

Belle/Belle II 上轻强子相关实验进展

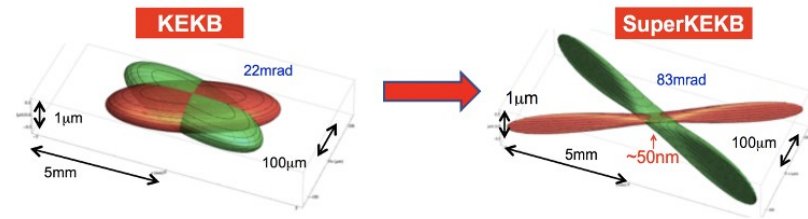
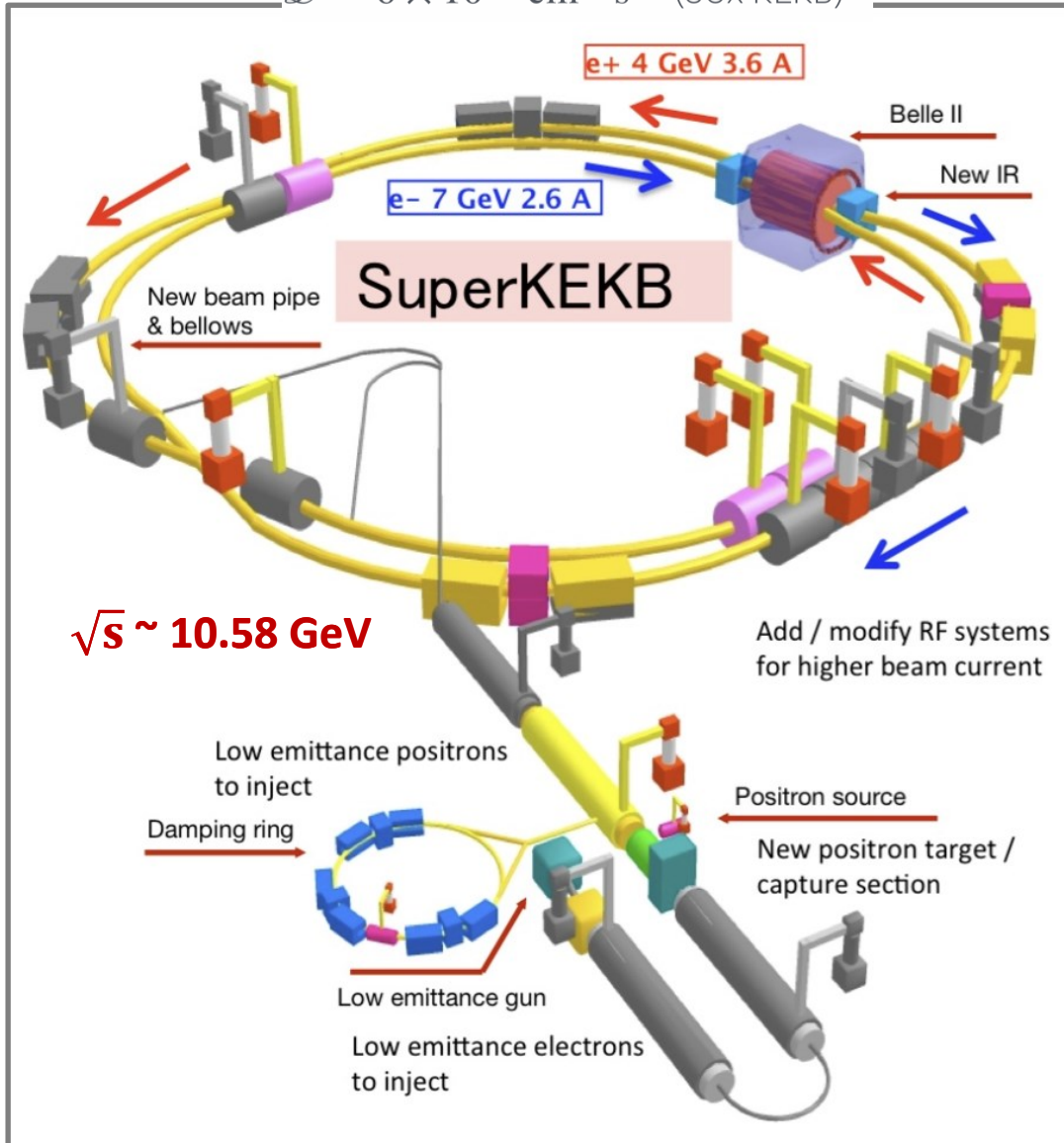
李素娴 (lisuxian@zzu.edu.cn)
郑州大学

2026年轻强子专题研讨会

2026年5月14-18日 河南商丘

SuperKEKB and Belle II

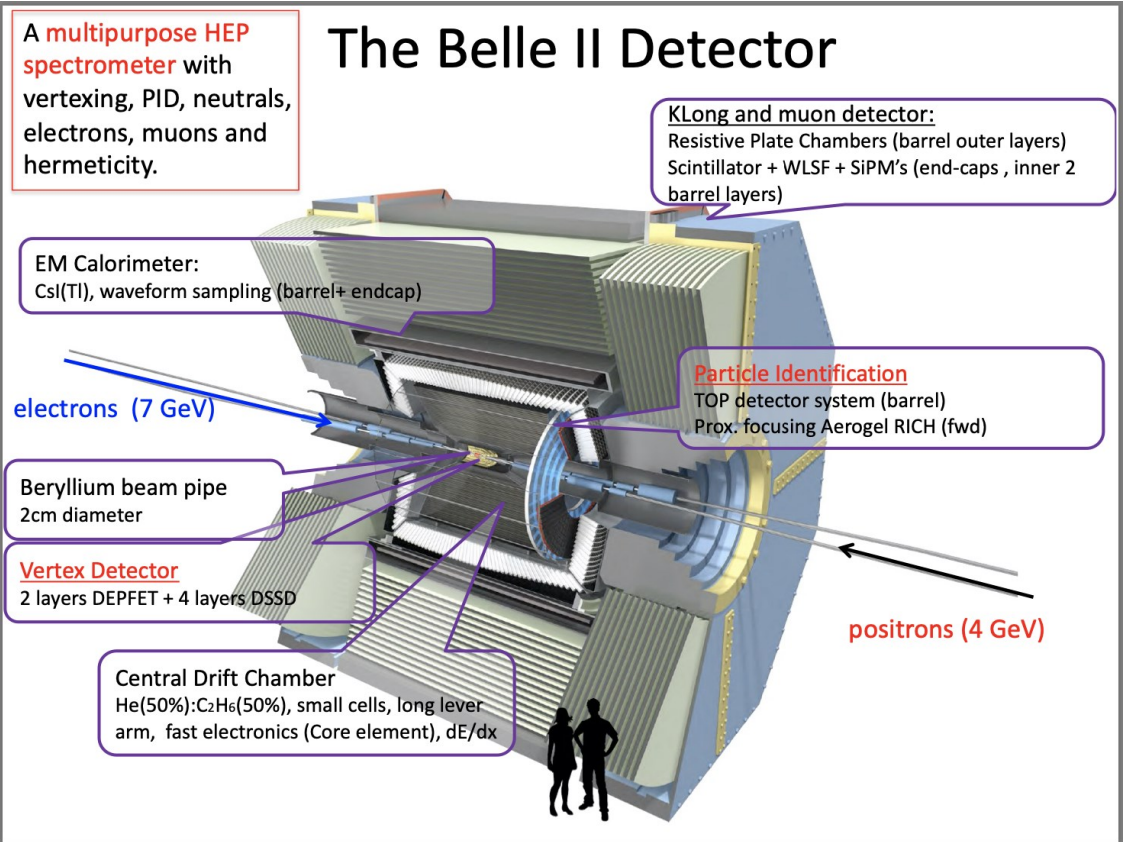
$$\mathcal{L} = 6 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \text{ (30x KEKB)}$$



Nano-beam design:

Beam squeezing: $\times 20$ smaller; Beam current: $\times 2$ larger

Target peak luminosity: KEKB $\times 30$

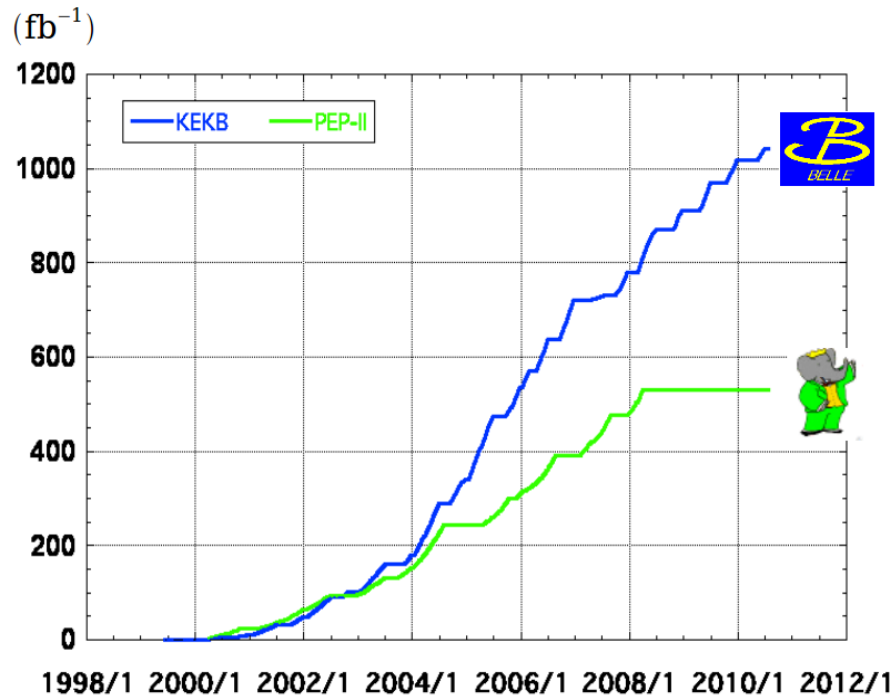


Belle and Belle II Datasets

- Belle (1999 - 2012)
- Belle II RUN-I (2019 - 2023)
- Belle II RUN-II (2024 - 2026)

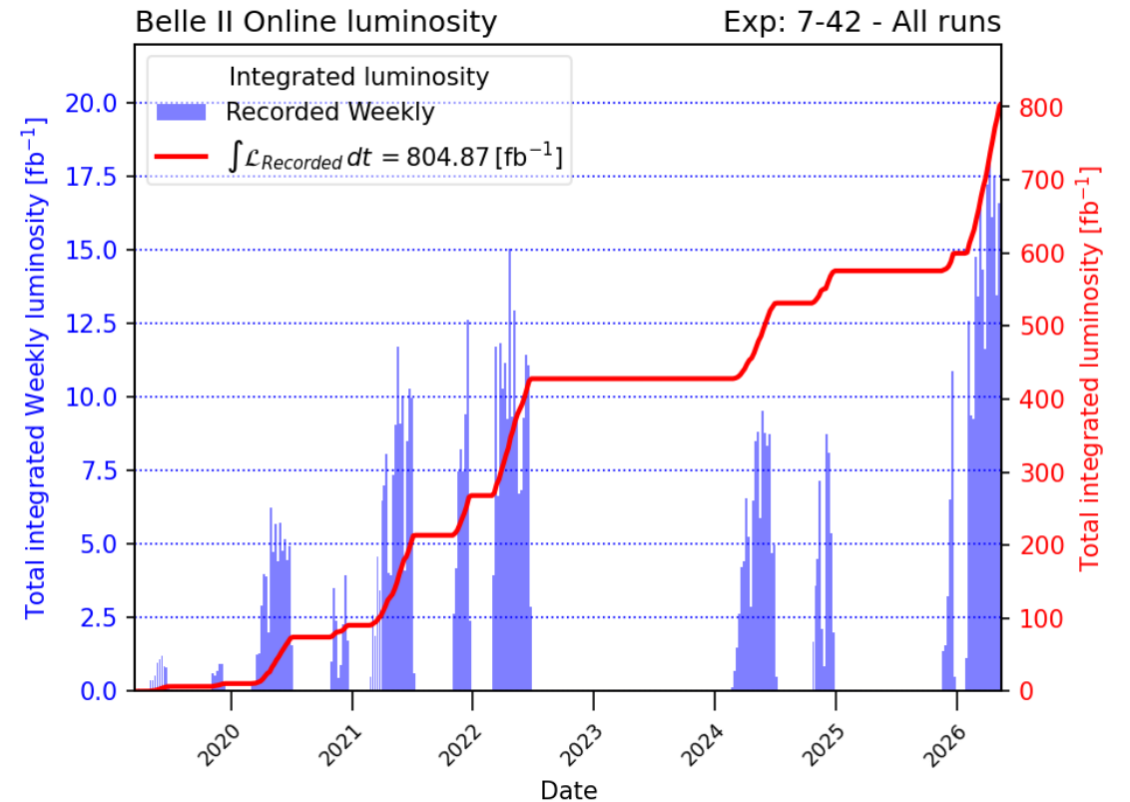
- Asymmetric electron-positron collider at $\Upsilon(4S)$
 - Target instantaneous luminosity: $\mathcal{L} = 6 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ (30x KEKB)
 - Max instantaneous luminosity: $\mathcal{L} = 5.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (World record!)

Integrated luminosity of B factories



> 1 ab⁻¹
On resonance:
 $\Upsilon(5S)$: 121 fb⁻¹
 $\Upsilon(4S)$: 711 fb⁻¹
 $\Upsilon(3S)$: 3 fb⁻¹
 $\Upsilon(2S)$: 25 fb⁻¹
 $\Upsilon(1S)$: 6 fb⁻¹
Off reson./scan:
 ~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
 $\Upsilon(4S)$: 433 fb⁻¹
 $\Upsilon(3S)$: 30 fb⁻¹
 $\Upsilon(2S)$: 14 fb⁻¹
Off resonance:
 ~ 54 fb⁻¹



Most data at or near the $\Upsilon(4S)$ resonance, some below/above $\Upsilon(4S)$.

Outline:

- Fragmentation functions [PRD 111, 052003 (2025)]
- Search for $\Xi^0 N$ and $\Omega^- N$ dibaryons [Preliminary]
- $\Omega(2012) \rightarrow \Xi(1530)K$ [PLB 860, 139224 (2025)]
- Threshold cusp [PRD 108, L031104 (2023), PRL 130, 151903 (2023)]

Fragmentation functions

Fragmentation functions

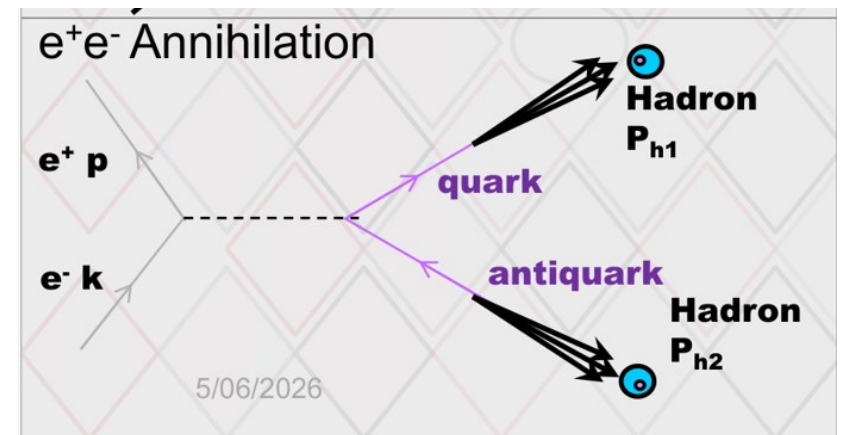
Fragmentation functions (FFs) describe the probability of a high-energy parton (quark or gluon) hadronizing into a specific hadron.

