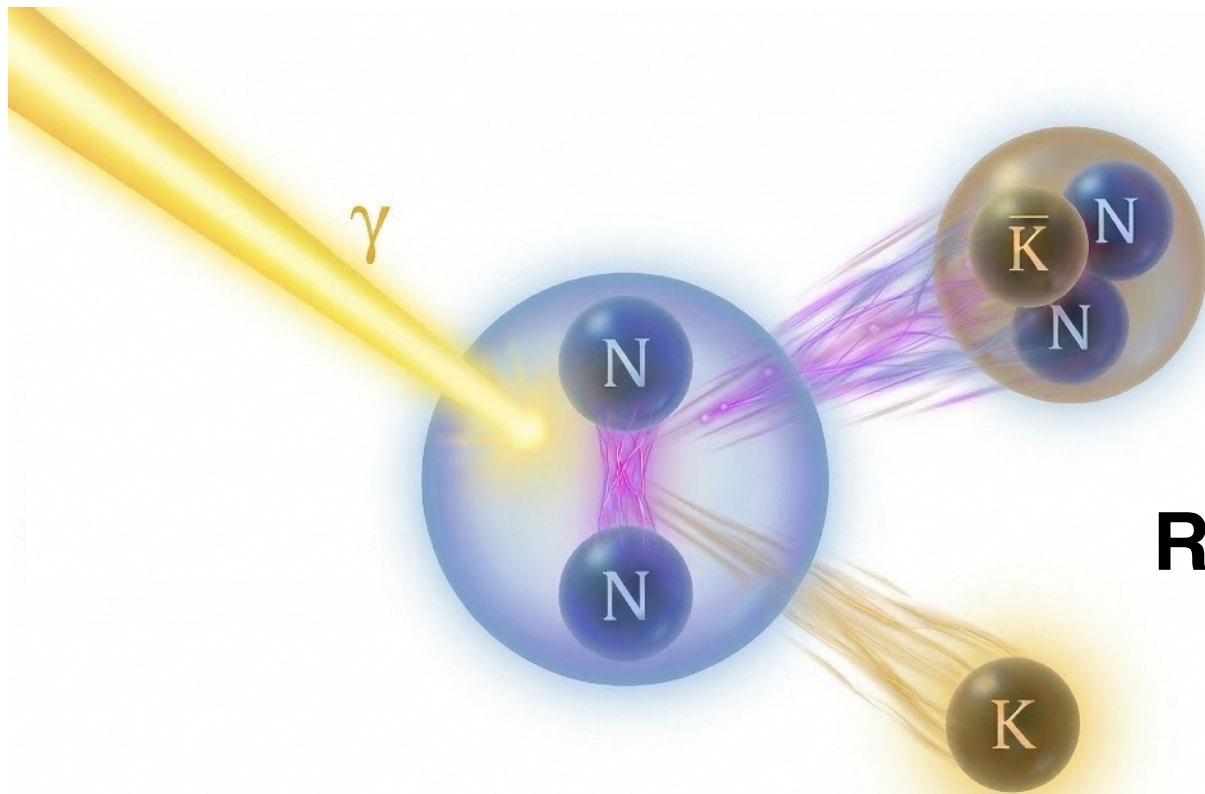


The Study of $\bar{K}NN$ state using photon beam

R. Kobayakawa et al., Phys. Lett. B 880, 140719 (2026)



Ryo Kobayakawa (RCNP, Univ. Osaka)

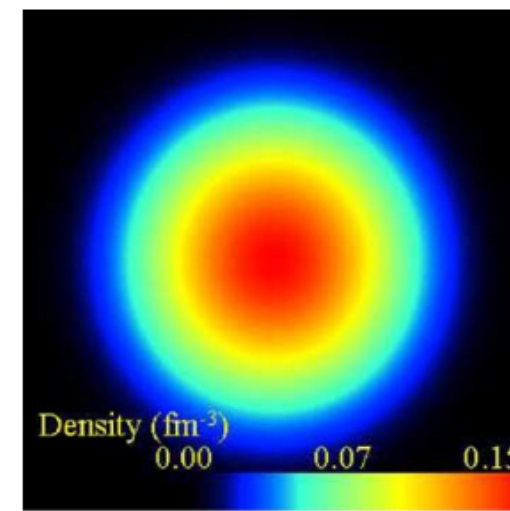
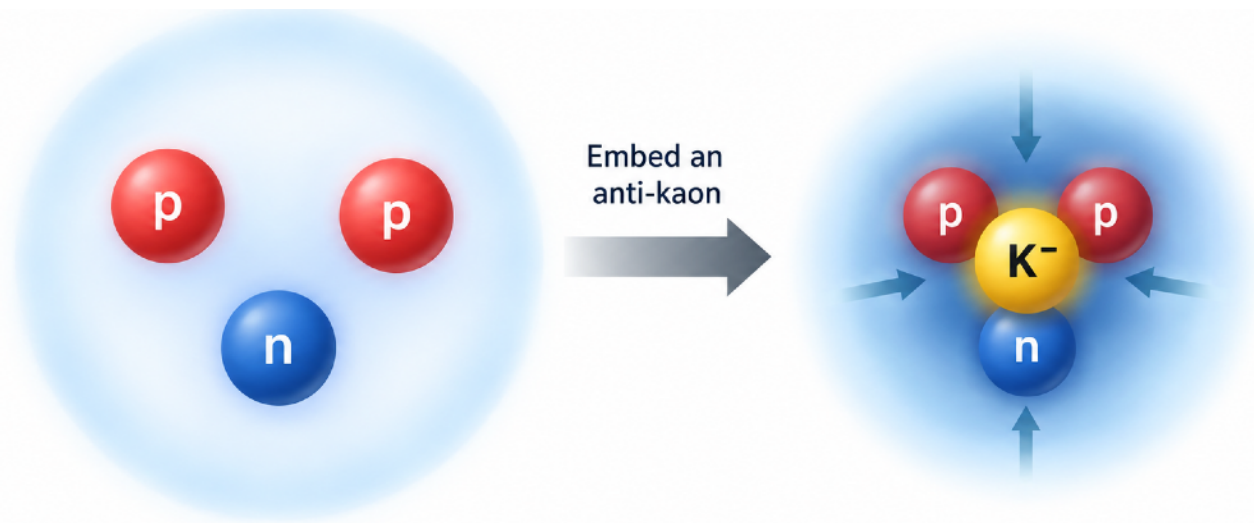
Contents

- **Physics Motivation**
- **Previous $\bar{K}NN$ Searches**
- **LEPS2 Measurement & Analysis**
- **Results & Interpretation**
- **Toward New Kaonic System**

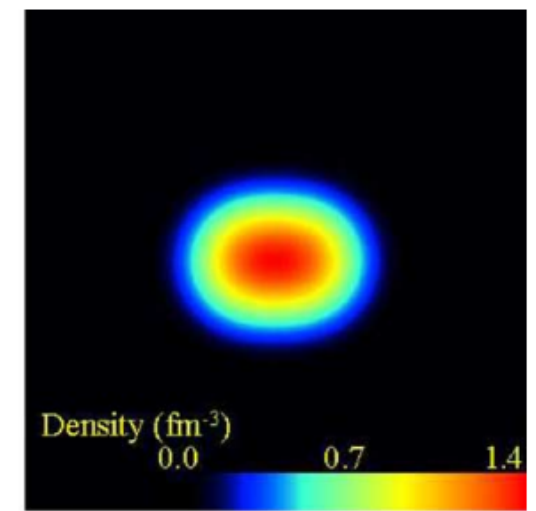
Can meson become a constituent of a nucleus?

how does an embedded meson change the surrounding nuclear system ?

One interesting example: Kaonic nuclei



(a) ${}^3\text{He}$



(b) ${}^3\text{He}K^-$

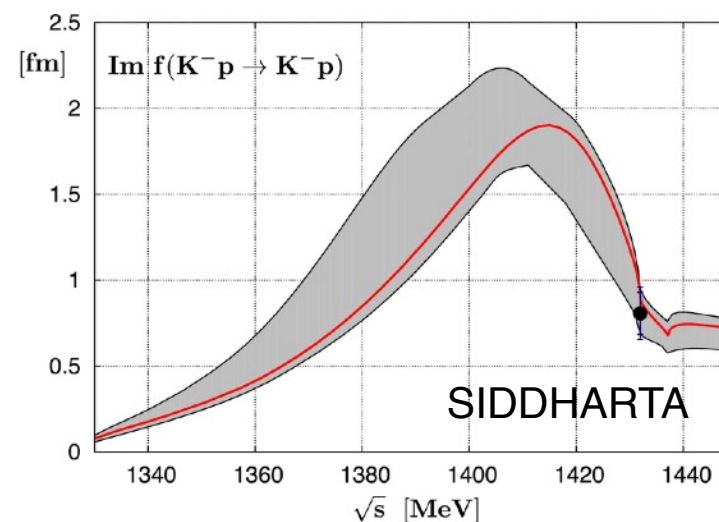
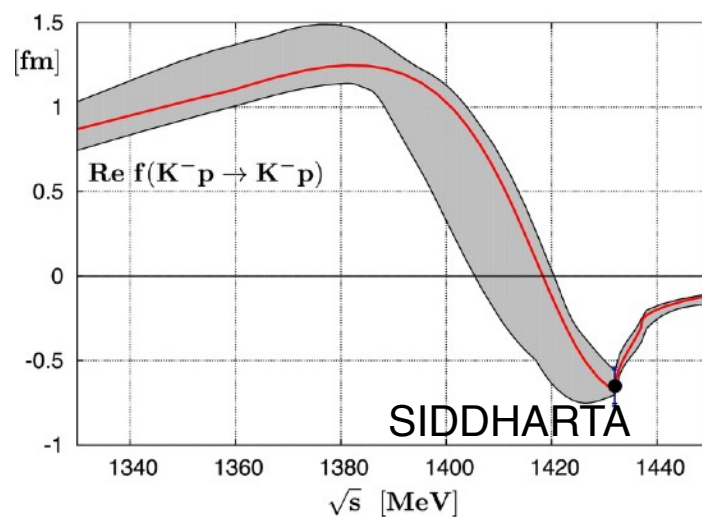
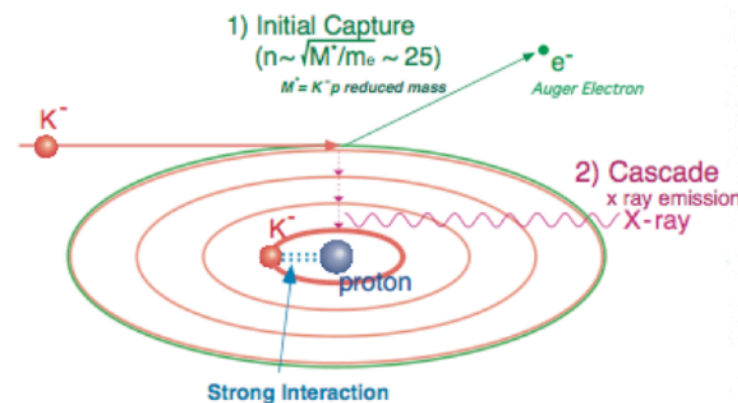
A. Doté et al. Physics Letters B 590 (2004) 51–56

A laboratory for studying how an anti-kaon modifies nuclear structure

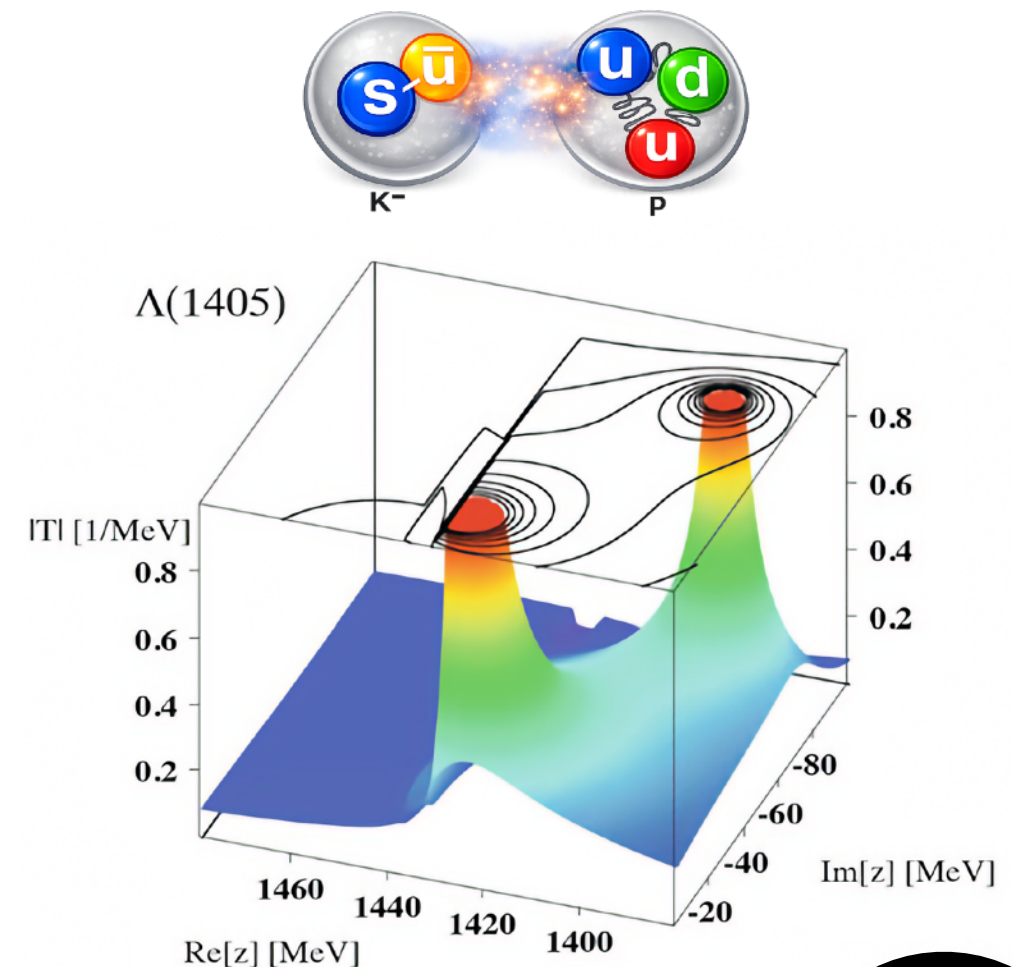
Strong $\bar{K}N$ Attraction

$\bar{K}N$ interaction is known to be strongly attractive ($l=0$ channel) from K-p atomic X-ray shift and low energy K- p scattering data

Kaonic Atom Formation



Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A **881**, 98 (2012)



The simplest Kaonic nucleus : $\bar{K}NN$

$$|\bar{K}[NN]_{I=0}\rangle_{I=1/2} = -\frac{1}{2} |[\bar{K}N]_{I=0}N\rangle_{I=1/2} + \frac{\sqrt{3}}{2} |[\bar{K}N]_{I=1}N\rangle_{I=1/2}$$

ground state

$$|\bar{K}[NN]_{I=1}\rangle_{I=1/2} = \frac{\sqrt{3}}{2} |[\bar{K}N]_{I=0}N\rangle_{I=1/2} + \frac{1}{2} |[\bar{K}N]_{I=1}N\rangle_{I=1/2}$$

$$|\bar{K}[NN]_{I=1}\rangle_{I=3/2} = |[\bar{K}N]_{I=1}N\rangle_{I=3/2}$$

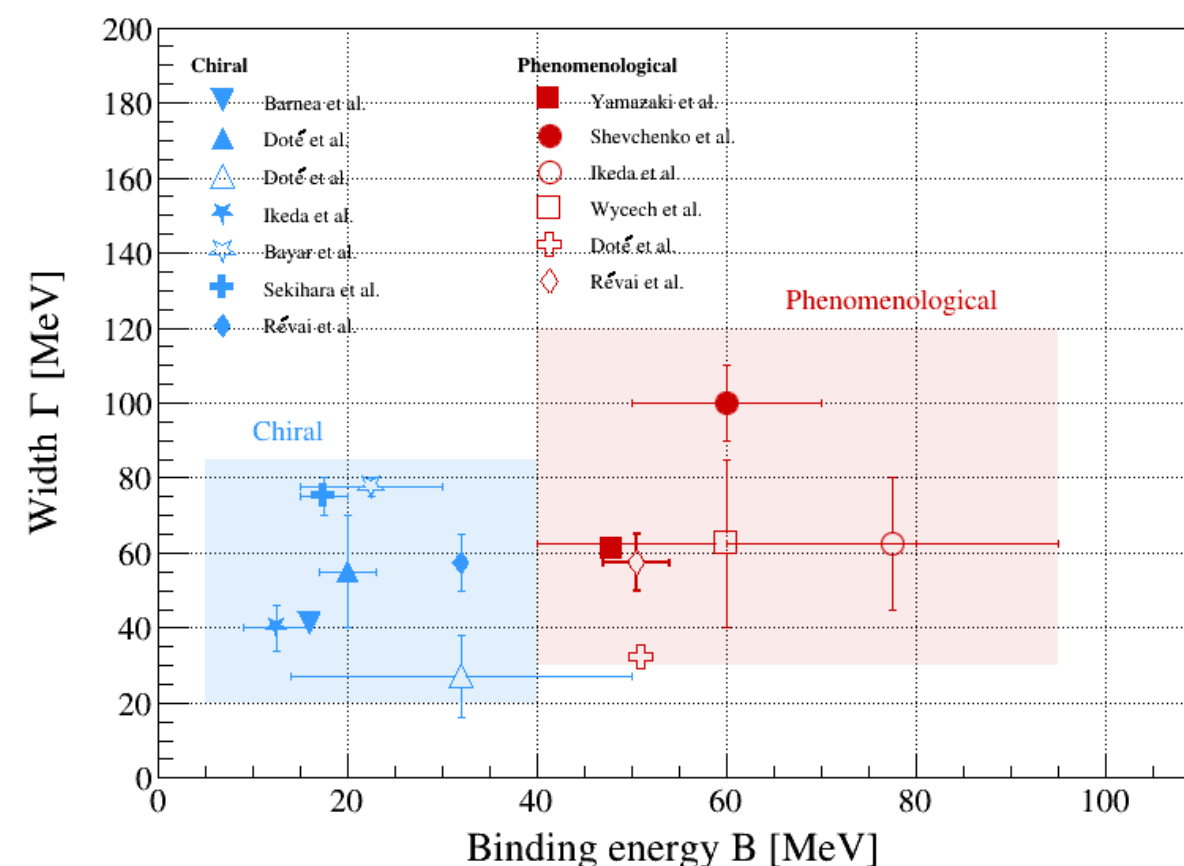
$$I_z = +1/2$$

$$K^-pp - \bar{K}^0pn$$

$$I_z = -1/2$$

$$K^-pn - \bar{K}^0nn$$

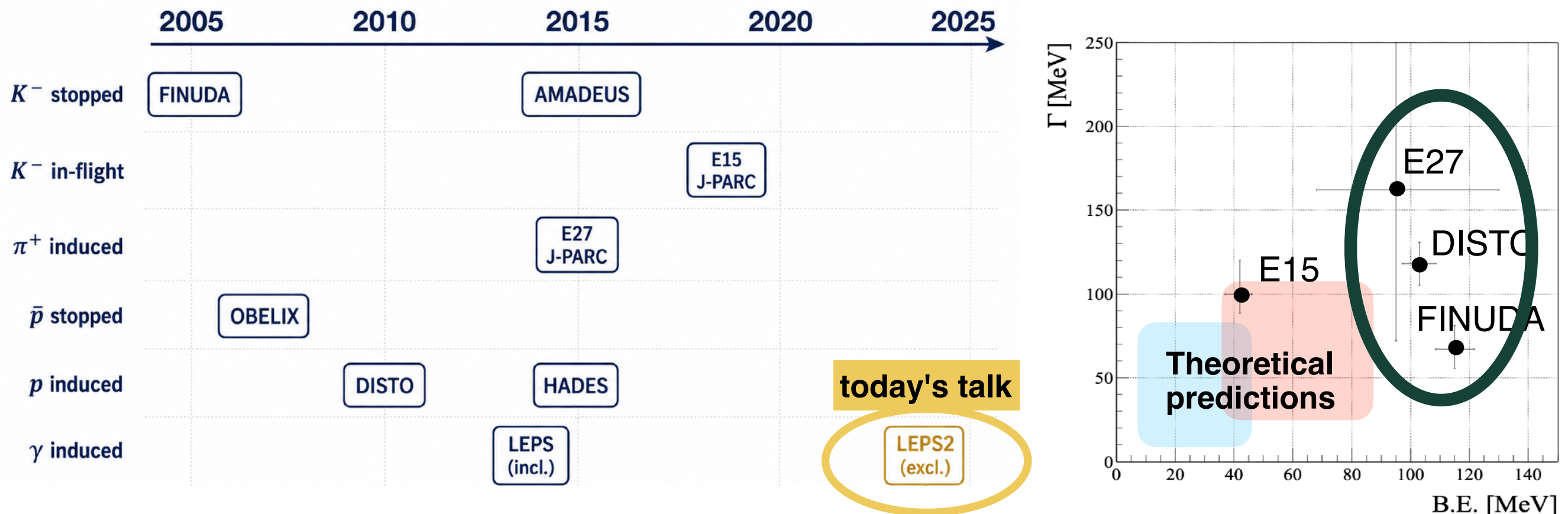
a $\bar{K}NN$ quasi bound state is predicted.



Chiral SU(3)-based, energy-dependent interactions → shallow binding

Phenomenological interactions → deeper binding

Experimental Status of $\bar{K}NN$ Searches



Some experiments reported peak structures below the K - pp threshold.

Interpretation as deeply bound state $\rightarrow$ still under debate

J-PARC E15 experiment (In flight Kaon) identified a clear signal component

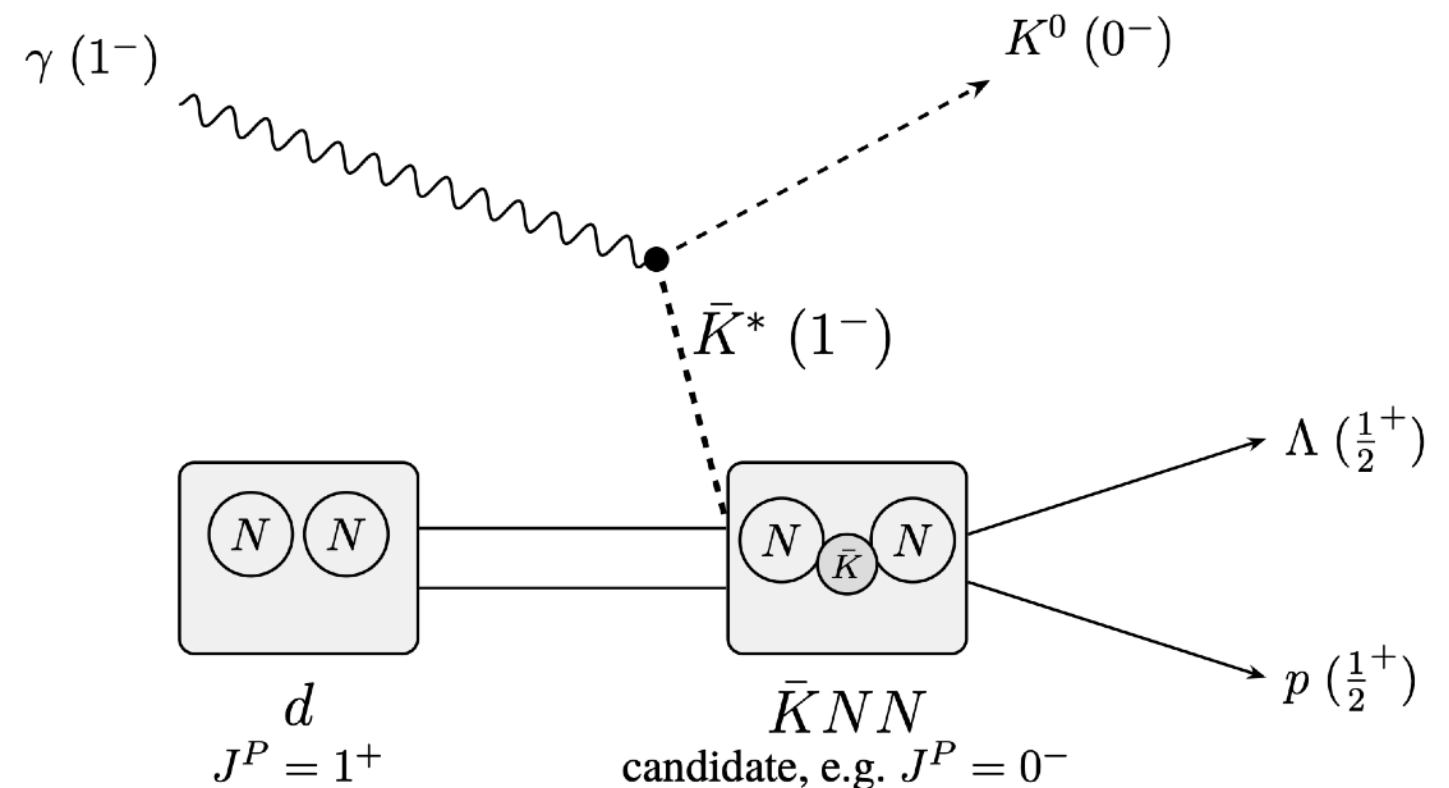
Why Photoproduction?

LEPS2@SPring-8

Exclusive measurement

$$\gamma d \rightarrow K^0 \Lambda p$$

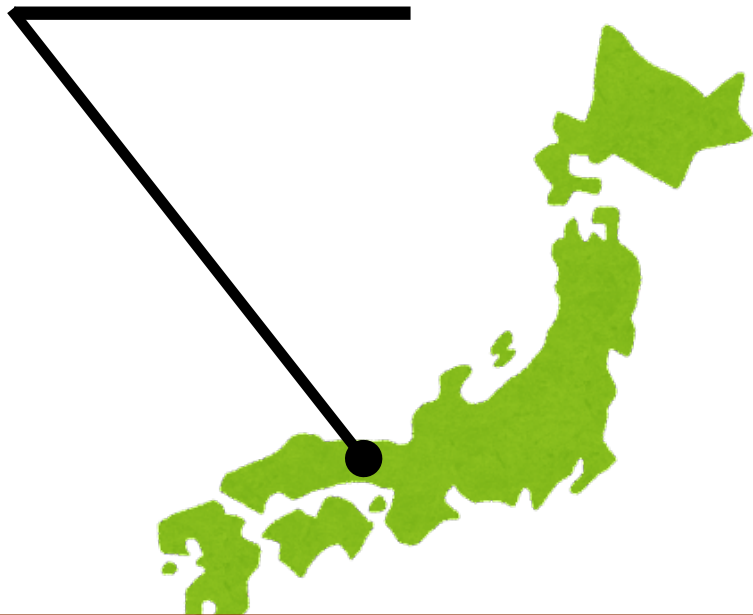
$$E_\gamma = 1.3 - 2.4 \text{ GeV}$$



- $\bar{K}NN$ is formed through an entrance channel completely different from kaon-induced reactions
- A simple initial state (Photon beam + deuteron target)
- Elementary background processes are constrained by existing measurements

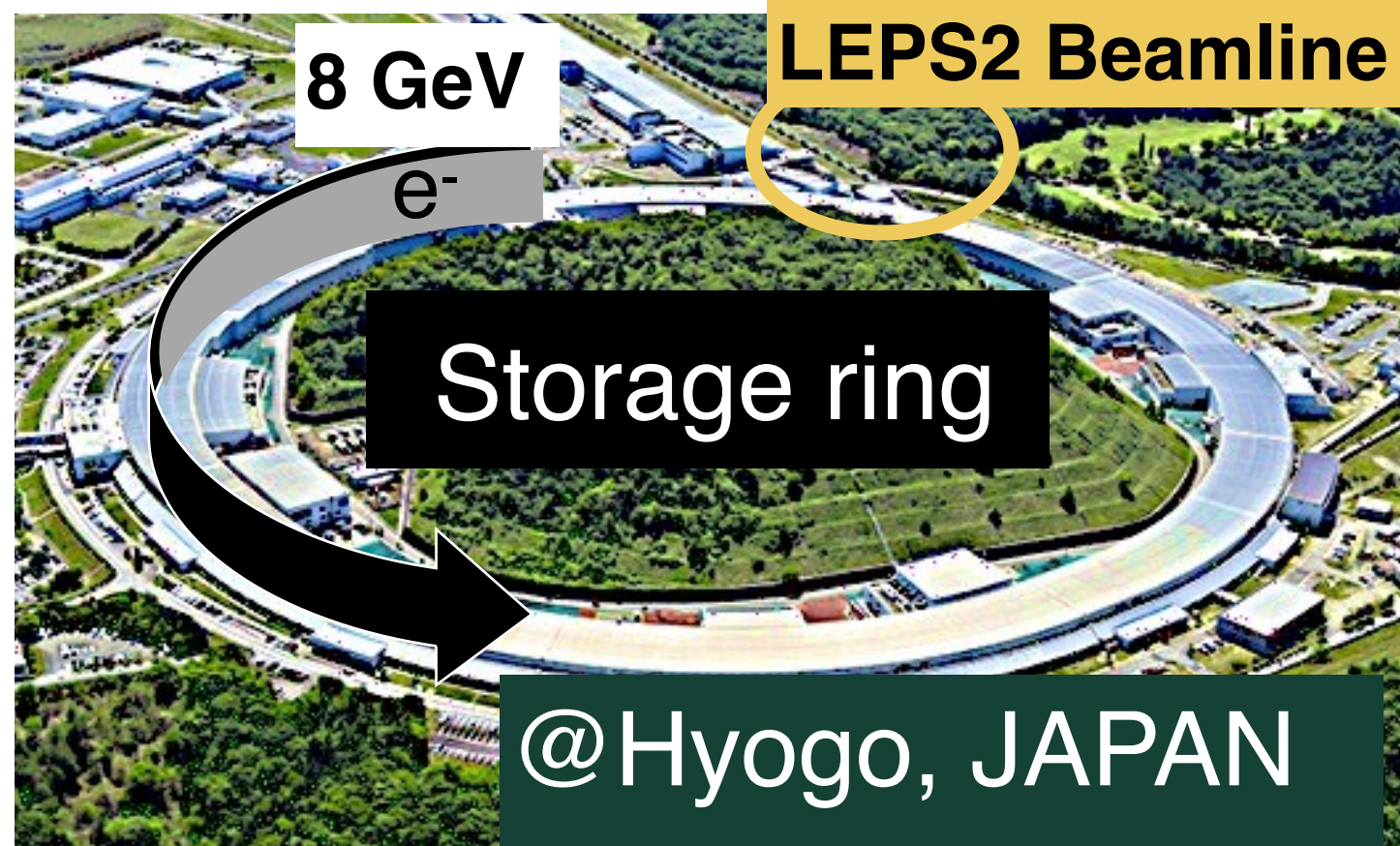
LEPS2 Solenoid Experiment at SPring-8

SPring-8

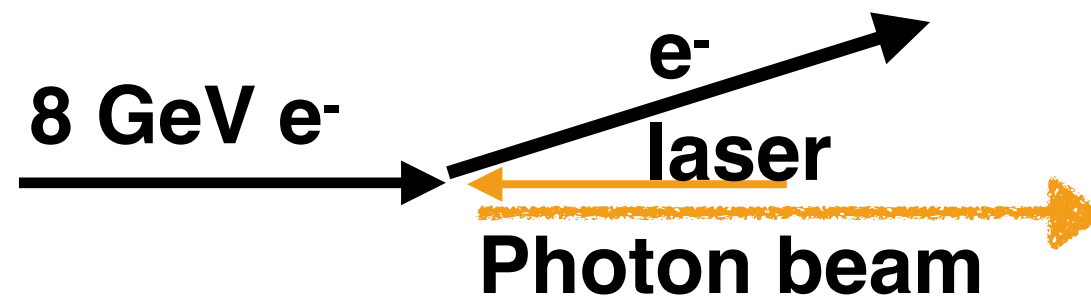


Photon Beam

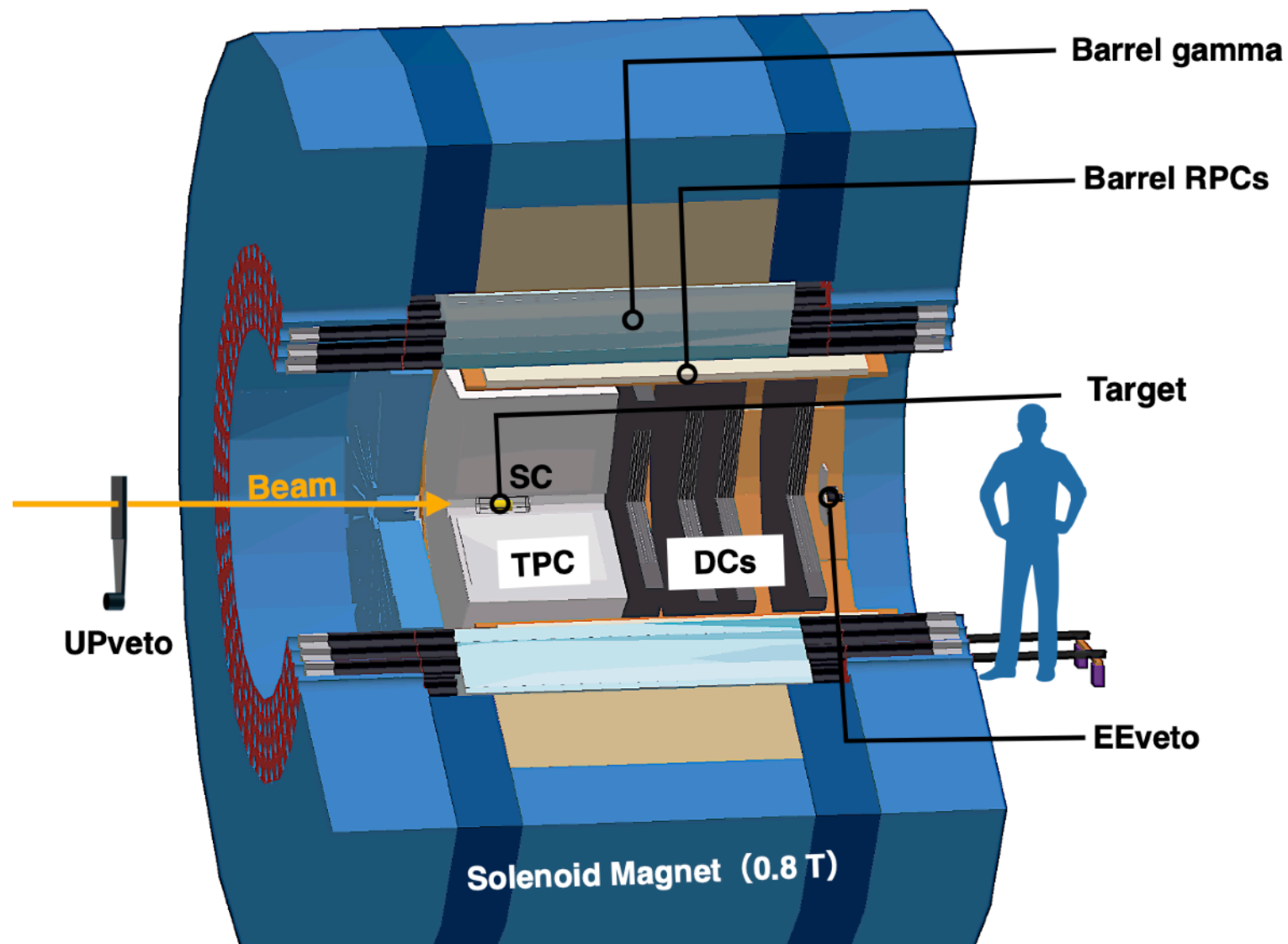
- Energy 1.3 – 2.4 GeV
- ΔE 12 MeV
- Intensity $\sim 1 \times 10^6$ cps



