NeΨ 23

NEW PHYSICS SIGNALS
1ST INTERNATIONAL WORKSHOP

UNIVERSITÀ DI PAVIA

INFN PAVIA

PHYS. LETT. B 829 (2022) 137138
WITH E. BUDASSI, C. M. CARLONI CALAME, F. PICCININI

Single pion production at MUonE

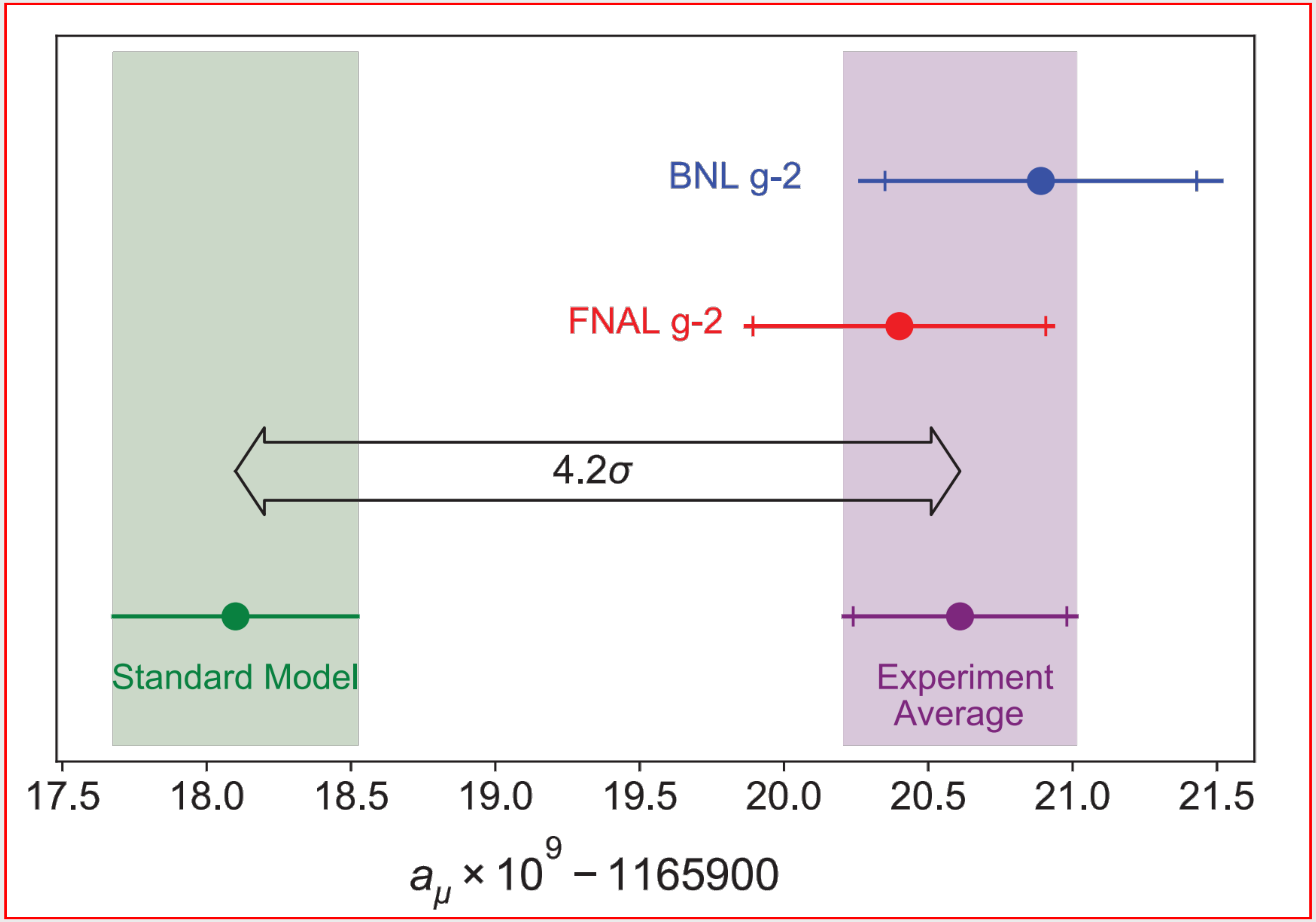
CLARA LAVINIA DEL PIO - UNIVERSITY OF PAVIA AND INFN PAVIA

The muon g-2

$$\vec{\mu} = g\left(\frac{e}{2m_\mu}\right)\vec{S}$$

$$a_\mu = \frac{g_\mu - 2}{2}$$

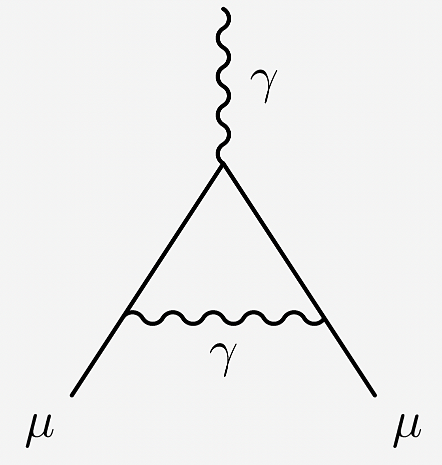
$$a_\mu^{avg} = 116592061(41) \times 10^{11}$$



The muon g-2

Aoyama, T., et al., Phys.Rept. 887 (2020) 1-166
Abi, B., et al., Phys. Rev. Lett. 126 (2021) 14 141801
Borsanyi, S., et al., Nature 593 (2021) 51–55

QED

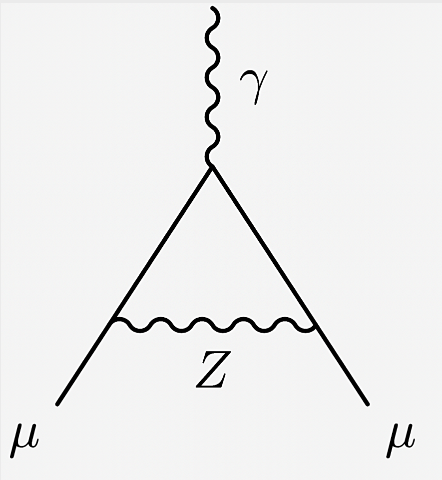


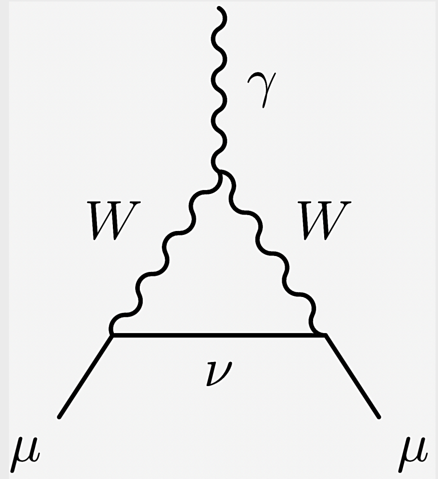
$+ \ldots$

$116584718.9(1) \times 10^{-11}$

0.001 ppm

Weak



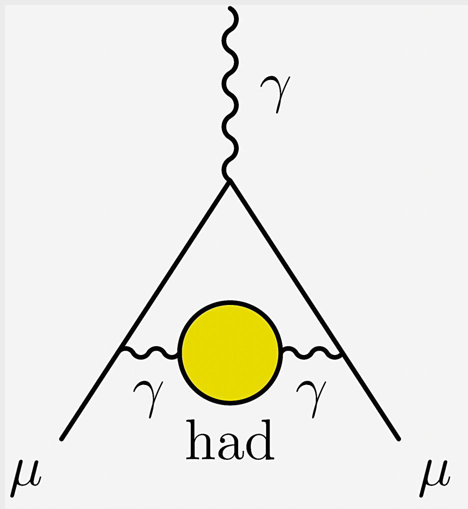


$+ \ldots$

$153.6(1.0) \times 10^{-11}$

0.01 ppm

Hadronic Vacuum Polarization (HVP)

