Study of $e^+e^- \to p\bar{p}K^+K^-$ above 4 GeV at BESIII

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Outline

Motivation

- Search for ψ or Y states via measuring cross section of $e^+e^- \to p\bar{p}K^+K^-$ decay above 4 GeV for the first time at BESIII, i.e.
  - $\psi(4160)$: seen only in channels of $\ell^+\ell^-$ and $D_{(s)}^{(*)}\bar{D}_{(s)}^{(*)}(\pi)$ ref. PDG. Not reported in non-charm meson processes except $e^+e^- \to \eta J/\psi$ via ISR process[a].
  - $Y(4260)/Y(4360)$: properties are different from a conventional $q\bar{q}$ state.
- Measure cross sections of intermediate processes above 4 GeV, i.e.
  - $e^+e^- \to p\bar{p}\phi$, observed ($> 5\sigma$)with J/ψ sample[b] and $\psi(3686)$ sample[c]. But it has NOT jet been reported above 4 GeV at BESIII.
  - $e^+e^- \to pK^-\bar{\Lambda}(1520)$, measured with evidence ($\geq 3\sigma$) in $e^+e^- \to pK_S^0\bar{n}K^-$ above 4 GeV at BESIII.[d]
  - $e^+e^- \to \Lambda(1520)\bar{\Lambda}(1520)$: only under 3σ C.L. in above reference. Considering a larger $\mathcal{BR}$ and higher efficiency for $\Lambda(1520) \to pK^-$ than that of $\bar{n}K_S^0$, a better measurement is prospective in our analysis.
- Investigate the intermediate states in any subsystems, i.e.
  - Search for $X(1835) \to p\bar{p}$, observed at $p\bar{p}$ threshold firstly in $J/\psi \to \gamma p\bar{p}$ decay;[e] Further, PWA of J/ψ or $\psi(3686) \to \gamma p\bar{p}$ decays determines $J^{PC}(X(1835)) = 0^{-+}$.[f]
  - Search for scalar particle $f_0(2100) \to p\bar{p}$ (needs confirmation in PDG).
  - Search for pentaquark [$uuds\bar{s}$] $P_s \to p\phi$, analogous to $P_c \to pJ/\psi$ process.

[a] X.L. Wang *et al.* (Belle Collaboration), Phys. Rev. D **87**, 051101 (2013)
[b] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **93**, 052010 (2016)
[c] M. Ablikim *et al.* (BESIII Collaboration), arXiv:1902.09756 [hep-ex]
[d] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **98**, 032014 (2018)
[e] J.Z. Bai *et al.* (BES Collaboration), Phys. Rev. Lett. **91**, 022001 (2003)
[f] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **108**, 112003 (2012)

Datasets

- Real data: all XYZ datasets above 4 GeV (22 energy points) + 3770 sample.[a]

Sample	3770	4009	4090	4180	4190	4200	4210	4220	4230
$\sqrt{s}$ (MeV)	3773	4007.62	4085.45	4178.37	4188.99	4199.03	4209.25	4218.84	4226.26
$\mathcal{L}$ (pb^{-1})	1989.27	482.0	52.86	3160	570.03	526.0	572.05	569.2	1100.94
Sample	4237	4245	4246	4260	4270	4280	4310	4360	4390
$\sqrt{s}$ (MeV)	4235.82	4241.66	4243.93	4257.97	4266.80	4277.74	4307.89	4358.26	4387.40
$\mathcal{L}$ (pb^{-1})	530.3	55.88	538.1	828.4	531.1	175.7	45.08	543.9	55.57
Sample	4420	4470	4530	4575	4600				
$\sqrt{s}$ (MeV)	4415.58	4467.06	4527.14	4574.5	4599.53				
$\mathcal{L}$ (pb^{-1})	1090.7	111.09	112.12	48.93	586.9				

