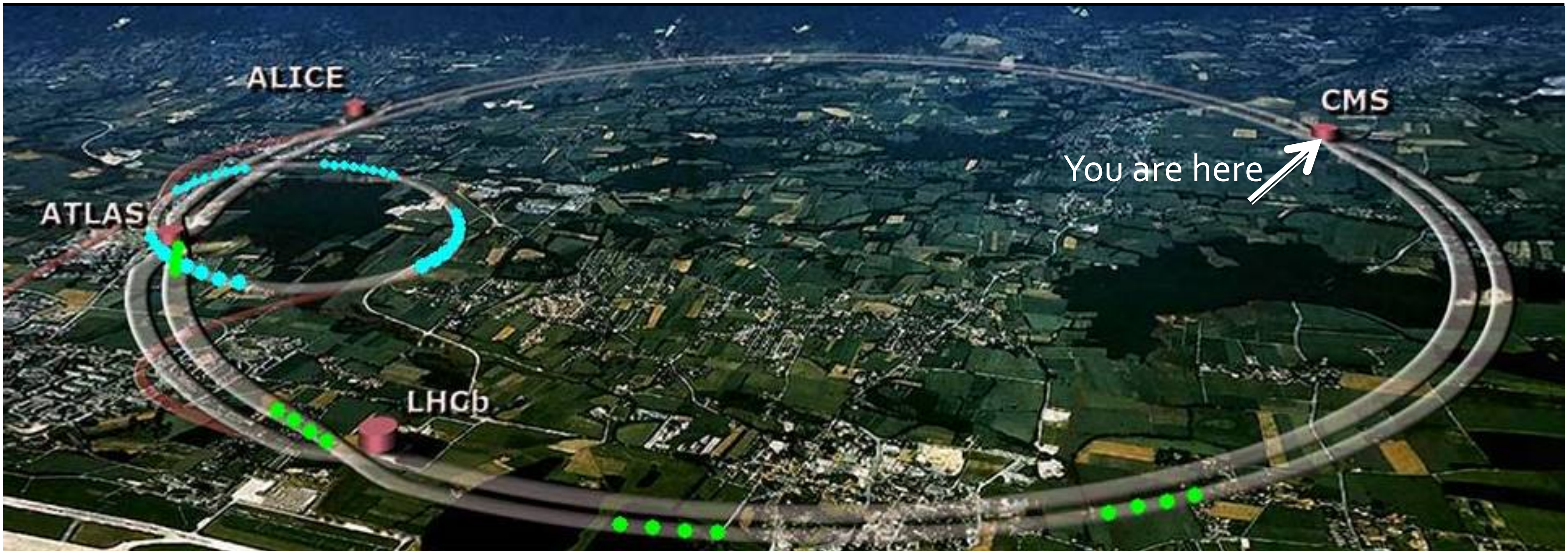
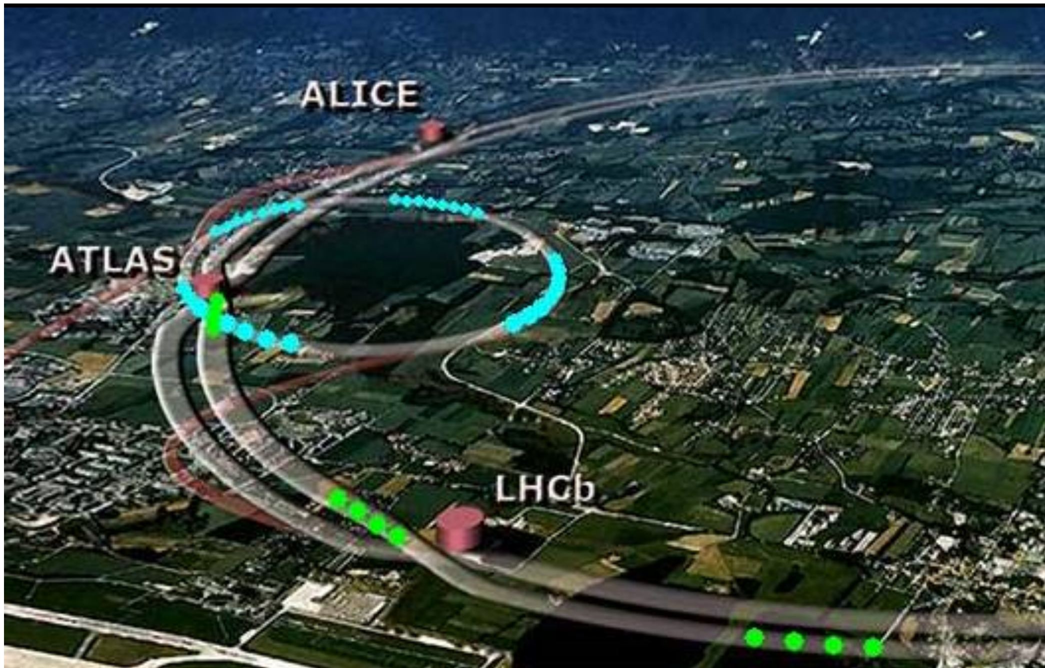


Recent Results on Searches for BSM at CMS

Andrew Askew

7-29-2011



Recent Results on BSM at C

Andrew Askew

7-29-2011

Recent Results on Searches for BSM at CMS

Andrew Askew

7-29-2011

The Truth is out there:

- We think that there is something beyond the Standard Model.
- There are plenty of theories about BSM phenomena. They seem to fall roughly into…

Mmmmmm.

SUSY

Exotica

- And so that brings us to my talk…

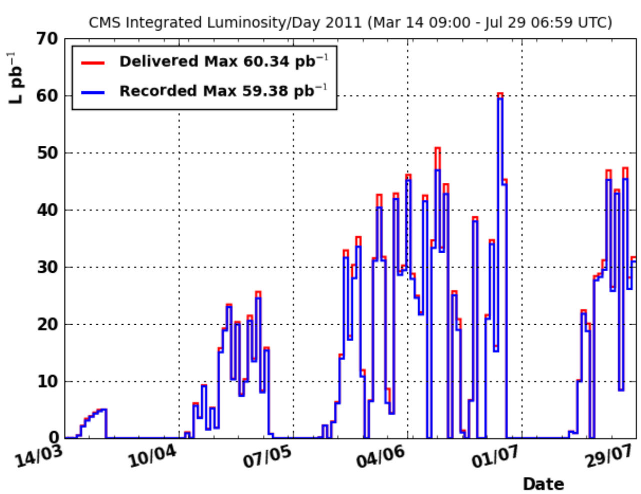
Outline:

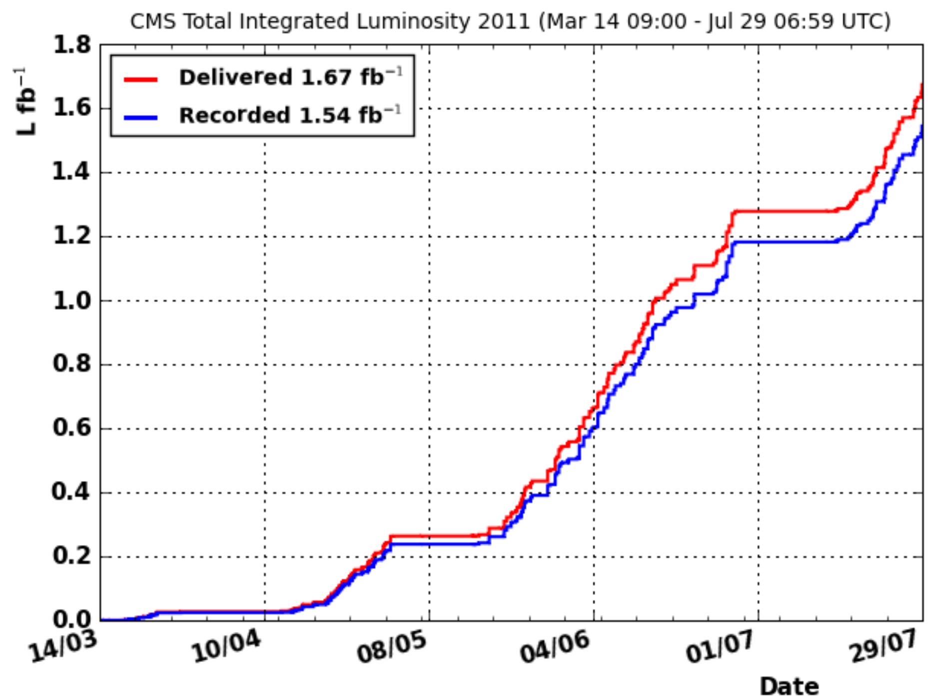
- The CMS Detector
- SUSY:
  - α_T
  - Same sign, and opposite sign lepton pairs
- Exotics:
  - Dijets (and multijets)
  - Z′ (including Z′→top pairs), W′ (including W_R)
  - Heavy Stable Charged Particles (HSCP)
  - Black Holes

Stand and Deliver!

A banner year:

Already have the promised 1 fb^{-1} (and more) delivered!

