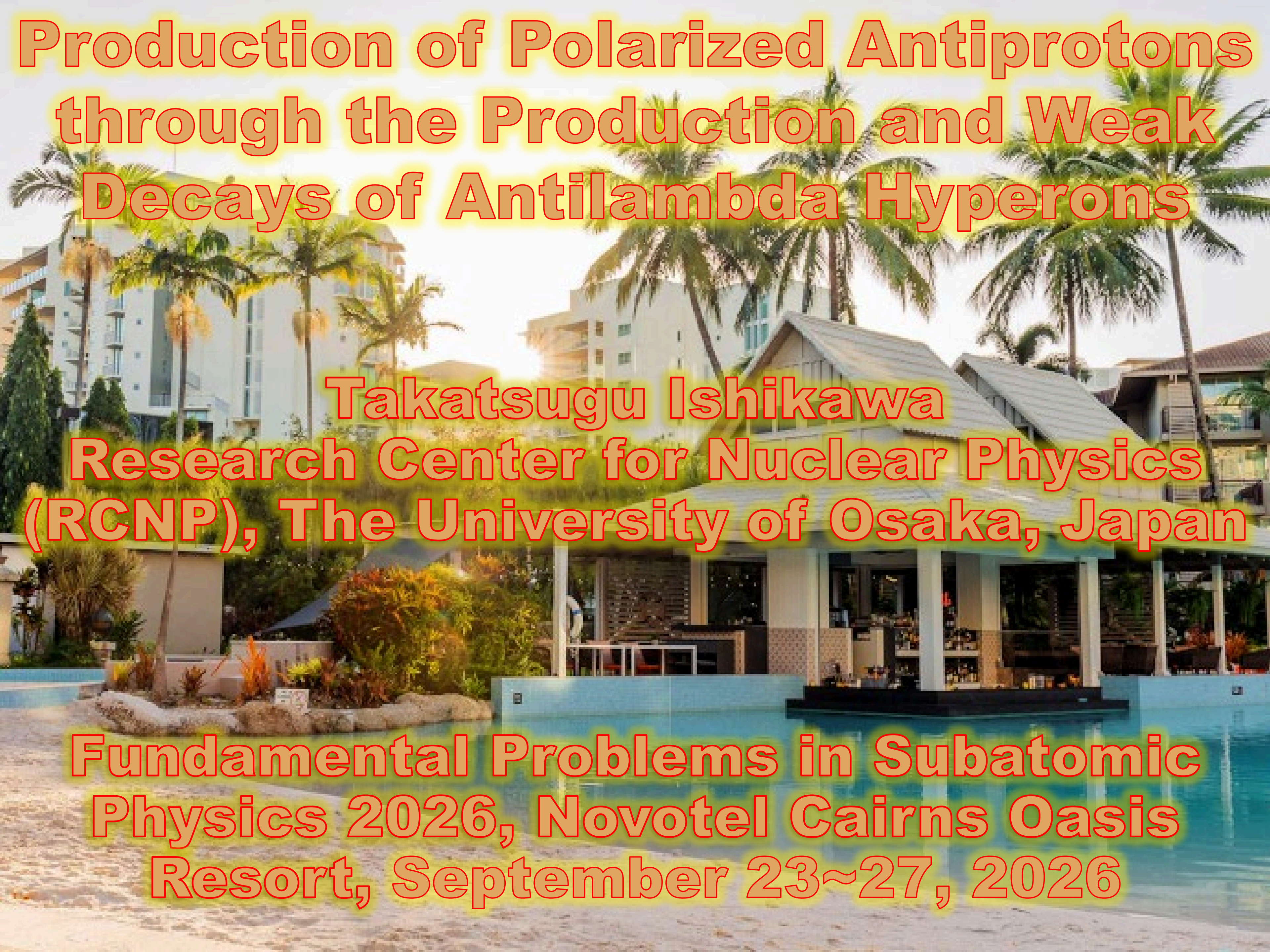

Production of Polarized Antiprotons through the Production and Weak Decays of Antilambda Hyperons

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Fundamental Problems in Subatomic Physics 2026, Novotel Cairns Oasis Resort, September 23~27, 2026

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Introduction

Physics with antiprotons

Why polarized antiprotons?

1. Annihilation ~ glueball/resonance
   $\bar{p}p \rightarrow \bar{\Lambda}\Lambda, \bar{\Sigma}\Sigma, \bar{\Xi}\Xi, \bar{\Omega}\Omega, \pi^+\pi^-, K^+K^-, \phi\phi$
   cleanest environments for gluon-rich annihilation and quark–antiquark hadronization

2. $\bar{N}N$ interaction ~ partial-wave analysis

Polarization observables provide access to interference between different partial waves.

Analyzing power

P_y perpendicular to the momentum vector gives the following cross section

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \left[1 + P_y A_y(\theta)\right],$$

yielding the left-right asymmetry:

$$(N_L - N_R)/(N_L + N_R) = P_y A_y(\theta)$$

$A_y(\theta) \Rightarrow$ interference between different initial-state partial-wave amplitudes

Unpolarized vs polarized

Unpolarized data:

$d\sigma/d\Omega$, excitation function, spin-density matrix elements $\rho_{\lambda\lambda'}$

Polarized data

spin correlations, which have direct sensitivity to interference and relative phases

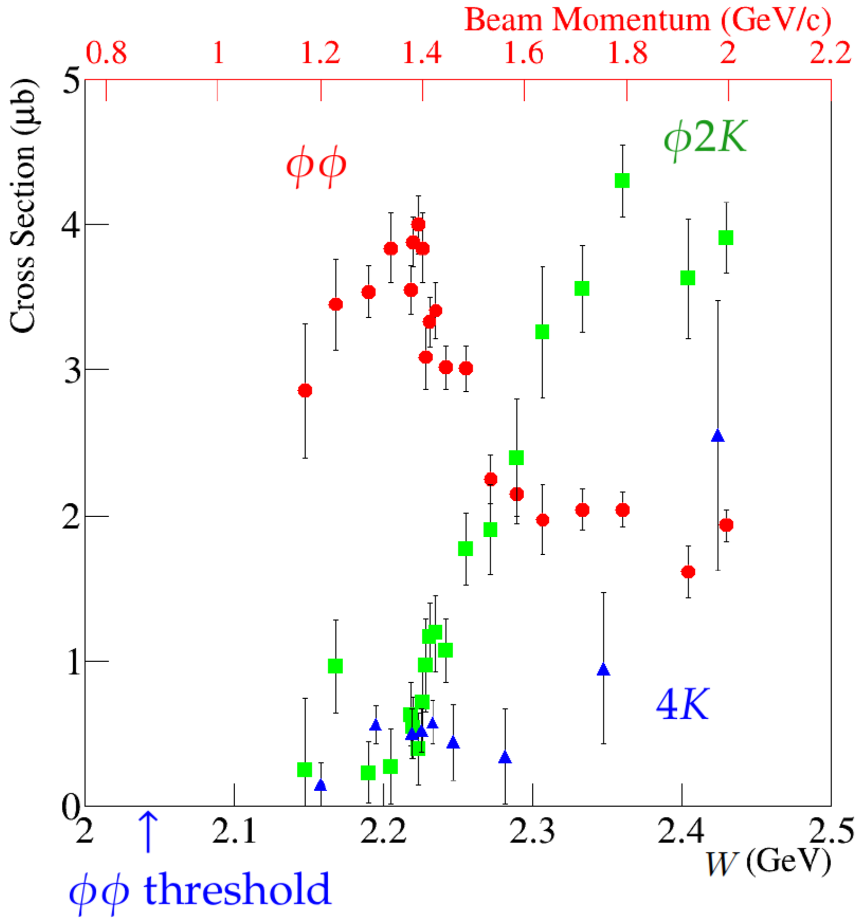
1) essential for partial-wave decomposition
2) stronger constraints on J^{PC} of intermediate resonance

OZI violation

A substantial OZI violation:

$$\sigma(\bar{p}p \to \phi\phi) = \tan^4\delta\theta \cdot \sigma(\bar{p}p \to \omega\omega)$$
$$\simeq 10\ \mathrm{nb}$$

a few μb!



Glueball search

Glueball search in $\bar{p}p \to \phi\phi$

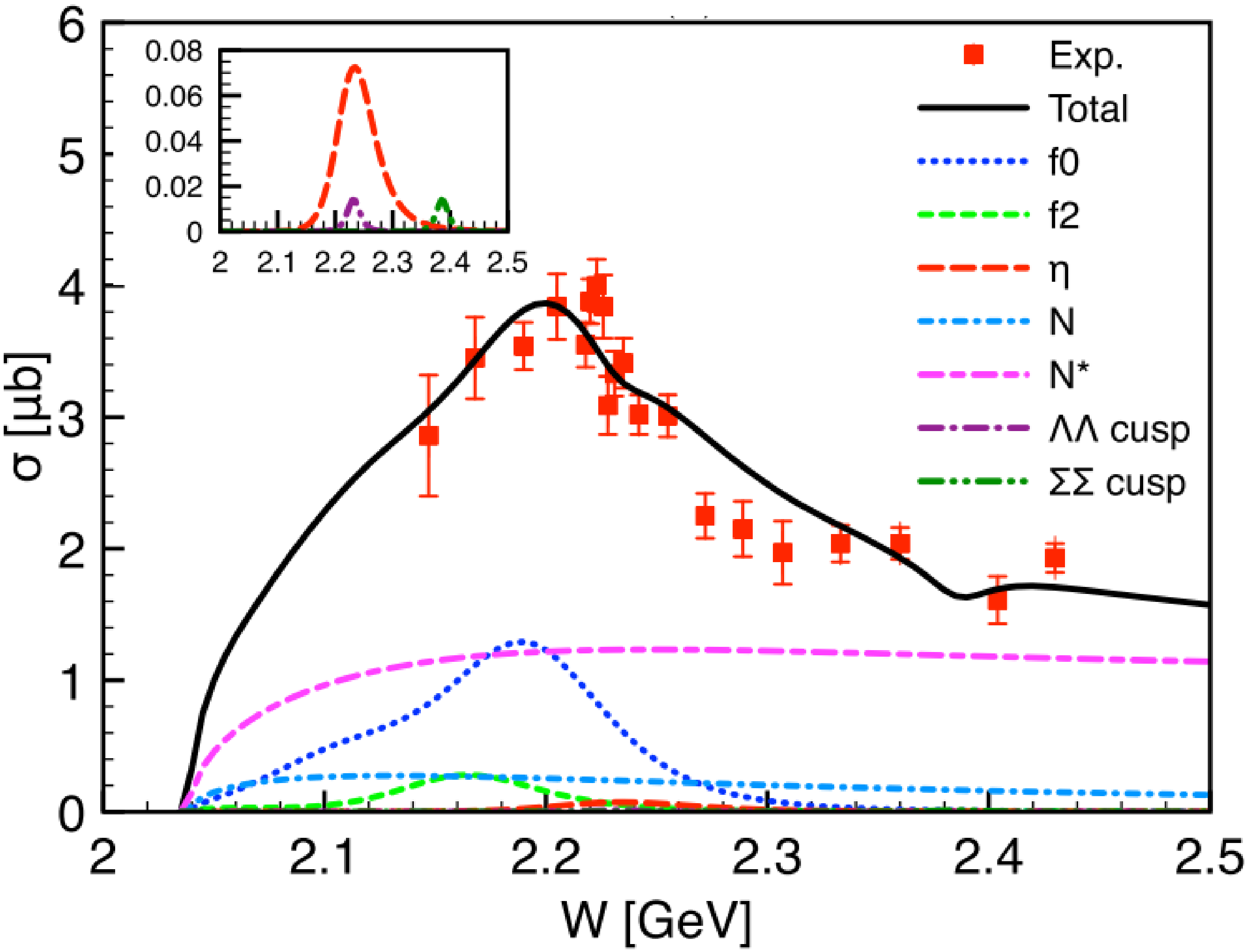
Glueballs are fundamental states predicted by QCD, dominated by gluonic degrees of freedom

$\bar{p}p \to \phi\phi$ is a promising channel
- unexpectedly large cross section
- gluon-rich annihilation process
- sensitive to resonances with several J^{PC}s

But a peak alone is not sufficient.
$\to$ identification requires J^{PC}, phase motion and interference

