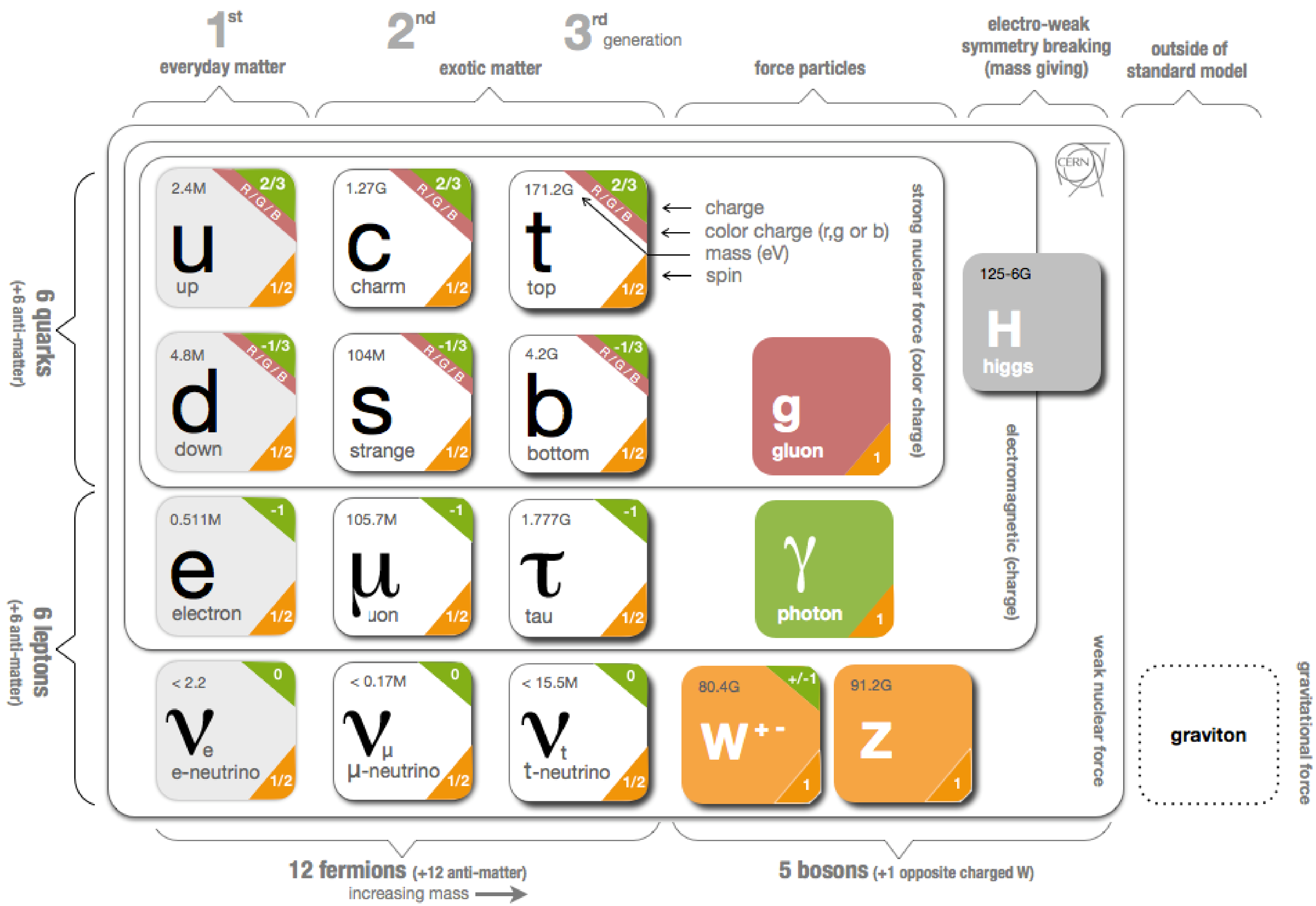
Measurement of The Higgs Boson Transverse Momentum and Its Sensitivity to Beyond Standard Model Physics

David Gossman
Supervised by Prof. B. Mellado
12 February 2015

- Introduction
  - Theory
- Problem and Reason for Study
- What was done
- Results
- Conclusions

Theory: Standard Model



Theory: Standard Model

- The mathematics of the SM comes from QFT
- Particles are considered fields permeating space time
- Interactions understood by Lagrangian mechanics
- General QFT method:
  - Internal symmetries of the system are defined
  - Most general renormalizable Lagrangian that obeys these symmetries is written down
- SM Symmetries:
  - $SU(3)_C$ – QCD (Strong interaction)
  - $SU(2)_L$ – Weak Interaction
  - $U(1)_Y$ – Electromagnetic Interaction

  (SU(2)_L and U(1)_Y: Electroweak interaction)
- The SM Lagrangian for these symmetries can be written in terms of the QCD sector and the EW sector:

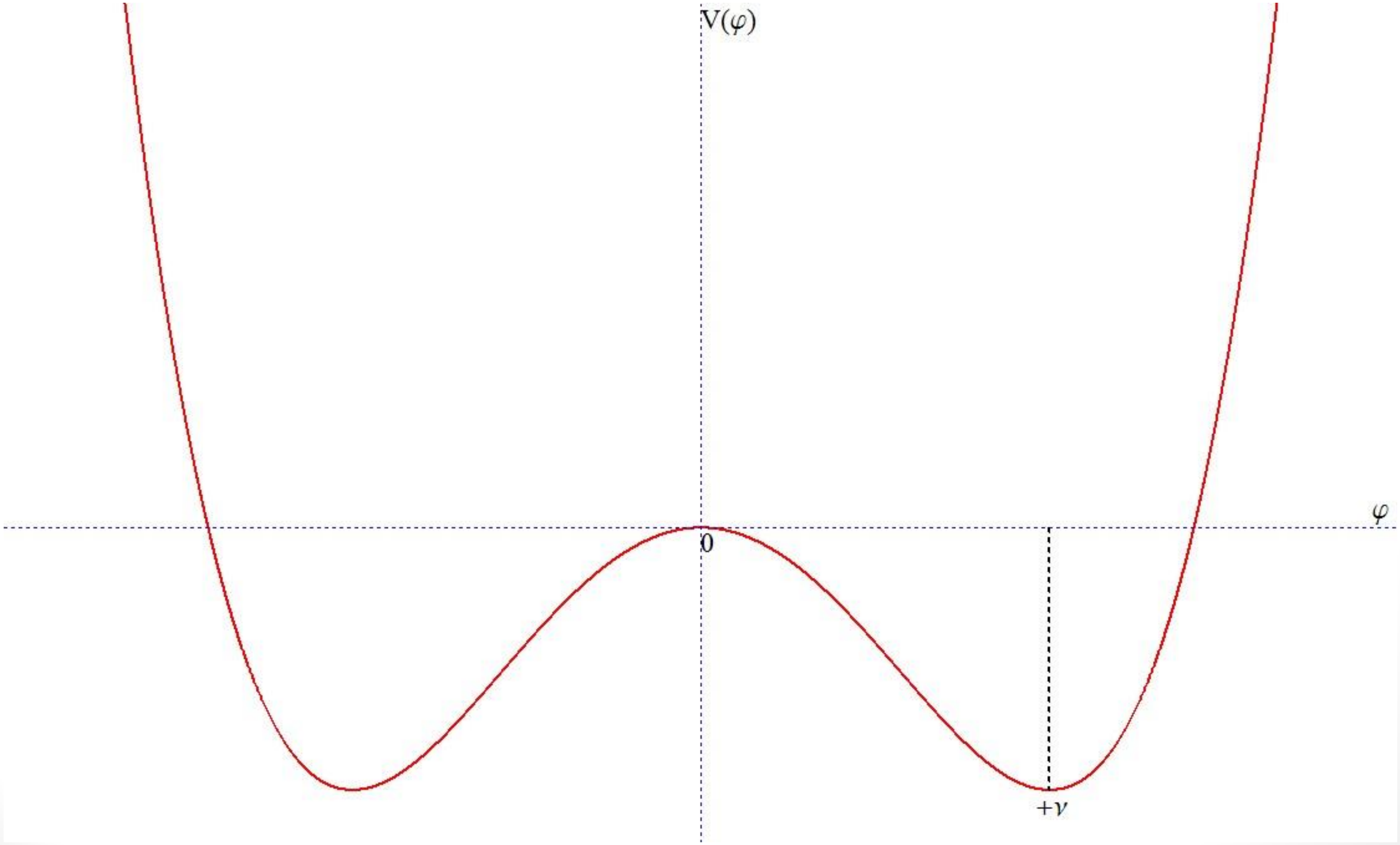
$$\mathcal{L}_{SM} = \mathcal{L}_{SU(3)} + \mathcal{L}_{SU(2)_L \times U(1)}$$

