

Recent results on τ lepton decays with the BABAR detector



Lake Louise Winter Institute

Lake Louise, Canada

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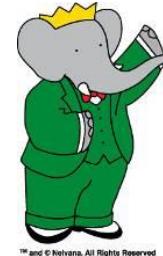
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IRFU, CEA, Université Paris-Saclay



on behalf of the BABAR Collaboration

Outline

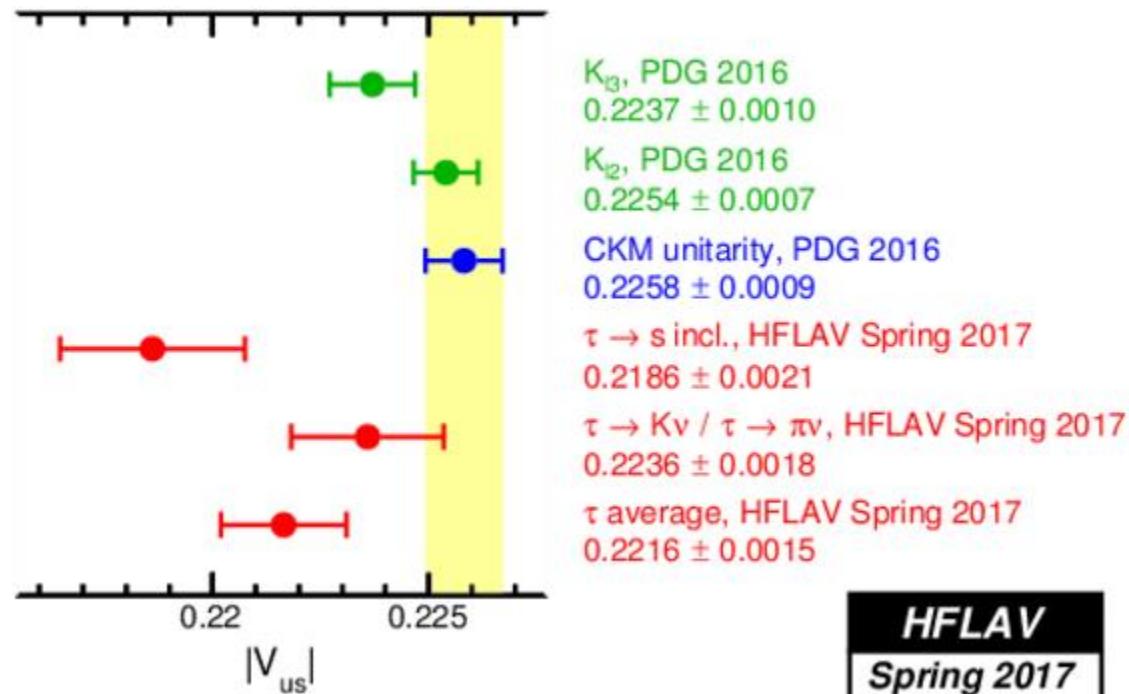
- $|V_{us}|$ from τ decays
- Measurement of branching fractions at BABAR
 - $\tau^- \rightarrow K^- \nu_\tau$
 - $\tau^- \rightarrow K^- \pi^0 \nu_\tau$
 - $\tau^- \rightarrow K^- \pi^0 \pi^0 \nu_\tau$
 - $\tau^- \rightarrow K^- \pi^0 \pi^0 \pi^0 \nu_\tau$
- Impact on $|V_{us}|$



Determining $|V_{us}|$

$|V_{us}|$ measurements:

- Kaons
 - $K \rightarrow \pi \ell \nu$ (K_{l3})
 - $K \rightarrow \ell \nu / \pi \rightarrow \ell \nu$ (K_{l2})



- CKM unitarity

- $\tau \rightarrow s$ inclusive
- $\tau \rightarrow K \nu / \tau \rightarrow \pi \nu$

