Recent results on tau lepton from BABAR

Alberto Lusiani

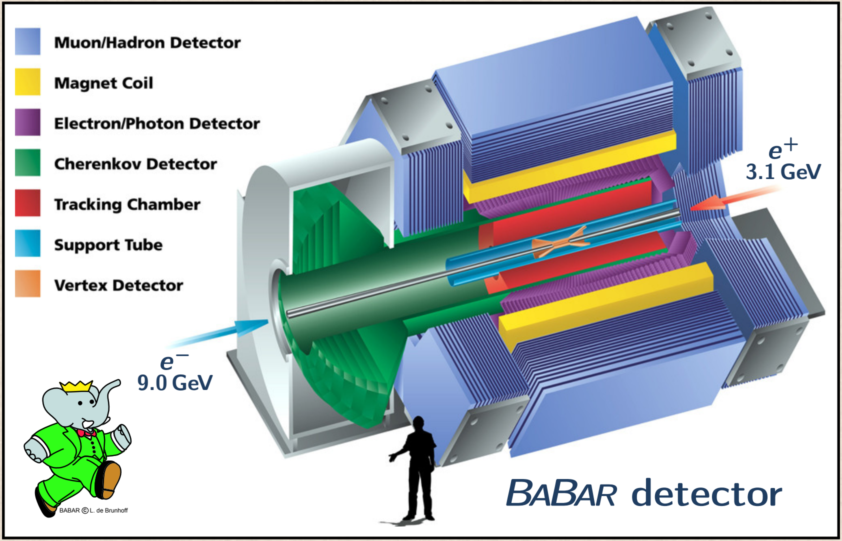
Scuola Normale Superiore and INFN, sezione di Pisa

on behalf of the BABAR Collaboration

Outline

- Introduction
- $\tau^- \to K^-(0,1,2,3)\pi^0\nu_\tau$, $\tau^- \to \pi^-(3,4)\pi^0\nu_\tau$, *BABAR* preliminary, ICHEP 2018
- $\tau^- \to K^- K^0_S \nu_\tau$, Phys. Rev. D 98 (2018) no.3, 032010
- Implications for $|V_{us}|$ from $\tau^- \to X_s^- \nu_\tau$

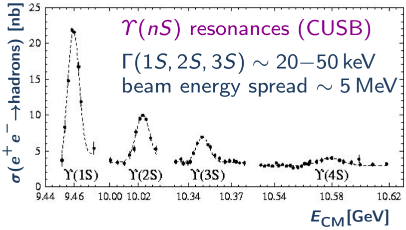
BABAR detector at PEP-II, SLAC National Accelerator Laboratory



main focus: study of CP violation in B mesons

BABAR: CM energy, collected luminosity

center-of-mass energies



$\Upsilon(nS)$ resonances (CUSB)

$\Gamma(1S, 2S, 3S) \sim 20\text{—}50$ keV

beam energy spread ~ 5 MeV

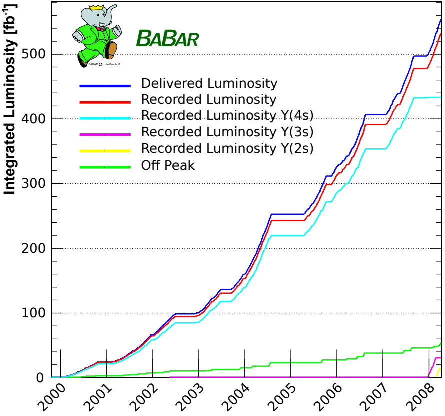
$\mathcal{L}$ vs. $\sqrt{s}$

energy	$\mathcal{L}(\text{fb}^{-1})$
$\Upsilon(4s)$	430
$\Upsilon(3s)$	30.2
$\Upsilon(2s)$	14.5
off-peak	54

pairs production

flavour	events
$B\bar{B}$	470×10^6
$c\bar{c}$	690×10^6
$\tau^+\tau^-$	485×10^6

integrated luminosity over time



data-taking ended in April 2008

$\tau^- \to K^-(0,1,2,3)\pi^0\nu_\tau, \quad \tau^- \to \pi^-(3,4)\pi^0\nu_\tau$

Motivation

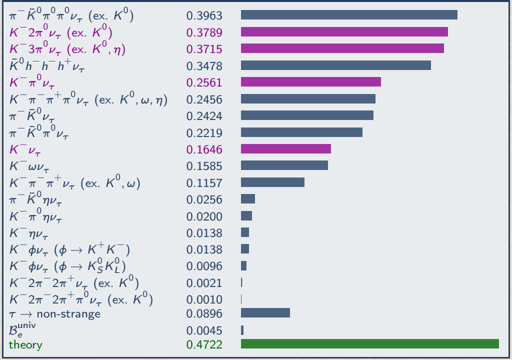
$|V_{us}|$ from $\tau\to X_s\nu_\tau$

$$|V_{us}|_{\tau s} = \sqrt{R_s \Big/ \left(\frac{R_{VA}}{|V_{ud}|^2} - \delta R_{\textbf{theory}}\right)} \quad \text{where} \quad R_s = \frac{\mathcal{B}(\tau\to X_{s=1}\nu)}{\mathcal{B}(\tau\to e\bar{\nu}_e\nu_\tau)} \quad R_{VA} = \frac{\mathcal{B}(\tau\to X_{s=0}\nu)}{\mathcal{B}(\tau\to e\bar{\nu}_e\nu_\tau)}$$