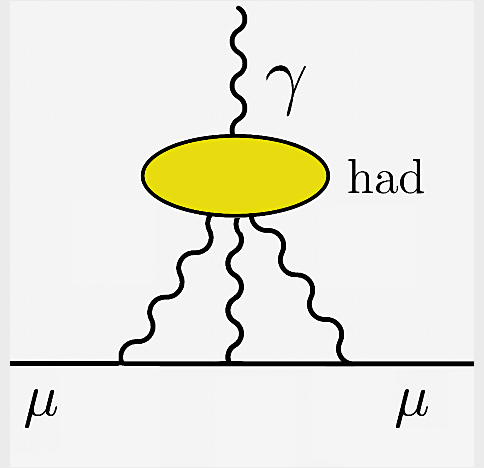


$+ \ldots$

$6845(40) \times 10^{-11}$

0.37 ppm

Light-by-Light (HLbL)



$+ \ldots$

$92(18) \times 10^{-11}$

0.15 ppm

The MUonE experiment

See talks by G. Abbiendi and E. Budassi

High-precision experiment (10 ppm on x-sec) to measure $\Delta\alpha_{\text{had}}$ with a spacelike process

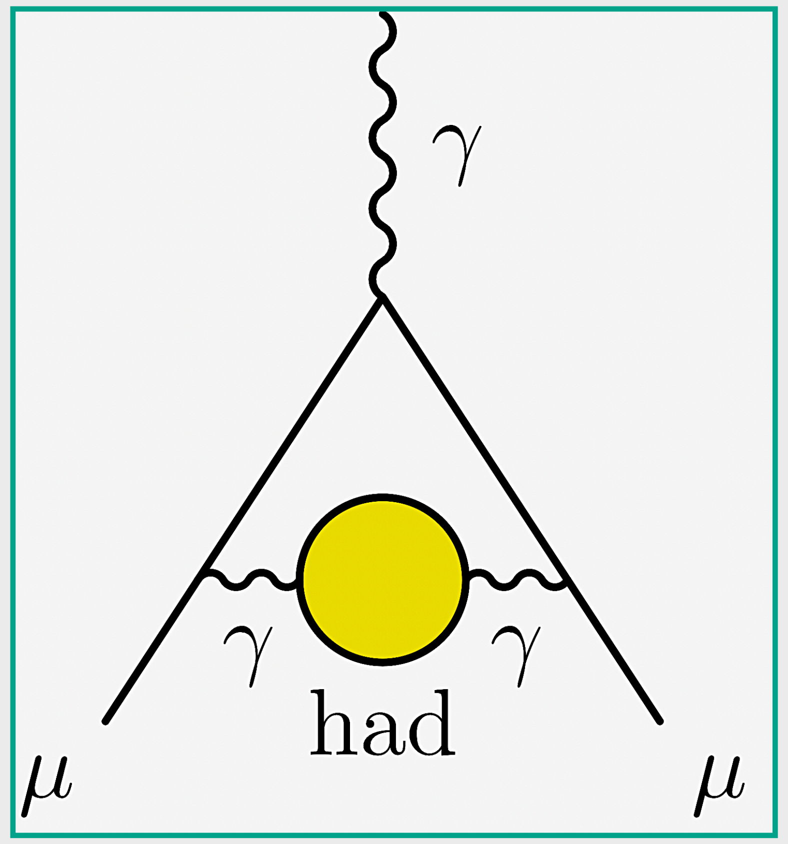
$$a_\mu^{\text{HLO}} = \frac{\alpha}{\pi}\int_0^1 dx\,(1-x)\Delta\alpha_{\text{had}}[t(x)]$$

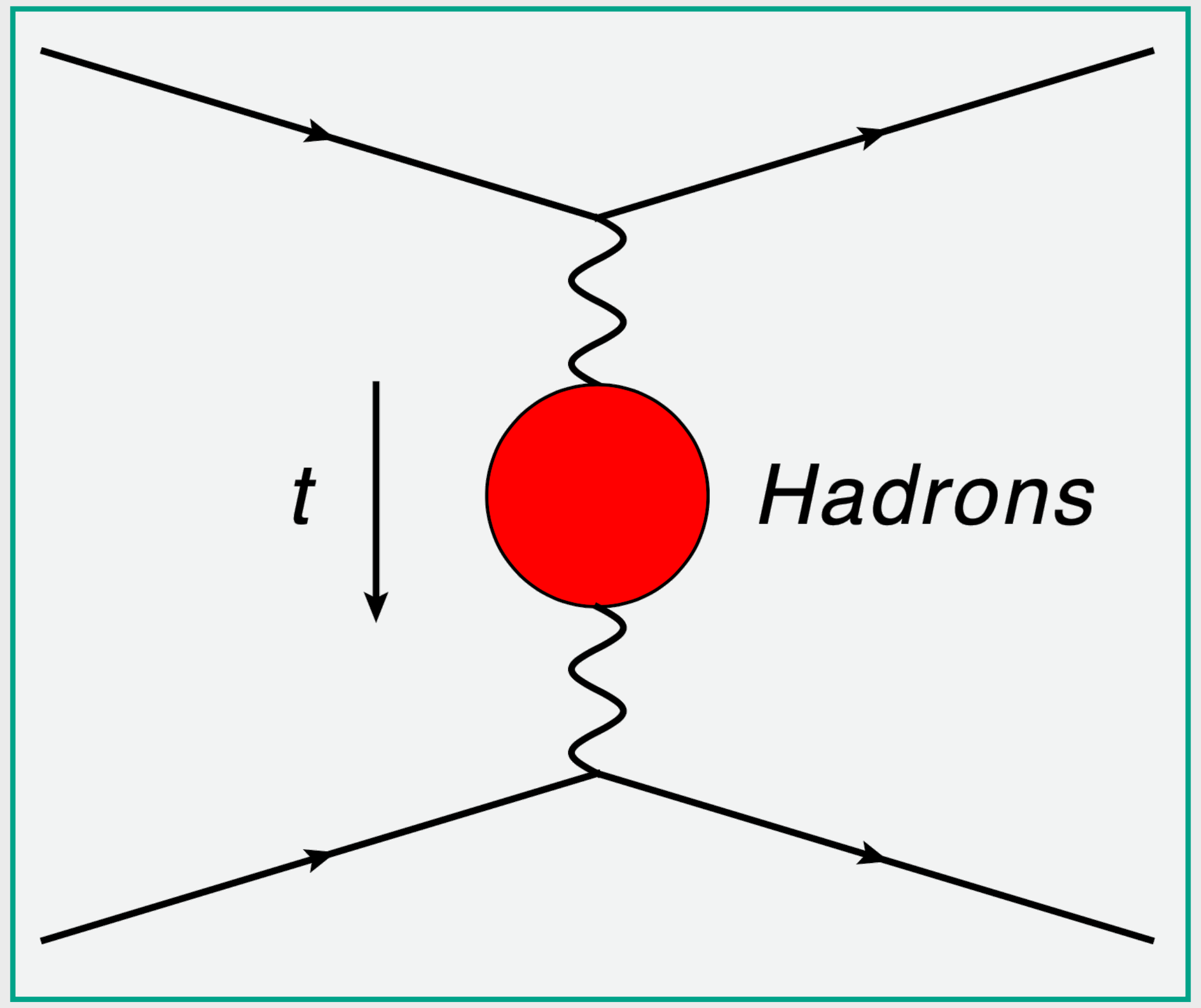
$$t(x) = \frac{x^2 m_\mu^2}{x-1} < 0$$

Lautrup, B. E., et al., Phys. Rept. 3 (1972) 193-259

Carloni Calame, C. M., et al., Phys. Lett. B 746 (2015) 325-329

Abbiendi, G., et al., Eur. Phys. Rev. J. C77 (2017) 3 139





$\mu - e$ scattering on low Z target

- pure t-channel process
- M2 muon beam ($E_\mu \simeq 160$ GeV) at CERN
- Good coverage of the integral with data ($\sqrt{s} \simeq 0.4$ GeV, -0.143 GeV$^2 < t < 0$ GeV^2)

