Expectations for Discoveries from the pre-HL-LHC

ShiP Colloquium

Nov 9th 2017

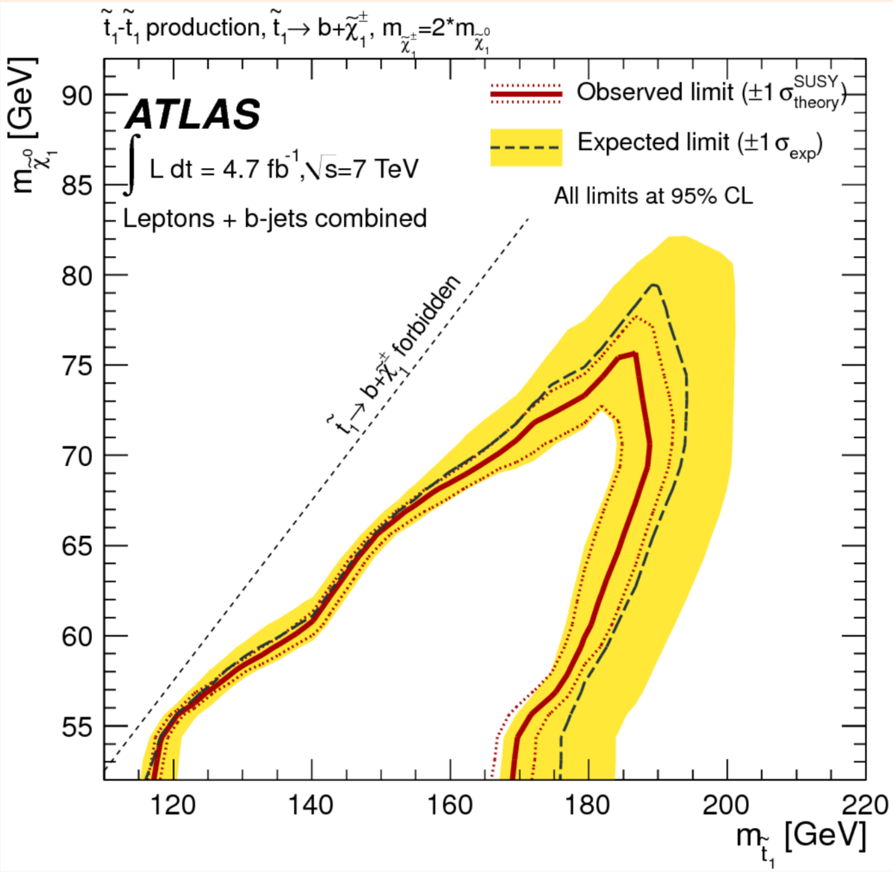
Matthew McCullough

CERN

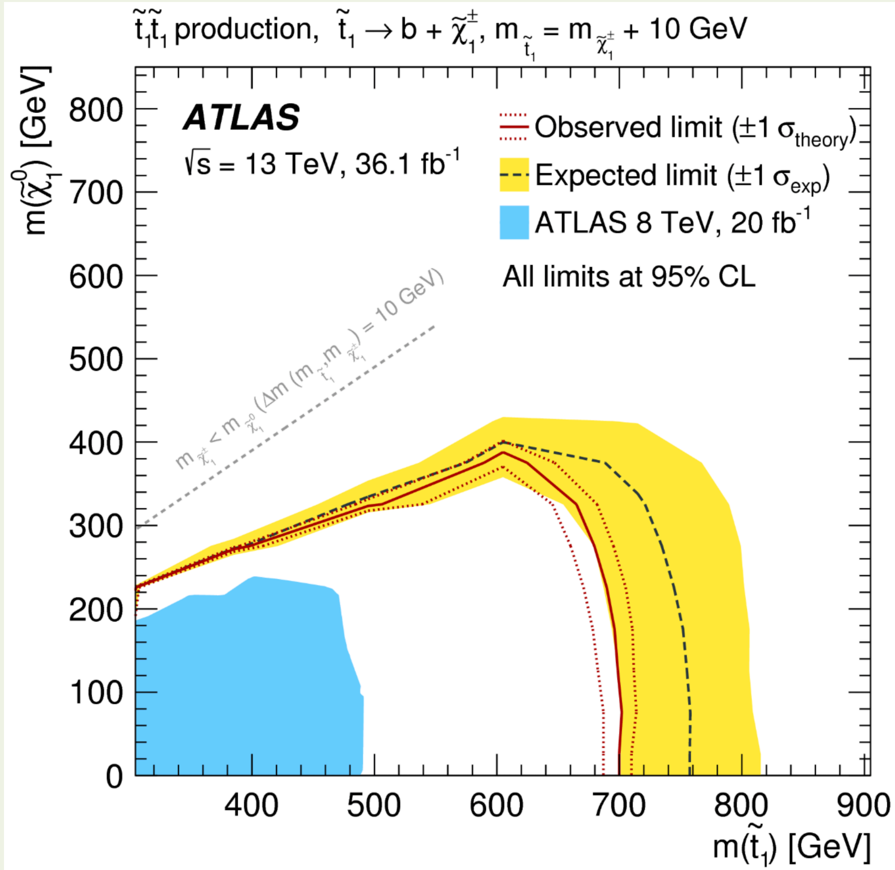
What a difference a decade makes.

LHC Research began March 2010. Just over 7 years ago. Let's compare to 2012...

Then:



Now:



What a difference a decade makes.

LHC Research began March 2010. Just over 7 years ago. Let's compare to 2012...

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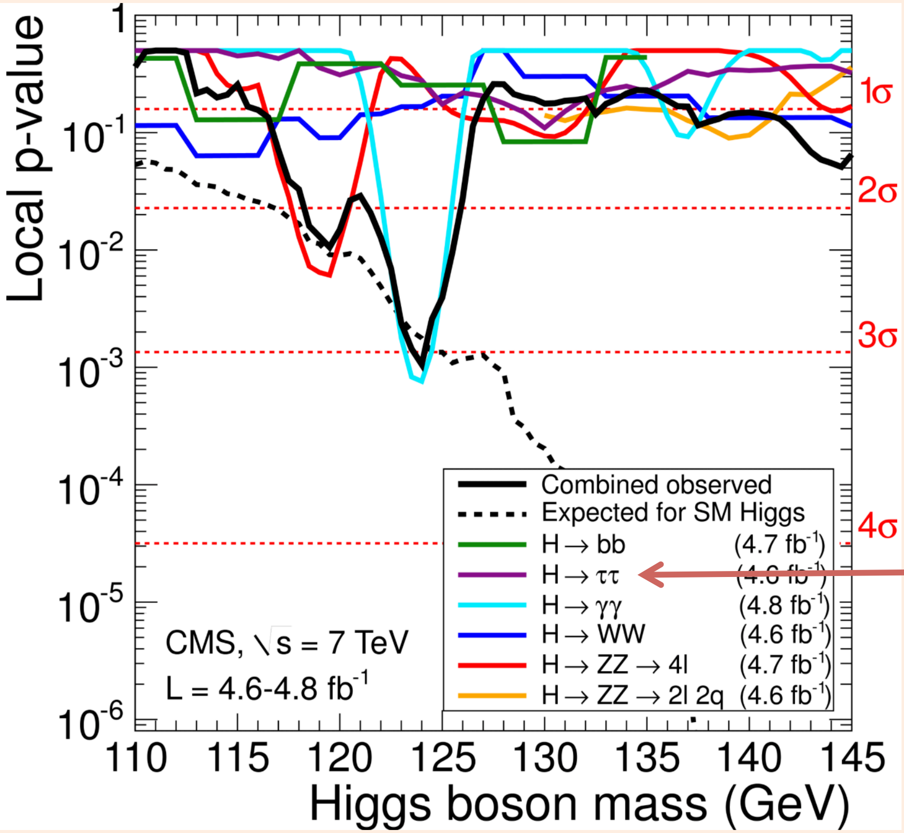

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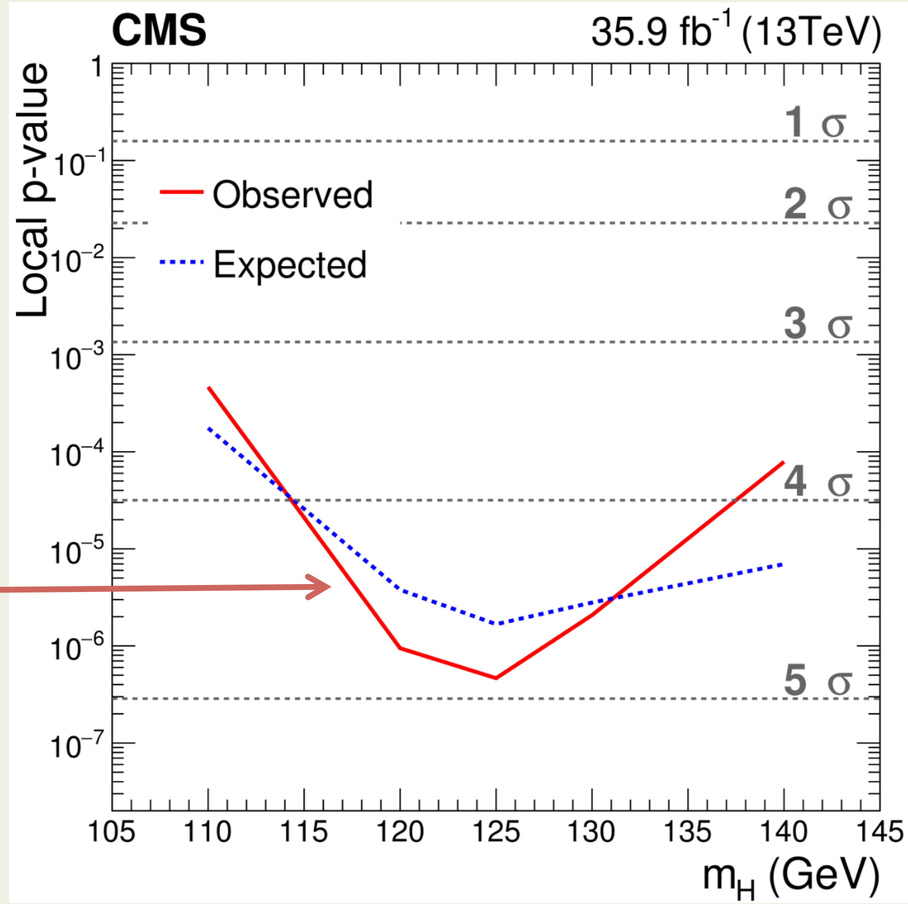