Theory: Gauge Theory

- Redundant degrees of freedom in the Lagrangian: Gauges
- Symmetry group that defines the transformations between these Gauges ($SU(3)_C$ for QCD)
- Group generators of Symmetry groups give rise to vector fields
- Vector fields added to Lagrangian, ensure invariance under transformations: gauge invariance.
- The quantization of these vector fields are then gauge bosons.
- For example $SU(3)_C$ has 8 group generators giving the 8 gluons in QCD
- Now the most general renormalizable SM Lagrangian that obeys $SU(3)_C X SU(2)_L X U(1)_Y$ gauge invariance predicts all the particles to be massless.
- Simply adding mass violates $SU(2)_L X U(1)_Y$ gauge invariance.

Theory: Spontaneous EW Symmetry Breaking

- $V(\varphi) = \frac{1}{2}\mu^2\varphi^2 + \frac{1}{4}\lambda\varphi^4$



Beyond the Standard Model (BSM)

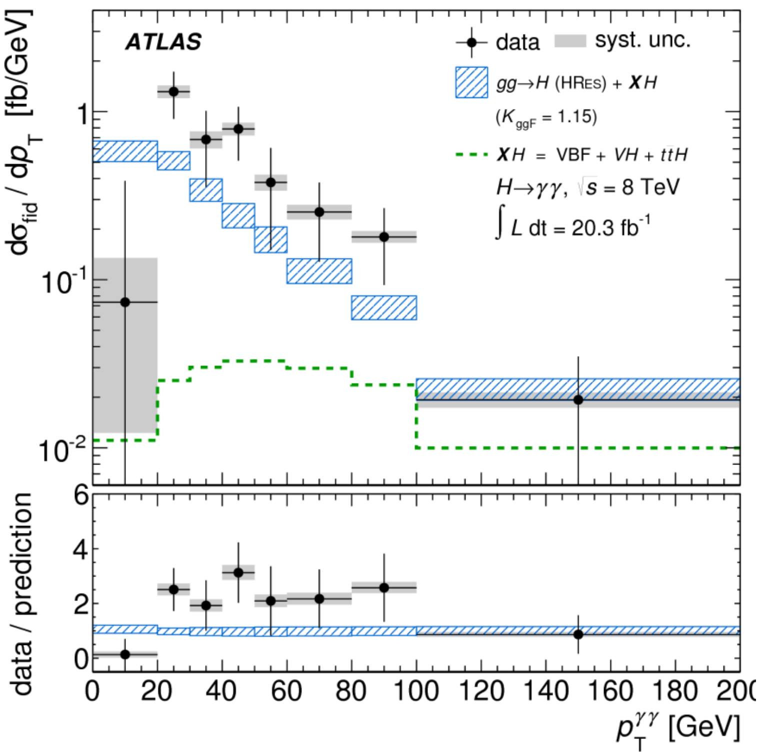
Deficiencies in the Standard Model:

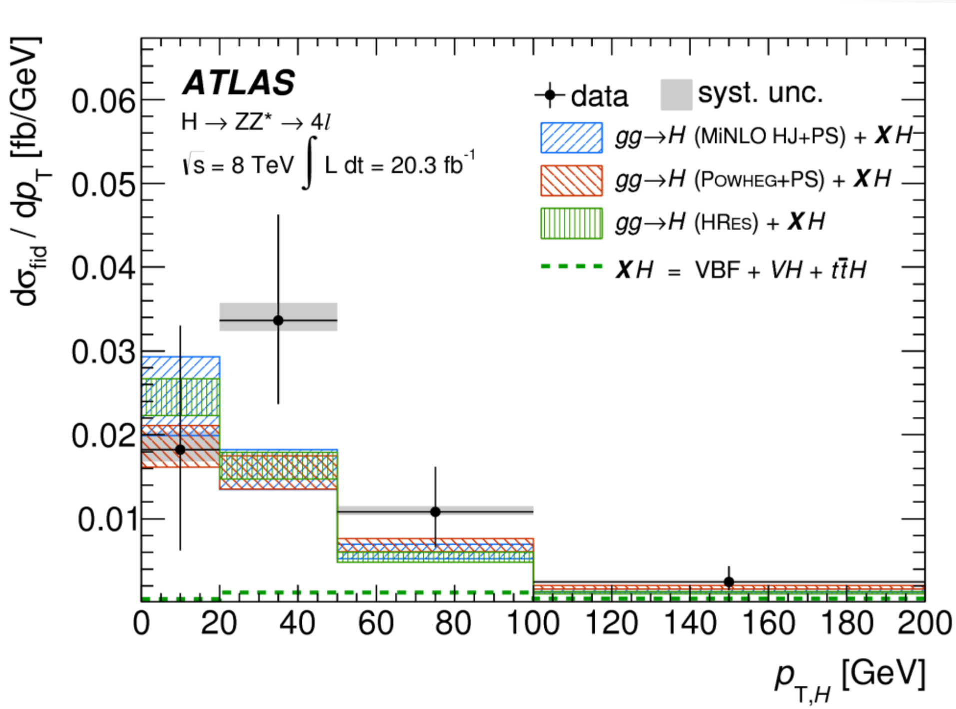
- Inconsistent with general relativity
- Matter–antimatter asymmetry
- Neutrino oscillation
- Dark matter and dark energy
- Etc.…

BSM Examples:

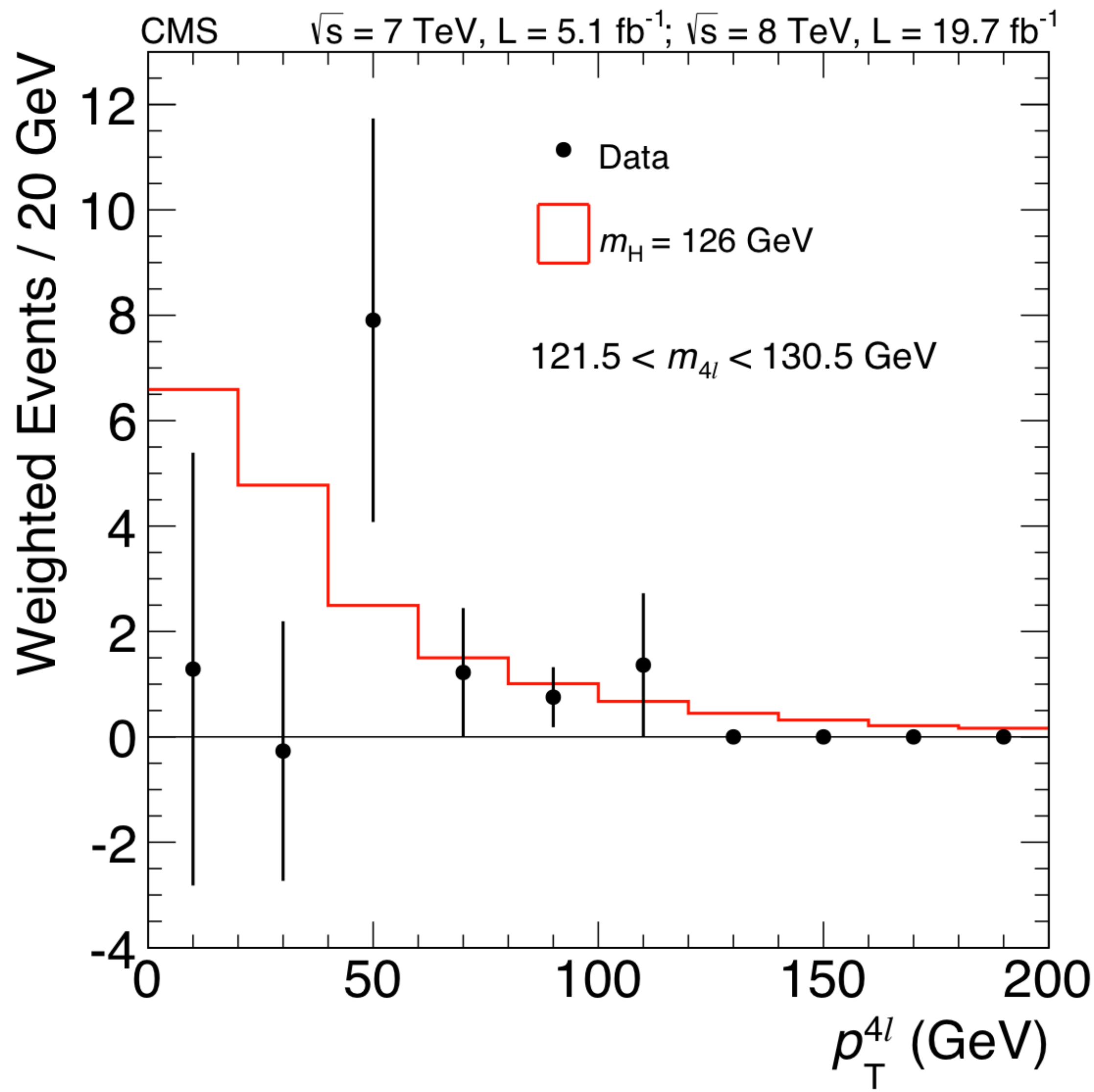
- Supersymmetry
- Minimal Supersymmetric Standard Model (MSSM)
- Next-to-Minimal Supersymmetric Standard Model (NMSSM)
- String theory
- M-theory
- Etc.…

