Broken scale invariant unparticle physics and its prospective effect on the MuonE experiment

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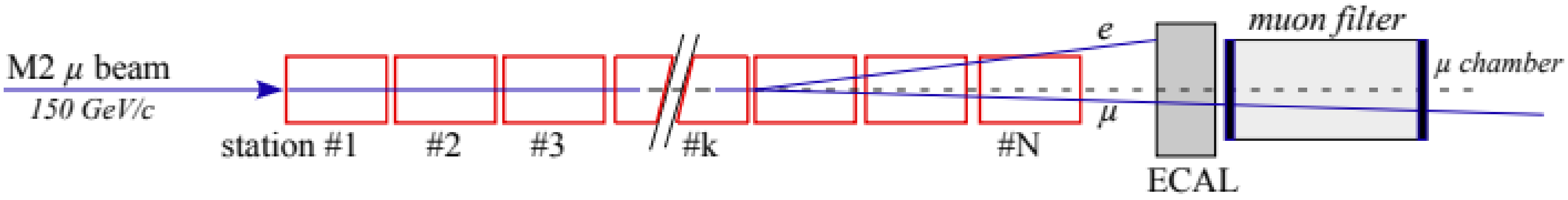
National Foundation for Science & Technology Development

MuonE Experiment



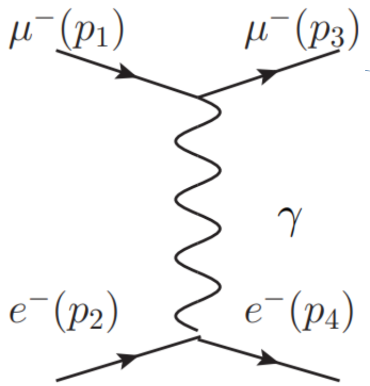
Proposed: 2017
Location: CERN
Experiment: $e\mu \to e\mu$
Purpose: evaluate $\Delta\alpha_{had}(t),\ t < 0$ $\sqrt{s} \approx 0.4\text{GeV}, t = (p_1 - p_3)^2$

Systematic accuracy: 10 ppm

→ Competitive: Sensitive to small new physics effects

→ Offer an independent measurement of a_μ^{had}

Measure cross $e\mu \to e\mu$



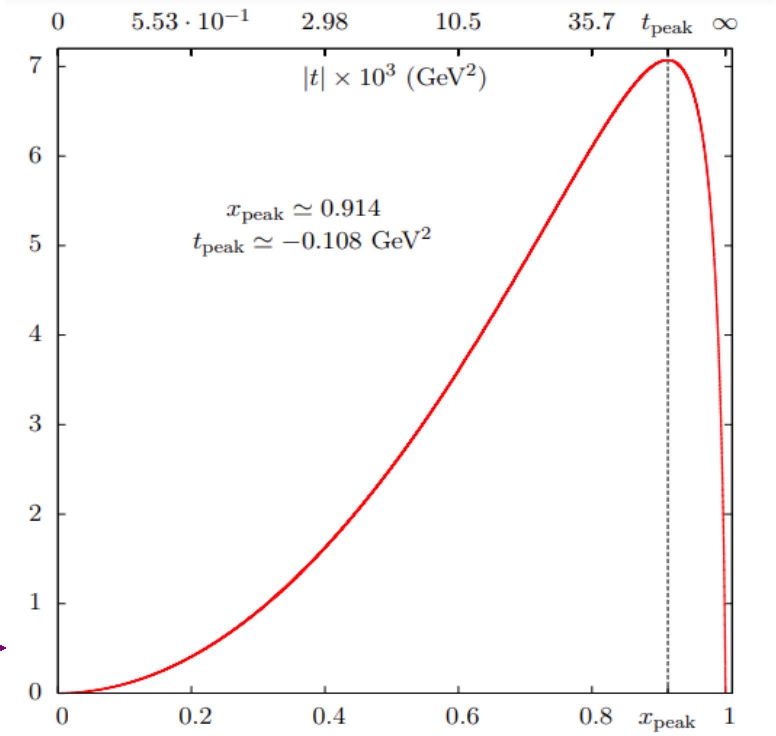
$$\sqrt{4\pi\alpha(t)}$$

$$\frac{\alpha(0)}{1-\Delta\alpha(t)}$$

pQCD + Exp. data

$$\Delta\alpha_{had}(t)+\Delta\alpha_{lep}(t)$$

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



Arxiv:1504.02228

Unparticle

- Unparticle was proposed by Howard Georgi in 2007 to discuss some simple aspects of the low-energy physics of a nontrivial scale invariant sector of an effective field theory.
- Can be directly detected at colliders as missing energy, e.g.

