Particle Phenomenology at NBI

Michael Trott, Niels Bohr Institute, Copenhagen, Denmark

Current:



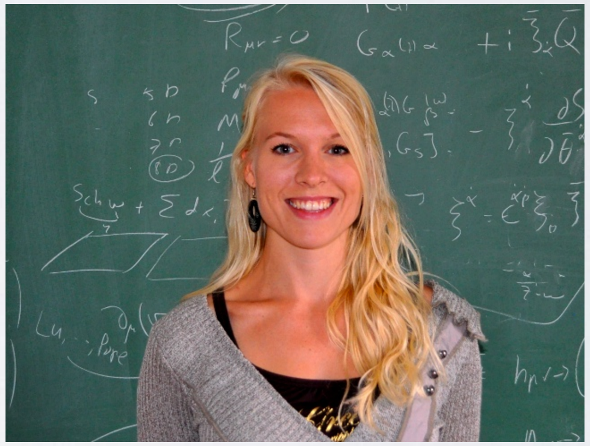


MSC:
Abdu
Barzinji

EFT phenomenology group

Graduated:



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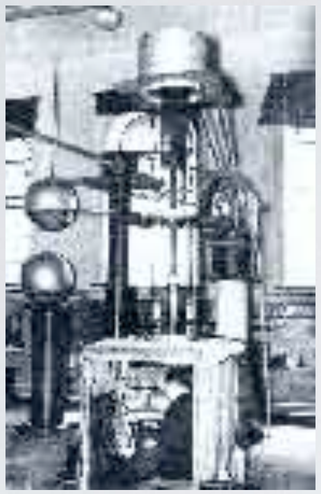
SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS


Our ability to learn from the vacuum - empty space, is profound

People noticed a while ago when you smash things together
very interesting things happen.

800 KeV



Cool 1930 tech !

Crockcroft and Walton in 1930-1932 used a large potential difference to smash a proton into lithium

So far so good   4p + 4n -> 4p + 4n   easy to understand.

People/Things born in 1930:

Increasing coolness.

Buffett

Eastwood

Connery

Particle Physics (arguably)

Why is the vacuum so exciting?

4.5 inch, 80 000 eV

COOLER 1931 tech !

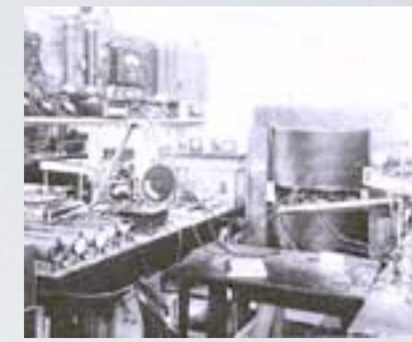
Around the same time Lawrence/Livingston cyclotron was developed

grad student who did the work

"Dr Livingston has asked me to advise you that he has obtained 1,100,000 volt protons. He also suggested that I add 'Whoopee'!"

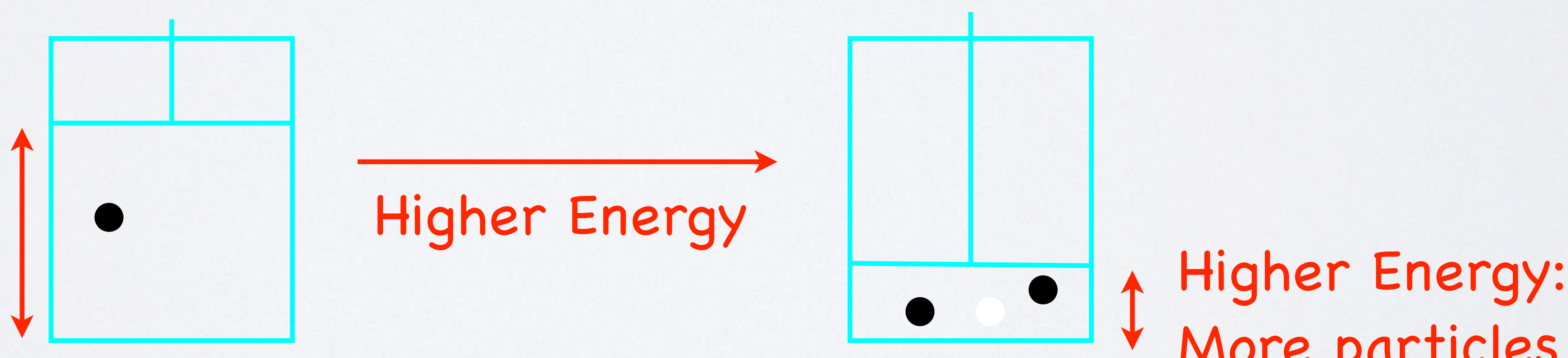
**—Telegram to Lawrence,
3 August 1931**

11 inch, 1 MeV



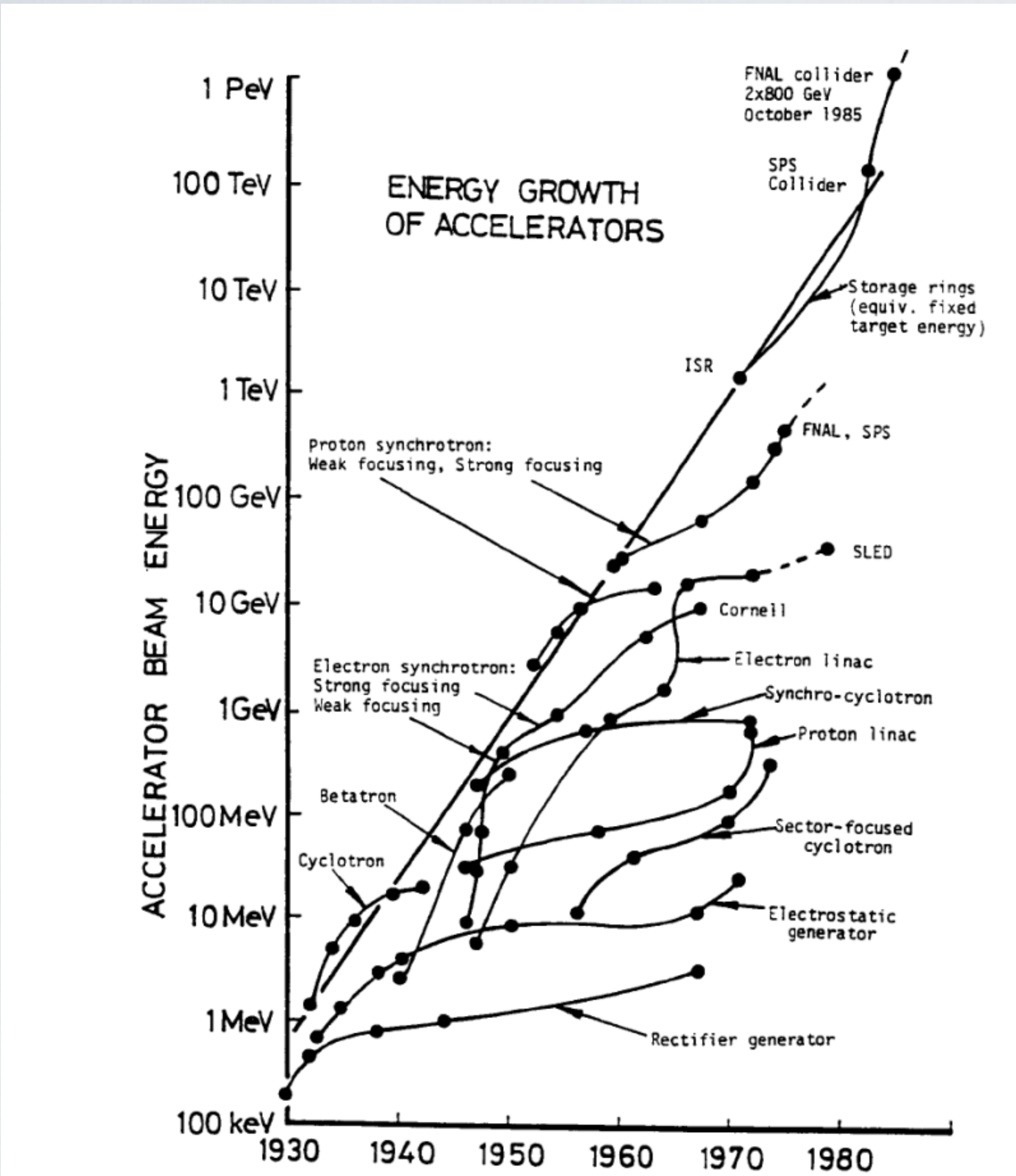
COOLEST 1931 tech !

