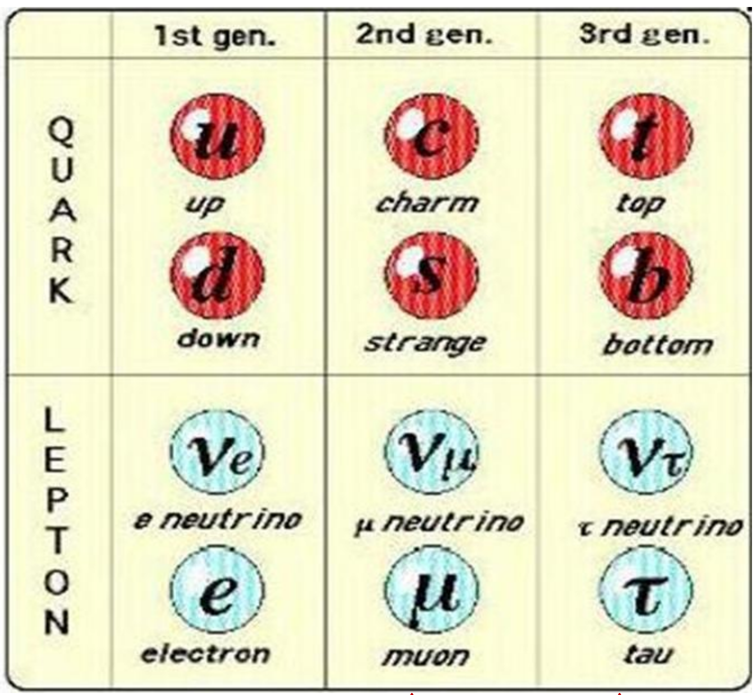
Измерение спектральной функции τ-лептона в распаде $\tau^- \to K^- K_S \nu_\tau$ в эксперименте BaBar

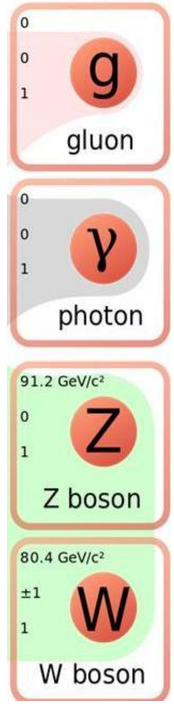
С. Середняков, В. Дружинин

Экспериментальный семинар ИЯФ,
22 июня 2018 г.

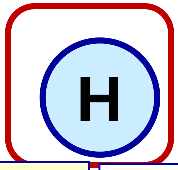
Fundamental particles

Matter ↓ s=1/2 Field ↓ s=1





r < 10^{-17} cm !



s=0

125 GeV

↑ ↑ ↑

Flavors

+3 colours for each quarks

3 generations

+ antiparticles

Total number : 60 + H = 61

All have spin excl H

M(matter) ~ 550 GeV

ΣQ(quarks) = - ΣQ(leptons) !

Что такое спектральная функция (SF); $\tau^- \to K^- K_S \nu_\tau$

$$V(m) = 2\frac{1}{N}\frac{dN}{dm}\frac{1}{m(M_\tau^2 - m^2)^2(M_\tau^2 + 2m^2)}\frac{B(\tau \to K_S K \nu)}{B(\tau \to e\nu\nu)}\frac{M_\tau^6}{12\pi V_{ud}^2}$$

V(m) описывает спектр масс адронов в распаде τ :   dN/dm ($K^- K_S$)

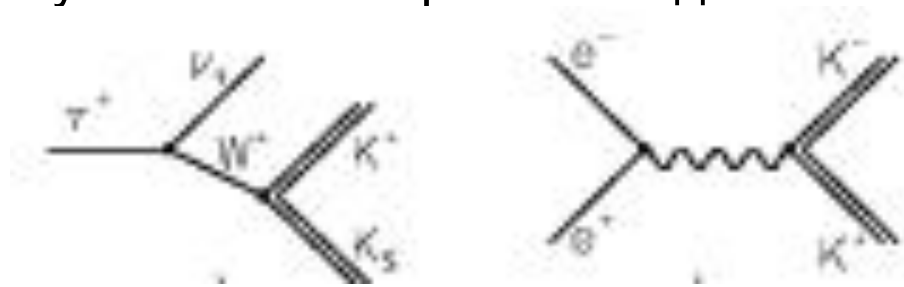
Согласно CVC   SF связывает спектр масс dN/dm с сечением e+e-

$$V(m) = \frac{m^2}{4\pi^2\alpha^2}\sigma_{e^+e^- \to K\bar{K}(I=1)}(m)$$

Мотивация данной работы:

- ✓ Измерение спектральной функции (SF) в распаде $\tau^- \rightarrow K^- K_S \nu_\tau$

- ✓ Используя CVC и SF получить изовекторный вклад в сечение e^+e^- -> K Kbar (I=1)



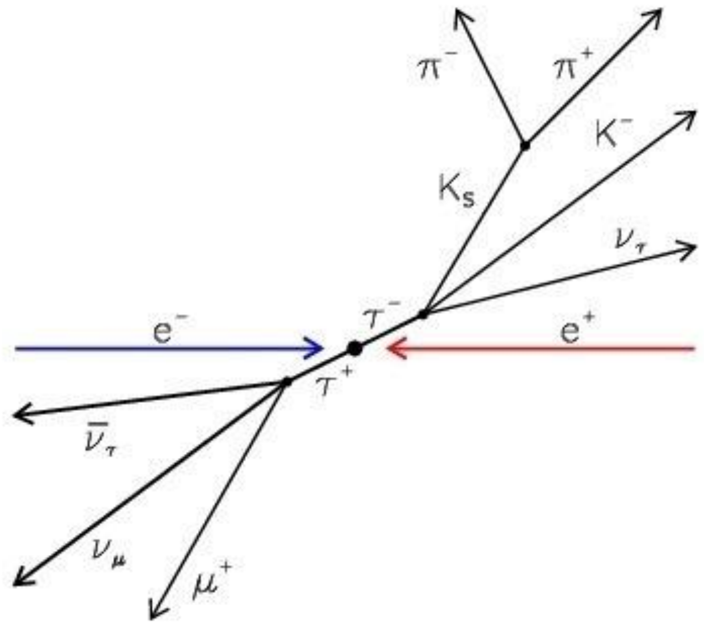
- ✓ Сравнить расчетные изовекторные вклады от e+e- и τ для процессов e^+e^- -> K Kbar (I=1)

- ✓ Корректировка массового спектра в MC генераторе τ -> $K^- K_S$ $\nu\tau$

τ – lepton production at BaBar

$$e^+e^- \rightarrow \tau^+ \tau^-$$

$$E_{c.m.} = m(\Upsilon(4S)) = 10.58 \text{ GeV}$$



$\sigma_{\tau\tau} = 0.92$ nb

$L \approx 0.5$ ab^{-1}

$N_{\tau\tau} \approx 10^9$

τ Branching Ratios (PDG 2016)

$BR(\tau^- \to K_S K^- \nu_\tau)$ = 0.740 +- 0.025 10^{-3}

$BR(\tau^- \to K_S \pi^- \nu_\tau)$ = 4.2 +- 0.07 10^{-3}

$BR(\tau^- \to K_S K^- \pi^0 \nu_\tau)$ = 0.75 +- 0.04 10^{-3}

$BR(\tau^- \to K^- \nu_\tau)$ = 0.696+- 0.01 %

$BR(\tau^- \to \pi^- \nu_\tau)$ = 10.82 +- 0.05 %

11.5% difference !

τ Branching Ratio in MC

$BR(\tau^- \to K_S K^- \nu_\tau)$ = 0.8255 10^{-3}

CLEO K^-K_S mass spectrum from τ decay.

