MENU2016
July 25-30, 2016 @ Kyoto

Recent result of an exclusive measurement of $^{3}\mathrm{He}(K^{-}, \Lambda p)n$ reaction to search for $\bar{K}NN$ bound state at J-PARC

Takumi Yamaga

Research Center for Nuclear Physics, Osaka university

For the J-PARC E15 collaboration

July 26, 2016

Contents

- Introduction of KNN bound state
- Experimental Procedure
- Analysis Method
- Results
- Summary

INTRODUCTION

Recent status of $\overline{K}NN$ bound state searching

Result of E15-1st

Kaonic Nuclei and $\bar{K}NN$ bound state

- **Kaonic nuclei**
  - **What's this?**
    - Bound state of anti-kaon and nucleus
  - **What's interest?**
    - $\bar{K}N$ interaction in the sub-threshold region

- **$\bar{K}NN$ bound state**
  - The simplest kaonic nucleus
    - » So-called K^-pp bound state

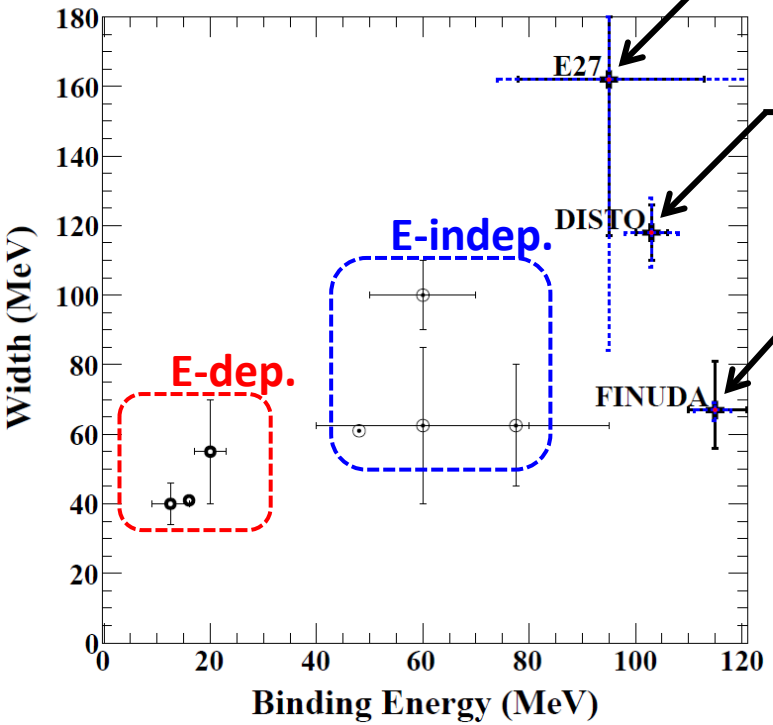
Recent status of K^-pp bound state

Recent results

Theoretical calc.

KbarN interaction model

E-dep. / ***E-indep.***



Experiments

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
$pp \to \Lambda pK^+$

K^-pp is still subject to refined experiments.

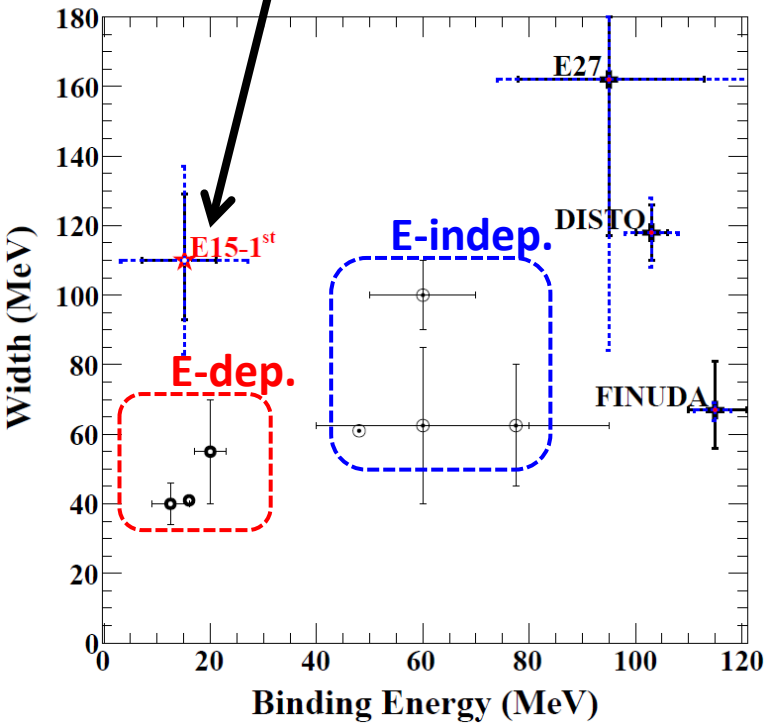
J-PARC E15
Using $(\text{in-flight}\ K^-, n)$ reaction

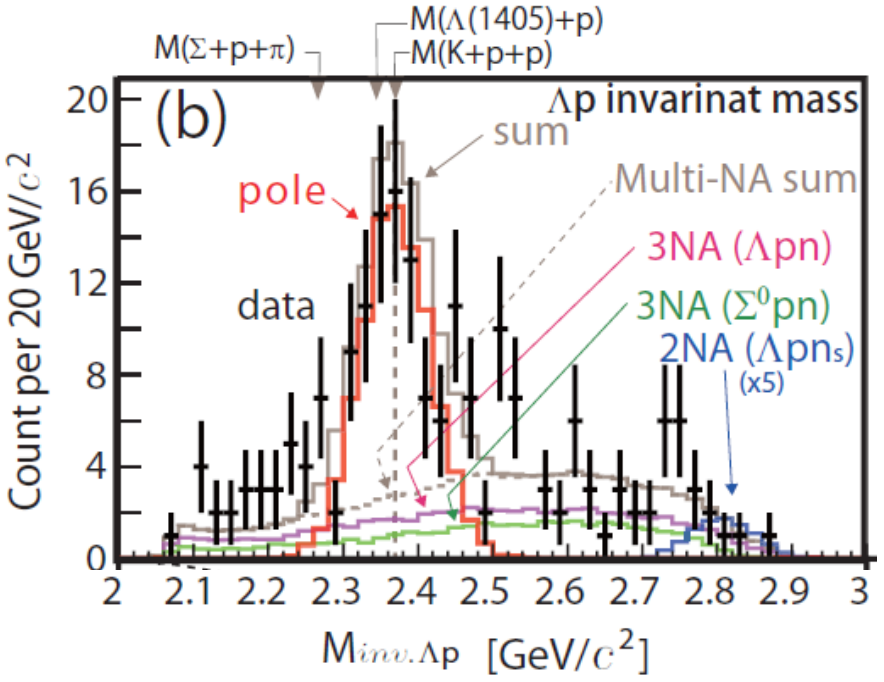
Recent status of K^-pp bound state

Recent results including E15

Y. Sada, et al, Prog. Theor. Exp. Phys. (2016) 051D01

Mass (MeV/c^2)	Width (MeV/c^2)
$2355^{+8}_{-6}\,(stat.)^{\pm 12}\,(sys.)$	$110^{+19}_{-17}\,(stat.)^{\pm 27}\,(sys.)$





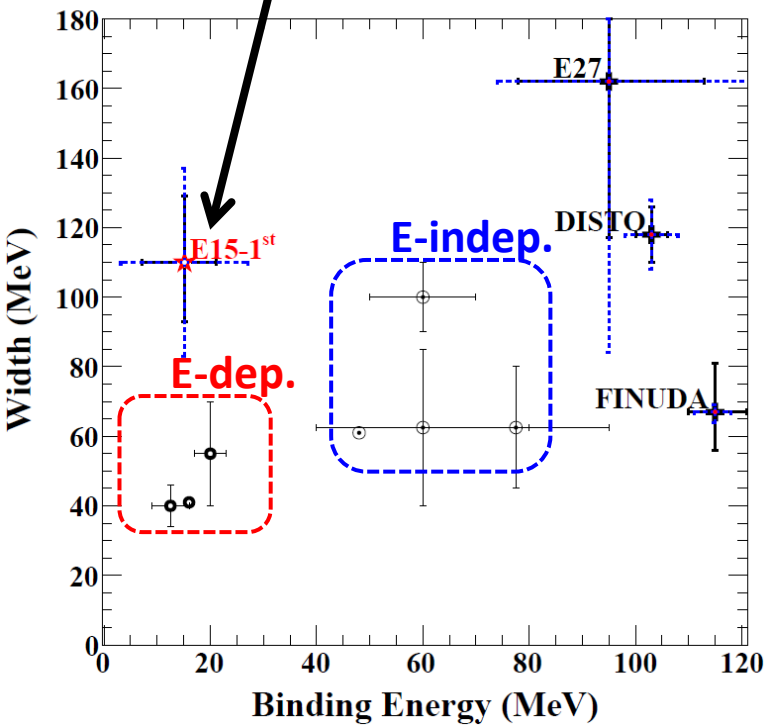
- **E15-1st experiment**
  - **Λp invariant mass analysis in $^3\mathrm{He}(K^-, \Lambda p)"n"$**
  - **Assuming simple Breit-Wigner**

Recent status of K^-pp bound state

Recent results including E15

Y. Sada, et al, Prog. Theor. Exp. Phys. (2016) 051D01

Mass (MeV/c^2)	Width (MeV/c^2)
$2355^{+8}_{-6}\,(stat.)^{\pm 12}\,(sys.)$	$110^{+19}_{-17}\,(stat.)^{\pm 27}\,(sys.)$



- **E15-1st experiment**
  - Lack of statistics
  - Assuming 1-pole structure

- **E15-2nd experiment**
  - 8-times more K^--beam
  - Dedicated trigger condition
    - » Statistics becomes larger.

More detail analysis can be performed.

