Measurements of $e^+e^- \to \phi K^+ K^-$ and $K^+K^- K^+K^-$ cross sections and observation of $\phi(2170) \to \eta' \phi$

(R-Scan Data: $\sqrt{s}$=2.0GeV~3.08GeV)

Yankun Sun

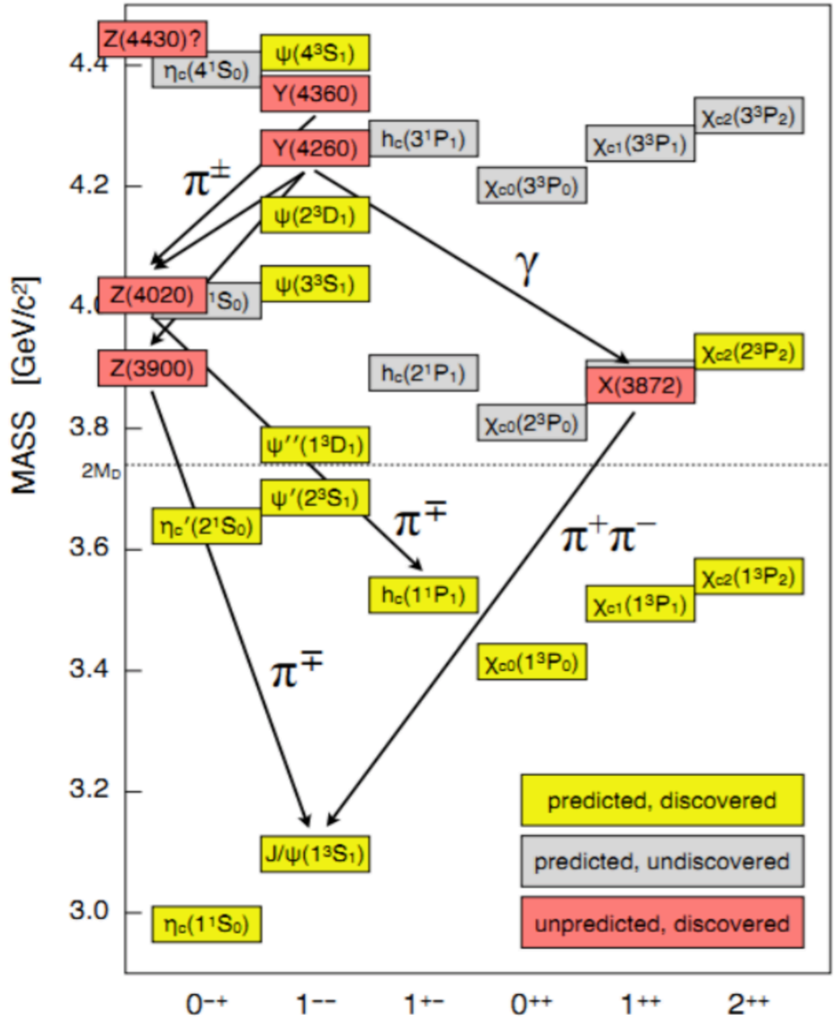
Supervisors: Guangshun Huang   Ming Shao

USTC

Outline

- What is XYZ state?
- BEPCII and BESIII.
- Measurements of cross sections of hadron processes
  - Measurements of cross sections of $e^+e^- \to \phi K^+ K^-$ and $K^+K^- K^+K^-$
  - Observation of resonant structure in the line shape of cross section of $e^+e^- \to \eta' \phi$
- Summary and Outlook

What is XYZ states?



X states: charmonium-like states with

$$J^{PC} \neq 1^{--}$$

Y states: charmonium-like states with

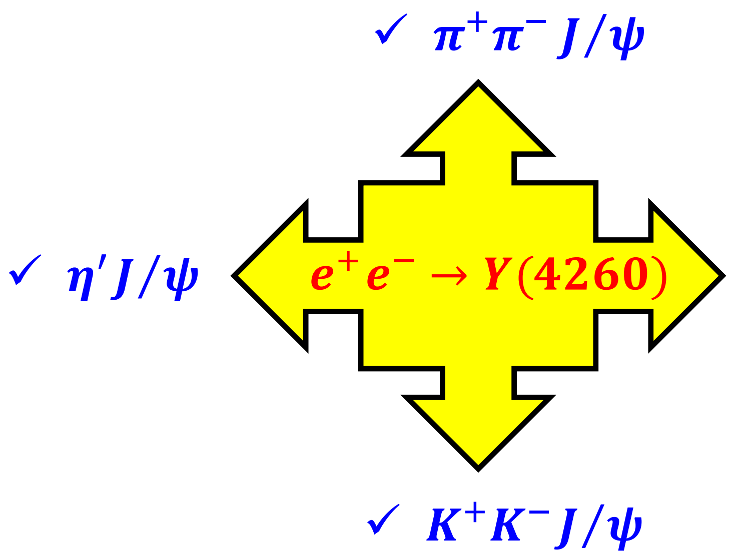
$$J^{PC} = 1^{--}$$

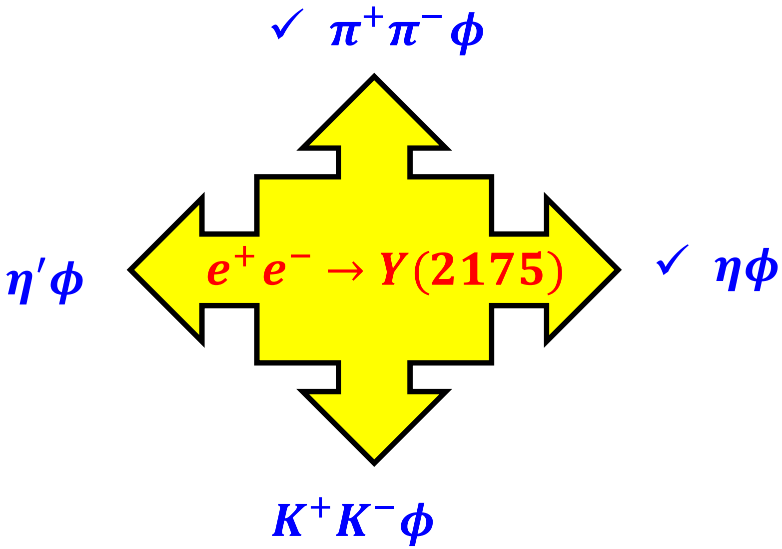
Z states: charmonium-like states contained at least a cc and a light qq pair

- **Below open-charm threshold:**
  - Good agreement between discovery and theoretical prediction.
- **Above open-charm threshold:**
  - Some new states: with charmonium in final states. (Charmonium-like or XYZ)

Y(4260) and Y(2175)

$$e^+e^- \to Y(4260) \to \pi Z_c \to \pi\pi J/\psi$$

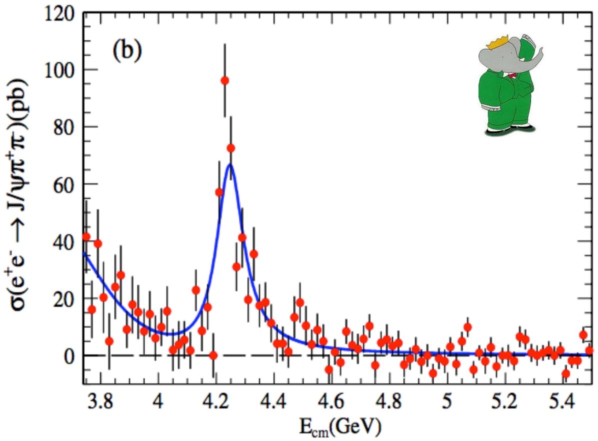




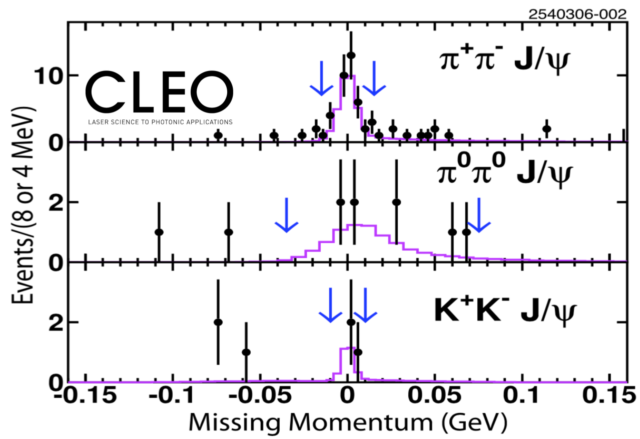
$$e^+e^- \to Y(2175) \to \pi Z_s \to \pi\pi\phi$$

Y(4260)

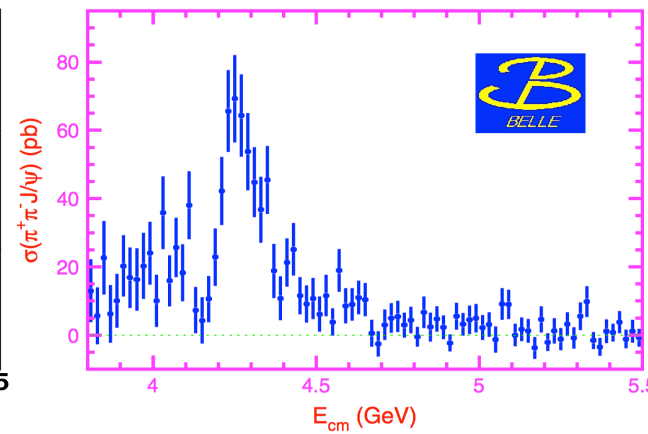
Phys. Rev. D 86, 051102(R)

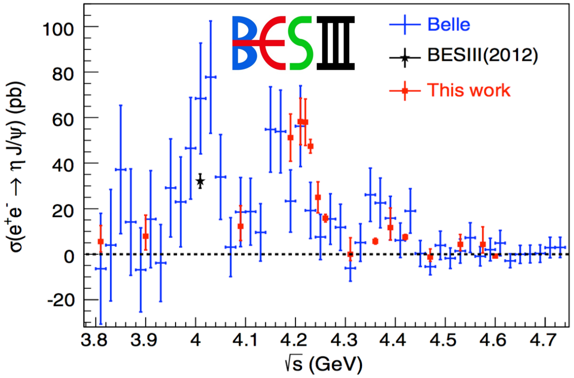


Phys. Rev. Lett. 96, 162003

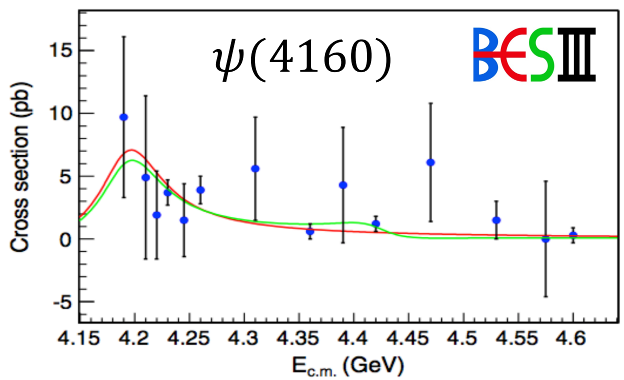


Phys. Rev. Lett. 99, 182004

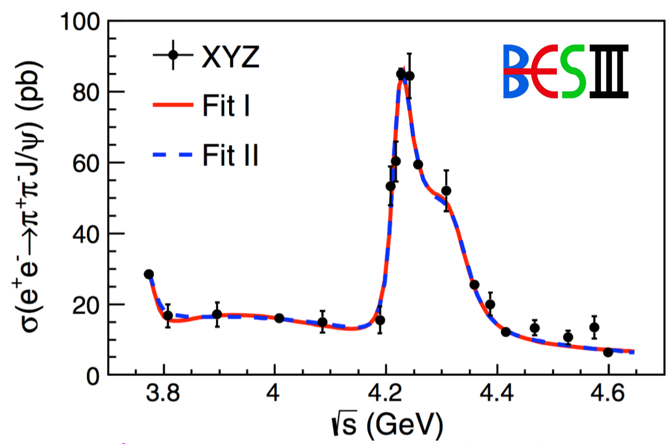




Phys. Rev. D 91, 112005



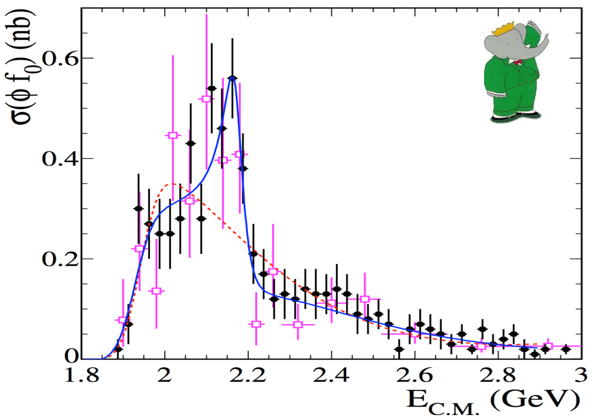
Phys. Rev. D 94, 032009



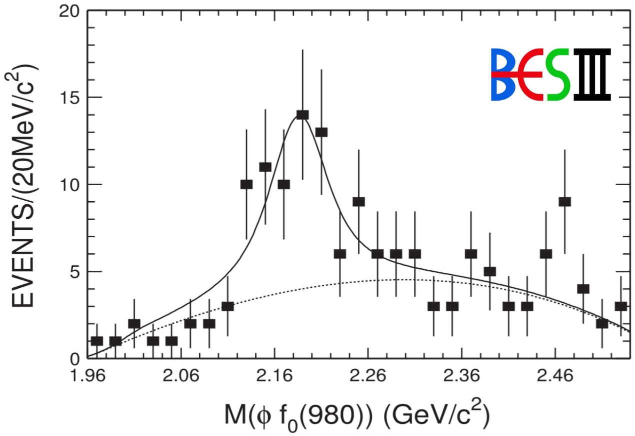
Phys. Rev. Lett. 118, 092001

Y(2175)

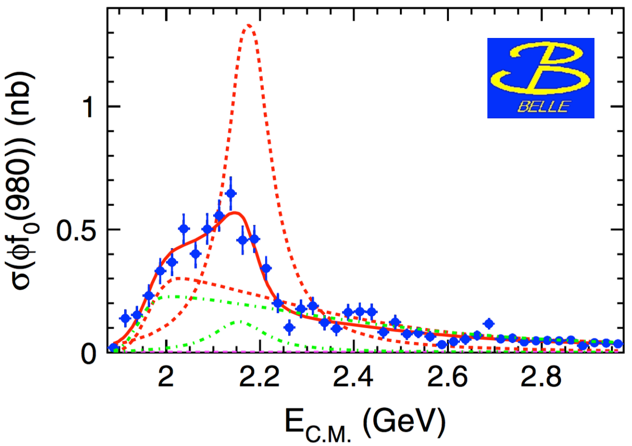
Phys. Rev. D74, 091103(R)

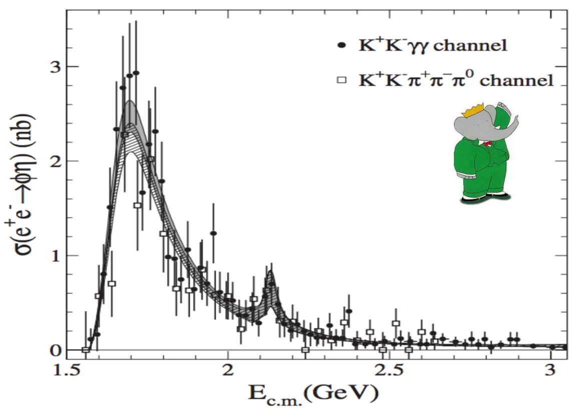


Phys. Rev. Lett. 100, 102003

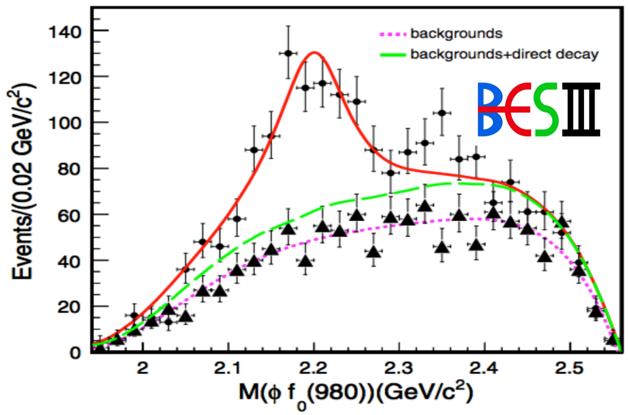


Phys. Rev. D 80, 031101(R)