Detection of scattered electrons

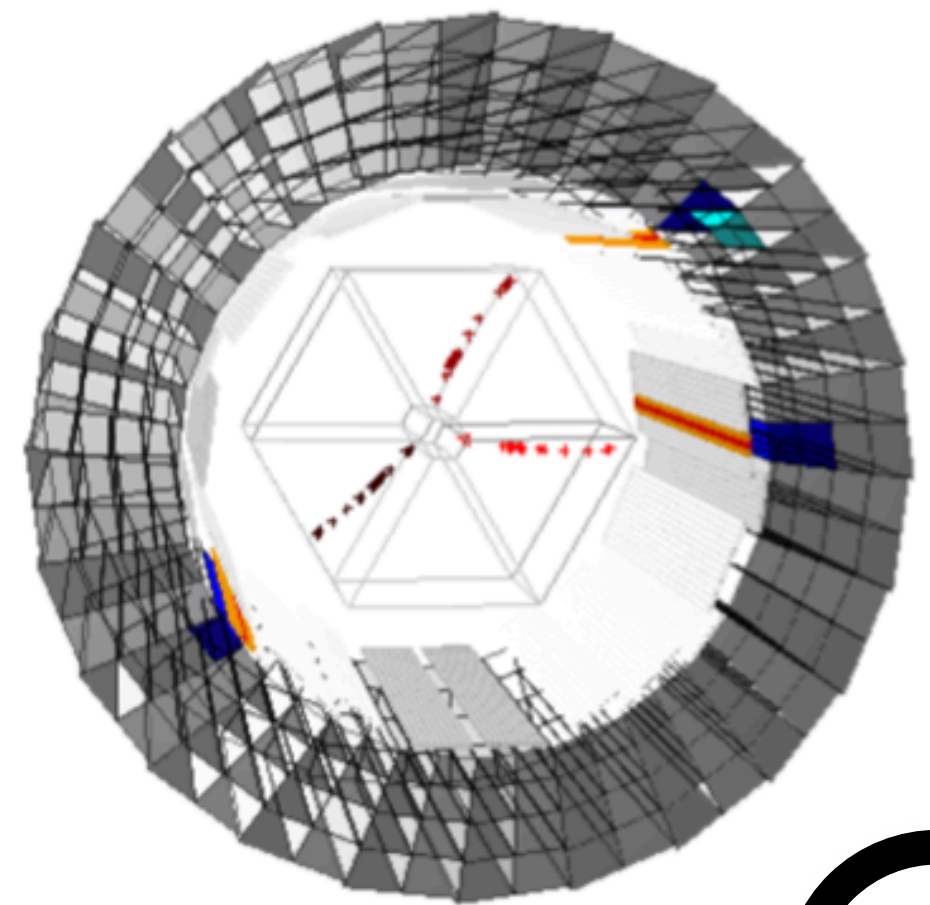


LEPS2 Solenoid Detectors



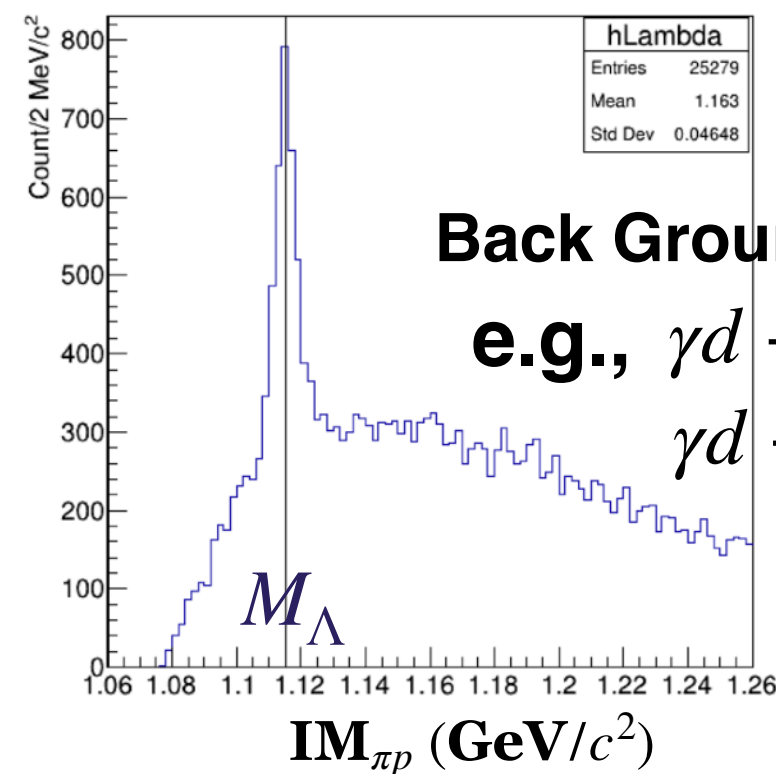
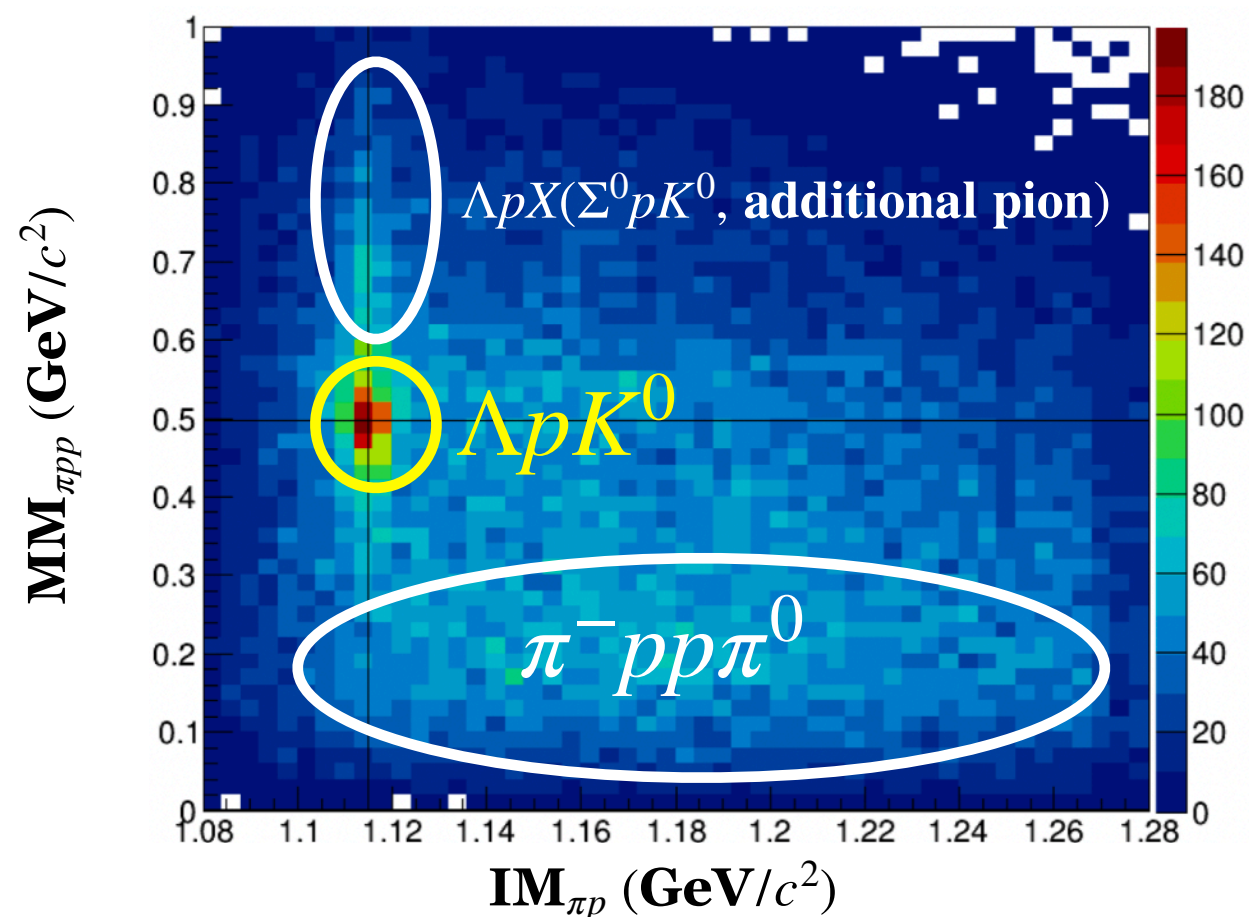
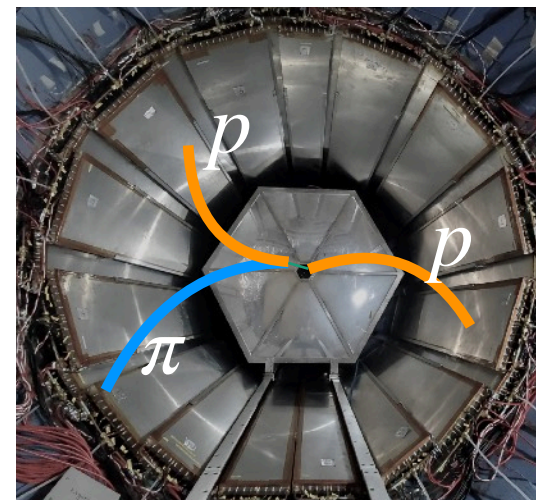
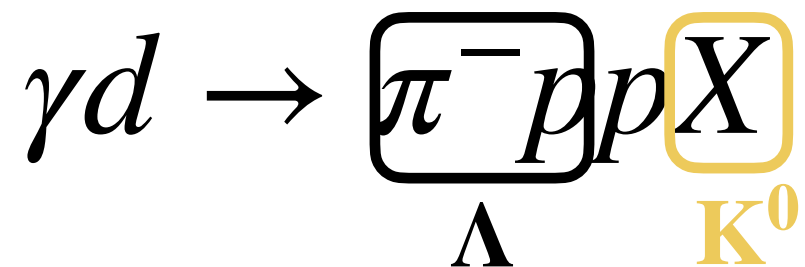
TPC & BRPC Acceptance
 $40^\circ - 110^\circ$ (Charged particles)

SC : Start Counter
 TPC : Time Projection Chamber
 RPC : Resistive Plate Chamber



Exclusive $K^0\Lambda p$ Event Selection

$(2p, \pi^-)$ in sideway region ($\theta_{Lab} > 40^\circ$)



Back Ground reaction

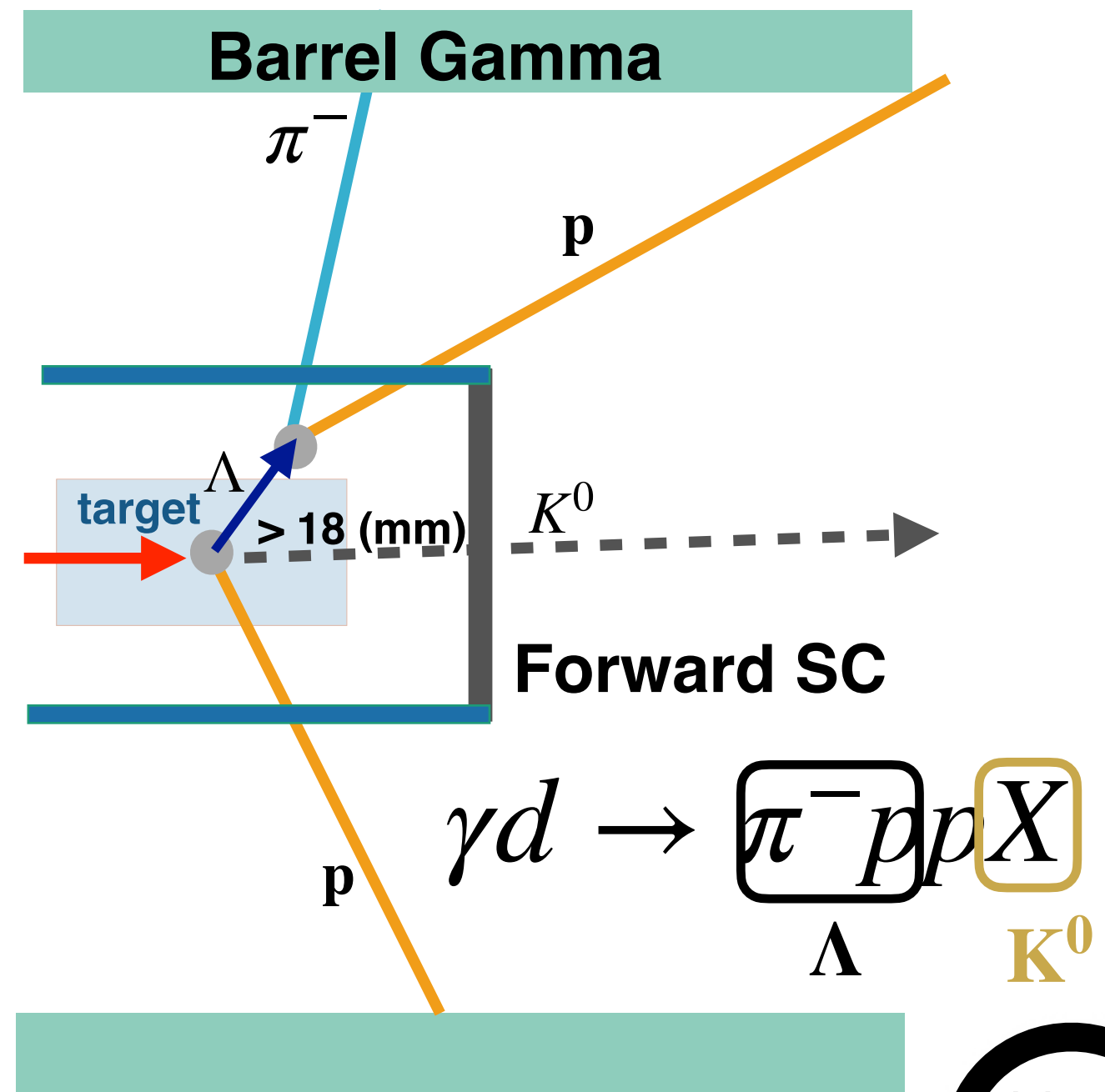
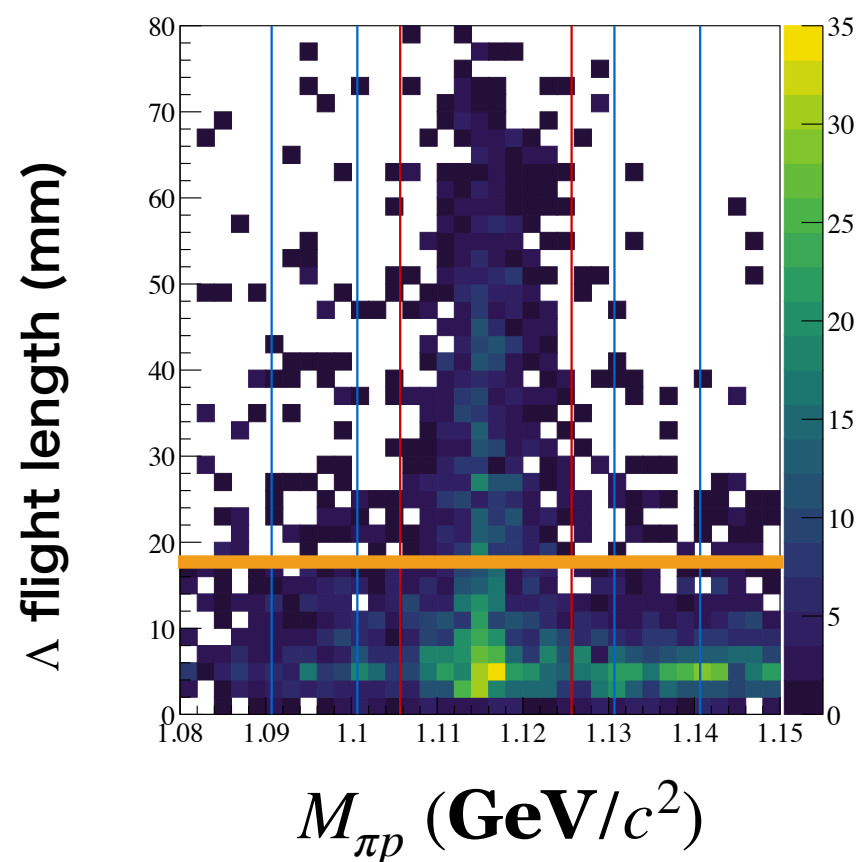
e.g., $\gamma d \rightarrow \pi^0 \pi^- p p$

$\gamma d \rightarrow 2\pi \pi^- p p \dots$

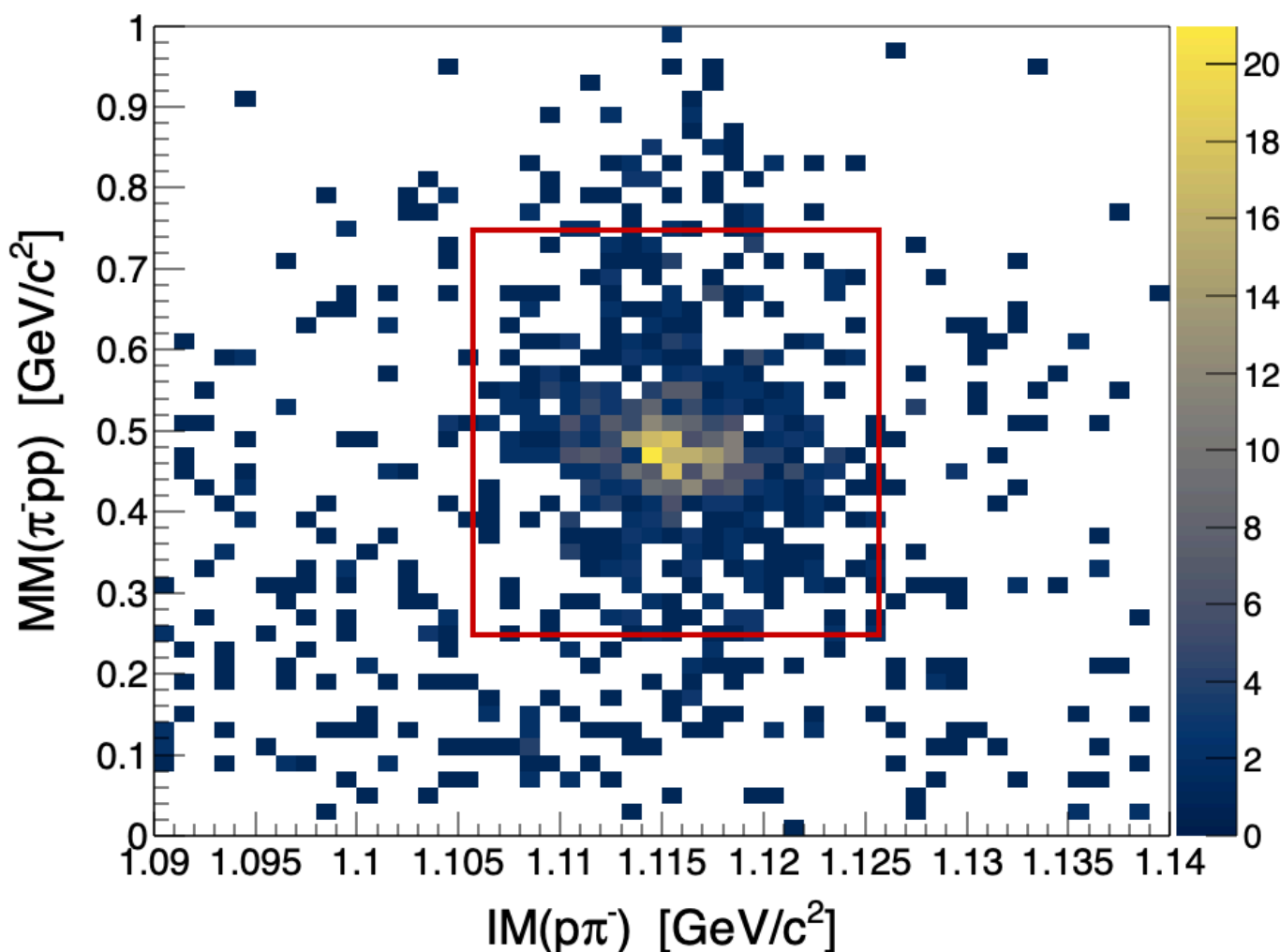
Exclusive $K^0\Lambda p$ Event Selection

To eliminate Background events

- Vertex information(Λ flight length > 18 [mm])
- Barrel Gamma veto
- Forward SC veto

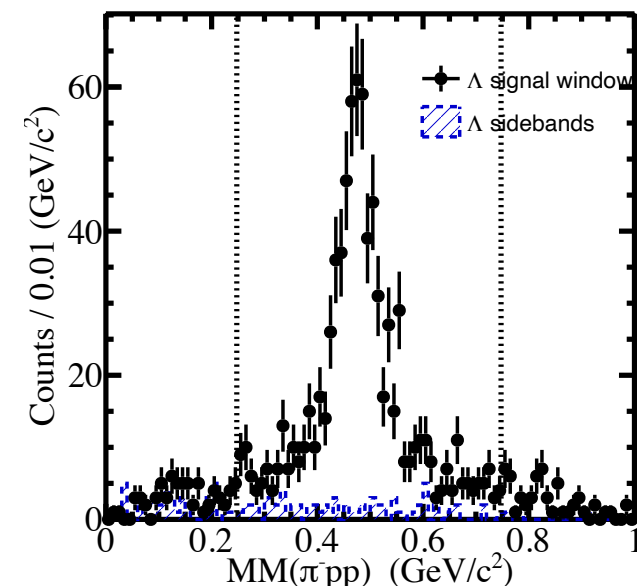
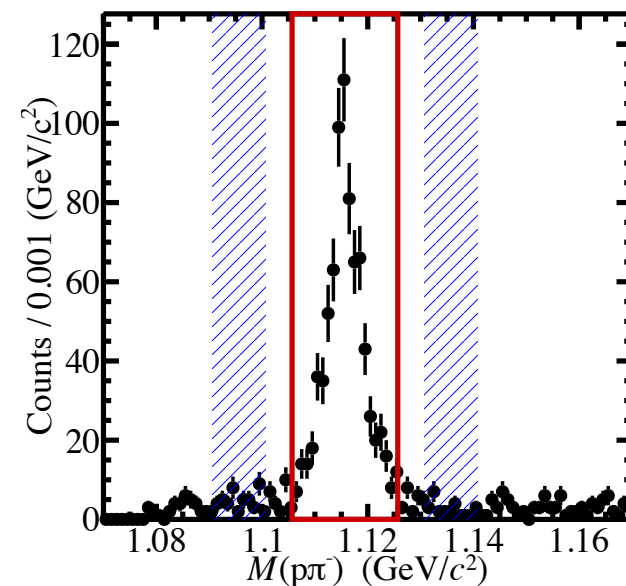


Exclusive $K^0\Lambda p$ Event Selection



Exclusive measurement

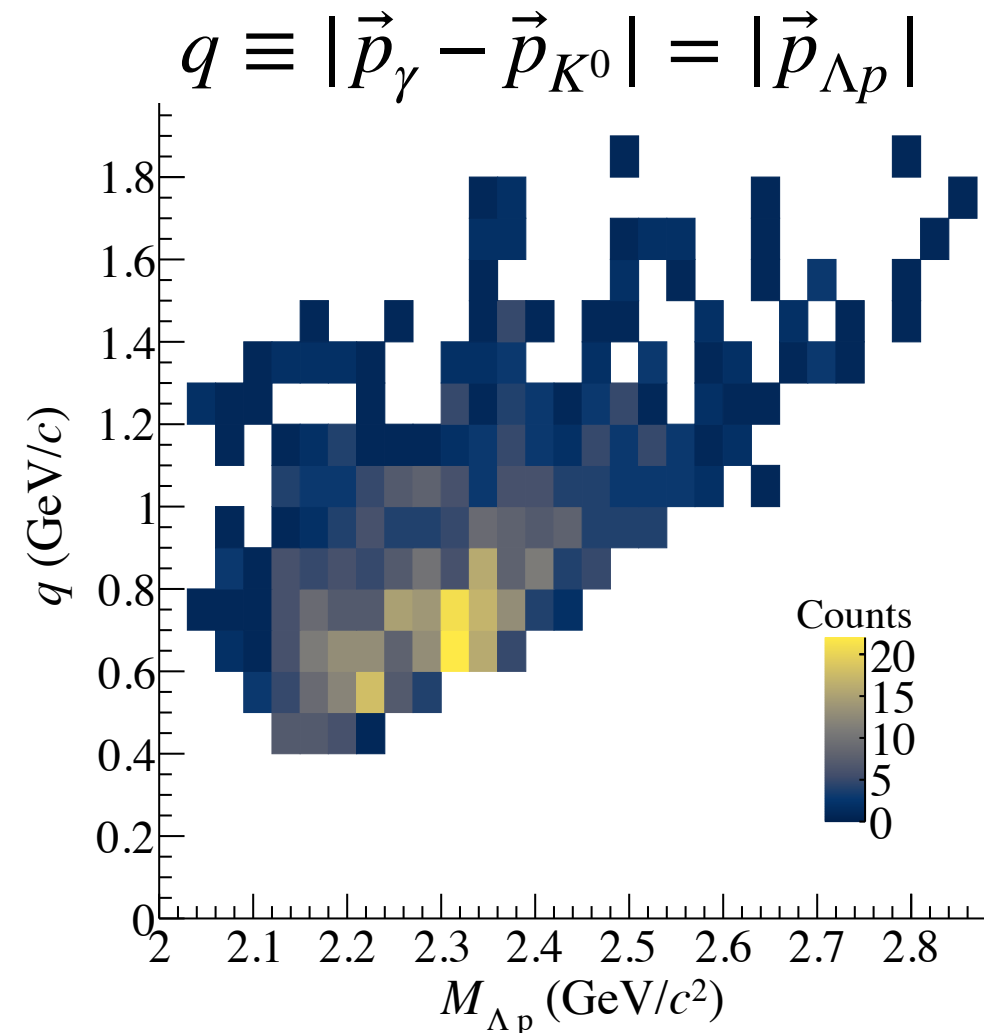
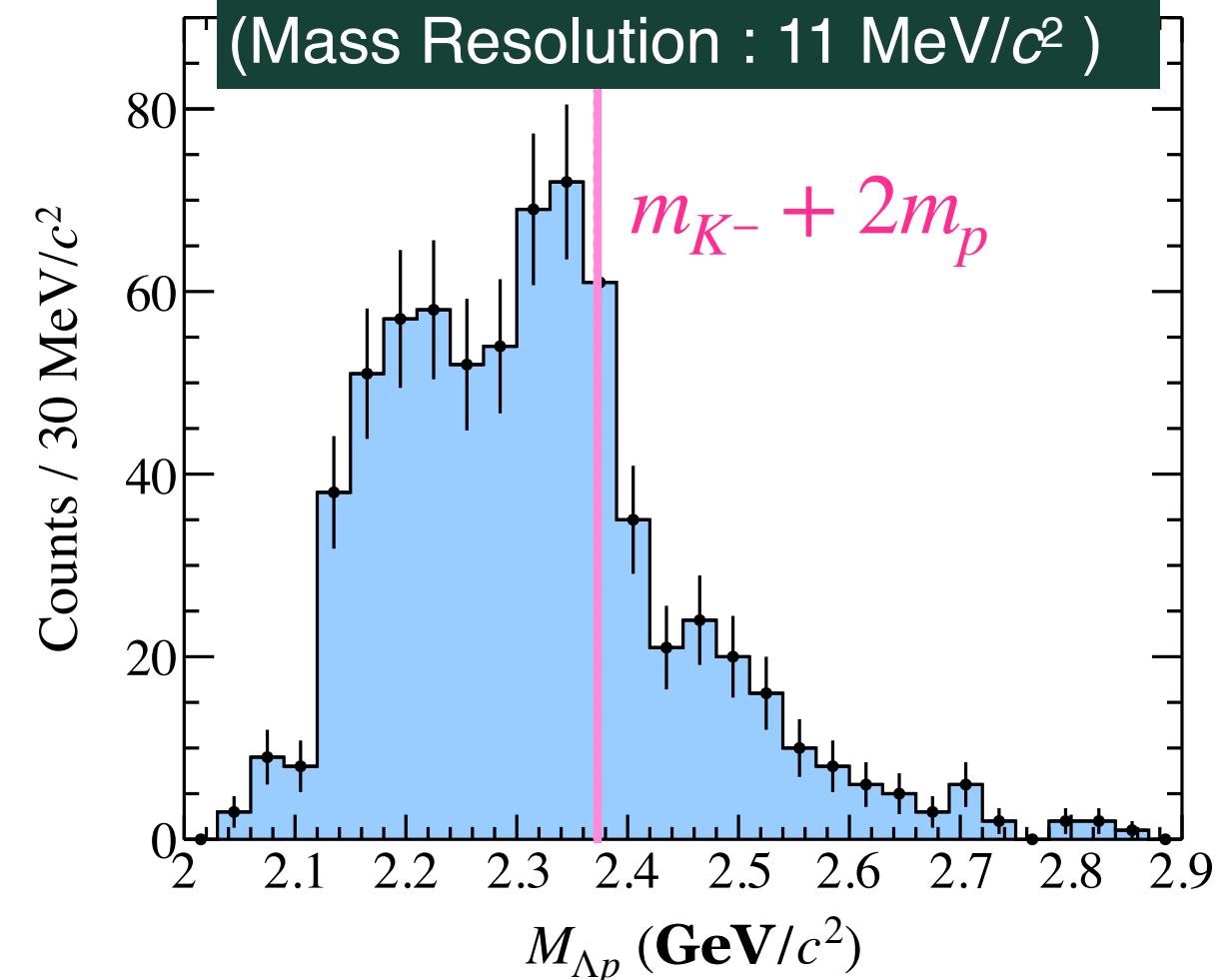
$$\gamma d \rightarrow \underbrace{\pi^- p p}_{\Lambda} \underbrace{K^0}_{K^0}$$



From $M_{\Lambda p}$ to the 2D ($M_{\Lambda p}$, q) Analysis

After Kinematical Fit

(Mass Resolution : 11 MeV/ c^2)



The key observable is not the 1D mass spectrum alone.

We analyse the event distribution in the ($M_{\Lambda p}$, q) plane.