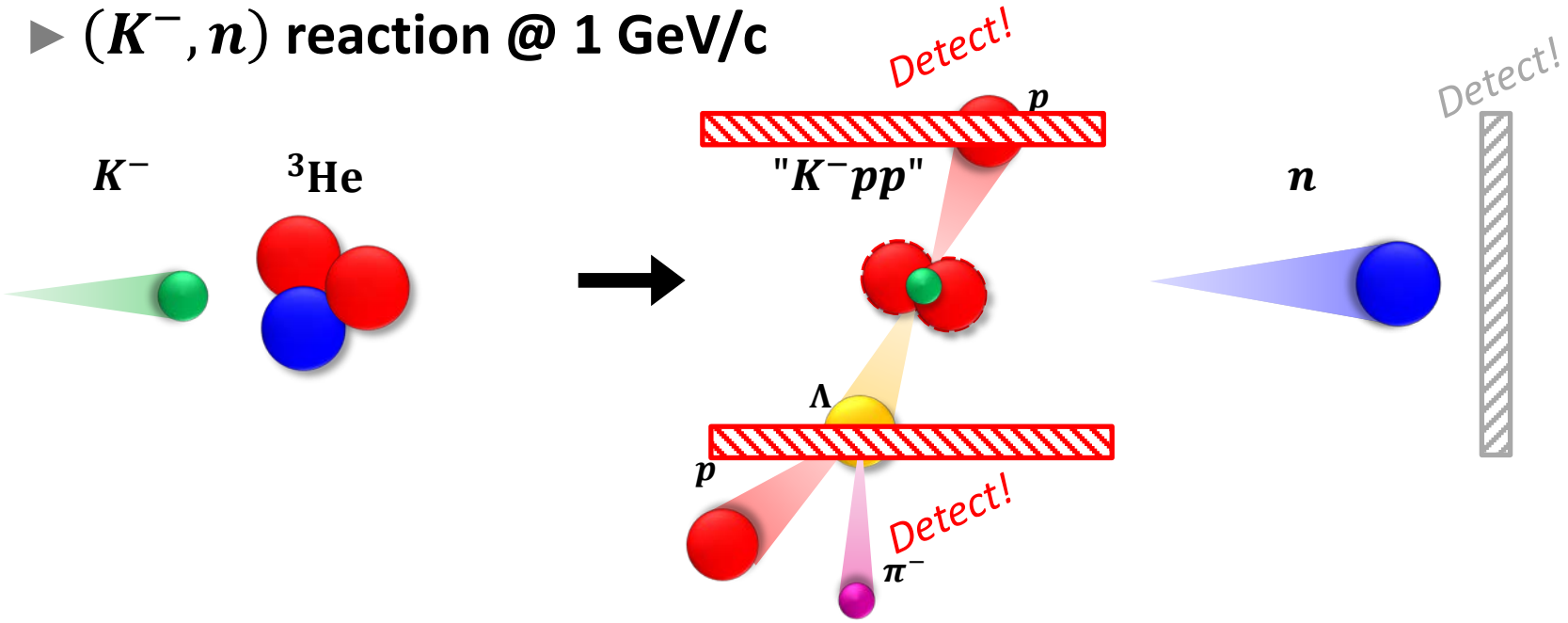
EXPERIMENTAL PROCEDURE

Overview of the J-PARC E15 Experiment

J-PARC E15 Experiment

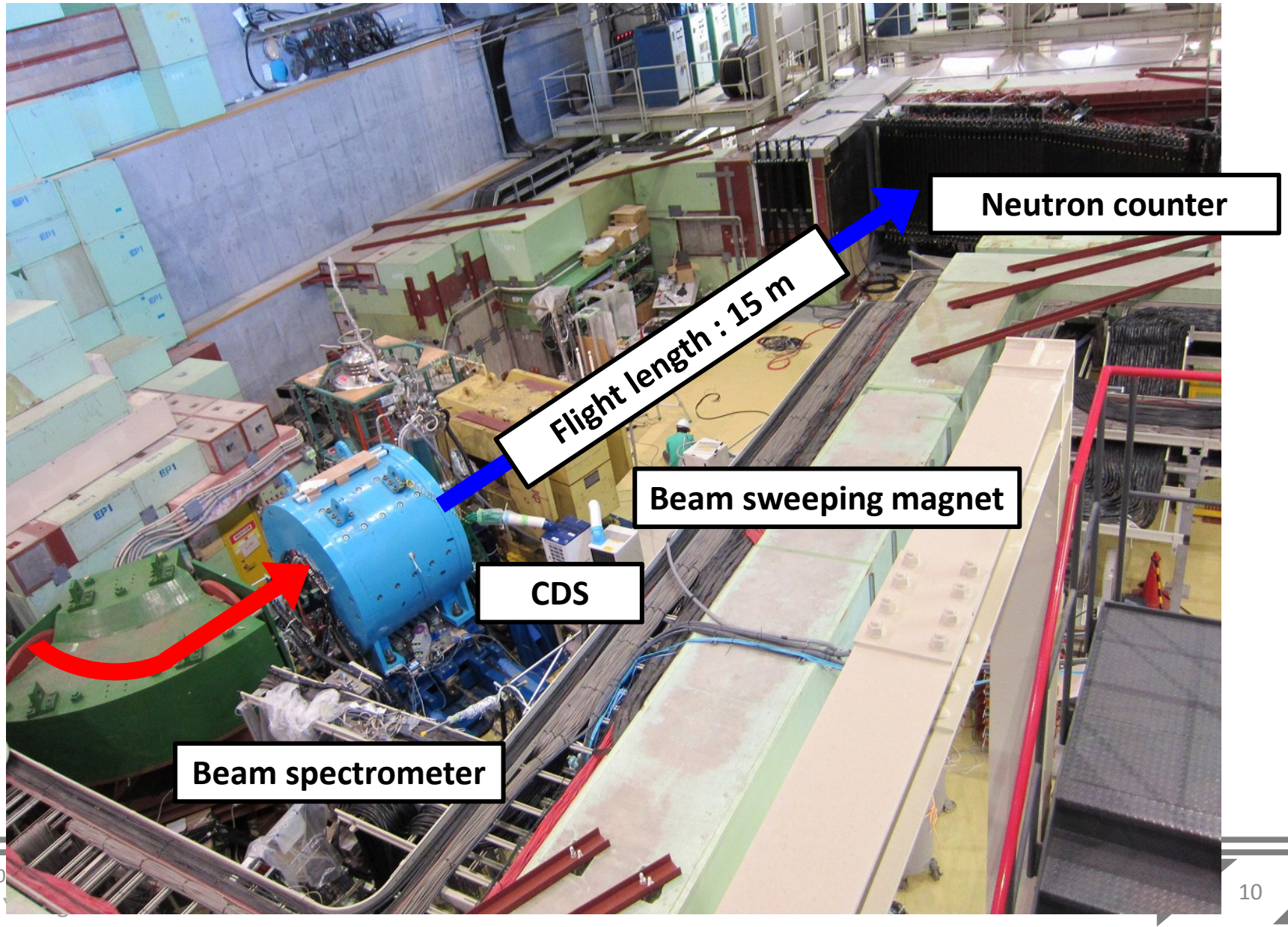
Searching for K^-pp

- (K^-, n) reaction @ 1 GeV/c



- **Detector for decay particles**
- Detector for neutron

J-PARC E15 Experiment

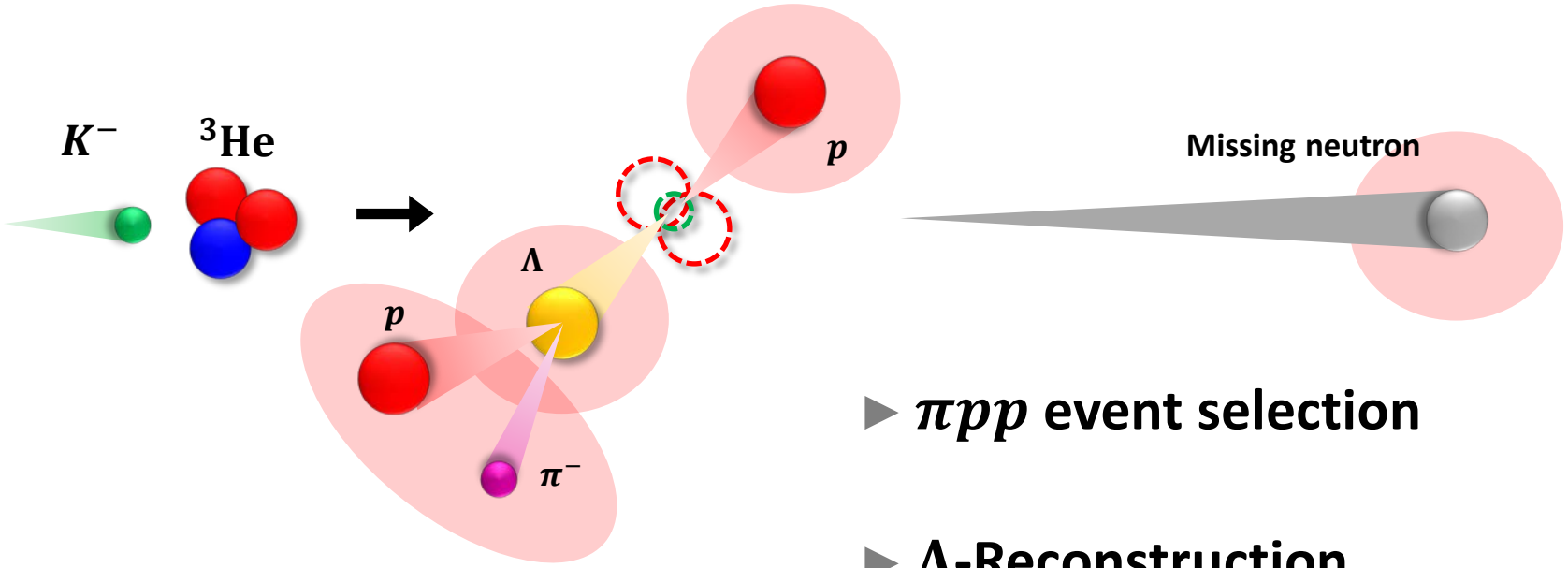


ANALYSIS METHOD

Procedure of the exclusive $^3He(K^-, \Lambda p)"n"$ analysis

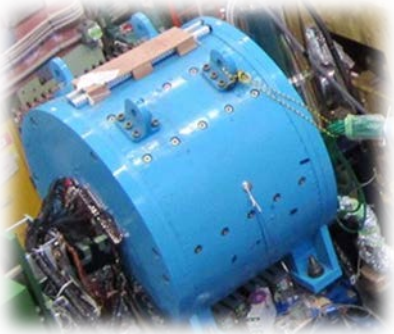
Analysis Overview

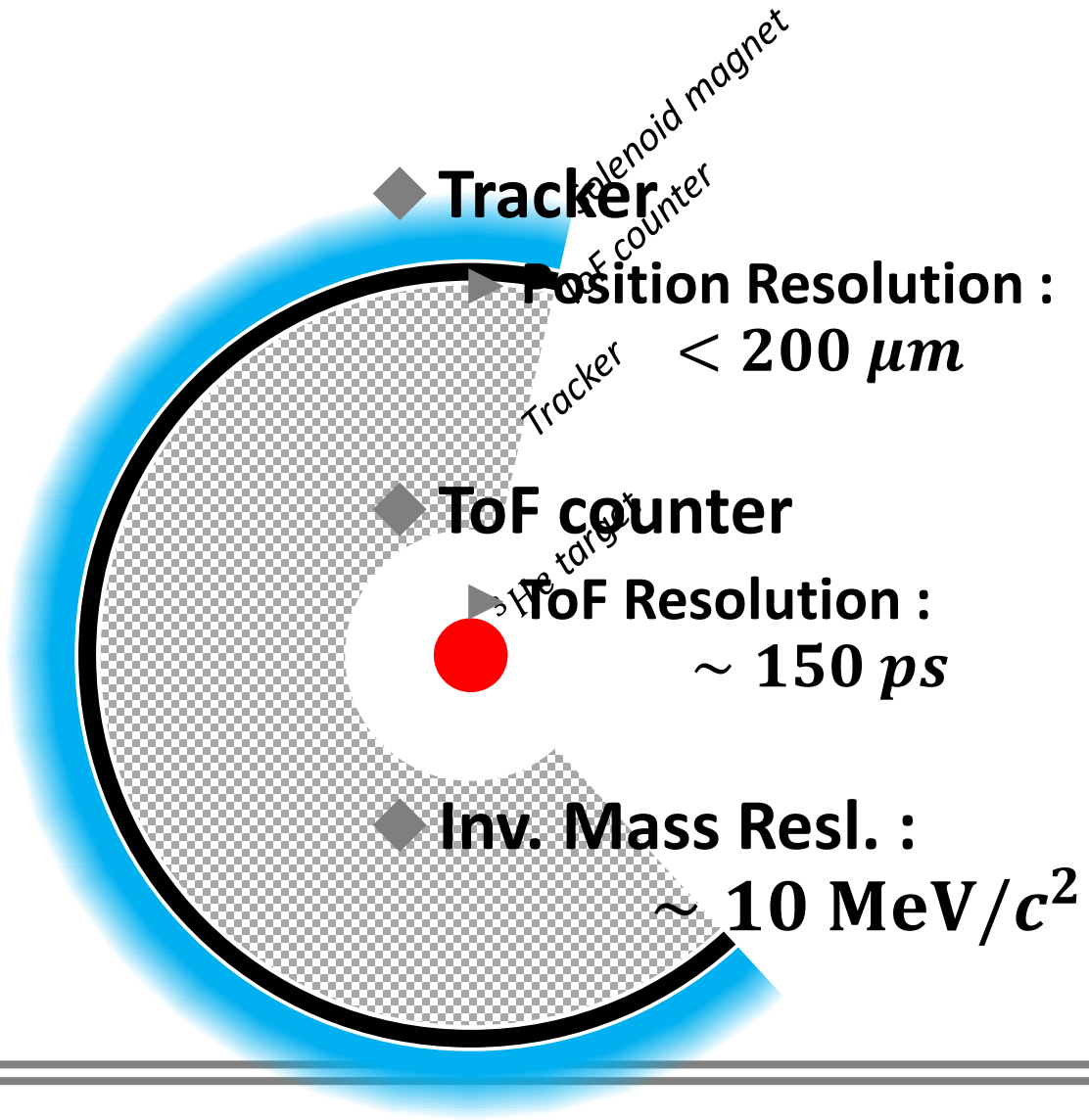
- Λp invariant mass spectroscopy in $^{3}\mathrm{He}(K^{-},\Lambda p)"n"$ reaction



- πpp event selection
- Λ-Reconstruction
- Missing neutron selection

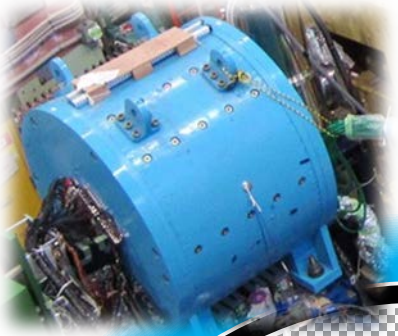
CDS Configuration



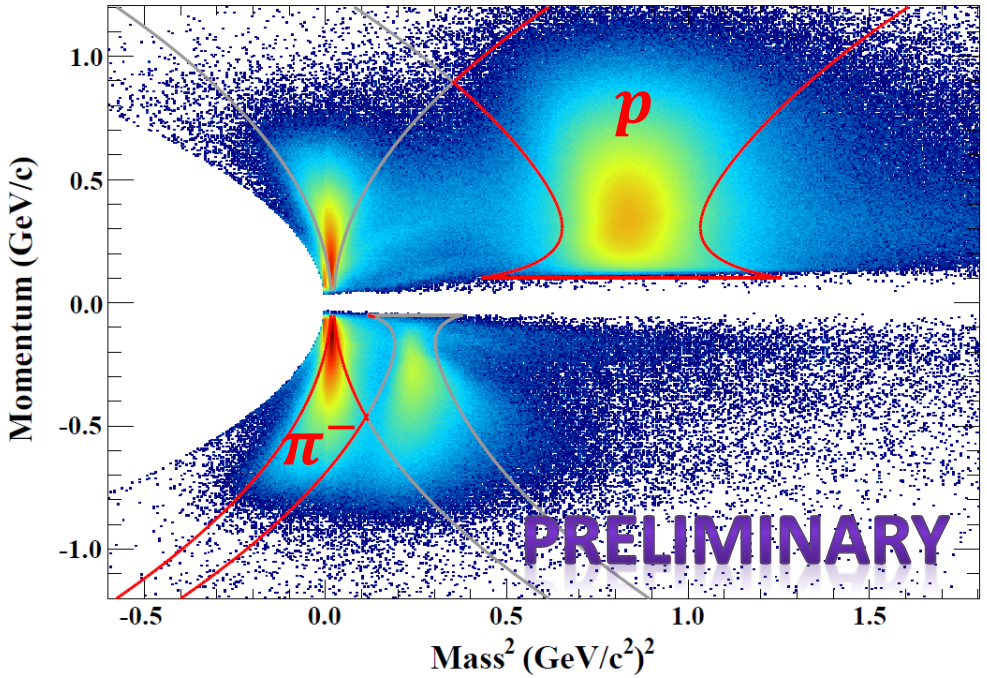


- **Tracker**
  - Position Resolution : $< 200\ \mu m$
- **ToF counter**
  - ToF Resolution : $\sim 150\ ps$
- **Inv. Mass Resl. :** $\sim 10\ \mathrm{MeV}/c^2$