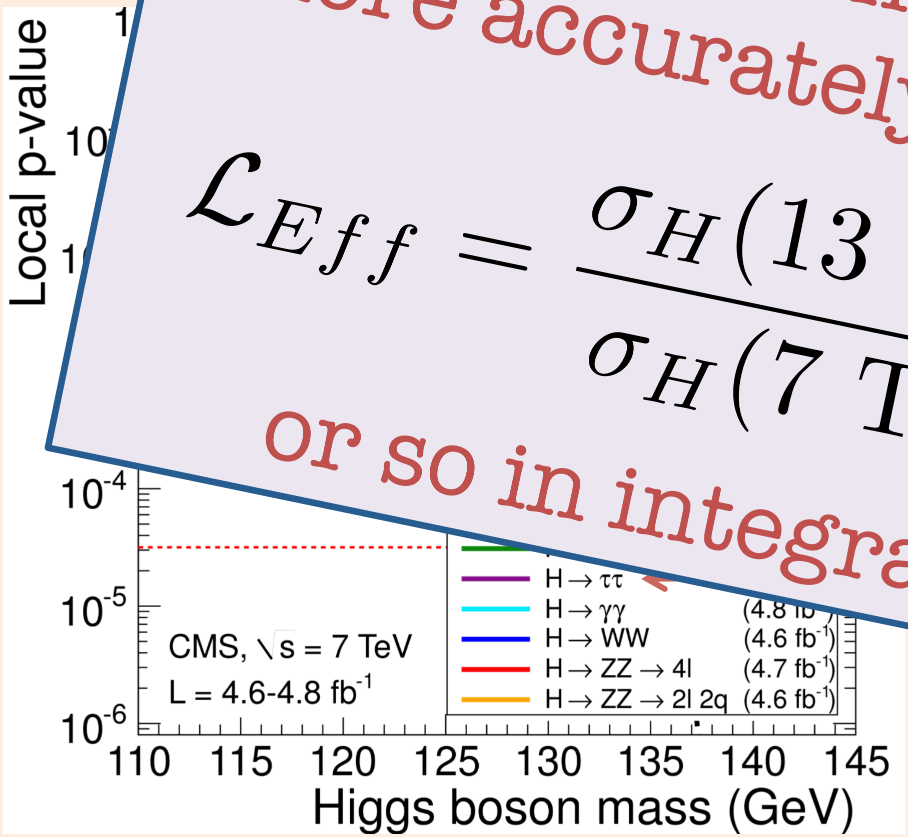
What a difference a decade makes.

LHC Research began March 2010. Just over 7 years ago. Let's compare to 2012...

A lot can change in a few years or, more accurately, an effective factor

$$\mathcal{L}_{Eff} = \frac{\sigma_H(13\ \mathrm{TeV})}{\sigma_H(7\ \mathrm{TeV})}\frac{36\ \mathrm{fb}^{-1}}{4.8\ \mathrm{fb}^{-1}} \approx 22$$

or so in integrated luminosity.



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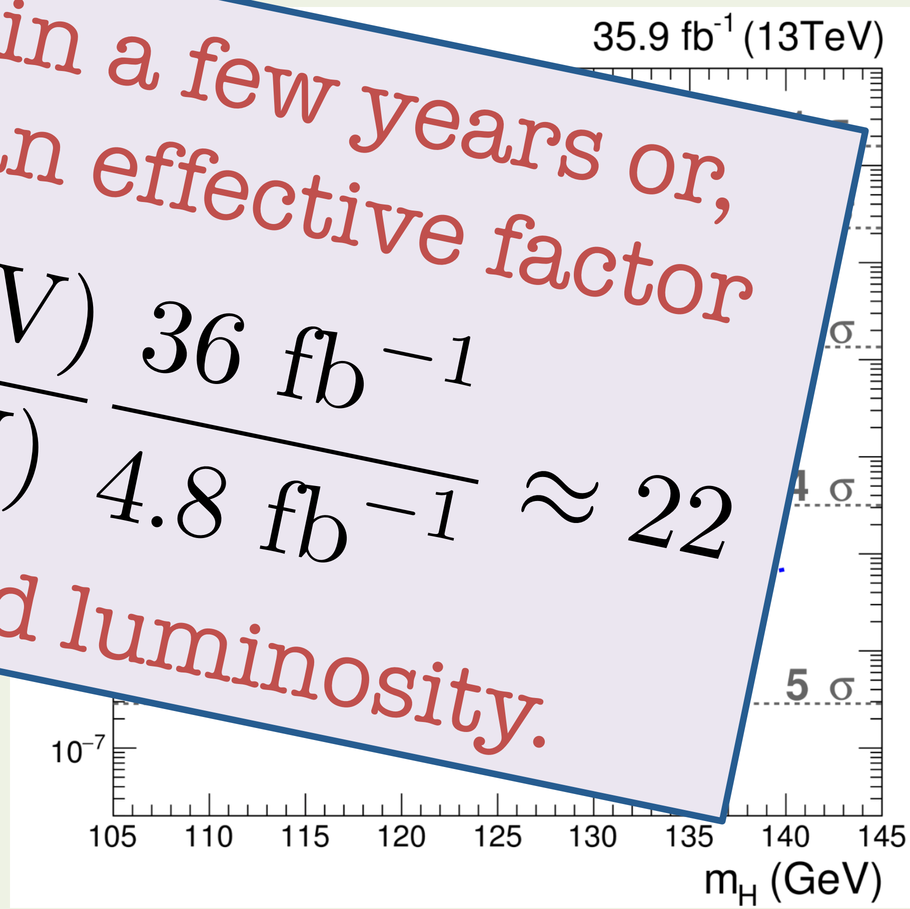
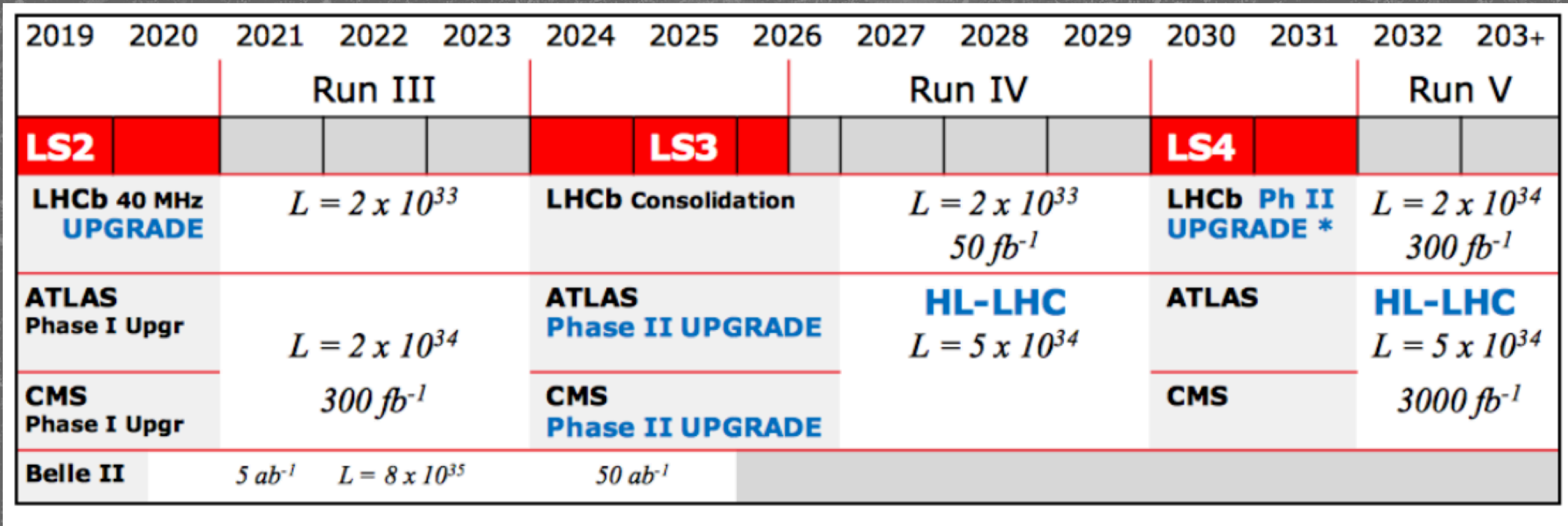


You Are Here

We currently stand just to the left of this plot, with analyses presented at 13 TeV with roughly 36 fb^{-1} of data.



What can we expect with the next order of magnitude in data?

