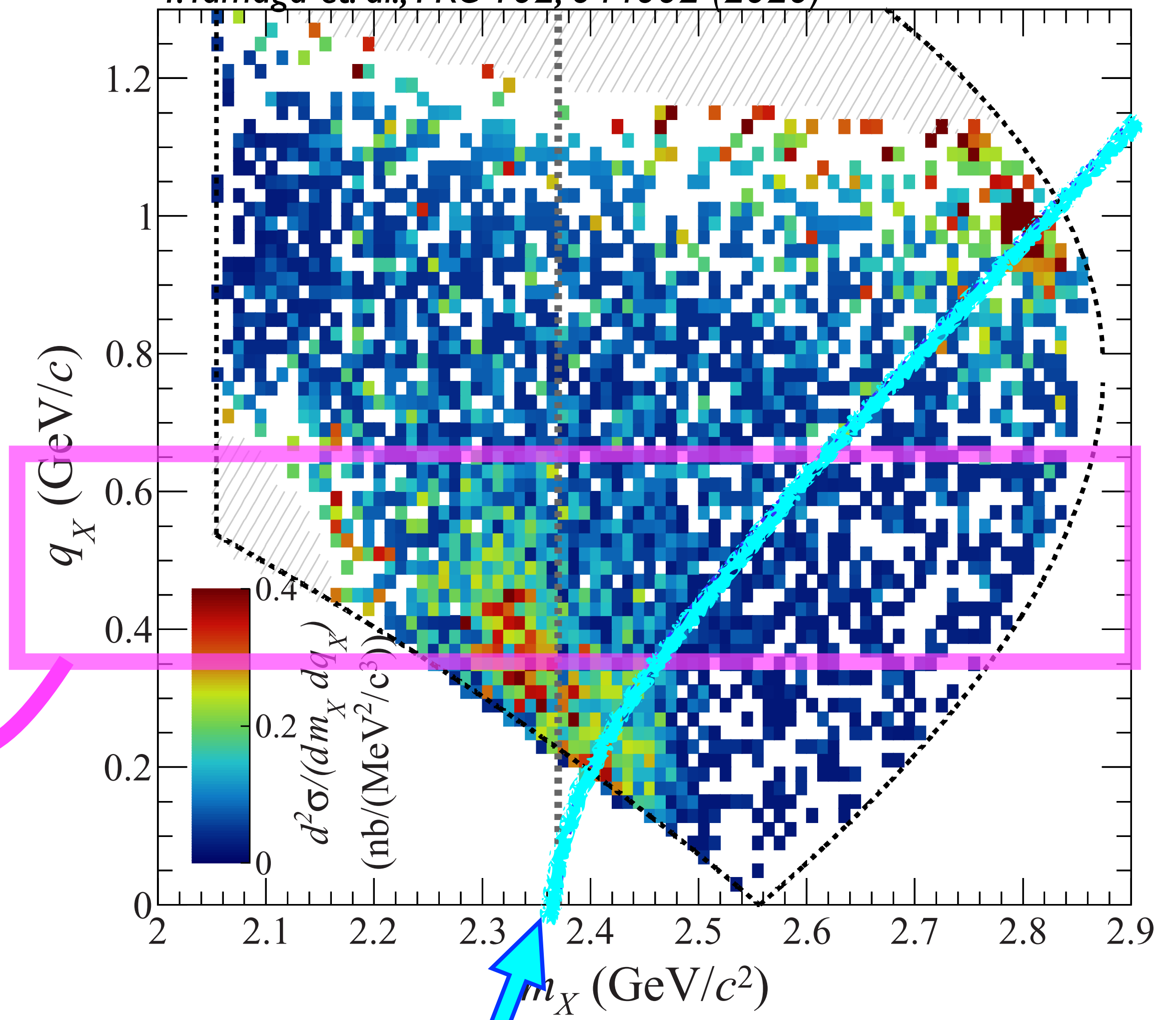
S. Ajimura et. al., PLB 789, 620 (2019)



Projection

J-PARC E15 exp. ^{3}He(K$^-$,Λp)n

T. Yamaga et. al., PRC 102, 044002 (2020)



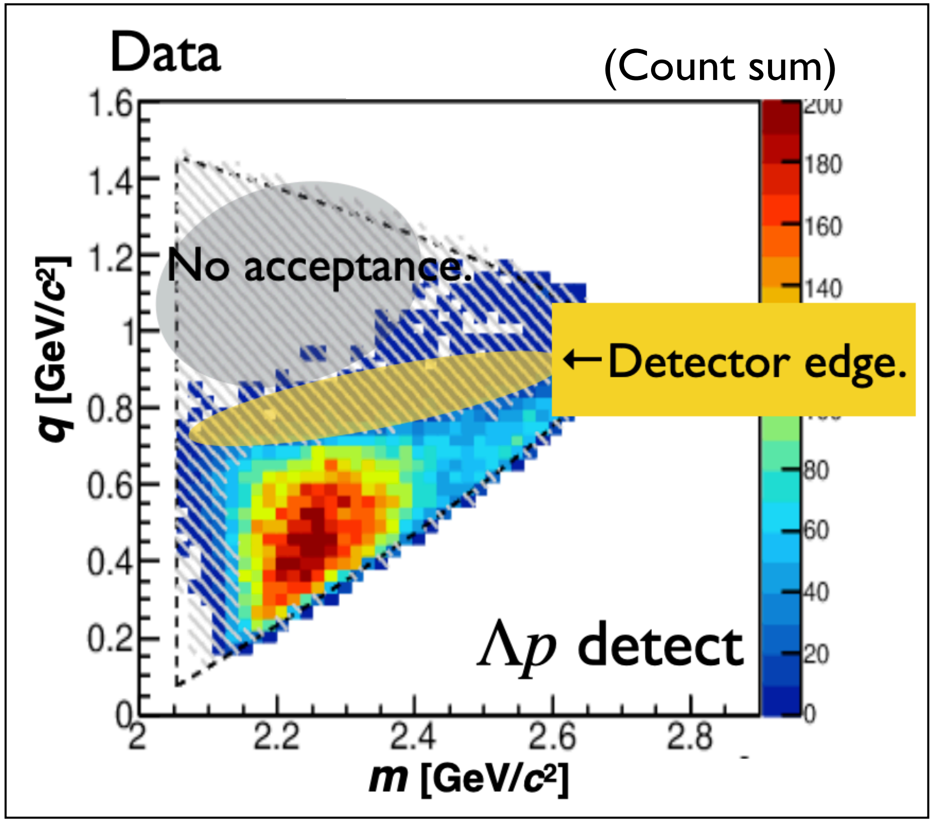
Background process
Quasi-free KN→Kn, KNN→Λp

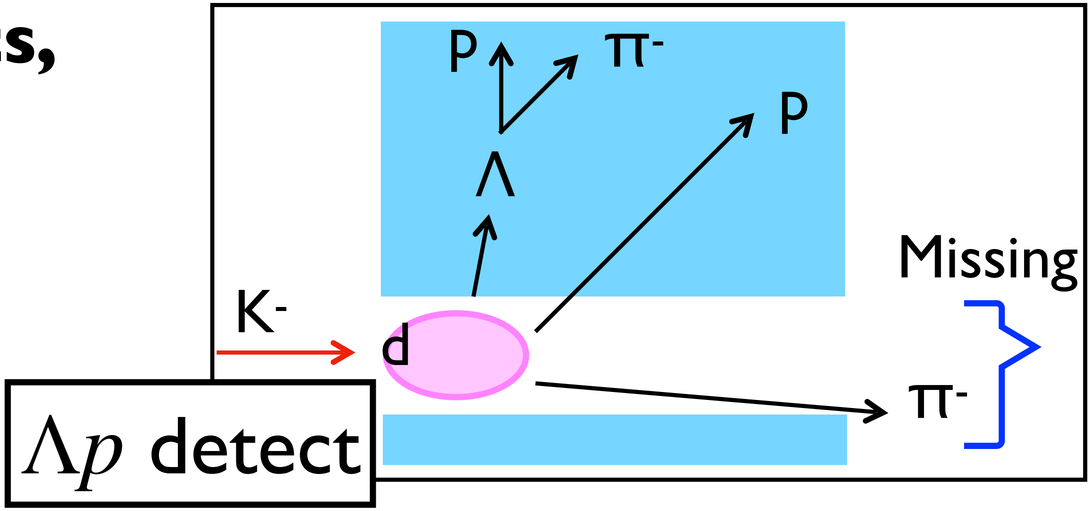
- Momentum transfer q
  $q(\Lambda p) = p_k - p_n$

