Overview of K10 Physics

What the K10 experiment aims to reveal

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1st J-PARC K10 Collaboration Meeting &
Workshop on K10 Physics and Detector Technology
Korea University, October 9, 2026

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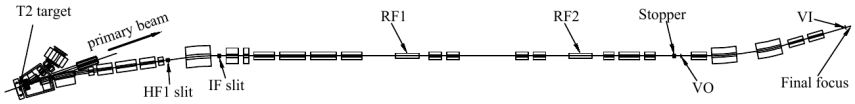
The K10 experiment in one page



[Fig. 87: layout of the RF-separator option, Third White Paper, arXiv:2110.04462]

- Beam line: RF-separated secondary beam line in the extended J-PARC Hadron Experimental Facility — high-intensity, high-purity K^-, π and $\bar{p}$ up to 10 GeV/c (possible extension to 15 GeV/c).
- Intensity (White Paper design, 25 kW loss on target): K^-: (4–9) $\times 10^6$/spill at 5–10 GeV/c ($\sim$12 times that at π20); $\bar{p}$: $\sim 10^7$/spill.
- Spectrometer: large-aperture superconducting dipole with wide acceptance for multi-particle final states, high-rate tracking and particle identification.
- Niche: $\sqrt{s} \simeq$ 2.2–4.5 GeV — where non-perturbative QCD turns into perturbative QCD; complementary to Belle II, LHC and EIC.

p_{beam} [GeV/c]	2	6	10
$\sqrt{s}$ (K^-p) [GeV]	2.23	3.52	4.46
$\sqrt{s}$ ($\bar{p}p$) [GeV]	2.43	3.63	4.54

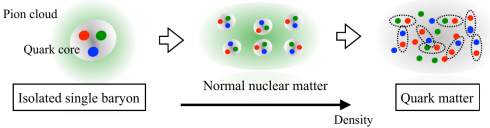
Physics pillars of K10

1. Hadron spectroscopy and exotic states
2. Non-perturbative $\rightarrow$ perturbative QCD: confinement mechanism
3. Time-like GPDs: internal structure of hadrons

Beam line and detectors: talks by Takahashi, Hwang, Shirotori, ...

The question behind K10: how do quarks build hadrons?

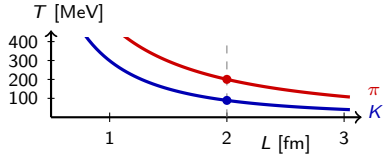
- QCD is the only strongly coupled gauge theory whose non-perturbative dynamics is directly accessible by experiments.
- Current quarks are not the building blocks directly: emergent effective degrees of freedom
  - constituent quarks and NG bosons (π, K) from spontaneous chiral symmetry breaking (instantons as a possible origin);
  - diquarks from the spin-dependent forces [one-gluon exchange (OGE), instanton-induced interaction (III), meson exchange] — widely used, but their correlation properties are not yet established.
- The strange quark sits in between light (u, d) and heavy (c, b) quarks relative to $\Lambda_{\rm QCD}$ $\Rightarrow$ nontrivial physics in multi-strangeness systems — the home ground of K10.
- Spectroscopy at zero density is the initial point of the extrapolation to dense matter (neutron-star cores, color superconductivity $\leftarrow$ diquarks).



[Fig. 69, Third White Paper, arXiv:2110.04462]

Why strangeness? $\Lambda(1405)$ and the kaon as a building block

- $\Lambda(1405)$ [$J^P = 1/2^-$, $I = 0$, $\Gamma \simeq 50$ MeV]: 27 MeV below the $K^- p$ threshold — the lightest negative-parity baryon despite its s quark. Quark models: $1P$ singlet uds ∼100 MeV too high; LS partner $\Lambda(1520)$ 115 MeV away [$N(1535)$–$N(1520)$: ∼15 MeV].
- Nature: $\bar{K}N$ quasi-bound state [Dalitz–Tuan 1959; chiral SU(3): two poles, $\simeq 1420$ ($\bar{K}N$), $\simeq 1380$ MeV ($\pi\Sigma$)] mixed with the P-wave three-quark state; lattice QCD favors $\bar{K}N$ [Hall *et al.* 2015]. A state that exists because of strangeness.
- Why a kaon, not a pion? Ground state of a 1D box of size $L = 2$ fm: $p_1 = \pi\hbar/L = 310$ MeV/c, $E_1 = \pi^2\hbar^2/2mL^2 \propto 1/m$: $E_\pi \simeq 340$ MeV vs. $E_K \simeq 100$ MeV; relativistic kinetic energy T: 200 vs. 90 MeV. The pion is still relativistic ($T/m \simeq 1.4$), the kaon is not ($T/m \simeq 0.2$): the kaon is much cheaper to localize.
- πN: no bound state [$\Delta(1232)$ is 155 MeV above threshold] → a cloud around the quark core; $\bar{K}N$: bound → a constituent.



1D box, $L = 2$ fm, $p_1 = 310$ MeV/c	π	K
$E_1 = \pi^2\hbar^2/2mL^2$ [MeV]	344	97
$T = \sqrt{p_1^2 + m^2} - m$ [MeV]	200	89
T/m	1.4	0.18

⇒ The kaon is heavy enough to be held in a hadron-sized volume, yet light enough to be a NG boson with strong (Weinberg–Tomozawa) attraction in $I = 0$ $\bar{K}N$.

