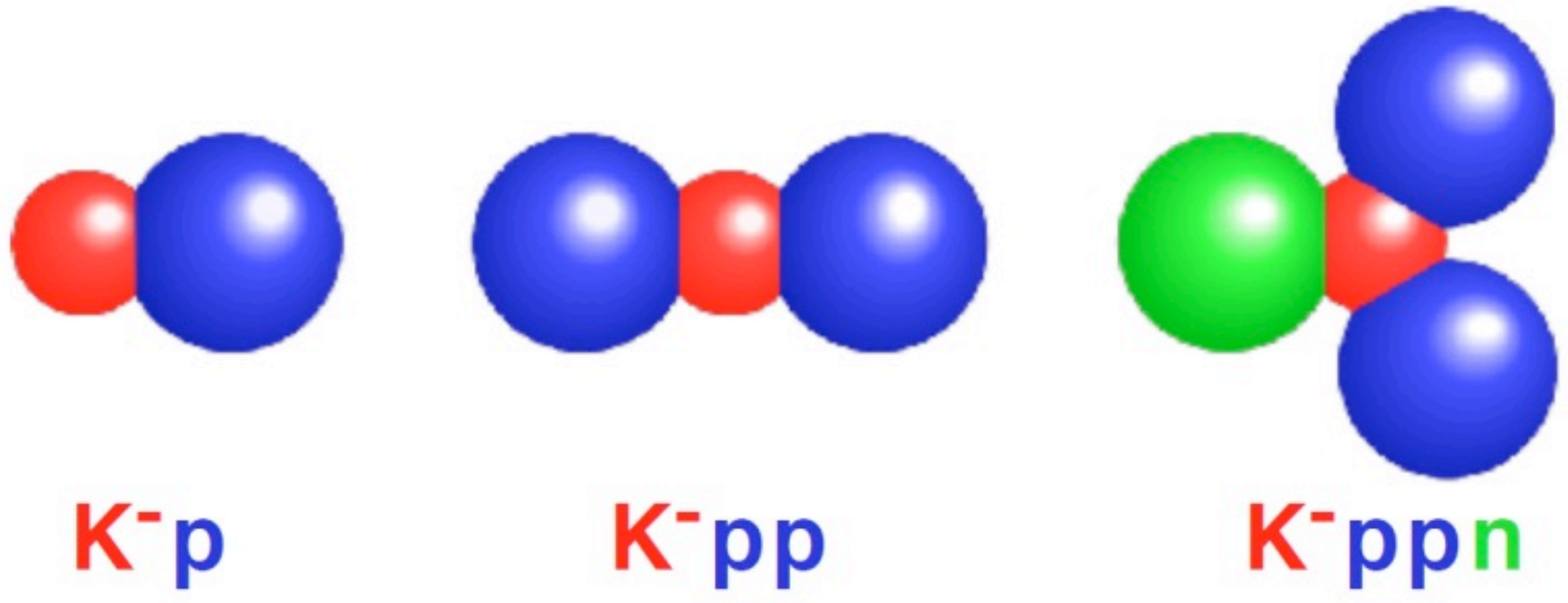
INPC 2025
May 25-30, 2025
DCC, Daejeon, Korea



Recent progress and prospects of kaonic nuclear bound states at J-PARC

Tadashi Hashimoto (RIKEN)
for J-PARC E15/E31/E73/E80 collaboration

RIKEN
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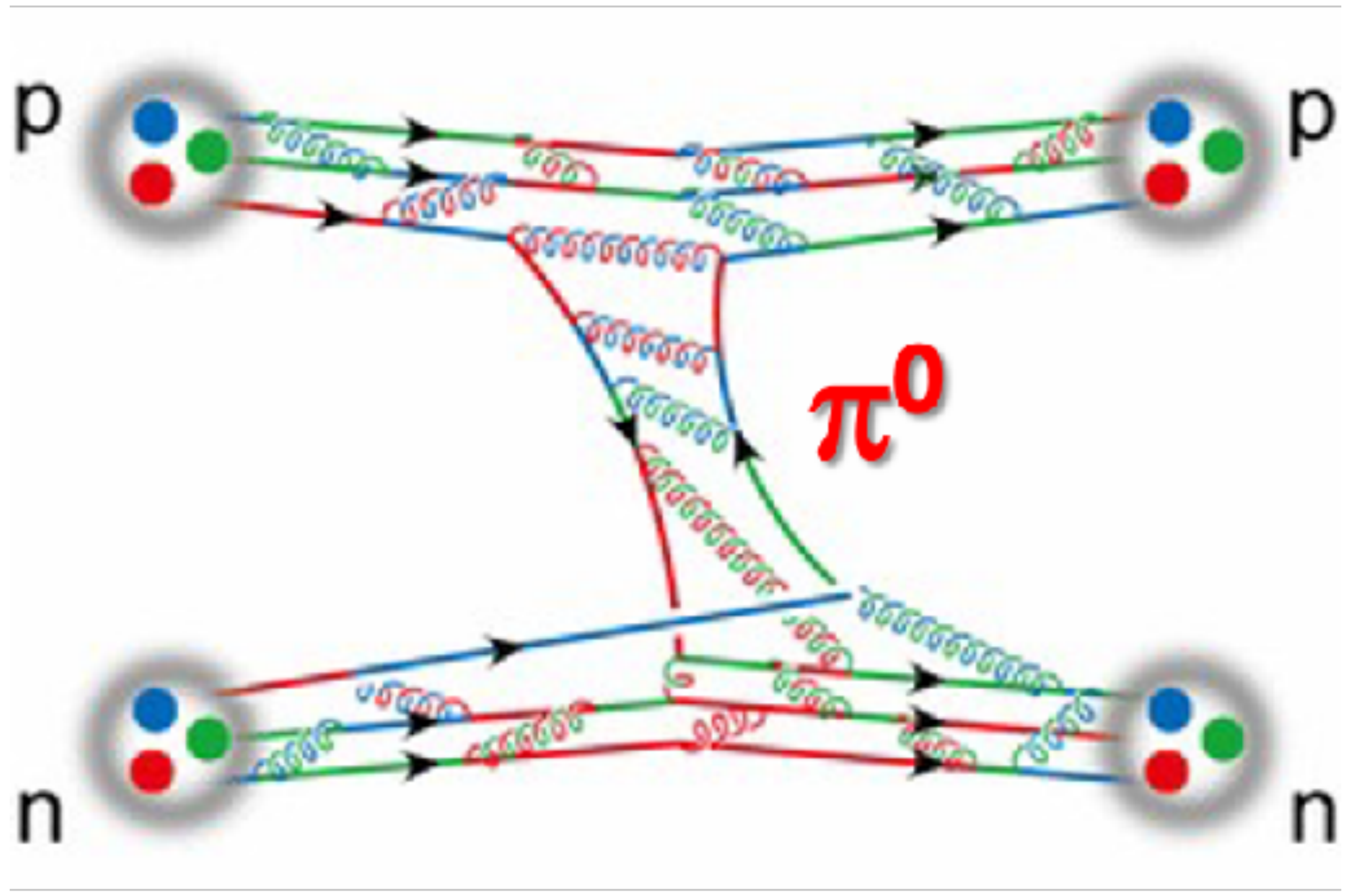
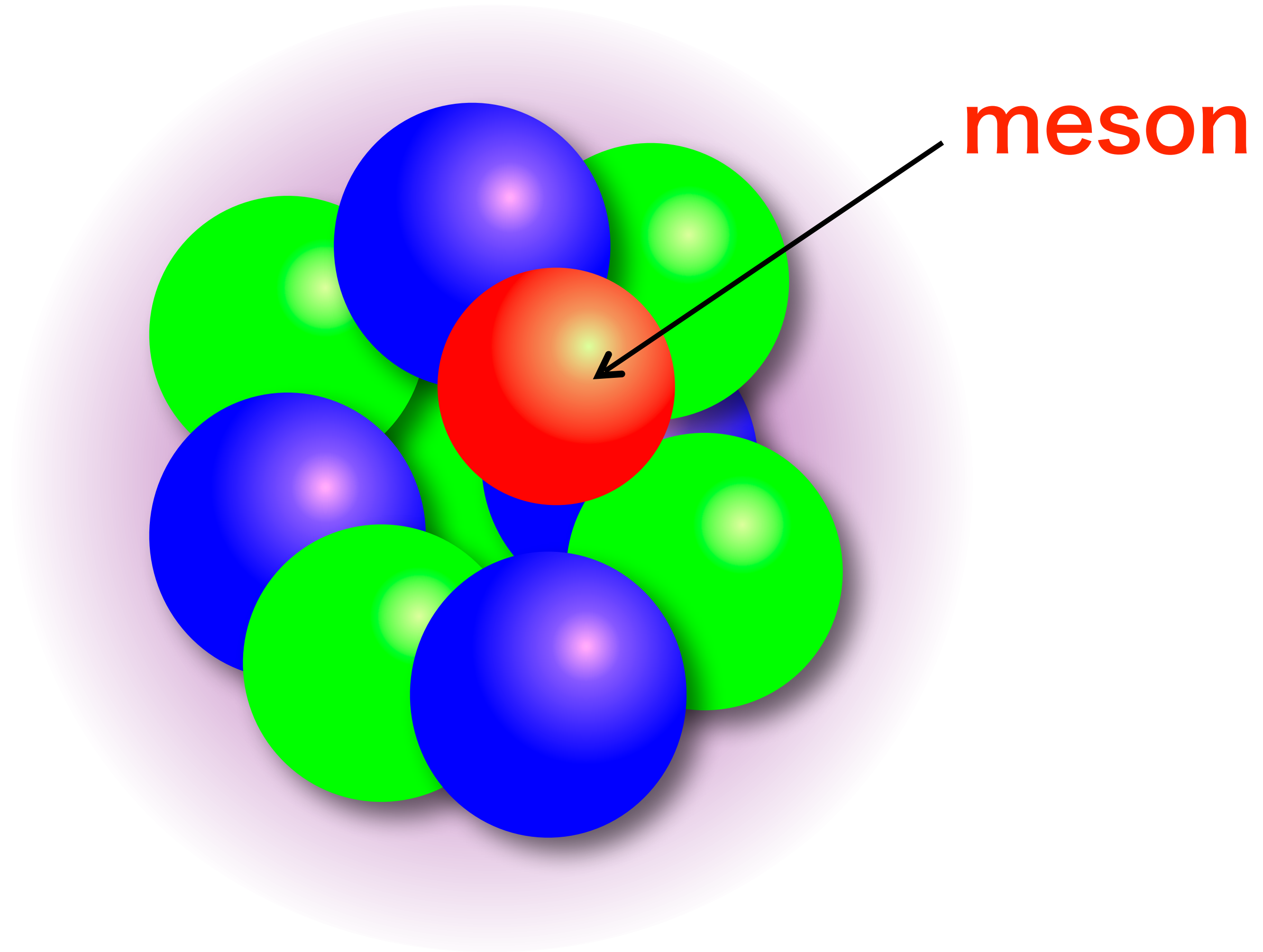
Meson in nuclei

meson: quark-antiquark ($\bar{q}q$) pair

- **In nuclei**, mesons are usually **viatual** particles and form nuclear potential (Yukawa theorem)
- **In vacuum**, mesons are **real** particles having own intrinsic masses (cf. meson beam)



