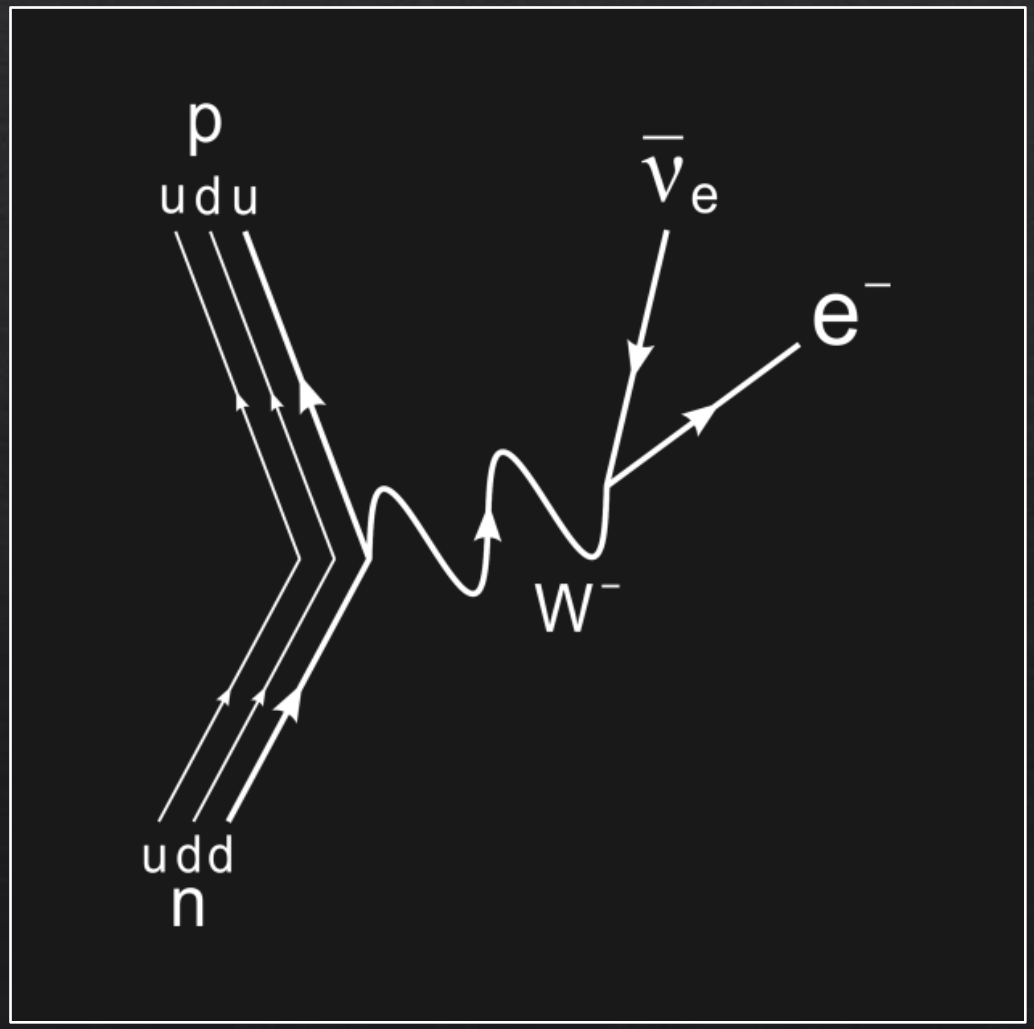
The Search for 2HDM

Dr. Chung Kao and Ishan Varma

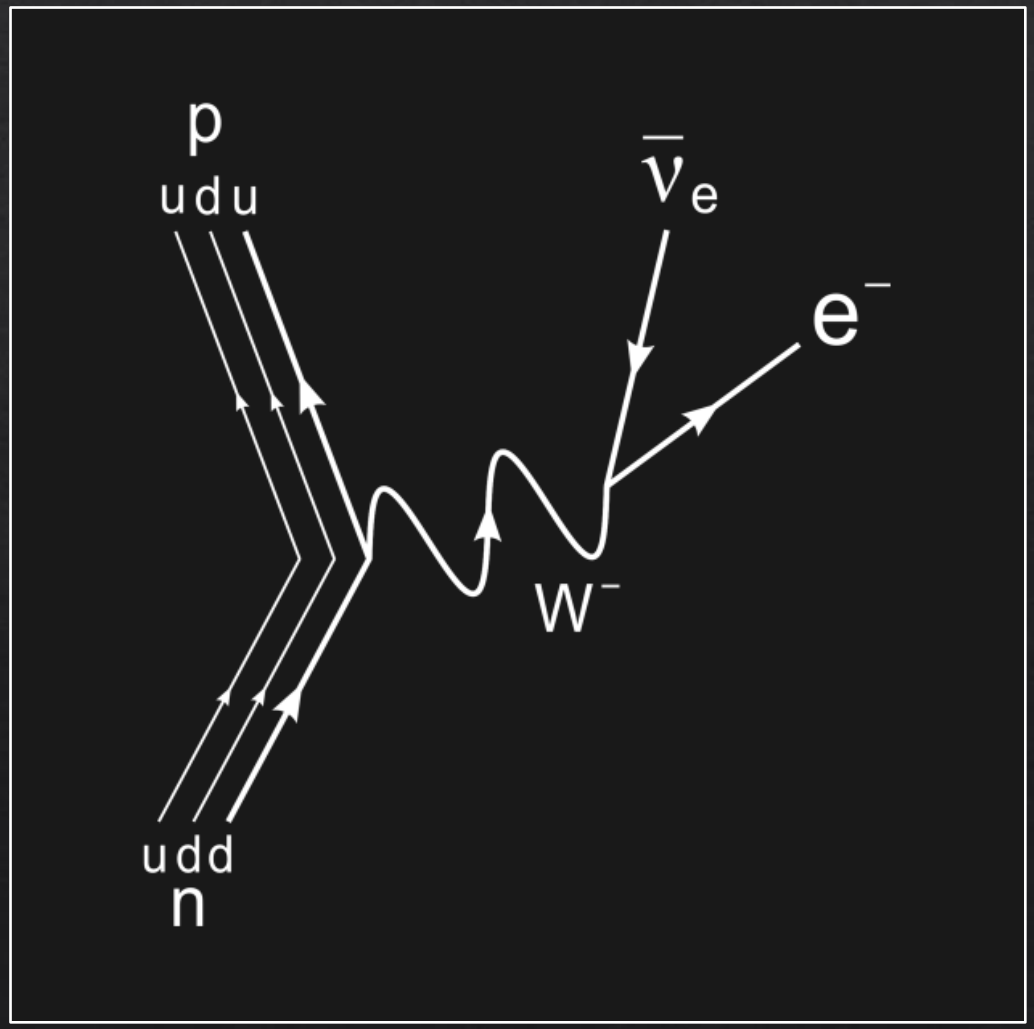
The Standard Model

- It's a quantum field theory



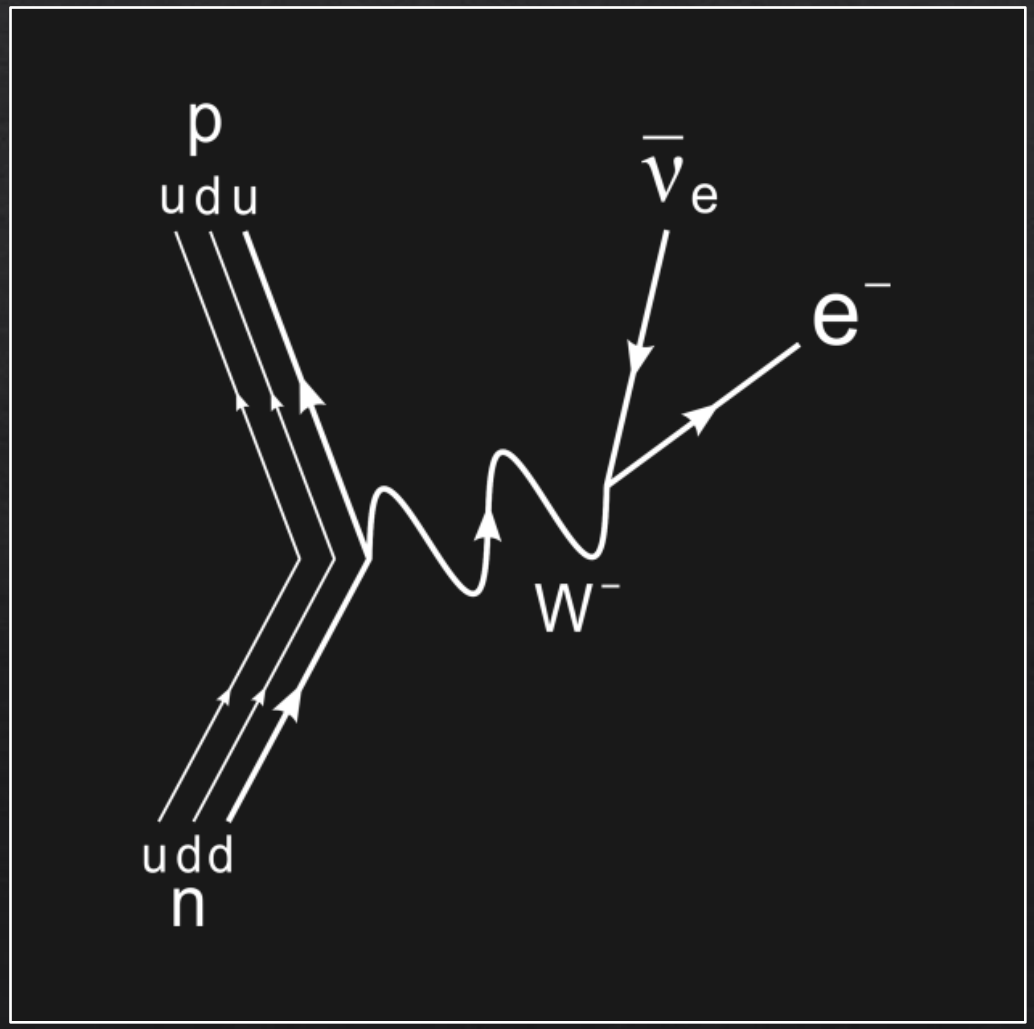
The Standard Model

- It's a quantum field theory