$$e^+ + e^- \to \gamma + unparticle$$

$$p + p \to jet + unparticle$$

- We only consider here the indirect effects of unparticle at the MuonE experiment

Unparticle scheme

E

Very high energy — SM $\overset{\Lambda_{UV}}{\longleftrightarrow}$ BZ (UV)

Scale M_{UV}

$$\frac{c_{UV}}{\Lambda_{UV}^{d_{SM}+d_{UV}-4}} O_{SM} O_{UV}$$

Scale Λ_U

$$\frac{c_U}{\Lambda_{UV}^{d_{SM}+d_U-4}} O_{SM} O_U$$

O_U: Scale invariant

O_U: non-integer dimension $d = 1.1, 1.2, \ldots$

Below scale μ — Scale invariant is broken

Effective interactions with fermions

$$\frac{c_U}{\Lambda_{UV}^{d_{SM}+d_U-4}} O_{SM} O_U \rightarrow \frac{\lambda_u}{M_Z^{d-1}} O_{SM} O_U \qquad parmeter: d, \lambda_i, \mu$$

Our convention

$$\frac{\lambda_S}{M_Z^{d-1}} \overline{f} f \mathcal{O}_{\mathcal{U}}, \quad \frac{\lambda_P}{M_Z^{d-1}} \overline{f} i\gamma^5 f \mathcal{O}_{\mathcal{U}}, \quad \frac{\lambda_V}{M_Z^{d-1}} \overline{f} \gamma_\mu f \mathcal{O}_{\mathcal{U}}^{\mu}, \quad \frac{\lambda_A}{M_Z^{d-1}} \overline{f} \gamma_\mu \gamma^5 f \mathcal{O}_{\mathcal{U}}^{\mu},$$

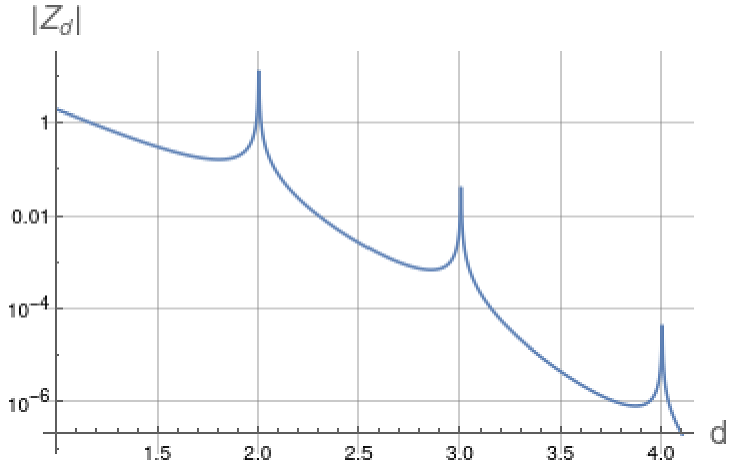
Scalar **P**seudo-scalar **V**ector **A**xial-vector