- Correlate a hadron in the final state with the partonic interactions:
- Closely related to confinement mechanism
- Denoted as $D_i^h(z, Q^2)$, z : momentum fraction

e^+e^- :

$$\sigma^h(z, Q^2, k_t) \propto \sum_q e_q^2 (D_{1,q}^h(z, k_t, Q^2) + D_{1,\bar{q}}^h(z, k_t, Q^2))$$

- No PDFs necessary
- Clean initial state, parton momentum known at LO
- Flavor structure not directly accessible*



Single/double hadron Fragmentation functions



Single hadron FF

| Unpolarized ingredients | Polarized ingredients | Flavor sensitivity |
|--|---|---|
| Single hadron cross sections: $e^+e^- \rightarrow hX$ $D_{1,q}^h(z, Q^2)$ PRL111 (2013) 062002 PRD101(2020) 092004 | Azimuthal asymmetries: $e^+e^- \rightarrow (h)(h)X,$ $\cos(\phi_1 + \phi_2)$ $H_{1,q}^{\perp(1)h}(z, Q^2)$ PRL 96 (2006) 232002 PRD 78 (2008) 032011 | Unpol SIDIS, pp: $\frac{d\sigma}{dz}$ $e^+e^- \rightarrow (h)(h)X$ PRD92 (2015) 092007 PRD101(2020) 092004 and scale dependence |
| Transverse momentum dependent FFs: $e^+e^- \rightarrow (h)X$ $D_{1,q}^h(z, k_T, Q^2)$ PRD 99 (2019) 112006 | Transverse momentum dependent asymmetries $e^+e^- \rightarrow (h)(h)X,$ $\cos(\phi_1 + \phi_2), Q_t$ $H_{1,q}^{\perp h}(z, k_T, Q^2)$ PRD100 (2019) 92008 | Polarizing Λ fragmentation $D_{1,q}^{\perp h}(z, k_T, Q^2)$ PRL 122 (2019), 042001 |



Dihadron FF (IFF)

| Unpolarized ingredients | Polarized ingredients | HF/resonances/hyperons |
|--|---|--|
| Dihadron cross sections $e^+e^- \rightarrow (hh)X$ $D_{1,q}^{h_1 h_2}(z, m, Q^2)$ PRD96 (2017) 032005 | Azimuthal asymmetries: $e^+e^- \rightarrow (hh)(hh)X,$ $\cos(\phi_1 + \phi_2),$ $H_{1,q}^{h_1, h_2, \triangleleft}(z, Q^2, M_h)$ PRL107 (2011) 072004 | $e^+e^- \rightarrow (\rho^+, \rho^0, \omega, \phi, K^{*+}, K^{*0}, K_S,$ $\eta, D^0, D^+, D^{*0}, D^{*+}, D_s^+, D_s^{*+}) X$ PRD 111 (2025) 052003 $e^+e^- \rightarrow (\Lambda, \Lambda_c, \Omega, \Sigma, \dots) X$ PRD97 (2018) 072005 |

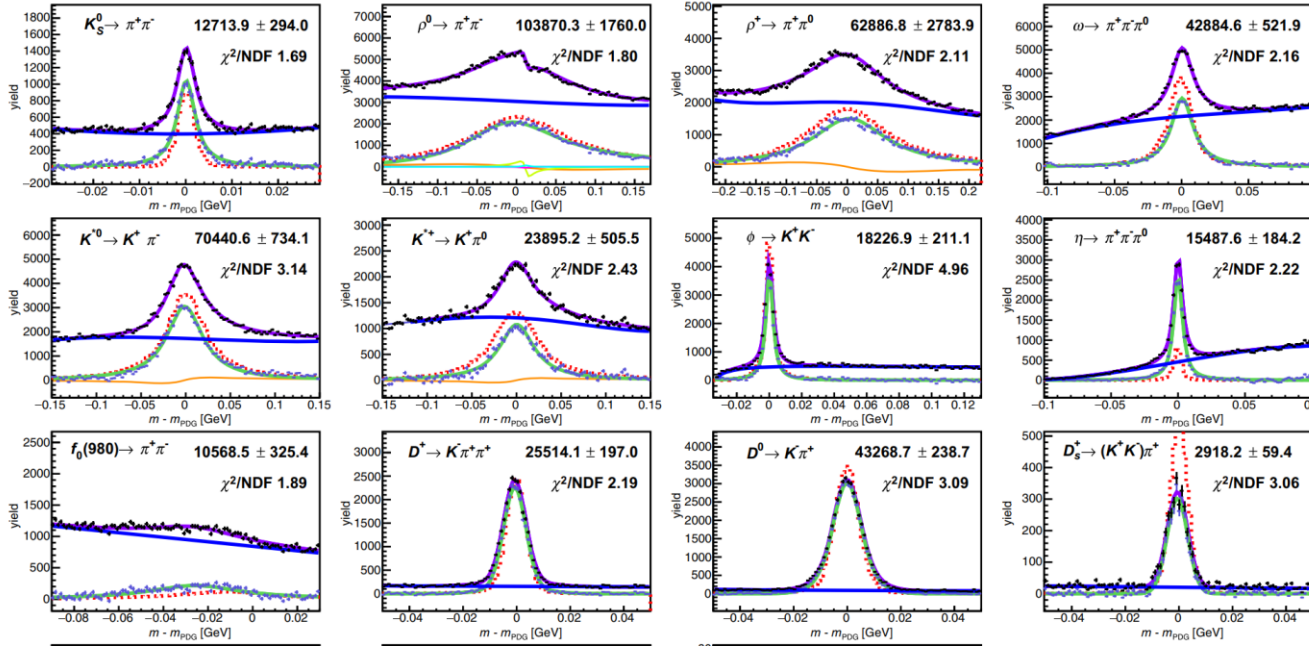
Production cross section: $e^+e^- \rightarrow hX$

PRD 111 (2025) 052003 (Belle)

Light hadron results: $e^+e^- \rightarrow (\rho^+, \rho^0, \omega, \phi, K^{*0}, K_S, \eta, f_0(980))X$ at 10.58 GeV

$$\sigma_{prod}(x_p), x_p = \frac{p_h}{\sqrt{s/4 - m_h^2}}, 40$$

Signal extraction:



- Peaking structure seen, increasing with mass as expected
- Systematics dominated for all measurements.
- **Vector mesons** extracted for **the first time** at B factory energies

Correction: luminosity, BF, x_p width, acceptance, efficiency, ISR

$$\frac{d\sigma}{dx_p} = \frac{N_{\text{Fit}} - N_{\text{non}q\bar{q}}}{\mathcal{L} \times \mathcal{B} \times \Delta x_p \epsilon_{\text{rec}} \times \epsilon_{\text{acc}} \times \epsilon_{\text{Low}p} \times \epsilon_{\text{ISR}}} \cdot 1$$

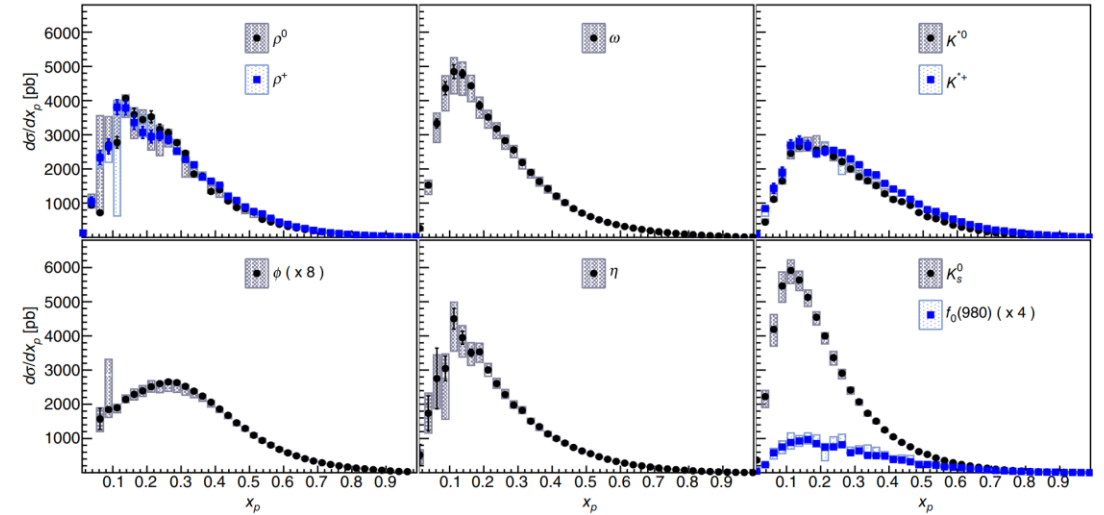
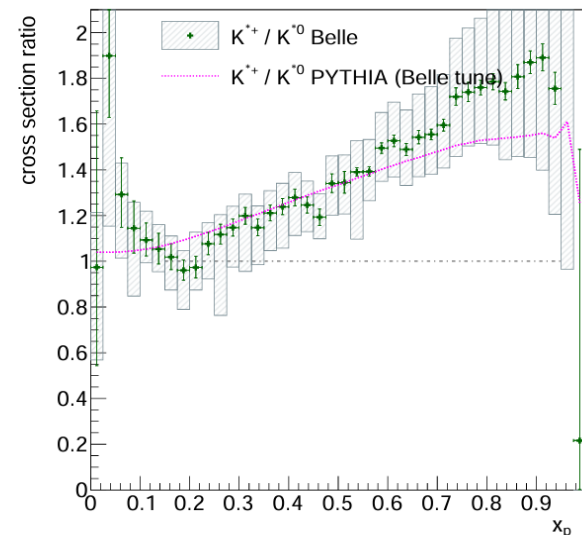
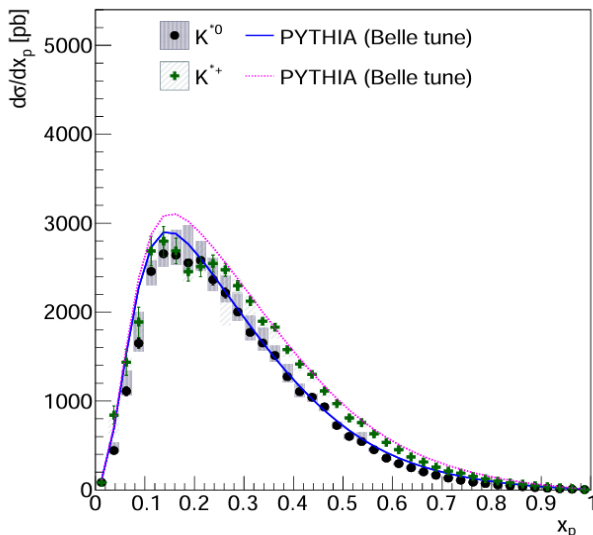
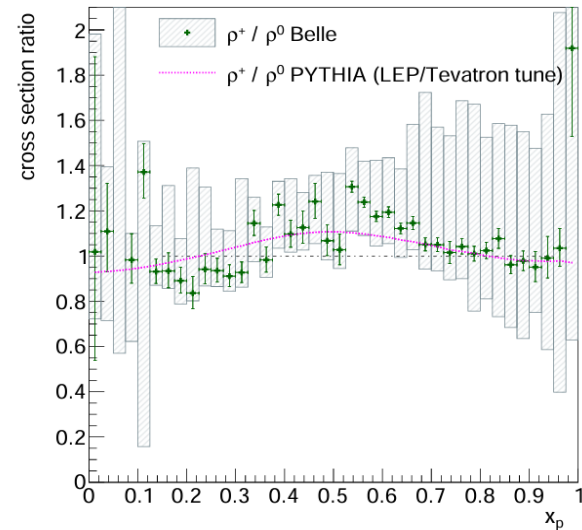
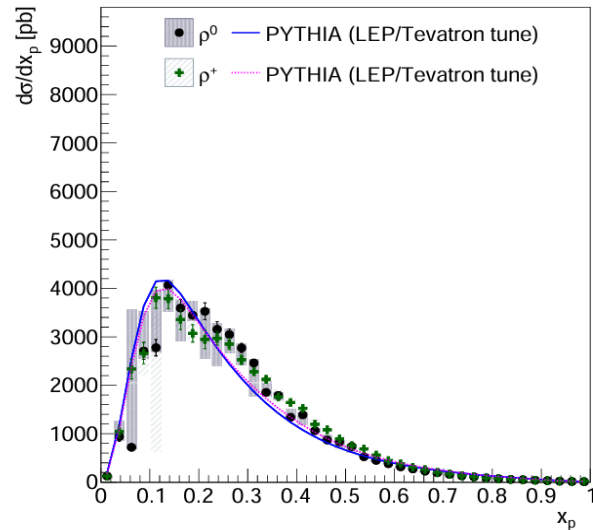


FIG. 9. Production cross sections as a function of x_p for ρ^+ , ρ^0 , ω , K^{*+} , K^{*0} , ϕ , η , K_S^0 , and $f_0(980)$. The ϕ and $f_0(980)$ cross sections are scaled by a factor of 8 and 4, respectively, for better visibility.

K^* : Charged to neutral ratios

PRD 111 (2025) 052003 (Belle)

- For K^{*+} and K^{*0} , FFs should be isospin symmetric
- But difference appears, charged exceed neutral



Charged and neutral ρ :

- Higher x_p , consistent with isospin symmetric
- Middle x_p , excess up to 20% for ρ^+ over ρ^0

Charged and neutral K^* :

- Enhancement of K^{*+} production over K^{*0}
- Increasing with x_p

In MC simulation:

- Strange quark fragmentation appears to be equal for both neutral and charged K^*
- In the e^+e^- annihilation initial process, $u\bar{u}$ and $d\bar{d}$ pairs are not produced equally (due to e_q^2 weight), resulting in a difference in the cross sections (Favored fragmentation $u \rightarrow K$ vs $d \rightarrow K$ different)

Search for Ξ^0 N and Ω^- N dibaryons

Search for $\Xi^0 p$, $\Omega^- p$ and $\Omega^- n$ bound states from $\Upsilon(1S, 2S)$ decay at Belle

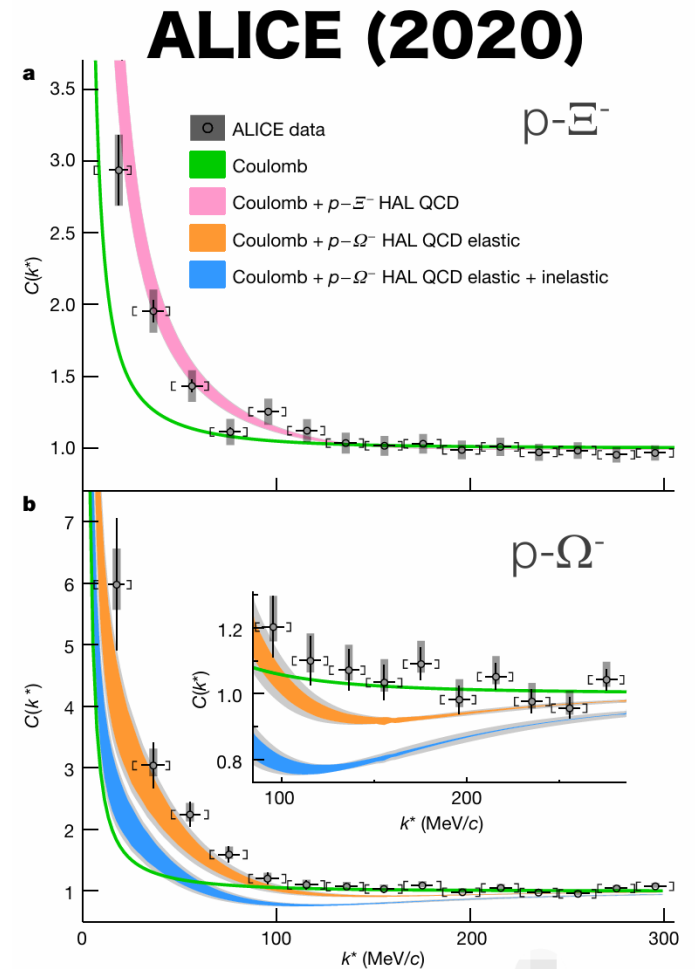
For ΞN system:

- lattice QCD and chiral effective field theory indicate a **moderately attractive** interaction, **but insufficient** to produce a bound state
 - **Agreement with the Ξp correlation function** measured by ALICE
- Phenomenological models allows a **stronger attraction** and predicts a **bound ΞN** state (binding energy ~ 1 MeV)

For ΩN system:

- **Stronger attraction** than in the ΞN system
- Measurements of the Ωp correlation function by ALICE **indicate a strong attractive** interaction
- Lattice QCD and constituent quark model suggest an **attraction sufficient to form a weakly bound ΩN state**

Direct production in $\Upsilon(1S, 2S)$ decays provides a clean, gluon-rich environment to search for near-threshold peaks



Search for $\Xi^0 p$, $\Omega^- p$ and $\Omega^- n$ bound states from $\Upsilon(1S, 2S)$

Analyzed 102M $\Upsilon(1S)$ + 158M $\Upsilon(2S)$ events

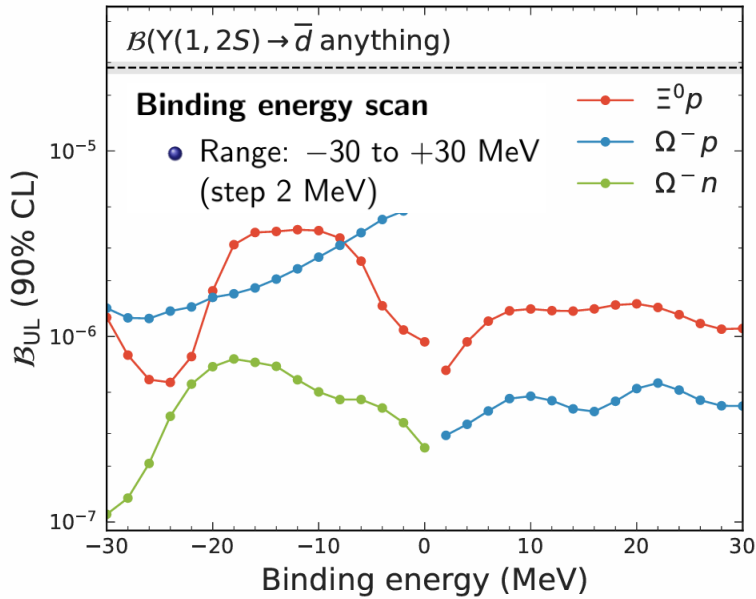
- Search for peaks in invariant mass near $\Xi^0 p$, $\Omega^- p$, $\Omega^- n$ thresholds.

$$M(\pi^0 \Lambda p), M(\Xi^0 p), M(\Xi^0 \Lambda), M(\Omega^- p), M(\Xi^- \Lambda)$$

No significant signal observed in any channel

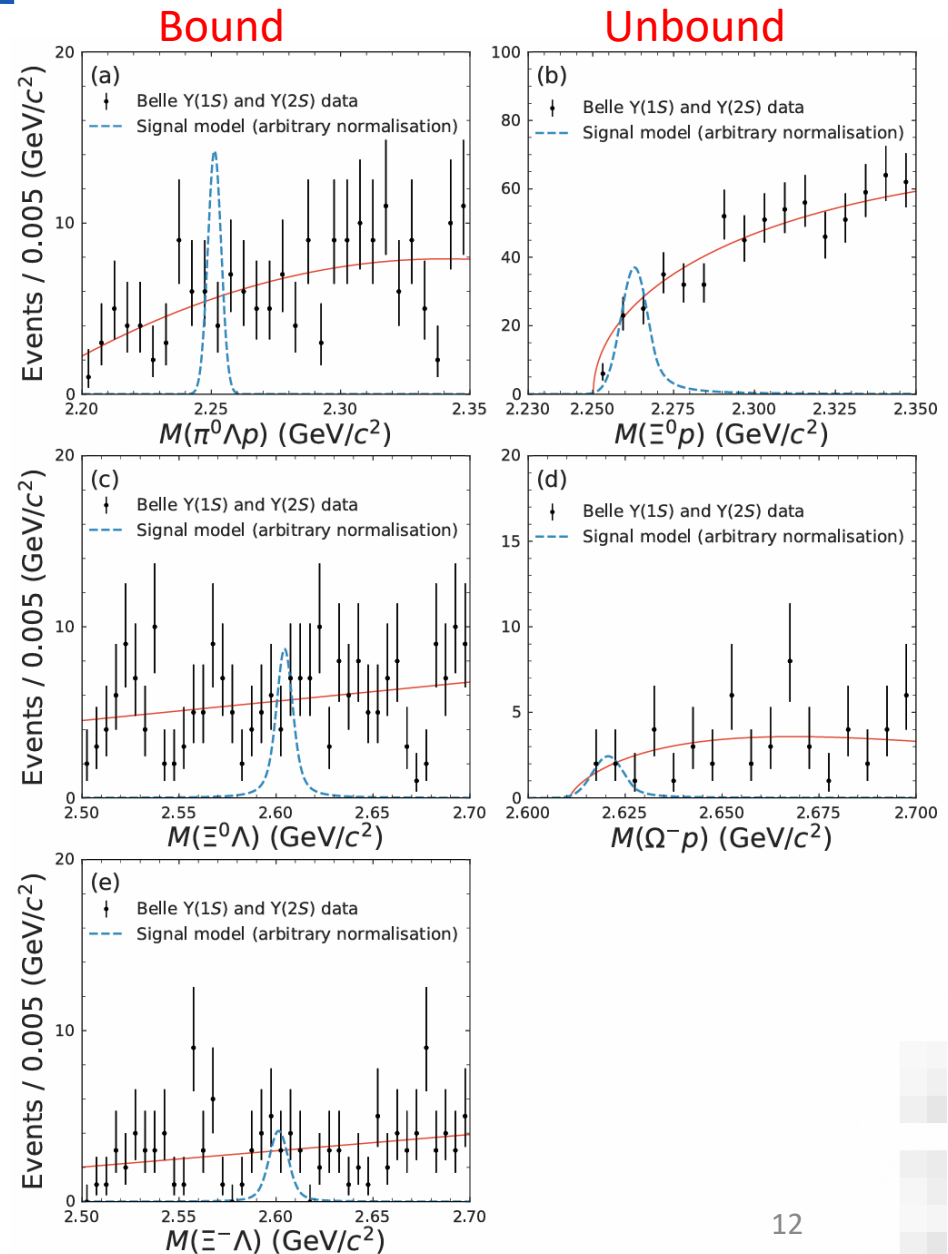
- Set 90% CL upper limits on the branching fractions

$$\mathcal{B} < \frac{N_{UL}}{2N_{\Upsilon(1S)+\Upsilon(2S)} \epsilon_{rec} \prod \mathcal{B}_{sub.}}$$



Upper limits: $\mathcal{O}(10^{-7})$ to $\mathcal{O}(10^{-6})$

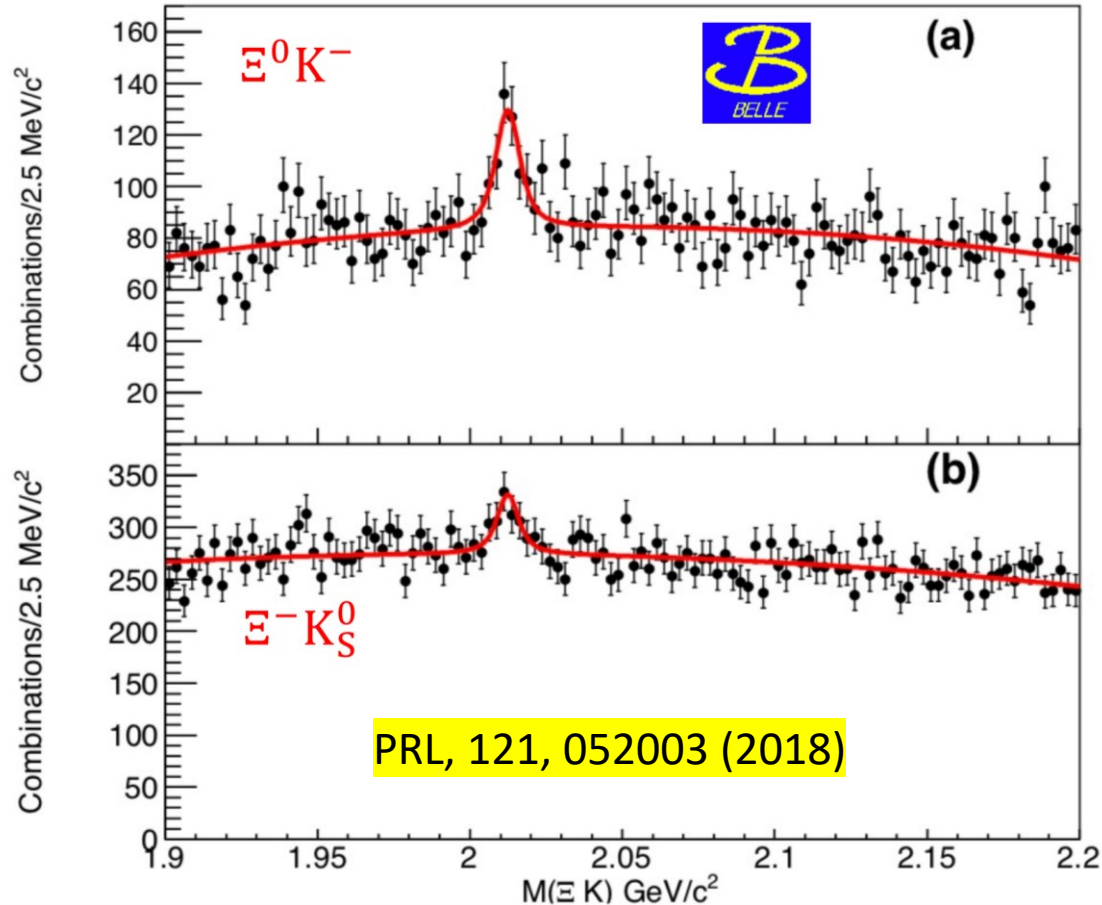
- New experimental constraint on multistrange dibaryon formation
- helps discriminate between competing theoretical models
- Future Belle II data will improve sensitivity



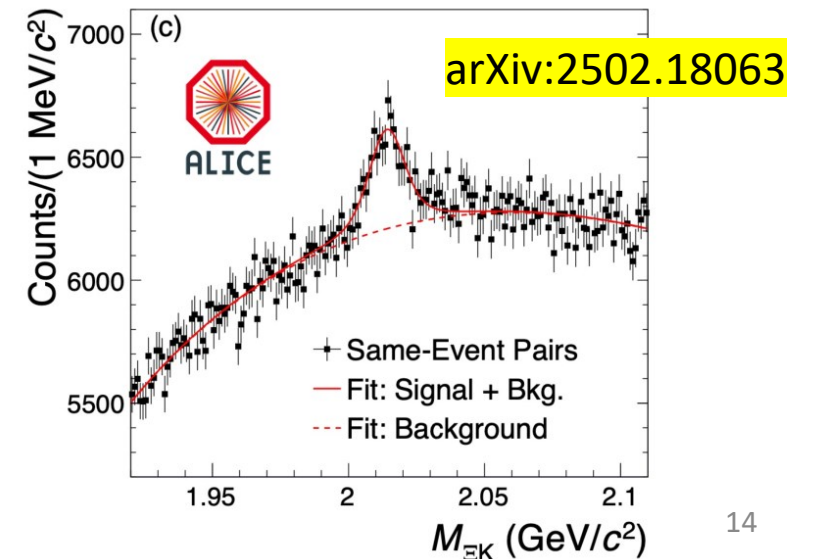
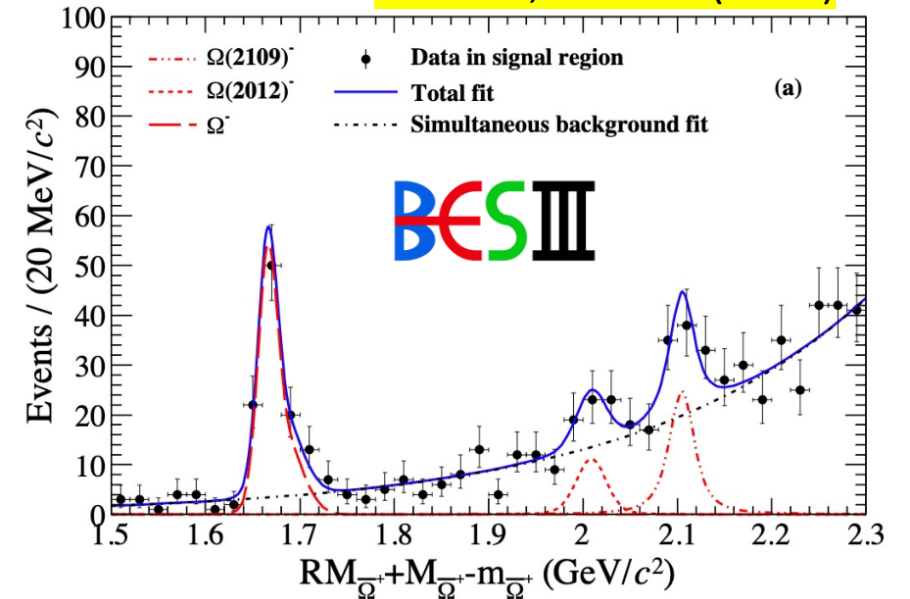
$$\Omega(2012)^- \rightarrow E(1530)\bar{K} \rightarrow E\pi\bar{K}$$

Discovery of $\Omega(2012)^-$

$\Omega(2012)$ was first observed by Belle in two-body (ΞK) decays, Confirmed by BESIII (low statistics) and ALICE (15σ).



PRL 134, 131903 (2025)



The $\Omega(2012)$ was interpreted as a standard baryon or a $\Xi(1530)\bar{K}$ molecule.

