Recent results and future prospects of kaonic nuclei at J-PARC

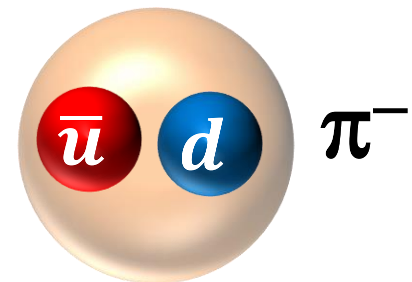
F. Sakuma, RIKEN

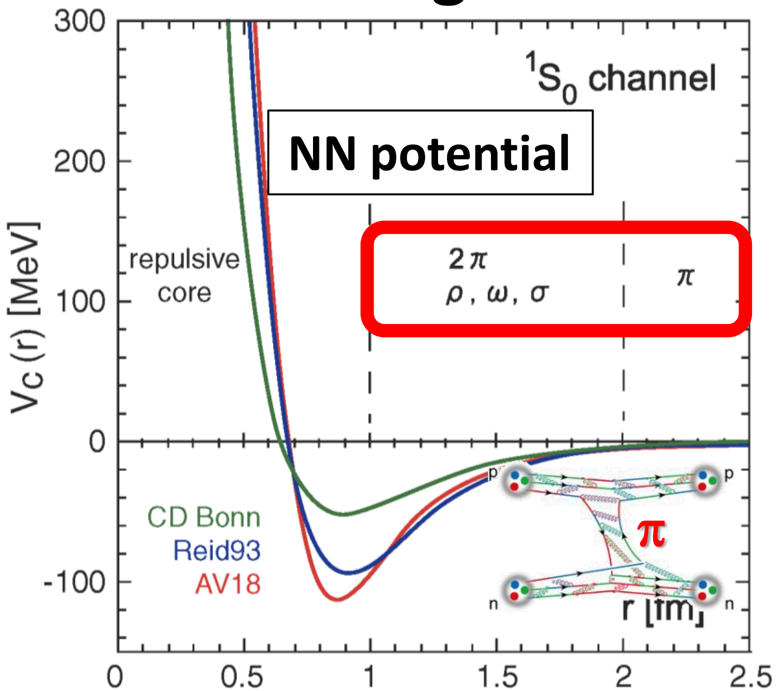
on behalf of the J-PARC E15 & P80 collaborations

APFB2020
Yamada Conference LXXII:
The 8th Asia-Pacific Conference on Few-Body Problems in Physics,
1-5 March 2021, Kanazawa, JAPAN

Meson-Baryon Interaction

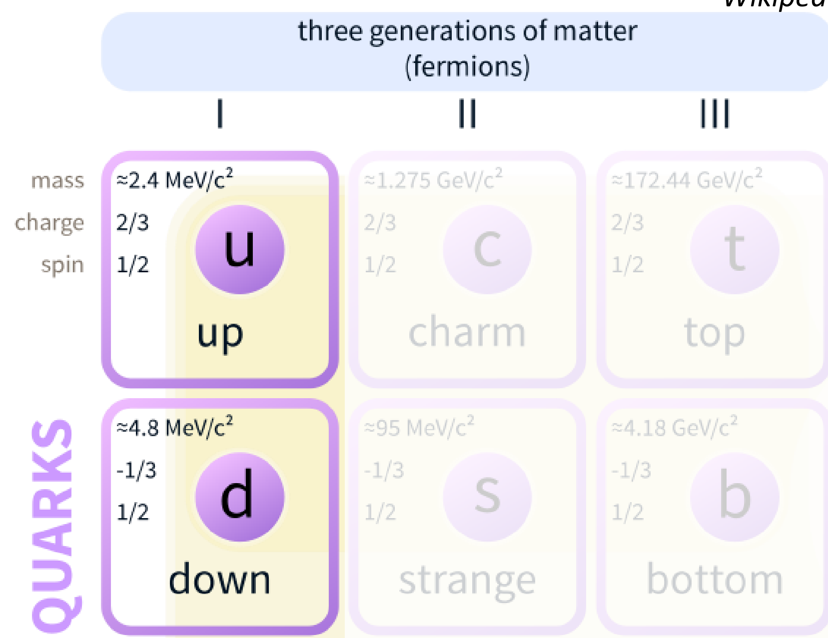
- light mesons with u/d quarks
  - play an important role in a nucleus as **“glue”**





PRL99(2007)022001.

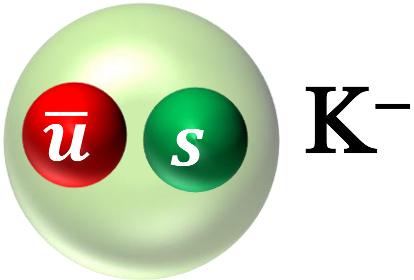
Wikipedia

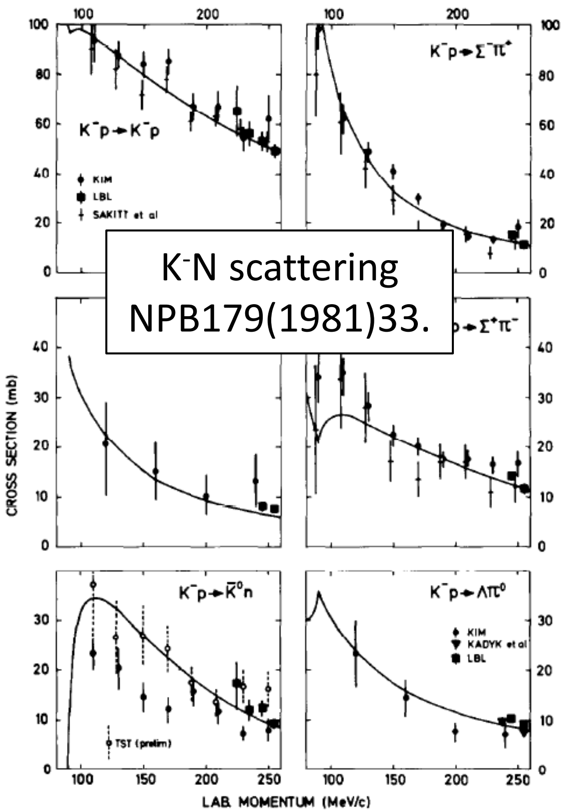


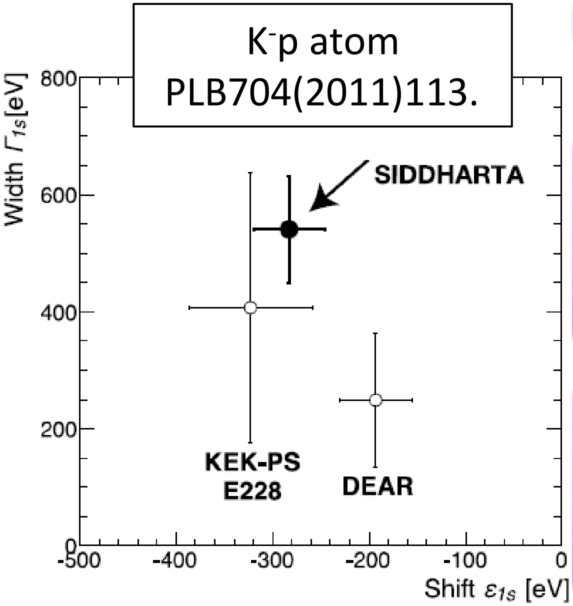
πN interaction is repulsive in S-wave → No nuclear bound state

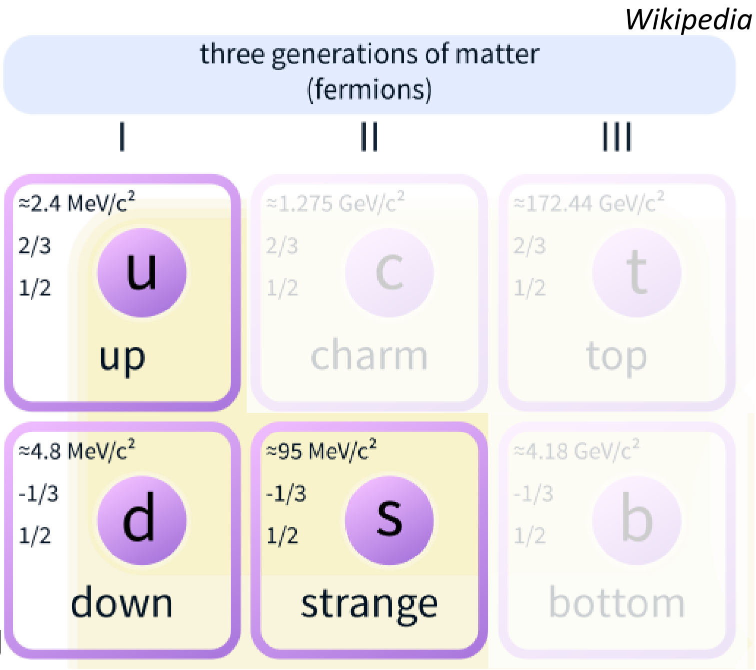
M-B Interaction in the Strange Sector

- **Lightest S=-1 meson, K^-**
  - $\bar{K}N$ interaction:
    strongly attractive in I=0



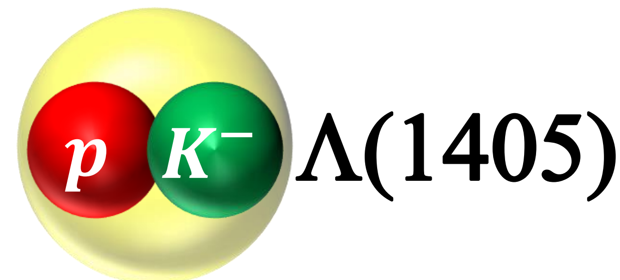






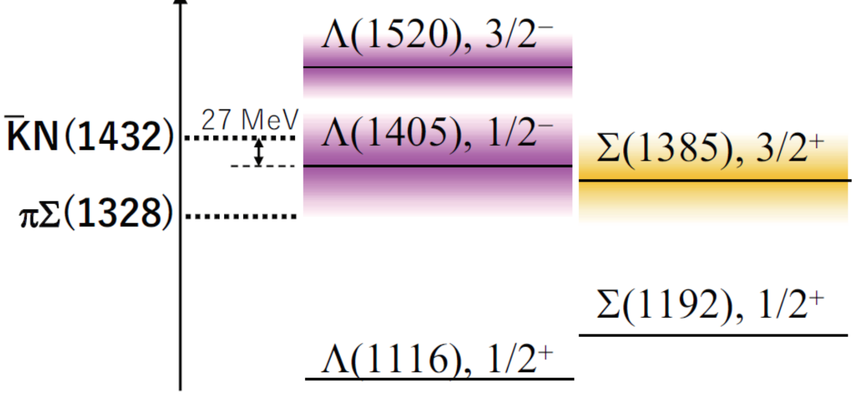
Can Kaon be Bound in Nuclei?

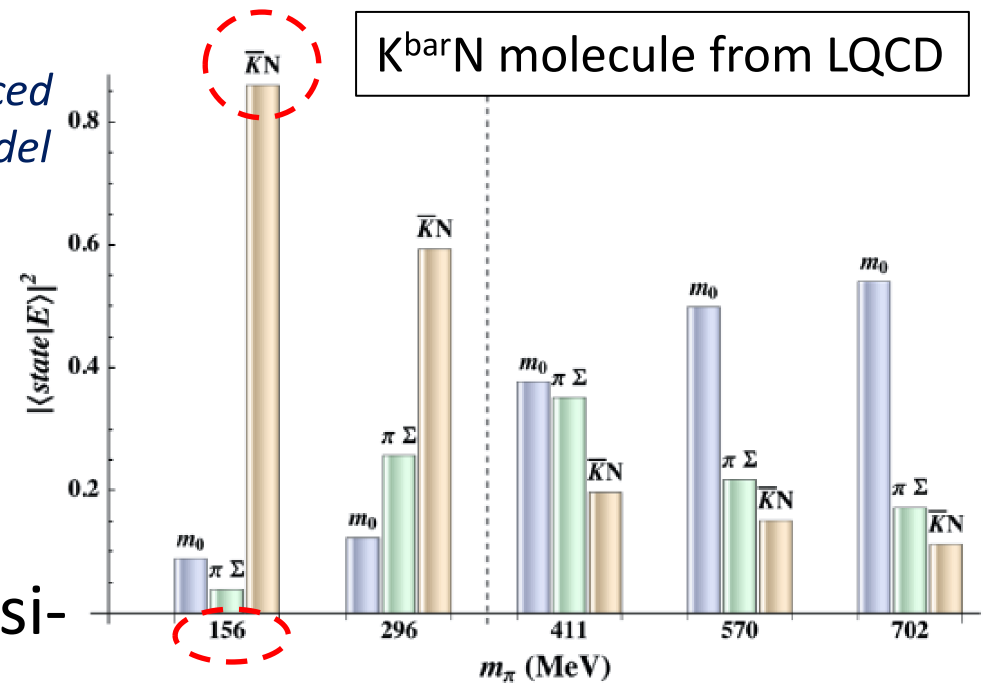
- **Lightest S=-1 meson, K^-**
  - $\bar{K}N$ interaction: ***strongly attractive in I=0***



- **Λ(1405)**

Λ(1405) cannot be reproduced by the constituent quark model





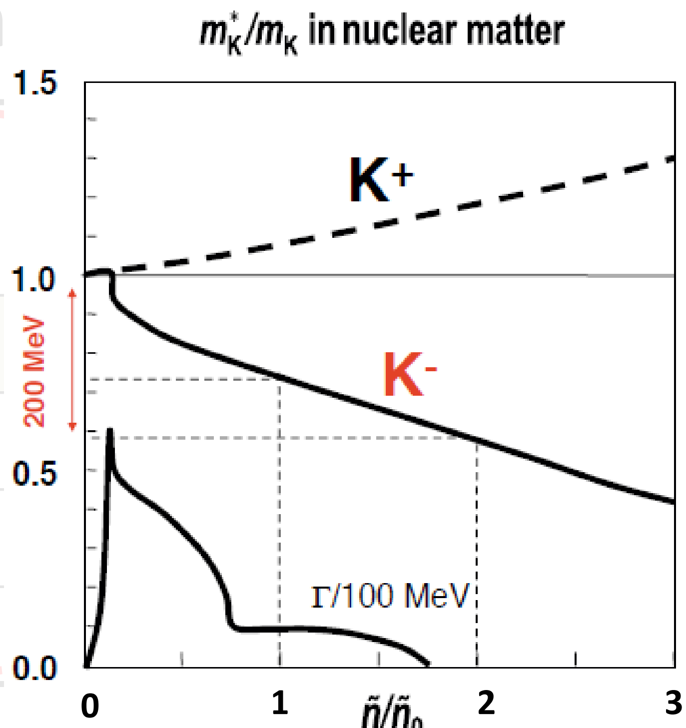
PRL114(2015)132002.

  - considered as a $\bar{K}N$ quasi-bound state

Kaonic Nuclei

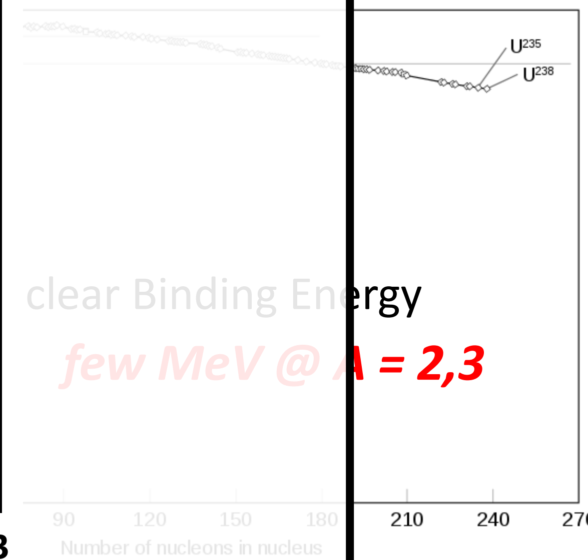
Predicted from … action in I=0

Kaonic Nuclei		Binding Energy [MeV]
Λ(1405) = K⁻p		27
K⁻pp		48
K⁻ppp		97
K⁻ppn		118



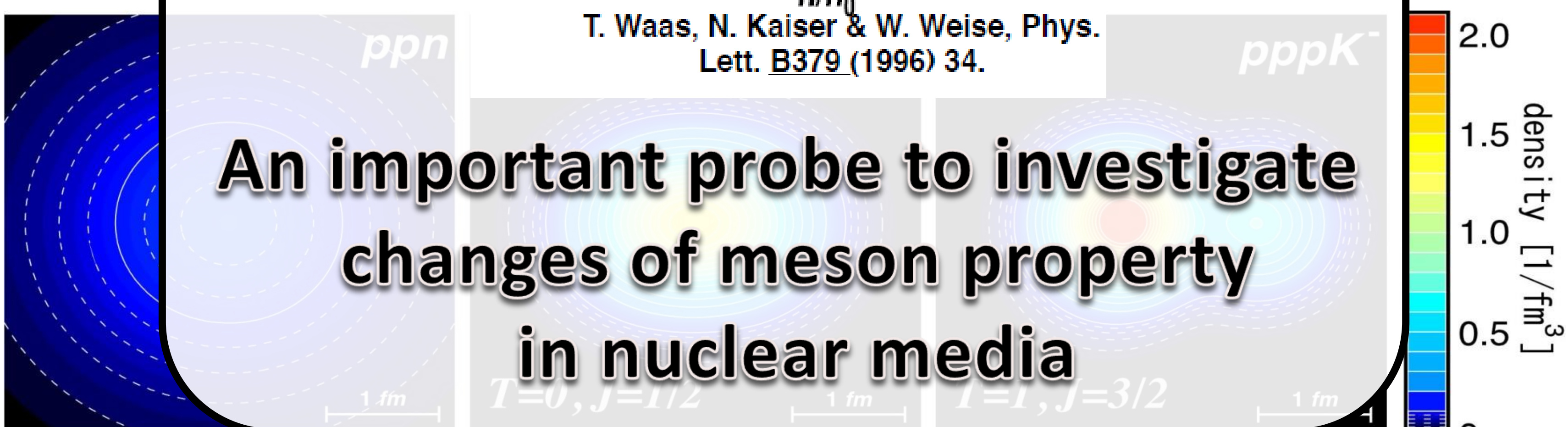
T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

…88., PRC65(2002)044005., etc.

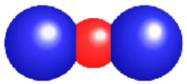


…clear Binding Energy

few MeV @ A = 2,3



An important probe to investigate changes of meson property in nuclear media

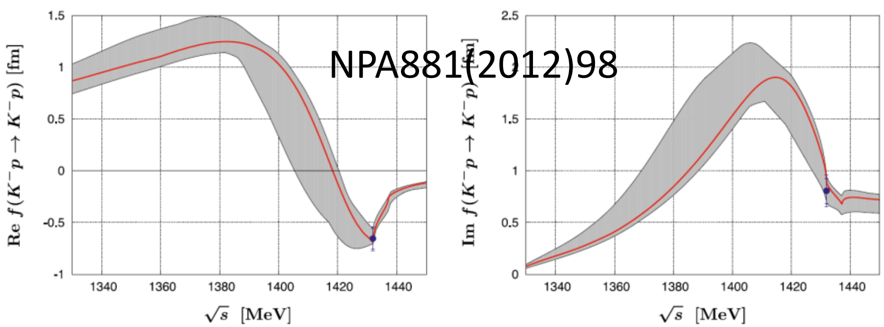


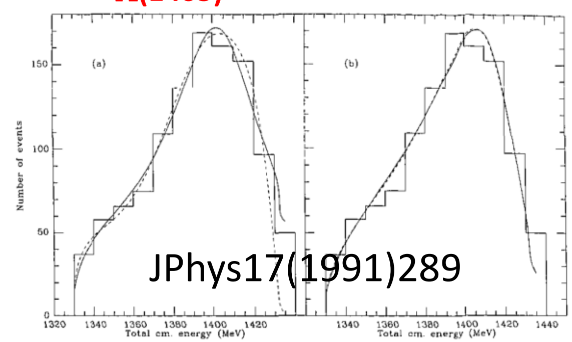
K⁻pp

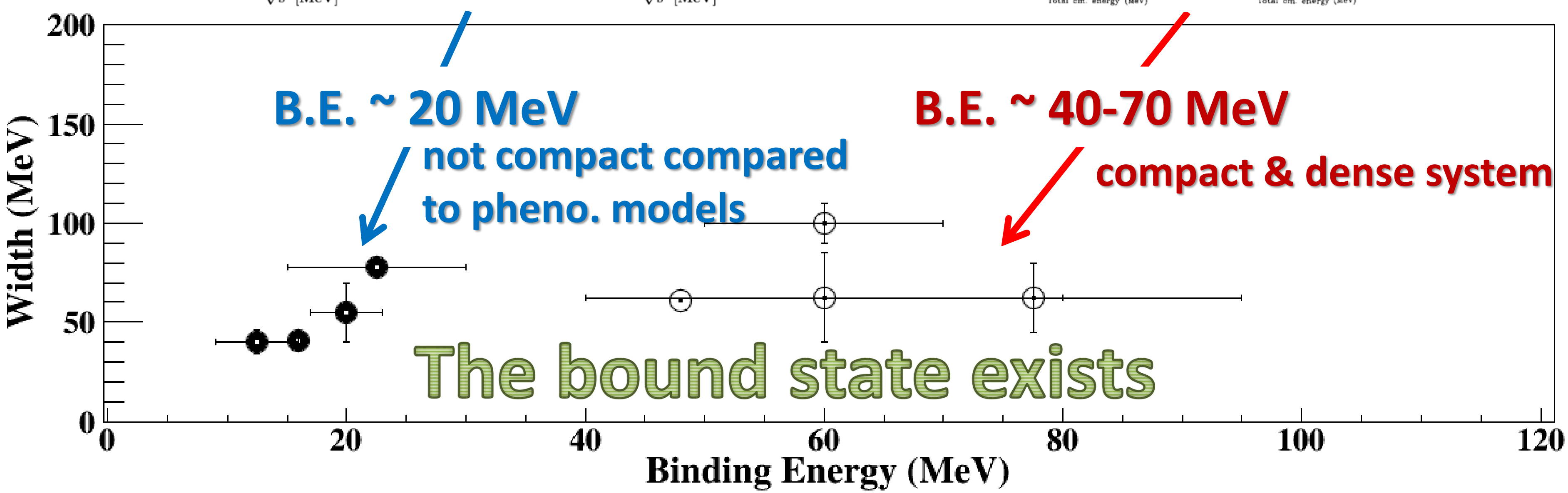
Theoretical Calculations on "K⁻pp"

The simplest kaonic nuclei, $\bar{K}NN$ ($J^P=0^-$, $I=1/2$)

$\bar{K}N$ int.	Chiral SU(3) (energy dependent)	Phenomenological (energy independent)
	$M_{\Lambda(1405)}$~1420, double pole	$M_{\Lambda(1405)}$~1405, single pole







Experimental Situation "before E15"

Negative results

Positive results

AMADEUS@DAΦNE ⟷ **FINUDA@DAΦNE** PRL**94**(2005)212303

$^{12}C(K^-_{stopped}, \Lambda p)$ EPJ**C79**(2019)190

$^{6}Li/^{7}Li/^{12}C(K^-_{stopped}, \Lambda p)$

Multi-NA processes?

