# Study of Momentum Imbalance Trigger for Supersymmetry Searches at CMS

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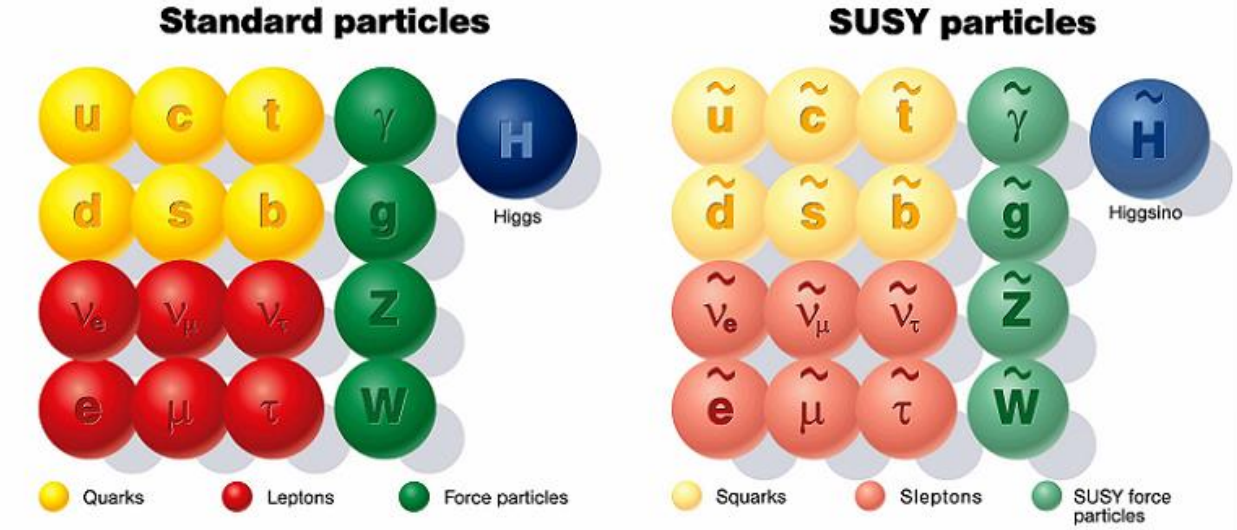
# Outline

- Supersymmetry
  - What is it? Who needs it?
  - New particles at the Large Hadron Collider (LHC)?
- Finding particles in colliders like the LHC
  - Does the detector record what we are looking for?
    - Why record based on momentum imbalance?
    - How efficient is the Compact Muon Solenoid (CMS)?
    - Are there any complications?

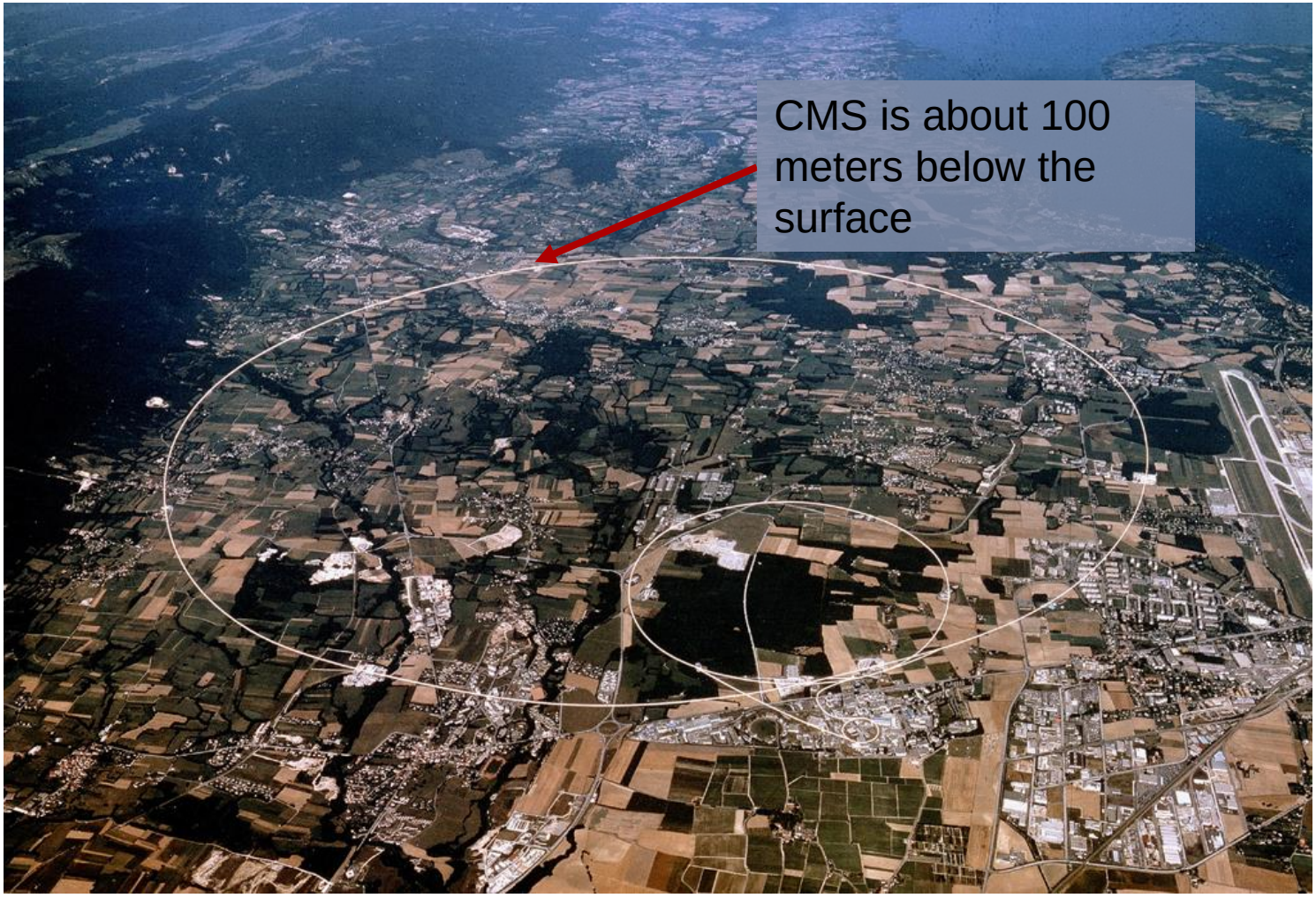
# Supersymmetry (SUSY)

- Very compelling in particle physics
  - Solves a host of problems with the Standard Model (SM)