The Discovery Factor

In an optimal scenario, with uncertainties dominated by statistics, the significance is

$$N_\sigma \approx \frac{S}{\sqrt{B}}$$

Thus, taking into account that the accelerator will, as always, exceed our expectations, and cross sections go up a bit for 14 TeV, then we can <u>expect an order of magnitude increase in effective integrated luminosity</u>.

The Discovery Factor

In an optimal scenario, with uncertainties dominated by statistics, the significance is

$$N_\sigma \approx \frac{S}{\sqrt{B}}$$

In the best case scenario a 1.6σ "fluctuation" today could be a 5σ discovery in ten years.

The Discovery Factor

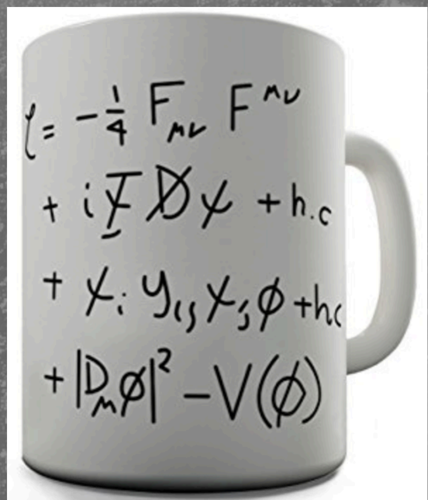
Where would I put my money? It's either Heaven:

Higgs Couplings.

Flavour.

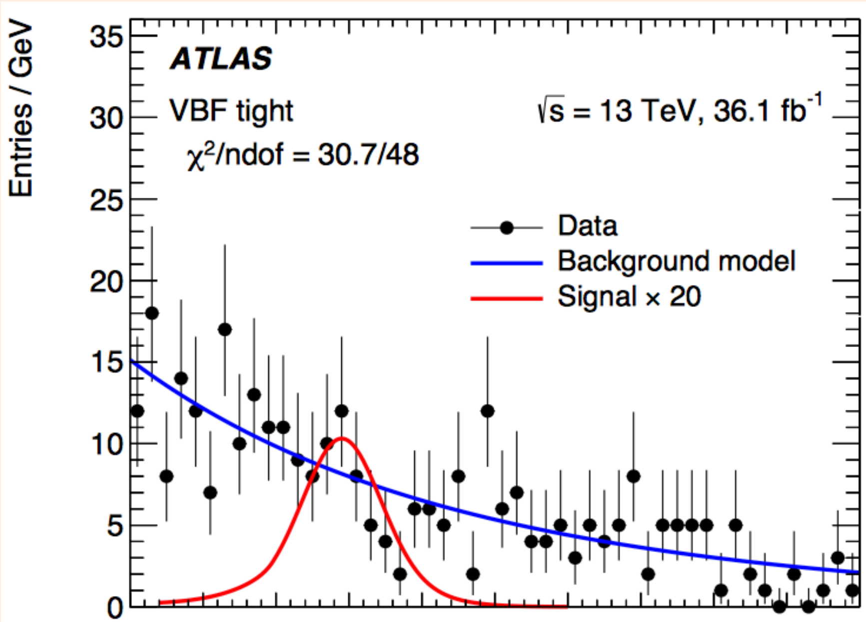
Exotic Exotica.

Or Hell:



Higgs Couplings: μμ

Now:



ATLAS currently places 2σ upper limit at a signal strength of 3xSM. With signal strength

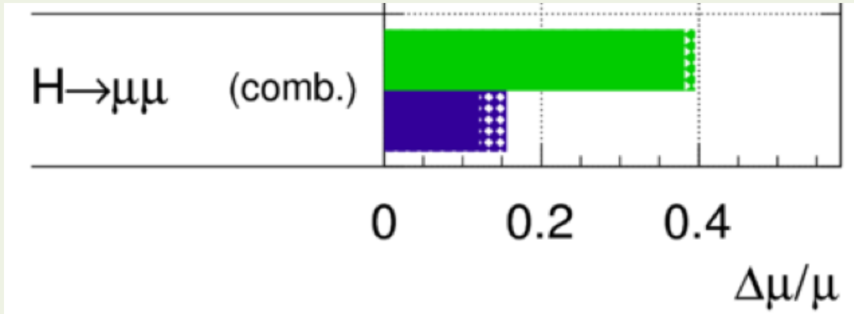
$$\mu_{\mu\mu} = -0.1 \pm 1.4$$

Ten Years:

ATLAS Simulation Preliminary

$\sqrt{s}$ = 14 TeV: $\int Ldt$=300 fb^{-1} ; $\int Ldt$=3000 fb^{-1}

300 fb^{-1} will mark a paradigm shift for second generation couplings. Higgs 2.0.

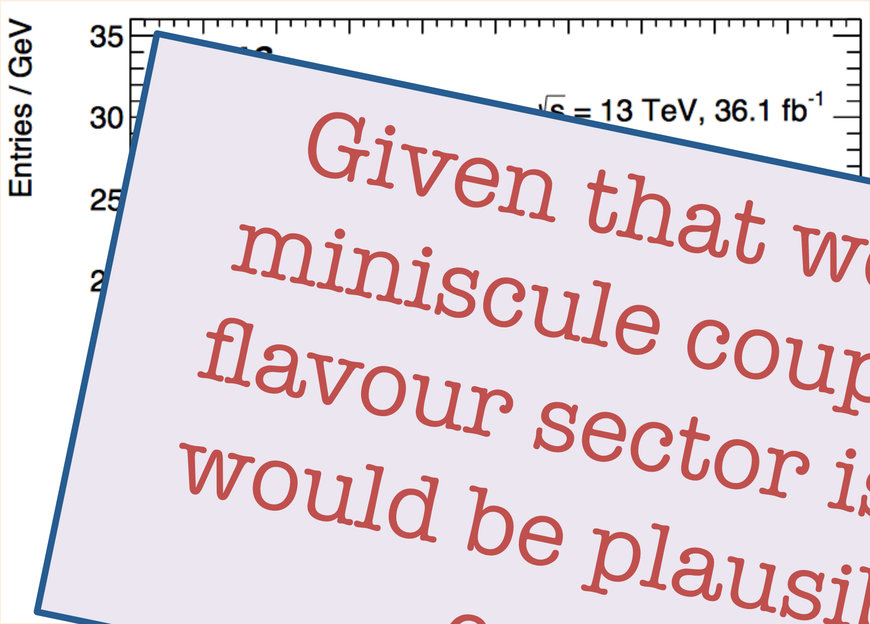


If the value is currently 3xSM then this would show up as a 5σ deviation in ten years from now.

From slides of Testa

Higgs Couplings: μμ

Now:



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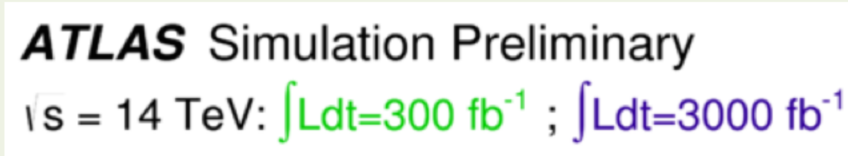


...0 fb^{-1} will mark a paradigm ...generation

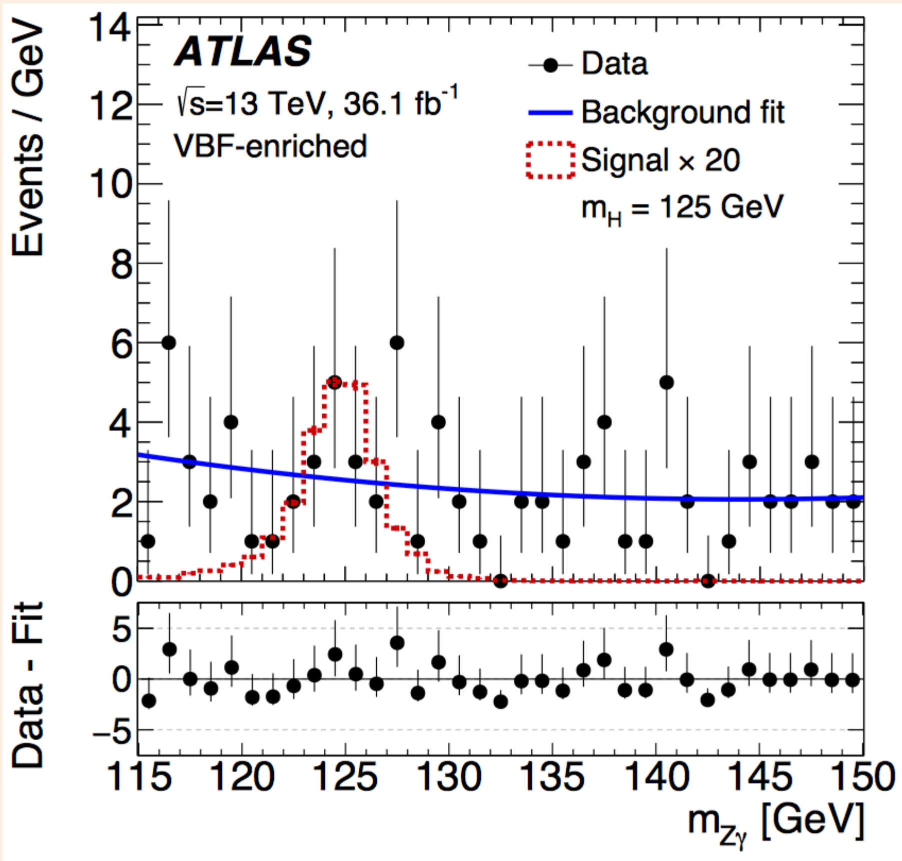
...μ/μ

...SM then this wo... a 5σ deviation in ten years from now.