- It's successful…



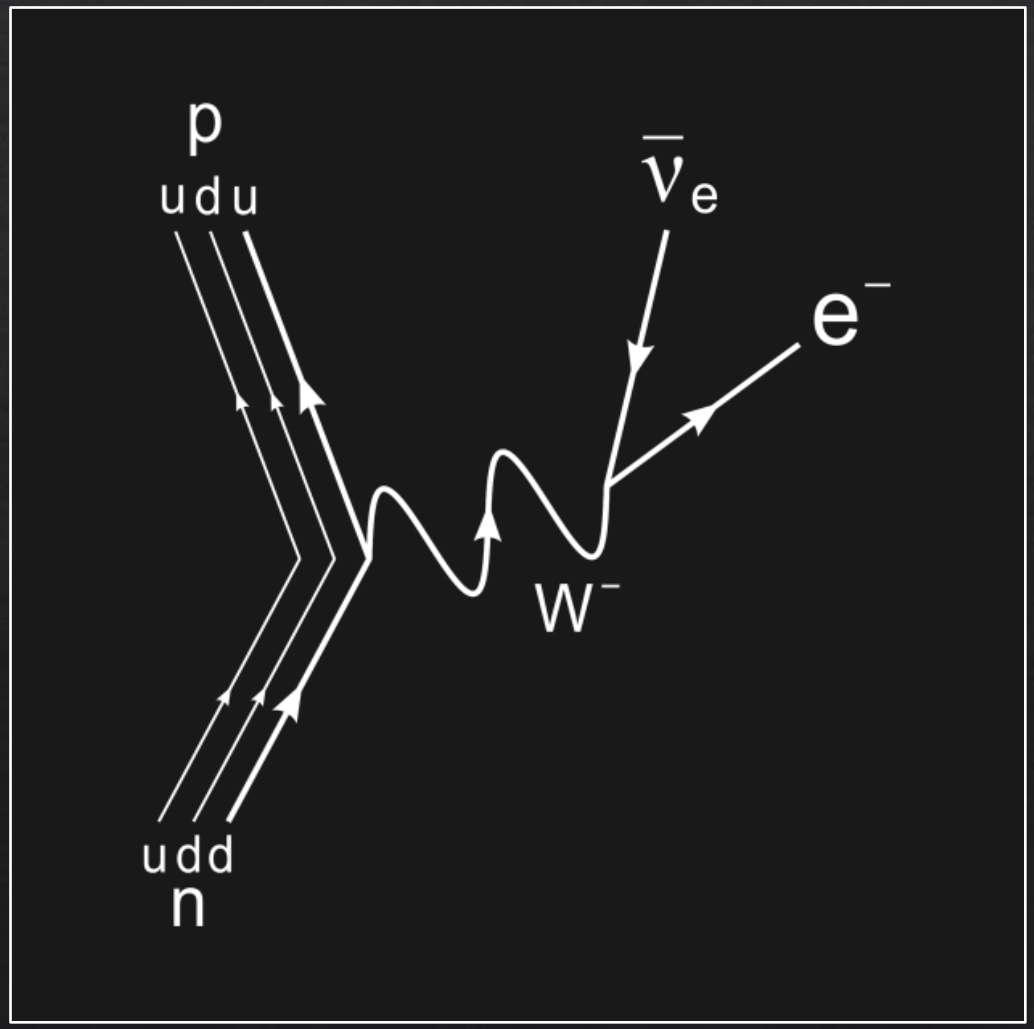
The Standard Model

- It's a quantum field theory
- It's successful…
- … for the most part



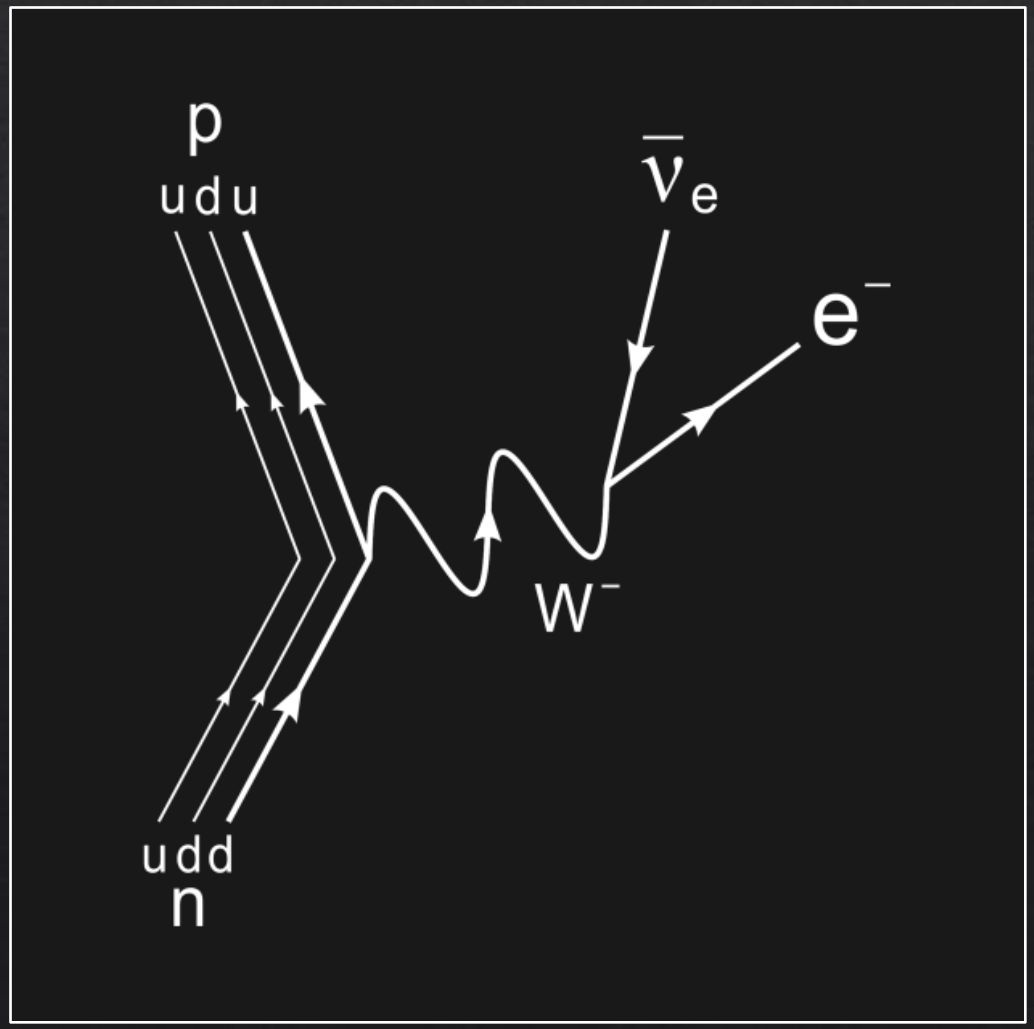
The Standard Model

- It's a quantum field theory
- It's successful…
- … for the most part