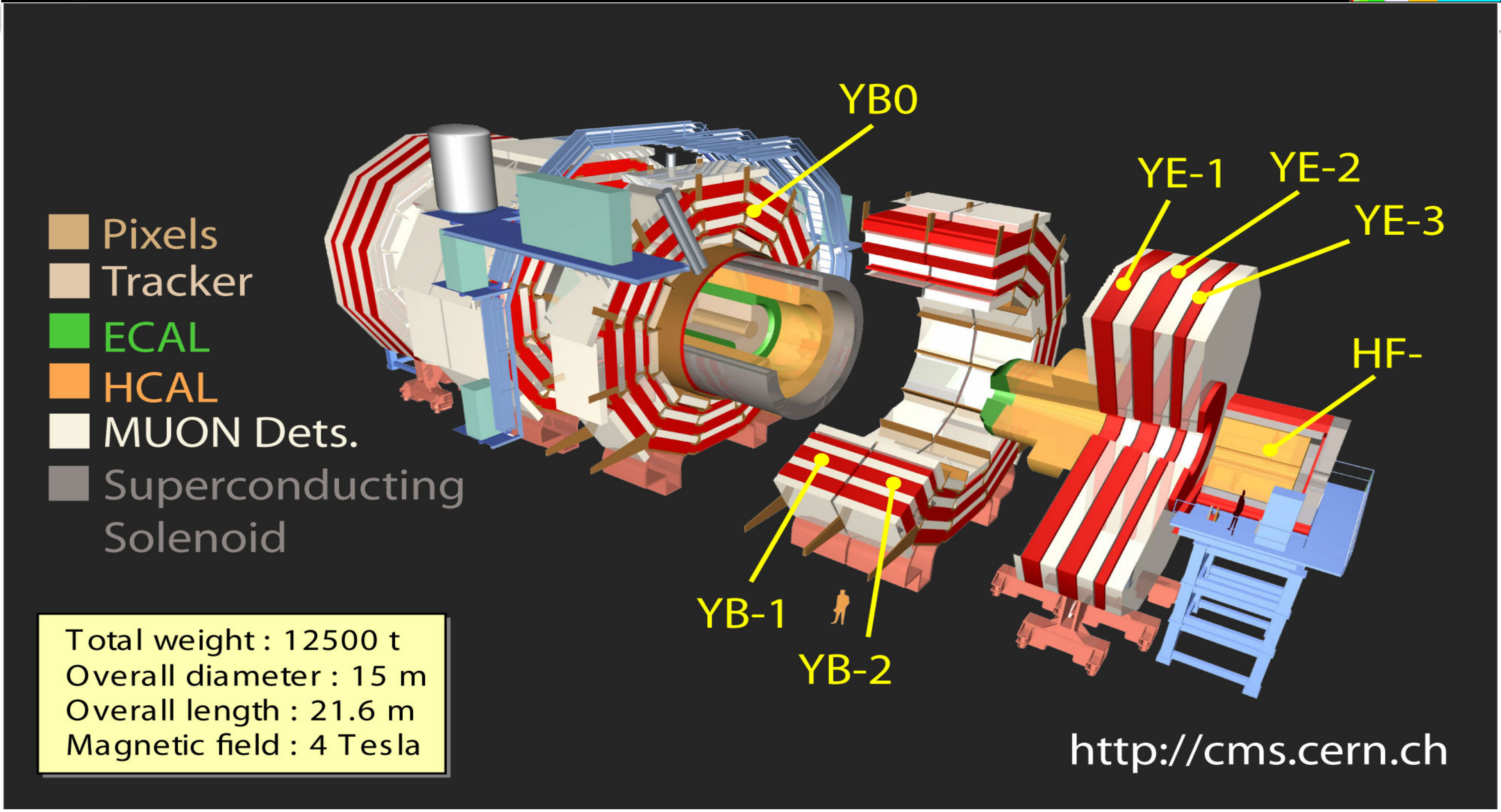




I will review analyses which have (mainly) used the much larger 2011 dataset.

Used here: 0.2 – 1.09 fb^{-1}

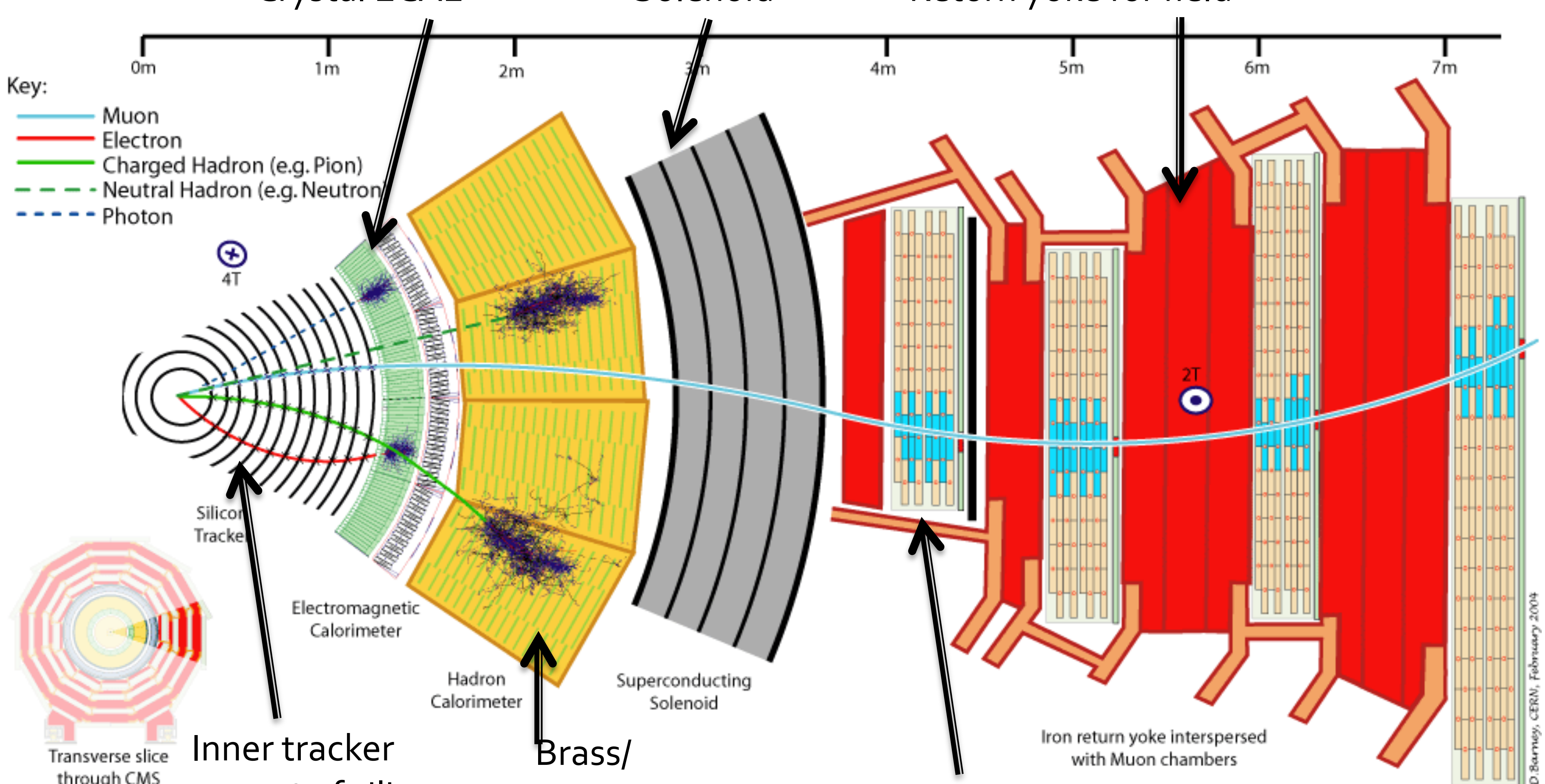
CMS Experiment:



In case you ever want to build your own.

CMS Experiment (2):

