Kaon masses. Why are they important?

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OUTLINE

1. Introduction
2. Status of $m(K^{\pm})$ measurements
3. Status of $m(K^0)$ measurements
4. Prospects

Introduction

- The $\pi^{\pm}$ mass accuracy is 1.2×10^{-6}, while for $K^{\pm}$ it is 20 times worse, 2.6×10^{-5}. The same accuracy has been achieved for the K^0 mass.
- The D^0-meson mass is restricted by the accuracy of $m(K^{\pm})$ and $m(K^0)$. In turn, masses of excited charmed mesons for which direct measurements are not precise, $D_1(2420)^0$, $D_2^*(2460)^0$ and $D_{s1}(2536)^{\pm}$, are precisely determined from a fit of measured masses and mass differences for D^0, $D^{\pm}$ and $D_s^{\pm}$.
- Knowledge of kaon masses affects our understanding of the $\chi_{c1}(3872)$ ($X(3872)$) nature - the first of X, Y, Z states, discovered by Belle in 2003. Its current explanation – a mixture of regular $c\bar{c}$ and $D^0\bar{D}^{*0}$ molecule. How close is $m(\chi_{c1}(3872))$ to the $D^0\bar{D}^{*0}$?
- The whole mass scale for charmed hadrons comes from the J/ψ and $\psi(2S)$: $3096.900 \pm 0.002 \pm 0.006$ MeV and $3686.099 \pm 0.004 \pm 0.009$ MeV measured by KEDR in Novosibirsk
  V.V. Anashin et al., Phys. Lett. B749 (2015) 50

D^0 and D^{*0} Masses

From the fit including $D^{\pm}$, D^0, $D_s^{\pm}$, $D^{*\pm}$, D^{*0}, $D^{*\pm}$, $D_1(2420)^0$, $D_2^*(2460)^0$, $D_{s1}(2536)^{\pm}$ masses and mass differences

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1864.83 ±0.05 OUR FIT					
1864.84 ±0.05 OUR AVERAGE					
1864.845±0.025±0.057	63k	[1] TOMARADZE	14		$D^0 \to K^- 2\pi^+ \pi^-$
1864.75 ±0.15 ±0.11		AAIJ	13V	LHCB	$D^0 \to K^+ 2K^- \pi^+$
1864.841±0.048±0.063	4.3k	[2] LEES	13S	BABR	$e^+ e^-$ at $\Upsilon(4S)$
1865.30 ±0.33 ±0.23	0.1k	ANASHIN	10A	KEDR	$e^+ e^-$ at $\psi(3770)$
1864.847±0.150±0.095	0.3k	CAWLFIELD	07	CLEO	$D^0 \to K_S^0 \phi$

[1] Obtained by analyzing CLEO-c data but not authored by the CLEO Collaboration. The largest source of error in the TOMARADZE 14 value is from the uncertainties in the K^- and K_S^0 masses. The systematic error given above is the addition in quadrature of $\pm 0.022 \pm 0.053$ MeV, where the second error is from those mass uncertainties.

[2] The largest source of error in the LEES 13S value is from the uncertainty of the K^+ mass. The quoted systematic error is in fact $\pm 0.043 + 3\,(m_{K^+} - 493.677)$, in MeV.