- It serves as the foundation for new theories



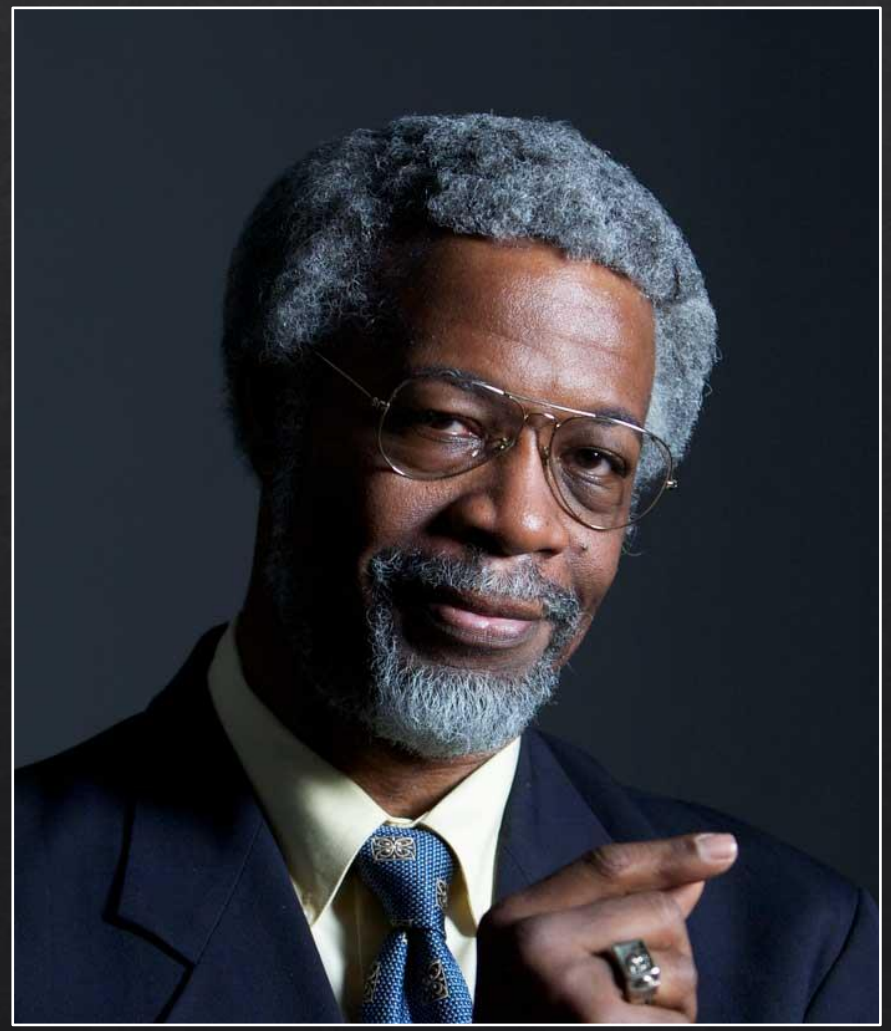
The Standard Model

- It's a quantum field theory
- It's successful…
- … for the most part
- It serves as the foundation for new theories
- It's often contained within new theories