Problem: ATLAS Data

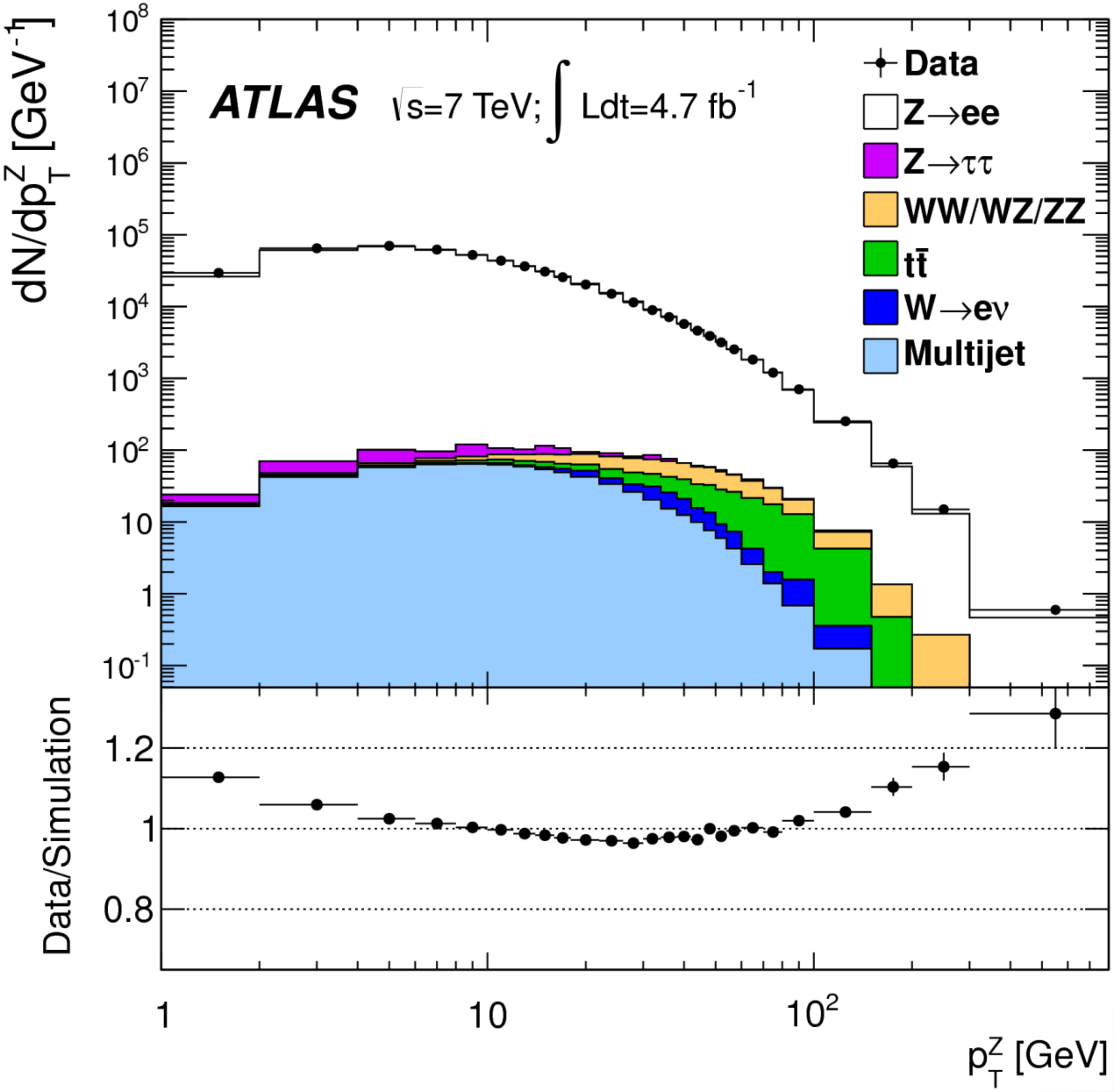




Problem: CMS Data



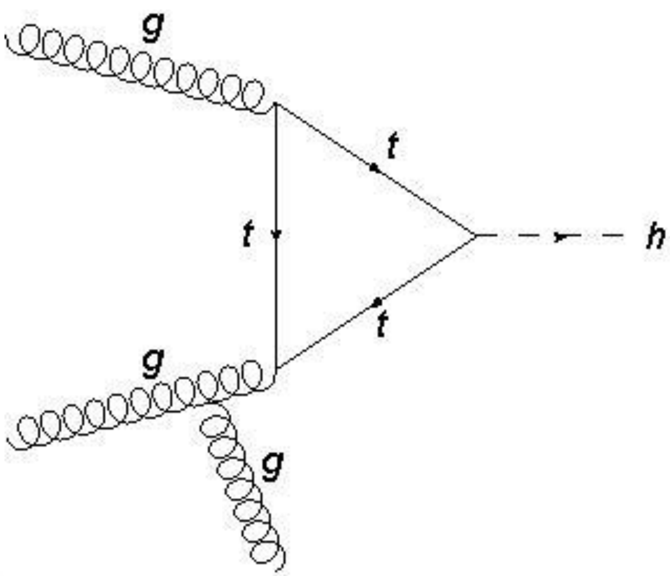
Problem: Z Boson Production



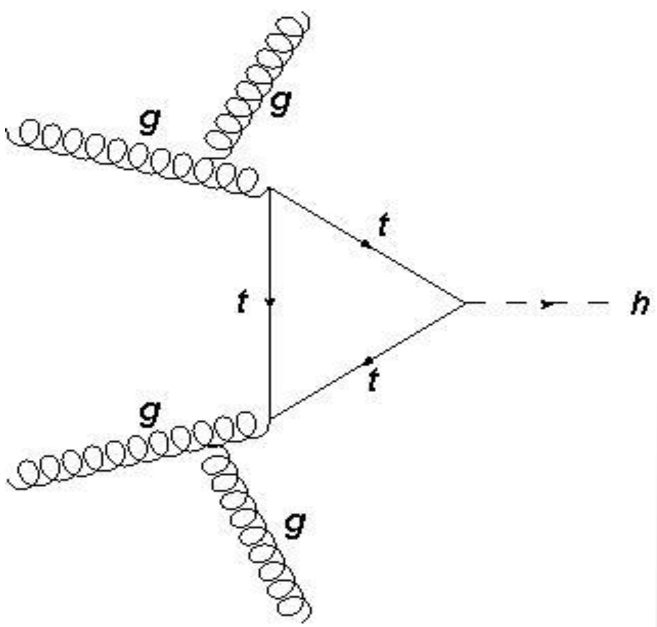
What was done

- Monte Carlo Simulation (MadGraph)
- Higgs Effective couplings to gluons model
- Two processes: $p\,p \longrightarrow h\,j$& $p\,p \longrightarrow h\,j\,j$
- Centre of mass energies: 8TeV to 14TeV in 1TeV steps