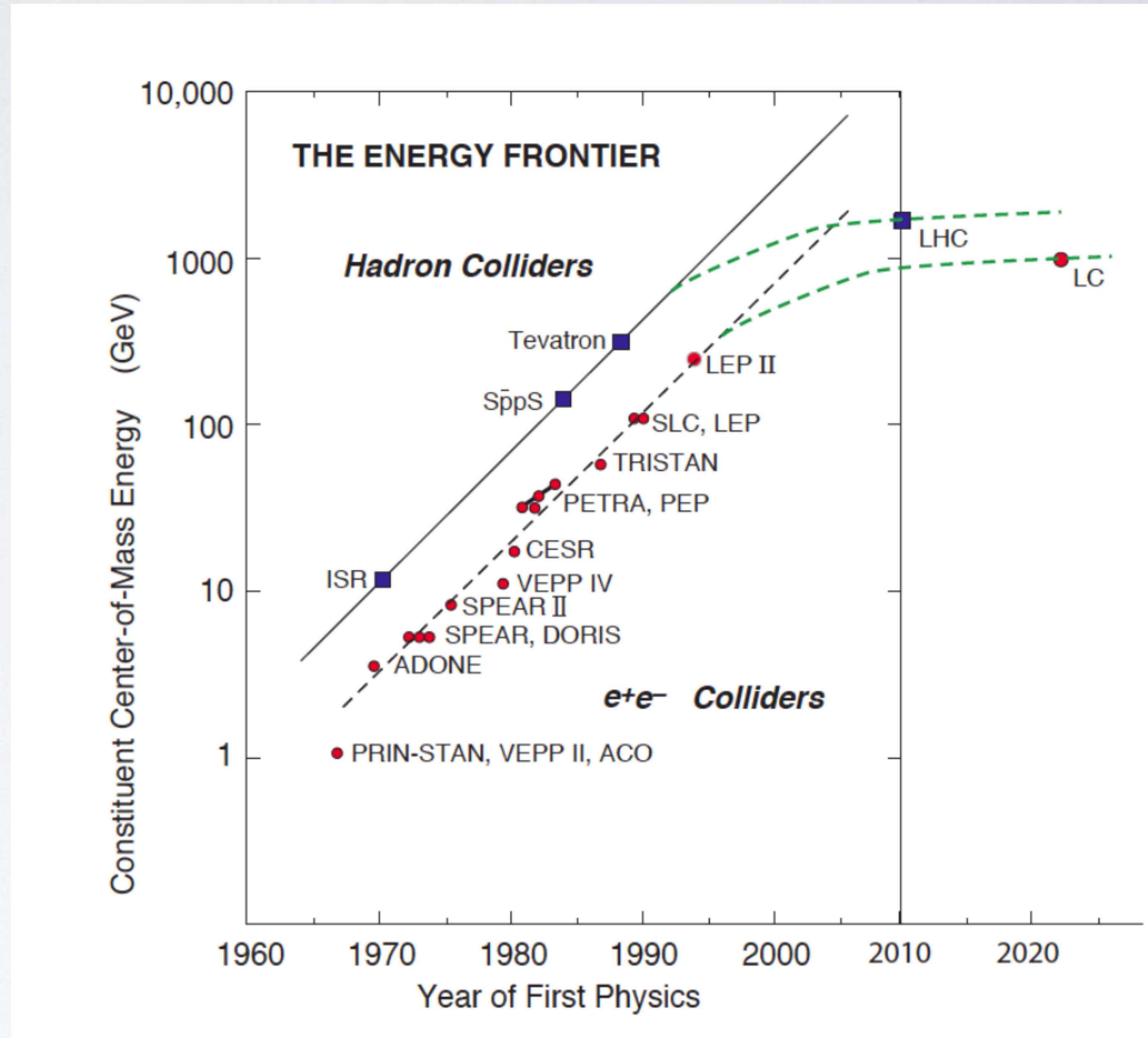
The mission to put more and more energy in small spaced is motivated out of the fact that if you do that - you can make profoundly new particles



This is due to the "uncertainty principle" and Quantum mechanics, as developed by NBI Alums Erwin Schrödinger, Niels Bohr etc

What is the big picture?





Livingston chart: 1985

Livingston chart: 2014

Images: http://www.hep.ucl.ac.uk/iop2010/talks/14.pdf

The ultimate atom smasher

So many decades later the ultimate large energy in a small space machine is the LHC

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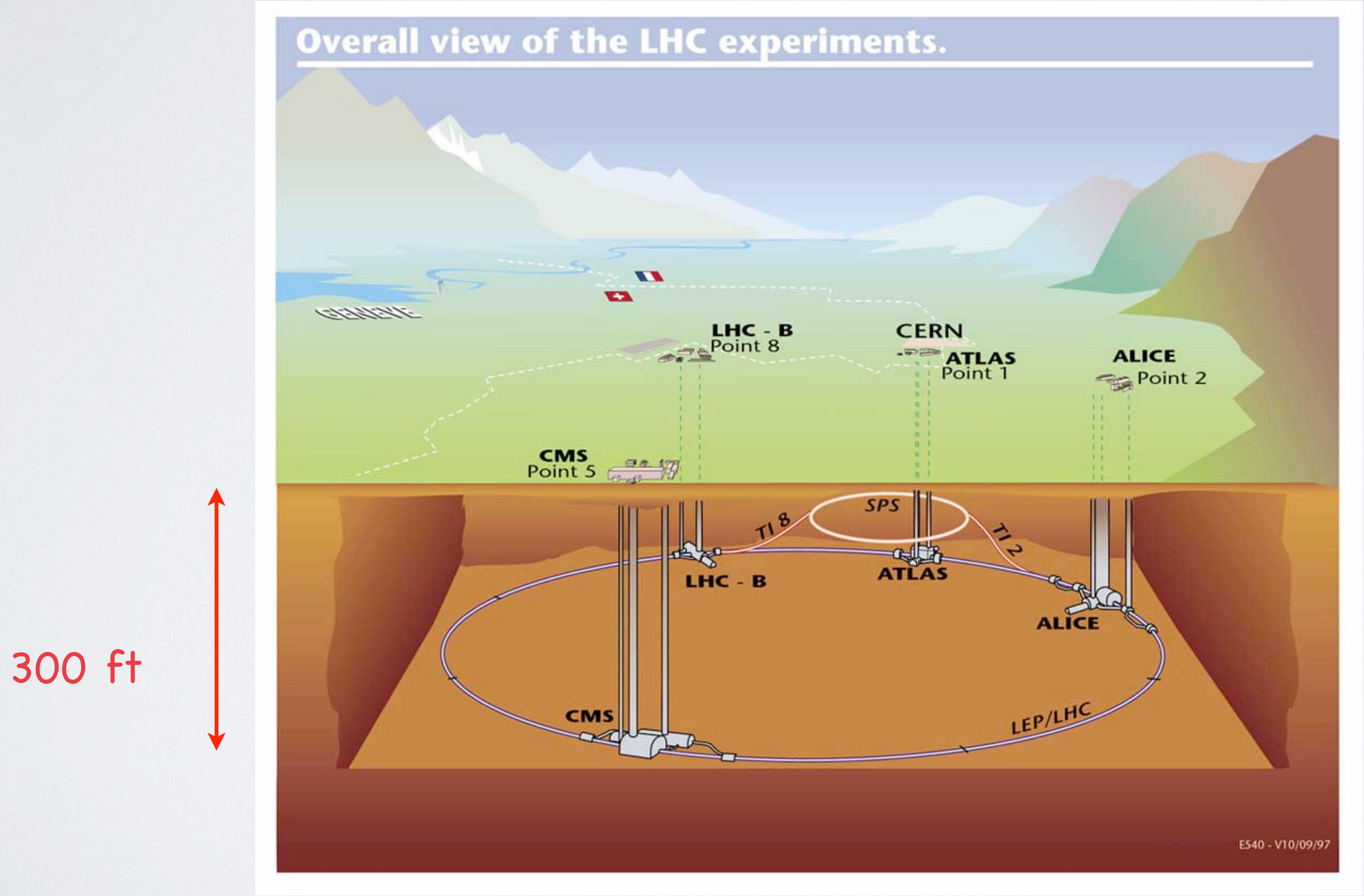
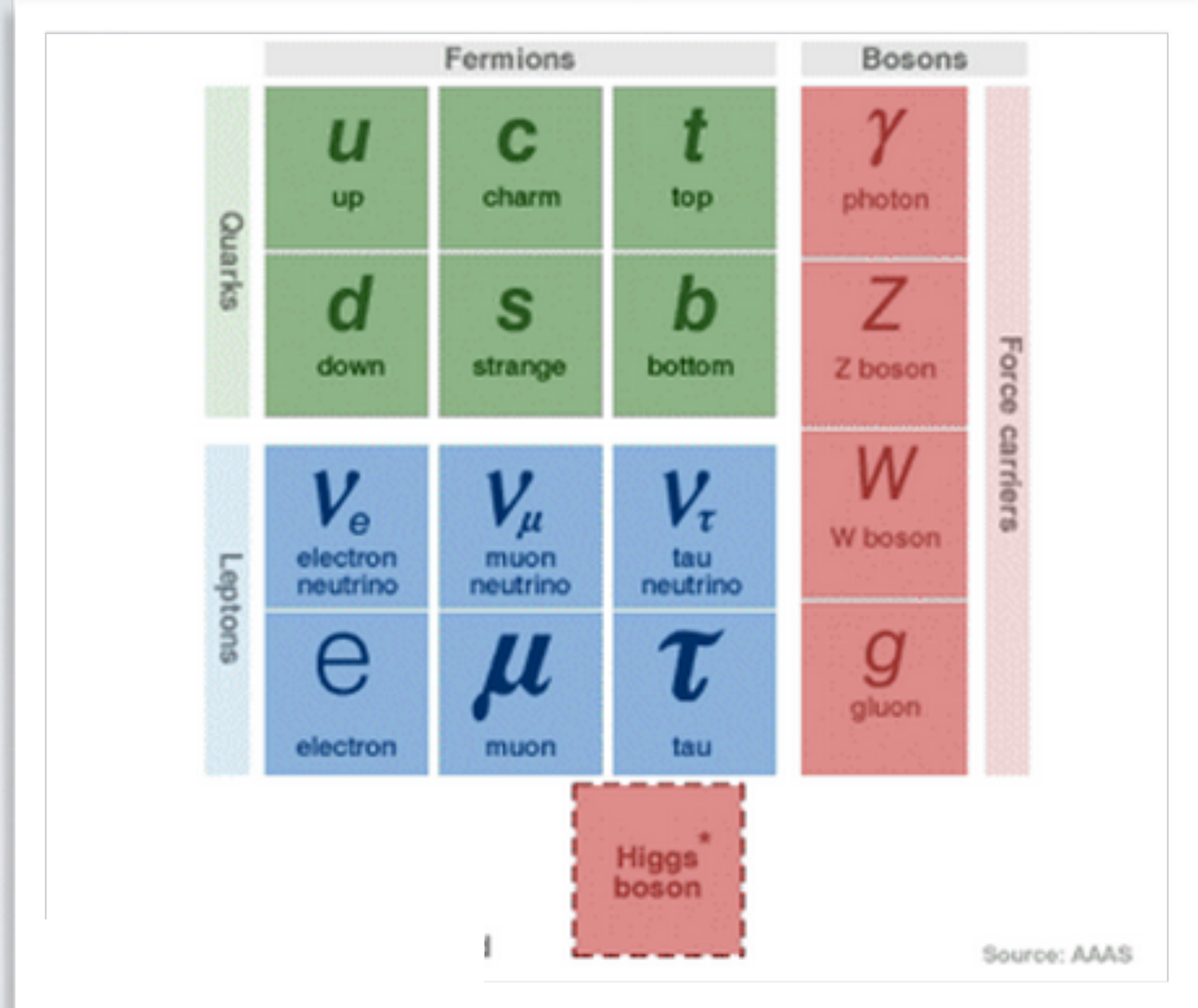
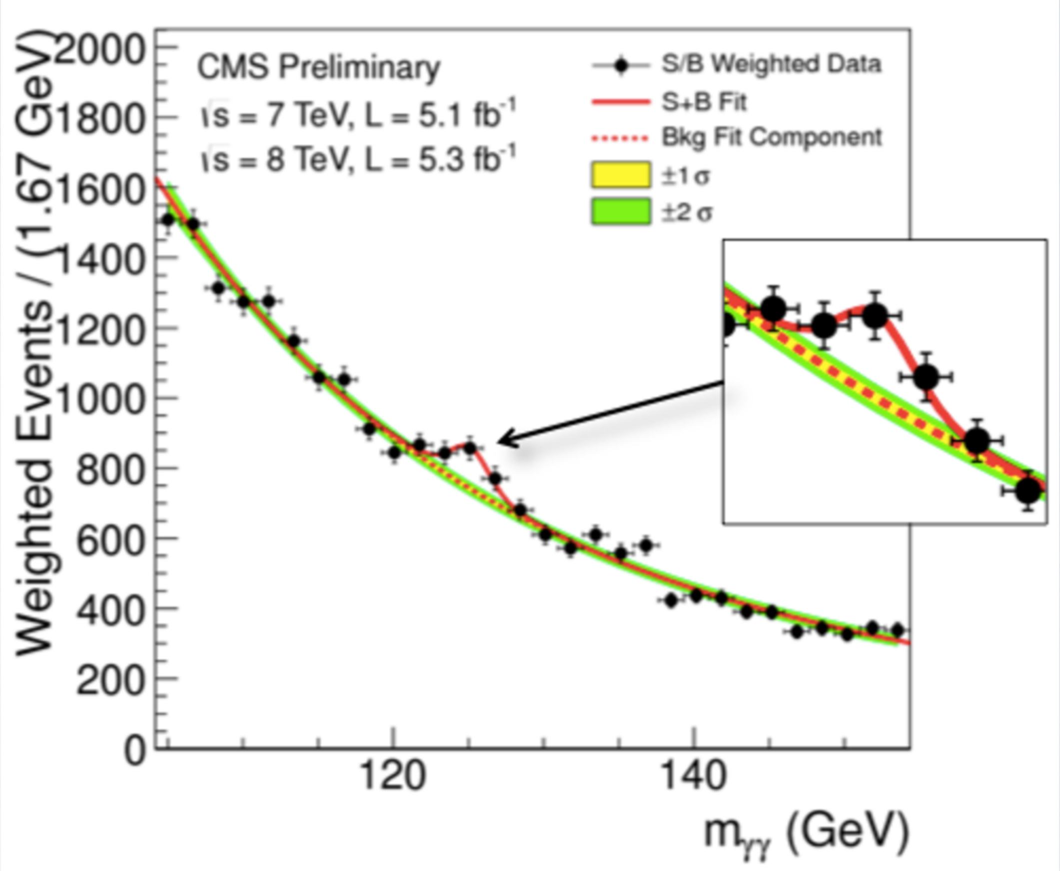