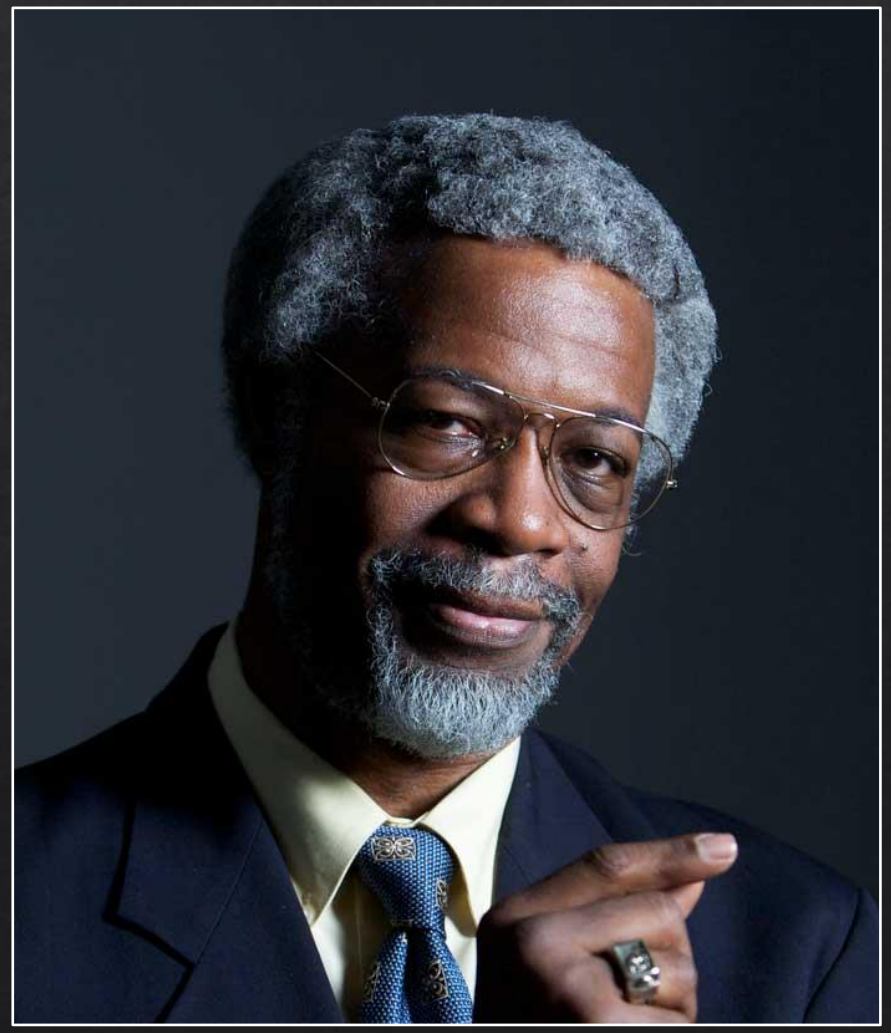
Beyond the SM

- Quantum gravity



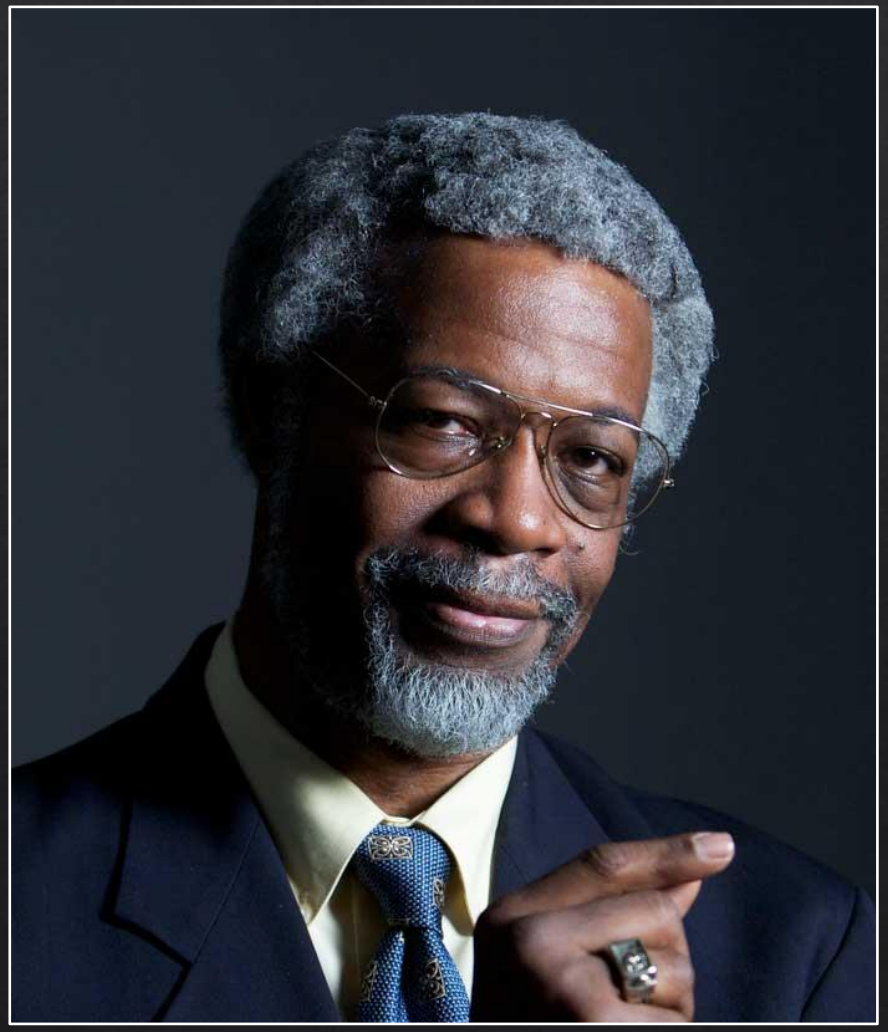
Beyond the SM

- Quantum gravity
- Neutrino oscillations



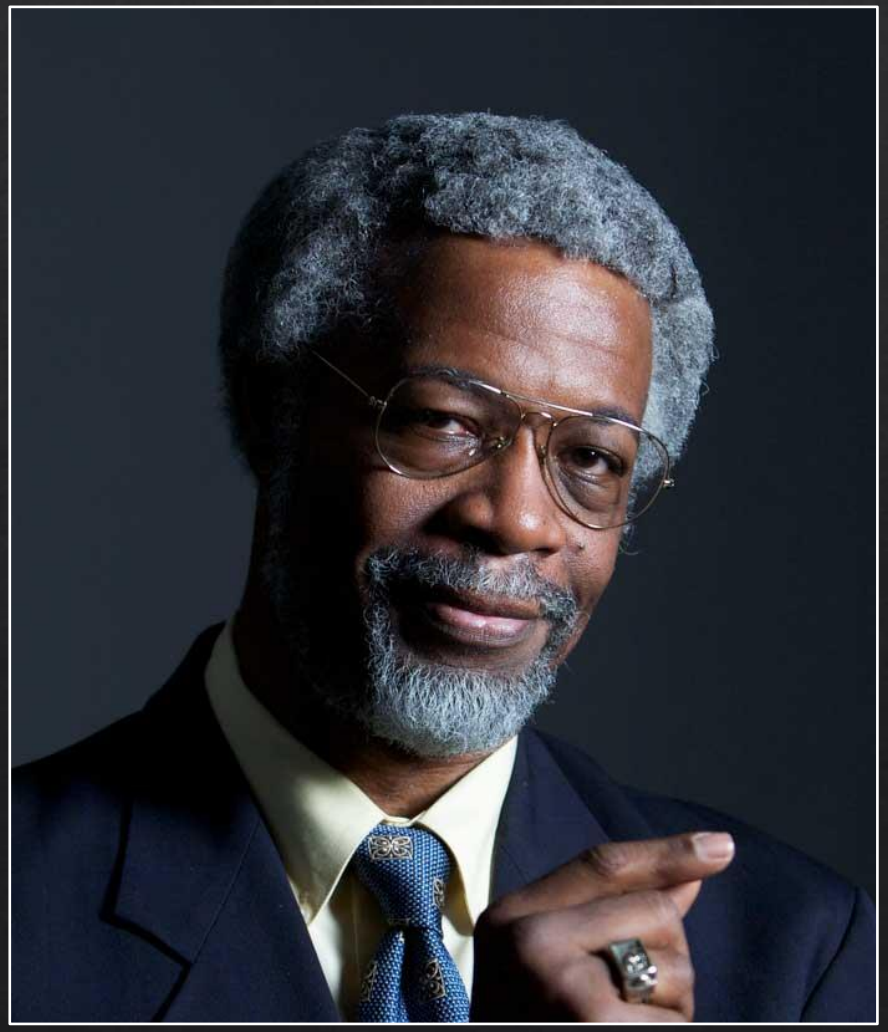
Beyond the SM

- Quantum gravity
- Neutrino oscillations
- Matter–antimatter asymmetry



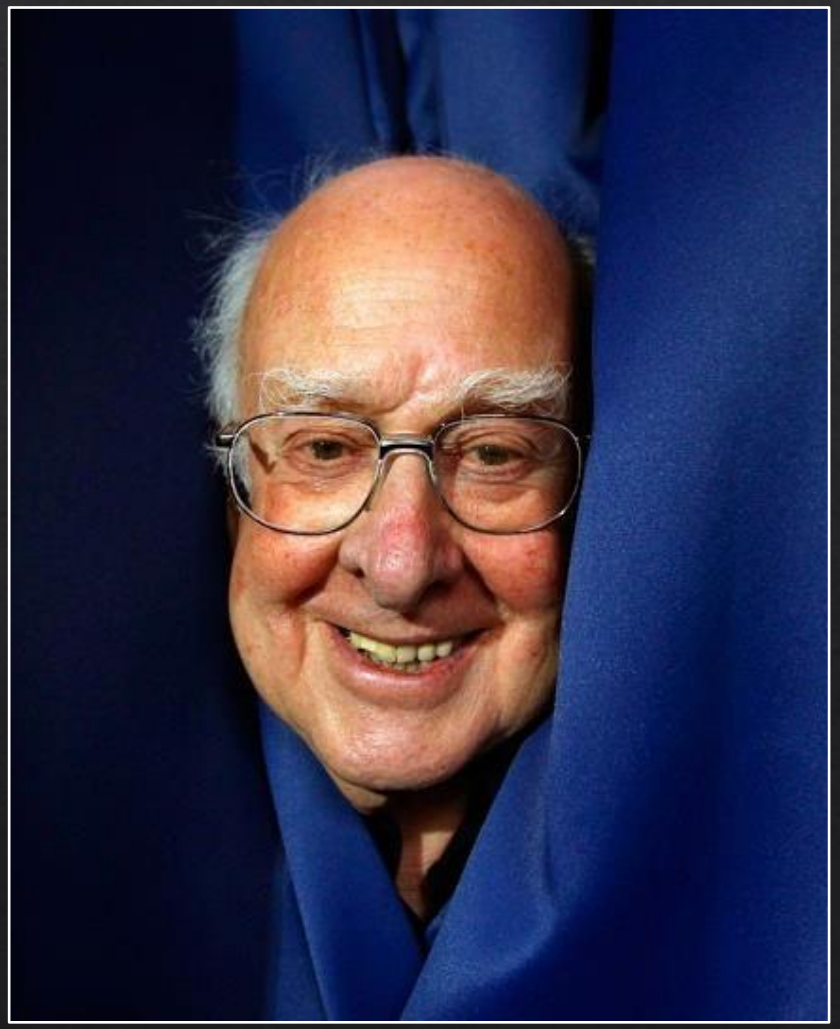
Beyond the SM

- Quantum gravity
- Neutrino oscillations
- Matter–antimatter asymmetry
- The hierarchy problem