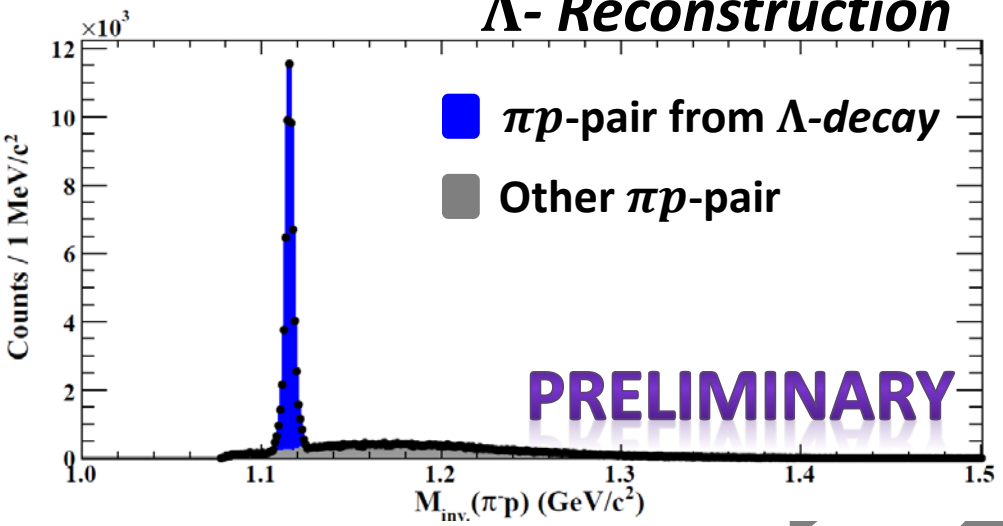
CDS Analysis



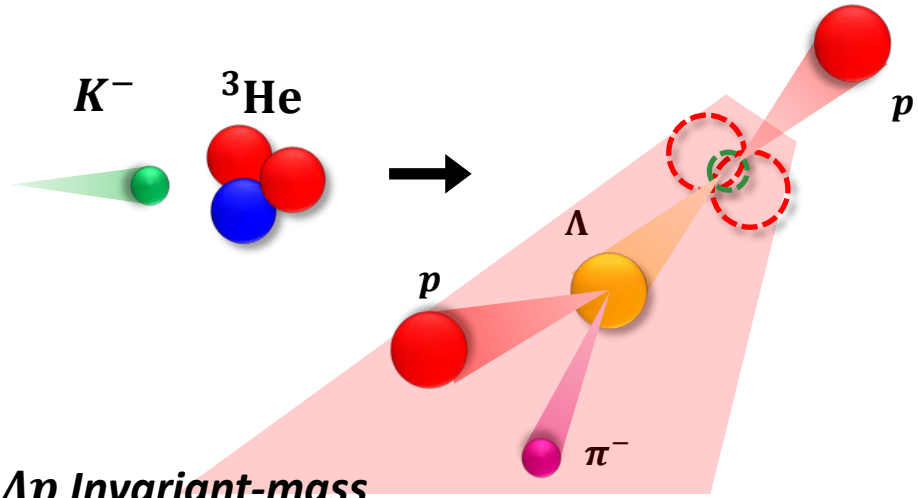
PID

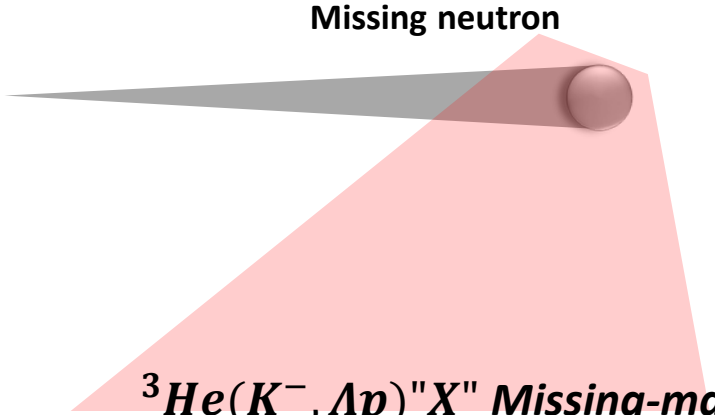


Λ- Reconstruction



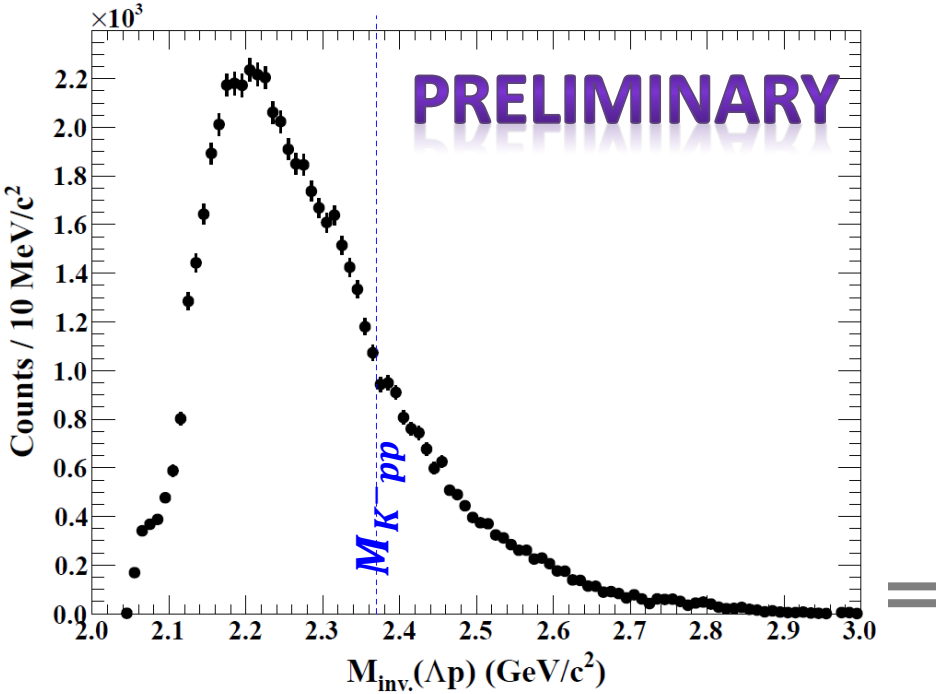
Analyzed Spectrum



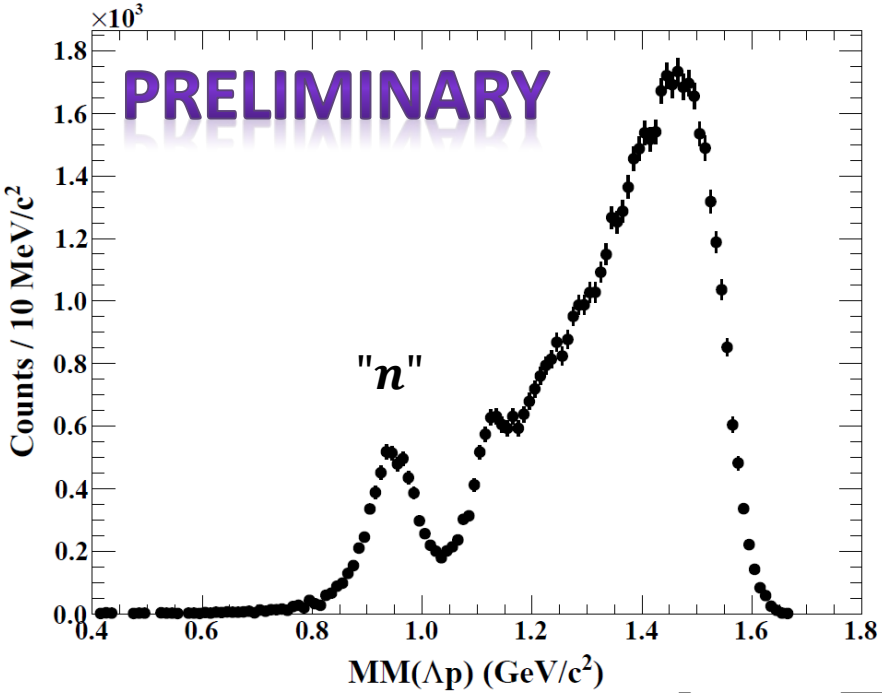


Λp Invariant-mass

$^3He(K^-, \Lambda p)"X"$ Missing-mass



=

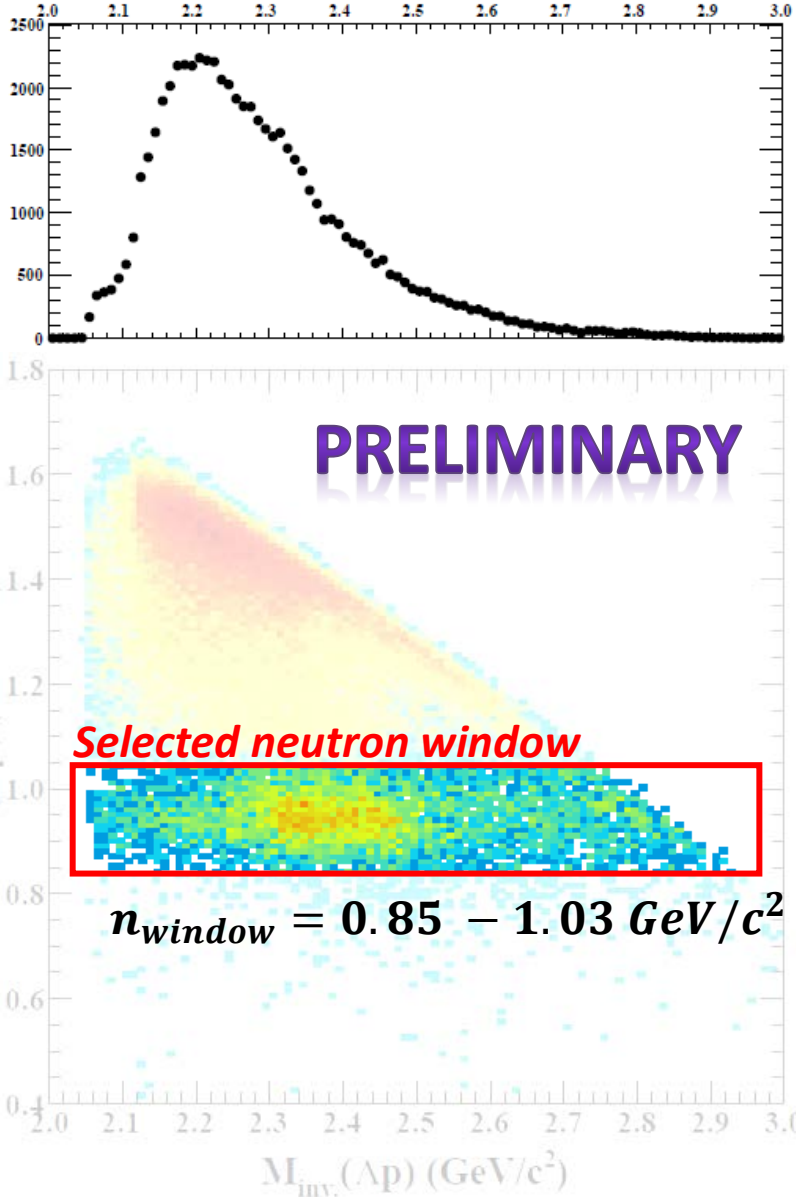


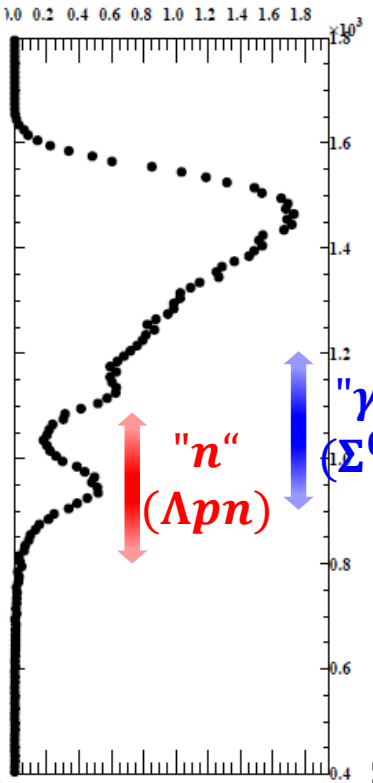
RESULTS

Results based on E15-2nd physics data taking

About 30 times larger events than E15-1st

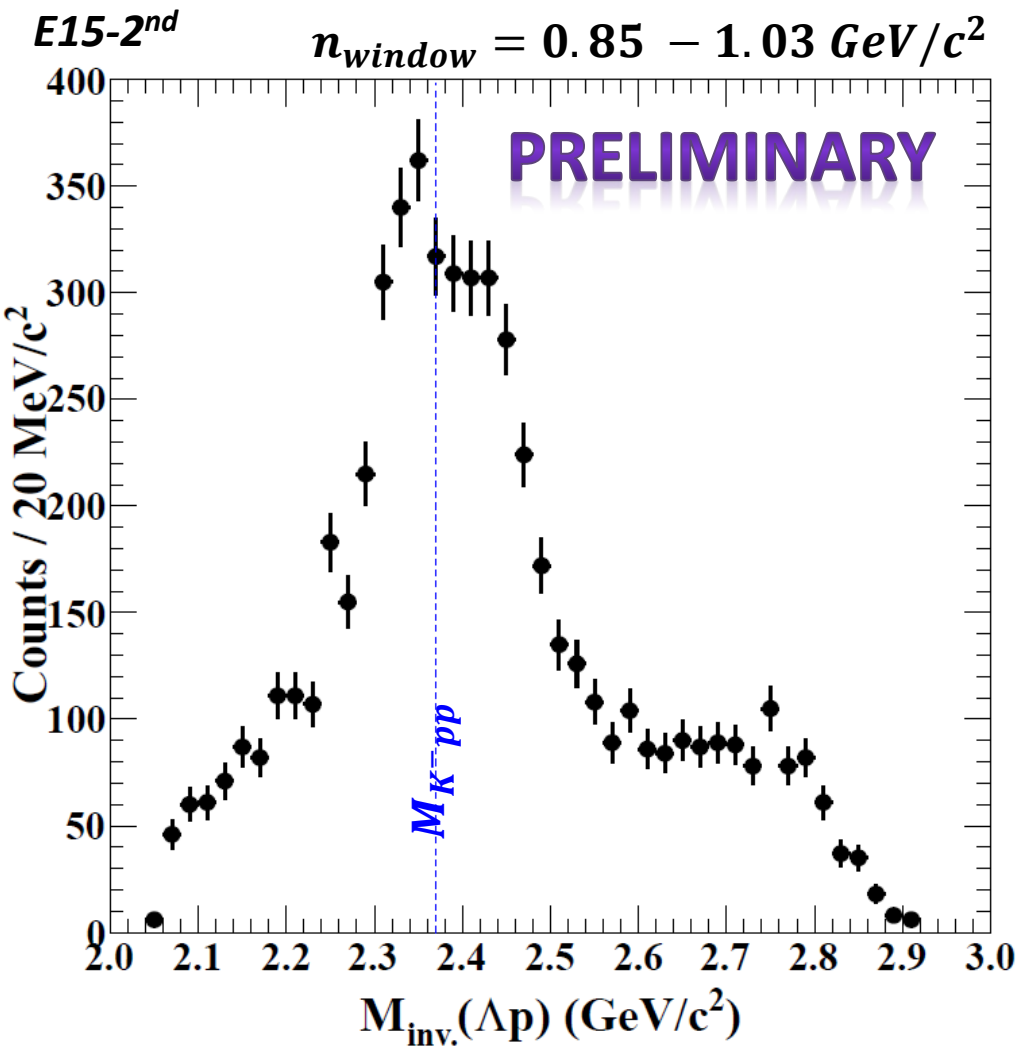
Λp IM vs. MM Plot



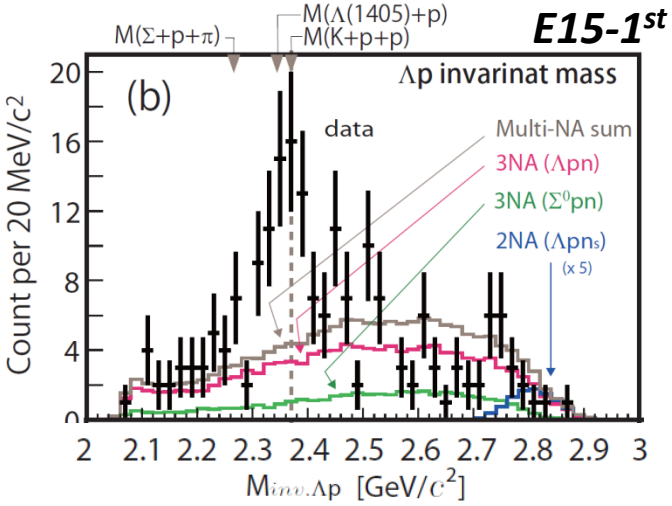


- **Final state identification**
  - Selecting Λpn final state

$IM(\Lambda p)$ in Λpn Final State

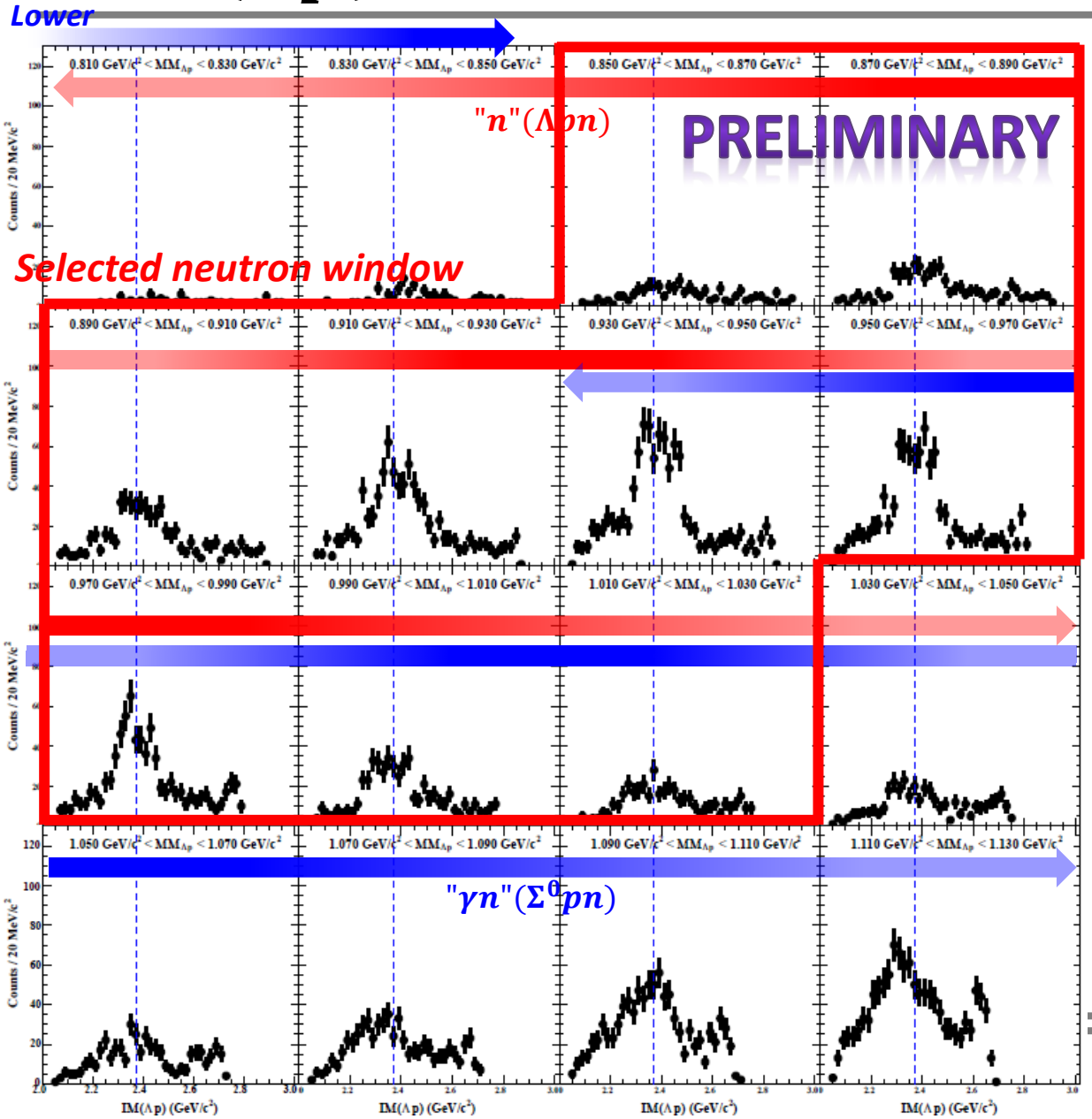


Y. Sada, et al, Prog. Theor. Exp. Phys. (2016) 051D01



- **Consistent with the E15-1st result**
  - **With in statistics**
- **Structure around M_{K^-pp}**

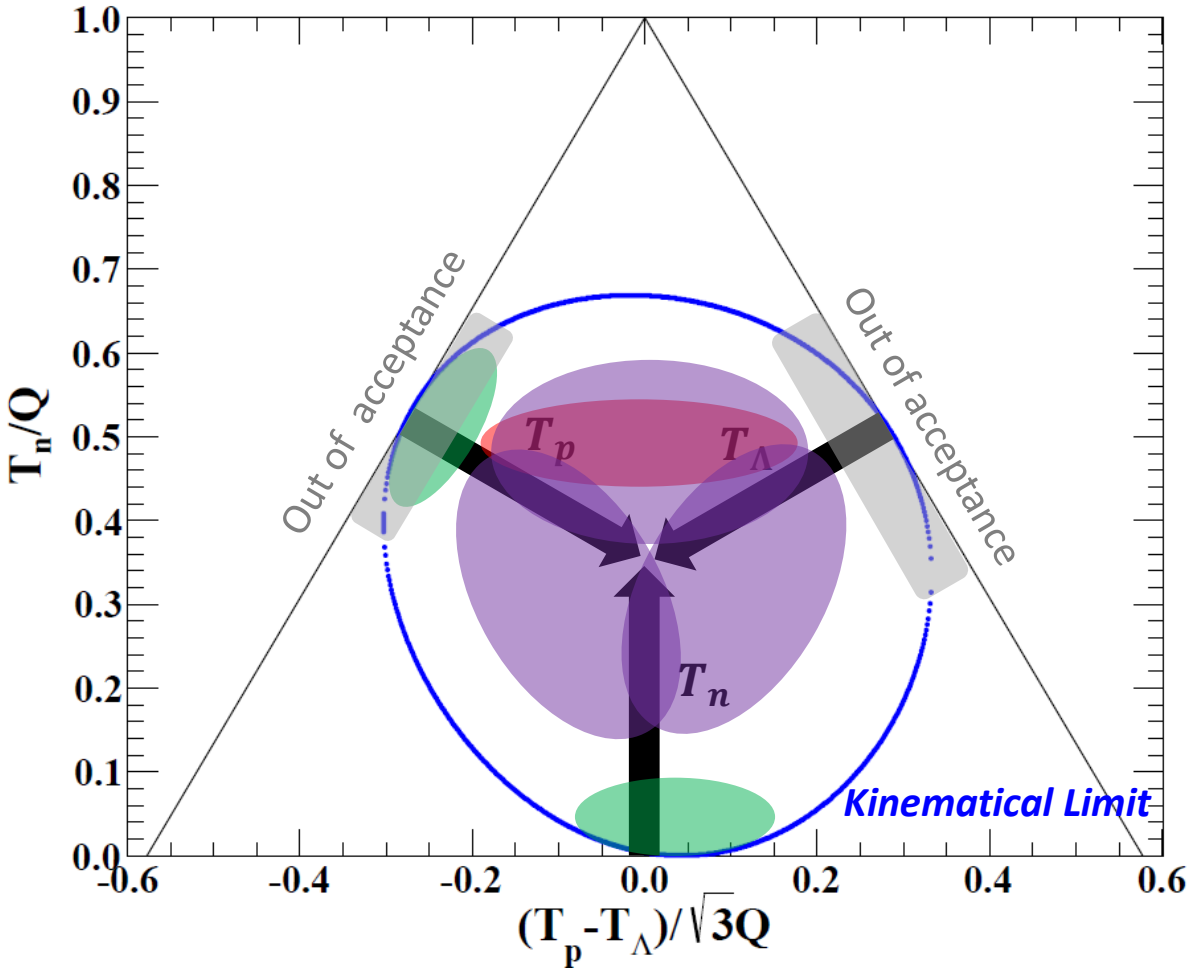
$MM(\Lambda p)$ Slice around "n" Region



*Sliced with $0.02\ \mathrm{GeV}/c^2$ bin

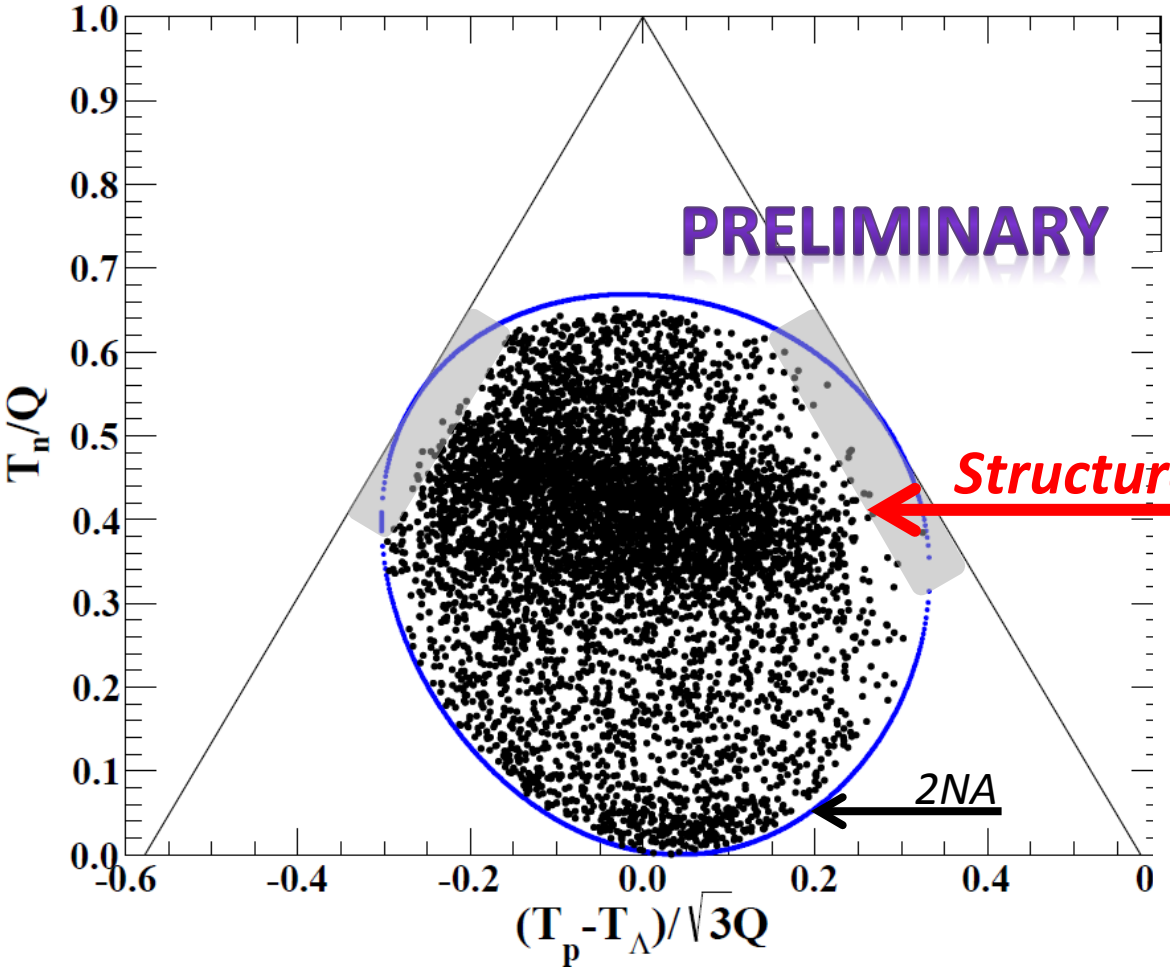
- Structure around M_{K^-pp}
  - $0.9 - 1.0\ \mathrm{GeV}/c^2$