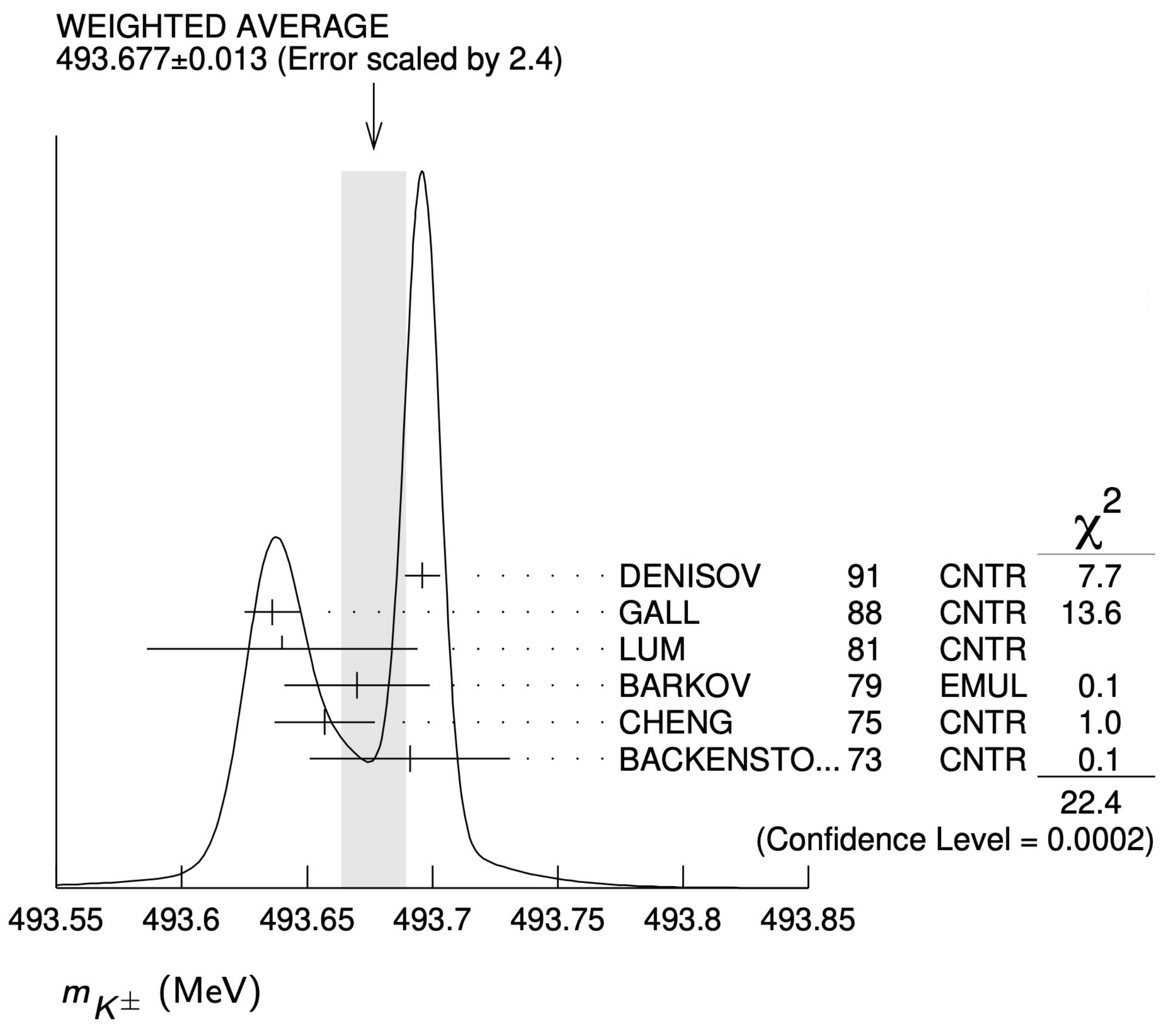
PDG 2020: $m(D^*(2007)^0) - m(D^0) = 142.014 \pm 0.030$ MeV

$\chi_{c1}(3872)$ and $D^0 D^{*0}$ Threshold

$$\delta E = m(D^0) + m(D^{*0}) - m(\chi_{c1}(3872))$$

Group	δE, MeV	Reference
BaBar	0.12 ± 0.24	Phys.Rev. D88 (2013) 071104
CLEO-c data	0.126 ± 0.204	Phys.Rev. D89 (2014) 031501
LHCb	0.07 ± 0.12	JHEP 2008 (2020) 123