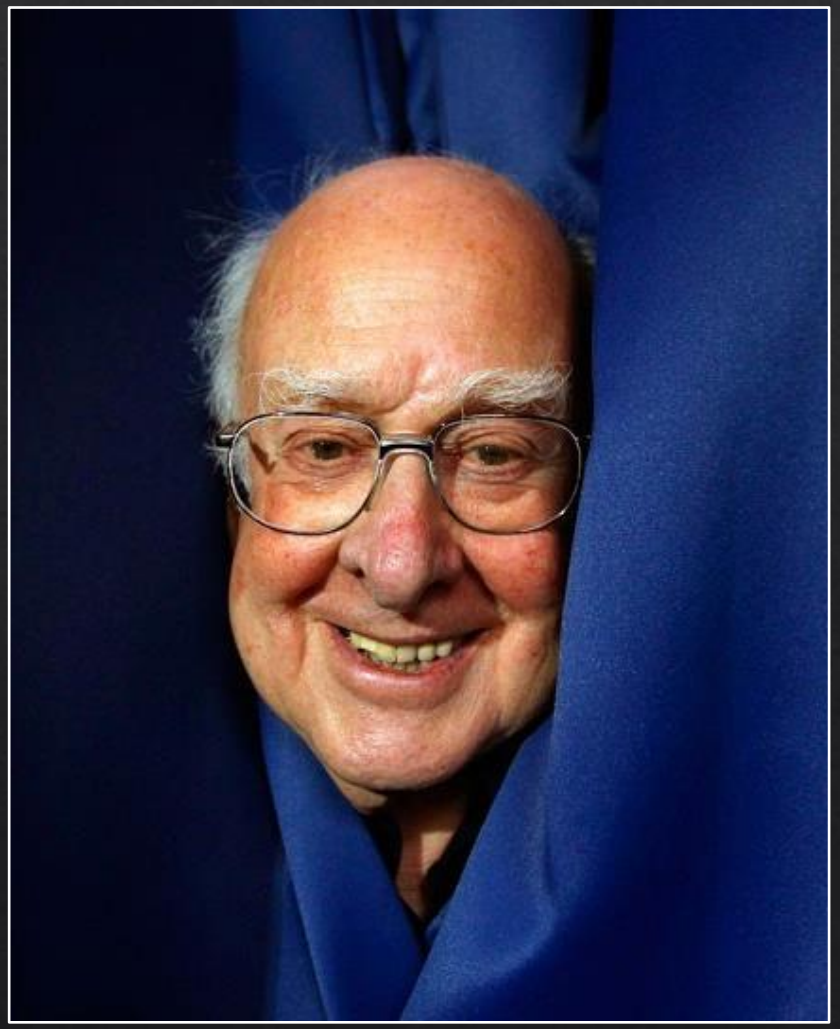
How About Two Higgs Doublets?

- The Two Higgs Doublet Model (2HDM) addresses several problems with the Standard Model



How About Two Higgs Doublets?

- The Two Higgs Doublet Model (2HDM) addresses several problems with the Standard Model
- 2HDM generally postulates five Higgs bosons including two Higgs doublets
  - h, H, A, and $H^{\pm}$



The Different Types of 2HDM

- Type I: one Higgs doublet couples to fermions

The Different Types of 2HDM

- Type I: one Higgs doublet couples to fermions
- Type II: the neutral member of one Higgs doublet couples to up type quarks while the neutral member of the other Higgs doublet couples to down type quarks and leptons

The Different Types of 2HDM

- Type I: one Higgs doublet couples to fermions
- Type II: the neutral member of one Higgs doublet couples to up type quarks while the neutral member of the other Higgs doublet couples to down type quarks and leptons
- Type III: a more general model for the Yukawa couplings involving flavor–changing–neutral–currents (FCNC's)

The Goal of a Monte Carlo Simulation

- Monte Carlo simulations allow us to make realistic predictions

The Goal of a Monte Carlo Simulation

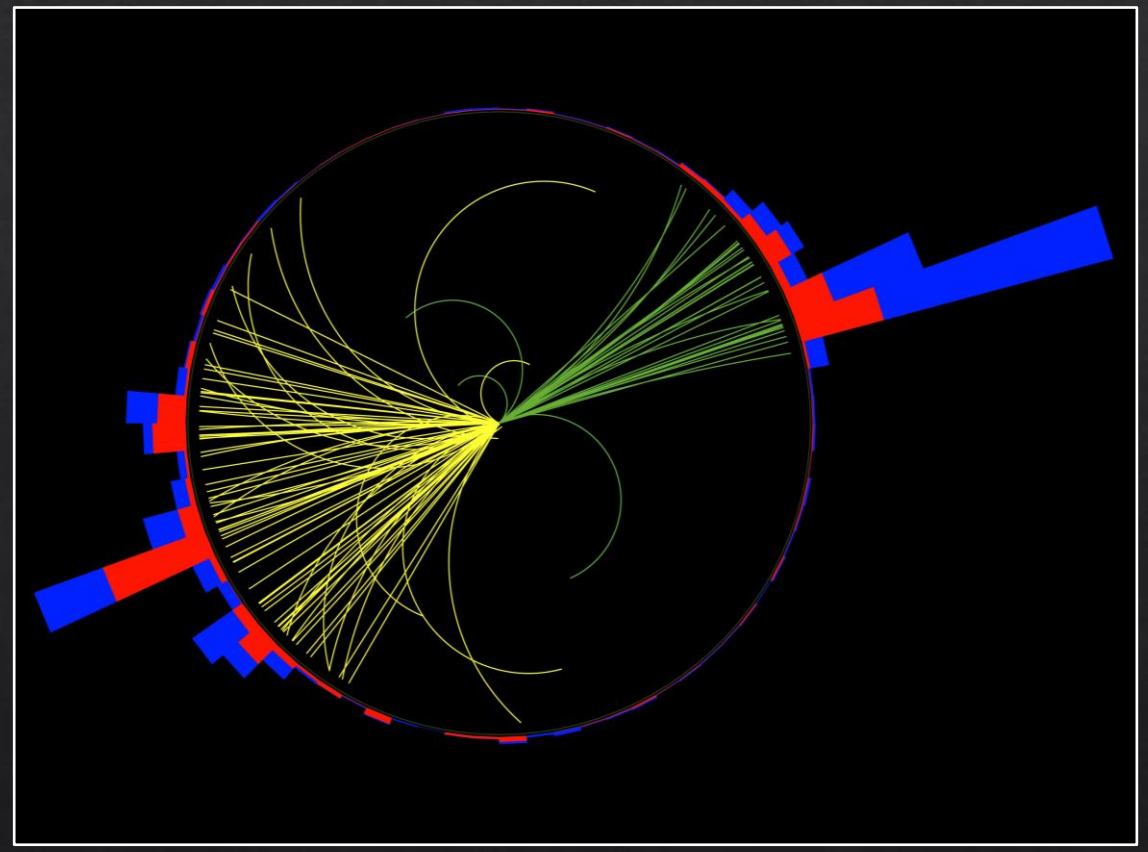
- Monte Carlo simulations allow us to make realistic predictions
- Signal and background predictions