Background Components in the 2D Fit

- Phase Space (PS)

Non-resonant $\gamma d \rightarrow K^0 \Lambda p$

- Non-Strangeness (NS)

Based on PS, constrained directly from Λ sideband

- Quasi-Free (QF)

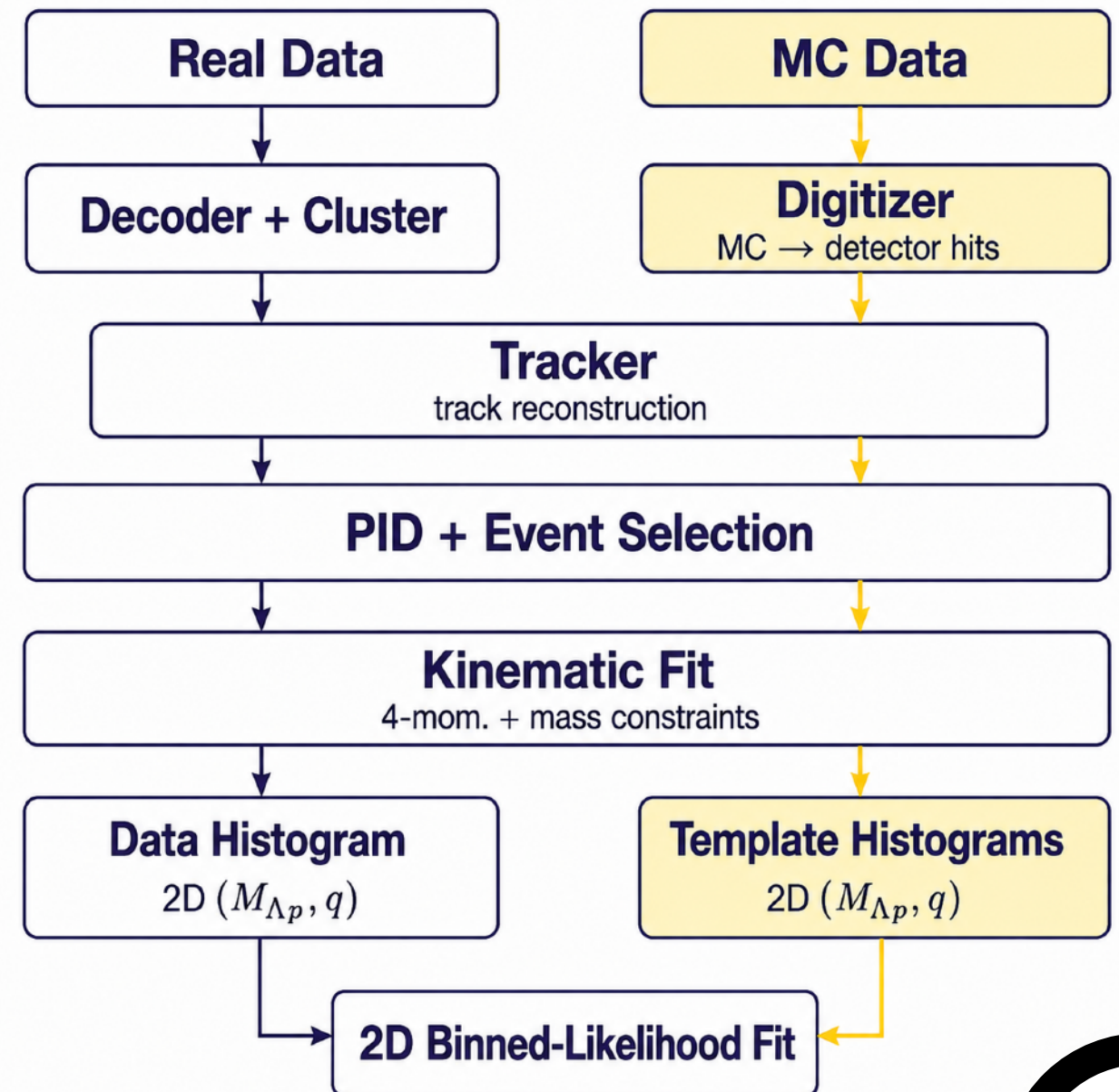
$\gamma n \rightarrow K^0 \Lambda$, proton spectator,
(constrained by CLAS data)

N. Compton et al., PRC 96, 065201 (2017)

- Two-Step (TS)

$\gamma p \rightarrow K^0 \Sigma^+, \Sigma^+ n \rightarrow \Lambda p$,
(constrained by SAPHIR Data)

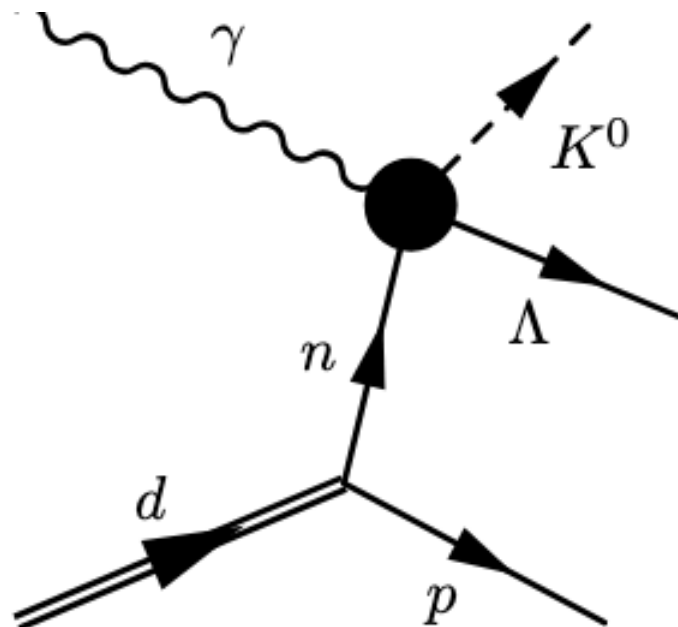
R. Lawall et al., EPJA 24, 275 (2005)



Main BackGround Reaction

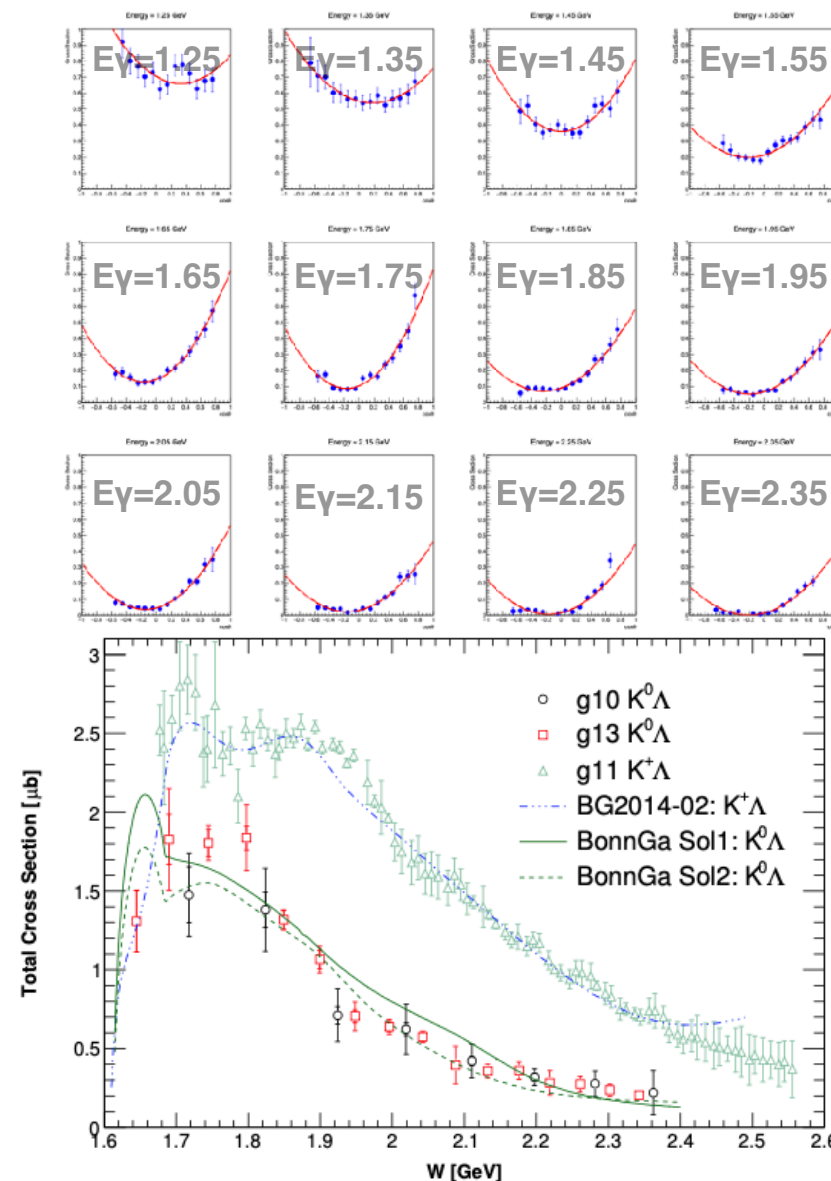
Quasi-Free (QF)

$\gamma n \rightarrow K^0 \Lambda$, proton spectator

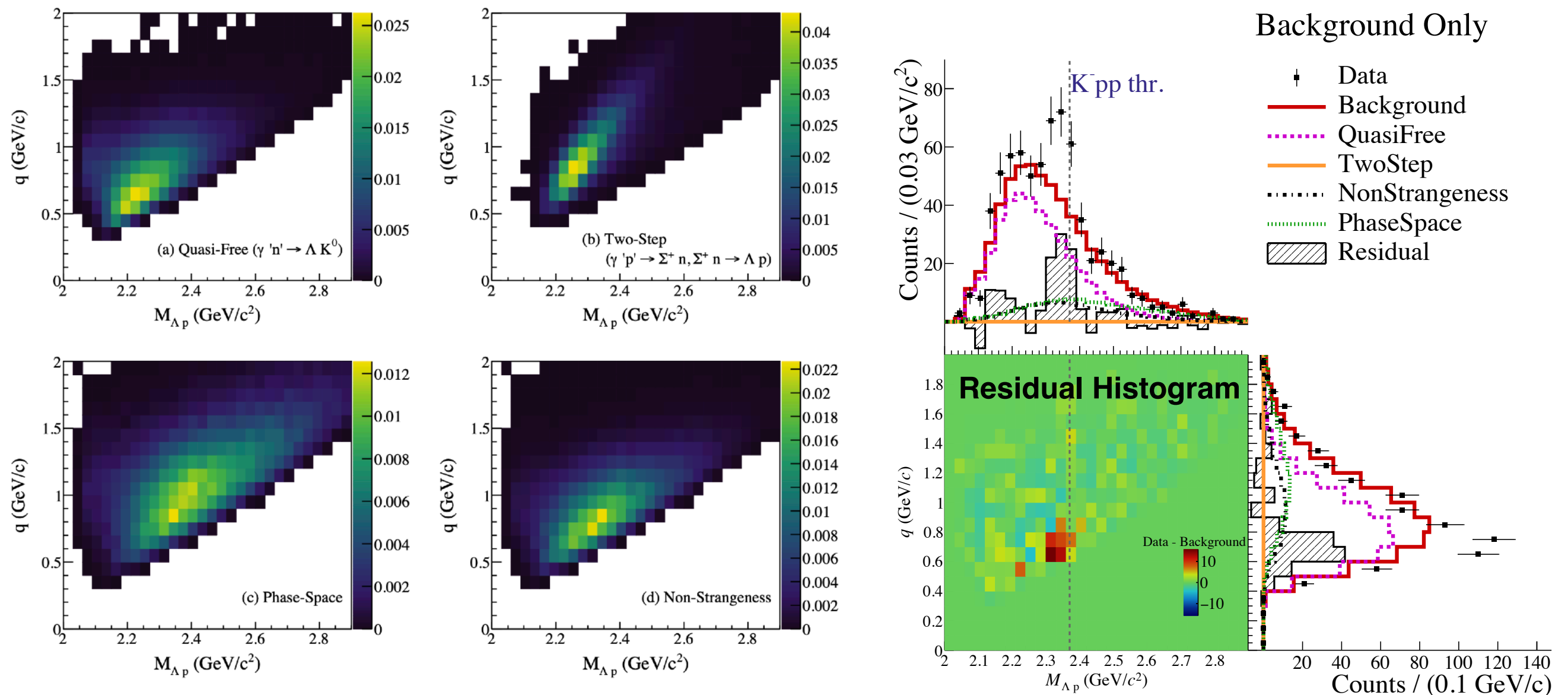


- Angular and W dependence from CLAS data
- Fermi momentum from Argonne V18 model

N. Compton et al., PRC 96, 065201 (2017)



Background-only hypothesis



A Localized Low- q Component Is Required

Signal Model on the ($M_{\Lambda p}$, q) plane

phase space
acceptance

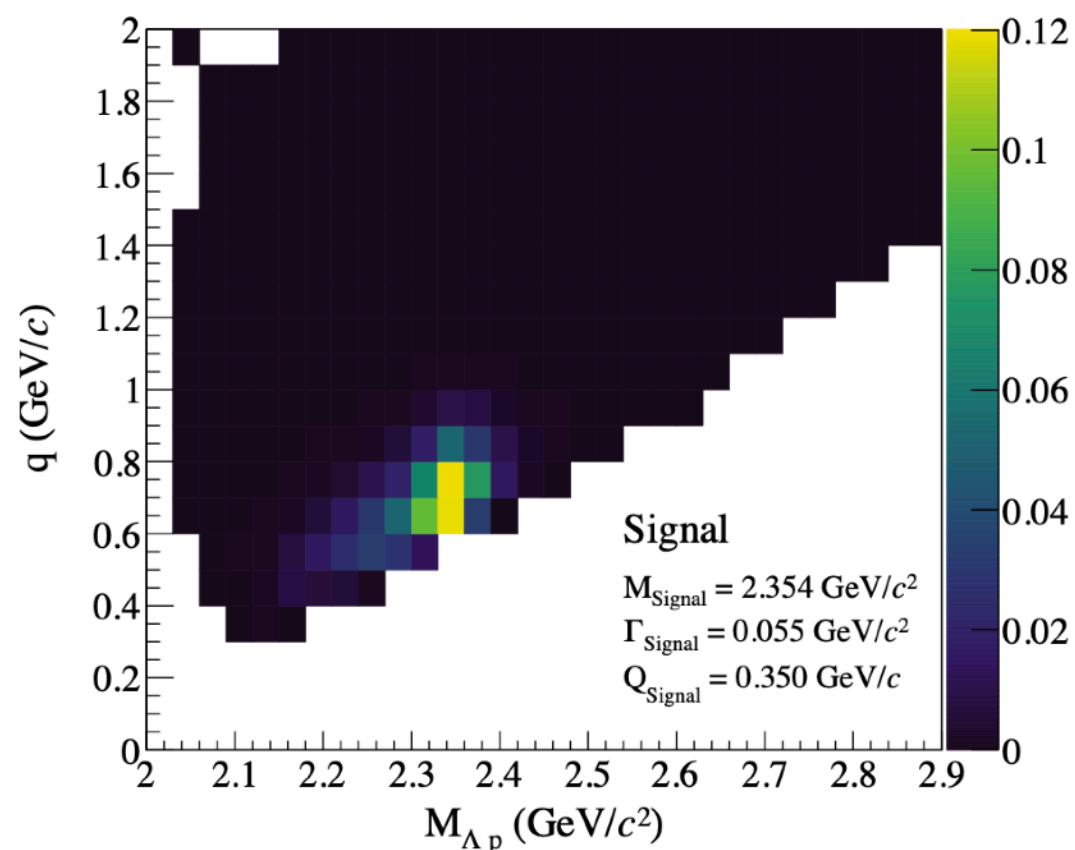
Resonance line shape

Form factor

$$T_{sig}(M_{\Lambda p}, q) = C_{sig} \cdot T_{PS} \cdot V(M_{\Lambda p}; \boxed{M, \Gamma}, \sigma_M) \exp(- (q^2 / \boxed{Q^2}))$$

Fit parameters

Template Histograms



Mass shape

Breit-Wigner $\otimes$ detector resolution ($\sigma_M = 11 \text{ MeV}/c^2$)

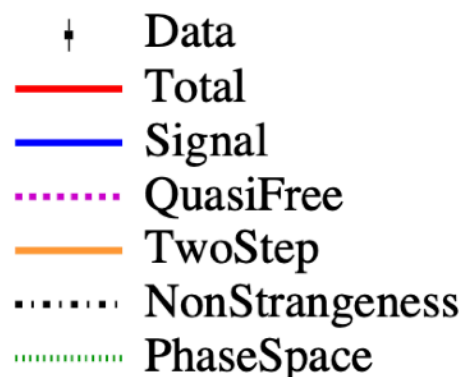
Momentum-transfer dependence

phenomenological form factor favoring low- q

Signal + Background Fit

Signal Included

Fit Parameters

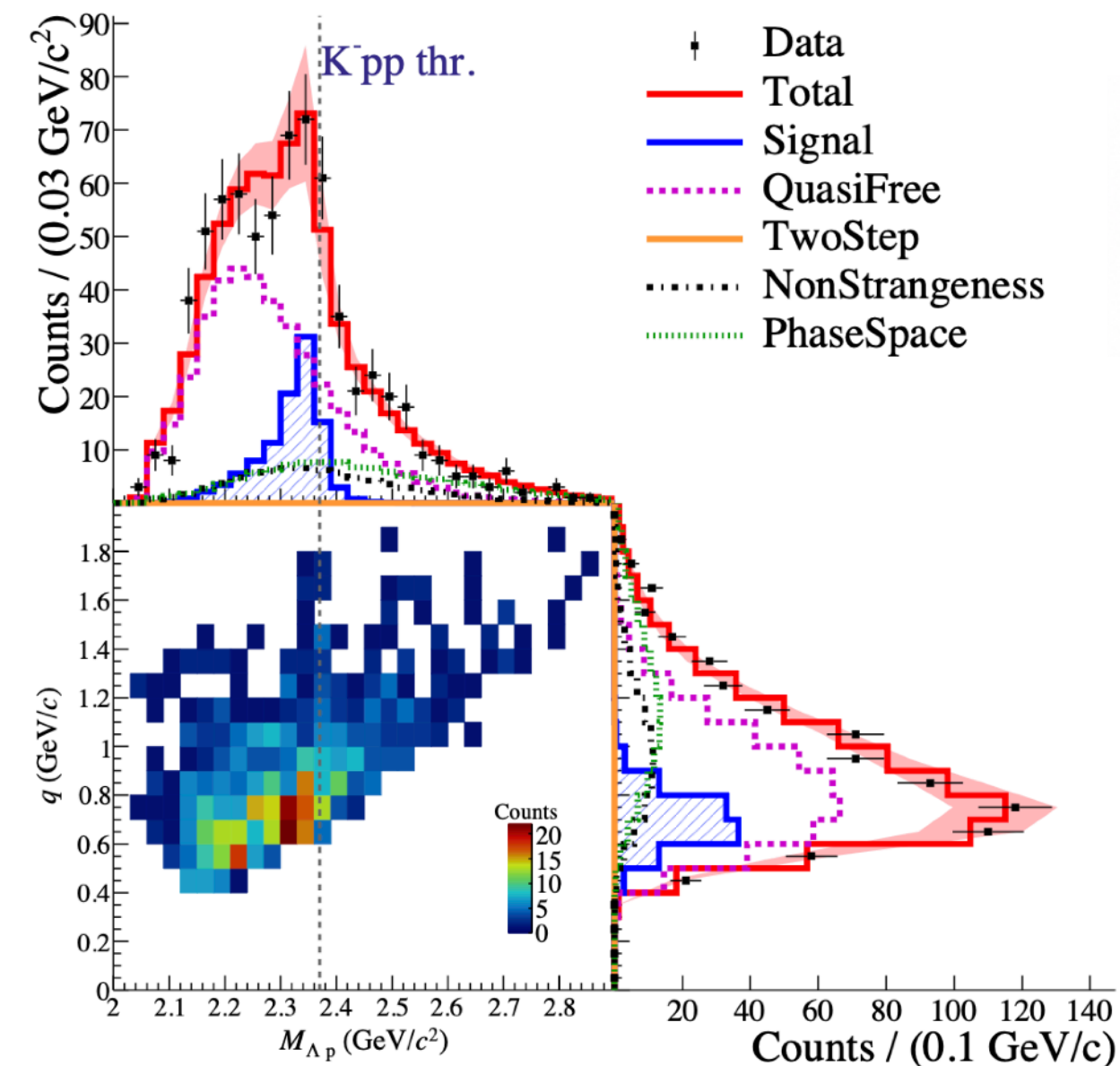


M [MeV/ c^2]	Γ [MeV/ c^2]	Q [MeV/ c]
2354 ± 11 (stat.)	55 ± 23 (stat.)	350 ± 41 (stat.)

$$2(NLL_{bg+sig} - NLL_{bg}) = 64.9$$

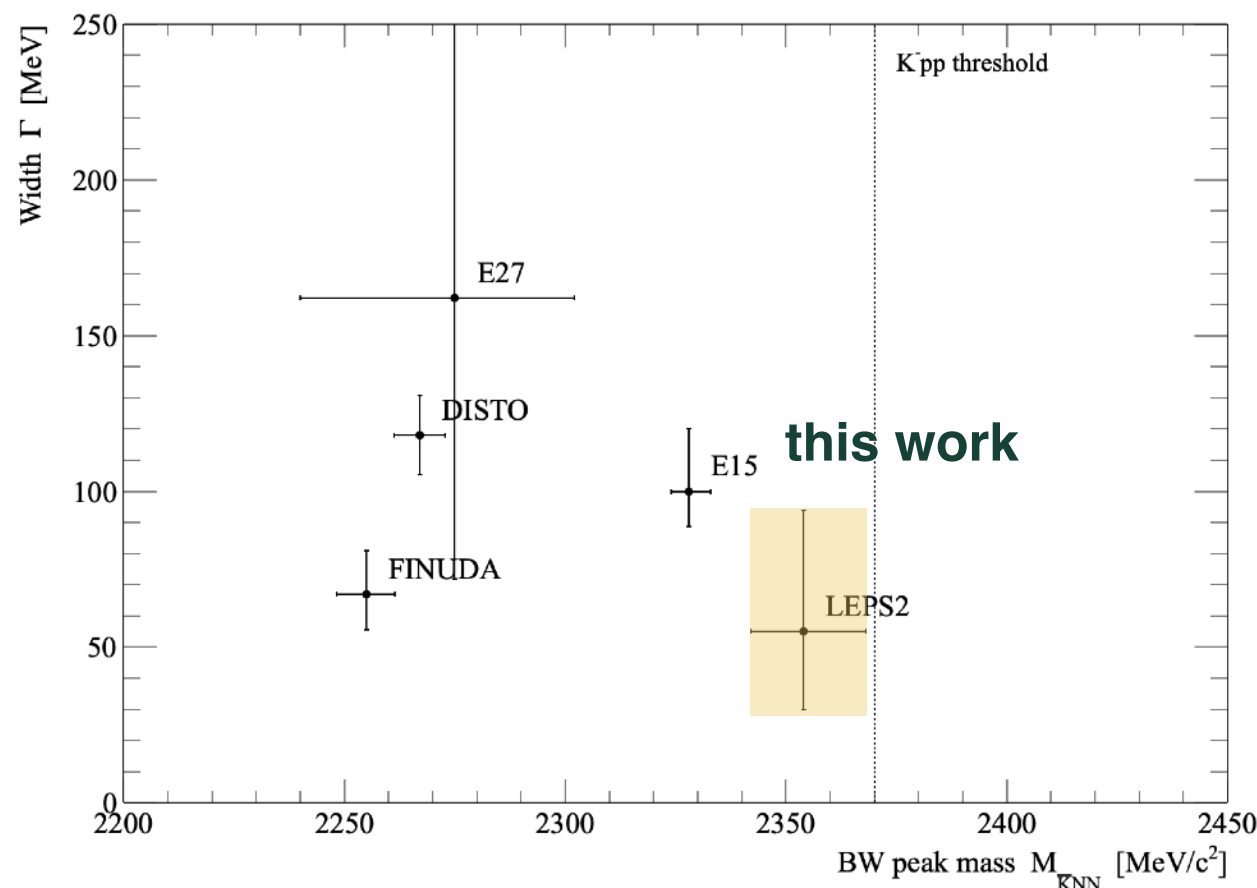
significance $\sim 7.3\sigma$

Signal Yield : 104 events (~ 5 nb)

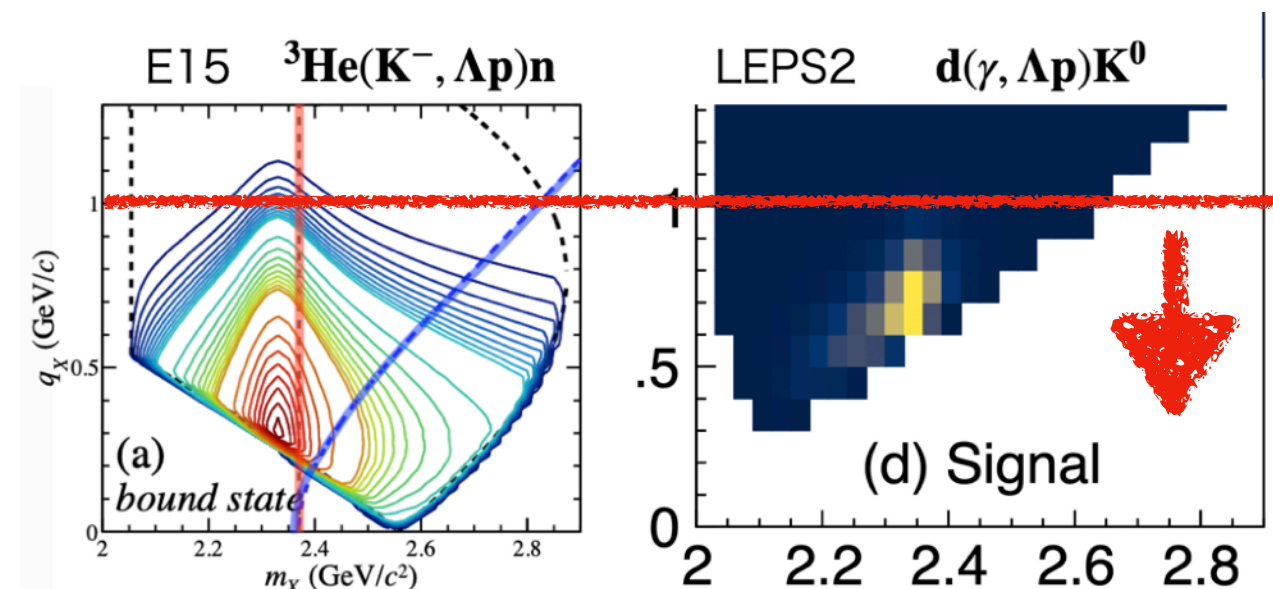


Comparison with Previous $\bar{K}^{*}NN$ Measurements

Experiment	M [MeV/ c^2]	Γ [MeV/ c^2]	Q [MeV/ c]
LEPS2	2354 ± 11 (stat.) $^{+9}_{-5}$ (syst.)	55 ± 23 (stat.) $^{+31}_{-9}$ (syst.)	350 ± 41 (stat.) $^{+35}_{-10}$ (syst.)
J-PARC E15	2328 ± 3 (stat.) $^{+4}_{-3}$ (syst.)	100 ± 7 (stat.) $^{+19}_{-9}$ (syst.)	383 ± 11 (stat.) $^{+4}_{-1}$ (syst.)



Extracted signal component



q dependence is consistent with E15

$$q = |p_{\text{Beam}} - p_{\text{Recoil}}| < 1 \text{ GeV}/c$$

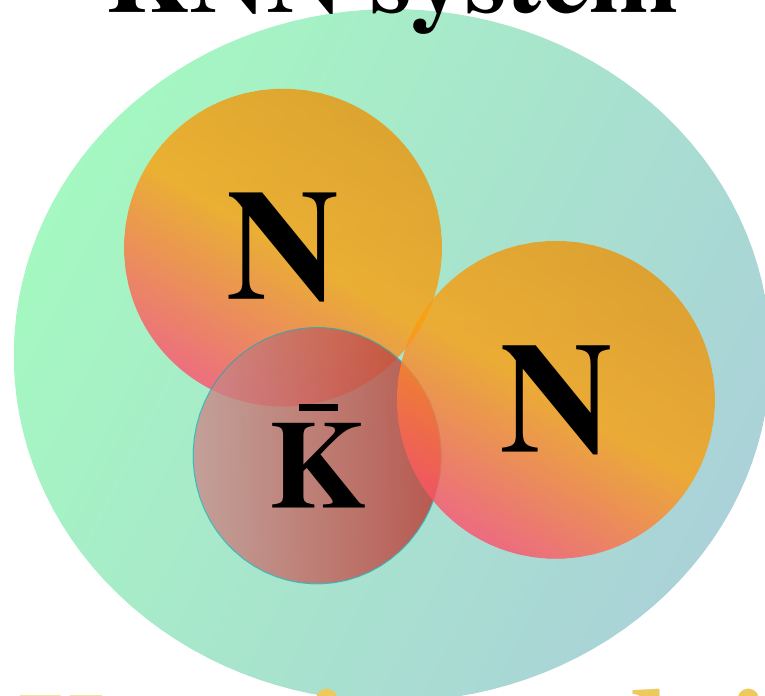
Kaonic Baryonium

- **Low q condition seems to be important for formation.**

→ Based on this idea, I consider a different few-body system.

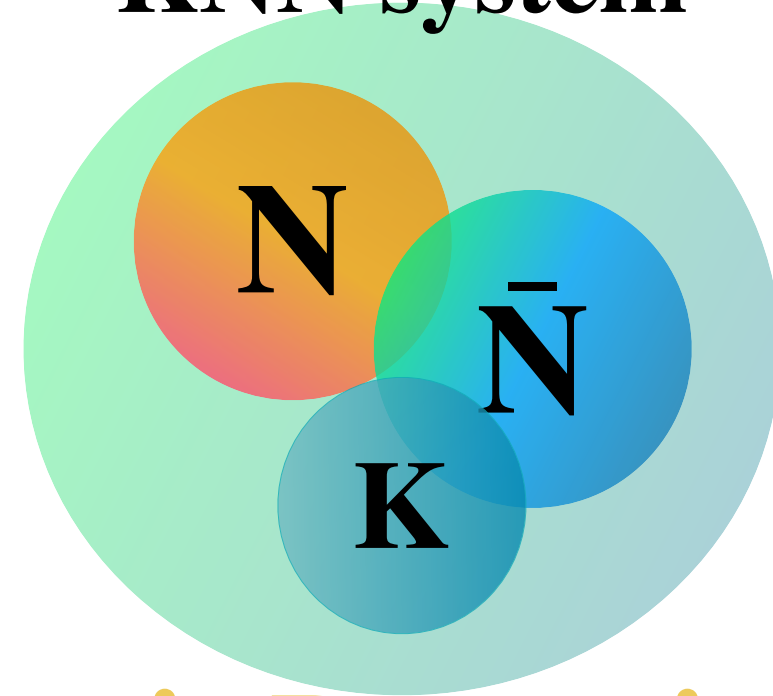
New Idea

$\bar{K}NN$ system



Kaonic nuclei

$KN\bar{N}$ system



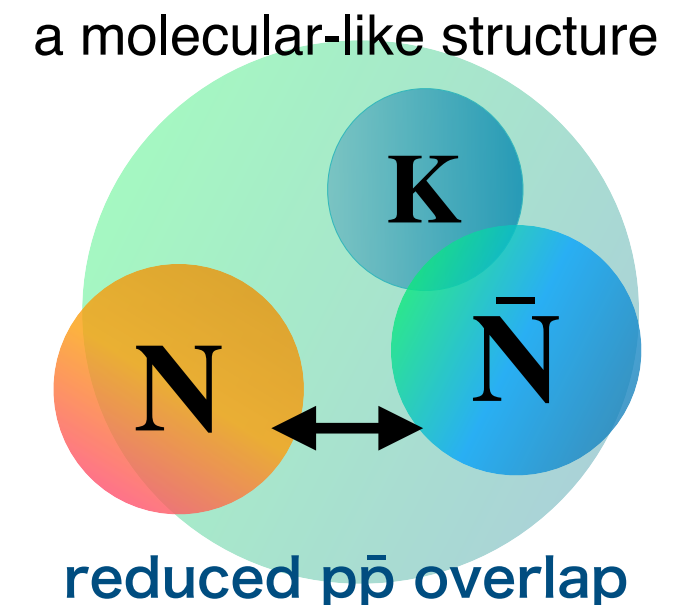
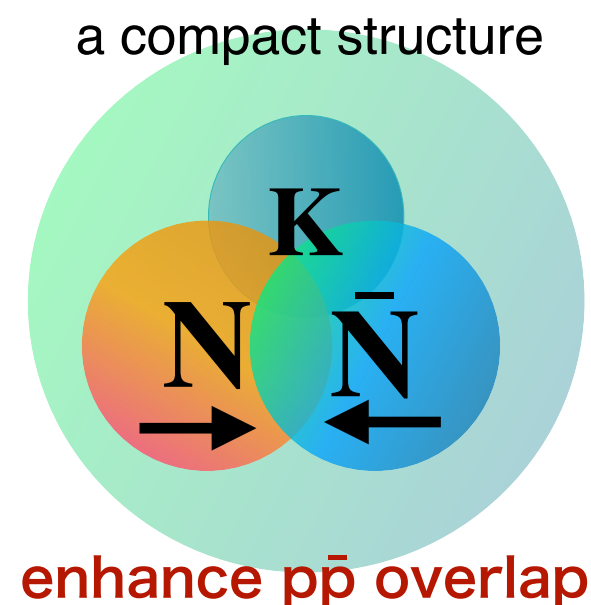
Kaonic Baryonium

Kaonic Baryonium

Role of the K meson in the nuclear system

Two Scenarios

Pairwise interaction	$KN\bar{N}$ system
Attractive pair I	$K\bar{N} \rightarrow \bar{\Lambda}(1405)$
Weak Repulsive pair	KN
Attractive pair II	$N\bar{N} \rightarrow \text{Baryonium?}$

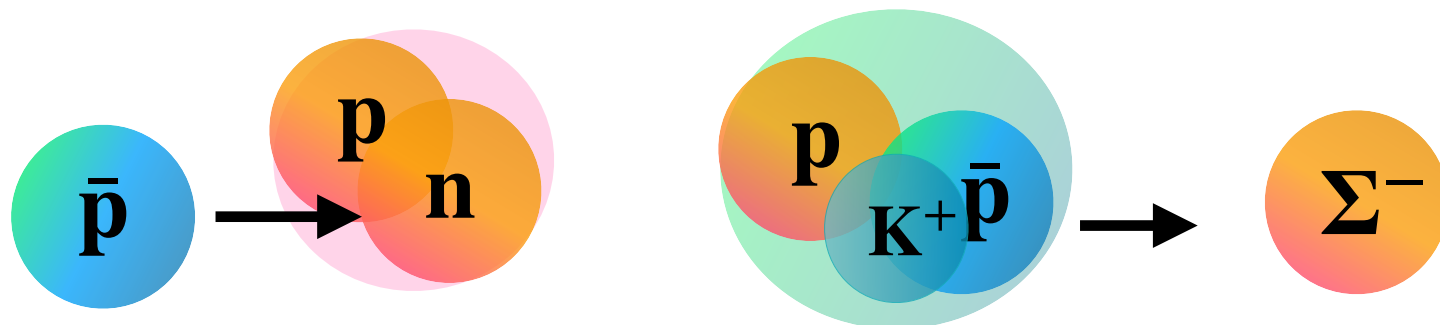
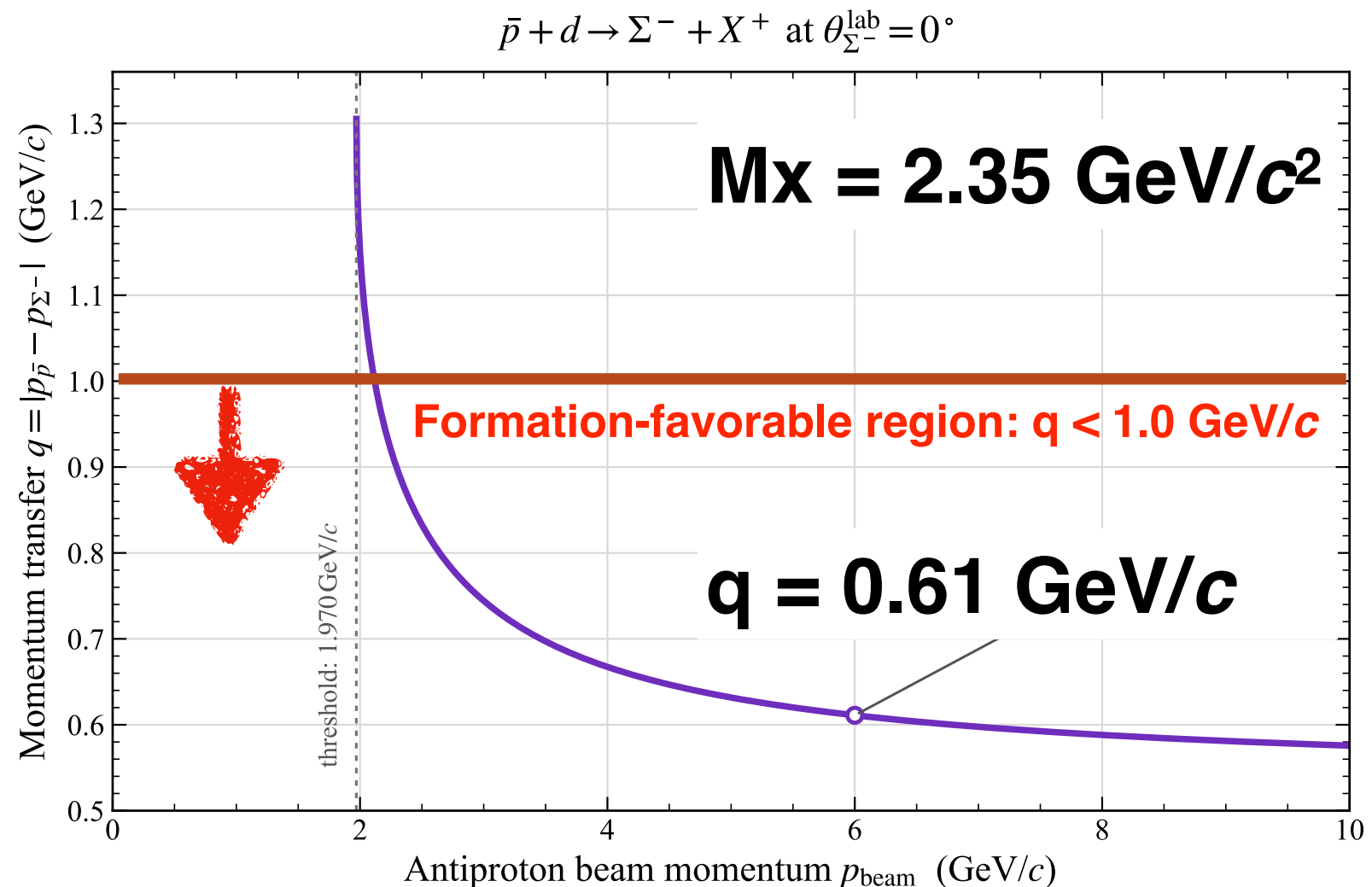


Probe how a kaon behaves in a nucleon system and modifies its surroundings

A Reaction for $K^+p\bar{p}$ Formation

$$\bar{p}d \rightarrow \Sigma^-(K^+p\bar{p})_{B.S.}$$

Antiproton beam with 4-10 GeV/c
will be available @ J-PARC K10



Summary

$\bar{K}NN$ study

- Strong attractive $\bar{K}N$ interaction motivates the search for the $\bar{K}NN$ quasi-bound state
- At LEPS2, the $\gamma d \rightarrow K^0 \Lambda p$ reaction was measured exclusively and analyzed in the $(M_{\Lambda p}, q)$
- A localized low- q , subthreshold component is favored beyond the constrained backgrounds.
- The observed component is consistent with a $\bar{K}NN$ quasi-bound-state candidate.