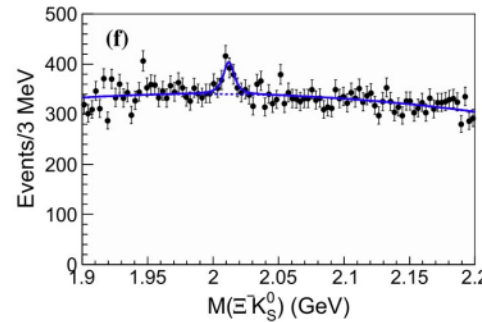
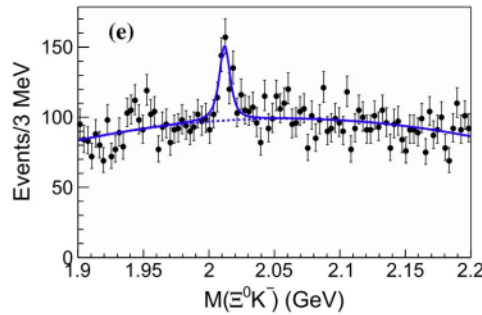
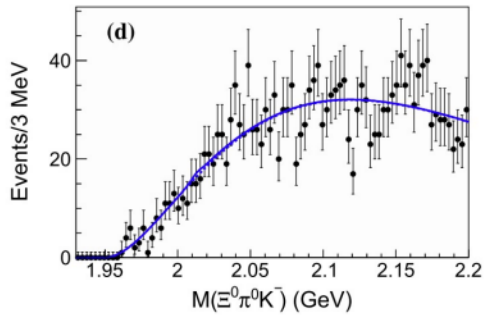
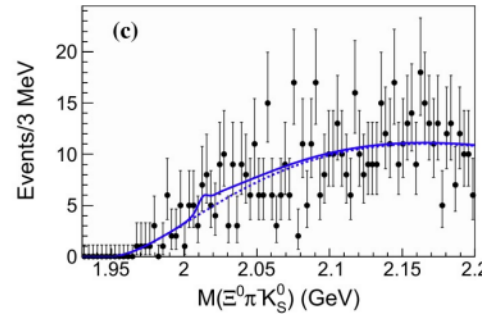
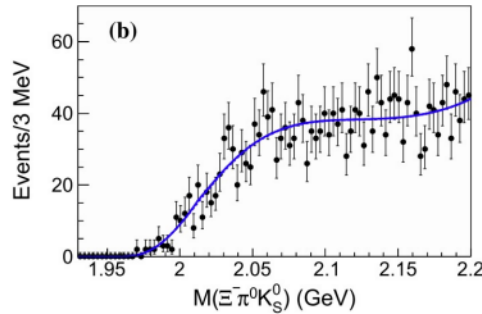
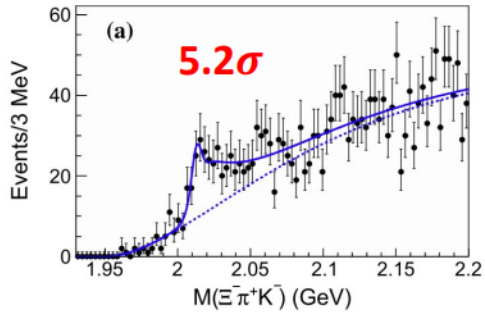
$\Omega(2012)^- \rightarrow \Xi(1530)\bar{K} \rightarrow \Xi\pi\bar{K}$

[PLB 860, 139224 (2025)]

The Flatté-like function [PRD 81, 094028 (2010)]

$$T_n(M) \equiv \frac{g_n k_n(M)}{|M - m_{\Omega(2012)^-} + \frac{1}{2} \sum_{j=2,3} g_j [\kappa_j(M) + ik_j(M)]|^2}$$

- g_n is the effective coupling of to the n -body final state.
- k_n and κ_n parameterize the real and imaginary parts of the $\Omega(2012)^-$ self-energy.



The mass and ratio of effective couplings :

| | |
|-----------------------|--------------------------------|
| $\Omega(2012)^-$ mass | $(2012.5 \pm 0.7 \pm 0.5)$ MeV |
| g_3/g_2 | $22.9^{+17.9}_{-22.4} \pm 2.2$ |

$$\mathcal{R}_{\Xi\pi\bar{K}}^{\Xi\bar{K}} = \frac{\mathcal{B}(\Omega(2012)^- \rightarrow \Xi(1530)\bar{K} \rightarrow \Xi\pi\bar{K})}{\mathcal{B}(\Omega(2012)^- \rightarrow \Xi\bar{K})}$$



$$0.99 \pm 0.26 \pm 0.06$$

| Mode | ϵ (%) | Y |
|--|-----------------|--------------|
| $\Omega(2012)^- \rightarrow \Xi(1530)^0 K^- \rightarrow \Xi^- \pi^+ K^-$ | 6.97 ± 0.07 | 267 ± 60 |
| $\Omega(2012)^- \rightarrow \Xi(1530)^- \bar{K}^0 \rightarrow \Xi^- \pi^0 \bar{K}^0$ | 1.06 ± 0.01 | 7 ± 2 |
| $\Omega(2012)^- \rightarrow \Xi(1530)^- \bar{K}^0 \rightarrow \Xi^0 \pi^- \bar{K}^0$ | 1.74 ± 0.02 | 23 ± 5 |
| $\Omega(2012)^- \rightarrow \Xi(1530)^0 K^- \rightarrow \Xi^0 \pi^0 K^-$ | 0.63 ± 0.01 | 12 ± 3 |
| $\Omega(2012)^- \rightarrow \Xi^0 K^-$ | 4.00 ± 0.04 | 242 ± 40 |
| $\Omega(2012)^- \rightarrow \Xi^- \bar{K}^0$ | 15.5 ± 0.16 | 293 ± 65 |

$$D_{s0}^*(2317) \rightarrow D_s^{*+} \gamma \Rightarrow \Omega(2012) \rightarrow \Omega \gamma$$

Threshold cusp

A peak at $\Lambda\eta$ threshold

➤ A trace of a peak structure is observed in the pK^- mass spectrum in the previous analysis of $\Lambda_c^+ \rightarrow pK^- \pi^+$ decay by the Belle. PRL, 117, 011801 (2016)

➤ LHCb performed an amplitude analysis of $\Lambda_c^+ \rightarrow pK^- \pi^+$. A similar structure is also seen. LHCb explained the structure using a BW form with fixed mass and width. PRD 108, 012023 (2023)

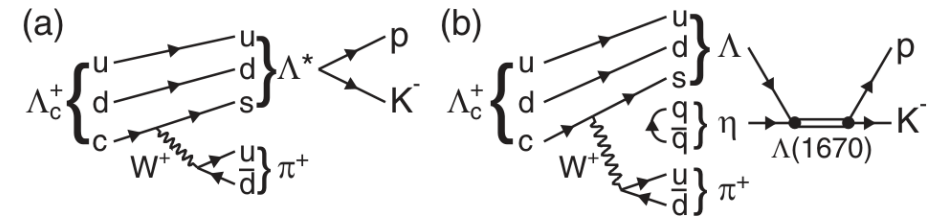
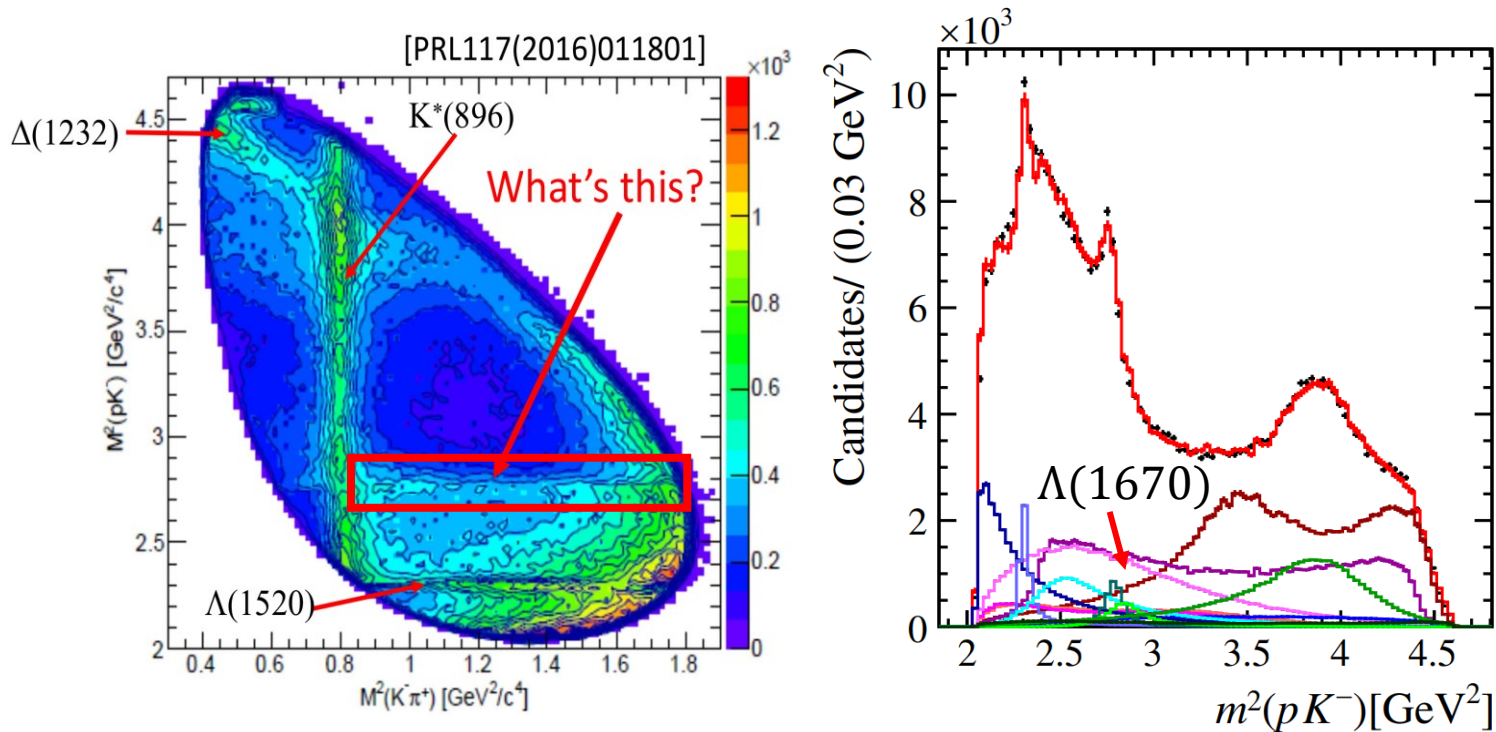


FIG. 1. Feynman diagrams for (a) a new Λ^* resonance and (b) a visible $\Lambda\eta$ threshold cusp enhanced by the $\Lambda(1670)$ pole in $\Lambda_c^+ \rightarrow pK^- \pi^+$ decay.

Two approach to describe this peak:

- ① BW function
- ② Flatté function

From the perspective of a new resonance

[PRD 108, L031104 (2023)]

➤ We perform a binned least- χ^2 fit to the efficiency-corrected $M(pK^-)$ distribution

- Fit to $M(pK^-)$ distribution using non-relativistic BW function.

$$\frac{dN}{dm} \propto |\text{BW}(m)|^2 = \left| \frac{1}{(m - m_0) + i \frac{\Gamma_0}{2}} \right|^2$$

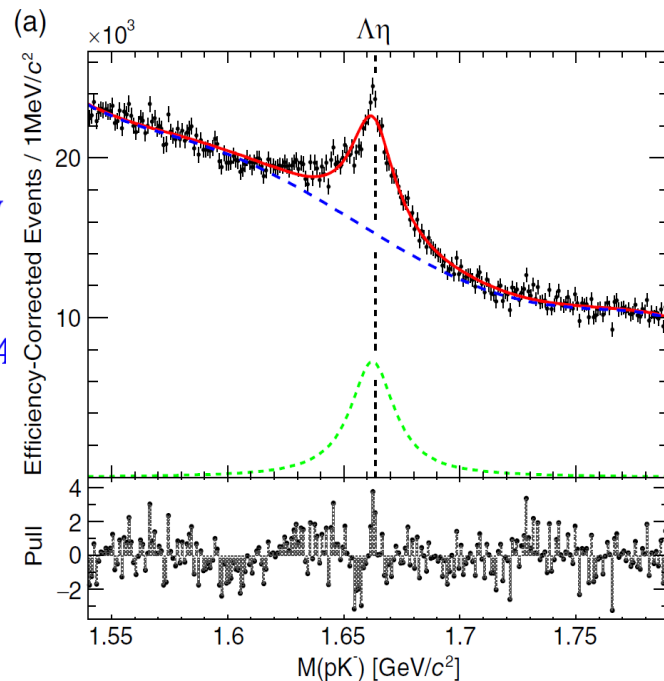
$$m_0 = (1662.4 \pm 0.3) \text{ MeV}$$

$$\Gamma_0 = (22.6 \pm 1.5) \text{ MeV}$$

$$\text{Reduced } \chi^2 / \text{ndf} = 328/243$$

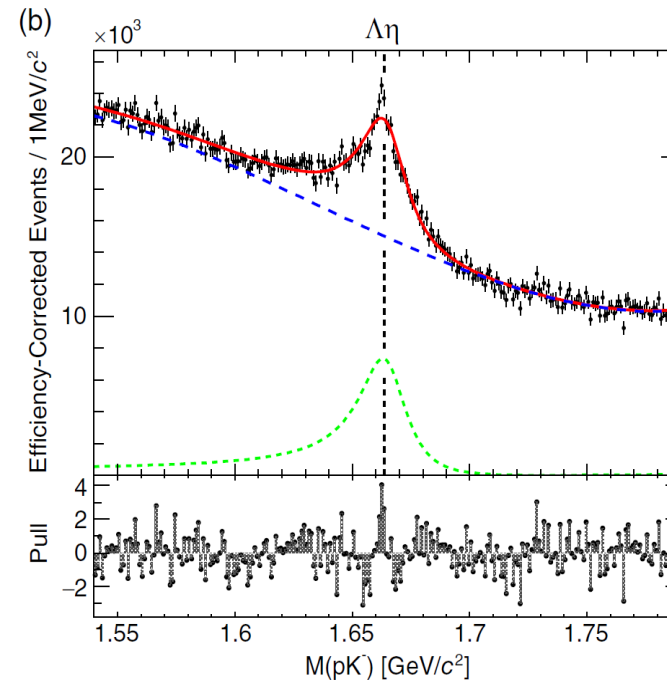
$$= 1.35$$

- Not very good especially near the peak.



- Fit to $M(pK^-)$ using BW with complex constant added coherently, leading to constructive interference below the $\Lambda\eta$ threshold and destructive above that.

$$\frac{dN}{dm} \propto |\text{BW}(m) + re^{i\theta}|^2 = \left| \frac{1}{(m - m_0) + i \frac{\Gamma_0}{2}} + re^{i\theta} \right|^2$$



$$m_0 = (1665.4 \pm 0.5) \text{ MeV}$$

$$\Gamma_0 = (23.8 \pm 1.2) \text{ MeV}$$

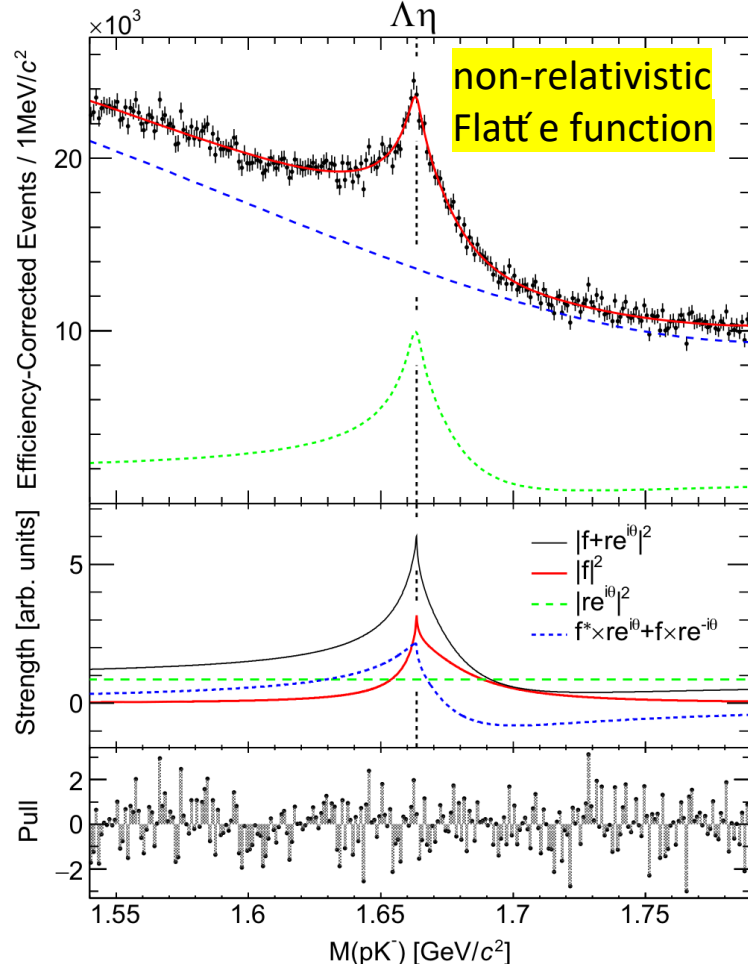
$$\text{Reduced } \chi^2 / \text{ndf} = 308/243$$

$$= 1.27$$

From the perspective of a cusp at $\Lambda\eta$ threshold

- Another possibility is that the peak structure is a cusp at the $\Lambda\eta$ threshold enhanced by the $\Lambda(1670)$ pole nearby.