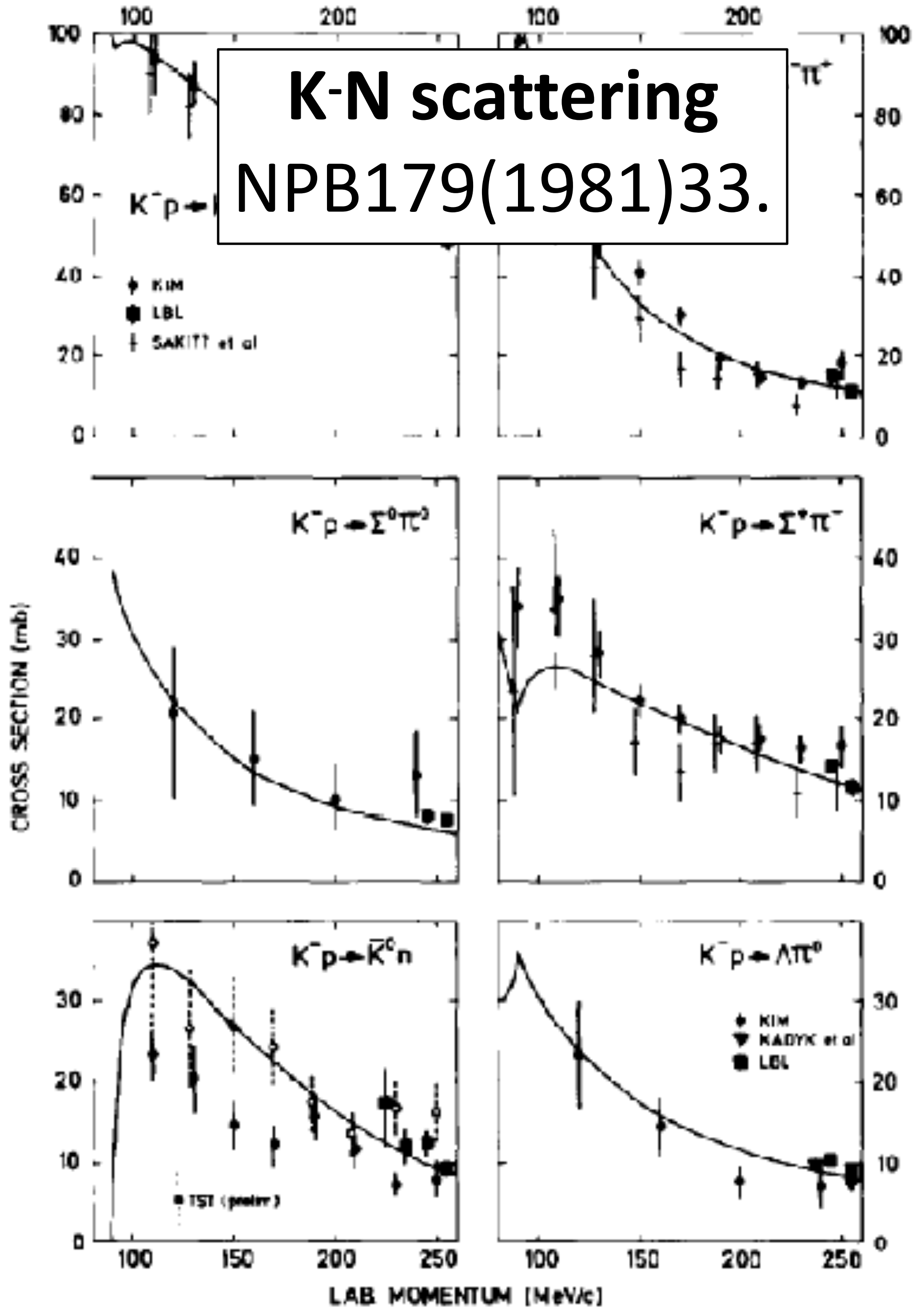


Can meson be a constituent particle forming nuclei?

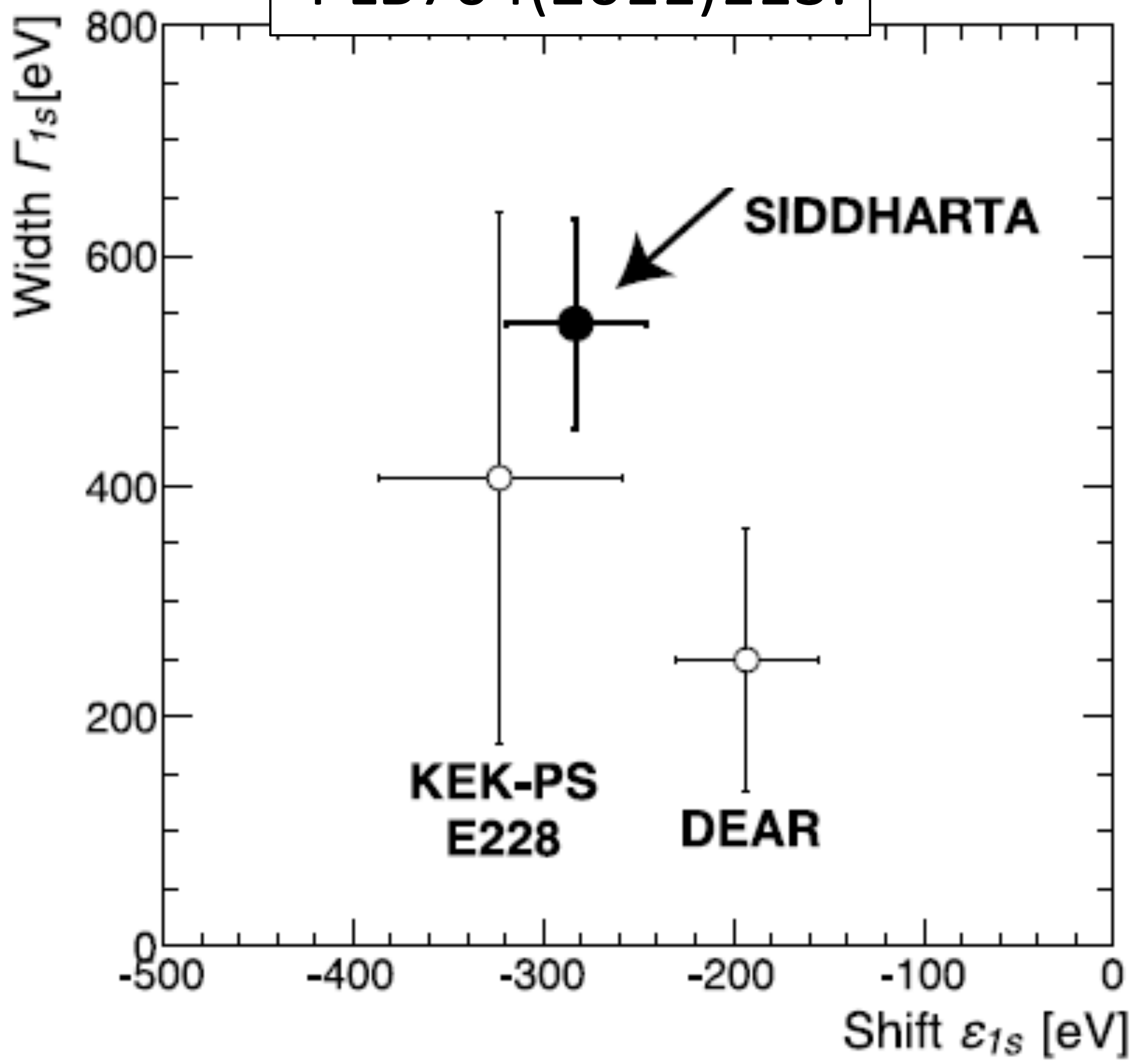
If yes, how do meson and core nucleus change?

K^barN interaction

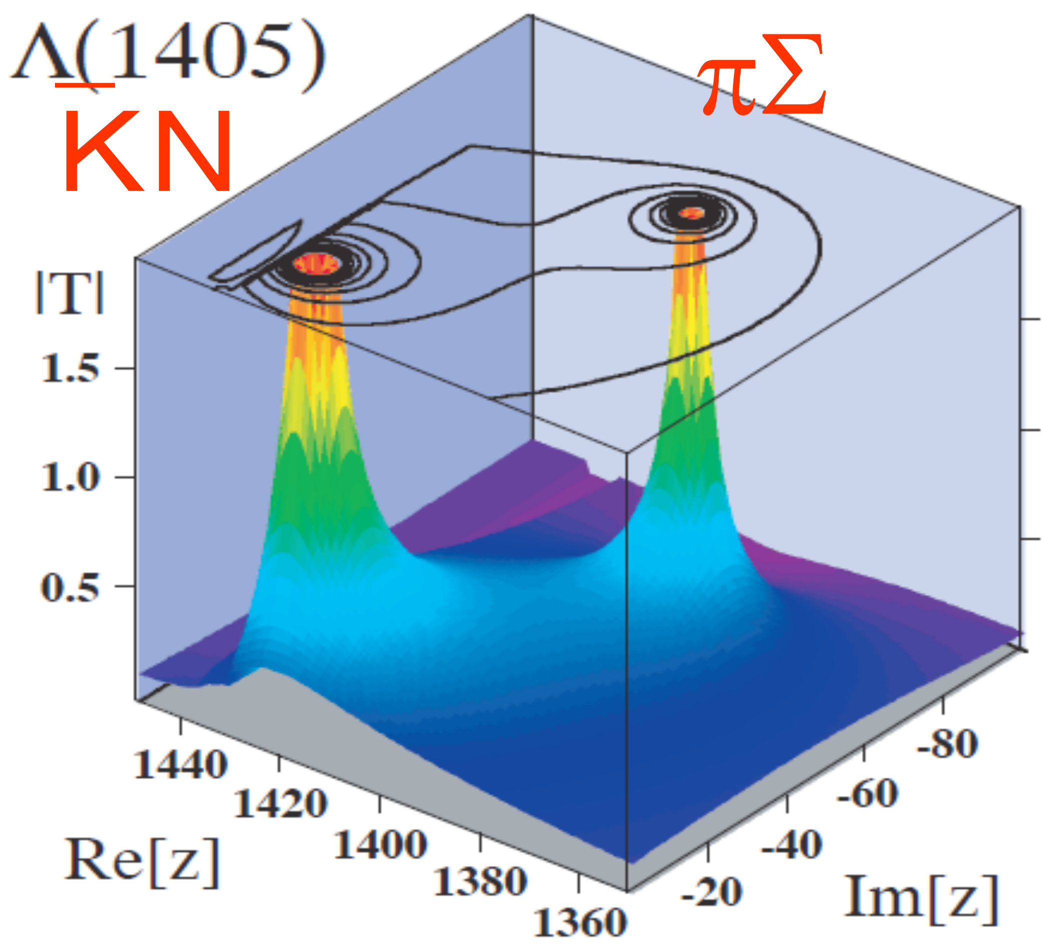
K-N scattering
NPB179(1981)33.