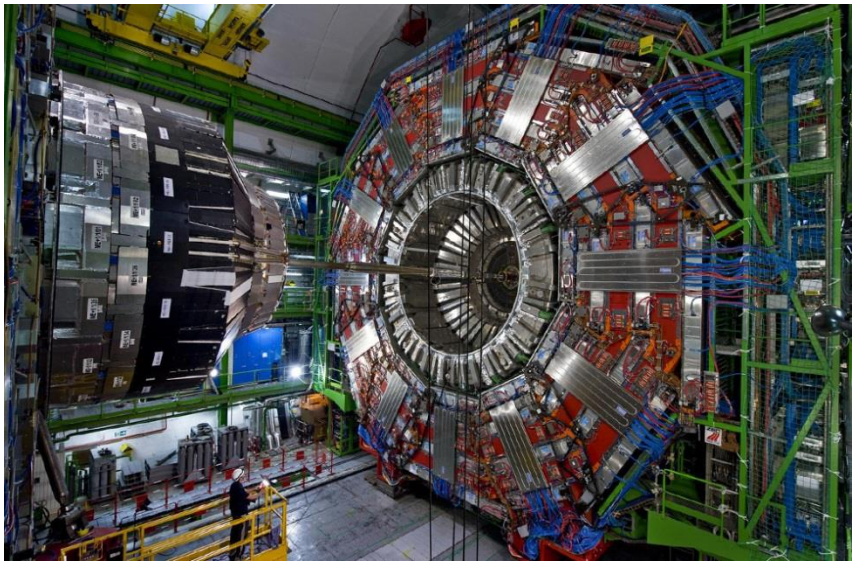


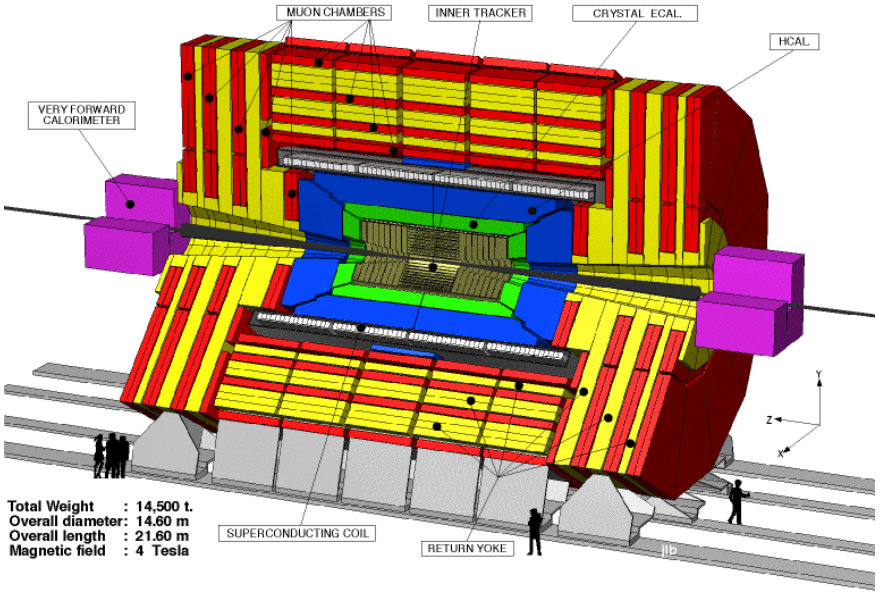

- SUSY particles much heavier than SM counterparts
- LHC has high-energy collisions at 8 TeV, soon to be 13
  - LHC should create these particles!

# The Large Hadron Collider and CMS



# CMS Detector





# Searching for New Particles

- Important equation to find new particles

- $N_{obs}$ = (Cross section) x (Luminosity) x (Acceptance)

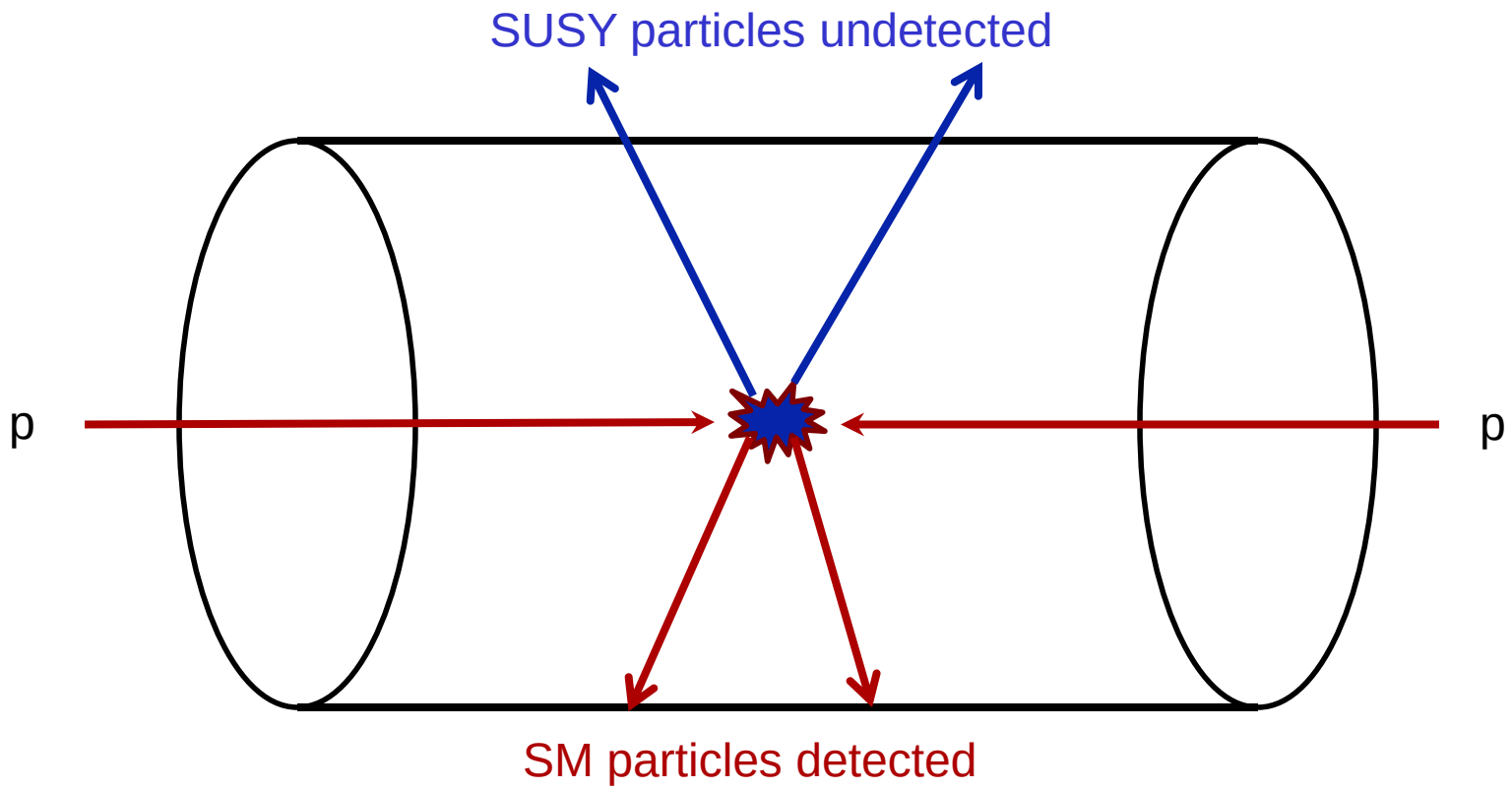
$\#\ \boldsymbol{Events\ Created}$ $\%\ \boldsymbol{Events\ Recorded}$

- Proton bunches collide every ~25 ns (40 MHz)
- Detector can't record every event
  - Only records ~100 events/second
  - How well does it record the events we are interested in?

- What do these events look like at the LHC?

# Collisions at the LHC

- What does a collision at the LHC look like with SUSY?

