学んだこと（失敗から学んだことを交えて）

Physical Research conducted at RIKEN
— as a Chief Scientist —

理研で取り組んだ物理

次世代研究者へ：失敗を恐れず挑戦的な研究を！

IWASK2024 — 05/03/2024

Masahiko IWASAKI

Meson Science Laboratory

IWASK2024 ..... Interdisciplinary Workshop for Advanced Science of Kaon and related topics

日時：2024年3月5日 (火) 9:30 - 18:00
場所：理化学研究所 大河内記念ホール

先ごろJ-PARCで生成・分光に成功した K^-pp 束縛核に関する一連の研究は、粒子描像があやうくなるほどコンパクトな陽子間距離を示唆し、高密度物質である原子核内におけるハドロンの粒子性と量子性という本質的問題を提起しています。ここで提起された問題は、原子核という舞台においてのみならず、固体凝縮物質中の電子が示す量子相転移とも密接な関係にあります。K中間子研究はハドロン研究の一分野としての位置づけを超え、物質の階層性をまたいだ新たな学際研究へと広がる可能性を秘めています。この好機に、K中間子および関連するトピックをあつめたワークショップを開催し、未来の中間子科学が取り組むべき課題は何か、指針を探る機会としたいと思います。

講演者
松田恭幸、石田勝彦、神田聡太郎、渡邊功雄、藤山茂樹、馬越、橋本直、西隆博、板橋健太、四日市悟、岡田信二、岩崎雅彦 (順不同)

申し込み方法
https://indico2.riken.jp/e/iwask2024
問い合わせ先 iwask2024@ml.riken.jp（板橋・藤山・山本）

全ての参加者に感謝を

— IWASK2024 —

To organizers, thank you for giving me a chance to talk.

To speakers, all the participants and secretaries, thank you for joining.

named and organized by K. Itahashi and S. Fujiyama
with helps from researchers who have been contributed
Meson Science Laboratory in RIKEN

I apologize for not being able to cover my contributions
as Chief Scientist at RIKEN due to time constraints.

I hope the missing parts are well covered by
the other speakers of IWASK2024.

Meson Science Laboratory

— covers wide variety of field
by the variety of researchers —

Nuclear physics

mesonic atoms (atomic physics / nuclear physics)

mesons in nuclei (nuclear physics) — today!

Λ in nuclei (nuclear physics)

IWASK2024 ではここの話を

Muon science

μCF : muon catalyzed fusion (chemistry / atomic physics / nuclear physics)

μSR : muon spin rotation / resonance ... (condensed matter physics)

μA* : muonic atoms (nuclear physics)

cold-μ : muon magnetic microscope / muon g-2
(particle / atomic physics / condensed matter physics)

Mössbauer / NMR / ESR

RI-beam Mössbauer spectroscopy (condensed matter physics)

Magnetic property probed by NMR / ESR

A Slide from Interim Review of Institute Laboratory Assessment in 2006

研究者としての来歴：決して成功ばかりじゃない…

nuclear physics

PhD student **UT** big leader T. Yamazaki *1982*

heavy neutrino search (particle physics) NG

hypernuclear study NG

TRIUMF pionic atom NG *PhD in 1987*

Σ-hypernucleus ! $_{\Sigma}^{4}$He

atomic meta-stable state in exotic helium! (atomic physics)

original

$\bar{p}$ physics @ ASAKUSA

UT-MSL vigorous leader K. Nagamine

PhD student **muon science**

Staff Scientist

research associate

construction

contribution to JHF stalled

(*RIKEN-RAL construction*)

DAQ

μ-CF

slow-μ

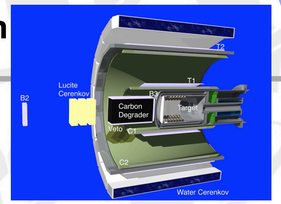
μ-radiography

完全オリジナル実験成功

KEK KpX E228

kaonic hydrogen atom

1990-1997

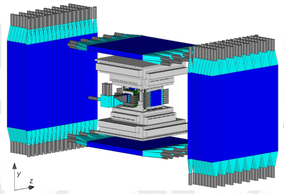


大失敗

enthusiastic promoter K. Nakai

NG

KEK - E471, E549, E570



INFN (SIDDHARTA) kaonic atom

INFN / SMI (DEAR) kaonic atom

GSI pionic atom

TI-Tech *1997*

associate professor

TI-Tech

visiting professor

E471 kaonic nucleus search NG

E549, E570 kaonic helium-3 search

kaonic helium-4 atom

BNL E821

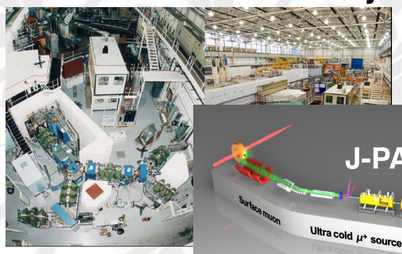
muon g-2 measurement

muon CBO (particle physics)

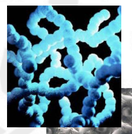
PI

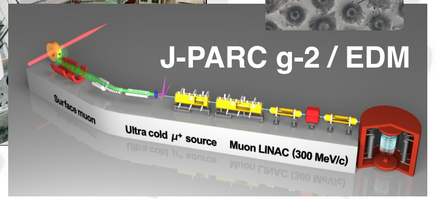
BNL E821

RIKEN-RAL muon facility



laser-drilled aerogel





2002 **RIKEN** chief scientist *2002*

last 22 years in RIKEN

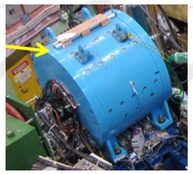
RIKEN-RAL operation

J-PARC P34 muon g-2 / EDM based on cold-μ

μ magnetic microscope

RNC inauguration

RIBF pionic atom



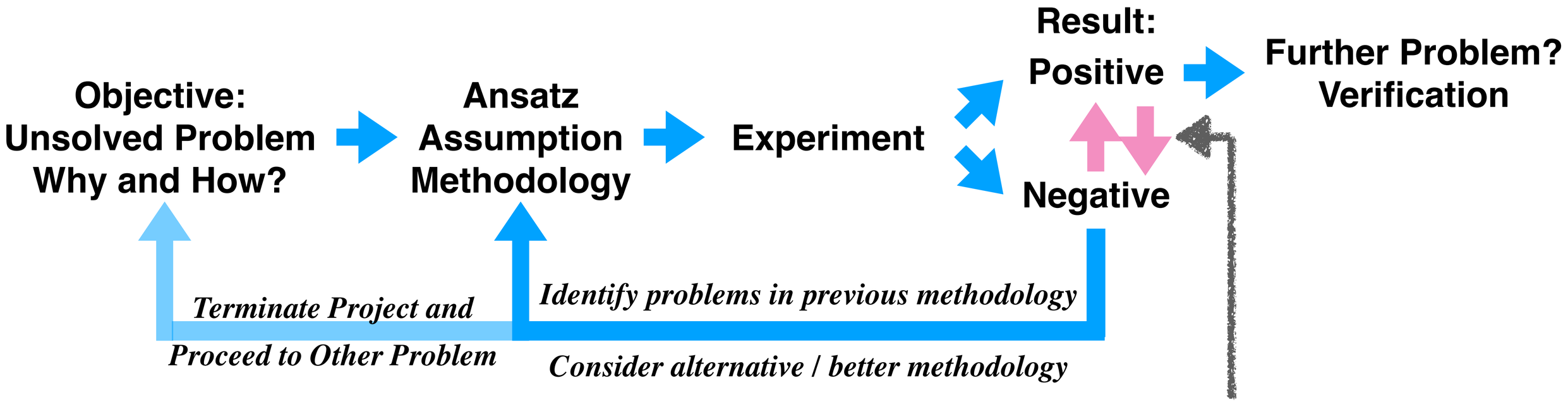
K中間子核観測成功

J-PARC E15 / E17 kaonic nucleus "Kpp" search kaonic helium-3 atom 2006-2019

ϕ & KK in nuclei

実験研究のサイクルの紹介

A Typical Experimental Research Cycle



↑ = { **mistake / hidden bias in the analysis** — *Must be corrected, and open that to public.*
— *To encourage ambitious research, failure must be embraced.*

完全にミスを防ぐことは不可能。間違いは許容されるべき

pretend to be positive — unacceptable scientific misconduct

決して許容できない。過度な倫理教育・研究者の引き締めは愚策

研究者としての最初の大成功

Let me start from a mile-stone experiment, which makes me to be a Principal Investigator (PI)

The KpX experiment

"It takes three years from gaining PhD in 1987 to develop original research ideas in 1990, and another seven years to get the first results reported in 1997."

… 本質的革新を齎すための手段を真摯に模索 …

… 良い研究は10年位は平然とかかる …

K中間子水素原子パズル

My first success as a researcher

Resolving the kaonic hydrogen puzzle is a must

PHYSICAL REVIEW D
VOLUME 50
1 AUGUST 1994

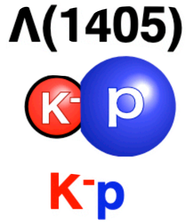
THE $\Lambda(1405)$ by R.H. Dalitz, Oxford University

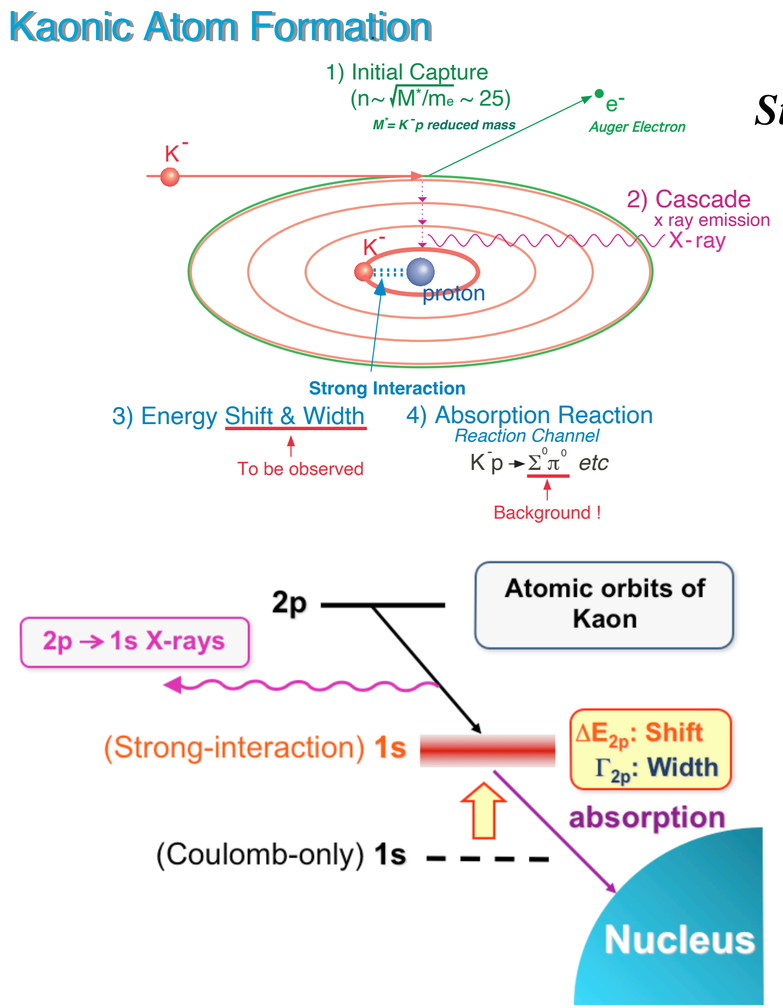
.....

The present status of the $\Lambda(1405)$ thus depends heavily on theoretical arguments, a somewhat unsatisfactory basis for a four-star rating. Nevertheless, there is no known reason to doubt its existence or quantum numbers. A measurement of the energy-level shifts and widths for the atomic levels of kaonic hydrogen (and deuterium) would give a valuable check on analysis of the $(\Sigma\pi, N\bar{K})$ amplitudes, since the energy of the K^-p atom lies roughly midway between those for the two sets of data. The three measurement of $(\Delta E\text{-}i\Gamma/2)$ for kaonic hydrogen are inconsistent with one another and require that the sign of $\mathrm{Re}(A_{I=0} + A_{I=1})$ be opposite that deduced from $N\bar{K}$ reaction data (see BATTY 89). Accurate measurements of $(\Delta E\text{-}i\Gamma/2)$ values for kaonic hydrogen are badly needed, but may not be possible until the KAON factory becomes operational.

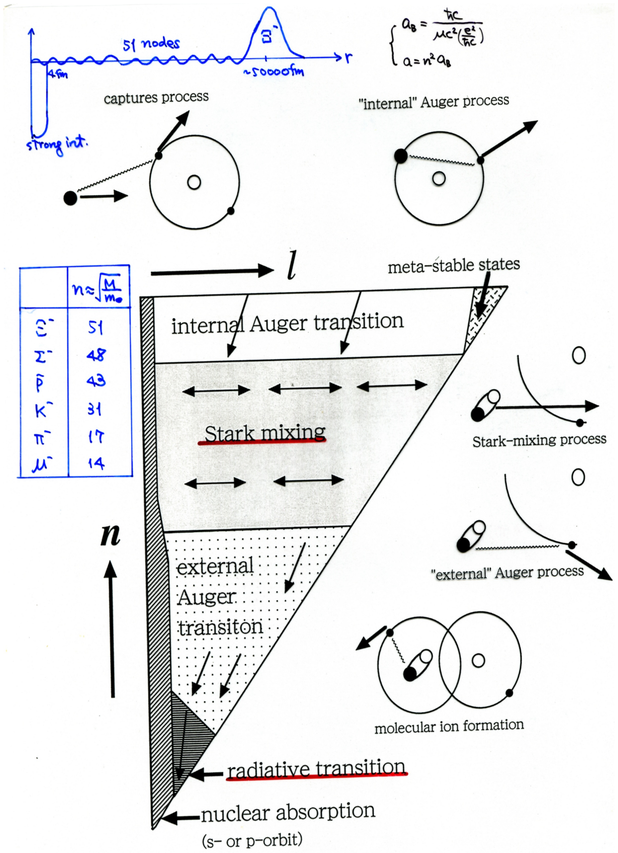
.....

→ Kaonic Hydrogen Puzzle!

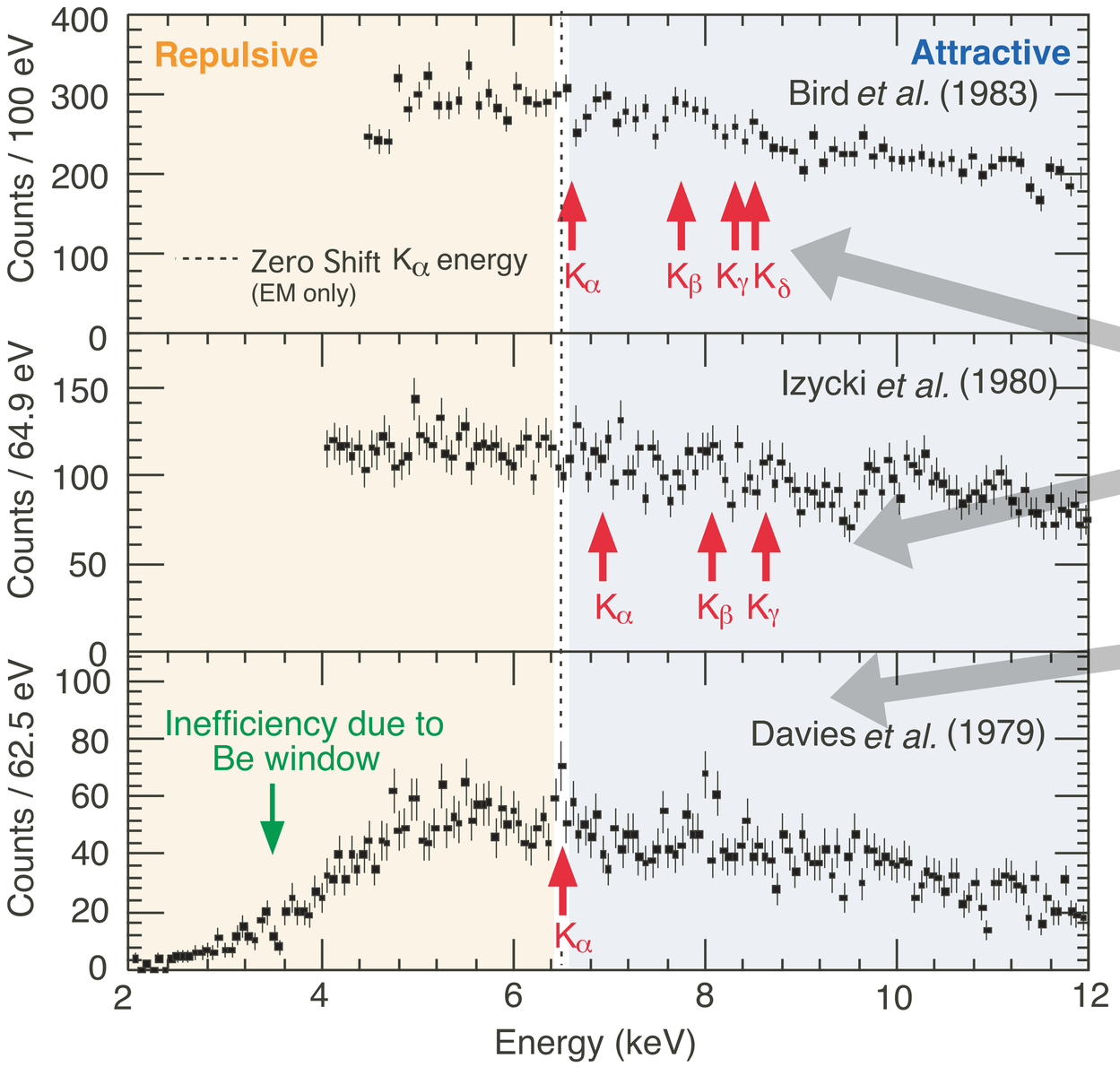




Stark-effect prevents x-ray observation

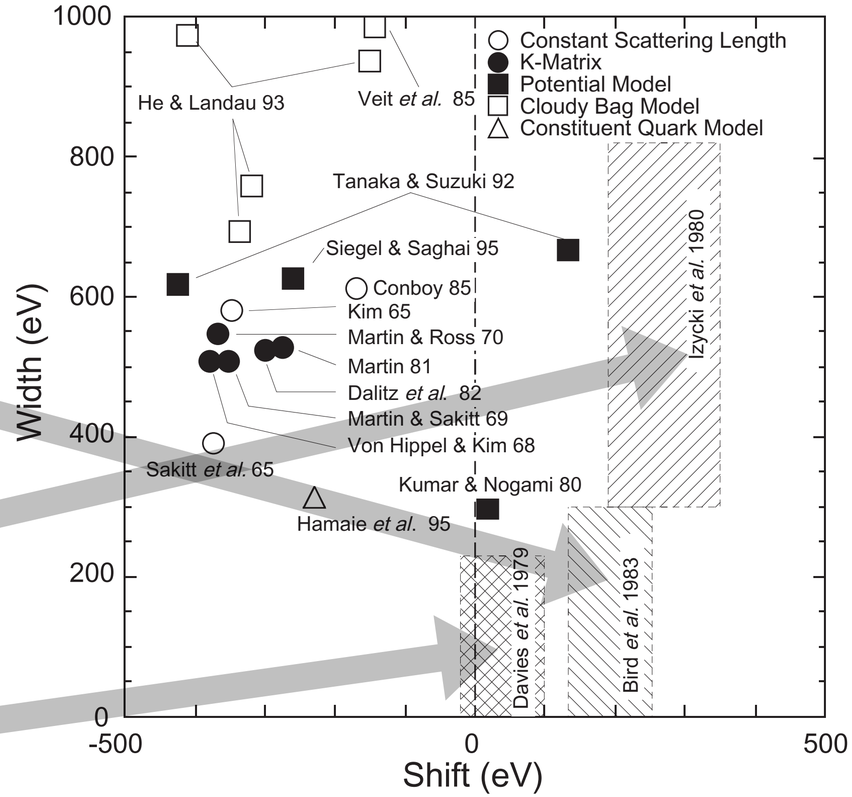


Previous data on the kaonic hydrogen



Can you really see signals in these spectra?

Theories and Experimental results are inconsistent



Most probably the applied experimental methods are insufficient!

How to improve?

過去の実験困難をどう乗り越える？

困難解決に向けた方策

My first proposal to PAC (実験課題審査会):

Simply REJECTED … Insufficient to convince reviewers

Consider more about how to initiate the break through to overcome experimental difficulties?

Second proposal to PAC: … break through ideas

- **Gas Target (liquid previously)**
  - Stark Free (drastically improve S/N)
- **Background Free (reduce noise)**
  - Final state tagging / Specify reaction point
  - Require kaonic hydrogen atom formation
- **X-ray detector in Hydrogen Gas**
  - Si(Li) without x-ray window
  - Drastically improve signal

ACCEPTED by fully convincing reviewers …

Won a strong budgetary support from KEK (K. Nakai)

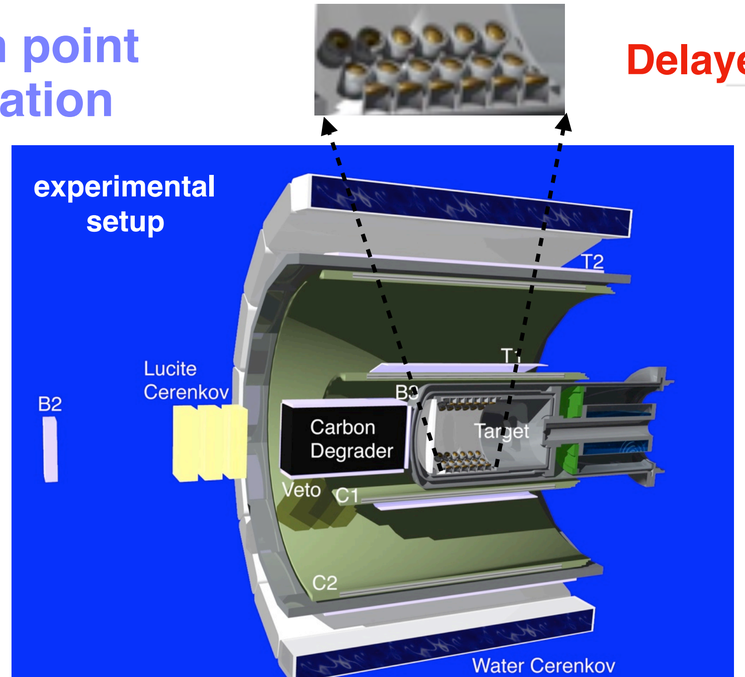
Reaction	Produced Particles	Branching Ratio	$\pi/\mu/e$ Multiplicity (> 150 MeV/c)	γ Multiplicity
		Free Decay of K^-		
$\mu^-\nu$	$\mu^-\nu$	63.5 %	1	0
$\pi^-\pi^o$	$\pi^-2\gamma$	21.2 %	1	2
$\pi^-\pi^-\pi^+$	$\pi^-\pi^-\pi^+$	5.59 %	0	0
$e^-\pi^o\nu$	$e^-2\gamma$	4.82 %	1	2
$\mu^-\pi^o\nu$	$\mu^-2\gamma$	3.18 %	1	2
		K^-p Reaction		
$\Sigma^+\pi^-$	$\pi^-2\gamma p$	10 %	1	2
$\Sigma^+\pi^-$	$\pi^-\pi^+n$	10 %	2	0
$\Sigma^-\pi^+$	$\pi^+\pi^-n$	46 %	2	0
$\Sigma^o\pi^o$	$\pi^-3\gamma p$	18 %	0	3
$\Sigma^o\pi^o$	$5\gamma n$	10 %	0	5
$\Lambda\pi^o$	$\pi^-2\gamma p$	4 %	1	2
			0	4

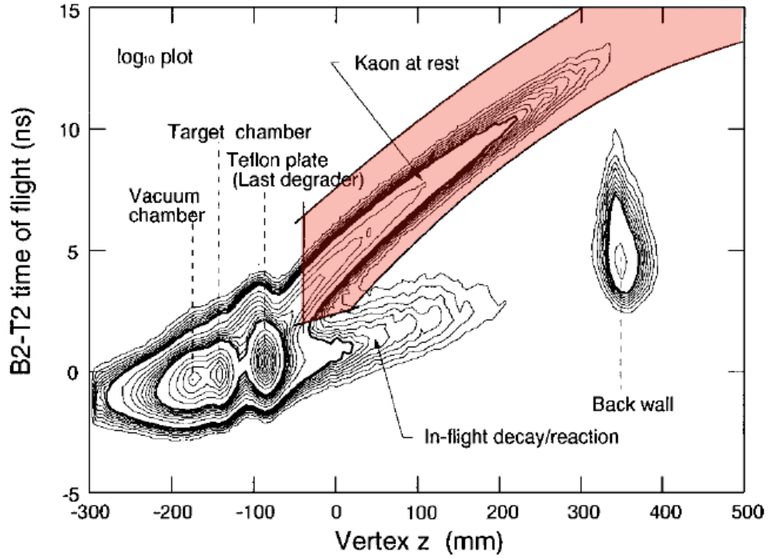
Two charged pion tagging

giving no γ as a background source

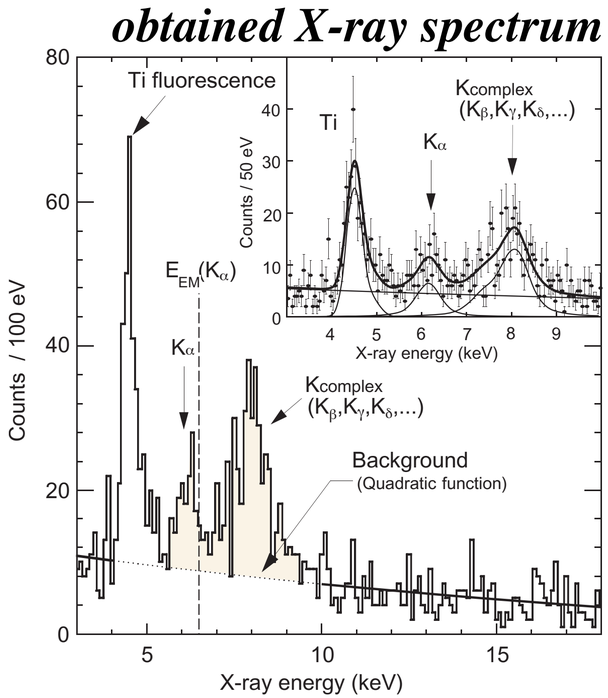
Delayed Kaon selection

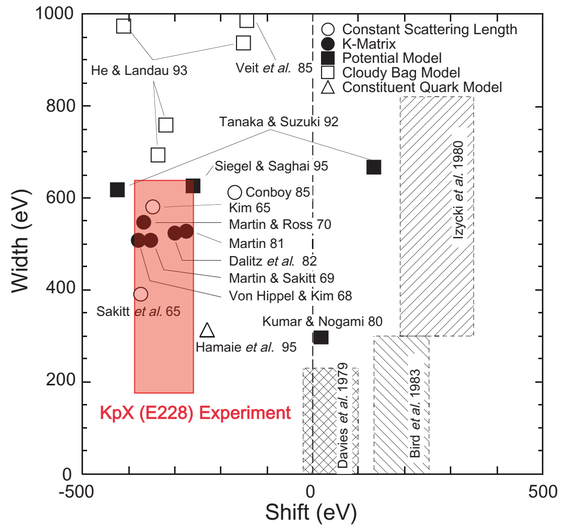
giving information where kaon stops





Succeeded in Kaonic Hydrogen x-ray Measurement





The European Physical Journal C

Volume 15 · Number 1-4 · 2000

THE $\Lambda(1405)$

Revised March 1998 by R.H. Dalitz, Oxford University

.....