State-of-art on theory side

μe scattering calculated today up to NNLO in QED

Mastrolia, P., Remiddi, E., Nucl. Phys. B 664 (2003) 341-356
Carloni Calame, C. M., et al., Phys. Lett. B 746 (2015) 325-329
Mastrolia, P., et al., JHEP 11 (2017) 198
Di Vita, S., et al., JHEP 09 (2018) 016
Alacevich, M., et al., JHEP 02 (2019) 155
Fael, M., Passera, M., Phys. Rev. Lett. 122 (2019) 19 192001
Fael, M., JHEP 02 (2019) 027
Carloni Calame, C. M., et al., JHEP 11 (2020) 028
Banerjee, P., et al., SciPost Phys. 9 (2020) 027
Banerjee, P., et al., Eur. Phys. J. C 80 (2020) 6, 591
Budassi, E., et al., JHEP 11 (2021) 098
Balzani, E., et al., Phys. Lett. B 834 (2022) 137462
Nesterenko, A. V., J. Phys. G49, 055001 (2022)
Bonciani, R., et al., Phys. Rev. Lett. 128 (2022) 2 022002
Engel, T., et al., JHEP 02 (2019) 18
Fael, M., et al., Phys. Rev. Lett. 128 (2022) 172003
Broggio, A., et al., JHEP 01 (2023) 112

Two numerical implementations:
MESMER (Monte Carlo generator)
McMULE (Monte Carlo integrator)

Possible contaminations from New Physics investigated

Masiero, A., et al., Phys.Rev.D 102 (2020) 7, 075013
Dev, P. S. B., et al., JHEP 05 (2020) 05

Single pion production: motivation

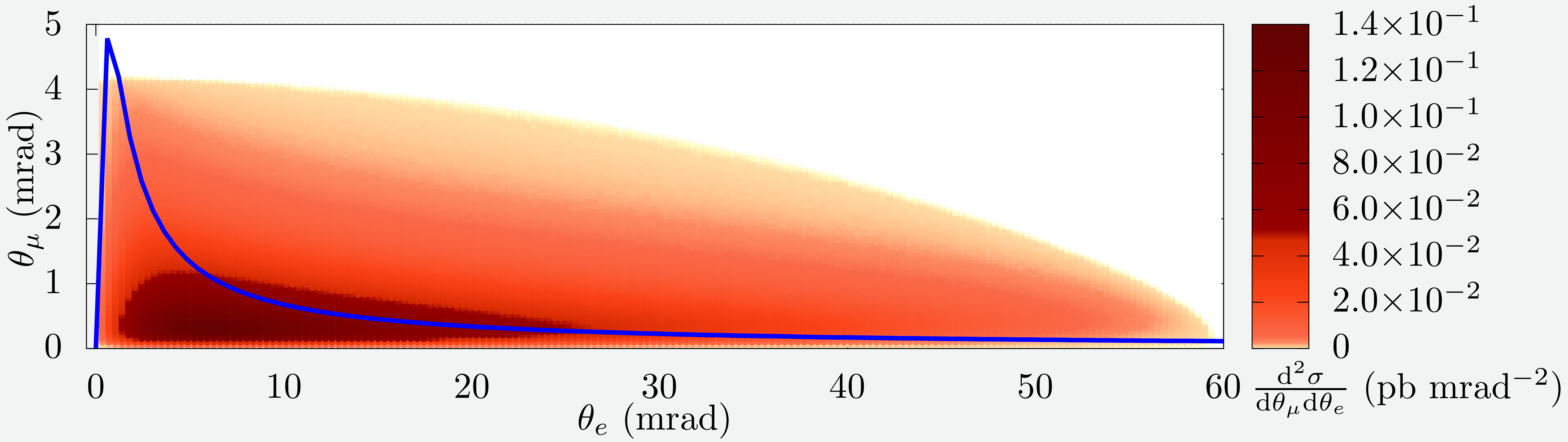
- Reliable estimates of possible backgrounds such as real and virtual hadronic contributions are needed
- Virtual hadronic contributions have been already discussed

M. Fael et al., JHEP 02 (2019) 027

M. Fael et al., Phys. Rev. Lett. 122 (2019) 192001

- Real-pair production does not contribute due to MUonE phase-space
- Potential important reducible background: $\mu^{\pm}e^{-} \rightarrow \mu^{\pm}e^{-}\pi^{0} \rightarrow \mu^{\pm}e^{-}\gamma\gamma$

Single pion production



Single pion production

$$\mathscr{L}_\mathrm{I} = \frac{g}{2!}\varepsilon^{\mu\nu\kappa\lambda}F_{\mu\nu}F_{\kappa\lambda}\varphi_\pi$$

