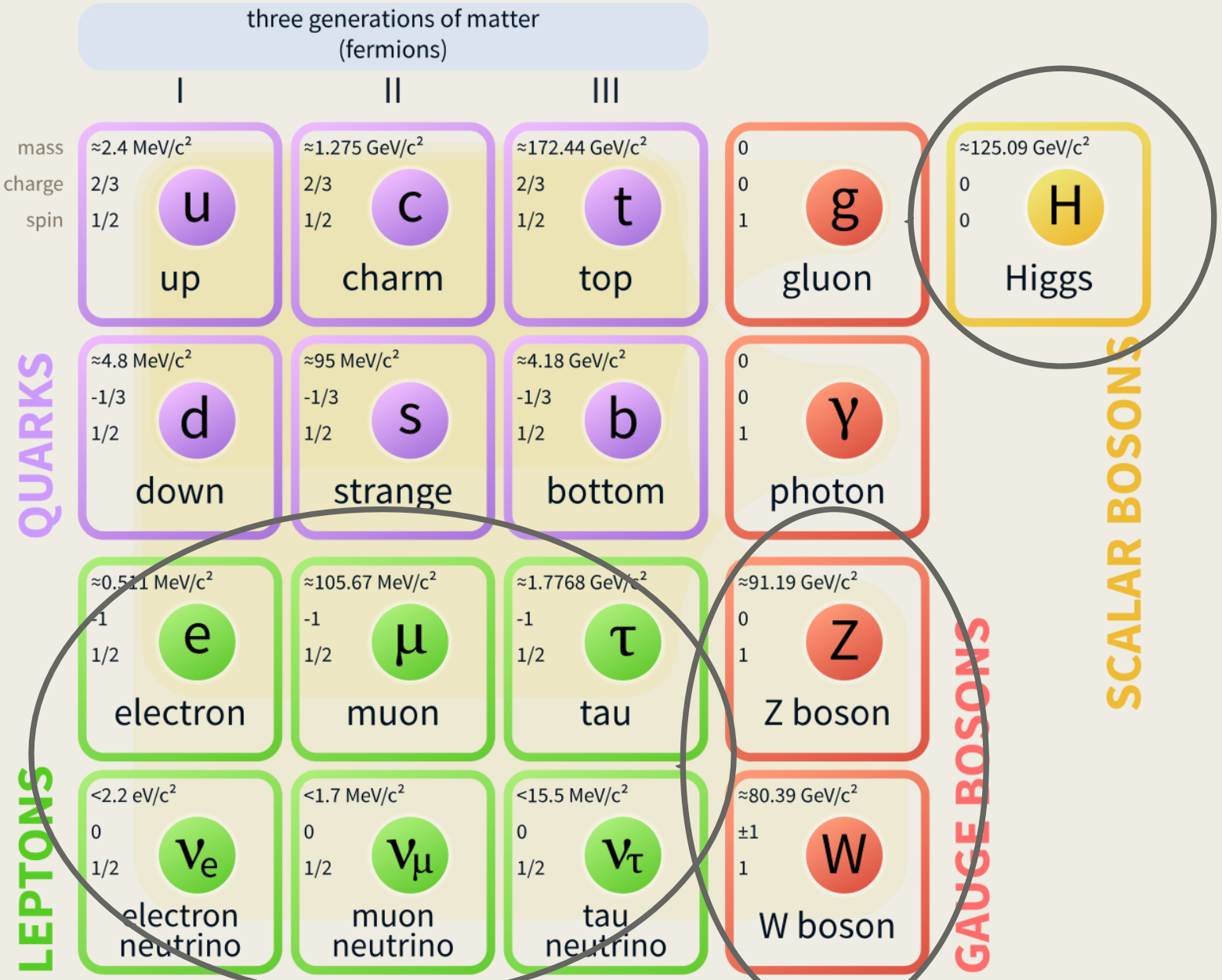
VECTORLIKE LEPTONS AT THE LARGE HADRON COLLIDER

Jon Franco

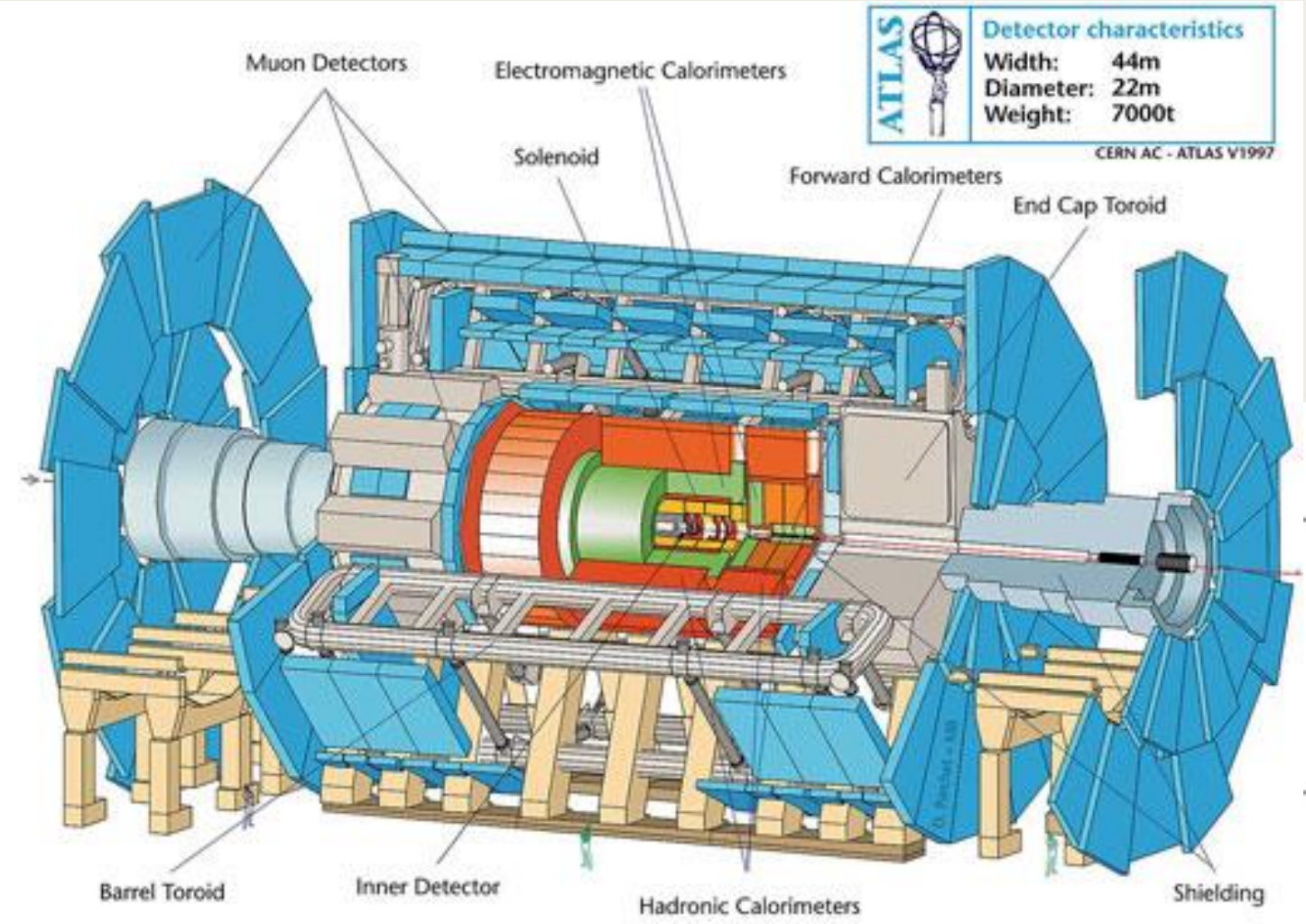
Standard Model of Elementary Particles

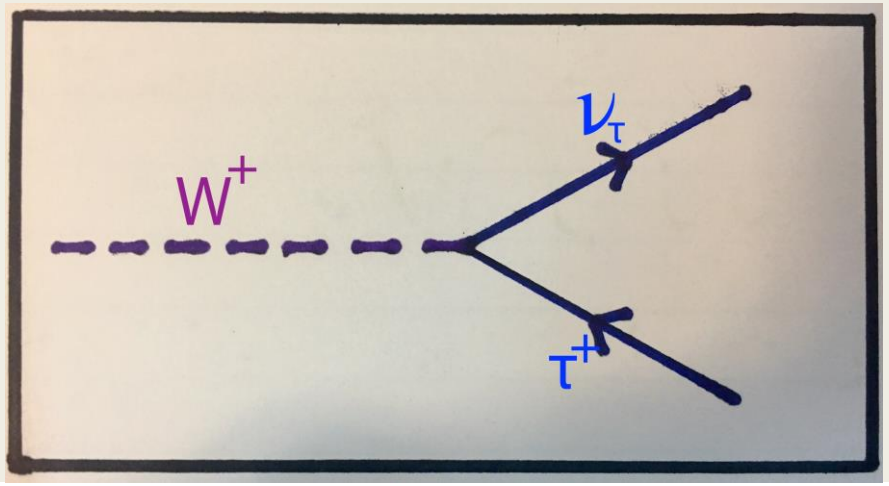


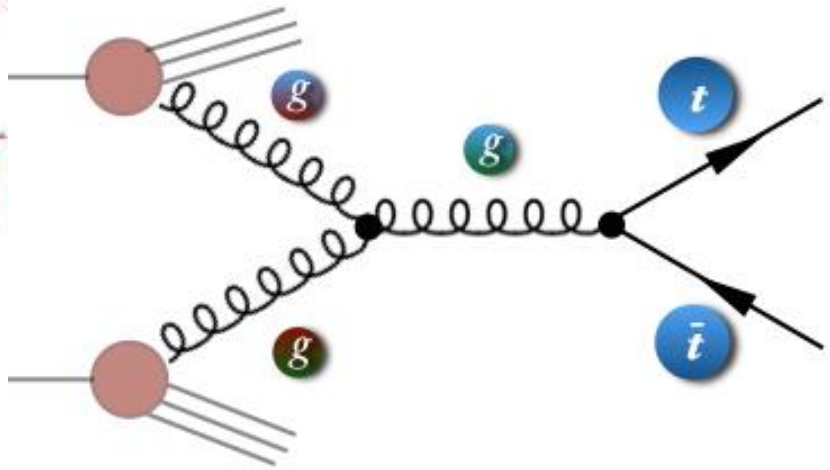
- Largest collider in the world functioning at the highest energy