- Generic MC: 5 streams (hadronic processes samples only).
- Signal MC: 0.1 million events per mode produced with KKMC-00-00-60.[b]
  - $e^+e^- \to p\bar{p}K^+K^-$ *PHSP*;
  - $e^+e^- \to p\bar{p}\phi$ *PHSP*, $\phi \to K^+K^-$ *VSS*;
  - $e^+e^- \to pK^-\bar{\Lambda}(1520)$ *PHSP*, $\bar{\Lambda}(1520) \to \bar{p}K^+$ *PHSP*;
  - $e^+e^- \to \Lambda(1520)\bar{\Lambda}(1520)$ *PHSP*, $\Lambda(1520) \to pK^-$ *PHSP* (+c.c);

[a] Y.F. Yang *et al.*, BESIII-DocDB-720; Charmonium WG wiki, https://docbes3.ihep.ac.cn/~charmoniumgroup/index.php/Datasets

[b] R.G. Ping, BESIII-DocDB-206; Z.T. Sun and C.Z. Yuan, BESIII-DocDB-717

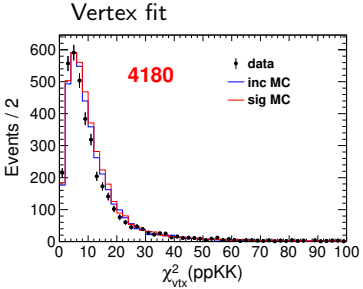
Event selection

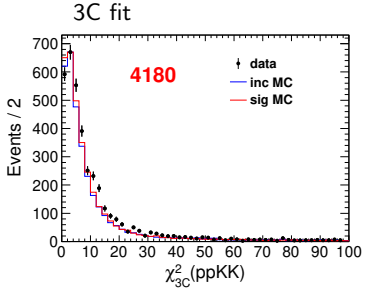
- BOSS: version 7.0.3.
- Charged tracks:
  - good tracks with $|V_r| < 1$ cm, $|V_z| < 10$ cm, $|\cos\theta| < 0.93$,
  - $N_{\text{good}} = 4$, $\sum_{i=1}^{4} Q_i = 0$
  - apply nominal PID, i.e. for p: $prob(p) > prob(K, \pi)$ and $prob(p) > 0.001$.
  - require $N(p) = 1$, $N(\bar{p}) = 1$, $N(\pi^+) = 1$ and $N(\pi^-) = 1$.
- Kinematic fit:
  - do vertex fit with a common vertex for four tracks of $p\bar{p}K^+K^-$, require $\chi^2_{vtx} < 100$, then update their kinematic info.
  - obtain the run-dependent C.M energies using MeasuredEcmsSvc package.
  - perform momentum-conservation constraint 3C fit on $p\bar{p}K^+K^-$ with $\chi^2_{3C} < 100$, and update their kinematic info.
- Define a scaled energy variable X_T, which is expected to be one due to energy conservation.

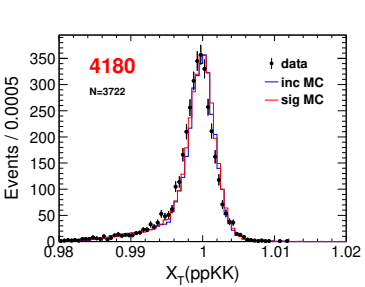
$$X_T = \sum_h E_h / E_{cm} \tag{1}$$

where h is final state particle (FSP), and we require $0.98 < X_T < 1.02$.

kinematic fit qualities and X_T @4180 sample







- No tight requirements on these two fit qualities.
- A very clear sample is obtained in X_T distribution.
- More info for other energy points are shown in backup.