HADES@GSI ⟷ **DISTO@SATURNE** PRL**104**(2010)132502

$p + p \rightarrow (\Lambda + p) + K^+$ @ 3.5GeV

PL**B742**(2015)242

$p + p \rightarrow (\Lambda + p) + K^+$ @ 2.85GeV

Intermediate $N^* \rightarrow pK^+$?

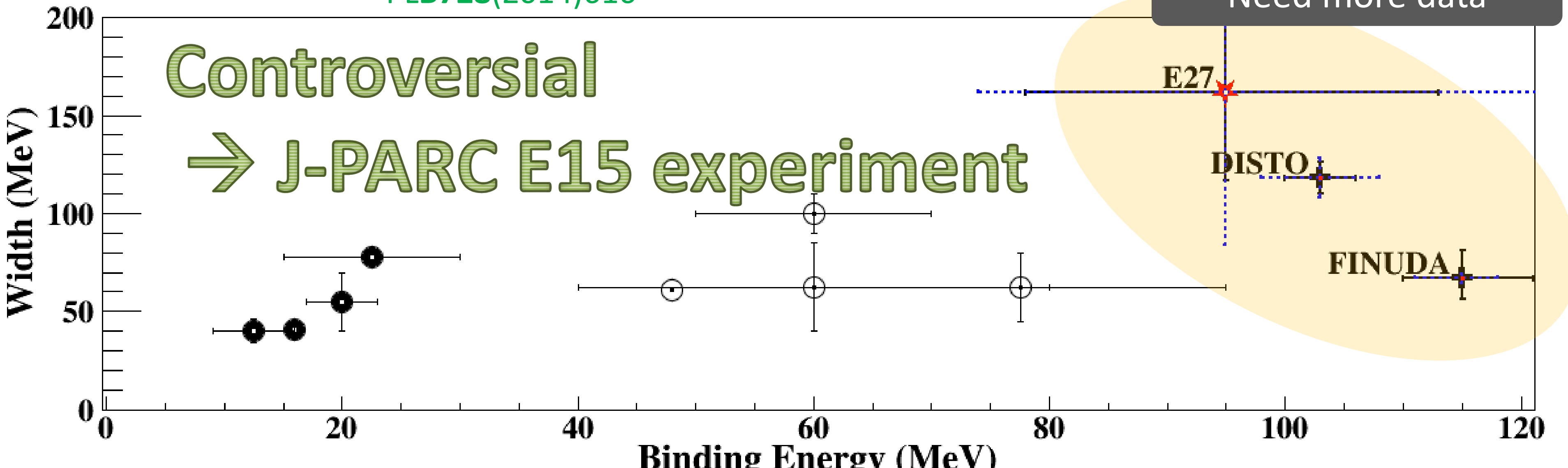
LEPS@SPring-8 ⟷ **E27@J-PARC** PTEP(2015)021D01.

$d(\gamma, \pi^- K^+)X$ @ 1.5-2.4 GeV

$d(\pi^+, K^+)\Sigma^0 p$ @ 1.69 GeV/c

Need more data

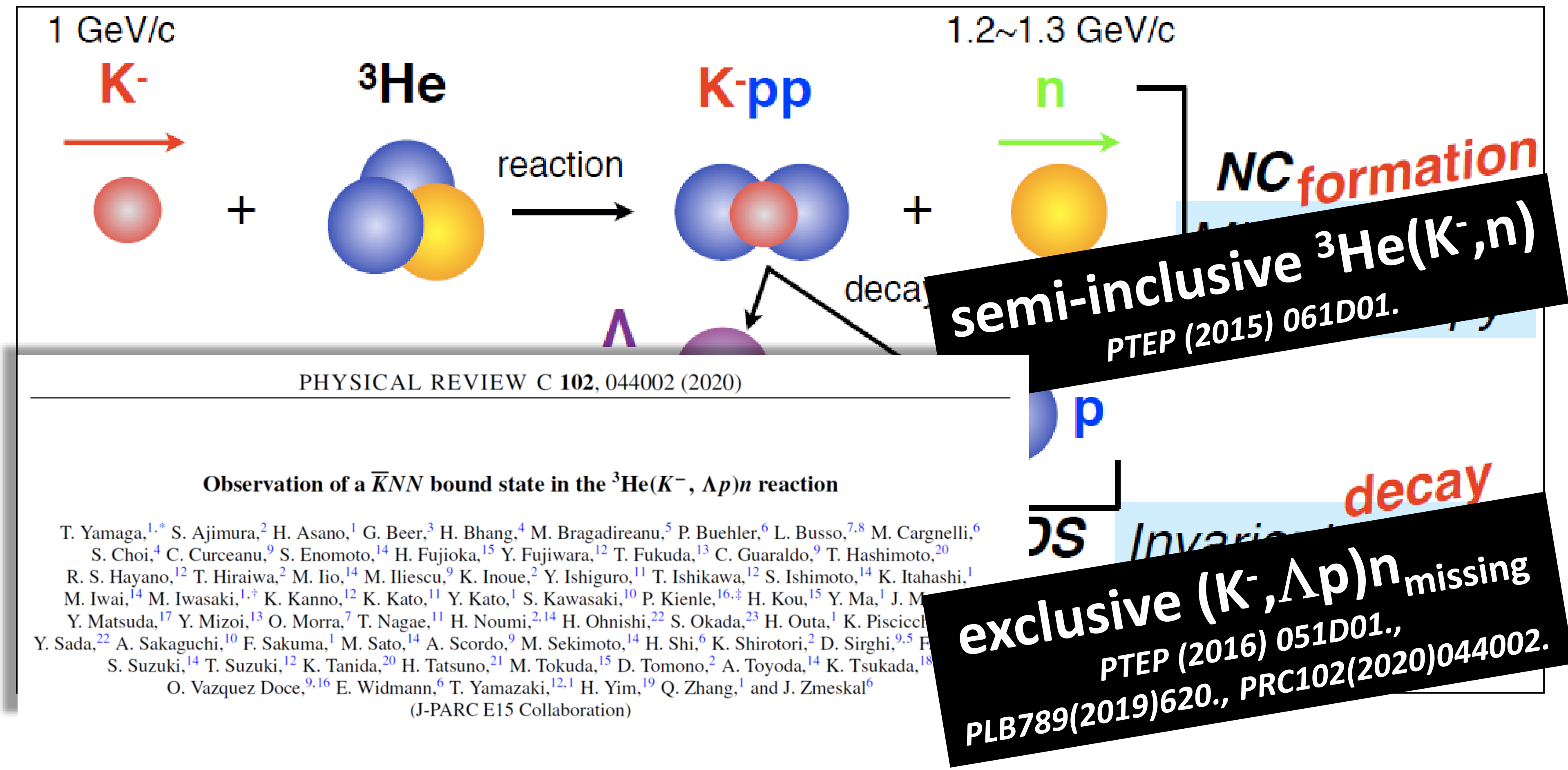
PL**B728**(2014)616



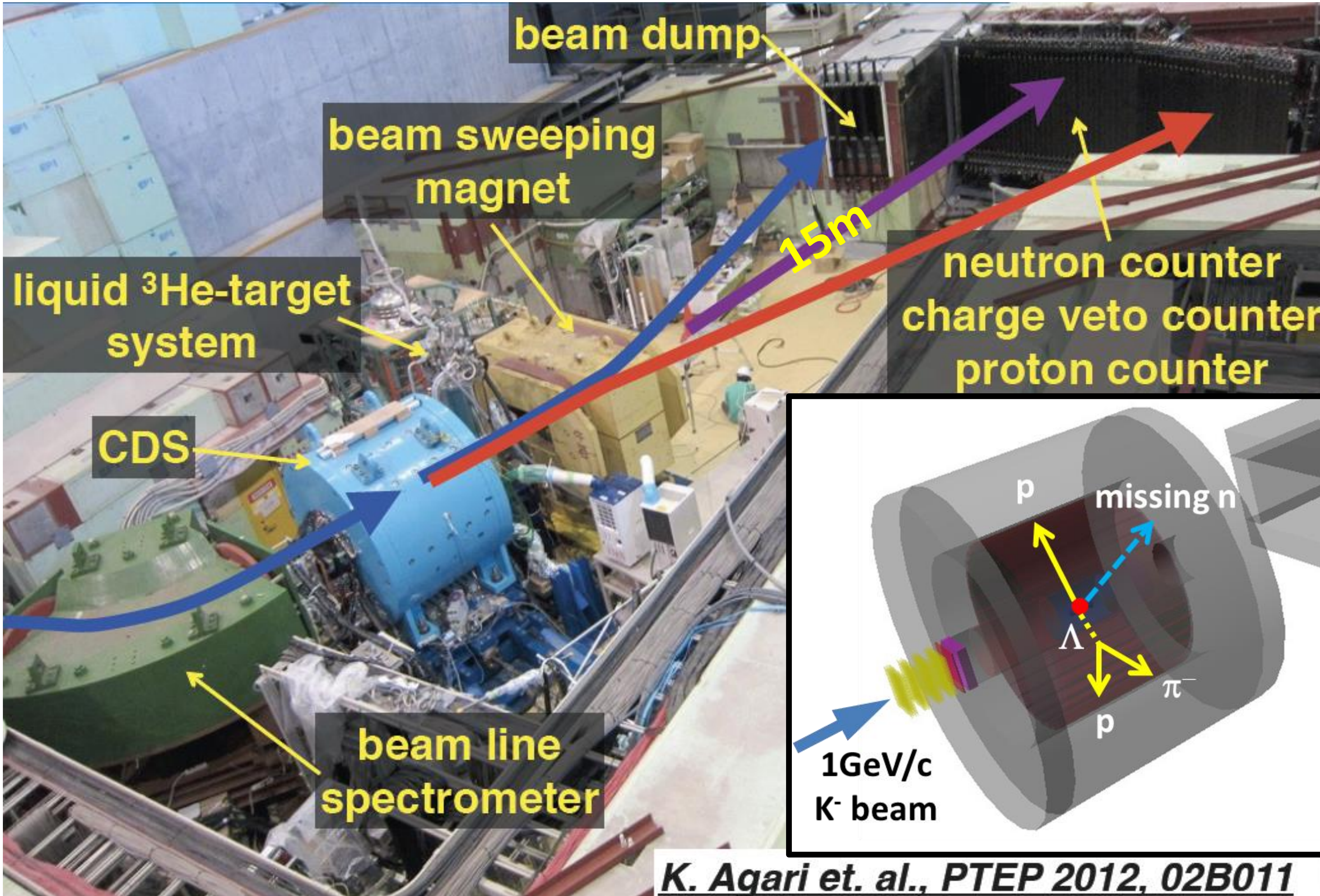
J-PARC E15 Experiment

- ^{3}He(*in-flight* K$^-$,n) reaction @ 1.0 GeV/c

2NΛ and Y decays can be discriminated kinematically



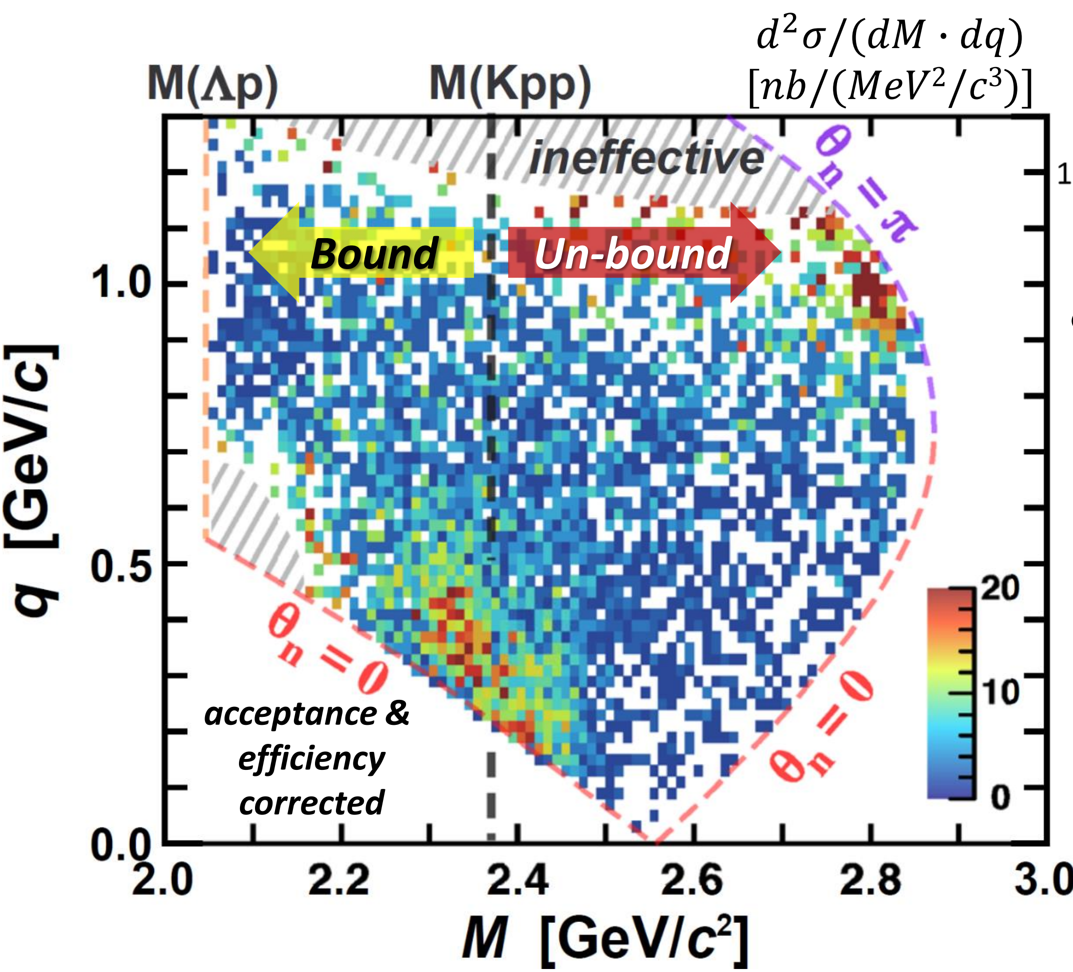
Experimental Setup @ K1.8BR



K. Agari et. al., PTEP 2012, 02B011

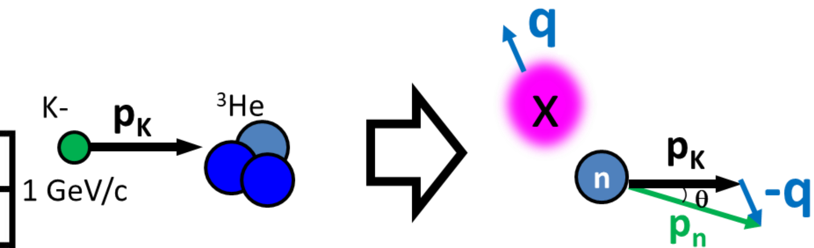
Exclusive ^{3}He(K$^-$,Λp)n

T.Yamaga et. al., PRC102(2020)044002.



q : *momentum transfer of (K-,n)*

M : *invariant mass of Λp*



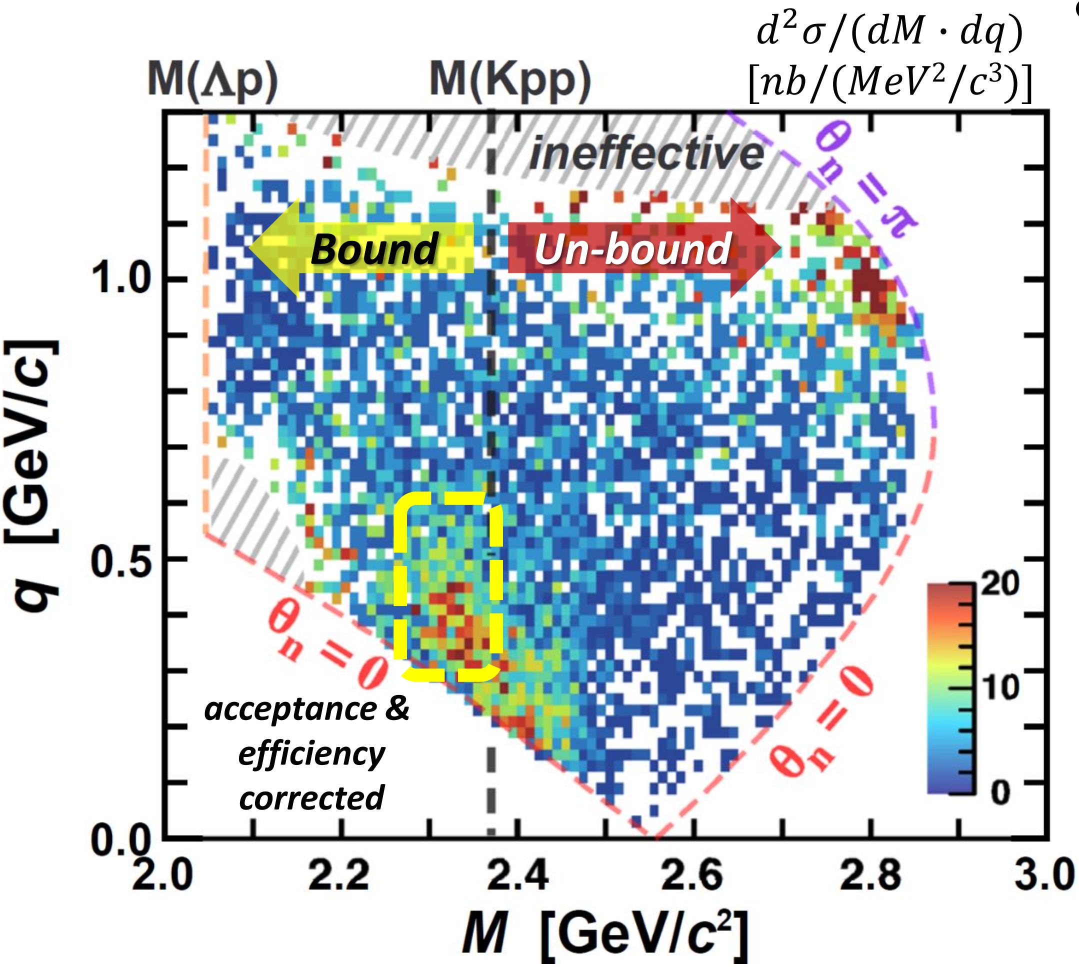
- **Momentum transfer analysis using the (K$^-$,n) reaction**