Negative-parity hyperons need the $\bar{K}$ degree of freedom explicitly, besides the quark orbital excitation: $\Lambda(1405) \sim \bar{K}N$, $\Xi(1690) \sim \bar{K}\Sigma$, $\Xi(1820) \sim \bar{K}\Sigma^*$, $\Omega(2012) \sim \bar{K}\Xi^*$ — the same mechanism for $S = -1, -2, -3$. A broad spectroscopy of Λ^*, Σ^*, Ξ^* and Ω^* (M, Γ, J^P, branching ratios) at K10 will reveal how the $3q$ core and the $\bar{K}B$ component mix.

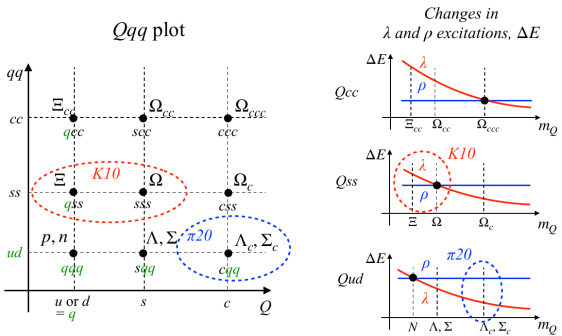
What we will explore at K10: the λ and ρ modes

Three key issues of baryon spectroscopy:

1. Flavor-dependent dynamics: QCD is flavor blind, quark masses are not.
2. Large spin-dependent forces $\rightarrow$ diquark correlations in spin-flavor antisymmetric pairs.
3. Spin–orbit (LS) force: suppressed for N^*, sizable for Λ_c^* — why?

λ and ρ modes — a flavor-sensitive probe:

- λ: motion of Q against the qq pair; ρ: internal excitation of the pair.
- Ordering changes with flavor (isotope shift): *cud*: λ lower; *qss* (Ξ): ρ lower; *sss* (Ω): degenerate.



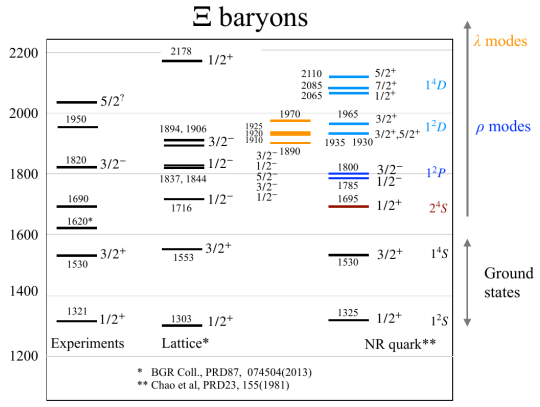
[Fig. 71, Third White Paper, arXiv:2110.04462]

K10: Ξ baryons $\rightarrow$ *su*, *ds* diquarks;
Ω baryons $\rightarrow$ no diquark, no pion cloud: the quark core itself.

Goal: one framework (quark models + chiral EFT + lattice QCD) explaining the spectrum consistently from light to heavy flavors.

Ξ baryons: the *s*-quark sector of diquark physics

- About ten excited states in the PDG, but J^P established for only two — the nature of the observed states is unclear.
- Lowest excitation: P-wave ρ mode of the ss pair. Pauli principle: $S_{ss} = 0 \Rightarrow$ a doublet $J^P = 1/2^-, 3/2^-$.
- So far only the $3/2^-$ state [Ξ(1820)] is known. Where is the $1/2^-$ partner?
  - close to $3/2^-$ if the LS force is small, as in N^*;
  - expected to be broad if it is a flavor octet — possibly why it has escaped detection.
- The ground-state octet–decuplet splitting and the ρ-mode states (with sq in S-wave) carry information on the su/ds diquark correlation.
- High-lying states, e.g. $\Xi(2370) \to \Omega\bar{K}$ $(9 \pm 4\%)$: doorway to Ω^*.



[Fig. 75, Third White Paper, arXiv:2110.04462]

Ω baryons (1): the cleanest window to the quark core

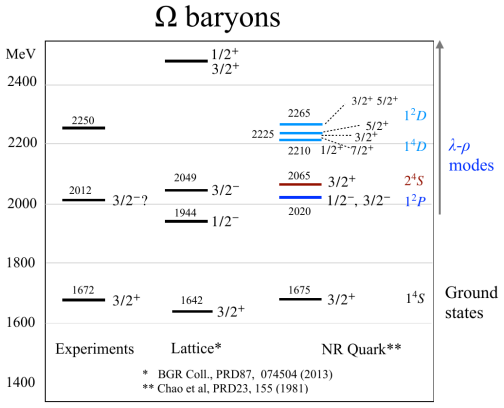
Unique features of the *sss* system:

1. Pauli constraints on the spin–orbital structure (some spin-dependent forces are switched off).
2. Kaon instead of pion: the heavier NG boson can be a constituent of hadronic molecules, as in $\Lambda(1405) \sim \bar{K}N$.
3. No pion cloud (isospin) ⇒ direct access to the quark core.