Topology of inclusive MC

- Negligible backgrounds ($\sim 0.3\%$) exist in 4180 inclusive MC.

primary decays	secondary decays	nEvts	nCmltEvts
$e^+e^- \to K^+K^-p\bar{p}$		9646	9646
$e^+e^- \to p\bar{p}f_0'$	$f_0' \to K^+K^-$	1784	11430
$e^+e^- \to p\bar{p}a_2^0$	$a_2^0 \to K^+K^-$	516	11946
$e^+e^- \to p\bar{p}f_2(1270)$	$f_2(1270) \to K^+K^-$	444	12390
$e^+e^- \to K^+K^-J/\psi$	$J/\psi \to p\bar{p}$	1	12391
$e^+e^- \to pK^-\pi^+\bar{\Sigma}^-$	$\bar{\Sigma}^- \to \pi^0\bar{p}$	1	12392
$e^+e^- \to p\bar{K}^*\bar{\Sigma}^-$	$\bar{\Sigma}^- \to \pi^0\bar{p}$, $\bar{K}^* \to K^-\pi^+$	1	12393
$e^+e^- \to p\bar{K}_0^{*0}\bar{\Sigma}^-$	$\bar{\Sigma}^- \to \pi^0\bar{p}$, $\bar{K}_0^{*0} \to K^-\pi^+$	1	12394
$e^+e^- \to \bar{p}K^{*}\Sigma^+$	$\Sigma^+ \to \pi^0 p$, $K^* \to K^+\pi^-$	1	12395
$D^{(*)}$-included backgrounds	each channel has one event	34	12429

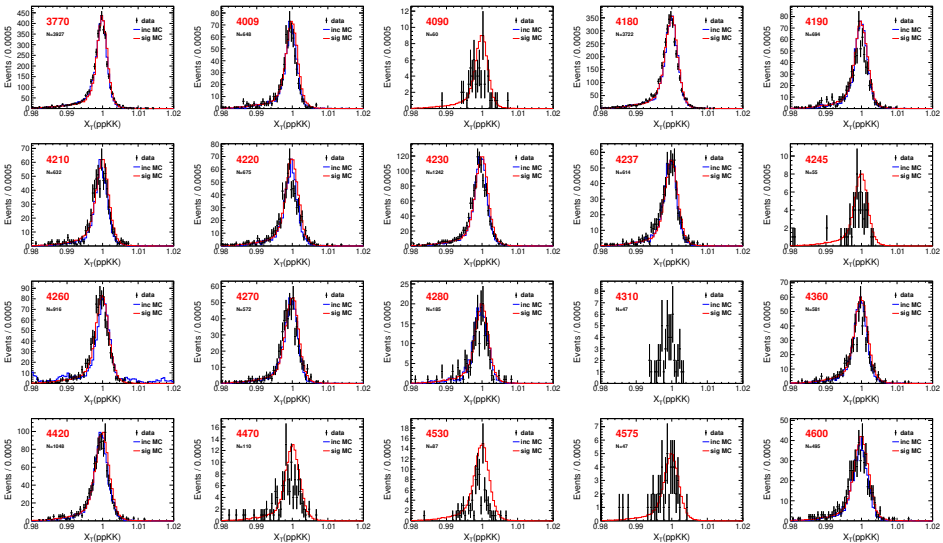
- None or negligible background event is remained in all other inclusive MC, i.e. 4190 and 4420 samples:

primary decays	secondary decays	nEvts	nCmltEvts
$e^+e^- \to K^+K^-p\bar{p}$		3438	3438
$e^+e^- \to p\bar{p}f_2(1270)$	$f_2(1270) \to K^+K^-$	88	3526
$e^+e^- \to p\bar{p}a_2^0$	$a_2^0 \to K^+K^-$	82	3608
$e^+e^- \to K^+K^-J/\psi$	$J/\psi \to p\bar{p}$	6	3614

primary decays	secondary decays	nEvts	nCmltEvts
$e^+e^- \to K^+K^-p\bar{p}$		4992	4992
$e^+e^- \to p\bar{p}f_2(1270)$	$f_2(1270) \to K^+K^-$	143	5135
$e^+e^- \to p\bar{p}a_2^0$	$a_2^0 \to K^+K^-$	135	5270
$e^+e^- \to K^+K^-J/\psi$	$J/\psi \to p\bar{p}$	13	5283
$e^+e^- \to p\bar{p}a_0^0$	$a_0^0 \to K^+K^-$	1	5284

- We will obtain signal yields by counting method.
- Intermediate states: $a_2(1320)^0$ and $f_2(1270)$ (or $a_0(980)^0$) in K^+K^- subsystem and $J/\psi \to p\bar{p}$.
- Not considered intermediate process $\Lambda(1520) \to pK^-$, neither does $\phi(1020) \to K^+K^-$.