The ultimate atom smasher

Leading up to LHC we had discovered all but the final box below at other atom smashers. Theoretical consistency implied that there should be something more.



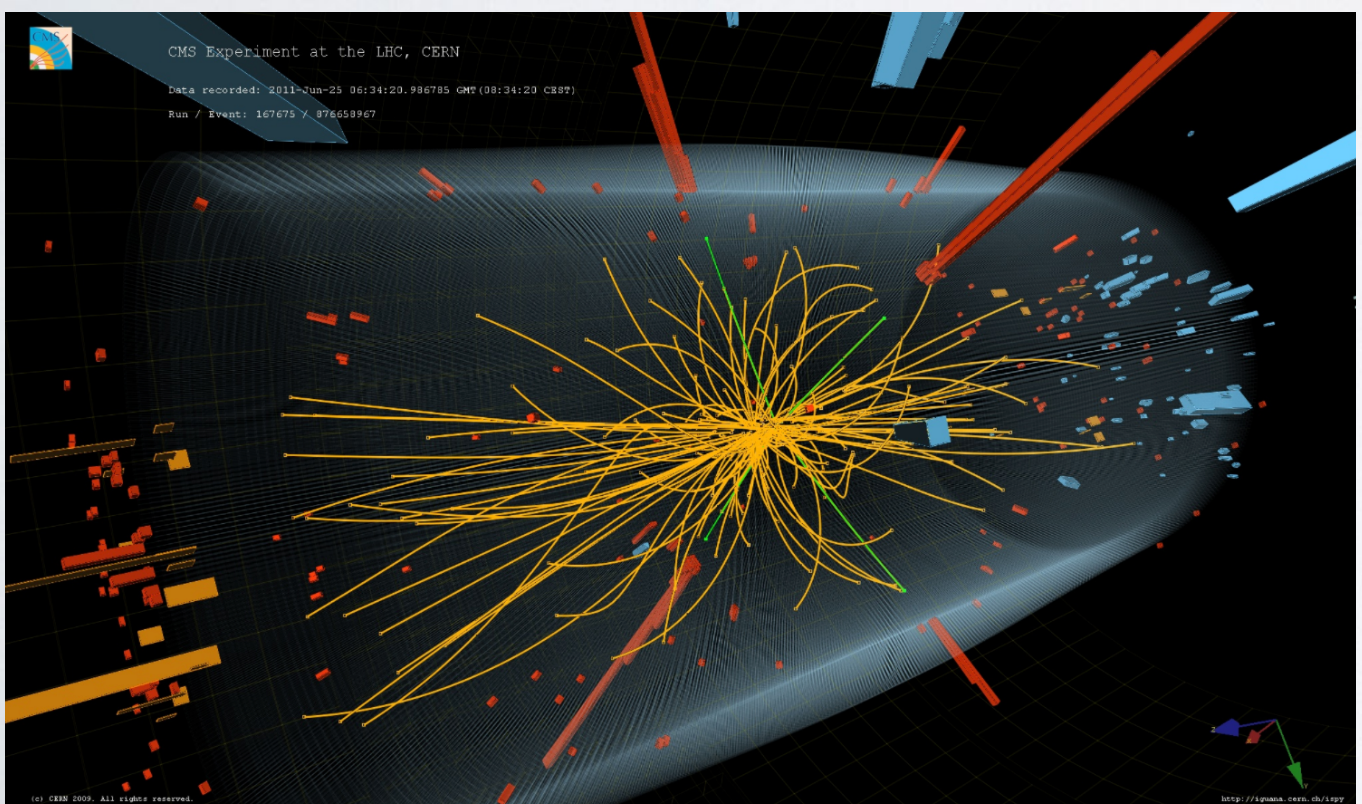


We smashed together protons and found it as a bump in photons:

p + p -> $\gamma\,\gamma$

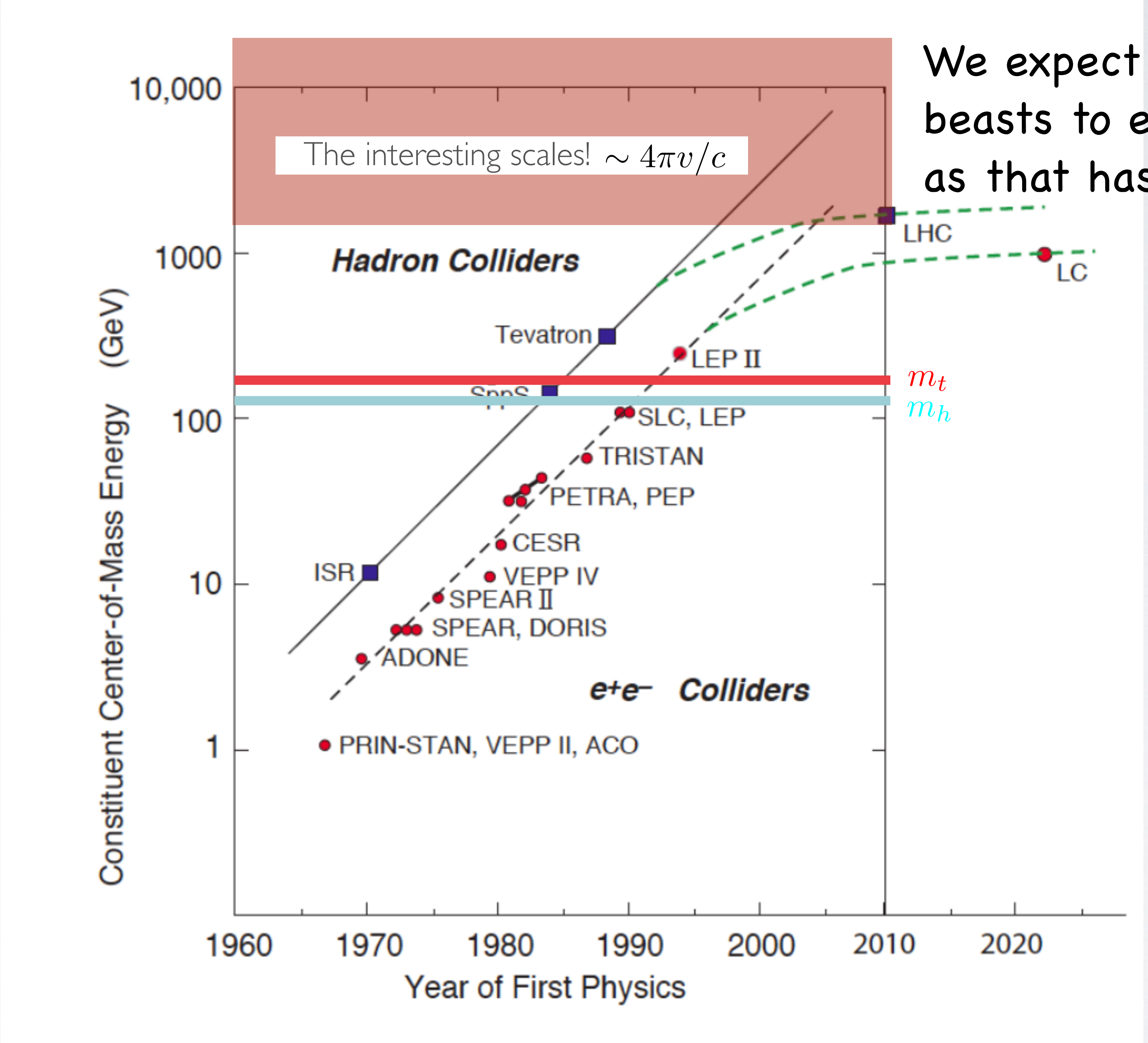
A beast has emerged from the vacuum like no other

CERN at the time of the discovery.



Was a bit hard to dig out, these gentleman supplied the theory that told us fundamentally its nature so we knew how to look for it in this mess.

So now what is the big picture?

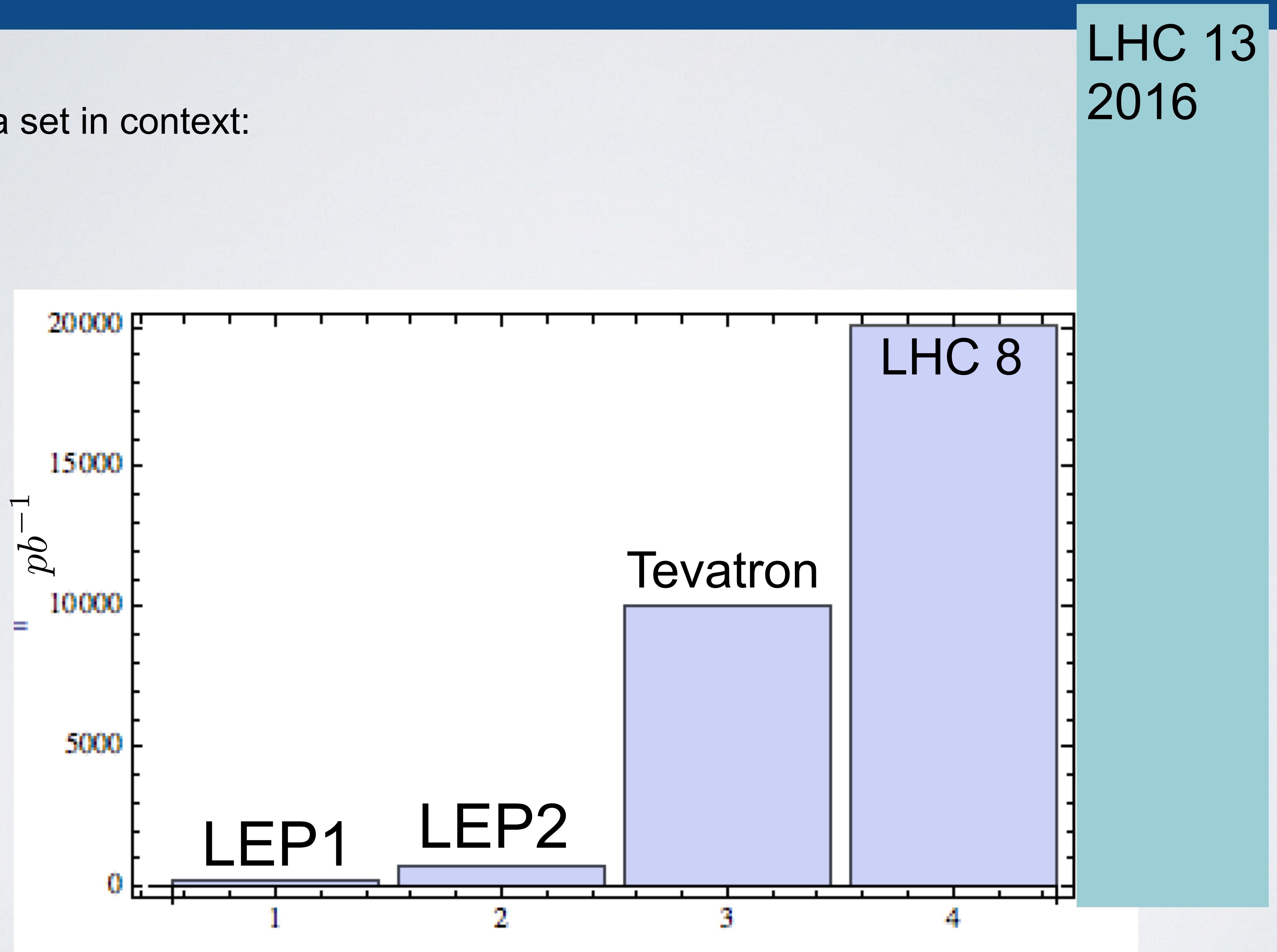


We expect even more vacuum beasts to exist at higher energies, as that has always been the case.

Images: http://www.hep.ucl.ac.uk/iop2010/talks/14.pdf

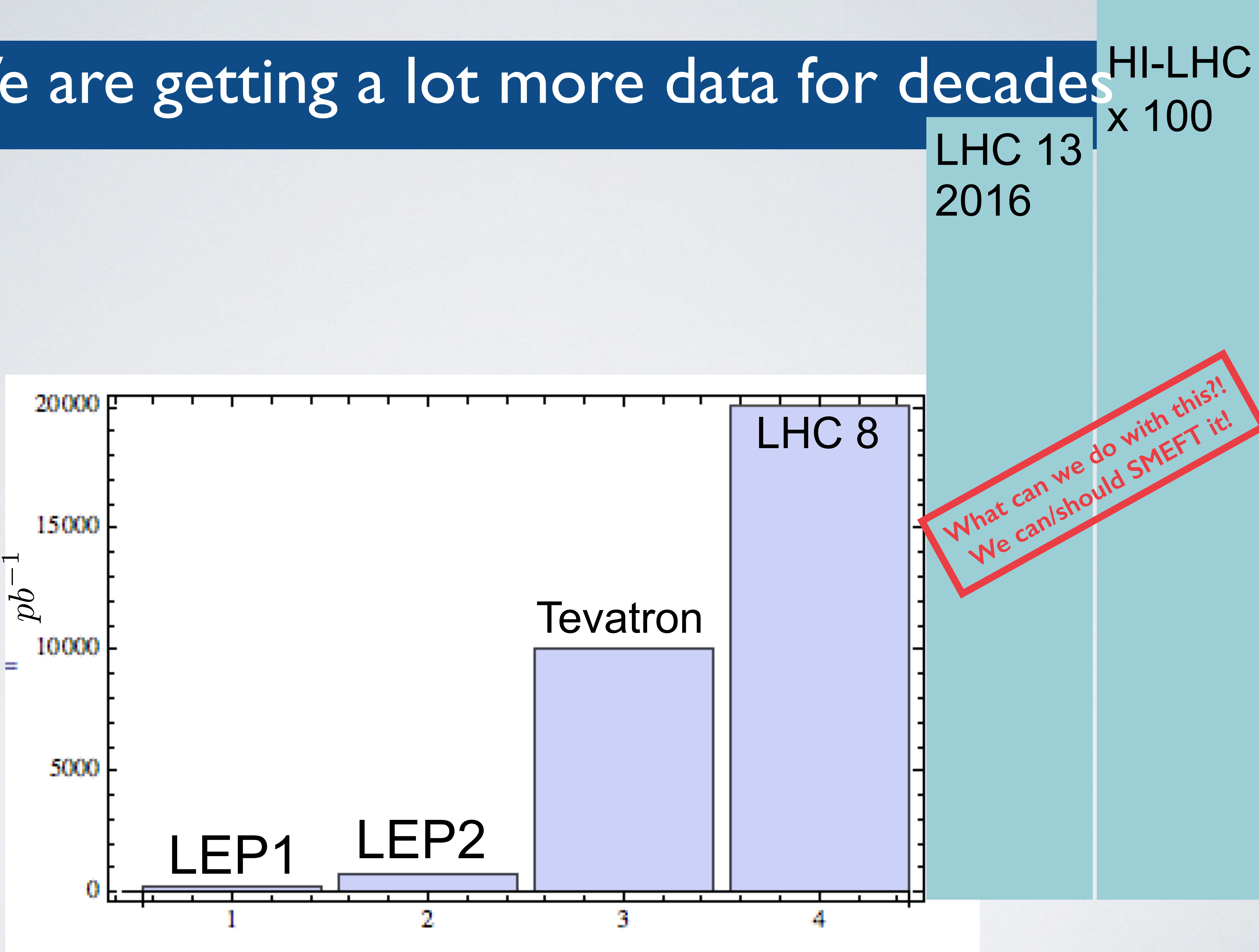
We are getting a lot more data for decades

