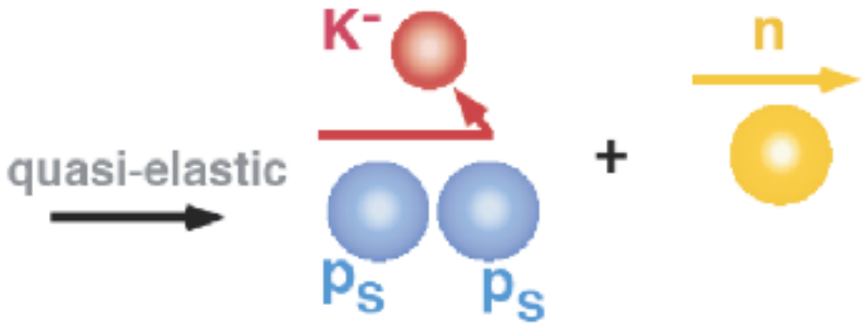


News about Latest Experiment at J-PARC

M. Iwasaki
RIKEN / TokyoTech
for E15 collaboration

23-27 January 2017 Bormio (Italy)

55th International Winter Meeting on Nuclear Physics

A subject for discussion: J-PARC E15

Key questions :

- **Can kaon (meson) be a member of nuclei?**
- **Kaon properties change in nuclear media?**

Hadron masses and χ-symmetry

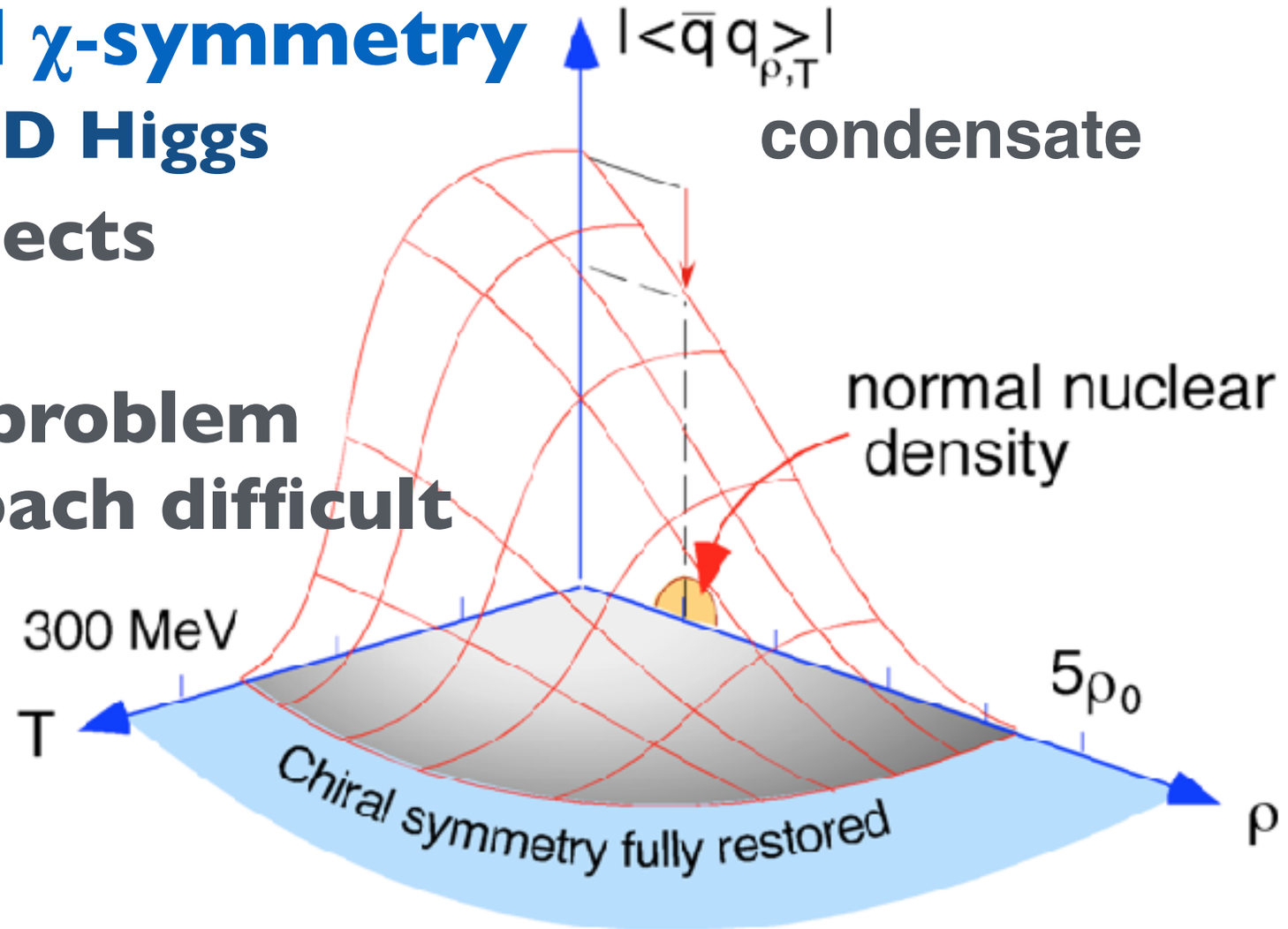
<q̄q> as QCD Higgs

Non-perturbative aspects

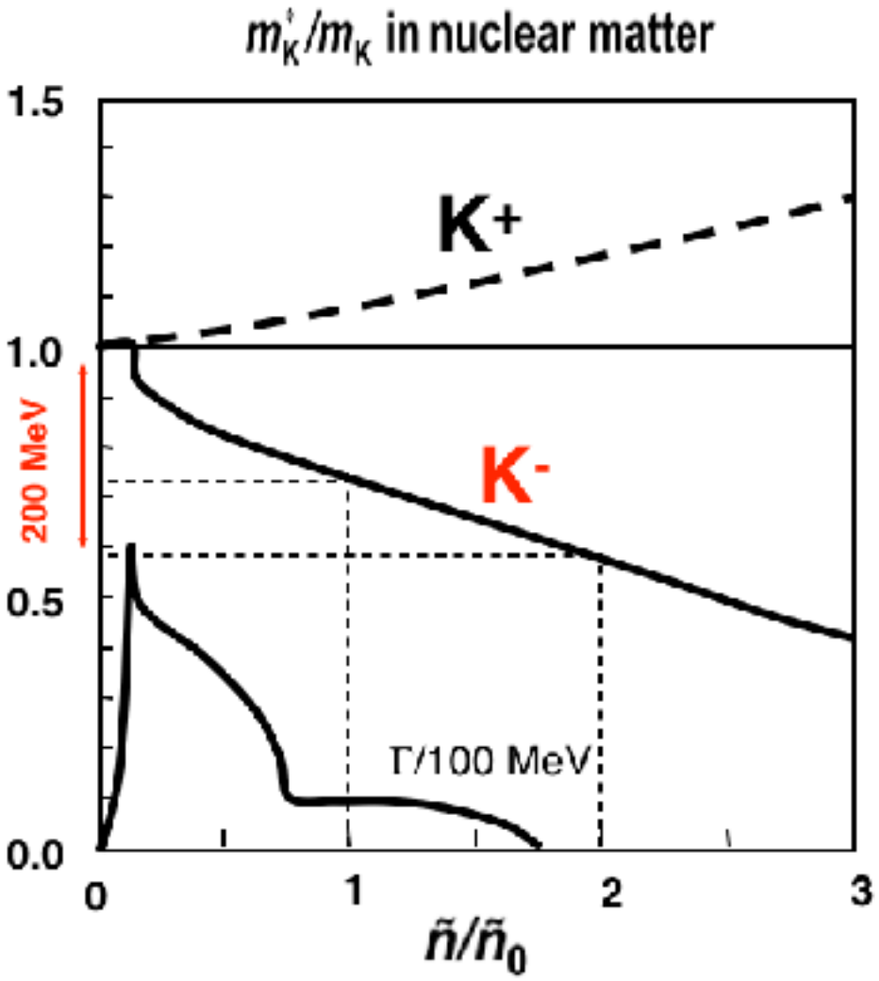
@ energy < Λ_{QCD}

Finite density → sign problem

Lattice-QCD approach difficult



Search for Kaonic nuclear states

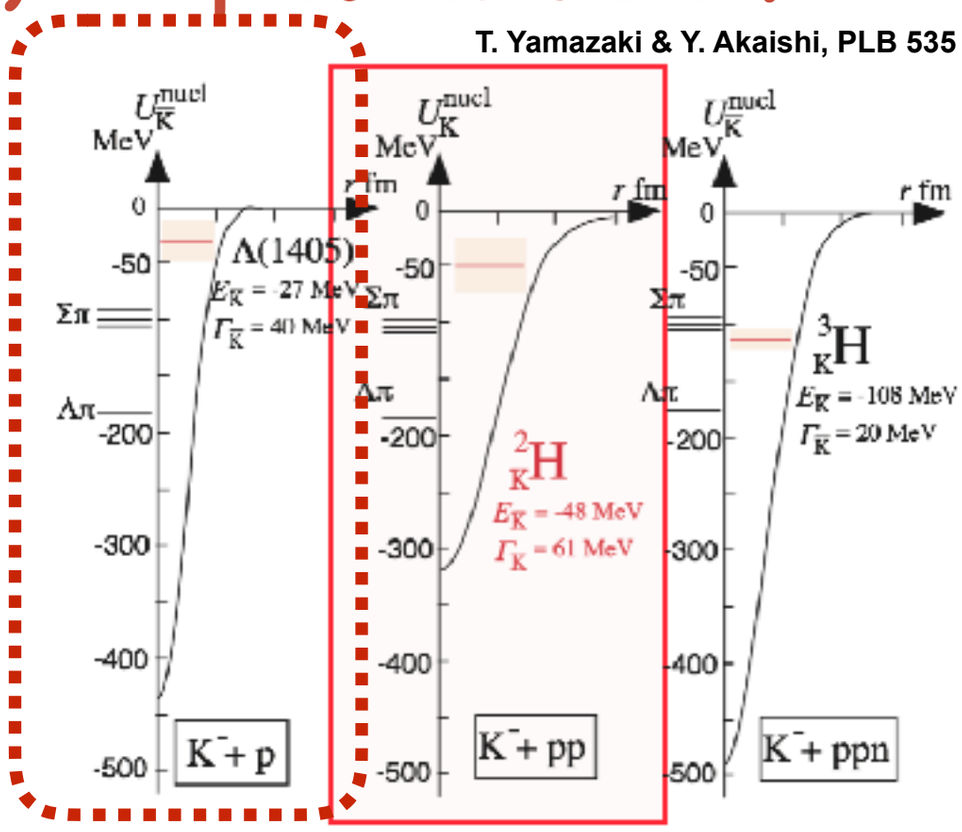


T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

strongly attractive in I=0 channel

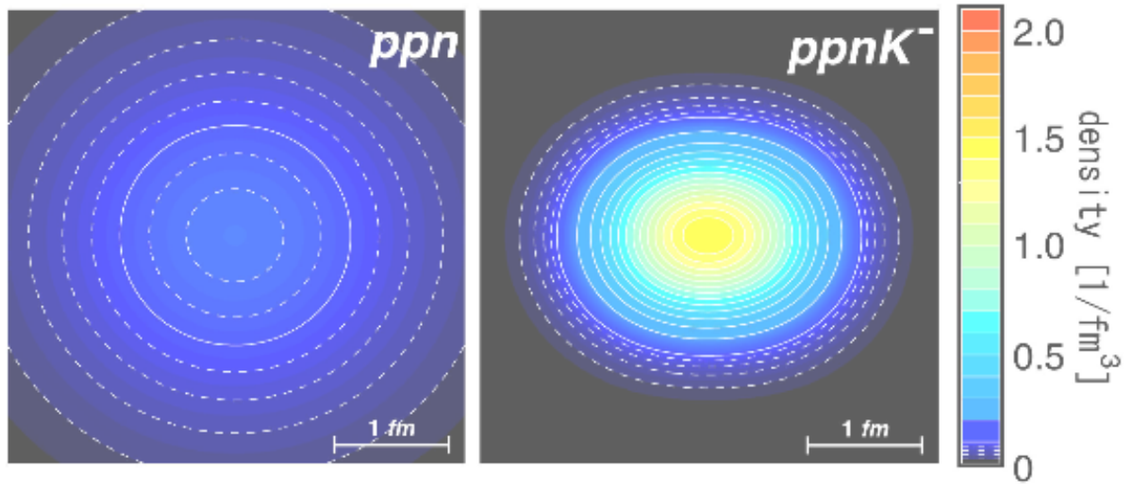
Λ(1405) = K^-p bound state ?

T. Yamazaki & Y. Akaishi, PLB 535 (2002) 70



$B_{\bar{K}}$ ~ 50 MeV!

Dote et al., PLB 590 (2004) 51



formation of high density matter?

nuclear state search

- simplest system K^-pp

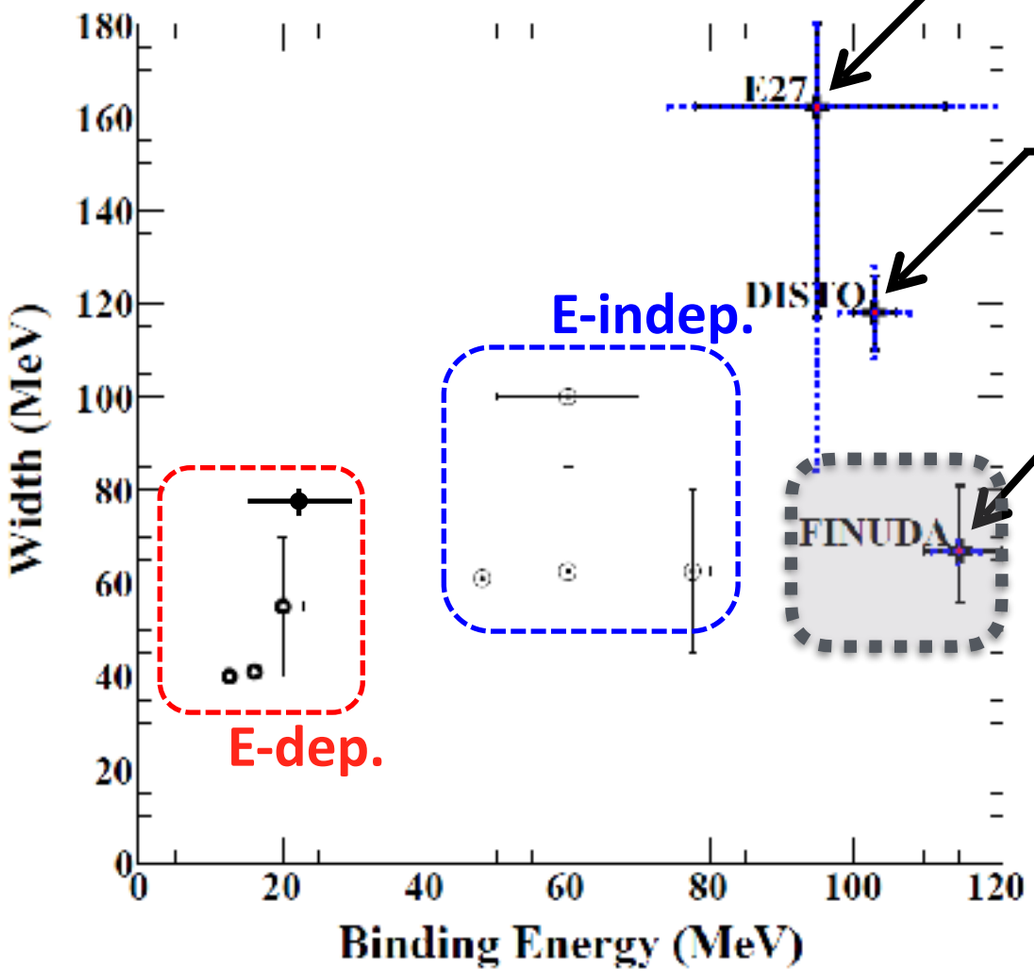
^{3}He(K^-, n) @ 1 GeV/c

Recent status of K^-pp bound state

- **Recent results**
  - **Theoretical calc.**
  - **Experiments**

$\bar{K}N$ interaction model

E-dep. / E-indep.