E.Gamiz *et al.*, JHEP 01 (2003) 060, E.Gamiz *et al.*, PRL 94 (2005) 011803

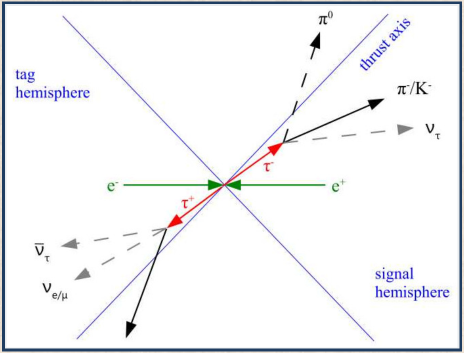
significant part of experimental uncertainty from $\mathcal{B}(\tau^-\to K^-(0\text{–}3)\pi^0\nu_\tau)$

$|V_{us}|$ from $\tau\to X_s\nu_\tau$ uncertainty budget



$\pi^-\bar{K}^0\pi^0\pi^0\nu_\tau$ (ex. K^0)	0.3963
$K^-2\pi^0\nu_\tau$ (ex. K^0)	0.3789
$K^-3\pi^0\nu_\tau$ (ex. K^0,η)	0.3715
$\bar{K}^0h^-h^-h^+\nu_\tau$	0.3478
$K^-\pi^0\nu_\tau$	0.2561
$K^-\pi^-\pi^+\pi^0\nu_\tau$ (ex. K^0,ω,η)	0.2456
$\pi^-\bar{K}^0\nu_\tau$	0.2424
$\pi^-\bar{K}^0\pi^0\nu_\tau$	0.2219
$K^-\nu_\tau$	0.1646
$K^-\omega\nu_\tau$	0.1585
$K^-\pi^-\pi^+\nu_\tau$ (ex. K^0,ω)	0.1157
$\pi^-\bar{K}^0\eta\nu_\tau$	0.0256
$K^-\pi^0\eta\nu_\tau$	0.0200
$K^-\eta\nu_\tau$	0.0138
$K^-\phi\nu_\tau$ ($\phi\to K^+K^-$)	0.0138
$K^-\phi\nu_\tau$ ($\phi\to K^0_SK^0_L$)	0.0096
$K^-2\pi^-2\pi^+\nu_\tau$ (ex. K^0)	0.0021
$K^-2\pi^-2\pi^+\pi^0\nu_\tau$ (ex. K^0)	0.0010
$\tau\to$ non-strange	0.0896
$\mathcal{B}_e^{\text{univ}}$	0.0045
theory	0.4722

Analysis method



- divide event in two hemispheres along thrust axis
- 1 identified e or μ in one hemisphere
- 1 oppositely charged π or K in other one
- no additional track
- from 0 to 4 $\pi^0 \to \gamma\gamma$
- no additional photon
- suppress two-photon processes

$$\frac{p_T}{E_{\text{miss}}} = \frac{(\vec{p}_1^{\,\text{CM}} + \vec{p}_2^{\,\text{CM}})_T}{\sqrt{s} - p_1^{\text{CM}} - p_2^{\text{CM}}} > 0.2)$$

- suppress di-leptons requiring missing mass on event and on signal hemisphere

signal samples

- $\tau^- \to K^-(n\pi^0)\nu_\tau, \quad n = 0, 1, 2, 3$
- $\tau^- \to \pi^-(n\pi^0)\nu_\tau, \quad n = 3, 4$

control samples

- $\tau^- \to \pi^-(n\pi^0)\nu_\tau, \quad n = 1, 2, 3$
- $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$

Selected events (full *BABAR* sample, 473.9 fb^{-1})

Selected mode	data	bkg from MC	ϵ from MC [%]
$\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau$	1075810	62364.0	0.74
$\tau^- \to \pi^-\nu_\tau$	1473594	340960.0	1.278
$\tau^- \to \pi^-\pi^0\nu_\tau$	6742483	368918.5	3.28
$\tau^- \to \pi^-2\pi^0\nu_\tau$	1268108	75058.7	1.55
$\tau^- \to \pi^-3\pi^0\nu_\tau$	58598	9698.1	0.49
$\tau^- \to \pi^-4\pi^0\nu_\tau$	1706	729.5	0.12
$\tau^- \to K^-\nu_\tau$	80715	18669.3	0.99
$\tau^- \to K^-\pi^0\nu_\tau$	146948	51983.2	2.16
$\tau^- \to K^-2\pi^0\nu_\tau$	17930	11128.8	1.34
$\tau^- \to K^-3\pi^0\nu_\tau$	1863	1467.7	0.13

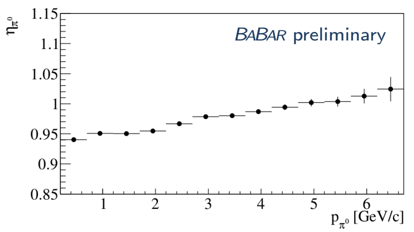
π^0 efficiency correction, f. of momentum