Signal yields N_{obs} at each energy point

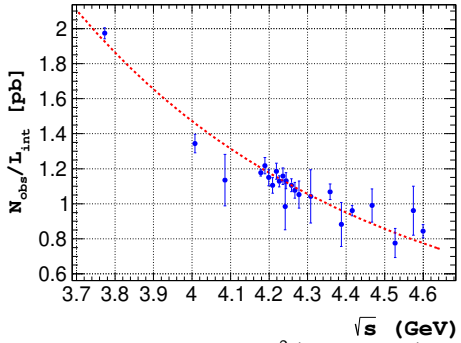


if blue (red) line absent, I do not run its inclusive MC (produce signal MC).

Glance to cross section lineshape

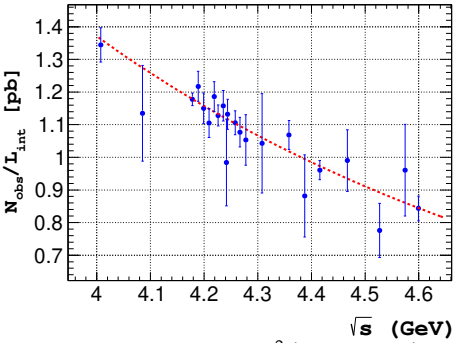
- Fitting $N_{obs}/\mathcal{L}_{int}$ with $f(\sqrt{s}) = a/(\sqrt{s})^b$, before considering efficiency/ISR factor/etc.

(a) with 3770 sample



$b = 2.30 \pm 0.07$ with $\chi^2/ndf = 26.3/21$

(b) without 3770 sample



$b = 1.73 \pm 0.16$ with $\chi^2/ndf = 11.3/20$

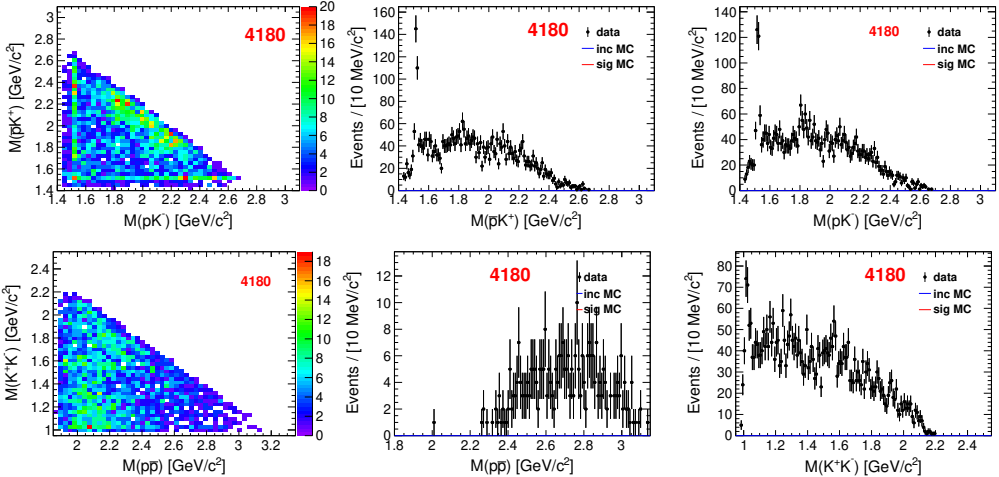
Efficiency determination

- Comparison with different intermediate channels, taking example of 4180 sample as