- ~ 40 Million collisions/s, recording only ~1000 collisions/s
- > 10^{10} events/year

$$\sqrt{s} = 13\ TeV$$

Collisions and Detectors

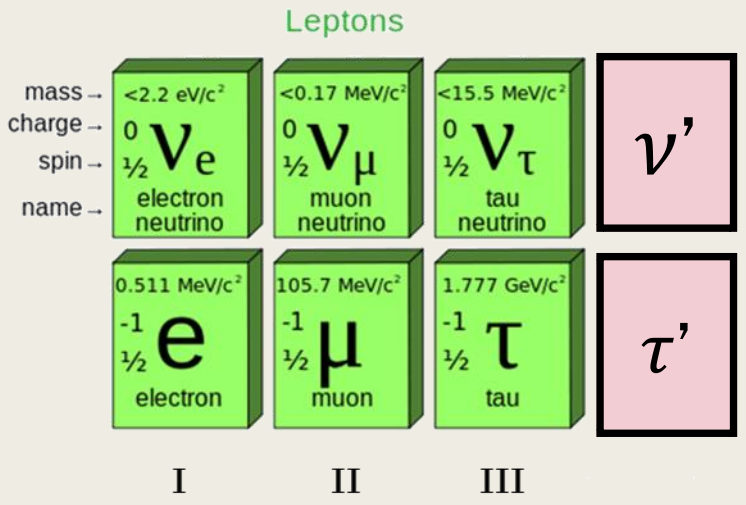






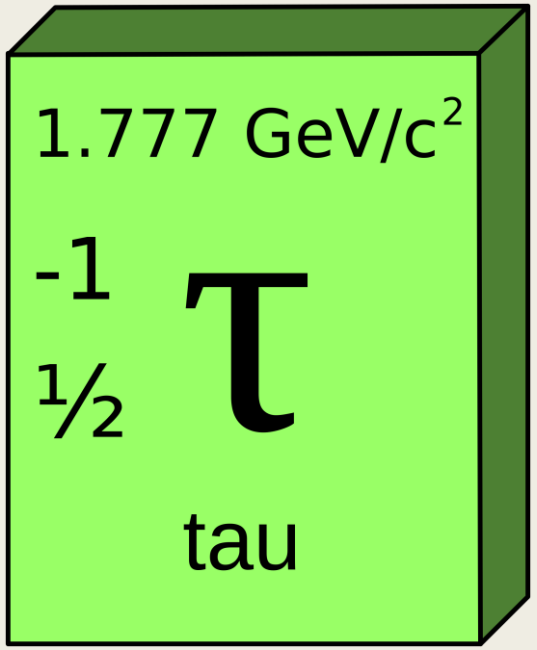
What is a vector-like lepton?

- We don’t know the mass
- Looking for it’s existence
- Based on measurements m > 100 GeV
- Heavy (theoretically ≃ mass of iron atom)
- Written as τ’, ν’



Theory

- τ'/ν' couples to τ
  - *Least well measured*
  - *Most room for extra-SM behavior*
- Several anomalies in our comparison to the standard model, and vectorlike leptons may help explain this.



Why?

