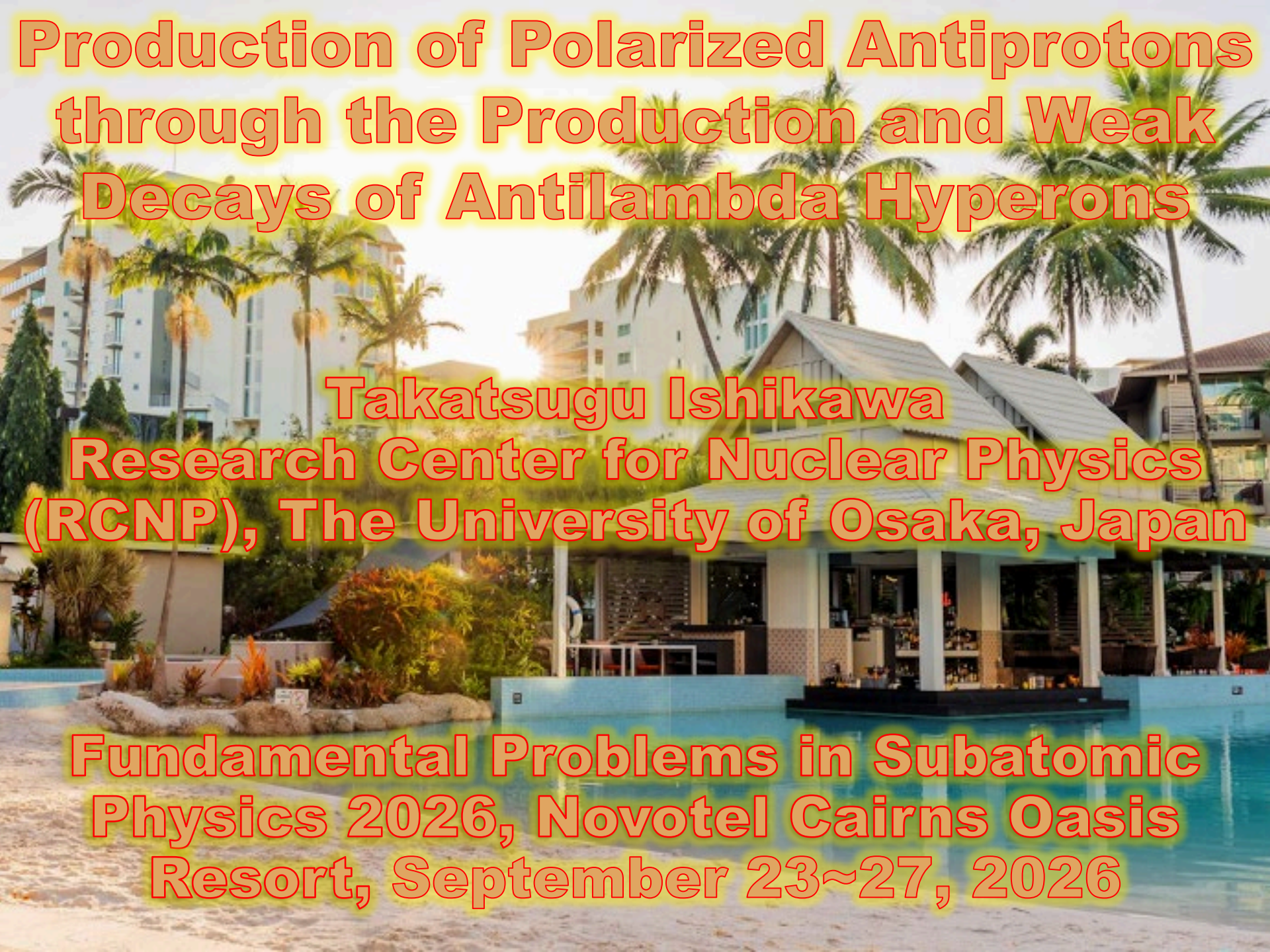
Production of Polarized Antiprotons through the Production and Weak Decays of Antilambda Hyperons



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Research Center for Nuclear Physics (RCNP), The University of Osaka, Japan

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

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1. Introduction
2. Production of Polarized Antiprotons
3. Expected Polarized Antiprotons
4. Summary



Introduction

Physics with antiprotons



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Why polarized antiprotons?

1. Annihilation ~ glueball/resonance
   $\bar{p}p \to \bar{\Lambda}\Lambda, \bar{\Sigma}\Sigma, \bar{\Xi}\Xi, \bar{\Omega}\Omega, \pi^+\pi^-, K^+K^-, \phi\phi$
   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:

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

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

Unpolarized vs polarized



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Unpolarized data:

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

Polarized data

spin observables including P_y, which have direct sensitivity to interference and relative phases

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

OZI violation

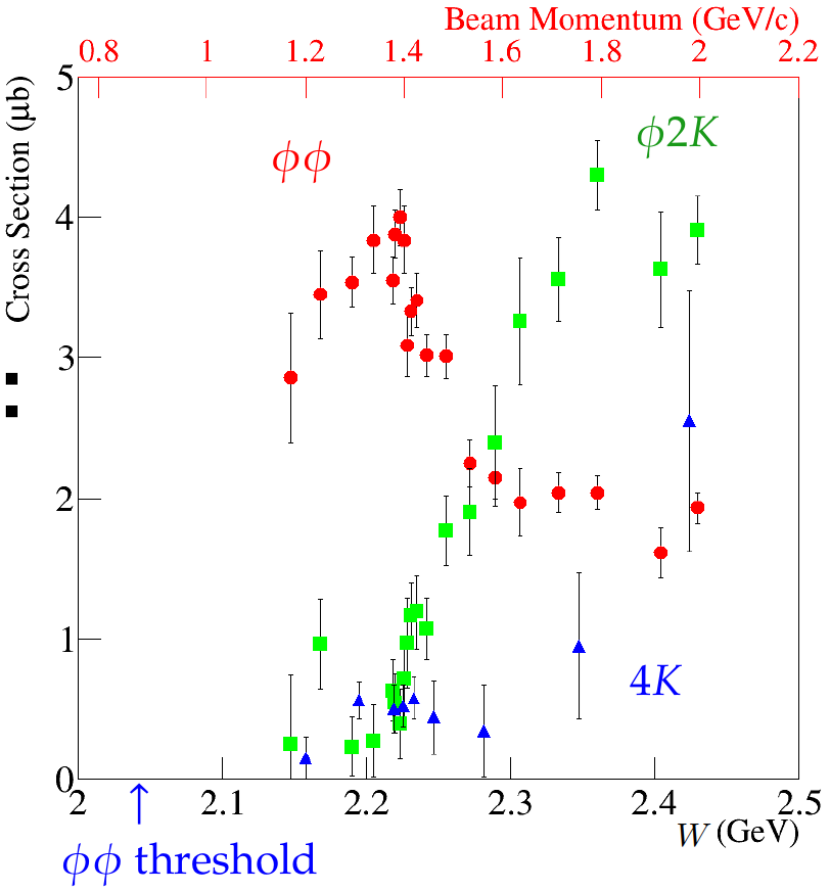


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A substantial Okubo-Zweig-Iizuka (OZI) violation:

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

Measured cross section: a few μb!



Glueball search



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

Glueballs: 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

Observing a peak alone is not sufficient.
→ identification requires J^{PC}, phase motion and interference

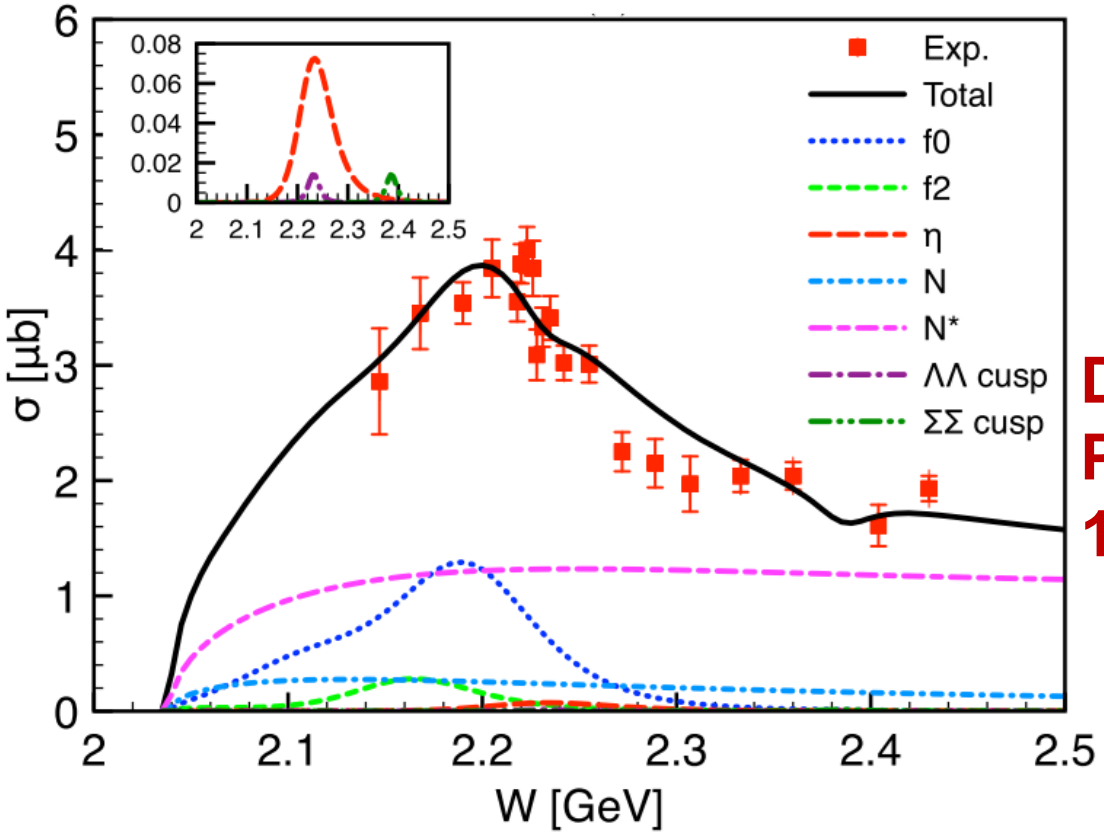
Polarization info. becomes particularly useful

Expected excitation function



Structures can be reproduced by several different contributions.

Cross sections alone may not be sufficient.