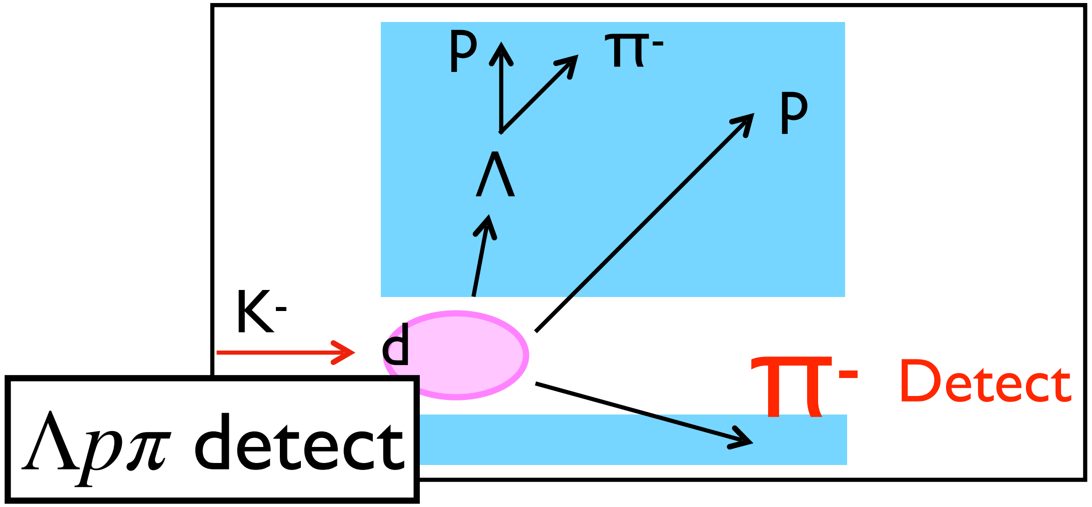
The advantage is the q dependence to understand background processes.

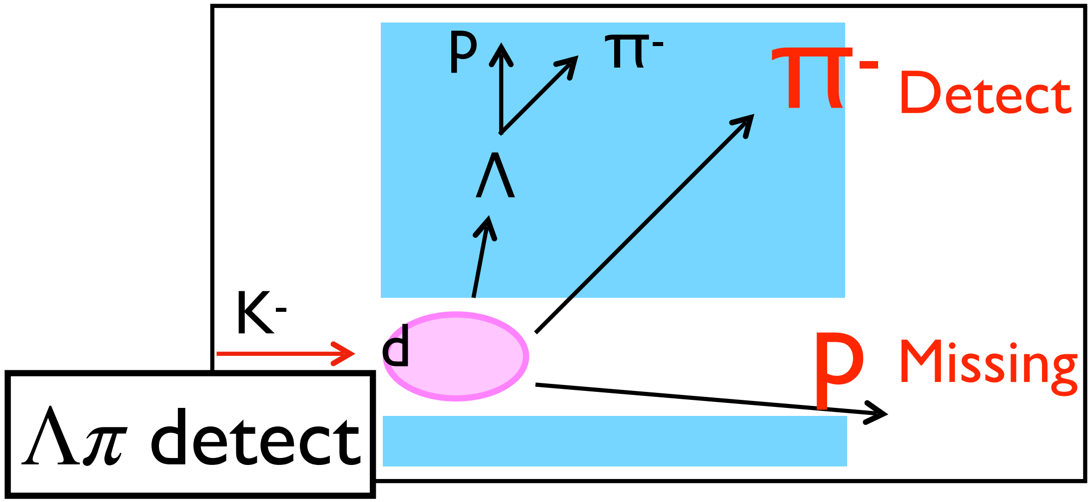
To know reaction dynamics, we need to expand the acceptance on (m, q).

When we require Λ detection, there are three possible event geometries to identify π⁻ Λ p final state.