$$g^2 = \frac{4\pi\Gamma_{\pi^0\to\gamma\gamma}}{m^3_{\pi^0}}$$

$$\Gamma_{\pi^0\to\gamma\gamma} = \frac{\alpha^2 m^3_{\pi^0}}{64\pi^3 f_\pi^2}$$

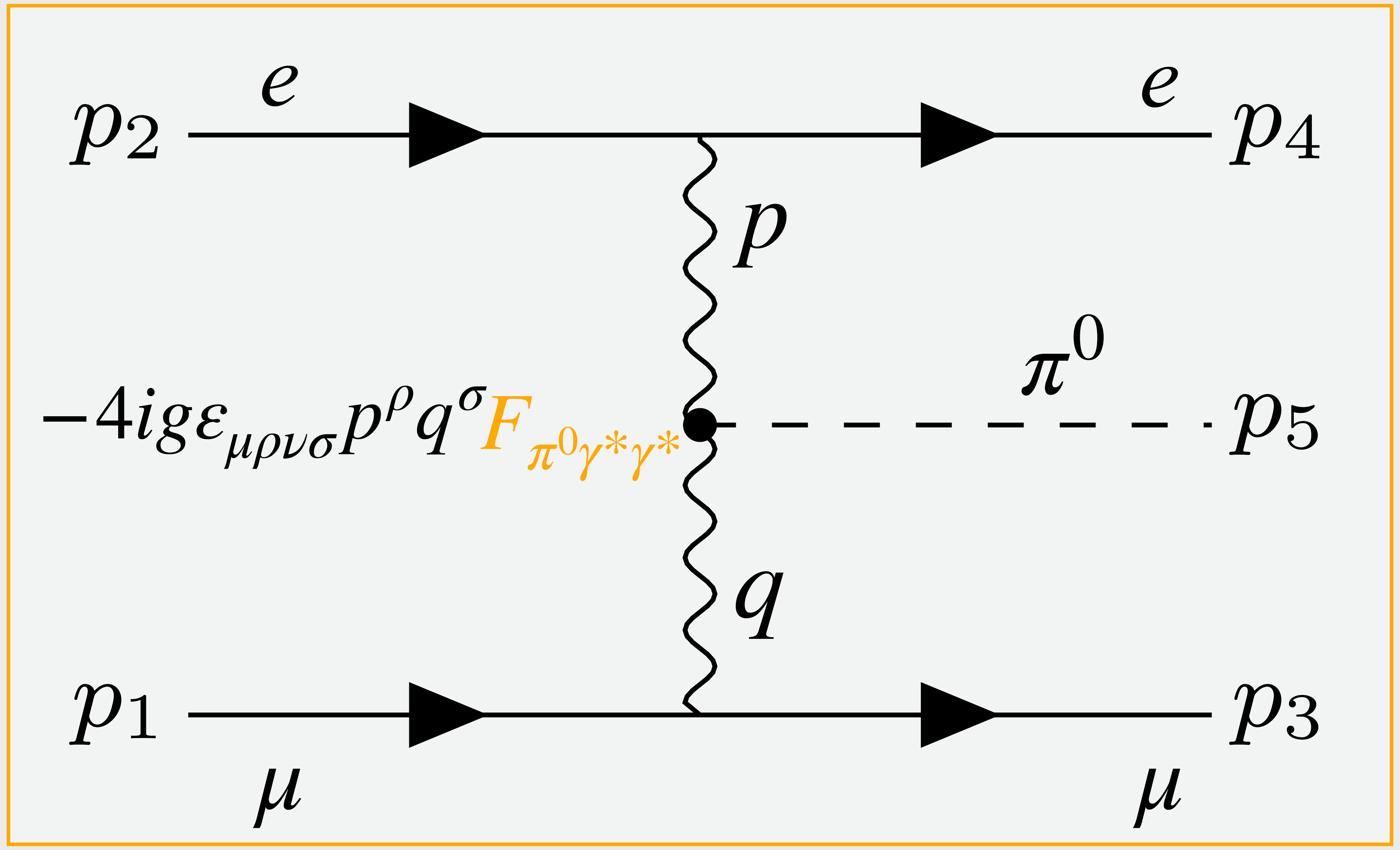
$$f_\pi = 0.092388 \text{ GeV}$$

$$\Gamma_{\pi^0\to\gamma\gamma} = 7.731 \text{ eV}$$

$$m_\pi = 134.9766 \text{ MeV}$$

*Brodsky, S. J., et al., Phys. Rev. D 4 (1971) 1532-1557

Czyz, H., et al., Phys. Rev. D 97 (1) (2018) 016006



Matrix element and phase space implemented in the Monte Carlo generator MESMER

https://github.com/cm-cc/mesmer

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Table 1 from * perfectly reproduced

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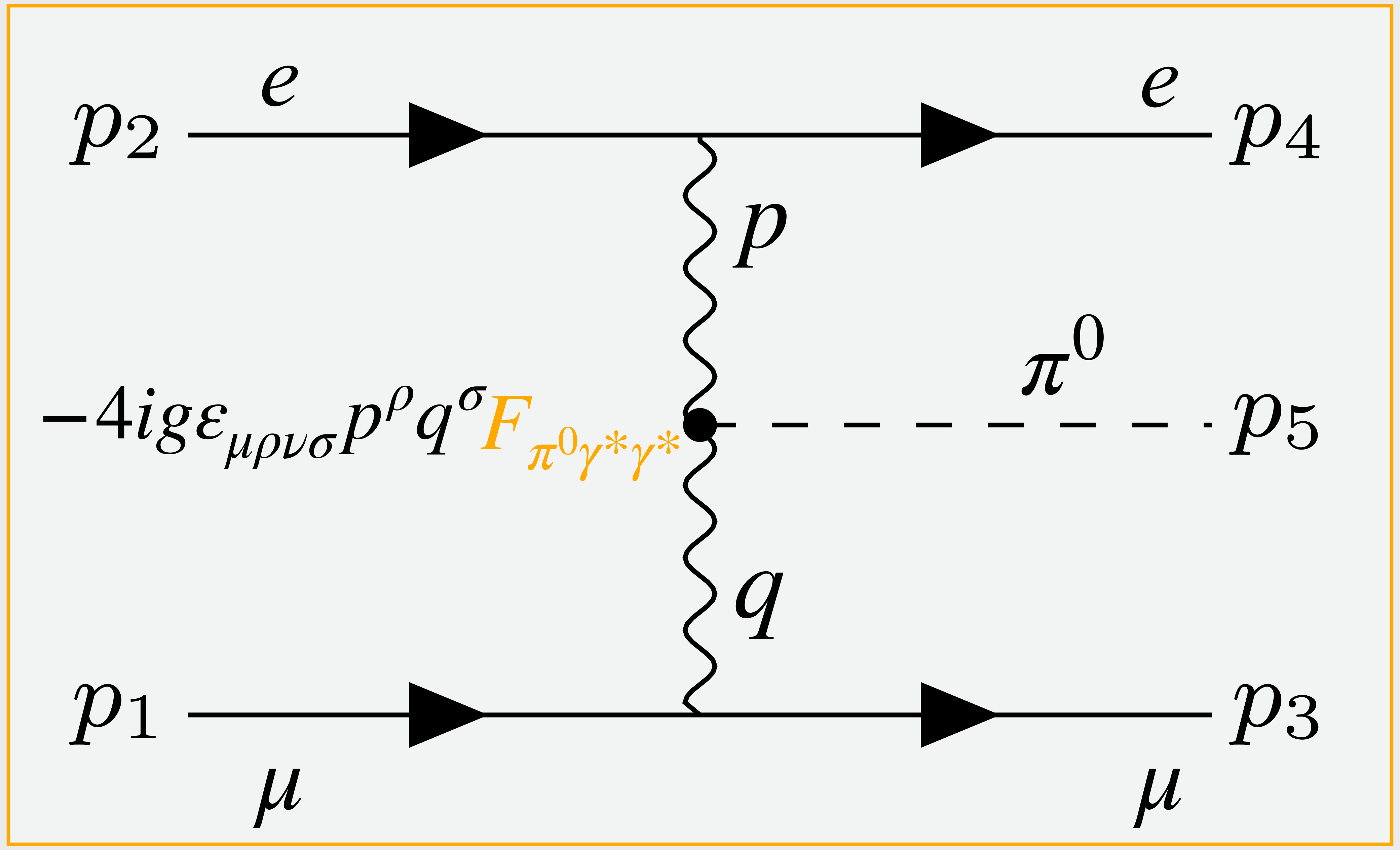
Czyz, H., et al., Phys. Rev. D 97 (1) (2018) 016006



Comparison with $e^+e^- \to e^+e^-\pi^0$ (t-channel only) with EKHARA

Czyz, H., et al., Comput. Phys. Commun. 182 (2011) 1338-1349

Czyz, H., et al., Comput. Phys. Commun. 234 (2019) 245-255

Numerical results

Total cross section: $\sigma_{\mu e \pi^0} = 6.53589(6)$ pb

Basic acceptance cuts
$\vartheta_\mu \leq 4.84$ mrad
$\vartheta_e < 100$ mrad
$E_\mu \geq 10.28$ GeV
$E_e > 0.2$ GeV

- basic acceptance cuts:

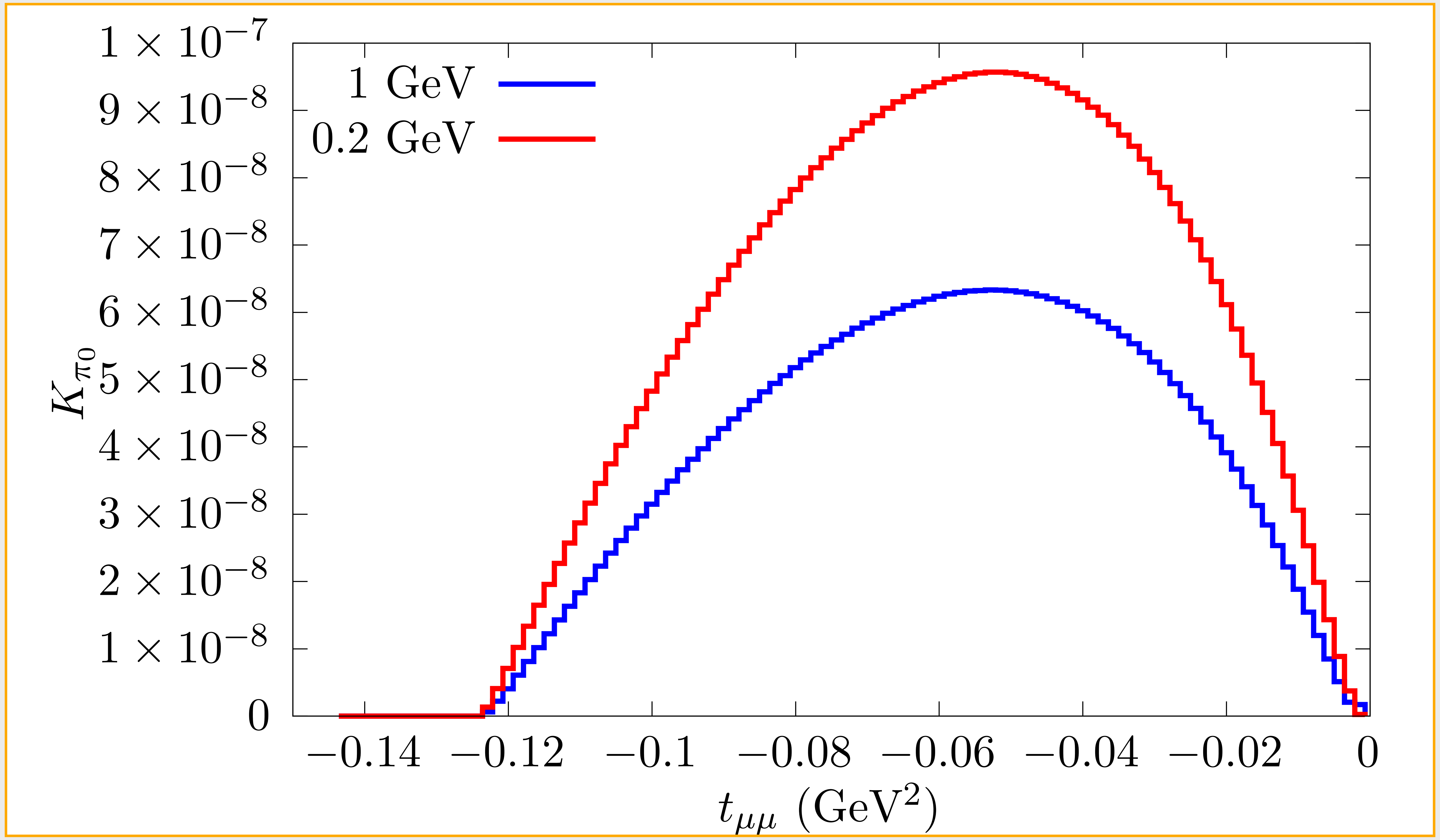
$\sigma^{0.2\,\mathrm{GeV}}_{\mu e \pi^0} = 2.69836(4)$ pb w.r.t. $\sigma^{0.2\,\mathrm{GeV}}_{\mathrm{LO}} \sim 1265\ \mu$b

- basic acceptance cuts + $E_e > 1$ GeV

$\sigma^{1\,\mathrm{GeV}}_{\mu e \pi^0} = 1.61597(3)$ pb w.r.t. $\sigma^{1\,\mathrm{GeV}}_{\mathrm{LO}} \sim 245\ \mu$b

Numerical results

Momentum transfer along muon line



Negligible contribution in differential distributions

$$K_{\pi^0} = \frac{d\sigma_{\pi^0}}{d\sigma_{\mathrm{LO}}}$$

New Physics searches @ MUonE

Asai, K., et al., Phys. Rev. D 106 (2022) L051702

Galon, I., et al., arXiv:2202.08843 [hep-ph]

Grilli di Cortona, G., Nardi, E., Phys. Rev. D 105 (2022) 11 L111701

Background for possible NP searches at MUonE in $2 \to 3$ processes: $\mu e \to \mu e Z' \to \mu e \nu \bar{\nu}$

$L_\mu - L_\tau$ gauge model with $m_{Z'} = 10 \sim 200$ MeV

Selection criteria: $\theta_\mu > 1.5$ mrad

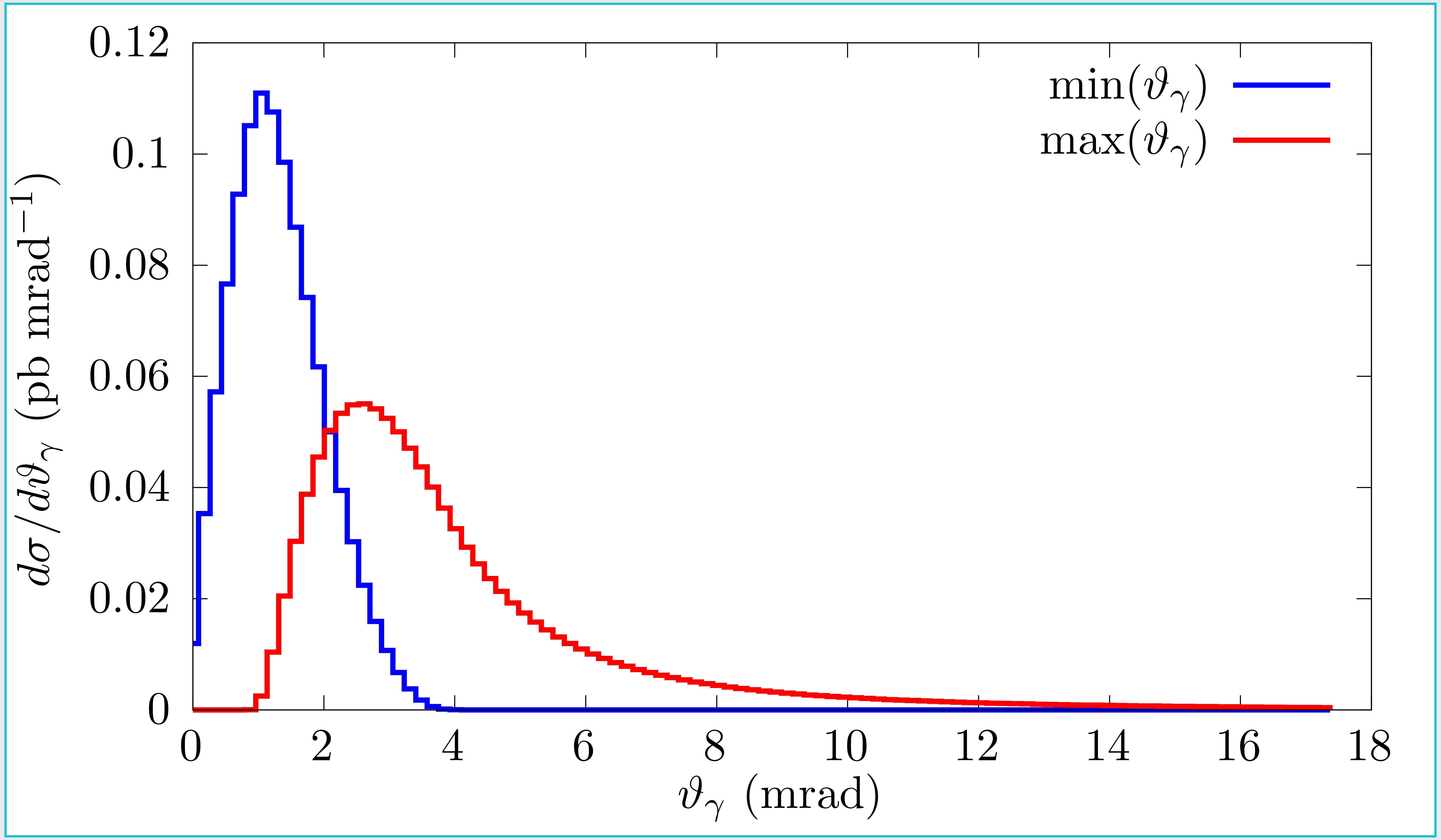
$1 \text{ GeV} < E_e < 25 \text{ GeV}$

$\sigma_{\mu e \pi^0} = 0.19210(1)$ pb

Integrated luminosity $= 15$ fb^{-1} $\to$ $N_{\pi^0} \sim N_{Z'} \sim 3 \times 10^3$ $\to$ photon veto strategy

