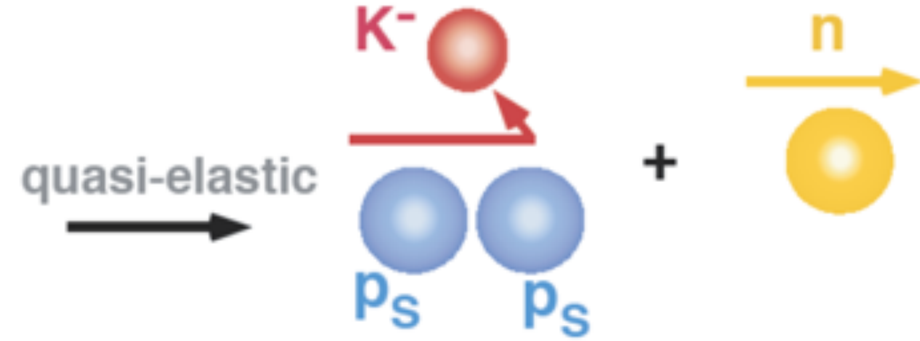


Kaonic nuclear state search by kaon reaction on ^{3}He target at 1GeV/c

M. Iwasaki

for E15 collaboration

YITP YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

RIKEN NISHINA CENTER

RIKEN

MIN16 - Meson in Nucleus 2016, 31 Jul - 2 Aug

RIKEN NISHINA CENTER

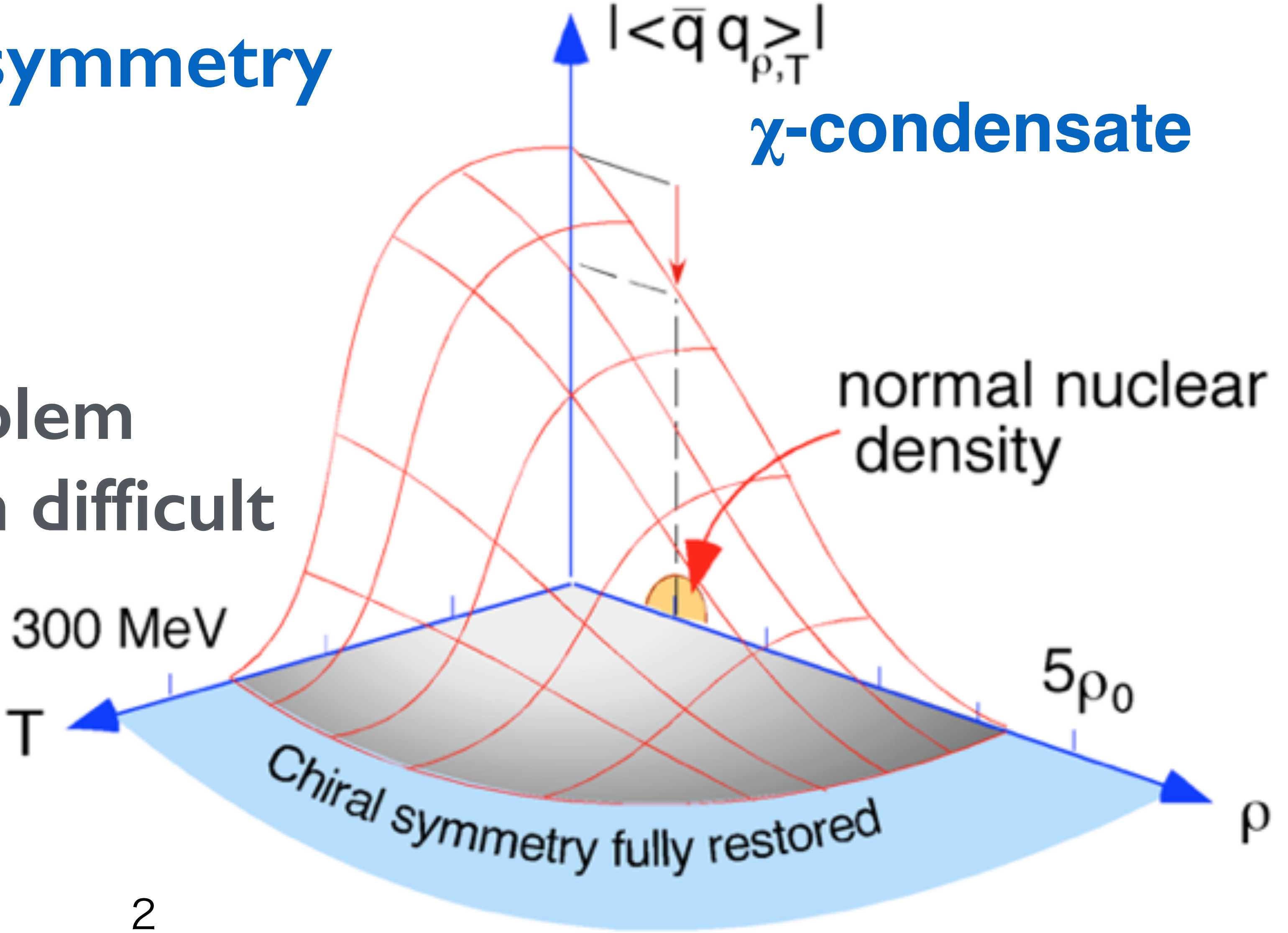
Objectives

Key questions :

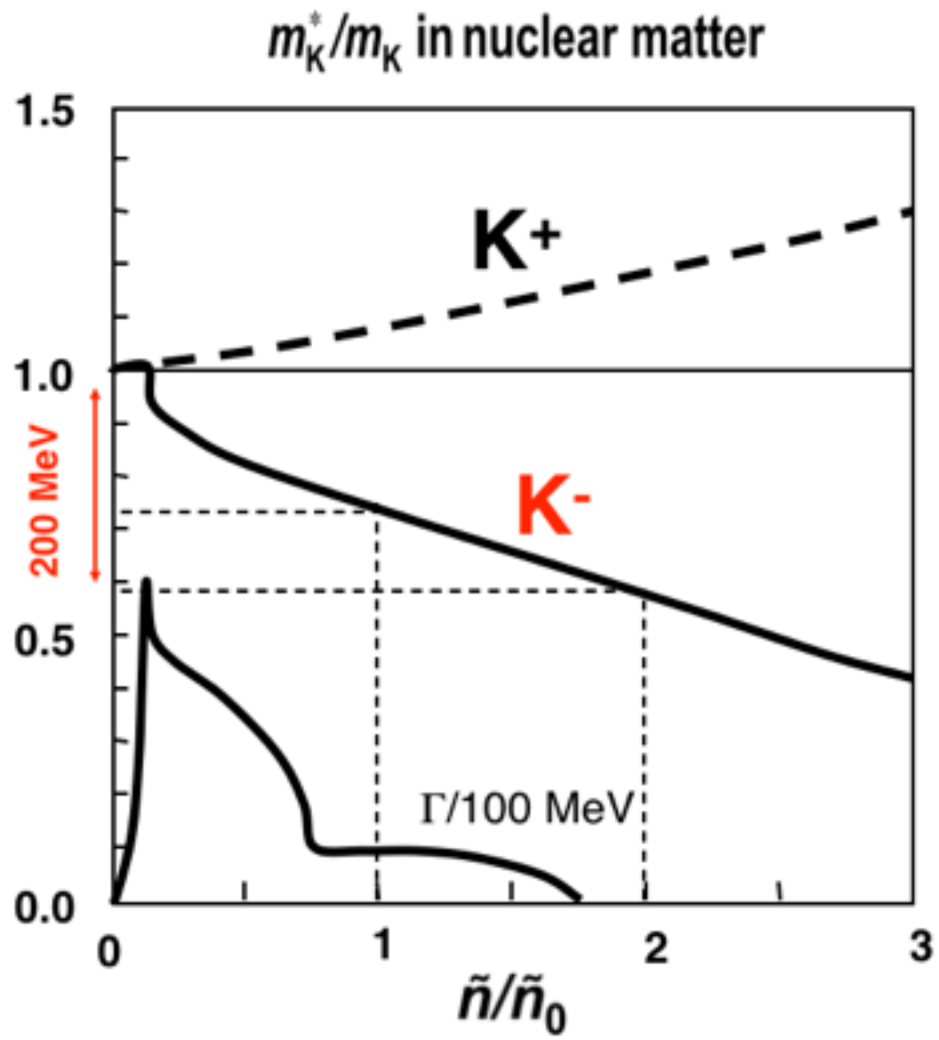
- Can kaon be a member of nuclei?
- Kaon properties change in nuclear media?

Hadron masses and χ-symmetry

Non-perturbative aspects
@ energy < Λ_{QCD}
Finite density → sign problem
Lattice-QCD approach difficult



Search for Kaonic nuclear states

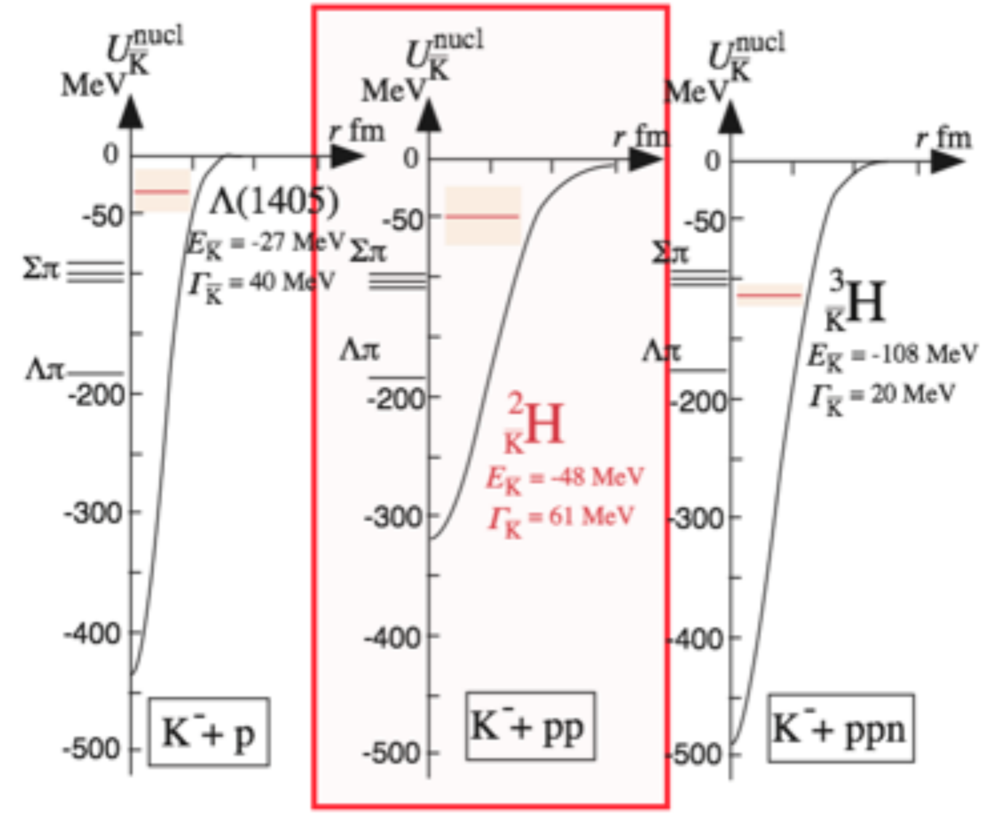


T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

strongly attractive in I=0 channel

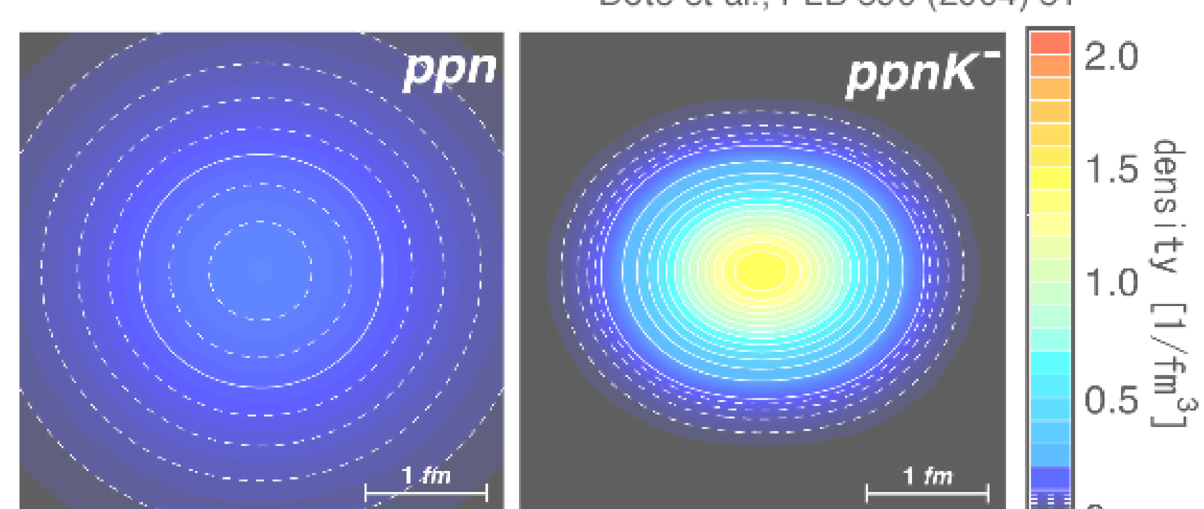
assuming Λ(1405) = K^-p bound state …

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



B_K ~ 50 MeV!

Dote et al., PLB 590 (2004) 51



formation of high density matter?

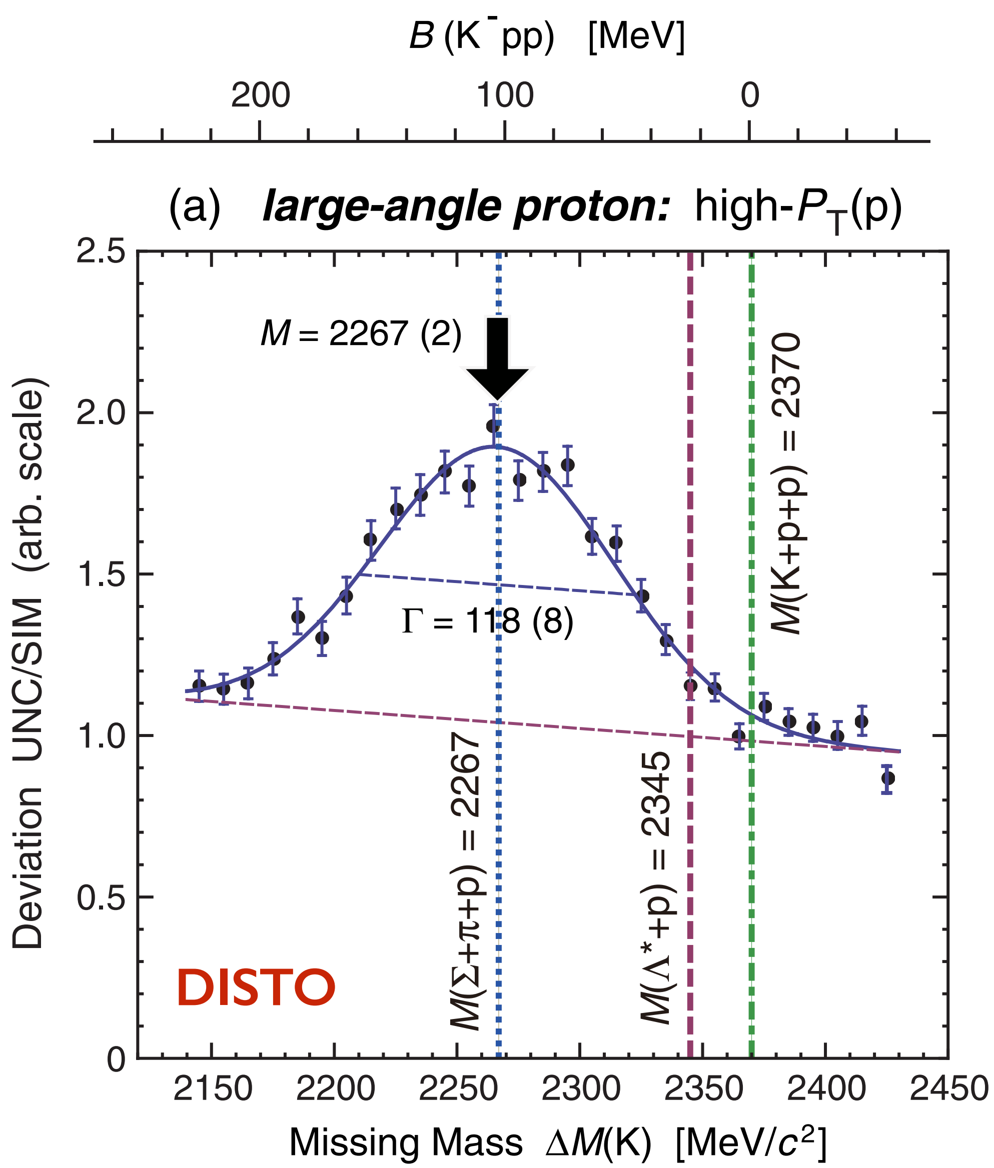
nuclear state search

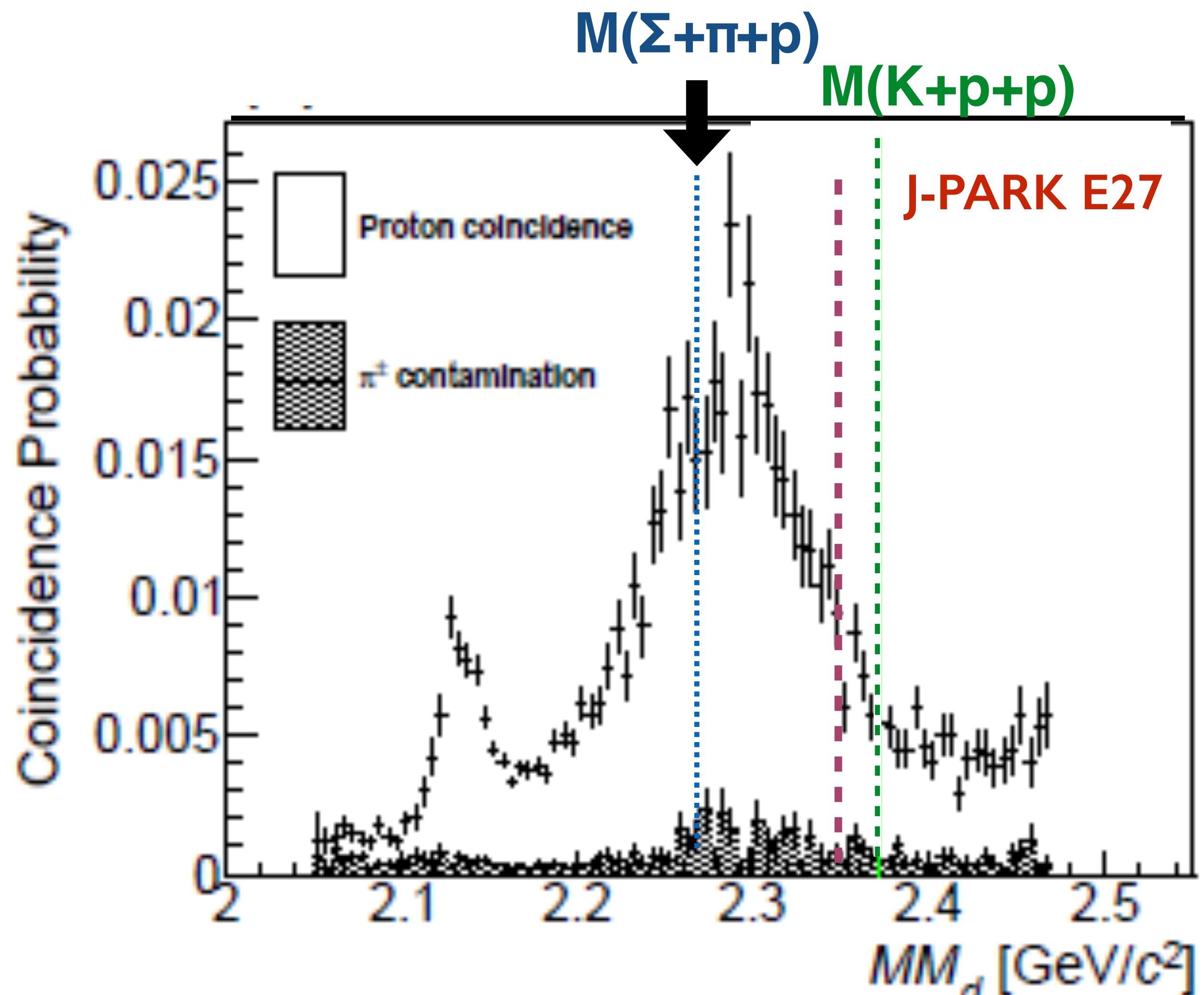
- **simplest system** *K^-pp*

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

present "Kpp" candidates @ B_K~100 MeV

hyper deep ??





Many objections exist, though…

why no threshold (Σπp) effect seen?

why no quasi-elastic K seen?

$p+p \rightarrow p+N^+(1710) \rightarrow p+(\Lambda+K^+)$

¿$\rightarrow (p+\Lambda)+K^+$?

…

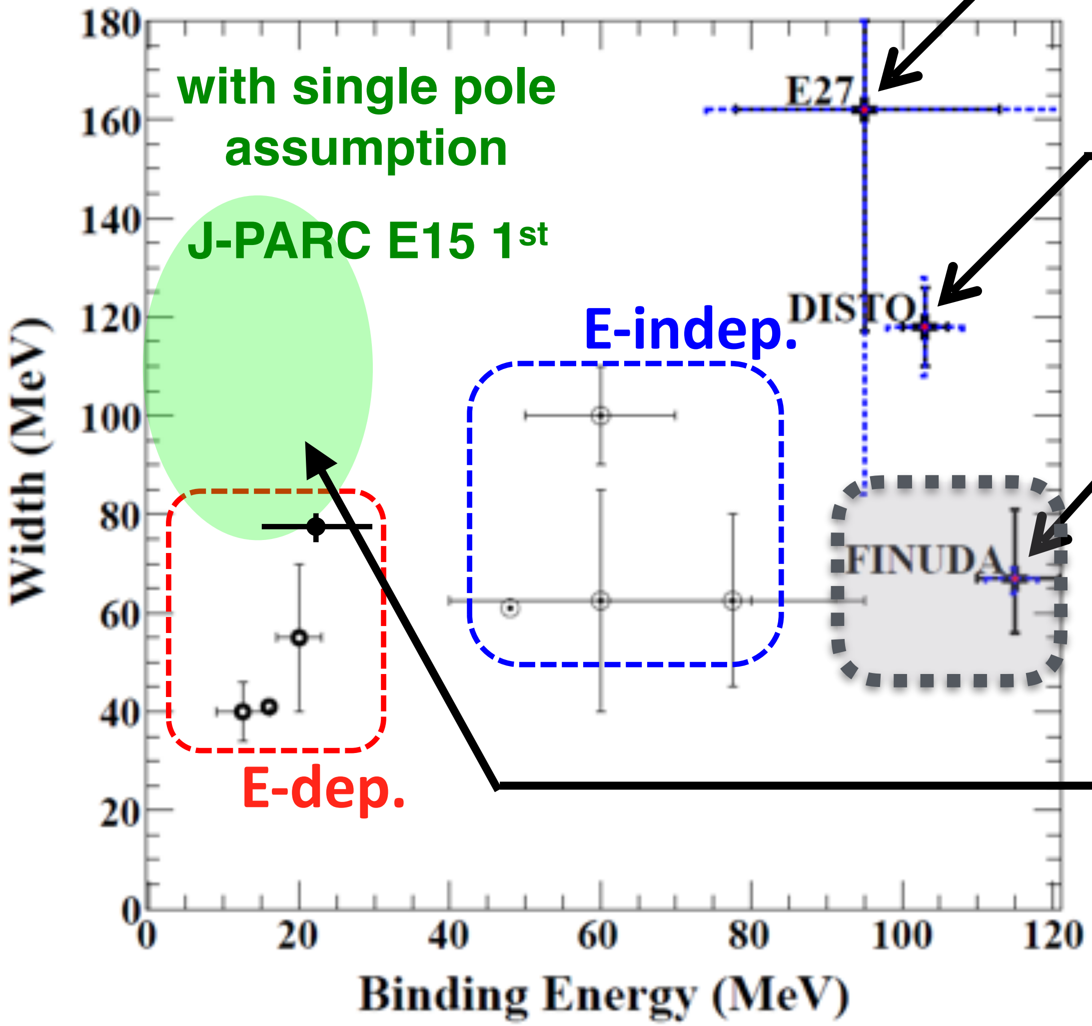
Recent status of $K^- pp$ bound state

- 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
$pp \rightarrow \Lambda p K^+$

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

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

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

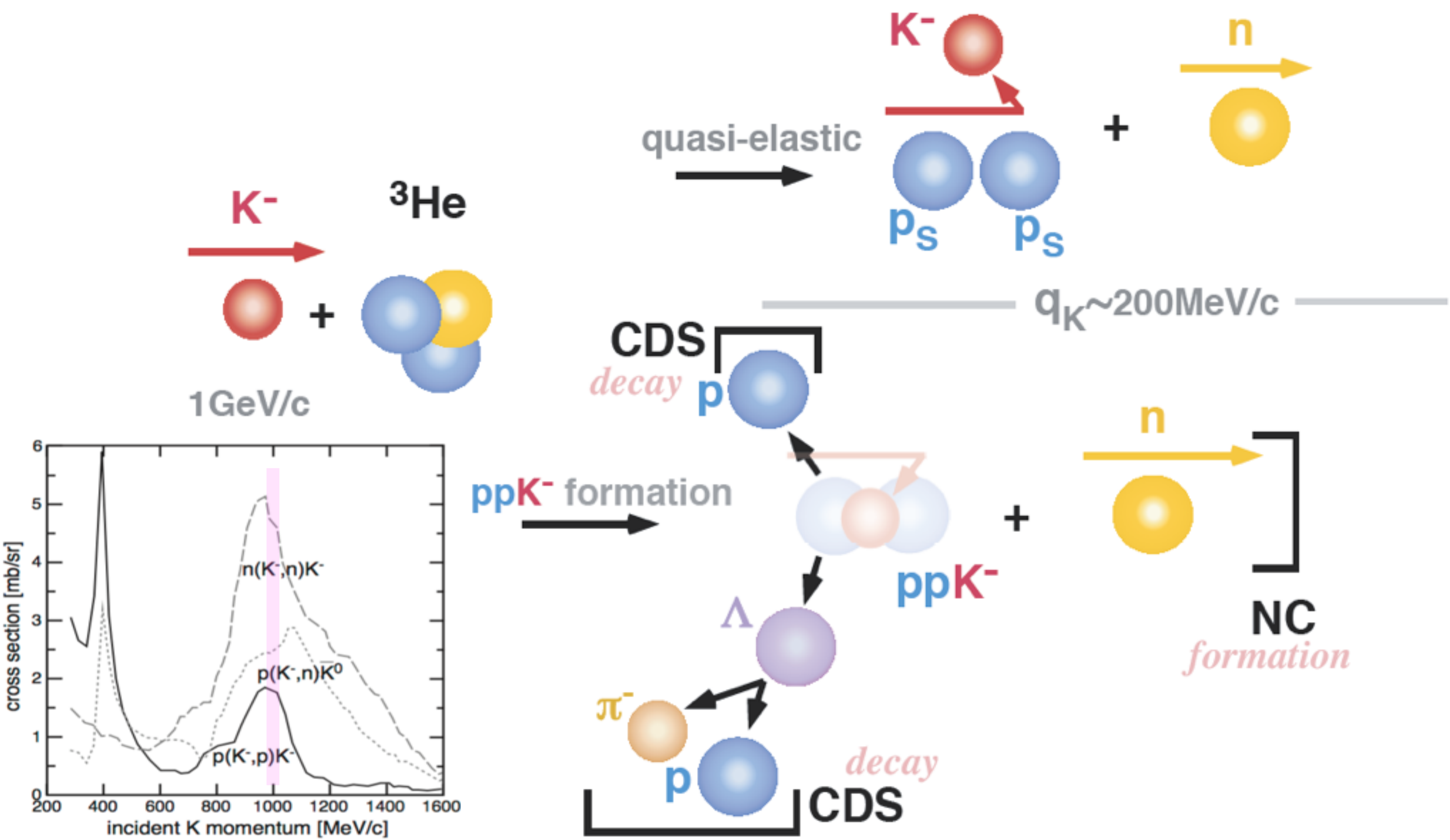
HADES
$pp \rightarrow \Lambda p K^+$

FINUDA ?