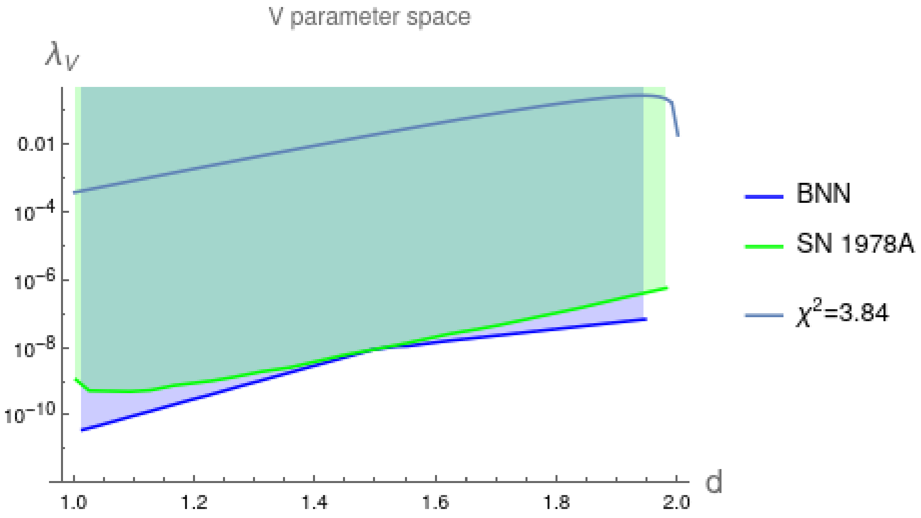
Ref: Georgi, 2007; Cheung, Keung, Yuan, 2007

Propagator and implementation broken scale invariant

$$\Delta_F(k) = \frac{iZ_d}{(-k^2 - i\epsilon)^{2-d}}$$

$$\Delta_F^{\mu\nu}(k) = \frac{iZ_d}{(-k^2 - i\epsilon)^{2-d}}(-g^{\mu\nu} + a\frac{k^\mu k^\nu}{k^2})$$





$$\Delta_F(k) = \frac{iZ_d}{(-k^2 + \mu^2 - i\epsilon)^{2-d}}$$

$$\Delta_F^{\mu\nu}(k) = \frac{iZ_d}{(-k^2 + \mu^2 - i\epsilon)^{2-d}}(-g^{\mu\nu} + a\frac{k^\mu k^\nu}{k^2})$$

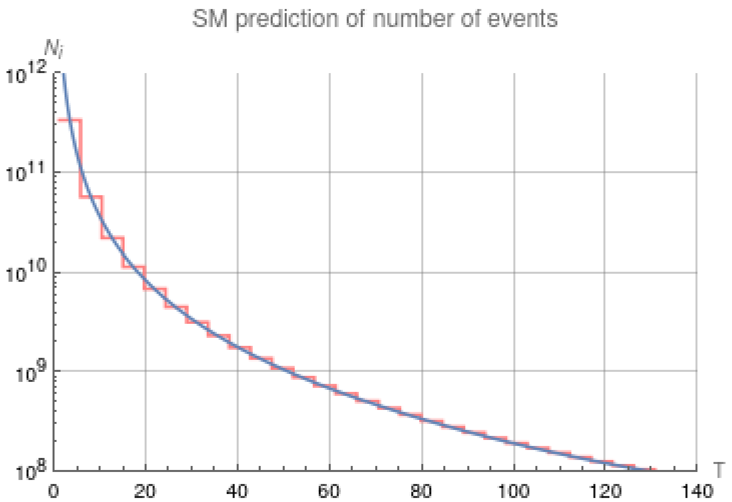
We can evade these constraints by simply choosing $\mu \geq 1\, GeV$

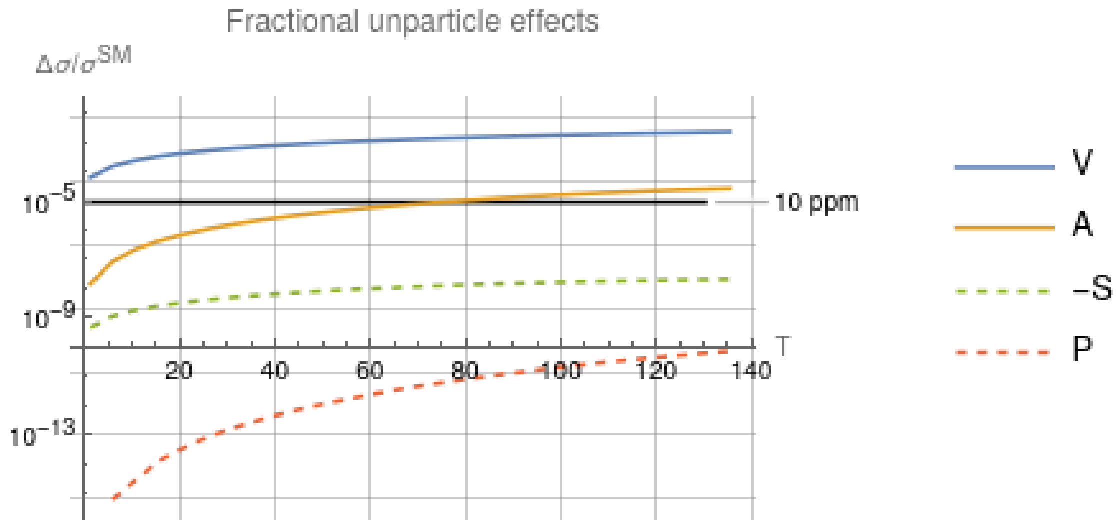
V. Barger, Y. Gao, W.-Y. Keung, D. Marfatia and V. N. Senoguz [arxiv:0801.3771]