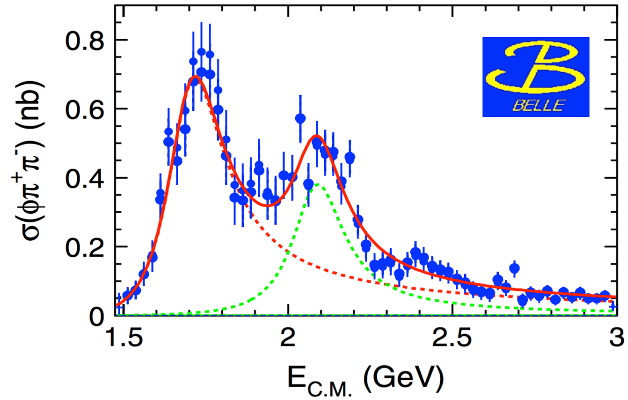




Phys. Rev. D 77, 092002

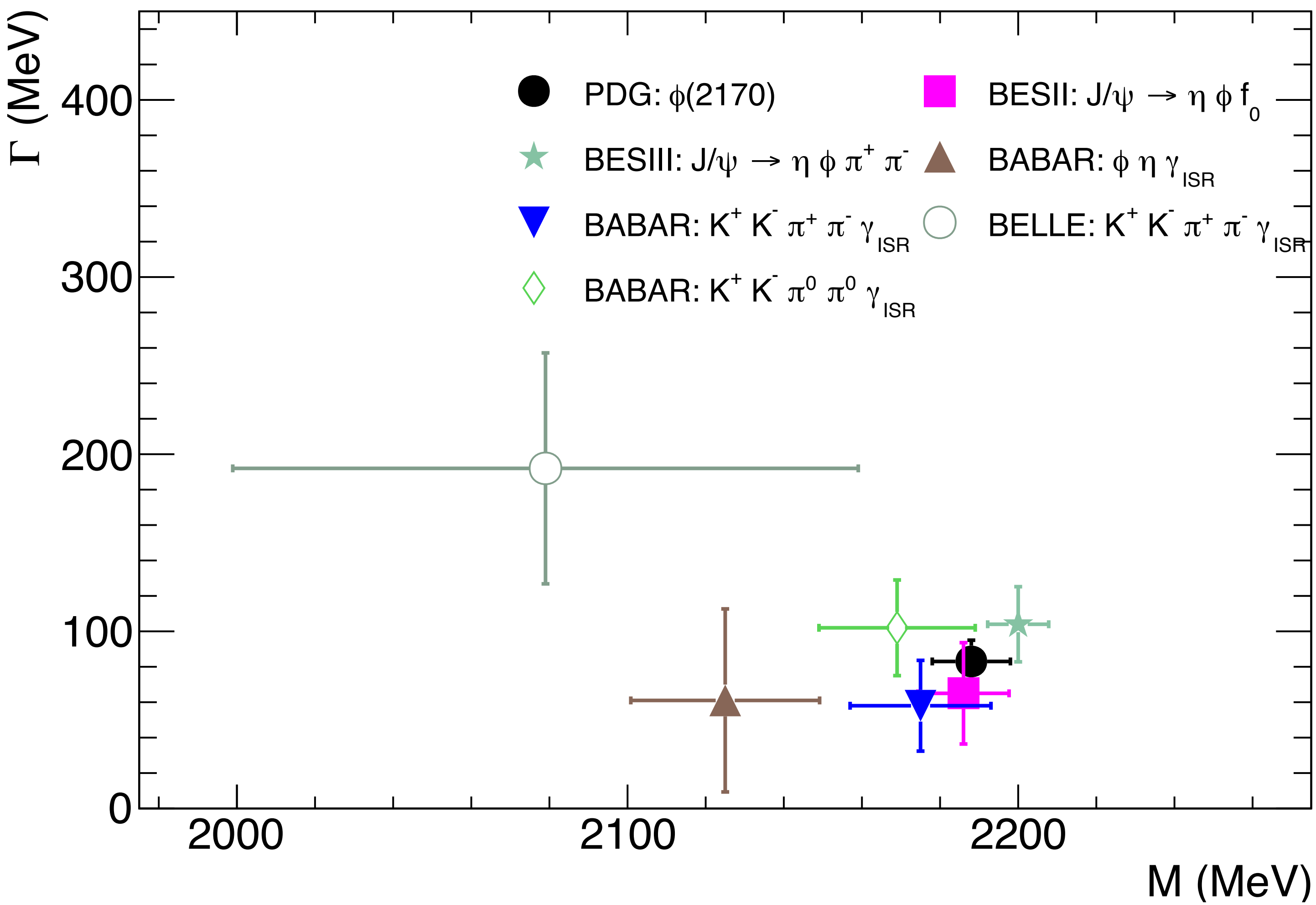


Phys. Rev. D 91, 052017



Phys. Rev. D 80, 031101(R)

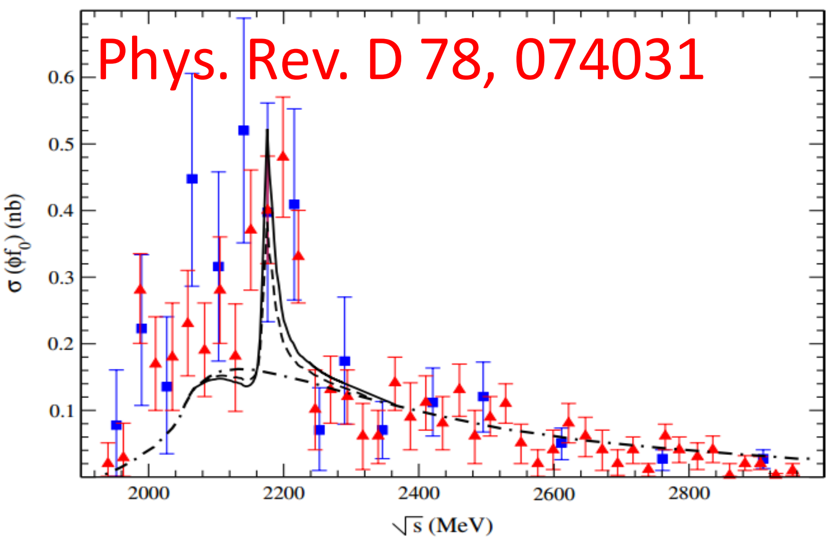
Y(2175)


PDG: ϕ(2170)
BESII: J/ψ → η ϕ f0
BESIII: J/ψ → η ϕ π+ π-
BABAR: ϕ η γISR
BABAR: K+ K- π+ π- γISR
BELLE: K+ K- π+ π- γISR
BABAR: K+ K- π0 π0 γISR
Γ (MeV)
M (MeV)
0
100
200
300
400
2000
2100
2200

Y(2175)

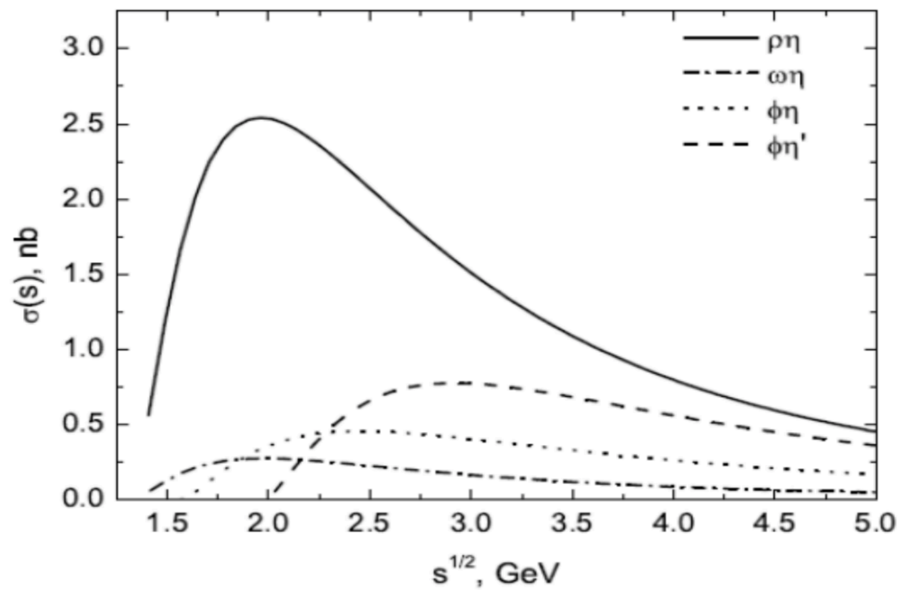
- The states with $J^{PC} = 1^{--}$ include ϕ(2170), ρ(2150) and so on. ϕ(2170) is interpreted as a $s\bar{s}g$ hybrid; a $2^3D_1 s\bar{s}$ state; or a $s\bar{s}s\bar{s}$ tetraquark state.

- Theorists have predicted a neat resonance peak around 2.150 GeV in the three-meson system ϕK^+K^- (the solid). Experimental data is from BABAR Collaboration.



$e^+e^- \to Y(2175) \to \phi f_0(980) \to \phi K^+K^-$

Int. J. Mod. Phys. A. 23, 14 (2009)



Y(2175)

- **Theorists have studied different decay modes of Y(2175) as shown in the table. So we want to distinguish these theory modes by measuring cross section line shape of $e^+e^- \to \phi\, \eta'$.**

$Y(2175)$ as $2\,^3D_1 s\bar{s}$ quarkonium			$Y(2175)$ as $s\bar{s}g$ hybrid [2]	$Y(2175)$ as $3\,^3S_1$ $s\bar{s}$ quarkonium [6]
Decay modes	Γ_{LJ} in $^3P_0$ model	Γ_{LJ} in flux tube model	In flux tube model	In $^3P_0$ model
KK	$\Gamma_{P0}=9.8$	$\Gamma_{P0}=23.1$	0	0
K^*K	$\Gamma_{P1}=1.3$	$\Gamma_{P0}=11.7$	3.7	20
$\phi\eta$	$\Gamma_{P1}=0$	$\Gamma_{P1}=0$	1.2	21
$\phi\eta'$	$\Gamma_{P1}=2.9$	$\Gamma_{P1}=2.8$	0.4	11
K^*K^*	$\Gamma_{P0}=0.76$	$\Gamma_{P0}=0$	0	102
	$\Gamma_{P1}=0^*$	$\Gamma_{P1}=0^*$		
	$\Gamma_{P2}=0.15$	$\Gamma_{P2}=0$		
	$\Gamma_{F2}=17.2$	$\Gamma_{F2}=23.5$		
$K(1460)K$	$\Gamma_{P0}=58.3$	$\Gamma_{P0}=50.2$	0	29
$K^*(1410)K$	$\Gamma_{P1}=31.9$	$\Gamma_{P1}=26.0$	23	93
$h_1(1380)\eta$	$\Gamma_{S1}=3.6$	$\Gamma_{S1}=3.5$	0	8
$K_1(1270)K$	$\Gamma_{S1}=2.3$	$\Gamma_{S1}=20.5$	35.3	58
	$\Gamma_{D1}=19.6$	$\Gamma_{D1}=25.9$		
$K_1(1400)K$	$\Gamma_{S1}=3.0$	$\Gamma_{S1}=0.8$	70.1	26
	$\Gamma_{D1}=5.6$	$\Gamma_{D1}=8.6$		
$K_2(1430)K$	$\Gamma_{D2}=10.8$	$\Gamma_{D2}=15.3$	15.0	9
$\Gamma_{\rm tot}$	167.21	211.9	148.7	378

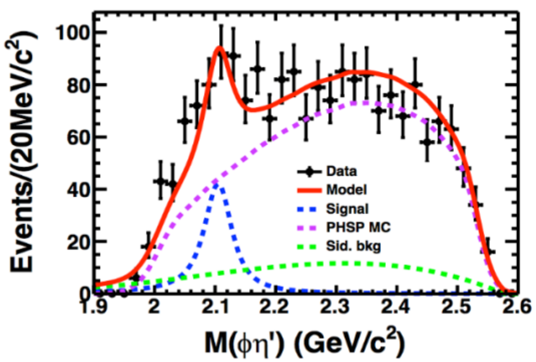
Phs. Lett. B 657,49 (2007)

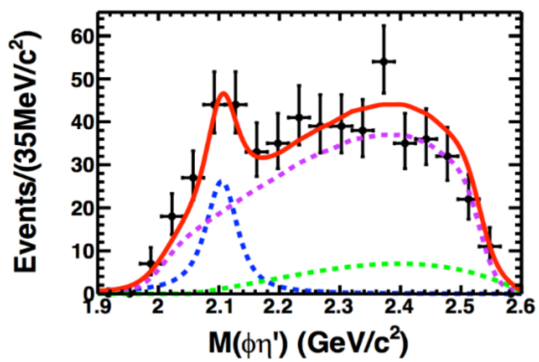
Observation of ϕ (2170) $\longrightarrow \phi\eta'$

- From 232fb^{-1} of BABAR data, signal of $e^+e^- \rightarrow \gamma_{ISR}\ \phi\eta'$ are observed. Because of the low statistics, no further study is carried out.

- The following result is from $J/\psi \longrightarrow \eta\ \phi\eta'$ process.(Yunfei Long)

$\eta' \rightarrow \pi^+\pi^-\gamma$



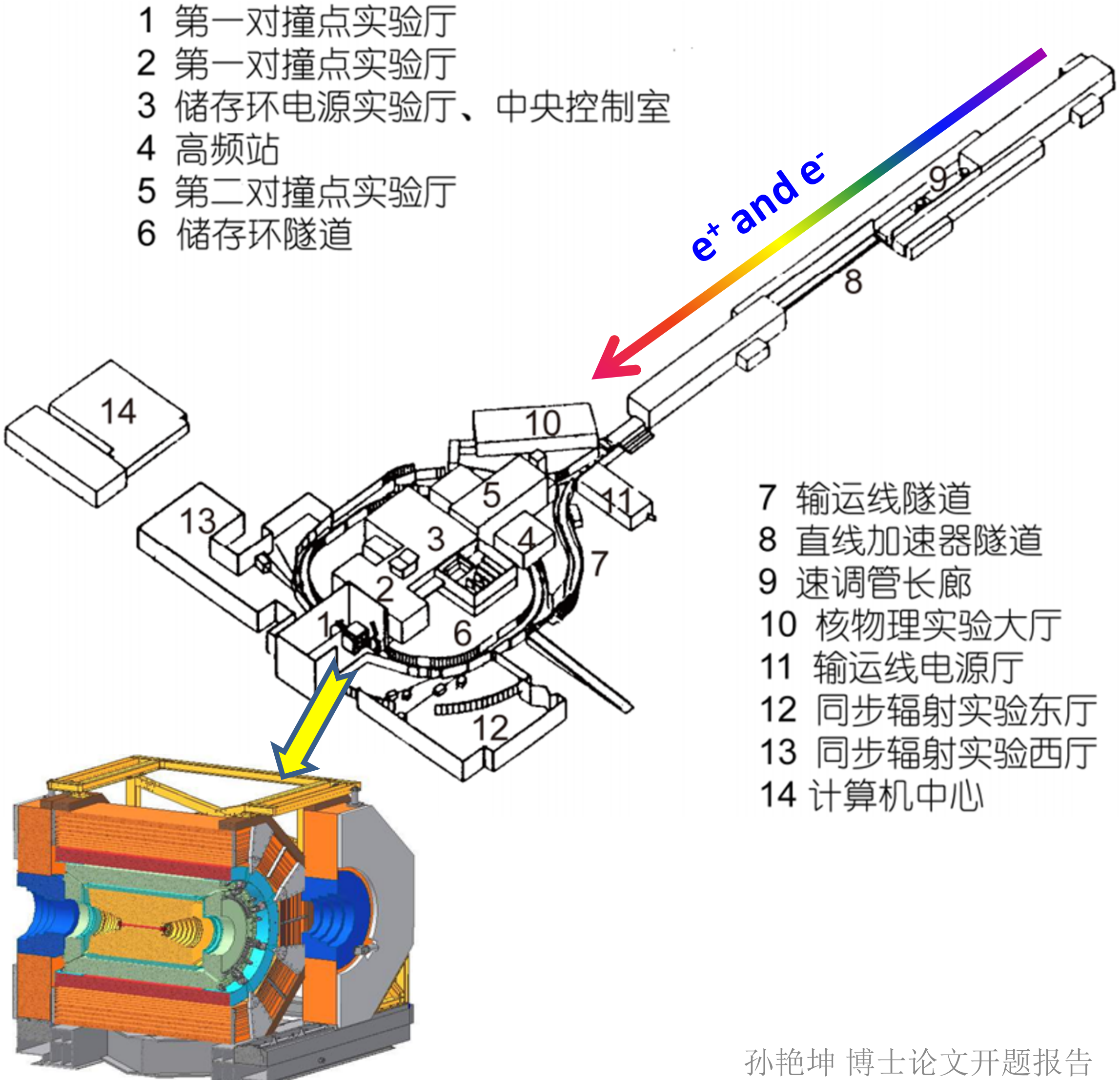


$\eta' \rightarrow \eta\pi^+\pi^-$

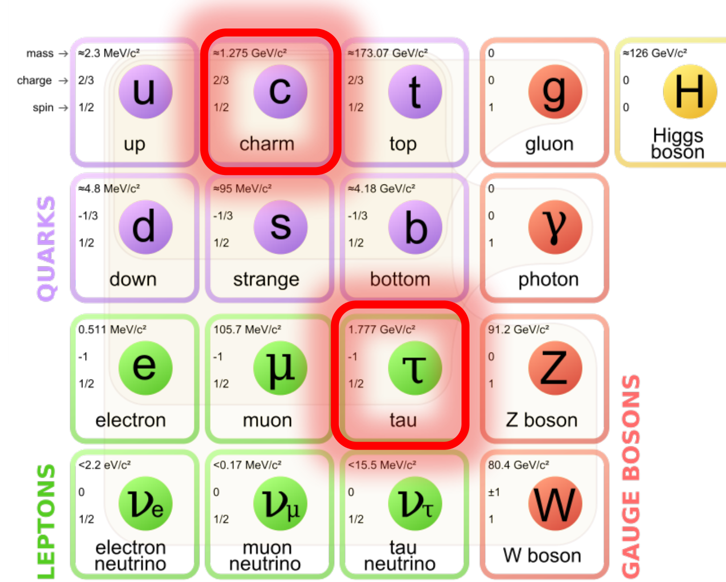
Final states	mean (MeV/c^2)	Γ (MeV/c^2)	N_{sig}	N_{bkg1}	$\chi^2/ndof$
First ($\eta' \rightarrow \gamma\pi^+\pi^-$)	2109.0 ± 5.2	48 ± 10	162 ± 27	1535 ± 49	1.40
Second ($\eta' \rightarrow \eta\pi^+\pi^-$)	2109.0 ± 5.2	48 ± 10	63 ± 15	428 ± 26	0.99

http://indico.ihep.ac.cn/event/6754/contribution/1/material/slides/0.pdf

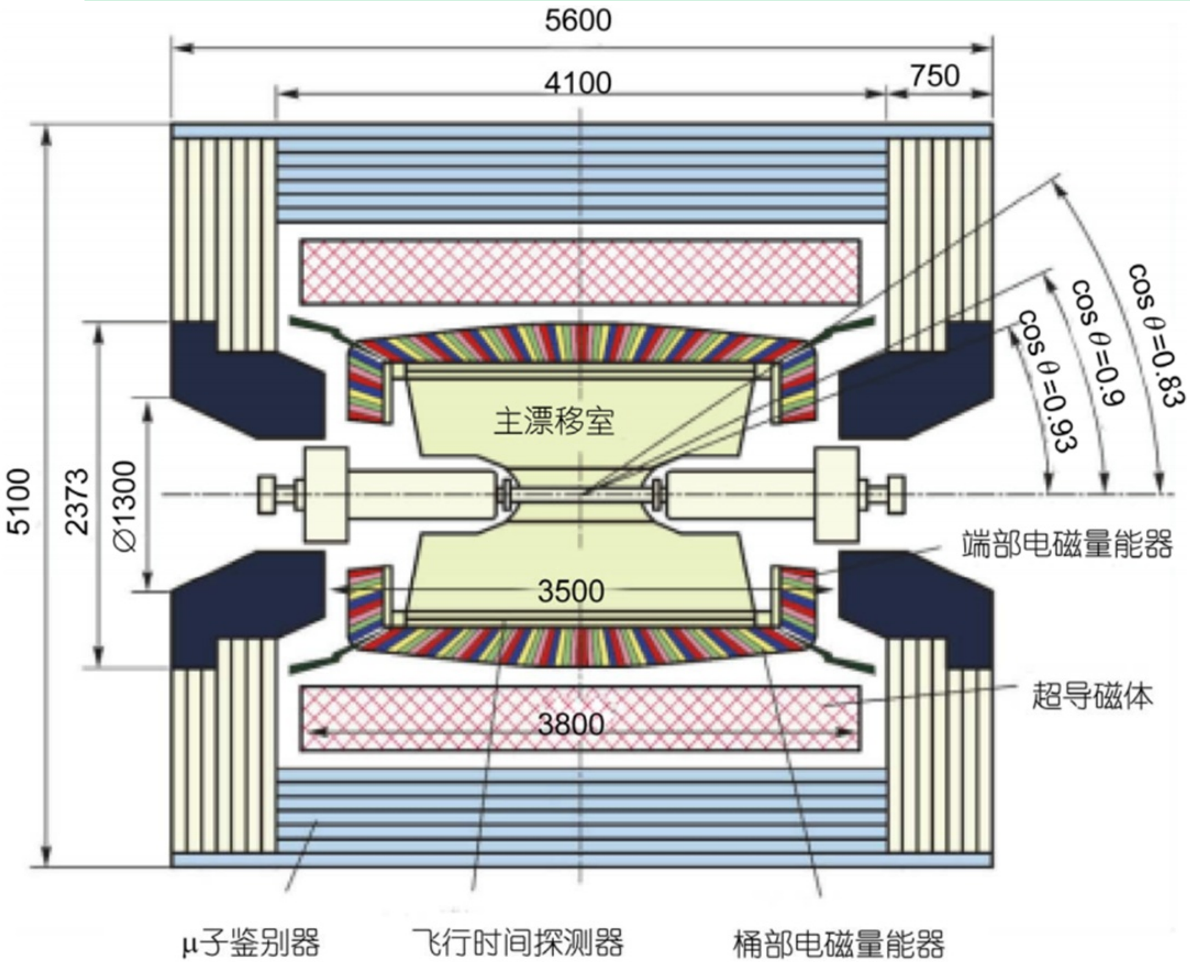
Beijing Electron Positron Collider II [BEPCII]