- compare control channels $\tau^- \to t^-\nu_\tau$ with $\tau^- \to t^-\pi^0\nu_\tau$ (track t: no PID except $e^\pm$-veto)
- correction factor (in p_{π^0} bins):

$$\eta = \frac{N(\tau^- \to t^-\pi^0\nu_\tau)^{\text{data}}}{N(\tau^- \to t^-\pi^0\nu_\tau)^{\text{MC}}}\frac{N(\tau^- \to t^-\nu_\tau)^{\text{MC}}}{N(\tau^- \to t^-\nu_\tau)^{\text{data}}}$$

- η weight for each reconstructed π^0 in MC
- validated on $\tau^- \to \pi^- 2\pi^0\nu_\tau$ control sample

π^0 efficiency correction vs. p_{π^0}



PID efficiency corrections, f. of momentum

- correct standard *BABAR* PID simulated efficiencies using data control samples for identifying $\pi^\pm$ as $\pi^\pm$, $K^\pm$ as $K^\pm$, and for mis-identifying $\pi^\pm$ as $K^\pm$
- use control samples with 3-1-topology $\tau^+\tau^-$ events:
  - $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$
  - $\tau^- \to \pi^- K^+ K^-\nu_\tau$
- identify 2 of the three tracks ⇒ third track is ∼pure identified sample

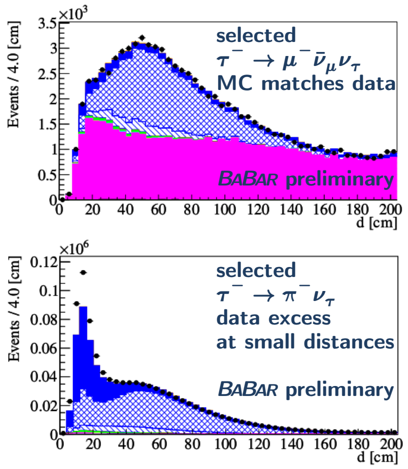
Split-off correction

- *Split-offs*: neutrons in hadronic showers in the EMC can travel and cause a secondary shower which is then identified as photon
- not well modeled in MC
  - MC matches data for muon tracks
  - data eccess near pion tracks
- obtain correction factor to weight MC events with hadron track to reproduce extra photon veto efficiency on data using $\tau^- \to \pi^-\nu_\tau$ control sample:

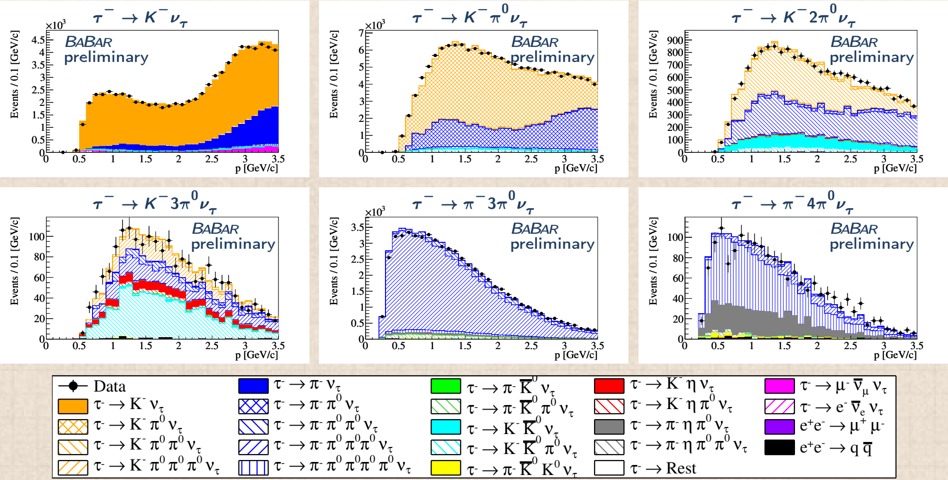
$$\eta = \frac{N^{\text{data}}(d{<}40\,\text{cm}) - N^{\text{MC}}(d{<}40\,\text{cm})}{N^{\text{data}}}$$

$$w = 1 - \eta = 0.972 \pm 0.014$$

EMC neutral clusters vs. distance of closest track



Yields vs. signal track momentum for data and simulation



- simulated events have all correction weights

Determine signal subtracting backgrounds and cross-feeds

1) subtract backgrounds other than from other signal channels using simulation

2) simultaneously determine signal and cross-feeds for the 6 signal channels

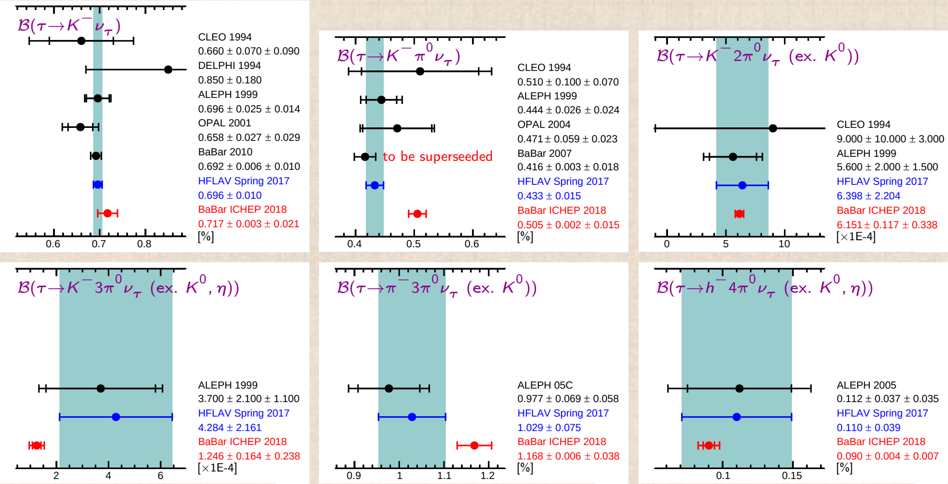
- *migration matrix* M_{ij}, estimated with MC simulation
  - M_{ij}: probability of reconstructing true produced signal i as candidate signal channel j
- obtain produced signal inverting M_{ij}: $N_i^{\text{prod}} = \left(M^{-1}\right)_{ij} \left(N_j^{\text{sel}} - N_j^{\text{sel MC bkg}}\right)$
  - N_i^{prod}: true produced signal events
  - N_j^{sel}: number of selected data events
  - $N_j^{\text{sel MC bkg}}$: MC-estimated number of background events for channel j
- branching fractions are calculated as: $\mathcal{B} = 1 - \sqrt{1 - \dfrac{N^{\text{prod}}}{\mathcal{L}\sigma}}$
  - signal event defined as event with one or two signal decays (unconventional)

