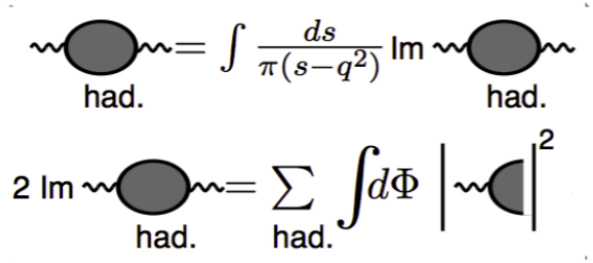
Study of the process $e^+e^- \to K_S K^\pm \pi^\mp$ with CMD-3 detector

Budker Institute of Nuclear Physics

Artem Uskov

Channels contribution to HVP



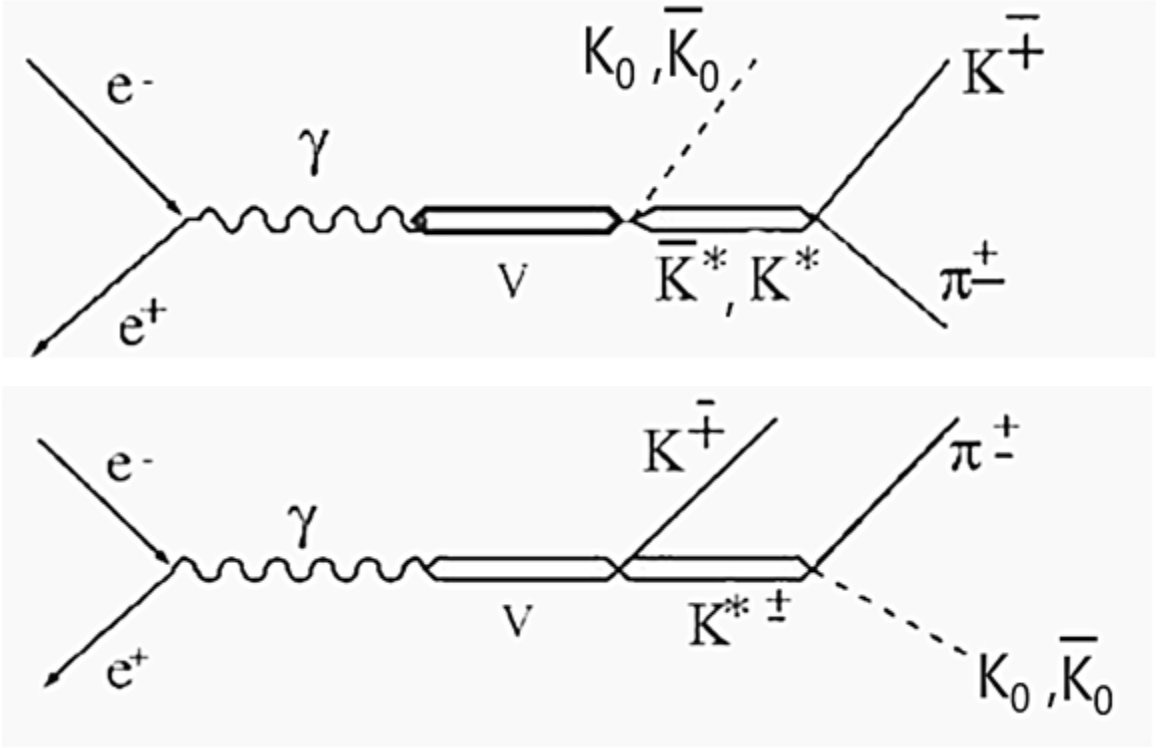
$$a_\mu^{\text{had,LO}} = \frac{m_\mu^2}{12\pi^3}\int_{s_{\text{th}}}^{\infty} ds\ \frac{1}{s}\hat{K}(s)\sigma_{\text{had}}(s)$$

$\eta\pi^+\pi^-$	0.88 ± 0.10
K^+K^-	22.09 ± 0.46
$K_S^0K_L^0$	13.32 ± 0.16
$\omega\pi^0$	0.76 ± 0.03
$\pi^+\pi^-$	505.65 ± 3.09
$2\pi^+2\pi^-$	13.50 ± 0.44
$3\pi^+3\pi^-$	0.11 ± 0.01
$\pi^+\pi^-\pi^0$	47.38 ± 0.99
$\pi^+\pi^-2\pi^0$	18.62 ± 1.15
$\pi^0\gamma$	4.54 ± 0.14
$\eta\gamma$	0.69 ± 0.02
$\eta2\pi^+2\pi^-$	0.02 ± 0.00
$\eta\omega$	0.38 ± 0.06
$\eta\phi$	0.33 ± 0.03
$\phi(\rightarrow$ unaccounted)	0.04 ± 0.04

$K\bar{K}\pi$	2.77 ± 0.15
$K\bar{K}2\pi$	3.31 ± 0.58
$K\bar{K}3\pi$	0.08 ± 0.04
$\omega\left(\rightarrow \pi^0\gamma\right)K\bar{K}$	0.01 ± 0.00
$2\pi^+2\pi^-\pi^0(\text{ no }\eta)$	1.20 ± 0.10
$\pi^+\pi^-3\pi^0(\text{ no }\eta)$	0.60 ± 0.05
$\omega\left(\rightarrow \pi^0\gamma\right)2\pi$	0.11 ± 0.02
$2\pi^+2\pi^-2\pi^0(\text{ no }\eta)$	1.80 ± 0.24
$\pi^+\pi^-4\pi^0(\text{ no }\eta)$	0.28 ± 0.28
$\omega\left(\rightarrow \pi^0\gamma\right)3\pi$	0.22 ± 0.04
$\eta\pi^+\pi^-(\text{data})$	0.98 ± 0.24
$\eta\omega$ (data)	0.42 ± 0.07
$\eta\phi$ (data)	0.46 ± 0.03
$\eta2\pi^+2\pi^-(\text{data})$	0.11 ± 0.02
$\eta\pi^+\pi^-2\pi^0$	0.11 ± 0.06

Motivation

- Study the mechanism of final state birth in the reaction $e^+e^- \to K_sK\pi$
- Determine the cross section vs energy of the process $e^+e^- \to K_sK\pi$
- Find the parameters of φ(1680), ρ(1450) (mass, width, branching)
- Improve calculation accuracy of the hadronic contribution in $(g-2)_\mu$



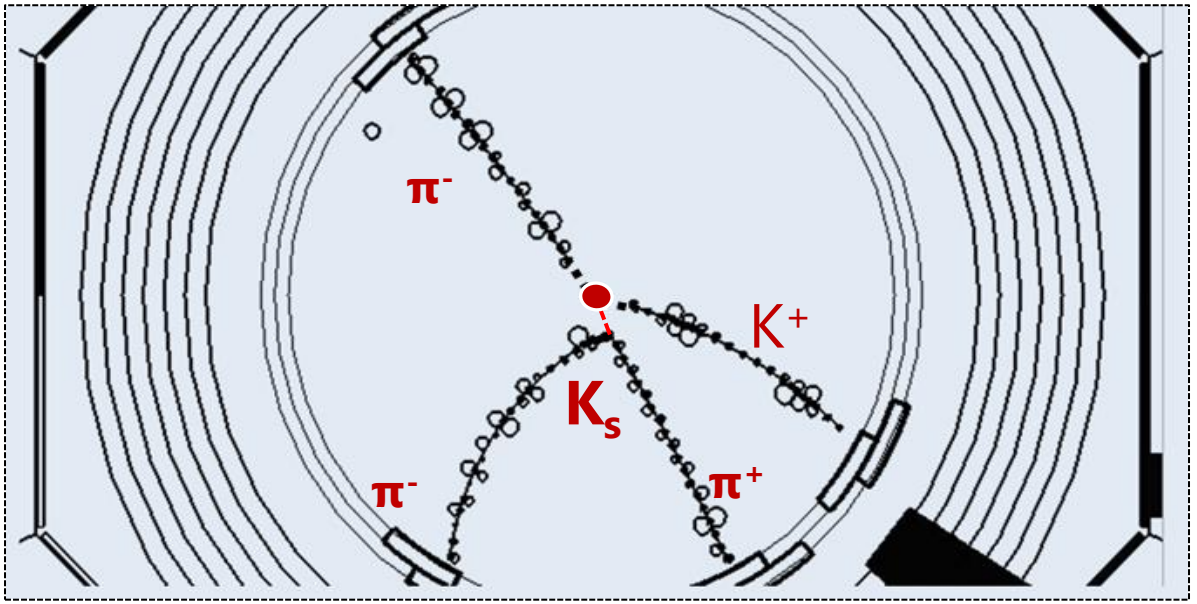
= $K_sK\pi$

Work content:

- Develop optimal criteria to select events of $e^+e^- \to KK^* \to K_sK\pi$ (signal events).
- Study background processes that mimic signal events.
- Assess efficiency of registration by simulation with radiative corrections.
- The systematic errors are included in analysis.
- Obtained parameters φ(1680), ρ(1450) (mass, width, branching) using Vector Model of Dominance.

