中国科学技术大学
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Cross Section Measurements of $e^+e^- \to K^+K^-$ via tagged ISR technique and study of Bose-Einstein correlations by $\pi^0\pi^0$ pairs at BESIII

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Thesis proposal report
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- **Cross Section Measurements of $e^+e^- \rightarrow K^+K^-$ via tagged ISR technique**
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  - Motivation
  - Analysis Strategy
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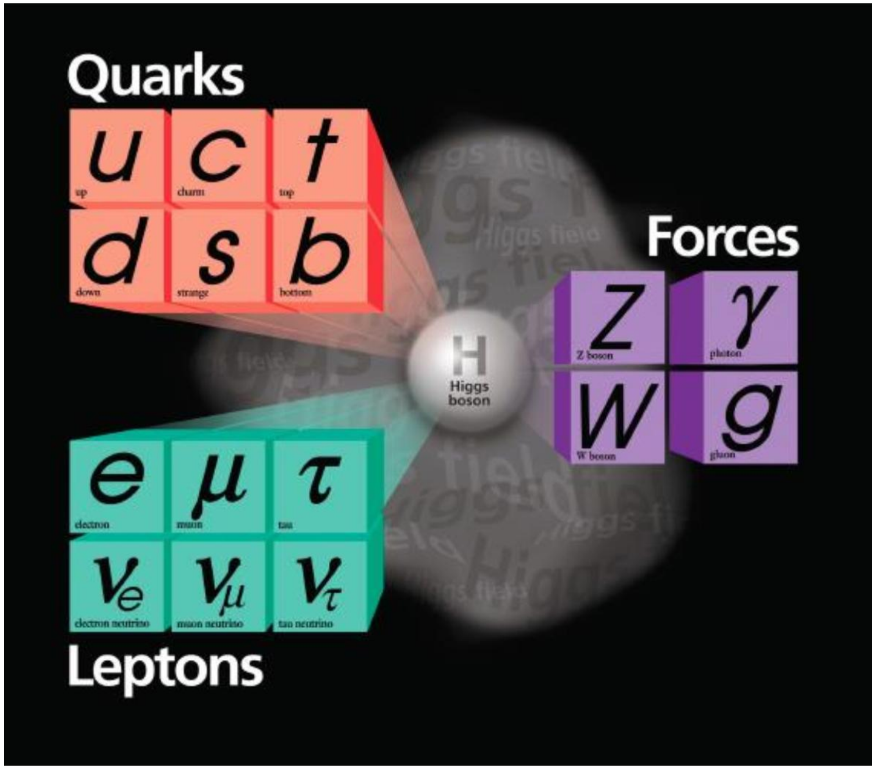
- **Summary and prospect**

Introduction

Overview

- Standard Model (SM):
  - ✓ Describes the fundamental particles that make up the visible world of matter and how they interact with each other.

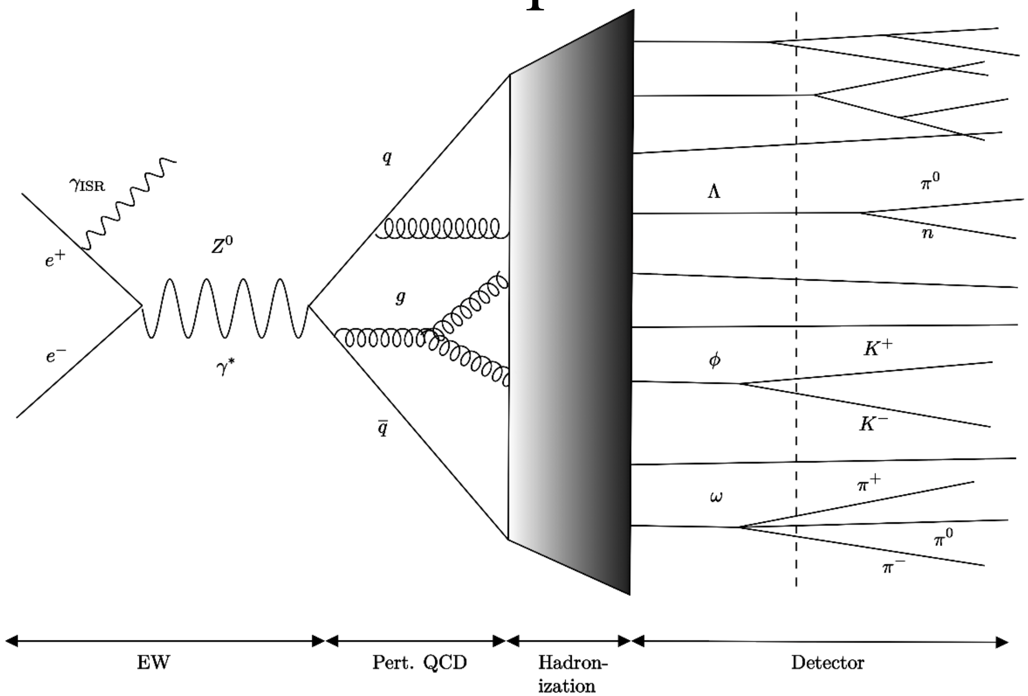


- Strong interaction is an important and secret part in SM
  - Non-point like structure of hadrons
  - Calculate non-perturbatively in low Q^2
  - Picture of production lacks clarity.

Experimental study attaches great importance in strong interaction study!

Overview

- Process of hadron production:



- ☐ QED process (e^+e^- annihilation, ISR process, etc)
- ☐ Parton evolution in pQCD
- ☐ Non-pQCD hardronization, formation of hadron source
- ☐ Production of final hadrons

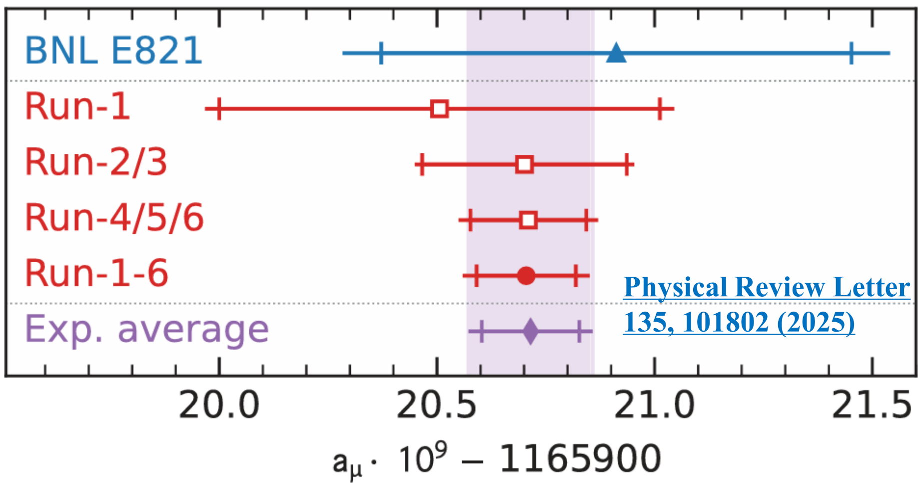
- The hadron source structure:
  - ☐ No reliable theoretical predictions in this field.
  - ☐ Bose-Einstein correlations : probe hadron source

- Final hadron production for low energy process:
  - ☐ Cross section measurement (muon anomaly a_μ and hardronic spectrum)
  - ☐ Electromagnetic form factor
  - ☐ Fragmentation Function.

Muon anomaly

➢ Measurement of muon anomaly (a_μ)

- Precise experimental and theoretical value of a_μ: stringent test of the SM.
- High precision experimental value (a_μ^{exp}) by Brookhaven National Lab (NML) and Fermilab(FNAL)≅ $2 \times 10^{-5}\%$
- Precision of theoretical calculations (a_μ^{SM}) ≅ $5 \times 10^{-5}\%$



Physical Review Letter 135, 101802 (2025)

- $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{Had}\ (a_\mu^{HVP} + a_\mu^{LBL}\ )$

Item	Method	a_μ^{SM} portion	δa_μ^{SM} portion
a_μ^{QED}	perturbative	~99.99%	~0.001%
a_μ^{EW}	Perturbative	~1ppm	~0.2%
a_μ^{HVP}	Non-perturbative	~59ppm	~84%
a_μ^{LBL}	Non-perturbative	~1ppm	~16%

- a_μ^{HVP} is the largest contributor to δa_μ^{SM}
- Two methods are used:
  - Data driven, dispersive approach
  - A first-principle, lattice-QCD

Muon anomaly

➢ Tension between a_μ^{exp} and a_μ^{SM}

? How to calculate a_μ^{HVP} by data driven

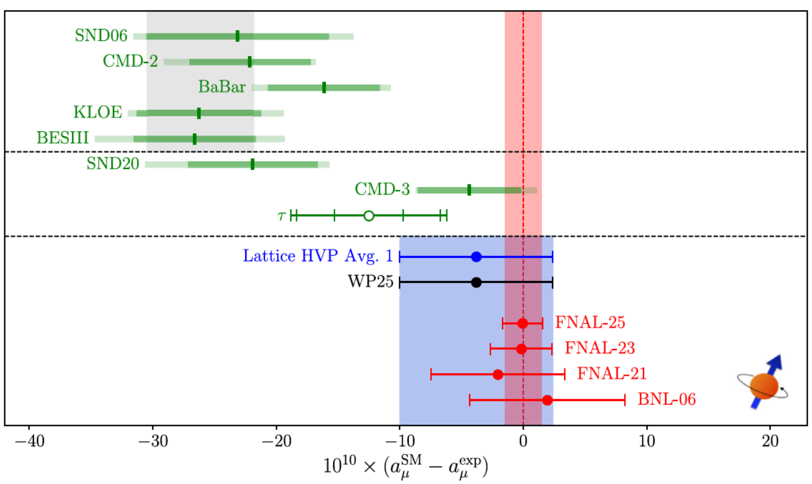
$$a_\mu^{HVP,LO} = \frac{\alpha^2}{3\pi^2}\int_{m_\pi^2}^{+\infty}\frac{ds}{s}R(s)K(s)$$

$R(s) = \frac{\sigma_{had}(s)}{4\pi\alpha^2/(3s)}$ is the hadronic R ratio

✓ Precise measured data required !