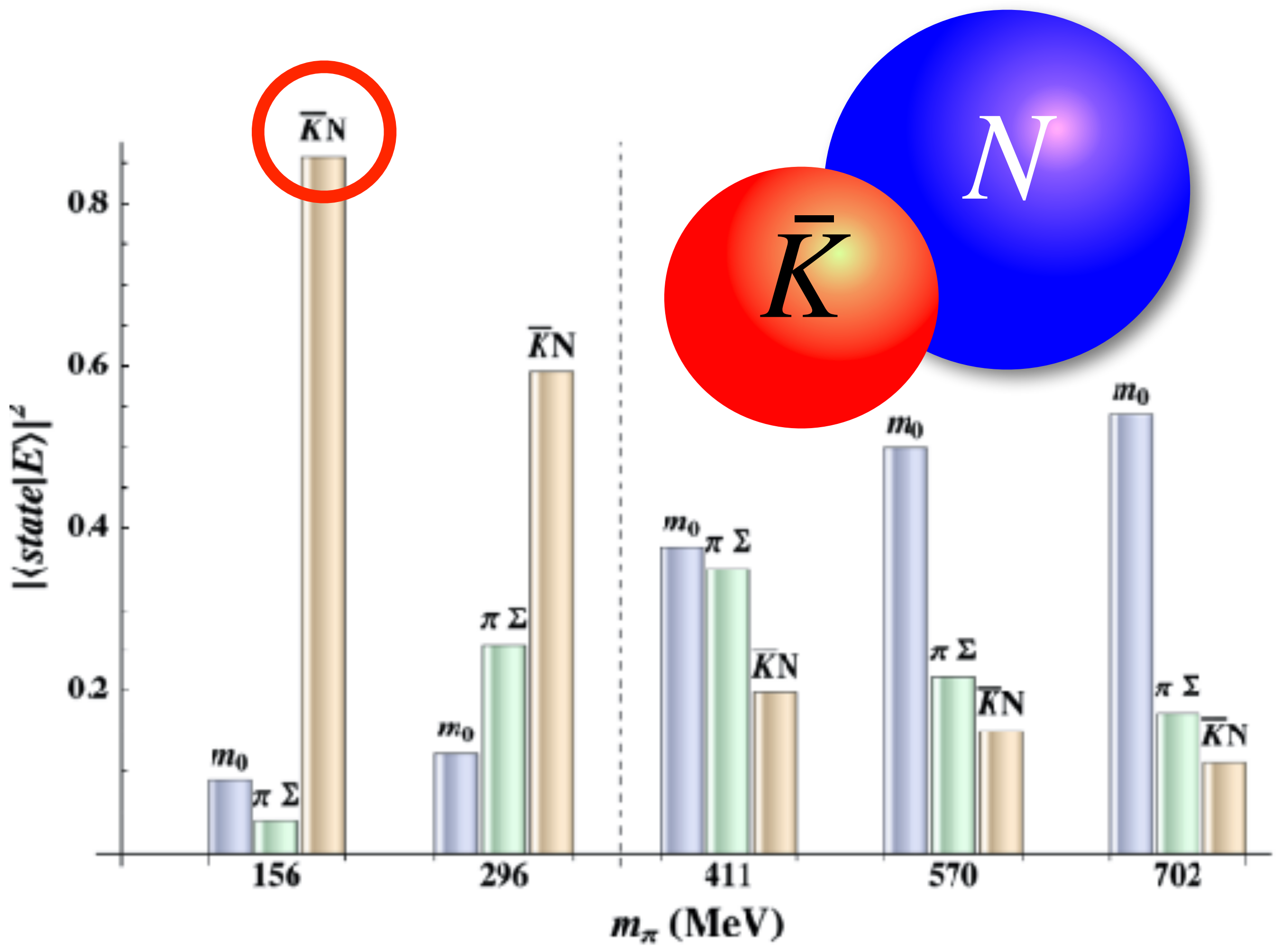
K-p atom
PLB704(2011)113.



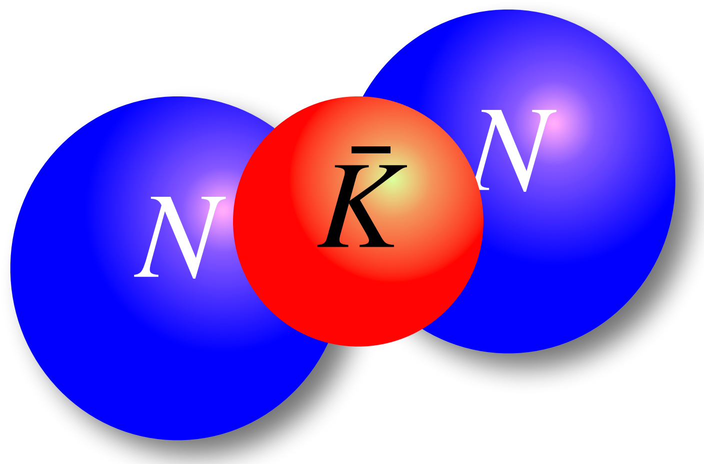
Λ(1405) in
chiral unitary model
T. Hyodo



K^barN molecule from **Lattice QCD**
PRL114(2015)132002.



- Strong attraction in I=0 from scattering and X-ray experiements.
- $\Lambda(1405) = \bar{K}N$ molucle picture is now widely accepted

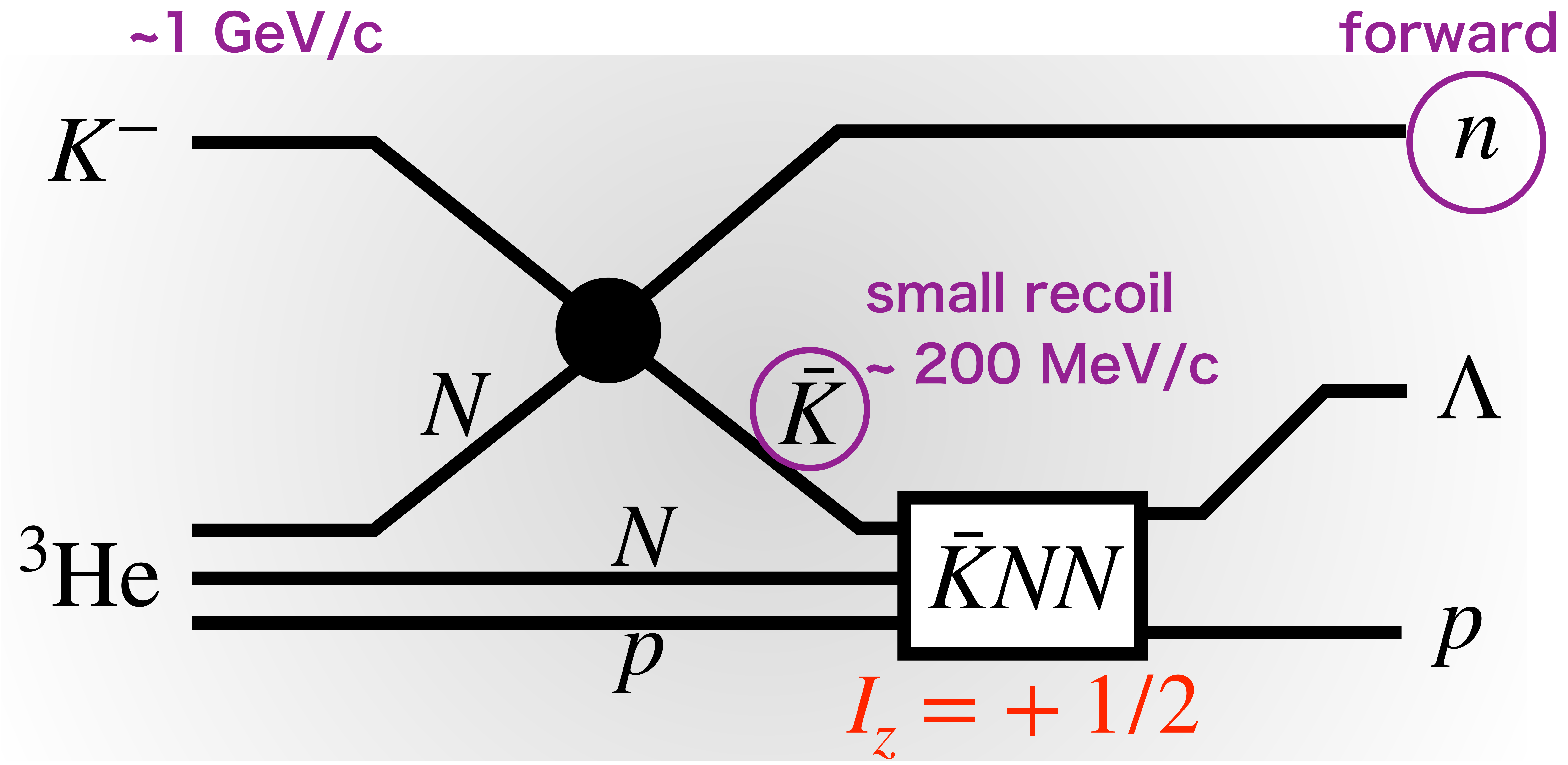


Why not kaonic nucleus with additional nucleons?