Events in CMD3

A single signal event of $K_S K^{\pm}\pi^{\mp}$ shown on CMD-3 visualization



● - beam axis, ╲ - K_s decay length

Event:

One Ks: found by kinematic fit (= *kinfit*), energy-momentum conservation required

Two opposite charged tracks from interaction point (= *IP*)

Two opposite charged tracks from **Ks** decay

Tracks:

Polar track angle **1**< Θ_{tr} < **π - 1**

Number of hits per track ≥ **10**

Track momentum from **60** to **800** MeV/c

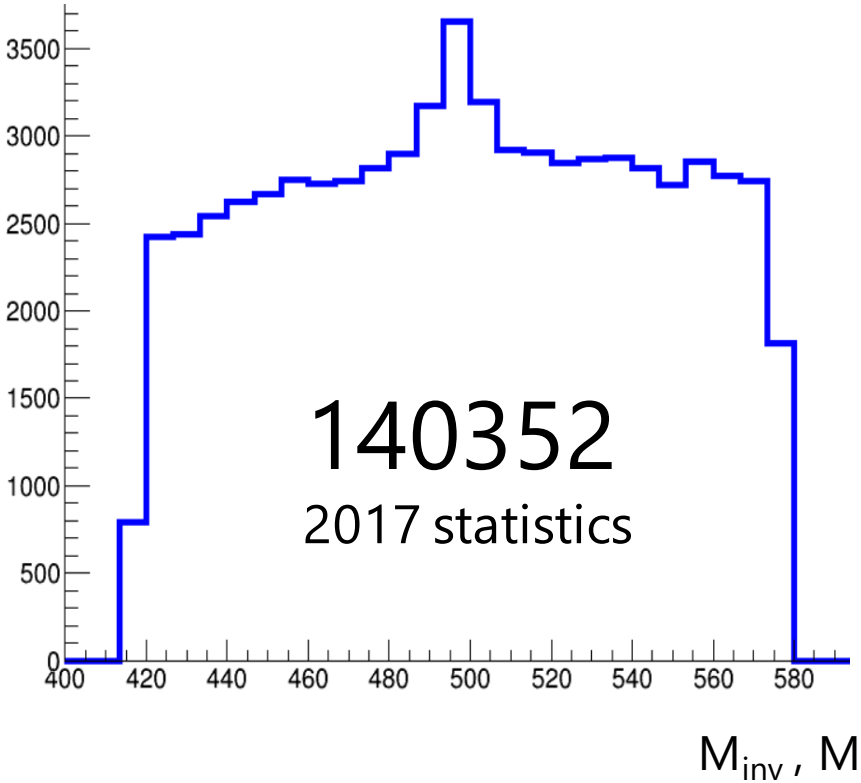
Track z along the beam axis < **12** cm

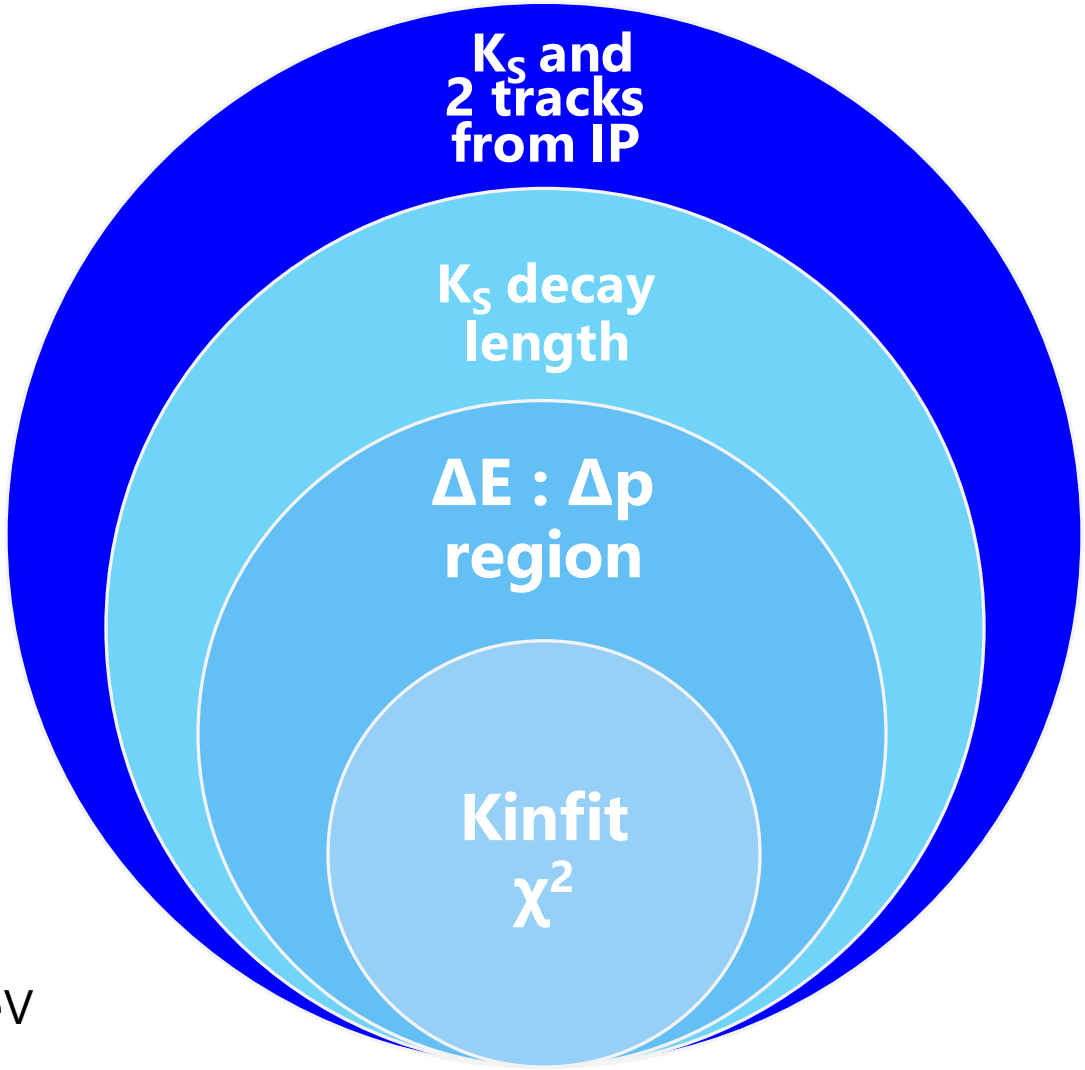
Track (not from Ks) impact parameter < **0.1** cm

The K_s invariant mass after pre-selection

All pairs of tracks with opposite signs are searched.
They are ascribed a mass of pions and an invariant mass is constructed.