The data set in context:



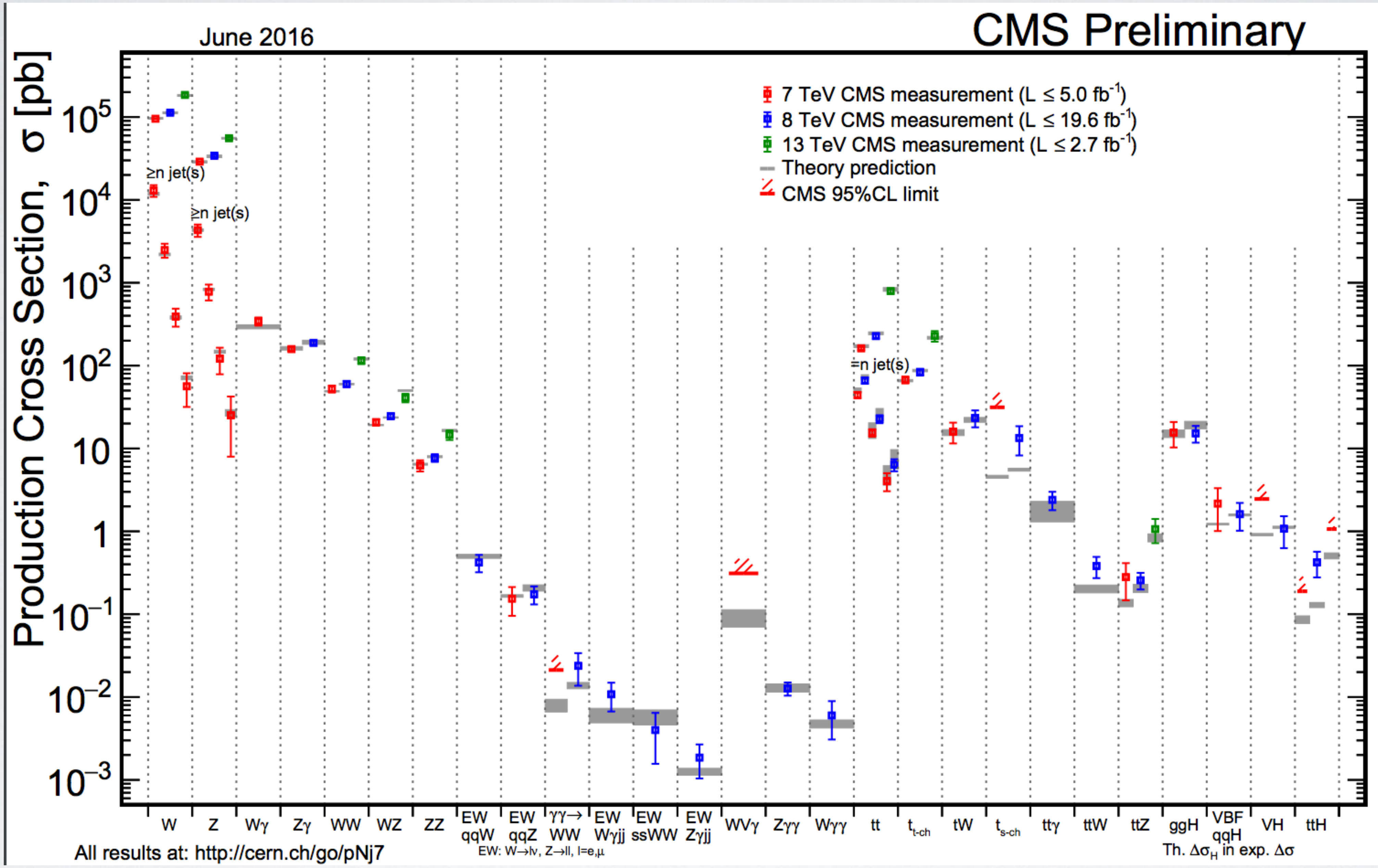
1990's data 2000's data Higgs Discovery data

We are getting a lot more data for decades



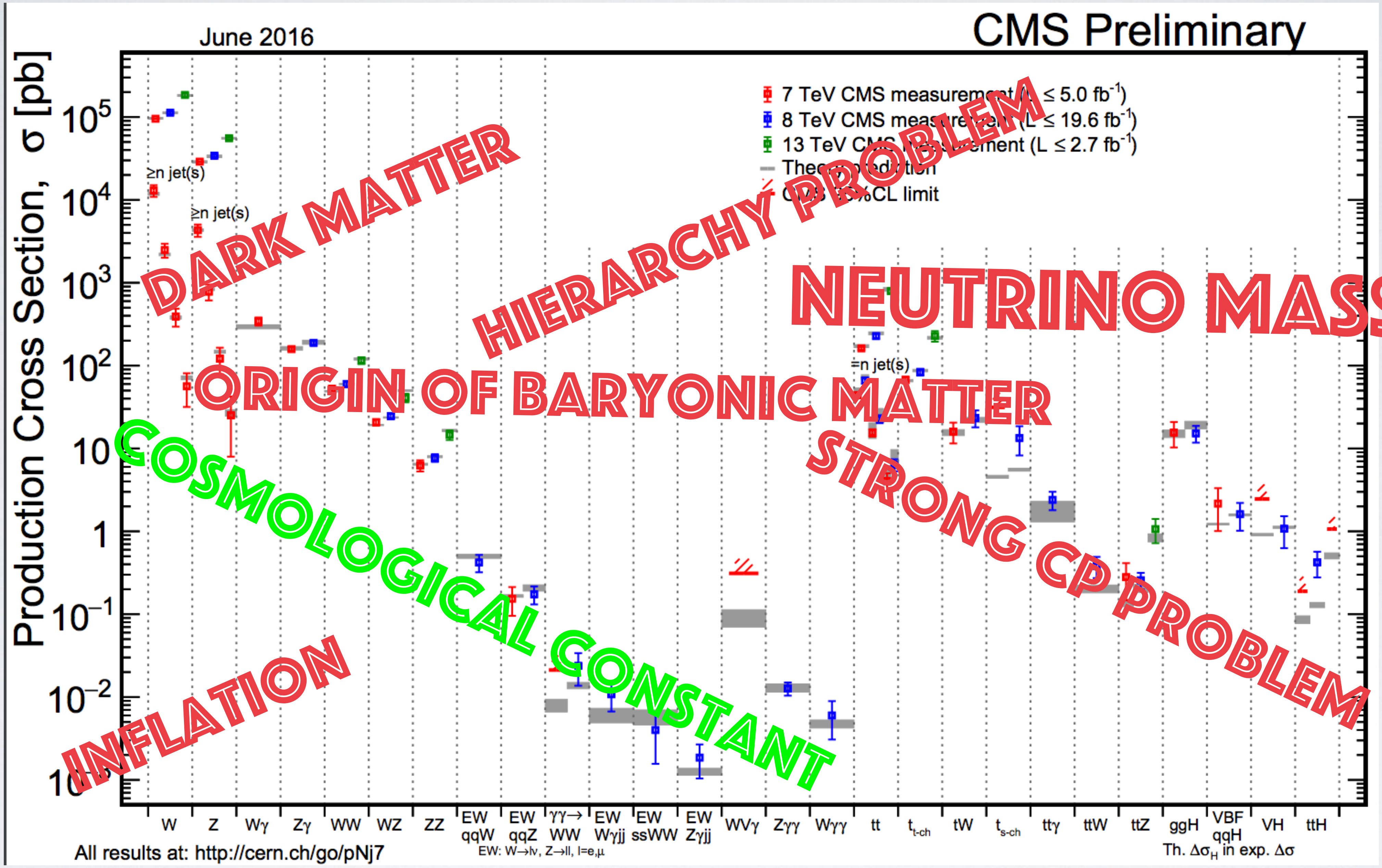
1990's data 2000's data Higgs Discovery data

Big picture: SM a very good approx.