Reports structure / NO structure

J-PARC E27
$d(\pi^+, K^+)X$

DISTO
$pp \to \Lambda pK^+$

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

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

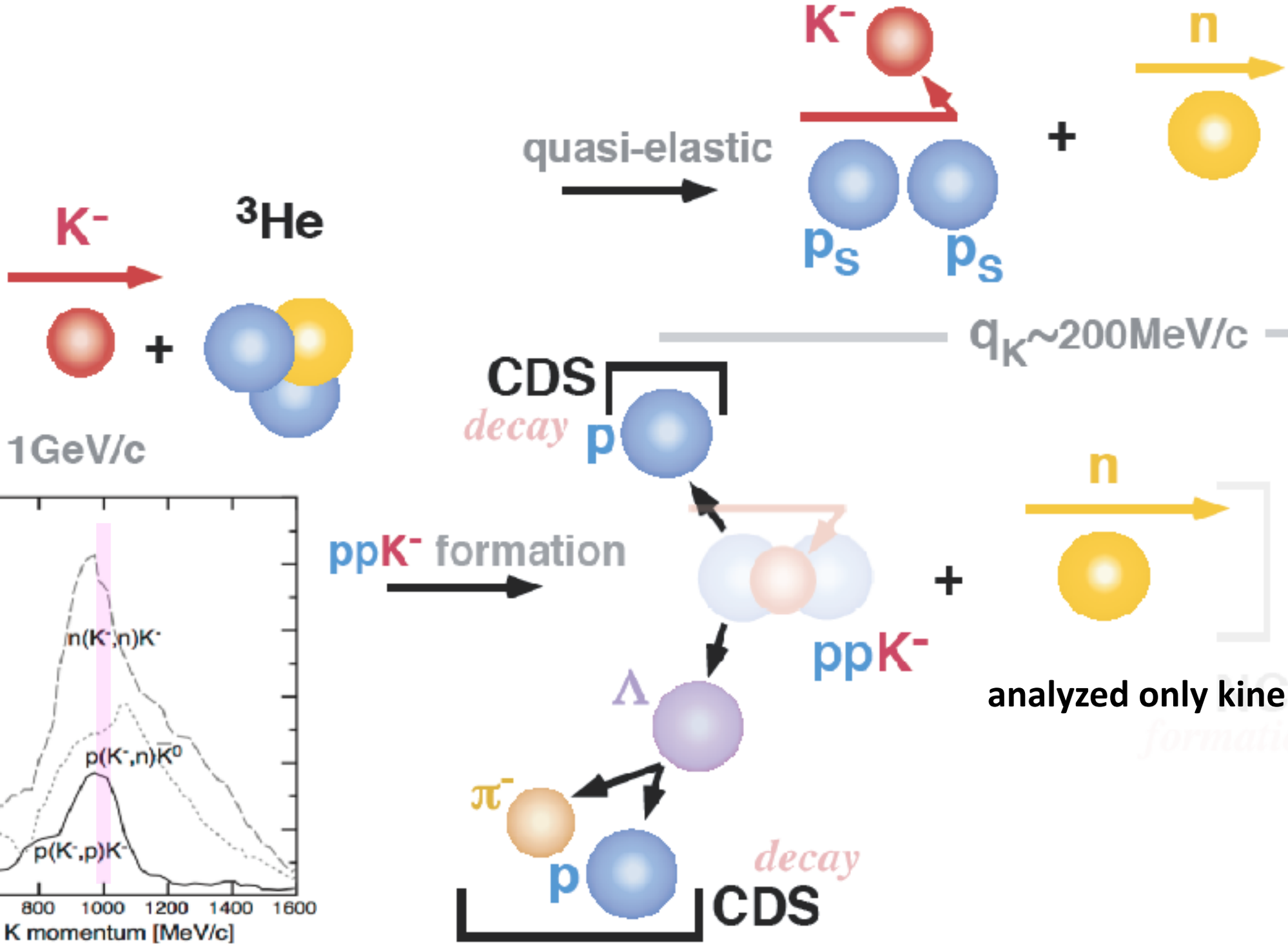
HADES
$pp \to \Lambda pK^+$
$N^* \to \Lambda K^+$?

FINUDA ?

Kpp should be studied more

"K^-pp" search via $^3He(K^-,n)$ @p_K=1GeV/c

for efficient "ppK" formation $q_K = p_n - p_K$ (~ 200MeV/c)



analyzed only kinematically

Published E15[1st] data

PTEP

Prog. Theor. Exp. Phys. 2015, 061D01 (11 pages)
DOI: 10.1093/ptep/ptv076

Letter

^{3}He(K$^-$, n) — semi-inclusive

Search for the deeply bound $K^- pp$ state from the semi-inclusive forward-neutron spectrum in the in-flight K^- reaction on helium-3

J-PARC E15 Collaboration
T. Hashimoto[1,*,†], S. Ajimura[2], G. Beer[3], H. Bhang[4], M. Bragadireanu[5], P. Buehler[6], L. Busso[7,8], M. Cargnelli[8], S. Choi[4], C. Curceanu[9], S. Enomoto[2], D. Faso[6,7], H. Fujioka[10], Y. Fujiwara[1], T. Fukuda[11], C. Guaraldo[9], R. S. Hayano[1], T. Hiraiwa[2], M. Iio[2], M. Iliescu[9], K. Inoue[13], Y. Ishiguro[10], T. Ishikawa[1], S. Ishimoto[12], K. Itahashi[13], M. Iwai[12], M. Iwasaki[14,15], Y. Kato[14], S. Kawasaki[13], P. Kienle[16,‡], H. Kou[14], J. Marton[8], Y. Matsuda[17], Y. Mizoi[11], O. Morra[6], T. Nagae[10], H. Noumi[1], H. Ohnishi[14,2], S. Okada[14], H. Outa[14], K. Piscicchia[9], M. Poli Lener[9], A. Romero Vidal[9], Y. Sada[10], A. Sakaguchi[13], F. Sakuma[14], M. Sato[14], M. Sekimoto[12], H. Shi[9], D. Sirghi[9,5], F. Sirghi[9,5], S. Suzuki[12], T. Suzuki[18], H. Tatsuno[1], M. Tokuda[15], D. Tomono[10], A. Toyoda[12], K. Tsukada[18], O. Vazquez Doce[9,19], E. Widmann[8], T. Yamaga[13], T. Yamazaki[1,14], H. Yim[20], Q. Zhang[14], J. Zmeskal[8]

Only 3 days!
(suspended by the earthquake)

PTEP

Prog. Theor. Exp. Phys. 2016, 051D01 (11 pages)
DOI: 10.1093/ptep/ptw040

Letter

^{3}He(K$^-$, Λp) n — exclusive

Structure near the $K^- + p + p$ threshold in the in-flight ^{3}He$(K^-, \Lambda p)n$ reaction

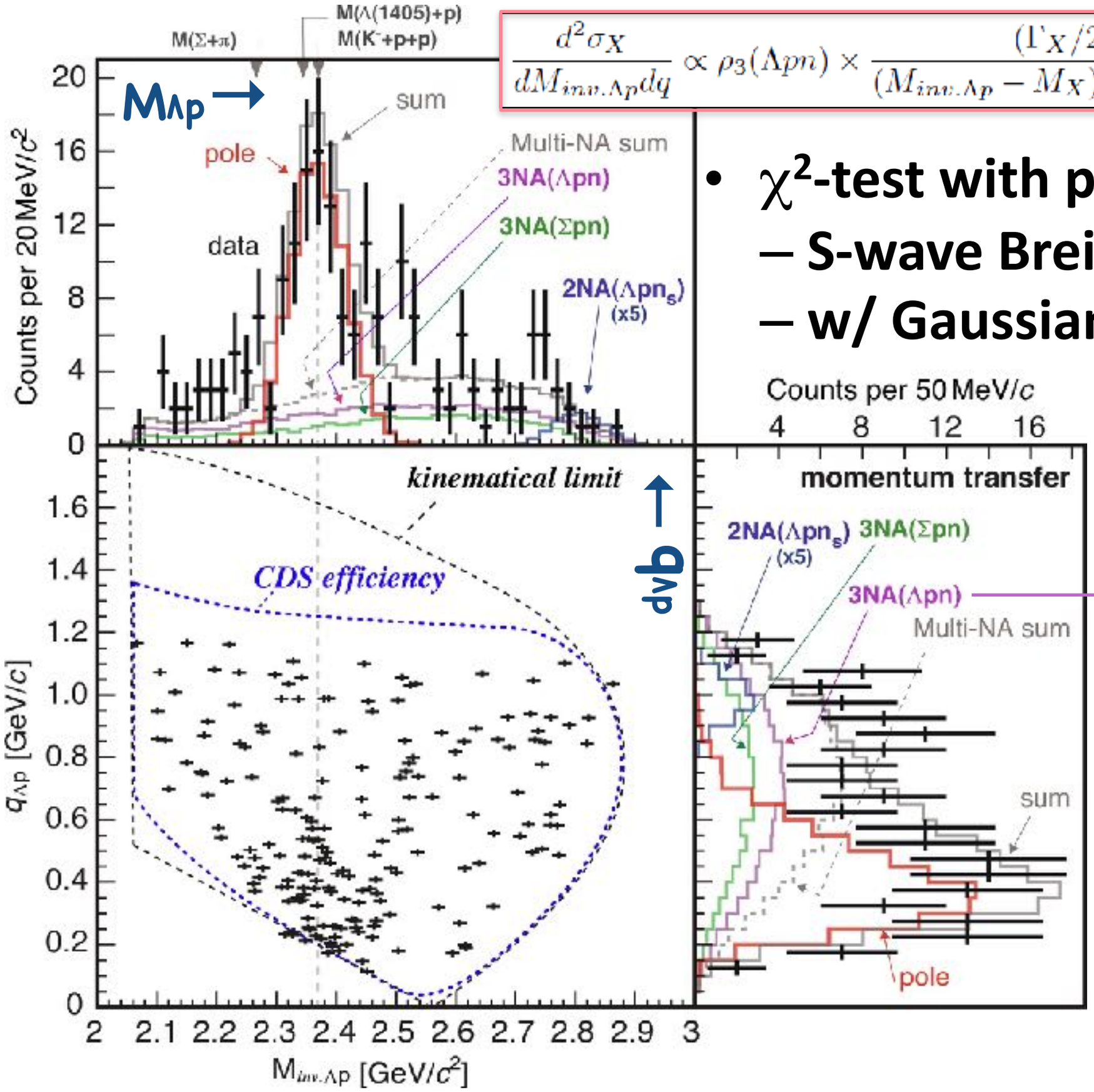
J-PARC E15 Collaboration
Y. Sada[1,*], S. Ajimura[1], M. Bazzi[2], G. Beer[3], H. Bhang[4], M. Bragadireanu[5], P. Buehler[6], L. Busso[7,9], M. Cargnelli[6], S. Choi[4], C. Curceanu[2], S. Enomoto[8], D. Faso[7,9], H. Fujioka[10], Y. Fujiwara[11], T. Fukuda[12], C. Guaraldo[2], T. Hashimoto[13], R. S. Hayano[11], T. Hiraiwa[1], M. Iio[8], M. Iliescu[2], K. Inoue[1], Y. Ishiguro[10], T. Ishikawa[11], S. Ishimoto[8], T. Ishiwatari[6], K. Itahashi[13], M. Iwai[8], M. Iwasaki[13,14], Y. Kato[13], S. Kawasaki[15], P. Kienle[†,16], H. Kou[14], Y. Ma[13], J. Marton[6], Y. Matsuda[17], Y. Mizoi[12], O. Morra[7], T. Nagae[10], H. Noumi[1], H. Ohnishi[13,1], S. Okada[13], H. Outa[13], K. Piscicchia[2], A. Romero Vidal[2], A. Sakaguchi[15], F. Sakuma[13], M. Sato[13], A. Scordo[2], M. Sekimoto[8], H. Shi[2], D. Sirghi[2,5], F. Sirghi[2,5], K. Suzuki[6], S. Suzuki[8], T. Suzuki[11], K. Tanida[18], H. Tatsuno[19], M. Tokuda[14], D. Tomono[1], A. Toyoda[8], K. Tsukada[20], O. Vazquez Doce[2,21], E. Widmann[6], B. K. Wuenschek[6], T. Yamaga[15], T. Yamazaki[11,13], H. Yim[22], Q. Zhang[13], and J. Zmeskal[6]

with new data!

E15 1st result

$K^- + {}^3He \rightarrow \Lambda + p + n_{mis.}$

$$\frac{d^2\sigma_X}{dM_{inv.\Lambda p}dq} \propto \rho_3(\Lambda pn) \times \frac{(\Gamma_X/2)^2}{(M_{inv.\Lambda p} - M_X)^2 + (\Gamma_X/2)^2} \times |\exp(-q^2/2Q_X^2)|^2,$$



- χ^2-test with pole & 3NA(Ypn)
  - S-wave Breit-Wigner pole
  - w/ Gaussian form-factor

$$\frac{d^2\sigma_{3\mathrm{NA}(\Lambda\mathrm{pn})}}{dT_n^{CM}d\cos\theta_n^{CM}} \propto \rho_3(\Lambda pn)$$

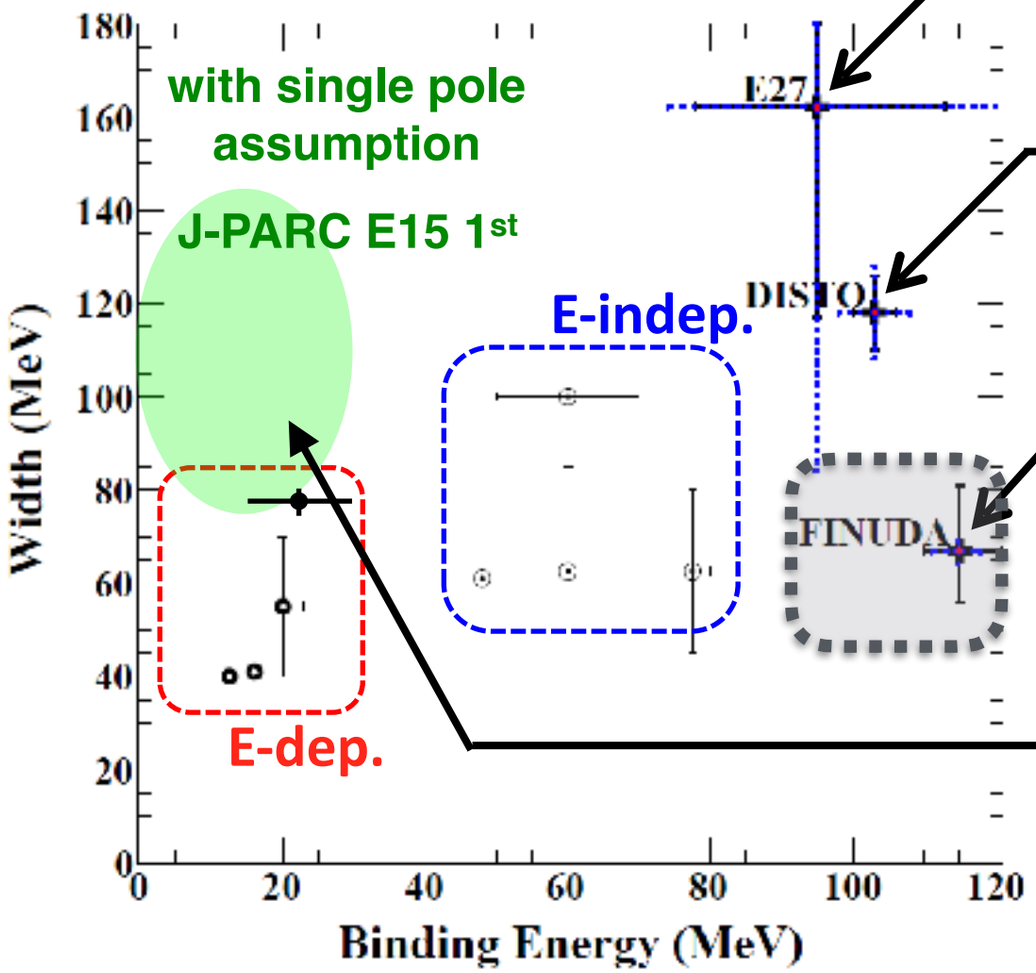
B(X) ~ 15 MeV
Γ(X) ~ 110 MeV
Q(X) ~ 400 MeV/c

Recent status of K^-pp bound state

- **Recent results**
  - **Theoretical calc.**
  - **Experiments**

$\bar{K}N$ interaction model

E-dep. / E-indep.