- Fourth generation lepton
  - *Could redefine boundary of lepton flavor violation*
  - *May explain muon g-2 anomaly*
  - *Give insight to large dimension behavior*
- String theory
  - *Predicts vectorlike particles*
- We’re looking for a discrepancy from the Standard Model

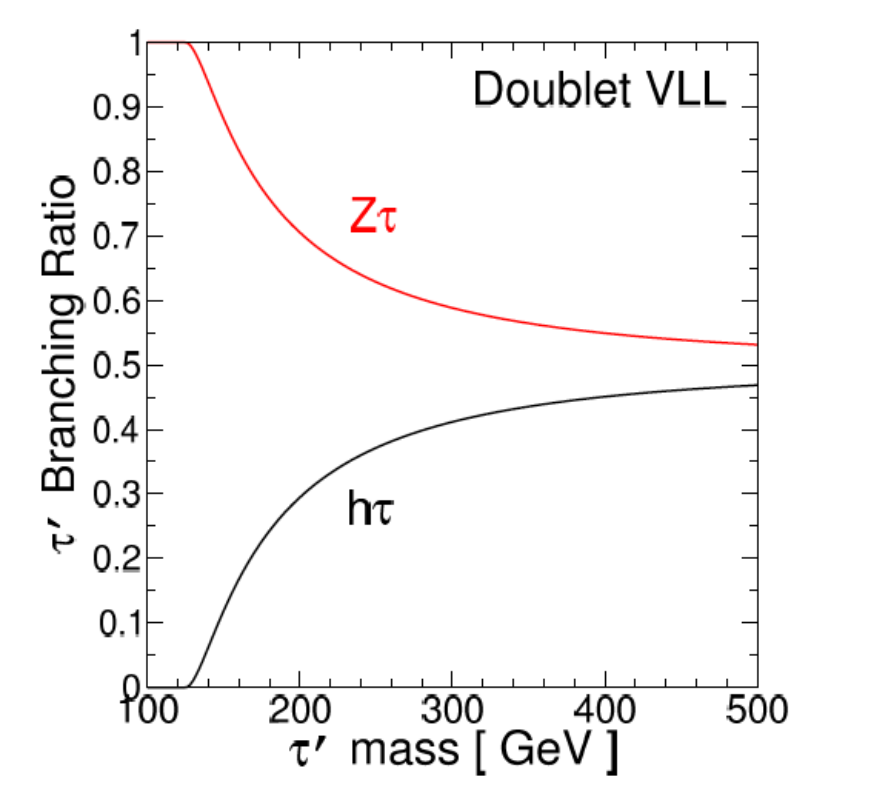
Finding a Region of Interest

- Understand theoretical model
- Create simulations for both theoretical and standard models
- Look at regions that high expected signal and low background
- Signal vs. Background

Decay paths of Tau prime

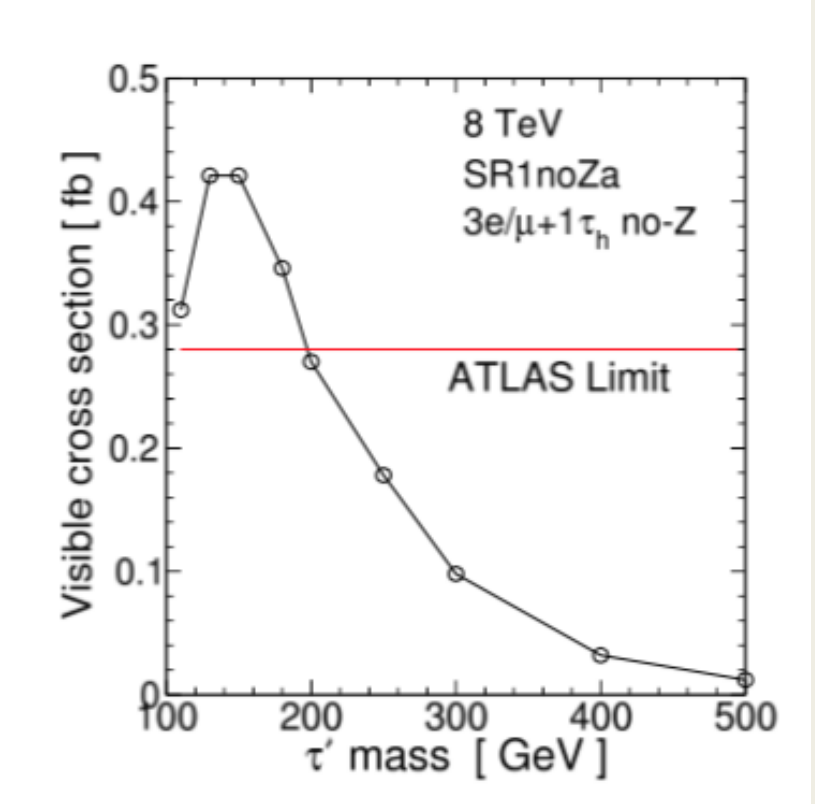
- Particle discovery
  - Look at theoretical behavior of particle
  - Look for rare signatures
    - Decays to tau/boson pairs
  - Decays with more than two leptons are extremely rare but common in theoretical decays of τ'
- τ' can decay into
  - Zτ
  - Hτ
- ν' can decay into
  - Wτ
- Initial decays:

(PP $\rightarrow \tau'\tau' \rightarrow$ ZτZτ)
(PP $\rightarrow \tau'\tau' \rightarrow$ ZτHτ)
(PP $\rightarrow \tau'\tau' \rightarrow$ HτHτ)
(PP $\rightarrow \tau'\nu' \rightarrow$ ZτWτ)
(PP $\rightarrow \tau'\nu' \rightarrow$ HτWτ)
(PP $\rightarrow \nu'\nu' \rightarrow$ WτWτ)



Regions

- How are we going to search for these particles?
  - *W decays to leptons*
  - *Z decays to two leptons*
  - *H decays to WW then to multiple leptons*
- Expect large amounts of leptons
- Multiple lepton events are rare in the standard model
- Searching for events with a large amount of leptons



Signal vs. Background

SM Backgrounds	σ_b (fb) in $\geq 3e/\mu + 1\tau_h$		σ_b (fb) in $\geq 2e/\mu + 2\tau_h$		σ_b (fb) in $\geq 4e/\mu$	
	incl.	no-Z	incl.	no-Z	incl.	no-Z
$pp \to WZ$	0.0637	0.0000	0.0127	0.0127	0.0000	0.0000
$pp \to ZZ$	0.7840	0.0242	0.4555	0.0302	14.7263	0.0121
$pp \to t\bar{t}W$	0.0080	0.0057	0.0028	0.0025	0.0000	0.0000
$pp \to t\bar{t}Z$	0.0249	0.0045	0.0059	0.0033	0.0508	0.0014
$pp \to t\bar{t}h$	0.0071	0.0049	0.0071	0.0056	0.0052	0.0026
$pp \to hh$	0.0012	0.0004	0.0008	0.0004	0.0016	0.0004
$pp \to hZ$	0.1377	0.0084	0.0588	0.0051	0.2418	0.0067
$pp \to WWZ$	0.0193	0.0034	0.0025	0.0017	0.0986	0.0026
$pp \to WZZ$	0.0062	0.0004	0.0015	0.0004	0.0423	0.0005
$pp \to ZZZ$	0.0030	0.0001	0.0013	0.0002	0.0282	0.0002
Total Background	1.055	0.0520	0.549	0.0619	15.1950	0.0265

$M_{\tau'}$ (GeV)	σ_s (fb) in $\geq 3e/\mu + 1\tau_h$		σ_s (fb) in $\geq 2e/\mu + 2\tau_h$		σ_s (fb) in$\geq 4e/\mu$	
	inclusive	no-Z	inclusive	no-Z	inclusive	no-Z
110	3.048	0.490	1.353	0.636	2.632	0.000
130	5.126	0.782	2.402	0.729	2.877	0.302
150	4.123	0.533	1.896	1.008	3.050	0.214
180	2.712	0.538	1.158	0.670	1.913	0.193
200	2.173	0.533	0.958	0.507	1.558	0.177
250	1.037	0.267	0.495	0.312	0.740	0.108
300	0.549	0.178	0.257	0.178	0.456	0.098
400	0.188	0.068	0.095	0.085	0.170	0.036
500	0.081	0.033	0.035	0.033	0.066	0.016
Total Background	1.055	0.052	0.549	0.062	15.195	0.027

