Snowmass 2021

Delta Observables to establish New Physics, and MC simulations

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virtually@Snowmass 21 Cincinnati

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Alexander von Humboldt
Stiftung/Foundation

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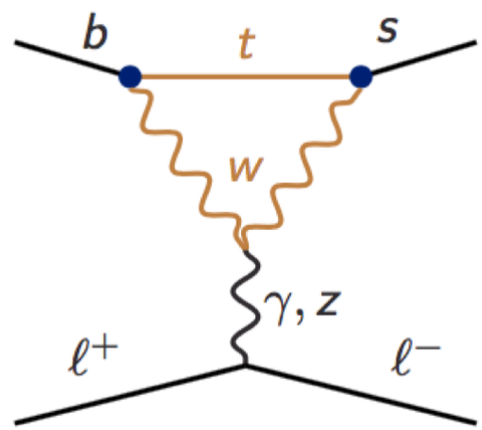
Plan

- Neutral Current (NC)

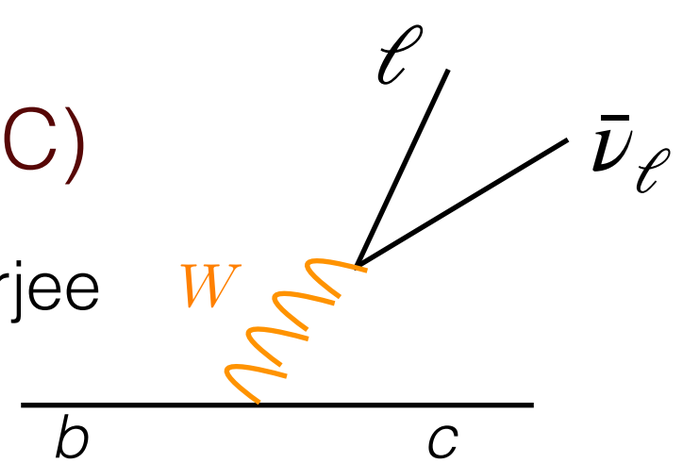


Interesting modes

- $B \to K\ell^-\ell^+$
- $B \to K^*\ell^-\ell^+$
- $B_s \to \phi\ell^-\ell^+$

- Charged Current (CC)

talk by Lopamudra Mukherjee



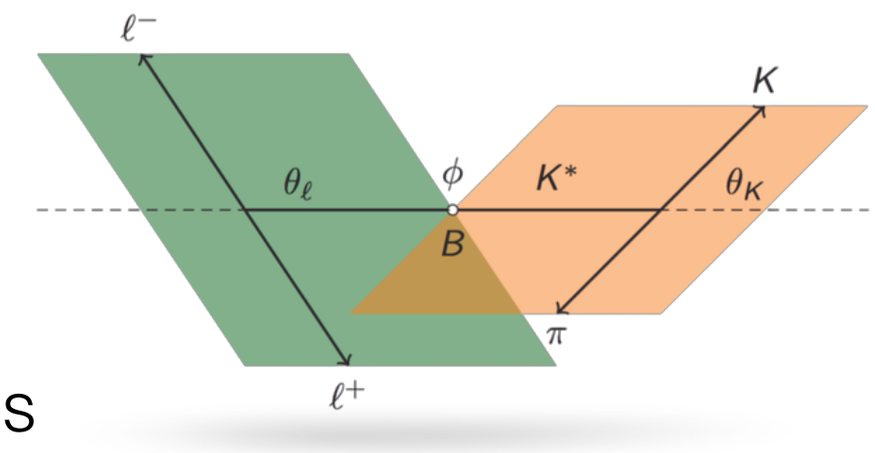
Interesting modes

- $B \to D\ell\bar{\nu}_\ell$
- $B \to D^*\ell\bar{\nu}_\ell$

Angular analysis

4-body decay in helicity frame

$$\frac{d^4\Gamma(B \to K^*(\to K\pi)\ell^+\ell^-)}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = \sum_i S_i(q^2) f_i(\theta_l, \theta_K, \phi)$$



