Measurement of kaon FF via initial state radiation

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Workshop on Radiative Corrections and Monte Carlo Simulations at Electron-Positron Colliders

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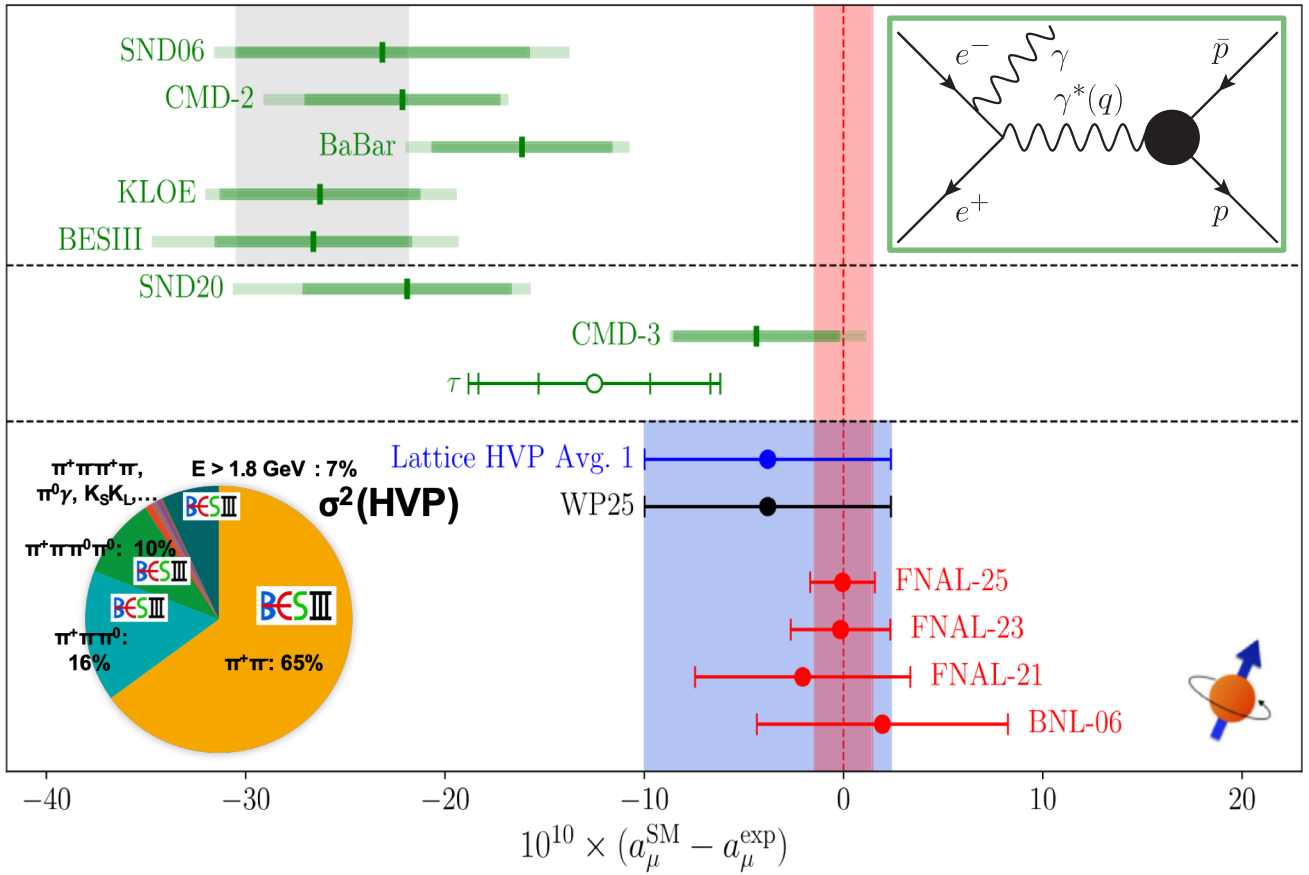
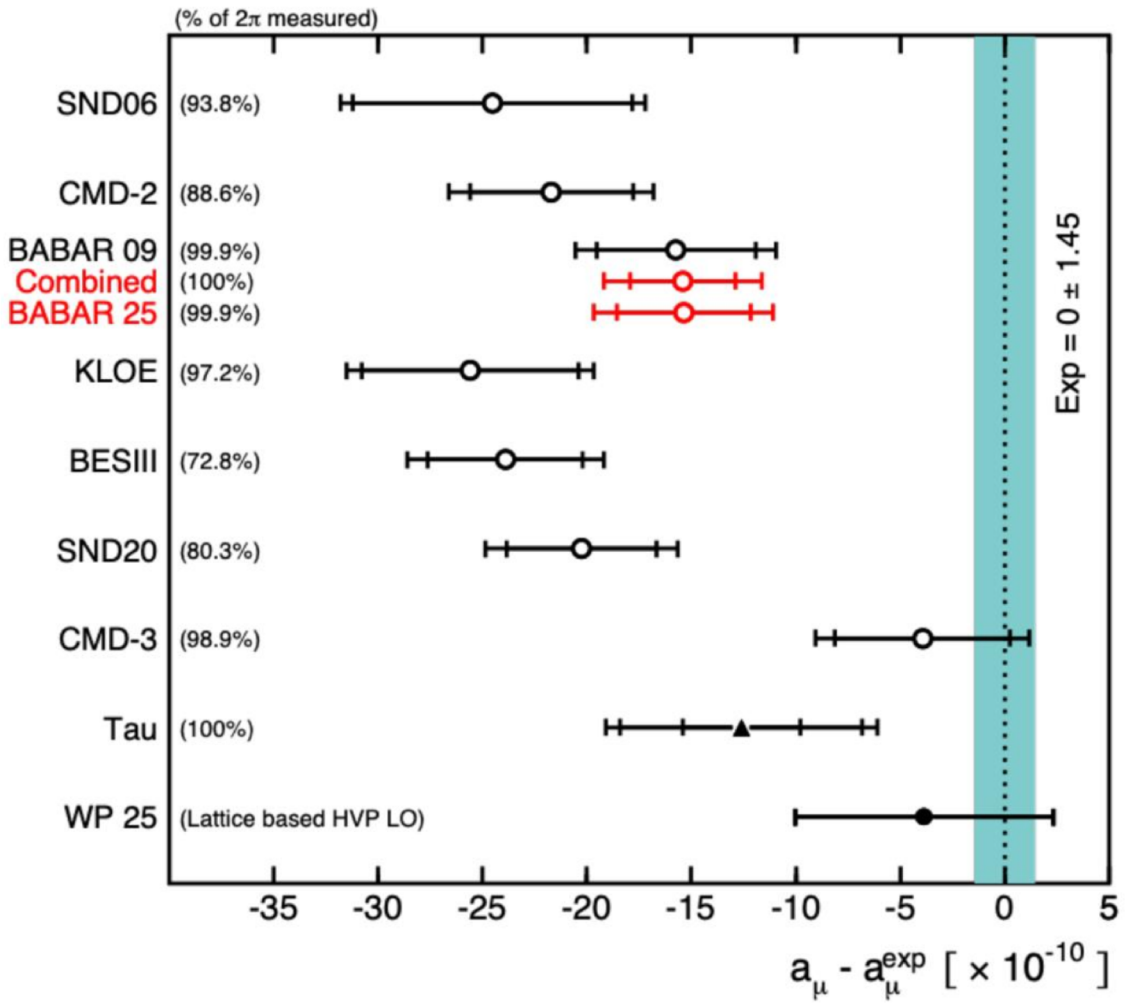
Muon anomaly puzzle



- Experimental measurements are consistent with each other and achieve to a precision of 127 ppb
- Lattice QCD calculation is consistent with the experimental result
- Most Data-driven calculations are lower than exp. and do not converge
- CMD-3 result is higher than the others

Systematic under-estimation in previous data-driven methods?

Muon anomaly puzzle



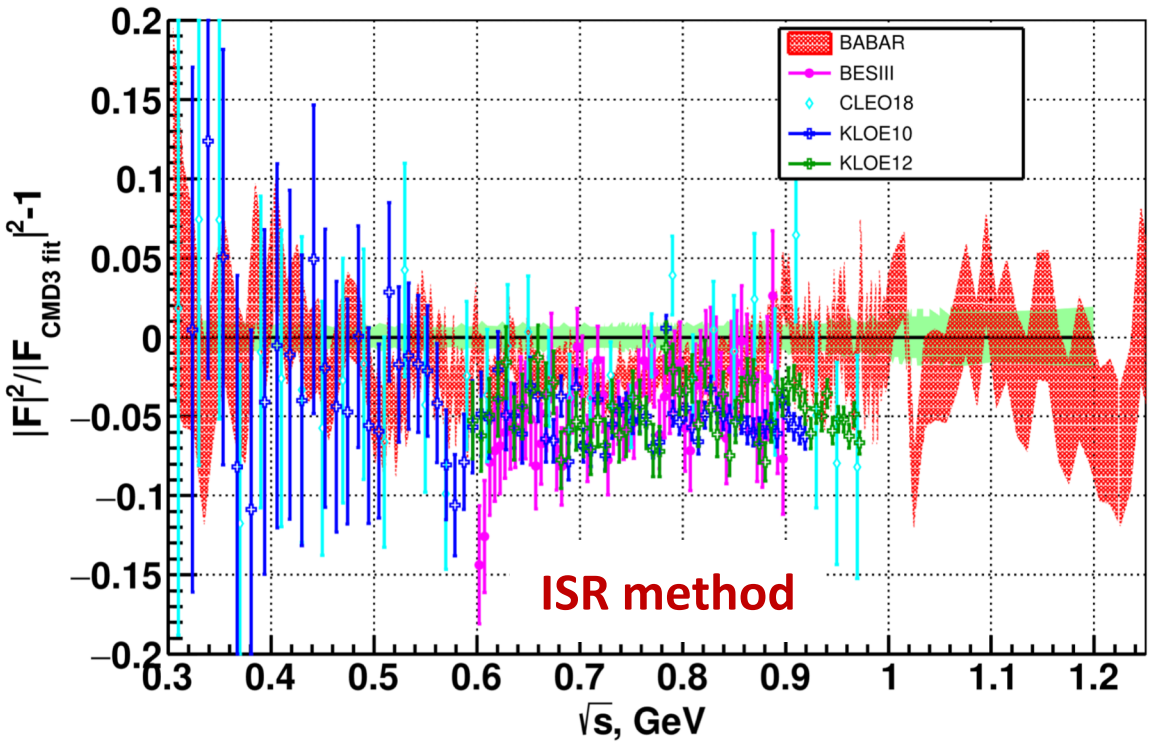
CMD-3 result [PRD **109**, 112002 (2024)]:

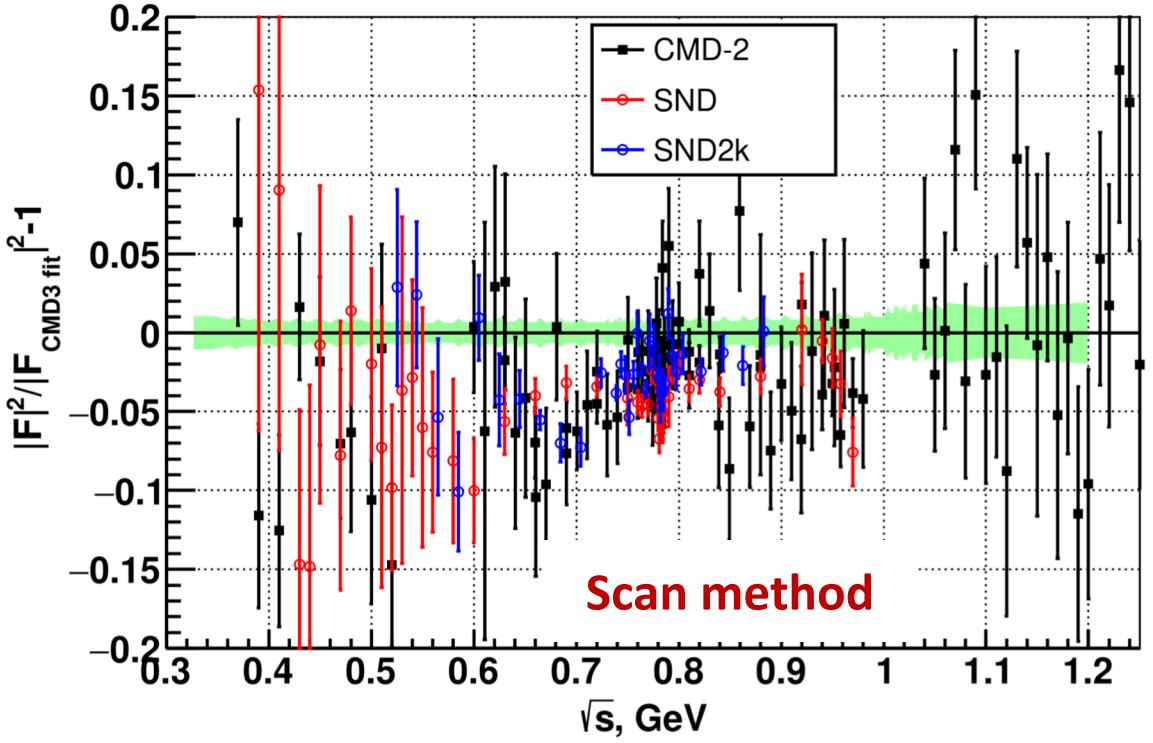
- Energy-scan measurement
- 0.7~0.9% precision
- Validated by QED with the $\mu^+\mu^-$ process

Puzzling picture:

- CMD-3 result is higher than the others
- BaBar gives consistent result with a completely different method

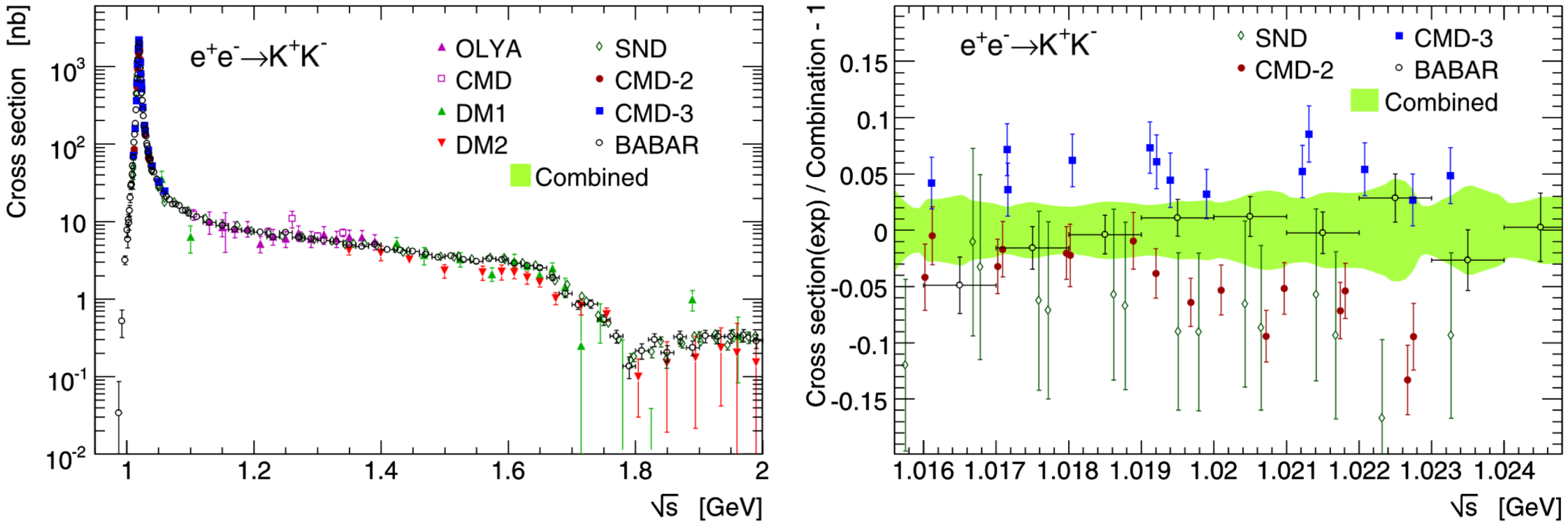
Muon anomaly puzzle: $\pi^+\pi^-$ channel





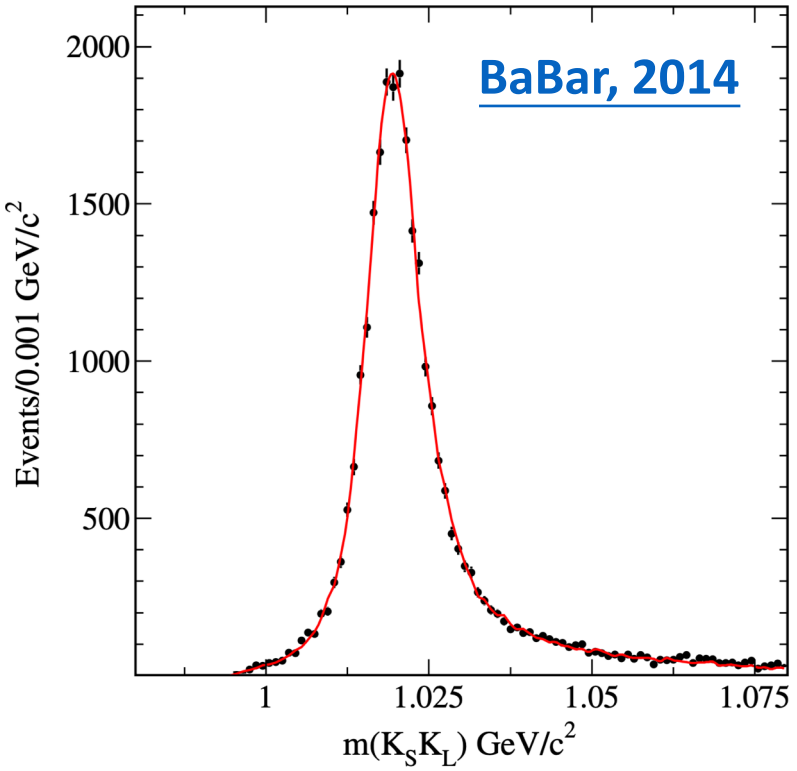
- Common and flat disagreement around $\rho(770)$
- Consistency at higher and lower energy regions

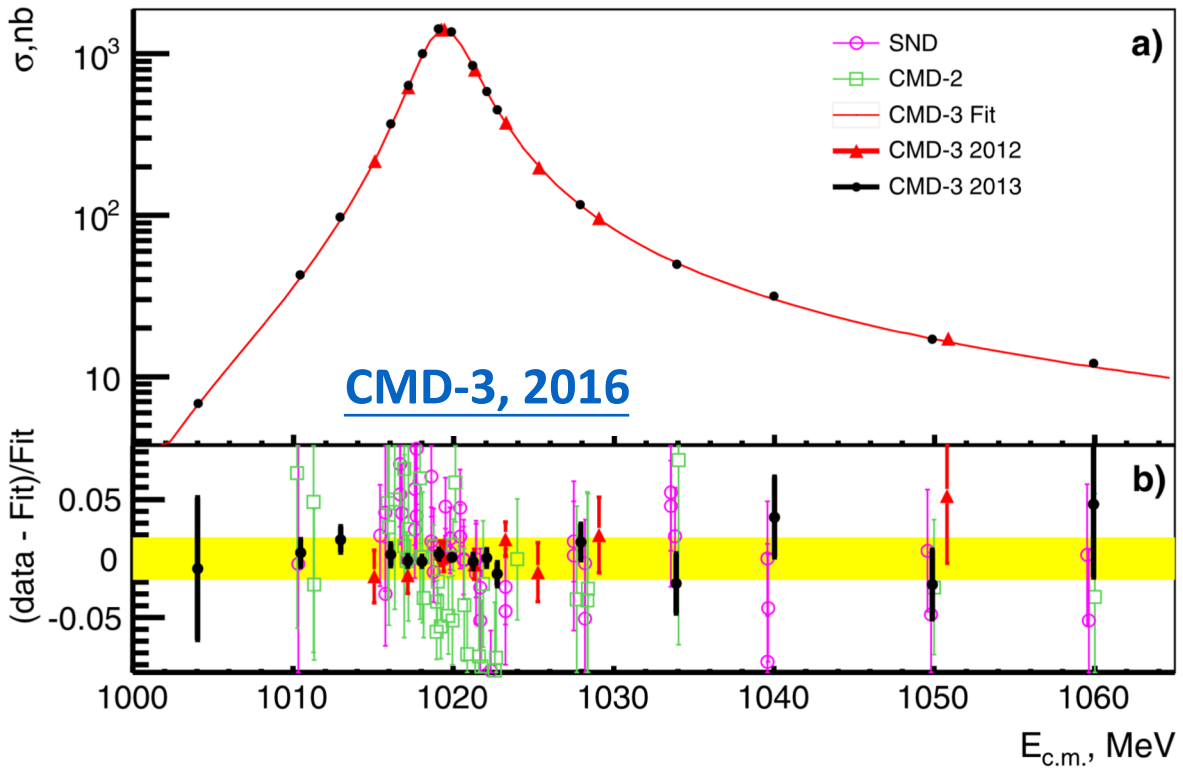
Muon anomaly puzzle: K^+K^- channel



- Global relative deviations are also observed in K^+K^- channel
- Similar difference between CMD-3 and CMD-2/SND