- E_{beam}: 1.0~2.3 GeV
- **Double ring:** e^+ and e^-
- **Multi-bunch:** 93
- **Peak Luminosity:** $1.0\times10^{33}\ cm^{-2}s^{-1}$ @3770GeV



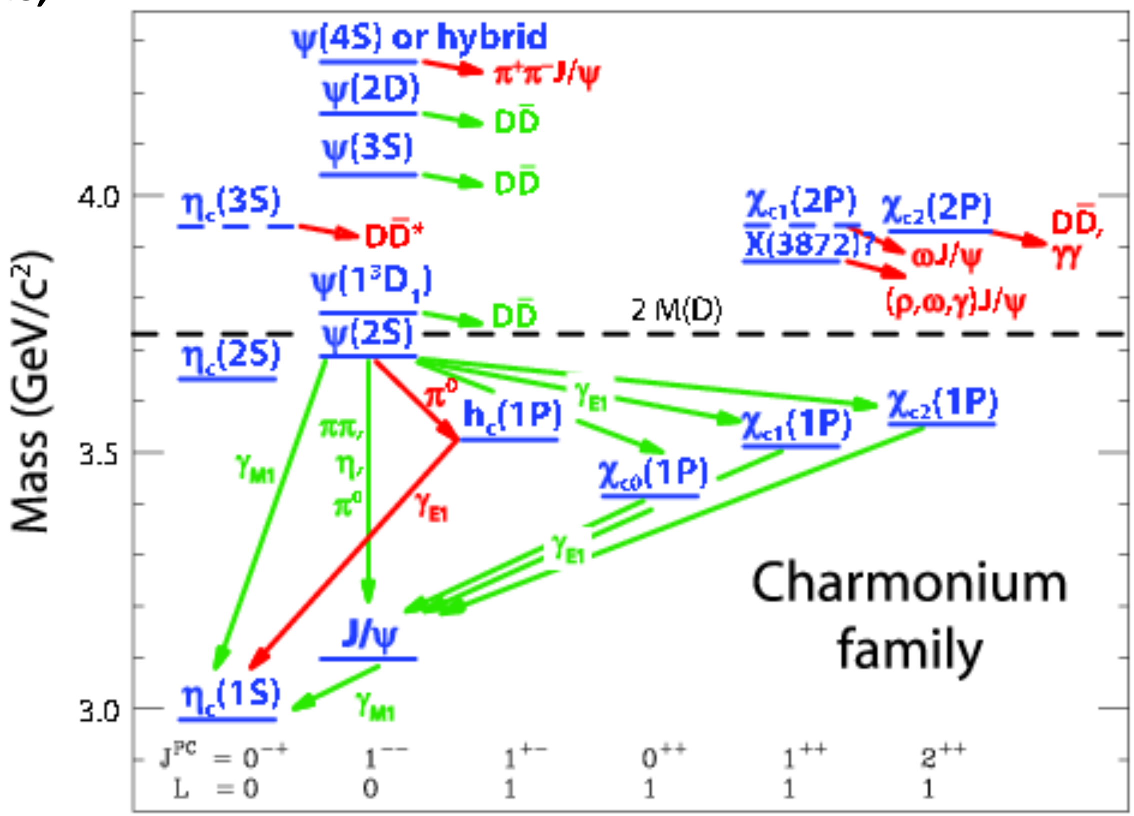
BeiJing Spectrometer III
[BESIII]



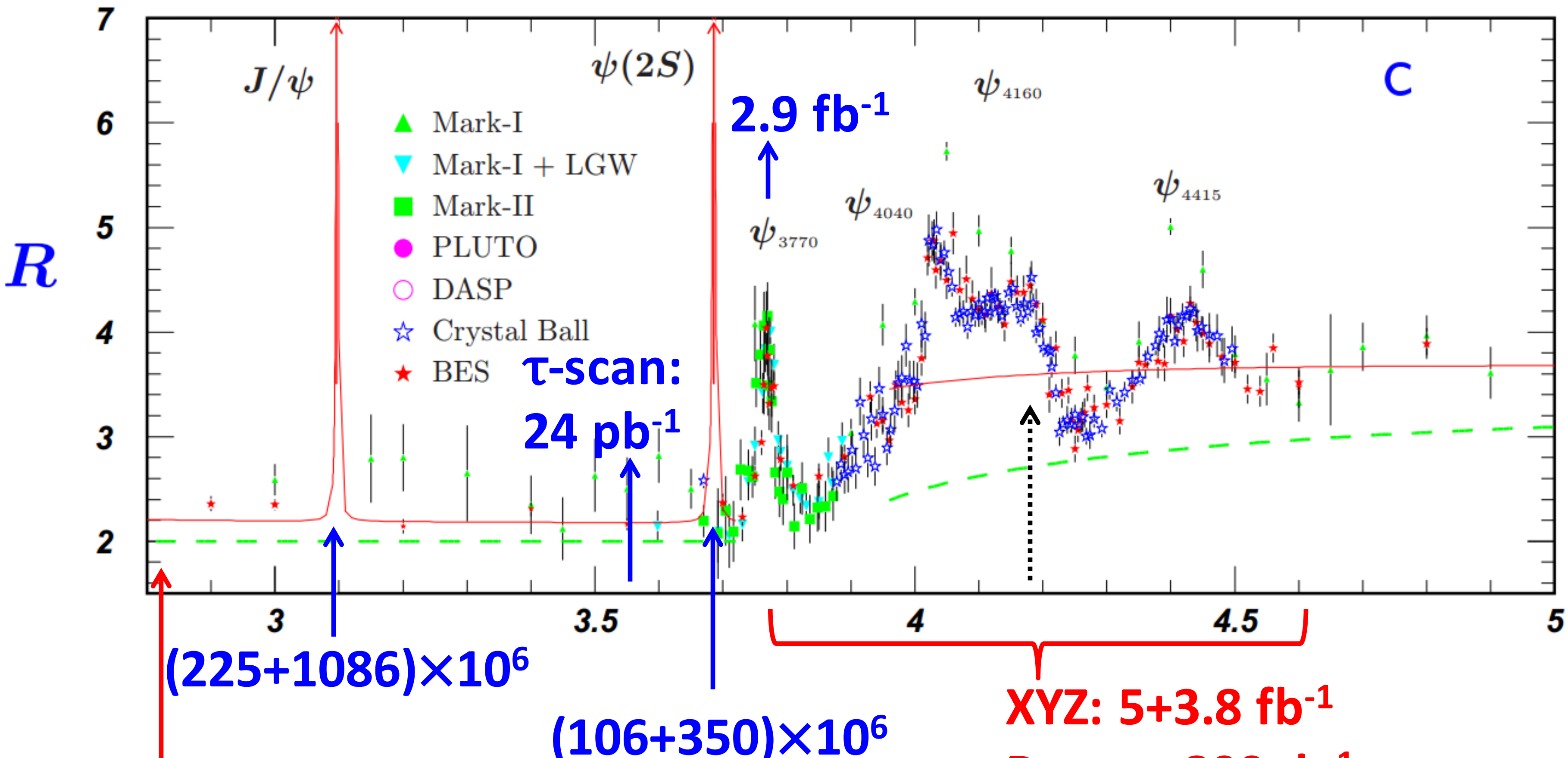
- **MDC: (He/C_3H_8 = 60/40)**
  - ✓σ_{xy}=130μm, dE/dx~6%
  - ✓σ_p/p =0.5% at 1GeV
- **TOF: (Plastic scintillator)**
  - ✓σ_{time}(barrel)=80ps
  - ✓σ_{time}(endcap)=110ps
- **EMC: (CsI(Tl) crystal)**
  - ✓σ_E/E(barrel)=2.5% at 1GeV
  - ✓σ_E/E(endcap)=5% at 1GeV
- **SC magnet: (B = 1T)**
- **RPC μ Counter: (μ/π PID)**
  - ✓Barrel: 9 layers
  - ✓Endcaps: 8 layers
  - ✓ $\sigma_{spatial}$ =2.0 cm

Physics at BESIII

- **Charmonium spectroscopy and decays:**
  - ✓Test of QCD: $(\gamma/\pi\pi/\eta/\pi^0)$transitions;
  - ✓Studies of XYZ states;
- **Light hadrons:**
  - ✓Hadron spectroscopy;
  - ✓Search "exotic" hadrons: guleball, hybrid, tetraquarks …
- **Charm physics:**
  - ✓CKM matrix, semi-leptonic decay;
  - ✓Decay constants f_D and f_Ds;
  - ✓D^0-$\bar{D}^0$ mixing, CP violation;
- **R-QCD:**
  - ✓R measurement;
  - ✓τ-physics;
  - ✓Form factor of hadrons.



Data samples at BESIII



➢ R-scan:

√s = 2.000-3.080GeV: ~650 pb^{-1}

Measurements of cross sections of hadron processes

1. Data sets and MC simulation

2. Observation of ϕ (2170)$\rightarrow \eta' \phi$

3. Study of $e^+e^- \rightarrow \phi K^+K^-$

4. Study of $e^+e^- \rightarrow K^+K^- K^+K^-$

Data sets and MC simulation

1. BOSS665p01.

2. R-scan data sets: (2015)

√s (GeV)	Lum. (pb^{-1})
3.080	126.185
3.020	17.290
3.000	15.881
2.981	16.071
2.950	15.942
2.900	105.253

√s (GeV)	Lum. (pb^{-1})
2.800	1.008
2.700	1.034
2.6464	34.003
2.6444	33.722
2.500	1.098
2.396	66.869

√s (GeV)	Lum. (pb^{-1})
2.3864	22.549
2.3094	21.089
2.2324	11.856
2.200	13.699
2.175	10.625
2.150	2.841

√s (GeV)	Lum. (pb^{-1})
2.125	108.49
2.100	12.167
2.050	3.343
2.000	10.074

3. 100K Signal MC by “ConExc” at each energy point.

Observation of $\phi(2170) \to \eta' \phi$

Event selection ($\eta' \to \pi^+\pi^-\gamma$, $\phi \to K^+K^-$)

- **Good Charged Track:**

  $|V_z| < 10.0$ && $|V_r| < 1.0$ && $|\cos\theta| < 0.93$;

  N_{Good} ==3||4; (To improve statistics: Missing one Kaon.)

- **PID with dE/dx and TOF:**

  Pion: prob_π >prob_K && prob_π>prob_p;

  $N(\pi^+) = N(\pi^-) = 1$;

  Kaon: prob_K>prob_p && prob_K>prob_π;

  At least one Kaon are indentified:

  $N(K^+) = N(K^-) = 1$; or $N(K^+) = 1$ && $N(K^-) = 0$; or $N(K^+) = 0$ && $N(K^-) = 1$;

- **Good Photon:**

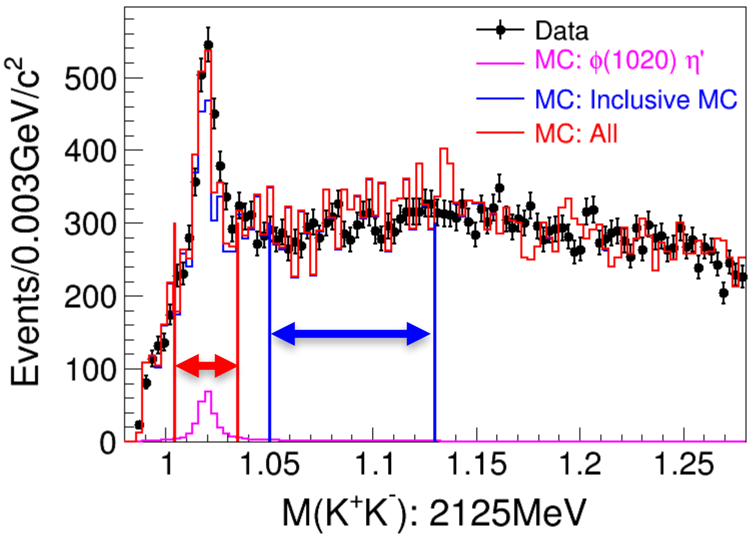
  $E_{barrel} > 25$MeV; $E_{endcap} > 50$MeV; $0 \le Time \le 14$(Unit 50ns);

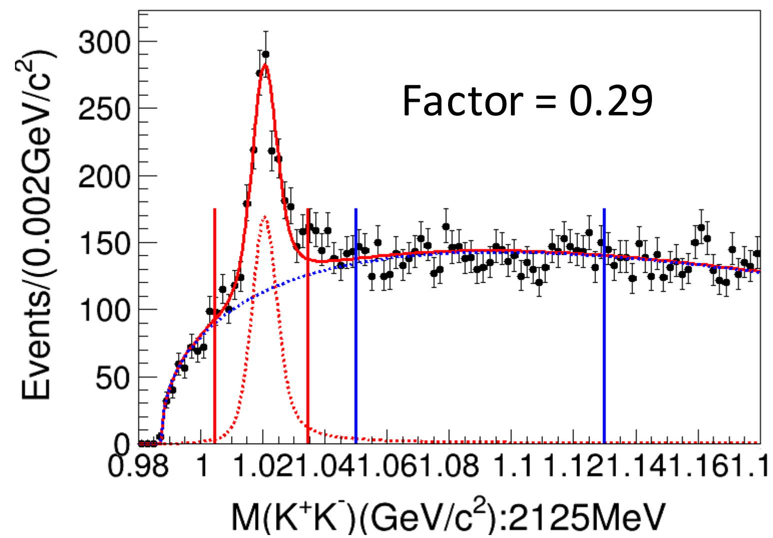
  $N_\gamma \ge 1$.

- **Vertex fit ($\pi^+\pi^-K^\pm$).**

- **1C kinematic fit ($\pi^+\pi^-K^\pm\gamma$):** $\chi^2_{1C}(K^+K^-K^\pm\gamma) < 20$;

@2125MeV: $L=108.49\,pb^{-1}$



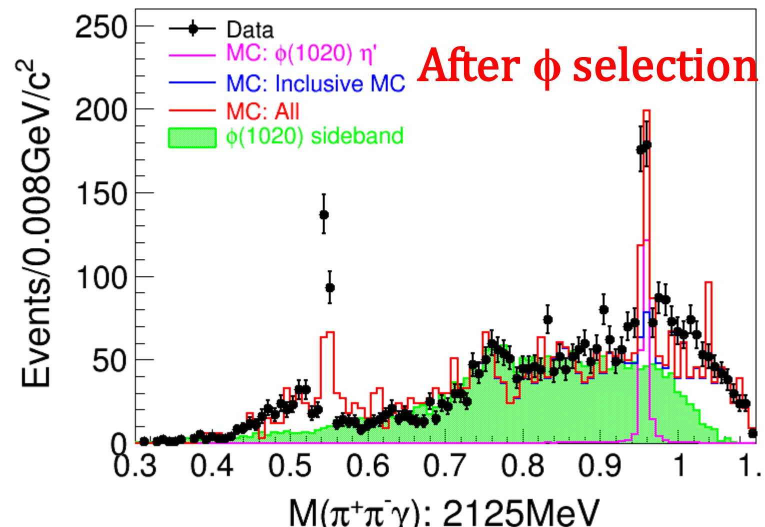


(1) $\chi^2_{1C}(K^+K^-\pi^+\pi^-\gamma) < 20$;

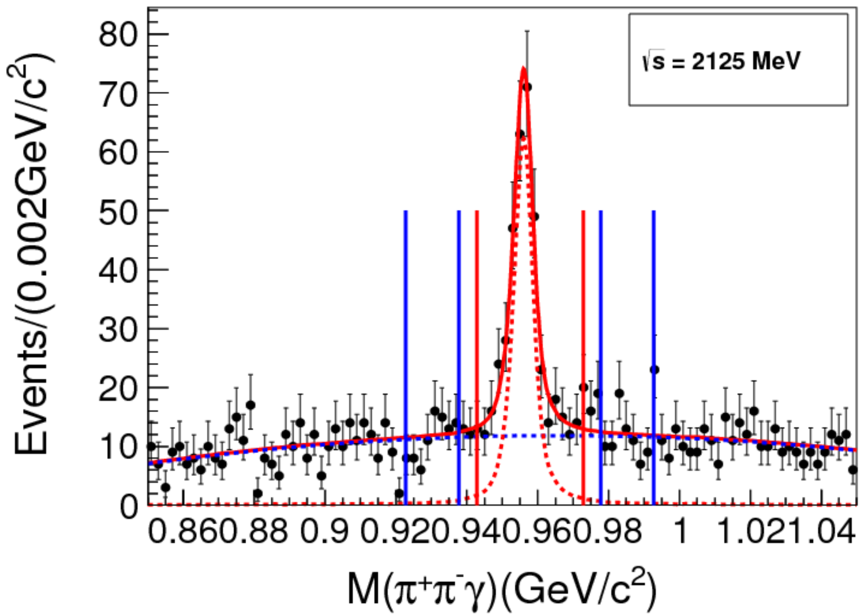
(2) $|M(K^+K^-)-M_\phi|<0.015GeV/c^2$;

(3) $E(\gamma)>0.07GeV/c^2$;

There is no peaking background. We can get the number of signal events by fitting invariant mass distribution.