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

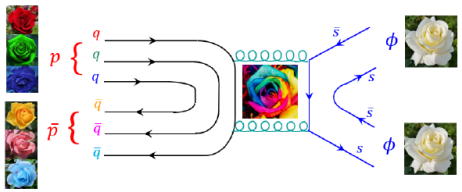
New J-PARC experiment



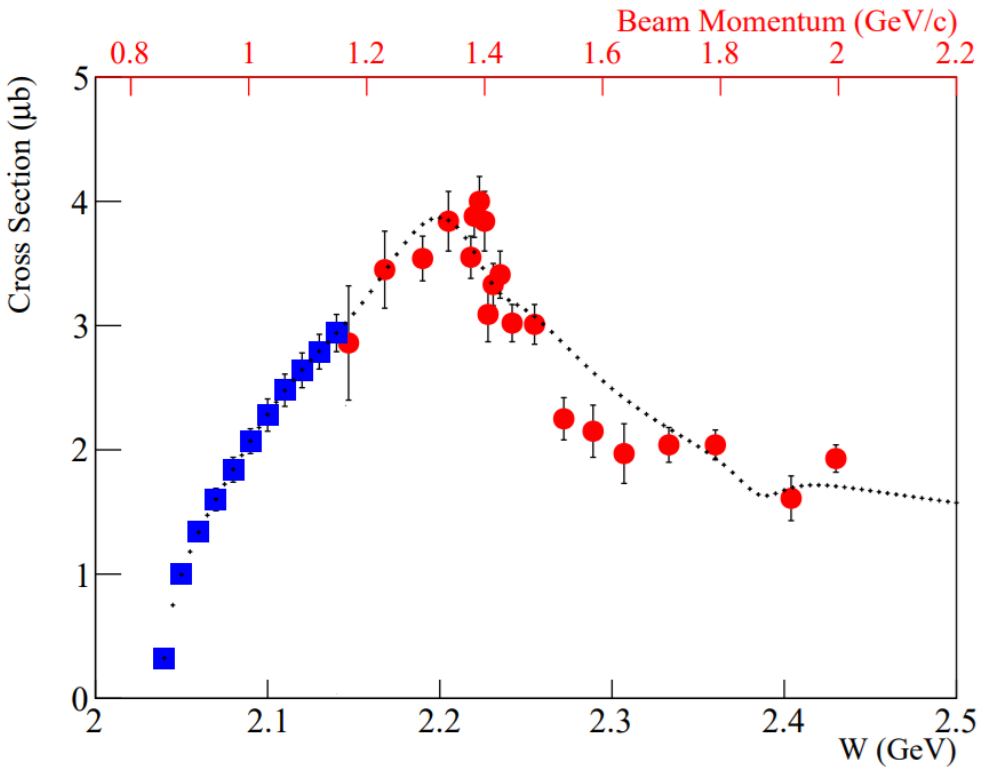
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E104 measures cross sections with higher statistics using an unpolarized antiproton beam

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



Spokesperson	Jung Keun Ahn (Korea University)
Beam line	K1.8BR
Beam	$\bar{p}$/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	$\bar{p}p \to \phi\phi$
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



Polarization provides additional info.

pp and $\bar{p}p$



NN interaction: strongly constrained by extensive scattering data

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

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

- opposite for σ, ρ exchanges ($G = +$)
- same for π, ω exchanges ($G = -$)

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

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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 $\bar{p}$s



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J-PARC

Japan Proton Accelerator Research Complex



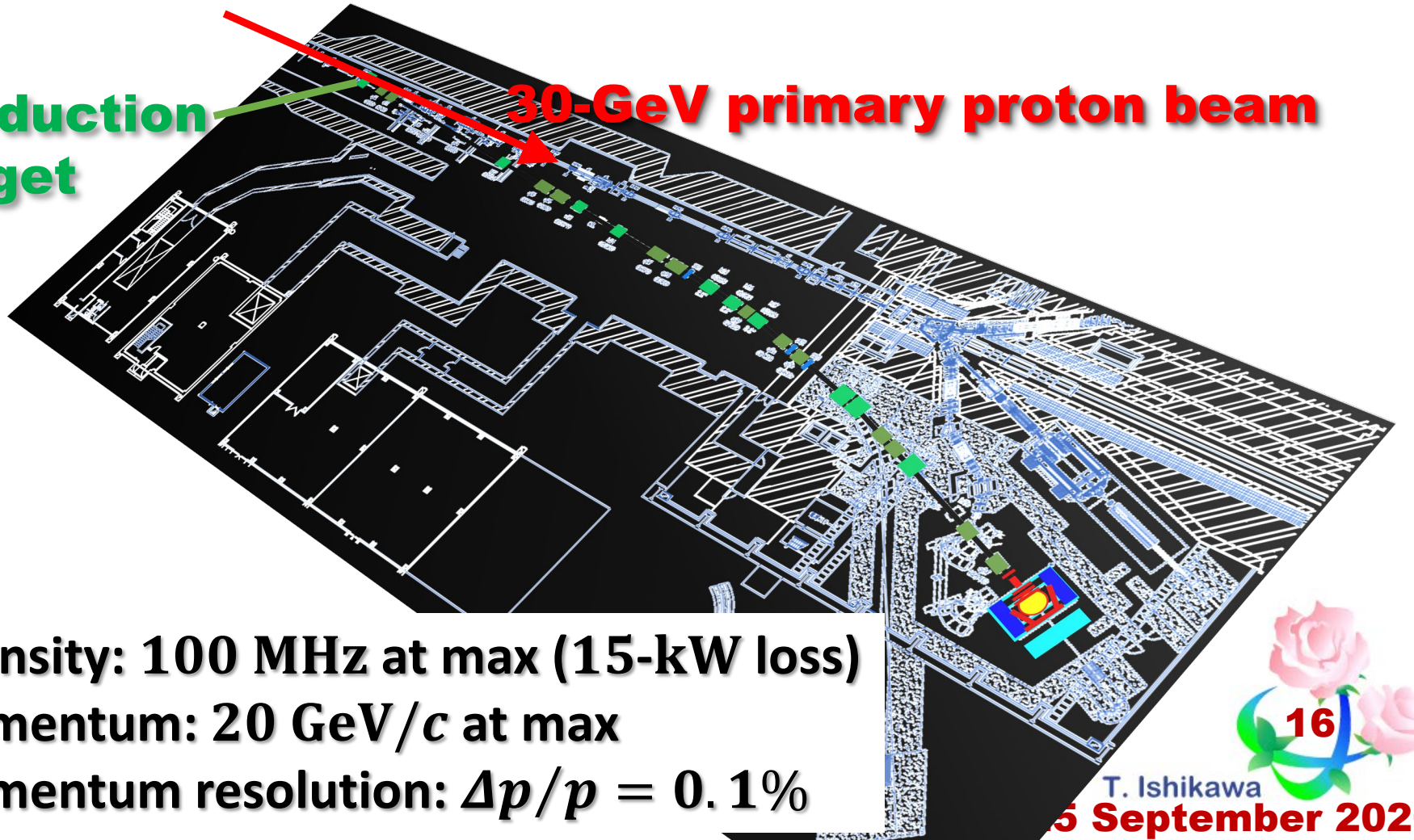
Secondary $\bar{p}$s

30-GeV primary proton beam: extracted & delivered

Production of secondary $\bar{p}$s



π20 beamline: under construction

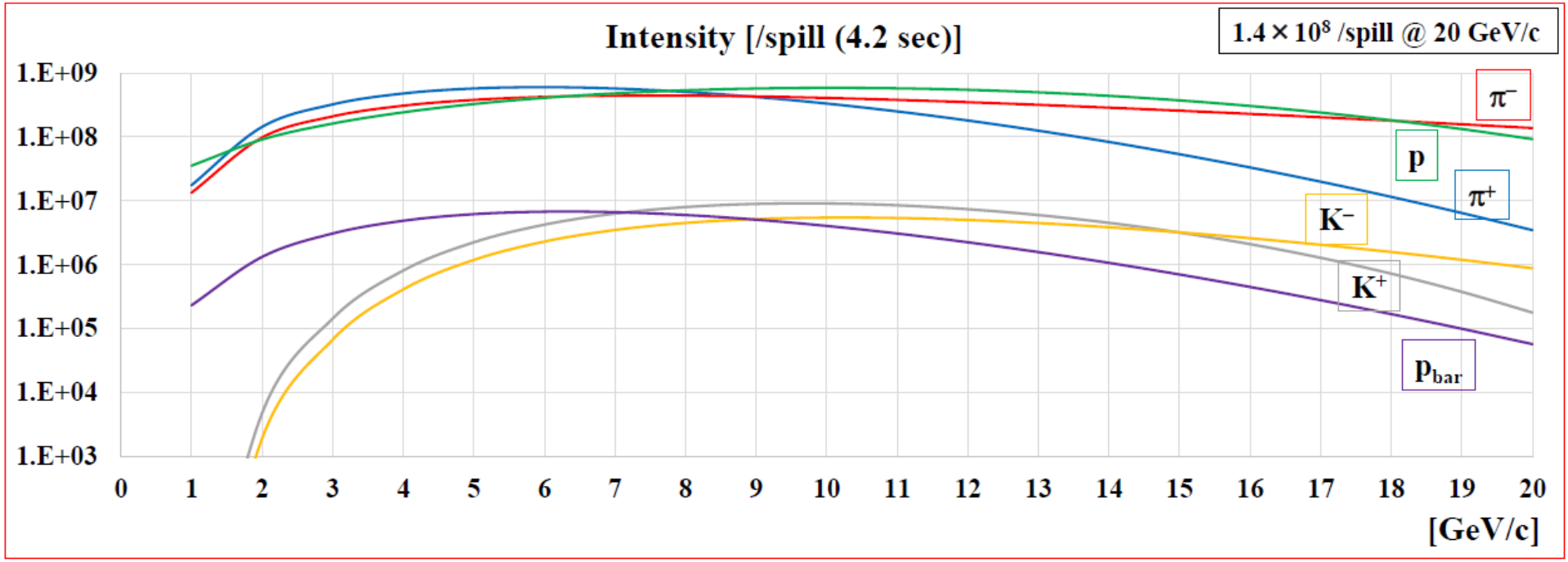


intensity: 100 MHz at max (15-kW loss)
momentum: 20 GeV/c at max
momentum resolution: $\Delta p/p = 0.1\%$