Decay channel	$N_{gen.}$	$N_{rec.}$	ϵ (%)	$\delta\epsilon/\epsilon$
$e^+e^- \to p\bar{p}K^+K^-$	100,000	32571	32.6	–
$e^+e^- \to \Lambda(1520)\bar{\Lambda}(1520)$	100,000	38521	38.5	+18%
$e^+e^- \to pK^-\bar{\Lambda}(1520)$	100,000	31053	31.1	−4.6%
$e^+e^- \to p\bar{p}\phi$	100,000	33849	33.8	+3.7%

- A difference between these efficiencies from different decay channels. Currently, efficiency from the first channel with PHSP model is used. We will consider a better model in furture.
- Efficiencies of each channel at different C.M energy points are listed in table of final cross sections in **??**.
- Besides, ISR radiative factor and vacuum polarization factor are also obtained separately in above productions of different signal MC samples.

Search for Intermediate States in Subsystems @ 4180 sample



- Clear signals of $\Lambda(1520)$ and $\phi(1020)$ are observed.

Summary

- Observation of $e^+e^- \to p\bar{p}K^+K^-$ above 4 GeV are reported for the first time at BESIII with XYZ datasets. The Born cross sections will be measured after efficiency is obtained.
- Some significant intermediate processes are found.
  - $e^+e^- \to pK^-\bar{\Lambda}(1520)$
  - $e^+e^- \to \Lambda(1520)\bar{\Lambda}(1520)$
  - $e^+e^- \to p\bar{p}\phi$,

Back up

Thank you for your attention.

