Which Way Beyond the Standard Model?

Measurements at the LHC
Motivations for new physics
Does the Higgs point the way?
Experimental anomalies?
Flavour non-universality in B meson decays?
Anomalous magnetic moment of the muon?
Mass of the W boson?
New ways to search for dark matter

John Ellis

KING'S College LONDON

Summary of the Standard Model

- Particles and SU(3) × SU(2) × U(1) quantum numbers:

L_L E_R	$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L, \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L$ e^-_R, μ^-_R, τ^-_R	$(\mathbf{1},\mathbf{2},-1)$ $(\mathbf{1},\mathbf{1},-2)$
Q_L U_R D_R	$\begin{pmatrix} u \\ d \end{pmatrix}_L, \begin{pmatrix} c \\ s \end{pmatrix}_L, \begin{pmatrix} t \\ b \end{pmatrix}_L$ u_R, c_R, t_R d_R, s_R, b_R	$(\mathbf{3},\mathbf{2},+1/3)$ $(\mathbf{3},\mathbf{1},+4/3)$ $(\mathbf{3},\mathbf{1},-2/3)$

- Lagrangian:

$$\begin{aligned} \mathcal{L} &= -\frac{1}{4} F^a_{\mu\nu} F^{a\,\mu\nu} \\ &+ i\bar{\psi}\, \not{D}\psi + h.c. \\ &+ \psi_i y_{ij} \psi_j \phi + h.c. \\ &+ |D_\mu \phi|^2 - V(\phi) \end{aligned}$$

gauge interactions

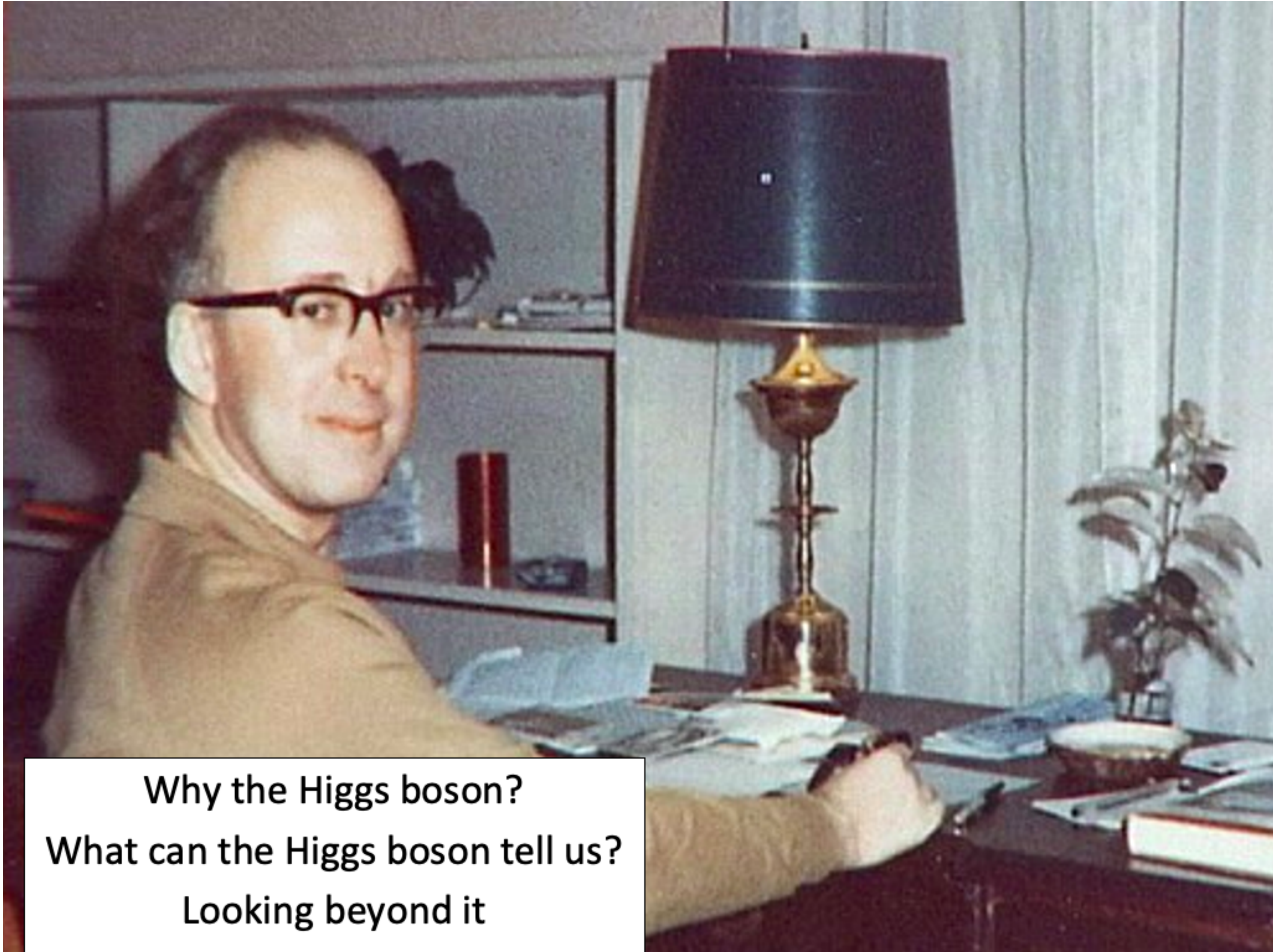
matter fermions

Tested < 0.1% before LHC

Yukawa interactions

Higgs potential

Testing now in progress



Why the Higgs boson?

What can the Higgs boson tell us?

Looking beyond it

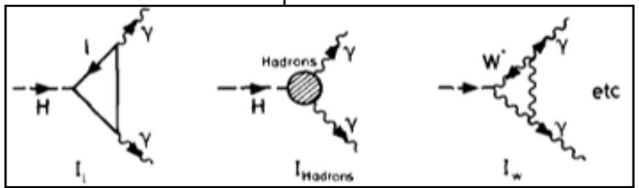
A Phenomenological Profile of the Higgs Boson

- First attempt at systematic survey

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

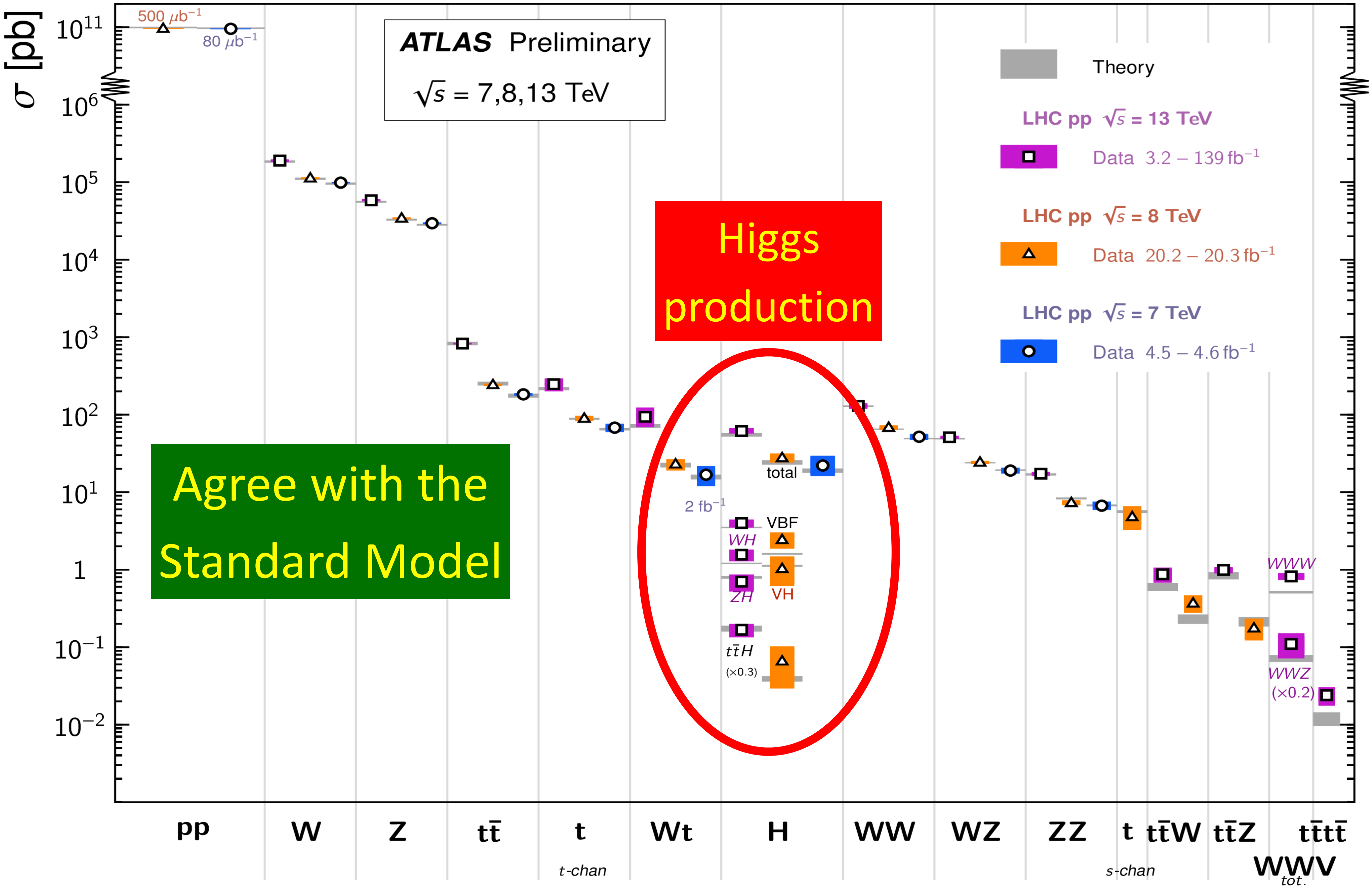
Received 7 November 1975



A discussion is given of the production, decay and observability of the scalar Higgs boson H expected in gauge theories of the weak and electromagnetic interactions such as the Weinberg-Salam model. After reviewing previous experimental limits on the mass of

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

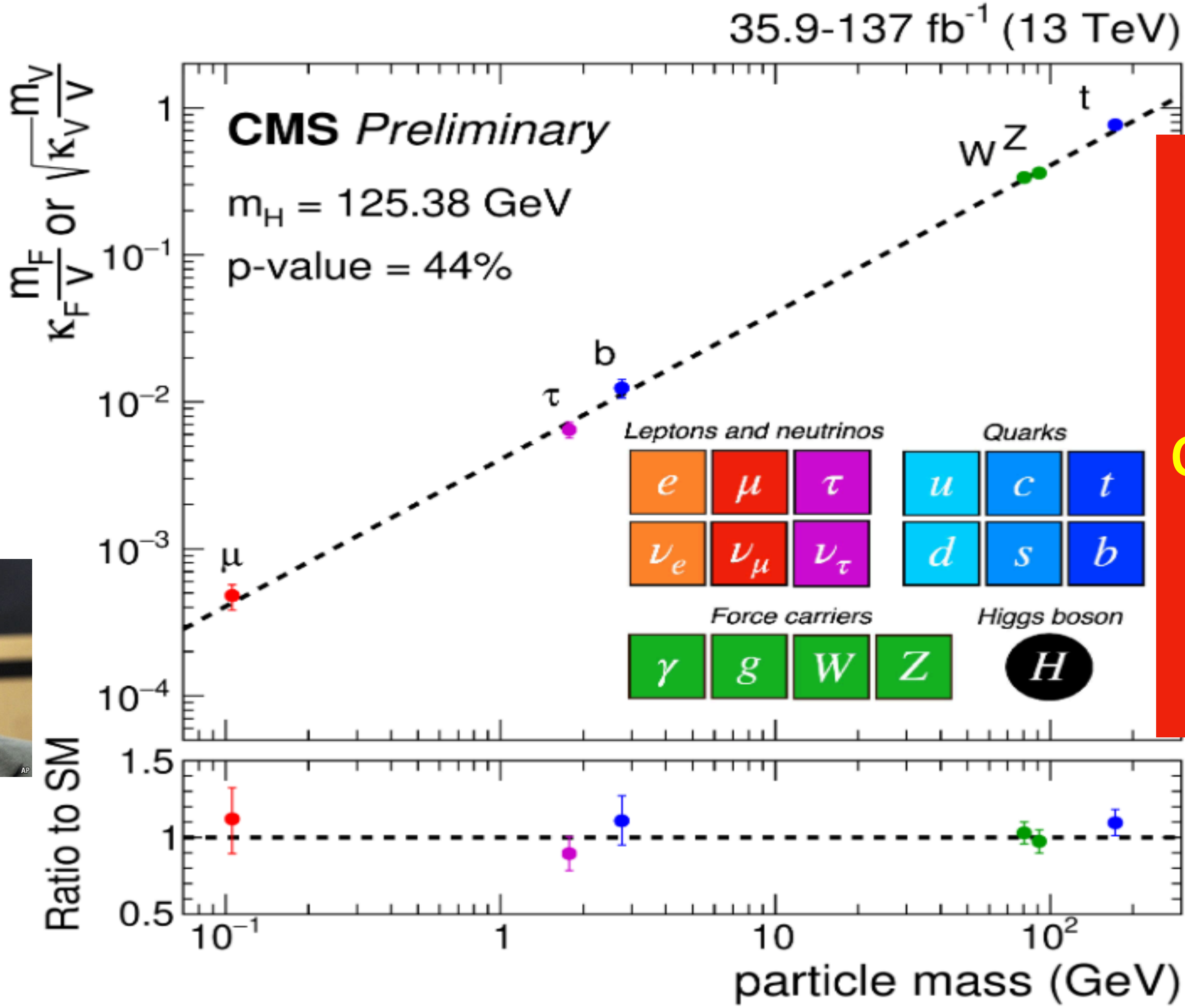
LHC Measurements



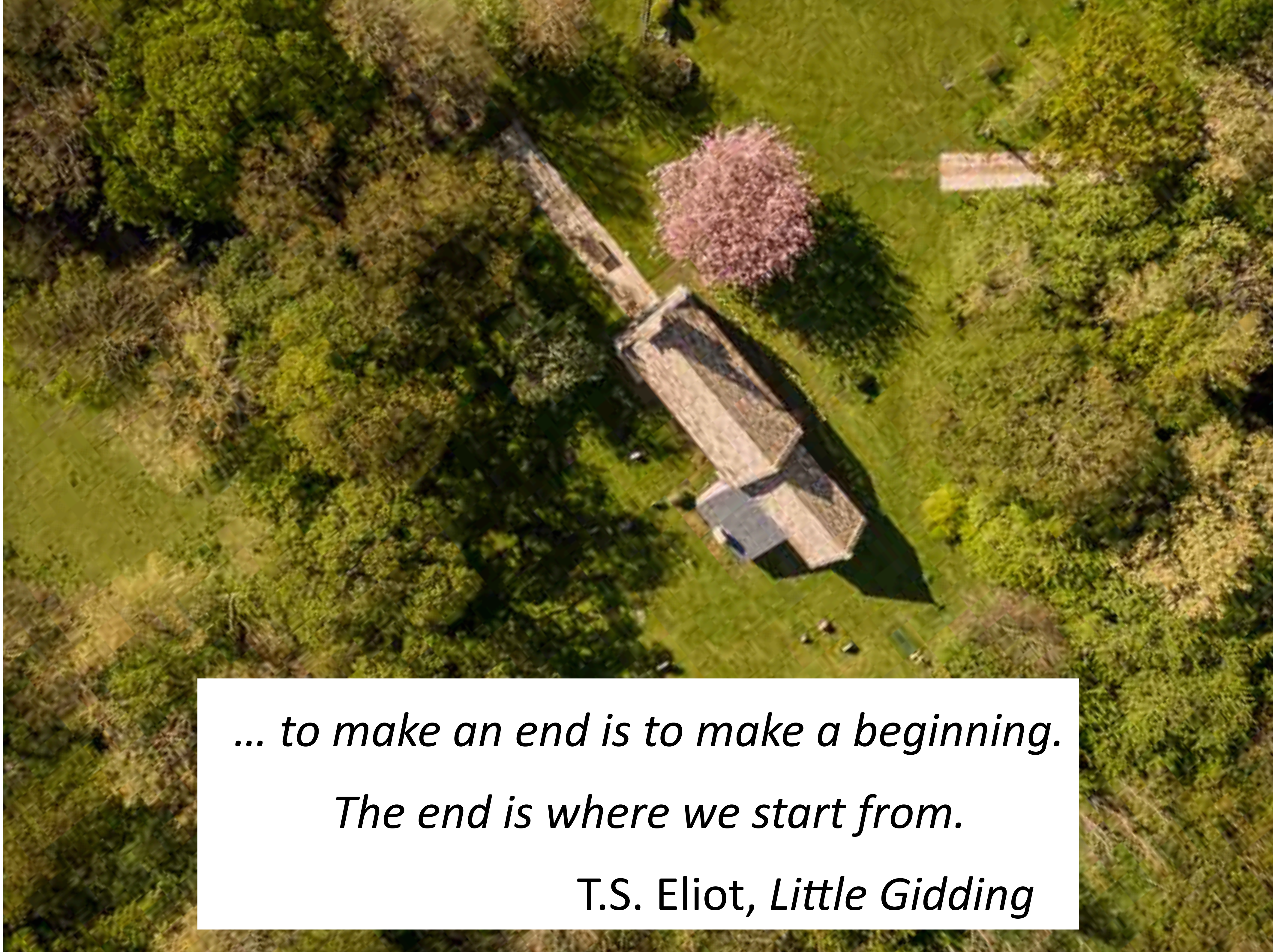
It Walks and Quacks like a Higgs

- Do couplings scale ~ mass? With scale = v?

Global fit



But what is origin of hierarchy of masses & mixing?



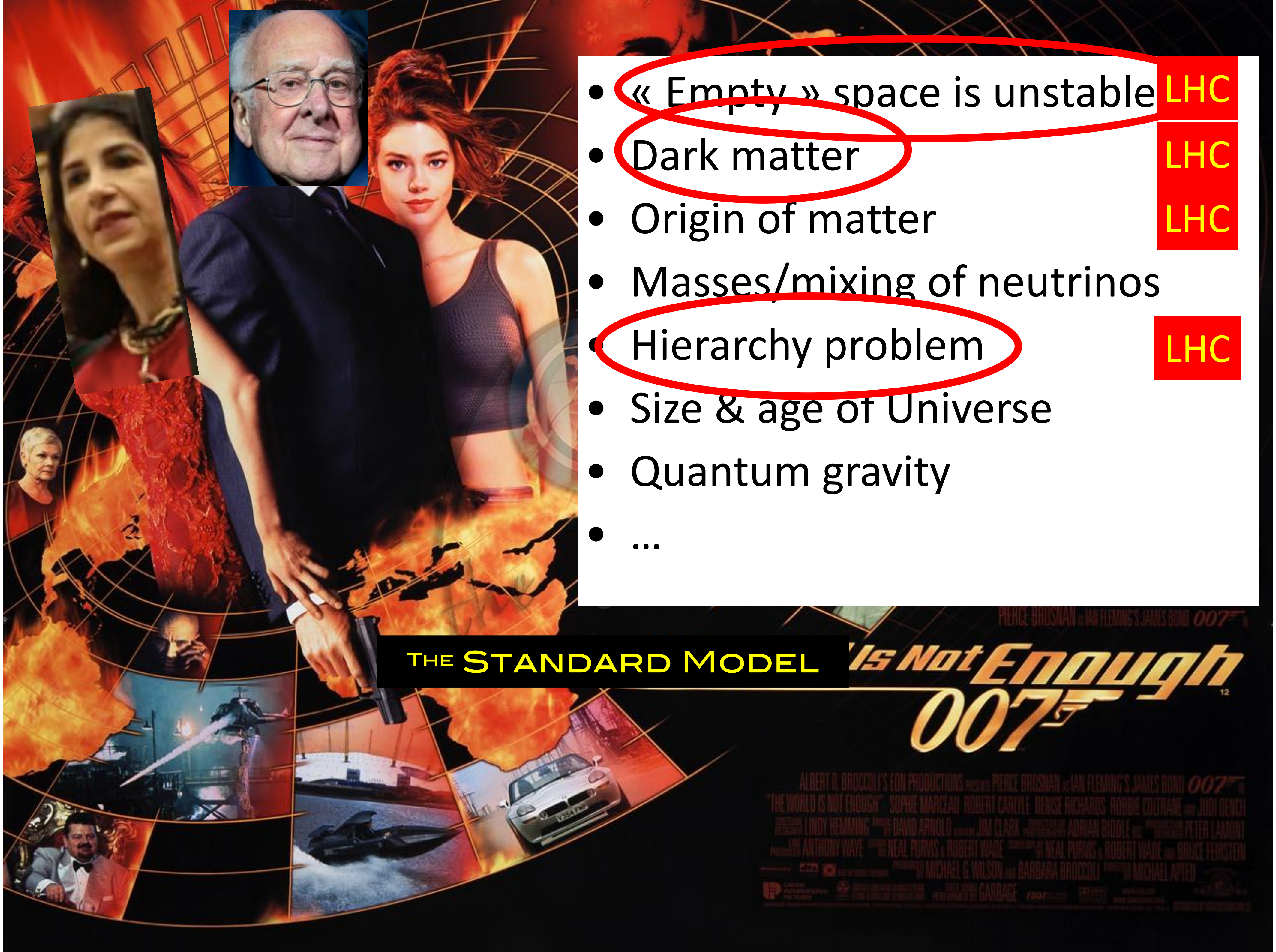
… to make an end is to make a beginning.

The end is where we start from.

T.S. Eliot, *Little Gidding*


ALBERT R. BROCCOLI'S EON PRODUCTIONS
PIERCE BROSNAN IAN FLEMING'S JAMES BOND 007
The World Is Not Enough
007
12
ALBERT R. BROCCOLI'S EON PRODUCTIONS PIERCE BROSNAN IAN FLEMING'S JAMES BOND 007
"THE WORLD IS NOT ENOUGH" SOPHIE MARCEAU ROBERT CARLYLE DENISE RICHARDS ROBBIE COLTRANE JUDI DENCH
LINDY HEMMING DAVID ARNOLD JIM CLARK ADRIAN BIDDLE PETER LAMONT
ANTHONY WAYE NEAL PURVIS ROBERT WADE NEAL PURVIS ROBERT WADE BRUCE FEIRSTEIN
MICHAEL G. WILSON BARBARA BROCCOLI MICHAEL APTED
GARBAGE

- « Empty » space is unstable LHC
- Dark matter LHC
- Origin of matter LHC
- Masses/mixing of neutrinos
- Hierarchy problem LHC
- Size & age of Universe
- Quantum gravity
- …



Everything about Higgs is Puzzling

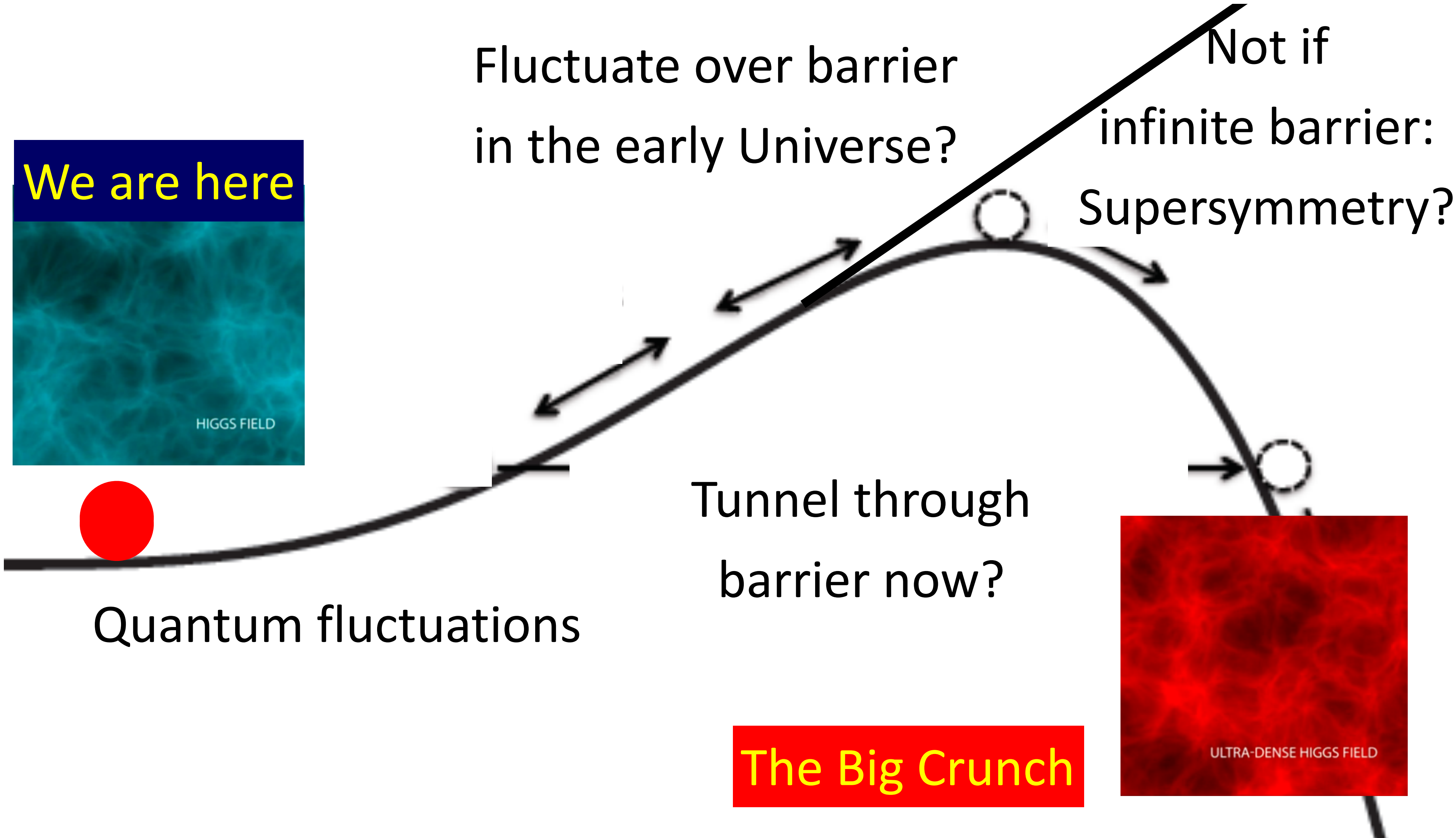
$$\boxed{\mathcal{L} = yH\psi\overline{\psi} + \mu^2|H|^2 - \lambda|H|^4 - V_0} \boxed{+ \ldots}$$

- Pattern of Yukawa couplings y:
  - **Flavour problem**
- Magnitude of mass term μ:
  - **Naturalness/hierarchy problem**
- Magnitude of quartic coupling λ:
  - **Stability of electroweak vacuum**
- Cosmological constant term V_0:
  - **Dark energy**

$\boxed{\text{Higher-dimensional terms due to heavy particles?}}$

Will the Universe Collapse?

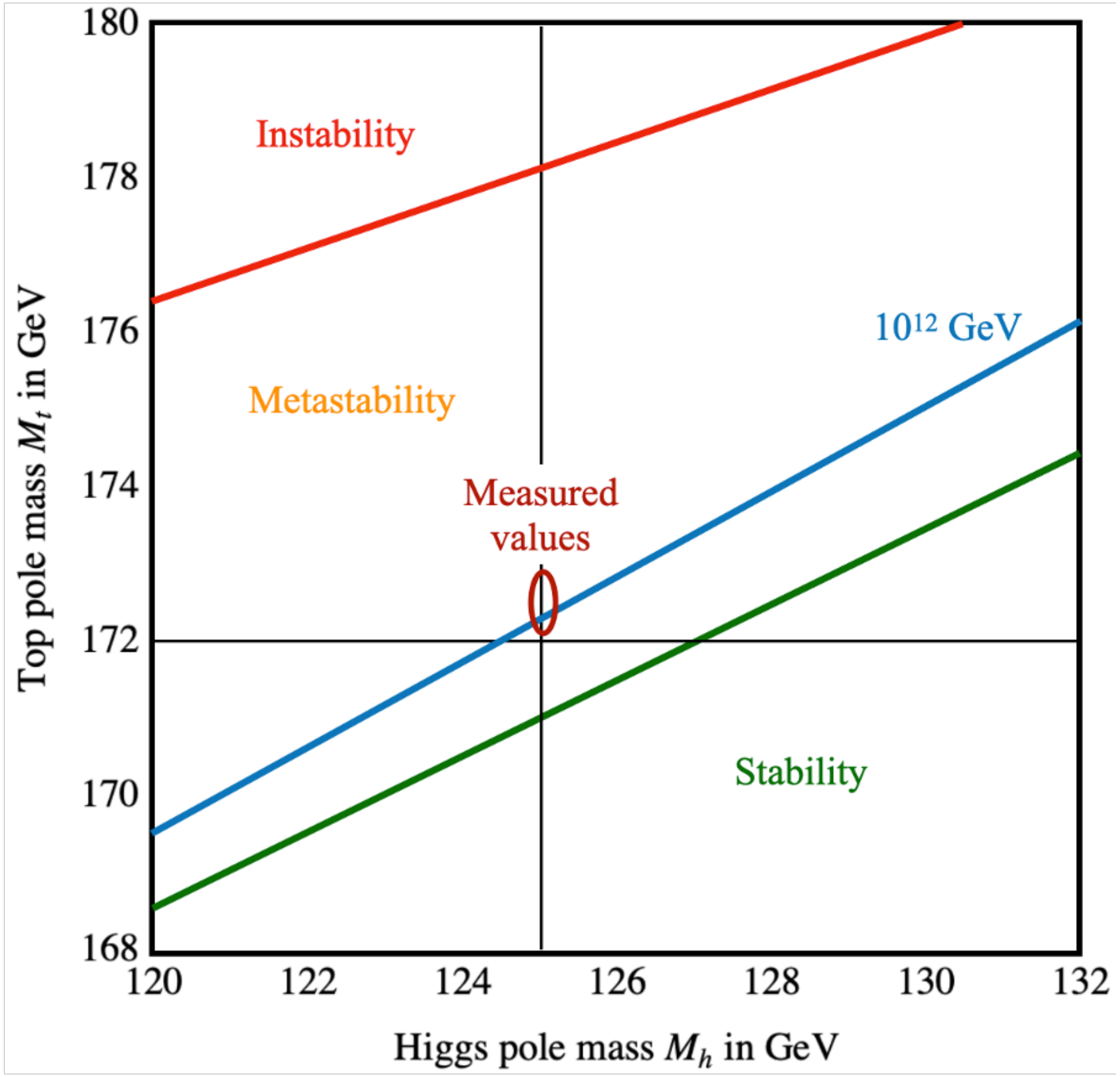
Should it have Collapsed already?



Is "Empty Space" Unstable?

Depends on masses of Higgs boson and top quark

Are we in metastable region of parameters?



Looking Beyond the Standard Model with the SMEFT

"...the direct method may be used...but indirect methods will be needed in order to secure victory...."

"The direct and the indirect lead on to each other in turn. It is like moving in a circle...."

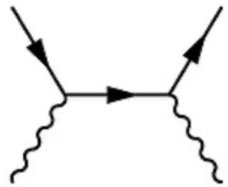
Who can exhaust the possibilities of their combination?"

Sun Tzu

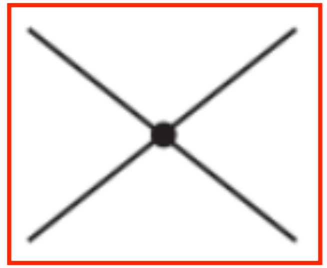
Effective Field Theories (EFTs)

a long and glorious History

- 1930's: "Standard Model" of QED had d=4

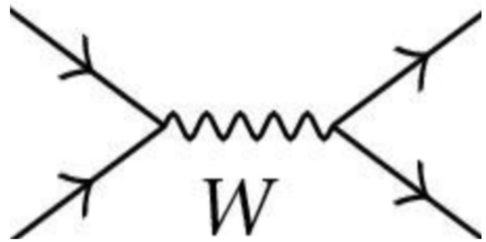


- **Fermi's four-fermion theory of the weak force**

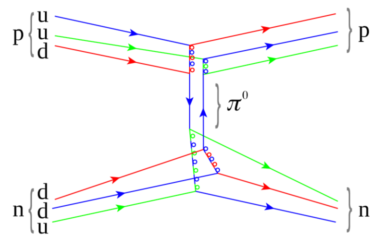


- Dimension-6 operators: form = S, P, V, A, T?
  – Due to exchanges of massive particles?

- V-A ➔ massive vector bosons ➔ gauge theory



- Yukawa's meson theory of the strong N-N force
  – Due to exchanges of mesons? ➔ pions



- Chiral dynamics of pions: (∂π∂π)ππ clue ➔ QCD

Standard Model Effective Field Theory

a more powerful way to analyze the data

- Assume the Standard Model Lagrangian is correct (quantum numbers of particles) but incomplete
- Look for additional interactions between SM particles due to exchanges of heavier particles
- Analyze Higgs data together with electroweak precision data and top data
- Most efficient way to extract largest amount of information from LHC and other experiments
- **Model-independent way to look for physics beyond the Standard Model (BSM)**

JE, Madigan, Mimasu, Sanz & You, arXiv:2012.02779

Summary of Analysis Framework

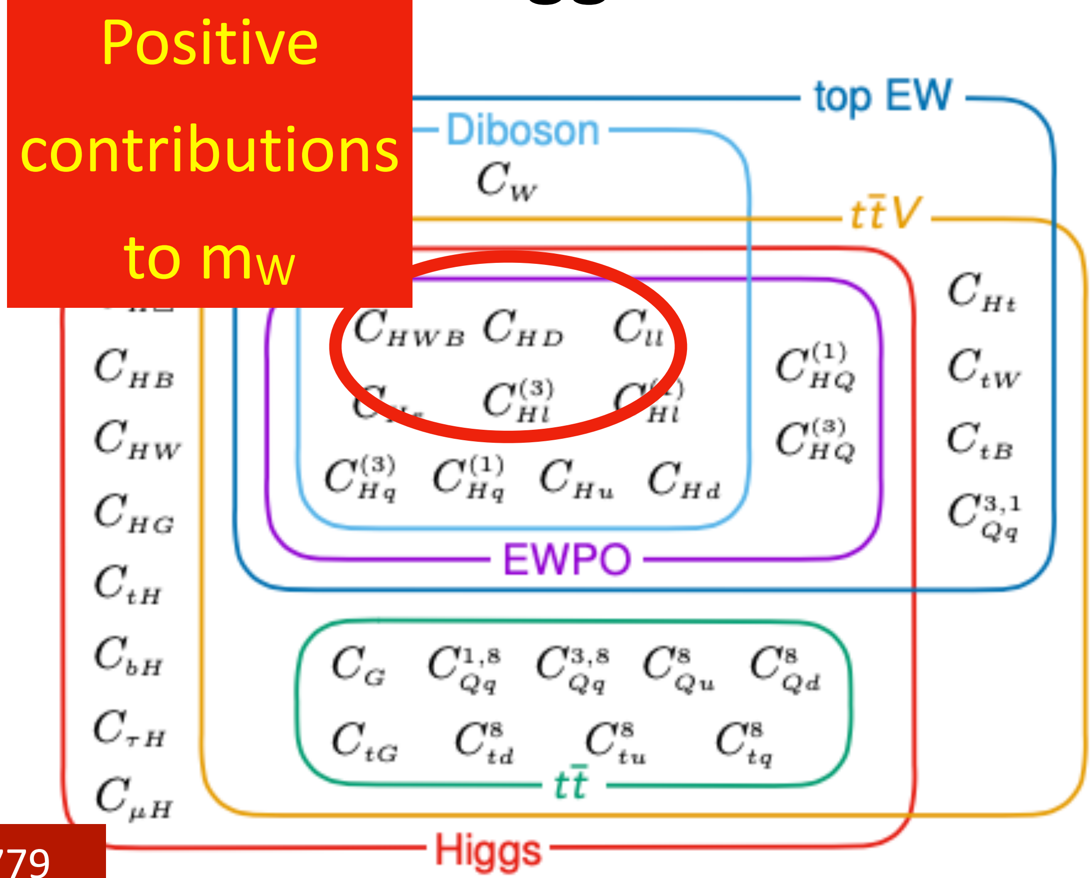
- Include all leading dimension-6 operators?

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i=1}^{2499} \frac{C_i}{\Lambda^2} \mathcal{O}_i$$

- Simplify by assuming flavour $SU(3)^5$ or $SU(2)^2 \times SU(3)^3$ symmetry for fermions
- Work to linear order in operator coefficients, i.e. $\mathcal{O}(1/\Lambda^2)$
- Use G_F, M_Z, α as input parameters

Global SMEFT Fit
to Top, Higgs, Diboson, Electroweak Data

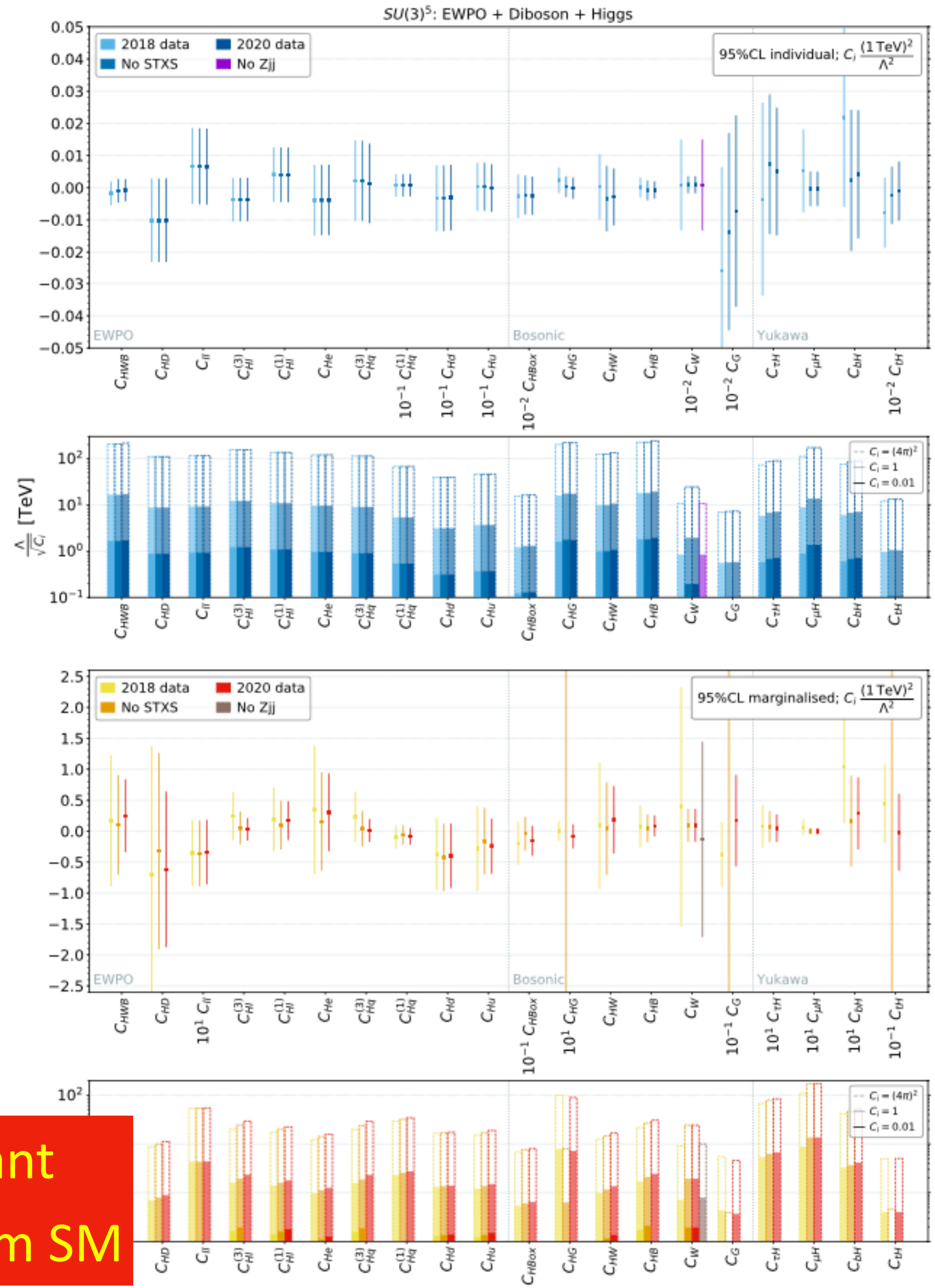
- Global fit to dimension-6 operators using precision electroweak data, W^+W^- at LEP, top, Higgs and diboson data from LHC Runs 1, 2
- Search for BSM
- Constraints on BSM
  - At tree level
  - At loop level



JE, Madigan, Mimasu, Sanz & You, arXiv:2012.02779

Dimension-6 Constraints with Flavour-Universal $SU(3)^5$ Symmetry

- **Individual operator coefficients**
- **Marginalised over all other operator coefficients**



No significant deviations from SM

JE, Madigan, Mimasu, Sanz & You, arXiv:2012.02779

Lepton Flavour Universality Violation in $B \to K\ell^+\ell^-$ Decays?

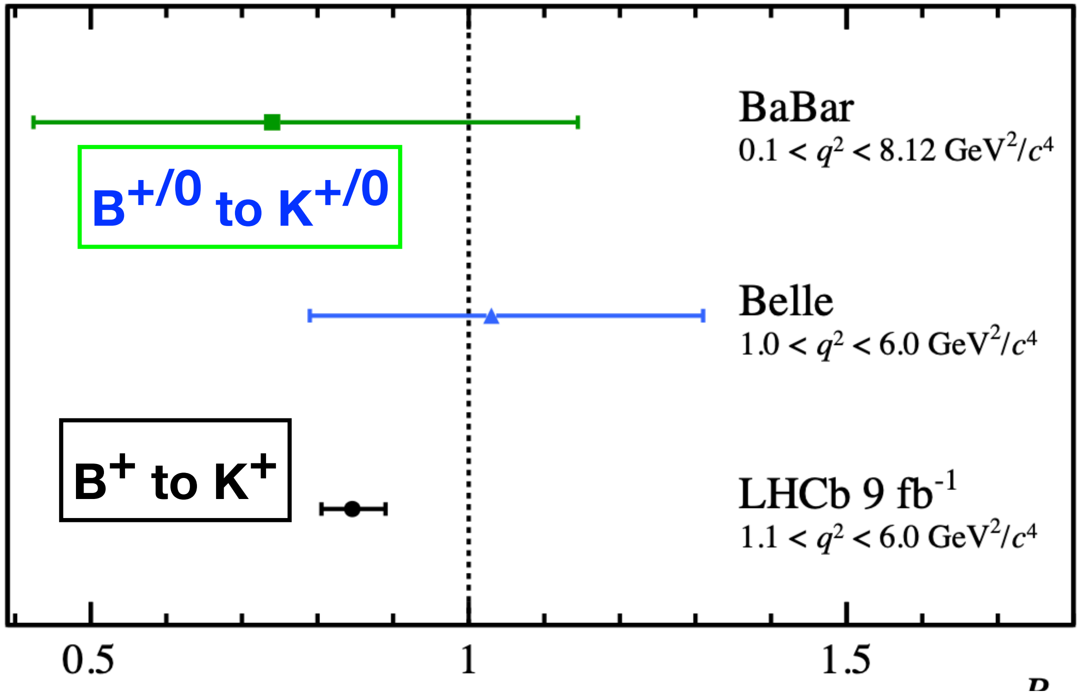
B decays to $e^+e^- > \mu^+\mu^-$

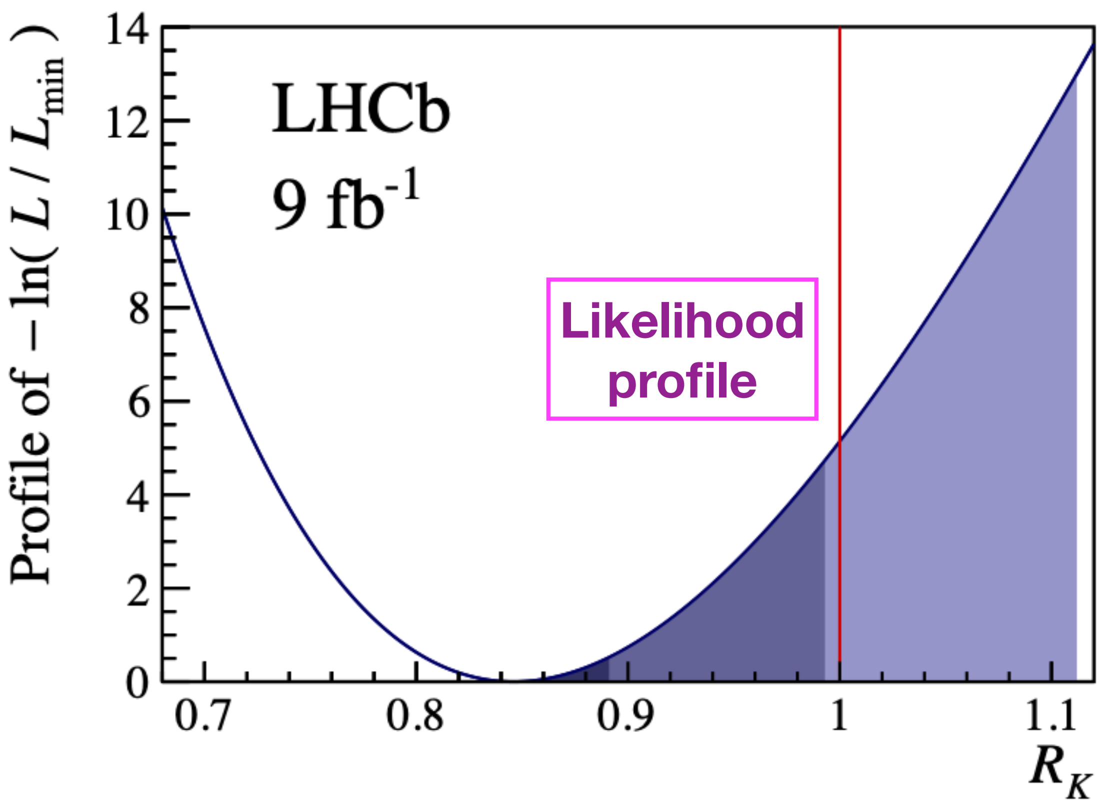
Prima facie violation of lepton universality

SM interactions flavour-universal

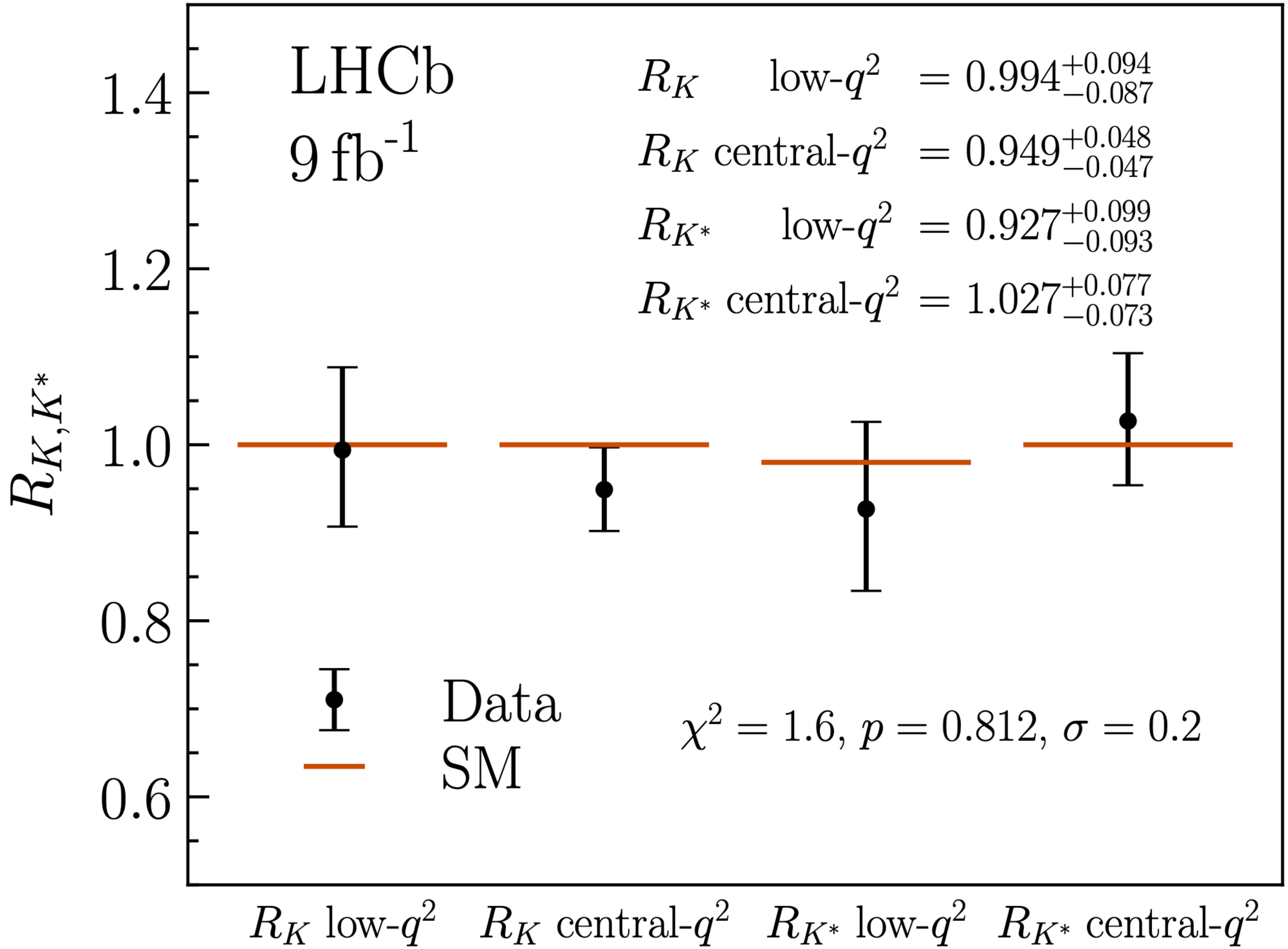
Except for Higgs couplings ∝ masses

LHCb Collaboration, arXiv:2103.11769





Sic Transit Gloria Anomaliae



LHCb Collaboration, arXiv:2212.09152, …3

$g_\mu - 2$:

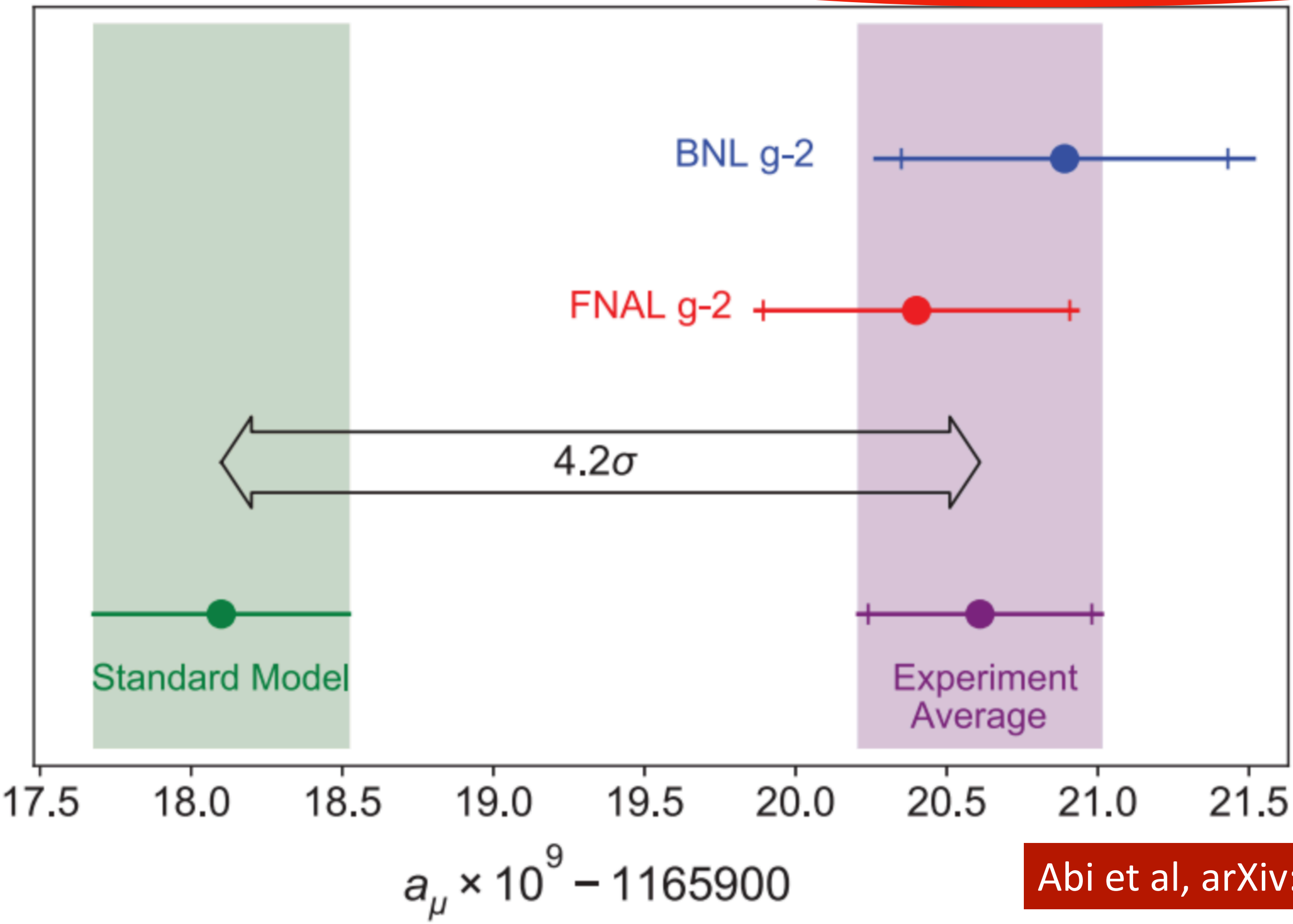
dawn of new physics or its sunset?

Fermilab Measurement

FNAL result: $a_\mu(\mathrm{FNAL}) = 116\,592\,040(54) \times 10^{-11} \quad (0.46\,\mathrm{ppm})$

Combined result: $a_\mu(\mathrm{Exp}) = 116\,592\,061(41) \times 10^{-11} \quad (0.35\,\mathrm{ppm})$

Difference from Standard Model: $a_\mu(\mathrm{Exp}) - a_\mu(\mathrm{SM}) = (251 \pm 59) \times 10^{-11}$



Abi et al, arXiv:2104.03281

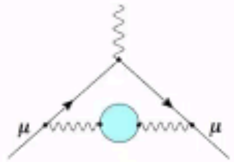
Interpretation Papers

2104.05685	Vector LQ	B	Du
5656	L_\mu - L_\tau	DM	Borah
5006	B_q - L_\mu	B	Cen
4494	LFV	LFV	Li
4503	Pseudoscalar	DM, H decays	Lu
4456	2HDM	DM	Arcadi
3542	B-LSSM	H decays	Yang
3701	Leptophilic spin 0	H factory	Chun
3839	SUSY	HL-LHC	Aboubrahim
3691	Survey	DM, LHC	Athron
3705	Seesaw	g_e	Escribano
3699	Gauged 2HDM	B	Chen
3239	SUSY	Gravitino DM	Gu
3284	NMSSM	DM	Cao
3262	GUT-constrained SUSY	DM, LHC	Wang
3292	MSSM	CPV	Han
3296	lepton mass matrix	Flavour	Calibbi
3280	Z_d	Cs weak charge	Cadeddu
3334	E_6 3-3-1	H stability	Li
3242	\mu-\tau-philic H	\tau decays, LHC	Wang
3259	Anomaly mediation	DM	Yin
3245	pMSSM	DM, fine-tuning	Van Beekveld
3274	NMSSM	DM, AMS-02 pbar	Abdughani
3290	MSSM	DM	Cox
3367	2HDM	V-like leptons	Ferreira
3267	Axion	Low-scale	Buen-Abad
3340	L_\mu - L_tau	AMS-02 positrons	Zu
3282	ALP	V-like fermions	Brdar
3301	Lepton portal	DM	Bai
3276	Dark axion portal	Dark photon	Ge
3491	GmSUGRA	LHC	Ahmed
3227	2HDM	LHC	Han
3302	SUSY	small \mu	Baum
3238	Scalar	DM, p radius	Zhu
3489	\mu \nu SSM	B, H decays	Zhang
3287	pMSSM	ILC	Chakraborti
3228	DM	B, H decays	Arcadi

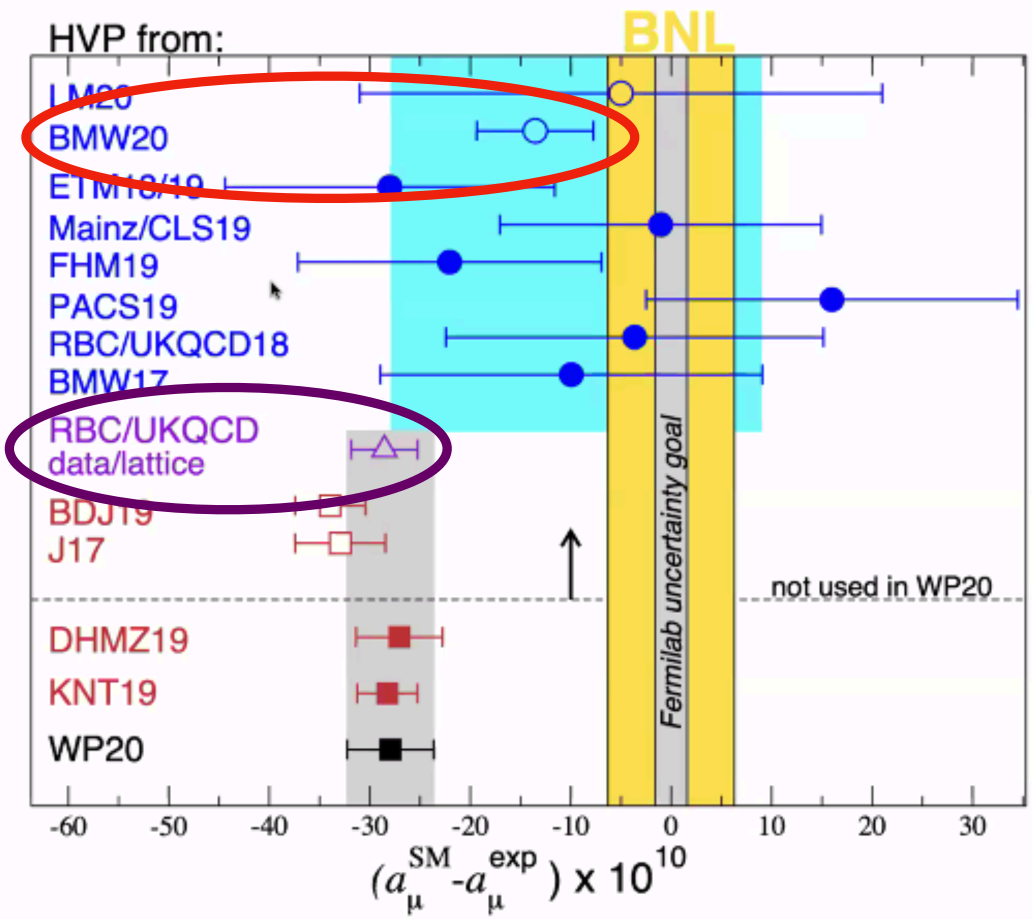
Leptoquarks
Extra U(1)
Extra Higgs
Supersymmetry
Axion

890	Radiative seesaw		Chiang
2103.13991	Scalar LQ	B, H decays	Greljo
2012.11766	DM		D'Agnolo
2012.07894	Axions		Darmé
1812.06851	Charmphilic LQ		Kowalska
2104.04458	GUT-constrained SUSY	DM	Chakraborti
5730	LQ + charged singlet	B, Cabibbo	Marzocca
6320	L-R symmetry		Boyarkin
6858	L_\mu - L_\tau	\nu masses	Zhou
6854	D-brane	U(1), Regge	Anchordoqui
6656	vector LQ	B	Ban
7597	SUSY	LHC, landscape	Baer
7047	3HDM	Fermion masses	Carcamo
7680	Leptophilic Z'	Global analysis	Buras
8289	Custodial symmetry	Light scalar + pseudoscalar	Balkin
9205	U(1)D	Neutrino mass	Dasgupta
8819	Lepton non-universality	Naturalness	Cacciapaglia
8640	2x2x1	Higgses, heavy nus	Boyarkina
8293	Multi-TeV sleptons in FSSM	Extended H, tau decays	Altmannshofer
10114	SO(10)	Yukawa unification	Aboubrahim
7681	U(1)B-L	DUNE	Dev
10324	Gauged lepton number	Dark matter	Ma
10175	2HDM	Lighter Higgs?	Jueid
11229	LQ	Matter unification	Fileviez
15136	U(1)	HE neutrinos, H tension	Alonso
2105.00903	Anomalous 3-boson vertex	W mass	Arbuzov
7655	U(1)T3R	RK(*)	Dutta
8670	Leptoquark	nu mass, LFV	Zhang

Comparison of Calculations of Hadronic Vacuum Polarization



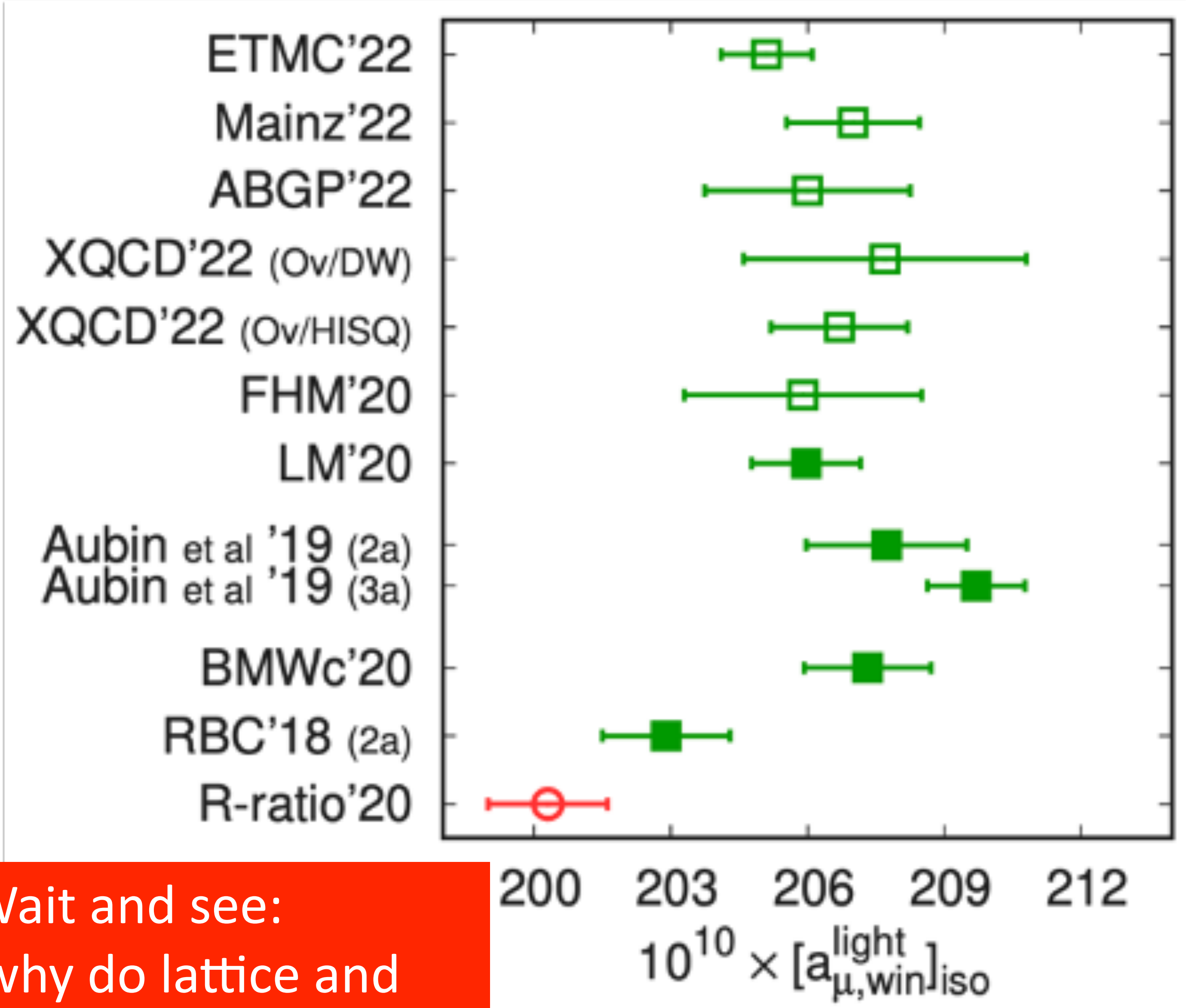
$$a_\mu^{\text{HVP}} + [a_\mu^{\text{QED}} + a_\mu^{\text{Weak}} + a_\mu^{\text{HLbL}}] > a_\mu^{\text{SM}}$$



Not such a big problem according to (some) lattice calculations

Aoyama et al, arXiv:2006.04822

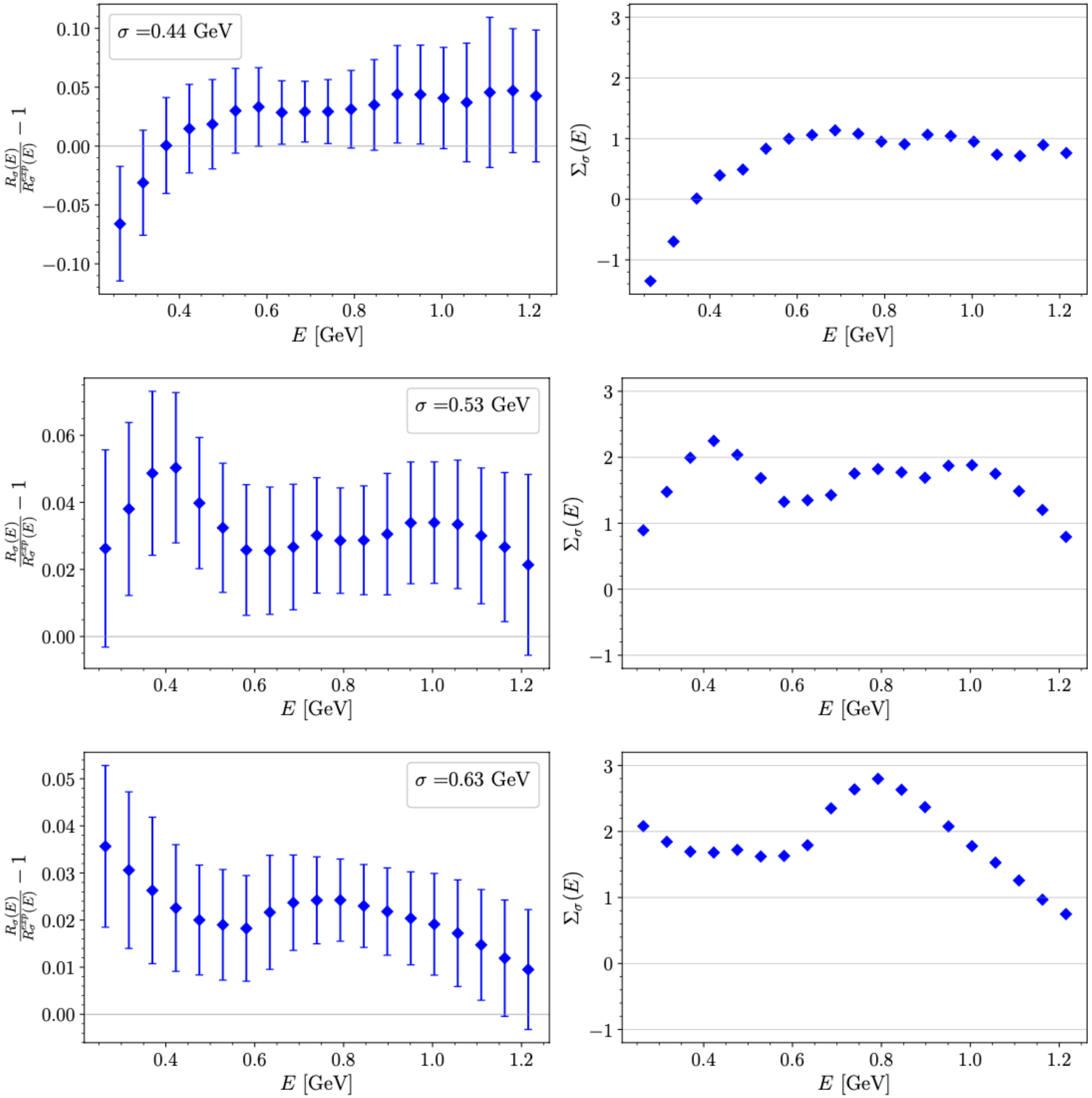
Update on Lattice Calculations



Wait and see:
How/why do lattice and
data-driven calculations differ?

Hadron Vacuum Polarization: Lattice vs Experiment

- $\dfrac{R_\sigma(E)}{R_\sigma^{exp}(E)} - 1$, pulls $\Sigma_\sigma(E)$ for smearing values σ
- Why the discrepancy?
- New physics hiding in experiment?

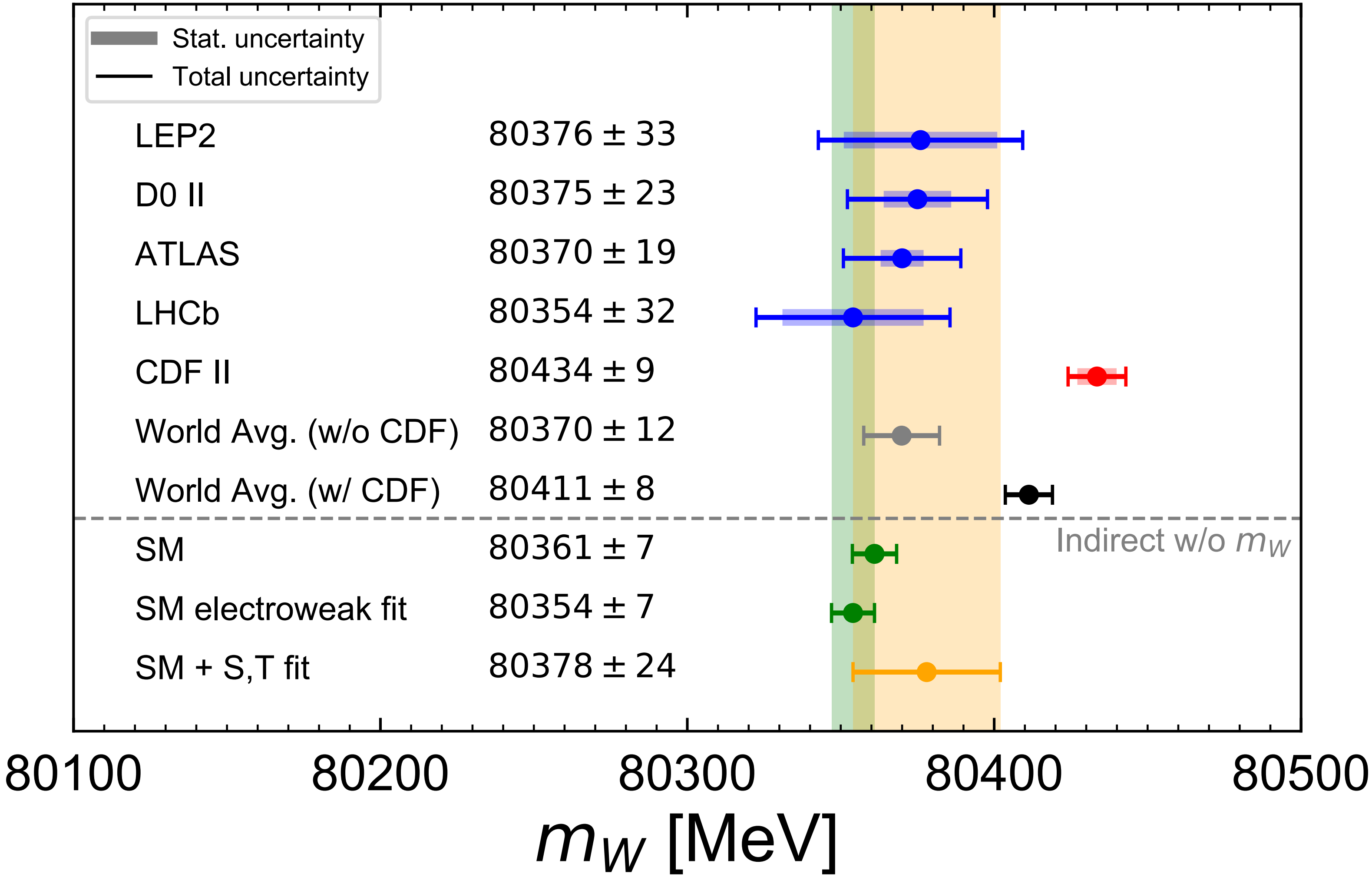


Alexandrou et al, arXiv:2212.08467

CDF Collaboration, *Science* 376 (2022) 6589, 170

CDF Measurement of m_W

compared with previous measurements



Tension: 7-σ discrepancy with Standard Model?

Theoretical Interpretations of W Mass

taking CDF measurement at face value

90 papers and counting!

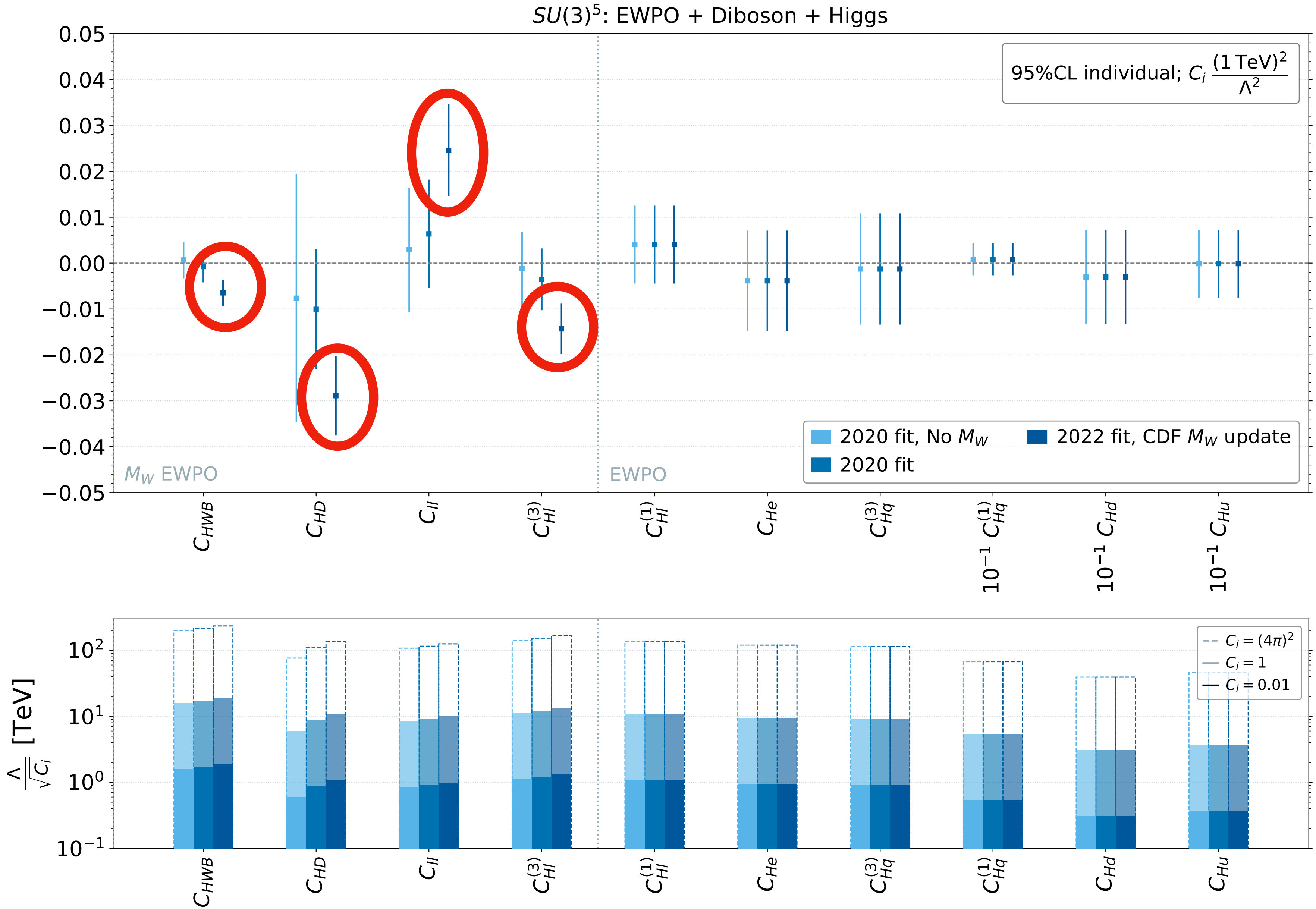
Supersymmetry?

3667	DM	Zhu
3693	Inert H	Fan
3797	EWPO	Lu
3996	Relation to g-2	Athron
4183	Axion, chameleon	Yuan
4191	EWPO	Strumia
4202	SUSY	Yang
4204	EWPO	de Blas
4286	SUSY GMSB	Du
4356	SUSY NMSSM	Tang
4514	non-standard H	Cacciapaglia
4559	RH neutrinos	Blennow
4710	SUSY NMSSM	Cao
5031	Seesaw triplet	Cheng
5085	2HDM	Song
5260	SMEFT	Bagnaschi
5267	Custodial symm	Paul
5269	2HDM	Bahl
5283	S&T	Asadi
5284	Higgs physics	Di Luzio
5285	FlexibleSUSY	Athron
5296	S&T, SMEFT	Gu
5302	D3-Brane	Heckman
5303	2HDM	Babu
5728	2HDM	Heo
5760	Georgi-Machacek	Du
5942	Leptoquark	Cheung
5962	VL quarks	Crivellin
5965	Single-field	Endo
5975	2HDM + singlet	Biekötter
5992	SMEFT	Balkin
6327	Non-local SM	Krasnikov
6485	2HDM	Ahn
6505	2HDM	Han
6541	RPV MSSM	Zheng
7022	Lepton portal DM	kawamura
7144	Triplet H	Fileviez

7970	GUT, finite group	Wilson
8067	Extra U(1)	Zhang
8266	Seesaw	Borah
8390	Zee model	Chowdhury
8406	2HDM	Arcadi
8440	Beta decay	Cirigliano
8546	Oblique	Carpenter
8568	Seesaw	Popov
9001	2HDM	Ghorbani
9029	Stueckelberg	Du
9031	Leptoquarks	Bhaskar
9376	Triplet	Batra
9477	VLQ	Cao
9487	Extra U(1)	Zeng
9585	Extra U(1)	Baek
9671	DM fermions	Borah
10130	SMEFT	da Silva
10156	Dark photon	Cheng
10274	Triplet seesaw	Heeck
10375	FOPT triplet	Addazi
10338	2HDM	Lee
11570	Extra U(1)	Cai
11755	2HDM	Benbrik
11871	nu-lepton collider	Yang
11945	Scotogenic DM	Batra
11991	Atomic PV	Tran Tan
12018	2HDM	Abouabid
12453	Colour-octet	Gisbert
12898	Georgi-Machacek	Chen
13027	Extra U(1)	Zhou
13690	RG running	Gupta
5.00758	Flipped SU(5)	Basiouris
783	DM	Wang

1115	2HDM	Botella
1437	2HDM	Kim
1699	Braneworld	Barman
1701	2HDM	Kim
1911	Dark photon	Thomas
2088	Leptoquark+VLQ	He
2205	bs anomalies	Li
2217	DM + g-2	Dcruz
2788	ResBos2	Isaacson
3877	GUT triplet	Evans
3917	VLQ	Chowdhury
3942	PDFs	Gao
4016	Lepton portal	Kim
4473	LLP	Giudice
4824	SO(10) axion	Lazarides
5022	SU(5)	Senjanovic
5041	Triplet	Ghosh
5610	Coloured scalars	Miralles
8215	SESM	Li
9109	SUSY 331	Rodriguez

SMEFT Fits with the Mass of the W Boson



Non-zero coefficients for any of four operators can fit W mass

Bagnaschi, JE, Madigan, Mimasu, Sanz & You, arXiv:2204.05260

Single-Field Extensions of the Standard Model

Name	Spin	SU(3)	SU(2)	U(1)	Name	Spin	SU(3)	SU(2)	U(1)
S	0	1	1	0	Δ_1	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
S_1	0	1	1	1	Δ_3	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
φ	0	[illegible]	2	$\frac{1}{2}$	Σ	$\frac{1}{2}$	1	3	0
Ξ	0	1	3	0	Σ_1	$\frac{1}{2}$	1	3	-1
Ξ_1	0	1	3	1	U	$\frac{1}{2}$	3	1	$\frac{2}{3}$
B	1	1	1	0	D	$\frac{1}{2}$	3	1	$-\frac{1}{3}$
B_1	1	1	1	1	Q_1	$\frac{1}{2}$	3	2	$\frac{1}{6}$
W	1	1	3	0	Q_5	$\frac{1}{2}$	3	2	$-\frac{5}{6}$
W_1	1	1	3	1	Q_7	$\frac{1}{2}$	3	2	$\frac{7}{6}$
N	$\frac{1}{2}$	1	1	0	T_1	$\frac{1}{2}$	3	3	$-\frac{1}{3}$
E	$\frac{1}{2}$	1	1	-1	T_2	$\frac{1}{2}$	3	3	$\frac{2}{3}$
T	$\frac{1}{2}$	3	1	$\frac{2}{3}$	TB	$\frac{1}{2}$	3	2	$\frac{1}{6}$

Spin zero

Vector

JE, Madigan, Mimasu, Sanz & You, arXiv:2012.02779

Single-Field Models that can Contribute to W Mass

Model	C_{HD}	C_{ll}	$C_{Hl}^{(3)}$	$C_{Hl}^{(1)}$	C_{He}	$C_{H\Box}$	$C_{\tau H}$	C_{tH}	C_{bH}
S_1		$\cancel{1}$							
Σ			$\cancel{\frac{1}{16}}$	$\frac{3}{16}$			$\frac{y_\tau}{4}$		
Σ_1			$\cancel{\frac{1}{16}}$	$-\frac{3}{16}$			$\frac{y_\tau}{8}$		
N			$-\frac{1}{4}$	$\frac{1}{4}$					
E			$-\frac{1}{4}$	$-\frac{1}{4}$			$\frac{y_\tau}{2}$		
B_1	$\cancel{1}$					$-\frac{1}{2}$	$-\frac{y_\tau}{2}$	$-\frac{y_t}{2}$	$-\frac{y_b}{2}$
B	-2						$-y_\tau$	$-y_t$	$-y_b$
Ξ	-2					$\frac{1}{2}$	y_τ	y_t	y_b
W_1	$-\frac{1}{4}$					$-\frac{1}{8}$	$-\frac{y_\tau}{8}$	$-\frac{y_t}{8}$	$-\frac{y_b}{8}$
W	$\cancel{2}$					$-\frac{1}{2}$	$-y_\tau$	$-y_t$	$-y_b$

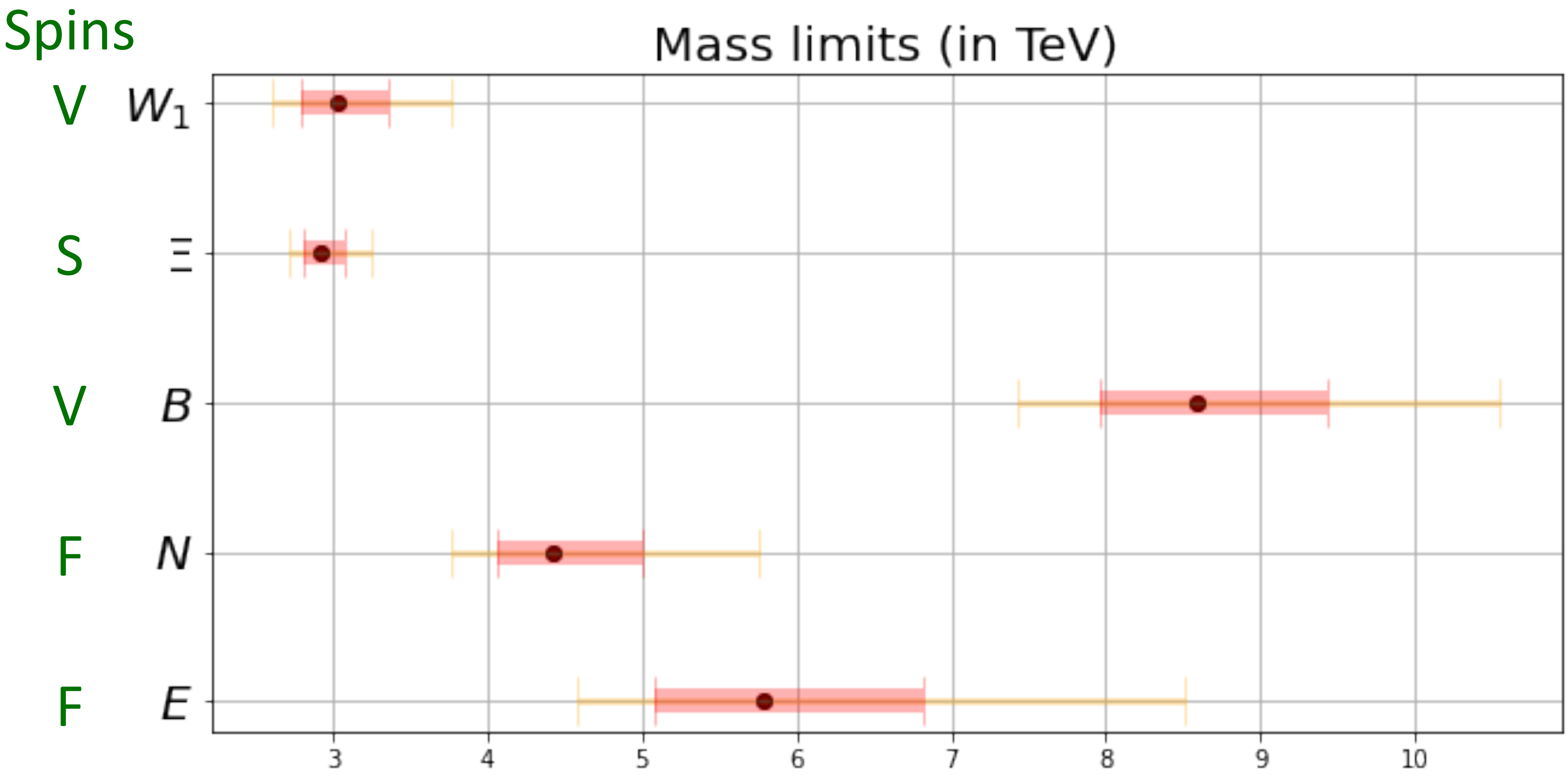
Wrong sign

Right sign

Operators contributing to m_W

Bagnaschi, JE, Madigan, Mimasu, Sanz & You, arXiv:2204.05260

Models Fitting the Mass of the W Boson



68 and 95% CL ranges of masses assuming unit couplings

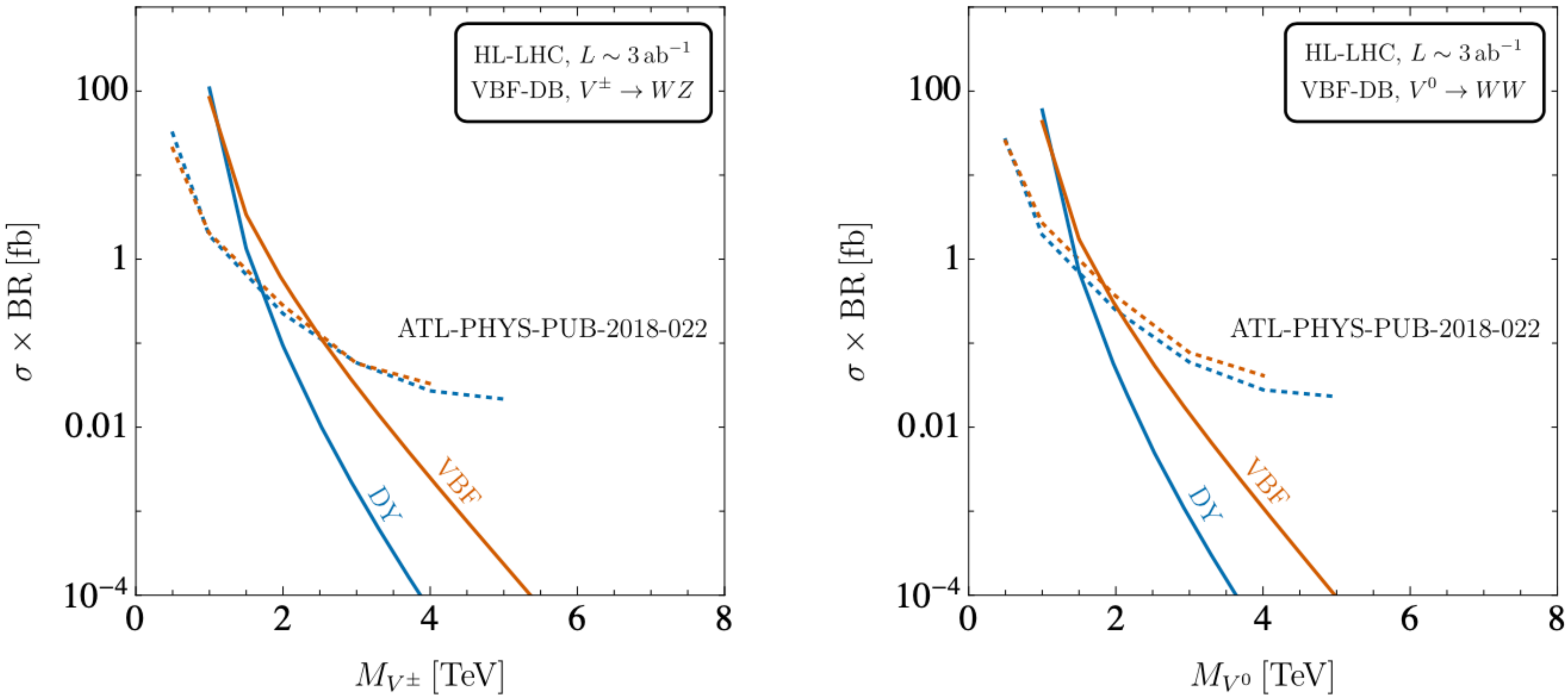
Bagnaschi, JE, Madigan, Mimasu, Sanz & You, arXiv:2204.05260

Searching for Models Fitting the Mass of the W Boson

- W: Isotriplet vector boson, mass ~ 3 TeV x coupling, electroweak production, accessible at LHC?
- B: Singlet vector boson, mass ~ 8 TeV x coupling, phenomenology depends on fermion couplings, too heavy for LHC?
- Ξ: Isotriplet scalar boson, mass ~ 3 TeV x coupling, detectable in LHC searches for heavy Higgs bosons?
- N: Isosinglet neutral fermion, mass ~ 4 TeV x coupling, similar to (right-handed) singlet neutrino
- E: Isosinglet charged fermion, mass ~ 6 TeV x coupling, similar to (right-handed) singlet electron

Bagnaschi, JE, Madigan, Mimasu, Sanz & You, arXiv:2204.05260

HL-LHC Search for Triplet Vector Boson

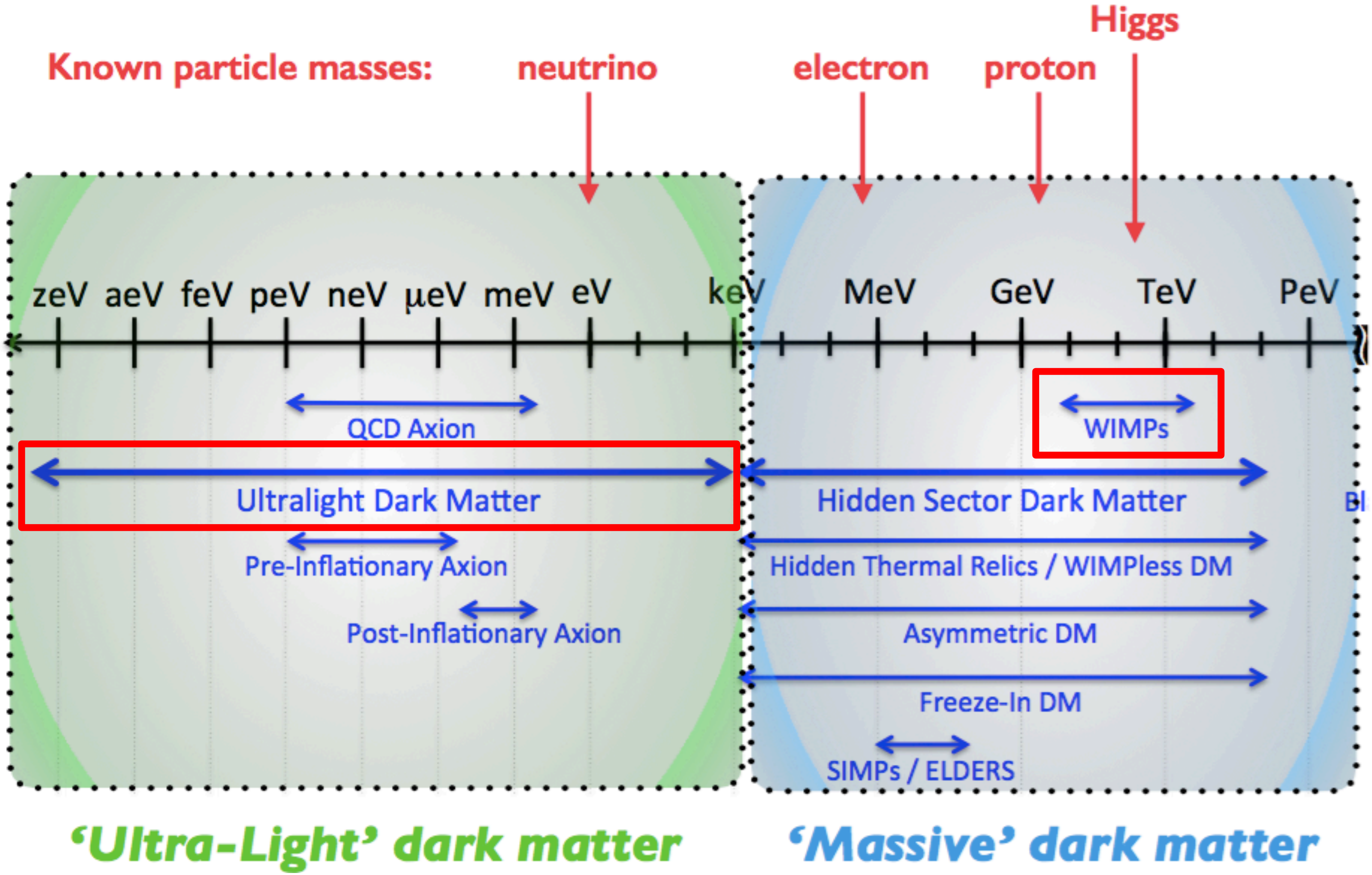


Wait and see:
Will LHC experiments confirm CDF?

Could be discovered with future LHC data

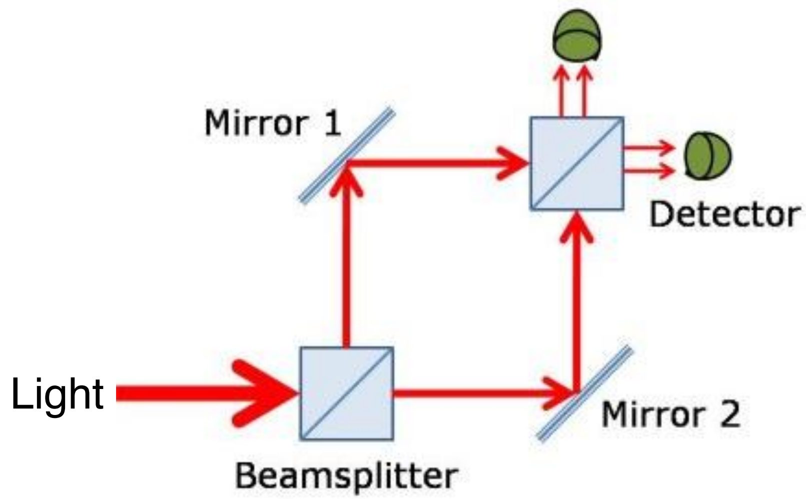
Baker, Martonhelyi, Thamm & Torre, arXiv:2207.05091

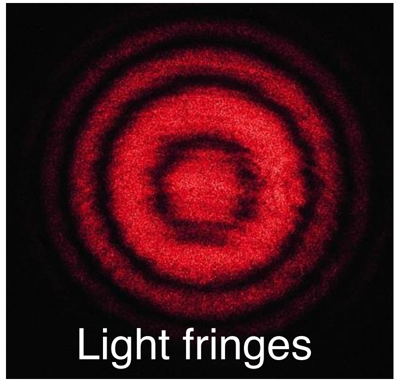
Searches for Dark Matter Particles



Principle of Atom Interferometry

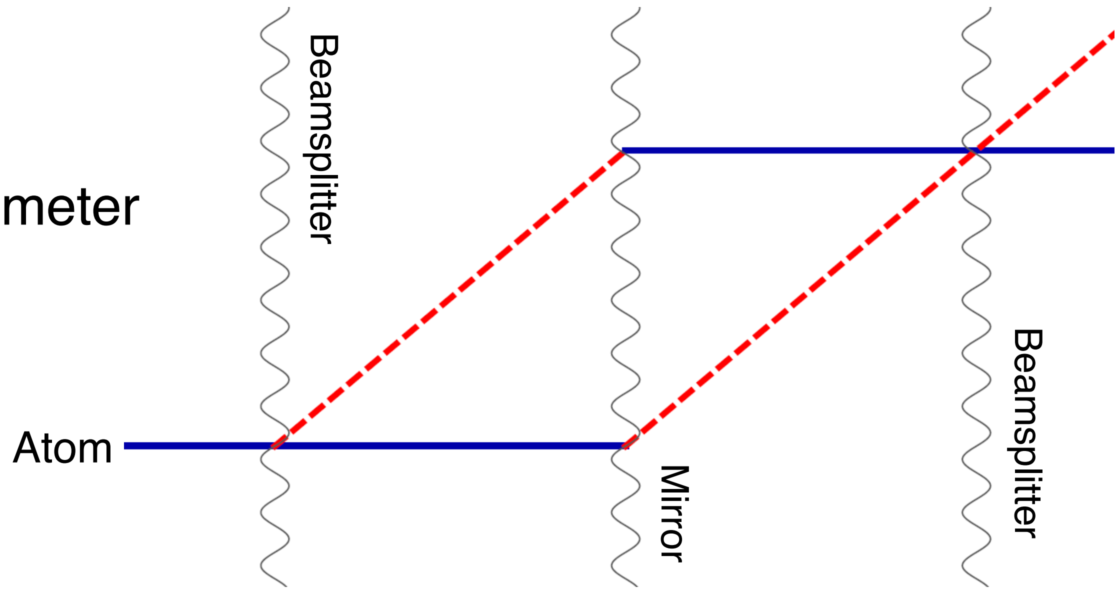
Light interferometer

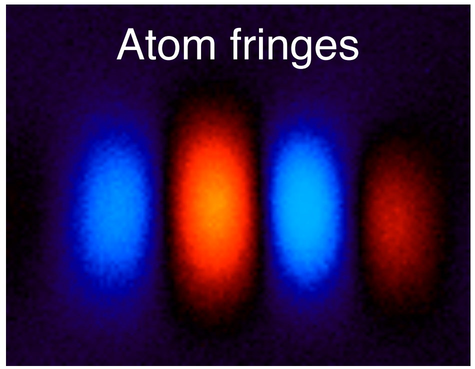




Atom interferometer

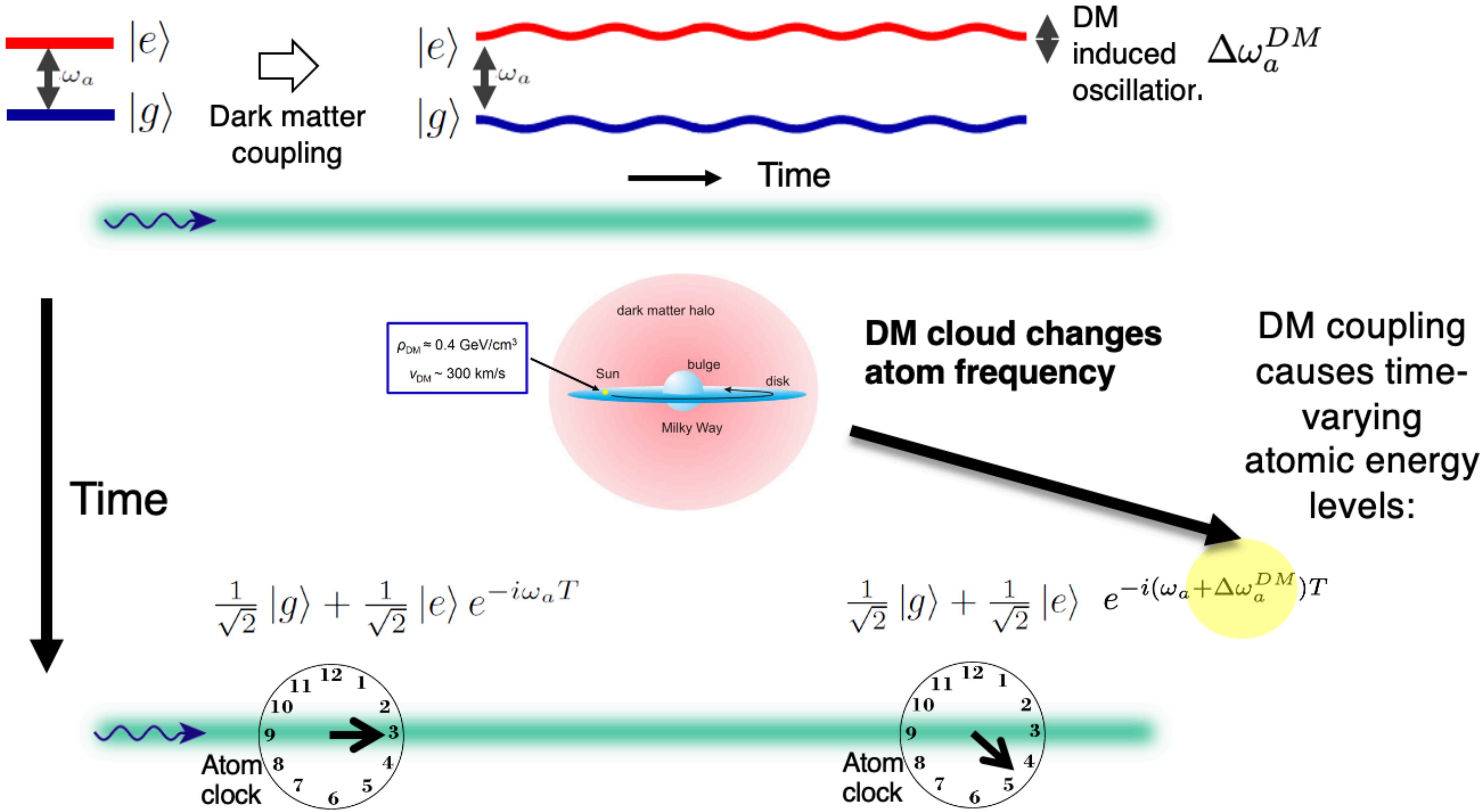
Laser pulses act as beamsplitters and mirrors





Can be used to search for ultralight dark matter and gravitational waves

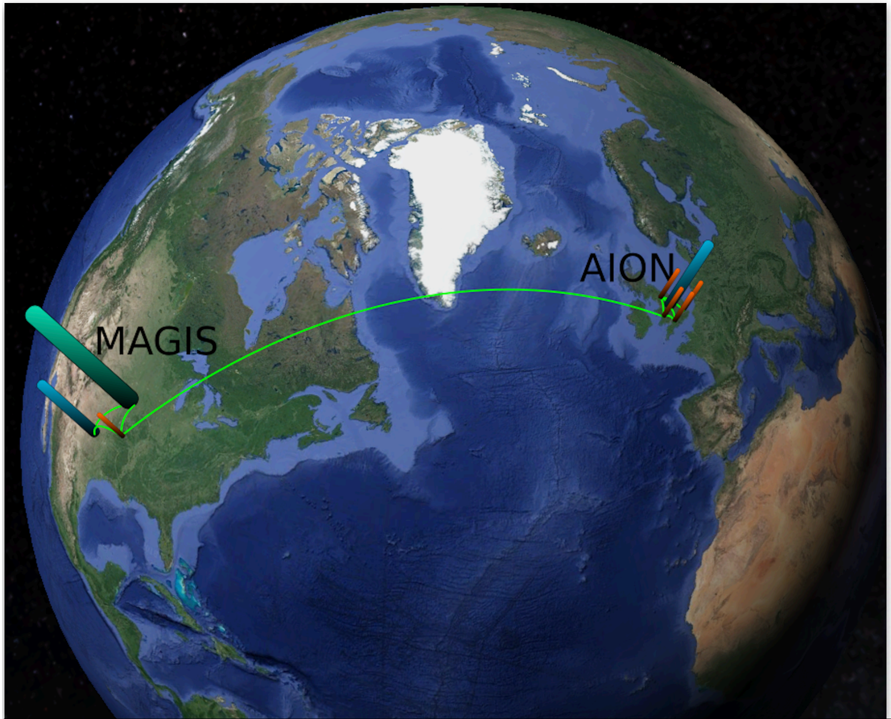
Effect of Dark Matter on Atom Interferometer



AION Collaboration

L. Badurina[1], S. Balashov[2], E. Bentine[3], D. Blas[1], J. Boehm[2], K. Bongs[4], A Beniwal[1], D. Bortoletto[3], T. Bowcock[5], W. Bowden[6,*], C. Brew[2], O. Buchmueller[6], J. Coleman[5], J. Carlton, G. Elertas[5], J. Ellis[1,&], C. Foot[3], V. Gibson[7], M. Haehnelt[7], T. Harte[7], R. Hobson[6,*], M. Holynski[4], A. Khazov[2], M. Langlois[4], S. Lellouch[4], Y.H. Lien[4], R. Maiolino[7], P. Majewski[2], S. Malik[6], J. March-Russell[3], C. McCabe[1], D. Newbold[2], R. Preece[3], B. Sauer[6], U. Schneider[7], I. Shipsey[3], Y. Singh[4], M. Tarbutt[6], M. A. Uchida[7], T. V-Salazar[2], M. van der Grinten[2], J. Vossebeld[4], D. Weatherill[3], I. Wilmut[7], J. Zielinska[6]

[1]Kings College London, [2]STFC Rutherford Appleton Laboratory, [3]University of Oxford, [4]University of Birmingham, [5]University of Liverpool, [6]Imperial College London, [7]University of Cambridge



Network with MAGIS project in US

MAGIS Collaboration (Abe et al): arXiv:2104.02835

AION – Staged Programme

- AION-10: Stage 1 [year 1 to 3]
  - 1 & 10 m Interferometers & site investigation for 100m baseline

Initial funding from UK STFC

- AION-100: Stage 2 [year 3 to 6]
  - 100m Construction & commissioning
- AION-KM: Stage 3 [> year 6]
  - Operating AION-100 and planning for 1 km & beyond
- AION-SPACE (AEDGE): Stage 4 [after AION-km]
  - Space-based version

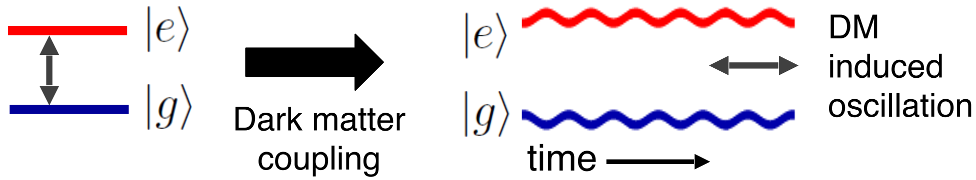
AION Collaboration (Badurina, …, JE et al): arXiv:1911.11755

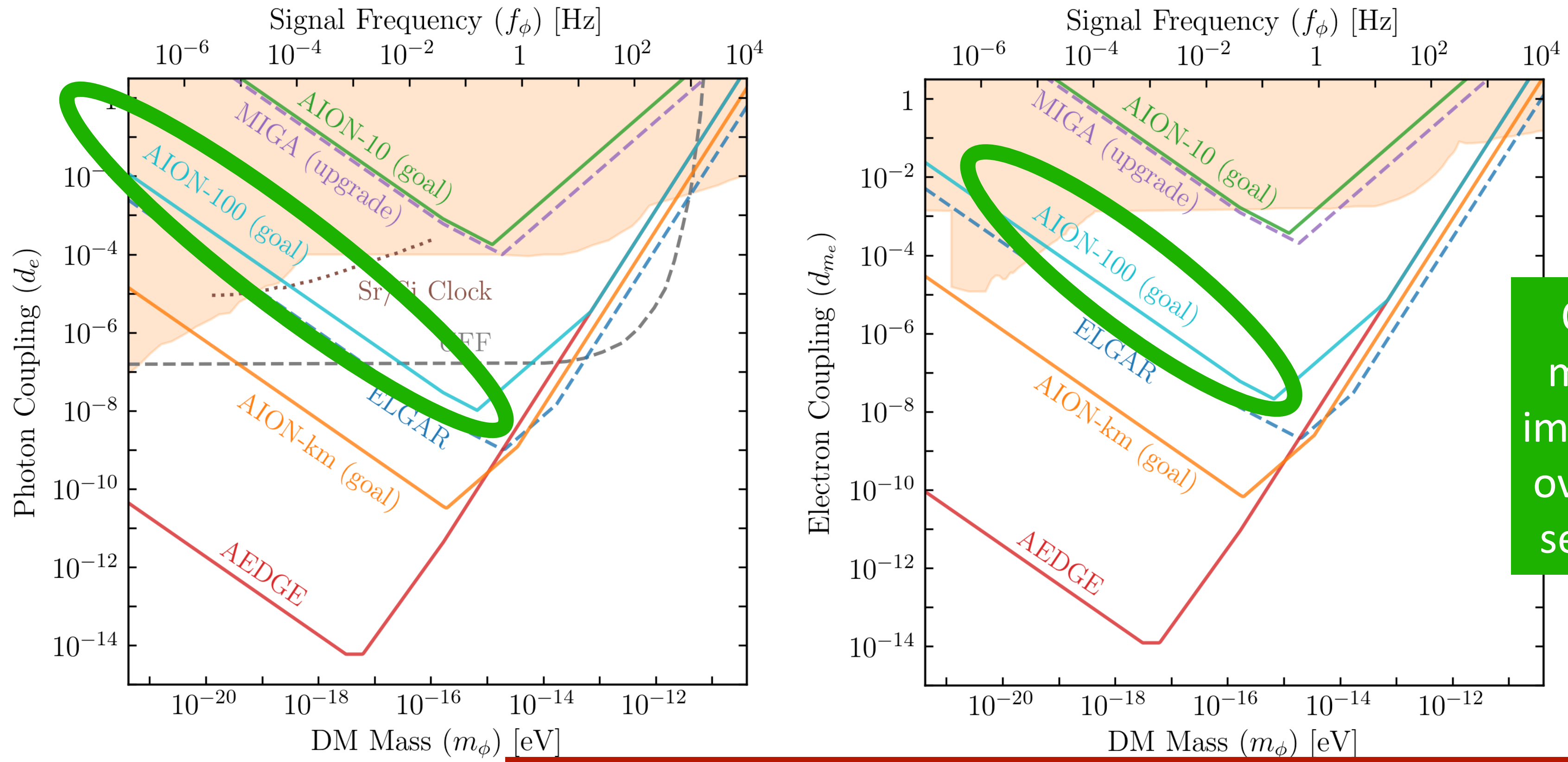
Searches for Light Dark Matter

AION

Linear couplings to gauge fields and matter fermions

$$\mathcal{L}_{\mathrm{int}\phi} = \kappa\phi \left[+\frac{d_e}{4e^2} F_{\mu\nu}F^{\mu\nu} - \frac{d_g \beta_3}{2g_3} F^A_{\mu\nu}F^{A\mu\nu} - \sum_{i=e,u,d} (d_{m_i} + \gamma_{m_i} d_g) m_i \bar{\psi}_i \psi_i \right]$$

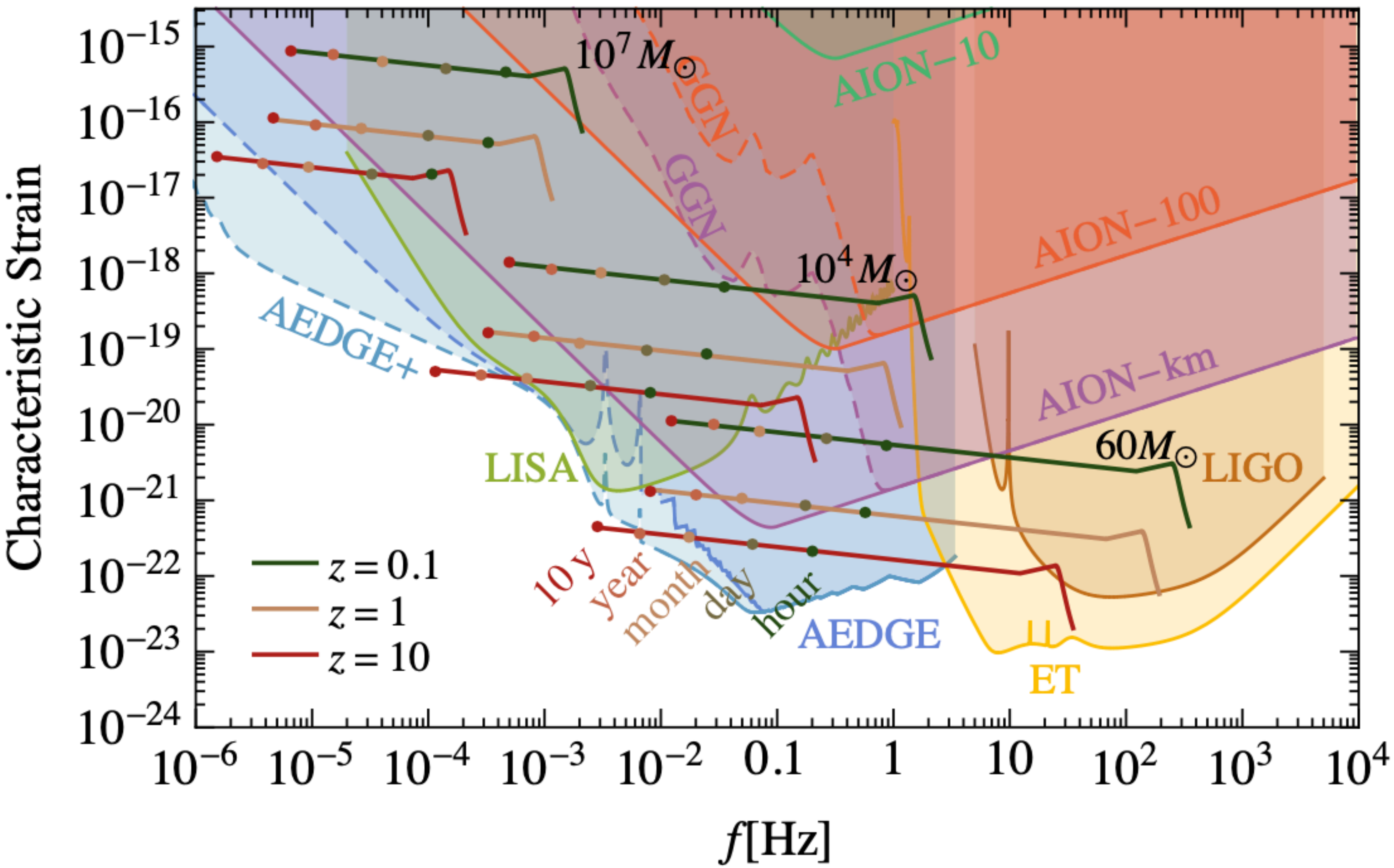




Orders of magnitude improvement over current sensitivities

AION Collaboration (Badurina, …, JE et al): arXiv:1911.11755; Badurina, Buchmueller, JE, Lewicki, McCabe & Vaskonen: arXiv:2108.02468

Gravitational Waves from IMBH Mergers

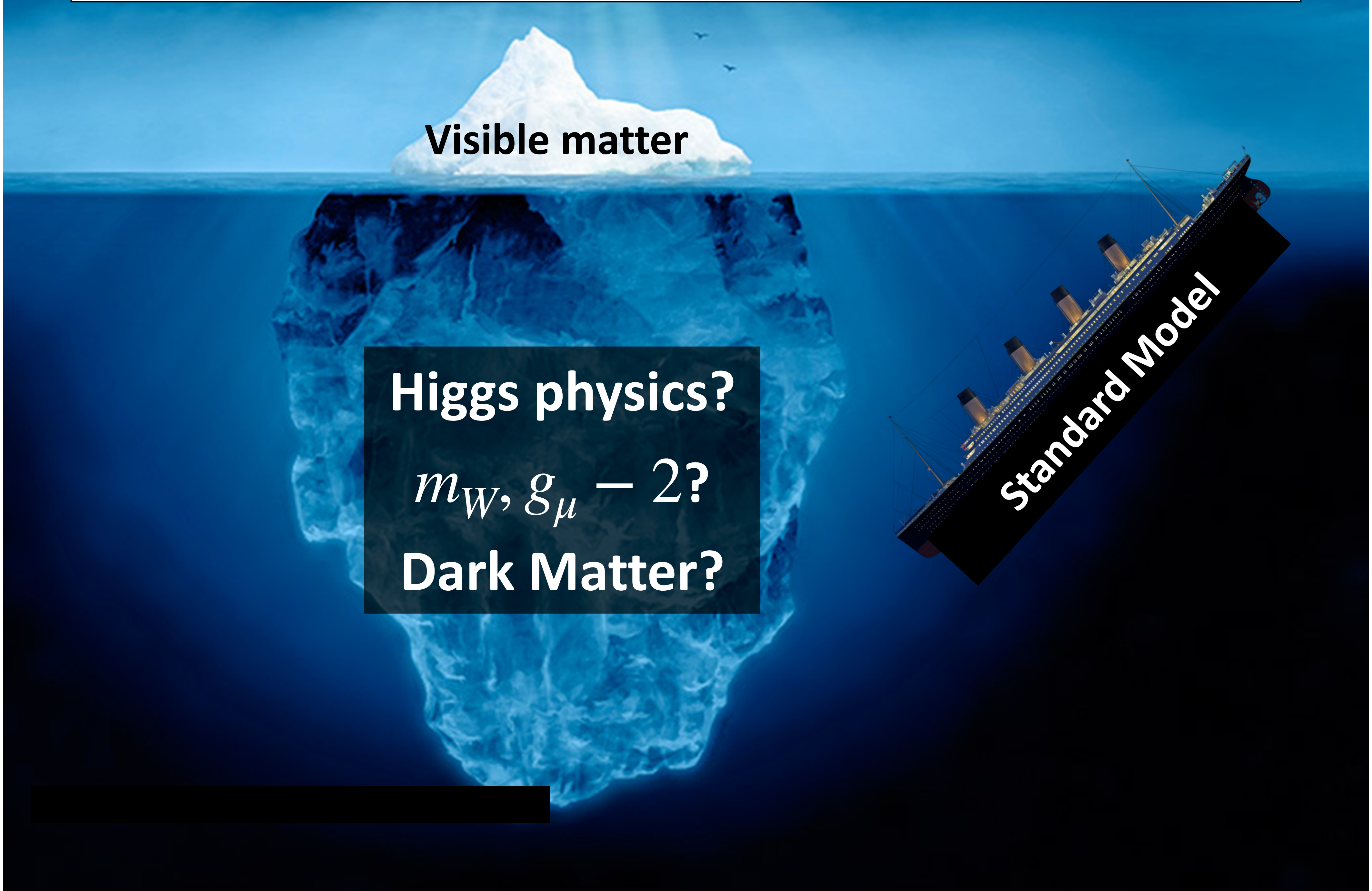


Probe formation of SMBHs

Synergies with other GW experiments (LIGO, LISA), test GR

Badurina, Buchmueller, JE, Lewicki, McCabe & Vaskonen: arXiv:2108.02468

Summary



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