Summary of τ-lepton Workshop

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and Lebedev Physical Institute RAS, Moscow, Russia

77 oral talks plus 18 posters presented

General

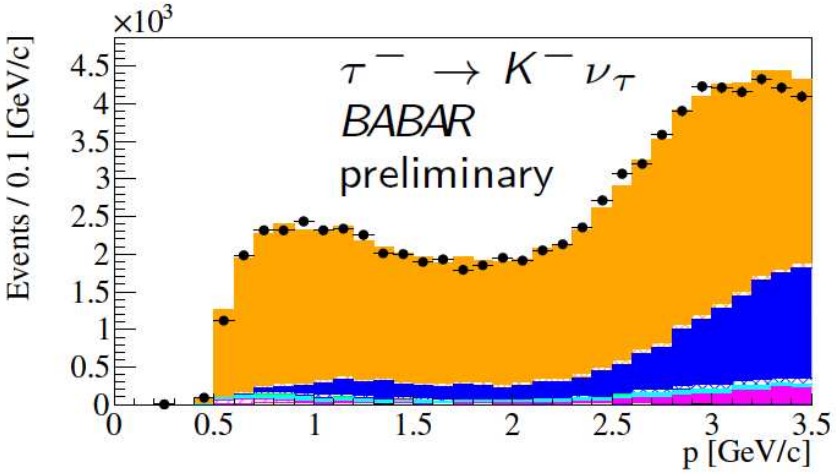
- τ lepton and its neutrino ν_τ – two of the six fundamental leptons: $e^-,\ \nu_e,\ \mu^-,\ \nu_\mu,\ \tau^-,\ \nu_\tau$
- As the heaviest lepton, τ decays into both leptons and hadrons: PDG-2018 lists 244 various decay modes of the τ
- All interactions allowed in the Standard Model as well as effects of New Physics can be studied in τ-lepton production and decays
- It is a very pure laboratory without hadrons in the initial and only a few in the final state (low decay multiplicity)
- Serious progress after 2005 is related to the B factories with $\sigma(\tau^+\tau^-) \approx 0.9$ nb, 1 fb$^{-1} \Rightarrow 9 \times 10^5\ \tau^+\tau^-$ pairs
- LHC experiments opened a new field - studies of and searches for heavy particles ($W,\ Z,\ H,\ \ldots$) with τ leptons among decay products

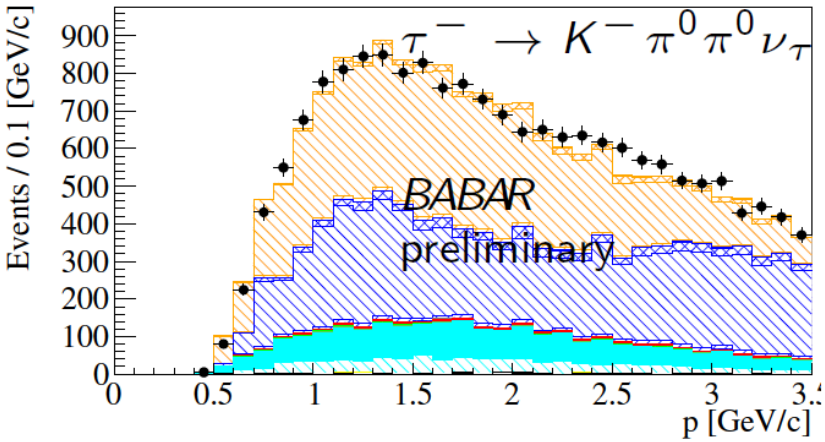
News from HFLAV

- HFAG $\rightarrow$ HFLAV, Eur. Phys. J. C77 (2017) 895
- In contrast to PDG, correlations and external parameters are taken into account, avoiding scale factors
- Special treatment of ALEPH data
- The fit used 170 measurements with 88 constraints, 135 final parameters
- Lepton Universality from leptonic decays:
  $g_\tau/g_\mu = 1.0010 \pm 0.0015$, $g_\tau/g_e = 1.0029 \pm 0.0015$, $g_\mu/g_e = 1.0019 \pm 0.0014$,
  combined with hadronic modes $g_\tau/g_\mu = 1.0000 \pm 0.0014$
- Various attempts to improve the situation with $|V|_{us}$

Alberto Lusiani, September 24

$\tau^- \to K^-(\pi^-)n\pi^0\nu_\tau$ at BaBar – I

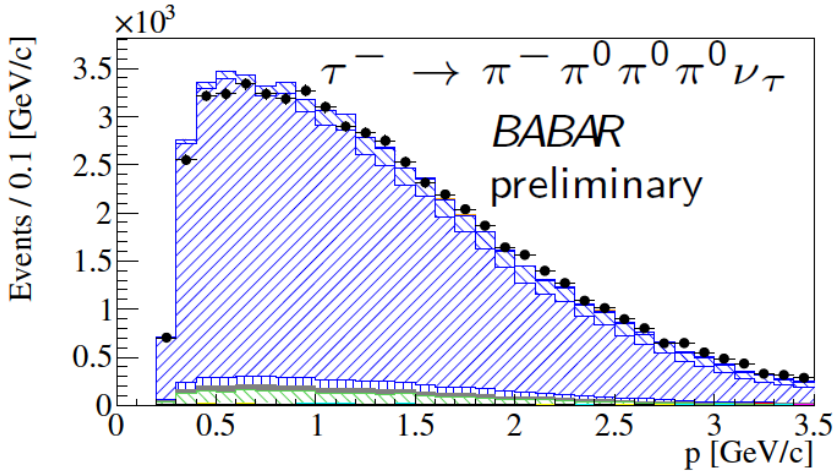


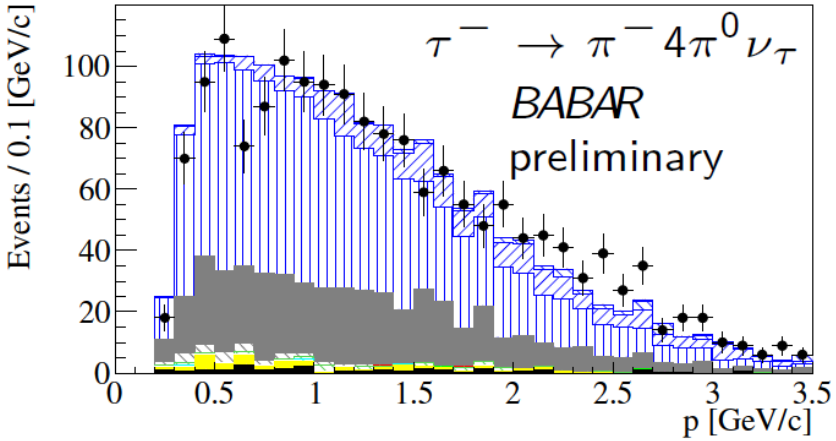


Mode	$N_{\rm ev}$	$\mathcal{B}, 10^{-3}$
$K^-\nu_\tau$	80715	$7.174 \pm 0.033 \pm 0.213$
$K^-\pi^0\nu_\tau$	146948	$5.054 \pm 0.021 \pm 0.148$