Production of secondary $\bar{p}$s



π20 beamline: under construction



All the negative particles are included

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

Production of secondary $\bar{p}$s

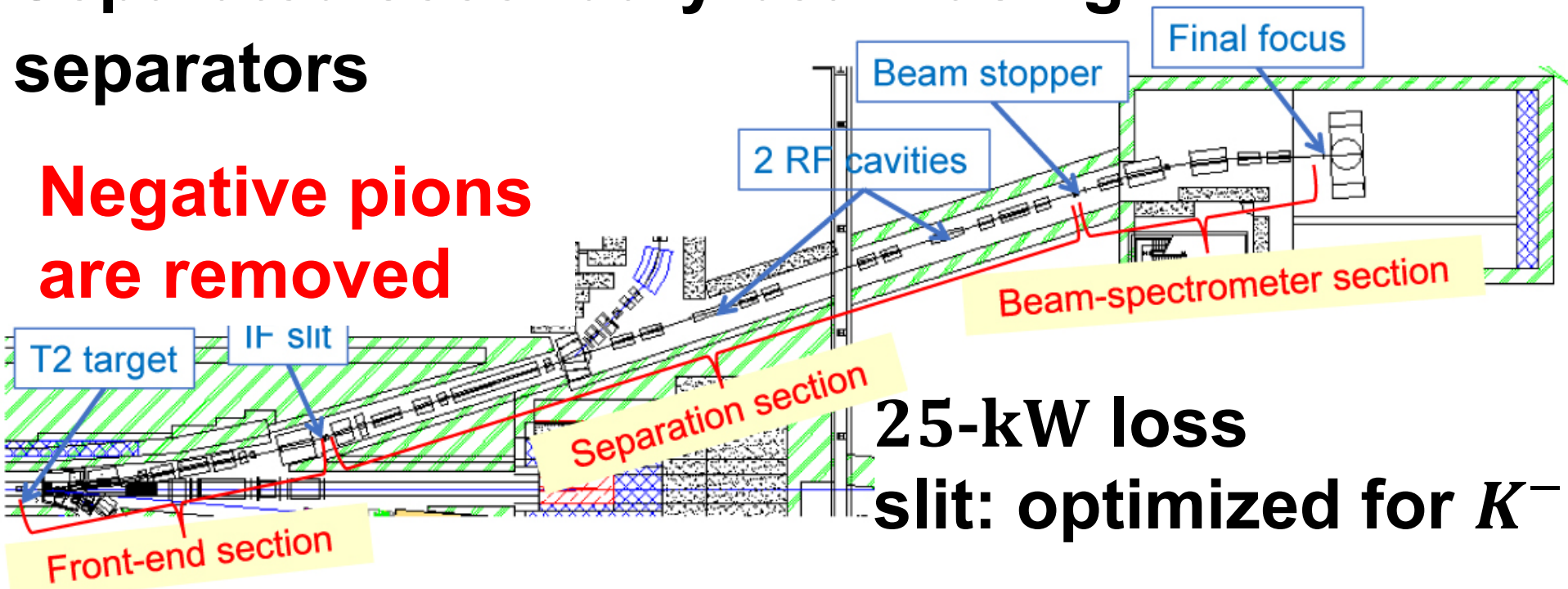


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$K10$ beamline: planned

Separated secondary beam using RF separators

Negative pions are removed



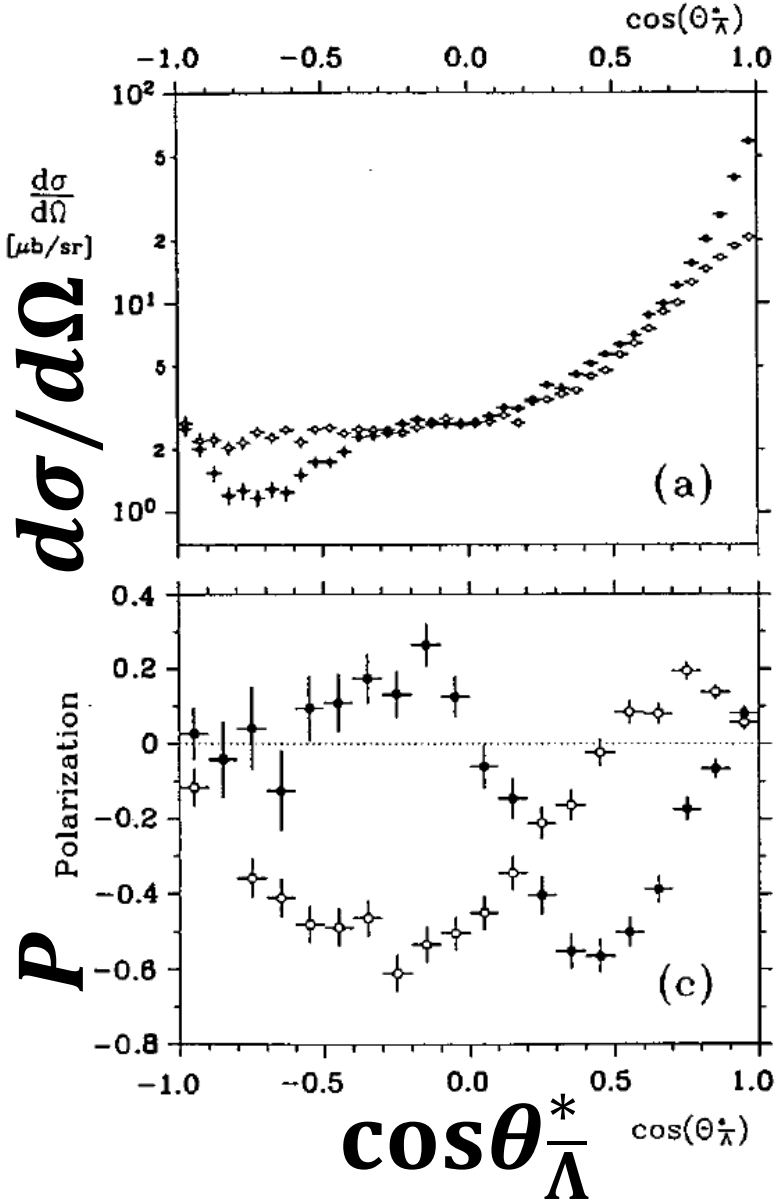
25-kW loss slit: optimized for K^-

Much higher $\bar{p}$ intensity

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

Production of $\overline{\Lambda}$s





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

$\overline{\Lambda}$s from $\overline{p} + p \rightarrow \overline{\Lambda} + \Lambda$ 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

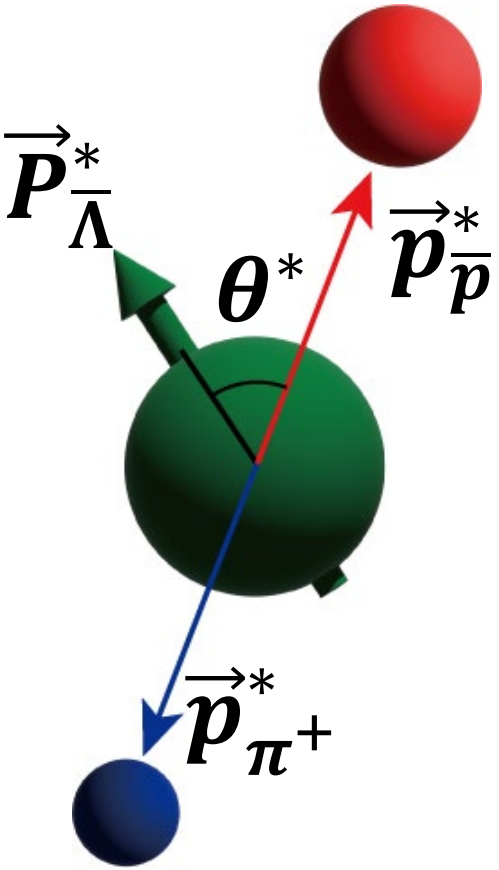
$$\frac{d\sigma}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_{\overline{\Lambda}} \vec{P}^*_{\overline{\Lambda}} \cdot \hat{p}^*_{\overline{p}}\right)$$

with

$\alpha_{\overline{\Lambda}}$: decay parameter

$\vec{P}^*_{\overline{\Lambda}}$: $\overline{\Lambda}$ polarization vector

$\hat{p}^*_{\overline{p}}$: 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 $\overline{\Lambda}$s into $\overline{p}$s



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Polarization vector of $\overline{p}$s

$\overrightarrow{P}^{\dagger}_{\overline{p}}$: $\overline{p}$ polarization in the $\overline{p}$ rest frame

$\overrightarrow{P}^{*}_{\overline{\Lambda}}$: $\overline{\Lambda}$ polarization in the $\overline{\Lambda}$ rest frame

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

$\overline{\Lambda}$ decay parameters

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

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

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

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

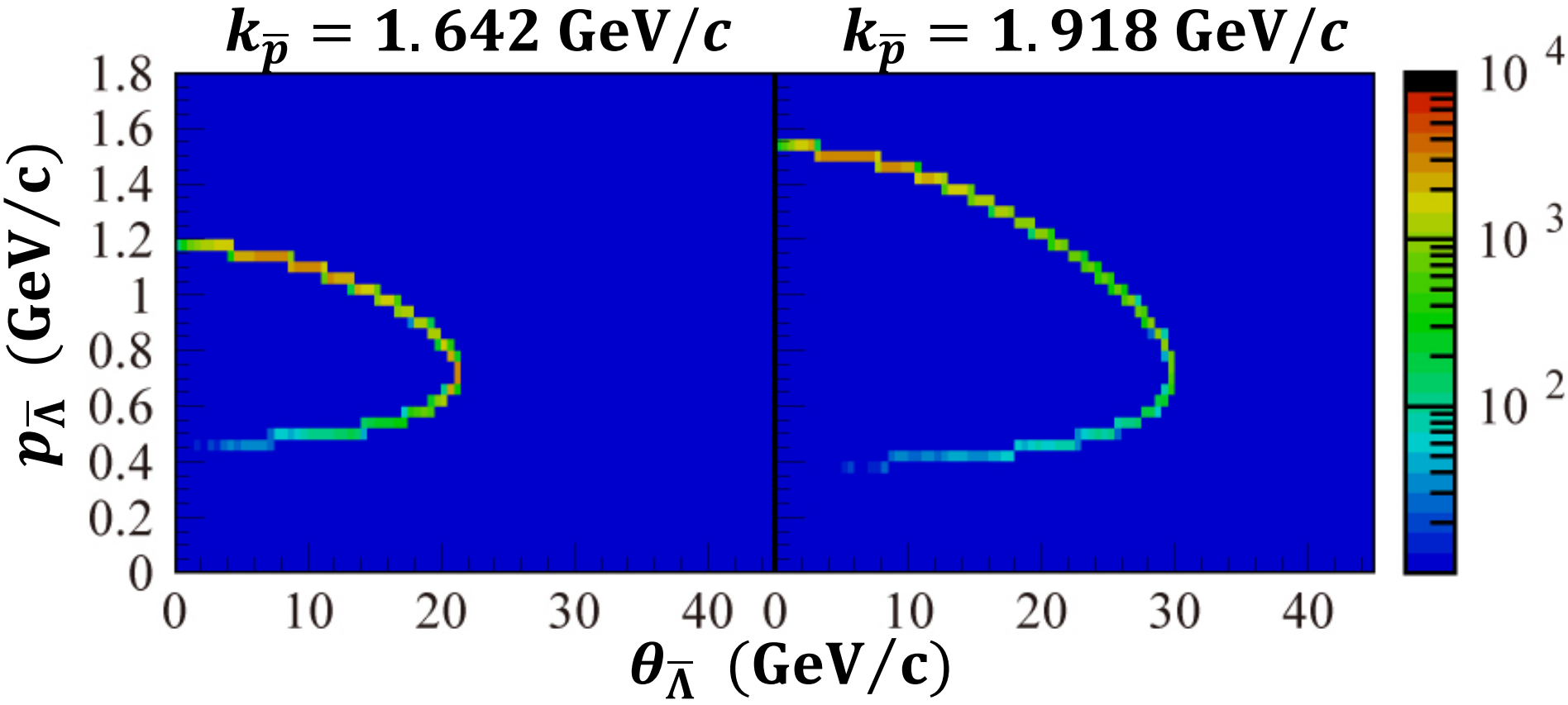
$$\tan\phi_{\Lambda} = \beta_{\Lambda}/\gamma_{\Lambda}$$