I. $\lesssim$ 2 GeV: exclusive final states (2π, 3π, 4π, $2K$…)
II. Largest contributor: 2π
III. $\gtrsim$ 2 GeV: inclusive measurement

- Prediction given by LQCD shows consistency with the experimental value.
- **5.8 σ** tension between data driven prediction (excluding CMD3 results) and a_μ^{exp}
- Results by CMD3 larger than others' and consistent with a_μ^{exp} caused by the 2π contribution



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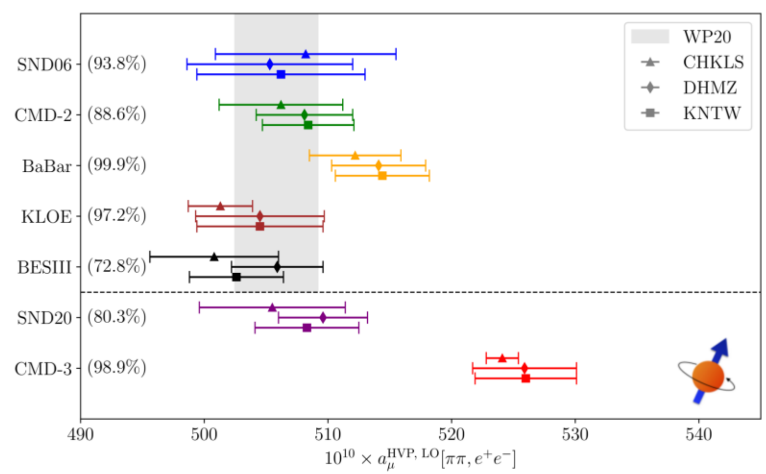


Muon anomaly

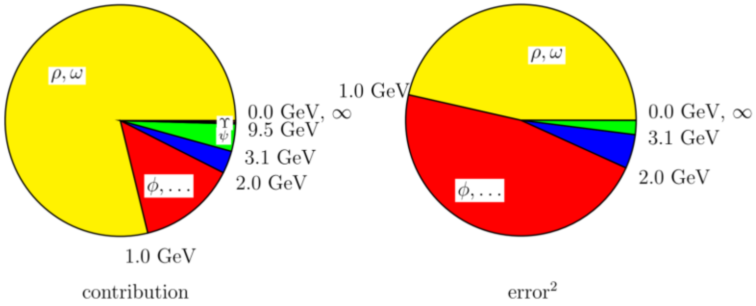
➢ BESIII contribution to HVP

✓ Published measurements:

- ISR $e^+e^- \to \pi^+\pi^-$ cross section: 600 - 900 MeV, Phys. Lett. B 753, 629-638 (2016)
- R measurement: 2.2324 - 3.6710 GeV, Phys. Rev. Lett. 128, 062004 (2022)
- Several exclusive channels between 2 and 3 GeV ($\pi^+\pi^-\pi^0$, $K_sK_L\pi^0$,$KK\pi\pi$, …)

✓ Preliminary results:

- ISR $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$: 0.9 to 3.3 GeV



✓ On going :

- ISR $e^+e^- \to K^+K^-$: 1.0 to 3.2 GeV (tagged and untagged)
- ISR $e^+e^- \to K_sK_L$: 1.0 to 2.0 GeV (tagged)

Working on

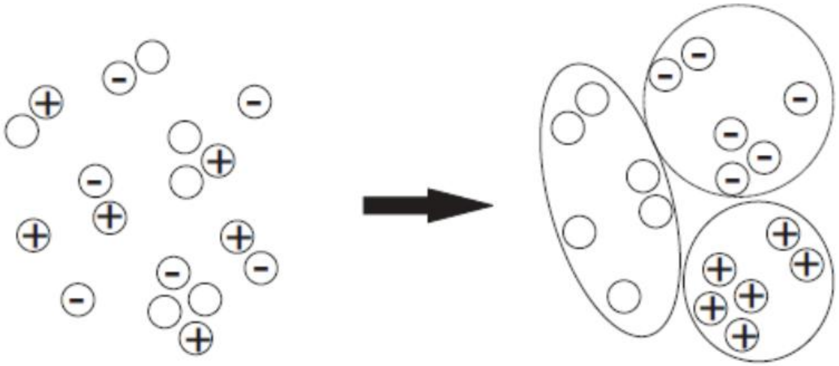
Participate

Bose-Einstein correlations

➢What and why Bose-Einstein correlations

- Origin: Wave function (WF) of a system of identical bosons symmetric under exchanging

- Higher probability of finding identical bosons in a small phase-space called
  Bose-Einstein correlations (BEC)



- Space-time structure (sp) described by f(x)

$$A_{12} = \frac{1}{\sqrt{2}}\sum(f(x_i)e^{ix_ip_1}\, f(x_j)e^{ix_jp_2} + f(x_i)e^{ix_ip_2}\, f(x_j)e^{ix_jp_1})$$

- Probability distributions of two particles:

$$P_{12} \propto \sum(\rho(x_i)\rho(x_j))(1 + e^{ix_ip_1}e^{ix_jp_2}e^{-ix_jp_1}e^{-ix_ip_2})\sim$$

$$\int_{-\infty}^{+\infty} dx_j dx_k \rho(x_i)\rho(x_j)[1 + e^{iq\Delta x}] = R^2(0)[1 + \boxed{\frac{R^2(q)}{R^2(0)}}] \rightarrow \boxed{\textbf{BEC term}}$$

[Chin.Phys.C 48 (2024) 11, 113106]

Where $q = p_1 - p_2$, $x = x_k - x_j$, $\boxed{R(q) = \int dx e^{iqx}\rho(x)}$, $\rho(x) = |f(x)|^2$

$R(0)$: uncorrelated part, got by unidentical bosons

.

BEC straightly reflects the space-time structure of source!

Bose-Einstein correlations

➢ Modulation and measurement of $R(Q^2)$

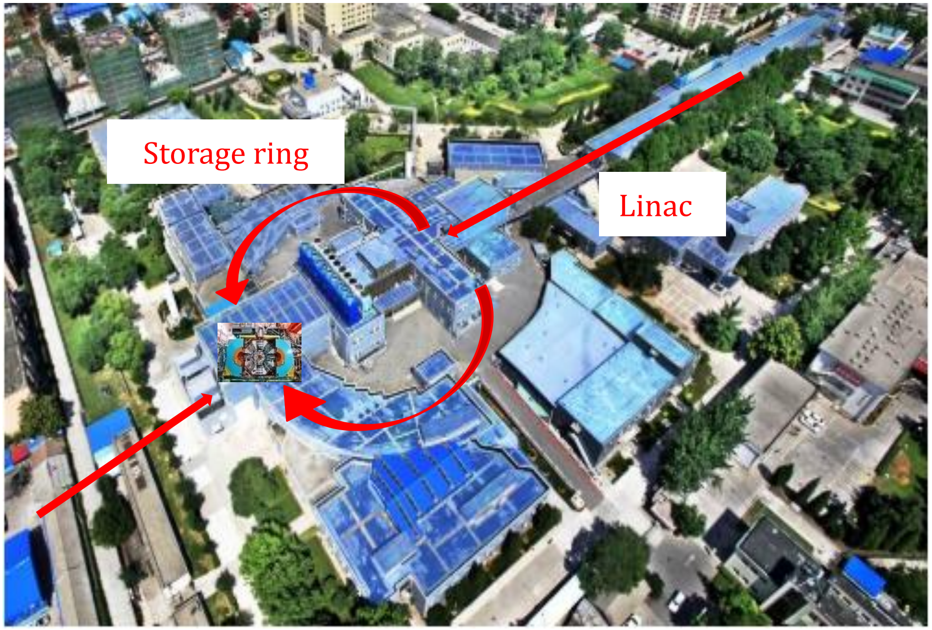
- Two models often used:
  - Gaussian source: $R(Q^2) \propto \lambda e^{-R^2Q^2}$, Exponential source: $R(Q^2) \propto \lambda e^{-RQ}$
  - λ, the correlation coefficient; R is the radius of the hadron source
  - Long distance interaction parameter: $1+\delta Q^2$
  - Thus $1+\frac{R(Q^2)}{R(0)} = N(1+\delta Q^2)(1+\lambda e^{-R^2Q^2})$ for gaussian source and
    $N(1+\delta Q^2)(1+\lambda e^{-RQ})$ for exponential source
- Measurement method:
  - Using the two identical particle correlation function:

$$C(Q^2) = \frac{\rho(Q^2)}{\rho_0(Q^2)}, \qquad Q^2 = -(q_1 - q_2)^2,$$

$\rho(Q^2)$: distribution of Q^2 and $\rho_0(Q^2)$: distribution of Q^2 from reference sample

  - Reference sample:
    - Like-sign pairs but opposite momentum of one particle (OHP)
    - Like-sign pairs but opposite transverse momentum of one particle(ROTA)
    - Particle pairs in different events (MIX)
      - Mix: mix events randomly
      - MixN: mix events with similar multiplicity of π^0
      - MixE: mix events with similar invariant mass of all π^0
  - Double ratio: $R(Q^2) = \frac{C^{data}(Q^2)}{C^{MC}(Q^2)}$ to remove other possible correlations

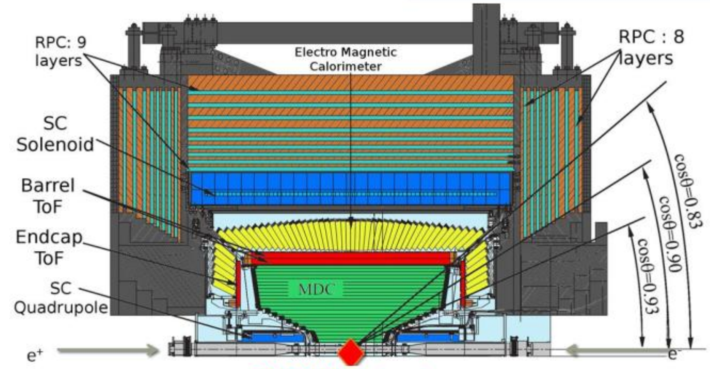
Beijing Electron and Positron Collider II (BEPCII) Beijing Spectrometer III (BESIII)