Future Experiment (Kaonic Baryonium)

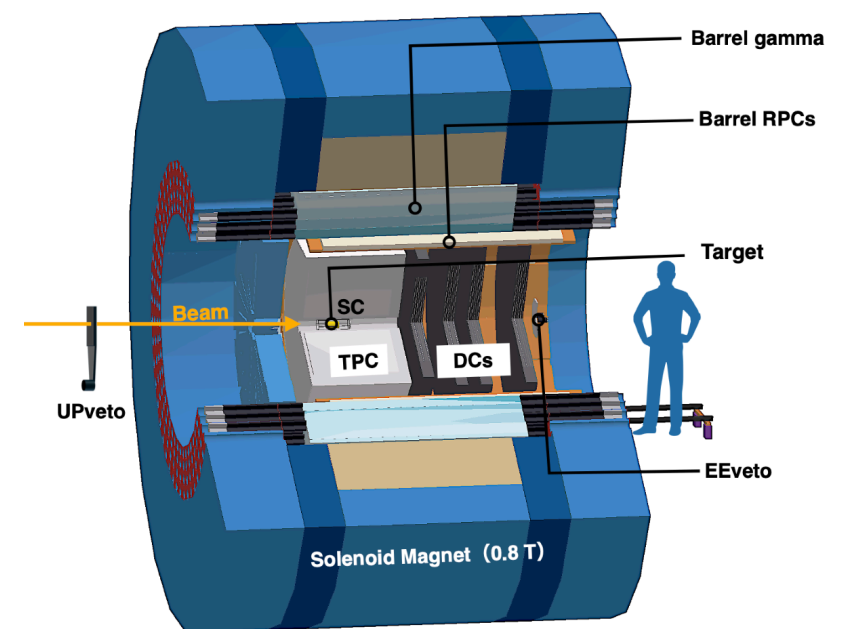
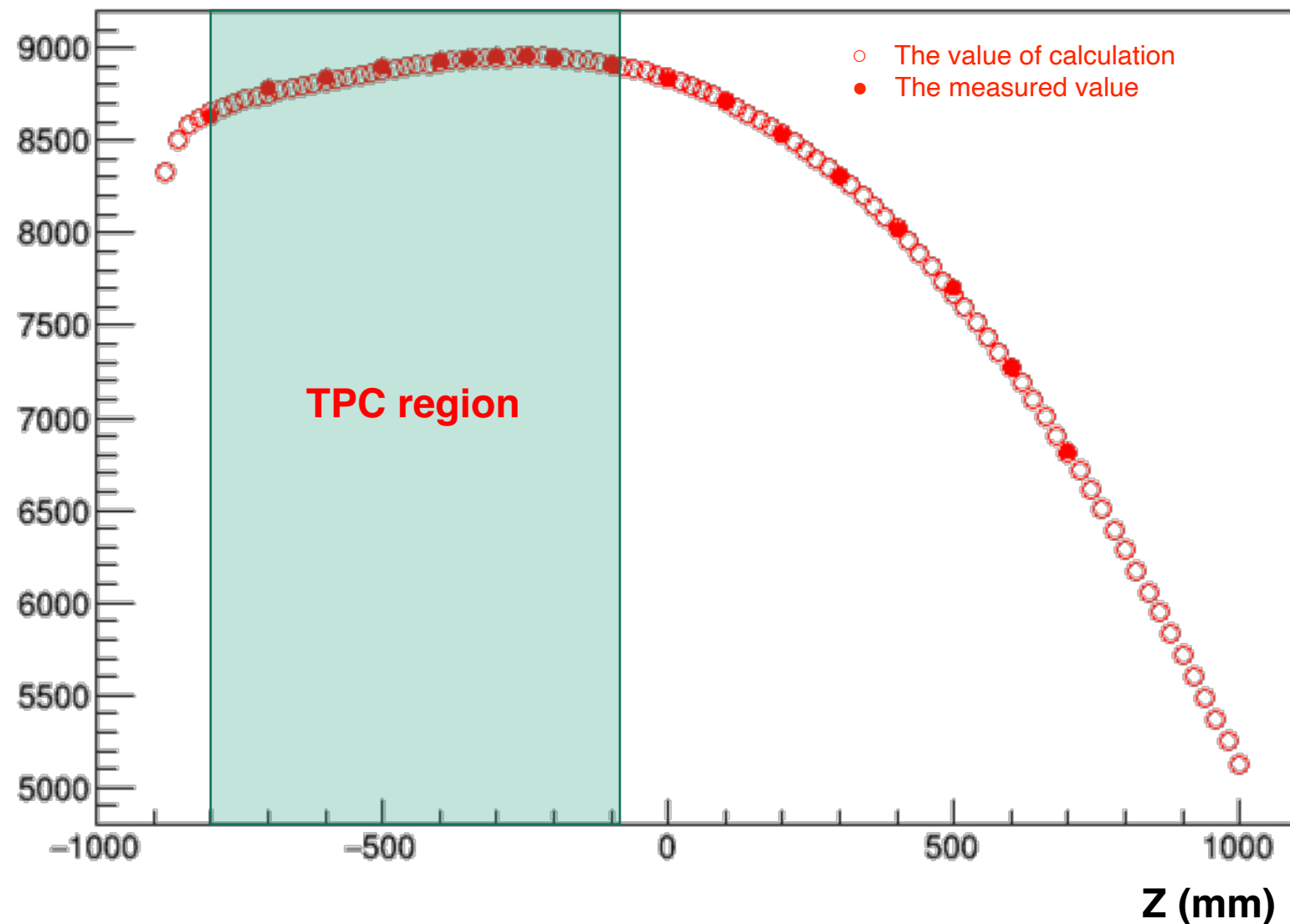
- Extension to a new few-body system, kaonic baryonium, which could be explored through $\bar{p}d \rightarrow \Sigma^- X^+$ at J-PARC K10 beamline.
- This study connects the physics of kaonic nuclei, $N\bar{N}$ baryonium, and few-body dynamics.

BackUp



LEPS2 Solenoid Magnet

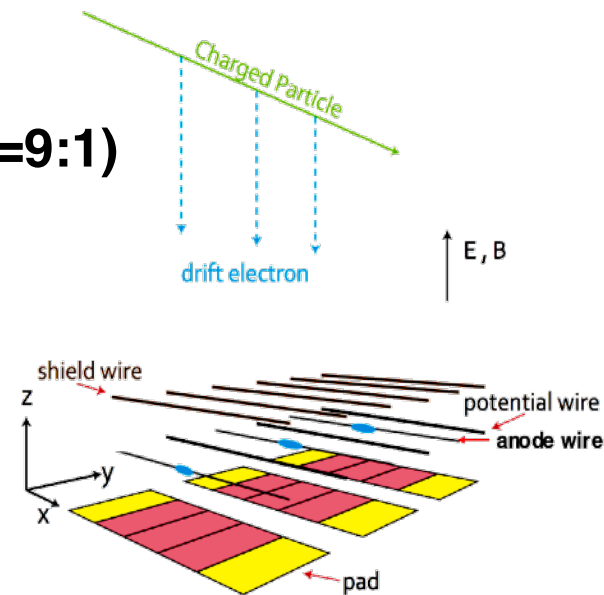
Bz (G) (@x=0,y=0 4014 A)



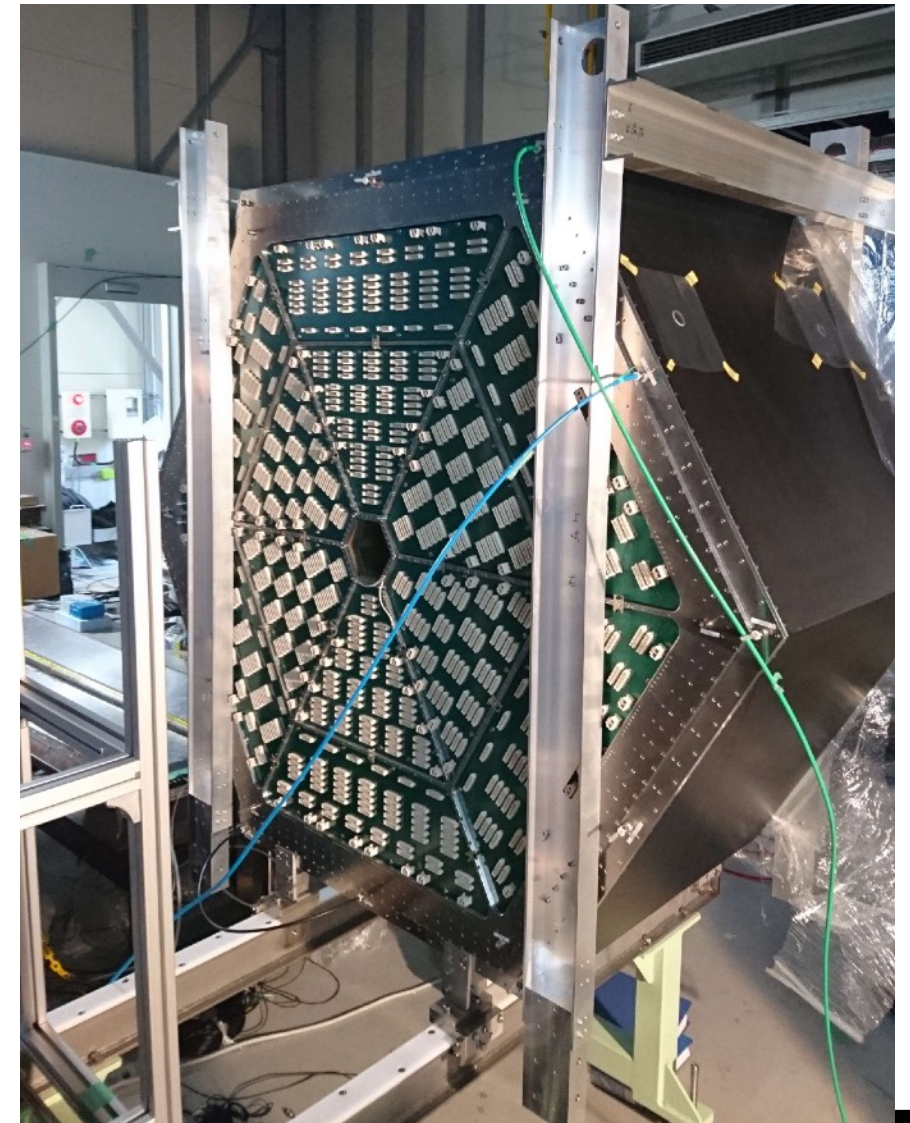
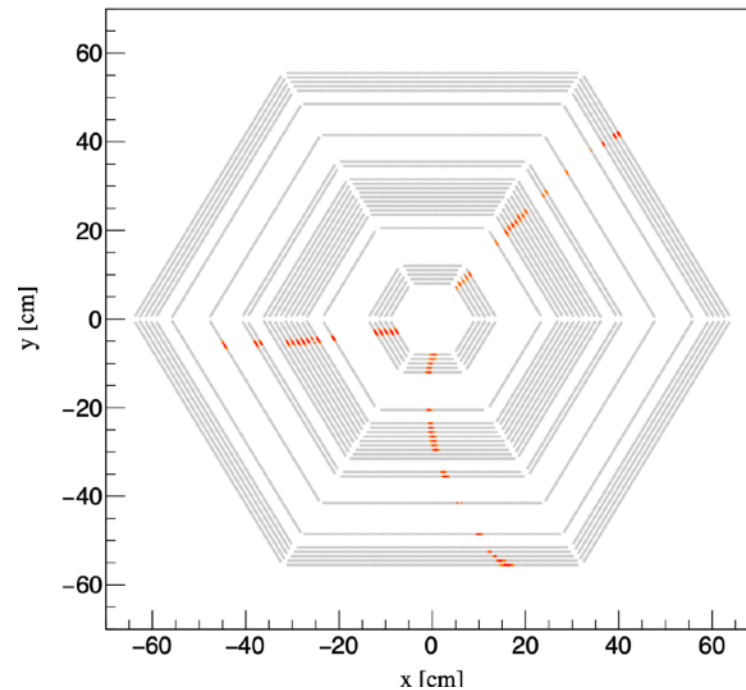
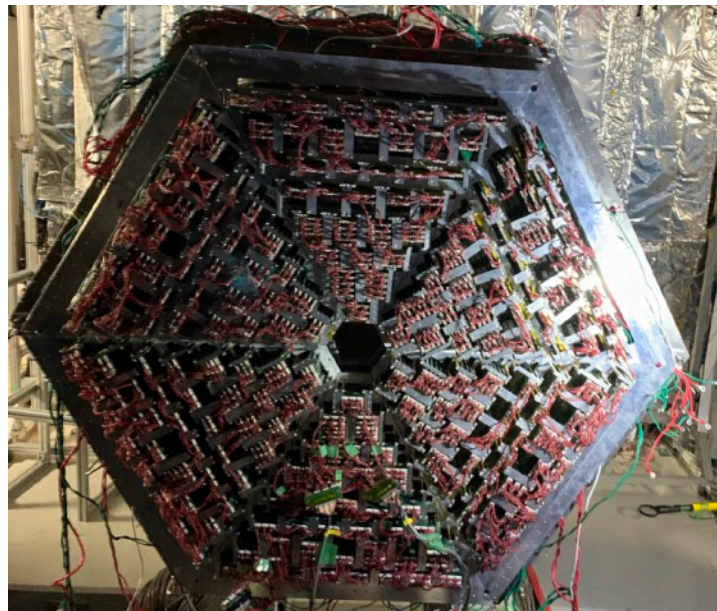
Solenoid current during data taking: 3600 A

Time Projection Chamber

P10 (Ar : CH₄=9:1)



Max drift length ~70 cm

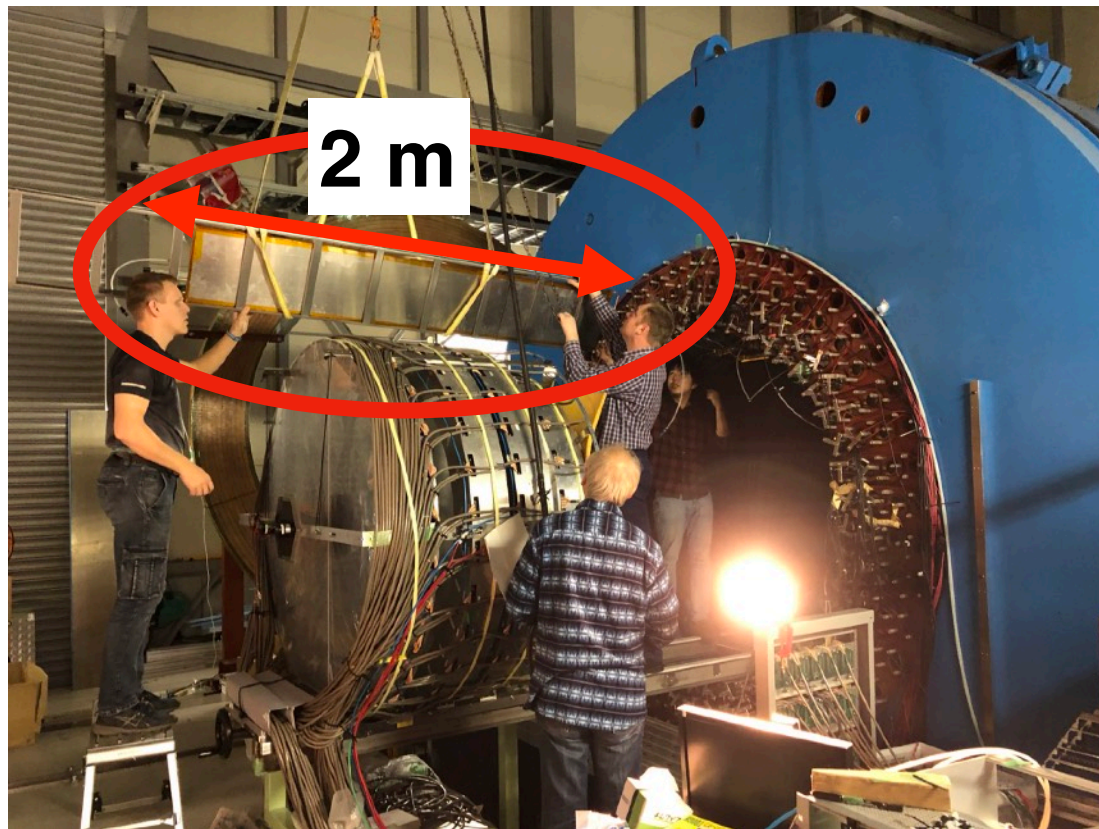


~9000 readout channels

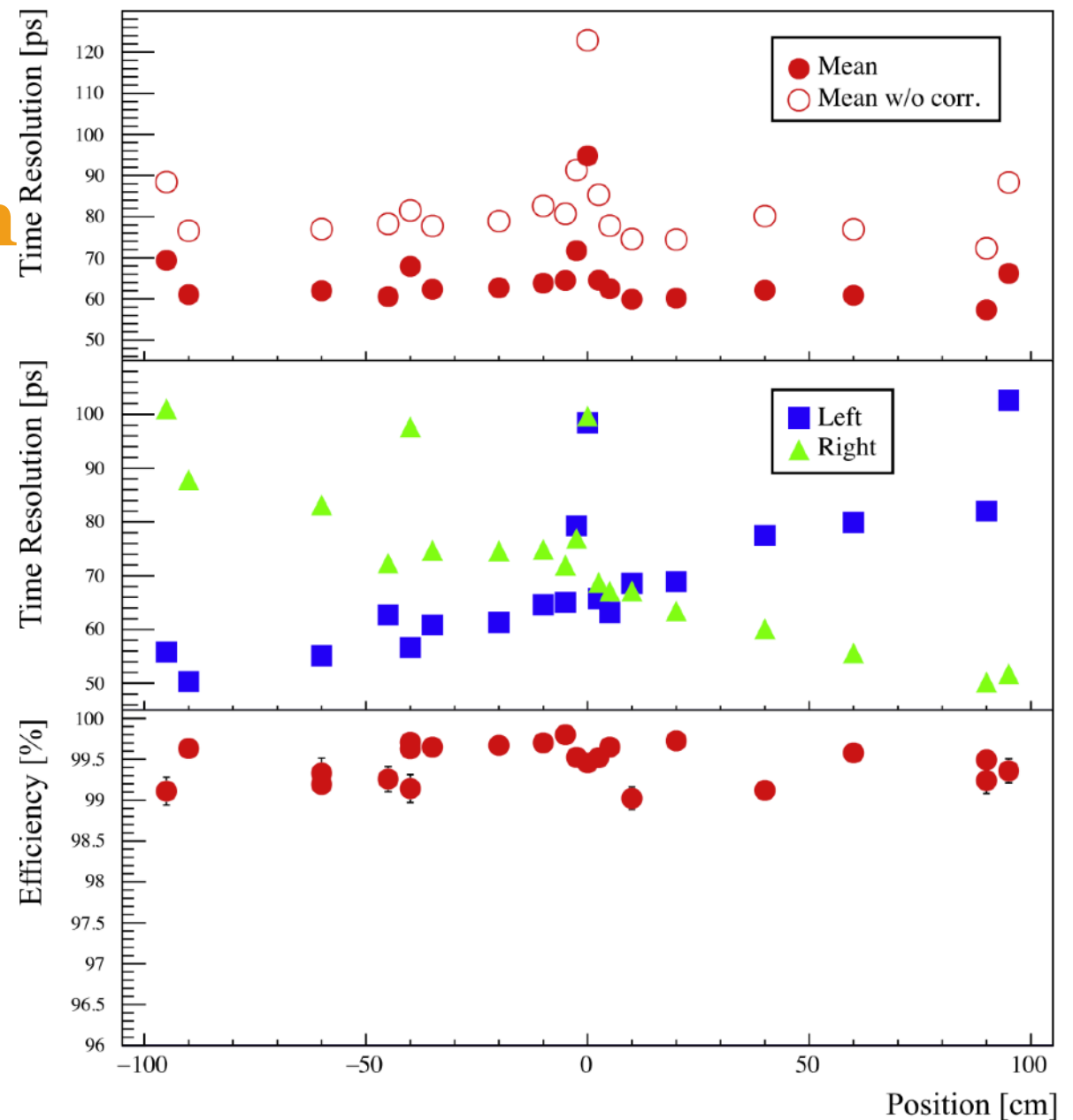
Position resolution ~ 0.5 mm(x), 1 mm(z)

Barrel Resistive Plate Chamber

NIM, A925 (2019) 188–192.



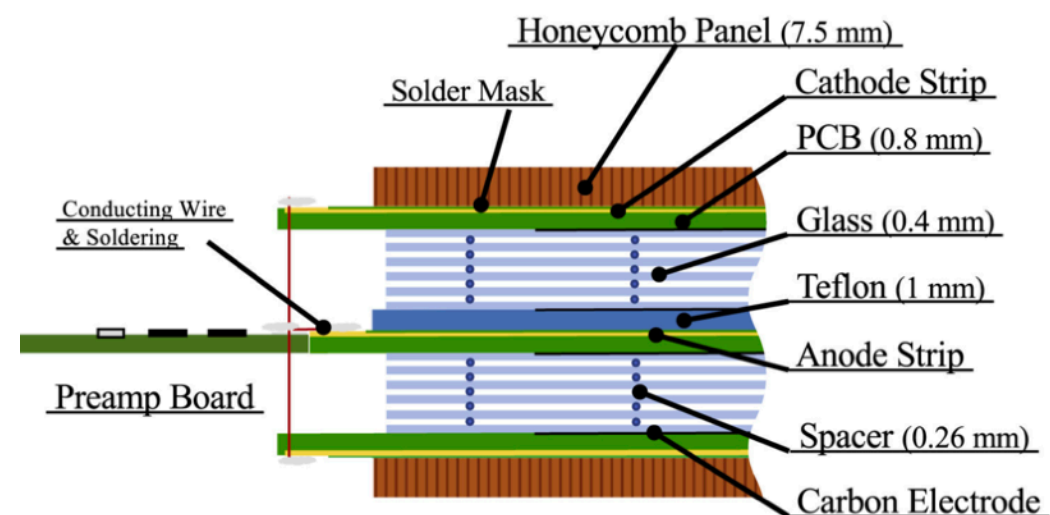
len



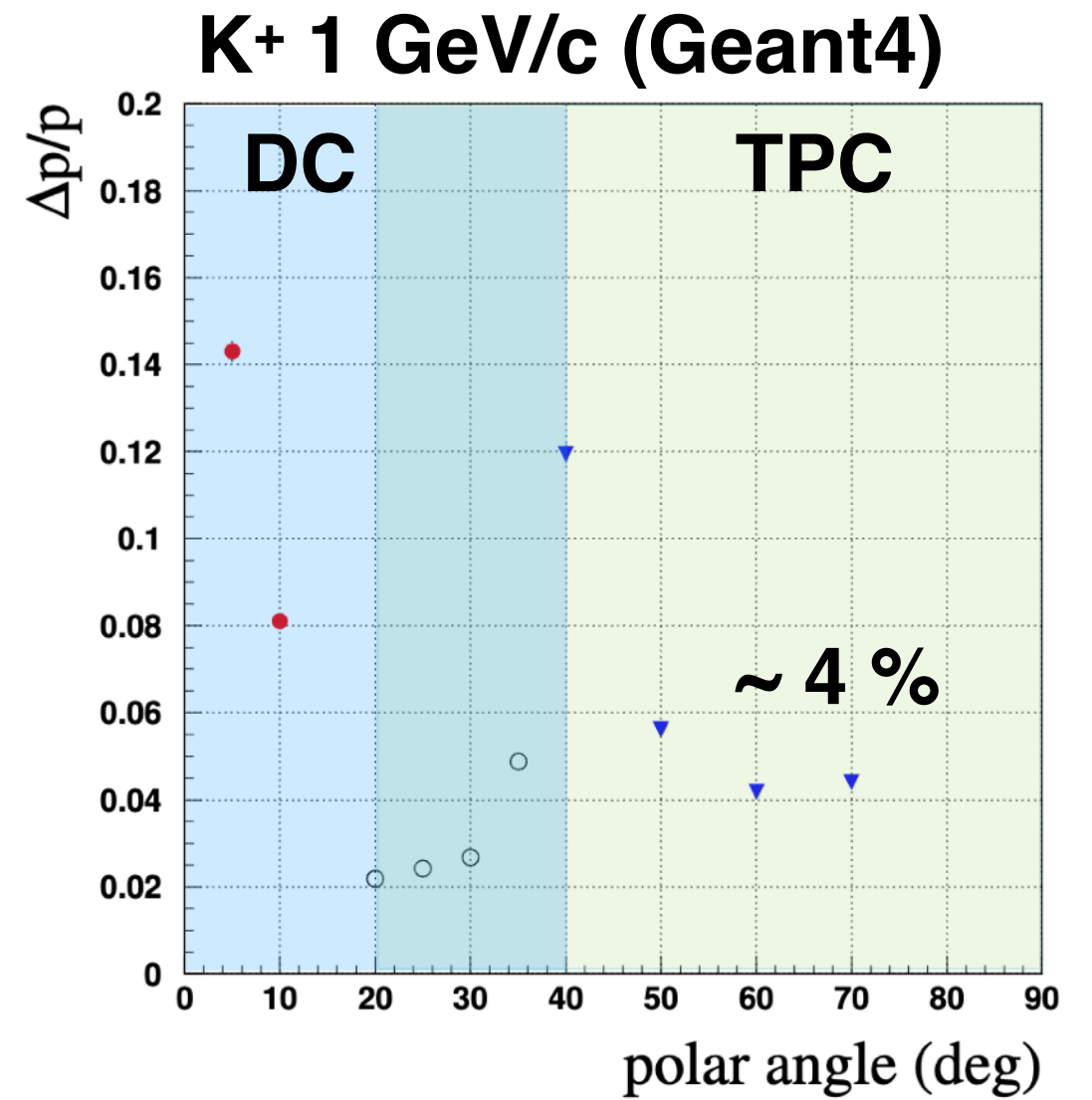
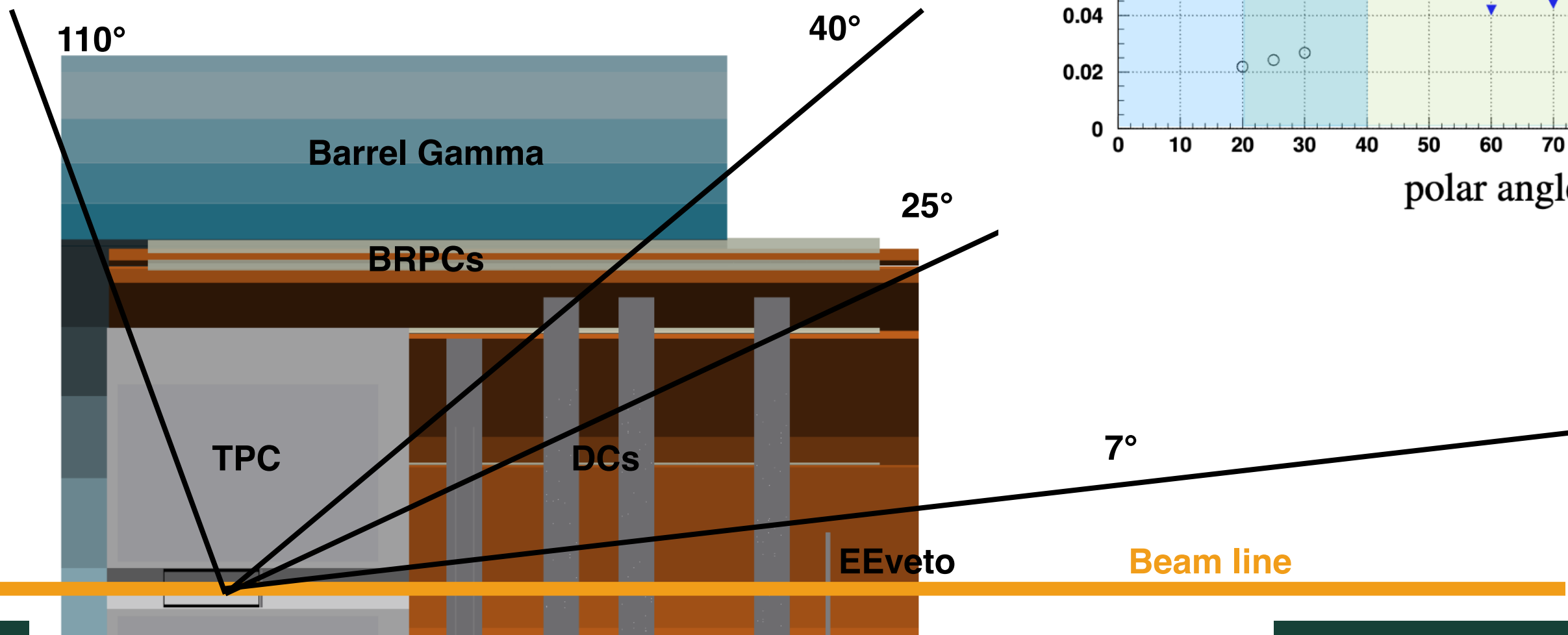
Time resolution

$$\sigma_t \sim 70 \text{ [ps]}$$

(b) Cross-sectional view.