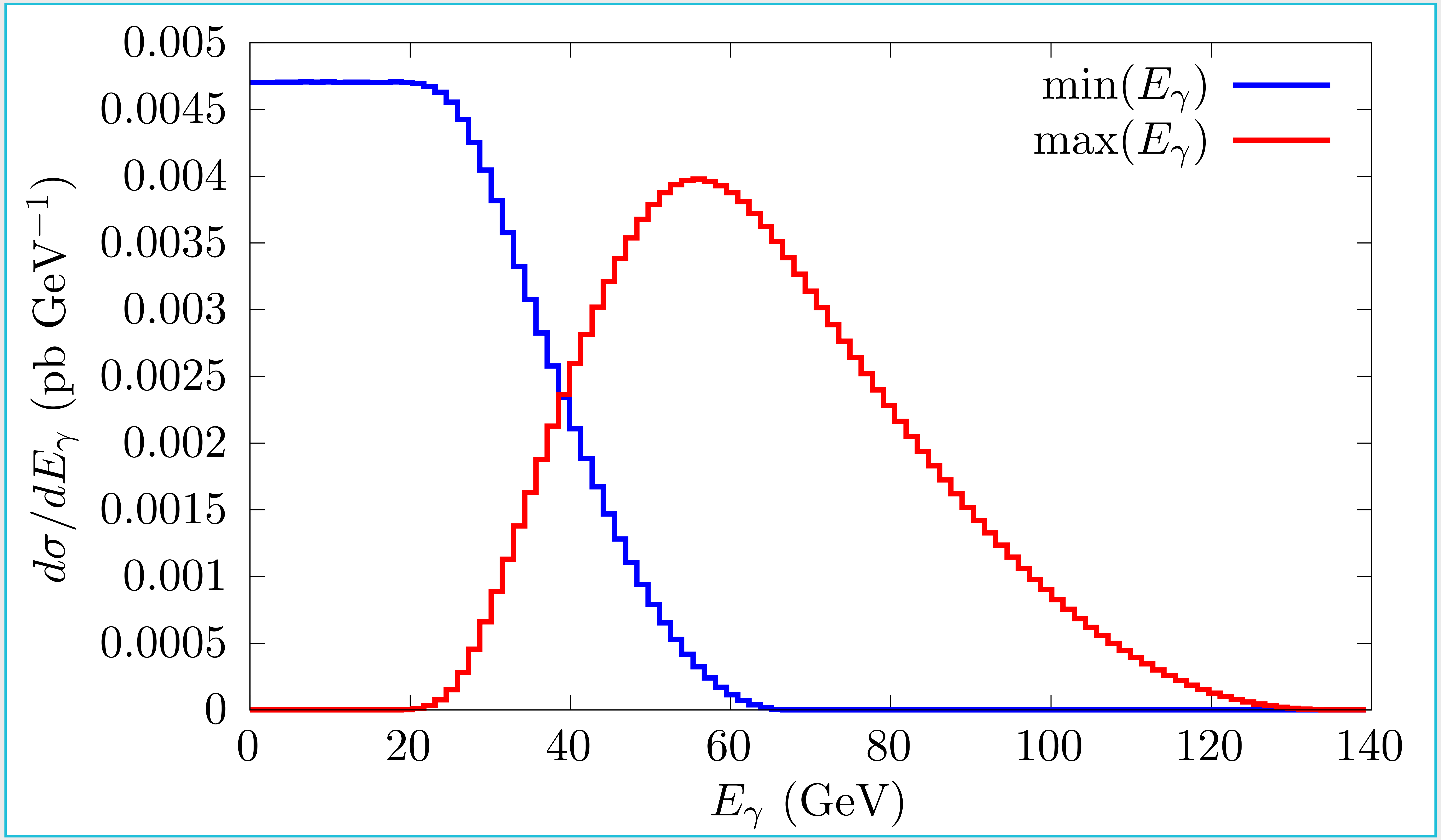
New Physics searches @ MUonE

Decay photon angle



New Physics searches @ MUonE

Decay photon energy



Summary

- The MUonE experiment will be crucial in addressing the $(g-2)_\mu$ problem
- Single π^0 production is a completely negligible reducible background to elastic μe scattering at MUonE
- However it could represent a background to NP searches at MUonE via $2 \to 3$ processes
- We characterised relevant distributions involving photons from π^0 decay, to be considered for a photon veto analysis strategy

Summary

- The MUonE experiment will be crucial in addressing the $(g-2)_\mu$ problem
- Single π^0 production is a completely negligible reducible background to elastic μe scattering at MUonE
- However it could represent a background to NP searches at MUonE via $2 \to 3$ processes
- We characterised relevant distributions involving photons from π^0 decay, to be considered for a photon veto analysis strategy

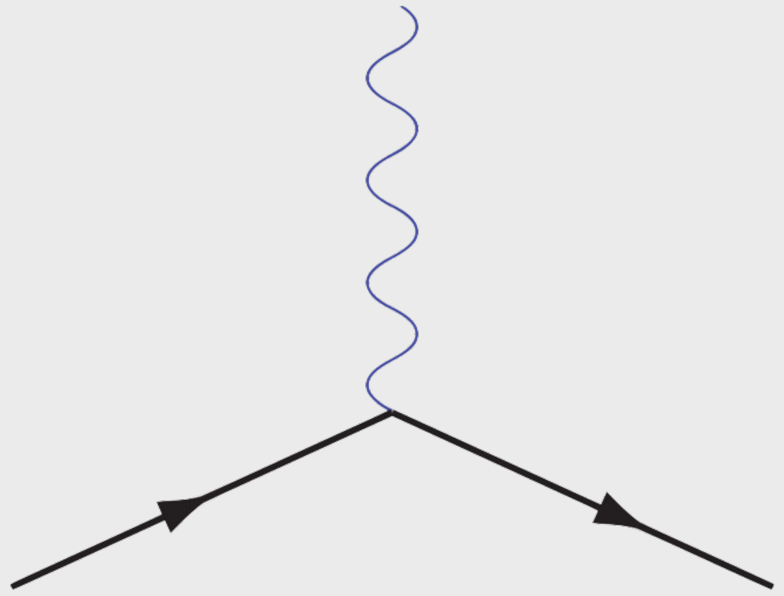
Thank you!