$E_{\mathrm{cm}} = 1.84 - 4.95$ GeV
Peak luminosity @$E_{\mathrm{cm}} = 3.773$ GeV:
$1.1 \times 10^{33}\ \mathrm{cm^{-2}s^{-1}}$
Circumference: 237.53 m
Crossing angle: 2×11 mrad

Electromagnetic Calorimeter
CsI(Tl): L = 28 cm
Barrel $\sigma_E = 2.5\%$
Endcap $\sigma_E = 5.0\%$

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



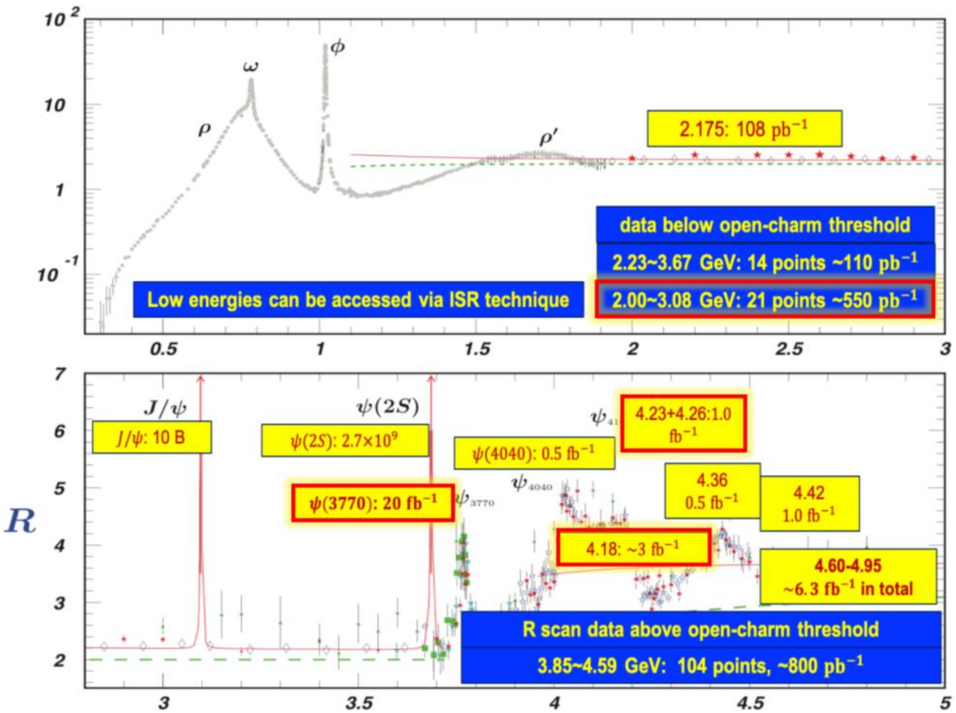
BESIII Detector

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

Time Of Flight
Plastic scintillator
σ_T(barrel) = 68 ps
σ_T(endcap) = 110 ps
(update to 60 ps with MRPC)

Datasets at BESIII

➢ Advantages in BESIII:



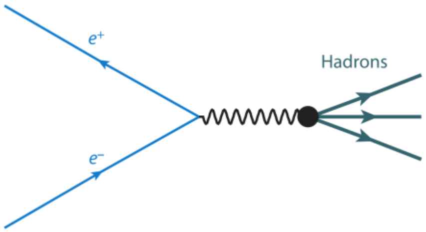
✓ Ideal environment to do inclusive/exclusive hardronic study!

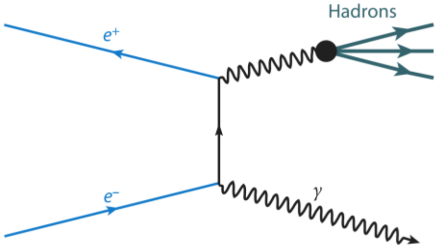
✓ Large datasets at tau-charm region

✓ Both energy scan and ISR methods can be used

I. Energy scan method
- Well-defined c.m. energy, low backgound
- Widely used in inclusive study

II. Initial state radiation method
- Colleting events from threshold to $\sqrt{s}$
- Widely used in study near threshold





Topic1:Cross Section Measurements of $e^+e^- \to K^+K^-$ via tagged ISR technique

Motivation

➢ Why $e^+e^- \to K^+K^-$ channel?

- The third contribution for HVP

Channel	HVP contribution (10^{-10})	Channel	HVP contribution (10^{-10})
$\pi^+\pi^-$	5078.5 ± 33.8	$\pi^+\pi^-\pi^+\pi^-$	180.3 ± 5.5
$\pi^+\pi^-\pi^0$	462.1 ± 14.5	$\pi^+\pi^-\pi^0\pi^0$	136.8 ± 3.0
K^+K^-	230.8 ± 4.4	K_sK_L	128.2 ± 2.4

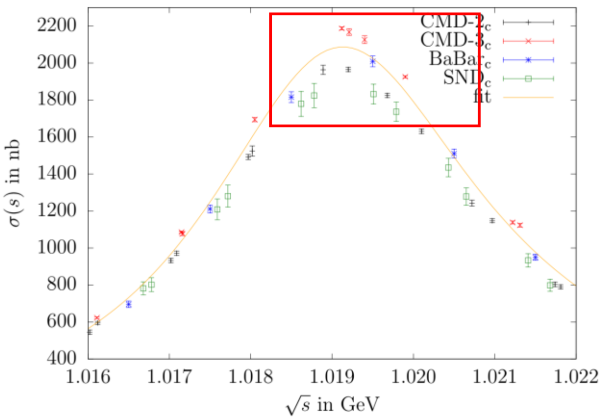
- The accuracy can be obtained in BESIII with 20 fb^{-1} datasets at $\psi(3770)$ peak
  - ✓ The most accuracy results are from BaBar
  - ✓ Around ϕ(1020) : statistical uncertainty with 1.4% → ~1.0%
  - ✓ 1.2 – 2.0 GeV : statistical uncertainty with 2.2% → ~1.5%
  - ✓ 2.0 – 3.2 GeV : statistical uncertainty with 10% → ~4.5%

BESIII expected

Motivation

➢Puzzle $e^+e^- \to K^+K^-$ channel

- Many results focusing on the $\boldsymbol{\phi(1020)}$ peak region (SND, CMD-2, CMD-3, BABAR).
  - **Tension** between the CMD-3's result and other groups' , similar with the case for $\pi^+\pi^-$.
  - **High precision** cross check could be offered by BESIII



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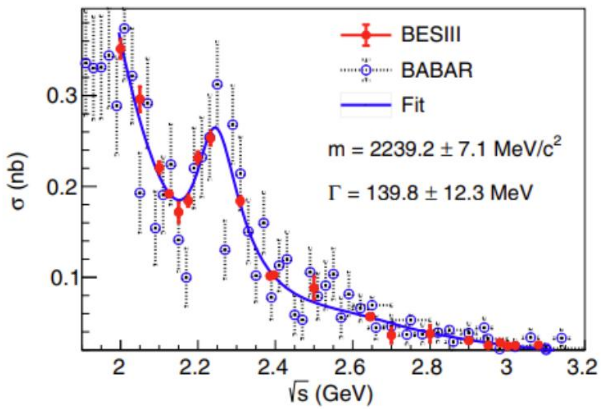
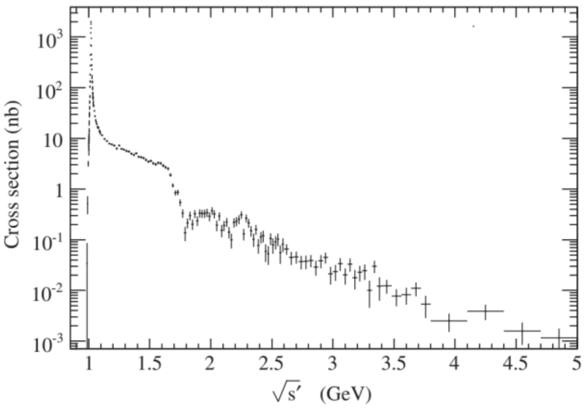


[Phys. Rev. D 99,032001(2019)]



[Phys. Rev. D 88, 032013 (2013)]

- Also fruitful results beyond the $\phi(1020)$
  - Substantial structure is evident in the center-of-mass energy range 1.1-2.4 GeV .
  - New resonance found in results by BESIII from 2.0-3.08 GeV

Event Selection

- Data Sets: $\sqrt{s}$=3.773 and 4.178 GeV, total luminosity: **23.452 $\mathbf{fb^{-1}}$**

- Good charged tracks:
  - $|\cos\theta| < 0.93$
  - $V_r < 1$ cm, $|V_z| < 10$ cm
  - $p/p_{\text{beam}} < 0.81$, p_{beam} is beam momentum
  - Depth in MUC < 40 cm
  - $N_{\text{Good}} = 2$

- Good photons:
  - EMC time: 0<t<700 ns
  - $|cos\theta_\gamma| < 0.8, E_\gamma > 25$ MeV for barrel
    $|cos\theta_\gamma| \in (0.86{,}0.92), E_\gamma > 50$ MeV for end cap
  - Angle from the nearest charged track>20°
  - Good photon with the largest energy is the nominal ISR photon

- PID ($\frac{dE}{dx}$ + TOF):
  - K: prob$(K) >$ prob(e)
  - $N_{K^+} = N_{K^-} = 1$

- Vertex fit and Kinematic fit
  - Successful Vertex fit by two Kaons
  - 4c kinematic fit and $\chi^2_{4c} < 50$
  - Looping good photon pairs to do 4c kinematic fit, choose the combination with minimum $\chi^2_{2\gamma,min}$
  - $\chi^2_{2\gamma,min} > \chi^2_{4c}$

- Special selection
  - For round03,04, $\sqrt{s}$=3.773 GeV data the E/p<0.8 for the good charged tracks

Background Analysis

- Background types and estimated ratio:

Type of MC	N_{survival}	ratio of the total background(%)	ratio of data(%)
$e^+e^- \to \pi^+\pi^-(\gamma_{\text{ISR}})$	188	13.0	0.3
$e^+e^- \to \mu^+\mu^-(\gamma_{\text{ISR}})$	103	7.1	0.2
$e^+e^- \to q\bar{q}$	1056	73.2	1.8
$e^+e^- \to e^+e^-(\gamma_{\text{ISR}})$	96	6.7	0.2
$e^+e^- \to \tau^+\tau^-(\gamma_{\text{ISR}})$	0	0.0	0.0
$e^+e^- \to e^+e^-X$	0	0.0	0.0

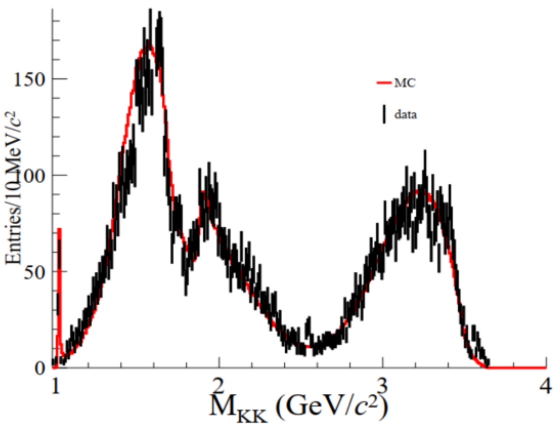
- Low background level (~3%).
- Background besides $q\bar{q}$ are estimated by MC, since those MC are accurate enough.
- $q\bar{q}$ means the hardonic backgrounds (excluding $\pi^+\pi^-\gamma_{ISR}$)

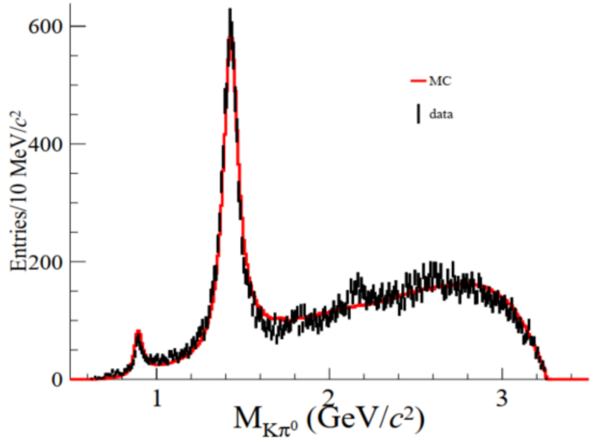
1	$x \to \pi^0 K^+ K^-$	$\pi^0 K^+ K^-$	0	501	501
2	$x \to vgam\gamma, vgam \to \pi^0 K^+ K^-$	$\pi^0 K^+ K^- \gamma$	1	209	710
3	$x \to \pi^+\pi^-\gamma^F\gamma^F$	$\pi^+\pi^-\gamma^F\gamma^F$	2	126	836
4	$x \to \pi^0\pi^+\pi^-\gamma^F$	$\pi^0\pi^+\pi^-\gamma^F$	3	81	917
5	$x \to \pi^+\pi^-\gamma^F$	$\pi^+\pi^-\gamma^F$	8	74	991
6	$x \to \pi^0\pi^+\pi^-\gamma^F\gamma^F$	$\pi^0\pi^+\pi^-\gamma^F\gamma^F$	6	52	1043

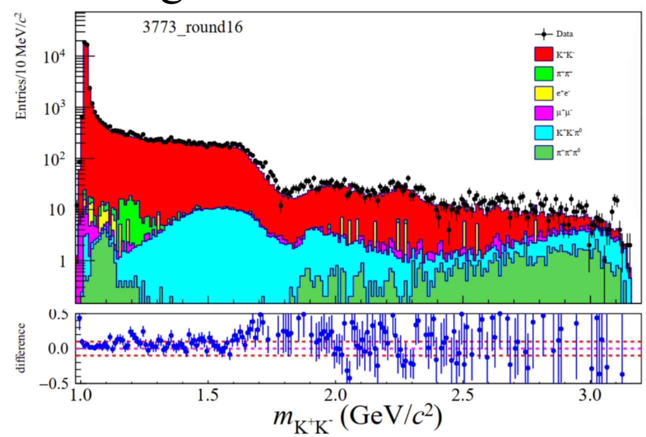
- The rest main hardronic backgrounds : $K^+K^-\pi^0$ and $\pi^+\pi^-\pi^0$. Others are ignored

Background Analysis

- Exclusive study for $K^+K^-\pi^0$
  1. Using the FDC package to get a PWA model
  2. Generating the MC by ConExc and using it to estimate the background







3.MC is reliable, about 1% in data

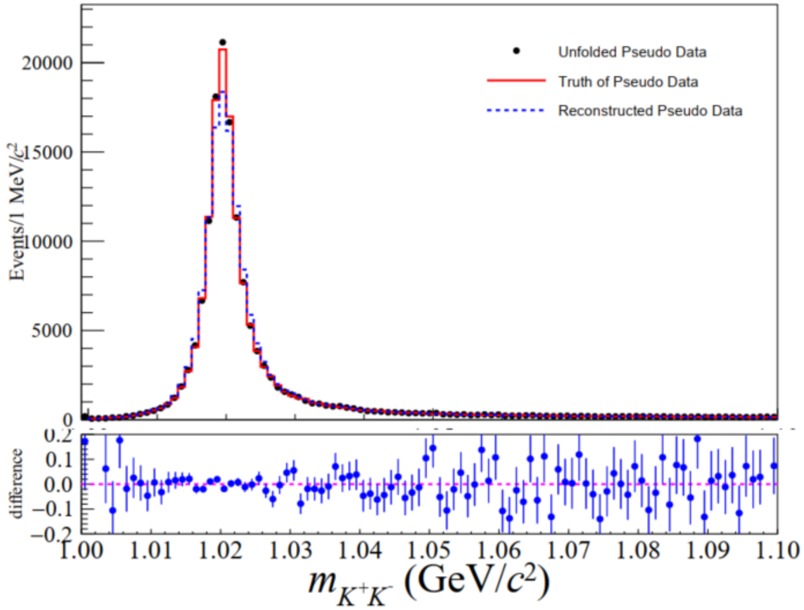
- Exclusive study for $\pi^+\pi^-\pi^0$
  1. Using the PHOKHARA to generate MC to estimate this background
  2. Result: about 0.5% in data

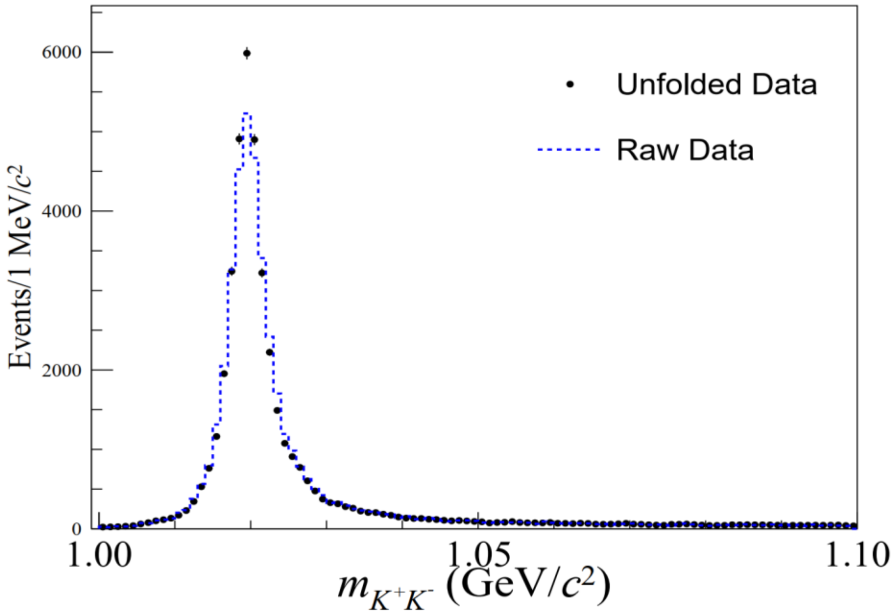
- Combined MC describes data well !

Unfolding

➢ Why and how to do unfolding?

- ☐ High precision needed near ϕ reasonance
- ☐ **Singular Value Decomposition (SVD)** is used to correct the smearing effects.





- ☐ SVD Effectively corrected the smearing effects, especially near the ϕ peak.

Systematic uncertainty

➢ Systematic uncertainty are listed below ($\sqrt{s} = 3.773$ GeV:

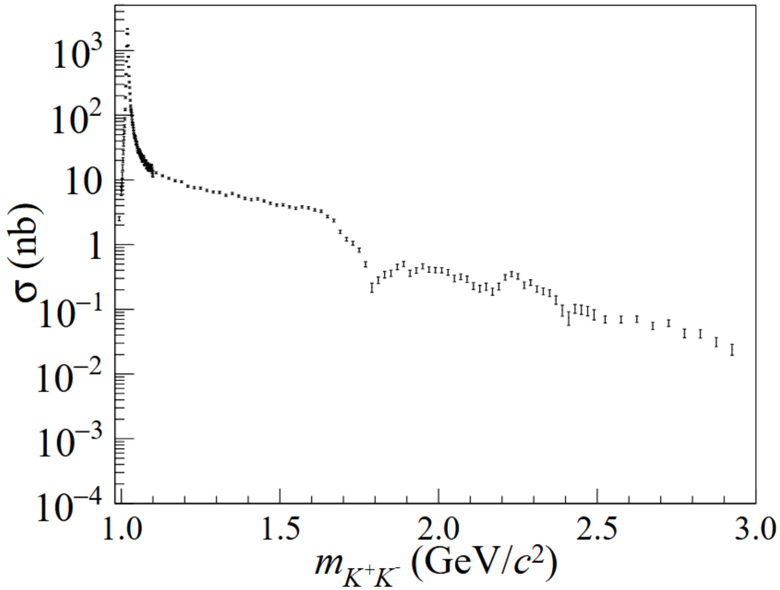
$M_{K^+K^-}$ (GeV) / Uncertainty type	**Threshold-1.1**	**1.1-2.5**	**2.5-3**	**Method**
$K^\pm$ tracking efficiency	0.1%	1.2%	2.0%	Control sample:$J/\psi \to K_s K\pi$
$K^\pm$ PID efficiency	0.1%	0.8%	2.0%	Control sample:$J/\psi \to K_s K\pi$
Photon efficiency	0.2%	0.2%	0.2%	Control sample:$e^+e^- \to \mu^+\mu^-\gamma_{ISR}$
MUC efficiency	0.1%	0.4%	1.0%	Control sample:$J/\psi \to K_s K\pi$
Unfolding	0.2%	0.0%	0.0%	Alternative line shape
Kinematic fit	0.5%	0.5%	0.5%	Correct the helicity parameters
VP correction	0.2%	0.2%	0.2%	Given by the theoretical calculation
Luminosity and Radiation function	0.7%	0.7%	0.7%	Given by the theoretical calculation and BESIII nominal result
overall	1.0%	1.7%	3.3%	