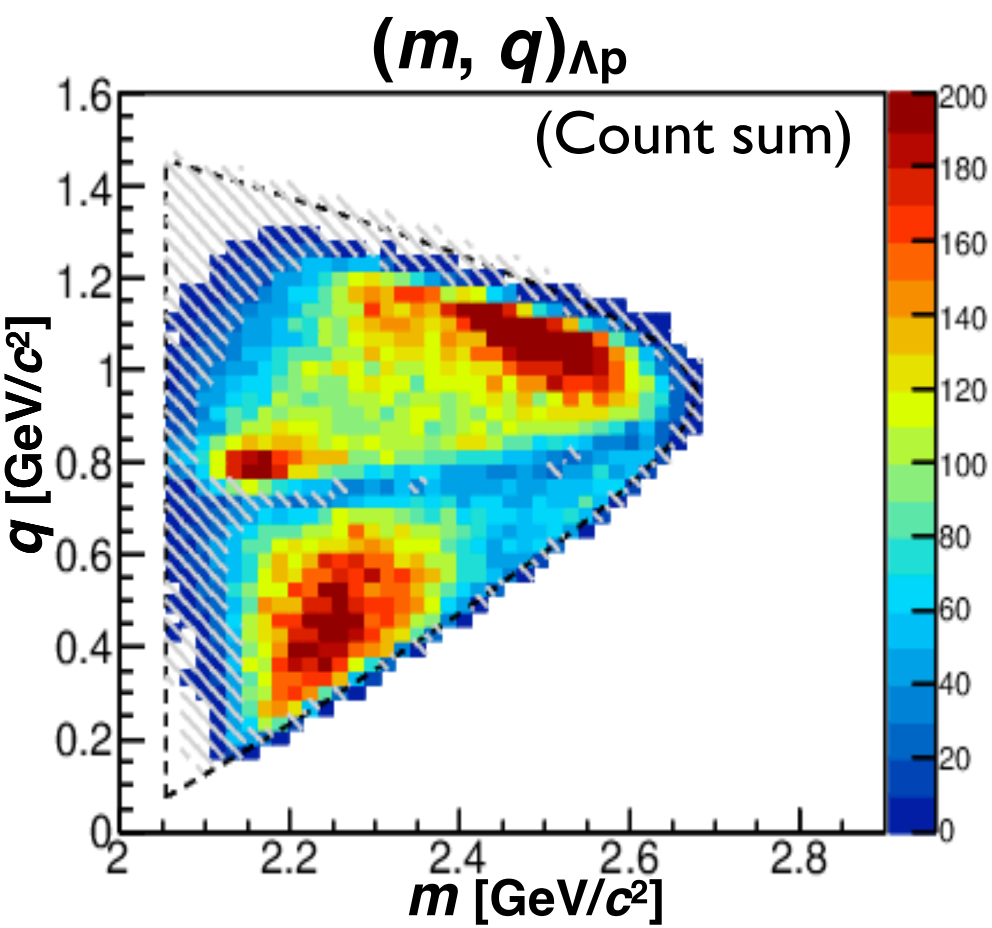


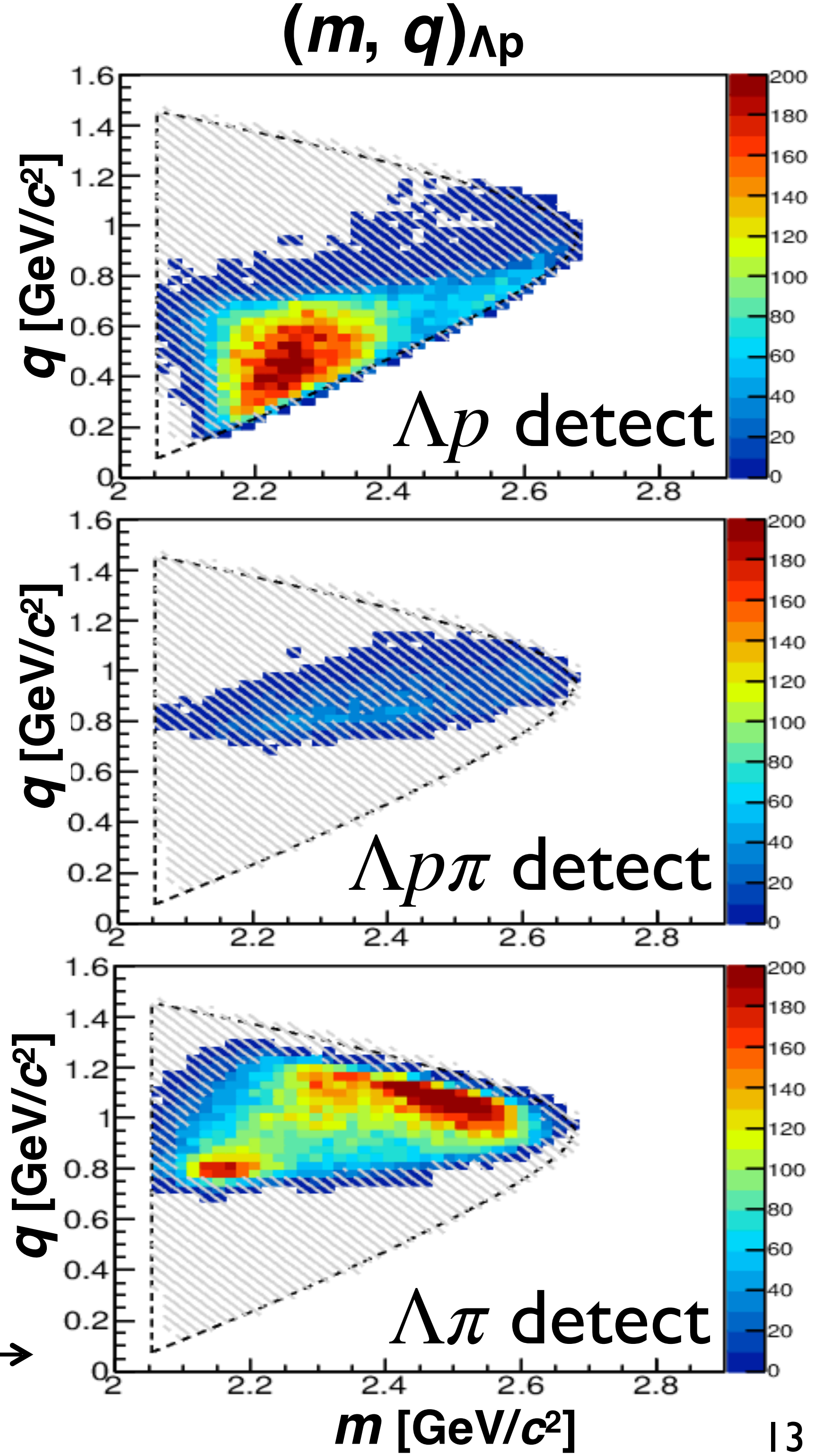






q vs m of Λp system as a count sum of Λp, $\Lambda p\pi$ and $\Lambda\pi$ detected





Momentum of p obtained from the detected particles.

Event distribution of $\Lambda p \pi^-$ final state

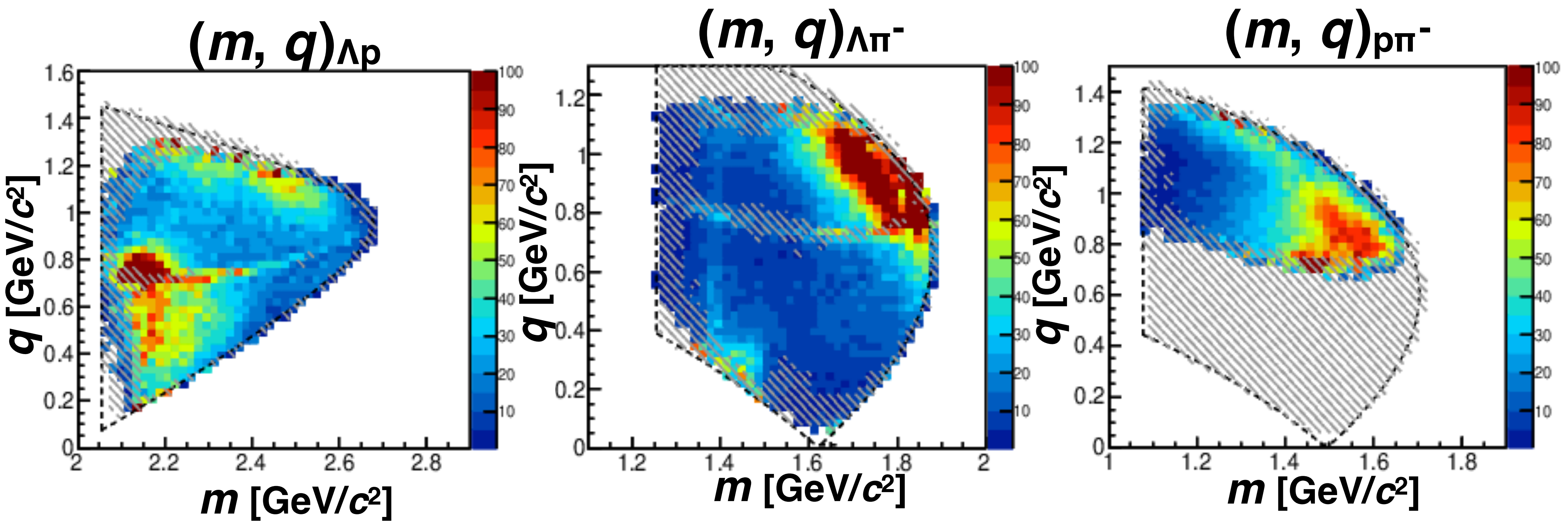
kinematical Degree-of-Freedom = 5

9 (3 on-shell particles) - 4 (energy-momentum conservation)

3 (*m*, *q*)-plots are ***more than sufficient*** to identify the event kinematics

➡ We can specify reaction dynamics by these 3 plots

m : invariant mass of a pair ***q*** : momentum transfer to the pair

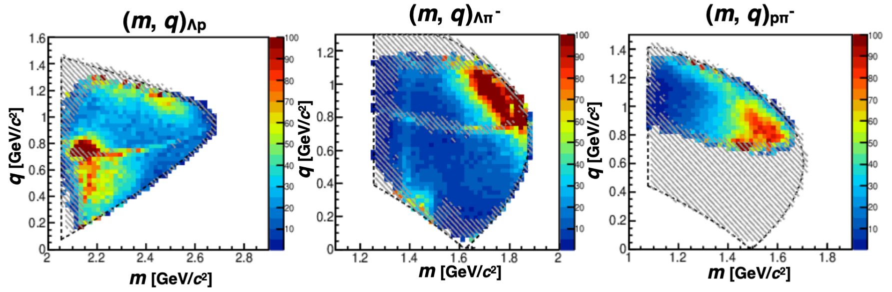


(Acceptance corrected)

