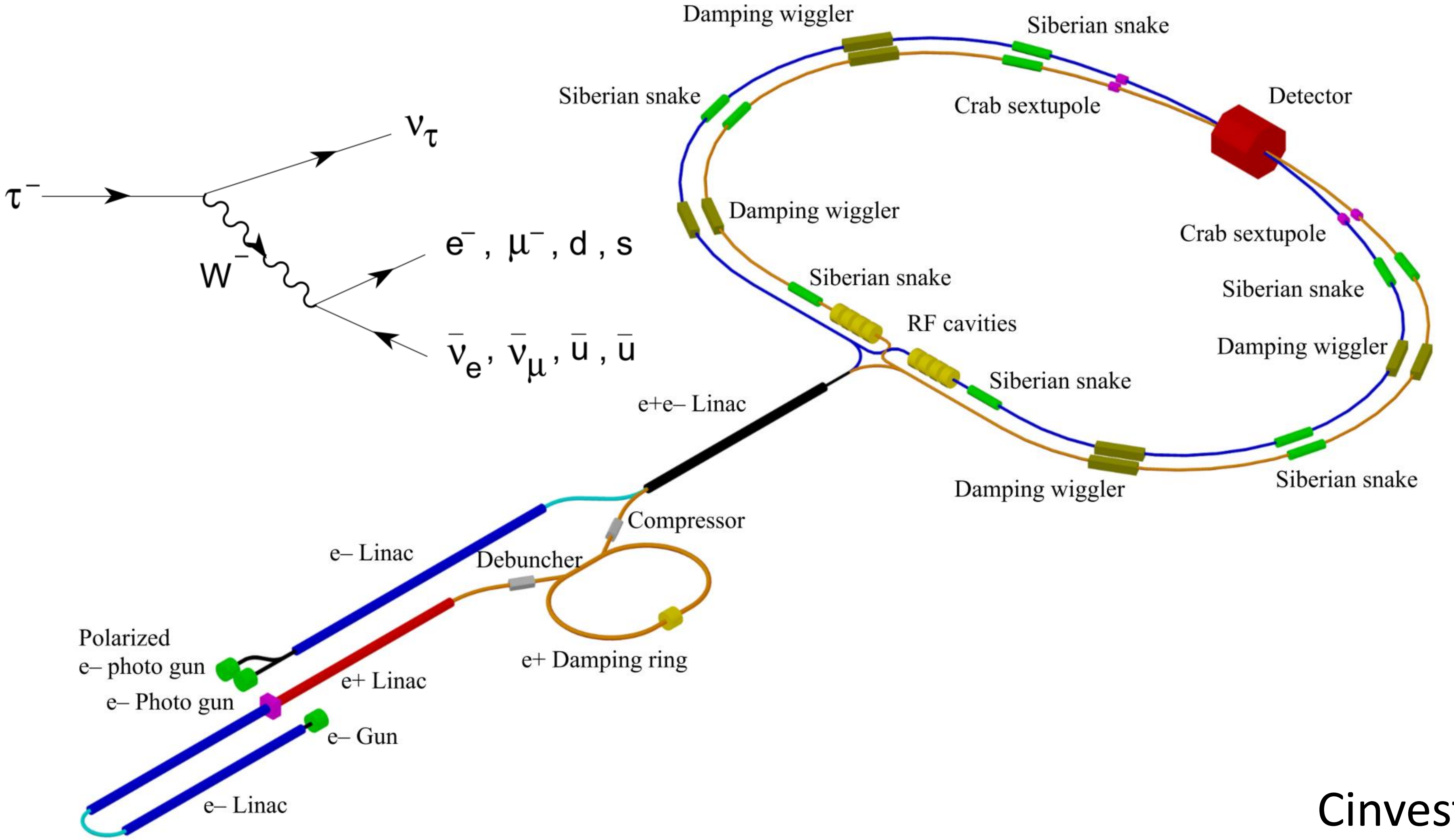
τ Physics Opportunities at Super Tau Charm Factory (STCF) in BINP



Disclaimer: Mainly highlights, not comprehensive. See **SCTF CDR**; talk by **S. Eidelman** in the SCTF meeting Dec. 2017; HFLAV Eur.Phys.J. C77 (2017) no.12 and **A. Lusiani** recent talks, 895; **Pich A.** Prog.Part.Nucl.Phys. 75 (2014) 41-85 ***and references therein***.

Pablo Roig
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STCF outstanding features for τ Physics

- Within the variable energy range of the machine (2-5 GeV), running at ~ 3.554 GeV produces $e^+e^- \to \tau^+\tau^-$ close to threshold, allowing for **precision** tau physics studies with ~ 50 fb^{-1} dataset (10^9 τs).

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- During STCF operation ~ 2.1×10^{10} τ pairs will be produced, an order of magnitude more than at BaBar&Belle, but less than at Belle-II (~ 4.6×10^{10} τ pairs). A **luminosity** of 10^{35} cm^{-2} s^{-1} is crucial.

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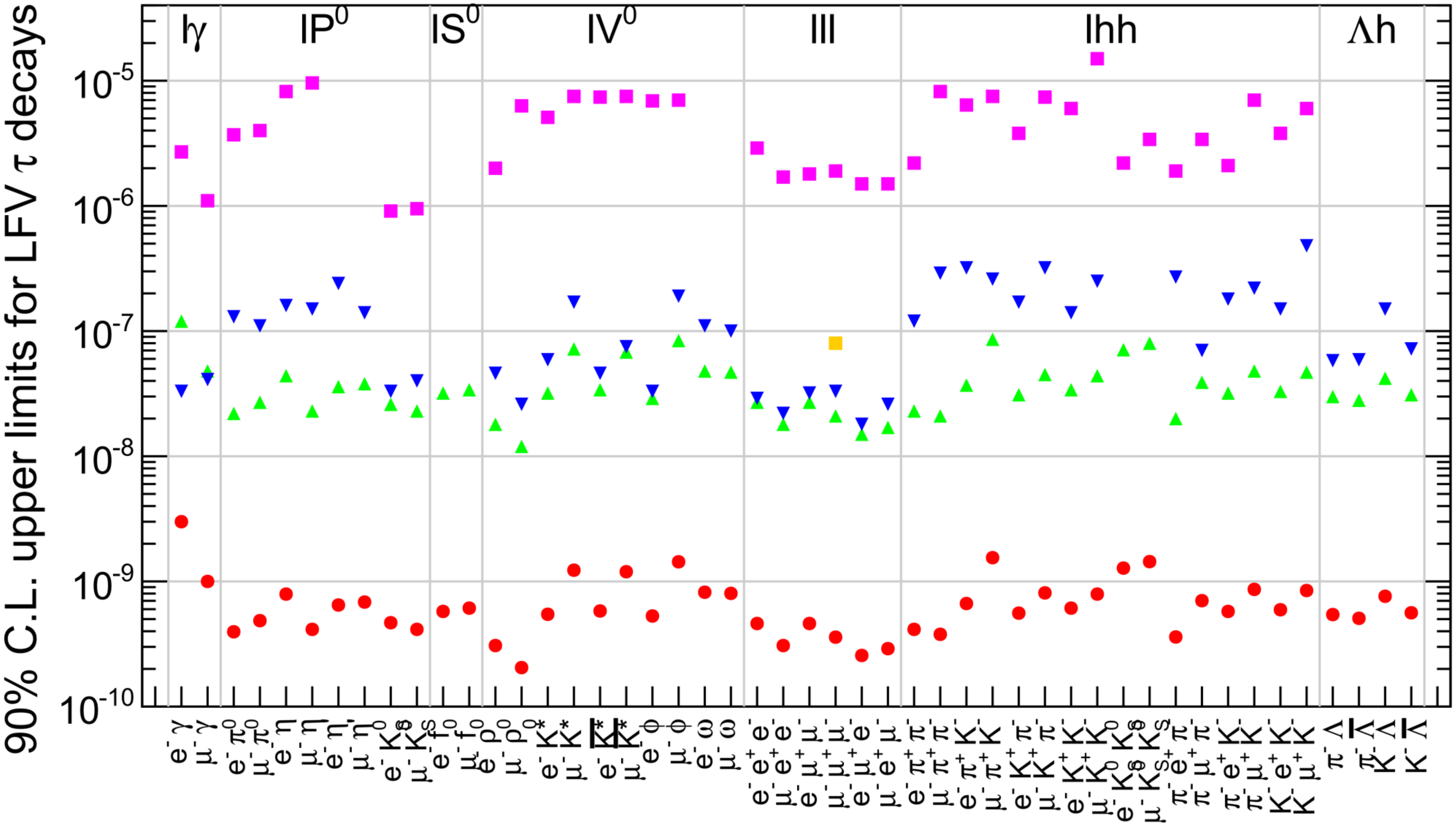
- At threshold, hadrons would be monochromatic in two-body tau decay: **precision in $\tau^- \to (\pi/K)^- \nu_\tau$** (**LU**).

τ Physics Opportunities

τ Physics Opportunities: Charged LFV

Observation = New Physics



Backgrounds are much smaller @STCF than at Belle-II. Even with less data more stringent limits can be achieved !!

($\tau \to \mu\gamma$ with $e^+e^- \to \tau\,\tau\,\gamma$)

- **CLEO**
- **BaBar**
- **Belle**
- **LHCb**
- **Belle II**

Also **LNV** & **BNV** will be searched for

τ Physics Opportunities: CPV

$$\mathcal{A}_\tau = \frac{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}$$

$$\mathcal{A}_\tau^{\mathrm{SM}} \simeq 2\mathrm{Re}(\epsilon) \simeq (0.36 \pm 0.01)\%$$

vs BaBar measurement: $\mathcal{A}_\tau = (-0.36 \pm 0.23 \pm 0.11)\%$

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$$\mathcal{A}_D = \frac{\Gamma(D^+ \to \pi^+ K_S) - \Gamma(D^- \to \pi^- K_S)}{\Gamma(D^+ \to \pi^+ K_S) + \Gamma(D^- \to \pi^- K_S)}$$

$$A_D = (-0.41 \pm 0.09)\%$$

In agreement with SM

$$A_\tau = -A_D$$

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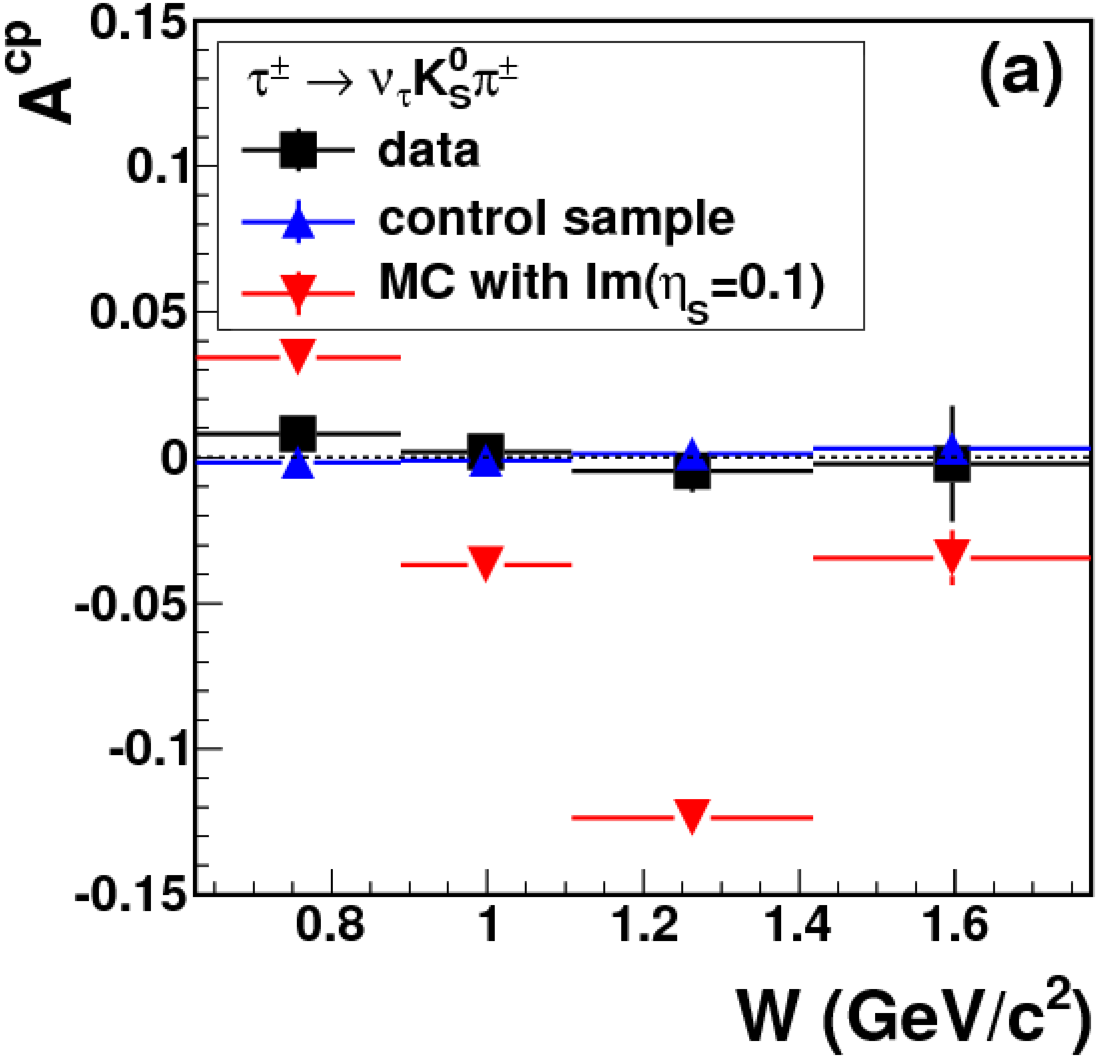
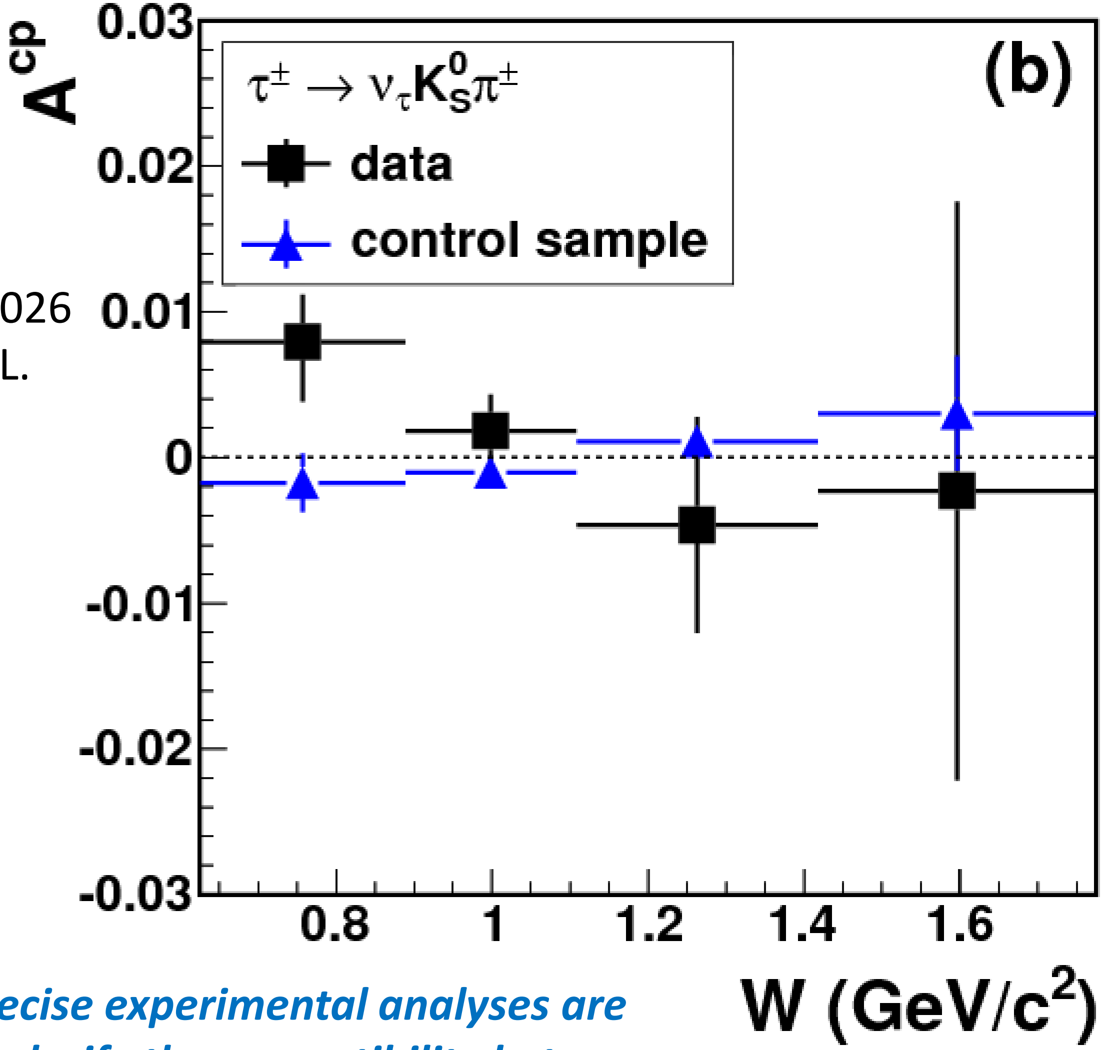
Triple product asymmetries can be measured @ STCF for the related channels $\tau^- \to (\pi^- \pi^0 K_S / K^- \pi^0 K_S / \ldots)\, \nu_\tau$ & provide complementary information.

τ Physics Opportunities: CPV

Belle Coll. has also searched for CPV through a possible difference in the $\tau^\pm$ angular distributions



$|\mathrm{Im}(\eta_S)| < 0.026$ @ 90% C.L.



More precise experimental analyses are needed to clarify the compatibility between the BaBar and Belle results.

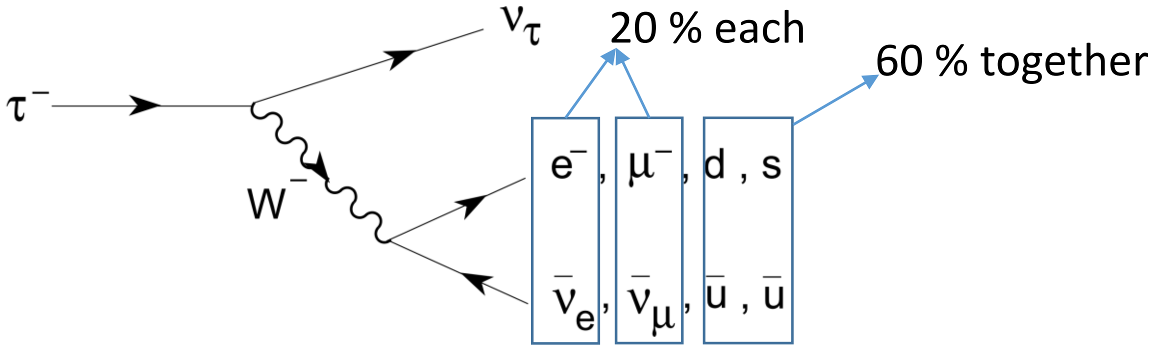
τ Physics Opportunities: M_τ & LU tests

$$\Gamma_{\ell\to\ell'} \equiv \Gamma[\ell^- \to \ell'^- \bar{\nu}_{\ell'}\nu_\ell(\gamma)] = \frac{G^2_{\ell'\ell} m_\ell^5}{192\pi^3} f\left(m^2_{\ell'}/m^2_\ell\right)\left(1+\delta^{\ell'\ell}_{\rm RC}\right)$$

Universality of W couplings to leptons in the SM

LU tests dominating **uncertainties: $B_{\tau\to\mu/e}$, τ_τ & M_τ**, which can be reduced by measurements at a STCF.

$$\tau_\tau \equiv \frac{1}{\Gamma(\tau)} \approx \left\{\Gamma(\mu)\left(\frac{m_\tau}{m_\mu}\right)^5\left[2+N_C\left(|V_{ud}|^2+|V_{us}|^2\right)\right]\right\}^{-1}$$



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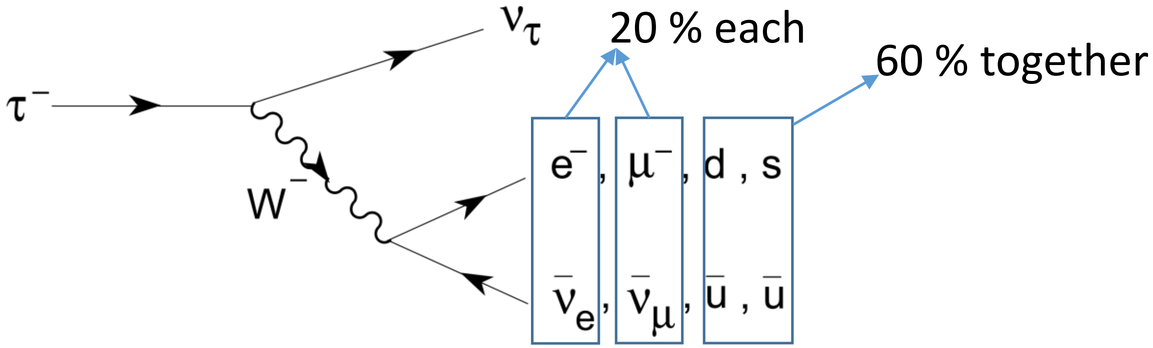

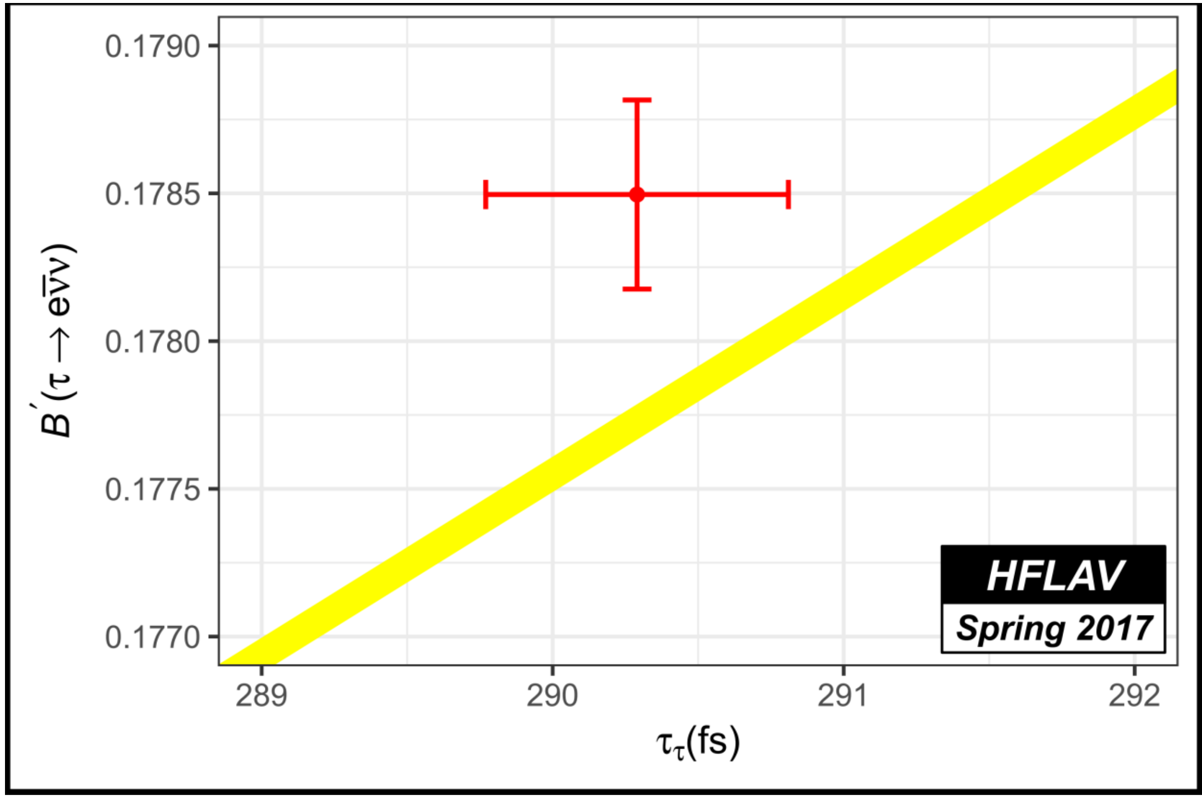

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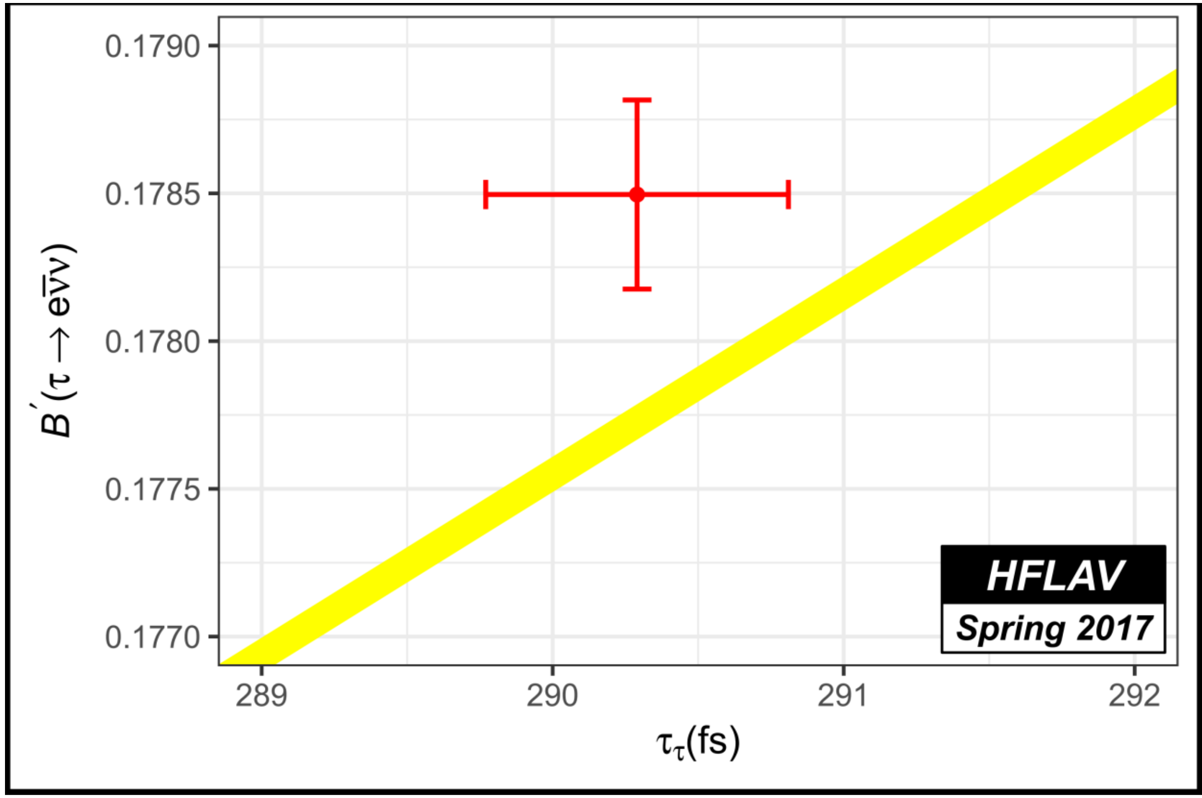
Other interesting LU tests can be performed comparing to π/K decays and also using semileptonic τ decays and W leptonic decays (hints of **several anomalies** appear: $\tau^- \to (\pi/K)^- \nu_\tau$ vs. $(\pi/K)^- \to \mu\, \nu_\mu$; $W^- \to \tau^- \nu_\tau$ vs. $W^- \to (\mu/e)^- \nu$).

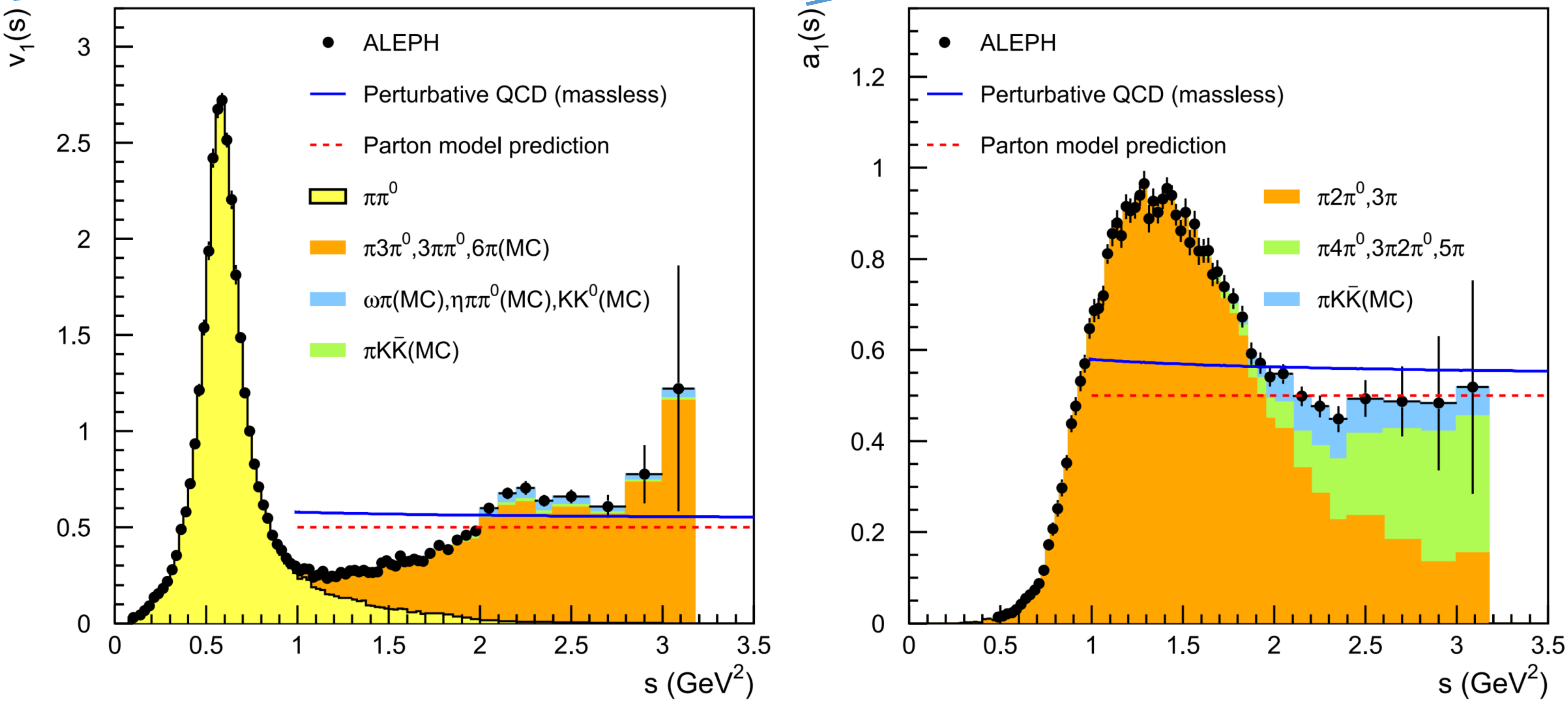
It can be measured with particular precisión at STCF!!



τ Physics Opportunities: α_S & V_{us}

Inclusive τ decays with odd number of kaons

'Non-strange' decays



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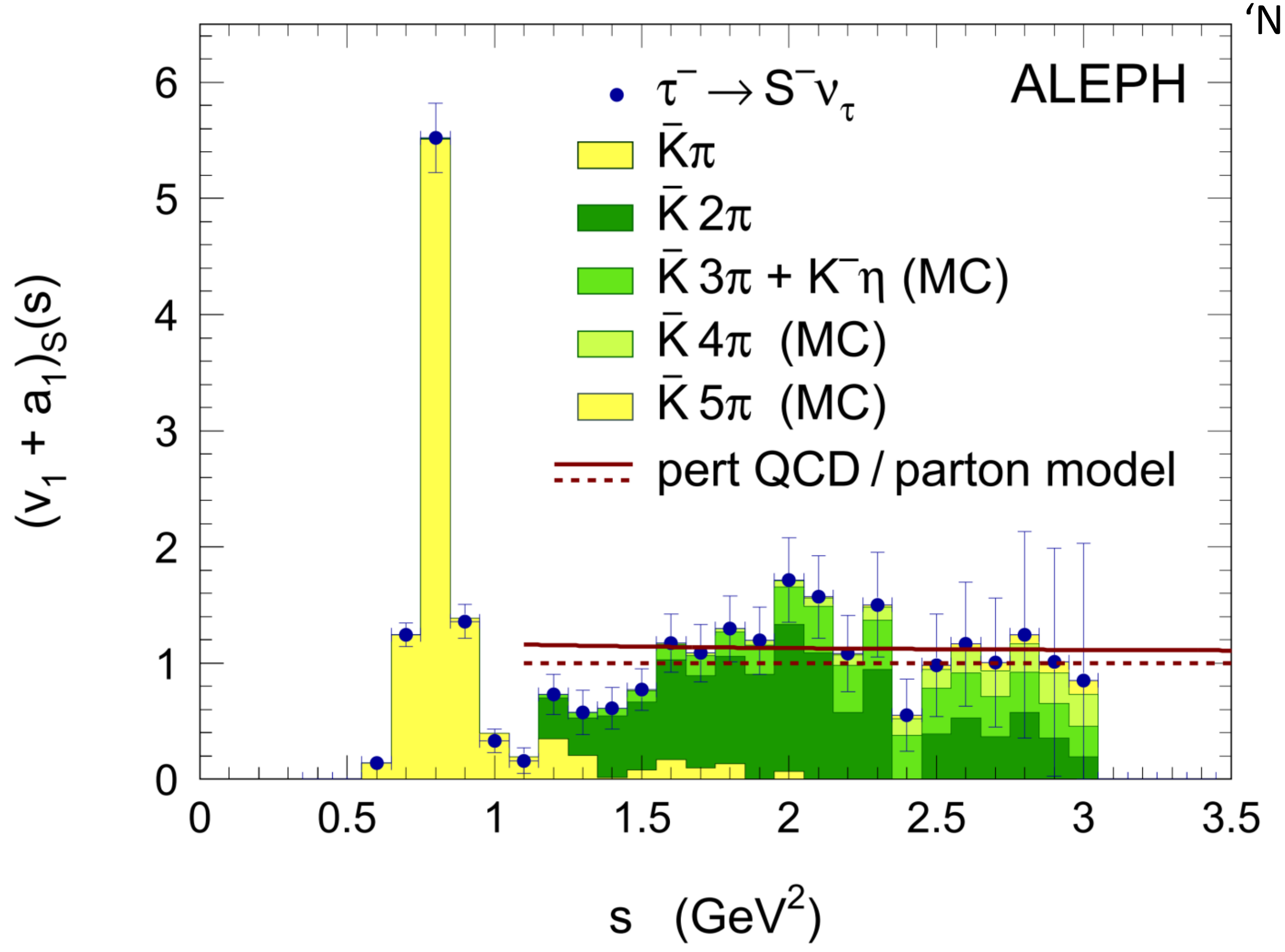

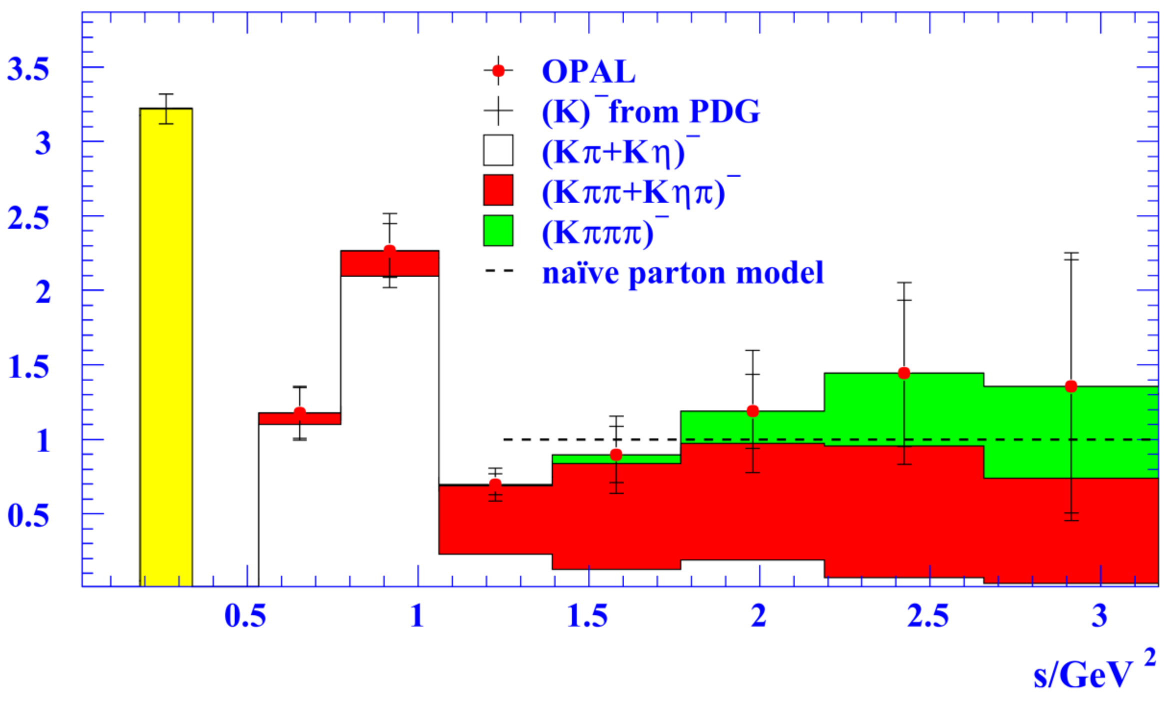

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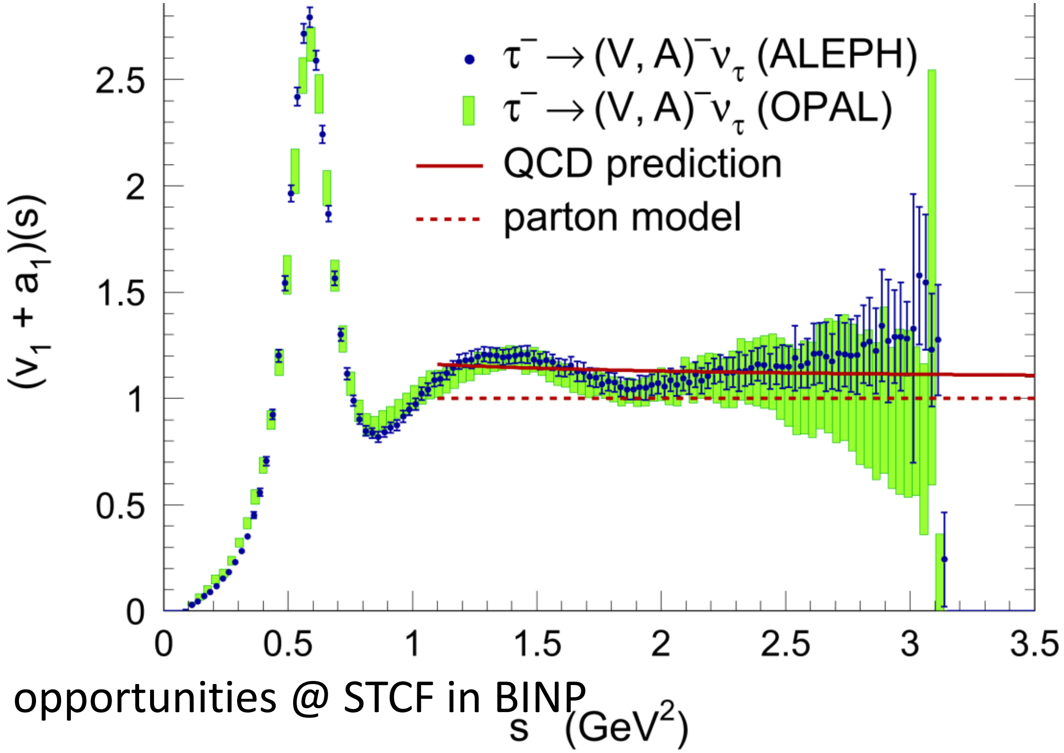
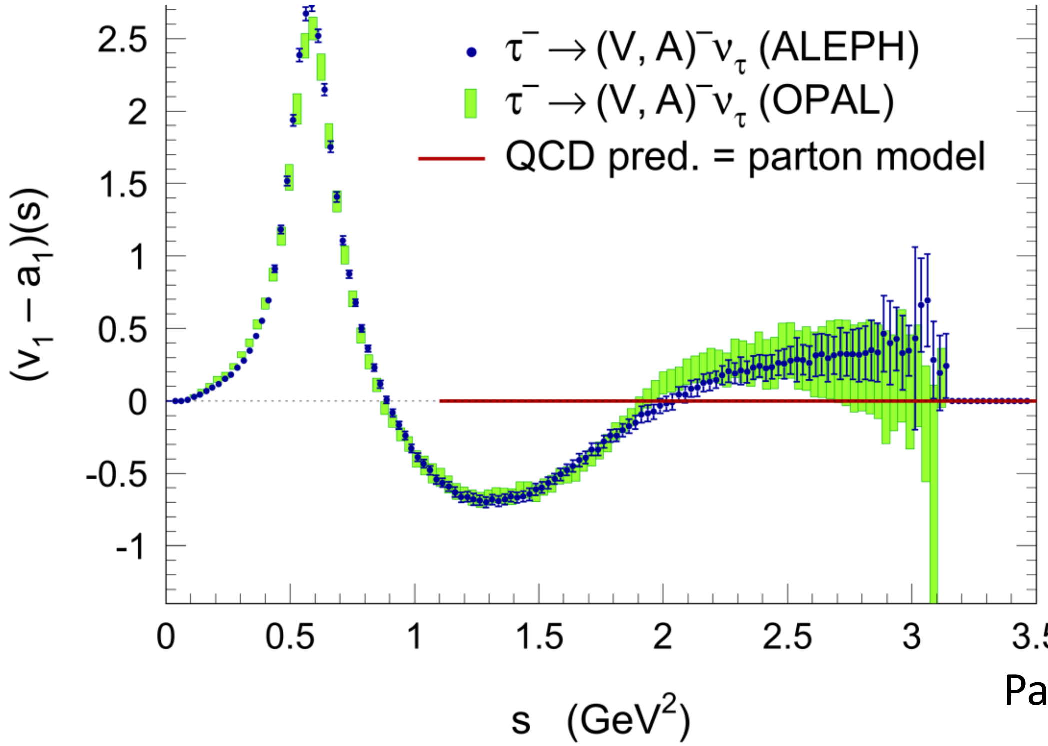
$$R_\tau \equiv \frac{\Gamma[\tau^- \to \nu_\tau \,\mathrm{hadrons}\,(\gamma)]}{\Gamma[\tau^- \to \nu_\tau e^- \bar{\nu}_e(\gamma)]}, \quad R_\tau = R_{\tau,V} + R_{\tau,A} + R_{\tau,S}\,.$$

$$R_{\tau,V/A} = \frac{3}{2}\,|V_{ud}|^2\, S_{\mathrm{EW}} \left(1 + \delta_P + \sum_{D=2,4\ldots} \delta^{(D)}_{ud,V/A}\right), \quad R_{\tau,S} = 3\,|V_{us}|^2\, S_{\mathrm{EW}} \left(1 + \delta_P + \sum_{D=2,4\ldots} \delta^{(D)}_{us}\right)$$





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- The spectral functions for these inclusive processes were measured by **ALEPH & OPAL** but not by BaBar & Belle systematically. Hopefully Belle-II will do it. Anyway, STCF results will be crucial to improve the determination of these SM parameters.

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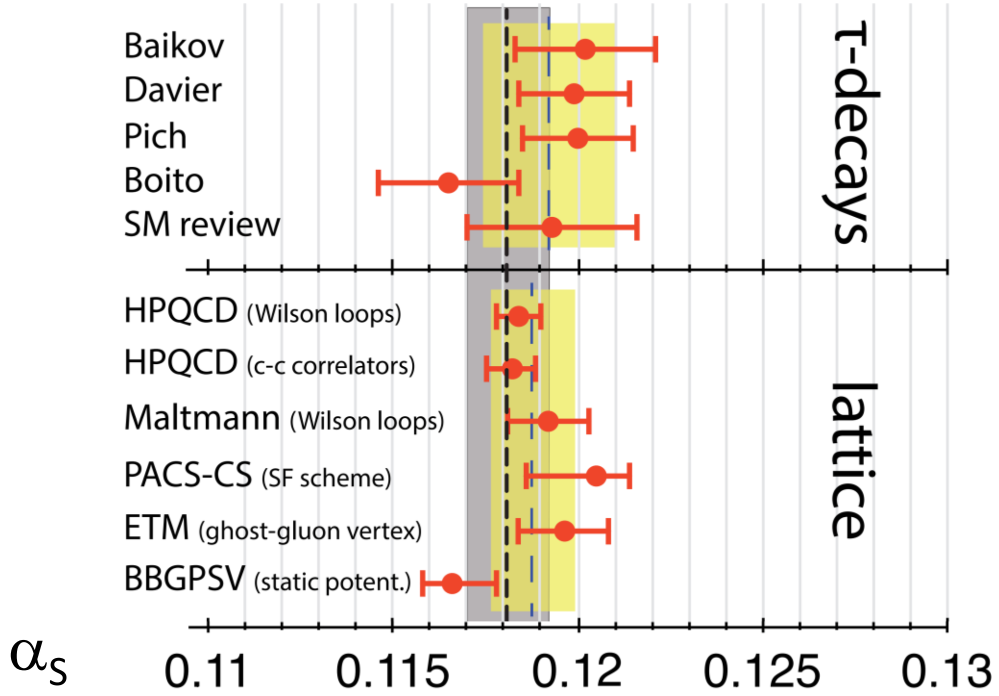
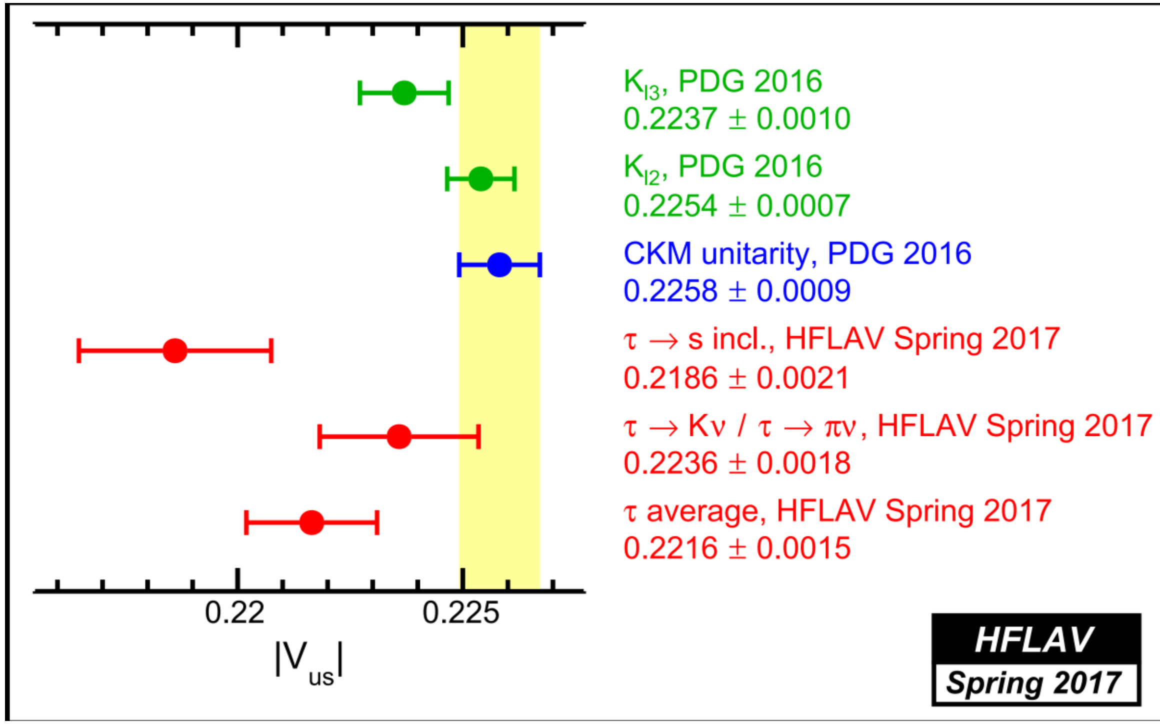
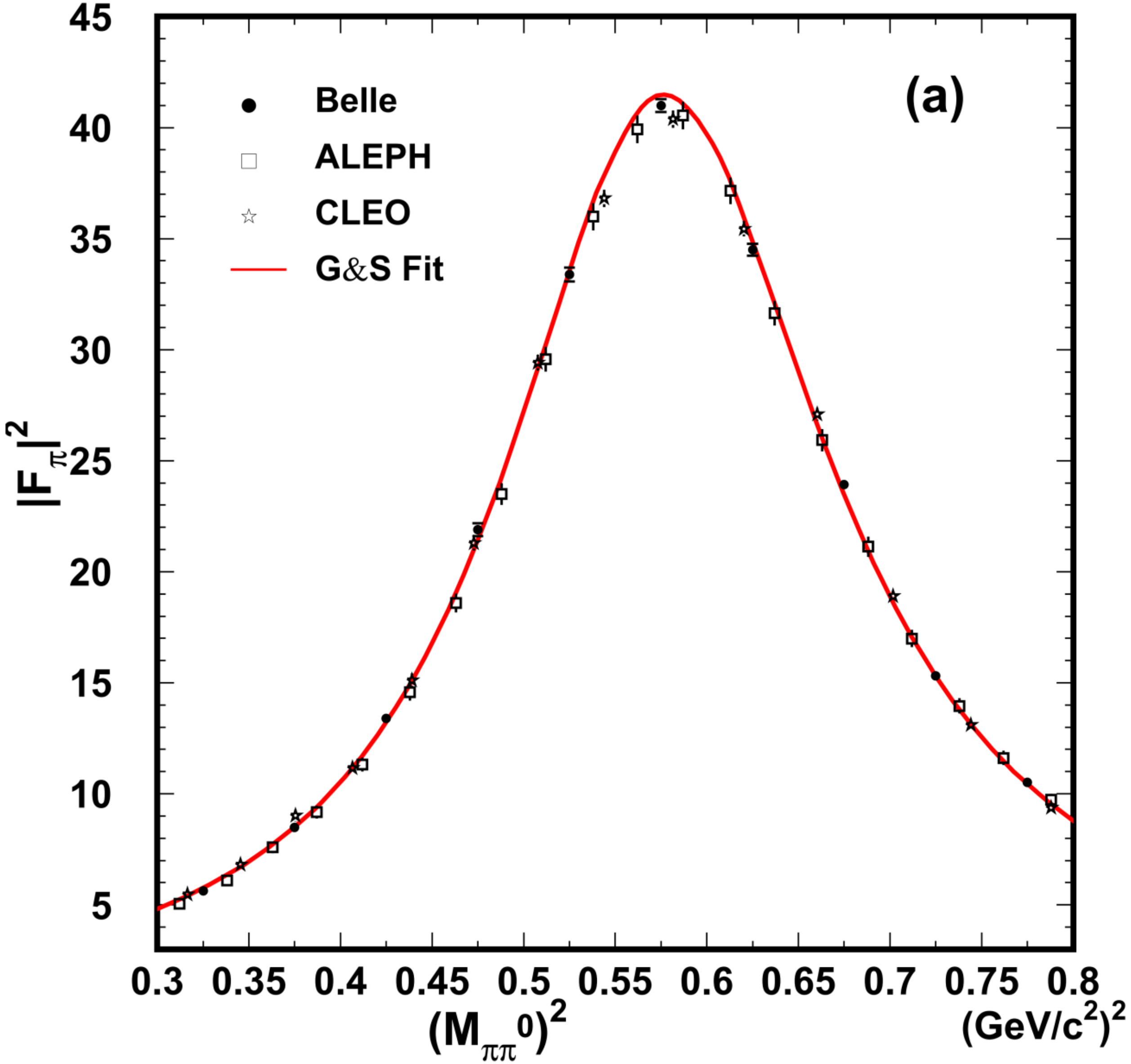
- α_S (M_τ) benefits from the **running** to M_Z to become the 2nd best determination at the reference scale.

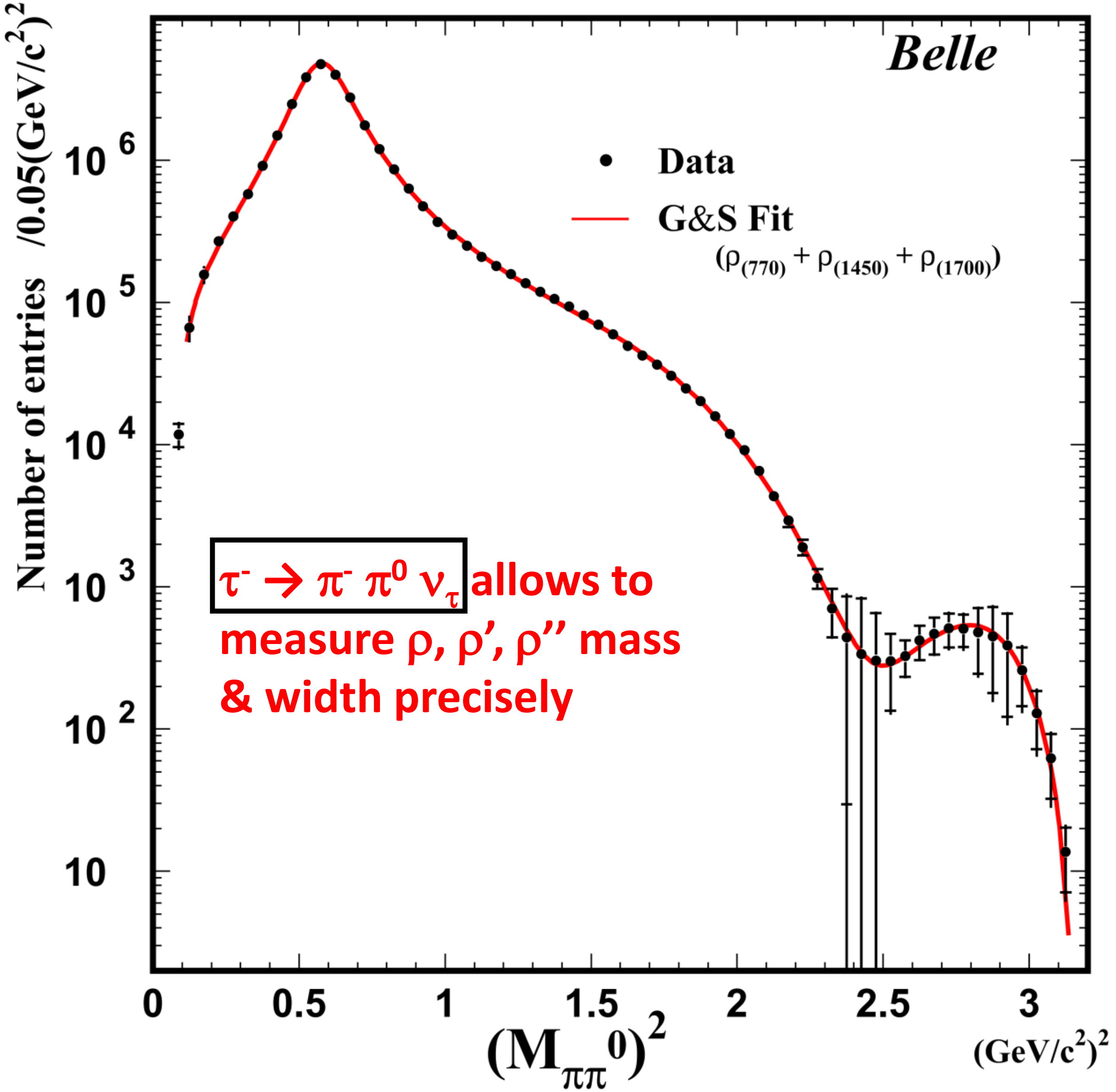
- V_{us} determination from τ decay data is dominated by **systematic uncertainties** (opportunity for STCF).





τ Physics Opportunities: Low-E QCD



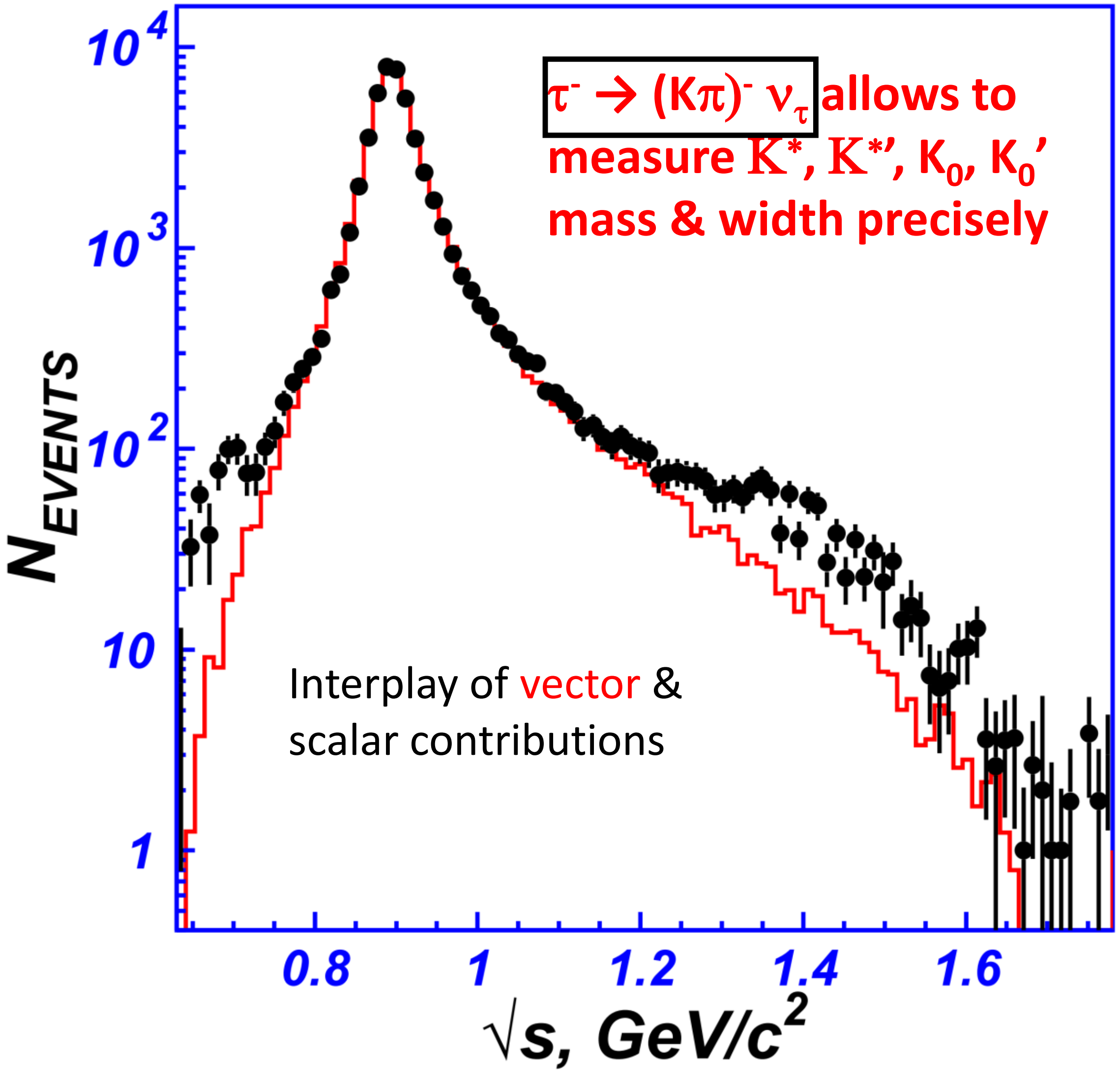


$\tau^- \to \pi^- \pi^0 \nu_\tau$ allows to measure ρ, ρ', ρ'' mass & width precisely

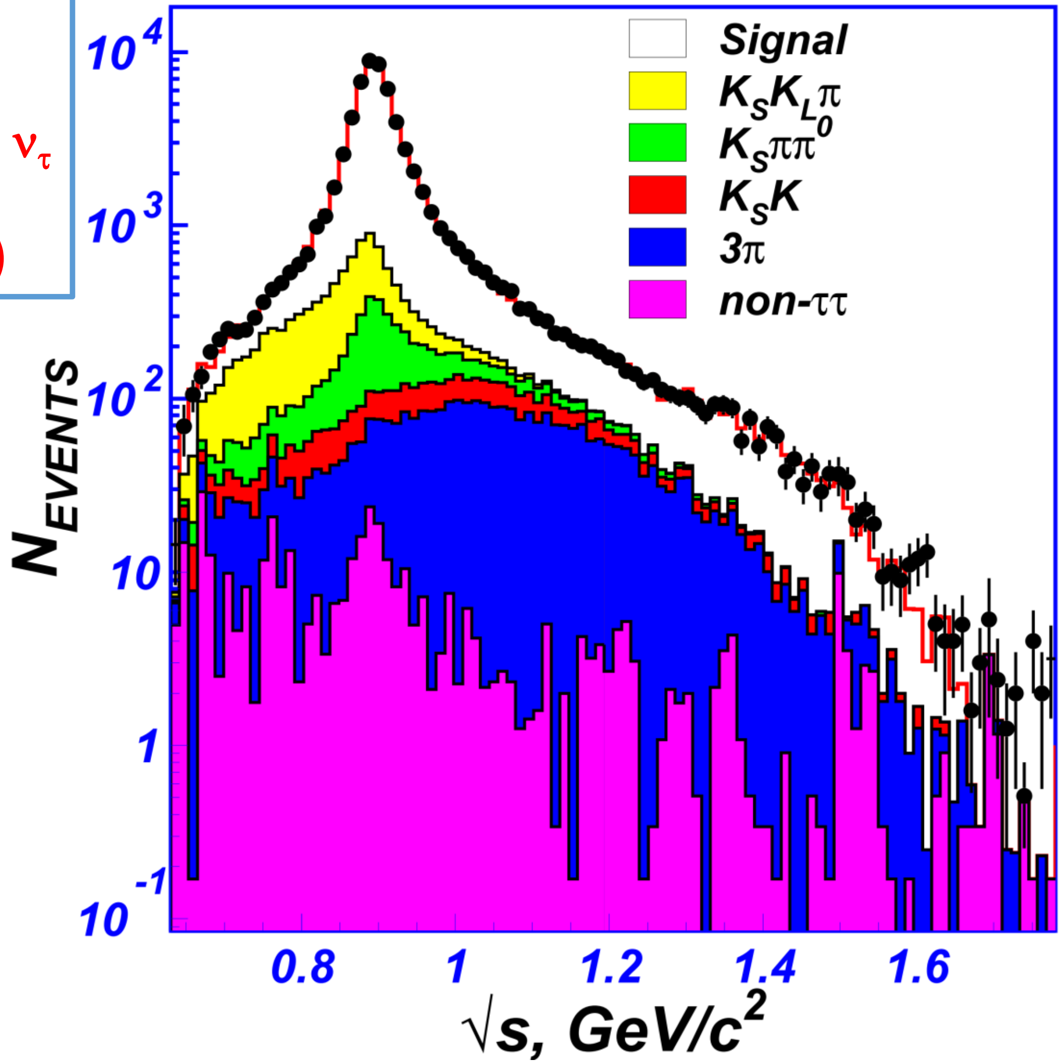
τ Physics Opportunities: Low-E QCD

$\tau^- \rightarrow (K\pi)^- \nu_\tau$ allows to measure K^*, $K^{*\prime}$, K_0, K_0' mass & width precisely

Interplay of vector & scalar contributions



$\tau^- \rightarrow K_S\pi^- \nu_\tau$ Belle data (BaBar $\tau^- \rightarrow K^-\pi^0 \nu_\tau$ spectra unsubtracted)



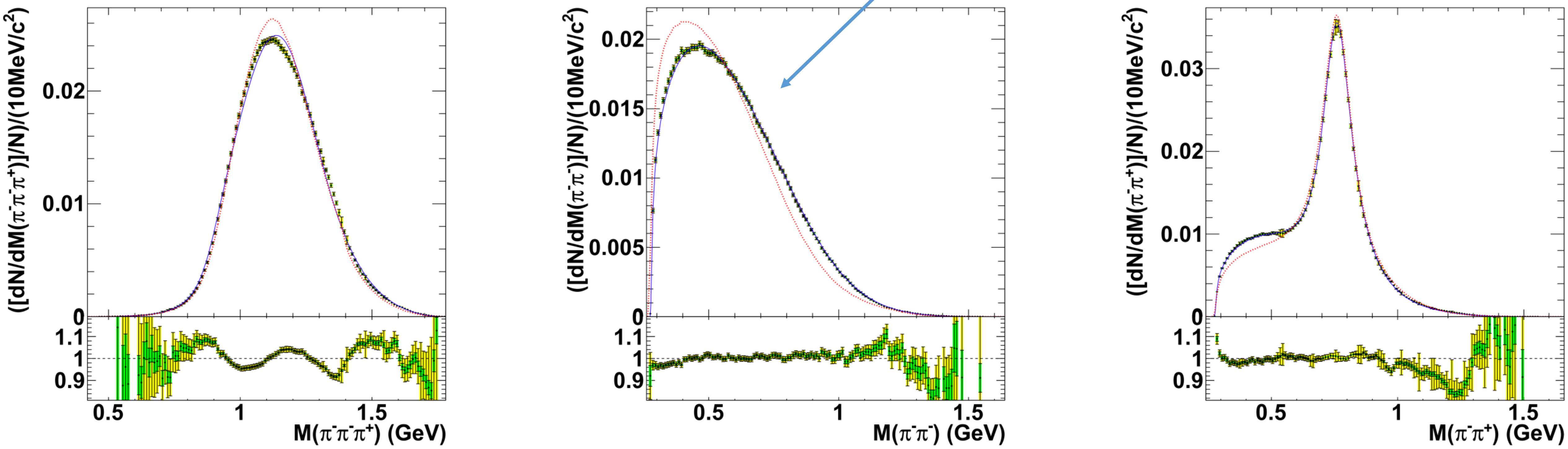
τ Physics Opportunities: Low-E QCD

$\tau^- \to (\pi\pi\pi)^- \nu_\tau$ **allows to measure a_1 (a_1') mass & width precisely**

(BaBar $\tau^- \to (hhh)^- \nu_\tau$ spectra unpublished)

(Belle $\tau^- \to h^-\pi^0 K^0 \nu_\tau$ spectra unpublished)

Still ALEPH data, & CLEO's is the most complete dataset: **New data needed**!!



(Analysis done within TAUOLA-RChL)

τ Physics Opportunities: EFT analyses

$$\ell^- \to \ell'^- \bar{\nu}_{\ell'} \nu_\ell$$

$$\mathcal{H} = 4\frac{G_{\ell'\ell}}{\sqrt{2}} \sum_{n,\epsilon,\omega} g^n_{\epsilon\omega} \left[\overline{\ell'_\epsilon}\Gamma^n (\nu_{\ell'})_\sigma\right] \left[\overline{(\nu_\ell)_\lambda}\Gamma_n \ell_\omega\right]$$

- EFT provide with a **model independent** analysis of (heavy) **NP** and can be applied to both leptonic and semileptonic τ decays.

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- Although Michel parameters measured in μ decay are unbeatable (but for η), additional parameters accessed through **radiative decays** can be most precisely extracted from τ decays (including polarization at STCF).
- Analogous analyses in semileptonic τ decays provide competitive limits on **non-standard tensor** ($\tau \to \pi\pi\nu_\tau$) **& scalar** ($\tau \to \eta\pi\nu_\tau$) **interactions**. Discovery of SCCs (SM) in $\tau \to \eta\pi\nu_\tau$ is still awaiting us.

BaBar limits

$$\mathrm{BR}_{\eta\pi} < 9.9 \times 10^{-5},\ 95\%\ \mathrm{CL}$$

$$\mathrm{BR}_{\eta'\pi} < 7.2 \cdot 10^{-6},\ 95\%\ \mathrm{CL}$$

Completely dominated by bkg, so improvable @ STCF !!

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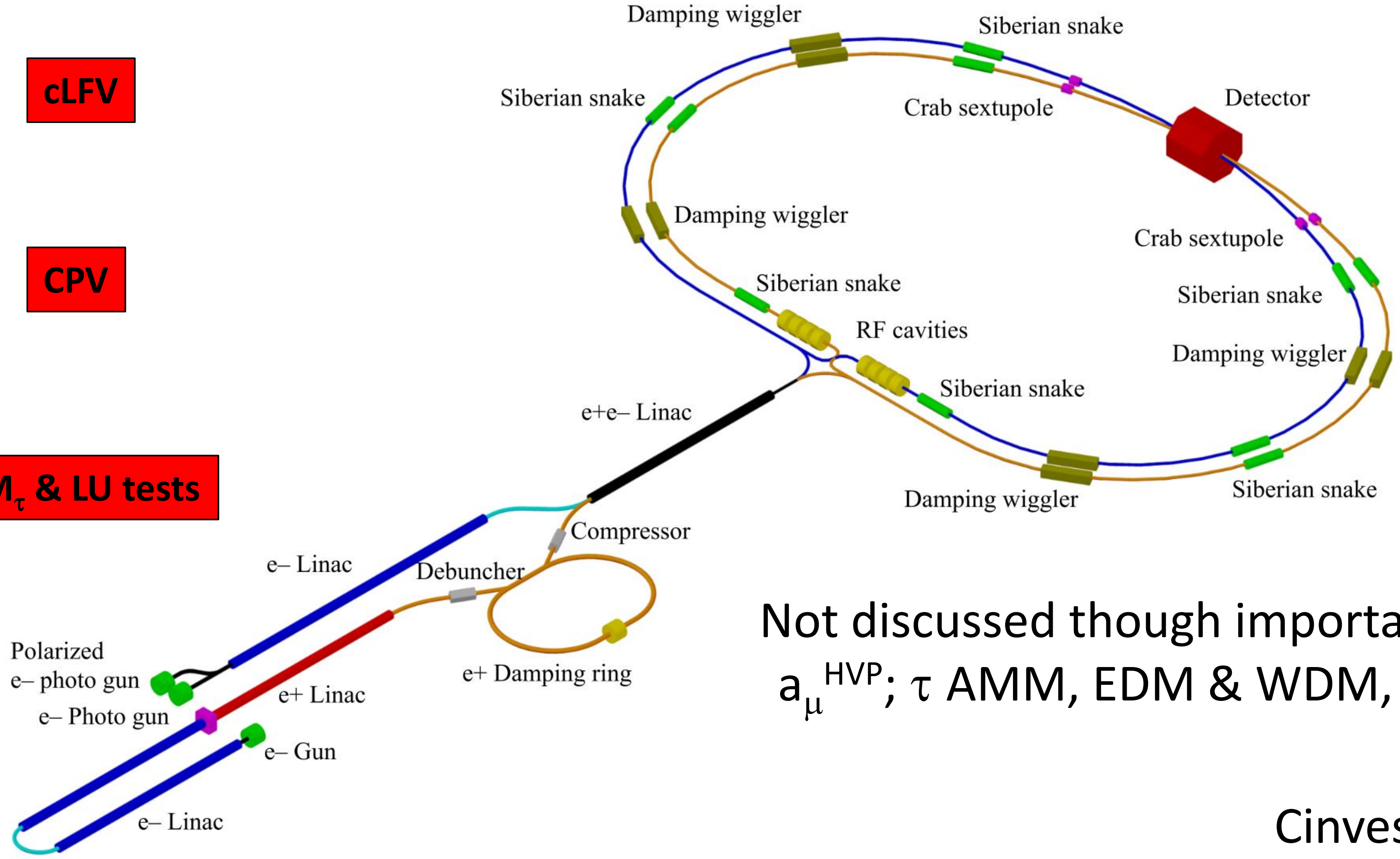
cLFV

CPV

M_τ & LU tests



α_s & V_{us}

Low-E QCD

EFT analyses

Not discussed though important: Had τ decays as input for a_μ^{HVP}; τ AMM, EDM & WDM, τ production in D decays, …

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