Fitting Method



(1) $\chi^2_{1C}(K^+K^-\pi^+\pi^-\gamma) < 20$;

(2) $|M(K^+K^-)-M_{\phi}|<0.015GeV/c^2$;

(3) $E(\gamma)>0.07GeV/c^2$;

(3) η' Fitting :

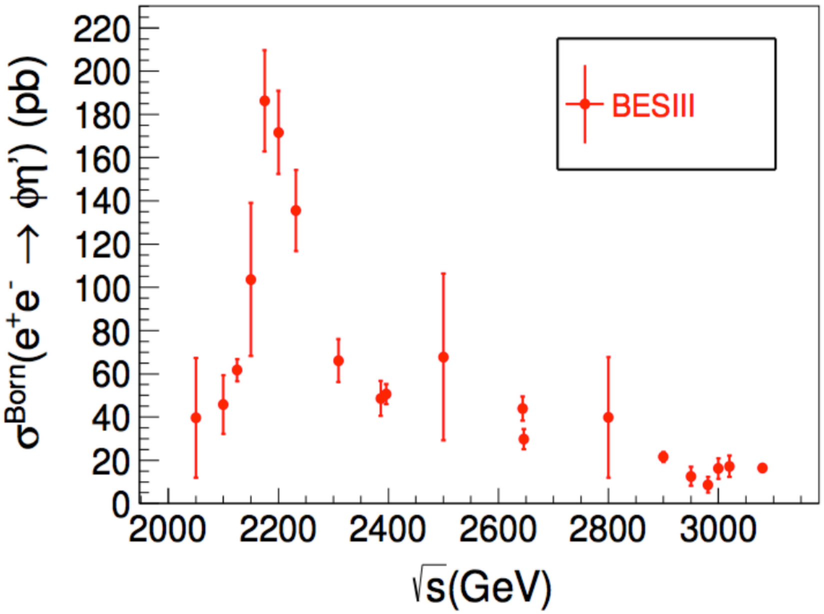
- Signal: MC shape $\otimes$ Gaussian;
- Background: 2rd Poly;
- N=267.7 $\pm$ 22.2

Signal region is between red lines;
Sideband region are between blue lines.
Factor2 = 1.02

$\sigma(e^+e^- \to \phi\eta')$: with $\eta' \to \pi^+\pi^-\gamma$

$$\sigma^B = \frac{N^{obs}}{\mathcal{L}_{int} \cdot (1+\delta) \cdot \epsilon \cdot \mathcal{B}(\phi \to K^+K^-) \cdot \mathcal{B}(\eta' \to \pi^+\pi^-\gamma)},$$

$\sqrt{s}$ (GeV)	L (pb^{-1})	$N^{obs}(\phi)$	$(1+\delta)$	ϵ	$\sigma(pb)$(stat±sys)
3.080	126.19	90.2±10.3	0.9056	0.3385	16.4±1.9±1.0
3.020	17.29	14.5±4.1	1.0080	0.3400	17.2±4.9±1.2
3.000	15.88	12.6±3.7	1.0109	0.3415	16.2±4.7±1.2
2.981	16.07	6.9±2.9	1.0124	0.3429	8.7±3.7±0.9
2.950	15.94	9.9±3.4	1.0130	0.3425	12.6±4.3±0.8
2.900	105.25	113.3±12.0	1.0110	0.3463	21.6±2.3±1.3
2.800	1.01	2.0±1.4	0.9964	0.3517	39.8±27.9±2.4
2.646	34.00	50.4±8.0	1.0093	0.3462	29.8±4.7±1.8
2.644	33.72	73.9±9.5	1.0091	0.3476	43.9±5.6±2.4
2.500	1.10	3.7±2.1	1.0069	0.3471	67.8±38.5±4.5
2.396	66.87	163.9±15.0	0.9939	0.3428	50.6±4.6±3.0
2.386	22.55	52.7±8.8	0.9923	0.3408	48.6±8.1±3.8
2.309	21.09	65.6±9.8	0.9772	0.3386	66.1±9.9±4.3
2.232	11.86	73.6±10.2	0.9720	0.3313	135.5±18.8±11.8
2.200	13.70	105.5±11.8	0.9640	0.3269	171.7±19.2±10.1
2.175	10.63	87.4±11.0	0.9567	0.3243	186.3±23.4±11.6
2.150	2.84	12.3±4.2	0.9483	0.3098	103.6±35.4±6.9
2.125	108.49	267.7±22.2	0.9382	0.2995	61.7±5.1±3.9
2.100	12.17	21.3±6.3	0.9258	0.2899	45.8±13.6±3.8
2.050	3.34	4.3±3.0	0.8878	0.2569	39.6±27.7±4.3



There is a significant structure at 2.2 GeV.

Systematic uncertainty

- **Luminosity**
  - Measured by large angle Bhabha events, BAM-157 and BAM-218
- **Tracking**
  - Control sample $K^+K^-\pi^+\pi^-$ at 3.08GeV and 2.90GeV
- **PID efficiency**
  - Control sample $K^+K^-\pi^+\pi^-$ at 3.08GeV and 2.90GeV
- **kinematic fit**
  - Estimated by correcting tracking parameters , parameters from BAM-229
- $(1+\boldsymbol{\delta}) = (1+\boldsymbol{\delta})^{ISR} \times (1+\boldsymbol{\delta})^{VP}$
  - Line shape iteration: difference between last two iteration

Systematic uncertainty

- **Fitting procedure**
  - Signal shape:
    - MC shape$\otimes$ Gaussian(free) $\rightarrow$ MC shape $\otimes$ Gaussian(fixed+1σ)
  - Fitting range:
    - [0.85, 1.05] $\rightarrow$[0.80, 1.10] GeV/c^2
  - Background shape
    - 2th polynomial $\rightarrow$ 3th polynomial
- **Mass window of ϕ**
  - **$|M(K^+K^-)-M_\phi|<0.015GeV/c^2 \rightarrow |M(K^+K^-)-M_\phi|<0.020GeV/c^2$**
- **Energy of gamma**
  - $E(\gamma)\geq0.07GeV \rightarrow E(\gamma)\geq0.06GeV$

Systematic uncertainty

- **Photon efficiency**
  - From the job of Jake and Gao Xinlei
- **Branch ratio**
  - **PDG2014, about 2.0%**
- **MC statistic**
  - Calculated by the following format

$$\sigma_{MCstat} = \frac{1}{\sqrt{N}} \cdot \sqrt{\frac{1-\varepsilon}{\varepsilon}}$$

Take 2.125 GeV as an example, we calculate the total systematic uncertainty.

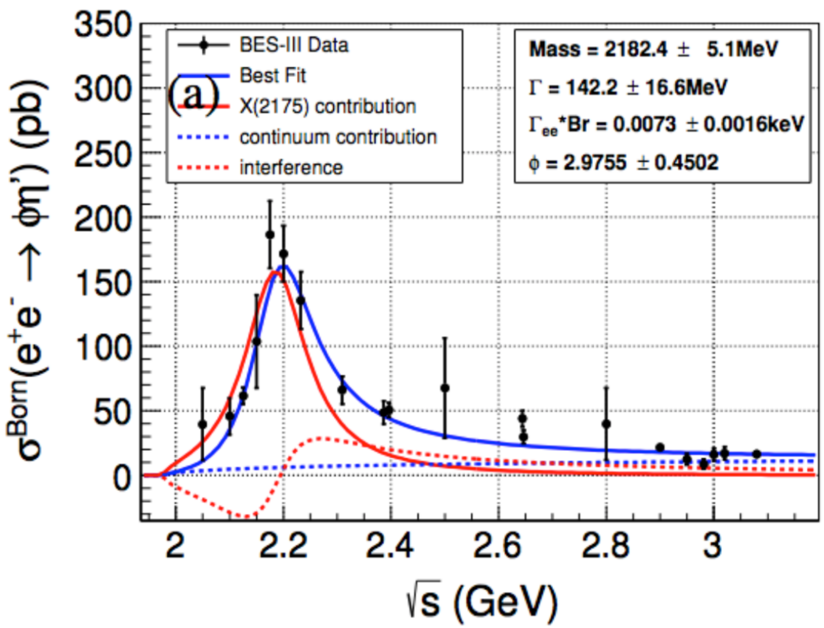
Source	Value
Luminosity	1.0
Tracking	3.0
Photon	1.0
PID	3.0
Kinematic fit	2.6
Signal shape	0.3
Background shape	0.4
Fitting range	1.5
ISR factor	0.8
Branching fraction	2.0
Mass window of ϕ	0.6
Energy of γ	2.2
MC	0.5
Combine	6.3

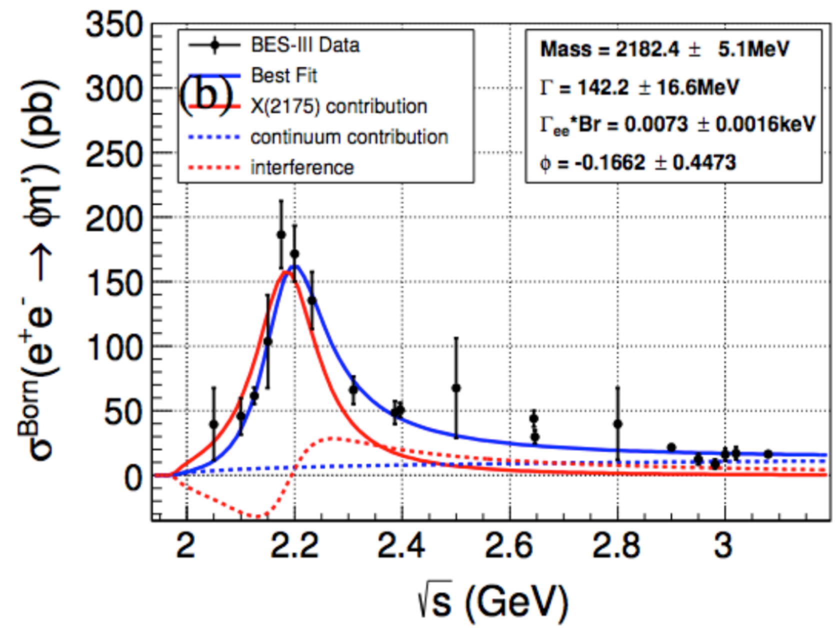
Systematic uncertainty

$\sqrt{s}$ (GeV)	Lum	Tracking	Photon	PID	Kinematic	Signal	BG	Range	ISR	ϕ Cut	γ Cut	MC	Branch	Total
3080.0	1.0	3.0	1.0	3.0	0.1	0.9	2.0	1.7	1.0	0.6	0.3	0.4	2.0	5.8
3020.0	1.0	3.0	1.0	3.0	0.0	0.7	2.1	0.5	0.2	4.2	0.0	0.4	2.0	6.8
3000.0	1.0	3.0	1.0	3.0	0.1	0.0	0.8	0.6	0.6	5.1	0.7	0.4	2.0	7.2
2981.0	1.0	3.0	1.0	3.0	0.0	0.0	0.0	5.6	0.2	7.7	2.0	0.4	2.0	10.9
2950.0	1.0	3.0	1.0	3.0	0.1	1.0	0.0	2.9	0.3	0.7	1.6	0.4	2.0	6.1
2900.0	1.0	3.0	1.0	3.0	0.3	1.3	0.3	1.6	0.1	3.2	0.1	0.4	2.0	6.2
2800.0	1.0	3.0	1.0	3.0	0.5	0.0	0.0	0.2	0.4	3.5	0.6	0.4	2.0	6.1
2646.0	1.0	3.0	1.0	3.0	0.8	0.0	1.4	1.6	0.2	1.8	1.7	0.4	2.0	6.0
2644.0	1.0	3.0	1.0	3.0	0.8	0.0	0.8	0.9	0.0	2.0	0.7	0.4	2.0	5.5
2500.0	1.0	3.0	1.0	3.0	1.6	0.0	2.7	2.4	0.9	2.0	0.4	0.4	2.0	6.7
2396.0	1.0	3.0	1.0	3.0	1.6	0.1	2.0	0.9	0.6	1.6	1.0	0.4	2.0	6.0
2386.0	1.0	3.0	1.0	3.0	1.9	2.5	4.7	1.4	0.3	0.5	1.4	0.4	2.0	7.8
2309.0	1.0	3.0	1.0	3.0	1.9	2.0	2.9	0.6	0.2	0.6	1.2	0.4	2.0	6.5
2232.0	1.0	3.0	1.0	3.0	2.4	1.9	1.5	1.1	0.1	6.2	0.6	0.4	2.0	8.7
2200.0	1.0	3.0	1.0	3.0	2.3	0.8	1.6	1.3	0.7	0.1	0.4	0.5	2.0	5.9
2175.0	1.0	3.0	1.0	3.0	2.0	1.5	0.7	2.1	1.0	1.1	0.7	0.5	2.0	6.2
2150.0	1.0	3.0	1.0	3.0	2.3	0.0	0.8	1.2	0.8	1.1	3.4	0.5	2.0	6.7
2125.0	1.0	3.0	1.0	3.0	2.6	0.3	0.4	1.5	0.8	0.6	2.2	0.5	2.0	6.3
2100.0	1.0	3.0	1.0	3.0	2.7	0.0	0.9	5.7	0.9	0.6	1.2	0.5	2.0	8.2
2050.0	1.0	3.0	1.0	3.0	3.0	0.0	0.0	8.9	0.1	0.6	2.5	0.5	2.0	10.9

In this table, we calculate systematic uncertainty at all of energy points.

Fit of cross section line shape





- Signal: a phase-space modified Breit-Wigner function:

$$BW(\sqrt{s}) = \frac{M_R}{\sqrt{s}} \frac{\sqrt{12\pi\Gamma^R_{e^+e^-}\mathcal{B}_R(\phi\,\eta')\Gamma^R_{tot}}}{s - M_R^2 + iM_R\Gamma^R_{tot}} \cdot \sqrt{\frac{PS(s)}{PS(M_R)}}$$

- Background: phase-space contribution: $\sqrt{PS(s)}$

$$|A(\sqrt{s})|^2 = |\sqrt{PS(s)} + e^{i\phi} \times BW(\sqrt{s})|^2$$

$significance = 12.47\sigma$, first observation!

Study of $e^+e^- \rightarrow \phi K^+K^-$

Event selection

- **Good Charged Track:**

  $|V_z| < 10.0$ && $|V_r| < 1.0$ && $|\cos\theta| < 0.93$;

  N_{Good} ==3||4; (To improve statistic uncertainty: Missing one Kaon.)

- **PID with dE/dx and TOF:**

  Kaon: prob_K>prob_p && prob_K>prob_π;

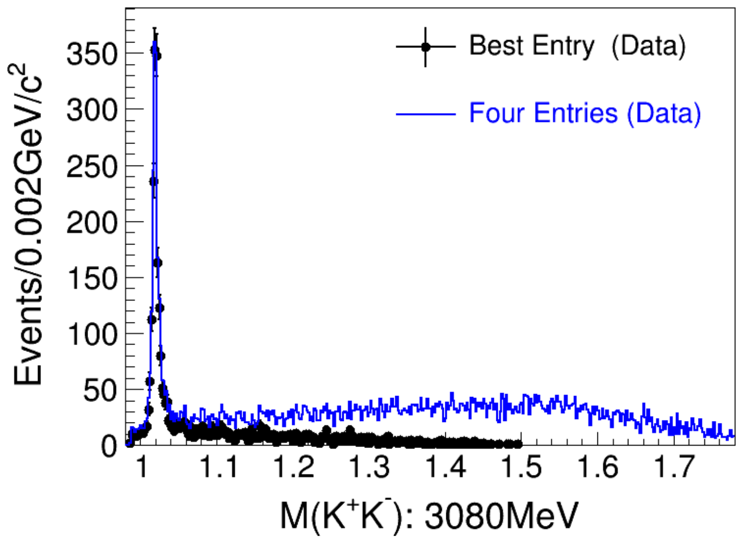
  At least three Kaons are indentified:

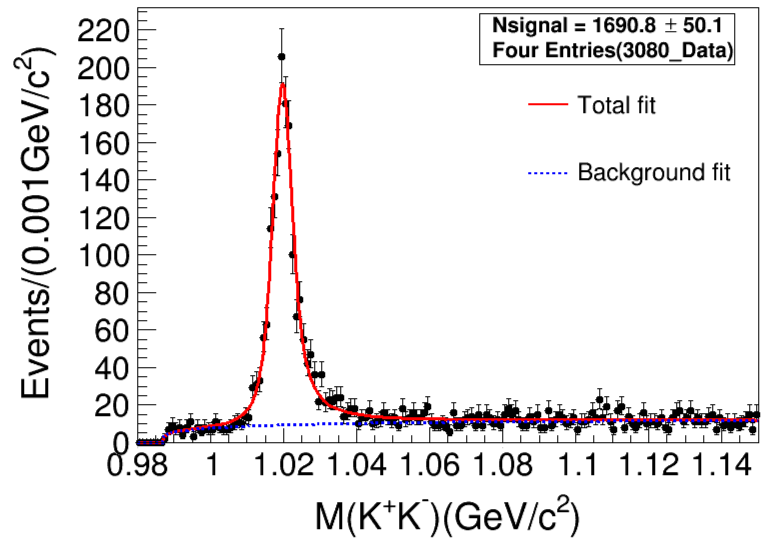
  N(K+) = N(K-) = 2; or N(K+) = 2 && N(K-) = 1; or N(K+)=1 && N(K-) = 2;

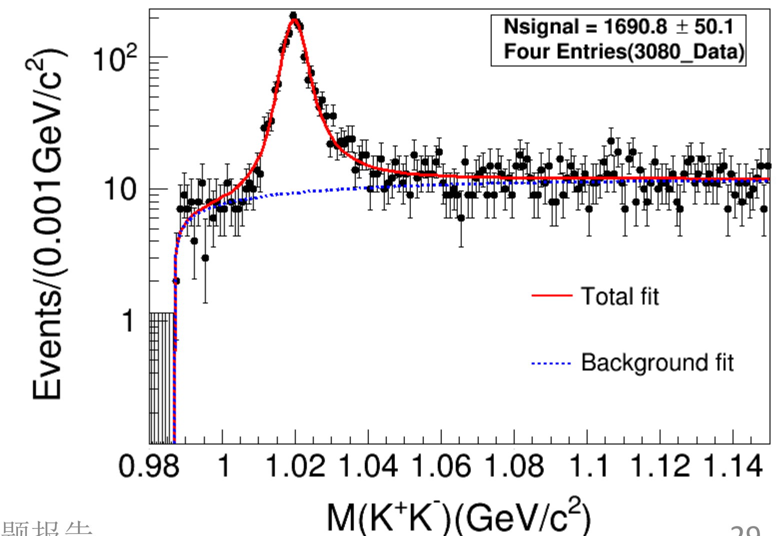
- **Vertex fit ($K^+K^-K^\pm$).**

- **1C kinematic fit ($K^+K^-K^\pm$):** ($\chi^2_{1C}(K^+K^-K^\pm) < 20$)