Differential cross section

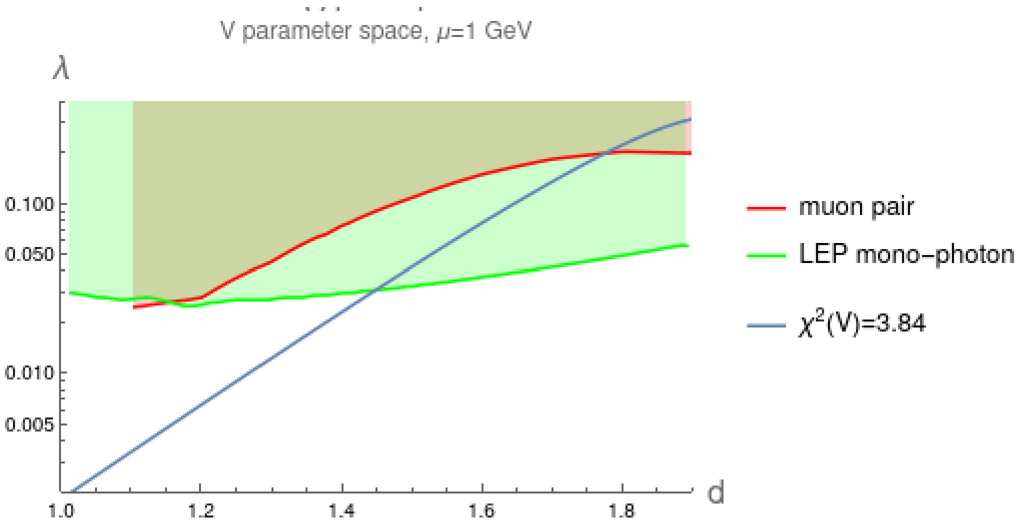
$$
\frac{d\sigma_X}{dT} = \mathrm{Tr}[\gamma\gamma]\frac{c_1^2\alpha^2(t)}{t^2} + \mathrm{Tr}[\gamma X]\frac{c_1\alpha(t)}{t}\frac{\lambda_X Z_d}{M_Z^{d-1}|t-\mu^2|^{2-d}} + \mathrm{Tr}[XX]\left[\frac{\lambda_X Z_d}{M_Z^{d-1}|t-\mu^2|^{2-d}}\right]^2
$$