Kpp should be studied more

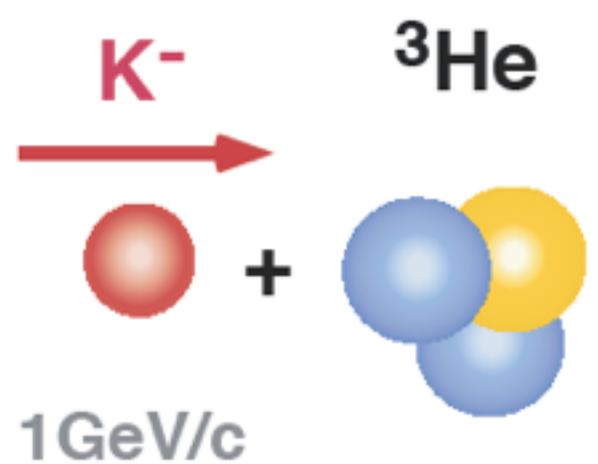
“K⁻pp” search via ^{3}He(K⁻,n) @p_K=1GeV/c

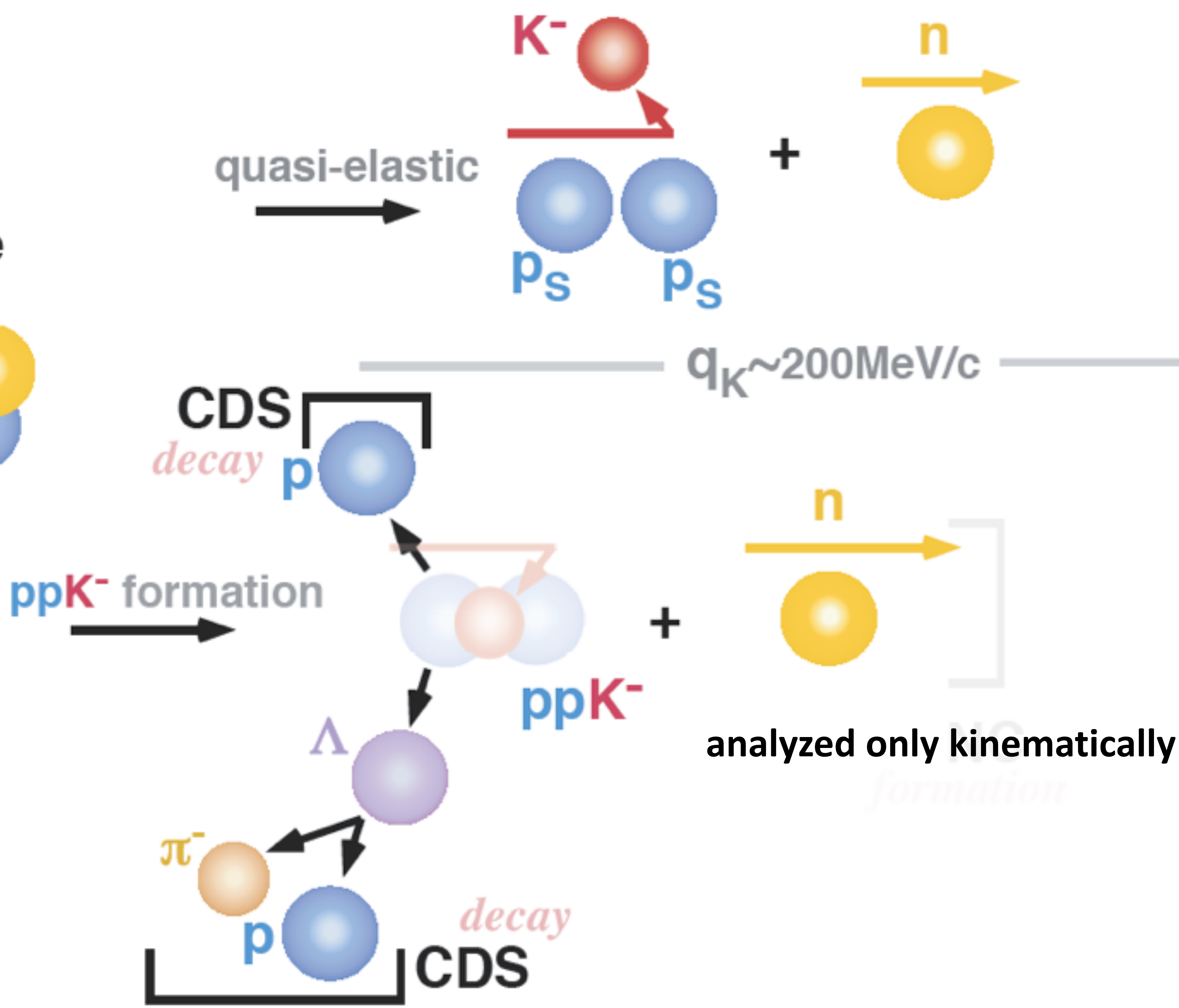
for efficient “ppK” formation q_K ~ 200 MeV/c

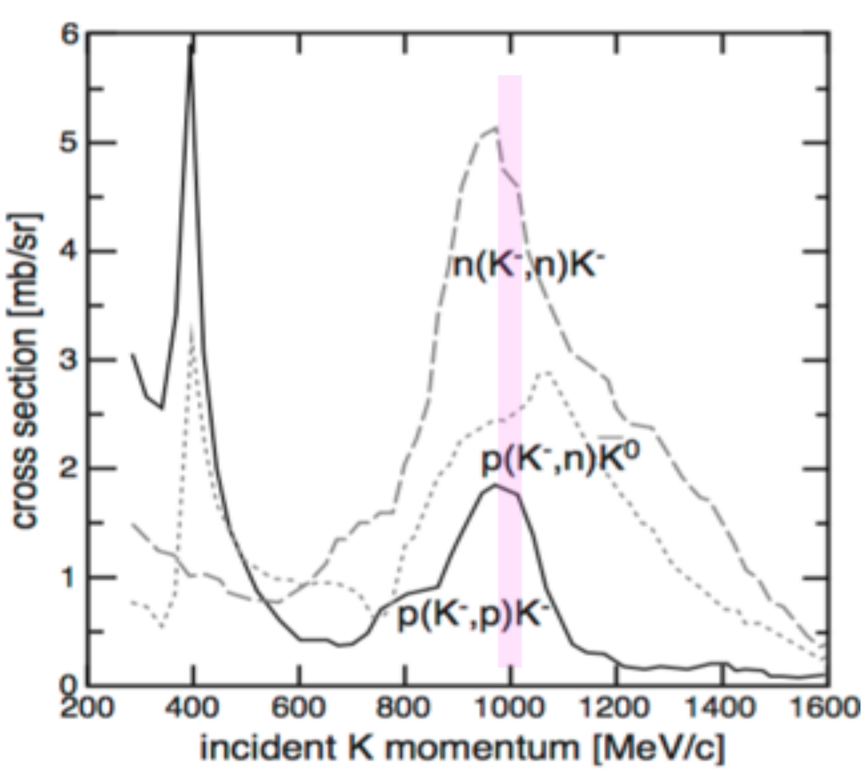


"K^-pp" search via $^3He(K^-,n)$ @p_K=1GeV/c

for efficient "ppK" formation $q_K \sim 200$ MeV/c







Published E15^{1st} data

Only 3 days!
(suspended by the earthquake)

presented at last NCAC

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

^{3}He(K$^-$, n) — semi-inclusive

Letter

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

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^{3}He(K$^-$, Λp) n — exclusive

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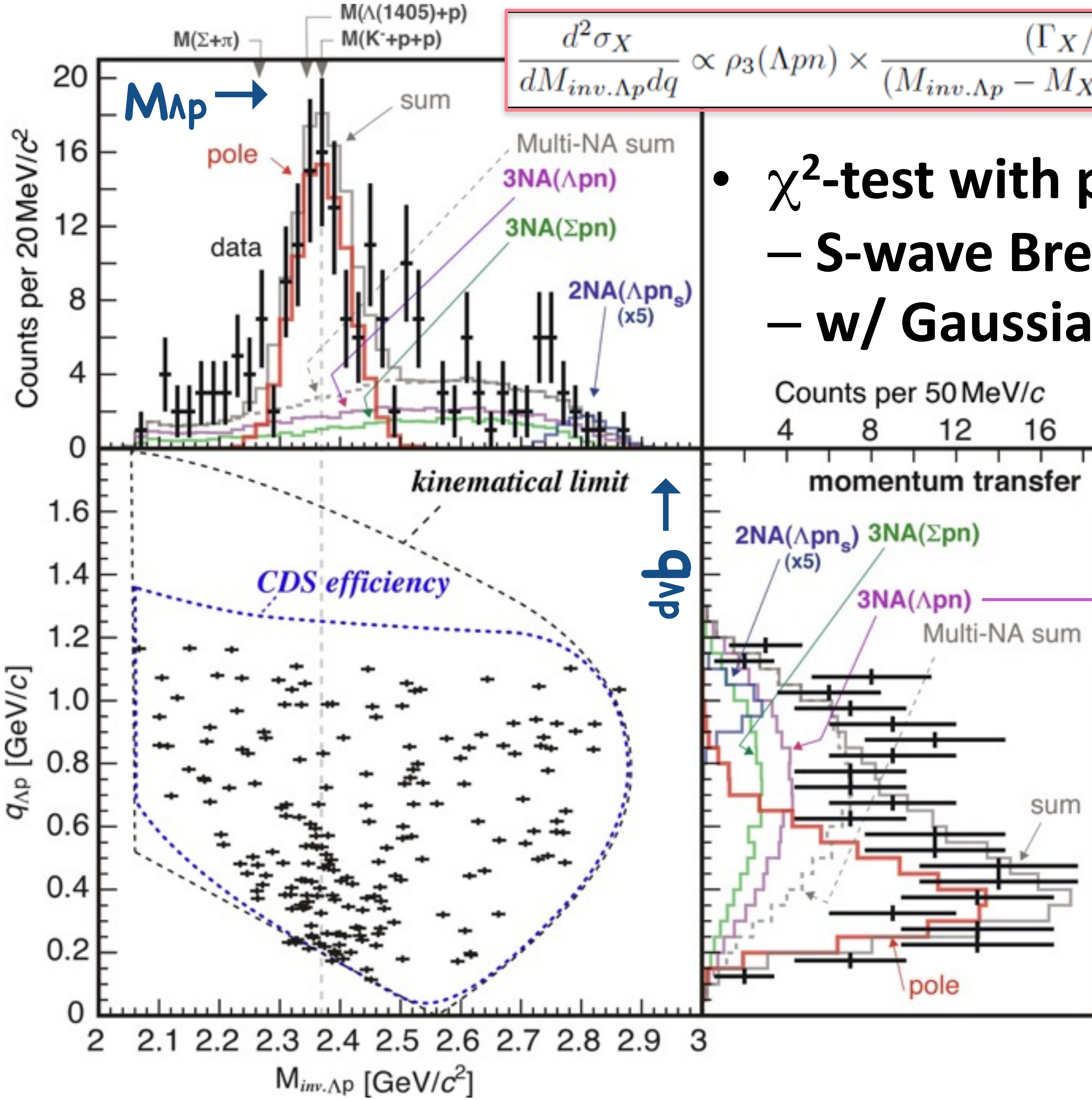
with new data!

Assuming a Breit-Wigner

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

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



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

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

B(X) ~ 15 MeV

Γ(X) ~ 110 MeV

Q(X) ~ 400 MeV/c

Assuming single pole (Breit-Wigner)

– introduce simplest assumption

S-wave pole & Breit-Wigner formula & Gaussian form-factor

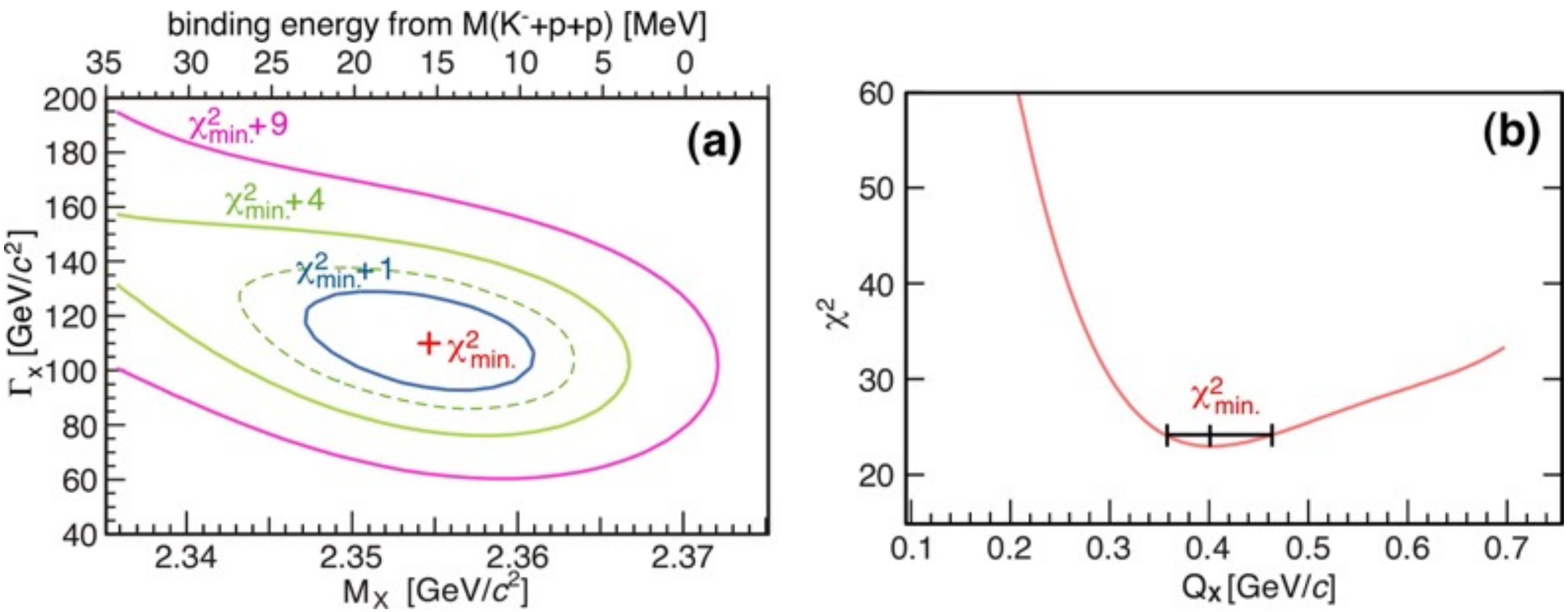
sticking probability to harmonic oscillator

Breit-Wigner

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

Lorentz invariant phase-space

form-factor^2



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

What is the structure found in E15^{1st} data?

Improving statistics via E15^{2nd} data

3 days → 3 weeks w/ higher priority to Λp in CDS

E15^{1st} E15^{2nd}

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

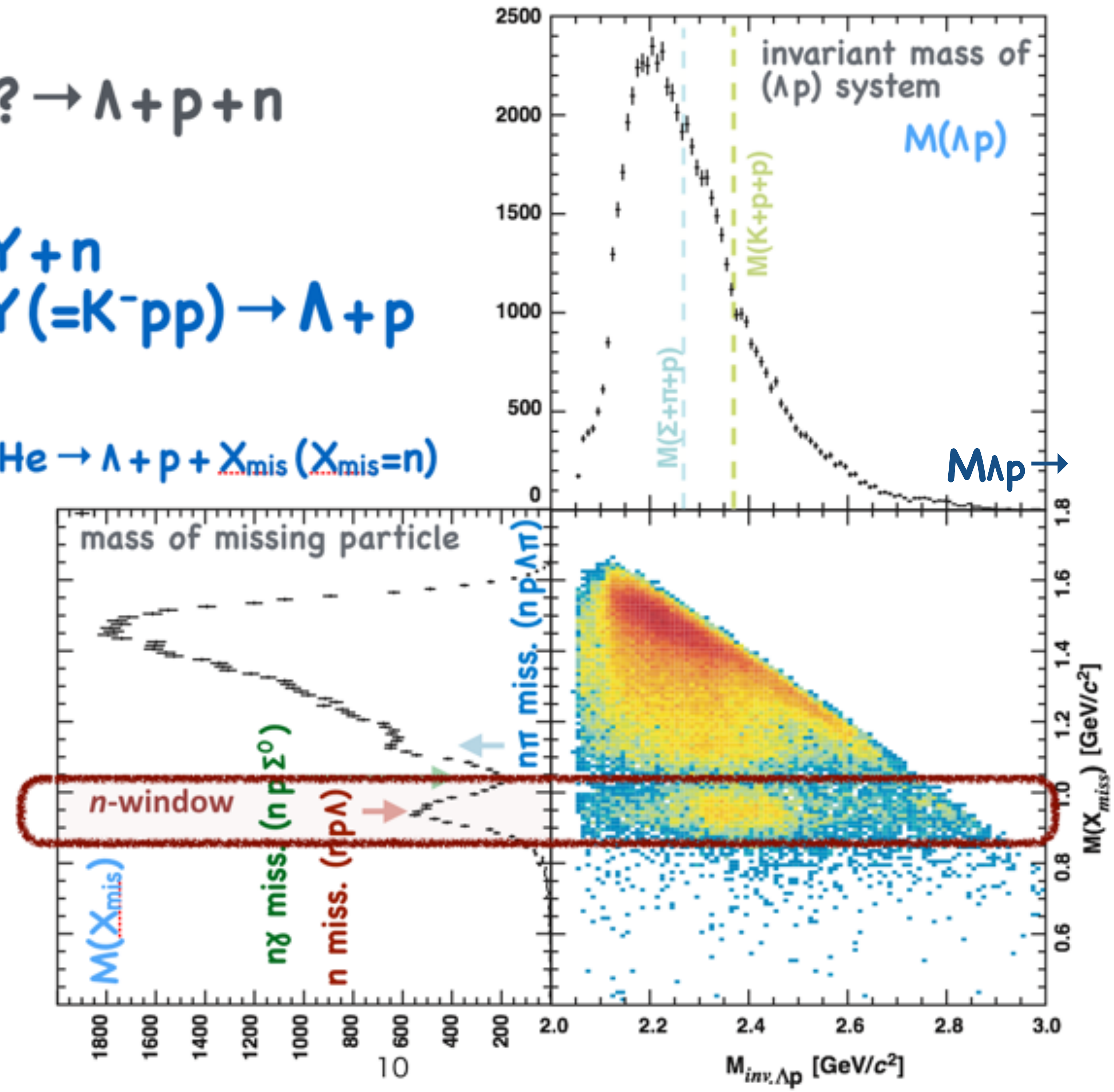
$K^- + {}^3He \rightarrow Y + n$

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

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

~ 6 times more data for forward neutron

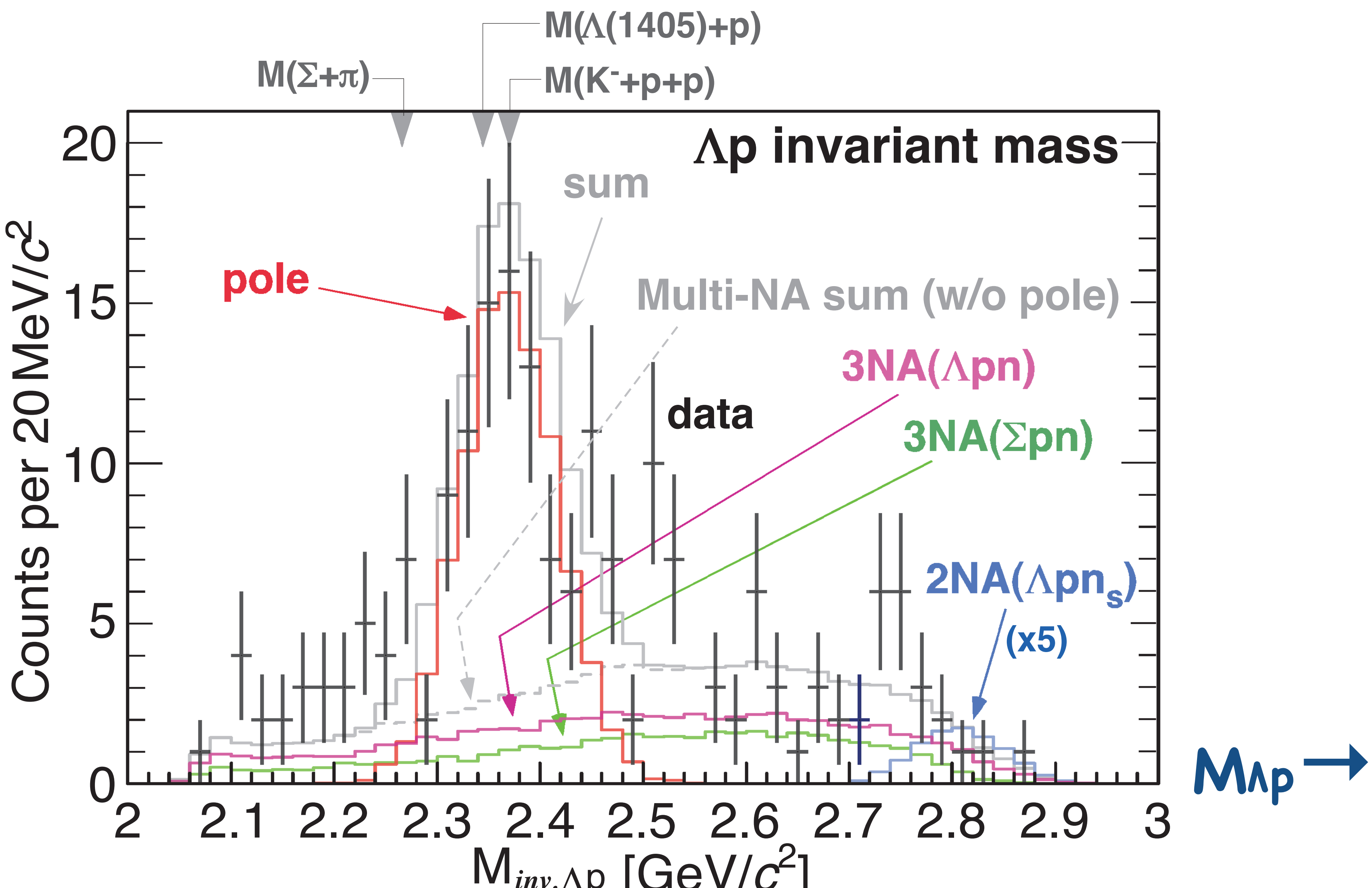
~ 30 times more data for Λpn final state



E15^{1st} and E15^{2nd} spectra consistent?

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

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



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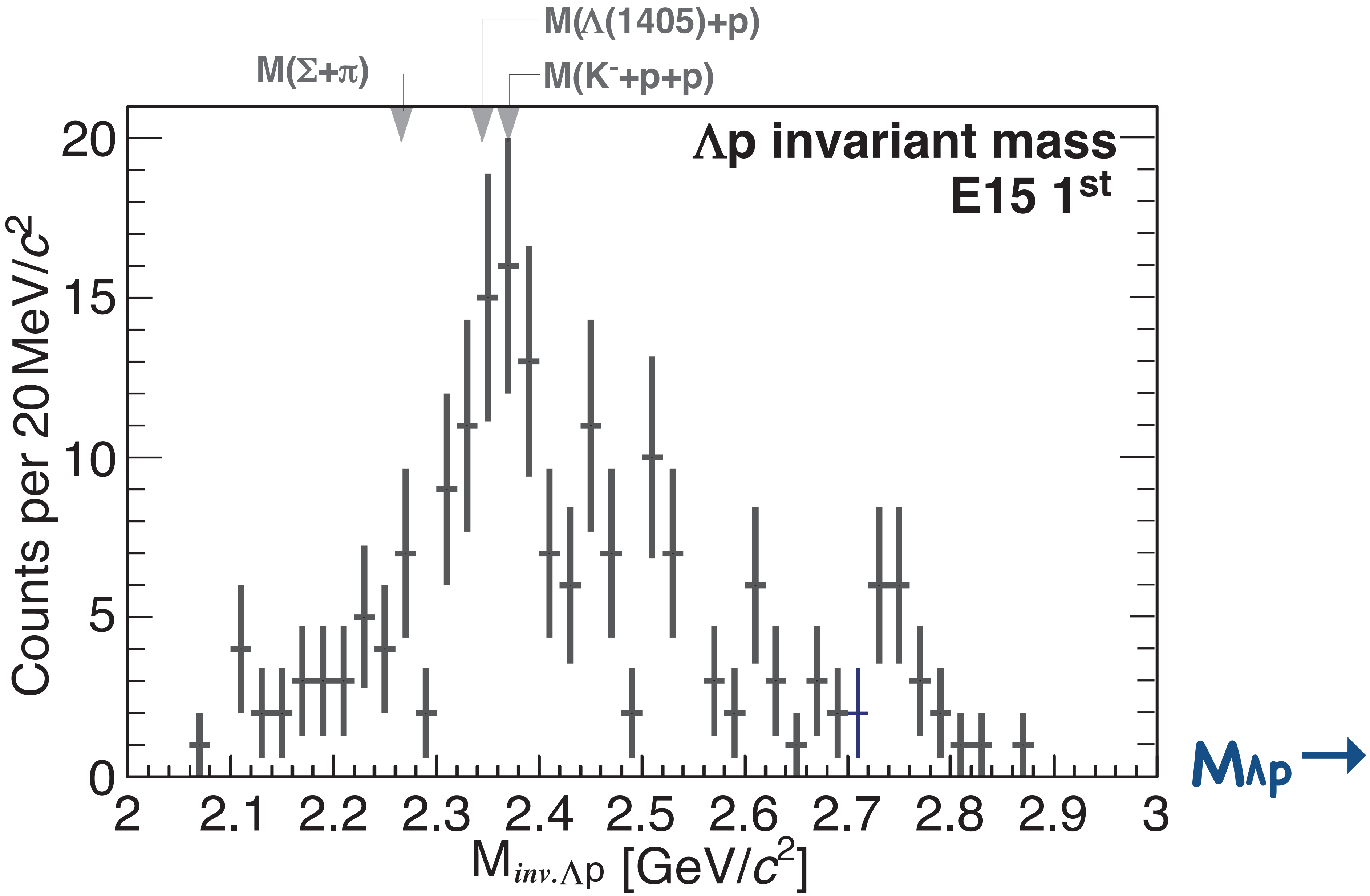
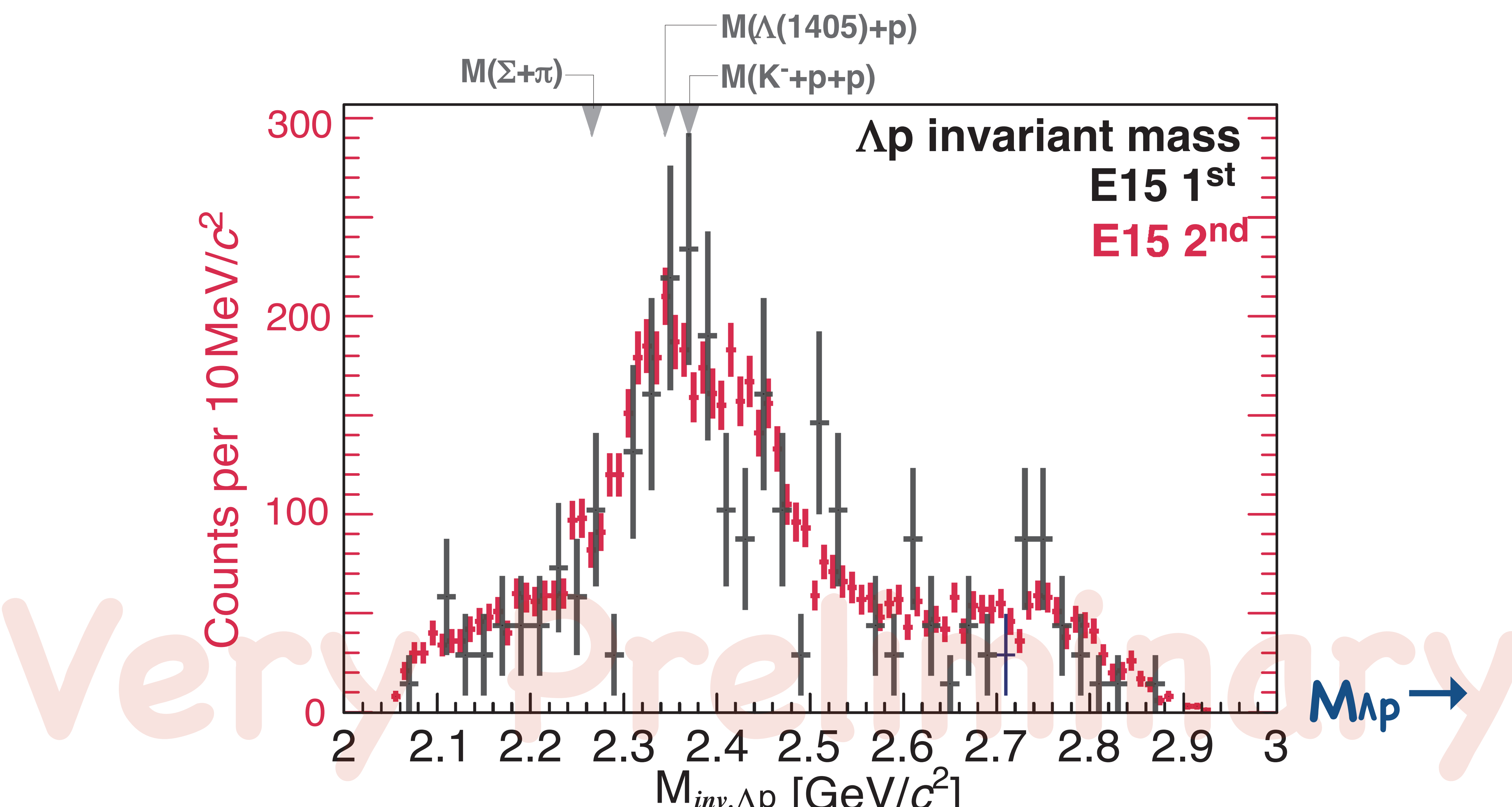


E15^{1st} and E15^{2nd} spectra consistent?

YES! They are consistent!

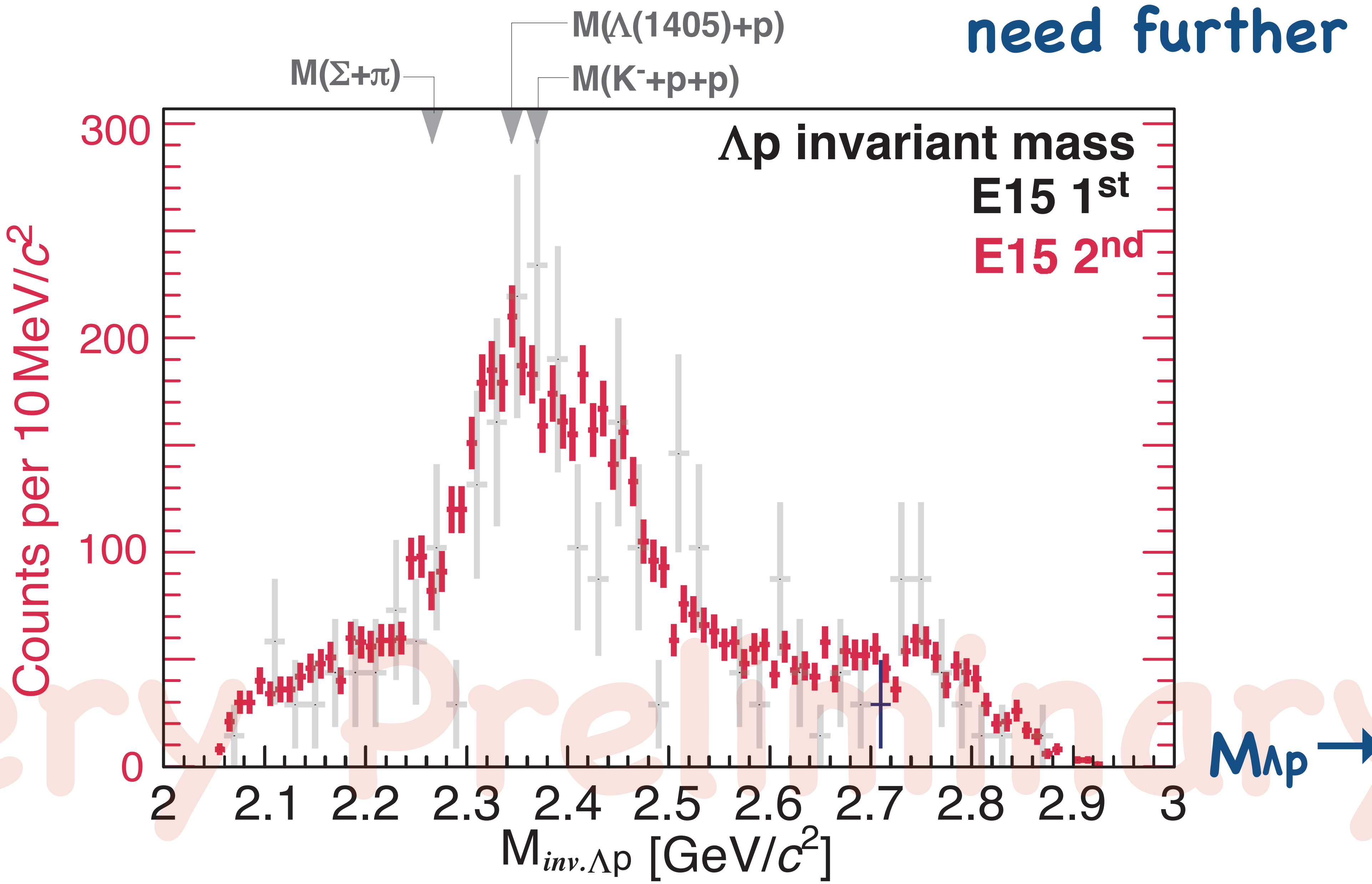


E15^{1st} and E15^{2nd} spectra consistent?