$gg \longrightarrow gH$



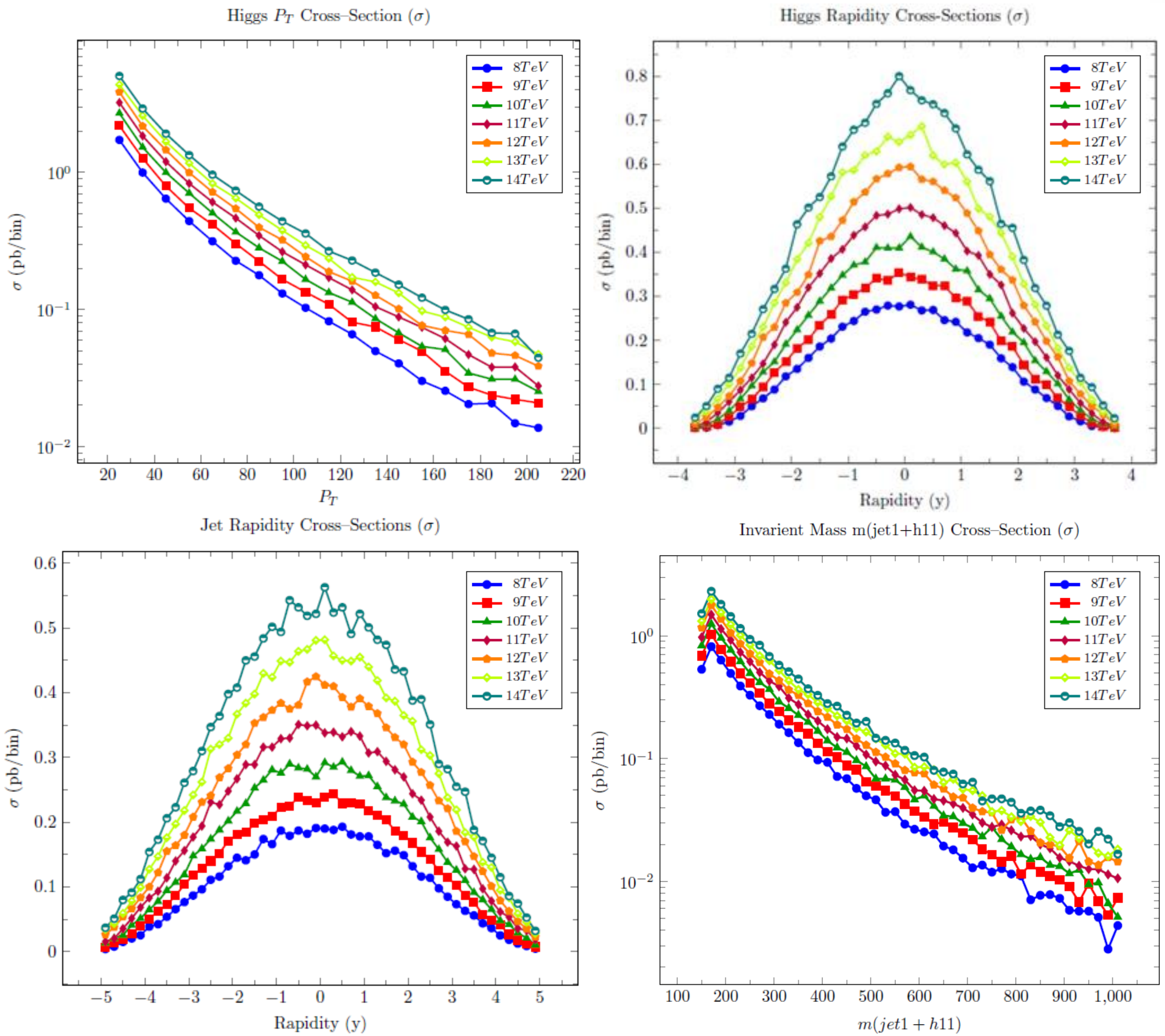
$gg \longrightarrow ggH$



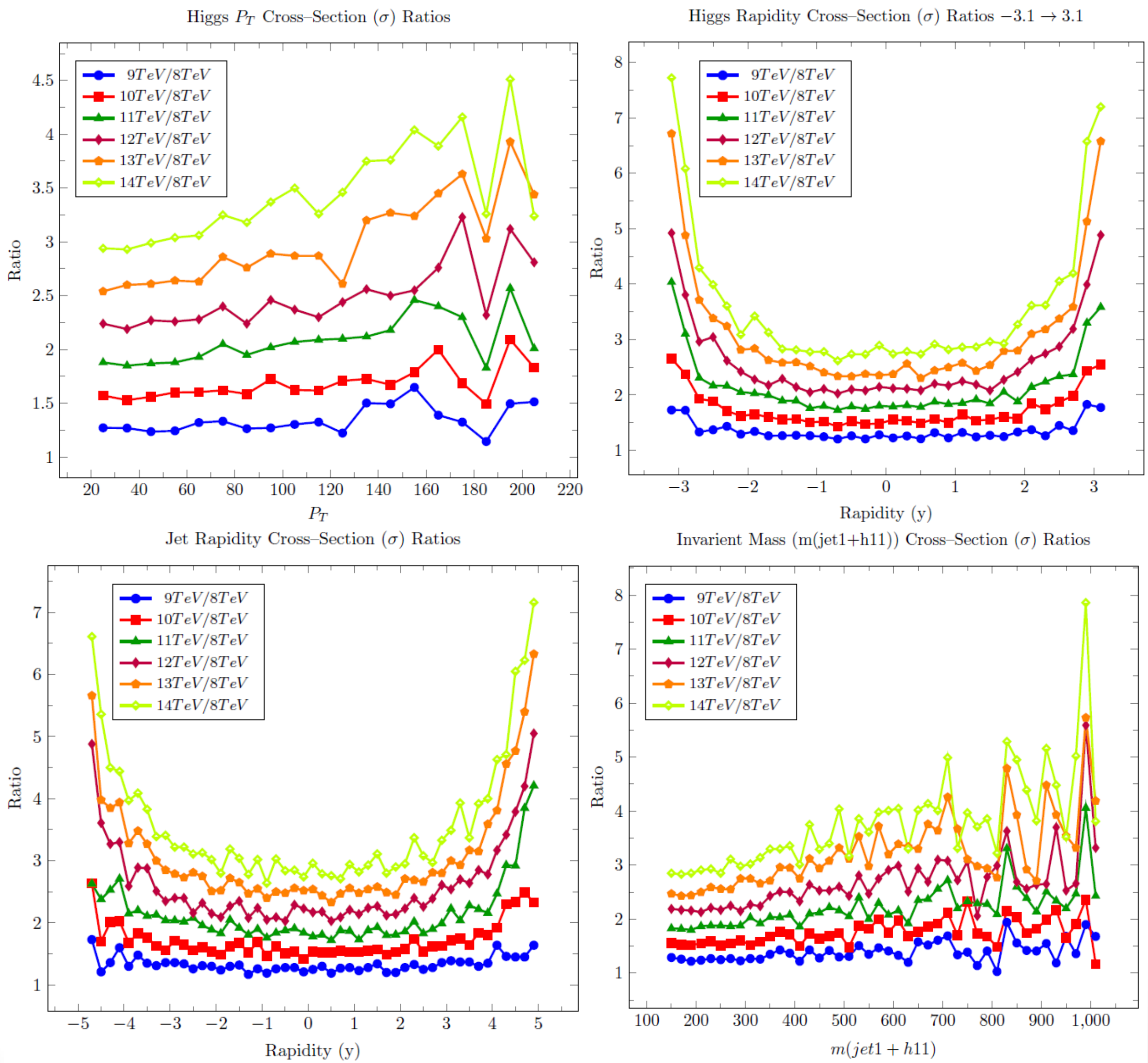
Parameters

```
#*********************
# Running parameters
#*********************
#
#*********************************************************************
# Tag name for the run (one word)                                    *
#*********************************************************************
 13TeV250GeV    = run_tag ! name of the run
#*********************************************************************
# Run to generate the grid pack                                      *
#*********************************************************************
  .false.     = gridpack  !True = setting up the grid pack
#*********************************************************************
# Number of events and rnd seed                                      *
# Warning: Do not generate more than 1M events in a single run       *
# If you want to run Pythia, avoid more than 50k events in a run.    *
#*********************************************************************
  50000 = nevents ! Number of unweighted events requested
      0       = iseed   ! rnd seed (0=assigned automatically=default))
#*********************************************************************
# Collider type and energy                                           *
# lpp: 0=No PDF, 1=proton, -1=antiproton, 2=photon from proton,      *
#                                         3=photon from electron     *
#*********************************************************************
        1     = lpp1    ! beam 1 type
        1     = lpp2    ! beam 2 type
     6500     = ebeam1  ! beam 1 total energy in GeV
     6500     = ebeam2  ! beam 2 total energy in GeV
#*********************************************************************
# Beam polarization from -100 (left-handed) to 100 (right-handed)    *
#*********************************************************************
        0     = polbeam1 ! beam polarization for beam 1
        0     = polbeam2 ! beam polarization for beam 2
```

