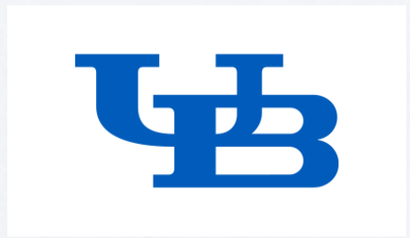
BSM PHYSICS FOR MUON-ELECTRON SCATTERING

Ulrich Schubert

SUNY Buffalo

In collaboration with C. Williams



MUON G-2

- **Muon magnetic moment**

$$\vec{\mu}_\mu = g_\mu \frac{Qe}{2m_\mu}\vec{s} \qquad\qquad g_\mu = 2(1 + a_\mu)$$

- **High precision test of Standard model**
  - E821 experiment at BNL measured

$$\mathbf{a}_\mu^{\mathrm{E821}} = \mathbf{116592091(63)} \times \mathbf{10^{-11}}$$ Bennett et al. [Muon g-2 Collaboration]

  - Standard model prediction

$$\mathbf{a}_\mu^{\mathrm{SM}} = \mathbf{116591821(38)} \times \mathbf{10^{-11}}$$ Keshavarzi, Nomura, Teubner

  - 3σ difference

$$\mathbf{\Delta a}_\mu = \mathbf{a}_\mu^{\mathrm{E821}} - \mathbf{a}_\mu^{\mathrm{SM}} = \mathbf{270(74)} \times \mathbf{10^{-11}}$$

- **Muon g-2 experiment at FNAL is analyzing first run**
  - Could push difference to 5σ

MUON G-2

- **Muon magnetic moment**

$$\vec{\mu}_\mu = g_\mu \frac{Qe}{2m_\mu}\vec{s} \qquad\qquad g_\mu = 2(1 + a_\mu)$$

- **High precision test of Standard model**
  - E821 experiment at BNL measured

$$\mathbf{a}_\mu^{\mathrm{E821}} = \mathbf{116592091(63)} \times \mathbf{10^{-11}}$$

Bennett et al. [Muon g-2 Collaboration]

  - Standard model prediction

$$\mathbf{a}_\mu^{\mathrm{SM}} = \mathbf{116591821(38)} \times \mathbf{10^{-11}}$$

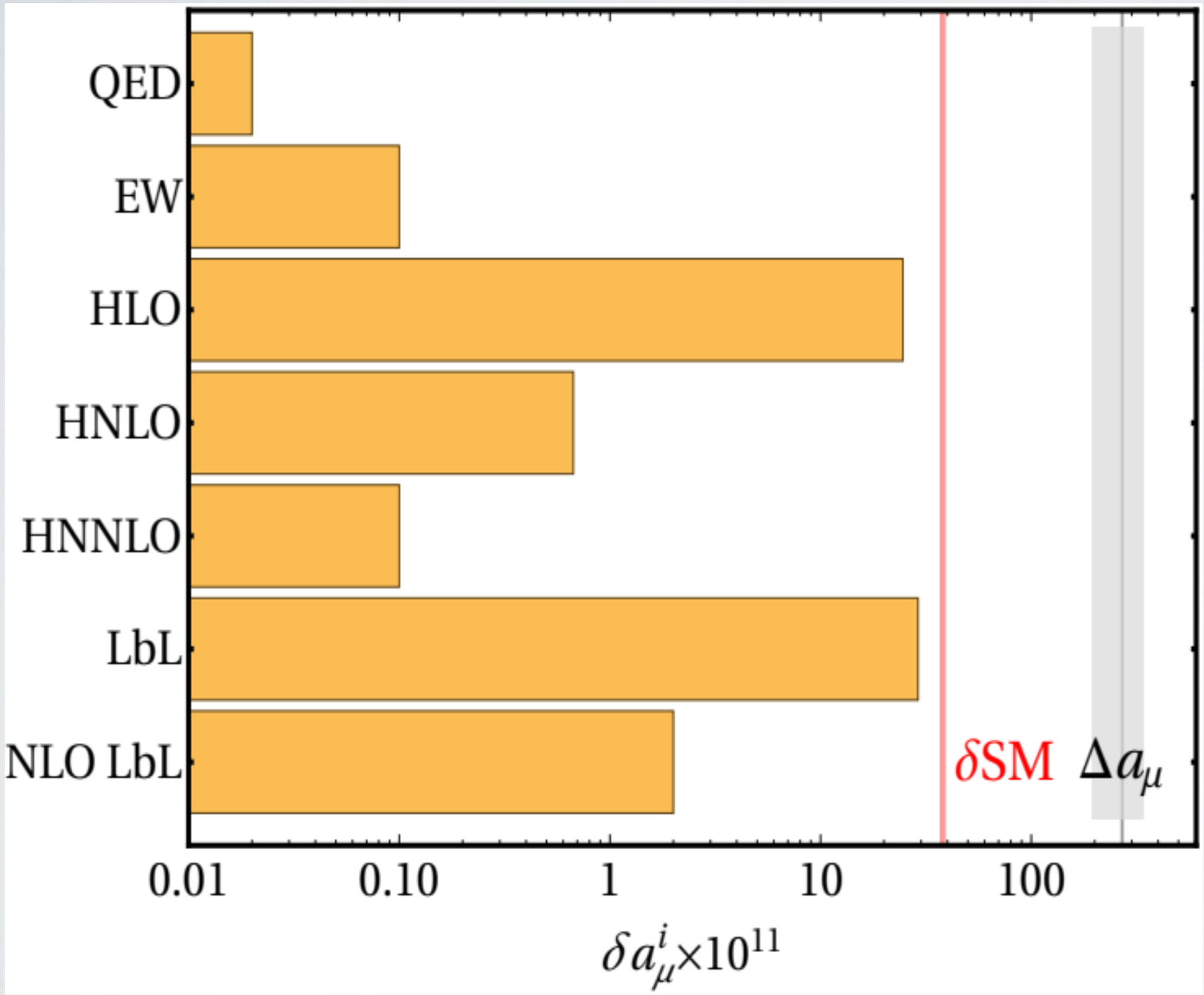
Keshavarzi, Nomura, Teubner

  - 3σ difference

$$\mathbf{\Delta a}_\mu = \mathbf{a}_\mu^{\mathrm{E821}} - \mathbf{a}_\mu^{\mathrm{SM}} = \mathbf{270(74)} \times \mathbf{10^{-11}}$$

- **Muon g-2 experiment at FNAL is analyzing first run**
  - Could push difference to 5σ → **Ensure theoretical error**

THEORETICAL ERROR BUDGET



Aoyama, Kinoshita, Nio

Gnedinger, Stöckinger, Stöckinger-Kim

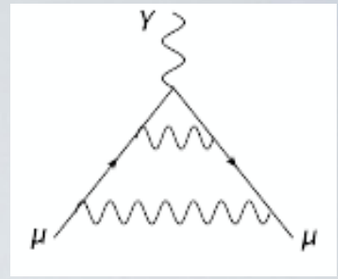
Keshavarzi, Nomura, Teubner

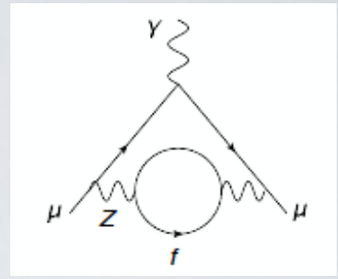
Jegerlehner

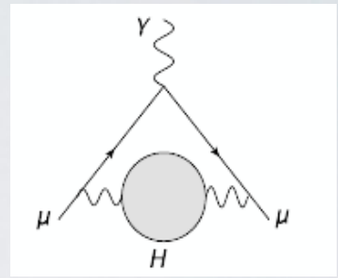
Kurz, Liu, Marquard, Steinhauser

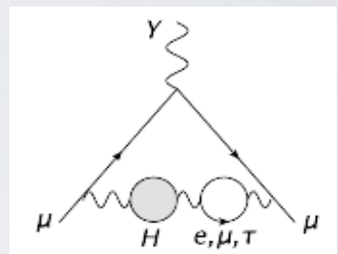
Jegerlehner

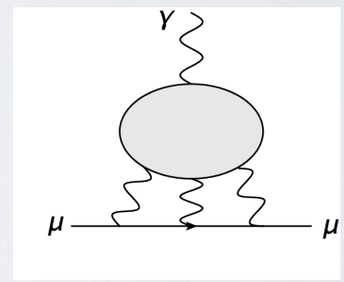
Colangelo, Hoferichter, Nyffeler, Passera, Stoffer