no conclusive evidence so far despite the worldwide efforts for decades…

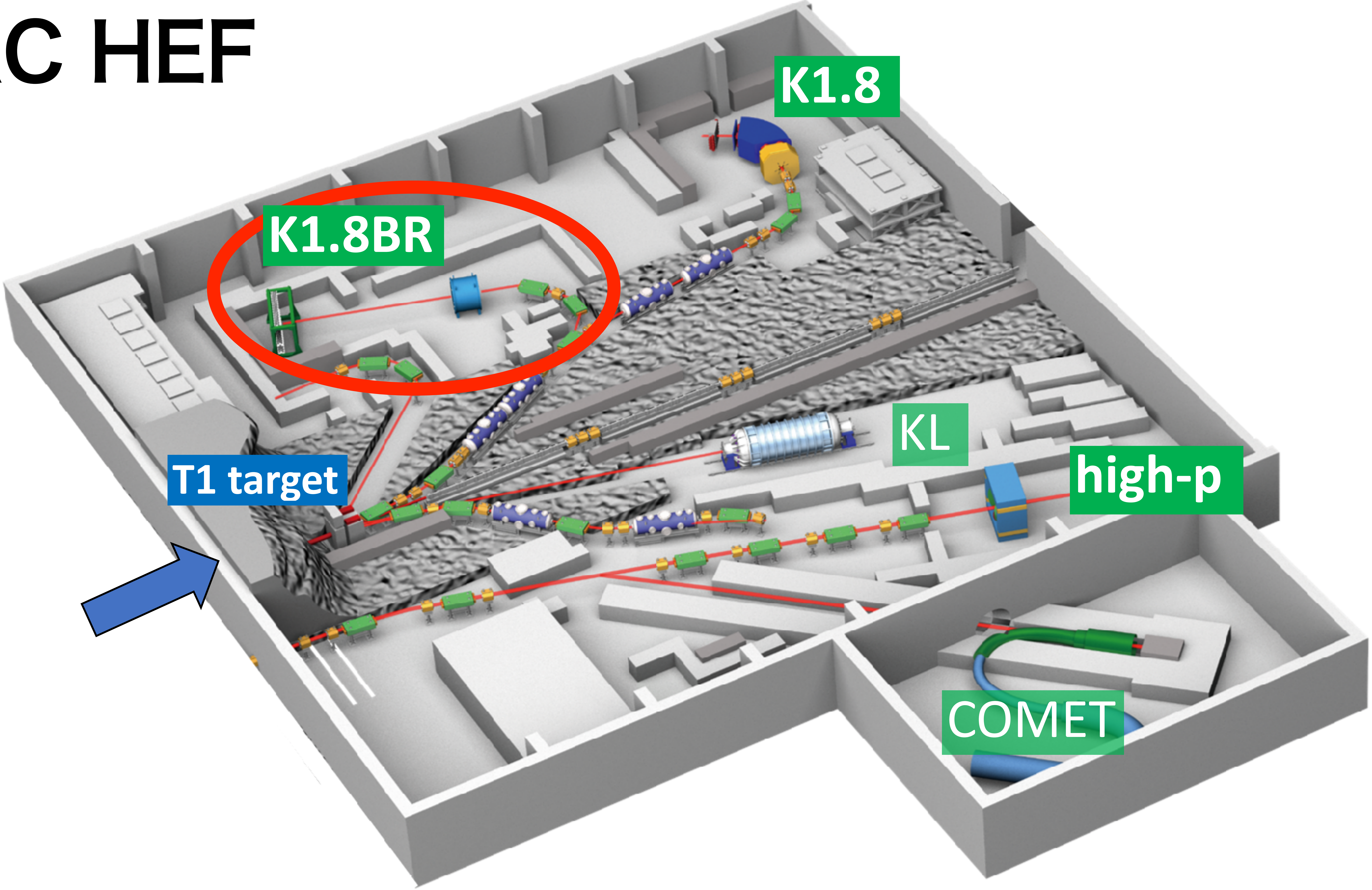
How to embed $\bar{K}$: in-flight (K^-, n)

T. Kishimoto
Phys. Rev. Lett. **83**, 4701 (1999).



- ✓ Effectively produce sub-threshold virtual $\bar{K}$
- ✓ Simplest target allows an exclusive analysis
- ✓ Large-acceptance detector to cover a wide range of kinematical region

J-PARC HEF



K1.8BR suitable for low-energy K^- beam below 1 GeV/c


J-PARC K1.8BR
beam dump
γ, n
p
beam sweeping magnet
15m
Liq. H2/D2/3/4He target system
neutron counter
charge veto counter
proton counter
CDS
K- beam
beam line spectrometer

Experiments with E15-CDS

- 2012: Completed the construction **[PTEP 02B011(2012)]**
- 2013: **E15** 1st, "K^-pp" search.
  [PTEP 061D01(2015), PTEP, 051D01(2016)}
- 2015: **E15** 2nd, "K^-pp" search
  [PLB789,620(2019). PRC102,044002(2020). PRC10,014002(2024).]
- 2018: **E31**, $\Lambda(1405)$
  [PLB837,137637(2023)]
- 2020: **T77**, ${}^4_\Lambda\mathrm{H}$ lifetime, ("K^-ppn" search)
  [PLB485, 138128 (2023)]
- 2021: **E73** 1st, ${}^3_\Lambda\mathrm{H}$ production cross section
- 2024~2025: **E73** 2nd, ${}^3_\Lambda\mathrm{H}$ lifetime, ("K^-pp" study)
  just completed!

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

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

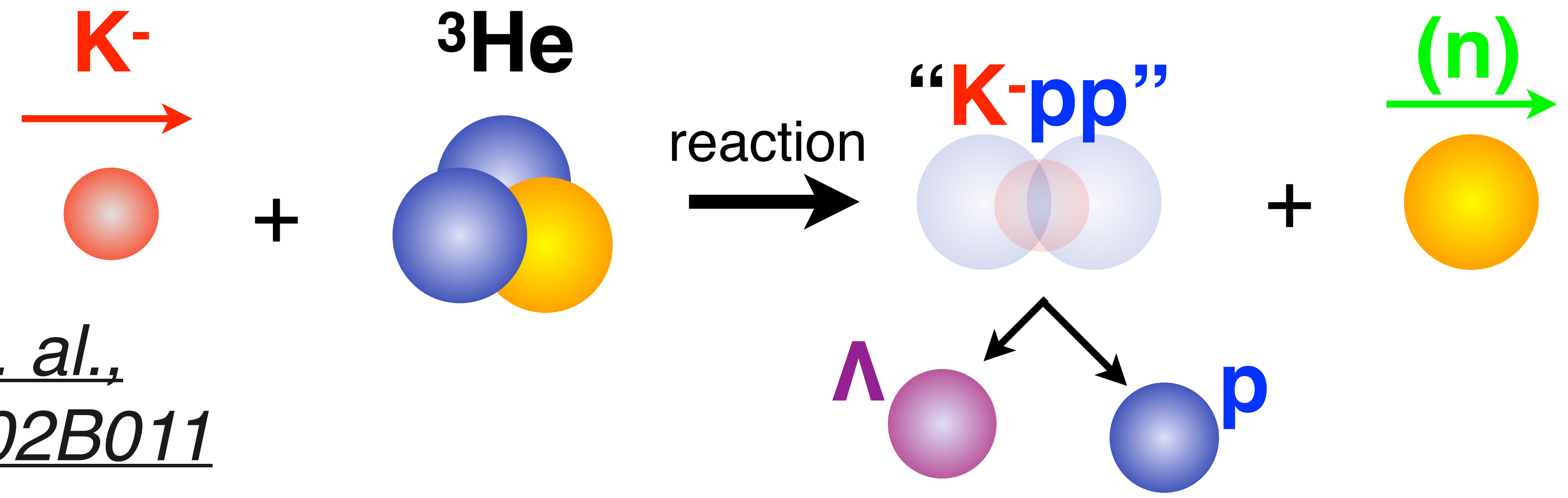
$K^- + {}^4\mathrm{He} \rightarrow {}^4_\Lambda\mathrm{H} + \pi^0$

$(K^- + {}^4\mathrm{He} \rightarrow K^-ppn + n)$

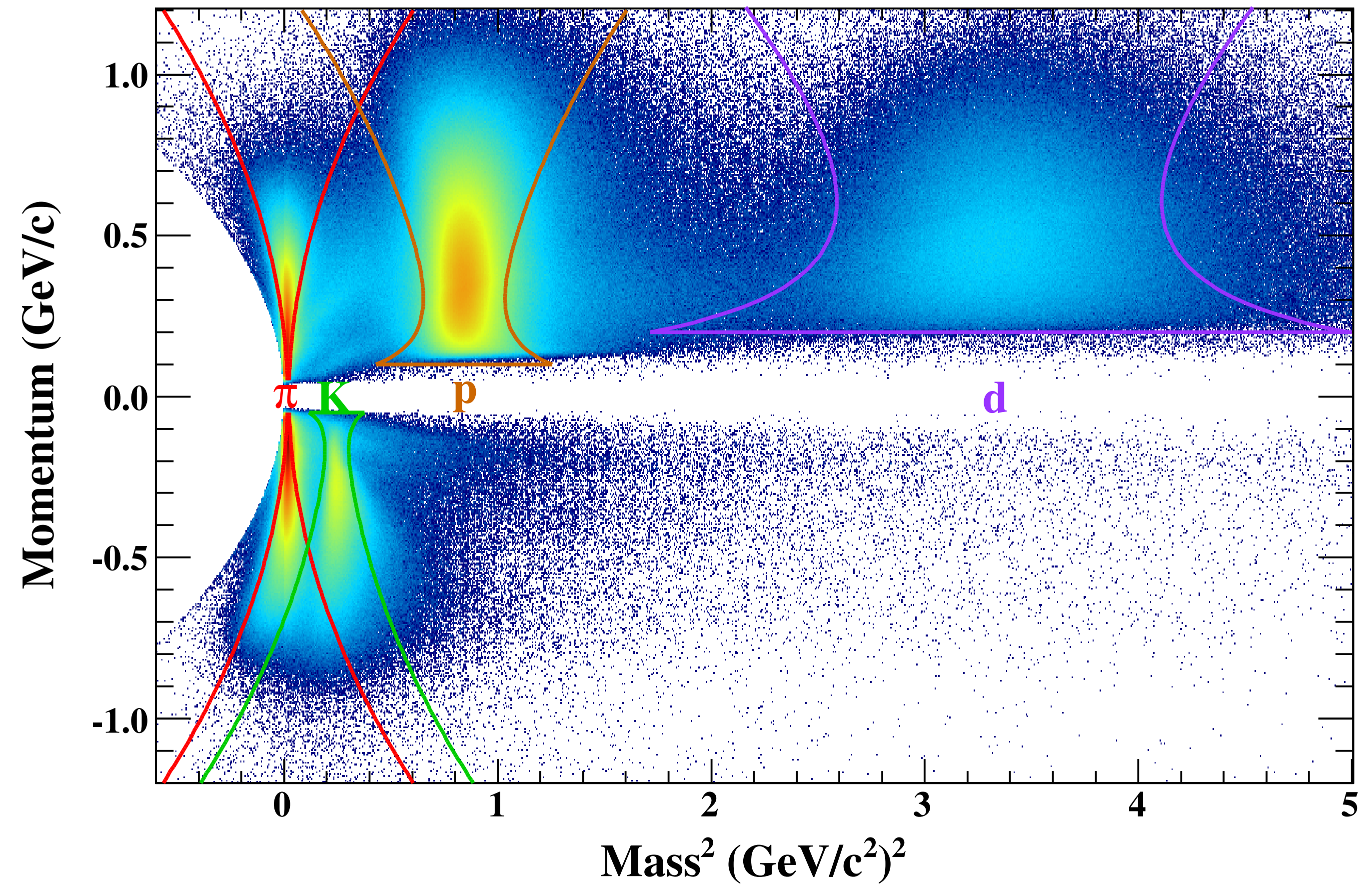
$K^- + {}^3\mathrm{He} \rightarrow {}^3_\Lambda\mathrm{H} + \pi^0$