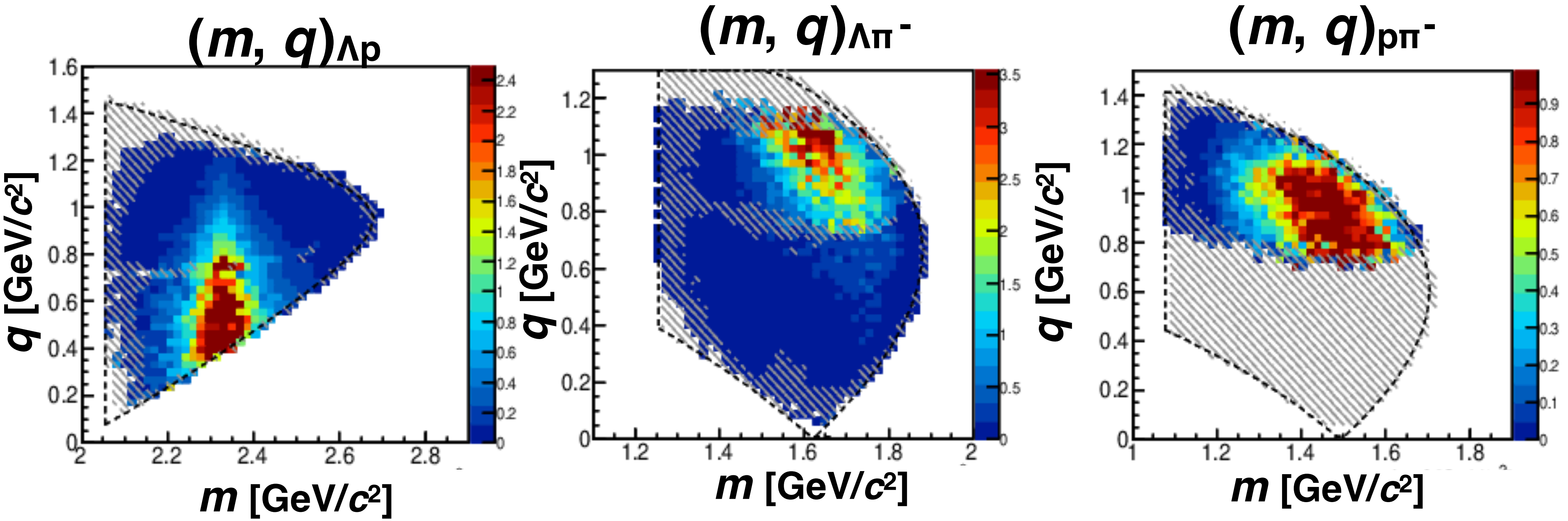
E15 "K-pp" signal region (against data)

signal cannot be identified in data without background suppression

data



simulated "K-pp" + π -



To identify "K-pp" signal, we need to understand background processes

and subtract those ***if possible***

Clearly identified background processes:

1) One nucleon reaction: $K^- n \rightarrow \Lambda \pi^-$
(or $\Sigma^0 \pi^-$)

2) Two nucleon reaction: $K^- p \rightarrow \bar{K}^0 p$
& $\bar{K}^0 n \rightarrow \Lambda \pi^-$
(or $\bar{K}^0 n \rightarrow \Sigma^0 \pi^-$)

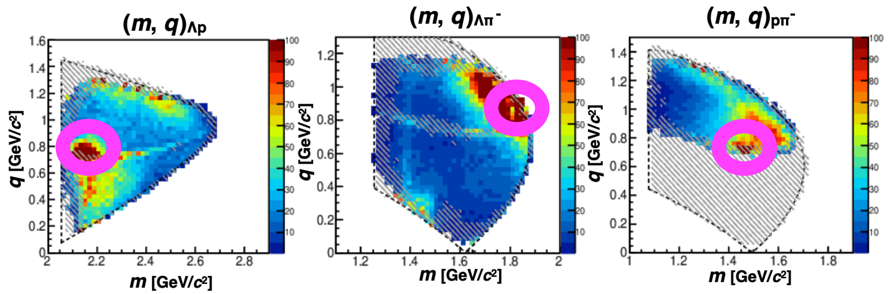
3) None-mesonic Y* production:
$K^- d \rightarrow \Sigma^-(1385)\, p$
& $\Sigma^-(1385) \rightarrow \Lambda \pi^-$

1) One nucleon reaction: $K^- n \rightarrow \Lambda \pi^-$

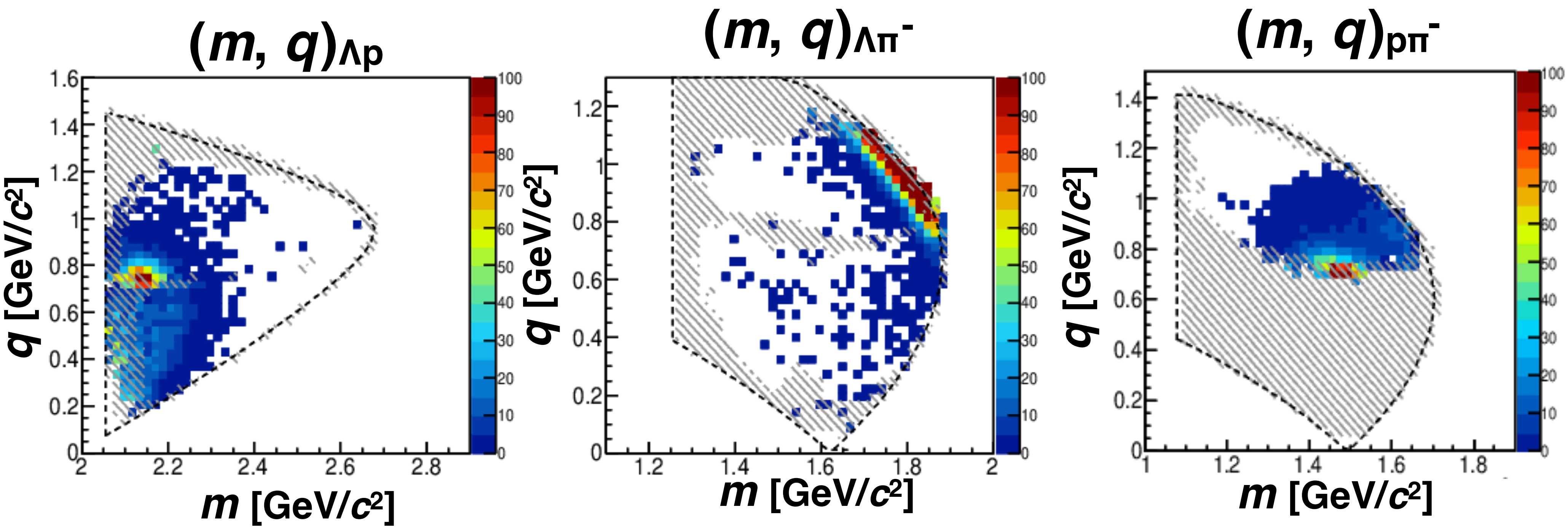
clearly identified in data

spectator proton fires trigger
via Fermi-motion tail = large $\boldsymbol{p}$

data



simulated one nucleon reaction $K^- n \rightarrow \Lambda \pi^-$

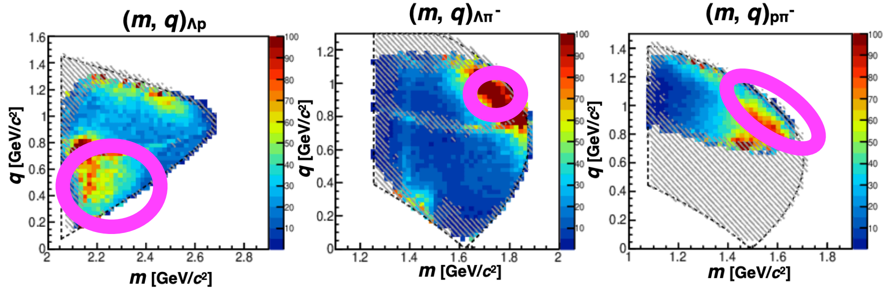


2) Two nucleon reaction: $K^{-} p \rightarrow \bar{K} p$ & $\bar{K} n \rightarrow \Lambda \pi^{-}$