- Tau leptons

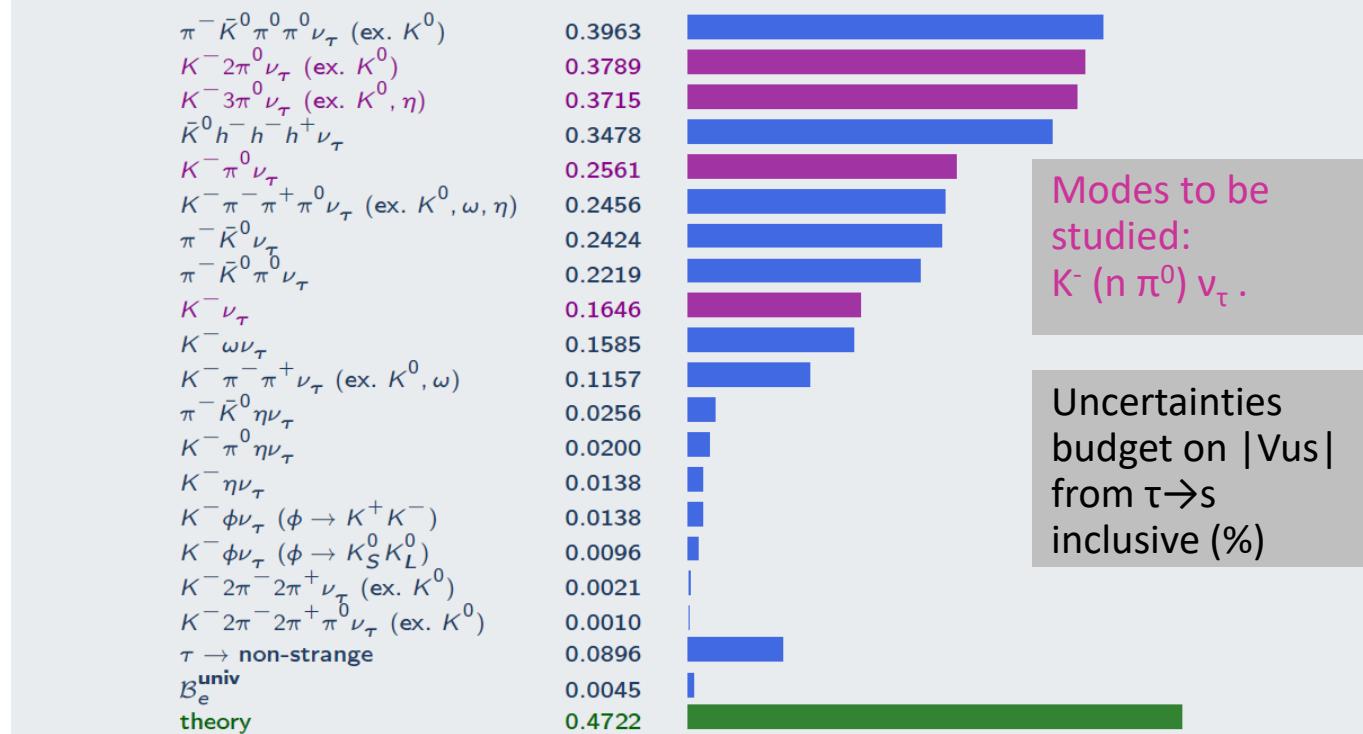
- Tension between result from $\tau \rightarrow s$ inclusive and other estimates (3.1σ with CKM unitarity)