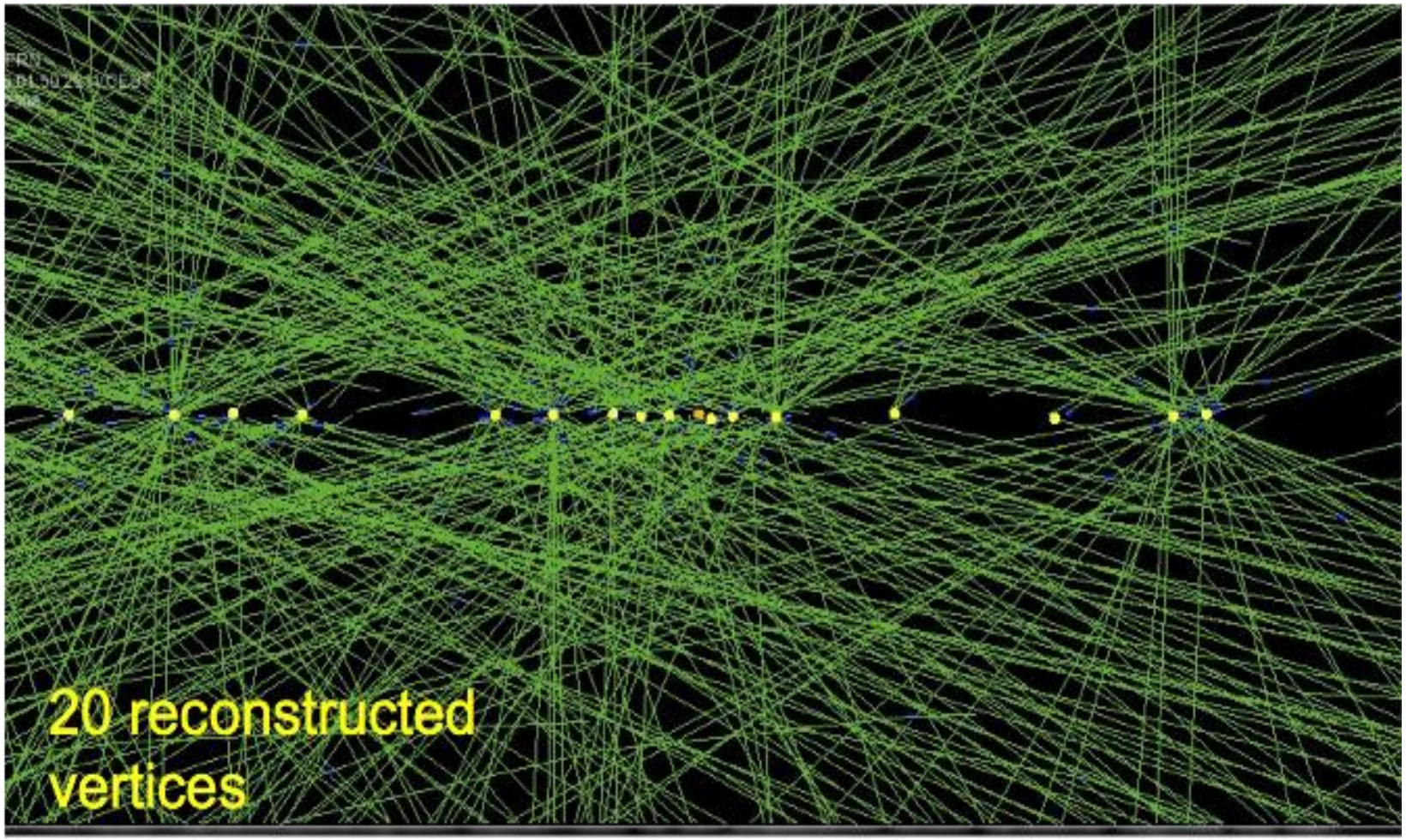



- Much more complicated than this in reality…

# A more correct picture

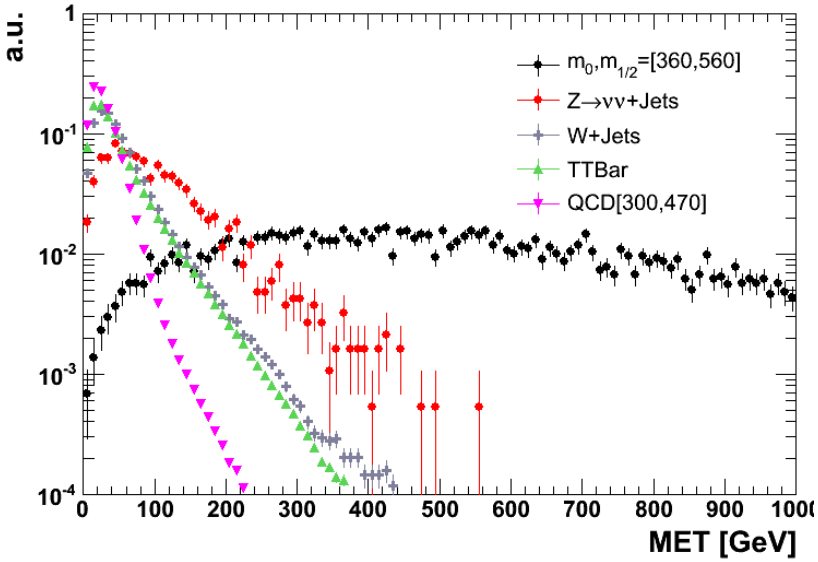
- At LHC, don't just send protons in one at a time.
  - They don't all interact in the middle either!
- ~$10^{11}$ protons in each beam crossing!
- Any number of them can collide
  - ~20 inelastic (head-on collisions) per crossing
- Around 1000 charged particles are created per collision
- What does this look like?

# Lots of Collisions and Particles!



# SUSY and Events

- Good to look at transverse momentum
  - SUSY events have large momentum imbalance (MET)
  - SM events have low MET



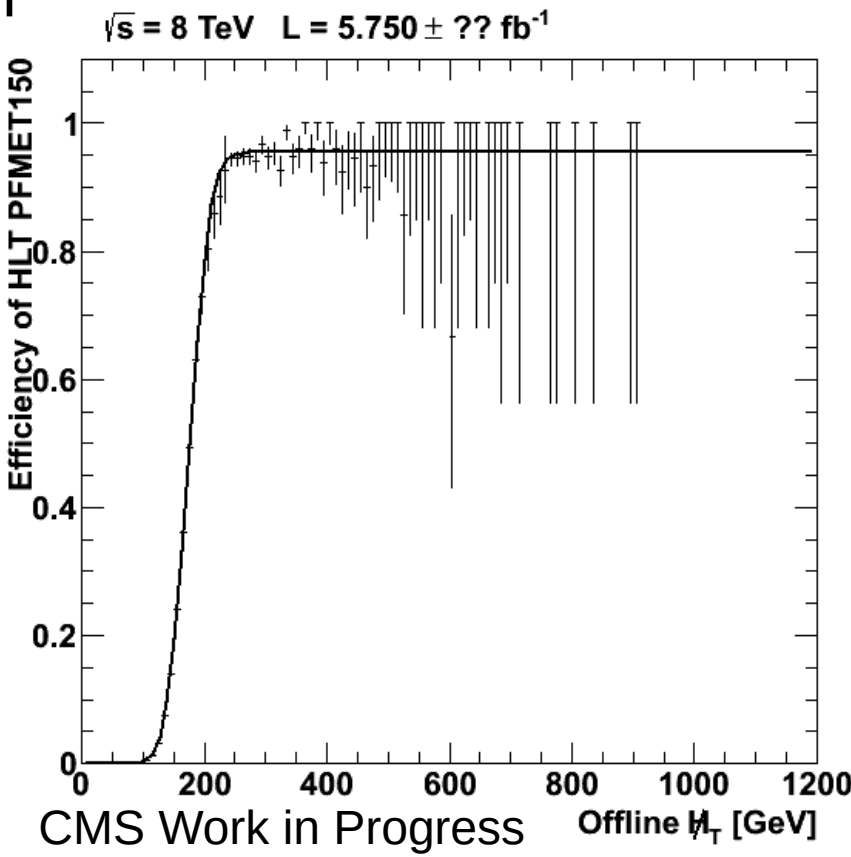

- If good at finding high MET, good at finding SUSY!
- How efficiently do we record events with high MET?