Expected excitation function

D. Lee, J.K. Ahn, S.-i. Nam, Phys. Lett. B 866, 139528 (2025)



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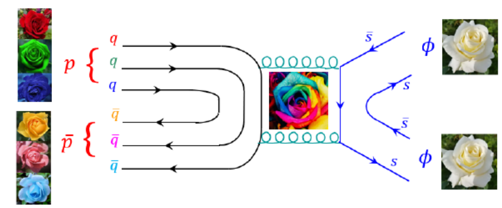
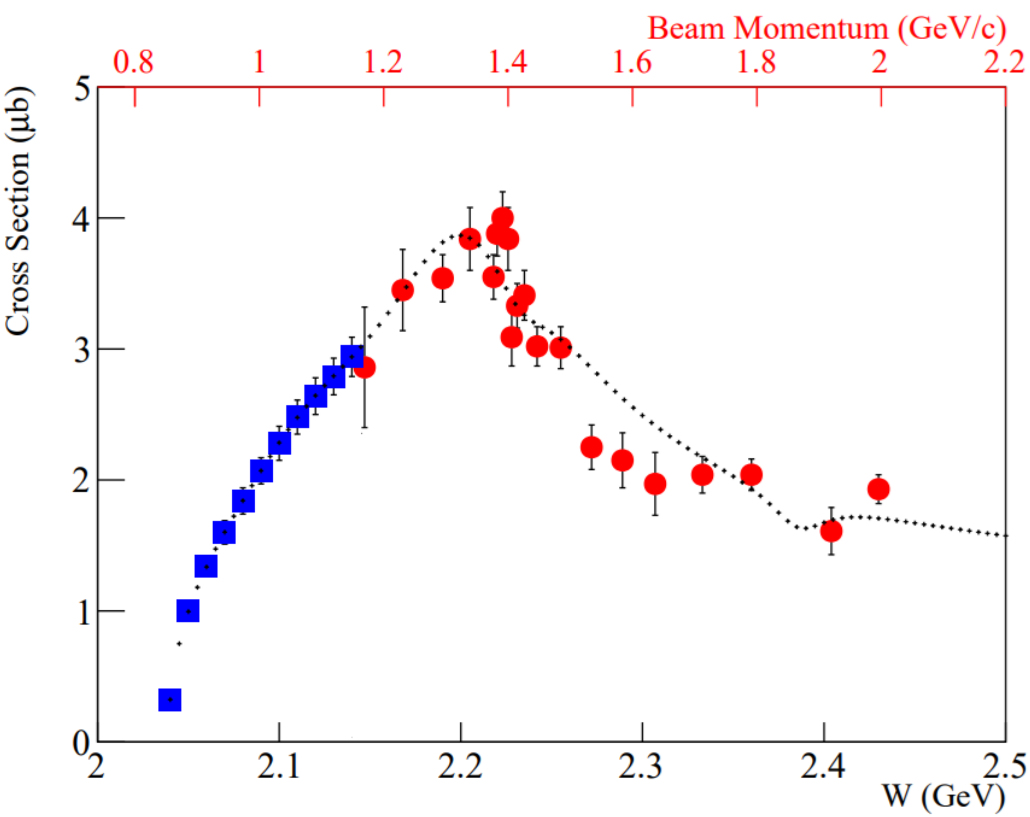
New J-PARC experiment

Double ϕ Production in $\overline{p}p$ Reactions near Threshold



Spokesperson	Jung Keun Ahn (Korea University)
Beam line	K1.8BR
Beam	$\overline{p}$/0.87–1.17 GeV/c
	(W = 2.04–2.14 GeV in 10 MeV increments)
Beam Intensity	2.7×10^5/ spill (4.24 s spill duration)
Target	Liquid hydrogen (80 mm ϕ)
Reaction	$\overline{p}p \rightarrow \phi\phi$
Detector	Hyperon Spectrometer (HypTPC)
Beam time	9 days
	(0.5 days for trigger study and 8.5 days for physics runs)
Expected yield	3×10^3 events



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25 September 2026

pp and $\bar{p}p$

The signs of pp and $\bar{p}p$ scattering amplitudes:

opposite for σ, ρ exchanges ($G = +$)

same for π, ω exchanges ($G = -$)

NN interaction: strongly constrained by extensive scattering data

$\bar{N}N$ interaction: annihilation + different G-parity structure

How well do we actually know the individual $\bar{N}N$ partial waves?

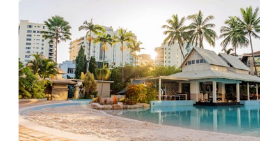
How is the origin of the repulsive core?

$\bar{N}N$ PWA

Nijmegen partial-wave analysis

D. Zhou and R. G. E. Timmermans, PRC 86, 044003 (2012).

- 3749 $\bar{p}p \to \bar{p}p$, $\bar{p}p \to \bar{n}n$ scattering data for $p_{\bar{p}} < 925\,\mathrm{MeV}/c$, giving excellent global description
- However, spin-dependent data are much more limited than for NN scattering
- Polarization data would provide additional constraints on individual partial waves



Production of Polarized Antiprotons

Production of polarized $\bar{p}$s

Three steps

1. Production of secondary $\bar{p}$s
   Unpolarized
2. Production of $\bar{\Lambda}$s from $\bar{p}p \to \bar{\Lambda}\Lambda$
   Polarized
3. Decay of $\bar{\Lambda}$s into $\bar{p}$s
   Polarized

Production of secondary $\overline{p}$s

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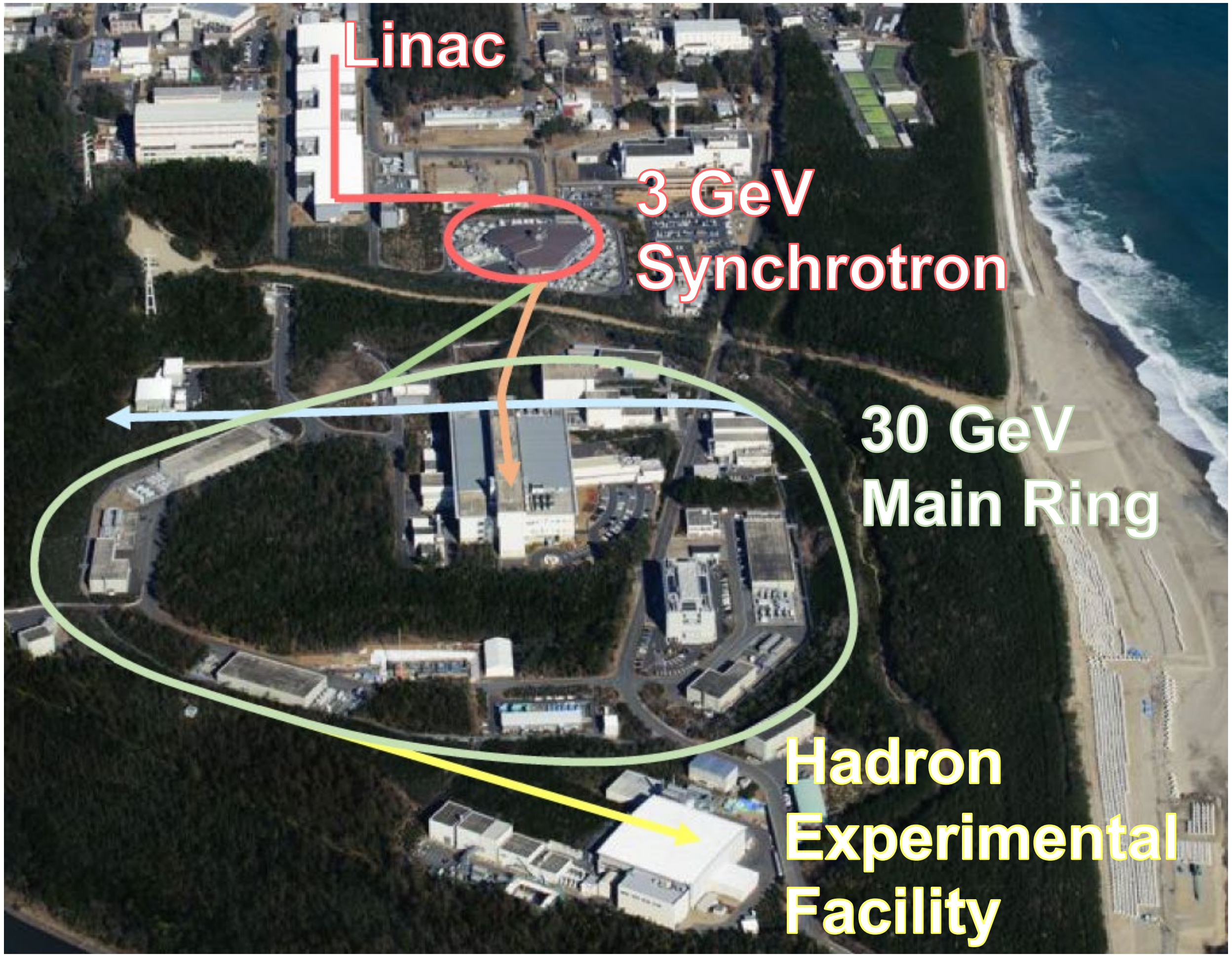
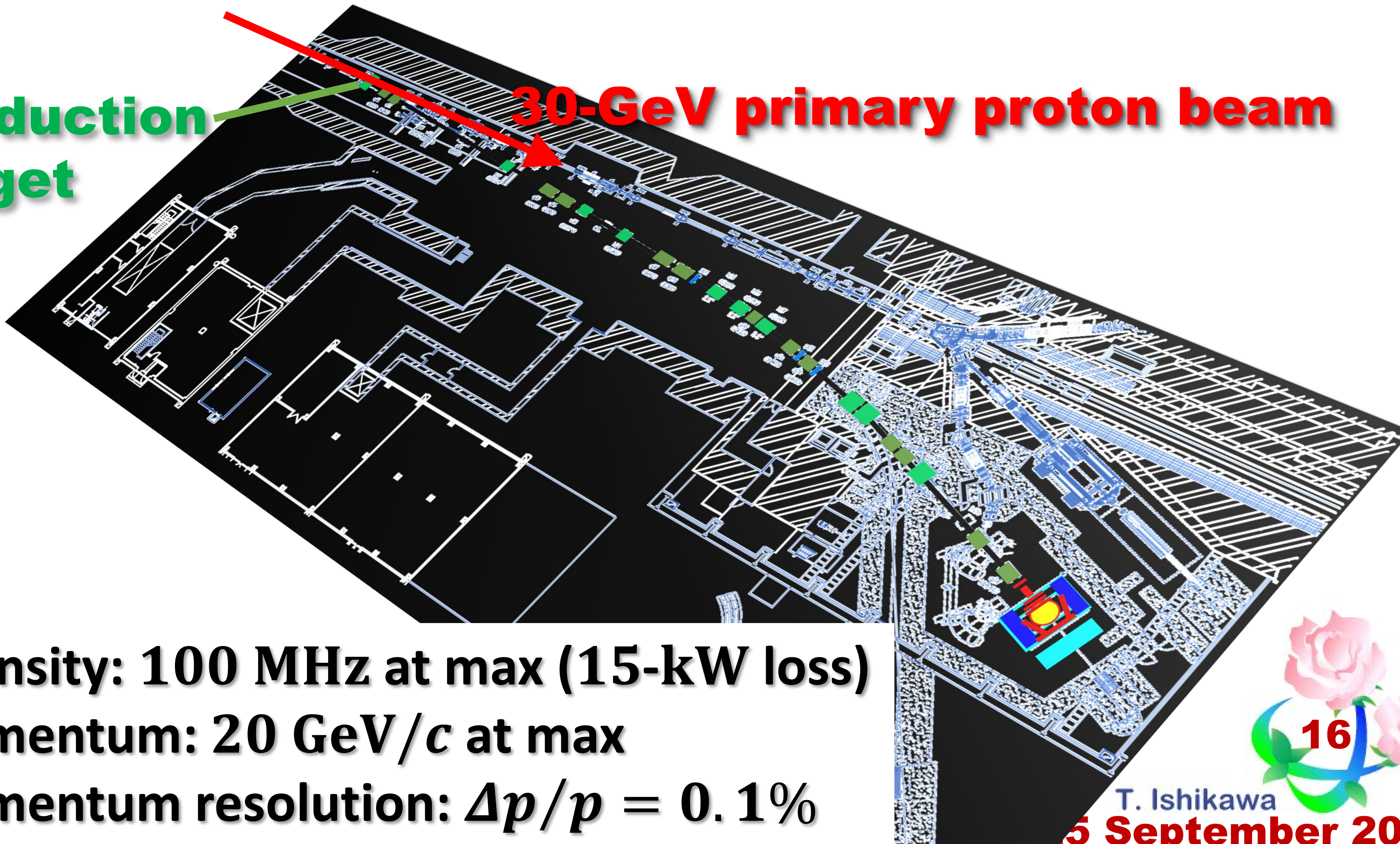
J-PARC