Status: beyond the ground state only Ω(2012), Ω(2250), Ω(2380), Ω(2470) — J^P unknown.

Measurement at K10 (White Paper estimate)

- $K^- p \to \Omega^{*-} K^+ K^{(*)0}$ at 7–10 GeV/c; the missing mass tags $S = -3$.
- $\sigma = 63$ nb assumed ⇒ $\sim 3 \times 10^5$ events per state in 100 days; $\sigma_M = 2.5$–4.5 MeV.
- J^P from $\Omega^{*-} \to \Xi^0 K^-$ angular distributions — only possible at K10.



[Fig. 78, Third White Paper, arXiv:2110.04462]

Ω baryons (2): Roper-like $2S$ state and the size of the quark core

- Roper-like states (same J^P as the ground state) appear universally $\sim$500 MeV above the ground state: $N(1440)$, $\Lambda(1600)$, $\Sigma(1660)$, $\Delta(1600)$, $\Xi_c(2970)$, $\Lambda_c(2765)$, $\Lambda_b(6072)$.
- Light sector: the quark model fails (mass too high, wrong ordering) $\rightarrow$ meson-cloud lowering? Heavy sector: the quark model works (λ-mode lowering).
  The two pictures must be reconciled — Ξ and Ω interpolate between them and fill the missing link.

Decay width of the Roper-like $\Omega^* \rightarrow \Xi\bar{K}$ as a probe of the core

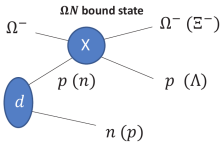
Chiral coupling of the NG kaon to quarks: $\mathcal{L}_{\phi qq} = \dfrac{g_A^q}{f_\pi}\,\bar{q}\gamma_\mu\gamma_5\lambda^a q\,\partial^\mu\phi^a$.

- Leading term $\vec{\sigma}\cdot\vec{q}$ vanishes (orthogonality of the radial wave functions); the $O(v)$ term is small.
- Dominant contribution at $O(v^2)$: transition $\propto \langle p^2\rangle \sim 1/\langle r^2\rangle \Rightarrow$ the width is dictated by the Fermi motion of the confined quarks = size of the quark core.
- Preliminary estimate: $\Gamma \sim 100$ MeV with the $O(v^2)$ terms (only ~ 20 MeV without).

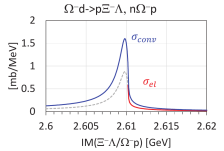
- K10: the broad ($\Gamma \sim 100$ MeV) Roper-like "$\Omega(2160)$" is observable with $\Omega^{*-} \rightarrow \Xi^0 K^-$ tagging, even if the cross section is 1/10 of the assumed 63 nb; radiative decays $\Omega^* \rightarrow \Omega\gamma$ also probe the wave functions.

ΩN interaction: baryon–baryon dynamics beyond the octet

- Flavor SU(3): $\mathbf{10} \otimes \mathbf{8} = \mathbf{35} \oplus \mathbf{27} \oplus \mathbf{10} \oplus \mathbf{8}$. ΩN ($S = -3$, $I = 1/2$) appears in all four: **8** (40%), **10** (25%), **27** (22.5%), **35** (12.5%).
- Same multiplets, same (S, I): $\Xi^*\Lambda$, $\Xi\Sigma^*$, $\Xi^*\Sigma$ (thresholds 2649, 2703, 2727 MeV), all above ΩN (2611 MeV): ΩN is the lowest decuplet–octet channel; the open octet–octet channels $\Xi\Lambda$, $\Xi\Sigma$ (2434, 2512 MeV) couple to ${}^5S_2$ only in D wave $\Rightarrow$ narrow.
- Lattice QCD (HAL QCD): no repulsive core in $\Omega N\,({}^5S_2) \Rightarrow$ shallow bound state, $B \simeq 1.5$ MeV.
- ALICE $\Omega^- p$ femtoscopy: attractive, bound state inconclusive.
- Meson-exchange model fitted to lattice [Sekihara *et al.*]: pole at $2611.3 - 0.7i$ MeV $\Rightarrow \Gamma \sim 1.5$ MeV.
- K10: Ω^- from $K^- p \to \Omega^- K^+ K^{(*)0}$ as a secondary beam ($p_\Omega \sim$ 2–4 GeV/c, weak decay only).
- $\Omega^- d \to \Xi^- \Lambda\, p_{\rm spec}$: the off-shell neutron (deuteron D wave, high-momentum tail) brings $\Omega^- n$ to and below threshold.
- Yield: $\sim$10 Ω^-/spill $\Rightarrow \sim$20/day, $\sim 2 \times 10^3$ in 100 days.



[Fig. 103, Third White Paper, arXiv:2110.04462]



[Fig. 106, Third White Paper, arXiv:2110.04462]

Narrow peak below the $\Omega^- N$ threshold in $M(\Xi^-\Lambda)$: a direct test of lattice QCD. Needs $\Delta p/p < 0.2\%$, vertexing, backward coverage.