✓M(Λp) vs. q

✓give a clear information on reaction processes

Exclusive ^{3}He(K$^-$,Λp)n

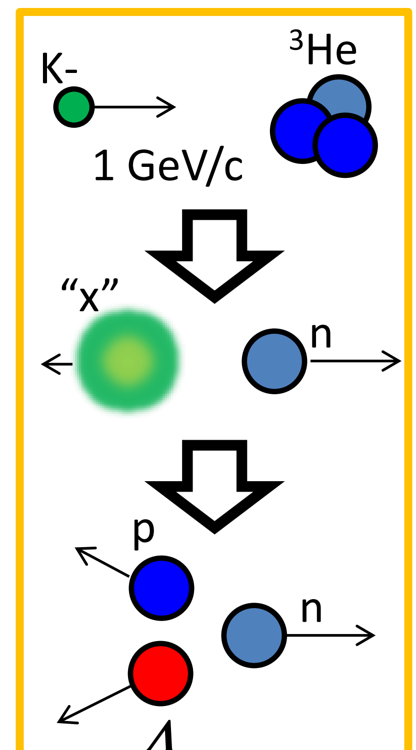
T.Yamaga et. al., PRC102(2020)044002.



q : *momentum transfer of (K-,n)*

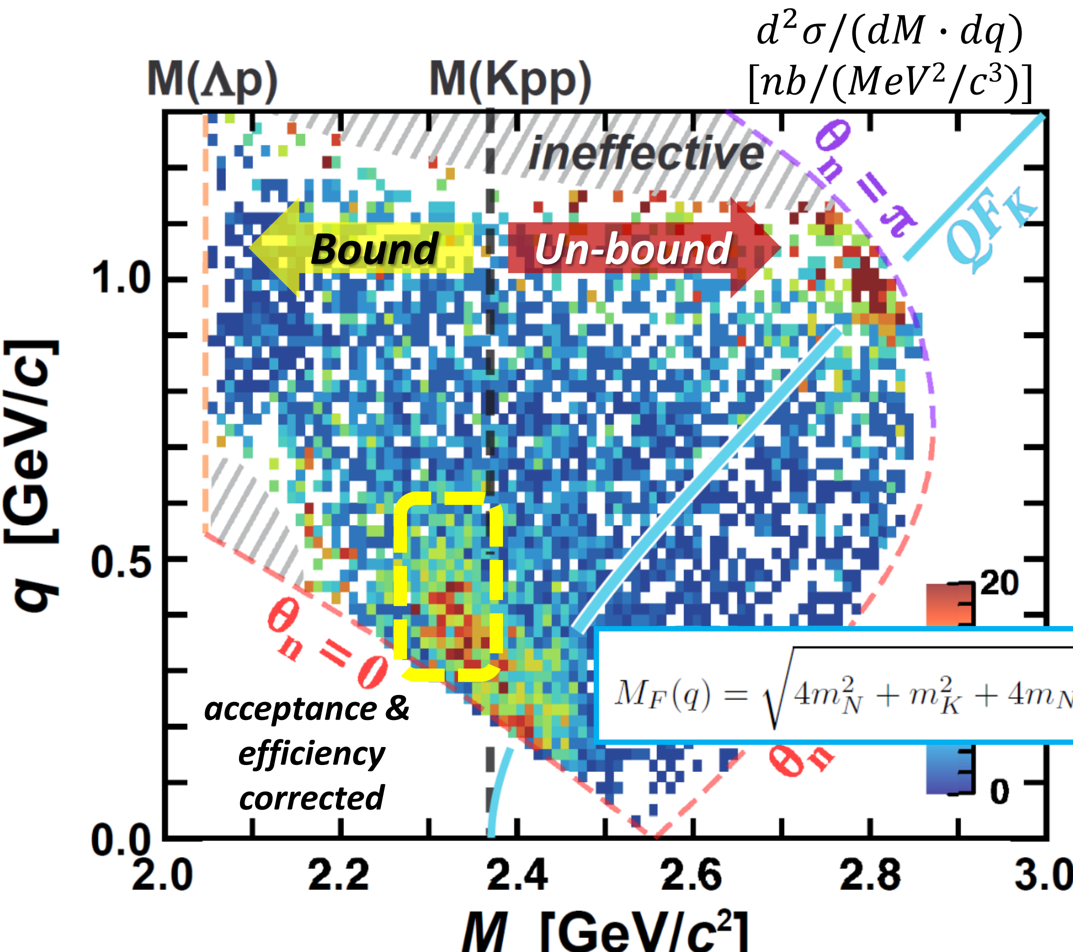
M : *invariant mass of Λp*

- **"K$^-$pp" bound state exists**
  - ✓ q-independent



Exclusive ^{3}He(K$^-$,Λp)n

T.Yamaga et. al., PRC102(2020)044002.

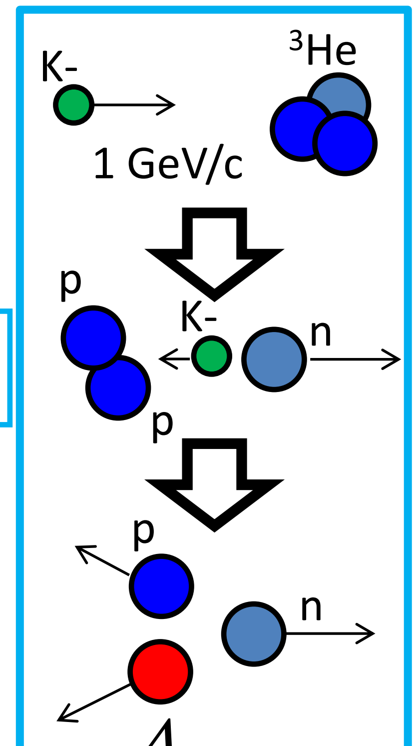


$$M_F(q) = \sqrt{4m_N^2 + m_K^2 + 4m_N\sqrt{m_K^2 + q^2}},$$

q : *momentum transfer of (K-,n)*

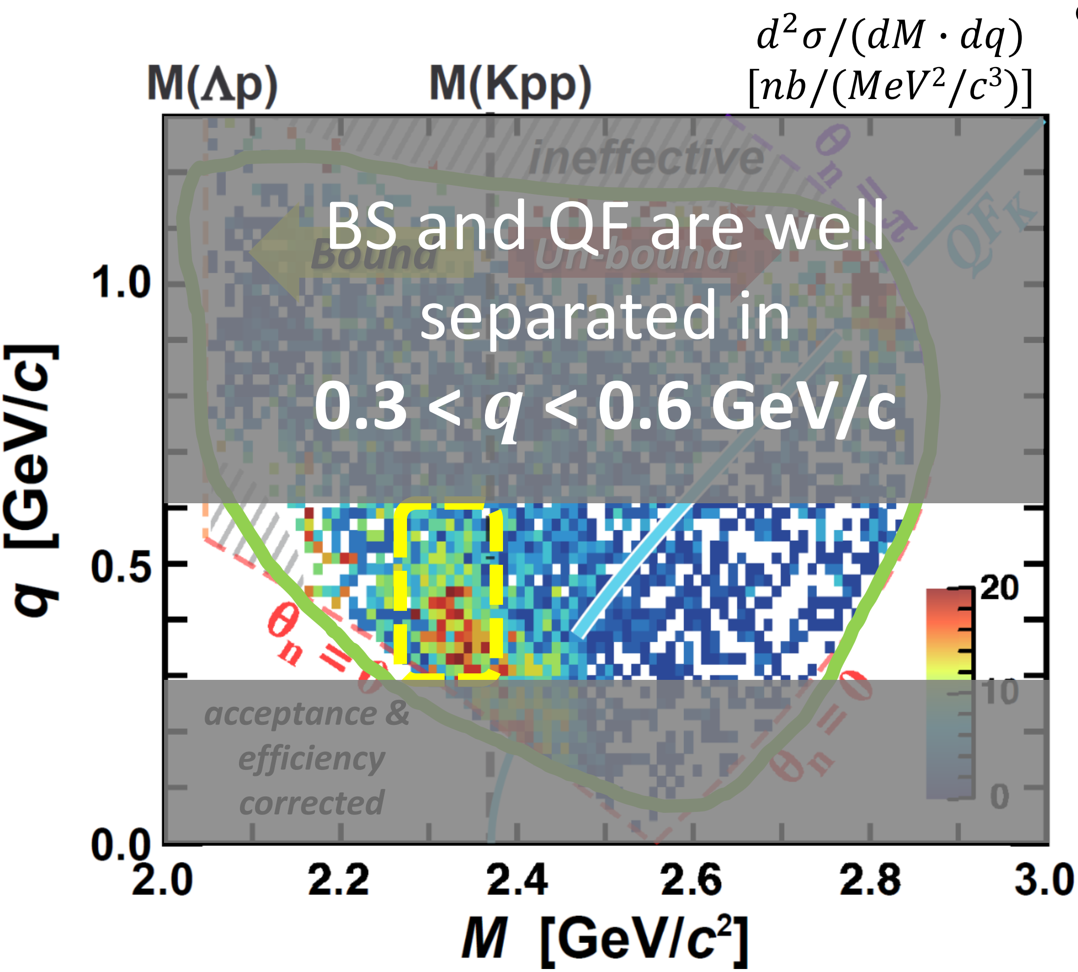
M : *invariant mass of Λp*

- **QF followed by 2NA**
  - ✓via "on-shell K$^-$"
  - ✓q-dependent



Exclusive ^{3}He(K^{-},Λp)n

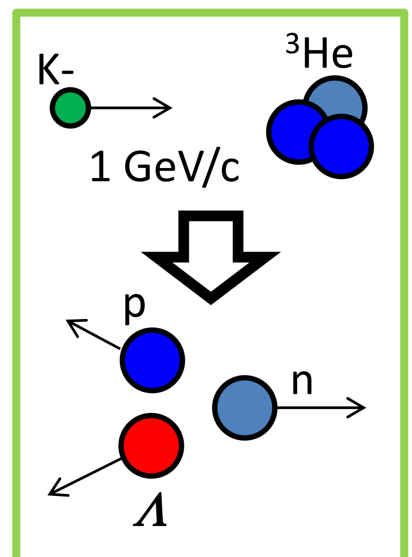
T.Yamaga et. al., PRC102(2020)044002.



q : momentum transfer of (K-,n)

M : invariant mass of *Λ*p

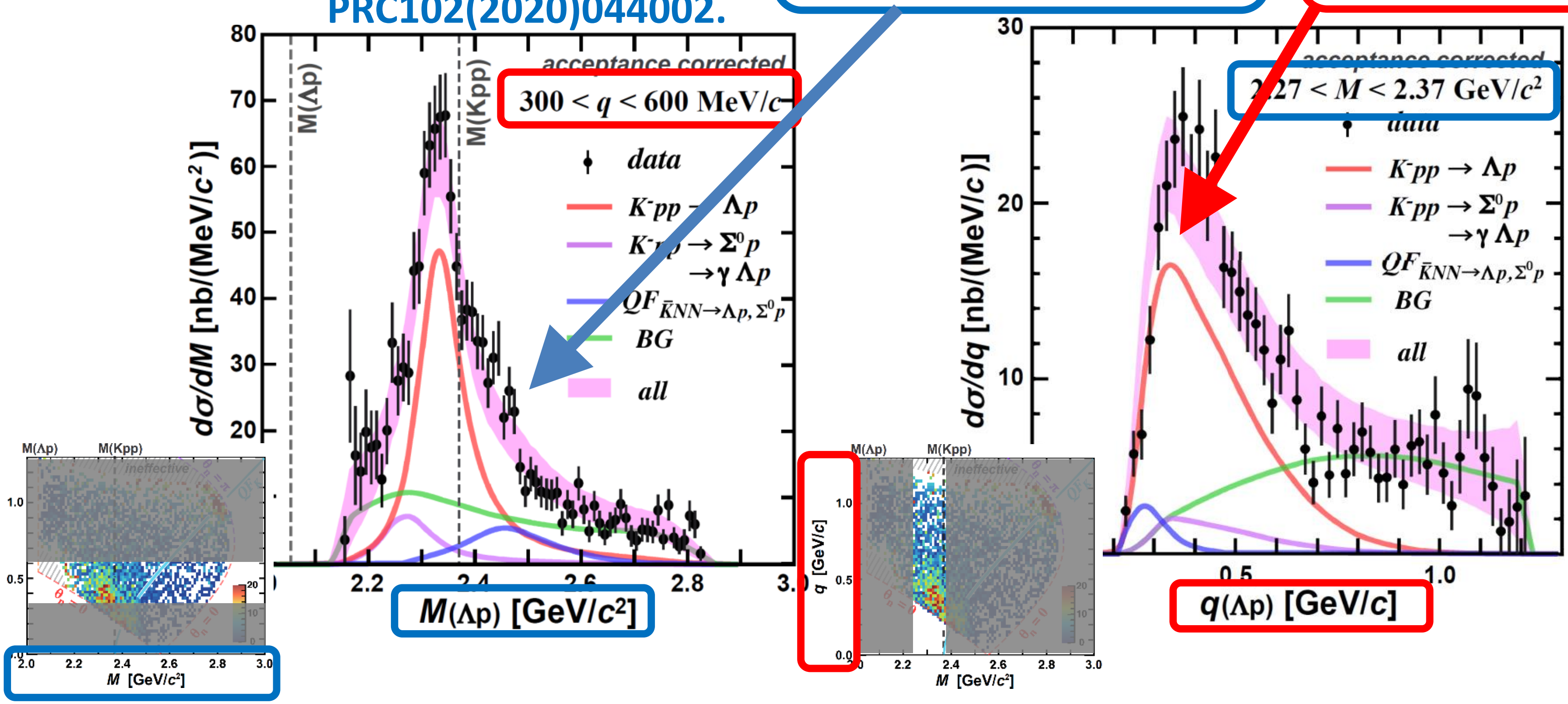
- **Broad Component**
  - ✓3NA reaction?
  - ✓Further investigations are ongoing



"K-pp" Bound State

Fit with PWIA $\sigma(M,q) \propto \rho(M,q) \times \frac{(\Gamma_{Kpp}/2)^2}{(M-M_{Kpp})^2+(\Gamma_{Kpp}/2)^2} \times exp\left(-\frac{q^2}{{Q_{Kpp}}^2}\right)$

PRC102(2020)044002.

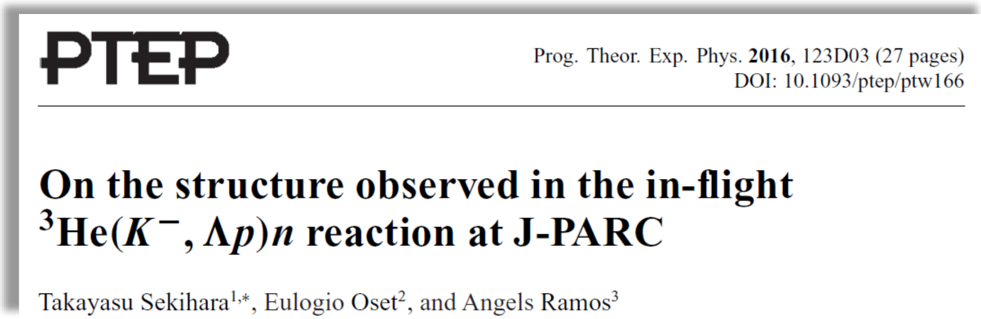


B_{Kpp} ~ 40 MeV, Γ_{Kpp} ~ 100 MeV
→ *large binding energy*

Q_{kpp} ~ 400 MeV (c.f. Q_{QF} ~ 200 MeV)
→ *wide momentum transfer*

A Theoretical Interpretation

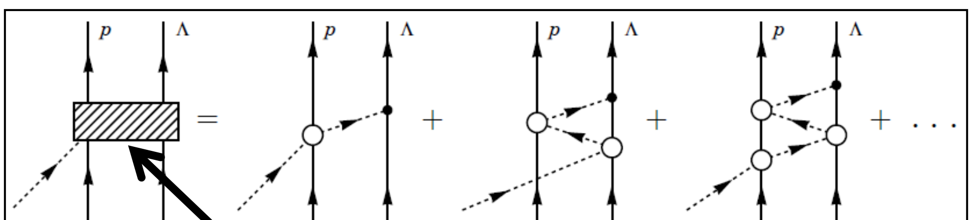
- A calculation with chiral unitary approach reproduces the mass spectrum with the $\bar{K}NN$

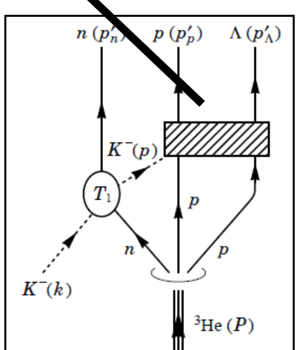

PTEP

Prog. Theor. Exp. Phys. **2016**, 123D03 (27 pages)
DOI: 10.1093/ptep/ptw166

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

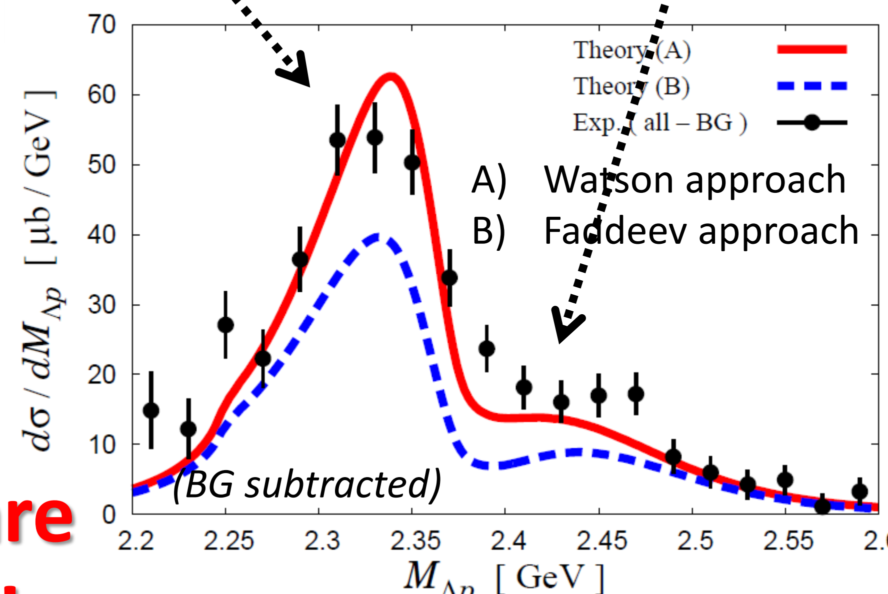
Takayasu Sekihara[1,*], Eulogio Oset[2], and Angels Ramos[3]





Kbar NN bound-state

quasi-elastic kaon scattering



Theoretical investigations are indispensable!

JPS Conf. Proc.26(2019)023009.

Size of "K⁻pp"?

Fit with PWIA $\sigma(M,q) \propto \rho(M,q) \times \frac{(\Gamma_{Kpp}/2)^2}{(M-M_{Kpp})^2+(\Gamma_{Kpp}/2)^2} \times exp\left(-\frac{q^2}{{Q_{Kpp}}^2}\right)$

B_{Kpp} ~ 40 MeV
→ *large binding energy*

Q_{kpp} ~ 400 MeV
→ *wide momentum transfer*

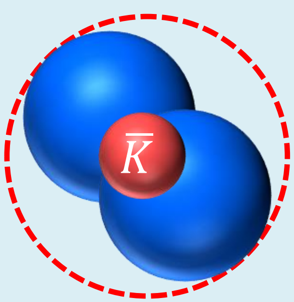
suggest the "K⁻pp" is quite compact (R_{Kpp} ~ 0.6 fm)

→ *Need more realistic theoretical calculations*

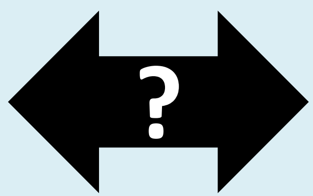
a whole new probe to reveal
the structure of a nucleon

Still an open question ($\bar{K}N$ – strong force)

Radius of "K⁻pp"



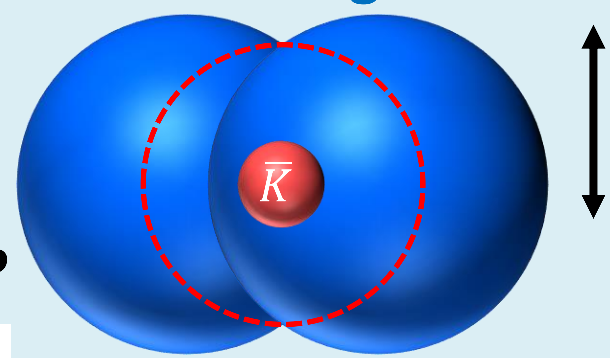
~ 0.6 fm



& effect of K size?

Charge radius
$\langle r \rangle = 0.560 \pm 0.031$ fm

Interaction range of "K⁻"



~ 0.8 fm

~ 0.6 fm

Many Questions to be Answered

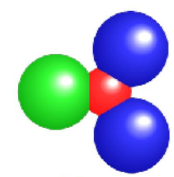
- Further details of the $\bar{K}NN$
  - Spin and parity of the "K⁻pp"?
  - Really compact and dense system?

