Belle II input to RF3: Fundamental physics in small experiments (g-2)

Based on “Opportunities for precision QCD physics in hadronization at Belle II -- a snowmass whitepaper” (2204.02280 [hep-ex])

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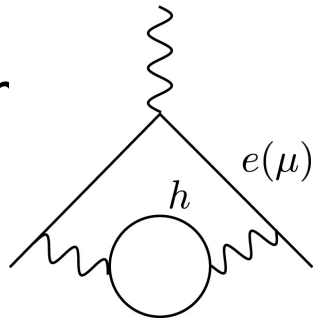
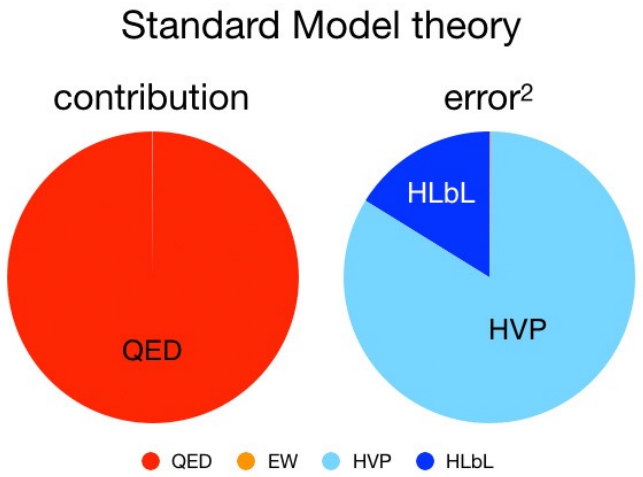
Motivation: Belle II needed to reduce uncertainty on a_μ

- Muon anomalous magnetic moment $a_\mu = \frac{g_\mu - 2}{2}$
- Currently: $a_\mu^{exp} - a_\mu^{SM} \widehat{=} 4.2\sigma$ with uncertainty on a_μ^{exp}, a_μ^{SM} comparable
- Plan to reduce $\sigma_{a_\mu^{exp}}$ by a factor 4:

→Discovery potential of experiment limited if $\sigma_{a_\mu^{SM}}$ is not reduced as well.

- "The dominant sources of theory error are by far the hadronic contributions, in particular, the $\mathcal{O}(\alpha^2)$HVP term and the $\mathcal{O}(\alpha^3)$ HLbL term





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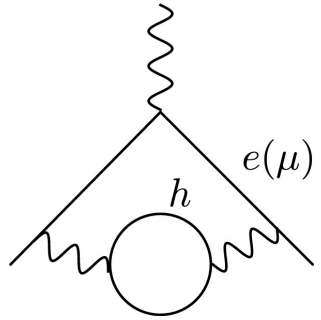

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- Gold Standard for HVP determination: Experimental measurement of $e^$ hadronic cross-section (R measurement)
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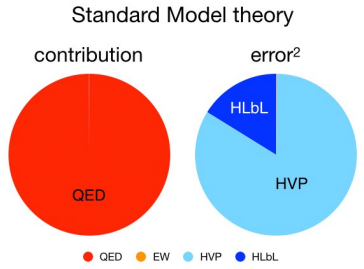

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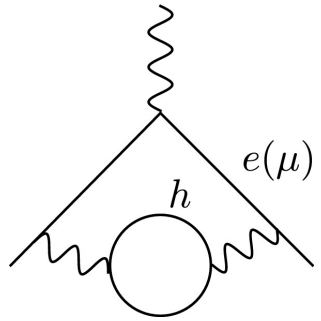
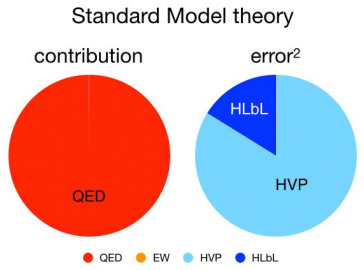
- Belle II will provide new input to resolve current tensions and work on reducing uncertainties on R meausurements ➔ Crucial for discovery potential of g-2 experiment
- A host of other measurements possible to reduce subdominant uncertainties and provide complementary information on HVP, Hlbl →more confidence in results