Results and systematic uncertainties *BABAR* preliminary

τ - Decay mode	$K^-\nu_\tau$ $(\times 10^{-3})$	$K^-\pi^0\nu_\tau$ $(\times 10^{-3})$	$K^-2\pi^0\nu_\tau$ $(\times 10^{-4})$	$K^-3\pi^0\nu_\tau$ $(\times 10^{-4})$	$\pi^-3\pi^0\nu_\tau$ $(\times 10^{-2})$	$\pi^-4\pi^0\nu_\tau$ $(\times 10^{-4})$
Branching fraction	7.174	5.054	6.151	1.246	1.168	9.020
Stat. uncertainty	0.033	0.021	0.117	0.164	0.006	0.400
Syst. uncertainty	0.213	0.148	0.338	0.238	0.038	0.652
Total uncertainty	0.216	0.149	0.357	0.289	0.038	0.765
Stat. uncertainty [%]	0.46	0.41	1.91	13.13	0.52	4.44
Syst. uncertainty [%]	2.97	2.93	5.49	19.13	3.23	7.23
Total uncertainty [%]	3.00	2.95	5.81	23.20	3.27	8.48
ϵ_{signal} [%]	0.27	0.27	0.87	3.99	0.27	1.50
ϵ_{bkg} [%]	0.15	0.15	0.87	6.32	0.11	1.67
Background $\mathcal{B}$'s[%]	0.18	0.30	1.44	11.52	0.21	3.49
BABAR PID [%]	0.15	0.11	0.18	0.71	0.08	0.20
Custom PID [%]	1.83	1.55	1.78	2.56	0.20	0.26
Muon mis-id [%]	1.48	0.01	0.00	0.00	0.00	0.00
n. of $\tau^+\tau^-$ pairs $(\mathcal{L}\cdot\sigma)$ [%]	0.79	0.93	1.40	2.62	0.71	0.98
Track efficiency [%]	0.43	0.50	0.76	1.42	0.38	0.53
Split-off correction [%]	1.52	1.84	2.77	5.18	1.40	1.94
π^0 correction [%]	0.03	1.20	3.63	10.56	2.76	5.36
$\pi 5\pi^0 \to \pi 4\pi^0$ migr. [%]	0.00	0.00	0.00	0.02	0.04	1.08
$K4\pi^0 \to K3\pi^0$ migr. [%]	0.00	0.00	0.13	4.78	0.00	0.00

- additional systematics from signal and backgrounds MC production models being studied

Results *BABAR* preliminary



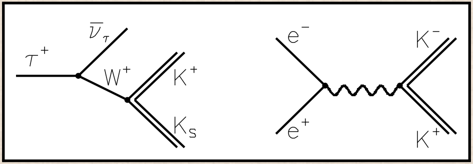
- *BABAR* 2007 $\mathcal{B}(\tau\to K^-\pi^0\nu_\tau)$ measurement will be superseeded (less refined than this study)
- presented by T. Lueck at ICHEP 2018

Branching fraction and spectral function of $\tau^- \to K^- K_S^0 \nu_\tau$

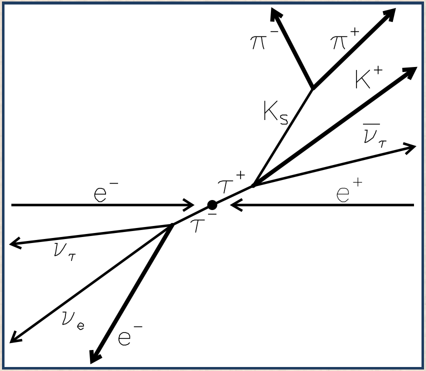
(work by V. P. Druzhinin and S. I. Serednyakov)