$pp \longrightarrow hj$: Cross-Sections

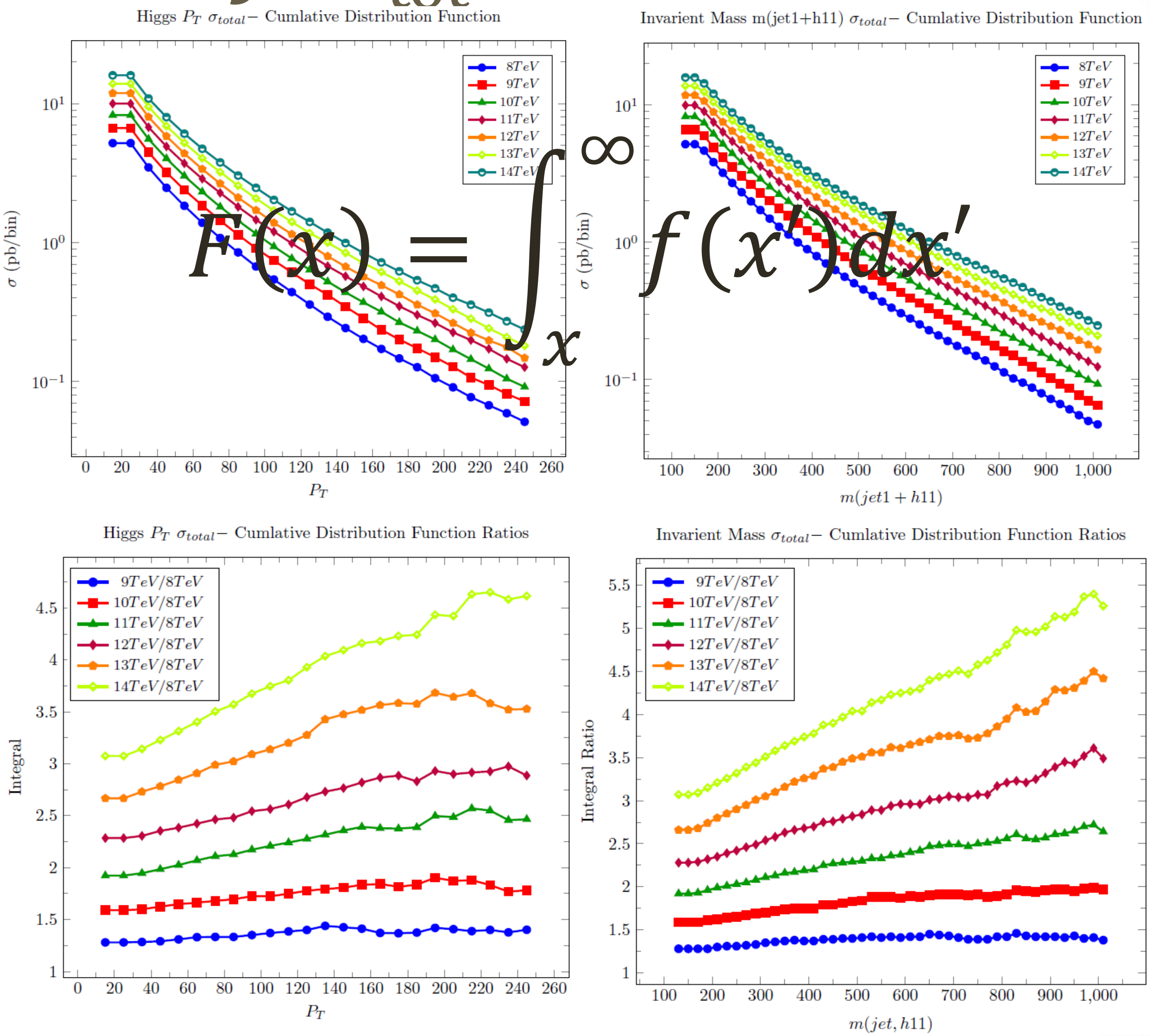


$pp \longrightarrow hj$: Cross-Section Ratios



$pp \longrightarrow hj$: σ_{tot} – CDF and Ratios

$$F(x) = \int_x^\infty f(x')dx'$$



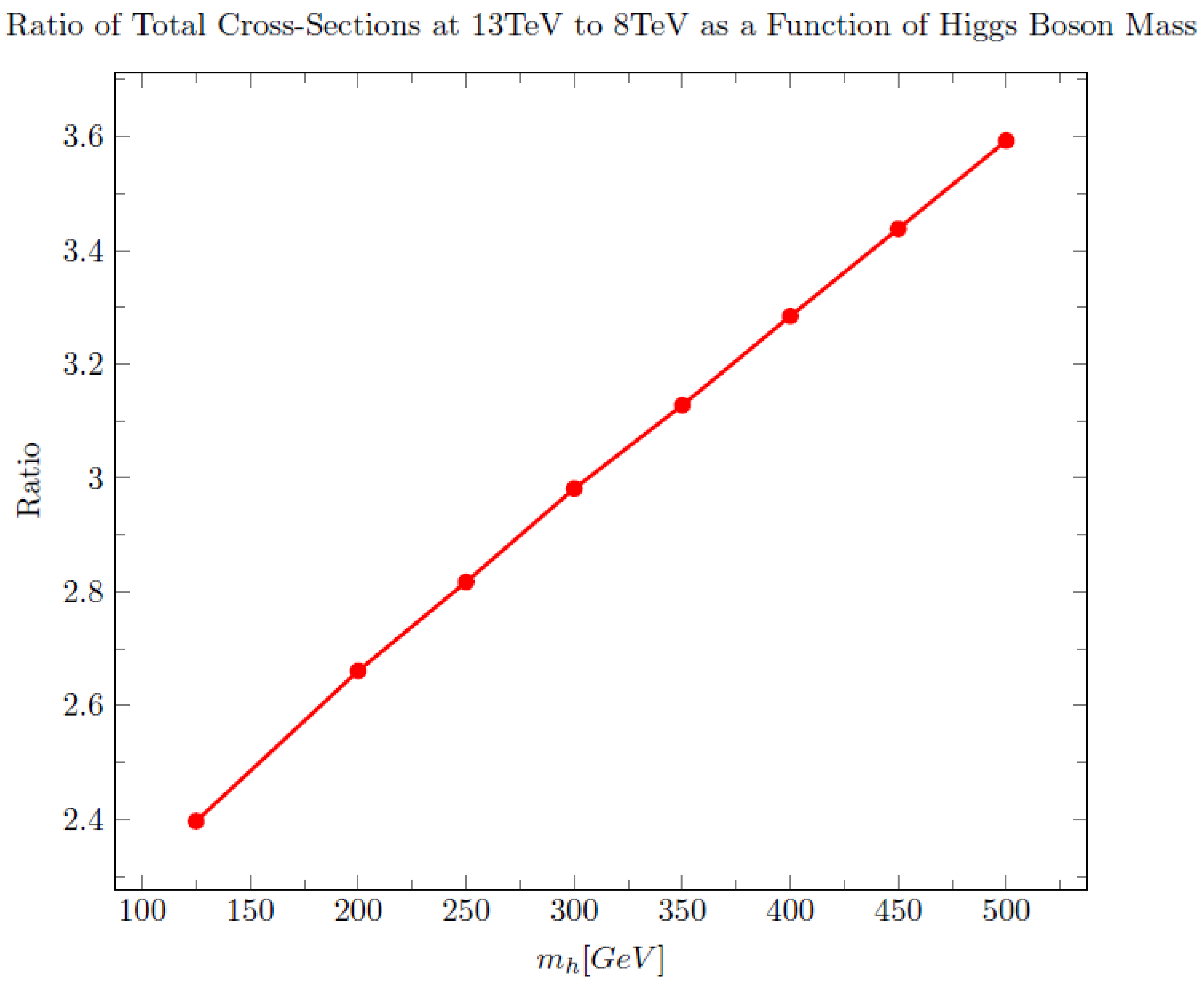
Heavy Pseudo-Scalar Boson Hypothesis

- Heavy pseudo-scalar boson hypothesis

$$A \longrightarrow h\ \mathrm{DM}$$

- Where DM stands for Dark Matter.
- Approximately simulate this with Higgs production for heavier m_h. $p\,p \longrightarrow h$
- Done for m_h=200GeV to 500GeV in 50GeV steps
- Ratio of total cross-section at 13TeV to 8TeV as a function of m_h was plotted.