From the measurement of $2p - 1s$ x rays from kaonic-hydrogen, the energy-level shift ΔE and width Γ of its 1s state can give us two further constraints on the $(\bar{\Sigma}\pi, NK)$ system, at an energy roughly midway between those from the low-energy hydrogen bubble chamber studies and those from $qR(\Sigma\pi)$ observations below pK^- threshold. IWASAKI 97 have reported the first convincing observation of this x ray, with a good initial estimate:

$$\Delta E - i\Gamma/2 = (-323 \pm 63 \pm 11) - i(204 \pm 104 \pm 50)\ \text{eV}. \quad (2)$$

the errors here encompass about half of the predictions made following various analyses and/or models for the in-flight K^-p and sub-threshold $qR(\Sigma\pi)$ data. Better measurements will be needed to discriminate between the analyses and predictions. ..., perhaps from the DAΦNE storage ring at Frascati, information vital for our quantitative understanding of the $(\Sigma\pi, NK)$ system in this region. .....

Kaonic hydrogen puzzle was resolved!

... leads Associate Professor position in TITech, and successively to Chief Scientist position in RIKEN

What's next in physics?

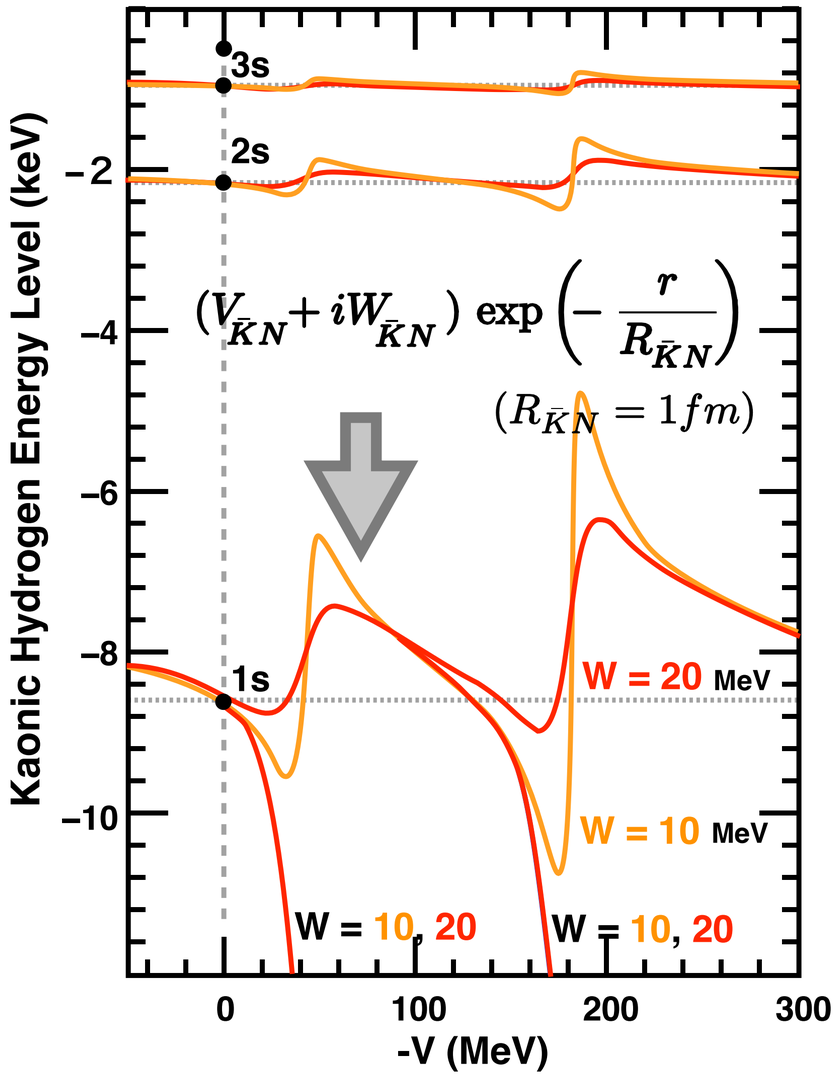
実験困難を越えた先?

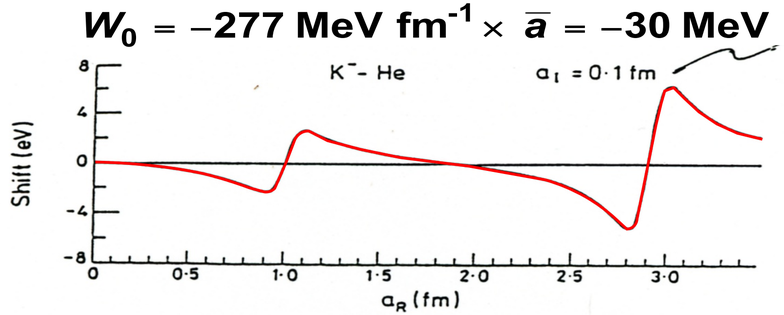
Observed Shift was REPULSIVE!

実験結果が示すもの？

Is $\bar{K}N$ interaction repulsive?

Coulomb + $\bar{K}$N interaction



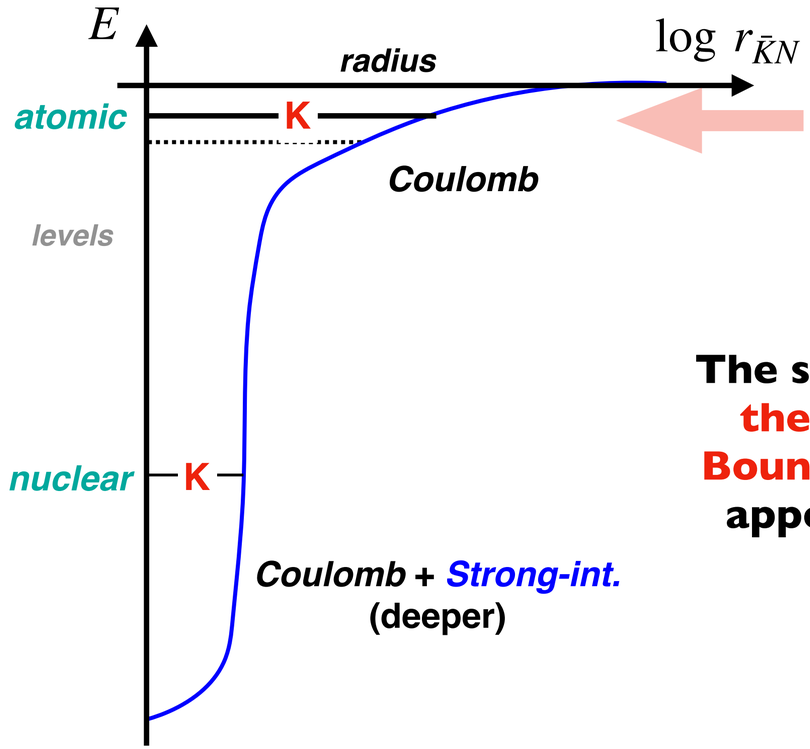


Theoretical calculations for realistic $\bar{K}N$ interaction

R. Seki, Phys. Rev. C5 (1972) 1196

S. Baird et al., Nucl. Phys. A392 (1983) 297

C.J. Batty, Nucl. Phys. A508 (1990) 89c

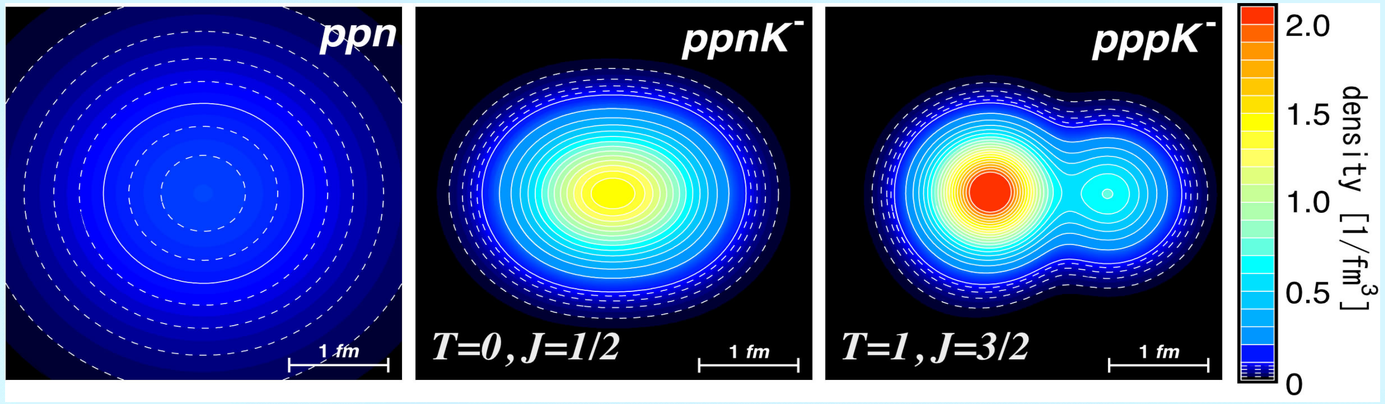


repulsive shift of atomic 1s

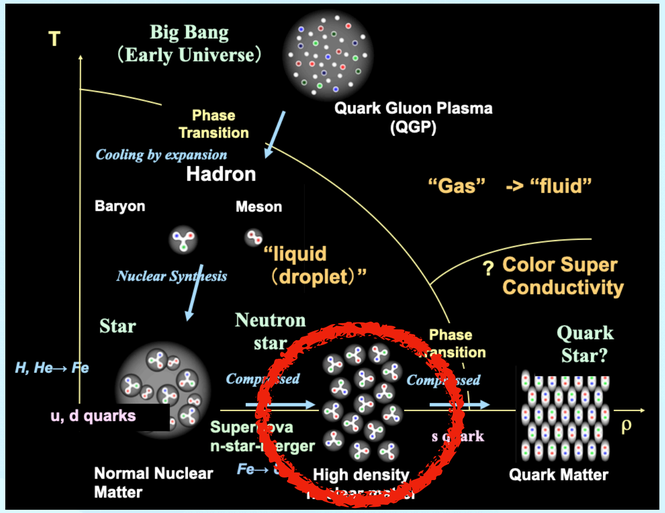
The sign flip of the energy shift suggests the existence of the Kaonic Nuclear Bound State because the repulsive shift appears only when the bound state is formed!

K束縛核の存在?!

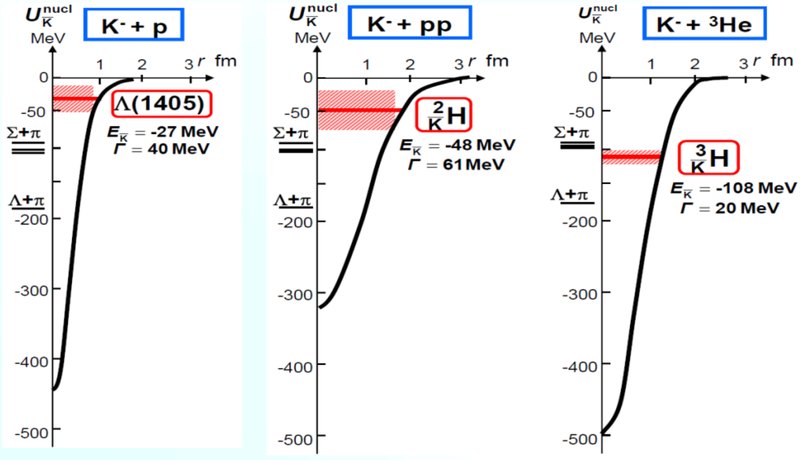
Illustrative Animation



探査競争



The KpX experiment triggers kaonic nuclear bound state search, world wide



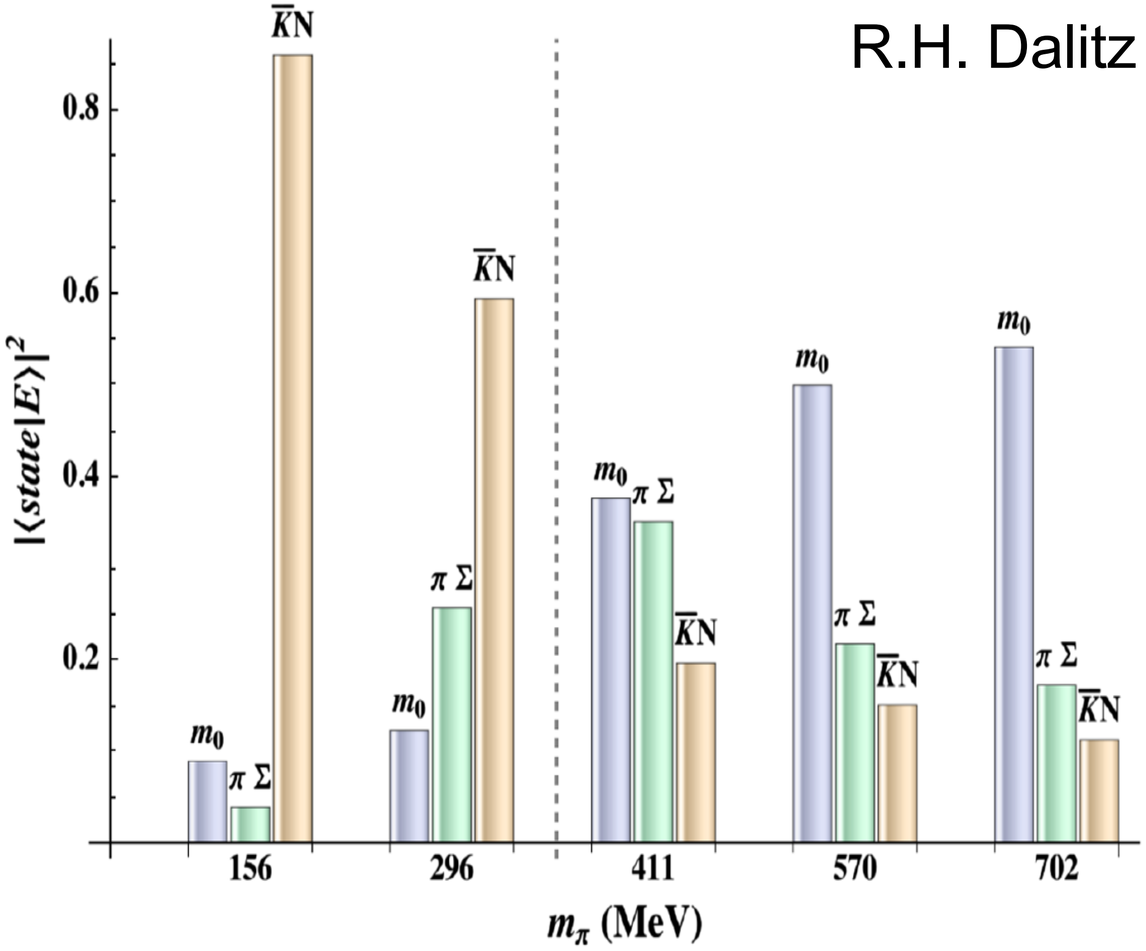
… K中間子原子核探査競争の時代へ …

Λ(1405)ってどういうもの？

What is Λ(1405)?

- Is it quark excited state of Λ baryon (*uds*)?

Λ(1405) = $\bar{K}N$ … a “molecule-like hadron composite”



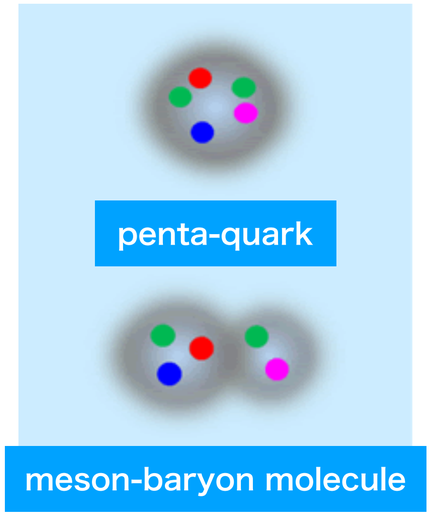
R.H. Dalitz and S.F. Tuan, Ann. Phys., 3, 307 (1960)

- **supported by kaonic hydrogen data**

  Phys. Rev. Lett., 78, 3067 (1997)

- **supported by Lattice QCD**

  J.M.M. Hall et al., Phys. Rev. Lett. 114(2015)132002.



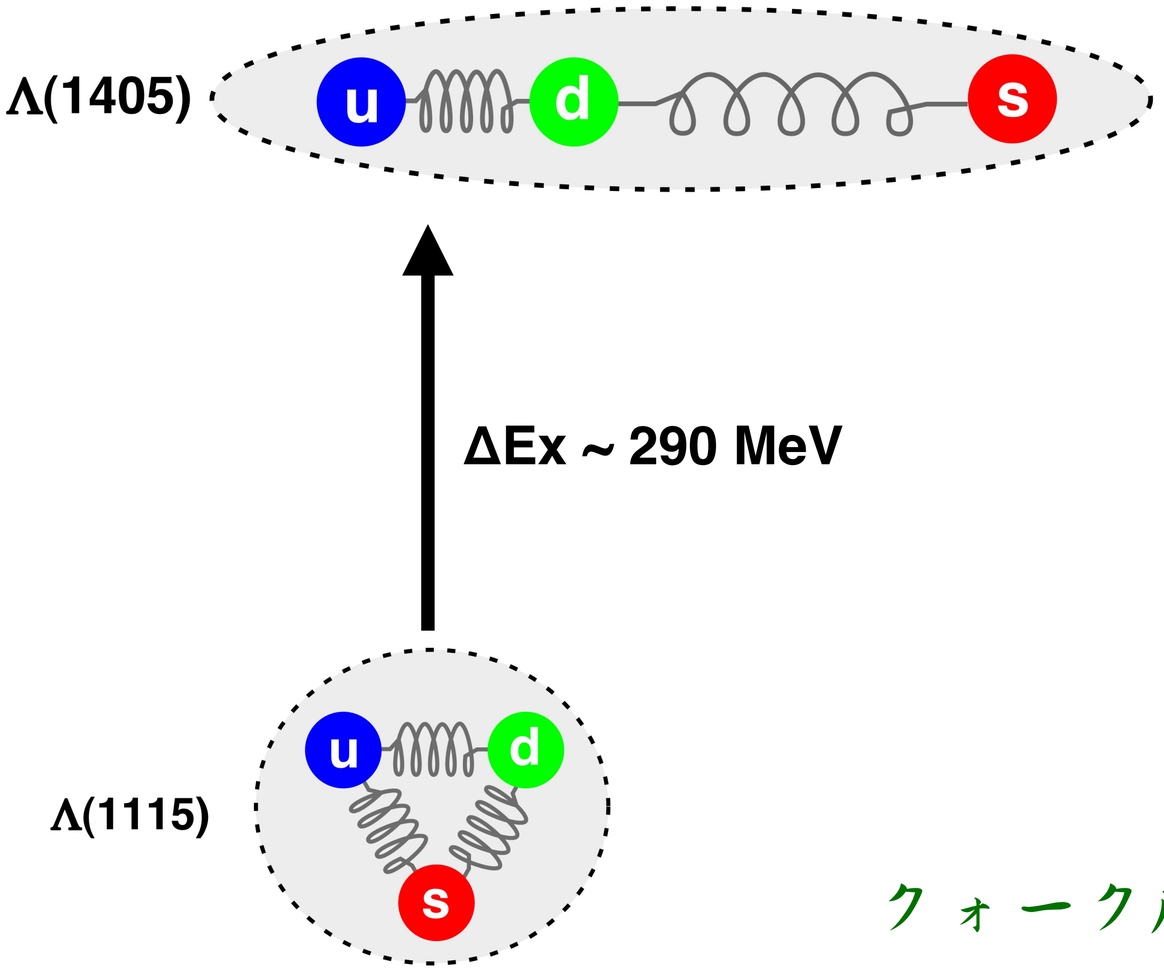
why not $\bar{K}NN$?

forming a nuclear bound state

From Λ(1405) to kaonic nuclei

クォーク励起状態?

Is Λ(1115) an excited state of *uds*?

