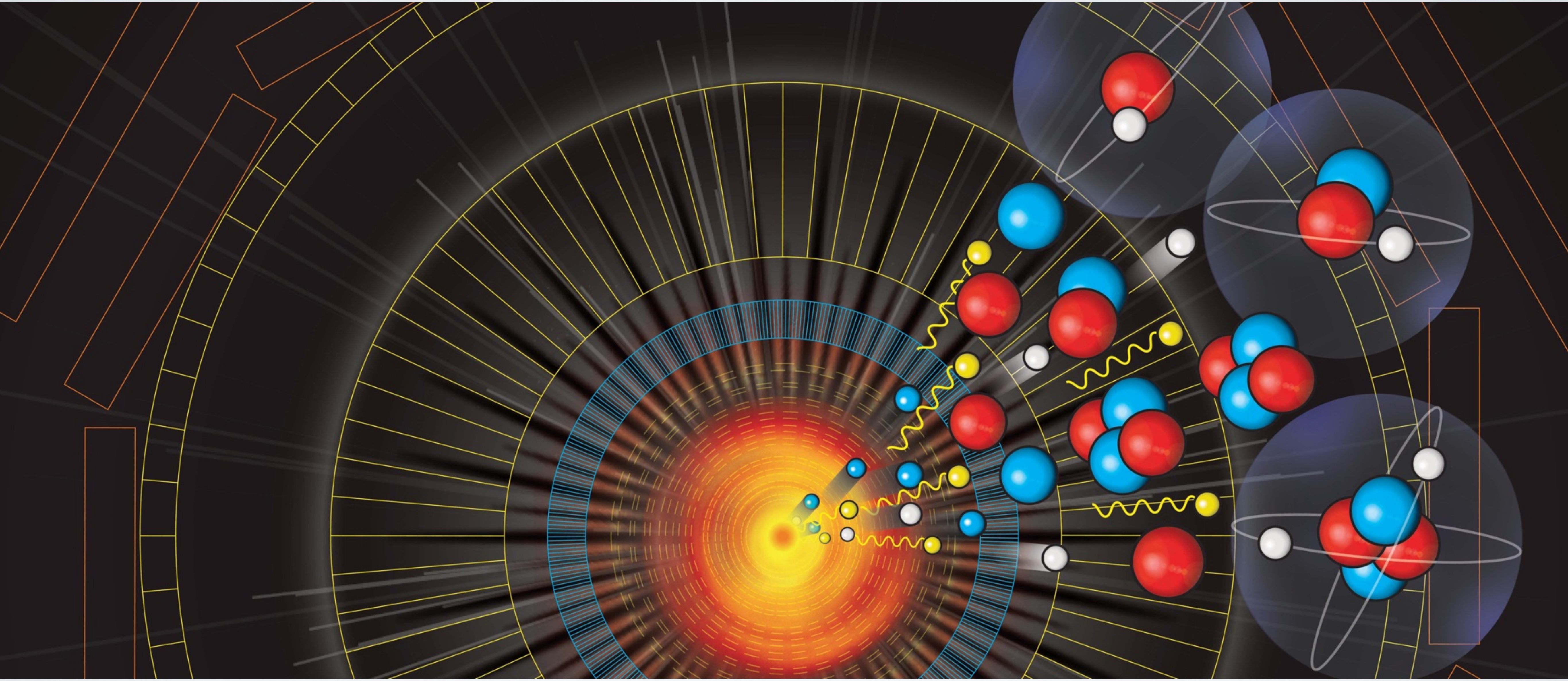
(Non) Standard Model Higgs

Francesco Sannino

2023



Standard model ~ 2023

$$L = -\frac{1}{2}F^2 + i\overline{Q}\gamma_\mu D^\mu Q + y(\overline{Q}_L H Q_R + \text{h.c.})$$

Yukawa

Gauge

$$\mathrm{Tr}\left[\mathrm{DH}^\dagger \mathrm{DH}\right] - \lambda_\mathrm{u} \mathrm{Tr}\left[(\mathrm{H}^\dagger \mathrm{H})^2\right] - \lambda_\mathrm{v} \mathrm{Tr}\left[(\mathrm{H}^\dagger \mathrm{H})\right]^2$$

Scalar selfinteractions

- Gauge structure established
- Yukawa structure to be determined
- Higgs (nature) self-coupling to be determined

What's left of the anomalies

D'Alise, De Nardo, Di Luca, Fabiano, Frattulillo, Gaudino, Iacobacci, Sannino, Santorelli, Vignaroli, JHEP 08 (2022) 125, 2204.03686

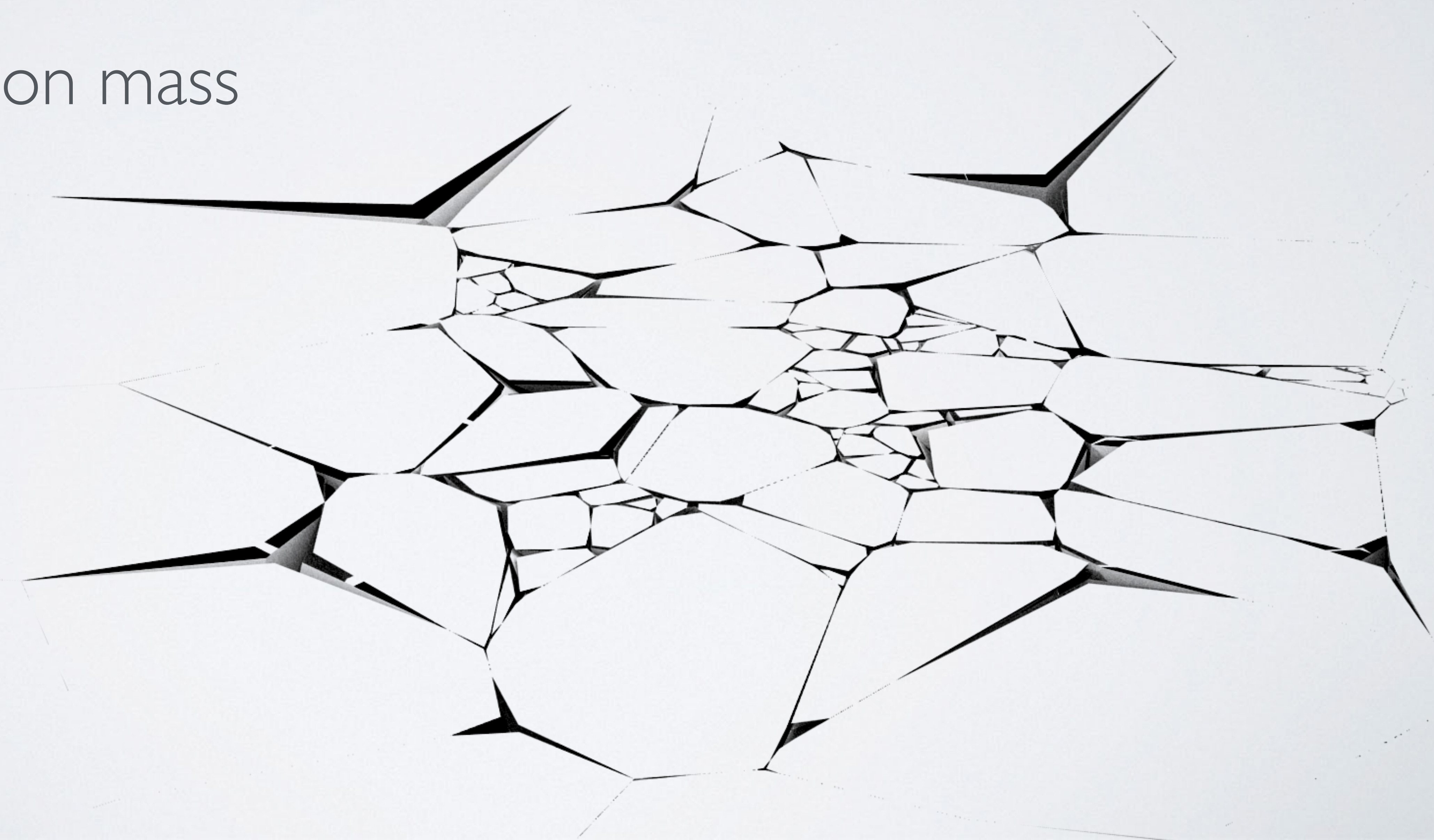
Calabrese, De Iorio, Cacciapaglia, Morisi, Sannino et al. PRD 107 (2023), 2210.0731

Cacciapaglia, Sannino PLB 832 (2022), 2204.04514

Cacciapaglia, Cot, Sannino, Phys. Lett. B 825 (2022) 2104.08818

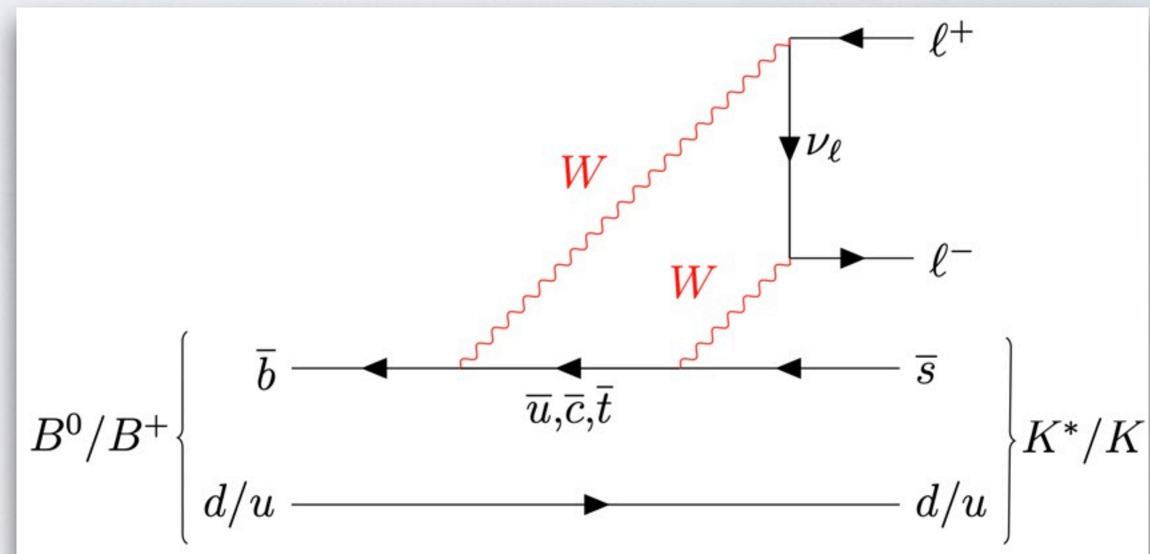
2022 ~ Cracks

- Lepton flavour (non) universality
- g-2 of the muon
- W boson mass



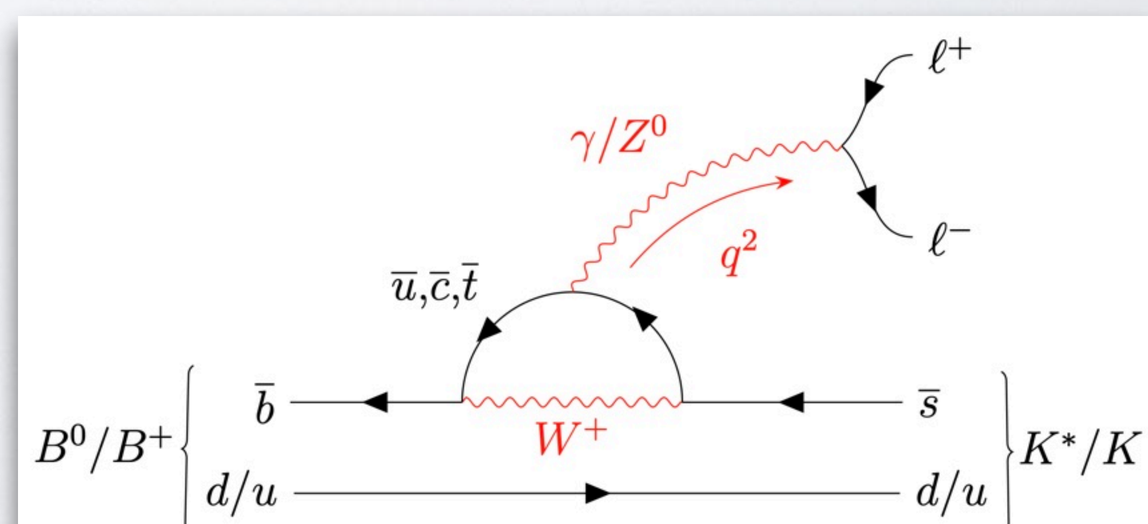
December 2022

- Lepton flavour (non) universality



(b) Box diagram for $B \to K^{(*)}\ell^+\ell^-$.