$(K^- + {}^3\mathrm{He} \rightarrow K^-pp + n)$

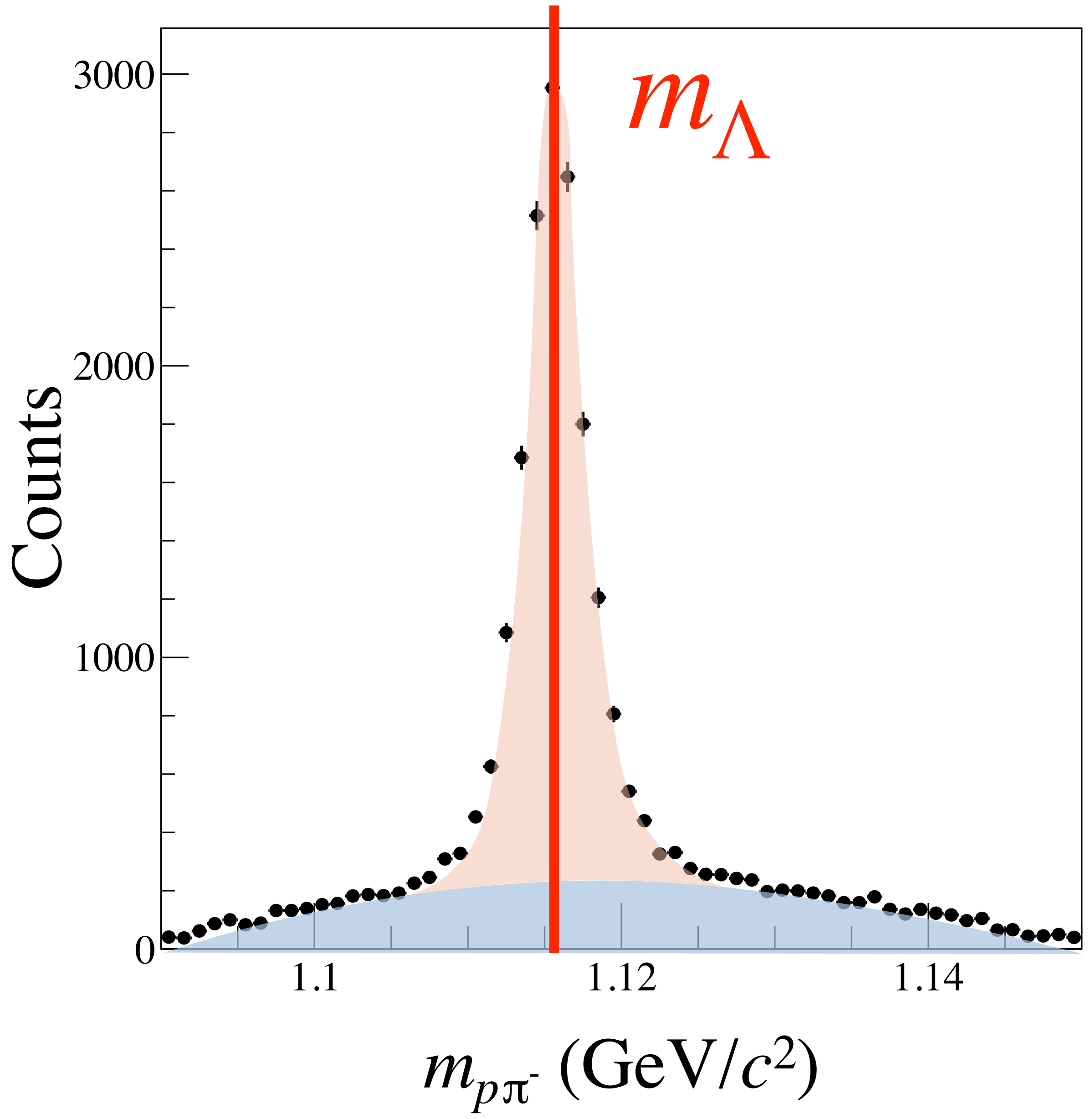
Λpn Exclusive measurement



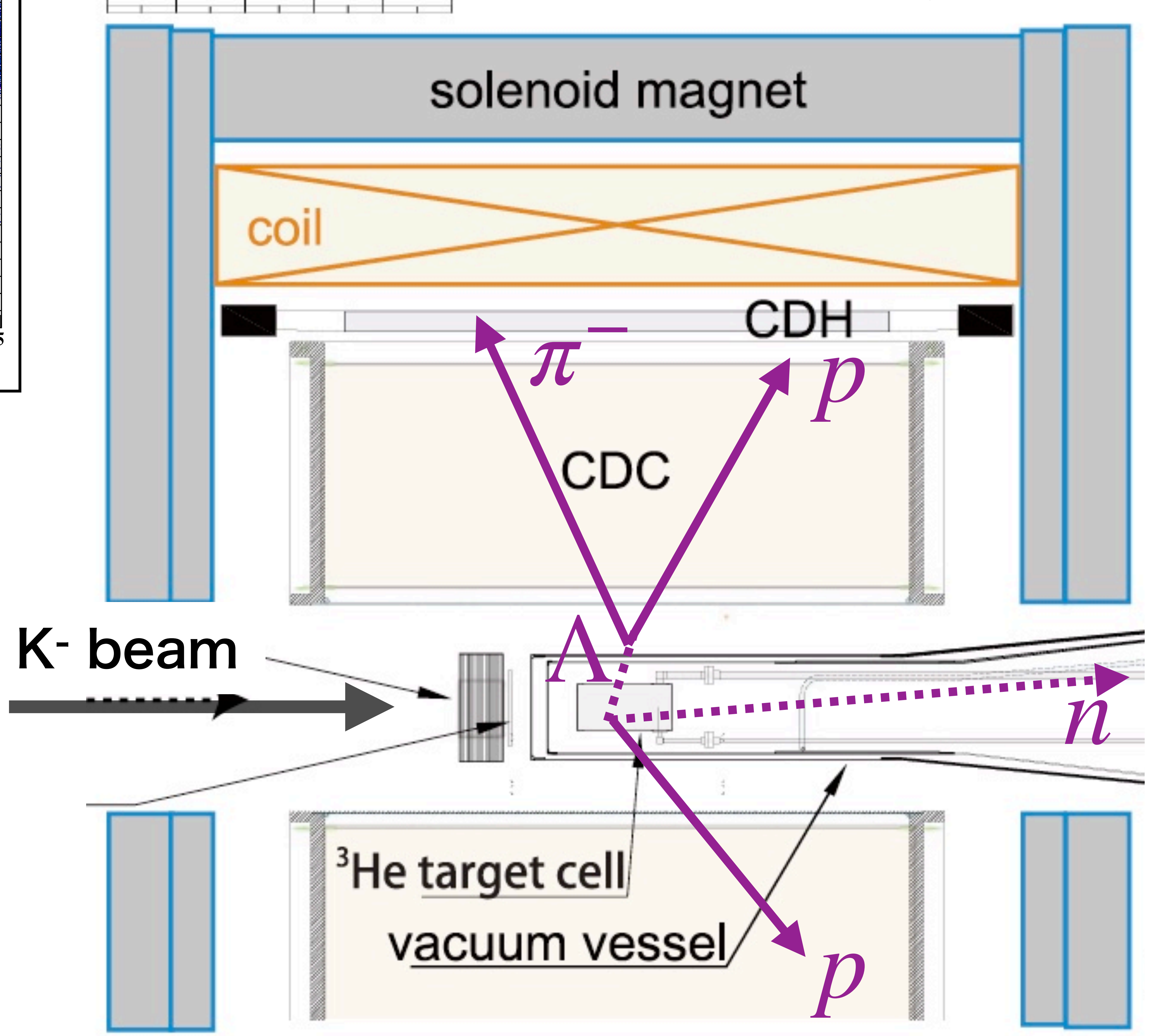
particle identification



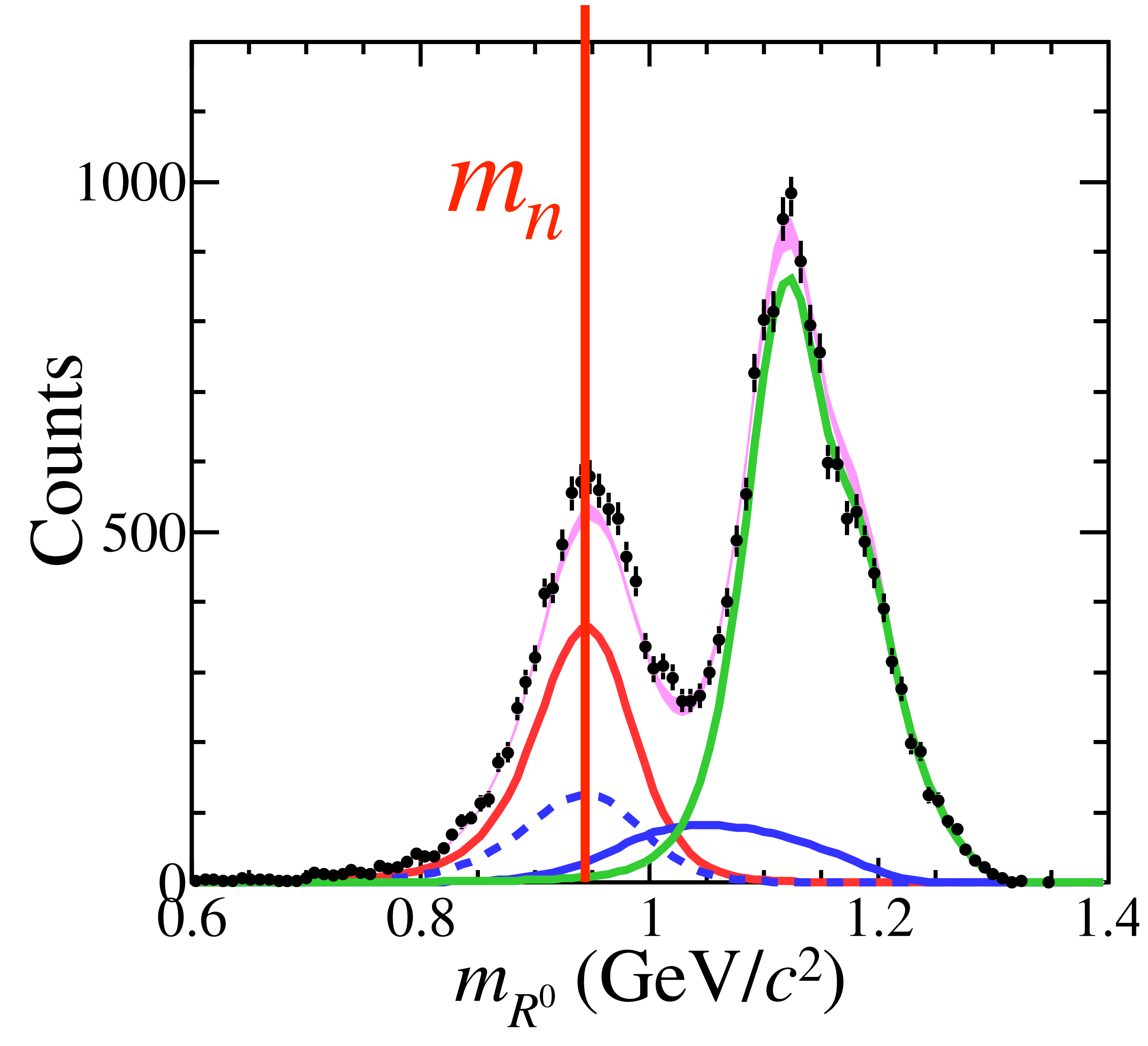
Λ reconstruction



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

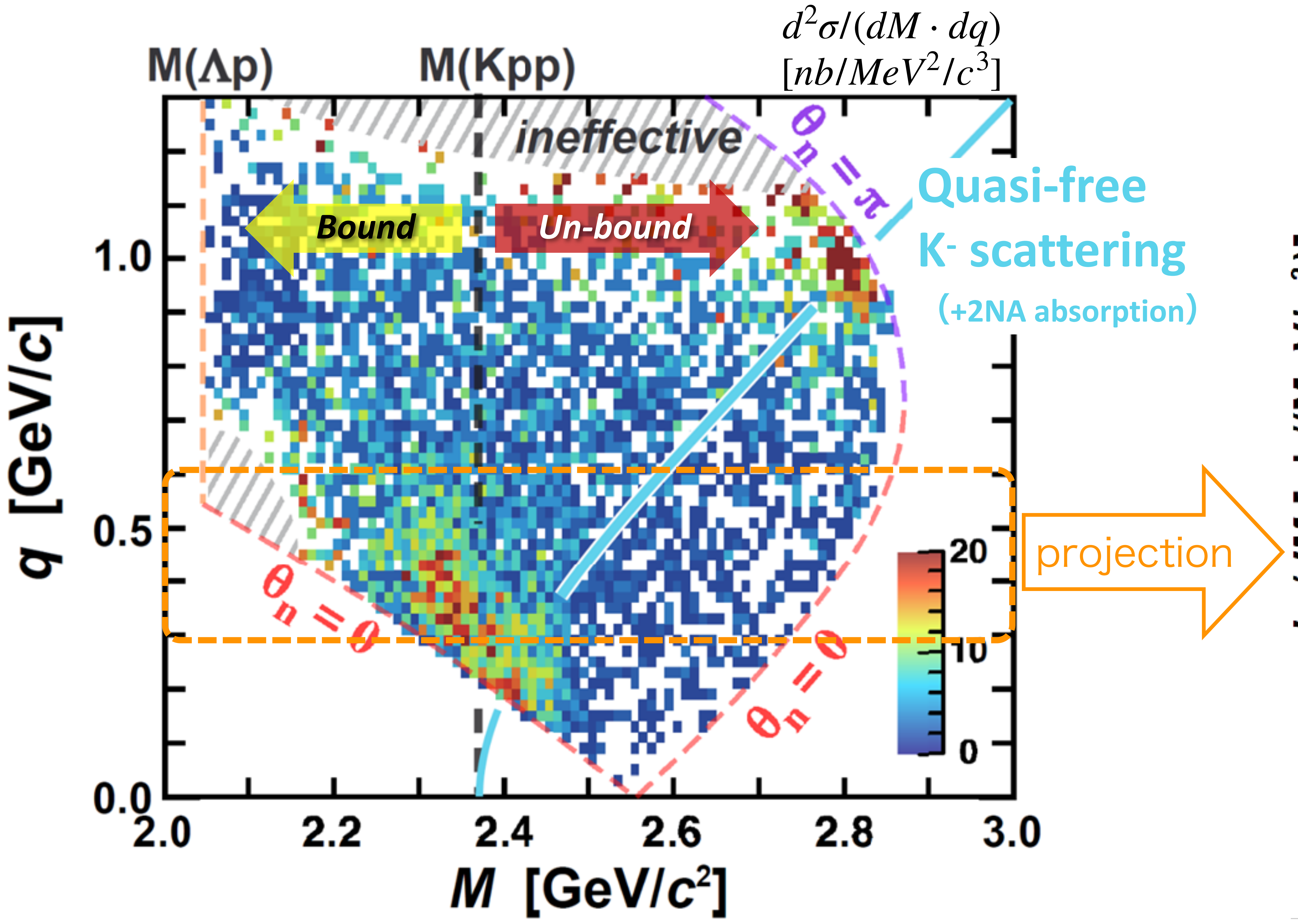


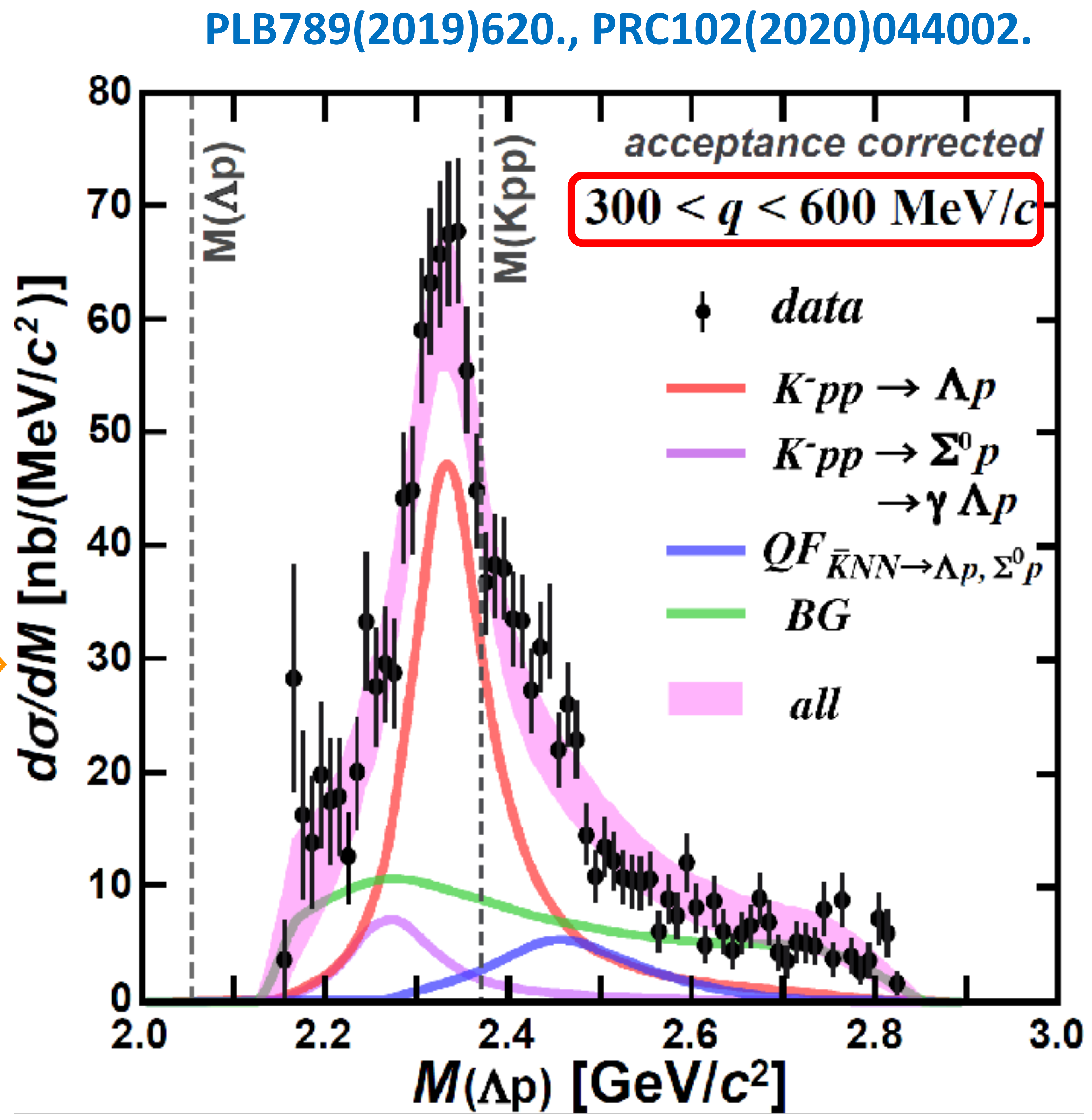
missing neutron selection



Purity of Λpn events ~ 80%