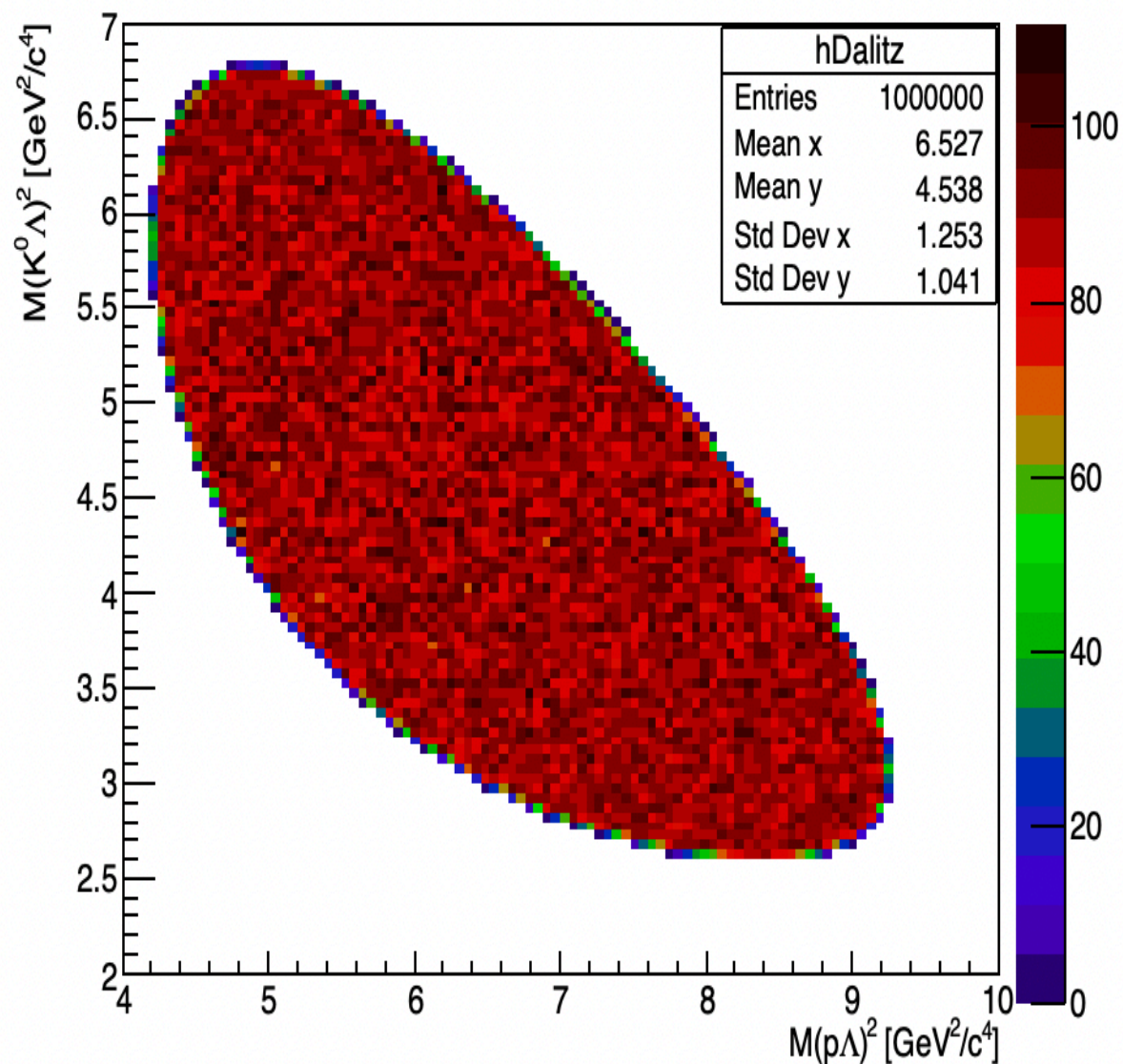
Cover Angle



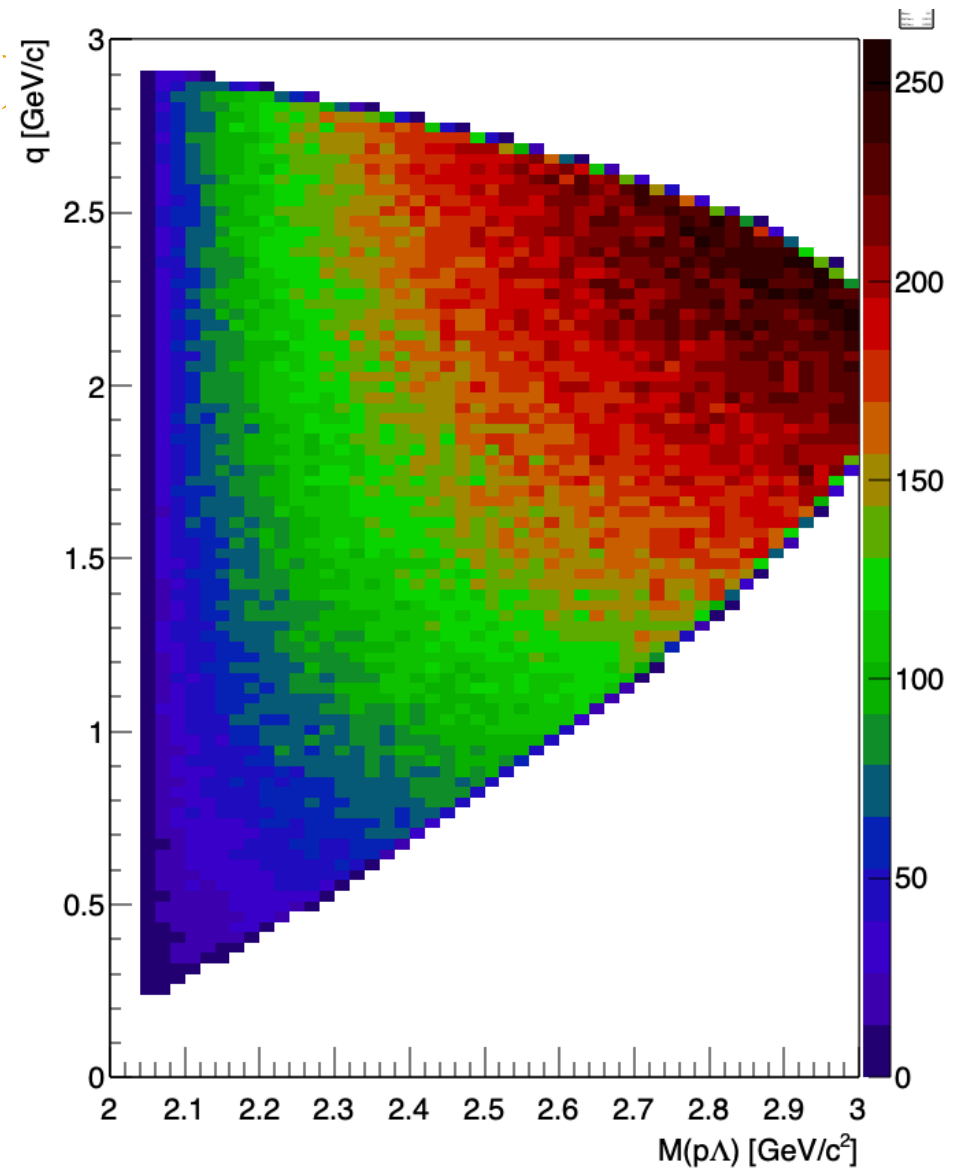
Toy MC

PhaseSpace等方3体崩壊

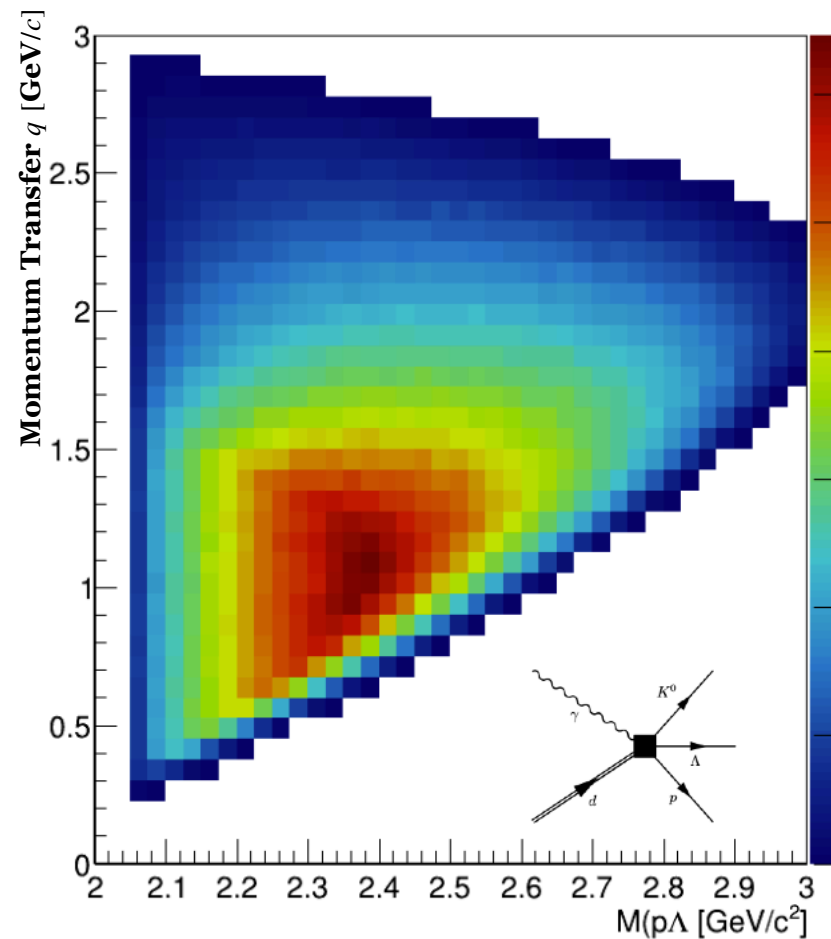
$$E_\gamma = 2.4 \text{ GeV}/c$$



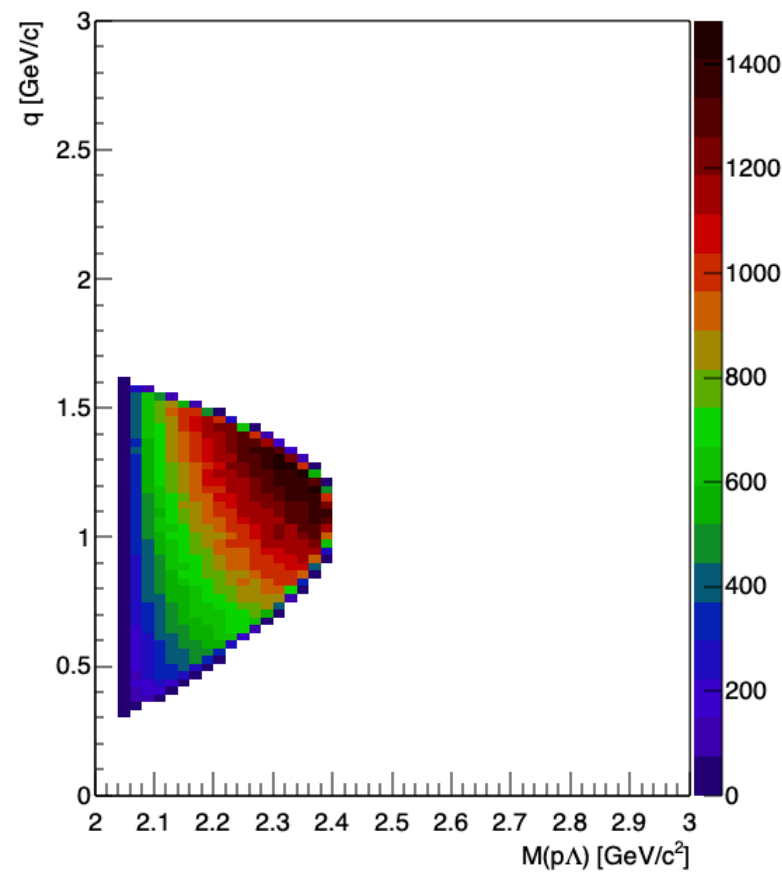
Phase等



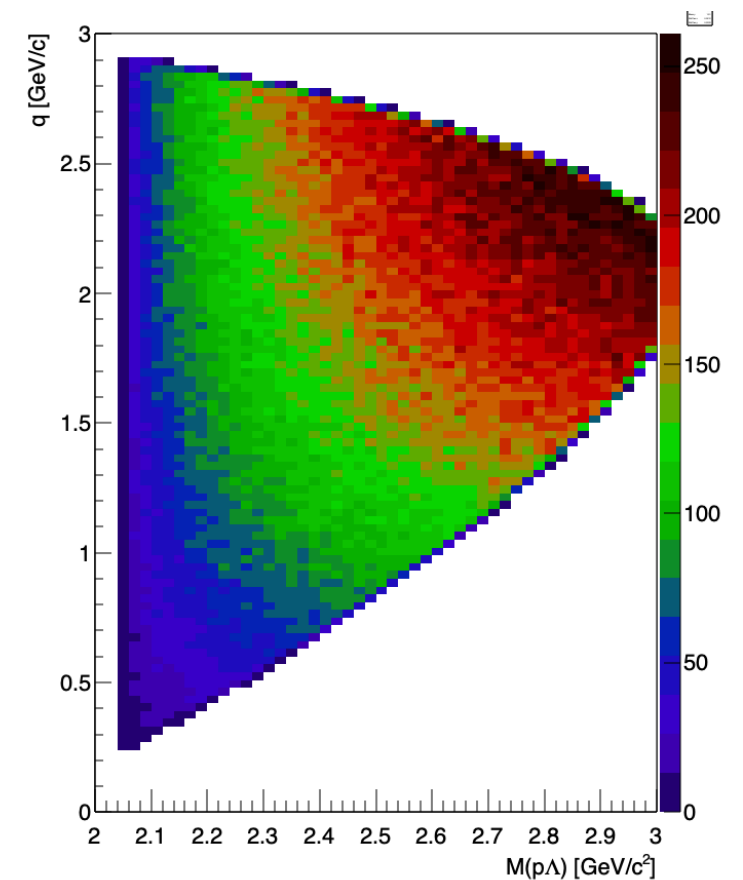
Q Plot (Uniform Phase Space)



PhaseSpace等方のバックグラウンド



$$E_\gamma = 1.3 \text{ GeV}/c$$



$$E_\gamma = 2.4 \text{ GeV}/c$$

逆コンプトン散乱

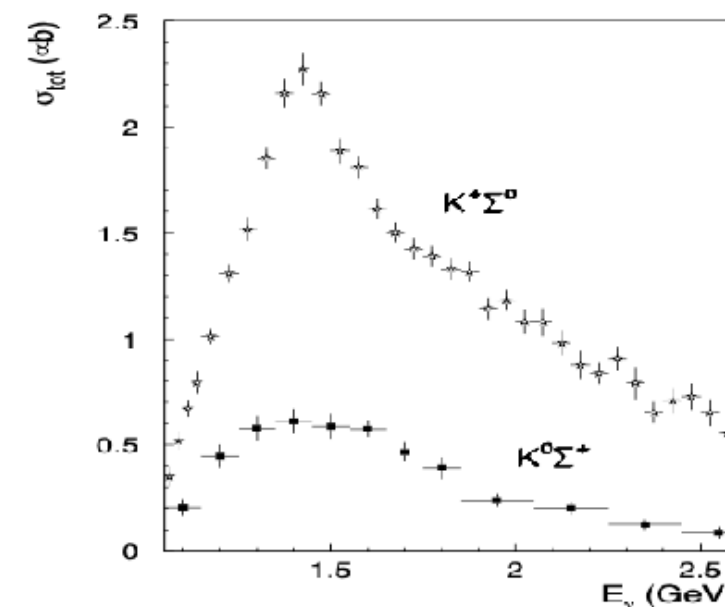
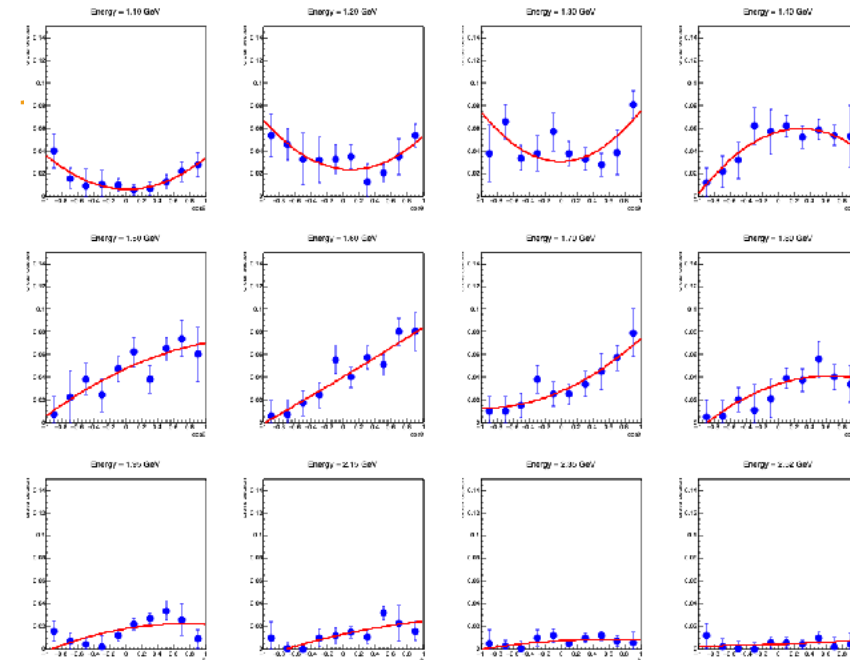
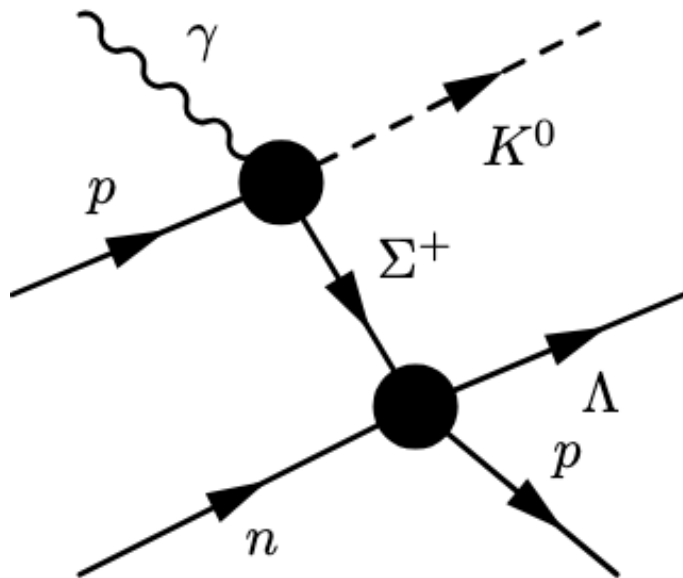
$$(E_\gamma = 1.3 - 2.4 \text{ GeV}/c)$$

Background Components in the 2D Fit

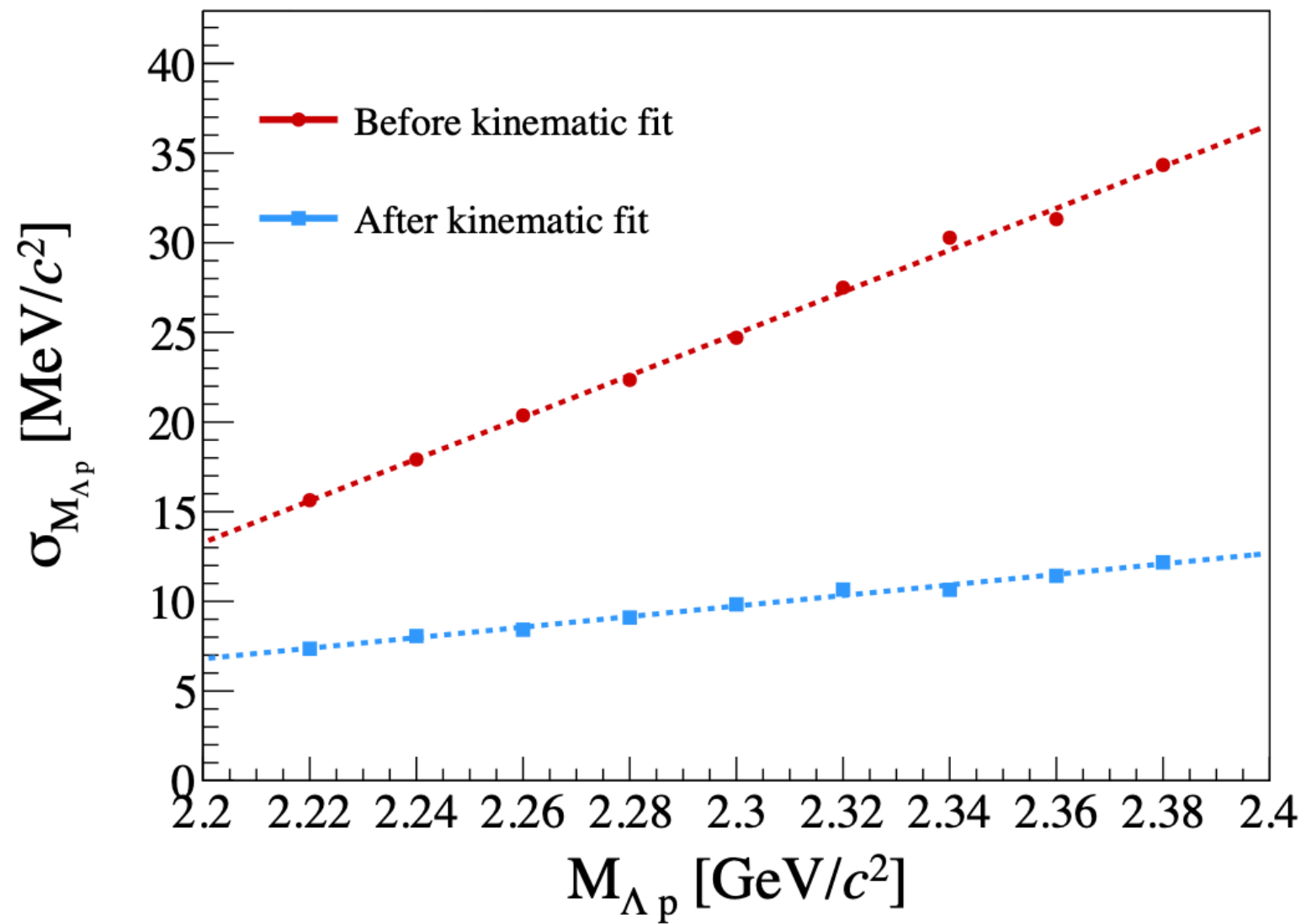
SAPHIR Data

R. Lawall et al., EPJA 24, 275 (2005)

Two-Step (TS)



- Angular and W dependence from ELSA data
- Fermi momentum from Argonne V18 model
- $\Sigma^+ n \rightarrow \Lambda p$ is isotropic decay



Few-body approach to structure of $\bar{K}$ -nuclear quasi-bound states

Shota Ohnishi,¹ Wataru Horiuchi,¹ Tsubasa Hoshino,¹ Kenta Miyahara,² and Tetsuo Hyodo³

¹*Department of Physics, Hokkaido University, Sapporo 060-0810, Japan*

²*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*

³*Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*

(Dated: October 18, 2018)

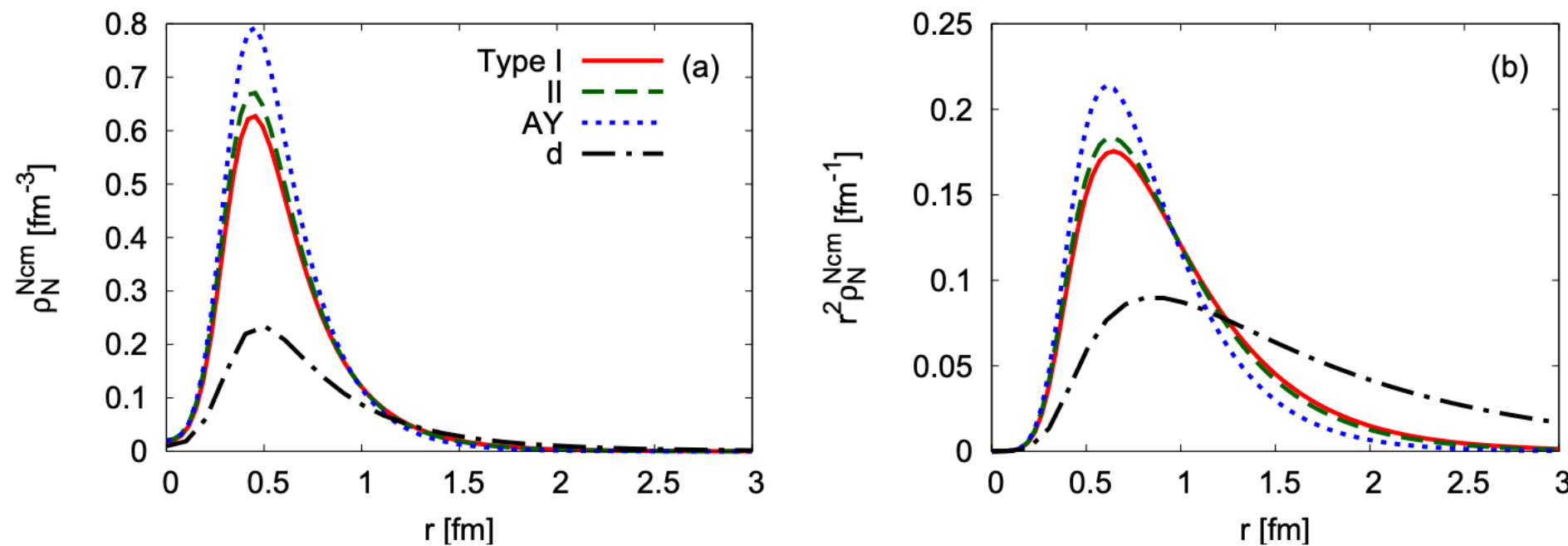


FIG. 3. (Color online) Nucleon density distributions (a) $\rho_N^{Ncm}(r)$ and (b) $r^2 \rho_N^{Ncm}(r)$ for $\bar{K}^-pp\text{-}\bar{K}^0pn$ system measured from the center-of-mass of nucleons. We employ the SIDDHARTA potential with the Types I and II $\bar{K}N$ two-body energies and the AY potential. The dotted-dashed curves show that of deuteron for comparison. Note that the spin parity is $J^\pi = 0^-$ for $\bar{K}NN$ but $J^\pi = 1^+$ for deuteron.

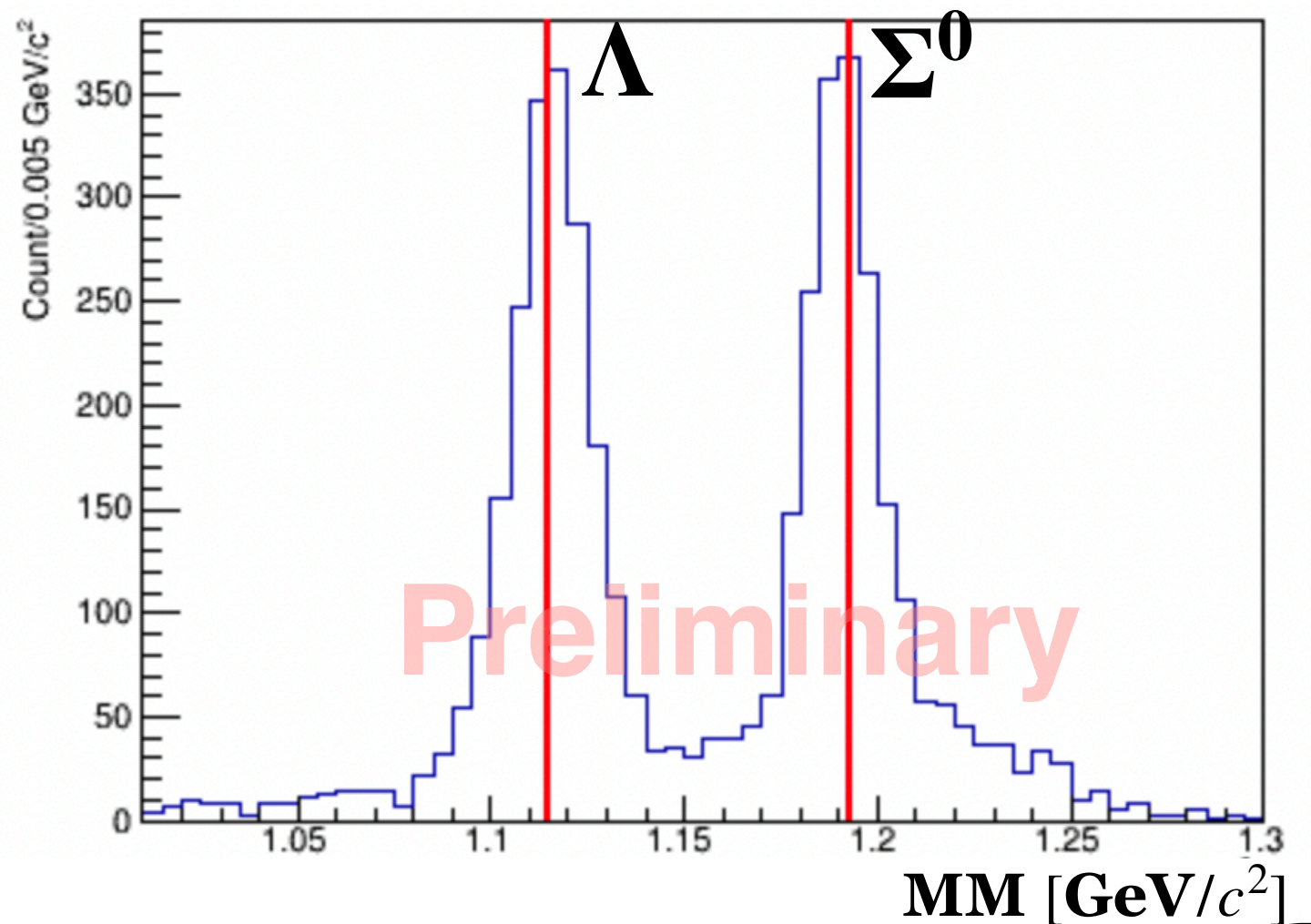
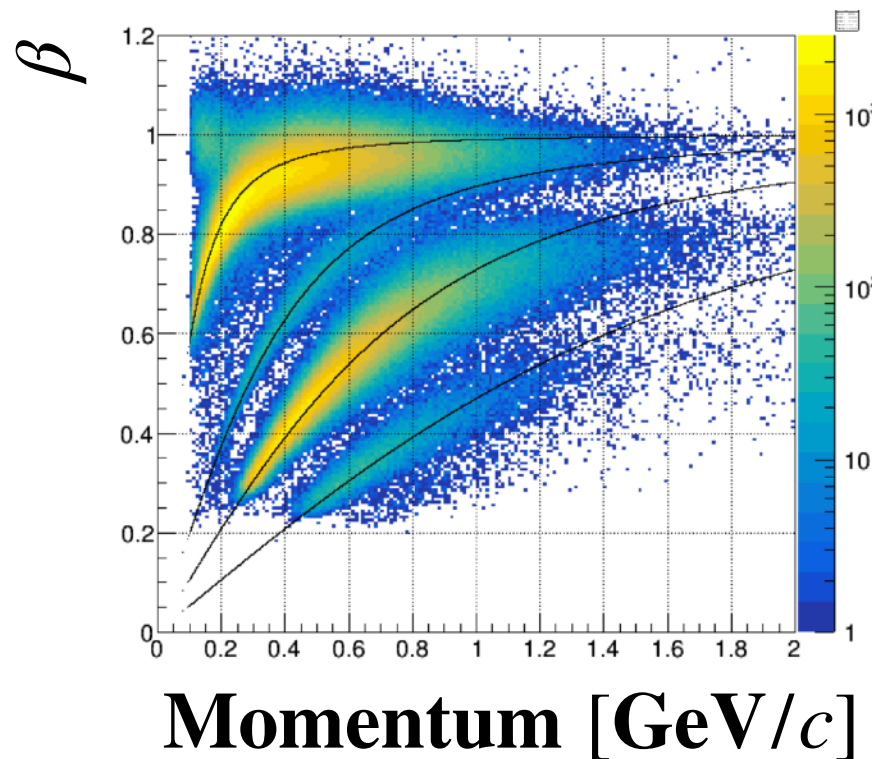
LH₂ Data Analysis for verifying momentum

Detected by TPC & BRPC

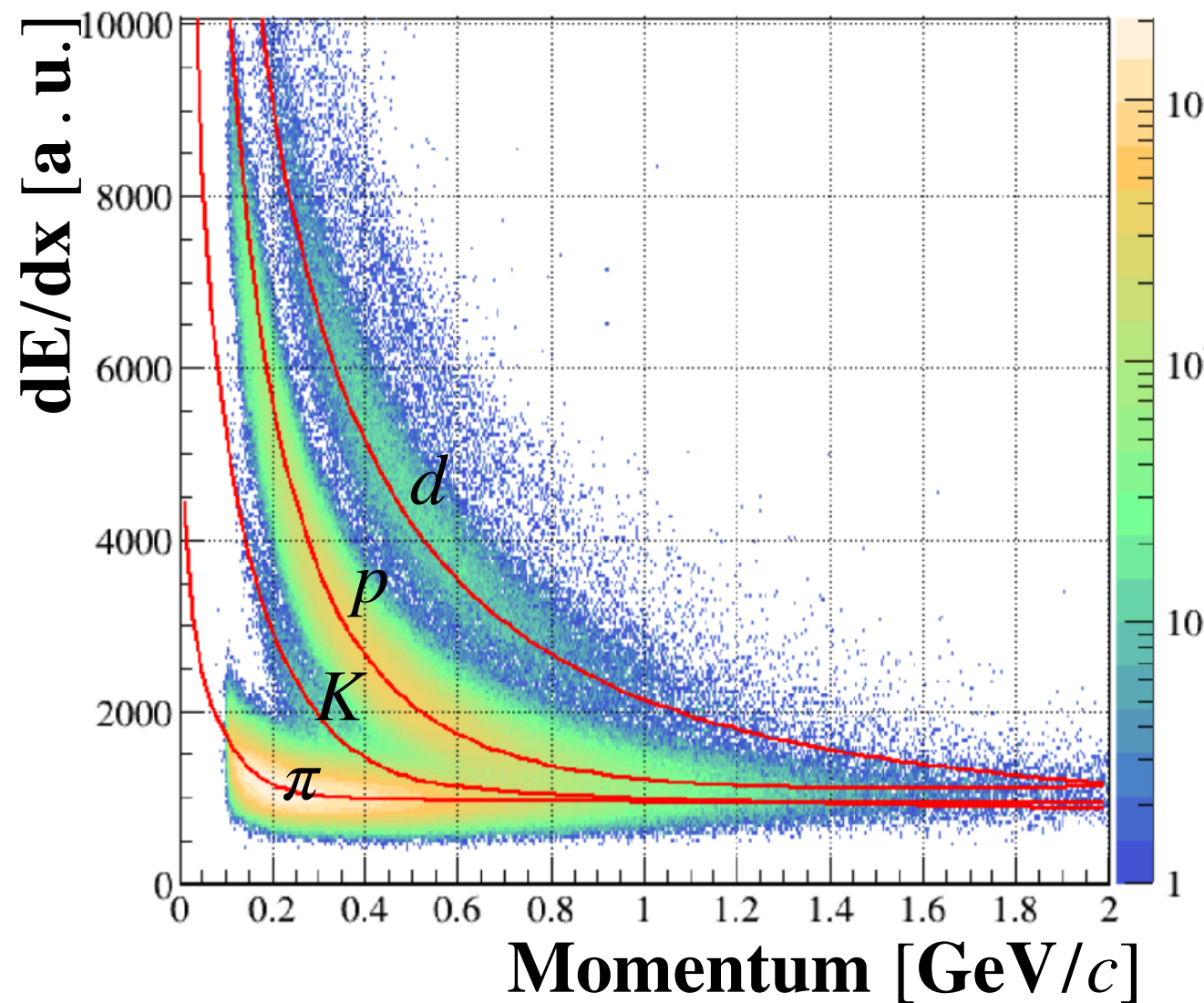
$$\gamma p \rightarrow \boxed{\mathbf{K}^+} X$$

$$E_\gamma < 1.5 \text{ GeV}$$

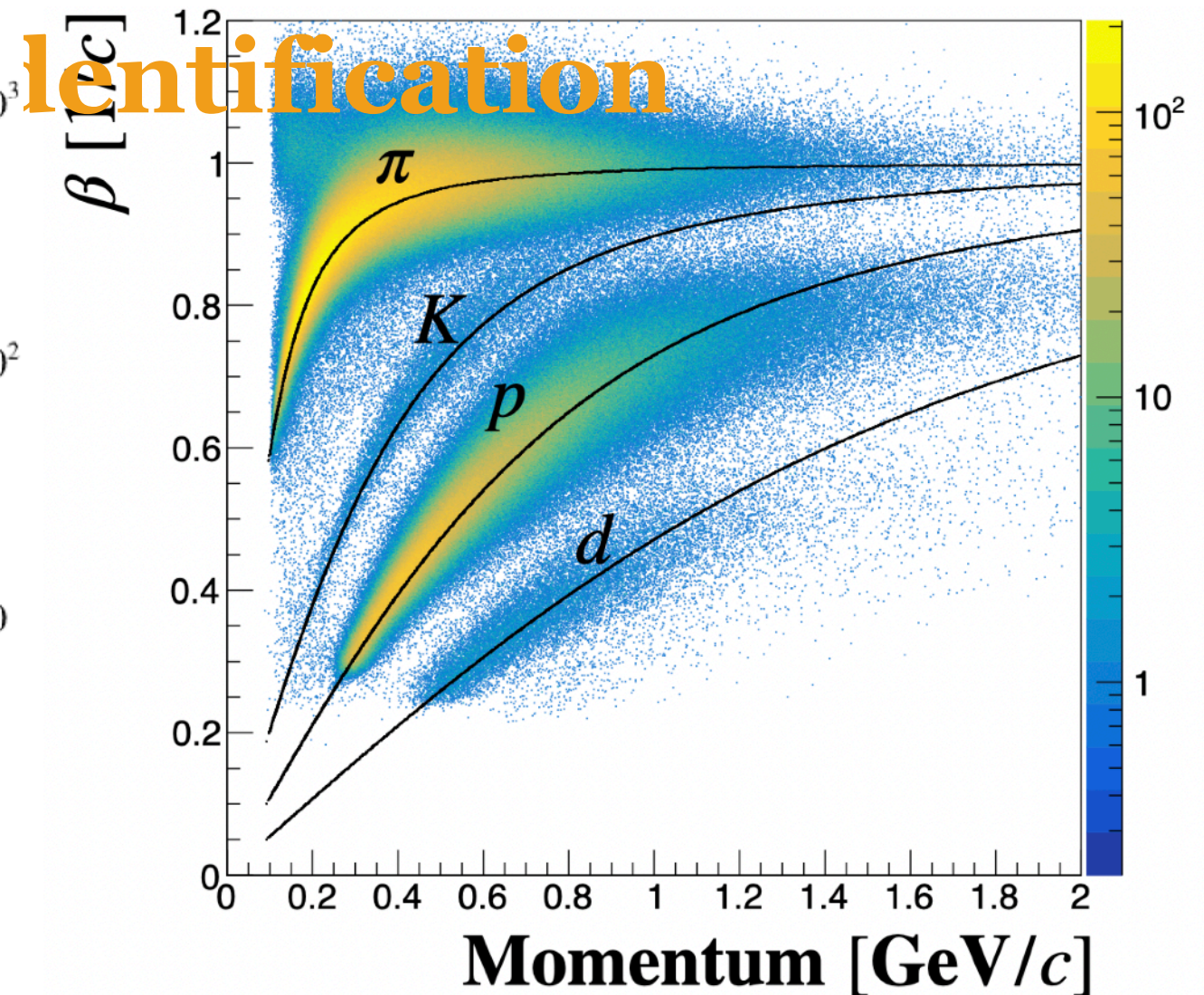
$$P_{\mathbf{K}^+} < 0.4 \text{ GeV}/c$$



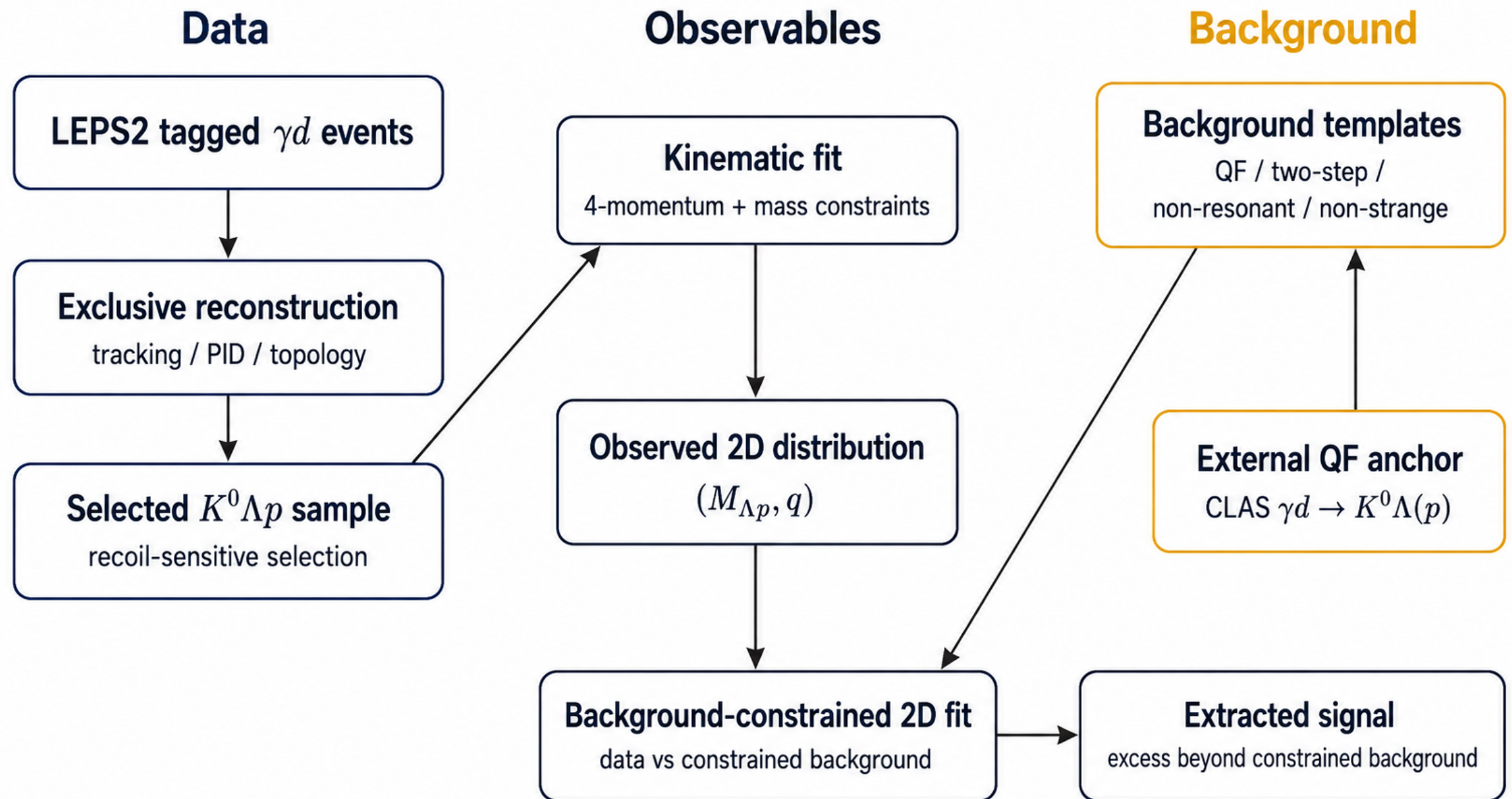
TPC dE/dx



path length(TPC), ToF(BRPC)