measurable @LHC, *B*-factories

short distance + long distance

Angular analysis

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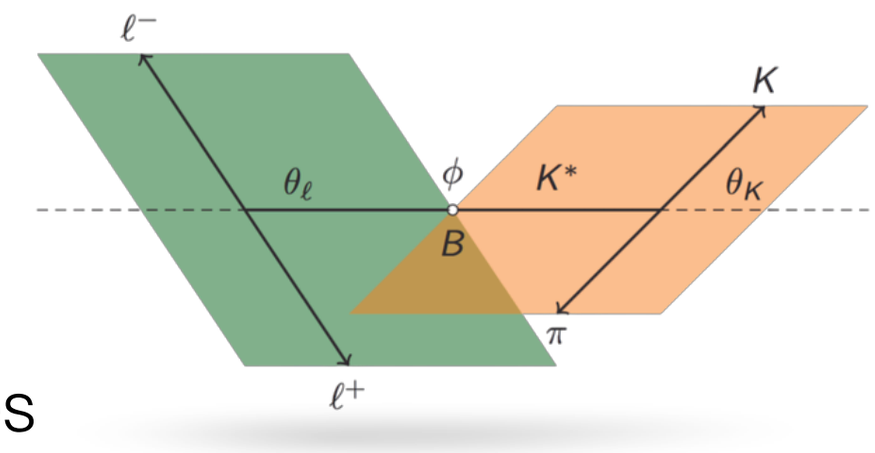

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Wilson coefficients: perturbatively calculable

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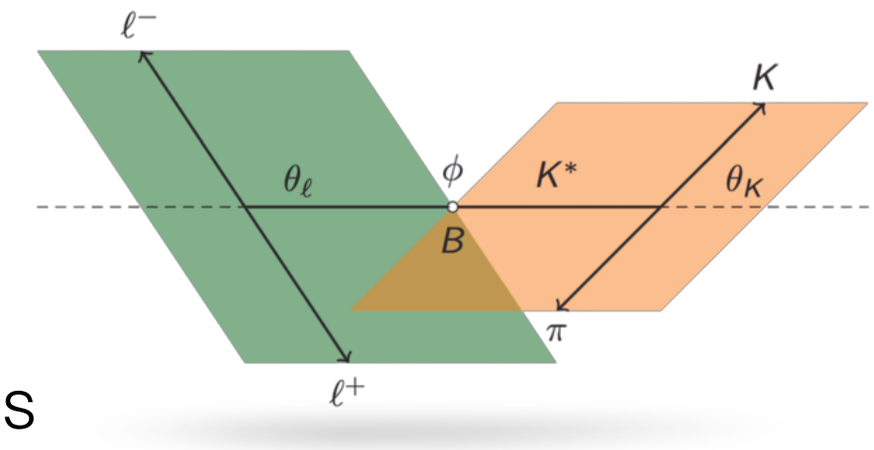

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Wilson coefficients:
perturbatively calculable

Form-factors:
non-perturbative estimates
from LCSR, HQET, Lattice …
tremendous effort since past

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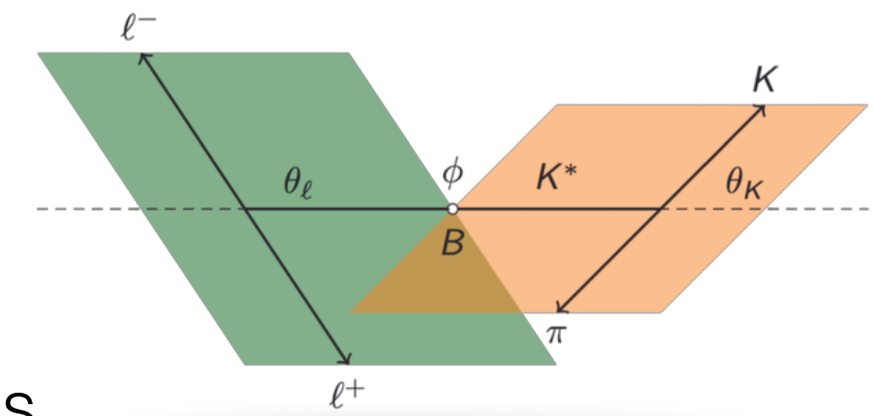