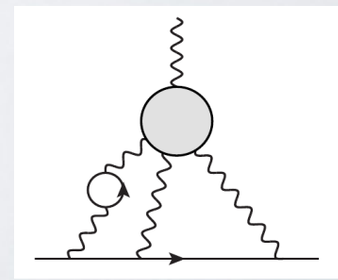












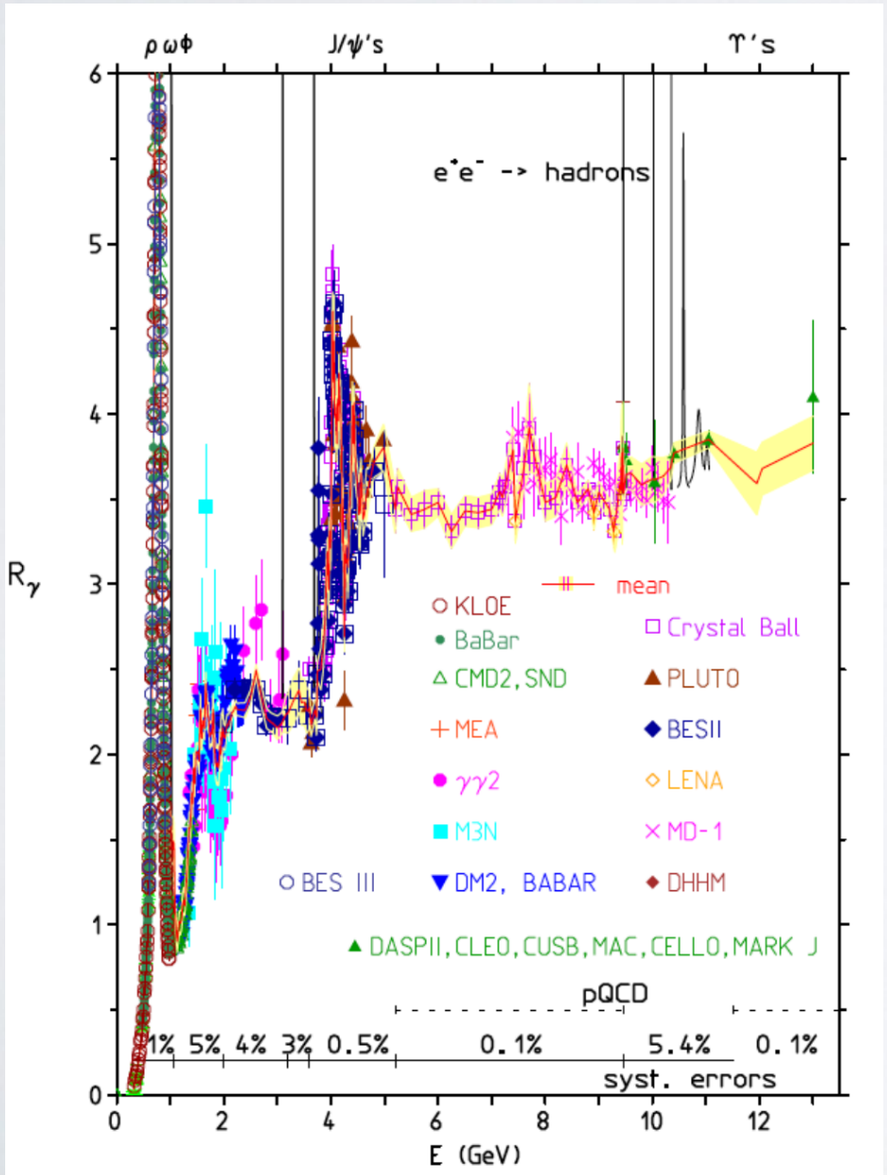
LEADING HADRONIC CONTRIBUTION

Time-like

- **Extract a_μ^{HLO} from R-Ratio**

Bouchiat; Michele; Durand;Gourdin, de Rafael

$$a_\mu^{\mathrm{HLO}} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds \int_0^1 dx \frac{x^2(1-x)}{x^2+(1-x)s/m_\mu^2} R^{\mathrm{had}}(s)$$



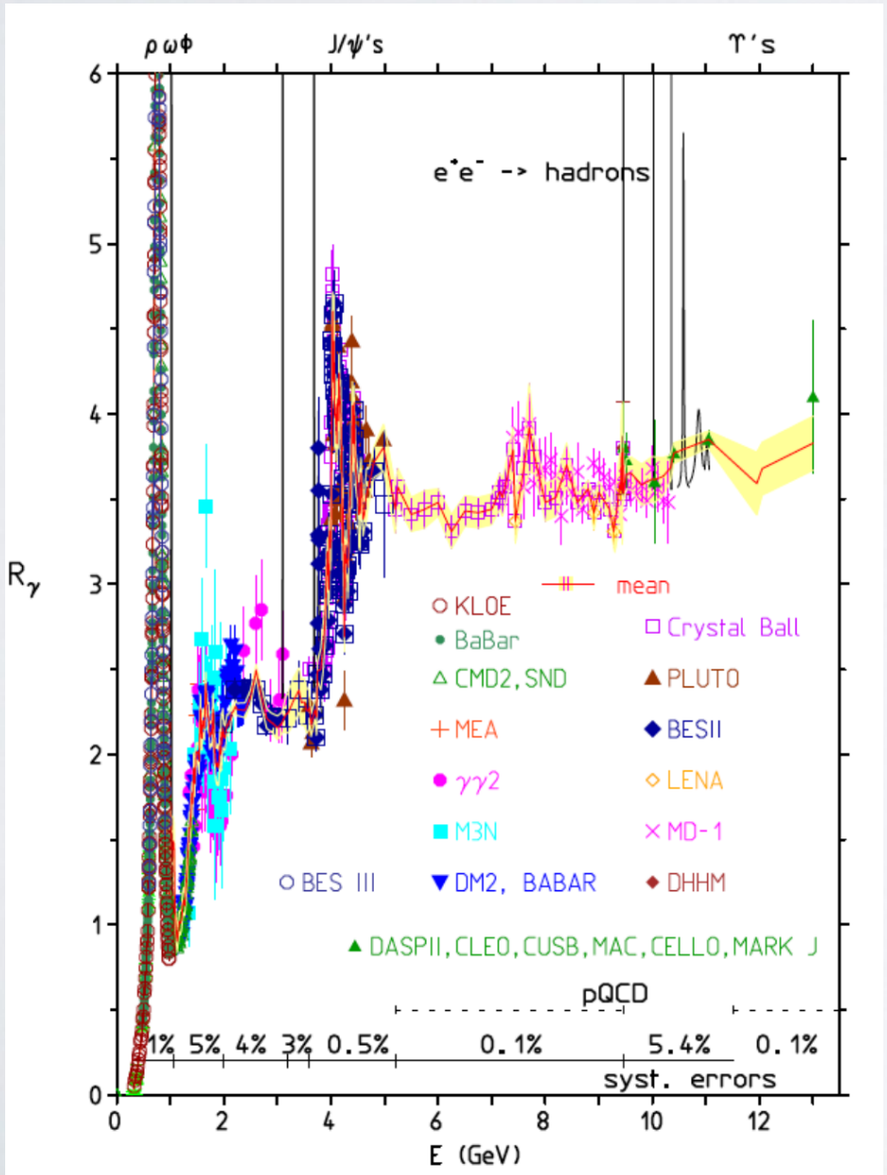
LEADING HADRONIC CONTRIBUTION

Time-like

- **Extract a_μ^{HLO} from R-Ratio**

Bouchiat; Michele; Durand;Gourdin, de Rafael

$$a_\mu^{HLO} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds \int_0^1 dx \frac{x^2(1-x)}{x^2+(1-x)s/m_\mu^2} R^{had}(s)$$