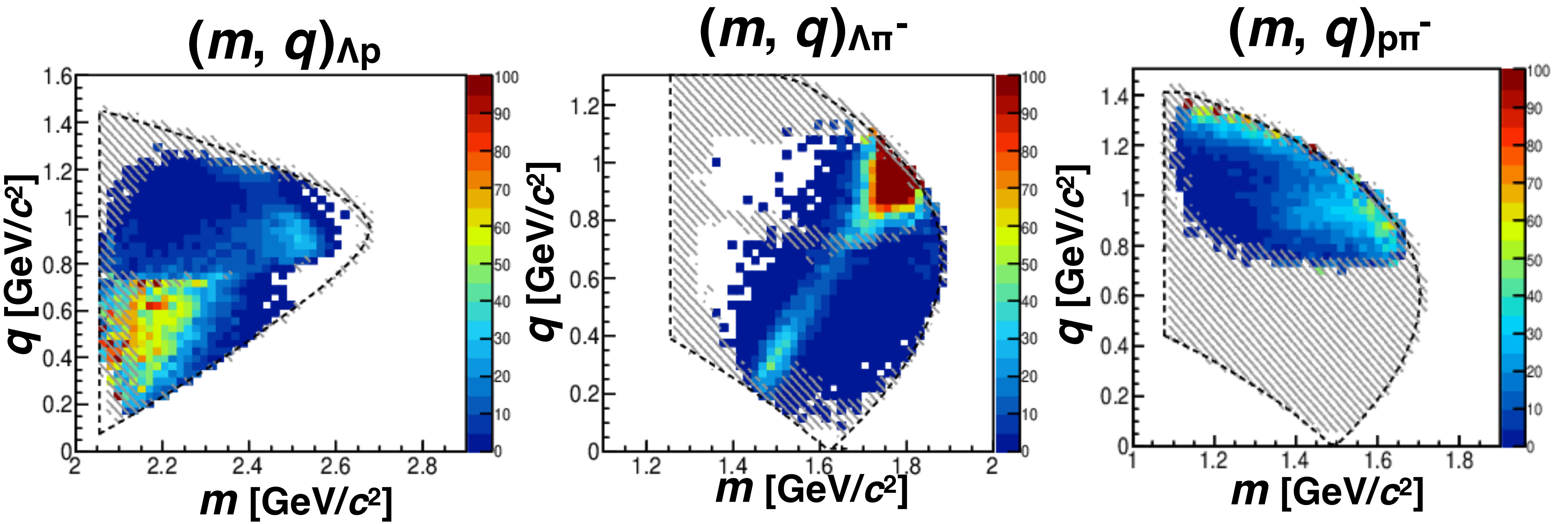
clearly identified in data

a little difference in the distribution
→Plan to change to function and parameters of E15 PRC.

data



simulated one nucleon reaction b/w inflight $\bar{K}$ and n after one nucleon reaction $K^{-} p \rightarrow \bar{K} p$



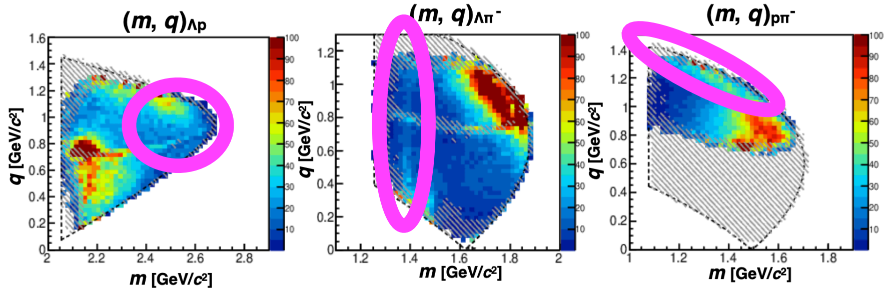
3) None-mesonic Y* production:

$K^- d \rightarrow \Sigma^-(1385)\, p$

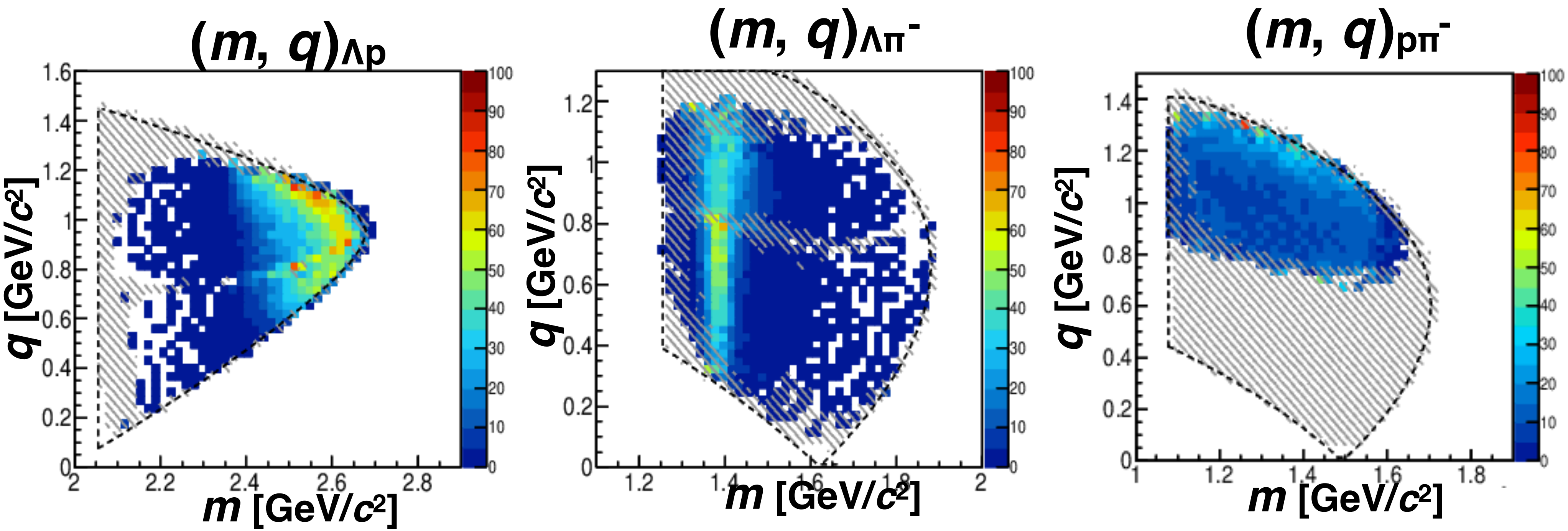
$\&\ \Sigma^-(1385) \rightarrow \Lambda\, \pi^-$

clearly identified in data

data



simulated flat two body interaction $K^- d \rightarrow \Sigma 1385)p\, \pi^-$



Summary of background-process comparisons

Background processes are mainly explained w/ these three.

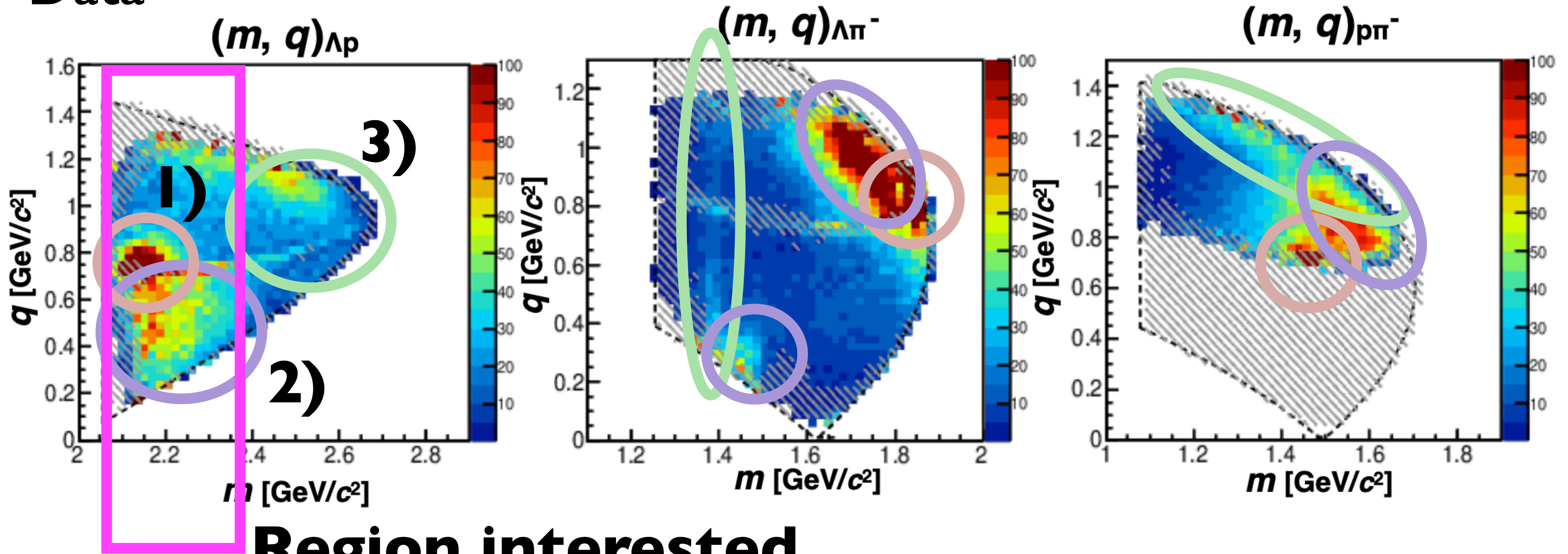
Clearly identified background processes:

1) One nucleon reaction: $K^- n \rightarrow \Lambda \pi^-$
(or $\Sigma^0 \pi^-$)

2) Two nucleon reaction: $K^- p \rightarrow \mathbb{K}^- p$
& $\mathbb{K}^- n \rightarrow \Lambda \pi^-$
(or $\mathbb{K}^- n \rightarrow \Sigma^0 \pi^-$)

3) None-mesonic Y* production:
$K^- d \rightarrow \Sigma^-(1385)\, p$
& $\Sigma^-(1385) \rightarrow \Lambda \pi^-$

Data



Summary

- E31 collaboration is investigating "Kpp" bound state using d(K^-, Λp)π^- reaction with the confirmation of all the kinematical freedoms.