Backup

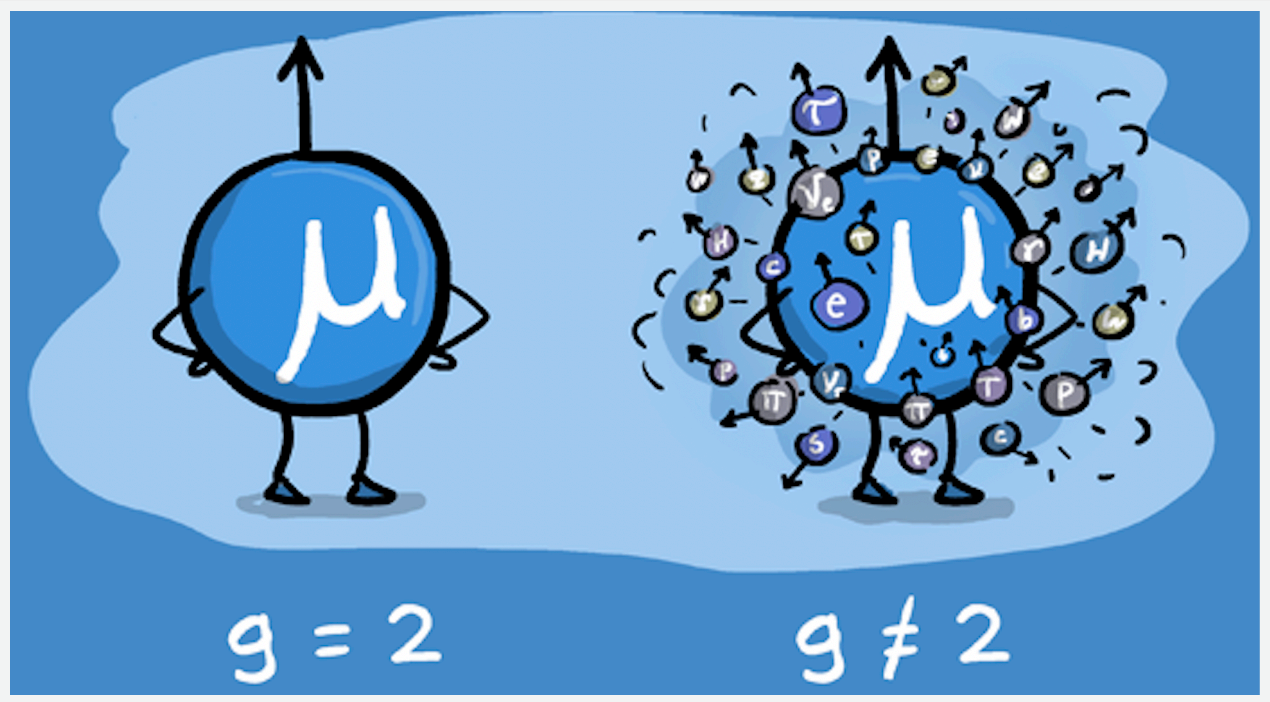
The muon g-2

$$\vec{\mu} = g\left(\frac{e}{2m_\mu}\right)\vec{S} \qquad m_\mu \simeq 105.6\ \text{MeV} \simeq 200\ m_e$$