Japan Proton Accelerator Research Complex



Production of secondary $\bar{p}$s

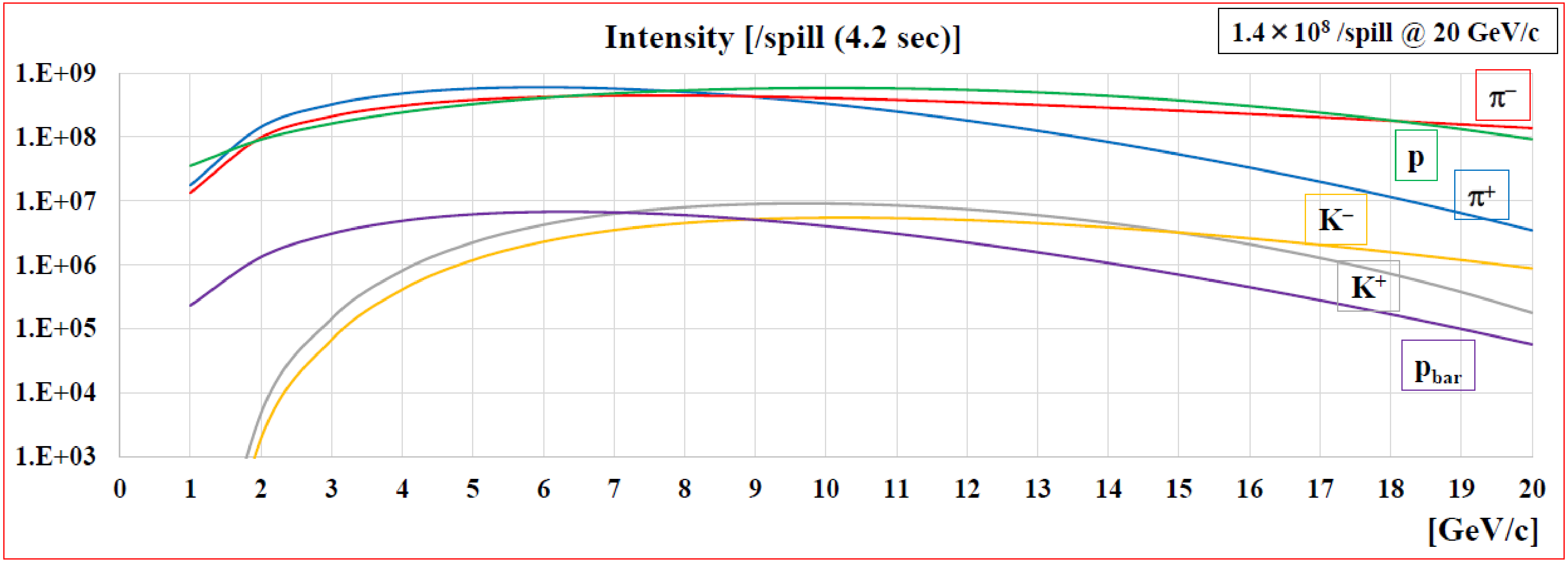
$\pi 20$ beamline: under construction



intensity: $100\ \mathrm{MHz}$ at max (15-kW loss)
momentum: $20\ \mathrm{GeV}/c$ at max
momentum resolution: $\Delta p/p = 0.1\%$

Production of secondary $\overline{p}$s

π20 beamline: under construction



All the negative particles are included

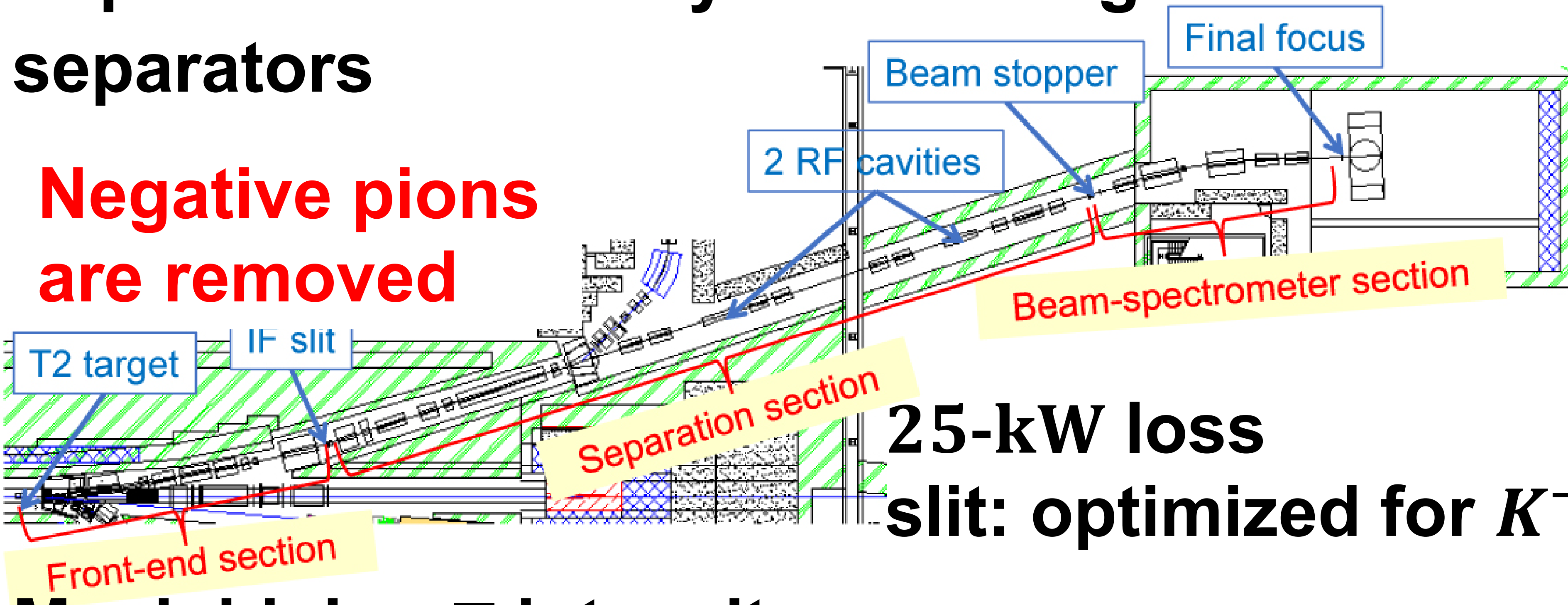
$$\overline{p}: \sim 10^6/\mathrm{spill}\ (4.2\ s)$$

Production of secondary $\overline{p}$s

$K10$ beamline: planned

Separated secondary beam using RF separators

Negative pions are removed



25-kW loss slit: optimized for K^-

Much higher $\overline{p}$ intensity

$\sim 7, 5, 2 \times 10^6/\mathrm{spill}$ for $6, 8, 10\ \mathrm{GeV}/c$

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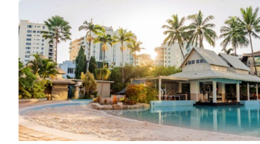
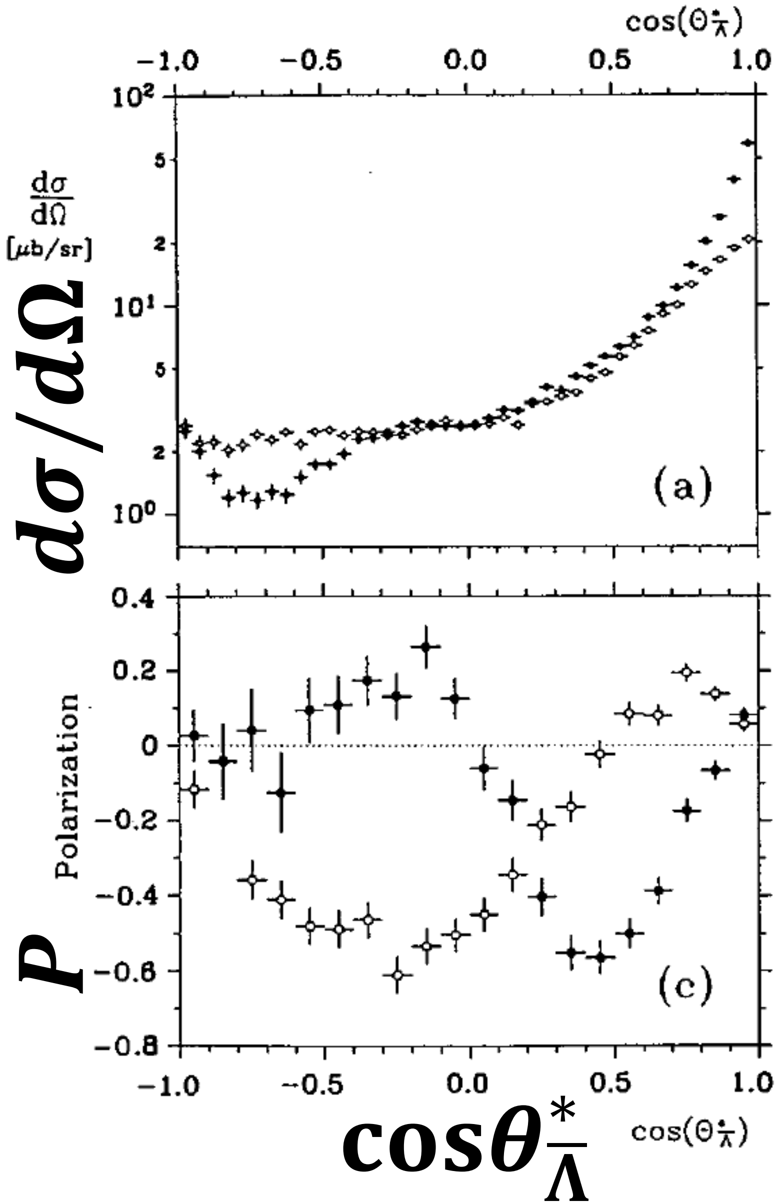
Production of $\bar{\Lambda}$s





P.D. Barnes et al., PRC54, 1877 (1996).

$\bar{\Lambda}$s from $\bar{p}+p \rightarrow \bar{\Lambda}+\Lambda$ are polarized

open circles:

$1.642\ \mathrm{GeV}/c$

filled circles:

$1.918\ \mathrm{GeV}/c$

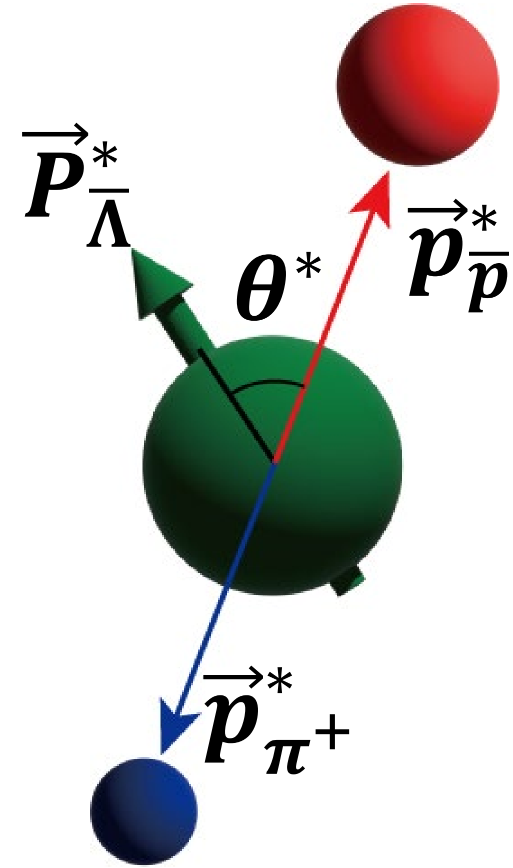
PS185 experiment at LEAR/CERN

Decay of $\overline{\Lambda}$s into $\overline{p}$s

Decay angular distribution

In the $\overline{\Lambda}$ rest frame

$$\frac{d\sigma}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_{\overline{\Lambda}} \overrightarrow{P}^*_{\overline{\Lambda}} \cdot \widehat{p}^*_{\overline{p}}\right)$$



with

- $\alpha_{\overline{\Lambda}}$: decay parameter
- $\overrightarrow{P}^*_{\overline{\Lambda}}$: $\overline{\Lambda}$ polarization vector
- $\widehat{p}^*_{\overline{p}}$: daughter antiproton direction (unit vector)