Signal extraction@3080MeV







(1) $\chi^2_{1C}(K^+K^-K^+K^-) < 20$;

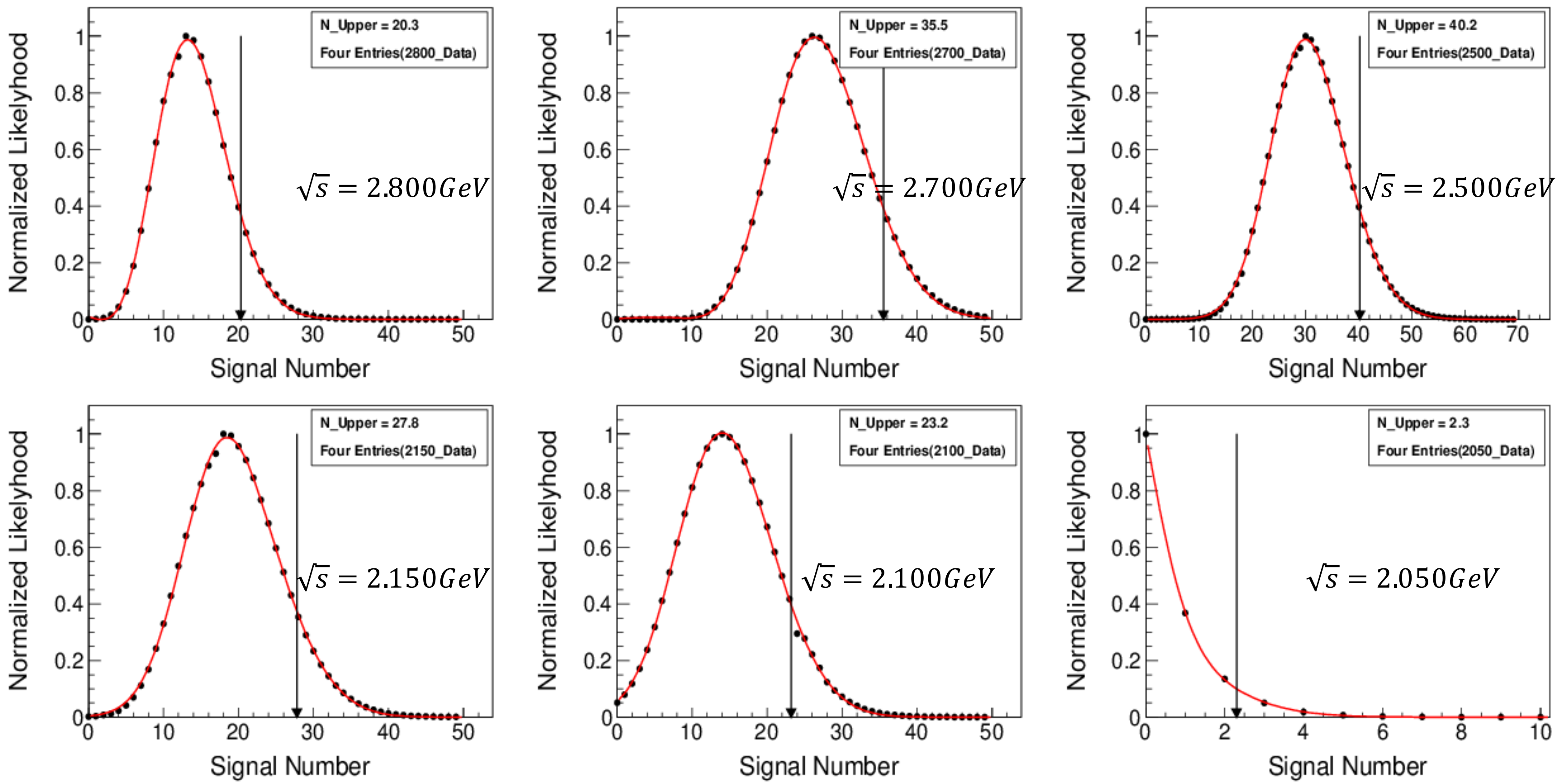
(2) $\phi(1020)$ Fitting :

Signal: P-wave BW⊗ Gaussian;

Background: Argus;

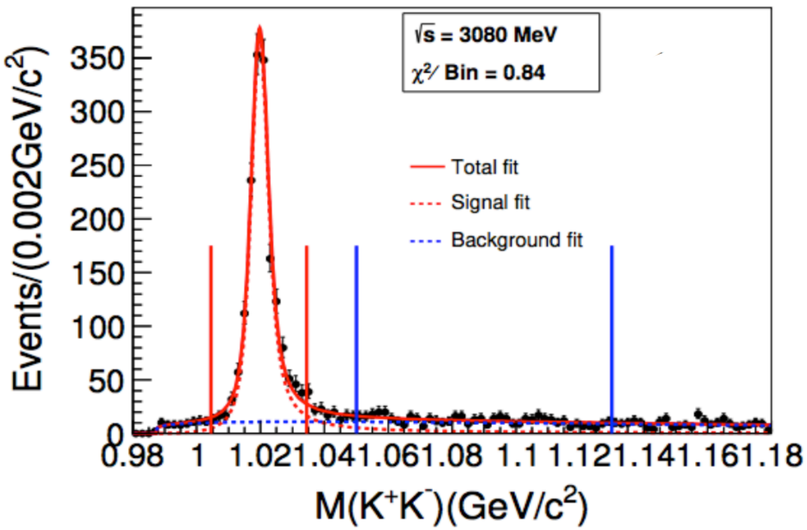
N=1690.8± 50.1

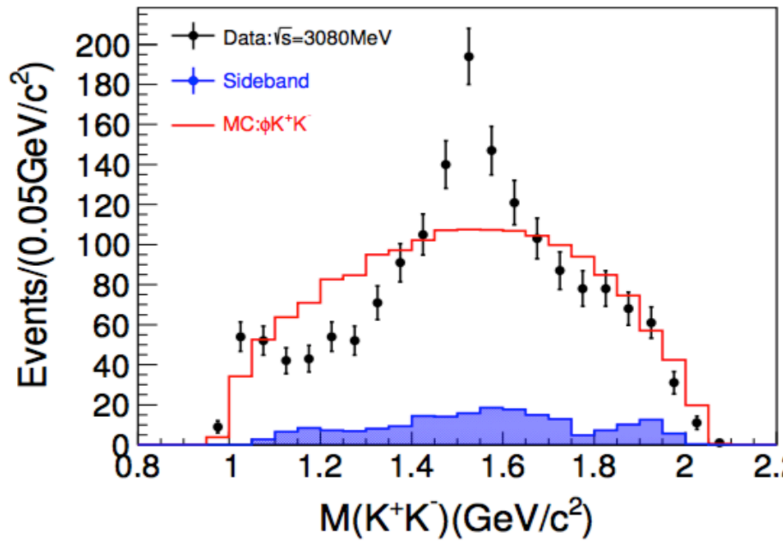
Upper Limit of ϕK^+K^-



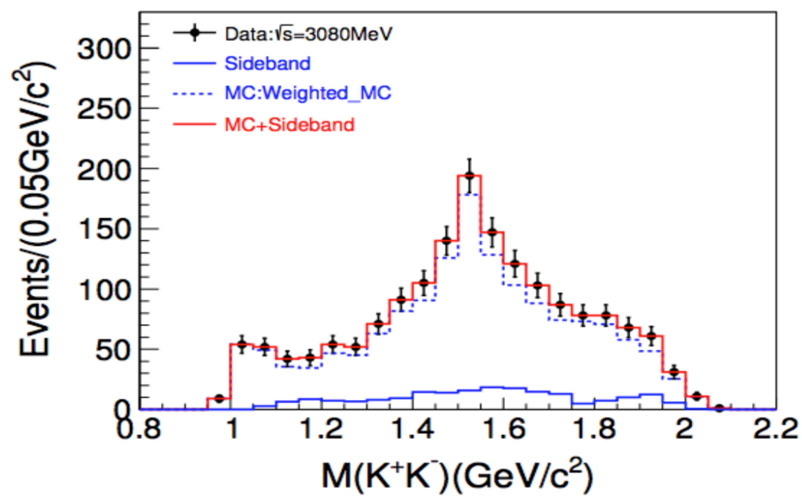
- ➢ Normalized likelihood value distributions versus the number of signal events.
- ➢ The upper limit determined by finding out the number of signal events corresponding to 90 % of the likelihood distribution.

Weighted MC@3080MeV





$$|M(K^+K^-) - 1.01946| \le 0.015\text{GeV}$$

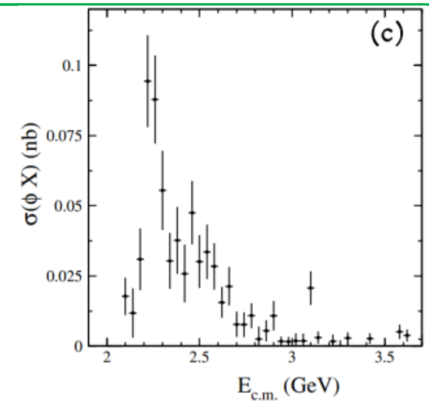


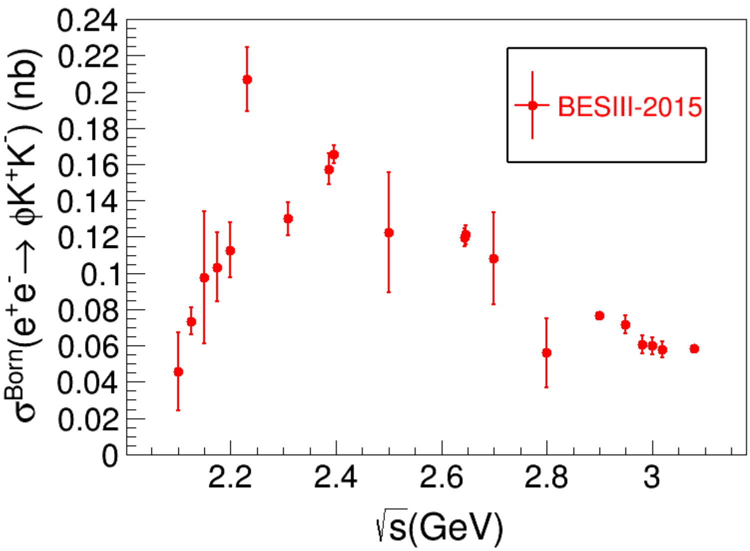
- ✓ The method of event-by-event weight is applied for M(K+K-) from ϕK^+K^-. The weight factor obtained by calculating the ratio of the number of signal events from data and MC bin-by-bin.

- ✓ Raw_MC from $e^+e^- \to \phi K^+K^-$ (PHSP).

Cross section: $\sigma(e^+e^- \to \phi K^+K^-)$

$\sqrt{s}$ (GeV)	L (pb^{-1})	N(ϕ)	$(1+\delta)$	$\epsilon(\%)$	$\sigma(pb)$(stat±sys)
3.080	126.19	1690.8±50.1	0.9656	46.5	58.5±1.7 ± 4.9
3.020	17.29	253.7±19.9	1.0870	47.3	57.7±4.5 ± 4.4
3.000	15.88	242.6±18.8	1.0967	47.1	59.9±4.6 ± 4.7
2.981	16.07	245.9±20.0	1.1022	46.4	60.8±4.9 ± 5.1
2.950	15.94	282.2±20.4	1.1048	45.5	71.7±5.2 ± 6.2
2.900	105.25	2010.8±54.4	1.0989	46.3	76.6±2.1 ± 7.0
2.800	1.01	13.2±4.5	1.0700	44.6	56.1±19.1 ± 7.0
2.700	1.03	26.0±6.1	1.0378	45.9	108.0±25.3 ± 11.3
2.646	34.00	901.3±37.7	1.0222	43.8	121.1±5.1 ± 10.3
2.644	33.72	883.1±37.5	1.0226	43.8	119.7±5.1 ± 10.9
2.500	1.10	25.5±6.9	0.9847	39.4	122.4±33.1 ± 16.8
2.396	66.87	1841.6±56.2	0.9617	35.4	165.4±5.0 ± 17.5
2.386	22.55	573.0±31.6	0.9598	34.4	157.7±8.7 ± 18.4
2.309	21.09	377.0±26.0	0.9485	29.7	130.0±9.0 ± 19.0
2.232	11.86	260.0±22.3	0.8610	25.4	206.7±17.7 ± 24.4
2.200	13.70	137.7±18.7	0.8744	20.5	112.7±15.3 ± 10.3
2.175	10.63	84.5±15.6	0.8713	17.8	103.4±19.1 ± 7.4
2.150	2.84	15.8±5.9	0.8580	13.4	97.4±36.4 ± 20.0
2.125	108.49	309.6±31.5	0.8376	9.3	73.4±7.5 ± 5.9
2.100	12.17	12.9±6.1	0.8094	5.7	45.6±21.6 ± 8.3
2.050	3.34		–	–	





- **Structure around 2.23 GeV?**

(Same behaviors in BABAR results)

Systematic uncertainty

(For Cross section Measurement of $e^+e^- \to \phi K^+K^-$)

$\sqrt{s}$ (GeV)	Lum	Tracking	PID	Kinematic fit	Signal	Background	Range	ISR	Eff	MC	Branch	Others	Total
3.080	1.0	3.0	4.5	1.4	0.7	0.0	1.2	0.1	5.7	0.3	1.1	1.0	8.3
3.020	1.0	3.0	4.5	1.9	2.7	0.8	0.8	0.6	4.0	0.3	1.1	1.0	7.7
3.000	1.0	3.0	4.5	0.7	0.4	1.3	3.0	0.1	4.1	0.3	1.1	1.0	7.9
2.981	1.0	3.0	4.5	2.0	1.7	0.4	1.3	0.1	5.6	0.3	1.1	1.0	8.4
2.950	1.0	3.0	4.5	1.5	2.2	0.3	0.7	0.1	6.0	0.3	1.1	1.0	8.7
2.900	1.0	3.0	4.5	0.3	2.2	0.1	0.1	4.5	5.0	0.3	1.1	1.0	9.2
2.800	1.0	3.0	4.5	6.2	7.1	0.0	0.0	0.0	8.5	0.3	1.1	1.0	12.5
2.700	1.0	3.0	4.5	0.8	7.7	0.0	0.0	0.3	3.9	0.3	1.1	1.0	10.5
2.646	1.0	3.0	4.5	1.6	2.5	0.5	0.9	0.2	5.5	0.3	1.1	1.0	8.5
2.644	1.0	3.0	4.5	0.4	2.5	1.9	2.1	0.3	5.7	0.3	1.1	1.0	9.1
2.500	1.0	3.0	4.5	1.7	6.7	0.0	3.3	0.1	9.8	0.4	1.1	1.0	13.7
2.396	1.0	3.0	4.5	1.0	5.6	0.1	1.6	0.1	6.5	0.4	1.1	1.0	10.6
2.386	1.0	3.0	4.5	0.9	7.3	0.9	2.1	0.4	6.5	0.4	1.1	1.0	11.7
2.309	1.0	3.0	4.5	4.8	12.0	0.8	1.0	0.6	5.3	0.5	1.1	1.0	14.6
2.232	1.0	3.0	4.5	2.9	8.8	0.4	0.0	2.5	4.2	0.5	1.1	1.0	11.8
2.200	1.0	3.0	4.5	1.1	3.6	2.2	2.9	0.5	4.3	0.6	1.1	1.0	9.1
2.175	1.0	3.0	4.5	0.8	2.2	1.2	2.2	0.4	1.7	0.7	1.1	1.0	7.2
2.150	1.0	3.0	4.5	10.5	17.6	5.9	5.9	1.2	1.2	0.8	1.1	1.0	20.5
2.125	1.0	3.0	4.5	1.3	0.0	2.8	3.4	1.8	2.2	1.0	1.1	1.0	8.1
2.100	1.0	3.0	4.5	13.9	7.7	0.0	15.4	0.4	0.7	1.3	1.1	1.0	18.3
2.050	1.0	3.0	4.5	—	—	—	—	—	—	—	—	—	—

Study of $e^+e^- \to K^+K^- K^+K^-$

Event selection($K^+K^- K^+K^-$)

- **Good Charged Track:**

  $|V_z| < 10.0$ && $|V_r| < 1.0$ && $|\cos\theta| < 0.93$;

  N_{Good} ==3||4; (To improve statistic uncertainty: Missing one Kaon.)

- **PID with dE/dx and TOF:**

  Kaon:prob_K>prob_p && prob_K>prob_π;

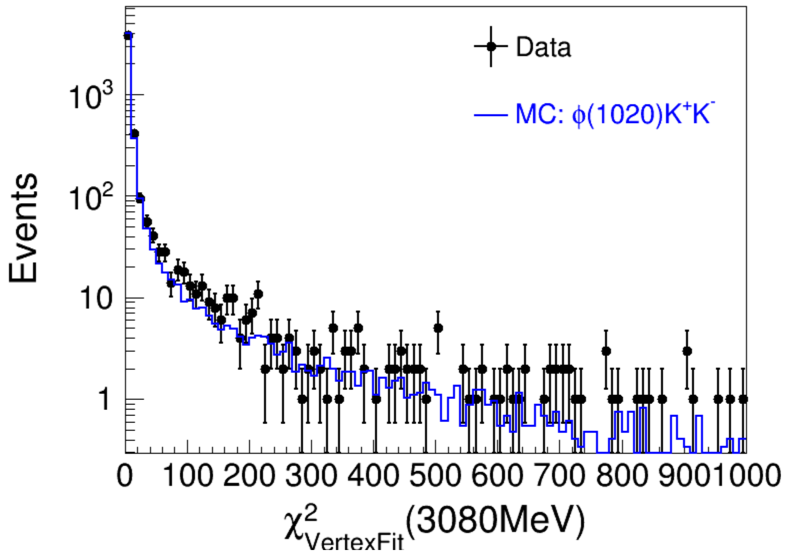
  At least three Kaons are indentified:

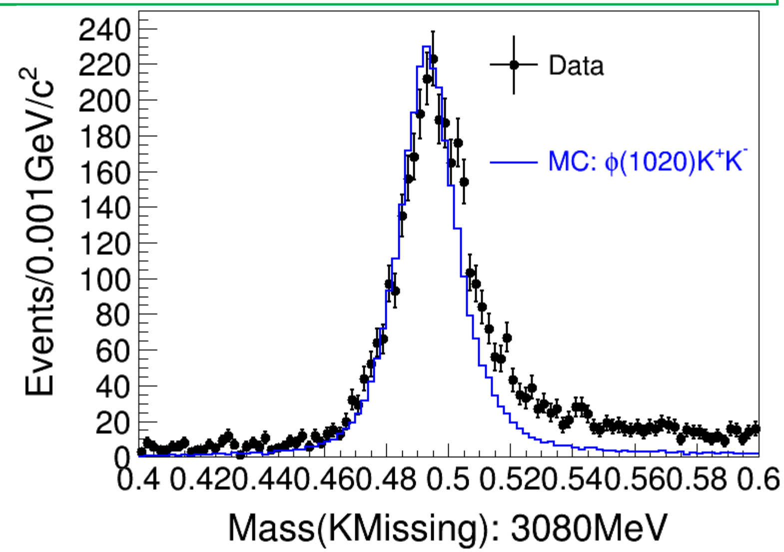
  $N(K^+) = N(K^-) = 2$; or $N(K^+) = 2$ && $N(K^-) = 1$; or $N(K^+)=1$ && $N(K^-) = 2$;

  Momentum(Kaon_PID)<=0.8*P_beam (To veto Bhabha events)

- **Vertex fit ($K^+K^-K^\pm$).** (The number of signal from fitting recoil kaon.)