Reports structure / ***NO structure***

J-PARC E27
$d(\pi^+, K^+)X$

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

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

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

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

HADES
$pp \to \Lambda p K^+$
$N^* \to \Lambda K^+$?

FINUDA ?

Kpp should be studied more

What is the structure found in E15[1st] data?

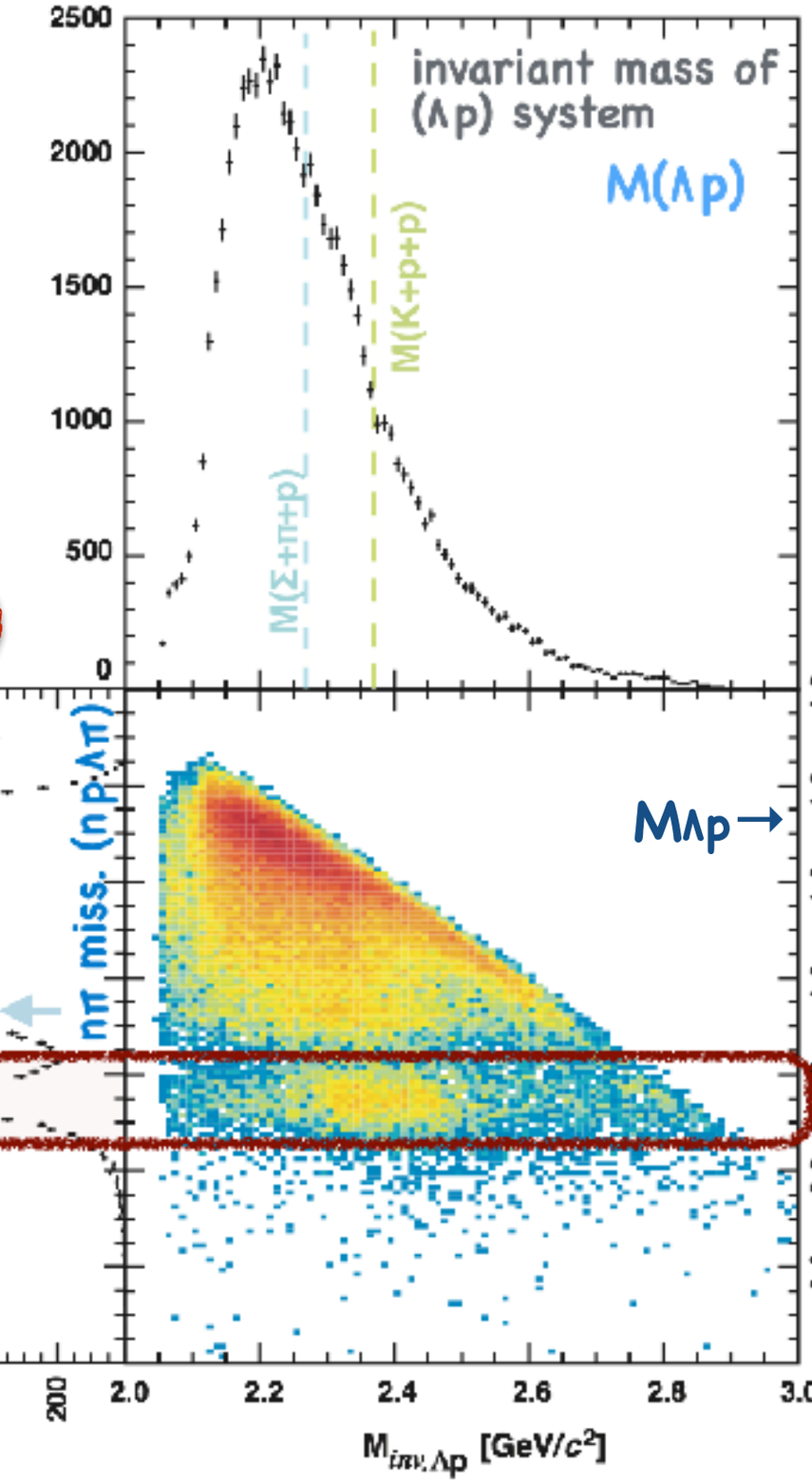
Improving statistics via E15[2nd] data

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

$K^- + {}^3He \rightarrow Y + n \quad (X=n)$

$Y(=K^-pp) \rightarrow \Lambda + p$

$K^- + {}^3He \rightarrow \Lambda + p + X_{mis}\ (X_{mis}=n)$



~ 30 times more data for Λpn final state

Dalitz Plot of Λpn in equal manner

$T_n + T_p + T_\Lambda = Q$ Viviani's theorem on equilateral triangle

PRELIMINARY

2NA??

$K^- + \text{“}pn + p_s\text{”} \rightarrow \Lambda n + p_s$??

T_n/Q

T_p/Q

T_Λ/Q

$(T_p - T_\Lambda)/\sqrt{3}Q$

structure(s)

2NA

$K^- + \text{“}pp + n_s\text{”} \rightarrow \Lambda p + n_s$

Counts / 20 (MeV/c^2)

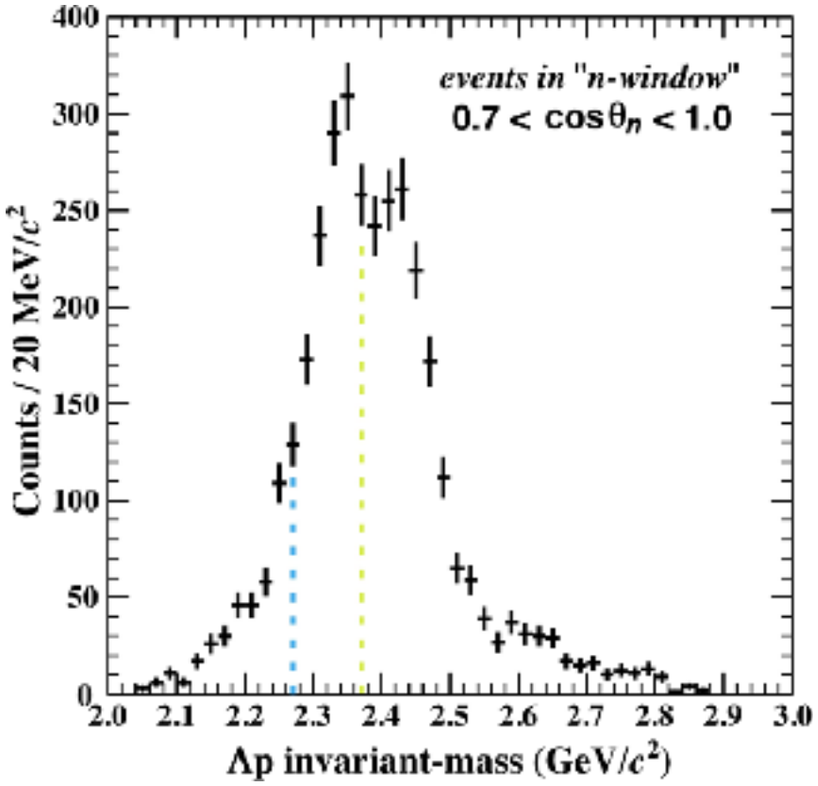
$M_{\Lambda p}$ ↓

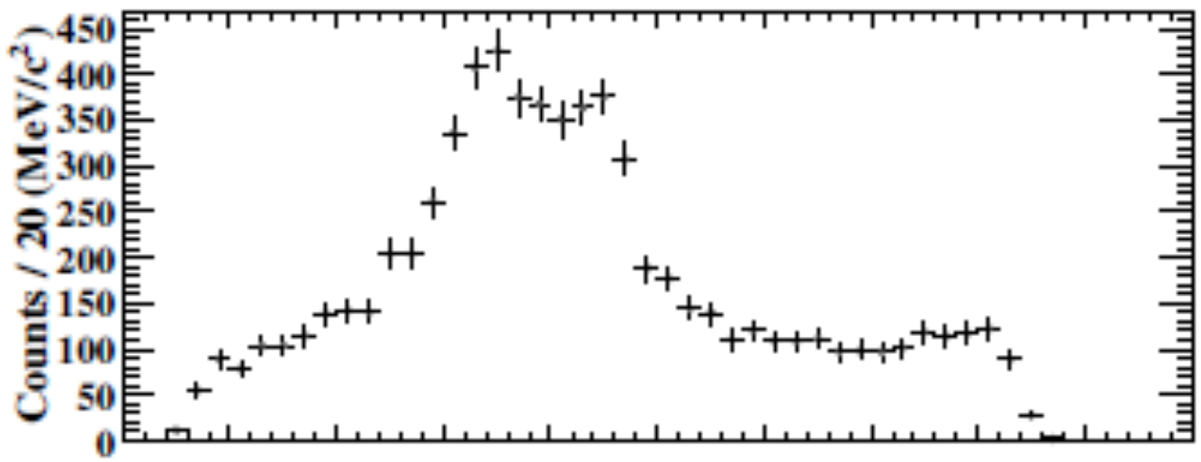
Λp invariant mass

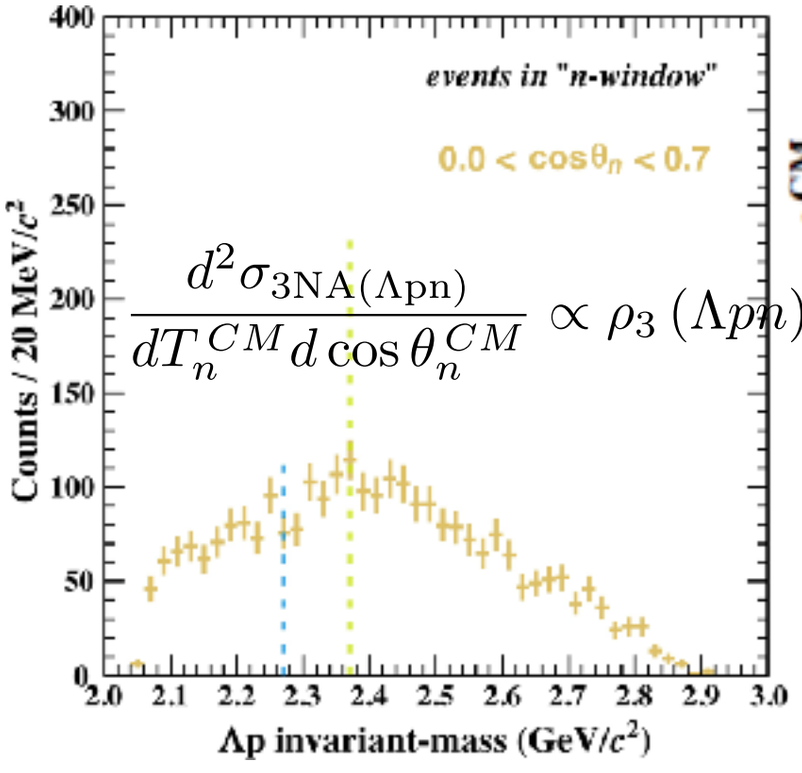
^{3}He(K^{-}, Λp)n:

Angular Dependence of n in CM

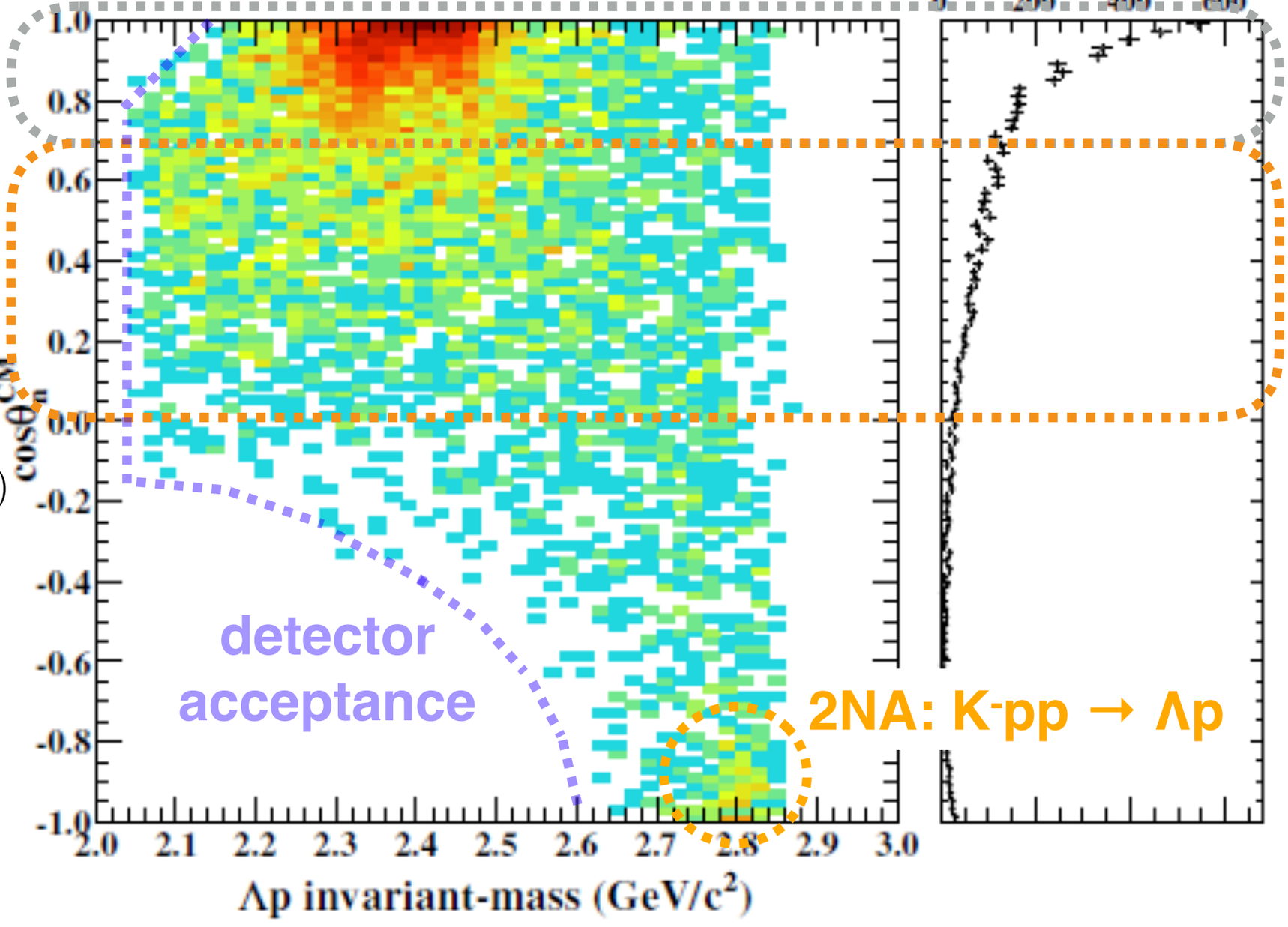
^{3}He(K$^-$, Λp)n: Angular Dependence





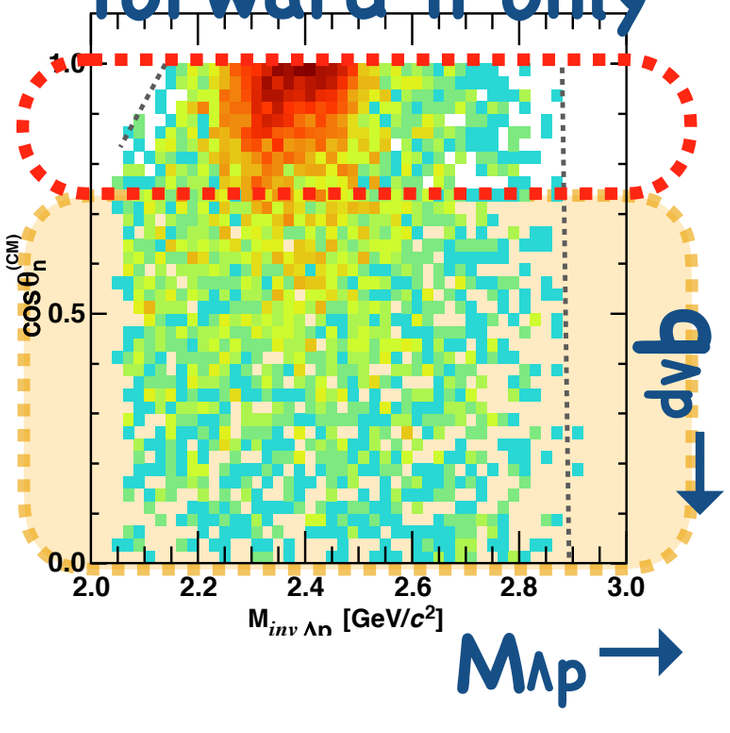


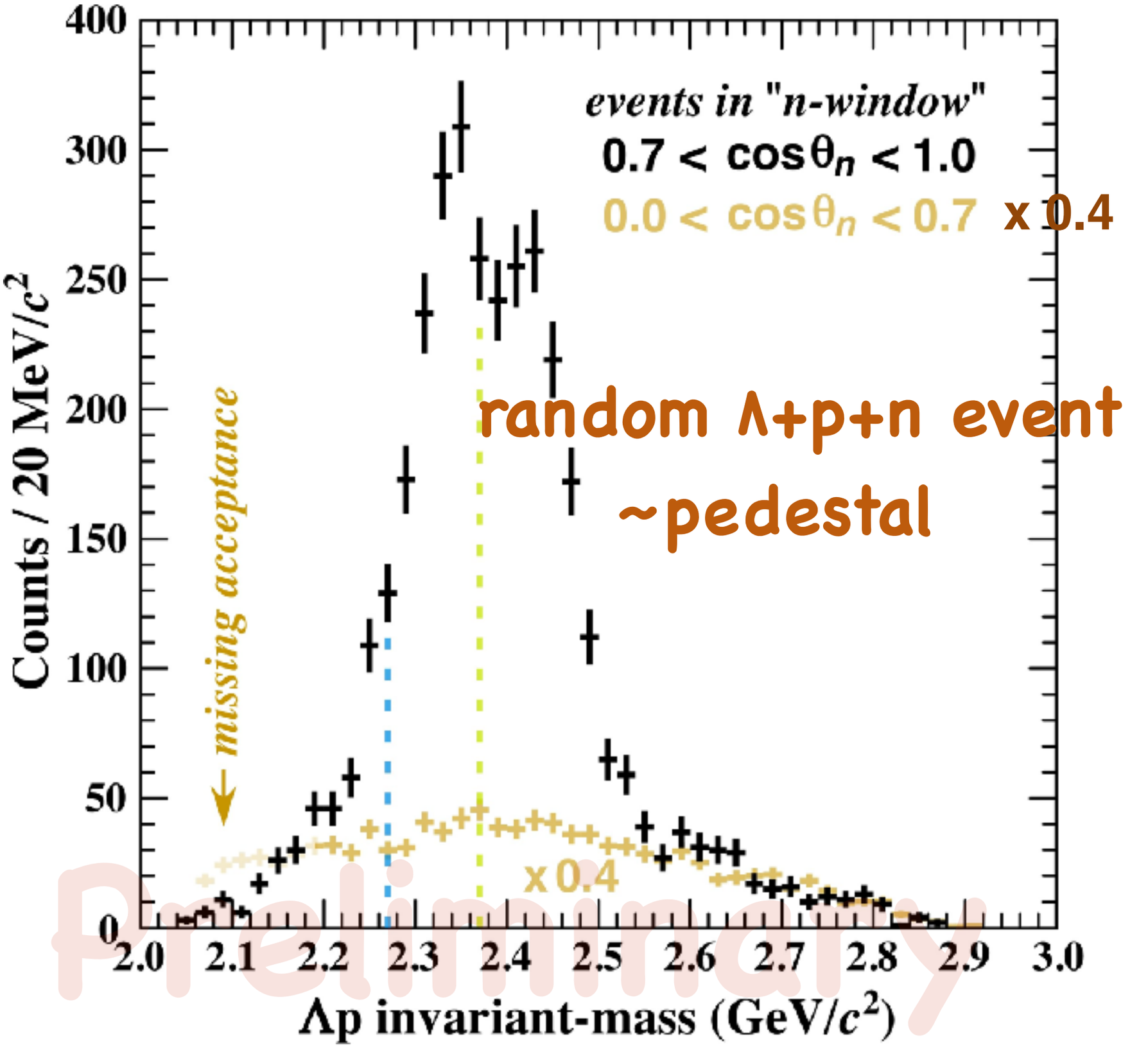
$$\frac{d^2\sigma_{3\mathrm{NA}(\Lambda \mathrm{pn})}}{dT_n^{CM} d\cos\theta_n^{CM}} \propto \rho_3\,(\Lambda pn)$$



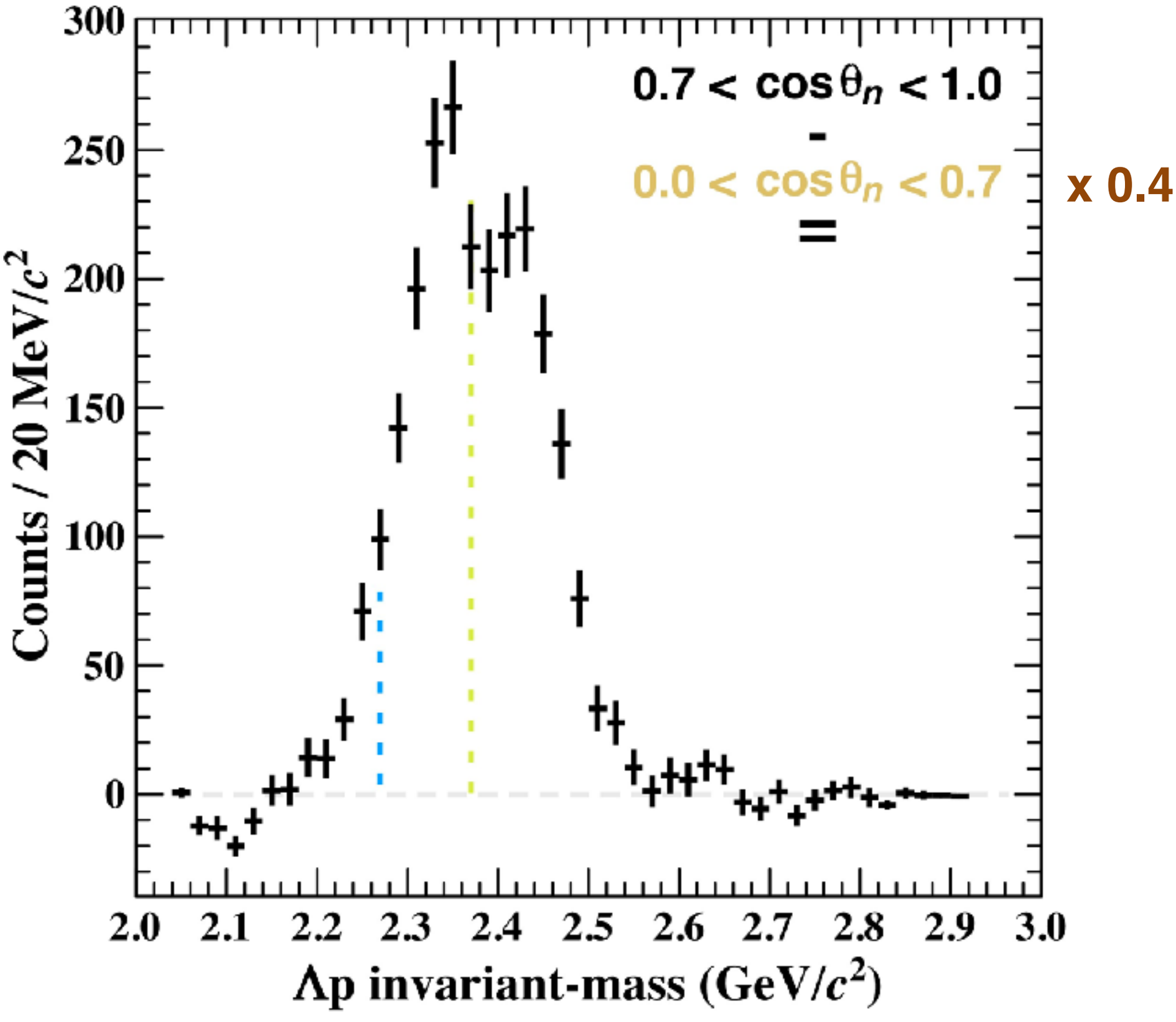
$K^-+{}^3He \rightarrow \Lambda+p+n$: randomly divided