CLEO Collab. Phys.Rev.D 53, 6037 (1996)

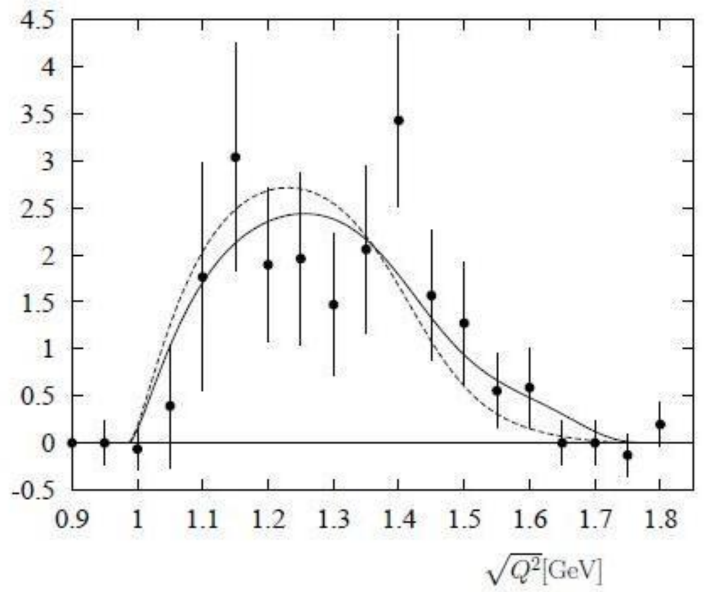


Figure 7: *The normaized distribution* $\frac{d\Gamma(\tau\to K^- K^0 \nu_\tau)/d\sqrt{Q^2}}{\Gamma(\tau\to K^- K^0 \nu_\tau)}$ *in the kaon pair invariant mass* $\sqrt{Q^2}$ *in units of* GeV^{-1} *obtained from the fitted kaon form factor; the solid (dashed) line corresponds to the constrained (unconstrained) fit. The event distribution measured by CLEO Collaboration [45] and normalized, dividing by the total number of events, is shown with points.*

DATA used in analysis

1. Run1-run6 - 468.3 fb^{-1}

   $kL = L_{MC} / Lrun$

2. MC $e^+e^- \to \tau^+\tau^-$, 816.3 fb^{-1} , kL = 1.74
3. MC $e^+e^- \to \tau^+\tau^- \to l^+ K_S K^- \nu_\tau$, 1088 fb^{-1} , kL = 2.32
4. MC $e^+e^- \to$ uds , 856 fb^{-1} , kL= 1.83
5. MC $e^+e^- \to$ c-cbar , 868.5 fb^{-1} , kL= 1.85
6. MC $e^+e^- \to$ B-Bbar, 1352.4 fb^{-1} , kL= 2.89

Selection criteria $\tau_1 \to KK_S, \tau_2 \to e\nu\nu, \mu\nu\nu$

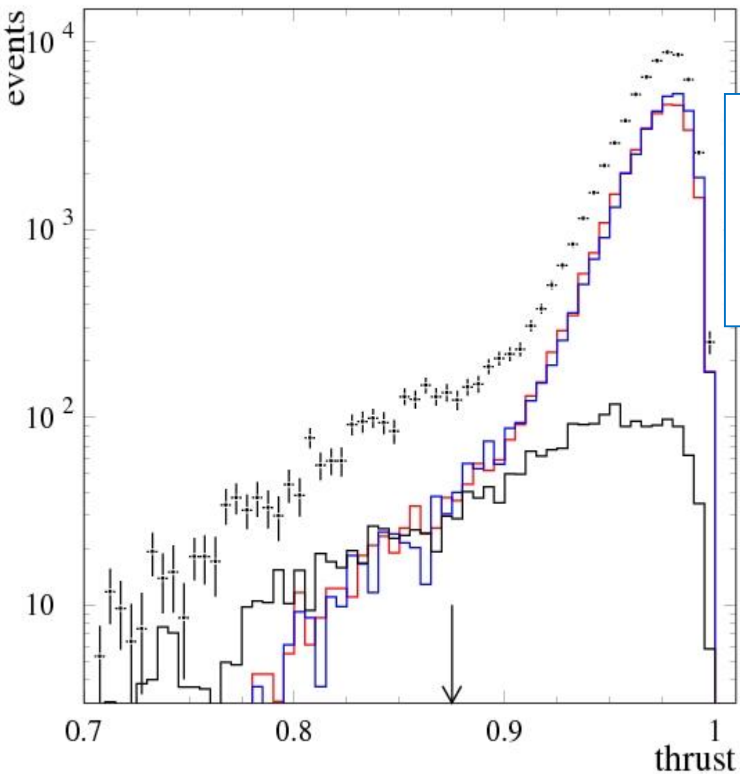
1. N(tracks)=4,
2. $N(K_S)=1$, $K_S \to \pi^+\pi^-$
3. $N(K^\pm)=1$, $N(\mu)$.or.$N(e)=1$
4. $r_{KS} = 1 – 70$ cm
5. thrust > 0.875
6. $K^\pm$: $p_{lab}= 0.4–5$,
7. e,μ : $\cos\theta_{lab}<0.9$, $p_{lab}>1.2$, $p_{cm} < 4.5$
8. $\theta_{CM} > 110^o$, - angle lept. <--> KK_S
9. $\Sigma E\gamma < 2$ GeV

Monte carlo selection of $\tau^+\tau^- \to l^+K_S\pi^-\nu_\tau$ mode :

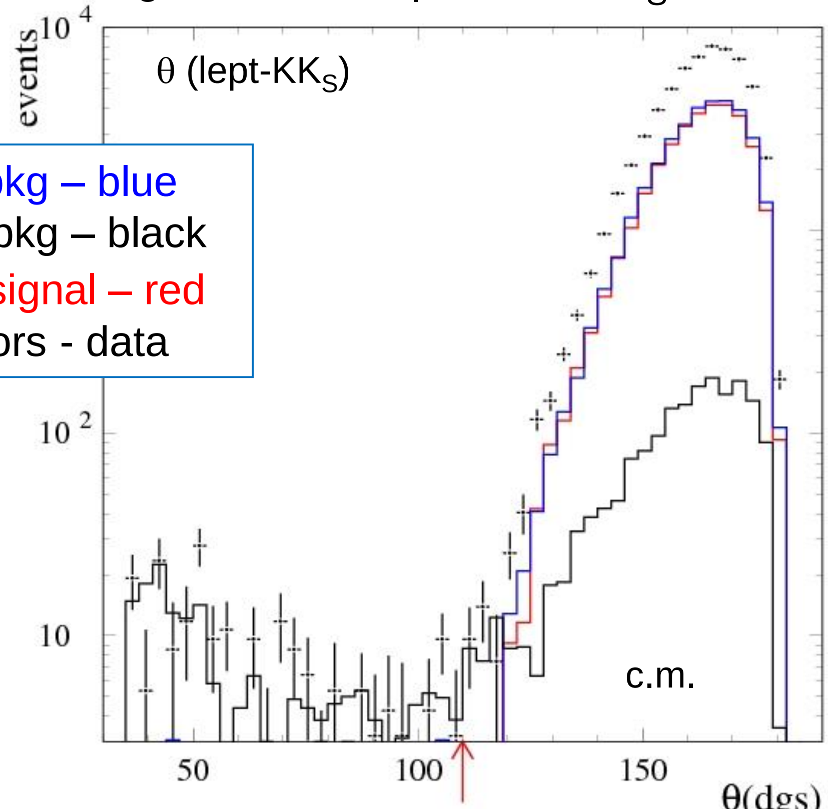
1. $N(K_S)=1$, $N(K^\pm)=1$
2. $N(\mu)$.or.$N(e)=1$
3. $N(\pi^0)=0$, $N(\pi^\pm)=0$

Comments to selection conditions

Thrust>0.875



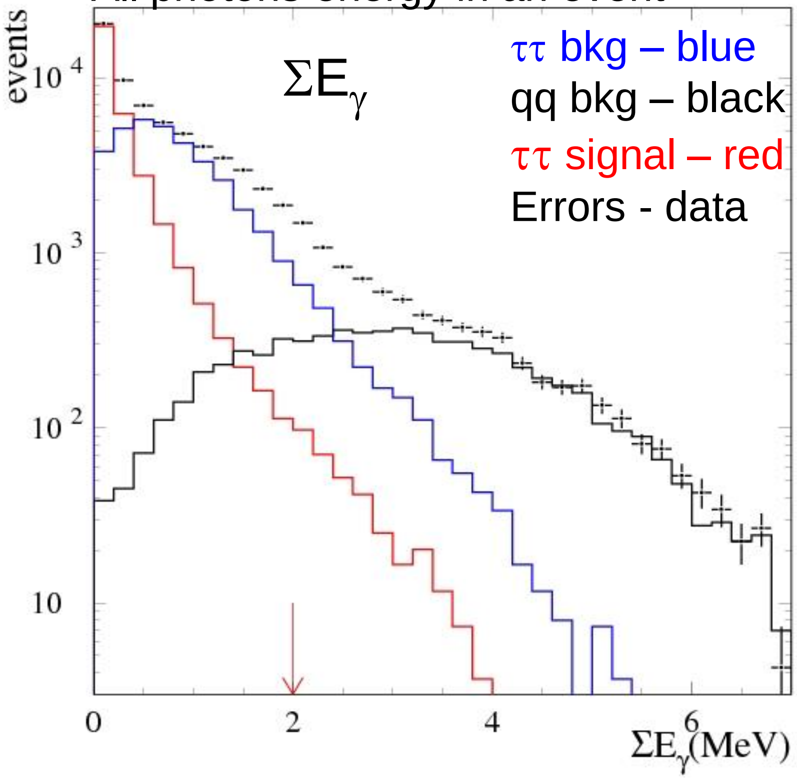
θ – angle between lepton and KK_S in c.m.