The K_s invariant mass



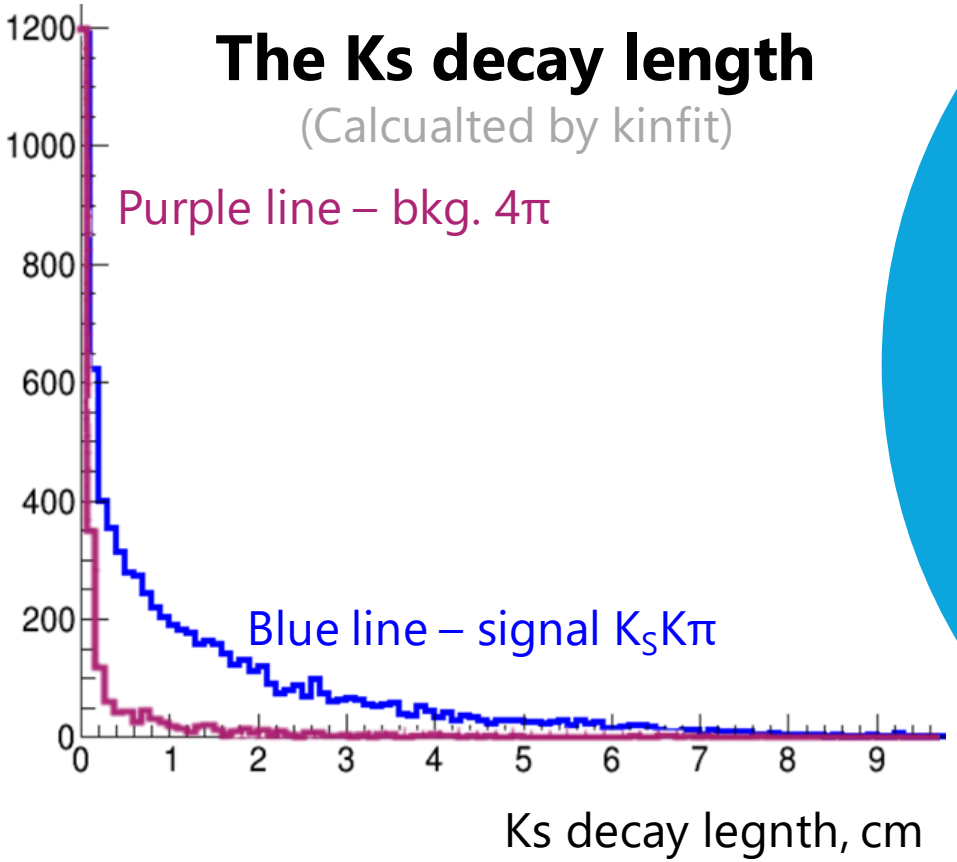


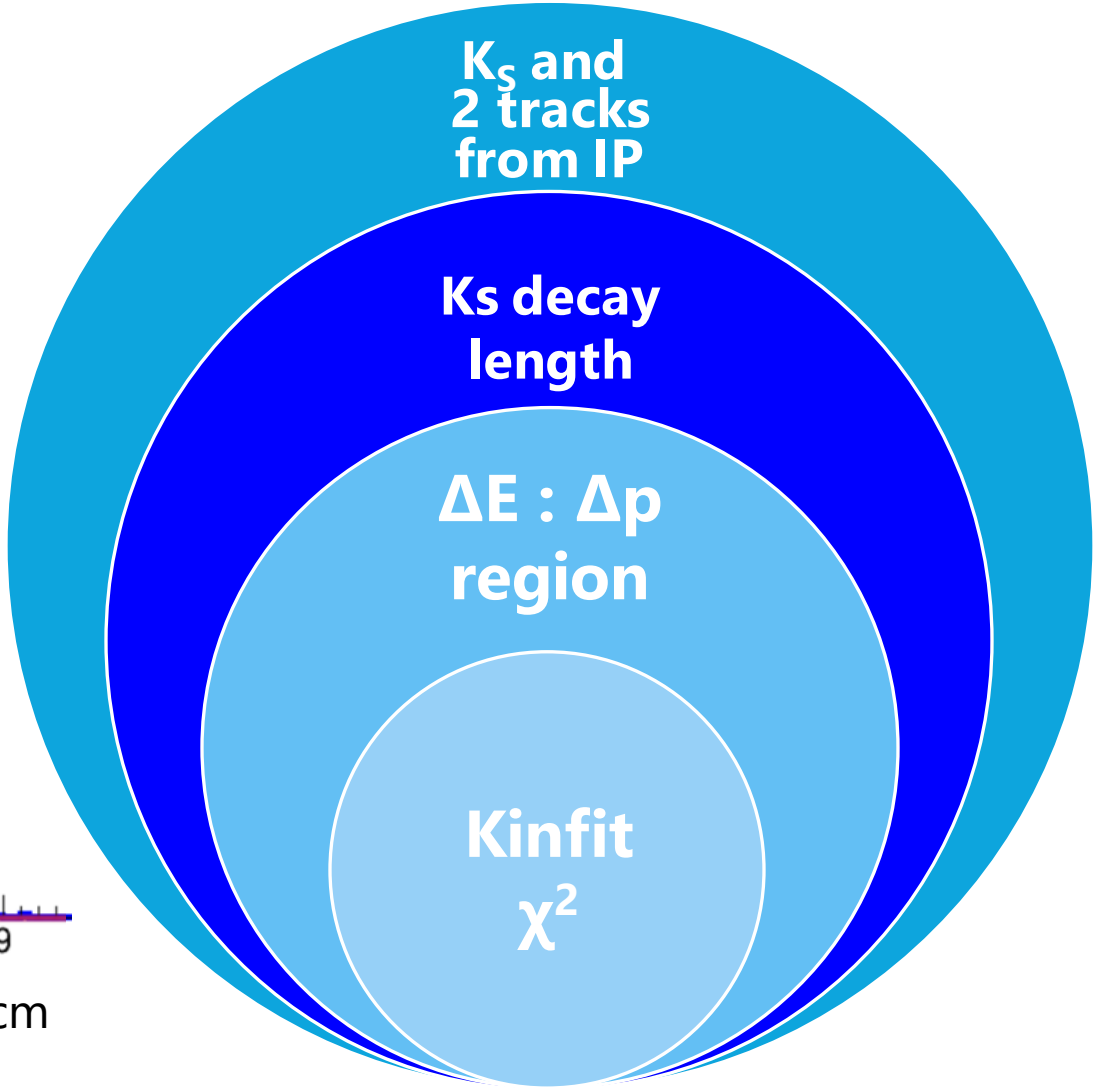
The invariant mass of Ks after the second selection

The Ks decay length is more than 0.2 cm from the beam.