Cross section measurement

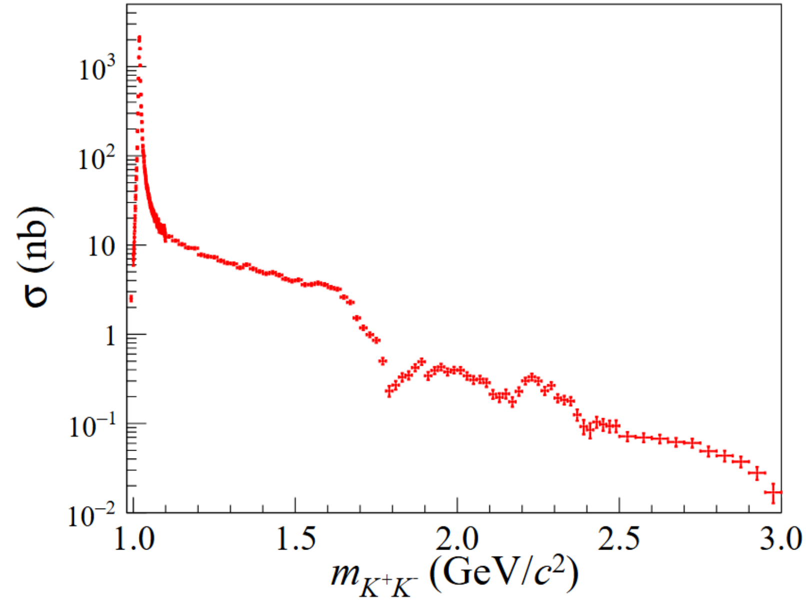
- In each interval, cross section is calculated by:

$$\sigma_{K^+K^-,\text{dressed}}\,(M_{K^+K^-}) = \frac{dN_{sig}/dM_{K^+K^-}}{\epsilon.d\mathcal{L}_{int}/dM_{K^+K^-}}, \qquad \frac{d\mathcal{L}_{\text{int}}}{dM_{K^+K^-}} = W(s.x)\mathcal{L}_{\text{int}}$$

$$\sigma_{K^+K^-,\text{Bare}} = \frac{\sigma_{K^+K^-,\text{dressed}}}{(\alpha(s)/\alpha(0))^2}$$



$\sigma_{K^+K^-,\text{dressed}}$



$\sigma_{K^+K^-,\text{Bare}}$

Cross section measurement

➢ Fit the lineshape

- The form factor is correlated to the $\sigma_{K^+K^-,\text{dressed}}$ by:

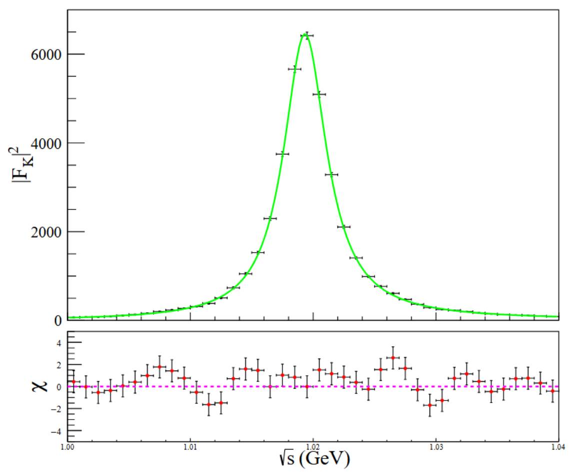
$$|F_k|^2(s') = \frac{3s'}{\pi\alpha^2(0)\beta_K^3}\frac{\sigma_{K^+K^-,\text{dressed}}(s')}{C_{FS}},$$ C_{FS} is the final-state radiation correction factor

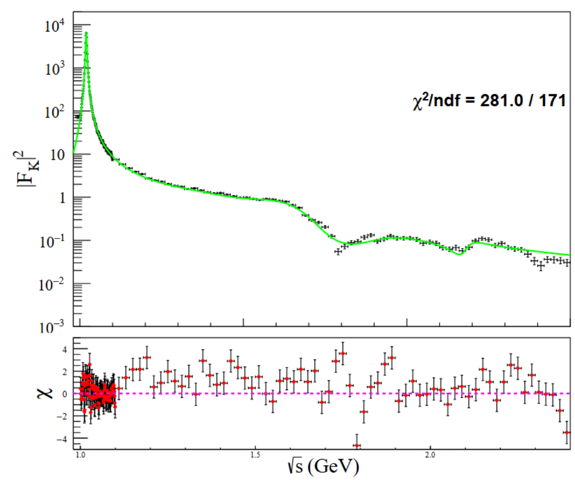
- The lineshape is fitted by the following model:

$$F_K(s) = \left(a_\phi BW_\phi + a_{\phi'} BW_{\phi'} + a_{\phi''} BW_{\phi''}\right)/3$$
$$+ \left(a_\rho BW_\rho + a_{\rho'} BW_{\rho'} + a_{\rho''} BW_{\rho''} + a_{\rho'''} BW_{\rho'''}\right)/2$$
$$+ \left(a_\omega BW_\omega + a_{\omega'} BW_{\omega'} + a_{\omega''} BW_{\omega''} + a_{\omega'''} BW_{\omega'''}\right)/6$$

With constraints

$$a_\phi + a_{\phi'} + a_{\phi''} = 1,$$
$$a_\rho + a_{\rho'} + a_{\rho''} + a_{\rho'''} = 1,$$
$$a_\omega + a_{\omega'} + a_{\omega''} + a_{\omega'''} = 1.$$

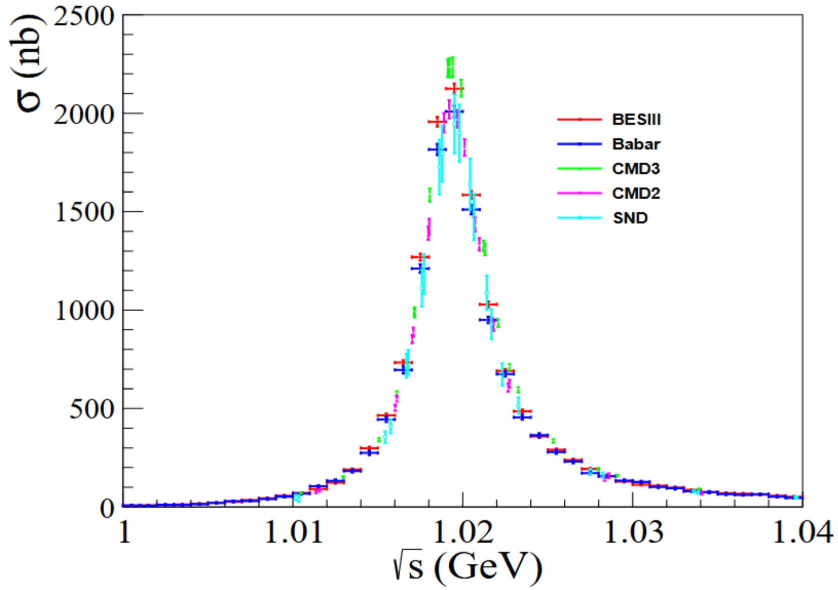




- Least χ^2 method is used to fit the line shape
- Reliable parameters of resonance near 2.2 is not obtained for the low statistics

➢ Summary of K^+K^-

- ✓ Based on 23.452 fb^{-1} data sets, cross section for process $e^+e^- \to K^+K^-$ is from $2m_K$ to 3.00 GeV/c^2 with tagged ISR technique
- ✓ Memo is completed and being reviewed.
- ✓ Between results of BaBar and CMD3's and having improved precision near the $\phi(1020)$ （0.7% for statistics and 1.0% for systematics)
- ✓ Unable to yield reliable parameters of resonance near 2.2 GeV/c^2 due to low statistics.



