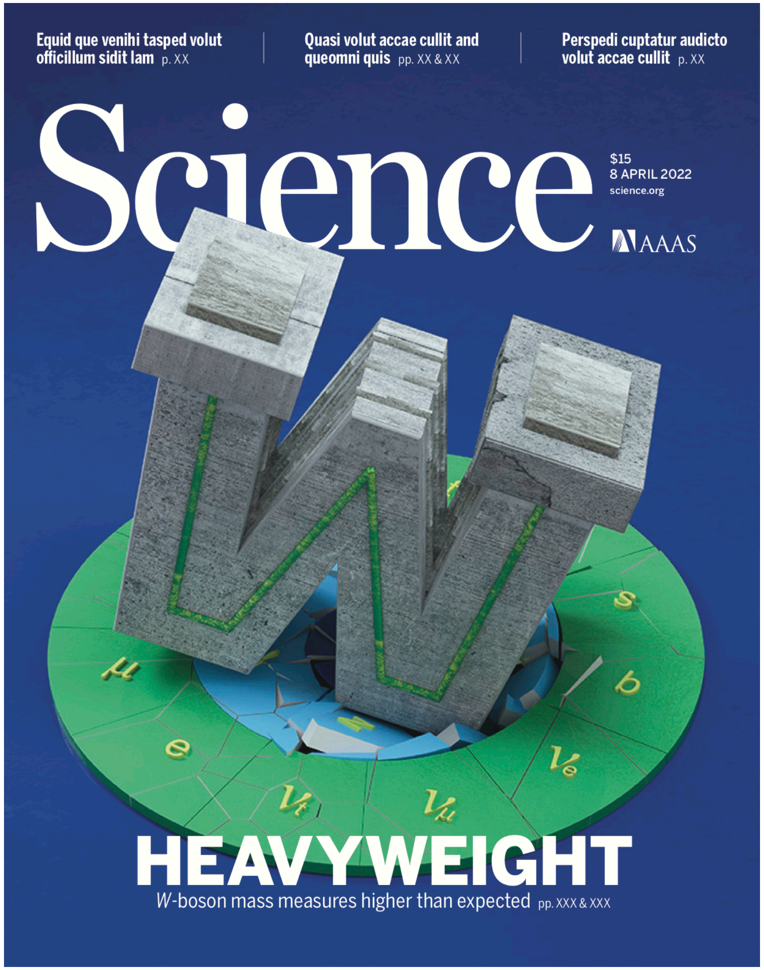
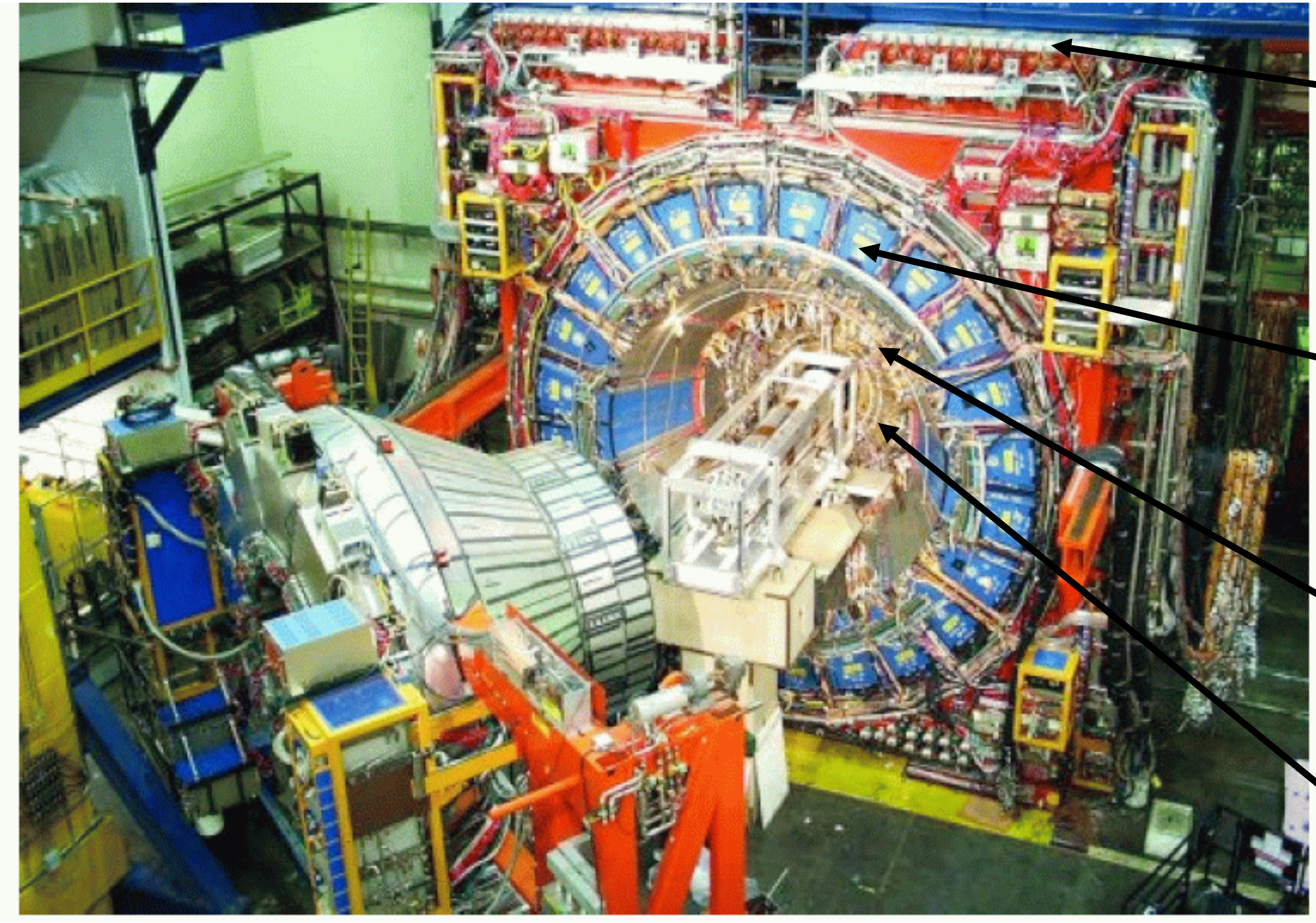
The Higgs is Not Enough