forward n only

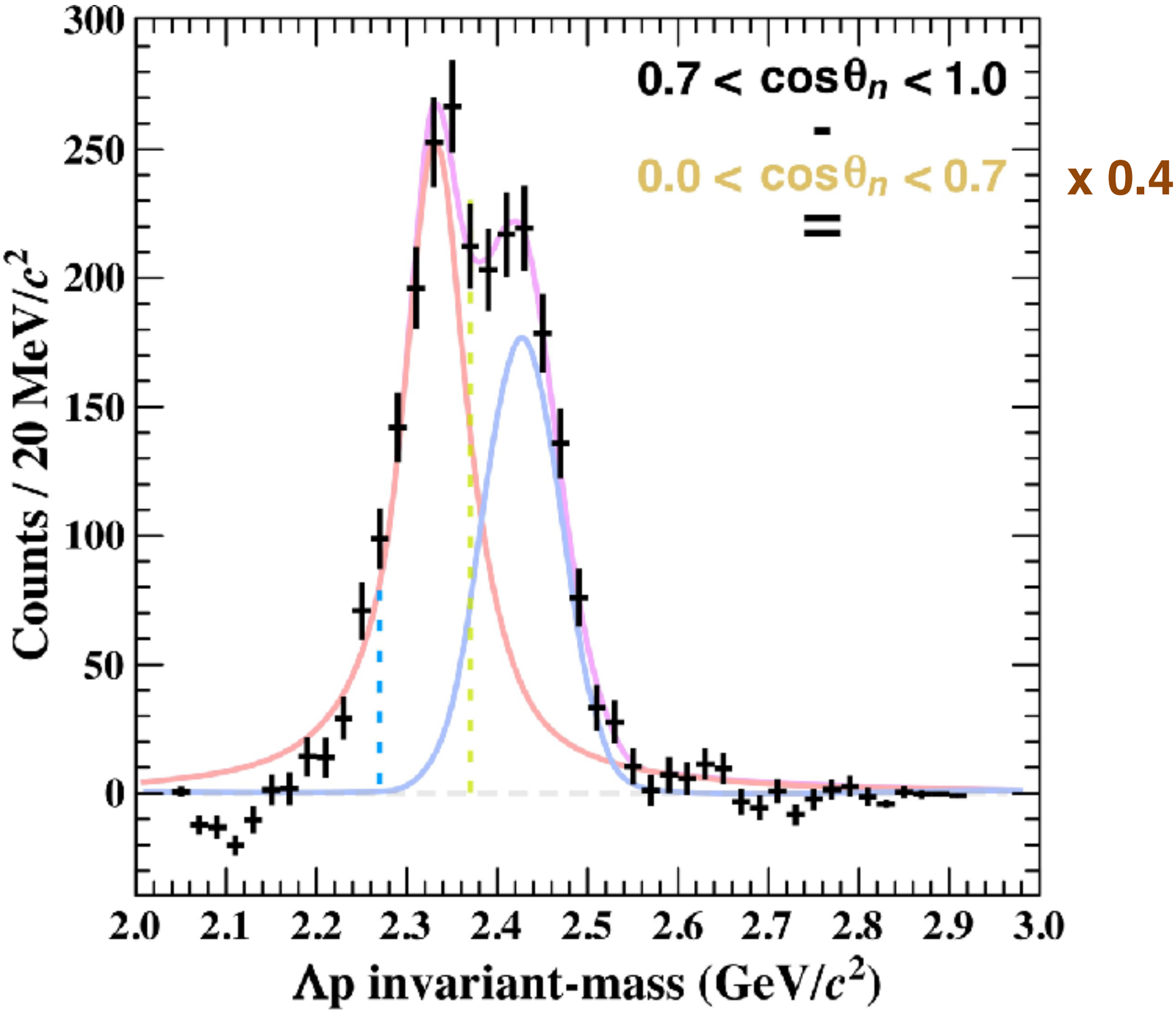




random Λ+p+n event subtraction



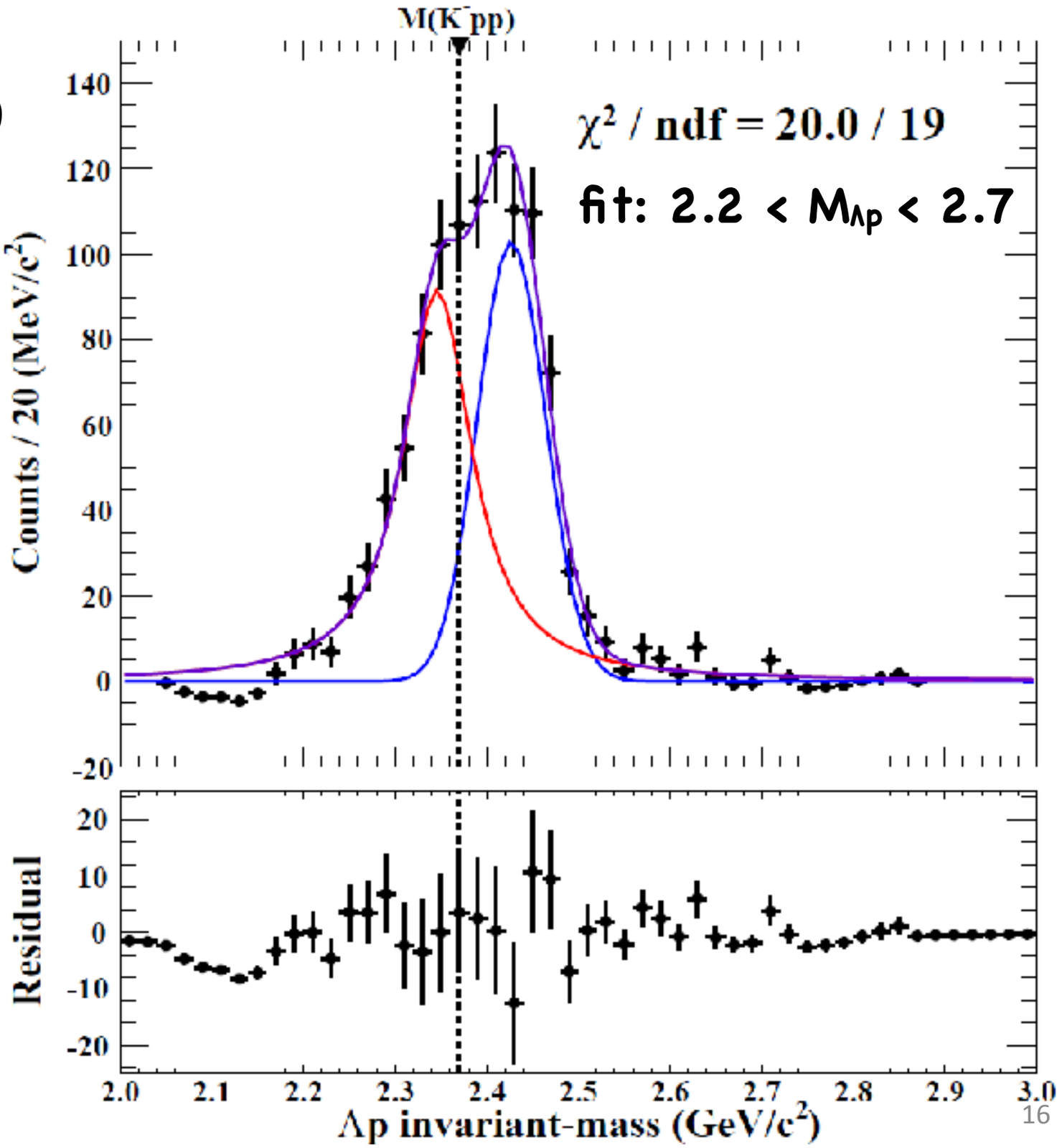
fit with Bright-Wigner + Gaussian



fit with Bright-Wigner + Gaussian

$\cos\theta_n$ slice

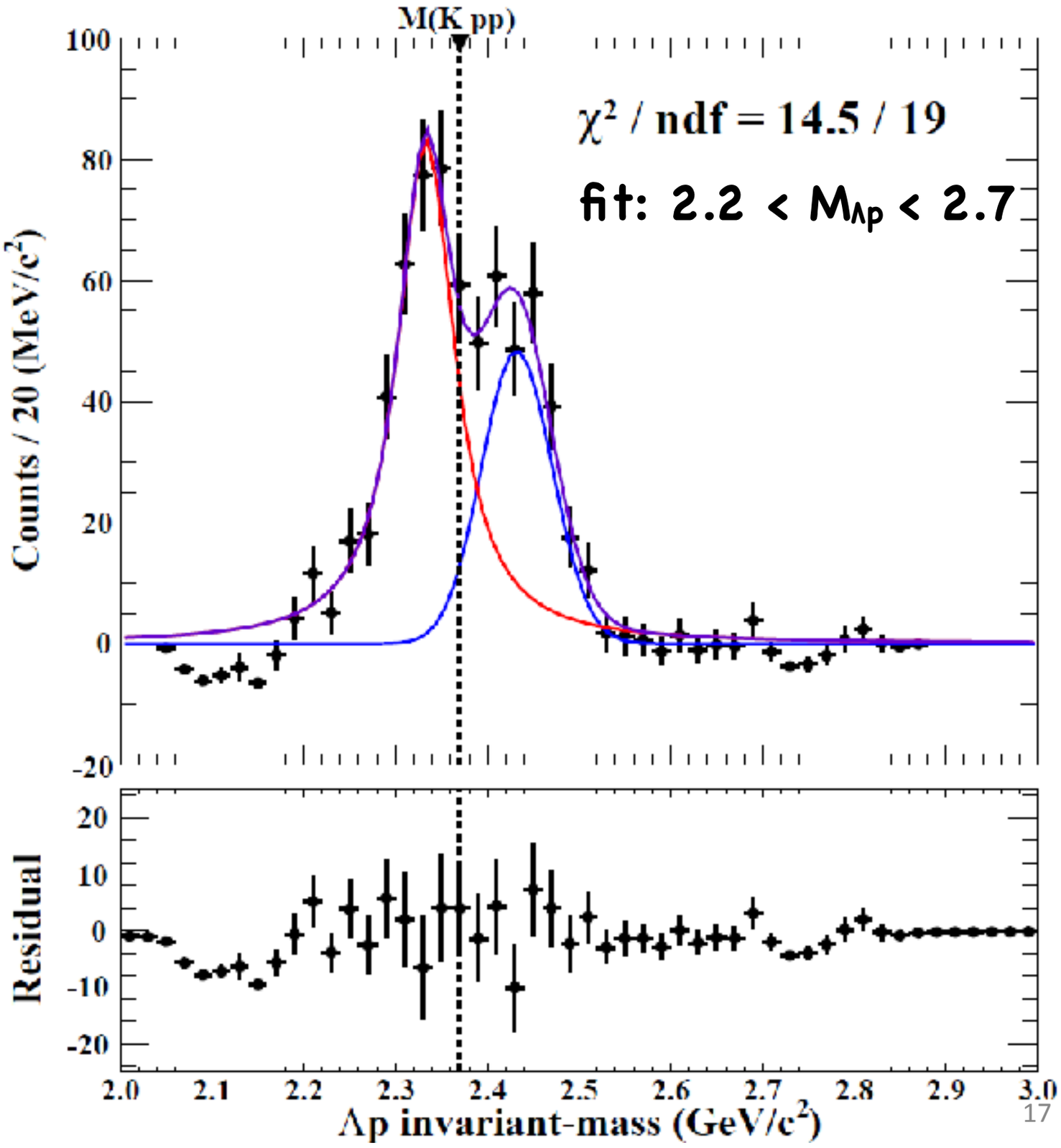
$0.95 < \cos\theta_n < 1.00$



fit with Bright-Wigner + Gaussian

$\cos\theta_n$ slice

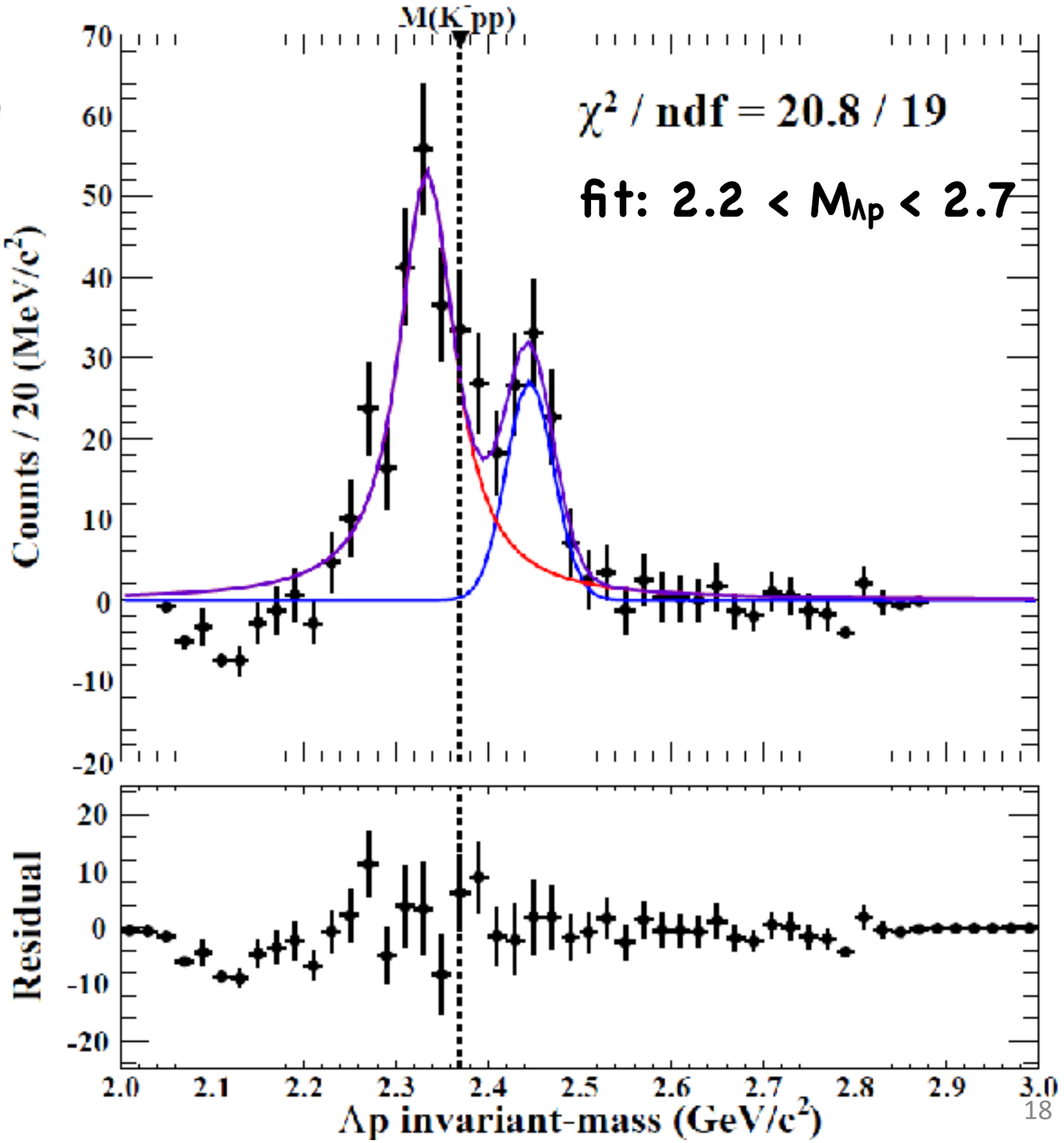
$0.90 < \cos\theta_n < 0.95$



fit with Bright-Wigner + Gaussian

$\cos\theta_n$ slice

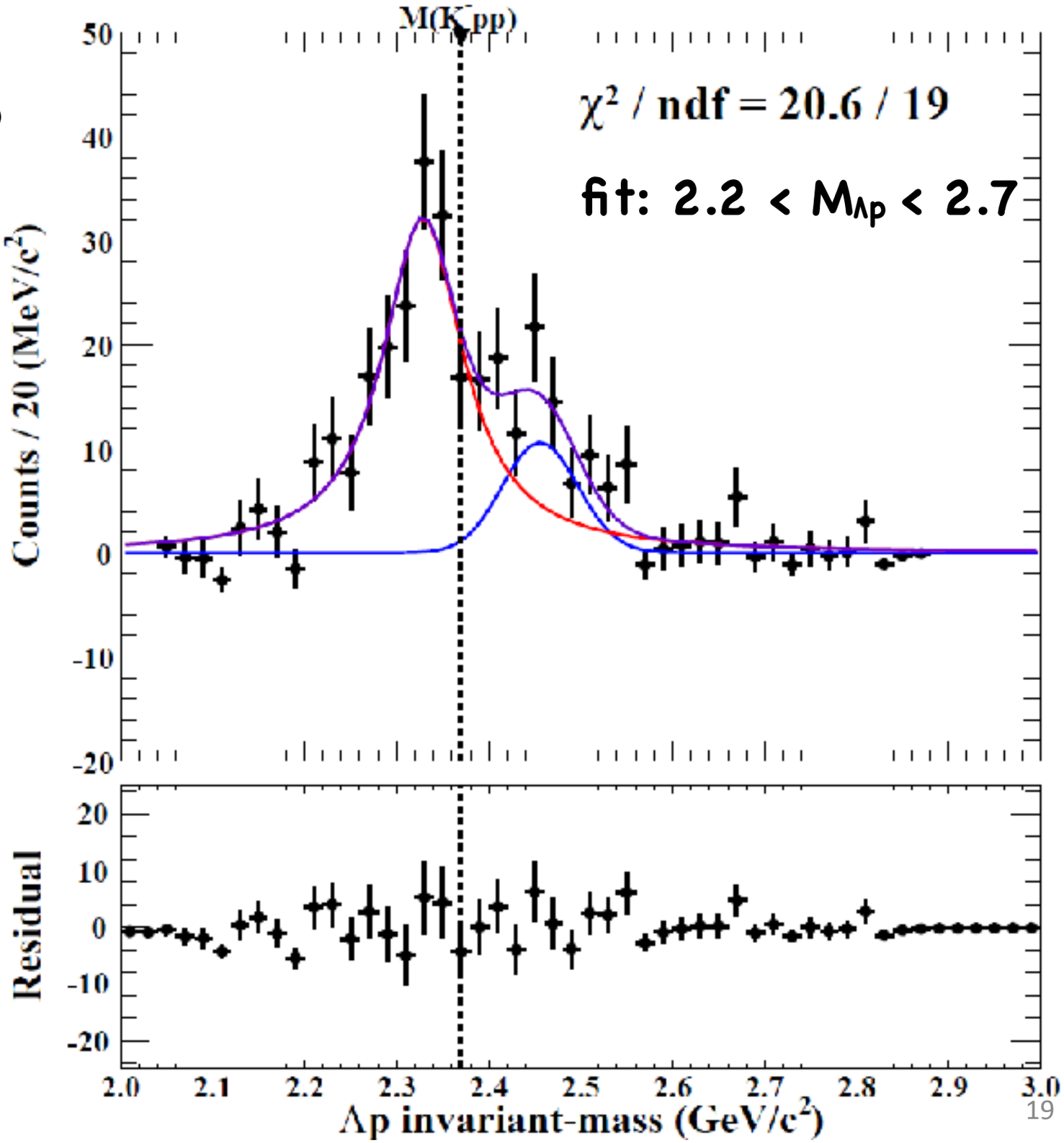
$0.85 < \cos\theta_n < 0.90$



fit with Bright-Wigner + Gaussian

$\cos\theta_n$ slice

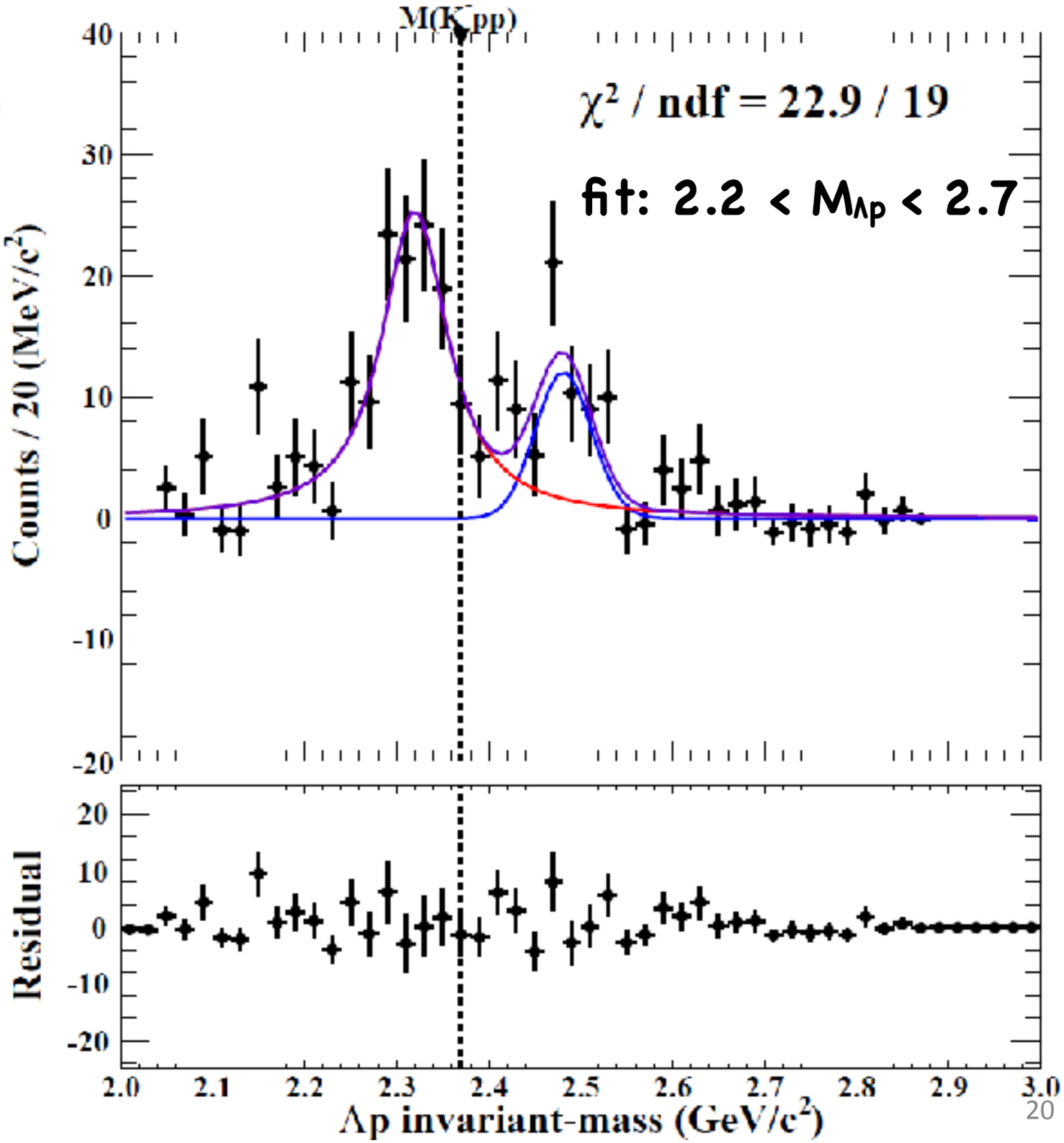
$0.80 < \cos\theta_n < 0.85$



fit with Bright-Wigner + Gaussian

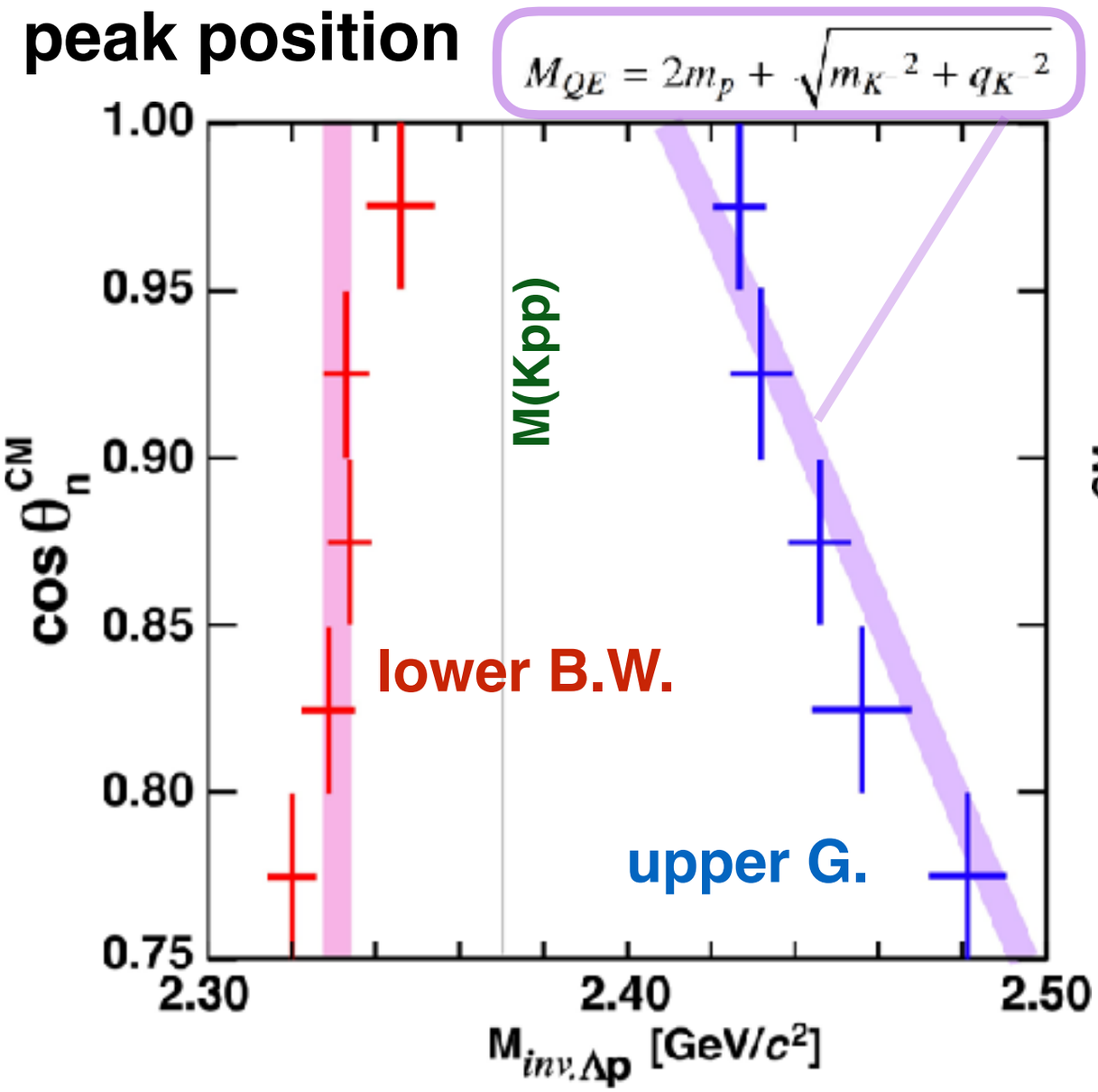
$\cos\theta_n$ slice

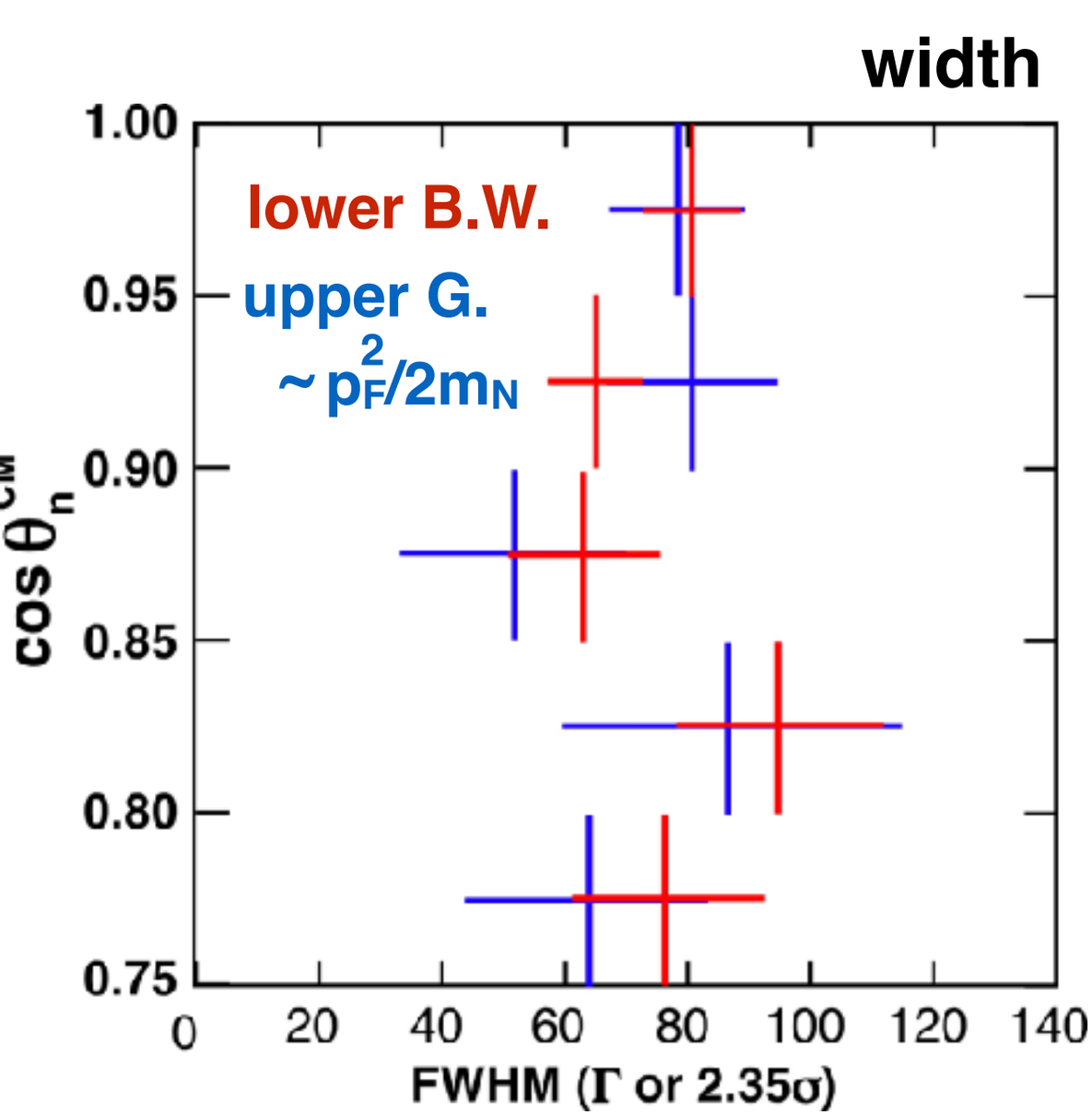
$0.75 < \cos\theta_n < 0.80$



fit with Bright-Wigner + Gaussian by slicing $\cos\theta_n$