$$\frac{dN}{dm} \propto |f(m)|^2 = \left| \frac{1}{m - m_f + \frac{i}{2}(\Gamma' + \bar{g}_{\Lambda\eta}k)} \right|^2$$



- The best fit with $\chi^2/\text{ndf}=1.06$ (257/243) is obtained at $m_f=1674.4$ MeV/c².
- The measured: $\Gamma' = (27.2 \pm 1.9^{+5.0}_{-3.9})$ MeV, $\bar{g}_{\Lambda\eta} = (258 \pm 23^{+61}_{-75}) \times 10^{-3}$

| | Our measurement | $\Lambda(1670)$ [PRD 103, 052005 (2021)] |
|-------------|---------------------------------------|---|
| mass | Fix $m_f = 1674.4$ MeV/c ² | $(1674.3 \pm 0.8 \pm 4.9)$ MeV/c ² |
| Total width | $(50.3 \pm 2.9^{+4.2}_{-4.0})$ MeV | $(36.1 \pm 2.4 \pm 4.8)$ MeV |

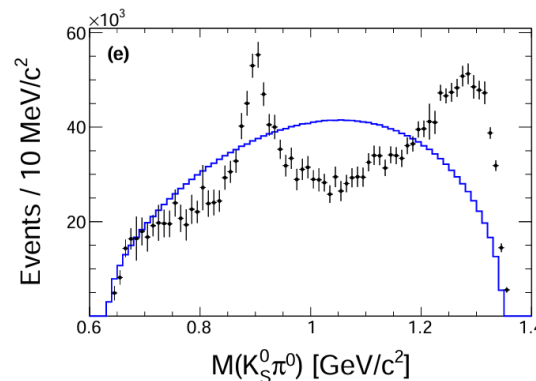
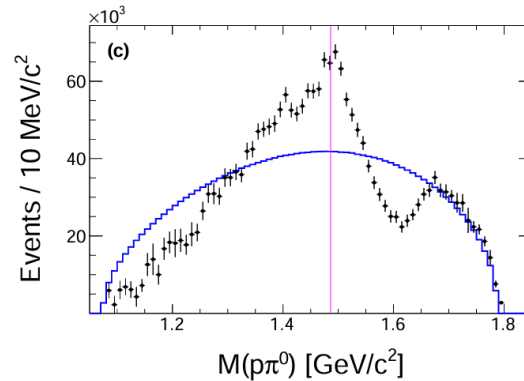
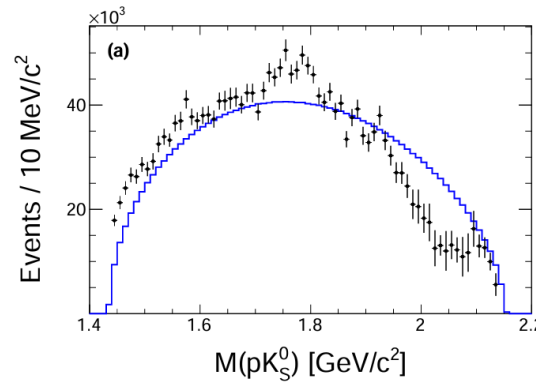
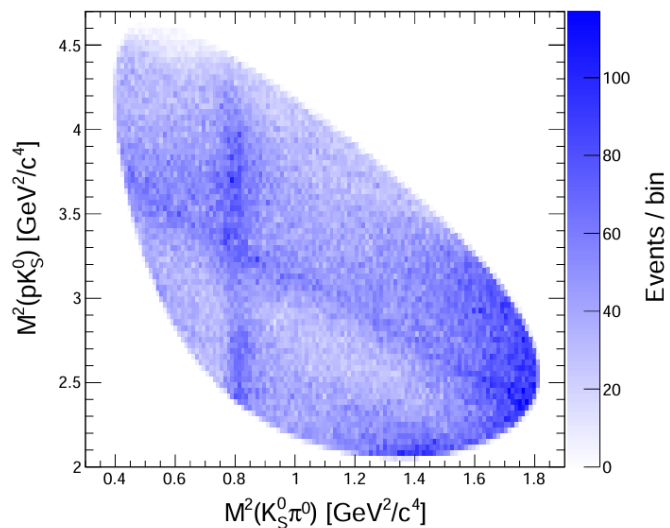
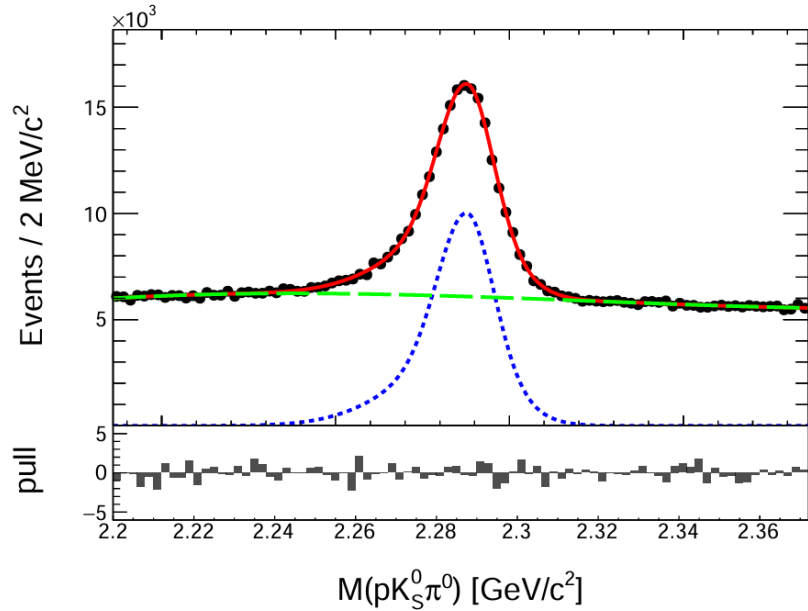
- The fit result with the Flatté function to which the constant is coherently added shows the best reduced χ^2/ndf of 1.06 (257/243, $p = 0.25$), while 1.27 (308/243, $p = 3.1 \times 10^{-3}$) from the best BW fit.
- The best fit explains the structure as a cusp at the $\Lambda\eta$ threshold.
- The obtained parameters are consistent with the known properties of $\Lambda(1670)$.

(See Duan, Bayar and Oset for a theoretical interpretation of this result. Phys. Lett. B 857 (2024), 139003)

First identification of a threshold cusp in hadrons from the spectrum shape

Peak at $p\eta$ threshold in $\Lambda_c^+ \rightarrow pK_S^0\pi^0$

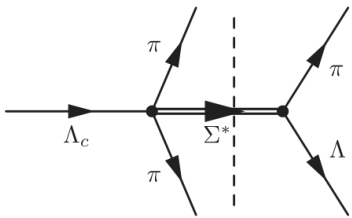
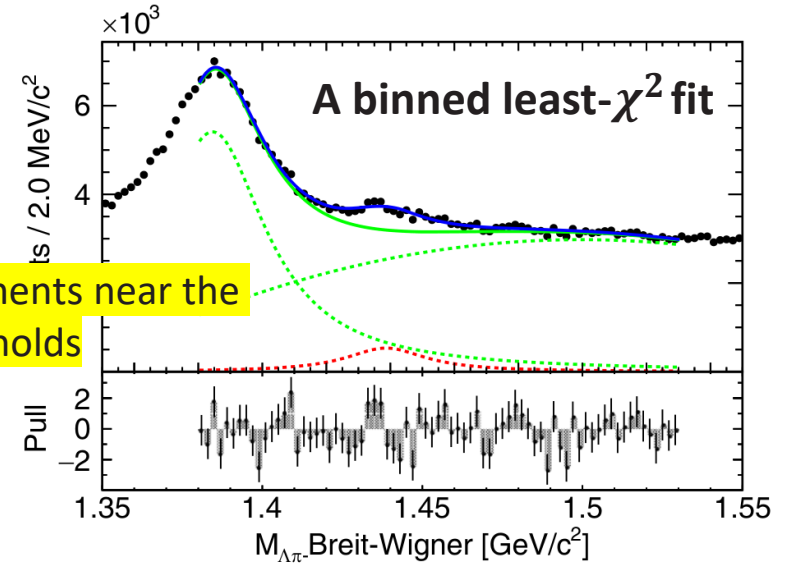
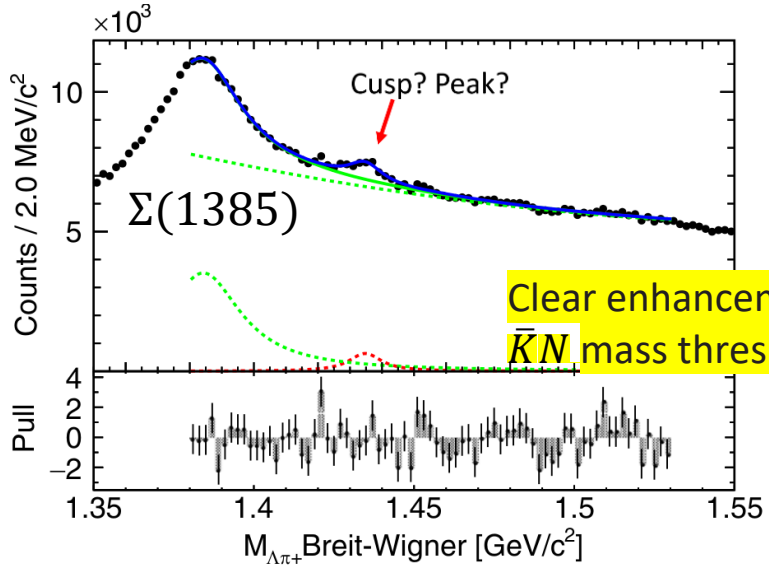
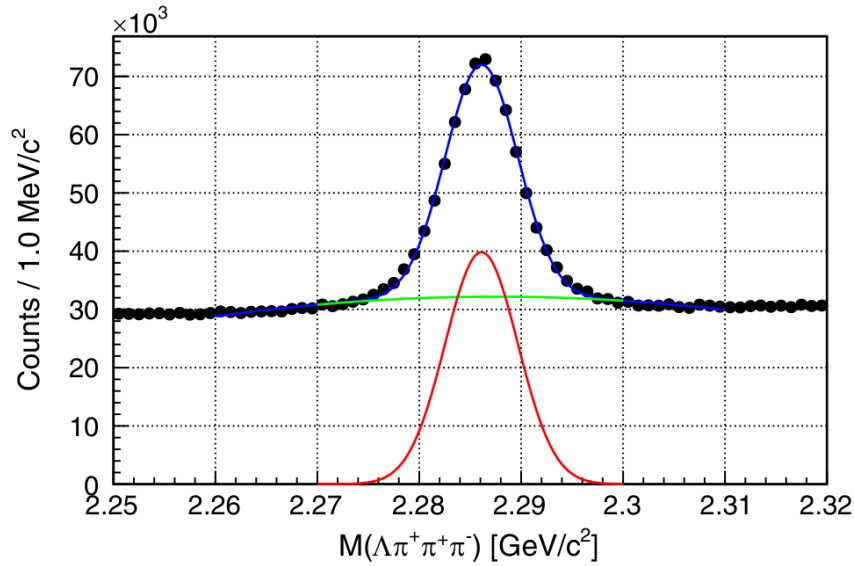
arXiv:2503.04371



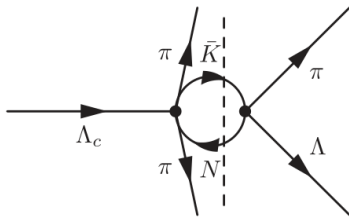
- A clear **peaking structure near the $p\eta$ mass threshold** is evident in the $M(p\pi^0)$ distribution.
- The same effect was observed in the $\Lambda_c^+ \rightarrow pK_S^0\eta$ study
- The similarity of this effect and the $\Lambda\eta$ threshold cusp, which was found to be amplified by the $\Lambda(1670)$ in the pK^- system
- Suggesting that the peak near the $p\eta$ threshold may also **be attributed to a threshold cusp enhanced by the $N(1535)^+$** .
- **A further analysis is planned for the near future**

Investigation of the $\Lambda\pi^\pm$ substructure [PRL 130, 151903 (2023)]

Cusp candidates are observed in $\Lambda\pi^\pm$ invariant mass spectra in $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^+\pi^-$ decay



(a)



(b)

➤ To interpret the signals as Σ^* resonances, we use a nonrelativistic Breit-Wigner

$$f_{\text{BW}} = \frac{\Gamma/2}{(E - E_{\text{BW}})^2 + \Gamma^2/4},$$

| Mode | E_{BW} (MeV/ c^2) | Γ (MeV/ c^2) | χ^2/NDF |
|----------------|-------------------------------|------------------------|---------------------|
| $\Lambda\pi^+$ | 1434.3 ± 0.6 | 11.5 ± 2.8 | 74.4/68 |
| $\Lambda\pi^-$ | 1438.5 ± 0.9 | 33.0 ± 7.5 | 92.3/68 |

• Significance $7.5(6.2)\sigma$

• This interpretation implies the existence of an exotic state, $\Sigma(1435)$.

(a) search for Σ^* resonances

(b) study $\bar{K}N$ rescattering with a cusp

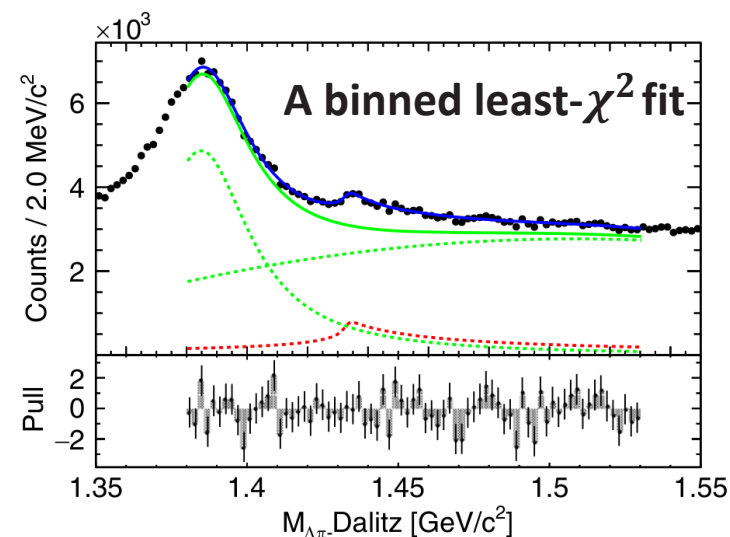
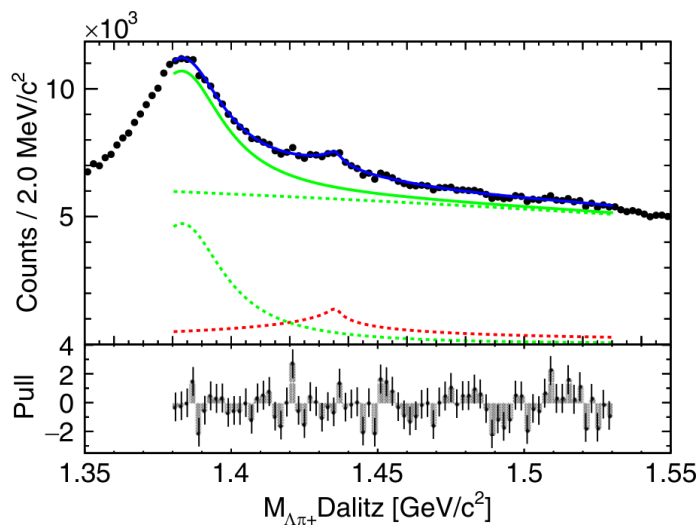
Investigation of the $\Lambda\pi^\pm$ substructure

- Dalitz model (describe a $\bar{K}N$ cusp) [Czech. J. Phys. B32, 1021 (1982)]
- $\bar{K}N$ cusp is related to the $\bar{K}N$ scattering length $A = a + ib$ and decay momentum $k/|k|$.

$$f_D = \frac{4\pi b}{(1 + kb)^2 + (ka)^2}, \quad E > m_{\bar{K}N}$$

$$= \frac{4\pi b}{(1 + \kappa a)^2 + (\kappa b)^2}, \quad E < m_{\bar{K}N},$$

| Mode | a (fm) | b (fm) | χ^2/NDF |
|----------------|-----------------|-----------------|---------------------|
| $\Lambda\pi^+$ | 0.48 ± 0.32 | 1.22 ± 0.83 | 68.9/68 |
| $\Lambda\pi^-$ | 1.24 ± 0.57 | 0.18 ± 0.13 | 78.1/68 |



Dalitz model gives slightly better χ^2 , but the difference is not significant.