Decay of $\overline{\Lambda}$s into $\overline{p}$s

Polarization vector of $\overline{p}$s

$\overline{p}$ polarization in the $\overline{p}$ rest frame can be given by the Lee-Yang's equation:

$$\vec{P}^{\dagger}_{\overline{p}} = \frac{1}{1+\alpha_{\overline{\Lambda}}\vec{P}^{*}_{\overline{\Lambda}}\cdot\hat{p}^{*}_{\overline{p}}}\left\{\left(\alpha_{\overline{\Lambda}}+\vec{P}^{*}_{\overline{\Lambda}}\cdot\hat{p}^{*}_{\overline{p}}\right)\hat{p}^{*}_{\overline{p}} + \beta_{\overline{\Lambda}}\vec{P}^{*}_{\overline{\Lambda}}\times\hat{p}^{*}_{\overline{p}} + \gamma_{\overline{\Lambda}}\hat{p}^{*}_{\overline{p}}\times\left(\vec{P}^{*}_{\overline{\Lambda}}\times\hat{p}^{*}_{\overline{p}}\right)\right\}$$

self-polarization: $\alpha_{\overline{\Lambda}}\hat{p}^{*}_{\overline{p}}$

spin transfer: $\vec{P}^{\dagger}_{\overline{p}} - \alpha_{\overline{\Lambda}}\hat{p}^{*}_{\overline{p}}$

using variables in the $\overline{\Lambda}$ rest frame

Decay of $\bar{\Lambda}$s into $\bar{p}$s

<u>Polarization vector of $\bar{p}$s</u>

$\vec{P}^{\dagger}_{\bar{p}}$: $\bar{p}$ polarization in the $\bar{p}$ rest frame

$\vec{P}^{*}_{\bar{\Lambda}}$: $\bar{\Lambda}$ polarization in the $\bar{\Lambda}$ rest frame

$\hat{p}^{*}_{\bar{p}}$: $\bar{p}$ direction in the $\bar{\Lambda}$ rest frame

$\bar{\Lambda}$ decay parameters

$$\alpha_{\Lambda}^2 + \beta_{\Lambda}^2 + \gamma_{\Lambda}^2 = 1$$

$$\tan\phi_{\Lambda} = \beta_{\Lambda}/\gamma_{\Lambda}$$

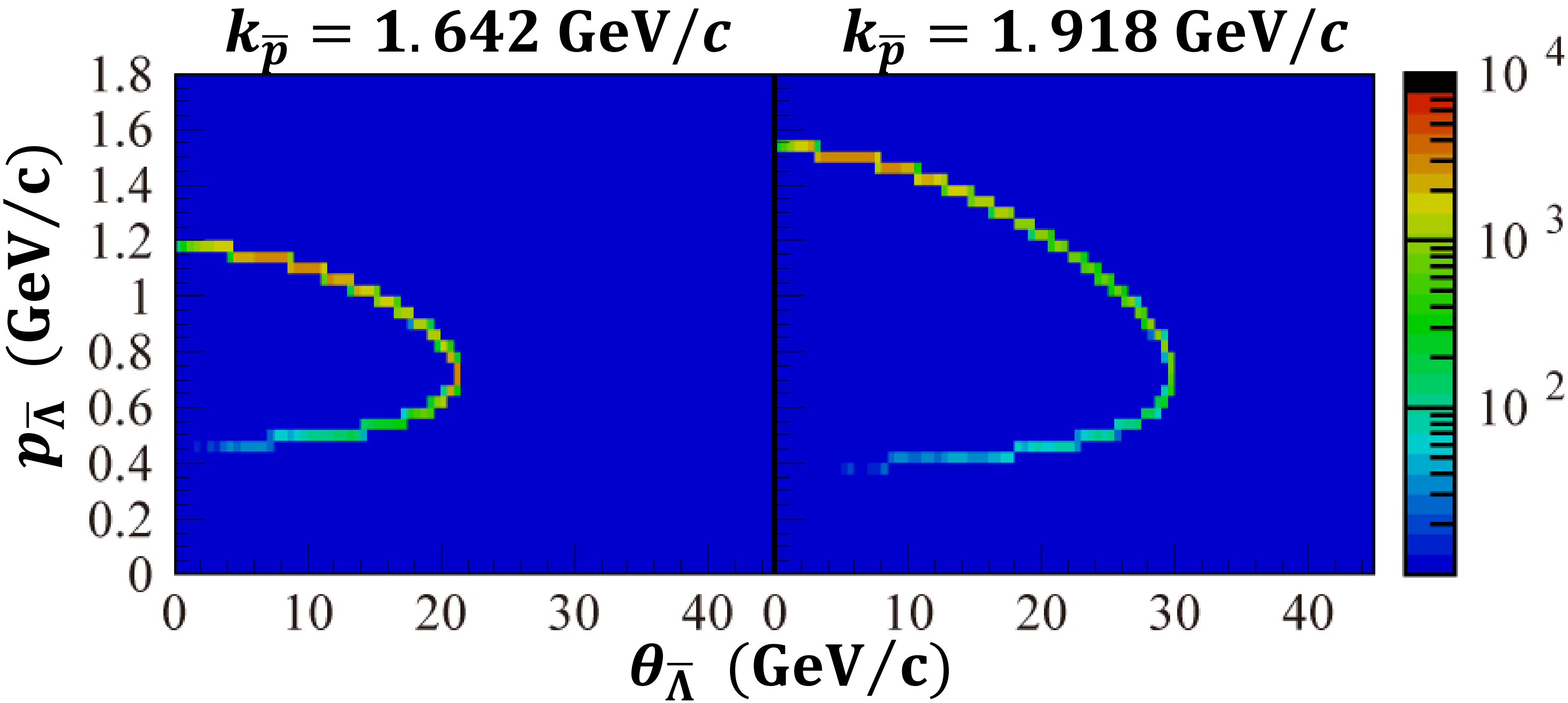
$$\alpha_{\bar{\Lambda}} = -\alpha_{\Lambda} = 0.748 \pm 0.008$$

$$\phi_{\bar{\Lambda}} = -\phi_{\Lambda} = +6.5^{\circ} \pm 3.5^{\circ}$$

$$\rightarrow \beta_{\bar{\Lambda}} = -\beta_{\Lambda} = 0.075, \gamma_{\bar{\Lambda}} = \gamma_{\Lambda} = +0.66$$

Expected Polarized Antiprotons

Production of $\bar{\Lambda}$s



Correlation between the momentum and emission angle for produced antihyperons

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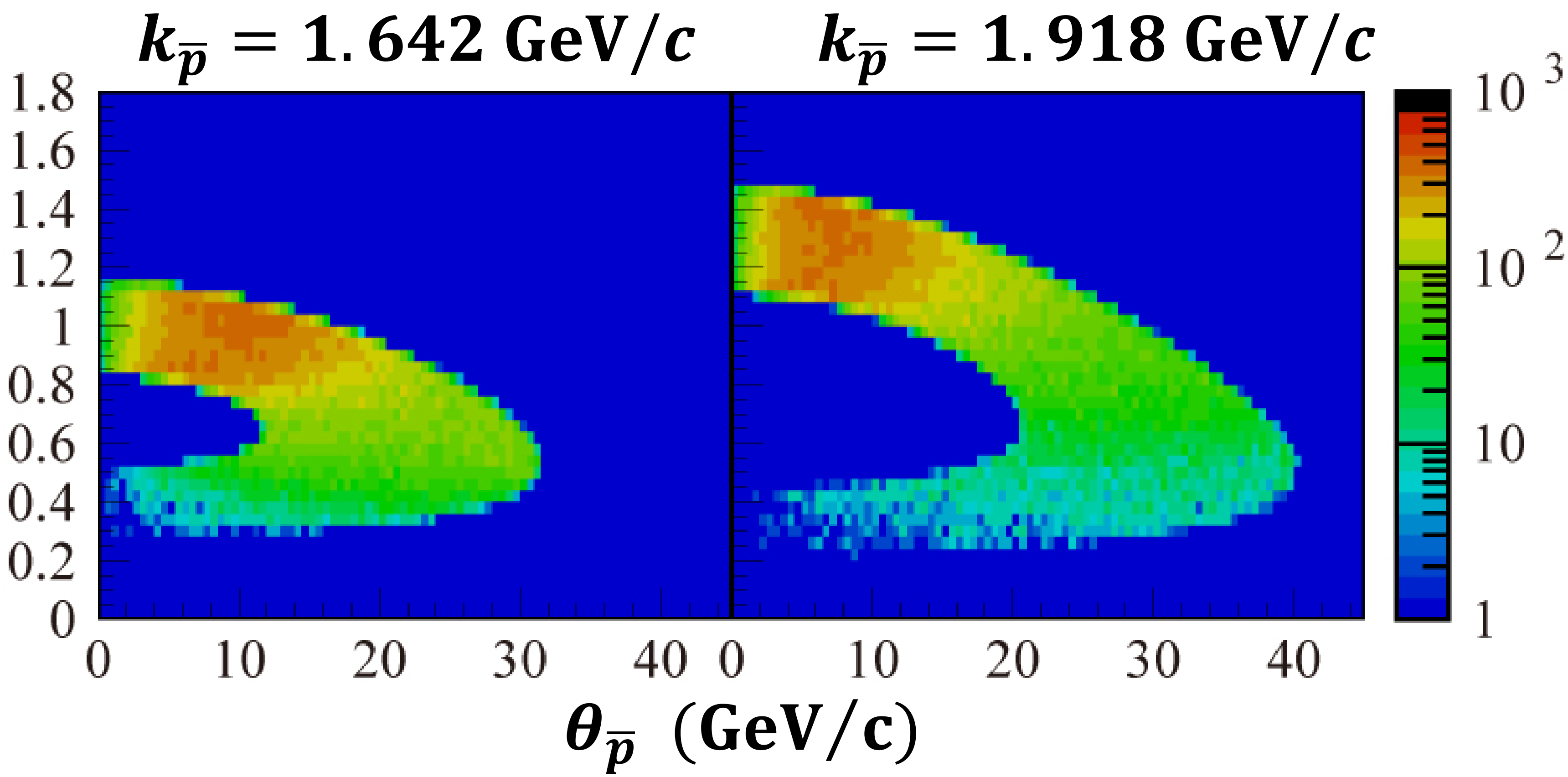
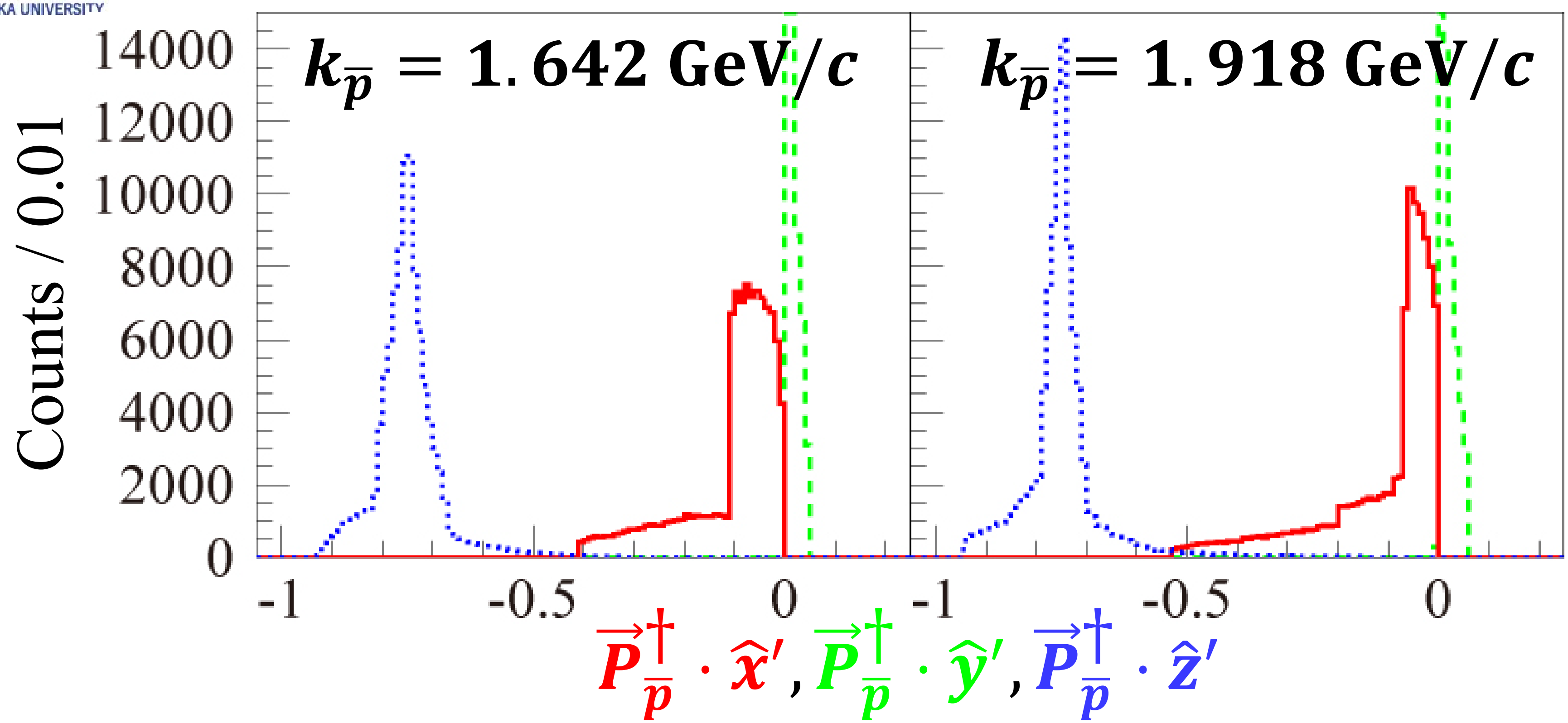
Decay of $\overline{\Lambda}$s into $\overline{p}$s