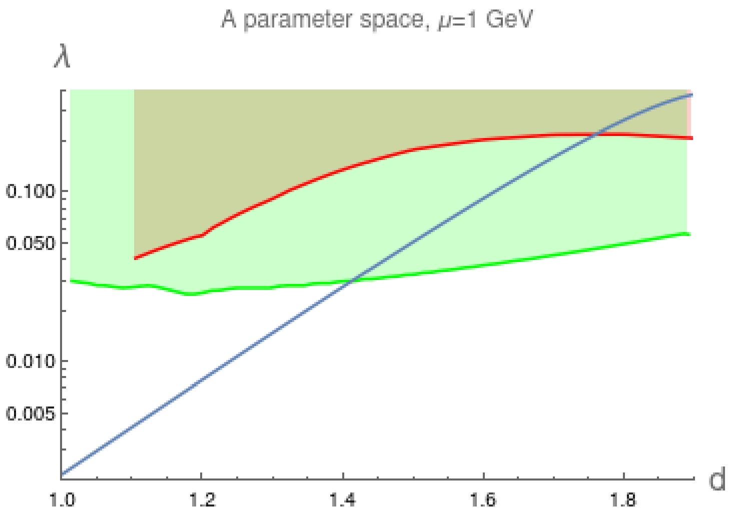
	type	T^0	T	T^2
$Tr[\gamma\gamma]$		$\underbrace{64E_\mu^2 m_e^2}$	$-64E_\mu m_e^2 - 32m_e^3 - 32m_e m_\mu^2$	$32m_e^2$
$Tr[XX]$	S	$64m_e^2 m_\mu^2$	$32m_e^3 + 32m_e m_\mu^2$	$16m_e^2$
	P	0	0	$16m_e^2$
	V	$\underbrace{64E_\mu^2 m_e^2}$	$-64E_\mu m_e^2 - 32m_e^3 - 32m_e m_\mu^2$	$32m_e^2$
	A	$\underbrace{64E_\mu^2 m_e^2} + 128m_e^2 m_\mu^2$	$-64E_\mu m_e^2 + 32m_e^3 + 32m_e m_\mu^2$	$32m_e^2$
$Tr[\gamma X]$	-S	$64E_\mu m_e^2 m_\mu$	$-32m_e^2 m_\mu$	0
	-P	0	0	0
	V	$\underbrace{64E_\mu^2 m_e^2}$	$-64E_\mu m_e^2 - 32m_e^3 - 32m_e m_\mu^2$	$32m_e^2$
	A	0	$64E_\mu m_e^2$	$-32m_e^2$