# MET Efficiency at CMS

- Take events from unrelated trigger
  - Then see how well MET trigger does
- Plateaus above ~220 GeV
  - High efficiency in this region

$$Efficiency = \frac{N_{pass}}{N_{total}}$$

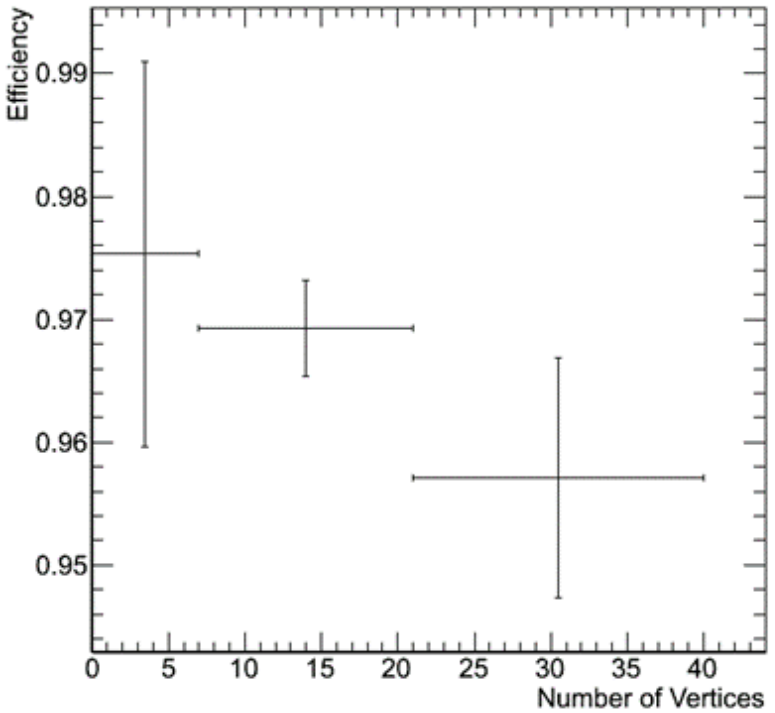
- Multiple collisions can occur
  - affects efficiency?



# Multiple Collisions in Detector

- How do different number of collisions affect efficiency?
  - “fake” MET counted in triggers
  - reconstructed offline
    - loss of efficiency
- Dependence on pileup!

PFMET150 Efficiency in Plateau Region




CMS Work in Progress

# Summary and Next Steps

- High momentum imbalance is signature of SUSY
  - High efficiency with high momentum imbalance events
  - Efficiency linear in plateau region…**Good!**
  - Dependent on pileup…**Bad!**

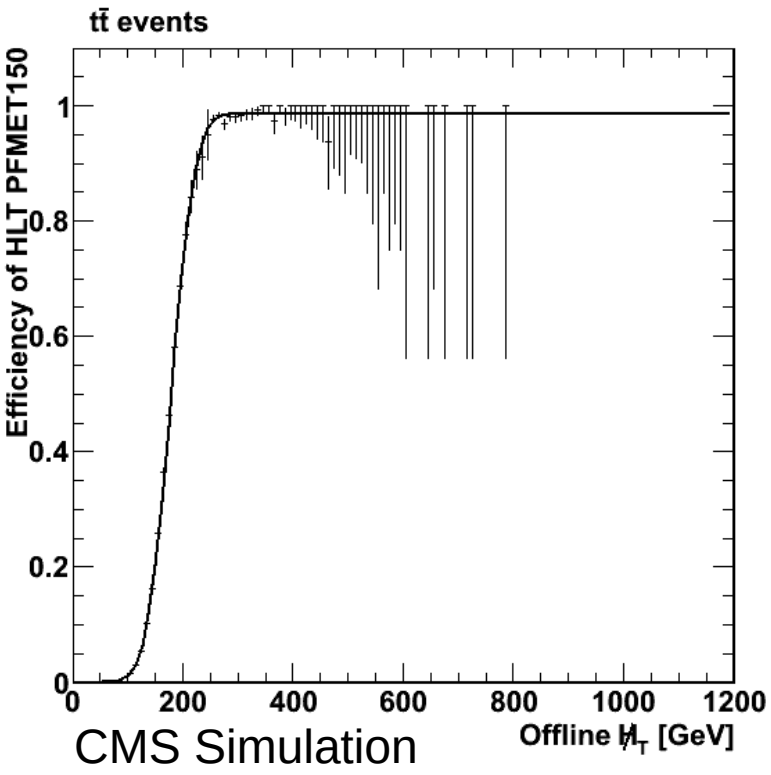
- Higgs recently found at 125 GeV
  - Newer SUSY models have another signature besides MET
  - Need to analyze those triggers too!

# BACKUP SLIDES

# Monte Carlo Simulations

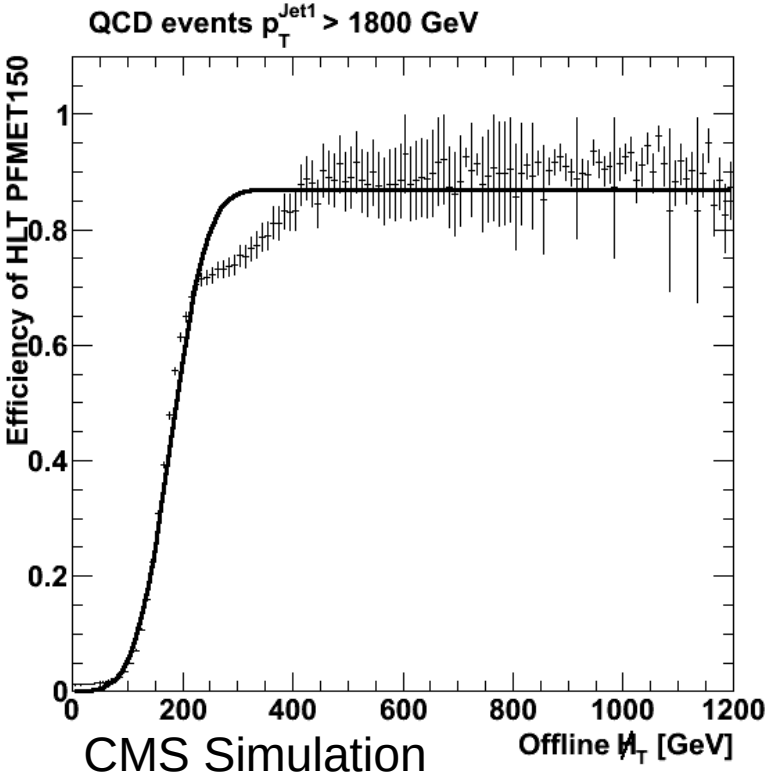
How well can we model these events?

Looks like the data!




CMS Simulation

Does not look like the data!