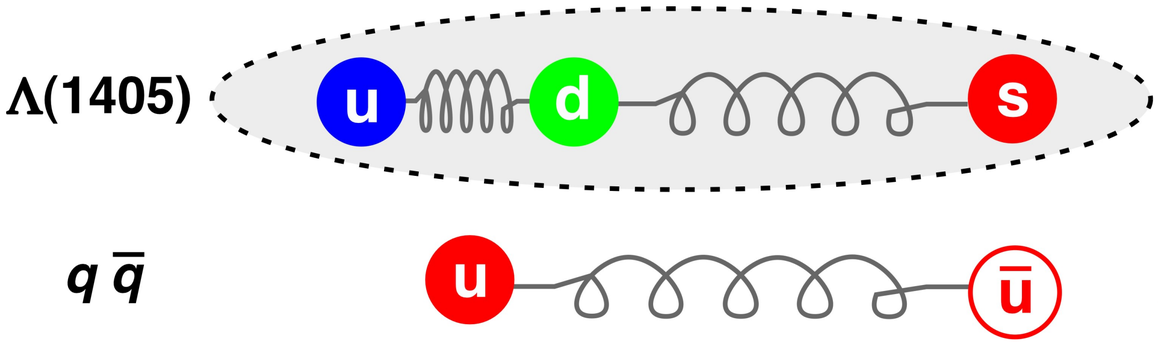


クォーク励起状態としてのΛ(1405)描像

From Λ(1405) to kaonic nuclei

カイラル凝縮との結合?

with $\bar{q}q$ (χ-condensate) in vacuum



真空は何もない空間ではなく、
$\bar{q}q$が対となって凝縮している
と思われている

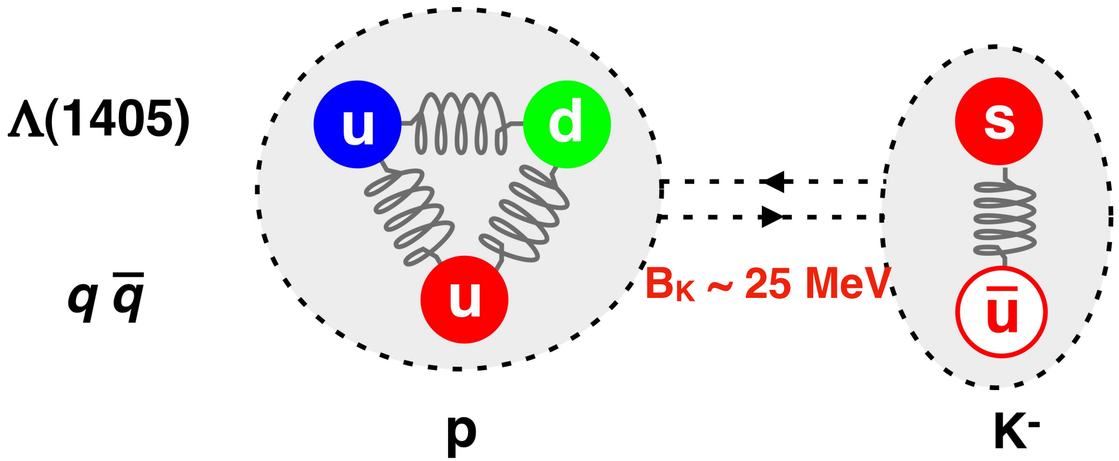
真空の $\overline{q}q$ 凝縮と $\Lambda(1405)$

From Λ(1405) to kaonic nuclei

分子的ハドロン結合状態?

two color-singlet objects bound by meson exchange :

p = K⁻



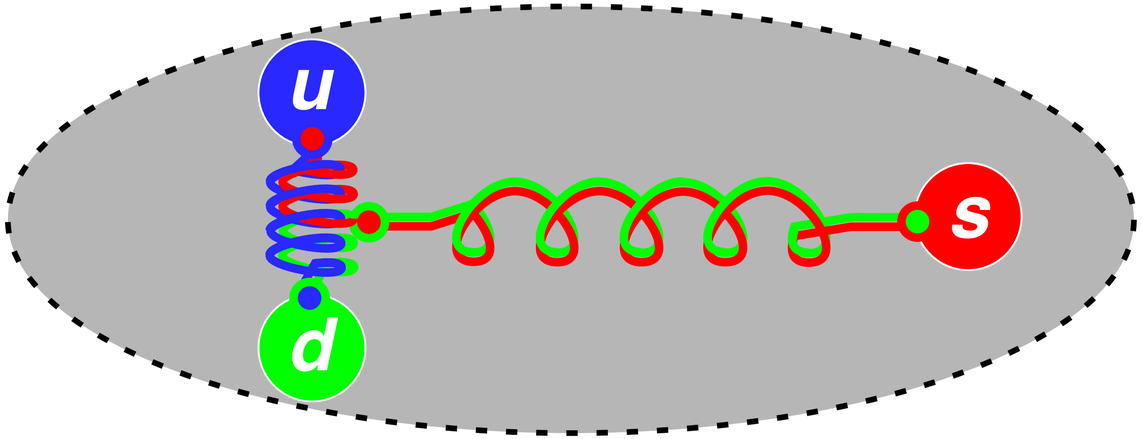
M(pK⁻) = 1432 MeV/c²

分子的ハドロン結合状態としてのΛ(1405)描像

Λ(1405) in *qqq* & meson-baryon

多彩なK中間子核の存在？

Λ(1405) :=*qqq*

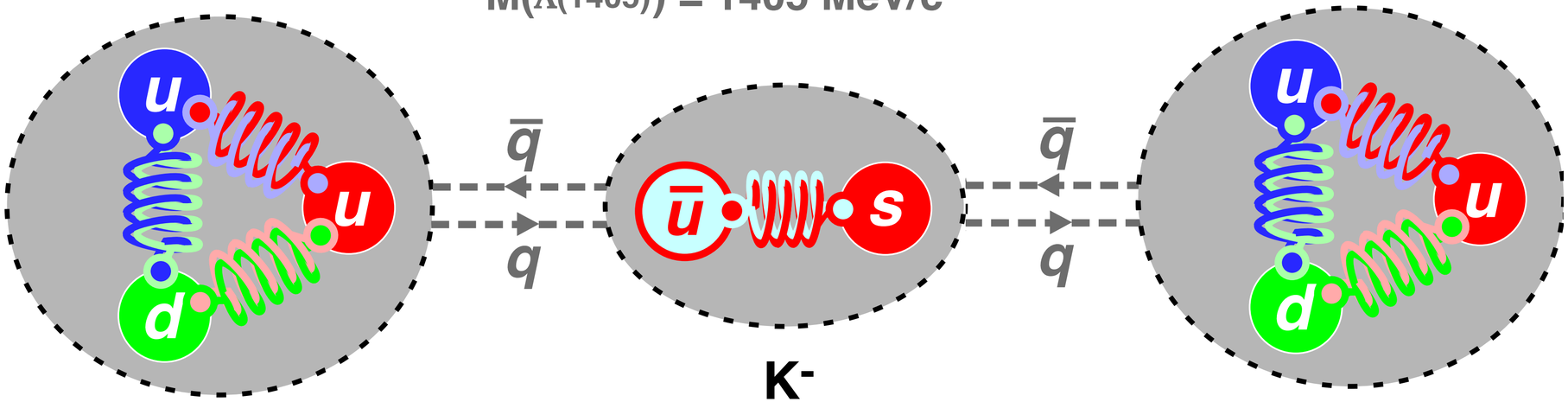


A quantum state known as Λ(1405) can be molecule-like hadron cluster composed of "$K^- p$"

Then you may put one more proton …

$M(\Lambda(1405)) = 1405\ \mathrm{MeV}/c^2$

"K^- p"



$M(pK^-) = 1432\ \mathrm{MeV}/c^2,\ B_K = 27\ \mathrm{MeV}$

Λ(1405) is on-site of "hadronization", where stretched-gluon capture $\bar{q}q$ from vacuum

"$K^- pp$" will exist

研究における最大の失敗

First trial to search for Kaonic Nuclei resulted in wrong interpretation in 2004.

The biggest Failure in research and the Specification of the Problem

“It was very difficult to overcome the challenges caused by the mistake.”

… 間違いに気がついた時は悪夢・問題特定とその公表に3年・観測成功(汚名返上?)に11年 …

最初のK中間子核探査研究

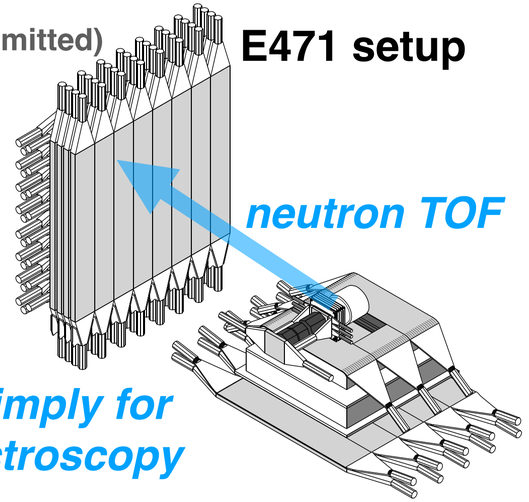
First trial to search for Kaonic Nuclei

via kaon absorption at-rest in ^{4}He target

Reaching wrong conclusion faked by data

(top and right detectors are omitted)

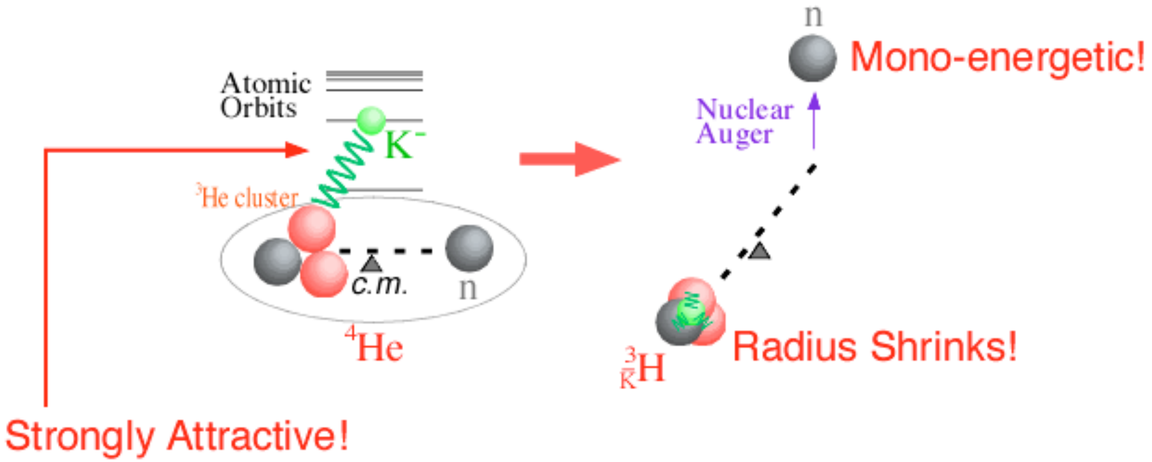
E471 setup



dedicative simply for neutron spectroscopy

Ansatz in E471

If kaonic nuclear bound state $K^- \oplus {}^3\mathrm{He}$ exist as it is predicted,



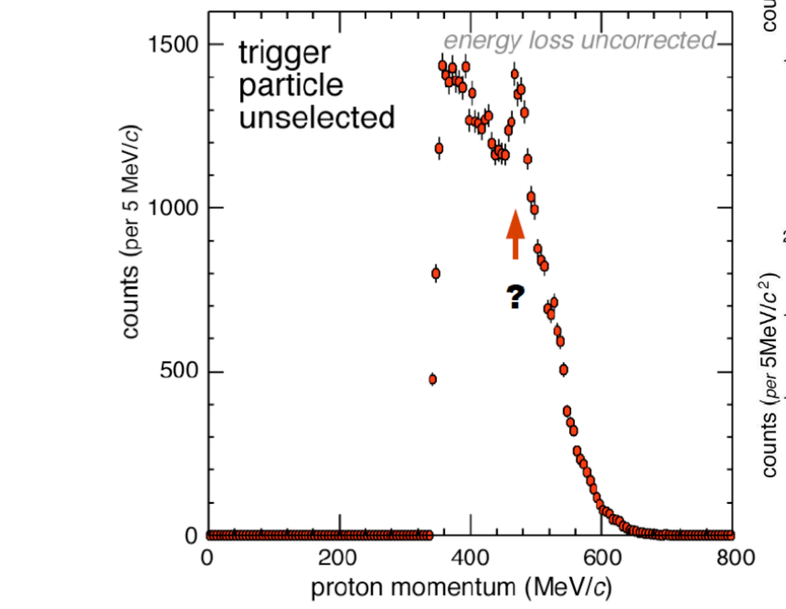
mono-energetic **neutron** will be emitted from kaon absorption reaction from kaonic helium atom via nuclear Auger effect by substituting neutron with kaon

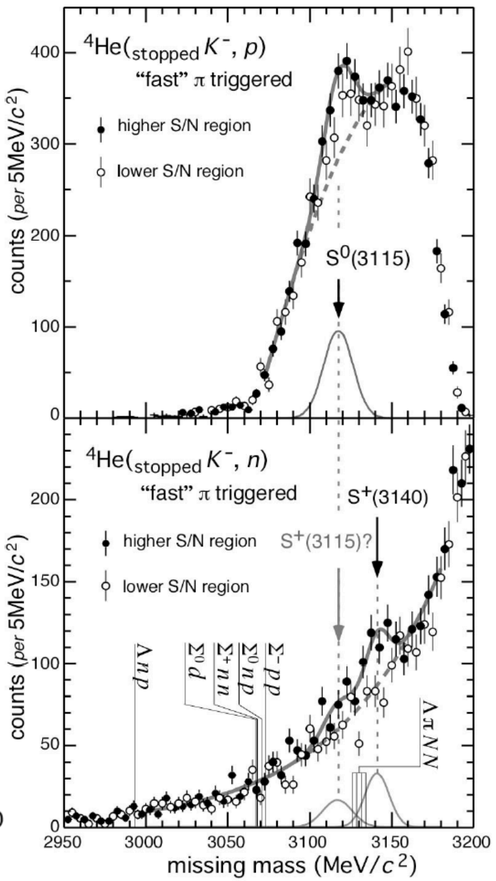
^{4}He(stopped K-, p) spectrum

previous result from E471

mono-energetic **proton** observed, instead

nucl-ex/0310018





K中間子核検証研究

何を間違ったか？

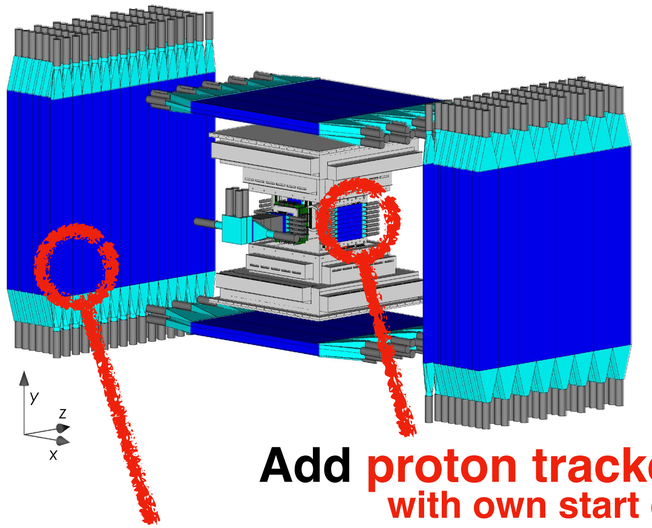
Verification Study by ourselves gave Negative Result!

Obviously, we were in BIG BIG trouble …

¡¿ What Happened ?!

Ansatz in E549 / E570

If we upgrade our setup dedicative for proton spectroscopy, we can get confirmative proton spectrum.



Add proton tracker
with own start counter

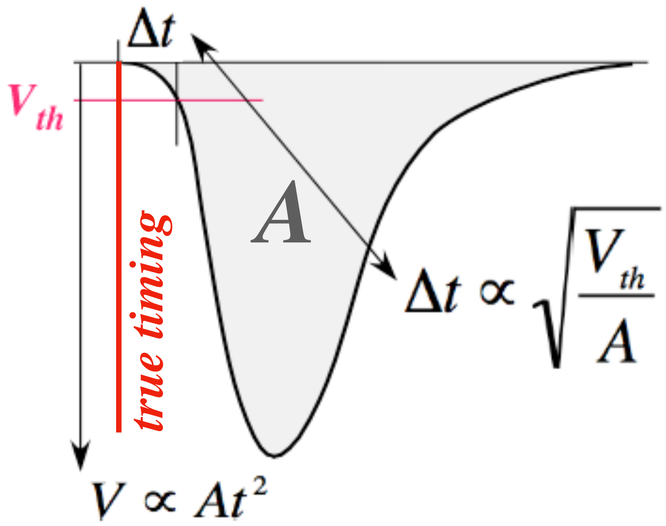
Replace thin charge-veto counters
to high resolution (thicker) counters
for proton TOF

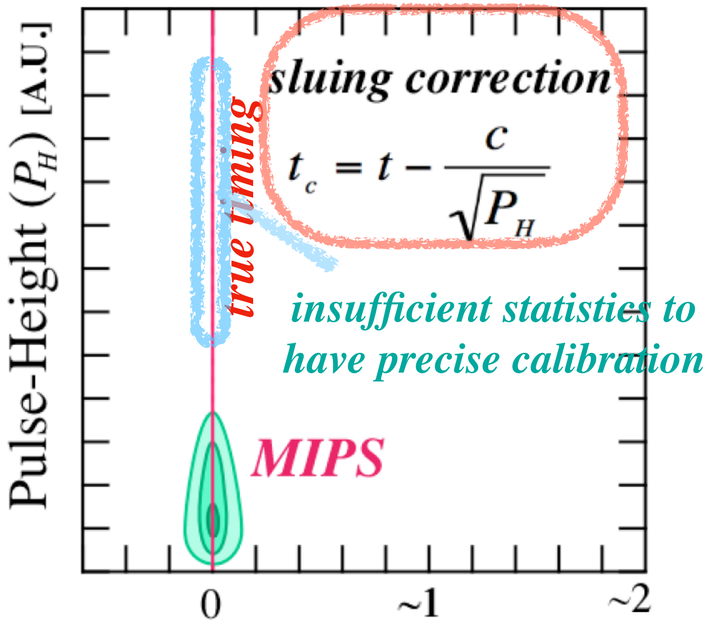
The answer is:

“The imperfect analysis hidden in insufficient experimental setup”

More specifically, imperfect sluing correction

What’s sluing correction?





MIPS: 標準的に較正に使われる高速粒子

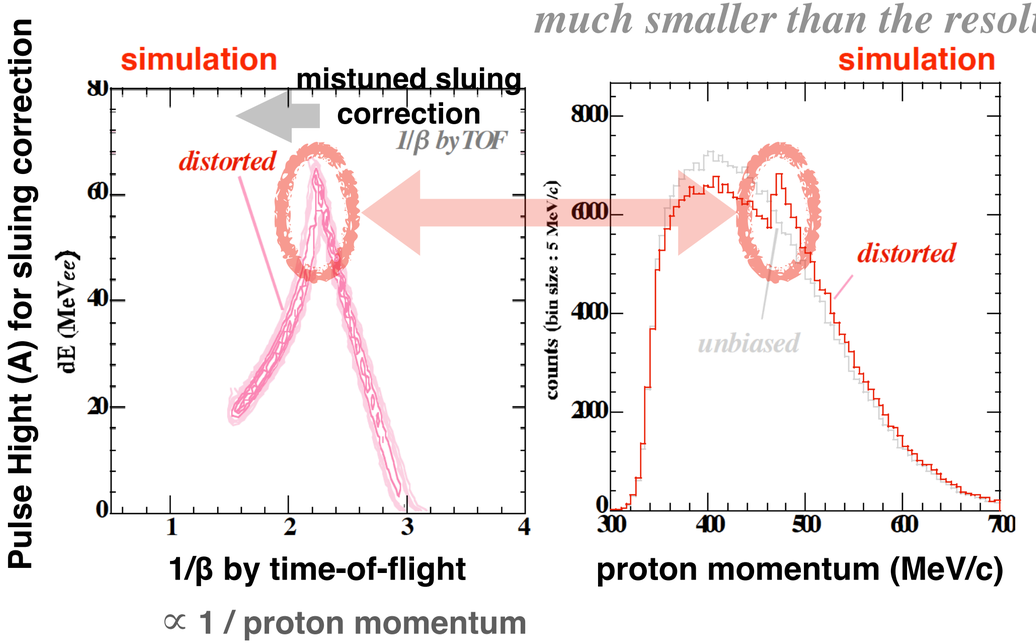
Why we were FAKED…

We shall publish the reason why we were faked, because we found our mistake by ourselves.

identified by M. Sato (the one who cannot come today) …

What will happen if sluing correction is slightly mistuned by 5 ps / MeV ?

much smaller than the resolution



∝ 1 / proton momentum

Pulse Hight anomaly forms a spurious peak in the momentum spectrum at exactly the same place where we found a fake signal

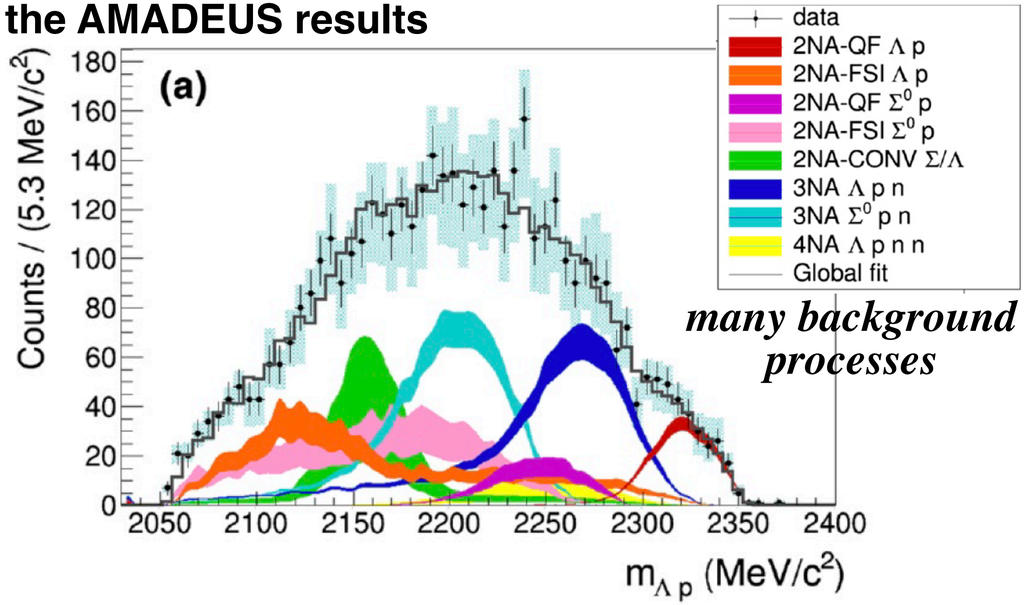
This is a very hard lesson for us.

This doesn't mean the non-existence of the kaonic nuclear bound state.

Background is very severe in kaon reaction at-rest.

Eur. Phys. J. C 79, 190 (2019)

the AMADEUS results



many background processes

How to discriminate K-nucl. formation signal out from severe backgrounds?

シグナルは巨大バックグランドの中に …

閑話休題：今一度どう取り組むべきか根本的に考える …

Let me digress on what I learned as a researcher on:

What is the most important point as a researcher to realize break through achievement

如何に革新的成果を導くか?

理研で研究者と切磋琢磨しながら感じたこと

Differentiate from previous approach

様々な角度からベストを探る

Looking at the same problem from a different angle can make it easier.

Communication with others

Nobody can do anything alone (at least for experimental research).
Communication is the starting point for the collaboration.
Diversity can be a source of unique idea.

一人じゃ何も出来ない
人との関わりによる相互触発

What questions to be addressed …

Why?

is the source of research

Perspective view

Summarize situation eventually…
To escape from local optimum.
Not to loose the way to go.

俯瞰的に考える

Having several strengths to be proud of as a researcher

Collaboration through division of speciality / role in the collaboration.

研究者としての強み

To researchers:

Keep asking why even to textbooks (common sense) … I hope you aim for discoveries that change the world or demand a rewrite of the textbooks.

世の中を変える、あるいは教科書の書き換えを迫るような発見を目指して!

Allocate time to ponder things and think holistically about how to approach and consider a problem, rather than constantly staying busy trying to solve the issue in front of you.

どう考えるべきかを沈思黙考する時間を取ることが大事!

Receiving critical reviews or opinions about your scientific achievements can be disheartening, but you can use them as a valuable teacher or source to identify even more challenging and/or essential problems to solve.

批判をも味方に、常に新たなことにチャレンジして!

To administrators:

Please prioritize securing research resources for researchers, including time for meditation, to maximize research outcomes, rather than strictly enforcing rules.

研究者が創造的であるためには常に忙しいことはNG

Please streamline lengthy documents and rulebooks, and explain the reason why these policies and regulations are essential by using the 5W1H method. Otherwise it won't be respected so efficiently.

所の政策や規定は出来るだけ省略・簡潔化(5W1H)。「何故不可避か」の説明

閑話休題：今少しの脱線…

Let me digress more in the context of scientific mistake and misconduct

研究上の間違い　　研究不正

What everyone knows …

Scientific misconduct never pay off !!

研究不正は割に合わない

The motivation for misconduct is the desire to be recognized as a researcher for significant scientific contributions.

Significant academic achievements will extensively be verified / examined.

Result of misconduct will never be verified, though…

承認欲求・不可避な検証・不正の露見

Why can't research misconduct be completely eradicated?

People could consider even a short-lived glory to be glory.

Without outstanding achievements, fixed-term researchers can't secure their next position. — This fact also makes it difficult to eradicate research misconduct.

三日天下でも天下は天下？けど、三日天下の先は奈落…

過度な成果創出ストレスも不正誘引事象（五神理事長の主導で緩和）

To researchers:

No matter how challenging, one should take essential efforts with a holistic perspective; otherwise, you may wandering around local (or selfish) optimum.

例え困難だろうと、俯瞰的視野を持ち「本質的取り組みは何か」を常に意識

Don't isolate yourself. Instead, find someone you trust. Who will help you to resist any temptation to misbehave. Moreover, they can boost your research.

表面的に取り繕うのではなく、本音をぶつけ合える仲間を！

To administrators:

Excessive ethics simply waste valuable research time *for sincere researchers. Ethics are of* ***no help to the fundamental solution****, as all the people already understand that misconduct is unacceptable.*

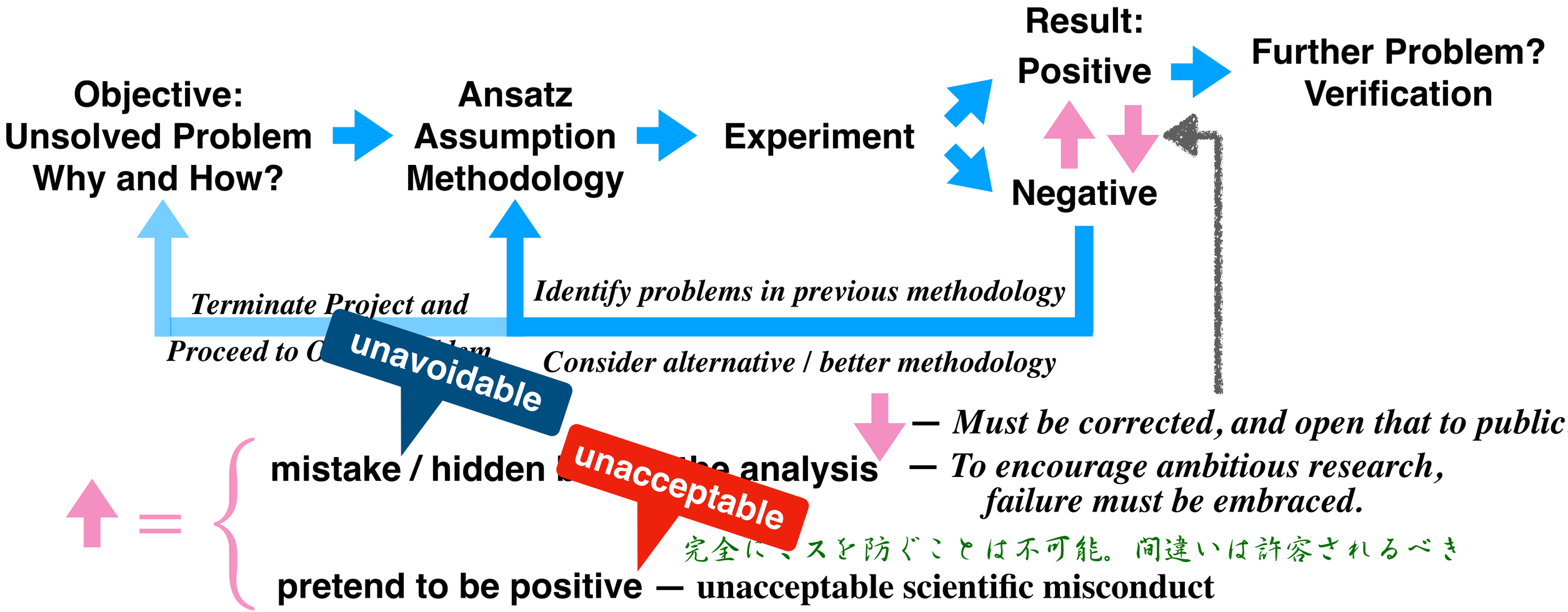
研究倫理教育拡充は本質的には愚策

Communication between research labs (or organizations) and creating an ***open minded atmosphere*** *where people freely express their opinions are essential for preventing misconduct — expanding projects that involve multiple research labs, such as* ***exploring new research areas****, is important for this purpose.*

本音をぶつけ合える環境を!! 矯正より開放的環境・新領域開拓課題の拡充等が有益

諦めない限り完全失敗ではない
失敗の訂正は大事
どう取り組む？

A Typical Experimental Research Cycle



完全にミスを防ぐことは不可能。間違いは許容されるべき

決して許容できない。過度な倫理教育・研究者の引き締めは愚策

J-PARC E15 実験へ

Back to the kaonic nuclear search

How to discriminate K-nucl. formation signal out from severe backgrounds, and make a breakthrough result?