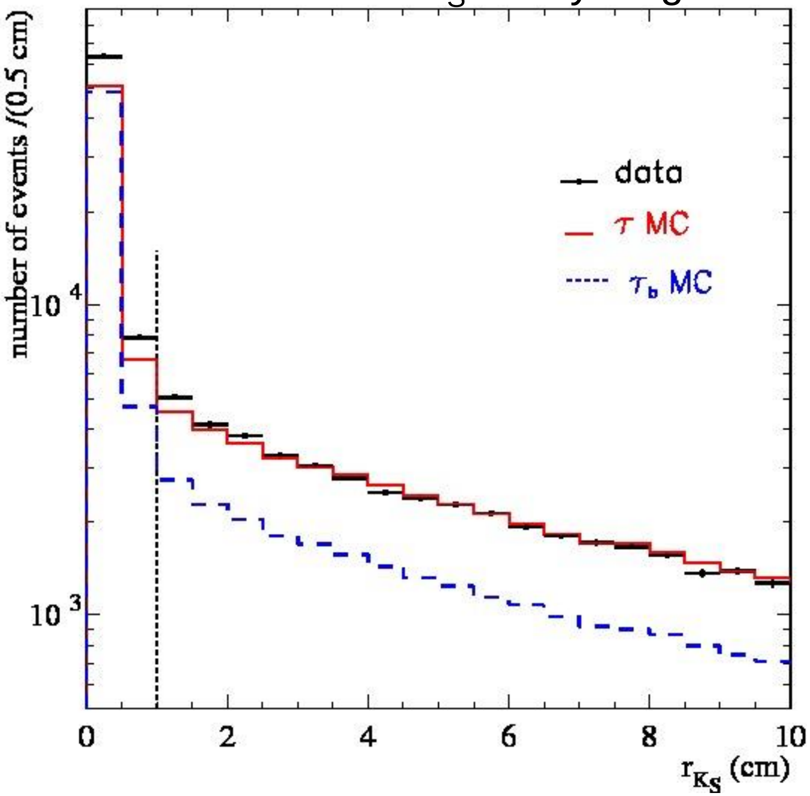
ττ bkg – blue
qq bkg – black
ττ signal – red
Errors - data

Comments to selection conditions

All photons energy in an event



K_S decay length



Signal and background suppression - all cuts applied

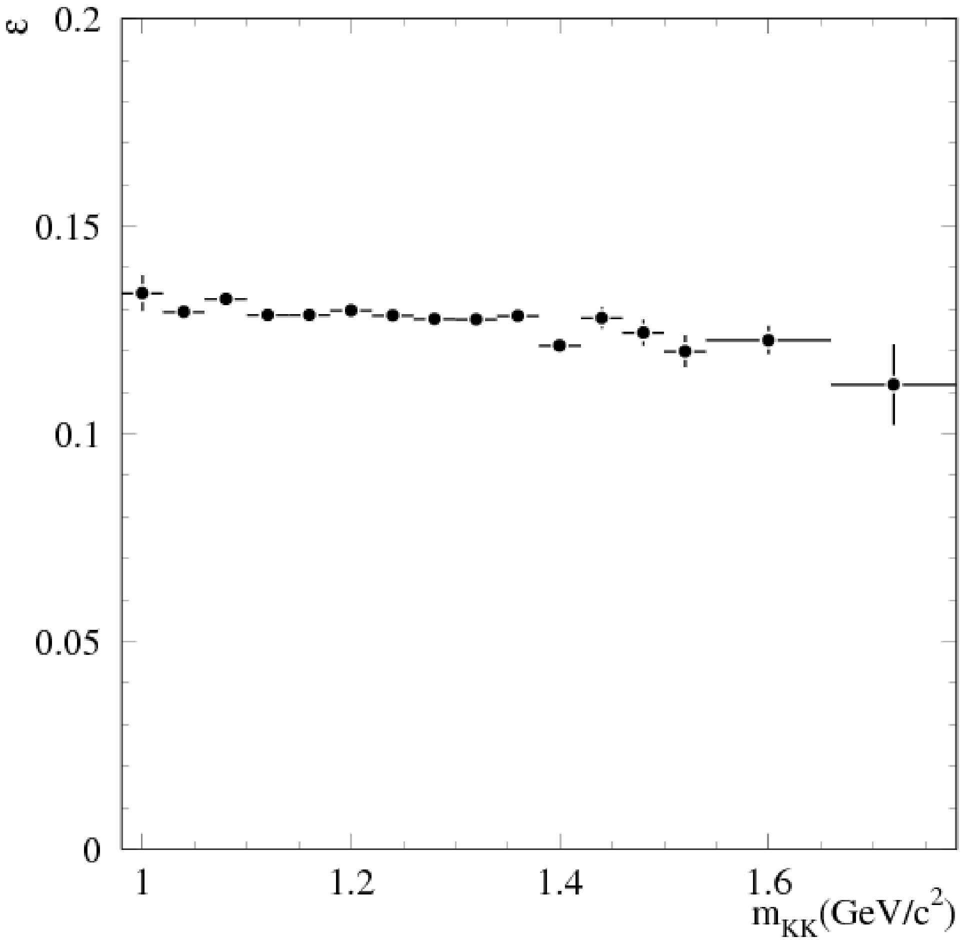
$\tau^+\tau^-$(MC) ~ 7.5 10^8 ev. → 1.2 10^5 ev. (~ 3.5 orders)

udscb(MC) ~ 4.3 10^9 ev. → 3.5 10^3 ev. (~ 6 orders)

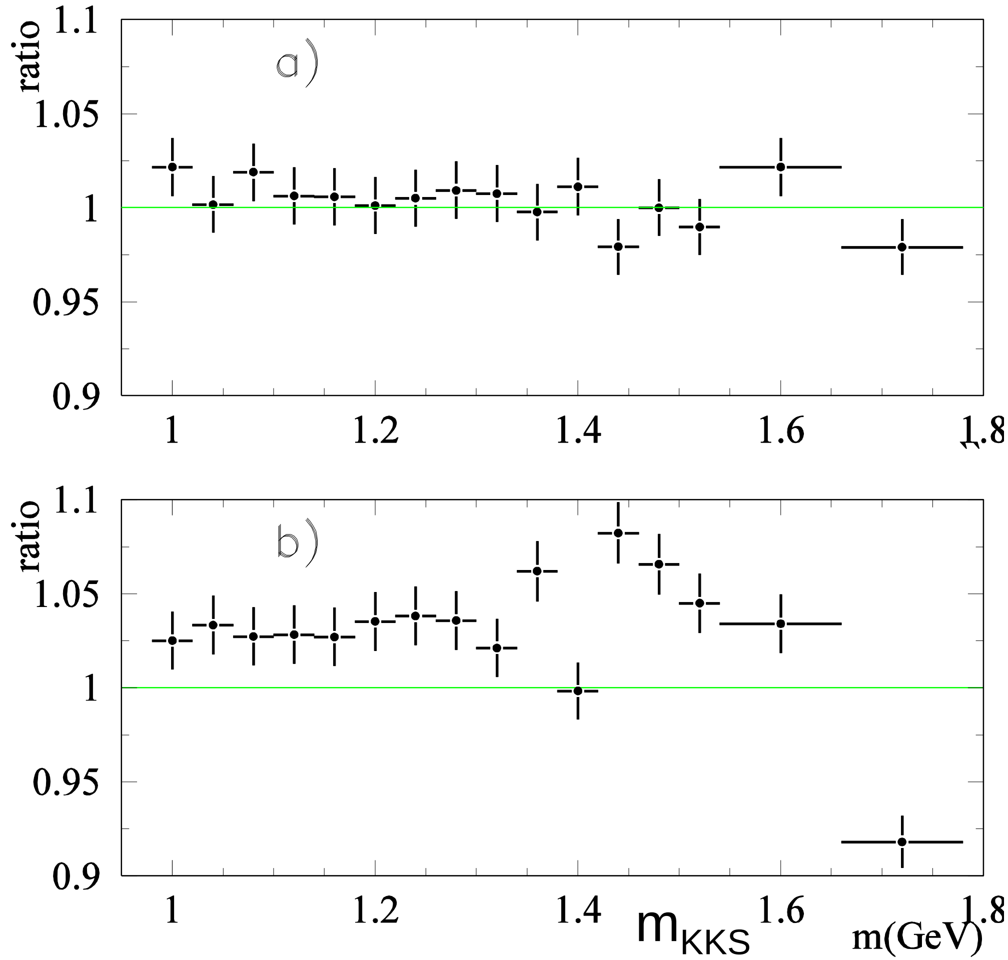
$\tau^+\tau^-$(KK_S,MC) ~ 3.10^5 ev. → 0.7 10^5 ev (~ 4 times)

data ~ 4.2 10^9 ev. → 1.4 10^5 ev (~ 4.5 order)