The Goal of a Monte Carlo Simulation

- Monte Carlo simulations allow us to make realistic predictions
- Signal and background predictions
- Examples include MadGraph and PYTHIA

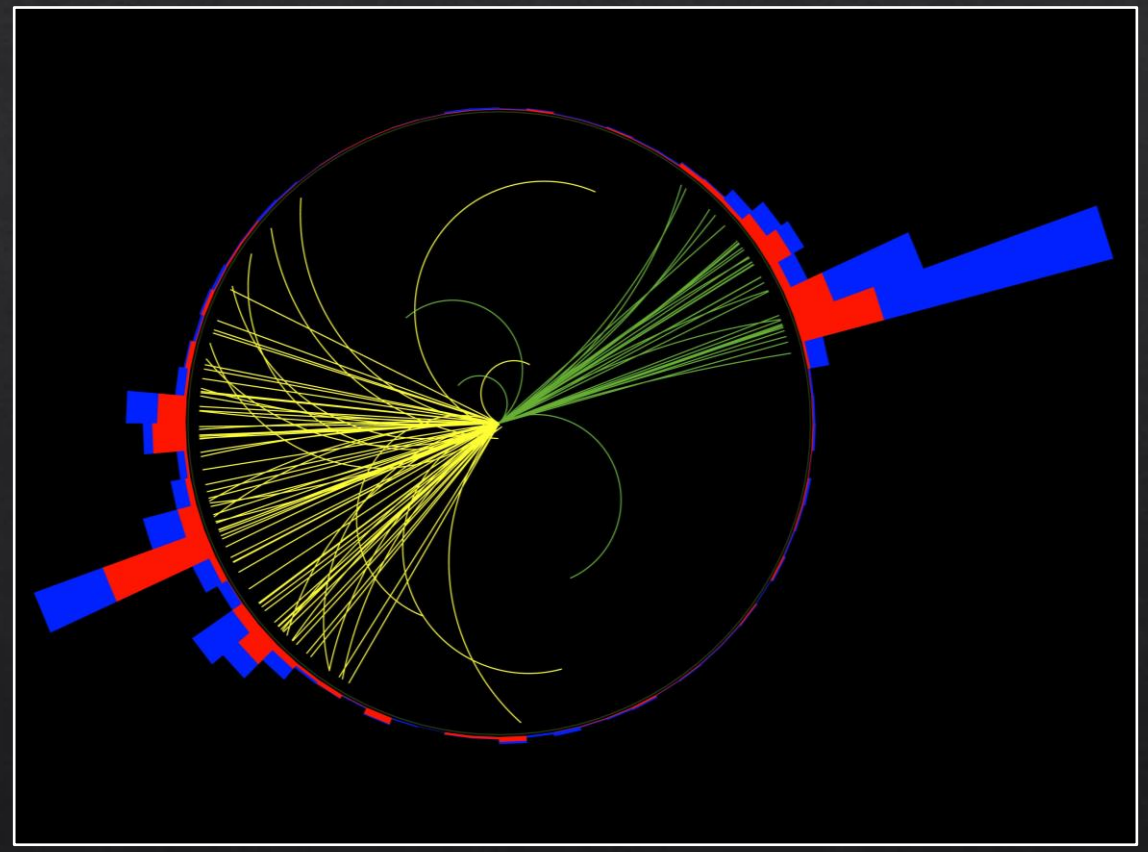
Running a Simulation

- To make theoretical changes, we adjust the parameters



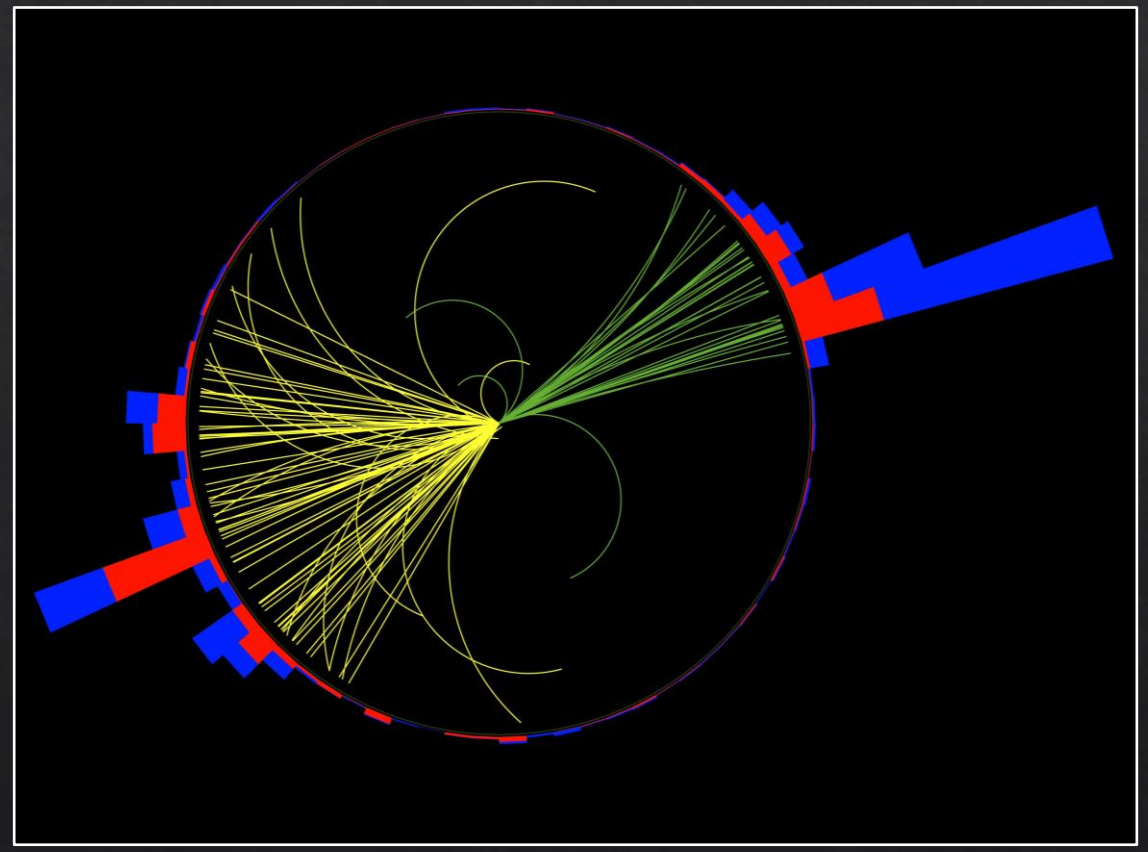
Running a Simulation

- To make theoretical changes, we adjust the parameters
- We can change the particle masses, Yukawa couplings, etc.