"K-pp" observation in J-PARC E15





q : (K-,n) momentum transfer, ***M*** : Λp invariant mass

Deep binding (B.E. ~ 40 MeV), Large decay width (Γ~ 100 MeV), Large momentum transfer

"K⁻pp": Mesonic decay modes

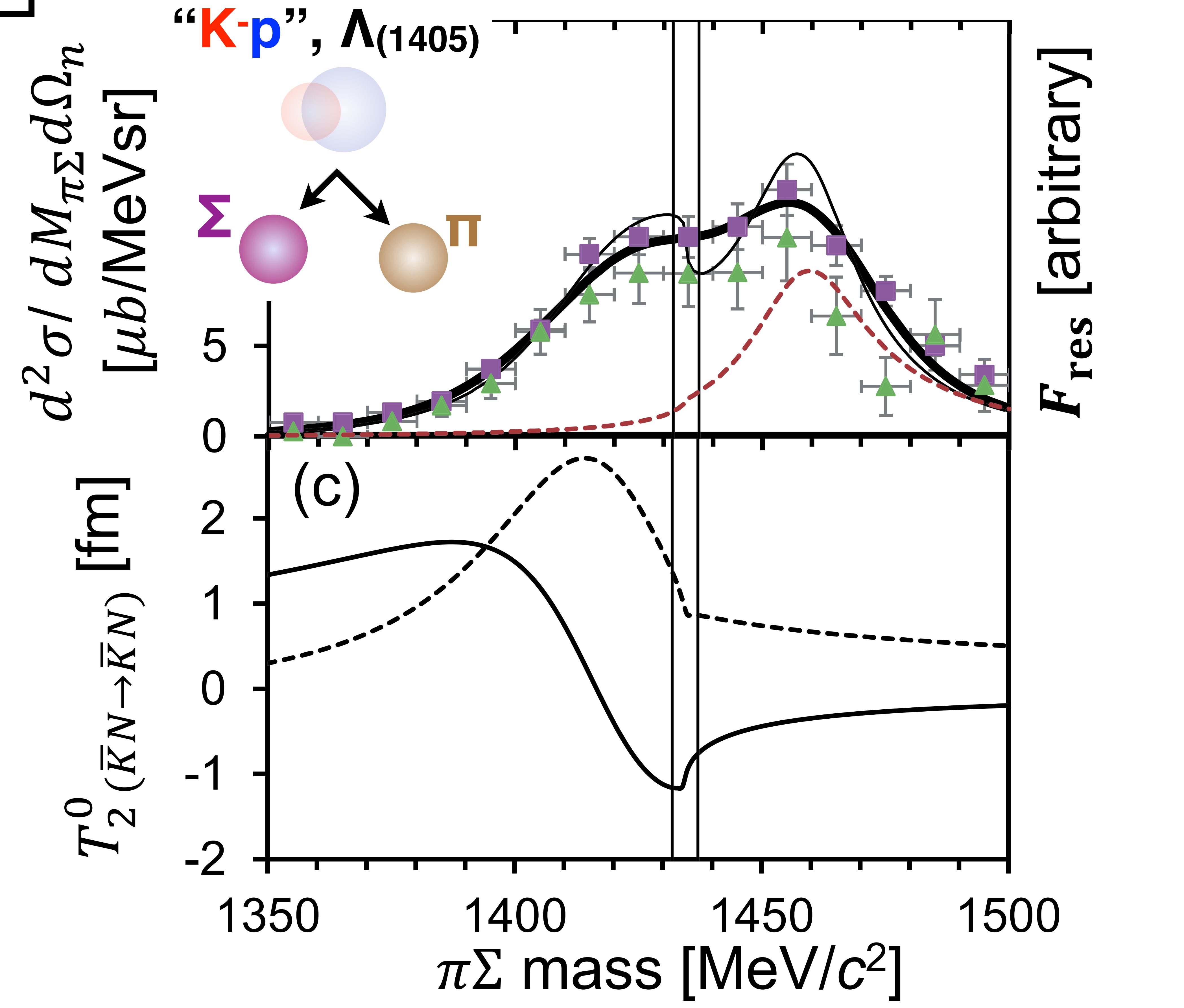
T. Yamaga et al., PRC 110, 014002 (2024)

Can be explained in common with $\Lambda p(n)$ events. $\Gamma_{\pi YN} \sim 10 \times \Gamma_{YN}$. $\Gamma_{\pi\Sigma N} \sim \Gamma_{\pi\Lambda N}$.