Correlation between the momentum and emission angle for daughter antiprotons

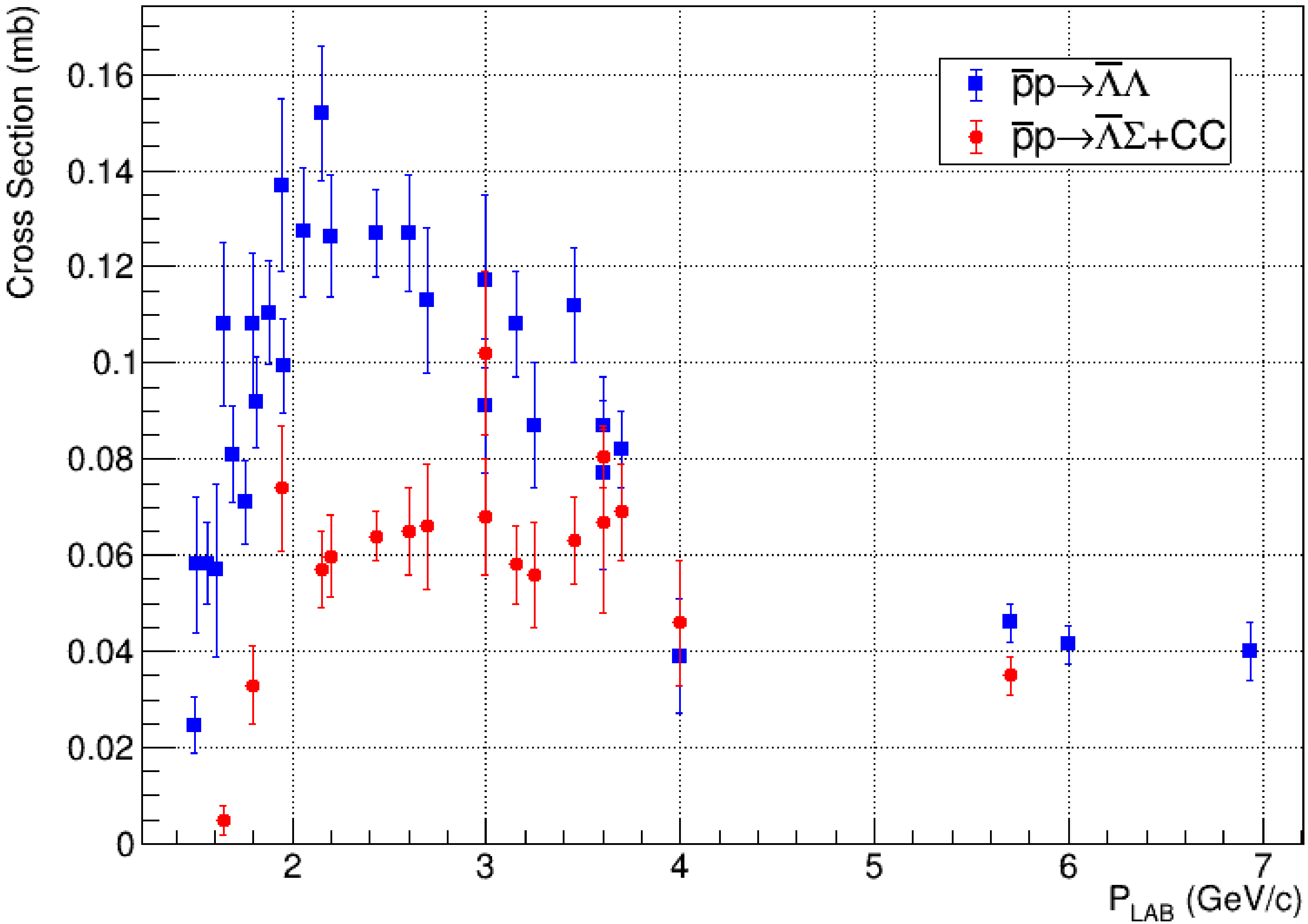
Decay of $\bar{\Lambda}$s into $\bar{p}$s



sideways, normal, longitudinal

A large longitudinal polarization can be rotated into a sizable transverse polarization during momentum analysis.

$\bar{\Lambda}$ yields



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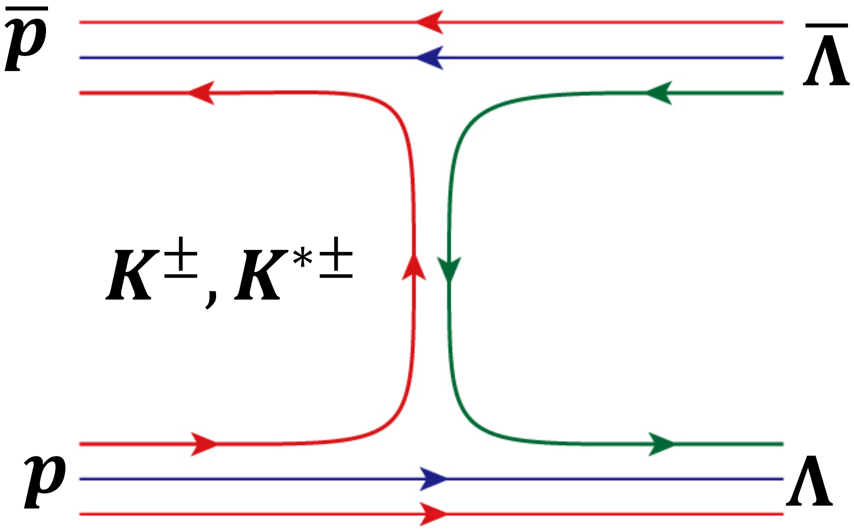
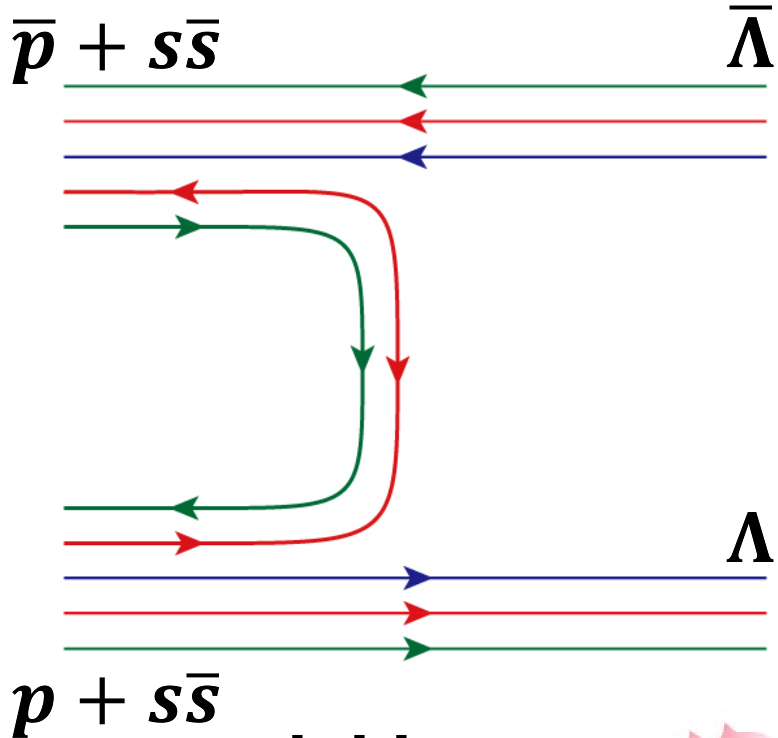
$\bar{\Lambda}$ polarization?

$\bar{\Lambda}\Lambda$ production mechanism

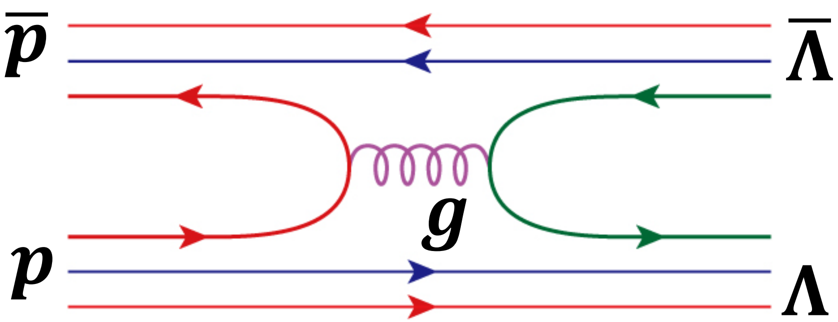
Colors indicate flavors here



t-channel meson exchange



picking up sea (anti)quarks



gluon-mediated $s\bar{s}$ production ($q\bar{q} \to s\bar{s}$)

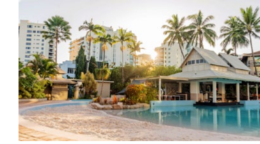
Summary

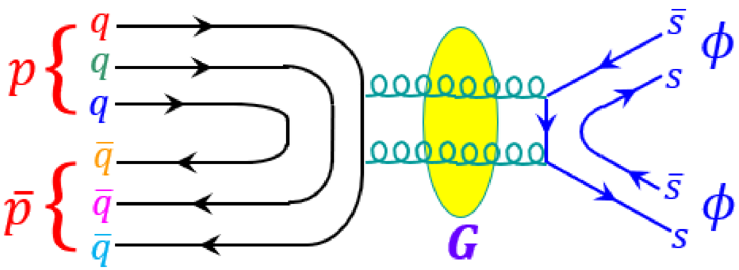
Summary

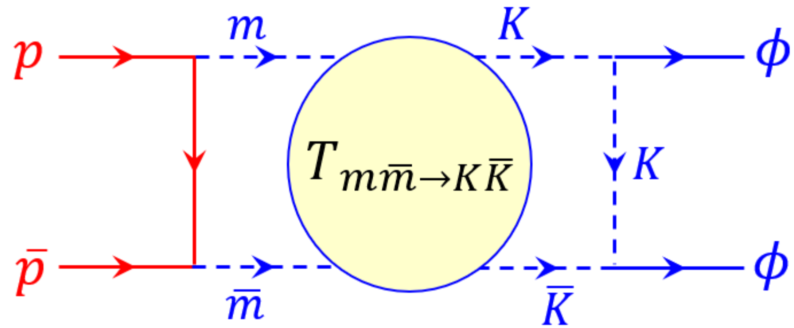
- Polarized antiprotons can be used for various hadron physics experiments.
- Polarized antiprotons can be produced from $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ and $\bar{\Lambda} \rightarrow \pi^{+}\bar{p}$
- High longitudinal polarization is available.
- For further discussion, we need to predict $\bar{\Lambda}$ polarization at a certain incident $\bar{p}$ momentum.