- Many theories predict a cusp here.
 - Due to the attraction between \bar{K} and N in the $l=1$ channel
- Obtained scattering lengths are larger than most theories, but with large uncertainties (Also, form factor is ignored.)

- Peak/cusp at $\bar{K}N$ threshold in $\Lambda_c \rightarrow \Lambda\pi^+\pi^+\pi^-$
 - Peak? Cusp?
 - Cannot be identified from the spectrum only due to poor S/N.
- More studies should be done with Belle II and other experiments.

Summary

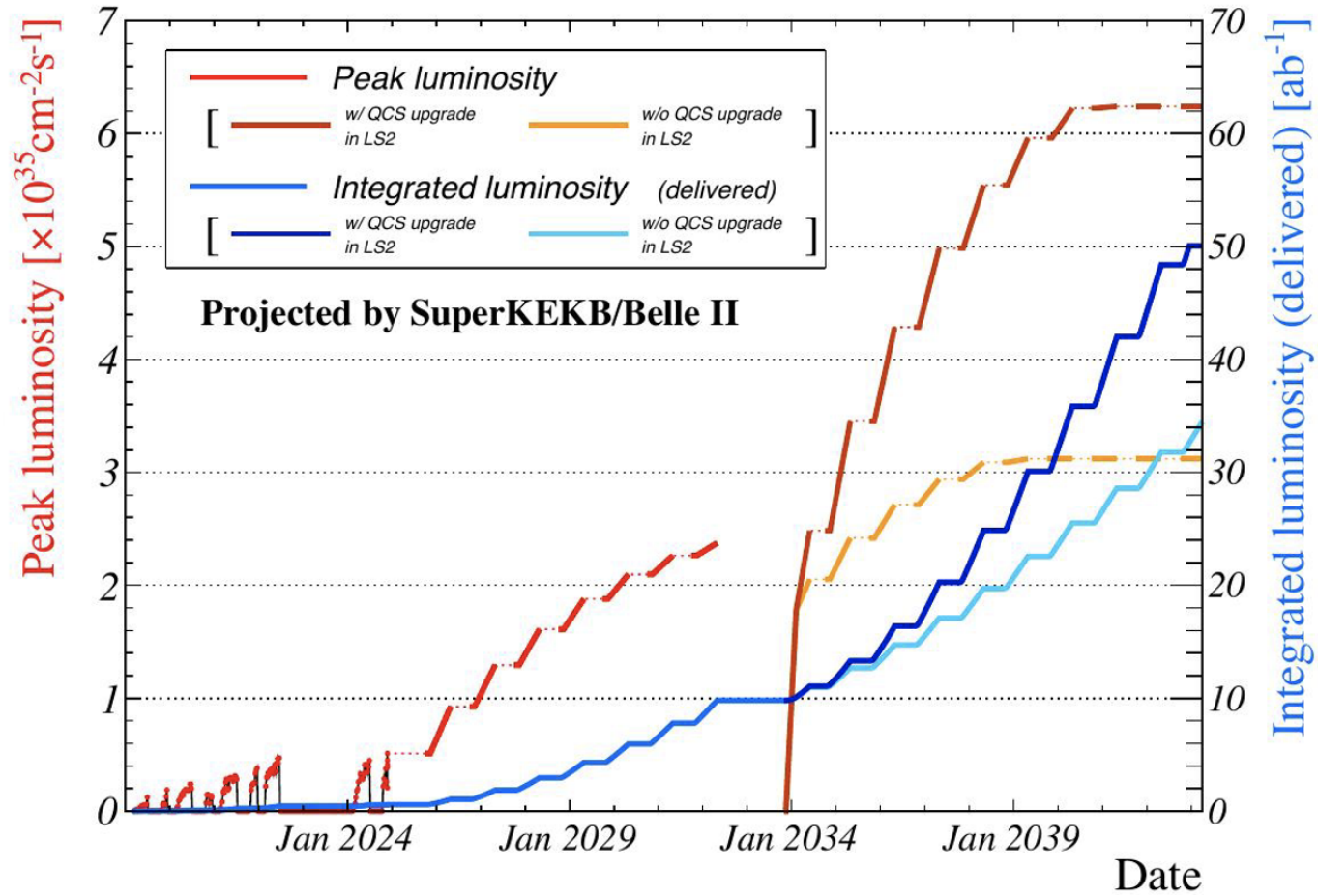
- Belle II and Belle hold a unique data sample. Some interesting measurement has been already performed in light hadron, such as
 - Fragmentation function for various light hadrons; Multistrange dibaryons; Discovered of a new $\Omega(2012)$ three-body decay, first determined a threshold cusp in experiments.
- Only $\sim 2\%$ of target luminosity collected so far. Stay tuned for more exciting results from Belle & Belle II.



***Thanks for your
attention!***

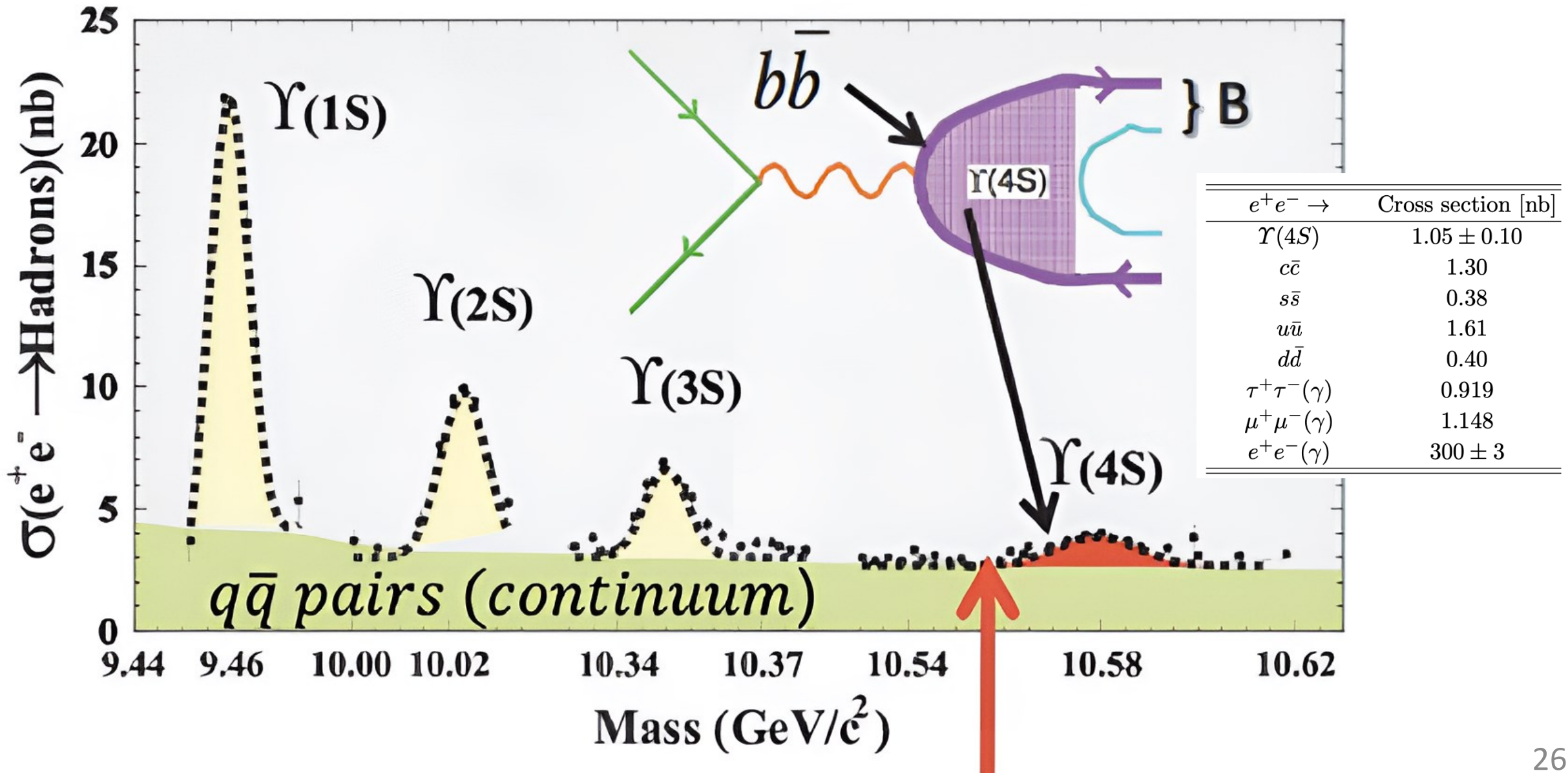
Backup slides

Data-taking plan at Belle II



- Until 2026, about 1 ab^{-1} data, comparable to Belle
- Until 2029, about 4 ab^{-1} data.

Belle II physics



Belle II physics

The Belle II Physics Book: [PTEP 2019 (2019) 12, 123C01]



A_{CP} in Charm

Charmed baryon

CKM matrix element

Lepton-Flavor universality

B rare decays

$\Upsilon(10753)$ study

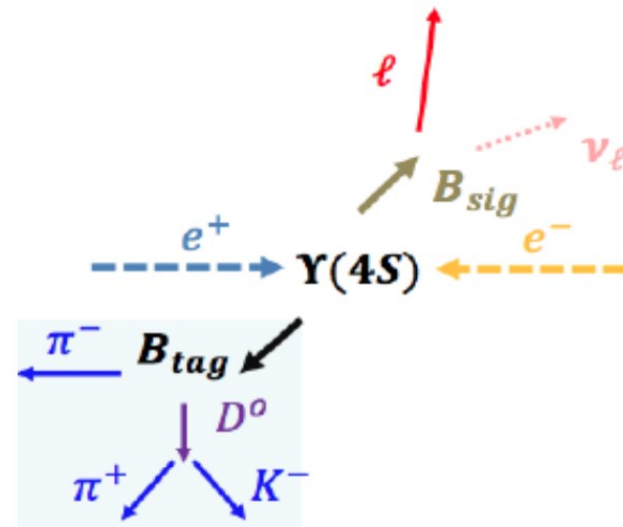
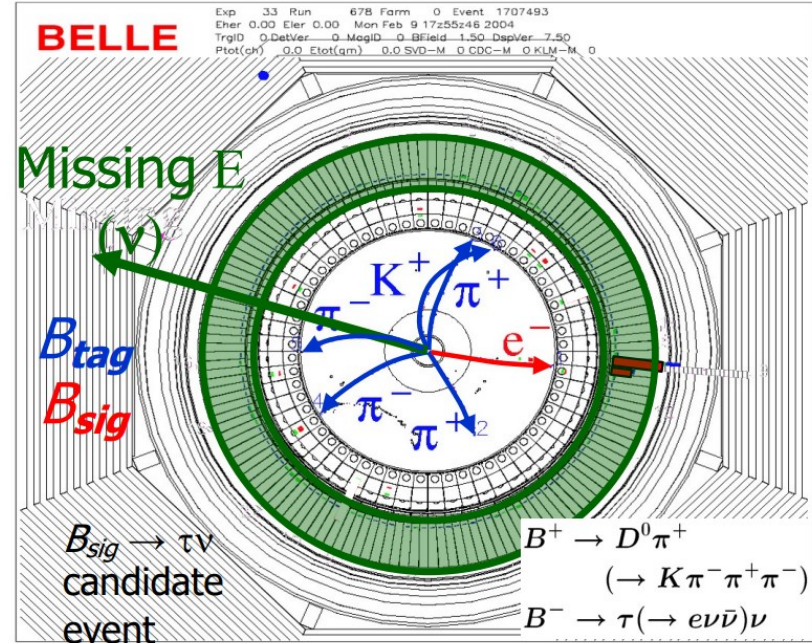
Dark Higgs

τ physics

Unique capabilities of Belle/Belle II

- **Beam energy constraint**
- **Clean experimental environment:** high B, D, K, τ lepton reconstruction efficiency
- Long lived particles (e.g. K_S), π^0 s and **photons** well reconstructed
- Capability of **inclusive measurements**
- **BB produced in quantum correlated state:** high flavour tagging effective efficiency (30% vs 5% @ LHCb)
- The **full reconstruction of one B (B_{tag})** constraints the 4-momentum of the other B (B_{sig})
- Reconstruction of **channels with missing energy**

$$p_\nu = p_{e^+e^-} - p_{B_{tag}} - p_{B_{sig}}$$



Access to Fragmentation functions

- **Semi-inclusive DIS (SIDIS):**

$$\sigma^h(x, z, Q^2, P_{h\perp}) \propto \sum e_q^2 q(x, p_t, Q^2) D_{1,q}^h(z, k_t, Q^2)$$

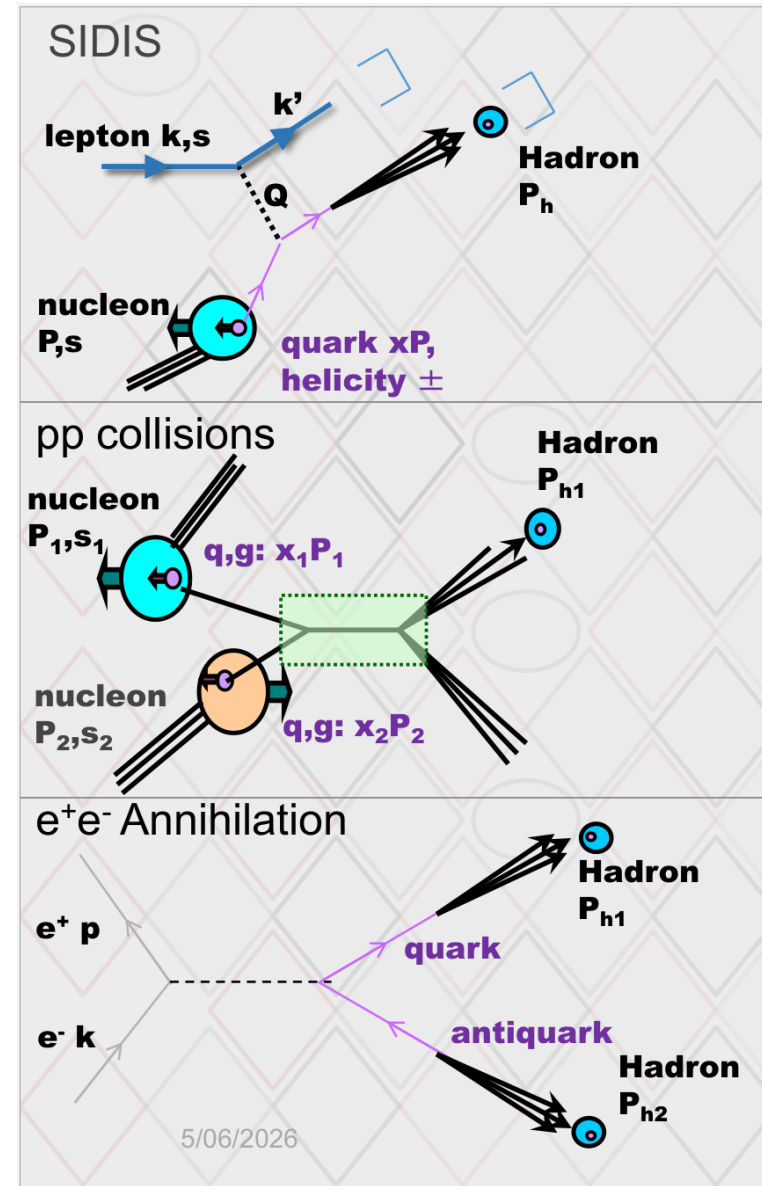
- Relies on unpol PDFs
- Parton momentum known at LO
- Flavor structure directly accessible
- Transverse momenta convoluted between FF and PDF