Signal extraction@3080MeV





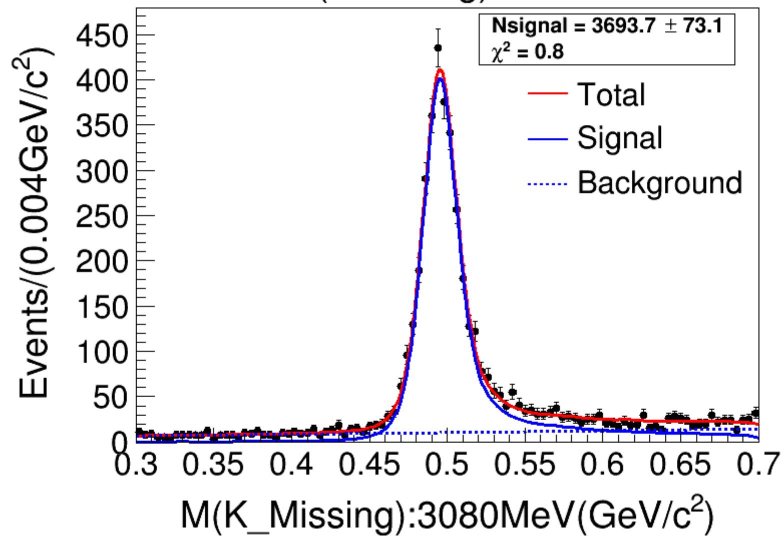
(1) $\chi^2_{vertexfit}(K^+K^-K^\pm)$ distribution;

(2) K_Missing Fitting :

Signal: MCShape⊗ Gaussian;

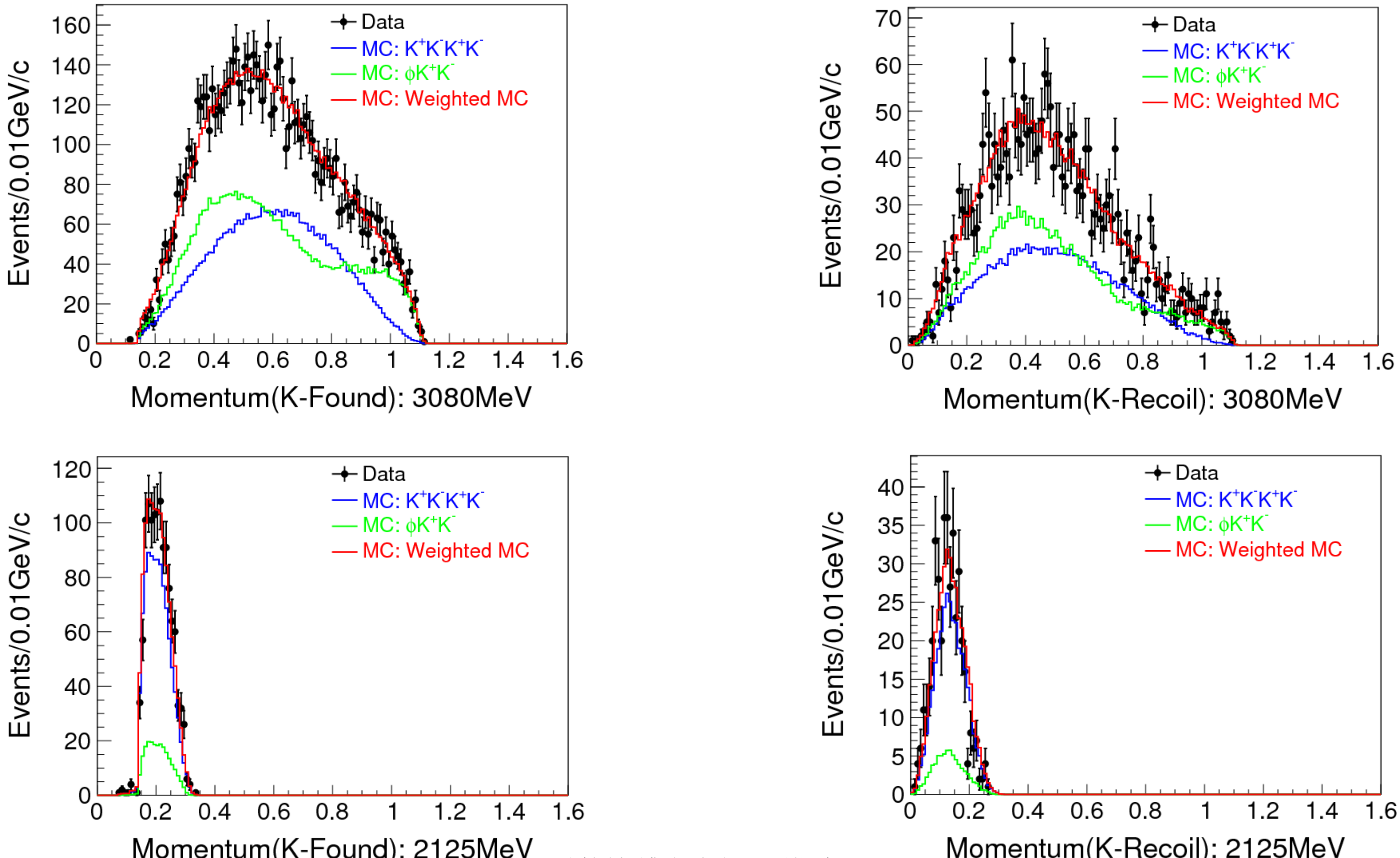
Background:

Chebyshev Polynominal;

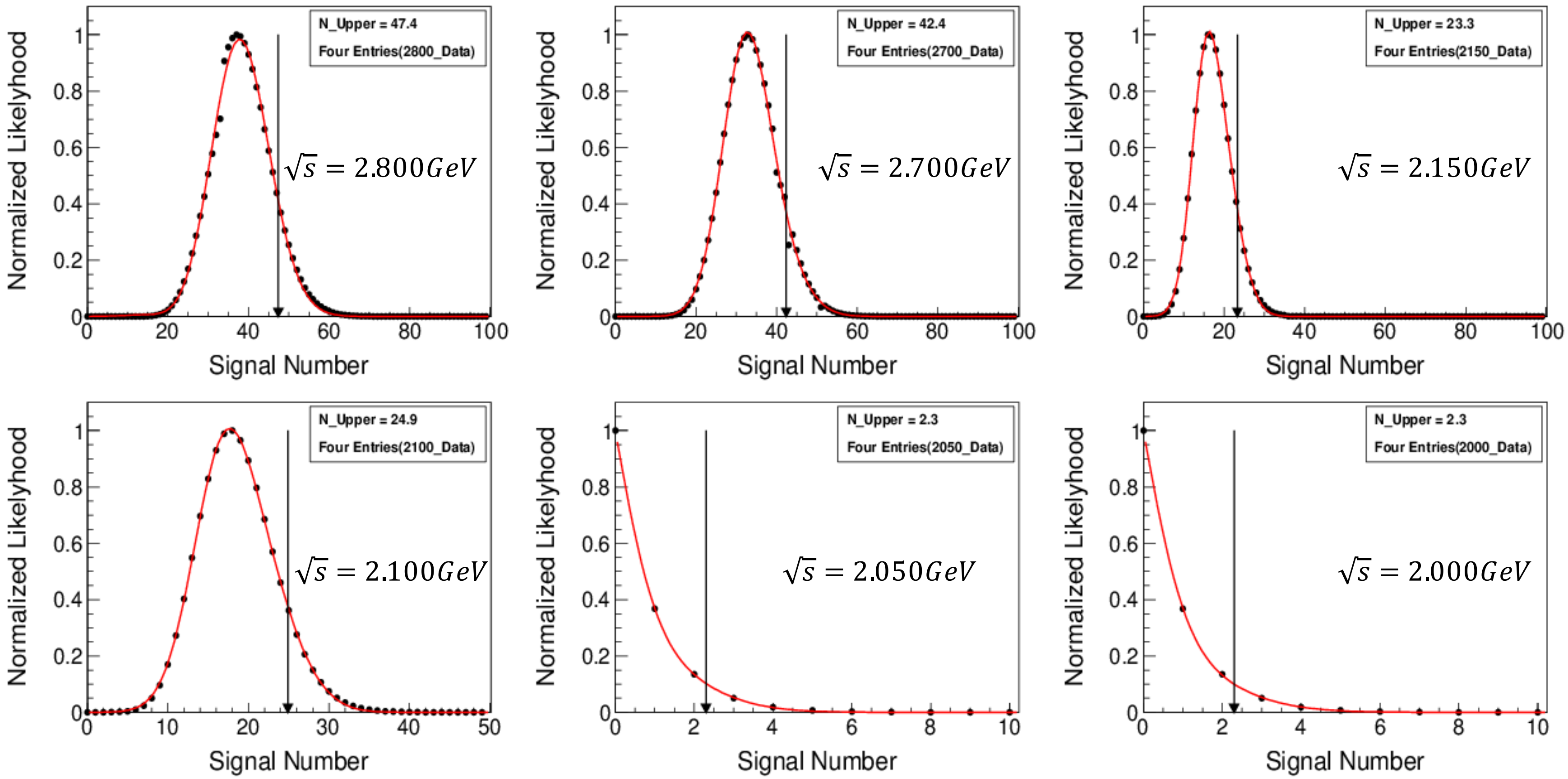


N=3693.7±73.1

Comparison of Momentum



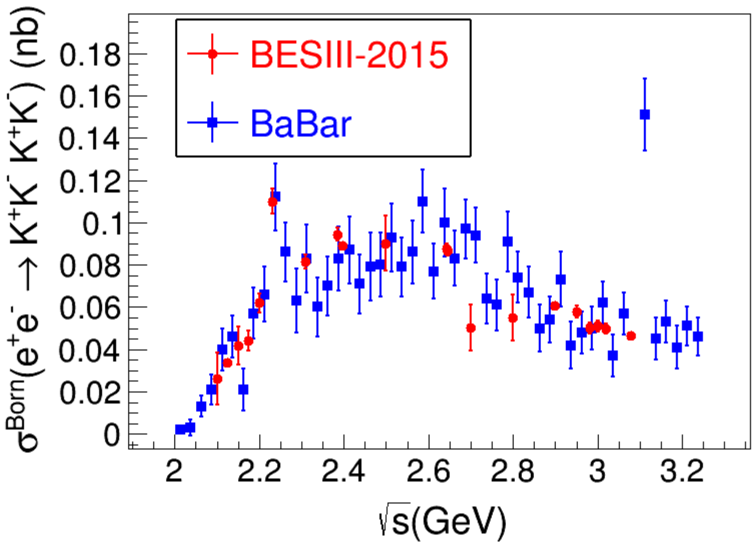
Upper Limit of $K^+K^-K^+K^-$



- Normalized likelihood value distributions versus the number of signal events.
- The upper limit determined by finding out the number of signal events corresponding to 90 % of the likelihood distribution.

Cross section: $\sigma(e^+e^- \rightarrow K^+K^-K^+K^-)$

$\sqrt{s}$ (GeV)	L (pb^{-1})	N($K^+K^-K^+K^-$)	$(1+\delta)$	ϵ(%)	$\sigma(pb)$(stat±sys)
3.080	126.19	3693.7±73.1	1.0185	61.91	46.4±0.9±2.6
3.020	17.29	591.4±29.2	1.0854	63.28	49.8±2.5±3.0
3.000	15.88	557.3±28.1	1.0860	63.31	51.0±2.6±2.9
2.981	16.07	555.6±28.1	1.0846	63.57	50.1±2.5±3.0
2.950	15.94	629.1±29.5	1.0799	63.14	57.9±2.7±3.3
2.900	105.25	4366.4±76.1	1.0686	63.98	60.7±1.1±3.4
2.800	1.01	37.25±7.3	1.0424	64.45	54.9±10.8±3.9
2.700	1.03	44.2±7.3	1.0173	62.65	50.2±10.8±4.7
2.646	34.00	1817.6±47.1	1.0049	61.25	86.8±2.3±4.9
2.644	33.72	1819.9±47.0	1.0044	61.43	87.5±2.3±4.9
2.500	1.10	55.3±8.0	0.9741	57.35	90.2±13.0±10.6
2.396	66.87	2838.7±57.4	0.9534	50.00	89.0±1.8±7.5
2.386	22.55	934.6±32.0	0.9515	46.10	94.5±3.2±5.4
2.309	21.09	682.3±28.0	0.9488	42.33	81.4±3.3±6.2
2.232	11.86	369.2±19.8	0.8505	30.99	110.0±5.9±6.3
2.200	13.70	206.6±15.3	0.8824	27.58	62.0±4.6±5.9
2.175	10.63	95.6±9.9	0.8750	23.24	44.2±4.6±4.2
2.150	2.84	17.8±3.9	0.8616	17.45	41.7±9.1±4.8
2.125	108.49	378.7±19.3	0.8437	12.24	33.8±1.7±4.2
2.100	12.17	18.9±8.8	0.8186	7.18	26.4±12.3±3.7



- **Structure around 2.23 GeV?**

(Same behaviors in BABAR results)

Systematic uncertainty

(For Cross section Measurement of $e^+e^- \to K^+K^- K^+K^-$)

Table 12: Systematic uncertainty of $e^+e^- \to K^+K^-K^+K^-$ at each energy point.

$\sqrt{s}$ (GeV)	Lum	Tracking	PID	Signal	Background	Range	ISR	Eff	MC	Others	Total
3.080	1.0	3.0	4.5	0.3	0.1	0.8	0.0	0.1	0.2	1.0	5.7
3.020	1.0	3.0	4.5	0.8	1.1	1.9	0.0	0.1	0.2	1.0	6.1
3.000	1.0	3.0	4.5	0.7	0.4	0.4	0.2	0.1	0.2	1.0	5.7
2.981	1.0	3.0	4.5	0.7	1.6	0.2	0.1	0.1	0.2	1.0	5.9
2.950	1.0	3.0	4.5	0.4	0.8	0.9	0.3	0.1	0.2	1.0	5.7
2.900	1.0	3.0	4.5	0.2	0.5	0.4	0.0	0.1	0.2	1.0	5.6
2.800	1.0	3.0	4.5	1.9	3.8	1.1	0.3	0.5	0.2	1.0	7.1
2.700	1.0	3.0	4.5	0.2	7.5	0.2	0.3	0.6	0.2	1.0	9.4
2.646	1.0	3.0	4.5	0.1	0.2	0.0	0.5	0.1	0.2	1.0	5.6
2.644	1.0	3.0	4.5	0.1	0.7	0.3	0.1	0.1	0.2	1.0	5.6
2.500	1.0	3.0	4.5	6.9	2.7	7.1	0.3	0.7	0.3	1.0	11.7
2.396	1.0	3.0	4.5	3.5	3.8	3.5	0.4	0.1	0.3	1.0	8.4
2.386	1.0	3.0	4.5	0.0	1.2	0.2	0.0	0.7	0.3	1.0	5.8
2.309	1.0	3.0	4.5	2.1	4.5	1.4	0.4	0.3	0.4	1.0	7.6
2.232	1.0	3.0	4.5	0.1	0.6	0.7	0.4	0.5	0.5	1.0	5.7
2.200	1.0	3.0	4.5	0.6	7.6	0.1	0.5	0.5	0.5	1.0	9.5
2.175	1.0	3.0	4.5	7.3	0.3	1.9	0.3	0.5	0.6	1.0	9.4
2.150	1.0	3.0	4.5	1.1	7.3	6.7	0.7	0.2	0.7	1.0	11.5
2.125	1.0	3.0	4.5	1.9	8.8	6.2	0.1	0.2	0.8	1.0	12.3
2.100	1.0	3.0	4.5	11.6	3.2	3.2	0.1	2.2	1.1	1.0	13.9

Summary and Outlook

- With R-scan data sets [2.0, 3.08]GeV, we search for new decay mode of Y(2175).
  - The process $e^+e^- \to \eta' \phi$ is observed for the first time. Possible structure around 2.2GeV is observed in the cross section line shape. Because the mass is close to be 2.175 GeV, it may be from Y(2175).
  - Measurements of cross sections of $e^+e^- \to \phi K^+ K^-$ and $K^+K^- K^+K^-$, we only observe an enhancement near threshold in the line shape of cross section.
- Next to do : Improve and complete the result of these analysis, prepare the paper publication and thesis.

