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BLOOMINGTON

Jefferson Lab

CEPC Tau Working Group: Status Report

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E. Stamou (Chicago University)

Outline :

1. Introduction and Motivation:
2. Lepton Universality tests
3. Lepton Flavour Violation
4. CP violation in tau decays
5. Conclusion and outlook

1. Introduction and Motivation

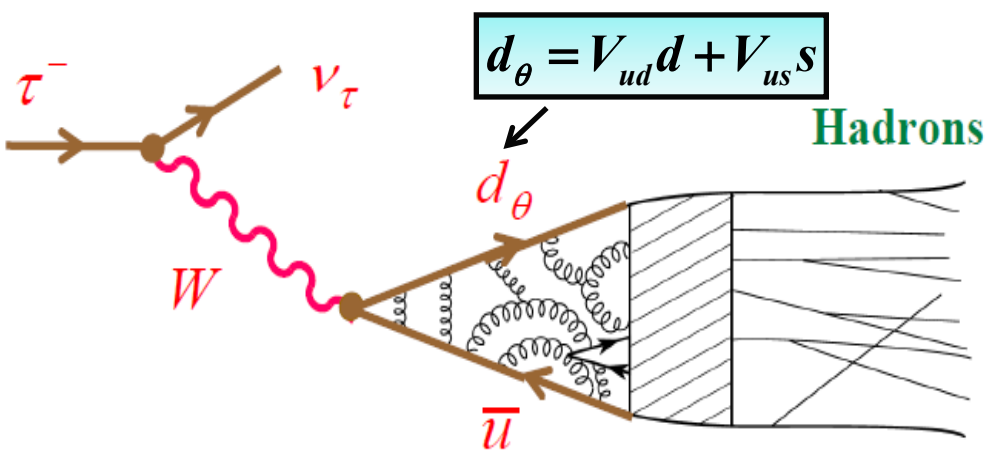
1.1 τ-decays

- τ lepton discovered in 1976 by M. Perl et al. (SLAC-LBL group)

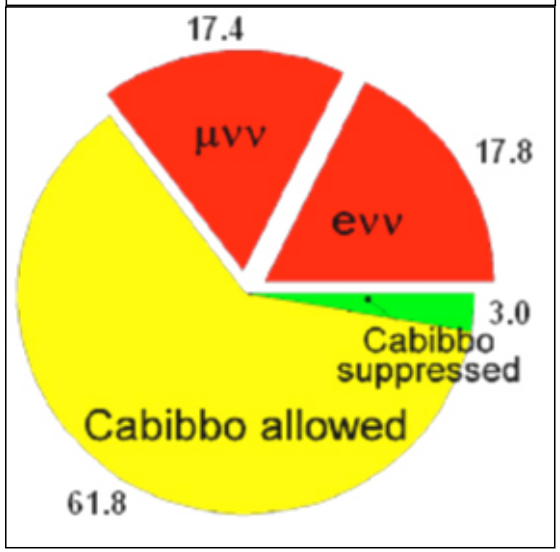
PDG'16

  - Mass : $m_\tau = 1.77682(16)\ \text{GeV}$
  - Lifetime : $\tau_\tau = 2.096(10)\cdot 10^{-13}\ s$

- The only lepton heavy enough to decay into hadrons : lots of semileptonic decays !



Including QED & QCD corrections:



1.1 τ-decays

- τ lepton discovered in 1976 by M. Perl et al. at SLAC-LBL *PDG'14*
  - Mass : $m_\tau = 1.77682(16)\ \mathrm{GeV}$
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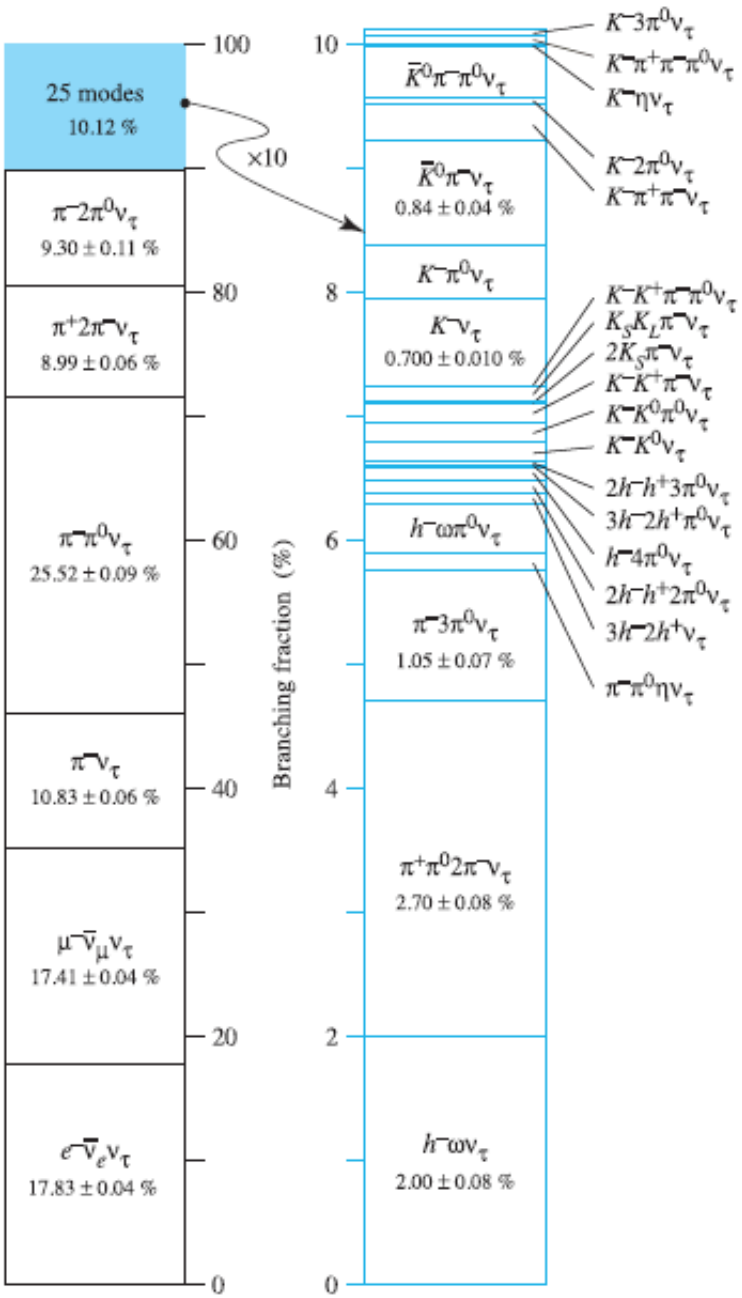
- The only lepton heavy enough to decay into hadrons : lots of semileptonic decays !

  ➡ Very rich phenomenology

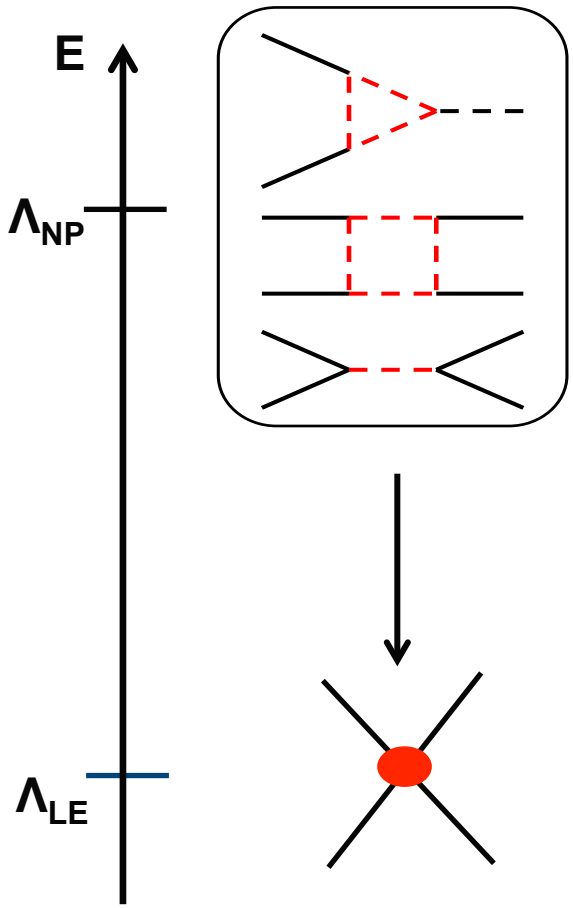
  Test of QCD and EW interactions

- For the tests:
  - Precise measurements needed
  - Hadronic uncertainties under control

PDG'14



1.2 τ lepton as a unique probe of new physics



- In the quest of New Physics, can be sensitive to very high scale:
  - Kaon physics: $[\varepsilon_K]$ $\frac{s\bar{d}s\bar{d}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^5$ TeV
  - Tau Leptons: $[\tau \to \mu\gamma]$ $\frac{\tau\bar{\mu} f\bar{f}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^2$ TeV
- At low energy: lots of experiments e.g., *BaBar*, *Belle*, *BESIII, LHCb* ⇨ important improvements on measurements and bounds obtained and more expected (*Belle II, CEPC, FCCe*)
- In many cases no SM background: e.g., LFV, EDMs
- For some modes accurate calculations of hadronic uncertainties essential, e.g. CPV in hadronic Tau decays

⇨ Tau leptons very important to look for *New Physics*!