(K⁻, n) reaction on other targets

d_2

PLB837,137637(2023)

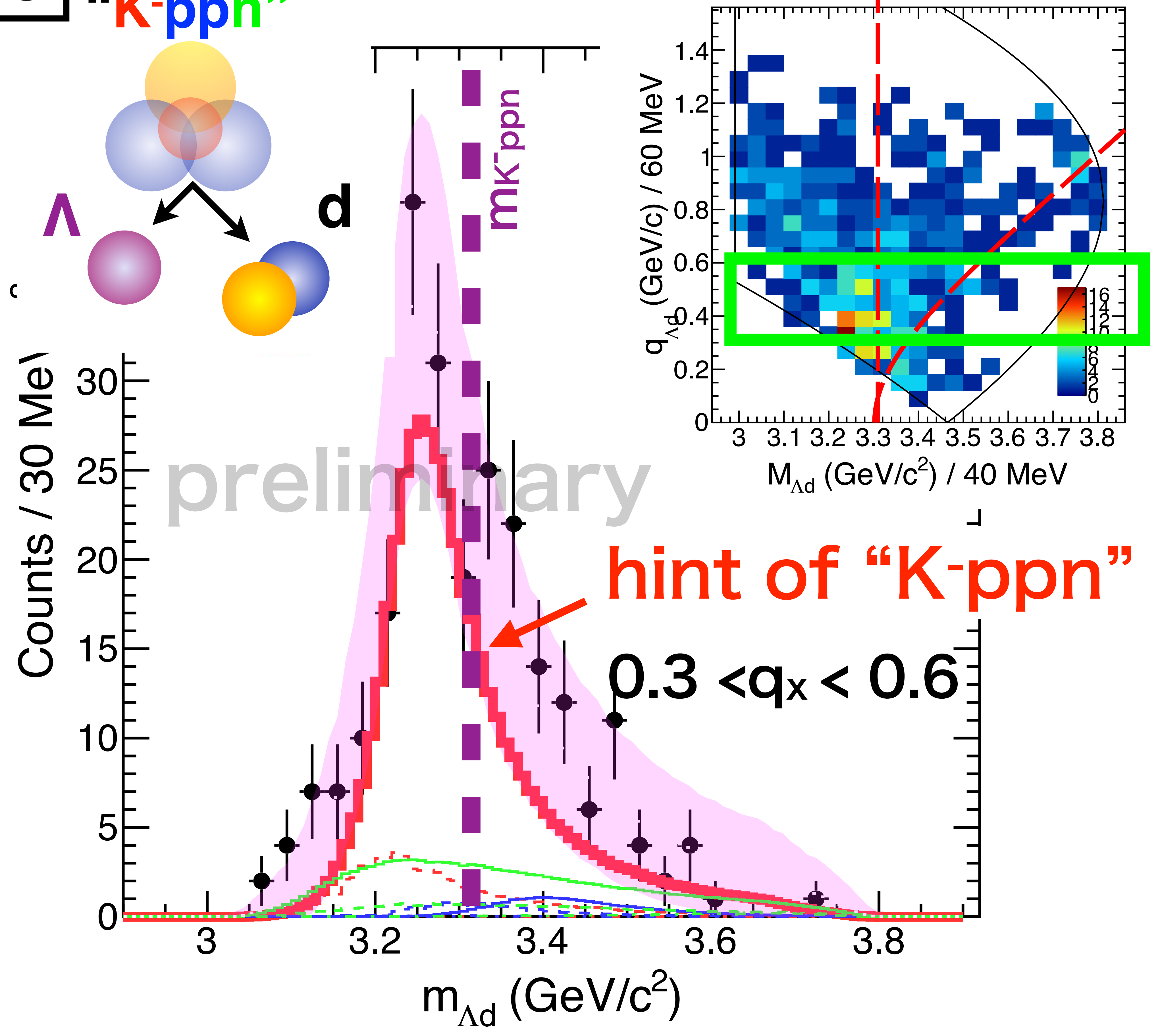


S-wave $\bar{K}N$ amplitude (I=0) was deduced with two-step reaction models

pole: 1417.7 – 26.1i [MeV]

^4He

only ~3 days data-taking



$B_{\bar{K}NNN} \sim 60 \pm 11\text{(stat) MeV}$

$\Gamma_{\bar{K}NNN} \sim 100$ MeV

$\sigma_{\bar{K}NNN \to \Lambda d} \sim 4\ \mu$b

$I(J^p) = 0(1/2^-)$

with high certainty

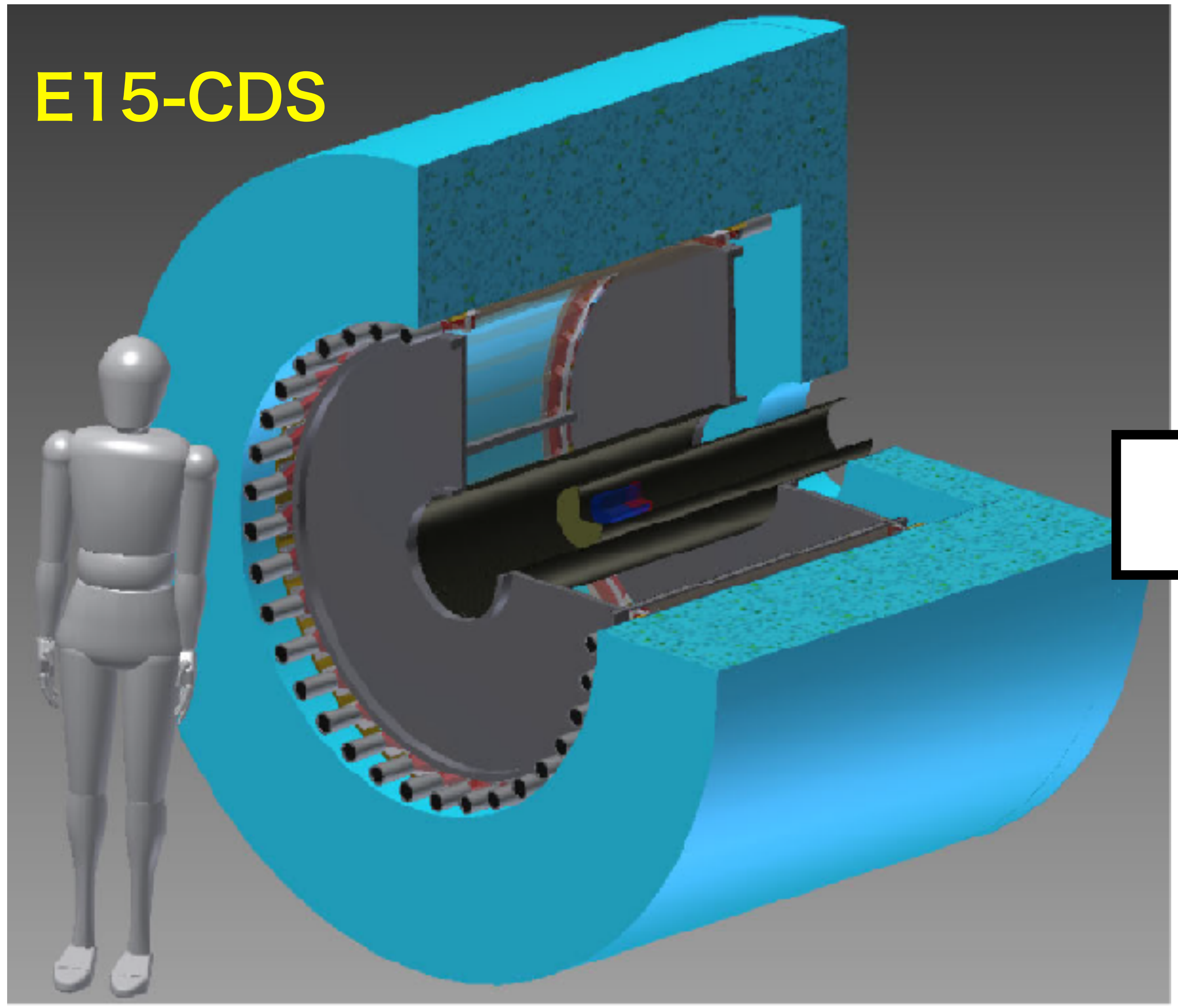
Achievement so far:
Established the production method of $\bar{K}$ nuclei

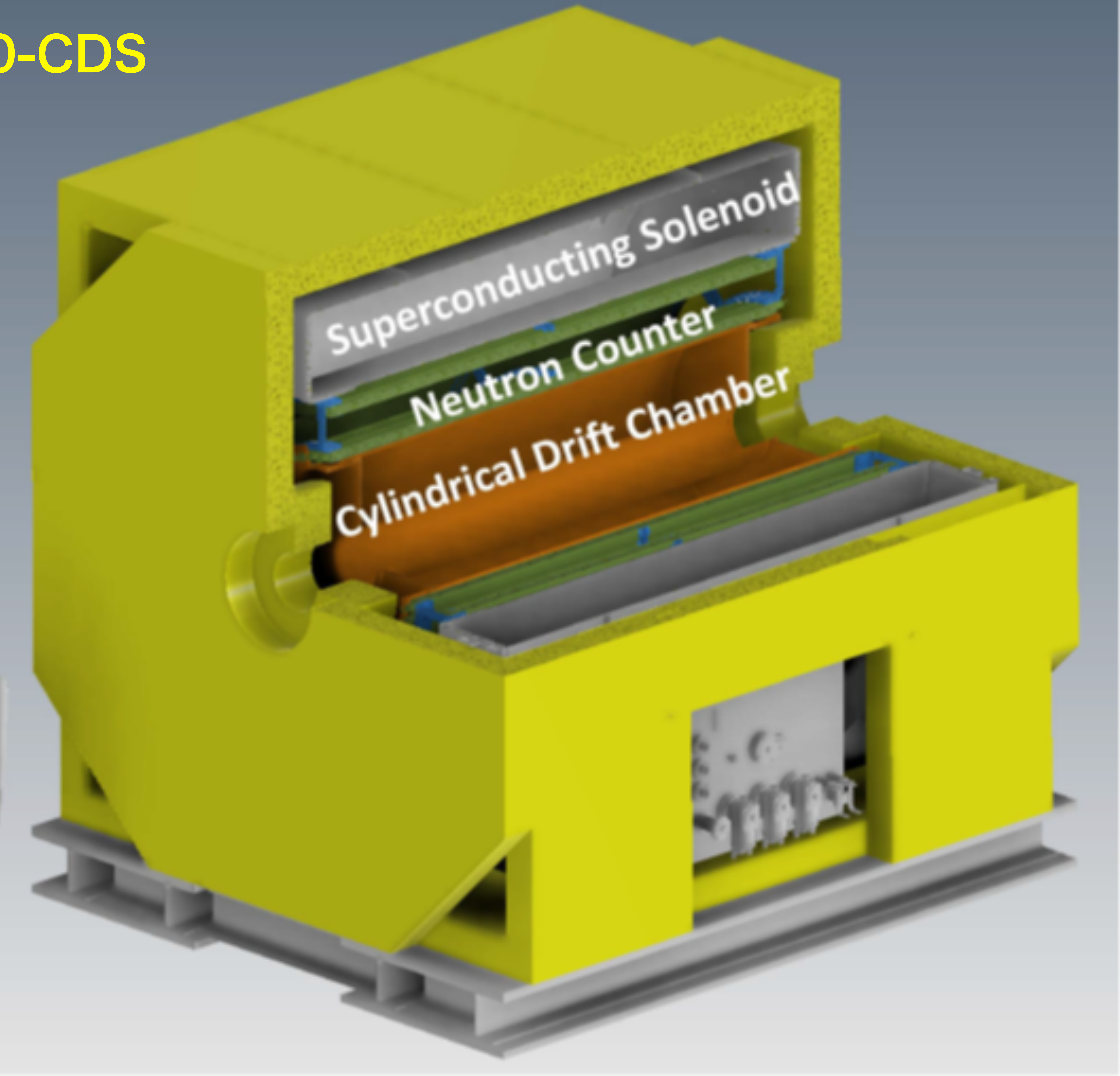
- **In-flight (K-, n)** is effective in exciting the sub-threshold $\bar{K}$ amplitude
- kaonic nuclei seem to exist more or less universally **"K-pp", "K-ppn"**, ⋯