Verdict from the Heavyweight W boson

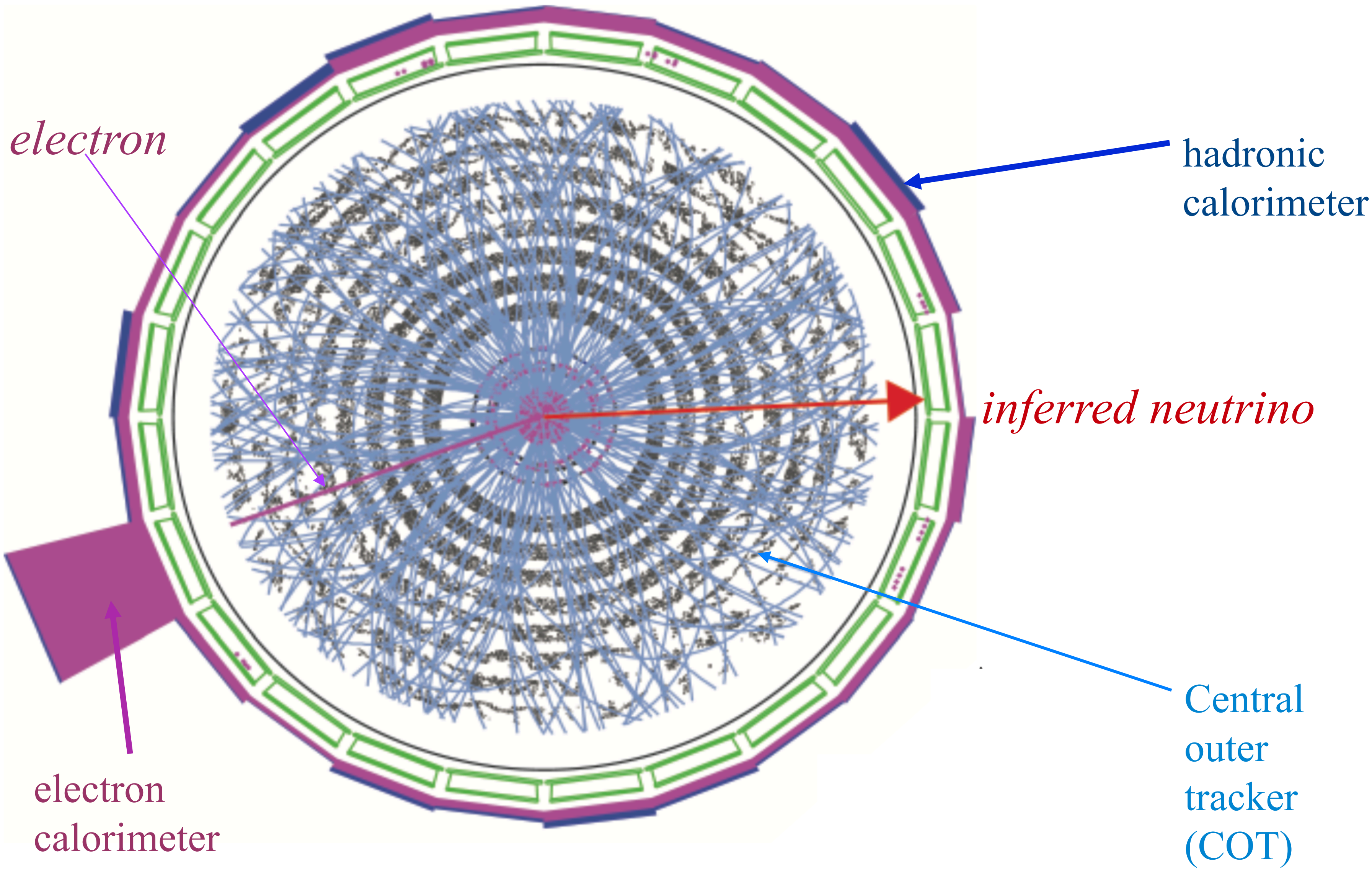


Ashutosh Kotwal
Duke University

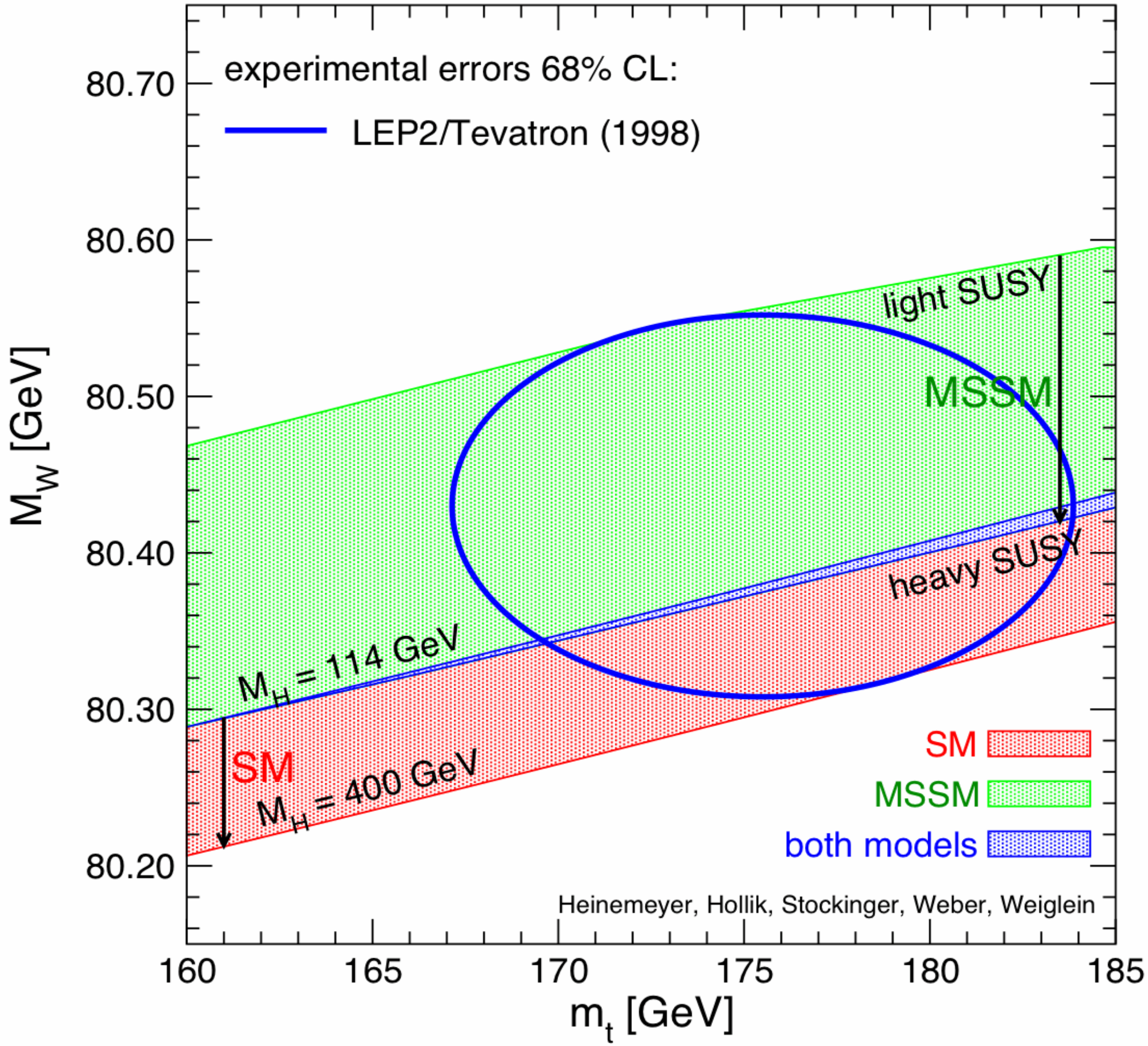
Collider Detector at Fermilab (CDF)



