Measurement of $e^+e^- \to K\bar{K}$ cross section via ISR method

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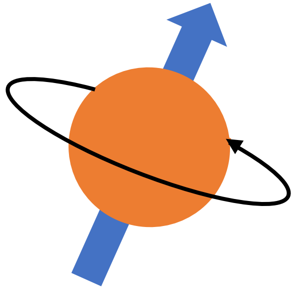
第十届BESIII R值与QCD强子结构研讨会

2025年7月28日 乌鲁木齐

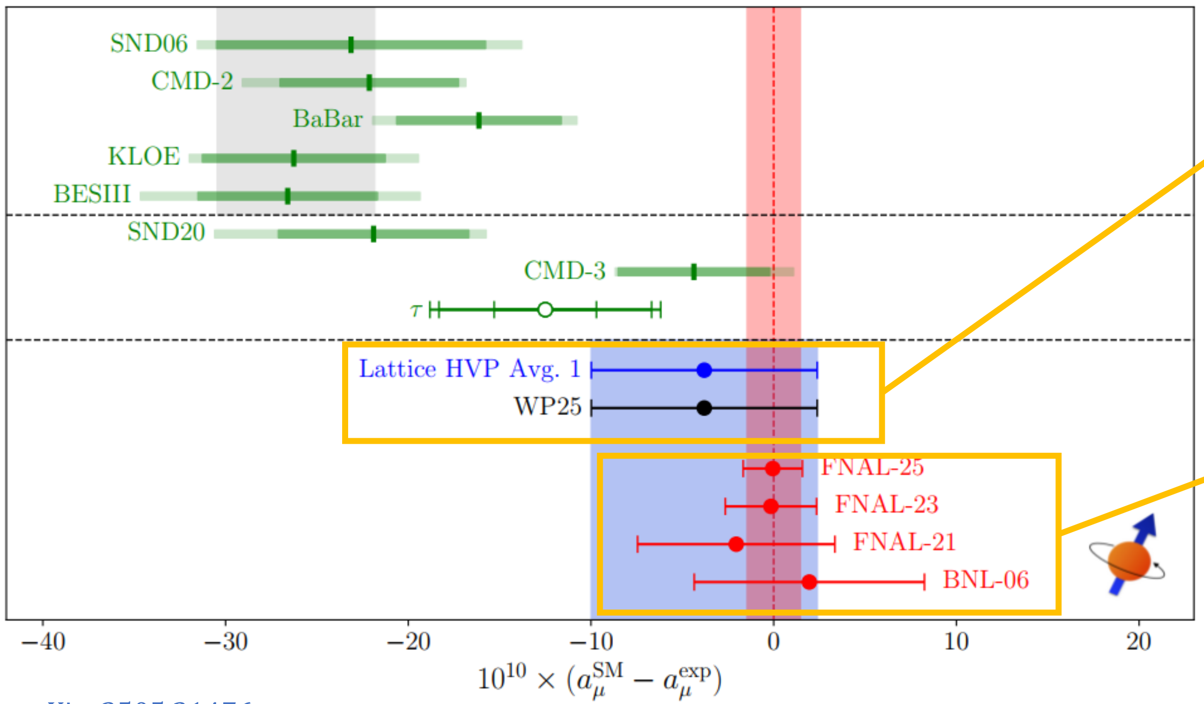
Outline

- Motivation
- BESIII Experiment: Advantage
- Initial State Radiation Method
- $K\overline{K}$ Cross Section
- Summary

Motivation



- The anomalous magnetic moment of muon ($a_\mu = (g-2)_\mu/2$)
  - The Dirac equation predicts a muon magnetic moment: $\vec{M} = g\frac{e}{2m_\mu}\vec{S}$ with $g = 2$
  - Magnetic anomaly to evaluate the deviation: $a_\mu \equiv \frac{g-2}{2}$



arXiv: 2505.21476

- Updated Standard Model prediction in WP25: a_μ^{SM}
  - ✓ Most important development since WP20: estimation of leading-order hadronic-vacuum-polarization (LO HVP) contribution, Data-driven → Lattice QCD calculation
- Experimental measurement: a_μ^{exp}
  - ✓ Brookhaven National Lab (BNL)
  - ✓ Fermilab (FNAL)

- No tension between a_μ^{SM} and a_μ^{exp} at the current precision
- Precision of a_μ^{SM} must be improved by about a factor of four to match the one of a_μ^{exp}

Motivation

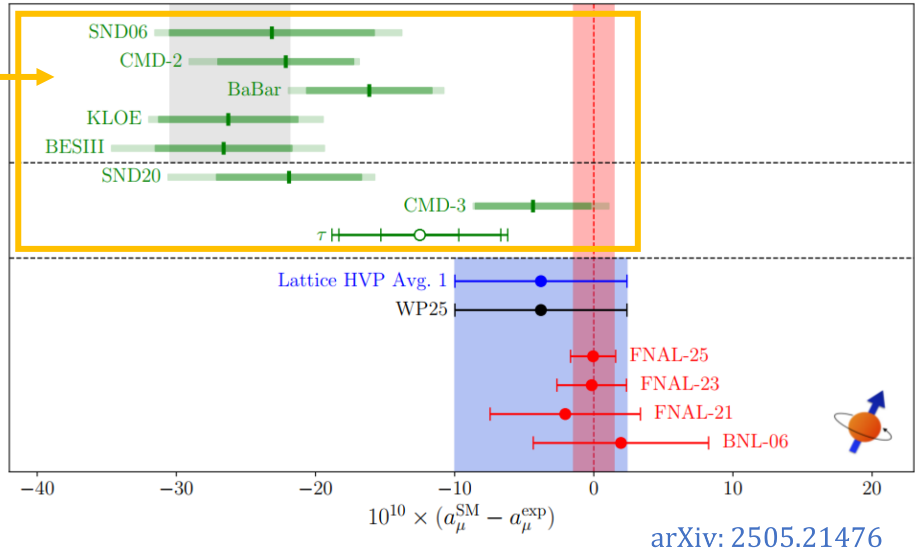
- Why lattice calculation used here?
  - Significant deviations in data-driven results among different collaborations
- How to understand these deviations and what can we do?
  - An improved understanding of higher-order radiative corrections