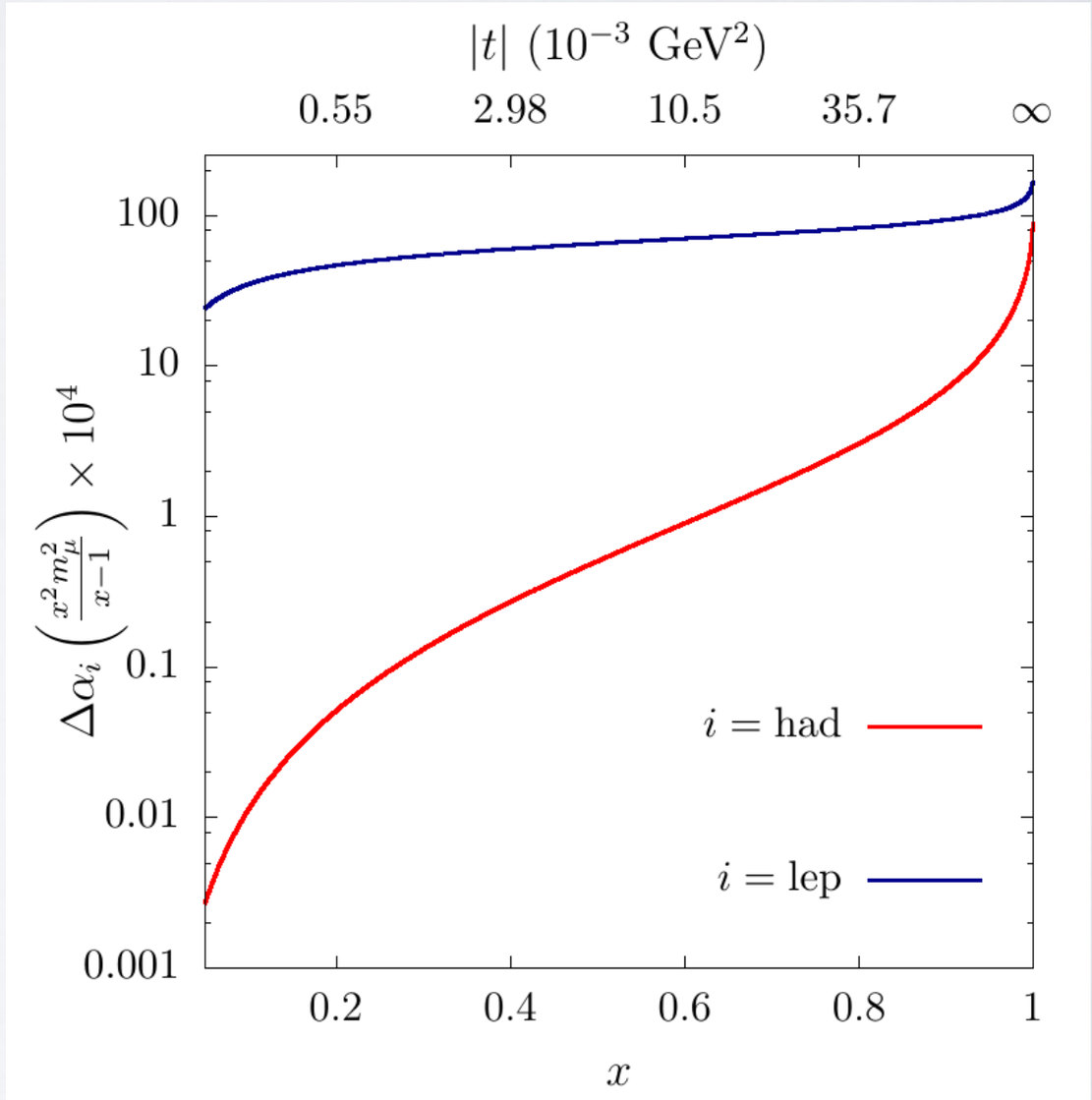


Space-like

- **Extract a_μ^{HLO} from running of α**

Carloni Calame, Passera, Trentadue, Venanzoni

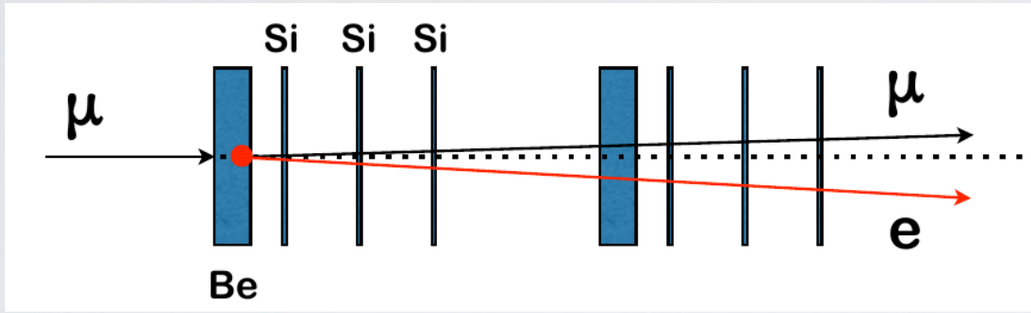
$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx (1-x)\Delta\alpha_{had}[t(x)]$$



MUONE EXPERIMENT

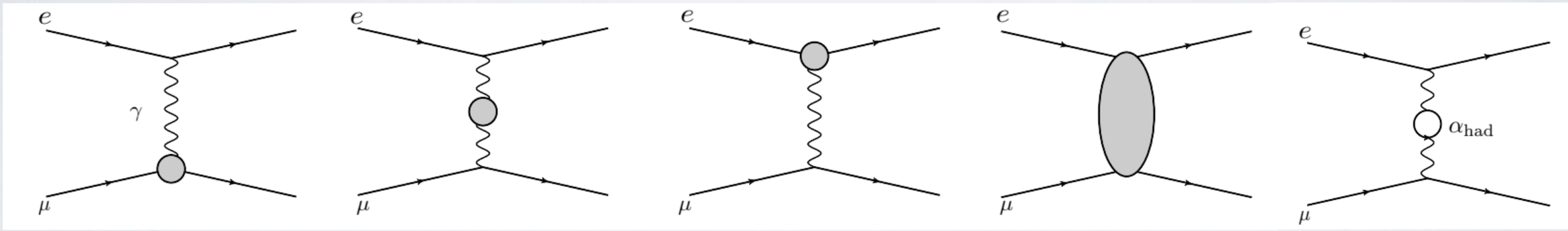
Carloni Calame, Passera, Trentadue, Venanzoni

- **Scatter 150 GeV muons of atomic electrons**



$$s = 0.164\,\mathrm{GeV}^2$$
$$-0.143\,\mathrm{GeV}^2 < t < 0\,\mathrm{GeV}^2$$
$$0 < x < 0.93$$