Thomas Lueck, September 24

$\tau^- \to K^-(\pi^-)n\pi^0\nu_\tau$ at BaBar – II



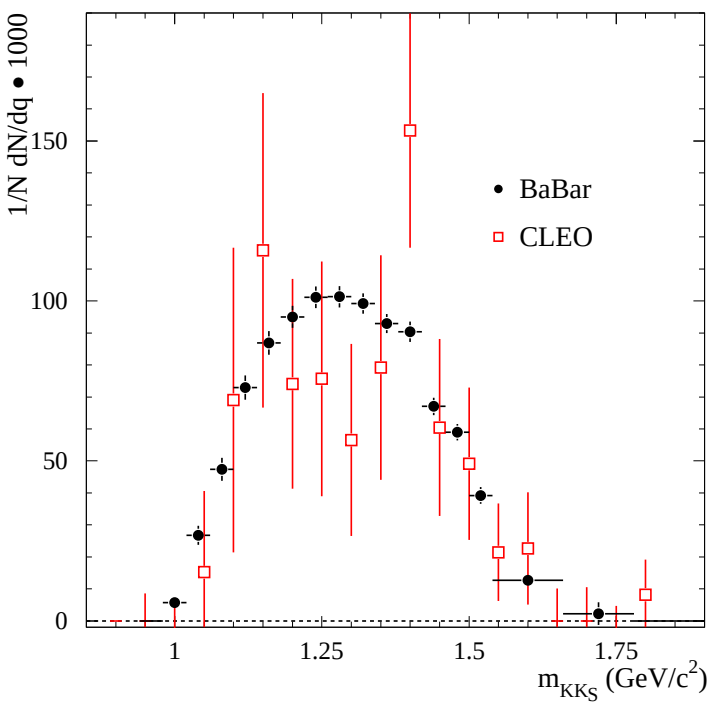


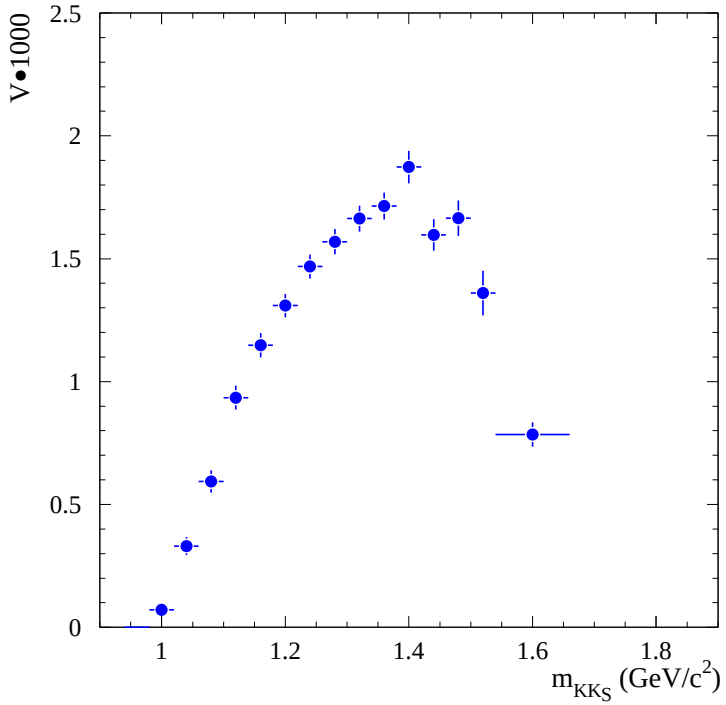
Mode	$N_{\rm ev}$	$\mathcal{B}, 10^{-2}$
$\pi^-3\pi^0\nu_\tau$	58598	$1.168 \pm 0.006 \pm 0.038$
$\pi^-4\pi^0\nu_\tau$	1706	$(9.020 \pm 0.400 \pm 0.652) \times 10^{-2}$

Thomas Lueck, September 24

$\tau^- \to K^- K^0_S \nu_\tau$ at BaBar

BaBar finds 223741 ± 3461 events from (468.0 ± 2.5) fb^{-1}



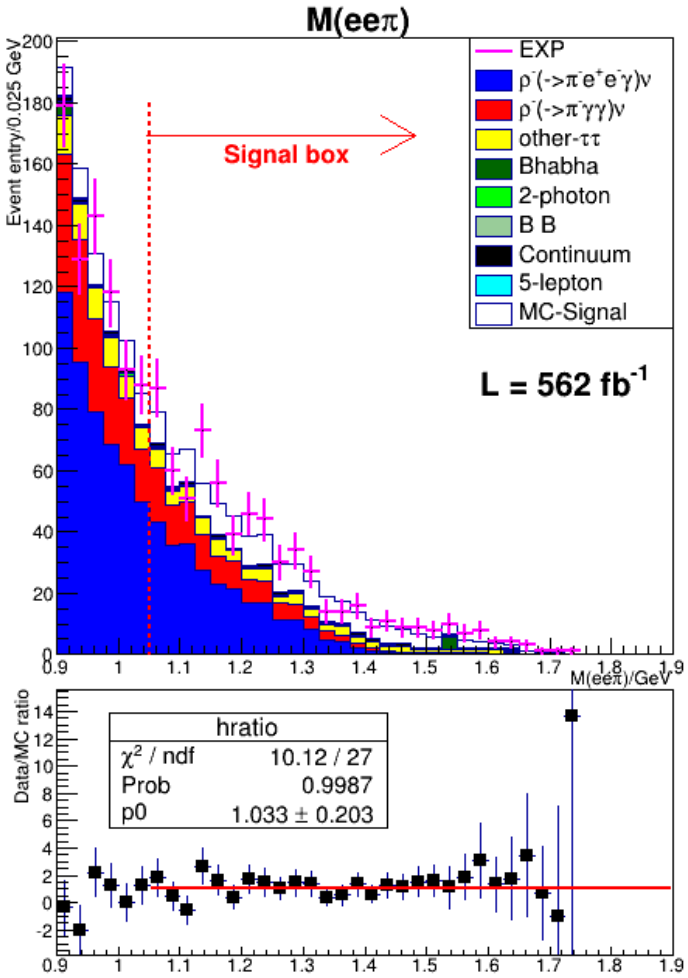


BaBar $\mathcal{B} = (0.739 \pm 0.011 \pm 0.020) \times 10^{-3}$ Phys.Rev. D98 (2018) 032010

Belle $\mathcal{B} = (0.740 \pm 0.007 \pm 0.027) \times 10^{-3}$ Phys.Rev. D89 (2014) 072009

BaBar Sergey Serednyakov September 24

$\tau^- \to \pi^- \nu_e l^+ l^-$ at Belle



Mode	$\mathcal{B}, 10^{-5}$
$\pi^- \nu_\tau e^+ e^-$	$2.11 \pm 0.19 \pm 0.30$
$\pi^- \nu_\tau \mu^+ \mu^-$	< 1.06

Theory:

$(1.4 - 2.8) \cdot 10^{-5}$ for $e^+ e^-$,

$3 \cdot 10^{-7} - 1 \cdot 10^{-5}$ for $\mu^+ \mu^-$

Yifan Jin, September 24

Studies of $\tau^- \to l^- \bar{\nu}_l \nu_\tau l^+ l^-$ at Belle

Belle uses 711 fb^{-1}, the full $\Upsilon(4S)$ sample, to study five-lepton decays