Dispersion integrals

Data-driven

Experimentally measured cross section
$\sigma(e^+e^- \to \gamma^* \to \text{hadrons} + \gamma)$

$a_\mu^{\text{LO HVP}}$ contribution



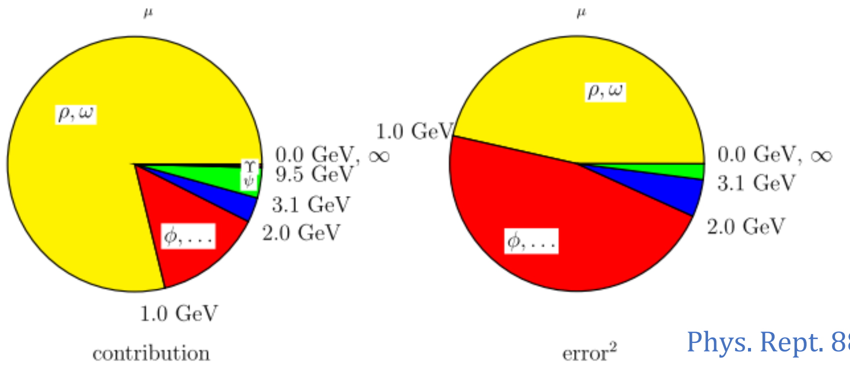
arXiv: 2505.21476

$$a_\mu^{\text{LO HVP}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{s_{\text{thr}}}^{\infty} ds \frac{\hat{K}(s)}{s^2} R_{\text{had}}(s)\,, R_{\text{had}}(s) = \frac{\sigma[e^+e^- \to \text{hadrons}(+\gamma)]}{4\pi\alpha^2/(3s)}$$

  - More precise measurements

I. $\lesssim 2$ GeV: exclusive final states $(2\pi, 3\pi, 4\pi, 2K(K^+K^-, K_S K_L), \ldots)$
inclusive R value via ISR or energy scan method

II. $\gtrsim 2$ GeV: inclusive hadronic R value

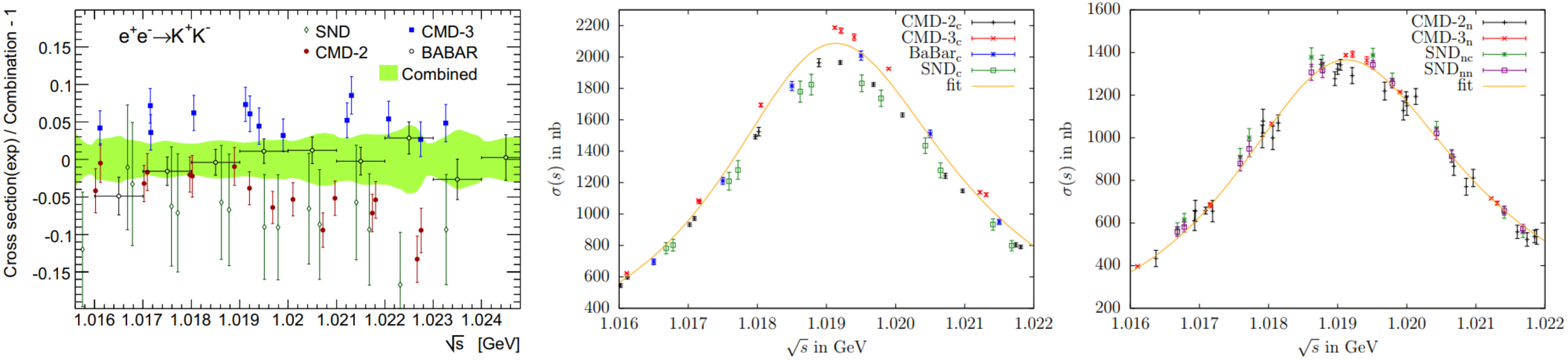


Phys. Rept. 887, 1-166 (2020)

Motivation

- Discrepancies between data from different experiments in KK channel
  - Tensions observed in K^+K^- channel around ϕ peak, not clear in K_SK_L channel

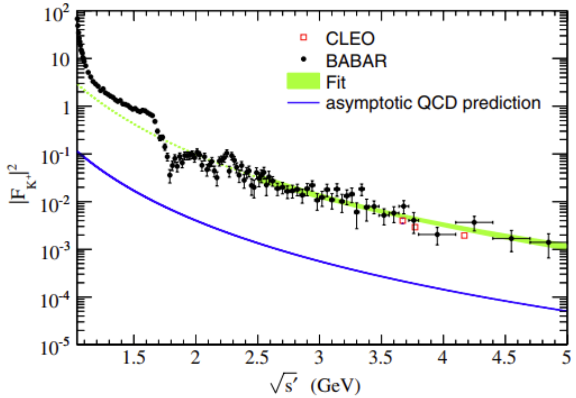
arXiv: 2505.21476
Phys. Rept. 887, 1-166 (2020)
Eur. Phys. J. C 80,241 (2020)