- All the kinematical freedoms are determined by the momentum transfer and invariant mass of Λp, Λπ^- and pπ^- systems.

- Distributions are mainly explained with 3processes: one nucleon reaction Kn→Λπ^-, two nucleon reaction Kp→Kp, Kn→Λπ^- and none-mesonic Y* production Kd→Σ(1385)p.

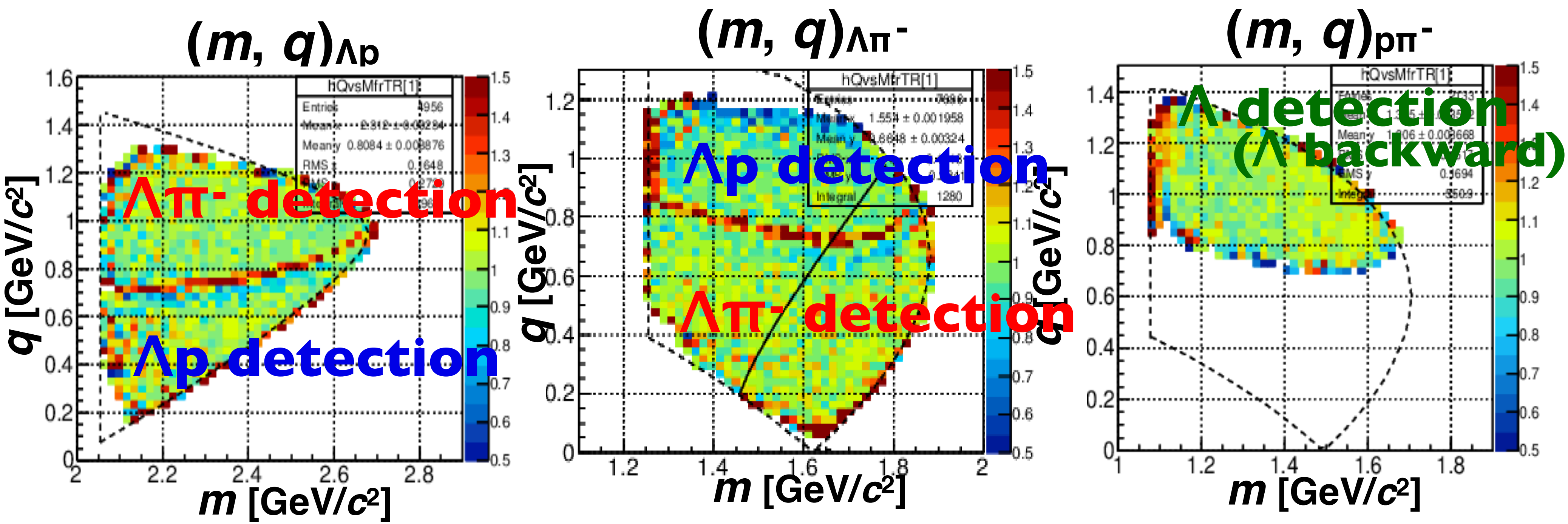
- Subtractions of the distributions are under investigation.

Backup

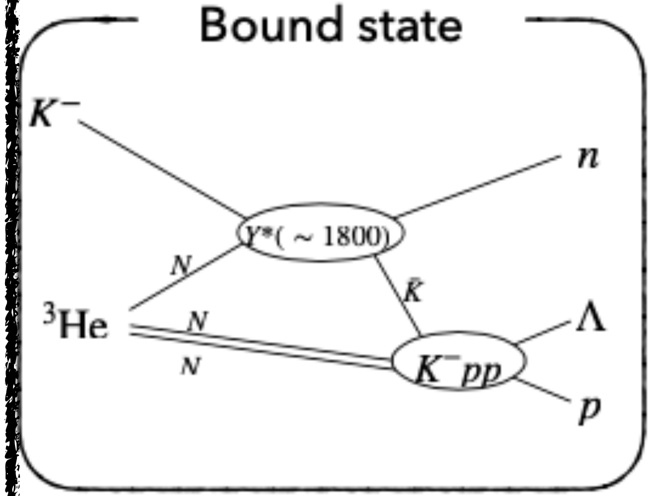
Kinematical anomaly caused by analysis procedure

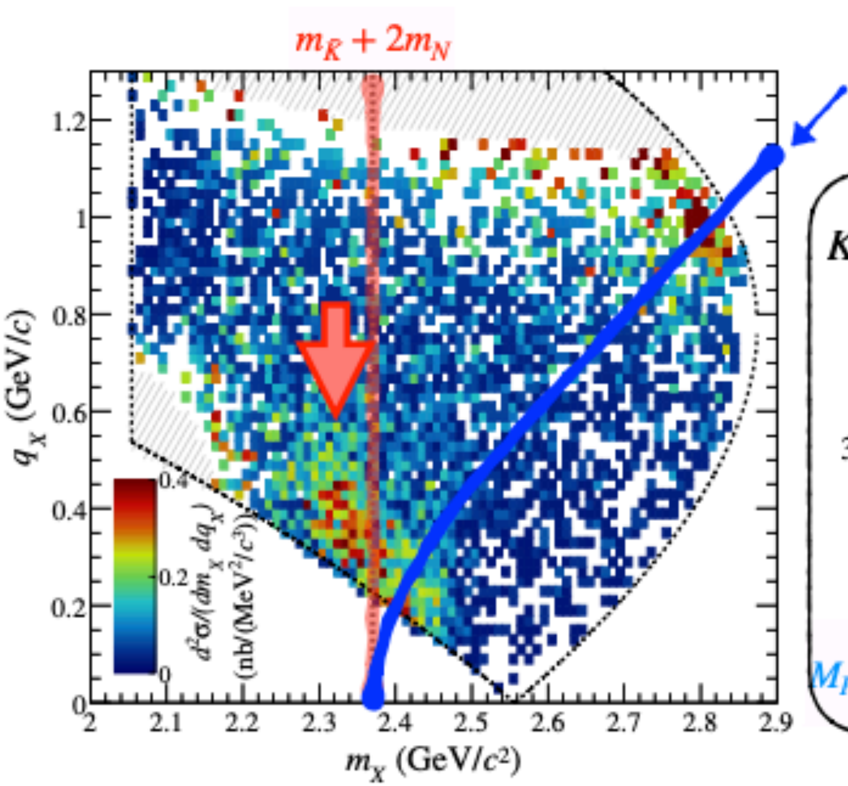
$$\frac{\text{simulation: after kinematical refit}}{\text{simulation: generated}} \neq \text{constant}$$

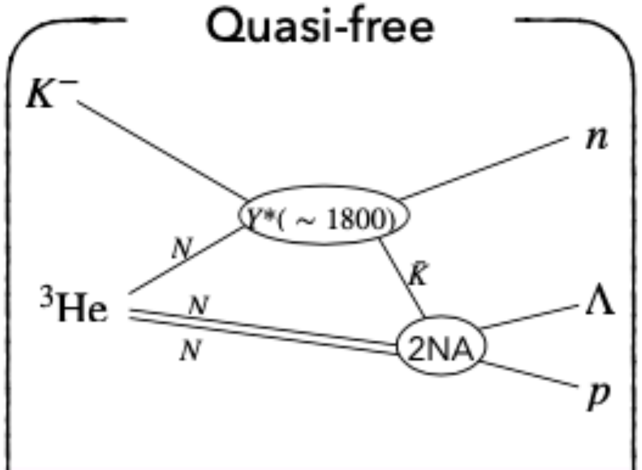
refit emphasize kinematical boundary between
Λp / Λπ⁻ detection