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HFLAV
Spring 2017

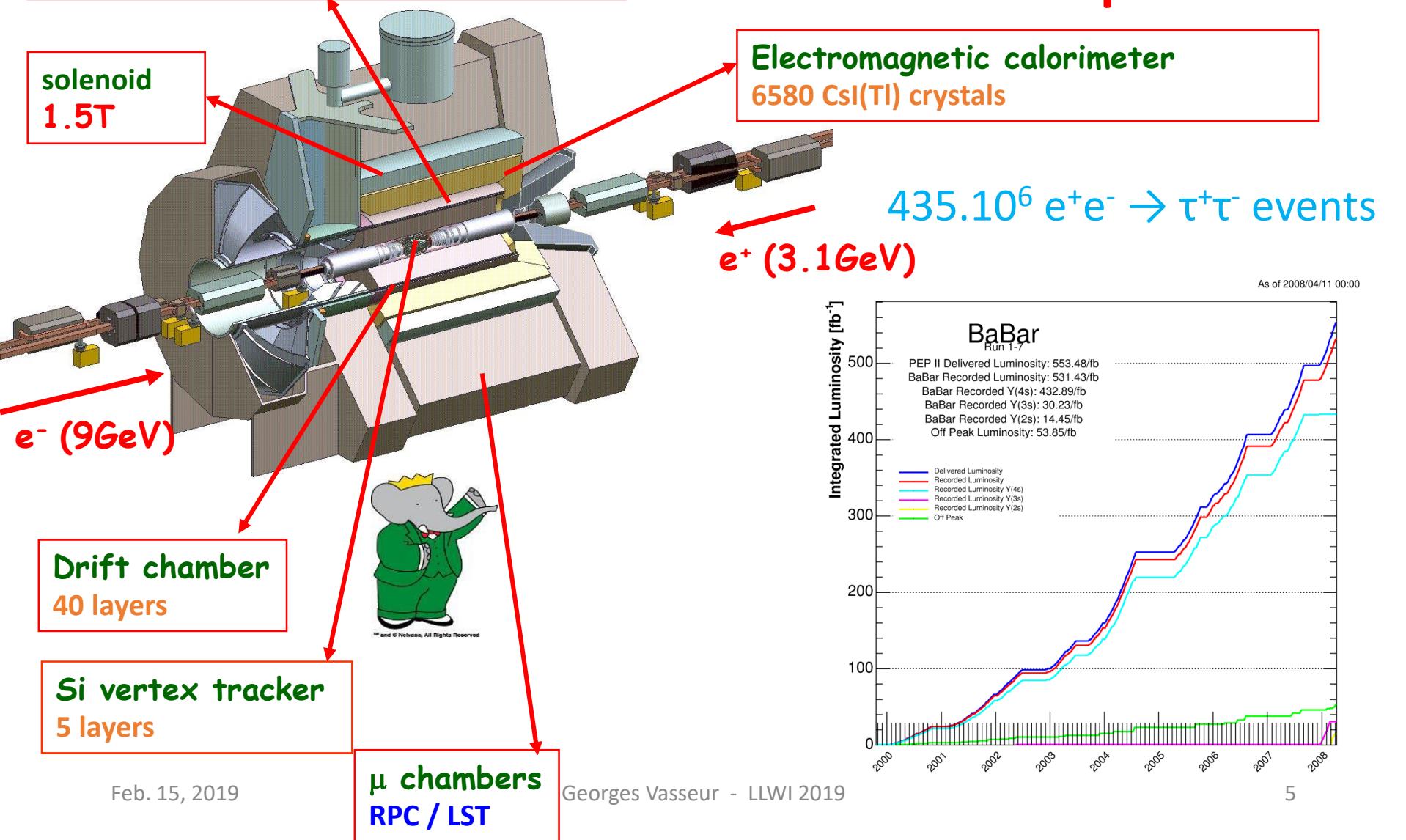
$\tau \rightarrow s$ inclusive

- Theoretical uncertainty through δR
- $$\frac{R(\tau \rightarrow X_{\text{strange}})}{|V_{us}|^2} = \frac{R(\tau \rightarrow X_{\text{non-strange}})}{|V_{ud}|^2} - \delta R_{\tau, \text{SU3 breaking}}$$
- $[R(\tau \rightarrow X) = \Gamma(\tau \rightarrow X)/\Gamma(\tau \rightarrow e\nu\bar{\nu})]$

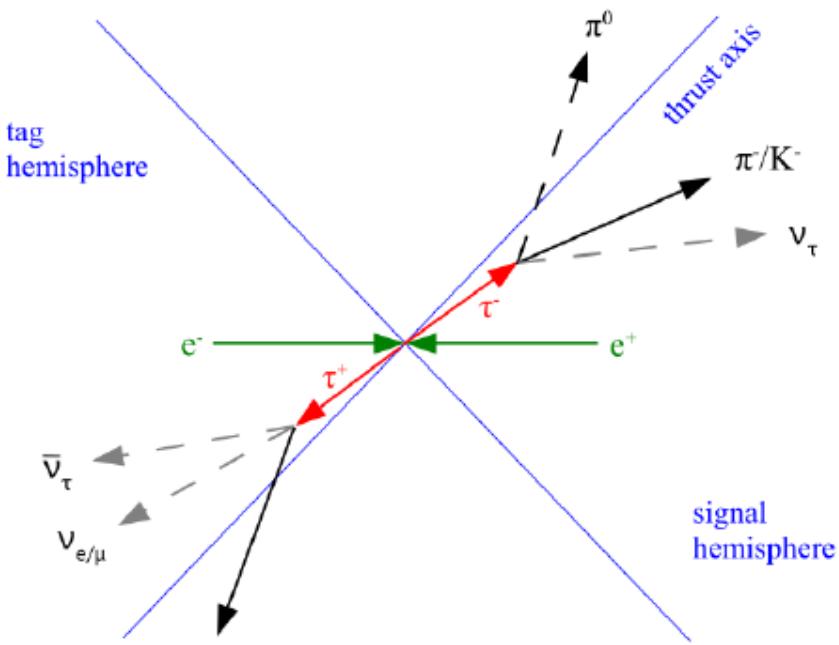


Detector and data sample

Cherenkov detector (DIRC)
144 quartz bars and 11000 PMTs



Analysis method



- 1-prong signal modes:
 - $\tau^- \rightarrow K^- (n \pi^0) v_\tau$, $n=0,1,2,3$
 - $\tau^- \rightarrow \pi^- (n \pi^0) v_\tau$, $n=3,4$
- 1-prong control samples:
 - $\tau^- \rightarrow \pi^- (n \pi^0) v_\tau$, $n=0,1,2$
 - $\tau^- \rightarrow \mu^- v_\mu v_\tau$
- Divide event into two hemispheres along thrust axis
- Require one track in each (oppositely charged)
 - ℓ (tag)
 - π or K (signal)
 - No additional tracks
- Reconstruct from 0 to 4 $\pi^0 \rightarrow \gamma\gamma$
 - No additional photons