The J-PARC E15 experiment and K-pp Observation

K中間子原子核探査で如何に革新的成果を導くか?

完全実験を目指そう!

今一度どう取り組むべきか根本的に考える …

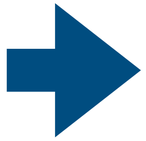
"The opposite of success is not failure. It's not trying."

- Attributed to Frank Candido Farmer.

"Failure happens when you stop trying. If you keep going until succeed, that's success." - Attributed to K. Matsushita, probably inspired by words of T. Edison.

Complicated dynamics

Insufficient information



Simplify formation channel: $K^{-}N \to \bar{K}N'$

Specify decay channel: $\bar{K}NN \to \Lambda p$

Study on multi-dimensional kinematics: $(m_{\Lambda p}, q_{\Lambda p})$

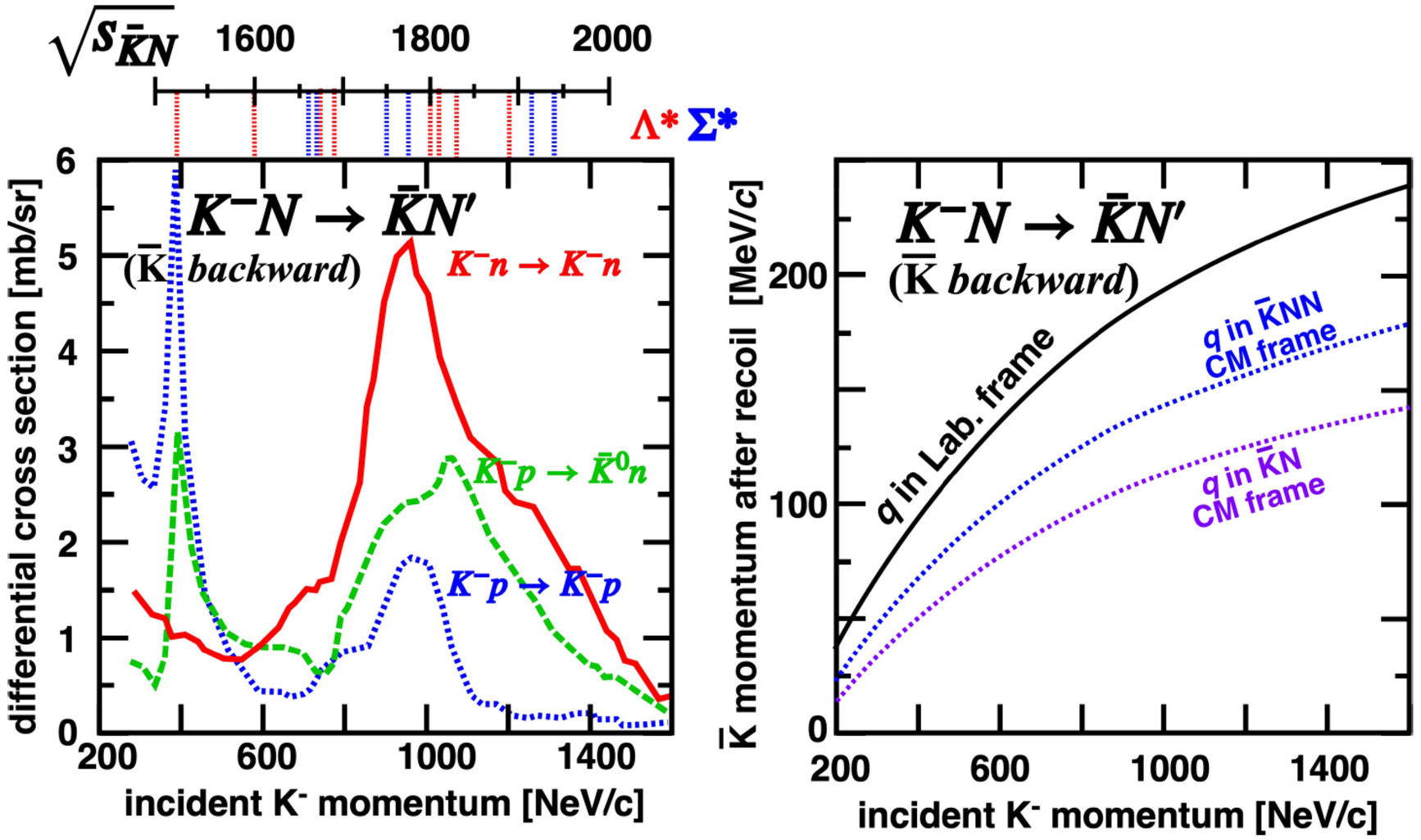
… observe both channel on formation and decay

Nucleon knockout reaction $K^-N \to \bar{K}N'$

理想的実験手法のヒント
核子反跳プロセス

Introduced by T. Kishimoto 1999

Why don't we knockout nucleon by kaon so as to form anti-kaon close to at-rest near residual nuclei?



Nucleon knockout reaction $K^-N \to \bar{K}N'$

理想的実験手法のヒント
核子反跳プロセス

Introduced by T. Kishimoto 1999

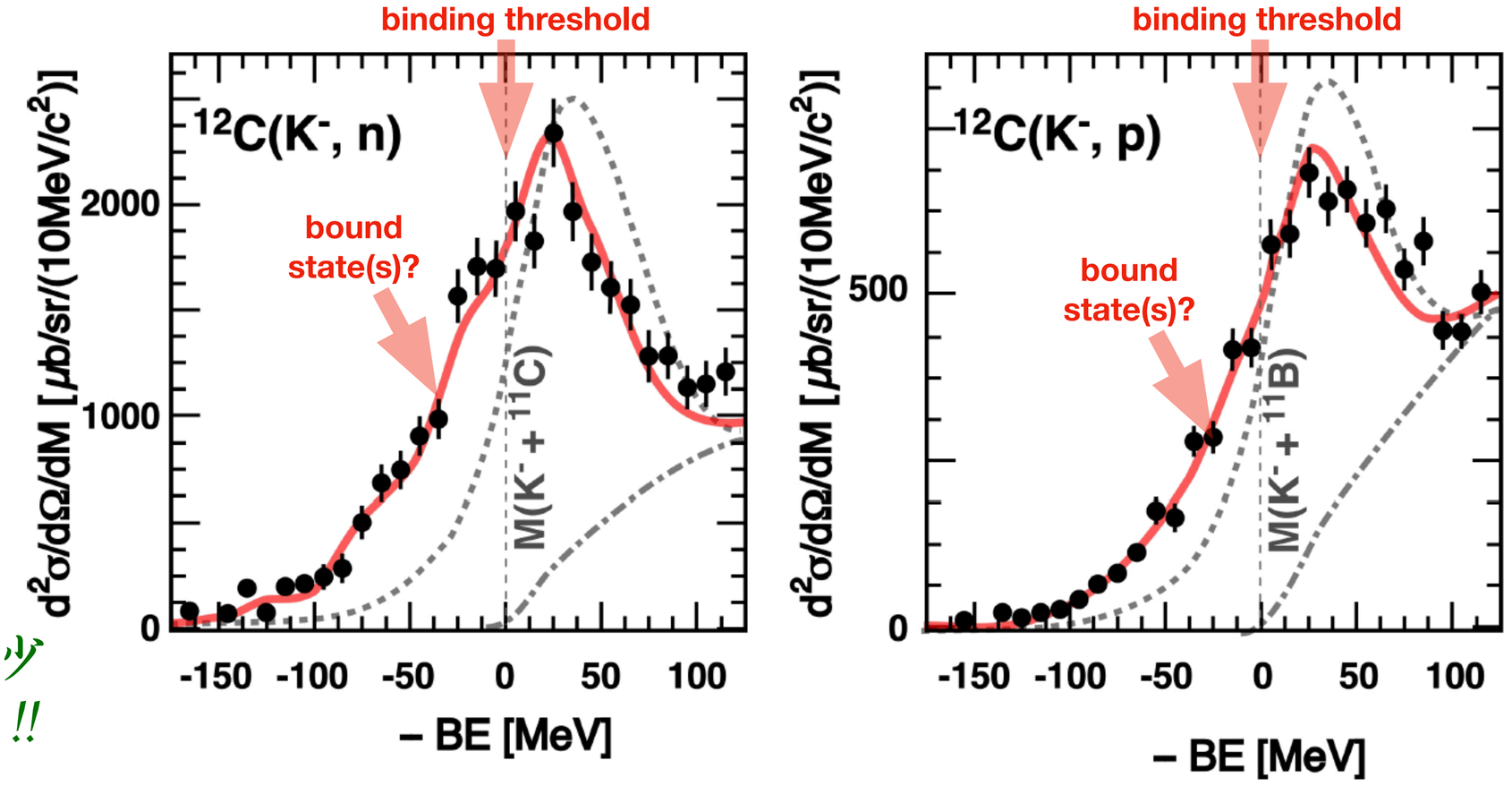
KEK-PS E548 led by T. Kishimoto: observe forward going nucleon produced by $K^-N \to \bar{K}N'$ reaction on carbon target. (missing mass spectroscopy)

The result suggests kaonic nuclear bound state formation, but the signal is not distinct to be identified as a peak

大変魅力的だけど
全体的になだらか
で確信には遠い

どうすれば良い？

バックグランド除去可能な少数系・完全実験を目指そう!!

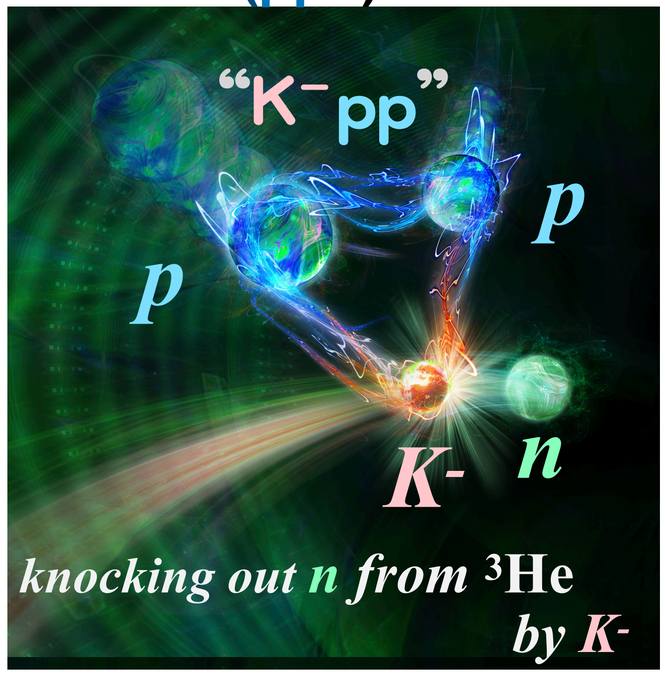


J-PARC E15: "K^-pp" Exploration

理想的実験を目指して

反応生成粒子の数を減らして、生成と崩壊の両チャネルから
反応力学を多次元的かつ詳細に観測!

K^- + ^{3}He (ppn)



$(K^- + pp)$ + n

substitute n in ^{3}He by K^-

minimize number
of particles

If "K^-pp" exits, a peak will be formed in invariant mass spectrum below M(K^-pp)

$$M(K^-pp) \equiv m_{K^-} + 2m_p$$

kinematically identified

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

$$(K^- + pp) \rightarrow \Lambda + p \quad \text{: decay } (M, q)$$

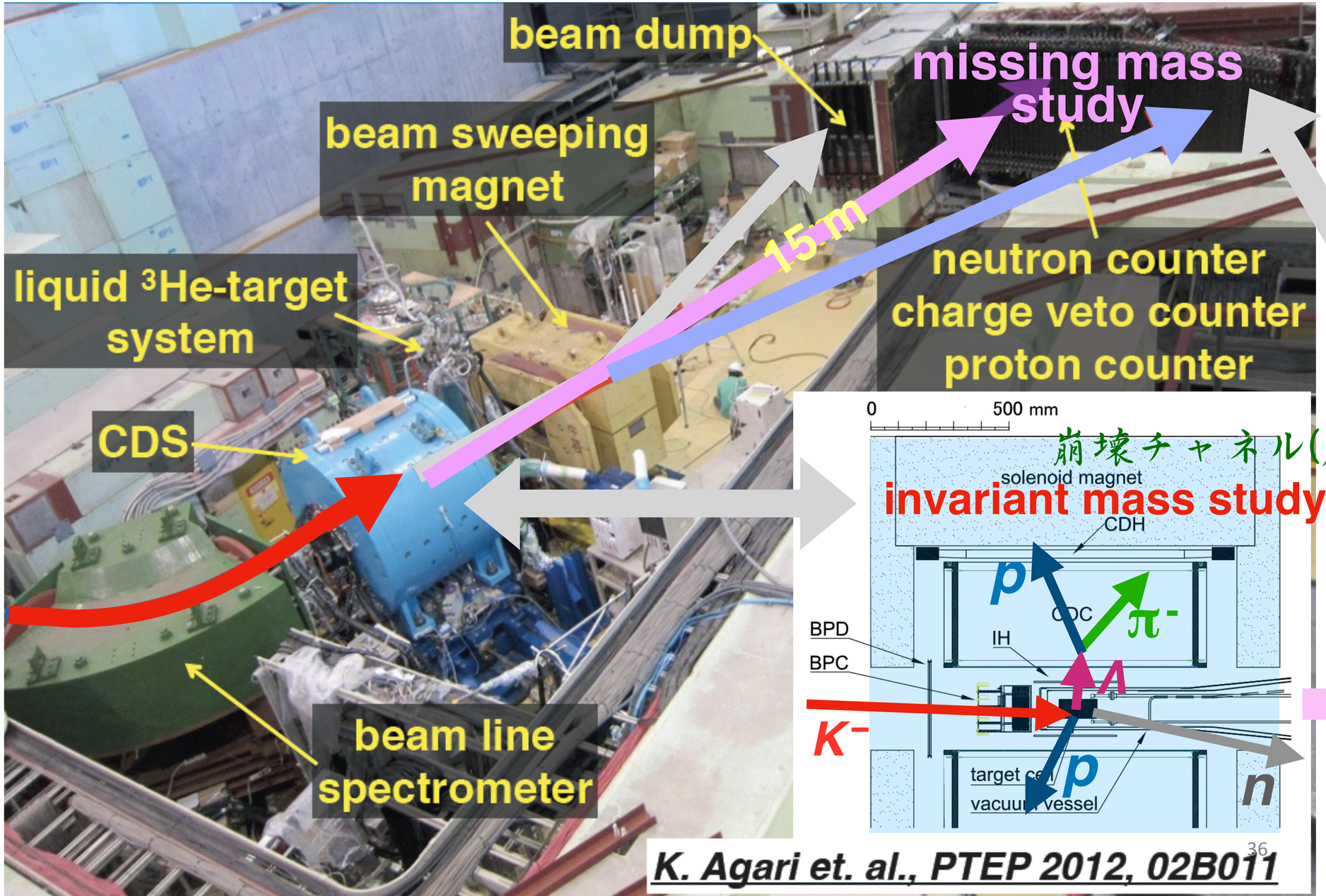
identified as charged particles

select $K^- + {}^3\mathrm{He} \rightarrow (\Lambda + p) + n$ events,
analyze *invariant mass* ***M*** of (K^- + pp)-system
and *momentum transfer* ***q*** to the system

provides multi-dimensional kinematical information

Experimental Setup for E15

J-PARC E15 実験概観



36

J-PARC E15 実験結果

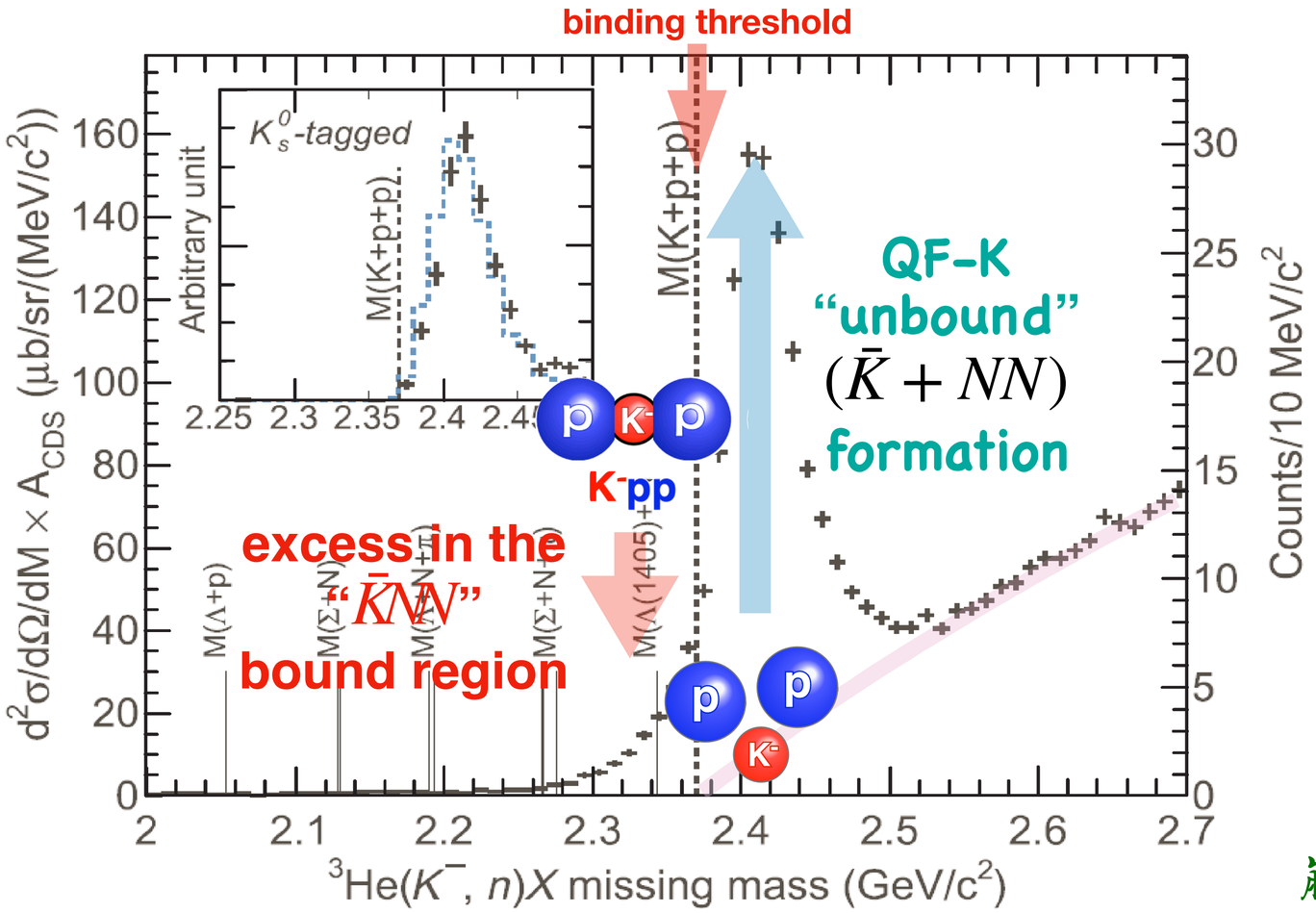
The result of the kaonic nuclear search

Observation of the simplest Kaonic Nucleus: K-pp

最も単純なK中間子原子核 K-pp 状態の発見

^{3}He(K$^-$, n$_{NC}$)X — missing mass study

$$K^- + {}^3\mathrm{He} \rightarrow (\bar{K} + NN) + n'$$



想定通りKN交換反応が主要成分:
K中間子が前方に核子を蹴り出すことで、反跳Kが遅くなり、容易に残核とK束縛状態を作ることが期待される

missing mass spectroscopy is insufficient to isolate K$^-$pp signal from QF-K leakage

生成チャネルの解析 (missing mass) だけでは不十分

How to study the excess?

The ideal decay channel is:

$$\bar{K} + NN \rightarrow \Lambda p.$$

Because it is the most simple reaction easy to analyze

崩壊チャネルの解析 (invariant mass) へ

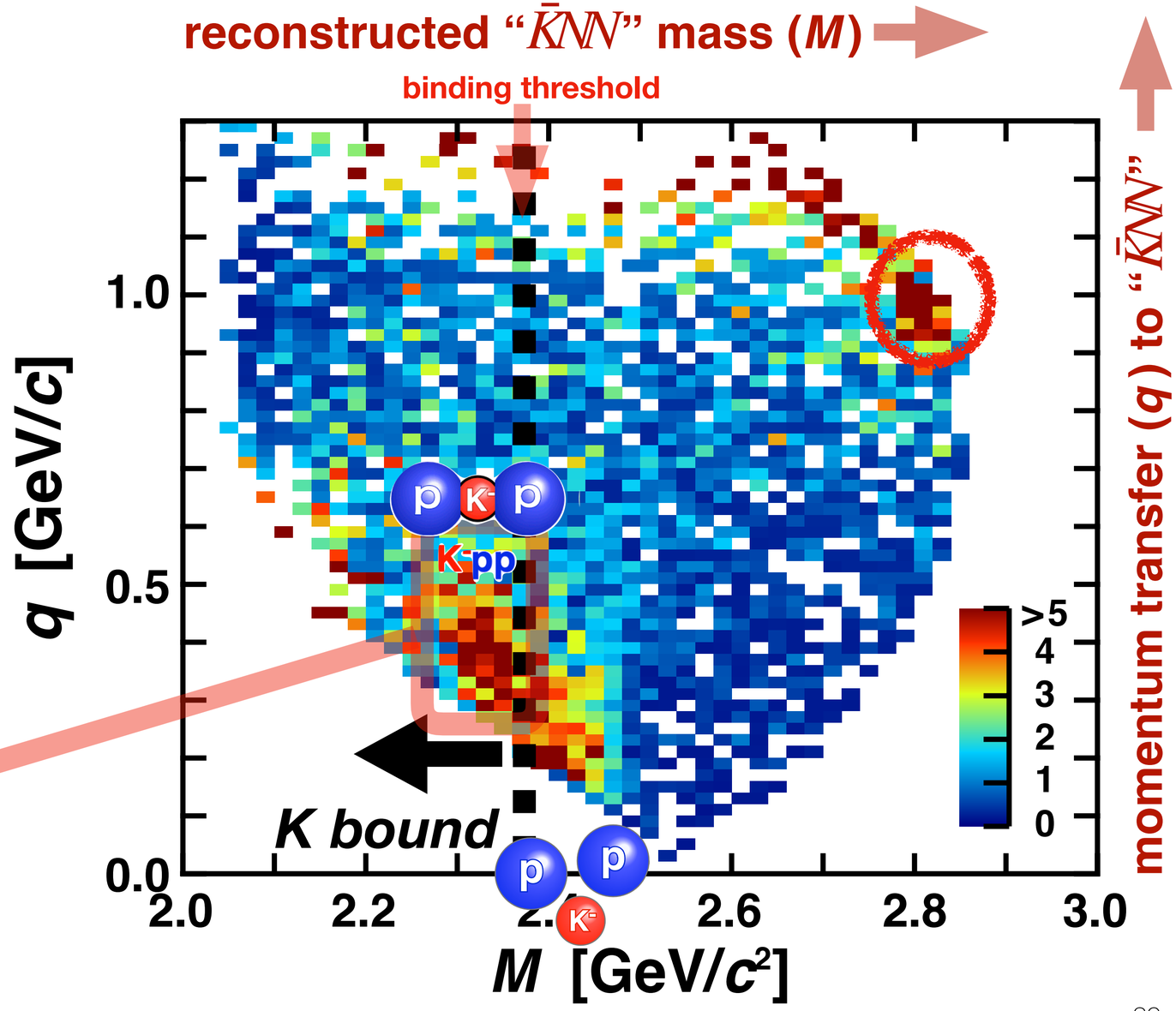
Dominance of nucleon knockout reaction, $K^-N \rightarrow \bar{K}n'$, is confirmed as a doorway

Λp 不変質量解析が示したもの

$\Lambda p + n$ events

on (*M*, *q*)-plane

Acceptance corrected event distribution on (M, q)



q-distribution: system size

— sticking probability: high-*q* capture happens if the system is compact —

M-distribution: binding energy & absorption width

—both information gives $\bar{K}N$ interaction strength —

The K⁻pp signal is clearly seen on (M, q)-plane!