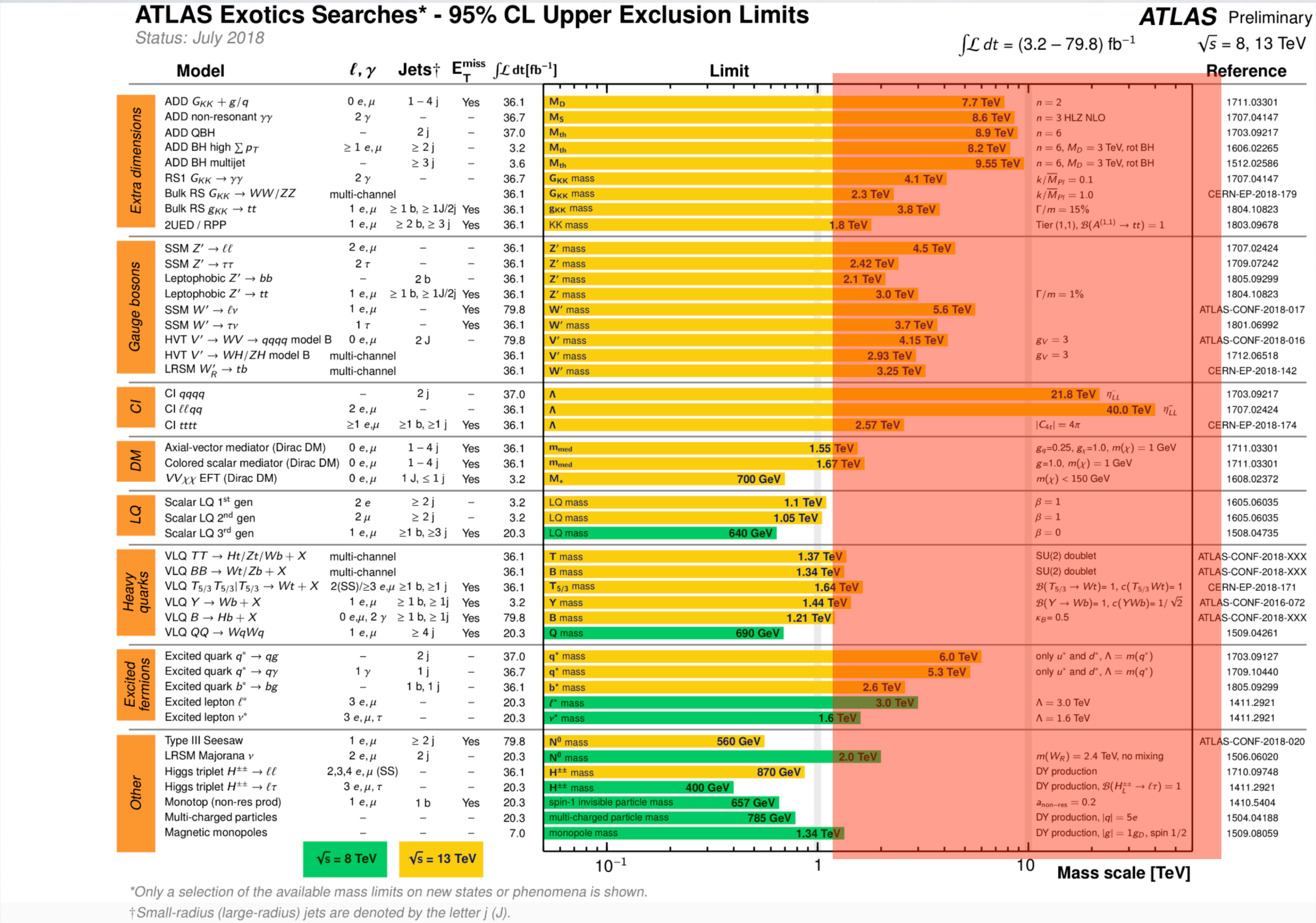
- The measurement precision and accuracy is generically not at the % level

How the heck is this holding up at all??



- Its a basic field theory fact (mostly) - decoupling.

RunII and beyond: Resonance limits to local operators



Now that these bounds have been pushed away from v

USE that

$$v/M < 1$$

to simplify/for more powerful conclusions:

- bound many models at once
- bound multiple resonances at same time

<u>Deviations then “look like” local contact operator effects in EFT</u>

General "BSM is heavy" approach is EFT

No BSM resonance seen (so far this is our situation)

$v/M < 1$

"Decoupling"

VERY! Efficient to constrain BSM/interpret the data in EFT

no other (hidden) light states

SMEFT

observed scalar in doublet

HEFT/nonlinear EFT

observed scalar not in doublet

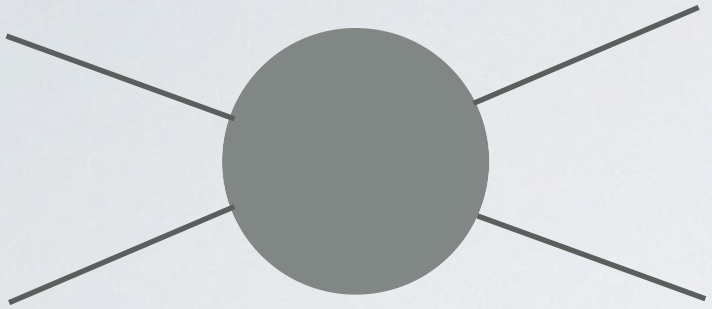
Basics of the SMEFT formulation:

IR operator form

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \mathcal{L}^{(5)} + \mathcal{L}^{(6)} + \mathcal{L}^{(7)} + \dots, \qquad \mathcal{L}^{(d)} = \sum_{i=1}^{n_d} \frac{C_i^{(d)}}{\Lambda^{d-4}} Q_i^{(d)} \quad \text{for } d > 4,$$

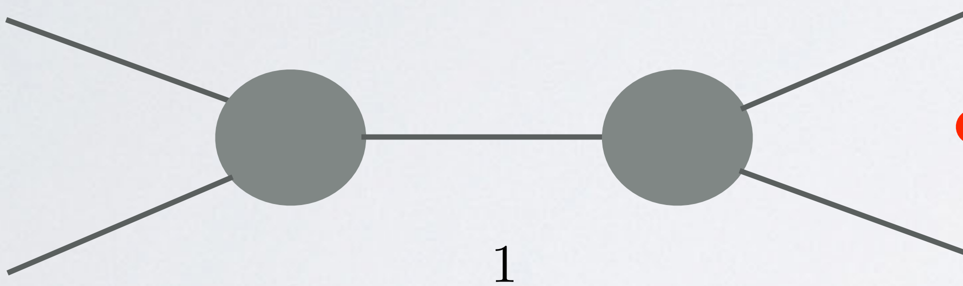
UV dependent Wilson coefficient and suppression scale

Probing an S-matrix below a particle threshold



- The observable is a function of the external Lorentz invariants: $f(s,t,u)$

- The observable is an analytic function of these invariants except in special regions of phase space where an internal state goes on-shell. This is the "Landau Principle".



$$\sim \frac{1}{s - m^2 + i\Gamma(s)\, m}$$

- IF the collision probe can never reach the $\sim m^2_{heavy}$ THEN the observable's dependence on that scale is DRAMATICALLY, practically, (wonderfully!) simplified

- No non-analytic behavior due to that state, and you can Taylor expand in LOCAL functions

$$\langle\rangle \sim O^0_{SM} + \frac{f_1(s,t,u)}{M^2_{heavy}} + \frac{f_2(s,t,u)}{M^4_{heavy}} + \cdots$$

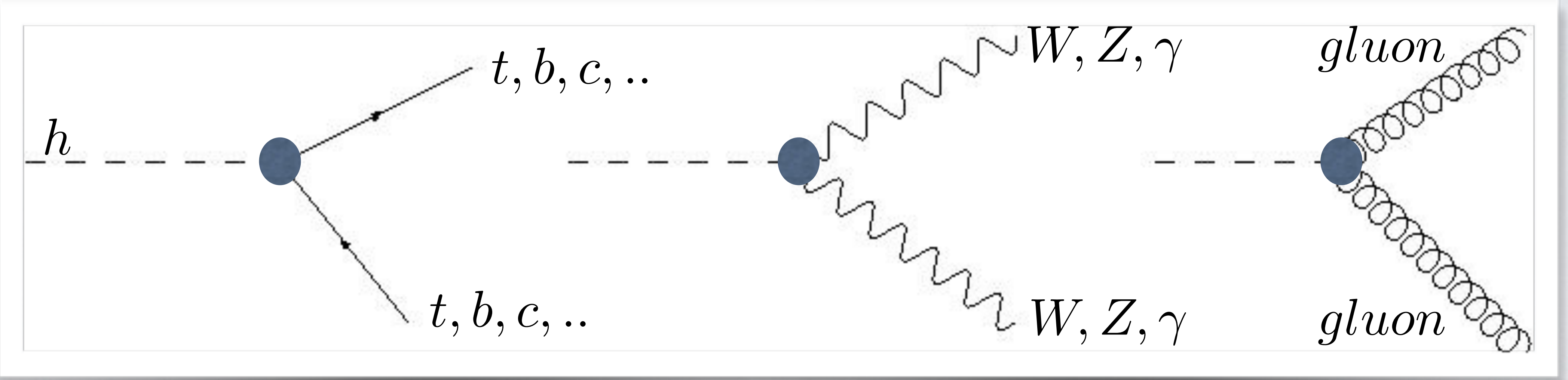
- The locality is due to the uncertainty principle