Crystal ECAL | Solenoid | Return yoke for field

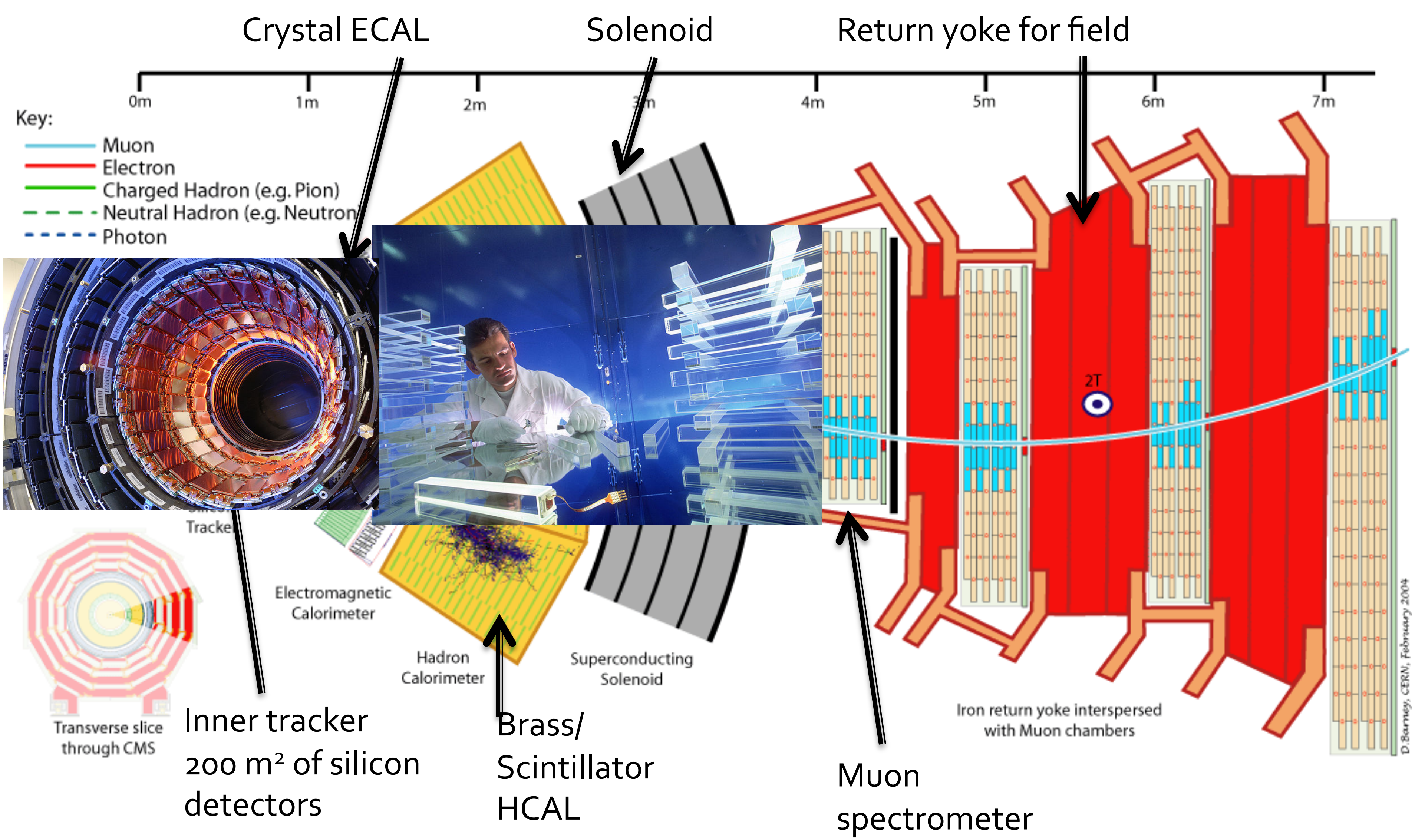


Inner tracker 200 m² of silicon detectors

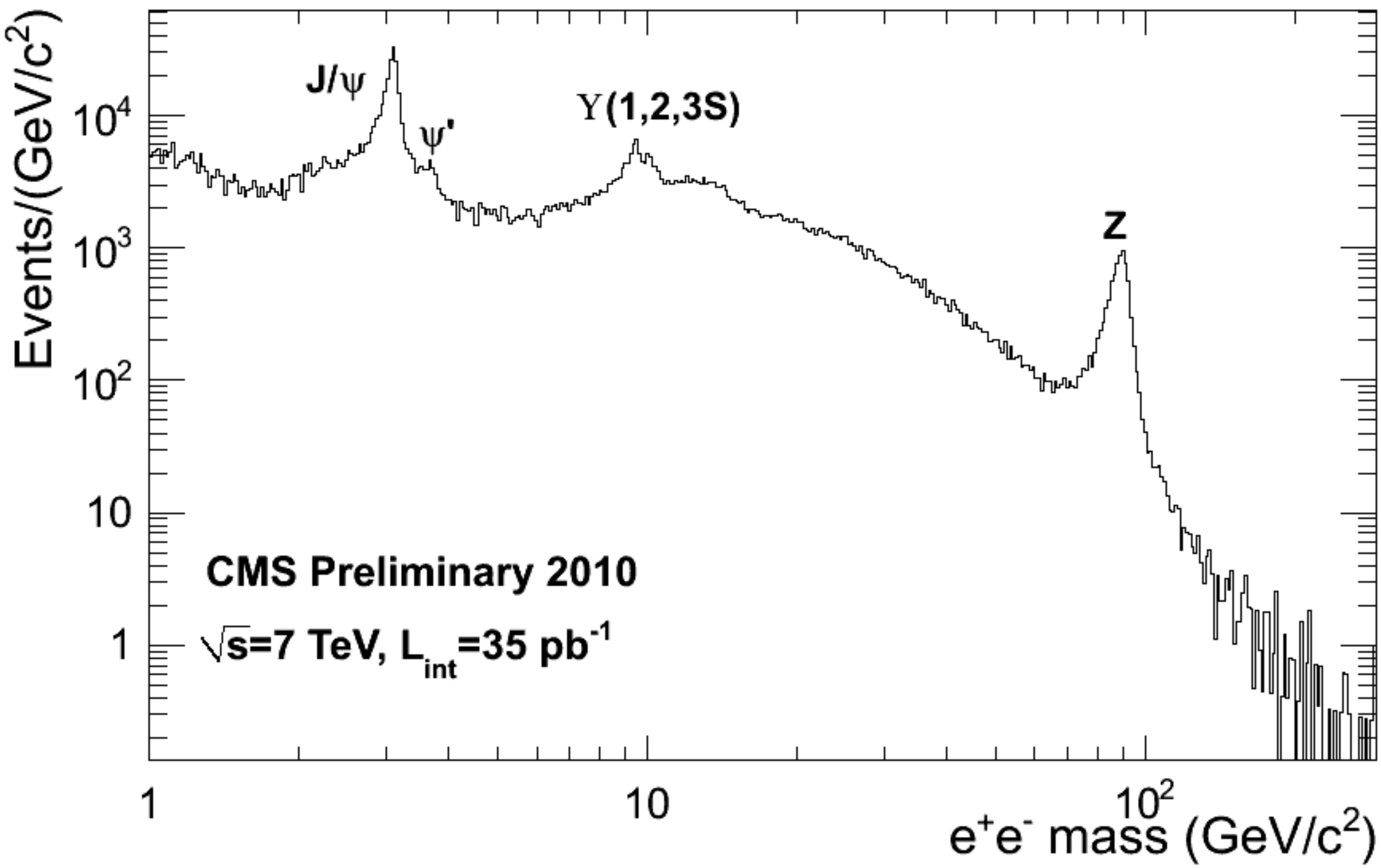
Brass/ Scintillator HCAL

Muon spectrometer

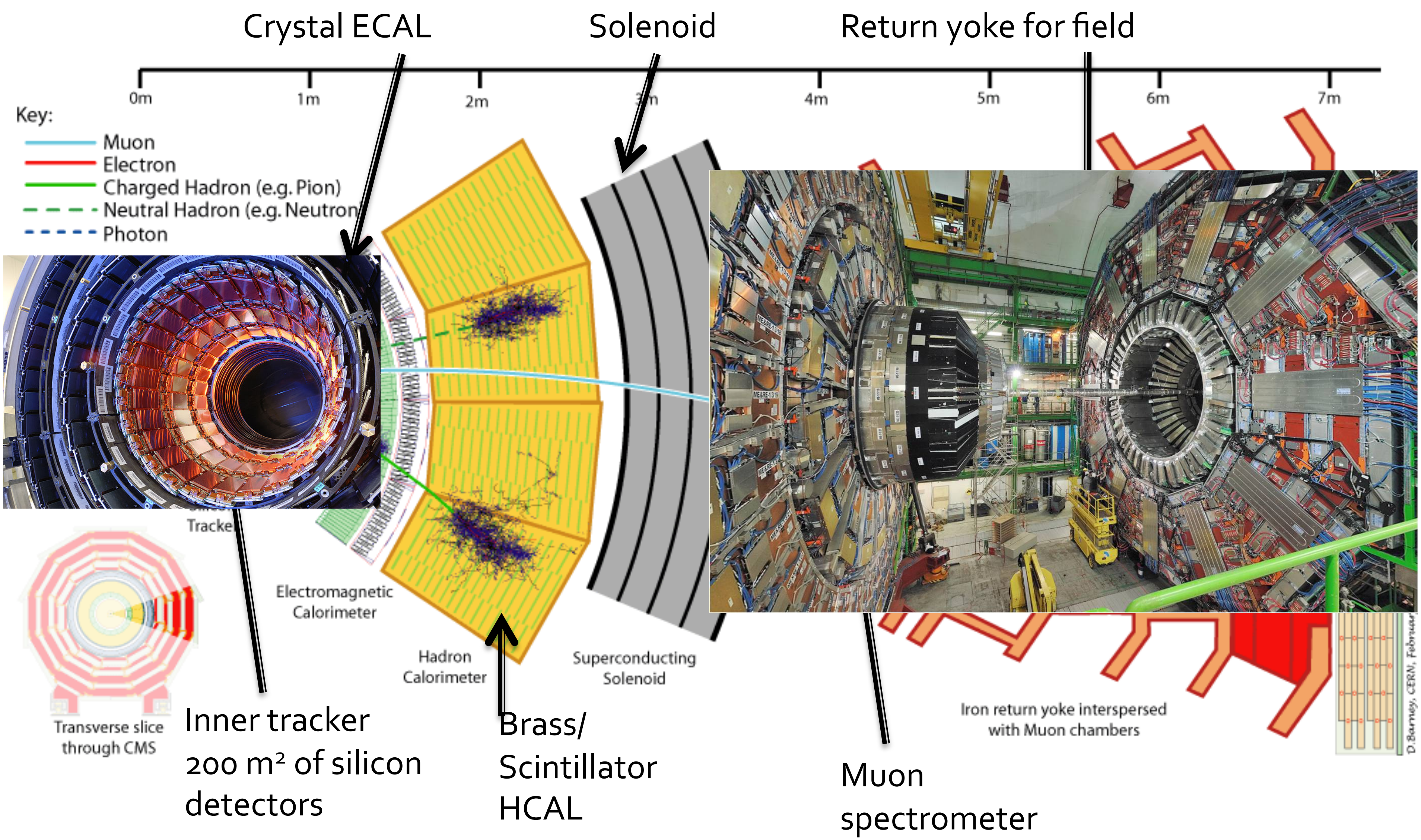
CMS Experiment: Electrons



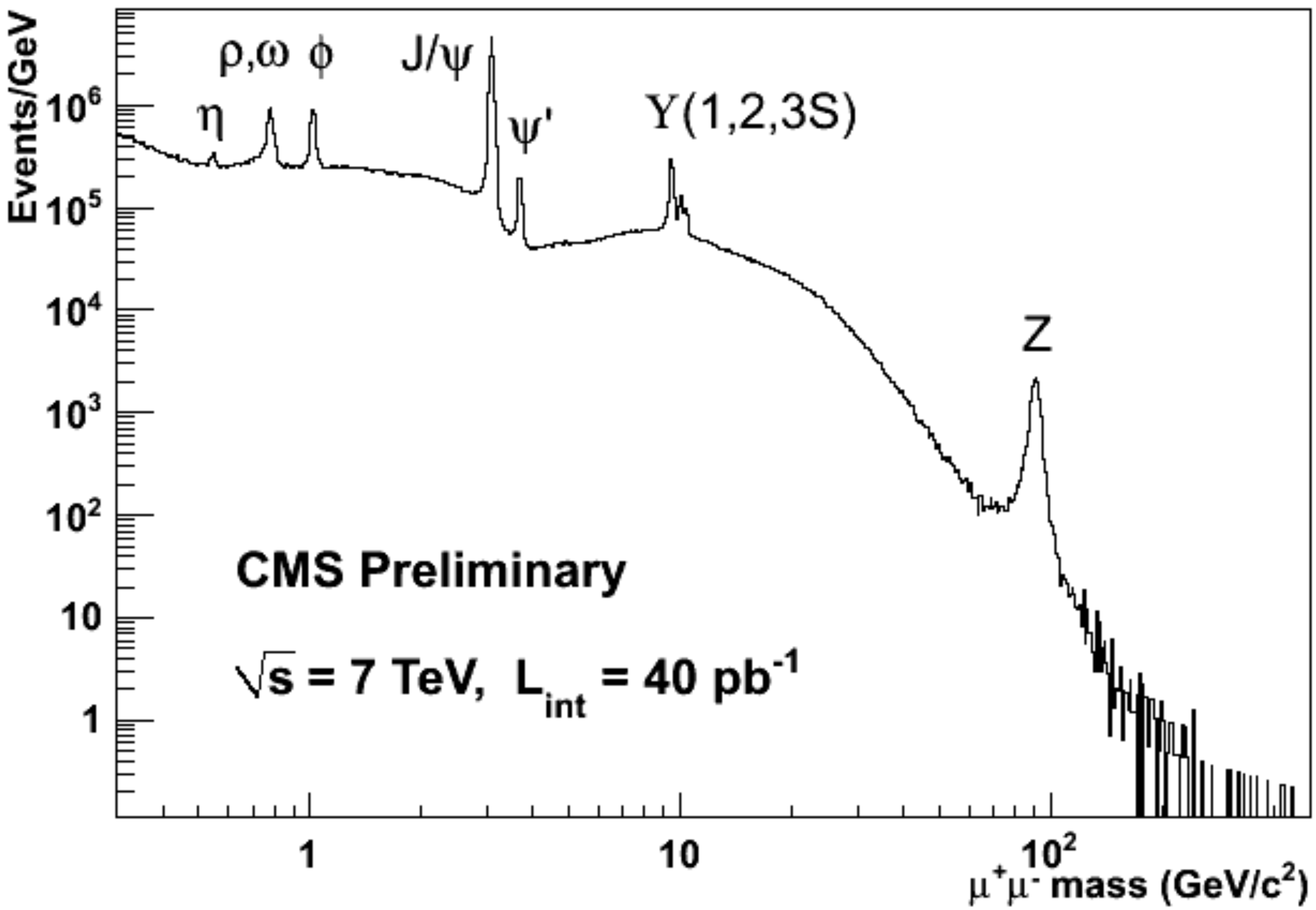
Invariant Mass:



CMS Experiment: Muons

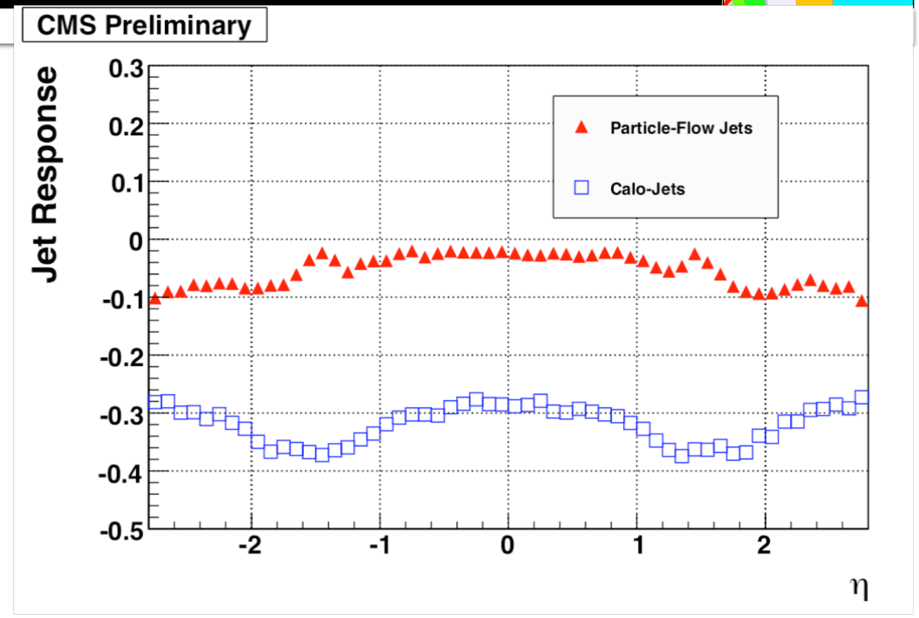


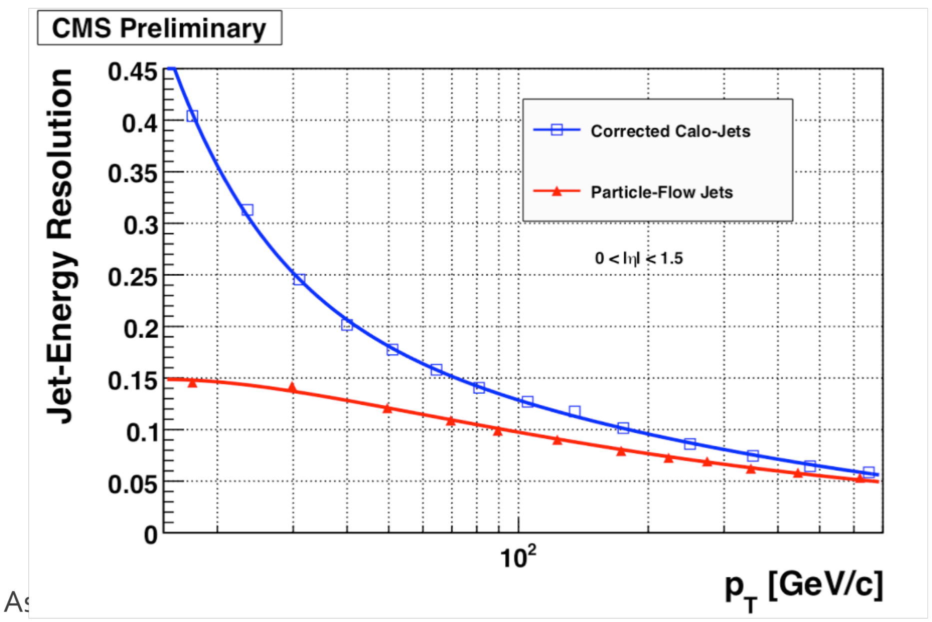
Invariant Mass:



Particle Flow and Jets/MET

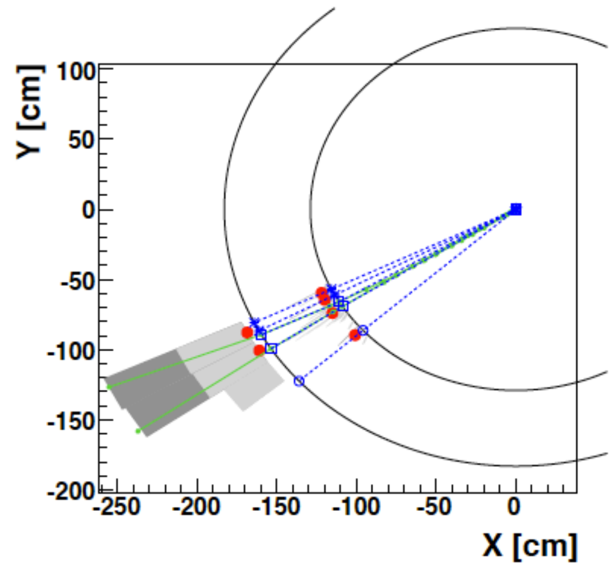
- As mentioned, optimizing the information from the detector as a whole can pay significant dividends.



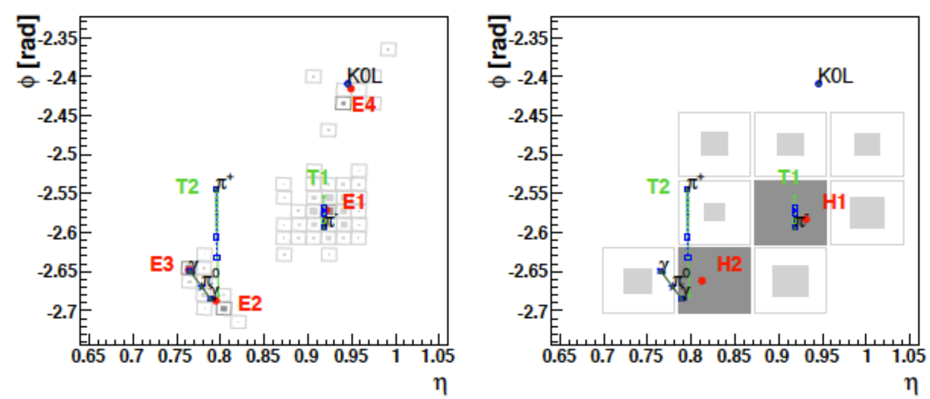


Particle Flow 101:

- Use the detector's best estimate of the particle energy:
  - Ex. :Charged pion →Tracker tracks
  - Ex.: Neutral pion/ photon: ECAL
- Accounting for each "particle" individually gives a much more accurate estimate for the visible energy and thus the missing E_T.



(a) The (x, y) view

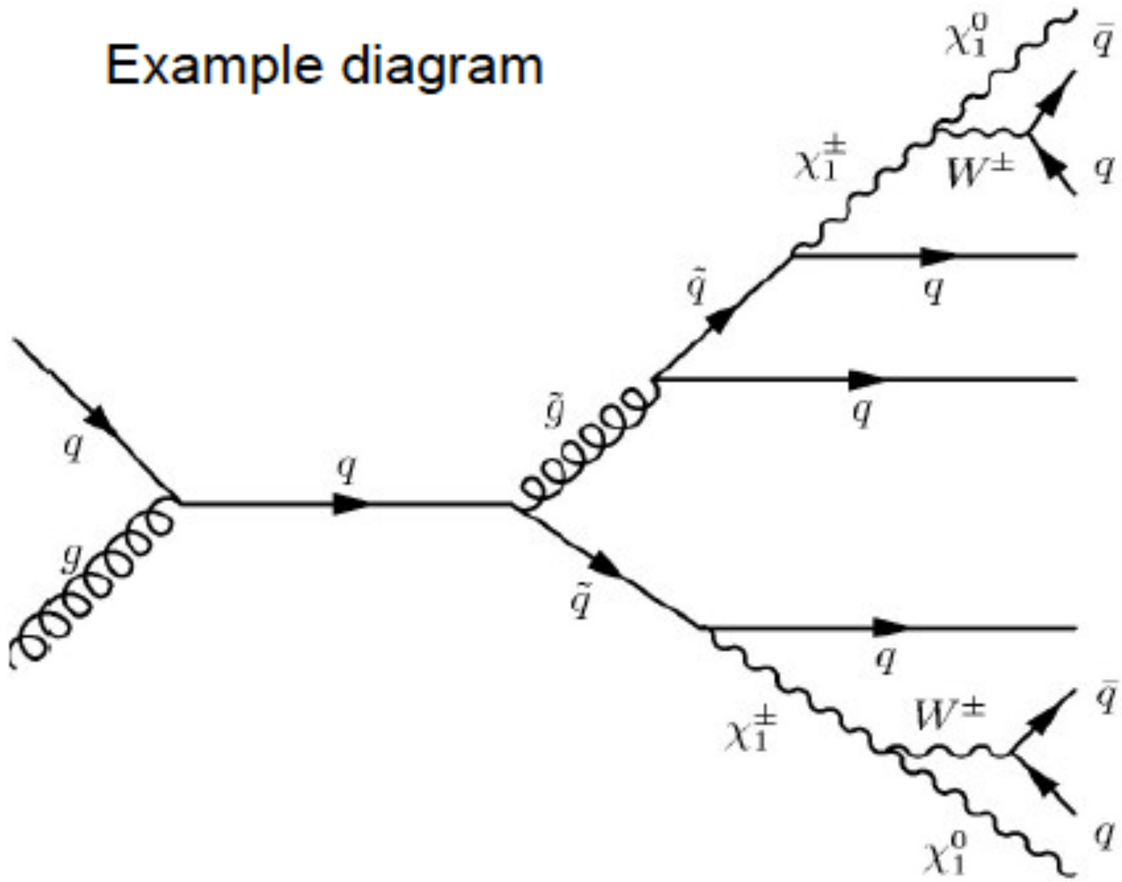


SUSY

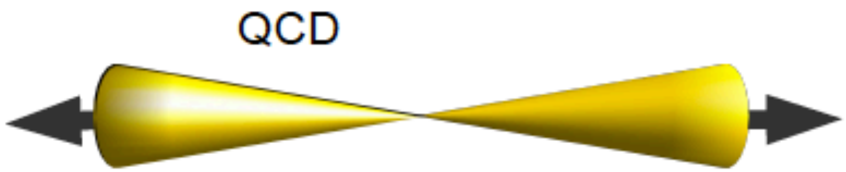
Hadronic SUSY Search:

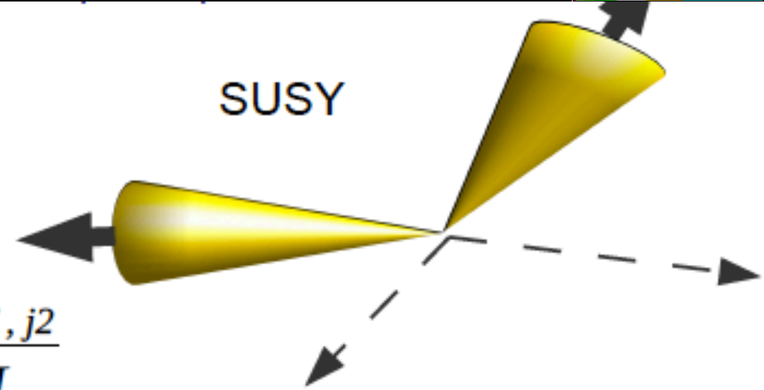
- It's a lovely little simple theory really.
- If you've conserved R-parity, one thing that you can bank on is:
  - Lots of hadronic activity
  - Missing E_T

Example diagram



Need to measure missing transverse energy well!