Signal selection

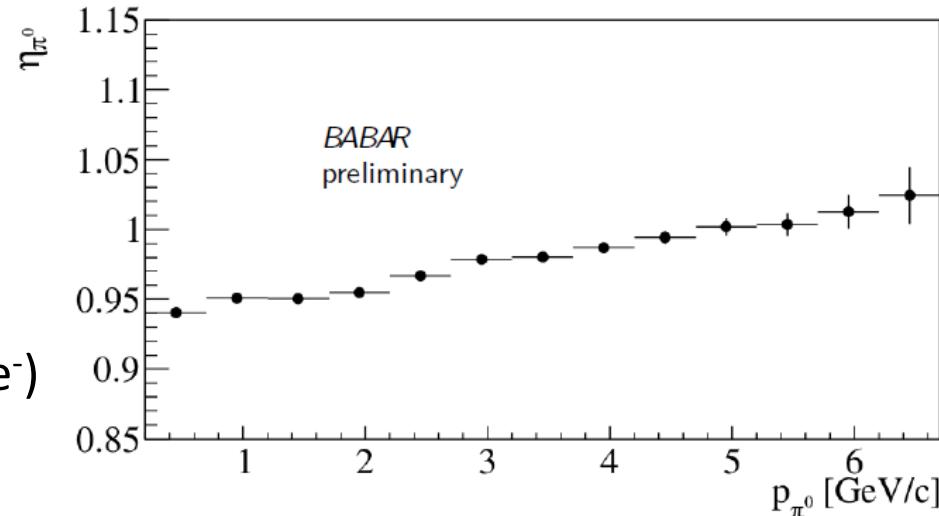
- Various cuts:
 - Event topology (thrust)
 - Missing mass in event
 - Missing mass in signal hemisphere
- to reject backgrounds:
 - $q\bar{q}$, dileptons, diphotons
 - other τ decays
- τ decays with $K_S \rightarrow \pi^0 \pi^0$ and $\eta \rightarrow \pi^0 \pi^0 \pi^0$ counted as background

Mode	# selected events	Purity (%)	ϵ (%)
$K^- \nu_\tau$	80 715	77	0.99
$K^- \pi^0 \nu_\tau$	146 948	65	2.16
$K^- 2\pi^0 \nu_\tau$	17 930	38	1.34
$K^- 3\pi^0 \nu_\tau$	1 863	21	0.13
$\pi^- 3\pi^0 \nu_\tau$	58 598	83	0.49
$\pi^- 4\pi^0 \nu_\tau$	1 706	57	0.12

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Efficiency correction

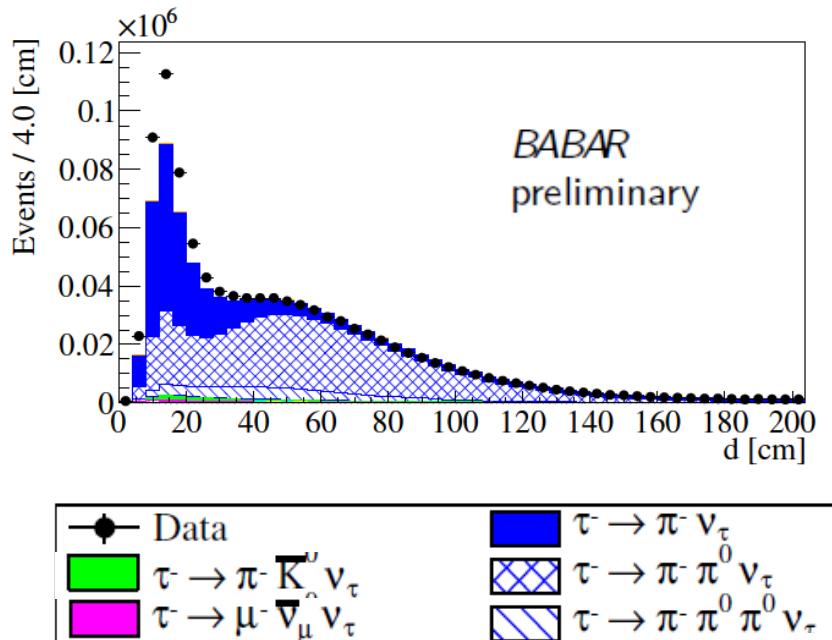
- For π^0 :
 - Correction factor from data-MC comparison of control samples:
 - $\tau^- \rightarrow t^- \pi^0 \nu_\tau$
 - $\tau^- \rightarrow t^- \nu_\tau$
 - (t^- track not identified as e^-)
 - as a function of p_{π^0}
- For charged particles:
 - Standard BABAR PID corrections
 - Additional correction to take into account difference in topology for π as π , K as K and π as K (mis-)ID
 - From the 3-1-topology $\tau^+\tau^-$ control samples $\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$ and $\tau^- \rightarrow \pi^- K^+ K^- \nu_\tau$: identify two tracks and check ID on the third track