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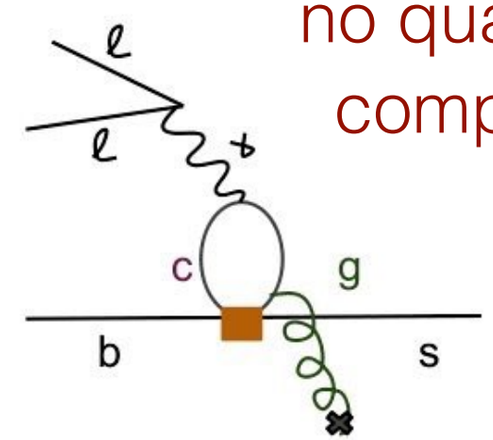
Wilson coefficients: perturbatively calculable

Form-factors: non-perturbative estimates from LCSR, HQET, Lattice … *tremendous effort since past*

Non-factorizable contributions: no quantitative computation



For comparison with data either estimate accurately or eliminate

Neutral current

- The SM hamiltonian and relevant operators for $b \to s\mu\mu$

$$\mathcal{H}^{\text{eff}} = \frac{-4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu)\mathcal{O}_i(\mu)\,,$$

Wilson coefficients:
perturbatively calculable

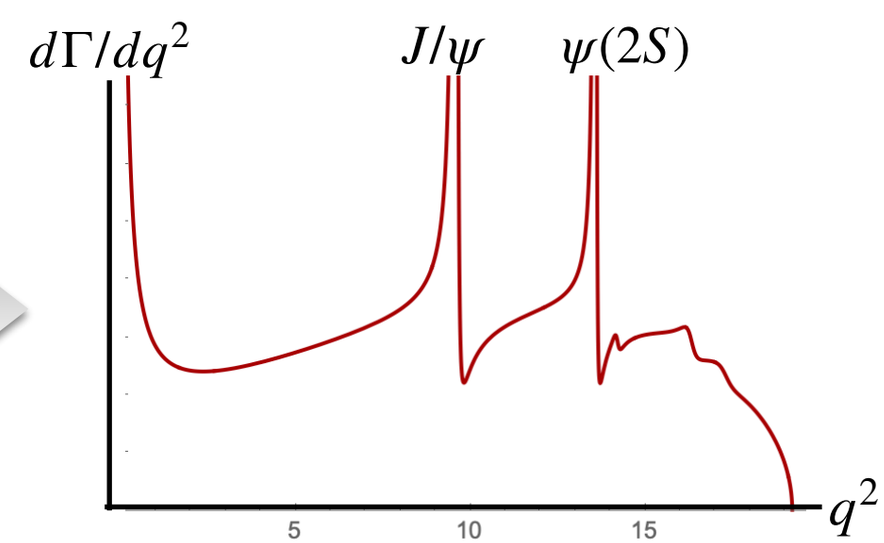
$$C_i \to C_i^{\text{SM}} + \delta C_i$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \left(\bar{s}\sigma_{\mu\nu}P_R b\right) F^{\mu\nu}$$