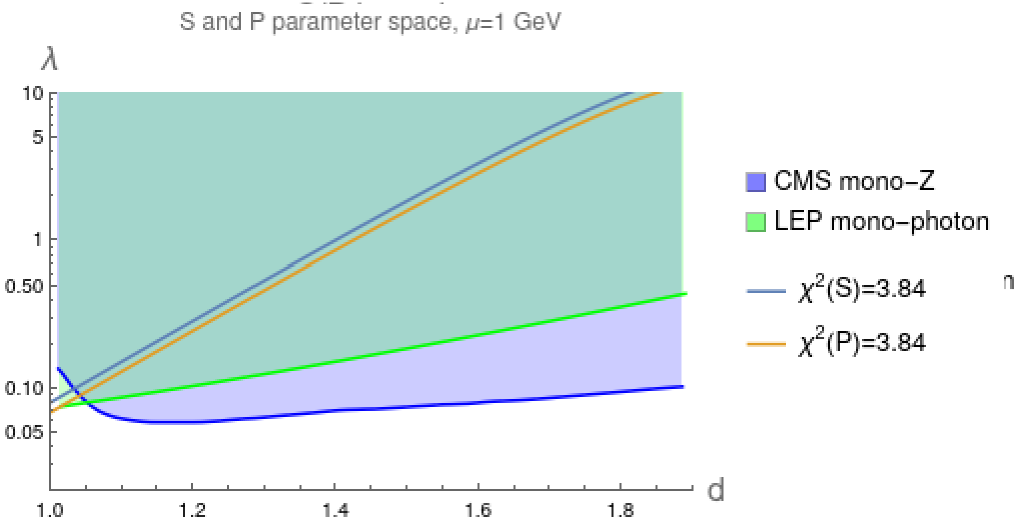




Sensitivity curves







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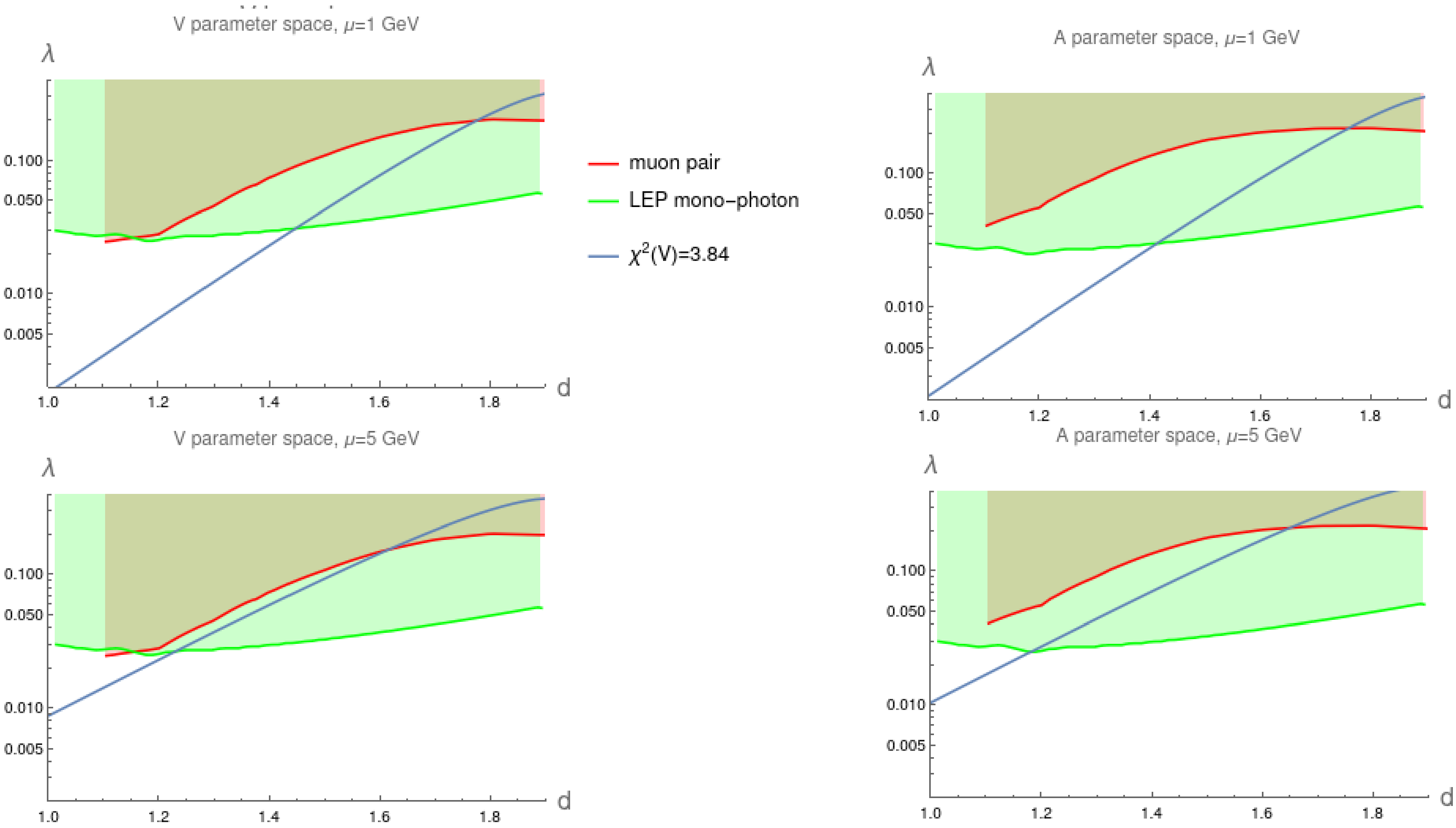