- α_T defined to limit contributions from mismeasured multijet events.
- In principle only those events with true missing E_T should be at large values of α.

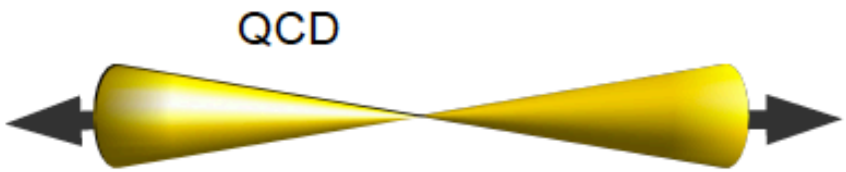
$$\alpha_T = \frac{p_{T,j2}}{M_T}$$

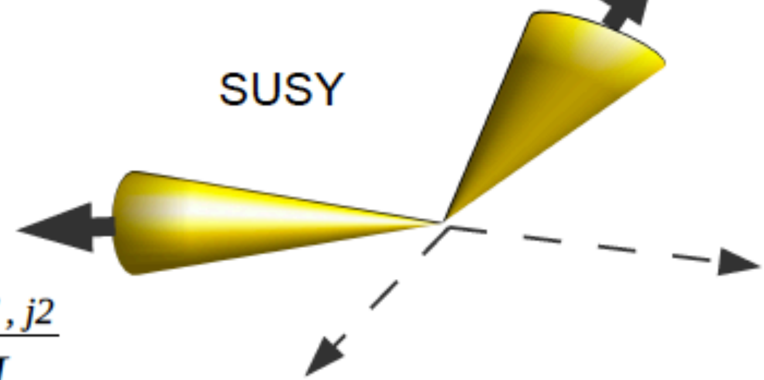
$$M_T = \sqrt{2 p_{T,j1} p_{T,j2} (1 - \cos(\Delta\phi))}$$

$$\rightarrow \alpha_T = \sqrt{\frac{p_{T,j2}/p_{T,j1}}{2(1 - \cos\Delta\phi)}}$$

In QCD: $\alpha_T \leq 0.5$ since $p_{T,j2}$ is by definition the lower momentum jet.
Exception: A third jet is completely lost.

Need to measure missing transverse energy well!





$$\alpha_T = \frac{p_{T,j2}}{M_T}$$

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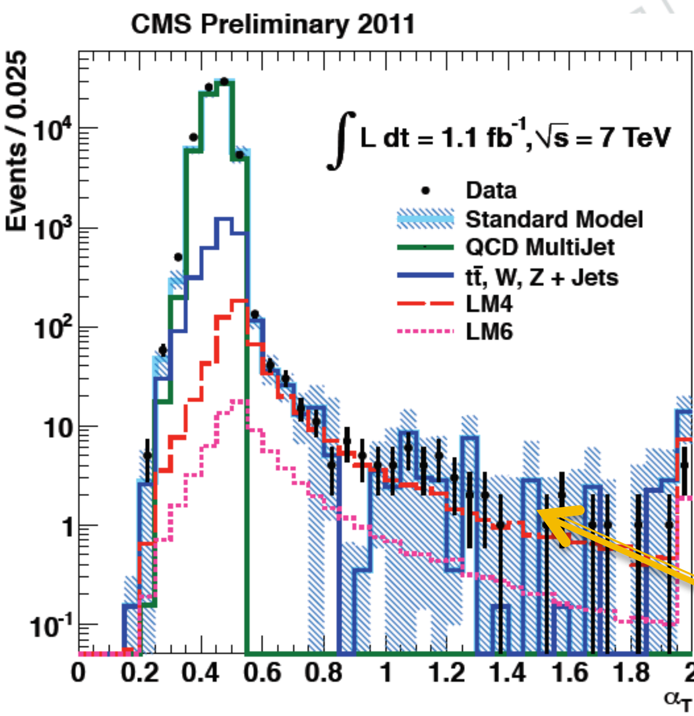
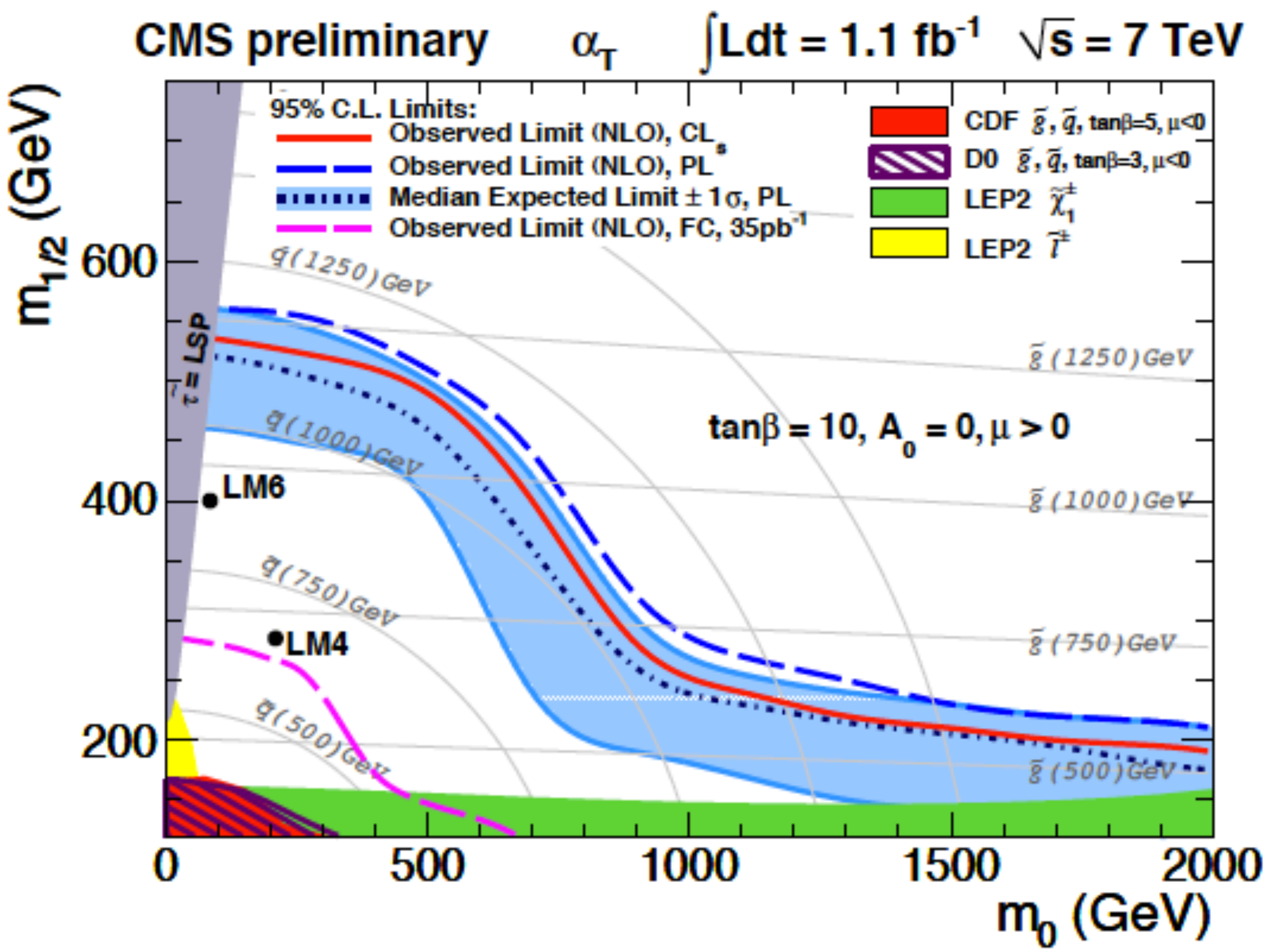


In QCD: $\alpha_T \leq 0.5$ since $p_{T,j2}$ is by definition the lower momentum jet.
Exception: A third jet is completely lost.

Also take SM EWK backgrounds from the data as much as possible.

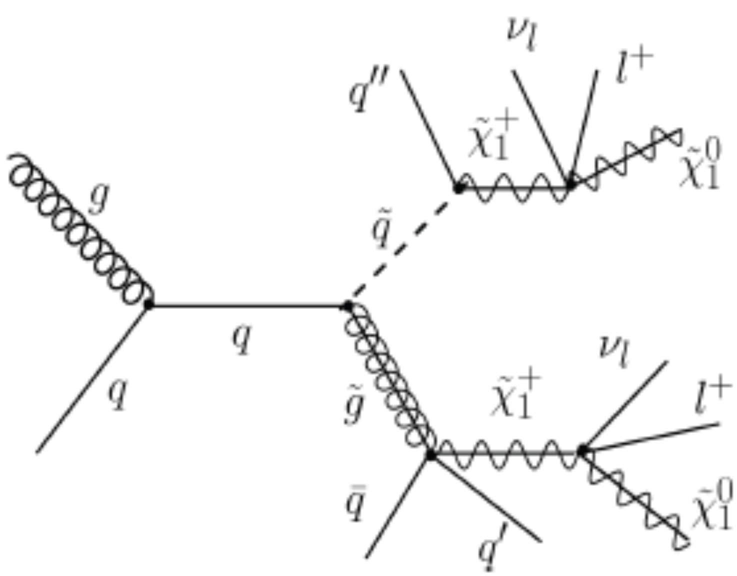
Limits:

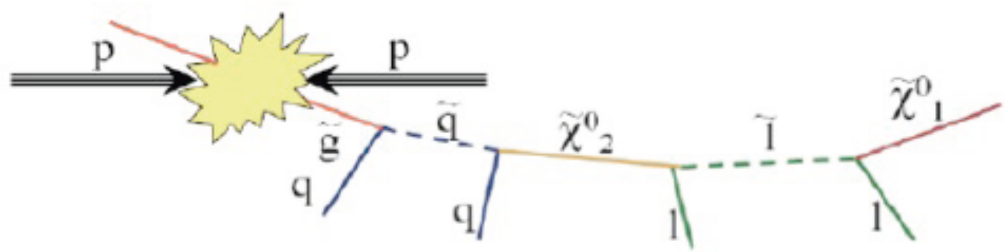


- New limits using α_T>0.55 in bins of H_T.
- Rules out a lot of landscape.