Motivation

- measure spectral function $V(q) = \dfrac{m_\tau^8}{12\pi q(m_\tau^2 - q^2)(m_\tau^2 + 2q^2)|V_{ud}|^2} \dfrac{\mathcal{B}(\tau^- \to K^- K_S \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \nu_\tau \bar{\nu}_e)} \dfrac{1}{N} \dfrac{dN}{dq}$
- determine isovector part of $\sigma(e^+e^- \to K\bar{K})$, $\dfrac{d\sigma^{I=1}(e^+e^- \to K\bar{K})}{dq} = \dfrac{4\pi^2\alpha^2}{q^2} V(q)$
- combine with *BABAR* and SND results on $\sigma(e^+e^- \to K^+K^-)$, $\sigma(e^+e^- \to K_S K_L)$
- obtain moduli of the isovector and isoscalar form factors and the relative phase between them can in a model-independent way
  (possibly use also for hadronic contribution to muon $g-2$)
- recent BR measurement by Belle, S.Ryu *et al.*, Phys. Rev. D 89, 072009 (2014)
- CLEO measured the spectral function, T.E.Coan *et al.*, Phys. Rev. D 53, 6037 (1996)



Event selection

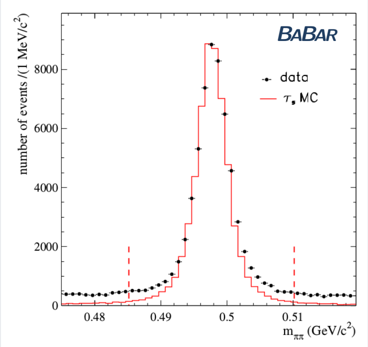


- tag side: $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$
  - require identified muon or electron
- signal side: $\tau^+ \to K^+ K_S \bar{\nu}_\tau$
  - require identified kaon
  - require $\pi^+\pi^-$ compatible with K_S^0, Lab K_S^0 decay length must be 1–70 cm
- suppress $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$
- suppress $e^+e^- \to q\bar{q}$ and $e^+e^- \to B\bar{B}$
- invariant mass $m(KK_S^0) < 2.2\,\text{GeV}$
- sum of photon energies $< 2\,\text{GeV}$ (bkg. with π^0 subtracted later)
- selection efficiency $\approx 13\%$

Subtraction of combinatorial $K^0_S \to \pi^+\pi^-$ background

- use data sidebands of K^0_S peak, subtract background bin-by-bin in $m(K^- K^0_S)$ $\Rightarrow$ independent of signal and bkg simulation (assume non-K^0_S background linear in $m_{K^0_S}$)
- background fraction in selected candidates:
  - $\approx 10\%$ for $m_{K^- K_S}$ around $1.3\,\mathrm{GeV}/c^2$
  - up to 50% for $m_{K^- K_S} > 1.6\,\mathrm{GeV}/c^2$

K^0_S candidates mass



Subtraction of background with $>0\pi^0$

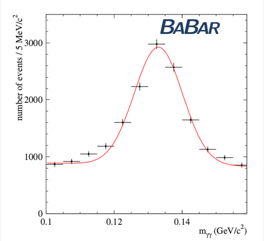
Main remaining background contributions

- $\tau^- \to K^- K_S \pi^0 \nu_\tau$ (79%);
- $\tau^- \to \pi^- K_S \nu_\tau$ (10%);
- $\tau^- \to \pi^- K_S \pi^0 \nu_\tau$ (3%)
- mis-id e/μ (7%), mainly from $\tau^- \to \pi^- (\pi^0) \nu_\tau$

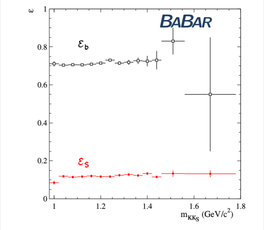
Background subtraction, bin-by-bin

- bin-by-bin candidates with 0 or >0 π^0:
  - >0 π^0: $N_{>0\pi^0} = \epsilon_s N_s + \epsilon_b N_b$
  - 0 π^0: $N_{0\pi^0} = (1-\epsilon_s) N_s + (1-\epsilon_b) N_b$
- ϵ_s: eff. to reconstruct (fake) >0 π^0 for signal events
- ϵ_b: eff. to reconstruct >0 for bkg's with π^0
- ϵ_s and ϵ_b from MC, with average data calibration
- solve for number of signal events N_S
- $\sim$independent of signal/bkg MC simulation
- other bkg. without π^0 subtracted using MC

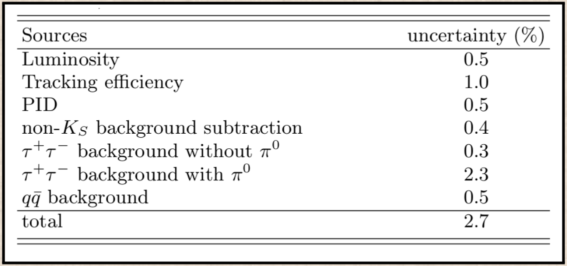
π^0 candidates mass



simulated π^0 efficiencers



Systematic uncertainties on the branching fraction

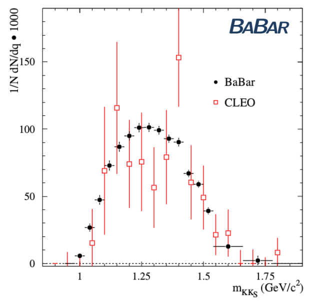


Sources	uncertainty (%)
Luminosity	0.5
Tracking efficiency	1.0
PID	0.5
non-K_S background subtraction	0.4
$\tau^+\tau^-$ background without π^0	0.3
$\tau^+\tau^-$ background with π^0	2.3
$q\bar{q}$ background	0.5
total	2.7