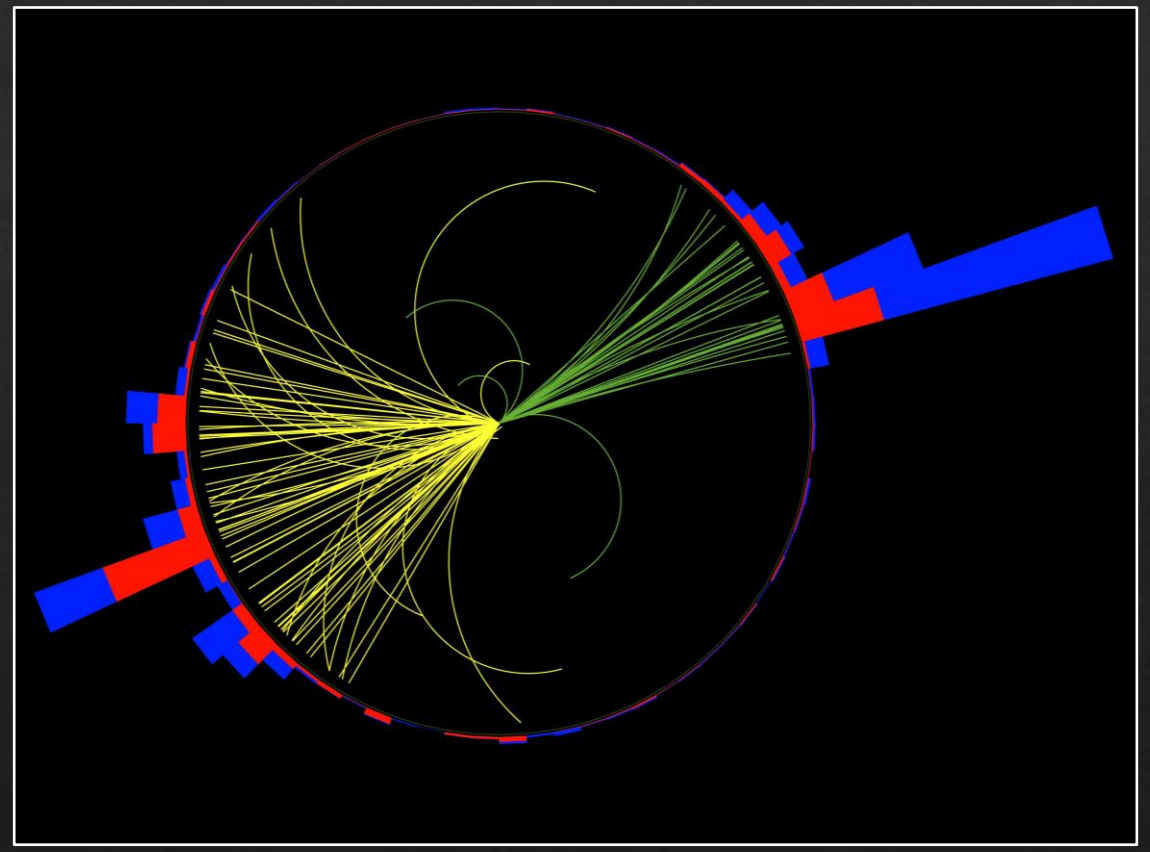
Running a Simulation

- To make theoretical changes, we adjust the parameters
- We can change the particle masses, Yukawa couplings, etc.
- We then adjust our simulations based on which detector we're simulating for



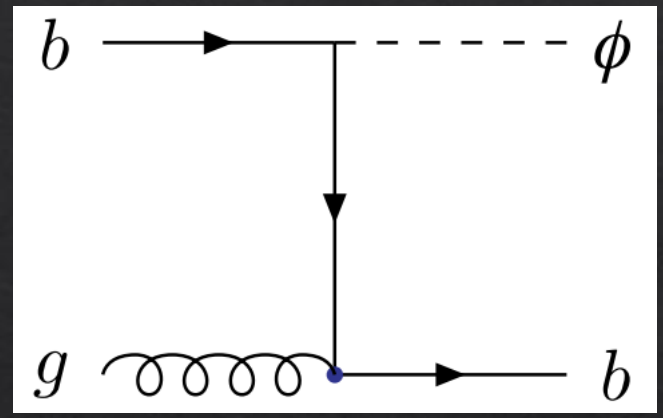
Running a Simulation

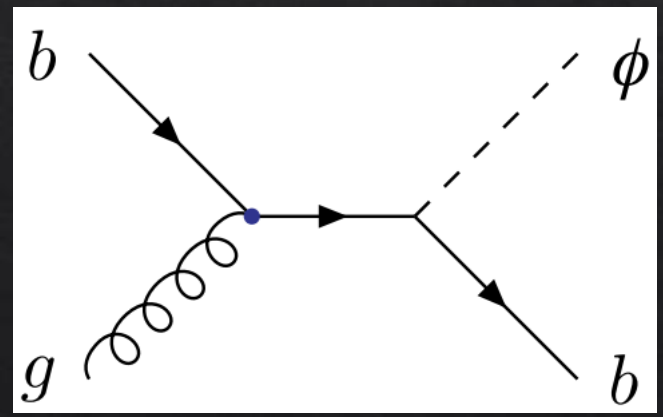
- To make theoretical changes, we adjust the parameters
- We can change the particle masses, Yukawa couplings, etc.
- We then adjust our simulations based on which detector we're simulating for
- This means making the right cuts for pseudo–rapidity, distance between jets, etc.



The “b g > b φ, φ > b b~” Process

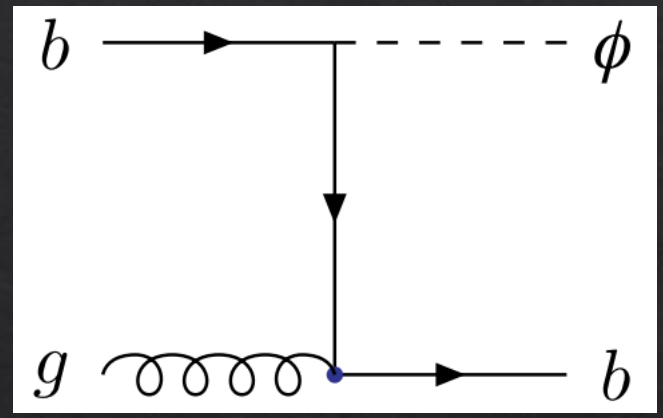
- The Higgs to b b~ signal is notoriously difficult to detect due to large backgrounds

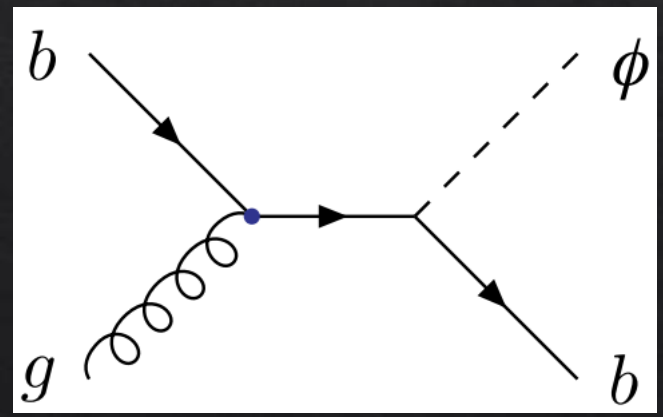




The “b g > b φ, φ > b b~” Process

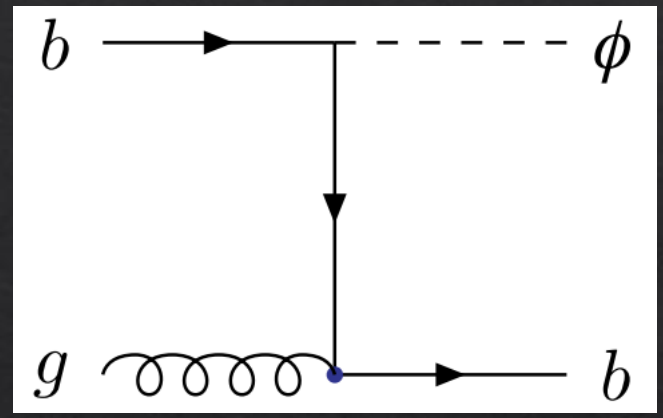
- The Higgs to b b~ signal is notoriously difficult to detect due to large backgrounds
- This makes it a rich area for study

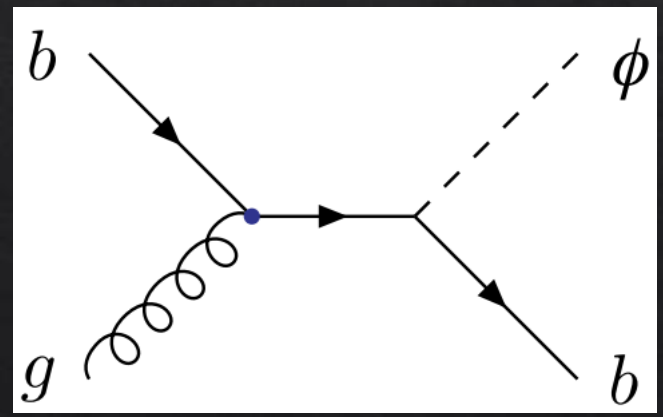




The “b g > b φ, φ > b b~” Process

- The Higgs to b b~ signal is notoriously difficult to detect due to large backgrounds
- This makes it a rich area for study
- We can use MadGraph to change not only the mass of the Higgs boson involved but also the type of Higgs boson





Getting Results

Results in the MSSM_SLHA2 for b g > b h3, h3 > b b~ , g b > b h3, h3 > b b~ , b~ g > b~ h3, ...