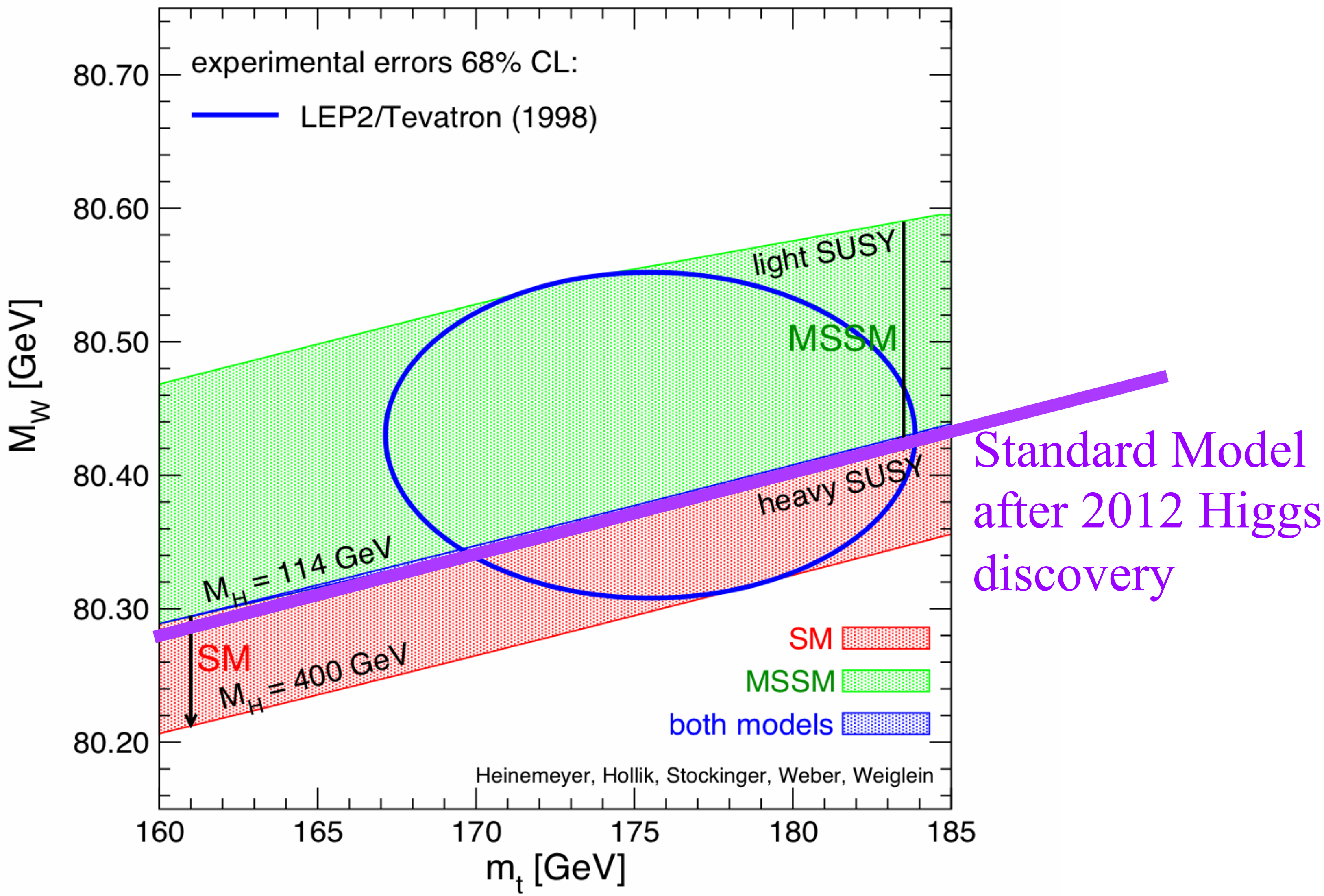
W boson Production Event



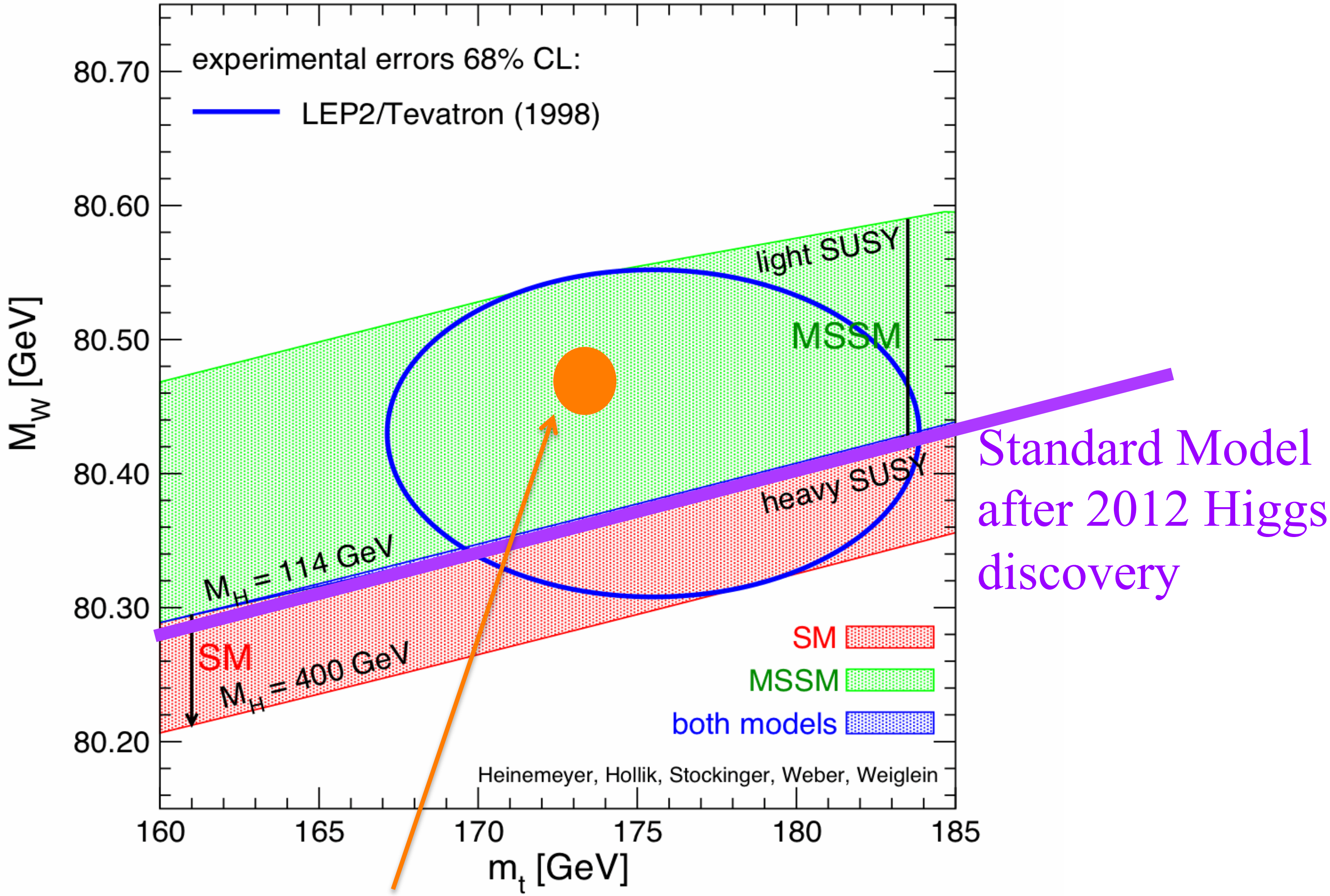
1998 Status of M_W *vs* M_{top}



1998 Status of M_W *vs* M_{top}



2022 Status of M_W *vs* M_{top}



Science **376**, 170 (April 7, 2022); DOI: 10.1126/science.abk1781

Synopsis

- The *W* boson mass is sensitive to new laws of nature through quantum fluctuations