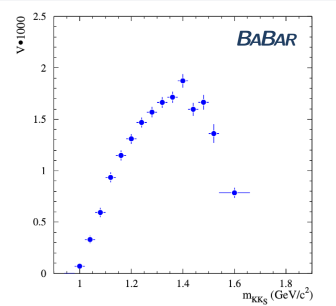
Results [Phys. Rev. D 98 (2018) no.3, 032010]

- $N_{\text{sig}} = 223741 \pm 3461$ (stat.err. only, bkg-subtracted, eff-corrected), $\mathcal{L} = (468.0 \pm 2.5)\,\text{fb}^{-1}$
- $\mathcal{B}(\tau^- \to K^- K_S \nu_\tau) = \dfrac{N_{\text{sig}}}{2\mathcal{L}\mathcal{B}(\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau)\sigma_{\tau\tau}} = (0.739 \pm 0.011 \pm 0.020) \times 10^{-3}$
- [Belle 2014: $\mathcal{B}(\tau^- \to K^- K^0_S \nu_\tau) = (0.740 \pm 0.007 \pm 0.027) \times 10^{-3}$]

Normalized $K^- K^0_S$ mass spectrum



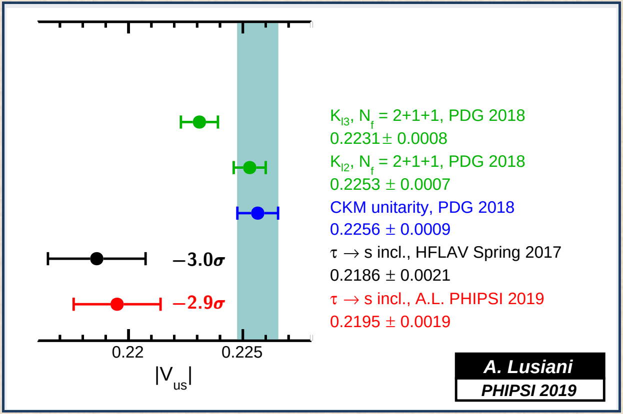
Spectral function



- plots report only statistical errors, paper reports table including systematic errors

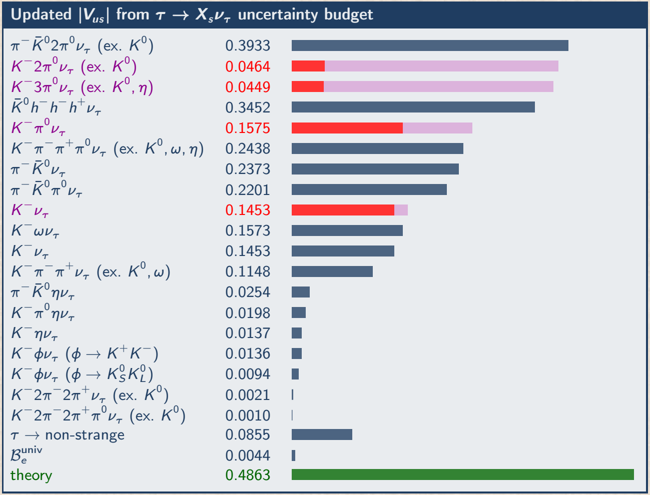
Impact on $|V_{us}|$ from $\tau^- \to X_s^- \nu_\tau$

$|V_{us}|$ from $\tau^- \to X_s^- \nu_\tau$, elaboration for PHIPSI 2019



- improved precision, small reduction of discrepancy vs. $|V_{us}|$ from CKM unitarity

Impact on $|V_{us}|$ from $\tau \to X_s \nu_\tau$



Updated $|V_{us}|$ from $\tau \to X_s \nu_\tau$ uncertainty budget

$\pi^- \bar{K}^0 2\pi^0 \nu_\tau$ (ex. K^0)	0.3933
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.0464
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.0449
$\bar{K}^0 h^- h^- h^+ \nu_\tau$	0.3452
$K^- \pi^0 \nu_\tau$	0.1575
$K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.2438
$\pi^- \bar{K}^0 \nu_\tau$	0.2373
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	0.2201
$K^- \nu_\tau$	0.1453
$K^- \omega \nu_\tau$	0.1573
$K^- \nu_\tau$	0.1453
$K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	0.1148
$\pi^- \bar{K}^0 \eta \nu_\tau$	0.0254
$K^- \pi^0 \eta \nu_\tau$	0.0198
$K^- \eta \nu_\tau$	0.0137
$K^- \phi \nu_\tau$ ($\phi \to K^+ K^-$)	0.0136
$K^- \phi \nu_\tau$ ($\phi \to K^0_S K^0_L$)	0.0094
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	0.0021
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	0.0010
$\tau \to$ non-strange	0.0855
$\mathcal{B}_e^{\text{univ}}$	0.0044
theory	0.4863

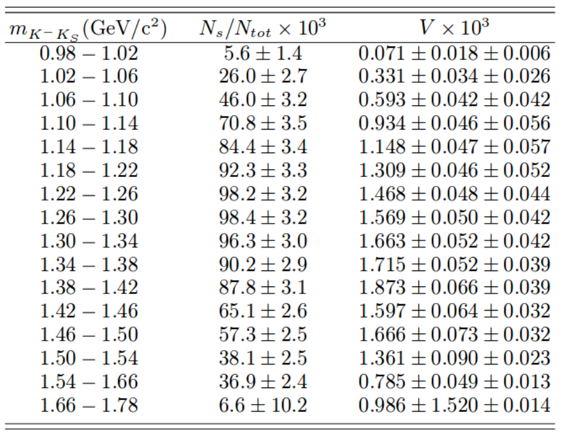
- significant improvements on several modes reported by *BABAR* at ICHEP 2018
- several modes still need improvements