Expectations:

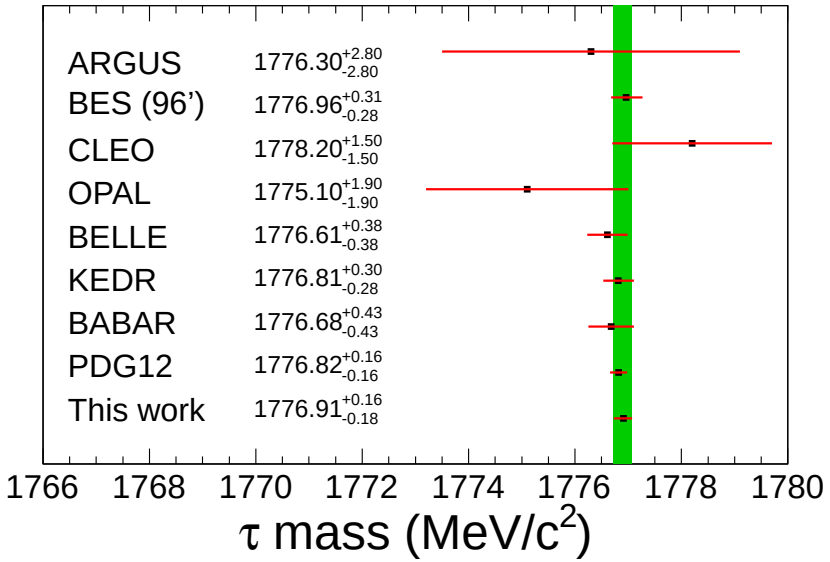
Mode	$N_{\rm ev}$
$\tau^- \to e^- \bar{\nu}_e \nu_\tau e^+ e^-$	1300
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau e^+ e^-$	430
$\tau^- \to e^- \bar{\nu}_e \nu_\tau \mu^+ \mu^-$	8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau \mu^+ \mu^-$	4

Yifan Jin, September 24

Other Studies of τ Properties at Belle

- τ Michel Parameters:
  $\rho,\ \eta,\ \xi,\ \xi\delta$ studied with an order of magnitude better stat. accuracy
  Denis Epifanov
- Studies of three-body decays $\pi^-\pi^-\pi^+,\ K^-\pi^-\pi^+,\ K^-K^-\pi^+,\ K^-K^-K^+$ to understand the contradiction of $\mathcal{B}$'s between Belle and BaBar

τ Lepton Mass Measurement at BESIII



$$M_\tau = 1775.91 \pm 0.12^{+0.10}_{-0.13} \text{ MeV}$$

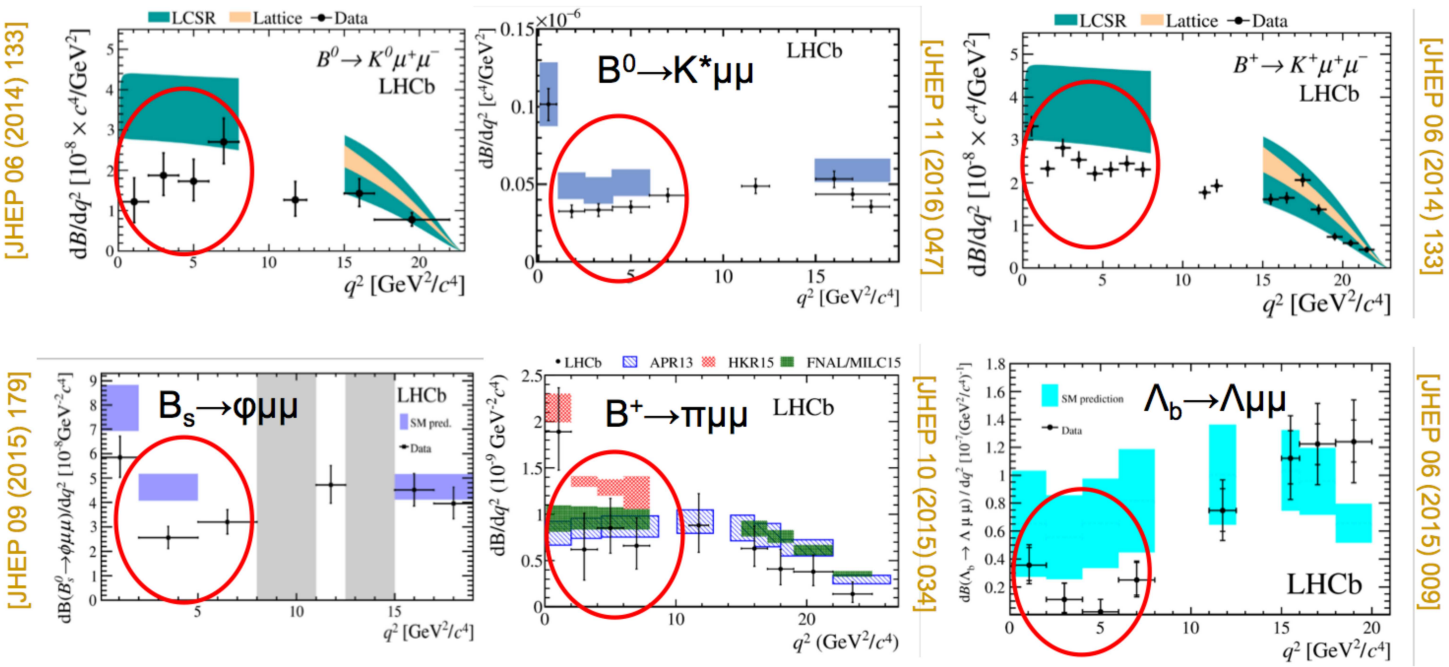
- A new measurement with 130 pb^{-1}
- 13 τ decay modes will be used
- 0.044 MeV (stat.) and 0.090 MeV (syst.) uncertainties