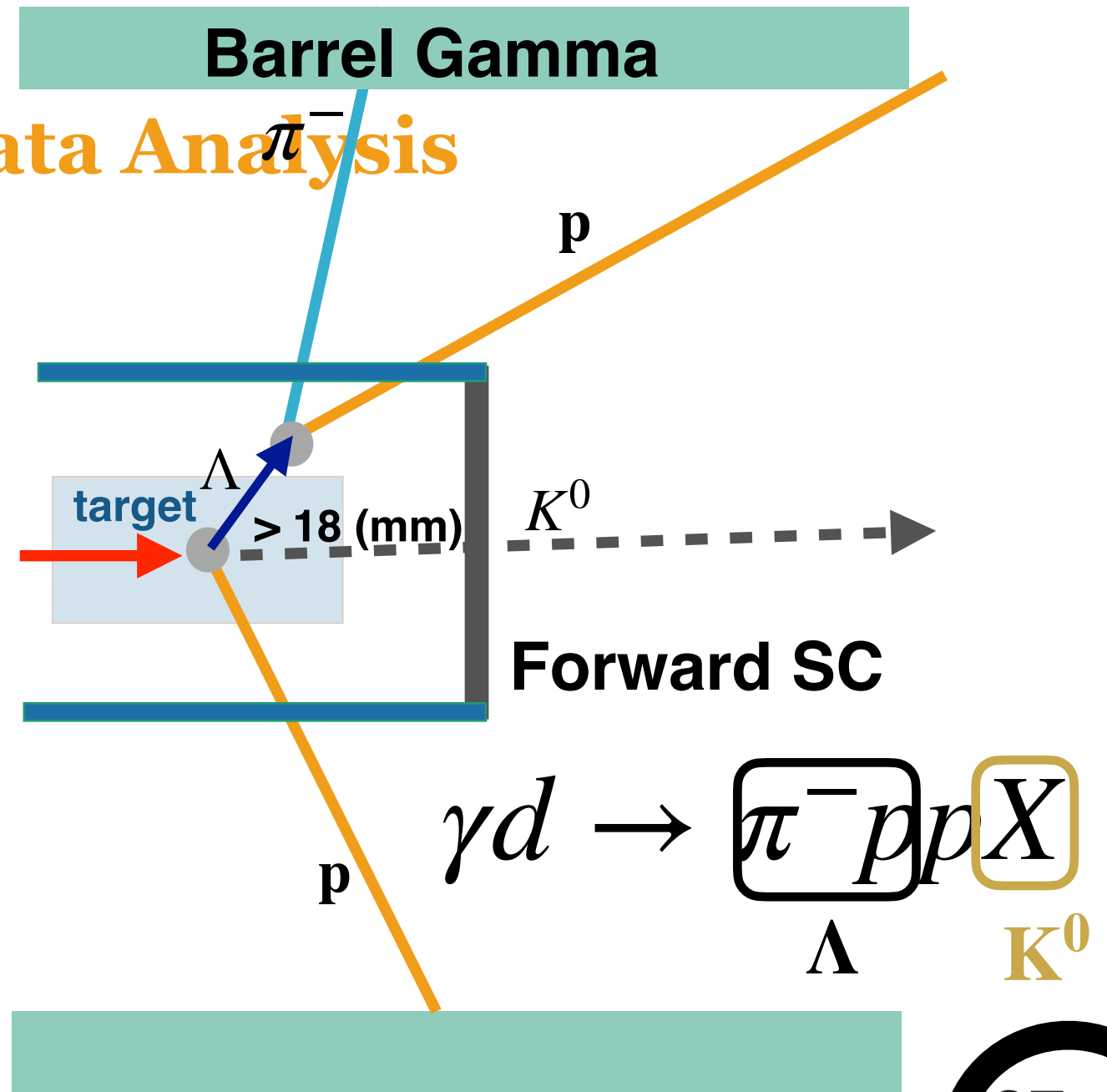
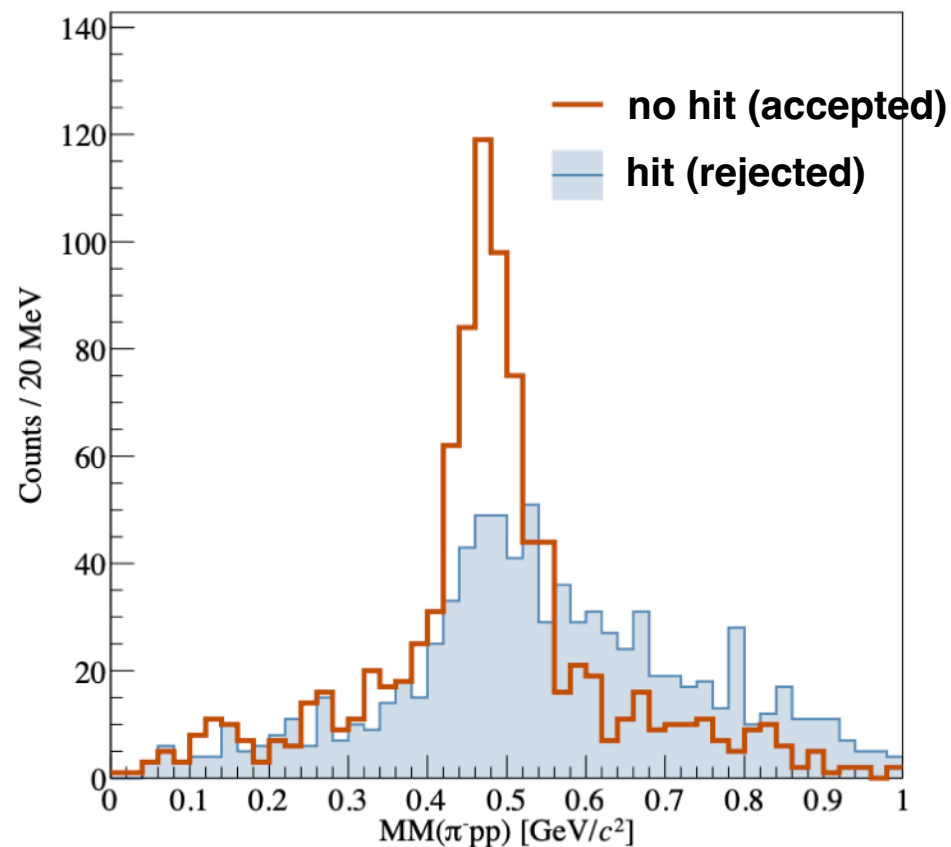
Data Analysis Strategy for $\bar{K}^{*}NN$ study



Exclusive $K^0\Lambda p$ Event Selection

To eliminate Background events

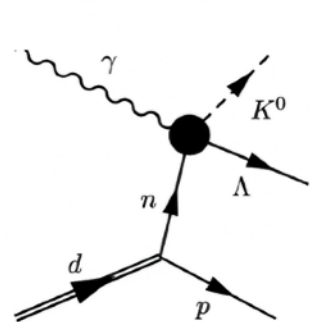
- Vertex information(Λ flight length > 18 [mm])
- Barrel Gamma veto
- Forward SC veto



Test of the Quasi-Free Spectator Hypothesis

Main contribution

Quasi-Free $\gamma n \rightarrow K^0 \Lambda$ reaction(QF)



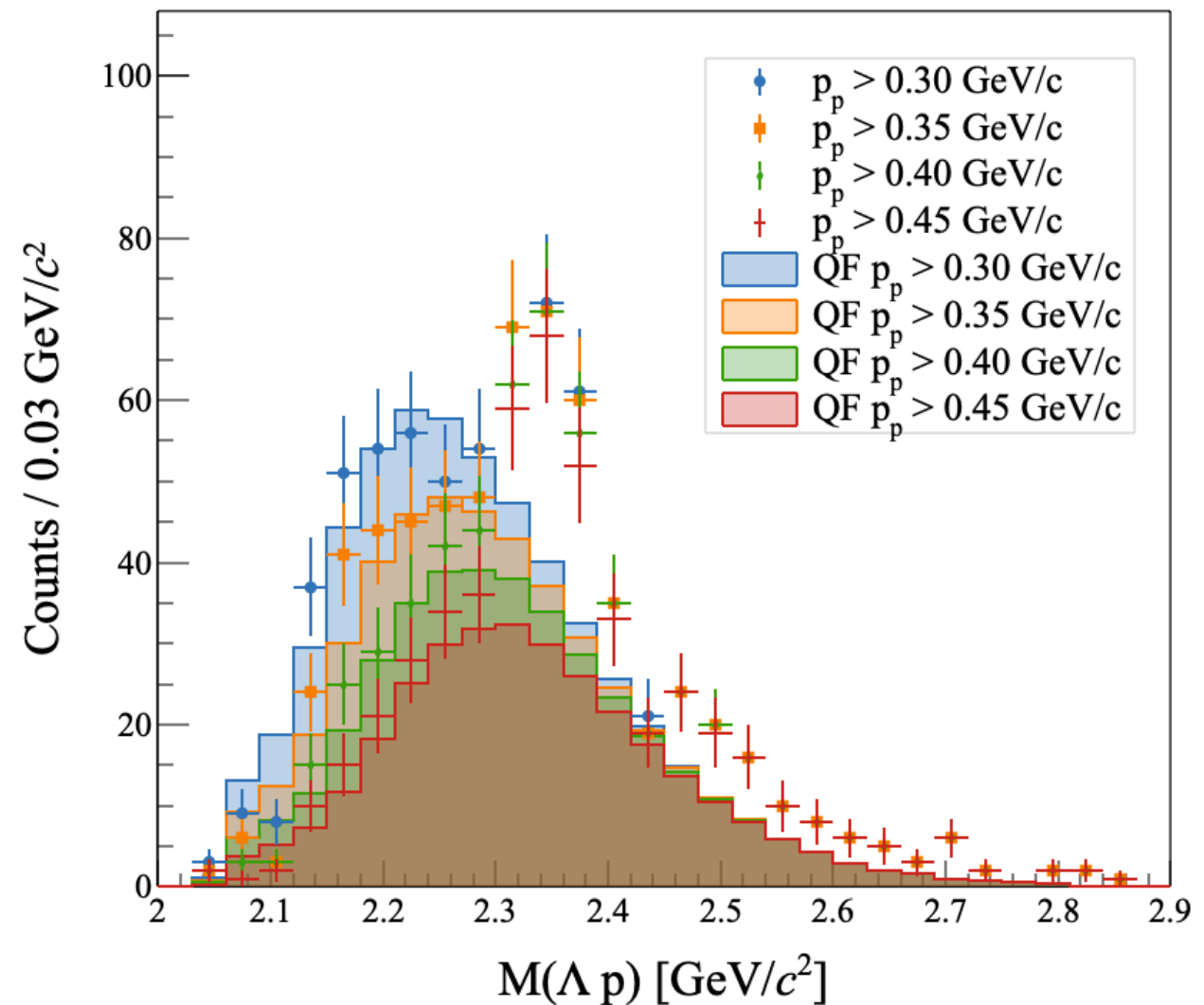
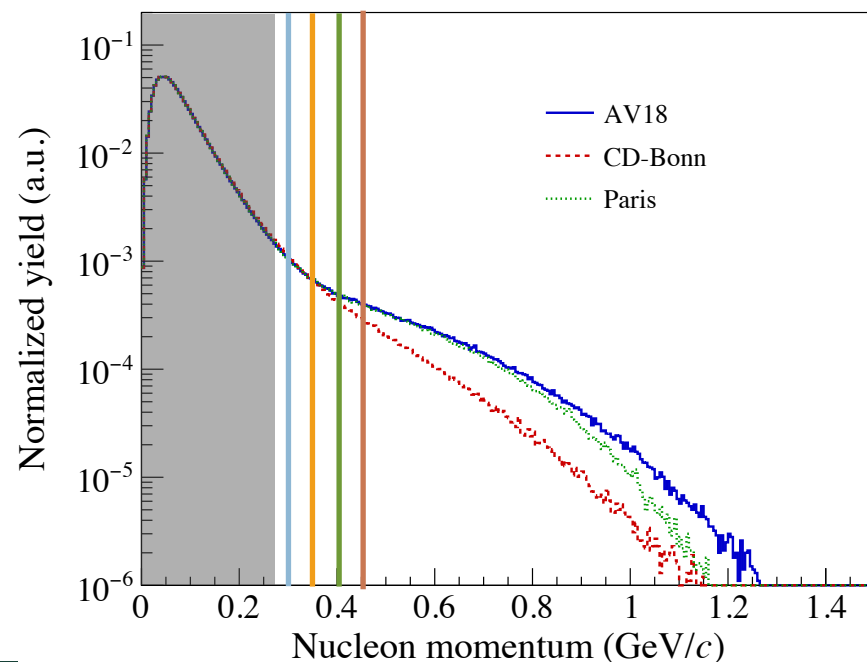
$$\gamma n \rightarrow K^0 \Lambda$$

- W dependence
- K^0 angle dependence

CLAS Results
(PRC96, 065201 (2017))

Fermi momentum : Argonne V18

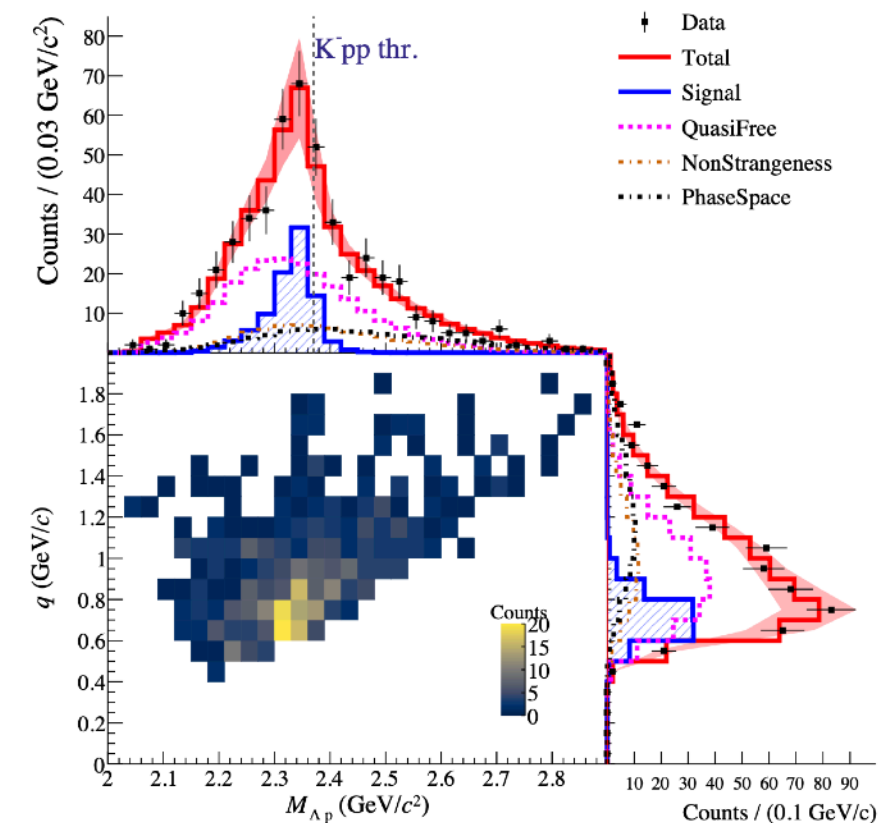
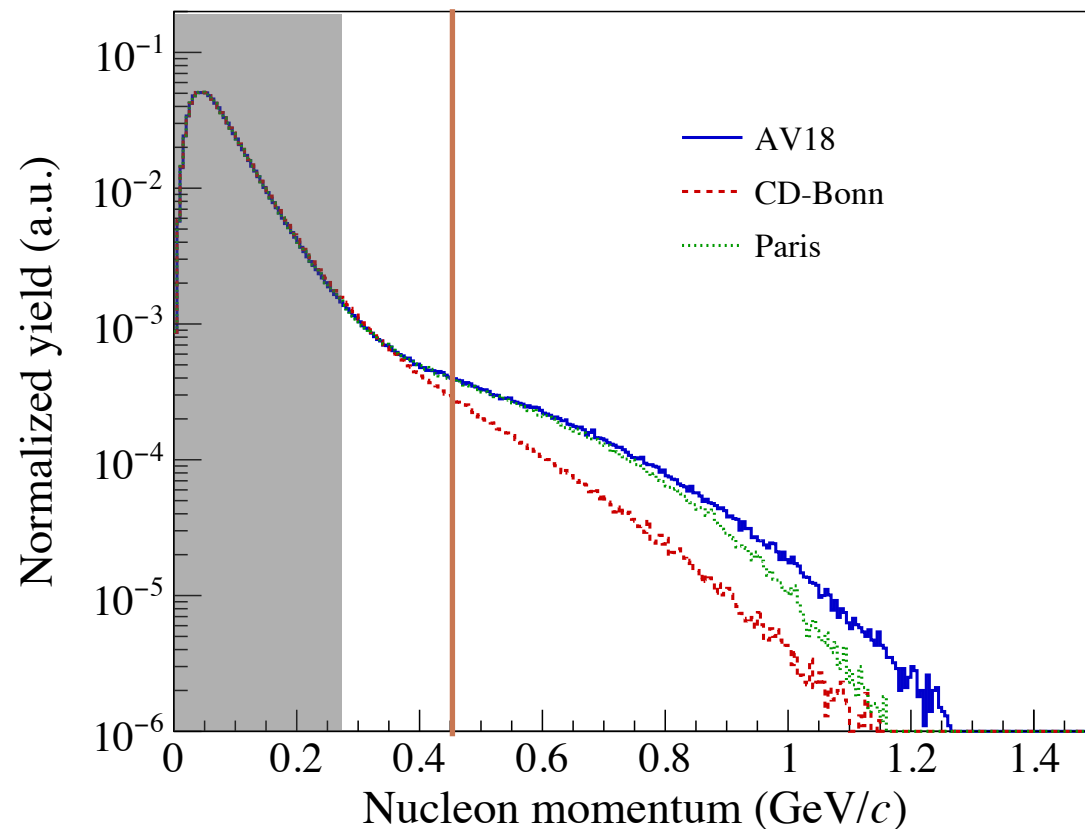
Proton detection limit: ~ 0.27 GeV/c



Higher proton-momentum cut suppresses the QF structure, but not the 2.35 GeV/c² component.

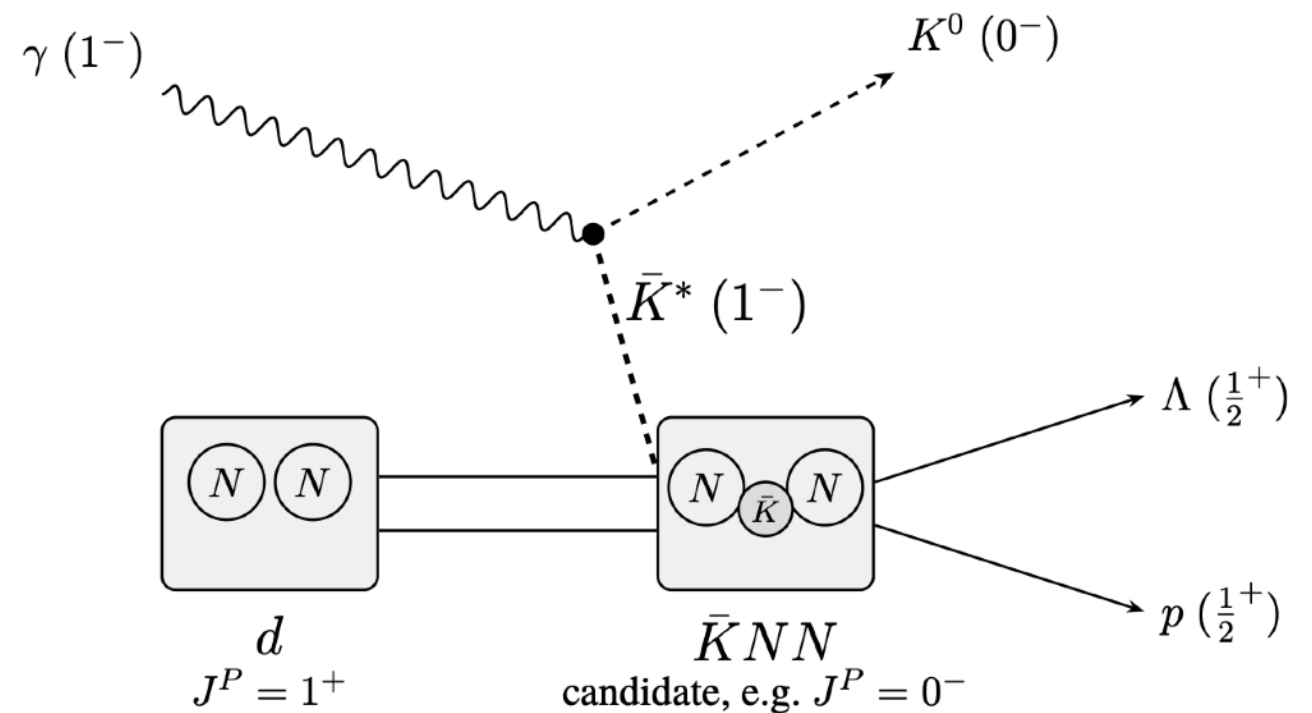
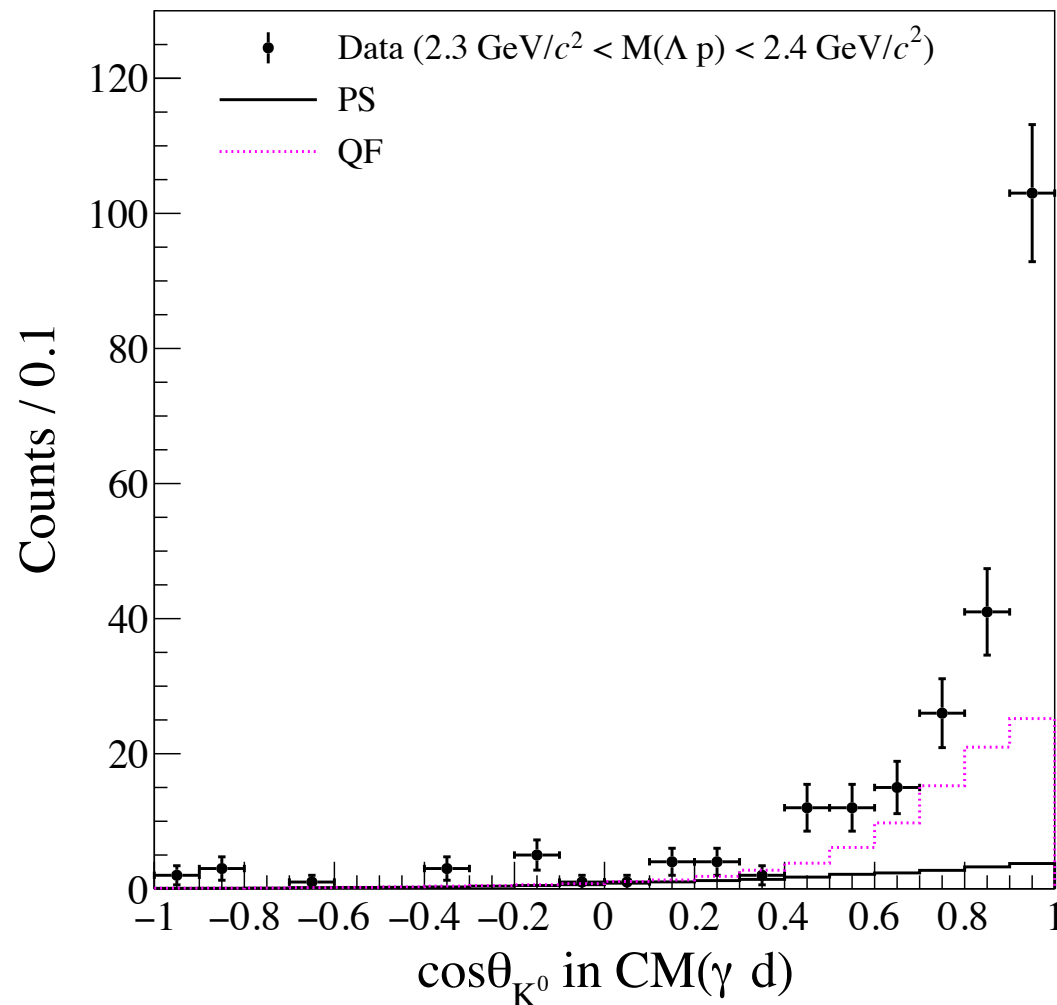
Signal Stability

under a Raised Proton-Momentum Cut



Fit condition	Mass M [MeV/ c^2]	Width parameter	Form factor
		Γ [MeV/ c^2]	Q [MeV/ c]
Nominal	2354 ± 11	55 ± 23	350 ± 41
$p > 0.45$ GeV/ c	2351 ± 11	52 ± 23	363 ± 47

Forward K^0 Production in the Signal Region



The signal-region events show a strong forward K^0 tendency.

This is consistent with a production mechanism favoring small momentum transfer.

K^* exchange is one possible mechanism.

Interpretation of the Component

Observed component

A low- q component around $M_{\Lambda p} \simeq 2.35 \text{ GeV}/c^2$, localized in $(M_{\Lambda p}, q)$.

Robustness checks

- Excess beyond constrained backgrounds
- Stable under a tighter primary- p cut
- Consistent with the forward- K^0 tendency and E15 low- q component

Interpretation status

Disfavored in the present analysis

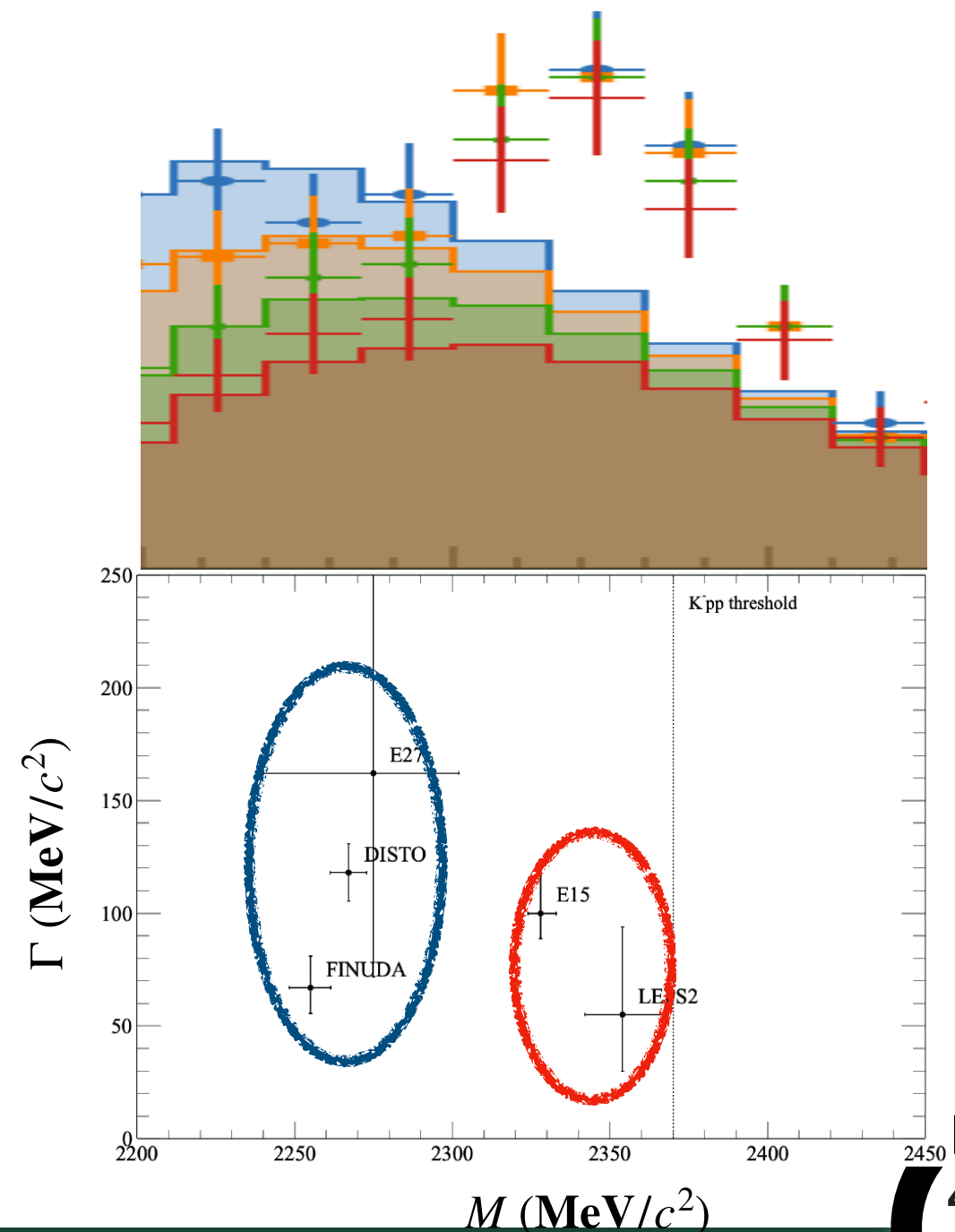
- Quasi-free spectator tail
- Simple Λp FSI / ΣN cusp
- Association with previously claimed deeply bound states ($M \simeq 2.26\text{--}2.28 \text{ GeV}/c^2$)

Still open

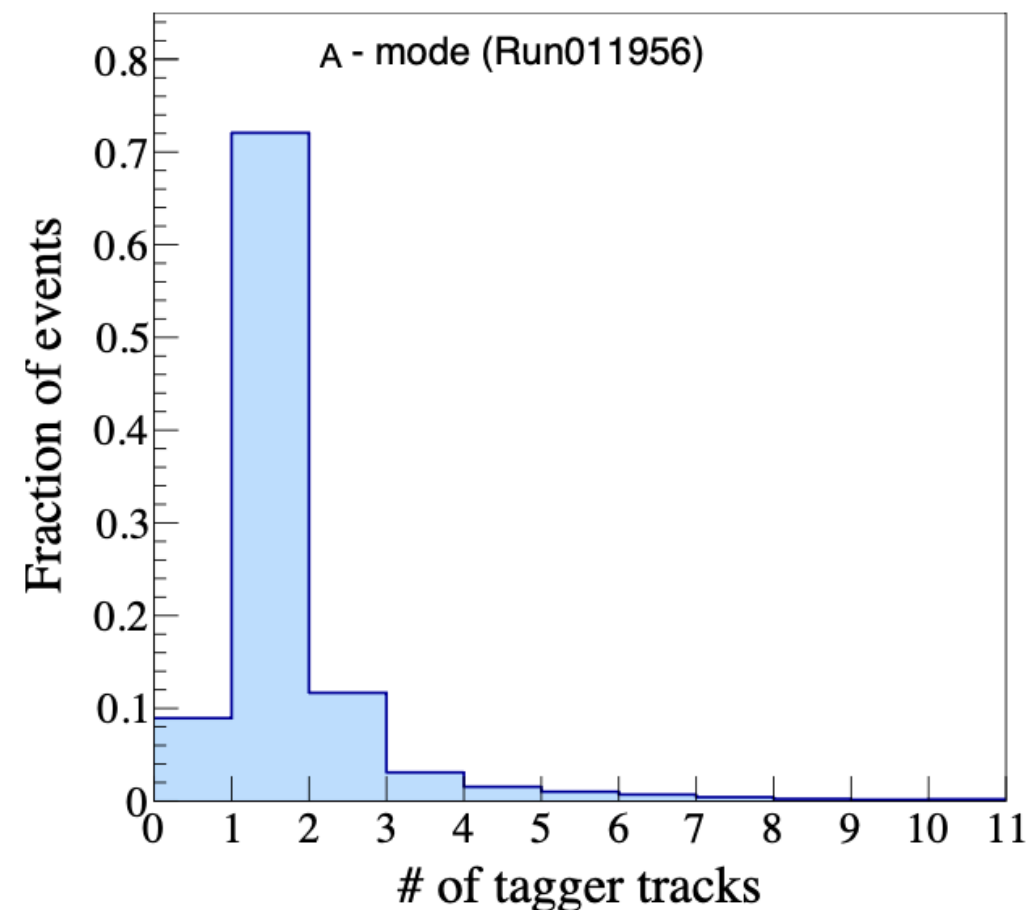
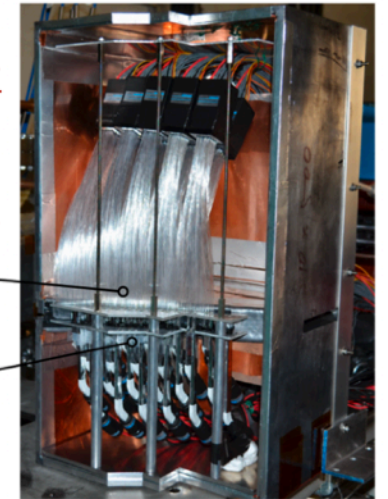
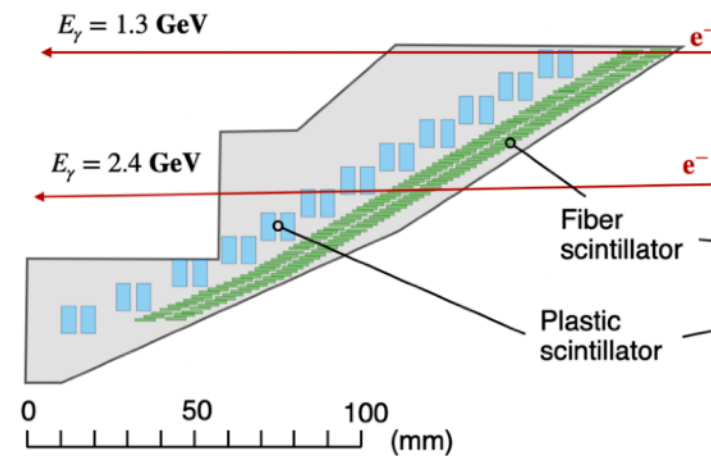
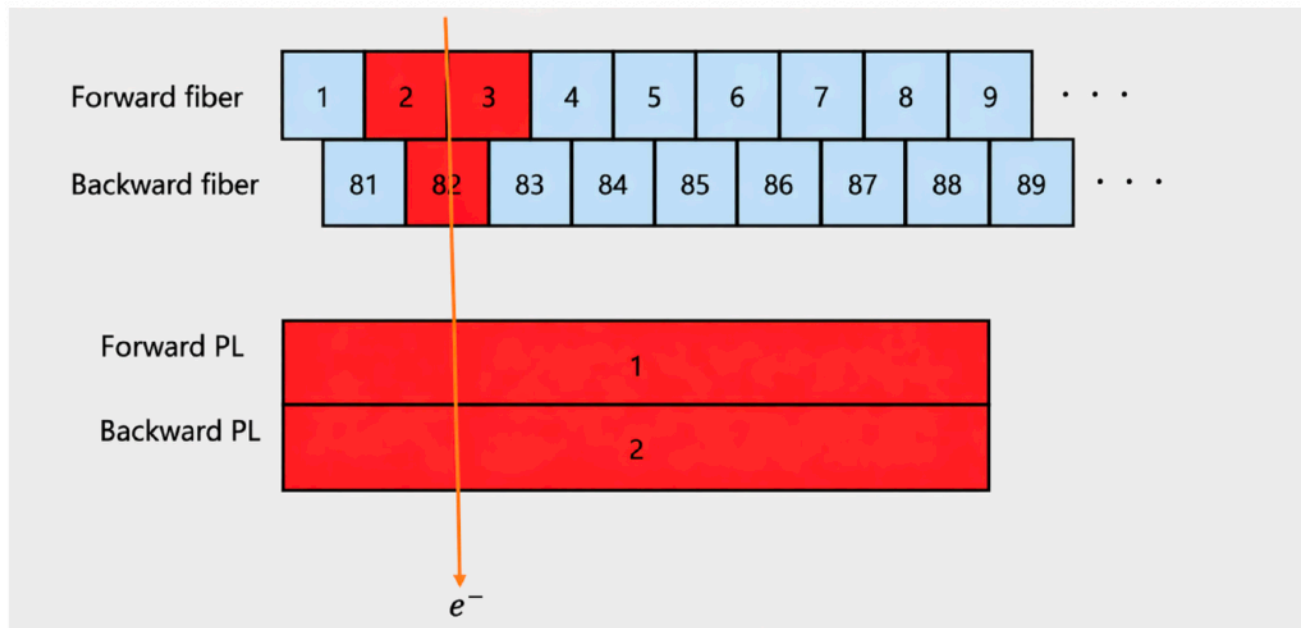
- Y^*N effects
- Triangle and box mechanisms (kinematical effects)

Present interpretation

The observed structure is a $\bar{K}NN$ quasi-bound-state candidate for the present data.