Exotic hadrons with strangeness: strange partners of P_c and Z_c

- Exotic hadrons started from strange hadrons: $\bar{K}N$ molecule $\to \Lambda(1405)$ (Dalitz–Tuan 1959); $f_0(980)$, $a_0(980) \sim K\bar{K}$.
- $N^*(1535) \sim s\bar{s}uud$ ($K\Sigma$–$K\Lambda$–ηN) $\xrightarrow{s\bar{s} \to c\bar{c}}$ prediction of the $\bar{D}^{(*)}\Sigma_c$ molecules = the P_c states of LHCb.
- Then hundreds of strange partners of P_c, Z_c, ... should exist near meson–baryon and meson–meson thresholds:

Sector	Thresholds $\to$ candidates	Access at K10
N^* ($S=0$)	$K\Sigma^* \to N(1875)$, $K^*\Sigma \to N(2080)$, $K^*\Sigma^* \to N(2270)$	$\pi^- p$, $\bar{p}p$
Λ^* ($S=-1$)	$K\Xi$ (1.81), $K\Xi^*$ (2.03), $K^*\Xi$ (2.21), $K^*\Xi^*$ (2.43 GeV)	$K^- p \to K^+\Xi^-$ formation
Ξ^* ($S=-2$)	$\bar{K}\Sigma \to \Xi(1690)$, $\bar{K}\Sigma^* \to \Xi(1820)$, $\bar{K}^*\Sigma$ (2.08), $\bar{K}^*\Sigma^*$ (2.28 GeV)	$K^- p \to K^{(*)}\Xi^*$
Ω^* ($S=-3$)	$\bar{K}\Xi^* \to \Omega(2012)$	$K^- p \to \Omega^* K^+ K^{(*)0}$
Mesons	$\bar{K}^*K \to f_1(1420)$, $a_1(1420)$, $h_1(1380)$; $\bar{K}^*K^* \to f_0(1710)$, $a_0(1710)$; $\bar{K}K_1(1400) \to \eta_1(1855)$ $[1^{-+}]$	$K^- p$, $\bar{p}p$
$B\bar{B}$	$\Lambda\bar{\Lambda} \to \phi(2170)$, $\eta(2225)$; $\Sigma\bar{\Sigma} \to \eta(2320)/X(2370)$	$\bar{p}p$

Same states, two pictures: three-quark ρ/λ excitation [$\Xi(1820)\,3/2^-$, $\Omega(2012)$ in the White Paper] vs. hadronic molecule — J^P, widths, branching ratios and production rates at K10 will tell; quark models must be unquenched near thresholds.

[B. S. Zou, "Exotic hadrons with strangeness"]

Exotic hadron spectroscopy with K10: new reaction channels

- Two criteria for exotics: states that do not fit the $q\bar{q}/qqq$ spectrum; production by mechanisms that disfavor ordinary hadrons $\Rightarrow$ K10 offers a controlled production mechanism.
- Antihyperon production in $K^- p$ — largely unexplored:
  - $\bar{\Lambda}$ production: multi-strange dibaryons and $\Lambda\Lambda\bar{\Lambda}$ systems;
  - $\bar{\Xi}$ production: $K^- p \to d_{N\Omega}\,\bar{\Xi}^0$.
- Hidden charm near threshold with meson beams:
  - $\pi^- p \to J/\psi\, n$: $p_{\rm th} = 8.2$ GeV/c; $K^- p \to J/\psi\,\Lambda$: $p_{\rm th} = 8.8$ GeV/c;
  - strange hidden-charm pentaquarks in $K^- p$ formation: $P_{c\bar{c}s}(4338)$ at 9.4 GeV/c, $P_{c\bar{c}s}(4459)$ at 10.0 GeV/c — at the top of the K10 range;
  - $X_{0,1}(2900)$ ($ud\bar{s}\bar{c}$) in $K^+ p \to X\,\Sigma_c^{++}$: 14.5 GeV/$c$ $\Rightarrow$ a case for the 15 GeV/c extension.
- Is there an observable upper mass limit of hyperon resonances? Broadening widths, vanishing two-body decays, a universal "disappearance line" near 3 GeV.
- $K^{\mp} p$ total and exclusive cross sections at $W = 3$–5 GeV: the bridge between the low-energy (chiral) and high-energy (Regge, pQCD) regimes.

[J. K. Ahn, "Exotic Hadron Spectroscopy with K10", RCNP, Aug. 2026]

Antiproton beam at K10: a unique, glue-rich probe

- Formation of any (non-exotic) J^{PC}: $\bar{p}p$ annihilation is not limited to 1^{--} as e^+e^-; $\sqrt{s}$ is set by the beam momentum $\Rightarrow$ direct resonance scan.
- Glue-rich: $\bar{p}p$ is $I = 0 \oplus 1$ [SU(3): $\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}$, singlet only 1/8]; when all three $q\bar{q}$ pairs annihilate, $\sim$2 GeV goes into a purely gluonic, flavor-singlet ($I = 0$) state — efficient for glueballs and hybrids; connected quark lines feed ordinary $q\bar{q}$ mesons.
- Symmetric strangeness/charm production: $\bar{p}p \to \bar{Y}Y$ ($\bar{\Lambda}\Lambda$, $\bar{\Xi}\Xi \sim 1\,\mu$b, $\bar{\Omega}\Omega$ unmeasured), $\bar{\Lambda}_c\Lambda_c$; self-analyzing weak decays of Y and Λ_c give full spin observables (polarization, spin correlations) that discriminate the $s\bar{s}/c\bar{c}$ creation mechanism.
- Nuclear targets: hadrons produced at low momentum in the medium; $\bar{p}$–nucleus cross sections for cosmic-ray antimatter searches.
- Polarized $\bar{p}$? K10 is an extracted beam at a finite production angle — the geometry needed to test polarization at production.