K⁻pp

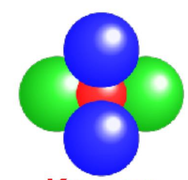
- $\Lambda(1405)$ state
  - $\bar{K}N$ quasi-bound state as considered?
  - Size?
  - Relation between $\bar{K}N$ and $\bar{K}NN$?

K⁻p

- **More heavier kaonic nuclei?**
  - Mass number dependence?



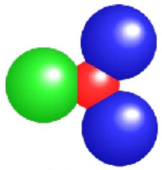
K⁻ppn



K⁻ppnn

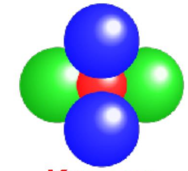
- Double kaonic nuclei?
  - Much compact and dense system?

K⁻K⁻pp



K⁻ppn

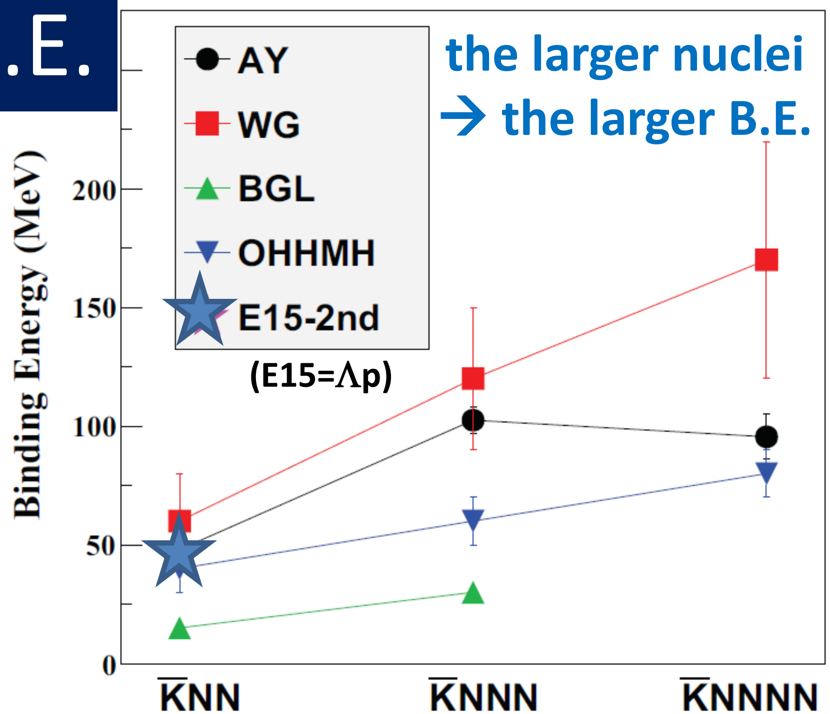
$\bar{K}NNN$ and $\bar{K}NNNN$



K⁻ppnn

- More heavier system must be explored to provide more conclusive evidence of the kaonic nuclei

B.E.



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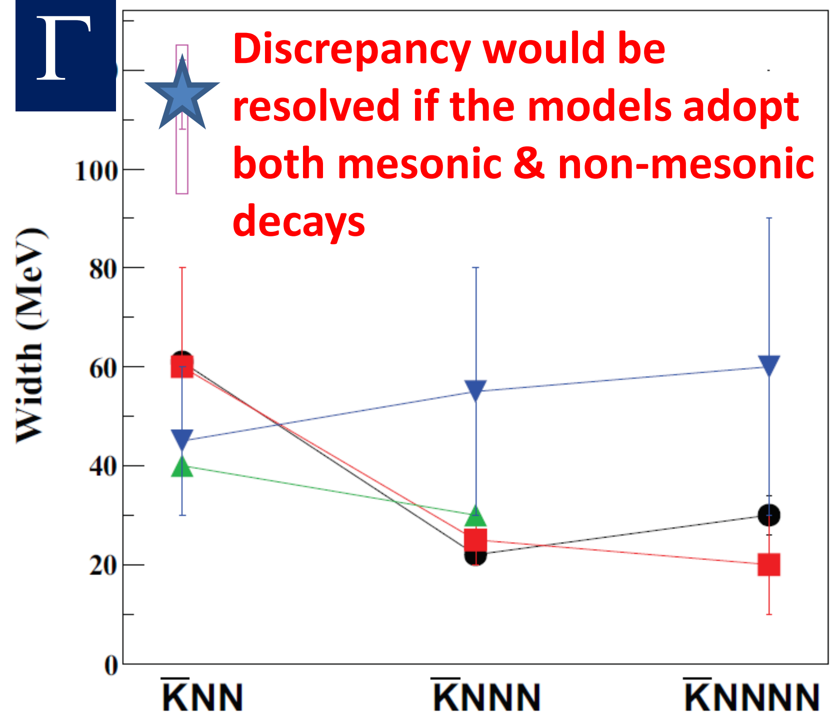
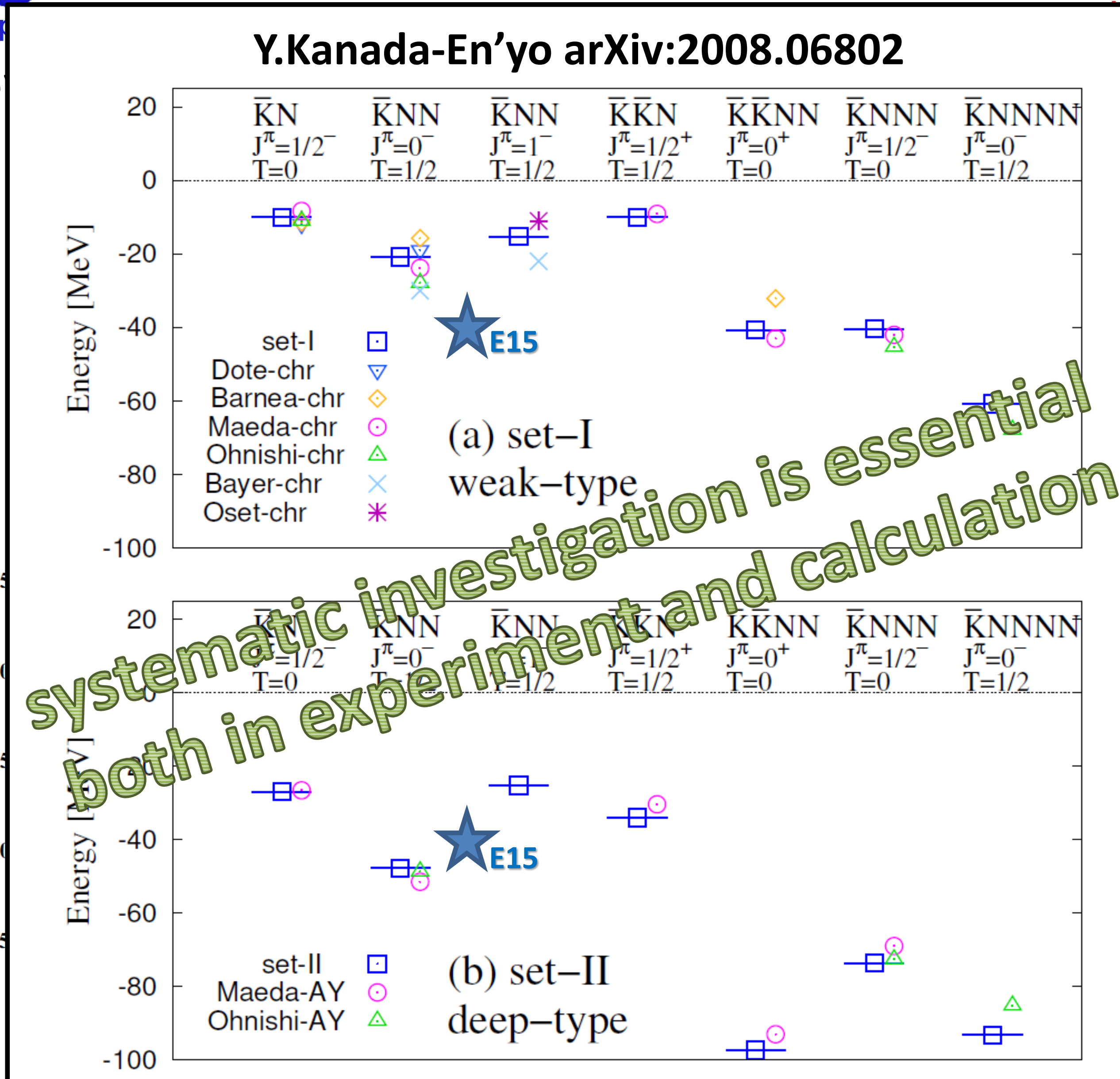


➢ The $\bar{K}NNNN$ system is expected to be the most compact system due to an α particle configuration

$\bar{K}NNN$ and $\bar{K}NNNN$

K⁻pp ... ppnn

- Be... ust
  be...
  - ✓ ... to be
    ...e



if

...onic

Binding Energy (MeV)

...NNNN

New Project @ J-PARC

-- systematic investigation of the light kaonic nuclei --

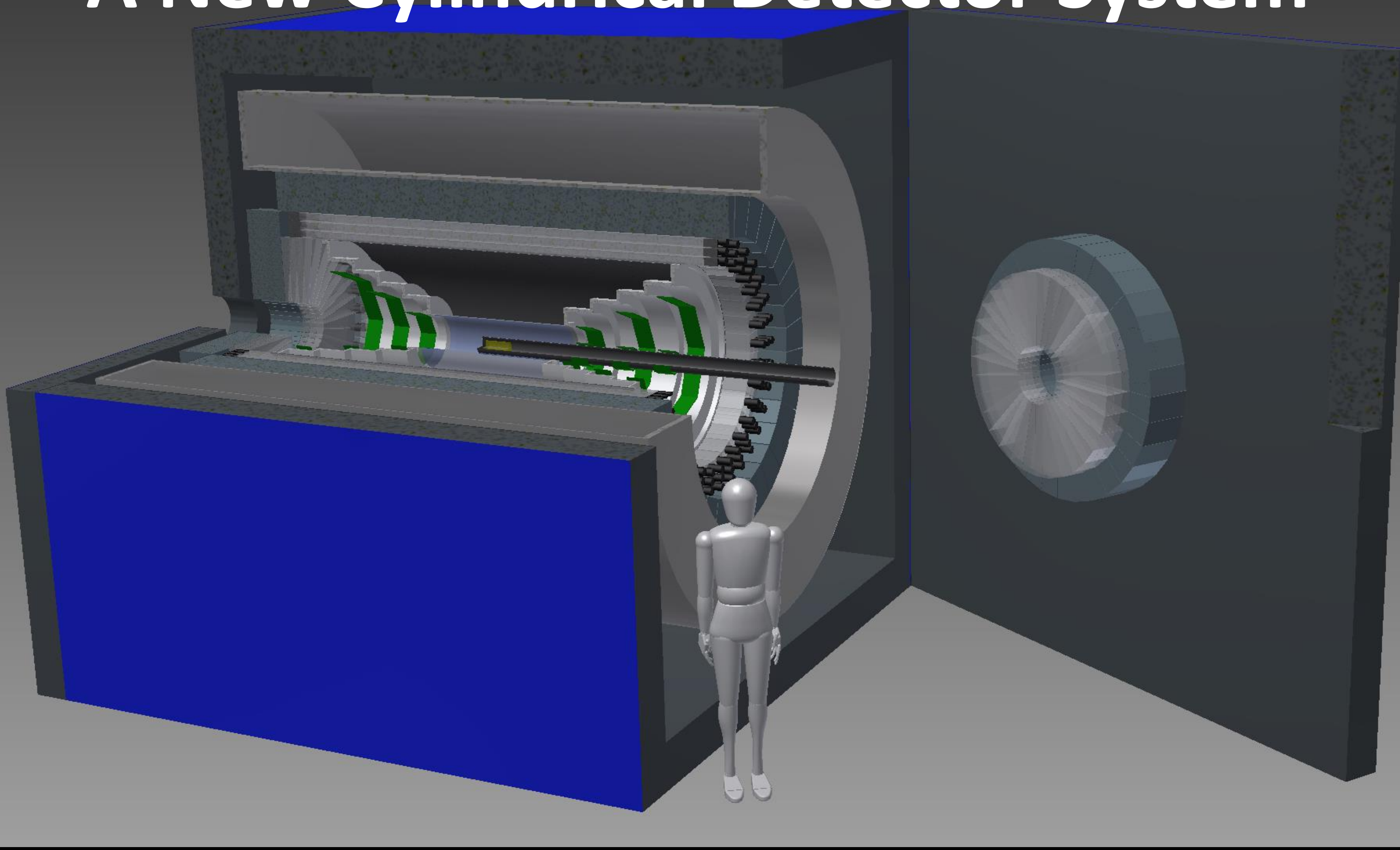
Strategy of the New Project

- for systematic study from the $\bar{K}N$ to $\bar{K}NNNN$ systems -

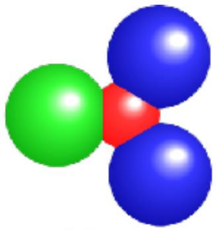
	Reaction	Decays	Key
$\bar{K}N$	d(K⁻,n)	$\pi^{\pm 0}\Sigma^{\mp 0}$	F-factor → n/γ identification
$\bar{K}NN$	^{3}He(K⁻,N)	Λp/Λn	J^P → polarimeter
$\bar{K}NNN$	^{4}He(K⁻,N)	Λd/Λpn	large acceptance **← A first step**
$\bar{K}NNNN$	*^{6}Li(K⁻,d)*	*Λt/Λdn/Λpnn*	*many body decay*
$\bar{K}\bar{K}NN$	*$\bar{p}$ + ^{3}He*	*ΛΛ*	*$\bar{p}$ beam yield*

- To realize the systematic measurements, we need
  - ☐ **a large acceptance spectrometer** **← new CDS**
    - detect/identify all particles to specify the reaction
  - ☐ **high-intensity kaon beam** **← modified K1.8BR**
    - more K⁻ yield than the existing beamline
- *We take a **step-by-step** approach*

A New Cylindrical Detector System



A new 4π spectrometer with n/γ detection capability



K⁻ppn

Expected Spectra of $K^{-}+{}^{4}He$

B_{Kppn} ~ 40 MeV

Γ_{Kppn} ~ 100 MeV

Q_{kppn} ~ 400 MeV/c

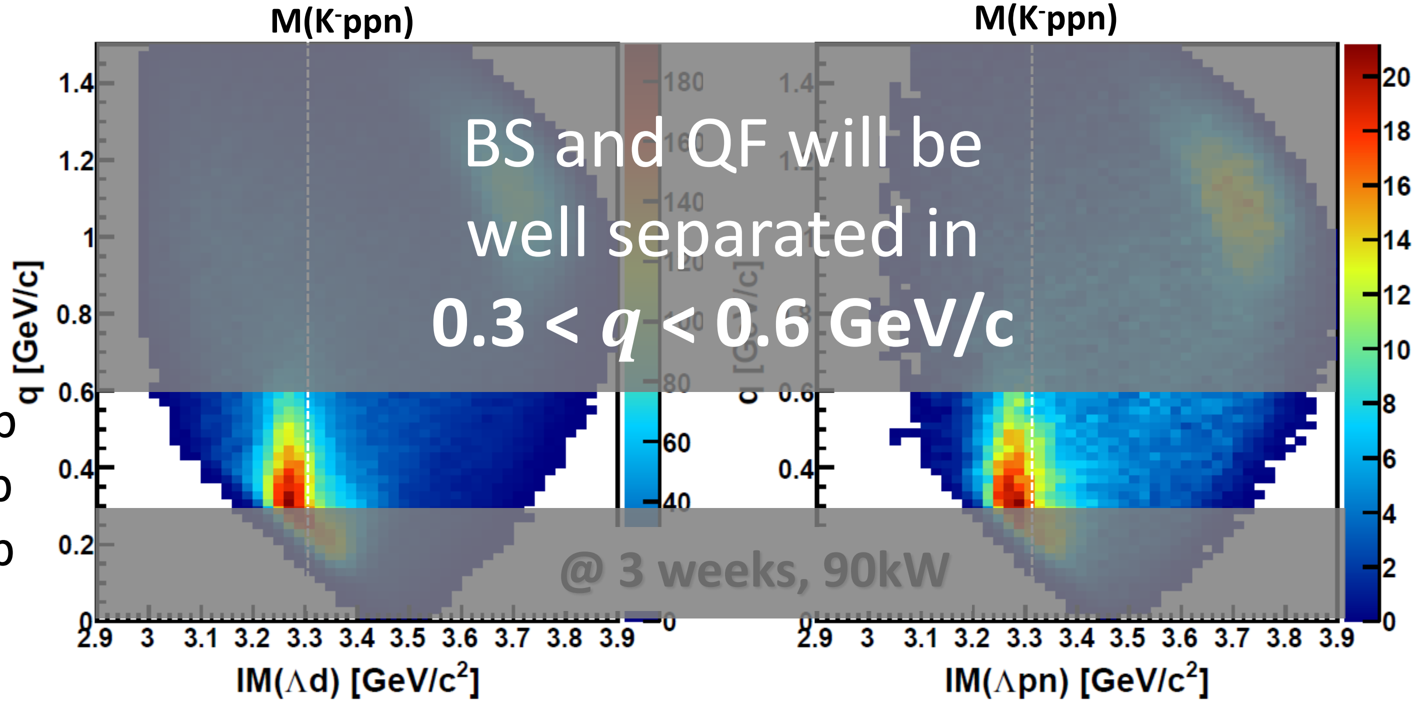
$\sigma(K^{-}ppn)*Br$ ~ 10 μb

$\sigma(QF)$ ~ 10 μb

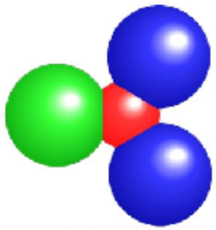
$\sigma(BG)$ ~ 20 μb

$K^{-}+{}^{4}He \rightarrow \Lambda d+n$

$K^{-}+{}^{4}He \rightarrow \Lambda pn+n$



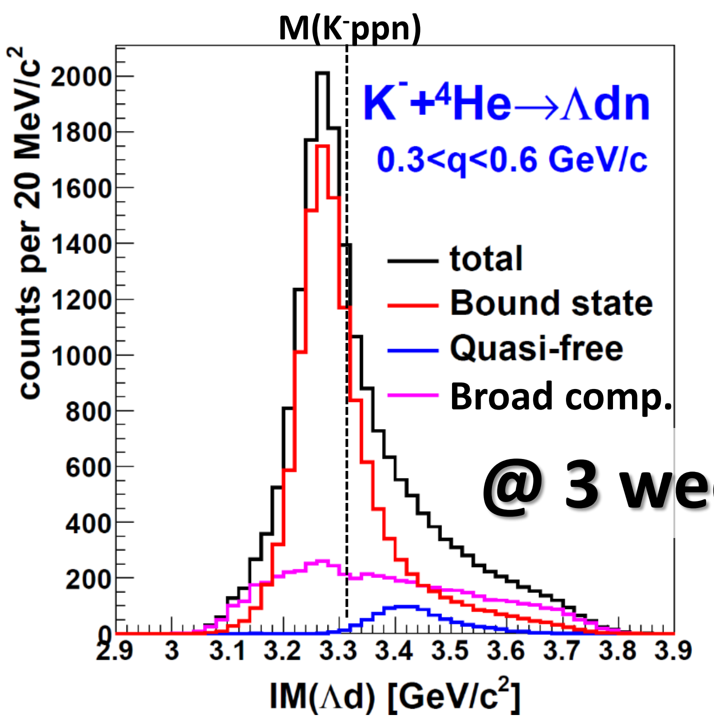
- Similar parameters obtained with the $K^{-}+{}^{3}He \rightarrow \Lambda pn$ (PRC102(2020)044002.) are adopted to $K^{-}ppn$/QF/BG shapes
- **K-ppn signal [<u>q-independent</u>] will be seen clearly**