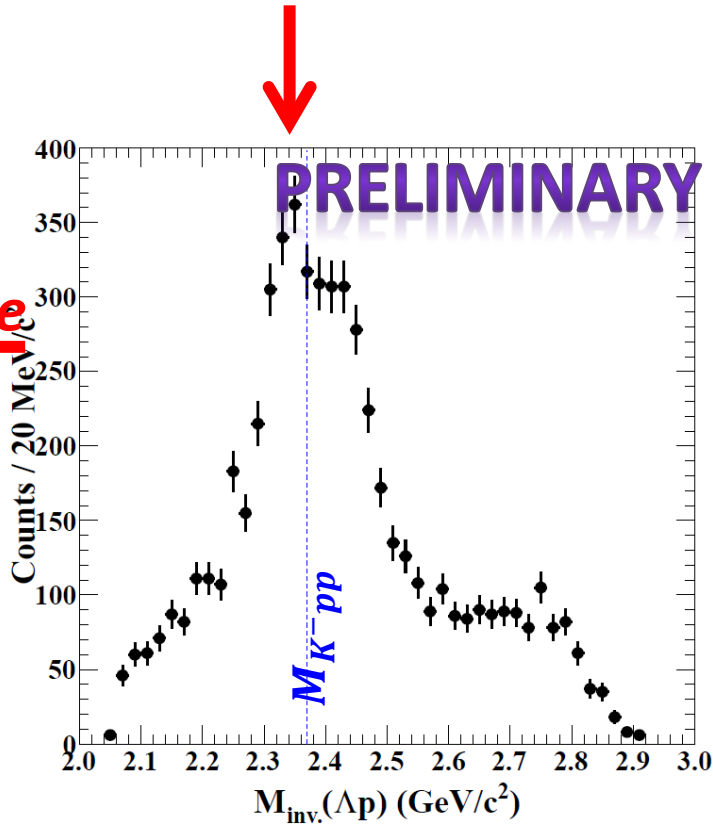
Dalitz Plot of Λpn



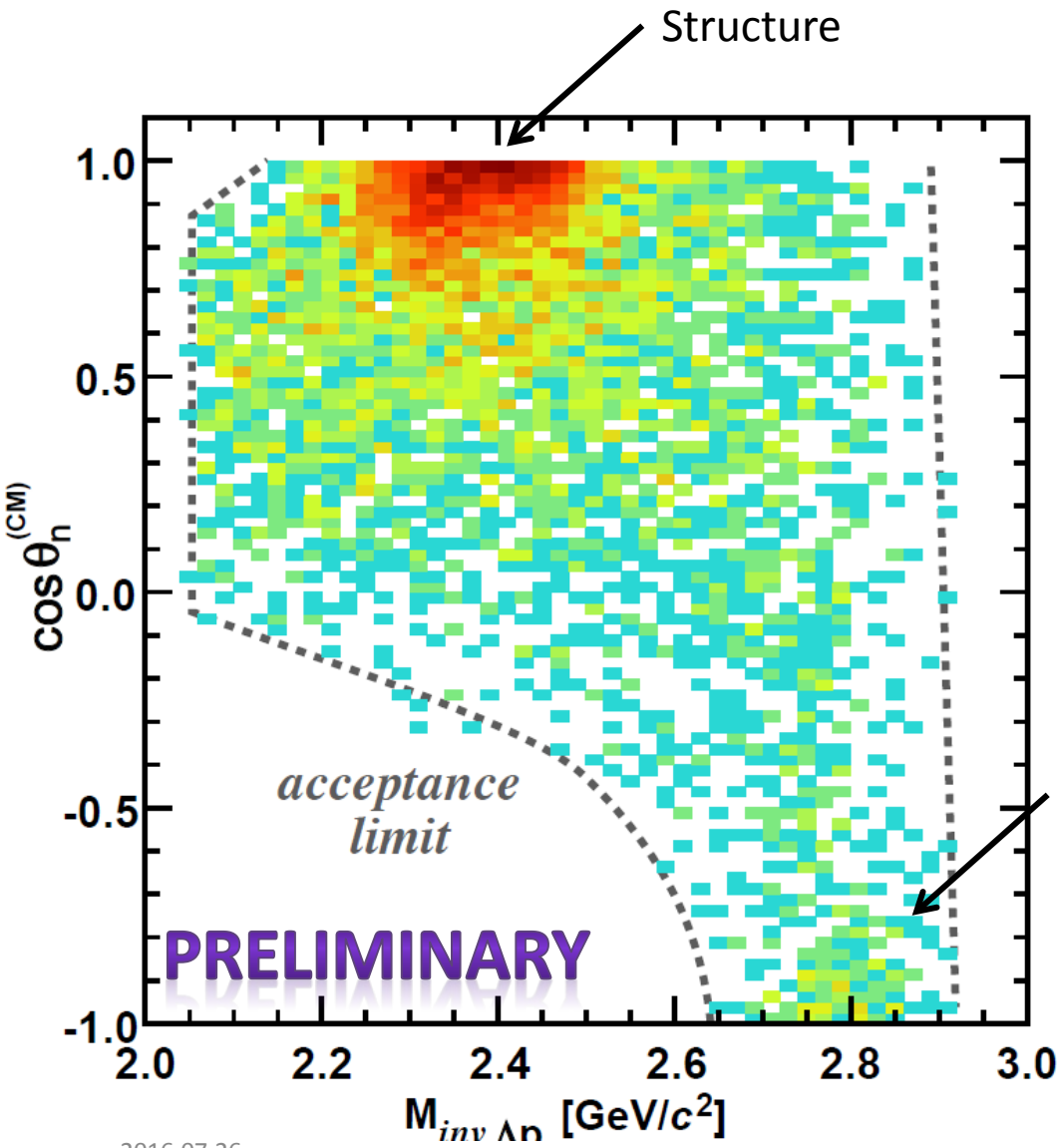
- 3NA process
  - K^-pp formation
- 2NA process
  - One spectator
    - n_{spec} / ~~p_{spec}~~
- 2-step process

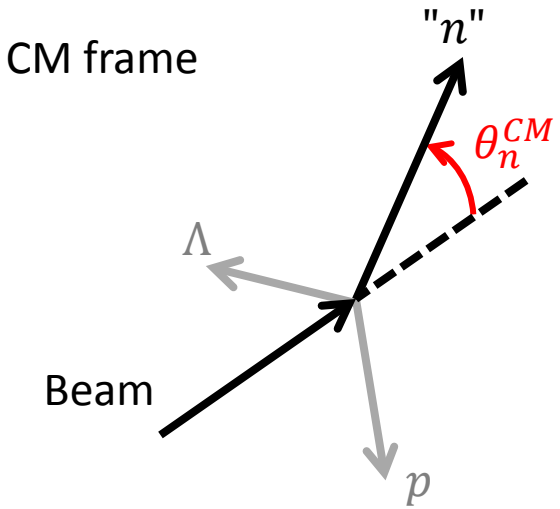
Dalitz Plot of Λpn



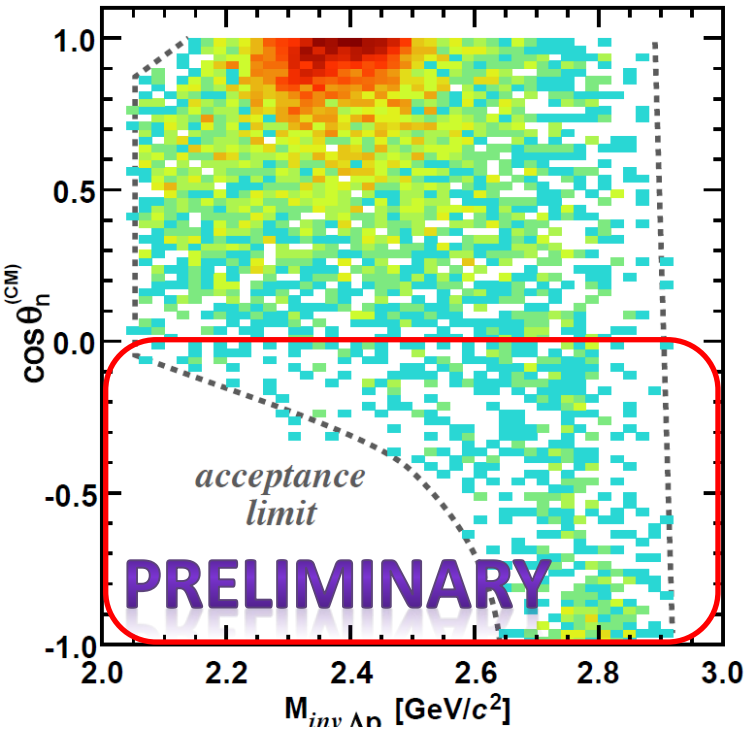


$IM(\Lambda p)$ vs. $\cos\theta_n{}^{CM}$ Plot

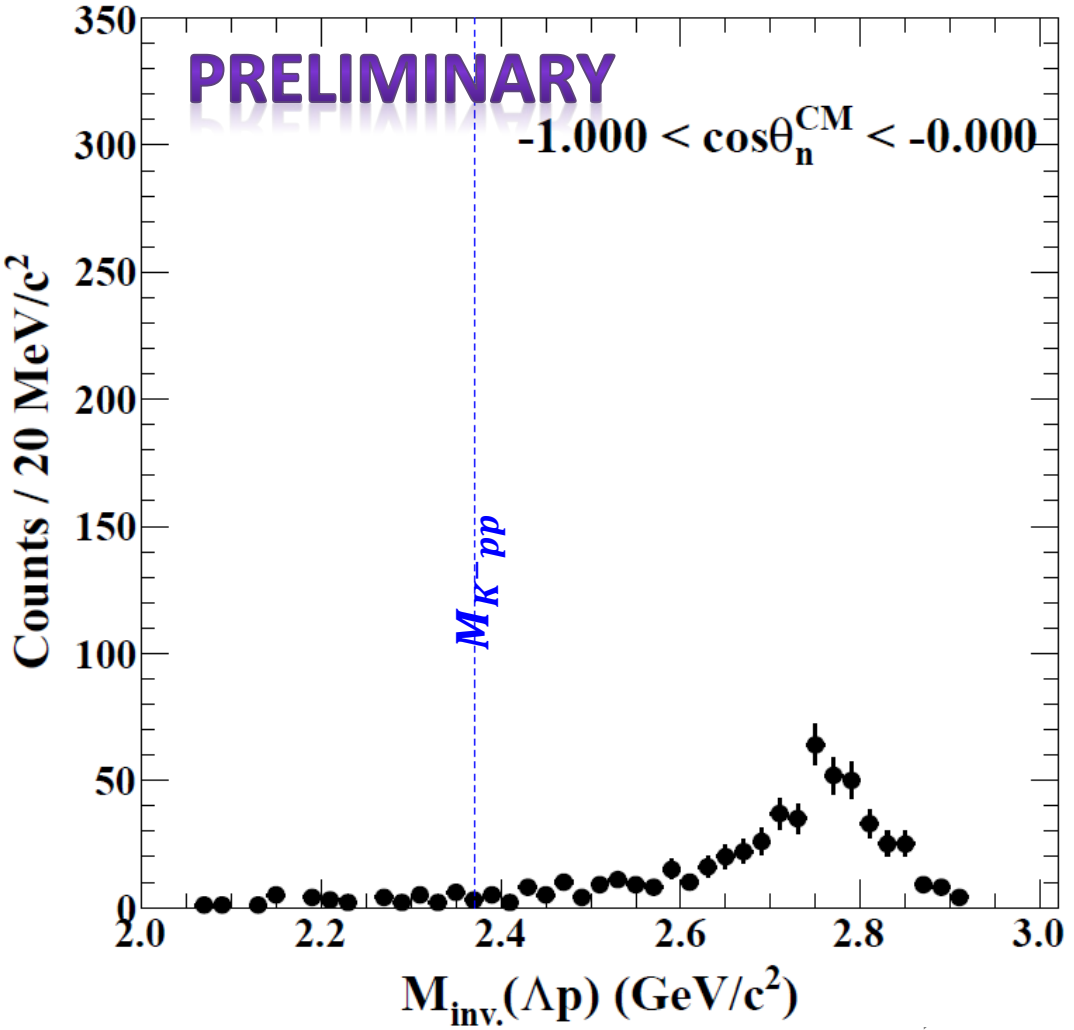




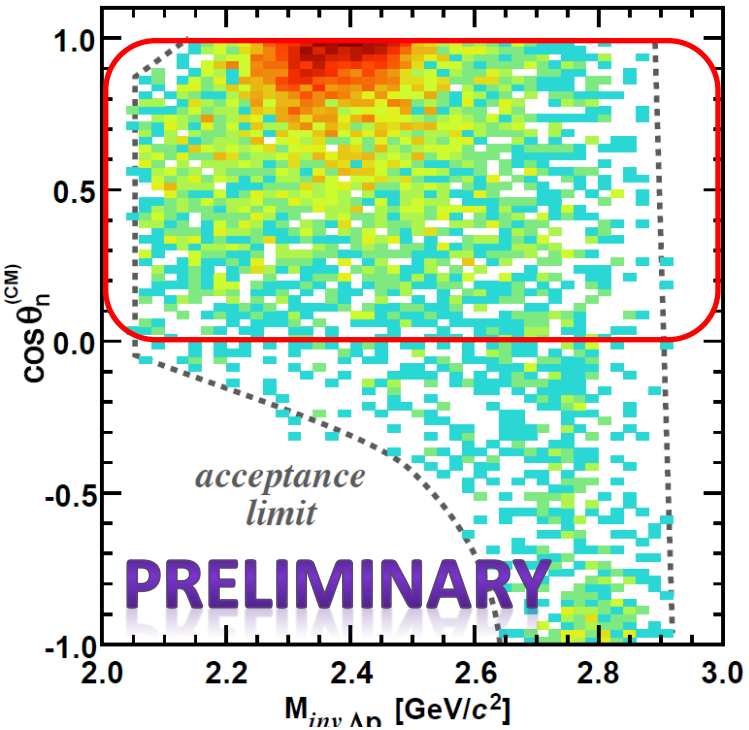
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



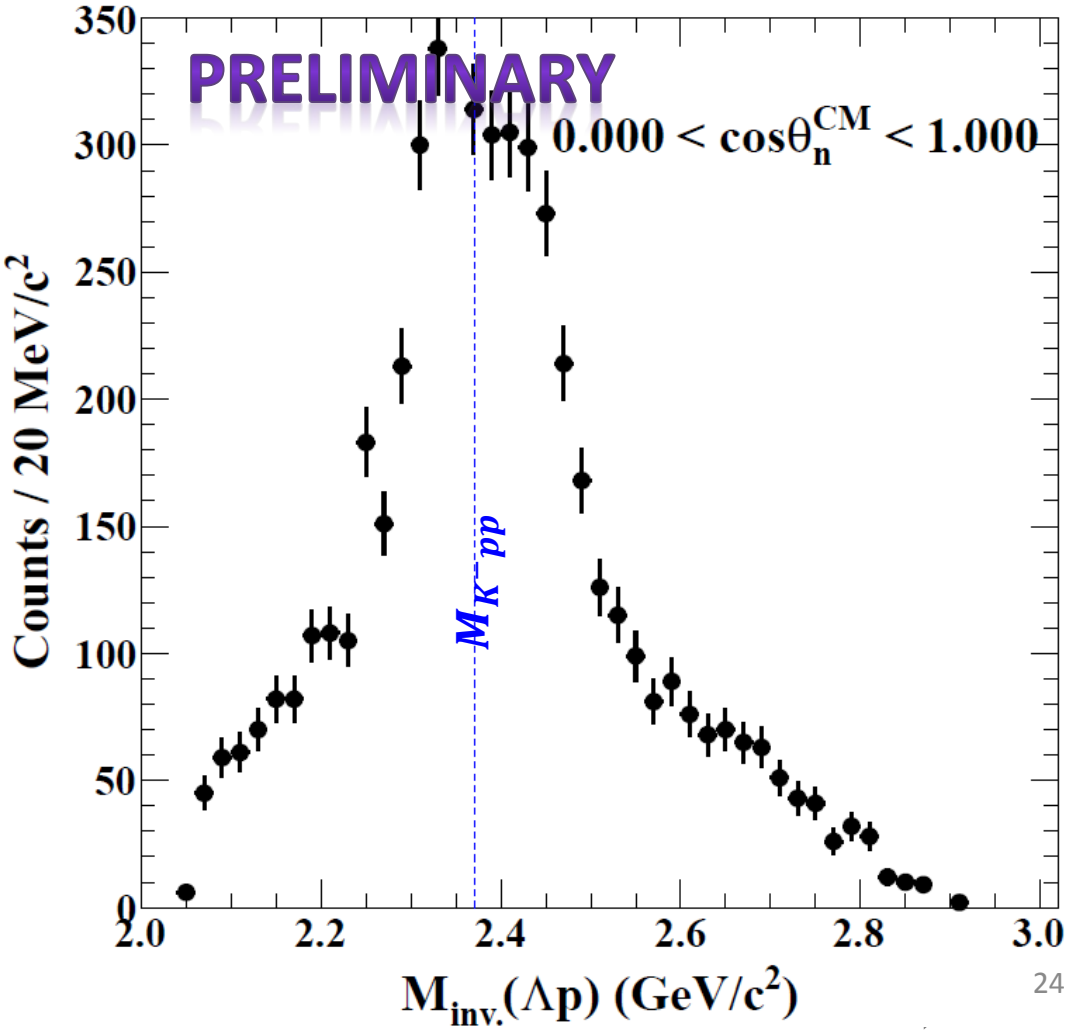
- $-1.0 < \cos\theta_n^{CM} < 0.0$
  - 2NA process



$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

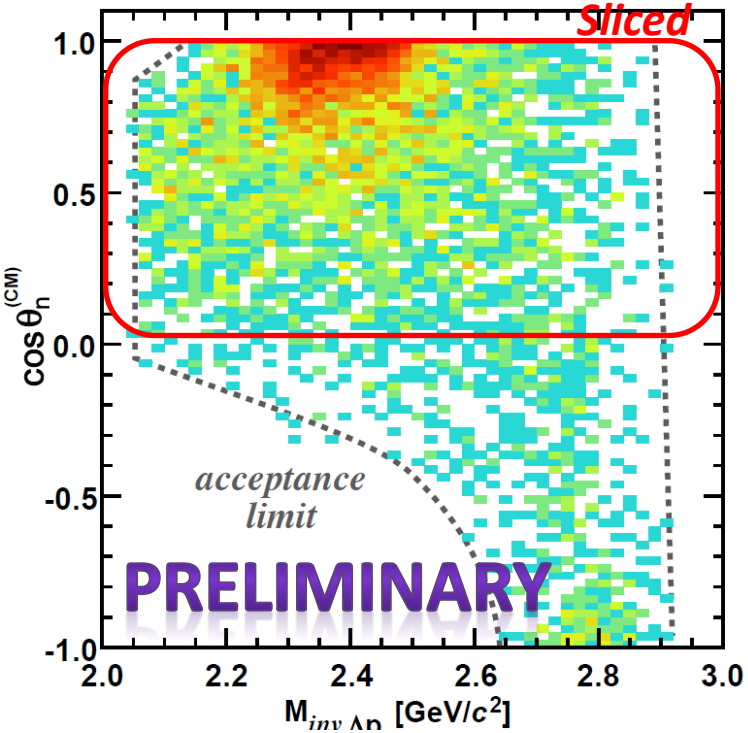


- $0.0 < \cos\theta_n^{CM} < 1.0$
  - Structure around M_{K^-pp}
  - To be sliced