CMS Simulation

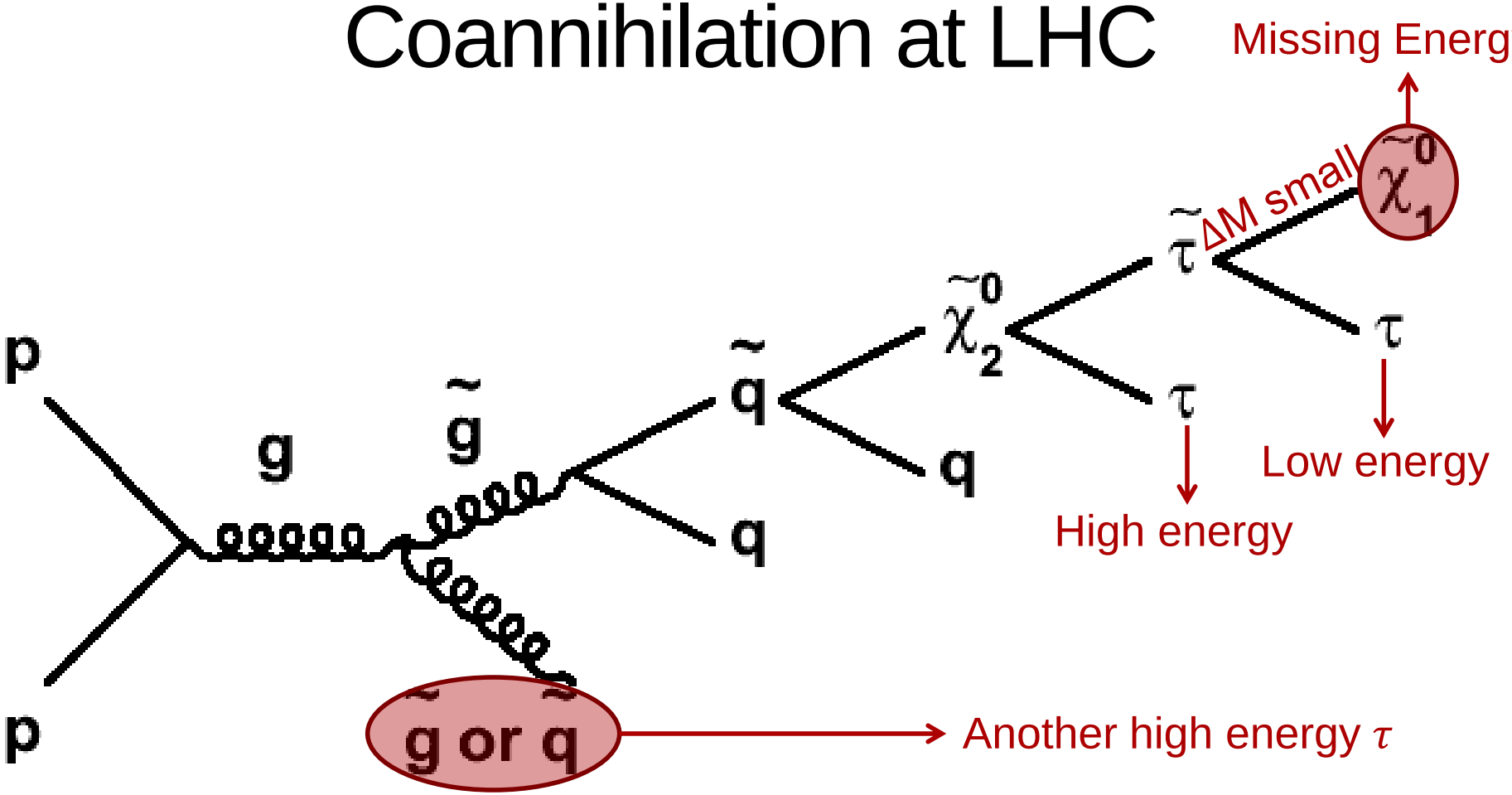
# Coannihilation

- Particular model of SUSY that is cosmologically motivated
  - Allows for the lightest neutralino to be Dark Matter
- ⇒ Predicts Dark Matter relic density
  - Neutralino and stau annihilate in early universe

See R. Arnowitt, *et al.*, Phys. Rev. Lett. **100**, 231802 (2008)

- So how do we go about finding new particles?

# Coannihilation at LHC

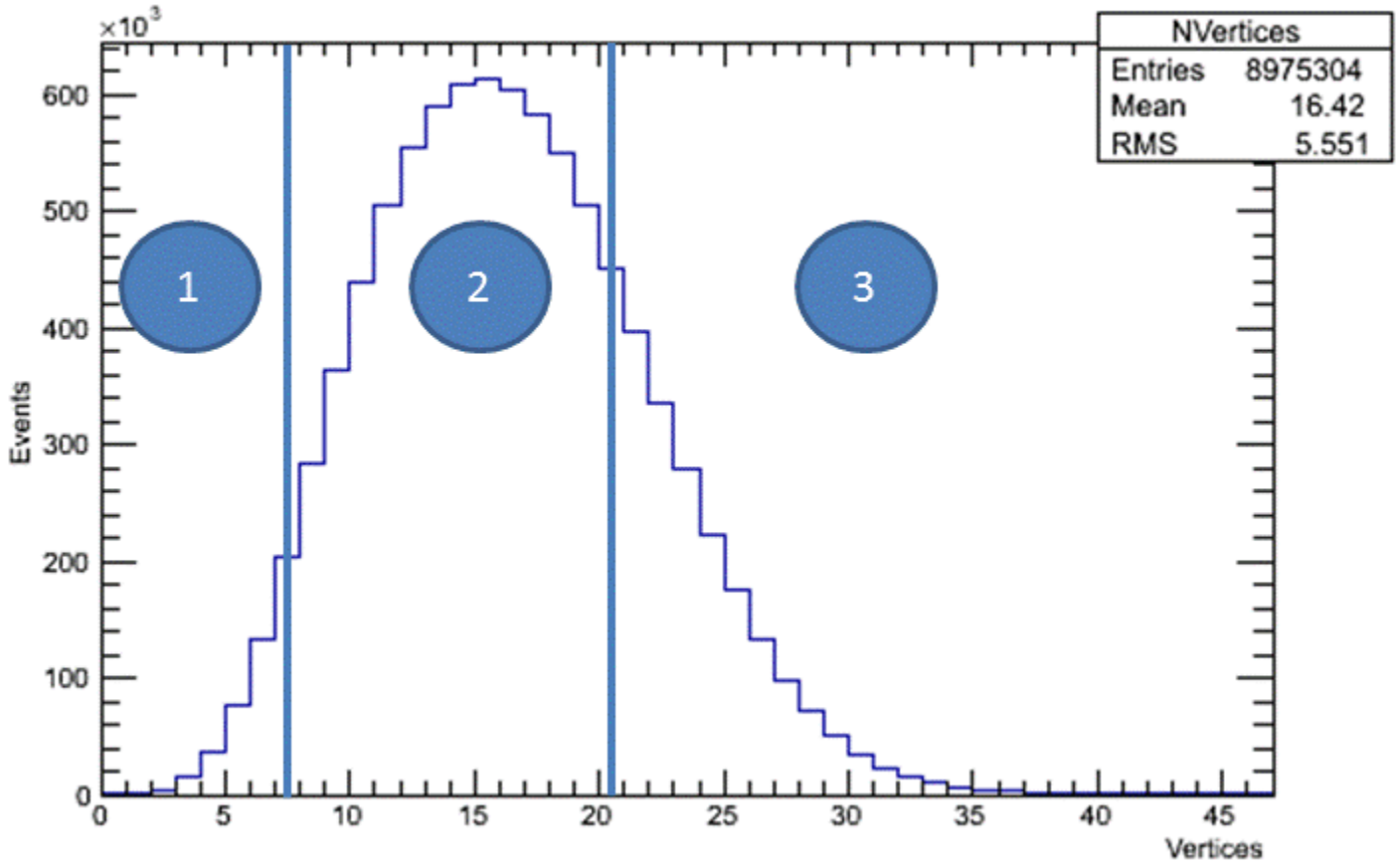


# Coannihilation (CA) Region of SUSY

- Part of a minimal supergravity model, mSUGRA
- Mass of lightest neutralino $\tilde{\chi}_1^0$ similar to the $\tilde{\tau}$
  - $\Delta M \sim 5 - 15\ GeV$
  - All other SUSY particles have much higher masses
  - Branching ratio for $\tilde{\tau} \rightarrow \tau + \tilde{\chi}_1^0$ about 100%
- $\tilde{\chi}_1^0$ and $\tilde{\tau}$ annihilation predicts dark matter relic density
  - Lightest neutralino, $\tilde{\chi}_1^0$, is dark matter
  - See R. Arnowitt, *et al.*, Phys. Rev. Lett. **100**, 231802 (2008)
- How do we find it?