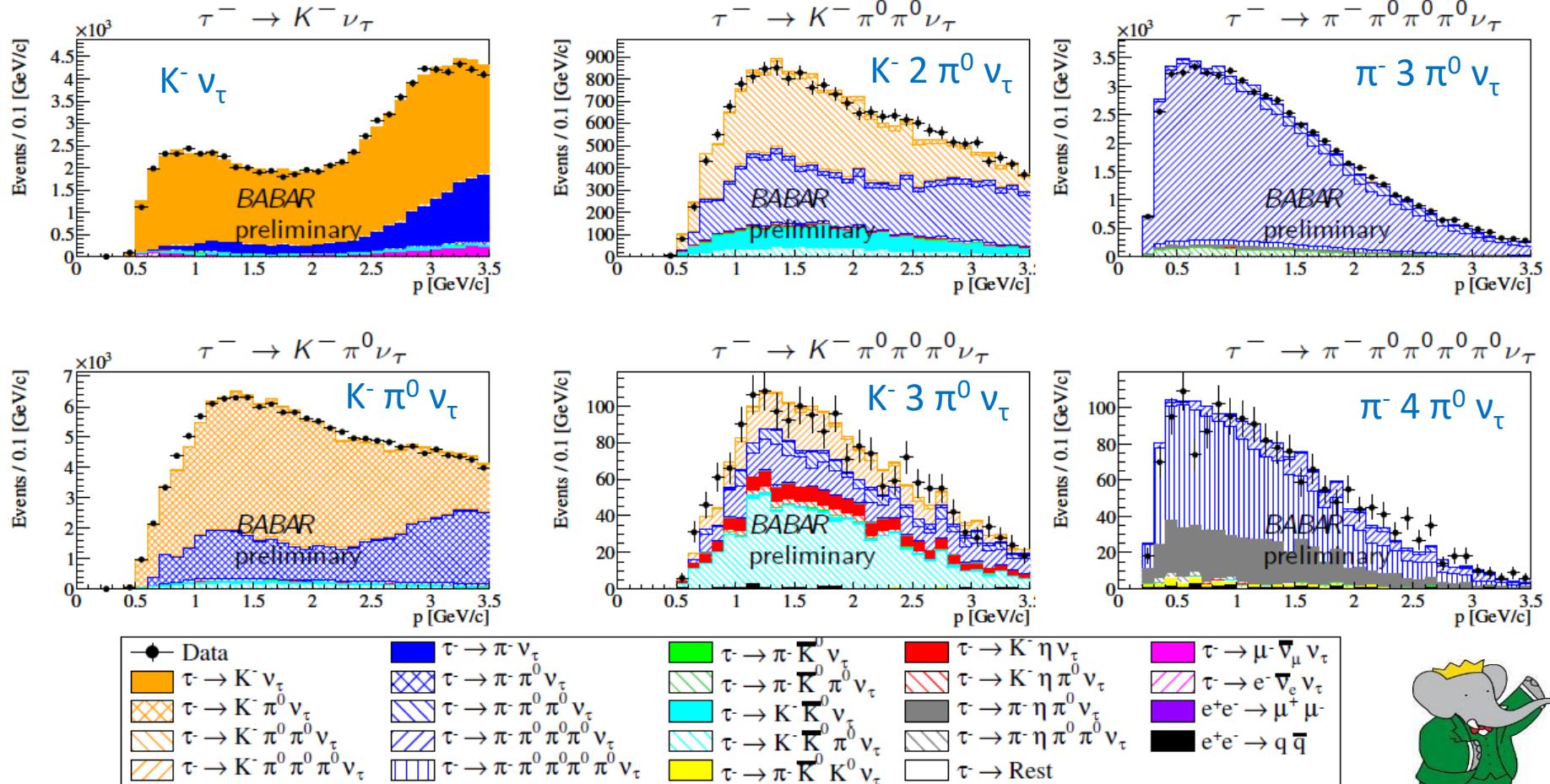
Split-off correction

- Fake photons by neutrons from hadronic showers
- Not well modelled in MC
- Use $\tau^- \rightarrow \pi^- \nu_\tau$ control mode
- Relative excess in data:
$$\eta = \frac{N^{data}(d < 40\text{cm}) - N^{MC}(d < 40\text{cm})}{N^{data}}$$
- Correction factor applied to the simulation:
 - $w = 1 - \eta = 0.972 \pm 0.014$

d : distance between the track intersection with calorimeter and the nearest cluster



Background and cross-feed



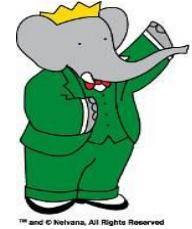
Plots of the momentum of the track in the signal hemisphere



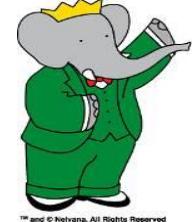
Uncertainties

- Analysis systematics limited
- Main sources : π^0 , PID, split-off corrections
 - Backgrounds for modes with large number of π^0 's