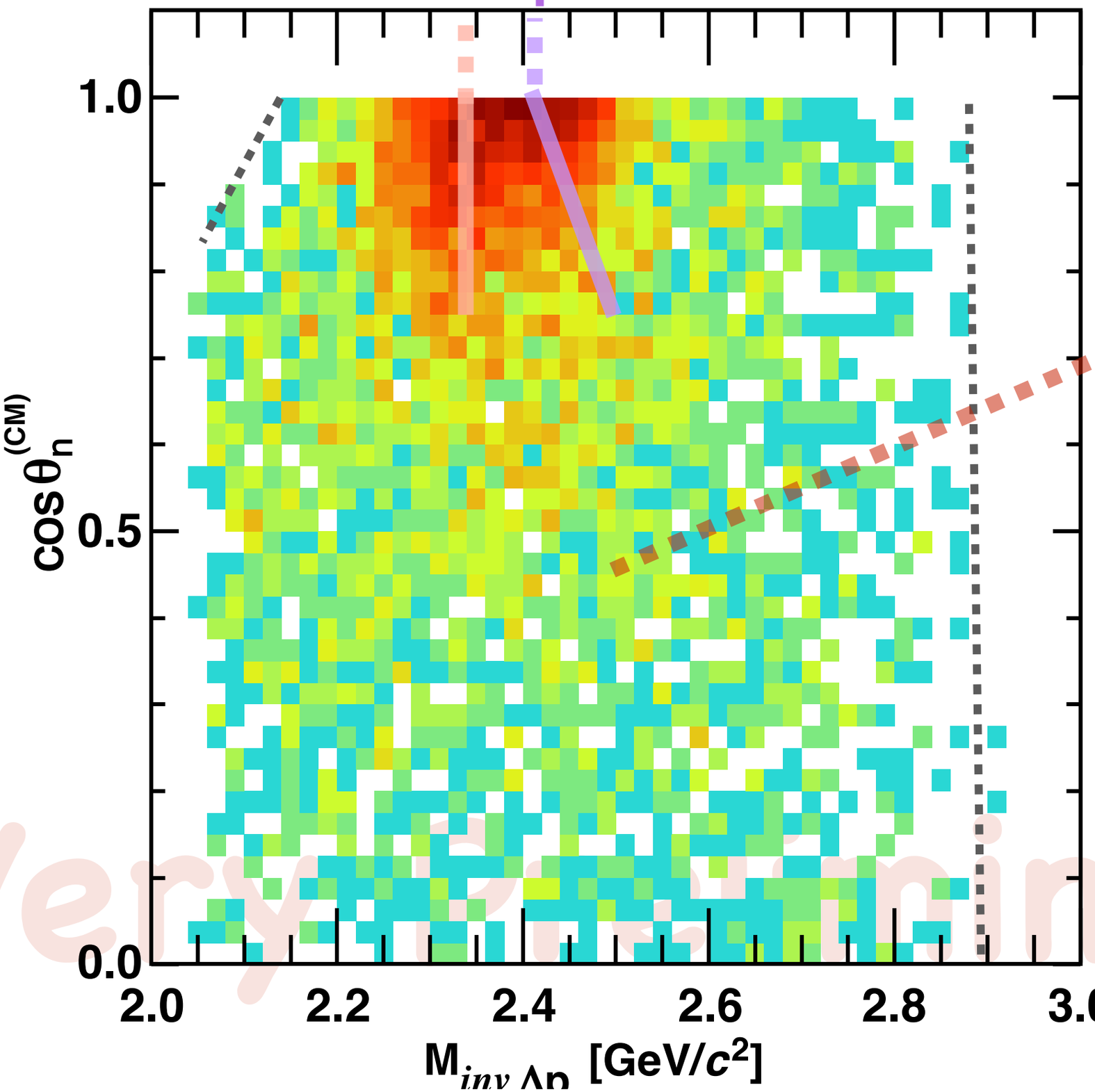
upper peak shift by recoil kaon energy !!





^{3}He(K$^-$, Λp)n: Angular Dependence

nuclear bound state quasi-elastic + internal conv.



3N phase space?

$$\frac{d^2\sigma_{3\mathrm{NA}(\Lambda pn)}}{dT_n^{CM}\, d\cos\theta_n^{CM}} \propto \rho_3\,(\Lambda pn)$$

^{3}He(K^-, Λp)n @ p_K=1GeV/c consist from

1) flat distribution proportional to phase space ?

- kaon total energy randomly divided into Λ+p+n
- point-like 3NA reaction??

2) peak in unbound region (above M(Kpp))

- peak shift: $M_{\Lambda p}^{QF} \sim 2m_p + m_K + q^2/2m_K$

quasi-elastic K scattering x internal conversion

$q^2/2m$ simply consumed as Λp kinetic energy!

- good agreement with $\sigma(KN \rightarrow NK) \times \sigma(Kpp \rightarrow \Lambda p)$
- $\sigma(Kpp \rightarrow \Lambda p) \sim$ no q dependence $\propto q^{-1}$

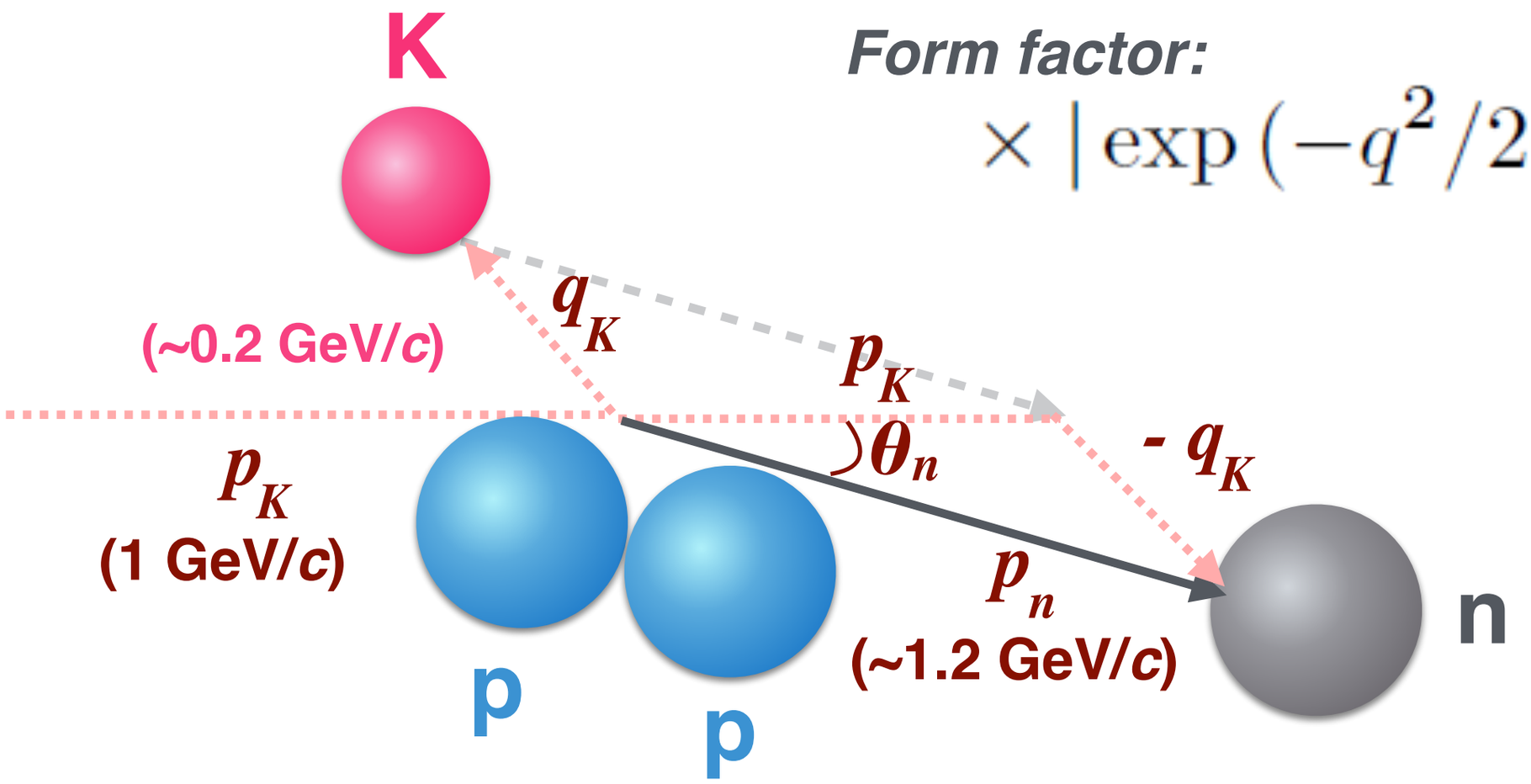
3) peak in bound region (below M(Kpp))