	$p_{\bar{p}}$ [GeV/c]	$\Delta p/p$	intensity
PANDA	1.5–15	10^{-4}–10^{-5}	<20 MHz*
K1.8BR	< 2		2 M/spill
π20	2–20	1×10^{-3}	7 M/spill
K10	2–10	2×10^{-3}	6.5 M/spill

*interaction rate; J-PARC values at 7 GeV/c (K1.8BR: 1.8 GeV/c)

$\bar{p}p \to$	$p_{\bar{p}}$ [GeV/c]
$\bar{\Lambda}\Lambda$ / $\bar{\Sigma}\Sigma$ / $\bar{\Xi}\Xi$ / $\bar{\Omega}\Omega$ thresholds	1.44 / 1.85 / 2.62 / 4.94
η_c / J/ψ / $\psi(2S)$ / $X(3872)$	3.69 / 4.07 / 6.23 / 6.99
$D\bar{D}$ / $\bar{\Lambda}_c\Lambda_c$ thresholds	6.41 / 10.16

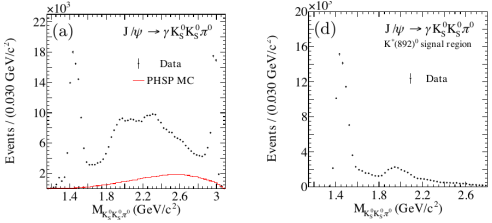
[K. Suzuki, "Physics of Antiproton Beam at π20 and K10", RCNP, Aug. 2026]

LEAR (0.1–2 GeV/c) ended in 1996: 30-year hiatus above 2 GeV/c. PANDA = precision (storage ring); J-PARC π20/K10 = intensity and discovery.

A glueball candidate: $X(2370)$ [BESIII, arXiv:2607.20366]

- Lattice QCD: lightest 0^{-+} glueball at 2.3–3.0 GeV.
- $X(2370)$ in $J/\psi \to \gamma X$ with 10^{10} J/ψ: $J^{PC} = 0^{-+}$; $M \simeq 2359$ MeV, $\Gamma \simeq 170$ MeV; seen in $\pi\pi\eta'$, $K\bar{K}\eta'$, $K\bar{K}\pi$, $\pi\pi\eta$.
- New: $X(2370) \to K^*(892)\bar{K}$ is not seen ($\mathcal{B} < 1.6\%$, $\Gamma_{K^*\bar{K}} < 2$ MeV)
  $\Rightarrow$ flavor singlet (a 0^{-+} singlet cannot decay to $K^*\bar{K}$: generalized G parity) — the first flavor-singlet light hadron above 1 GeV.
- Further glueball-like properties:
  - large production rate, $\mathcal{B}(J/\psi \to \gamma X) > 10^{-3}$;
  - decay pattern similar to η_c; partial widths of a few MeV;
  - $X \to \gamma\omega$, $\gamma\phi$ strongly suppressed.
- BESIII: the lightest 0^{-+} glueball is the dominant constituent.

But $X(2370)$ sits at the $\Sigma\bar{\Sigma}$ threshold (2.38 GeV): a $\Sigma\bar{\Sigma}$ molecule ($\bar{s}s\,\bar{q}^2q^2$)? [Zou] BESIII disfavors it.
So far one production mechanism only (J/ψ radiative decay) $\Rightarrow$ an independent, glue-rich probe is needed: $\bar{p}p$.



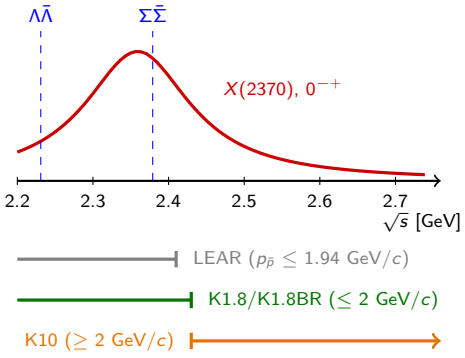
[Fig. 1(a),(d) of BESIII, arXiv:2607.20366]

$M(K^0_SK^0_S\pi^0)$ in $J/\psi \to \gamma K^0_SK^0_S\pi^0$. Left: $X(2370)$ and η_c visible. Right: with $K^*(892)^0$ selected — no $X(2370)$.