—relatively deep and wide, and extended to high-*q* region —

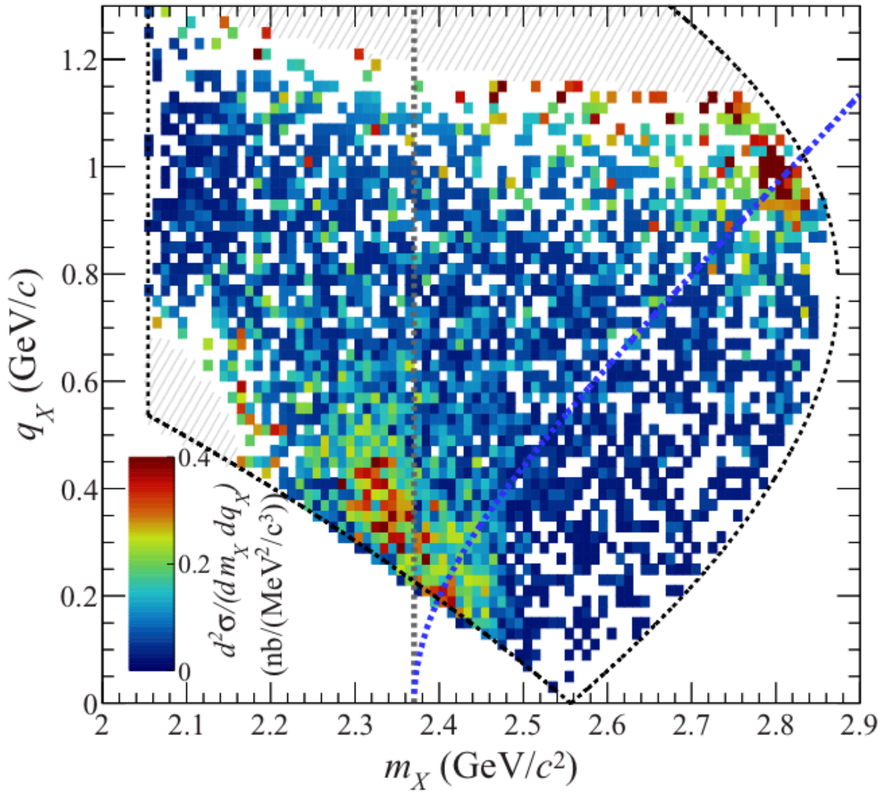
$\Lambda p + n_{\mathrm{miss}}$

フィット関数

model fitting function in (m, q)-plane

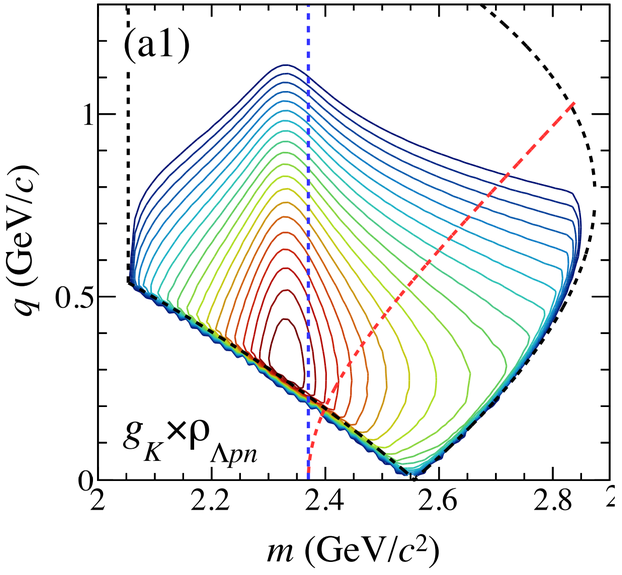
ρ : Lorentz-invariant phase-space

$$f_{\bar{K}NN}(m,q) \times \rho_{\{\Lambda pn\}}(m,q) \quad f_{QF\text{-}\bar{K}}(m,q) \times \rho_{\{\Lambda pn\}}(m,q)$$



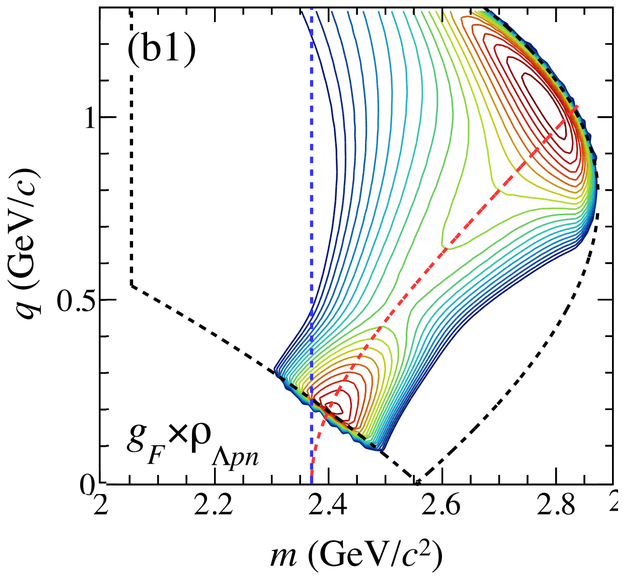
≈

$\bar{K}NN$ production



+

QF-$\bar{K}$ absorption



$f_{\bar{K}NN}(m,q)$: $B.W.(m)$ x $form\ factor(q)$

$f_{QF\text{-}\bar{K}}(m,q)$: *quasi-free (on mass-shell) K abs.*

PWIA based interpretation

(plane wave impulse approximation)

$$\sigma(M, q) \propto \rho_{3B}(M, q) \times \frac{\left(\Gamma_{Kpp}/2\right)^2}{\left(M - M_{Kpp}\right)^2 + \left(\Gamma_{Kpp}/2\right)^2} \times \exp\left(-\frac{q^2}{Q_{Kpp}^2}\right)$$

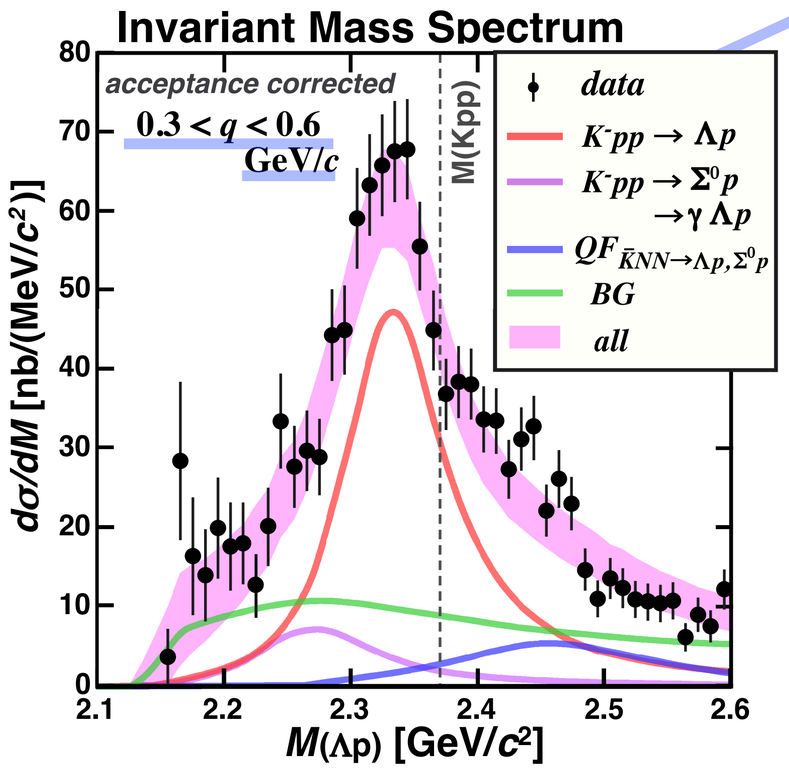
Differential cross section

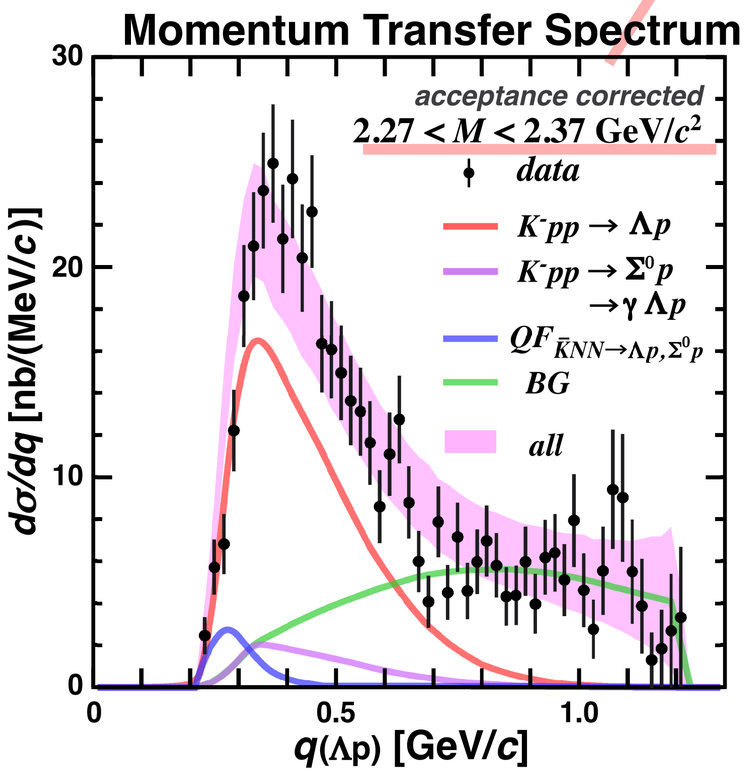
Lorentz invariant phase space (Λpn)

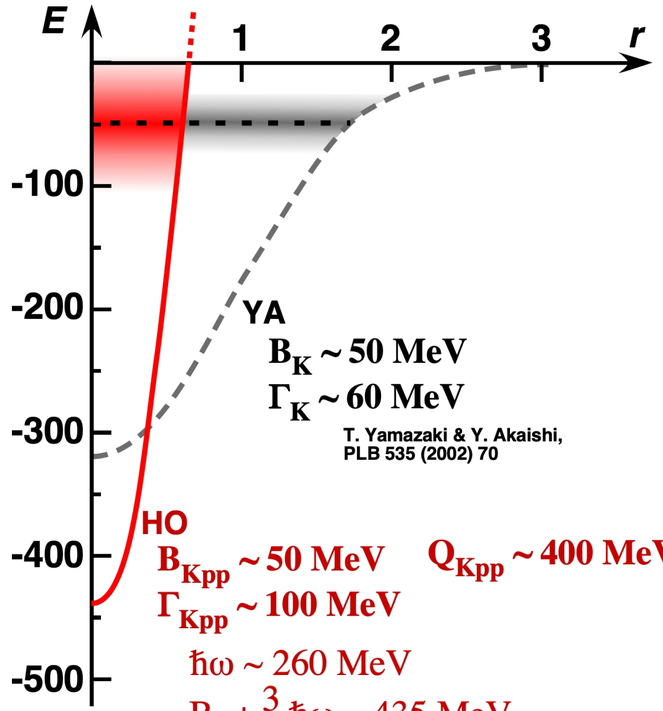
— from time integral —
B.W. / Lorentzian

form factor / structure factor

Fourier Transformation of S-wave Harmonic Oscillator (HO)
— from spatial integral —







strong binding (K̄N attraction)

$B_{Kpp} \sim 40$ MeV, $\Gamma_{Kpp} \sim 100$ MeV

wide momentum width

$Q_{Kpp} \sim 400$ MeV/c

... could be quite compact ...

($R_{Kpp} \sim 0.6$ fm (H.O.)) コンパクト？

PWIA based interpretation

補足: PWIAでの形状(構造)因子計算

The scattering amplitude $f(\mathbf{p_K}, \mathbf{p_n})$ ***is given as:***

$$f(\mathbf{p_K}, \mathbf{p_n}) \propto \langle f|\, V\, |i\rangle + \langle f|\, V \frac{1}{E - H_0 + i\epsilon} V\, |i\rangle + \ldots$$

the time integral of a pole at $(M_{Kpp}, \Gamma_{Kpp}/2)$ ***naturally gives B.W.***

$$f_0(\mathbf{p_K}, \mathbf{p_n}) \propto \frac{1}{(M - M_{Kpp}) + i\Gamma_{Kpp}/2} \qquad \frac{d\sigma_0}{d\Omega} \propto |f_0(q)|^2 \propto \frac{1}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2},$$

for the spatial integral on the Harmonic Oscillator (Gaussian distribution function) can be given as;

in PWIA

$$V = \frac{V_0}{4\pi}\delta(\mathbf{x}' - \mathbf{x})$$

$$f_0(\mathbf{p_K}, \mathbf{p_n}) \propto \left\langle \exp\left(-i\frac{\mathbf{p_n}\cdot\mathbf{x}'}{\hbar}\right)\exp\left(-\frac{\mathbf{x}'^2}{2{R_{\mathrm{Kpp}}}^2}\right)\middle|\, V \,\middle|\exp\left(i\frac{\mathbf{p_K}\cdot\mathbf{x}}{\hbar}\right)\exp\left(-\frac{\mathbf{x}^2}{2{R_{\mathrm{He}}}^2}\right)\right\rangle$$

$$\propto \frac{V_0}{4\pi}\int d^3x \exp\left(-i\frac{(\mathbf{p_K} - \mathbf{p_n})\cdot\mathbf{x}}{\hbar}\right)\exp\left(-\left(\frac{1}{{R_{\mathrm{Kpp}}}^2} + \frac{1}{{R_{\mathrm{He}}}^2}\right)\frac{\mathbf{x}^2}{2}\right)$$

$$= \frac{V_0}{4\pi}\int d^3x \exp(i\,\mathbf{k}\cdot\mathbf{x})\exp\left(-\frac{\mathbf{x}^2}{2R^2}\right), \qquad R = R_{\mathrm{Kpp}}\left(1 + \left(\frac{R_{\mathrm{Kpp}}}{R_{\mathrm{He}}}\right)^2\right)^{-1/2}$$

$$= \sqrt{\frac{\pi}{2}} V_0 R^3 \exp\left(-\frac{R^2k^2}{2}\right)$$

$$\frac{d\sigma_0}{d\Omega} \propto |f_0(q)|^2 \propto \exp\left(-\frac{R^2q^2}{\hbar^2}\right) = \exp\left(-\frac{q^2}{Q^2}\right), \qquad \boxed{Q = \frac{\hbar}{R}}$$

運動量広がりは
サイズの逆数

E15 result

Succeeded in Observing First Clear “K⁻pp” Signal

Strong binding ($\bar{K}N$ attraction)

Large width (very unstable)

Large Q (could be very compact)

π中間子放出を伴う崩壊チャネル分岐比は？

Mesonic decay branch of $\bar{K}NN$?

核子密度の2乗に比例? vs. 核子密度の1乗に比例?

for example:

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

vs.

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

— will be sensitive to the internal structure (compactness) of $\bar{K}NN$.

— will be sensitive to the isospin partner of $\bar{K}NN$.

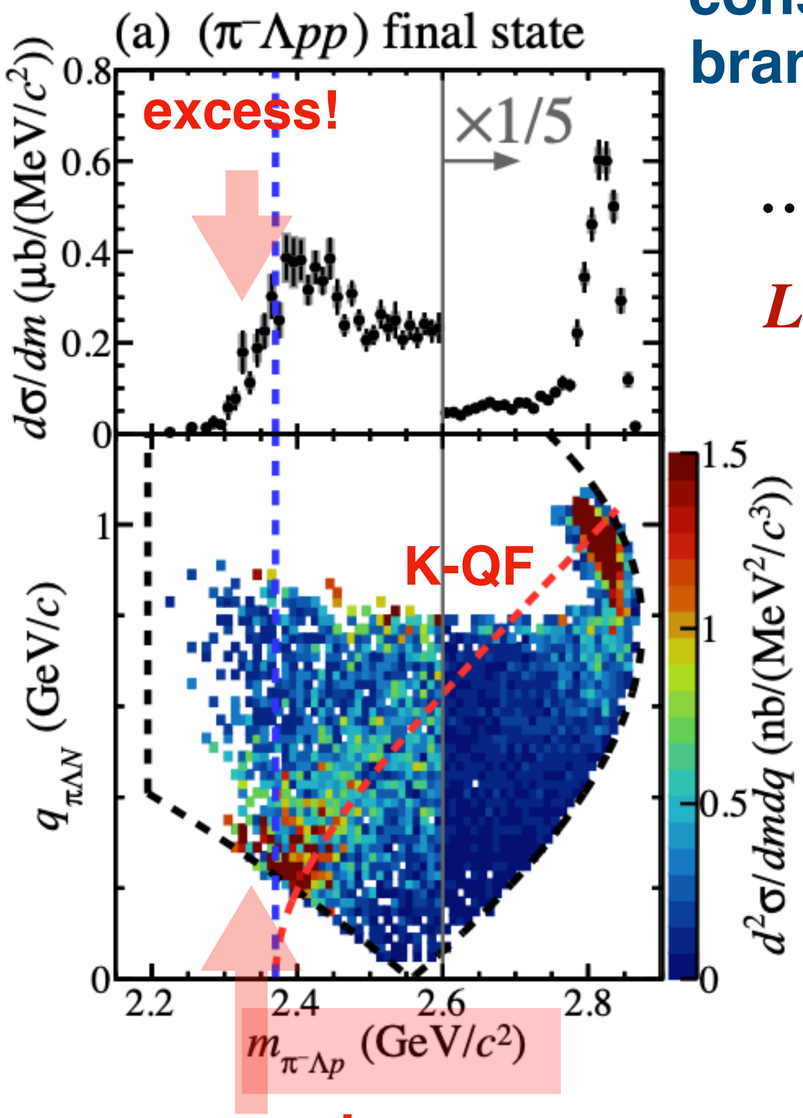
$((K^- + n)p) \equiv (\bar{K}^0 + nn)$

$\bar{K}NN$ isospin partner: $K^- pp \leftrightarrow \bar{K}^0 nn$ — 鏡像核の存在は必須!

… done by T.Yamaga

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

consistent with $K^- + {}^3He \rightarrow \Lambda pn$ reaction
branch seems to be oder bigger



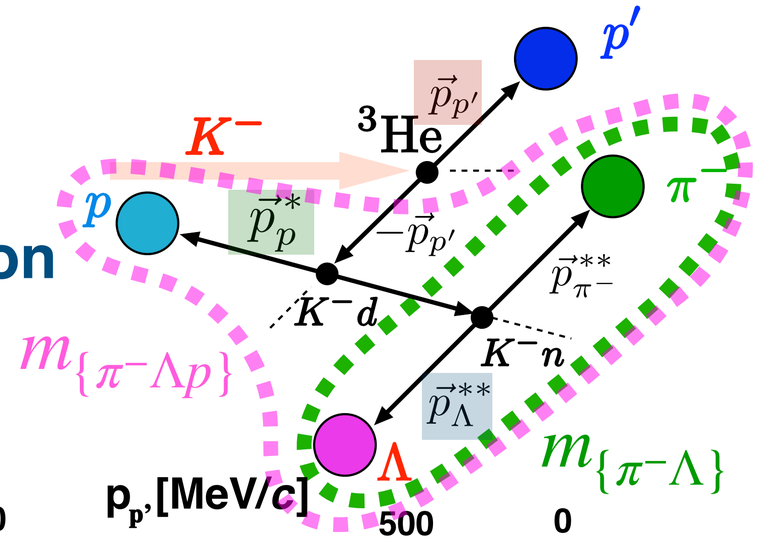
… *excess is not easy to see* …

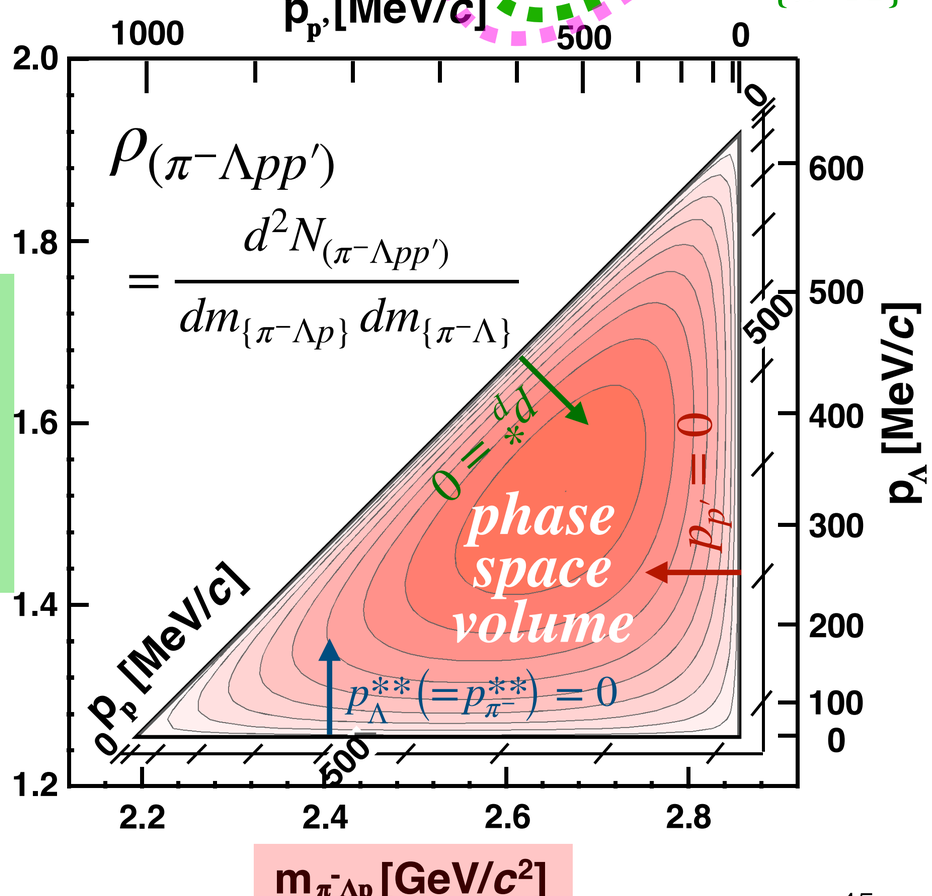
Let's normalize event density by 4-body phase space

*The normalization by **4-body phase space**, i.e., **final-state-density***

$$\rho_{(\pi^-\Lambda pp')} = \frac{d^2N_{(\pi^-\Lambda pp')}}{dm_{\{\pi^-\Lambda p\}}\, dm_{\{\pi^-\Lambda\}}}$$

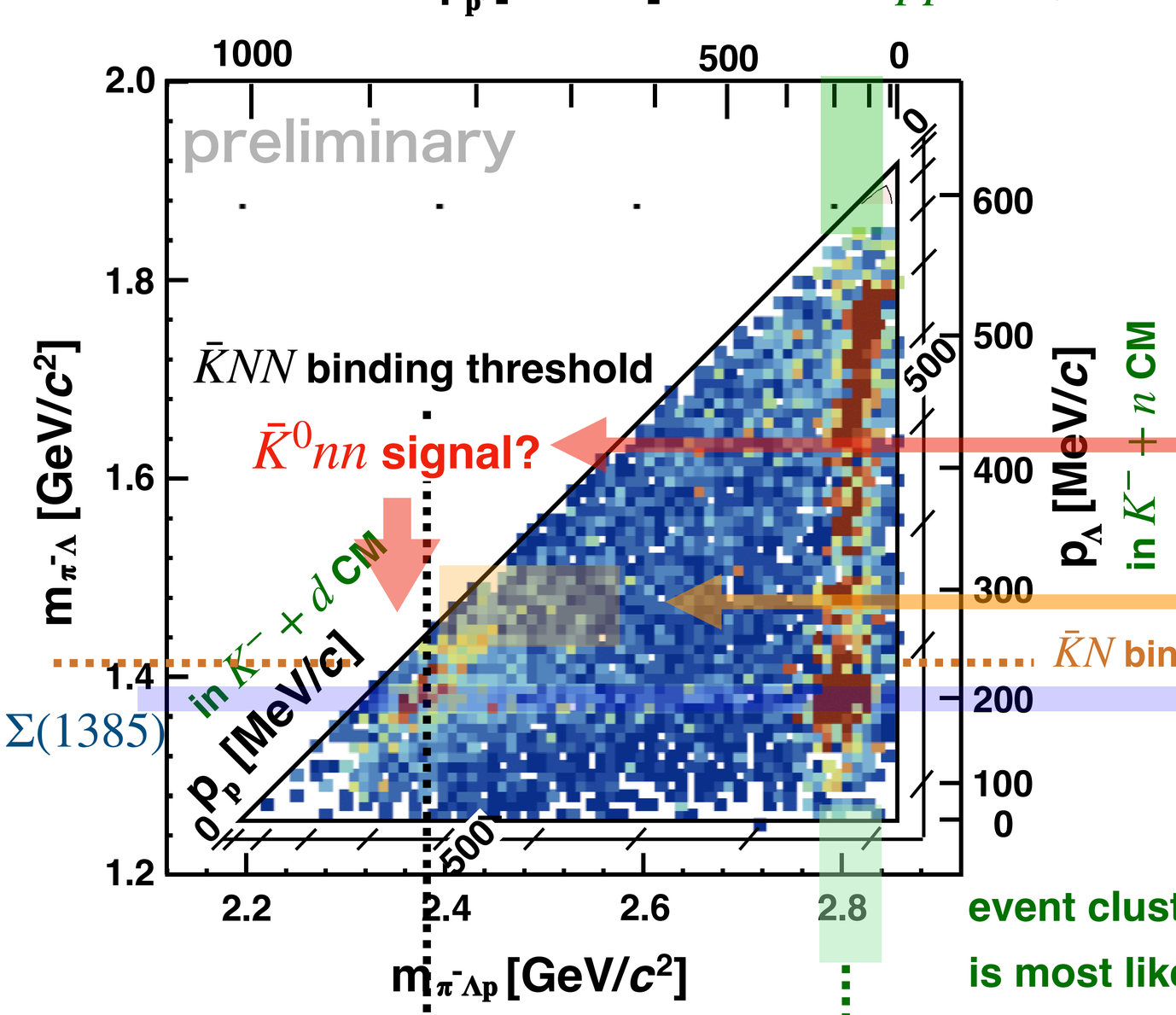
$$\propto p_{p'} \times p_p^* \times p_\Lambda^{**}$$

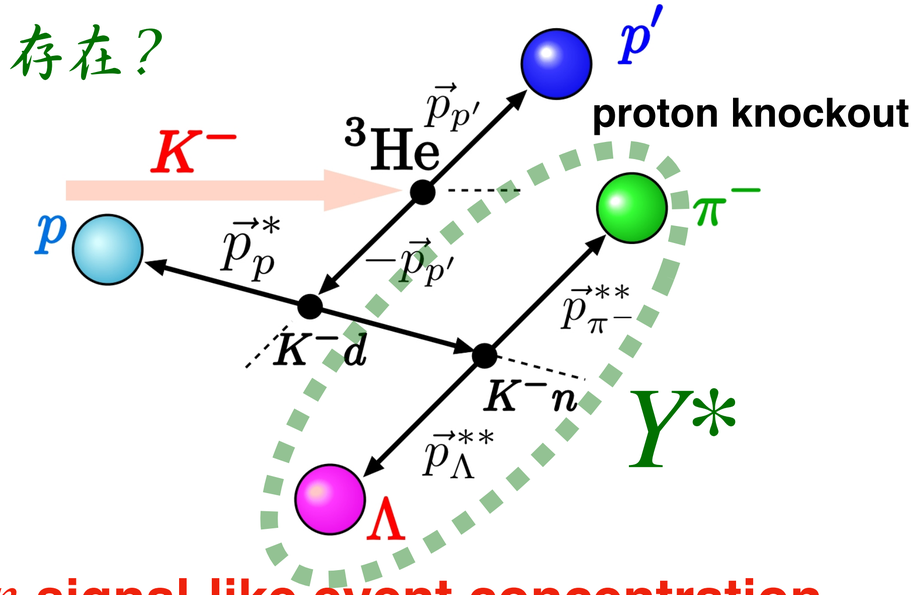




… *analyzed by T. Yamaga*

“K^-pp”鏡像核“$\bar{K}^0nn$”の存在？





$\bar{K}^0nn$ signal-like event concentration below $\bar{K}$-bound threshold is seen?