Expected Polarized Antiprotons

Production of $\bar{\Lambda}$s



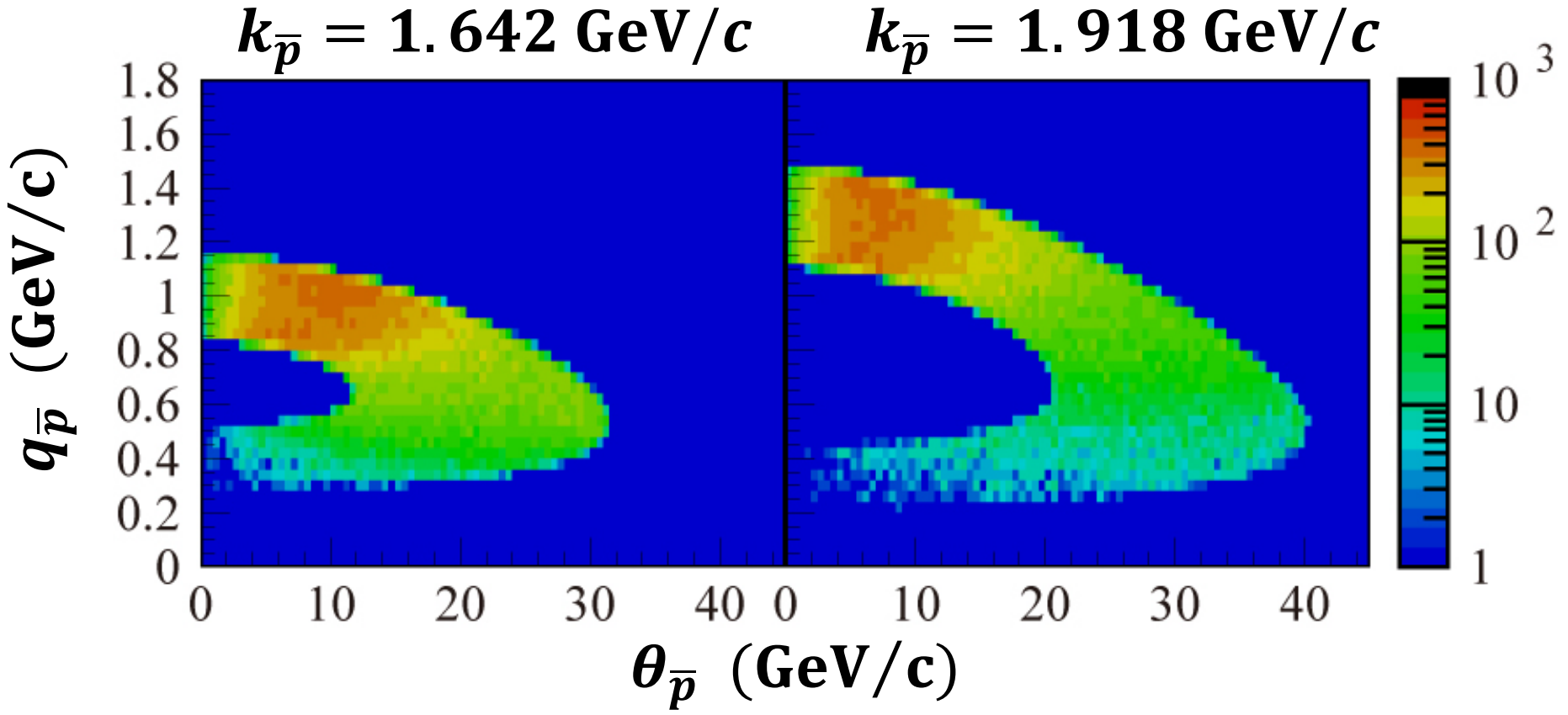


Correlation between the momentum and emission angle for produced antihyperons

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



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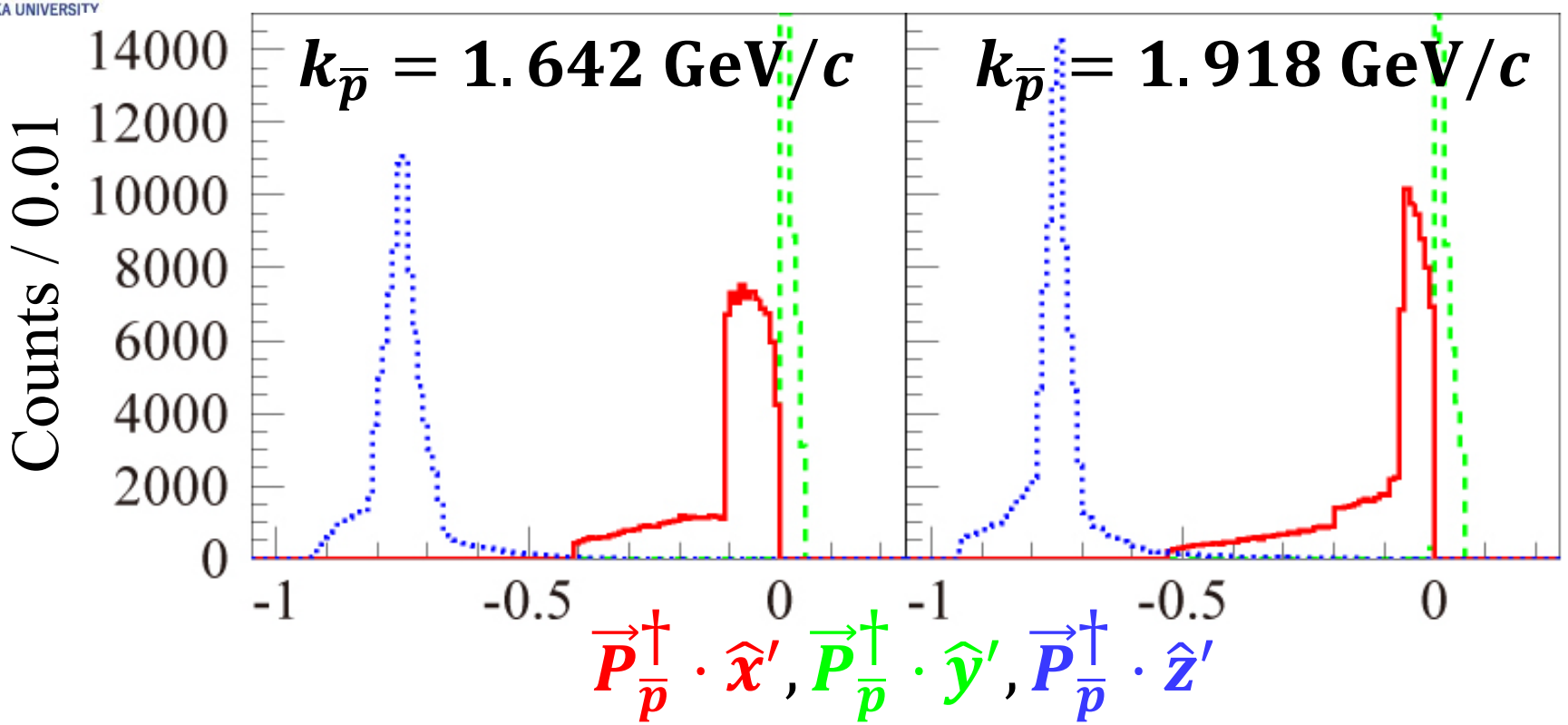


Correlation between the momentum and emission angle for daughter antiprotons

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



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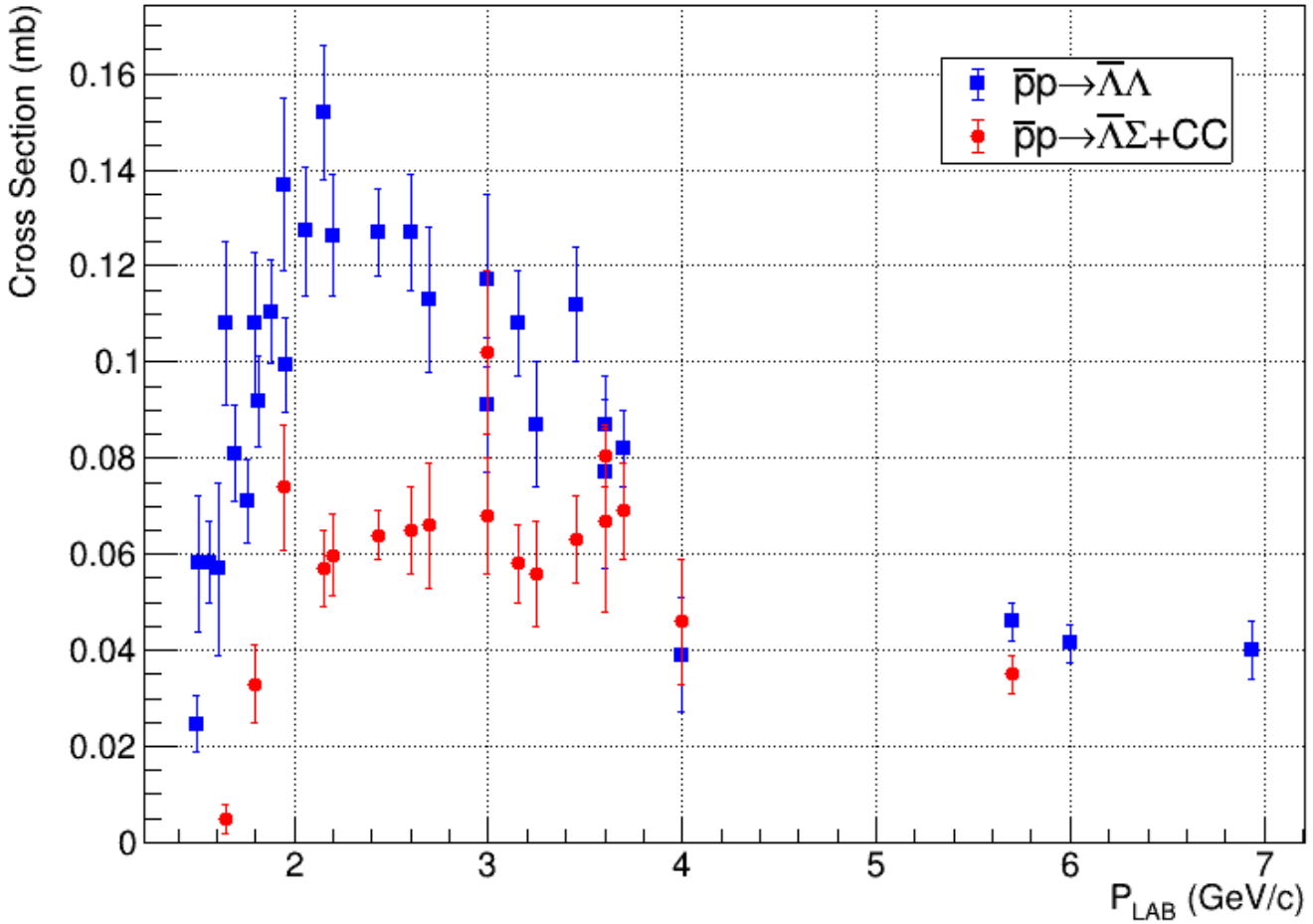