- More accurate cross section measurement around ϕ peak are needed

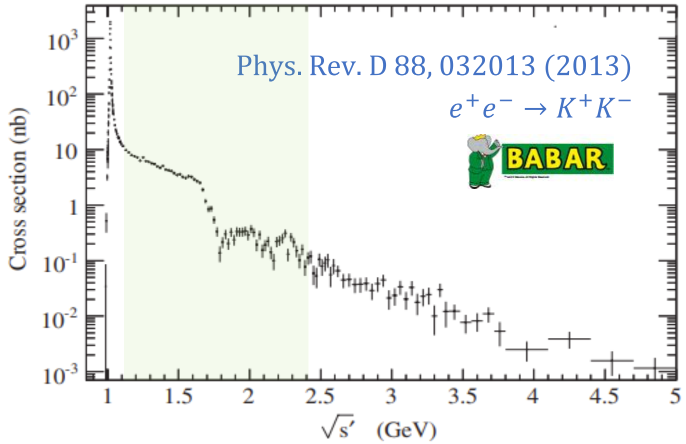
Motivation

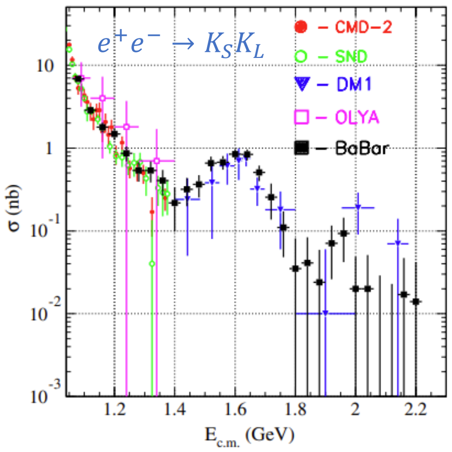
- Kaon electromagnetic form factor
  - Direct insight into the distribution of charges, currents, color and flavor
  - Charged Kaon form factor:
    - Energy-dependent form factor at higher-energy data is consistent with the asymptotic form predicted by pQCD
    - Their magnitude is about 4 times higher than the predicted asymptotic value
  - How about neutral Kaon?



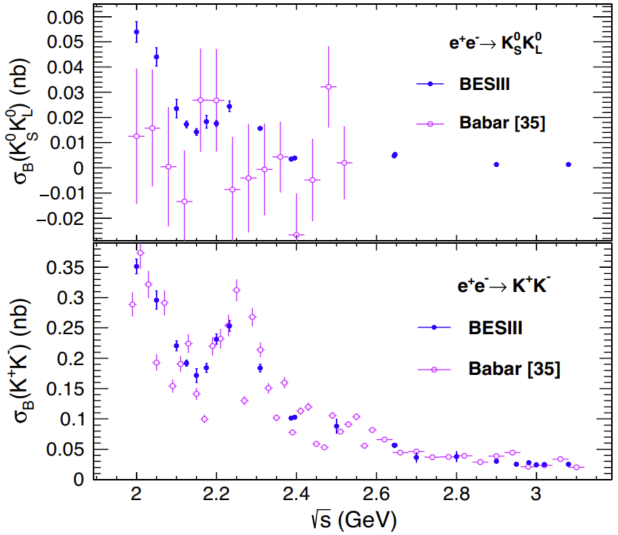
Phys. Rev. D 104, 092014(2021)
Phys. Rev. D 99, 032001 (2019)

- Substantial structures are evident in the center-of-mass energy range 1.1 − 2.4 GeV



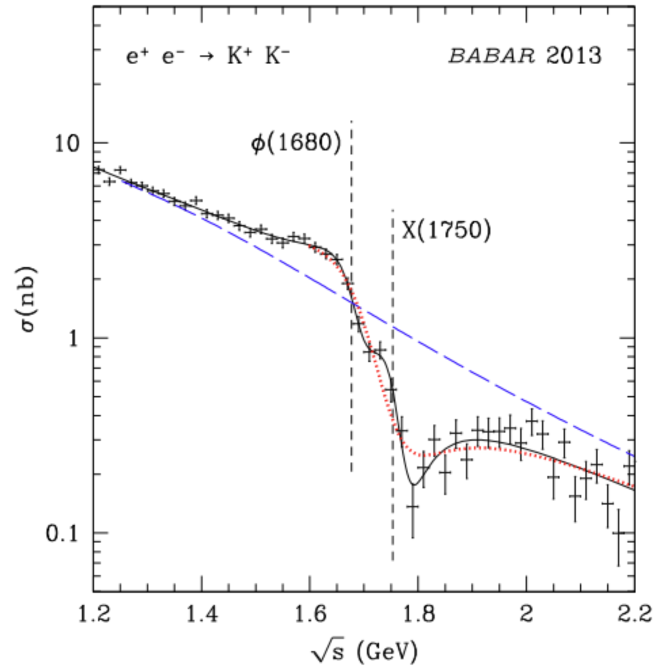


Phys. Rev. D 89, 092002 (2014)