谢谢！

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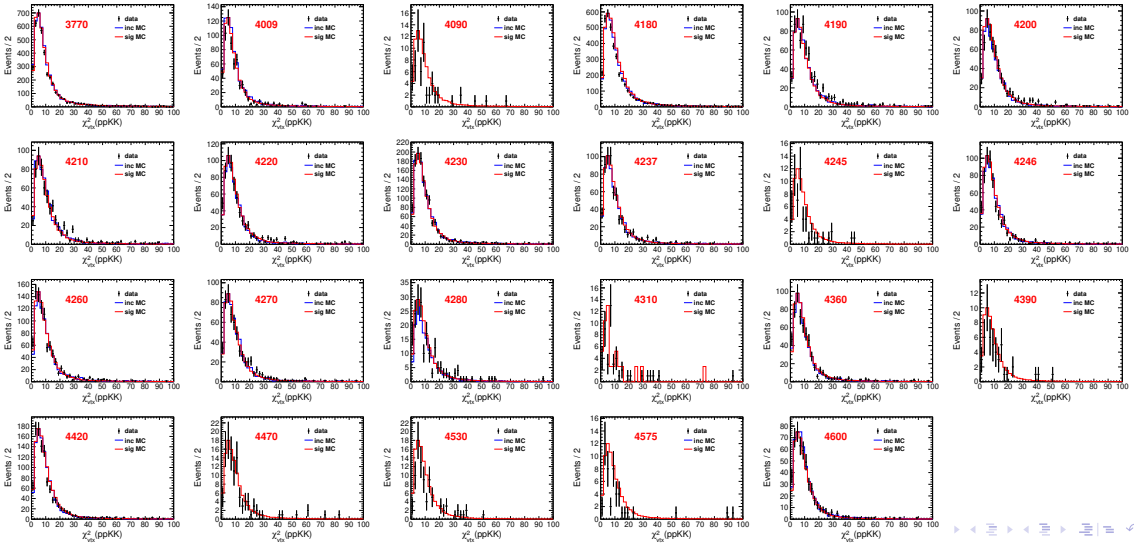
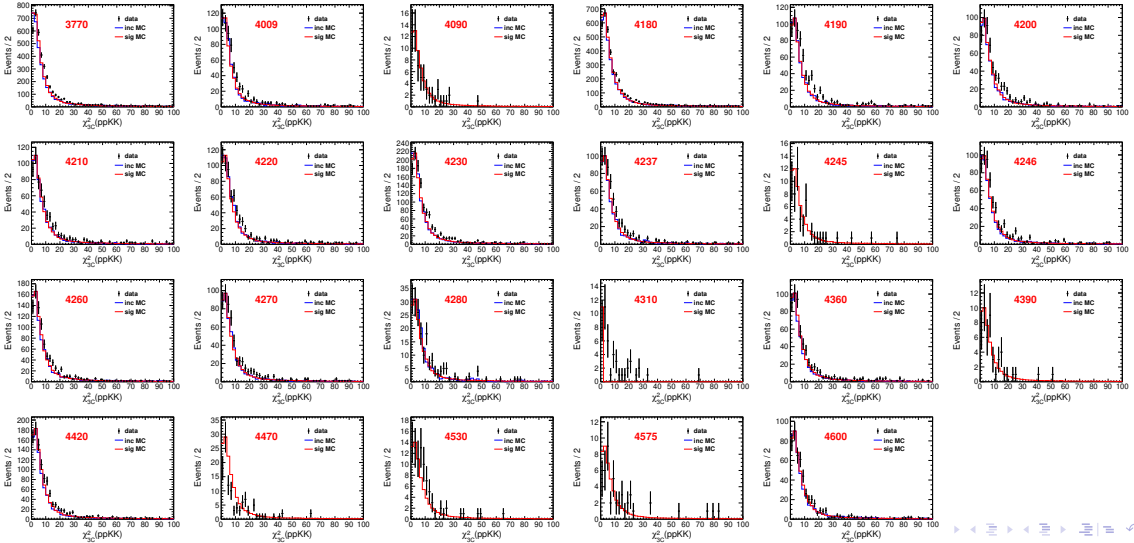
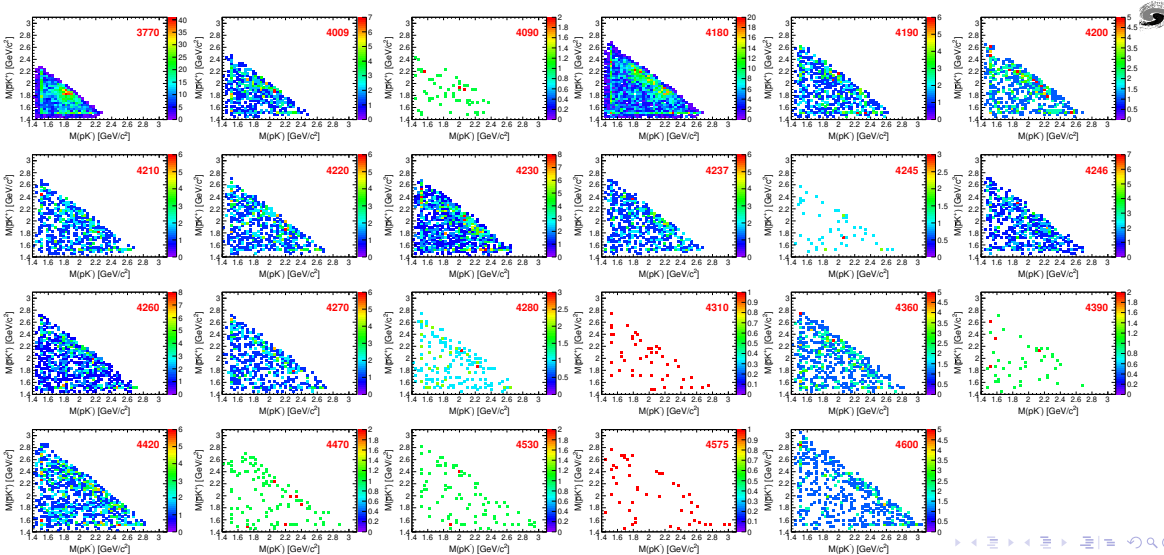
χ^2 of vertex fit for each dataset



χ^2 of 3C fit for each dataset



$M(pK^-)$ Vs. $M(\bar{p}K^-)$ in $e^+e^- \to p\bar{p}K^+K^-$



$M(p\bar{p})$ Vs. $M(K^+K^-)$ in $e^+e^- \to p\bar{p}K^+K^-$