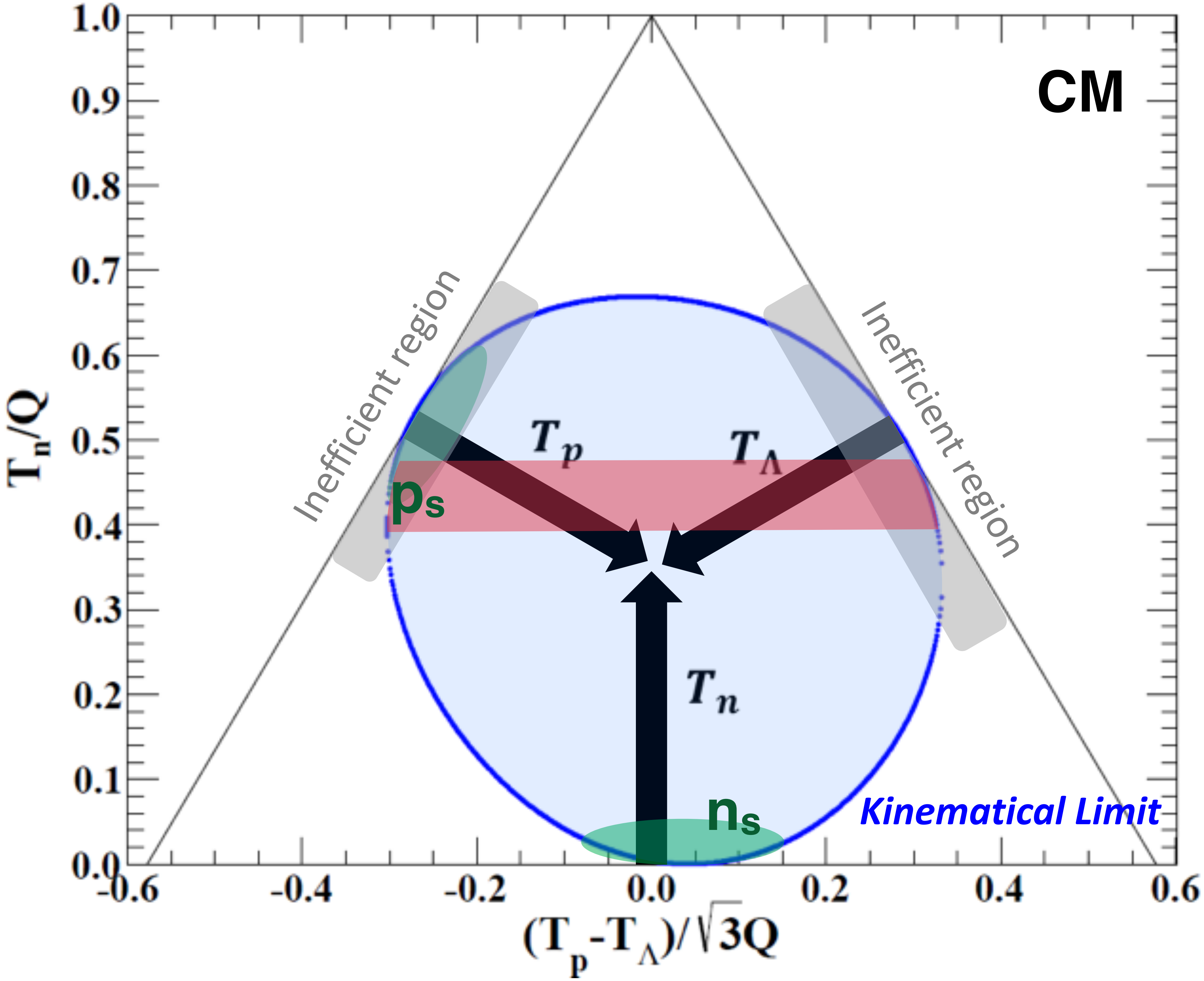
YES! They are consistent!

E15^{2nd} spectrum does not allow single pole assumption

looks like trapezoidal??
need further study



Dalitz Plot of Λpn



kinematical limit

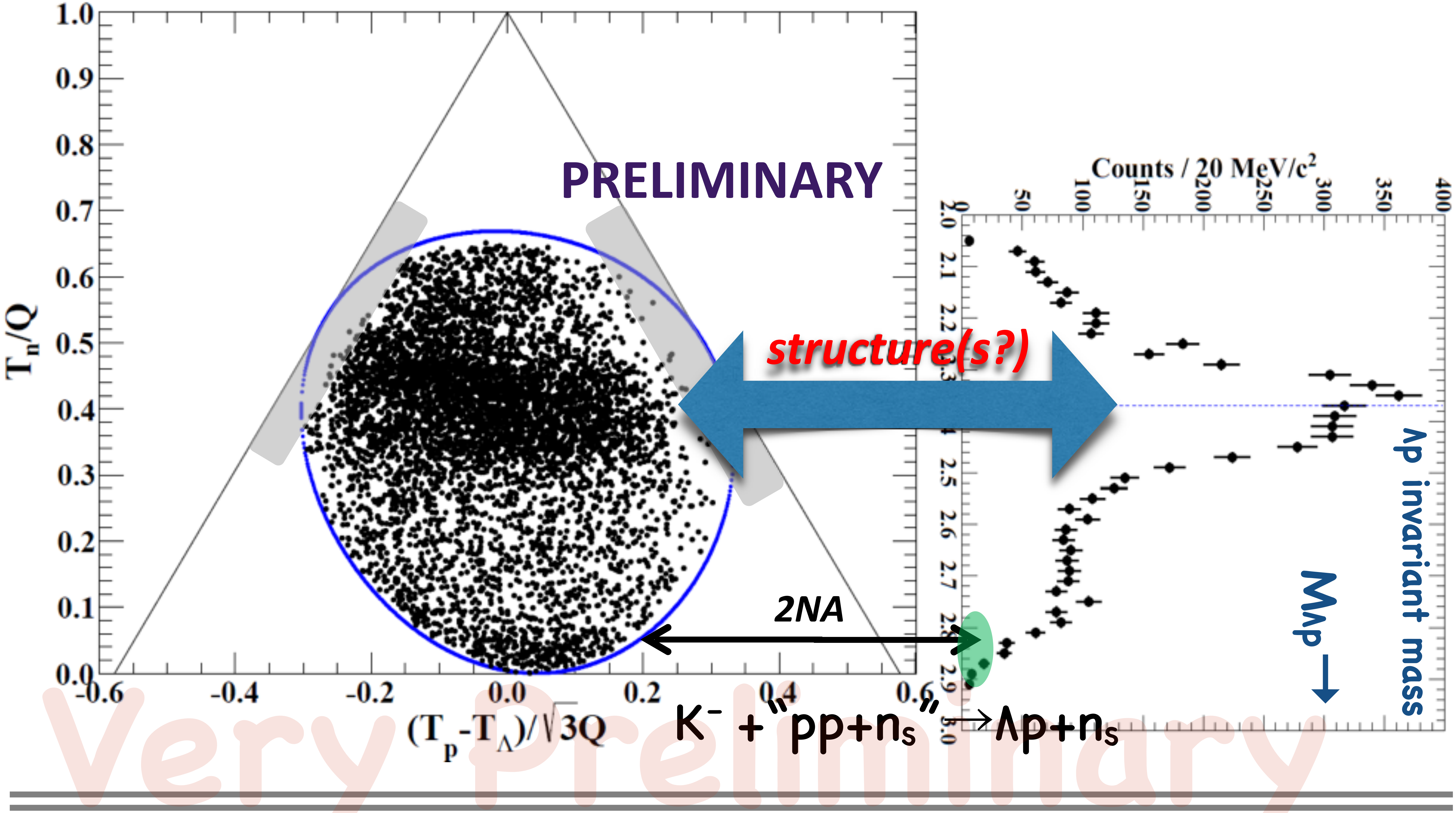
K^-pp formation

flat for point-like 3NA

Is ^3He point-like?

2NA process
with spectator
n_s / p_s

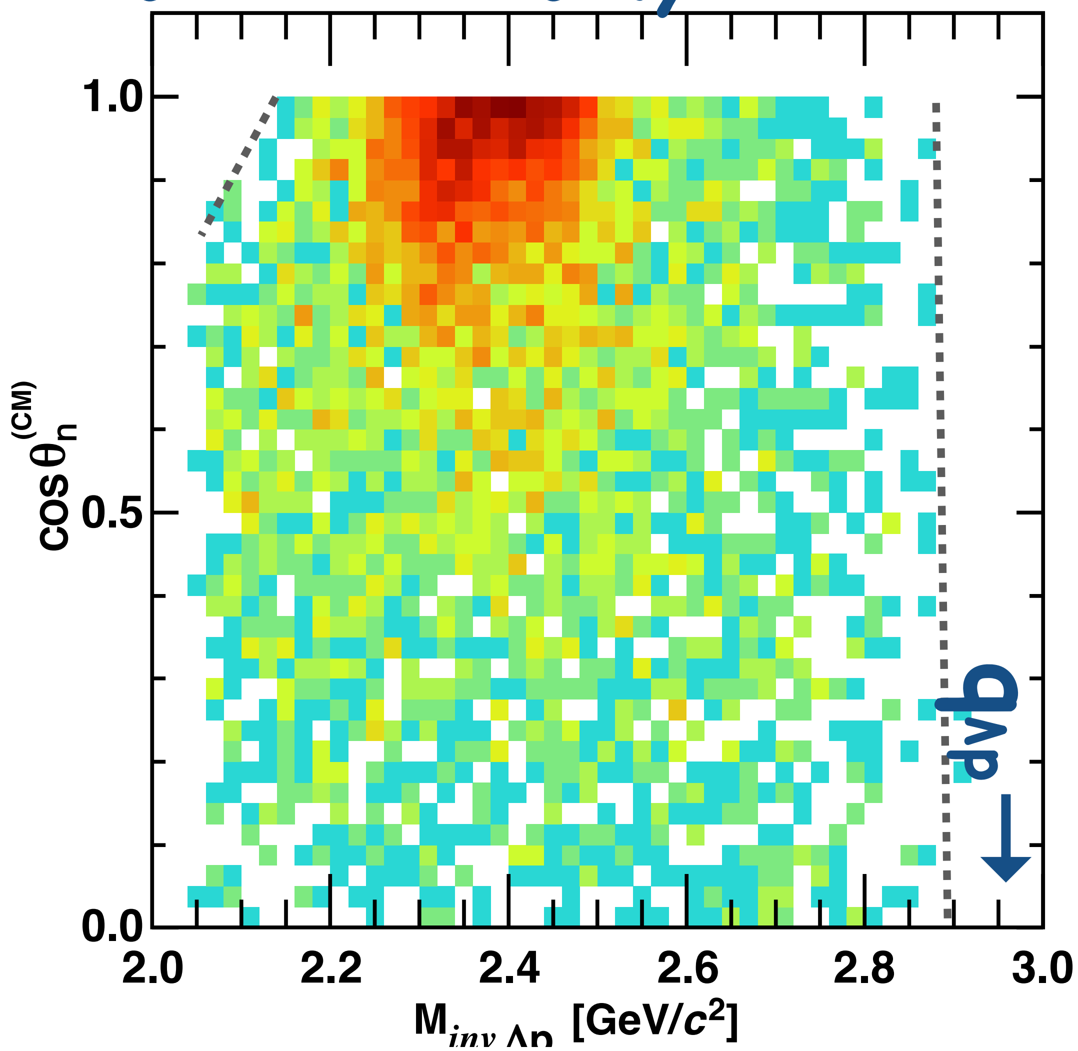
Dalitz Plot of Λpn



$^{3}He(K^{-}, \Lambda p)n$:
Angular Dependence of n in CM

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

forward n only



Very Preliminary

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

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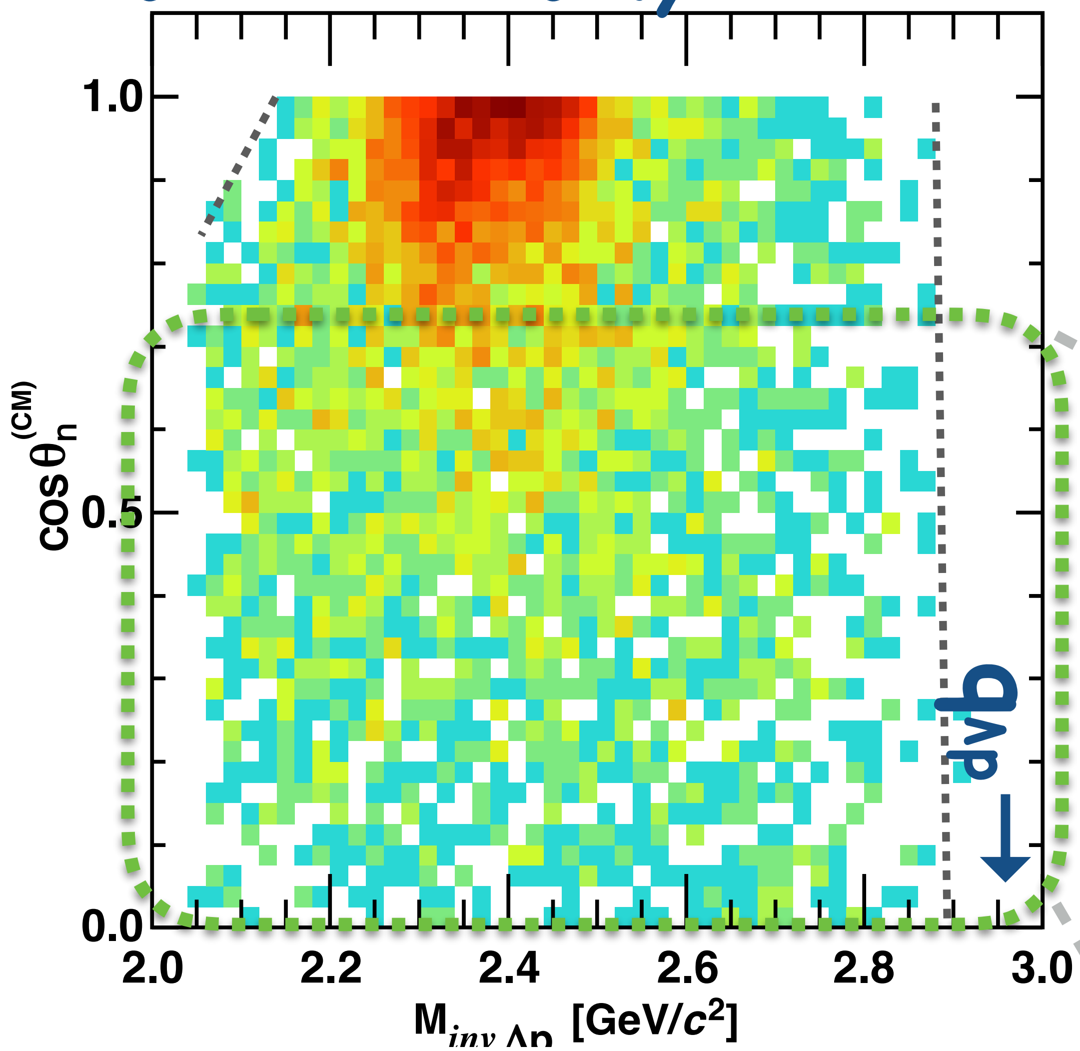
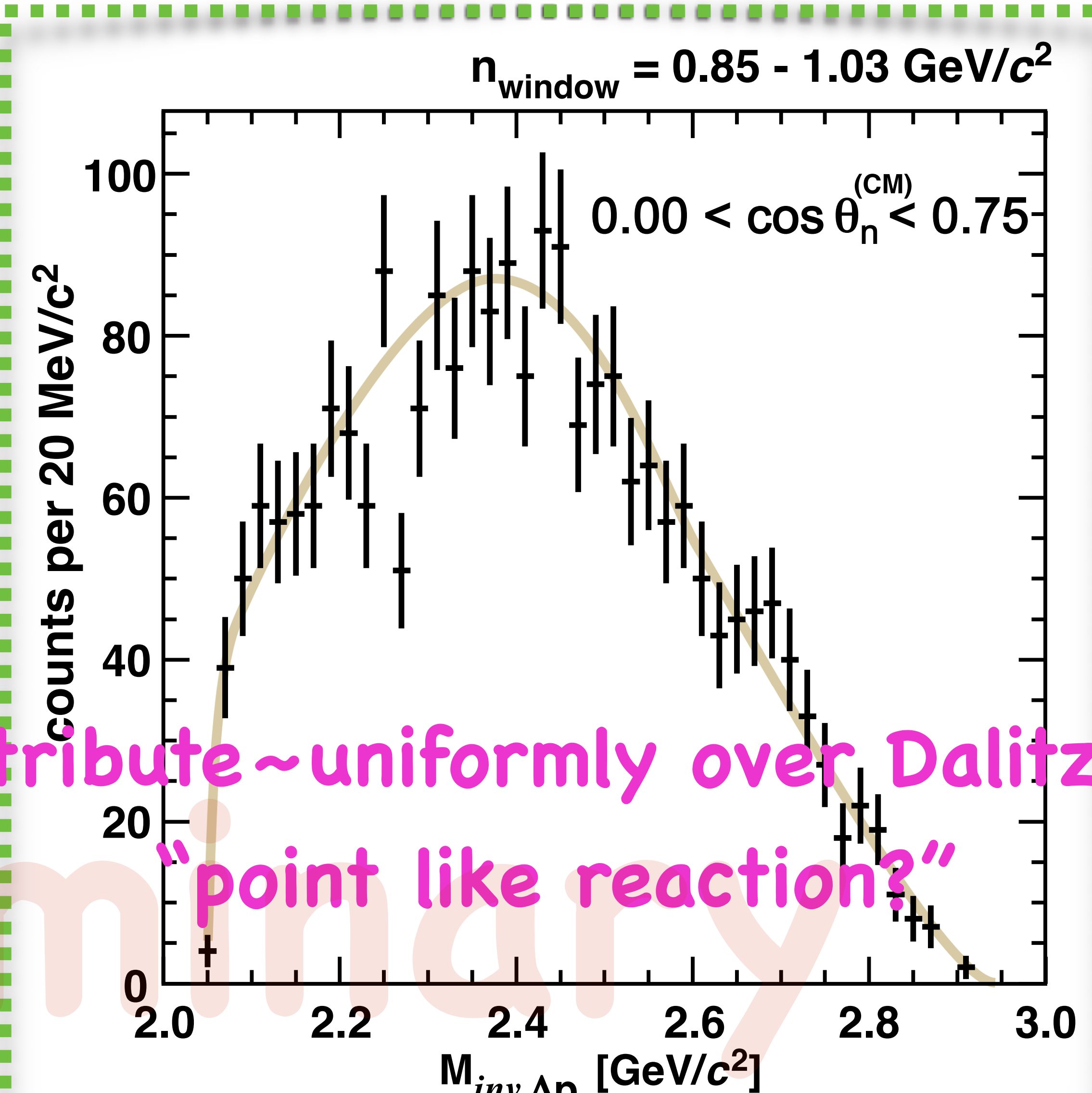


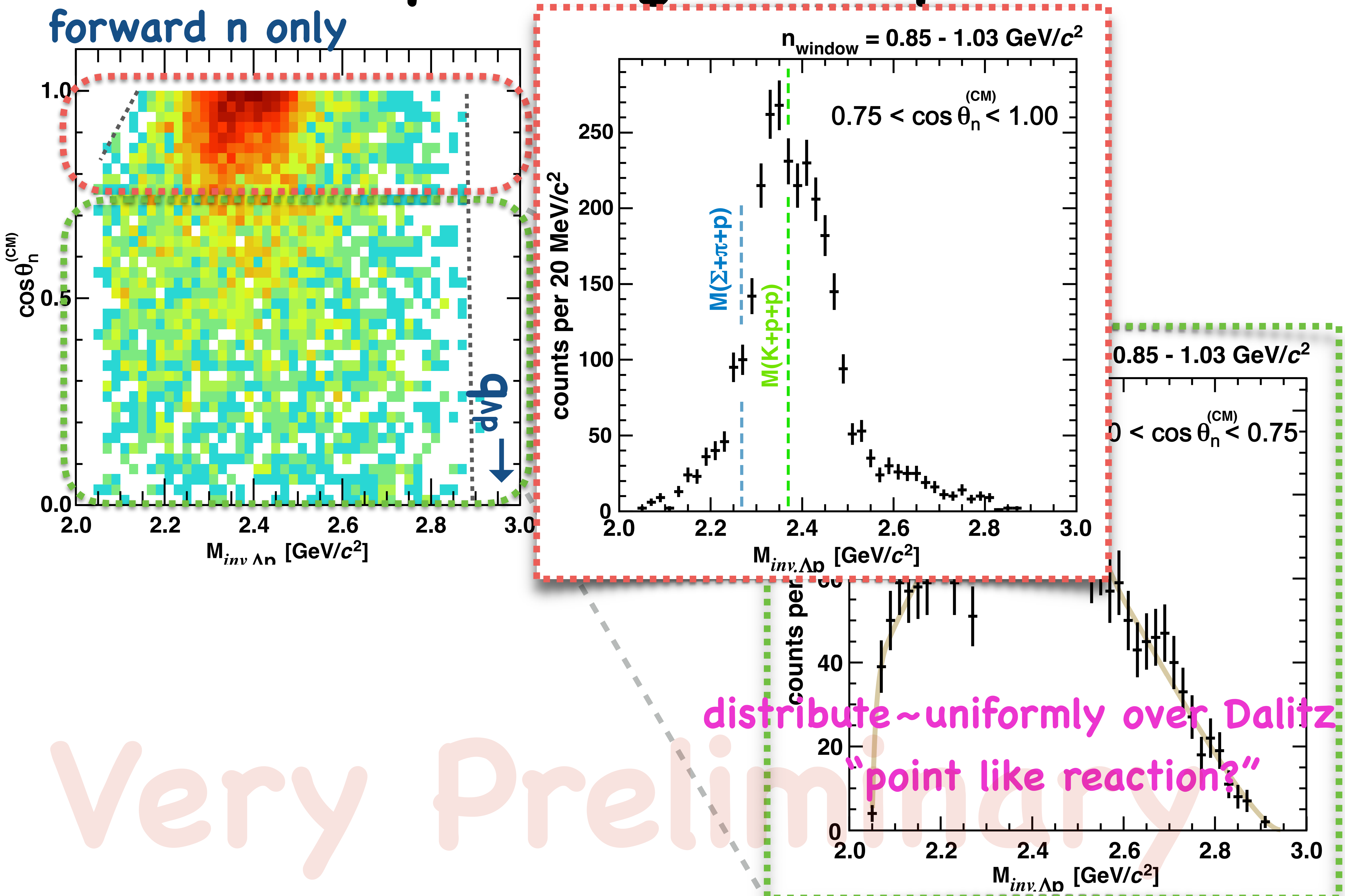


distribute~uniformly over Dalitz

"point like reaction?"

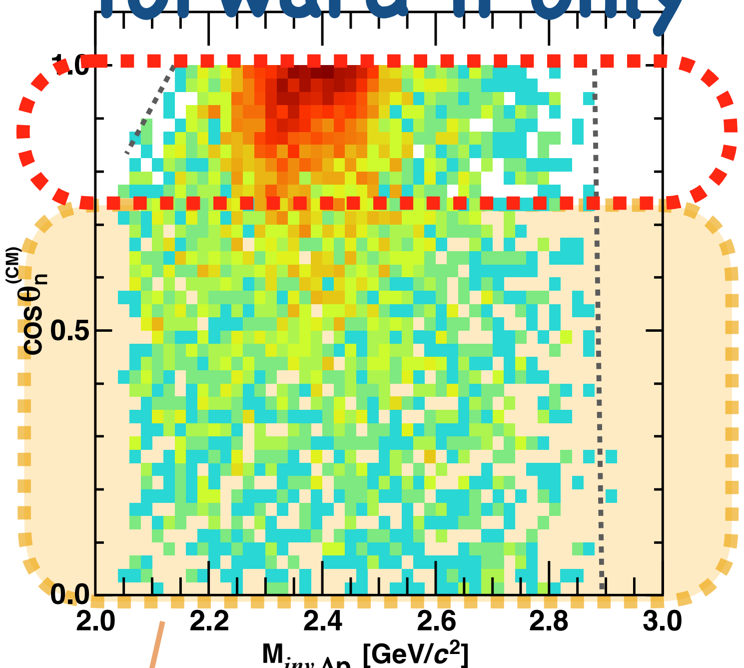
Very Preliminary

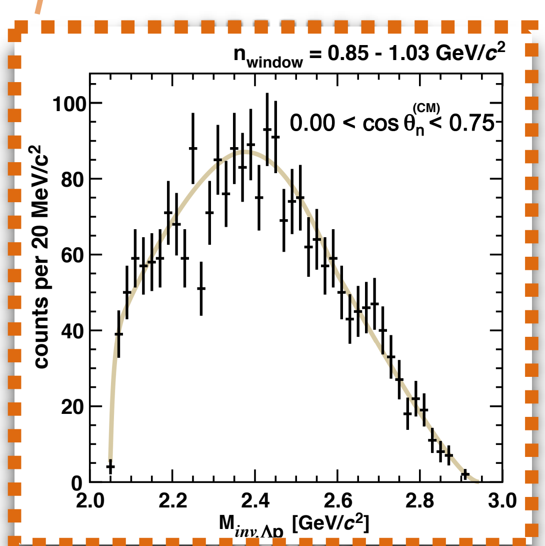
$^3He(K^-, \Lambda p)n$: Angular Dependence

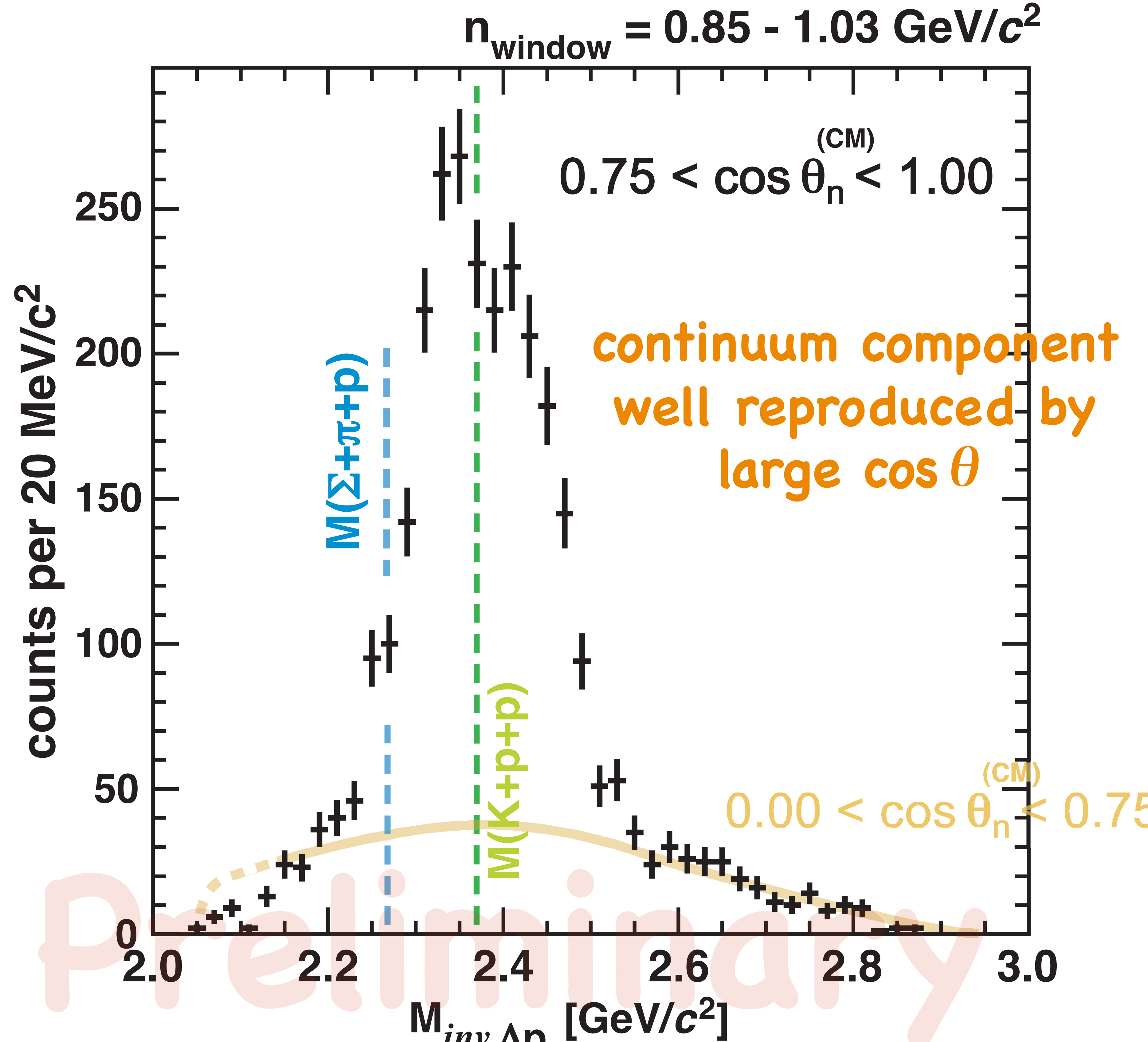


^{3}He(K$^-$, Λp)n: Angular Dependence

forward n only



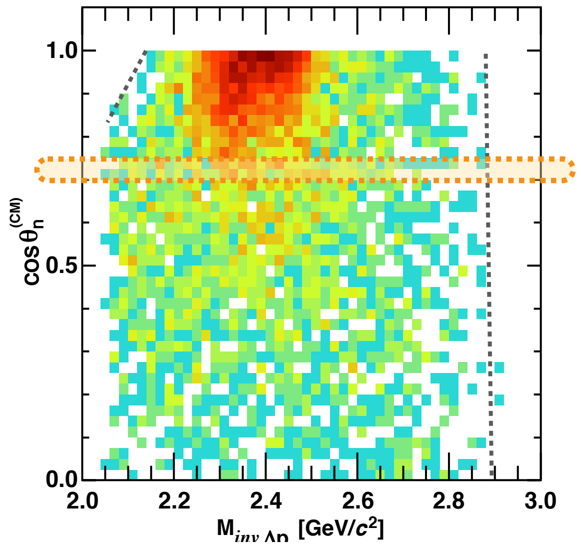


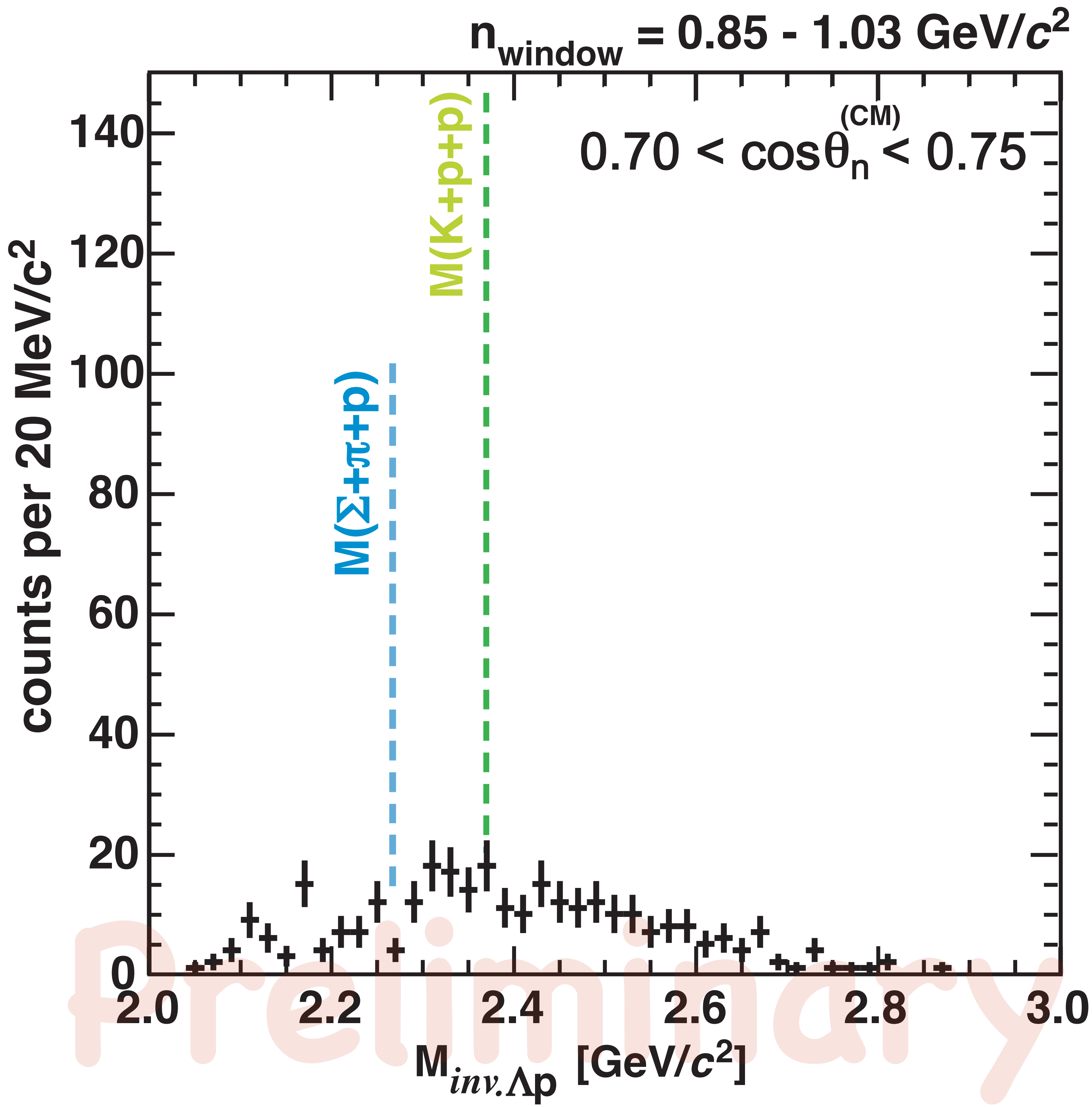


$^{3}He(K^{-}, \Lambda p)n$:
Angular Dependence of n in CM

in more detail
as a clue to understand

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





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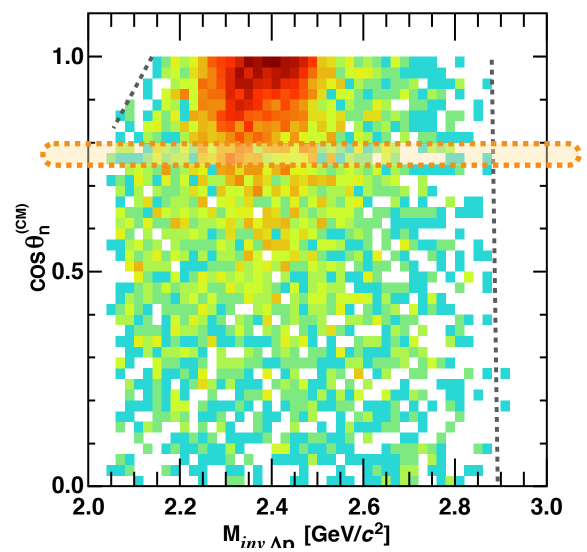