- **Extract $\Delta\alpha_{Had}$ from Muon-Electron scattering**



- **Unaccounted BSM contributions are fitted into $\Delta\alpha_{Had}$**

$$\Delta\alpha_{\mathrm{Had}} = \frac{\left|\begin{array}{c} e \\ \alpha_{\mathrm{had}} \\ \mu \end{array}\right|^2 - \left|\begin{array}{c} \\ \\ \end{array}\right|^2}{\left|\begin{array}{c} \\ \\ \end{array}\right|^2} \qquad \Delta\alpha_{\mathrm{BSM}} = \frac{\left|\begin{array}{c} e \\ \mathrm{BSM} \\ \mu \end{array}\right|^2 - \left|\begin{array}{c} \\ \\ \end{array}\right|^2}{\left|\begin{array}{c} \\ \\ \end{array}\right|^2}$$

DARK PHOTON

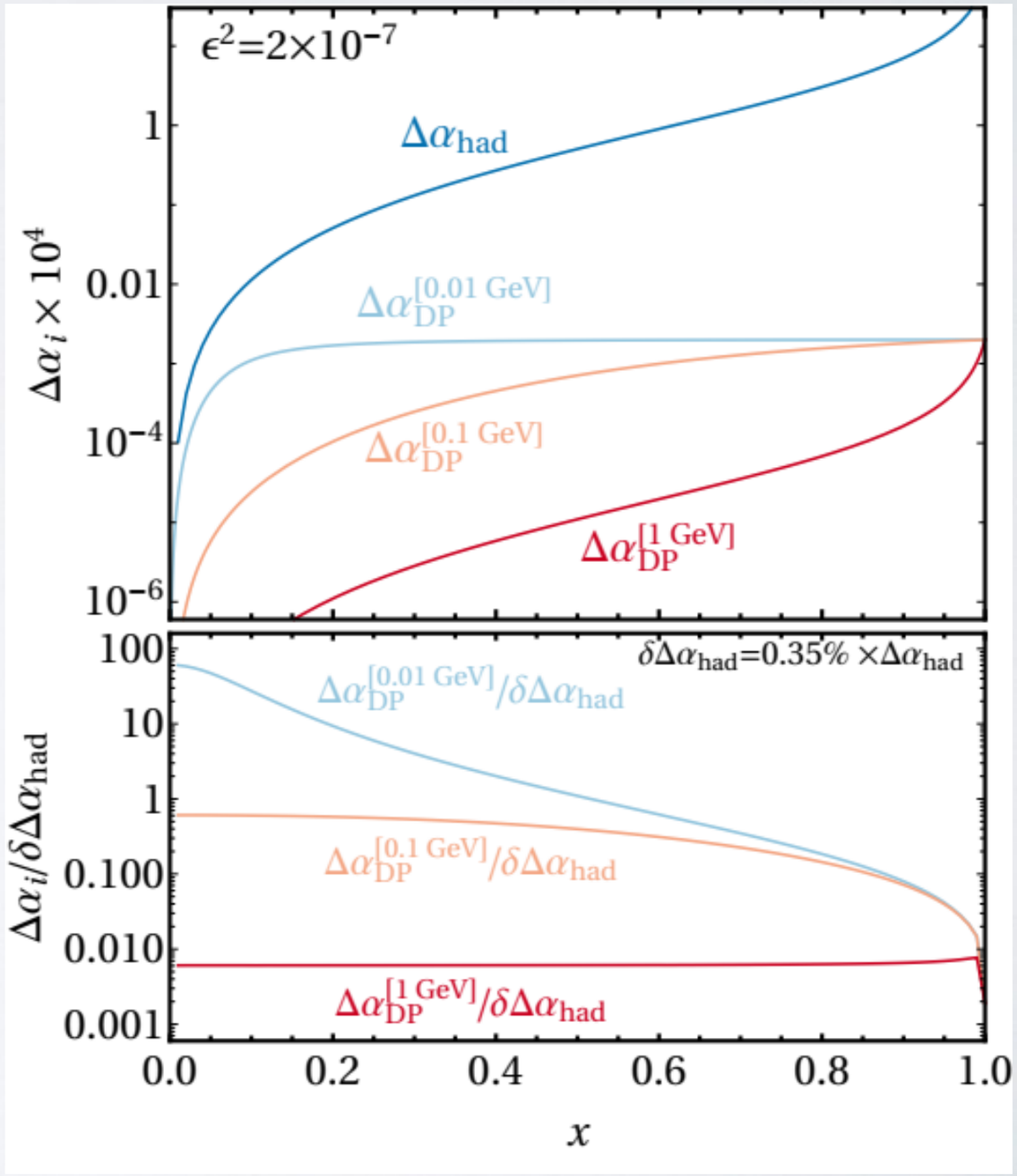
$$s = 0.164\,\mathrm{GeV}^2$$
$$-0.143\,\mathrm{GeV}^2 < t < 0\,\mathrm{GeV}^2$$
$$0 < x < 0.93$$

- **Mixes with Standard Model photon**

$$\Delta\alpha_{\mathrm{DP}} = \frac{\epsilon^2 t}{t - m_{A'}^2}$$

$$\mathcal{L} = -\frac{1}{4}\hat{F}_{\mu\nu}\hat{F}^{\mu\nu} - \frac{\epsilon'}{2}\hat{F}_{\mu\nu}\hat{X}_{\mu\nu} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} - g' y_\mu^Y \hat{B}^\mu + \frac{1}{2}\hat{M}_X^2 \hat{X}_\mu X^\mu$$

- **Gives measurable contribution**



DARK PHOTON

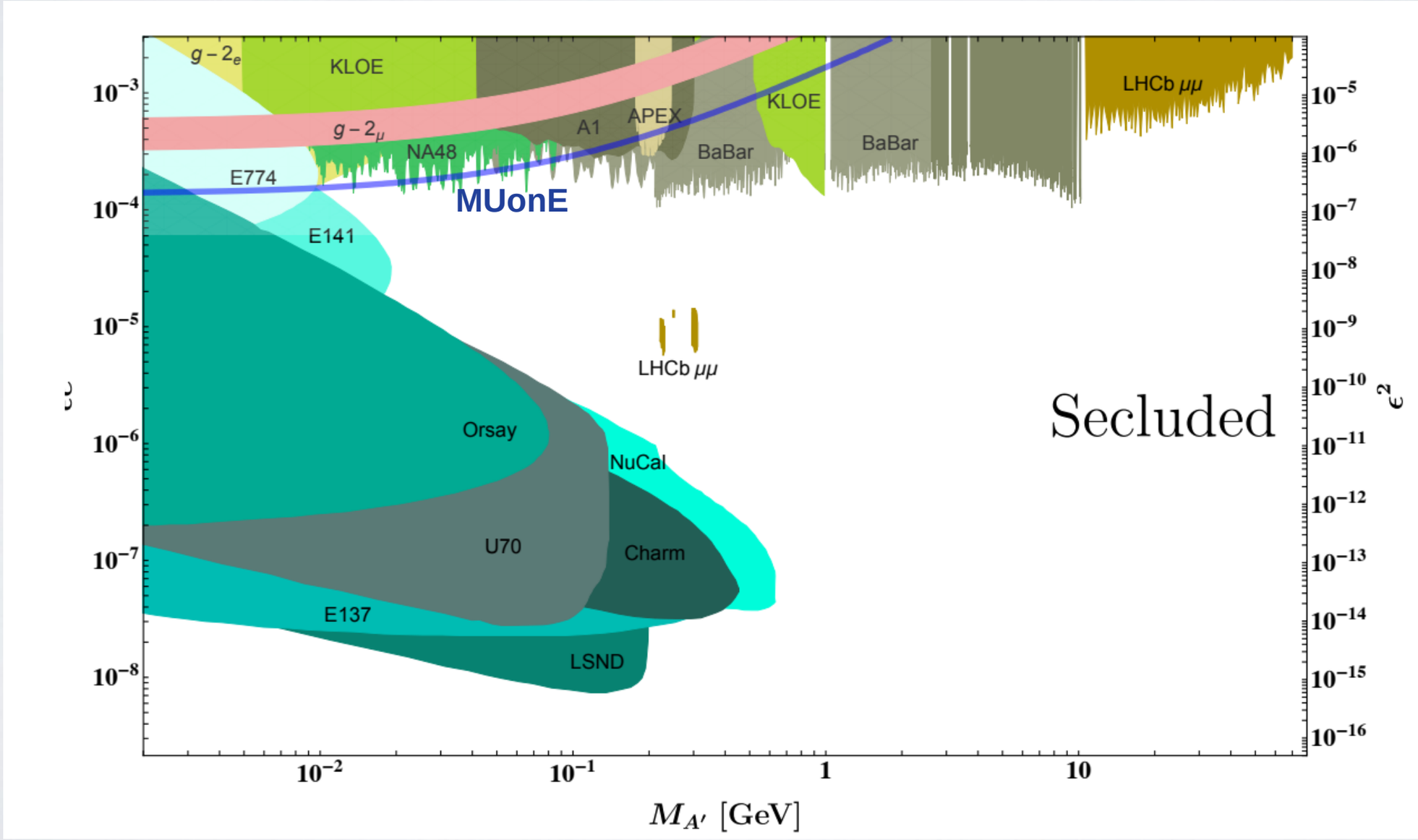
$$s = 0.164\,\mathrm{GeV}^2$$
$$-0.143\,\mathrm{GeV}^2 < t < 0\,\mathrm{GeV}^2$$
$$0 < x < 0.93$$