Measurement of $K^{\pm}$ Mass – I



Measurement of $K^{\pm}$ Mass – II

$K^{\pm}$ MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
493.677±0.016 OUR FIT Error includes scale factor of 2.8.					
493.677±0.013 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below.					
493.696±0.007	[1] DENISOV	91	CNTR	–	Kaonic atoms
493.636±0.011	[2] GALL	88	CNTR	–	Kaonic atoms
493.640±0.054	LUM	81	CNTR	–	Kaonic atoms
493.670±0.029	BARKOV	79	EMUL	±	$e^+e^- \rightarrow K^+K^-$
493.657±0.020	[2] CHENG	75	CNTR	–	Kaonic atoms
493.691±0.040	BACKENSTO...	73	CNTR	–	Kaonic atoms
• • • We do not use the following data for averages, fits, limits, etc. • • •					
493.631±0.007	GALL	88	CNTR	–	K^- Pb (9→ 8)
493.675±0.026	GALL	88	CNTR	–	K^- Pb (11→ 10)
493.709±0.073	GALL	88	CNTR	–	K^- W (9→ 8)
493.806±0.095	GALL	88	CNTR	–	K^- W (11→ 10)
493.640±0.022±0.008	[3] CHENG	75	CNTR	–	K^- Pb (9→ 8)
493.658±0.019±0.012	[3] CHENG	75	CNTR	–	K^- Pb (10→ 9)
493.638±0.035±0.016	[3] CHENG	75	CNTR	–	K^- Pb (11→ 10)
493.753±0.042±0.021	[3] CHENG	75	CNTR	–	K^- Pb (12→ 11)
493.742±0.081±0.027	[3] CHENG	75	CNTR	–	K^- Pb (13→ 12)

Measurement of $(m(K^+) + m(K^-))/2$ at VEPP-2M – I

$e^+e^- \to \phi \to K^+K^-$

The average mass $(m(K^+) + m(K^-))/2$ was measured as a difference of the beam energy and kaon kinetic energy T_K.

Beam energy from resonance depolarization with 10 keV accuracy ($\Delta E/E \approx 2 \times 10^{-5}$).

T_K determined from the kaon range in the nuclear emulsion.

121 events selected in two runs.