Muon anomaly puzzle: $K_S^0 K_L^0$ channel

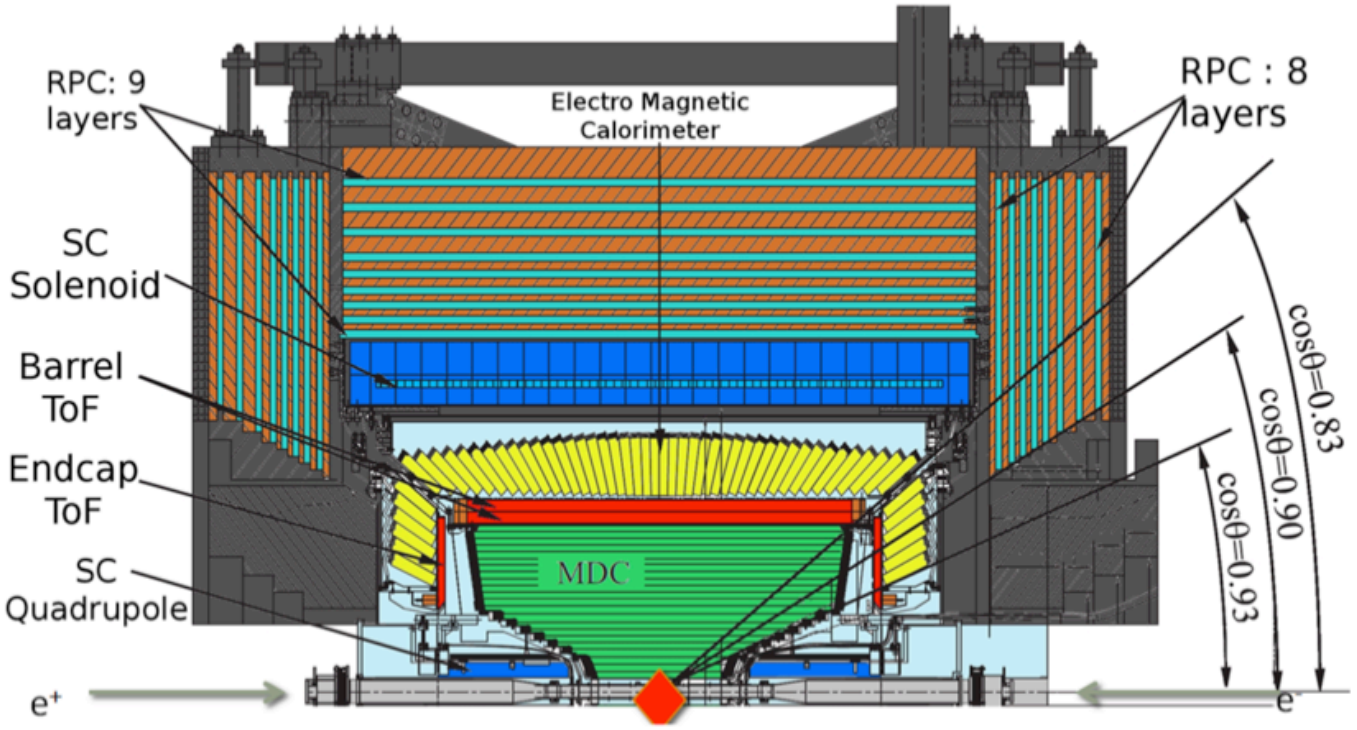




- BaBar did not report the bin-by-bin cross sections for $\phi \to K_S^0 K_L^0$
- No global deviation is observed in $K_S^0 K_L^0$ channel measured with scan method

BESIII could contribute based on the 20 fb^{-1} $\psi(3773)$ data

BESIII experiment



- Multilayer drift chamber: $\sigma_{r\phi} \sim 130\ \mu m$ (single wire), $\sigma_{p_t}/p_t \sim 0.5\%$@ $1\ \mathrm{GeV}/c$
- Time-of-Flight system: $\sigma_t \sim 68$ ps (barrel), $\sigma_t \sim 110 \rightarrow 65$ ps (end-cap)
- Electromagnetic calorimeter: $\sigma_E/E < 2.5\%$ (barrel), $\sigma_E/E < 5.0\%$ (end-cap) at 1 GeV
- Resistive plate chamber Muon counter: $\Delta\Omega/4\pi = 93\%$

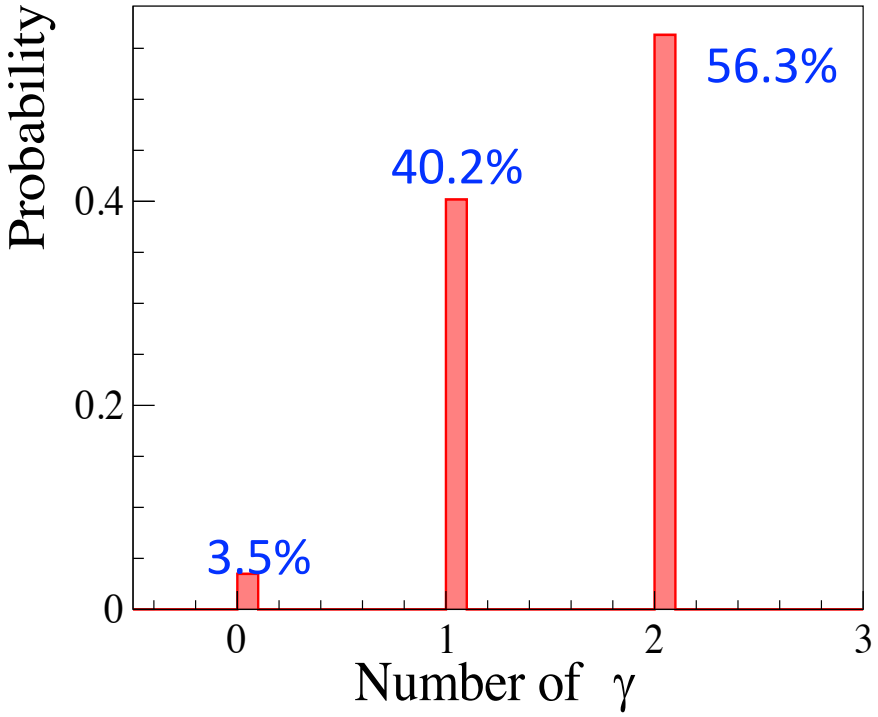
✓ Symmetric electron-positron beams with c.m. energy between 1.84~4.95 GeV

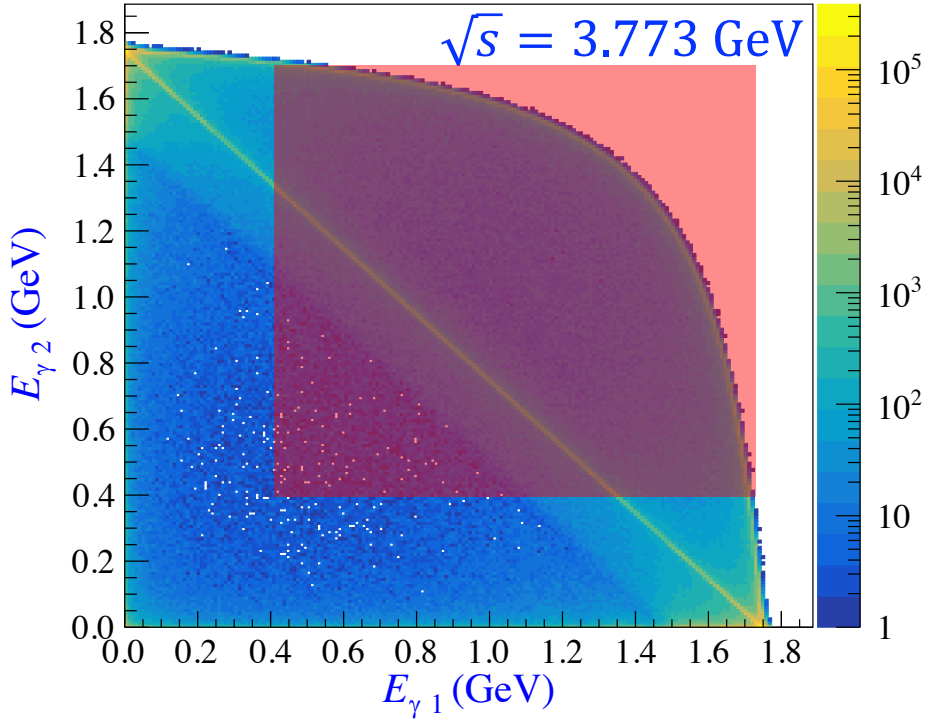
✓ Maximum luminosity reaches $1.1\times10^{33}\ \mathrm{cm^{-2}s^{-1}}$ at $\psi(3773)$ peak, $20\ \mathrm{fb^{-1}}$ in total