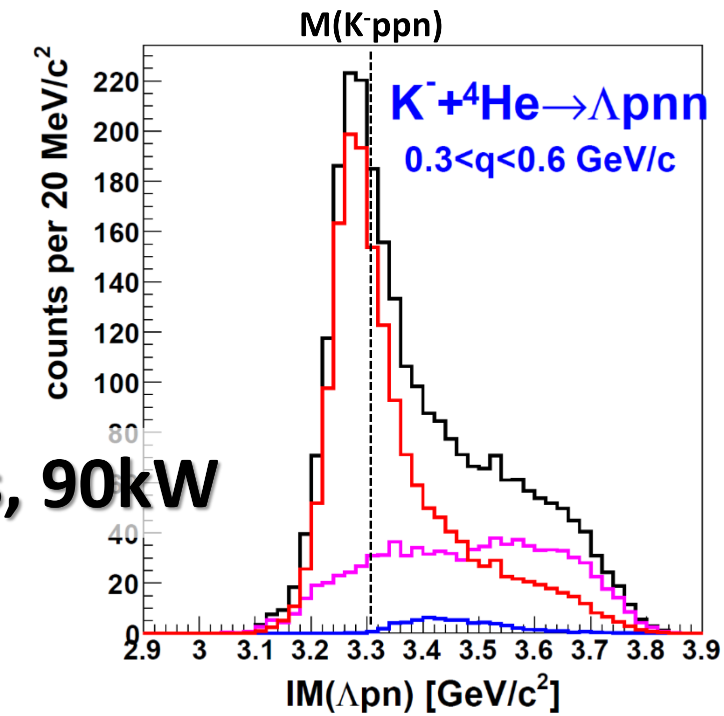


Expected Spectra of $K^{-}+{}^{4}He$

$K^{-}+{}^{4}He \rightarrow \Lambda d+n$

$K^{-}+{}^{4}He \rightarrow \Lambda pn+n$





@ 3 weeks, 90kW

- Assumption: similar parameters obtained at E15
- **Mass-number dependence of the kaonic nuclei will be provided for the first time.**

Summary

- **We observed the "K^-pp" bound state in $^3He(K^-,\Lambda p)n$**
  - ✓ PLB789(2019)620., PRC102(2020)044002.
- **As the next step, the new project has been launched to reveal the properties of the light kaonic nuclei from the $\bar{K}N$ to $\bar{K}NNNN$**
  - ➢ a powerful probe to understand low energy QCD
  - ➢ the best approach to cold & high-density nuclear matter
- We take a step-by-step approach:
  - **a $\bar{K}NNN$ search via 4He(K-,N) reactions as a first step**
  - followed by a spin/parity measurement of the $\bar{K}NN$, soon
  - experimental challenges of $\bar{K}N$, $\bar{K}NNNN$, and $\bar{K}\bar{K}NN$ will also be followed

J-PARC E15 Collaboration

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J-PARC P80 Collaboration

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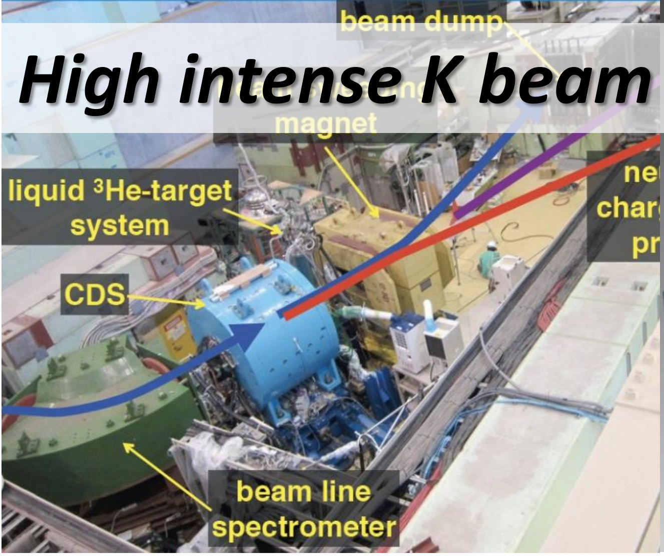
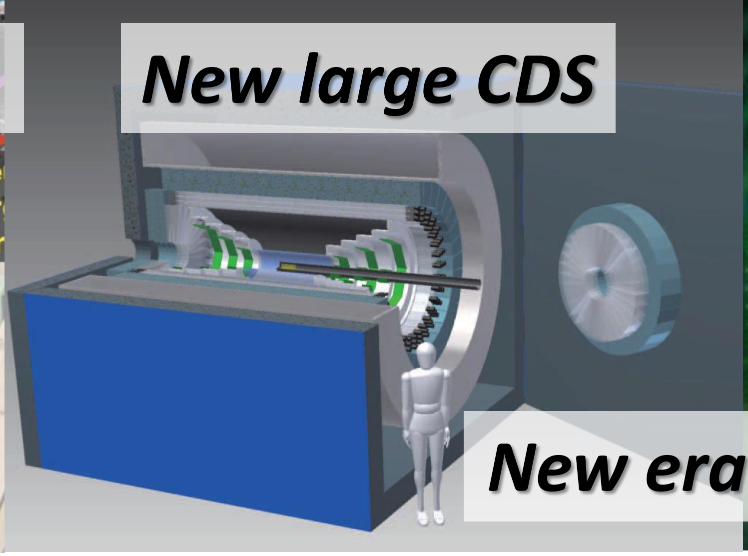
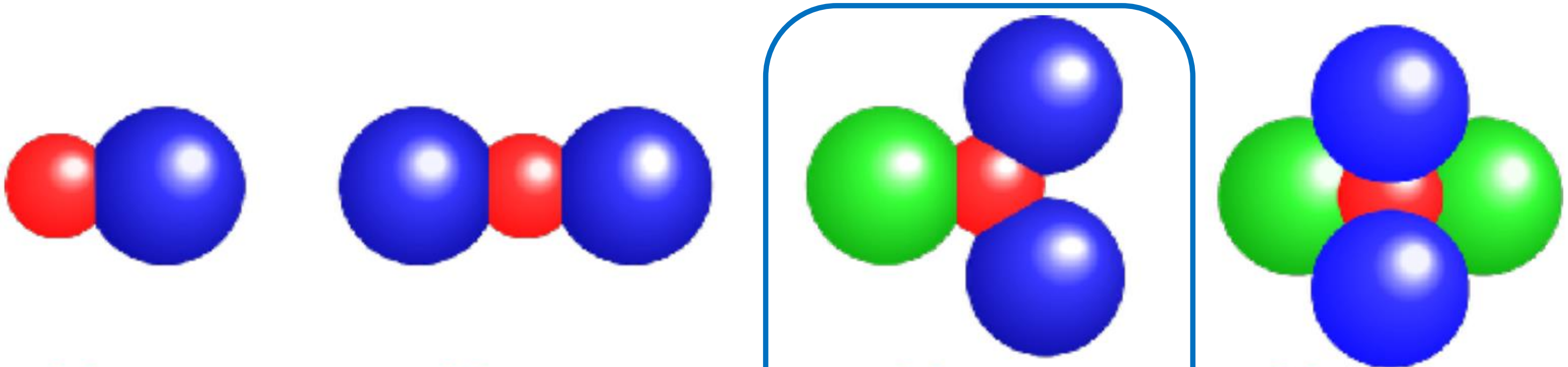
We're looking for new collaborators!





Thank you for your attention!

A first step of the new project



K^-p K^-pp K^-ppn K^-ppnn

via in-flight $^4He(K^-,N)$

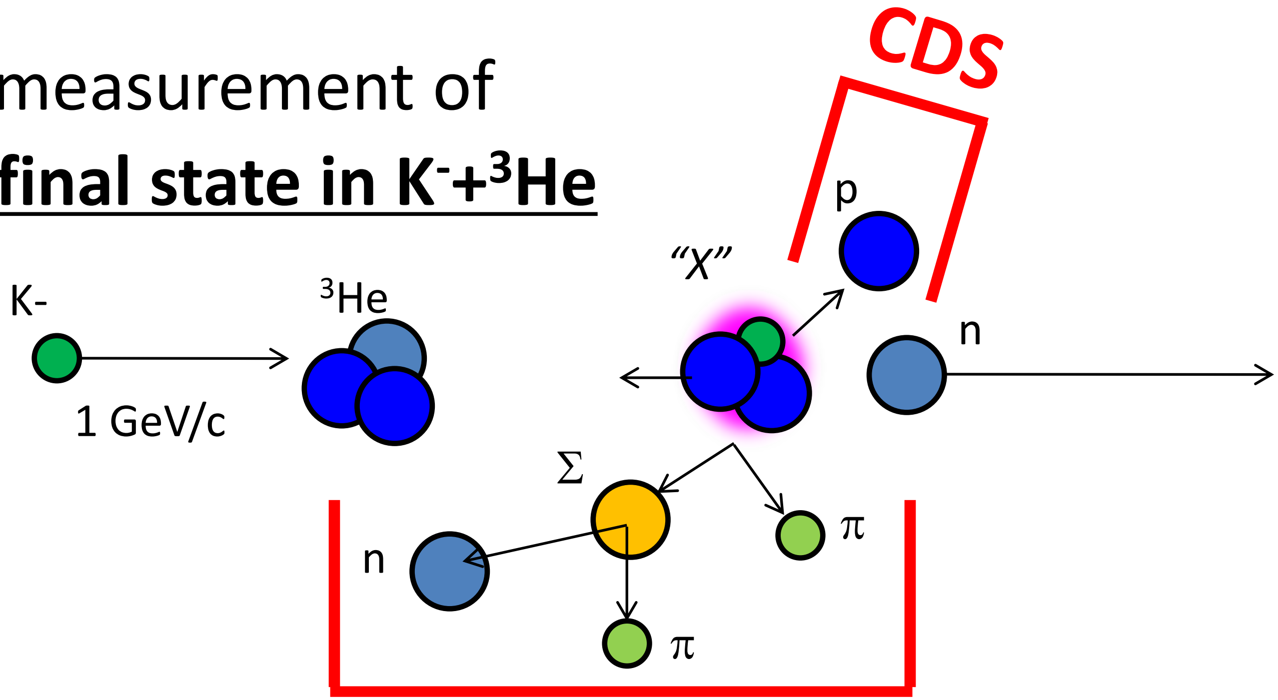
Many Questions to be Answered

- **Further details of the $\bar{K}NN$**
  - Spin and parity of the "K^-pp"?
  - Really compact and dense system?
  - Other decay modes?

- **πΣN mesonic decay**
  - expected to be the dominant channel
    - only YN non-mesonic decays were reported
- **Reaction mechanism**
  - relation between Λ(1405)="K^-p" & "K^-pp"
    - "K^-pp" is expected to be produced via Λ(1405)+p→"K^-pp" door-way process

K^{-} $^{3}He \rightarrow \pi\Sigma pn$ @ E15

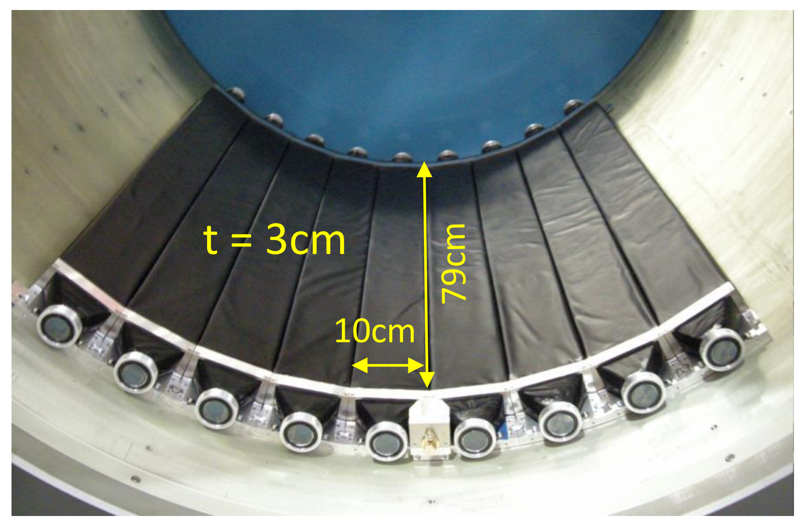
- Exclusive measurement of **$\pi^{\pm}\Sigma^{\mp}pn$ final state in K^{-}+^{3}He**



- **Experimental challenge** of neutron detection with thin scintillation counter (t=3cm)

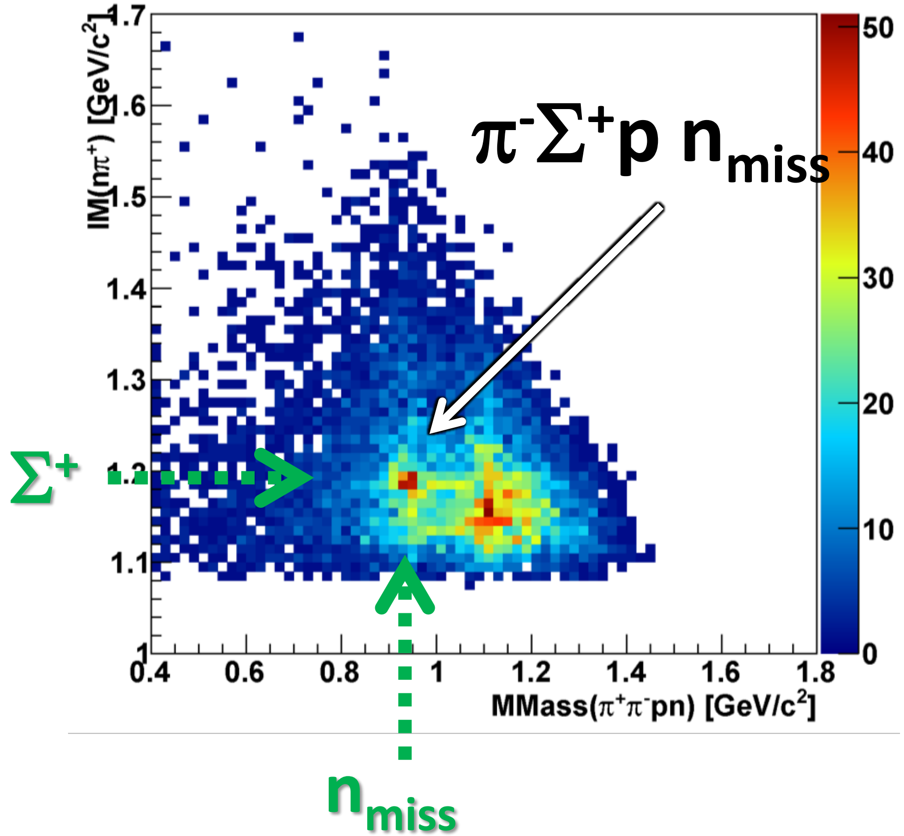
  n detection efficiency ~ 3-10%

CDS

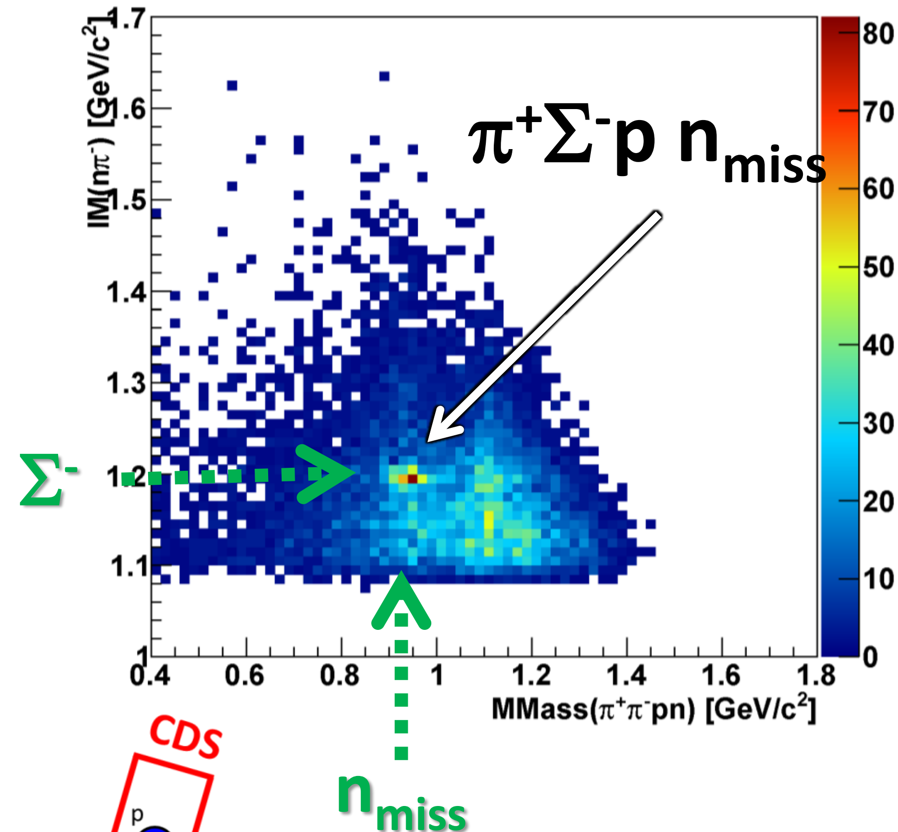


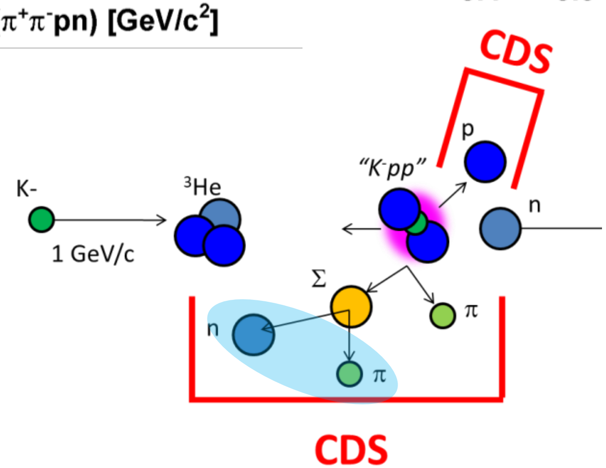
πΣpn Events

IM($n\pi^+$) vs MM($\pi^+\pi^-pn$)

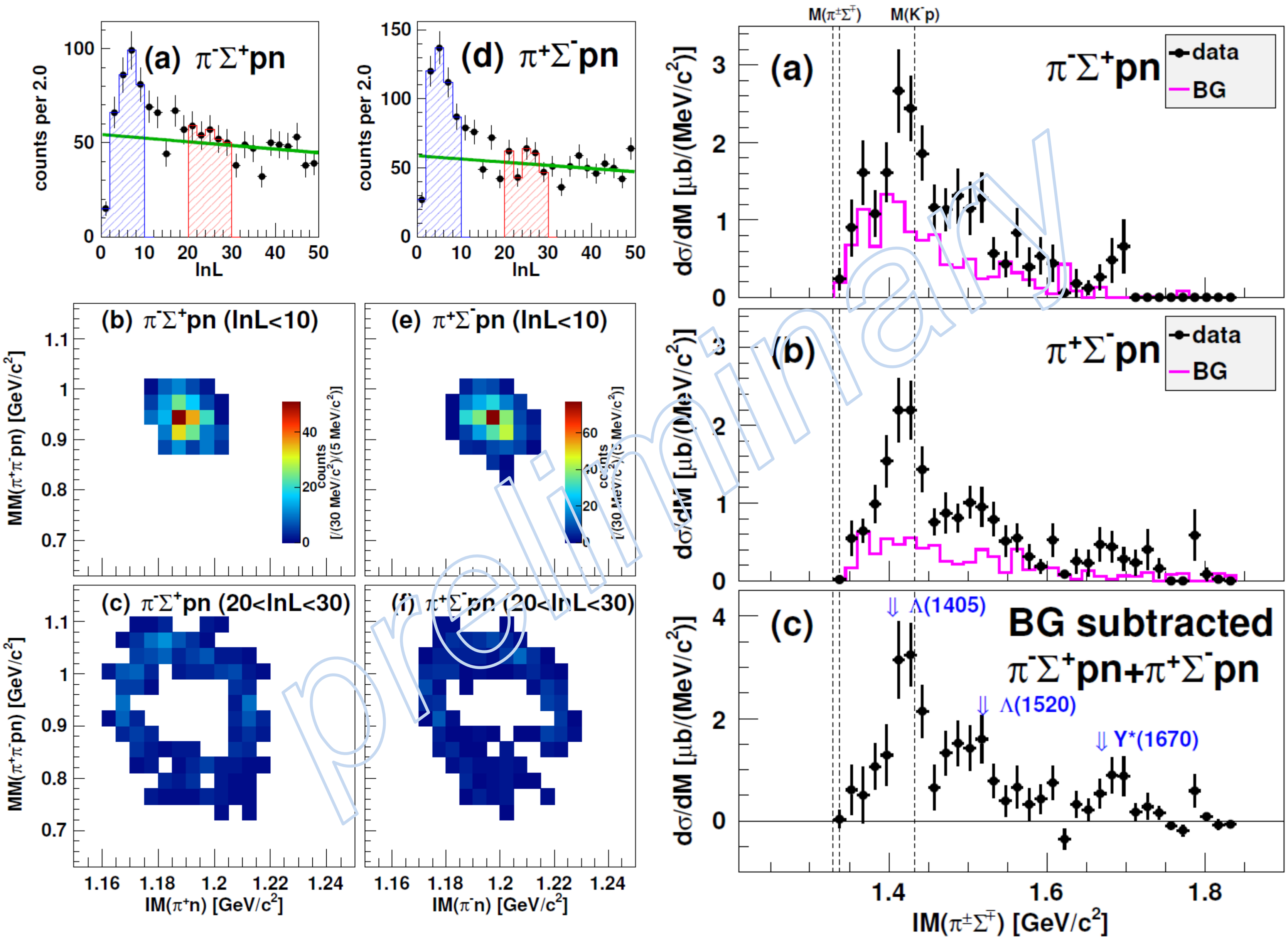


IM($n\pi^-$) vs MM($\pi^+\pi^-pn$)