Detection efficiency vs KK_S mass – all cuts applied



Data/MC efficiency corrections



a) – signal $\tau \rightarrow KK_S\nu_\tau$

b) - non $\tau \rightarrow KK_S\nu_\tau$

Used PID Tables from:
muSelectorsMap(21)
KselectorsMap(26)
eSelectorsMap(8)

Corrected MC efficiencies:

$K \rightarrow K$, $\pi \rightarrow K$

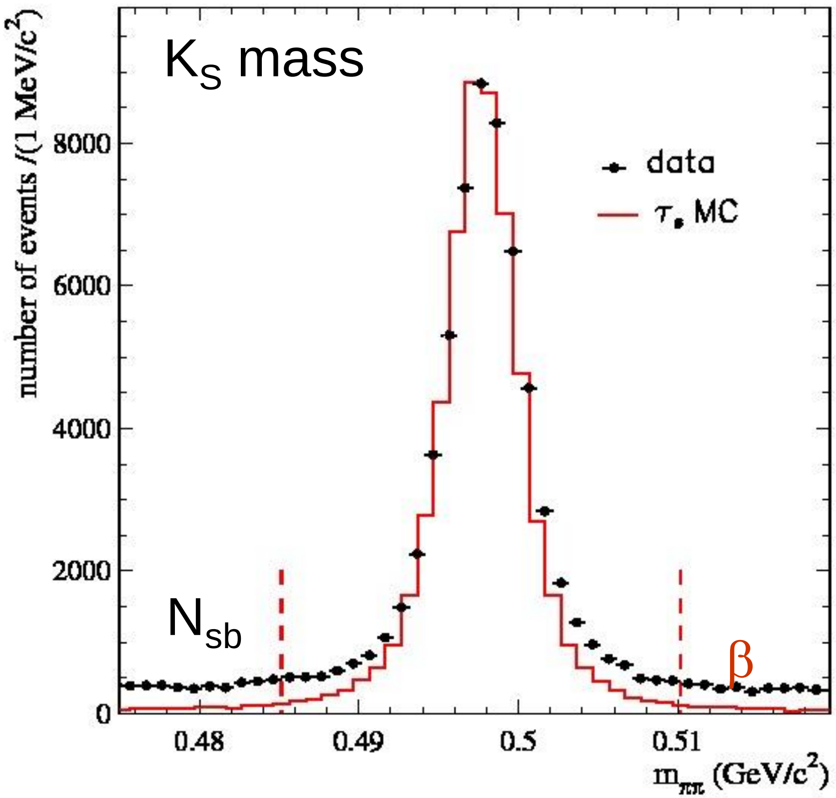
$\mu \rightarrow \mu$, $\pi \rightarrow \mu$

$e \rightarrow e$, $\pi \rightarrow e$

Corrections applied
to value of ε
in previous slide

K_S background subtraction

Δm=0.472-0.522=0.050 GeV

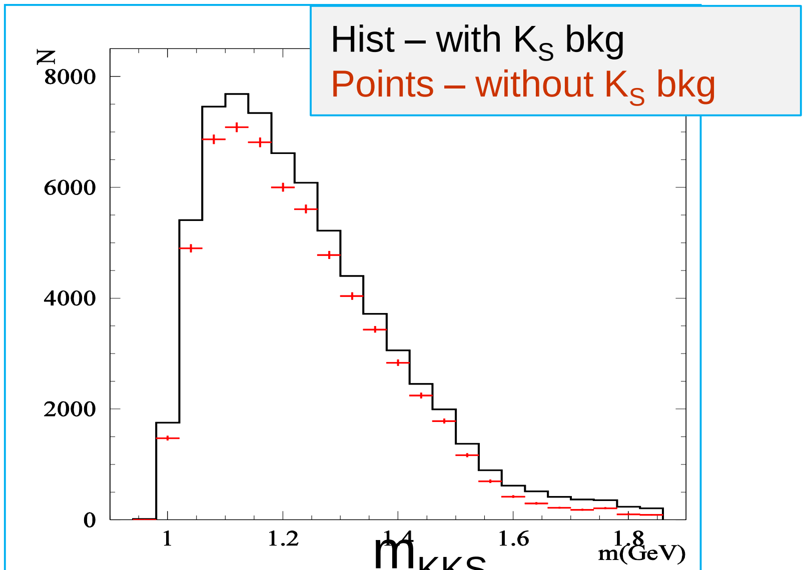


Sideband subtraction

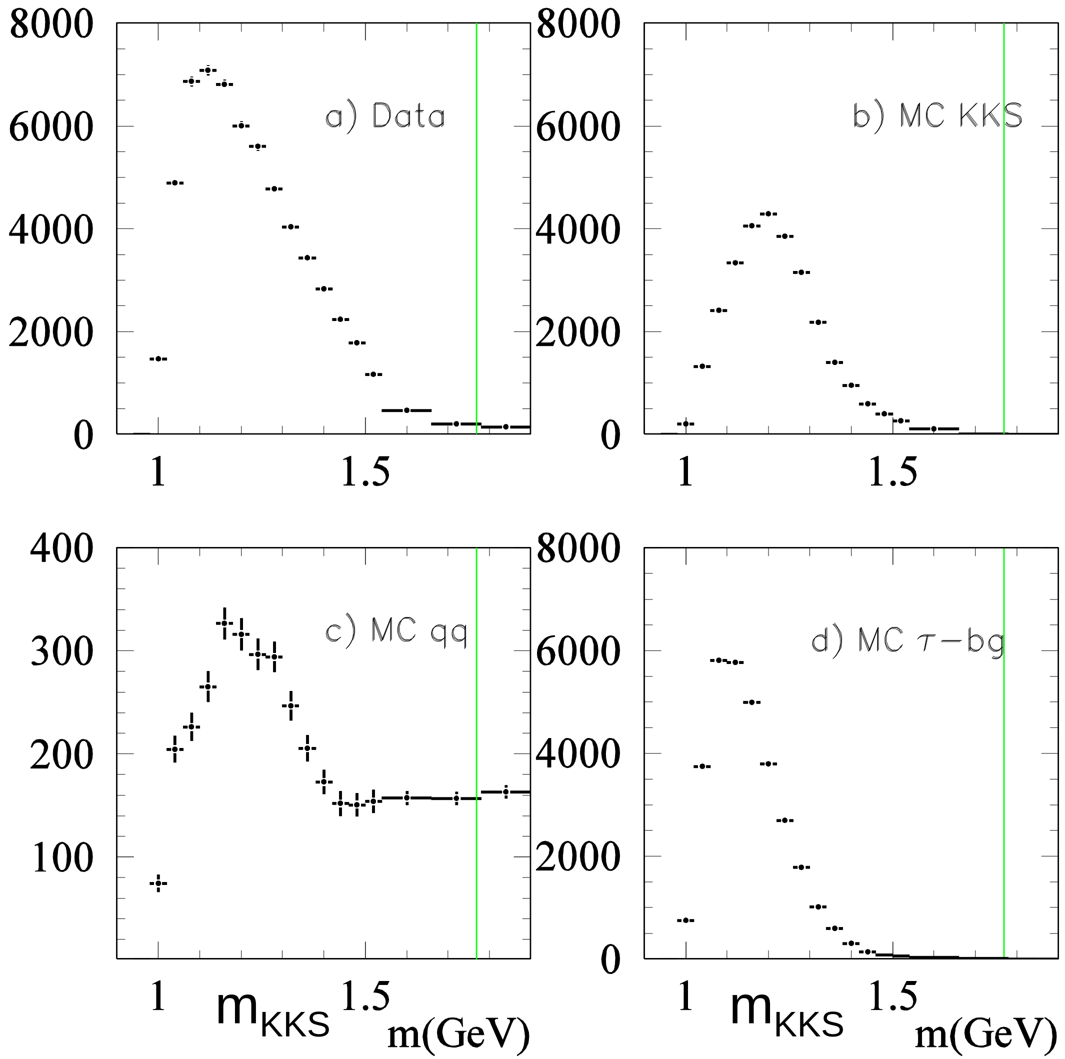
$N_{KS}=(\alpha N - N_{sb})/(\alpha-\beta)$,