sideways, **normal**, **longitudinal**

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

$\bar{\Lambda}$ yields





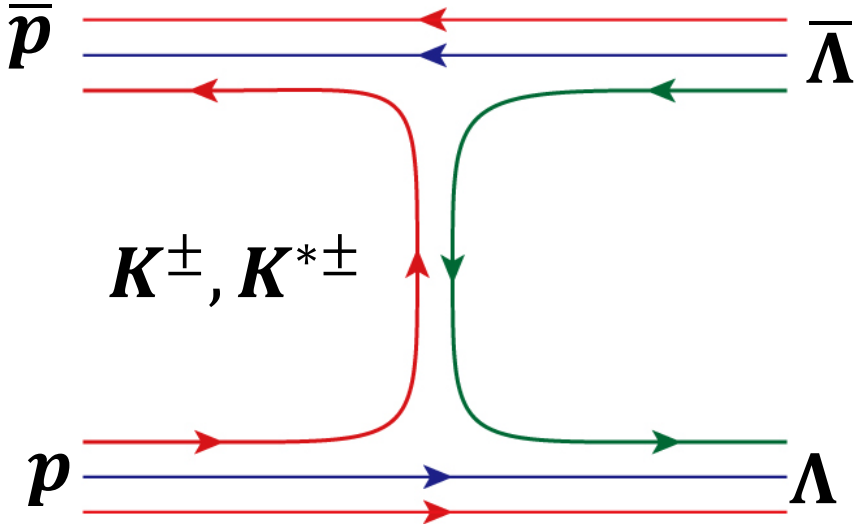
Predictions are needed over a much wider momentum range

$\overline{\Lambda}$ polarization?

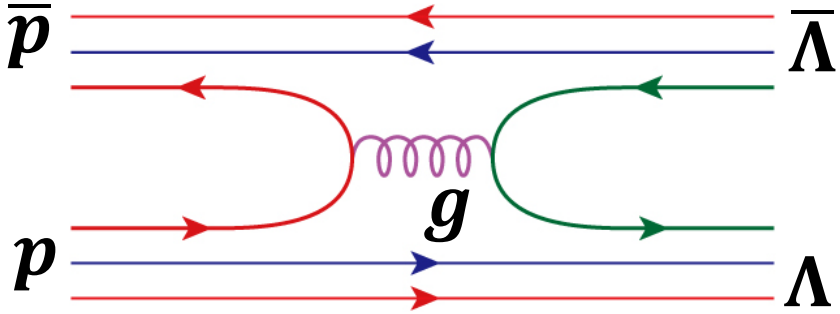


$\overline{\Lambda}\Lambda$ production mechanism

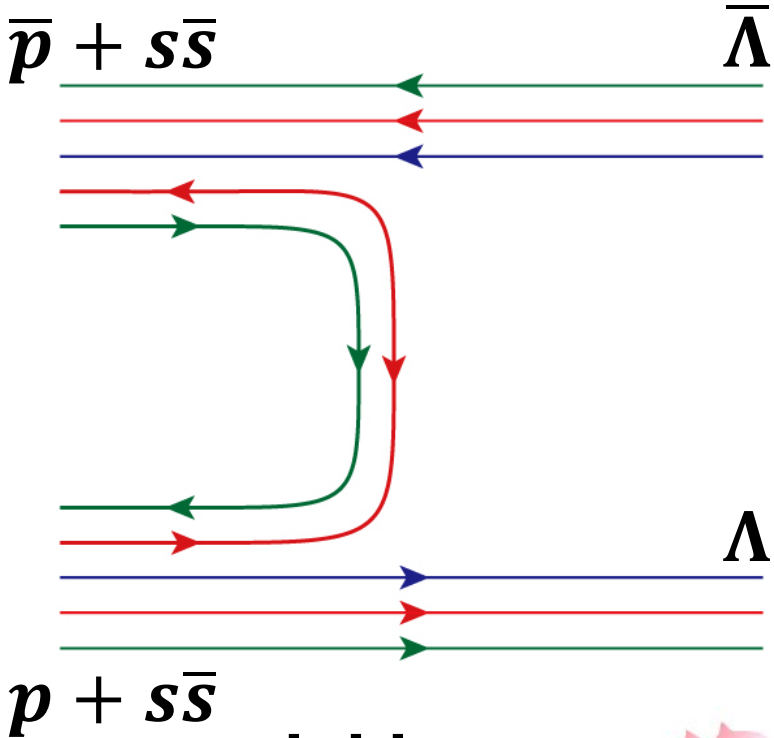
Colors indicate flavors here



t-channel meson exchange



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



picking up sea (anti)quarks



Summary

Summary

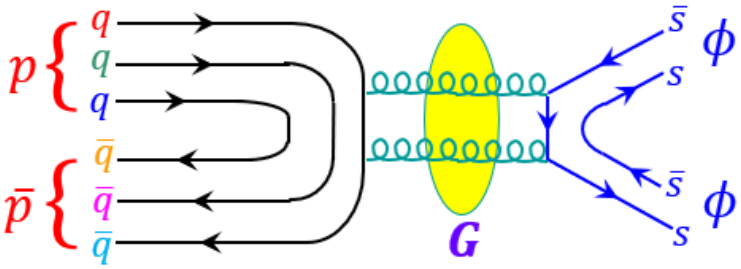


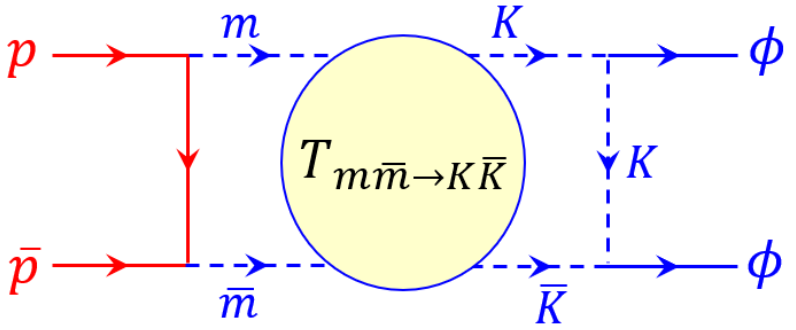
- Polarized antiprotons can be used for various hadron physics experiments.
- Polarized antiprotons can be produced from $\bar{p}p \to \bar{\Lambda}\Lambda$ and $\bar{\Lambda} \to \pi^{+}\bar{p}$
- High longitudinal polarization is available.
- For further discussion, we need to predict $\bar{\Lambda}$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