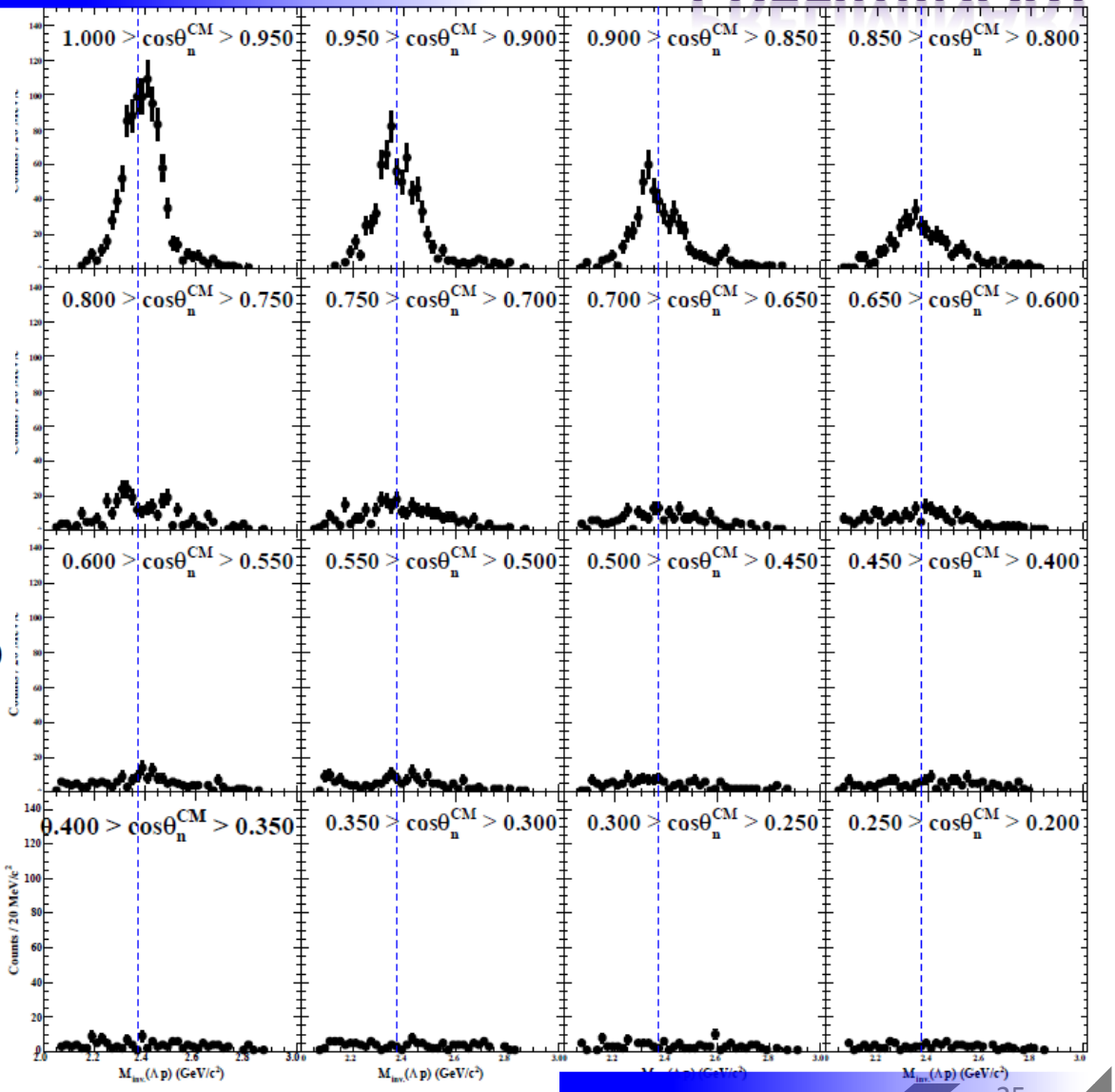
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

*Sliced with 0.05 bin



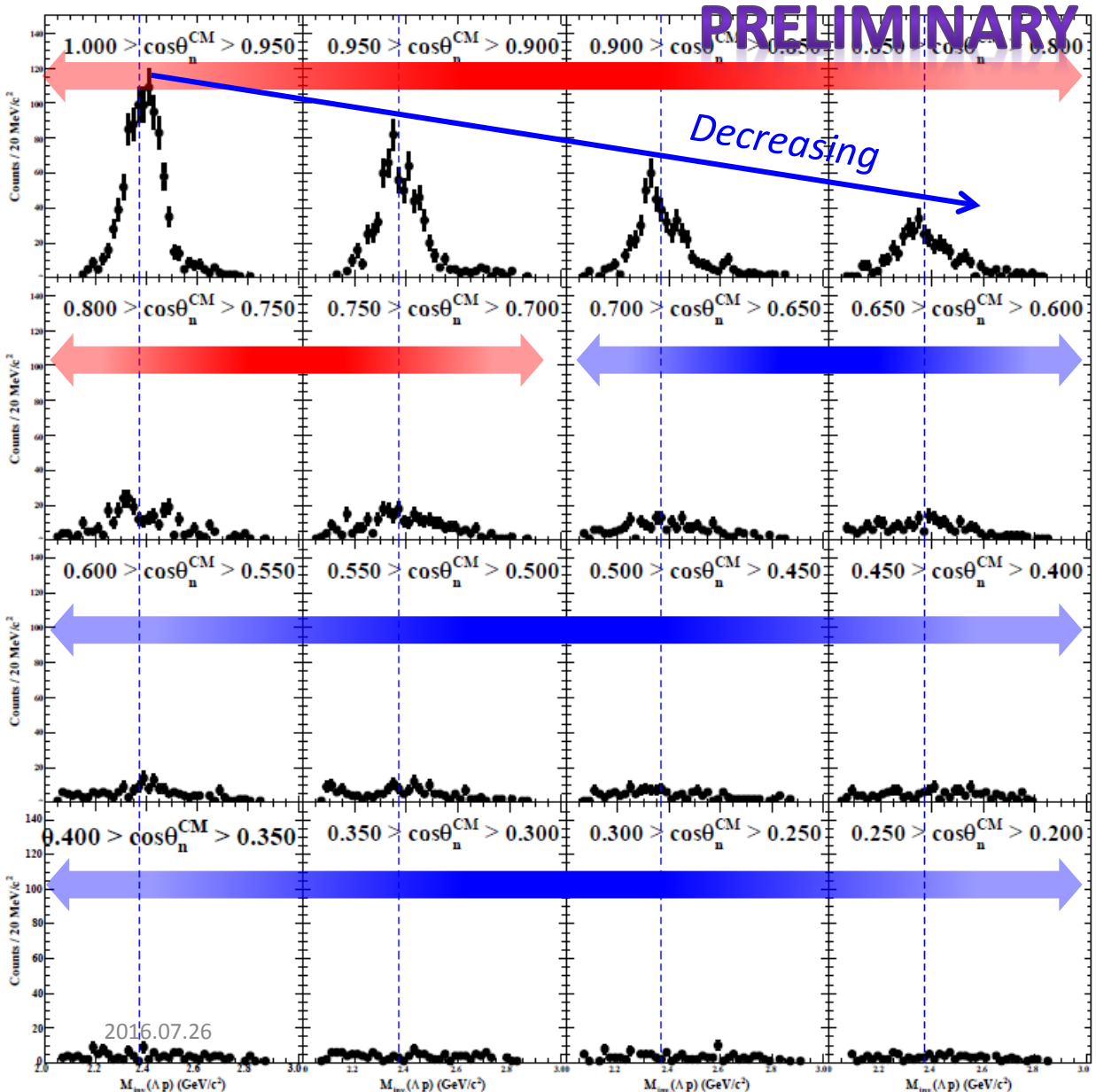
Higher

PRELIMINARY



Lower

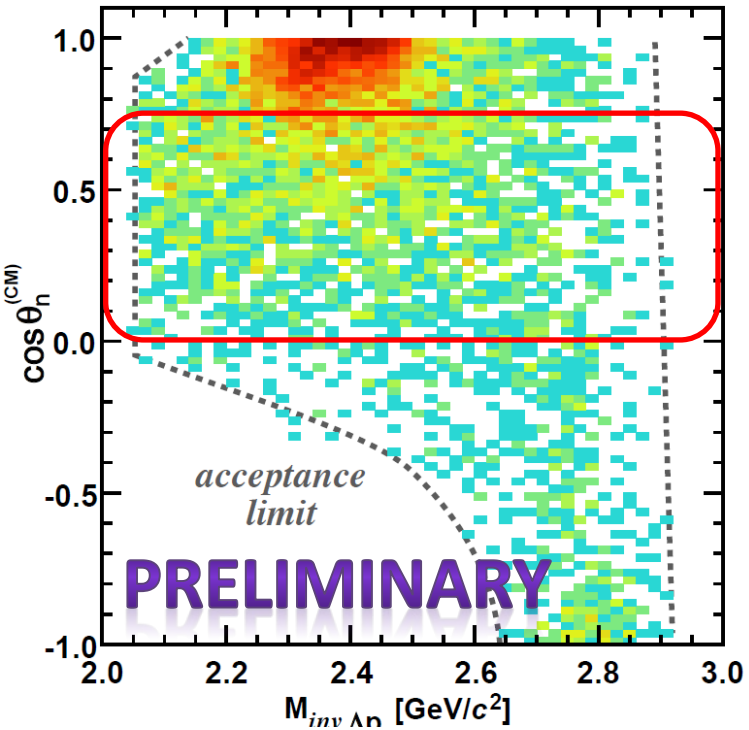
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



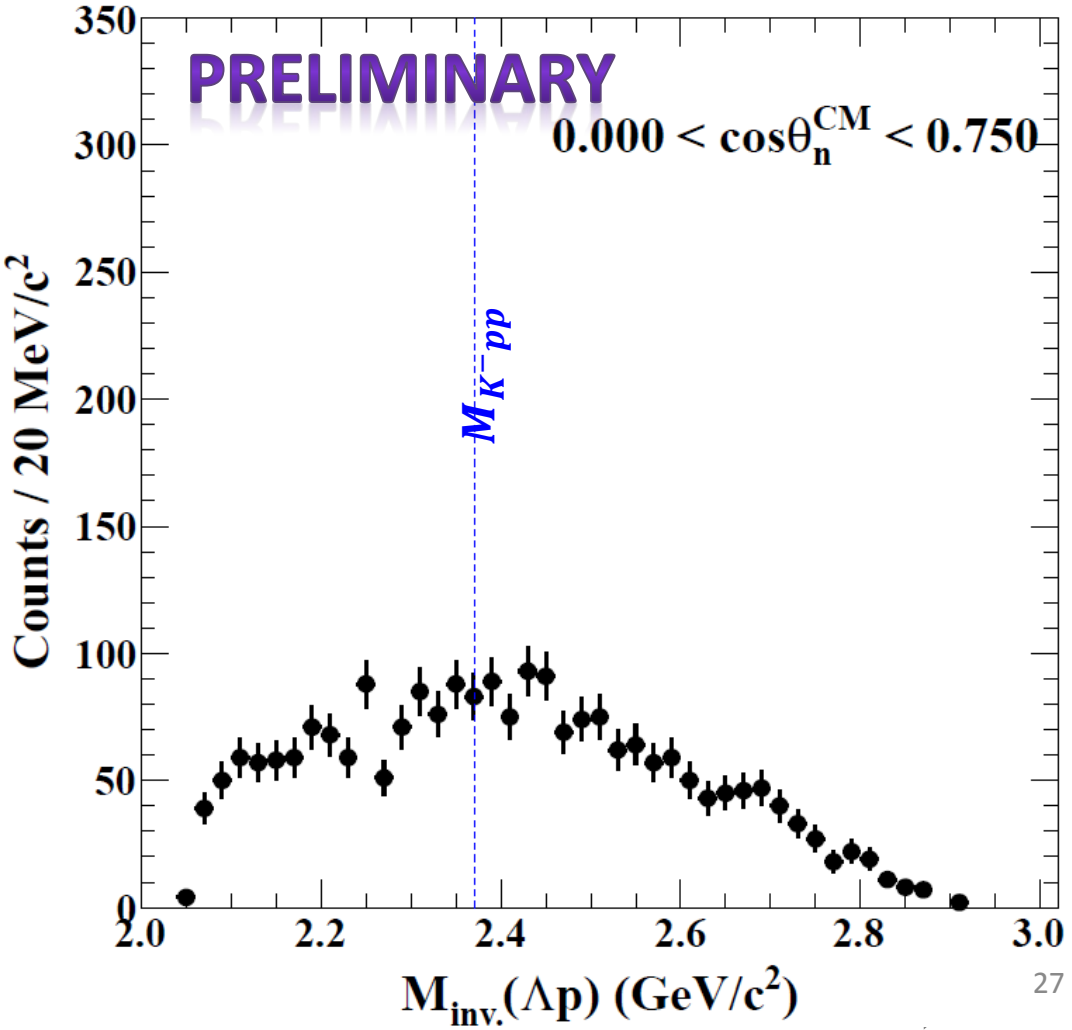
*Sliced with 0.05 bin

- **Higher Opening angle**
  - 0.75 – 1.0
  - ▶ Structure observed
- **Lower O.A.**
  - 0 – 0.75
  - ▶ No structure
  - ▶ Small event