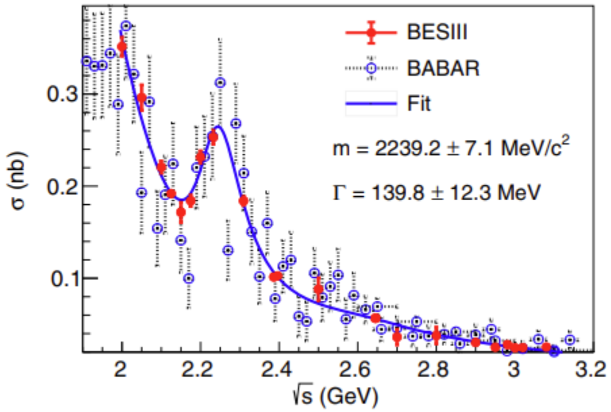
Motivation

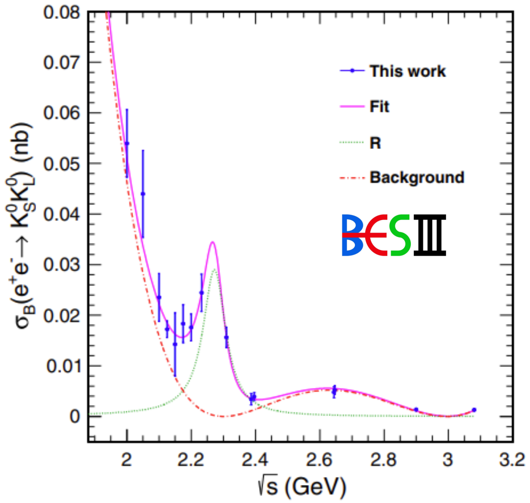
- Provide more information about the vector resonances
  - ? Can the X(1750) be a $\phi(1750)$?



Phys. Rev. D 111, L071903(2025)

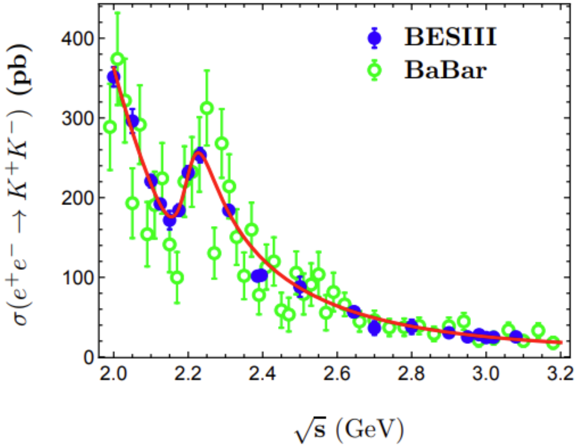
  - ? $\phi(2170)$?

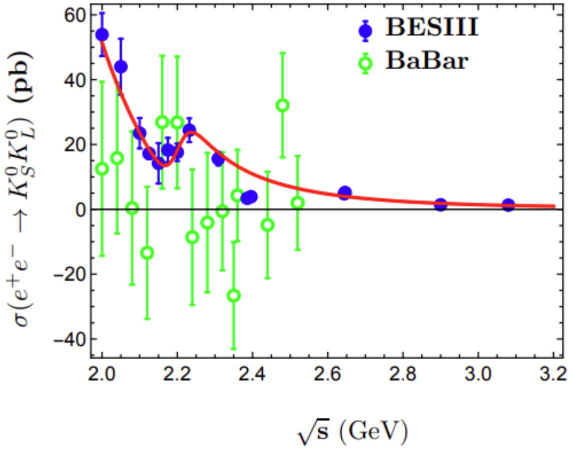




arXiv: 2504.18797

  - ? Y(2240)?

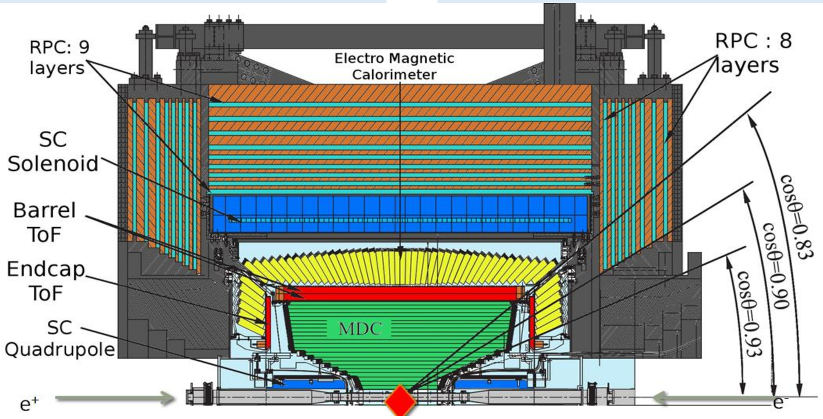




BESIII Experiment: Advantages

Electromagnetic Calorimeter
CsI(Tl): L = 28 cm
- Barrel $\sigma_E/E = 2.5\%$ @ 1 GeV
- Endcap $\sigma_E/E = 5.0\%$ @ 1 GeV

Muon Counter RPC
Barrel: 9 layers
Endcaps: 8 layers
- $\sigma_{\text{spatial}} = 1.48$ cm