Signal events ↓ **1.2** times

Background ↓ **10** times





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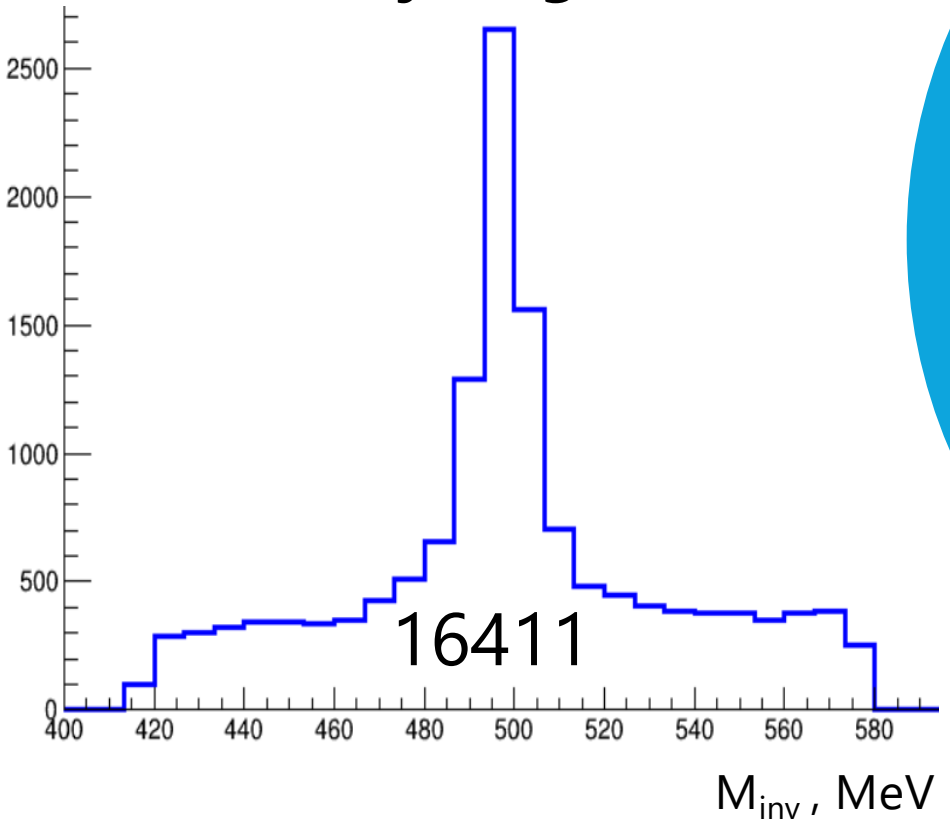
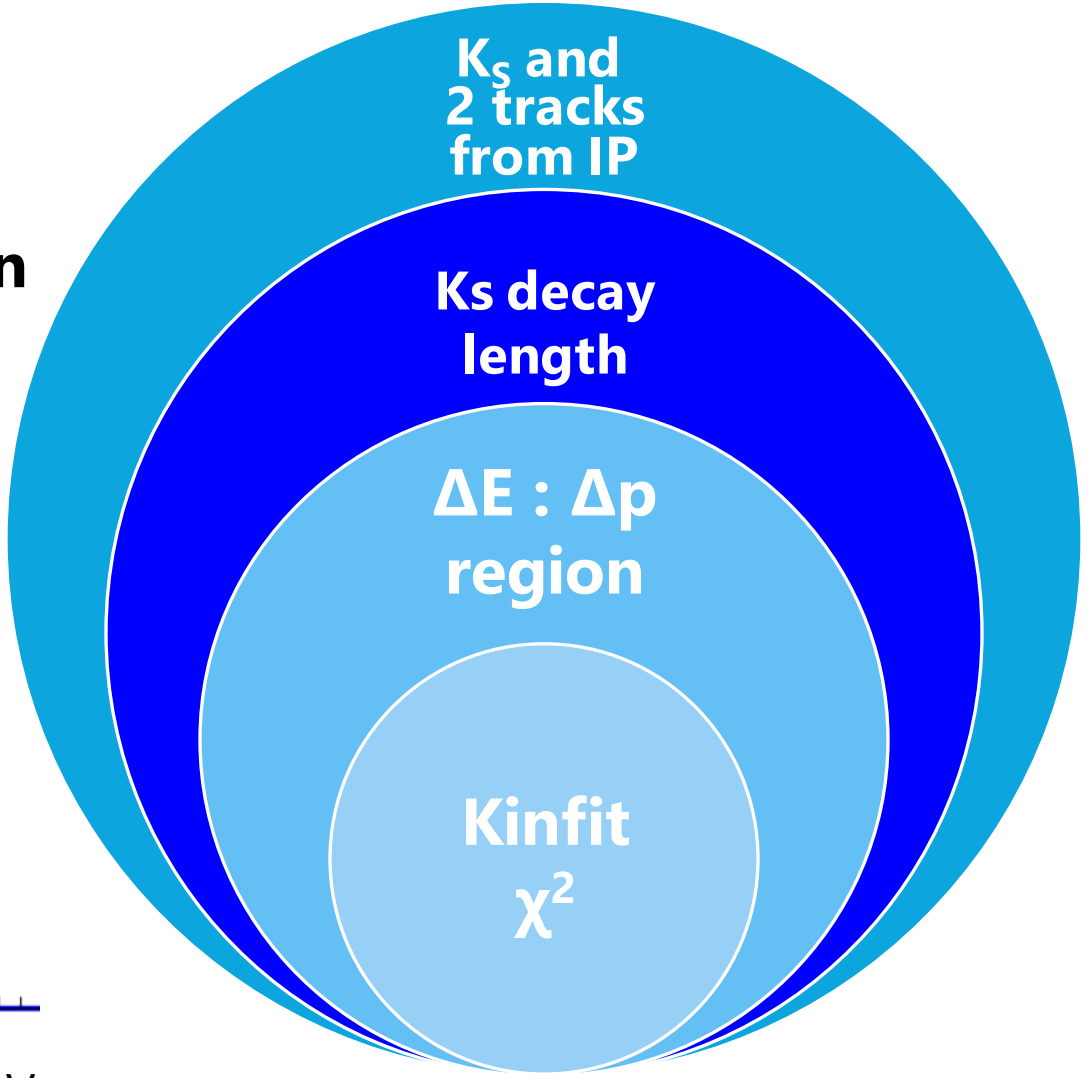