Talks

1) Observation of $e^+e^- \to \eta' \phi$

- Workshop in Spring of 2017, Mar. 15-18, SUN Yat-Sen University, Guangzhou, Guangdong
- BESIII Collaboration Meeting in Winter of 2016, November 12-16, IHEP, Beijing

2) Measurements of cross sections of $e^+e^- \to \phi K^+K^-$ and $K^+K^- K^+K^-$

- The BESIII Collaboration Summer Meeting 2016, June 13-17 ,Central China Normal University(CCNU),Wuhan, Hubei

3) Study of $e^+e^- \to \phi K^+K^-$

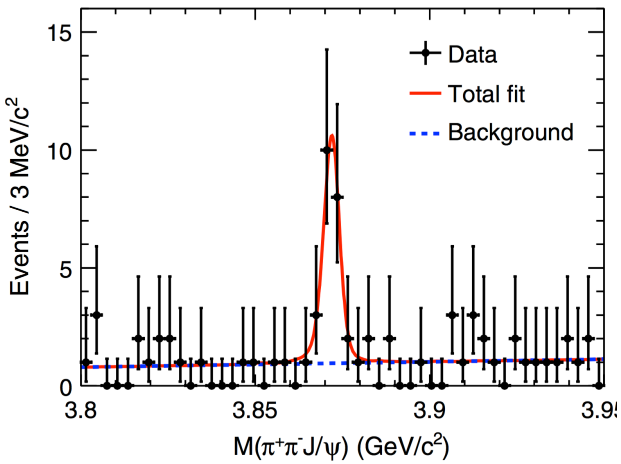
- BESIII Collaboration Meeting in Winter of 2015, December 12-16, IHEP, Beijing

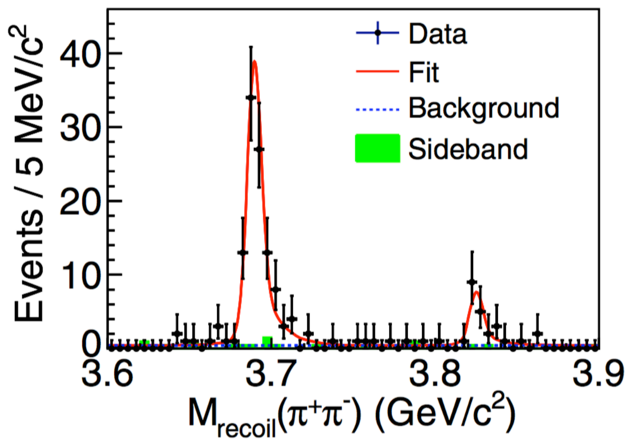
Backup

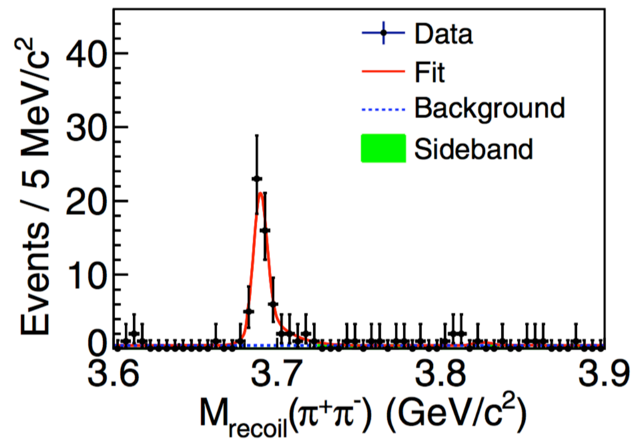
X states at BESIII

$e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c2}$







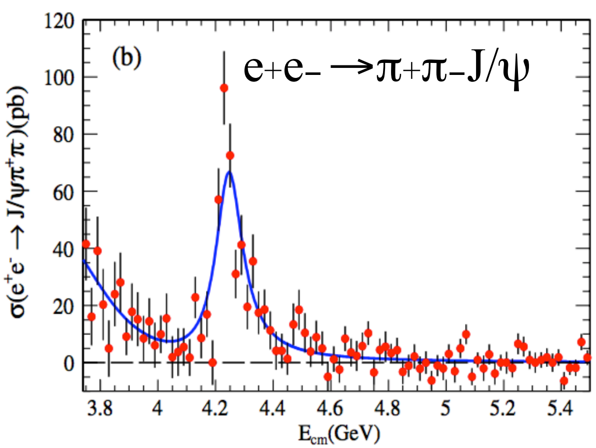
$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$

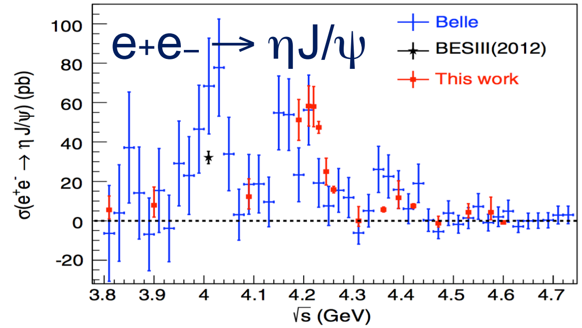
Phys. Rev. Lett. **112**, 092001

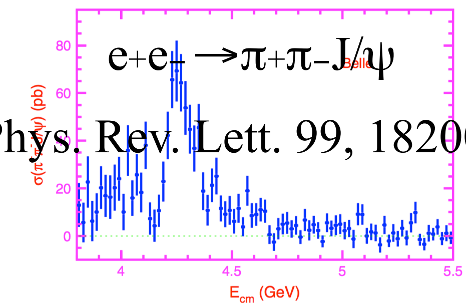
Phys. Rev. Lett. **115**, 011803

Y states

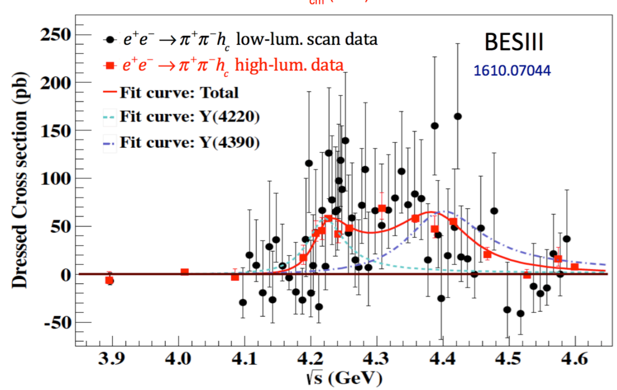
Phys. Rev. D **86**, 051102



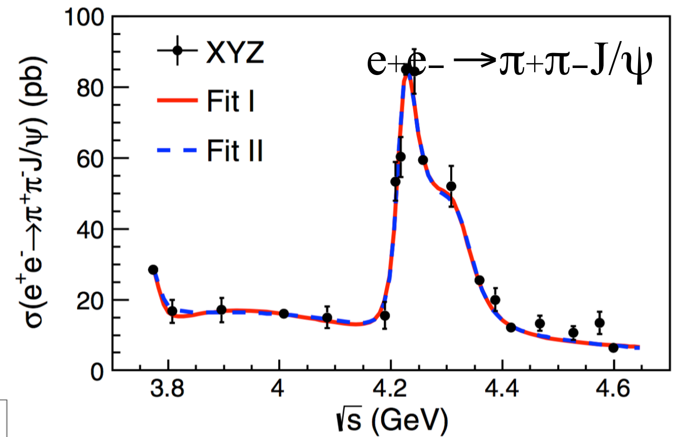




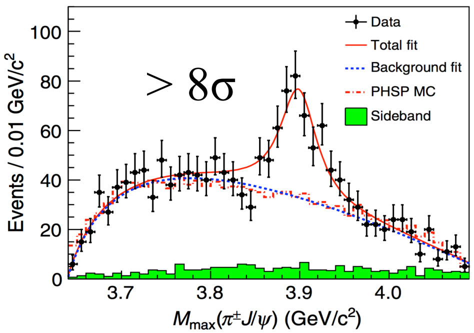
Phys. Rev. Lett. 99, 182004



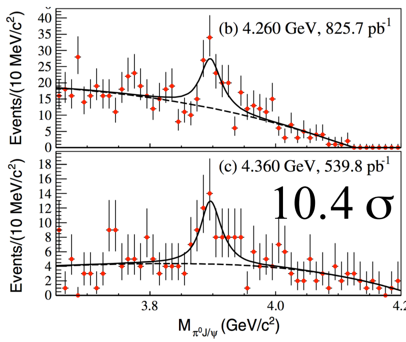
Phys. Rev. Lett. 118, 092001



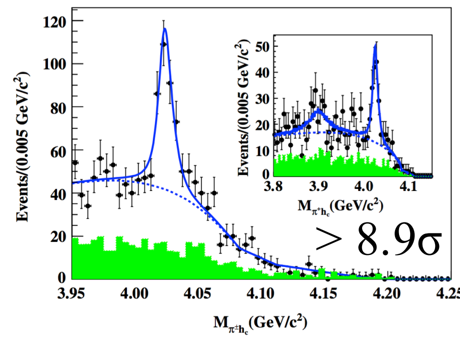
Z states at BESIII



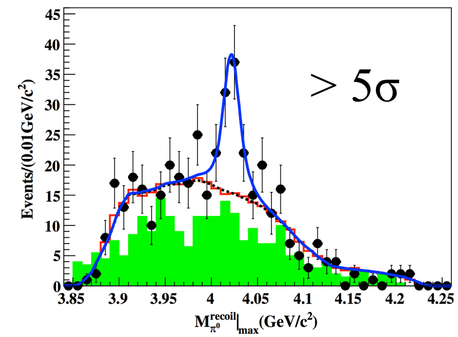
Phys. Rev. Lett. 110, 252001



Phys. Rev. Lett. 115, 112003



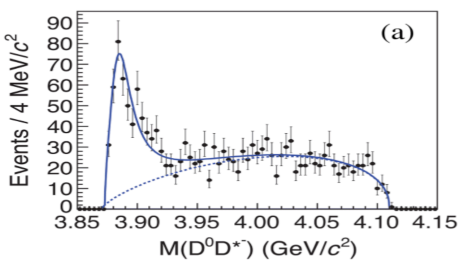
Phys. Rev. Lett. 111, 242001



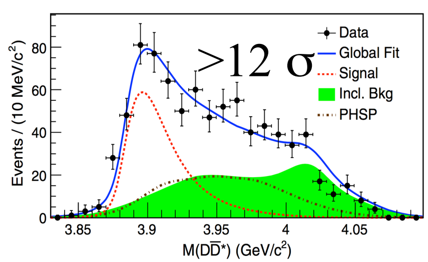
Phys. Rev. Lett. 113, 212002

$e^+e^- \to \pi^+\pi^- J/\psi$ $\quad$ $e^+e^- \to \pi^0\pi^0 J/\psi$ $\quad$ $e^+e^- \to \pi^+\pi^- h_c$ $\quad$ $e^+e^- \to \pi^0\pi^0 h_c$

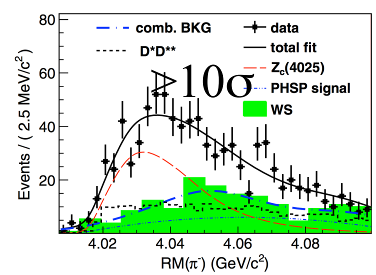
$Z_c(3900)^{\pm}$ $\quad$ $Z_c(3900)^0$ $\quad$ $Z_c(4020)^{\pm}$ $\quad$ $Z_c(4020)^0$



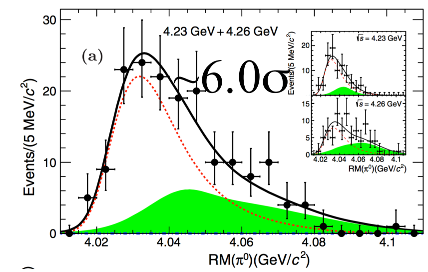
Phys. Rev. Lett. 112, 022001



Phys. Rev. Lett. 115, 222002



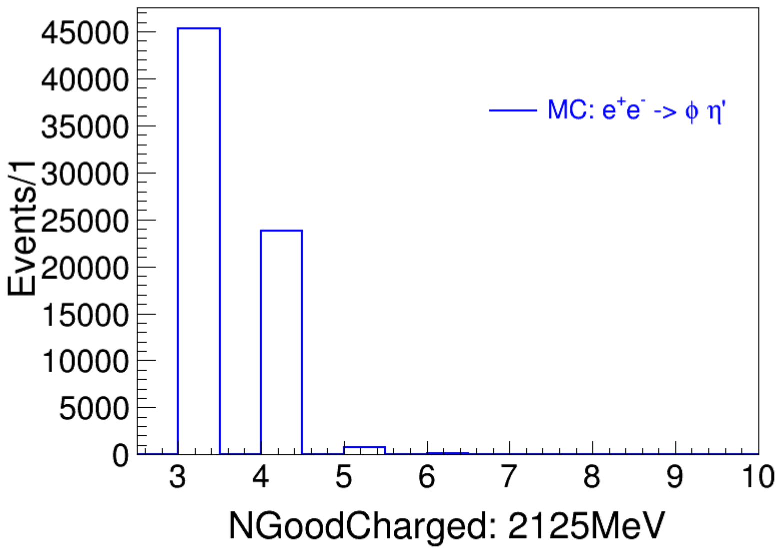
Phys. Rev. Lett. 112, 132001

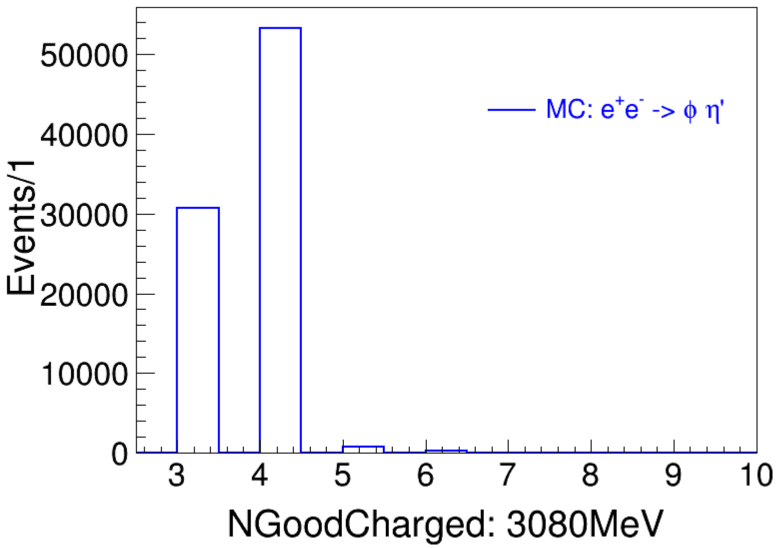


Phys. Rev. Lett. 115, 182002

$e^+e^- \to \pi^+(D\bar{D}^*)^-$ $\quad$ $e^+e^- \to \pi^0(D\bar{D}^*)^0$ $\quad$ $e^+e^- \to \pi^+(D^*\bar{D}^*)^-$ $\quad$ $e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

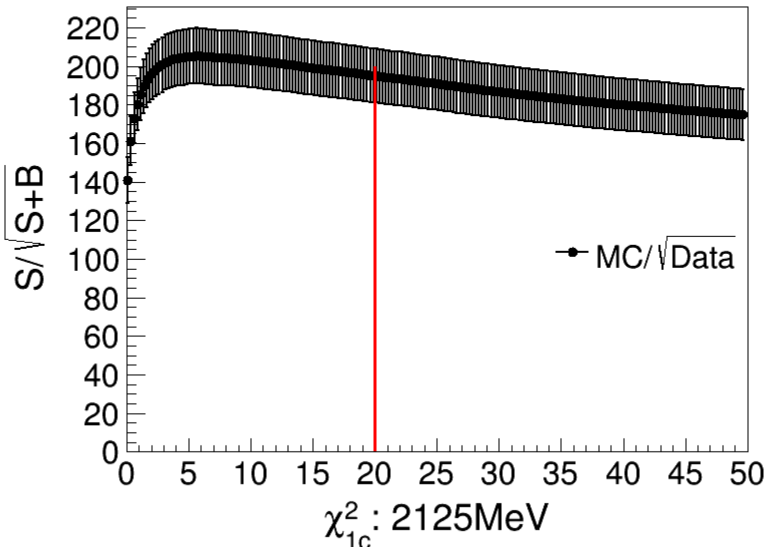
Observation of $e^+e^- \to \eta' \phi$

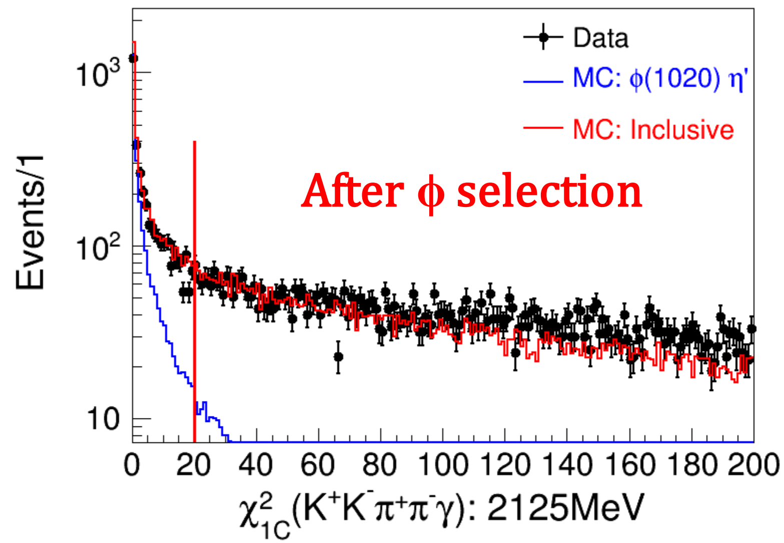




From the multiplicity of charged particles, we can improve statistics of signal events.

Observation of $e^+e^- \to \eta' \phi$ @2.125 GeV





(1) $\chi^2_{1C}(K^+K^-\pi^+\pi^-\gamma) < 20$;

(2) $|M(K^+K^-)-M_\phi|<0.015GeV/c^2$;

Plot 1: Signal to noise ratio;

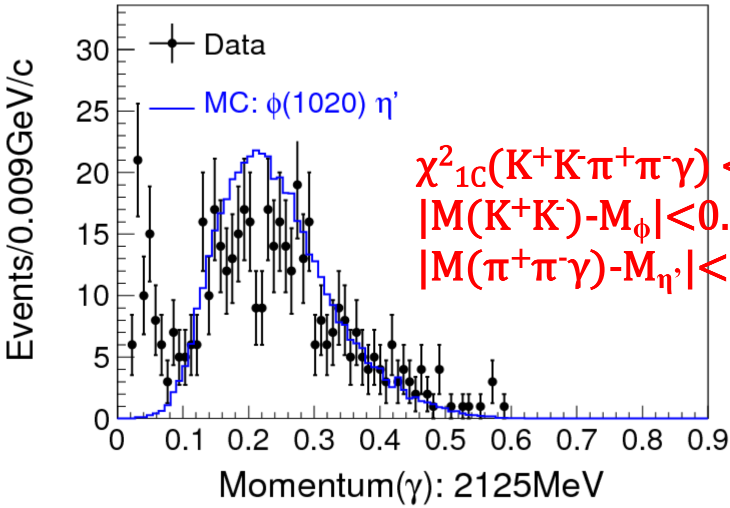
Plot 2: χ^2_{1C} distribution from MC samples, data and inclusive MC.