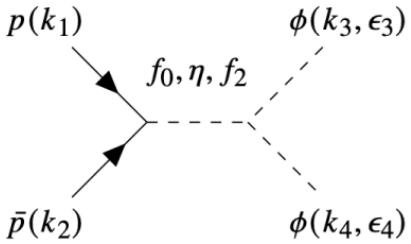


Backup

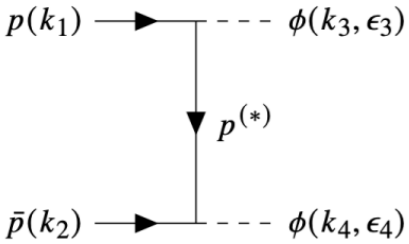
Reaction mechanisms



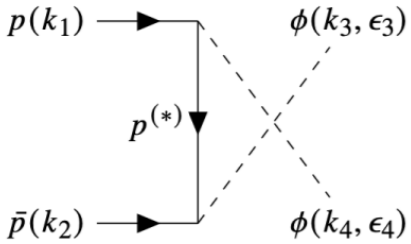




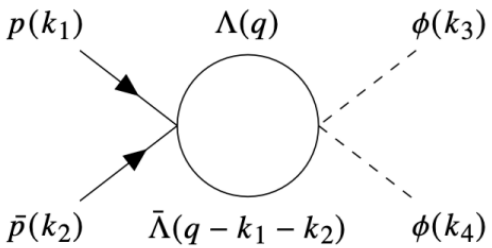
s channel

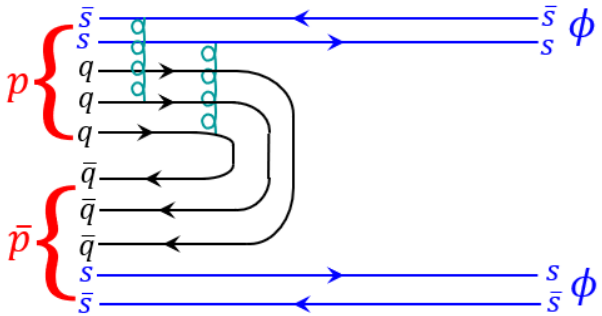


t channel



u channel



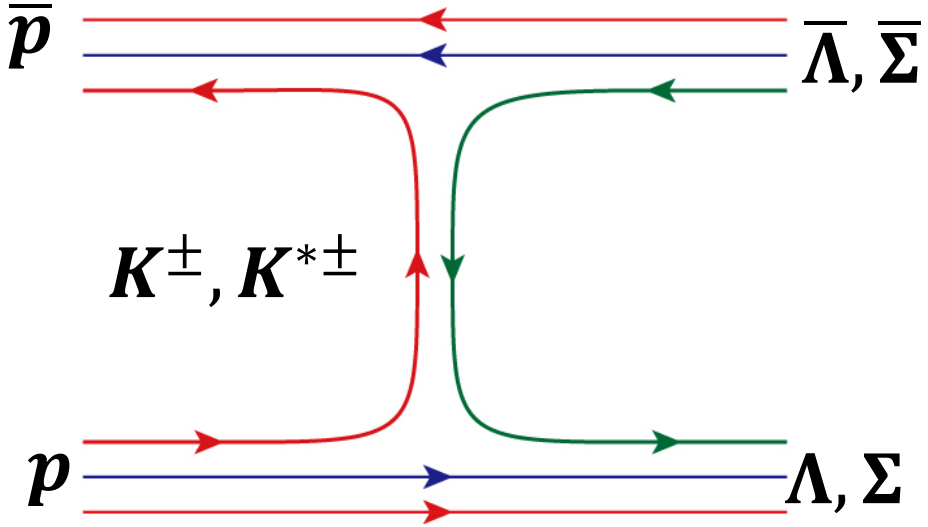


Annihilation processes

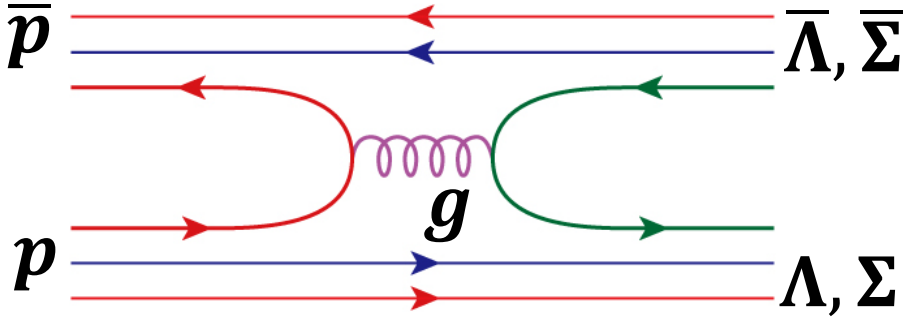


Production mechanism of $Y\overline{Y}$

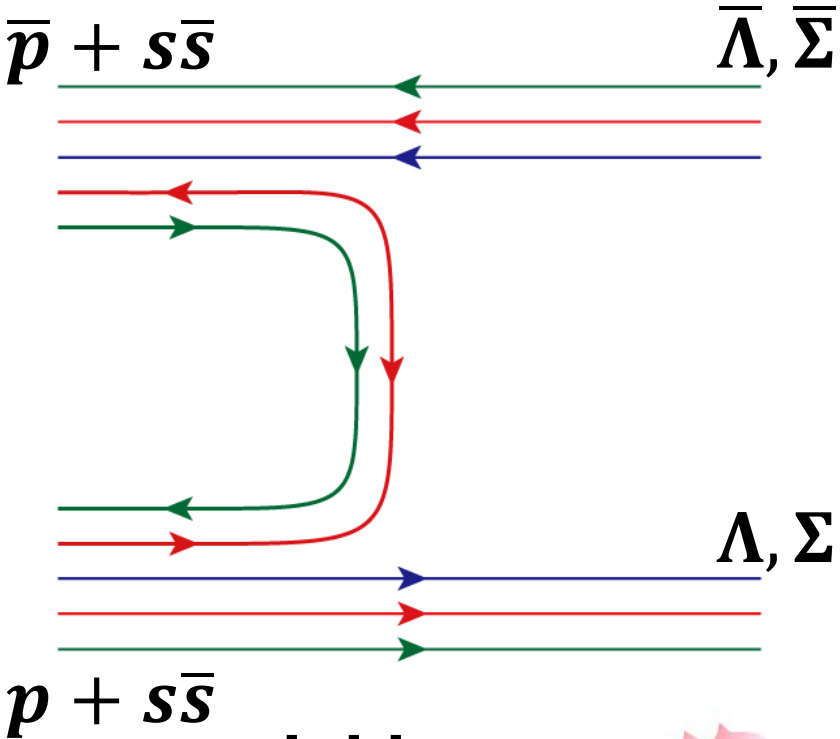
Colors indicate flavors here



t-channel meson exchange



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



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
#$q\bar{q} \rightarrow g \rightarrow s\bar{s}$	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



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Annihilation

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

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

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

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

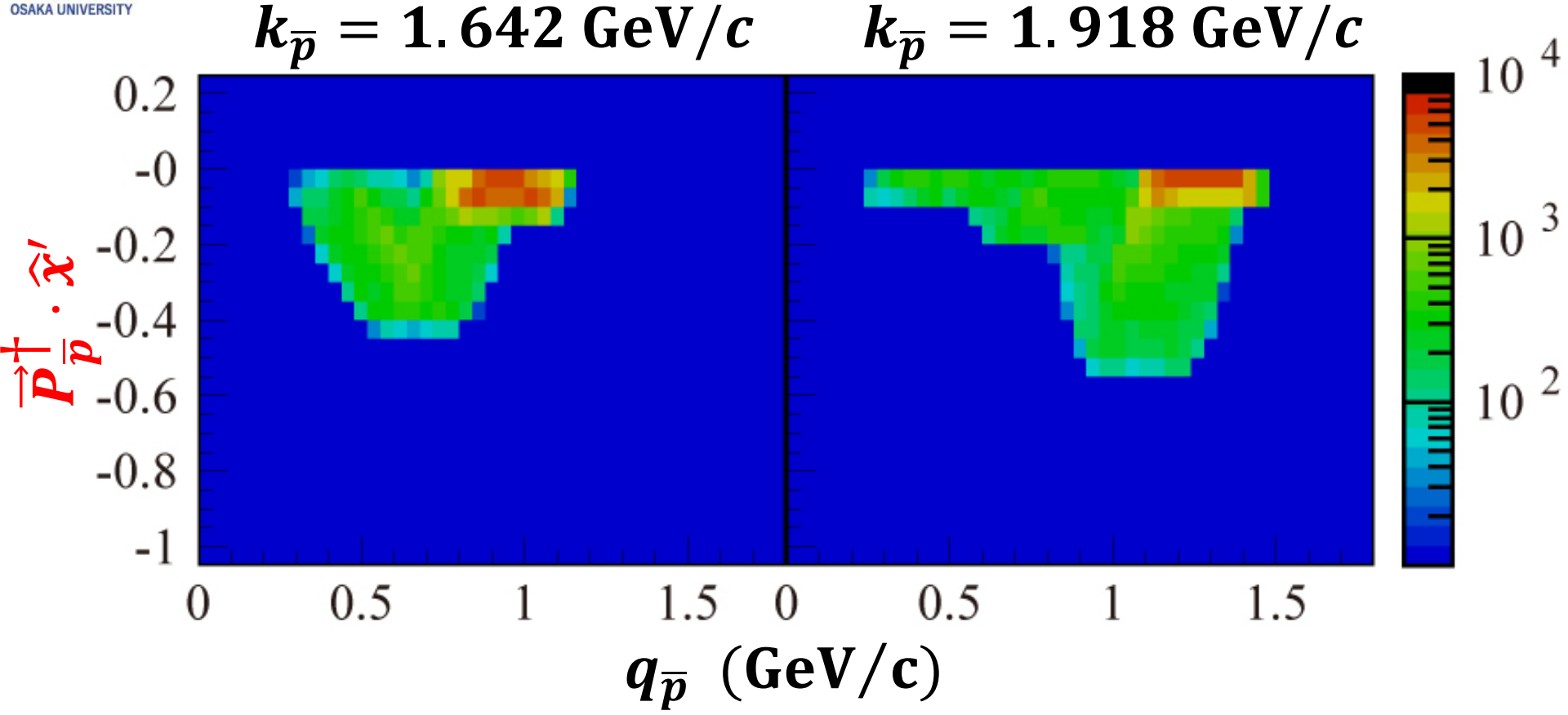
   cleanest environments for quarks and antiquarks into hadrons

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

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



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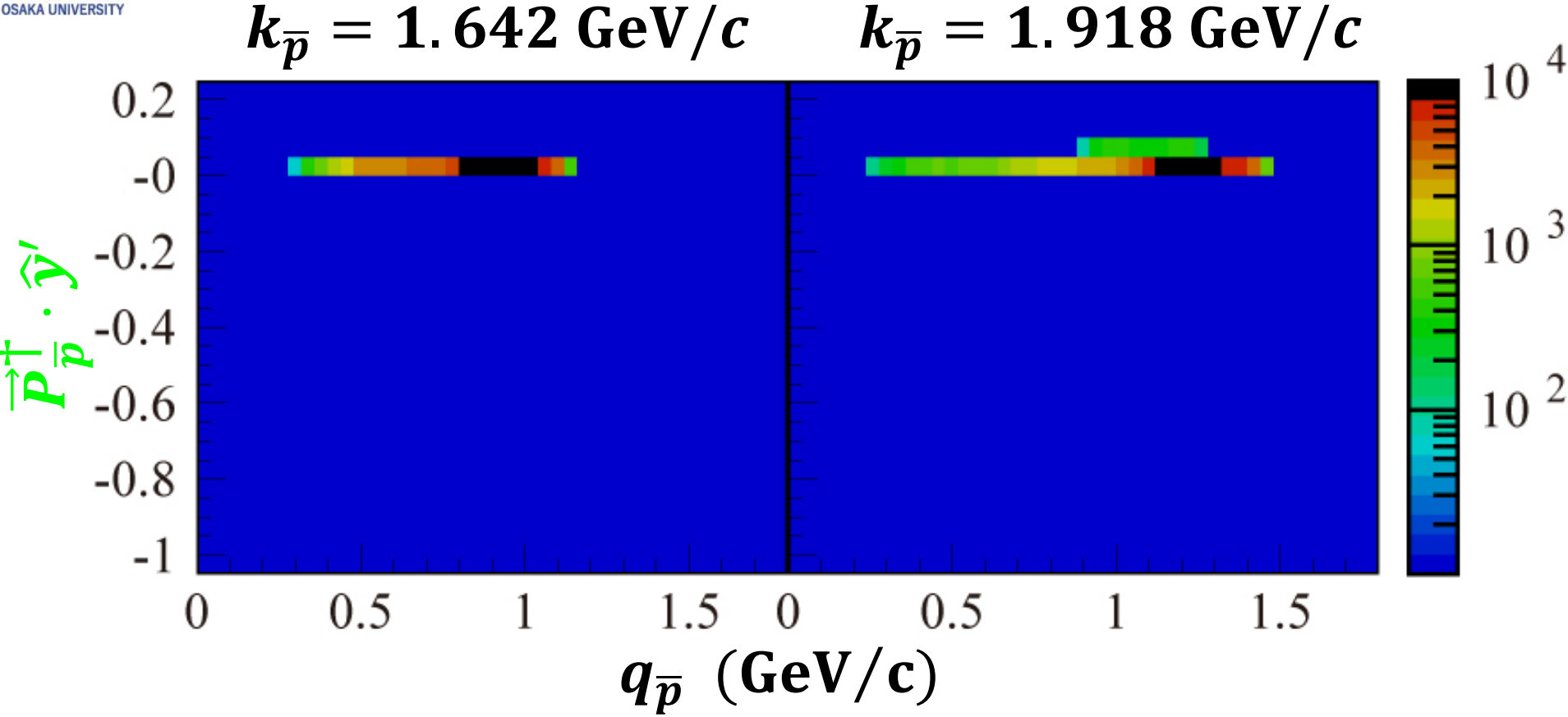


Correlation between the sideways component of polarization and momentum for daughter antiprotons