Signal simulation model: K^+K^- channel

PHOKHARA is used with following configuration:

- ✓ `Scanmode = 1`
- ✓ `NLO = 1`
- ✓ `FSR = 0`
- ✓ `VP = 1`
- ✓ Updated Kaon form factor



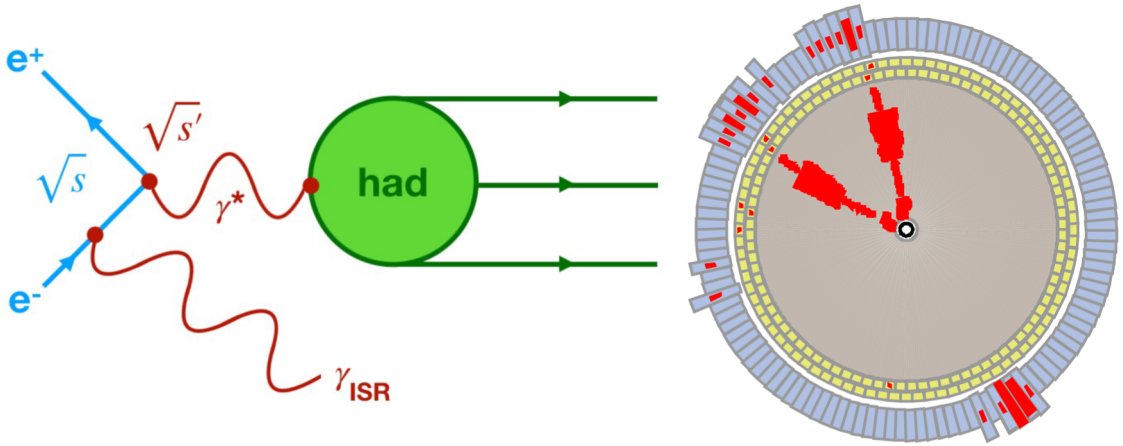


- Interference between ISR and FSR is currently not working in Phokhara for Kaon mode
- 56.3% events with two photons, two energetic photons are highly possible (~14%)

Analysis strategy: tagged K^+K^- channel

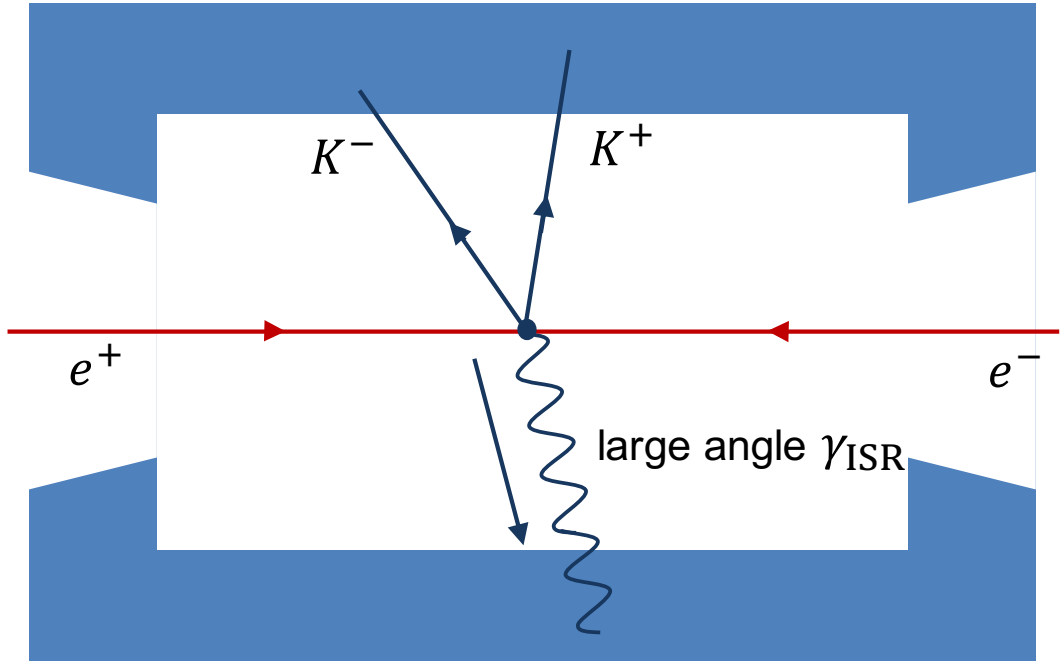
ISR photon

- At least one shower with $E_\gamma > 0.4$ GeV in electromagnetic calorimeter
- The most energetic photon is regarded as the ISR photon



Good charged tracks

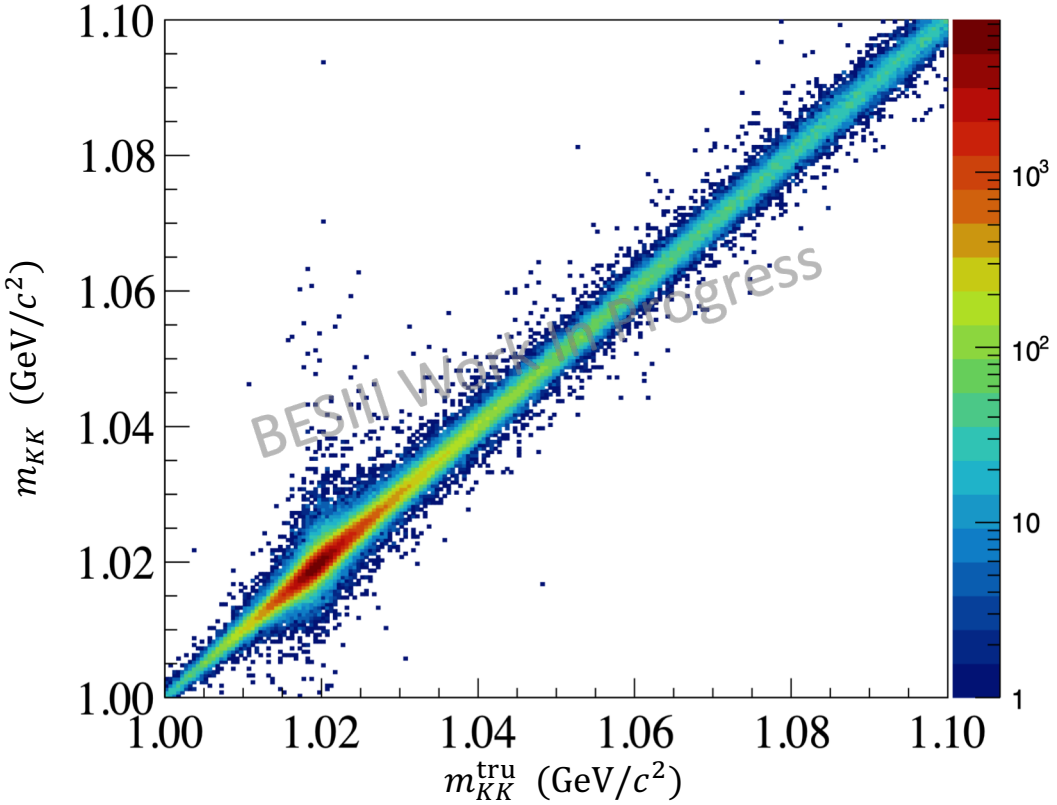
- $N(K^+) = N(K^-) = 1$
- Vertex fit with the two Kaon tracks

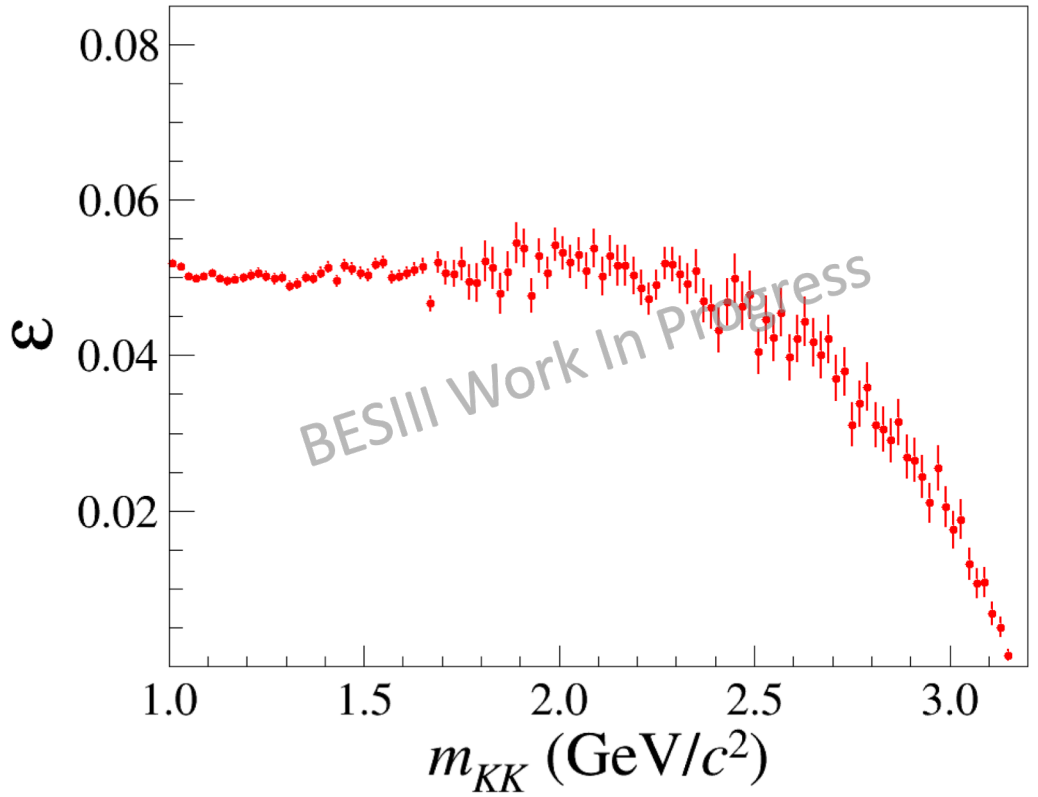


Kinematic fit

- 4C kinematic fit with two Kaon and the tagged ISR photon by requiring energy-momentum conservation