BG Subtracted IM($\pi^{\pm}\Sigma^{\mp}$) in $\pi^{\pm}\Sigma^{\mp}pn$



$Y^{*}pn$ Final State

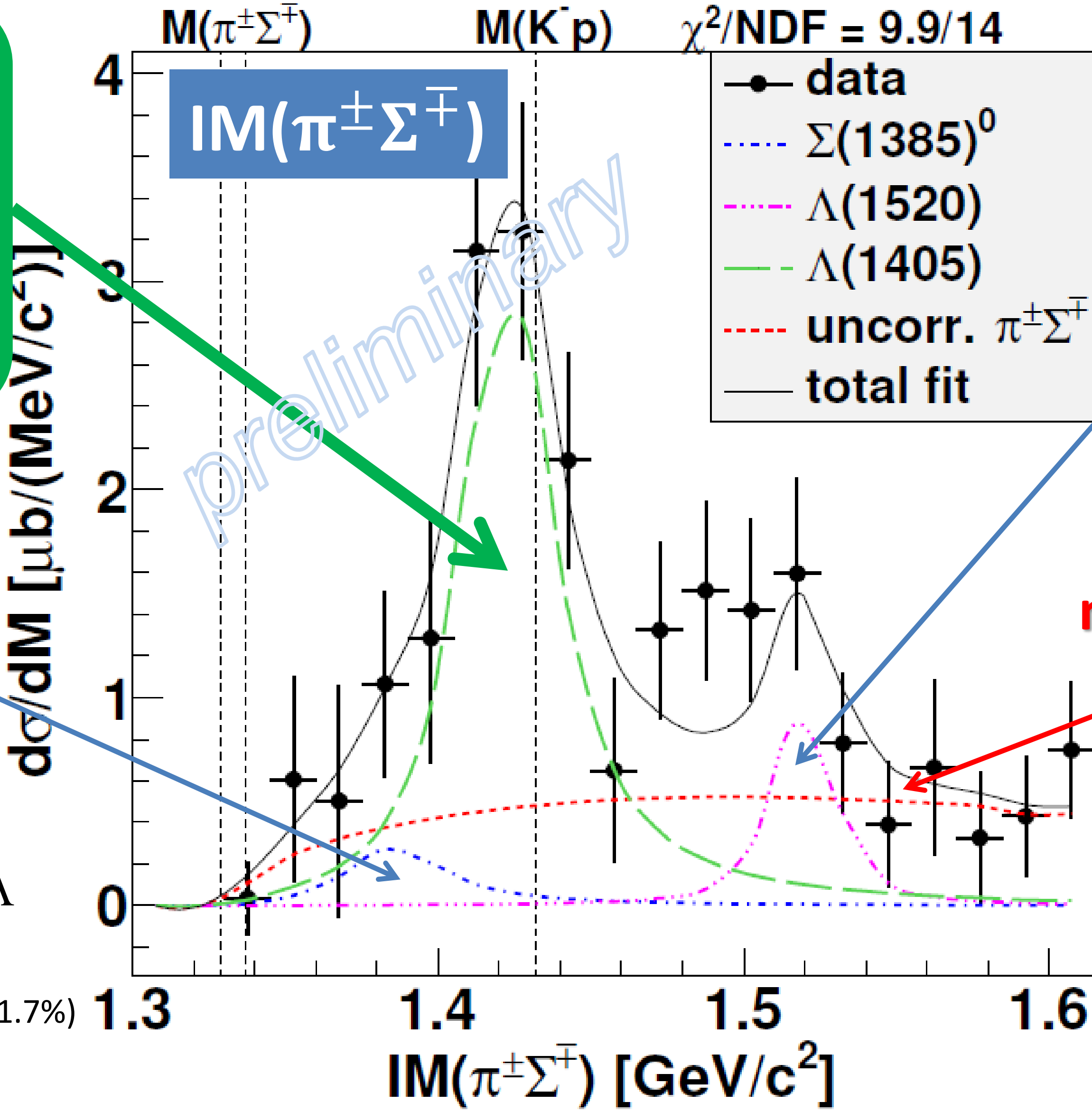
Λ(1405)

~ 250 μb

Fit with BW:

M ~ 1422 MeV

Γ ~ 40 MeV



Λ(1520)

~ 100 μb

πΣpn non-resonant

Σ (1385) ^{0}

~ 100-150 μb

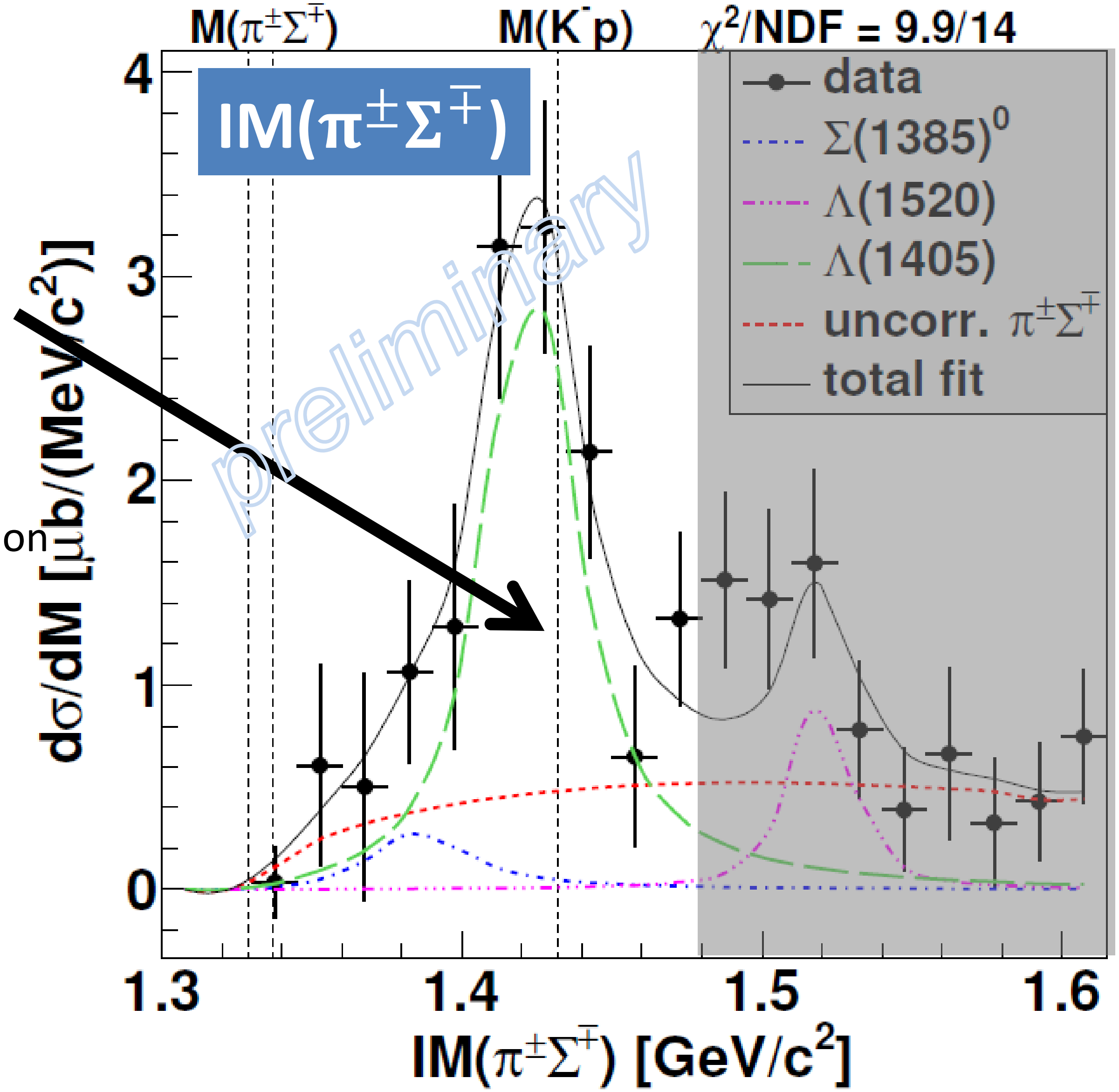
[evaluated from $\Sigma(1385)^{+/-} \rightarrow \pi^{+/-}\Lambda$ measurement]

($\Sigma(1385) \rightarrow \pi\Lambda/\pi\Sigma$: 87.0/11.7%)

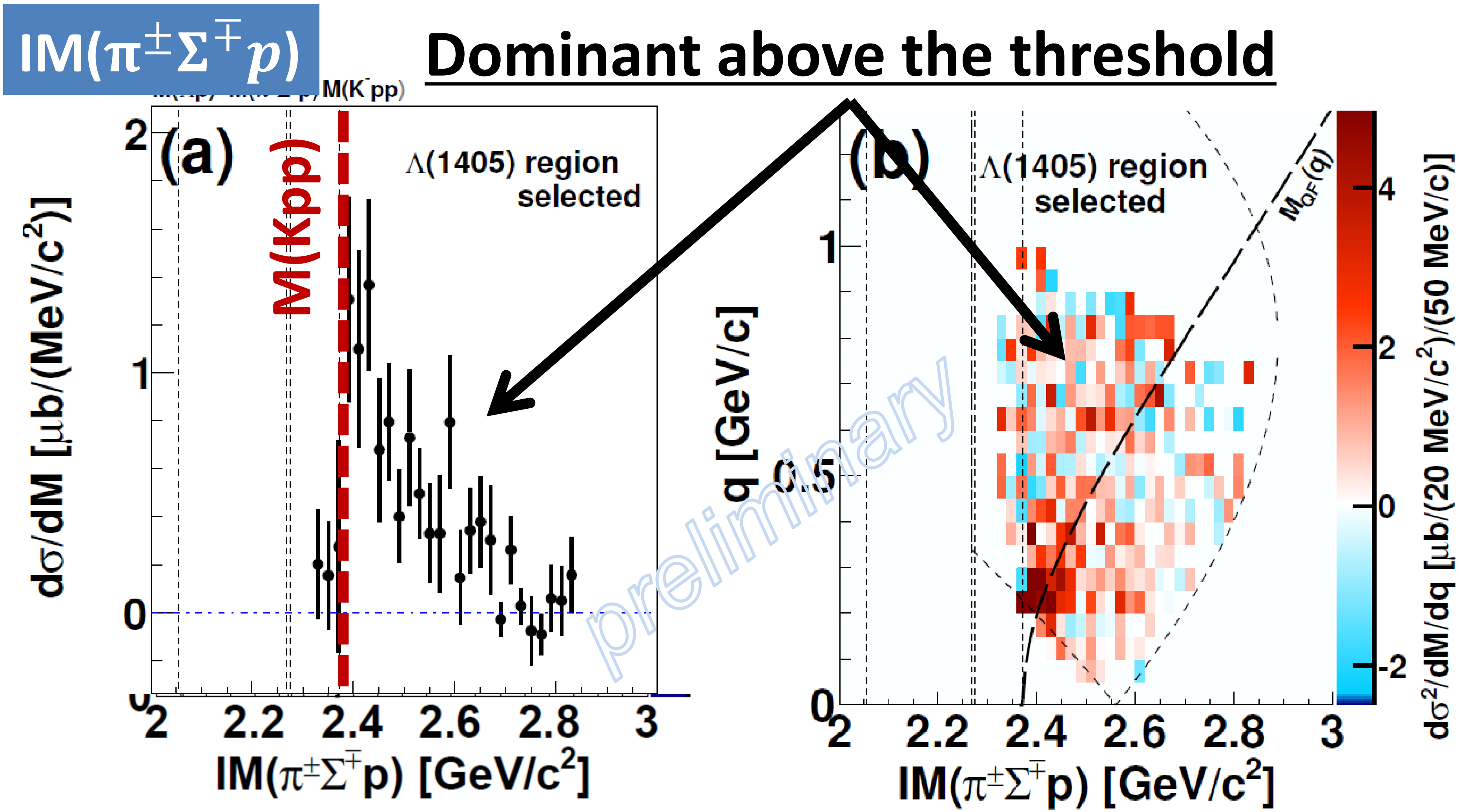
$\Lambda(1405)pn$ Final State Selection

Select $\Lambda(1405)$ region

- Below $\Lambda(1520)$
- Small contribution from $\Sigma(1385)$



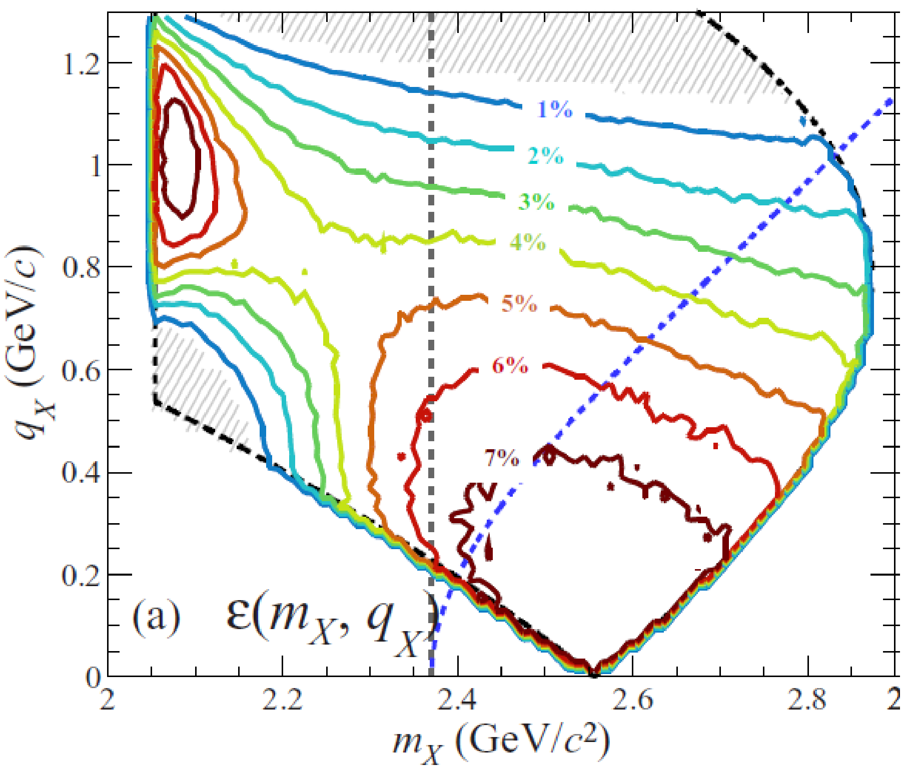
IM(πΣp) in Λ(1405)pn Final State



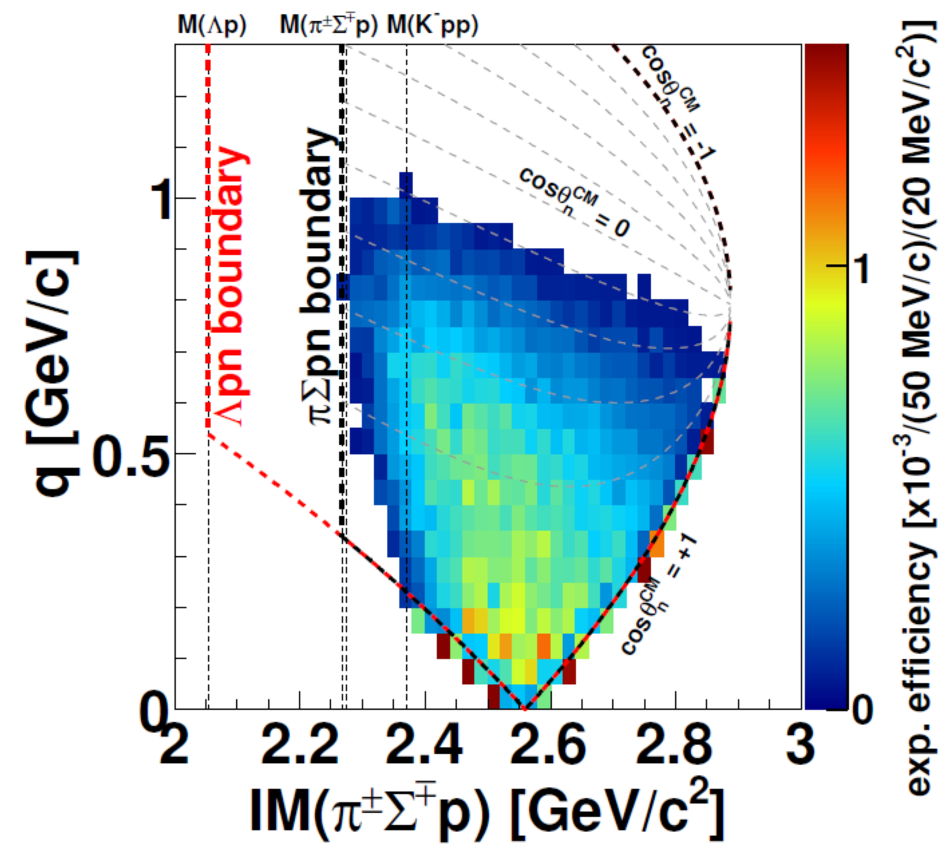
- IM(Λ(1405)p) distributes above the M(Kpp)
- QF $K^-N \rightarrow K^{bar}n$ followed by $K^{bar}NN \rightarrow \Lambda(1405)p$

Detector acceptances of Λpn and πΣpn

Λp

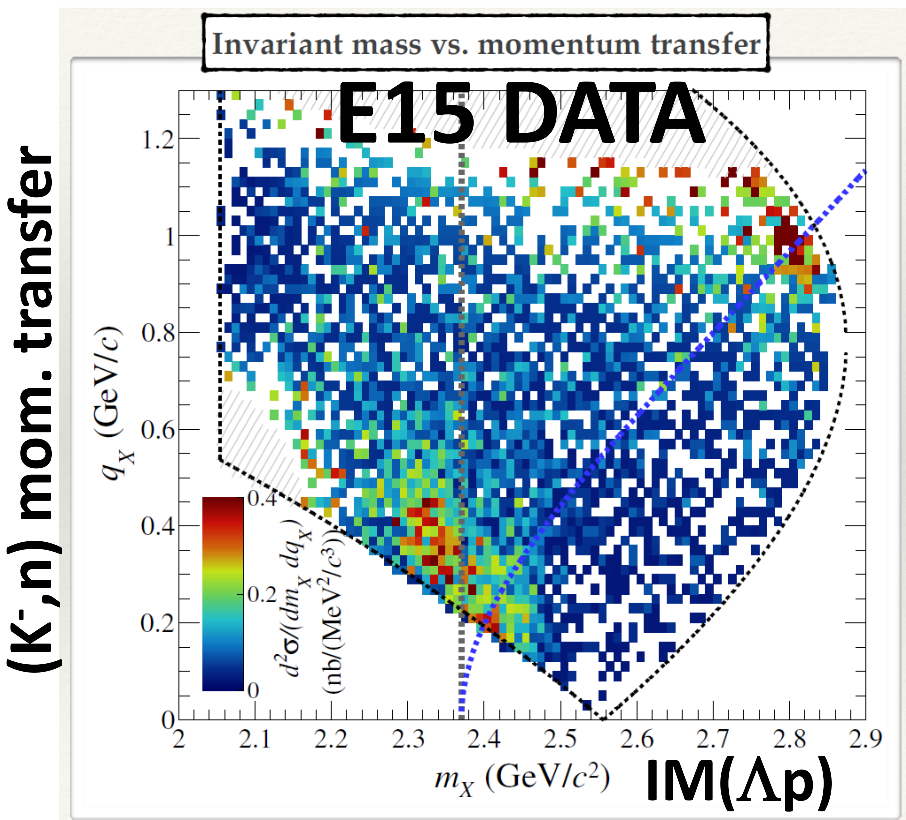


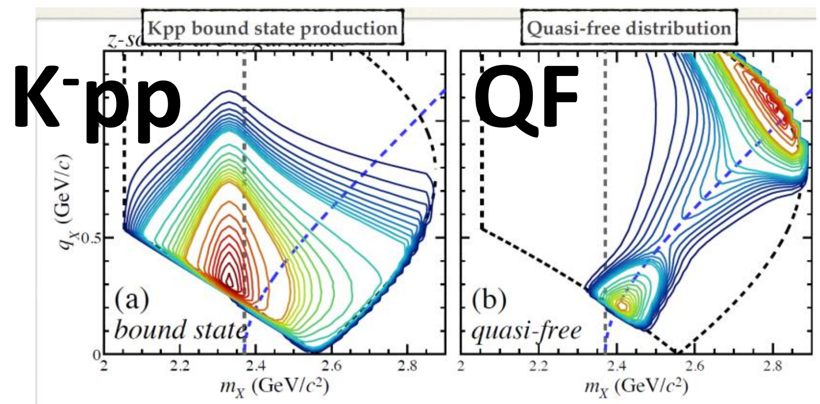
πΣp

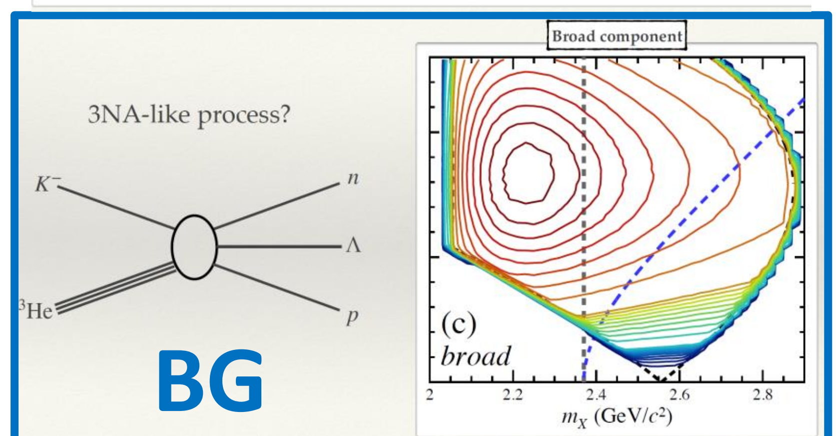


Recent progress of the E15 analysis

- In the E15 analysis so far, we assumed a point-like 3NA process for the background to explain the IM(Λp) spectrum, by parametrizing a fitting function