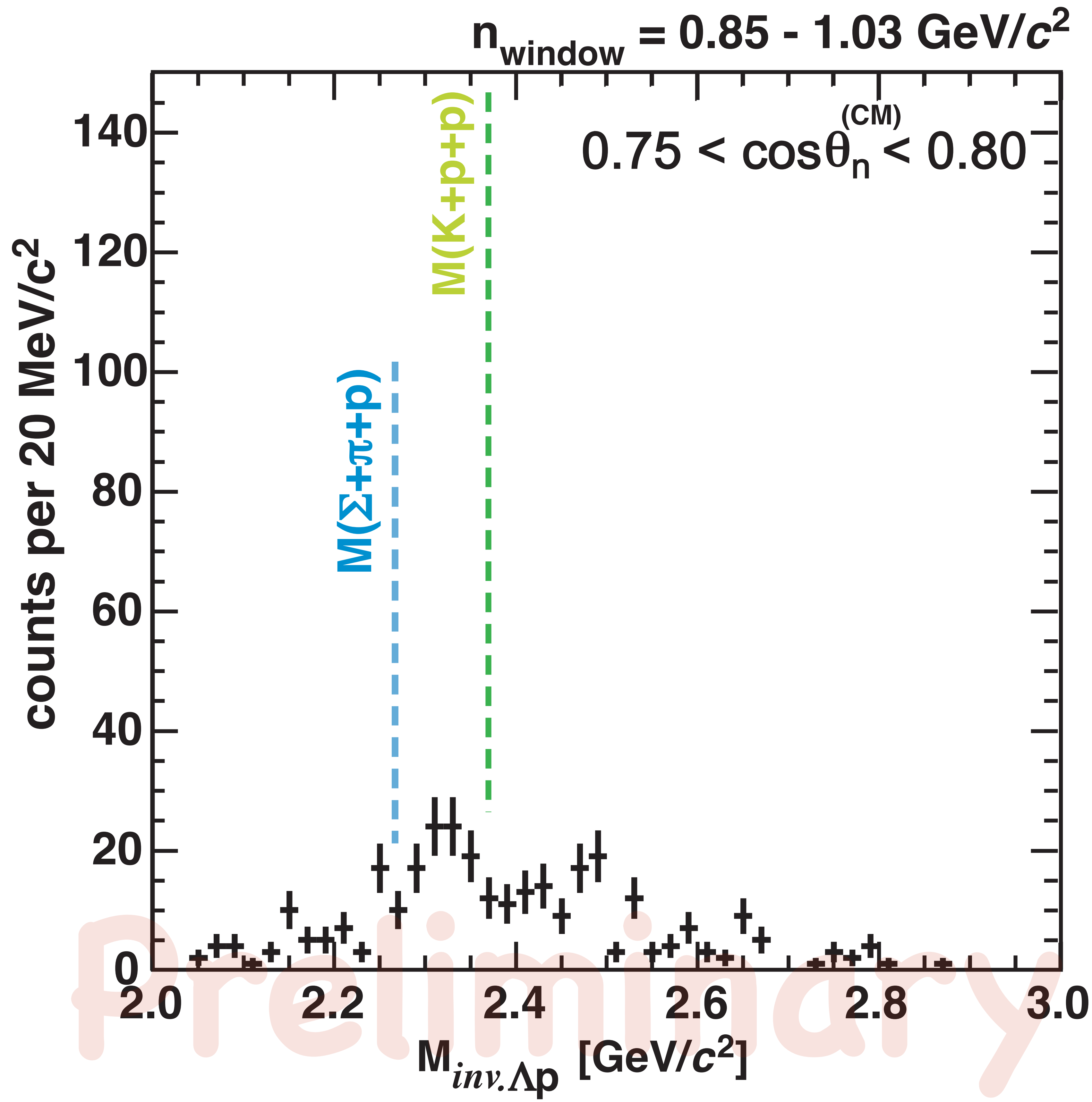

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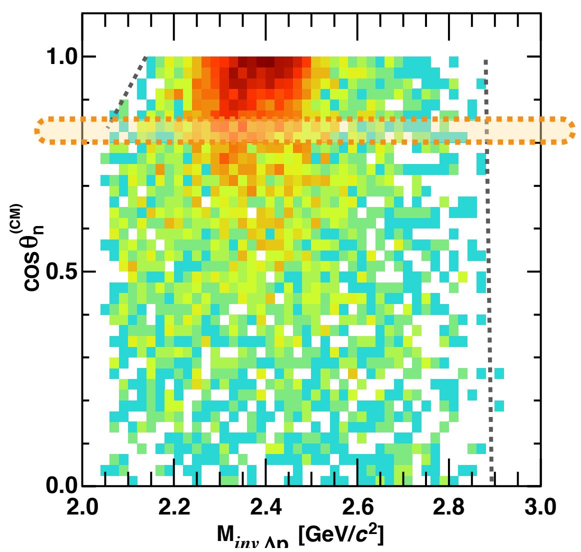
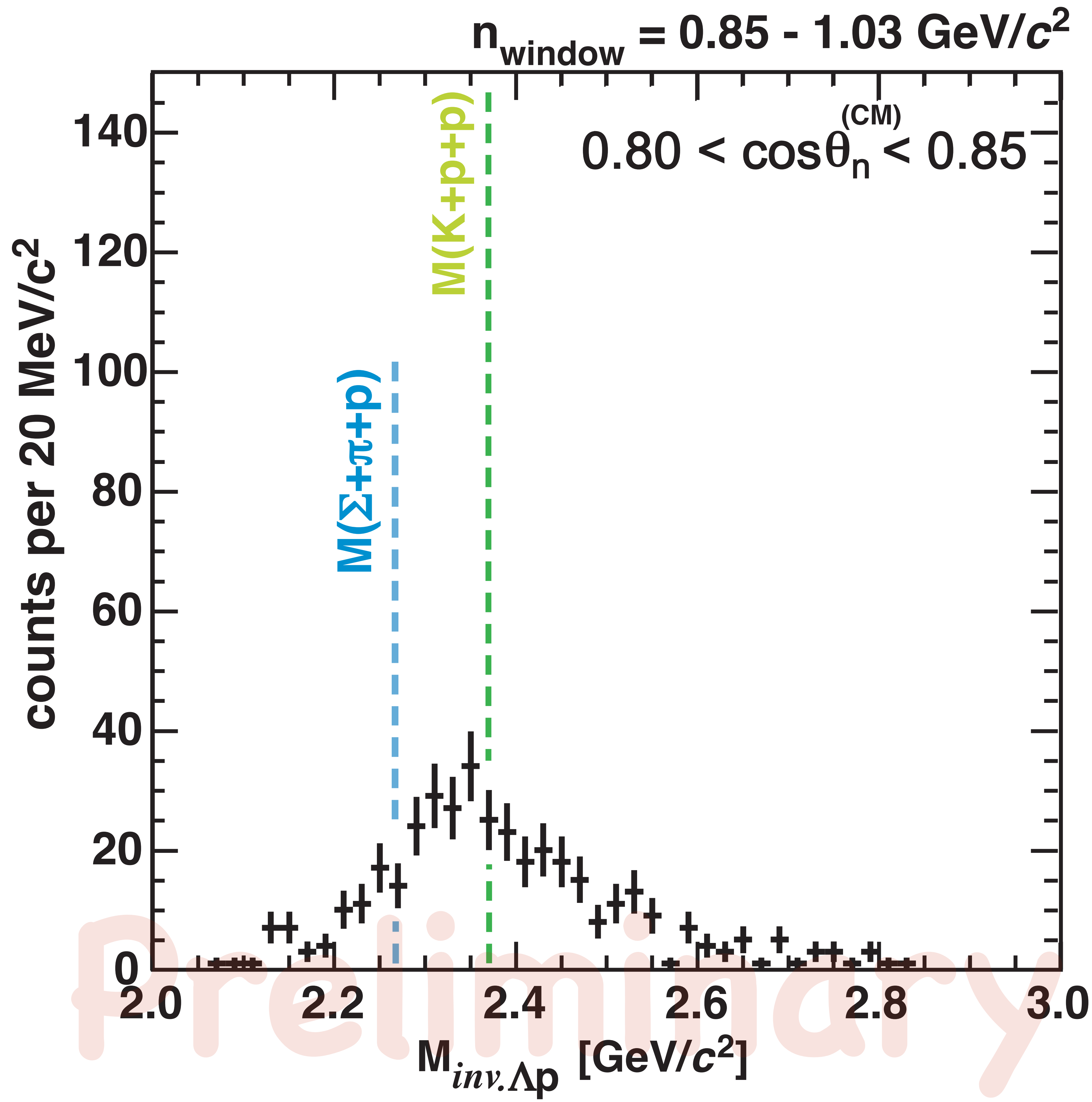
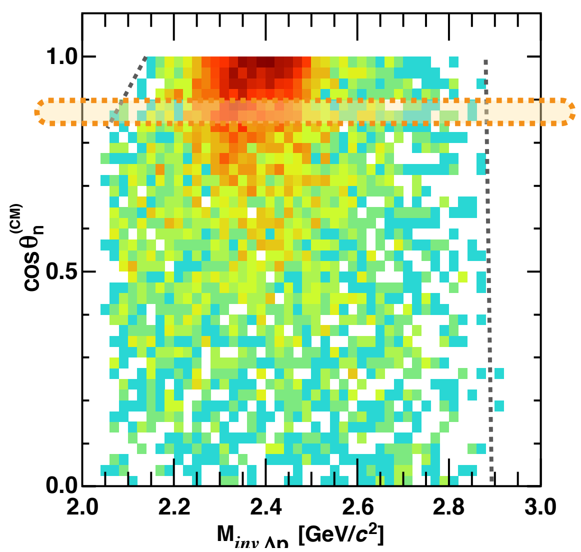
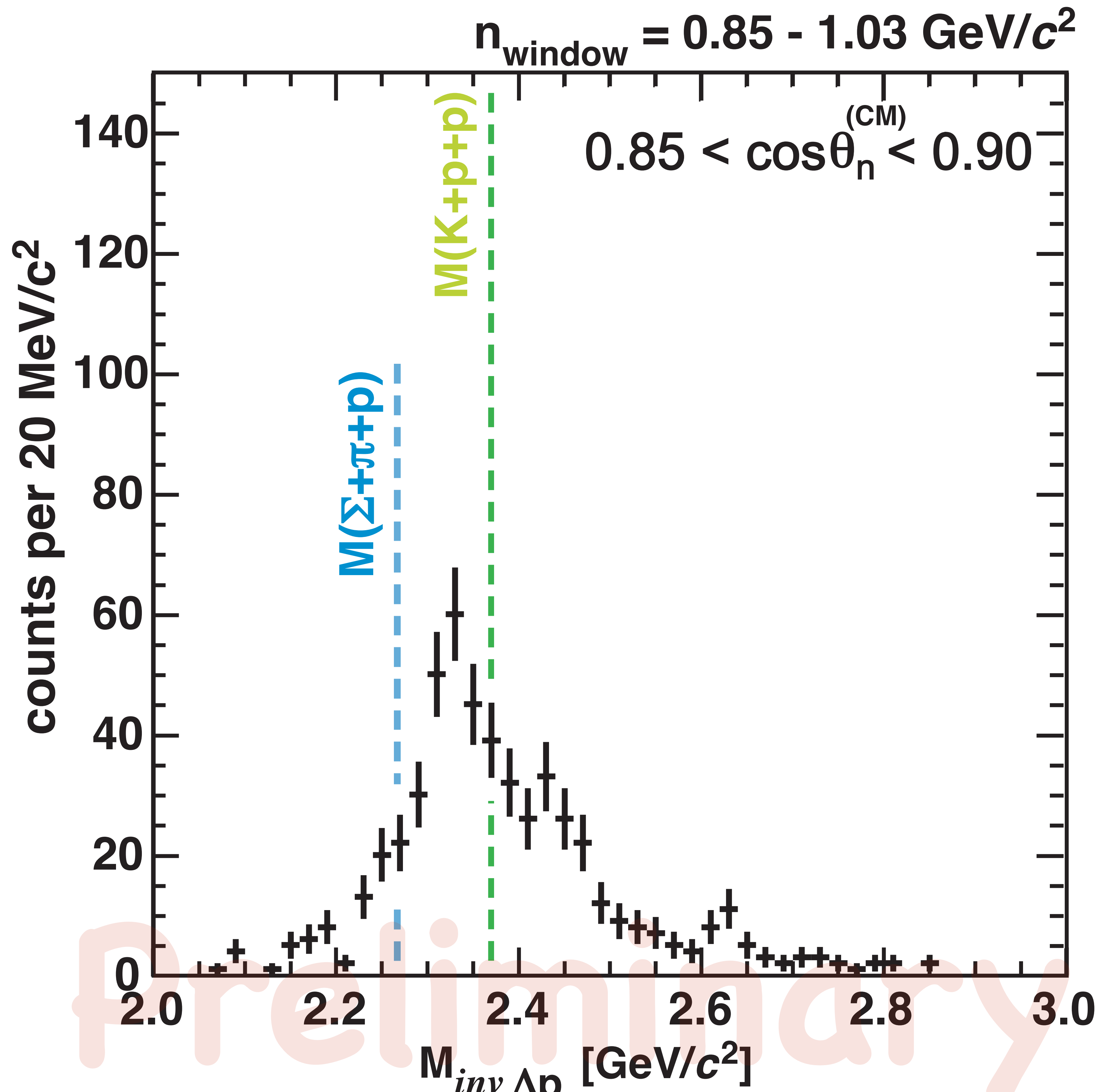




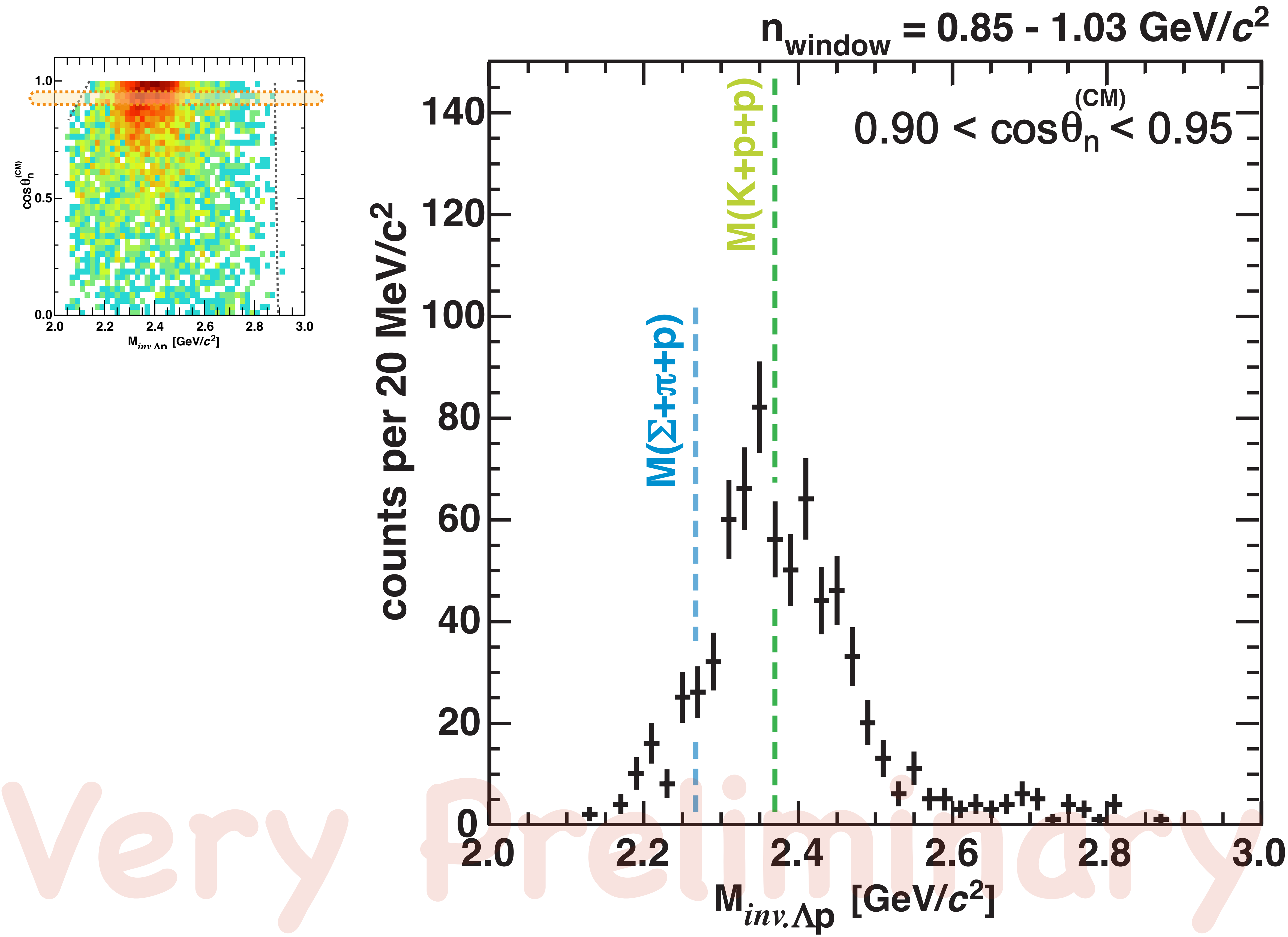
Very Preliminary

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

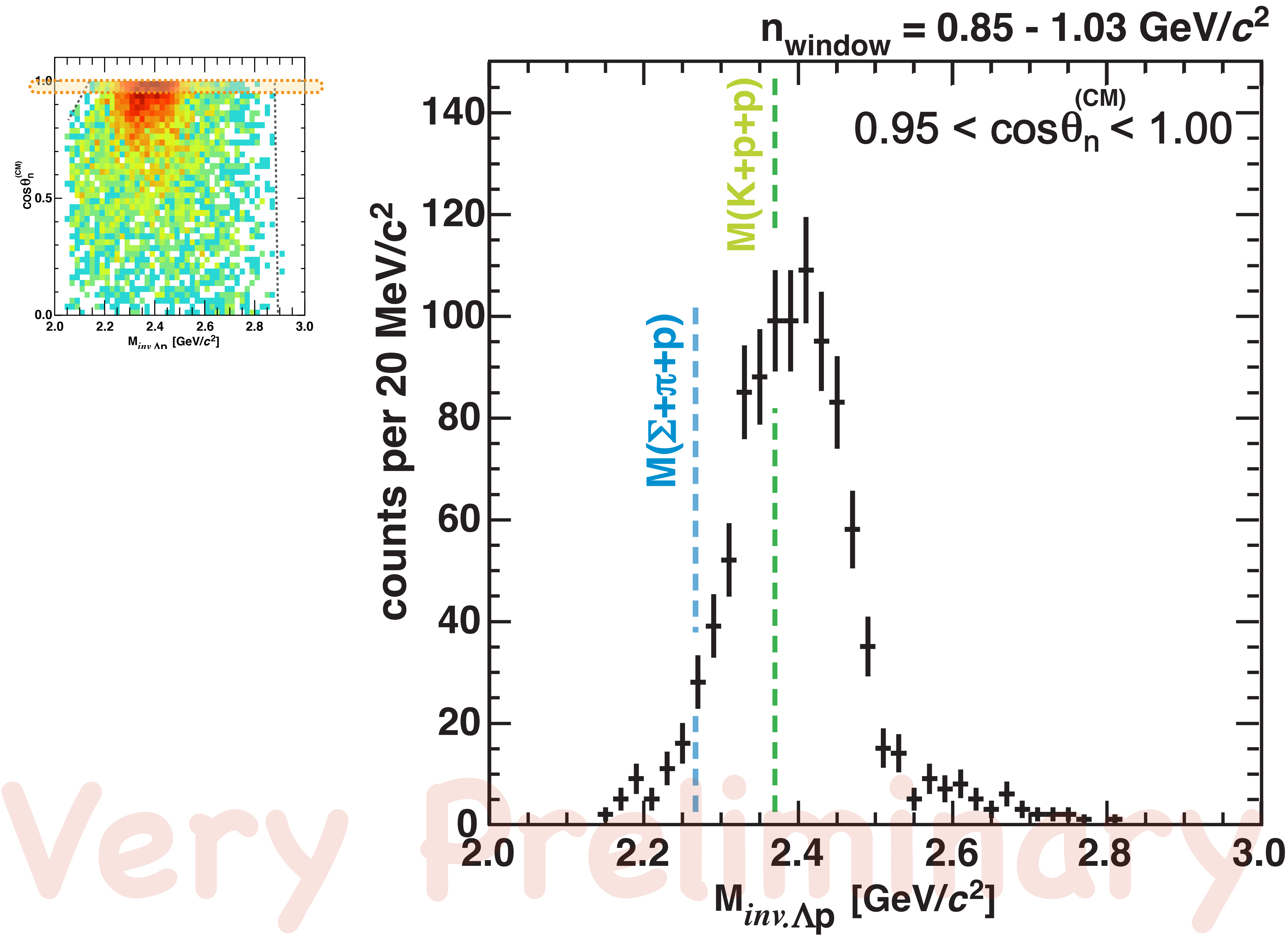




$^3He(K^-, \Lambda p)n$: Angular Dependence



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



$^3He(K^-, \Lambda p)n$: Angular Dependence of n in CM

two components exist?

if that is the case,

bound region : forward peaking	unbound region : very forward peaking
S-wave would be OK	bit strongly depend to cosθ
weakly depend to cosθ	lower Q preferred

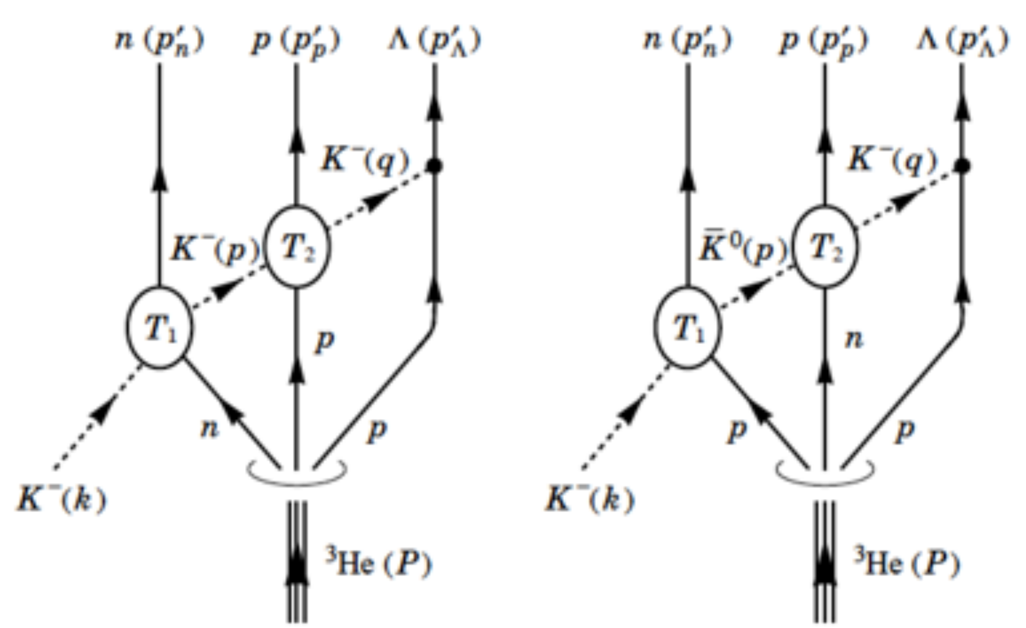
typical momentum transfer $Q_K \sim 400 MeV/c$

^{3}He(K$^-$, Λp)n:

Not like semi-inclusive spectrum,
"quasi-free K" excluded by the final state: Λpn,
but still need to ask ...

Structure can be explained with quasi-elastic K scattering?

through uncorrelated Λ(1405)p channel



Sekihara Oset Ramos

PTEP

Prog. Theor. Exp. Phys. **2013**, 00000 (27 pages)
DOI: 10.1093/ptep/0000000000

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

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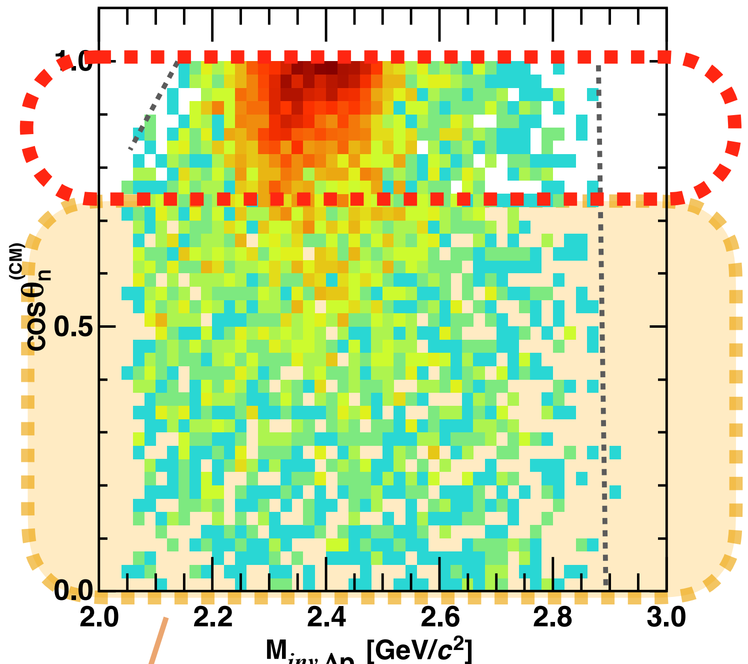
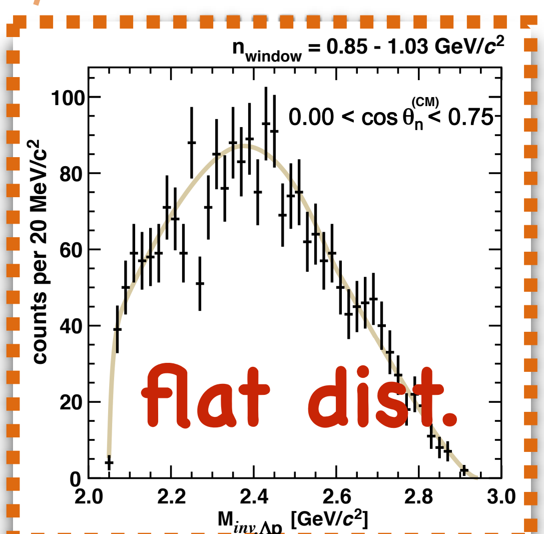
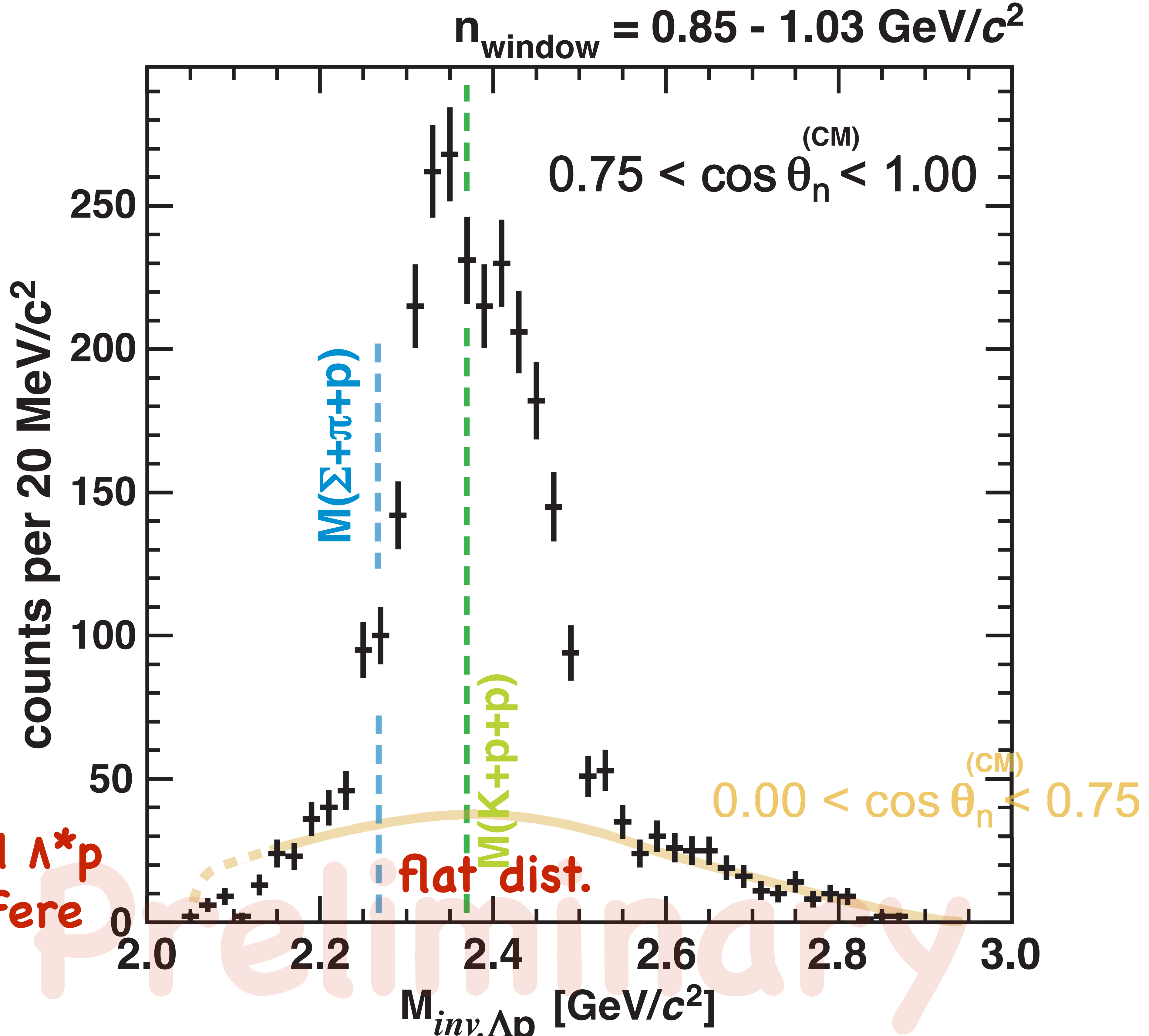
[2]*Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Aptdo. 22085, 46071 Valencia, Spain*
[3]*Departament de Física Quàntica i Astrofísica and Institut de Ciències del Cosmos, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain*
*E-mail: sekihara@post.j-parc.jp