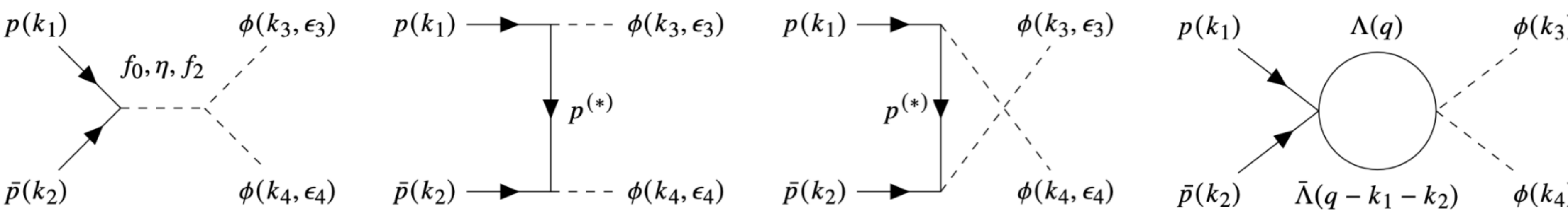
Backup

Reaction mechanisms

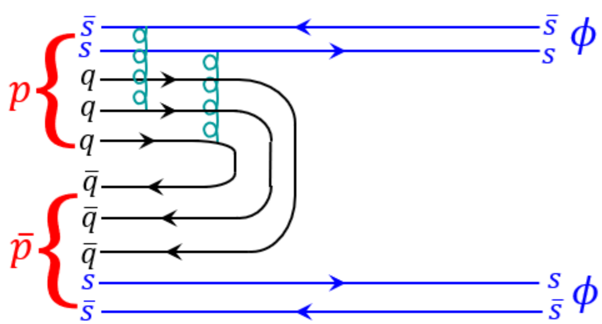








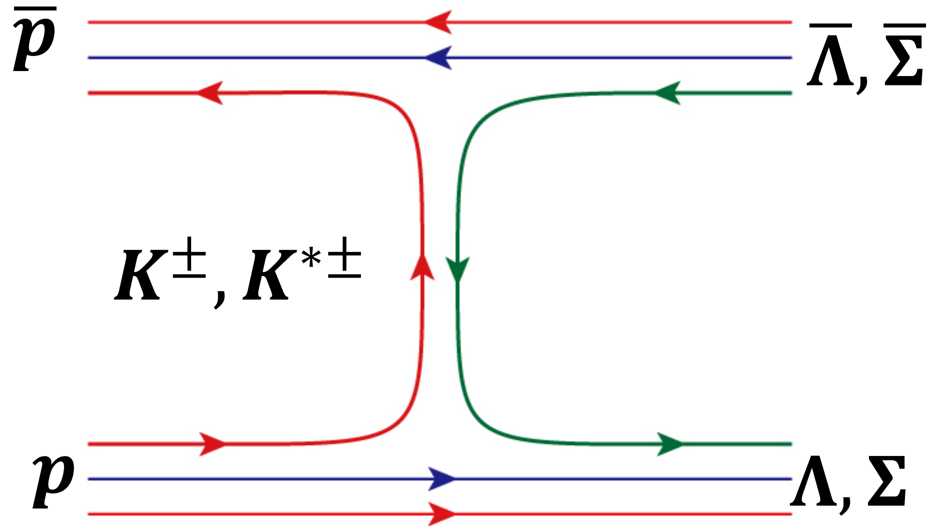
s channel *t* channel *u* channel



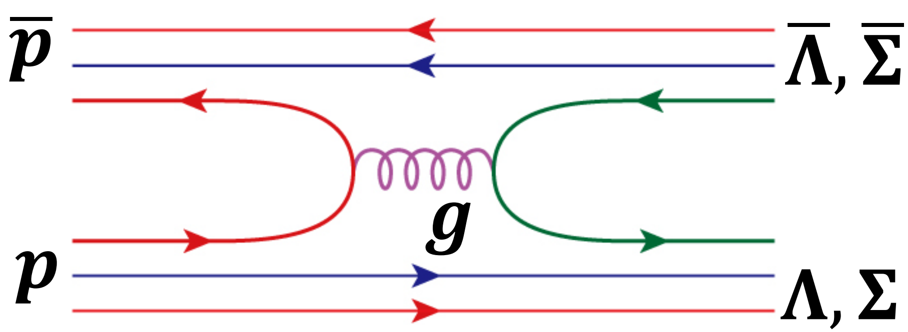
Annihilation processes

<u>Production mechanism of $Y\bar{Y}$</u>

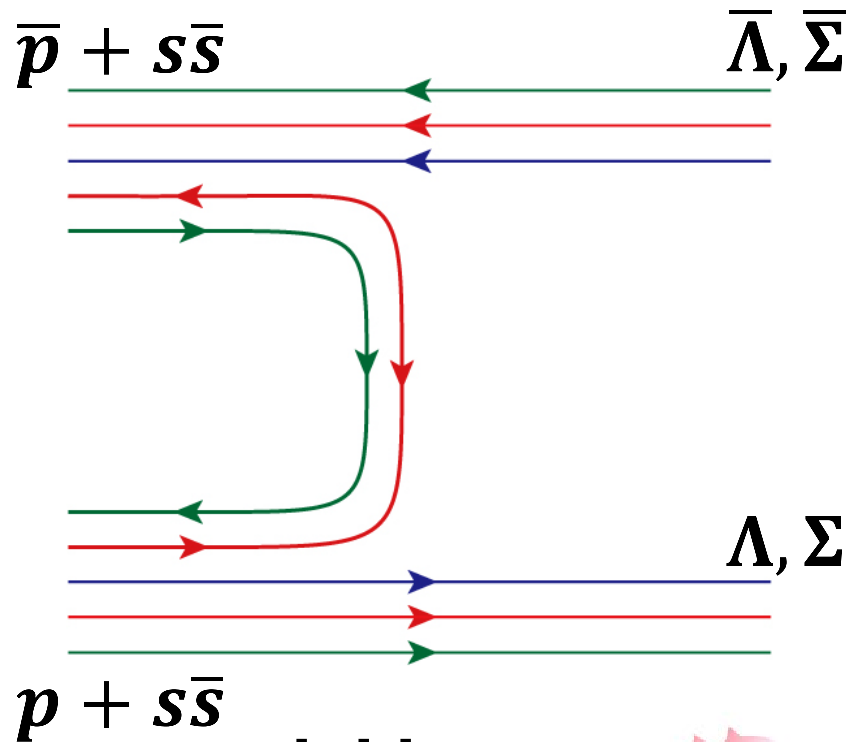
Colors indicate flavors here



***t*-channel meson exchange**



gluon-mediated $s\bar{s}$ production ($q\bar{q} \to s\bar{s}$)



picking up sea (anti)quarks

Annihilation processes

Production mechanism of $Y\bar{Y}$

Different mechanisms are expected especially for $\bar{\Xi}\Xi$ and $\bar{\Omega}\Omega$

$Y\bar{Y}$	$\Lambda\bar{\Lambda}$	$\Sigma\bar{\Sigma}$	$\Xi\bar{\Xi}$	$\Omega\bar{\Omega}$
#K exchange	1	1	2	3
#$q\bar{q} \to g \to s\bar{s}$	1	1	2	3
#$s\bar{s}$ in (anti)proton	1	1	2	3

Unpolarized-antiproton studies are expected to advance first.

Usage of polarized antiprotons

Annihilation

$$\vec{\vec{\bar{p}}}p \rightarrow \pi^{+}\pi^{-}, K^{+}K^{-}$$

π, K: spinless particles

No final-state polarization

No spin-transfer

Correlation between the orientations between the $\bar{p}$ polarization and reaction plane

$A_y(\theta)$ ⇒interference between different initial-state partial-wave amplitudes

Physics with using antiprotons

Two key physics topics

1. Annihilation processes

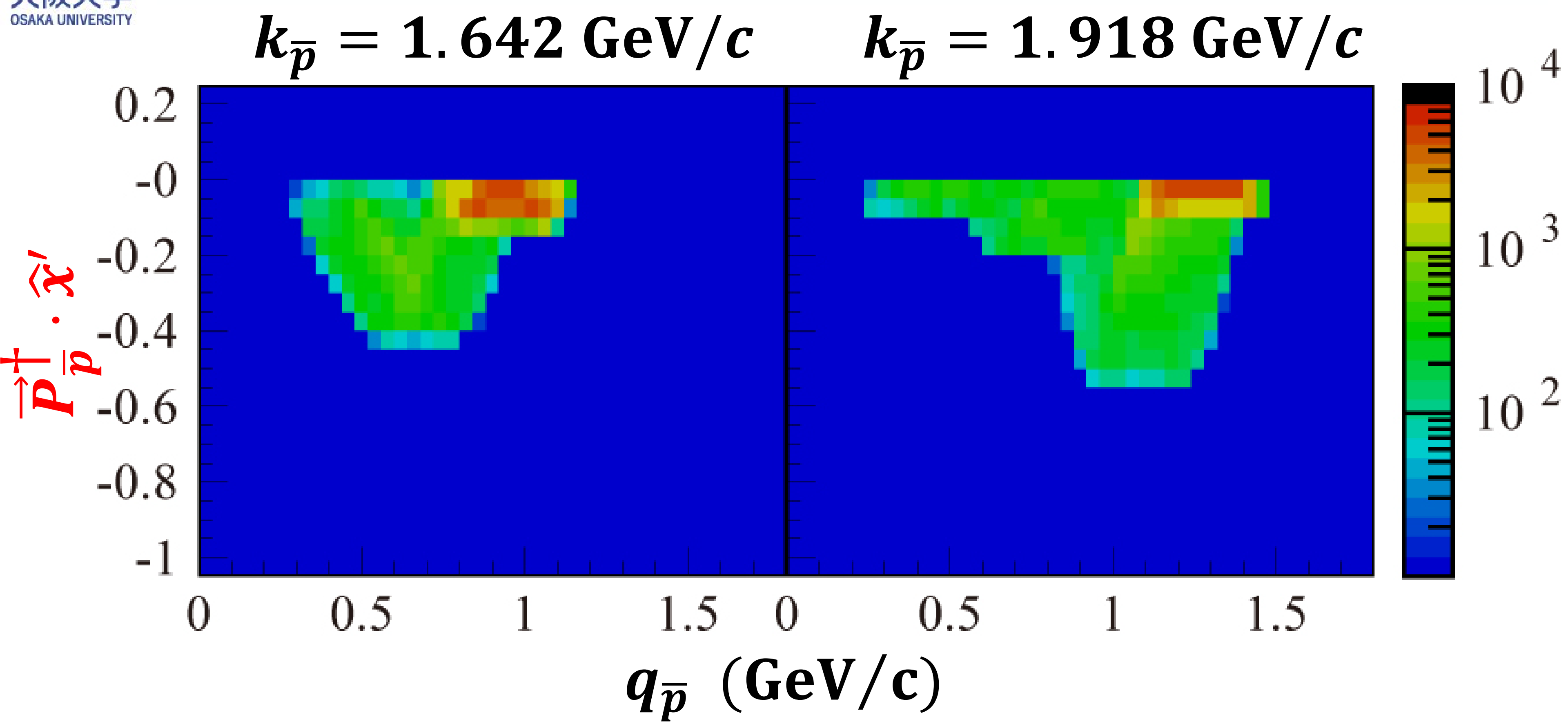
$$\bar{p}p \to \bar{\Lambda}\Lambda, \bar{\Sigma}\Sigma, \bar{\Xi}\Xi, \bar{\Omega}\Omega$$