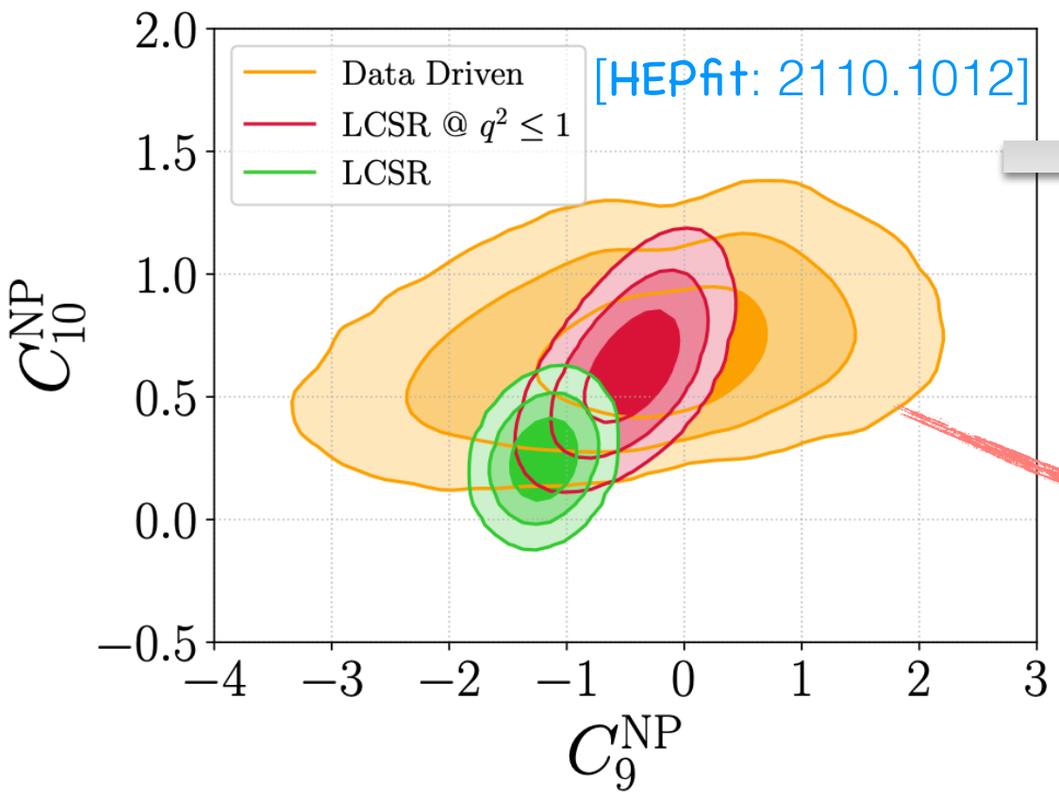
$$\mathcal{O}_9 = \frac{e^2}{16\pi^2} \left(\bar{s}\gamma_\mu P_L b\right)\left(\bar{\mu}\gamma^\mu \mu\right)$$

$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2} \left(\bar{s}\gamma_\mu P_L b\right)\left(\bar{\mu}\gamma^\mu \gamma_5 \mu\right)$$

δC_9 : New Physics
+
non factorizable [Khodjamirian *et. al* '10]
charm loop contributions
+
$c\bar{c}$ resonance effects [Kruger *et. al* '96]