How to measure HVP in e^+e^-

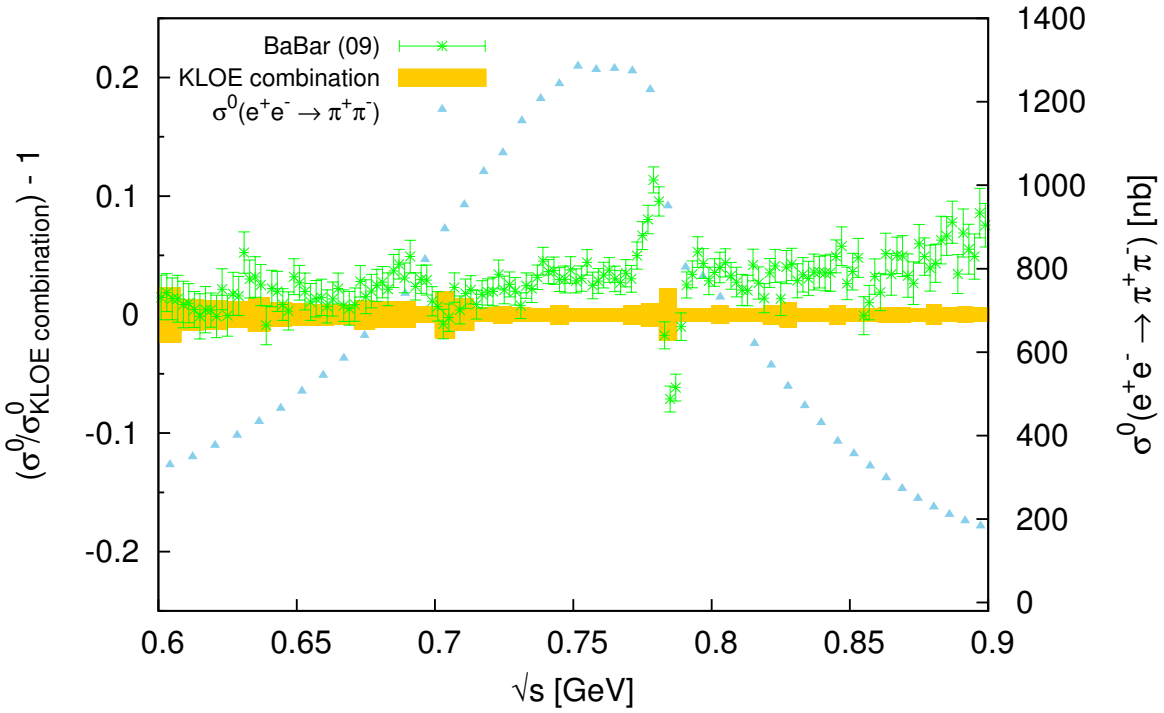
- Use dispersion relation

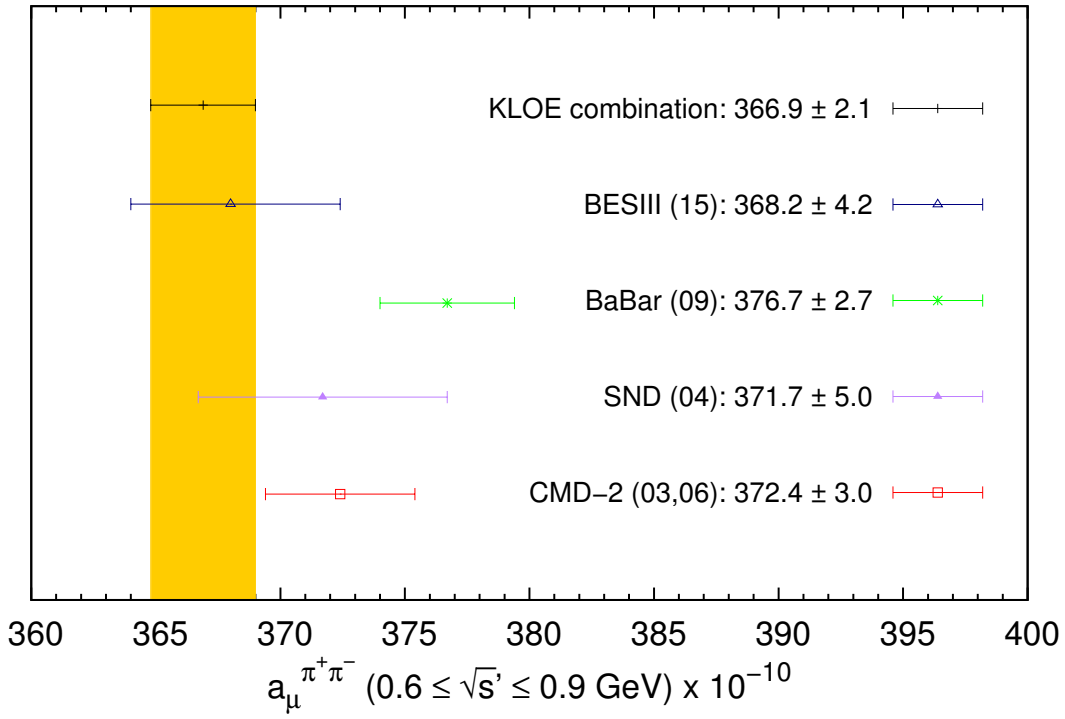
$$a_\mu^{HVP,LO} = \frac{\alpha^2}{2\pi^2}\int_{M_\pi^2}^{\infty}\frac{K(s)}{s}R(s)ds$$