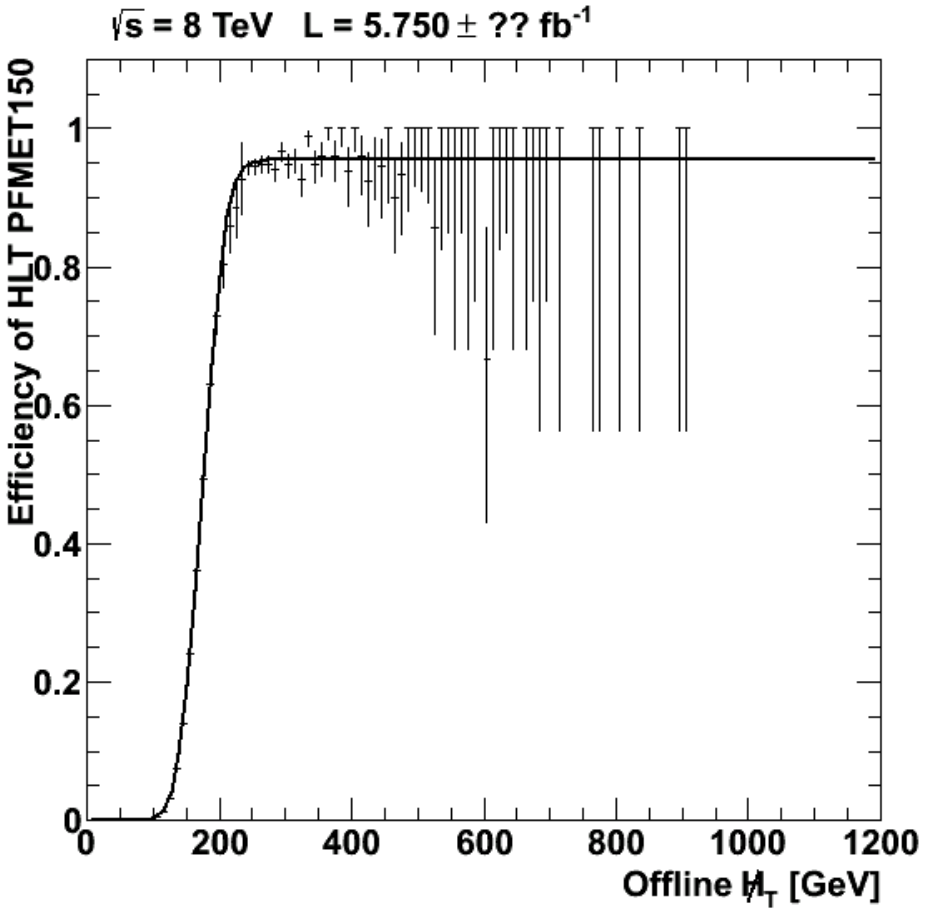
# Trigger

- $$MHT = -\sum_{jets} p_T \ \forall \ p_T > 30 \ GeV$$
- Offline MHT is the MHT that is recorded after the jets are reconstructed by a higher level trigger
  - More precise than what is measured by the trigger itself


×10^3
600
500
400
300
200
100
0
Events
0
5
10
15
20
25
30
35
40
45
Vertices
NVertices
Entries 8975304
Mean 16.42
RMS 5.551
1
2
3

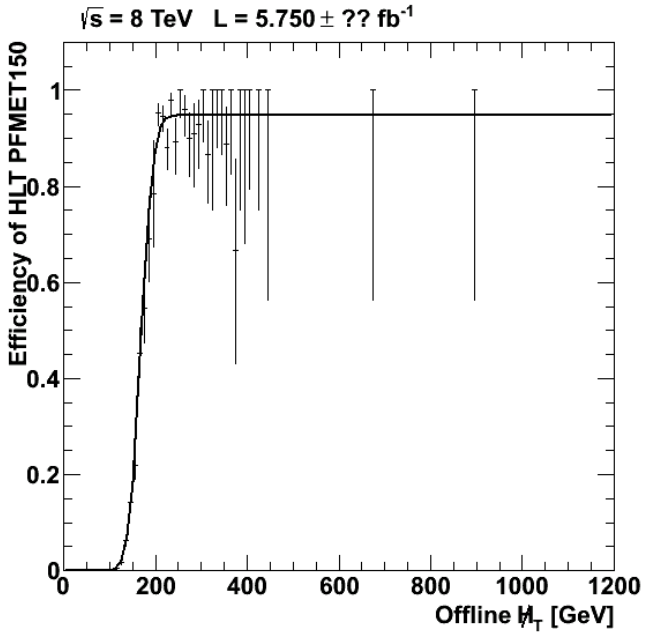
# All Data

Fit: [0]*0.5*(Erf((x-[1])*0.5/[2])+1)

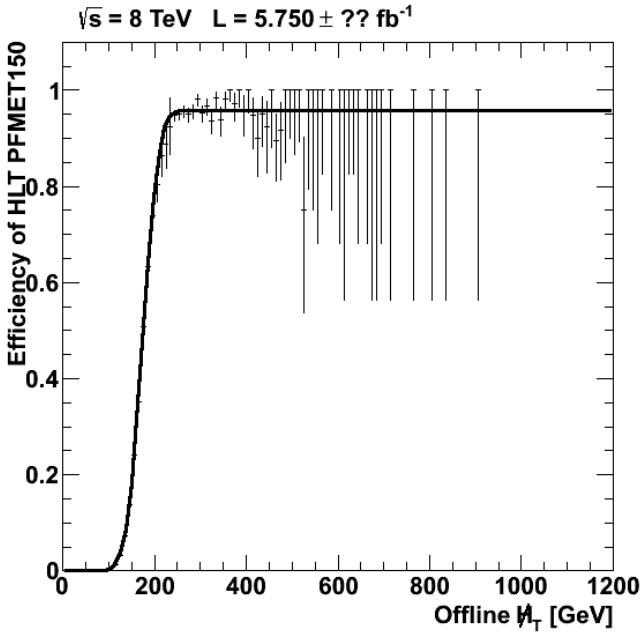



| Parameter | 0 (Eff) | 1 (Thresh) | 2 (Width) |
|---|---|---|---|
| | .09545±.0036 | 174.26±.44 | 19.43±.16 |

