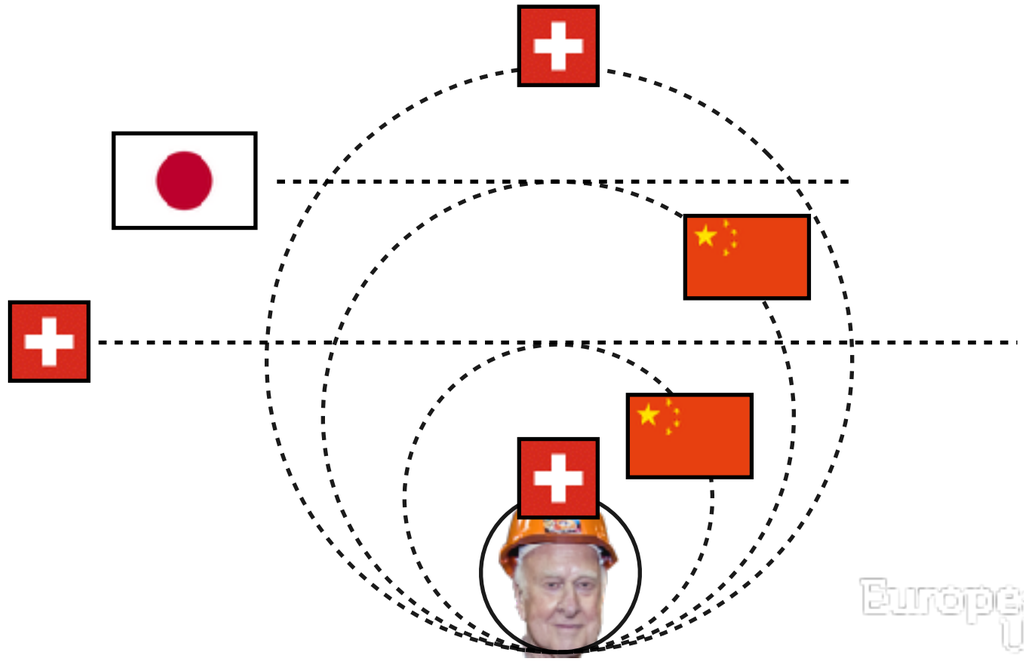
Beyond the Standard Model
(theory perspective)

Beauty 2020

"IPMU on Zoom", September 24, 2020



Christophe Grojean

DESY (Hamburg)
Humboldt University (Berlin)

(christophe.grojean@desy.de)

Outline

As soon as BSM will be discovered, it will become part of SM
So BSM is an evolving notion. BSM approaches have also changed over the year as a result of exp. progress

- Higgs and BSM ← good motivations for a Higgs factory
- BSM @ TeV ← scale theory driven, would have been the only part I would have discussed 10 years ago
- BSM @ Intensity Frontiers ← mostly signature driven, can probe new theoretical ideas
- BSM in the Dark Sectors ← remains one of the best evidences for BSM
- GW probe of BSM

— Disclaimer —
I won't discuss how BSM can explain the flavour anomalies
since G. Isidori already did that beautifully in his talk on Monday.

Higgs and BSM

Probing the Unknown

The Standard Model is not enough:

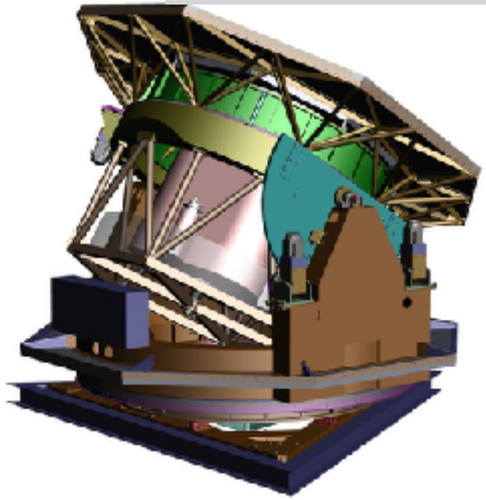
Many questions about the Universe (Dark Energy, DM, Matter-Antimatter) + anomalies (galatic center excess, H_0 tension);

Several puzzling colliders data (B-anomalies in particular, but flavour hierarchy and CP in general, g-2…);

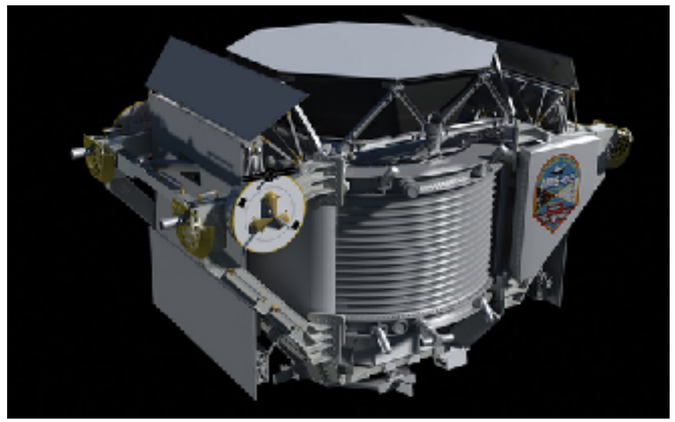
And many theory questions (BH information paradox, unification, hierarchy, confinement…).

No doubt that there is something else beyond SM

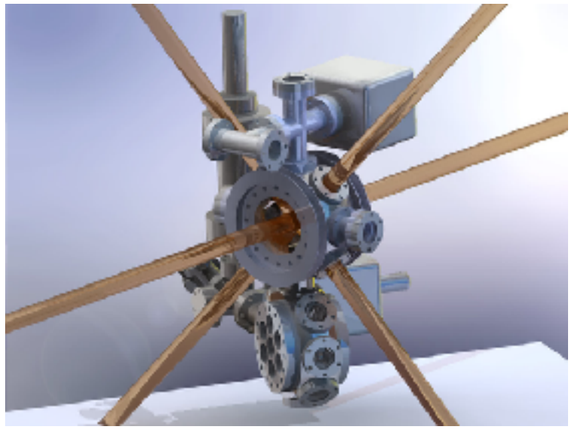
— no clear path BSM : new tools needed to explore different horizons —



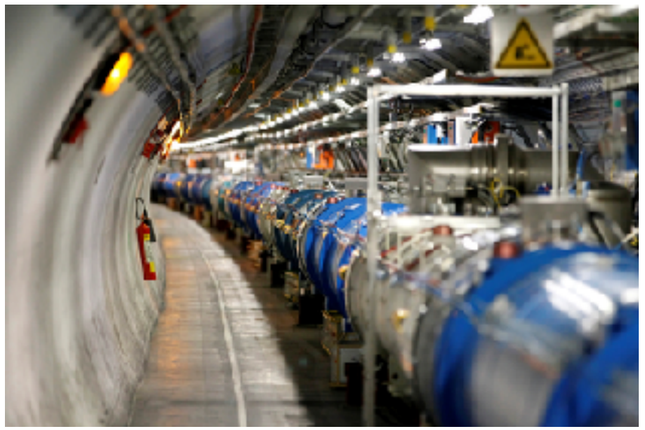
Cosmology frontier



Astroparticle frontier



Intensity frontier



Energy frontier

These days, the best tool that would ensure big progress in science is

SM Chirality

SM = S(R+Q)M

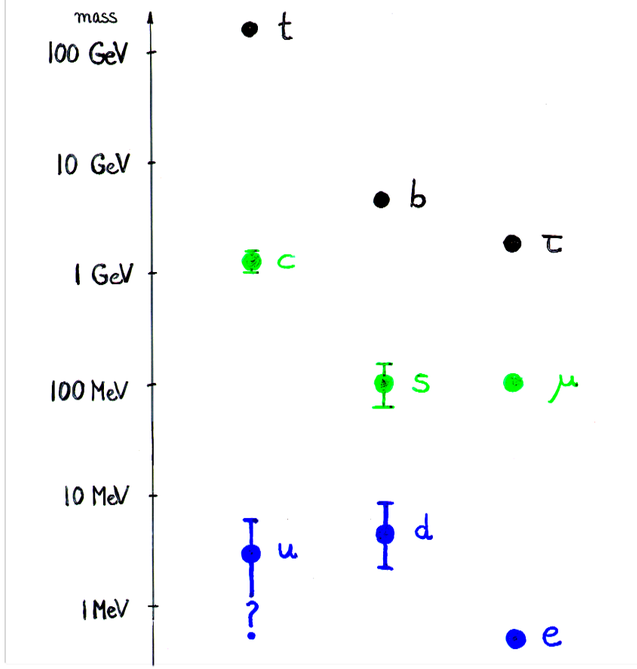
triumph of Quantum Mechanics + Special Relativity

particles = representations of Poincaré group, labelled by (according to Coleman-Mandula)

(spin, mass) ⊗ internal quantum numbers

quantised — continuous — at least SU(3)xSU(2)xU(1)

A priori in agreement with data ⟺



(picture: courtesy of A. Weiler)

BUT

spectrum is incompatible with **chiral** nature of gauge symmetries

chiral fermion ⇏ m=0 only

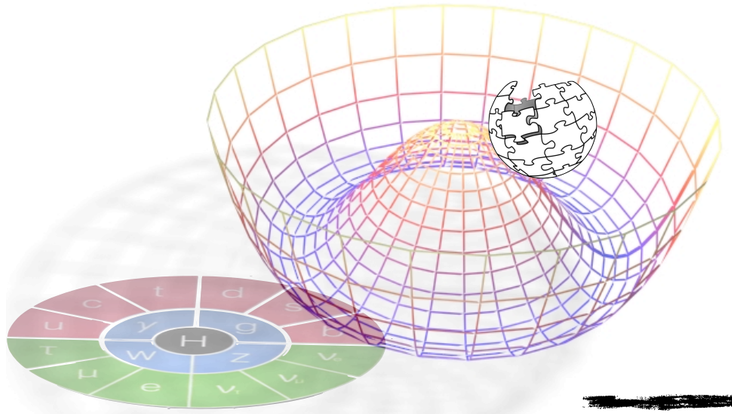
gauge boson ⇏ m=0 only

In **molecular biology**, chirality seems an **emergent** property.

Are the chiral nature of the **weak** interactions **emergent** too?

Spontaneous Symmetry Breaking

Short-distance interactions ≠ Long-distance interactions
The masses are emergent due to a non-trivial structure of the vacuum



vacuum = a space entirely devoid of matter

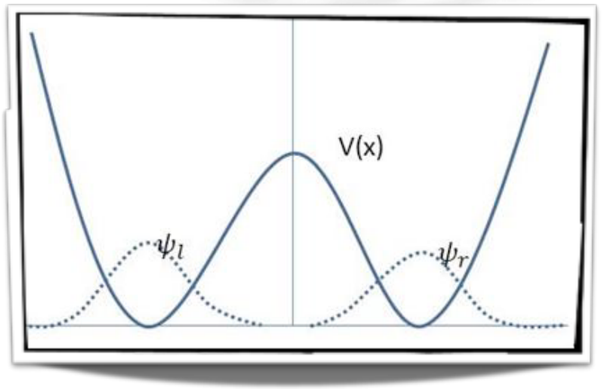
Oxford English

vacuum = a space filled with Higgs substance

Physics English

QM vs QFT

(courtesy of J. Lykken@Aspen2014)



Ground state of QM double well potential
is a superposition of two states localised on one minimum,
and this superposition preserves the Z_2 symmetry of the potential

In QFT, it is more difficult to transition between degenerate vacua
and spontaneous symmetry breaking can occur
(or more correctly, the symmetry is non-linearly realised in Hilbert space)

The vacuum of the SM breaks SU(2)xU(1) to $U(1)_{em}$ via the dynamics of an elementary scalar field

The Higgs Boson

The Higgs Boson is Special

The Higgs discovery in 2012 has been an important milestone for HEP.
And many of us are still excited about it.
And others, especially in other fields of science, should be excited too.

Higgs = **new forces** of different nature than the gauge interactions known so far

- No underlying local symmetry
- No quantised charges
- Deeply connected to the space-time vacuum structure

The knowledge of the values of the **Higgs couplings**
is essential to our understanding of the deep structure of matter

- Up- and Down-quark Yukawa's decide if $m_{proton}<m_{neutron}$ i.e. stability of nuclei
- Electron Yukawa controls the size of the atoms
- Top quark Yukawa decides (in part) of the stability of the EW vacuum
- The Higgs self-coupling controls the (thermo)dynamics of the EW phase transition ($t\sim10^{-10}s$)

(and therefore might be responsible of the dominance of matter over antimatter in the Universe)

The Higgs : source of the SM puzzles

The gauge sector of the SM is fully understood and is under control
This is not the case of the Higgs interactions that are arbitrary and associated to SM puzzles

$$\mathcal{L}_{\rm Higgs} = V_0 - \mu^2 H^\dagger H + \lambda \left(H^\dagger H\right)^2 + \left(y_{ij}\bar{\psi}_{Li}\psi_{Rj}H + h.c.\right)$$

vacuum energy
cosmological constant

$V_0 \approx (2\times 10^{-3}\ \mathrm{eV})^4 \ll M_{\rm PL}^4$

hierarchy problem

$m_H \approx 100\ \mathrm{GeV} \ll M_{\rm Pl}$

triviality/stability
of EW vacuum

mass and mixing
hierarchy

flavour & CP

Higgs as a compass to BSM

Bottom-up **rigidity** of the SM: given the low-energy spectrum, all the Higgs couplings are uniquely fixed
(G_F, m_W, m_Z, m_{quark}, m_{lepton})

New physics can alter this structure and induce a deformation of the Higgs couplings:

$$\frac{\delta g_h}{g_h} \sim \frac{v^2}{f^2} = \frac{g_*^2\, v^2}{\Lambda^2_{\rm BSM}}$$

current (and future) LHC sensitivity
O(10-20)% ⇔ Λ_{BSM} > 500(g_*/g_{SM}) GeV

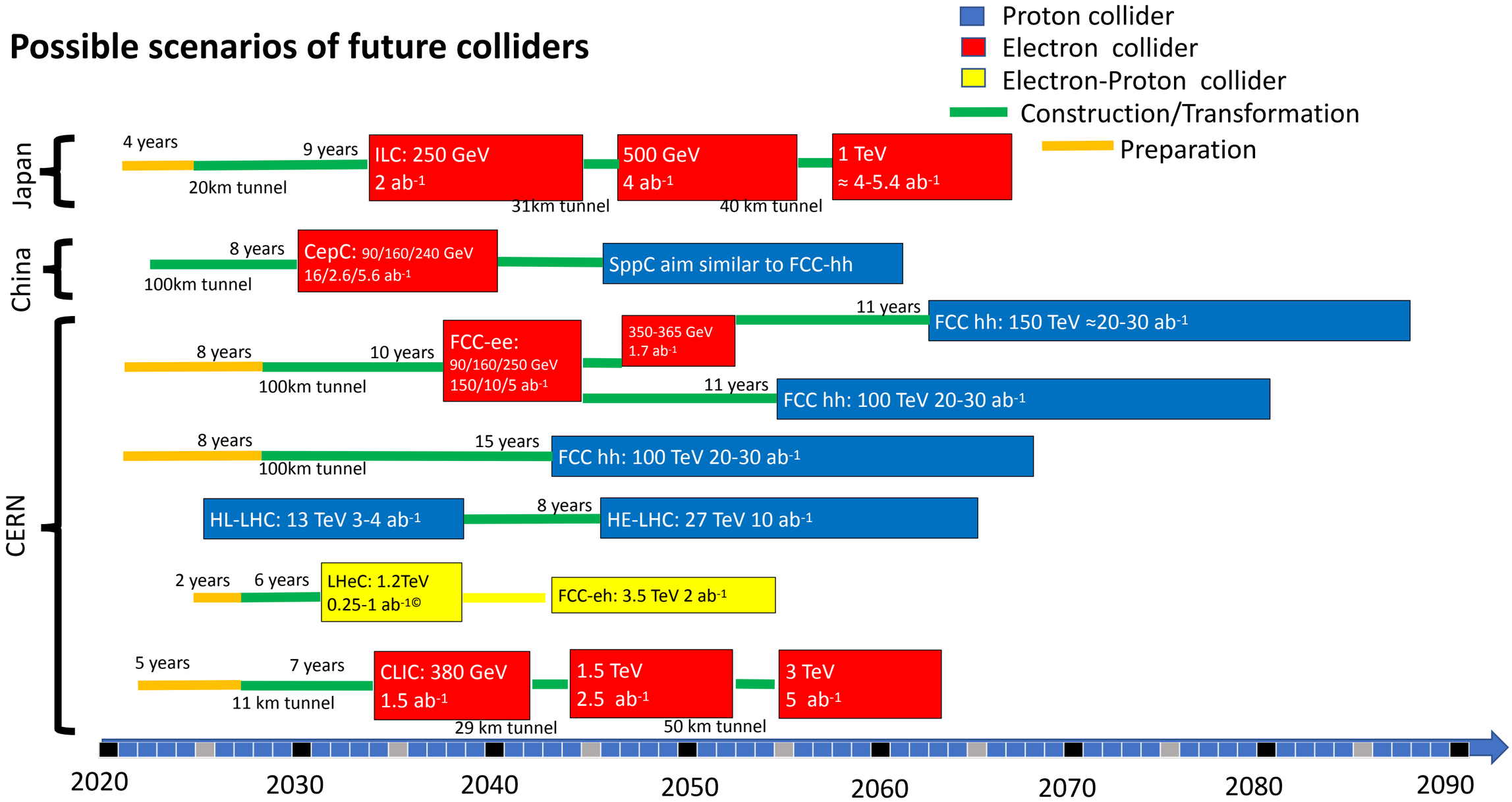
not doing better than direct searches unless in the case of strongly coupled new physics
(notable exceptions: New Physics breaks some structural features of the SM
e.g. flavor number violation as in $h \to \mu\tau$)

Higgs precision program is very much wanted to probe BSM physics

1% is also a magic number to probe naturalness of EW sector

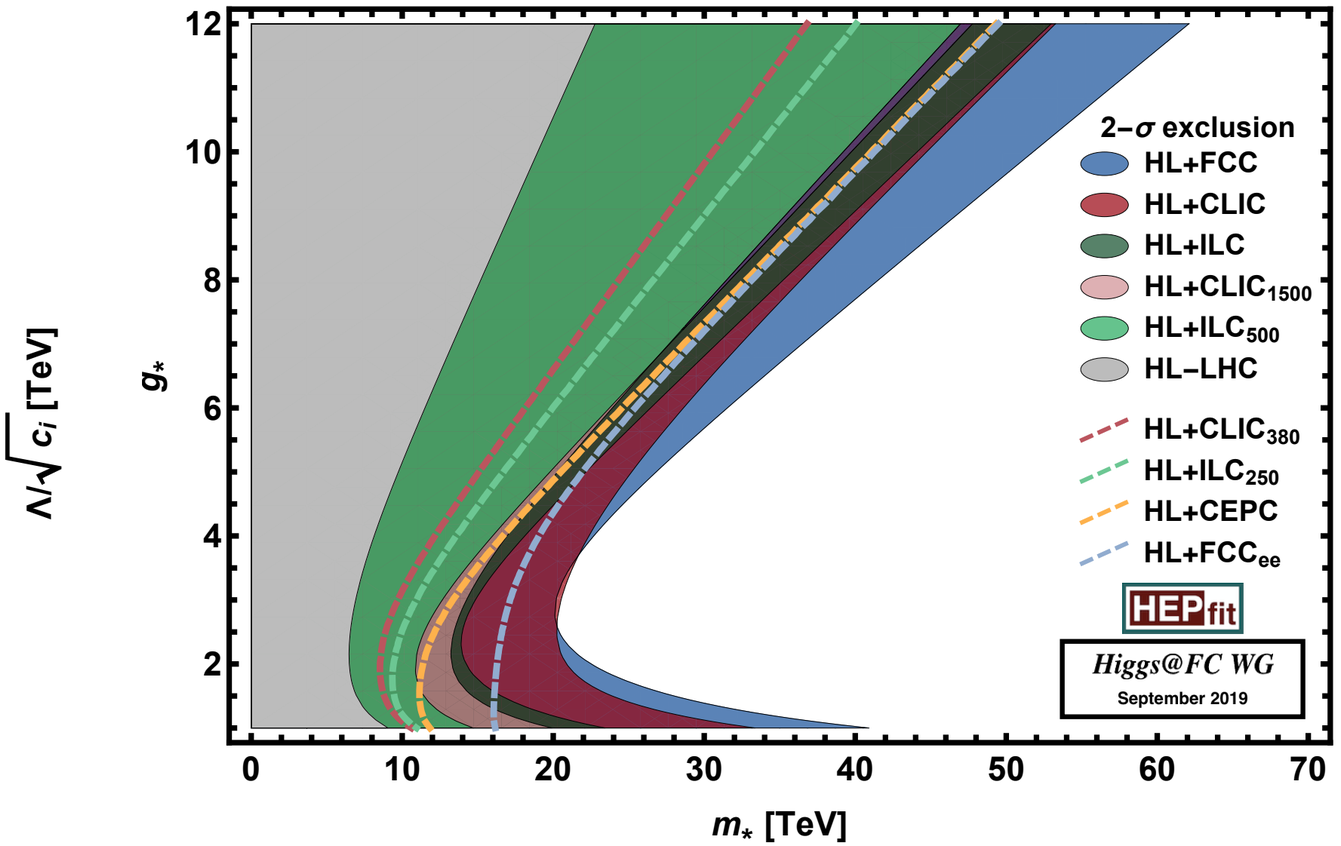
Higgs as a compass to BSM

Possible scenarios of future colliders



Higgs as a compass to BSM

Indirect constraints from Higgs measurements
on new physics states in composite Higgs models



will overpass by one order of magnitude direct searches

BSM @ TeV

What is the scale of New Physics?

High Scale Wishes

small FCNC: $\frac{gF_{\mu\nu}\bar{\psi}H\sigma^{\mu\nu}\psi}{M_{\rm NP}^2}$ 10^3TeV?

tiny neutrino masses: $\frac{(LH)^2}{M_{\rm NP}}$ 10^{14}GeV?

slow proton decay: $\frac{UUDE}{M_{\rm NP}^2}$ 10^{16}GeV?

Low Scale Wishes

small EDMs: $\arg\det \mathrm{Y} \leq 10^{-10}$

↳ axion?

tiny vacuum energy: $\Lambda \approx M_{\rm NP}^4 \gg \left(10^{-3}\mathrm{eV}\right)^4$

↳ ?

light Higgs boson: $m_H^2 \approx M_{\rm NP}^2 \gg (125\mathrm{GeV})^2$

↳ light susy?

Where is everybody?

even new physics at few hundreds of GeV might be difficult to see and could escape LHC detection

- **compressed spectra**
- **displaced vertices**
- **no MET, soft decay products, long decay chains**
- **uncoloured new physics**

~~R~~-susy

Neutral naturalness
(twin Higgs, folded susy)

Relaxion

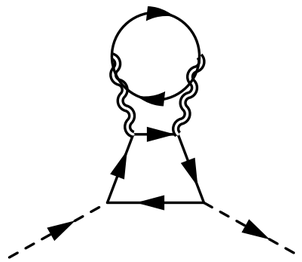
Hierarchy Problem

The potential of an elementary scalar field is highly sensitive to UV physics:
Is the EW vacuum compatible with new physics at higher energy (aka **hierarchy/naturalness** problem)?

Conspiracy/intelligent design

Arrange high-scale physics,
including quantum gravity,
to give small enough corrections
to Higgs potential

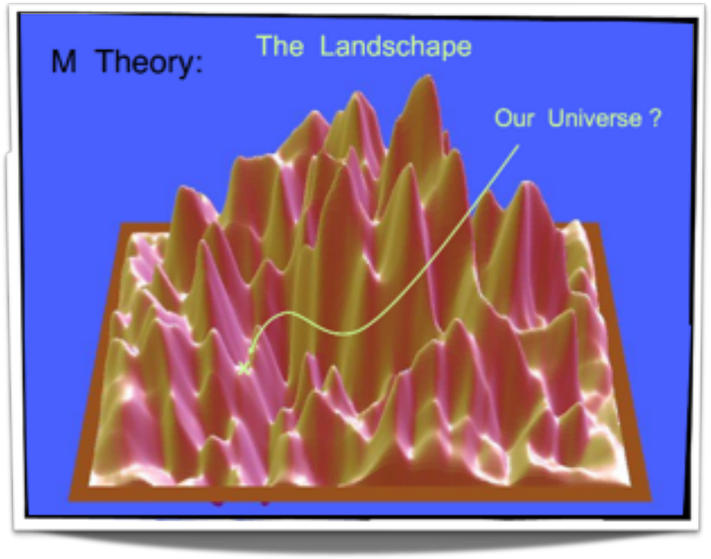
— Challenge —



$$\delta m_H^2 \sim \frac{6y_t^2}{(16\pi^2)^3}\frac{m_\Psi^6}{M_{Pl}^4}$$

Even new physics
only gravitationally coupled to SM
can generate large corrections
because off-shell couplings to gravitons

Anthropic selection in multiverse



Particles and fields are not
the building blocks of matter.
Strings and D-branes are.
Non-trivial fluxes generate multiverse

Dynamical screening

More conservative approach

Add new physics
to stabilise the EW vacuum

- New spacetime symmetry (supersymmetry)
- New forces/new particles (composite Higgs)
- New vacua

One Vacuum Natural Models

Dynamical screening of the UV corrections to Higgs potential

- **Single vacuum**

New particles
with couplings related to SM ones by
symmetry cancel the large corrections

1. a symmetry (**Susy, PQ**)
2. a form factor (**composite Higgs**)

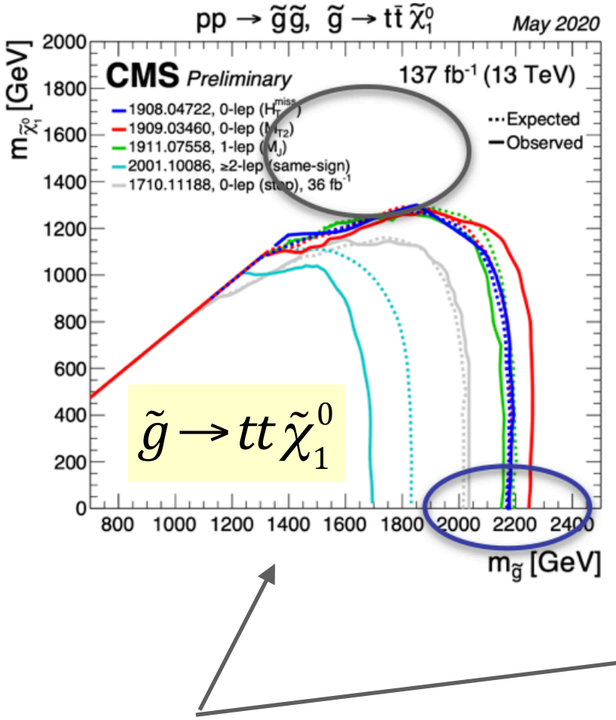
Low scale of quantum gravity

1. Large extra dimensions (**ADD**)
2. Gravitational sequestering (**RS**)

Combination of the above

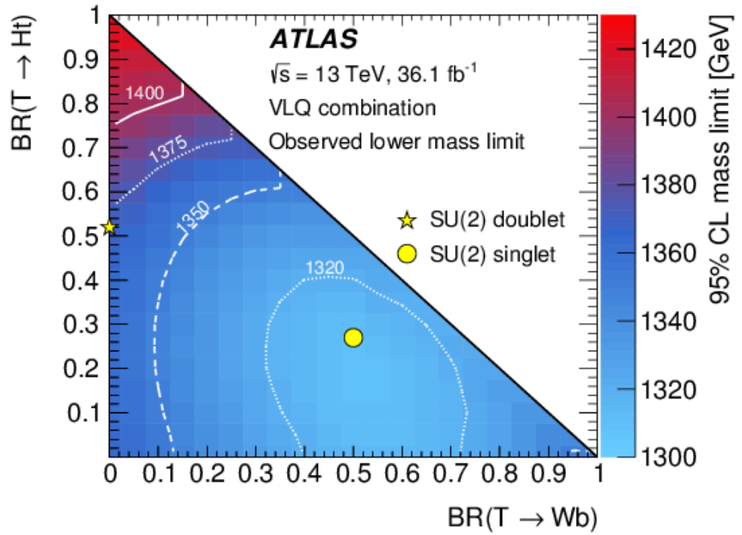
TeV scale new physics

SUSY Searches



Vanilla models are getting
in their tuned region

Composite Higgs top partners searches



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New Natural Models

	Scalar Top Partner	Fermion Top Partner
All SM Charges	SUSY	pNGB/RS composite
EW Charges	Folded SUSY	Quirky Little Higgs
No SM Charges	???	Twin Higgs

Neutral Naturalness

new "exotic" signatures
- displaced vertices
- emerging jets

Last
model building
opportunities
filled up recently

Singlet scalar top partners from accidental supersymmetry

Hsin-Chia Cheng,[a,b] Lingfeng Li,[a] Ennio Salvioni[c] and Christopher B. Verhaaren[a]

The Hyperbolic Higgs

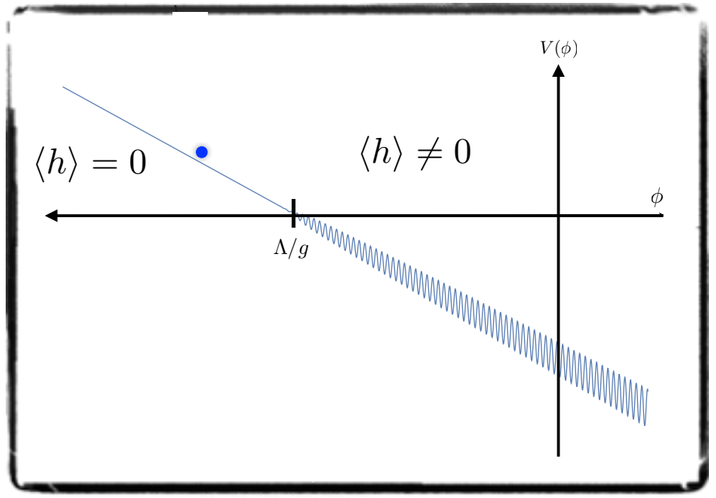
Timothy Cohen,[a] Nathaniel Craig,[b] Gian F. Giudice[c] and Matthew McCullough[c]

Multi Vacua Natural Models

Dynamical screening of the UV corrections to Higgs potential

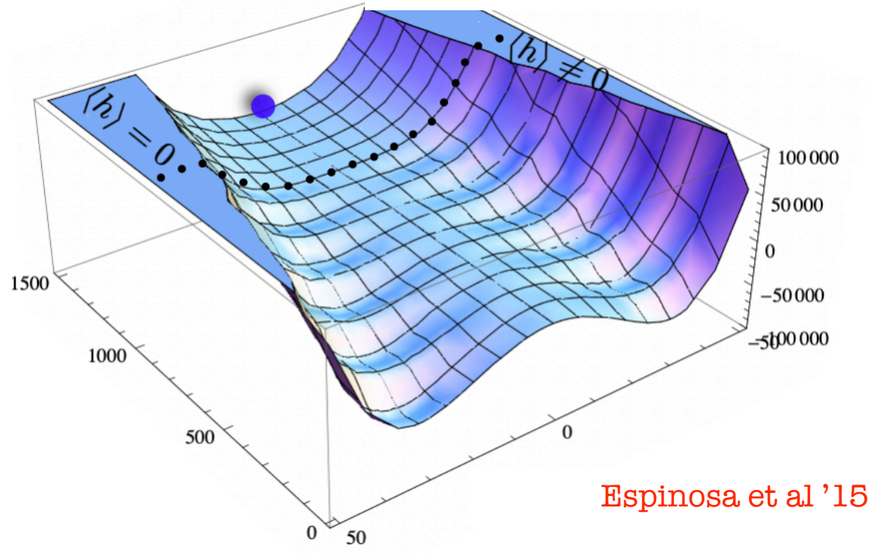
- **Multiple vacua**

many metastable vacua with a vast range of values for m_H
Dynamical selection of $m_H \ll \Lambda$



Graham, Kaplan, Rajendran '15

1. **NNaturalness**: The patches with different Higgs VEVs expand differently: either they shrink to nothing or they expand too fast and no particle reheating possible. The patch with the right EW vacuum is selected.
2. **Relaxion**: Cosmological scanning with non-trivial back reaction that stops the exploration of the vacuum manifold at the right place



Espinosa et al '15

Paradigm shift

light new physics expected to address the hierarchy problem

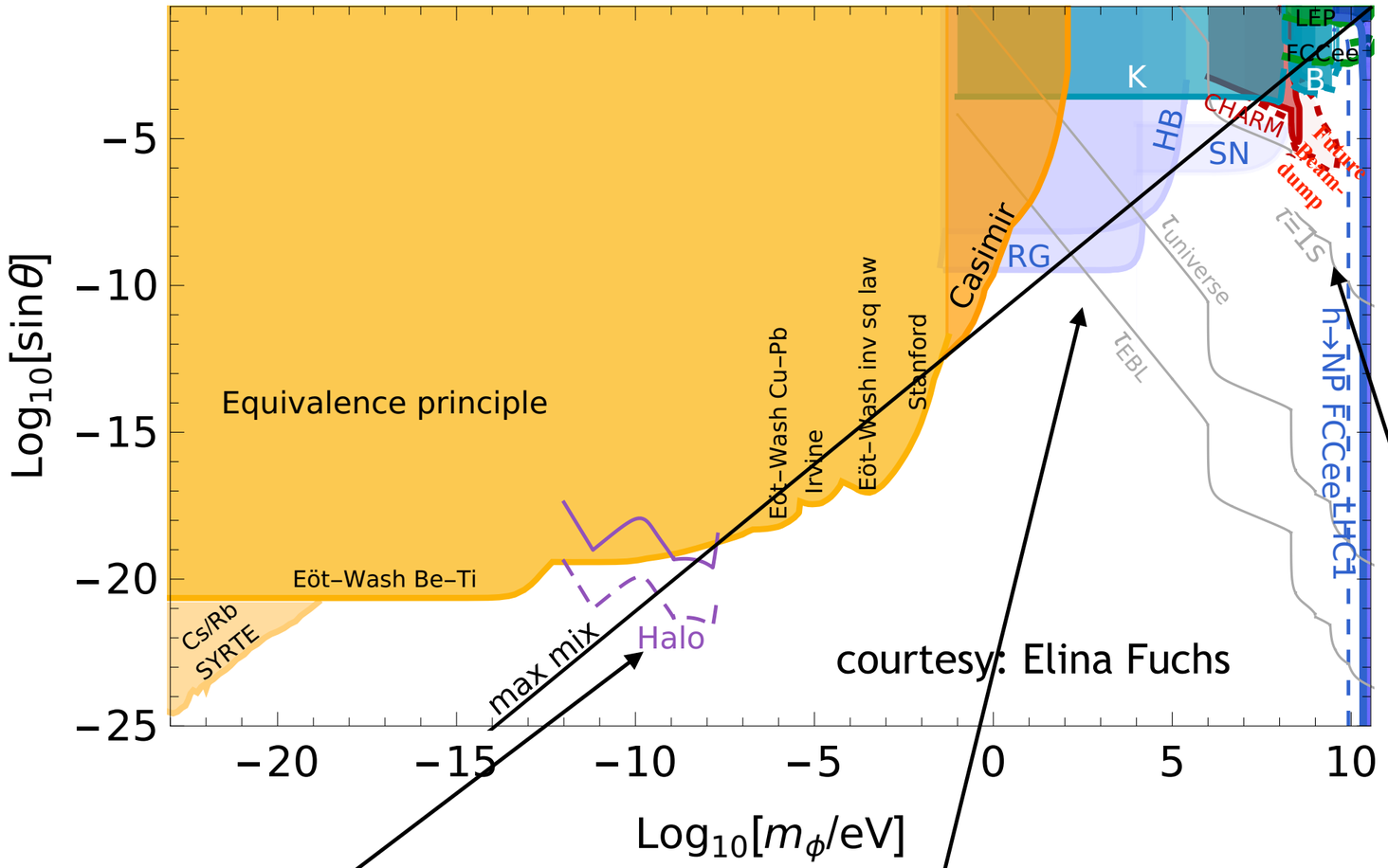
LHC/energy frontier is not the unique place to probe "natural" models

BSM @ Intensity Frontiers

The *log* Crisis of the Higgs

G. Perez et al '17-'19

Overview plot: the relaxion 30-decade-open parameter space



Rich opportunities at different scales

"fun signatures"

Precision frontier

Higgs vev oscillates

Astro frontier

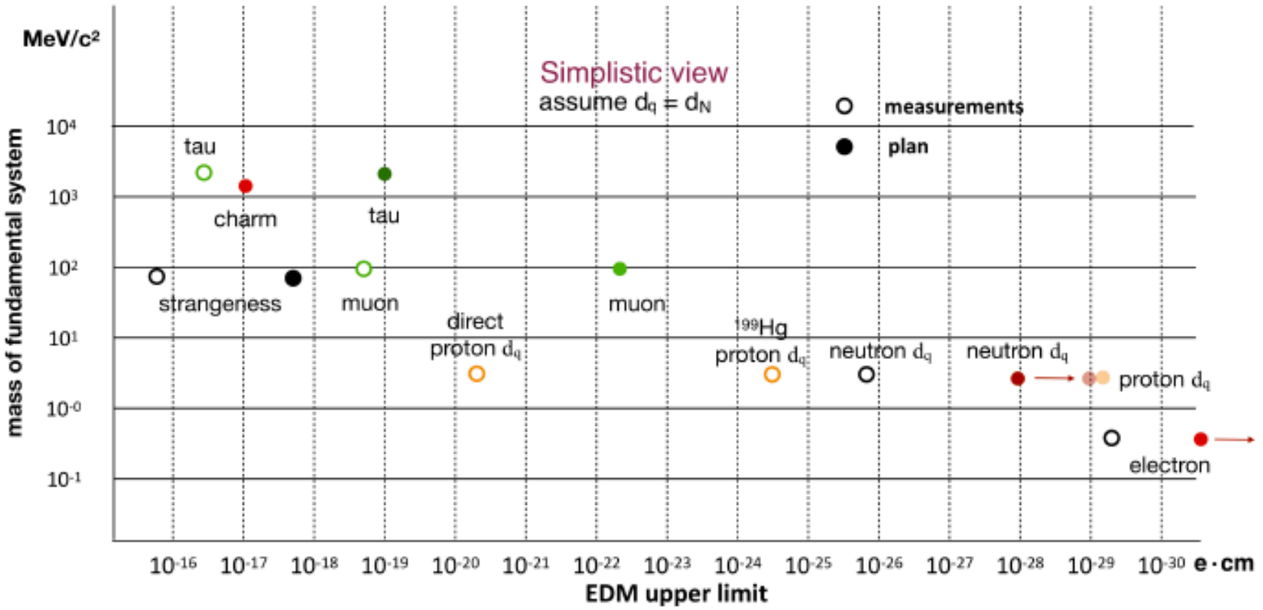
DM halo, super radiance

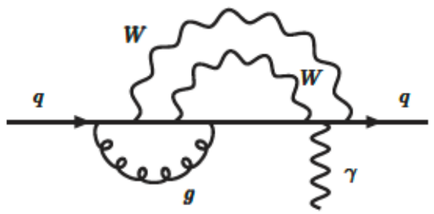
Collider frontier

Invisible Higgs decays

Precision Probes BSM

EDM



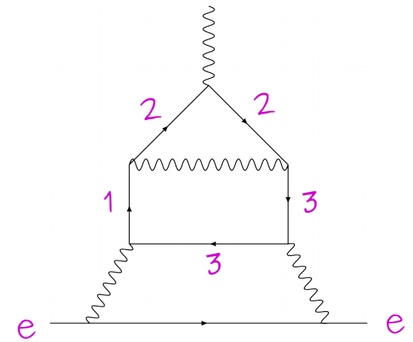


$$\mathcal{L}_{dipole} = -\frac{\mu}{2}\bar{\Psi}\sigma^{\mu\nu}F_{\mu\nu}\Psi - \frac{d}{2}\bar{\Psi}\sigma^{\mu\nu}i\gamma^5 F_{\mu\nu}\Psi$$

Non-relativistic limit

$$H = -\mu\,\vec{B}\cdot\frac{\vec{S}}{S} - d\,\vec{E}\cdot\frac{\vec{S}}{S}$$

SM predictions



$$\rightarrow d_e/e \sim 10^{-40}\ cm$$

SM contribution is ridiculously small
EDM is clear signal of New Physics

$|d_e| < 9.4 \cdot 10^{-29}\, e\,\mathrm{cm}$ (ACME @ 90% CL)

$|d_e| \lesssim 0.5 \cdot 10^{-29}\, e\,\mathrm{cm}$ (ACME II)

$|d_e| \lesssim 0.3 \cdot 10^{-30}\, e\,\mathrm{cm}$ (ACME III)

Pushing the EDM Frontier

M. Reece @ Pheno2020

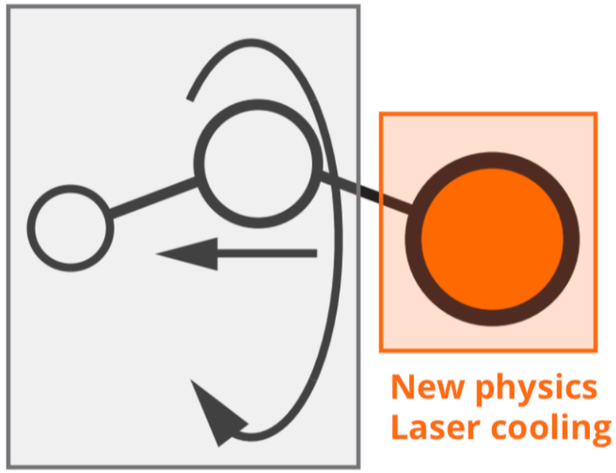
To improve, need more molecules, longer coherence times. Need special molecules:

Laser cooling can produce many slow-moving molecules to study. Avoid exciting molecular rotational, vibrational modes.

EDM systematics need "internal co-magnetometer."

Hutzler & Kozyryev 2017: **polyatomic molecules can give both! (ex: YbOH)**

Polyatomic EDM



from slide by N. Hutzler

Time scale of 5-10 years:

$$|d_e| \lesssim 10^{-32}\, e\,\mathrm{cm}$$

1-loop, PeV scale sensitivity

Other planned experiments: trapped molecular ions (Cornell, Ye, JILA), YbF (Hinds, Imperial), EDM^3 (Vutha, Horbatsch, Hessels, Toronto/York), …

EDM Probes BSM

e.g., EDM can help testing the presence of top partners in composite Higgs models far beyond direct reach

arXiv:1712.06337

$$g_{WX_{5/3}t_R} = \frac{g}{\sqrt{2}} c_t \frac{v}{f}$$

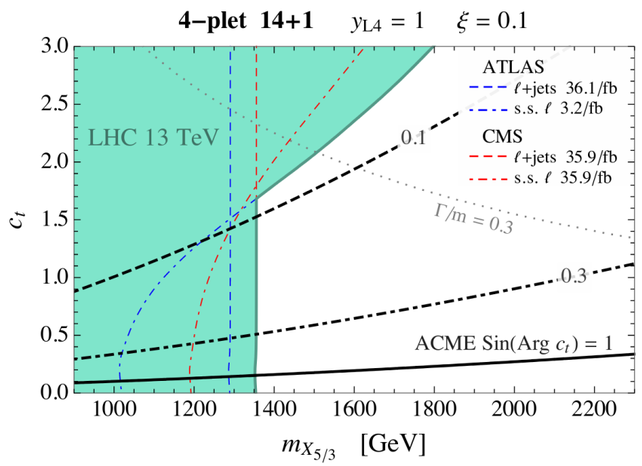
$$\xi = \frac{v^2}{f^2}$$

$$\xi = 0.1 \leftrightarrow f \approx 800\,\text{GeV}$$

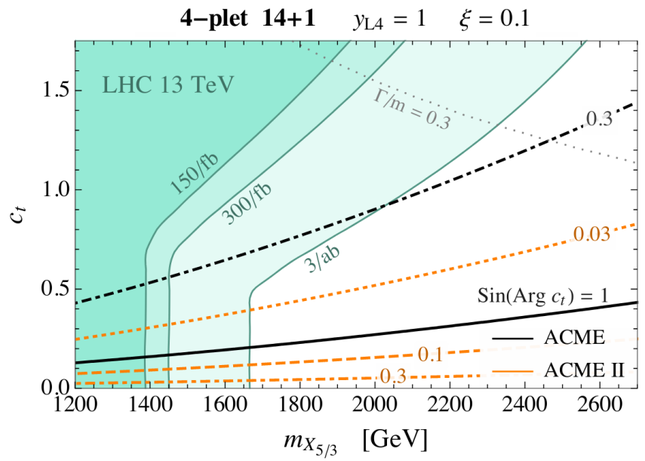
$$\xi = 0.05 \leftrightarrow f \approx 1100\,\text{GeV}$$

$$\xi = 0.001 \leftrightarrow f \approx 8000\,\text{GeV}$$

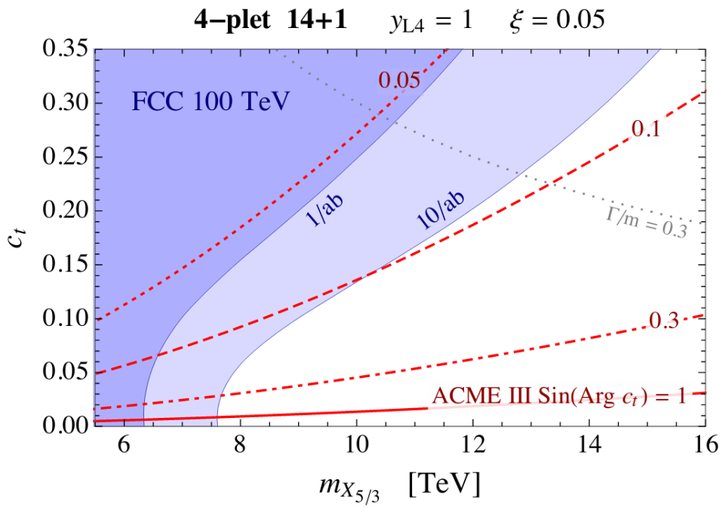
LHC



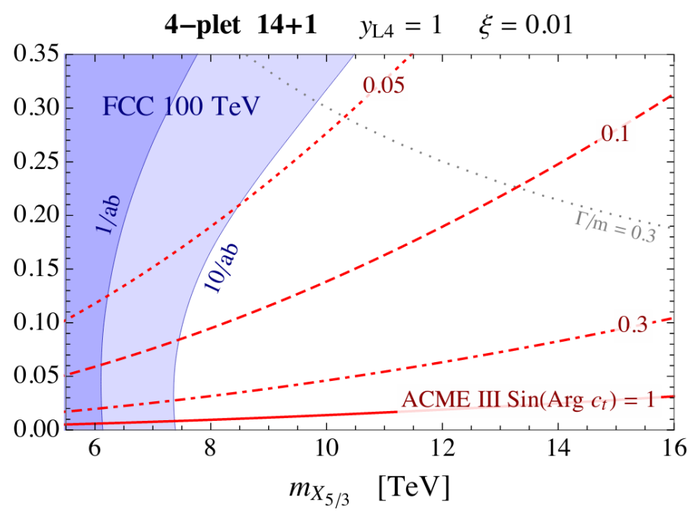
HL-LHC



FCC-hh



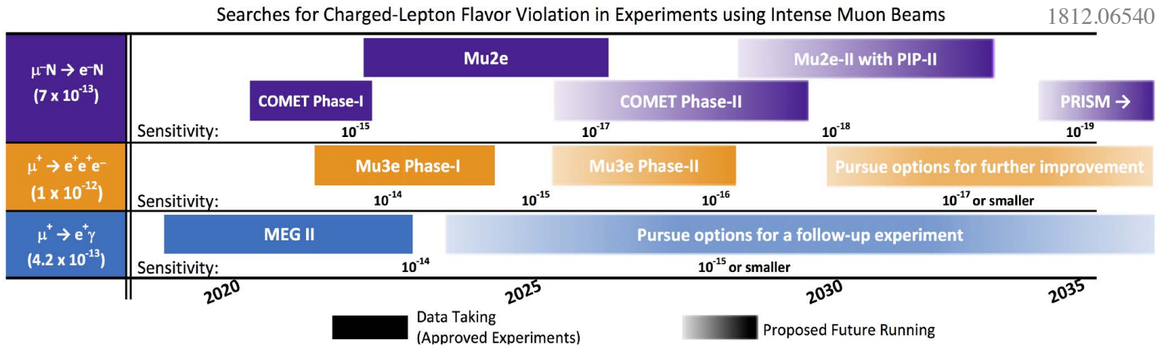
FCC-hh



Precision Probes BSM

ESU, arXiv:1910.11775

LFV



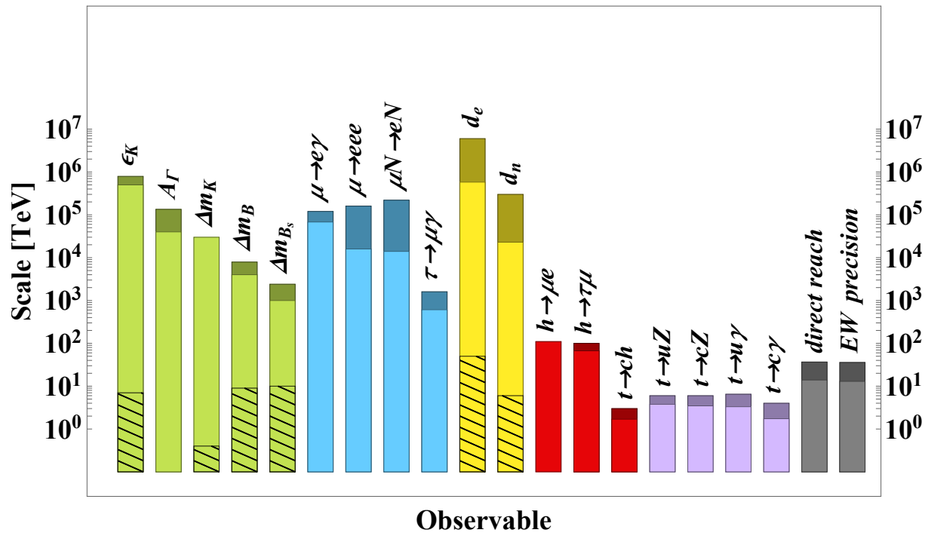
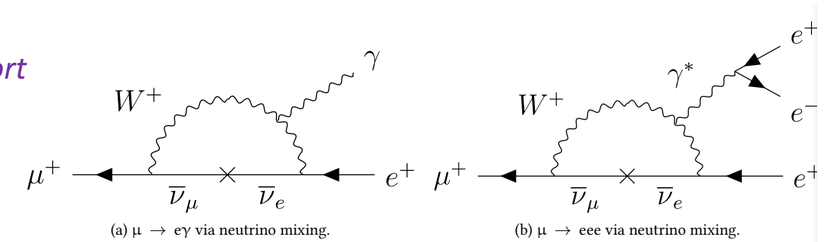


Fig. 5.1: Reach in new physics scale of present and future facilities, from generic dimension six operators. Colour coding of observables is: green for mesons, blue for leptons, yellow for EDMs, red for Higgs flavoured couplings and purple for the top quark. The grey columns illustrate the reach of direct flavour-blind searches and EW precision measurements. The operator coefficients are taken to be either ~ 1 (plain coloured columns) or suppressed by MFV factors (hatch filled surfaces). Light (dark) colours correspond to present data (mid-term prospects, including HL-LHC, Belle II, MEG II, Mu3e, Mu2e, COMET, ACME, PIK and SNS).

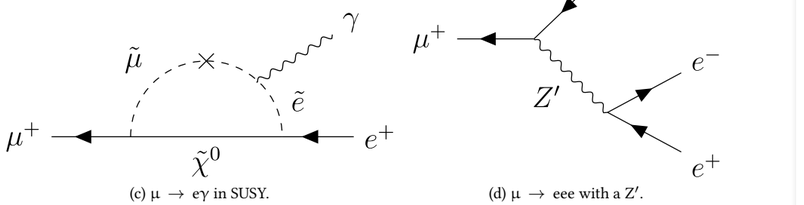
Figures from A-K Perrevoort

SM: BR<10^{-54}



(a) μ → eγ via neutrino mixing. (b) μ → eee via neutrino mixing.

BSM

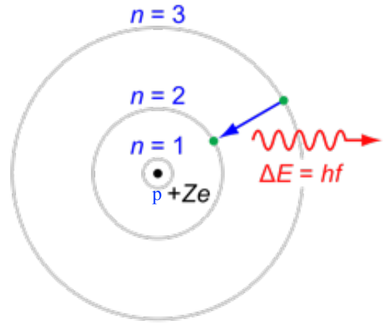


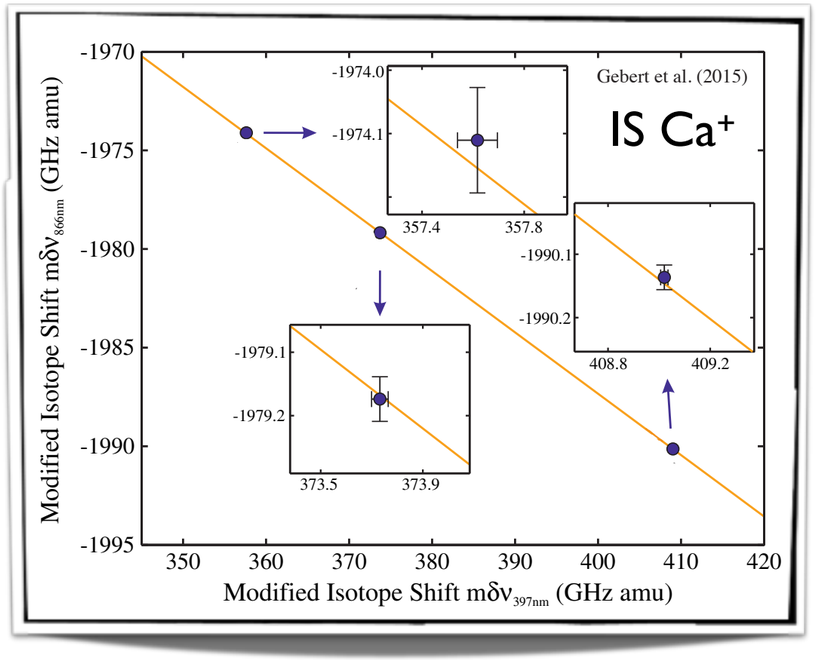
(c) μ → eγ in SUSY. (d) μ → eee with a Z′.

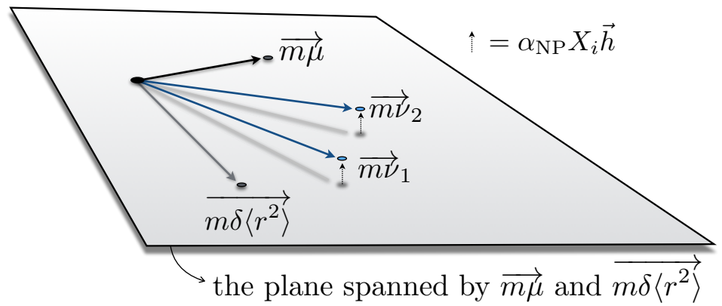
LFV processes give strongest constraints on MVF models

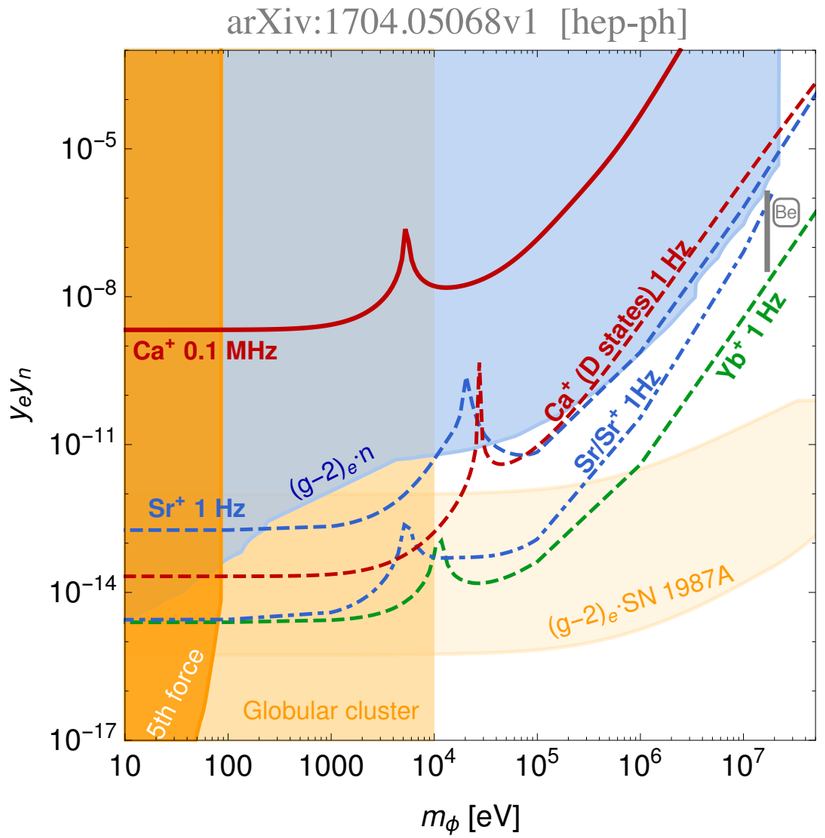
HEP Meets AMO

O(10-18) sensitivity in atomic clock measurements
can be used to detect new (long range) forces









can only probe long-range force
(no bound on e- Yukawa, unfortunately)

Spectacular experimental progress very recently

2004.11383
Yb+ King plot (300 Hz)

2005.00529
Ca+ King plot (20 Hz)

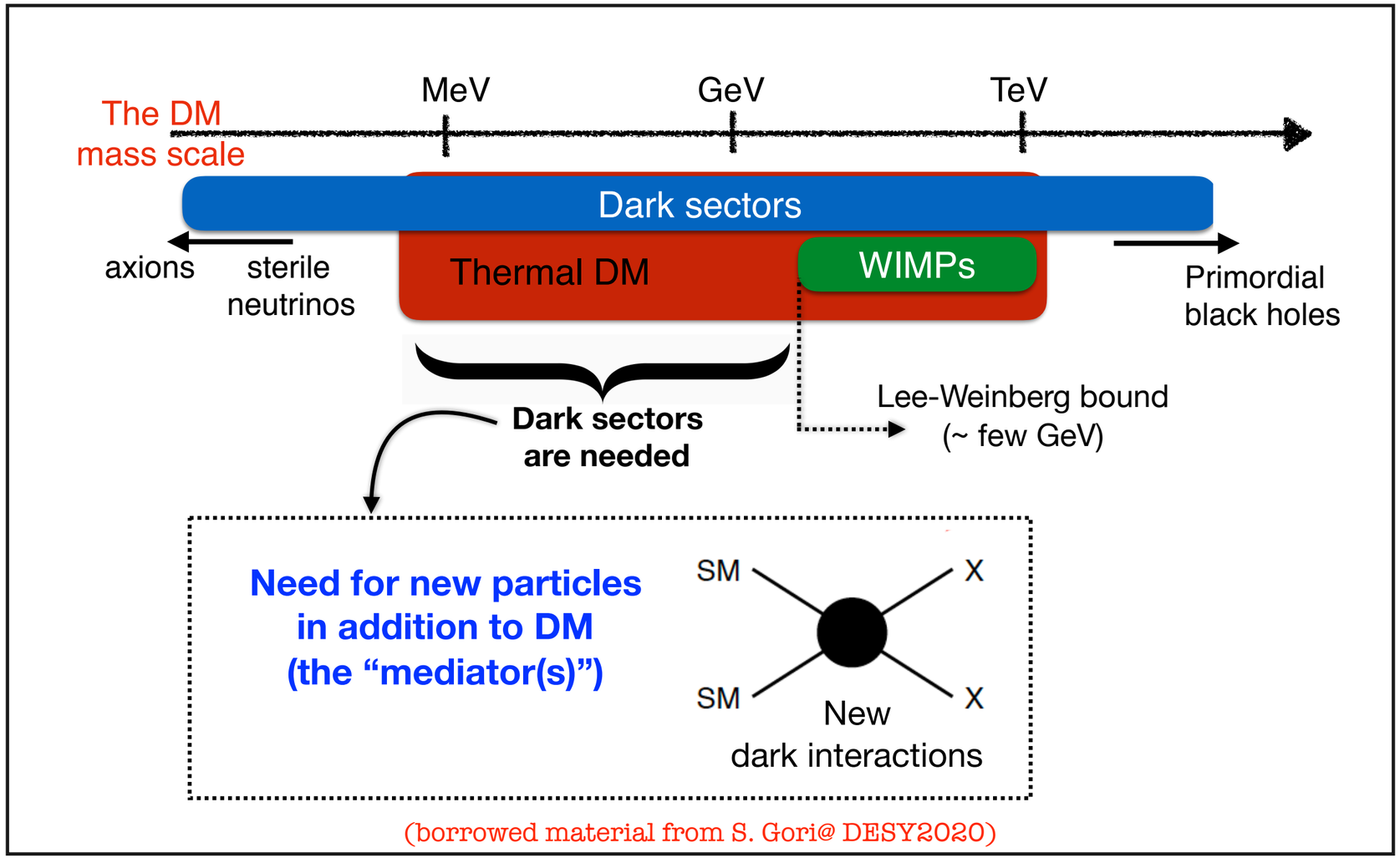
BSM in the Dark Sector

Scale of DM

The prediction about the mass scale of DM comes with large error bars:

$$10^{-22}\,\mathrm{eV} < m_{DM} < 10^{20}\,\mathrm{GeV}$$

(ALPs) (Wimpzillas, Q-balls)



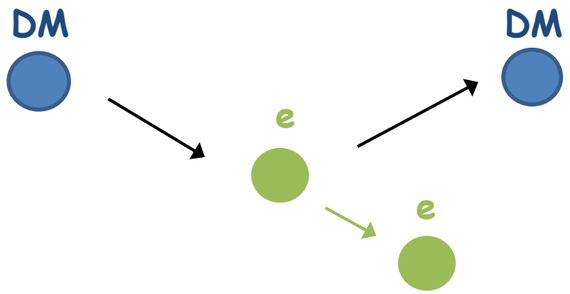
(borrowed material from S. Gori@ DESY2020)

WIMP and Beyond

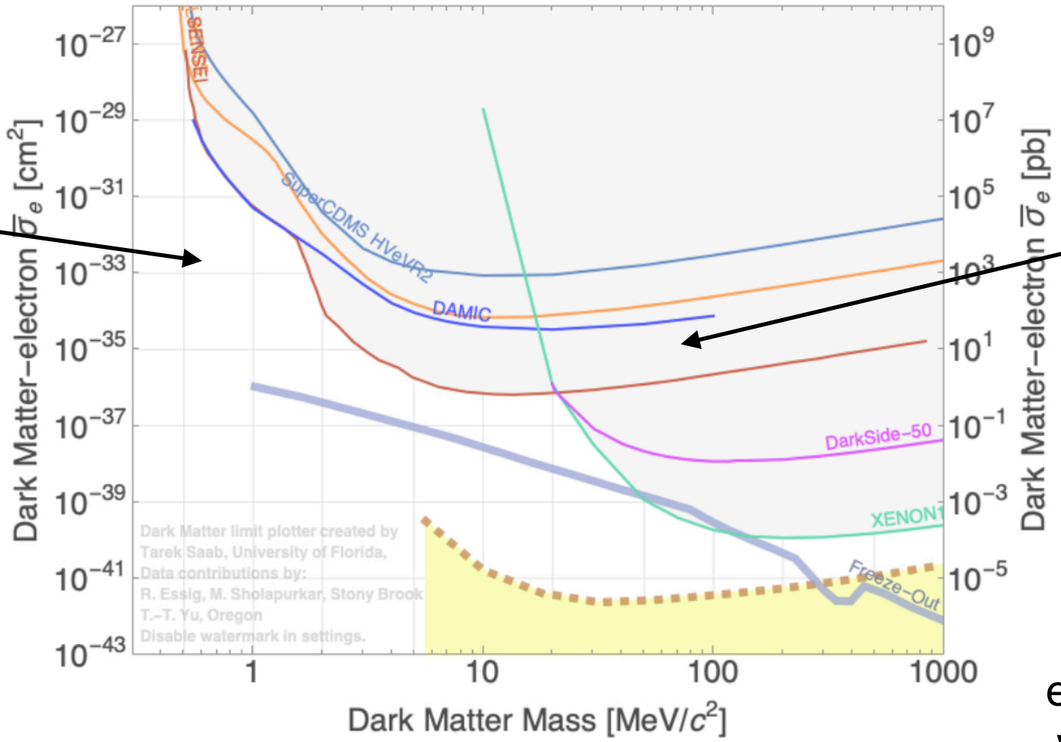
WIMP miracle/accident: DM can can be naturally linked to the weak scale

thermal freeze-out: $\Omega_{\rm DM} \sim 0.3 \, \frac{g^2_{\rm DM\text{-}SM}}{4\pi\,\alpha} \left(\frac{100\,{\rm GeV}}{m_{\rm DM}}\right)^2$

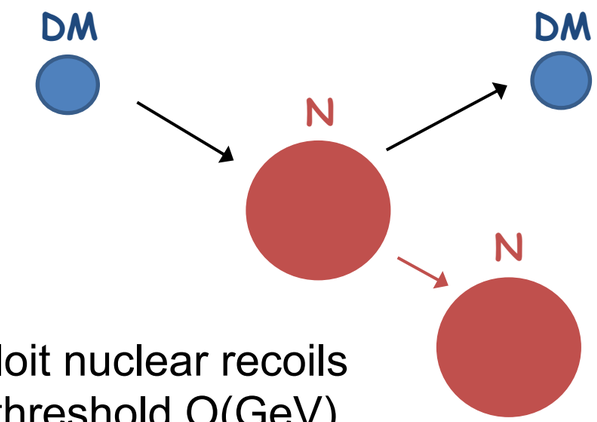
light DM
region is subject
to weaker constraints



exploit electron recoils
w/ threshold O(keV)



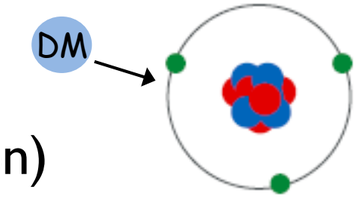
WIMP region is well explored
and no signal (yet)



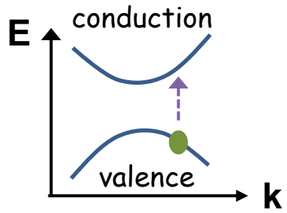
exploit nuclear recoils
w/ threshold O(GeV)

(borrowed material from Y. Hochberg @ DESY2020)

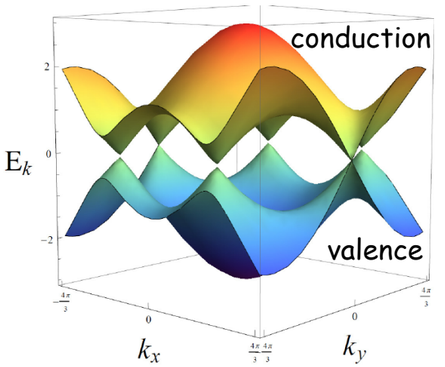
The light DM frontier



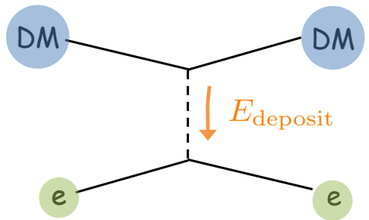
- Atomic ionization (Xenon)

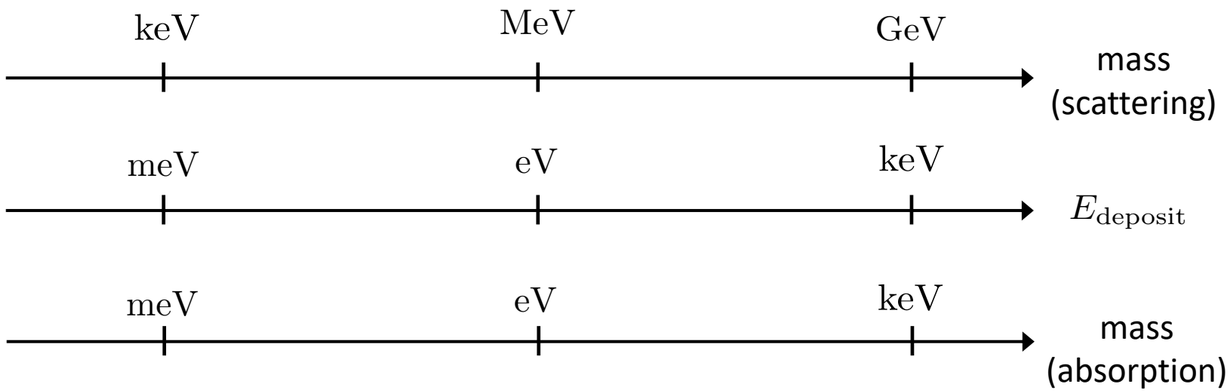


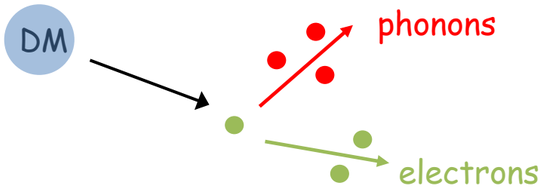
- Semiconductors (Sensei)
- Superconductors (SNSPDs) DM scatters on Cooper pairs and break them
- Graphene/vanishing bandgap (Ptolemy): DM scatters with valence e$^-$ and eject them



- Dirac material







(see Y. Hochberg @ DESY2020)

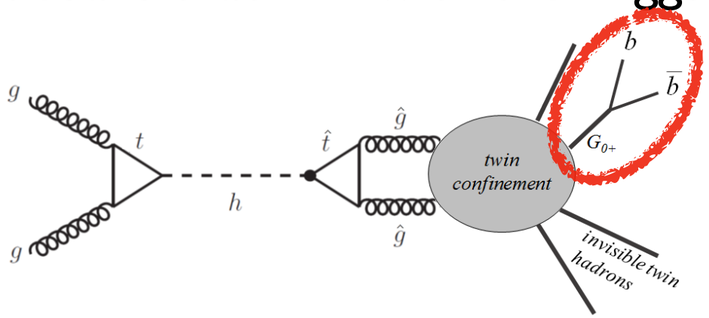
Searches for the light dark states

(see S. Gori @ DESY2020)

- **LLP searches with displaced vertices**

  e.g. in twin Higgs models glueballs that mix with the Higgs and decay back to b-quarks

arXiv:1501.05310



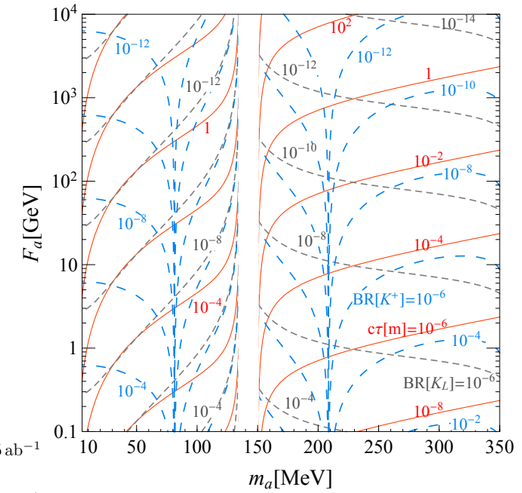
Mathulsa, Faser…
or precise timing detector @ ATLAS/CMS

- **Rare decays**

  e.g. ALP mixing w/ SM mesons:

$$K_L \to \pi^0 a \to \pi^0 \gamma\gamma \text{ (KOTO)}$$
$$K^+ \to \pi^+ a \to \pi^+ \gamma\gamma \text{ (NA62)}$$

$$\mathcal{L} = \frac{\alpha_s}{8\pi F_a} a G_{\mu\nu} \tilde{G}^{\mu\nu}$$

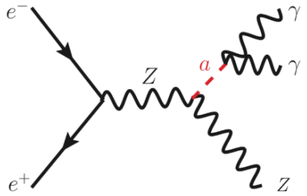


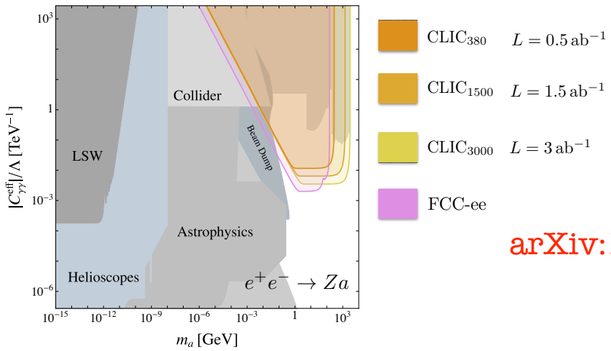
arXiv:2005.05170

- **ALPs@ colliders**

  e.g. $e^+e^- \to Za$

  $e^+e^- \to ha$

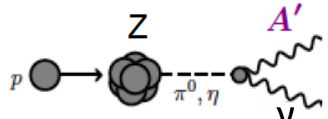




arXiv:1808.10323

- **Beam-dump experiments**

  e.g. kinetic mixing with dark photon



e.g. SHiP: arXiv:1504.04855

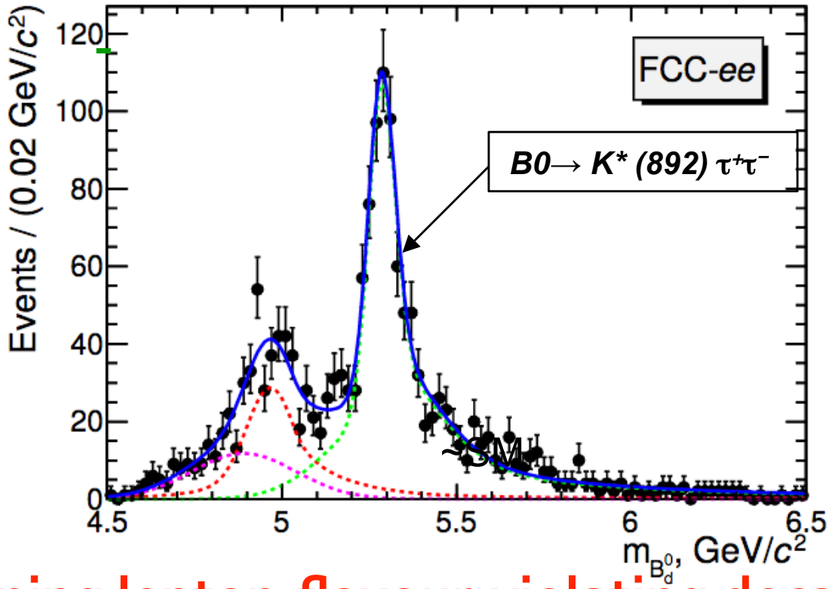
SHiP, DarkQuest

Z-Factories are also Flavour Factories

- **Lepton flavour universality is challenged in b → s $\ell^+\ell^-$ transitions @ LHCb**
  - **This effect, if real, could be enhanced for $\ell = \tau$, in $B \to K^{(*)}\tau^+\tau^-$**
    - **Extremely challenging in hadron colliders**
    - **With 10^{12} Z → bb, FCC-ee is beyond any foreseeable competition**
      - ➨ **Decay can be fully reconstructed; full angular analysis possible**

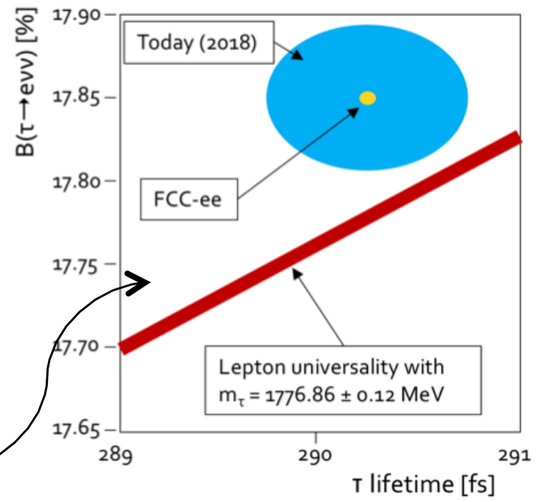
Material from P. Janot

J.F. Kamenik et al.
arXiv:1705.11106



Also 100,000 $B_S \to \tau^+\tau^-$ @ FCC-ee
Reconstruction efficiency under study

- **Not mentioning lepton-flavour-violating decays**
  - **BR(Z → eτ, μτ) down to 10^{-9} (improved by 10^4)**
  - **BR(τ → μγ, μμμ) down to a few 10^{-10}**
  - **τ lifetime vs BR(τ → $e\nu_e\nu_\tau$,$\mu\nu_\mu\nu_\tau$) : lepton universality tests**



Z-Factories are also Flavour Factories

Observable	Current sensitivity	Future sensitivity	Tera-Z sensitivity
$\mathrm{BR}(B_s \to ee)$	2.8×10^{-7} (CDF) [10]	$\sim 7 \times 10^{-10}$ (LHCb) [18]	$\sim$ few $\times 10^{-10}$
$\mathrm{BR}(B_s \to \mu\mu)$	0.7×10^{-9} (LHCb) [8]	$\sim 1.6 \times 10^{-10}$ (LHCb) [18]	$\sim$ few $\times 10^{-10}$
$\mathrm{BR}(B_s \to \tau\tau)$	5.2×10^{-3} (LHCb) [9]	$\sim 5 \times 10^{-4}$ (LHCb) [18]	$\sim 10^{-5}$
R_K, R_{K^*}	$\sim 10\%$ (LHCb) [5, 4]	$\sim$few% (LHCb/Belle II) [18, 40]	$\sim$few %
$\mathrm{BR}(B \to K^*\tau\tau)$	–	$\sim 10^{-5}$ (Belle II) [40]	$\sim 10^{-8}$
$\mathrm{BR}(B \to K^*\nu\nu)$	4.0×10^{-5} (Belle) [44]	$\sim 10^{-6}$ (Belle II) [40]	$\sim 10^{-6}$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	1.0×10^{-3} (LEP) [15]	–	$\sim 10^{-6}$
$\mathrm{BR}(\Lambda_b \to \Lambda\nu\bar{\nu})$	–	–	$\sim 10^{-6}$
$\mathrm{BR}(\tau \to \mu\gamma)$	4.4×10^{-8} (BaBar) [24]	$\sim 10^{-9}$ (Belle II) [40]	$\sim 10^{-9}$
$\mathrm{BR}(\tau \to 3\mu)$	2.1×10^{-8} (Belle) [37]	$\sim$ few $\times 10^{-10}$ (Belle II) [40]	$\sim$ few $\times 10^{-10}$
$\frac{\mathrm{BR}(\tau\to\mu\nu\bar{\nu})}{\mathrm{BR}(\tau\to e\nu\bar{\nu})}$	3.9×10^{-3} (BaBar) [23]	$\sim 10^{-3}$ (Belle II) [40]	$\sim 10^{-4}$
$\mathrm{BR}(Z \to \mu e)$	7.5×10^{-7} (ATLAS) [3]	$\sim 10^{-8}$ (ATLAS/CMS)	$\sim 10^{-9} - 10^{-11}$
$\mathrm{BR}(Z \to \tau e)$	9.8×10^{-6} (LEP) [17]	$\sim 10^{-6}$ (ATLAS/CMS)	$\sim 10^{-8} - 10^{-11}$
$\mathrm{BR}(Z \to \tau\mu)$	1.2×10^{-5} (LEP) [13]	$\sim 10^{-6}$ (ATLAS/CMS)	$\sim 10^{-8} - 10^{-10}$

Material from CepC CDR

GW probe of BSM

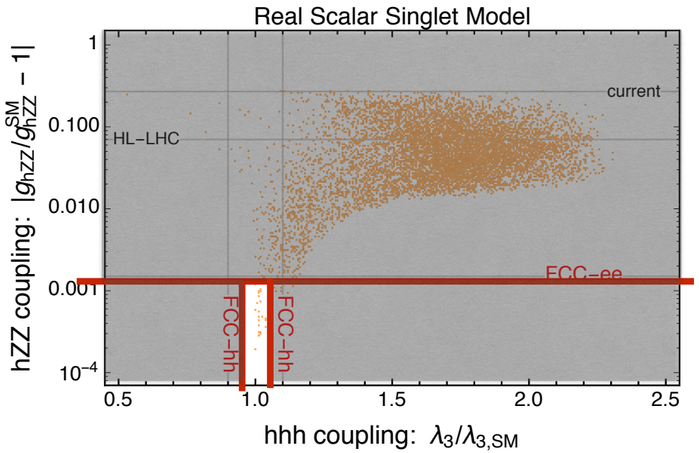
Which GW?

cosmological origin

- inflation/initial quantum fluctuations
- cosmological phase transition
- topological defects

unique information about early universe

Combined constraints from precision Higgs measurements at FCC-ee and FCC-hh

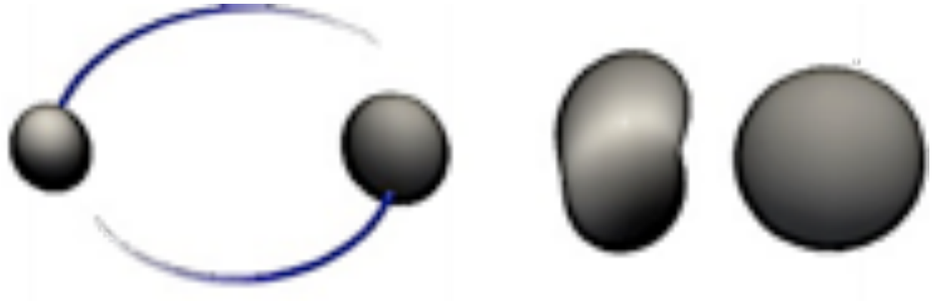


Parameter space scan for a singlet model extension of the Standard Model. The points indicate a first order phase transition.

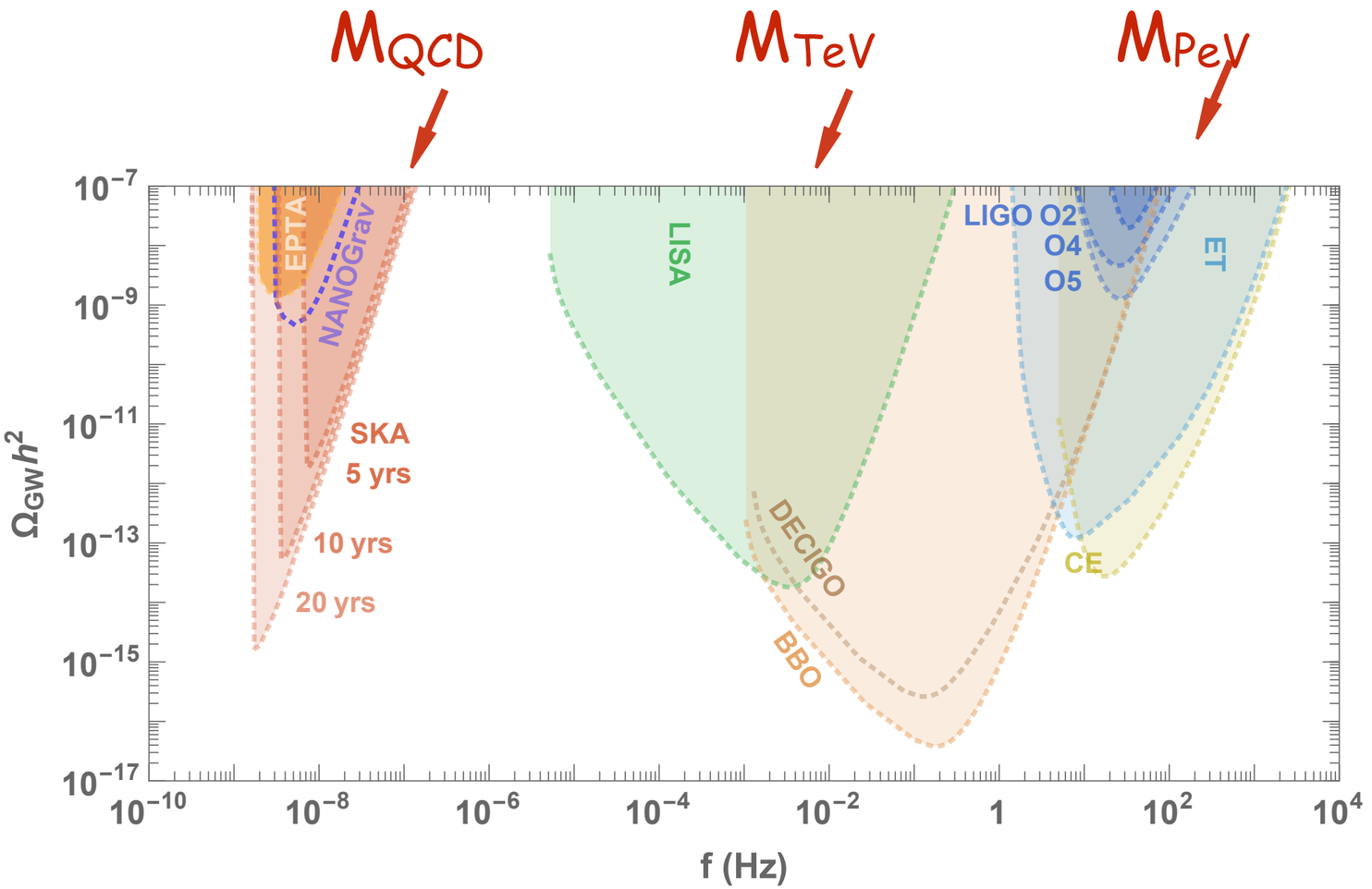
astrophysics origin

- BH/NS mergers
-

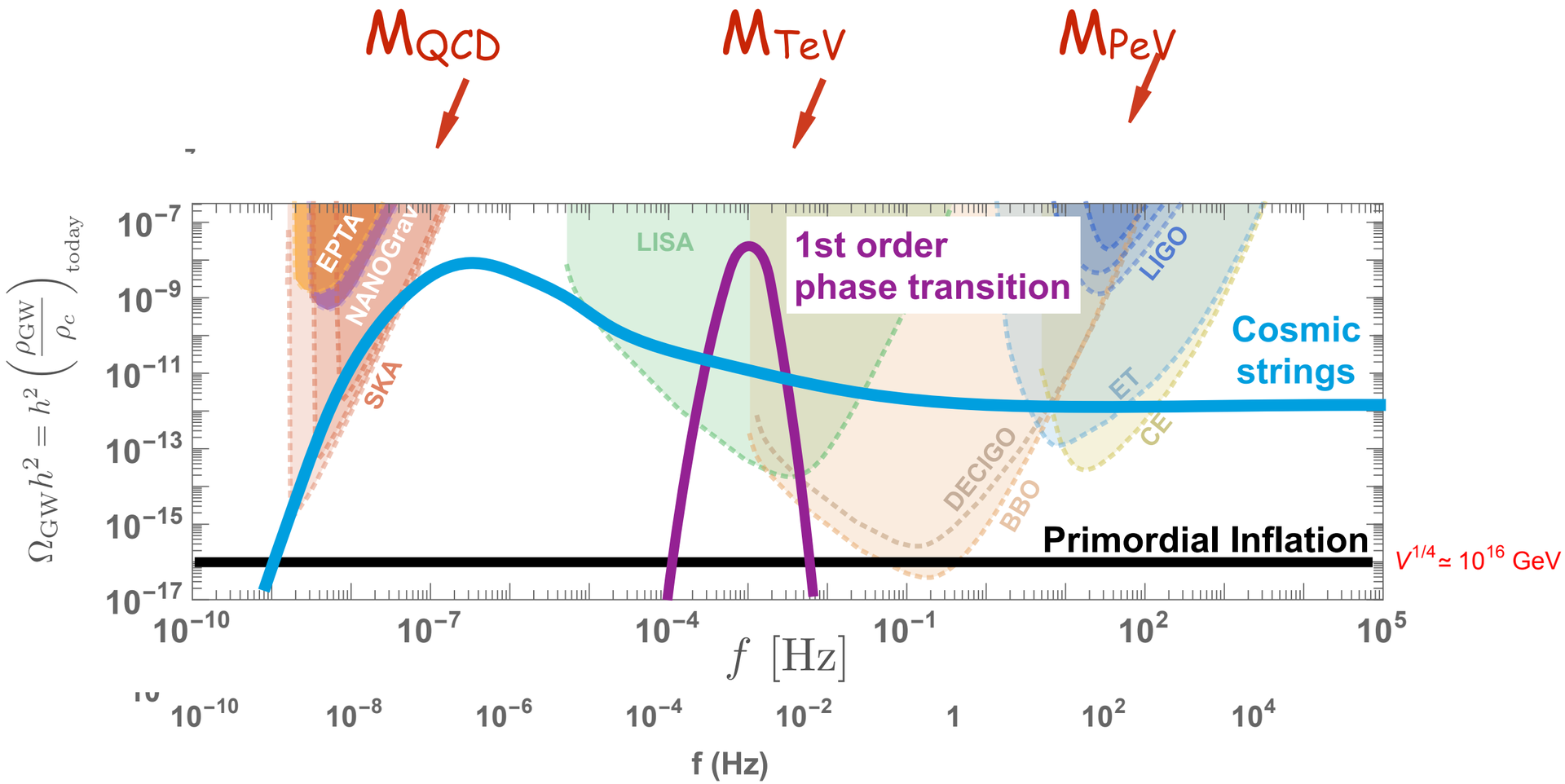
unique information strong gravity regime
tests GR



Cosmological GW and Early Universe

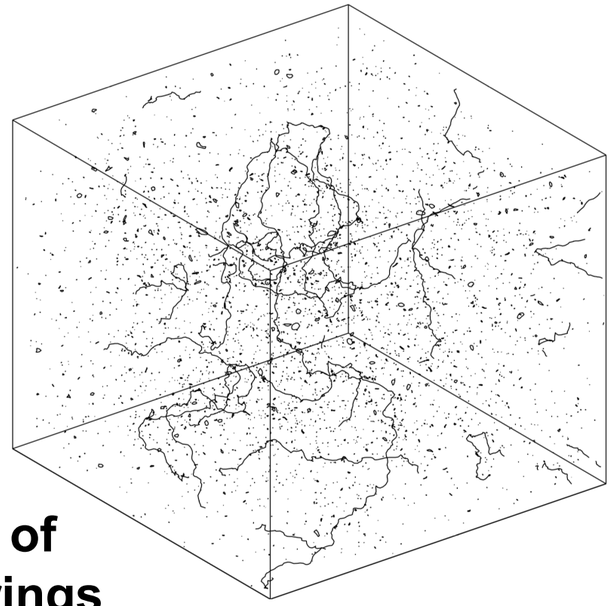


Cosmological GW and Early Universe



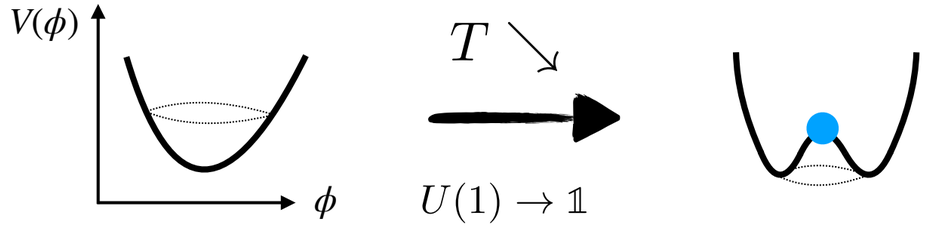
GW from cosmic strings

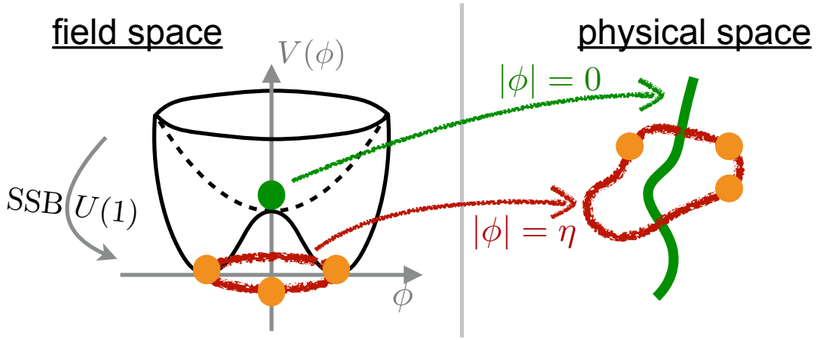
Topological defects generated during a **spontaneous symmetry-breaking phase transition with** $\pi_1(G/H) \neq 1$ [Kibble1976]



Network of cosmic strings

[Allen & Shellard, 1990]





string network acts as a long-lasting GW source
probe the entire cosmic history

…non-standard cosmology, modified equation of state of the universe with respect to radiation domination (early matter or kination eras, secondary short intermediate inflation era…

Astrophysical GW: Tests of GR

∃ inconsistencies between gravity and QM:
e.g. BH information paradox & existence of naked singularities in classical GR

- Recent progress: entanglement entropy and geometry, soft theorems, asymptotic symmetries
- GW propagation and graviton mass (alternative to Dark Energy?)
- GW from BH: imprints in the gravitational waveform → probe of modified GR

  - hairy BH in f(R) gravity/Chern-Simons gravity

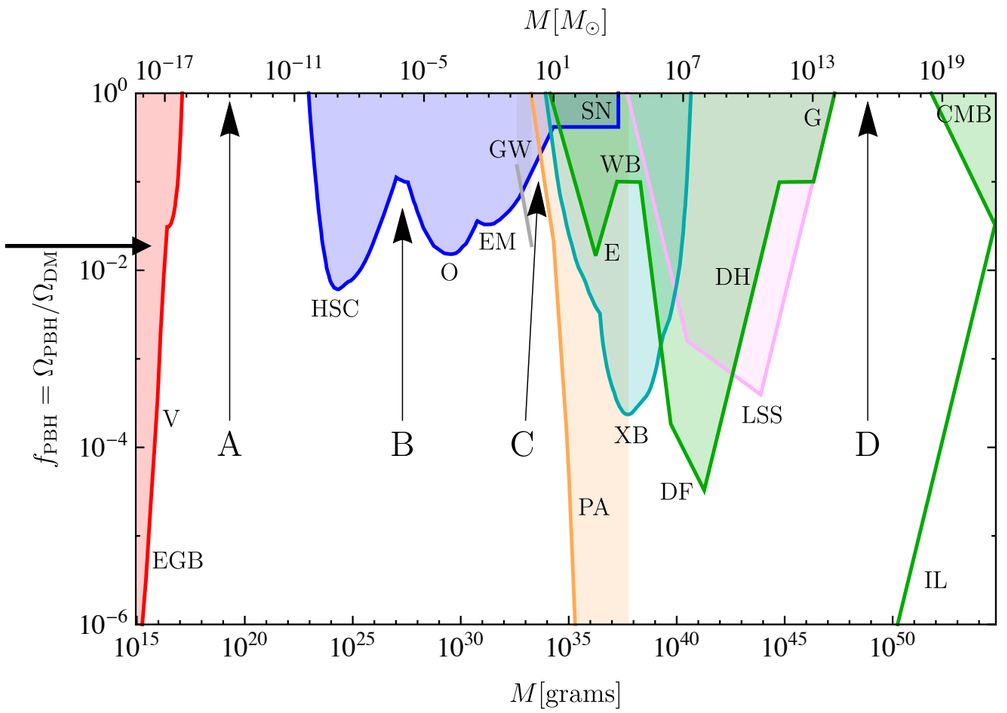
  - quantum modifications on horizon scales for macroscopic BHs: features of the near-horizon region, tidal deformability, and energy dissipation at the horizon characteristic imprints in the gravitational waveforms

A precise monitoring of the phase of inspiralling binaries can constrain
- equation of states of compact objects (Neutron stars…)
- new additional propagating fields
- local environment (local dark matter density → dynamical friction)

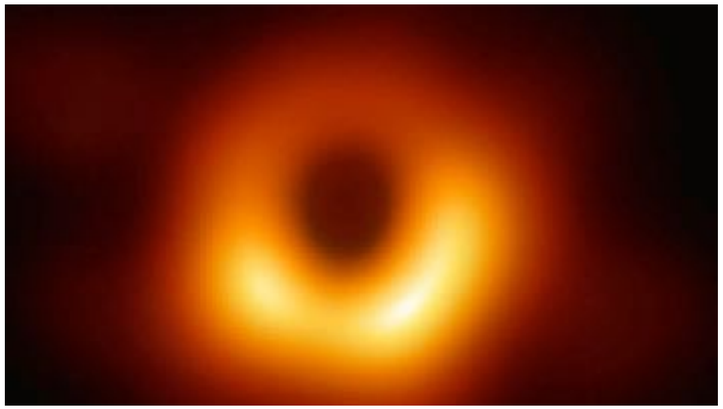
BH and DM

- Gravitational waveforms from BH mergers are sensitive to local environment → use BH to measure local DM density
- Ultra-light particles (axions…) → superradiance (spin distributions of BHs), BH surrounded by “boson” clouds
- primordial BHs as DM

Hawking radiation

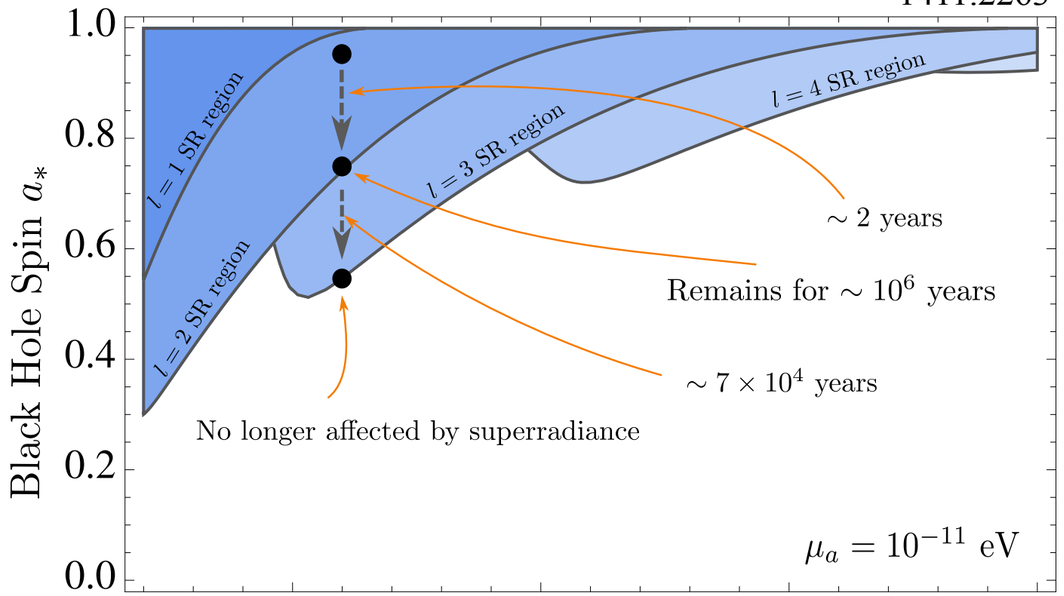


Superradiance

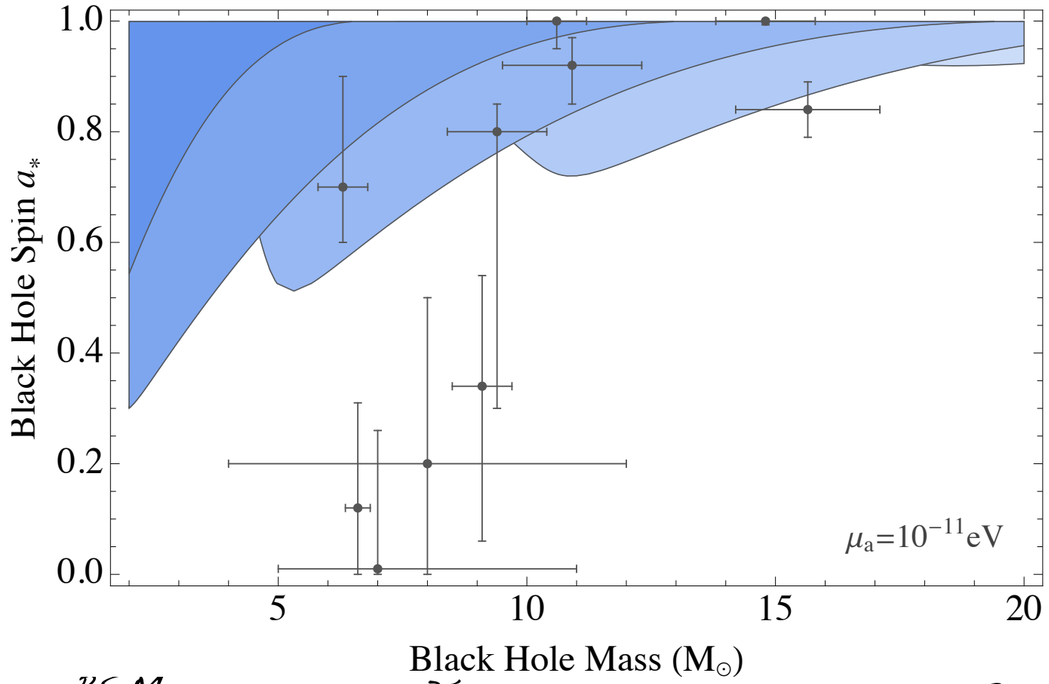


Event Horizon Telescope, Astrophys.J. 875 (2019) no.1, L6

1411.2263



BH mass vs. spin



BH spin distribution can probe the existence of very light scalars

Conclusions

Conclusions

We don't know what BSM is! So we should keep searching:

" Looking and not finding is different than not looking!"

There is a vigorous experimental program on a vast range of energy scales.
It will surely guide us to a new understanding of nature.

Guaranteed deliverables from a **Higgs factory**:

* Legacy measurements that will go into textbook
* Reach in BSM discoveries
* Refinements in our understanding of Nature (EW phase transition, naturalness…)

But there is also a complementary **diversity** program searching for the unknown

- Beam Dump Facility (SHiP, TauFV)
- eSPS (LDMX)
- CPEDM (Julich), ESSvSB (ESS), PERLE(Saclay), LFV(PSI), ...
- COMPASS/AMBER as QCD facility, MUonE, KLEVER, nuSTORM, MATHUSLA, FASER, CODEX-b, milliQan, LHCSpin, REDTOP, DIRAC, ...