JianYong Zhang, September 24

Some Theory Related to τ Properties

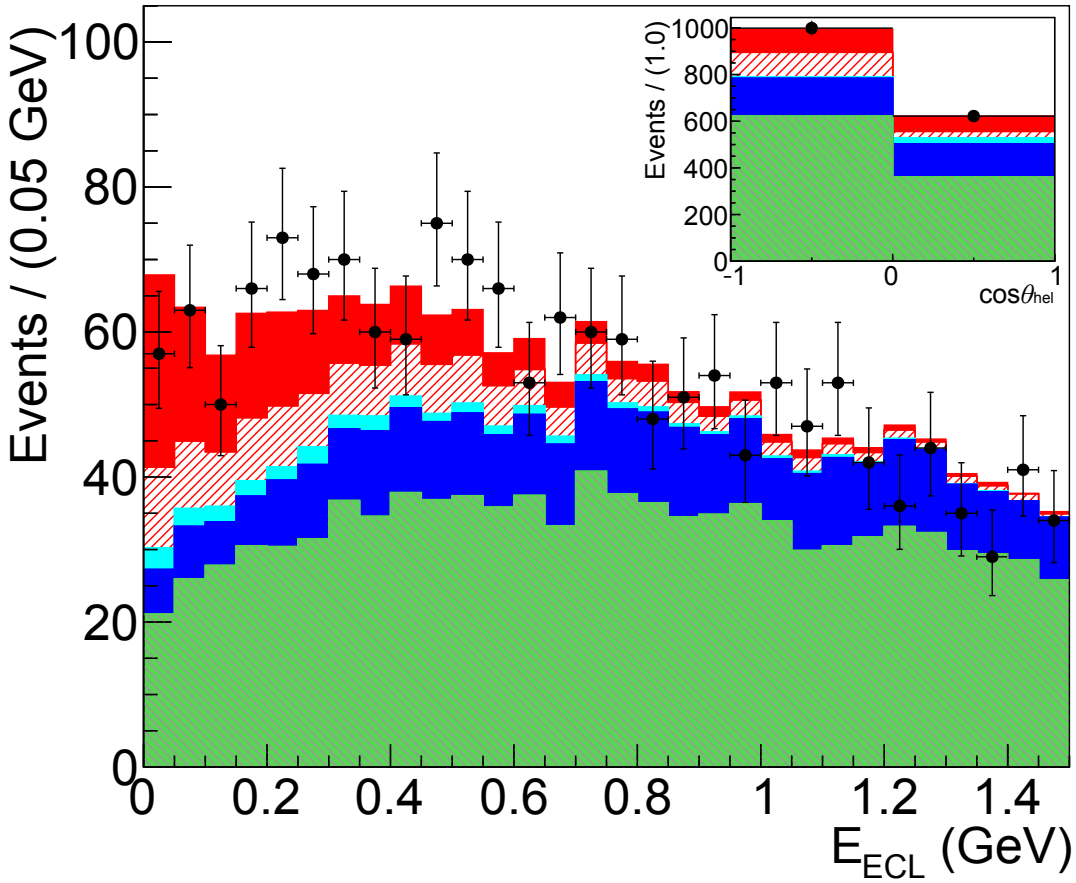
- M. Fael: the differential decay rates and $\mathcal{B}$'s for muon decays to five leptons, $\tau(\mu) \to lll\nu\nu^{'}$, in the SM at NLO. The shift is $\sim 0.1\%$ for $\tau \to e(\mu)ee\nu\nu$ and $\sim 1\%$ for $\tau \to e(\mu)\mu\mu\nu\nu$. Confirmed by the A. Signer's group at PSI.
  Also showed $\mathcal{B}$'s for $\tau \to l\nu\nu$ + hadrons to be $\mathcal{O}(10^{-8})$, within Belle-II reach.
- G. Lopez Castro: impact of new interactions on $\eta\pi^-\nu_\tau$, $\pi^-\pi^0\nu_\tau$ decays
- K. Maltman: issues with $|V|_{us}$