- **Mixes with Standard Model photon**

$$\Delta\alpha_{\mathrm{DP}} = \frac{\epsilon^2 t}{t - m_{A'}^2}$$

$$\mathcal{L} = -\frac{1}{4}\hat{F}_{\mu\nu}\hat{F}^{\mu\nu} - \frac{\epsilon'}{2}\hat{F}_{\mu\nu}\hat{X}_{\mu\nu} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} - g' y_\mu^Y \hat{B}^\mu + \frac{1}{2}\hat{M}_X^2 \hat{X}_\mu X^\mu$$

- **MuonE can set exclusion limits**



Bauer, Foldenauer, Jaeckel

$$s = 0.164\,\mathrm{GeV}^2$$
$$-0.143\,\mathrm{GeV}^2 < t < 0\,\mathrm{GeV}^2$$
$$0 < x < 0.93$$

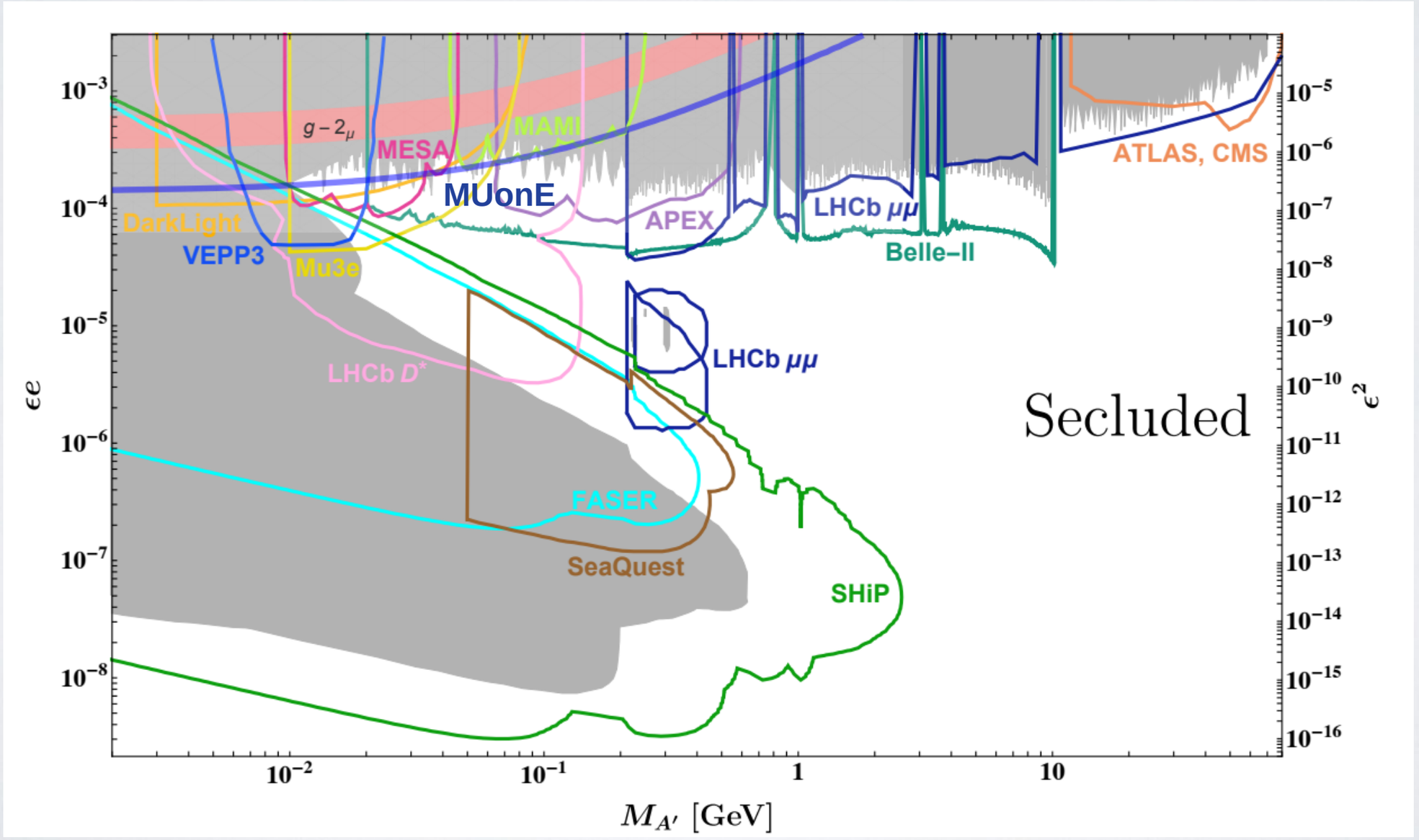
DARK PHOTON

- **Mixes with Standard Model photon**

$$\Delta\alpha_{\mathrm{DP}} = \frac{\epsilon^2 t}{t - m_{A'}^2}$$

$$\mathcal{L} = -\frac{1}{4}\hat{F}_{\mu\nu}\hat{F}^{\mu\nu} - \frac{\epsilon'}{2}\hat{F}_{\mu\nu}\hat{X}_{\mu\nu} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} - g' y_\mu^Y \hat{B}^\mu + \frac{1}{2}\hat{M}_X^2 \hat{X}_\mu X^\mu$$