Signal is part of the measurement which corresponds to what we are looking for

Control regions are a spot we expect minimal signal, and high background

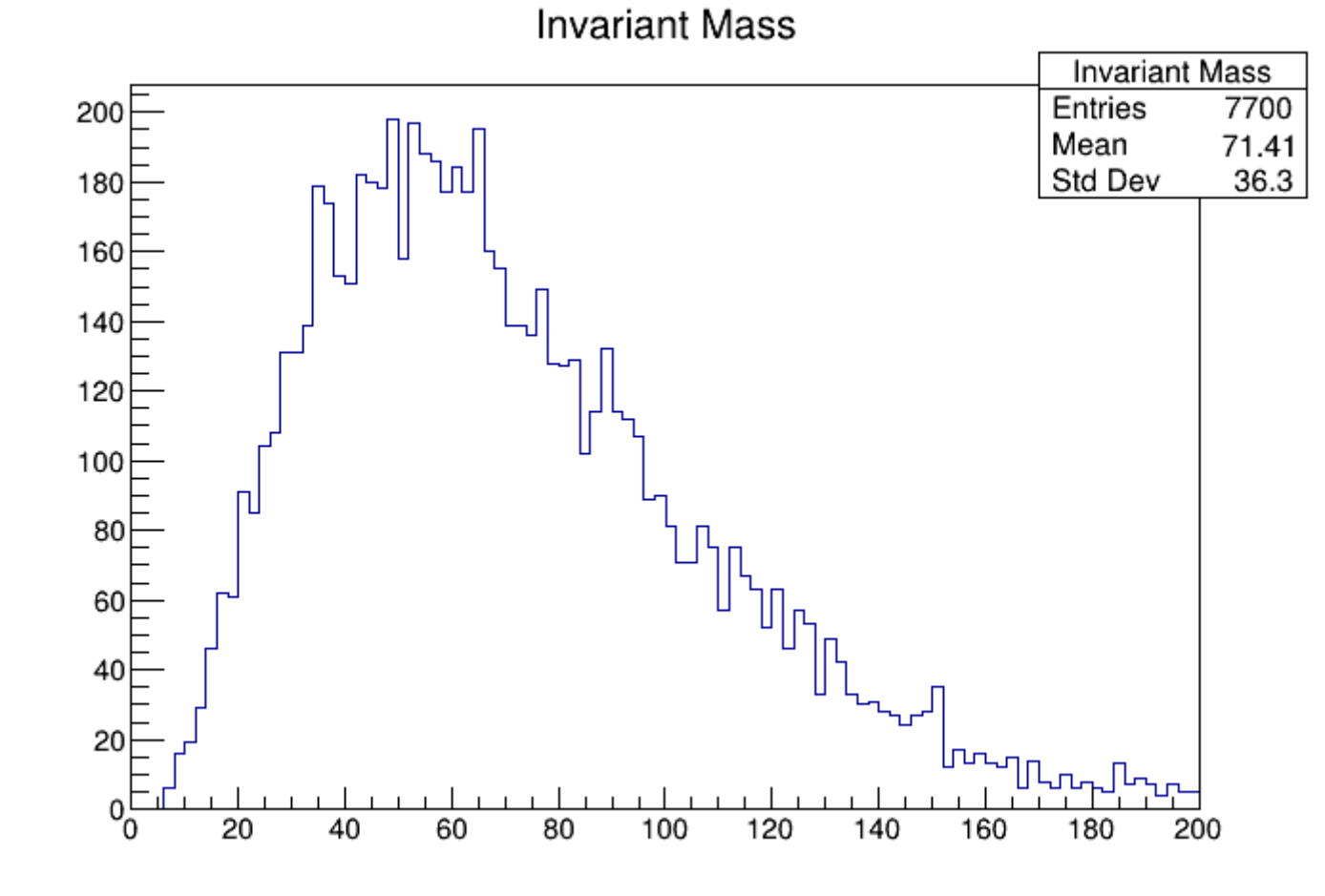
Background is everything else

Control Regions

- A region where we expect overwhelming background in comparison to signal
- Blind study
- Simulations in Monte Carlo (MC)
- Multi lepton events
  - *Fake leptons*