- New measurement is twice as precise as previous measurements

  - $M_W = 80433.5 \pm 9.4$ MeV

- Significant difference from Standard Model calculation of $M_W = 80{,}357 \pm 6$ MeV

    - significance of 7.0σ (>5σ is considered scientific discovery)

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  - significance of 7.0σ (>5σ is considered scientific discovery)
  - The Higgs boson is not the end of the story

CDF M_W *vs* m_{top}

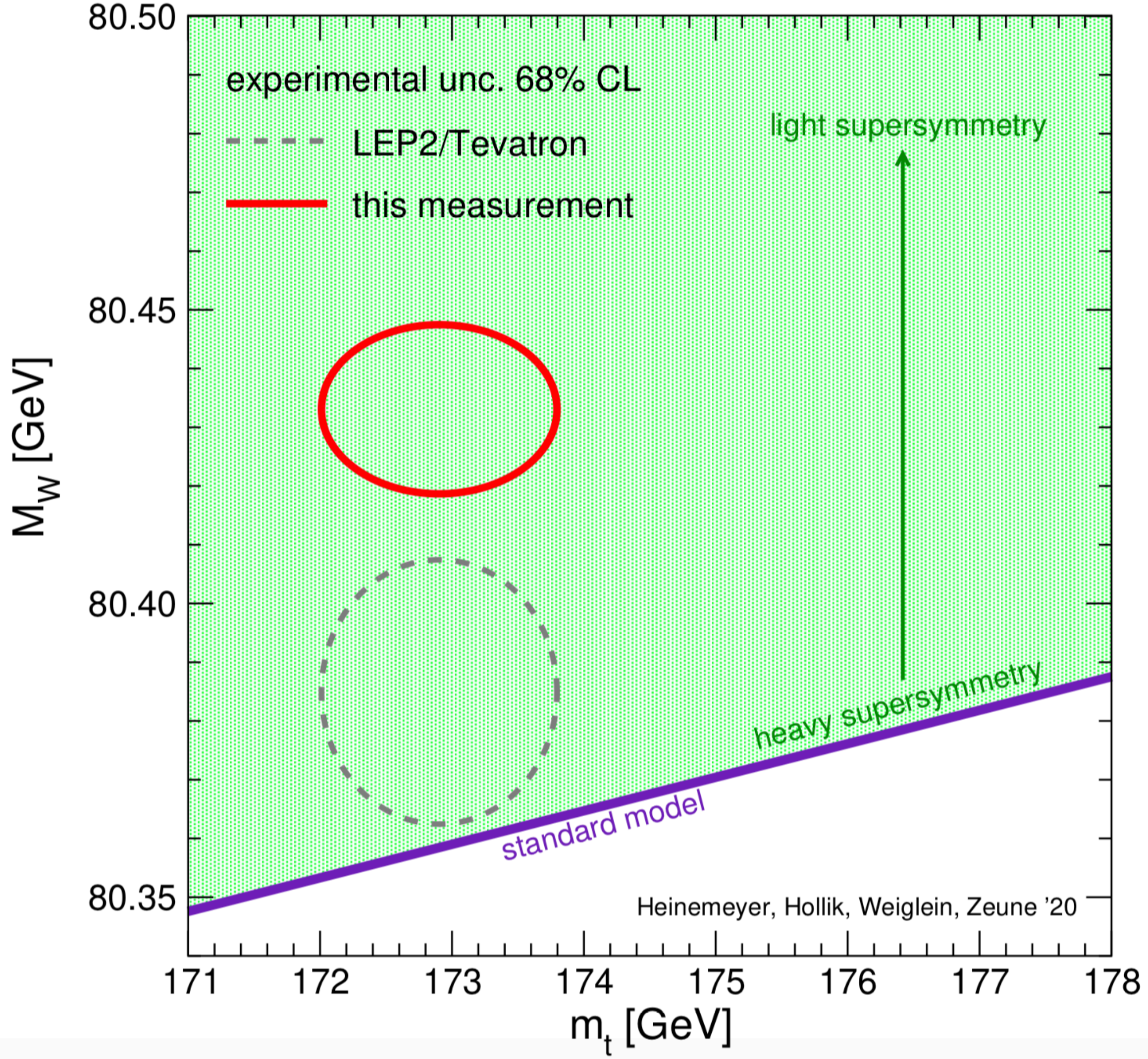


Fig. 1
from paper

7 sigma difference from Standard Model theory

(exceeds 5 sigma scientific threshold for discovery)