$J/\psi \to \gamma X(2370) \to$	$\mathcal{B}$ $[10^{-4}]$
$\gamma K\bar{K}\pi$	$3.25 \pm 0.25^{+0.73}_{-0.75}$
$\gamma\pi\pi\eta$	$3.2 \pm 0.1^{+0.9}_{-1.0}$
$\gamma\pi\pi\eta'$	$1.94 \pm 0.04^{+0.33}_{-0.88}$
$\gamma K\bar{K}\eta'$	$0.39 \pm 0.05 \pm 0.10$

Can we see $X(2370)$ with the $\bar{p}$ beam? (1) Formation

- Quantum numbers match: 0^{-+}, $I = 0$ is the $^1S_0$ state of $\bar{p}p$ $\Rightarrow$ direct s-channel formation in an S wave.
- Kinematics: $\sqrt{s} = M_X$ at $p_{\bar{p}} = 1.80$ GeV/c; $M_X \pm \Gamma/2 \leftrightarrow p_{\bar{p}} = 1.56$–$2.04$ GeV/c.
- No storage ring needed: $\Delta p/p = 2 \times 10^{-3} \Rightarrow \delta\sqrt{s} \simeq 1.3$ MeV $\ll \Gamma$.
  A broad glueball candidate is an ideal target for an intense extracted beam.
- Precedent at LEAR (Crystal Barrel, $p_{\bar{p}} \leq 1.94$ GeV/c): a 0^{-+} state $\eta(2320)$ in $\bar{p}p \to \eta\eta\eta$, $\sigma \sim$ few μb — probably the same state; the data stop at $\sqrt{s} = 2.41$ GeV, just above the peak.



Rate estimate (Breit–Wigner, my rough estimate)

$$\sigma_{\rm peak}(\bar{p}p \to X \to f) = \frac{\pi}{k^2}\,\mathcal{B}_{\bar{p}p}\,\mathcal{B}_f \simeq 2.4\ {\rm mb} \times \mathcal{B}_{\bar{p}p}\,\mathcal{B}_f$$

$\mathcal{B}_{\bar{p}p} \sim 10^{-3}$ [cf. $\mathcal{B}(\eta_c \to p\bar{p}) = 1.3 \times 10^{-3}$], $\mathcal{B}_f \sim 0.1$–$0.3 \Rightarrow$ $\sigma \sim 0.2$–0.7 μb

10^6–10^7 $\bar{p}$/spill on 10 cm LH_2: 10^3–10^4 events/day per 0.5 μb.

$X(2370)$ lies just at the lower edge of K10: K10 at 2–2.5 GeV/c covers the upper half and the unexplored region above; K1.8 the lower half. Question to the beam-line design: can K10 deliver $\bar{p}$ down to $\sim$1.5 GeV/c?

Can we see $X(2370)$ with the $\bar{p}$ beam? (2) Strategy at K10

(a) What to measure in formation

- Energy scan + partial-wave analysis: isolate the $^1S_0$ wave (many waves contribute at $k \simeq 0.7$ GeV/c) — large acceptance is essential.
- Charged final states for a dipole spectrometer: $K^0_S K^\pm \pi^\mp$, $\pi^+\pi^-\eta'$, $K^+K^-\eta'$, $\phi\phi \to 2(K^+K^-)$.
- Flavor-singlet tests proposed by BESIII: $K^*\bar{K}$ suppressed; $\phi\phi \approx \omega\omega$, $\omega\phi$ suppressed.
- Neutral modes ($\eta\eta\eta$, $\pi^0\pi^0\eta$) need photon detection ⇒ input to the detector design.

(b) Glueball or $\Sigma\bar{\Sigma}$ molecule?

- $\bar{p}p \to \bar{\Lambda}\Lambda$, $\bar{\Sigma}\Sigma$ near threshold (1.44, 1.85 GeV/c): $^1S_0$ strength and line shape at the $\Sigma\bar{\Sigma}$ threshold.
- Glueball: flavor-symmetric couplings to $B\bar{B}$; molecule: dominant coupling to $\Sigma\bar{\Sigma}$, threshold cusp.

(c) Production with a recoil — in the natural K10 range

- $\bar{p}p \to X(2370)\,\pi^0$, $X\pi\pi$, $X\eta$: thresholds at 2.2, 2.6, 3.4 GeV/c.
- No low-momentum beam needed.

(d) Beyond $X(2370)$: the glueball spectrum

J^{PC}	2^{++}	0^{-+}	1^{+-}	2^{-+}	3^{+-}	3^{++}
M [GeV]	2.39	2.56	2.98	3.04	3.60	3.67

J^{PC}	1^{--}	2^{--}	3^{--}	2^{+-}	0^{+-}
M [GeV]	3.83	4.01	4.20	4.23	4.78

[quenched lattice QCD, Y. Chen *et al.*, PRD 73, 014516 (2006)]

- K10 with $\bar{p}$: $\sqrt{s} = 2.43$–4.54 GeV — all non-exotic glueballs above the 2^{++} can be formed directly; the exotic ones (gray) only via production with a recoil: $2^{+-}\pi^0$ within 10 GeV/c; $0^{+-}\pi^0$ needs 11.9 GeV/c (15 GeV/c extension).

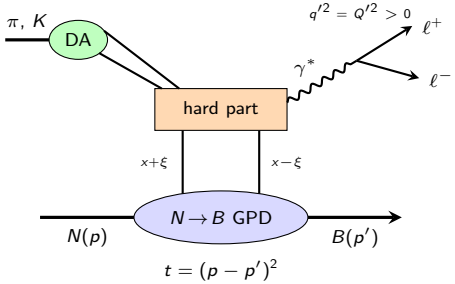
$X(2370)$ in $\bar{p}p$: a second, independent production mechanism — a decisive test of the glueball interpretation and the entrance to glueball spectroscopy at K10.