$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

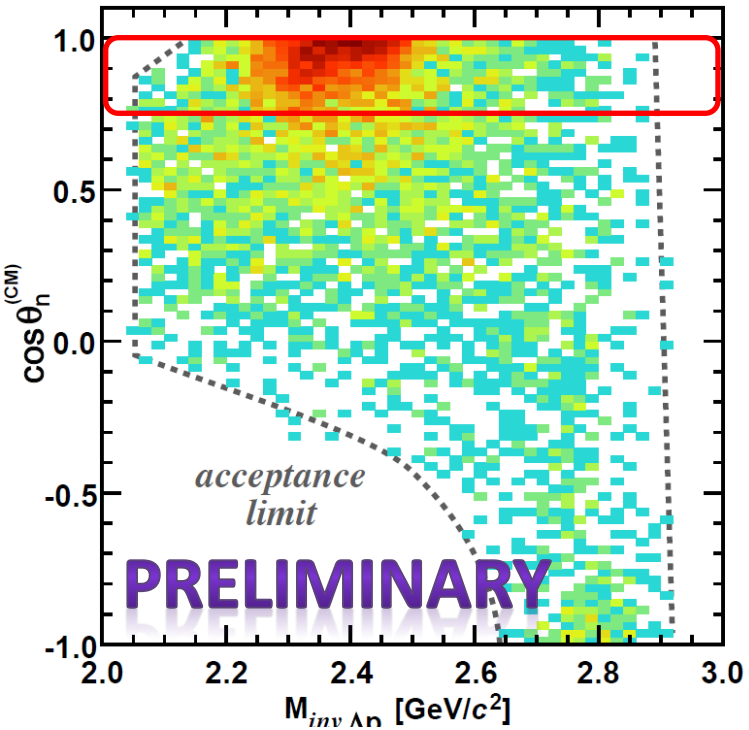


- $0.0 < \cos\theta_n^{CM} < 0.75$
  - 3NA

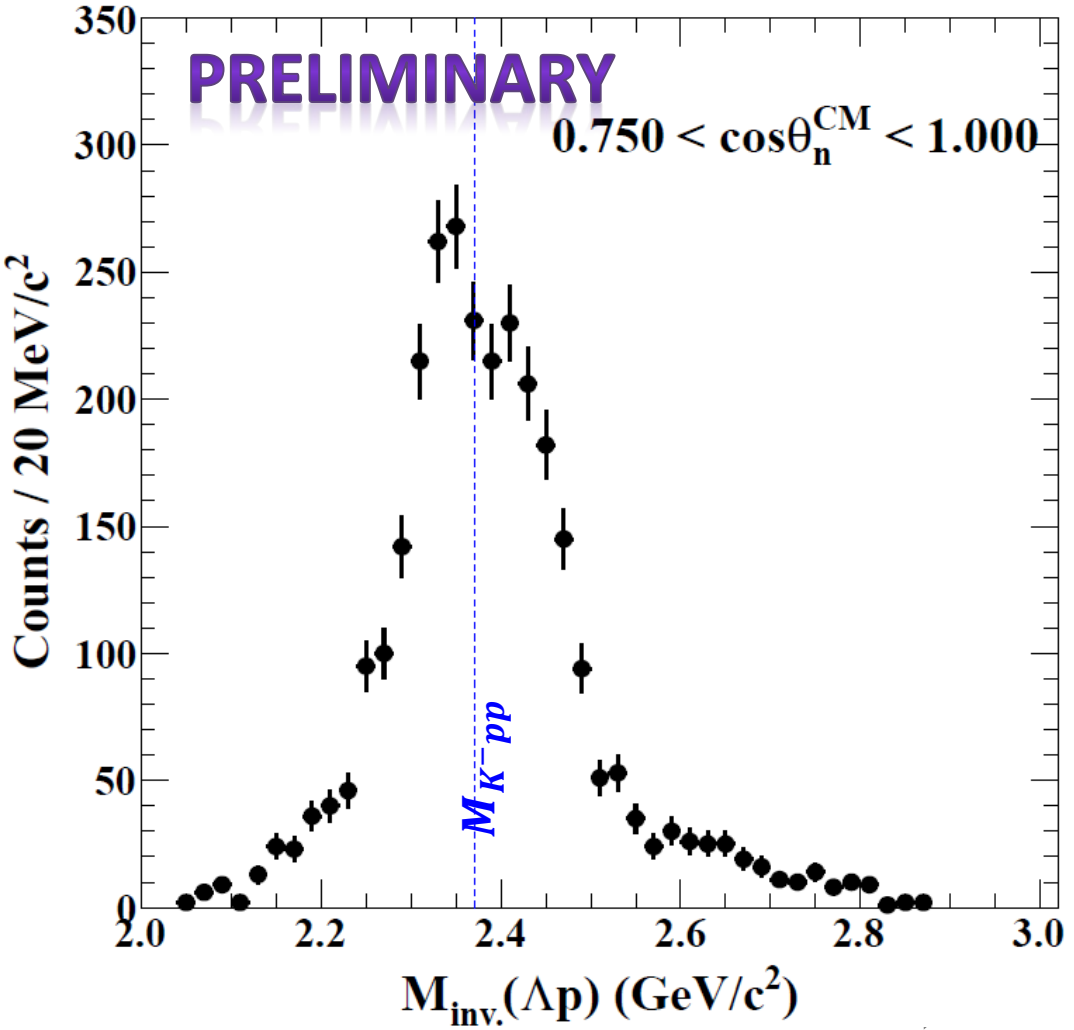


- No Structure

$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



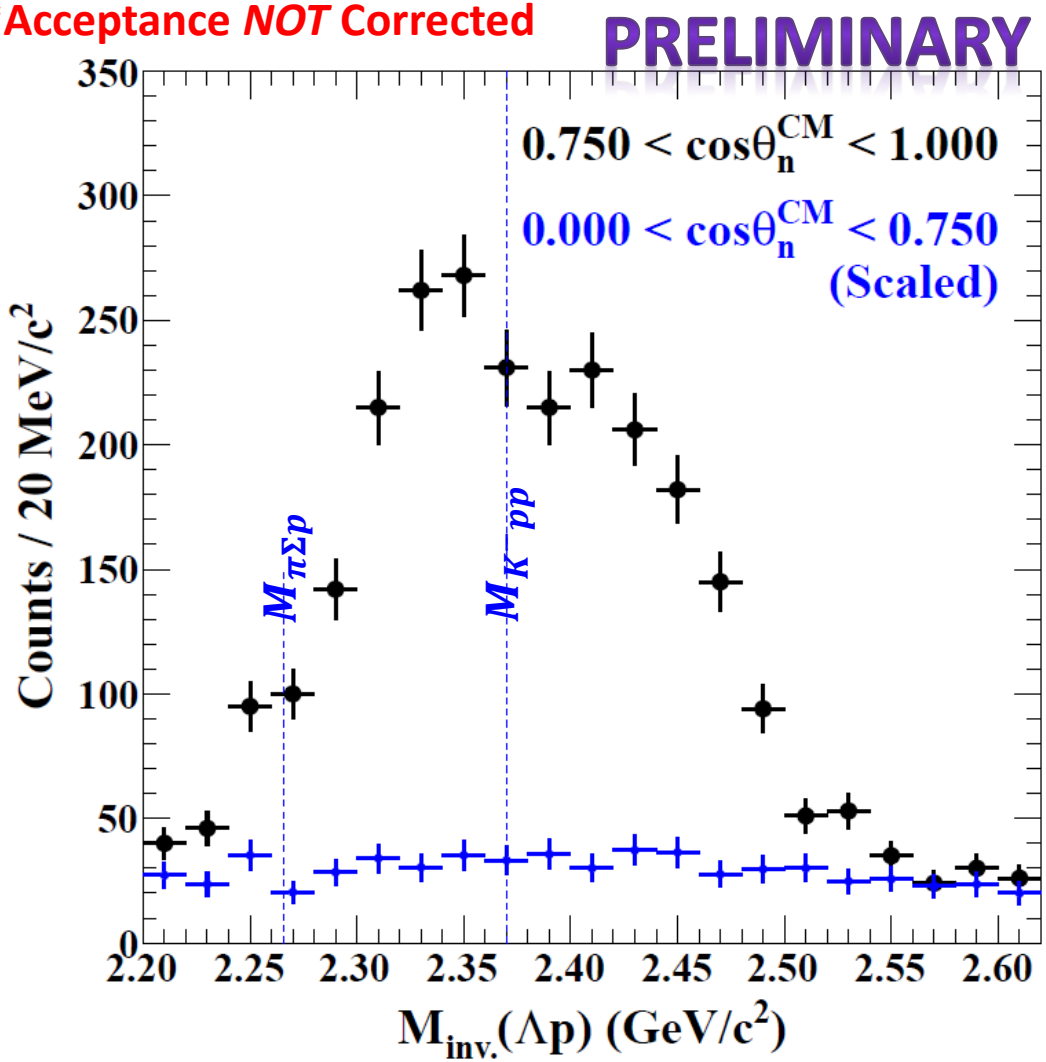
- $0.75 < \cos\theta_n^{CM} < 1.0$
  - Structure + 3NA

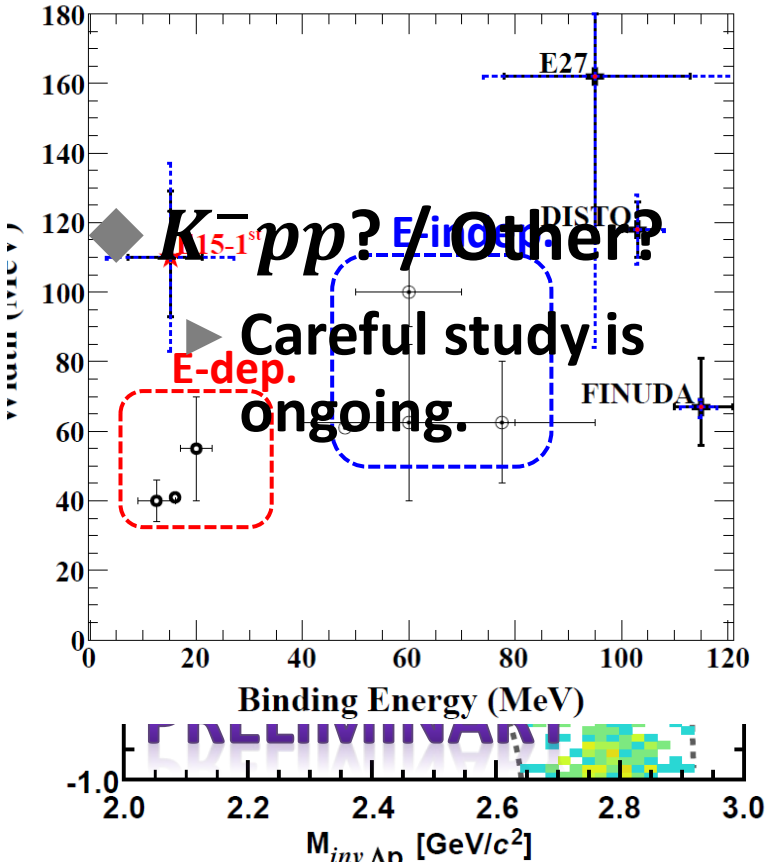


- Structure enhanced

$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

*Acceptance *NOT* Corrected





- K^-pp? / Other?
- Careful study is ongoing.

Summary

- **First preliminary results are presented based on high statistic data of the E15-2nd run.**
  - **Totally consistent with the results obtained from the E15-1st run**
- **Structures below and above the K^-pp mass threshold are observed.**
  - **Located in the region of $\cos\theta_n^{CM} > 0.75$**
  - **Is it the K^-pp state?**

Thank you for your attention

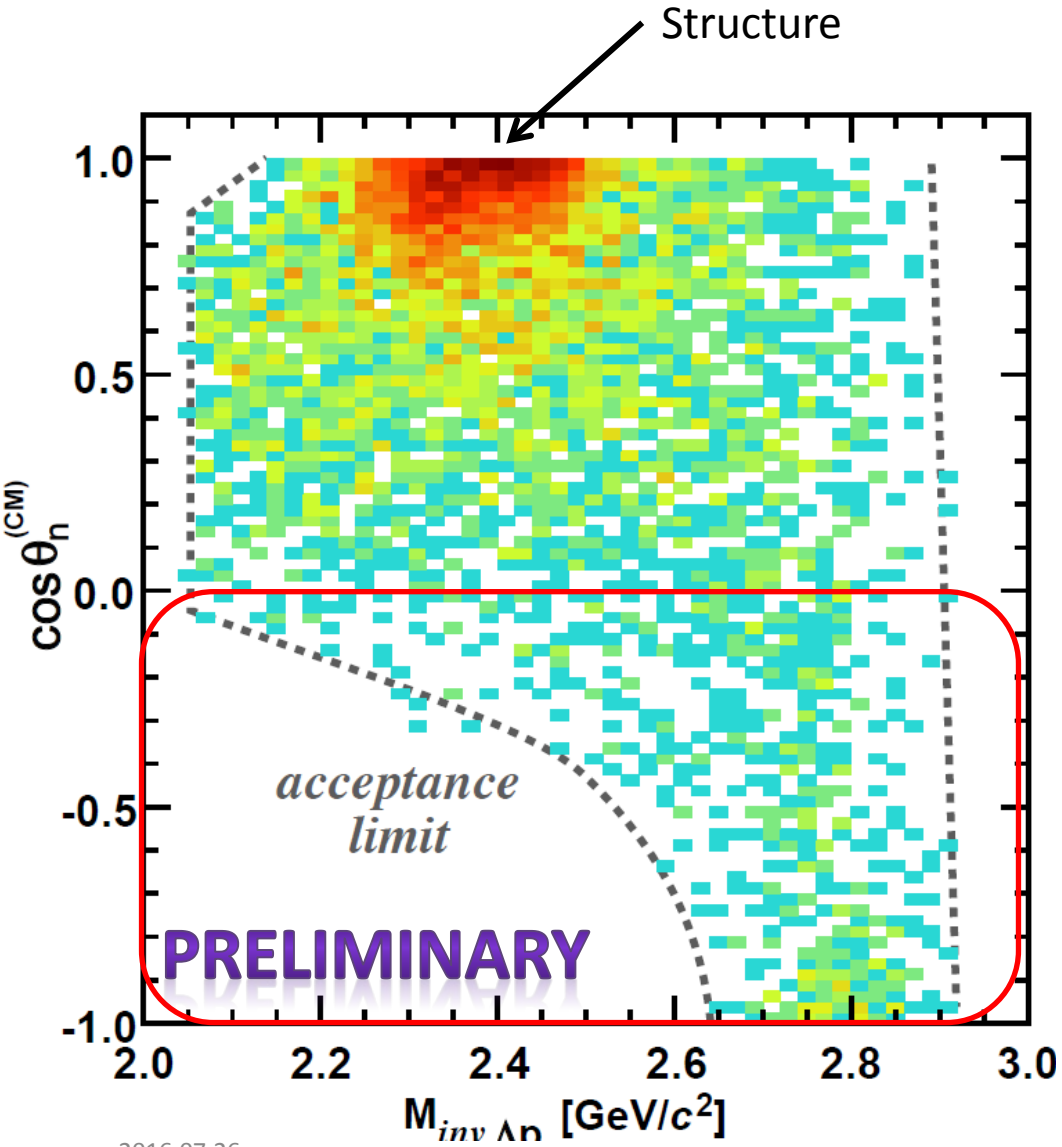
~ The E15 collaboration ~

S. Ajimura[a], G. Beer[b], C. Berucci[e], H. Bhang[c], M. Bragadireanu[d], P. Buehler[e], L. Busso[f,g], M. Cargnelli[e], S. Choi[c], C. Curceanu[h], S. Enomoto[n], D. Faso[f,g], H. Fujioka[j], Y. Fujiwara[k], T. Fukuda[l], C. Guaraldo[h], T. Hashimoto[m], R. S. Hayano[k], T. Hiraiwa[a], M. Iio[n], M. Iliescu[h], K. Inoue[a], Y. Ishiguro[j], T. Ishikawa[k], S. Ishimoto[n], T. Ishiwatari[e], K. Itahashi[m], M. Iwai[n], M. Iwasaki[o,m*], K. Kanno[k], K. Kato[j], Y. Kato[m], S. Kawasaki[i], P. Kienle[p], T. Kim[o], H. Kou[o], Y. Ma[m], J. Marton[e], Y. Matsuda[q], Y. Mizoi[l], O. Morra[f], T. Nagae[j†], H. Noumi[a], H. Ohnishi[m,a], S. Okada[m], H. Outa[m], K. Piscicchia[h], A. Romero Vidal[h], Y. Sada[a], A. Sakaguchi[i], F. Sakuma[m], M. Sato[m], A. Scordo[h], M. Sekimoto[n], H. Shi[h], K. Shirotori[a], D. Sirghi[h,d], F. Sirghi[h,d], K. Suzuki[e], S. Suzuki[n], T. Suzuki[k], K. Tanida[u], H. Tatsuno[v], M. Tokuda[o], D. Tomono[a], A. Toyoda[n], K. Tsukada[r], O. Vazquez Doce[h,s], E. Widmann[e], B. K. Wuenschek[e], T. Yamaga[i], T. Yamazaki[k,m], H. Yim[t], Q. Zhang[m], and J. Zmeskal[e]

(J-PARC E15 Collaboration)

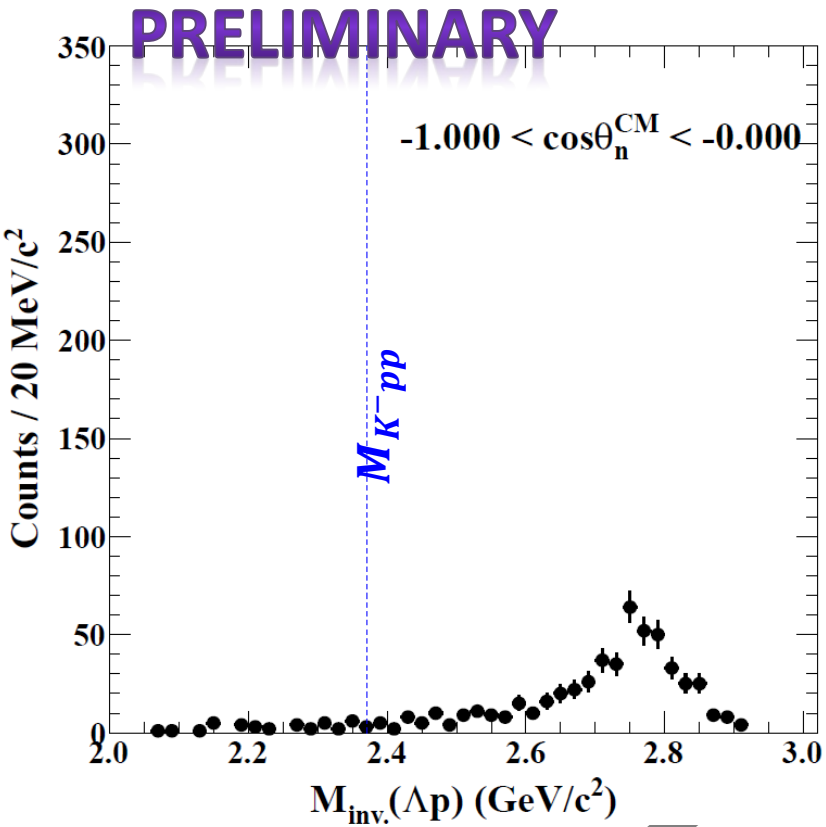
(a) *Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, 567-0047, Japan*
(b) *Department of Physics and Astronomy, University of Victoria, Victoria BC V8W 3P6, Canada*
(c) *Department of Physics, Seoul National University, Seoul, 151-742, South Korea*
(d) *National Institute of Physics and Nuclear Engineering - IFIN HH, Romania*
(e) *Stefan-Meyer-Institut für subatomare Physik, A-1090 Vienna, Austria*
(f) *INFN Sezione di Torino, Torino, Italy*
(g) *Dipartimento di Fisica Generale, Universita' di Torino, Torino, Italy*
(h) *Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy*
(i) *Department of Physics, Osaka University, Osaka, 560-0043, Japan*
(j) *Department of Physics, Kyoto University, Kyoto, 606-8502, Japan*
(k) *Department of Physics, The University of Tokyo, Tokyo, 113-0033, Japan*
(l) *Laboratory of Physics, Osaka Electro-Communication University, Osaka, 572-8530, Japan*
(m) *RIKEN Nishina Center, RIKEN, Wako, 351-0198, Japan*
(n) *High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan*
(o) *Department of Physics, Tokyo Institute of Technology, Tokyo, 152-8551, Japan*
(p) *Technische Universität München, D-85748, Garching, Germany*
(q) *Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, 153-8902, Japan*
(r) *Department of Physics, Tohoku University, Sendai, 980-8578, Japan*
(s) *Excellence Cluster Universe, Technische Universität München, D-85748, Garching, Germany*
(t) *Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, 139-706, South Korea*
(u) *ASRC, Japan Atomic Energy Agency, Ibaraki 319-1195, Japan*
(v) *Department of Chemical Physics, Lund University, Lund, 221 00, Sweden*