^{3}He(K$^-$, Λp)n:

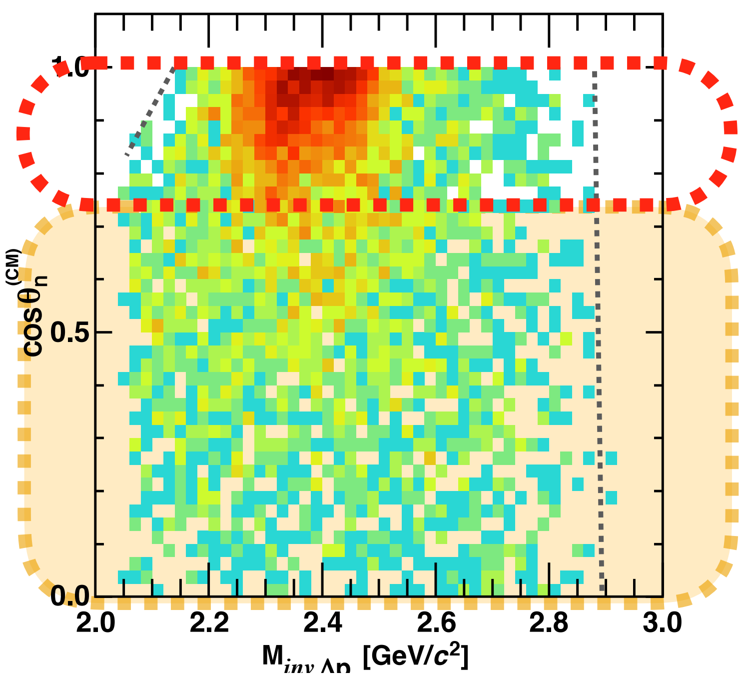




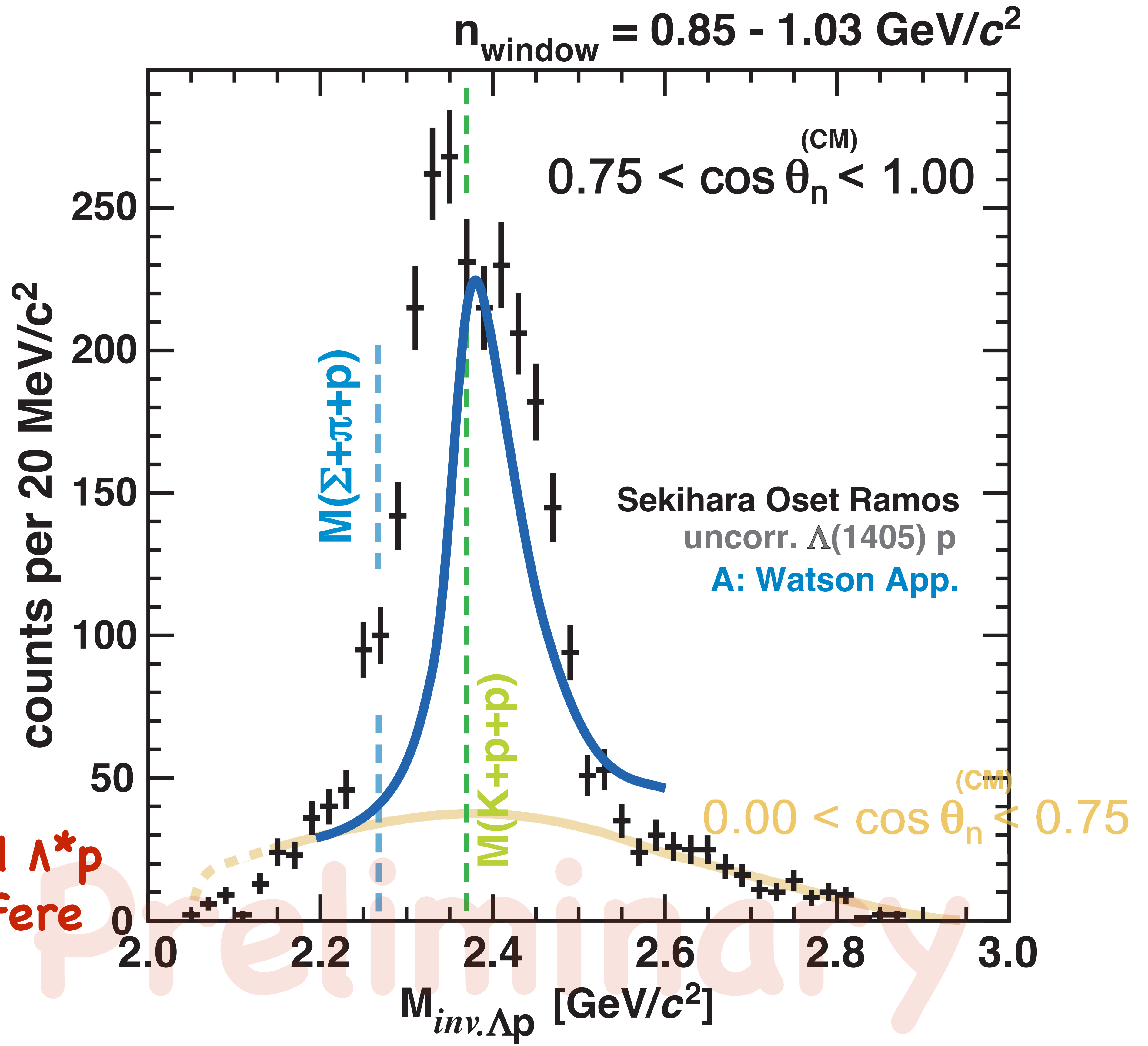
assuming uncorrelated Λ*p channel do not interfere with flat dist.



$^3He(K^-, \Lambda p)n$: Quasi-elastic?



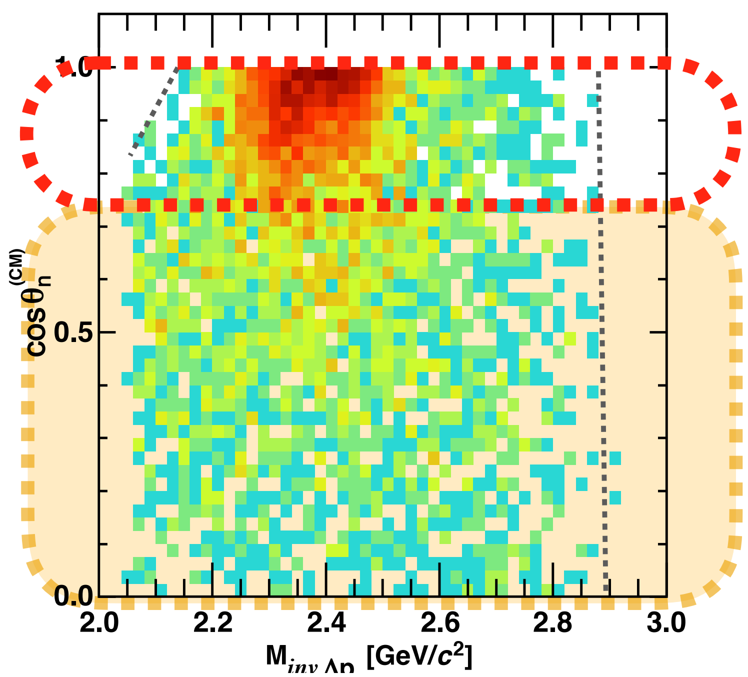
simple QE?



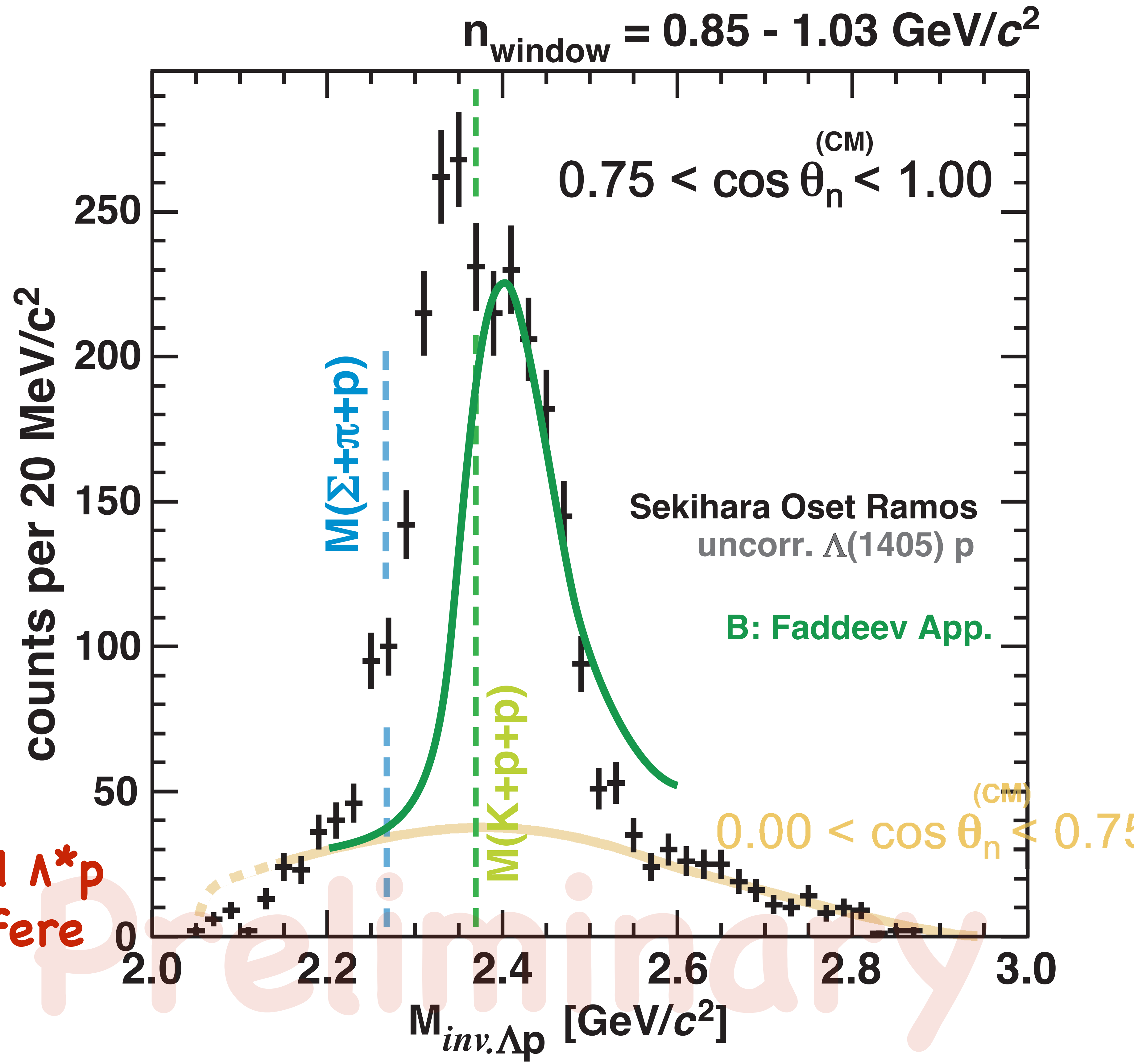
assuming uncorrelated Λ*p channel do not interfere with flat dist.

Very Preliminary

^{3}He(K$^-$, Λp)n: Quasi-elastic?



simple QE?



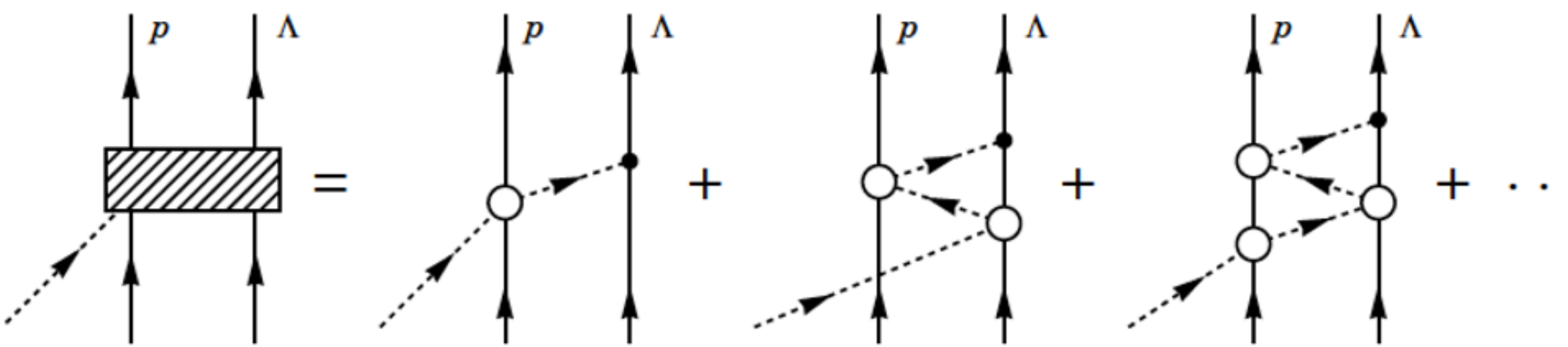
assuming uncorrelated Λ*p channel do not interfere with flat dist.

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

Structure can be explained with "quasi-elastic K scattering" ? ➡ NO!

Need deeper strength!

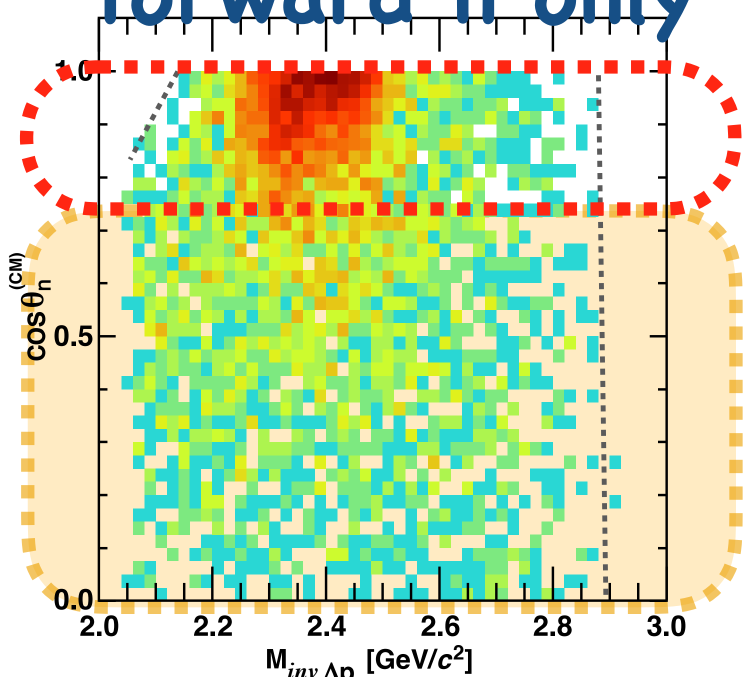
Sekihara Oset Ramos



K multiple scattering = "Kpp"

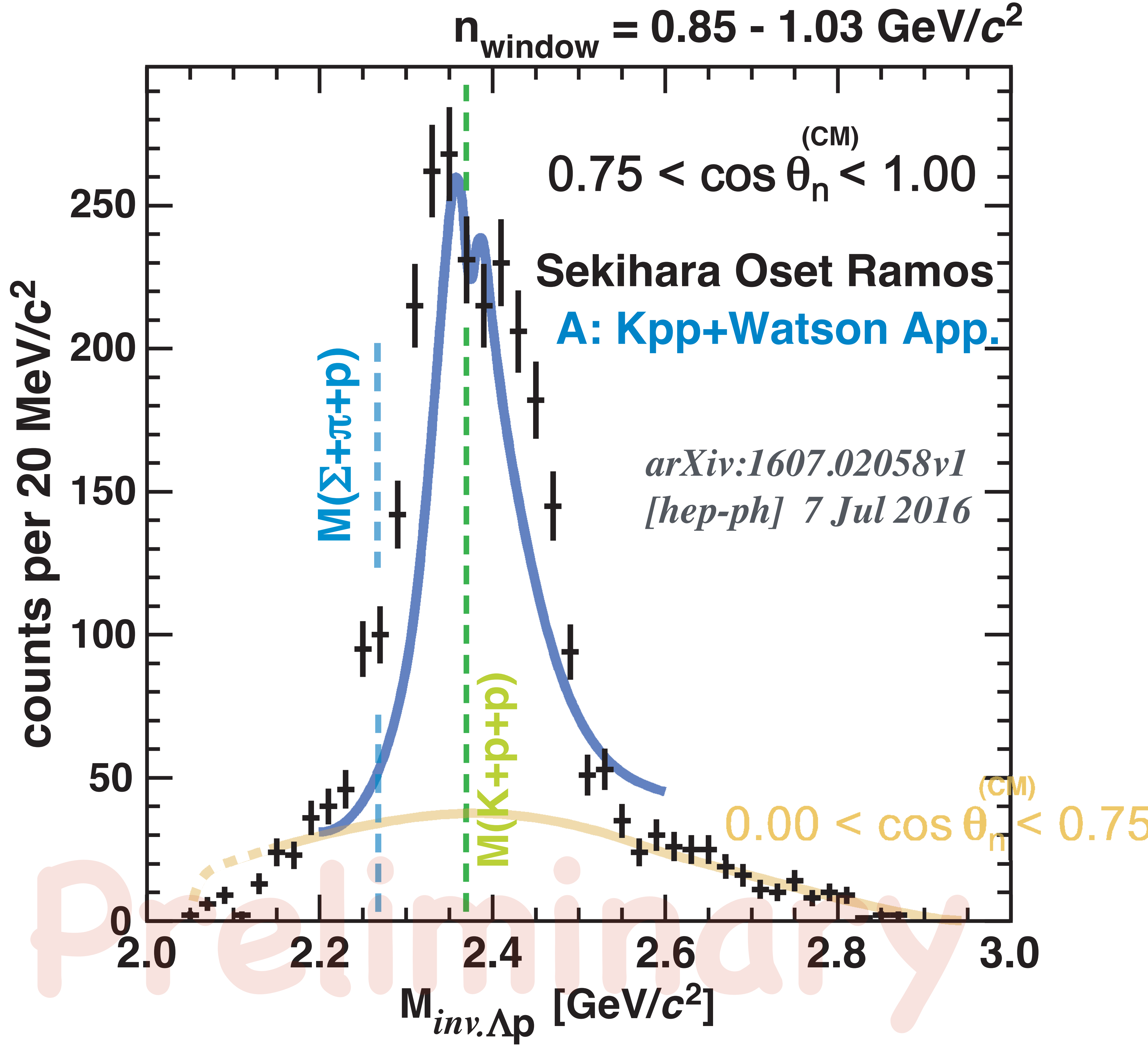
$^3He(K^-, \Lambda p)n$: comparison with SOR

forward n only



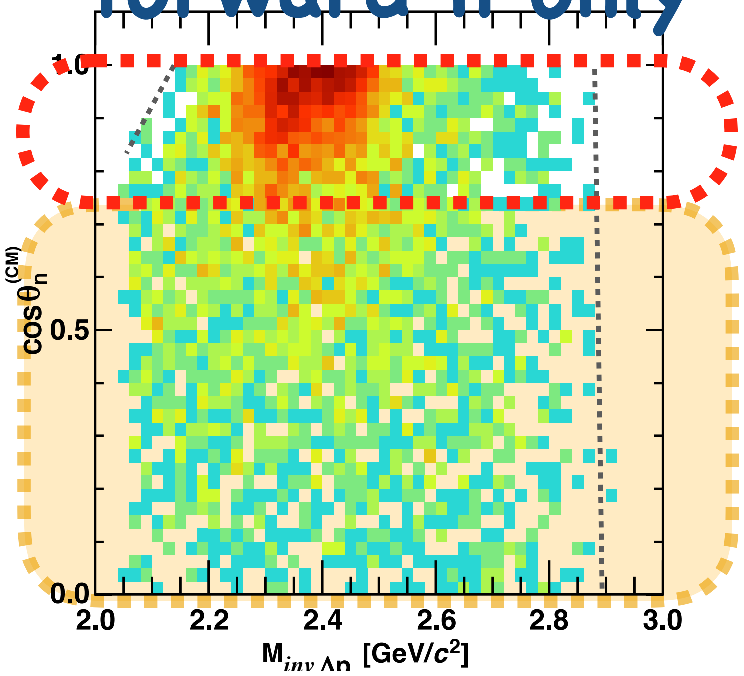
QE + "Kpp"

K multiple scattering



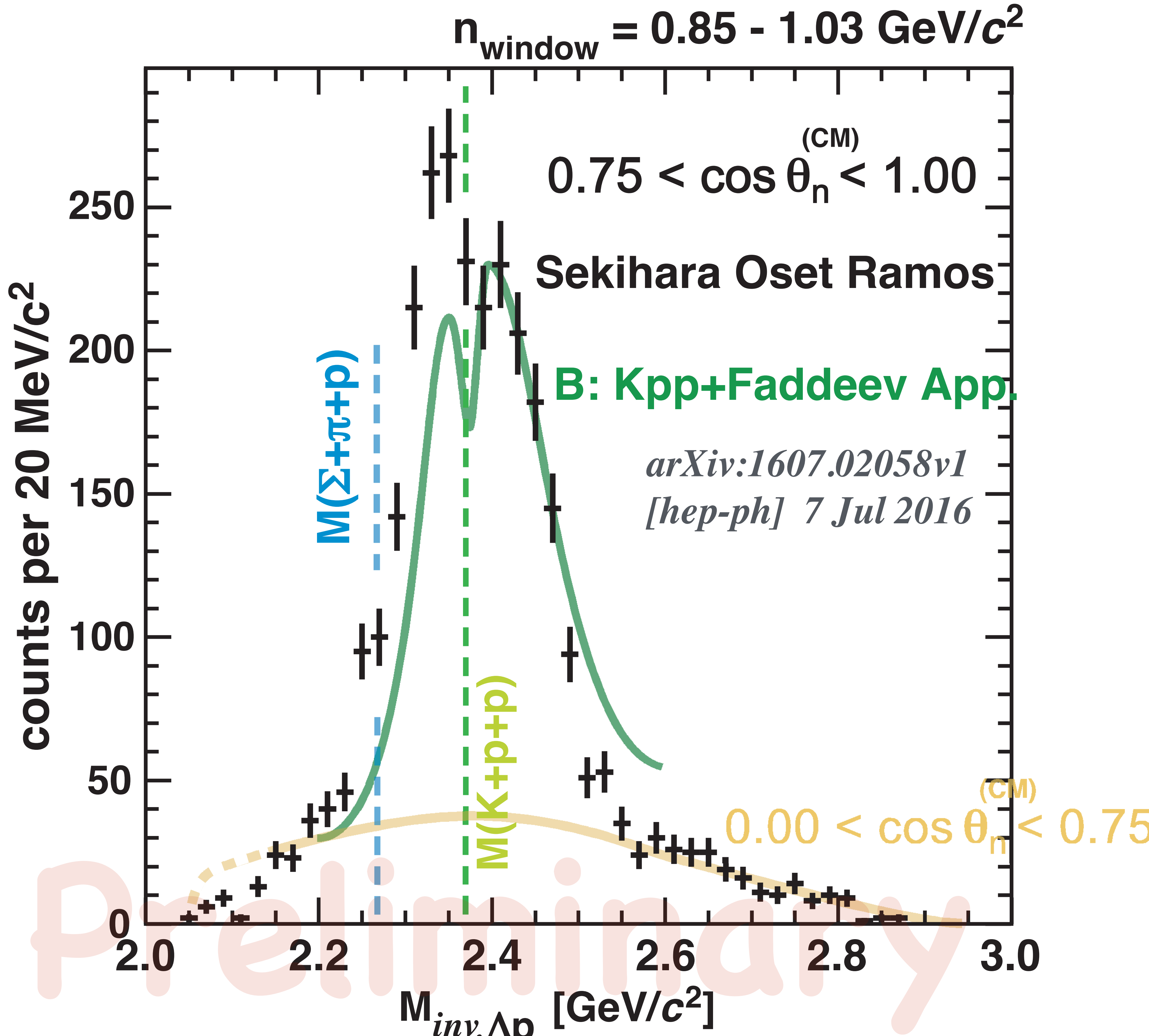
$^3He(K^-, \Lambda p)n$: comparison with SOR

forward n only



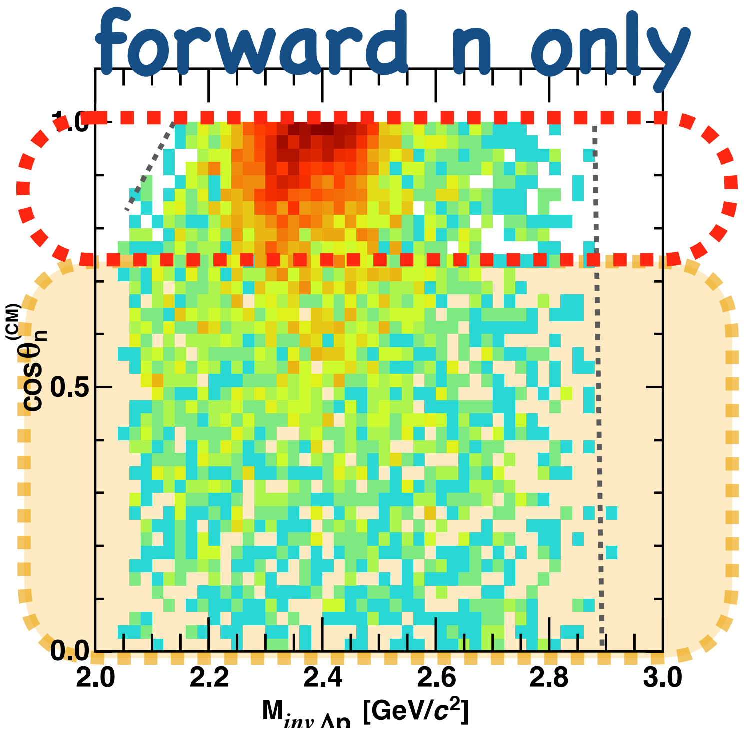
QE + "Kpp"

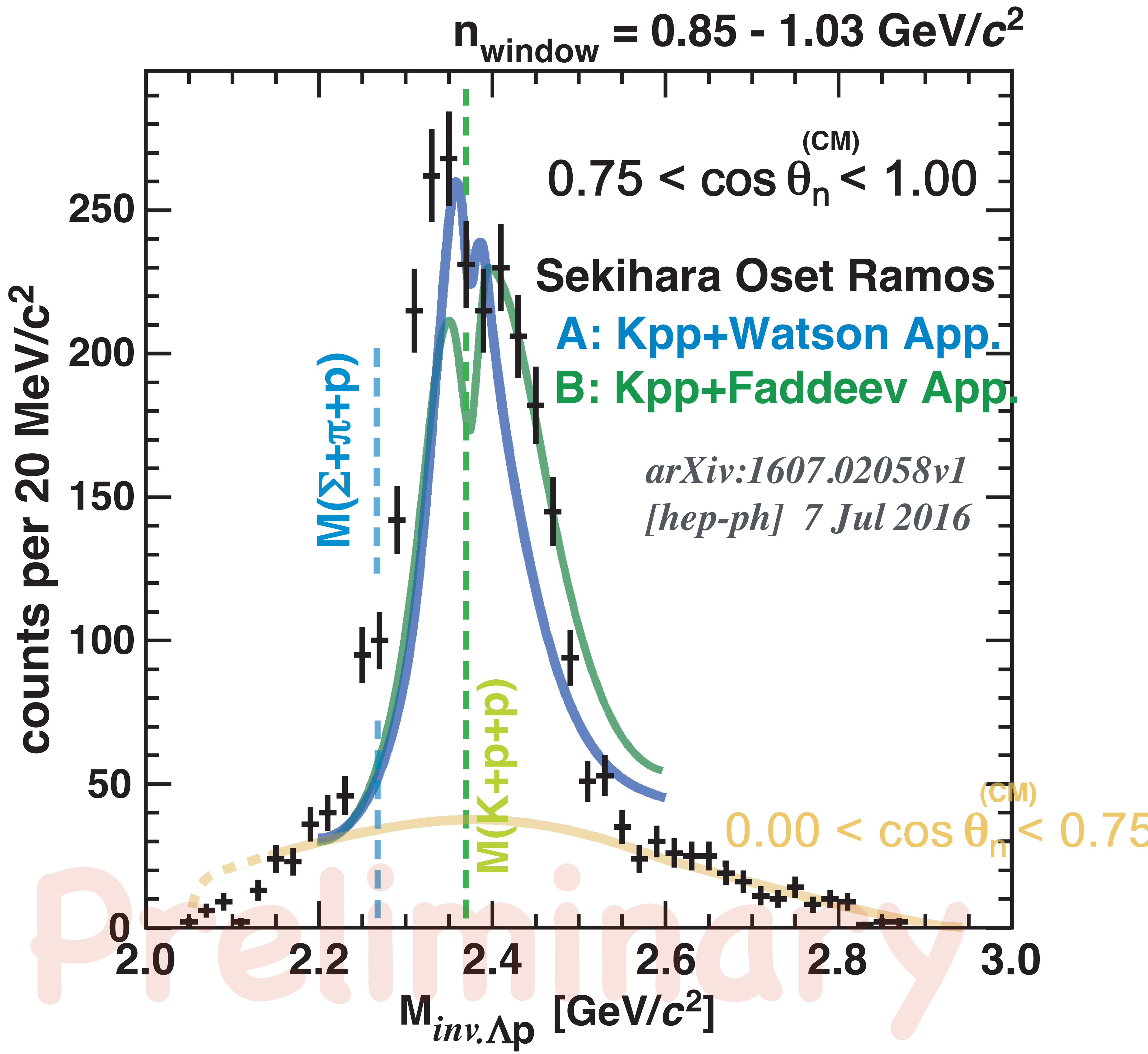
K multiple scattering



Very Preliminary

^{3}He(K$^-$, Λp)n: comparison with SOR





Qualitatively in good agreement!

calculated without knowing E15 2nd spectrum

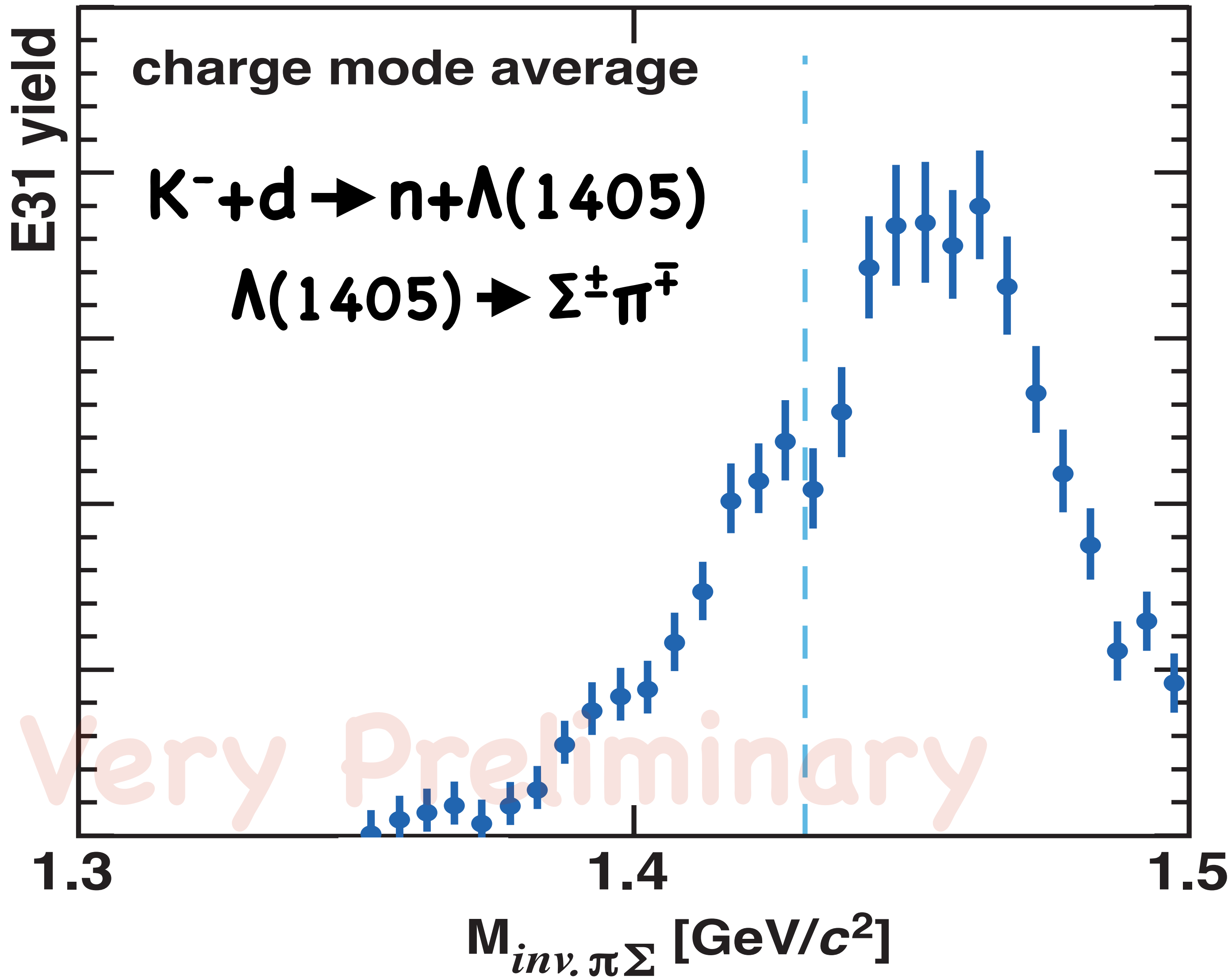
^{3}He(K$^-$, Λp)n:

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

↓ qualitatively YES! but ...