- no peak shift: $M_{\Lambda p}^{Kpp} \sim 2m_p + m_K - B_{Kpp}$
- **nuclear bound state**: i.e. associated with QF = QE + IC

one can pull out the constituent particle from Kpp!

momentum transfer q_K & $\cos\theta_n$

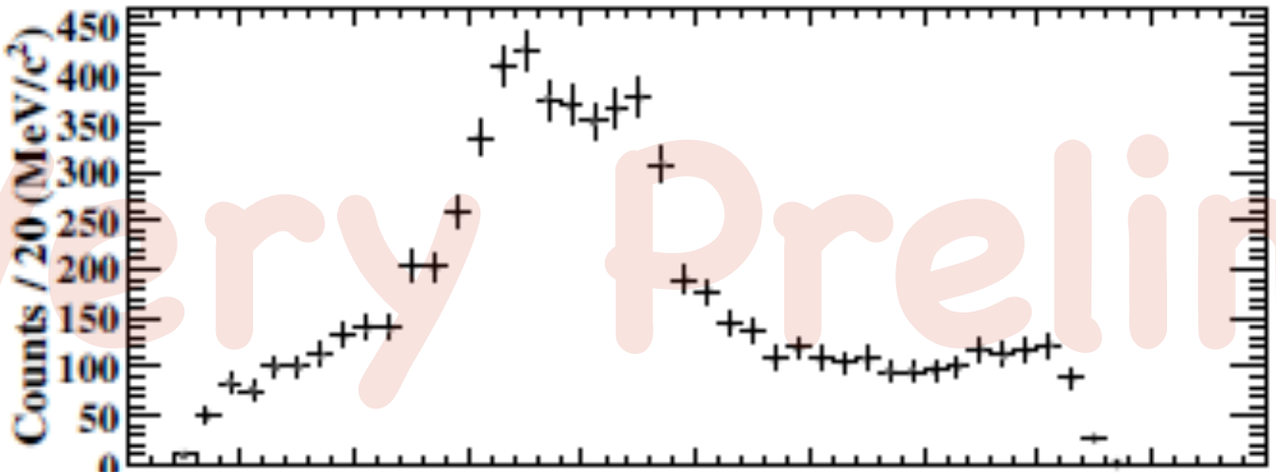
$q_K = p_K - p_n$ *(~ 200MeV/c)*



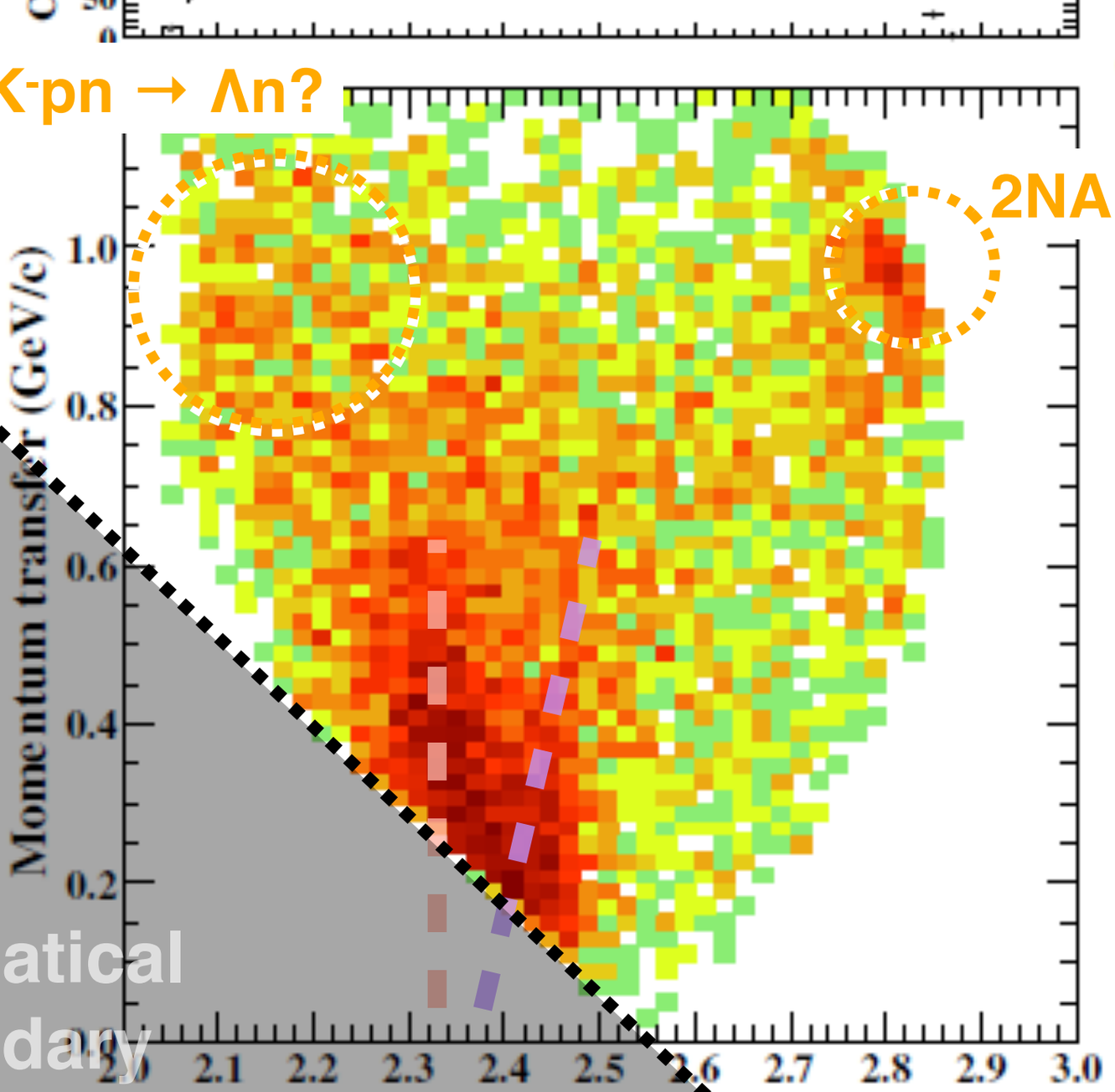
Form factor:

$$\times \left| \exp\left(-q^2/2Q_X^2\right)\right|^2,$$

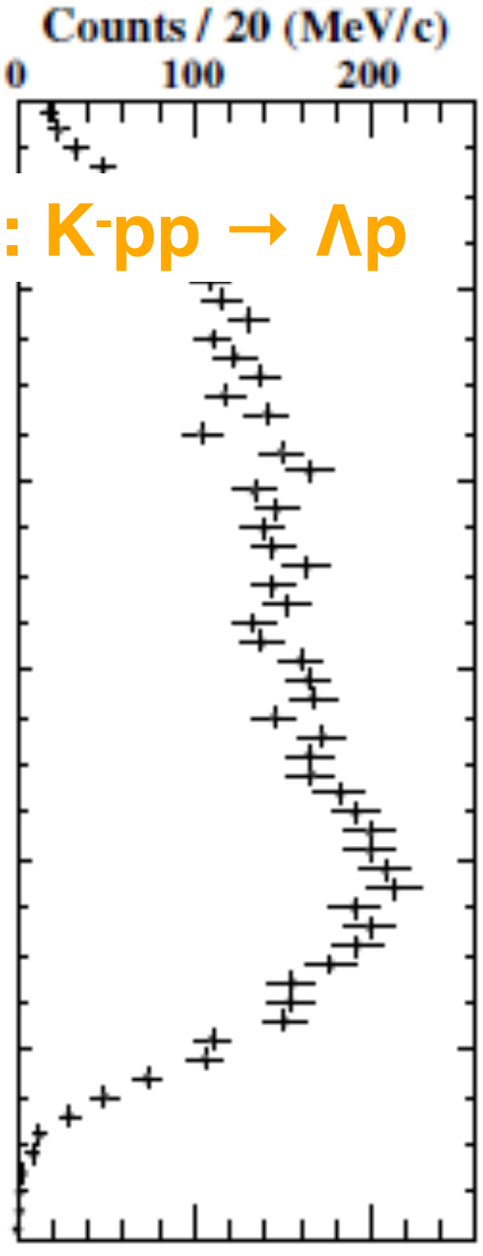
$$q_K^2 = p_K^2 + p_n^2 - 2\, p_K\, p_n \cos\theta_n$$



2NA: K⁻pn → Λn?