Tagged Photon Reconstruction



$$E_{\gamma} = (E_{\gamma f}(x_f) + E_{\gamma b}(x_b))/2$$

Select events with exactly one reconstructed track.

Lessons from previous searches

- Use the simplest possible few-body system
- Understand and **constrain background processes**
- Constrain the final state through **exclusive measurements**
- Use **momentum transfer** for kinematic separation

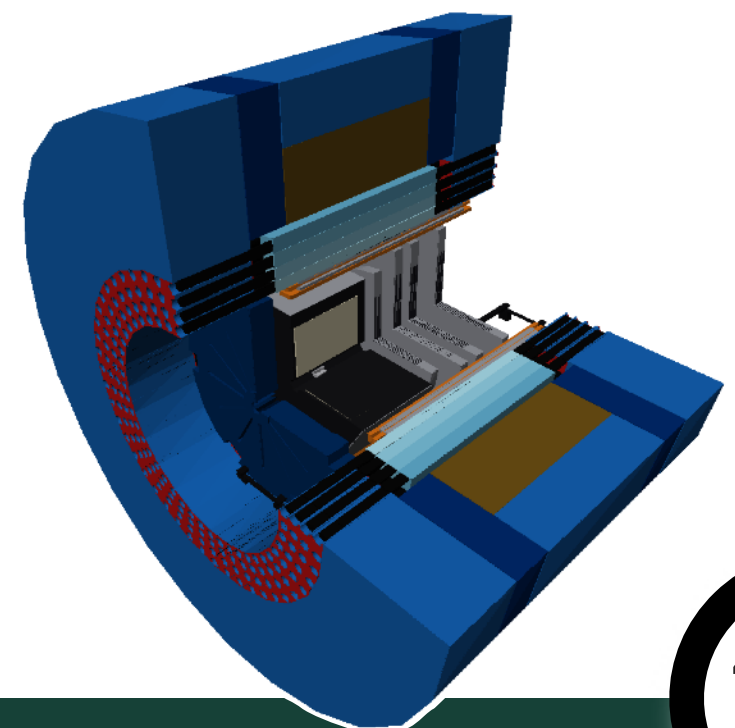


Exclusive measurement

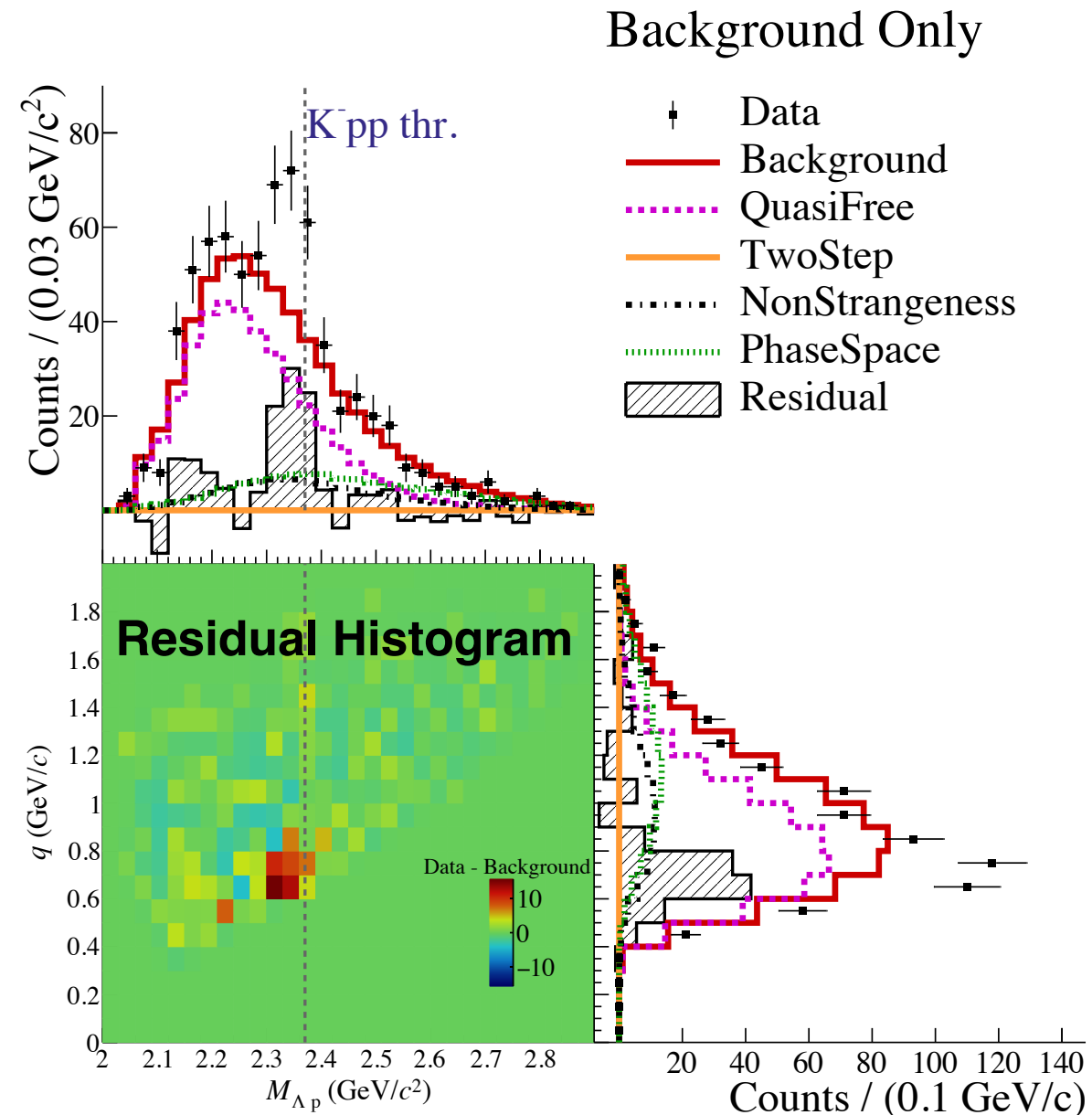
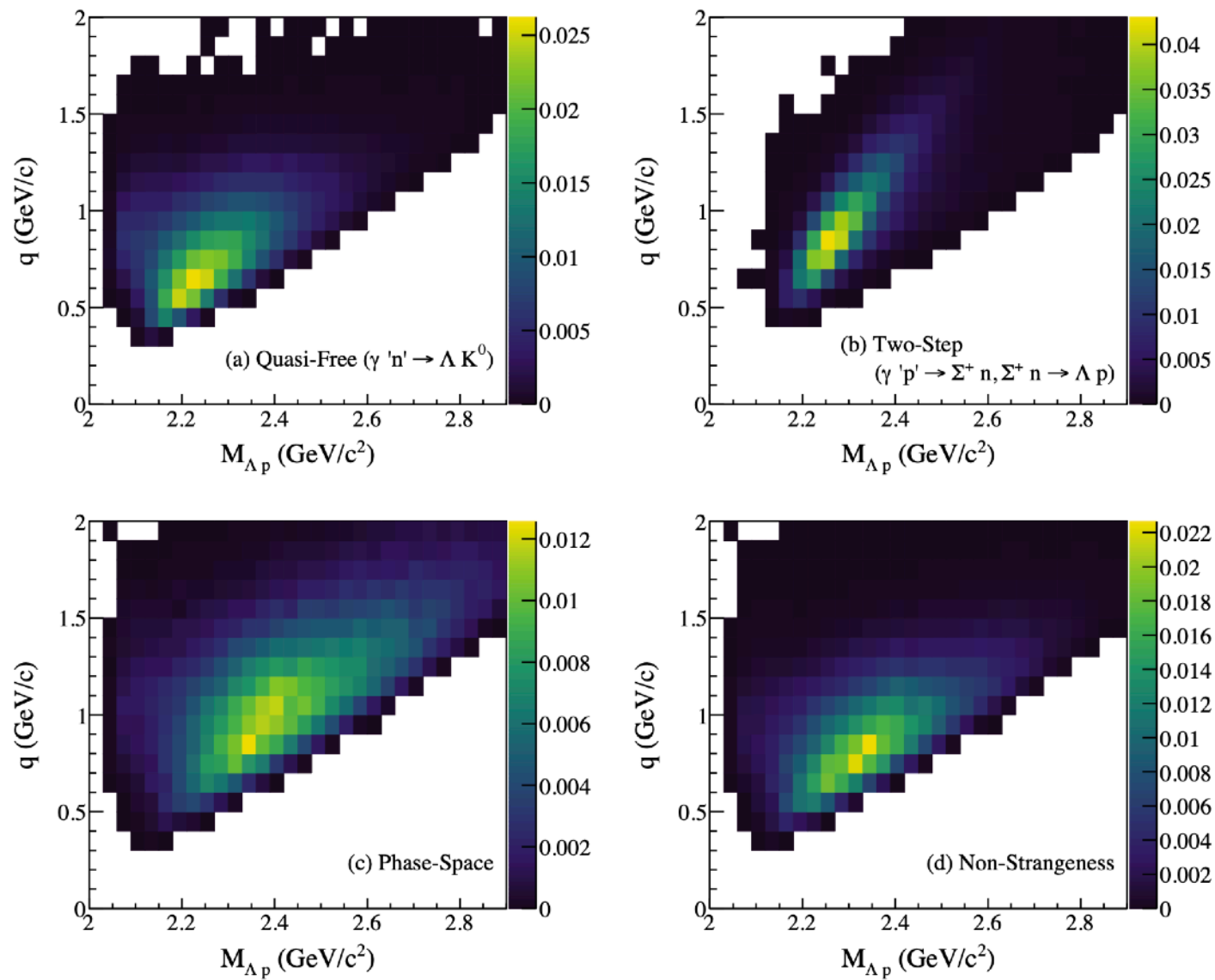
$$\gamma d \rightarrow K^0 \Lambda p$$

$$E_\gamma = 1.3 - 2.4 \text{ GeV}$$

LEPS2@SPring-8



Background-only hypothesis



A Localized Low- q Component Is Required

Summary of Previous $\bar{K}NN$ Searches

Kaon

stopped

FINUDA @DAΦNE
AMADEUS @DAΦNE

Many backgrounds from multi-NA

In-flight

E15 @J-PARC

Neutron knockout reaction,
Good S/N by selecting q value.

Pion

E27 @J-PARC

Many backgrounds from
hyperon production
Improve S/N by tagged side-way protons.

Proton

DISTO @SATURNE
HADES @GSI

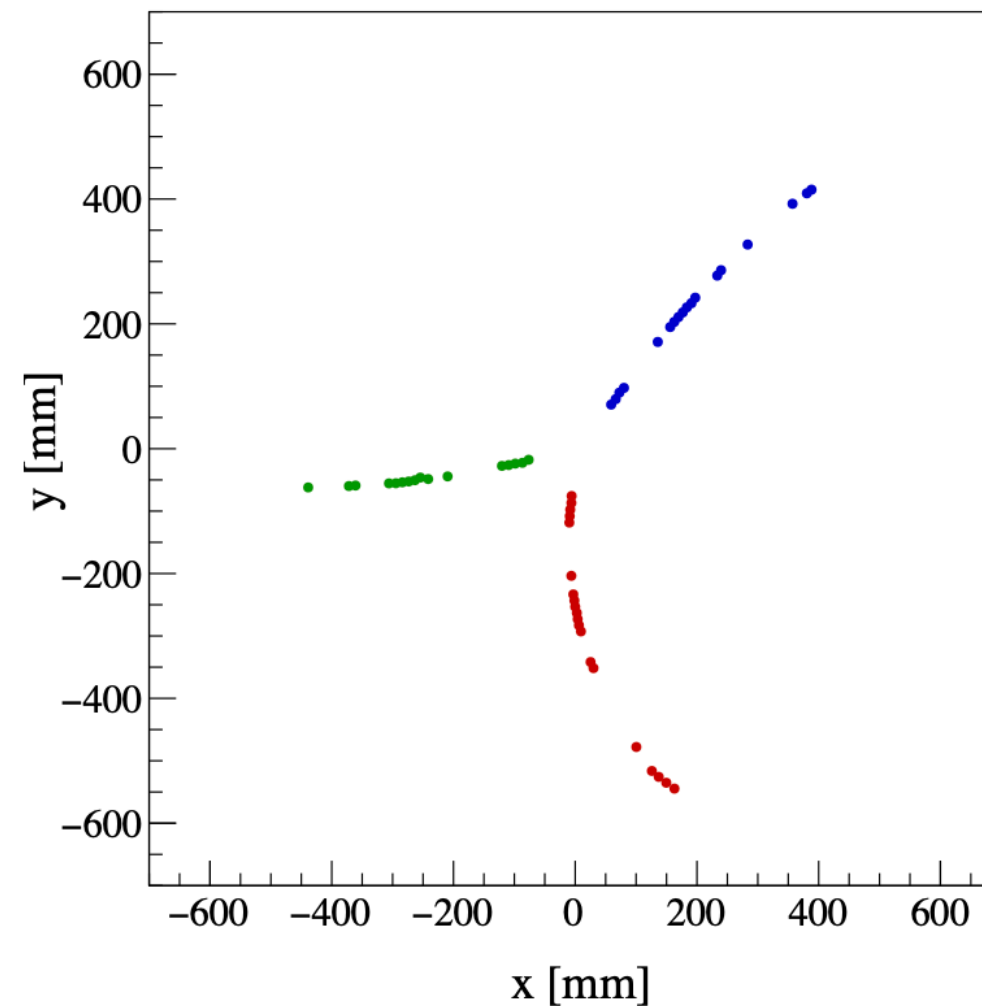
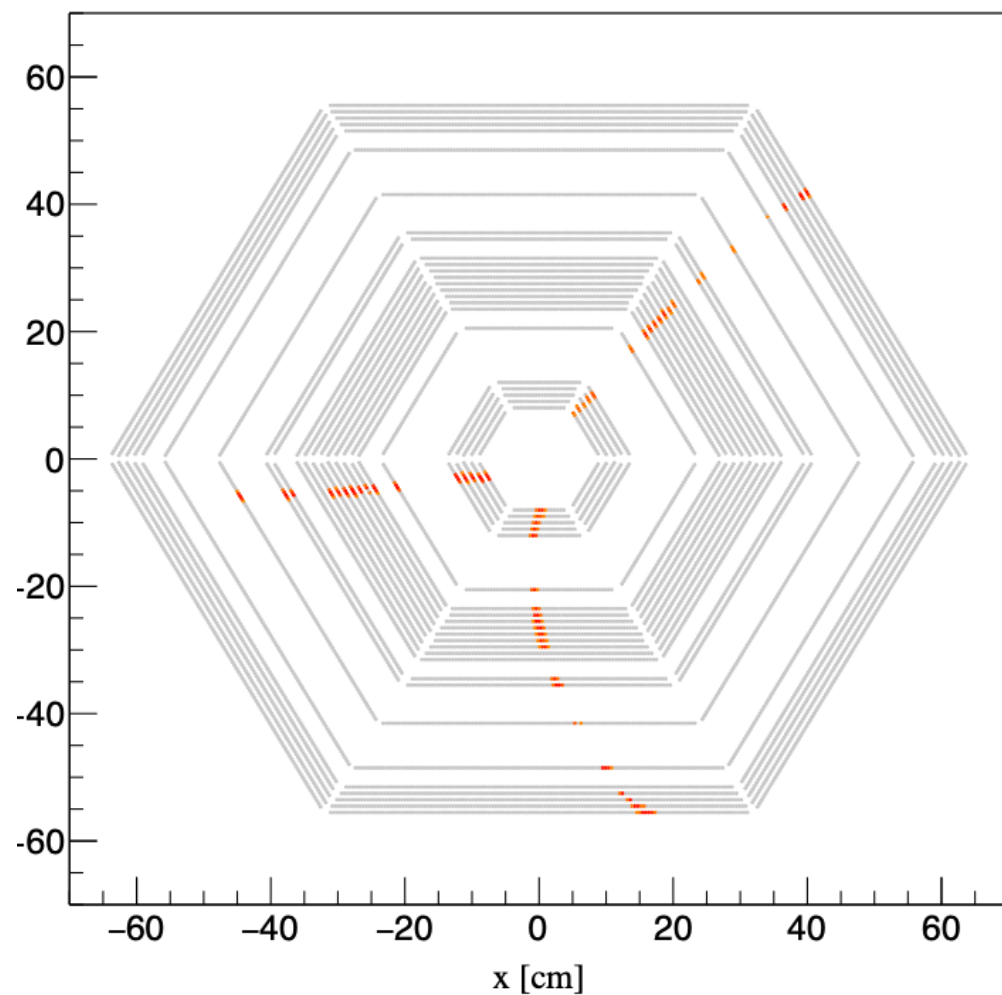
Exclusive $pp \rightarrow K^+ \Lambda p$
Need to consider $N^* \rightarrow K^+ \Lambda$

Photon

LEPS @SPring-8

Many backgrounds from hyperon production

TPC Event Display Run 012800 Event 112 nHit 200



Obtain reconstruct momentum ($\Delta p/p \sim 3\text{-}5\%$)

$p\bar{p}$ system (Baryonium)

• Strong $p\bar{p}$ attraction

- Strong attraction in the $l = 0, S = 0$ channel.

(OPE : Three times stronger than the deuteron channel.

→ possible $p\bar{p}$ baryonium.

B.S. Zou and H.C. Chiang, Phys. Rev. D 69, 034004 (2004)

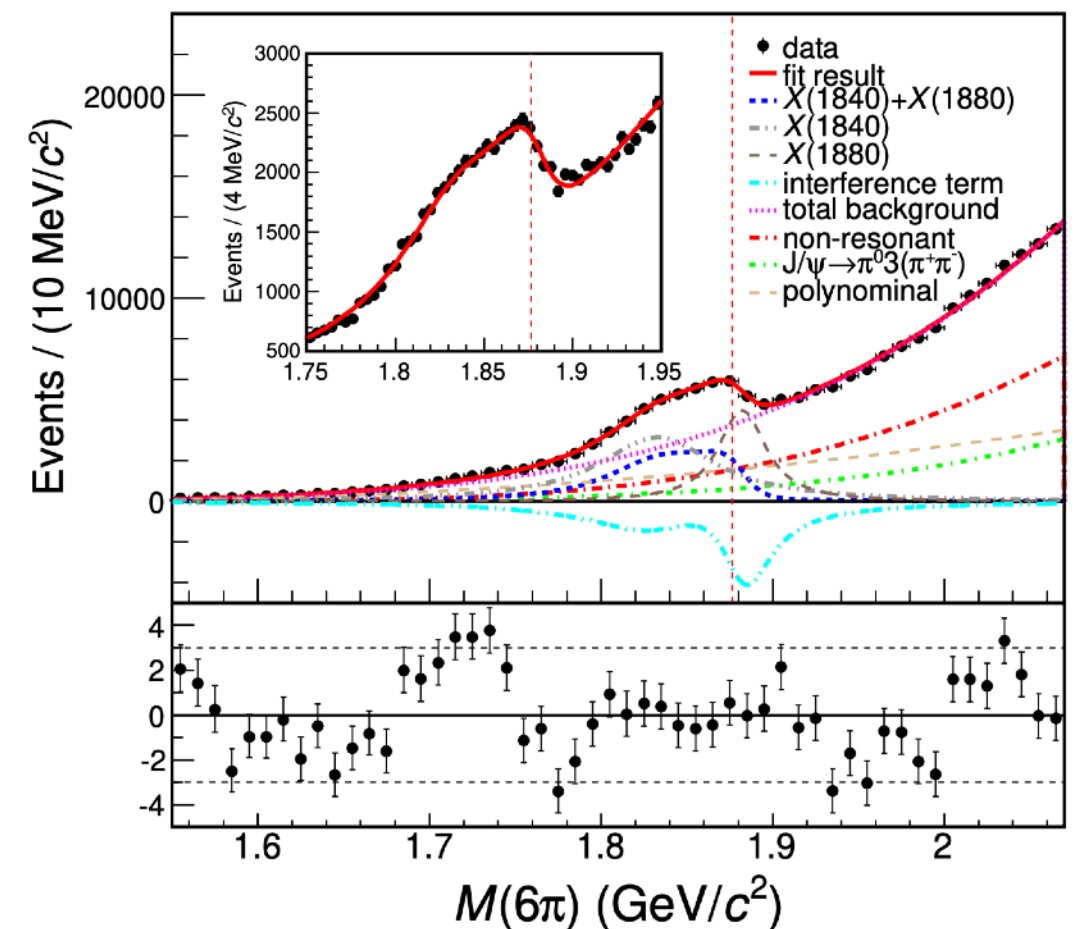
• Annihilation problem

- Dominant final states : 4-7 mesons

→ Difficult spectroscopy

M.-L. Yan, arXiv:hep-ph/0605303 (2006)

BESIII Collaboration

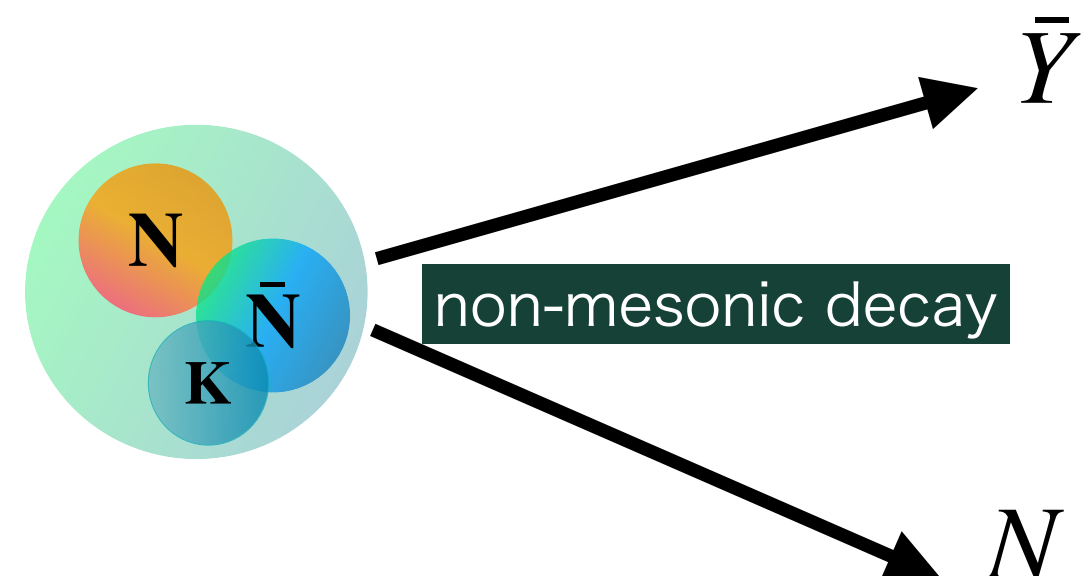
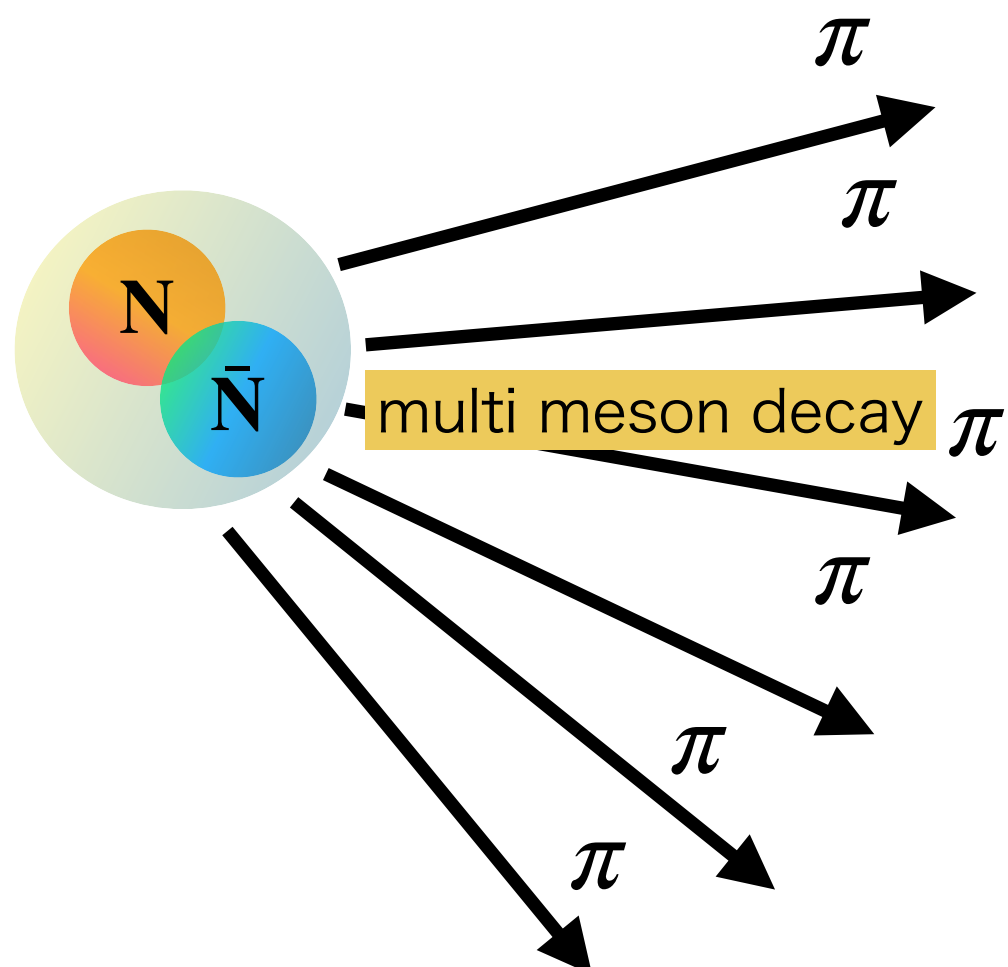


M. Ablikim et al. (BESIII), Phys. Rev. Lett. 132, 151901 (2024)

Why add a "Kaon" to $p\bar{p}$ system?

Advantages of introducing a K meson

- A possible $p\bar{p}$ bound state mainly decays via multi-meson annihilation
- Adding a K meson open baryonic decay channels such as $\bar{Y}N$.



Previous Experimental Result

WA 60–79 (1979) Baryonium and Strangeonium production
Bari, Birmingham, CERN, Milan, Paris-6, Pavia.

[https://doi.org/10.1016/0550-3213\(83\)90564-3](https://doi.org/10.1016/0550-3213(83)90564-3)

EVIDENCE FOR RESONANT STRUCTURES IN THE $\Lambda\bar{p}$ SYSTEM

Bari⁽¹⁾-Birmingham^(2,)-CERN⁽³⁾-Milan⁽⁴⁾-Paris^(5,**)-Pavia⁽⁶⁾ Collaboration*

WA60

$$K^-p \rightarrow \Lambda\bar{p}p$$

An analysis of the $\Lambda\bar{p}$ system produced forward in the reaction $K\bar{p} \rightarrow \Lambda\bar{p}p$ at 18.5 GeV/c is presented. The data come from an experiment using the CERN Ω' spectrometer. Structures are observed in the $\Lambda\bar{p}$ mass spectrum and in the double moments H_{LMlm} describing the decay of the $\Lambda\bar{p}$ system and the subsequent Λ decay, for $L \leq 8$. A partial wave analysis interprets these structures as resonances of spin parities 2^- and 3^+ , masses and widths $M = 2200 \pm 40$ MeV, $\Gamma = 150 \pm 30$ MeV and $M = 2330 \pm 40$ MeV, $\Gamma = 150 \pm 30$ MeV respectively.

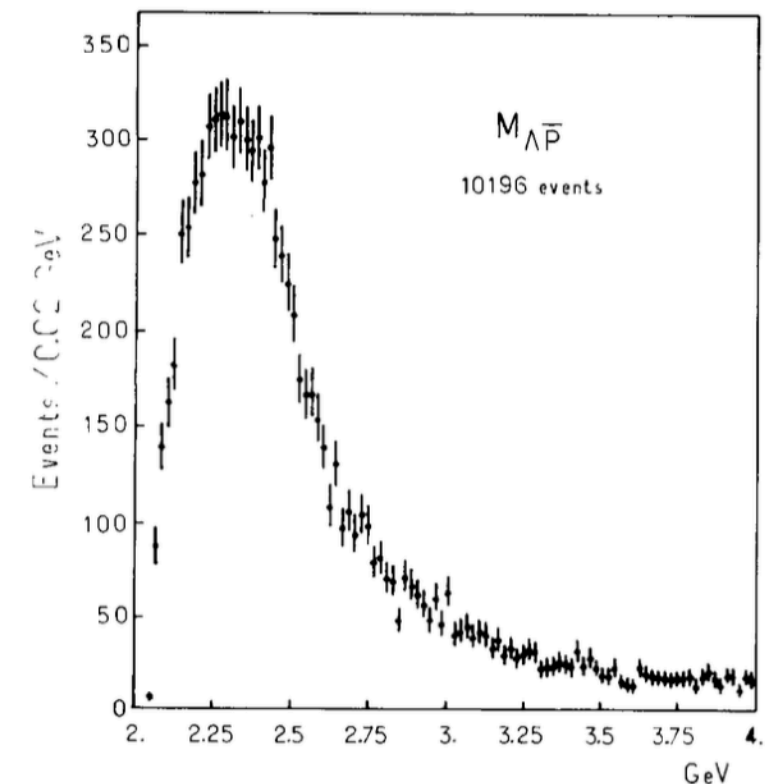


Fig. 4. Effective mass spectrum of the $(\Lambda\bar{p})$ system (uncorrected for acceptance).

The $K^*(2250,2320)$ States

$$K^- p \rightarrow \Lambda \bar{p} p$$

DOI: 10.1016/0550-3213(83)90564-3

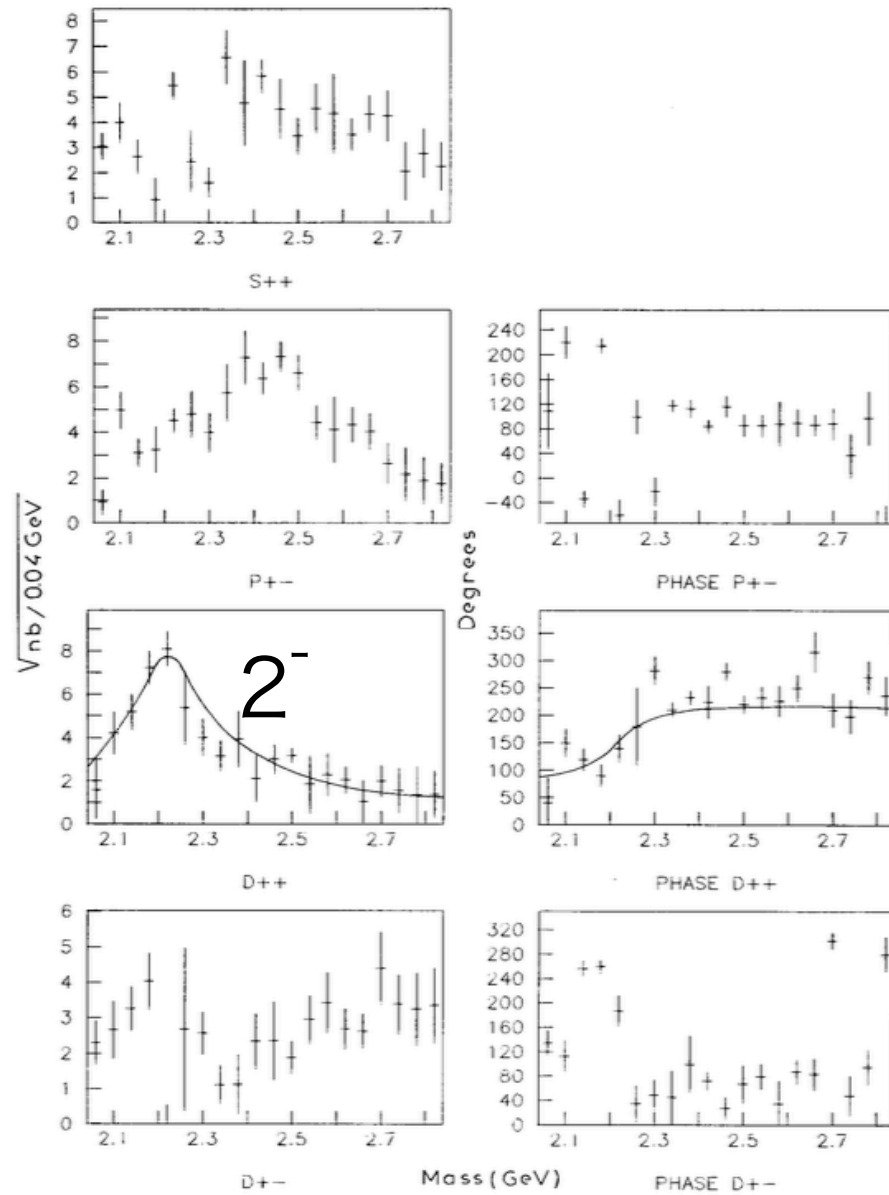


Fig. 9 (continued).