Hadron structure at K10 (1): GPDs and gravitational form factors

- GPDs $H, E, \tilde{H}, \tilde{E}(x, \xi, t)$: forward limit $\to$ PDFs; zeroth moments $\to$ form factors; first moments ($\int dx\, x$) $\to$ gravitational form factors (GFFs) of the energy–momentum tensor:

$$\int dx\, x\, H^q = A^q(t) + \xi^2 D^q(t), \quad \int dx\, x\, E^q = B^q(t) - \xi^2 D^q(t)$$

- What the GFFs tell us:
  - origin of the nucleon mass (quark and gluon energies, quark mass, trace anomaly);
  - origin of the nucleon spin: $J^q = \frac{1}{2}[A^q(0) + B^q(0)]$;
  - pressure and shear forces (D term): peak pressure $\sim 10^{35}$ Pa, higher than in a neutron star — a window on confinement.
- Space-like probes: DVCS, DVMP (JLab, AMBER, EIC, EicC). Time-like probes: exclusive Drell–Yan with meson beams — related by $s \leftrightarrow u$ crossing.
- J-PARC is the place for the time-like approach: a test of GPD universality and factorization.



$\pi^- p \to \mu^+\mu^- n$, $K^- p \to \mu^+\mu^- \Lambda$:
cross sections grow toward small $s \Rightarrow$ 10–20 GeV/c beams are optimal; exclusivity from the missing mass.

[S. Kumano; W.-C. Chang; S. Son; RCNP, Aug. 2026; Sawada *et al.*, PRD 93, 114034 (2016)]

Hadron structure at K10 (2): what the kaon beam adds

Transition GPDs with strangeness

- $K^- p \to \gamma^* \Lambda$, $K^- n \to \gamma^* \Sigma^-$: $N \to Y$ transition GPDs
  - SU(3) relations to the nucleon GPDs $\Rightarrow$ flavor decomposition;
  - $\tilde{E}^{N \to Y}$ (kaon pole) is sensitive to SU(3) breaking; kaon distribution amplitude.
- $K^- p \to \gamma^* \Lambda(1405)$, $\gamma^* \Lambda(1520)$: GPDs of exotic hadron candidates — tomography of $\Lambda(1405)$; no theoretical study yet.
- Non-diagonal energy–momentum tensor form factors ($N \to \Delta$, $N \to Y^*$): how spin, flavor and mechanical properties are rearranged in an excitation.

Partonic structure of the kaon

- Kaon PDFs are almost unknown (huge uncertainties in global fits); NA10: $\bar{u}$ in K^- is softer than in π^- — SU(3) breaking at the parton level.
- K-induced Drell–Yan and J/ψ production (sensitive to the gluon in K); inclusive hadron and photon production for large-x PDFs and TMDs.
- Caveat: inclusive high-mass Drell–Yan cross sections are small at 10 GeV/c; J/ψ is near threshold.

Nuclear targets

- J/ψ and Drell–Yan in hA: parton energy loss and absorption in cold nuclear matter.

A natural bridge inside K10:
spectroscopy (which Y^* exist?) $\leftrightarrow$ structure (what are they made of?).

Requirements: lepton-pair identification, missing-mass resolution to isolate Λ, Σ, Y^*, and high rates $\Rightarrow$ input to the detector design.

[W.-C. Chang; S. Kumano; S. Son; K. Watanabe; RCNP, Aug. 2026; P. Kroll, EPJA 55 (2019)]

A new direction: high-orbital kaon excitations in $K^- p$

- The kaon family is far from established: many $1F$, $1G$ states are only candidates [e.g. $K_3'(2120)$, $K_4(2210)$: COMPASS 2025] or predictions.
- Model: $K^- p \to K_J\, p$ via Reggeized t-channel π, ρ, ω exchange (effective Lagrangians); couplings fixed by decay widths; one cutoff $\Lambda_t = 1.5 \pm 0.2$ GeV, validated with $K_3^*(1780)$ data.
- Predictions: μb-level cross sections, strongly forward peaked, maximal at $\sqrt{s} \sim 3.5$–5 GeV.

Why K10?

- $\sqrt{s} = 3.2$–4.5 GeV (5–10 GeV/c) is exactly where the cross sections peak; $1\,\mu\text{b} \Rightarrow O(10^4)$ events/day.
- Same beam and spectrometer as for Ξ^*/Ω^*: $K_J \to K\pi$, $K^*\pi$, $K\rho$, $K\omega$, $K\phi$.
- High L: Regge trajectories and confinement; ${}^1L_J$–${}^3L_J$ mixing probes the LS and tensor forces in $\bar{s}q$.