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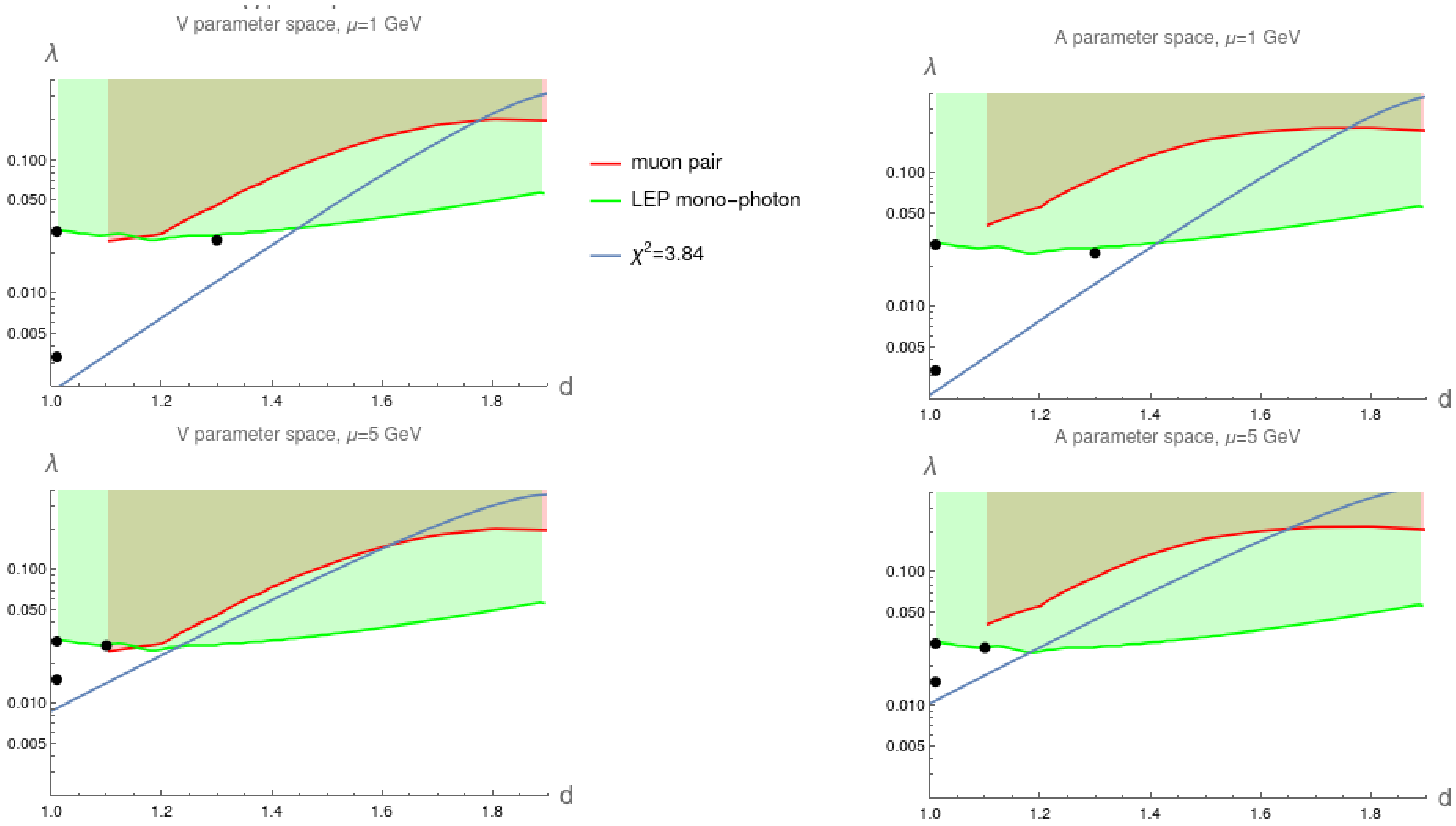

Unparticle effects on the measurement of a_μ^{had}

	SM	Axial-vector	Vector
P1	$6903(29) \times 10^{-11}$	$6957(29) \times 10^{-11}$	$6986(29) \times 10^{-11}$
Pull	0	1.9	2.8
P2	–	$6980(29) \times 10^{-11}$	$7019(29) \times 10^{-11}$
Pull	–	2.6	4.0
P3	–	$11073(29) \times 10^{-11}$	$13250(29) \times 10^{-11}$
Pull	–	143	218
P4	–	$6954(29) \times 10^{-11}$	$6979(29) \times 10^{-11}$
Pull	–	1.7	2.6
P5	–	$6971(29) \times 10^{-11}$	$7006(29) \times 10^{-11}$
Pull	–	2.3	3.5
P6	–	$7091(29) \times 10^{-11}$	$7186(29) \times 10^{-11}$
Pull	–	6.4	9.7

$$Pull = (a^{had,new} - a^{had,SM}) / \Delta_{SM}$$

Sumary and outlook

- MUonE promise a novel approach of evaluating the hadronic contribution to the muon's g-2.
- Such a precise experiment can help us to detect small new physics effect such as unparticles.
- Unparticles with broken scale invariance are still possible, but the parameter space is shrinking.
- MUonE is sensitive to (axial-)vector unparticles with $1 < d \leq 1.4$ and $1 \leq \mu \leq 12$ GeV.
- Further works: re-do the constraints (lepton magnetic moments, CMS mono-Z) carefully with $\mu > 0$.

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