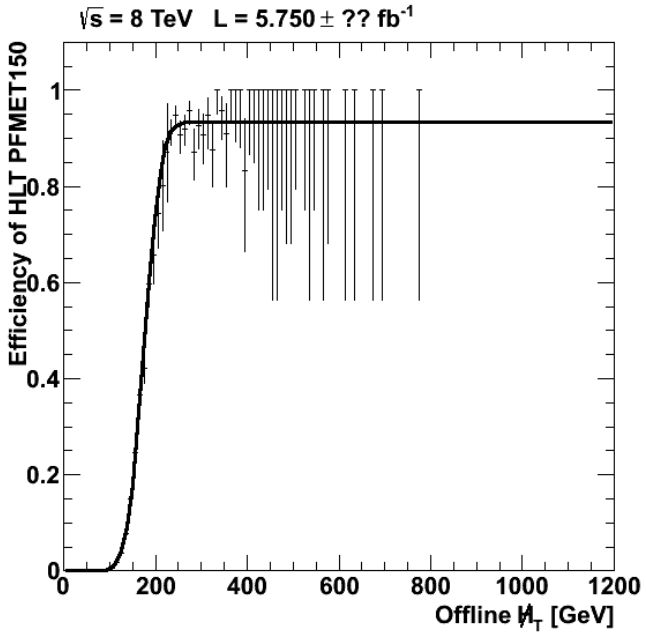
1




2




3

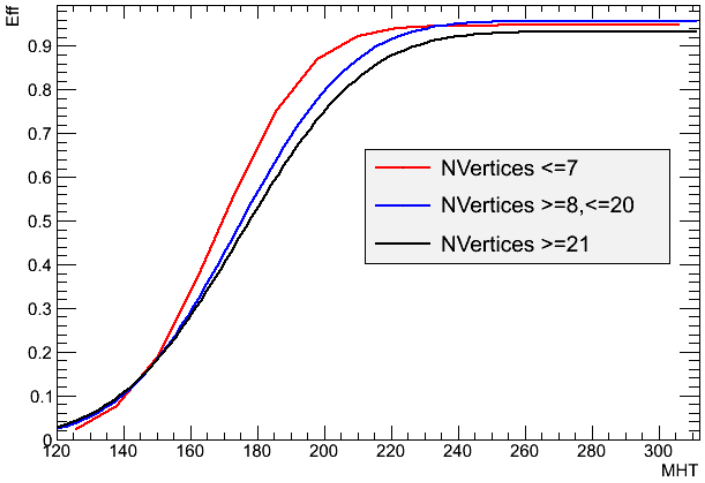


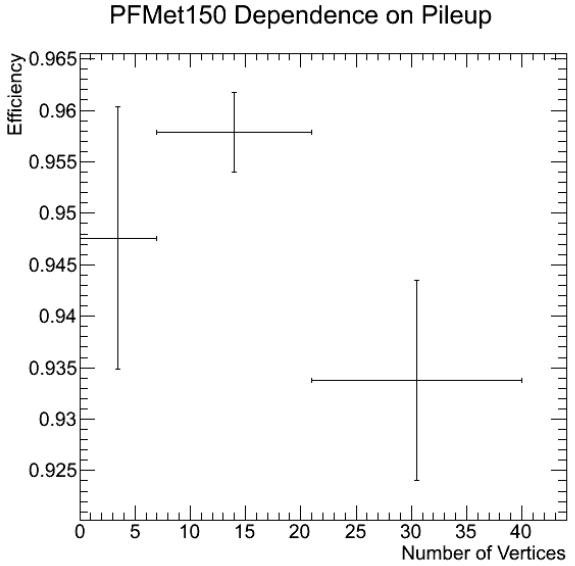

| | 0 (Eff) | 1 (Thresh) | 2 (Width) |
|---|---|---|---|
| 1 | 0.9476±.0127 | 168.32±1.46 | 15.18±.63 |
| 2 | 0.9579±.0039 | 174.09±.50 | 19.22±.18 |
| 3 | 0.9337±.0097 | 175.30±1.08 | 20.54±.35 |

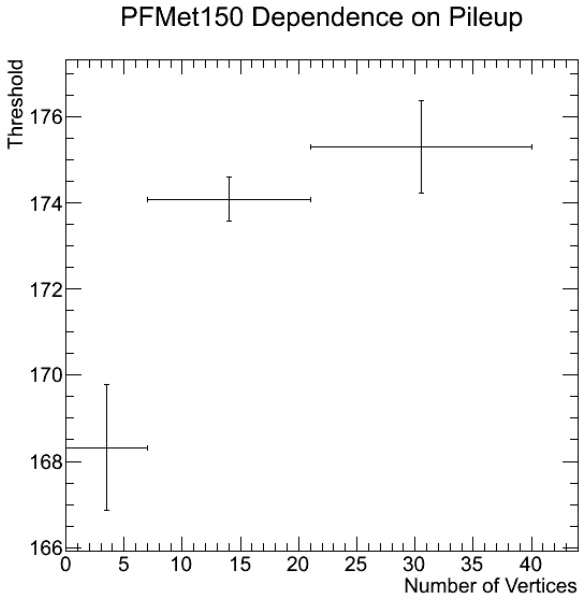
# Fits

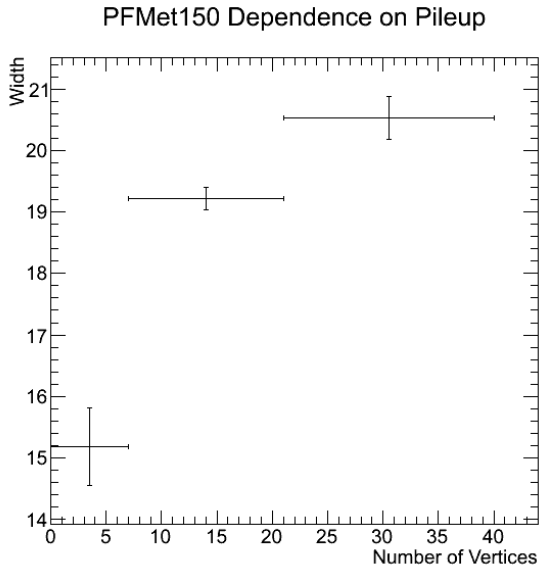
| 0 (Eff) | 1 (Thresh) | 2 (Width) |
|---|---|---|

Fit: [0]*0.5*(Erf((x-[1])*0.5/[2])+1)