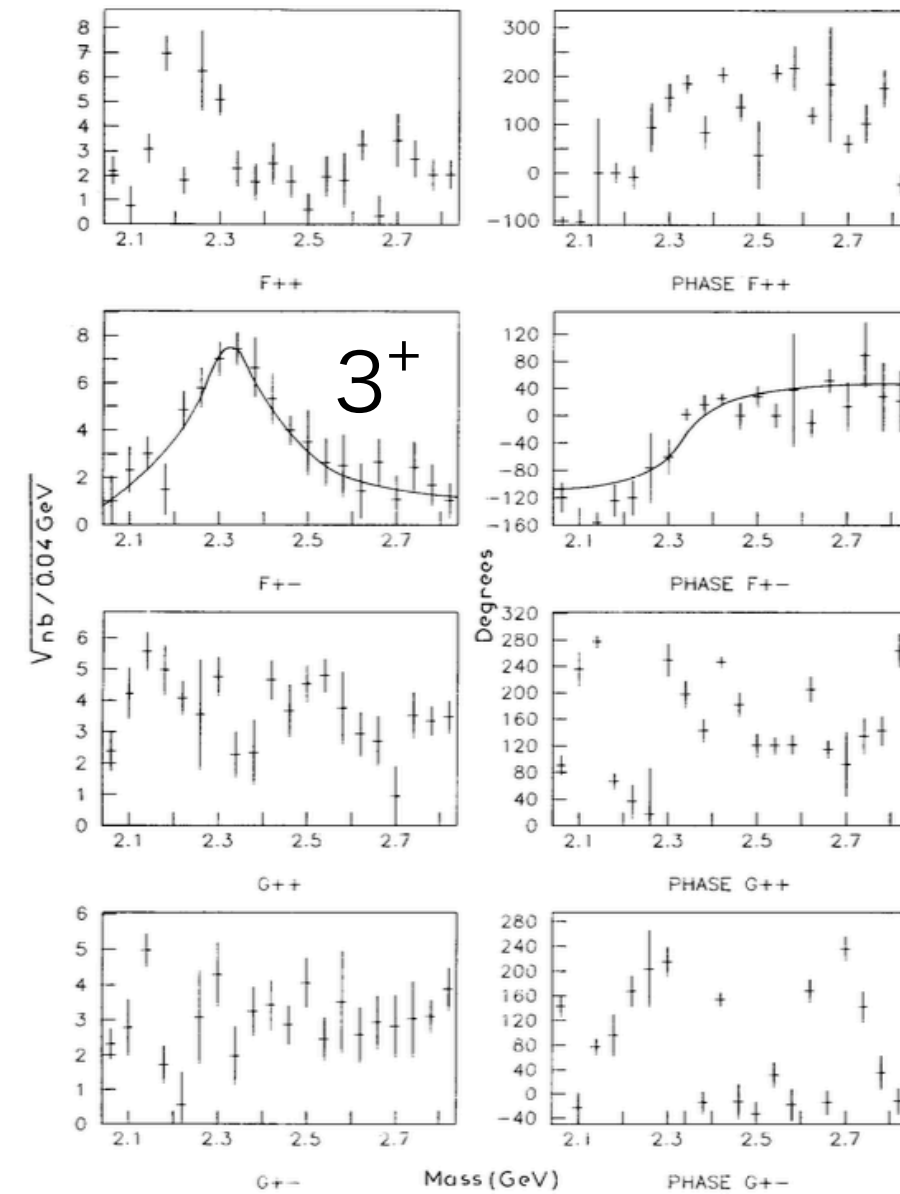


Fig. 9. Moduli and phases of the fitted waves. The curves show the Breit-Wigner functions with the fitted parameters given in table 1.

K(2)(2250)

K(3)(2320)

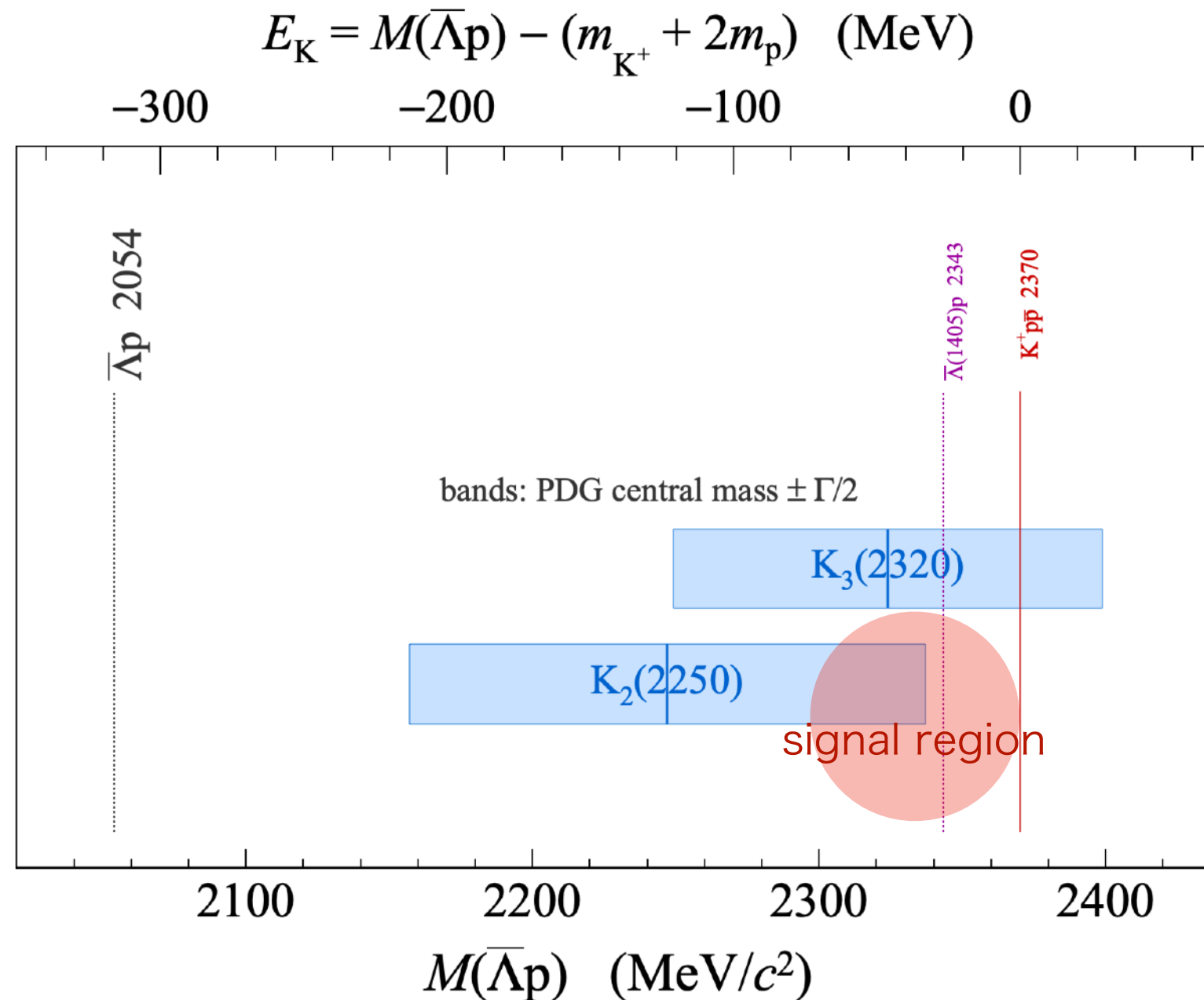
PDF

pdgLive

PDF

pdgLive

Discrimination from the $K^*(2250, 2320)$ States



- Kinematic selection to enhance bound-state formation
- Determination of spin-parity (separate from the $K^*(2^-, 3^+)$)

Similar few body system

$KN\bar{K}$ vs $KN\bar{N}$

$K\Lambda(1405)$ configuration of the $K\bar{K}N$ system

A. Martínez Torres¹ and D. Jido¹

¹*Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*

(Dated: October 30, 2018)

We study the $K\Lambda(1405)$ configuration of the $K\bar{K}N$ system by considering $K\pi\Sigma$ as a coupled channel. We solve the Faddeev equations for these systems and find confirmation of the existence of a new N^* resonance around 1920 MeV with $J^\pi = 1/2^+$ predicted in a single-channel potential model and also found in a Faddeev calculation as an $a_0(980)N$ state, with the $a_0(980)$ generated in the $K\bar{K}, \pi\eta$ interaction.

Pairwise interaction	$K\bar{K}N$ system	$KN\bar{N}$ system
Attractive pair I	$\bar{K}N \rightarrow \Lambda(1405)$	$K\bar{N} \rightarrow \bar{\Lambda}(1405)$
Repulsive pair	KN	KN
Attractive pair II	$K\bar{K} \rightarrow a_0(980)$	$N\bar{N} \rightarrow \text{Baryonium?}$

p_{beam}	6 GeV/c
標的	液体 D_2 , 長さ 20 cm
n_d	$9.75 \times 10^{23} \text{ cm}^{-2}$
$I_{\bar{p}}$	$1.5 \times 10^6 \text{ s}^{-1}$
T	15 日 = $1.296 \times 10^6 \text{ s}$
$N_{\bar{p}}$	1.944×10^{12}
L_{int}	$1.895 \times 10^{36} \text{ cm}^{-2} = 1.895 \text{ pb}^{-1}$

成分	反応	断面積	生成数 (15 日)	生成数比
信号	$\bar{p}d \rightarrow \Sigma^- X^+, X^+ \rightarrow \bar{\Lambda}p$	10 nb	1.90×10^4	1
BG1	$\bar{p}d \rightarrow \Sigma^- \bar{\Lambda}p$ (コヒーレント)	1 μb	1.90×10^6	100
BG2	$\bar{p}n \rightarrow \Sigma^- \bar{\Lambda}$ (p_{spec})	10 μb	1.90×10^7	1000

Kinematic Separation of Signal and Background

$$\bar{p}d \rightarrow \Sigma^- X^+, X^+ \rightarrow p \bar{\Lambda}$$

$$T_{sig} = V(M_{\Lambda p}; M, \Gamma) \exp\left(-\frac{q^2}{Q^2}\right) T_{PS}$$

signal parameters same as $\bar{K}NN$

$$M = 2.35 \text{ GeV}/c^2$$

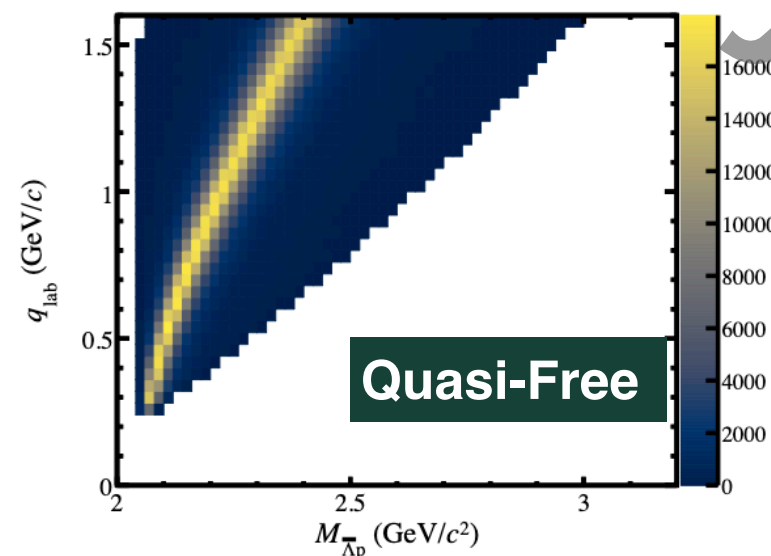
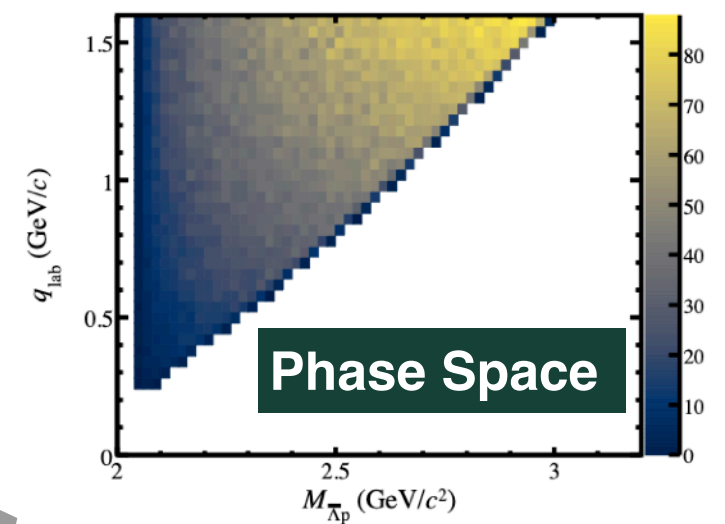
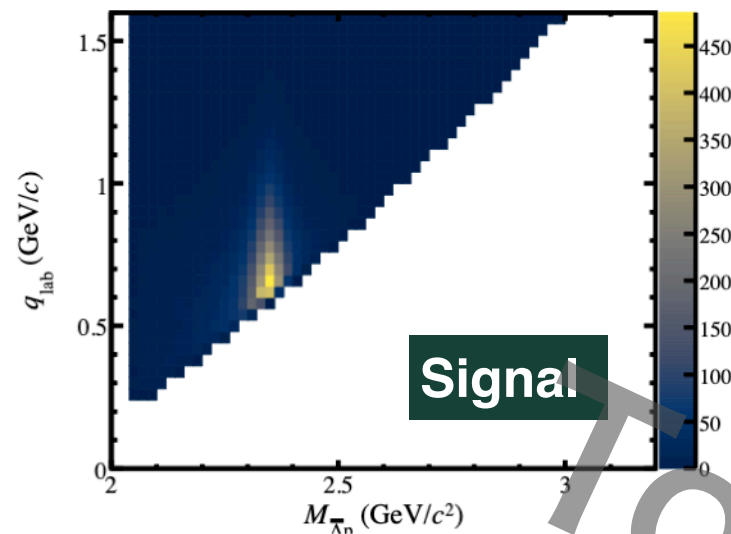
$$W = 0.05 \text{ GeV}/c^2$$

$$Q = 0.35 \text{ GeV}/c$$

$$\bar{p}n(p_{spec.}) \rightarrow \Sigma^- \bar{\Lambda}(p_{spec.})$$

Fermi momentum (AV 18)

$$\bar{p}d \rightarrow \Sigma^- p \bar{\Lambda}$$



$$@ P_{\bar{p}} = 6.0 \text{ GeV}/c$$

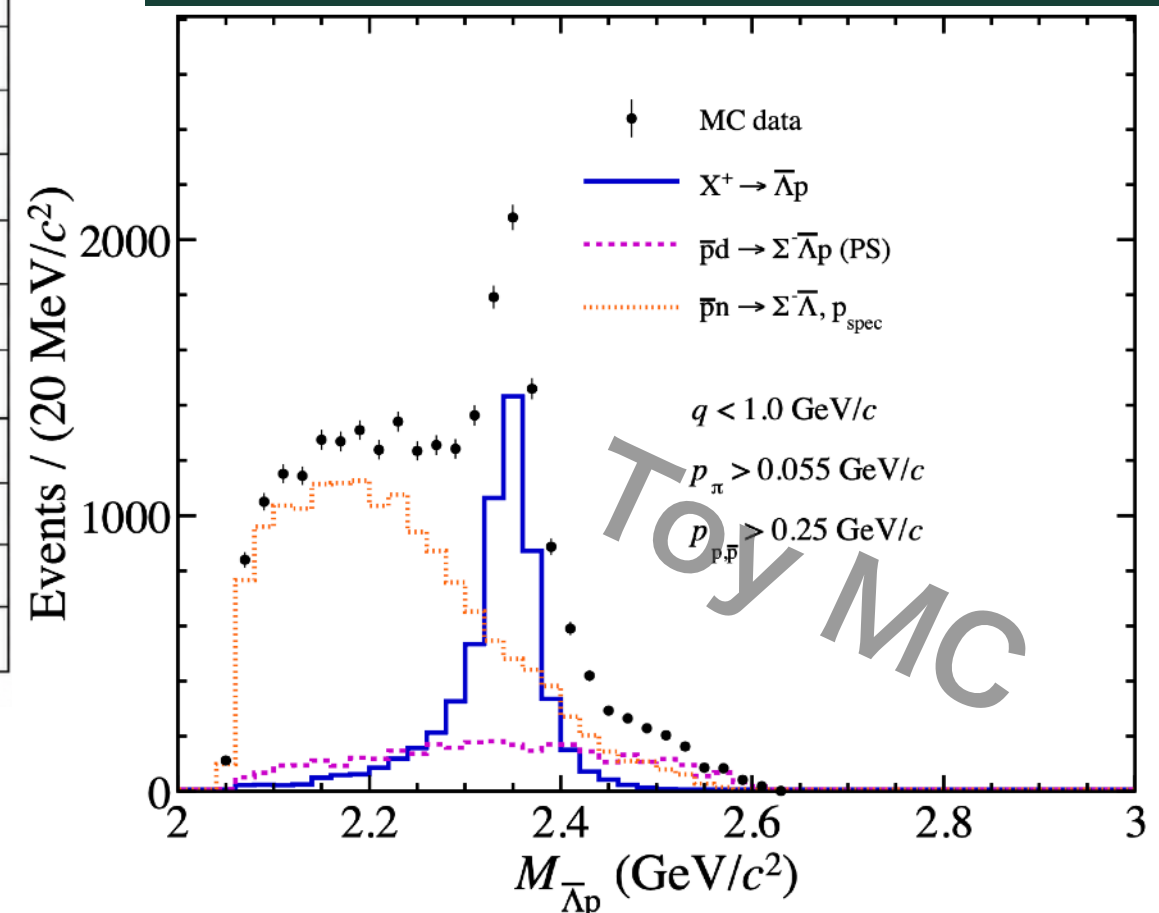
Kinematic Separation of Signal and Background

$$\bar{p}d \rightarrow \Sigma^- p\bar{\Lambda} \quad @ P_{\bar{p}} = 6.0 \text{ GeV}/c$$

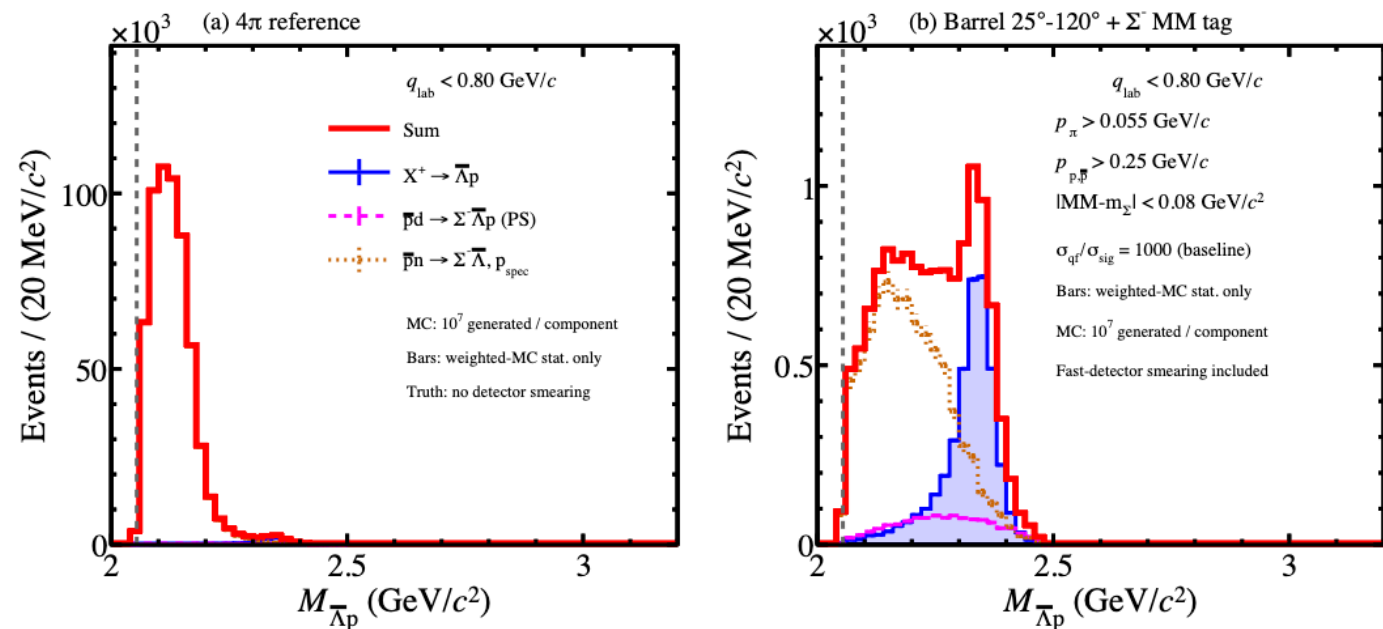
Beam Conditions	
$\bar{p}$ beam momentum	6 GeV/c
Liquid D ₂ target	20 cm
$\bar{p}$ beam rate	$1.5 \times 10^6 \text{ s}^{-1}$
Running time	15 days ($1.296 \times 10^6 \text{ s}$)
Total antiprotons $N_{\bar{p}}$	1.944×10^{12}
Integrated luminosity L_{int}	$1.895 \times 10^{36} \text{ cm}^{-2} = 1.895 \text{ pb}^{-1}$
Assumed Cross Sections	
Signal	10 nb
Quasi-Free	$10 \mu\text{b}$
Phase Space	$1 \mu\text{b}$

(QF : PS : Signal = 1000 : 100 :1)

Low-q region + side $p\bar{\Lambda}$ detected (25-120°)



段階	信号	BG1 (3 体)	BG2 (準自由)
$\bar{\Lambda} \rightarrow \bar{p}\pi^+$ 分岐後	1.211×10^4	1.211×10^6	1.211×10^7
荷電 3 本を $25^\circ\text{--}120^\circ$ で検出	6.584×10^3	3.325×10^5	1.369×10^5
Σ^- missing-mass tag	6.256×10^3	2.190×10^5	1.070×10^5
$q < 0.80 \text{ GeV}/c$	5.648×10^3	7.872×10^3	1.669×10^4

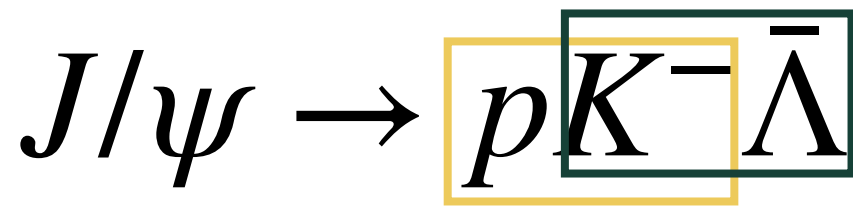


J/ψ Decay reaction

An enhancement near the $m_p + M_\Lambda$ mass threshold is observed in the combined $p\bar{\Lambda}$ and $\bar{p}\Lambda$ invariant-mass spectrum from $J/\psi \rightarrow pK^-\bar{\Lambda} + \text{c.c.}$ decays. It can be fit with an S -wave Breit-Wigner resonance with a mass $m = 2075 \pm 12(\text{stat}) \pm 5(\text{syst})$ MeV and a width of $\Gamma = 90 \pm 35(\text{stat}) \pm 9(\text{syst})$ MeV; it can also be fit with a P -wave Breit-Wigner resonance. Evidence for a similar enhancement is also observed in $\psi' \rightarrow pK^-\bar{\Lambda} + \text{c.c.}$ decays. The analysis is based on samples of $5.8 \times 10^7 J/\psi$ and $1.4 \times 10^7 \psi'$ decays accumulated in the BES II detector at the Beijing Electron-Positron Collider.

DOI: 10.1103/PhysRevLett.93.112002

PACS numbers: 12.39.Mk, 12.40.Yx, 13.20.Gd, 13.75.Ev



Λ1520 and 1690 , N*

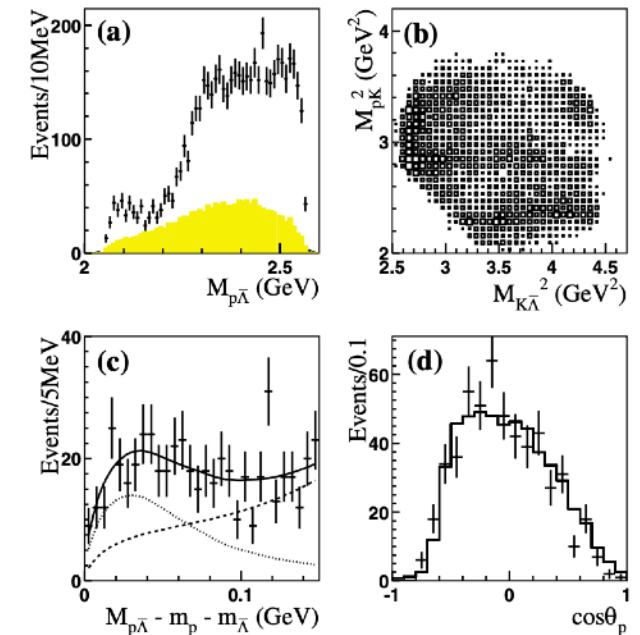
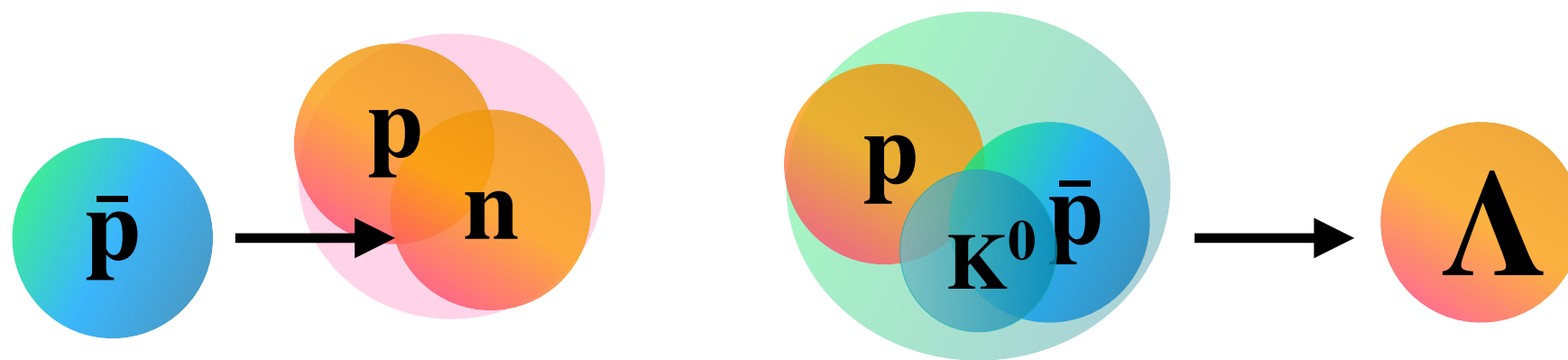
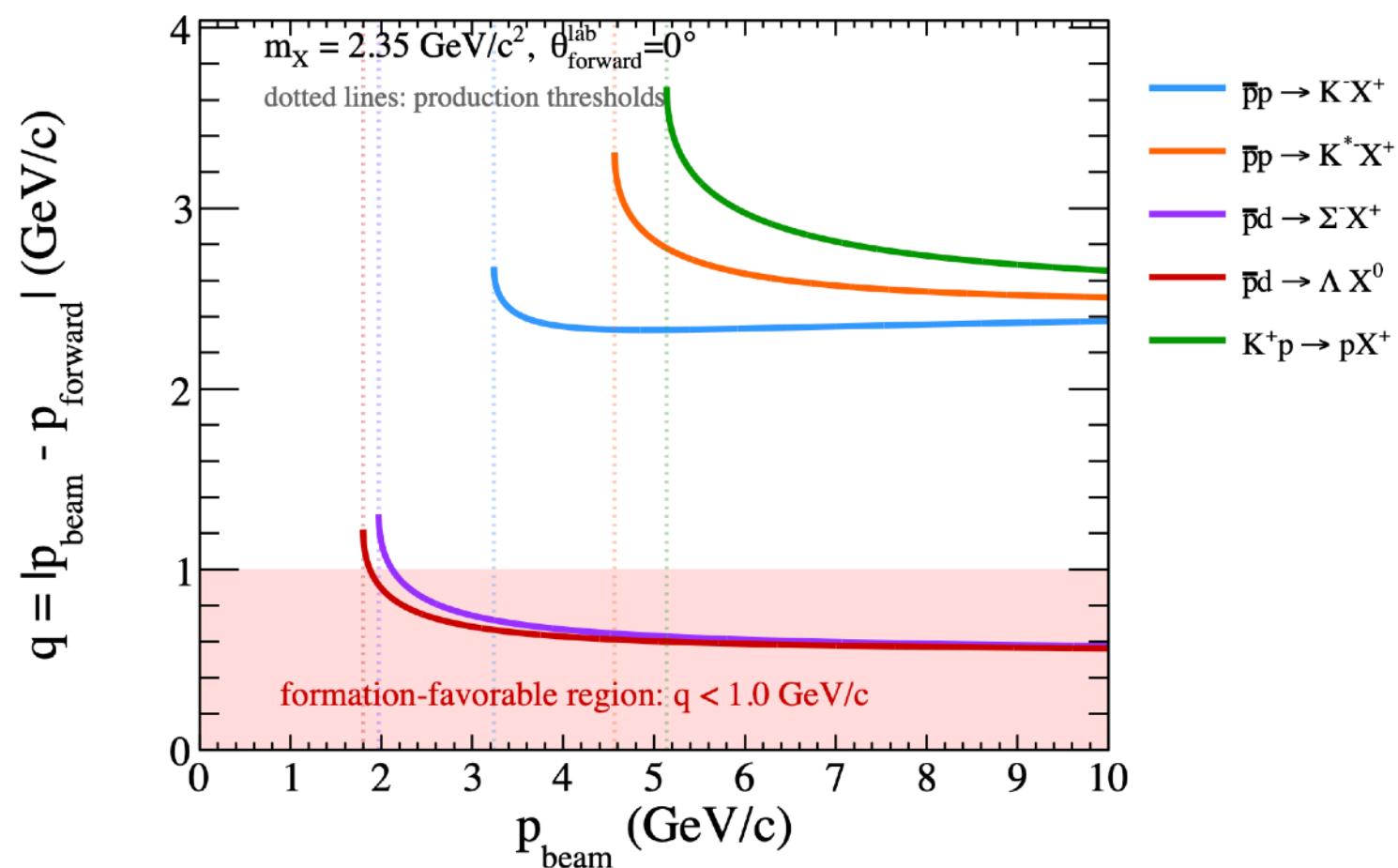
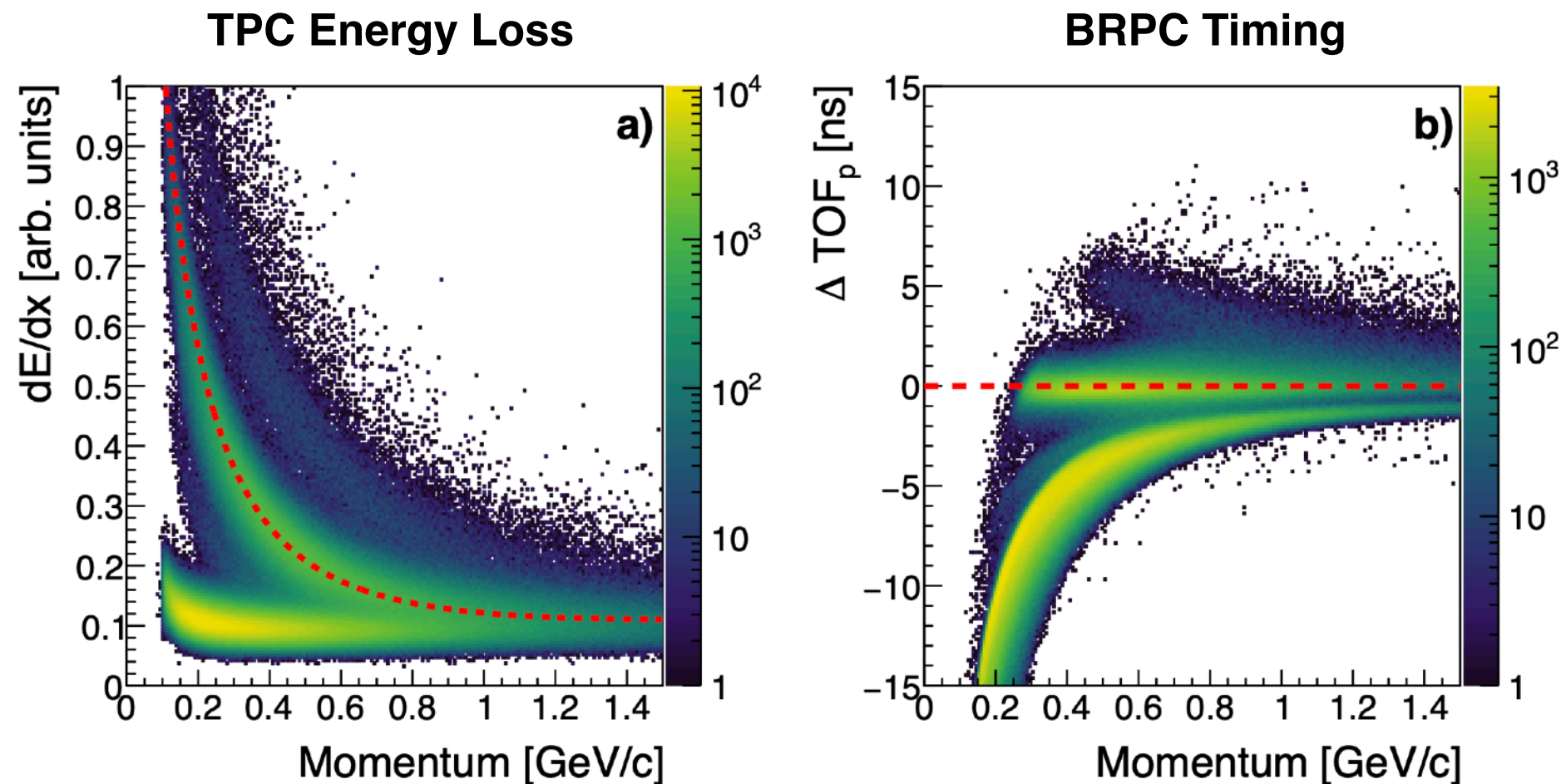


FIG. 2 (color online). (a) The points with error bars indicate the measured $p\bar{\Lambda}$ mass spectrum; the shaded histogram indicates phase-space MC events (arbitrary normalization). (b) The Dalitz plot for the selected event sample. (c) A fit (solid line) to the data. The dotted curve indicates the Breit-Wigner signal and the dashed curve the phase-space background. (d) The $\cos\theta_p$ distribution under the enhancement; the points are data and the histogram is the MC (normalized to data).

The Kinematics of Reactions





$$L_{TPC}(H_i) = \mathcal{N}(\Delta dEdx_i(p); 0, \sigma_{dEdx}(p)) \quad L_{BRPC} = \mathcal{N}(\Delta ToF_i; 0, \sigma_{ToF})$$

$$L(H_i) = L_{TPC} \times L_{BRPC}.$$

$$P_p = \frac{L(H_p)}{\sum_{i=\pi, K, p, d} L(H_i)} > 0.1$$