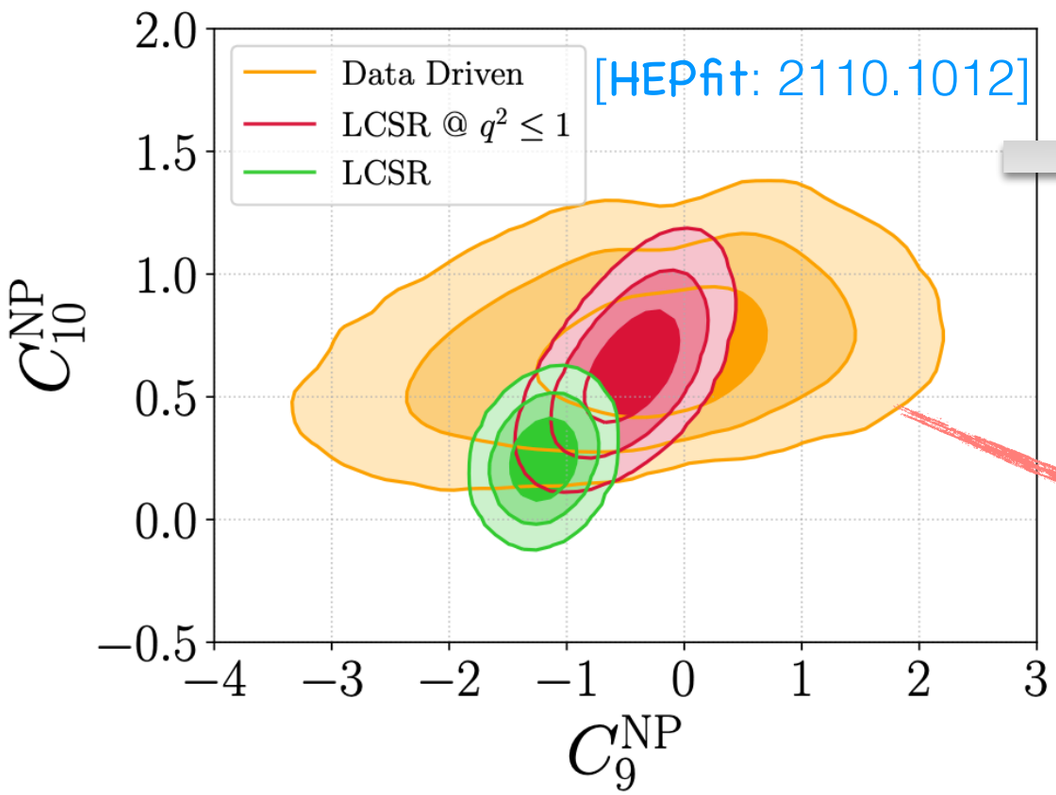
Angular analysis



Global fits to current $b \to s\ell\ell$ data with three different treatments to parametrize charm-loop effects

Hadronic uncertainties due to long distance physics can overshadow new physics

Angular analysis



Global fits to current $b \to s\ell\ell$ data with three different treatments to parametrize charm-loop effects

Hadronic uncertainties due to long distance physics can overshadow new physics

Further cancellation required for angular observables

- ☑ use different lepton flavors: $\dfrac{S_i^{b\to s\mu\mu}(q^2)}{\Gamma_f^{b\to s\mu\mu}(q^2)} - \dfrac{S_i^{b\to see}(q^2)}{\Gamma_f^{b\to see}(q^2)}$

Q-observables
[Capdevila *et. al*, '16]
[Belle: '16]

- ☑ Directly extract $\Delta C_9 = \delta C_9^{b\to s\mu\mu} - \delta C_9^{b\to see}$

Fit to Monte Carlo

[Sibidanov *et. al*, 2203.06827]

- Unbinned likelihood fit to data generated in a new MC inside **EvtGen**
  - — updated form factors [Bharucha *et. al* '15]
  - — implemented all dim-6 NP operators: $C_7^{(\prime)}, C_9^{(\prime)}, C_{10}^{(\prime)}, C_S^{(\prime)}, C_P^{(\prime)}$.

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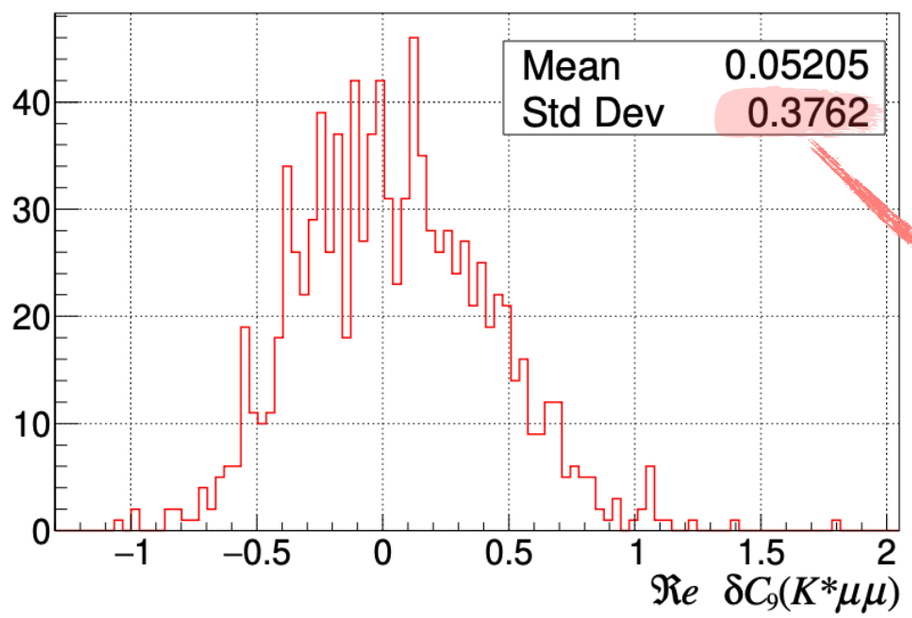