- $p\bar{p}$:
$$\sigma^h(P_T) \propto \int_{x_1, x_2, z} \sum_{a, a' \in q, g} f_a(x_1) \otimes f_{a'}(x_2) \otimes \sigma_{aa'} \otimes D_{1,q}^h(z)$$

- Relies on unpol PDFs
- leading access to gluon FF
- Parton momenta not directly known

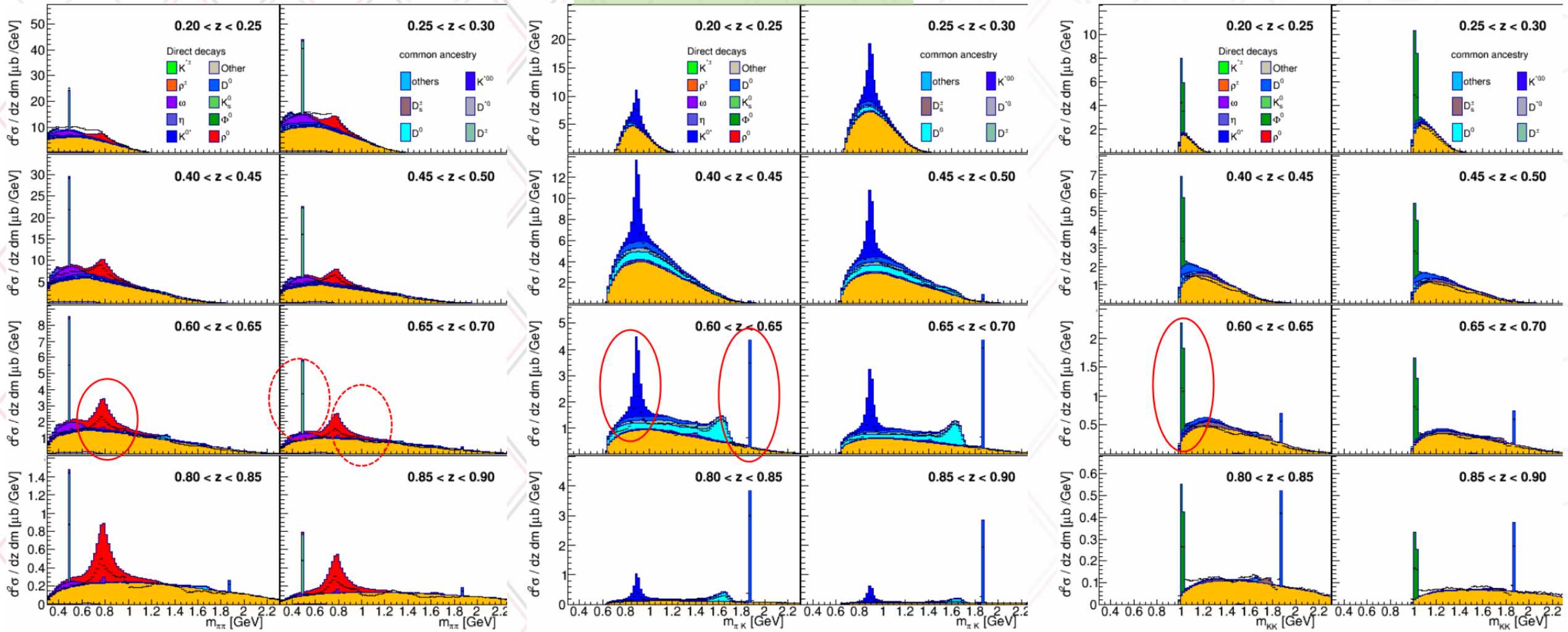
- e^+e^- :
$$\sigma^h(z, Q^2, k_t) \propto \sum_q e_q^2 (D_{1,q}^h(z, k_t, Q^2) + D_{1,\bar{q}}^h(z, k_t, Q^2))$$

- No PDFs necessary
- Clean initial state, parton momentum known at LO
- Flavor structure not directly accessible*



From mass cross sections to resonances

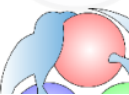
PRD96 (2017) 032005



$\pi^+\pi^-$

π^+K^-

K^+K^-

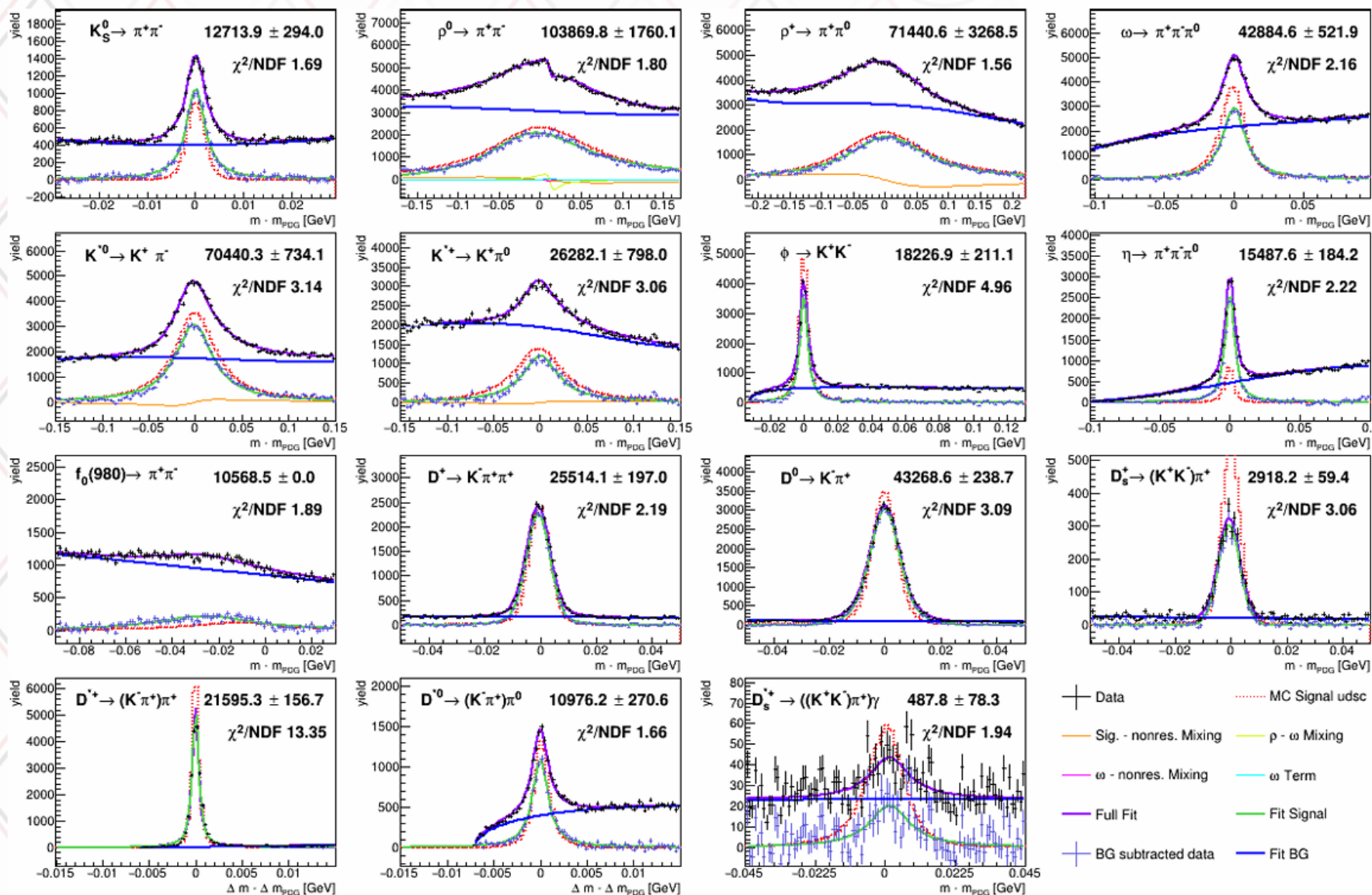


Analysis setup

- Use two/three-particle decays into charged pions, kaons and/or neutral pions
- Look for: $K_s \rightarrow \pi\pi$, $\rho^0 \rightarrow \pi\pi$, $\rho^+ \rightarrow \pi\pi$, $K^* \rightarrow K\pi$, $\phi \rightarrow KK$, $\eta \rightarrow \pi\pi\pi$, $\omega \rightarrow \pi\pi\pi$, $D^0 \rightarrow K\pi$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D^{*+} \rightarrow (K^-\pi^+)\pi^+$, $D^{*0} \rightarrow (K^-\pi^+)\pi^0$, $D_s^+ \rightarrow (K^-K^+)\pi^+$, $D_s^{*+} \rightarrow \gamma(K^-K^+)\pi^+$; recent PDG values for BR, consistency tests using $D^0 \rightarrow \pi\pi$, $D^0 \rightarrow KK$, $D^0 \rightarrow K^-\pi^+\pi^0$, $D_s^+ \rightarrow (\pi^-\pi^+)K^+$
- Additional Mass constraints for D^0 s from D^* decays and for ϕ , K_s from D_s decays
- Use $x_p = p/p_{\max}$ instead of z as fractional momentum due to mass constraints (runs truly from 0 to 1)
- Analyze on $Y(4S)$ resonance (75% $q\bar{q}$ production + $Y(4S)$ decays, 558 fb^{-1}) and off resonance (only $q\bar{q}$ production, 74 fb^{-1}) samples separately, merge at $x_p=0.55$
- Analysis process and sources of uncertainties:
 - Calculate yields in 40 x_p and 100 inv. mass bins \rightarrow Stat uncertainties
 - PID correction \rightarrow Unfolding method, random sampling of matrix uncertainties
 - Fit resonances, extract signal yields \rightarrow BG functional form, comparison to BG subtracted yields
 - Acceptance/efficiency correction within barrel, then to 4π \rightarrow MC stat uncertainties, MC tune variations
 - ISR correction \rightarrow MC Tune Variations

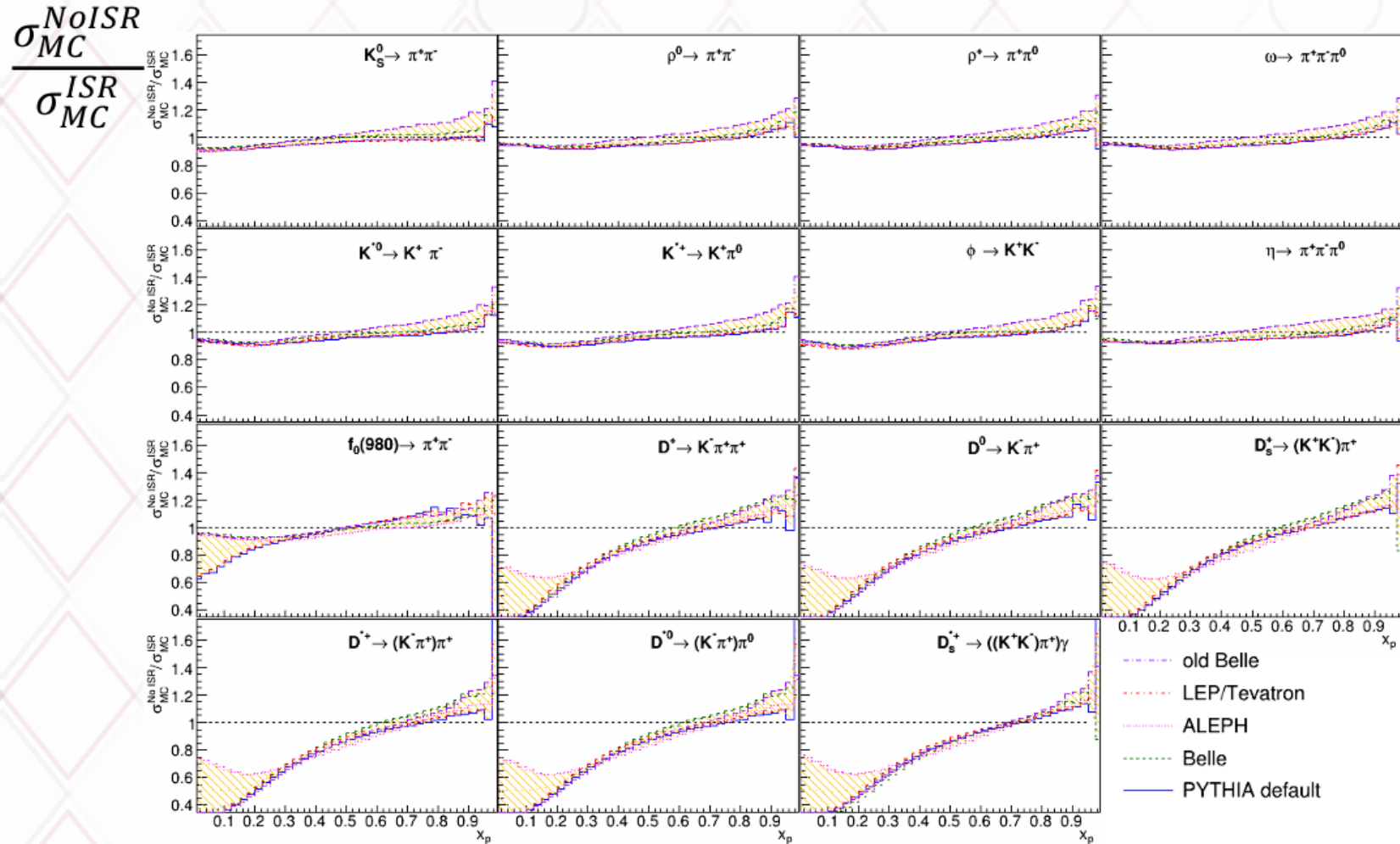
Mass fits

- Fit invariant masses by Breit-Wigners or Gaussians
- Backgrounds described by polynomials, except ϕ and D^* where threshold functions were used
- Interference with non-resonant background included for wide resonances, also with ω for ρ^0