L.M. Barkov et al., Nucl. Phys. B148 (1979) 53

Measurement of $(m(K^+) + m(K^-))/2$ at VEPP-2M – II

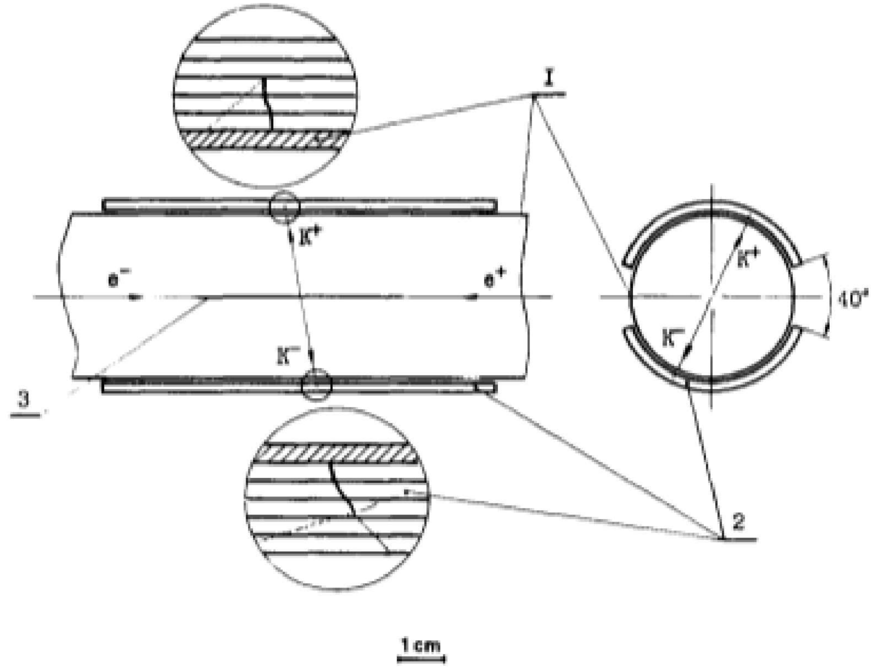
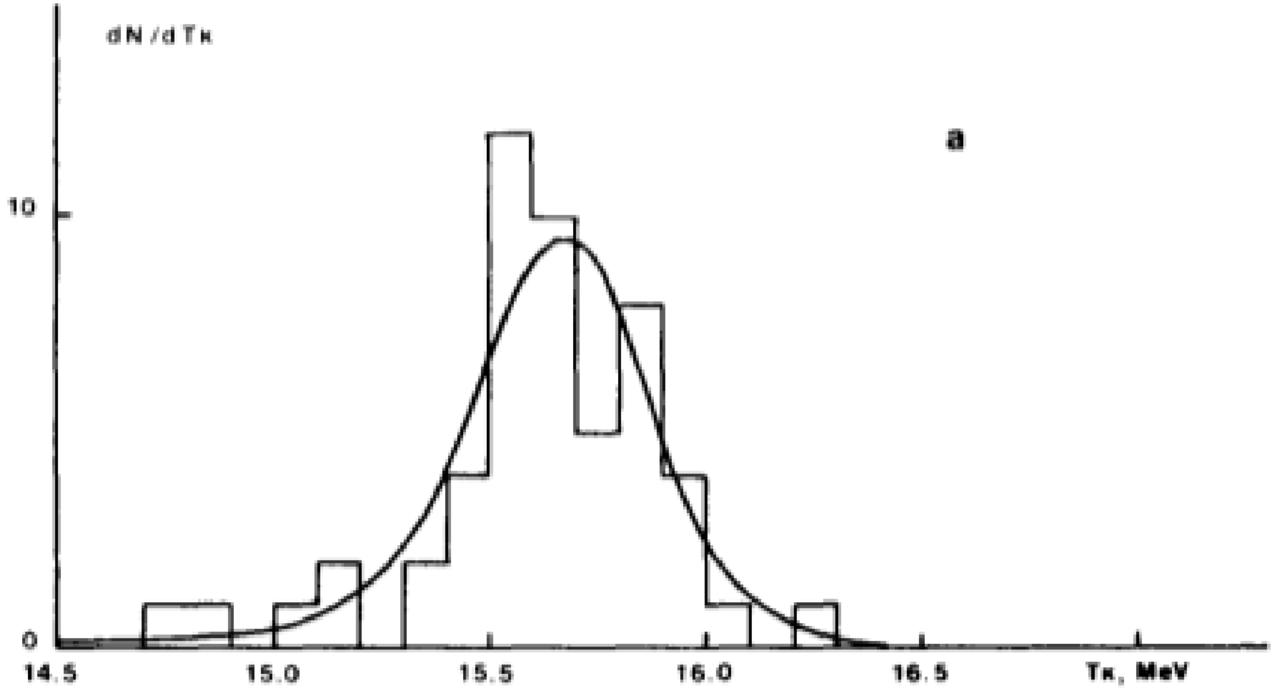


Fig. 1. The emulsion chamber scheme: 1, the storage ring vacuum tube; 2, the emulsion pellicles; 3, the interaction region.