Corrections via signal MC : tagged K^+K^- channel





- Unfolding is required around $\phi(1020)$ to cancel migration effects among m_{KK} bins
- Efficiency correction is applied in each m_{KK} bin after unfolding

Systematic uncertainties caused by signal MC

- With $20\ \mathrm{fb}^{-1}$ $\psi(3773)$ data and a bin-width of $1.0\ \mathrm{MeV}$, the statistical uncertainty around $\phi(1020)$ peak is expected to be $\mathbf{0.7\sim0.8\%}$
- After applying various corrections accounting for the data-MC difference, the total systematic uncertainty is about $\mathbf{1.0\%}$, dominated by 4C kinematic fit and radiator function
- The 4C fit is applied with $\gamma_{\mathrm{ISR}}K^+K^-$ -- events with one or more additional energetic ISR photons will be rejected (results in an uncertainty of $\sim\mathbf{0.6\%}$)
- Uncertainty from unaccounted higher order ISR is estimated as $\mathbf{0.5\%}$

Simulation model with accurate fractions of LO and NLO ISR events, and with even the NNLO ISR events included is desired

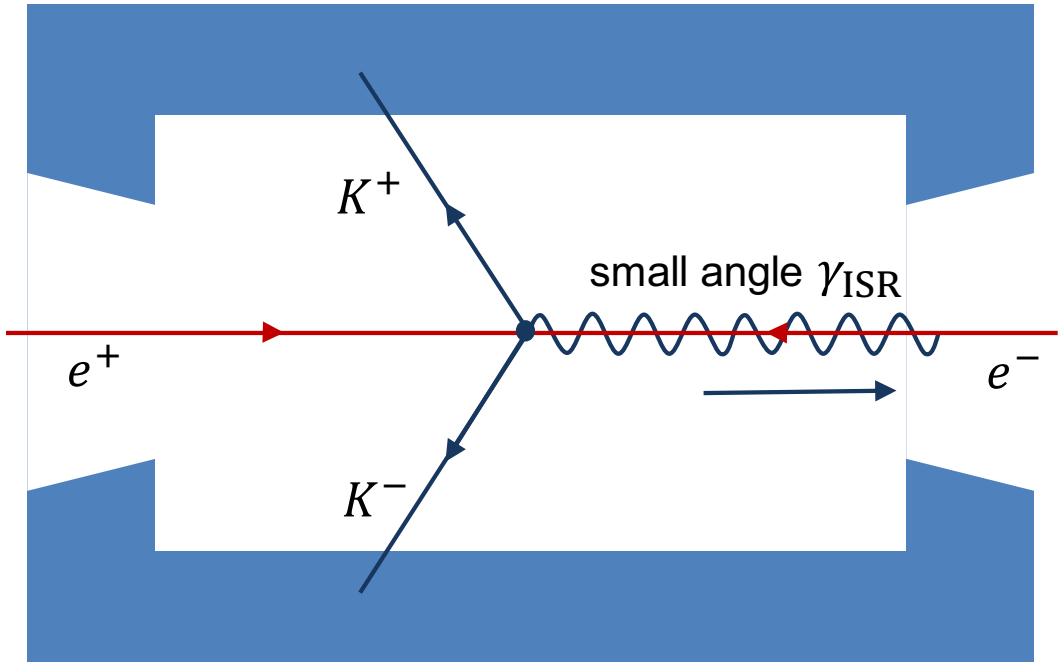
Analysis strategy: untagged K^+K^- channel

Good charged tracks

- $N(K^+) = N(K^-) = 1$
- Vertex fit with the two Kaon tracks

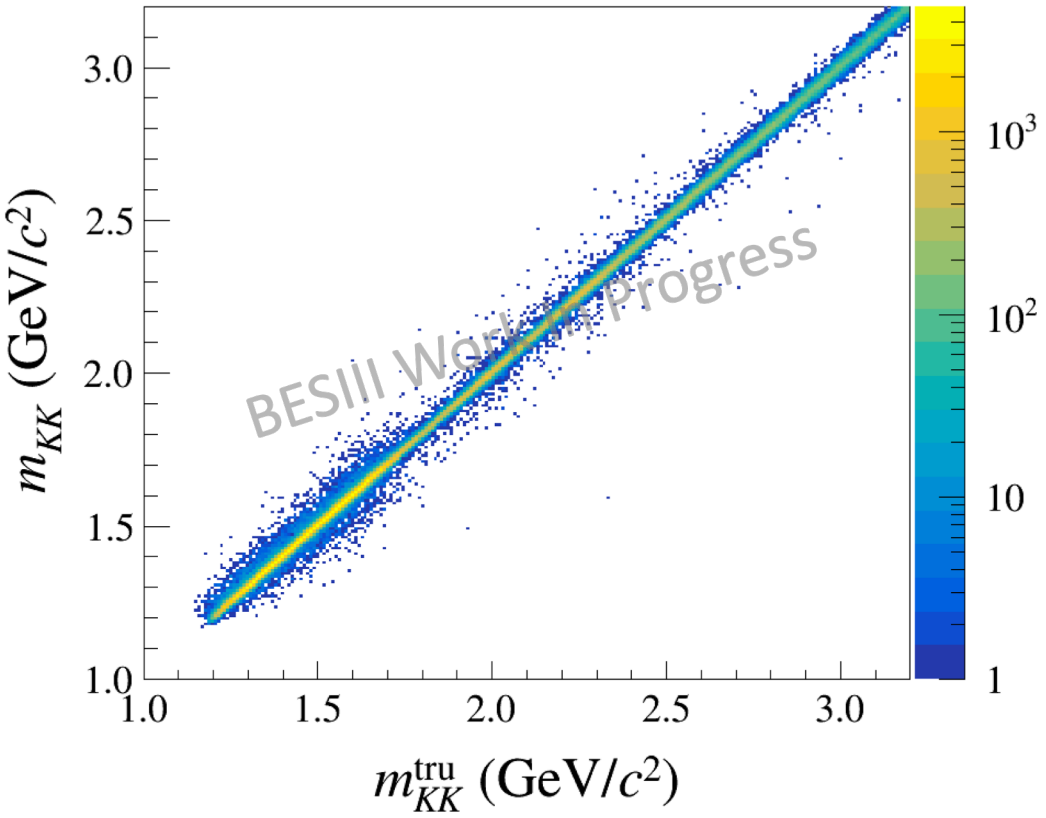
Signal extraction

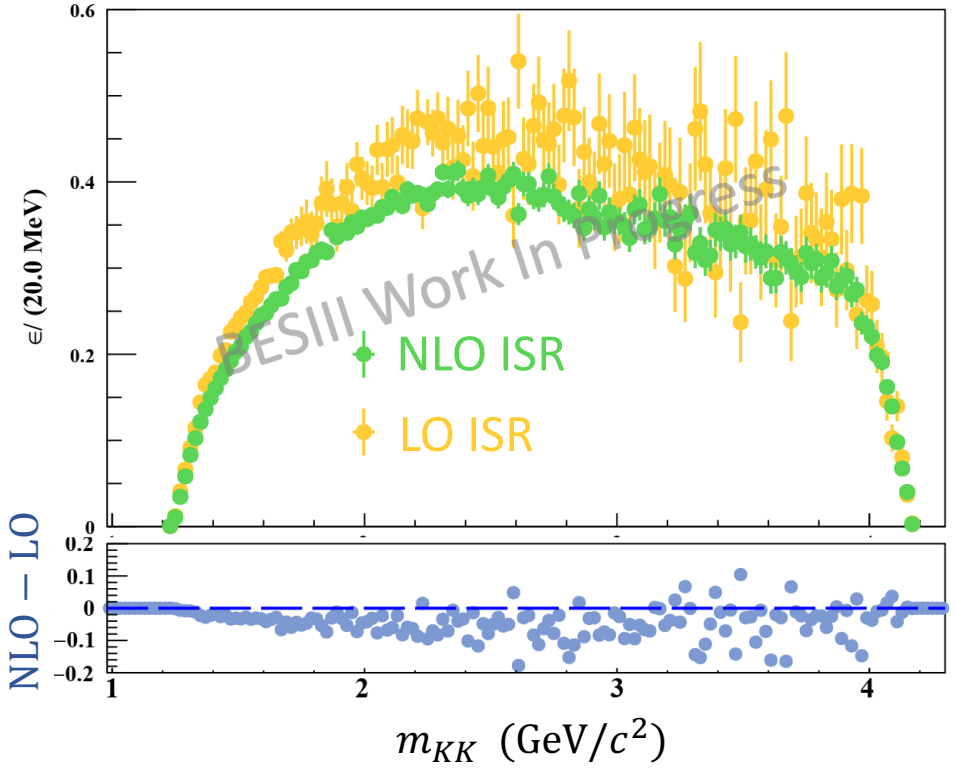
- A missing ISR photon is implied by requiring $|\cos\theta_{miss}| > 0.99$ where $P_{\rm miss} = P_{\rm c.m.} - P_{K^+} - P_{K^-} = (E_{\rm miss}, \vec{p}_{\rm miss})$
- Signal extracted by requiring $U_{\rm miss} = E_{\rm miss} - p_{\rm miss} \in [-0.1, 0.1]$ GeV



$\phi(1020)$ peak is no longer accessible due to the missing of an energetic ISR photon