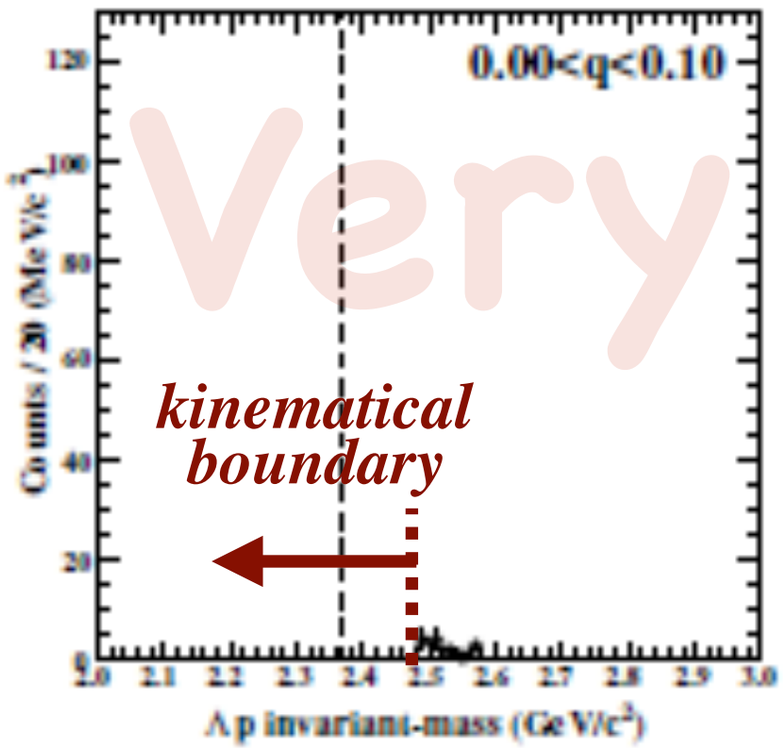


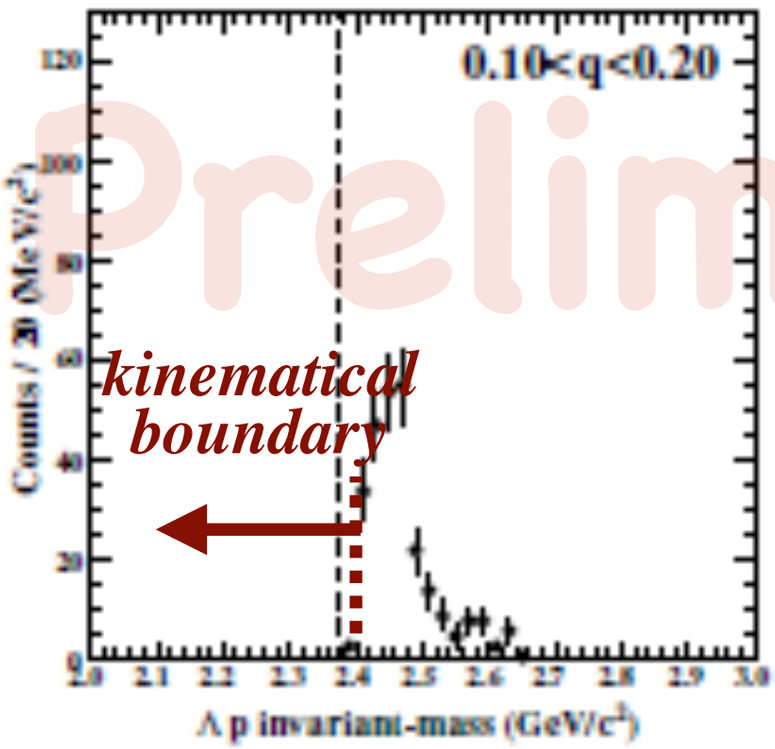
2NA: K⁻pp → Λp

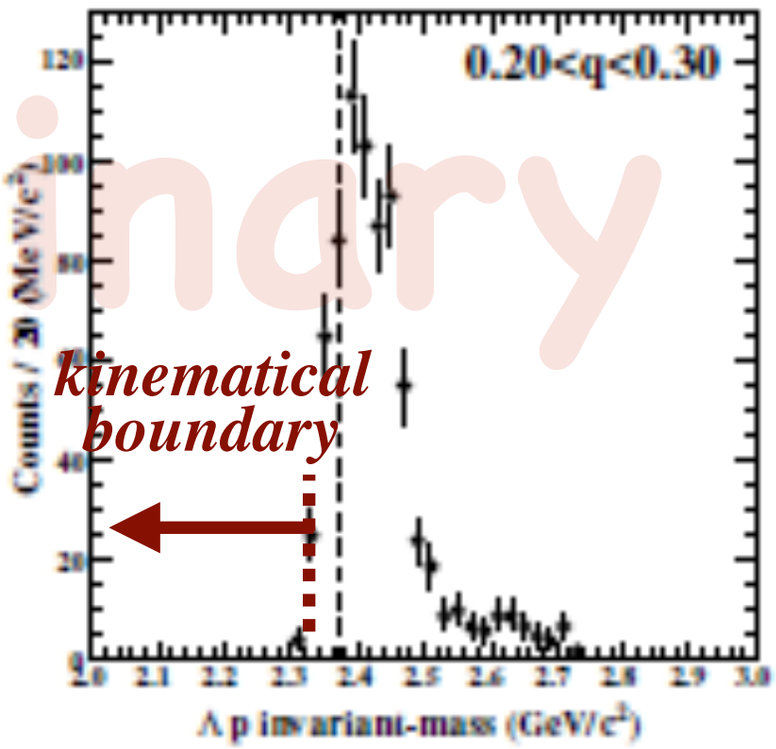


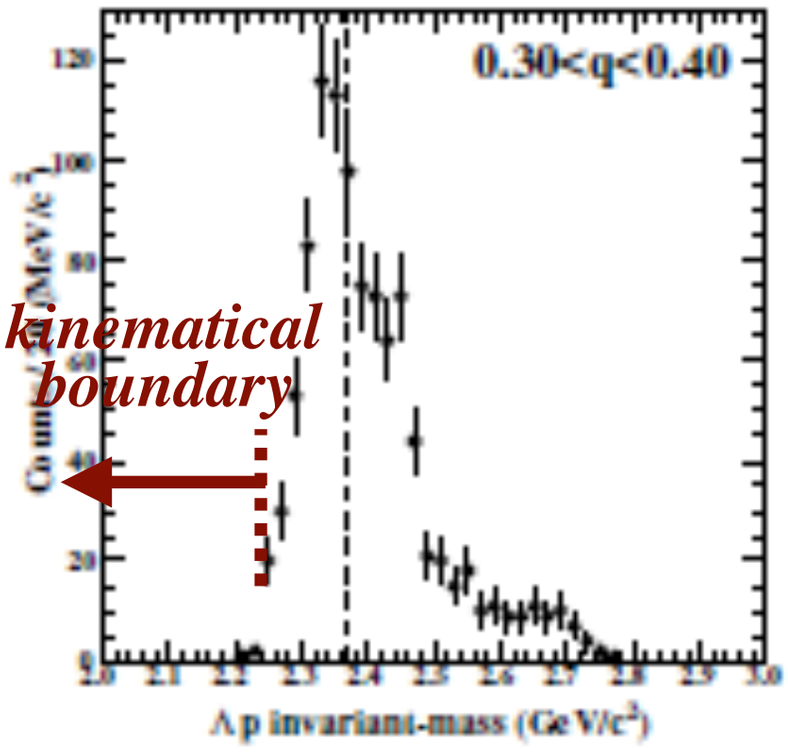
kinematical boundary

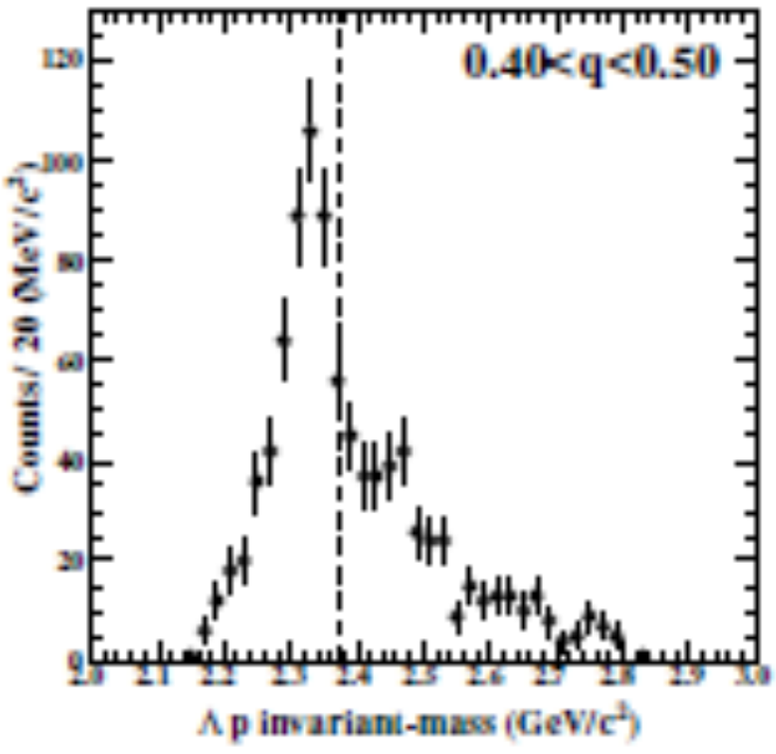
q_K slice by 100 MeV/c

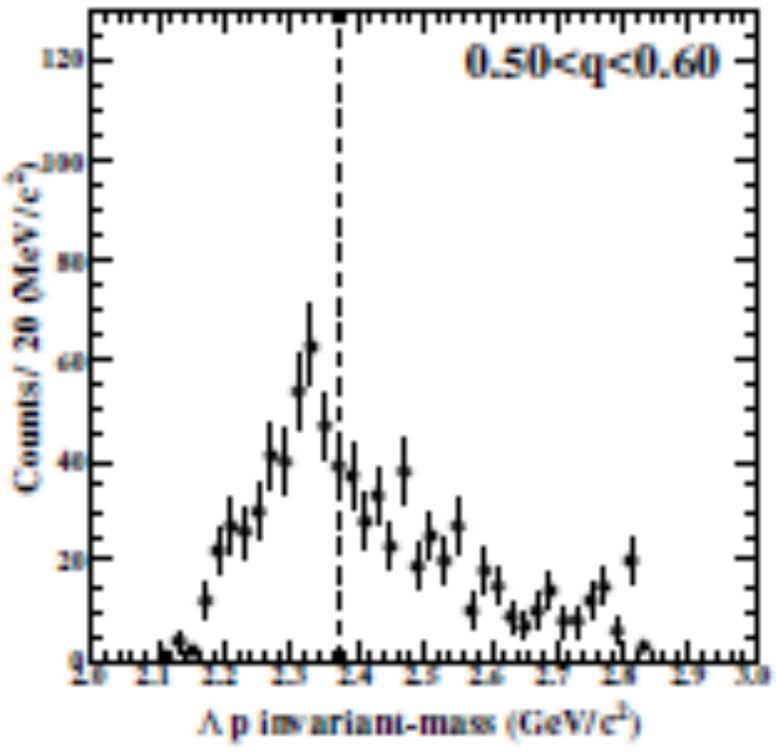












what we assumed in E15[1st]

existence of a pole in : $K^- + {}^3He \rightarrow \Lambda + p + n_{mis.}$

$$\frac{d^2\sigma_X}{dM_{inv.\Lambda p}dq} \propto \rho_3(\Lambda pn) \times \frac{(\Gamma_X/2)^2}{(M_{inv.\Lambda p} - M_X)^2 + (\Gamma_X/2)^2} \times \left|\exp\left(-q^2/2Q_X^2\right)\right|^2,$$

q is reaching as large as ~ 600 MeV/c!

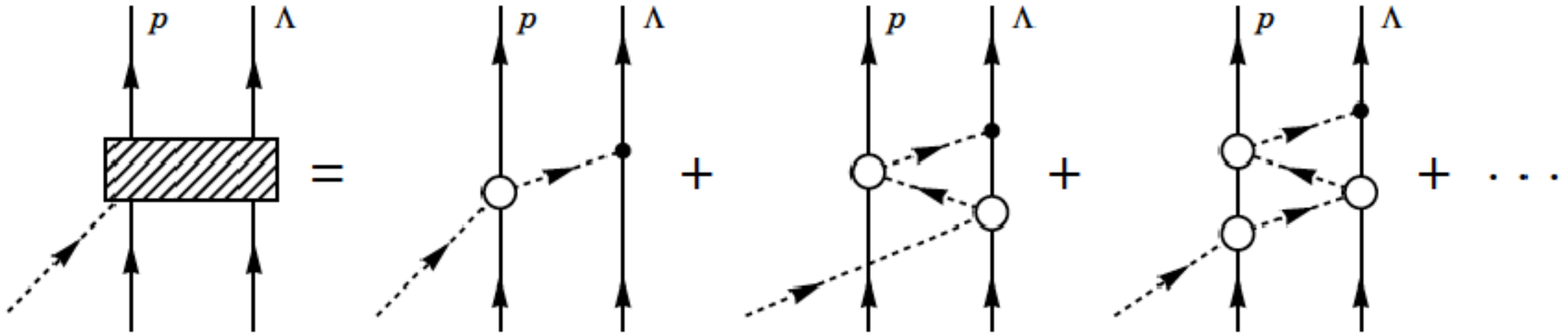
large Q_x implies realization of compact state

peak position changes due to kinematical boundary

^{3}He(K^{-}, Λp)n:
a theoretical prediction
based on the E15 1st run

^{3}He(K$^-$, Λp)n:

Structure can be explained with quasi-elastic K scattering & Kpp @ x-UM?



Sekihara Oset Ramos

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On the structure observed in the in-flight ^{3}He(K^-, Λp)n reaction at J-PARC

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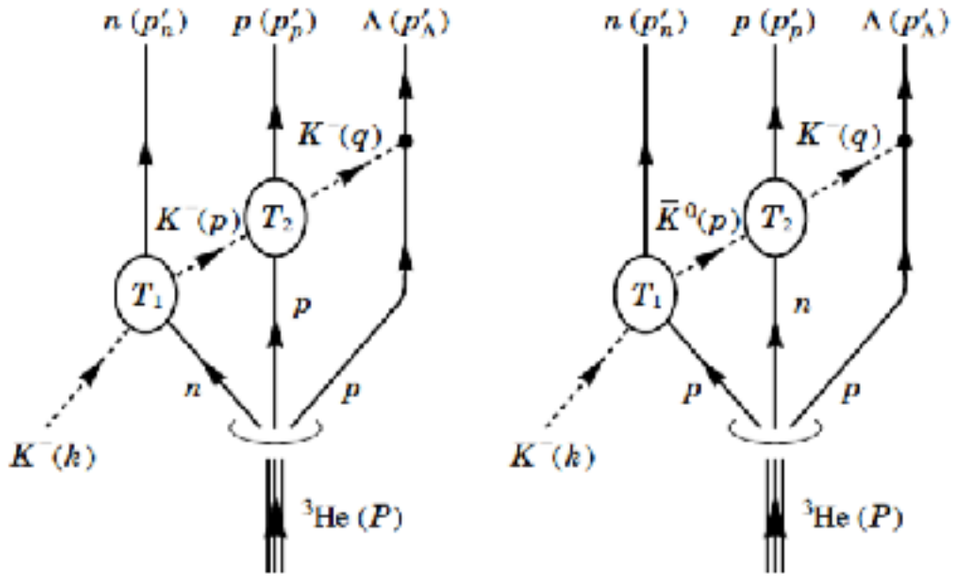
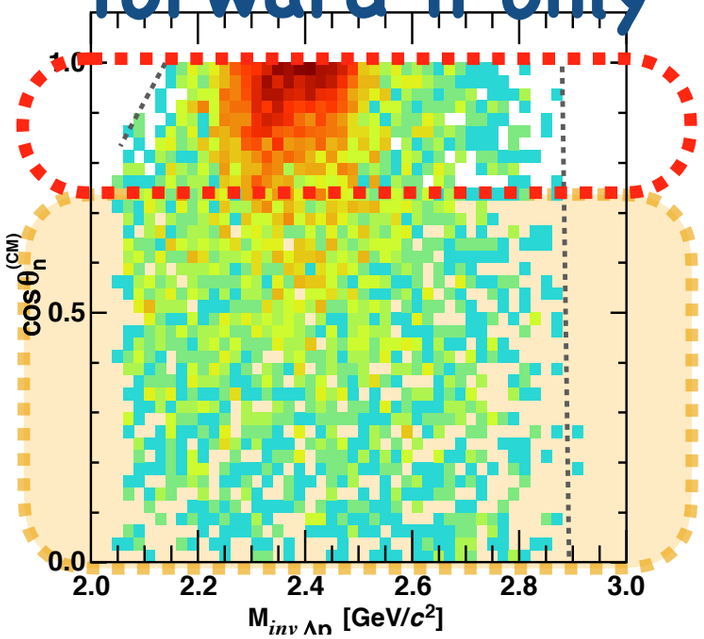


Qualitatively consistent with S.O.R.

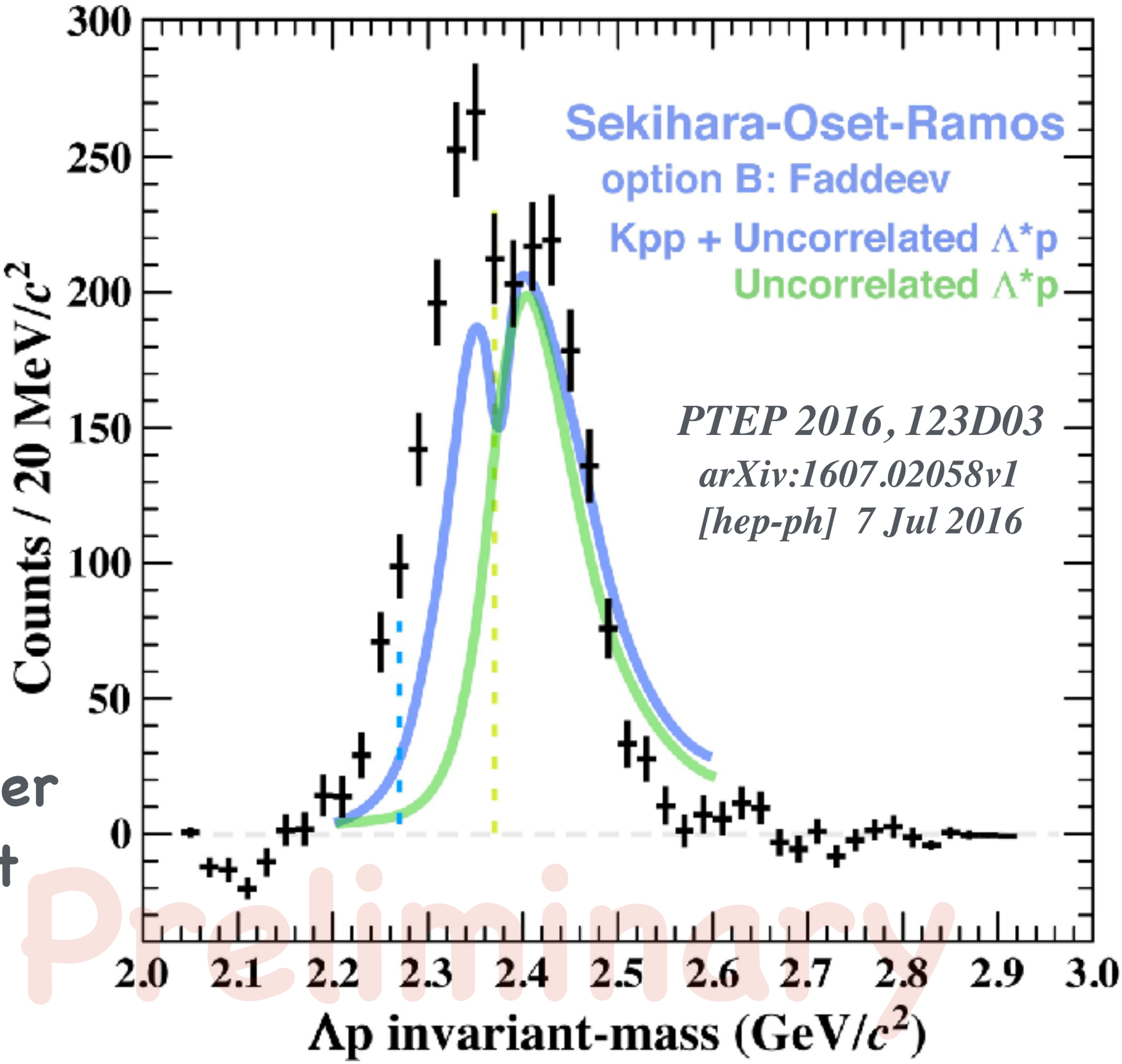
forward n only



QE + "Kpp"

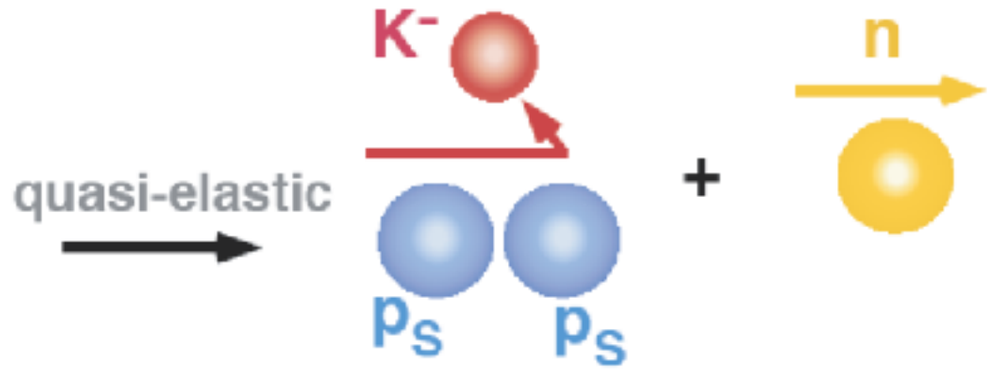
K multiple scattering

qualitatively rather good agreement



Summary

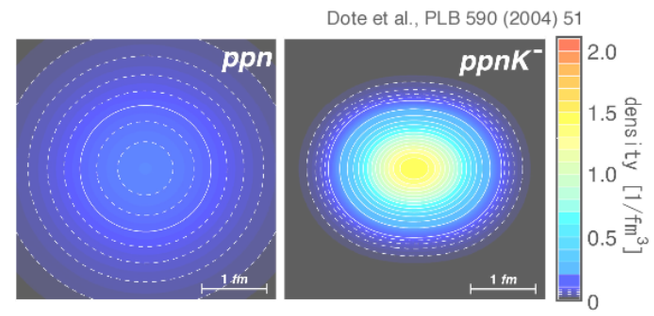
low q_K is key for the formation



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

convincing Kpp signal

compact deep bound system ?



associated with QF := QE → IC

- peak shift: $M^{QF}_{\Lambda p} = 2m_p + m_K + q^2/2m_K$

qualitatively consistent with χ-UM

bound is much deeper than χ-UM

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

$$\frac{d^2\sigma_{3\mathrm{NA}(\Lambda\mathrm{pn})}}{dT_n^{CM} d\cos\theta_n^{CM}} \propto \rho_3\,(\Lambda pn)$$

kaon total energy randomly divided into Λ+p+n

point-like 3NA reaction? — *another puzzle* —

2NA processes are relatively week

E15 collaboration

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