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	19.12	3.23	7.23
Total uncertainty [%]	3.00	2.95	5.81	23.19	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 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
# $\tau^+ \tau^-$ pairs [%]	0.79	0.93	1.40	2.61	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	5.17	1.40	1.94
π^0 correction [%]	0.03	1.20	3.63	10.56	2.76	5.36
$\pi 5\pi^0 \rightarrow \pi 4\pi^0$ migr. [%]	0.00	0.00	0.00	0.02	0.04	1.08
$K 4\pi^0 \rightarrow K 3\pi^0$ migr. [%]	0.00	0.00	0.13	4.78	0.00	0.00

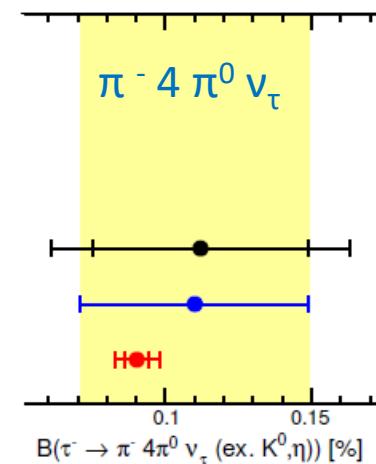
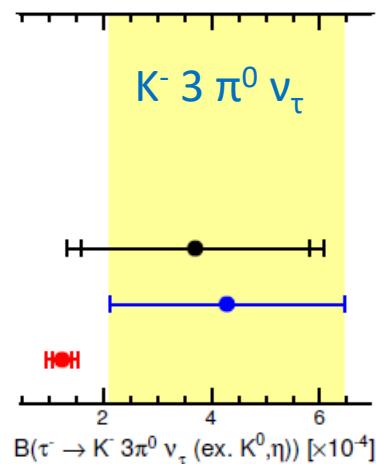
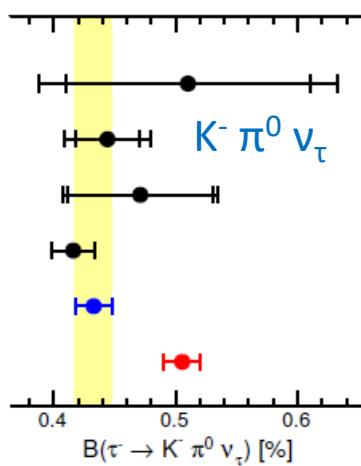
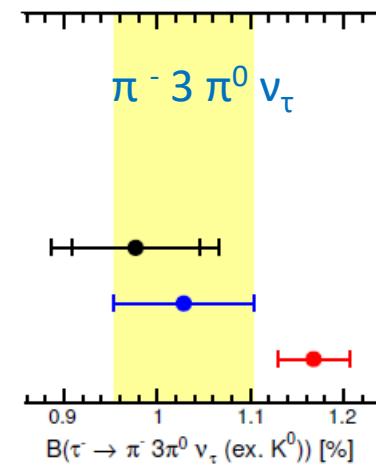
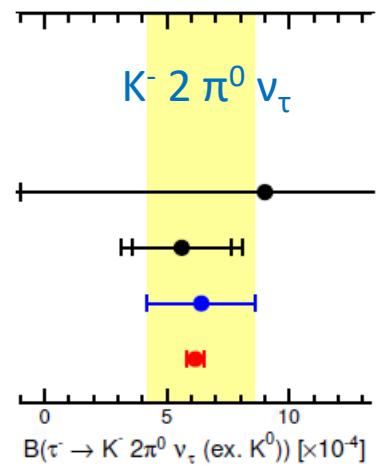
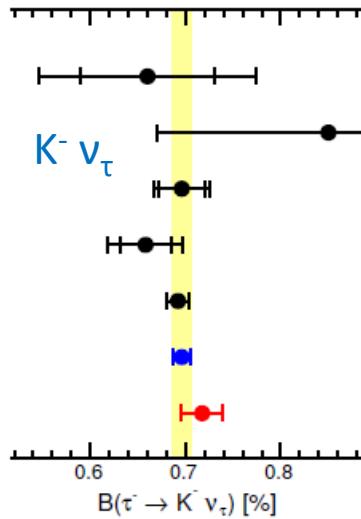