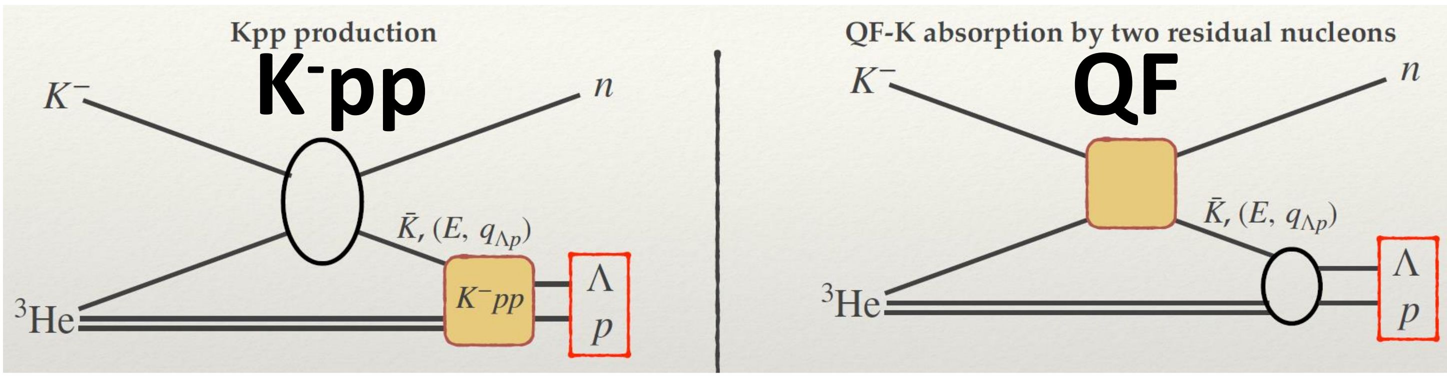




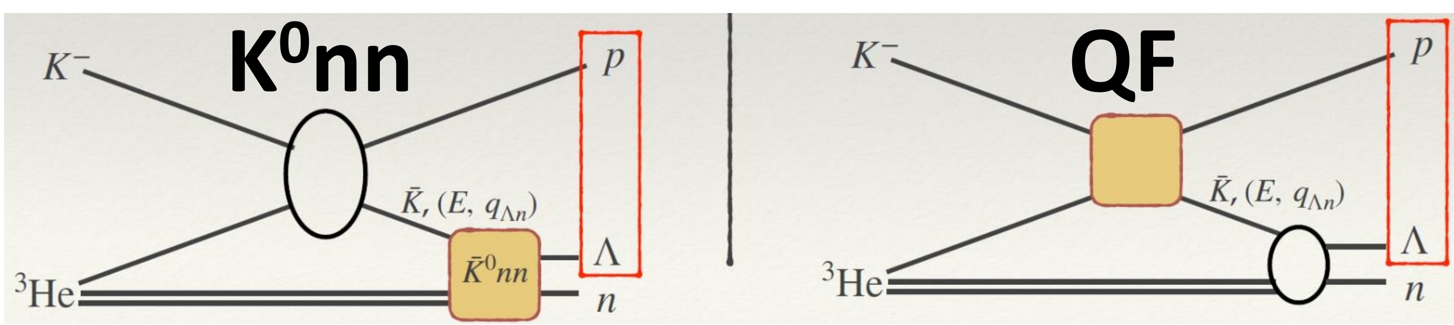


Recent progress of the E15 analysis

- For the $K^{-}pp$ and QF, we assume the following processes



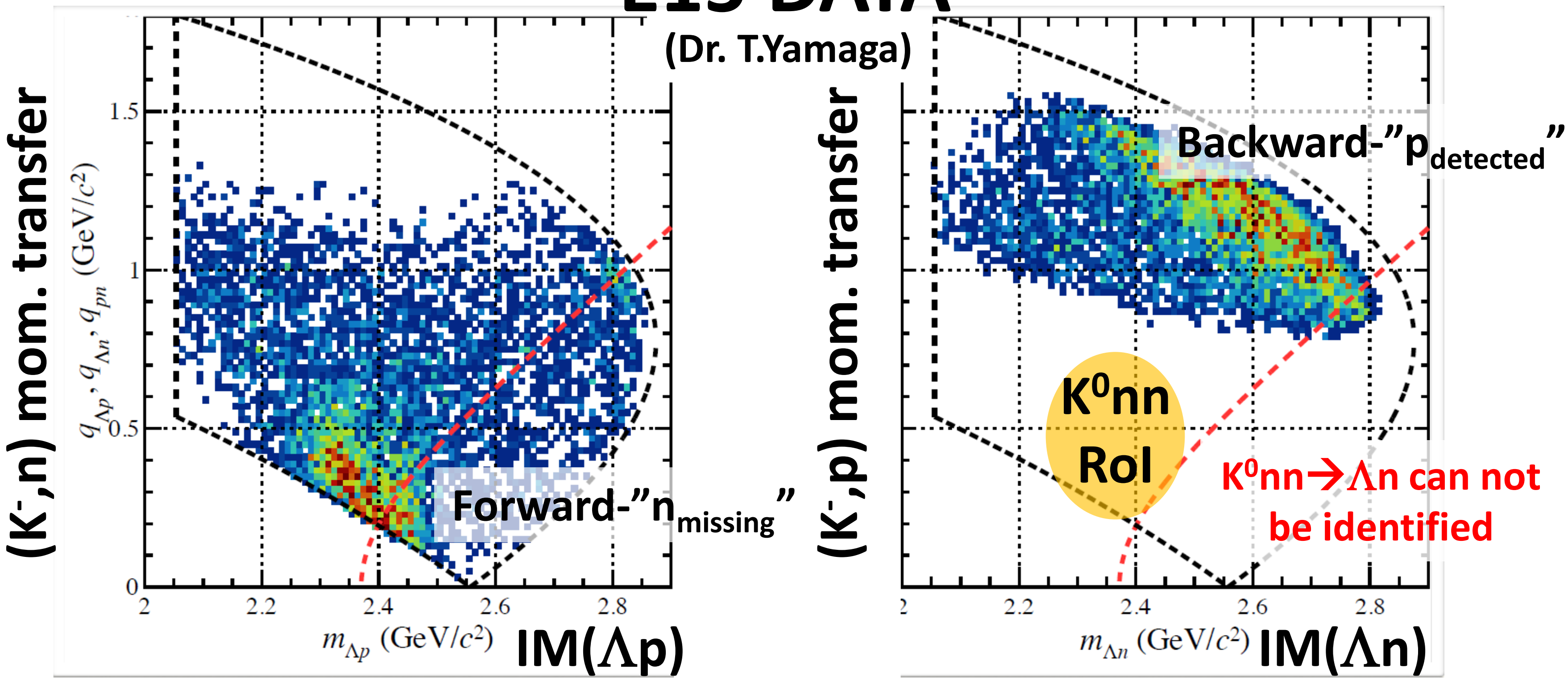
- On the other hand, "p" and "n" can be swapped in the reactions when the isospin partner of the $K^{-}pp$ (=$K^{0}nn$) is also generated



Recent progress of the E15 analysis

- IM(Λp) and IM(Λn)
  - ➢ Acceptances are quite different between the "Λp" and "Λn"
  - ➢ In IM(Λn), a forward going proton is out of the acceptance

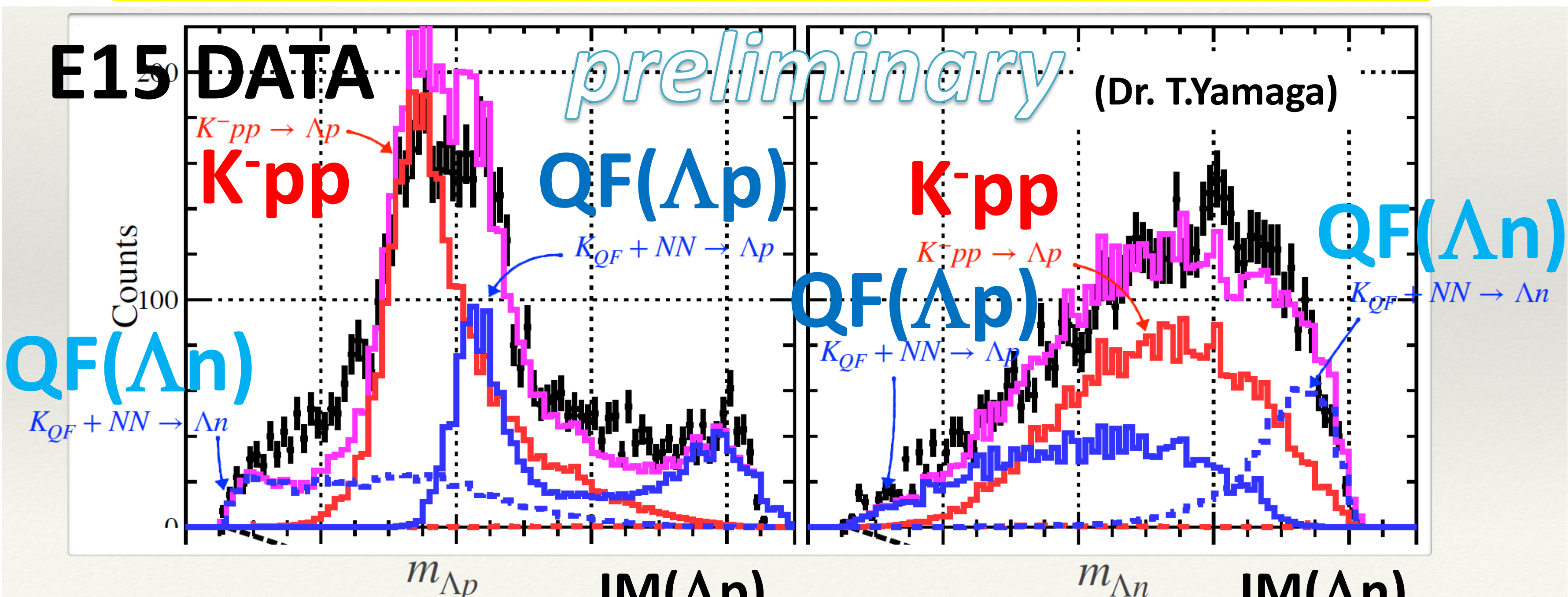
E15 DATA



Recent progress of the E15 analysis

- Both of IM(Λp) and IM(Λn) can be reproduced by the "signal" and "QFs"
  - Eye fit results → further analysis is on going

need further data with the new 4π spectrometer



(all mom. transfer region selected)

Σ^*N bound state? Other possibilities?

$\Sigma(1385)\ 3/2^+$ $\quad I(J^P) = 1(\frac{3}{2}^+)$

$\Sigma(1385)$ DECAY MODES	Fraction (Γ_i/Γ)
$\Lambda\pi$	(87.0 ± 1.5) %
$\Sigma\pi$	(11.7 ± 1.5) %

- Σ^* coupling through K^{bar}-N channel (P-wave) would be weak
  - ✓ A.Cieply et al., PRC84(2011)045206, etc.
- Naively, Σ^*N system with $1^+/2^+$ state (S-wave) could not be bound, because corresponding ΔN system (non-strangeness sector) is considered to be no-bound or quite-weakly bound
  - ✓ R. D. Mota et al., PRC59(1999)46, etc.

need J^P determination with a polarimeter

- The $K^{bar}NN$ state ($I=1/2$, $J^P=0^-$) is calculated with a $K^{bar}NN$-$\pi\Sigma N$-$\pi\Lambda N$ coupled channel system, where the $\pi\Lambda N$ coupling is expected to be small
- The $K^{bar}NN$ state with $J^P=1^-$ (K^{bar}-d like configuration) is expected to not be bound, or have small B.E.
  - ✓ S.Ohnishi et al., PRC95(2017)065202, etc.

Σ*N bound state? Other possibilities?

- One theoretical possibility is a "πΛN-πΣN dibaryon"

Nuclear Physics A 897 (2013) 167–178

Relativistic three-body calculations of a $Y = 1$, $I = \frac{3}{2}$, $J^P = 2^+$ $\pi\Lambda N$–$\pi\Sigma N$ dibaryon

H. Garcilazo [a], A. Gal [b,*]

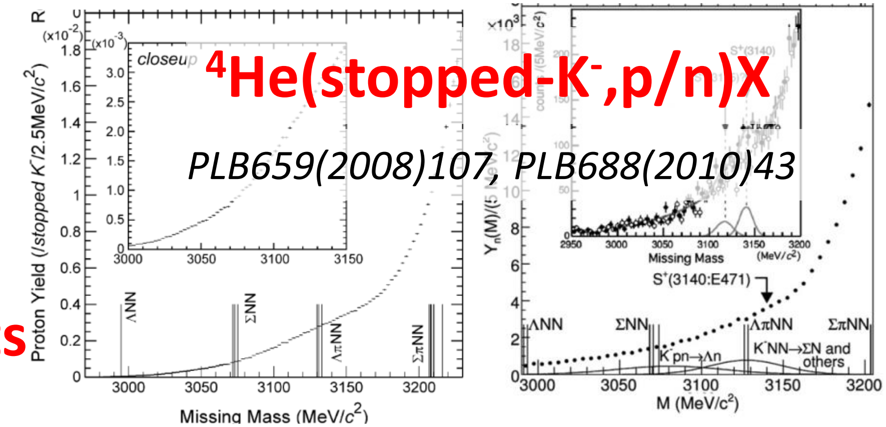
- Calculated πΛN resonance with **Σ*N-ΔΣ** configuration is:
  - I=1/2, $J^P=2^+$: **E = -10-i52 MeV**
  - I=3/2, $J^P=2^+$: **E = -120-i2.6 MeV** with respect to M(K^{bar}NN)

- The obtained K^-pp parameter at E15 is **E=-40-i50 MeV**
- Therefore, the "observed K-pp structure" would be different from the "πΛN-πΣN dibaryon"

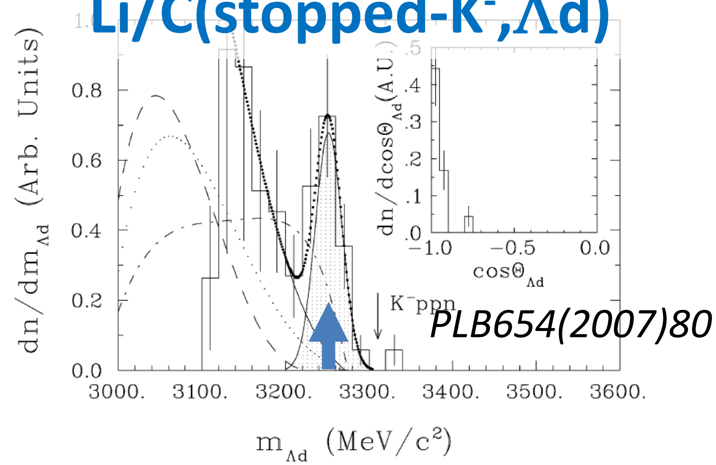
“K^{-}ppn” Candidates so far

- A few candidates have been reported in ***inclusive*** measurements

◆**E471/E549@KEK** ← **NULL results**
  - ^{4}He(stopped-K^{-},p/n)X

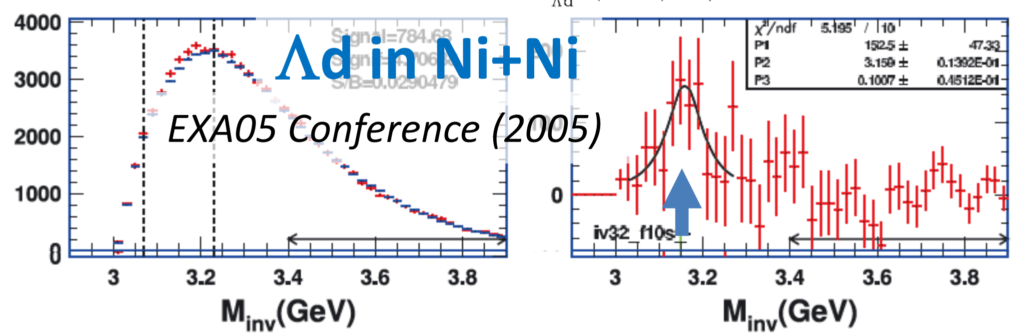


◆**FINUDA@DAΦNE** ← **Observed?**
  - Li/C(stopped-K^{-},Λd)



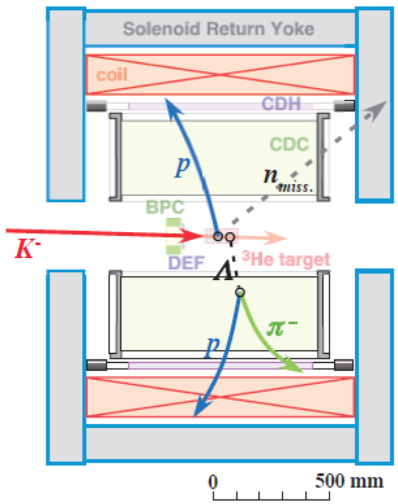
◆**FOPI@GSI** ← **Observed?**
  - Λd in Ni+Ni

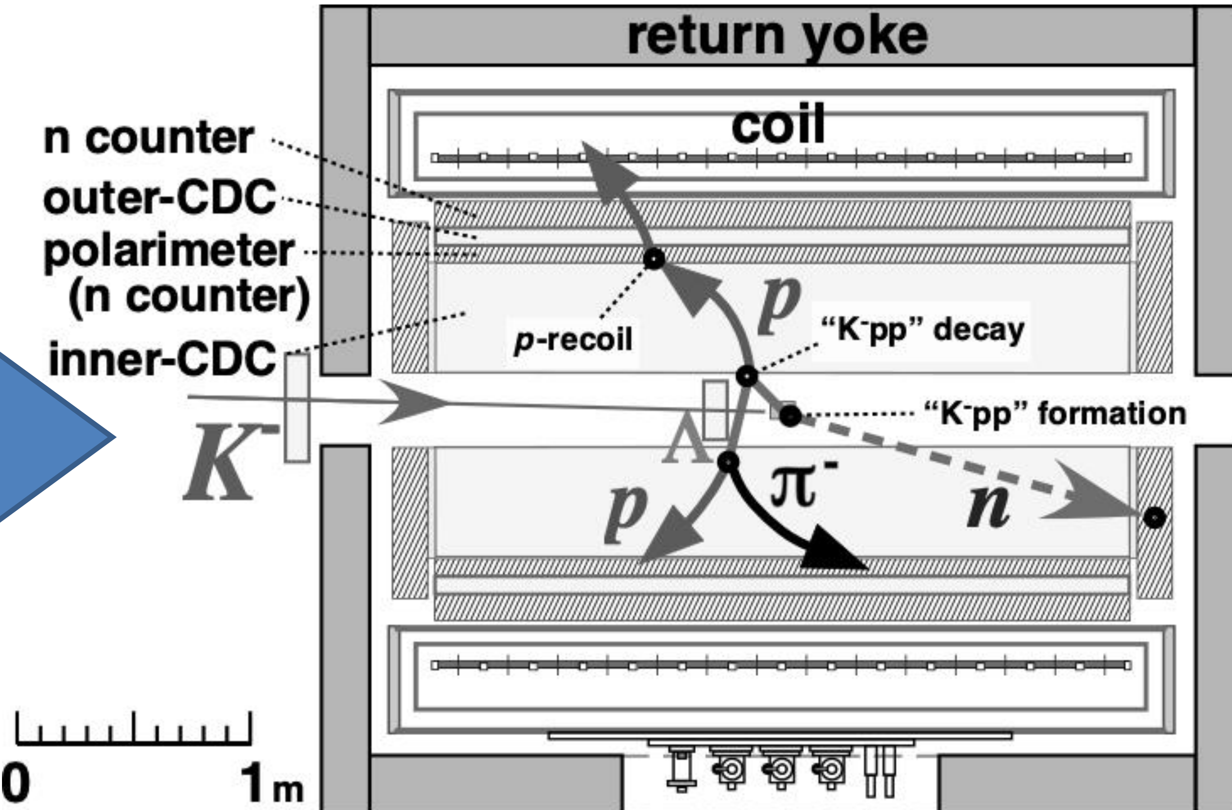
- **Exclusive measurement using a simple reaction (in-flight & light nuclei) is crucial**