Form-factors varied within 1σ uncertainty

sensitivity@Belle II with 50 fb^{-1}

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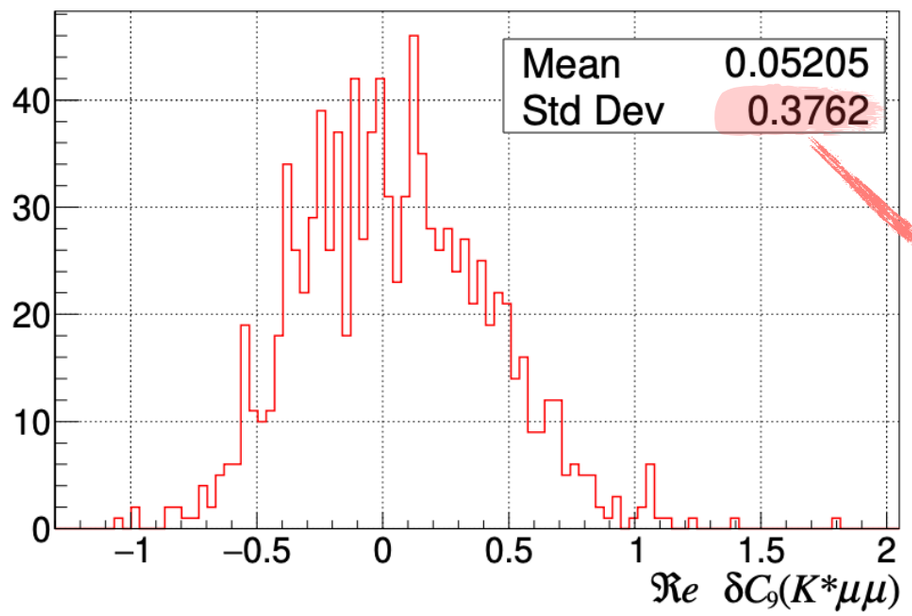

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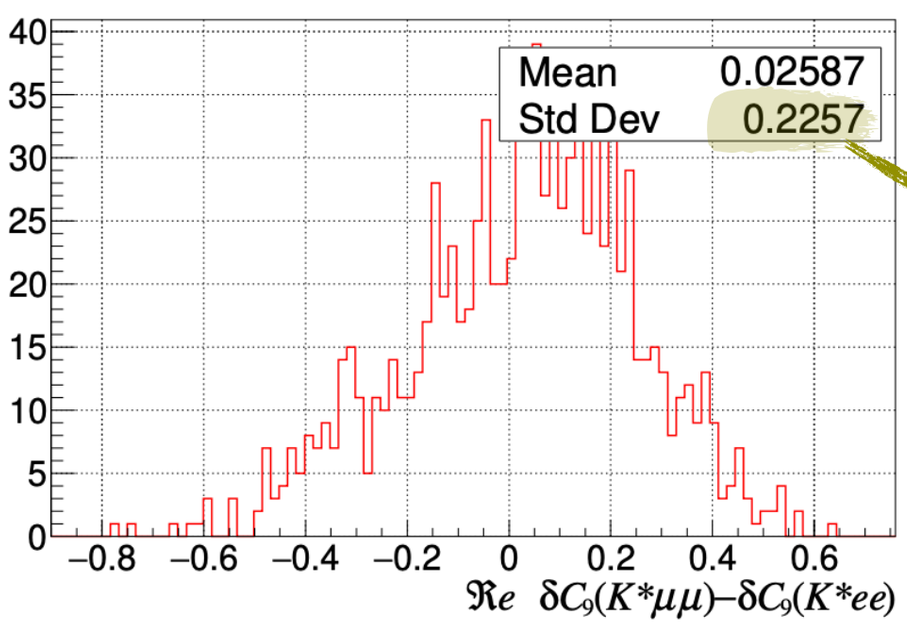

Reduced uncertainty which is limited only by statistics

Resonance effects

[Sibidanov *et. al*, 2203.06827]