Corrections via signal MC : untagged K^+K^- channel

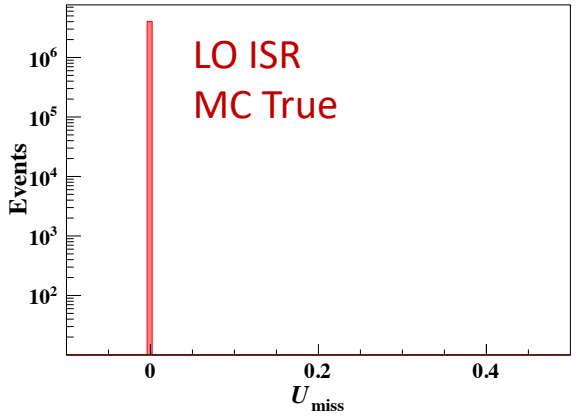


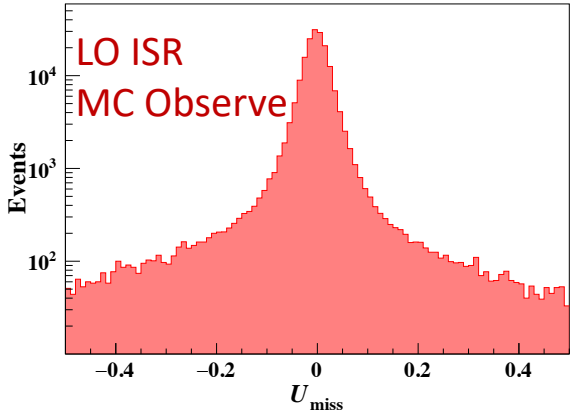


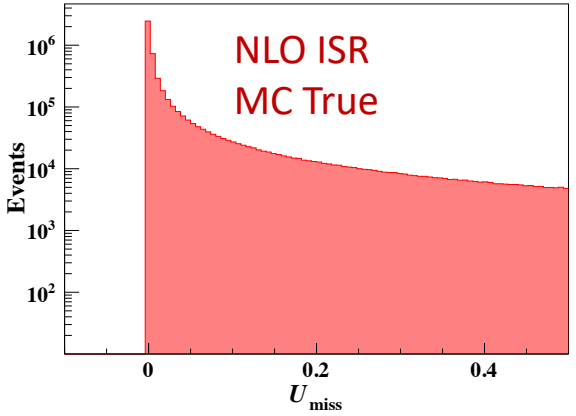
- Unfolding is necessary at lower m_{KK} bins to cancel migration effects
- With strict requirement on U_{miss}, a fraction of NLO ISR events are lost

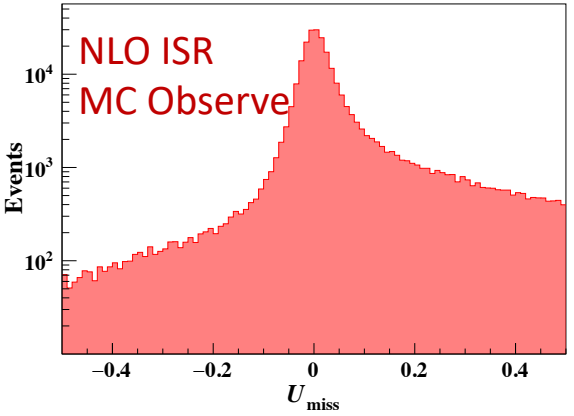
Systematic uncertainties caused by signal MC

- For the LO ISR events, U_{miss} peaks at 0 which corresponds to the mass of ISR photon. A symmetric requirement on U_{miss} reserves more than 90% LO small angle ISR events.
- For the NLO ISR events, U_{miss} could be significantly larger than 0 -- this directly affects the detection efficiency
- Again, uncertainty from unaccounted higher order ISR also contributes









Signal simulation model: $K_S^0 K_L^0$ channel

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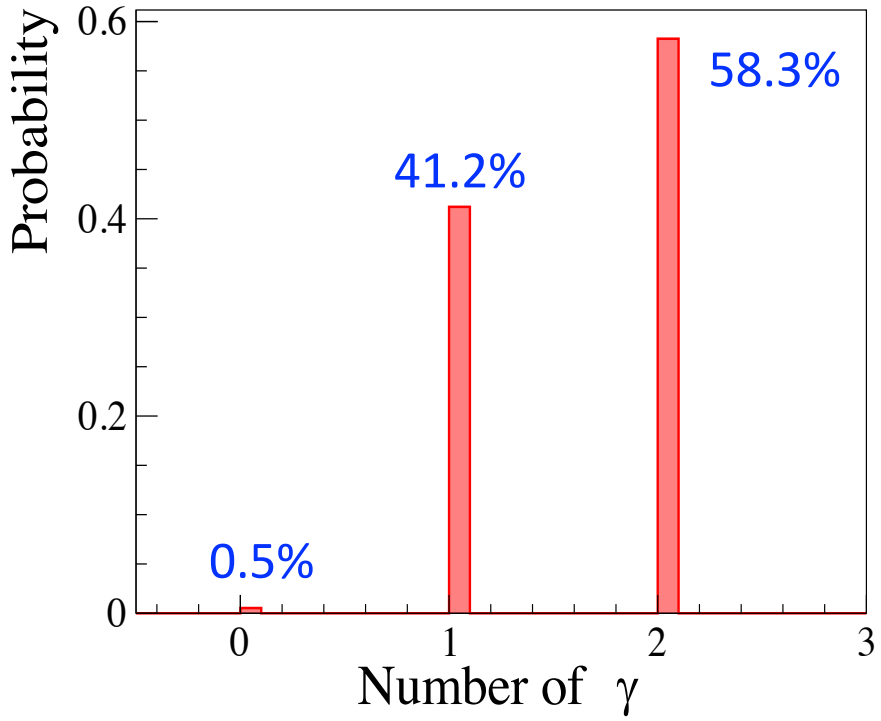

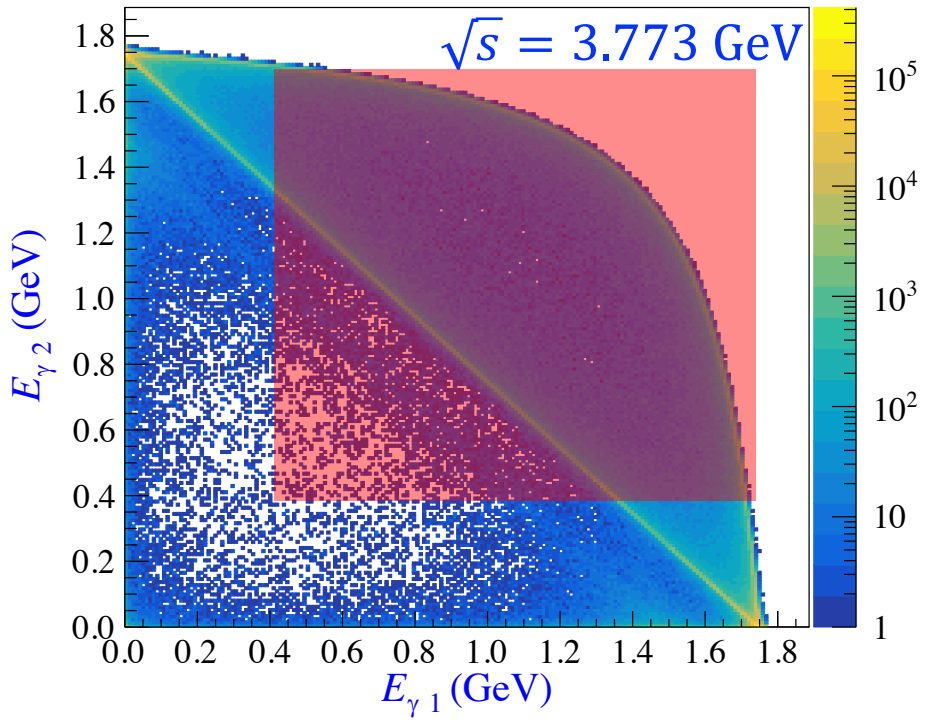

- ISR photons are simulated within Phokhara, while FSR of pions with PHOTOS
- 58.3% events with two ISR photons, where two energetic photons are possible (14%)

Analysis strategy: tagged $K_S^0 K_L^0$ channel

ISR photon

- At least one shower with $E_\gamma > 0.4$ GeV in electromagnetic calorimeter
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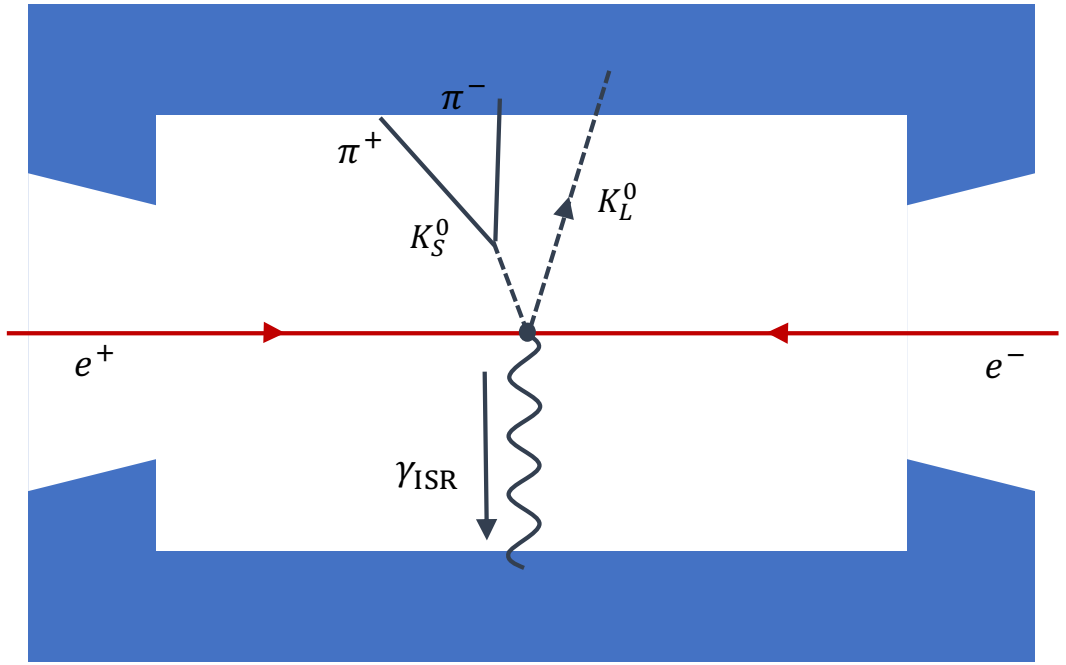