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



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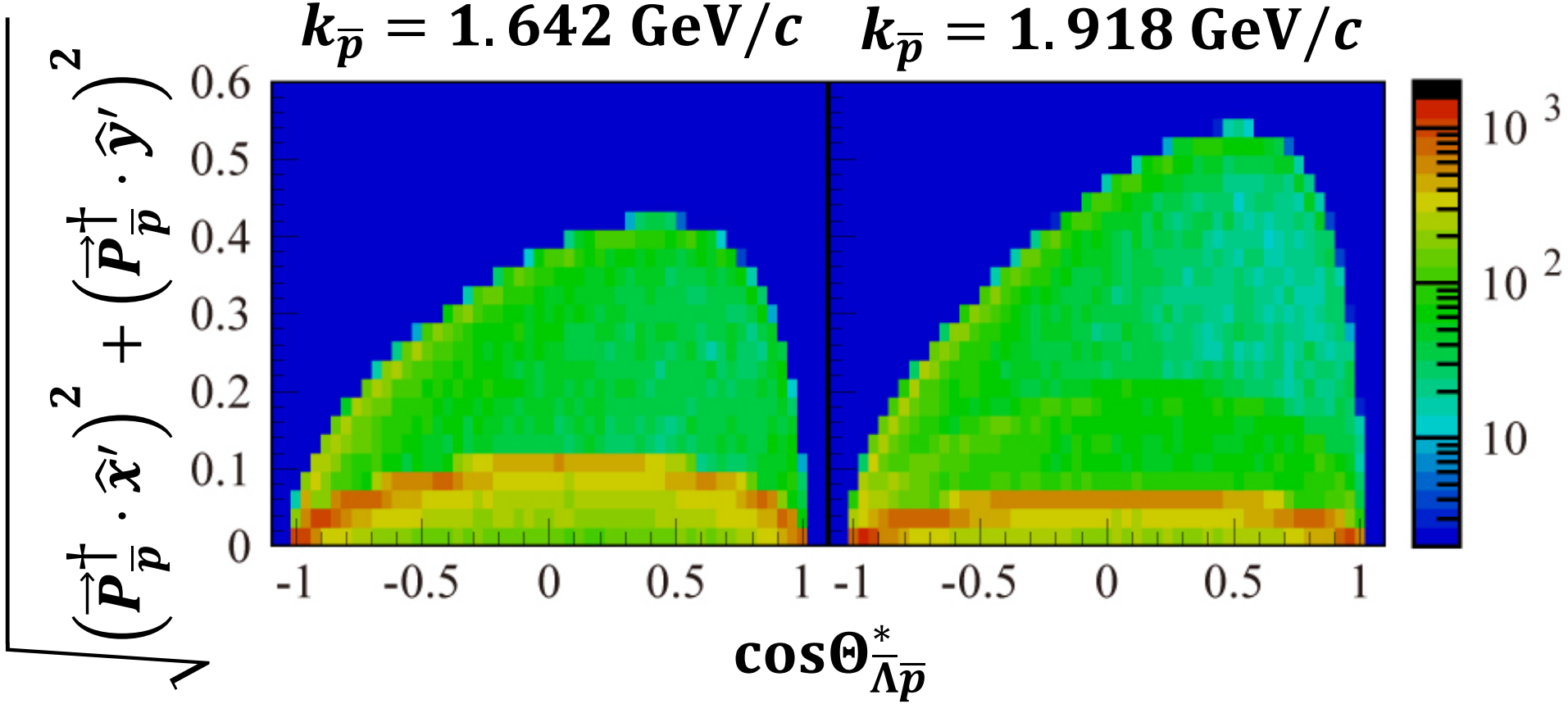


Correlation between the normal component of polarization and momentum for daughter antiprotons

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



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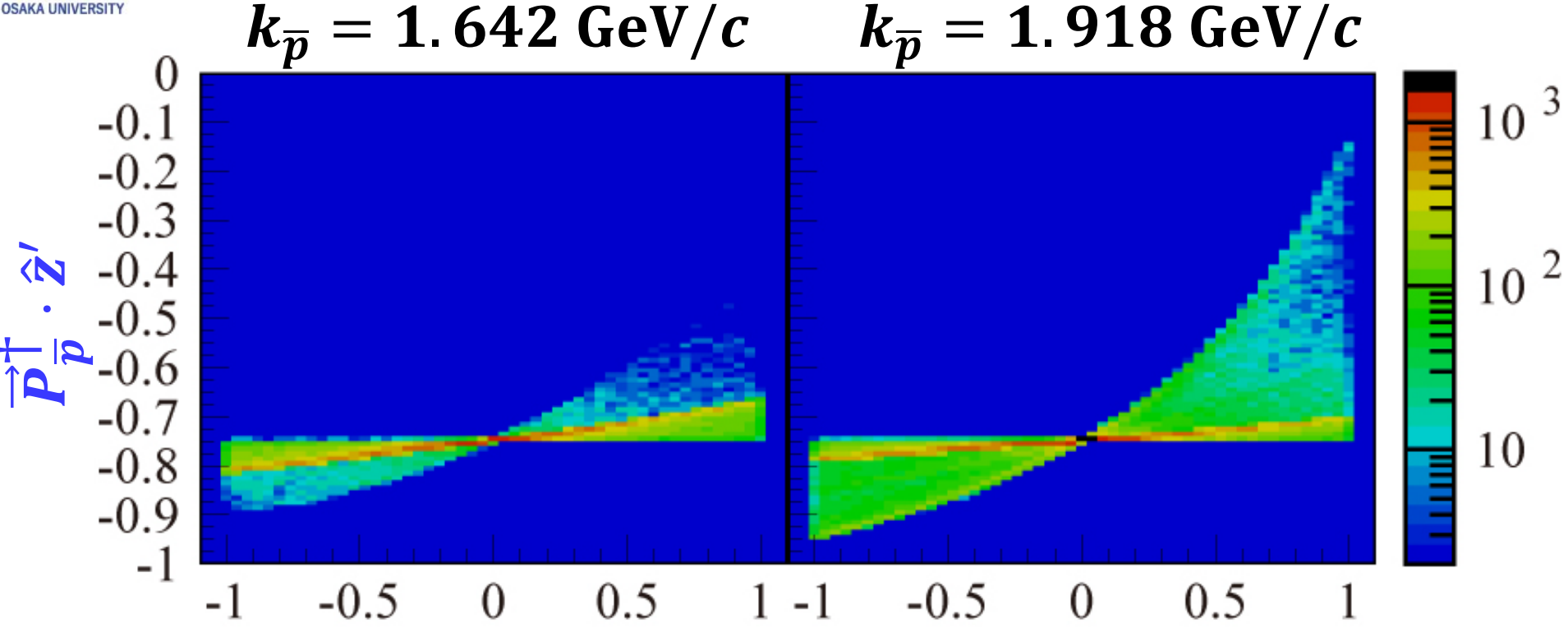


Correlation between the transverse component of $\bar{p}$ polarization and $\bar{\Lambda}$-polarization and $\bar{p}$-momentum opening angle

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



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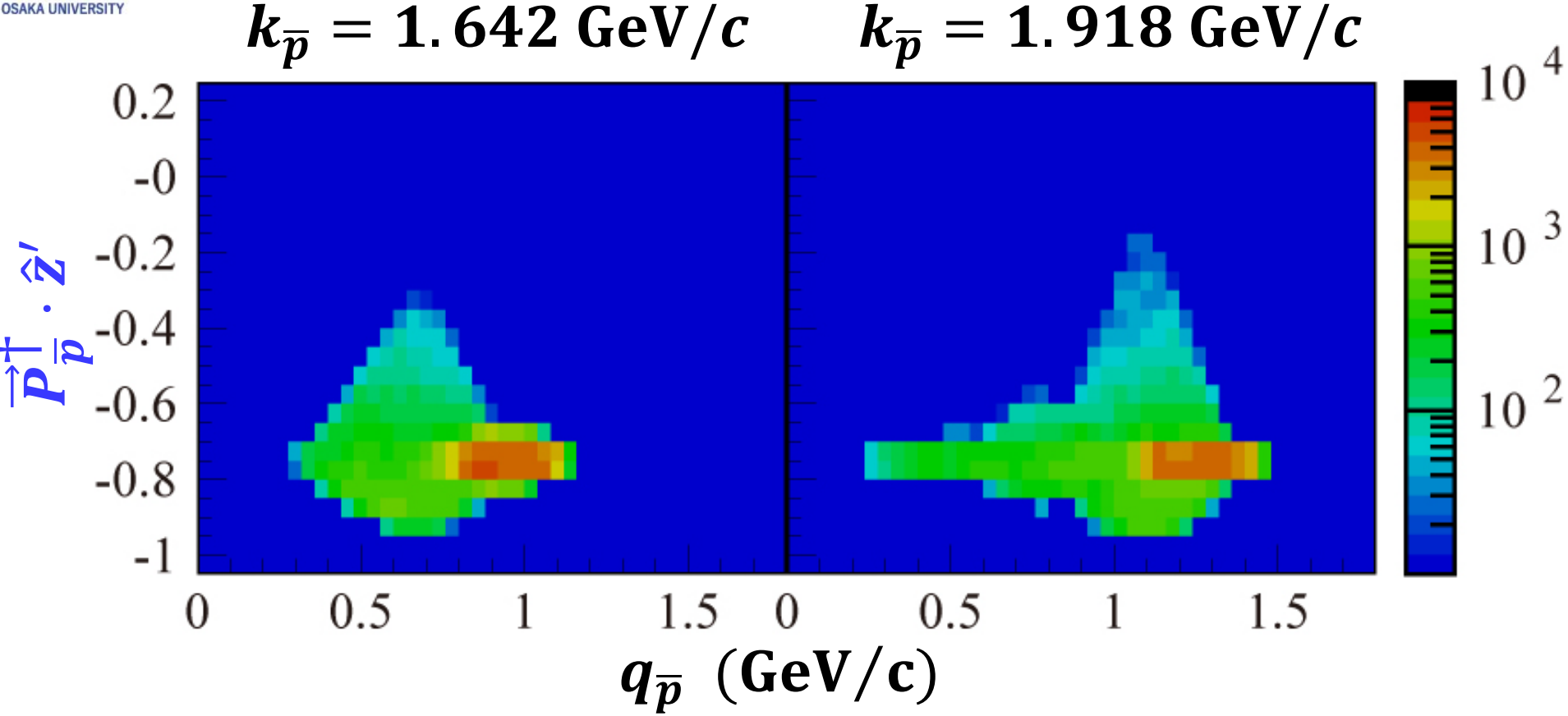


Correlation between the longitudinal component of $\bar{p}$ polarization and $\bar{\Lambda}$-polarization and $\bar{p}$-momentum opening angle