W Boson Mass Measurements from Different Experiments

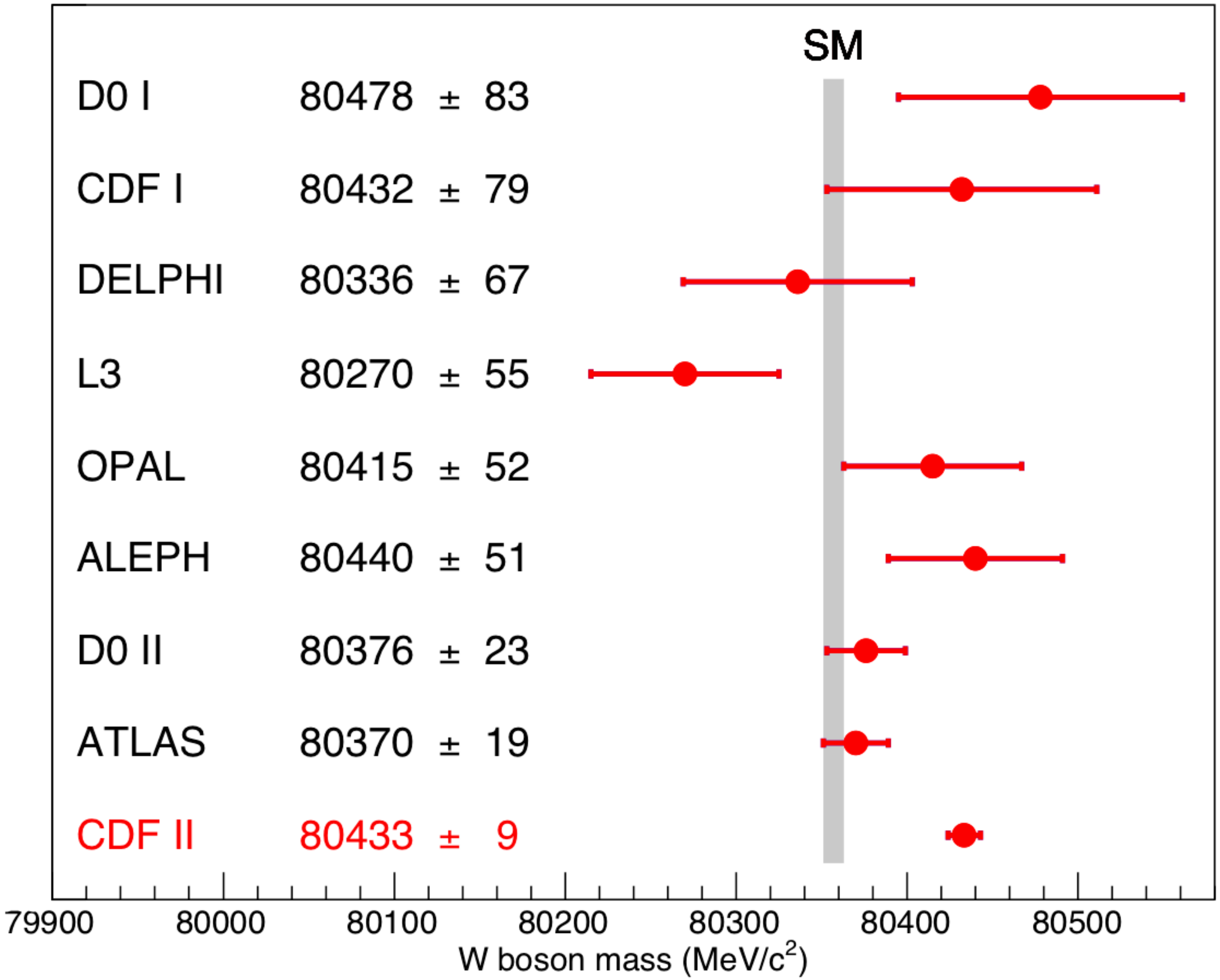


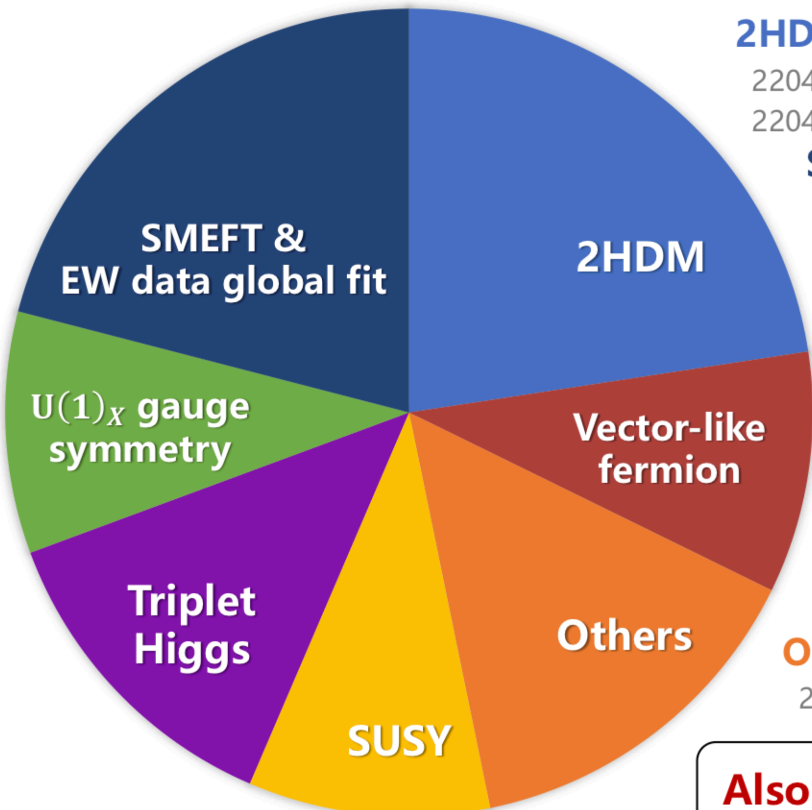
Fig. 5
from paper

SM expectation: $M_W = 80{,}357 \pm 4_{\text{inputs}} \pm 4_{\text{theory}}$ MeV

What's Next?

Citations in 2 months since publication (April 8, 2022): 133

CDF W mass



Total number: 62*

2HDM: 14
2204.03693/03767/04834/04688/06485/05085/05269/05303
2204.05975/09001/05728/08406/08390/10338

SMEFT & EW data global fit: 13
2204.04805/05260/05284/05267/05992/05965/05965/08546
2204.08440/10130/04191/05283/04204

Triplet Higgs: 8
2204.05031/05760/07144/07511/07844/08266/10274/10315

SUSY: 6
2204.04286/04356/04202/05285/06541/07138

$U(1)_X$ gauge symmetry: 6
2204.07100/08067/09487/09024/09585/10156

Vector-like fermion: 6
2204.07022/07411/08568/09477/09671/05024

Others: 9 (Non-unitarity, leptoquark, singlet scalar, ...)
2204.04559/04672/04770/04514/05302/06327/03996/05942/09031

* Preprints as of April 25th are counted.

Also related to
dark matter, neutrino masses/seesaw, flavor violation, muon g-2, flavor anomalies, gravitational waves, ...

The Heavyweight W boson

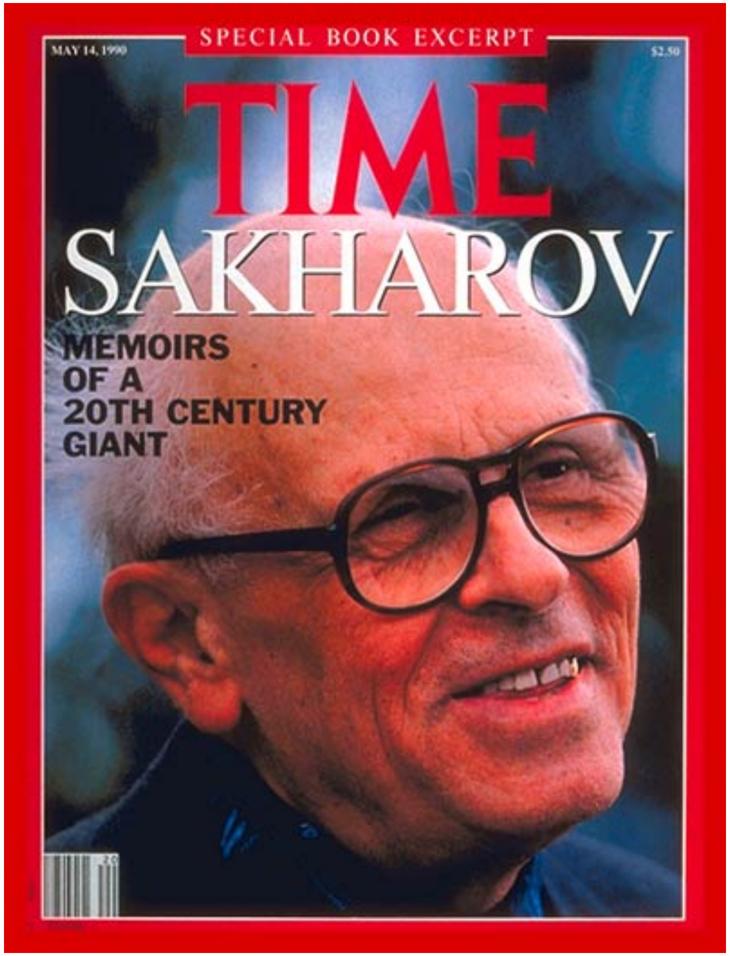
&

The Mystery of the Missing AntiMatter

Matter-AntiMatter Symmetry

- Laws of nature have been proven to be (almost) exactly identical for matter and antimatter
- There should be equal amounts of matter and antimatter in the Universe
- Where is the *MISSING* antimatter?
- *WE* need an excess of matter over antimatter in order for galaxies, stars, planets and *us* to exist…