Given that we are talking about miniscule couplings here, and the flavour sector is an utter mystery, would be plausible that something could show up here...

Higgs Couplings: Zγ

Now:



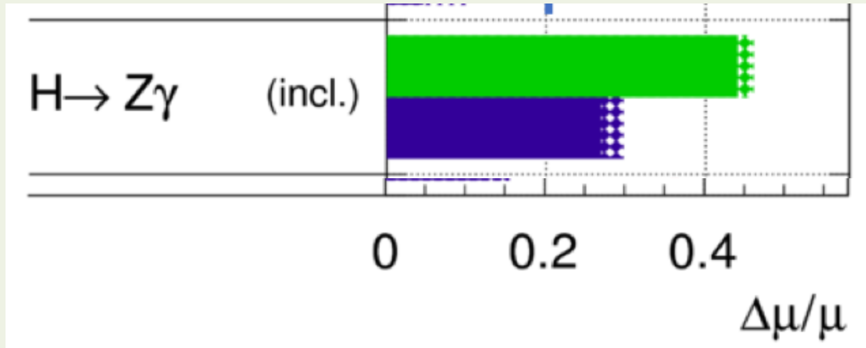
ATLAS currently places 2σ upper limit at a signal strength of 6.6xSM. Upward fluctuation..

Ten Years:

ATLAS Simulation Preliminary

$\sqrt{s}$ = 14 TeV: $\int$Ldt=300 fb^{-1} ; $\int$Ldt=3000 fb^{-1}

300 fb^{-1} will also mark a paradigm shift for rare Higgs decays:



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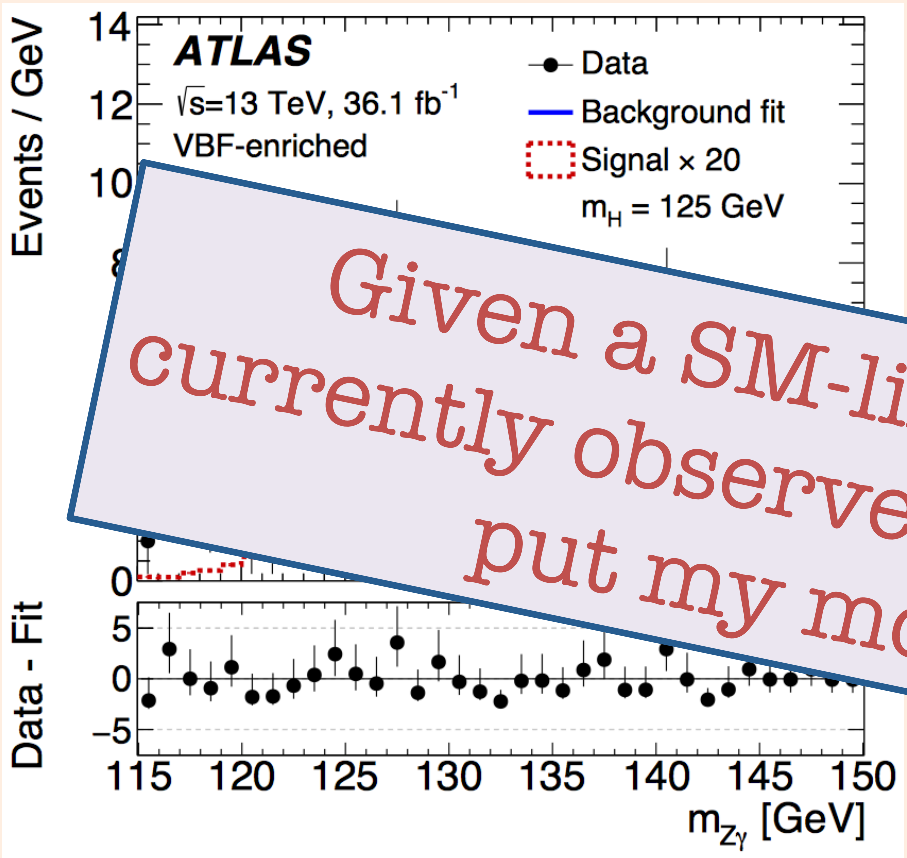
From slides of Testa

Higgs Couplings: Zγ

Now:



ATLAS currently places 2σ upper limit at a signal strength of 6.6xSM. Upward fluctuation..

Ten Years:

ATLAS Simulation Preliminary

$\sqrt{s}$ = 14 TeV: $\int Ldt=300\ fb^{-1}$; $\int Ldt=3000\ fb^{-1}$

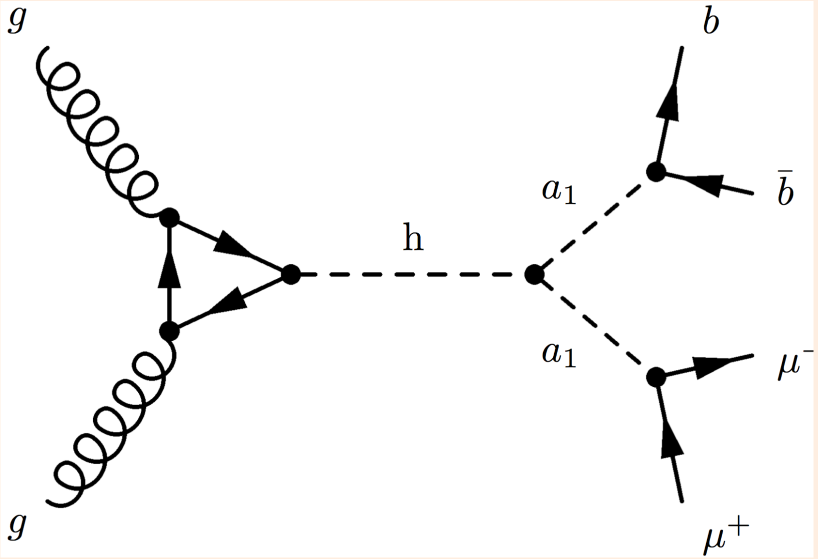
300 fb^{-1} will also mark a paradigm shift for rare Higgs

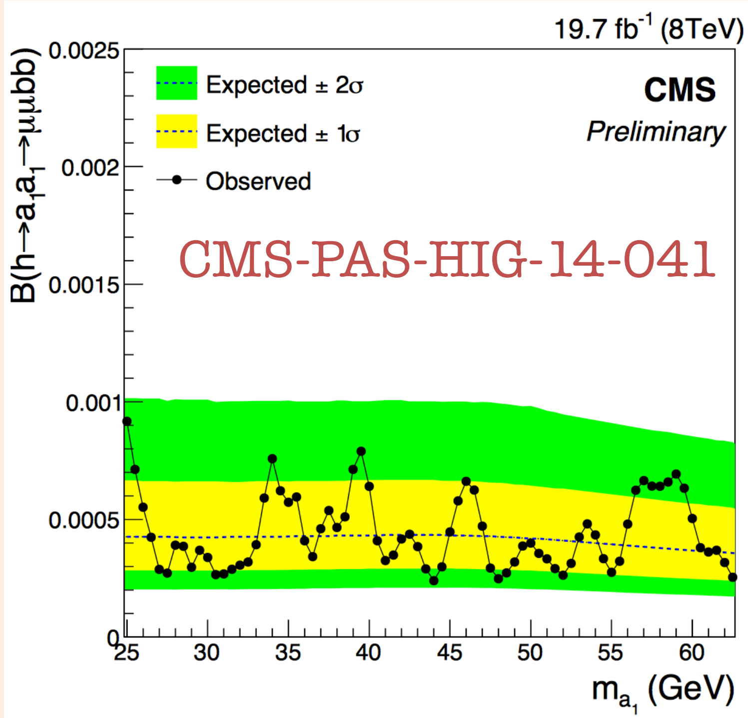
If the value is currently 3xSM then this would show up as a 5σ deviation in ten years from now.

Given a SM-like diphoton rate currently observed, I would not really put my money here…

Exotic Higgs Decays

Due to it's tiny width the Higgs can have significant exotic decay channels, even for small couplings. Consider one example:





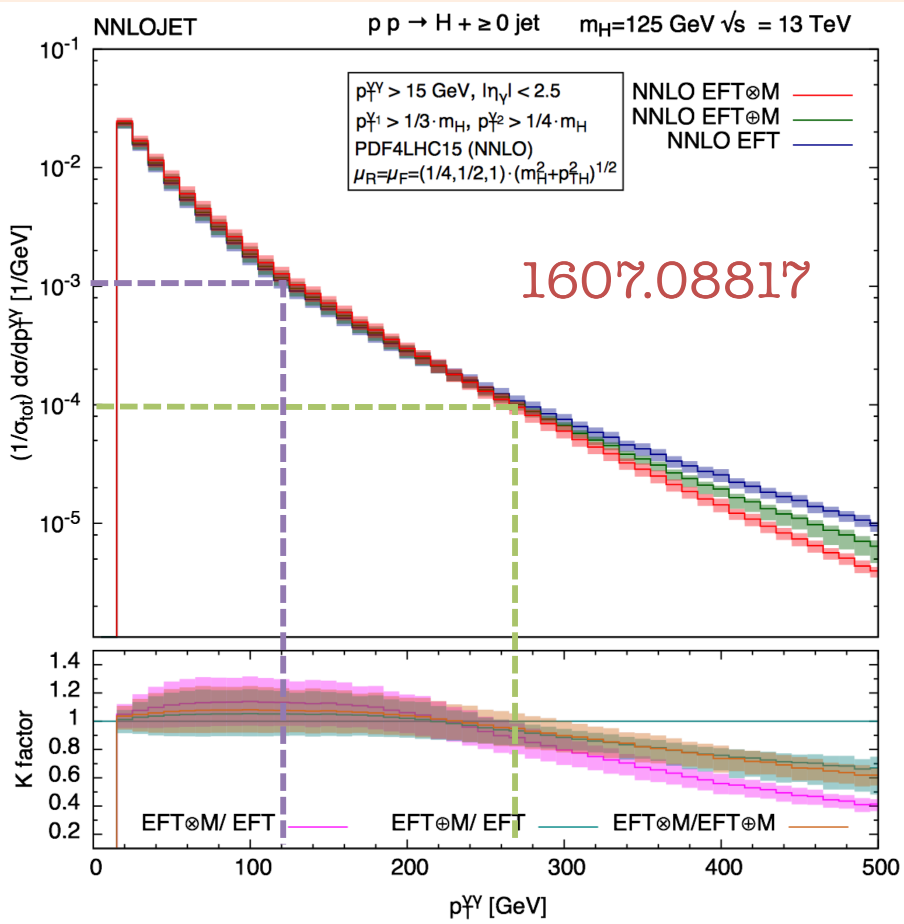
BR < 0.0005 corresponds to about 200 events.