Heavy Pseudo-Scalar Boson Hypothesis: Results



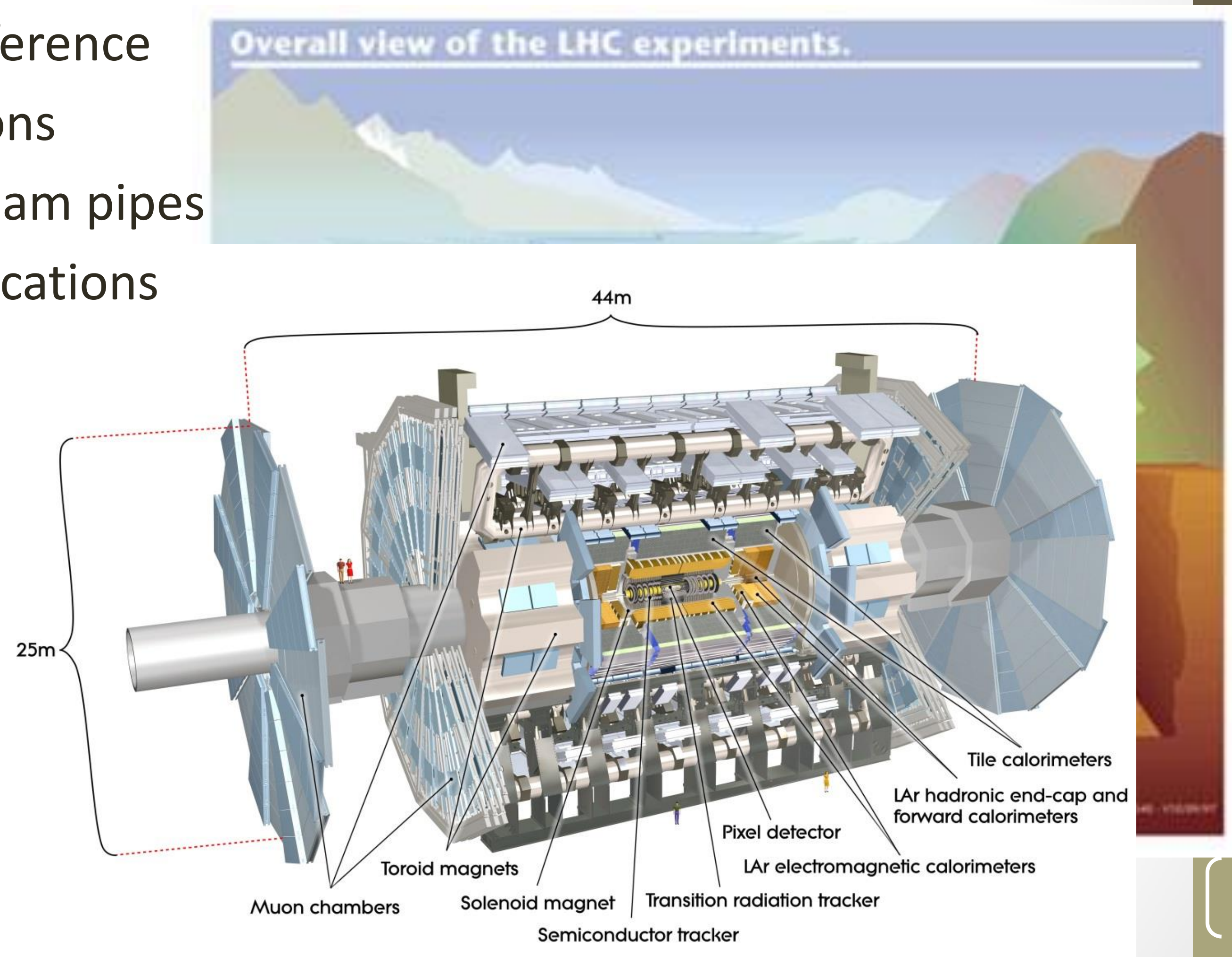
Conclusions

- The first simulations give predictions based on QCD and the SM which will provide a useful comparison for the data obtained at CERN for 13TeV and highlight areas of disagreement.
- They show that as the energy at the LHC increases we expect to have more Higgs bosons produced.
- They indicate that the rate at which the Higgs bosons, at higher P_T values, increases with increasing energy.
- The excess P_T seen in the data can be explained by a Heavy pseudo-scalar boson emitting Dark Matter and a Higgs boson, giving the Higgs extra P_T above what is predicted.
- The second simulations show that if a Heavy pseudo-scalar boson is being produced then we should see the cross-section increase faster than for SM h.

Questions?

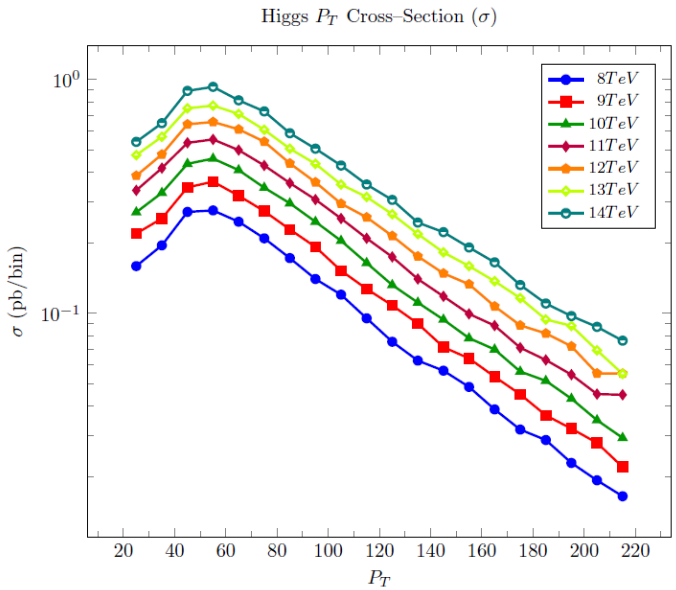
CERN Large Hadron Collider

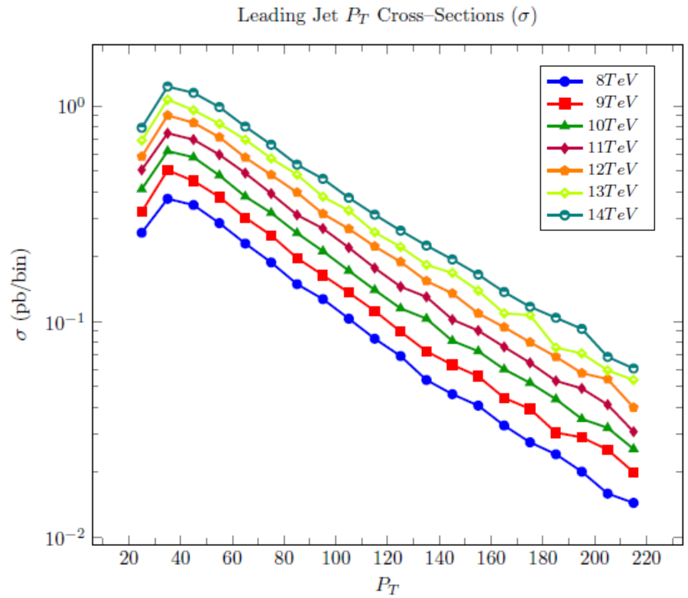
- Largest Particle Accelerator
- 27km circumference
- Collides protons
- 2 Separate beam pipes
- Collide at 4 locations
- Detectors:
  - ATLAS
  - CMS
  - ALICE
  - LHCb

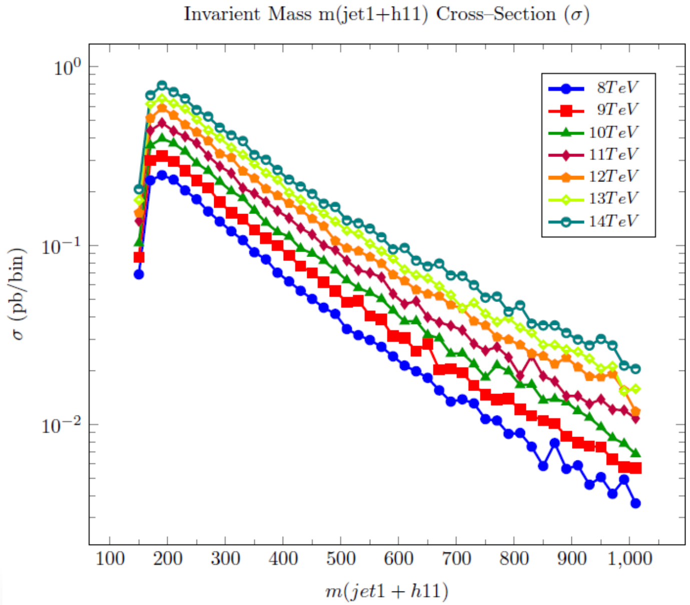


ATLAS Experiment © 2014 CERN

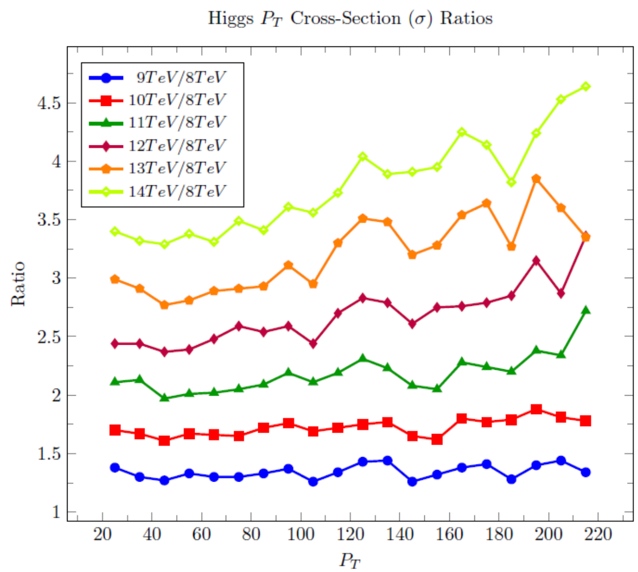
$pp \longrightarrow hjj$: Cross-Sections