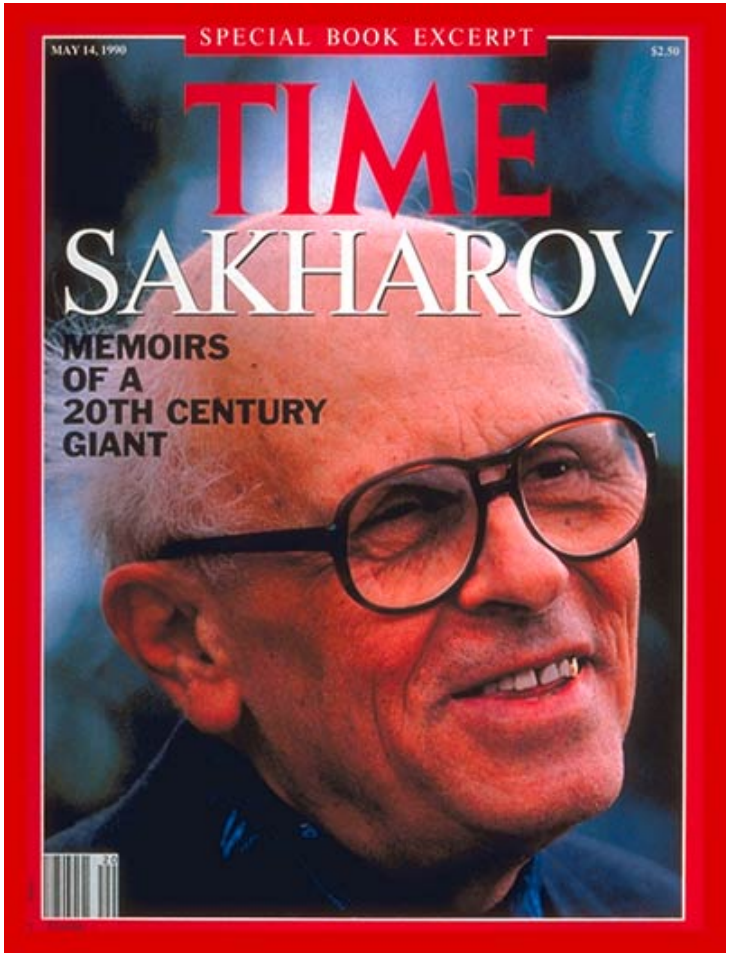
Sakharov Conditions for Matter Excess



Andrei Sakharov calculated three conditions that must exist in early Universe for creation of matter excess

The Standard Model of Particle Physics satisfies only one of these conditions

Sakharov Conditions for Matter Excess



If the Higgs boson had a partner

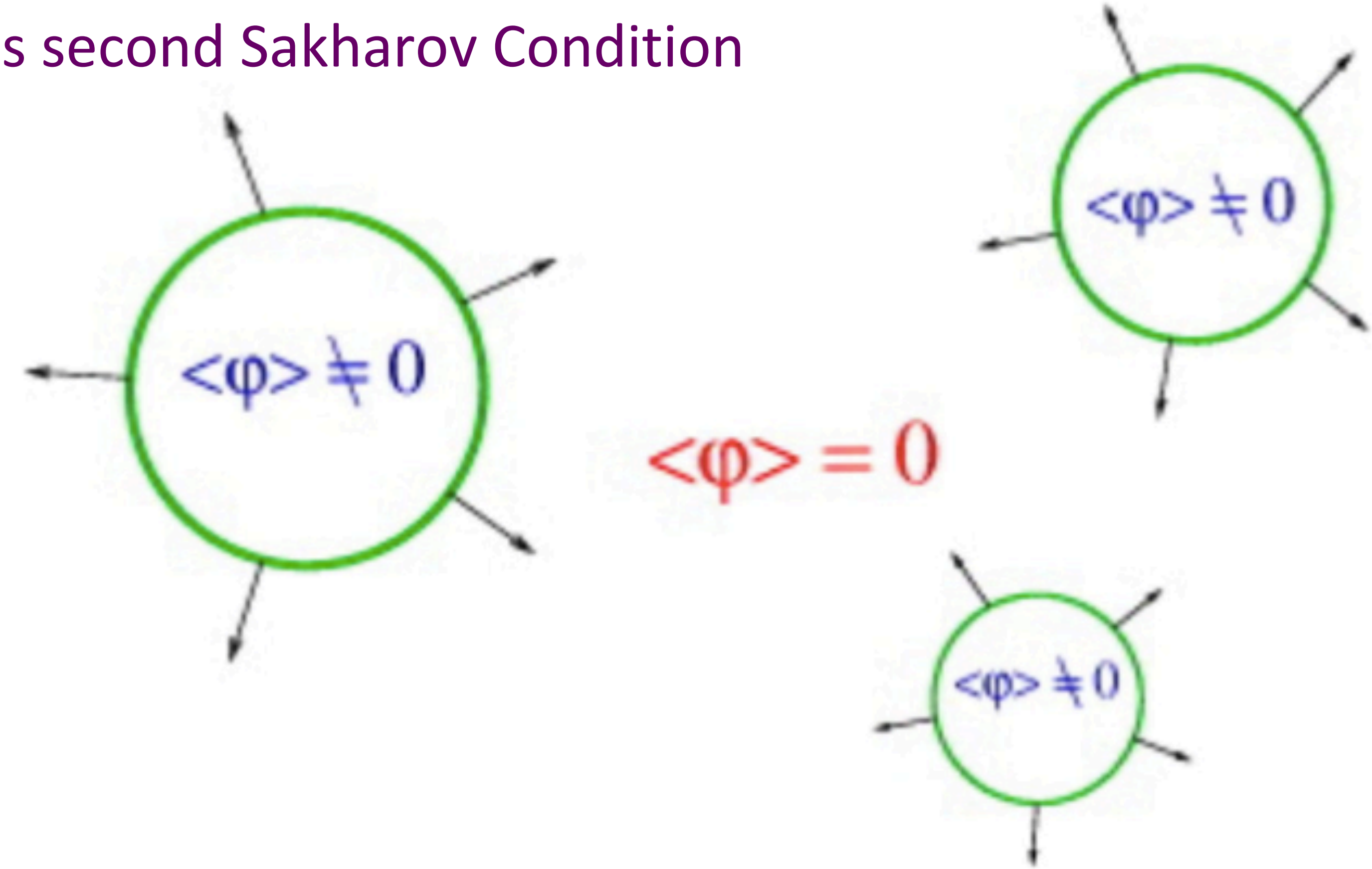
i.e. a second Higgs-like particle existed…

The second Sakharov condition can be satisfied !