$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

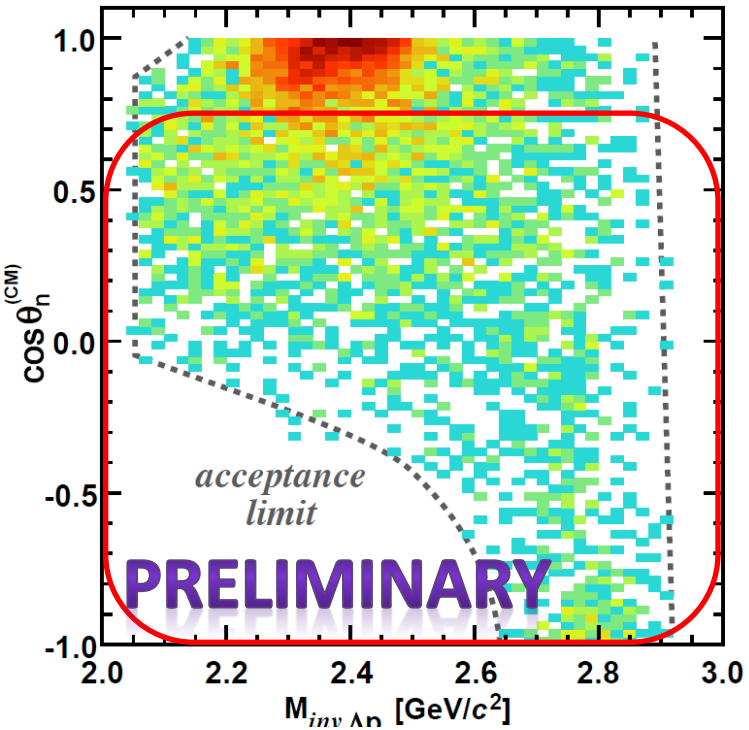


- $-1.0 < \cos\theta_n^{CM} < 0.0$

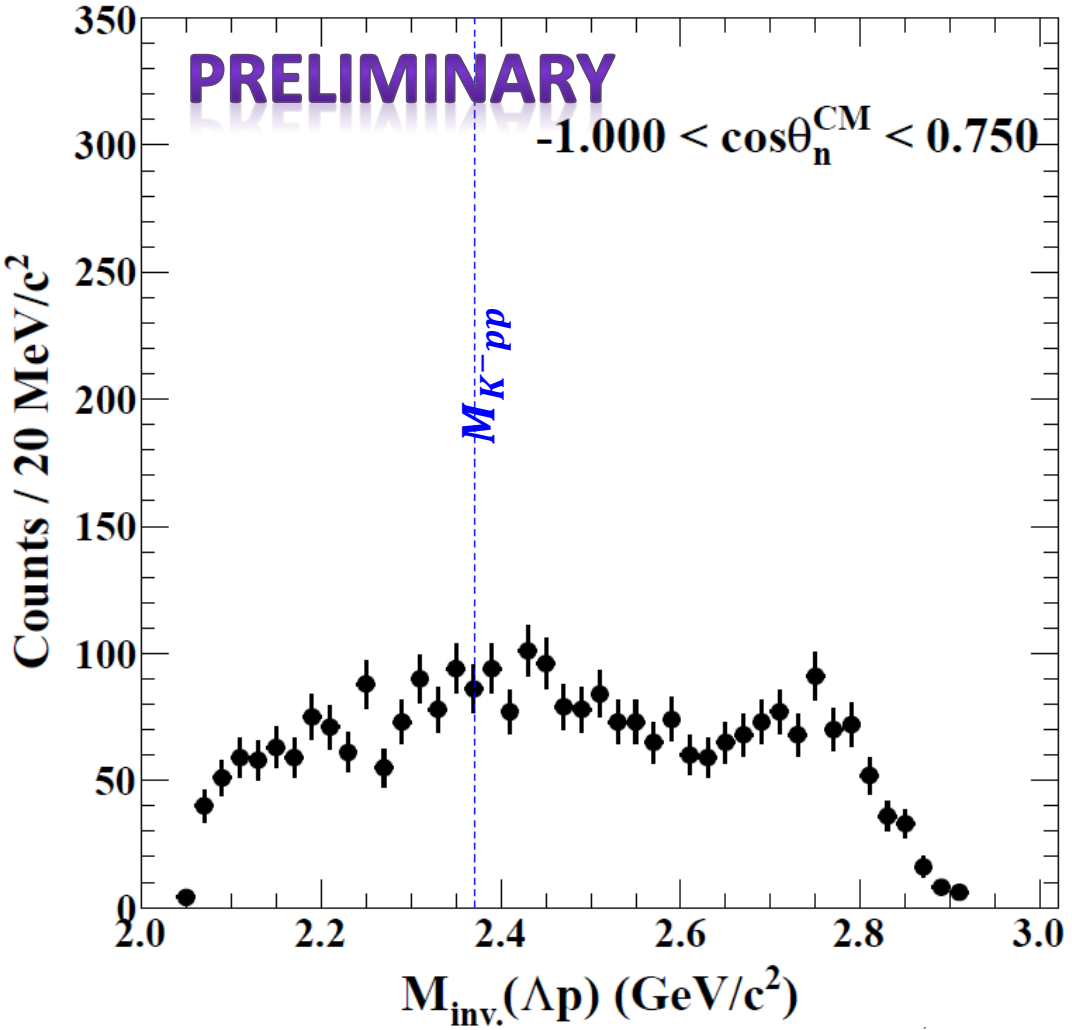
- 2NA process



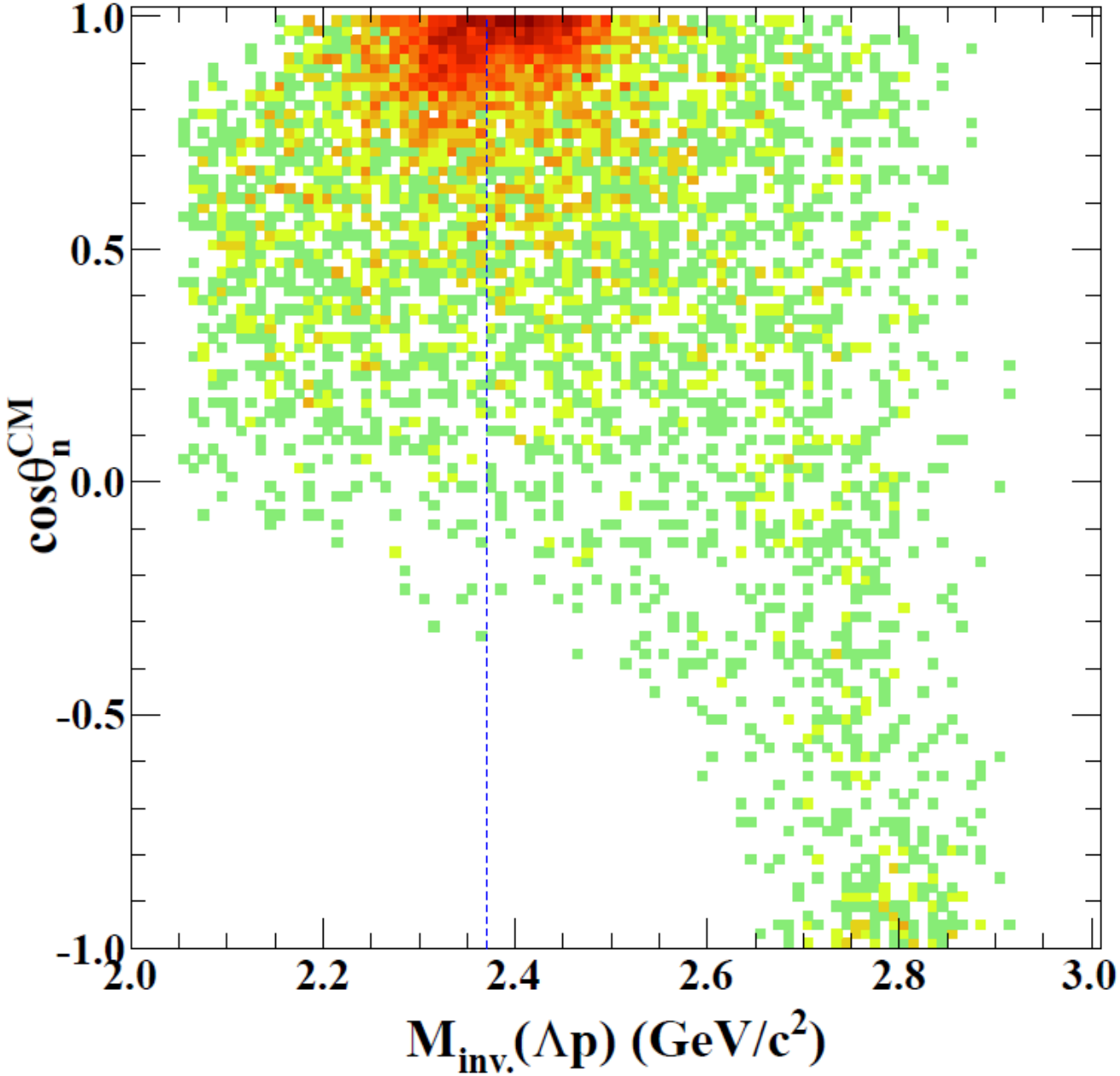
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

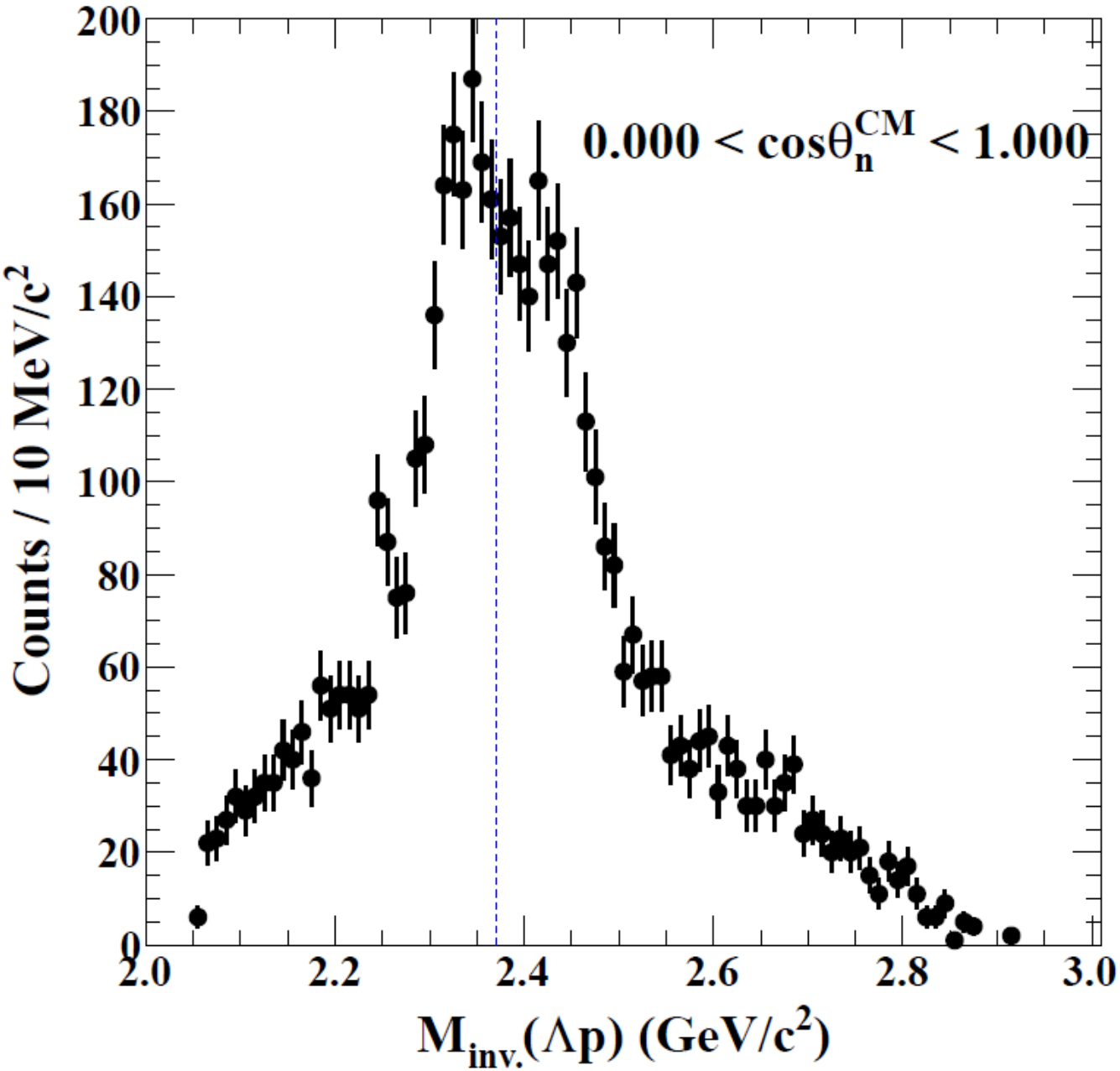


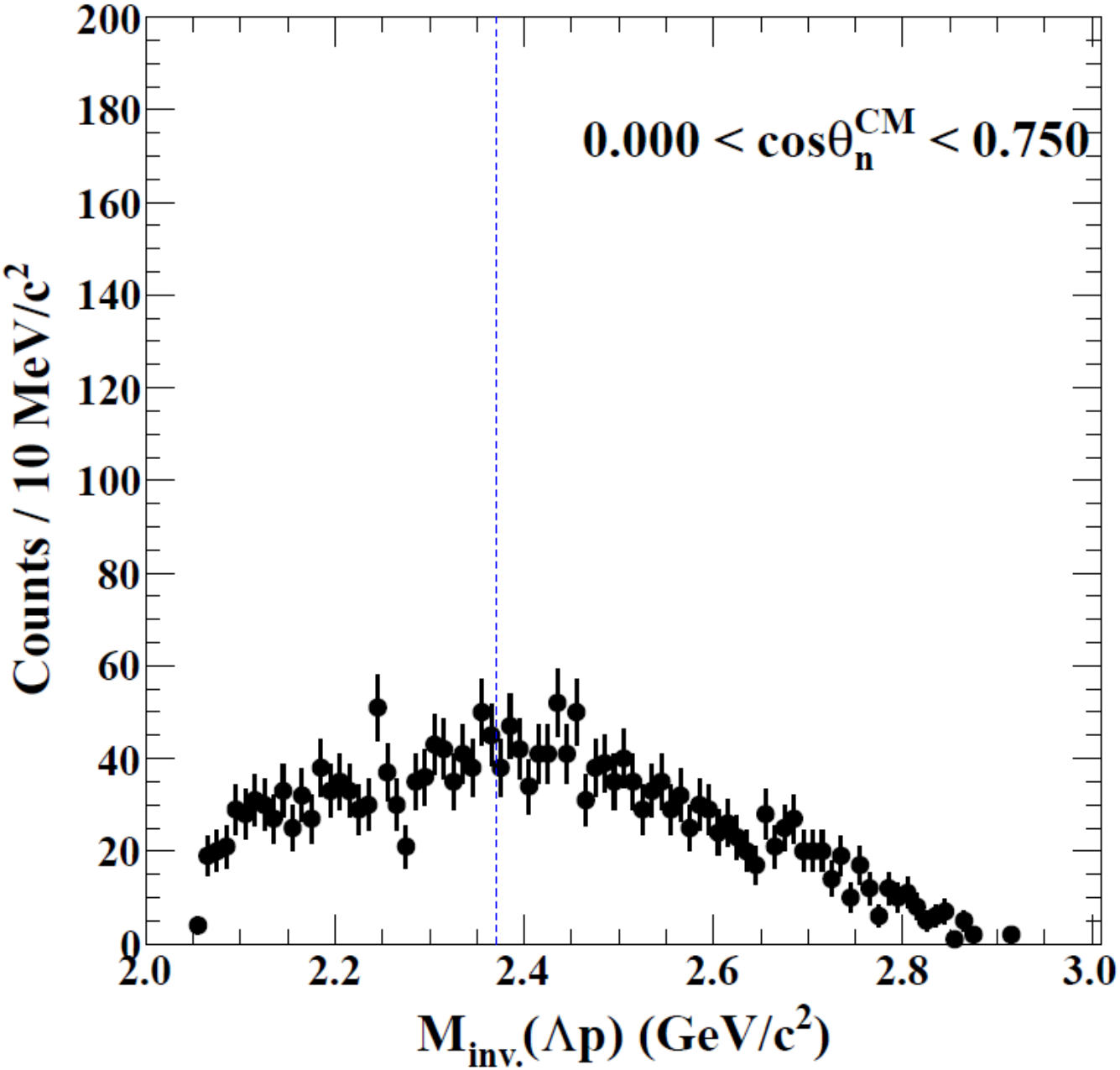
- $-1.0 < \cos\theta_n^{CM} < 0.75$
  - 3NA + 2NA

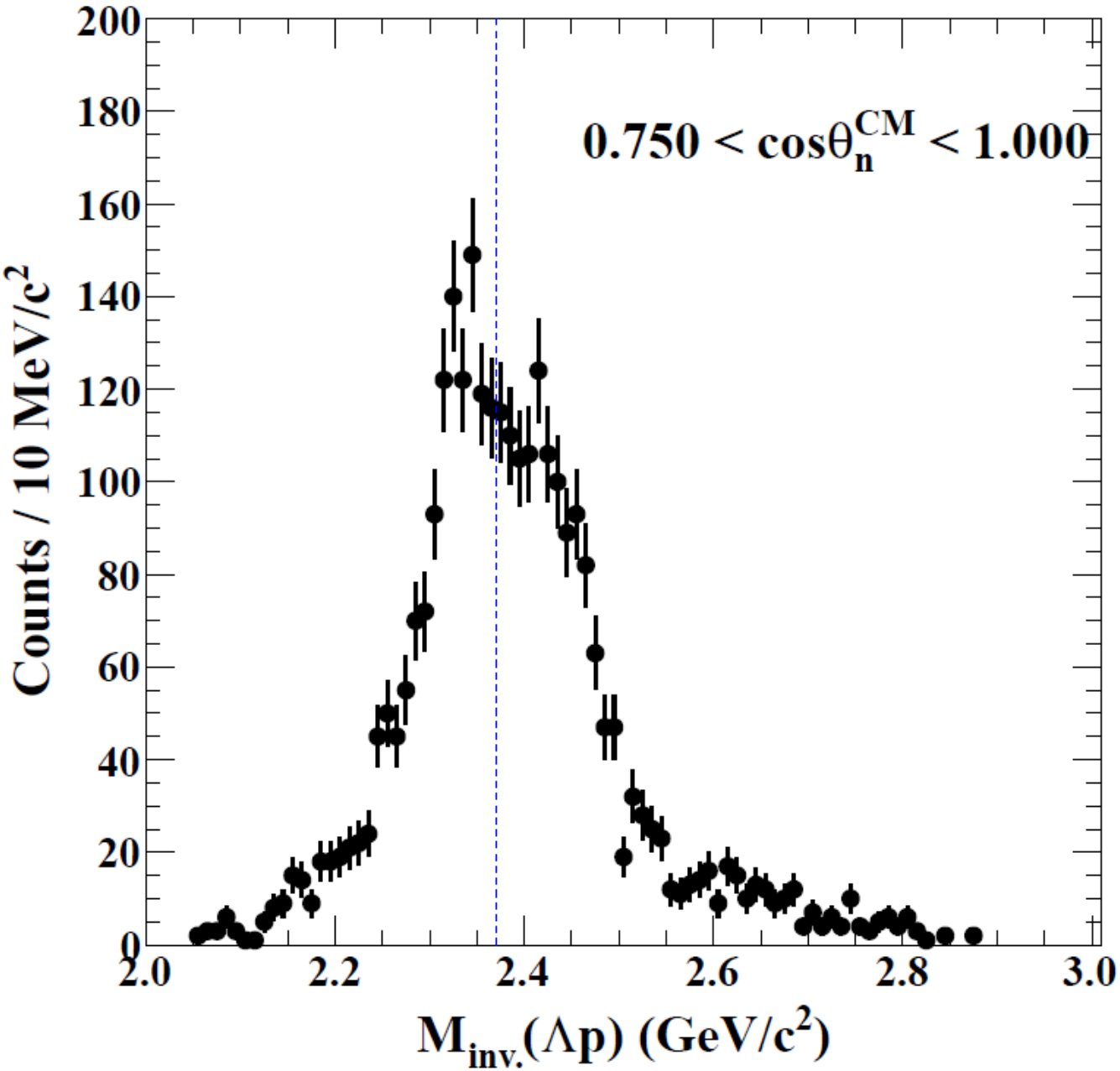


- No Structure

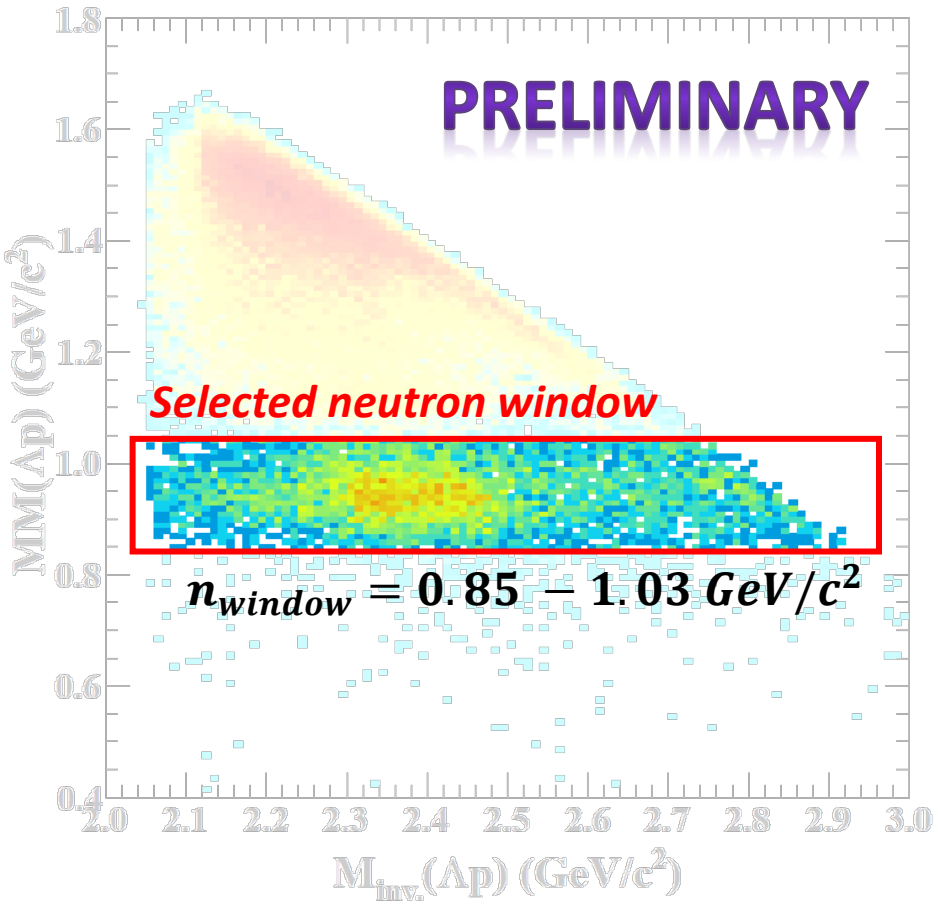

1.0
0.5
0.0
-0.5
-1.0
$\cos\theta_n^{CM}$
2.0
2.2
2.4
2.6
2.8
3.0
$M_{inv.}(\Lambda p)$ (GeV/c^2)