- R: hadronic R ratio: $R(s) = \frac{3s}{4\pi\alpha^2}\sigma_h(e^+e^- \to hadrons)$

- R is dominated by
  low s region
  → $e^+e^- \to \pi\pi$ (70%)
  →resonance region around ρ, ω
  Fixed energy B factories: ISR technique
- E.g. at BaBar effectively the ratio $\frac{\sigma(e^+e^-\to\pi\pi)}{\sigma(e^+e^-\to\mu\mu)}$ is measured
  →dominant systematic cancel
  →remaining systematics dominated by PID, ISR calculations

Tension in existing KLOE/BaBar measurements

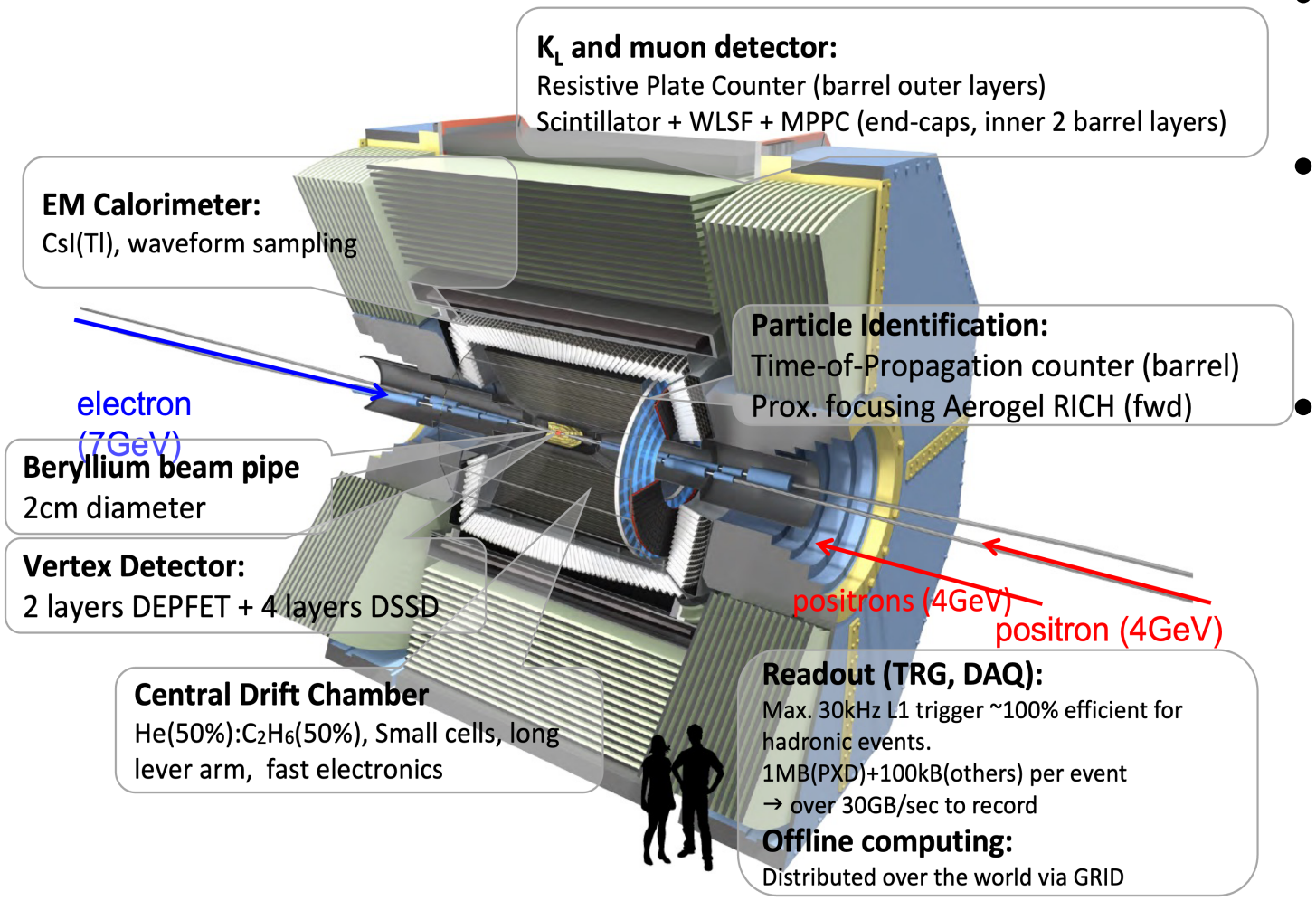