Higgs Condensation after Big Bang
aided by Higgs-like Partner

Higgs droplets form and expand, filling the whole Universe

Satisfies second Sakharov Condition



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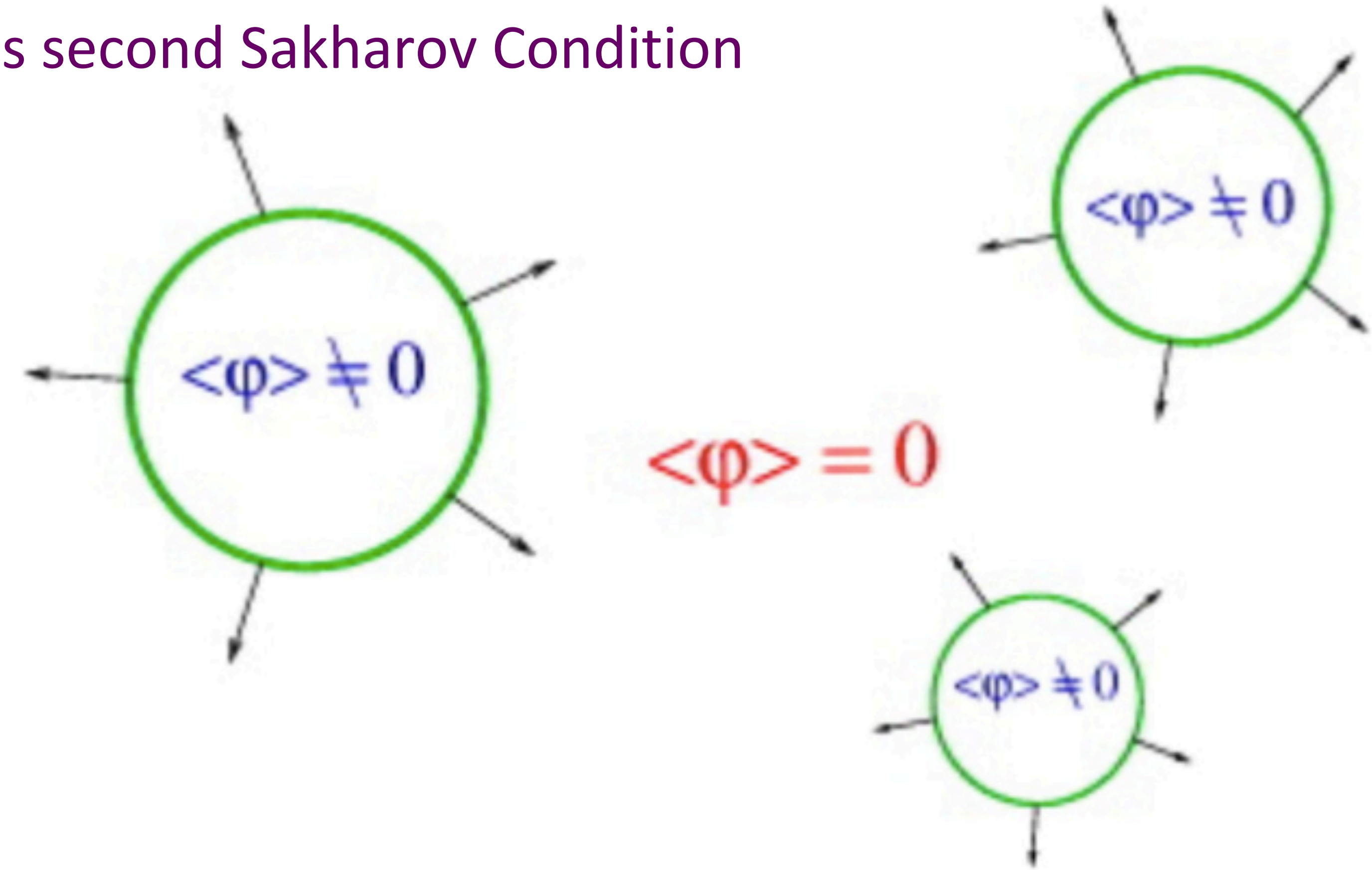
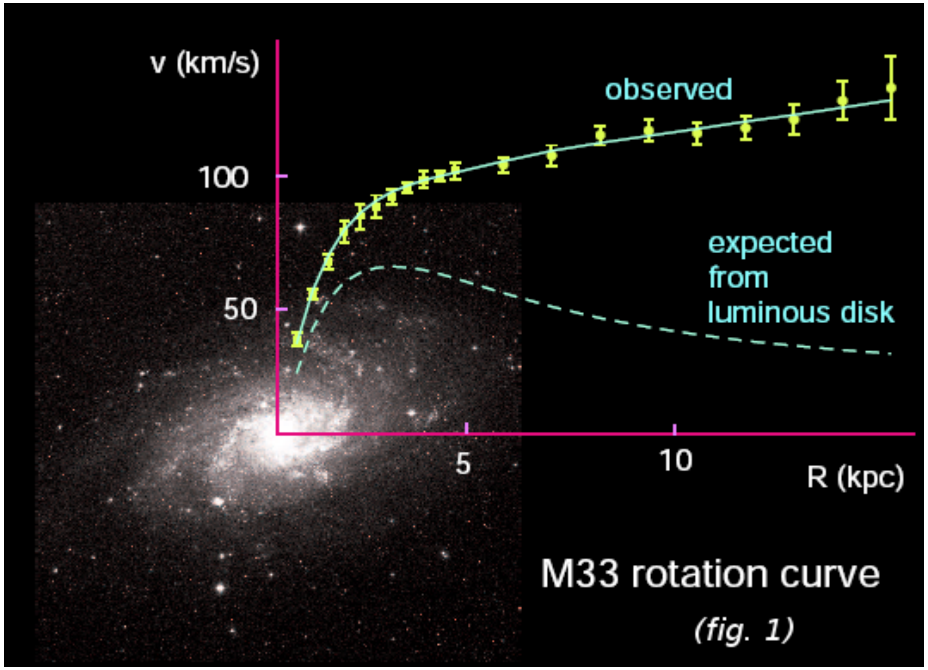
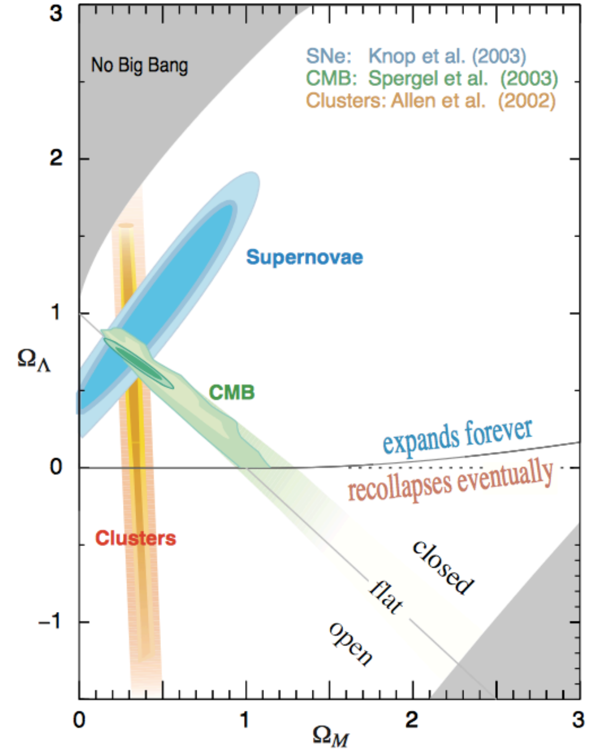
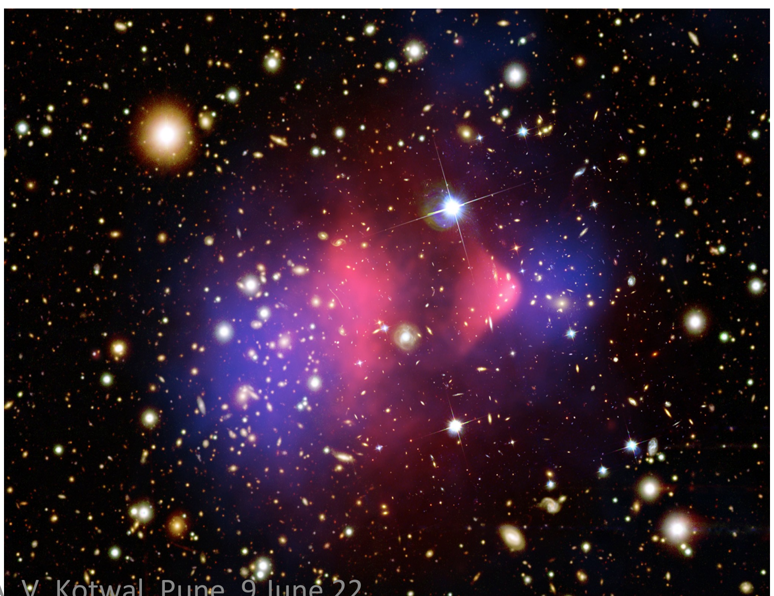