Same Sign, and opposite sign lepton pairs:

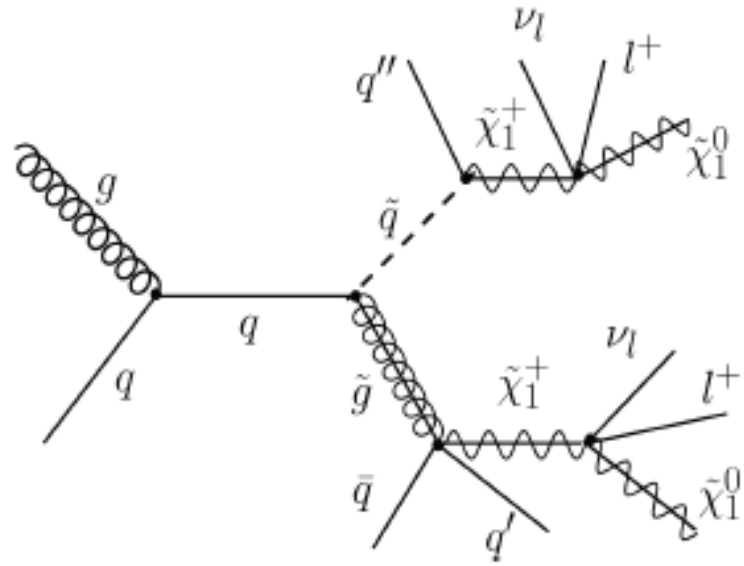
- Events with leptons with the same sign are rare in the SM, but easily allowed in SUSY scenarios.
- Events with opposite sign leptons are not as rare in the SM, but can still shed light on the potential SUSY mass spectrum.





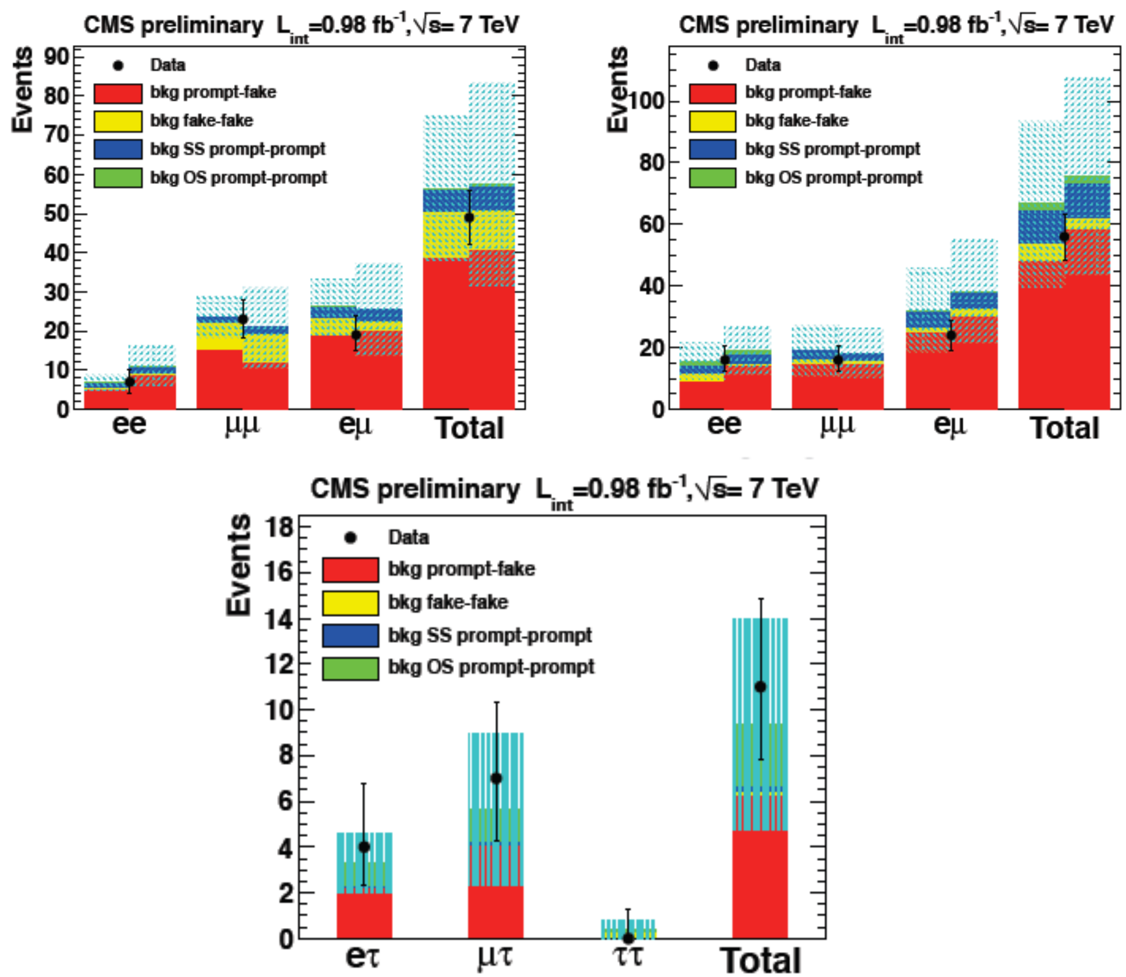
Same Sign:

- Two leptons (μ(5),e(10),τ(15)), two jets E_T>40 GeV:
  - Split into three categories:
    - Inclusive(ee,eμ, $\mu\mu$): two leptons + H_T>200 GeV
    - High p_T Leptons (ee, eμ, $\mu\mu$): one lepton above 20, one above 10, and H_T>80 GeV
    - Taus ($\tau\tau$, τe, $\tau\mu$), H_T > 350 GeV, missing E_T >80 GeV



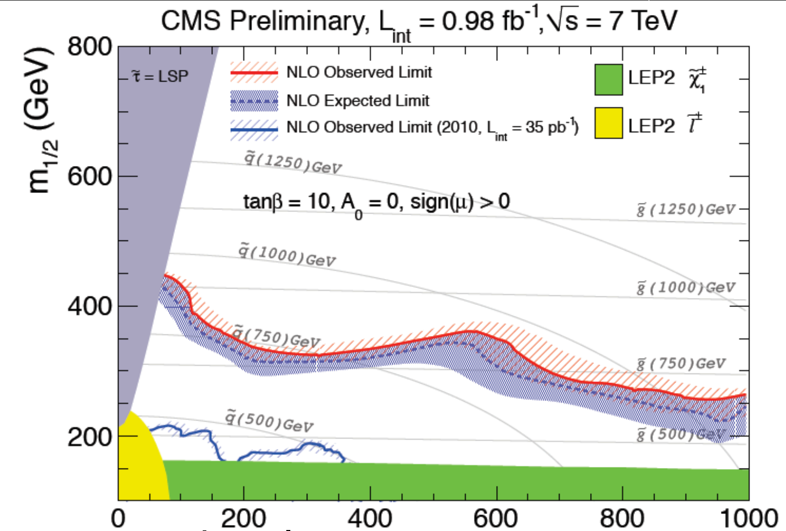
Expected backgrounds and candidates

- No significant excess observed:
  - Charge mis-id backgrounds small.
  - SM processes with same sign small, mainly fake leptons from QCD.

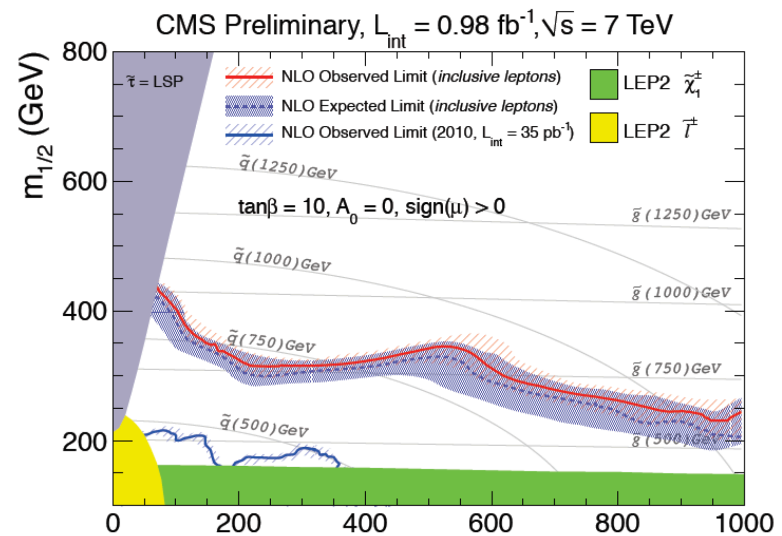


Limits:

- Previous result is shown as the blue line.
- Considerable improvement in both sets independently.