Possible Anomalies in b-quark Decays at LHCb

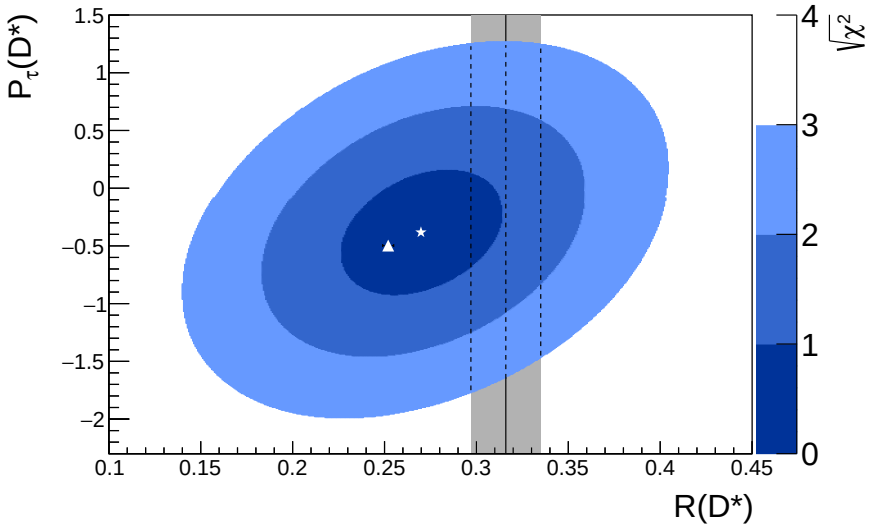


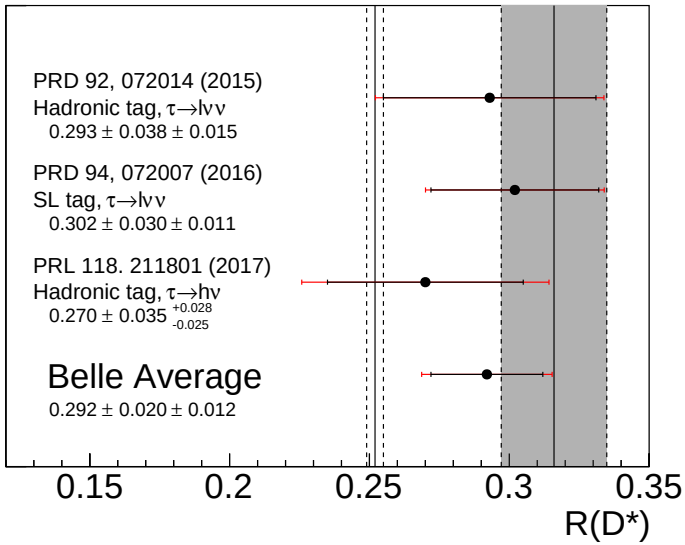
Sean Benson, September 25

Possible Anomalies in b-quark Decays at Belle – I



Possible Anomalies in b-quark Decays at Belle – II





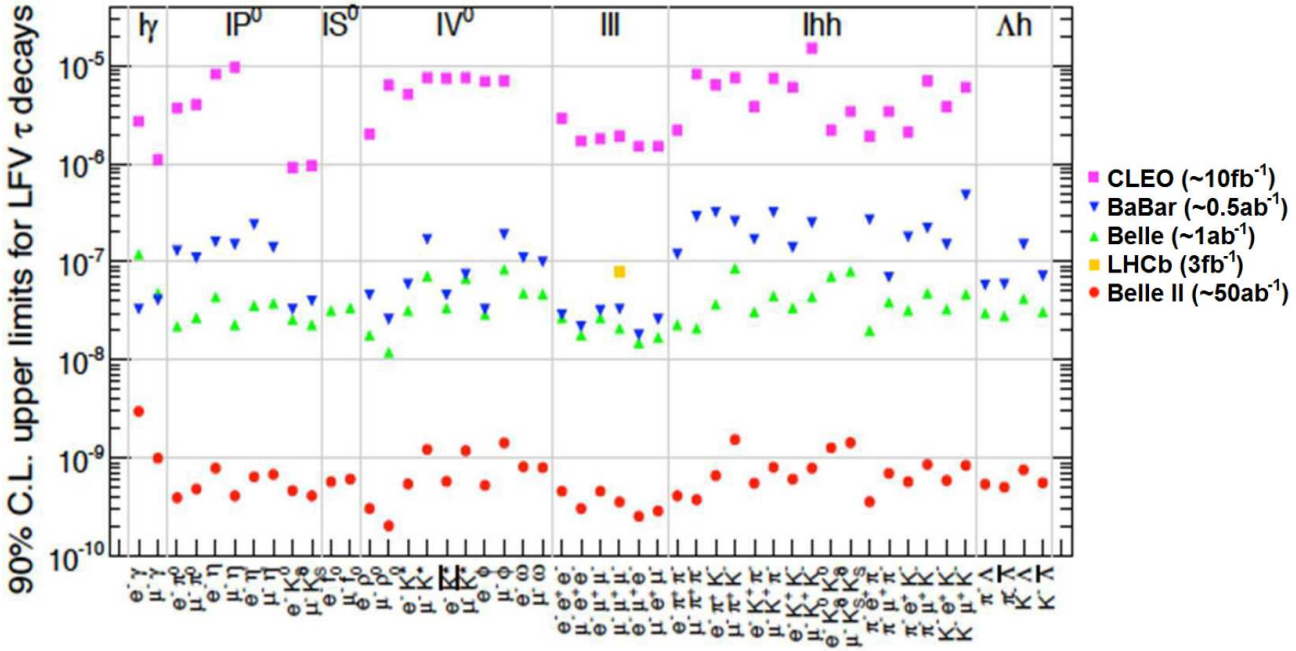
, September 25

LFU in $D(D_s)$ Decays at BESIII

	$D_s^+ \to \tau^+\nu_\tau / D_s^+ \to \mu^+\nu_\mu$	$D^+ \to \tau^+\nu_\tau / D^+ \to \mu^+\nu_\mu$
SM	9.74 ± 0.01	2.66 ± 0.01
BES3	10.19 ± 0.52	3.21 ± 0.64
	$D^0 \to K^-\mu^+\nu_\mu / D^0 \to K^-e^+\nu_e$	$D^+ \to \bar{K}^0\mu^+\nu_\mu / D^+ \to \bar{K}^0e^+\nu_e$
SM	0.975 ± 0.001	0.975 ± 0.001
BES3	0.978 ± 0.014	0.988 ± 0.033
	$D^0 \to \pi^-\mu^+\nu_\mu / D^0 \to \pi^-e^+\nu_e$	$D^+ \to \pi^0\mu^+\nu_\mu / D^+ \to \pi^0e^+\nu_e$
SM	0.985 ± 0.002	0.985 ± 0.002
BES3	0.905 ± 0.035	0.942 ± 0.946

Sifan Zhang, September 25

LFV Searches in τ-Lepton Decays



BelleII hopes to improve sensitivity to $\mathcal{O}(10^{-9})$ or $\mathcal{O}(10^{-10})$ (BG-free)

Will LHC be able to intervene?

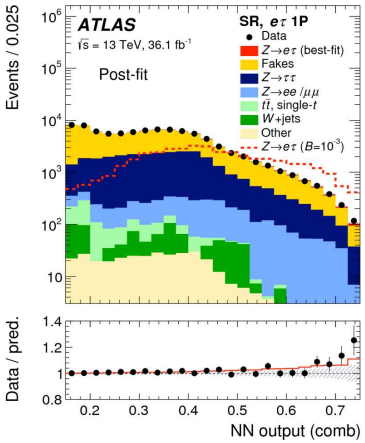
LFV Searches at ATLAS

Lepton Flavour Violation with ATLAS

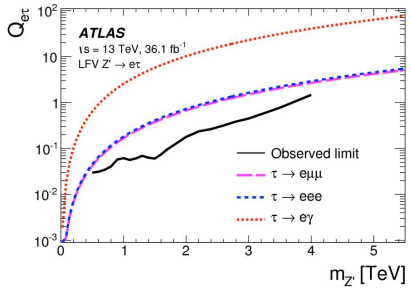
Brian Le

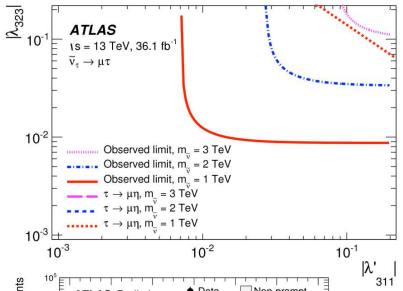
Z→μτ limit (1.3×10^{-5}) competitive with LEP

New Z→eτ result released (2.3σ excess)

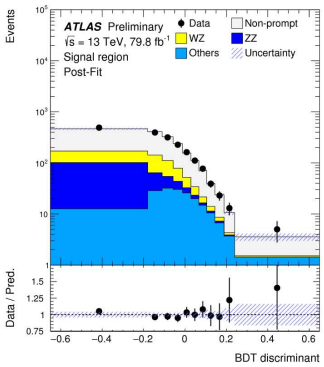


High mass search updated with 2015+2016 13 TeV dataset, better limits on Z' and RPV SUSY models