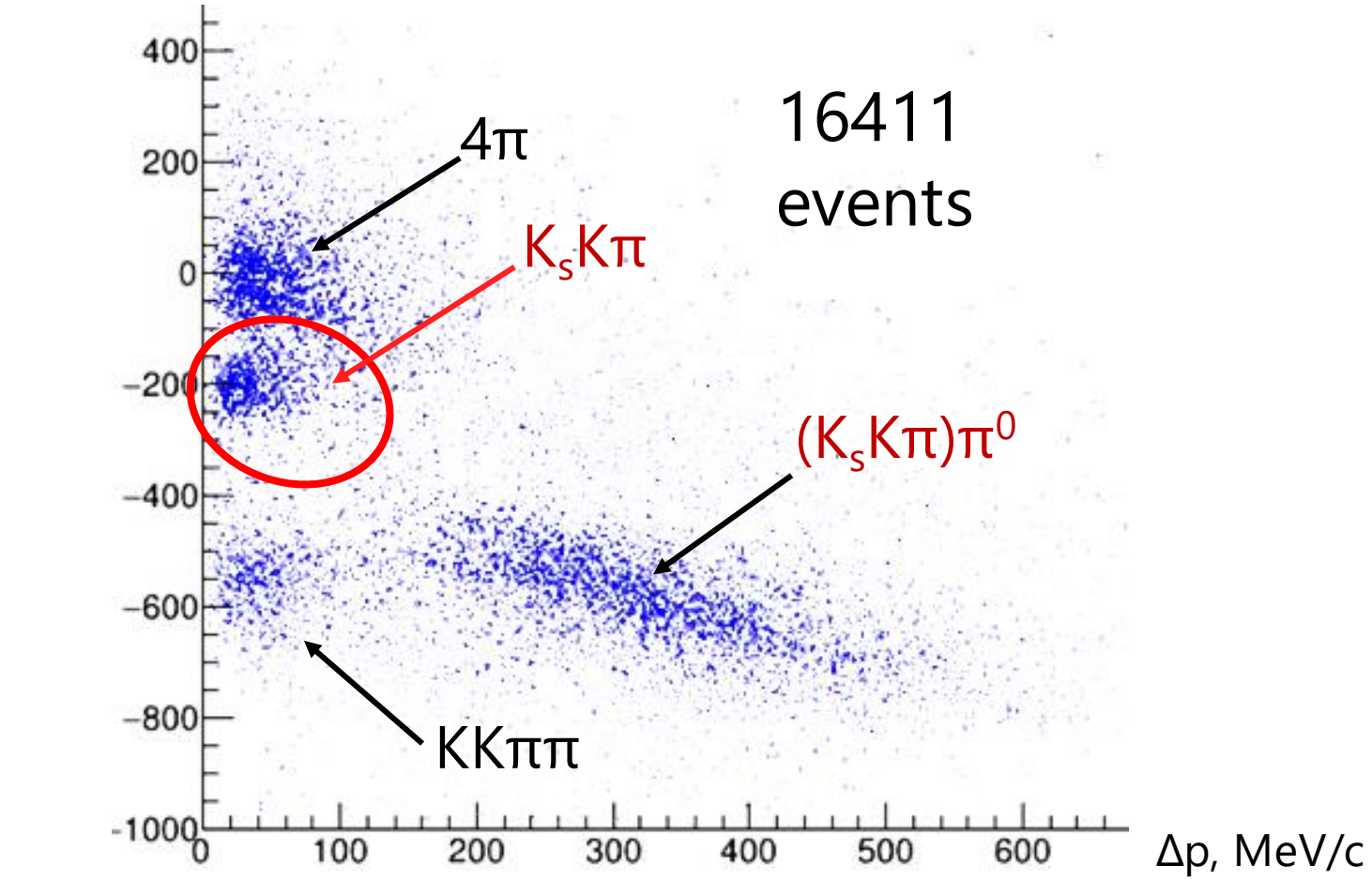


Highlight the events of $K_sK\pi$ process

All four tracks are assigned a mass of π

$$\Delta E = E_1 + E_2 + E_3 + E_4 - 2E_{beam}$$

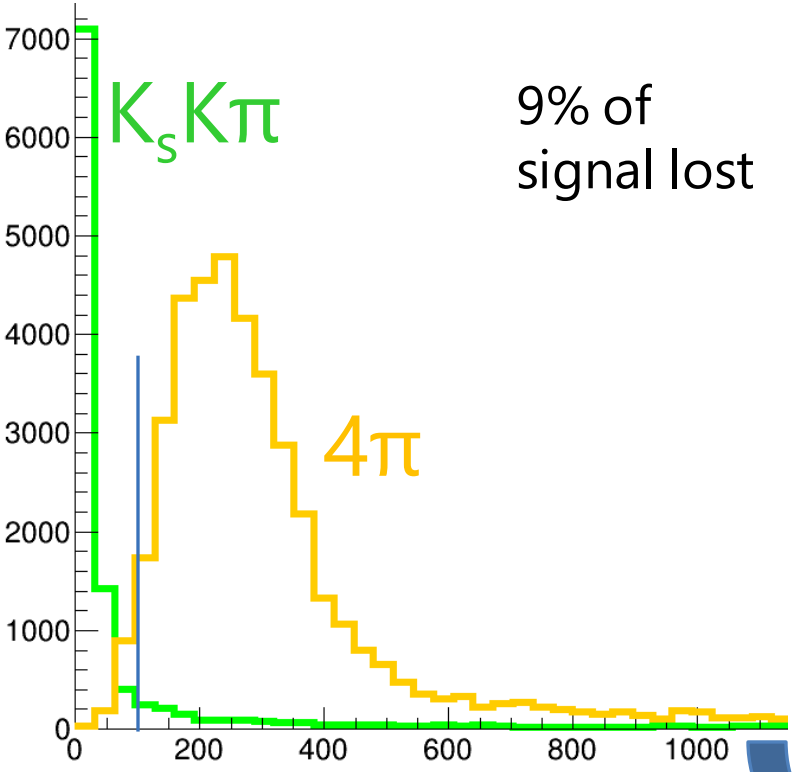
$$\Delta p = \|\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \vec{p}_4\|$$



Kinematic reconstruction is carried out in 2 stages

χ^2 of the kinematic reconstruction simulation (760 MeV)