Ten Years?

With the extra luminosity we can afford to cut harder and search for very rare signatures: Displaced, High Multiplicity, Leptons...

Boosted Higgses

High Velocity Higgs:



Plot normalised to total Higgs cross section.

Ten Years:

For comparison, what we can do with a p_T=120 GeV Higgs boson now, we should be able to do with a p_T=260 GeV Higgs in ten years!

Since heavy new physics can give corrections scaling as

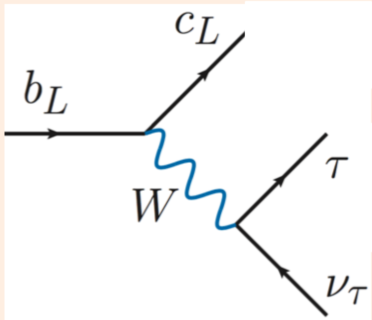
$$\mathcal{M} \propto \frac{p_T^2}{\Lambda^2}$$

We will be able to indirectly access higher scales of new physics.

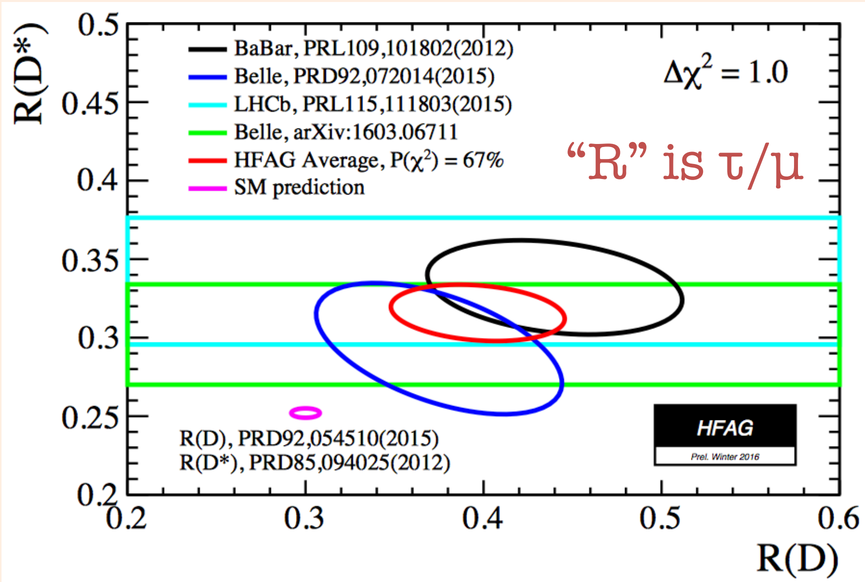
Flavour of the Month

$B \to D^{(*)} \tau \nu$

Tree-level in the SM:



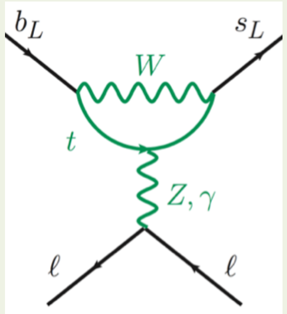
Currently 4σ tension:



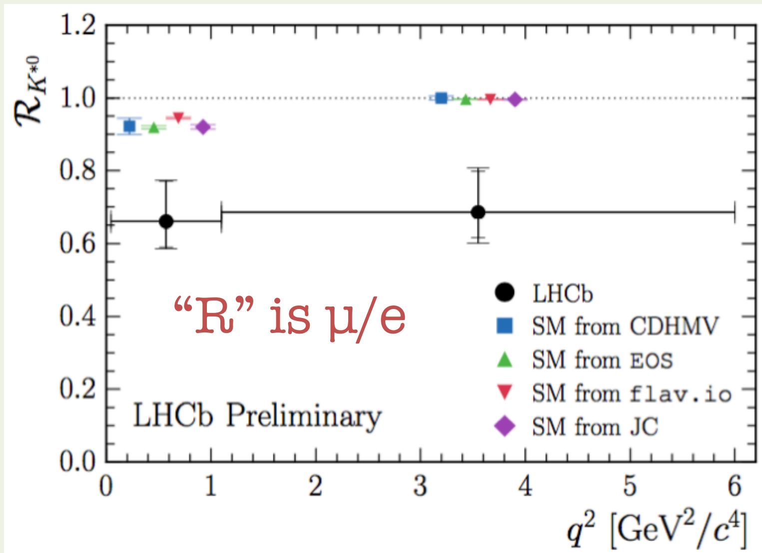
"R" is τ/μ

$B \to K^{(*)} \mu^+ \mu^-$

One-loop FCNC in the SM:



A number of 2σ tensions that can combine to exceed 4σ.

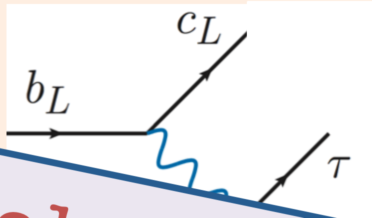


"R" is μ/e

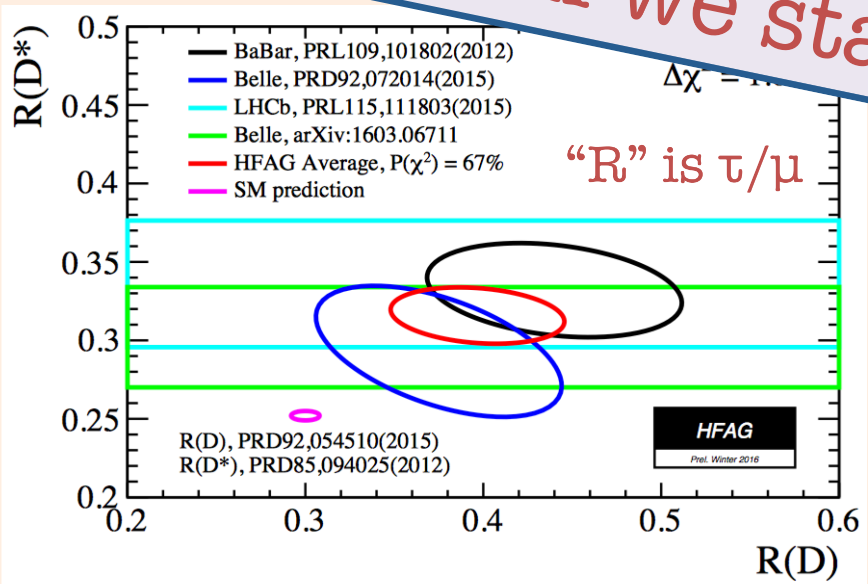
Flavour of the Month

$B \to D^{(*)}\tau\nu$

Tree-level in the SM:

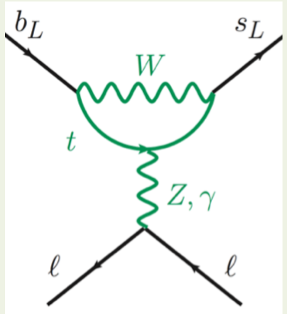


Curren

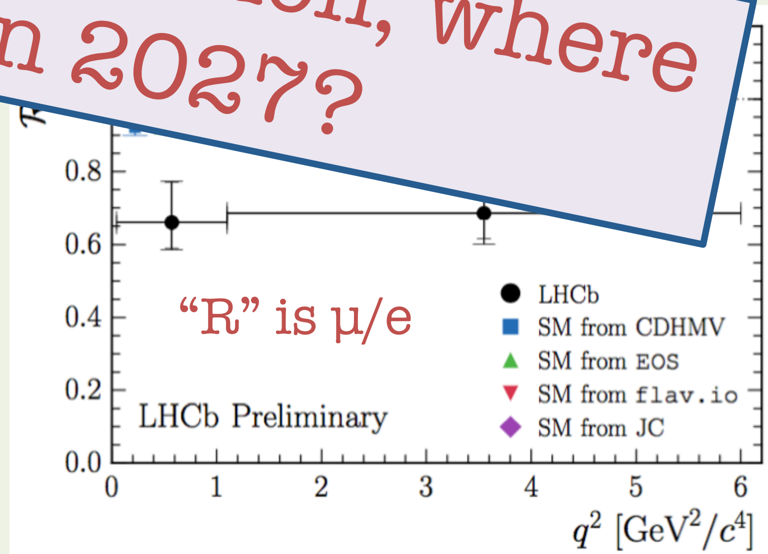


$B \to K^{(*)}\mu^+\mu^-$

One-loop FCNC in the SM:



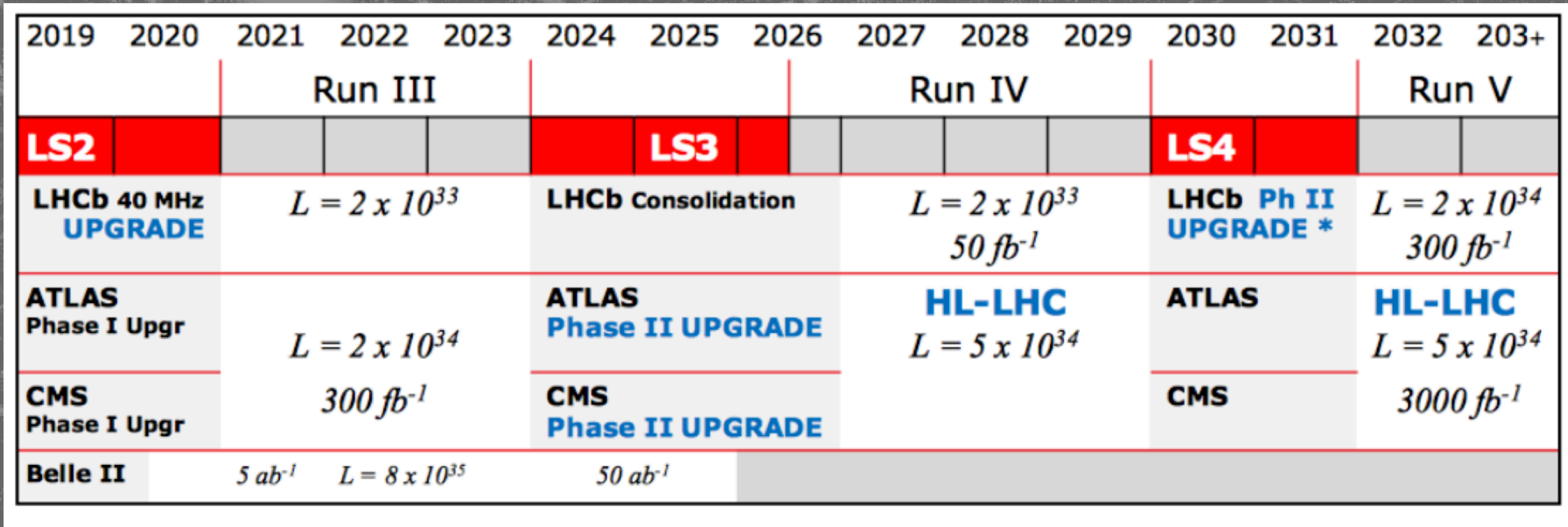
of 2σ tensions that



If already this level of tension, where will we stand in 2027?

Flavour of the Month

Flash forward to LHCb and Belle II expectations:



Estimated operating scenarios are:

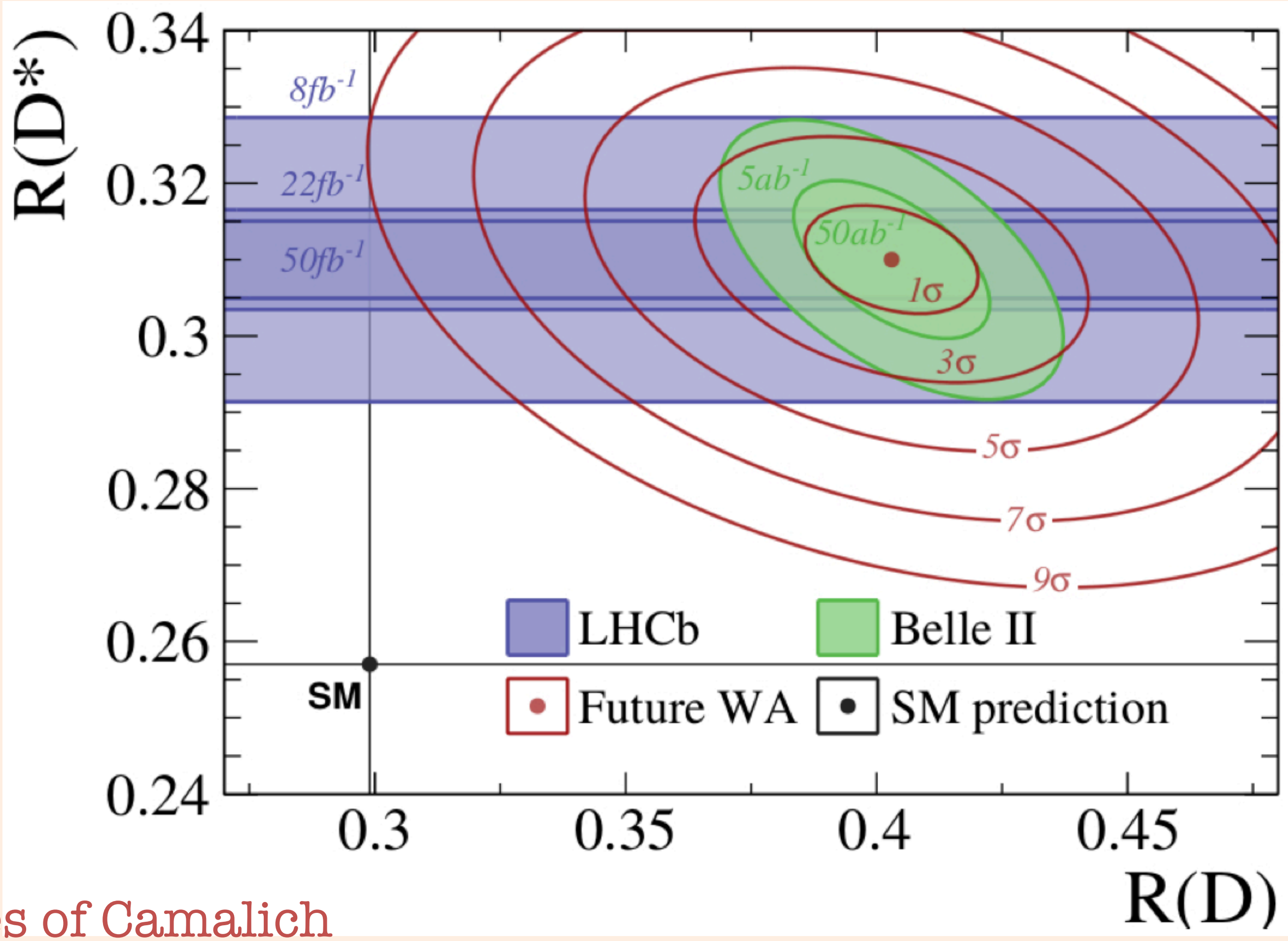
arXiv:1709.10308: J. Albrecht, F. U. Bernlochner, M. Kenzie, S. Reichert, D. M. Straub, A. Tully

Measurement	SM prediction	Current World Average	Current Uncertainty	Projected Uncertainty[1]				
				Belle II		LHCb		
				5ab^{-1}	50ab^{-1}	8fb^{-1}	22fb^{-1}	50fb^{-1}
				2020	2024	2019	2024	2030
$R(D)$	(0.299 ± 0.003)	$(0.403 \pm 0.040 \pm 0.024)$	11.6%	5.6%	3.2%	-	-	-
$R(D^*)$	(0.257 ± 0.003)	$(0.310 \pm 0.015 \pm 0.008)$	5.5%	3.2%	2.2%	3.6%	2.1%	1.6%

Flavour of the Month

$$B \to D^{(*)}\tau\nu$$

If average value holds then in ten years anomaly could pass the technically arbitrary, but still meaningful, “Bazillion Sigma” mark:



From slides of Camalich

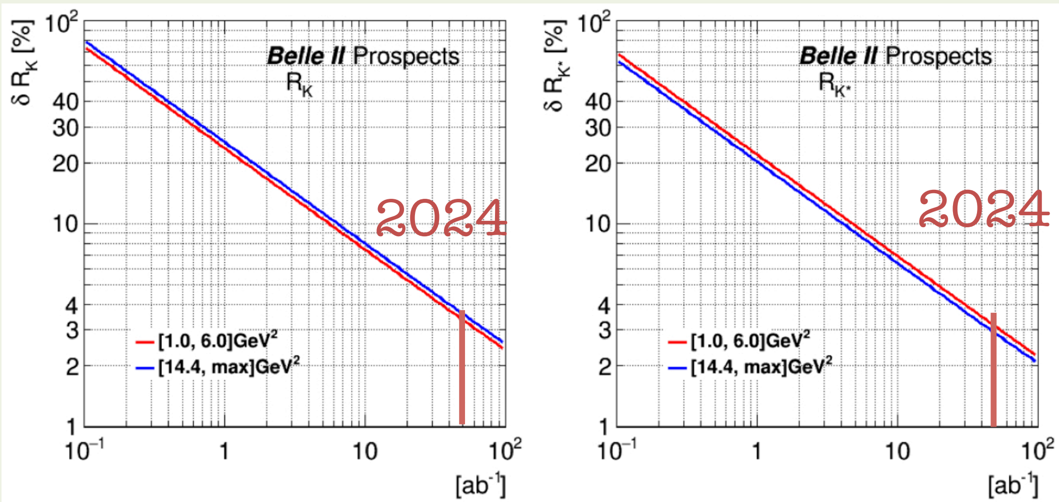
Flavour of the Month

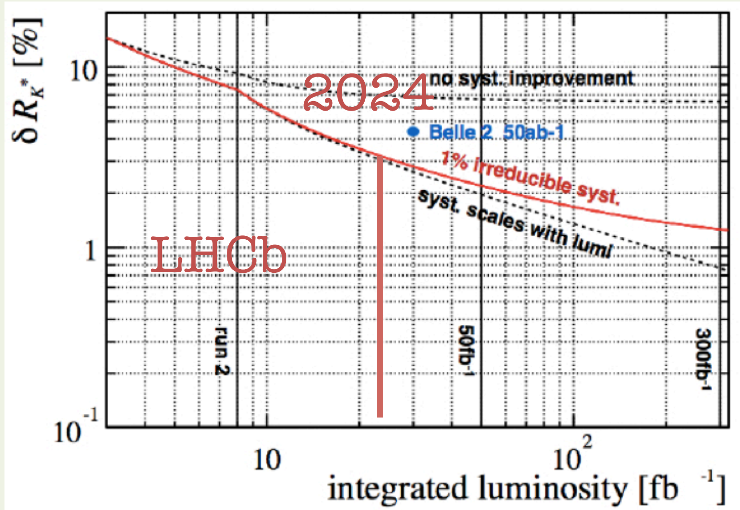
$$B \to K^{(*)} \mu^+ \mu^-$$

Current status of uncertainties in the regime of 10’s %.

LHCb Preliminary	low-q^2	central-q^2
$\mathcal{R}_{K^{*0}}$	$0.660\,^{+\,0.110}_{-\,0.070} \pm 0.024$	$0.685\,^{+\,0.113}_{-\,0.069} \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]
99.7% CL	[0.454–1.042]	[0.462–1.100]

At Belle II and LHCb these uncertainties would be at a few %:





If true, would also far surpass “discovery” level…

From slides of Camalich

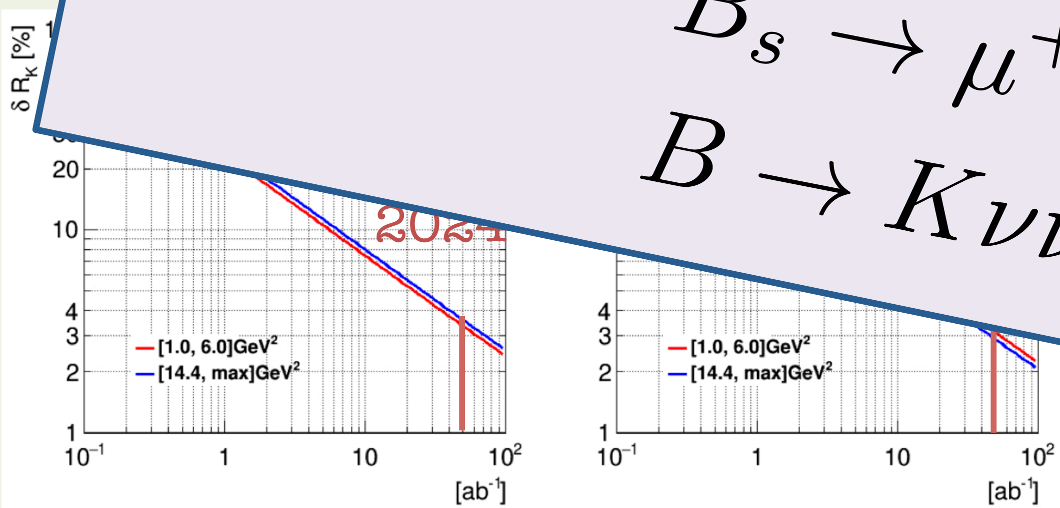
Flavour of the Month

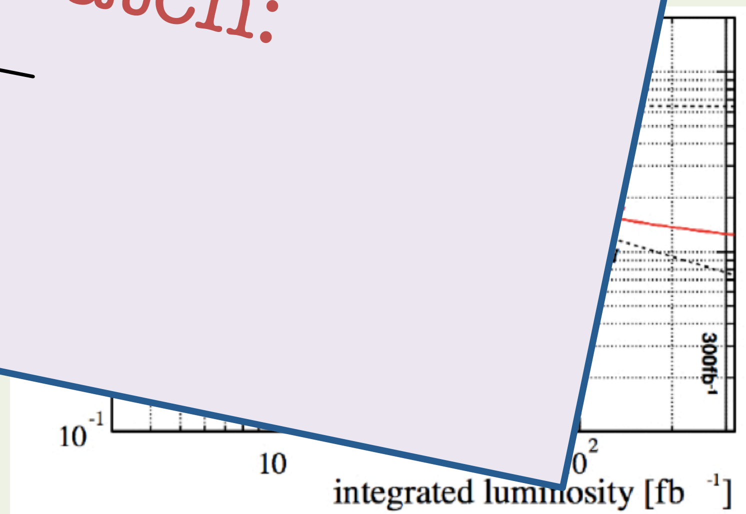
$$B \to K^{(*)}\mu^+\mu^-$$

Curre... ...alies in the regime of 10's %.

central-q^2
...113 ± 0.047

At ...





A taste of the future?

Other modes to watch:

$$B_s \to \mu^+\mu^-$$

$$B \to K\nu\nu$$

If true, would also far surpass "discovery" level...

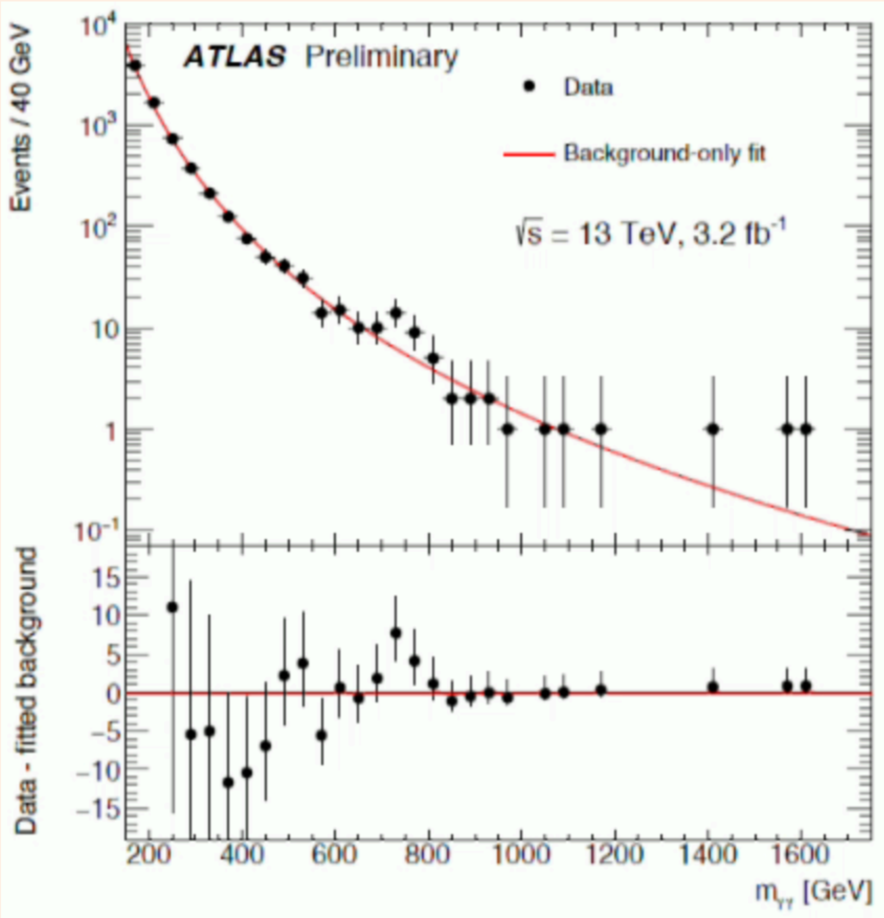
Away from the lampost.

There are still be new places to look…

hep-ph hep-ex

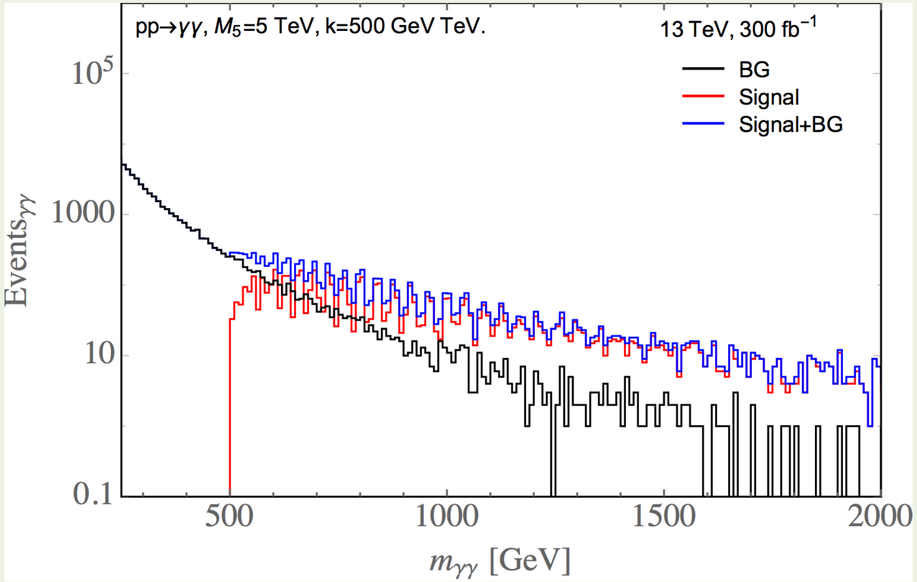
Some Fun (Serious) Ideas

Are we plotting on the wrong axes? Always expecting to see a plot like this:



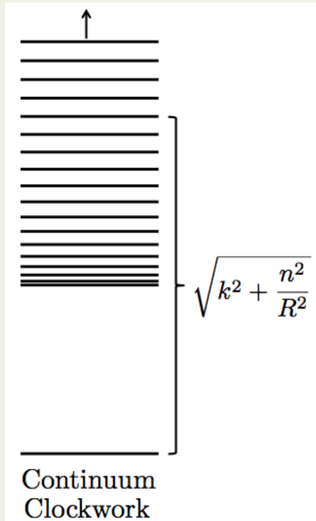
Particles = Bumps, right?