Observation of $e^+e^- \to \eta' \phi$ @2.125 GeV

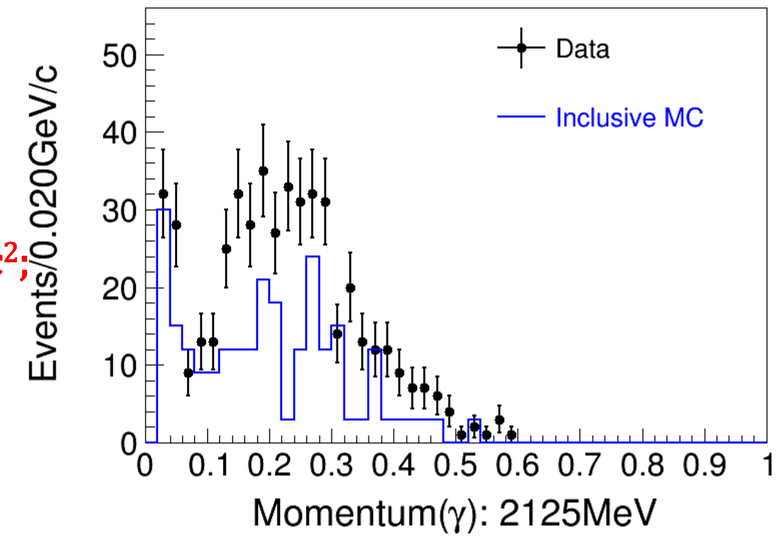
No.	decay chain	final states	iTopo	nEvt	nTot
0	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^-\pi^-\pi^+K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	2	329	329
1	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to \pi^-\pi^+\phi,\ \phi \to K^-K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	9	184	513
2	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^-\pi^+K^*,\ K^* \to \pi^-K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	6	162	675
3	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^-\rho^0K^+,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	3	84	759
4	$e^+e^- \to K^-\pi^-\pi^+K^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	5	66	825
5	$e^+e^- \to K^-\pi^-\pi^0\pi^+K^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-K^-$	8	65	890
6	$e^+e^- \to \pi^-\pi^+\phi,\ \phi \to K^-K^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	22	40	930
7	$e^+e^- \to K^-\omega K^+,\ \omega \to \pi^-\pi^0\pi^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-K^-$	26	40	970
8	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to \phi f_0(980),\ \phi \to K^-K^+,\ f_0(980) \to \pi^-\pi^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	4	39	1009
9	$e^+e^- \to \eta\phi,\ \eta \to \pi^-\gamma\pi^+,\ \phi \to K^-K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	1	38	1047
10	$e^+e^- \to \eta\phi,\ \eta \to \pi^-\pi^0\pi^+,\ \phi \to K^-K^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-K^-$	17	29	1076
11	$e^+e^- \to K^-\pi^+K^*,\ K^* \to \pi^-K^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	10	27	1103
12	$e^+e^- \to \phi f_0(980),\ \phi \to K^-K^+,\ f_0(980) \to \pi^-\pi^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	21	23	1126
13	$e^+e^- \to K^-\rho^0K^+,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	18	15	1141
14	$e^+e^- \to \gamma,\ \to K^-K^+\eta',\ \eta' \to \gamma\rho^0,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to \gamma\gamma K^+\pi^+\pi^-K^-$	13	11	1152
15	$e^+e^- \to K^-\pi^0K^{*+},\ K^{*+} \to \pi^+K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^0\pi^-K^-$	28	11	1163
16	$e^+e^- \to \pi^-\pi^+f_1(1285),\ f_1(1285) \to K^-\pi^0K^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-K^-$	36	11	1174
17	$e^+e^- \to \gamma,\ \to K^-\pi^-\pi^0\pi^+K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^0\pi^-K^-$	37	11	1185
18	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^{*-}\pi^0K^+,\ K^{*-} \to \pi^-K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \gamma K^+\pi^+\pi^0\pi^-\pi^-$	16	9	1194
19	$e^+e^- \to K^{*-}\pi^0K^+,\ K^{*-} \to \pi^-K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-\pi^-$	24	7	1201
20	$e^+e^- \to \omega f_0(980),\ \omega \to \pi^-\pi^0\pi^+,\ f_0(980) \to K^-K^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-K^-$	31	7	1208
21	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^-\pi^+K^*,\ K^* \to \pi^0K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^0\pi^-K^-$	30	6	1214
22	$e^+e^- \to K^-\pi^+K^*,\ K^* \to \pi^0K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^0\pi^-K^-$	23	5	1219
23	$e^+e^- \to \pi^-K^*K^+,\ K^* \to \pi^0K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-\pi^-$	15	5	1224
24	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^-\pi^0K^{*+},\ K^{*+} \to \pi^+K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^0\pi^-K^-$	70	5	1229
25	$e^+e^- \to K^-\rho^0K^+,\ \rho^0 \to \pi^-\gamma\pi^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	43	4	1233
26	$e^+e^- \to \gamma,\ \to \pi^-\pi^-K_L\pi^+K^+$	$e^+e^- \to \gamma K^+\pi^+K_L\pi^-\pi^-$	66	4	1237
27	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to K^-\pi^-\pi^0\pi^+K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^0\pi^-K^-$	29	4	1241
28	$e^+e^- \to \gamma,\ \to K^-\pi^-\pi^+K^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-K^-$	41	3	1244
29	$e^+e^- \to \gamma e^+e^-\gamma_{FSR},\ e^+e^-\gamma_{FSR} \to \eta\phi,\ \eta \to \pi^-\gamma\pi^+,\ \phi \to K^-K^+$	$e^+e^- \to \gamma\gamma K^+\pi^+\pi^-K^-$	20	3	1247

/besfs/groups/tauqcd/gaoxl/Omegaeta/SigBkgMC/qqbarMC/2125/MC

Observation of $e^+e^- \to \eta' \phi$



$\chi^2_{1C}(K^+K^-\pi^+\pi^-\gamma) < 20$;
$|M(K^+K^-)-M_{\phi}|<0.015GeV/c^2$;
$|M(\pi^+\pi^-\gamma)-M_{\eta'}|<0.015GeV/c^2$;

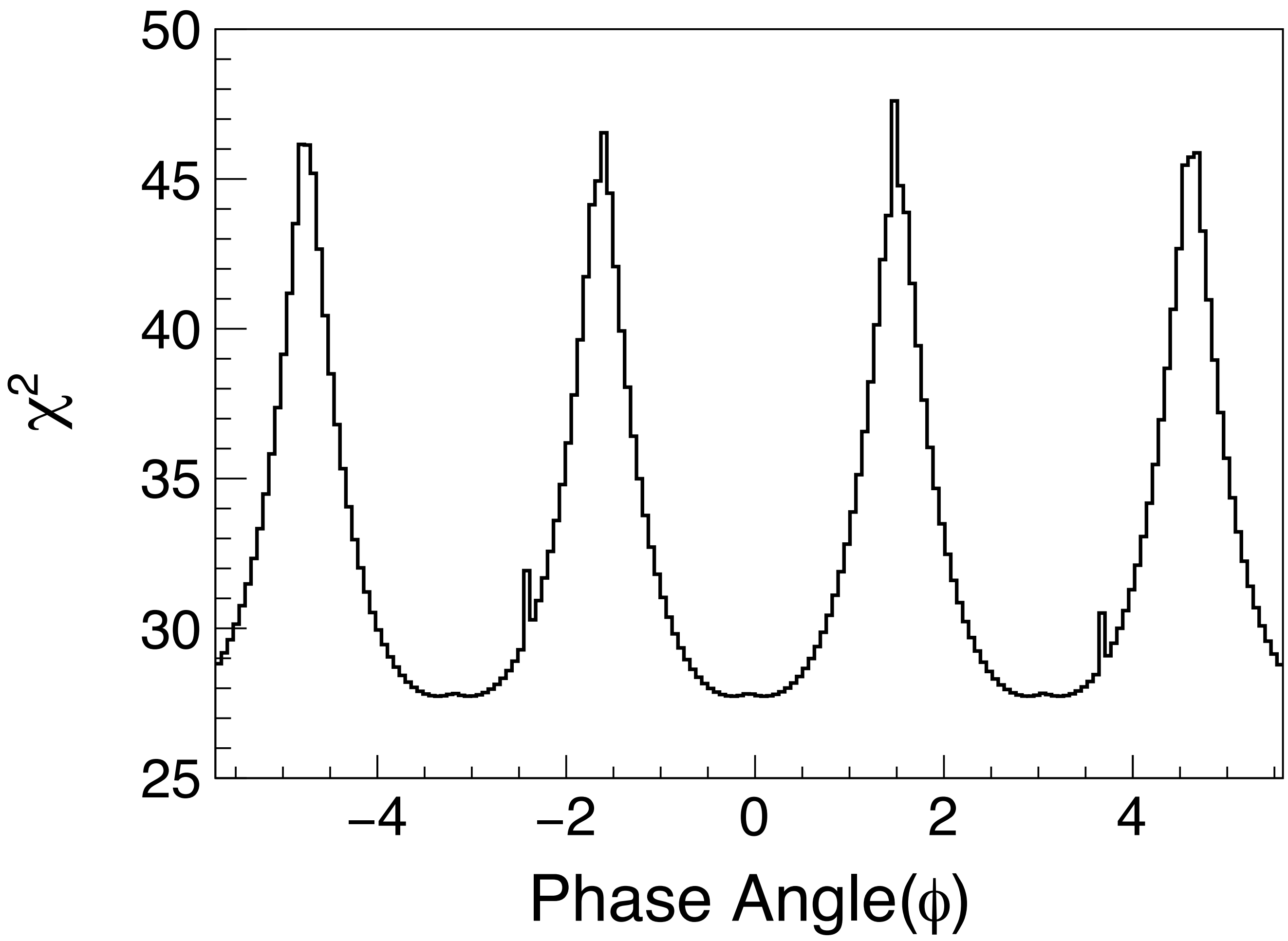


Momentum(γ)≤0.05GeV

No.	decay chain	final states	iTopo	nEvt	nTot
0	$e^+e^- \to \gamma_{ISR}\gamma^*,\ \gamma^* \to K^-\pi^+K^*,\ K^* \to \pi^-K^+$	$e^+e^- \to \gamma_{ISR}K^+\pi^+\pi^-K^-$	0	3	3
1	$e^+e^- \to \gamma_{ISR}\gamma^*,\ \gamma^* \to \phi f_0(980),\ \phi \to K^-K^+,\ f_0(980) \to \pi^-\pi^+$	$e^+e^- \to \gamma_{ISR}K^+\pi^+\pi^-K^-$	3	3	6
2	$e^+e^- \to \phi f_0(980),\ \phi \to K^-K^+,\ f_0(980) \to \pi^-\pi^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	5	3	9
3	$e^+e^- \to K^-\pi^-\pi^+K^+$	$e^+e^- \to K^+\pi^+\pi^-K^-$	4	2	11
4	$e^+e^- \to \gamma_{ISR}\gamma^*,\ \gamma^* \to \pi^-\pi^+\phi,\ \phi \to K^-K^+$	$e^+e^- \to \gamma_{ISR}K^+\pi^+\pi^-K^-$	2	1	12
5	$e^+e^- \to \gamma_{ISR}\gamma^*,\ \gamma^* \to K^-\pi^-\pi^+K^+$	$e^+e^- \to \gamma_{ISR}K^+\pi^+\pi^-K^-$	1	1	13
6	$e^+e^- \to \gamma_{ISR}\gamma^*,\ \gamma^* \to K^-K^+\eta',\ \eta' \to \gamma_{ISR}\rho^0,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to \gamma_{ISR}\gamma_{ISR}K^+\pi^+\pi^-K^-$	6	1	14

The low energy gamma is mainly from ISR, in order to veto these background events , we require E(γ)>0.07GeV.

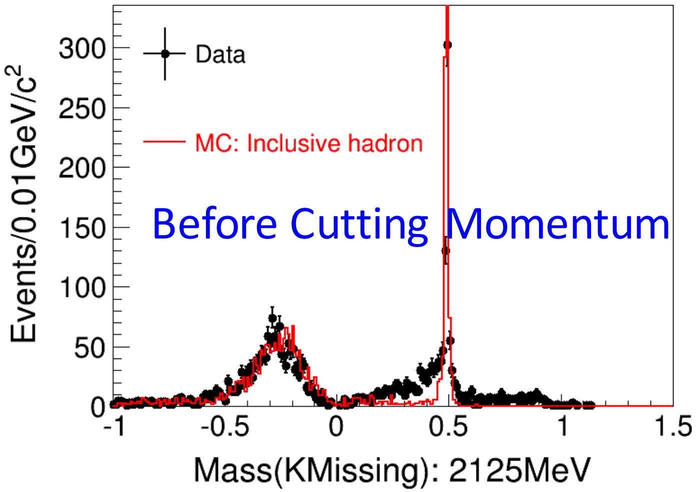
Observation of $e^+e^- \rightarrow \eta' \phi$

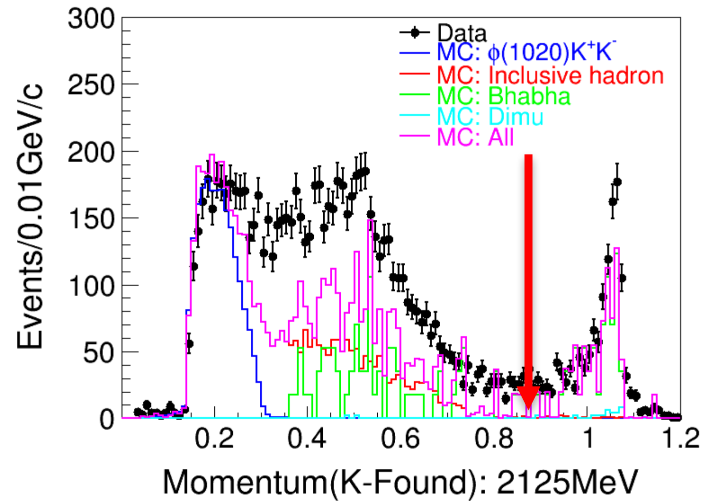


Study of $e^+e^- \to \phi K^+K^-$ @3.080 GeV

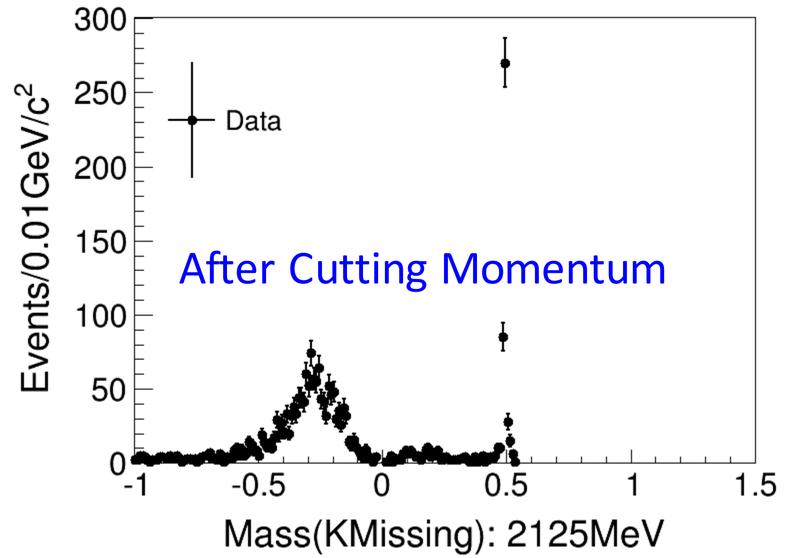
Source	Method	Value (%)
Luminosity*	Measurement of large angle Bhabha events	1.0
Tracking*	Control sample: $e^+e^-\to K^+K^-\pi^+\pi^-$	1.0×3
PID	Control sample: $e^+e^-\to K^+K^-\pi^+\pi^-$	1.5×3
Kinematic fit*	Track parameter correction	1.4
ISR factor	Line shape iteration: <1.0 % between two iteration	0.1
Background shape	ARGUS function $\to (m - m_a)^c \times (m_b - m)^d$	0.0
Signal shape	P-wave BW ⊗ Gaussian → MC shape ⊗ Gaussian	0.7
Fitting range	[0.99, 1.080] →[0.99, 1.095] GeV/c^2	0.1
Branching ratio*	PDG2014	1.1
Efficiency	Difference of efficiency between ϕK^+K^- and weighted MC	5.7
MC	Statistics of MC simulation	0.2
Others	Trigger, Start time, FSR	1.0
Total	Quadratic sum of the individual uncertainties	8.3

Study of $e^+e^- \to K^+K^- K^+K^-$ @2.125 GeV

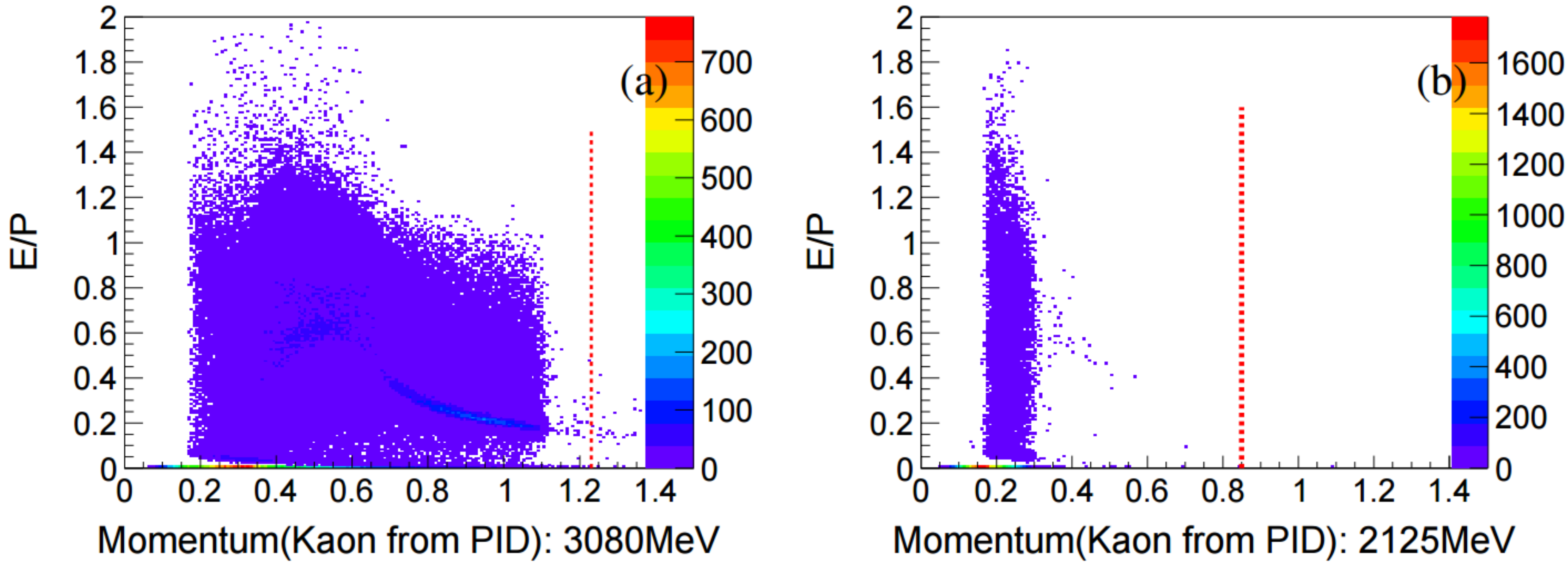




Momentum(Kaon_PID)≤0.8*P_beam(0.85GeV)
(To veto Bhabha events)



Study of $e^+e^- \rightarrow K^+K^-K^+K^-$



- Two dimensional distributions of E/p ratio and momentum from identified kaons, which is from MC sample: ϕK^+K^-.
- Momentum cut has no effect on MC efficiency.