- **MuonE can set exclusion limits**



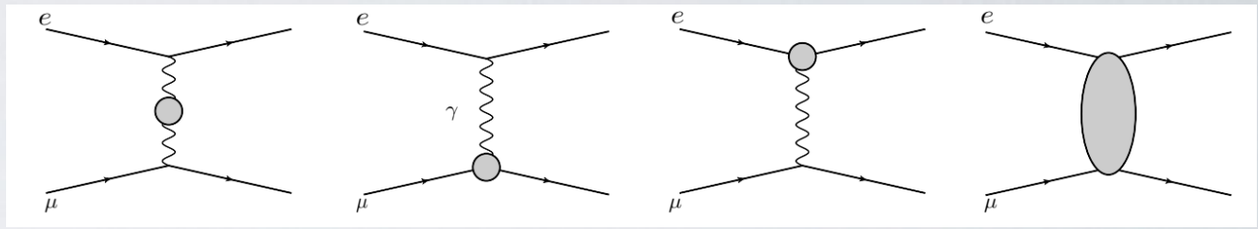
Bauer, Foldenauer, Jaeckel

$$s = 0.164\,\mathrm{GeV}^2$$
$$-0.143\,\mathrm{GeV}^2 < t < 0\,\mathrm{GeV}^2$$
$$0 < x < 0.93$$

BSM @ ONE-LOOP

- **Photon propagator corrections**

$$\Delta\alpha^{\gamma}_{BSM} = \Re[\Sigma^r(t)]$$

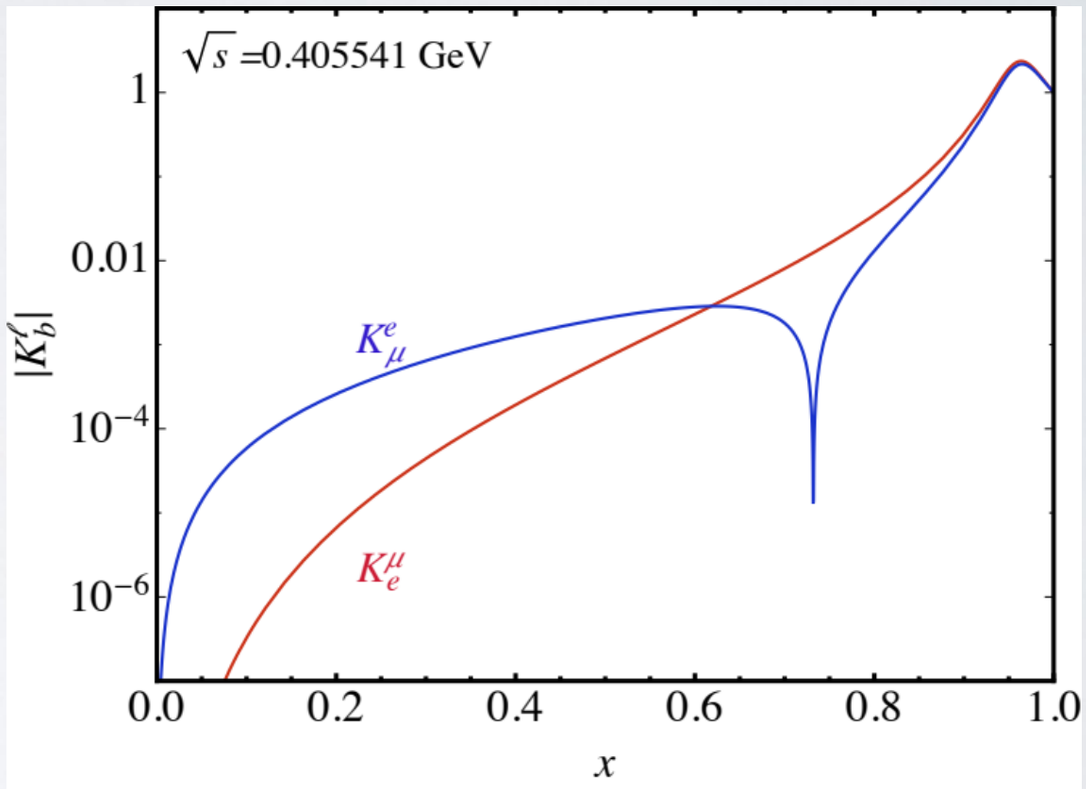


- **Vertex corrections**

$$\Delta\alpha^{\ell}_{BSM} = F^{r,\ell}_e(t) + K^{\ell}_b F^{r,\ell}_m(t)$$

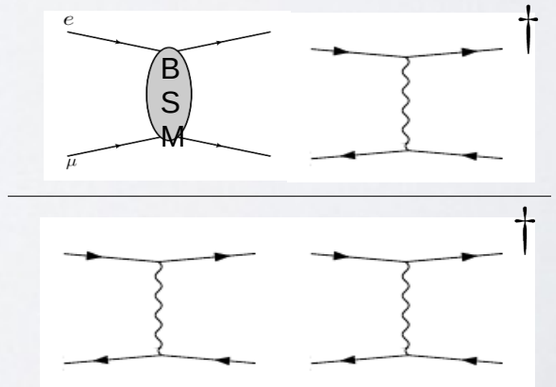
Recall:

$$F^{r,\ell}_m(0) = a_l$$



- **Box corrections**

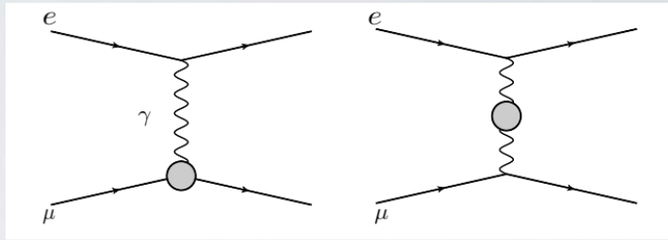
Suppressed by massless propagator



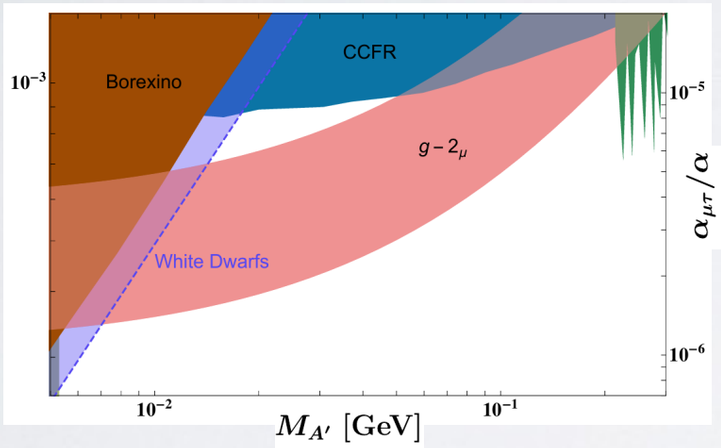
$$s = 0.164\,\mathrm{GeV}^2$$
$$-0.143\,\mathrm{GeV}^2 < t < 0\,\mathrm{GeV}^2$$
$$0 < x < 0.93$$