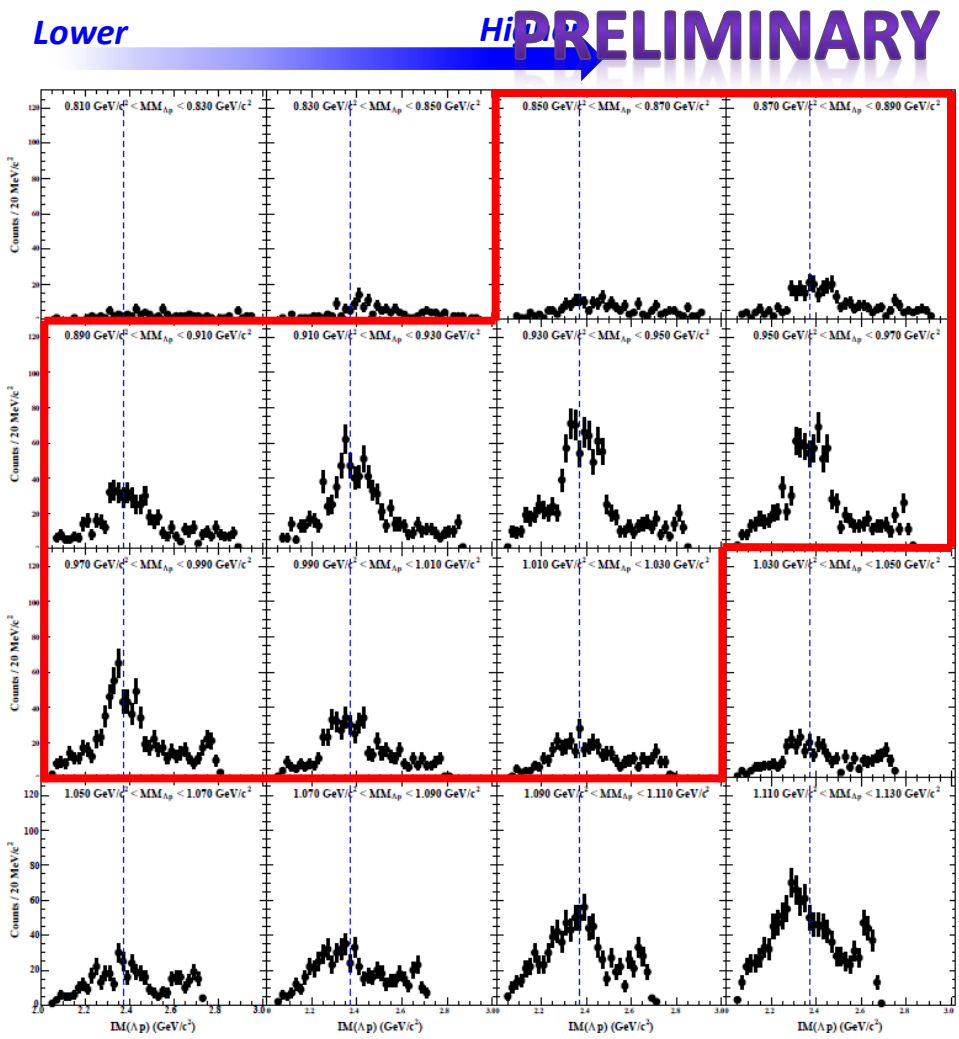

$0.000 < \cos\theta_n^{CM} < 1.000$
Counts / 10 MeV/c^2
$M_{inv.}(\Lambda p)$ (GeV/c^2)
0
20
40
60
80
100
120
140
160
180
200
2.0
2.2
2.4
2.6
2.8
3.0


$0.000 < \cos\theta_n^{CM} < 0.750$
Counts / 10 MeV/c^2
$M_{inv.}(\Lambda p)$ (GeV/c^2)
0
20
40
60
80
100
120
140
160
180
200
2.0
2.2
2.4
2.6
2.8
3.0

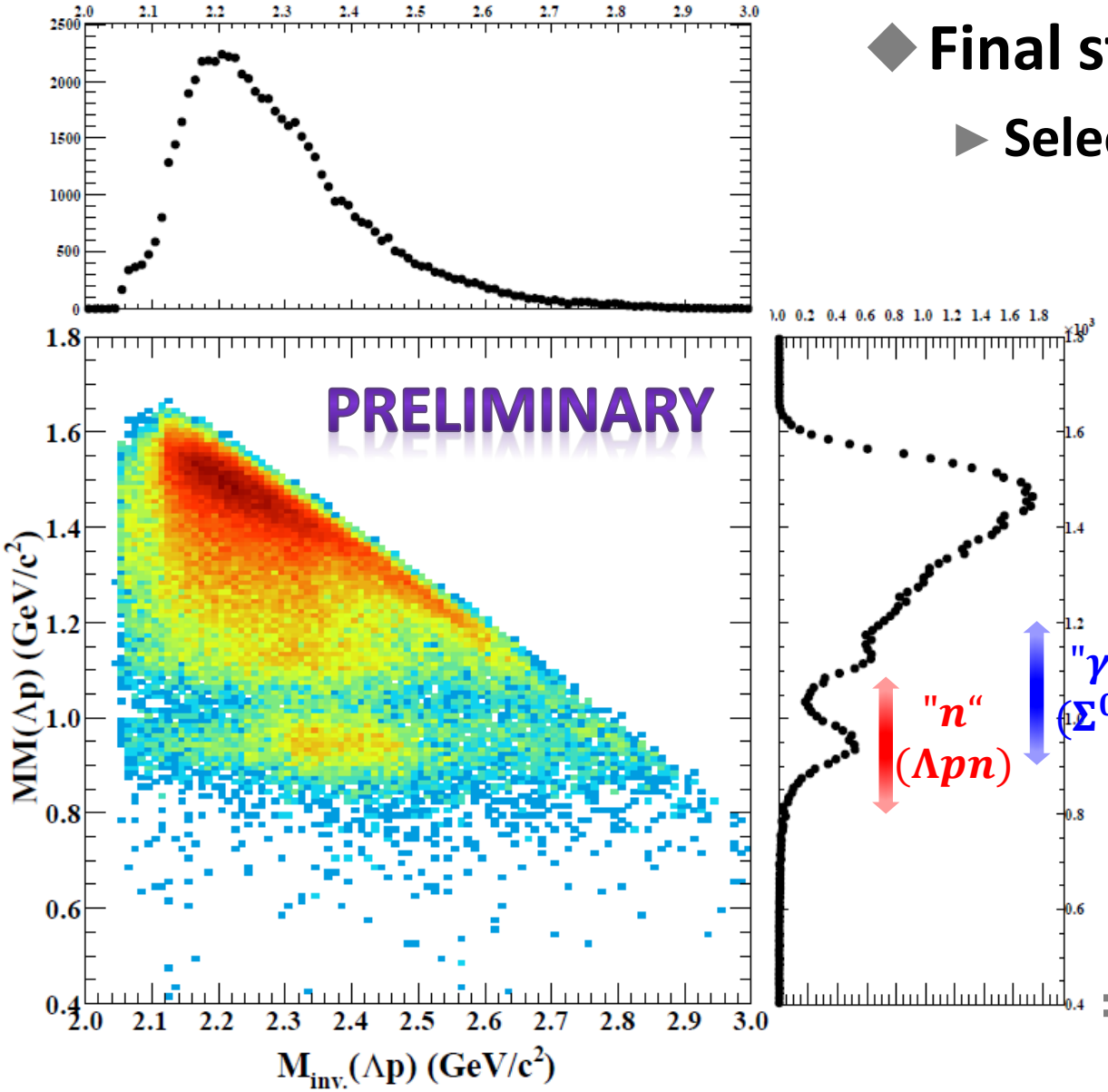

$0.750 < \cos\theta_n^{CM} < 1.000$
Counts / 10 MeV/c^2
$M_{inv.}(\Lambda p)$ (GeV/c^2)
0
20
40
60
80
100
120
140
160
180
200
2.0
2.2
2.4
2.6
2.8
3.0

Neutron Window for Λpn Selection





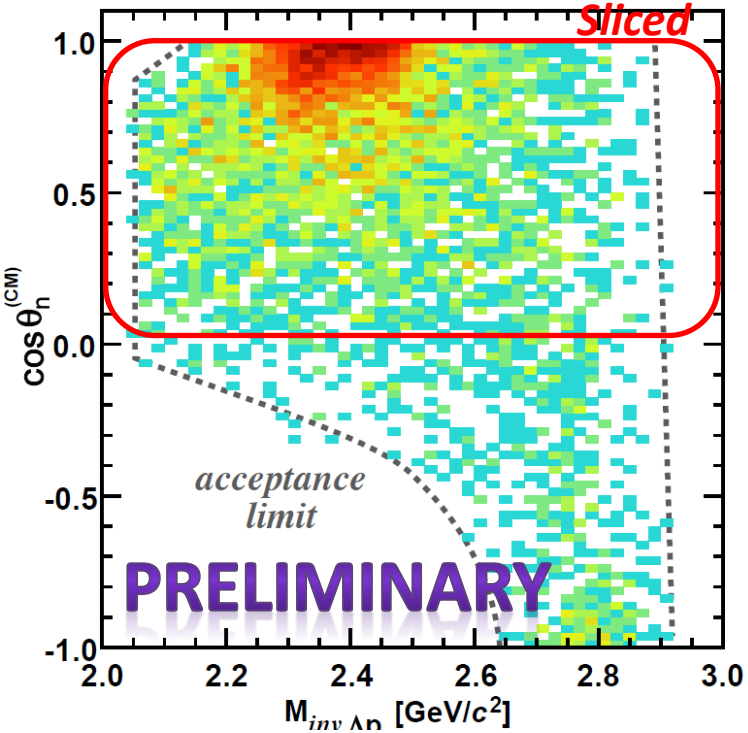
Λp IM vs. MM Plot



- **Final state identification**
  - Selecting Λpn final state

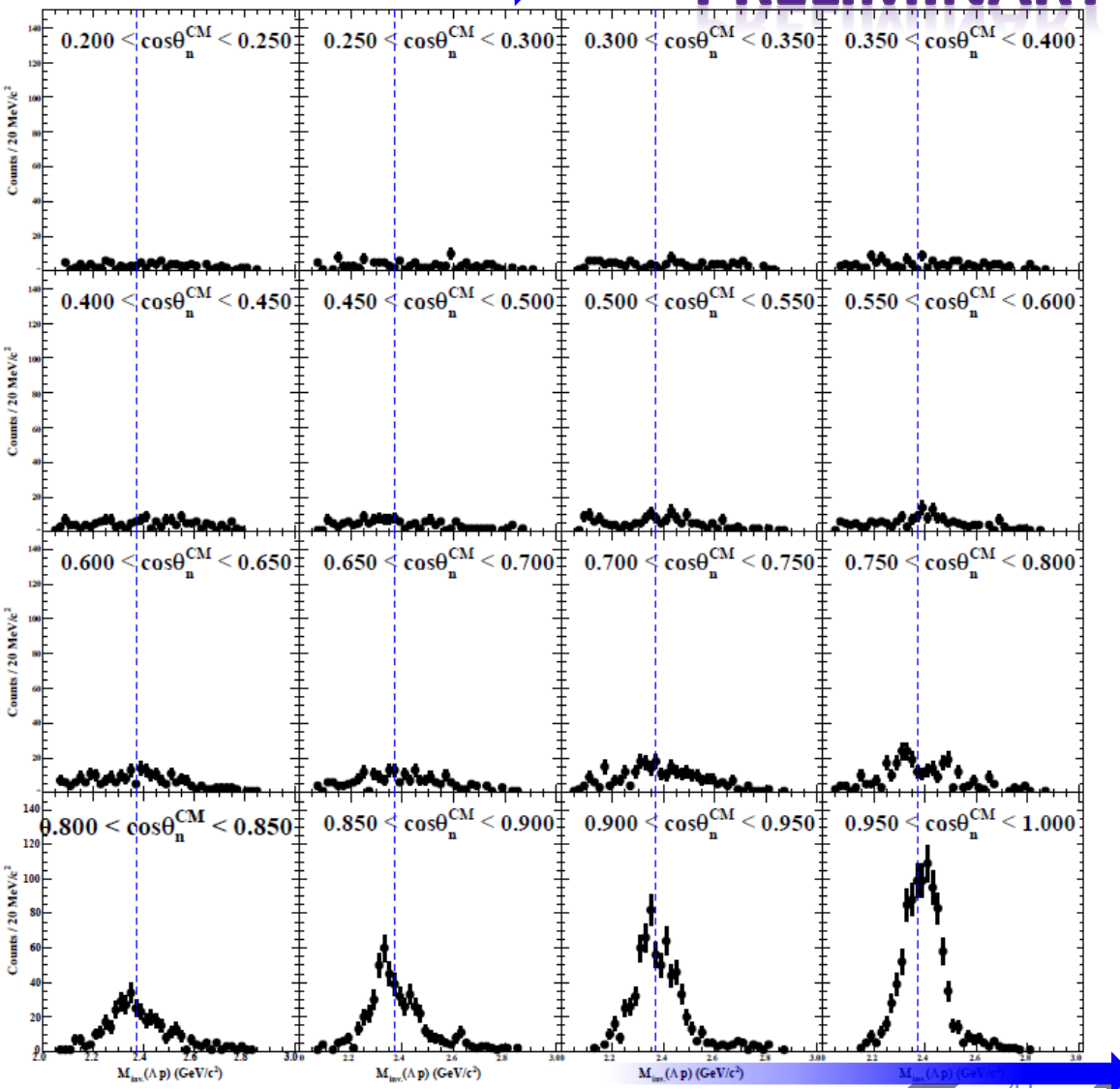
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

*Sliced with 0.05 bin



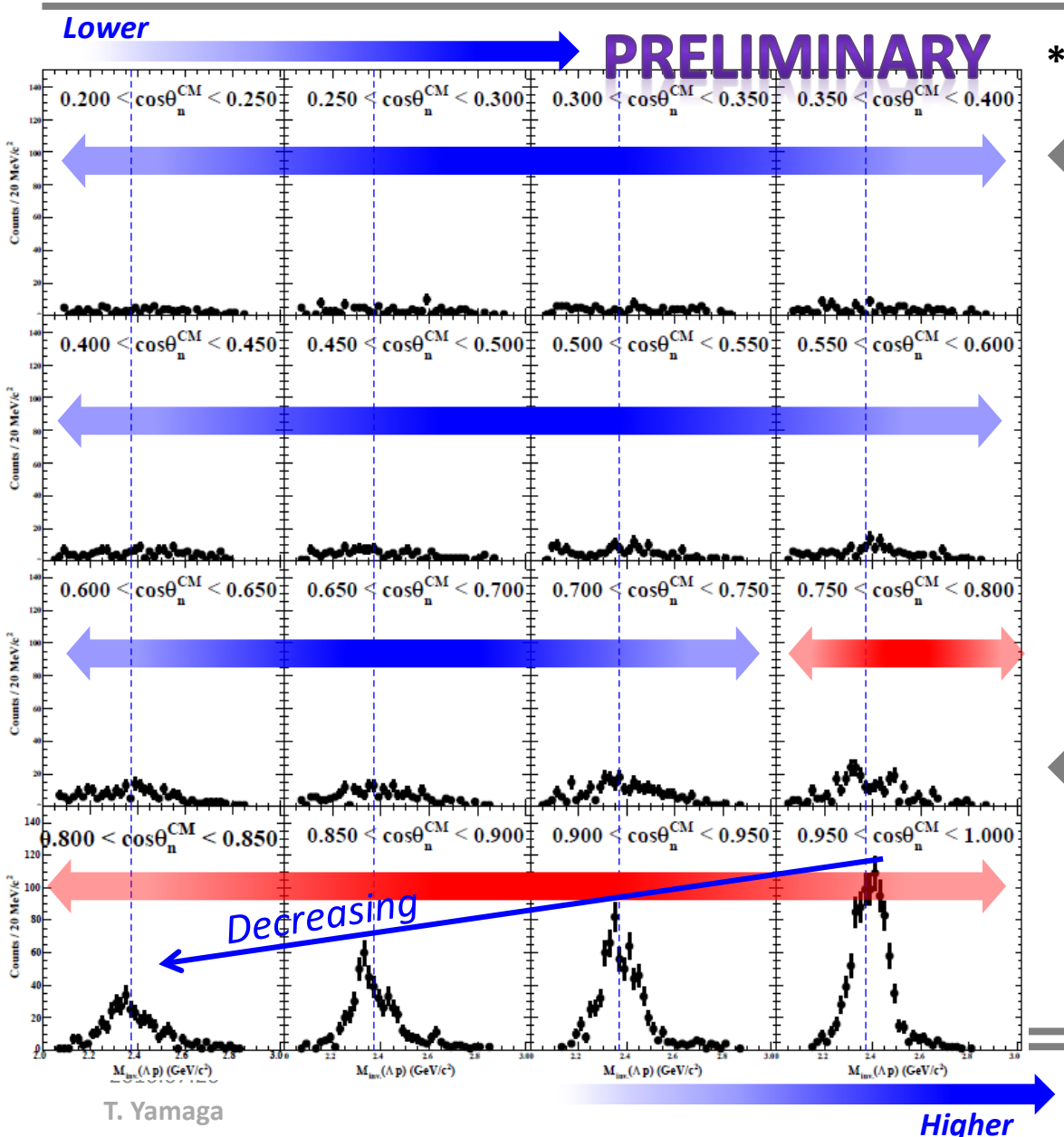
Lower

PRELIMINARY



Higher

$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



*Sliced with 0.05 bin

- **Lower Opening Angle**
  - 0 – 0.75
  - ▶ No structure
  - ▶ Small event
- **Higher O.A.**
  - 0.75 – 1.0
  - ▶ Structure observed

$MM(\Lambda p)$ Slice around "n" Region