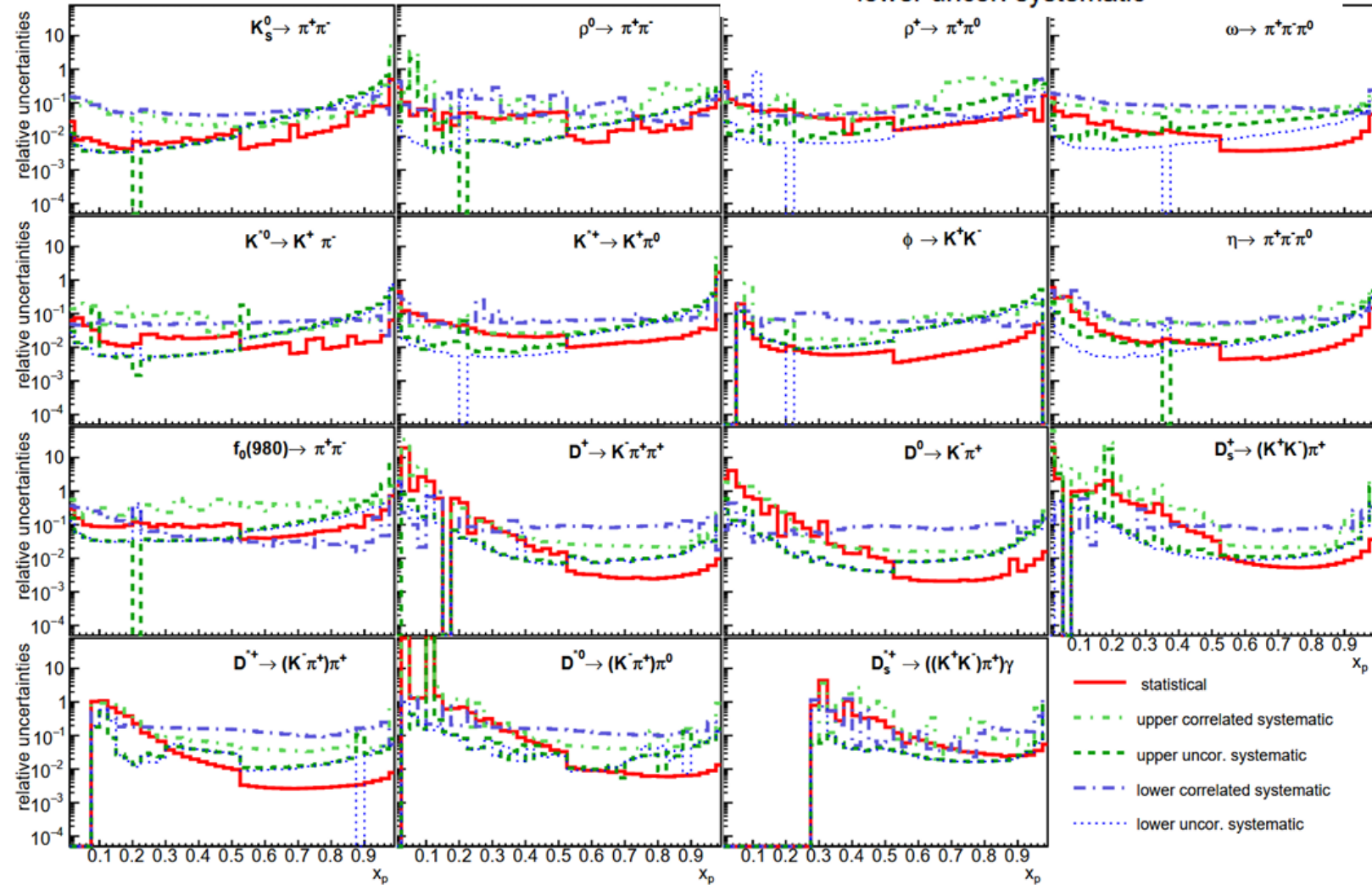
Initial state radiation correction

- Acceptance correction from Barrel to 4π and ISR correction performed with various Pythia6 tunes to estimate intrinsic θ and x_p dependence in corrections
- Variations assigned as systematic uncertainties
- D mesons with large correction due to FF peaks at higher x_p significantly migrating down with ISR

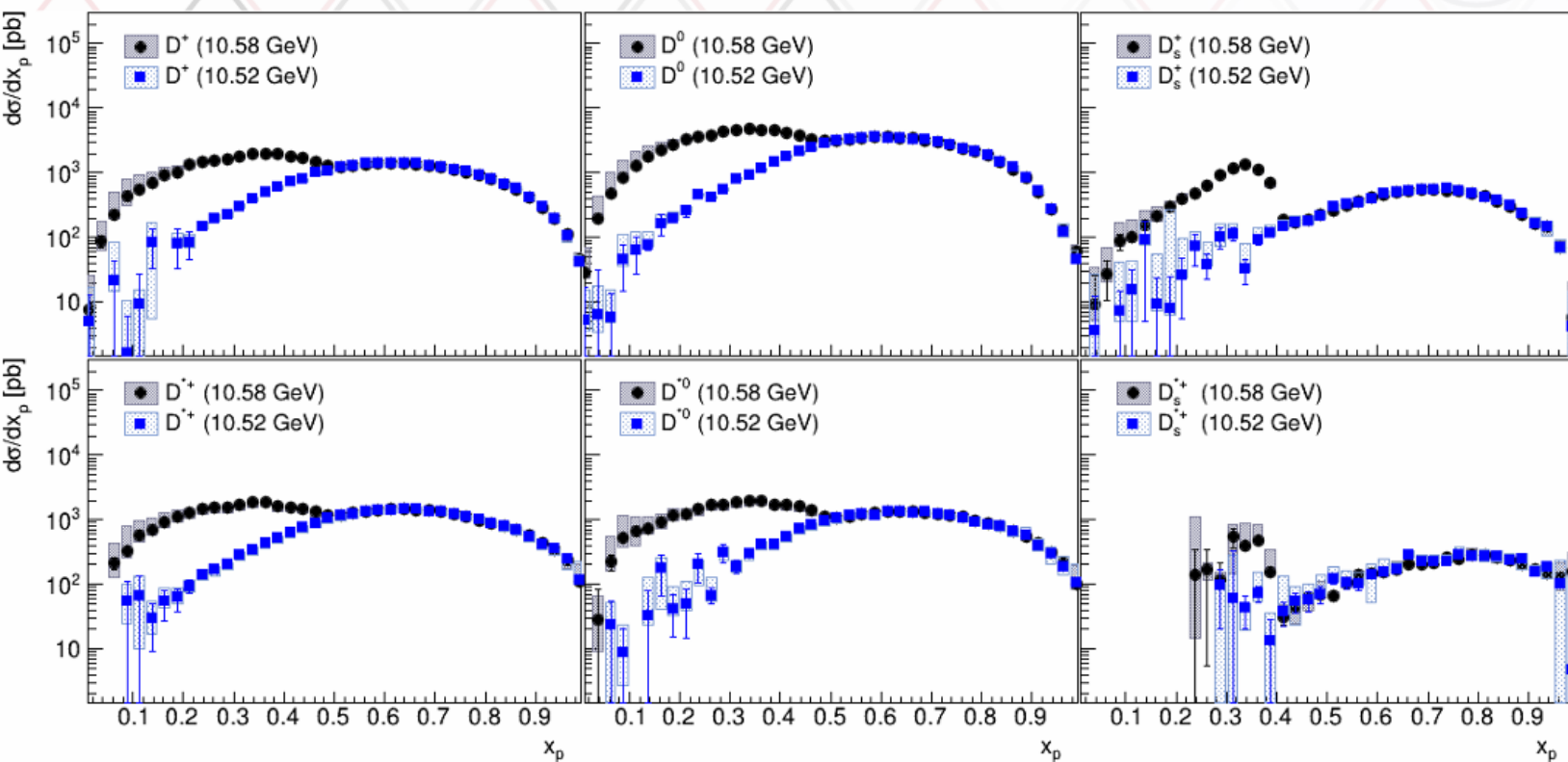


Systematics budget

- Results overall systematics limited, mostly from tune dependence, PID correction, and at low x_p (and all D^*) from uncertainties on low-momentum reconstruction efficiencies
- Drop of statistical uncertainties at 0.55 from using on-resonance dataset with more statistics (safe from B decays above 0.5)



Comparisons at resonance and below

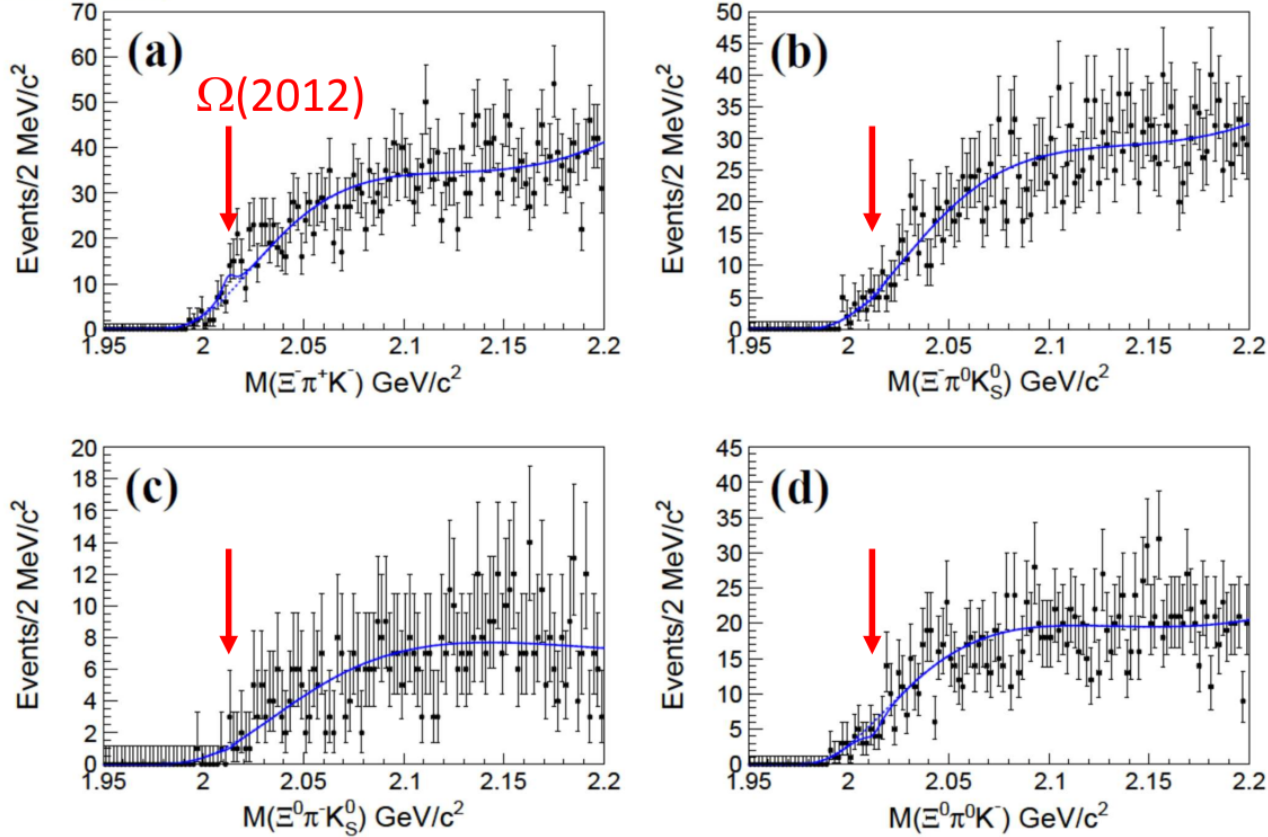


- Very clear distinction at low x_p from B decays
- Consistent for higher x_p where B decays cannot contribute
- Similarly for light hadrons except not as pronounced due to much lower x_p FF peaks



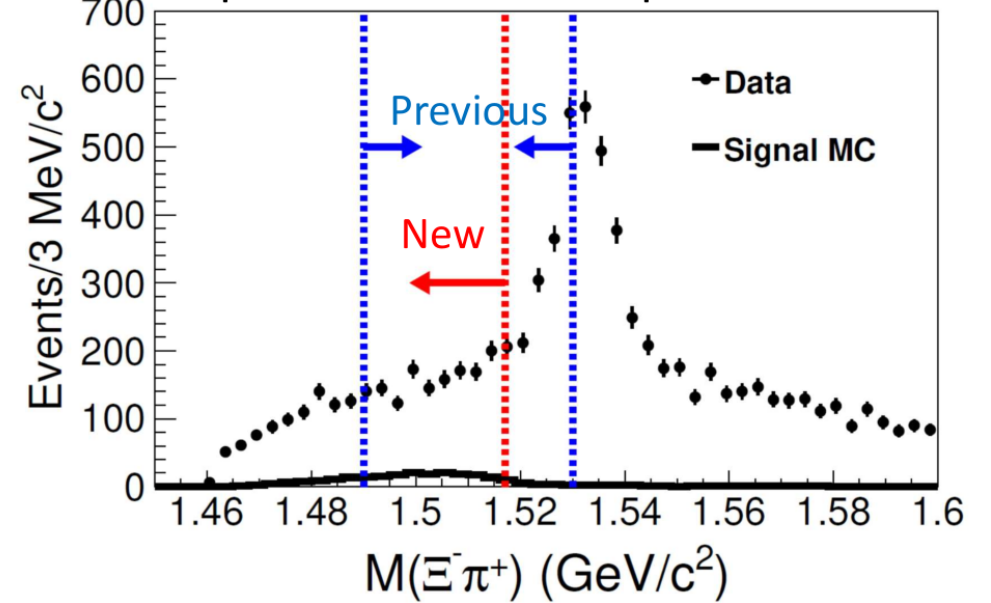
Previous study

[Belle, PRD 100 (2019) 032006]



What's the difference?

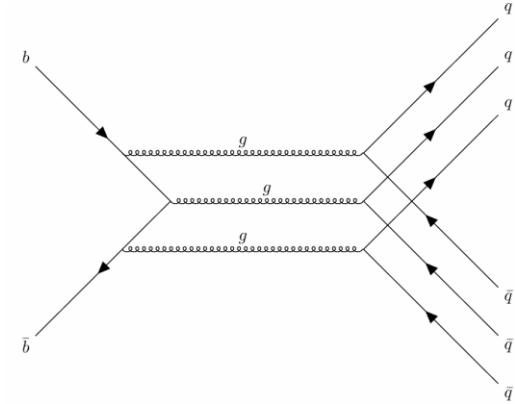
- Choice of $\Xi(1530)$
 - Phase space treatment is updated
- Additional cut on kaons from ϕ



Search for $\Xi^0 p$, $\Omega^- p$ and $\Omega^- n$ bound states from $\Upsilon(1S, 2S)$ decay at Belle

Why $\Upsilon(1S, 2S)$?

- Gluon-rich hadronization: $\mathcal{B}(\Upsilon(1S) \rightarrow ggg) = 81.7\%$,
 $\mathcal{B}(\Upsilon(2S) \rightarrow ggg) = 58.8\% \rightarrow$ enhances multibaryon production (e.g., antideuteron observed by BaBar/CLEO).



Key advantages

- Production distinct from hadronic/nuclear reactions
- Sensitive to weakly bound or unbound states near threshold
- Clean environment for multibaryon final states

Relevant decay channels

| Candidate | Hypothesis | Reconstructed final state |
|--------------|------------------|--|
| $\Xi^0 p$ | Bound Unbound | $\pi^0 \Lambda p$ (3-body) $\Xi^0 p$ with $\Xi^0 \rightarrow \pi^0 \Lambda$ |
| $\Omega^- p$ | Bound Unbound | $\Xi^0 \Lambda$ with $\Xi^0 \rightarrow \pi^0 \Lambda$ $\Omega^- p$ with $\Omega^- \rightarrow K^- \Lambda$ |
| $\Omega^- n$ | Bound | $\Xi^- \Lambda$ with $\Xi^- \rightarrow \pi^- \Lambda$ |

First search for $\Xi^0 p$, $\Omega^- p$, $\Omega^- n$ in Υ decays