Need even deeper strength!

How to understand whole structure?

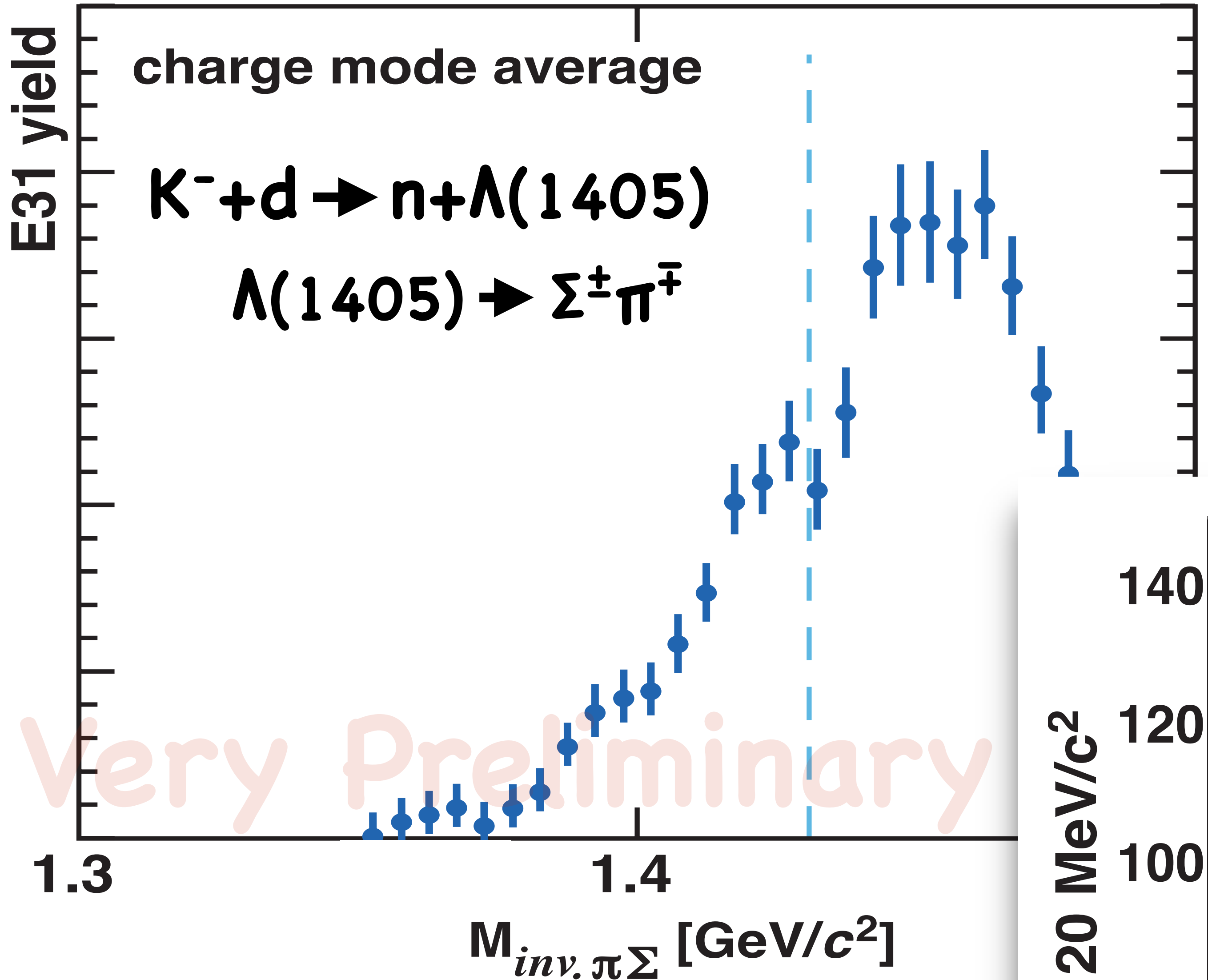


E31:

$K^- + d \rightarrow n + \Lambda(1405)$

$\Lambda(1405) \rightarrow \Sigma^\pm \pi^\mp$

Very Preliminary

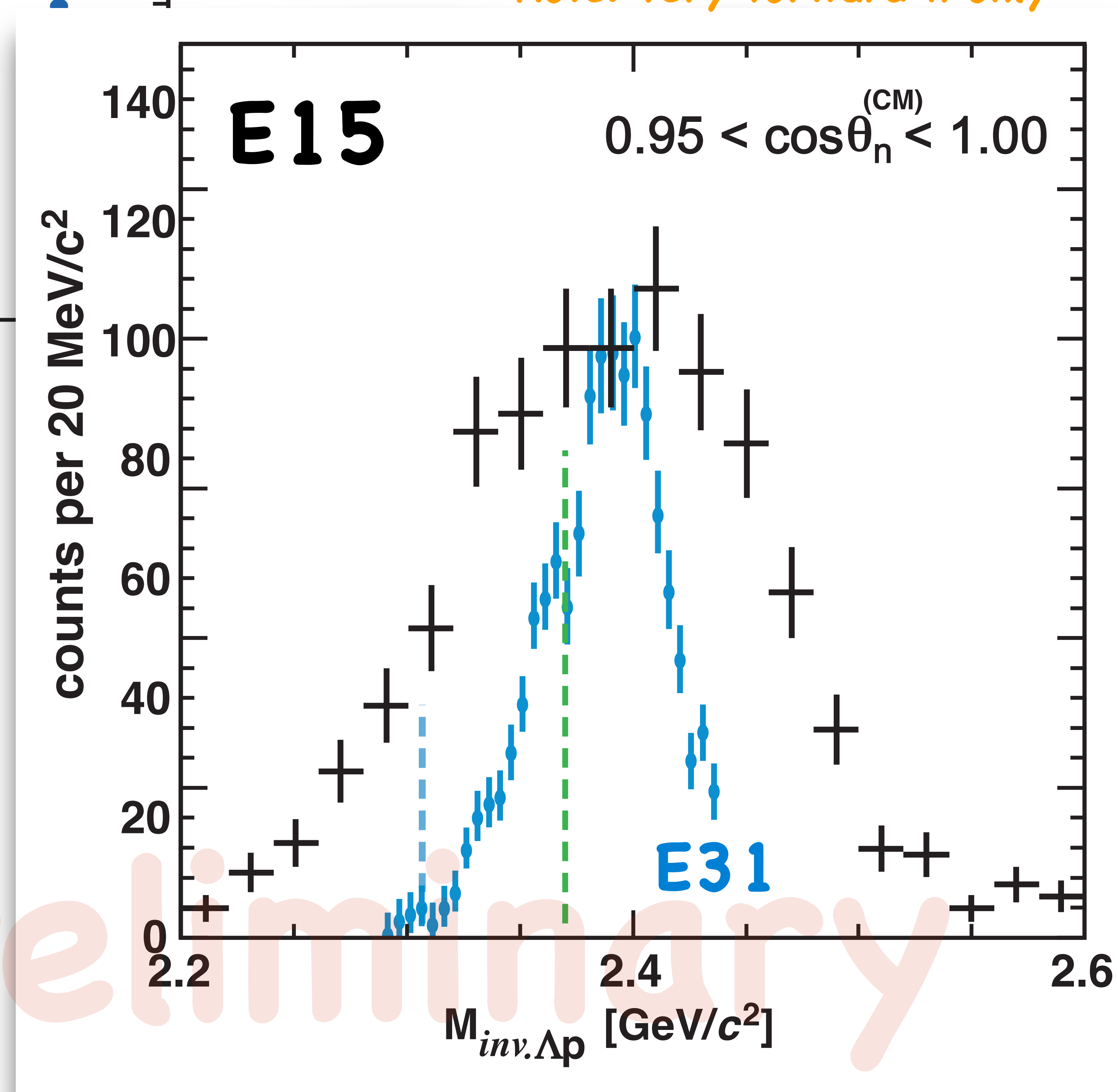


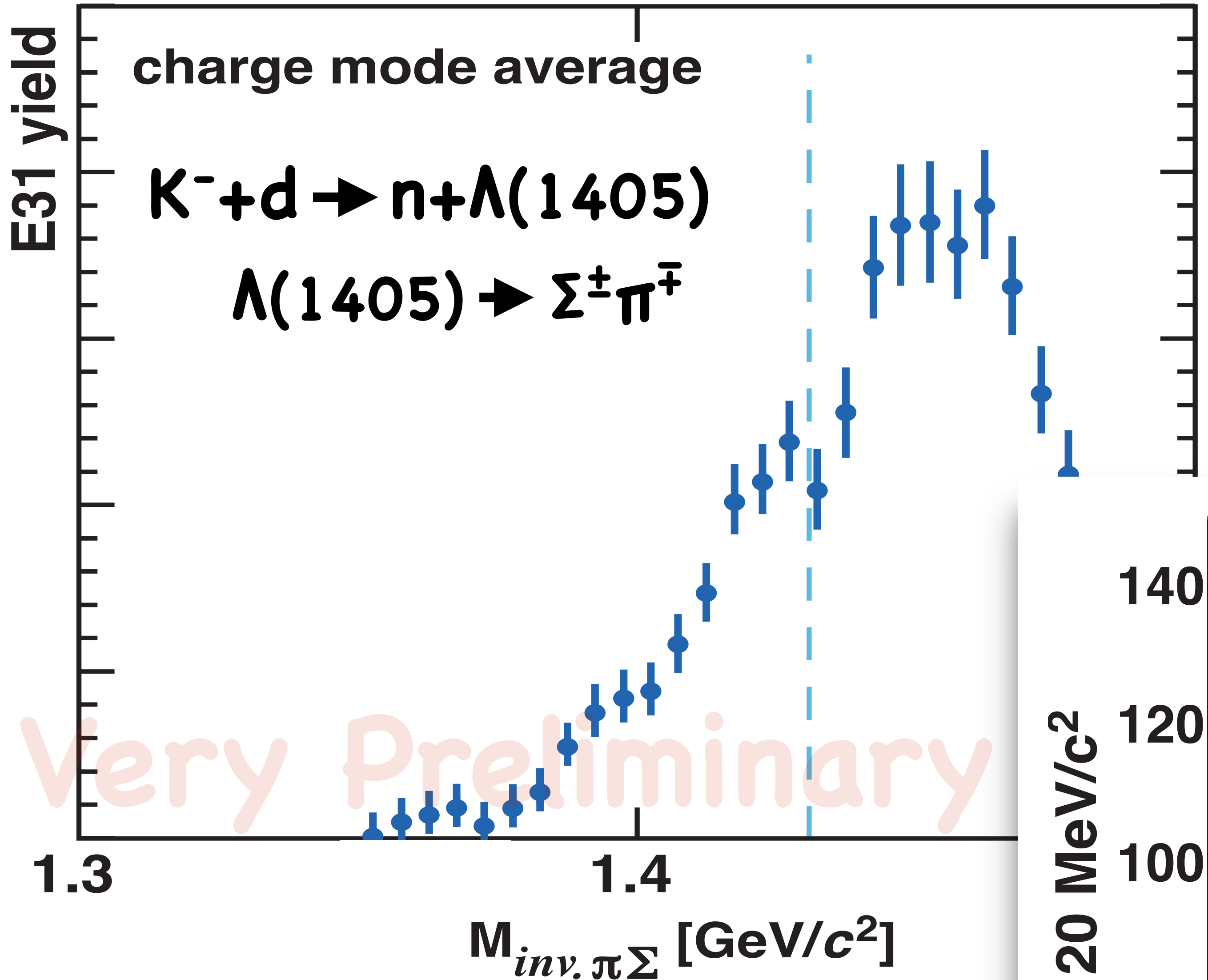
E31:

$K^- + d \rightarrow n + \Lambda(1405)$

$\Lambda(1405) \rightarrow \Sigma^{\pm}\pi^{\mp}$

Note: very forward n only





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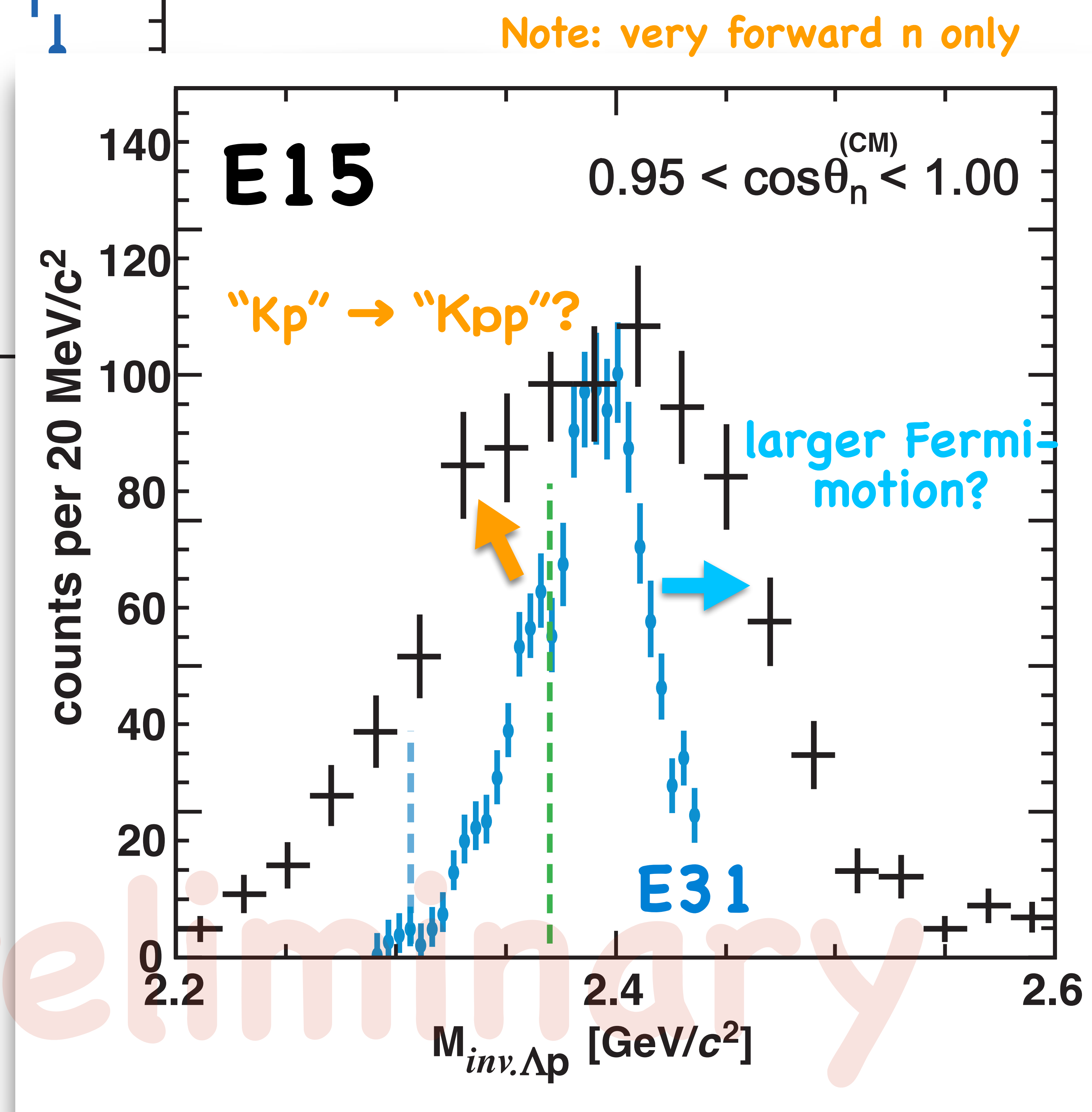
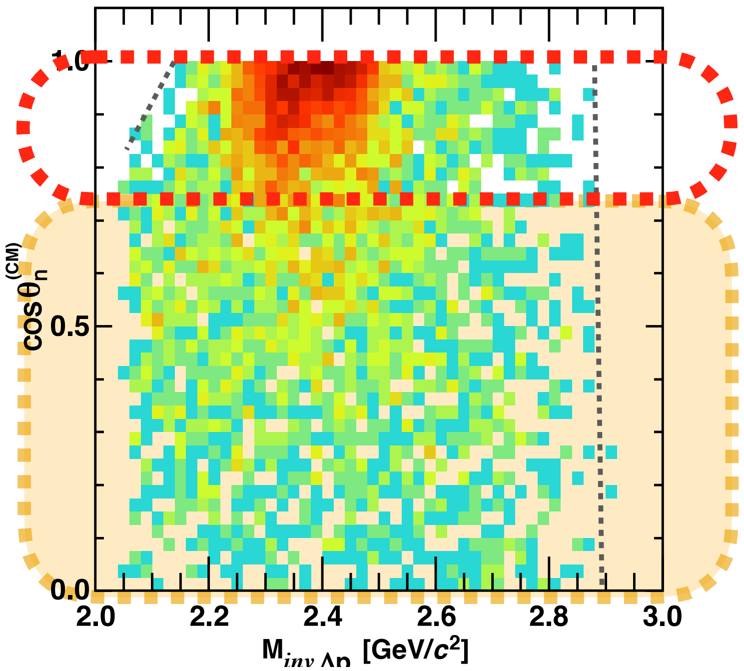
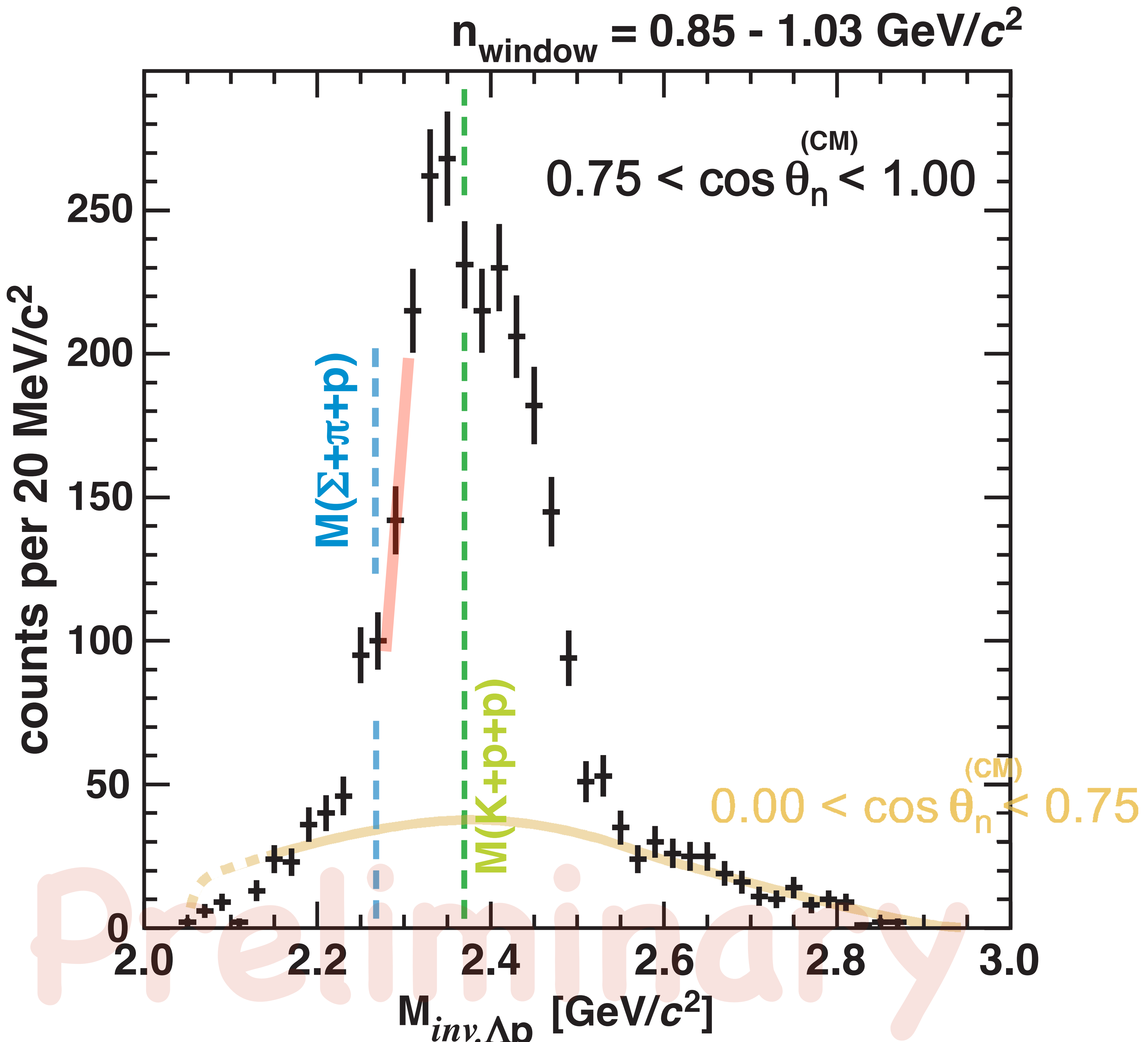


Very Preliminary

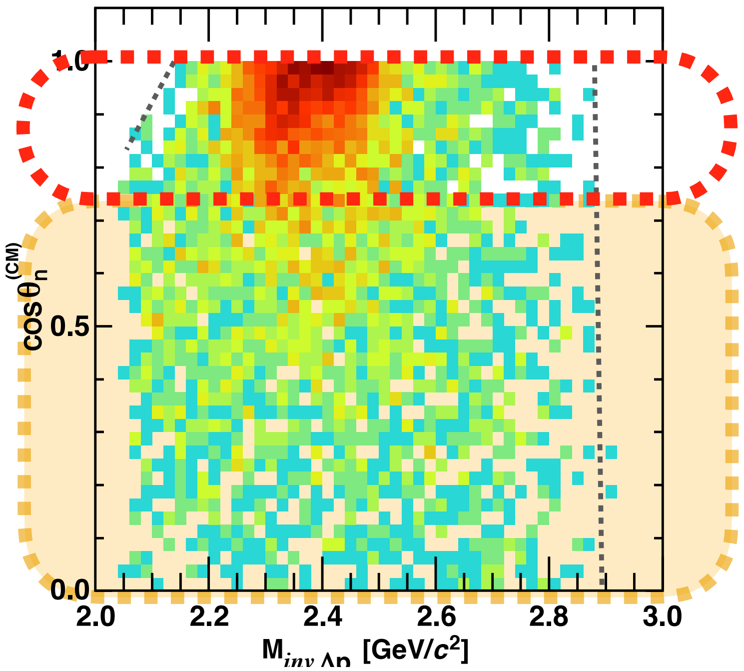
How to understand whole structure? $^3He(K^-, \Lambda p)n$:



from the shape of deeper region (sharp drop), the structure in bound region must be narrow (~60MeV)



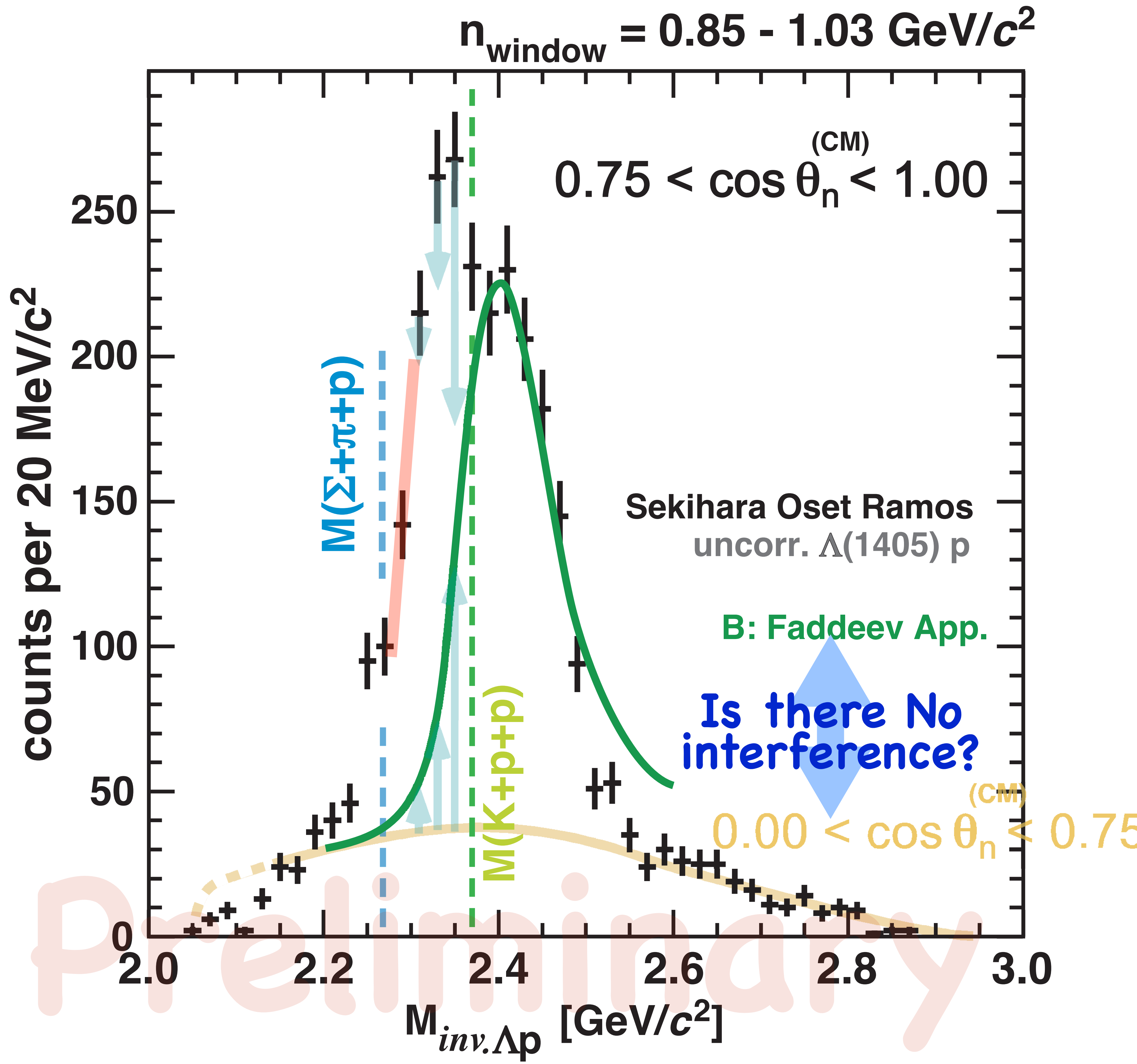
$^3He(K^-, \Lambda p)n$: QE + ?



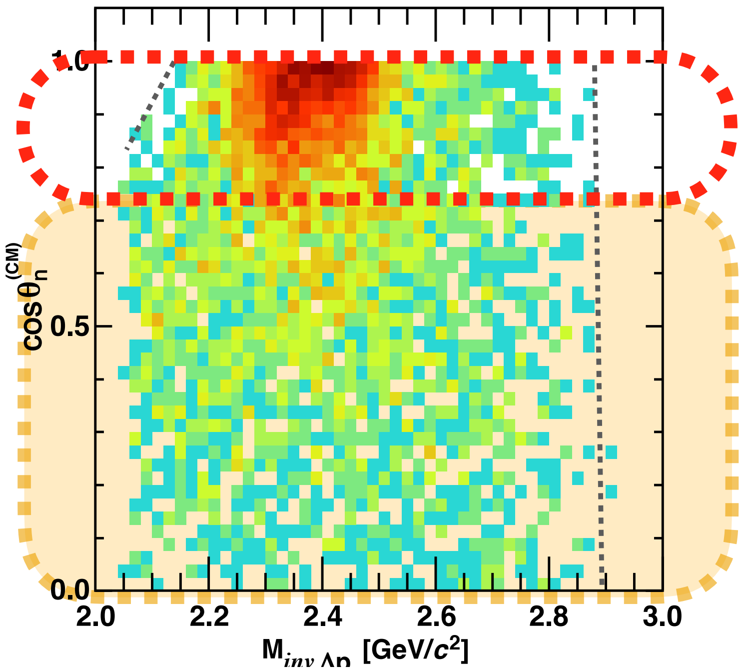
simple QE

+

?