Hypothesis $\mathbf{K_sK\pi}$

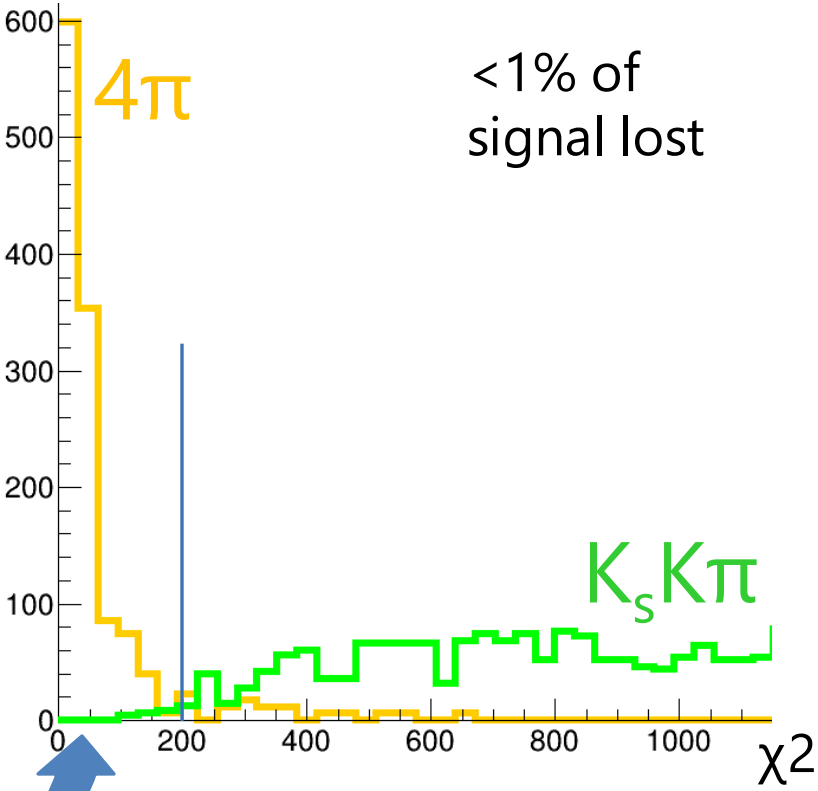


9% of signal lost

χ^2

$\chi^2 < 100$

Hypothesis $\mathbf{4\pi}$



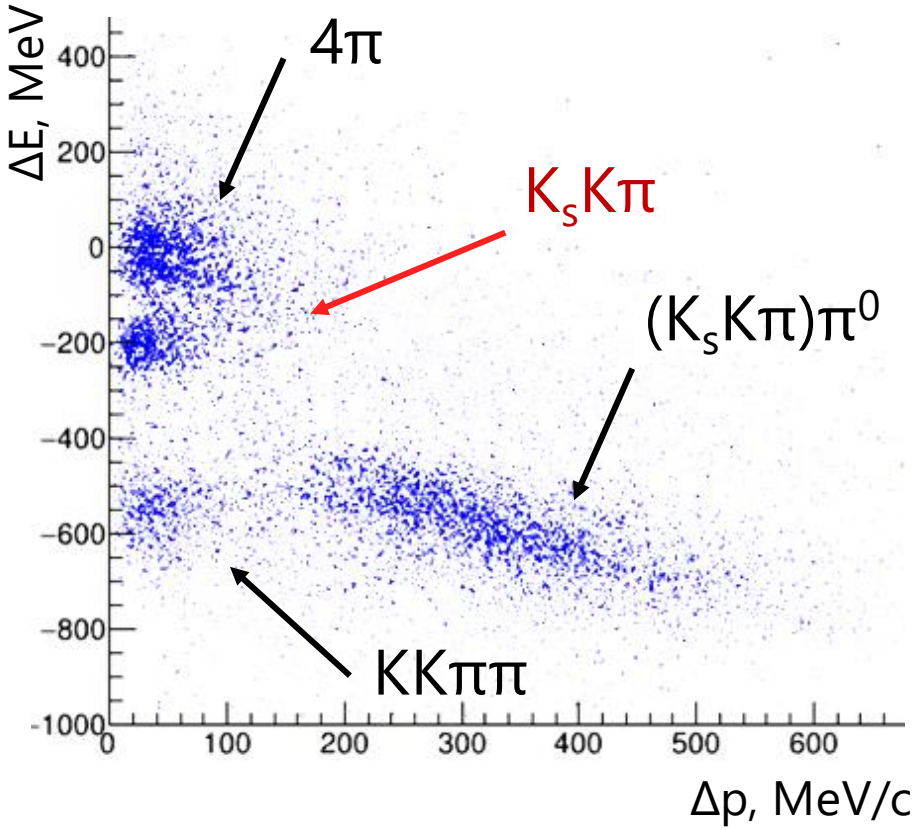
<1% of signal lost

$\chi^2 > 200$

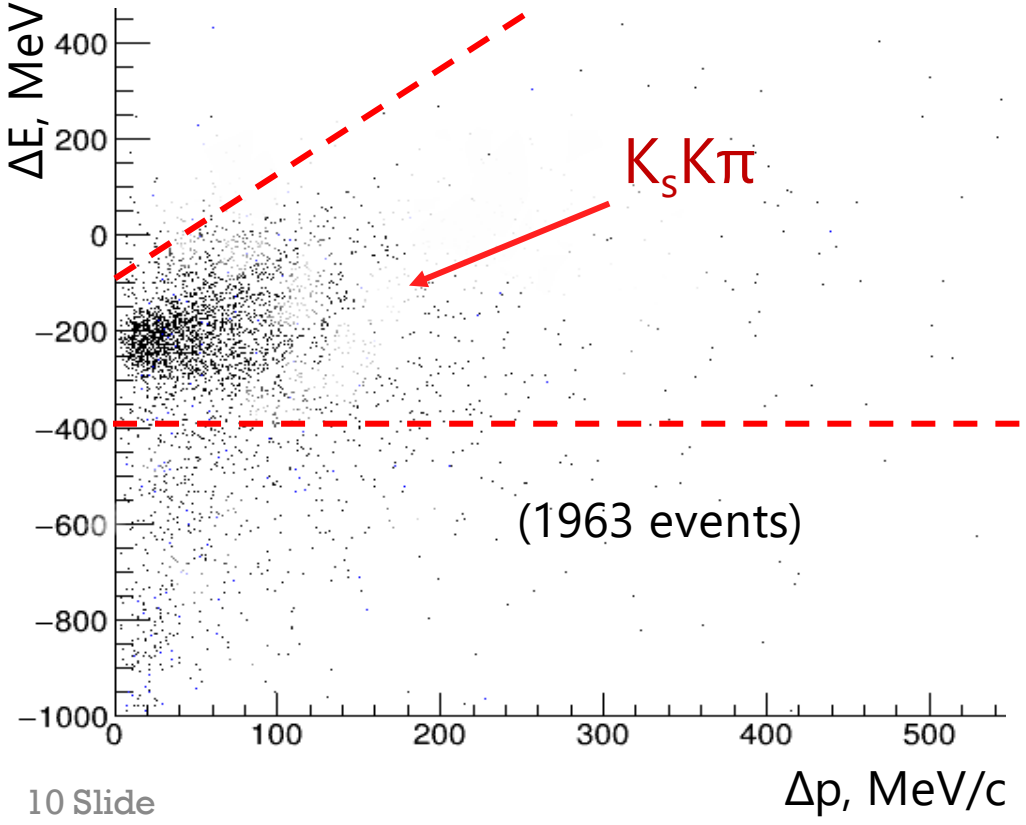
Physical background suppressed x5

Kinematic reconstruction with χ2 cut suppressed background

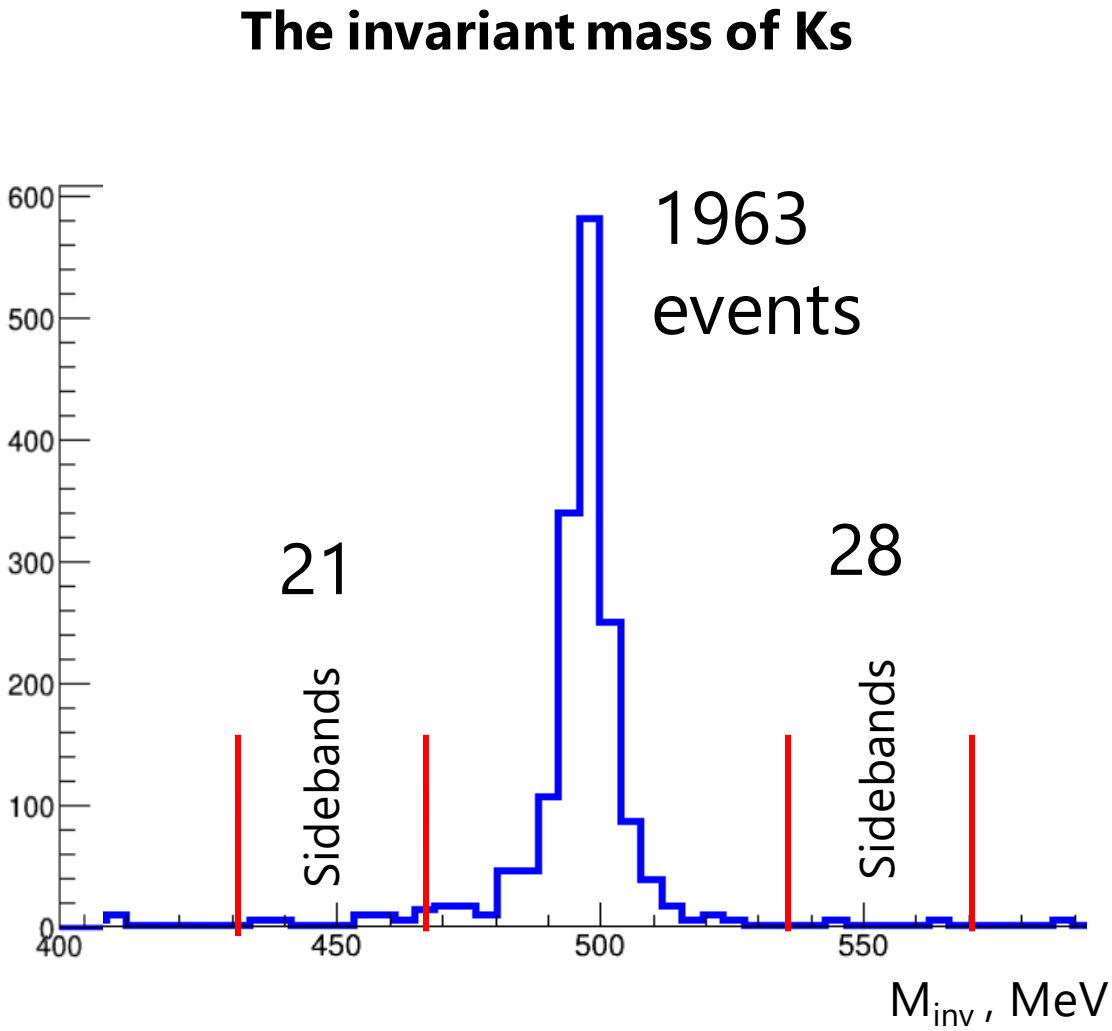
Before kinematic reconstruction χ2 cut (16411 events)