Topic2:Study of BEC by $\pi^0\pi^0$ pairs at BESIII

Motivation

➢ Experiment measurement of BEC

- Studied by different experiments (MARKII, ZEUS, CMS……)
- Fruitful results at high energy but rare results at low energy.
- Many results by $\pi^{\pm}\pi^{\pm}$ pairs but few by $\pi^{0}\pi^{0}$ pairs

Experiment	$\sqrt{s}$ (GeV)	r (fm)	λ	Exp. type
MARK II	29	0.97±0.11	0.27±0.04	e^+e^-
AMY	58	0.58±0.06	0.39±0.05	e^+e^-
OPAL	91	0.79±0.02	0.85±0.01	e^+e^-
NA22	21.7	0.83±0.06	0.33±0.02	π^+p
ZEUS	10.5	0.67±0.04	0.43±0.09	ep
CMS	900	0.90±0.03	0.63±0.02	pp
CMS	2360	1.12±0.10	0.66±0.07	pp
ATLAS	13000	2.12±0.08	1.00±0.08	pp

Results of $\pi^{\pm}\pi^{\pm}$pairs

Experiment	$\sqrt{s}$ (GeV)	r (fm)	λ	Exp. type
L3	91	0.31±0.10	0.16 ± 0.09	e^+e^-
OPAL	91	0.59±0.11	0.55±0.15	e^+e^-

Results of $\pi^{0}\pi^{0}$pairs

- ✓ BESIII fill the gap at few GeV region based on the R-scan data from 2.0-3.08 GeV (large primary idenctical $\pi\pi$ pair statistics)
- ✓ Preliminary results: by $\pi^{\pm}\pi^{\pm}$ pairs (Participate)
- On going: by $\pi^{0}\pi^{0}$pairs (working on)

Event Selection

- Data Sets: $\sqrt{s}$=2.125, 2.396, 2.645, 2.900, 3.080 GeV, total luminosity: ~500 pb^{-1},
- Two kinds of hadron MC samples used for analysis: Hybrid and Luarlw

➢ Good charged tracks
- $|\cos\theta| < 0.93$
- $V_r < 0.5$ cm, $|V_z| < 5$ cm
- $p/p_{\text{beam}} < 0.94$, p_{beam} is beam momentum
- $\chi_{\text{prob}} = \left(\left|\frac{dE}{dx}_{\text{measured}} - \frac{dE}{dx}_{\text{proton}}\right|\right)/\sigma_{\text{proton}} > 10$
- $N_{\text{good}} > 0$

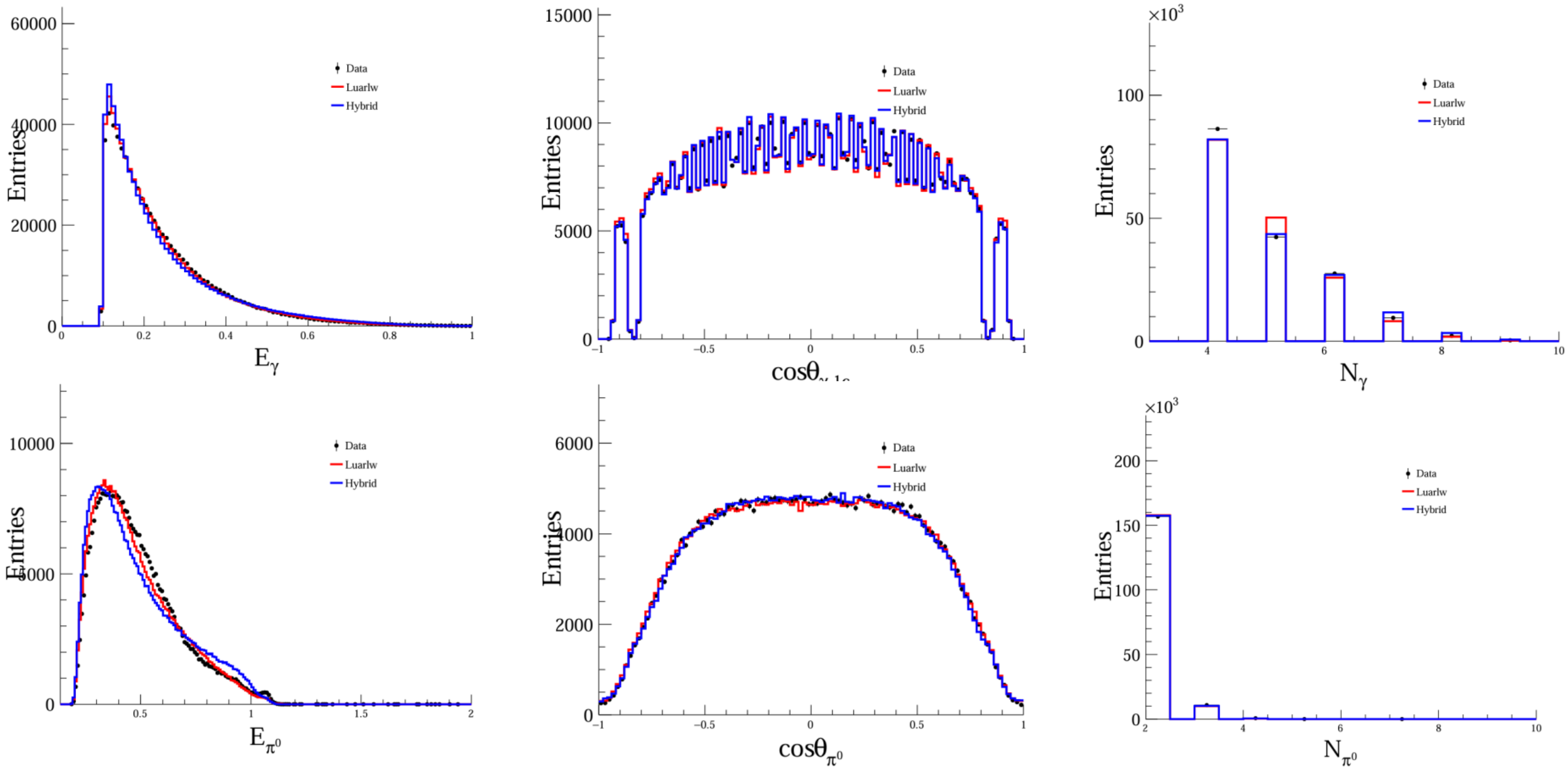
➢ Veto Bhabha and Di-gamma:
- Choose the two largest showers in EMC
- $E_{\text{largest}} < 0.65\ E_{\text{beam}}$
- $|\delta\theta| = |\theta_1 + \theta_2 - 180^\circ| < 10^\circ$

➢ Good photons:
- EMC time: 0<t<700 ns
- $|cos\theta_\gamma| < 0.8, E_\gamma > 25$ MeV for barrel
  $|cos\theta_\gamma| \in (0.86,0.92), E_\gamma > 50$ MeV for end cap
- $N_\gamma \geq 4$

➢ π^0 reconstruction
- All pairs of photons used to reconstruct π^0 list. For each π^0: $m_{\pi^0} \in [120,150]$ MeV
- 1C kinematic fit applied to each π0.
- Finding the largest π^0 subset without repeating photon and minimum $\sum\chi^2_{1c}$
- $N_{\pi^0} \geq 2$

Event Selection

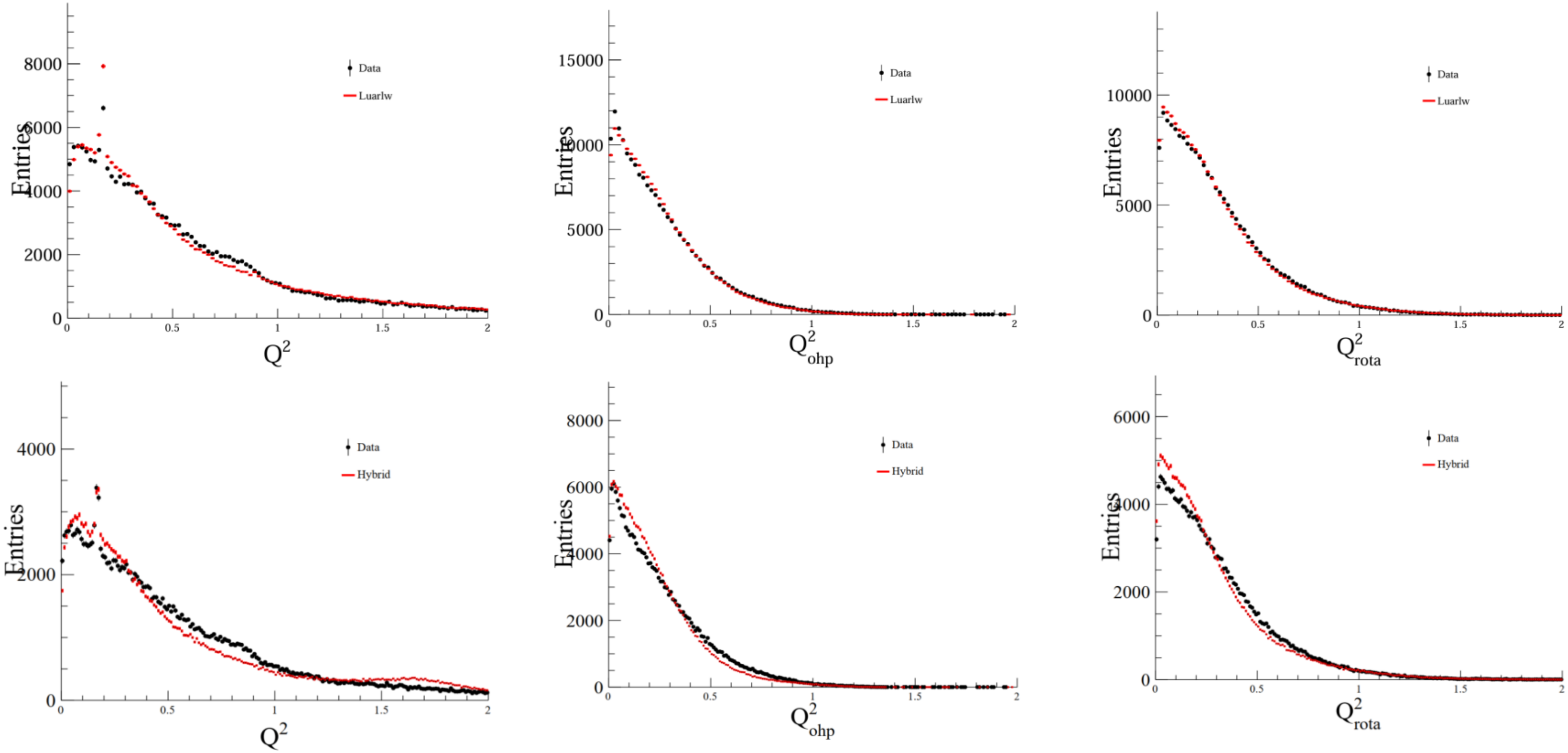
- Distributions of π^0 samples at $\sqrt{s} = 2.396$ GeV as an example



- ☐ First row is distributions correlated to γ, and second row is π^0's.
- ☐ Black dots are data, blue dots are Hybrid and red dots are Luarlw.