— twice more data become available in April —

QF-K induced reaction?

$\Sigma(1385)$ contribution is not negligible compared to $(\Lambda p)+n$ final state.

event cluster at $m_{\pi^-\Lambda p} \sim \sqrt{s_{K^-d}} \approx 2.83\,\mathrm{GeV}$ is most likely …

$M(\bar{K}^0nn) \sim 2377\,\mathrm{MeV}/c^2$

2NA: $K^-d \to Y^*p$ reaction

leaving p’ as a spectator

核内クラスター構造の存在？

— K^- seems to be sensitive to the deuteron cluster in ^{3}He —

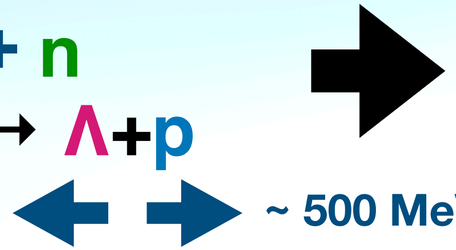
Further analysis on other data

もっと重いK中間子原子核はないのか?

Signal of $\bar{K}NNN$?

系統的研究への第一歩

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



~ 500 MeV/c

$K^- + {}^4\mathrm{He} \rightarrow (K^- + ppn) + n$
$(K^- + pd) \rightarrow \Lambda + d$
$d = (pn)$

competitive process: $((K^- + pp)n) \rightarrow (\Lambda + p) + n$

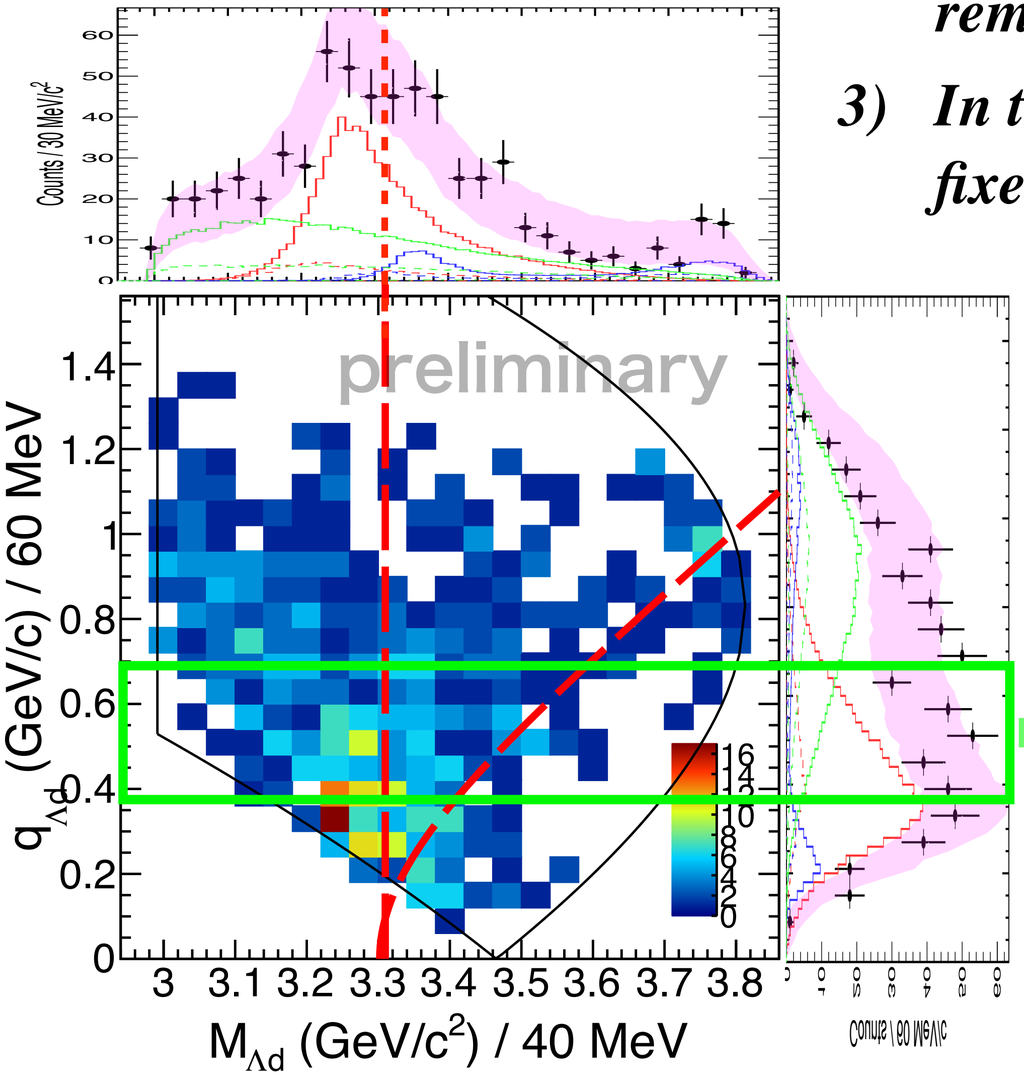
Preliminary data analysis for $\bar{K}NNN$ formation study utilizing ${}^4_\Lambda\mathrm{He}$ lifetime measurement via $K^- + {}^4\mathrm{He} \rightarrow \pi^0 + {}^4_\Lambda\mathrm{He}$ reaction giving us a very interesting result

… done by T. Hashimoto

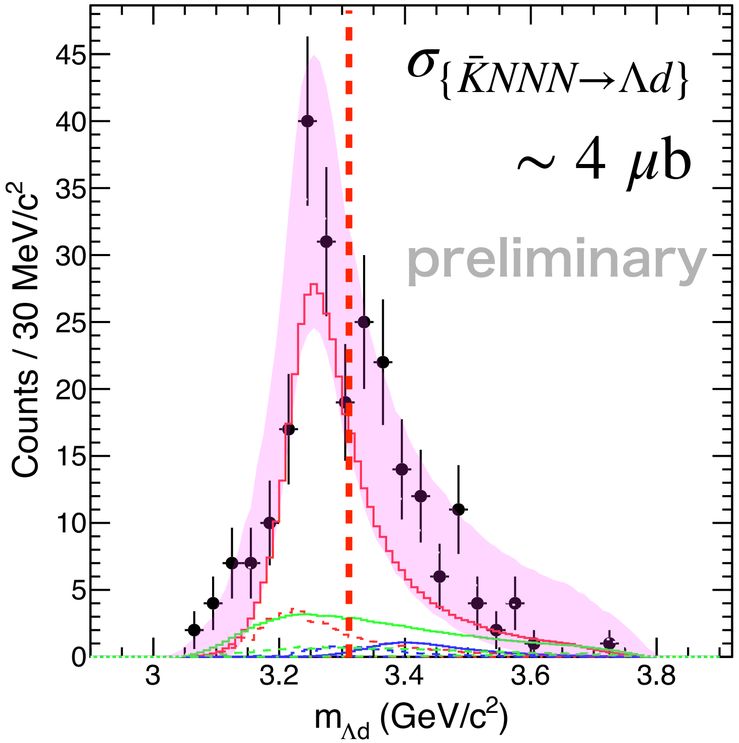
Λd decay

Promising signal is observed!

1) *It suggests kaonic nuclei exist more universally, not just in cases like K^-pp.*
2) *Despite more nucleons absorbing the K meson, the width remains unchanged, suggesting a near plateau.*
3) *In the case of K^-ppn, isospin and spin-parity $I(J^P)$, has been fixed to be $0(1/2^-)$ with high certainty through Λp decay.*



$0.3 < q_{\Lambda d} < 0.6$ GeV/c window



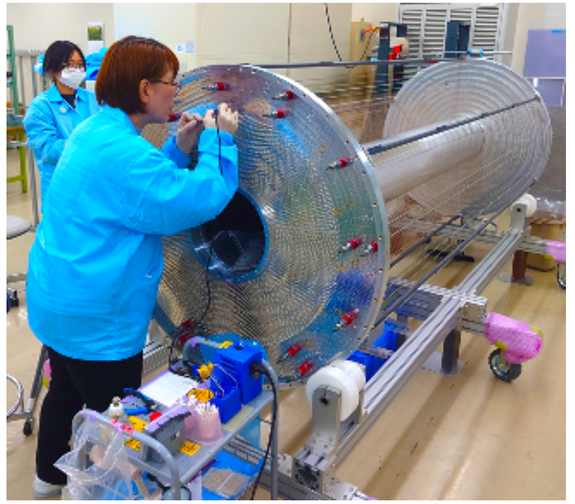
New Spectrometer under construction

Preparation of planned devices / detectors

Return Yoke

Super-conducting Solenoid Coil

under construction



Cylindrical Drift Chamber (CDC)

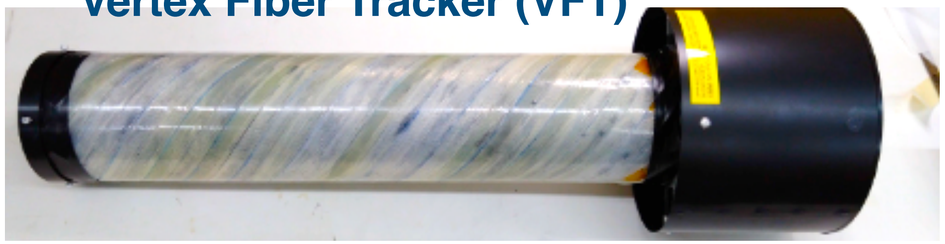
Additional detectors to improve

To detect the proton in Fermi-motion
& to drastically improve vertex resolution (Λ/Σ^0 separation)

フェルミ運動する陽子の検出と反応点分解能向上へ

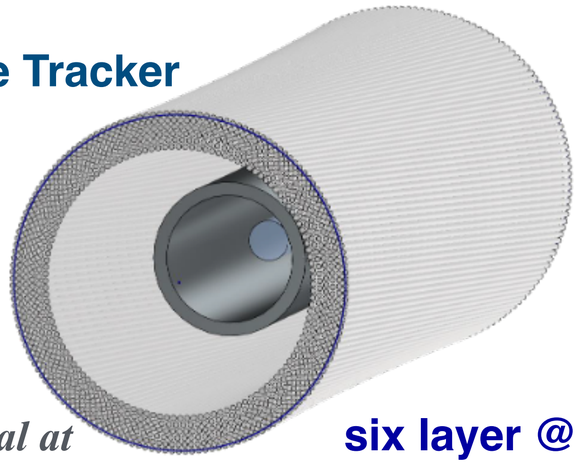
Constructed by T.Hashimoto

Vertex Fiber Tracker (VFT)



doble layer
@ crossing
angle ± 45°

Vertex Straw-tube Tracker
(VST)



Currently, J. Zmeskal at SMI is applying for funding.

six layer @
crossing angle ± 6°

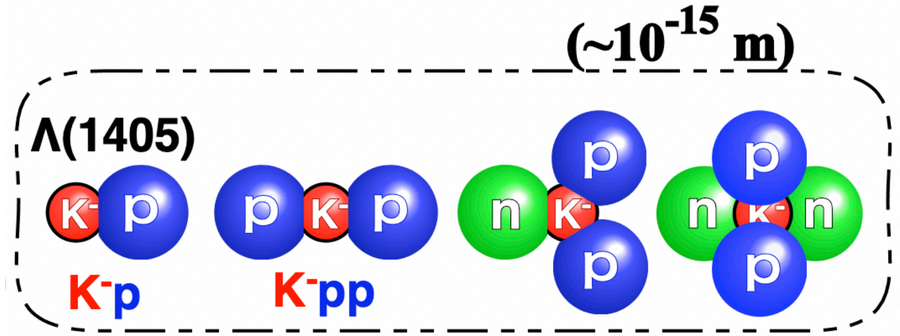
Toward next generation research

Does Isospin-partner $(\bar{K}^0nn)_{I_3=-1/2}$ exist?

Are kaonic nuclei really compact?

Theoretical exploration of Kaonic Nuclei.

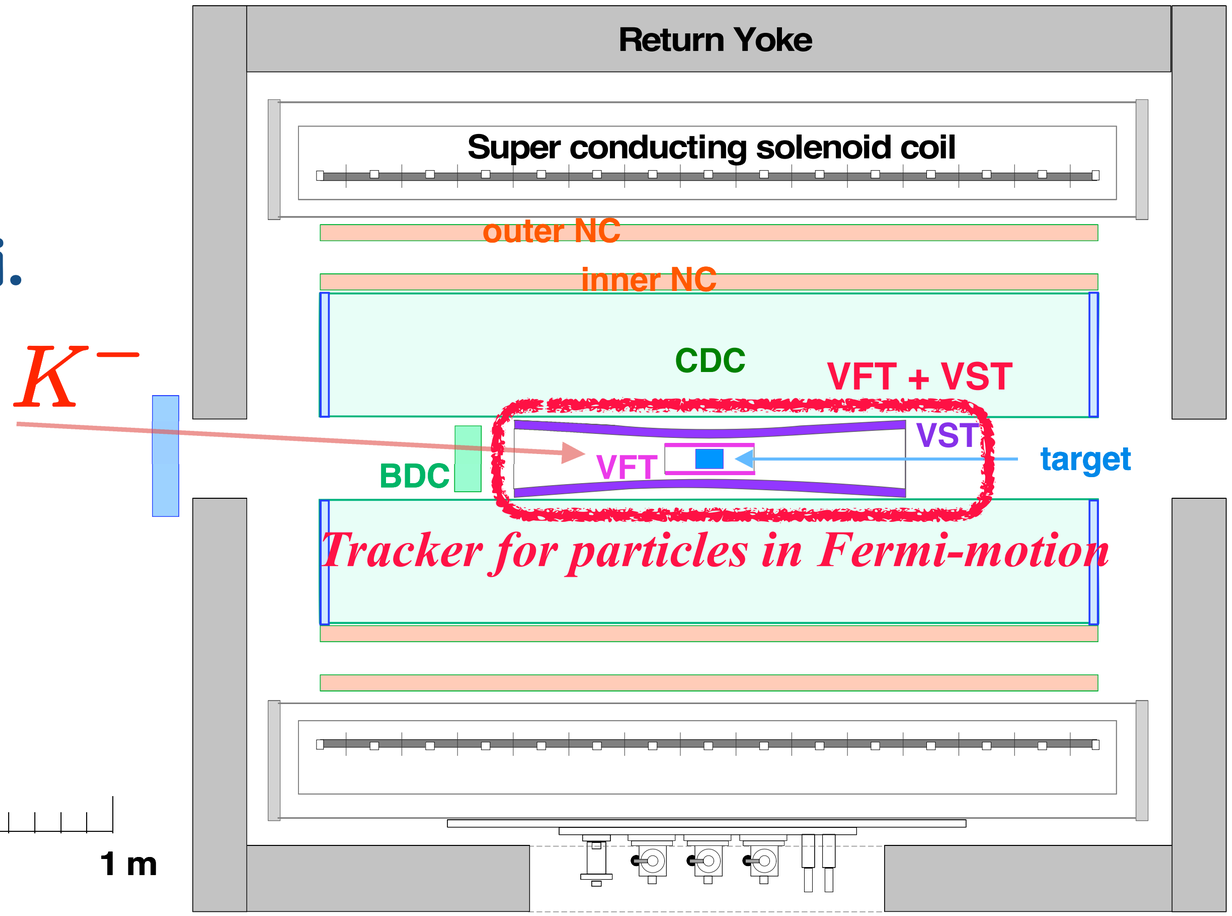
for the systematic study on



molecule-like hadronic nuclear cluster

"Does it have a unique shape like a chemical molecule?"

新型スペクトロメータ



… *Construction is in progress, led by F. Sakuma*

Spin-Parity I(J^P) Assignment for $\bar{K}NN$

… 量子状態の性質を決める最も基本的な量子数 …

… $I_{\bar{K}N} = 0$ チャネルが引力的なので、ほぼ間違いなく$I(J^P) = 1/2(0^-)$であろう。ただし、本質的な理解のために実験的に決めることが重要。しかし、その決定は極めて困難…

Two possible internal structures: $I(J^P)$?

スピンパリティ状態の2つの可能性

$\bar{K}NN$: I = 1/2, J^P = 0^-: $I_{NN} = 1$, $S_{NN} = 0$, $L_{\bar{K}} = 0$ — *most likely this is the case, due to stronger* $I_{\bar{K}N} = 0$

NN (isospin) symmetric (I_{NN} = 1) and spin anti-symmetric (S_{NN} = 0)

$\bar{K}NN$: I = 1/2, J^P = 1^-: $I_{NN} = 0$, $S_{NN} = 1$, $L_{\bar{K}} = 0$ — *dominant in* $I_{\bar{K}N} = 1$

NN (isospin) anti-symmetric (I_{NN} = 0) and spin symmetric (S_{NN} = 1)

What is clear:

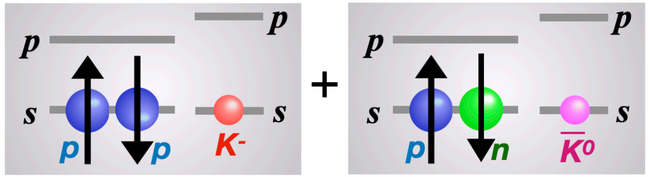
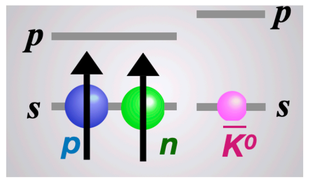
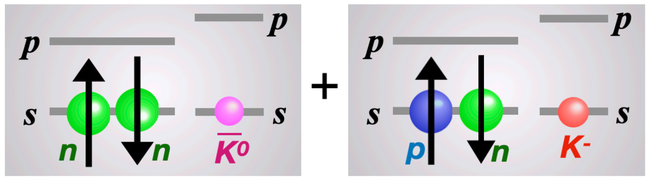
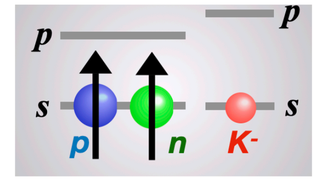
"K^-pp" $\to \Lambda p$ decay requires the isospin to be $I_{\bar{K}NN} = 1/2$.

Presence of kaon requires negative parity for $\bar{K}NN$, while both Λ and p are positive.

Thus, J^P = 0^- or 1^-

In the Λp decay:

The decay must be in P-wave due to the negative parity.

$I(\bar{K}NN)\,/\,J^P(\bar{K}NN)$	$(1/2)\,/\,(0^-)$	$(1/2)\,/\,(1^-)$
NN symmetry	$I(NN) = 1,\ S(NN) = 0$	$I(NN) = 0,\ S(NN) = 1$
"K^-pp" $I_3(\bar{K}NN) = +\frac{1}{2}$	 $-\sqrt{\frac{1}{3}}\left(\sqrt{2}K^-pp + \bar{K}^0\frac{pn+np}{\sqrt{2}}\right)\otimes\left(\frac{\uparrow\downarrow-\downarrow\uparrow}{\sqrt{2}}\right)$	 $\bar{K}^0\frac{(pn-np)}{\sqrt{2}}\otimes\left(\uparrow\uparrow,\ \frac{\uparrow\downarrow+\downarrow\uparrow}{\sqrt{2}},\ \downarrow\downarrow\right)$
"$\bar{K}^0nn$" $I_3(\bar{K}NN) = -\frac{1}{2}$	 $-\sqrt{\frac{1}{3}}\left(\sqrt{2}\bar{K}^0nn + K^-\frac{pn+np}{\sqrt{2}}\right)\otimes\left(\frac{\uparrow\downarrow-\downarrow\uparrow}{\sqrt{2}}\right)$	 $-K^-\frac{(pn-np)}{\sqrt{2}}\otimes\left(\uparrow\uparrow,\ \frac{\uparrow\downarrow+\downarrow\uparrow}{\sqrt{2}},\ \downarrow\downarrow\right)$
$\bar{K}N$ coupling	$\frac{\lvert I_{\bar{K}N}=0\rvert^2}{\lvert I_{\bar{K}N}=1\rvert^2} = \frac{3}{1}$	$\frac{\lvert I_{\bar{K}N}=0\rvert^2}{\lvert I_{\bar{K}N}=1\rvert^2} = \frac{1}{3}$
$\frac{\sigma_{\bar{K}^0nn}}{\sigma_{K^-pp}}$	$0.13 \sim 0.15$	~ 0.75

本当にK中間子原子核なのか、最後に残る懸念?

Is $\bar{K}NNN$ can be a $\Sigma(1385)NN$ system?

$K^- + {}^3He \rightarrow (K^- + pp) + n$ $\quad$ $K^- + {}^4He \rightarrow (K^- + ppn) + n$

$(K^- + pp) \rightarrow \Lambda + p$ $\quad$ $(K^- + pd) \rightarrow \Lambda + d$ $\quad$ $d = (pn)$

~ 600 MeV/c $\quad$ ~ 700 MeV/c

$I(J^P) =$

$\frac{1}{2}(0^-)$ or $\frac{1}{2}(1^-)$

$\frac{1}{2}(2^+)$

$((K^- + p)p) \rightarrow \Lambda\uparrow p\downarrow$ $\quad$ for $\frac{1}{2}(0^-)$

$(\Sigma(1385)\, p) \rightarrow \sim \Lambda\uparrow(p\downarrow + p\uparrow)/2$

$\Sigma^0(1385)p$ shall decay in D-wave with spin mixture of $S_{\Lambda p} = 0$ and 1 at a ratio of 2 : 3, respectively.

… It can be proven more clearly via spin-parity …

K existence is no doubt if $I(J^P)$ is measured!

$((K^- + p)d) \rightarrow \Lambda + d$ $\quad$ spectator

$(\Sigma(1385)\, pn) \rightarrow \Lambda + p + n$

~ 600 MeV/c $\quad$ *dominant*

Λd decay process suggests that the $\Sigma^0(1385)d$ possibility is already not likely.