- Likelihood modified J/ψ , $\psi(2S)$ resonances using [Kruger *et. al* '96]
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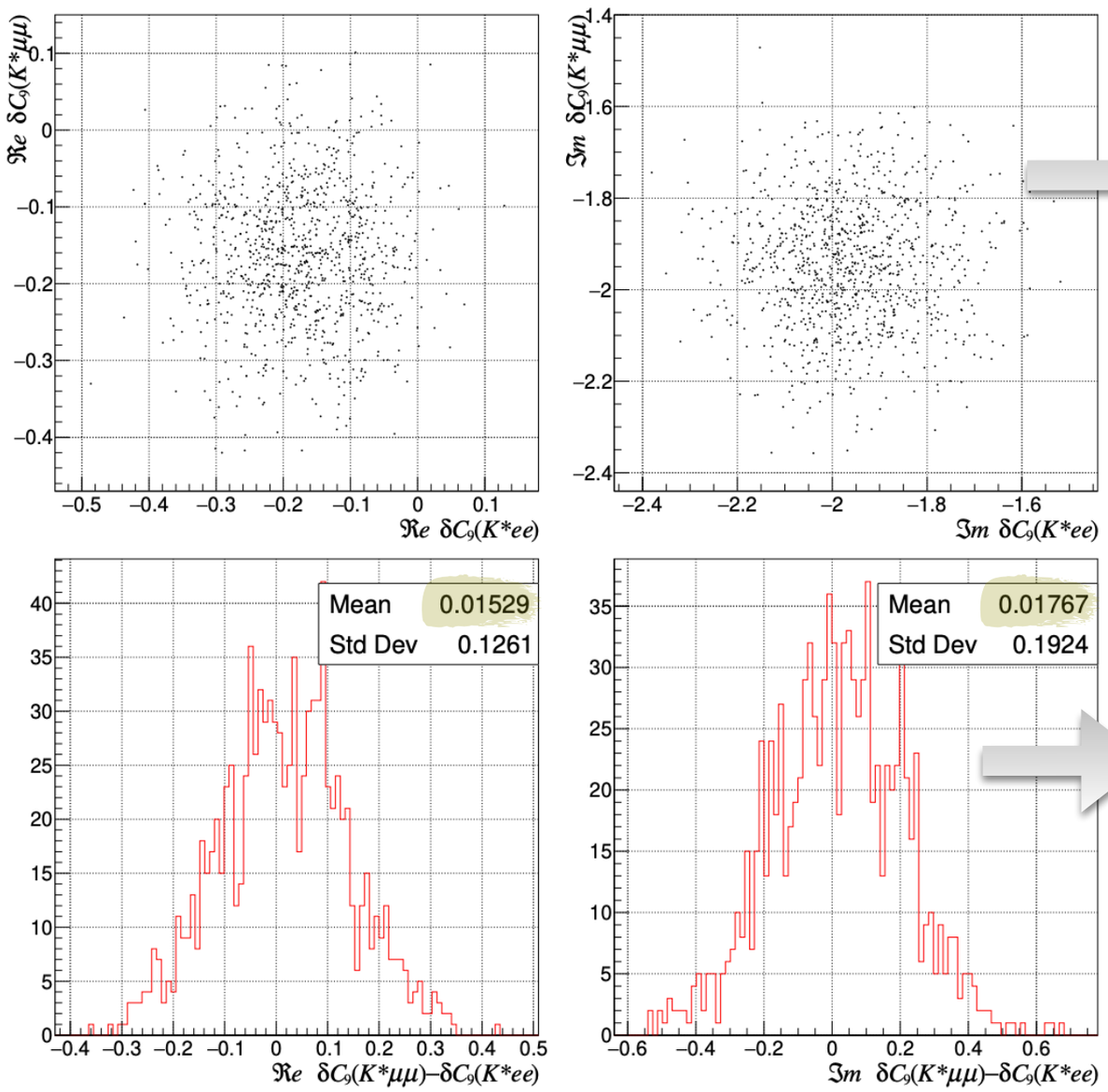

Individual δC_9 biased away from zero mimicking NP

$e-\mu$ removes the hadronic bias — sensitive probe of NP

Next is $B \to D^* \ell \bar{\nu}_\ell$