After kinematic reconstruction χ2 cut



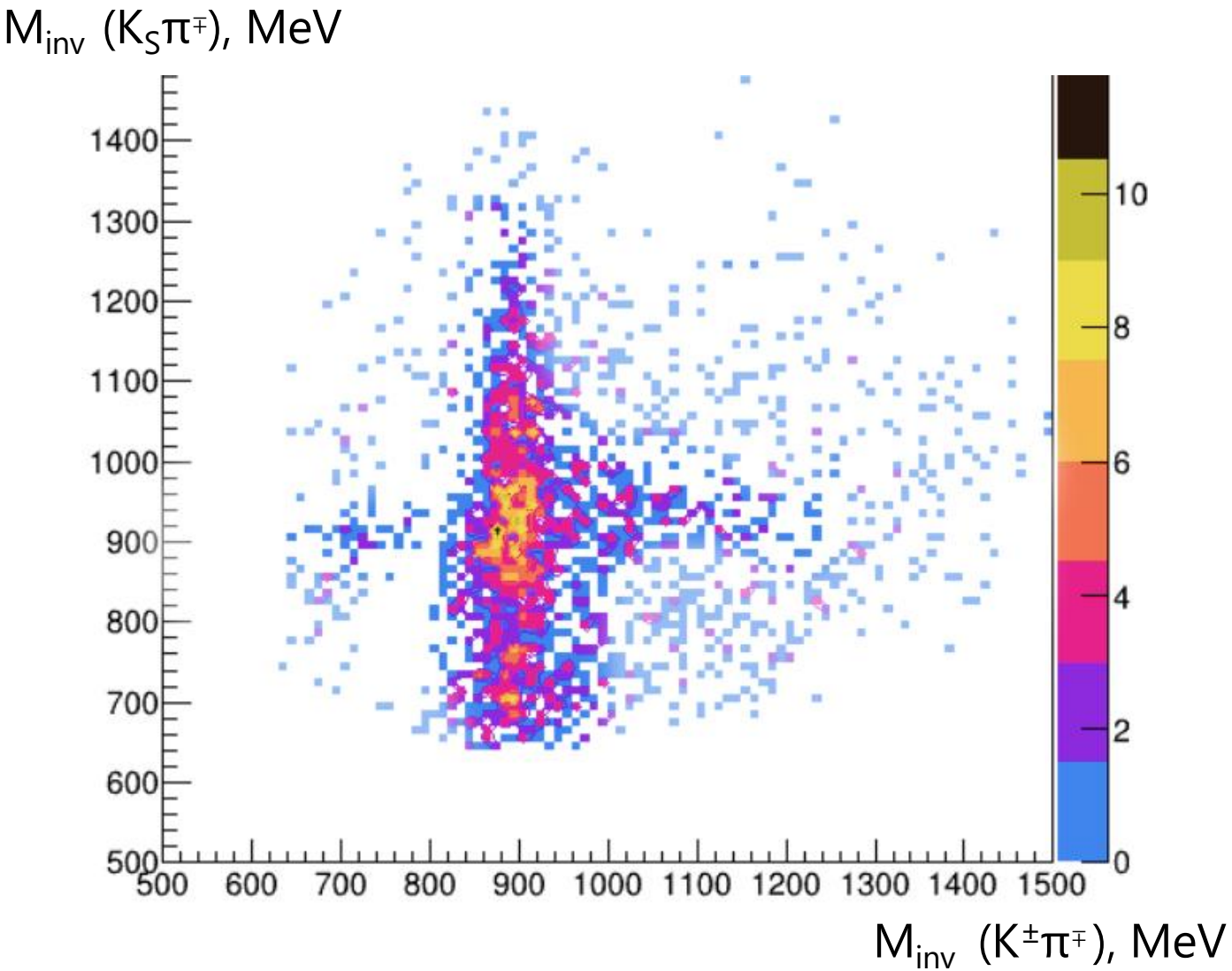
Count events. Subtract background.



Dynamics of the process $K_sK\pi$

$\mathbf{D_{K^{*0}}}$ – neutral K* propagator, depends on M_{inv} $(K^{\pm}\pi^{\mp})$
$\mathbf{D_{K^{*\pm}}}$ – charged K* propagator, depends on M_{inv} $(K_S\pi^{\mp})$

Isopin-1/2 ➡ $\mathbf{D_{K^{*0}}}$ enters the amplitude with $\mathbf{A_0} + \mathbf{A_1}$,
$\mathbf{D_{K^{*\pm}}}$ enters the amplitude with $\mathbf{A_0} - \mathbf{A_1}$, $\mathbf{A_0}$ and $\mathbf{A_1}$ are amplitudes for **isospin** 0 and 1

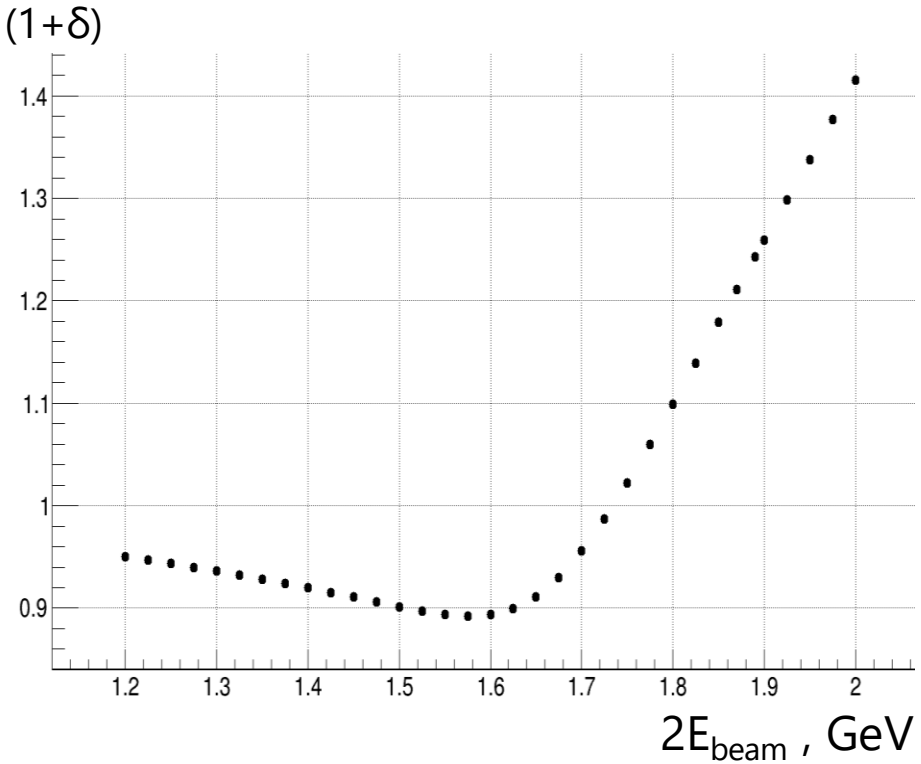


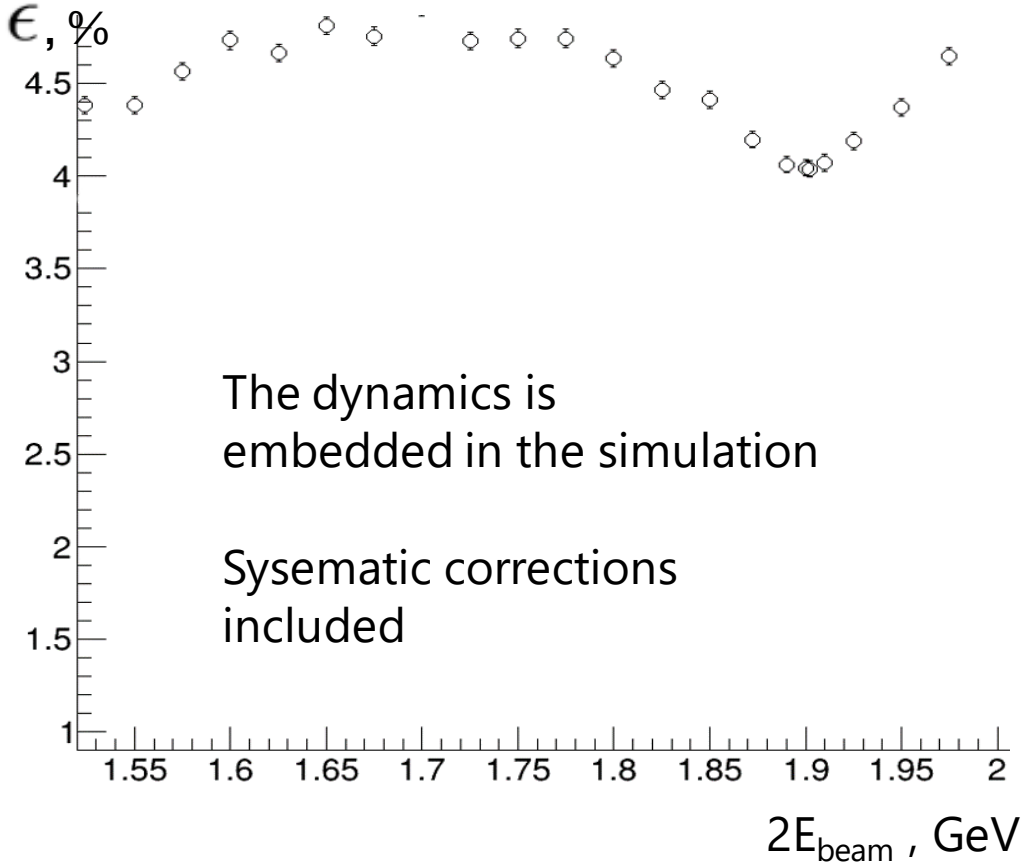
Registration Efficiency and Radiative Correction

$$\sigma_{visible} = \frac{N_{signal}}{L*\epsilon}$$

$$\sigma_{born} = \sigma_{vis} / (1 + \delta)$$

$$\sigma_{visible}(s) = \int_0^{\varepsilon} dx\, \sigma_{born}\big(s(1-x)\big)F(x,s)$$