Need to be resolved !

Figures from JHEP 03, 173 (2018), arXiv:1711.03085 [hep-ex]

Belle II outlook for $\sigma\left(e^+e^- \to \pi^+\pi^-(\gamma)\right)$ measurement



- Trigger on ISR photons➔$\approx$ 100% efficiency for ISR events
- SuperKEKB luminosities➔ Systematics will dominate over whole kinematic range
- State of the art experiment, PID performance matching that of BaBar

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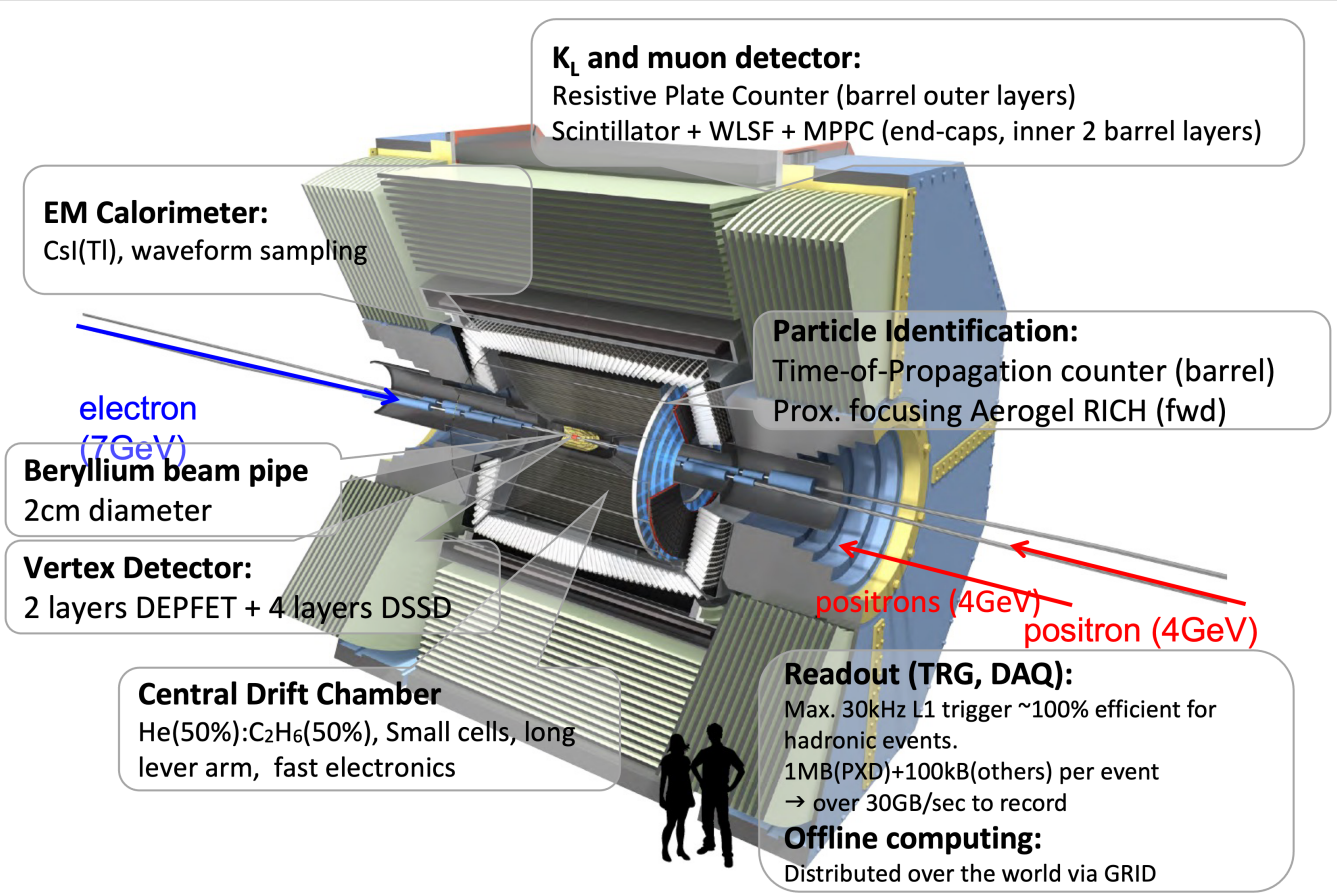