- BESIII Detector

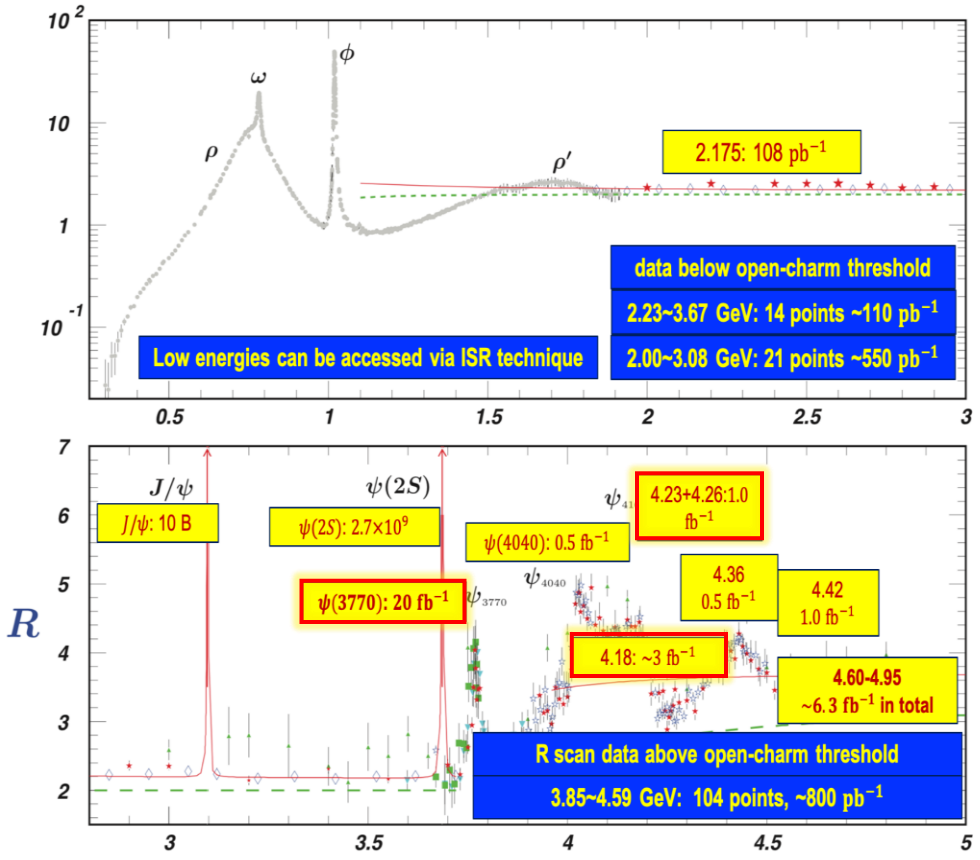
Main Drift Chamber
Small cell, 43 layer
- $\sigma_{xy} = 130$ μm
- $dE/dx \sim 6\%$
- $\sigma_p/p = 0.5\%$ @ 1 GeV/c

Time Of Flight
Plastic scintillator
- σ_T(barrel) = 68 ps
- σ_T(endcap) = 110 ps

(update to 60 ps with MRPC)

- ✓ Symmetric e^+e^- collisions
- ✓ Good resolution
- ✓ High detection efficiency
- ✓ Lower background

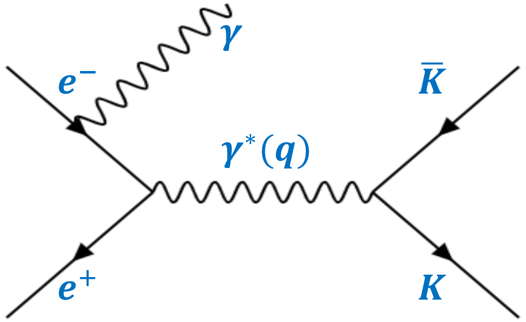
Nucl. Instrum. Meth. A 614, 345-399 (2010)



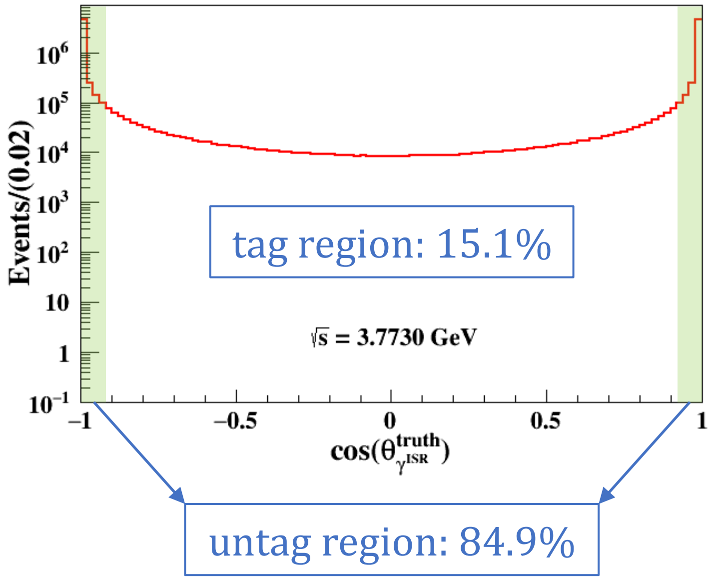
- ✓ Large datasets: 20 fb^{-1} at $\psi(3770)$, 10 fb^{-1} at XYZ region
- ✓ Ideal environment to measure $e^+e^- \to K\bar{K}$ cross section with initial state radiation method!
- ✓ Also for measurement by energy scan method

Initial State Radiation(ISR) Method

- **Initial State Radiation (ISR)** Method at a fixed c.m. energy
  - At a fixed c.m. energy $\sqrt{s}$, collecting events from threshold to $\sqrt{s}$
  - Systematic uncertainty in a coherent way
  - Large luminosity needed
  - Higher background than energy scan method



- Two reconstruction method
  - I. Events with a tagged ISR photon (tag)
    - ✓ From threshold → More contributions for $a_\mu^{\mathrm{LO\ HVP}}$
    - ☹ Low reconstruction efficiency
  - II. Events with an untagged ISR photon (untag)
    - ✓ High reconstruction efficiency → better to explore structures in $M(K\bar{K})$
    - ☹ Can't start from threshold



✓ ISR photons emitted mainly along the direction of beam pipe

$K\bar{K}$ cross section

- Datasets:

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (fb^{-1})
3.773	20.3
$4.008 \sim 4.157$	1.3
4.178	3.2
$4.189 \sim 4.288$	6.1

- MC samples:
  - Determine the detection efficiency
  - Estimate the background contributions