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	0.04457 ± 5.8e-05 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_02	p p 6500.0 x 6500.0 GeV	tag_1	0.01261 ± 1.8e-05 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_03	p p 6500.0 x 6500.0 GeV	tag_1	0.0032 ± 3.3e-06 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_04	p p 6500.0 x 6500.0 GeV	tag_1	0.001033 ± 1.4e-06 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_05	p p 6500.0 x 6500.0 GeV	tag_1	0.0003955 ± 5.6e-07 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_06	p p 6500.0 x 6500.0 GeV	tag_1	0.0001694 ± 2.4e-07 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_07	p p 6500.0 x 6500.0 GeV	tag_1	7.866e-05 ± 1.1e-07 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_08	p p 6500.0 x 6500.0 GeV	tag_1	3.883e-05 ± 6e-08 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_09	p p 6500.0 x 6500.0 GeV	tag_1	2.023e-05 ± 3.2e-08 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_10	p p 6500.0 x 6500.0 GeV	tag_1	1.092e-05 ± 1.5e-08 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation

Main Page

Getting Results

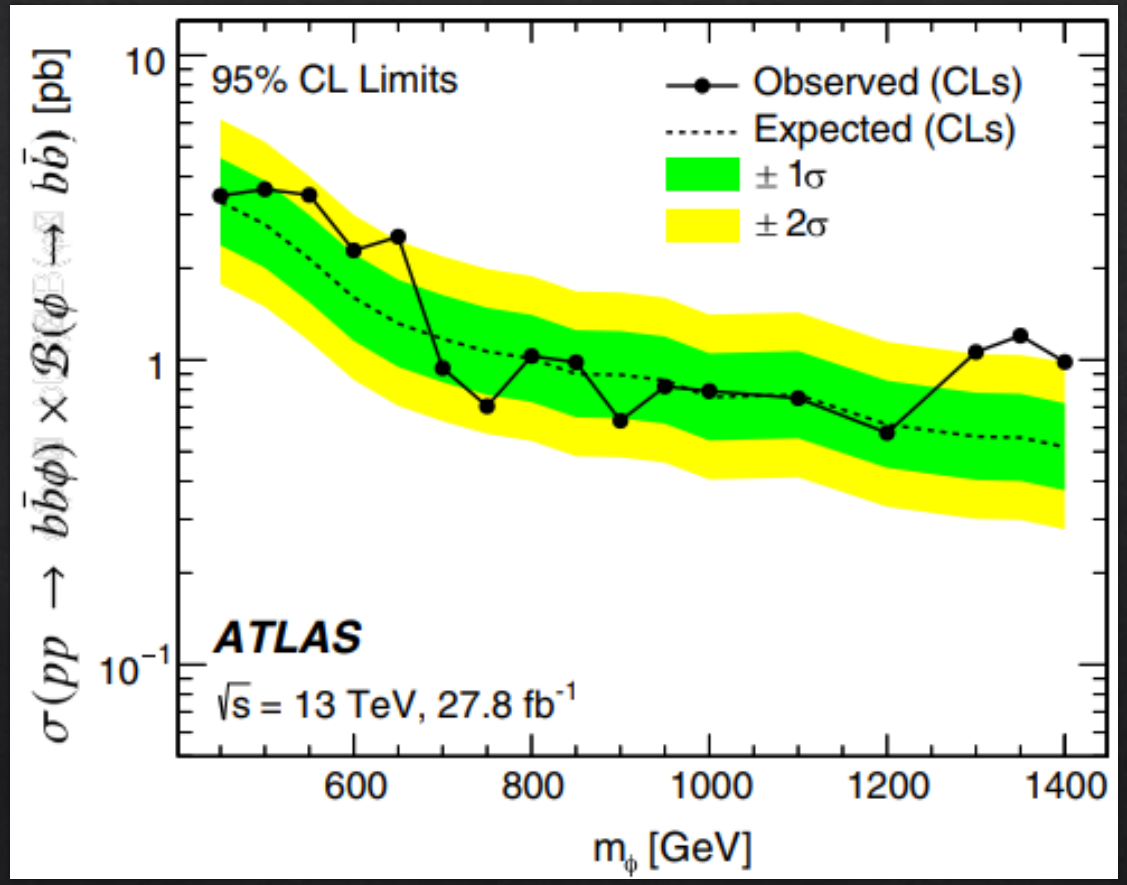
Results in the MSSM_SLHA2 for p p > b b b~ / h3 , p p > b~ b b~ / h3 , p p > b b~ j

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	4.642e+04 ± 40 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_02	p p 6500.0 x 6500.0 GeV	tag_1	1.525e+04 ± 14 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_03	p p 6500.0 x 6500.0 GeV	tag_1	4507 ± 4.3 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_04	p p 6500.0 x 6500.0 GeV	tag_1	1676 ± 1.6 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_05	p p 6500.0 x 6500.0 GeV	tag_1	724.9 ± 0.71 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_06	p p 6500.0 x 6500.0 GeV	tag_1	349.9 ± 0.33 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_07	p p 6500.0 x 6500.0 GeV	tag_1	184.2 ± 0.17 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_08	p p 6500.0 x 6500.0 GeV	tag_1	103.4 ± 0.098 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_09	p p 6500.0 x 6500.0 GeV	tag_1	60.72 ± 0.056 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation
run_10	p p 6500.0 x 6500.0 GeV	tag_1	37.21 ± 0.034 ± systematics	200000	parton madevent	LHE	remove run launch detector simulation

Main Page

Comparing with ATLAS



Acknowledgements

- Dr. Kao
- Dr. Abbott
- Dr. Strauss
- Chenyu Fang
- My fellow REU students
- The University of Oklahoma and the National Science Foundation

References

- https://res.cloudinary.com/teepublic/image/private/s--Uz1QIHXW--/t_Preview/b_rgb:191919,c_limit,f_auto,h_630,q_90,w_630/v1608279370/production/designs/17541390_0.jpg
- https://th.bing.com/th/id/R.b3fc0591636fbc113e24913e68525c88?rik=VWHAOOIfHC3Wdg&riu=http%3a%2f%2fwww.aps.org%2fpublications%2fapsnews%2f201602%2fimages%2fgates.jpg&ehk=wi%2fCYGFLpa%2fnTgg8UctNcnZs9Tq49ea9oL2MSq%2fsr3s%3d&risl=&pid=ImgRaw&r=0
- https://www.telegraph.co.uk/multimedia/archive/02438/Peter_Higgs_2438819k.jpg
- https://www-yukawa.phys.sci.osaka-u.ac.jp/en/wp-content/uploads/2018/10/yukawahideki01.jpg
- https://cms.cern/sites/default/files/styles/large/public/field/image/Event_candidate_EXO11006.jpg?itok=-HgaG9kC
- https://inspirehep.net/literature/589599#:~:text=A%20CP-even%20neutral%20Higgs%20boson%20with%20Standard-Model-like%20couplings,of%20the%20other%20Higgs%20bosons%20of%20the%20model.
- https://arxiv.org/abs/1907.02749

Thank You