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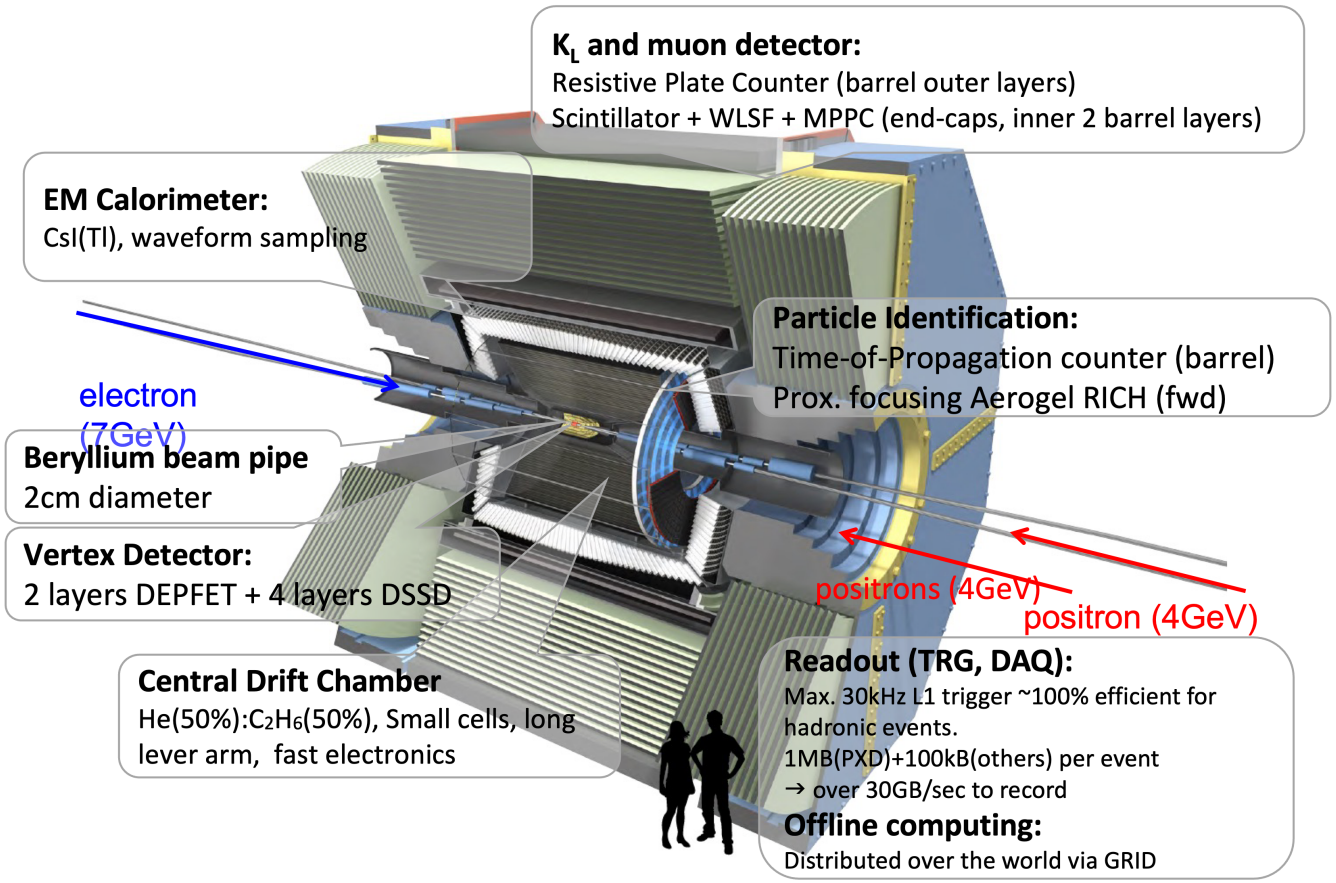