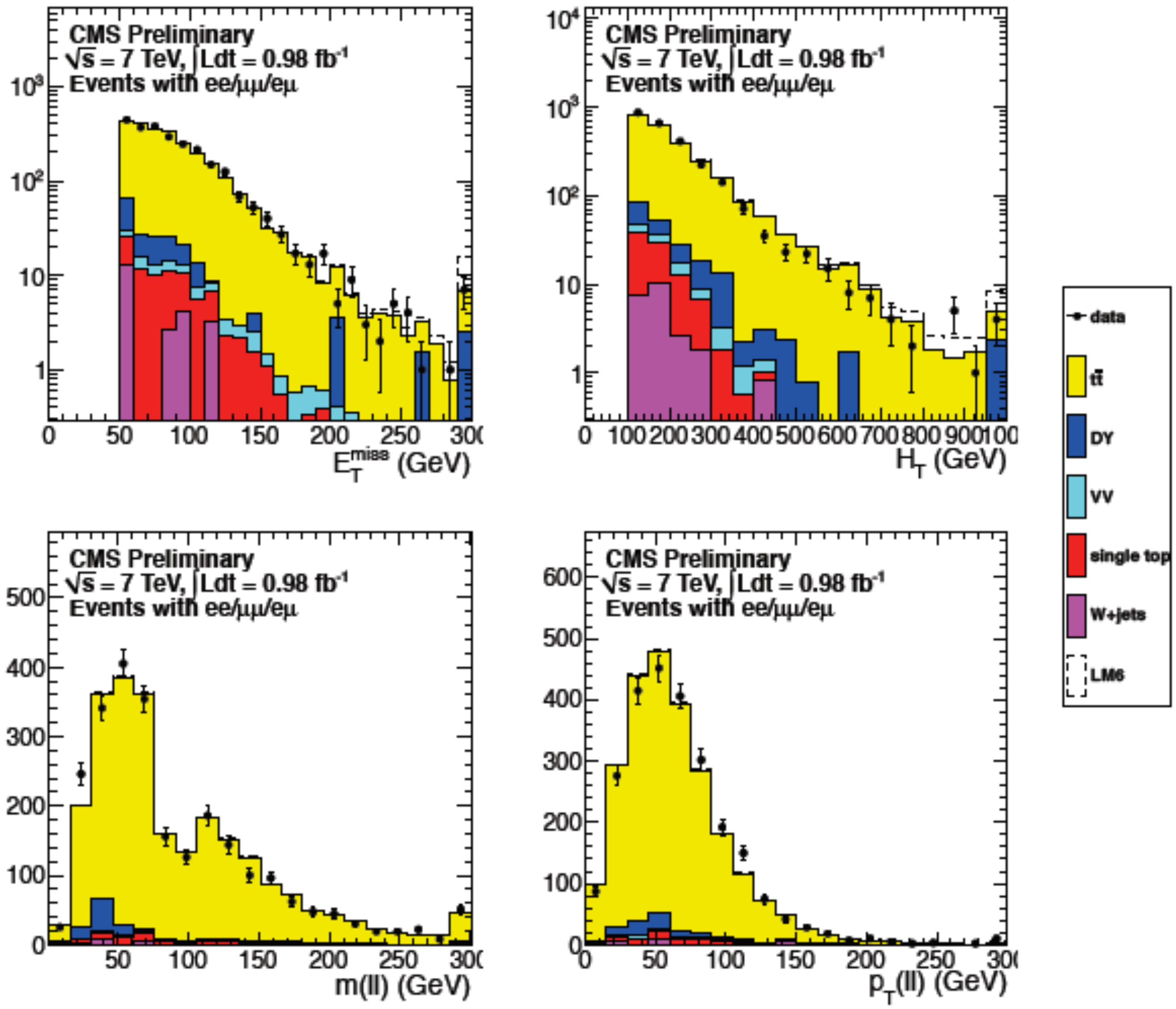
High p_T leptons



Inclusive leptons

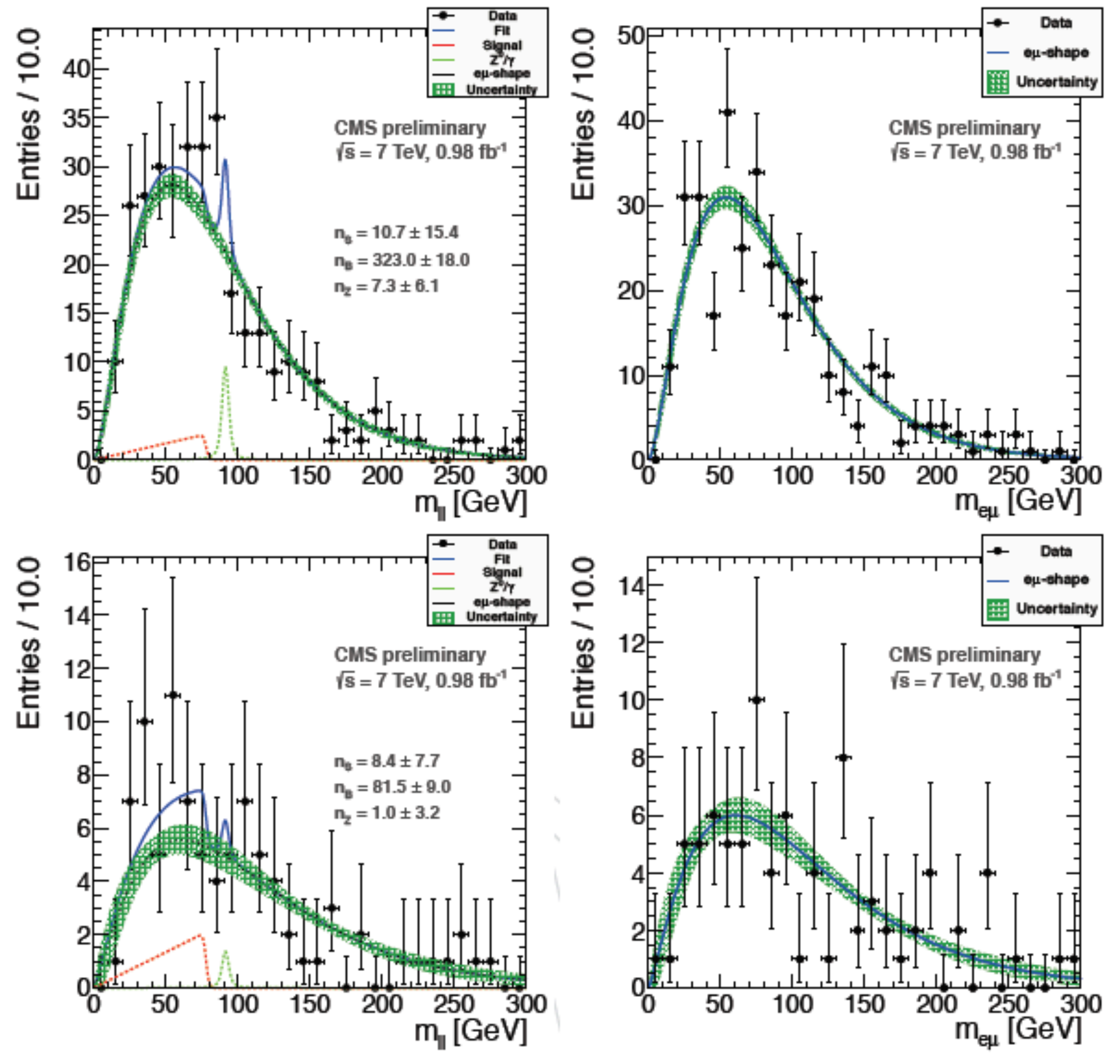
Opposite Sign:

- Similar to a top selection:
  - Two opposite sign leptons (e,μ) (veto on 76-106 GeV in mass)
  - Two jets $p_T > 30$ GeV



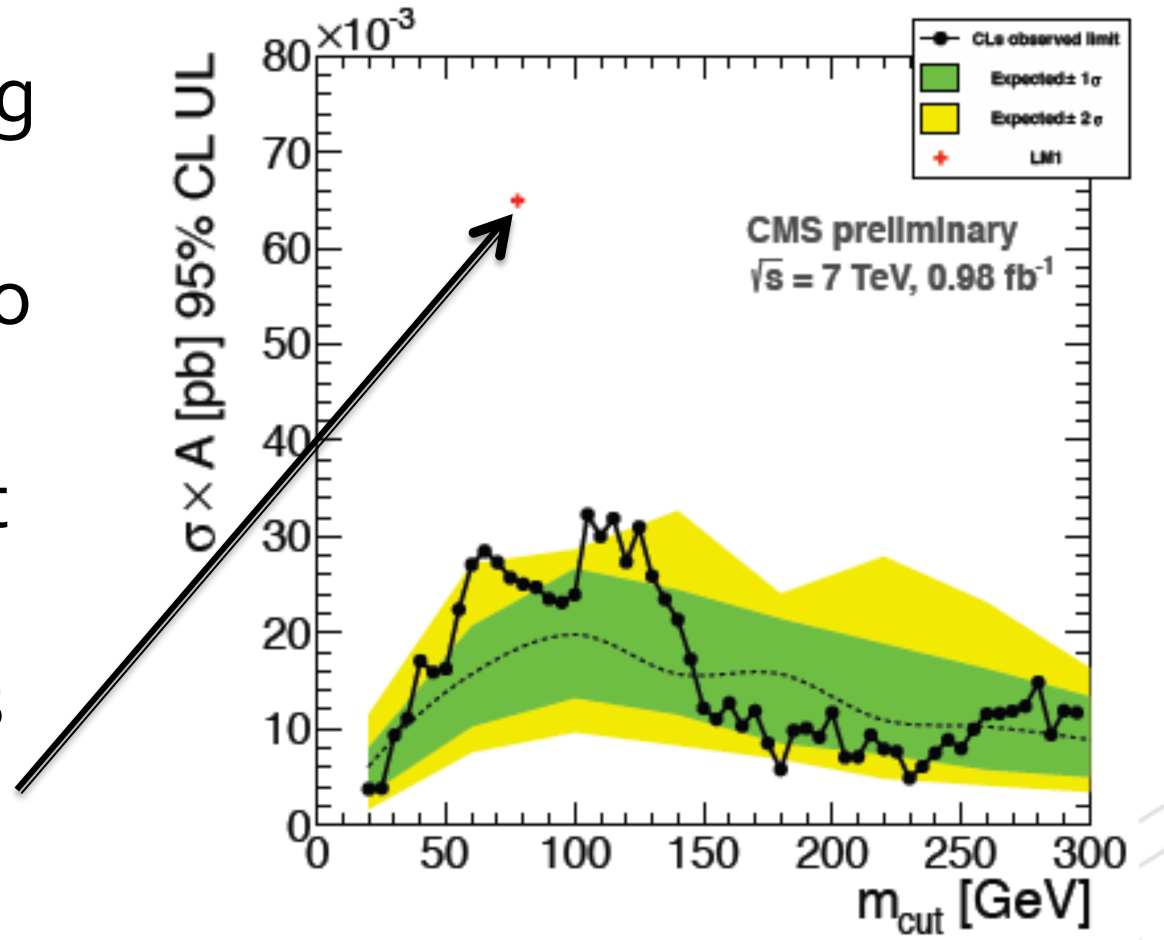
Fitting:

- Fit shape in lower H_T control region to get expectation for top.
- Then repeat in high H_T region including mass edge hypothesis.



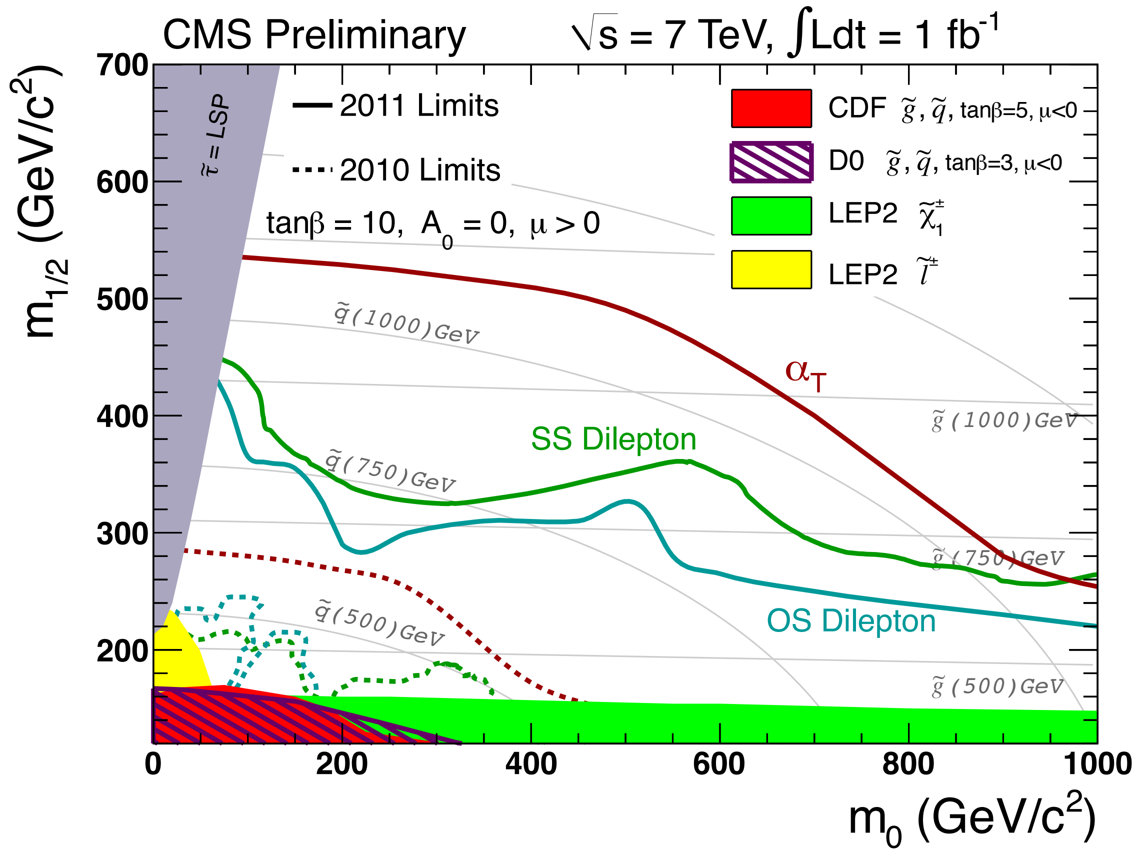
Limits:

- Use the fit allowing for a sharp mass edge hypothesis to set a limit as a function of the cut mass.
- LM1 SUSY point is in red on plot.