Result of E15







$$M_F(q_X) = \sqrt{4m_N^2 + m_{\bar{K}}^2 + 4m_N\sqrt{m_{\bar{K}}^2 + q_X^2}}$$

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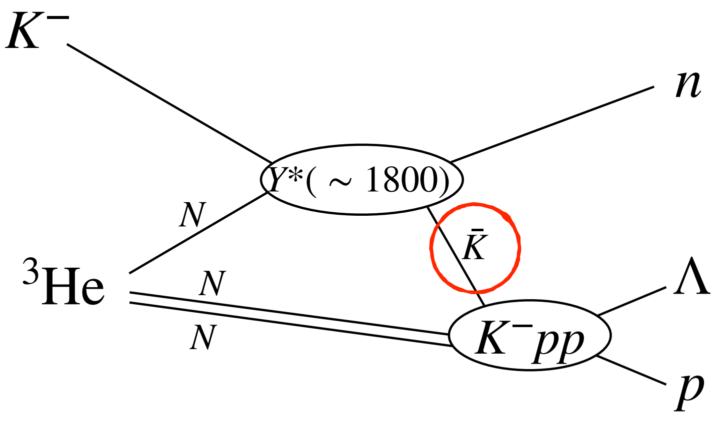
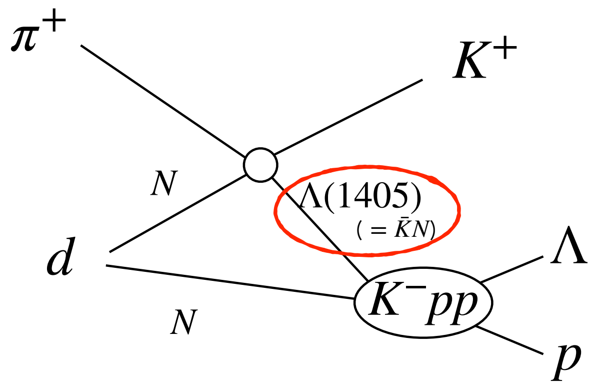
J-PARC E15

$^3\text{He}(K^-, n)\Lambda p$



J-PARC E27

$d(\pi^+, K^+)\Lambda p/\Sigma^0 p$



Production of K^-pp is essentially the same.
Occurred by intermediate $\bar{K}$ or $\bar{K}N$

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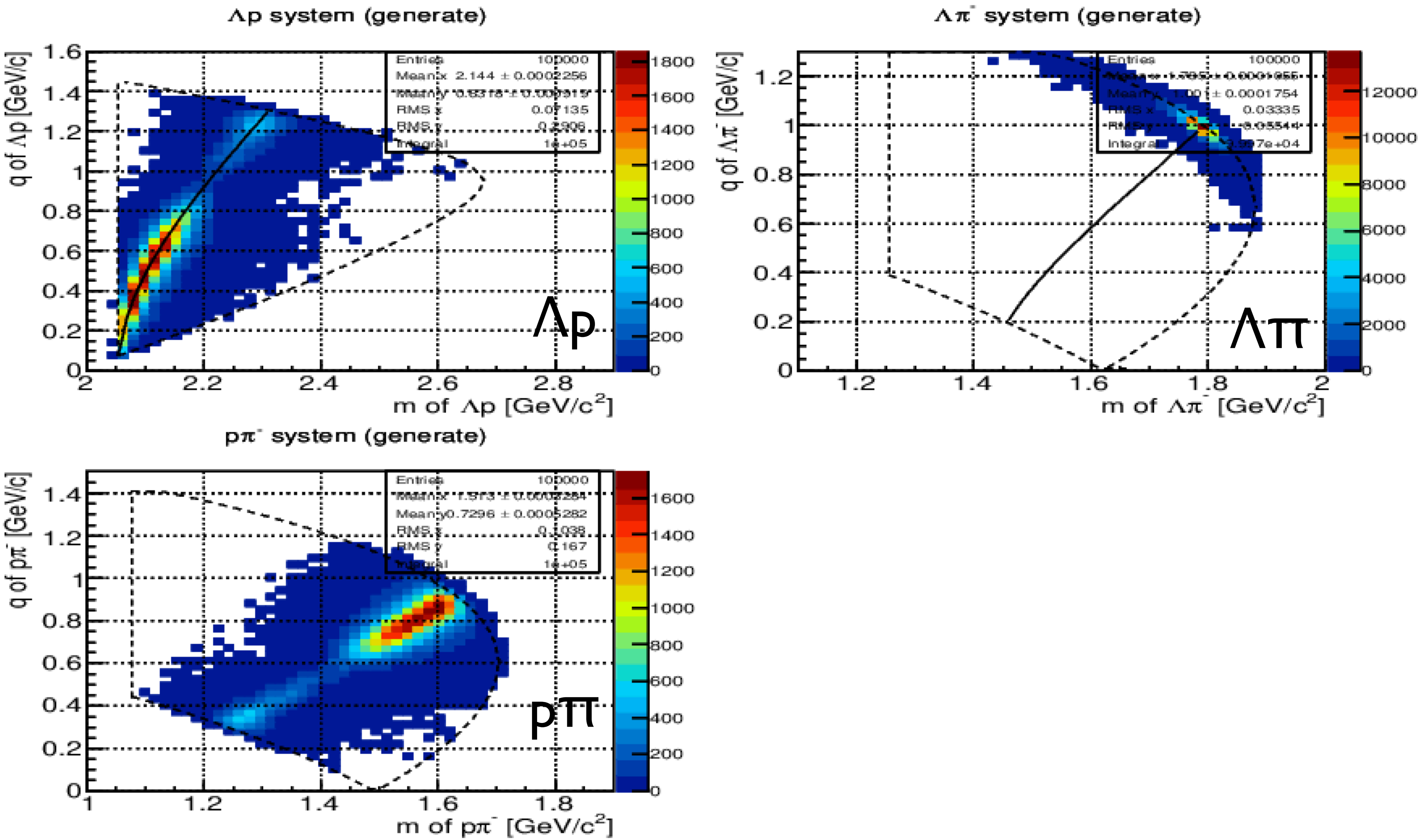
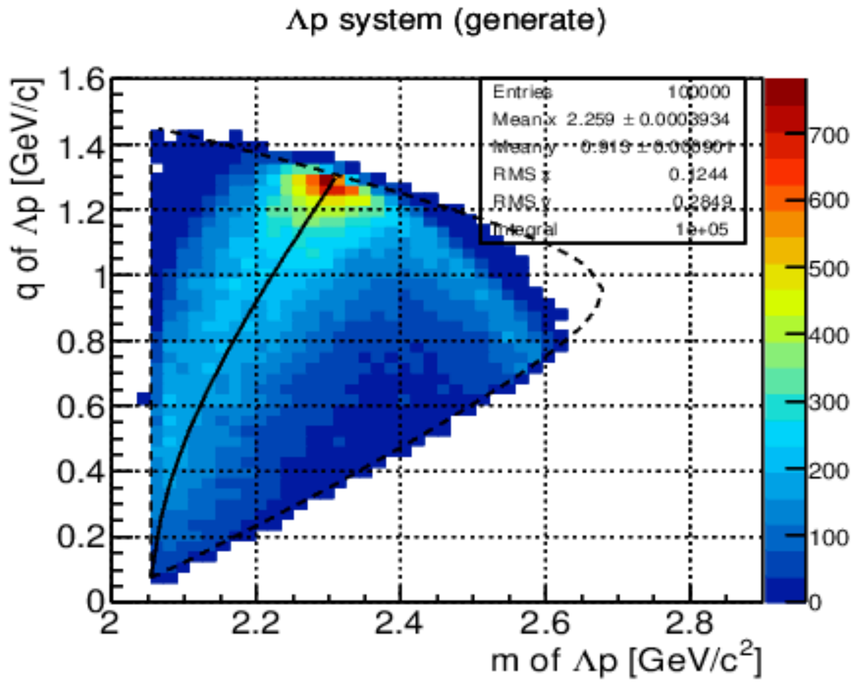
1N
$Kn \to \Lambda\pi^-$