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- Large luminosity will
  - facilitate systematic studies (in particular PID)
    → Expect significantly improvement of previous results
  - Help with subdominant channels like $K^+K^-, \pi^+\pi^-\pi^0, \pi^+\pi^-\pi^0\pi^0$

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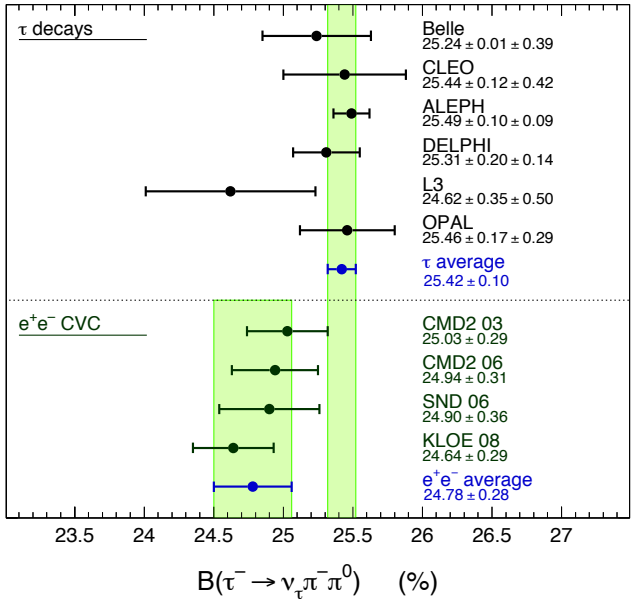
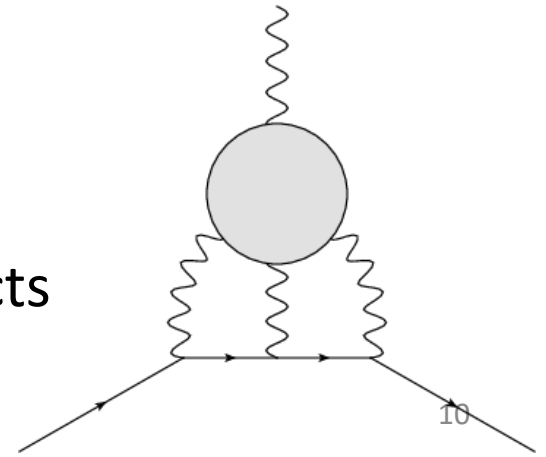
Additional Measurements related to g-2

- Conserved vector current (CVC):
  $\tau \to \pi^0 \pi \nu_\tau \leftrightarrow e^+e^- \to \pi\pi$

  - However: isospin breaking effects not fully understood
    →tension between τ decay and CVC e^+e^-
    →Future theory developments could bring this channel into play again
  - Belle II will provide further input



- Hadronic Light-by-Light (HLbL)
  - HLbL is $\mathcal{O}(\alpha^3)$ →needs to be known to within $\approx 10\%$
  - 4-point function →significantly more complex than HVP
    →experimental input is needed to validate theory models
    →See whitepaper for measurements validating different aspects of the calculations



Summary and Take away message

- a_μ measurements among the most sensitive to New Physics

BUT:

Discovery potential needs experimental input from e^+e^- to reduce theory uncertainty to same level as expected experimental uncertainties

Need:

→HVP from $e^+e^- \to \pi\pi$

→HLbL from form factors and $\gamma\gamma$ →hadrons

Belle II is a second generation B-factory

- State of the art detector optimized for precision physics with identified hadrons
- Will reduce systematics by resolving current experimental tension in HVP
- Excellent opportunity to reduce systematics to expected precision of a_μ^{exp}
- Must do experiment to validate theory calculations for HVP and HLbL

Details in "Opportunities for precision QCD physics in hadronization at Belle II -- a snowmass whitepaper" (2204.02280 [hep-ex])