But what if the new physics looks like this?



There are genuine sensible theories that generate this:

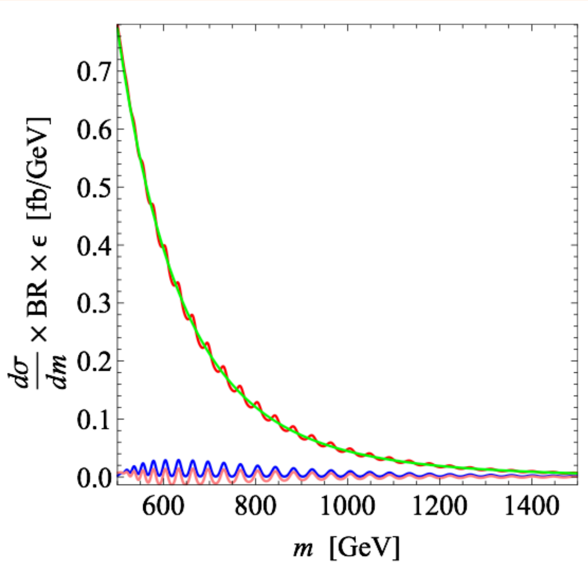
$$m_n \sim k\left(1 + \frac{n^2}{2(kR)^2}\right)$$



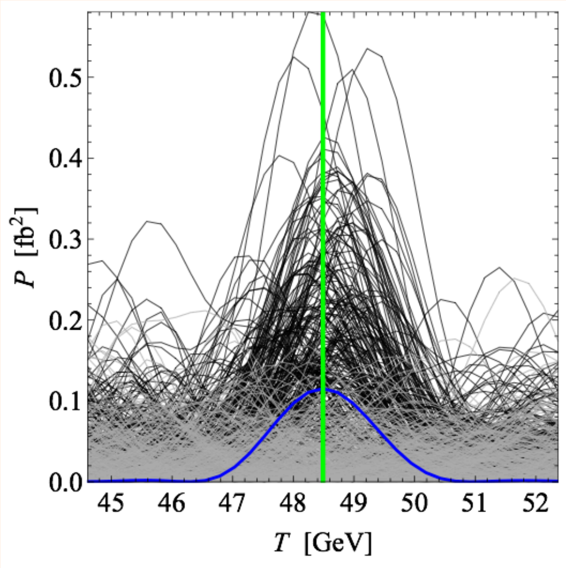
Linear dilaton/ clockwork.

Some Fun (Serious) Ideas

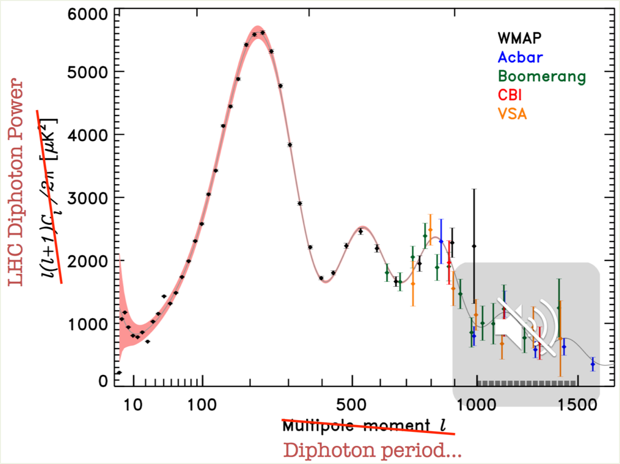
Maybe we should be looking in Fourier space?



Fourier Space

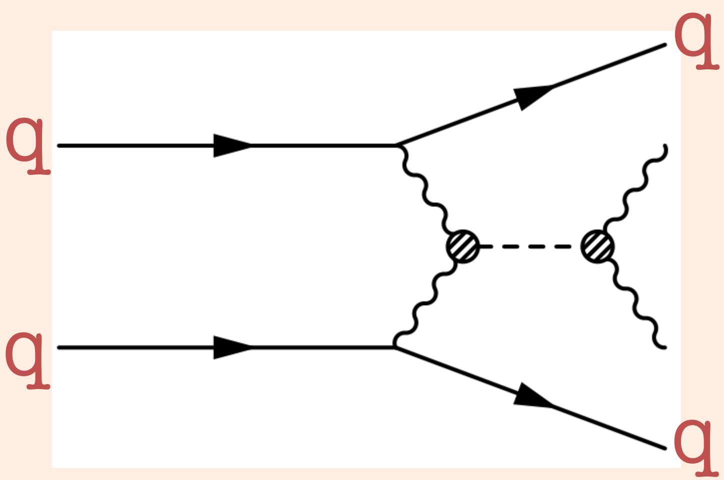


Maybe the next step is to start thinking like cosmologists with LHC data?

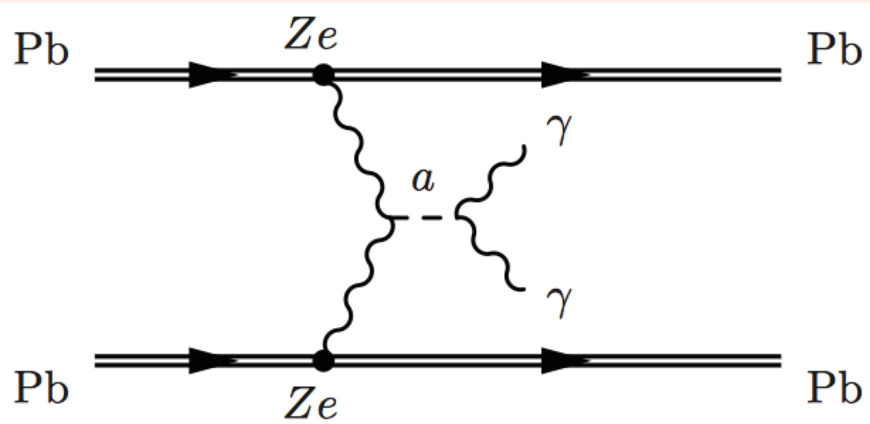


Some Fun (Serious) Ideas

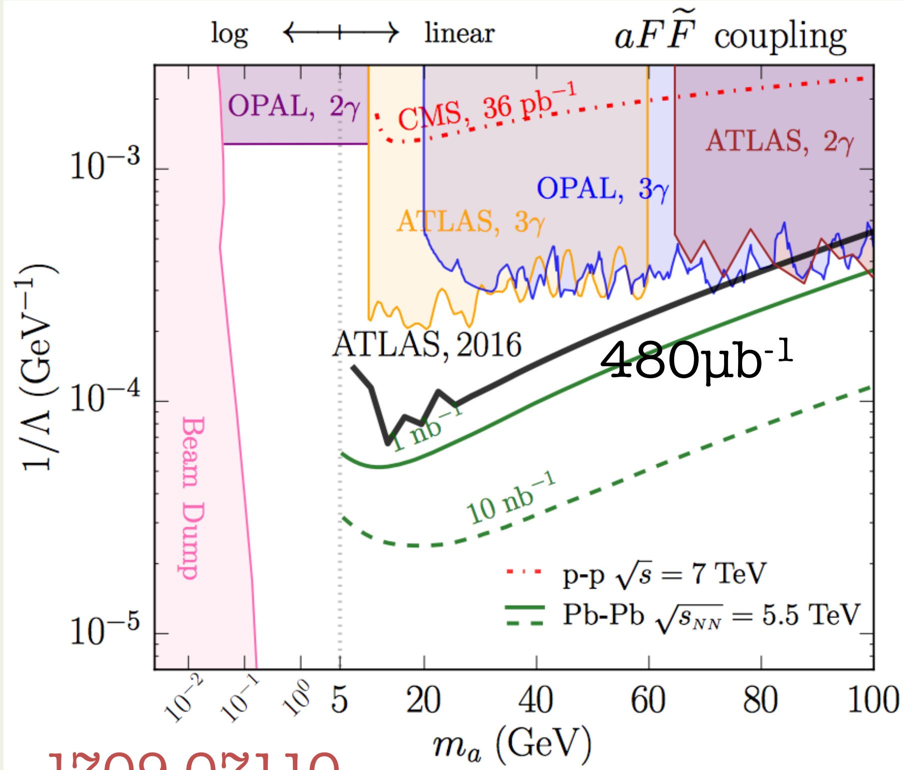
What if new neutral scalars only couple to the photon?



Why not let the heavy ions do the heavy lifting:



High-Z is intensity frontier, but at high energies!



1709.07110

In ten years we can realistically expect 3nb^{-1}. Is something going to show up in forward physics?

Conclusions

One order of magnitude in integrated luminosity can bring us to new territory, if we look in the right places.

I honestly don't know what to expect. Your bet is as good as mine!