BSM @ ONE-LOOP

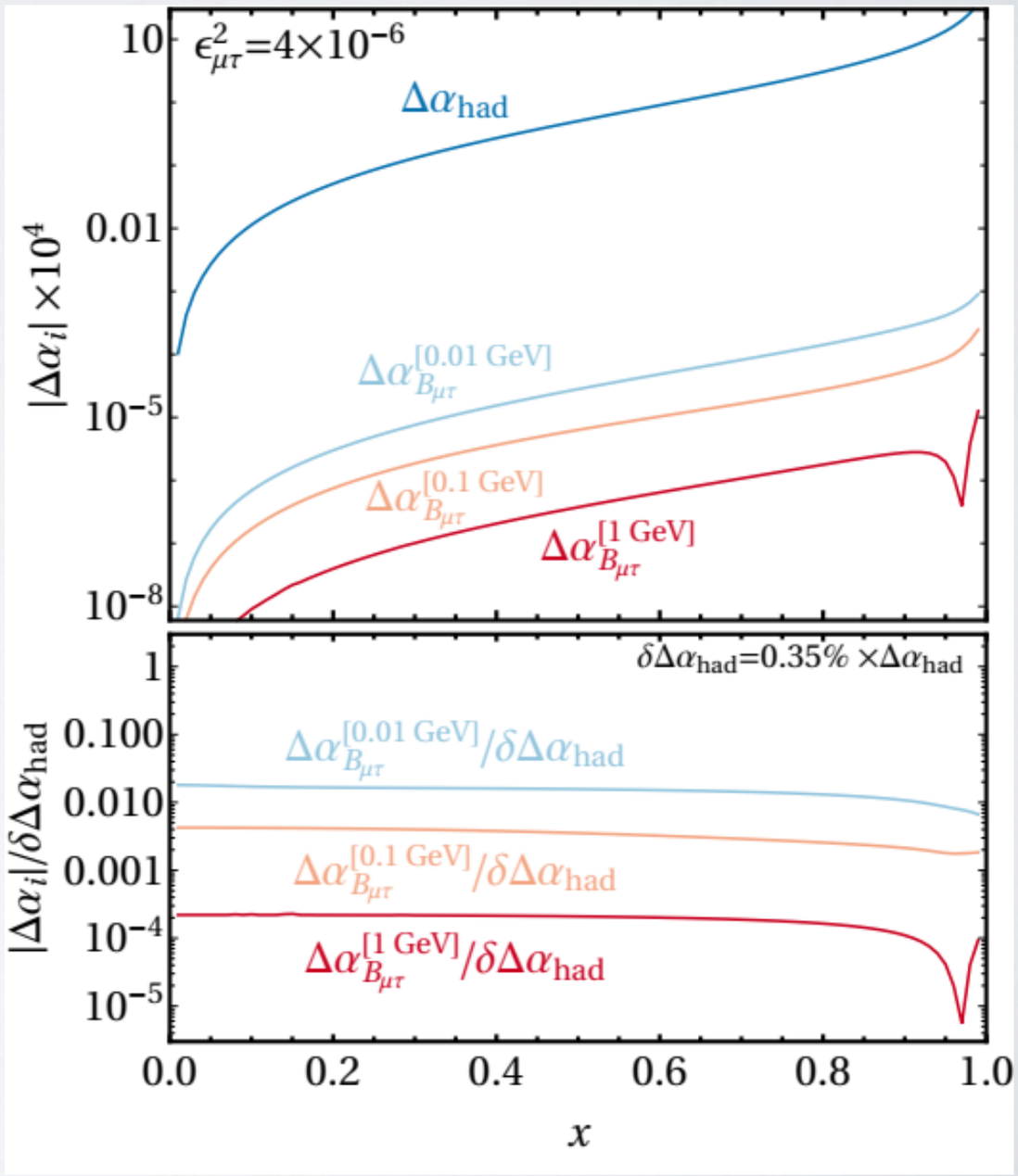
- **Dark photon coupling to μ and τ**



- **Viable muon g-2 explanation**



Bauer, Foldenauer, Jaeckel

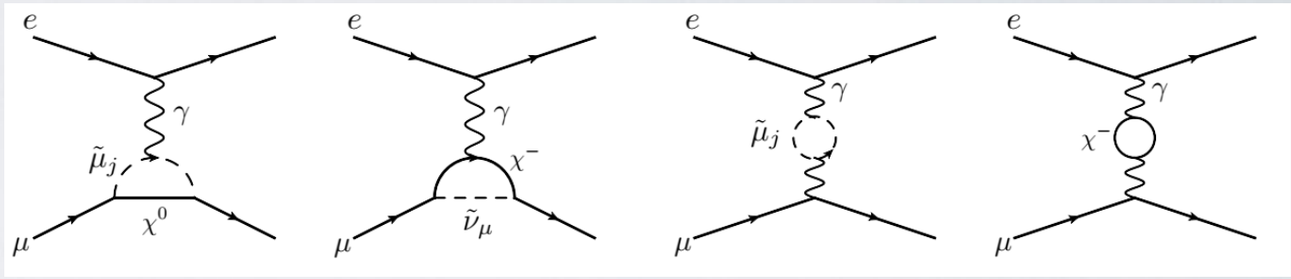


- **Negligible contribution to MUonE**

$$\mathbf{s = 0.164\,GeV^2}$$
$$\mathbf{-0.143\,GeV^2 < t < 0\,GeV^2}$$
$$\mathbf{0 < x < 0.93}$$

MSSM

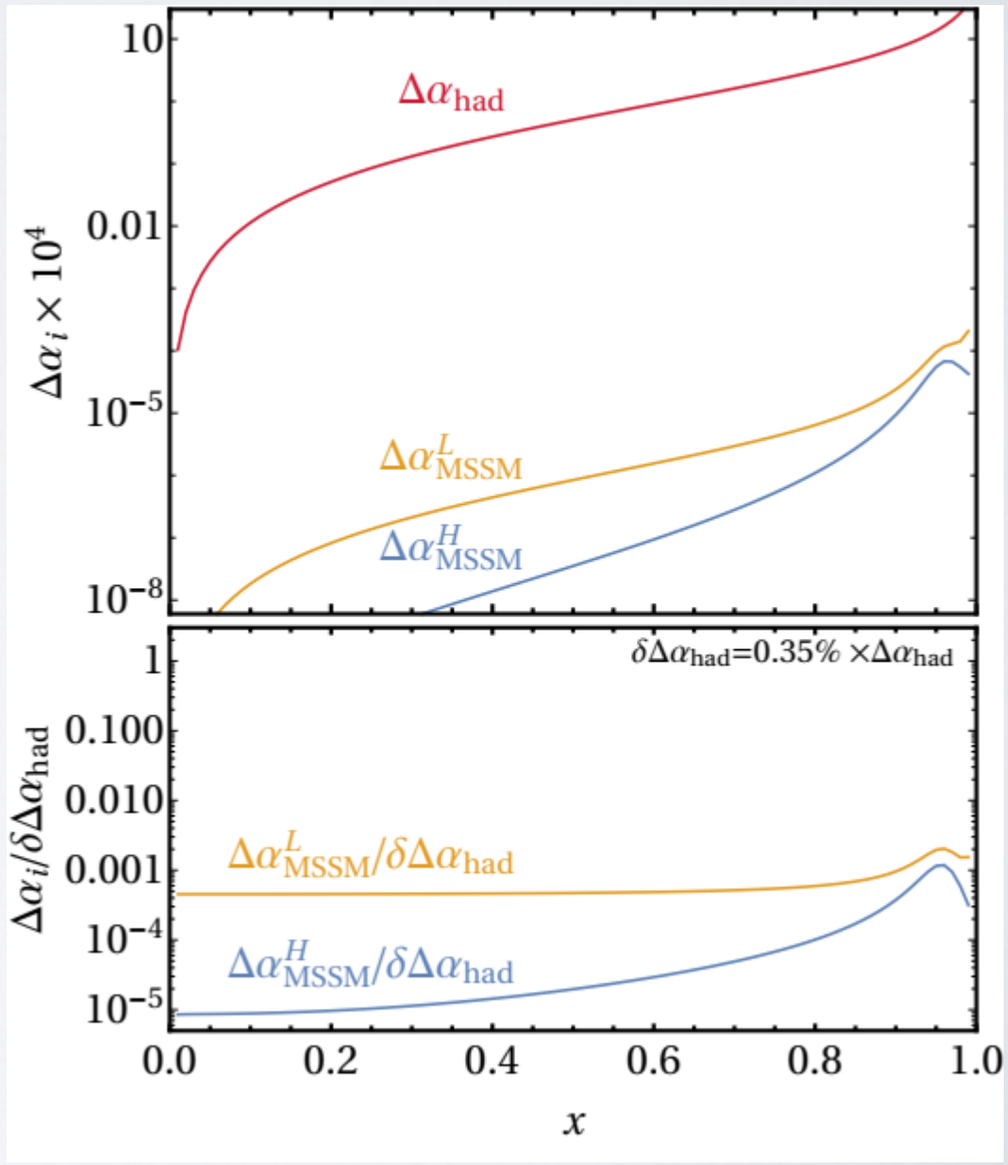
- **Contribution from Smuons-Neutralinos and Chargino-Sneutrinos**