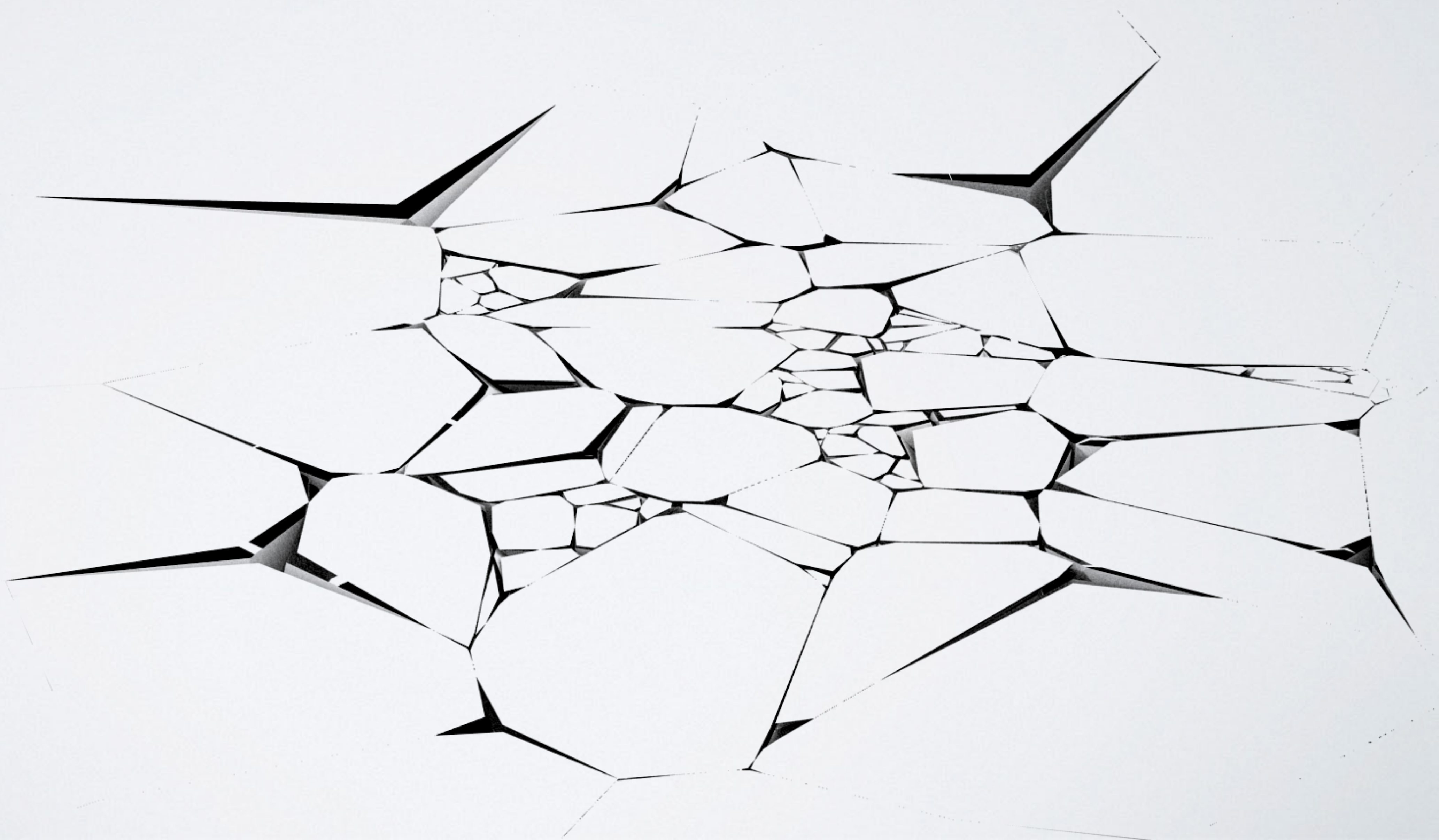
$$R_K \simeq 1 + 2\frac{\mathrm{Re}C^{\mathrm{BSM}}_{b_{L+R}(\mu-e)_L}}{C^{\mathrm{SM}}_{b_L\mu_L}}$$



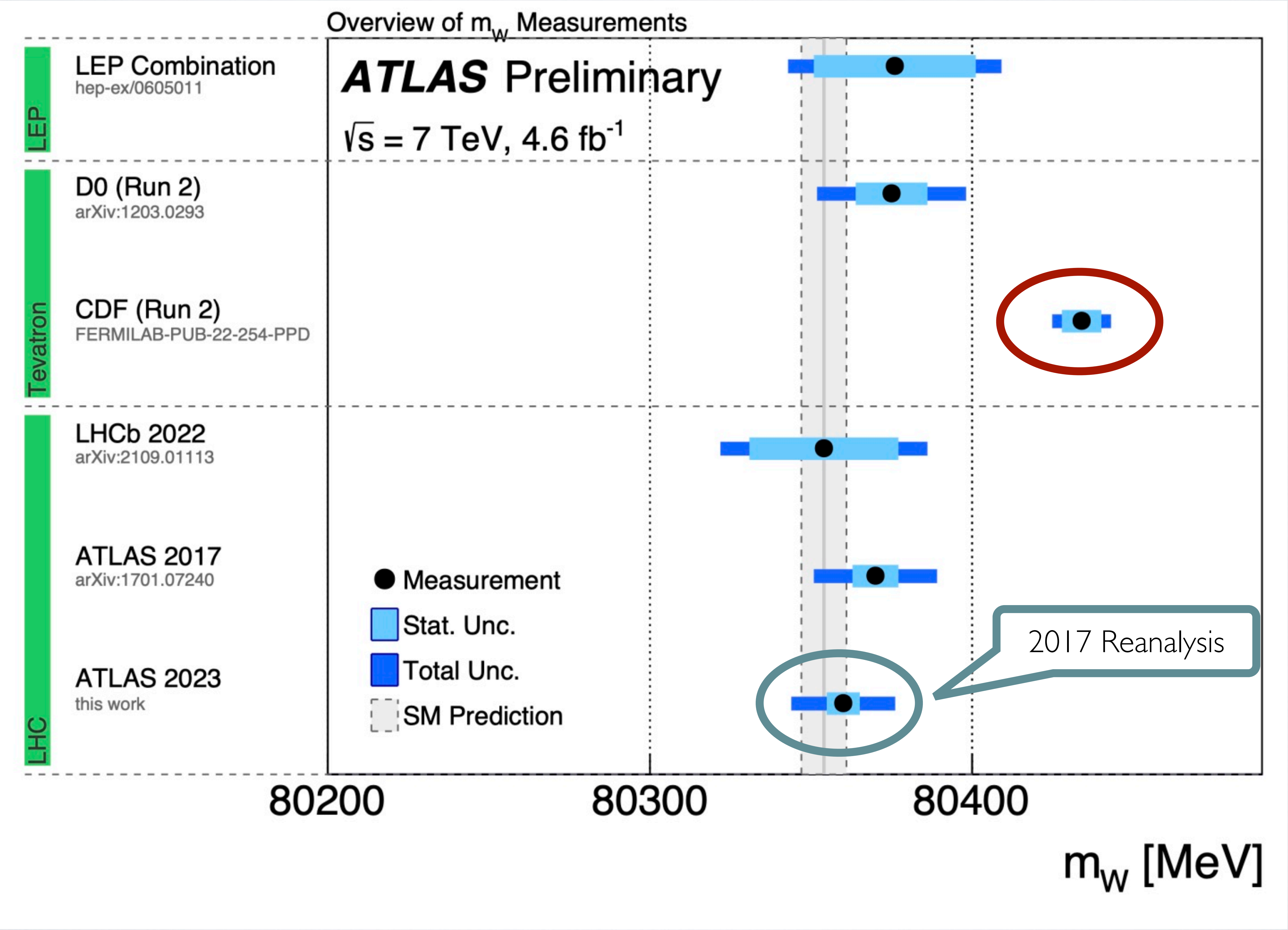
(a) Penguin diagram of $B \to K^{(*)}\ell^+\ell^-$.

2023/24 (on the way out?)

- W boson mass
- g-2 of the muon

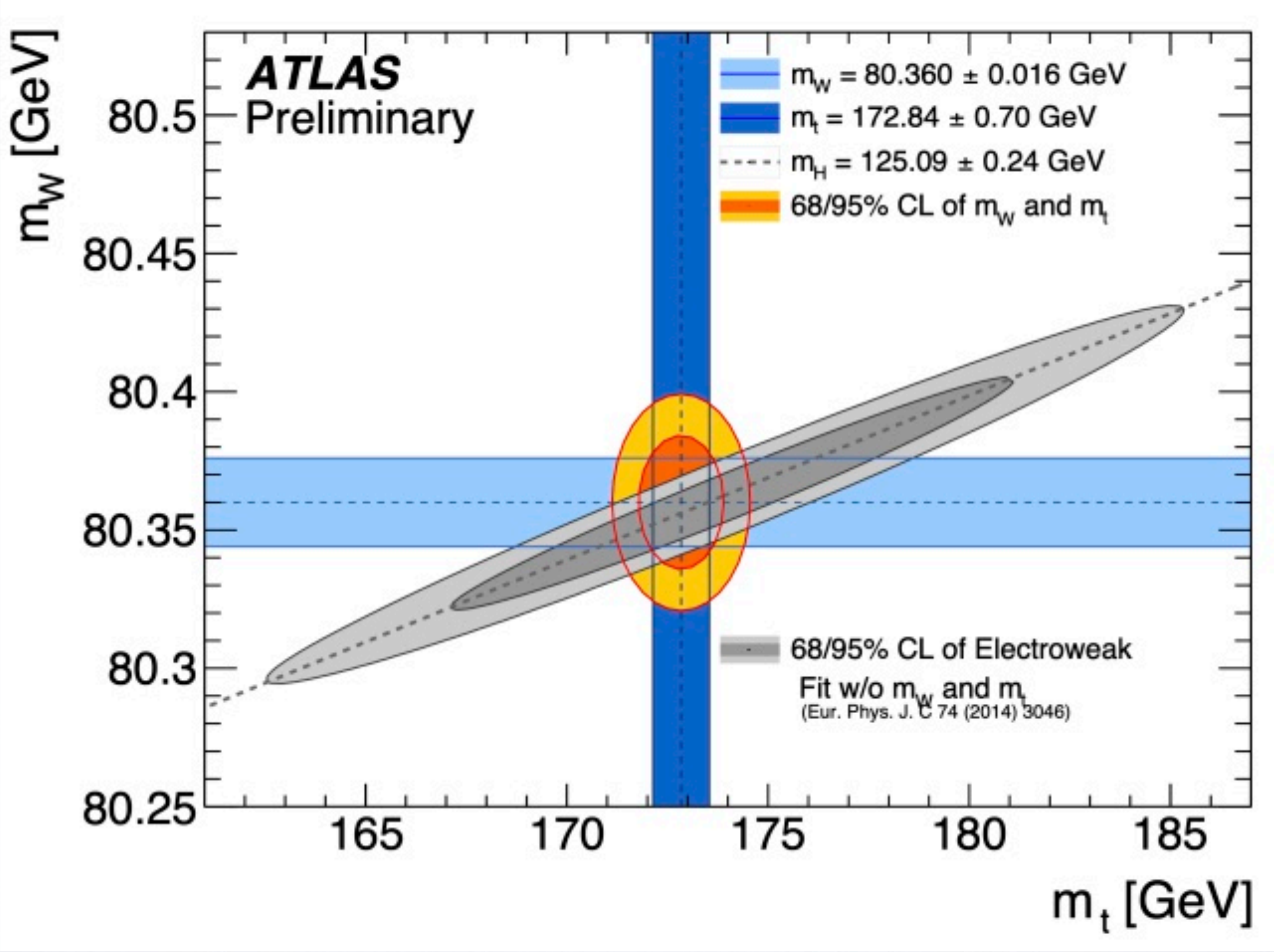


W - mass



Overview of m_W Measurements
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV, 4.6 fb^{-1}
LEP
LEP Combination
hep-ex/0605011
Tevatron
D0 (Run 2)
arXiv:1203.0293
CDF (Run 2)
FERMILAB-PUB-22-254-PPD
LHC
LHCb 2022
arXiv:2109.01113
ATLAS 2017
arXiv:1701.07240
ATLAS 2023
this work
Measurement
Stat. Unc.
Total Unc.
SM Prediction
2017 Reanalysis
80200
80300
80400
m_W [MeV]

Should one bet against the SM?



68% & 95% CL contours for W and top-mass from Global Electroweak Fit vs Atlas direct measurements

To good to be true ?

CDF

CDF claims increase statistics/better understanding of PDFs and detector (PDFs alone reduce uncertainty from 10 to 3.9 MeV)

CDF is in Tension with ATLAS measurement and SM!

Study correlations w.r.t. to PDFs, higher order QCD and QED effects.

What the numbers say

$$M_W\Big|_{SM} = 80{,}357 \pm 4_{\text{inputs}} \pm 4_{\text{theory}}\,\text{MeV}$$

$$M_W\Big|_{CDF} = 80{,}433.5 \pm 6.4_{\text{stat}} \pm 6.9_{\text{syst}} = 80{,}433.5 \pm 9.4\,\text{MeV}$$

$$M_W\big|_{ATLAS/23} = 80{,}360 \pm 16\,\text{MeV}$$

Naive weighted average

$$M_W\Big|_{AVG} = 80{,}405 \pm 7\,\text{MeV}$$

$$M_W(Erler)\Big|_{AVG} = 80{,}410 \pm 8\,\text{MeV}$$

Weighted average for incompatible measures

$$M_W\Big|_{AVG} = 80{,}408 \pm 19\,\text{MeV}$$

2.4 σ discrepancy with SM

(PDG) Uncertainty $\times \sqrt{\chi^2/\text{ndr}}$

See Erler and Ferro, Eur. Phys. J C 80 (2020) 6, 541 for PDG alternative

D'Alise, De Nardo, Di Luca, Fabiano, Frattulillo, Gaudino, Iacobacci, Sannino, Santorelli, Vignaroli, JHEP 08 (2022) 125, 2204.03686

Over coffe-break/lunch questions

Is it sensible to combine these measures ?

Are CDF and ATLAS measuring the same quantity ?

Could NP in PDFs explain the discrepancy ?

Is CDF wrong (see R_{K*}) ?

Are the exp results SM biased ?

Can precision ever replace a signal discovery?

Precision electroweak

$$\Delta M_W \approx 300\ \text{MeV} \times (1.43\ T - 0.86\ S)$$

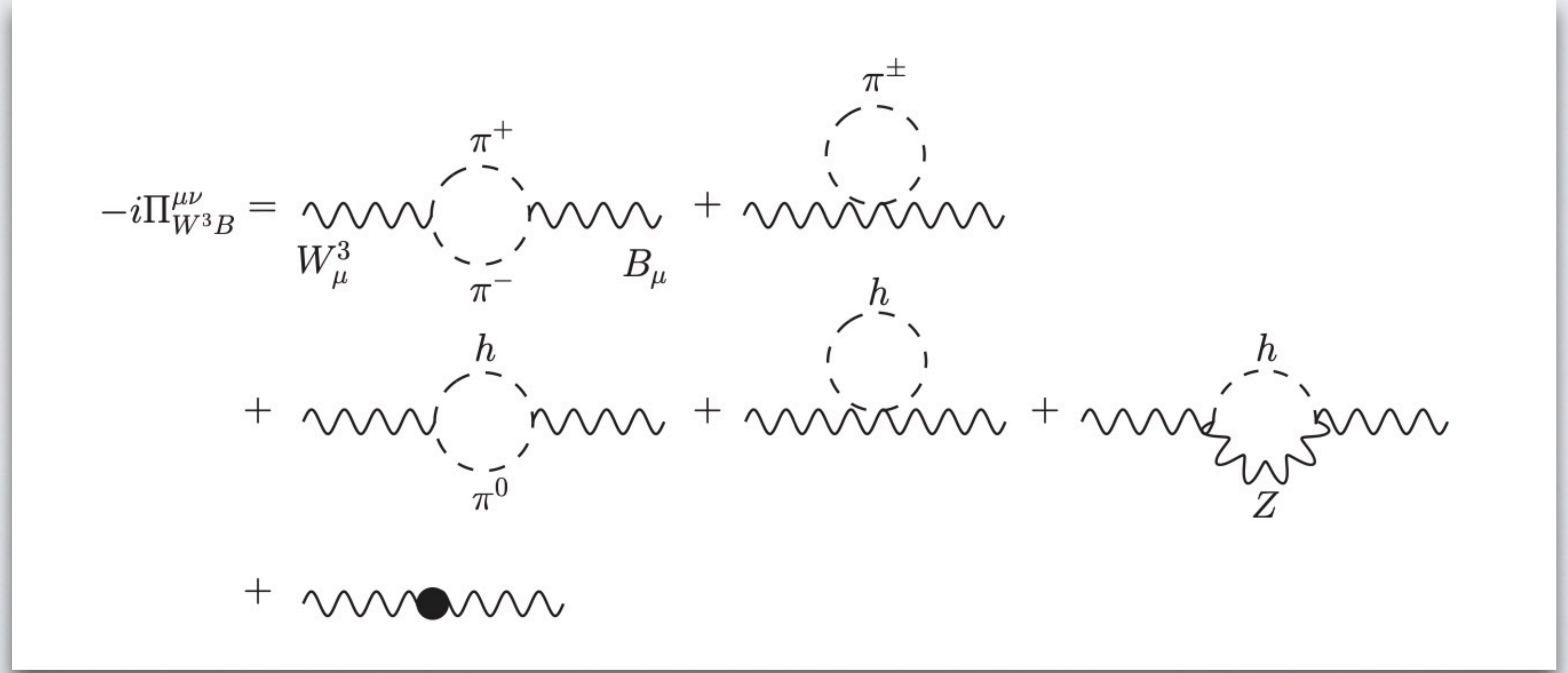
Altarelli, Barbieri, Caravaglios PLB 349, 145 (1995)

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Cacciapaglia, Sannino PLB 832(2022)137232 2204.04514

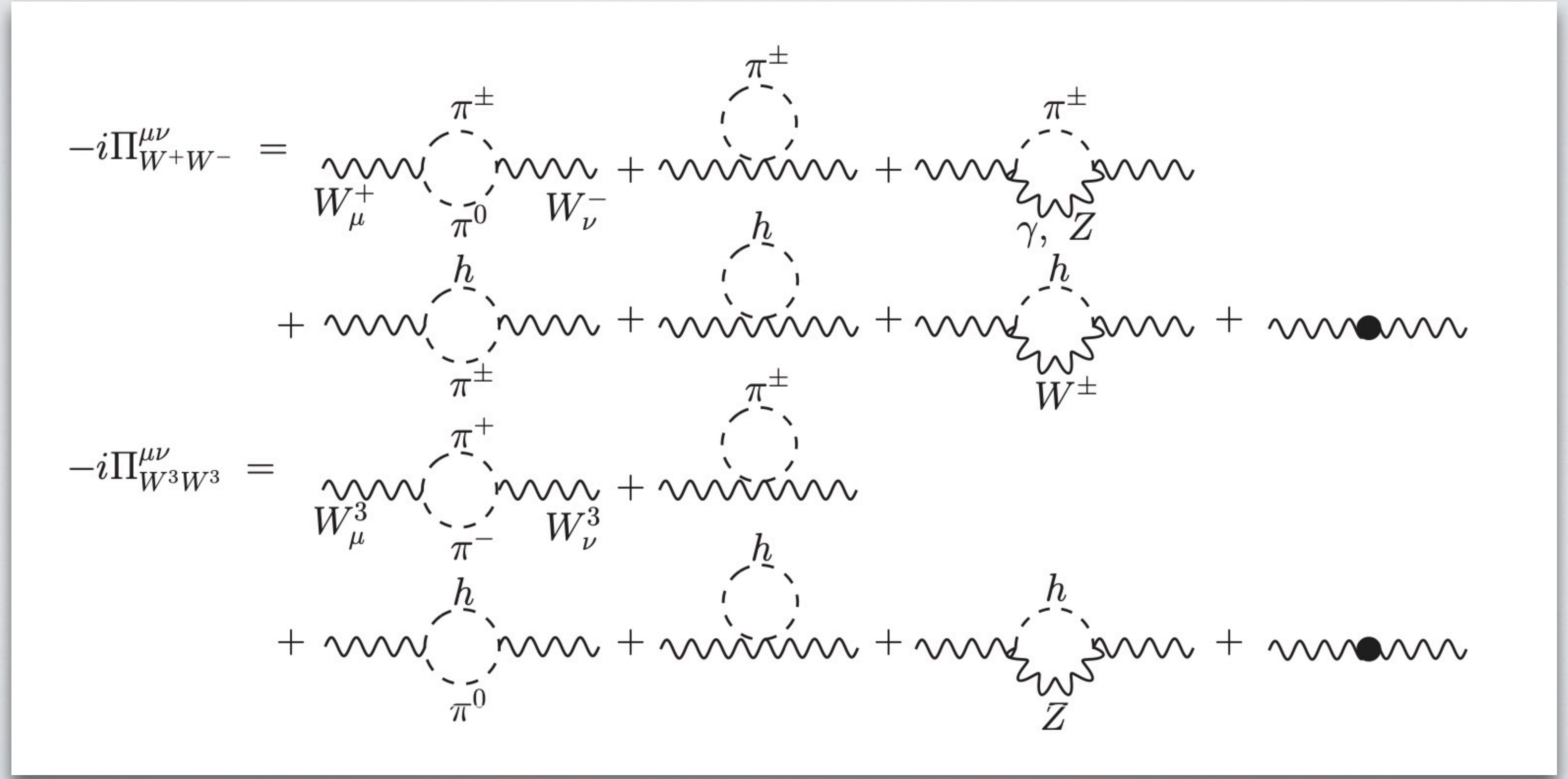
Electroweak parameters

$$S = -16\pi \frac{\Pi_{3Y}(M_Z^2) - \Pi_{3Y}(0)}{M_z^2}$$



Precision electroweak

$$T = 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 M_z^2}$$



Precision electroweak

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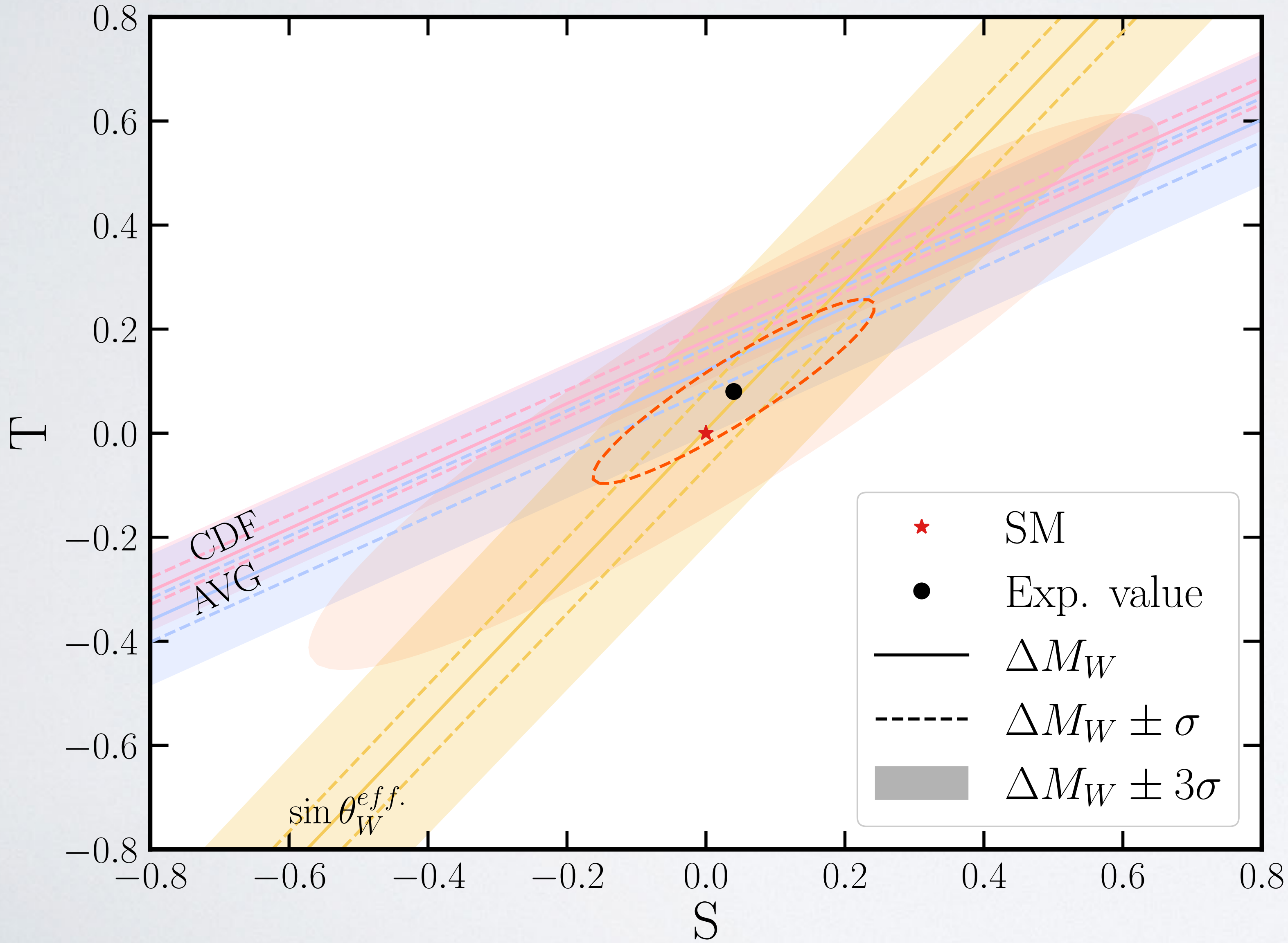


Yellow band = bound on direct s_W^2

Black dot - Mean value of S and T

Orange ellipses 3σ S & T region

Non Standard Higgs

Technical naturality

Physical parameters remain small under radiative corrections.

$$m_e = m_e^0 \, R\left(\mu / m_e^0\right) \qquad \text{protected}$$

$$m_H^2 = m_H^{0\,2} \, R\left(\mu / m_H^0\right) + ⊚ \, \Lambda^2 \qquad \text{unprotected}$$

depends on the physics.

Summary and references in

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Non-standard (composite) Higgs

Glueball:

Lightest glueball with string tension $\Lambda_H \neq v = 246$ GeV

Technicolor:

TC fermion bound state assume reference $\mathrm{SU}(\bar{N})$ (Fund. Rep.)

Large N Dilaton:

Couplings related and single scale $N\Lambda_H$

Goldstone/Holo:

EW vev misalignment $v = f \sin\theta \equiv f s_\theta$ with $s_\theta \ll 1$

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Glueball Higgs

$$\mathcal{L}_{\text{Glueball-Higgs}} = \mathcal{L}_{\overline{\text{SM}}} + \left(1 + \frac{2r_\pi}{N\Lambda_H}h + \frac{s_\pi}{N^2\Lambda_H^2}h^2\right)\frac{v^2}{4}\text{Tr}\, D_\mu U^\dagger D^\mu U$$
$$+ \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{m_h^2}{2}h^2\left[1 + \frac{V_{0,1}}{N}\frac{h}{\Lambda_H} + \frac{V_{0,2}}{N^2}\frac{h^2}{\Lambda_H^2}\right]$$
$$- \; m_t\left(1 + \frac{r_t}{N\Lambda_H}h\right)\left[\bar{q}_L\, U\left(\frac{1}{2} + T^3\right)q_R + \text{h.c.}\right]$$
$$- \; m_b\left(1 + \frac{r_b}{N\Lambda_H}h\right)\left[\bar{q}_L\, U\left(\frac{1}{2} - T^3\right)q_R + \text{h.c.}\right] + \cdots$$
$$+ \; O\left(\frac{1}{4\pi v}, \frac{\partial^2}{\Lambda_H^2}\right)$$

$$h \sim G_{\mu\nu}G^{\mu\nu}$$

Lightest SU(N) glueball

$\Lambda_H \neq v$ $\qquad v = 246$ GeV

N-independent String Tension

$$U = \exp\left(i2\pi^a T^a/v\right)$$

$$D_\mu U = \partial_\mu U - igW_\mu^a T^a U + ig' U B_\mu T^3$$

$$V_{a,b} \sim \mathcal{O}(1)$$

$V_{0,b}$ Non-derivative series in h

SM for

$$r_\pi = r_t = r_b = N\frac{\Lambda_H}{v} \qquad s_\pi = N^2\frac{\Lambda_H^2}{v^2}$$

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Technicolor Higgs

$$\mathcal{L}_{TC}(N) = \mathcal{L}_{\overline{SM}} + \left(1 + g\frac{2r_\pi}{2m_W}h + g^2\frac{s_\pi}{4m_W^2}h^2\right)\frac{m_W^2}{g^2}\mathrm{Tr}\, D_\mu U^\dagger D^\mu U$$
$$+ \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{m_h^2}{2}h^2\left[1 + gV_{0,1}\frac{h}{2m_W} + g^2 V_{0,2}\frac{h^2}{4m_W^2}\right]$$
$$- m_t\left(1 + g\frac{r_t}{2m_W}h\right)\left[\bar{q}_L\, U\left(\frac{1}{2} + T^3\right)q_R + \mathrm{h.c.}\right]$$
$$- m_b\left(1 + g\frac{r_b}{2m_W}h\right)\left[\bar{q}_L\, U\left(\frac{1}{2} - T^3\right)q_R + \mathrm{h.c.}\right] + \cdots$$

$$h \sim \frac{\overline{\mathcal{F}}\mathcal{F}}{F_\Pi^2} \qquad F_\Pi^2 = N\Lambda_{TC}^2$$

$$v = F_\Pi \qquad m_q = y_q v \frac{N}{2\overline{N}}$$

$$m_W^2 = g^2 v^2 \frac{N}{4\overline{N}} \qquad \sqrt{\frac{N}{\overline{N}}}\, v = 2\frac{m_W}{g}$$

Pions ~ Higgs dynamics governed by N (via F_Π)

g monitors $1/\sqrt{N}$ cost of extra h

SM recovered for (up to Higgs potential)

$$r_\pi = r_t = r_b = \frac{2m_W}{v\ g} \qquad s_\pi = \frac{4m_W^2}{v^2\ g^2}$$

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Pseudo Dilaton Higgs

$$\begin{aligned}\mathcal{L}_{\text{Dilaton}}(N) &= \mathcal{L}_{\overline{\text{SM}}} + \left(1 + \frac{2h}{N\Lambda_H} + \frac{h^2}{N^2\Lambda_H^2}\right)\frac{v^2}{4}\text{Tr}\, D_\mu U^\dagger D^\mu U \\ &+ \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{m_h^2}{2}h^2\left[1 + \frac{V_{0,1}}{N}\frac{h}{\Lambda_H} + \frac{V_{0,2}}{N^2}\frac{h^2}{\Lambda_H^2}\right] \\ &- m_t\left(1 + \frac{h}{N\Lambda_H}\right)\left[\bar{q}_L\, U\left(\frac{1}{2} + T^3\right) q_R + \text{h.c.}\right] \\ &- m_b\left(1 + \frac{h}{N\Lambda_H}\right)\left[\bar{q}_L\, U\left(\frac{1}{2} - T^3\right) q_R + \text{h.c.}\right] + \cdots\end{aligned}$$

Higgs via near conformal dynamics

$f_d = N\Lambda_H$ (Large N dynamics)

Coefficients dictated by conformality

Higgs dilaton-potential coefficients $V_{0,i}$ depend on conformal dynamic breaking

SM recovered for

$f_d = v$

General Non-Standard Higgs Lagrangian

$$\mathscr{L} = \mathscr{L}_{\overline{\mathrm{SM}}} + \xi_V \left(1 + 2\kappa_V \frac{h}{v} + \kappa_{2V}\frac{h^2}{v^2}\right)\frac{v^2}{4}\mathrm{Tr}\, D_\mu U^\dagger D^\mu U + \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{\tilde{m}_h^2}{2}h^2\left(1 + V_{0,1}\lambda_{3h}\frac{h}{v}\right)$$

$$- \frac{\tilde{y}_t v}{\sqrt{2}}\xi_t\left(1+\kappa_t\frac{h}{v}\right)\left[\overline{q}_L\, U\left(\frac{1}{2}+T^3\right)q_R + \mathrm{h.c.}\right] - \frac{\tilde{y}_b v}{\sqrt{2}}\xi_b\left(1+\kappa_b\frac{h}{v}\right)\left[\overline{q}_L\, U\left(\frac{1}{2}-T^3\right)q_R + \mathrm{h.c.}\right] + \cdots$$

$$U = \exp\left(i2\pi^a T^a/v\right) \qquad v = 246\ \mathrm{GeV}$$

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Cacciapaglia, Sannino PLB 832 (2022), 2204.04514

Non-standard Higgs coupling to WW/ZZ

$$\kappa_V^2 = \frac{\sigma_{\mathrm{VBF}}}{\sigma_{\mathrm{VBF}}^{\mathrm{SM}}} \equiv \frac{\Gamma_{h\to WW/ZZ}}{\Gamma^{\mathrm{SM}}_{h\to WW/ZZ}}$$

	ξ_V	κ_V	κ_{2V}	λ_{3h}	ξ_f	κ_f	higher orders
Glueball	1	$\frac{r_\pi v}{N\Lambda_H}$	$\frac{s_\pi v^2}{N^2\Lambda_H^2}$	$\frac{v}{N\Lambda_H}$	1	$\frac{r_f v}{N\Lambda_H}$	$\frac{1}{4\pi v}, \frac{\partial^2}{\Lambda_H^2}$
Technicolor-like	$\frac{\overline{N}}{N}$	$r_\pi\sqrt{\frac{\overline{N}}{N}}$	$s_\pi\frac{\overline{N}}{N}$	$\sqrt{\frac{\overline{N}}{N}}$	$\sqrt{\frac{\overline{N}}{N}}$	$r_f\sqrt{\frac{\overline{N}}{N}}$	$\frac{1}{4\pi v}, \frac{\partial^2}{v^2}$
pseudo-dilaton	1	$\frac{v}{N\Lambda_H}$	$\frac{v^2}{N^2\Lambda_H^2}$	$\frac{v}{N\Lambda_H}$	1	$\frac{v}{N\Lambda_H}$	
Goldstone/Holographic	1	c_θ	$c_{2\theta}$	c_θ	1	c_θ	$\frac{1}{4\pi f}, \frac{\partial^2}{f^2}$

Non-standard S & T

Sannino, Phys. Rev. D. 93 (2016), 1508.07413
Cacciapaglia, Sannino PLB 832 (2022), 2204.04514

$$S = \frac{1}{12\pi}(1-\kappa_V^2)\ln\frac{\Lambda^2}{m_h^2} + \Delta S_{\rm UV}$$

$\Delta S_{\rm UV}$ = unknown UV contributions

Assuming UV custodial

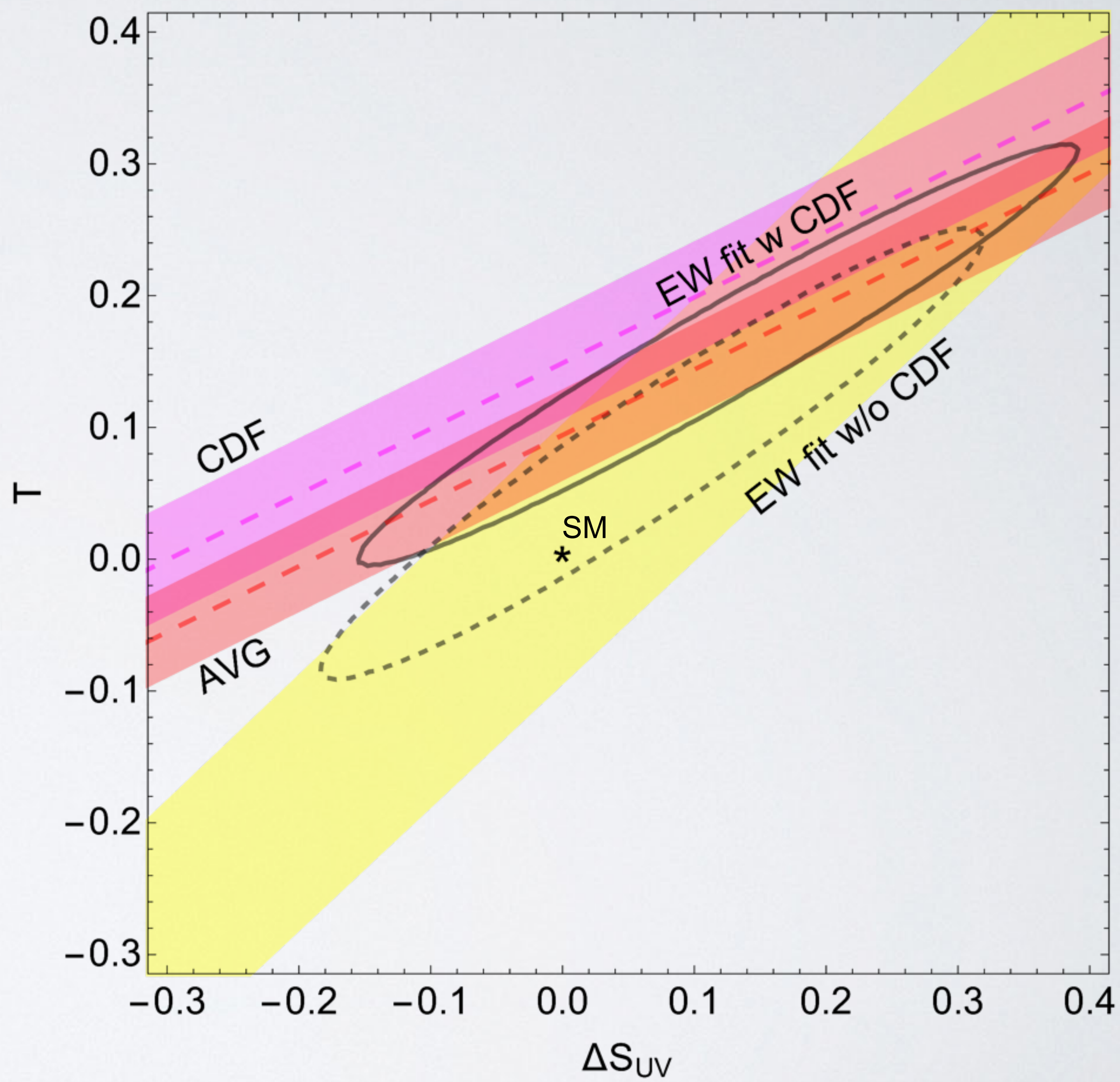
$$T = -\frac{3}{16\pi c_W^2}(1-\kappa_V^2)\ln\frac{\Lambda^2}{m_h^2}\,,$$

$$S = -\frac{4}{9}c_W^2 T + \Delta S_{\rm UV}$$

$$\Delta S_{\rm UV} = \frac{n_d}{6\pi}$$

Reference UV model

n_d = # weak doublets

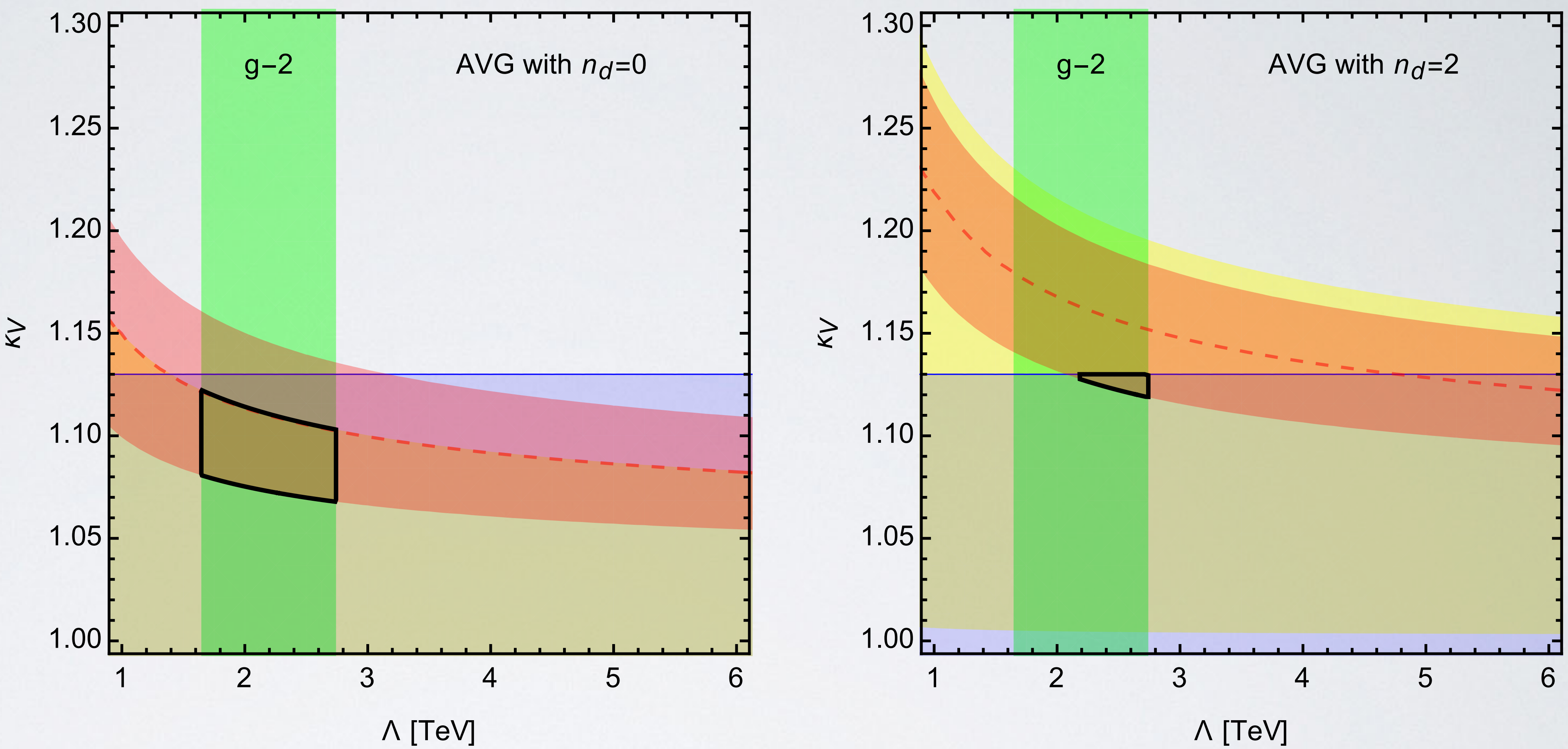


CDF - W (magenta) and s_W^2 (yellow) ⇒ small positive $\Delta S_{\rm UV}$ & positive T

Constraints

$$\Delta S_{\rm UV} = \frac{n_d}{6\pi}$$

$$\Delta a_\mu = \frac{m_\mu^2}{\Lambda^2}$$



$\kappa_V = 1.05 \pm 0.04$

G. Aad et al. (ATLAS), Phys. Rev. D 101, 012002 (2020)

Yellow band = bound on s_W^2

Blue region allowed by ATLAS

Orange is fit to Mw average to 2σ

Cacciapaglia, Sannino PLB 832 (2022), 2204.04514

Sannino, Phys. Rev. D. 93 (2016), 1508.07413

Positive enhancement of around 5% for κ_V

General results

Goldstone/Holo $\Rightarrow \kappa_V = c_\theta \leq 1$

Dilaton, TC and Glueball Higgs $\Rightarrow \kappa_V \geq 1$ for $\Lambda < v$ and/or $r_\pi > 1$

Dilaton, TC & Glueball Higgs work but small coupling for Goldstone/Holo Higgs

Natural composite dynamics can address W and g-2 anomalies

Compositeness

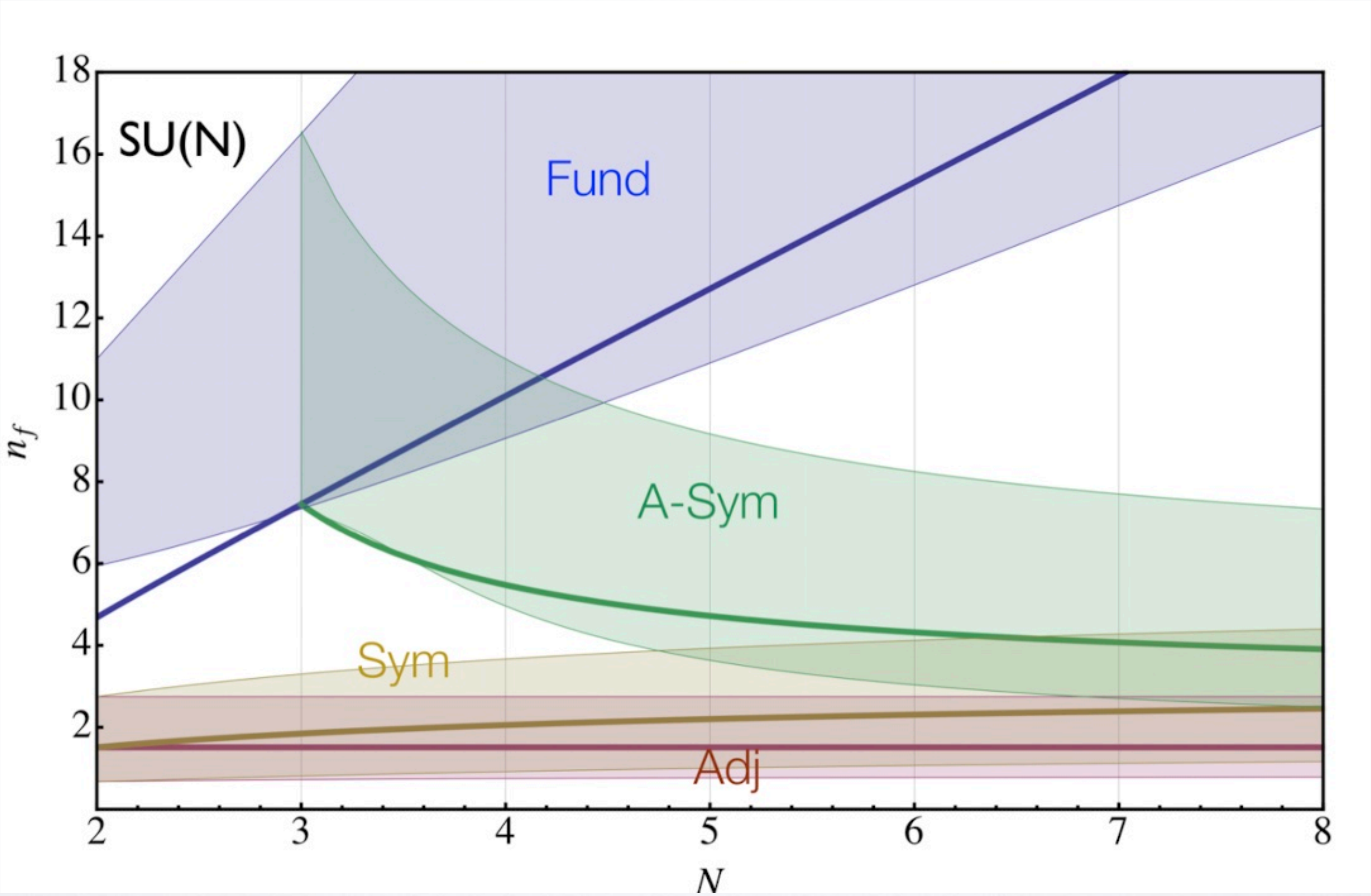
Composite landscape

	Interactions	Rep	UV
G_μ	$-\frac{1}{4g^2} G_{\mu\nu} G^{\mu\nu}$	Adj	Free
$G_\mu + \psi$	$\ldots + i\bar{\psi}\gamma_\mu D^\mu \psi$	Fund, Adj, …	Free/ NP safe?
$G_\mu + \phi$	$\ldots + D^\mu \bar{\phi} D_\mu \phi - \lambda \left(\bar{\phi}\phi\right)^2$	Fund, Adj, …	Landau pole
$G_\mu + \psi + \phi$	$\ldots + y\bar{\psi}\phi\psi$	Repr. dependent	Free/safe

It can be (partially) supersymmetric

If extra dimensions seen as non-perturbative QFT

Phase diagram for gauge-fermion sector



Sannino, Tuominen Phys. Rev. D71 (2005) 051901

Dietrich, Sannino Phys. Rev. D. 75 (2007) 085018

Applications

Bright

Dark

- Colliders
- Early universe
- Compact stars

QCD

- Strong CP
- Axions
- …

- Technicolor
- Composite (GB) Higgs
- Fundamental partial compositeness

Novel Composite Dynamics

- Dark baryons
- Dark pions
- SIMPs
- Composite inflation
- Secluded dark sectors

Sannino. Acta Phys. Polon. B 40 (2009) 3533-3743, 0911.0931

Cacciapaglia, Pica, Sannino, Phys. Rept. 877 (2020) 1-70, 2002.04914

Final considerations

Landscape of strongly interacting theories is vastly unknown

Relevant, for example, to address g-2

Phase diagram of strongly interacting theories very much needed

New promising analytic and numeric methodologies underway

To be continued…

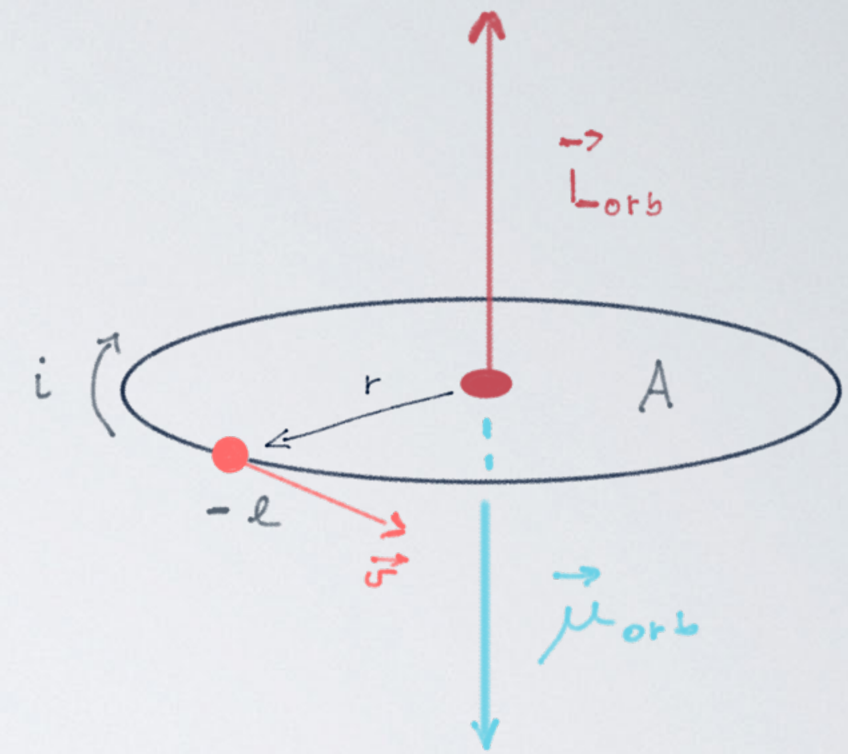
Back up

Muon g-2

Orbital magnetic moment

$$\vec{\mu}_{orb} = i\vec{A} = -\frac{e}{2\pi r} v\pi r^2 \hat{A} = -\frac{e}{2m}\vec{L}_{orb}$$

$$\vec{L}_{orb} = \vec{r} \wedge m\vec{v}$$



Intrinsic angular momentum $\vec{\mu} = g\frac{q}{2m}\vec{S}$

$g = 2$ Dirac equation

PHYSICAL REVIEW VOLUME 72, NUMBER 3 AUGUST 1, 1947

Fine Structure of the Hydrogen Atom by a Microwave Method* **

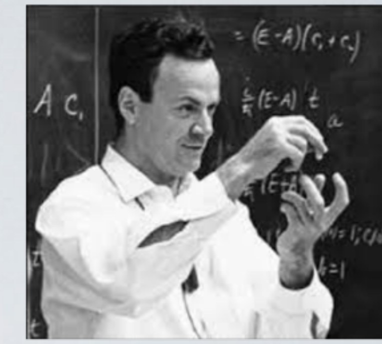
Willis E. Lamb, Jr. and Robert C. Retherford
Columbia Radiation Laboratory, Department of Physics, Columbia University, New York, New York
(Received June 18, 1947)

1955

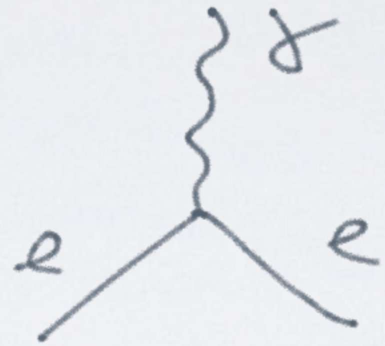
$g > 2$

QED

Schwinger, Tomonaga, Feynman

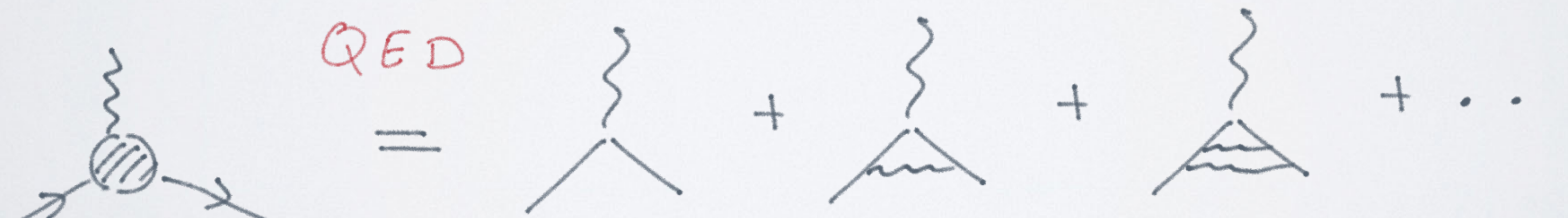


Elementary process

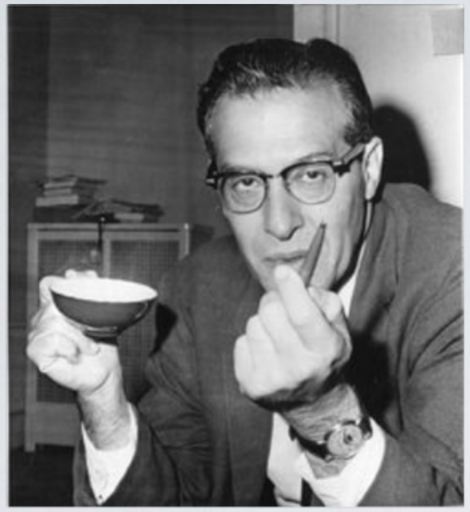


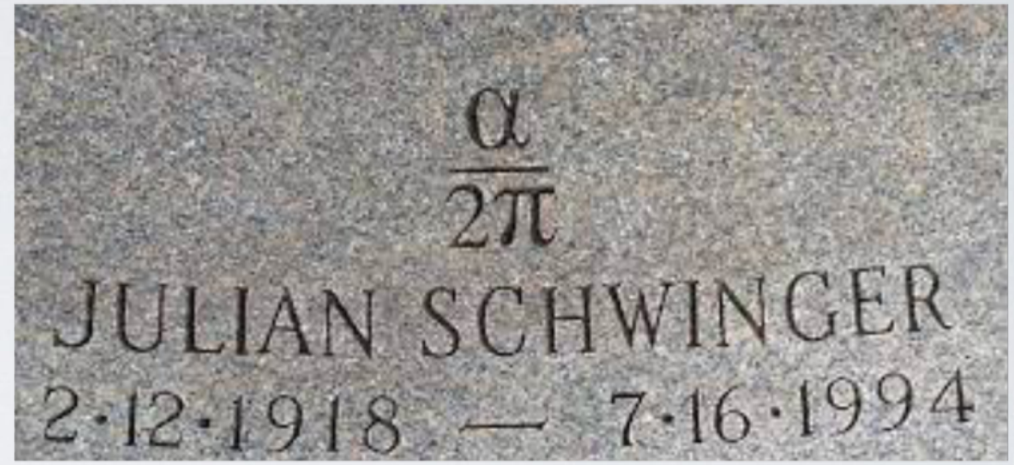
Schwinger's One loop computation

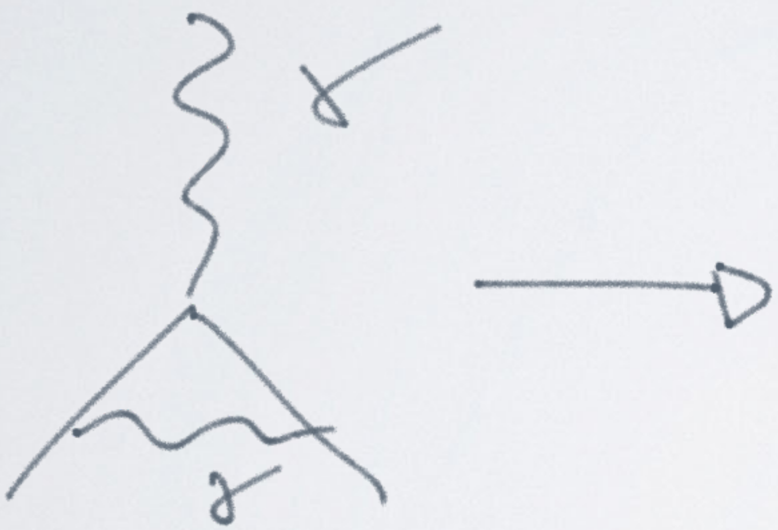
QED



↳ Dirac's limit



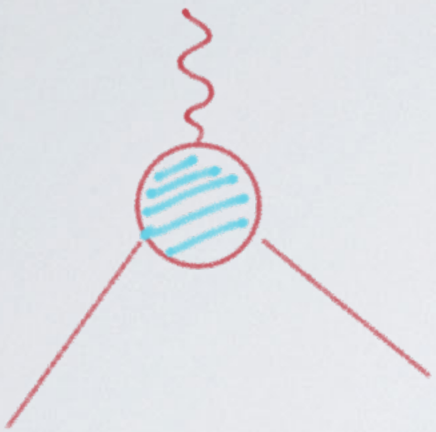




$$\frac{g_e - 2}{2} = a_e = \frac{\alpha}{2\pi} + \mathcal{O}(\alpha^2)$$

1948

Muon g-2

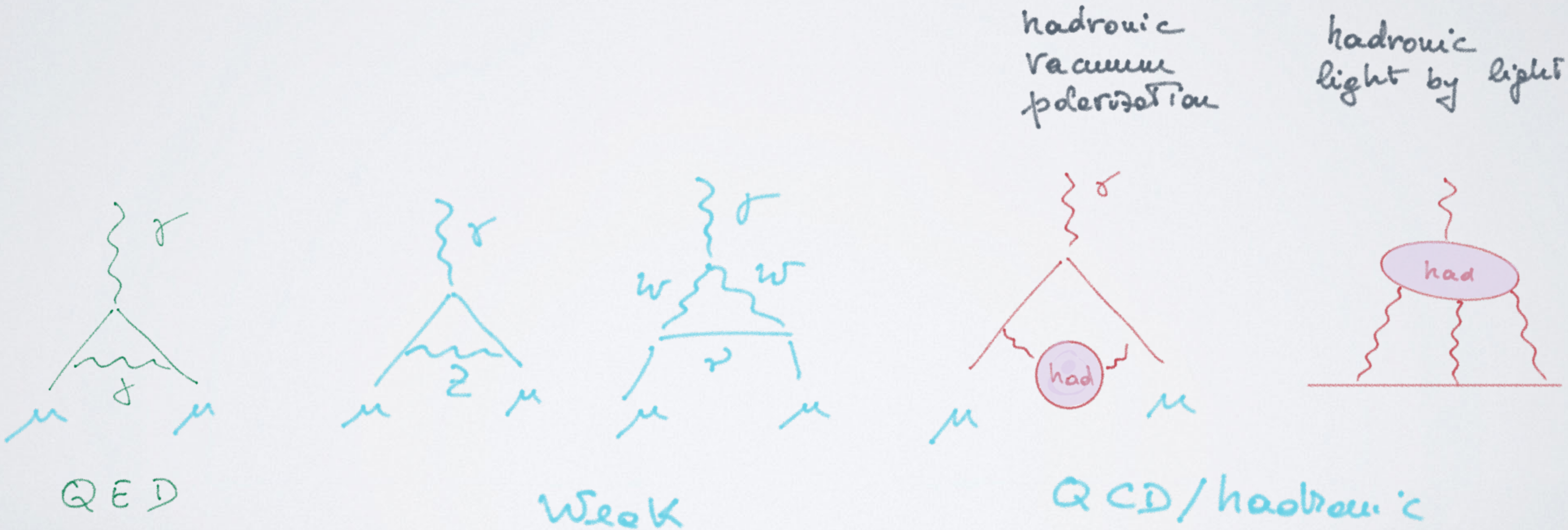


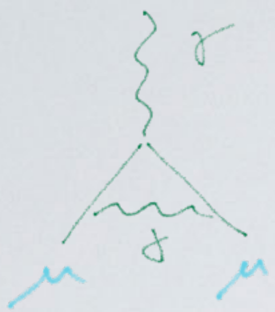
g-2 anomaly

$$a_{lepton} = \frac{g_\ell - 2}{2} = \underbrace{a_\ell^{QED} + a_\ell^{weak} + a_\ell^{hadronic}}_{SM} + \underbrace{a_\ell^{NP}}_{BSM}$$

Standard Model Corrections

Representative contributions





QED

α^5 5^{th}-order

$116\,584\,718.9(1) \times 10^{-11}$ 0.001 ppm

Weak

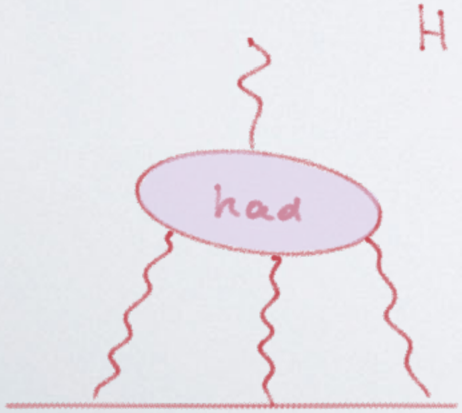
α^3

$153.6\ (1.0) \times 10^{-11}$ 0.01 ppm

HVP

α^2

$6845\,(40) \times 10^{-11}$ 0.37 ppm

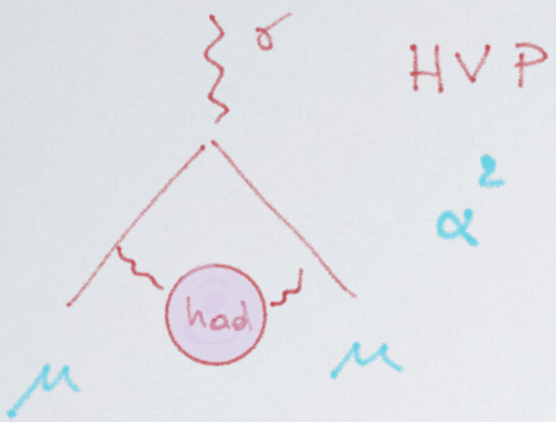


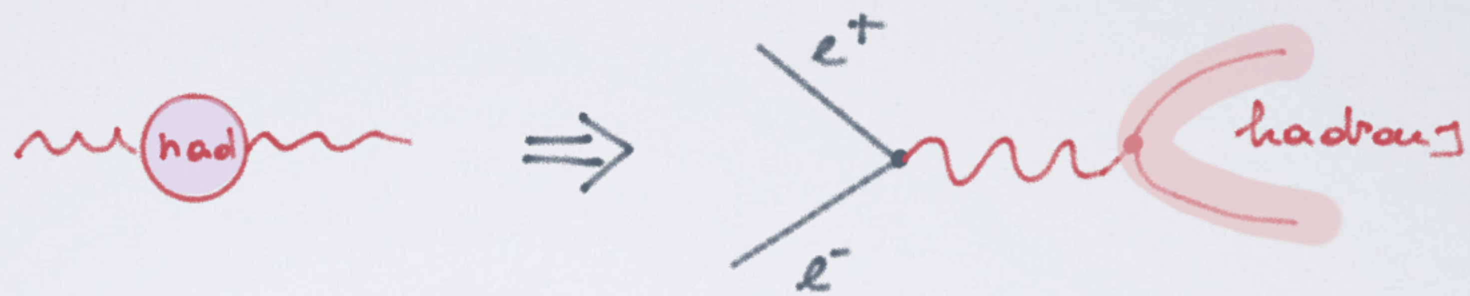
HLbL

α^3

$92(18) \times 10^{-11}$ 0.15 ppm

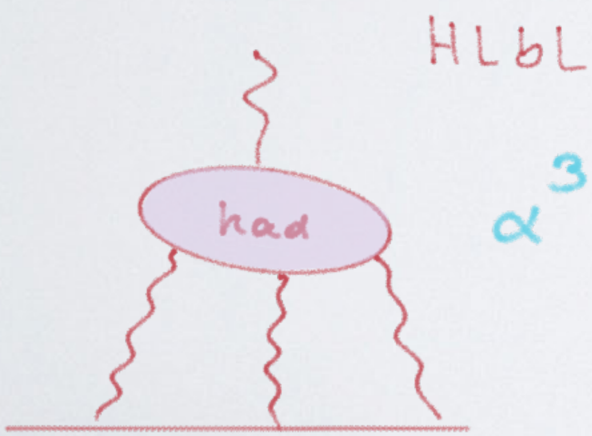
Dispersive approach





Experimental data + dispersion theory

⇒ HVP with ~ 0.6% error

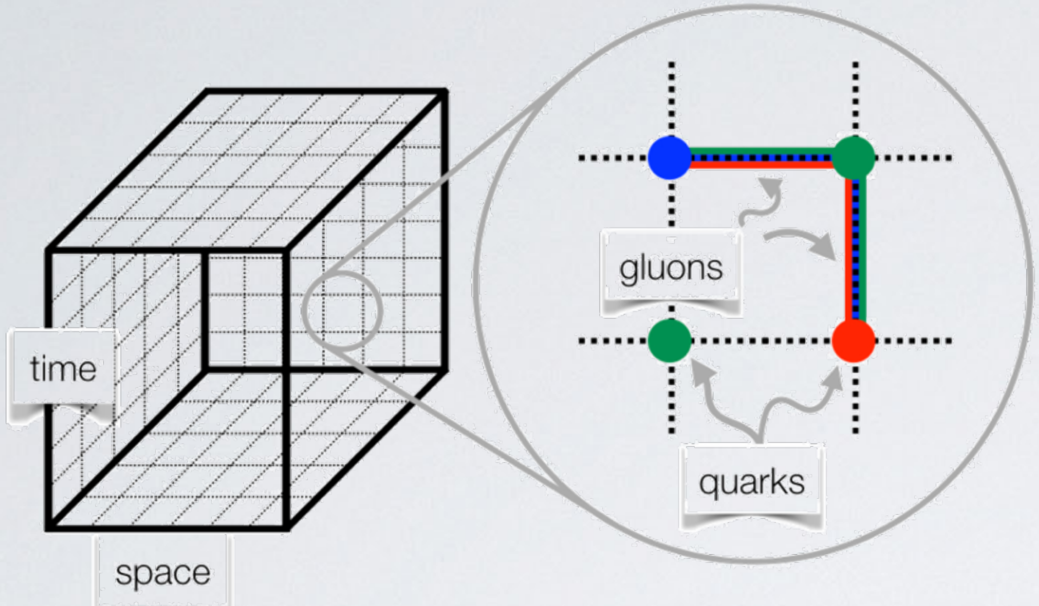


Allows data-driven evaluation with 20% error.

(HLbL subleading)

Data driven

Lattice QCD



Discrete space-time

Finite spatial volume

Finite time extent

Expensive

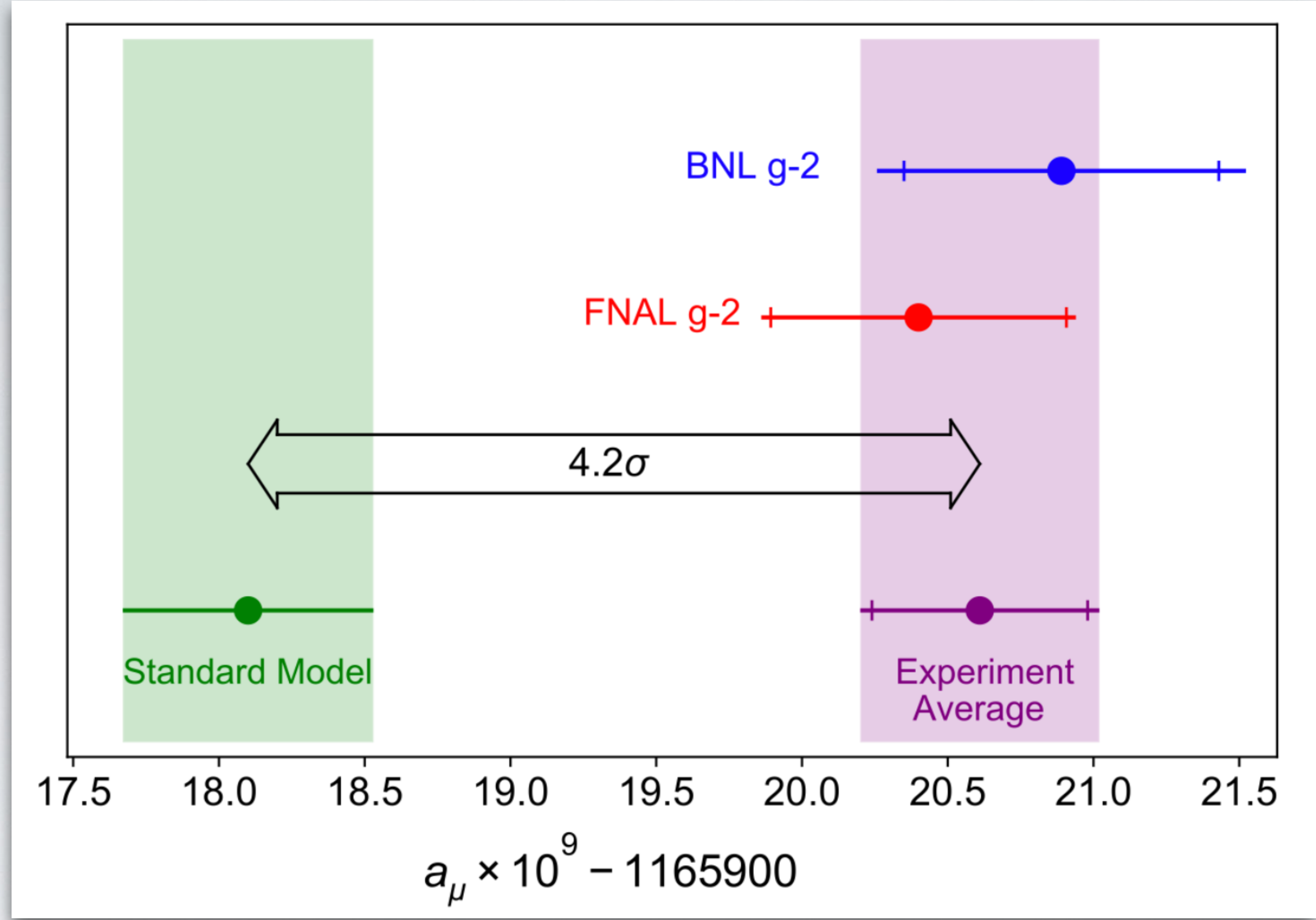
Ab-initio QCD

SM-based evaluations

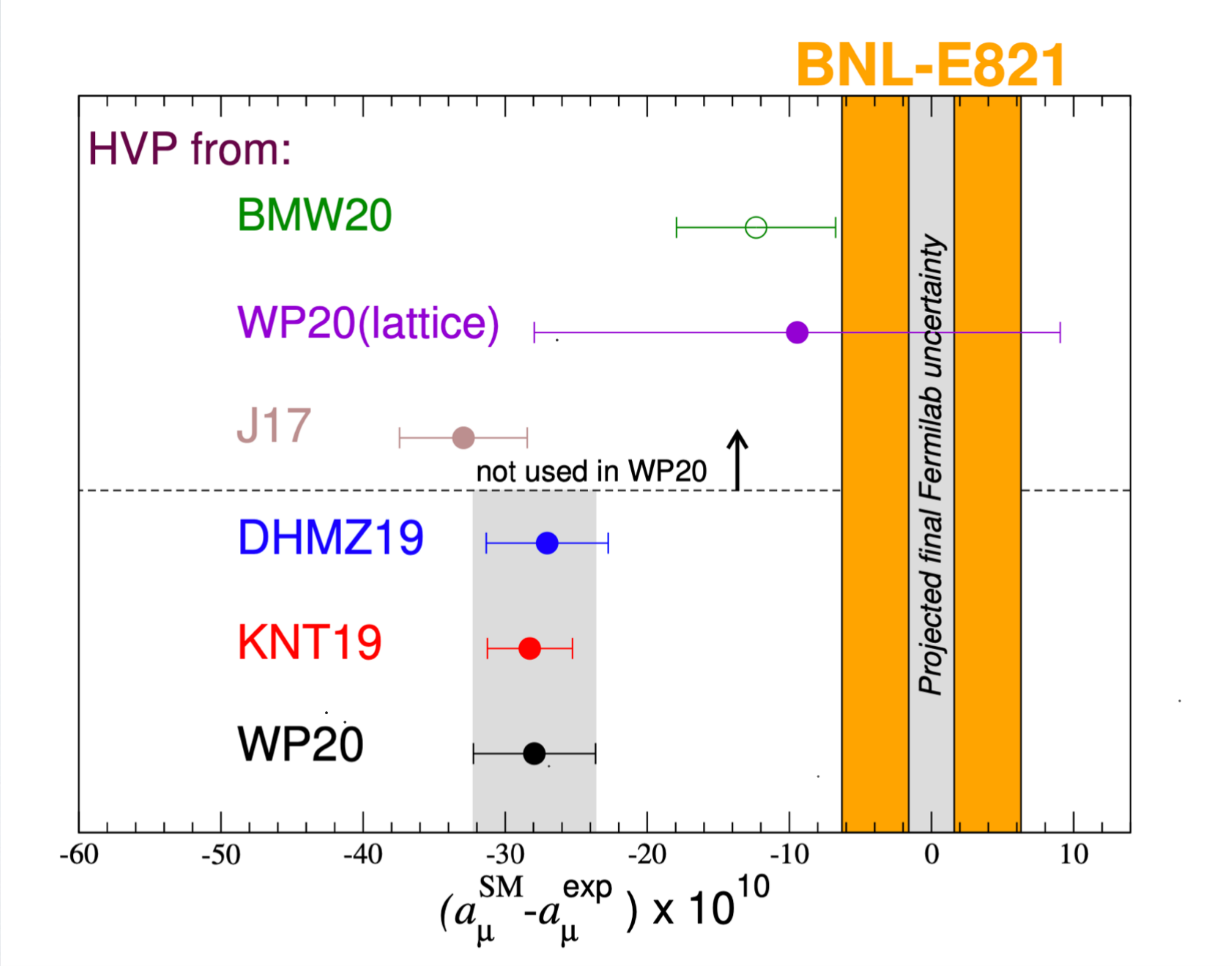
HVP : ~ 2% error vs 0.2% dispersive*

HLbL : ~ 45% error vs 20% dispersive

BMW20*



$$\Delta a_\mu = a_\mu(\text{Exp}) - a_\mu(\text{SM}) = (251 \pm 59) \times 10^{-11}$$



BNL-E821
HVP from:
BMW20
WP20(lattice)
J17
not used in WP20
DHMZ19
KNT19
WP20
Projected final Fermilab uncertainty
-60
-50
-40
-30
-20
-10
0
10
$(a_\mu^{SM} - a_\mu^{exp}) \times 10^{10}$

Fundamental Composite Physics

Sannino, Acta Phys. Polon. B 40 (2009) 3533-3743, 0911.0931

Sannino, Strumia, Tesi, Vigiani, JHEP 11 (2016) 029, 1607.01659

Cacciapaglia, Pica, Sannino, Phys. Rept. 877 (2020) 1-70, 2002.04914

Strategy

- Skeleton model
- Varying degree of naturality // compositness
- Compare with anomalies

Skeleton Lagrangian

$$-\mathcal{L}_{NP} = y_1^{ij} L^i \mathcal{F}_L S_E^{j*} + y_E E^c \mathcal{F}_N^c S_E + y_Q Q \mathcal{F}_L S_D^* + y_U U^c \mathcal{F}_E^c S_D + y_D D^c \mathcal{F}_N^c S_D$$

$$+ \sqrt{2}\, k \left(\mathcal{F}_L \mathcal{F}_N^c + \mathcal{F}_E \mathcal{F}_L^c \right) \phi_H + h.c.$$

	G_{TC}	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
$\mathcal{F}_L$	$\square$	1	$\square$	Y
$\mathcal{F}_N^c$	$\bar{\square}$	1	1	$-Y-1/2$
$\mathcal{F}_E^c$	$\bar{\square}$	1	1	$-Y+1/2$
S_E^j	$\square$	1	1	$Y-1/2$
S_D^j	$\square$	$\square$	1	$Y+1/6$

Template for

- (Walking) TC
- Composite Goldstone Higgs
- Non standard Higgs
- Radiative models

If new scalars are composite $\Rightarrow$ natural

Radiative models

Cabibbi, Ziegler, Zupan, 1804.00009
Arnan, Hofer, Mescia, Crivellin, 1608.07832,
with DM Arcadi, Cabibbi, Fedele, Mescia, 2104.03228

What does it embrace ?

Weak dynamics

Model

1] $\mathcal{G}_{TC} \approx$ (quasi) global symmetry $\Longrightarrow$ Perturbative

$\mathcal{F}$, S are weakly coupled

L. Calibbi, R. Ziegler, J. Zupan, 1804.00009
P. Arnan, L. Hofer, F. Mescia, A. Crivellin, 1608.07832
with DM Arcadi, Calibbi, Fedele, Mescia, 2104.03228
⋮

Strong dynamics

Fund. Partial Compositeness

2] g_{TC} strongly coupled

S fundamental Scalar

$\mathcal{F}S$ ~ Composite Baryons

ψB ~ Partial Compositeness

$\Longrightarrow$

- Composite Goldstone Higgs ✓
- Traditional Technicolor ✗
- Near conformal TC ✓
  [Higgs ~ pseudo-dilaton]

Cacciapaglia, Sannino 1402.0233

Sannino, Strumia, Tesi, Vigiani 1607.01659

Partial Compositeness

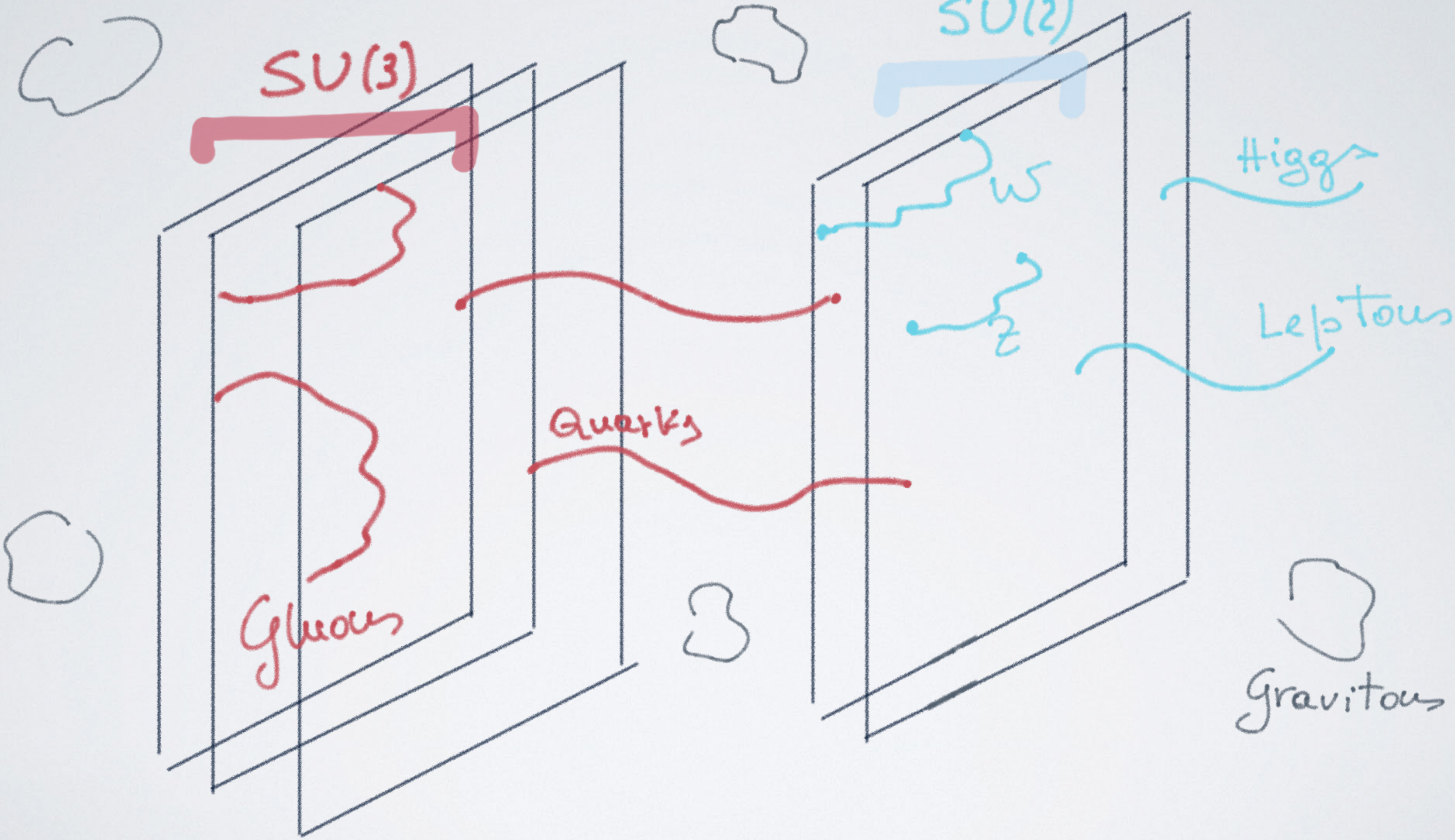
3] As in 2] but with

$S \sim \mathcal{F}\mathcal{F} \sim \chi\mathcal{F}, \chi\chi, \chi\mathcal{Z}$

$\mathcal{F}, \chi, \mathcal{Z}$ all fermions

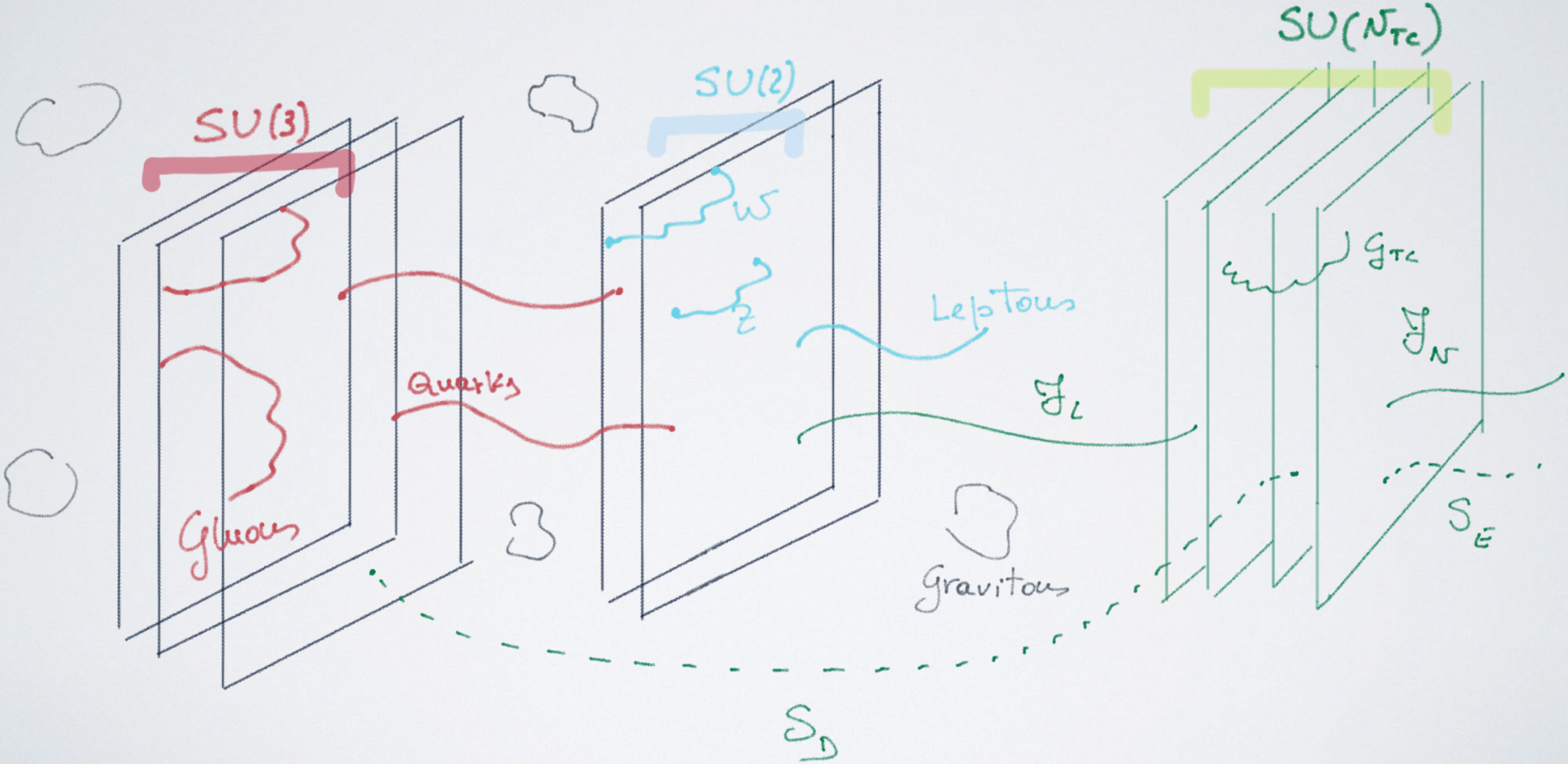
Ferretti and Karateev, 1312.5330

Stringy Standard Model

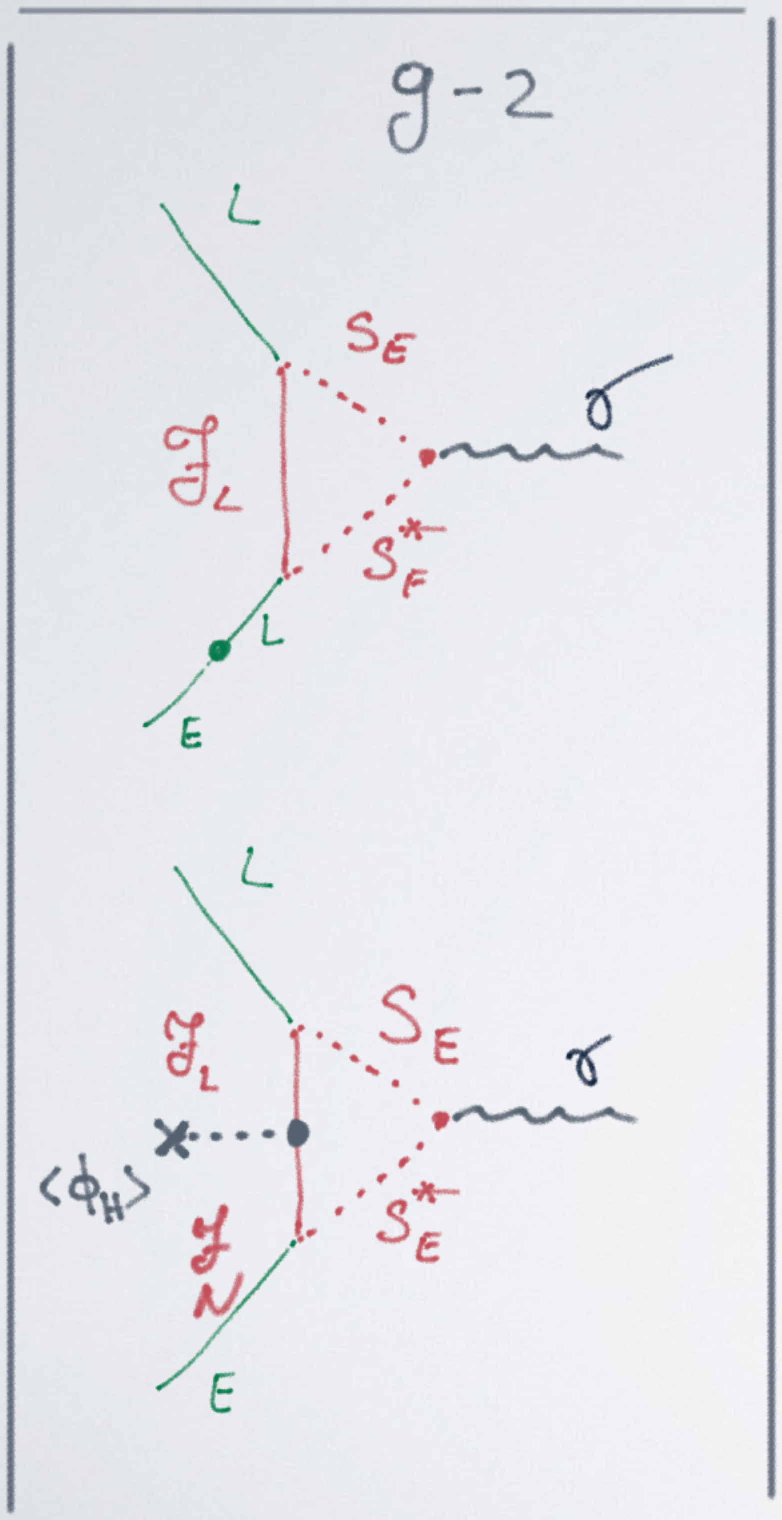


Aldazabal, Ibanez, Quevedo, Uranga hep-th/0005067

Stringy // holographic version



Skeleton diagrams/estimates



Exp. value for TC scale $\Lambda \approx 2\ \mathrm{TeV}$

$$\Delta a_\mu \approx \frac{m_\mu^2}{\Lambda^2}$$

Cacciapaglia, Cot, Sannino, Phys. Lett. B 825 (2022) 2104.08818

Composite Goldstone Higgs

$$\Delta a_\mu(CH) \approx \frac{v^2}{f_{CH}^2}\frac{m_\mu^2}{\Lambda^2}$$

$$\Lambda \approx 4\pi v \approx 2\ \mathrm{TeV}$$

$f_{CH} \approx (4-5)\ \mathrm{TeV} \Rightarrow$ too small Δa_μ

Frigerio, Nardecchia, Serra, Vecchi 1807.04279

General observations

- Theory uncertainty for g - 2
- No $R_K^{(*)}$ anomalies ⇒ back to lepton flavour universality
- (Natural) composite model works for g-2
- Non-standard Higgs as pseudo-dilaton (near conformal)