L.M. Barkov et al., Nucl. Phys. B148 (1979) 53

Measurement of $(m(K^+) + m(K^-))/2$ at VEPP-2M – III



$$(m(K^+) + m(K^-))/2 \;=\; (493.670 \pm 0.029)\ \mathrm{MeV}$$

L.M. Barkov et al., Nucl. Phys. B148 (1979) 53

Measurement of K^0 Mass

K^0 MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
497.611±0.013 OUR FIT	Error includes scale factor of 1.2.				
497.611±0.013 OUR AVERAGE	Error includes scale factor of 1.2.				
497.607±0.007±0.015	261k	[1] TOMARADZE	14		$\psi(2S) \to K^0_S X$
497.583±0.005±0.020	35k	AMBROSINO	07B	KLOE	$e^+ e^- \to K^0_L K^0_S$
497.625±0.001±0.031	655k	LAI	02	NA48	K^0_L beam
497.661±0.033	3713	BARKOV	87B	CMD	$e^+ e^- \to K^0_L K^0_S$
497.742±0.085	780	BARKOV	85B	CMD	$e^+ e^- \to K^0_L K^0_S$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
497.44 ±0.50		FITCH	67	OSPK	
498.9 ±0.5	4500	BALTAY	66	HBC	K^0 from $\overline{p}p$
497.44 ±0.33	2223	KIM	65B	HBC	K^0 from $\overline{p}p$
498.1 ±0.4		CHRISTENS...	64	OSPK	

[1] Obtained by analyzing CLEO-c data but not authored by the CLEO Collaboration.

Measurement of $m(K^0)$ at VEPP-2M – I

$e^+e^- \to \phi \to K^0_S K^0_L,\ K^0_S \to \pi^+\pi^-$ at 1018.64±0.03 MeV

The minimal angle $\psi(\pi^+, \pi^-) \approx 150^\circ$,

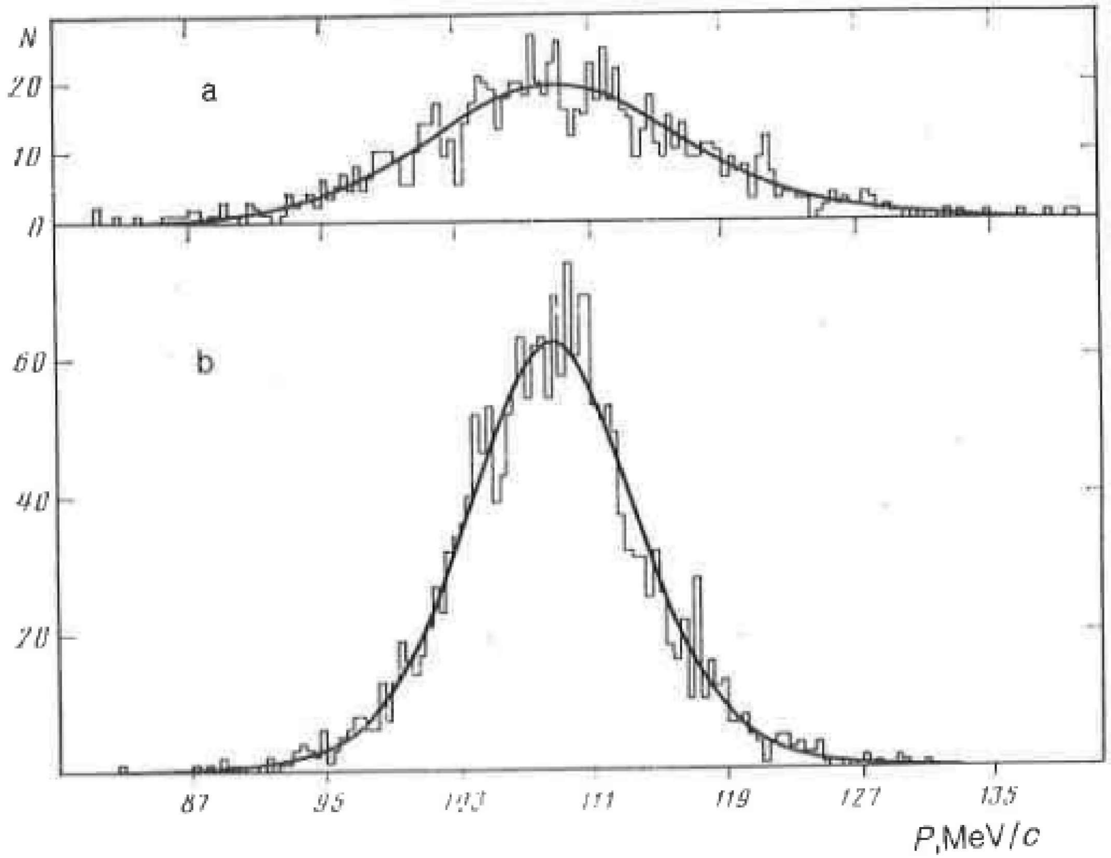
the kaon momentum is 108.3 MeV/c.