Event Selection

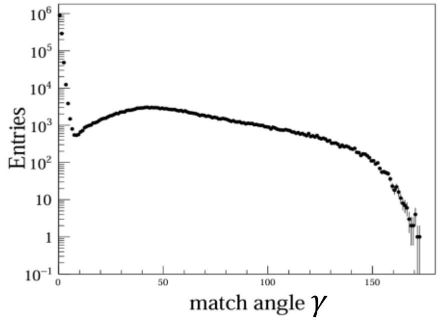
➢ Distributions of Q^2

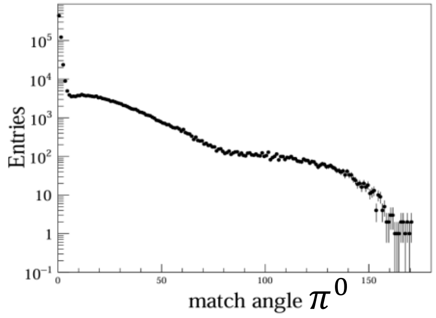


- ☐ First row is distributions of Luarlw, and second row is Hybrid.
- ☐ Luarlw could better describe the data.
- ☐ Distinction between data and MC near 0.8.

Study of fake π^0

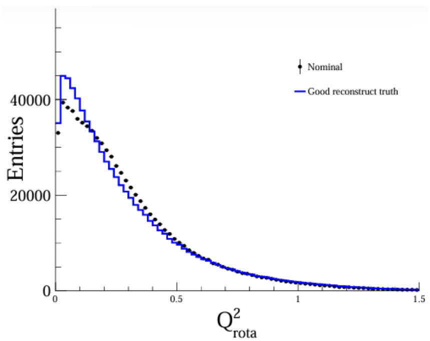
Match of π^0 and photons

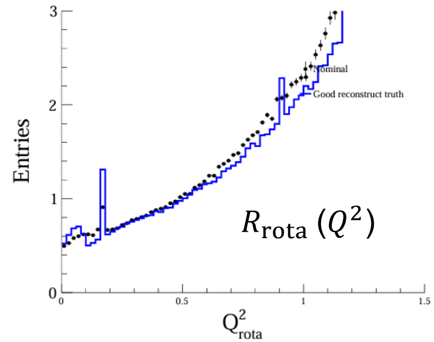


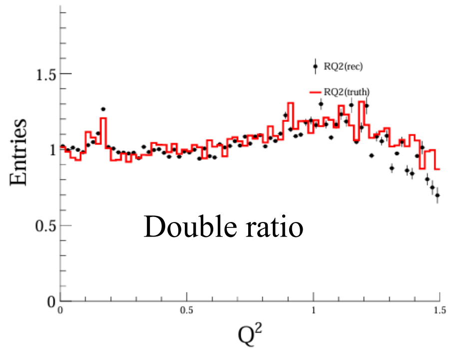


- $R_{\pi^0_{\text{fake}}} = 10\%, R_{\gamma_{\text{fake}}} = 12.6\%$, here the "fake" means the truth match angle is larger than 20°
- Mainly caused by the fake photon by charged tracks and difficult to exclude.

Check the effect of fake π^0



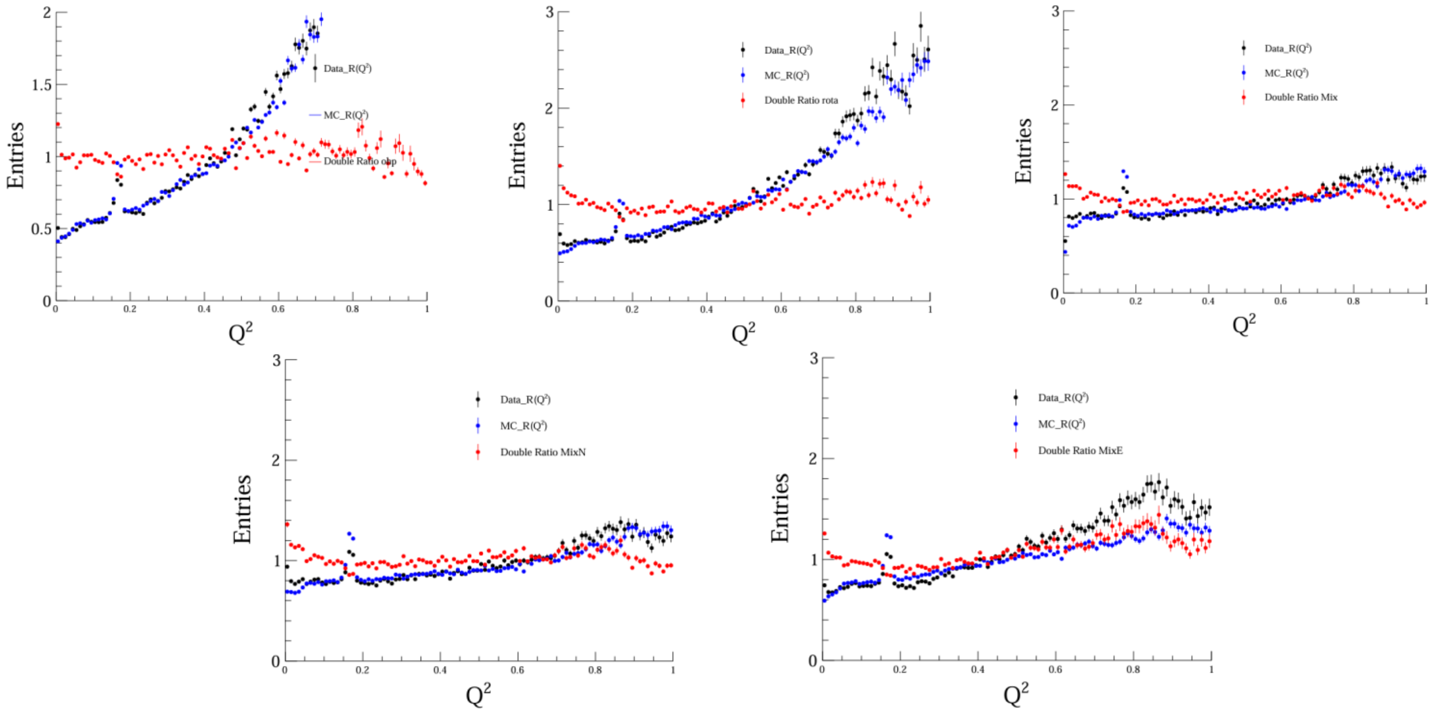




- First two pictures: black dots are detector level and blue dots are truth level.
- Third picture: double ratio is got by the two MC. Red is from truth and black is got from detector level.
- Great effect to $Q^2$and $R(Q^2)$ distribution, but little to the double ratio.

BEC parameter yield

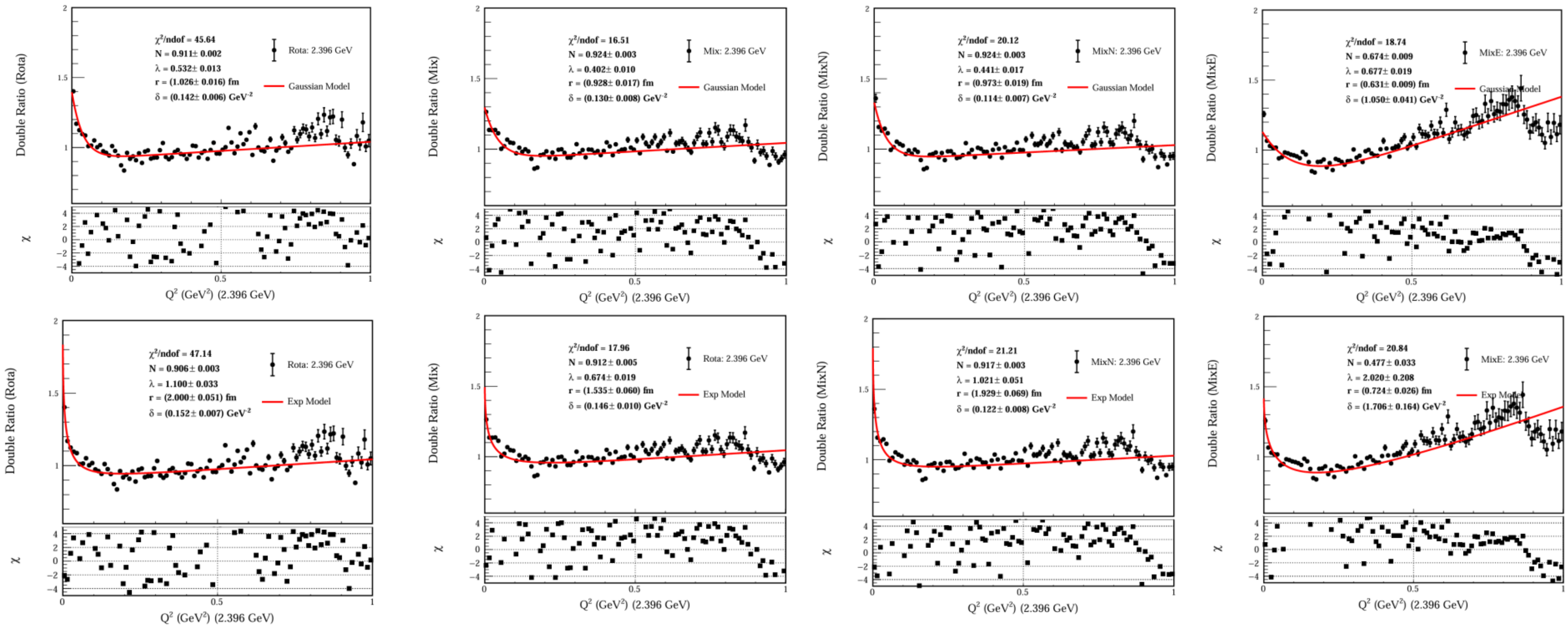
- Distributions of double ratio



- Peak near 0.18 is caused by the $K_s \rightarrow \pi^0\pi^0$.
- Obvious BEC effect can be observed.
- Unmatch of double ratio when Q2 comes up.