$^3He(K^-, \Lambda p)n$: QE + Kpp



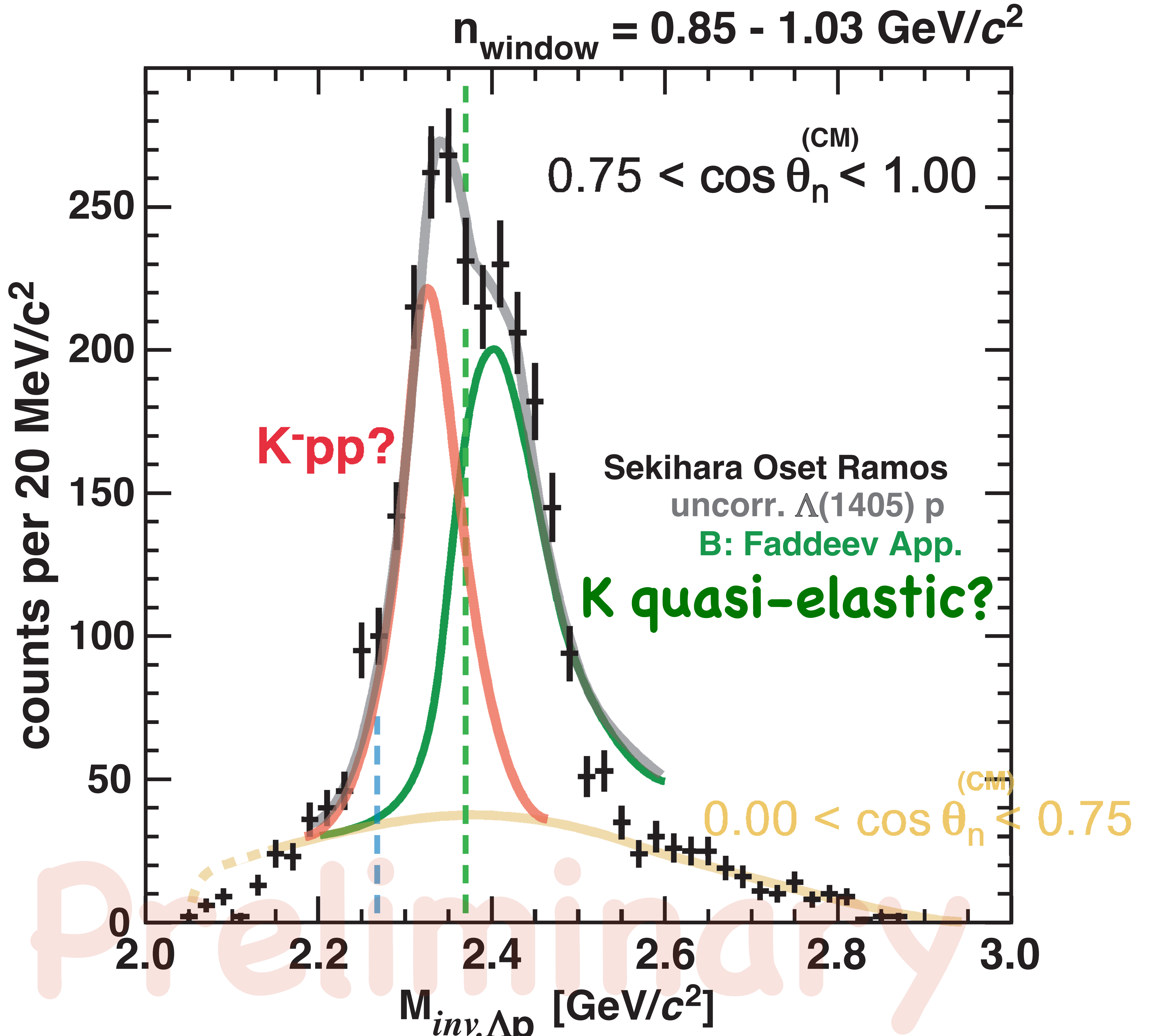
simple QE

+

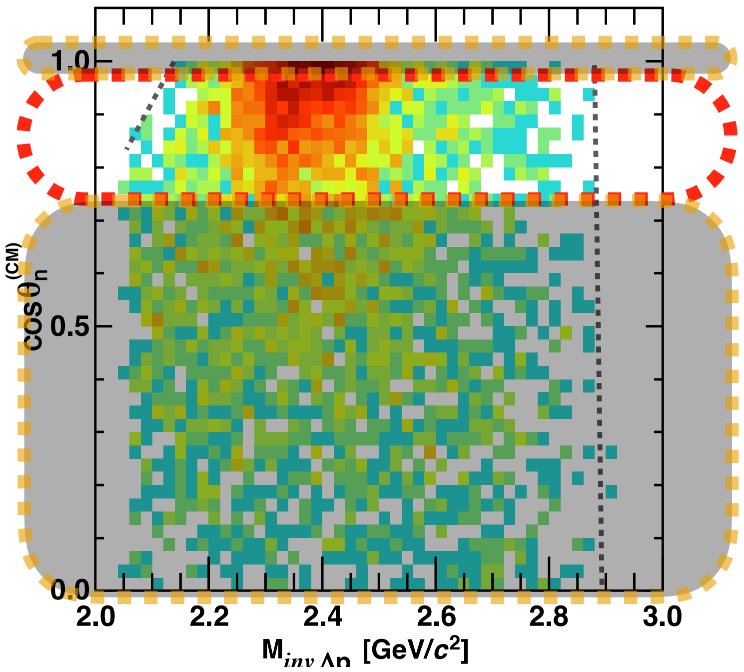
Kpp?

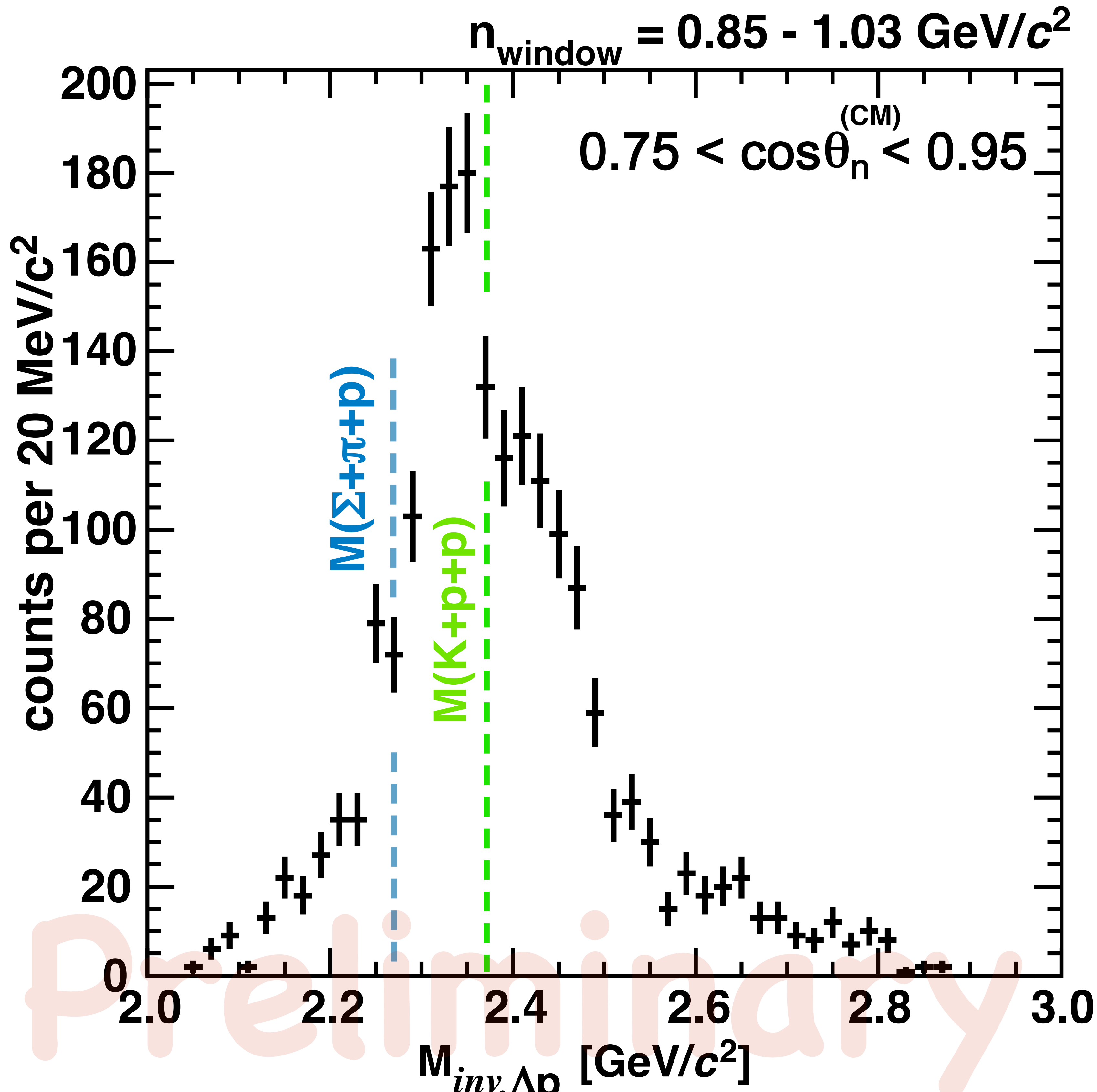
if we can neglect interference

rather deep & narrow in width



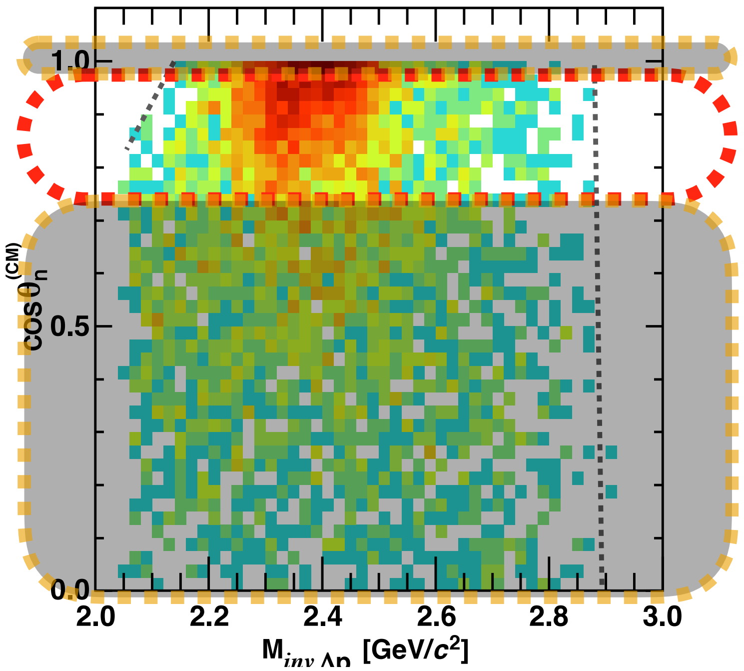
$^3He(K^-, \Lambda p)n$:





Very Preliminary

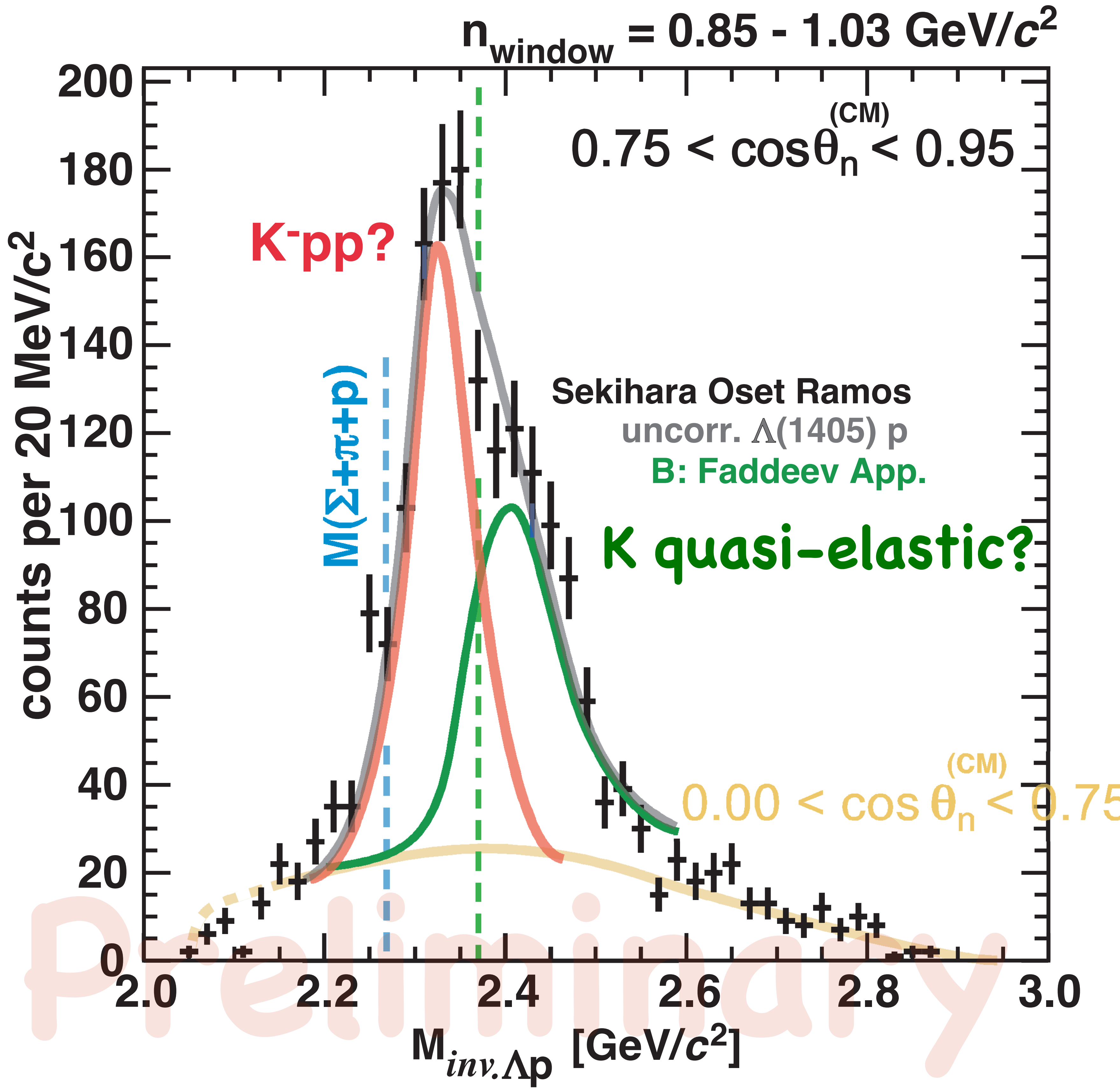
$^3He(K^-, \Lambda p)n$:



if we can neglect interference

rather deep & narrow in width

could be OK

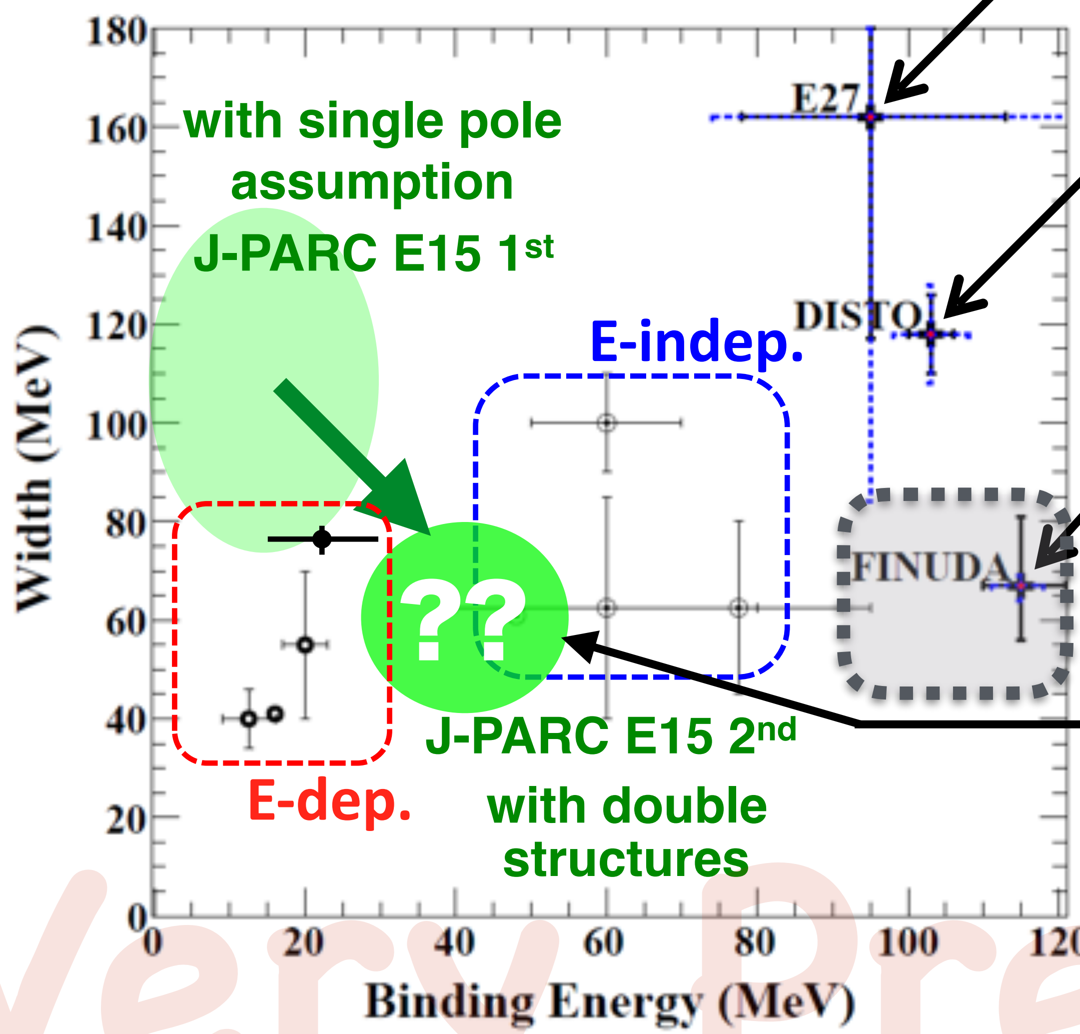


Recent status of $K^{-}pp$ bound state

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

$\bar{K}N$ interaction model

E-dep. / E-indep.



Reports structure / *NO structure*

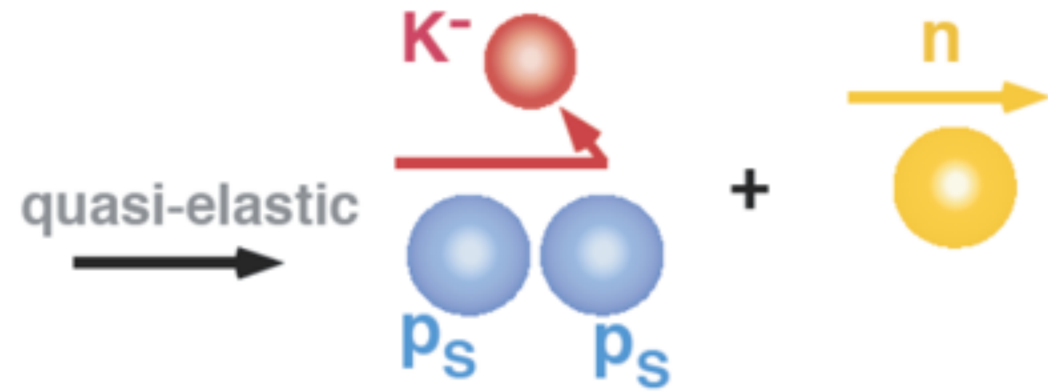
Reports structure	NO structure
J-PARC E27 $d(\pi^{+}, K^{+})X$	LEPS $p(\gamma, \pi^{-}K^{+})X$
DISTO $pp \rightarrow \Lambda p K^{+}$	HADES $pp \rightarrow \Lambda p K^{+}$
FINUDA $(stopped\ K^{-}, \Lambda p)$	FINUDA ?
J-PARC E15 $^{3}He(K^{-}, \Lambda p)n$:	

could be the first convincing data

... after a long journey ...

Very Preliminary

Summary



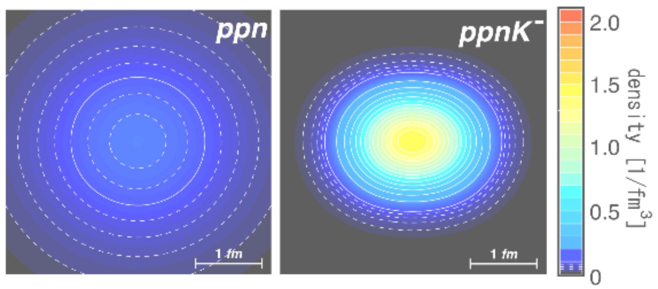
first convincing Kpp signal

probably, $B_K \sim 100$ MeV would be excluded

compact system ?

Q(K) ~ 400 MeV/c → ~ 0.5 fm?

Dote et al., PLB 590 (2004) 51



deeper than χ-UM ?

cf. arXiv:1607.02058 → $M_{\Lambda p} = 2354 - 36i$ MeV

low q_K is key for the formation

B(K) ~ 15 MeV

Γ(K) ~ 70 MeV

what needed to be finalize? ↑ what is flat dist. over Dalitz?

Λpn

finish analysis, *including* ***E31?***

full kinematical refit / angular distributions …

further theoretical inputs?

examine other possibilities: *uncorrelated Σ* p?*

University of Victoria | British Columbia Canada

大阪大学 OSAKA UNIVERSITY

THE UNIVERSITY OF TOKYO

서 울 대 학 교 SEOUL NATIONAL UNIVERSITY

CENTRO FERMI
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百 年
RIKEN CENTENNIAL
Since 1917

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

RCNP

THANKS

TUM

LMU

IFIN-HH

KOREA INSTITUTE OF RADIOLOGICAL & MEDICAL SCIENCES

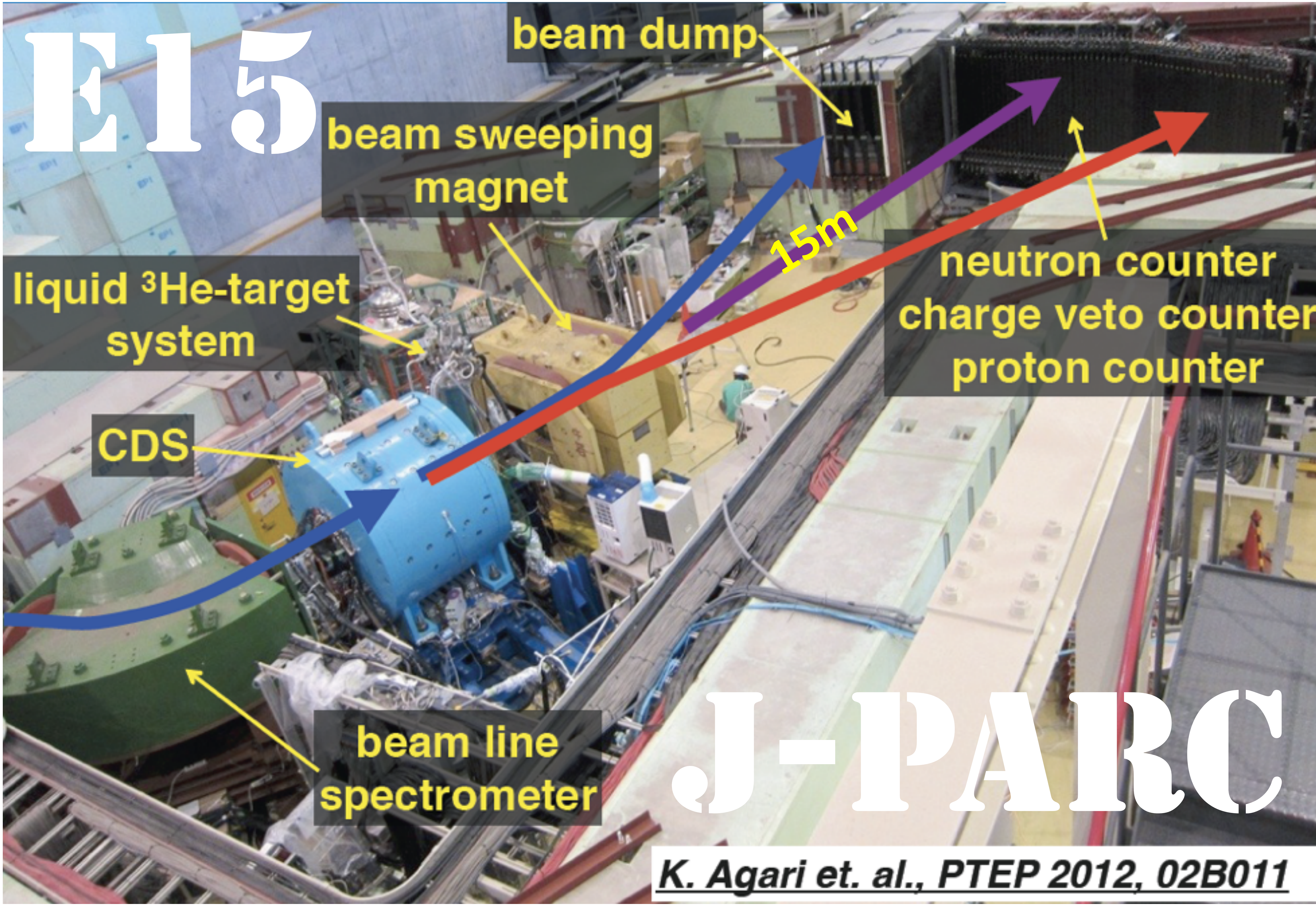
JAGIELLONIAN UNIVERSITY IN KRAKOW

RIKEN

東北大学 TOHOKU UNIVERSITY

KEK

BACKUPS

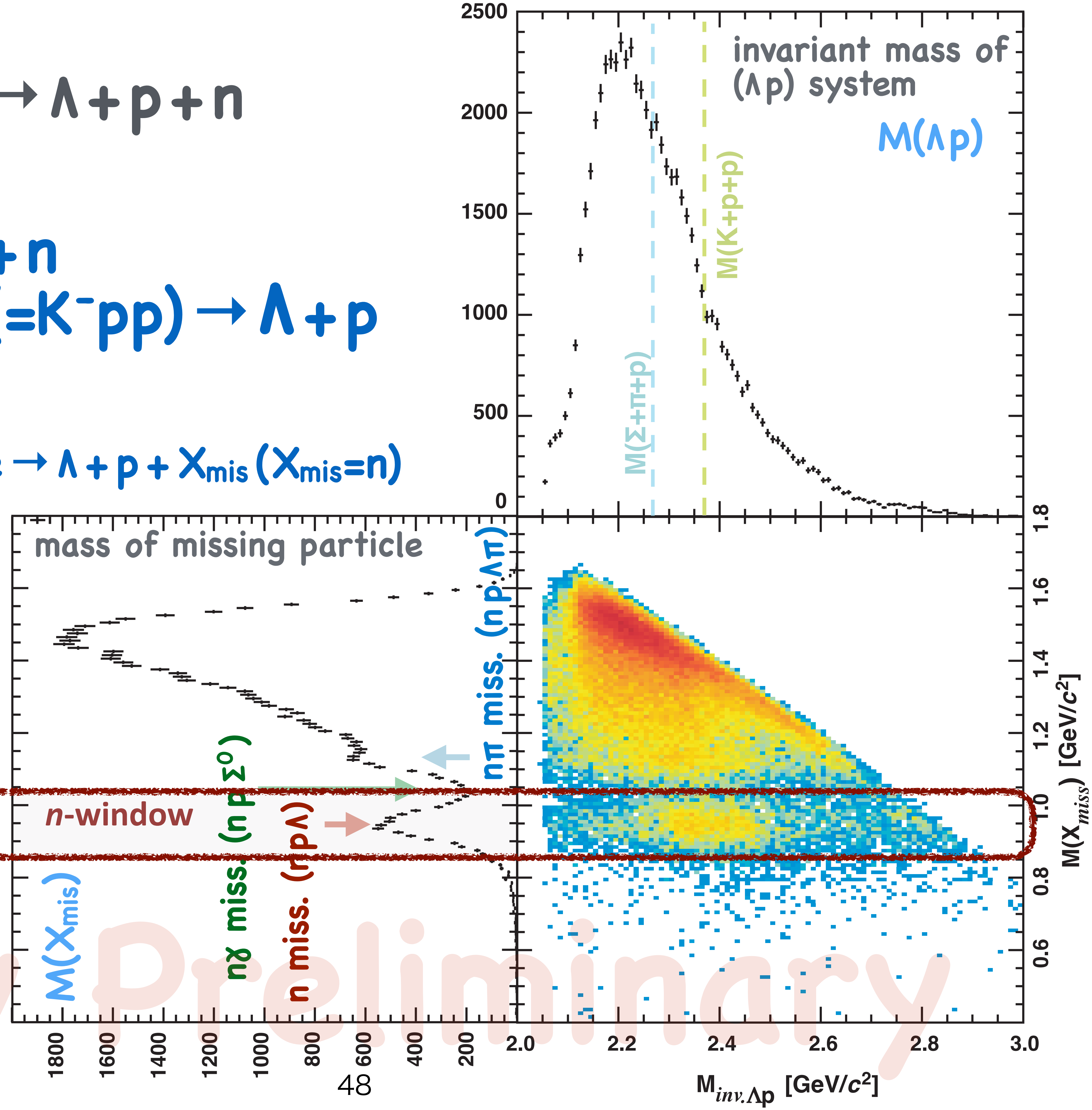

E15
beam dump
beam sweeping magnet
15m
liquid ³He-target system
neutron counter
charge veto counter
proton counter
CDS
beam line spectrometer
J-PARC
K. Agari et. al., PTEP 2012, 02B011