α=0.5, β=0.0315

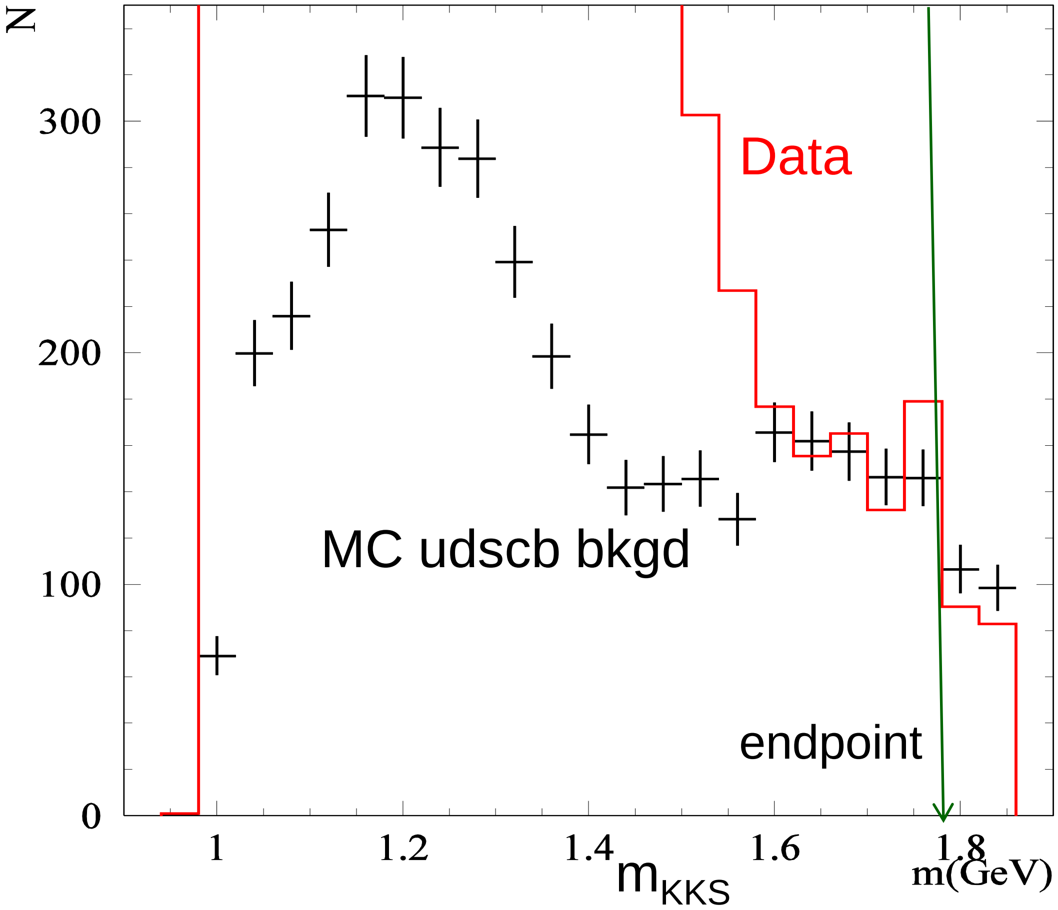
Effect of K_S background subtraction



KK_S mass spectra in data and MC after applying selection cuts. K_S bkgd subtracted

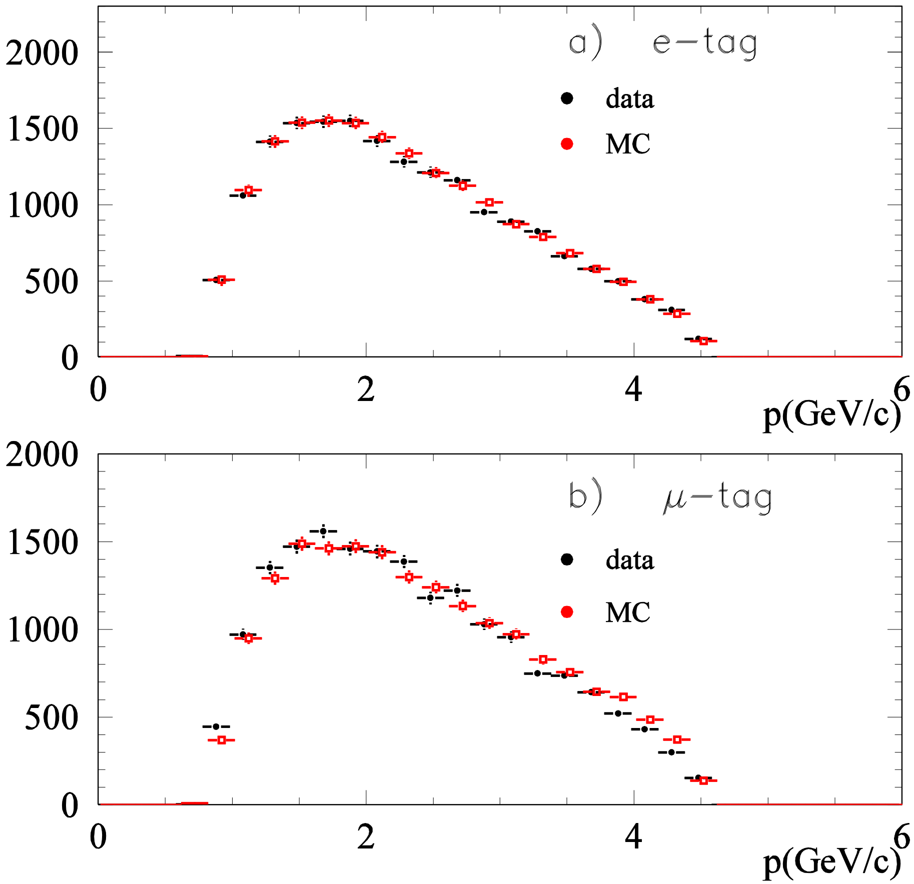


$q\bar{q}$ background contribution



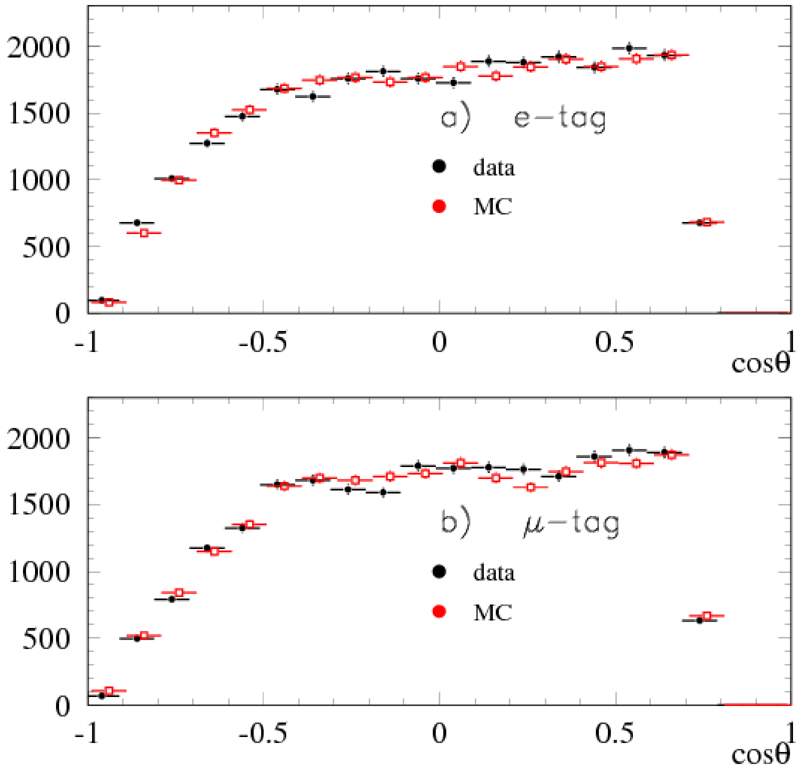
Data agree with MC near endpoint at $m(KK_S) \sim m(\tau)$!