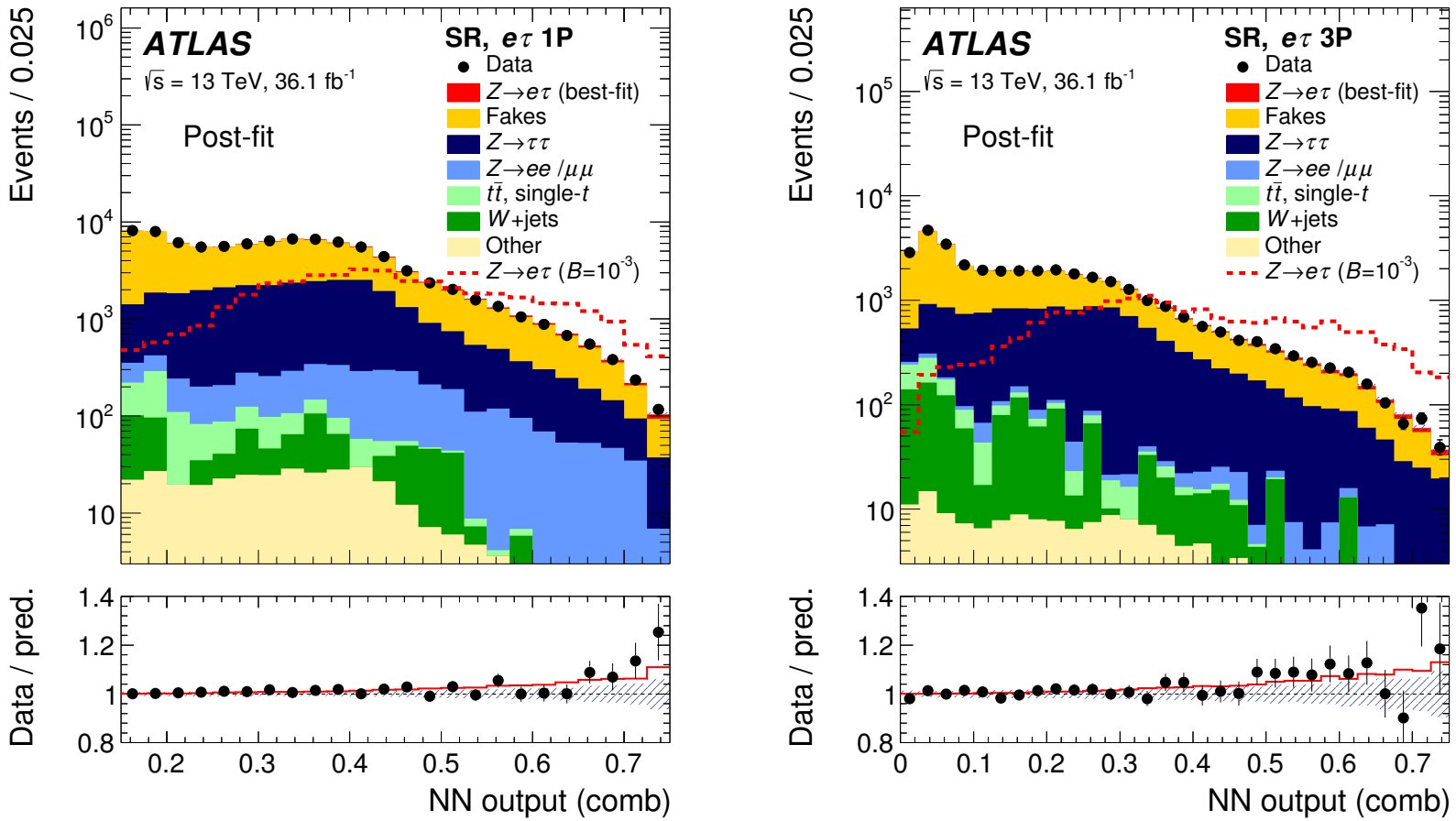


New search in top quark decays (right)



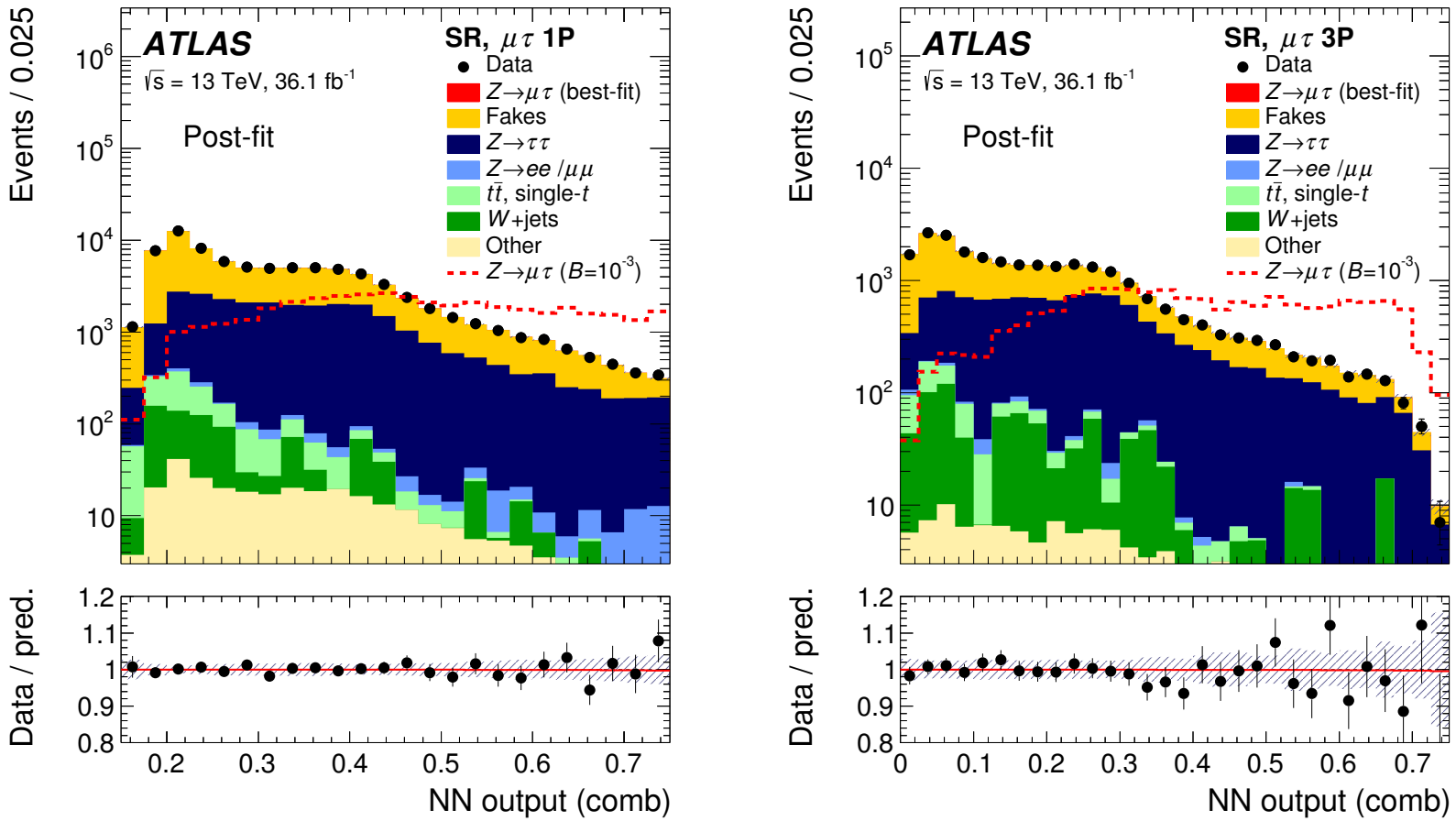
Search for H→lτ still in progress for 13 TeV

Search for LFV Z Decays at ATLAS



$\mathcal{B}(Z \to e^{\pm}\tau^{\mp}) < 5.8 \times 10^{-5}$ Brian Le

Search for LFV Z Decays at ATLAS

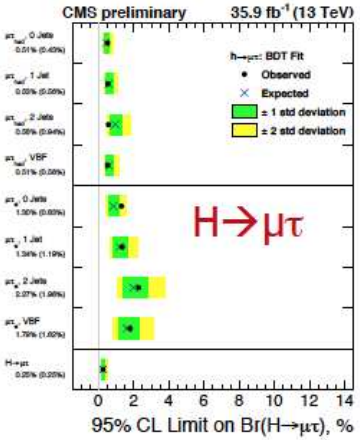


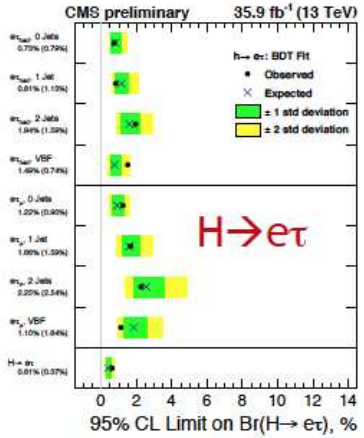
$\mathcal{B}(Z \to e^{\pm}\tau^{\mp}) < 2.4 \times 10^{-5}$, combined $< 1.3E-5$ Brian Le

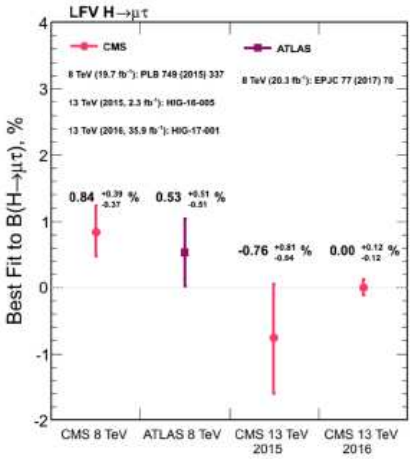
Search for LFV Higgs Decays at CMS

Results of H->μτ and H->eτ searches

The most stringent to date







- No excess of data
- Best fit branching ratio: 0.00±0.12%
- Br(H->μτ) < 0.25% @ 95% CL