The collected luminosity is 17.7/nb and 35.3/nb

at the field value of 14.93 kG and 24.70 kG

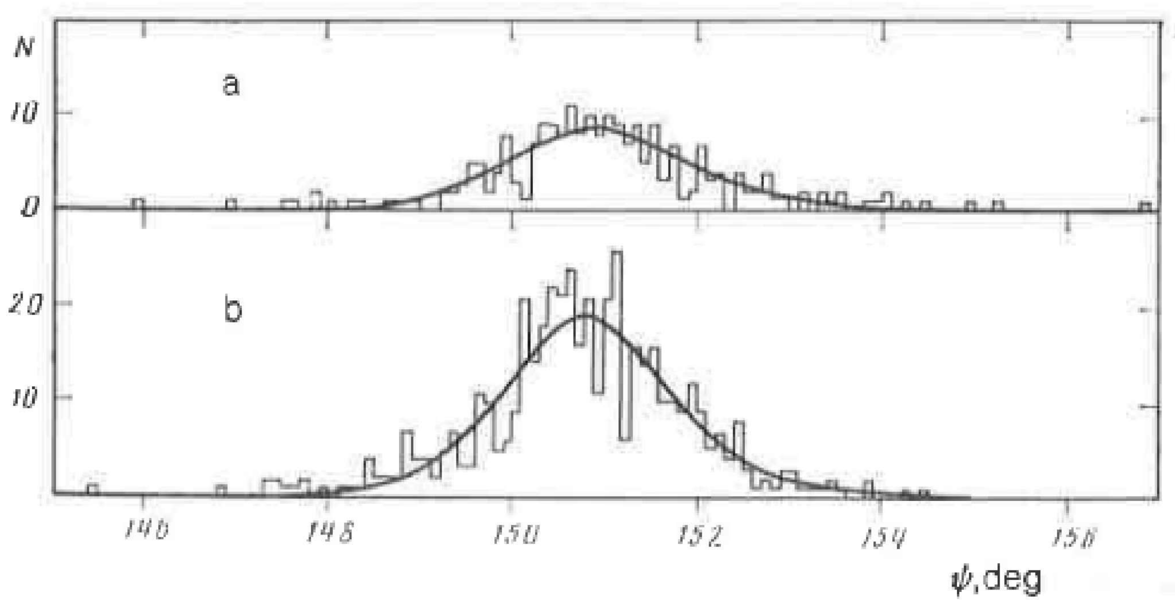
L.M. Barkov et al., Sov. J. Nucl. Phys. 46 (1987) 630

Measurement of $m(K^0)$ at VEPP-2M – II



L.M. Barkov et al., Sov. J. Nucl. Phys. 46 (1987) 630

Measurement of $m(K^0)$ at VEPP-2M – III



The average of four measurements is $m(K^0) = 497.661 \pm 0.033$ MeV

L.M. Barkov et al., Sov. J. Nucl. Phys. 46 (1987) 630

Measurement of $K^{\pm}$ and K^0 Mass Difference

$$m_{K^0} - m_{K^{\pm}}$$

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
3.934±0.020 OUR FIT	Error includes scale factor of 1.6.					
• • • We do not use the following data for averages, fits, limits, etc. • • •						
3.95 ±0.21	417	HILL	68B	DBC	$+$	$K^+ d \to K^0 p p$
3.90 ±0.25	9	BURNSTEIN	65	HBC	$-$	
3.71 ±0.35	7	KIM	65B	HBC	$-$	$K^- p \to n \overline{K}^0$
5.4 ±1.1		CRAWFORD	59	HBC	$+$	
3.9 ±0.6		ROSENFELD	59	HBC	$-$	