1.2 τ lepton as a unique probe of new physics

- A lot of progress in tau physics since its discovery on all the items described before ➡ important experimental efforts from *LEP*, *CLEO, B factories: Babar, Belle, BES, VEPP-2M, LHCb, neutrino experiments*,…

  ➡ More to come from *LHCb, BES, VEPP-2M, Belle II, CMS, ATLAS, FCC-ee, CEPC*

- Much better efficiency at CEPC than Belle II similar when comparing LEP with B factories

  ➡ *CEPC* wonderful for τ physics

- But τ physics has still potential "*unexplored frontiers*"

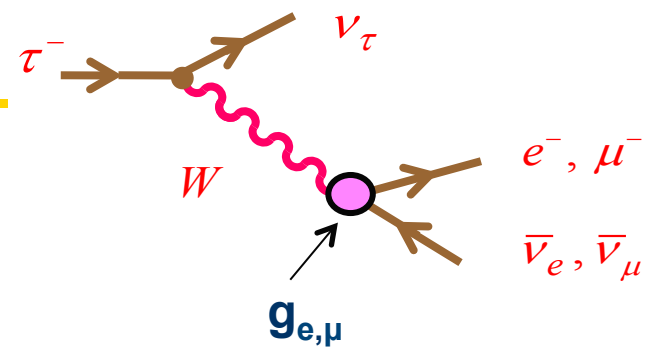
  ➡ deserve future exp. & th. efforts

- In the following, some selected examples

Experiment	Number of τ pairs
LEP	~3×10^{5}
CLEO	~1×10^{7}
BaBar	~5×10^{8}
Belle	~9×10^{8}
Belle II	~10^{12}
CEPC/ FCC-ee	~1.7×10^{11}

2. Lepton Universality

2.1 Introduction



- The leptonic decay width:

$$\Gamma(\tau \to \nu_\tau\, l\, \bar{\nu}_l) = \frac{G_F^2\, m_\tau^5}{192\,\pi^3}\, f(m_l^2/m_\tau^2)\,\left(1+\delta_{\rm RC}\right)$$

Experimental inputs:

$\Gamma(\tau_{l3})$ Rates with well-determined treatment of radiative decays
- Branching ratios
- Tau lifetimes

Inputs from theory: *Marciano'88*

δ_{RC} Radiative corrections

M. Dam@Tau'18

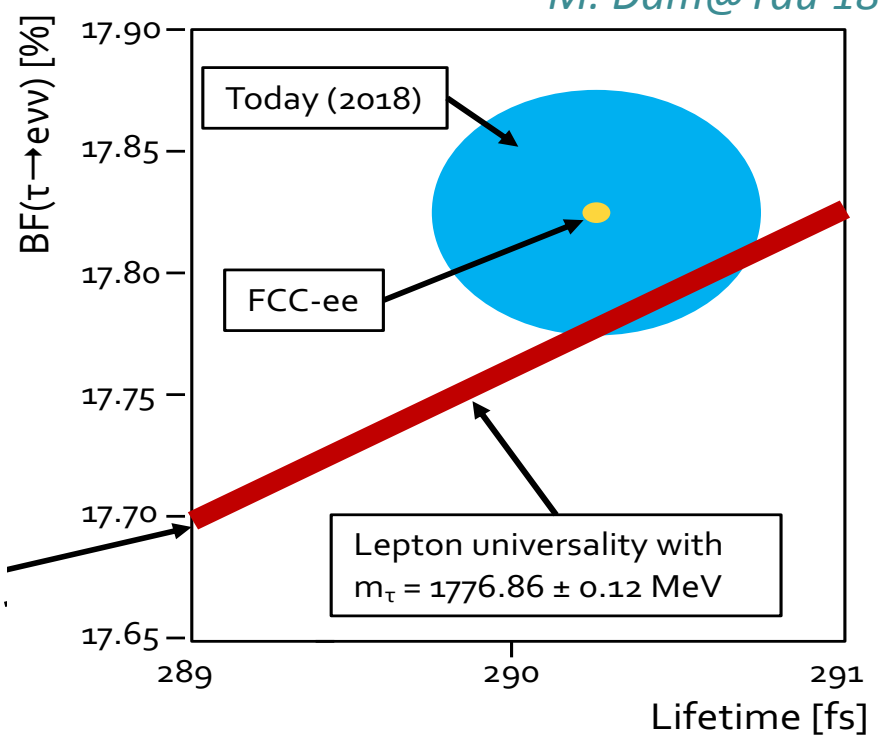
- Test of μ/e universality:

$$\left(B_\mu/B_e\right)_{\rm exp} = 0.9761 \pm 0.0028$$

Non-BF: 0.9725 ± 0.0039

BaBar '10: 0.9796 ± 0.0039

$$\left(\frac{g_\tau}{g_\mu}\right)^2 \simeq \frac{\tau_\mu}{\tau_\tau}\mathrm{BF}(\tau^- \to e^-\bar{\nu}_e\nu_\tau)\left(\frac{m_\mu}{m_\tau}\right)^5$$



2.2 FCC-ee prospects (similar results expected for CEPC)

Tau Leptonic Branching Fractions

M. Dam@Tau'18

- **World average**
  - **$B(\tau \to e\nu\nu) = 17.82 \pm 0.05$ %** ; **$B(\tau \to \mu\nu\nu) = 17.39 \pm 0.05$ %**
- Dominated by ALEPH
  - **$B(\tau \to e\nu\nu) = 17.837 \pm 0.072_{stat} \pm 0.036_{syst}$ %** ; **$B(\tau \to \mu\nu\nu) = 17.319 \pm 0.070_{stat} \pm 0.032_{syst}$ %**
- Three uncertainty contributions were dominant in the Aleph measurement
  - Selection efficiency: 0.021 / 0.020 %
  - Non-$\tau^+\tau^-$ background: 0.029 / 0.020 %
  - Particle ID: 0019 / 0.021 %
  - All of these are limited by statistics: size of test samples, etc.
- Prospects at FCC-ee
  - Enormous statistics:

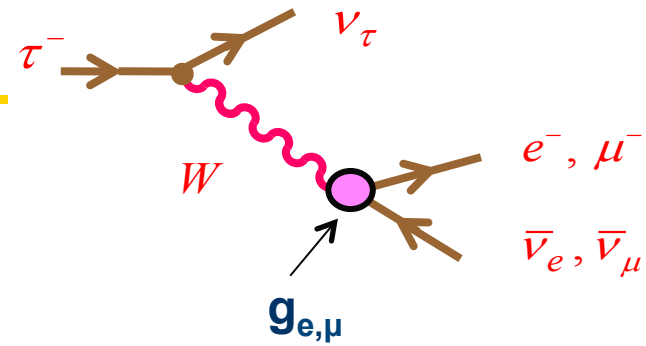
$$\delta_{stat} = 0.0001 \ \%$$

  - Systematic uncertainty is hard to (gu)estimate at this point.
    - Depends intimately on the detailed performance of the detector(s)
      - At the end of the day, between LEP experiments, δ_{syst} varied by up to a factor 3
        - Lesson: Design your detector with care!

Let me put here as *a* *<u>placeholder</u>* a suggested factor 10 improvement wrt ALEPH:

$$\delta_{syst} = 0.003 \ \%$$

2.2 Prospects for CEPC

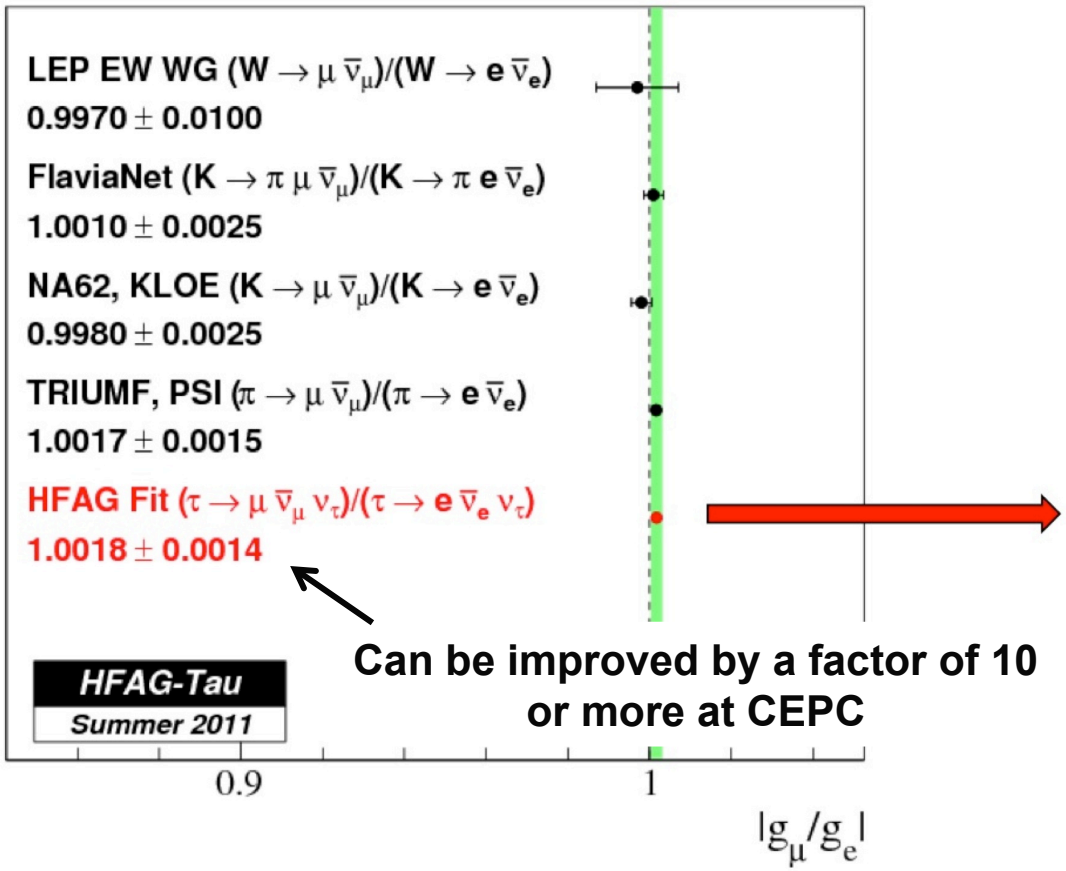


- Summary of the studies at FCC-ee (similar results expected for CEPC)