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

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

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

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



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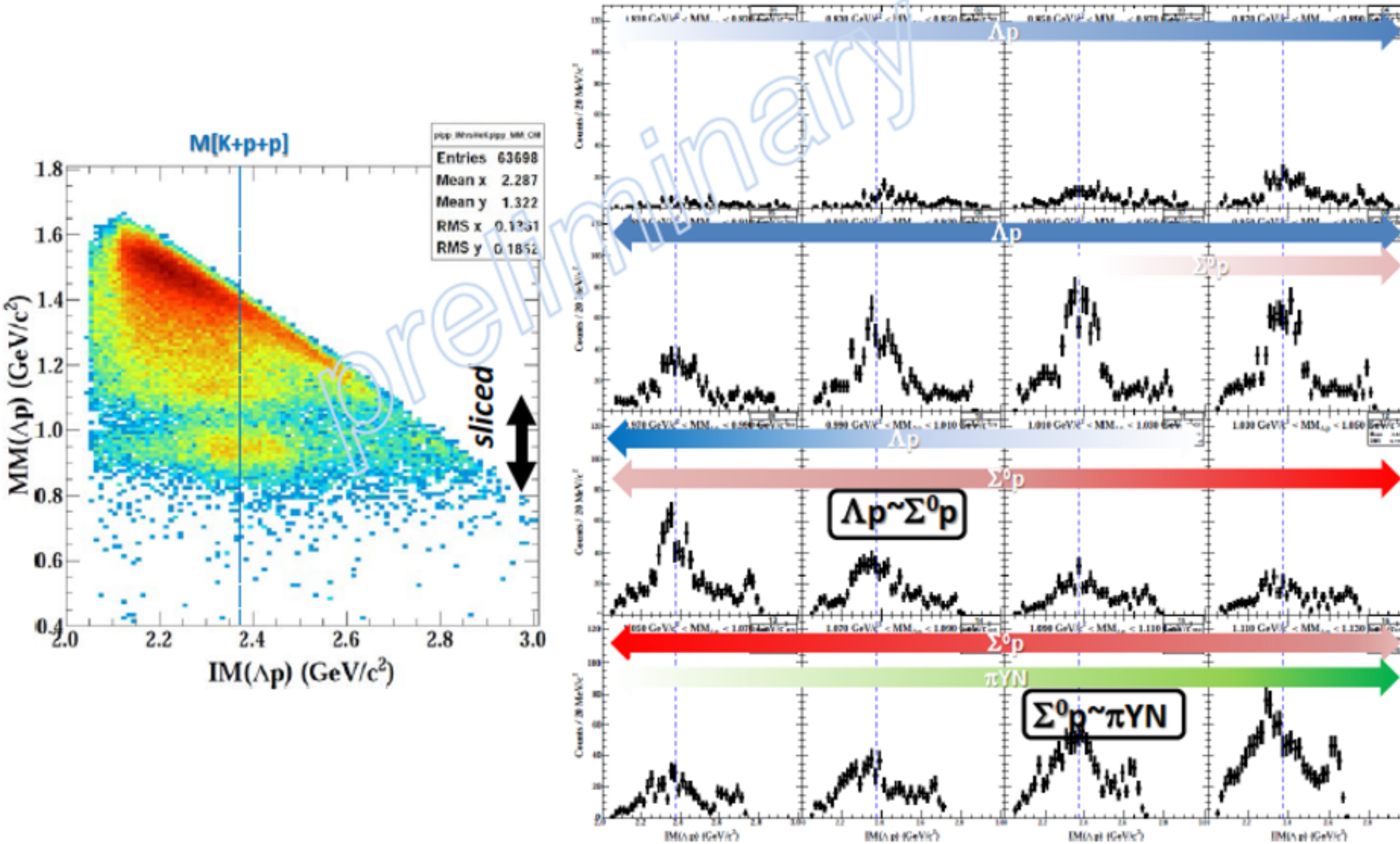
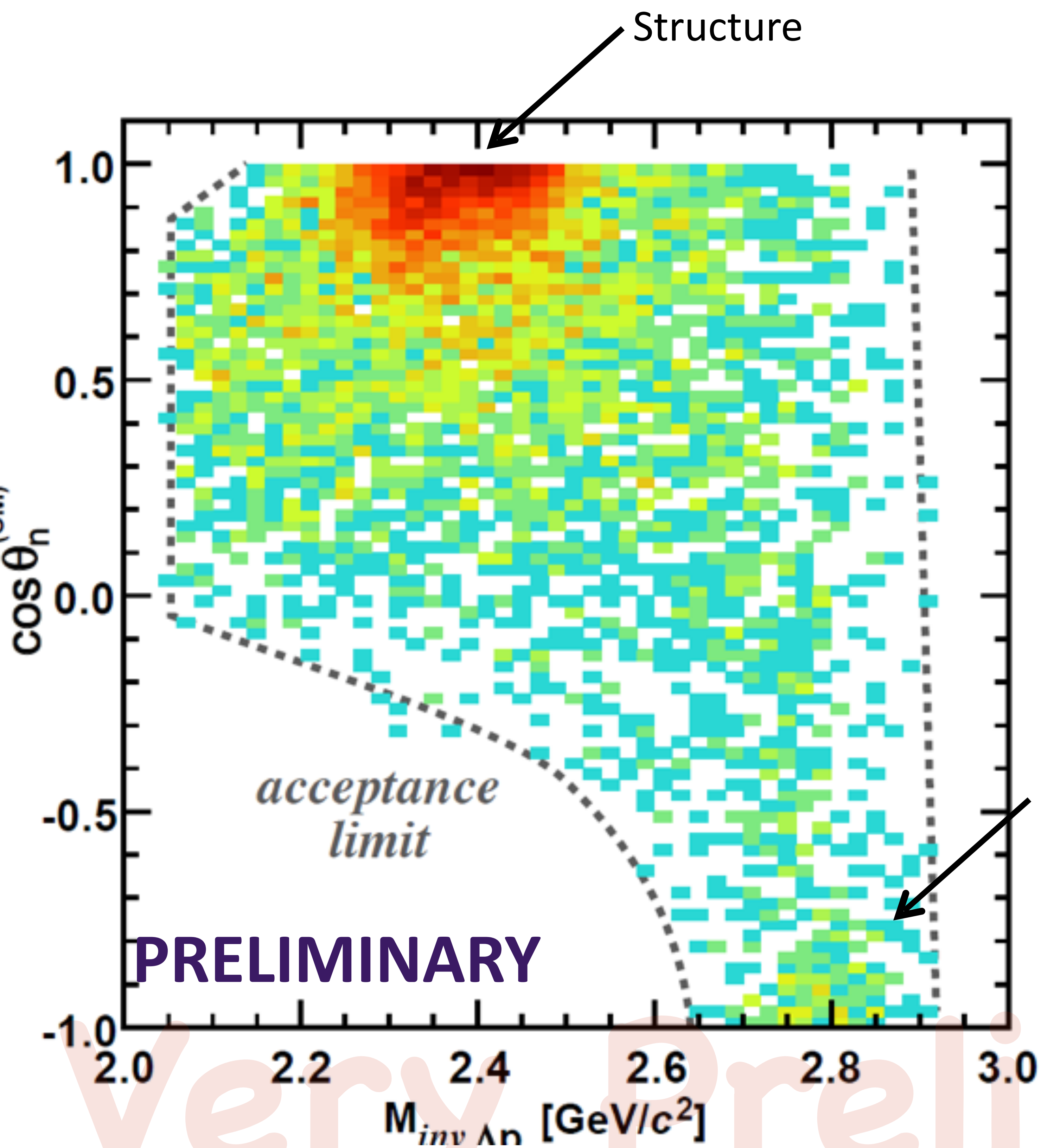
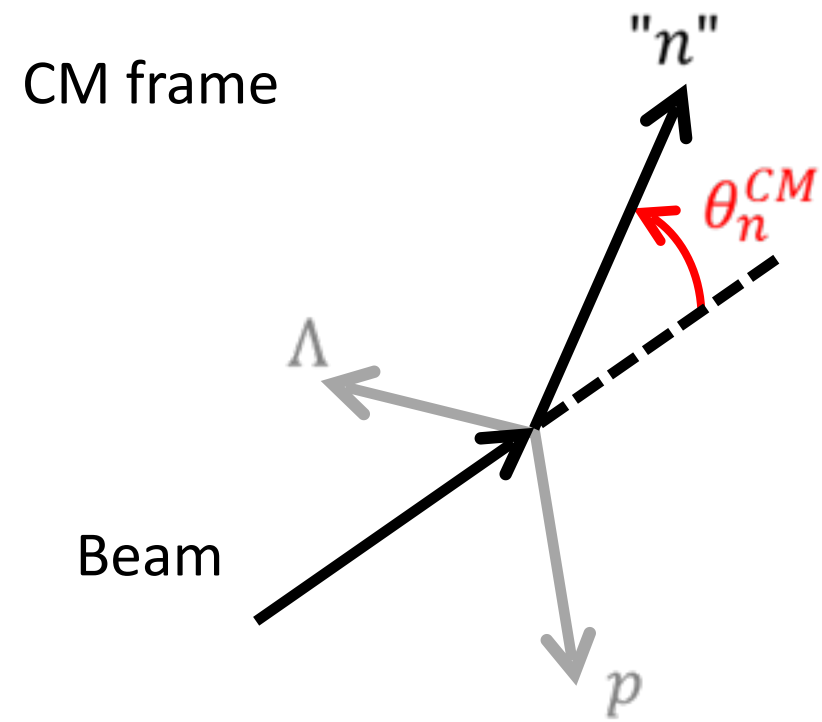
^{3}He(K$^-$,Λp)n: Decay Channel



Γ(Λp) > Γ(Σ^{0}p) !?

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



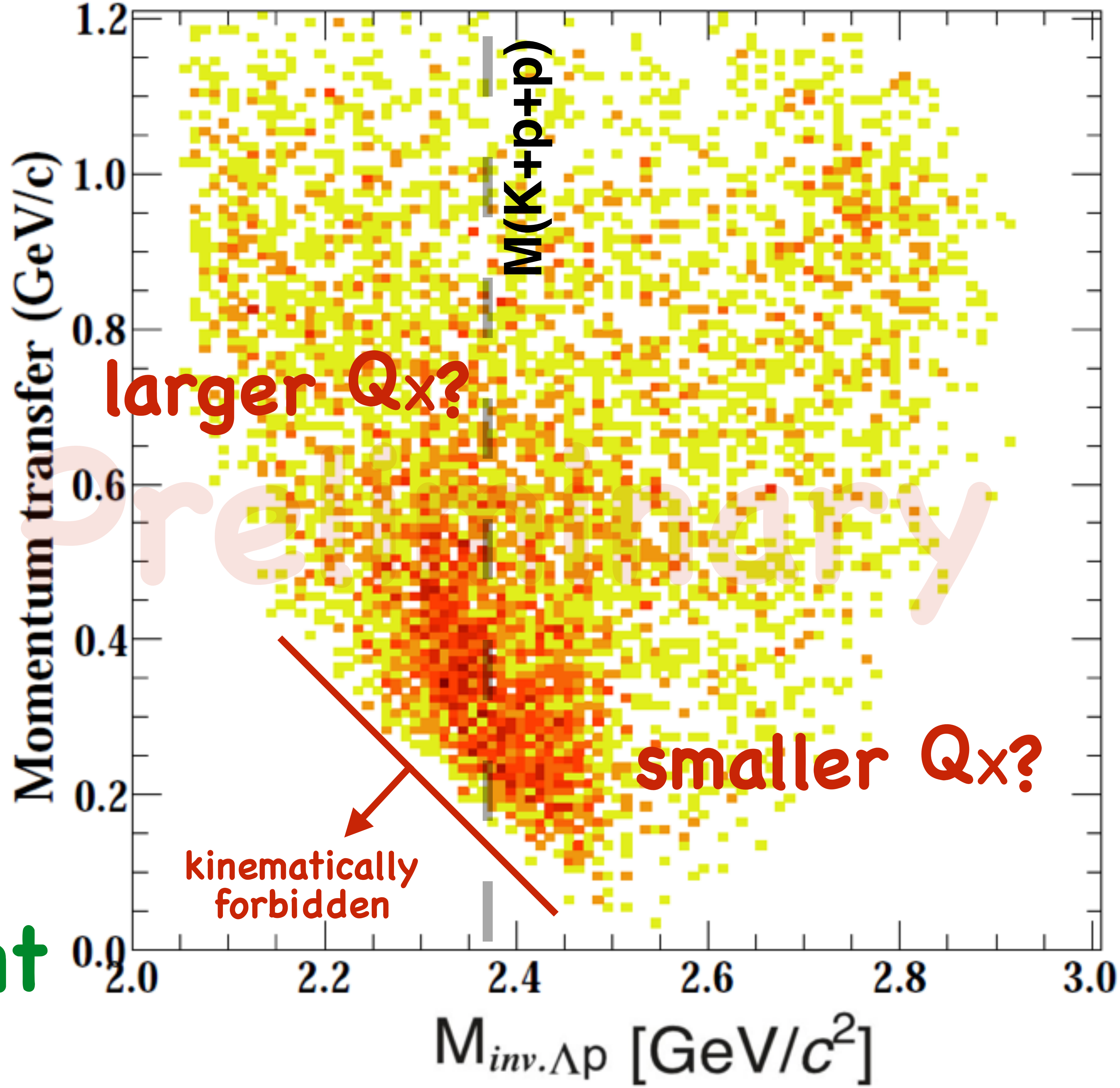


$K^- + {}^3He$:

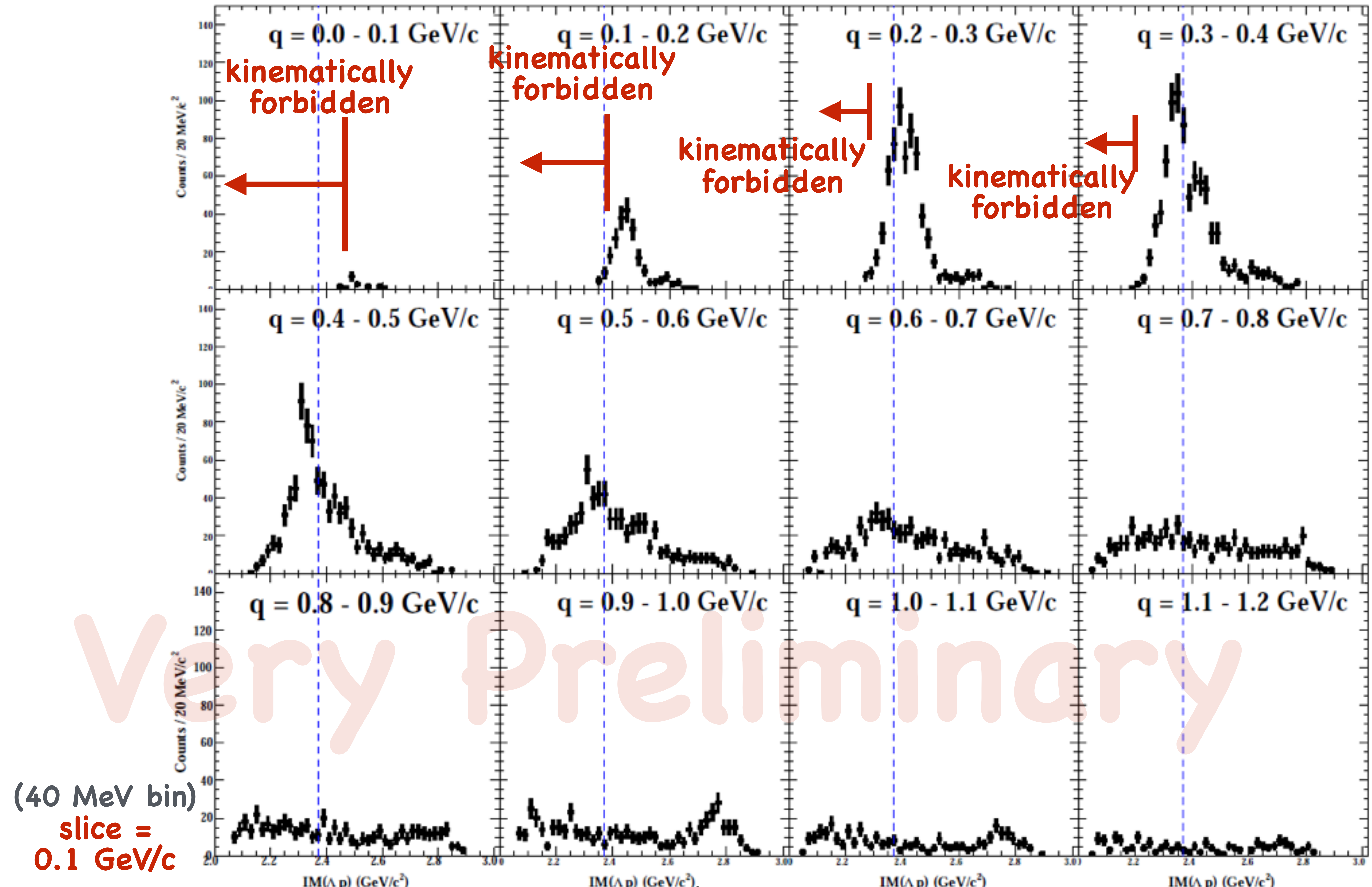
K^- + "$pp+n_s$" $\rightarrow \Lambda p + n_s$

backward

qx dependence



two components? with different qx?


q = 0.0 - 0.1 GeV/c
q = 0.1 - 0.2 GeV/c
q = 0.2 - 0.3 GeV/c
q = 0.3 - 0.4 GeV/c
q = 0.4 - 0.5 GeV/c
q = 0.5 - 0.6 GeV/c
q = 0.6 - 0.7 GeV/c
q = 0.7 - 0.8 GeV/c
q = 0.8 - 0.9 GeV/c
q = 0.9 - 1.0 GeV/c
q = 1.0 - 1.1 GeV/c
q = 1.1 - 1.2 GeV/c
kinematically forbidden
kinematically forbidden
kinematically forbidden
kinematically forbidden
Counts / 20 MeV/c²
IM(Λ p) (GeV/c²)
Very Preliminary
(40 MeV bin)
slice = 0.1 GeV/c

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

T. Hashimoto et al., PTEP (2015) 061D01.
n : semi-inclusive

Y. Sada et al., PTEP (2016) 051D01.
Λpn : single-pole?

E15[1st] B(X) ~ 15 MeV
Γ(X) ~ 110 MeV
Q(X) ~ 400 MeV/c

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

E15[2nd] two structures & Kpp for deeper one!!

B(X) ~ 50 ?? MeV … very deep (not hyper deep, though)
Γ(X) ~ 60 ?? MeV … rather narrow
Q(X) ~ 400 ?? MeV/c … very compact (< 0.5 fm ?)

remaining mystery "point like reaction in Λpn final state"

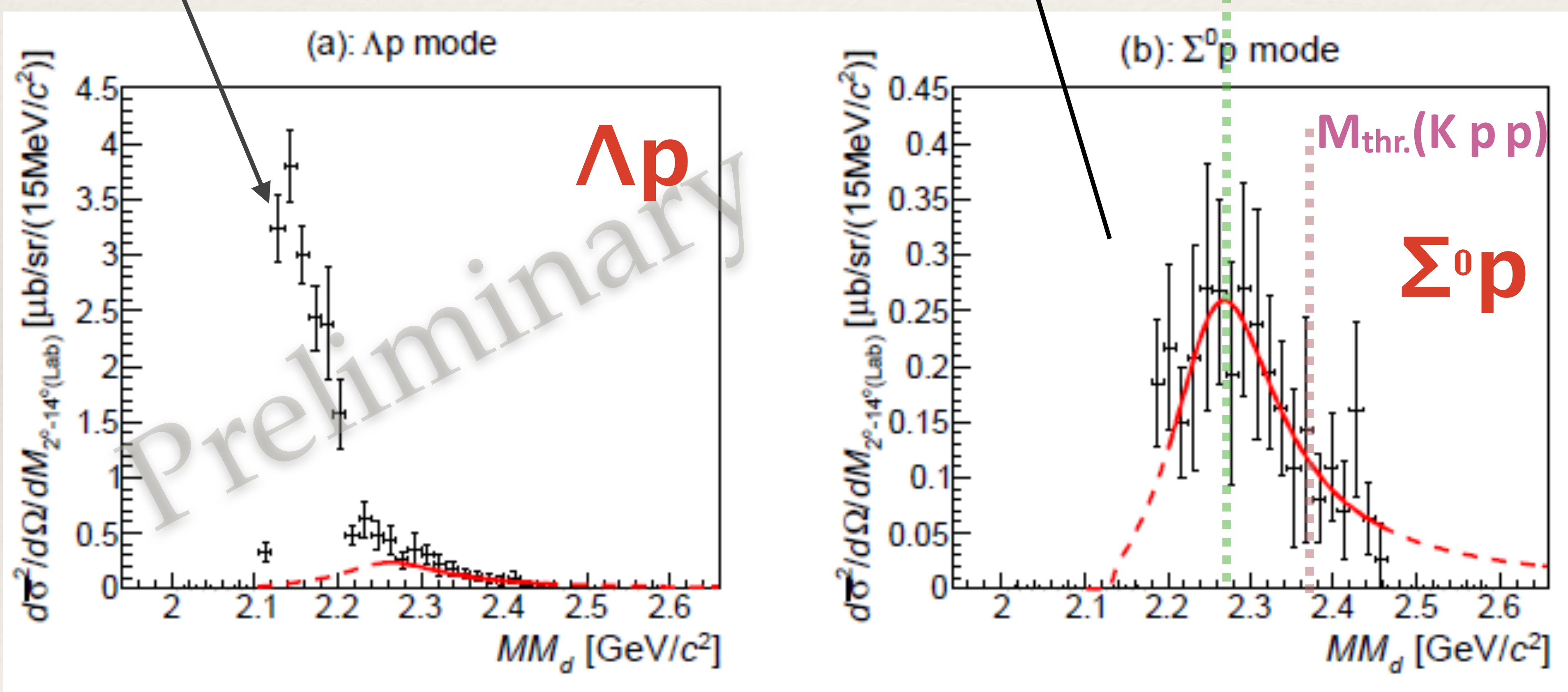
T. Nagae

K^-pp–like structure in $\Sigma^0 p$

$\Lambda p/\Sigma^0 p$

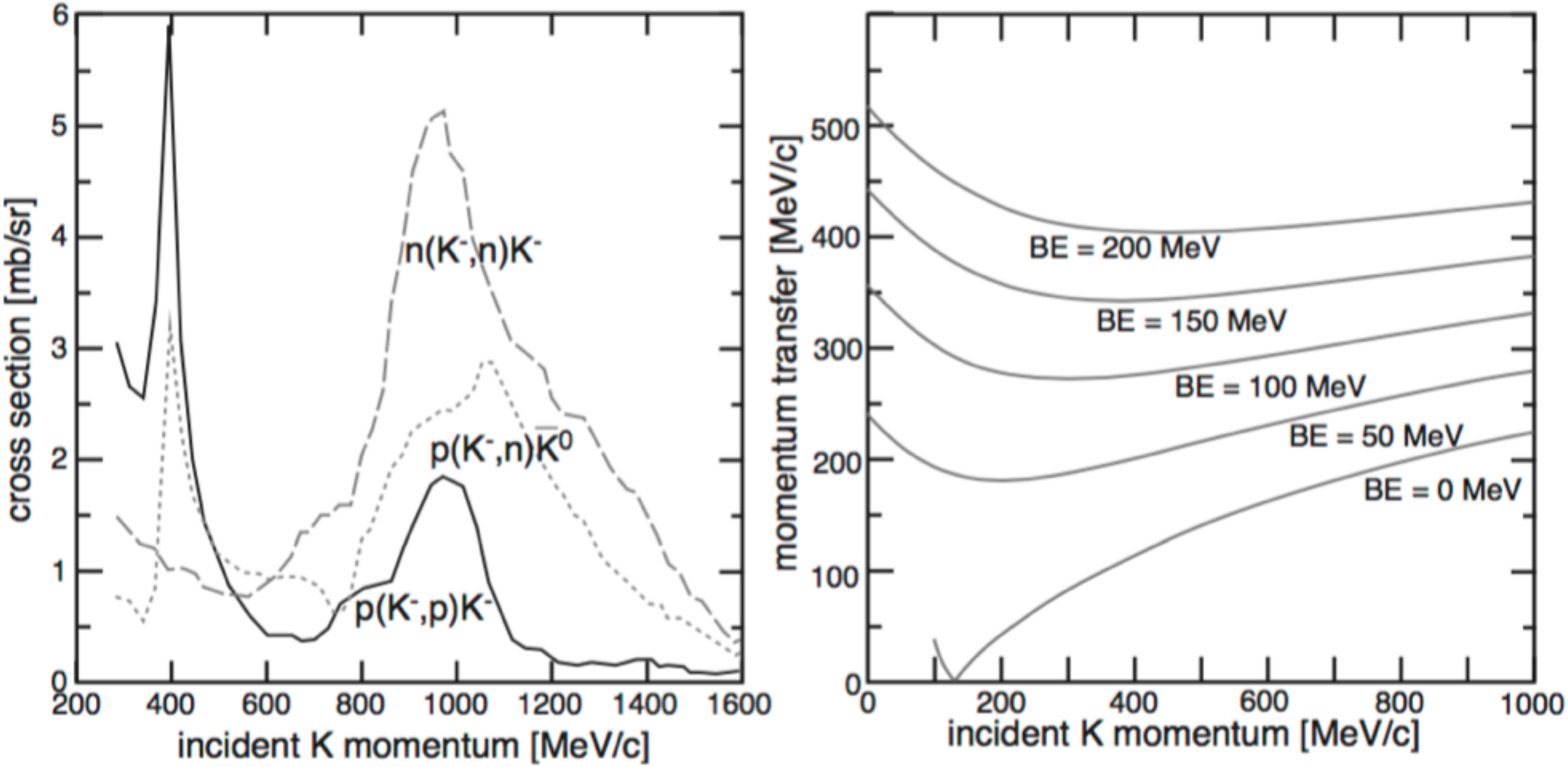
- **Mass :** $2275^{+17}_{-18}(\text{stat.})^{+21}_{-30}(\text{syst.})\ \text{MeV}/c^2$
- **Width :** $162^{+87}_{-45}(\text{stat.})^{+66}_{-78}(\text{syst.})\ \text{MeV}$
- **Binding Energy** $95\ ^{+18}_{-17}\ (\text{stat.})\ ^{+30}_{-21}\ (\text{syst.})\ \text{MeV}$

ΣN cusp +
ΣN→ΛN conversion



$$\frac{\Gamma_{\Lambda p}}{\Gamma_{\Sigma^0 p}} = 0.92^{+0.16}_{-0.14}(stat)^{+0.60}_{-0.42}(syst)$$

No threshold effect seen?!

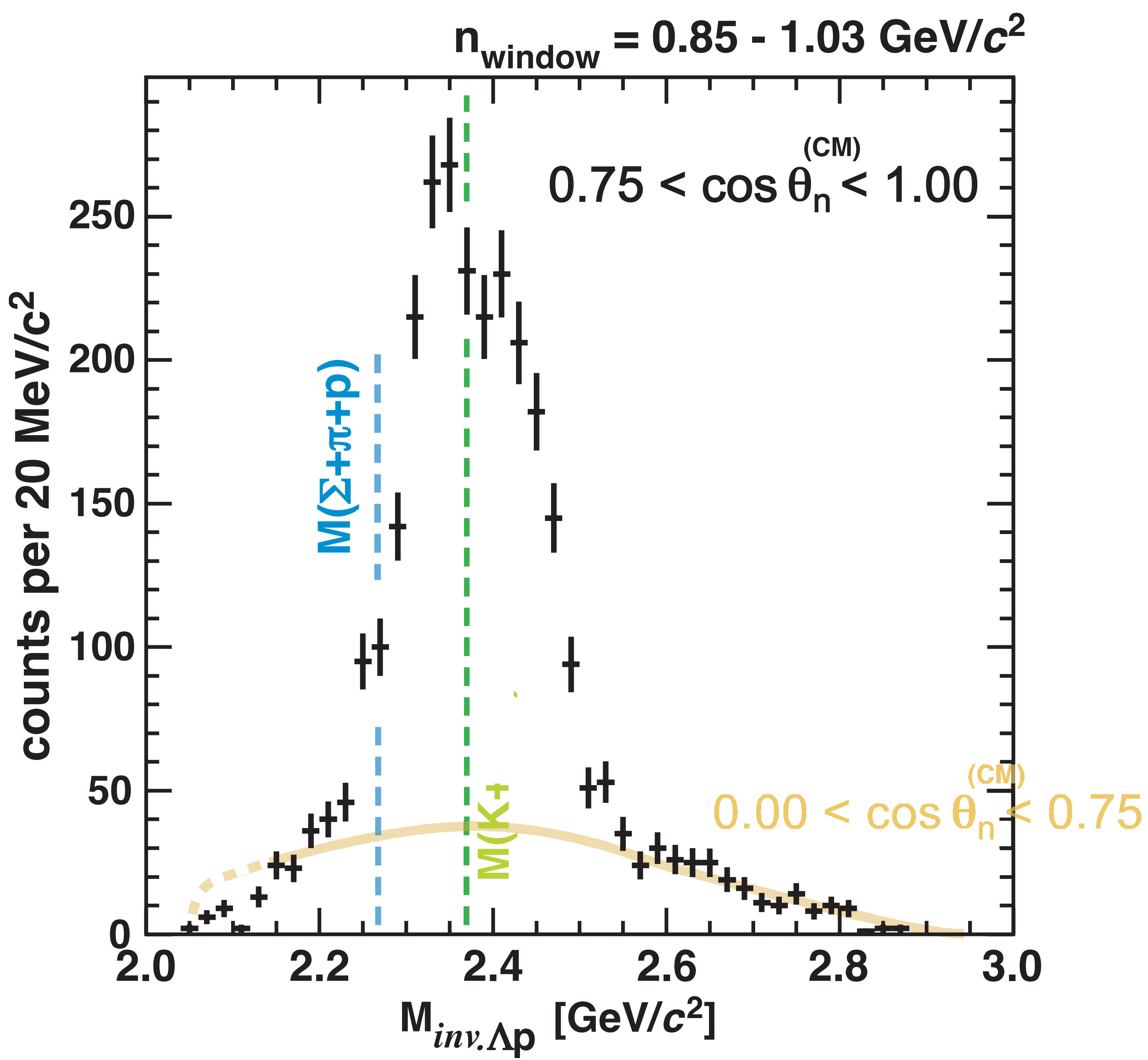


cross section [mb/sr]
incident K momentum [MeV/c]
n(K⁻,n)K⁻
p(K⁻,n)K̄⁰
p(K⁻,p)K⁻
momentum transfer [MeV/c]
BE = 200 MeV
BE = 150 MeV
BE = 100 MeV
BE = 50 MeV
BE = 0 MeV

E31:

$K^- + d \rightarrow n + \Lambda(1405)$

$\Lambda(1405) \rightarrow \Sigma^{\pm}\pi^{\mp}$



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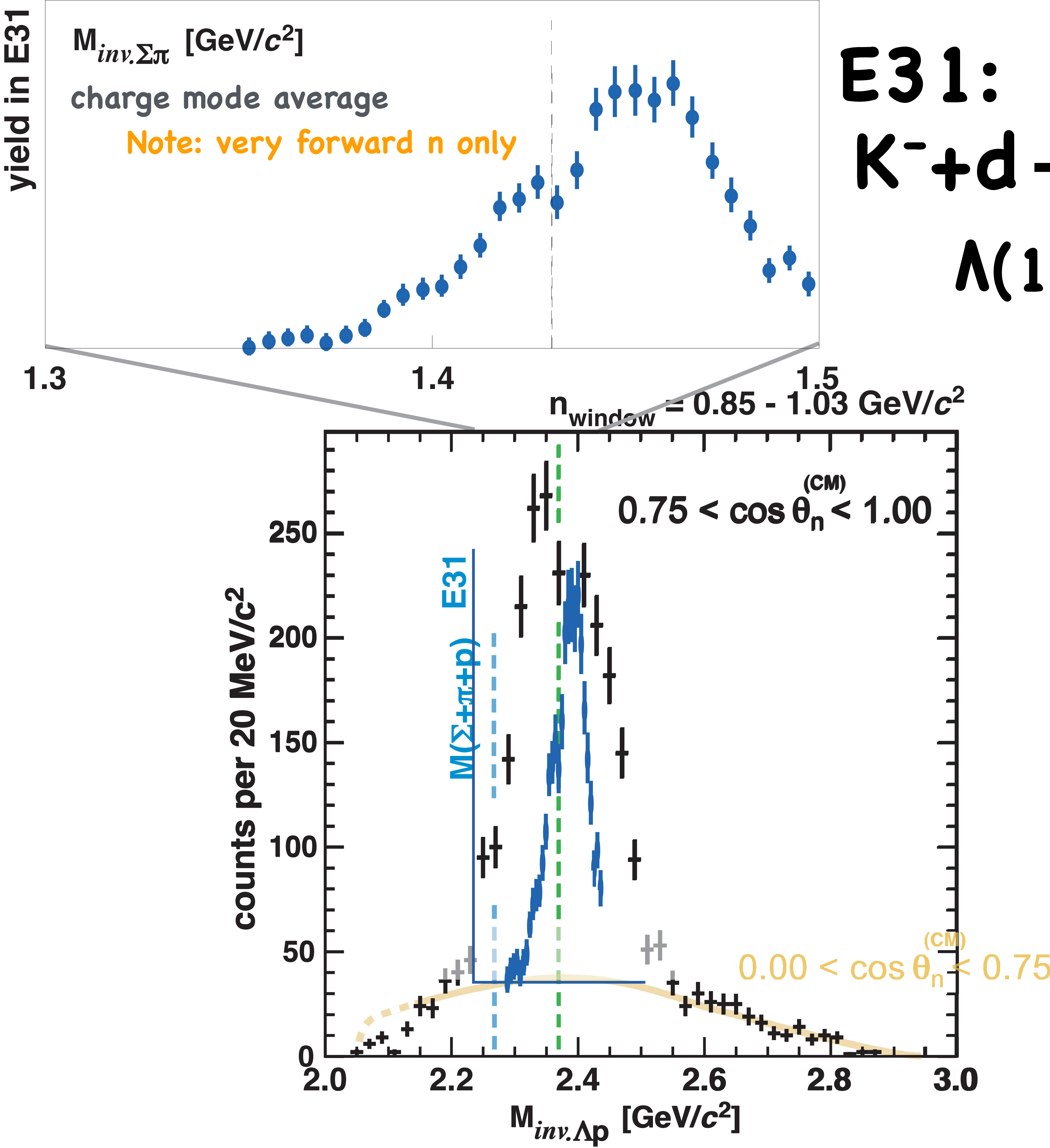

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