Lepton CM momentum, data-MC comparison



$q\bar{q}$ background subtracted from data

Leptons CM cosθ, data-MC comparison



$q\bar{q}$ background subtracted from data

Distribution of selected events over subprocesses

Data events number (69286 ev.) =

Tau MC $\tau^+\tau^- \to l^- K_S K^+$
events number (32341 ev.)

+

Tau MC $\tau^+\tau^- \to$ non $l^- K_S K^+$
events number (35441 ev.)

+

MC hadron bkgd
$e^+e^- \to$ udscb
events number (5382 ev.)

Structure of τ background

1. $\tau^- \to K_S K^- \pi^0 \nu_\tau$ ~ 70%
2. $\tau^- \to \pi^- K_S \nu_\tau$ ~10%
3. $\tau^- \to \pi^- K_S \pi^0 \nu_\tau$ ~ 6%
4. $\tau^- \to \pi^- \nu_\tau$ ~ 8%
5. $\tau^- \to \pi^- \pi^0 \nu_\tau$

Background without π^0, well measured, subtracted using MC

Background with π^0 ~ 80%, mass spectra not measured, subtracted using data

Structure of qq background

uds ~ 80% , cc ~ 15%, bb ~ 5%

Subtraction of π^0 background

System of linear equations (in each KK_S mass bin)

Eq.1

$$N_{ex0} = (1-\varepsilon_S)N^{\tau}_{sig} + (1-\varepsilon_b)N^{\tau}_{bg}$$

$$N_{ex1} = \varepsilon_S N^{\tau}_{sig} + \varepsilon_b N^{\tau}_{bg}$$

$N_{\pi^0}=0$, number of found π^0

$N_{\pi^0}>0$,

$$N_{ex0} = N_{dt0} - N^{\tau,0}_{bg,0} - N_{qq0}$$

$$N_{ex1} = N_{dt1} - N^{\tau,0}_{bg,1} - N_{qq1}$$

Eq.2

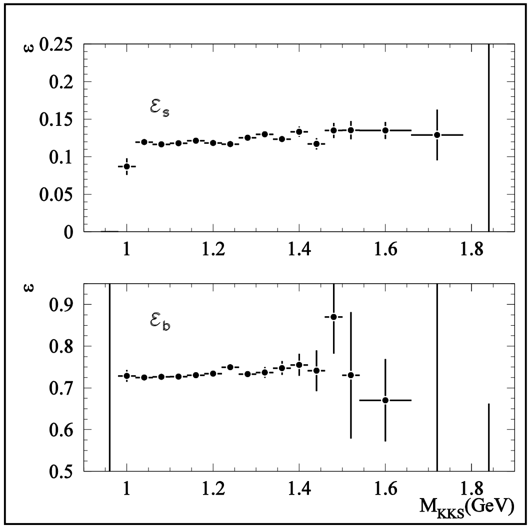
$$\varepsilon_S = N^{\tau,0}_{sig,1}/(N^{\tau,0}_{sig,1}+N^{\tau,0}_{sig,0})$$

$$\varepsilon_b = N^{\tau>0}_{bg,1}/(N^{\tau>0}_{bg,1}+N^{\tau>0}_{bg,0})$$

Eq.3

From MC

Solution of linear equations gives the signal (N^{τ}_{KS}) and background (N^{τ}_{bg}) KK_S mass spectra



Correction to π^0 efficiency:

$\delta\varepsilon$=1-(0.024+-0.08)=

= 0.976+-0.008

(BAD 2621)

$$\varepsilon_S \neq 0$$

Extraction of KKS mass spectrum from the system of linear equations (in each KK_S mass bin)

Eq.1

$$N_{ex0} = (1-\varepsilon_S)N^{\tau}_{sig} + (1-\varepsilon_b)N^{\tau}_{bg}$$

$$N_{ex1} = \varepsilon_S N^{\tau}_{sig} + \varepsilon_b N^{\tau}_{bg}$$

$N_{\pi^0}=0$, number of found π^0

$N_{\pi^0}>0$,

Eq.2

$$N_{ex0} = N_{dt0} - N^{\tau,0}_{bg,0} - N_{qq0}$$

$$N_{ex1} = N_{dt1} - N^{\tau,0}_{bg,1} - N_{qq1}$$

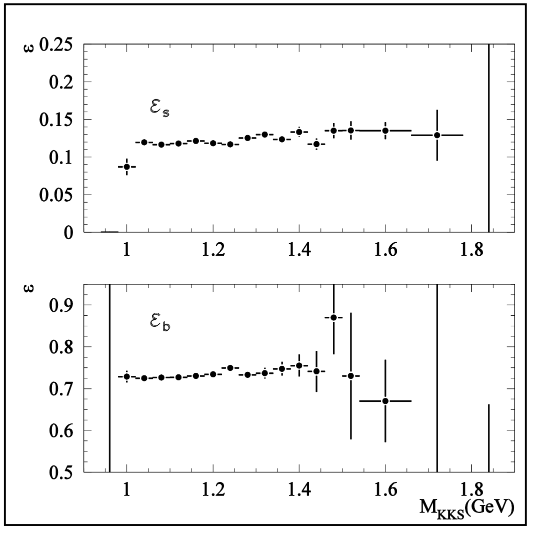
Eq.3

$$\varepsilon_S = N^{\tau,0}_{sig,1} / (N^{\tau,0}_{sig,1} + N^{\tau,0}_{sig,0})$$

$$\varepsilon_b = N^{\tau>0}_{bg,1} / (N^{\tau>0}_{bg,1} + N^{\tau>0}_{bg,0})$$

From MC

Solution of linear equations gives the signal (N^{τ}_{KS}) and background (N^{τ}_{bg}) KK_S mass spectra



Correction to π^0 efficiency:

$\delta\varepsilon$=1-(0.024+-0.08)=

= 0.976+-0.008

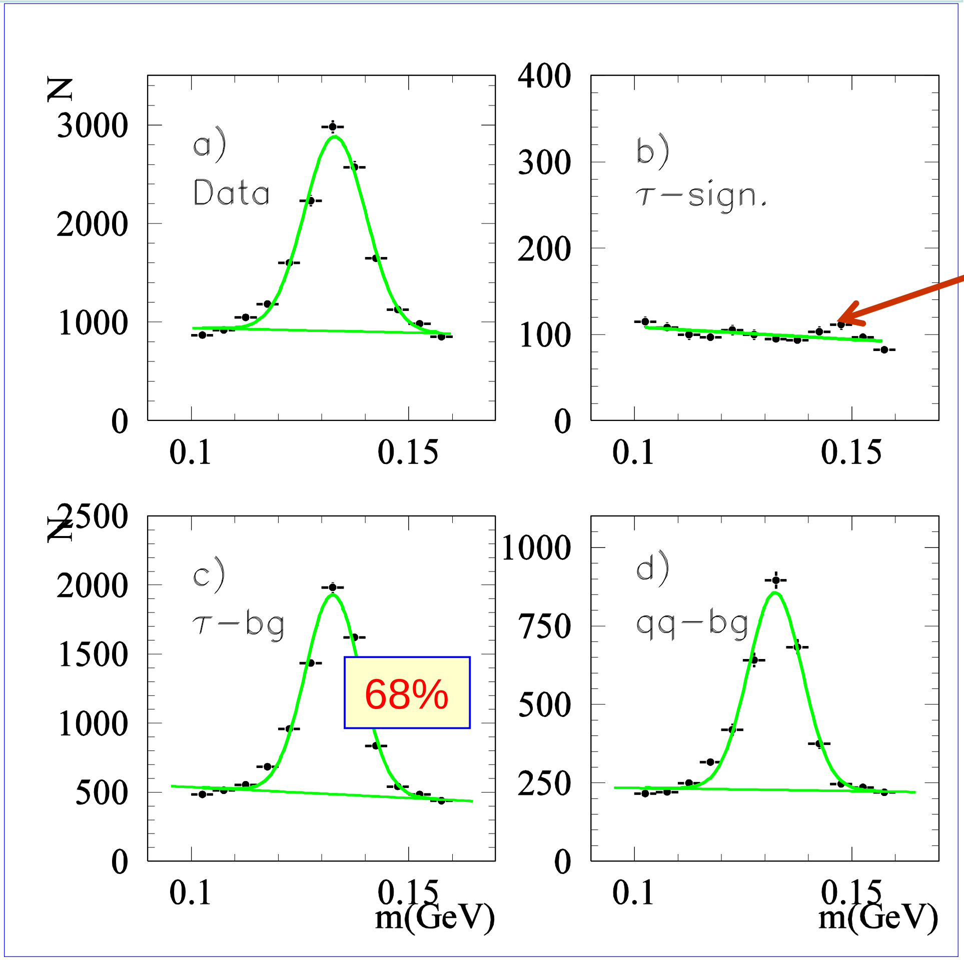
(BAD 2621)