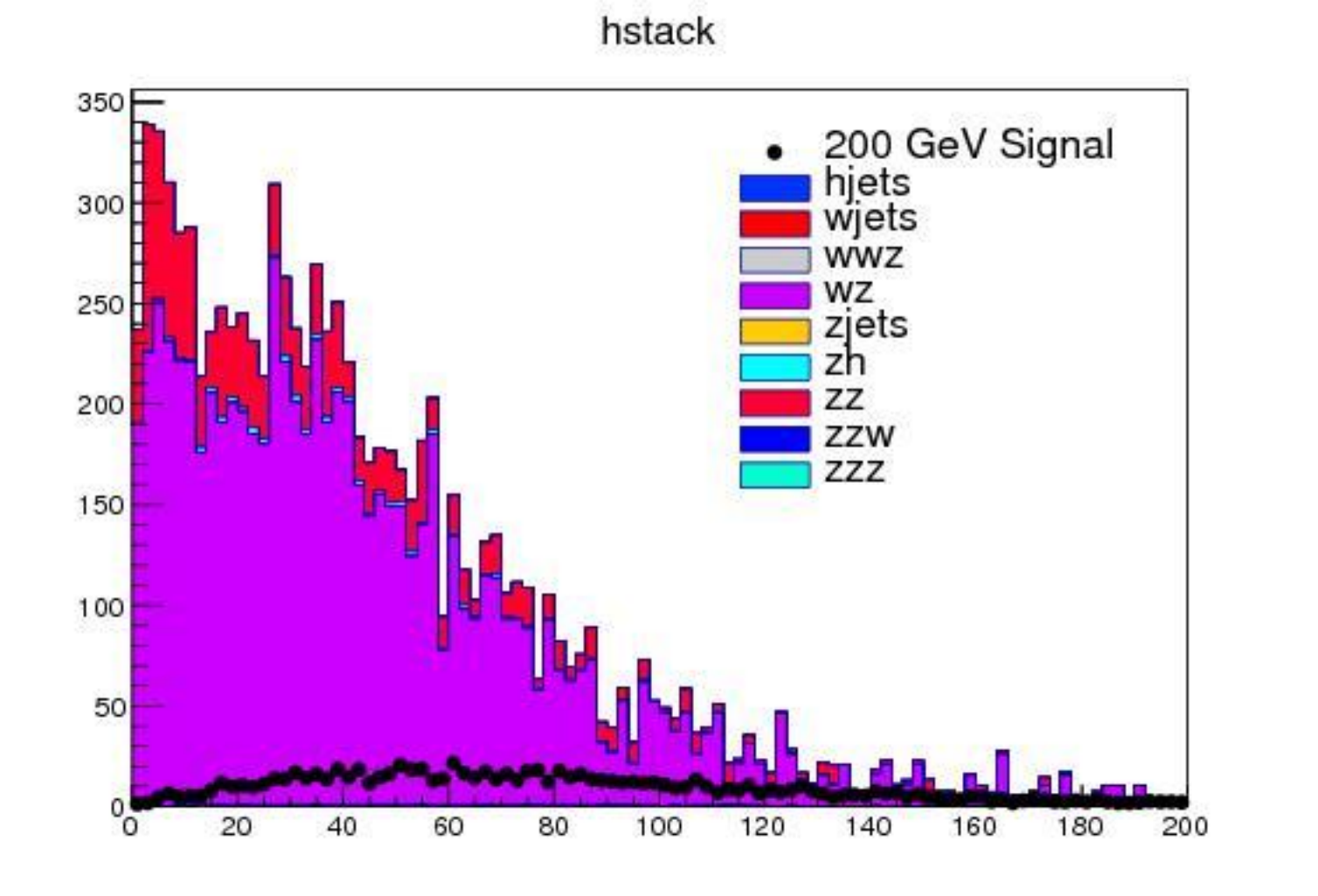
Preliminary predictions

- Mass of different bosons



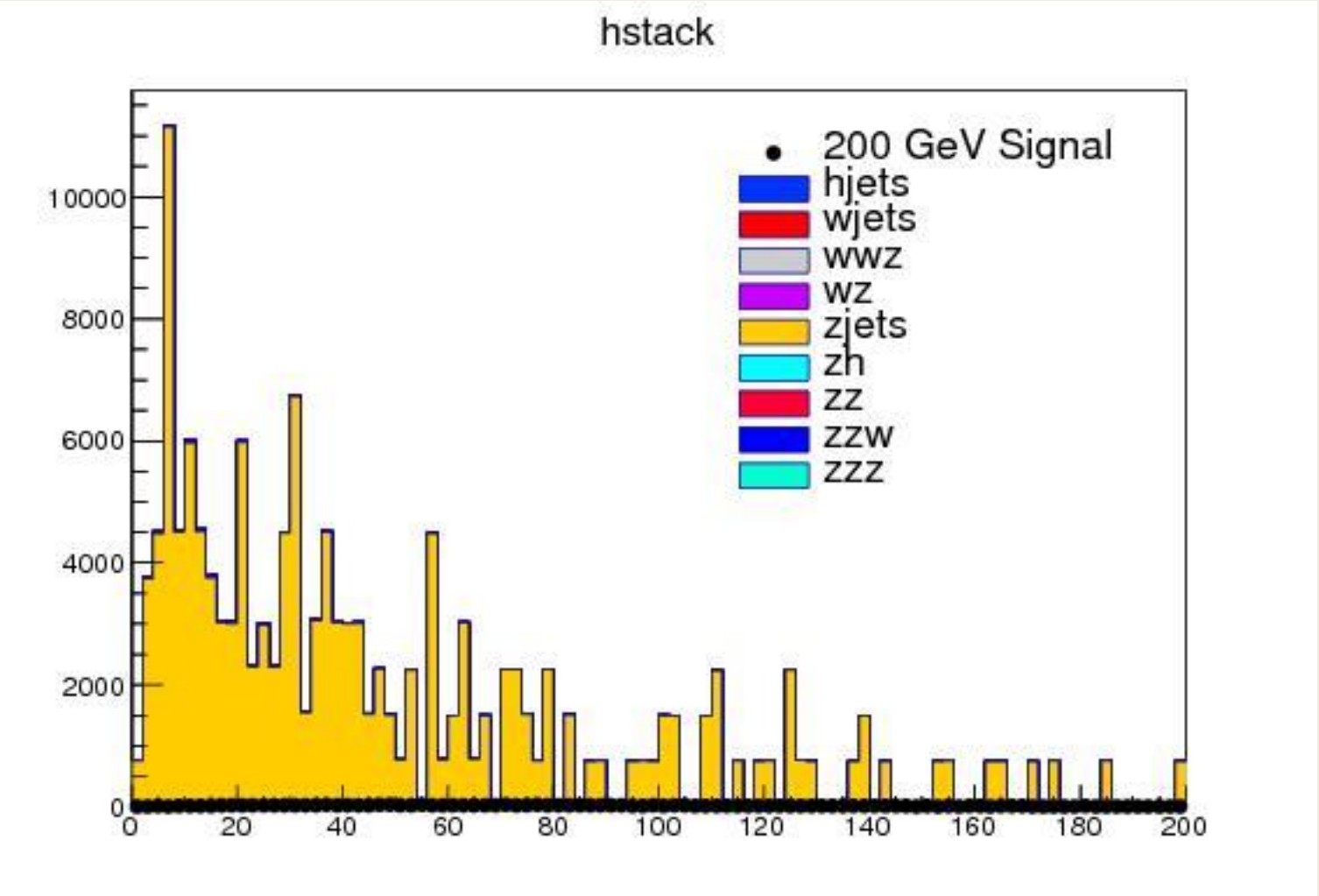
WZ W-jets

High background, low signal.



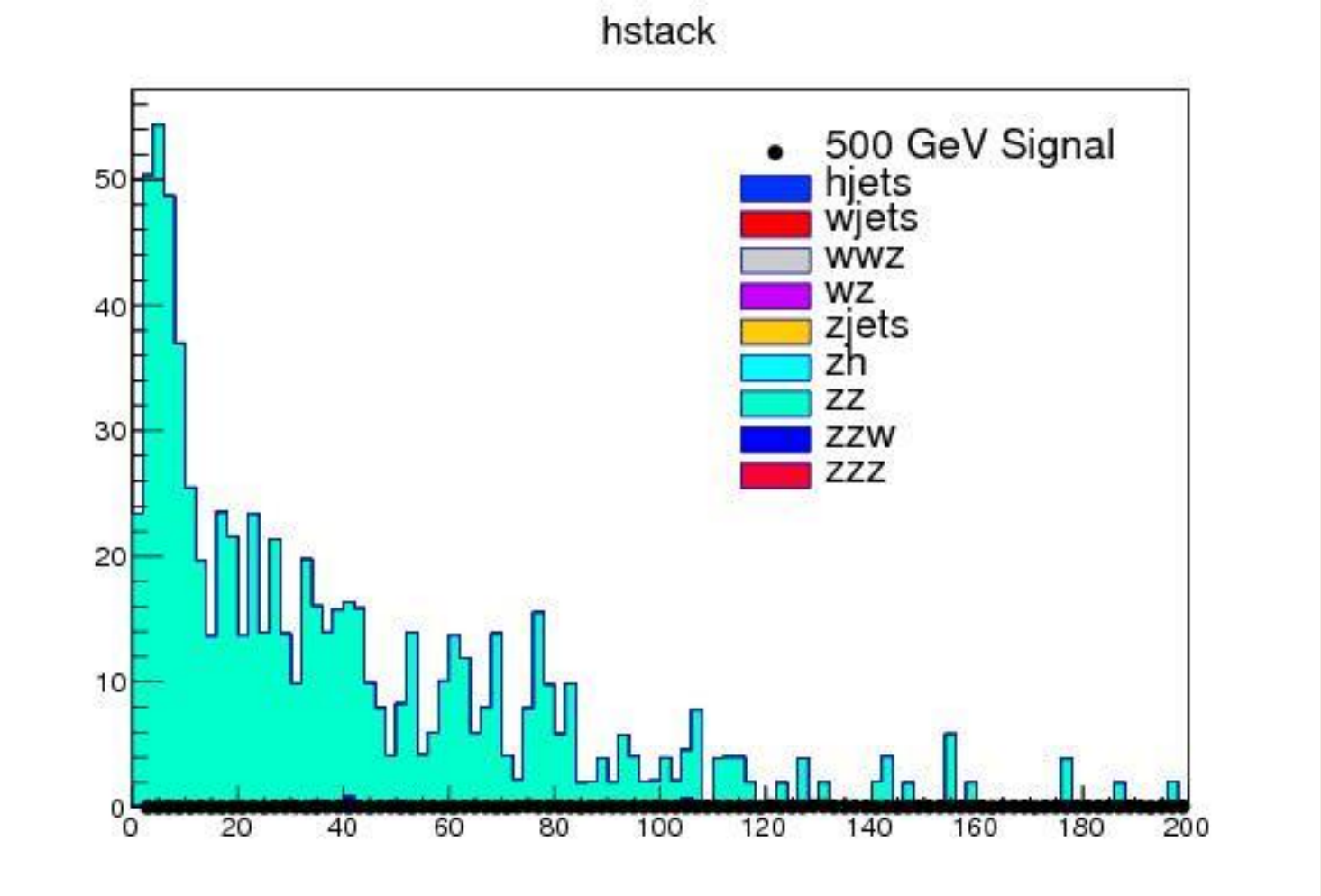
Z-jets

High background, low signal.



ZZ

High background, low signal.



Conclusions

- The accuracy of these simulations is an insight to real physical processes
- Continue search for the particle