Prospects

- New $m(K^{\pm})$ measurements planned with kaonic atoms, see the talks by A. Scordo and D. Bosnar this afternoon
- A new $m(K^{\pm})$ measurement with emulsions is tempting, but very challenging, expertise in the field needed!
- Is a high-statistics measurement of the mass difference feasible at CERN or JLAB?
- CMD-3 plans a feasibility study of the $m(K^{0})$ measurement at VEPP-2000
- Is a threshold measurement of kaon mass possible, similar to the one of the τ-lepton mass, how large are strong form factor uncertainties?

Threshold Measurement of τ Lepton Mass – I

The $e^+e^- \to \tau^+\tau^-$ cross section is known precisely from QED, the only parameter is τ-lepton mass, $\sigma(s = 4m_\tau^2) = 0$.

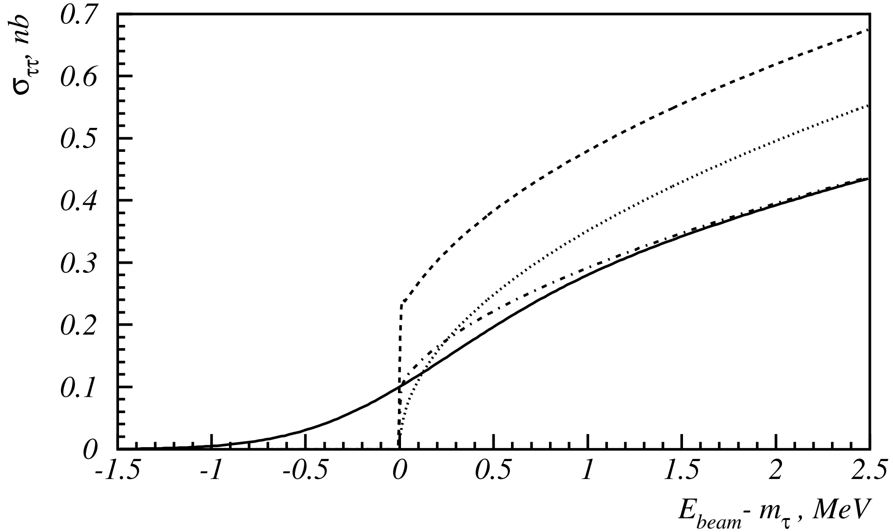
Various corrections affect $\sigma(s)$ and smear 0:

- Coulomb interaction
- Radiative corrections (ISR – initial, FSR – final)
- Vacuum polarization (lepton and hadron loops)

$$\sigma(W) = \frac{1}{\sqrt{2\pi}\sigma_W} \int dW' \exp\left\{-\frac{(W-W')^2}{2\sigma_W^2}\right\} \int dx\, F_c(x, W')\, \sigma_{fs}(W'\sqrt{1-x}),$$