Higgs-like partner's existence increases the W boson mass by the observed 0.1%

Dark Matter Particles







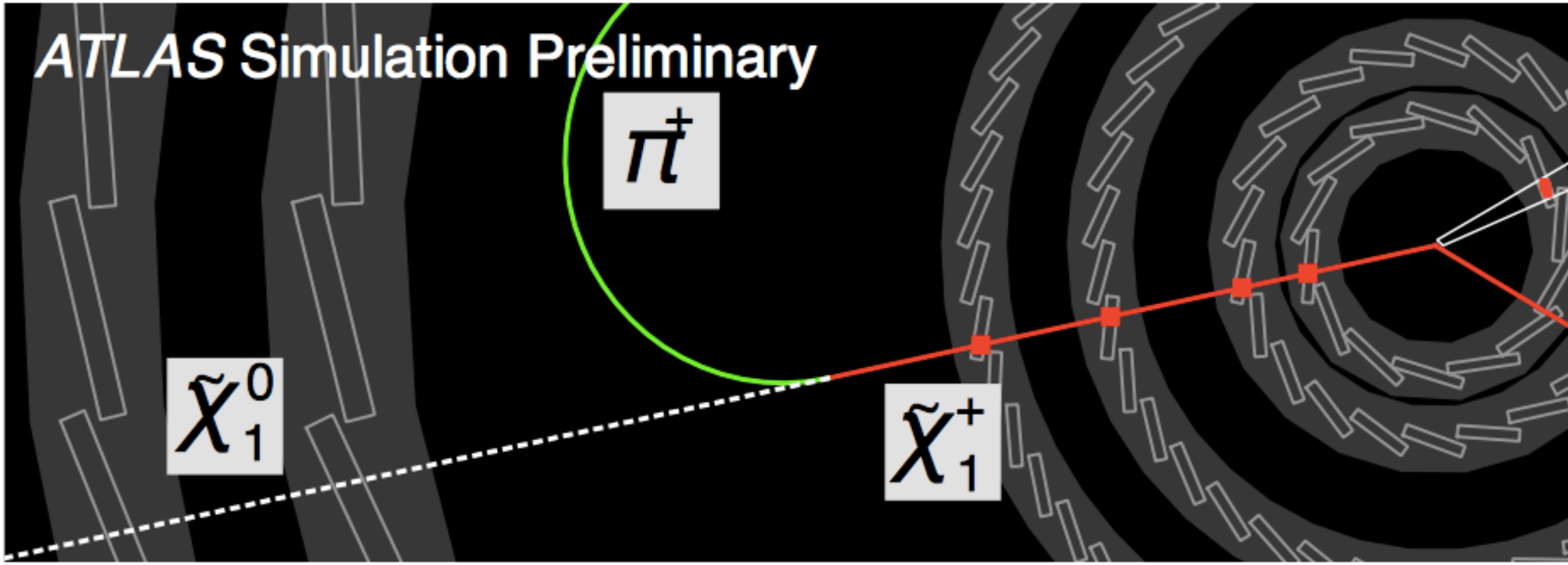
A consistent hypothesis is the existence of new particles beyond the Standard Model

W boson mass is sensitive to new, dark matter particles

My Next Research Project

Detect Dark Matter Production at Large Hadron Collider (LHC)

Dark Matter Production at Large Hadron Collider (LHC)



Explains Dark Matter production by the Big Bang in the Universe

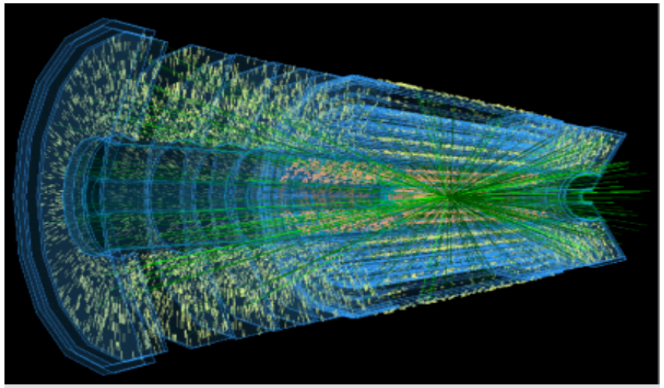
I have designed a silicon chip that uses Artificial Intelligence to identify this process at the LHC

Published in Nature Scientific Reports 11, 18543 (2021)

Operates 100 times faster than latest computers

Capturing secrets of the Universe on a silicon chip

September 27, 2021



Rendering of a collision of particle beams at the LHC (Credit: ATLAS Experiment © 2021 CERN)

Imagine taking a snapshot of the Big Bang with a computer chip. Ashutosh Kotwal, Fritz London Professor of Physics at Duke University, thinks we may have a first step in that direction.

In a paper published last week in the journal Nature Scientific Reports, Kotwal melds two fascinating ideas from technology and physics - the use of artificial intelligence and machine learning for image recognition and the search for dark matter, the mysterious stuff that makes up 84% of the total amount of matter in the universe.

As a particle physicist, Kotwal is pursuing the hypothesis that dark matter is made up of exotic particles – particles that are poorly understood or that don't behave according to the known physics laws. Just like electrons, protons, neutrons and neutrinos, such stable dark matter particles would have been produced in a fraction of a second after the Big Bang, in those early moments when the universe was extremely hot.

The Large Hadron Collider (LHC) at the CERN Laboratory in Switzerland, the world's highest energy proton-proton collider, helps physicists study and understand how exotic particles are produced. Could some of the processes active at the time of the Big Bang also occur at the LHC, leading to dark matter production? And if so, how can we catch these processes in action?

The catch is that dark matter by its very nature interacts very weakly with ordinary matter. In fact, all we know about dark matter is that it obeys the law of gravity. Its gravitational effects in and around the galaxies of the cosmos have been observed. However, the gravitational force is far too weak

https://physics.duke.edu/news/capturing-secrets-universe-silicon-chip