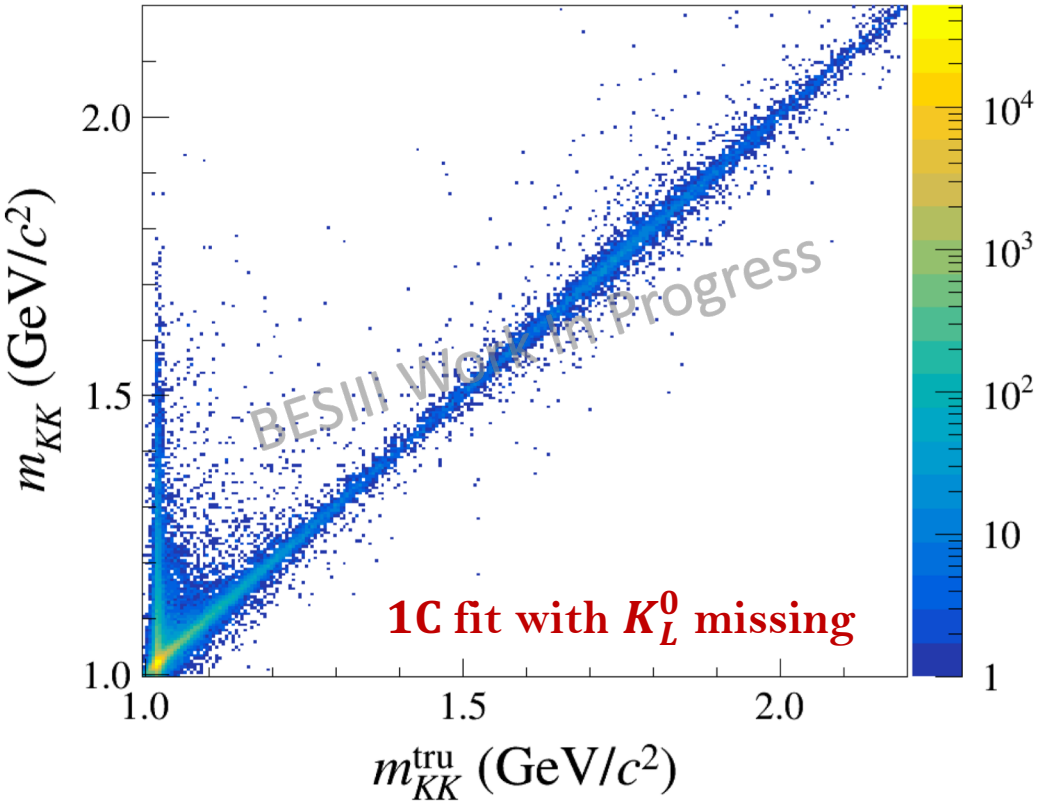
Good charged tracks

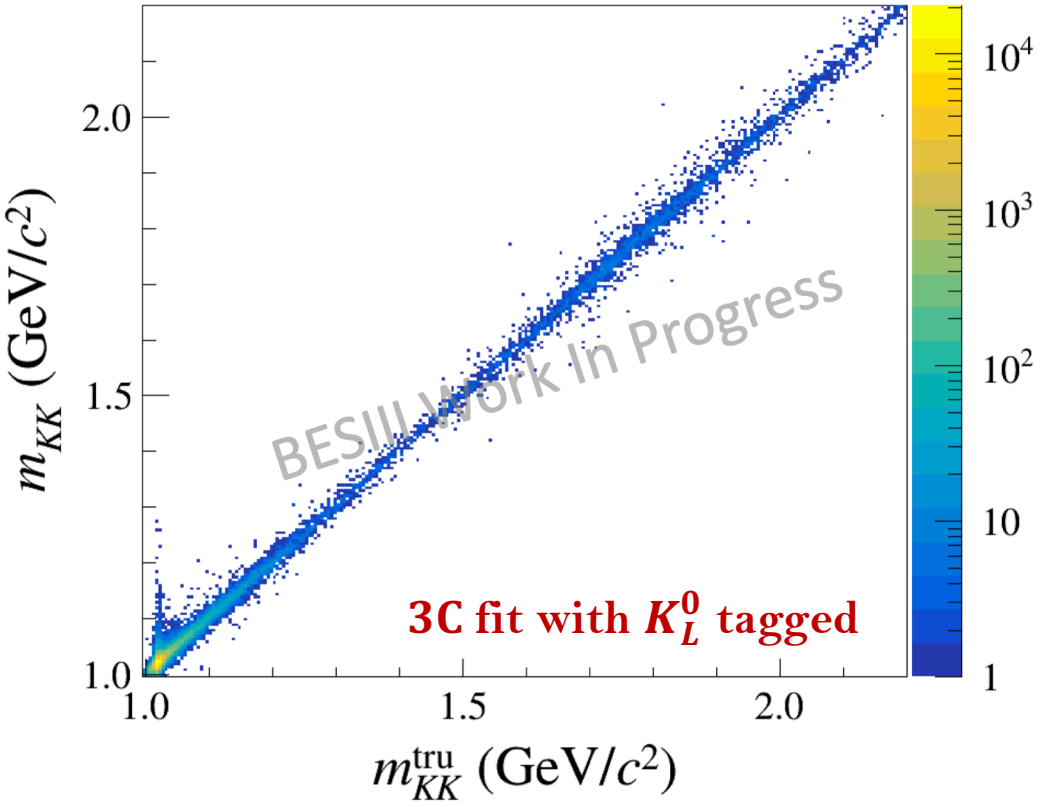
- $N(\pi^+) = N(\pi^-) = 1$
- Secondary vertex fit with $K_S^0 \to \pi^+\pi^-$

Kinematic fit

- 1C kinematic fit with K_L^0 missing to reserve sufficient statistics around $\phi(1020)$
- 3C kinematic fit with direction of K_L^0 tagged to suppress background above $\phi(1020)$

Corrections via signal MC : tagged $K_S^0 K_L^0$ channel

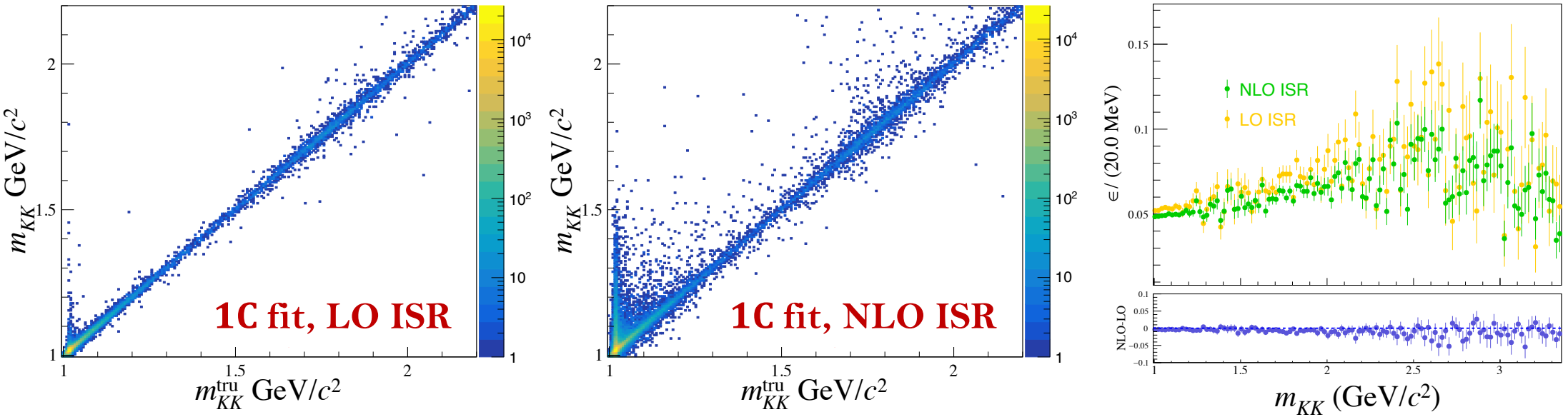




- Significant event migrations around $\phi(1020)$ with the K_L^0 missing
- Roughly 50% signal events will be lost with direction of K_L^0 tagged in EMC
- An unfolding is necessary around $\phi(1020)$

Systematic uncertainties caused by signal MC

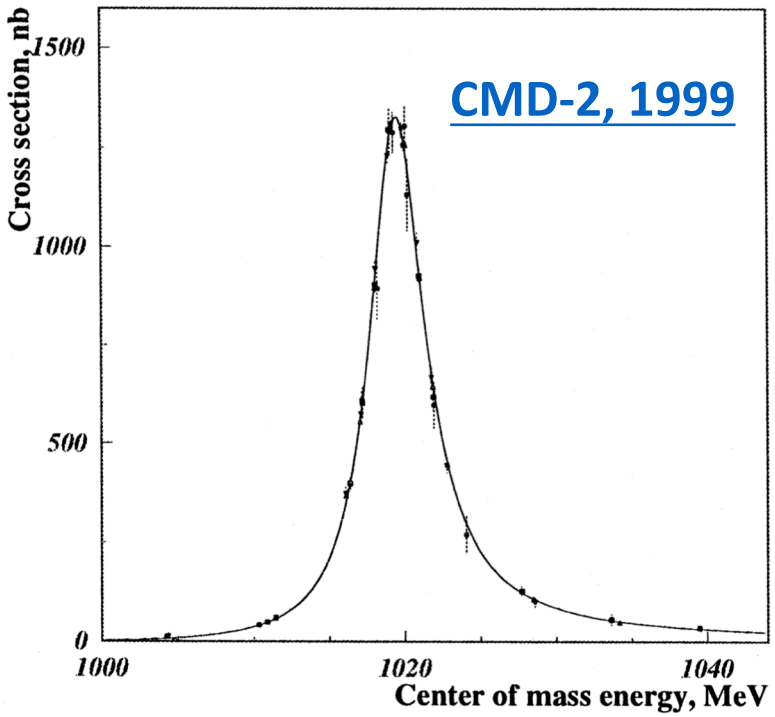
- Due to the different masses of ISR photon and K_L^0, the additional ISR photon will decrease the efficiency of the 1C kinematic fit
- The 3C Kinematic fit is applied with the $\gamma_{\rm ISR}K_S^0K_L^0$ combination, the additional energetic ISR photon will affect the identification of K_L^0