What is Next?: systematic study

- **Further investigation of the $\bar{K}NN$ system J-PARC E89**
    - Search for the isospin partner "$\bar{K}^0 nn$" via $\bar{K}^0 nn \to \Lambda + n$ decay
    - Spin-parity of "$K^- pp$"→spin-spin correlation measurement of Λ & p
- **Confirmation of "$K^- ppn$" $\to \Lambda + d,\ \Lambda + p + n$ J-PARC E80**
    - mass-number dependence
- **Spatial size, heavier system, double $\bar{K}$ nuclei…**

New CDS





- ✓ **Solid angle: x1.6** (59%→93%)
- ✓ **Neutron eff. x4** (3%→12%)
- ✓ forward TOF counters
- ✓ (proton polarimeter in future)

Construction status

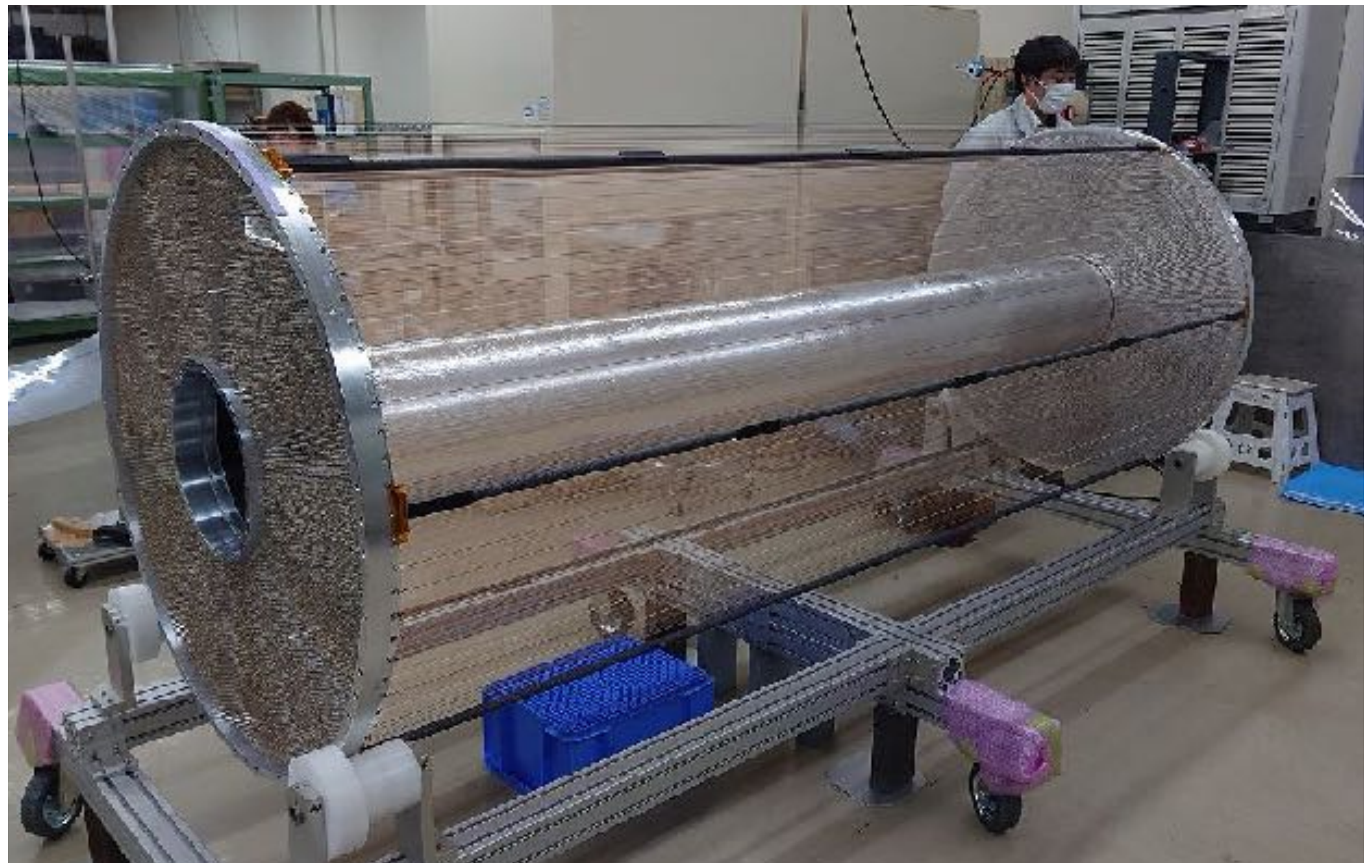
Solenoid york

completed in JFY2022

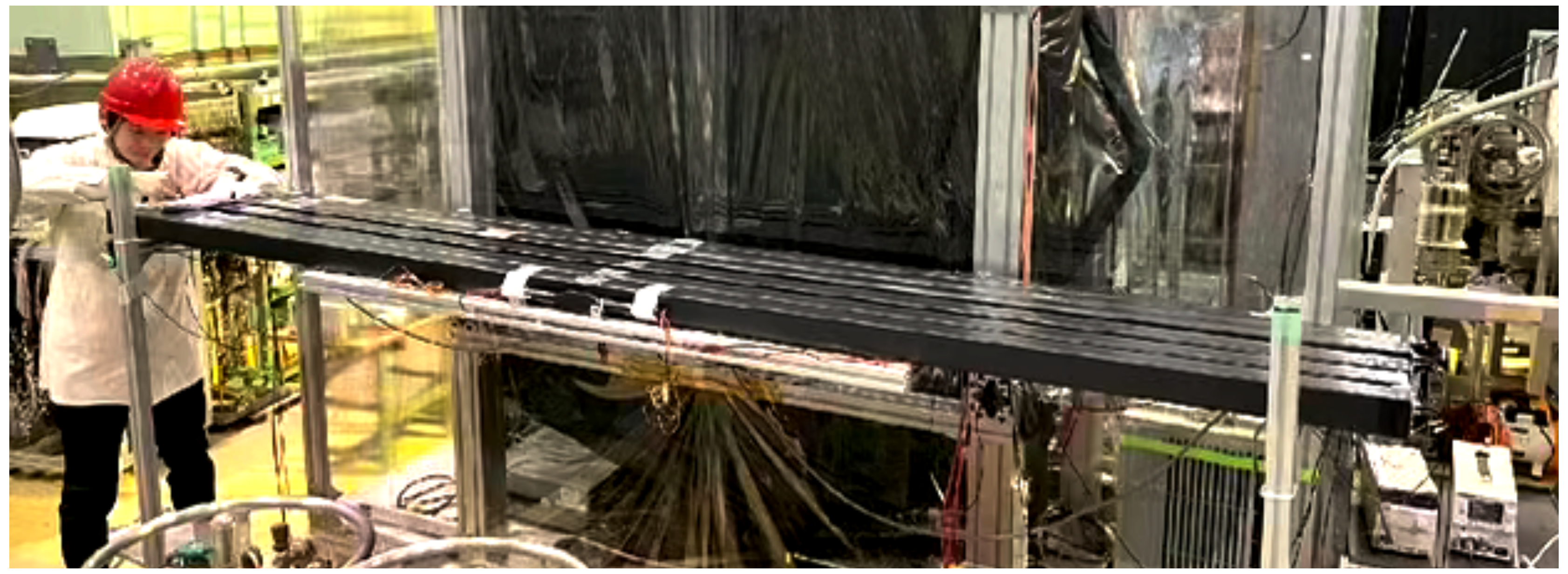
Superconducting solenoid

completed in JFY2024
(copy of COMET-DS)

CDC: Commissioning started



CNC: readout test with beam



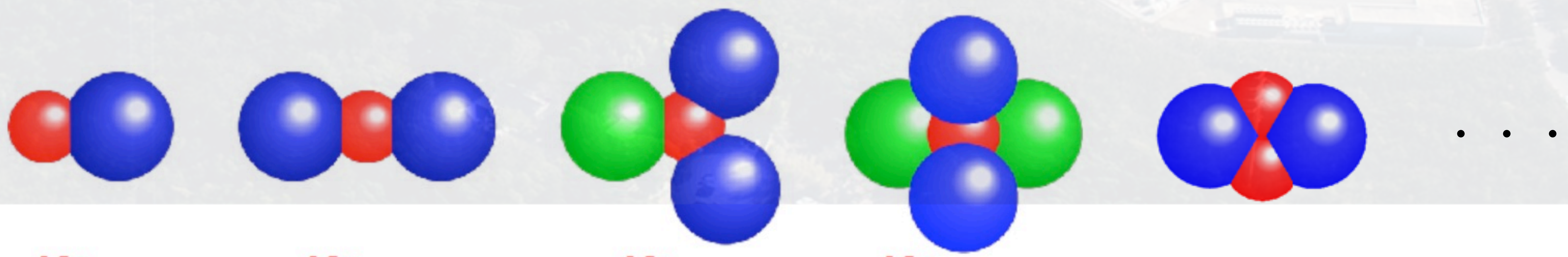
We would like to start beam commissioning by the end of JFY2026

Summary

- Kaonic nuclei would open a new field of nuclear physics with anti-kaon as a new probe.

- We established the production of kaonic nuclei via (K^-, n).
  "K^-p" as $\Lambda(1405)$, **"K^-pp", "K^-ppn"**

- We are developing a new solenoid spectrometer, aiming to elucidate the properties of kaonic nuclear systems.



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