L	State	Status	σ_{peak} [μb]
$1D$	$K_3^*(1780)$	established	data
	$K_2(1820)$, $K_2(1770)$	established	data
	$K^*(1680)$	established	π exch.
$1F$	$K_4^*(2045)$	established	25.6
	$K_3'(2120)$	candidate	1.1
	$K_3(1F)$	predicted	0.9
	$K_2^*(1980)$	candidate	0.5
$1G$	$K_5^*(2380)$	candidate	6.5
	$K_3^*(1G)$	predicted	0.46
	$K_4'(1G)$	predicted	0.32
	$K_4(2210)$	candidate	0.29

$\theta_{1D} = -30^\circ$ fits the $K_2(1770)$, $K_2(1820)$ data

[T.-Y. Li, Z.-Y. Bai, X. Liu, arXiv:2606.15736; RCNP, Aug. 2026]

The meson counterpart of the Ξ^*/Ω^* program: spin-dependent forces in the $\bar{s}q$ system.

Summary: the physics that K10 aims to reveal

1. How quarks build baryons with strangeness: Ξ^* — the missing $1/2^-$ partner and the su/ds diquark correlation; Ω^* — no diquark, no pion cloud: the quark core.
2. Roper-like $2S$ states and the size of the quark core: the decay width of $\Omega^* \to \Xi\bar{K}$ probes the Fermi motion of the confined quarks.
3. Three quarks or hadronic molecules? $\Omega(2012)$, $\Xi(1690)$, $\Xi(1820)$, ... and the strange partners of P_c, Z_c; strange hidden-charm pentaquarks at the top of the K10 range.
4. Baryon–baryon interaction beyond the octet: the ΩN bound state — a direct test of lattice QCD.
5. Glue: with the $\bar{p}$ beam, the glueball candidate $X(2370)$ can be formed directly in $\bar{p}p\,(^1S_0)$ at $\sim$1.8 GeV/c and produced with a recoil above 2.2 GeV/c; heavier glueballs lie inside $\sqrt{s} = 2.4$–4.5 GeV.
6. Hadron structure: time-like GPDs and gravitational form factors via exclusive Drell–Yan; $N \to Y$ transition GPDs and the kaon structure are unique to the kaon beam.
7. New: high-orbital kaon excitations with μb cross sections.

Requests from physics to the beam line and the spectrometer

Large acceptance for multi-particle final states and partial-wave analyses; $\Delta p/p \lesssim 0.2\%$ and vertexing (ΩN); lepton pairs and photons (GPDs, glueball decays); $\bar{p}$ at the lowest momenta ($\lesssim 2$ GeV/c) and K^- at the highest (≥ 10 GeV/c).

From the quark core to glue and hadron tomography — **let us shape the K10 physics program and the Yellow Report together.**

Backup: kinematics at K10

$K^- p$

Reaction	p_K [GeV/c]
$K^- p \to \Omega^- K^+ K^0$ (threshold)	3.14
$K^- p \to \Omega(2012)^- K^+ K^{*0}$ (thr.)	5.55
$K^- p \to J/\psi\,\Lambda$ (threshold)	8.84
$K^- p \to P_{c\bar{c}s}(4338)$ (formation)	9.42
$K^- p \to P_{c\bar{c}s}(4459)$ (formation)	9.98
$\sqrt{s}$ [GeV] at 5 / 8 / 10 GeV/c	3.25 / 4.02 / 4.46

$\bar{p}p$

Reaction	$p_{\bar{p}}$ [GeV/c]
$\bar{p}p \to X(2370)$ (formation)	1.80
$M \pm \Gamma/2$ ($\Gamma = 170$ MeV)	1.56–2.04
$\bar{p}p \to X(2370)\,\pi^0$ / $\pi\pi$ / η (threshold)	2.18 / 2.61 / 3.44
$\bar{p}p \to \bar{\Lambda}\Lambda$ / $\bar{\Sigma}^-\Sigma^+$ (threshold)	1.44 / 1.85
$\bar{p}p \to \bar{\Xi}^+\Xi^-$ / $\bar{\Omega}^+\Omega^-$ (threshold)	2.62 / 4.94
$\bar{p}p \to J/\psi$ / $\psi(2S)$ / $X(3872)$ (formation)	4.07 / 6.23 / 6.99
$\bar{p}p \to D^0\bar{D}^0$ / $\bar{\Lambda}_c\Lambda_c$ (threshold)	6.41 / 10.16
$\sqrt{s}$ [GeV] at 2 / 6 / 10 GeV/c	2.43 / 3.63 / 4.54

Formation cross section of $X(2370)$ in $\bar{p}p$

$$\sigma(\sqrt{s}) = \frac{2J+1}{(2s_1+1)(2s_2+1)}\,\frac{\pi}{k^2}\,\frac{\Gamma_{\bar{p}p}\,\Gamma_f}{(\sqrt{s}-M)^2+\Gamma^2/4}, \quad J=0,\ k=0.715\ \text{GeV}/c \text{ at } \sqrt{s}=2.359\ \text{GeV} \Rightarrow$$

$$\sigma_{\text{peak}} = \frac{\pi}{k^2}\,\mathcal{B}_{\bar{p}p}\mathcal{B}_f = 2.4\ \text{mb} \times \mathcal{B}_{\bar{p}p}\mathcal{B}_f.$$

Luminosity: 10^7 $\bar{p}$/spill $\times$ 10 cm LH_2 (4.2×10^{23} cm^{-2}) $= 4 \times 10^{30}$ cm^{-2}/spill; 1.7×10^4 spills/day (5.2 s cycle).