$\varepsilon_S \neq 0$

Subtraction of π^0 background

Structure of π^0 background

π^0 spectra for sum of events in all Δm bins



$M(\pi^0) = M_{\gamma\gamma} =$
$=100\text{-}160$ MeV

Fitting gives:
$N_{\pi 0} = N_{GAUSS} +$
$+N_{RANDOM}$

Only N_{RANDOM}

68% - is the part of events with true π^0 in τ background

Split lower line in Eq.1 p.24 (for sum of events)

Transformation of lin.equations

$$N_{\mathbf{ex0}} = (1-\varepsilon_{\mathbf{S}})N^{\tau}_{\mathbf{sig}} + (1-\varepsilon_{\mathbf{b}})N^{\tau}_{\mathbf{bg}}$$

$$N^{0}{}_{\mathbf{ex1}} = \varepsilon_{\mathbf{S}}N^{\tau}_{\mathbf{sig}} + 0.32 \bullet \varepsilon_{\mathbf{b}}N^{\tau}_{\mathbf{bg}}$$

Without true π^0

$$N^{*}{}_{\mathbf{ex1}} = \ldots\ldots\ldots\ldots\ldots 0.68 \bullet \varepsilon_{\mathbf{b}}N^{\tau}_{\mathbf{bg}}$$

With true π^0

Corrections to background subtraction
(for sum of events in all Δm bins)

Ideal equation system

$$N^*_{ex0} = N^{\tau}_{sig} + (1-\varepsilon^*_b) N^{\tau}_{bg}$$

$$N^*_{ex1} = \varepsilon^*_b N^{\tau}_{bg}$$

ε_b

$\varepsilon^*_S = 0$!

ε^*_b -> 0.68 * 0.72 = 0.49

Fraction of events with π^0

N^*_{ex0} – events without π^0 + lin. background

N^*_{ex1} – events with π^0 from Gaussian fit to the π^0 spectrum only

N^{τ}_{sig} (modified) = 1.01 N^{τ}_{sig} (p.24)

Return to eq,1 p.24 with division into KK_S mass bins with corrected efficiencies

$$N_{ex0} = (1-\varepsilon'_S)N^{\tau}_{sig} + (1-\varepsilon'_b)N^{\tau}_{bg}$$

$$N_{ex1} = \varepsilon'_S N^{\tau}_{sig} + \varepsilon'_b N^{\tau}_{bg}$$

Corrected efficiencies:

ε'_S -> ε_S (1.05+-0.05)

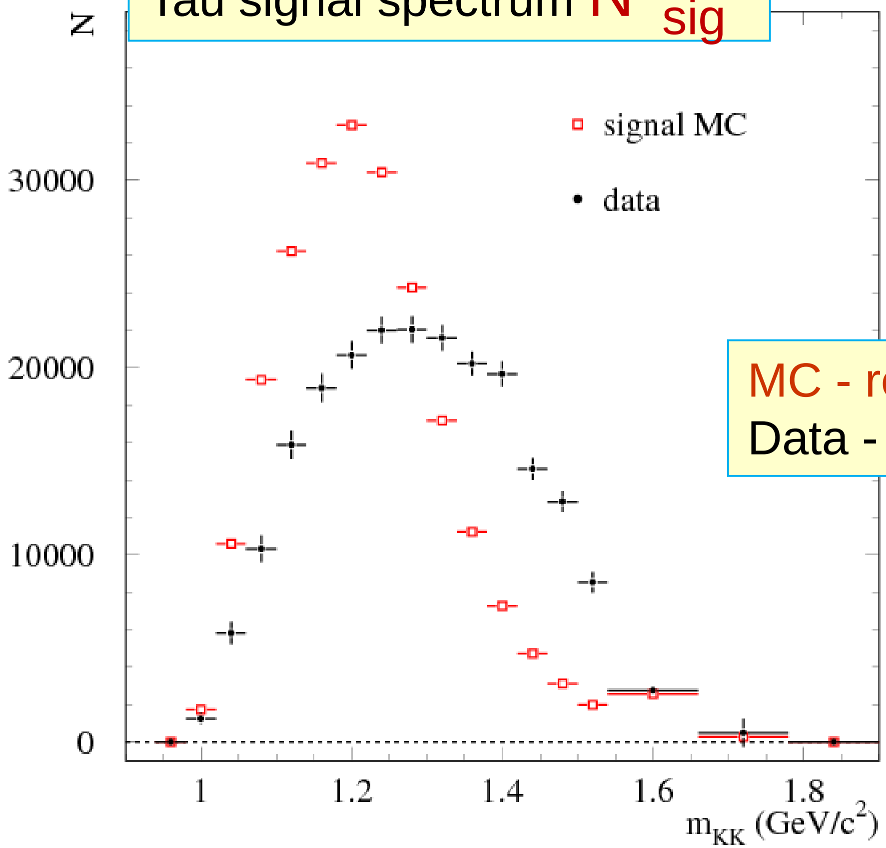
ε'_b -> ε_b 0.984

- π^0 efficiency correction
- spurious photon correction
- 0.984 = 1 – 0.024*0.68

Fraction of events with π^0

The final KK_S mass spectra for tau signal and background

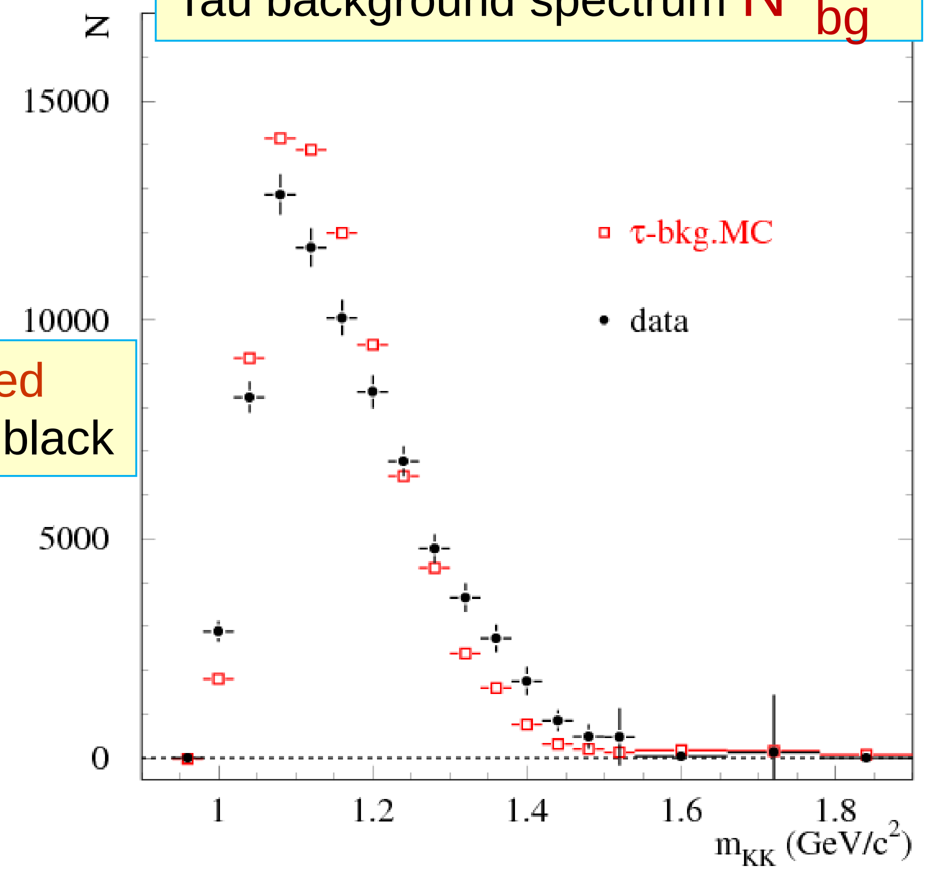
Tau signal spectrum N^{τ}_{sig}



MC - red

Data - black

Tau background spectrum N^{τ}_{bg}



Branching fraction BF($\tau^- \to KK_S\nu_\tau$)

$$BF = \frac{N_{exp}}{LB_{lep}\sigma_{\tau\tau}} = 0.740 \pm 0.011 \times 10^{-3}(stat) \pm 0.021 \times 10^{-3}(sys)$$