Summary

- *BaBar* measured
  - $\tau^- \to K^-(0,1,2,3)\pi^0\nu_\tau$, $\tau^- \to \pi^-(3,4)\pi^0\nu_\tau$, *BaBar* preliminary, ICHEP 2018
    best results except for $\tau^- \to K^-\nu$
  - $\tau^- \to K^- K^0_S\nu_\tau$, Phys. Rev. D 98 (2018) no.3, 032010
    comparable precision of recent Belle measurement,
    S. Ryu et al. (Belle Collaboration), Phys. Rev. D 89, 072009 (2014)
    much more precise spectral function than before (CLEO)
- $|V_{us}|$ from $\tau^- \to X_s^-\nu_\tau$
  - precision improved
  - small reduction on $\sim 3\sigma$ discrepancy w.r.t. CKM unitarity $|V_{us}|$ determination

Backup Slides

Numerical results for the spectral function of $\tau \to K^- K_S \nu_\tau$



$m_{K^-K_S}$ (GeV/c^2)	$N_s/N_{tot} \times 10^3$	$V \times 10^3$
0.98 – 1.02	5.6 ± 1.4	$0.071 \pm 0.018 \pm 0.006$
1.02 – 1.06	26.0 ± 2.7	$0.331 \pm 0.034 \pm 0.026$
1.06 – 1.10	46.0 ± 3.2	$0.593 \pm 0.042 \pm 0.042$
1.10 – 1.14	70.8 ± 3.5	$0.934 \pm 0.046 \pm 0.056$
1.14 – 1.18	84.4 ± 3.4	$1.148 \pm 0.047 \pm 0.057$
1.18 – 1.22	92.3 ± 3.3	$1.309 \pm 0.046 \pm 0.052$
1.22 – 1.26	98.2 ± 3.2	$1.468 \pm 0.048 \pm 0.044$
1.26 – 1.30	98.4 ± 3.2	$1.569 \pm 0.050 \pm 0.042$
1.30 – 1.34	96.3 ± 3.0	$1.663 \pm 0.052 \pm 0.042$
1.34 – 1.38	90.2 ± 2.9	$1.715 \pm 0.052 \pm 0.039$
1.38 – 1.42	87.8 ± 3.1	$1.873 \pm 0.066 \pm 0.039$
1.42 – 1.46	65.1 ± 2.6	$1.597 \pm 0.064 \pm 0.032$
1.46 – 1.50	57.3 ± 2.5	$1.666 \pm 0.073 \pm 0.032$
1.50 – 1.54	38.1 ± 2.5	$1.361 \pm 0.090 \pm 0.023$
1.54 – 1.66	36.9 ± 2.4	$0.785 \pm 0.049 \pm 0.013$
1.66 – 1.78	6.6 ± 10.2	$0.986 \pm 1.520 \pm 0.014$

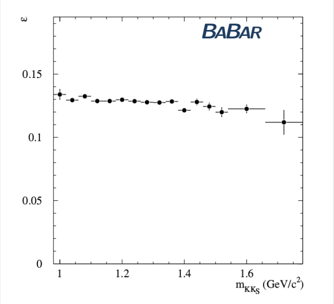
- uncertainties are statistical and systematic

Event selection for $\tau^- \to K^- K^0_S \nu_\tau$

Selection requirements

- 4 tracks from IP (total charge zero)
- Particle IDentification (PID) for lepton ($e^\pm$ or $\mu^\pm$) and kaon (opposite charge)
- quality cuts on track momentum and angle: good PID; and reject $e^+e^- \to e^-e^+$ and $e^+e^- \to \mu^-\mu^+$
- remaining tracks: $K_S \to \pi^-\pi^+$ with $m_{\pi\pi}$ within 25 MeV of $m(K_S)$
- flight length of $K_S > 1cm$
- $\sum E_{\text{neutral}} < 2GeV$
- Thrust > 0.875 (charged tracks)
- angle KK_S - lepton $> 110^\circ$

Selection efficiency vs. m_{KK_S}

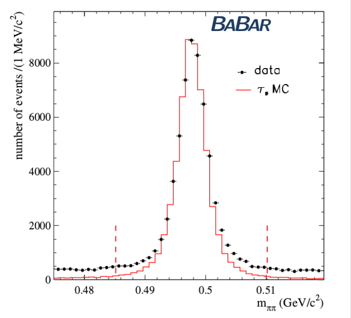


- average selection efficiency ≈ 13%

Subtraction of non-K_S background

- subtract non-K_S background by using sidebands and assuming a flat distribution
  - reconstructed events composed of background and true K_S: $N = N_{K_S} + N_b$
  - number of events in the side-band: $N_{sb} = \alpha N_b + \beta N_{K_S}$
  - solve for the number of true K_S: $$N_{K_S} = \frac{\alpha N - N_{sb}}{\alpha - \beta}$$
- subtract bin by bin in m_{KK_S}
- fraction of non- K_S bkg: $\approx 10\%$ for $m_{KK_S} < 1.3 GeV$ increases to up to 50% for $m_{KK_S} > 1.6 GeV$