$$\bar{p}p \to \pi^+\pi^-, K^+K^-, \phi\phi$$

cleanest environments for quarks and antiquarks into hadrons

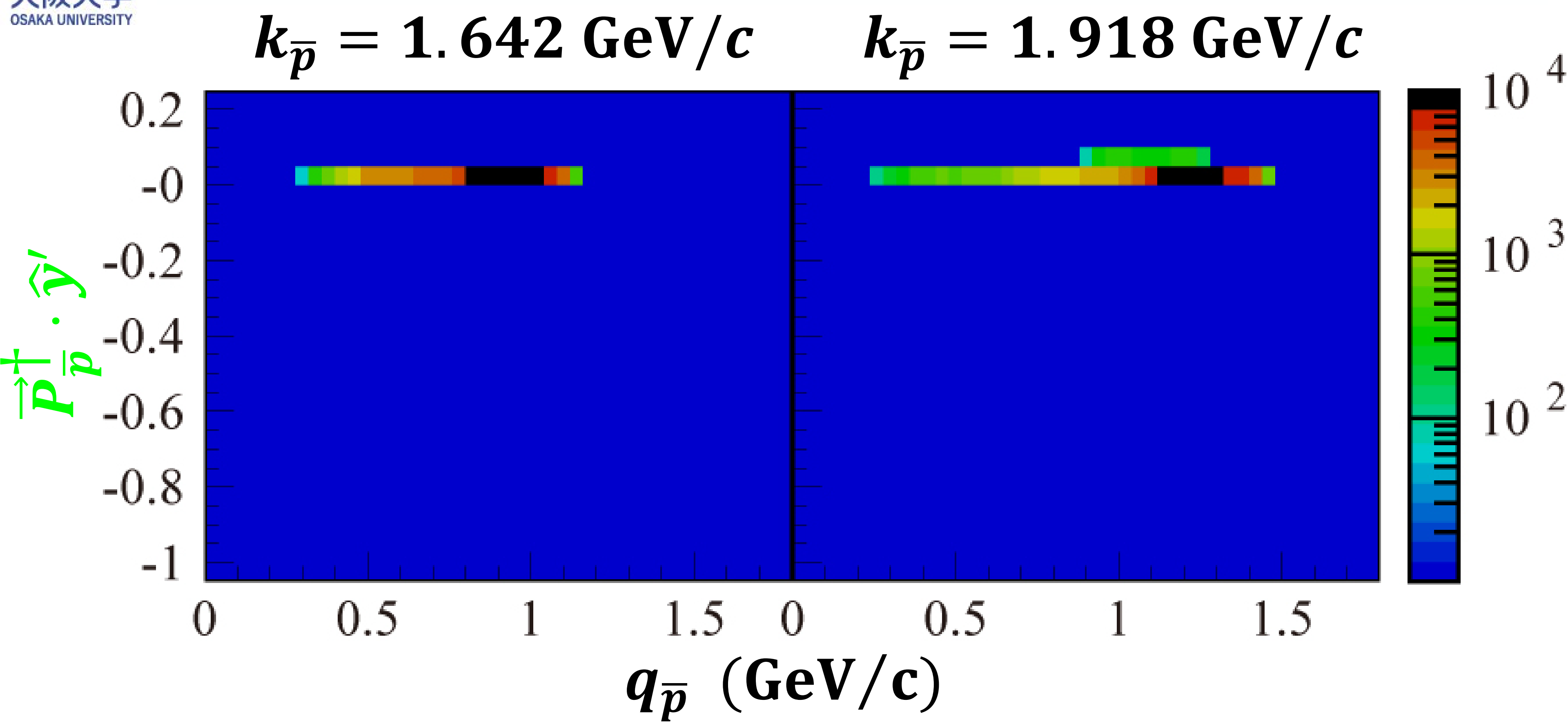
2. Difference between pp and $\bar{p}p$ interactions

Decay of $\overline{\Lambda}$s into $\overline{p}$s



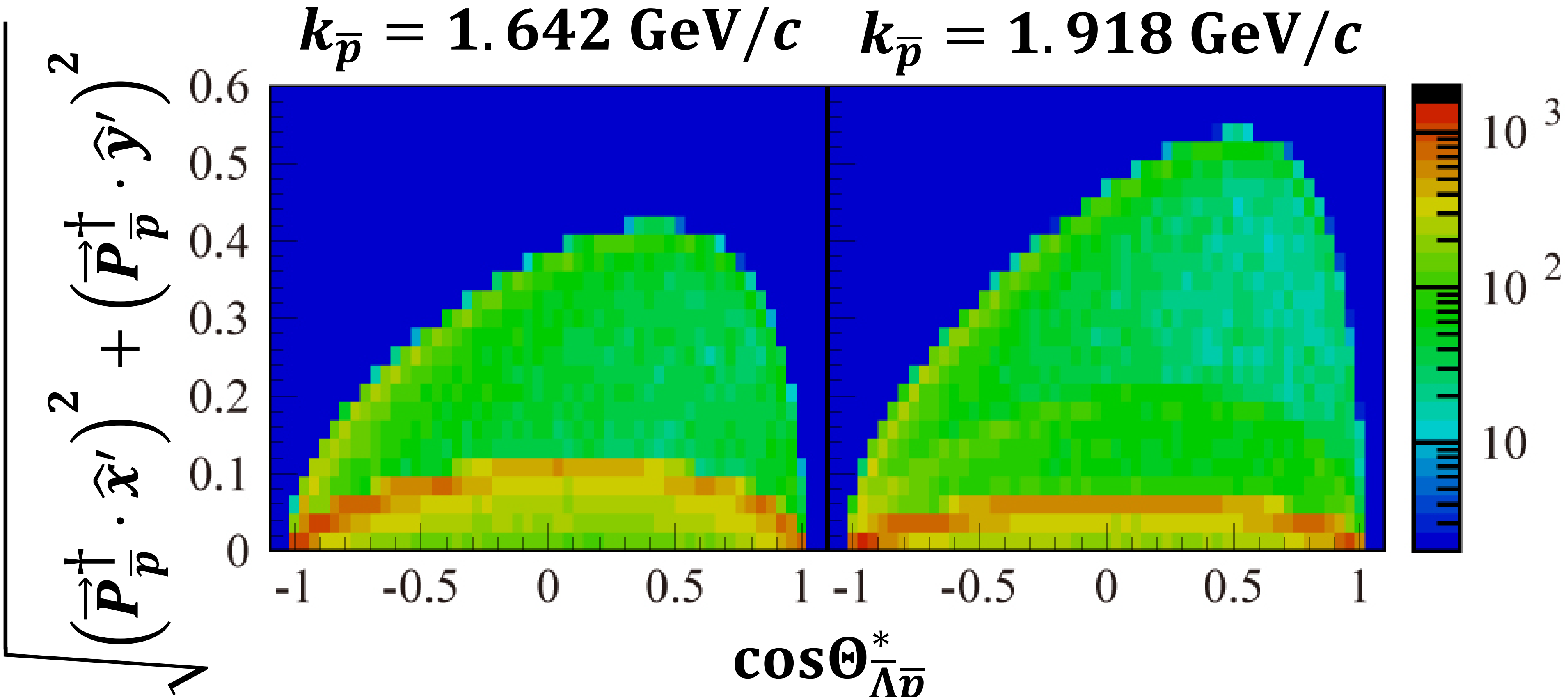
Correlation between the sideways component of polarization and momentum for daughter antiprotons

Decay of $\overline{\Lambda}$s into $\overline{p}$s



Correlation between the normal component of polarization and momentum for daughter antiprotons

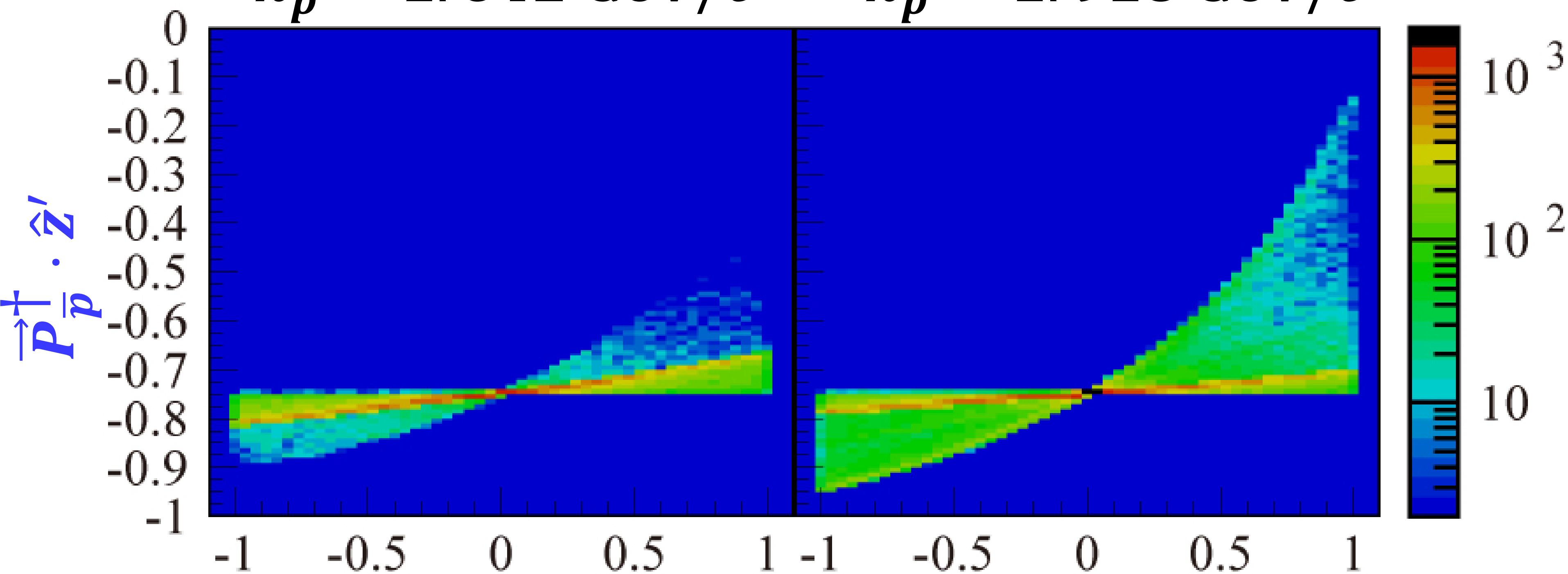
Decay of $\overline{\Lambda}$s into $\overline{p}$s



Correlation between the transverse component of $\overline{p}$ polarization and $\overline{\Lambda}$-polarization and $\overline{p}$-momentum opening angle

Decay of $\overline{\Lambda}$s into $\overline{p}$s

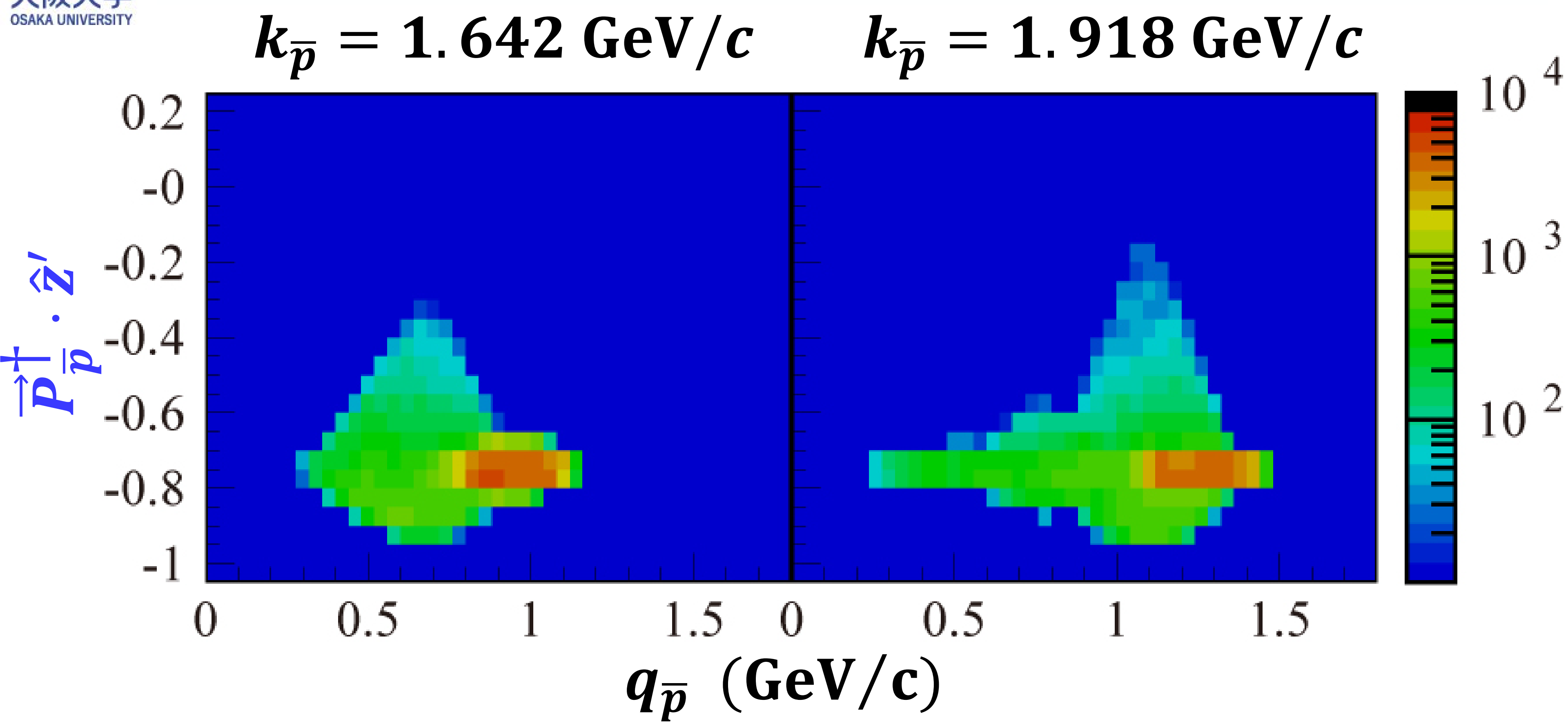
$k_{\overline{p}} = 1.642\ \mathrm{GeV}/c$ $\quad$ $k_{\overline{p}} = 1.918\ \mathrm{GeV}/c$