N_{exp}= (223741+-3461 - total number of signal events,

L=468+-2.5 inv.fb, B_{lep} =0.3521+-0.0006, $\sigma_{\tau\tau}$ =0.919+-0.003 nb

Total error (stat+syst) = 3.2%

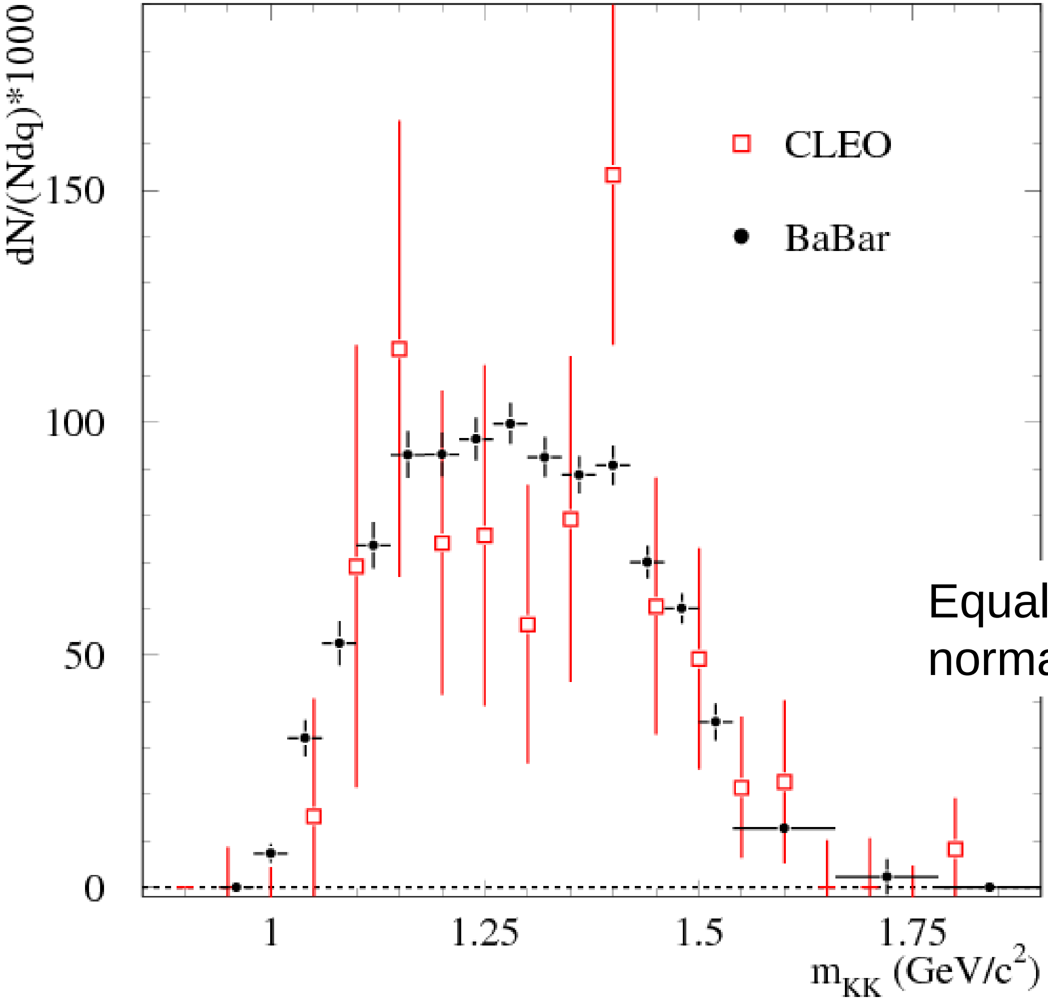
BF (PDG_2016) = 0.740+-0.025

Summary of systematic to BF($\tau^- \to K_S K^- \nu_\tau$)

1 - K_S bkgd – 0.4%
2 - luminosity – 0.5%
3 – hadron bkgd subtr, - 0.5%
4 – track efficiency – 1.0%
5 - PID – 0.5%
6 - τ bkgd with π^0 – 2.3%
7 - τ bkgd without π^0 – 0.3%

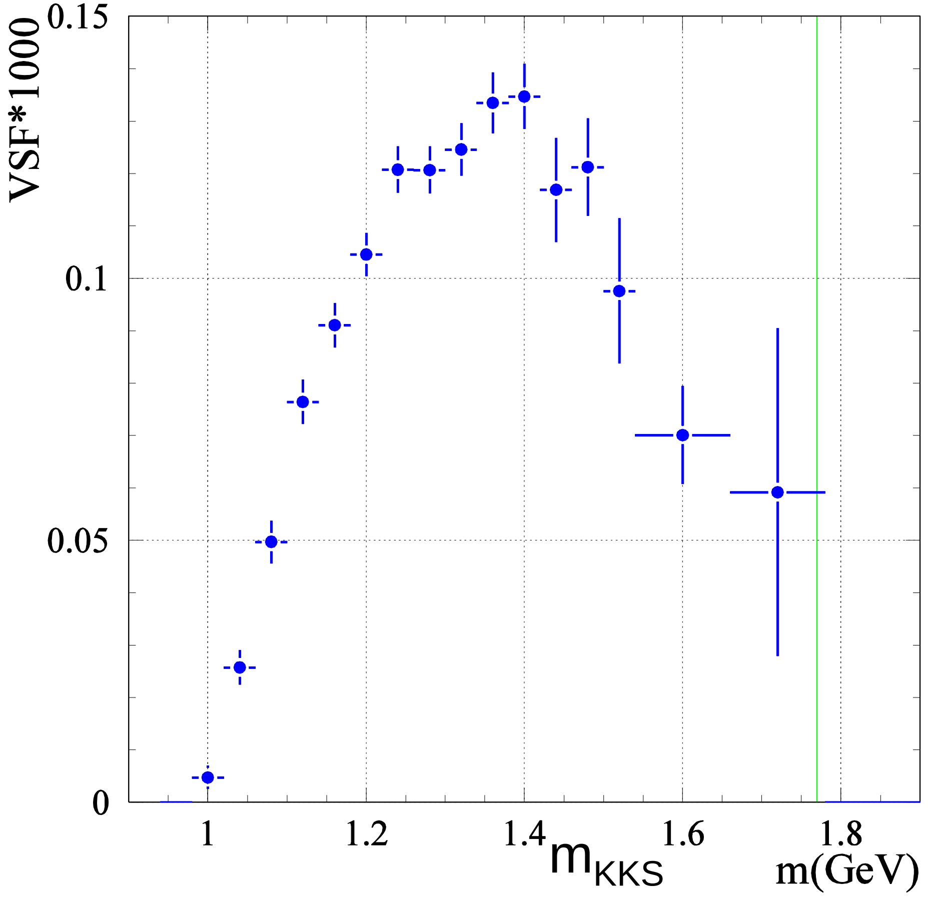
Total – 2.7%

BaBar-CLEO KK_S mass spectra comparison



Equal events number normalization

Vector spectral function for $\tau^- \to K_S K^- \nu_\tau$ process,
- first measurement



Заключение

1. В процессе $\tau^- \to K_S K^- \nu_\tau$ измерен массовый спектр $K_S K^-$ системы с точностью значительно лучше чем в предыдущих измерениях

2. Измеренная вероятность распада $\tau^- \to K_S K^- \nu_\tau$ хорошо согласуется со среднемировым значением

3. Впервые построена векторная спектральная функция распада $\tau^- \to K_S K^- \nu_\tau$.

To be submitted to Phys.Rev. D, rapid communication