- **Negligible contribution to MUonE**

$\mathbf{L}$:
$$\mathbf{M_2 = 200\,GeV}$$
$$\mu = \mathbf{200\,GeV}$$
$$\tan\beta = \mathbf{4}$$
$$\mathbf{m_{\mu,L} = 100\,GeV}$$
$$\mathbf{m_{\mu,R} = 100\,GeV}$$
$$\mathbf{A_\mu = 0}$$

$\mathbf{H}$:
$$\mathbf{M_2 = 700\,GeV}$$
$$\mu = \mathbf{700\,GeV}$$
$$\tan\beta = \mathbf{30}$$
$$\mathbf{m_{\mu,L} = 300\,GeV}$$
$$\mathbf{m_{\mu,R} = 100\,GeV}$$
$$\mathbf{A_\mu = 0}$$



CONCLUSIONS

- New results from Muon g-2 at Fermilab expected this summer
  - Could push tension with Standard Model to 5σ
- Main theoretical errors from δa_μ^{HLO} and δa_μ^{LbL}
- MUonE provides new and independent way to measure a_μ^{HLO}
- Unaccounted BSM physics contributes to δa_μ^{HLO}
- Light new physics coupling at tree-level has biggest impact
  - MuonE could set exclusion limits on dark photon models
- BSM explanations of g-2 are kinematically suppressed
  - Loop contributions from MSSM and $B_{\mu\tau}$ negligible

BACKUP SLIDES

Future plans

- CERN's Physics Beyond Colliders Working Group Report:
  "The aim of the MUonE proposal… would be an extremely valuable independent determination for the value of $(g-2)_\mu$"

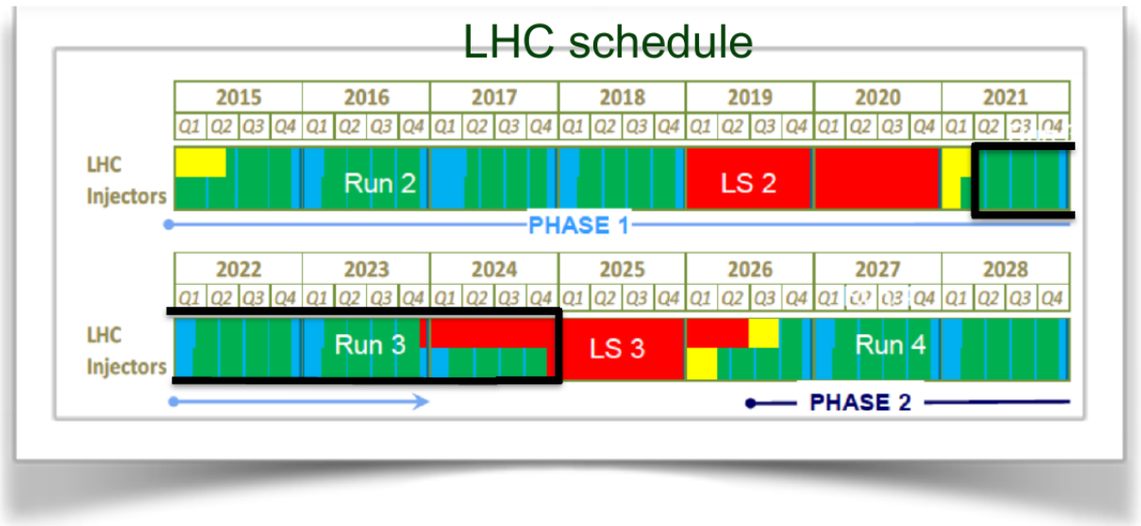
  A. Dainese et al., CERN-PBC-REPORT-2018-008, arXiv:1901.04482

- 2019
  - Letter of Intent planned to CERN's SPSC
  - Detector optimisation-test beam

- 2020-21
  - Detector construction & installation
  - Pilot run in 2021

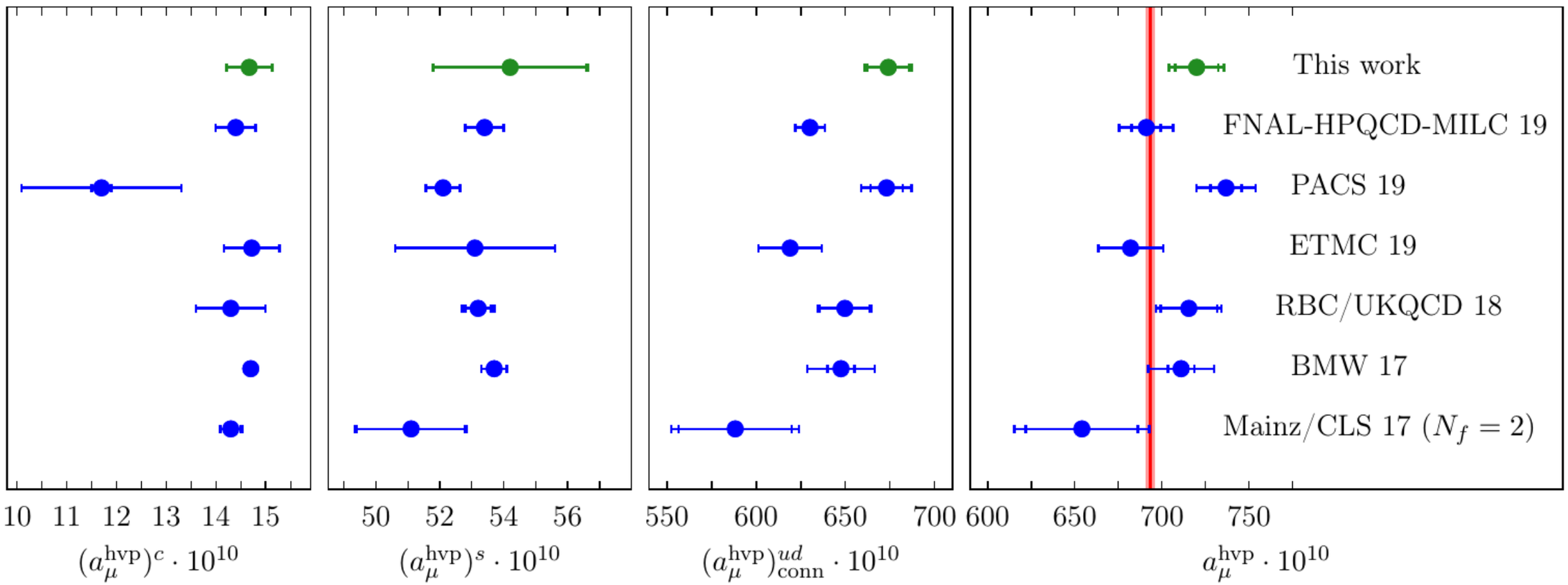
- 2022-24
  - 1st run: scaled detector and reduced accuracy

See Marconi's & Venanzoni's talks



M. Passera's talk @ MuonE Workshop

LATTICE RESUTLS



Gérardin, Cè, von Hippel, Hörz, Meyer, Mohler, Ottnad, Wilhelm, Wittig