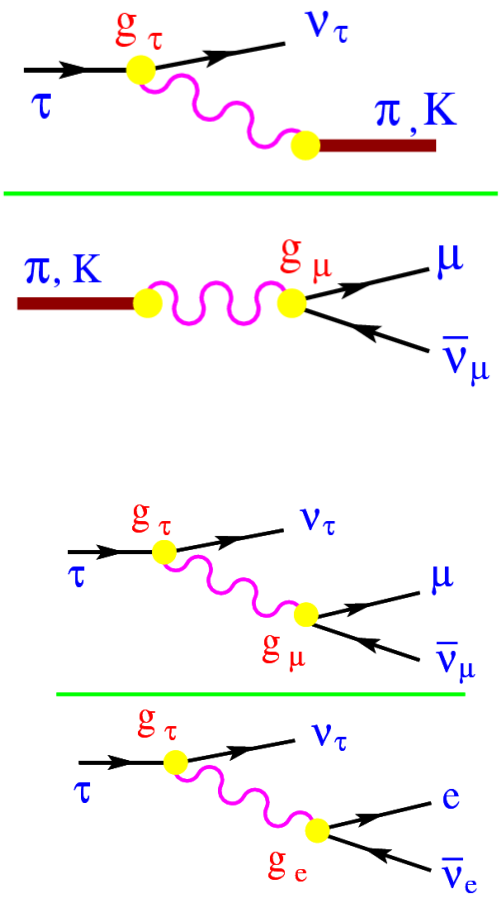
M. Dam@Tau'18

Observable	Measurement	Current precision	FCC-ee **stat.**	**Possible syst.**	Challenge
m_τ [MeV]	Threshold / inv. mass endpoint	1776.86 **± 0.12**	**0.005**	**0.12**	Mass scale
τ_τ [fs]	Flight distance	290.3 **± 0.5 fs**	**0.005**	**< 0.040**	Vertex detector alignment
B(τ→eνν) [%]	Selection of $\tau^+\tau^-$, identification of final state	17.82 **± 0.05**	**0.0001**	**No estimate; possibly 0.003**	Efficiency, bkg, Particle ID
B(τ→μνν) [%]		17.39 **± 0.05**			

2.3 Lepton Universality μ/e

- 

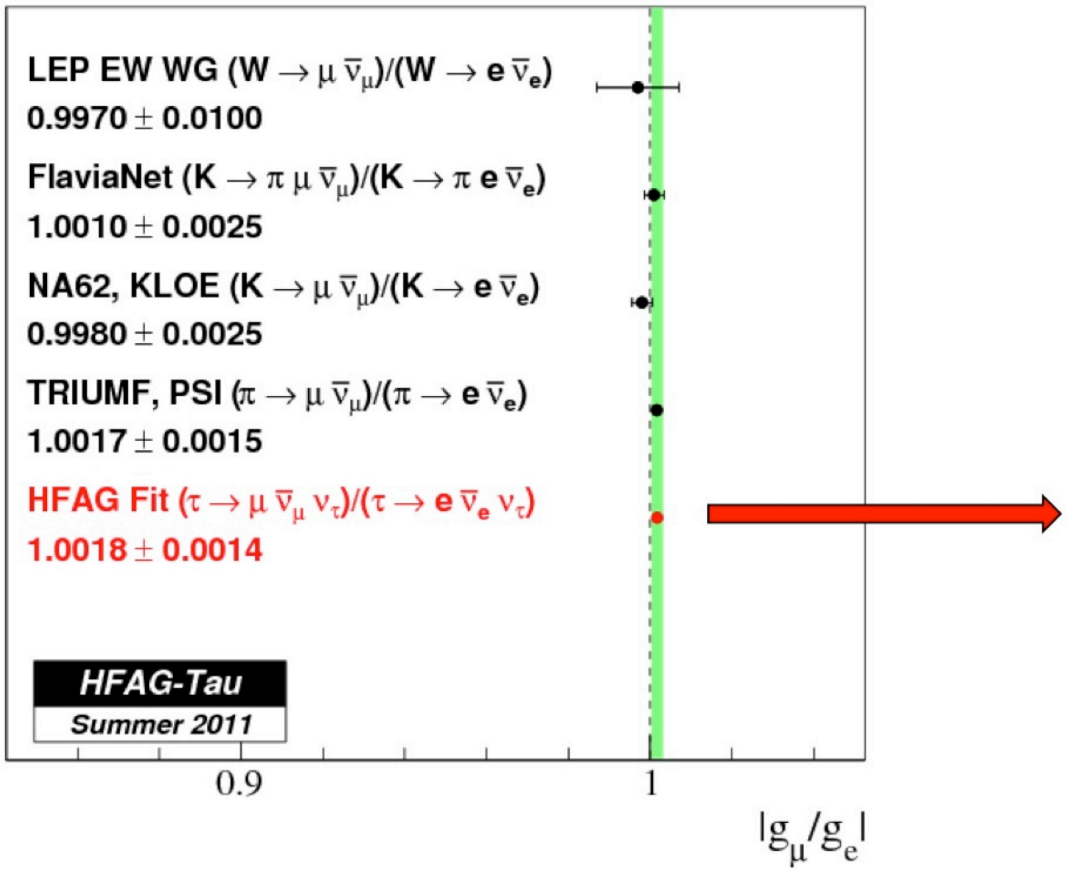
Can be improved by a factor of 10 or more at CEPC

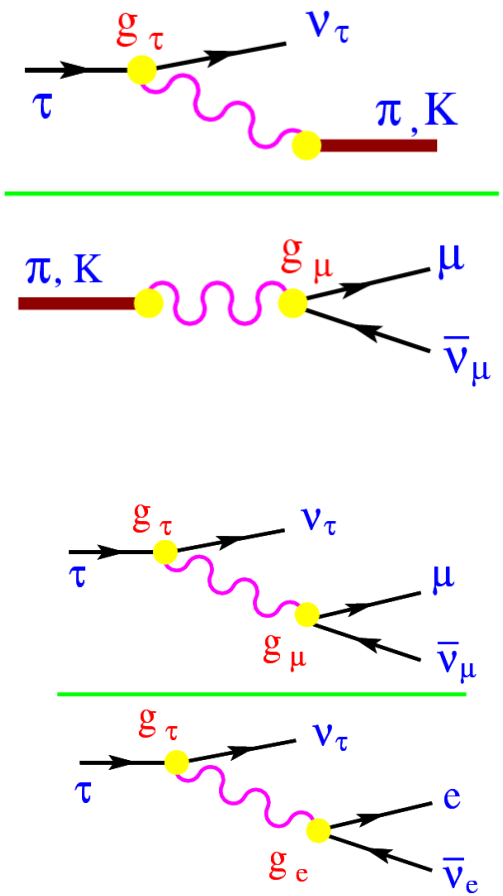


- Tested at *0.14%* from Tau leptonic Brs! (0.28% in Z decays)
- Can be improved by a factor of 10 or more at CEPC

2.3 Lepton Universality μ/e

- Test of μ/e universality:

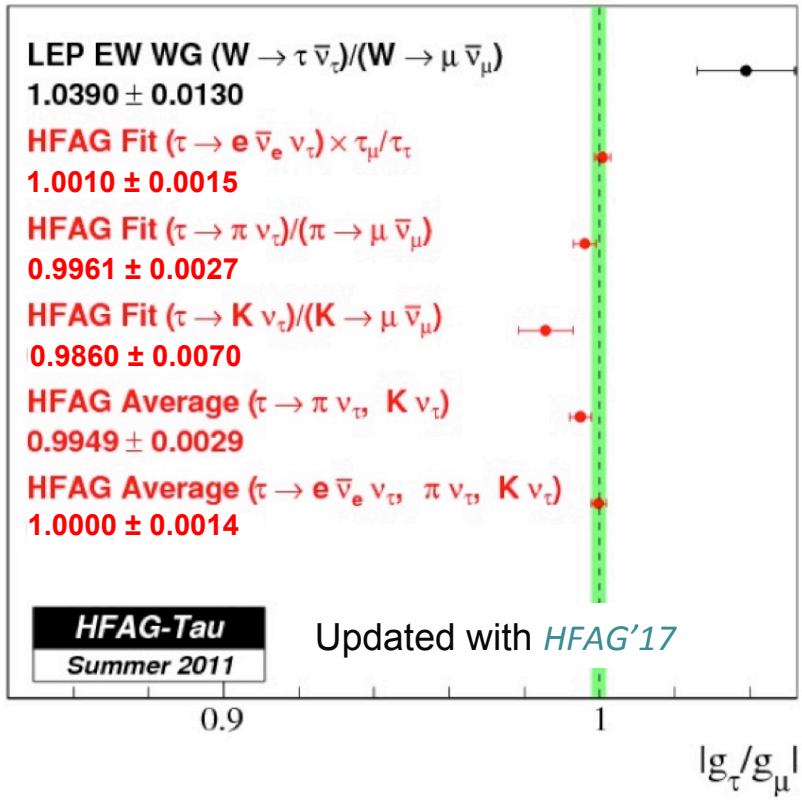


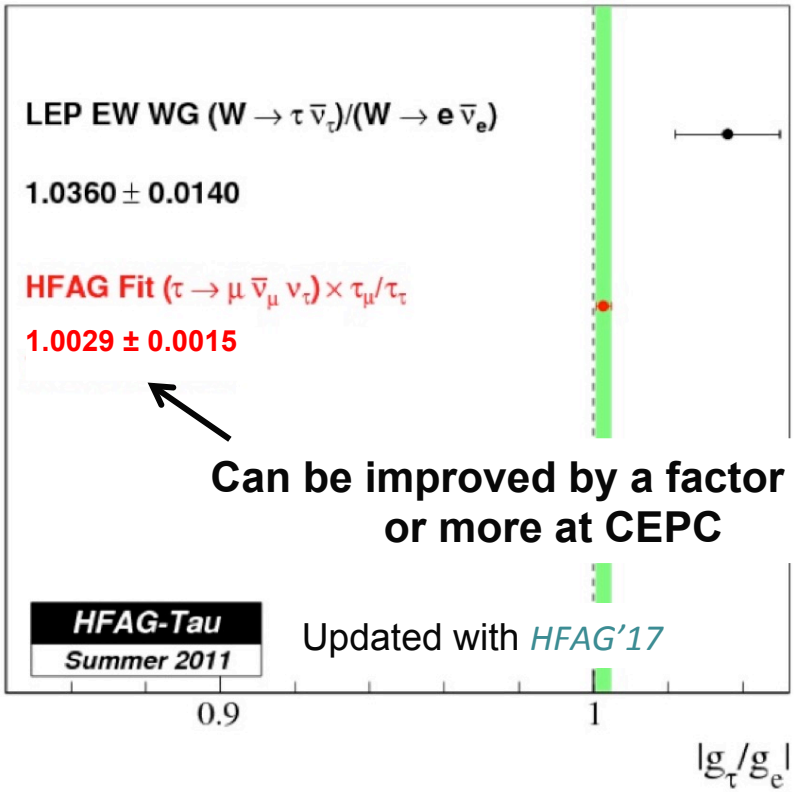


- Tested at *0.14%* from Tau leptonic Brs! (0.28% in Z decays)
- What about the *third family*?