$\cos\Theta^*_{\overline{\Lambda}\overline{p}}$ for $q_{\overline{p}} \geq 0.8\ \mathrm{GeV/c}$

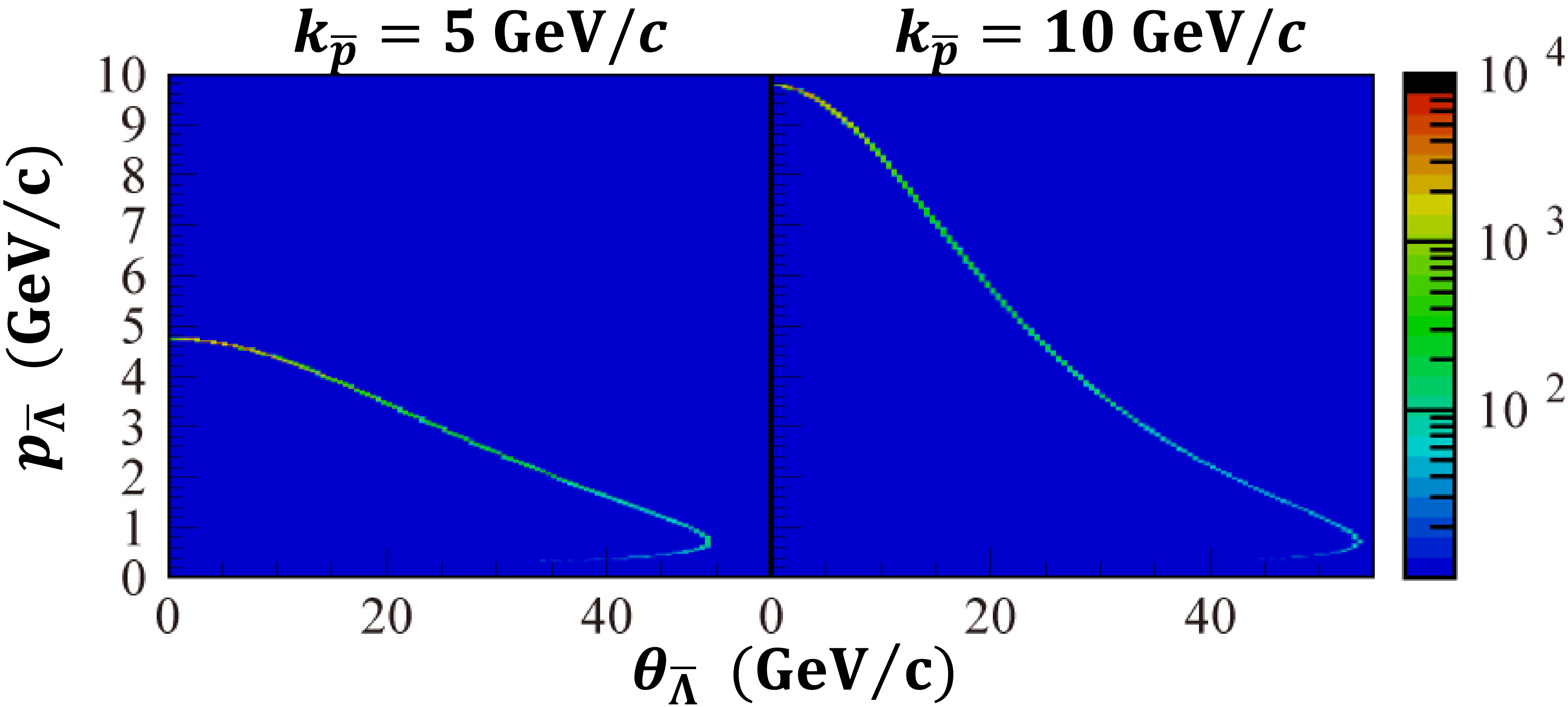
Correlation between the longitudinal component of $\overline{p}$ polarization and $\overline{\Lambda}$-polarization and $\overline{p}$-momentum opening angle

Decay of $\overline{\Lambda}$s into $\overline{p}$s



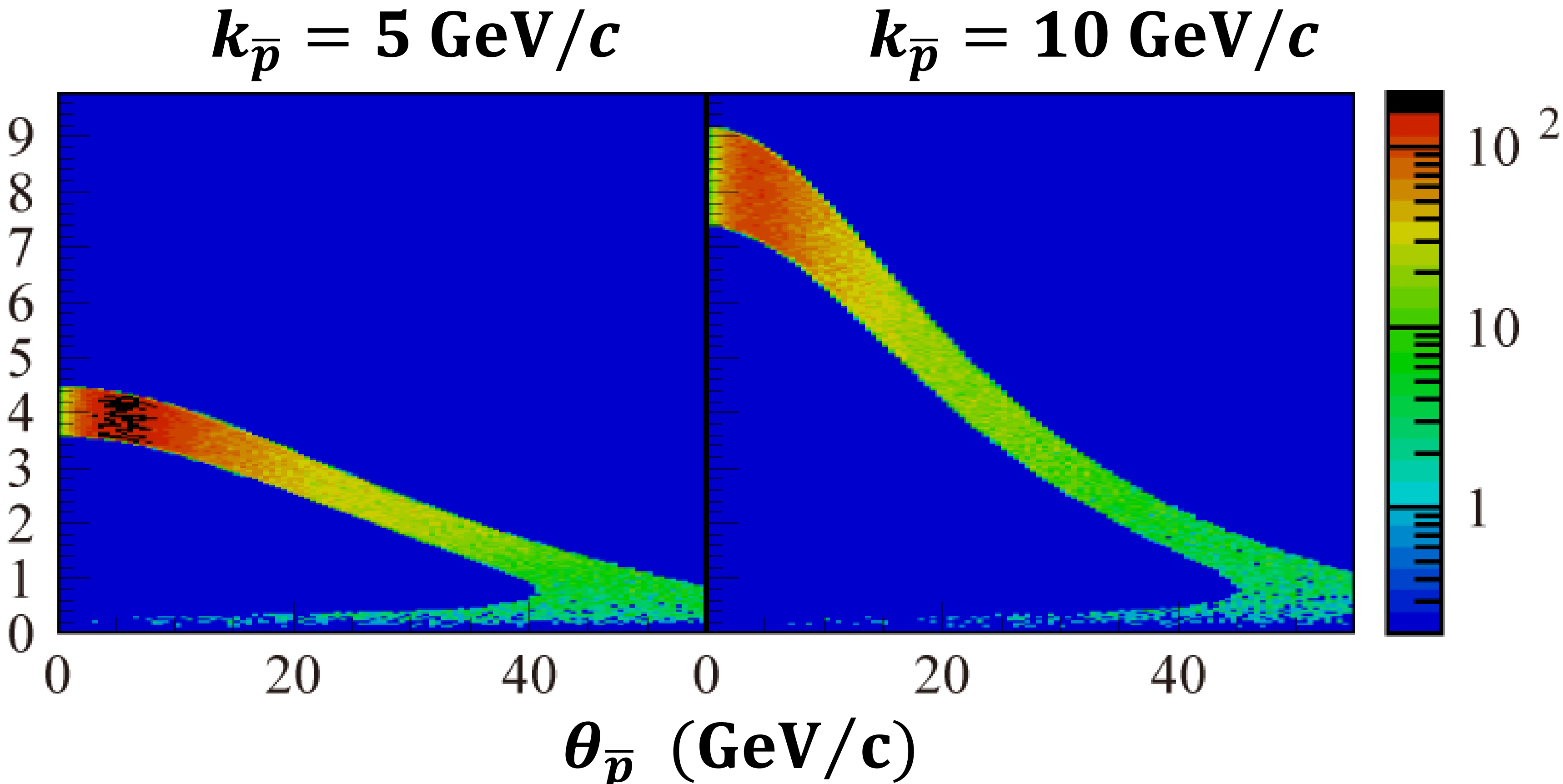
Correlation between the longitudinal component of polarization and momentum for daughter antiprotons

Production of $\overline{\Lambda}$s



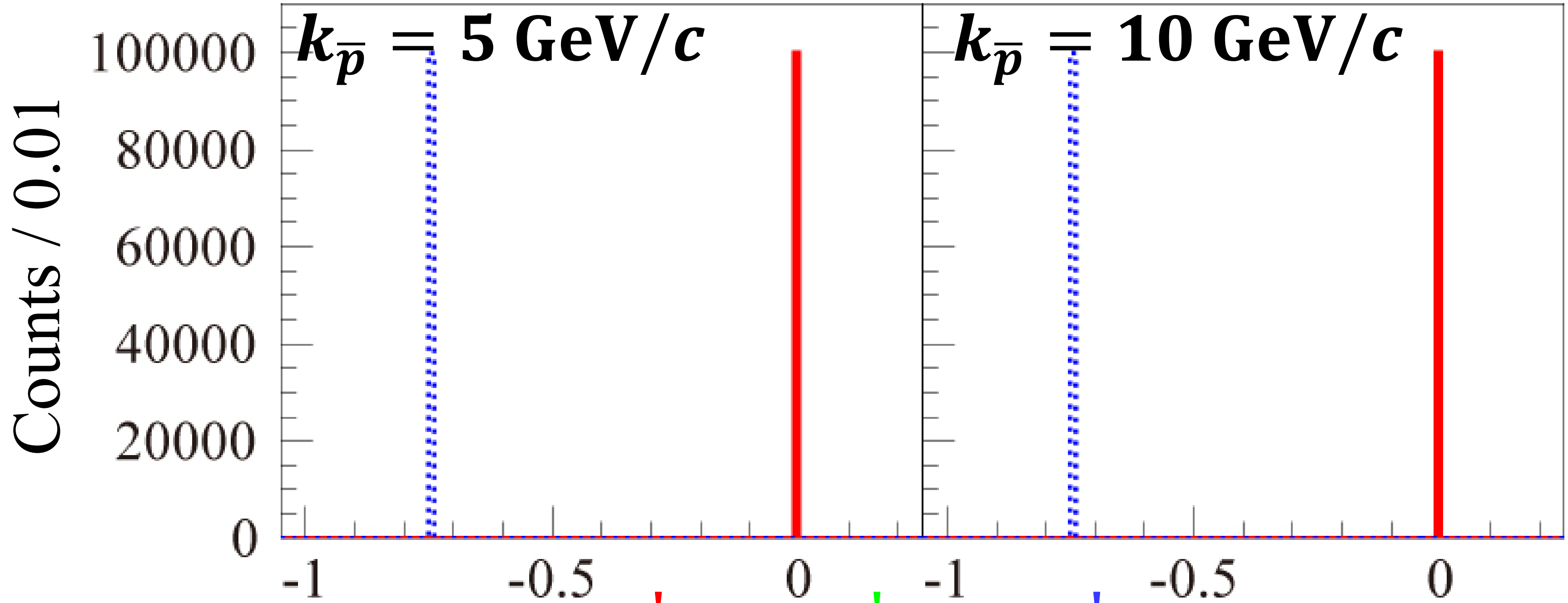
Correlation between the momentum and emission angle for produced antihyperons

Decay of $\overline{\Lambda}$s into $\overline{p}$s



Correlation between the momentum and emission angle for daughter antiprotons

Decay of $\overline{\Lambda}$s into $\overline{p}$s



$\vec{P}^{\dagger}_{\overline{p}} \cdot \hat{x}', \vec{P}^{\dagger}_{\overline{p}} \cdot \hat{y}', \vec{P}^{\dagger}_{\overline{p}} \cdot \hat{z}'$

sideways, normal, longitudinal

A large longitudinal polarization can be rotated into a sizable transverse polarization during momentum analysis.