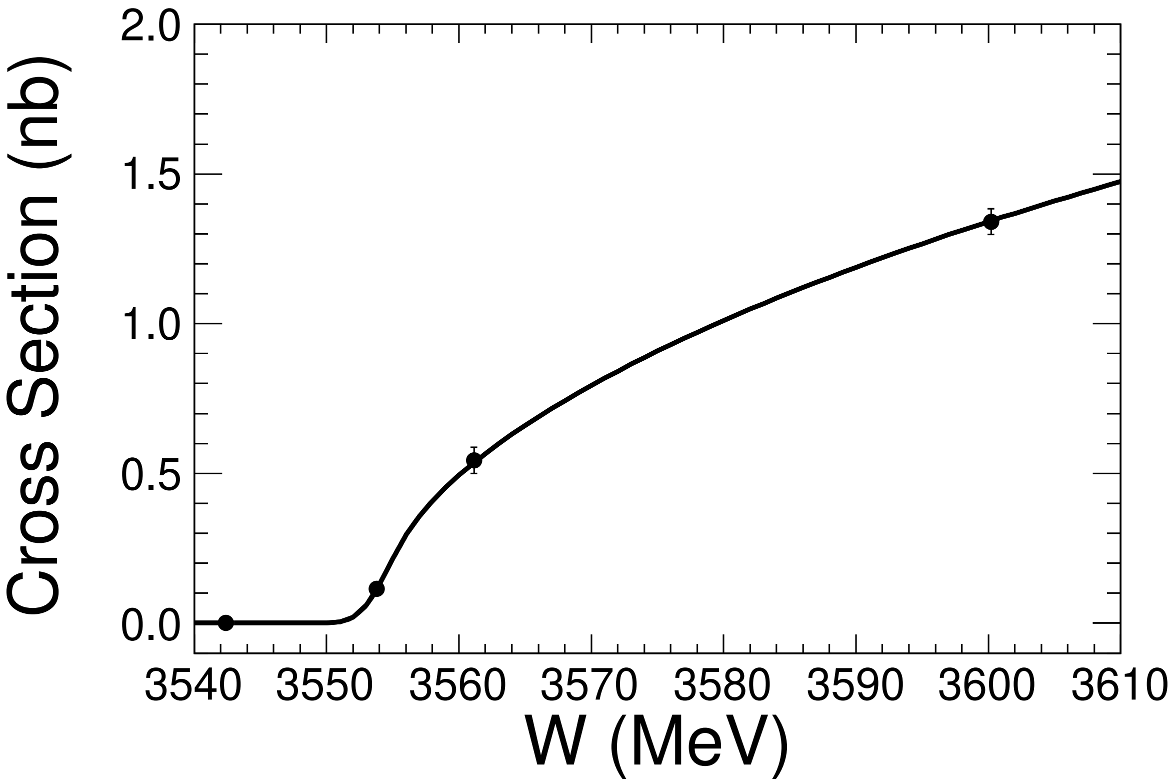
$$F_c(\beta) = (\pi\alpha/\beta)/(1-\exp(-\pi\alpha/\beta)), \quad \beta = (1-(2m_\tau/W)^2)^{1/2}$$

Threshold Measurement of τ Lepton Mass – II



- ... – Born cross section
- - - – Coulomb, FSR and VP corrections
- -.- – ISR corrections
- — – Beam energy spread

m_τ Measurement at BESIII



BESIII (24 pb^{-1} at 4 points, 1171 events)

$m_\tau = 1776.91 \pm 0.12^{+0.10}_{-0.13}$ MeV

M. Ablikim et al., Phys. Rev. D90, 012001 (2014)

$e^+e^- \to K^+K^-$ Cross Section near Threshold

$$\sigma = \frac{8\pi\alpha\beta^3}{3s} F_c(s) T_R(s),$$

where

$$T_R(s) = |\frac{g_{\phi\gamma} g_{\phi K\bar{K}}}{D_\phi(s)} + A_\rho + A_\omega + A_{\rho',\omega',\phi'}|^2,$$

the inverse propagator

$$D_V(s) = m_V^2 - s - i\sqrt{s}\Gamma_V(s),$$

the total width - the sum of partial widths

$$\Gamma_V(s) = \Gamma_V \Sigma \mathcal{B}_i P_i(s),$$

with $\mathcal{B}_i$ - branching, $P_i(s)$ - phase space of the i-th partial width.

E.A. Kozyrev et al., Phys. Lett. B779 (2018) 64

Conclusions

- Accuracy of the charged and neutral kaon masses is a limiting issue in various applications
- $m(K^{\pm})$ and $m(K^0)$ as masses of the ground-state strange hadrons are of interest for theory in potential models and lattice calculations
- Different ideas of improving the accuracy exist and various laboratories can contribute !