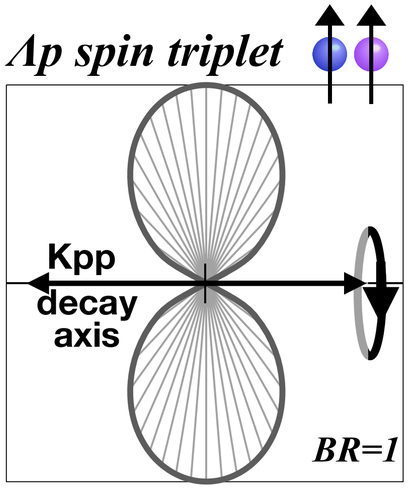
The measurement of $I(J^P)$ dispels the final concern regarding whether K can remain in the nucleus as a meson.

Λp decay axis and spin axis of $\bar{K}NN$ J^P

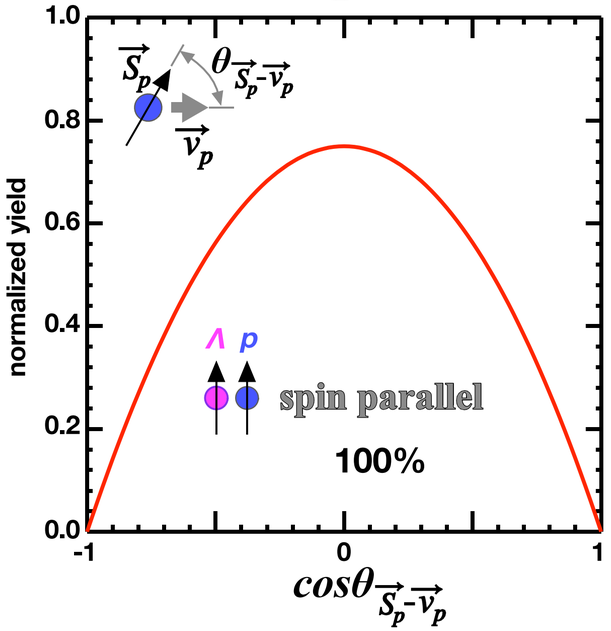
崩壊軸とスピン軸

proton spin orientation referring to the decay axis

$\bar{K}NN$: I = 1/2, J^P = 0^-: I_{NN} = 1, S_{NN} = 0, $L_{\bar{K}}$ = 0



symmetric around Kpp decay axis



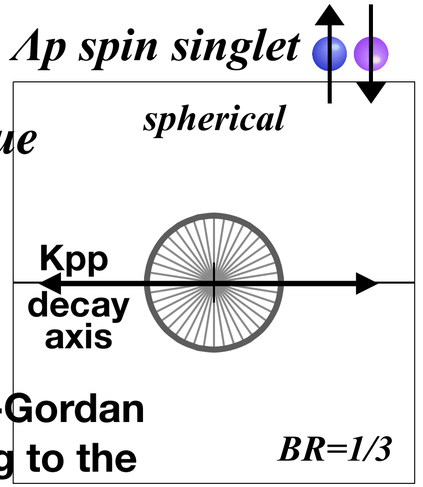
Both in P-wave decay due to the negative parity.

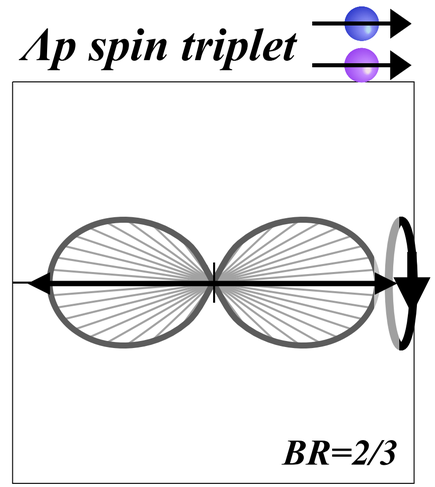
Angular momentum & Clebsch-Gordan define spin orientation referring to the decay axis.

Orthogonal spin (referring to its motion cosθ=0) can be efficiently measured.

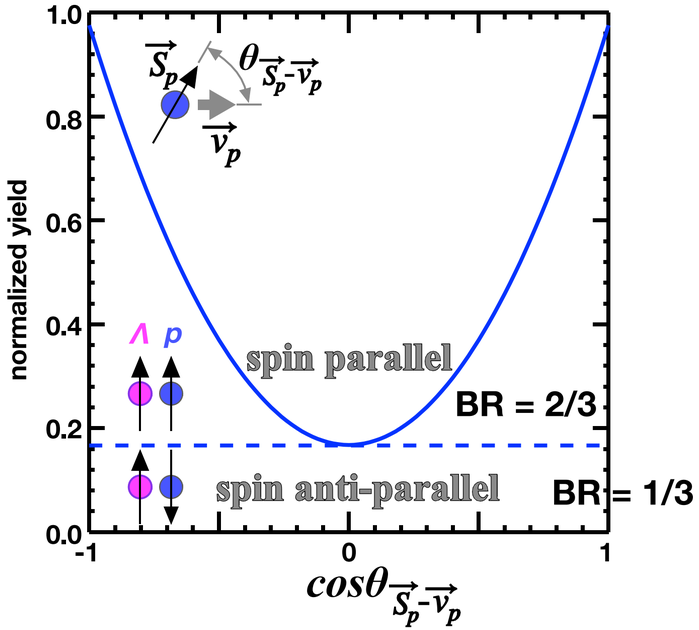
Strong Λp spin-spin correlation can be measured in J^P = 0^-, not in 1^-.

$\bar{K}NN$: I = 1/2, J^P = 1^-: I_{NN} = 0, S_{NN} = 1, $L_{\bar{K}}$ = 0





symmetric around Kpp decay axis

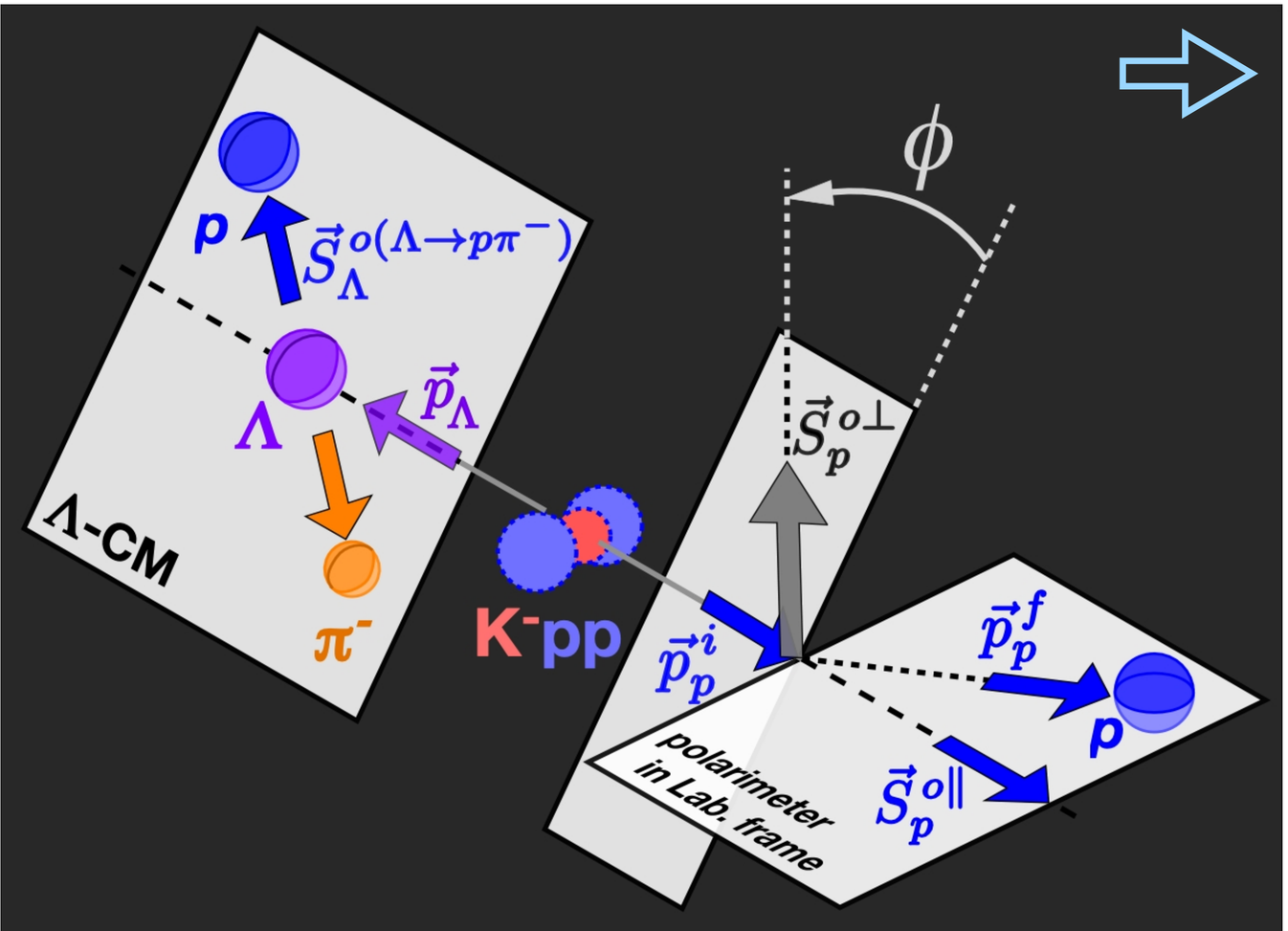


How to measure spin-spin correlation 崩壊軸と反跳軸の相対角度ϕで測定

– spin asymmetry measurement using $\Lambda \to p\pi^-$ & p-C(H) scattering–

p*-C(H) *scattering sensitive only on ϕ asymmetry

$\vec{S}_\Lambda^{o(\Lambda\to p\pi^-)} \approx \vec{v}_p^{\,(\Lambda\to p\pi^-)}(in\ \Lambda\text{–}CM)$



$$N(\phi)\,d\phi \propto (1 + r \cdot \alpha_{\Lambda p}\cos\phi)\,d\phi$$

r : scaling factor

$$r = A_\Lambda \cdot A_{pC} \cdot \vec{S}\cdot\vec{S}^{\parallel} \cdot c_{conv}$$

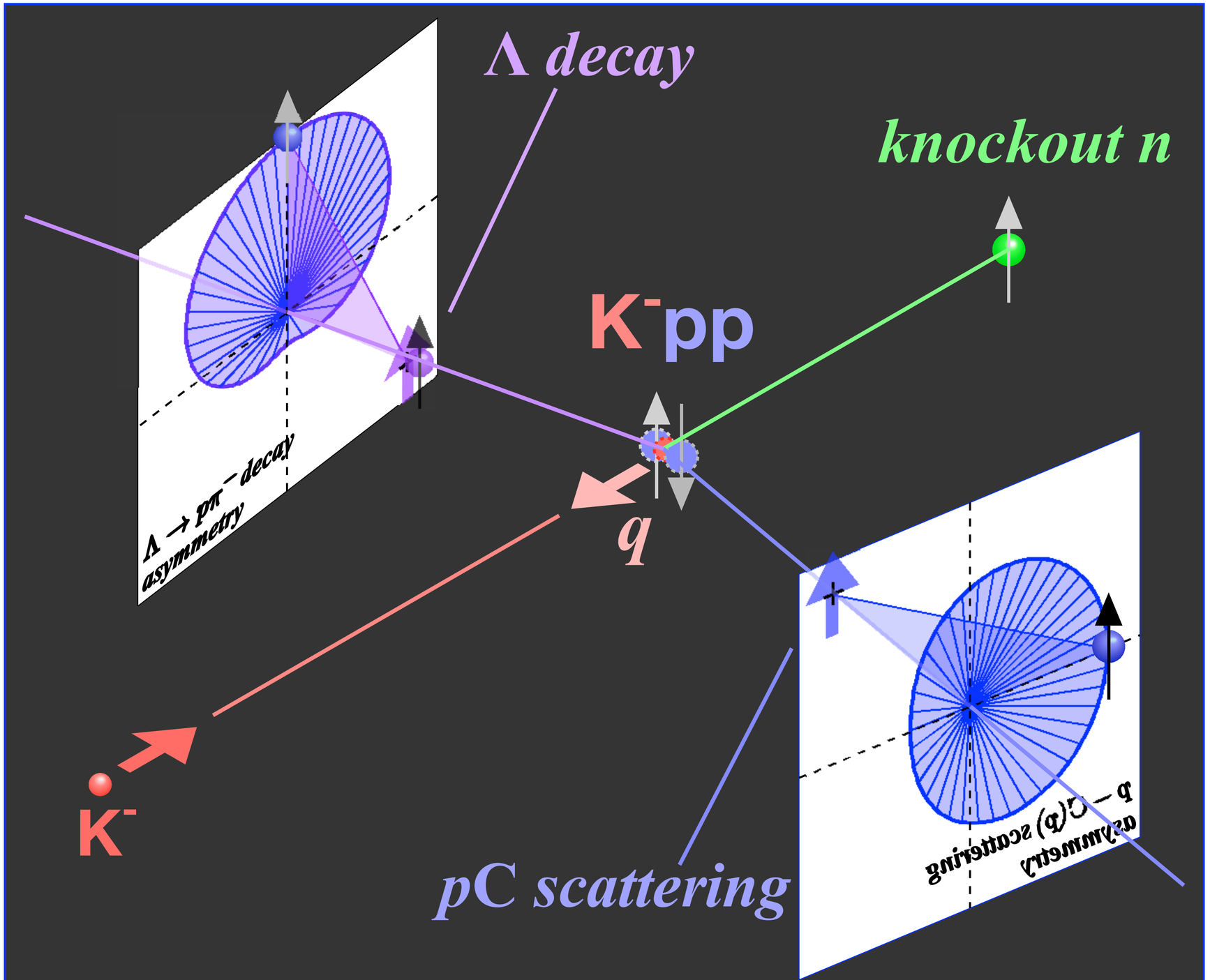
A_Λ : Λ asymmetry parameter

A_{pC} : proton spin-analyzing-power on carbon (and on p)

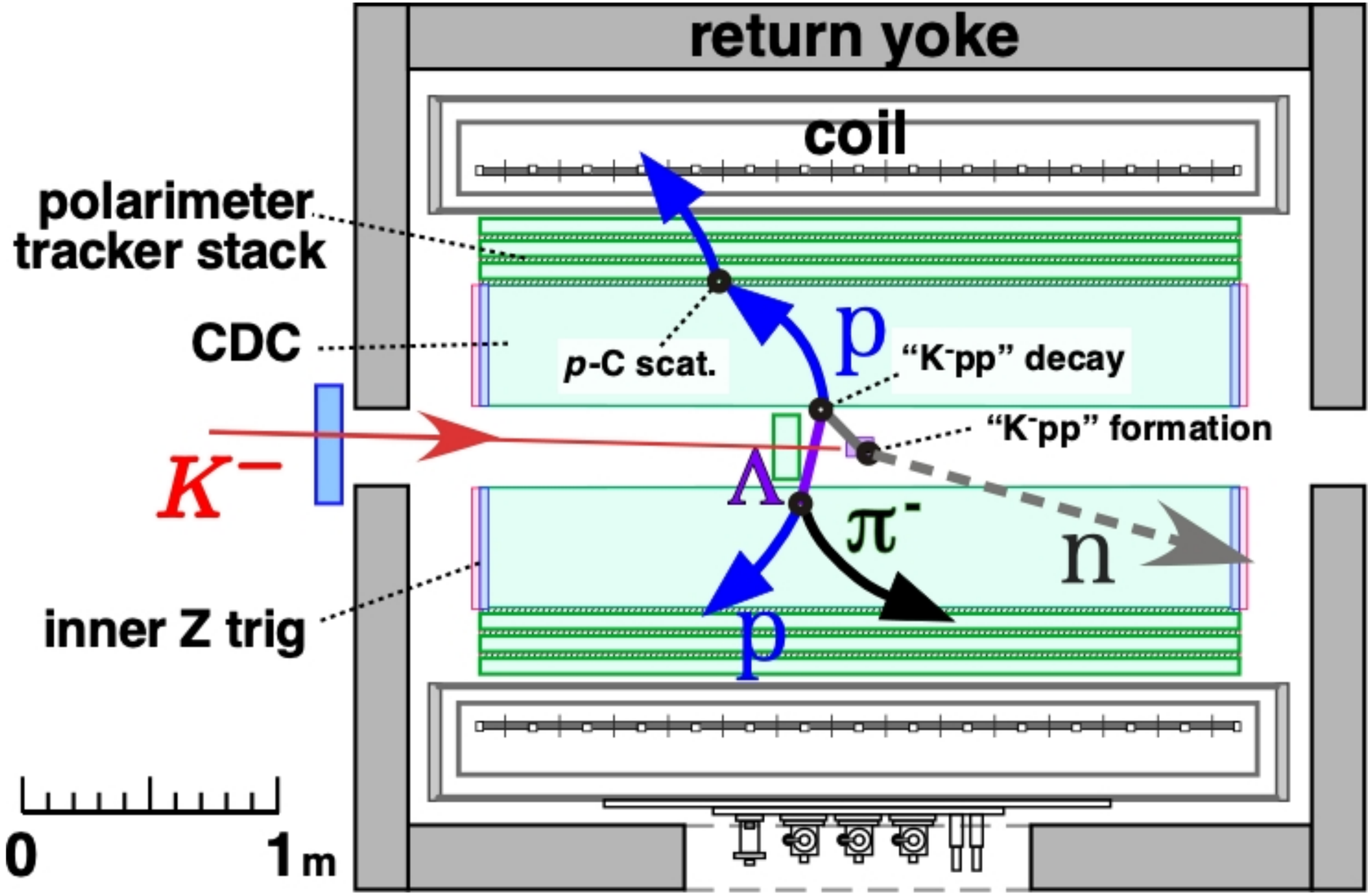
$\vec{S}\cdot\vec{S}^{\parallel}$ ($\equiv \vec{S}_p\cdot\vec{S}_p^{\parallel}$) : spin sensitivity referring to motional axis

c_{conv} : convolution coefficient between two asymmetries

非対称度計測概念図

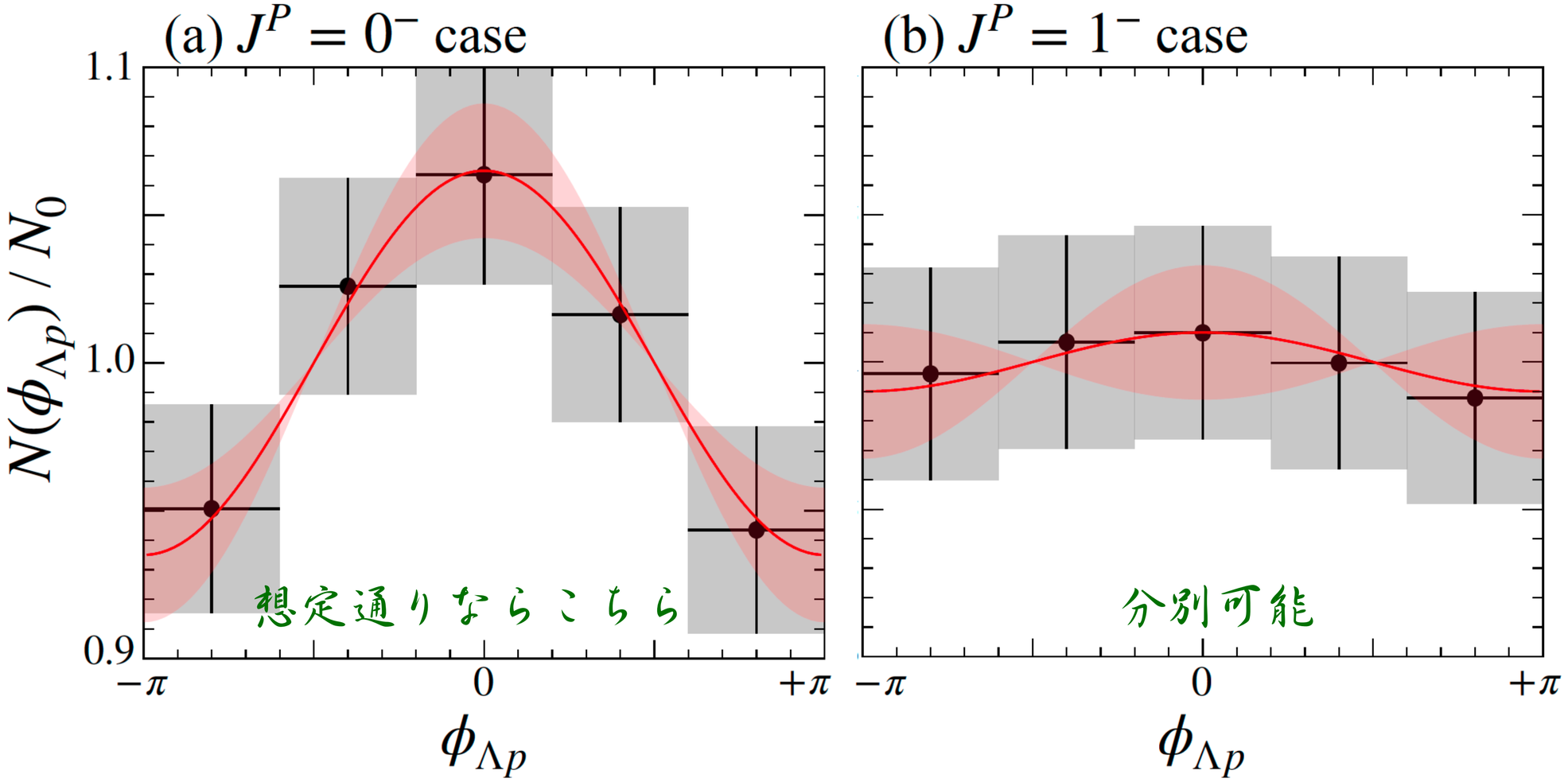

Λ decay
knockout n
K⁻pp
q
K⁻
pC scattering
Λ → pπ⁻ decay asymmetry
p – C(p) scattering asymmetry

Toward J^P (spin · parity) study of K⁻pp with ³He target



非対称度計測想定スペクトル

Λp spin-spin asymmetry



(c) $J^P = 2^+$; $\Sigma^0(1385)p$ case $\alpha^{pol}_{\Lambda p}(J^P{=}2^+) = 1/4\,\alpha^{pol}_{\Lambda p}(J^P{=}1^-)$

The detail can be found:

— in a review —

$\bar{K}N$ interaction study via kaonic atom

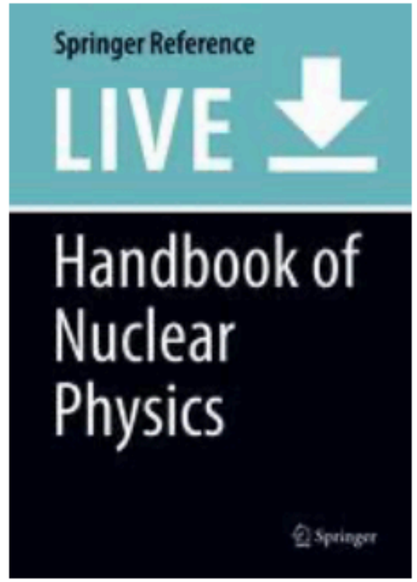
Search for $\bar{K}NN$ nuclear bound state as a natural extension of $\Lambda(1405) \equiv \bar{K}N$

Recent results on $\bar{K}$ bound state

This is a fee-based literature.

K中間子核探査研究の最近のレビュー

Kaonic Nuclei from the Experimental Viewpoint



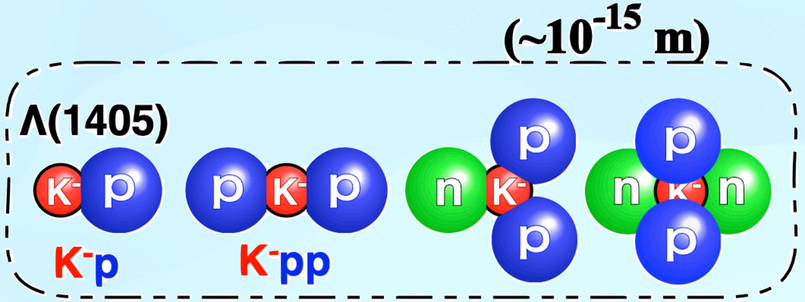
Iwasaki, M. (2022).
Kaonic Nuclei from the Experimental Viewpoint.
In: Tanihata, I., Toki, H., Kajino, T. (eds)
Handbook of Nuclear Physics . Springer, Singapore.
https://doi.org/10.1007/978-981-15-8818-1_37-1

https://link.springer.com/referenceworkentry/10.1007/978-981-15-8818-1_37-1

新型スペクトロメータで目指すもの

With new spectrometer, we will conduct

— a systematic study on light kaonic nuclei —

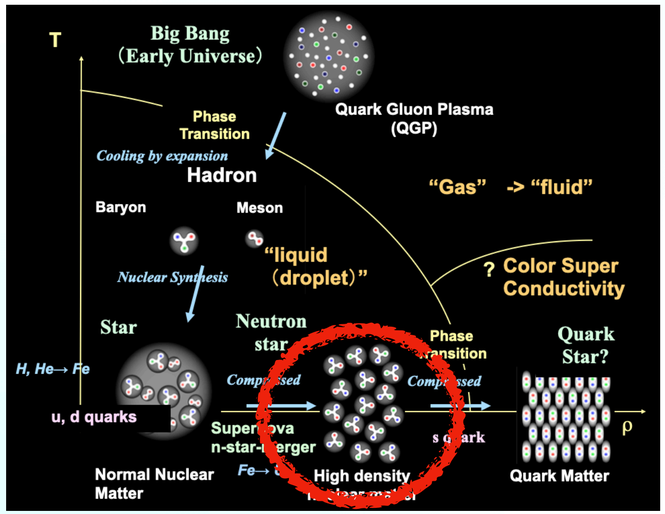


粒子数が多いと不変質量法は厳しい

中重核へは質量欠損法への橋渡し？

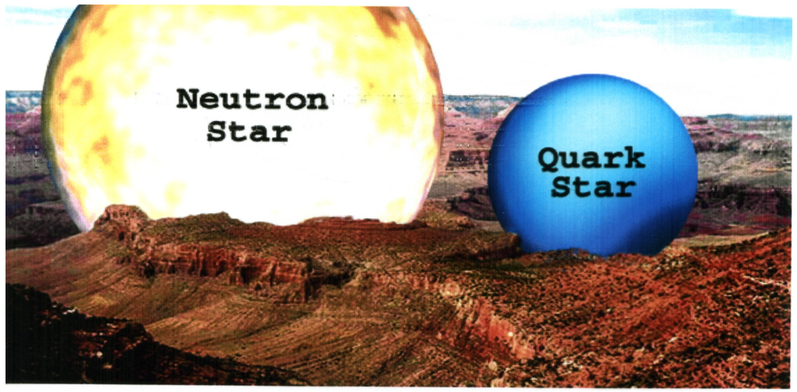
molecule-like hadronic nuclear cluster

"Does it have a unique shape like a chemical molecule?"