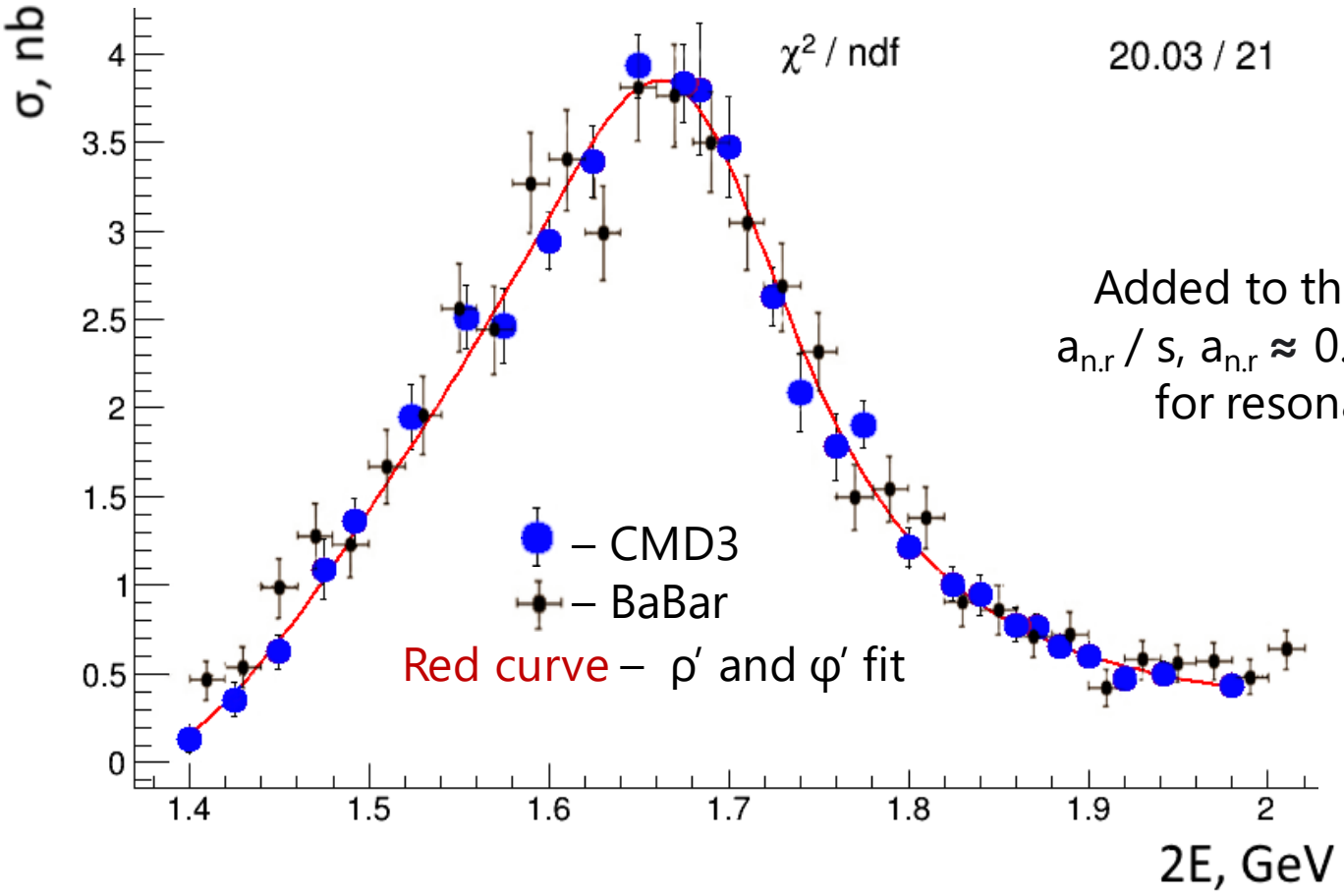
The dynamics is embedded in the simulation

Sysematic corrections included

Cross section of the process $e^+e^- \to K_sK\pi$

Approximation with two resonances ρ'(1450) and φ'(1680)
plus resonance tail below threshold (red curve)

- The analysis is based on an integral luminosity of 127 pb $^{-1}$ **6019** events selected
- Points less than 5 MeV apart in energy were combined according to luminosity weights



Added to the amplitude
$a_{n.r} / s$, $a_{n.r} \approx 0.3 \pm 0.08$ MeV
for resonance tails

Systematic Uncertainties and Corrections

Accuracy of luminosity measurements, difference of simulation and experiment, model assumptions – all contribute to systematic errors.

We applied corrections, and then estimated errors by varying parameters.

Table 1: Systematic errors of cross-section measurement.

Source	Value, %
Polar angle variation	1.3
Variation of the upper dotted line on dE:dP	1.1
Variation of the bottom dotted line	1.3
Variation of K_S decay vertex distance	1.5
Correction to the reconstruction of tracks in the DC	1.3
Correction to events selection by χ^2	1.1
Background Subtraction	1.2
Luminosity	1.5
Total	3.7

Contributions from uncertainties: branching of K_S to $\pi^+\pi^-$, energy spread, trigger efficiency, radiative correction – are negligible.

Results:
mass, width, and lepton branchings

φ′

	$\Gamma_{ee}^{\varphi'} Br_{KK^*(892)}^{\varphi'}$ (eV)	$M_{\varphi'}$ (MeV)	$\Gamma_{\varphi'}$ (MeV)
This paper 10.1088/1402-4896/abb694	$374 \pm 80 \pm 29$	$1699 \pm 7 \pm 11$	$207 \pm 26 \pm 15$
CMD-3 10.1016/j.physletb.2019.134946	–	$1667 \pm 5 \pm 11$	$176 \pm 23 \pm 38$
BaBar	367 ± 50	1709 ± 19	325 ± 68
PDG	–	1680 ± 20	150 ± 50

ρ'

	$\Gamma_{ee}^{\rho'} Br_{KK^*(892)}^{\rho'}(eV)$	$M_{\rho'}(MeV)$	$\Gamma_{\rho'}(MeV)$
This paper	$105 \pm 17 \pm 13$	$1495 \pm 26 \pm 15$	$361 \pm 29 \pm 18$
CMD-3 10.1007/JHEP01(2020)112	–	1502 ± 11	315 ± 27
BaBar	129 ± 15	1508 ± 19	418 ± 26
PDG	–	1465 ± 25	400 ± 60

Systematic errors include uncertainties of:
cross-section, branchings in **Γ(s),** resonance tails $\mathbf{a_{n.r}}$

Summary

- Developed selection criteria for the processes $e^+e^- \to K_S K^{\pm}\pi^{\mp}$ and $e^+e^- \to K_S K^{\pm}\pi^{\mp}\pi^0$
- Confirmed the dominance of the neutral channel $K^0K^{*0}(892)$
- Measured the cross section of the process $e^+e^- \to K_S K^{\pm}\pi^{\mp}$ with a systematic accuracy better than 4%
- Approximated cross section of the process $e^+e^- \to K_S K^{\pm}\pi^{\mp}$ with two resonances φ(1680), ρ(1450). Measured parameters of these resonances with the world average accuracy.