A New Cylindrical Detector System

present setup





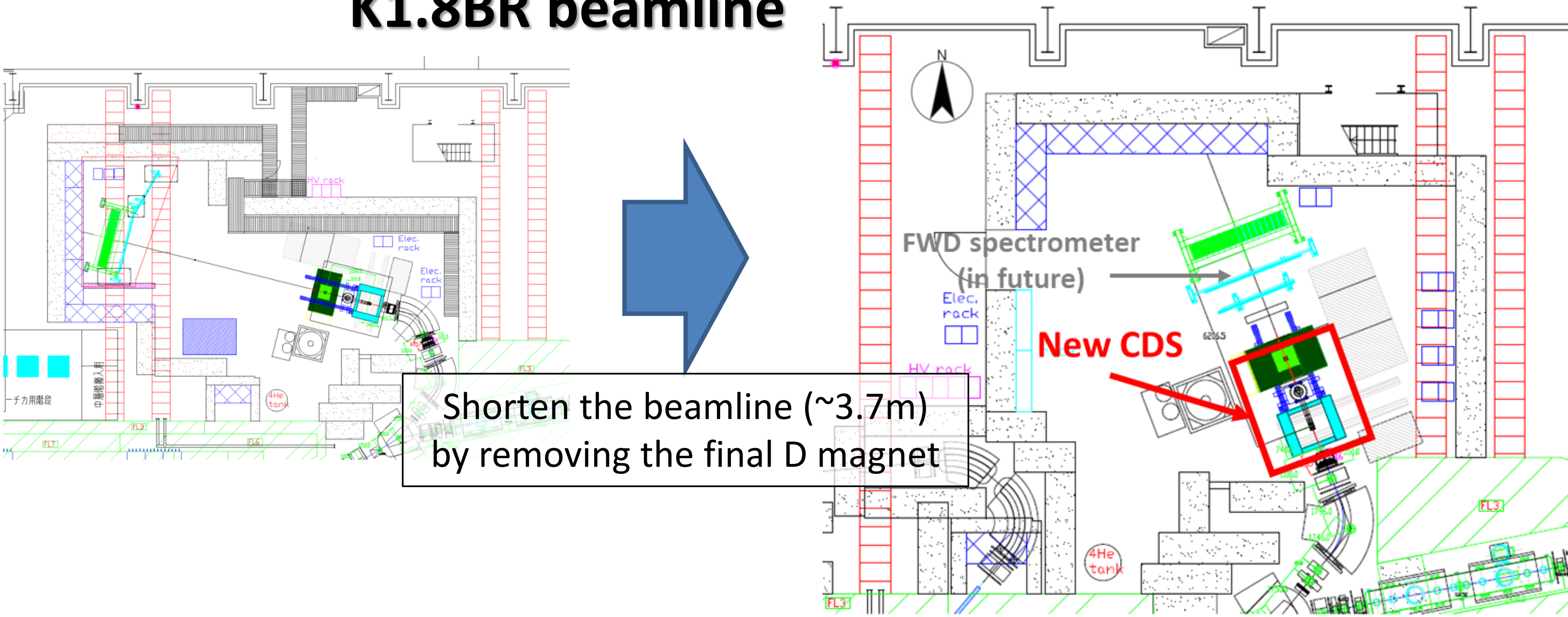
- **SC Solenoid Magnet**
- **Cylindrical Drift Chamber**
- **Neutron Counter**
- FWD/BWD Drift Chambers
- Vertex Fiber Tracker
- Electromagnetic Calorimeter (constructed in 2nd-stage)

Solid angle: ~x1.5 (~90%)

Neutron detection capability: ~x10 (~1.5x15%)

Improvement of Kaon Intensity

K1.8BR beamline



- **We propose a new configuration of the beamline**
  - K- yield is expected to increase by **~ 1.4 times @ 1.0 GeV/c**

Expected Yield of $\bar{K}NNN$

$$N = \sigma \times N_{beam} \times N_{target} \times \epsilon,$$
$$\epsilon = \epsilon_{DAQ} \times \epsilon_{trigger} \times \epsilon_{beam} \times \epsilon_{fiducial} \times \Omega_{CDS} \times \epsilon_{CDS},$$

- We assume the K^-ppn cross section of

$$\sigma(K^-ppn) \cdot Br(\Lambda d) \sim 10\ \mu b$$
$$\sigma(K^-ppn) \cdot Br(\Lambda pn) \sim 10\ \mu b$$

  - ◆ The same CS of "K-pp"→Λp in E15
  - ◆ *As for Λd decay, we refer to the absorption of stopped K^- on ^{4}He*

    → decay fraction to Σ^-pd : Σ^-ppn ~ 1 : 1

absorption of stopped K^- on ^{4}He

Reaction	Events/(stopping K^-) (%)
$K^-He^4 \to \Sigma^+\pi^-H^3$	9.3±2.3
$\to \Sigma^+\pi^- dn$	1.9±0.7
$\to \Sigma^+\pi^- pnn$	1.6±0.6
$\to \Sigma^+\pi^0\ nnn$	3.2±1.0
$\to \Sigma^+\ \ nnn$	1.0±0.4
Total $\Sigma^+ = (17.0\pm2.7)\%$	
$K^-He^4 \to \Sigma^-\pi^+H^3$	4.2±1.2
$\to \Sigma^-\pi^+ dn$	1.6±0.6
$\to \Sigma^-\pi^+ pnn$	1.4±0.5
$\to \Sigma^-\pi^0\ He^3$	1.0±0.5
$\to \Sigma^-\pi^0\ pd$	1.0±0.5
$\to \Sigma^-\pi^0\ ppn$	1.0±0.4
$\to \Sigma^-\ \ pd$	1.6±0.6
$\to \Sigma^-\ \ ppn$	2.0±0.7
Total $\Sigma^- = (13.8\pm1.8)\%$	
$K^-He^4 \to \pi^-\Lambda\ He^3$	11.2±2.7
$\to \pi^-\Lambda\ pd$	10.9±2.6
$\to \pi^-\Lambda\ ppn$	9.5±2.4
$\to \pi^-\Sigma^0\ He^3$	0.9±0.6
$\to \pi^-\Sigma^0\ (pd,ppn)$	0.3±0.3
$\to \pi^0\Lambda\ (\Sigma^0)\ (pnn)$	22.5±4.2
$\to \Lambda\ (\Sigma^0)\ \ (pnn)$	11.7±2.4
$\to \pi^+\Lambda\ (\Sigma^0) nnn$	2.1±0.7
Total $\Lambda\ (\Sigma^0) = (69.2\pm6.6)\%$	
Total $= \Lambda + \Sigma = (100_{-7}^{+0})\%$	

PRD1(1970)1267

Expected Yield of $\bar{K}NNN$

$$N = \sigma \times N_{beam} \times N_{target} \times \epsilon,$$
$$\epsilon = \epsilon_{DAQ} \times \epsilon_{trigger} \times \epsilon_{beam} \times \epsilon_{fiducial} \times \Omega_{CDS} \times \epsilon_{CDS},$$

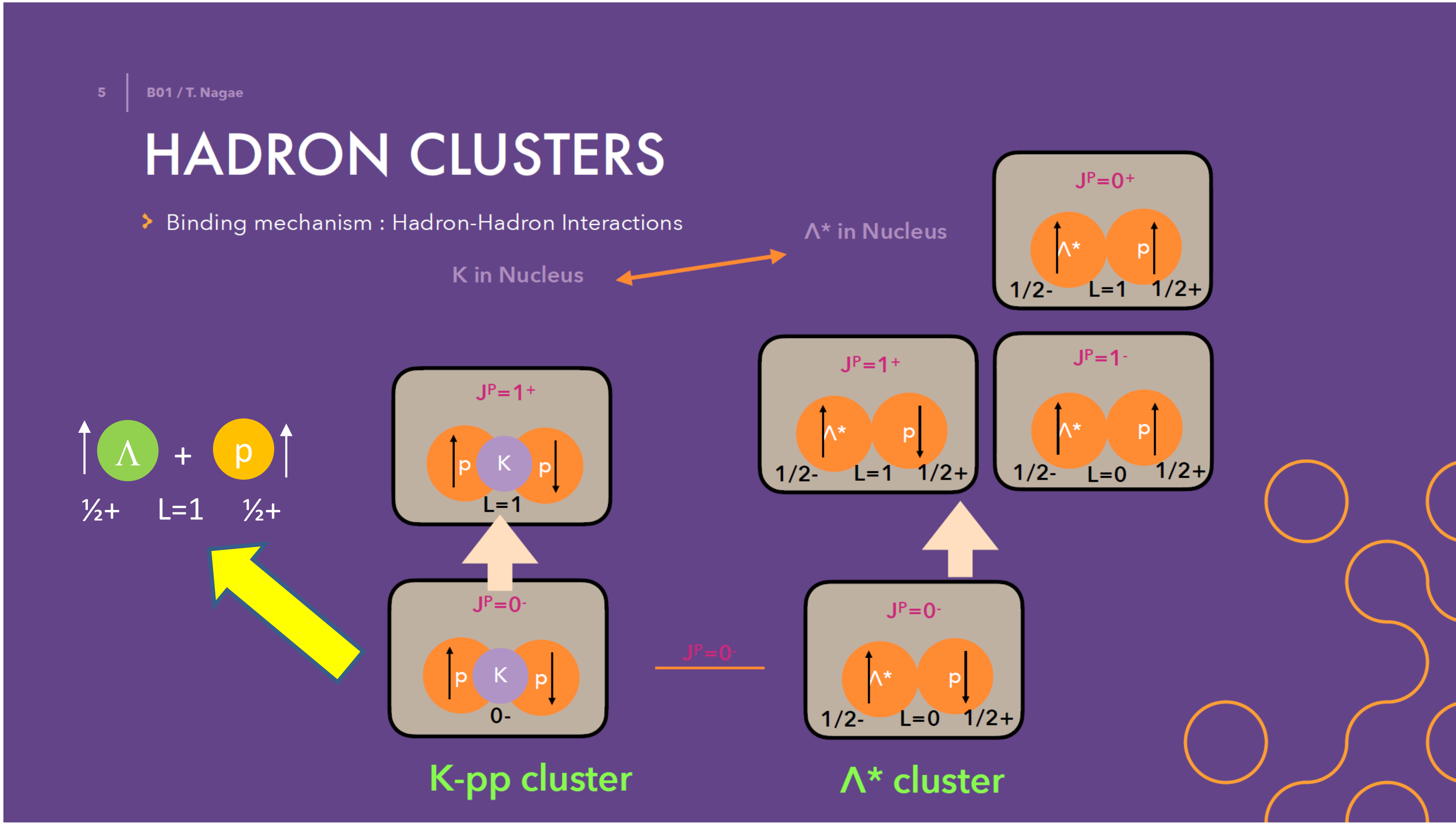
- N_{beam} = **100 G** K- on target
  - under the MR beam power of **90 kW** with **5.2 s** repetition cycle.
    - 3.2 x 10^5 K- on target / spill @ 1.0 GeV/c

  around 2024
  - **3 weeks** data taking (90% up-time)
- **N(K$^-$ppn→Λd) ~ 2 x 10^4**
- **N(K$^-$ppn→Λpn) ~ 3 x 10^3**
  - c.f. 1.7 x 10^3 "K$^-$pp"→Λp accumulated in E15-2nd (40 G K$^-$)

	Λd / Λpn
σ(K$^-$ppn)*Br	10 μb
N(K$^-$ on target)	100 G
N(target)	2.65 x 10^{23}
ε(DAQ)	0.9
ε(trigger)	0.93
ε(beam)	0.55
Ω(CDC)	0.27 / 0.077
ε(CDC)	0.6 / 0.3
N(K$^-$ppn)	19 k / 2.8 k

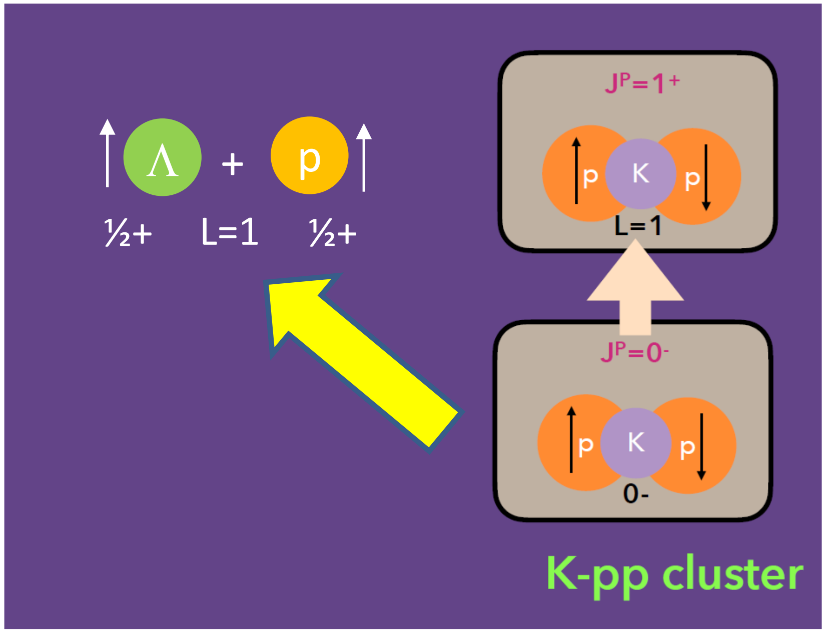
**** improved from E15***

Spin-Parity of $\bar{K}NN$

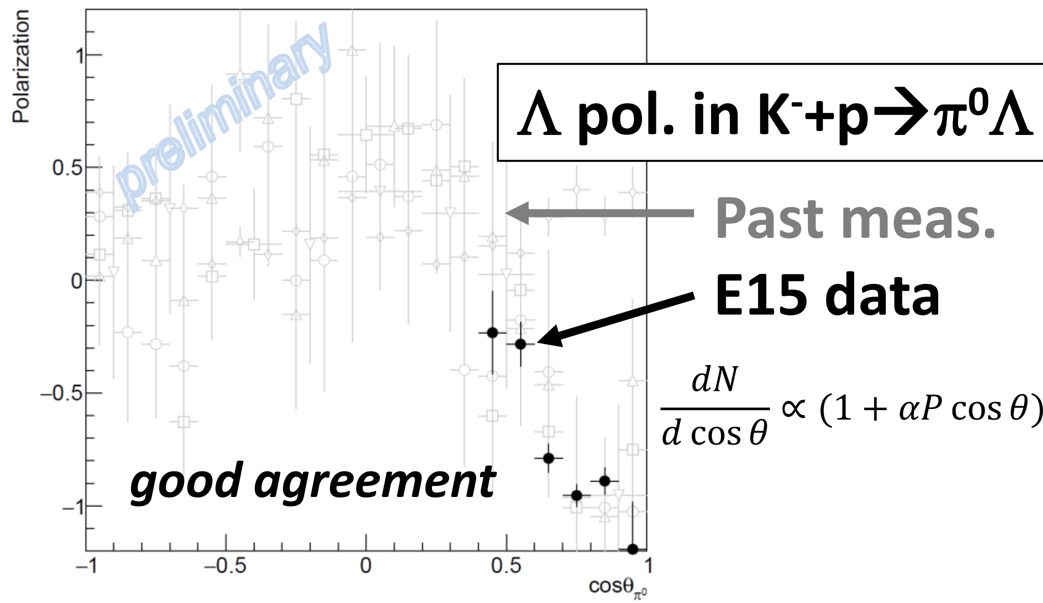


T.Nagae, “The 4th Symposium on Clustering as a window on the hierarchical structure of quantum systems”, May 28th, 2020

Spin-Parity of $\bar{K}NN$

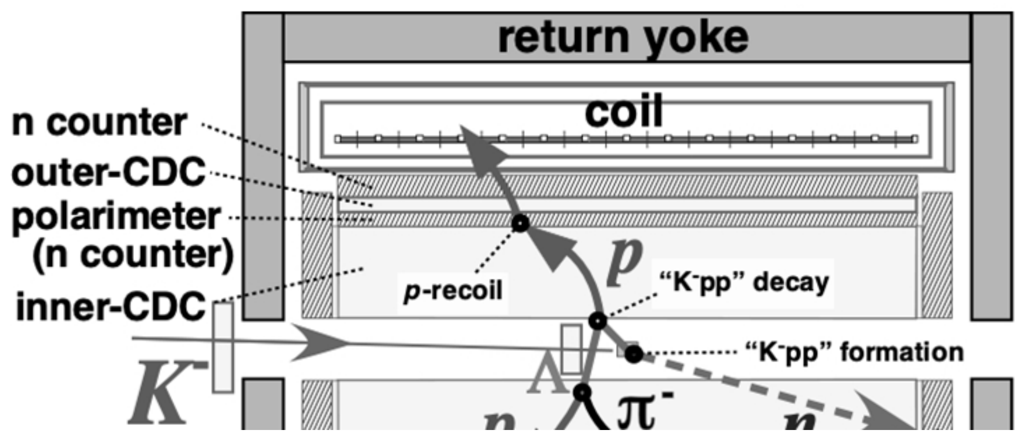


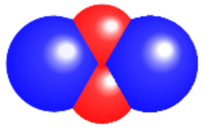
- **Λ polarization** can be measured via π^-p decay



$$\frac{dN}{d\cos\theta} \propto (1 + \alpha P \cos\theta)$$

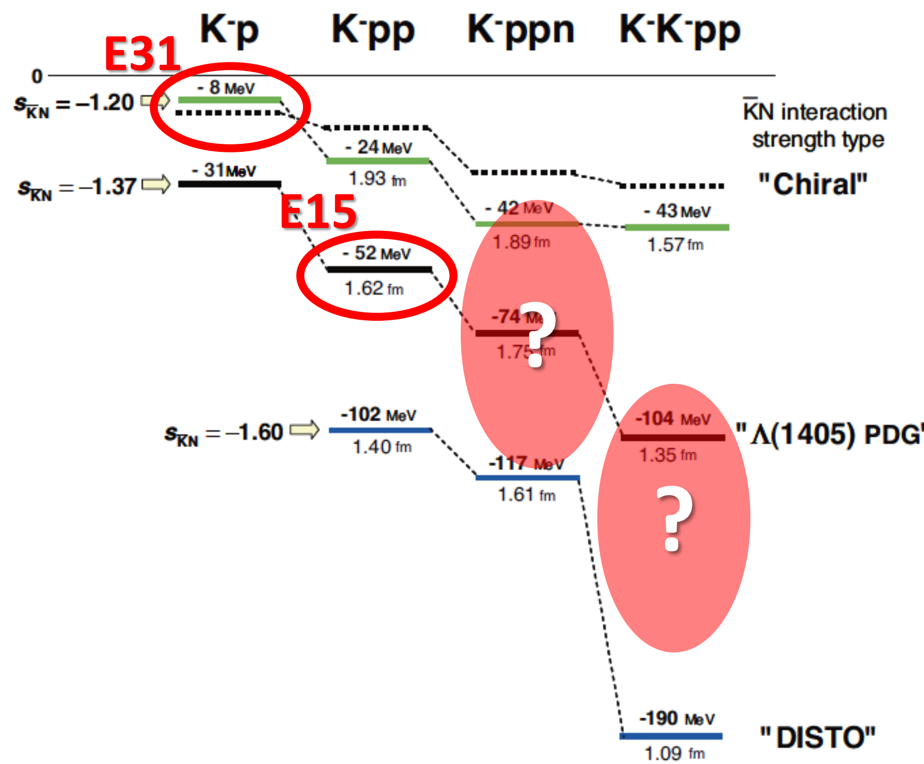
- **Proton polarization** is measured with a polarimeter
  - Tracking system
  - Plastic scintillator





Toward $\bar{K}\bar{K}NN$

- We also wish to access the S = −2 kaonic nuclei such as the theoretically predicted "K⁻K⁻pp" state
  - ✓ as previously submitted LoI
  - ✓ A good probe to the $\bar{K}N$ int.



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- The $\bar{K}\bar{K}NN$ system could give us a chance to access much higher density than the S = −1 kaonic nuclei

The $\bar{K}\bar{K}NN$ production cross section would be quite small → roughly 1/1000 of that of the $\bar{K}NN$