  See the review for the basics (1706.08945 Brivio,MT)

The research program

Now that we have found a Higgs:

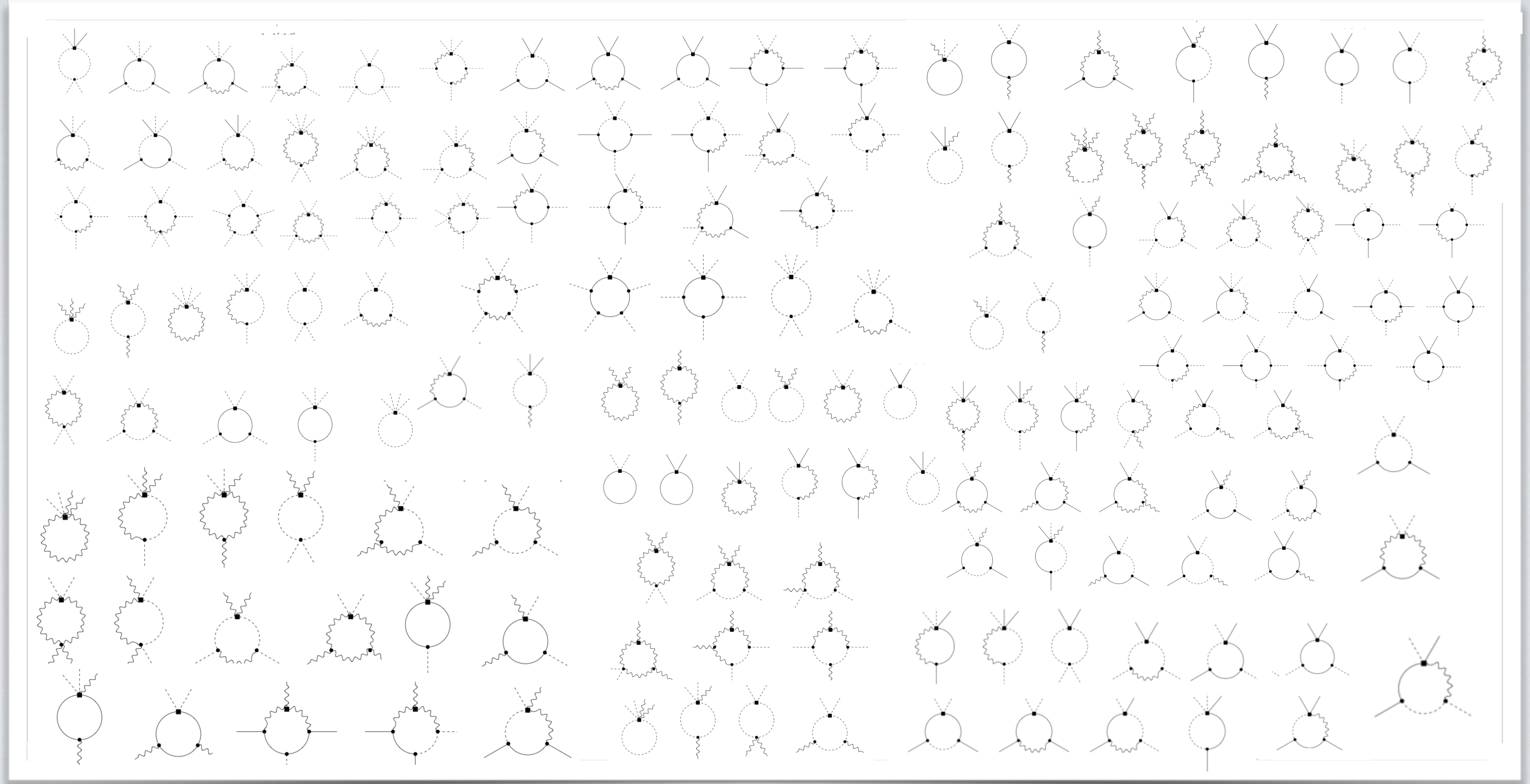
- We must calculate in a theory that takes into account that the Standard Model should be extended



- All interactions modified to most general ones allowed by symmetry and experimental bounds.
- Interaction pattern in the minimal theory can be broken. The Higgs is now a microscope for new physics.

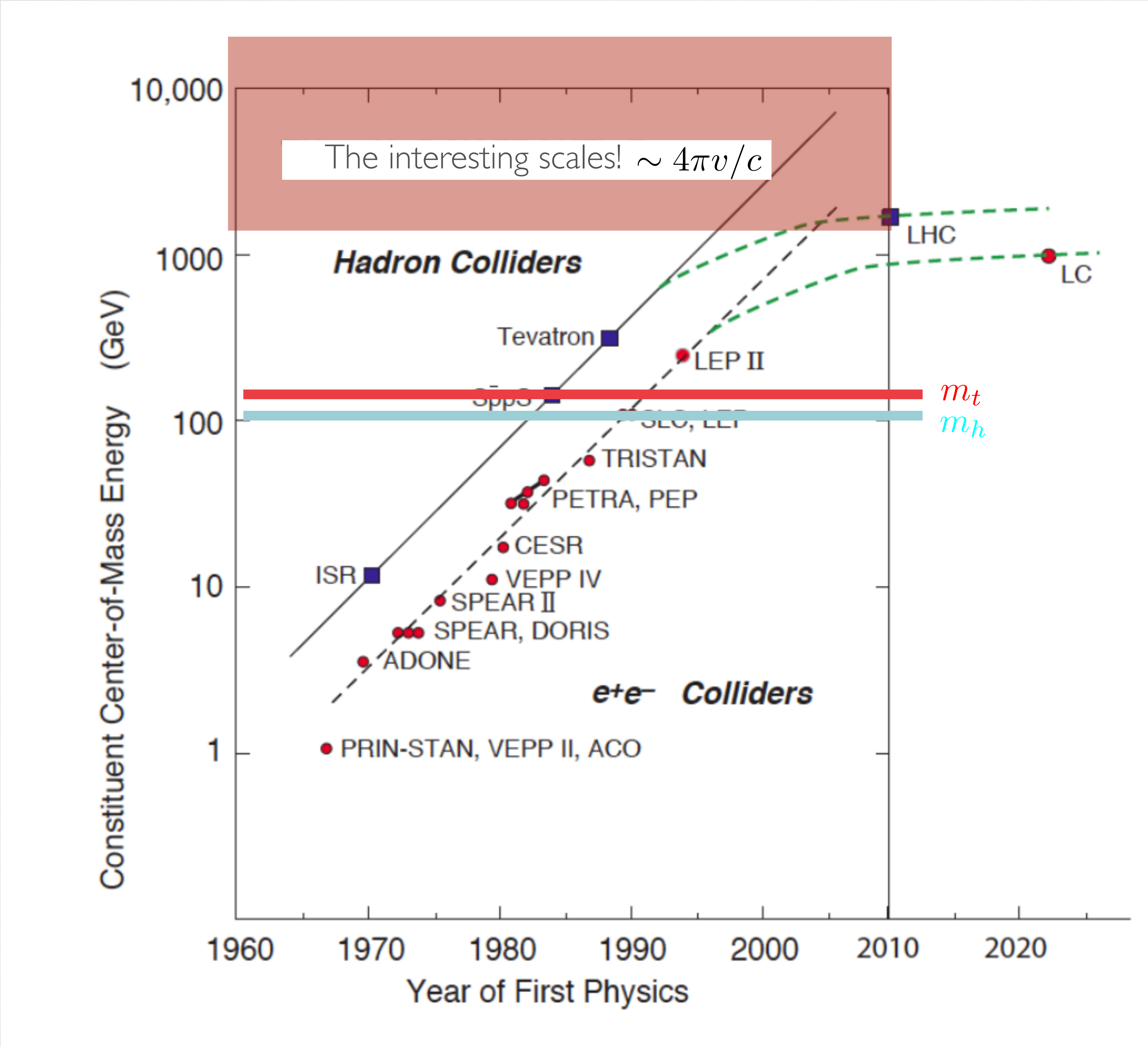
Not a trivial exercise

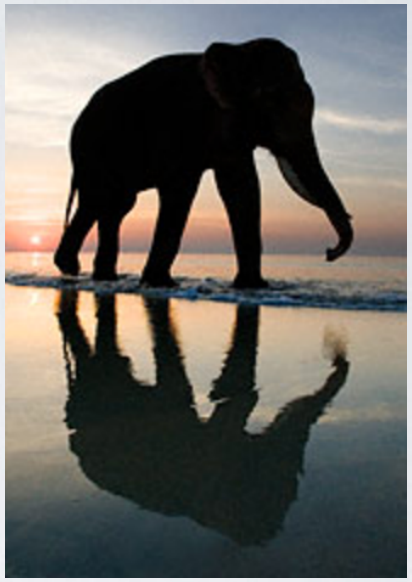
- Quantum mechanical corrections required. Such as



- Each dot can be 59 types of :

What are we doing in the EFT pheno group?