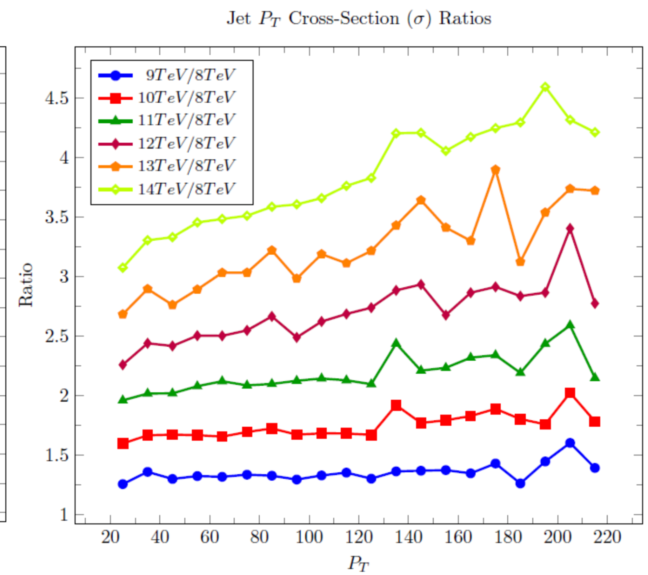


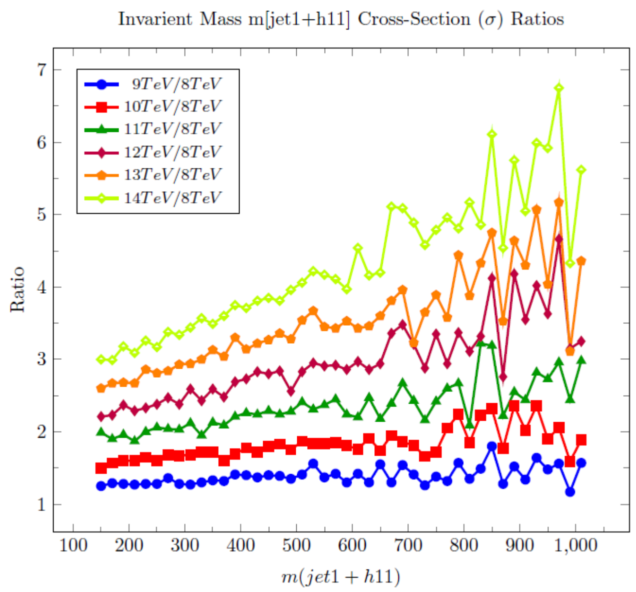




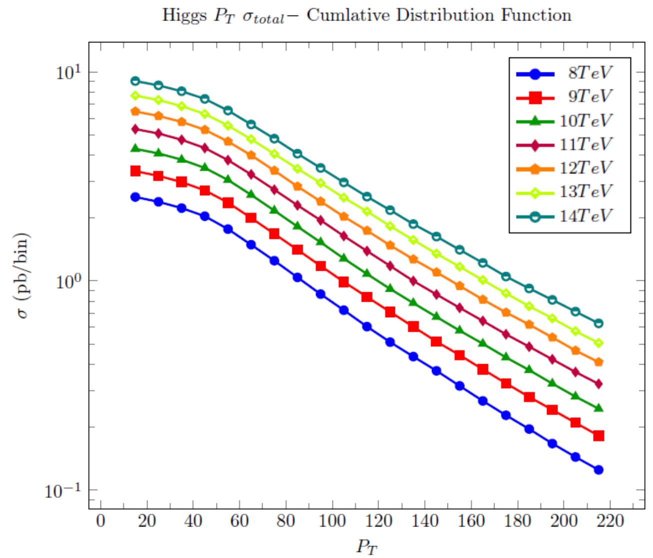
$pp \longrightarrow hjj$:Cross-Section Ratios

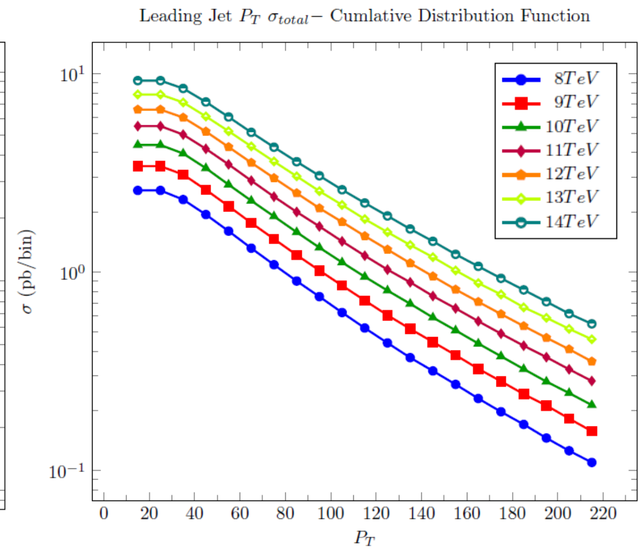


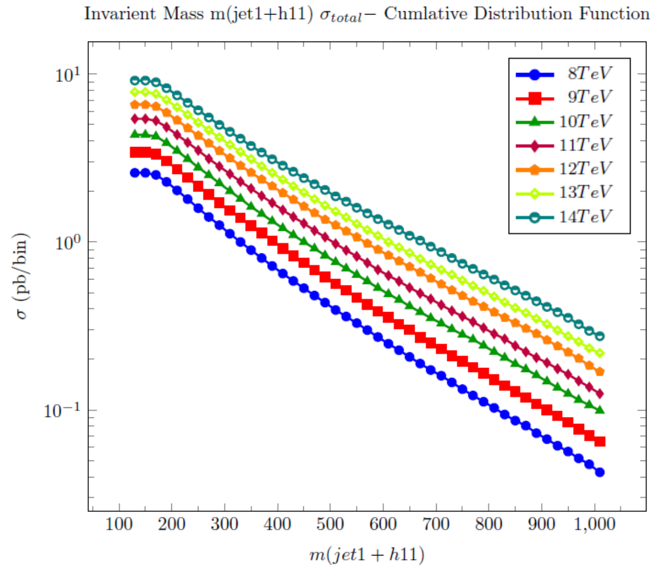




$pp \longrightarrow hjj$: σ_{tot} – CDF







$pp \longrightarrow hjj$: σ_{tot} – CDF Ratios