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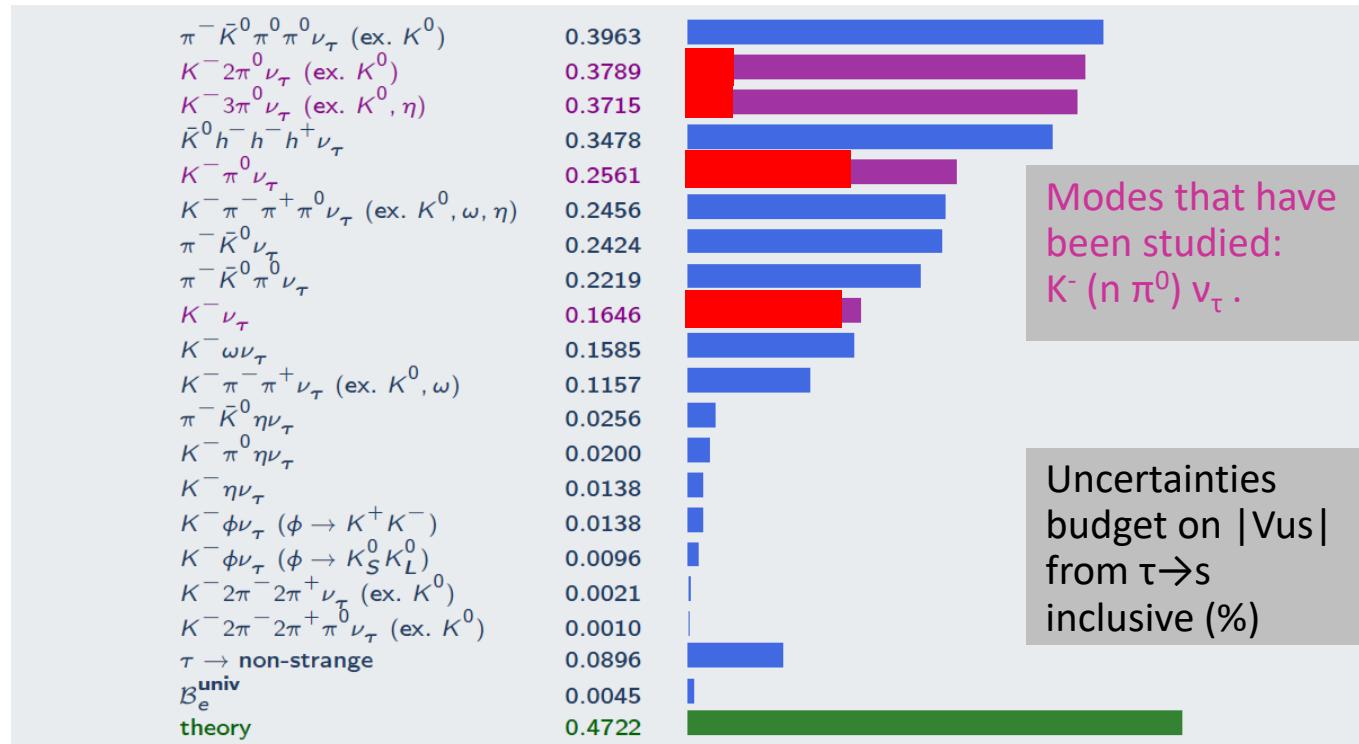
Branching fraction results