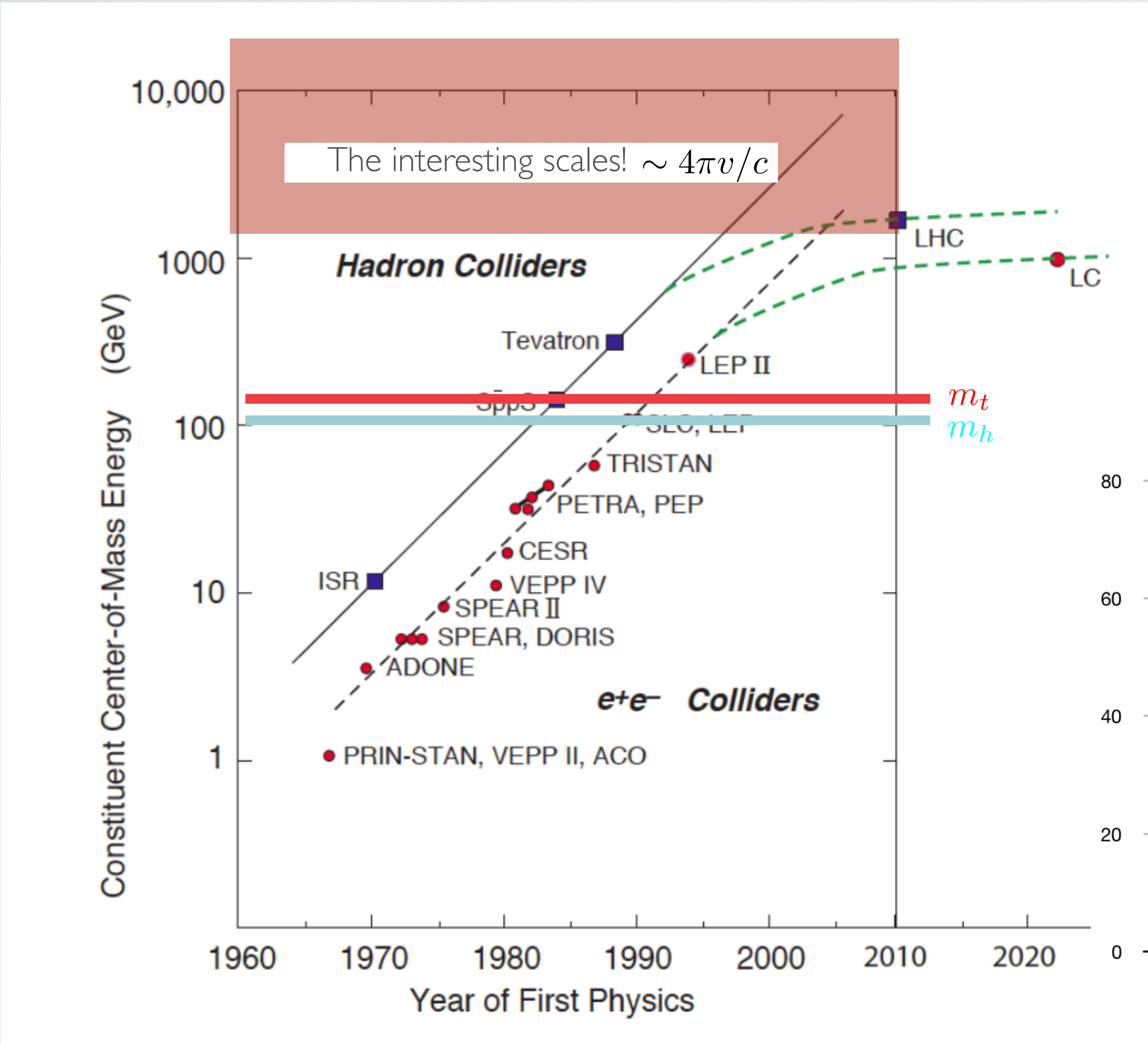


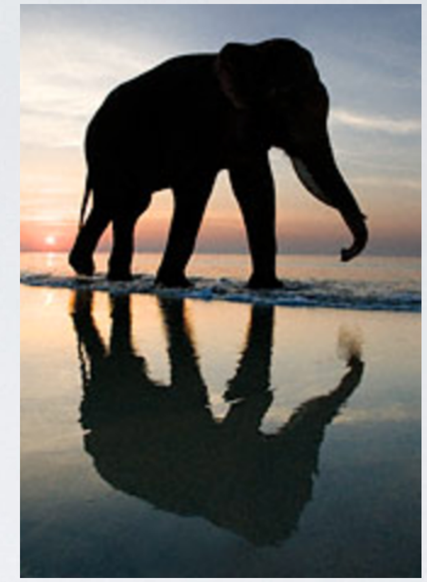
If the elephant is too heavy to make directly, look for its shadow

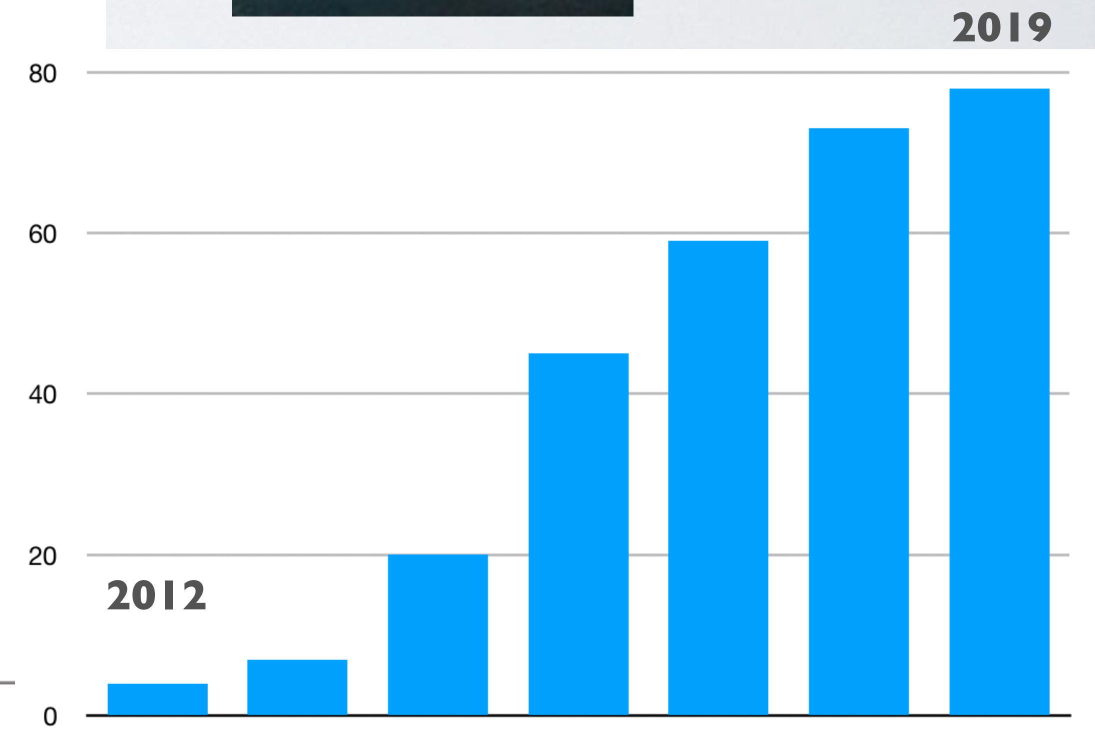
$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{SMEFT}$$

we work on interpreting the shadow of even newer beasts in the LHC data.

What are we doing in the EFT pheno group?







Papers each year
with SMEFT In title

What do students do?

Ward Identities for the Standard Model Effective Field Theory

Tyler Corbett,* Andreas Helset,† and Michael Trott‡

Consistent constraints on the Standard Model Effective Field Theory

e Berthier and Michael Trott

The Z decay width in the SMEFT: y_t and λ corrections at one loop.

Christine Hartmann[a], William Shepherd[a,b] and Michael Trott[a]

Equations of motion, symmetry currents and EFT below the electroweak scale

Andreas Helset and Michael Trott

Higgs Decay to Two Photons at One Loop in the Standard Model Effective Field Theory.

Christine Hartmann and Michael Trott,

Interpreting W mass measurements in the SMEFT.

Mikkel Bjørn and Michael Trott,

On one-loop corrections in the Standard Model Effective Field Theory; the $\Gamma(h \to \gamma\gamma)$ case.

Christine Hartmann and Michael Trott,

Towards consistent Electroweak Precision Data constraints in the SMEFT

Laure Berthier and Michael Trott

Effective interpretations of a diphoton excess

Laure Berthier,[a] James M. Cline,[a,b] William Shepherd,[a] Michael Trott[a]

On interference and non-interference in the SMEFT

Andreas Helset and Michael Trott

Gauge fixing the Standard Model Effective Field Theory

Andreas Helset[a],* Michael Paraskevas[b],† and Michael Trott[a]‡

Incorporating doubly resonant $W^{\pm}$ data in a global fit of SMEFT parameters to lift flat directions.

Laure Berthier, Mikkel Bjørn and Michael Trott

On expansions in neutrino effective field theory

Gitte Elgaard-Clausen and Michael Trott

Equations of Motion for the Standard Model Effective Field Theory: Theory and Applications.

Abdurrahman Barzinji, Michael Trott and Anagha Vasudevan,

Recent Phd school slides with info:

yumpu.com/en/document/view/62870587/marialaach

The research of this group is defining the LHC physics legacy:

https://indico.cern.ch/event/826136/contributions/3603139/attachments/1928348/3195116/MethodologyEF_STXS.pdf