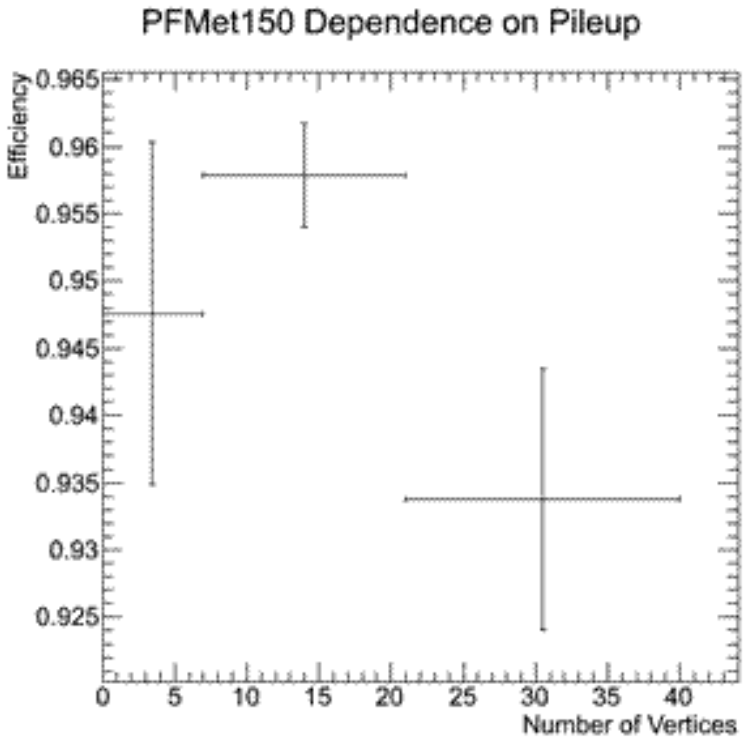



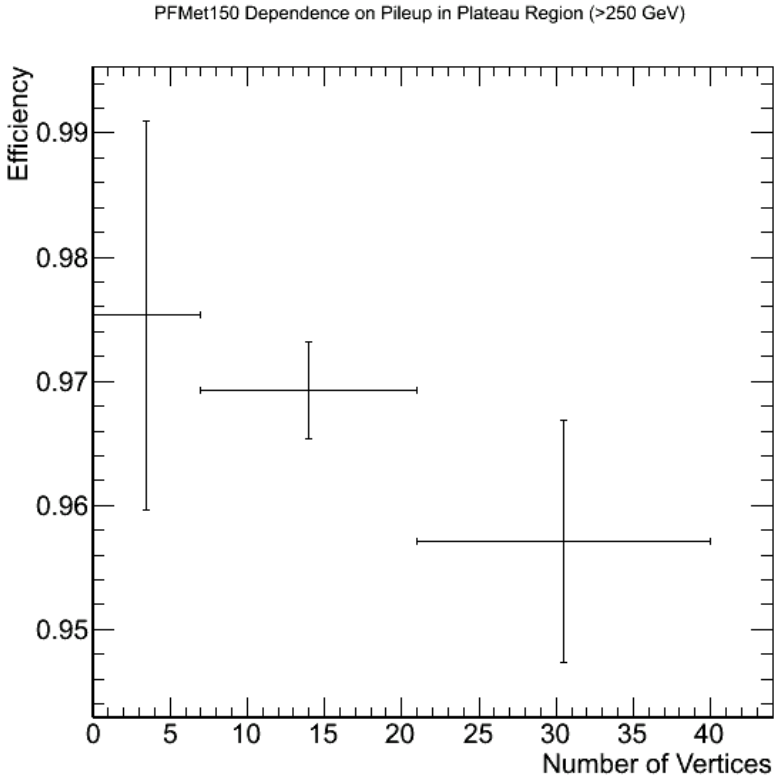



# Efficiency

## Using gaussian fit

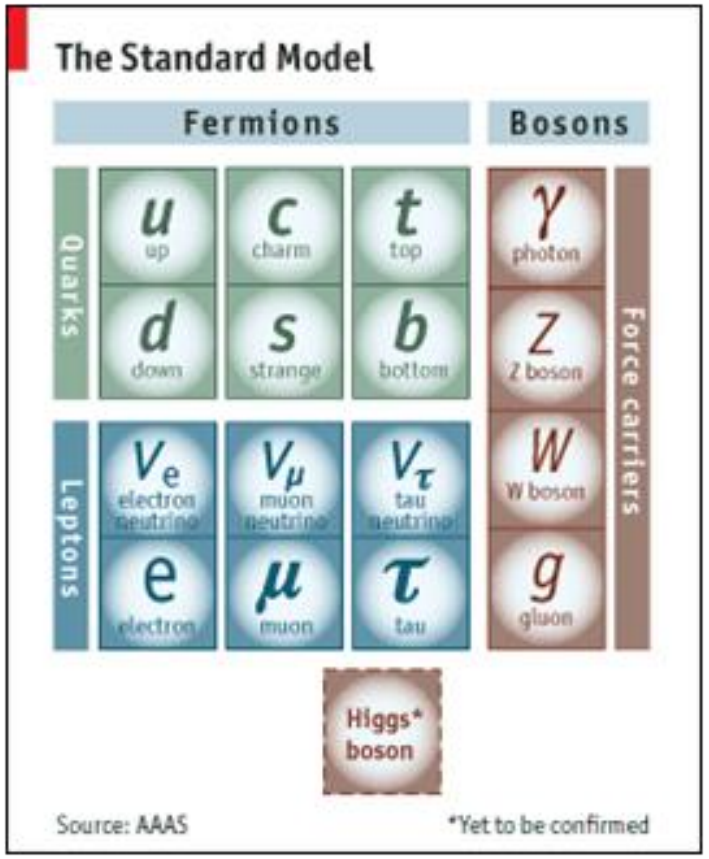



## Using linear fit in plateau region



# Standard Model

- Explains nearly all of particle physics
- Correctly predicted new particles
- Fermions
  - Half-integer spin
- Bosons
  - Integer spin
- Not the whole story…



# Beyond the Standard Model

- Two big problems for the Standard Model

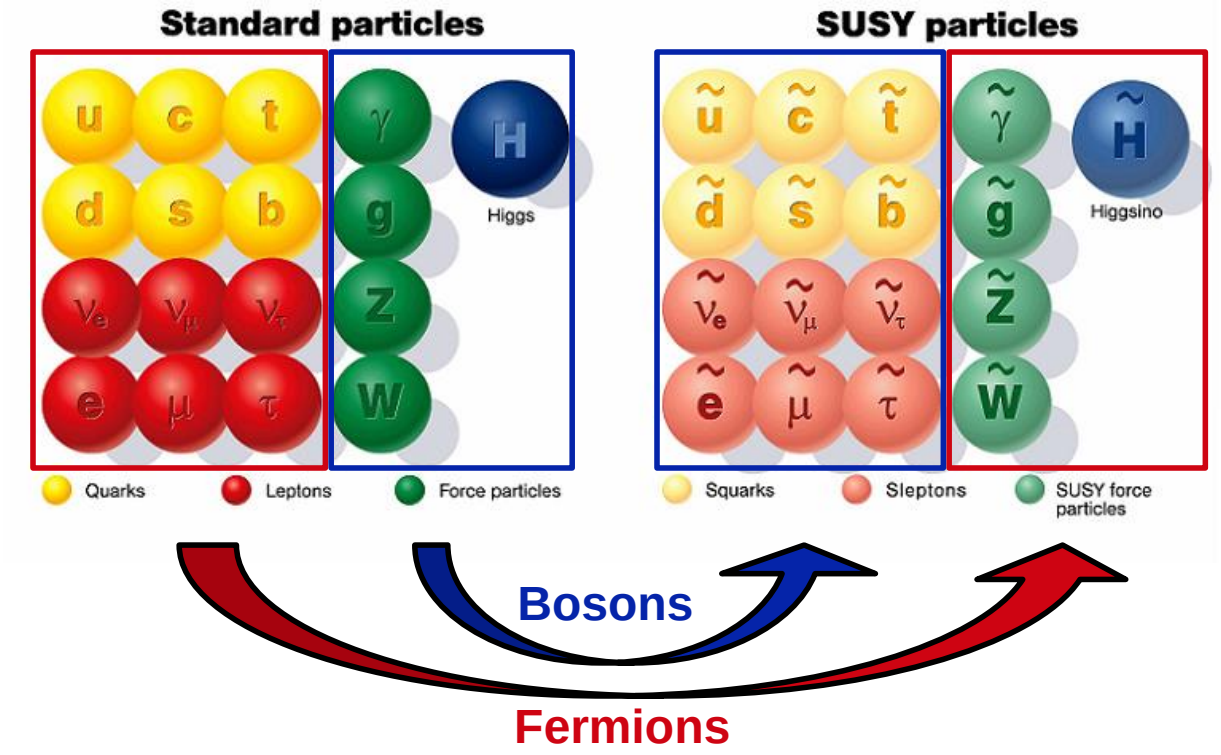
1. Higgs mass difficult to calculate
   - Diverges without fine-tuning
   - Likely a Higgs with a finite mass

2. No SM particle can explain dark matter
   - Strong evidence for dark matter as a particle

- Something new must be out there

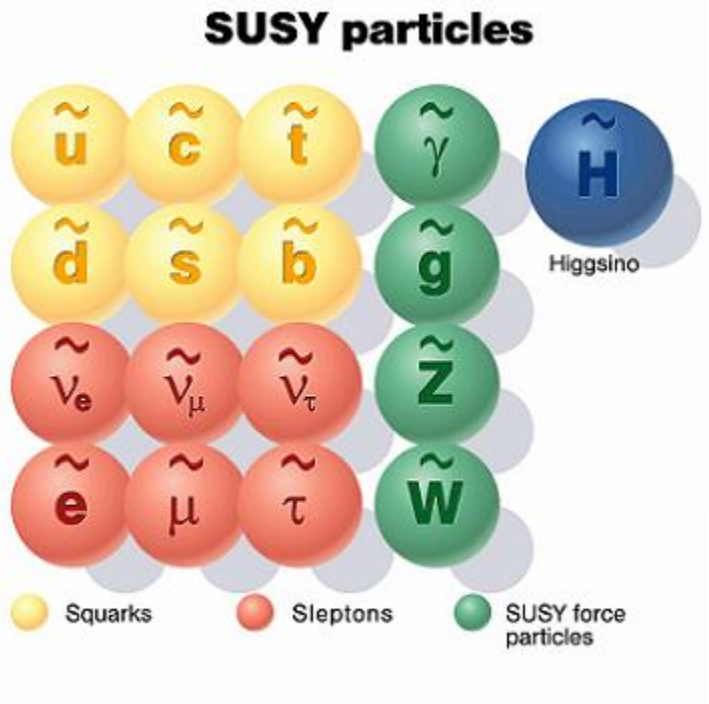
# Standard Model (SM) and Supersymmetry (SUSY)

Similar to how there is a symmetry between matter and anti-matter, there is a symmetry between SM and SUSY.



# Supersymmetry (SUSY)

- Every particle has a supersymmetric "partner"
- Fermions↔Bosons
- Removes divergence of Higgs Mass
  - No need for fine-tuning
- R-parity conservation gives dark matter candidate
- Force particle states mix to form charginos and neutralinos



# Outline

- What is supersymmetry? Coannihilation? Why do we need it?
- How do we find it? What do we look for?
- Are the detectors we have good at finding the evidence? Are we good at simulating the data?
- What are the next steps to finding it, if it's out there?