BEC parameter yield

- BEC parameter fitting



- ☐ Poor description by fitting results to data by both model
- ☐ Mainly caused by Q^2description.
- ☐ MC tuning is needed

Summary of BEC

➢ Summary of BEC

- ✓ Feasibility study has been performed at 2.396 GeV and obvious BEC effect is observed.
- ✓ Effect of fake π^0 has been checked.
- ✓ Five Ref. samples have been checked and BEC parameters have been extracted with Rota and MIX samples.

Channel	Events	Ratio
$\pi^+\pi^-2\pi^0$	94707	30.0%
$\pi^+\pi^-3\pi^0$	43493	13.8%
$\pi^+\pi^-4\pi^0$	23090	5.7%
$\pi^+\pi^-5\pi^0$	17990	1.2%
$2\pi^+2\pi^-2\pi^0$	38970	12.3%
$2\pi^+2\pi^-3\pi^0$	16283	5.1%
$2\pi^+2\pi^-4\pi^0$	9406	3.0%
$K^\pm\pi^\mp3\pi^0$	7886	2.3%
$\pi^+\pi^-2\pi^0\eta(\eta\to\gamma\gamma)$	6040	1.9%
Sum over	257868	81.6%

- ☐ Q^2 distributions of MC couldn't describe data well, MC will be tunned exclusively.
- ☐ Check the dependences on K_T, which is meaningful for the electron-positron collider.
- ☐ Systematic uncertainty and so on.

Summary and prospects

- ✓ Cross section measurement of $e^+e^- \to K^+K^-$ via initial state radiation technique has been completed and memo is being reviewed.

- ☐ Study of two-particle Bose-Einstein Correlations just started but has been reported at the BESIII collaboration meeting.
  - MC tuning will be performed.
  - Dependence of K^T or other observable will be studied.
  - More energy points will be used in this analysis
  - Systematic uncertainties will be studied.

Back up

Back up: Selection of $K^+K^-\pi^0$

- Good charged tracks:
  - $|\cos\theta| < 0.93$
  - $V_r < 1$ cm, $|V_z| < 10$ cm
  - $N_{\text{Good}} = 2$
- Good photons:
  - EMC time: 0<t<700 ns
  - $|cos\theta_\gamma| < 0.8, E_\gamma > 25$ MeV for barrel
    $|cos\theta_\gamma| \in (0.86,0.92), E_\gamma > 50$ MeV for end cap
  - Angle from the nearest charged track>10°
  - $N_\gamma \geq 2$
- PID ($\frac{dE}{dx}$ + TOF):
  - K: prob(K) > prob(π), prob(K)>prob(p)
  - $N_{K^+} = N_{K^-} = 1$
- Vertex fit and Kinematic fit
  - Successful Vertex fit by two Kaons
  - 4c kinematic fit and $\chi^2_{4c} < 60$
  - Looping single good photon to do 4c kinematic fit, choose the combination with minimum $\chi^2_{\gamma,min}$
  - $\chi^2_{\gamma,min} > \chi^2_{4c}$
- Further selection
  - $M_{2\gamma} \in [120,150]$ MeV

Back up: $J/\psi \to K^+K^-$

- 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:

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$$\sigma(s) = \frac{12\pi^2\Gamma(V \to e^+e^-)\mathcal{B}(V \to f)}{m_V s} W(s, x_0)$$

  - $\Gamma(V \to e^+e^-)$: electronic width of the vector meson V
  - m_V: mass of the vector meson V
  - $x_0 = 1 - m_V^2/s$
  - $\mathcal{B}(V \to f)$: branching fraction of V to final state f
  - $W(s, x_0)$: probability function for ISR photon emission

- Value of the $\Gamma(V \to e^+e^-)\mathcal{B}(V \to f)$ can be determined by measuring the cross section, then $\mathcal{B}(V \to f)$ can be obtained
- Experimentally, cross section of the process $e^+e^- \to \gamma^{\text{ISR}} J/\psi \to \gamma^{\text{ISR}} K^+K^-$ is:

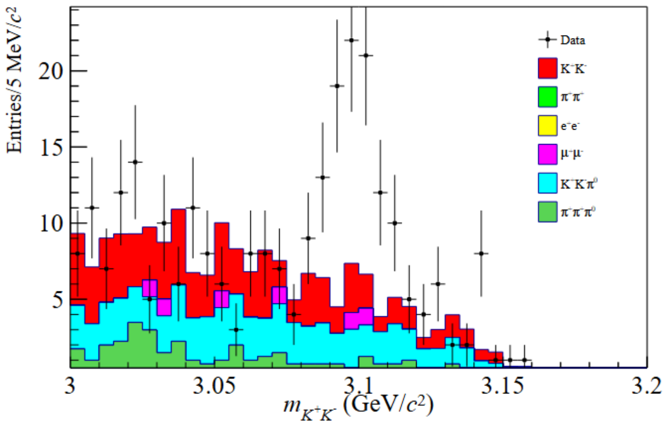
$$\sigma(s) = \frac{N_{J/\psi}}{\varepsilon \cdot \mathcal{L}}$$

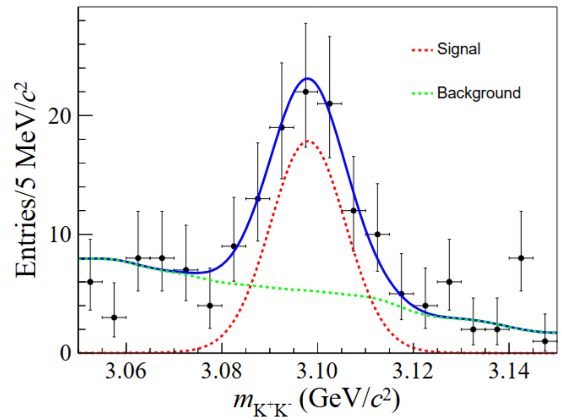
  - $N_{J/\psi}$: number of J/ψ events
  - ε: detection efficiency estimated by 1M MC
  - $\mathcal{L}$: luminosity of data, $\mathcal{L} = 3.1945$ fb

$e^+e^- \to \gamma^{\text{ISR}} J/\psi$ is generated by VECTORISR;
$J/\psi \to K^+K^-$ is generated by VSS

Back up: $J/\psi \to K^+K^-$

- An unbinned maximum likelihood fit used to extract signal yield:





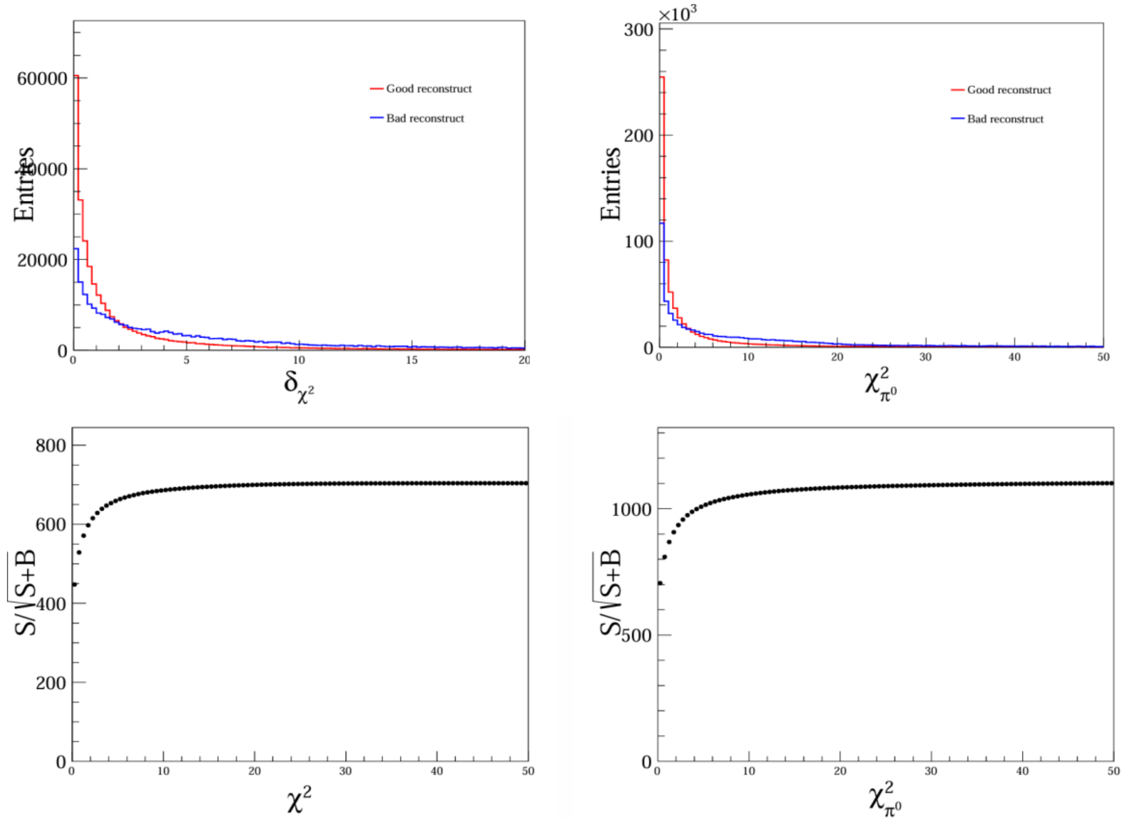
- Total fit= signal model⊗Gaussain+combined background model
- Summary of cross section of $e^+e^- \to \gamma^{ISR} J/\psi \to \gamma^{ISR} K^+K^-$:

$\sqrt{s}$(GeV)	$N_{J/\psi}$	ϵ	W(s,x_0)	$\Gamma(J/\psi \to e^+e^-)$ (keV)	$\mathcal{B}(J/\psi \to K^+K^-)$
3.773	71.1±12.7	1.4%	0.171	5.529±0.106	$(2.57 \pm 0.46) \times 10^{-4}$

- PDG: $(2.86 \pm 0.21) \times 10^{-4}$

Back up: efforts to suppress the fake π^0

➢Kinematic fit:



$$\delta_{\chi^2} = |\chi^2_{\text{full } \pi^0}/n_{\text{full}} - \chi^2_{\text{one less } \pi^0}/(n_{\text{full}}-1)|$$

Back up: efforts to suppress the fake π^0

- BDT: