Physics landscape
incl. current anomalies

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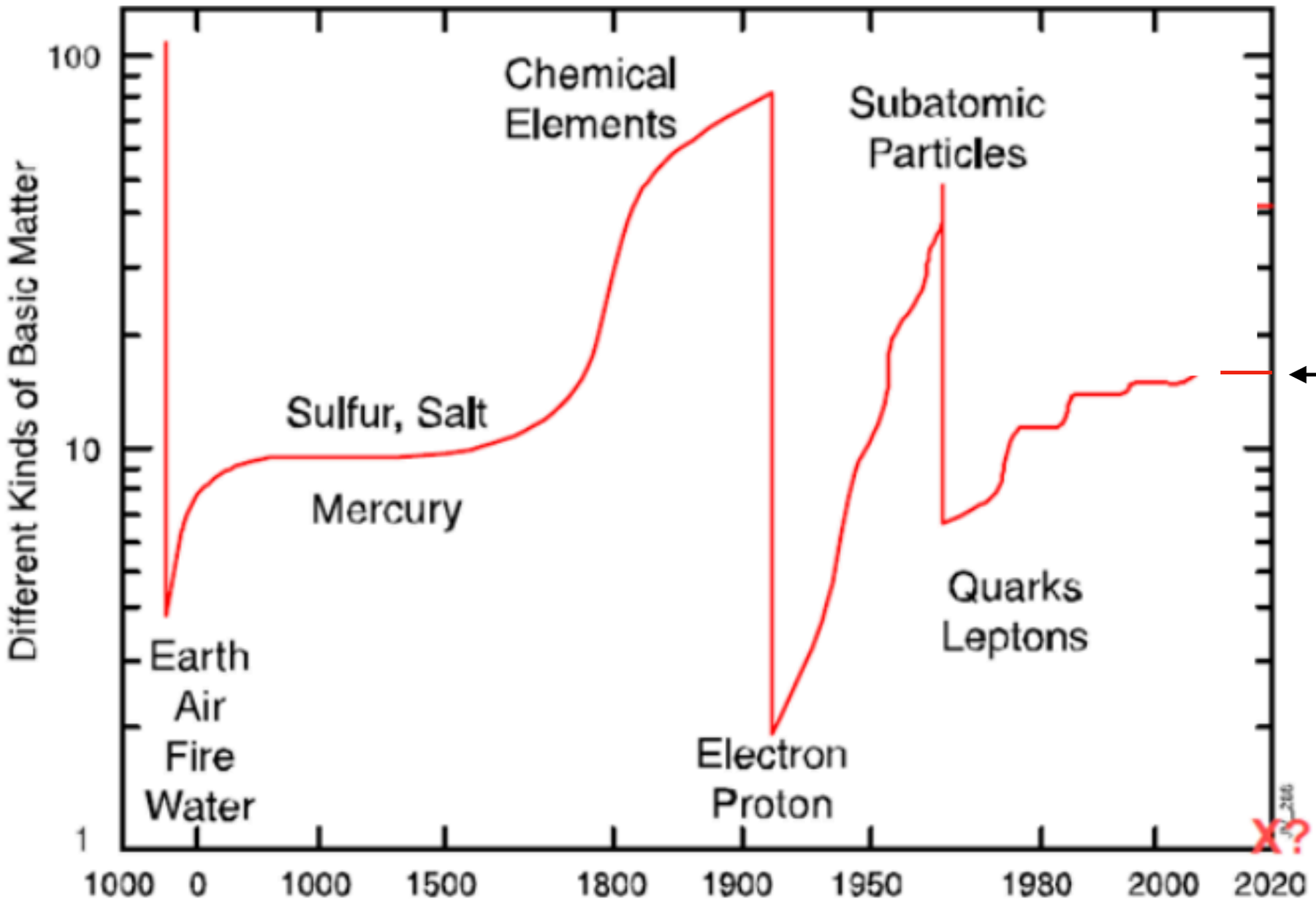
ECR forum on future colliders
Birmingham, 25th April 2022

Science and
Technology
Facilities Council

Fundamental matter constituents and interactions



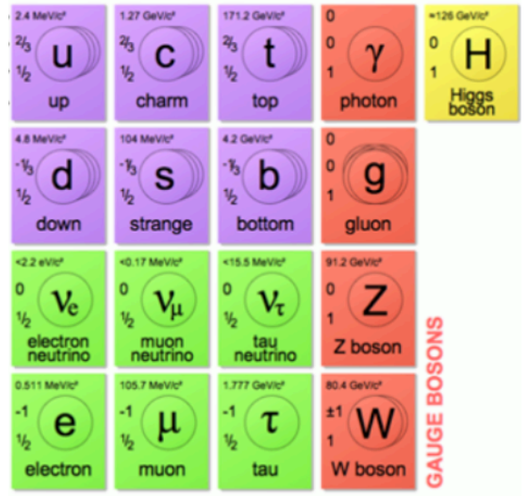
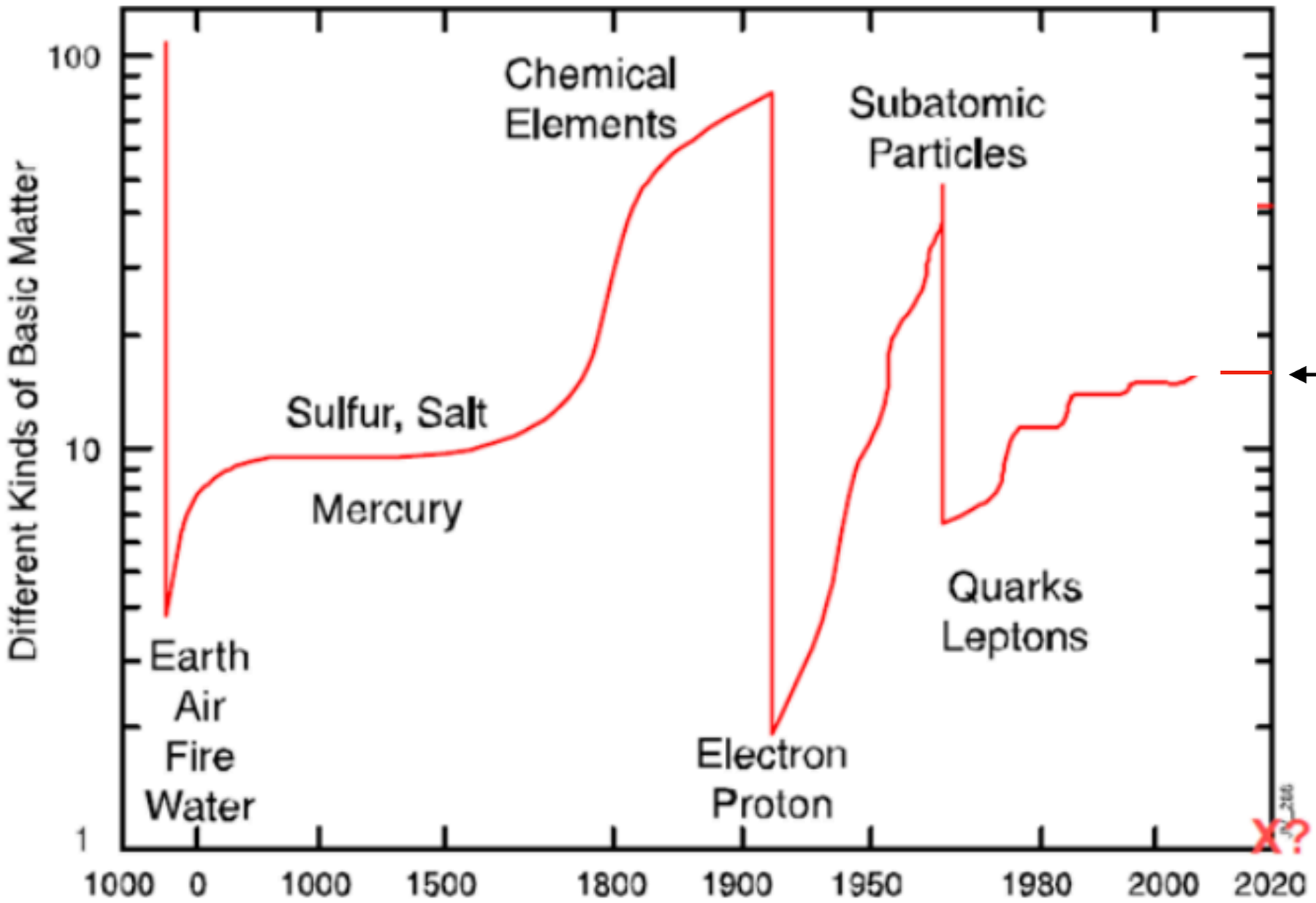


Figure from P. Pralavorio, https://arxiv.org/abs/1311.1769

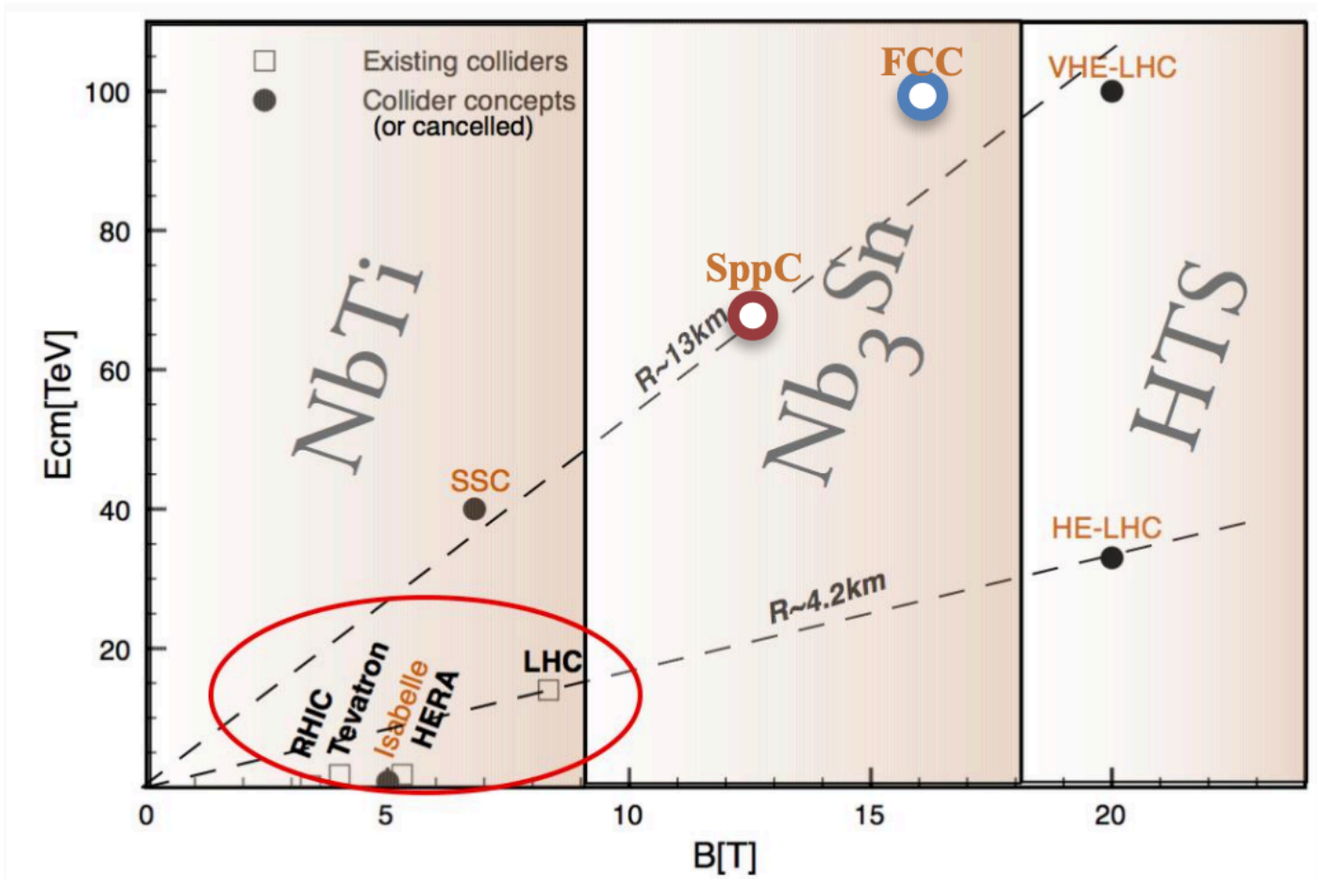
Fundamental matter constituents and interactions

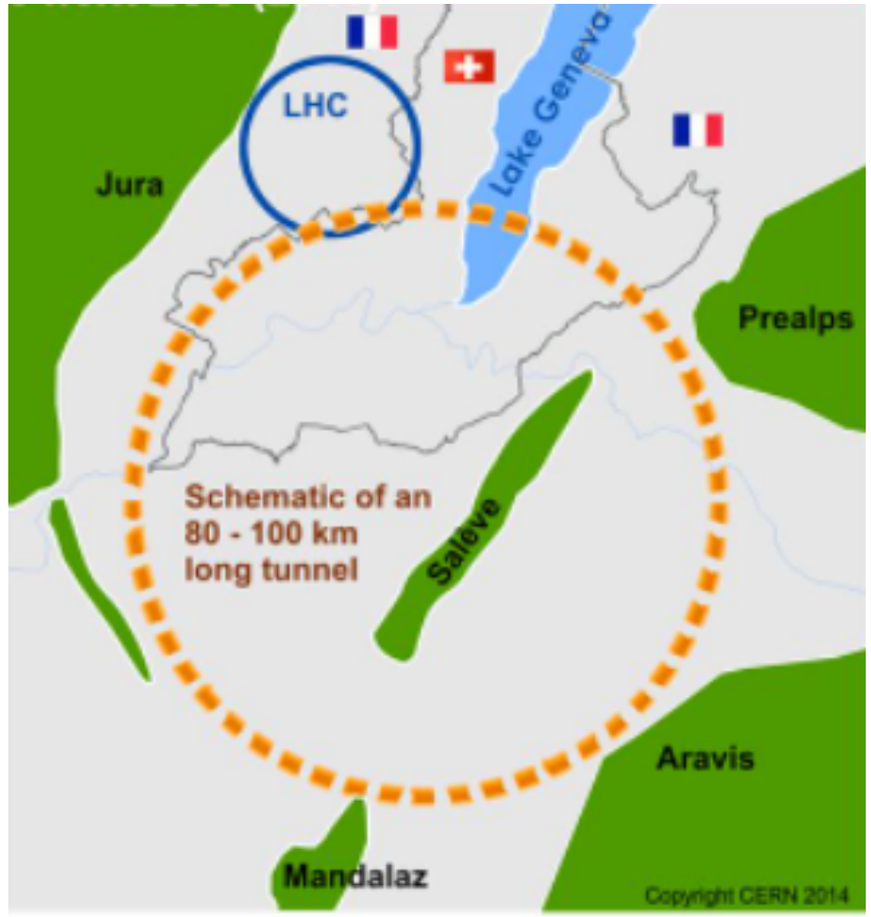


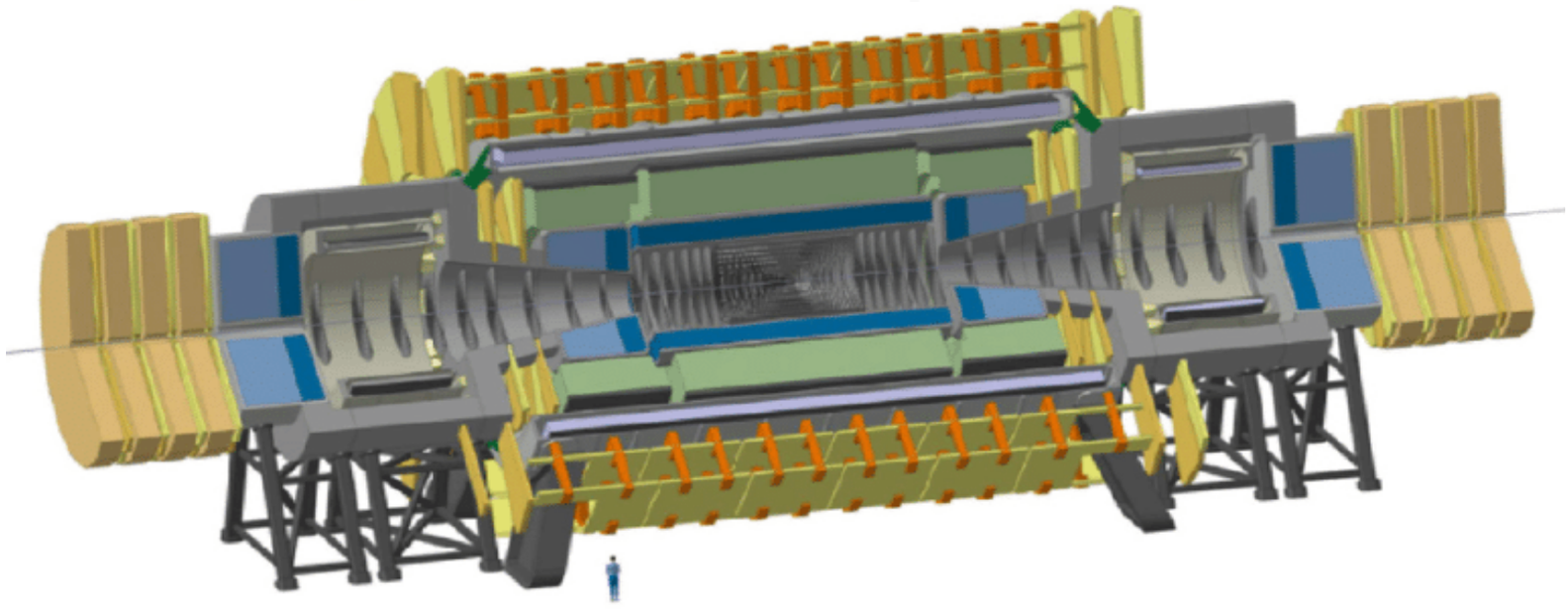
Surely we're not the generation that gives up on this quest, because the next collider facility is challenging?

Figure from P. Pralavorio, 1311.1769

FCC-hh: the challenges are clear



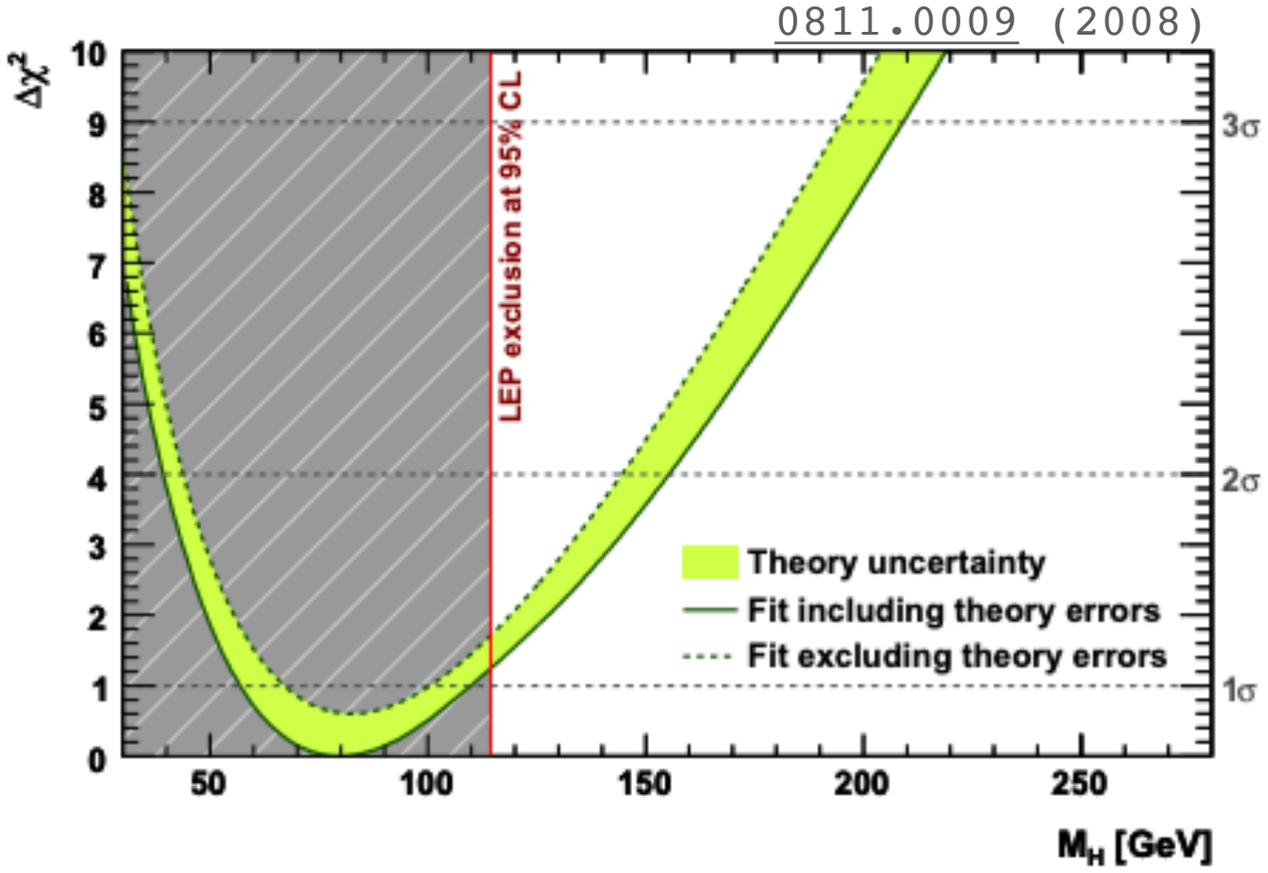




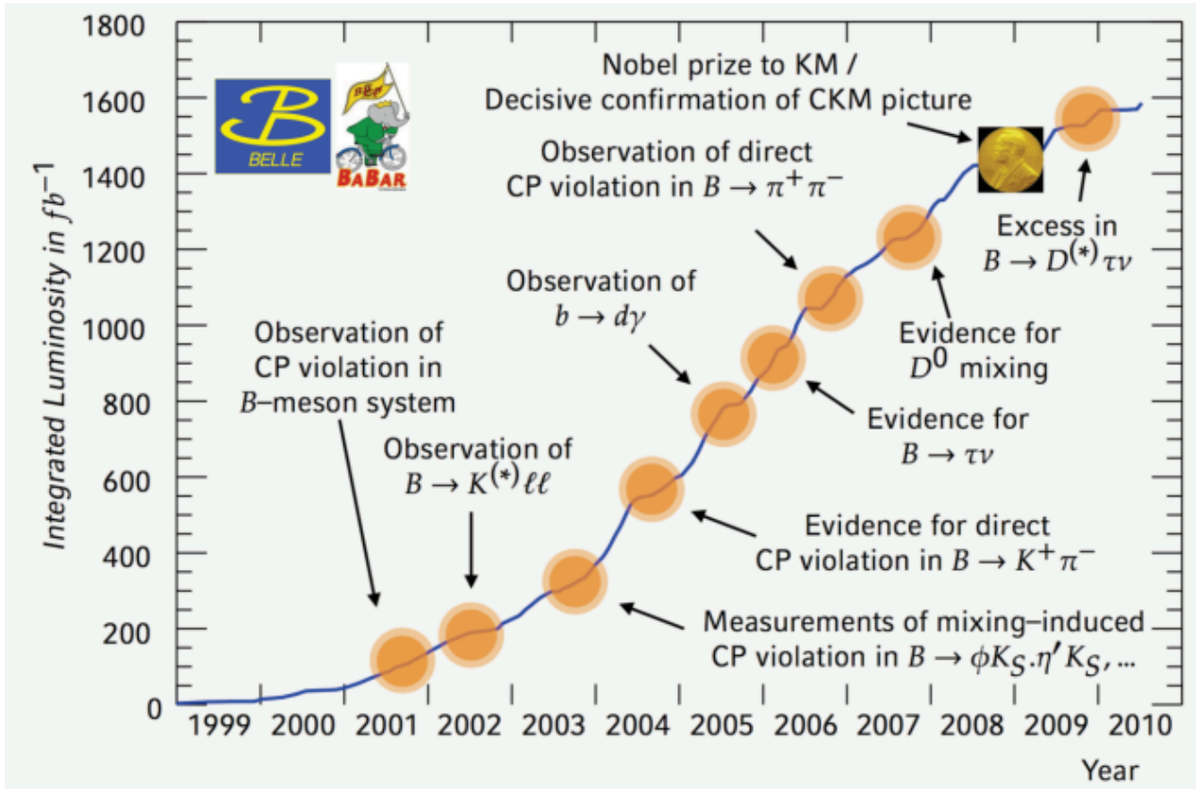
I think we agree that this is the ultimate discovery machine on the horizon.

State of field before LHC

Tevatron measurements of m_{top} and m_W had firmly established the “no-lose” scenario for the LHC’s test of EWSB.

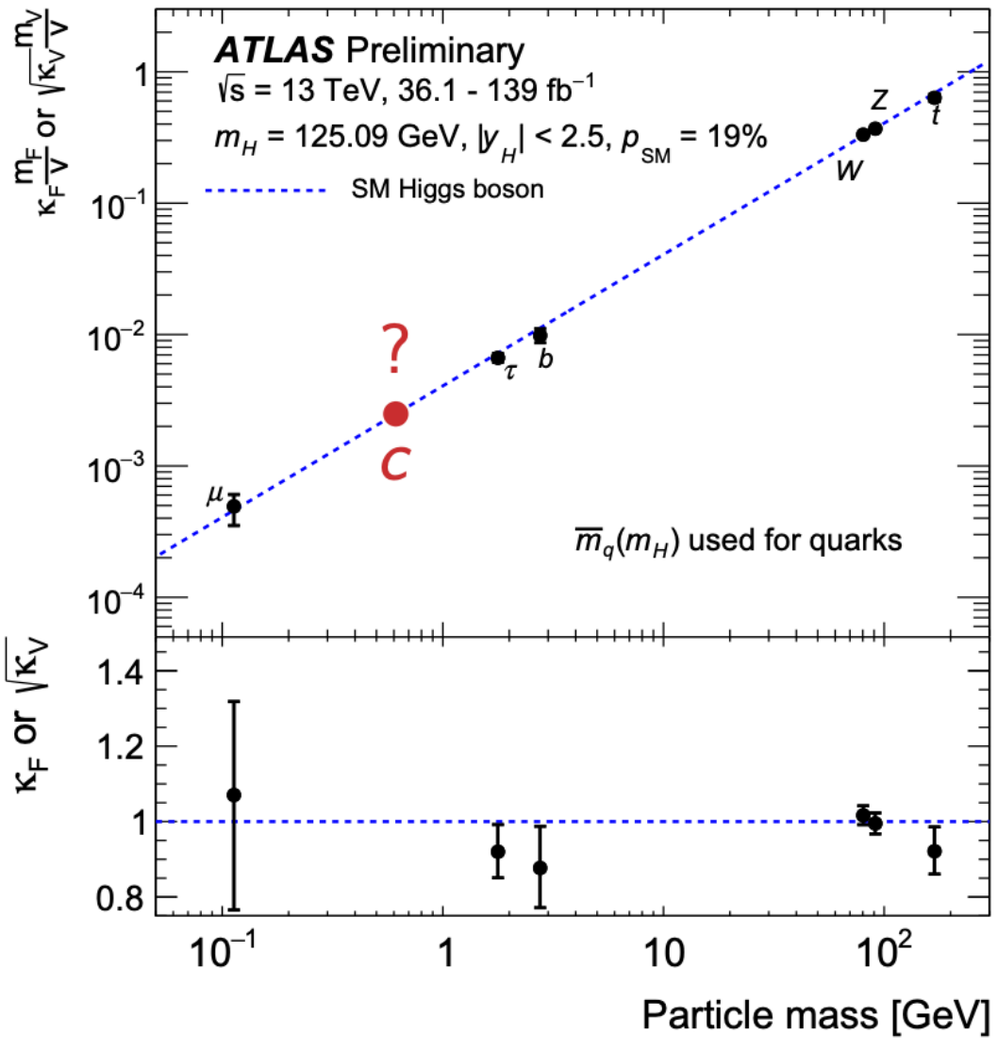


B-factories confirm the CKM picture to 1st order. Birth of era of precision B physics



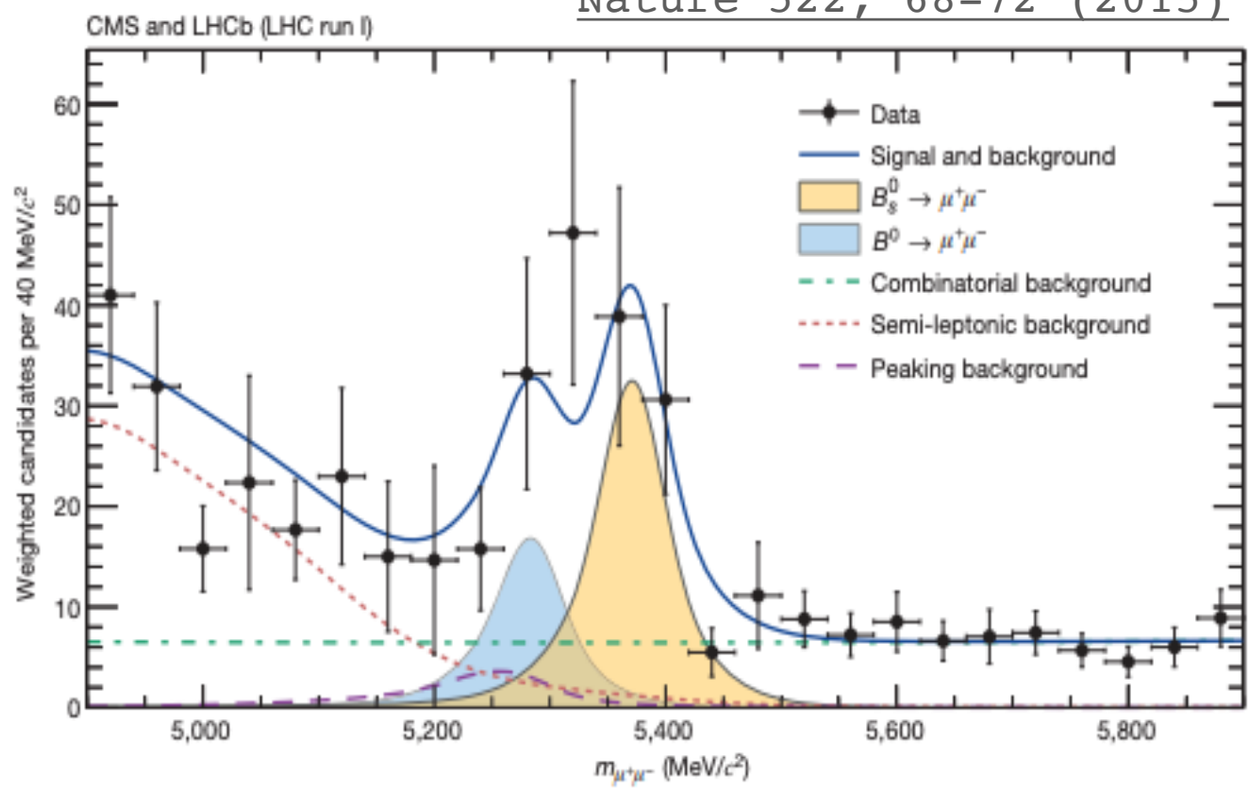
And so much more, e.g: a rapidly developing field of neutrino oscillation physics, discoveries of rarer and rarer SM processes/decays, the birth of the g-2 anomaly, …

And today



Higgs discovery complemented by a huge breadth of physics, especially in quark-flavour: E.g. $B_s \rightarrow \mu\mu$ discovery.

Nature 522, 68–72 (2015)



All of the SM's particles directly observed and no directly-produced BSM signals thus far.

SM is consistent with *almost* all laboratory tests: good *approximation* to at least the TeV scale…

European Strategy for Particle Physics

CERN Council updated the European Strategy for Particle Physics in June 2020

Scientific recommendations:

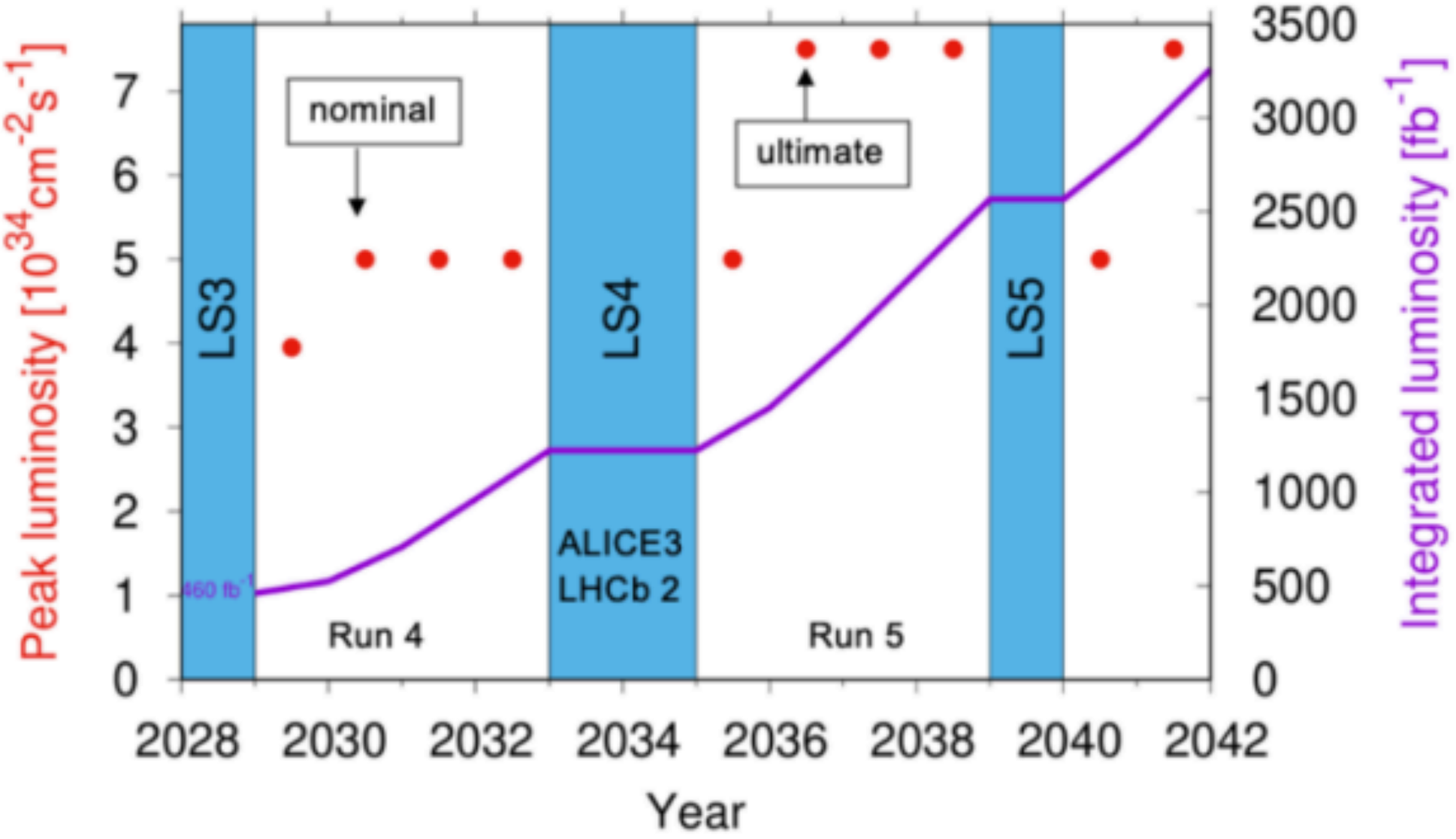
- full exploitation of the LHC and HL-LHC
- highest-priority next collider: e+e- Higgs factory
- increased R&D on accelerator technologies
- investigation of the technical and financial feasibility of a future ≥ 100 TeV hadron collider
- long-baseline neutrino projects in US and Japan
- high-impact scientific diversity programme complementary to high-energy colliders
- R&D on detector and computing
- theory

Other high priority items:

- Exploit synergies with neighboring field, in particular nuclear and astroparticle physics
- Mitigate environmental impact of particle physics
- Invest in next generation of researchers
- Support knowledge and technology transfer
- Public engagement, education and communication

The Snowmass process in the US should also conclude soon.

The HL-LHC



$\int L_{HL\text{-}LHC} / \int L_{today}$ ~20-30+ (ATLAS,CMS,LHCb) will permit a significant step in precision of e.g. Higgs couplings and flavour observables, but many key scientific tests remain out of reach…

Looking forward

Snowmass 2021 Energy Frontier Collider Study Scenarios

Collider	Type	$\sqrt{s}$	P [%] e^-/e^+	L_{int} ab^{-1}
FCC-hh	pp	100 TeV		30
LHeC	ep	1.3 TeV		1
FCC-eh	ep	3.5 TeV		2
muon-collider (higgs)	$\mu\mu$	125 GeV		0.02
High energy muon-collider	$\mu\mu$	3 TeV		1
		10 TeV		10
		14 TeV		20
		30 TeV		90

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Collider	Type	$\sqrt{s}$	P [%] e^-/e^+	L_{int} ab^{-1}
HL-LHC	pp	14 TeV		6
ILC	ee	250 GeV	$\pm 80/\pm 30$	2
		350 GeV	$\pm 80/\pm 30$	0.2
		500 GeV	$\pm 80/\pm 30$	4
		1 TeV	$\pm 80/\pm 20$	8
CLIC	ee	380 GeV	$\pm 80/0$	1
		1.5 TeV	$\pm 80/0$	2.5
		3.0 TeV	$\pm 80/0$	5
CEPC	ee	M_Z		16
		$2M_W$		2.6
		240 GeV		5.6
FCC-ee	ee	M_Z		150
		$2M_W$		10
		240 GeV		5
		2 M_{top}		1.5

- An e^+e^- Higgs factory for %-level measurements of couplings and a model independent measurement of Γ_H.

  FCC-ee offers a broad program of intensity frontier physics at the Z, WW threshold and $2m_{top}$

- FCC-hh: ultimate discovery machine and probe the Higgs potential via a ~5% measurement of the Higgs' self-coupling.

  Option with e-h provides precision PDFs and broad program of precision Higgs, top, EW, QCD studies.

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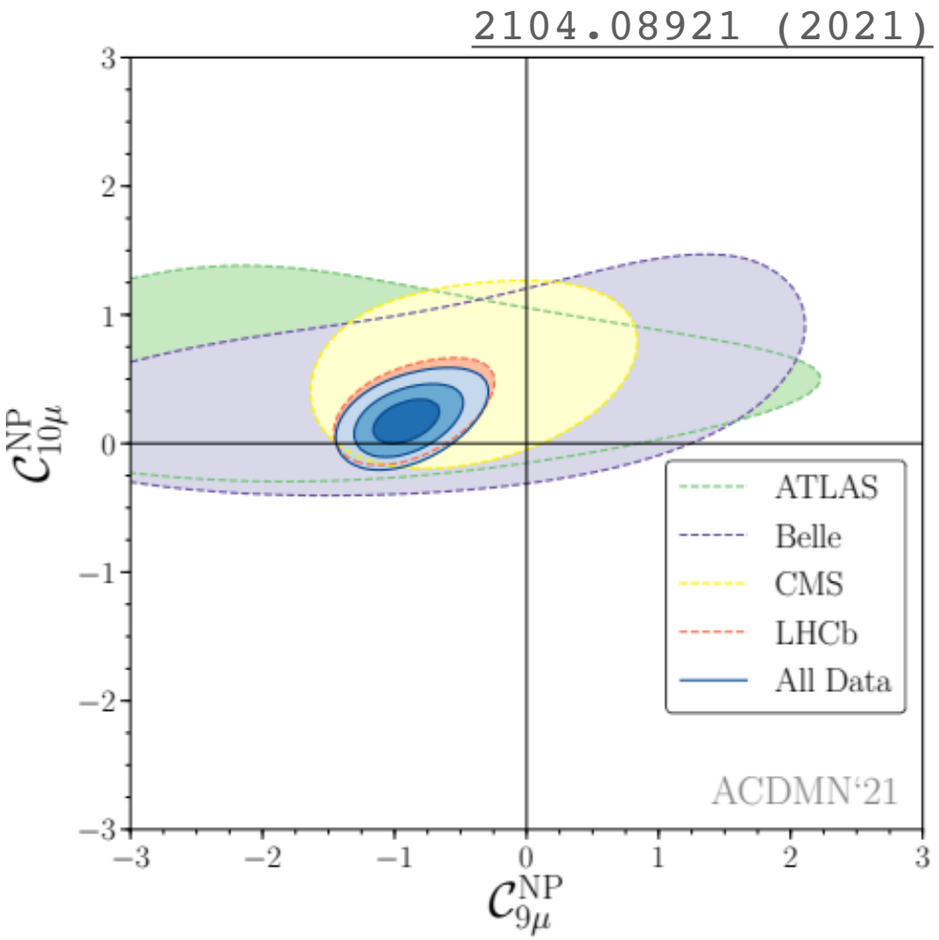
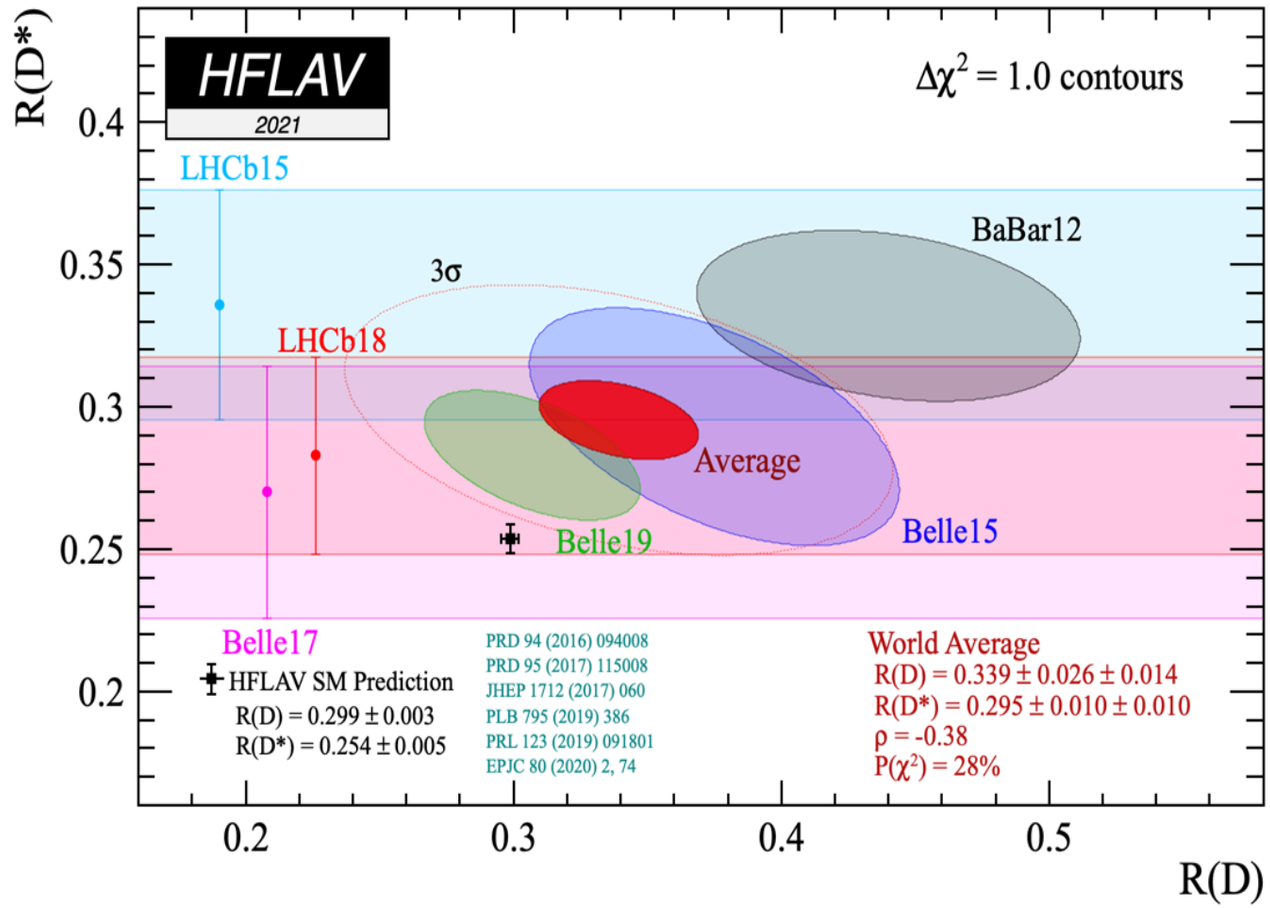
What would *really* strengthen the case is to have a BSM **mass scale.**

Current B anomalies

Neutral current



Charged current

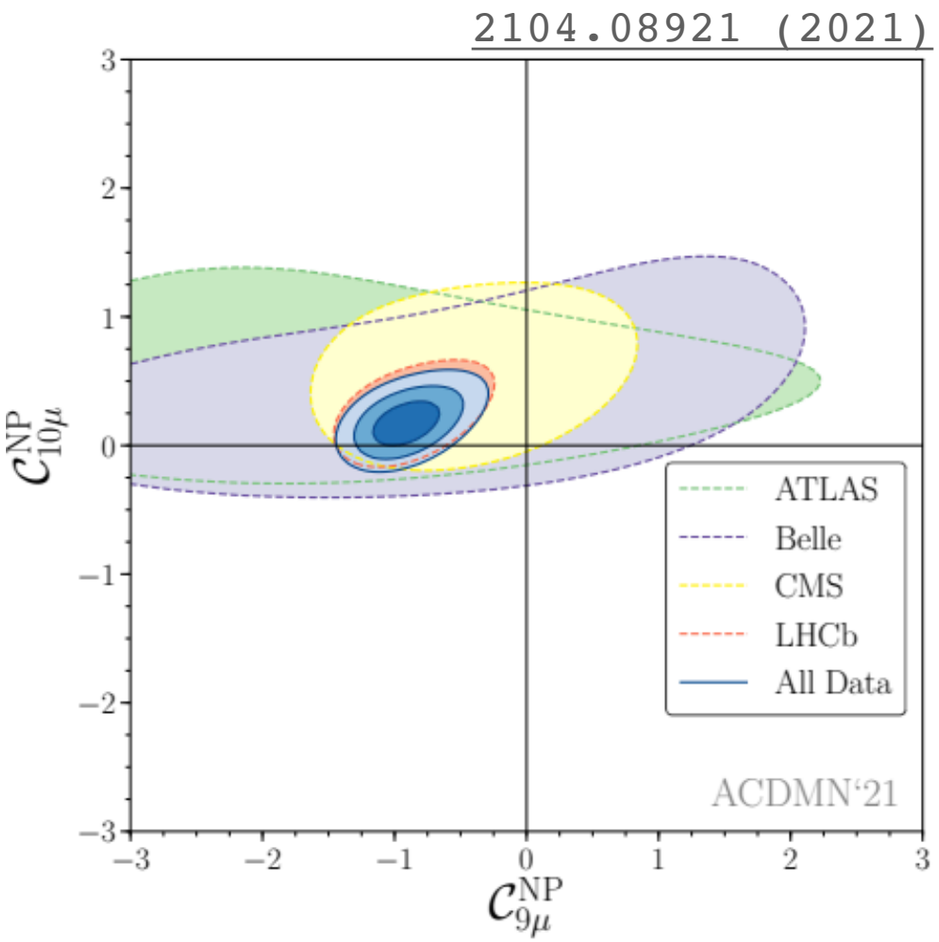


Each set of anomalies has its own caveats but reason to be *cautiously* excited, in anticipation of higher precision measurements.

Can we make a *model-independent* statement about mass scales?

Current B anomalies

Neutral current



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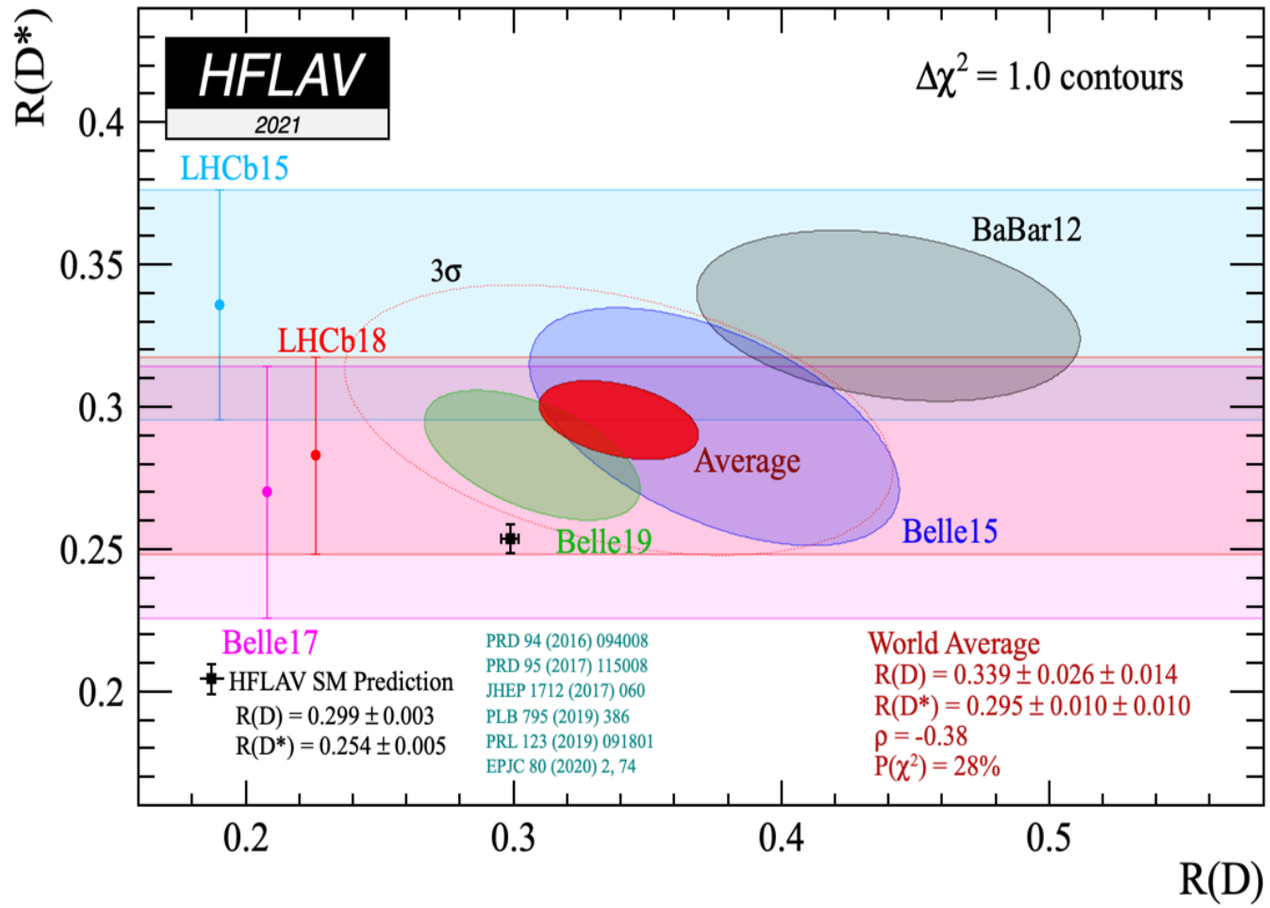


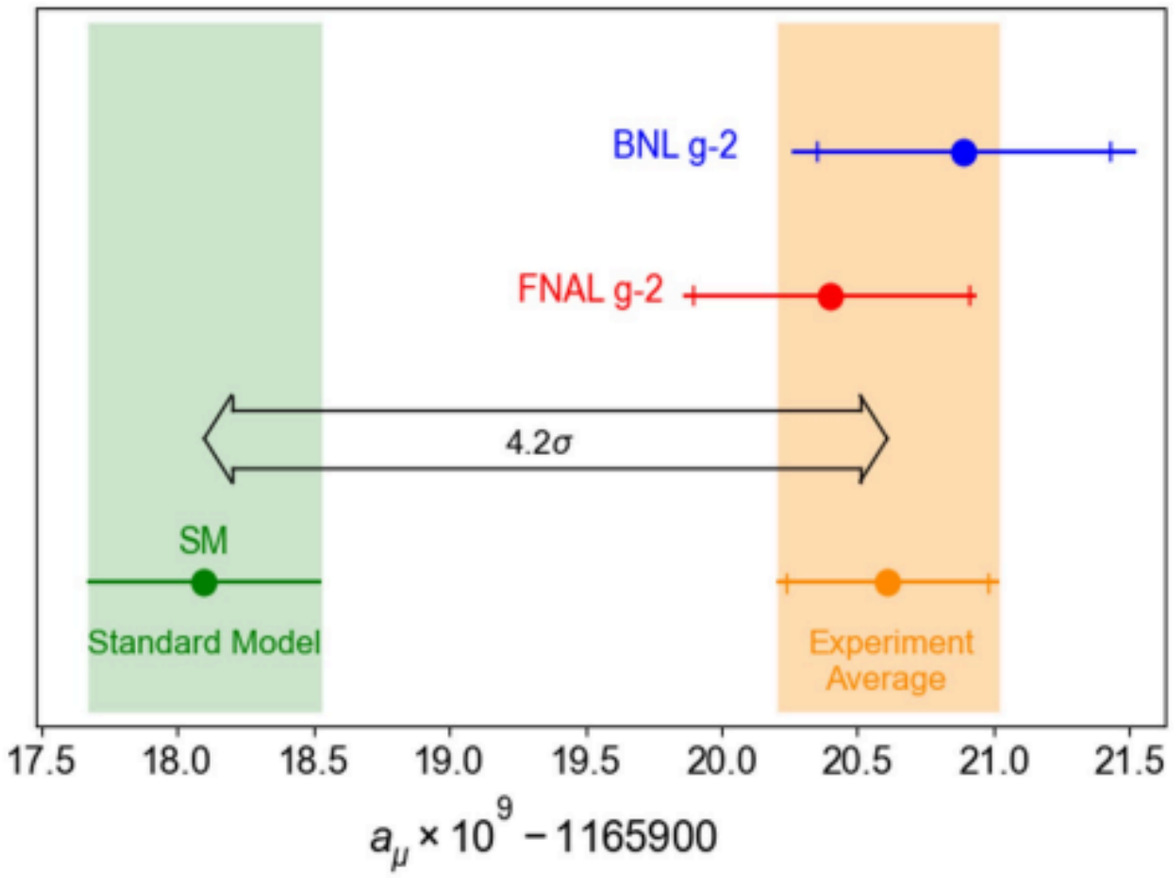
~20% effect in b→sμμ

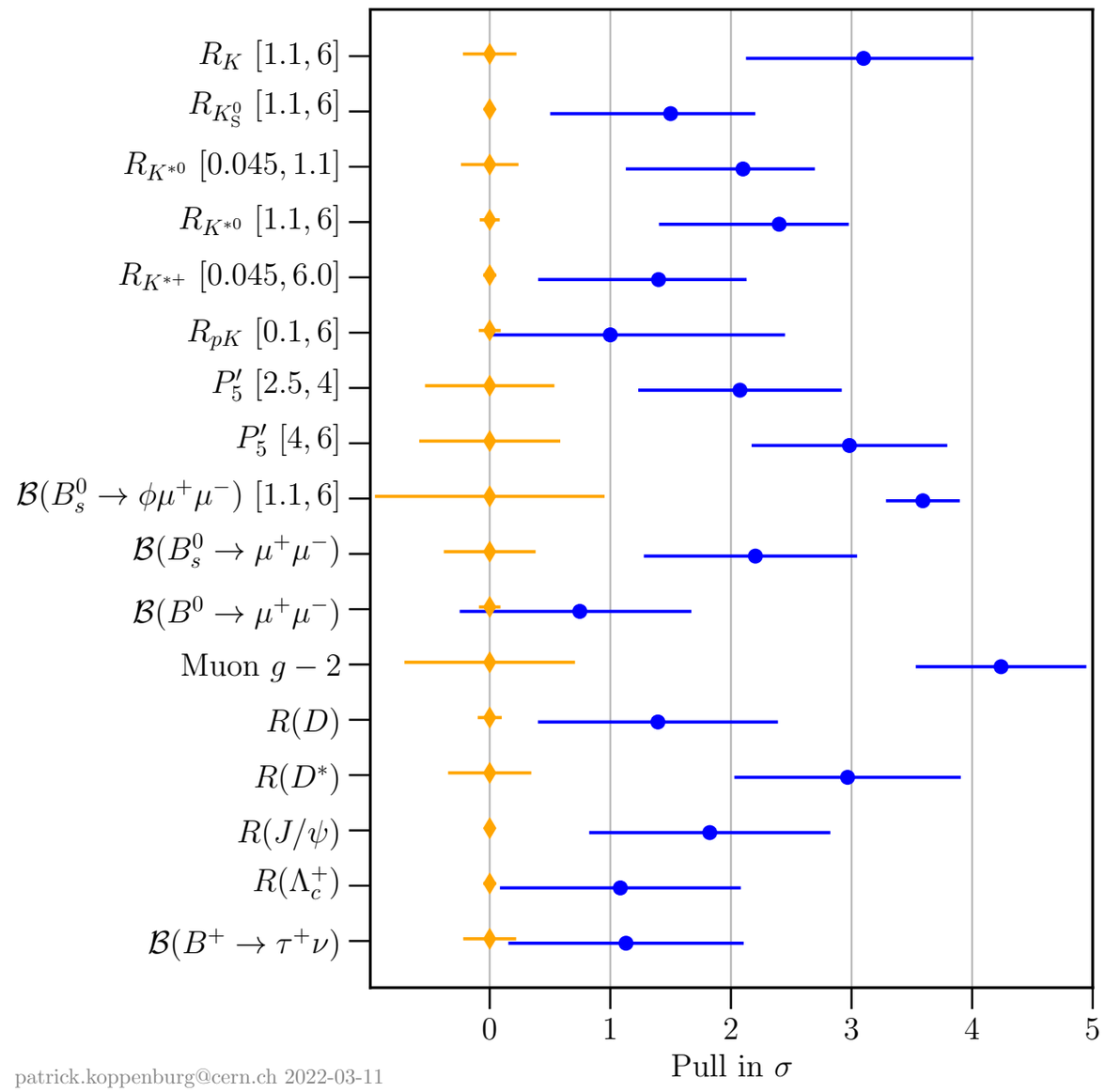
$$\left(\frac{g^2}{\Lambda^2}\right) \sim \left(\frac{1}{30\ \text{TeV}}\right)^2$$

~20% effect in b→cτν

$$\left(\frac{g^2}{\Lambda^2}\right) \sim \left(\frac{1}{1\ \text{TeV}}\right)^2$$

Muon g-2





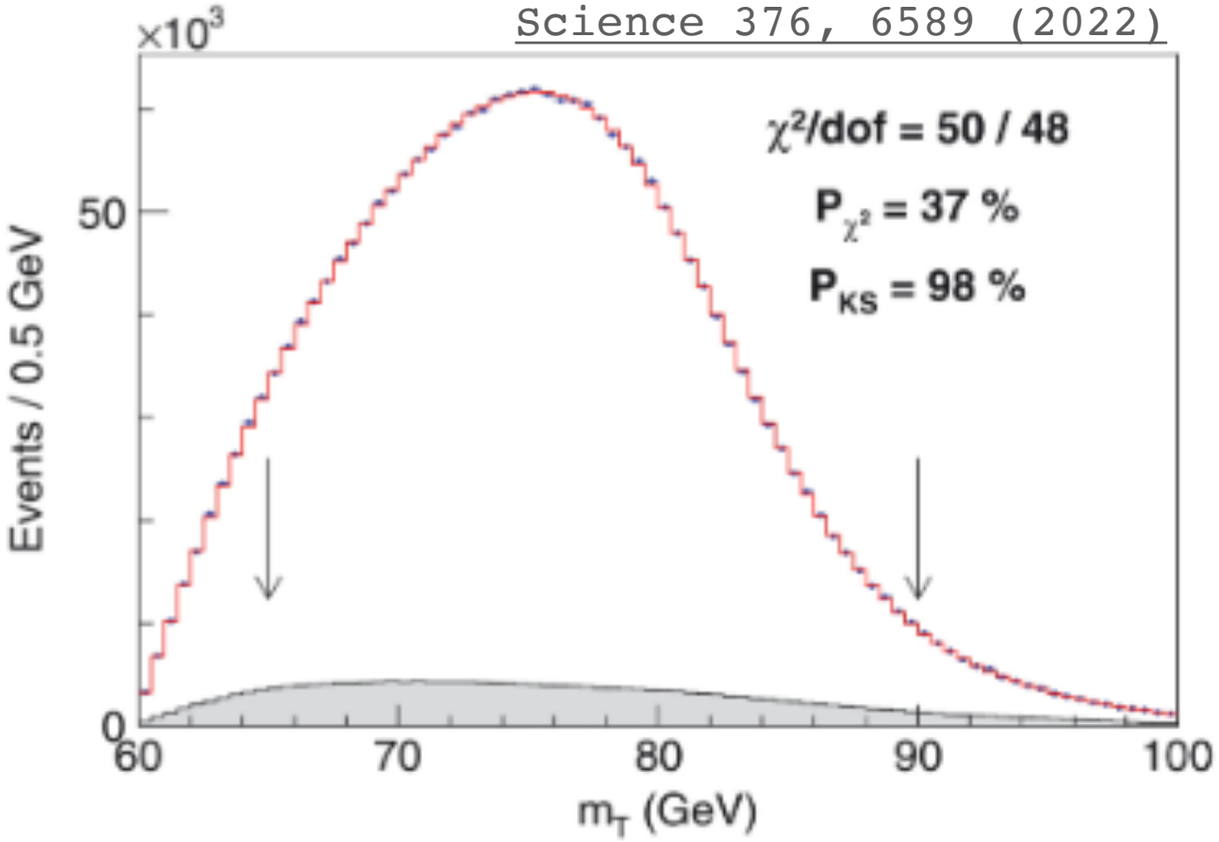
Unitarity bound ~ 1 PeV[1] → model (weakly coupled) required to turn g-2 anomaly into a no-lose theorem.

Were I giving this talk ~3 weeks ago we could stop here.

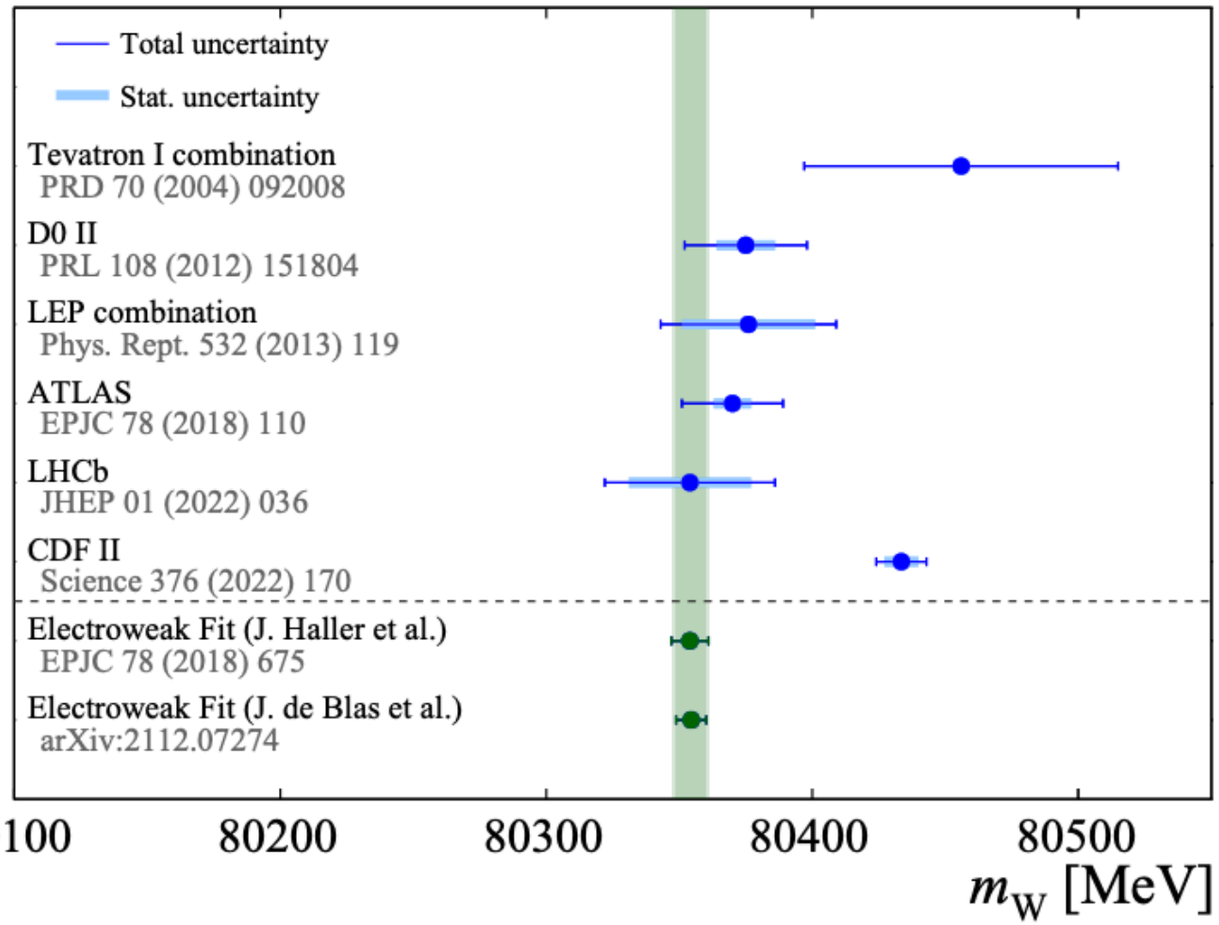
[1] PRD 104, 055035 (2021) 2105.13981

W mass

Science 376, 6589 (2022)



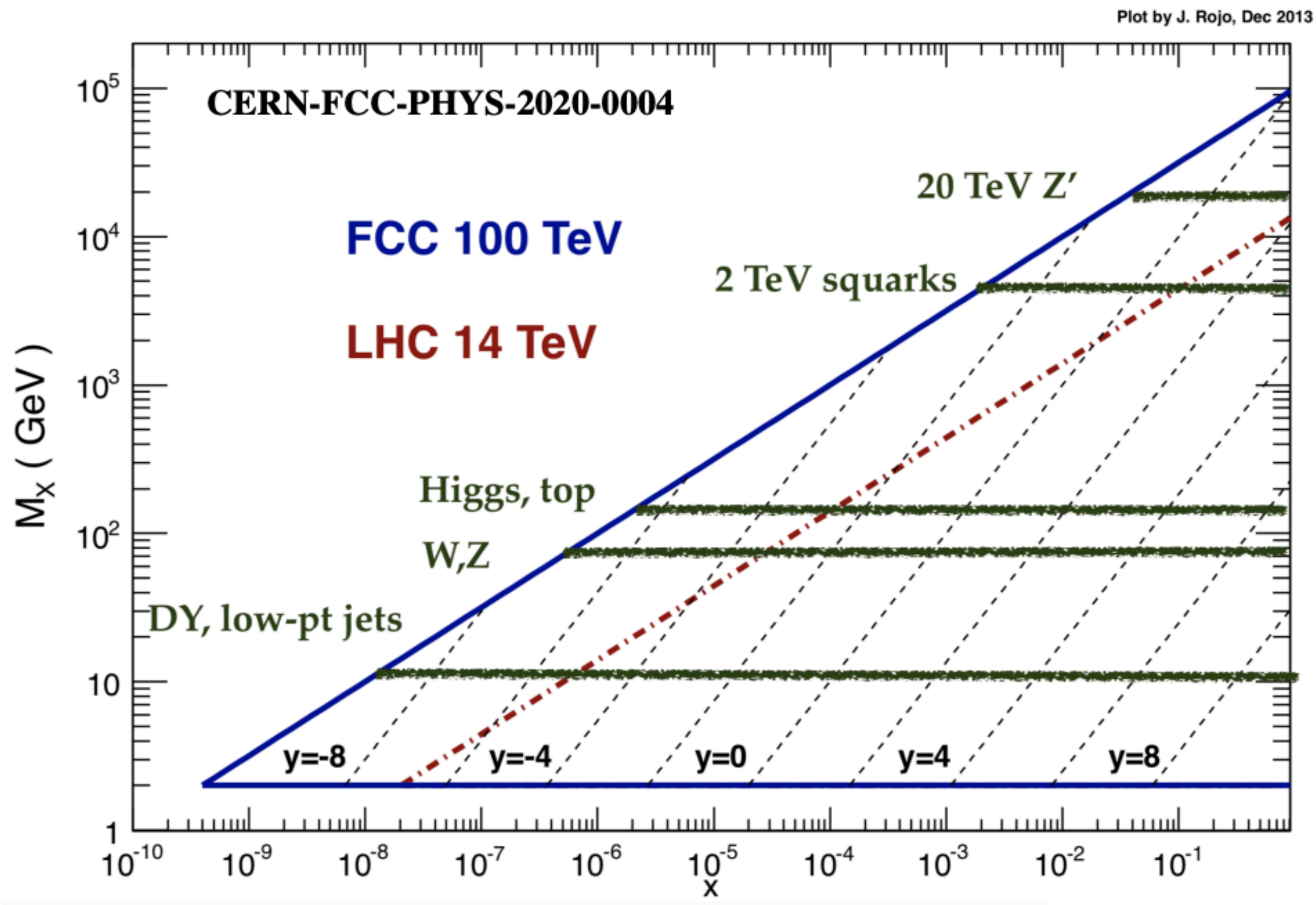
LHCb-FIGURE-2022-003



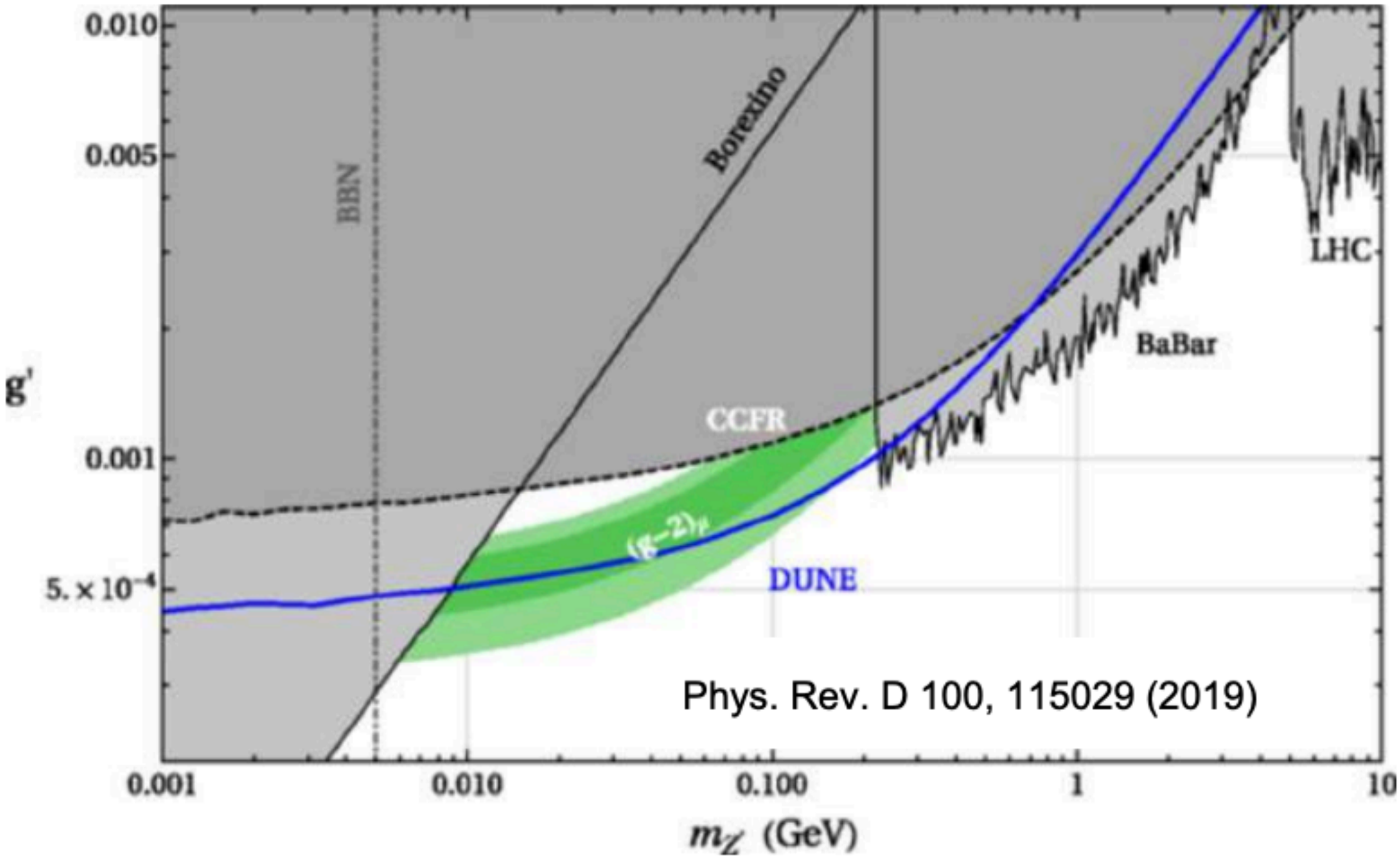
Now *this* was a surprise, but before we take seriously the (7σ) tension with the SM we need to resolve the 4σ tension between the experiments.

Discussion time

Kinematics of a 100 TeV FCC



E.g., light Z′ explanation of g-2 anomaly



Phys. Rev. D 100, 115029 (2019)