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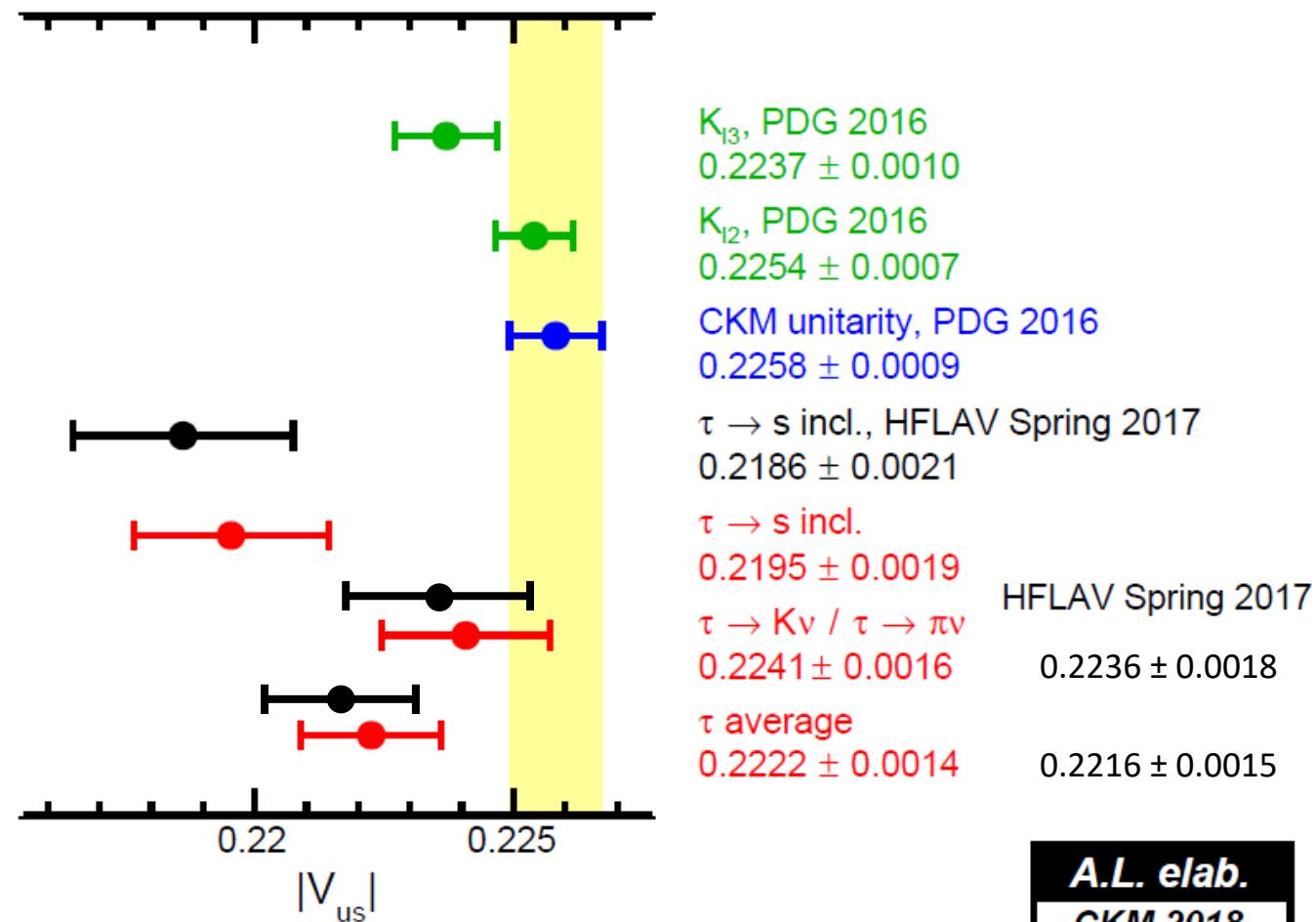
Impact on uncertainties on $|V_{us}|$

- Substantial improvement for the modes under study
- Other modes still to improve



Impact on $|V_{us}|$

- With new measurements:
- $|V_{us}|$ increased a bit
- Uncertainty slightly reduced
- Still 3 σ discrepancy on $\tau \rightarrow s$ inclusive



A.L. elab.
CKM 2018

Summary

- BABAR has measured 1-prong τ decay branching fractions:
 - $\tau^- \rightarrow K^- (n \pi^0) \nu_\tau$, $n=0,1,2,3$
 - $\tau^- \rightarrow \pi^- (n \pi^0) \nu_\tau$, $n=3,4$
- They are the most precise measurements to date
 - Except for $\tau^- \rightarrow K^- \nu_\tau$
- They improve the $\tau \rightarrow s$ inclusive $|V_{us}|$ measurement
 - But discrepancy with CKM unitarity still at 3σ
- Publication expected in 2019