- Analyses ongoing:
  - $e^+e^- \to K^+K^-$ with a tagged ISR photon(tag K^+K^-)
  - $e^+e^- \to K^+K^-$ with an untagged ISR photon(untag K^+K^-)
  - $e^+e^- \to K_SK_L$ with a tagged ISR photon(tag K_SK_L)

Regard as a missing particle

$K_S \to \pi^+\pi^-$

Process	Generator	Samples	Process	Generator	Samples
$e^+e^- \to \gamma^{\text{ISR}}K^+K^-$	PHOKHARA	$\sim$11×	$e^+e^- \to \gamma^{\text{ISR}}J/\psi$	BesEvtGen	$\sim$40×
$e^+e^- \to \gamma^{\text{ISR}}K_SK_L$	PHOKHARA	$\sim$118×	$e^+e^- \to \gamma^{\text{ISR}}\psi(2S)$	BesEvtGen	$\sim$40×
$e^+e^- \to q\bar{q}$	KKMC/LundAreaLaw	$\sim$8×	$\gamma\gamma \to K^+K^-$	cppGamGam	$\sim$30×
$e^+e^- \to \psi(3770) \to$ non-DD	KKMC+BesEvtGen	$\sim$40×	$\gamma\gamma \to \pi^+\pi^-$	GALUGA2.0	$\sim$1×
$e^+e^- \to \gamma^{\text{ISR}}\pi^+\pi^-$	PHOKHARA	$\sim$6×	$\gamma\gamma \to \mu^+\mu^-$	DIAG36	$\sim$1×
$e^+e^- \to \gamma^{\text{ISR}}e^+e^-$	BABAYAGA	$\sim$0.25×	$\gamma\gamma \to e^+e^-$	DIAG36	$\sim$2×
$e^+e^- \to \gamma^{\text{ISR}}\mu^+\mu^-$	PHOKHARA	$\sim$10×	$\gamma\gamma \to \eta$	EKHARA	$\sim$1×
$e^+e^- \to \gamma^{\text{ISR}}\tau^+\tau^-$	KKMC	$\sim$40×	$\gamma\gamma \to \eta'$	EKHARA	$\sim$1×

Background Analysis Method

- Background level in each analysis

Analysis	tag K^+K^-			untag K^+K^-		tag K_SK_L	
$M(K\bar{K})$ region	$[M(K^+K^-)_{\text{th}}, 1.1]$	$[1.1, 2.5]$	$[2.5, 3.0]$	$[1.2, 2.5]$	$[2.5, 3.2]$	$[M(K_SK_L)_{\text{th}}, 1.1]$	$[1.1, 2.0]$
Background(%)	0.8	2.2	25.7	4.2	9.0	9.2	80.1

- How to estimate backgrounds
  - MC estimation

Line shape input → Background MC generated by ConExc $\xrightarrow{\text{Signal selection criteria}}$ $M(K^+K^-)$ spectrum × scale factor

  - Data driven

Background MC → Signal selection criteria → Signal MC efficiency

Background MC → Background selection criteria → Background MC efficiency

Signal MC efficiency ÷ Background MC efficiency = Relative MC efficiency

Data → Background selection criteria → $M(K^+K^-)$ spectrum × Relative MC efficiency

  - Sideband

Flat background distribution on $M(K_S)$ → Data in sideband region to estimate background in signal region

ISR Radiation Function

- Comparison between calculation and MC generator PHOKHARA
  - Strategy:
    - 20M $e^+e^- \to \gamma^{\text{ISR}}\mu^+\mu^-$ MC, generated by PHOKHARA, NLO ISR enabled, FSR and VP switched off
    - $\frac{L_i}{L} = \frac{\sigma_i^{e^+e^-\to\gamma^{\text{ISR}}\mu^+\mu^-}}{\sigma_i^{e^+e^-\to\mu^+\mu^-}}$ $\qquad \sigma_{e^+e^-\to\mu^+\mu^-} = \frac{86.8}{s}\,\text{nb}$

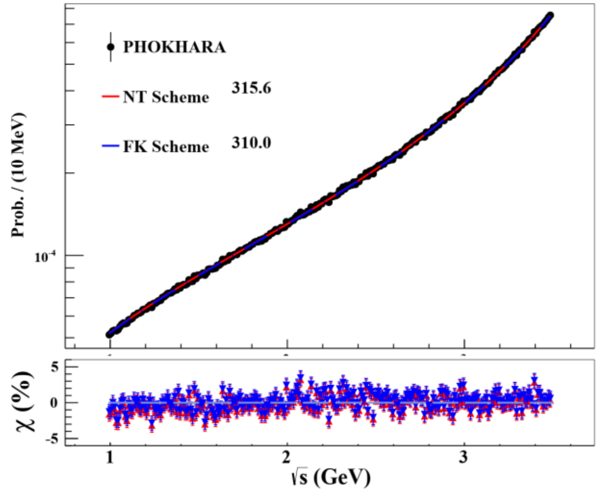
Nucl. Phys. B 318, 1-21 (1989)

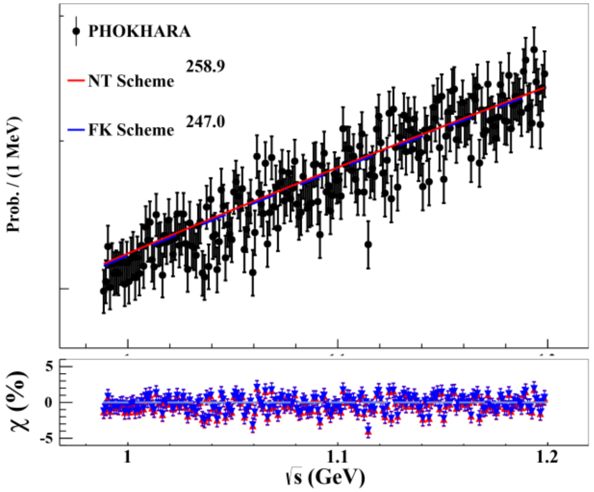
  - Function:

Used
    - $\boxed{\mathrm{F}_{\mathrm{SF}}^{\mathrm{FK}}(x,s)} = \beta x^{\beta-1}\left[1+\frac{\alpha}{\pi}\left(\frac{\pi^2}{3}-\frac{1}{2}\right)+\frac{3}{4}\beta-\frac{\beta^2}{24}\left(\frac{1}{3}L+2\pi^2-\frac{37}{4}\right)\right]-\beta\left(1-\frac{1}{2}x\right)-\frac{1}{8}\beta^2\left[4(2-x)\ln x+\frac{1+3(1-x)^2}{x}\ln(1-x)+6-x\right]$ $\qquad \beta = 2\alpha(L-1)/\pi,\ L=\ln(s/m_e^2)$
    - $\mathrm{F}_{\mathrm{SF}}^{\mathrm{NT}}(x,s) = \beta x^{\beta-1}\Delta-\beta\left(1-\frac{1}{2}x\right)-\frac{1}{8}\beta^2\left[4(2-x)\ln x+\frac{1+3(1-x)^2}{x}\ln(1-x)+6-x\right],$

$$\Delta = 1+\frac{\alpha}{\pi}\left(\frac{3}{2}L+\frac{\pi^2}{3}-2\right)+\left(\frac{\alpha}{\pi}\right)^2\left\{\left[\frac{9}{8}-2\zeta(2)\right]L^2+\left[-\frac{45}{16}+\frac{11}{2}\zeta(2)+3\zeta(3)\right]L-\frac{6}{5}[\zeta(2)]^2-\frac{9}{2}\zeta(3)-6\zeta(2)\ln 2+\frac{3}{8}\zeta(2)+\frac{57}{12}\right\}$$

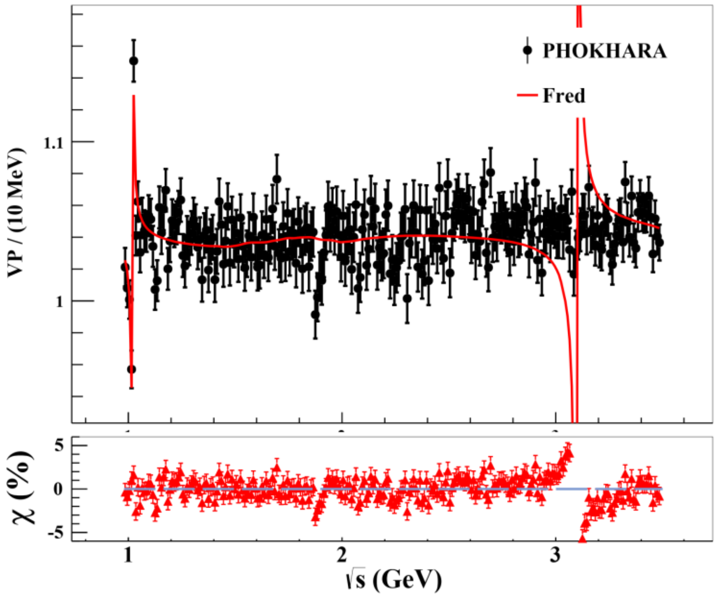
  - Result:

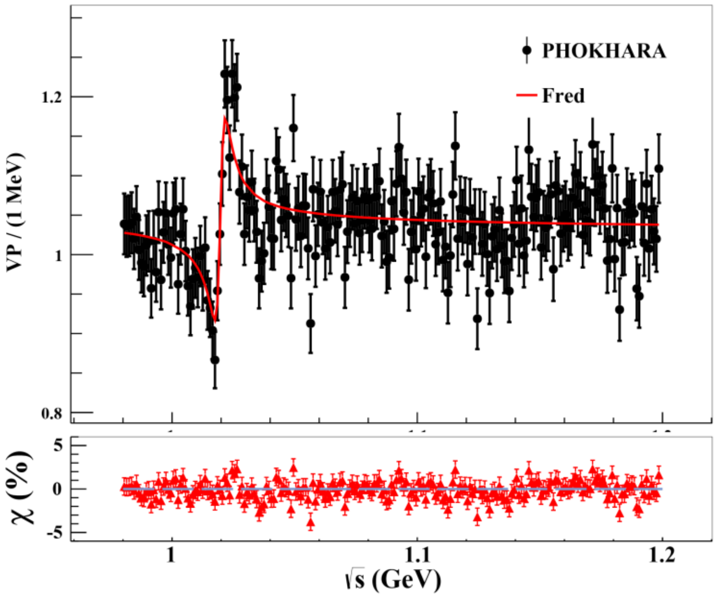




Vacuum polarization

- Comparison between calculation and MC generator PHOKHARA
  - Strategy:
    - 10M $e^+e^- \to \gamma^{\text{ISR}}\mu^+\mu^-$ MC, generated by PHOKHARA, NLO ISR and VP enabled, FSR switched off, J/ψ is excluded in MC generated
    - $\frac{\sigma_i^{e^+e^-\to\gamma^{\text{ISR}}\mu^+\mu^-}}{\sigma_i^{e^+e^-\to\mu^+\mu^-}} = w(x,s)\cdot f_{\text{vp}}$ $\quad \sigma_{e^+e^-\to\mu^+\mu^-} = \frac{86.8}{s}\,\text{nb} \quad w(x,s) = \text{F}_{\text{SF}}^{\text{FK}}(x,s)$
  - Result:





$K\bar{K}$ cross section

- Resolution

Analysis	tag K^+K^-			untag K^+K^-		tag K_SK_L	
$M(K\bar{K})$ region	$[M(K^+K^-)_{\mathrm{th}}, 1.1]$	$[1.1, 2.5]$	$[2.5, 3.0]$	$[1.2, 2.5]$	$[2.5, 3.2]$	$[M(K_SK_L)_{\mathrm{th}}, 1.1]$	$[1.1, 2.0]$
Resolution	1 MeV(unfolding)	4 MeV	7 MeV	8 MeV	13 MeV	1 MeV(unfolding)	10 MeV

- Cross section measurement in each $M(K\bar{K})$ interval

$$d\sigma(K^+K^-)/dM(K^+K^-) = \frac{dN_{\mathrm{sig}}/dM(K^+K^-)}{\epsilon \cdot d\mathcal{L}_{\mathrm{int}}/dM(K^+K^-)} \qquad \frac{d\mathcal{L}_{\mathrm{int}}}{dM(K^+K^-)} = w(s,x) \cdot \mathcal{L}_{\mathrm{int}}$$

- Branching fraction measurement of $J/\psi \to K\bar{K}$
  - Cross section for ISR production of a narrow resonance (vector meson V), such as J/ψ, decaying in the final state f can be calculated by:

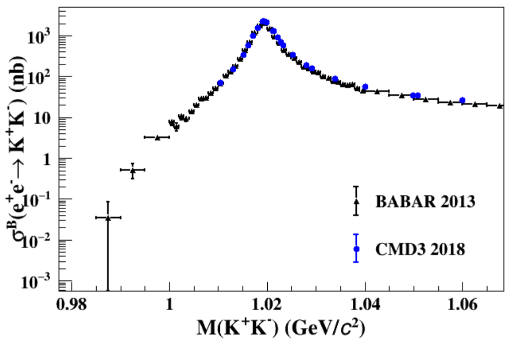
$$\sigma(s) = \frac{12\pi^2\Gamma(V \to e^+e^-)\mathcal{B}(V \to f)}{m_V s} W(s, x_0) \boxed{= \frac{N_{J/\psi}}{\varepsilon \cdot \mathcal{L}} \quad \text{Experimentally}}$$

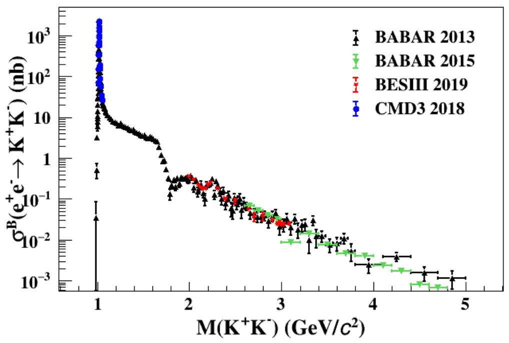
Mod. Phys. Lett. A 14, 2605(1999)

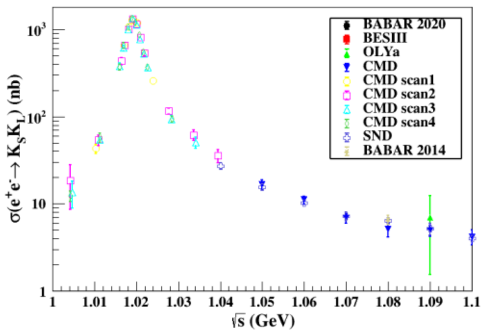
$K\bar{K}$ cross section

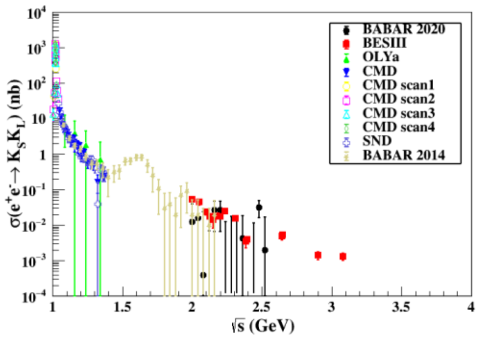
- Accuracy can be obtained at BESIII with 20 fb^{-1} datasets at $\psi(3770)$ and 10 fb^{-1} datasets at XYZ region

Strategy	ISR Method(%)	Energy Scan Method(%)	ISR Method(%)
$e^+e^- \to K^+K^-$	Most accuracy results(statistical uncertainty only)		BESIII expected
Around ϕ peak	1.4 BABAR	0.3 CMD-3	1.0
$1.2-2.0$ GeV	2.2 BABAR		1.5
$2.0-3.2$ GeV	10.0 BABAR	0.9 BESIII	4.5
$e^+e^- \to K_SK_L$	Most accuracy results(statistical uncertainty only)		BESIII expected
Around ϕ peak	2.2 BABAR	1.7 CMD-3	1.2
$1.2-2.0$ GeV	14.0 BABAR		8.2









Summary

- Measurements of $e^+e^- \to K\overline{K}$ cross section via Initial State Radiation method are performed at BESIII with the large datasets(20 fb^{-1} datasets at $\psi(3770)$ and 10 fb^{-1} datasets at XYZ region)
  - $e^+e^- \to K^+K^-$ with a tagged ISR photon
  - $e^+e^- \to K^+K^-$ with an untagged ISR photon
  - $e^+e^- \to K_S K_L$ with a tagged ISR photon
- High precision results will be obtained
- More results will come soon …

Thank you !