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



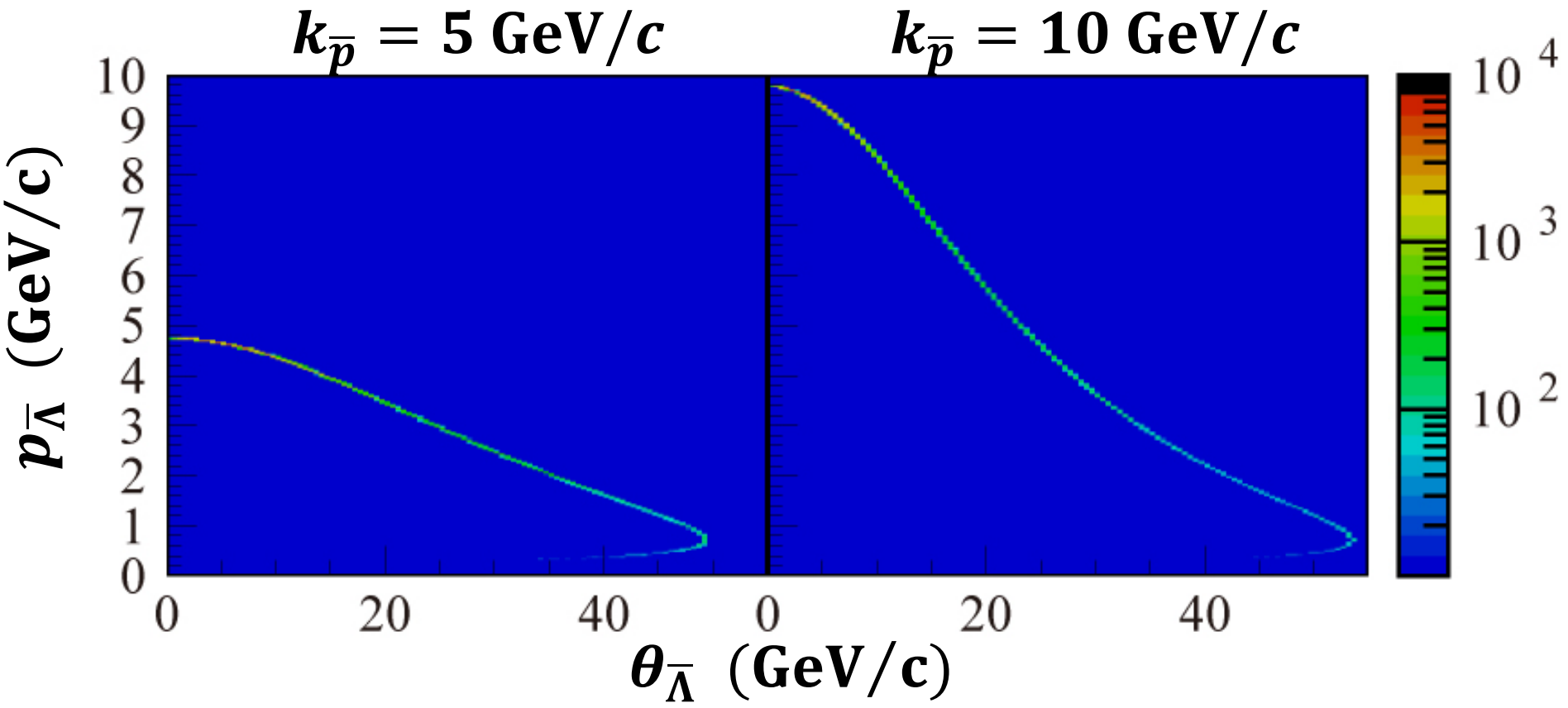
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Correlation between the longitudinal component of polarization and momentum for daughter antiprotons

Production of $\bar{\Lambda}$s



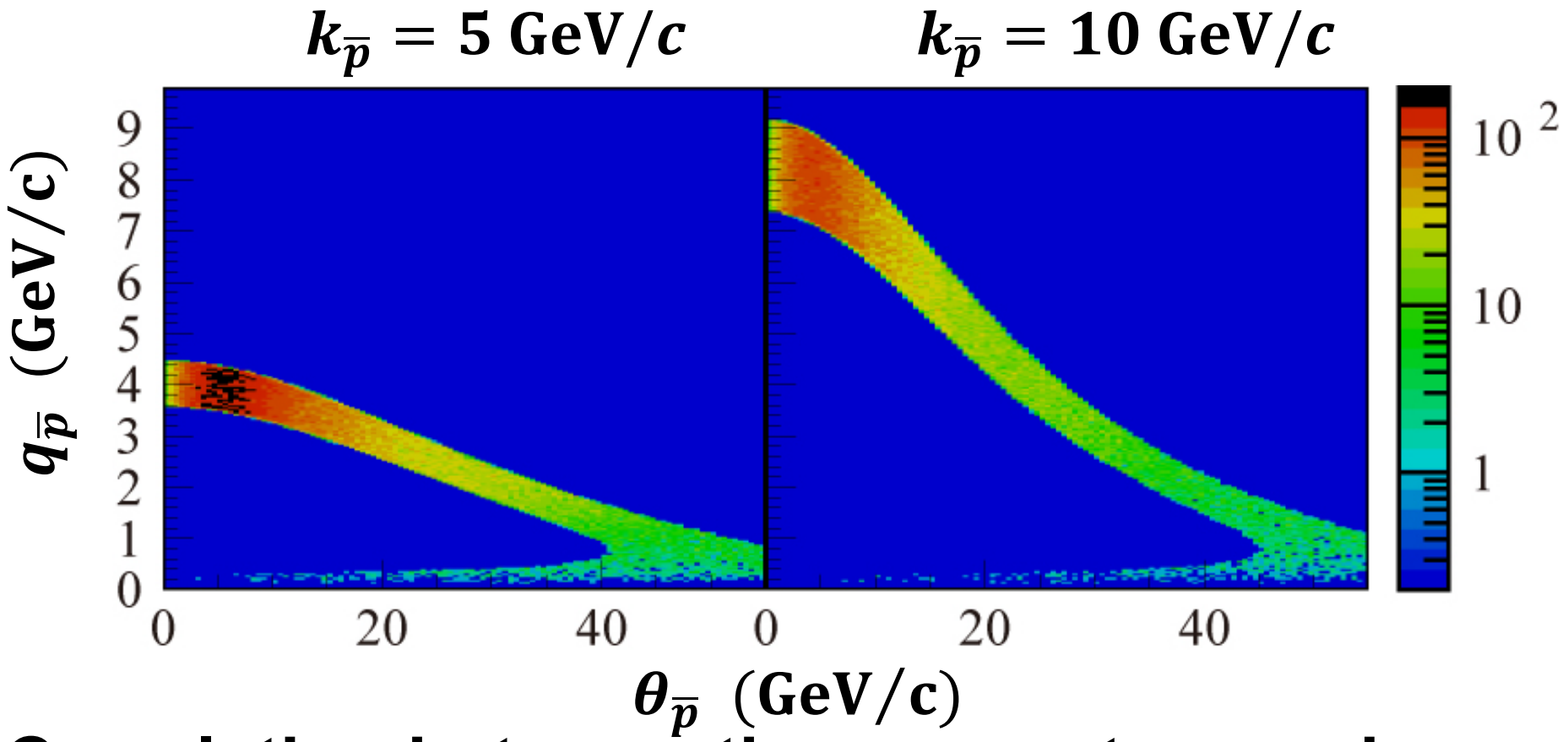


Correlation between the momentum and emission angle for produced antihyperons

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



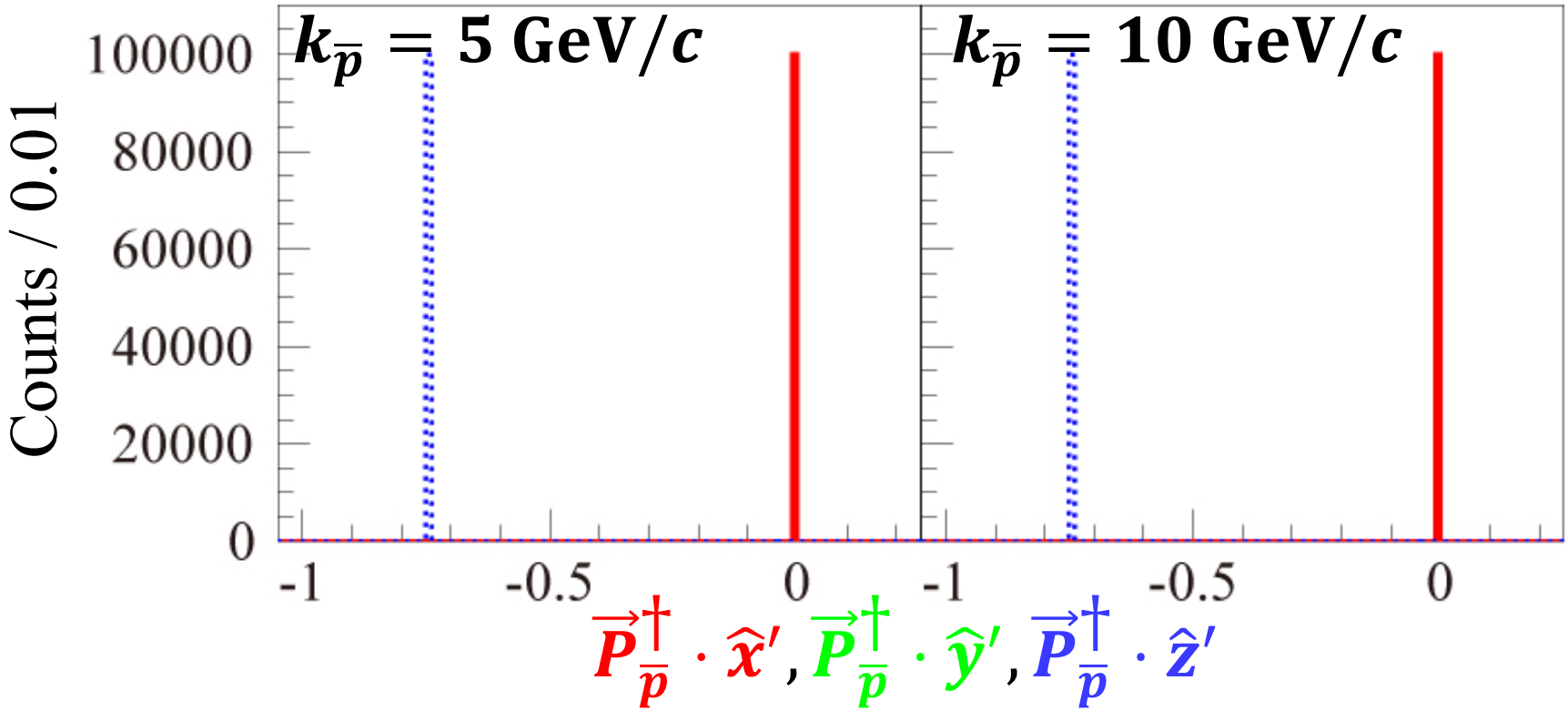
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Correlation between the momentum and emission angle for daughter antiprotons

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





sideways, normal, longitudinal

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