- Slight excess of data (1.6σ)
- Best fit branching ratio: 0.30±0.18%
- Br(H->eτ) < 0.61% @ 95% CL

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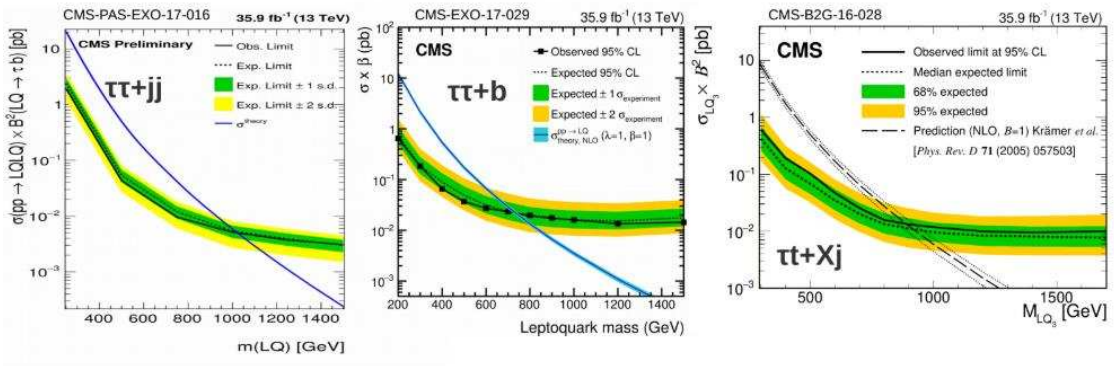
Jian Wang, September 25

Search for Leptoquarks at CMS

LQ results



- LQ with tau final states are of huge interest
- No deviation from the standard model seen for $M_{LQ} < 1020$GeV
- Strongest deviation in ττ+b ~500GeV within 1σ

16

K Padeken

Neutrino Studies – I

The # of talks shows that presently ν physics is experimentally driven,
a laboratory to study (not a search!) New Physics beyond the SM

- Are νs Majorana?
  L.Cardani (exp. overview), V. Cirigliano (theory overview)
- Absolute neutrino masses
  V. Hannen KATRIN expects first results soon
- Mass Ordering $(3 < - > 2)$
  P.Fernandez-Menendez (LBL Oscillation experiments),
  L.Cardani+V.Cirigliano $0\nu 2\beta$ decays, where experiments are close to probing the hierarchy of ν masses

Courtesy of Yu. Kudenko and V. Paolone

Neutrino Studies – II

- Do other (sterile) neutrino exist?
  I.Esteban (review), W.Tang (MicroBooNE), D.van Eijk, H.Seo A serious conflict between the appearance (LSND and MiniBooNe) and disappearance (Daya Bay, Minos+, IceCube) data,
  The reactor anomaly most likely explained by a smaller contribution to the neutrino flux from U-235 relative to the theoretical flux as found by Daya Bay and RENO

- CP violation in the lepton sector?
  I.Esteban (T2K, NOvA)
  Indications of non-zero $Delta_{CP}$ - T2K excludes CP conservation at 2σ level and prefers maximal CP violation

Neutrino Studies – III

- ν oscillation experiments presented (PMNS mixing matrix elements)
  P.Fernandez-Menendez (T2K, NOvA, MINOS(+)), H.Seo (Reactor experiments, G.Galati (OPERA)
- New window to the workings of the universe: Neutrinos in Multi-Messenger Astronomy and stellar processes
  D.van Eijk (IceCube), P.Bocan (Solar Neutrinos)

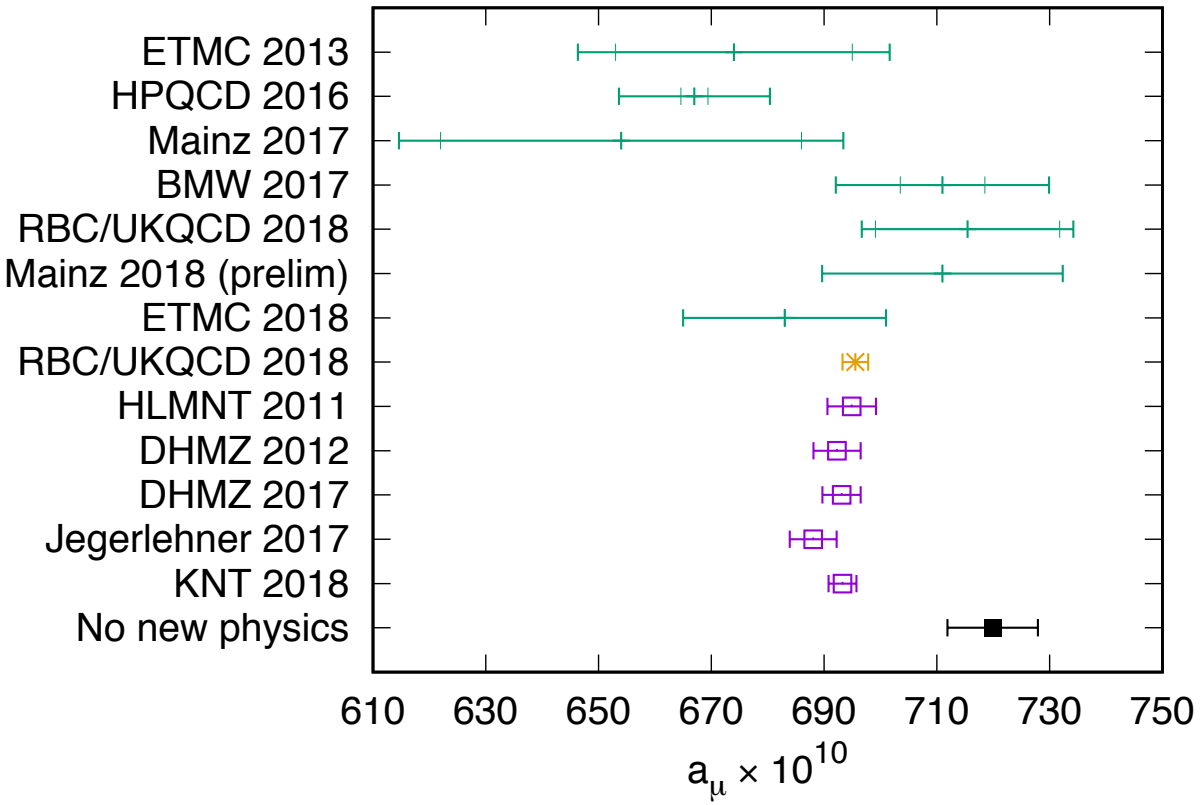
- Tau neutrino interactions
  D.van Eijk IceCube - "double bang" events, G.Galati OPERA - from appearance LBL oscillations
- With improved analysis techniques ν_τ appearance is confirmed at $\sim 6\sigma$ by OPERA

Muon $g-2$ – I

Theory Predictions

- Introduction
  Bill Marciano $a_\mu^{\rm exp} - a_\mu^{\rm th} = 3.7\sigma$, $a_e^{\rm exp} - a_e^{\rm th} = -2.2\sigma$
- HVP from the lattice
  Christoph Lehner
- HLbL from the Lattice
  Harvey Meyer