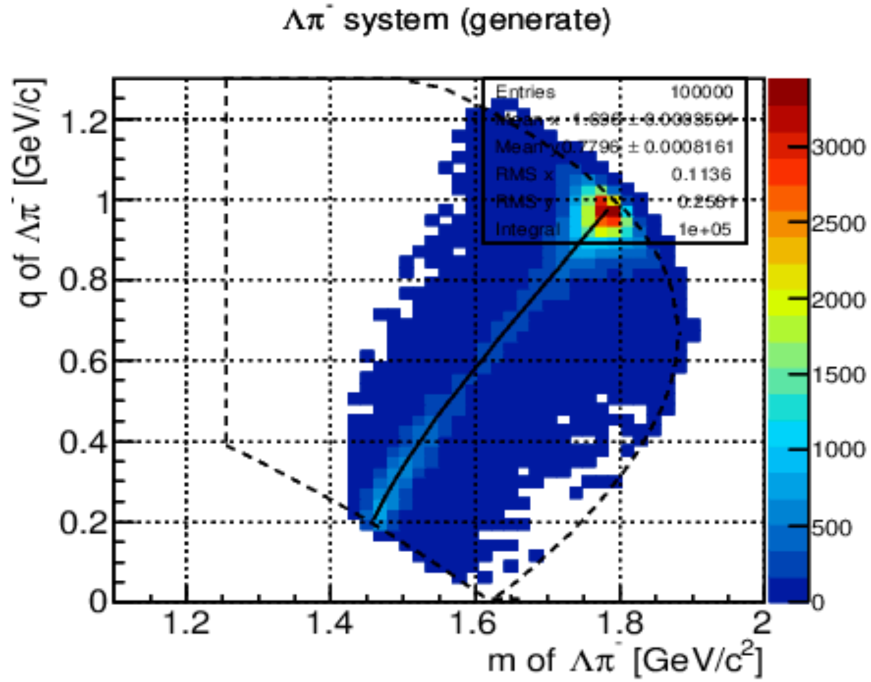
Generate

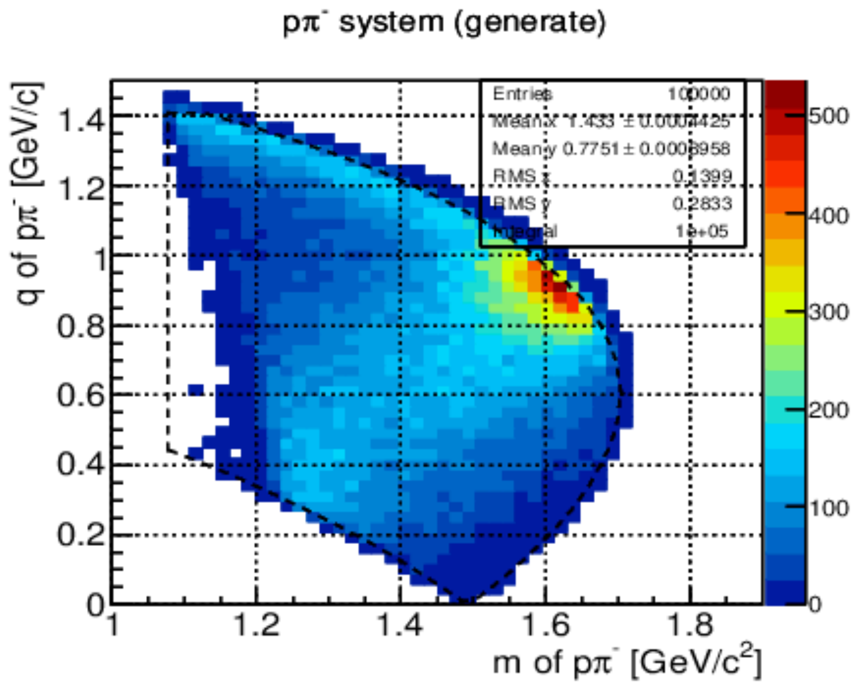


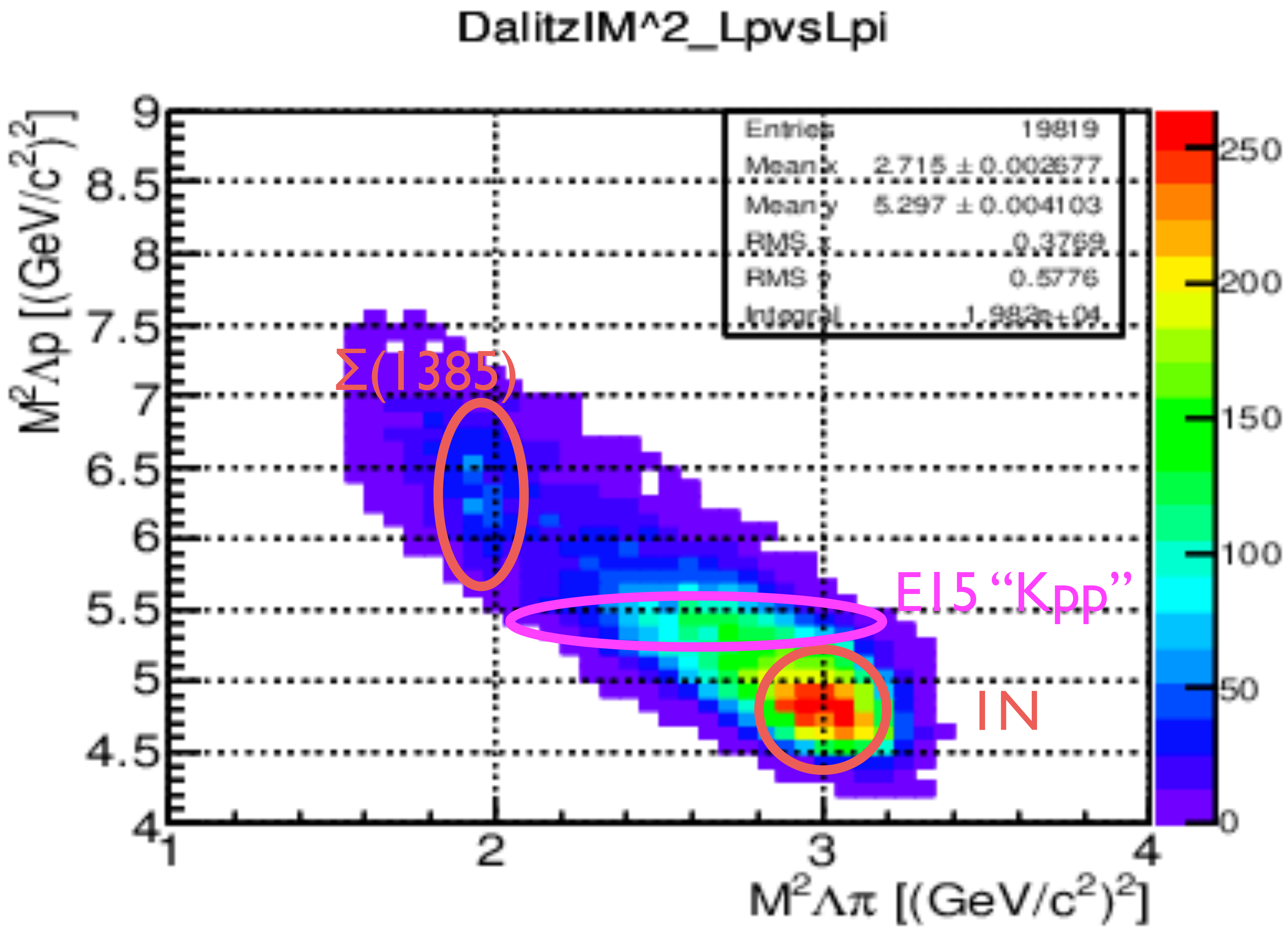
QF Kp→Kp,
Kn→Λπ⁻

Generate









DalitzIM^2_LpvsLpi
Entries 19819
Mean x 2.715 ± 0.002677
Mean y 5.297 ± 0.004103
RMS x 0.3769
RMS y 0.5776
Integral 1.982e+04
Σ(1385)
E15 "Kpp"
1N
M²Λp [(GeV/c²)²]
M²Λπ [(GeV/c²)²]