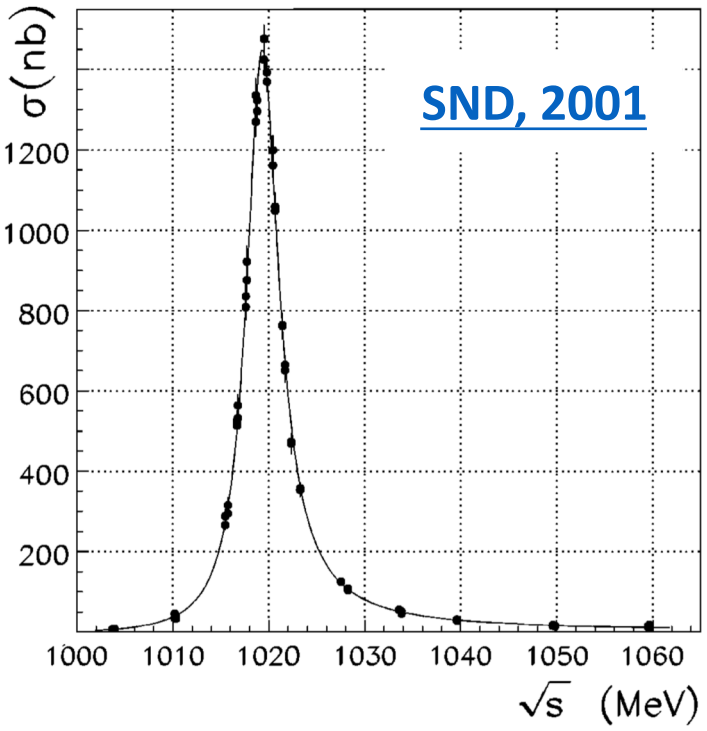


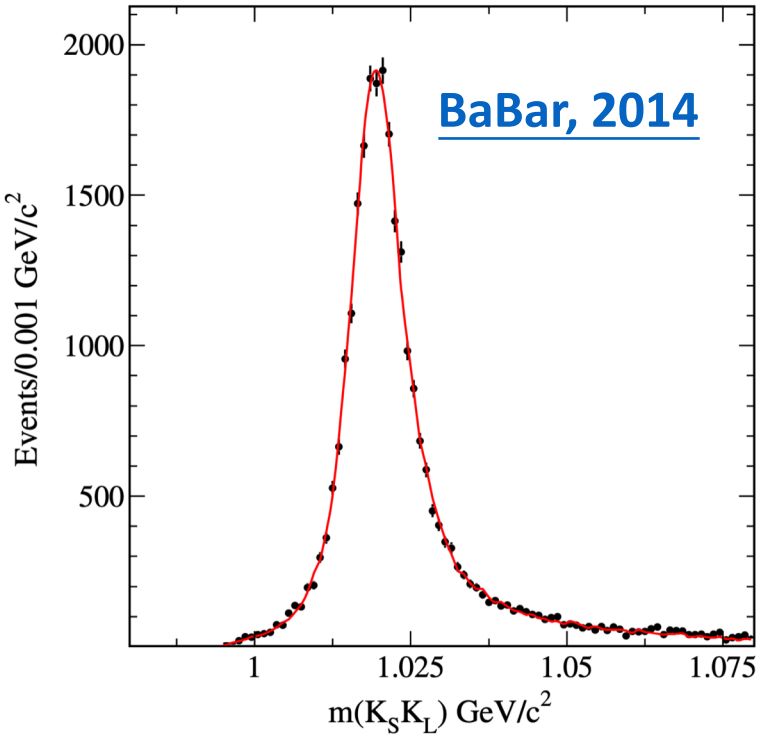
Summary

- Measurement of $e^+e^- \to \gamma_{\rm ISR}K^+K^-$ and $\gamma_{\rm ISR}K_S^0K_L^0$ will definitely contribute to improve our understanding of the muon anomaly
- Using the PHOKHARA model, BESIII has the opportunity to measure these two processes with different methods and high precision
- Since the kinematic fits, such as 4C, 1C, and 3C fits, are necessary to extract signals, a signal simulation model beyond NLO radiative correction is desired, especially for tagged $e^+e^- \to \gamma_{ISR}K^+K^-$ analysis

Muon anomaly puzzle: $K_S^0 K_L^0$ channel

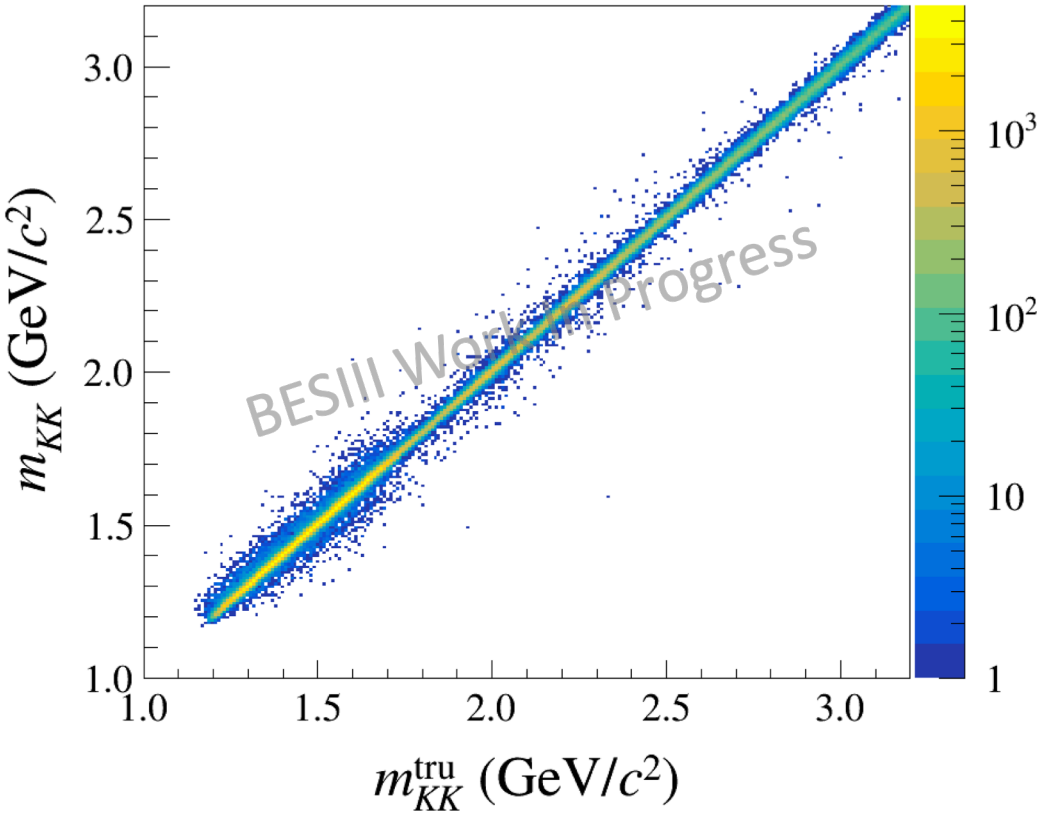


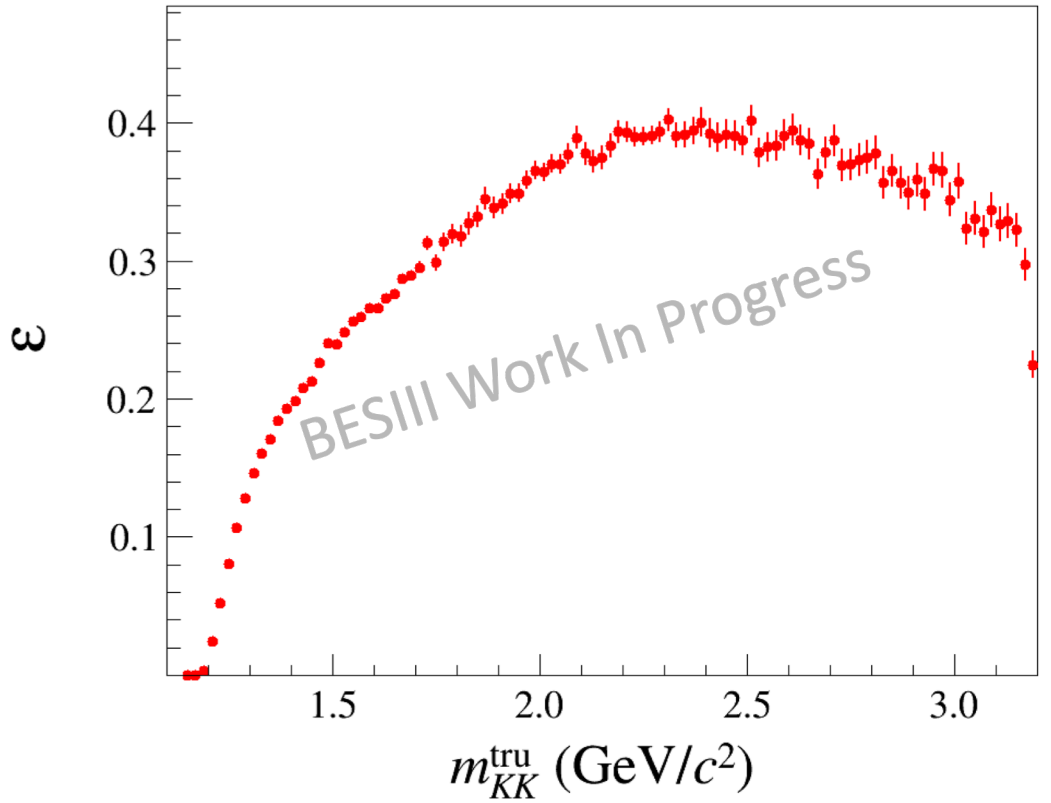




- Global relative deviations are also observed in K^+K^- channel
- Similar difference between CMD-3 and CMD-2/SND
- BESIII could contribute based on the foreseen $\psi(3773)$ data

Corrections via signal MC : untagged K^+K^- channel





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