Muon $g-2$ – II


ETMC 2013
HPQCD 2016
Mainz 2017
BMW 2017
RBC/UKQCD 2018
Mainz 2018 (prelim)
ETMC 2018
RBC/UKQCD 2018
HLMNT 2011
DHMZ 2012
DHMZ 2017
Jegerlehner 2017
KNT 2018
No new physics
610
630
650
670
690
710
730
750
$a_\mu \times 10^{10}$

Muon $g-2$ – III

- At the 2018 Lattice conference, RBC-UKQCD has presented a preliminary lattice result : $a_\mu^{\rm hlbl} = (119 \pm 53) \cdot 10^{-11}$. This updates the published result of T. Blum et al, PRL118 (2017) no.2, 022005.
- Expect also first results from Mainz in the next six months.
- Mainz delivered a calculation of the pi^0 transition form factor. in the dispersive framework $a_\mu^{{\rm hlbl},\pi^0} = (60.43.6) \cdot 10^{-11}$. (presented at Mainz g-2 theory workshop). This compares well with the recent dispersive result $a_\mu^{\pi^0} = 62.6^{+3.0}_{-2.5} \cdot 10^{-11}$ by Kubis et al. PRL121, 112002 (2018).

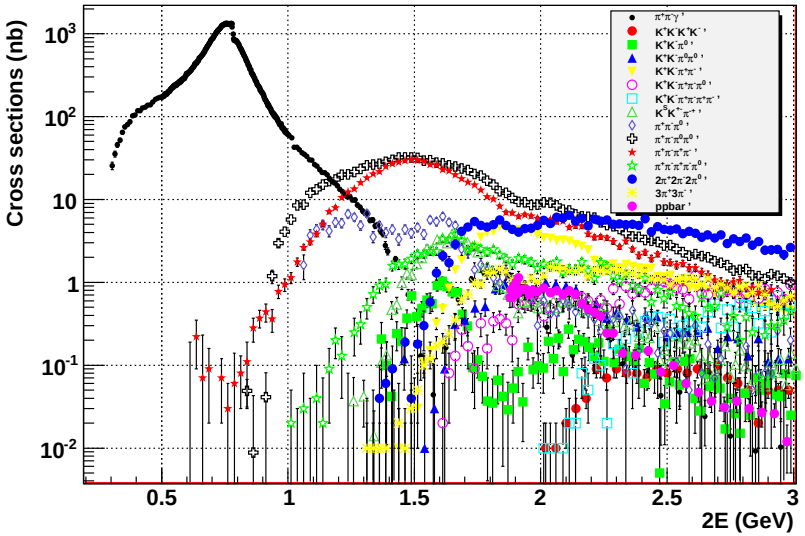
Muon $g-2$ – IV

Measurements

- Historical Overview
  From the first measurements and theory to BNL
  Lee Roberts
- E989 at Fermilab
  Running, publication in 2019 with the BNL accuracy, in a few years x4 better accuracy
  Anna Driutti
- E34 at J-PARC
  New low energy way, the same x4 better accuracy, R&D
  Tsutomu Mibe
- MUSEUM at J-PARC
  From HFS in muonium Koichiro Shimomura

Experimental input to HVP

Experimental input to HVP

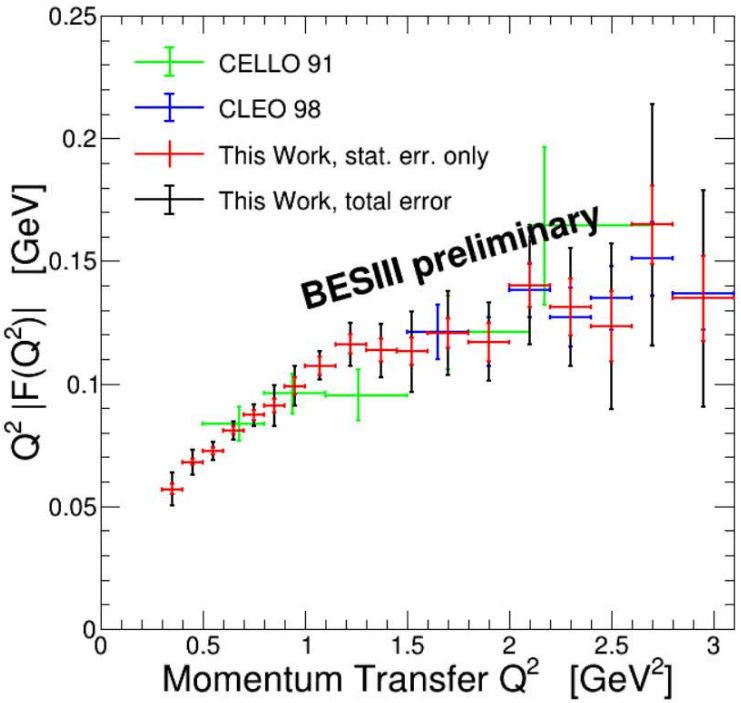


Great progress in the scan method at VEPP-2000 in Novosibirsk, $0.32 < \sqrt{s} < 2$ GeV, $\mathcal{L} = 3 \times 10^{31}\text{cm}^{-2}\text{s}^{-1}$

Boris Shwartz

Muon $g-2$ – VI

TFF, $\mathcal{F}_{\gamma^*\gamma^*}(q_1^2, q_2^2)$, in the new data-driven dispersive methos based on $\gamma\gamma$ data



BESIII will measure TFF for η and η'

Y. Guo

BaBar has just announced double-tag study of the η'

α_s Determination

- From the lattice calculations
  $\alpha_s(M_Z^2) = 0.1185(8)(9)$, PDG 0.1174(16) Stefan Sint
- From τ decays and QCD
  Toni Pich
- From $e^+e^- \to$ hadrons and QCD
  Maartin Golterman
- Strong dispute around Duality Violation
  Diego Boito

Muon Experiments

- General features of LFV searches, Y. Kuno
- Mu3e, Search for $\mu^+ \to e^+e^+e^-$ at PSI, A. Bravar
- Mu2e at Fermilab, R. Bonventre
- COMET at J-PARC, N. Teshima
- $mu \to e\gamma$II at PSI, T. Iwamoto

New facilities – I

- τ Physics at High Lumi LHC E. Passemar
- τ Physics at CEPC/ILC M. Ruan
- τ Physics at FCC M. Dam
- GRAND Ch. Timmermans
- Status of DUNE A. Tonazzo
- SHIP K. Bondarenko

New facilities – II

- HIEPA G. Huang $2 < \sqrt{s} < 7$ GeV, $\mathcal{L} = 10^{35}\text{cm}^{-2}\text{s}^{-1}$
- Novosibirsk Super-$c-\tau$ Factory P. Piminov $2 < \sqrt{s} < 6$ GeV, $\mathcal{L} = 10^{35}\text{cm}^{-2}\text{s}^{-1}$,
  Longitudinal polarization of e^-

Conclusions

- Properties of τ are known very well
- Next breakthrough expected at the BelleII and Super-$c-\tau$
- τ leptons became a powerful tool at LHC
- No significant LFV anomalies
- A lot of new facilities to study leptons