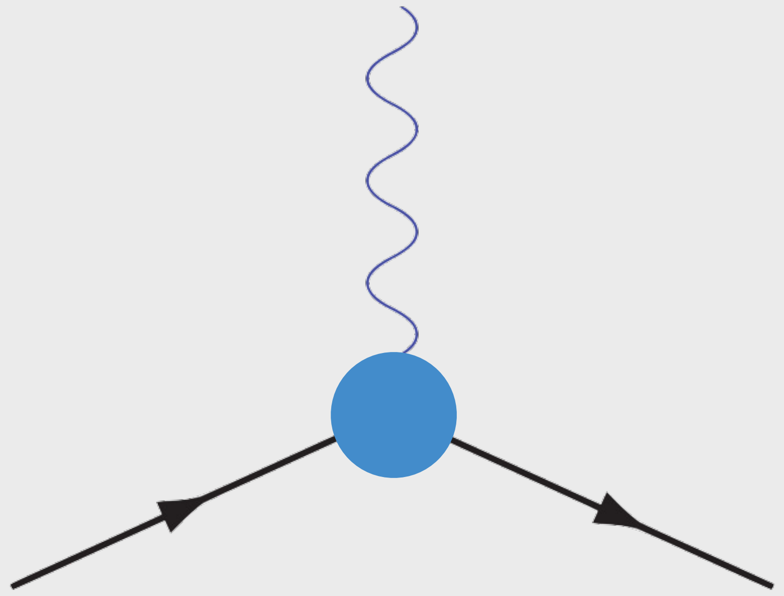
Dirac theory: $g = 2$



Quantum effects



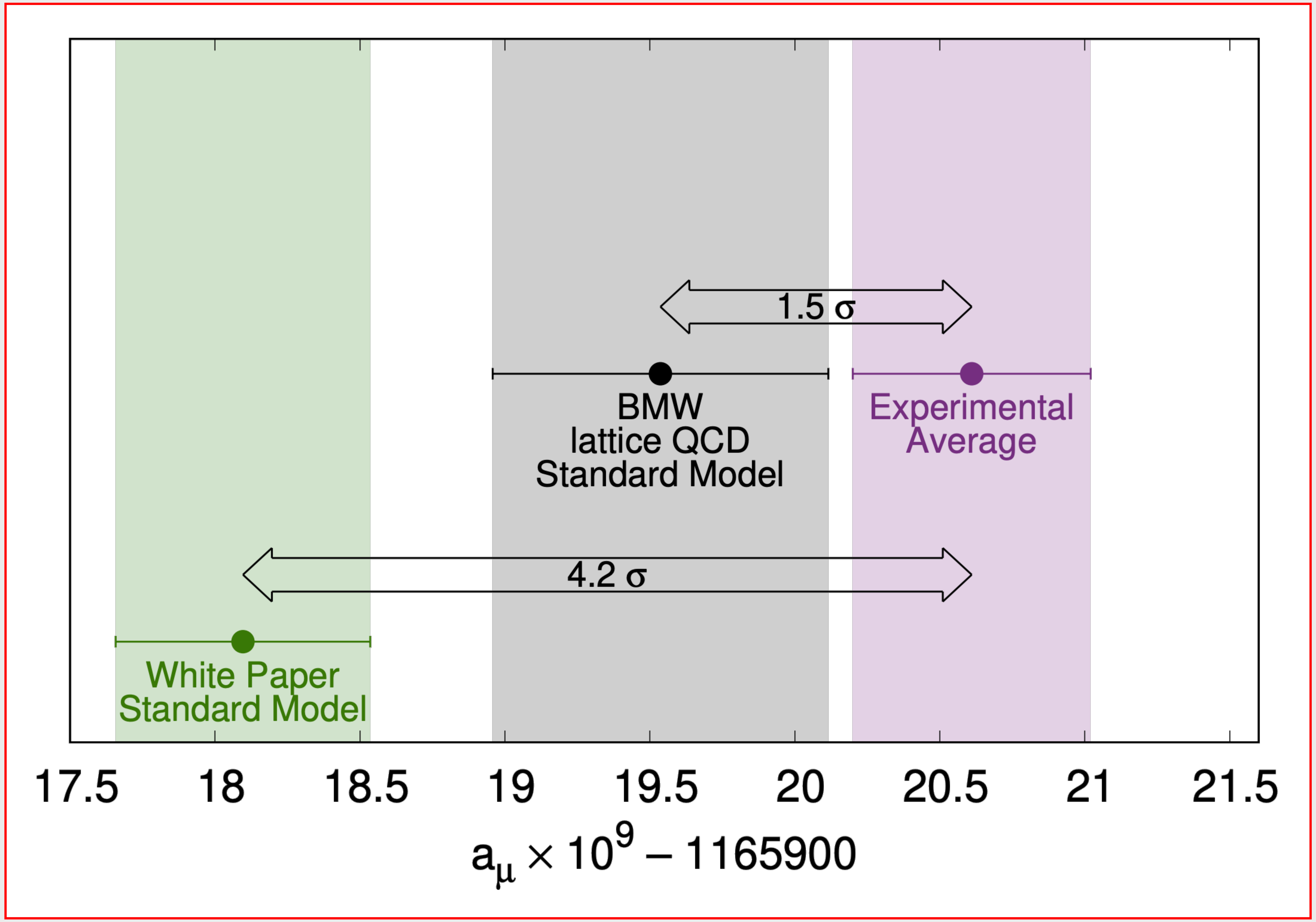
SM: $g > 2$



$$a_\mu = \frac{g_\mu - 2}{2}$$

The muon g-2

$$a_\mu^{avg} = 116592061(41) \times 10^{11}$$

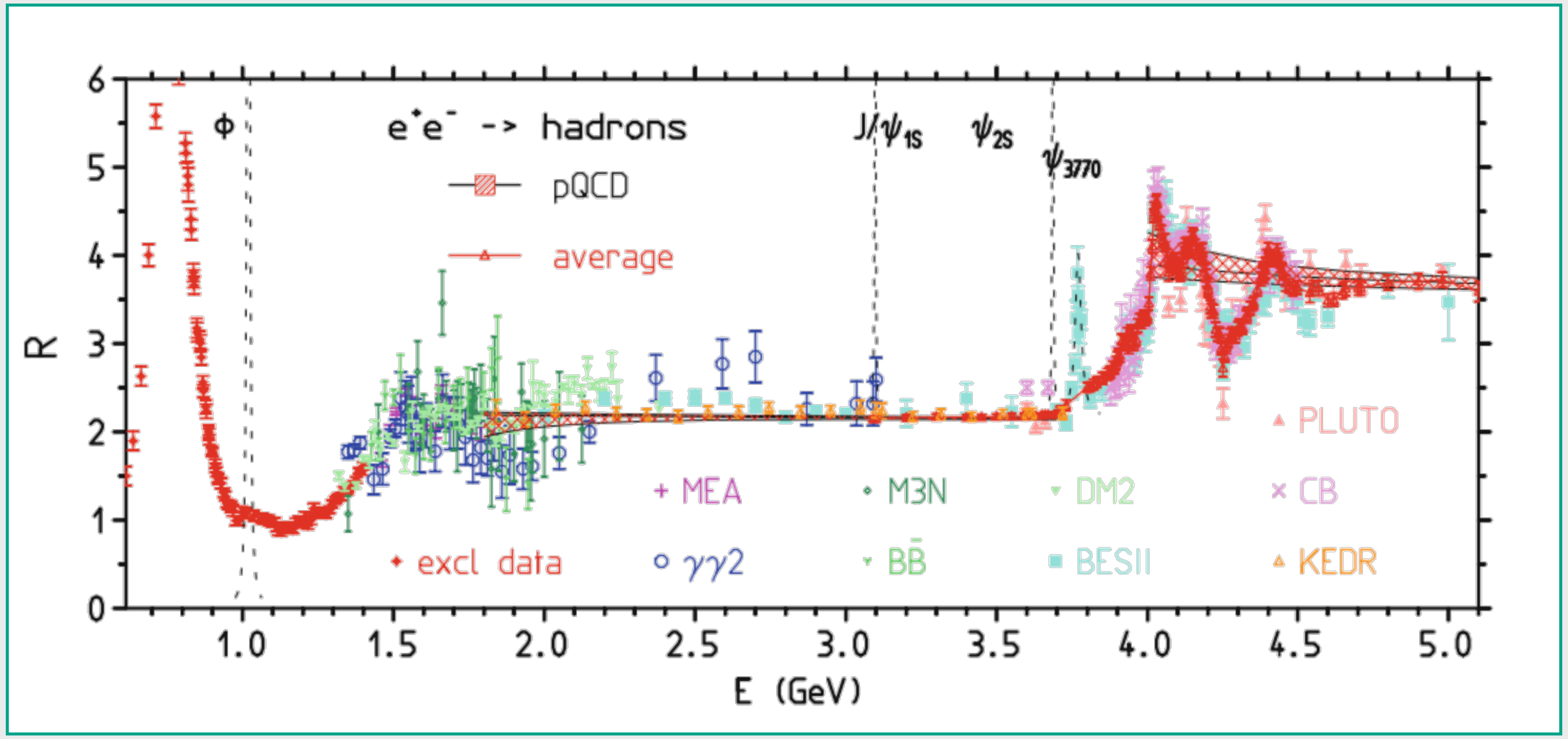


The μONe experiment

Time-like approach:

$$a_\mu^{\text{HLO}} = \frac{\alpha^2}{3\pi^2}\int_{m_\pi^2}^{\infty} ds\, \frac{K(s)}{s} R(s)$$

$$R(s) = \frac{\sigma(e^+e^- \to \text{had})}{\frac{4\pi\alpha^2}{3s}}$$



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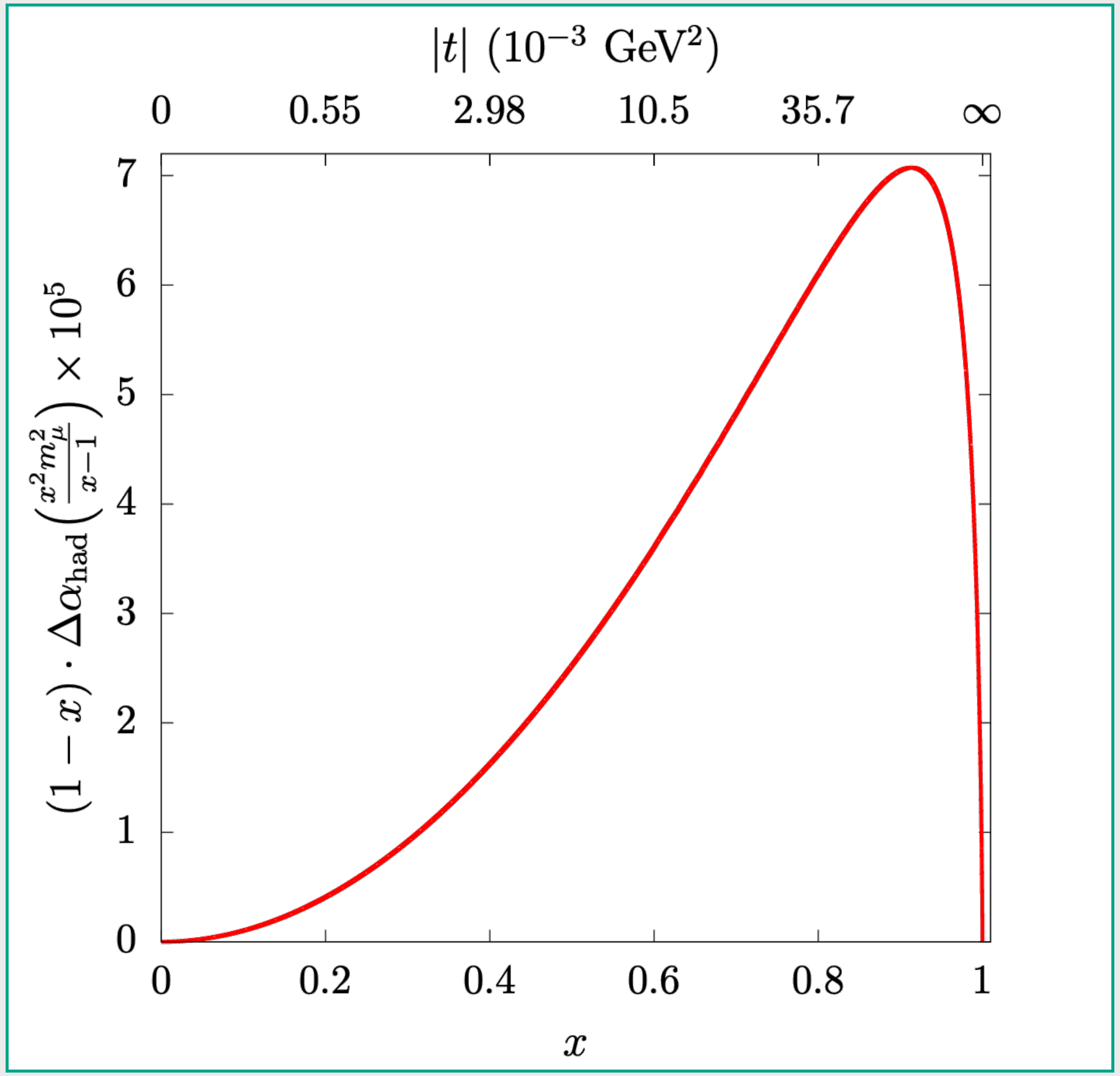
Carloni Calame, C. M., et al., Phys. Lett. B 746 (2015) 325-329

The μONe experiment

Space-like approach:

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

$$t(x) = \frac{x^2 m_\mu^2}{x-1} < 0$$



Carloni Calame, C. M., et al., Phys. Lett. B 746 (2015) 325-329

Abbiendi, G., et al., Eur. Phys. Rev. J. C77 (2017) no.3 139

The μONe experiment

$\mu - e$ scattering on Be target:

- 40 modules
- M2 muon beam ($E_\mu \simeq 160$ GeV) available at CERN
- $\Delta\alpha_{\text{had}}(q^2)$ exacted by template fit method from distributions in θ_μ and θ_e