2.4 Lepton Universality τ/μ

- What about the *third family*?





Can be improved by a factor of 10 or more at CEPC

- Universality tested at 0.15% level and good agreement except for
  - W decay old anomaly
  - B decays ⇨ *See talks in this morning Flavour session*

3. Charged Lepton-Flavour Violation

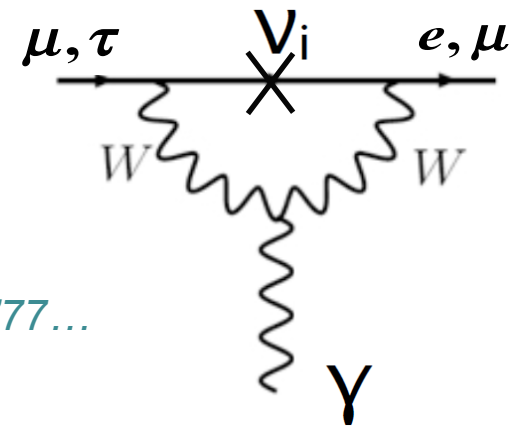
3.1 Introduction and Motivation

- Lepton Flavour Number is an « accidental » symmetry of the SM (m_ν=0)

- In the *SM* with massive neutrinos effective CLFV vertices are tiny due to GIM suppression ⇨ *unobservably small rates!*

E.g.: $\mu \to e\gamma$

$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$



Petcov'77, Marciano & Sanda'77, Lee & Shrock'77…

$$\left[Br(\tau \to \mu\gamma) < 10^{-40}\right]$$

- Extremely *clean probe of beyond SM physics*

- In New Physics models: seazible effects
  Comparison in muonic and tauonic channels of branching ratios, conversion rates and spectra is model-diagnostic

3.1 Introduction and Motivation

- In New Physics scenarios CLFV can reach observable levels in several channels

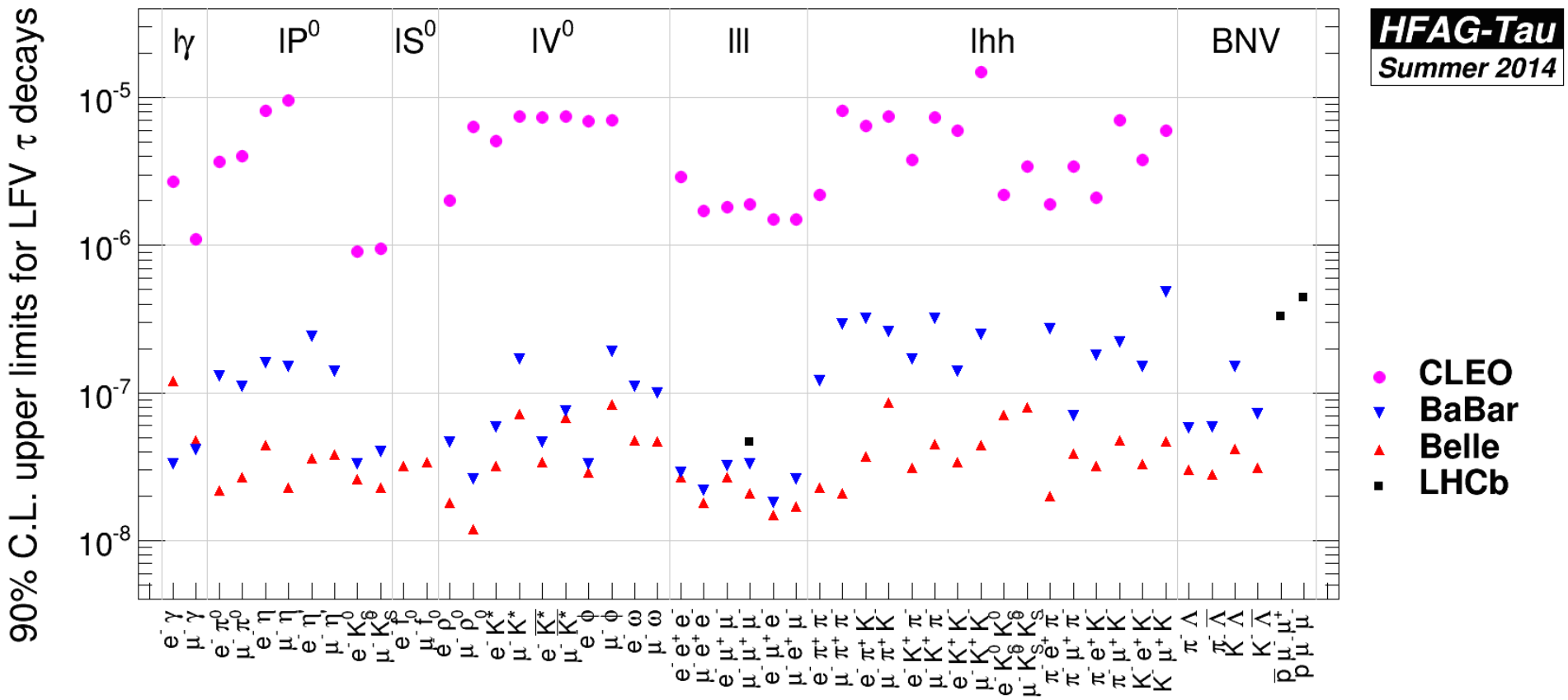
Talk by D. Hitlin @ CLFV2013

		$\tau \to \mu\gamma$	$\tau \to \ell\ell\ell$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	Undetectable	
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

- But the sensitivity of particular modes to CLFV couplings is model dependent
- Comparison in muonic and tauonic channels of branching ratios, conversion rates and spectra is model-diagnostic

3.2 CLFV processes: tau decays

- Several processes: $\tau \to \ell\gamma$, $\tau \to \ell_\alpha \bar{\ell}_\beta \ell_\beta$, $\tau \to \ell Y$ ← P, S, V, $P\bar{P}$,...



- 48 LFV modes studied at Belle and BaBar

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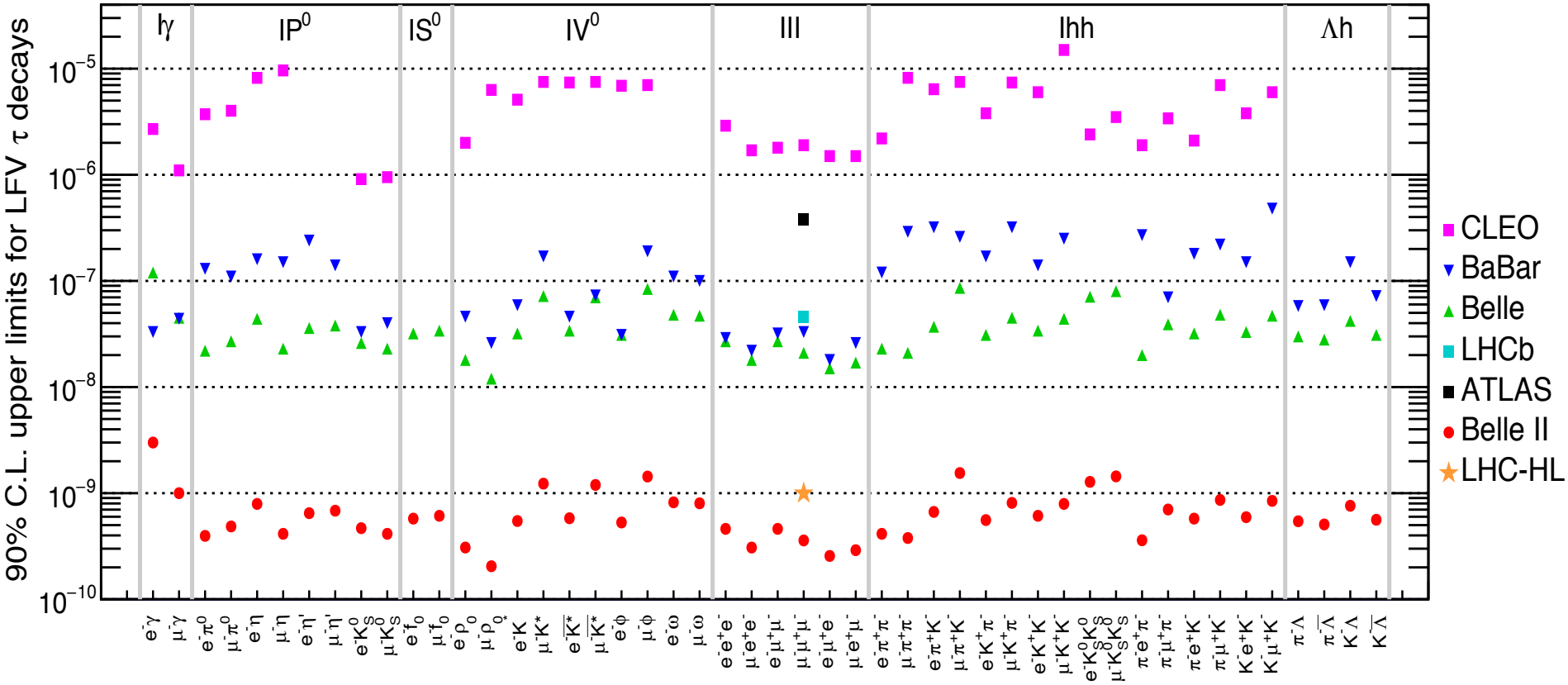
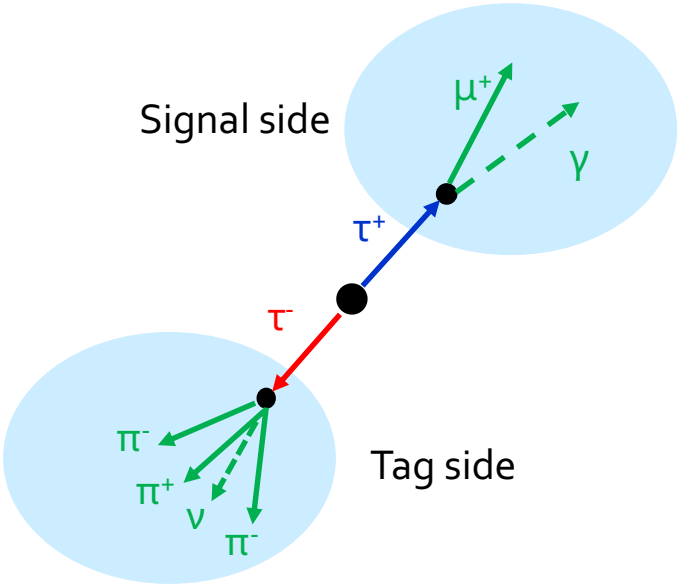
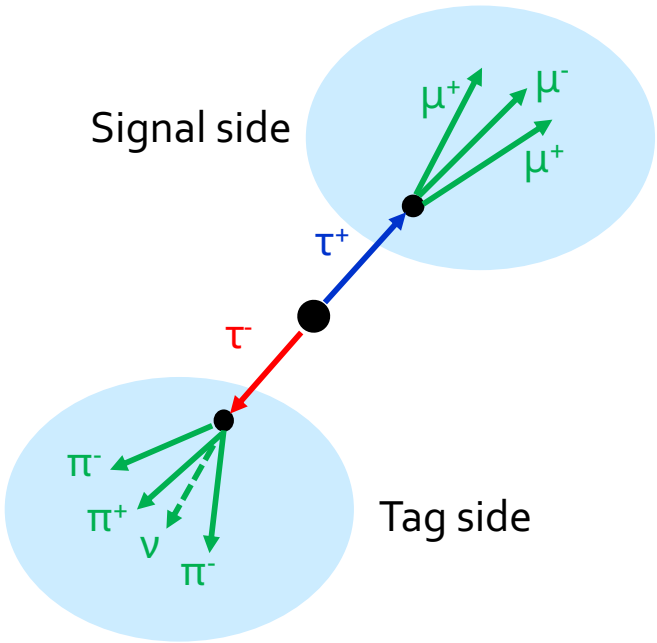


- Expected sensitivity 10^{-9} or better at *LHCb, Belle II, HL-LHC, CEPC?*

3.3 Prospects for radiative and leptonic tau LFV





- Bounds on $\tau \longrightarrow 3\mu$ can be rescaled compared to LEP experiments, no background (is it really the case?)

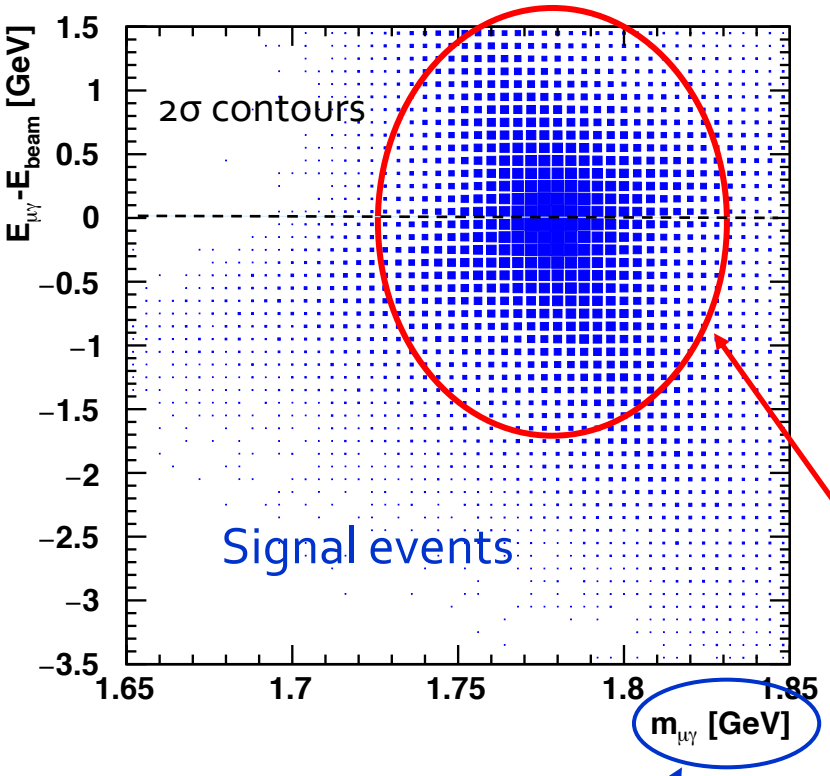
  ➡ Br ≤ 10^{-10} *M. Dam@Tau'18*

- For $\tau \rightarrow \mu\gamma$ situation needs to be studied because of the background mainly radiative events (IRS+FSR) $e^+e^- \rightarrow \tau\tau\,\gamma$ *M. Dam@Tau'18*

  ➡ Br ≤ 2×10^{-9} based on 1.7×10^{11} $\tau^+\tau^-$ events at FCC-ee,

3.3 Prospects for radiative and leptonic tau LFV

- Generate **signal events** with pythia8: $e^+e^- \rightarrow Z \rightarrow \tau^+\tau^-(\gamma)$, with $\tau^- \rightarrow \mu^-\gamma$



Smear with assumed FCC-ee detector resolutions:

- Muon momentum [GeV]

  $\sigma(p_T)/p_T = 2\times10^{-5} \times p_T \oplus 1\times10^{-3}$
- Photon ECAL energy [GeV]

  $\sigma(E)/E = 0.165/\sqrt{E} \oplus 0.010/E \oplus 0.011$
- Photon ECAL spatial

  $\sigma(x) = \sigma(y) = (6/E \oplus 2)$ mm

From this, determine **FCC-ee** effective detector resolution for $\tau \rightarrow \mu\gamma$

$\sigma(m_{\gamma\mu}) = 26$ MeV; $\sigma(E_{\gamma\mu}) = 850$ MeV

In order to de-correlate the E and m variables, this mass, $m_{\gamma\mu}$, is in fact the measured mass scaled by measured energy over beam energy:

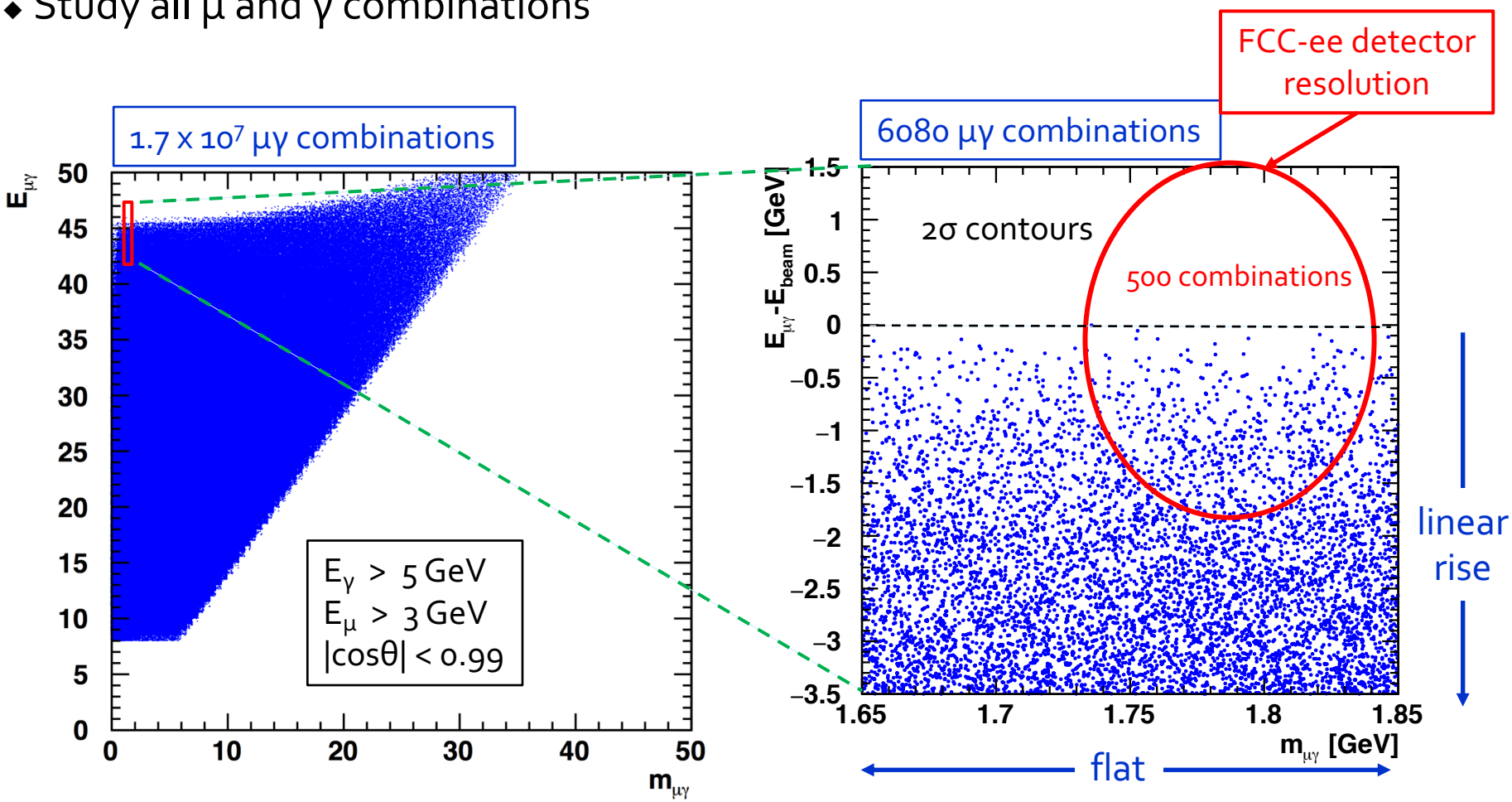
$$m_{\gamma\mu} = m_{raw} \times (E_{\gamma\mu}/E_{beam})$$

Study for FCC-ee by M. Dam@Tau'18

3.3 Prospects for radiative and leptonic tau LFV

- Background: Generate 5 x 10^8 events $e^+e^- \rightarrow Z \rightarrow \tau^+\tau^-(\gamma) \rightarrow (\mu^+\nu\nu)(\mu^-\nu\nu)(\gamma)$
  - 1 x 10^9 $\tau \rightarrow \mu\nu\nu$ decays corresponding to
    - 5.7 x 10^9 τ decays from 8.4 x 10^{10} Z decays
- Study all μ and γ combinations

Study for FCC-ee by M. Dam@Tau'18



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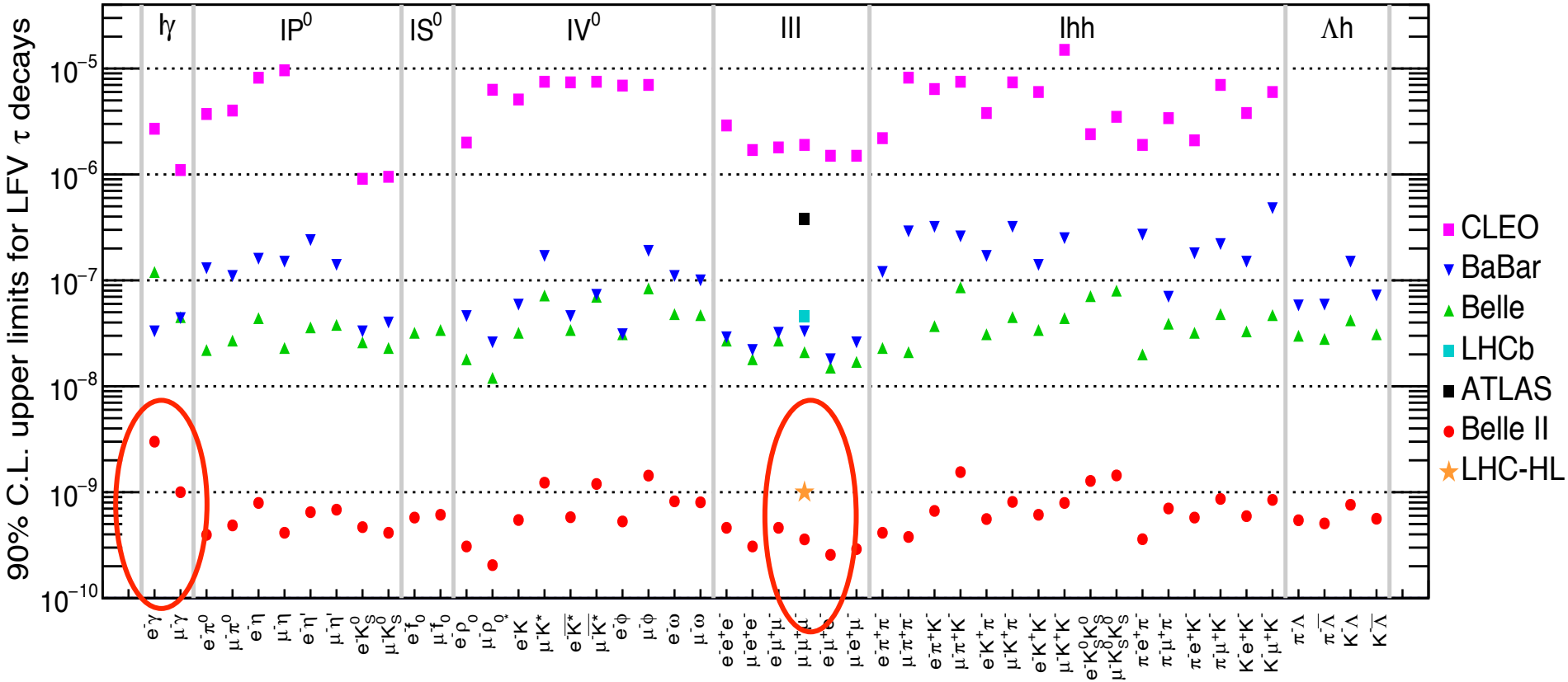


- Similar sensitivity for CEPC and FCC-ee as Belle II for $\tau \to \mu\gamma$:

  $Br(\tau \to \mu\gamma) \sim 2 \times 10^{-9}$, better for $\tau \to 3\mu$: $Br(\tau \to 3\mu) \sim 10^{-10}$

3.4 Model discriminating power of Tau processes

Celis, Cirigliano, E.P.'14

- Summary table:

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$O^{4\ell}_{S,V}$	✓	–	–	–	–	–
O_D	✓	✓	✓	✓	–	–
O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
O_{GG}	–	–	✓	✓	–	–
O^q_A	–	–	–	–	✓ (I=1)	✓ (I=0)
O^q_P	–	–	–	–	✓ (I=1)	✓ (I=0)
$O_{G\tilde{G}}$	–	–	–	–	–	✓

- In addition to leptonic and radiative decays, *hadronic decays* are very important ⇨ sensitive to large number of operators!

- BSM scenarios explaining B anomalies predict sizeable $\tau \to \mu\phi$

Effective Field Theory approach

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda} O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \ldots$$

See e.g.
Black, Han, He, Sher'02
Brignole & Rossi'04
Dassinger et al.'07
Matsuzaki & Sanda'08
Giffels et al.'08
Crivellin, Najjari, Rosiek'13
Petrov & Zhuridov'14
Cirigliano, Celis, E.P.'14

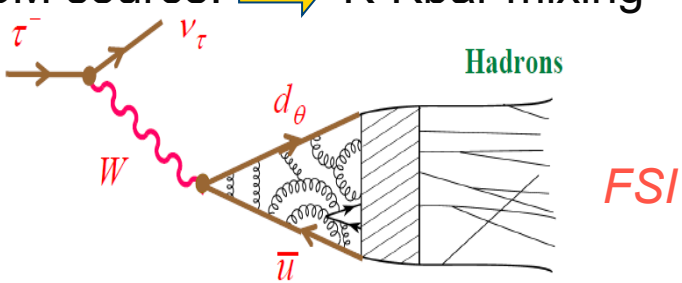
- Build all D>5 LFV operators:
  - Dipole: $\mathcal{L}_{eff}^{D} \supset -\frac{C_D}{\Lambda^2} m_\tau \bar{\mu} \sigma^{\mu\nu} P_{L,R} \tau F_{\mu\nu}$
  - Lepton-quark (Scalar, Pseudo-scalar, Vector, Axial-vector): $\mathcal{L}_{eff}^{S} \supset -\frac{C_{S,V}}{\Lambda^2} m_\tau m_q G_F \bar{\mu}\, \Gamma P_{L,R} \tau\, \bar{q} \Gamma q$
  - Lepton-gluon (Scalar, Pseudo-scalar): $\mathcal{L}_{eff}^{G} \supset -\frac{C_G}{\Lambda^2} m_\tau G_F \bar{\mu} P_{L,R} \tau\, G_{\mu\nu}^a G_a^{\mu\nu}$
  - 4 leptons (Scalar, Pseudo-scalar, Vector, Axial-vector): $\mathcal{L}_{eff}^{4\ell} \supset -\frac{C_{S,V}^{4\ell}}{\Lambda^2} \bar{\mu}\, \Gamma P_{L,R} \tau\, \bar{\mu}\, \Gamma P_{L,R} \mu$
- Each UV model generates a *specific pattern* of them

$\Gamma \equiv 1, \gamma^\mu$

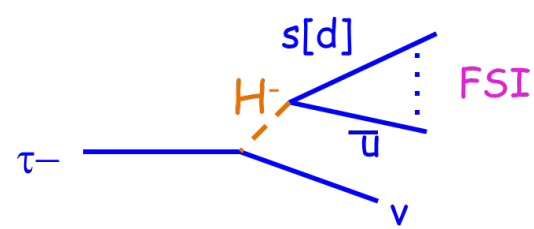
4. LFC processes: CPV in tau decays

4.1 Introduction

- CP violation measured in K and B decays ⇨ in agreement with SM
- Not enough CP violation to explain asymmetry matter/anti-matter
- Look elsewhere:
  - Neutrinos
  - Charged leptons
  - Electric dipole moments
- Aim: pin down new sources of CPV in the lepton sector and discriminating between NP scenarios
- Study of tau decays:
  - CPV in tau pair production ($e^+e^- \rightarrow \tau^+\tau^-$) ⇨ EDM
  - CPV in hadronic tau decays
    - SM source: ⇨ K-Kbar mixing



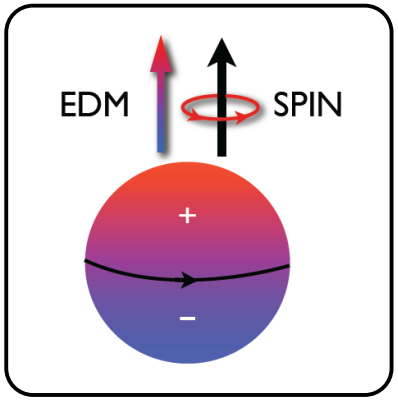
NP source: In the vertex



4.2 EDM of the Tau

- Probe to test new sources of CP violation

No SM background



P and T violation:

$$\vec{d} \propto \vec{J}$$

$$\mathcal{H} \sim d\,\vec{J}\cdot\vec{E}$$

EDMs in $e \cdot cm$ *From V. Cirigliano*

System	current	projected	SM (CKM)
e	$\sim 10^{-28}$	10^{-29}	$\sim 10^{-38}$
μ	$\sim 10^{-19}$		$\sim 10^{-35}$
τ	$\sim 10^{-16}$		$\sim 10^{-34}$
n	$\sim 10^{-26}$	10^{-28}	$\sim 10^{-31}$
p	$\sim 10^{-23}$	10^{-29} **	$\sim 10^{-31}$
^{199}Hg	$\sim 10^{-29}$	10^{-30}	$\sim 10^{-33}$
^{129}Xe	$\sim 10^{-27}$	10^{-29}	$\sim 10^{-33}$
^{225}Ra	$\sim 10^{-23}$	10^{-26}	$\sim 10^{-33}$
...	...		...

- CPV in tau pair production ($e^+e^- \rightarrow \tau^+\tau^-$) ⇒ EDM
- Very challenging measurement for τ
- Measured using spin correlations of decay product of taus
- Help of polarized beams?

4.2 EDM of the Tau

- The squared spin density matrix for $e^+(\mathbf{p})\, e^-(-\mathbf{p}) \to \gamma^* \to \tau^+(\mathbf{k},\mathbf{S}_+)\, \tau^-(-\mathbf{k},\mathbf{S}_-)$

$$\mathcal{M}^2 = \mathcal{M}^2_{SM} + \mathrm{Re}(\mathrm{d}_\tau)\mathcal{M}^2_{\mathrm{Re}} + \mathrm{Im}(\mathrm{d}_\tau)\mathcal{M}^2_{\mathrm{Im}} + |\mathrm{d}_\tau|^2\mathcal{M}^2_{\mathrm{d}^2}$$

- Study of spin momentum correlations:

$$\boxed{\begin{aligned} \mathcal{M}^2_{\mathrm{Re}} &\propto (S_+ \times S_-)\cdot\hat{k}, \quad (S_+ \times S_-)\cdot\hat{p}, \\ \mathcal{M}^2_{\mathrm{Im}} &\propto (S_+ - S_-)\cdot\hat{k}, \quad (S_+ - S_-)\cdot\hat{p}, \end{aligned}}$$

τ spin vector

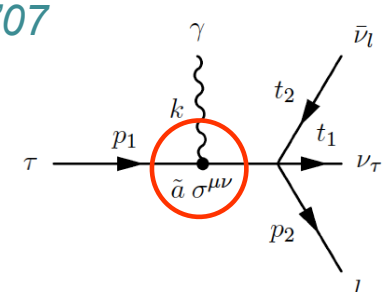
unit vectors of momenta of τ and e^- in CMS

Belle'02

$$\boxed{-0.22 < \mathrm{Re}\,(d_\tau) < 0.45 \quad (10^{-16} e\cdot\mathrm{cm})} \quad \text{and} \quad \boxed{-0.25 < \mathrm{Im}\,(d_\tau) < 0.08 \quad (10^{-16} e\cdot\mathrm{cm})}$$

- Polarized beams will help since the decay products of only one tau could be studied *Bernabeu, Gonzalez-Sprinberg, Vidal'04,'07*

- Radiative decay possibility
  Eidelmana, Epifanov, Fael, Mercolli, Passera'16



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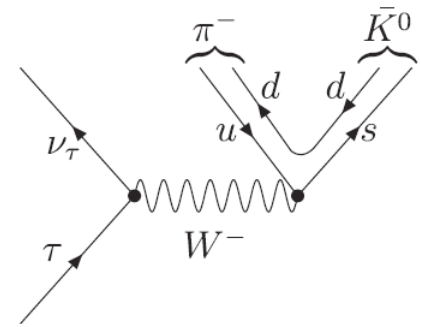
Prospects for CEPC?

4.3 $\tau \to K\pi\nu_\tau$ CP violating asymmetry



- $$A_Q = \frac{\Gamma\left(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K_S^0 \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K_S^0 \nu_\tau\right)}$$

$$= |p|^2 - |q|^2 \approx (0.36 \pm 0.01)\%$$ in the SM

Bigi & Sanda'05
Grossman & Nir'11

$$\left|K_S^0\right\rangle = p\left|K^0\right\rangle + q\left|\overline{K}^0\right\rangle$$
$$\left|K_L^0\right\rangle = p\left|K^0\right\rangle - q\left|\overline{K}^0\right\rangle$$

$$\left\langle K_L \middle| K_S \right\rangle = |p|^2 - |q|^2 \simeq 2\,\mathrm{Re}\left(\varepsilon_K\right)$$

- Experimental measurement : *BaBar'11*

$$A_{Q\,\mathrm{exp}} = \left(-0.36 \pm 0.23_{\mathrm{stat}} \pm 0.11_{\mathrm{syst}}\right)\%$$ ⇨ 2.8σ from the SM!

- CP violation in the tau decays should be of opposite sign compared to the one in D decays in the SM

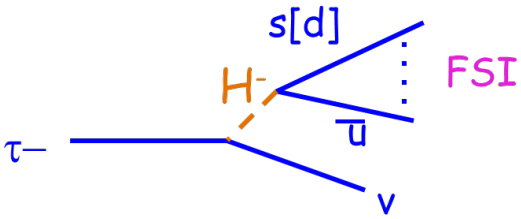
Grossman & Nir'11

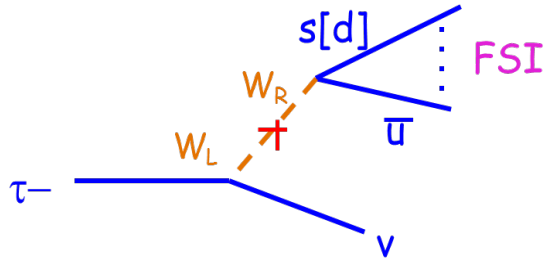
$$A_D = \frac{\Gamma\left(D^+ \to \pi^+ K_S^0\right) - \Gamma\left(D^- \to \pi^- K_S^0\right)}{\Gamma\left(D^+ \to \pi^+ K_S^0\right) + \Gamma\left(D^- \to \pi^- K_S^0\right)} = (-0.54 \pm 0.14)\%$$

Belle, Babar, CLEO, FOCUS

4.3 $\tau \to K\pi\nu_\tau$ CP violating asymmetry

- New physics? Charged Higgs, W_L-W_R mixings, leptoquarks, tensor interactions (*Devi, Dhargyal, Sinha'14, Cirigliano, Crivellin, Hoferichter'17*)?





Bigi'Tau12

Very difficult to explain!

- Need to investigate how large can be the prediction in realistic new physics models: it looks like *a tensor interaction* can explain the effect but in conflict with bounds from neutron EDM and $D\bar{D}$ mixing

Cirigliano, Crivellin, Hoferichter'17

⇨ light BSM physics?

- Anomaly should be confirmed : ⇨ *Prospects for CEPC?*

4.3 $\tau \to K\pi\nu_\tau$ CP violating asymmetry

- In this measurement, need to know hadronic part ⇨ form factors

$$\langle K\pi | \bar{s}\gamma_\mu u | 0 \rangle = \left[(p_K - p_\pi)_\mu + \frac{\Delta_{K\pi}}{s}(p_K + p_\pi)_\mu \right] f_+(s) - \frac{\Delta_{K\pi}}{s}(p_K + p_\pi)_\mu f_0(s)$$

vector scalar

with $s = Q^2 = (p_K + p_\pi)^2$

$$\Delta_{K\pi} = \left(M_K^2 - M_\pi^2\right)$$

⇨ *See talk by S. Gonzalez-Solis*

4.3 $\tau \to K\pi\nu_\tau$ angular CP violating asymmetry

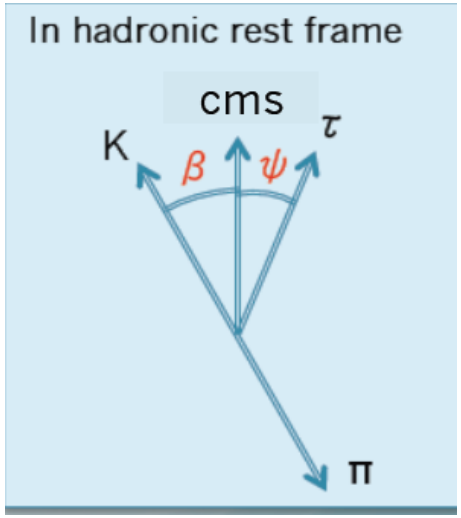
- Measurement of the angular CP asymmetry from Belle:

$$\frac{d\Gamma\left(\tau^- \to K\pi^-\nu_\tau\right)}{d\sqrt{Q^2}\, d\cos\theta\; d\cos\beta} = \left[A(Q^2) - B(Q^2)\left(3\cos^2\psi - 1\right)\left(3\cos^2\beta - 1\right)\right]\left|f_+(s)\right|^2 + m_\tau^2\left|\tilde{f}_0(s)\right|^2 - C(Q^2)\cos\psi\cos\beta\,\mathrm{Re}\left(f_+(s)\tilde{f}_0^*(s)\right)$$

CP violating term
S-P interference

  - $A(Q^2)$, $B(Q^2)$, $C(Q^2)$: kinematic factors
  - Angles:
    in $K\pi$ rest frame
    - β: angle between kaon and e^+e^- CMS frame
    - Ψ: angle between τ and CMS frame

    in τ rest frame
    - θ: angle between τ direction in CMS and direction of $K\pi$ system (dependence with Ψ)



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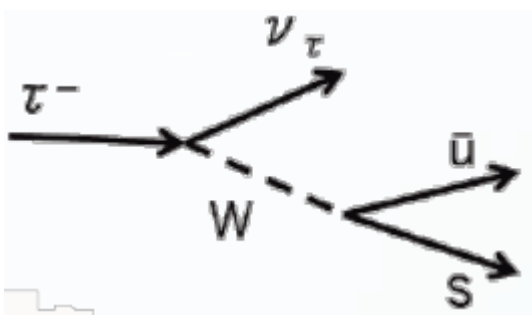
CP violating term
S-P interference

– $A(Q^2)$, $B(Q^2)$, $C(Q^2)$: kinematic factors

Charged Higgs contribution



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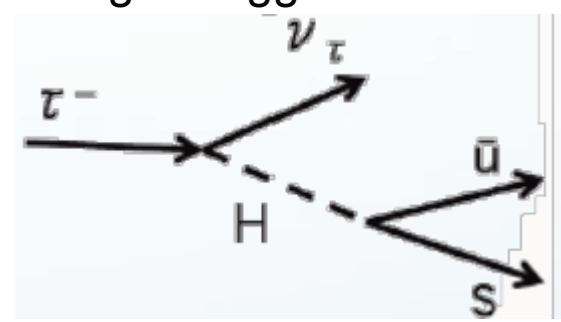


Khün & Mirkes'05

$$\tilde{f}_0(s) = f_0(s) + \frac{\eta^2}{m_\tau^2} f_H(s)$$

with $$f_H(s) = \frac{s}{m_u - m_s} f_0(s)$$

4.3 $\tau \to K\pi\nu_\tau$ CP violating asymmetry

- In this measurement, need to know hadronic part ⇨ form factors

$$\langle K\pi | \bar{s}\gamma_\mu u | 0 \rangle = \left[(p_K - p_\pi)_\mu + \frac{\Delta_{K\pi}}{s}(p_K + p_\pi)_\mu \right] f_+(s) - \frac{\Delta_{K\pi}}{s}(p_K + p_\pi)_\mu f_0(s)$$

with $s = Q^2 = (p_K + p_\pi)^2$

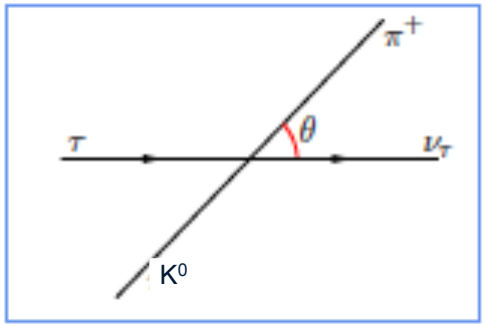
vector

scalar

- Up to now know from decay spectrum but difficult to disentangle scalar and vector form factor ⇨ consider the FB asymmetry instead

$$A_{FB} = \frac{d\Gamma(\cos\theta) - d\Gamma(-\cos\theta)}{d\Gamma(\cos\theta) + d\Gamma(-\cos\theta)}$$

Beldjoudi & Truong'94
Moussallam, B2TIP



- Formula: can disentangle scalar and vector FF easily

$$A_{FB}(s) = \frac{3\Delta_{\pi^+K^0}\sqrt{\lambda_{\pi^+K^0}(s)}|f_V^{K\pi}(s)||f_0^{K\pi}(s)|\cos\left(\delta_1^{1/2} - \delta_0^{1/2}\right)}{\underbrace{|f_V^{K\pi}(s)|^2\lambda_{\pi^+K^0}(s)}_{\text{vanishes at threshold}}(1 + 2s/m_\tau^2) + 3|f_0^{K\pi}(s)|^2\Delta^2_{\pi^+K^0}}.$$

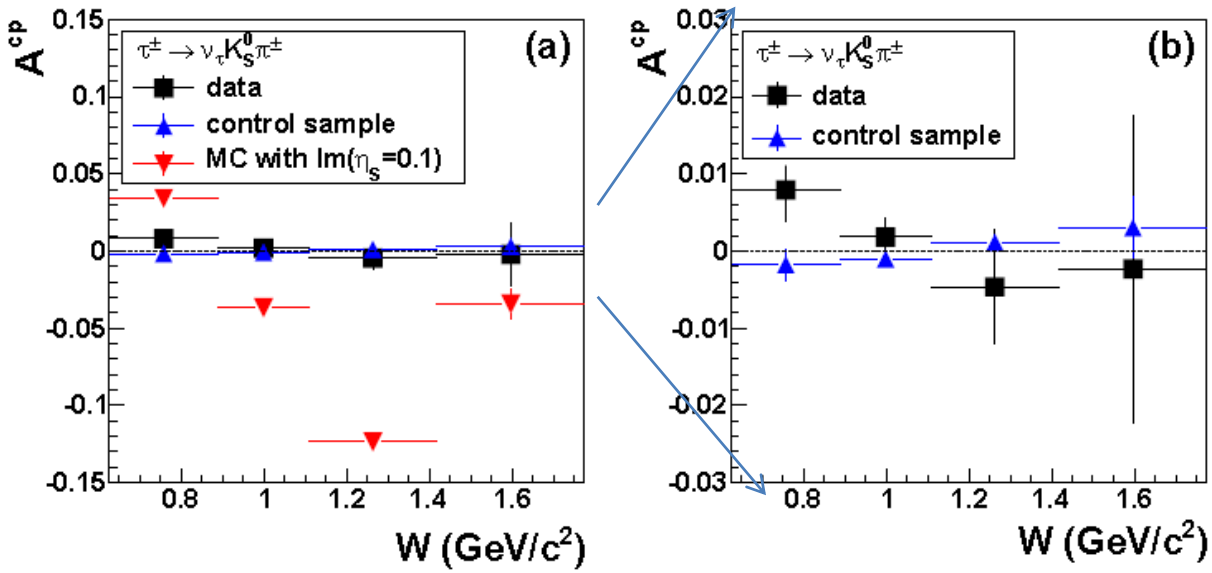
⇨ Never done before: Feasible at *CEPC*?

4.3 $\tau \to K\pi\nu_\tau$ CP violating asymmetry

- Measurement of the direct contribution of NP in the angular CP violating asymmetry done by *CLEO* and *Belle*

  ➡ Belle does not see any asymmetry at the *0.2 - 0.3% level*

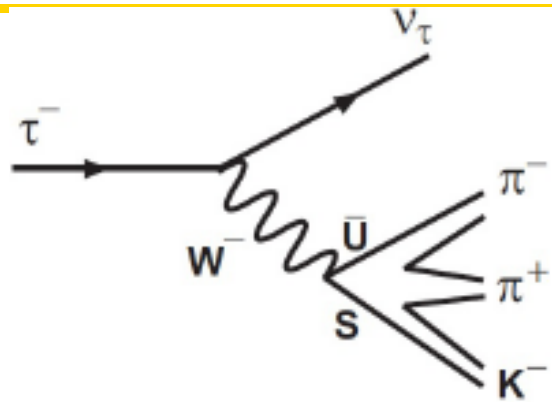
Belle'11



- Problem with this measurement? ➡ It would be great to have other experimental measurements from *Belle II or CEPC*

4.4 Three body CP asymmetries

- Ex: $\tau \to K\pi\pi\nu_\tau$



e.g., Choi, Hagiwara and Tanabashi'98
Kiers, Little, Datta, London et al.,'08
Mileo, Kiers and, Szynkman'14

- A variety of CPV observables can be studied : $\tau \to K\pi\pi\nu_\tau$, $\tau \to \pi\pi\pi\nu_\tau$ rate, angular asymmetries, triple products,….

  Same principle as in charm, *see Bevan'15*

  Difficulty : Treatement of the hadronic part
  Hadronic final state interactions have to be taken into account!
  ➡ Disentangle weak and strong phases

- More form factors, more asymmetries to build but same principles as for 2 bodies

5. Conclusion and outlook

Conclusion and outlook

- CEPC would be a fantastic machine for studying *tau physics*
- In the tau Working Group we select several topics to study in priority where CEPC would have a great impact:
  - Lepton Universality and tau leptonic BRs
  - LFV bounds: $\tau \to 3\mu$ and $\tau \to \mu\gamma$
  - CPV in the tau sector: There is a hint of new dynamics in CPV asymmetries in the tau sector
    BaBar result does not agree with SM expectation but needs to be confirmed ⇨ A lot of new measurements possible (A_{CP}, A_{FB}, etc.) to shed light on CP violation
  - EDM, g-2 of the tau also very interesting to study but difficult
- Several interesting topics I did not address: study of hadronic τ decays
  - Inclusive for α_S, $|V_{us}|$ and m_s
  - Exclusive for form factors extraction, $|V_{us}|$, resonances etc..

⇨ *See talk by S. Gonzalez-Solis*

Conclusion and outlook

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  - EDM, g-2 of the tau also very interesting to study but difficult
- At present the only study that exists come from FCC-ee simulations
  ⇨ we are hoping to work on sensitivity studies on all these topics within the next months