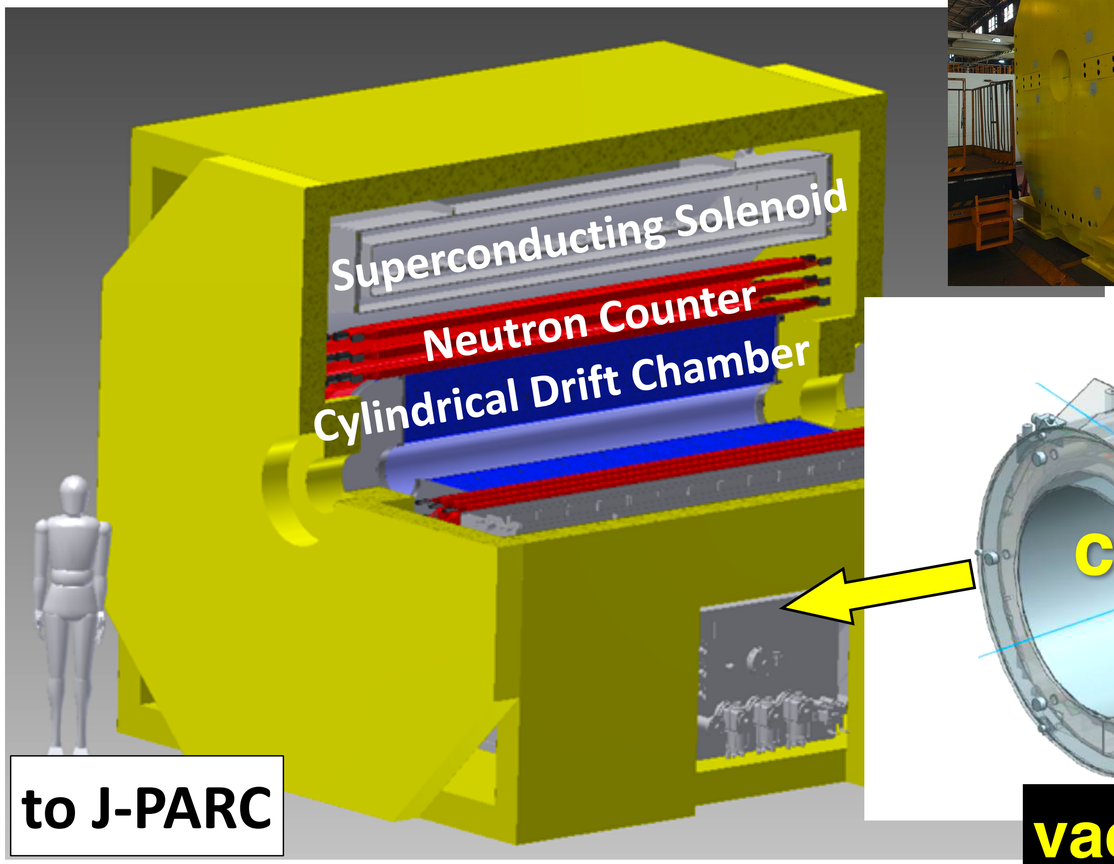


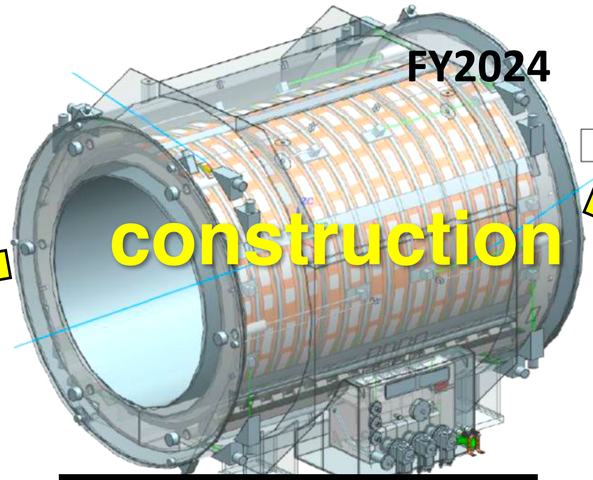
— in future —

We wish to know
how hadron mass is generated
and
physics at high density



Superconducting Solenoid Magnet





建設中の新型スペクトロメータの現状

Proposed K1.8BR Upgrade

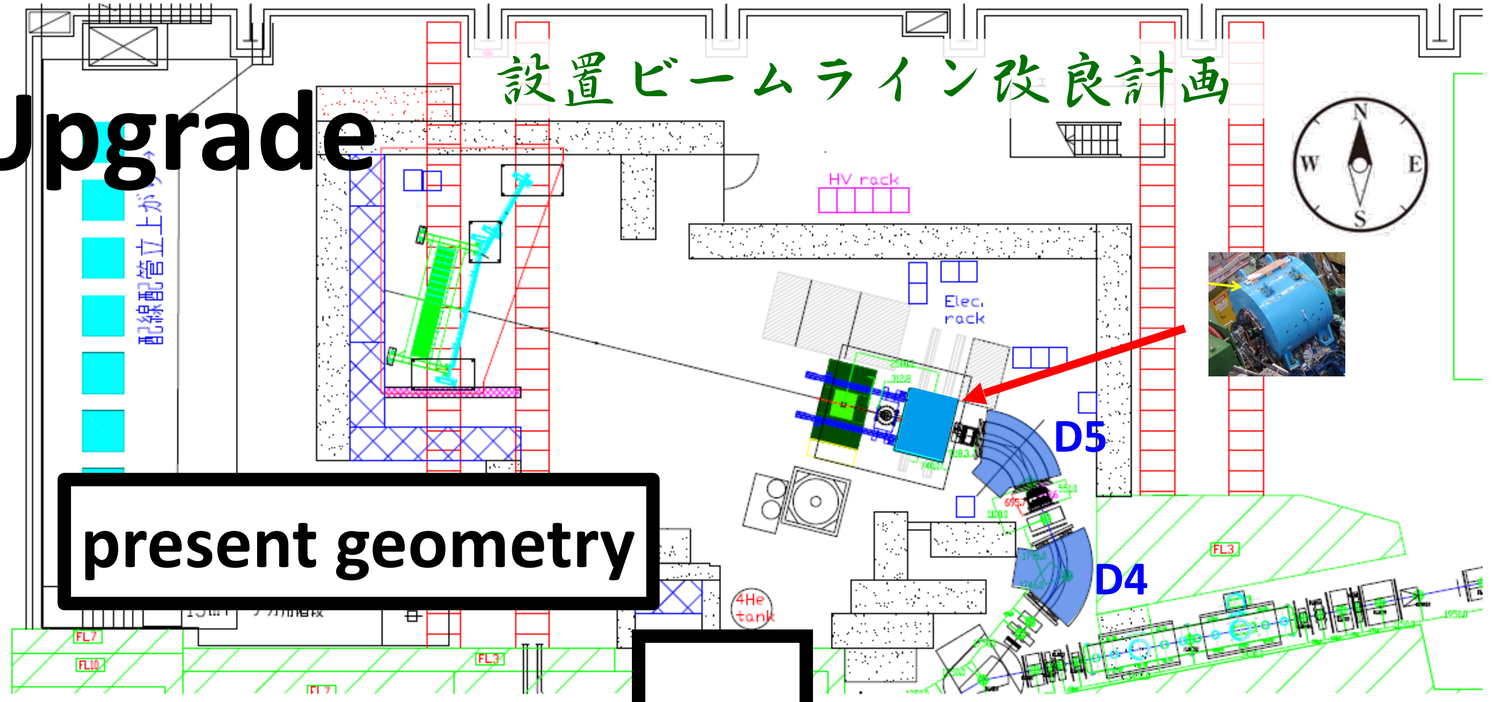
- **Shortened beam line to enhance Kaon yield**

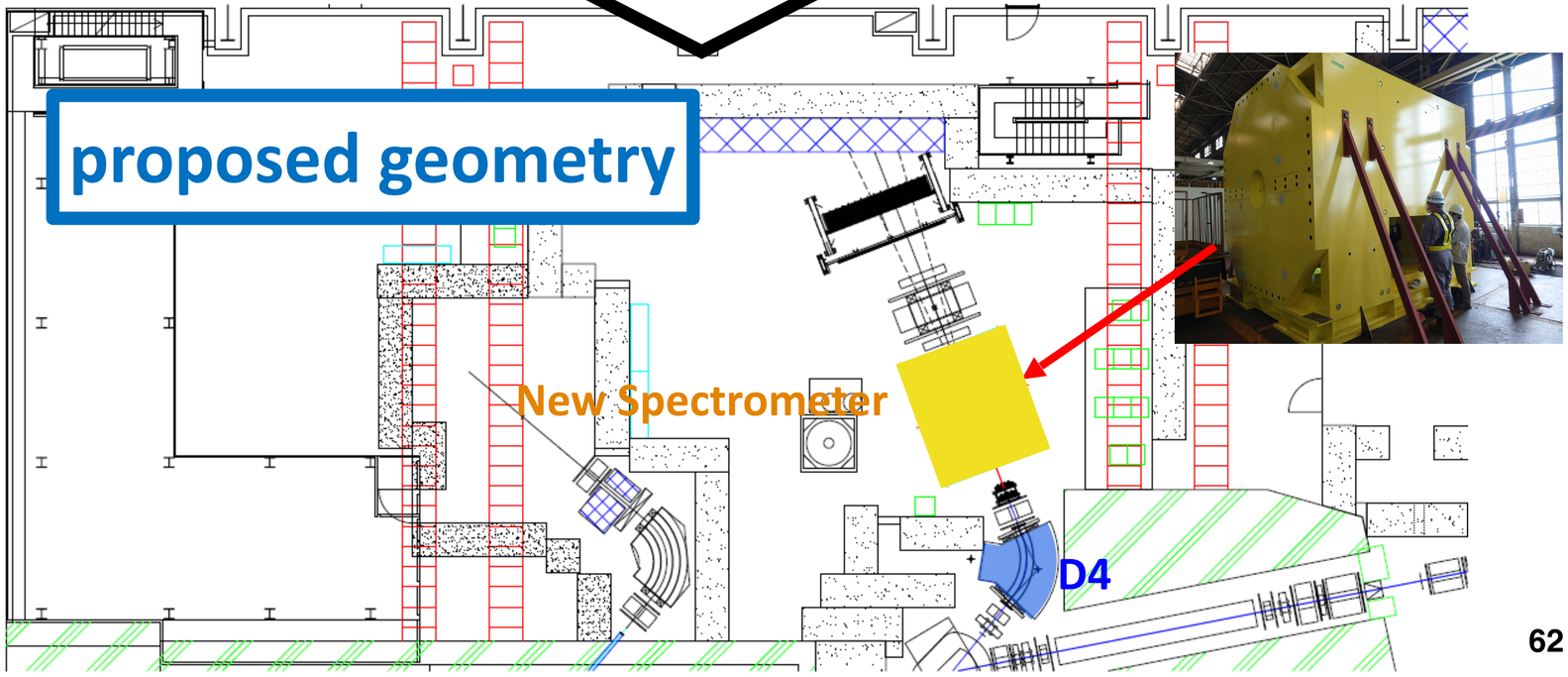
Shorten the beam line (~2.5m) by removing the final D5 magnet

with π/K ratio ~ 2

Relative beam-line length (m)	@ D5	@ D4
Present CDS	0	-3.7
New CDS	+1.2	**-2.5**

➢ K- yield increases by
~ 1.4 times @ 1.0 GeV/c





Yet Another Extension:

$\bar{K}\bar{K}$ bound state via $\bar{p}$ annihilation?

ϕN bound state via $\bar{p}$ annihilation?

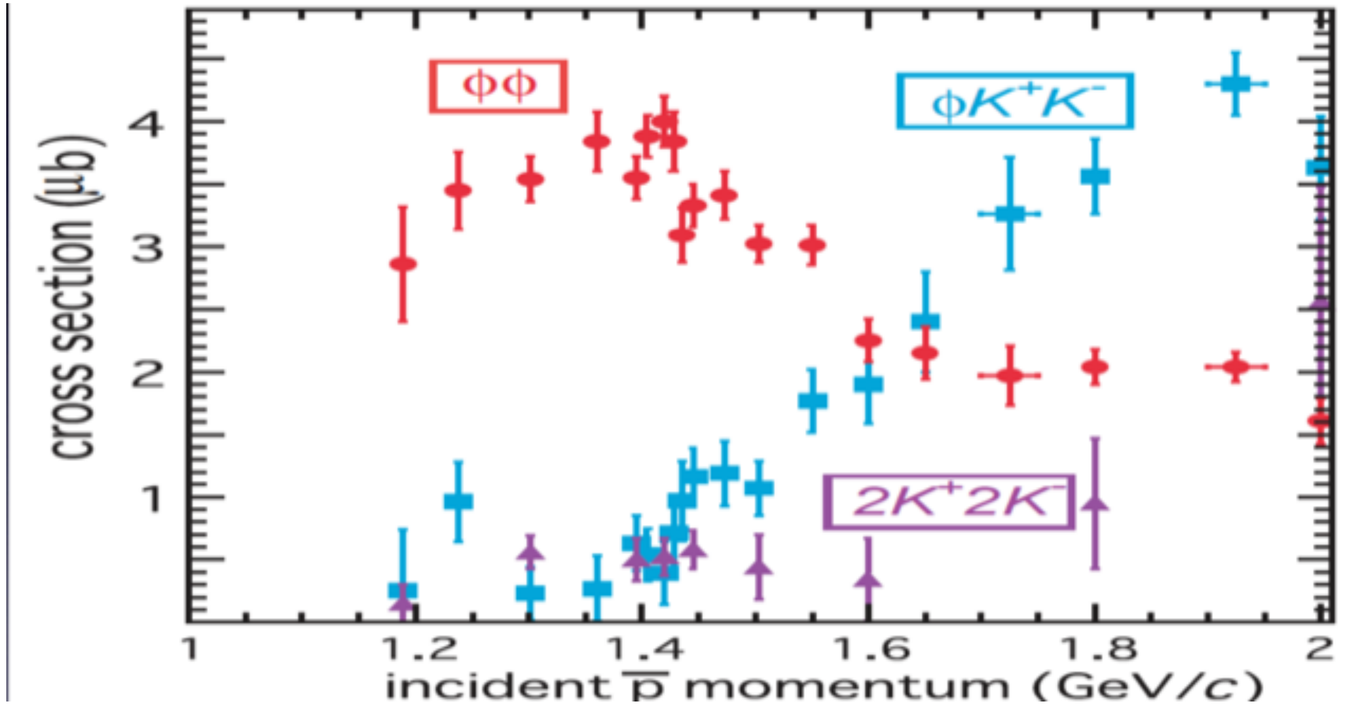
さらなる発展の可能性?

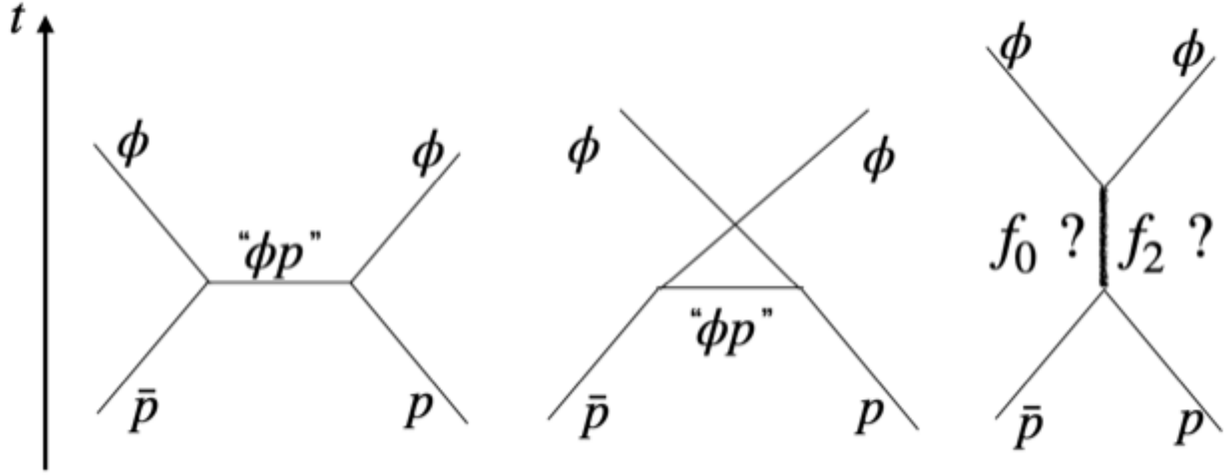
arXiv:2212.12690

Evidence of a p–ϕ bound state

Emma Chizzali[a,b,*], Yuki Kamiya[c,d,**], Raffaele Del Grande[b], Takumi Doi[d], Laura Fabbietti[b], Tetsuo Hatsuda[d], and Yan Lyu[d,e]

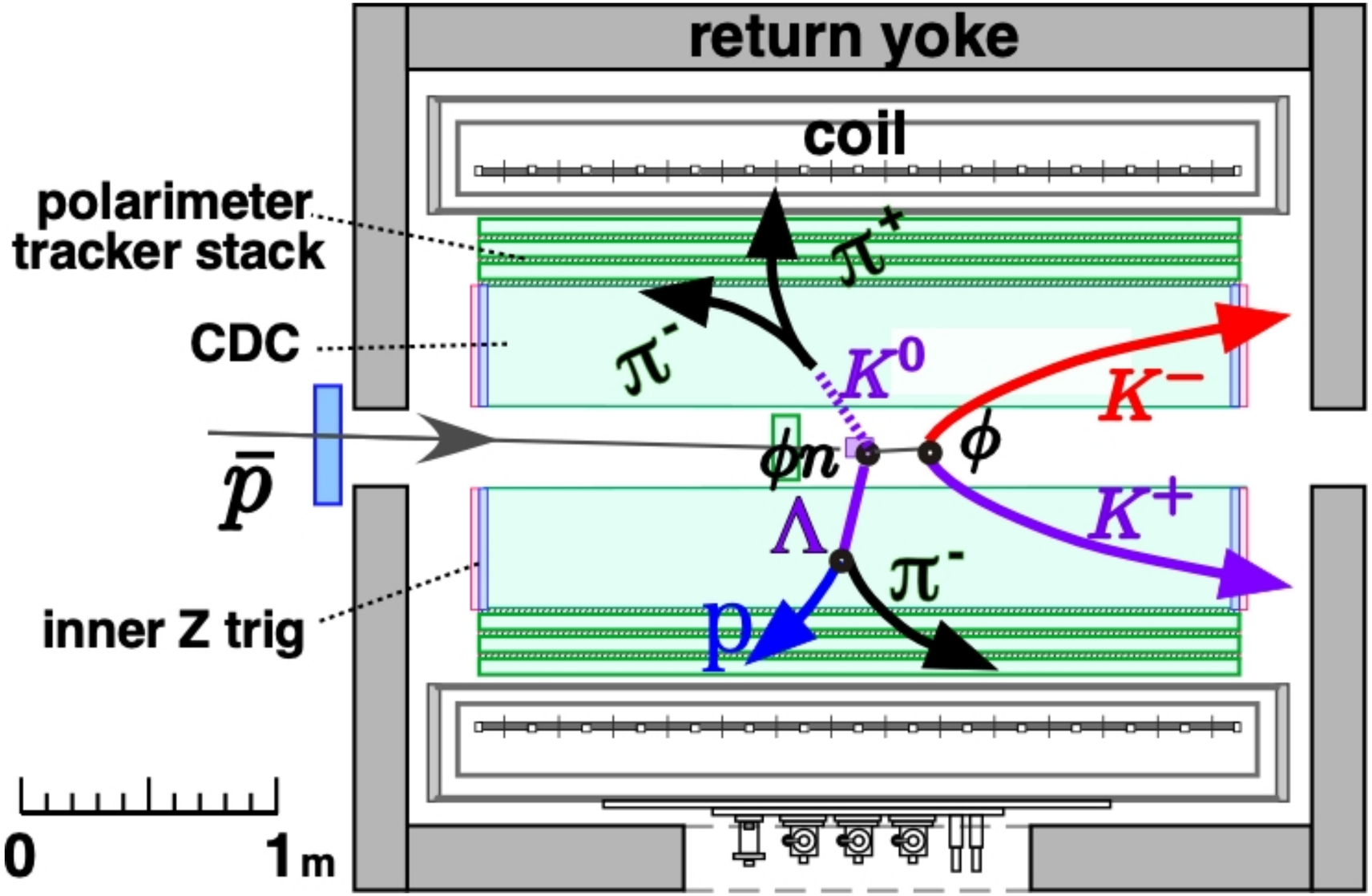
The possibility of the existence of a ϕN bound state ($J = 1/2$) as a novel molecular hadron cluster has been pointed out. This is consistent with $\phi\phi$ dominance near the production threshold of the $\bar{p}p$ reaction channel.





… H. Onishi

If exist, nuclear ϕ bound states search is of interest



ϕN bound state search?

分子状ハドロン等更なる
エキゾチックハドロン探査?

… H. Onishi

Please collaborate with us, if you are interested in.

…ここでの物理や実験装置に興味があったら是非協力しませんか?…

… という訳で、私は「普通の研究員に戻ります」…

I'm going back to being an ordinary researcher for three years to conduct a Grant-in-Aid for Specially Promoted Research — as a play on the Candy's retirement in 1977—

… なんと50年近く前 … 今どきの若者には通用しないか …

Thank You for Attention!

次世代に更なる面白い物理の発展を期待します!

質疑応答は質問の音声が上手く拾えてなかったので、割愛します。

Thank you for watching and participating in the workshop.

I'm very happy to be with you all.

Bonus topics:

— What I learned with the Talk —

おまけ：トークを通して気づけたこと等

トークすることで気づけたことなど
トークをすることで俯瞰的視野を持てる

Bonus topic 1:

It is important:

When you make matters clear and organized, you may realize the essence of a problem that you were not aware of, and you may also have more perspective view to identify a better way to resolve a problem.

In the talk, I realized that my materials in not sufficiently clear and organized, so I updated the this materials.

問題を整理し人に伝える必要のあるトークをすることは、
問題を俯瞰的に捉える視野を醸成し本質を捉えるのに役立
つ。 十分整理されていなかった点は以下にまとめ直す。

批判的意見も力に

Bonus topic 2:

The critical questions:

En'yo-san raised question: "What will you do, if the charge mirror state $\bar{K}^0nn$ do not exist?"

鏡像核が存在しなかったらどうするのか？

As the sign of the existence already seen in the analysis, speculating about the non-existent is a pointless exercise, often termed the devil's proof as it is impossible to prove.

存在の兆候が見えている以上、存在しない可能性に思い煩うのは無為

Instead, we aim to verify the signs of existence that we have seen in our experimental study of the $\pi^-\Lambda p + p'$ final state.

むしろ$\pi^-\Lambda p + p'$終状態研究で見えた鏡像核の存在兆候を検証したい

トークで受けた気が付きにくい実験バイアスに関する指摘

Bonus topic 3:

実験家への有用な情報

Possible bias generated in mixed-trigger:

— mentioned by K. Itahashi

To study the systematic error, we often utilize Mixed Trigger, but it may fake us on DAQ efficiency.

To study the systematic error, we usually utilize Mixed Trigger, but it may fake us on DAQ efficiency. Y. Tanaka realized that the DAQ efficiency is not a general number, but it differs for trigger conditions. — Self-inefficiency for pre-scaled trigger is very low by definition, but the inefficiency caused by pre-scaled trigger to the crucial one is not. Thus, the stability of the DAQ efficiency shall be studied as a function of pre-scaling factors in a systematic manner, if one wish to apply mixed-trigger on an experiment. It may fake us on the total cross section!

隠れたバイアスの例…

研究者に成果を挙げさせるために
管理対象という認識を排し、如何に活用するか

Bonus topic 4:

事務部門への期待

To improve effectiveness in enforcing compliance with the rules:

One needs a reason to follow, especially for Scientist who trained to raise question even to the textbook or supervisor, and requested not to follow blindly.

Ex. Rule: Never cross a crosswalk at a red light.

I followed the rule ever since I was asked "What ethical responsibility can you take, if some children imitates you in time and involved in a car accident?"

ルールは強制ではなく共感を …