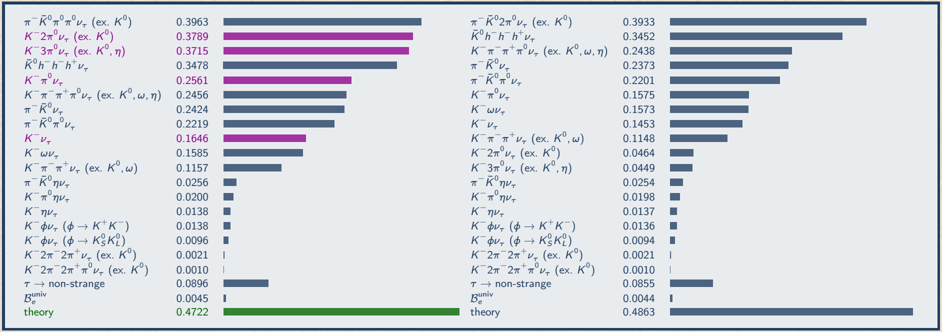
K_S candidates mass



Event Selection for $\tau^- \to h^- n\pi^0 \nu_\tau$

- two oppositely charg. tracks from IP: PID $\ell^\pm$ (tag), $K^\pm$ or $\pi^\pm$ (sig.)
- reconstruct up to 4 $\pi^0 \to \gamma\gamma$
- reject events with additional photons
- several track and photon quality cuts: ensure good PID; reject bkg
- $0.88 <$ thrust of event $T < 0.99$
- angle between lepton and signal hadron $> 2.95\,\text{rad}$
- cuts on missing mass of event and signal τ-decay to reject bkg. $(e^+e^- \to \ell^+\ell^-)$
- reject two-photon events: $\frac{p_T}{E_{\textbf{miss}}} = \frac{(\vec{p}_1^{\,\textbf{CM}} + \vec{p}_2^{\,\textbf{CM}})_T}{\sqrt{s} - p_1^{\textbf{CM}} - p_2^{\textbf{CM}}} > 0.2$

$|V_{us}|$ error bugdet before and after the *BABAR* 2018 results



$\pi^-\bar{K}^0\pi^0\pi^0\nu_\tau$ (ex. K^0)	0.3963	$\pi^-\bar{K}^0 2\pi^0\nu_\tau$ (ex. K^0)	0.3933
$K^- 2\pi^0\nu_\tau$ (ex. K^0)	0.3789	$\bar{K}^0 h^- h^- h^+\nu_\tau$	0.3452
$K^- 3\pi^0\nu_\tau$ (ex. K^0, η)	0.3715	$K^-\pi^-\pi^+\pi^0\nu_\tau$ (ex. K^0, ω, η)	0.2438
$\bar{K}^0 h^- h^- h^+\nu_\tau$	0.3478	$\pi^-\bar{K}^0\nu_\tau$	0.2373
$K^-\pi^0\nu_\tau$	0.2561	$\pi^-\bar{K}^0\pi^0\nu_\tau$	0.2201
$K^-\pi^-\pi^+\pi^0\nu_\tau$ (ex. K^0, ω, η)	0.2456	$K^-\pi^0\nu_\tau$	0.1575
$\pi^-\bar{K}^0\nu_\tau$	0.2424	$K^-\omega\nu_\tau$	0.1573
$\pi^-\bar{K}^0\pi^0\nu_\tau$	0.2219	$K^-\nu_\tau$	0.1453
$K^-\nu_\tau$	0.1646	$K^-\pi^-\pi^+\nu_\tau$ (ex. K^0, ω)	0.1148
$K^-\omega\nu_\tau$	0.1585	$K^- 2\pi^0\nu_\tau$ (ex. K^0)	0.0464
$K^-\pi^-\pi^+\nu_\tau$ (ex. K^0, ω)	0.1157	$K^- 3\pi^0\nu_\tau$ (ex. K^0, η)	0.0449
$\pi^-\bar{K}^0\eta\nu_\tau$	0.0256	$\pi^-\bar{K}^0\eta\nu_\tau$	0.0254
$K^-\pi^0\eta\nu_\tau$	0.0200	$K^-\pi^0\eta\nu_\tau$	0.0198
$K^-\eta\nu_\tau$	0.0138	$K^-\eta\nu_\tau$	0.0137
$K^-\phi\nu_\tau$ ($\phi \to K^+K^-$)	0.0138	$K^-\phi\nu_\tau$ ($\phi \to K^+K^-$)	0.0136
$K^-\phi\nu_\tau$ ($\phi \to K^0_S K^0_L$)	0.0096	$K^-\phi\nu_\tau$ ($\phi \to K^0_S K^0_L$)	0.0094
$K^- 2\pi^- 2\pi^+\nu_\tau$ (ex. K^0)	0.0021	$K^- 2\pi^- 2\pi^+\nu_\tau$ (ex. K^0)	0.0021
$K^- 2\pi^- 2\pi^+\pi^0\nu_\tau$ (ex. K^0)	0.0010	$K^- 2\pi^- 2\pi^+\pi^0\nu_\tau$ (ex. K^0)	0.0010
$\tau \to$ non-strange	0.0896	$\tau \to$ non-strange	0.0855
$\mathcal{B}_e^{\text{univ}}$	0.0045	$\mathcal{B}_e^{\text{univ}}$	0.0044
theory	0.4722	theory	0.4863