All on one slide:

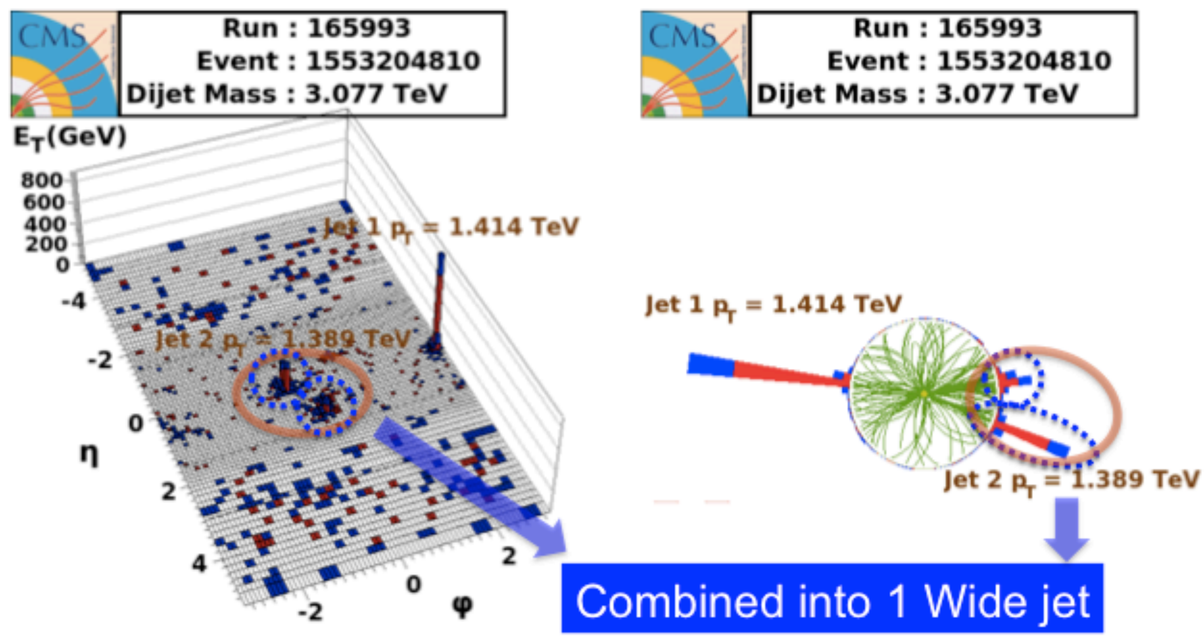
- All three results I just showed in the same exclusion plane.



EXOTICS

Dijet Mass:

- Traditionally, one goes and looks for new heavy resonances in dijets.
- A laundry list of different BSM phenomena would show dijet resonances:
  - Z′,W′, scalar diquarks, excited quarks, RS gravitons, the list goes on.

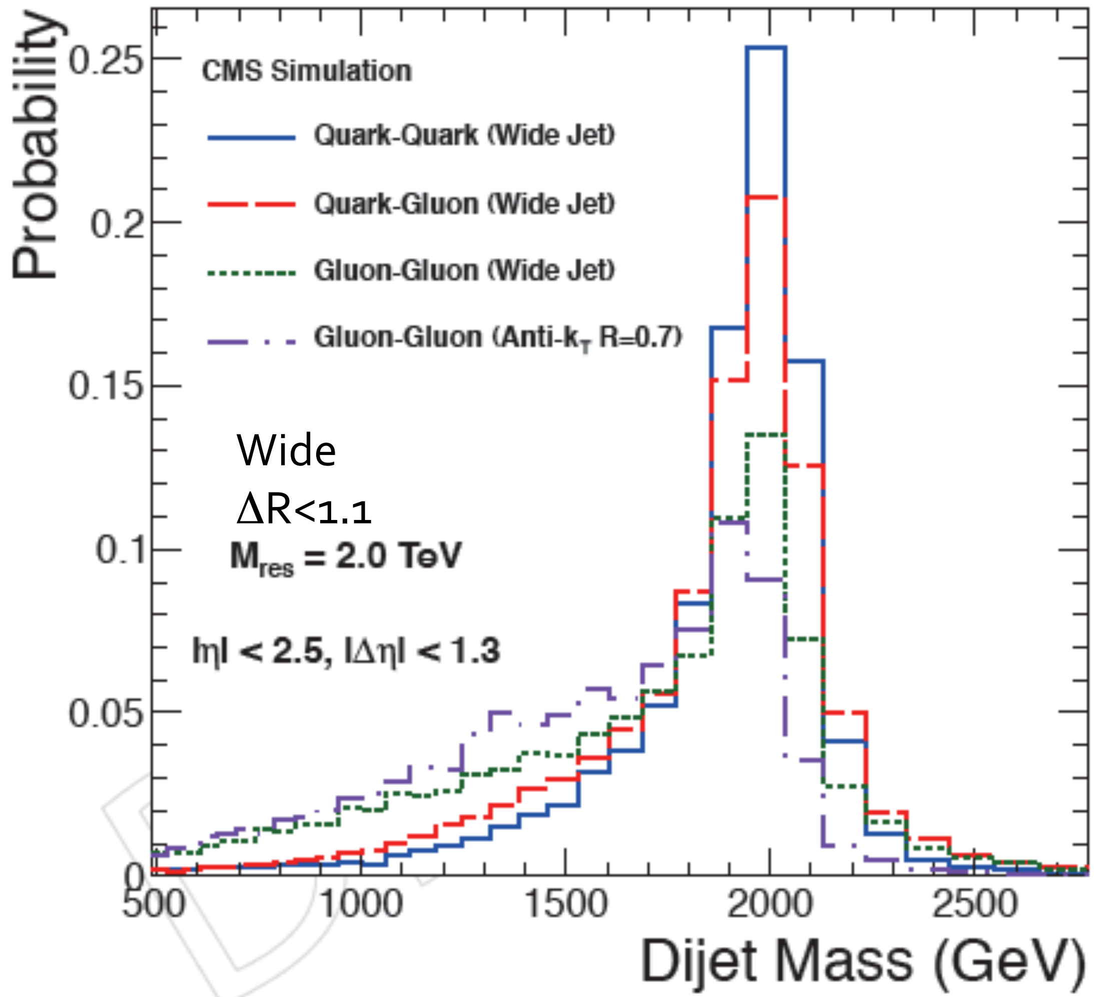


Wide
$\Delta R<1.1$

Combine jets which have split due to radiation into “Wide” jets.

Dijet Mass:

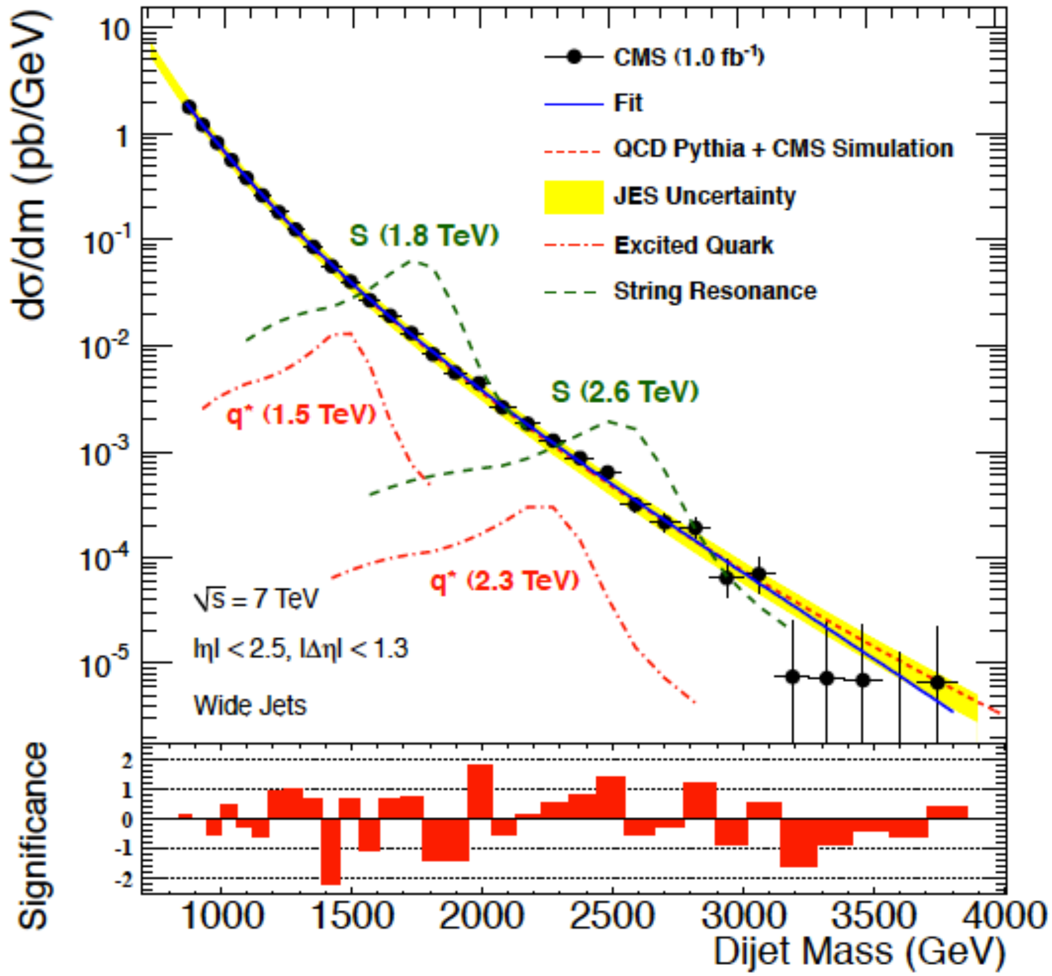
- Traditionally, one goes and looks for new heavy resonances in dijets.
- A laundry list of different BSM phenomena would show dijet resonances:
  - Z′,W′, scalar diquarks, excited quarks, RS gravitons, the list goes on.



Dijet mass resolution for CMS for 2 TeV resonance decay to different partons.

Check the smoothness…

- We fit an ansatz to the dijet mass distribution.
- No deviation from a smoothly falling distribution is observed, χ^2/dof = 27.5/28



$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

Check the smoothness…

- We fit an ansatz to the dijet mass distribution.
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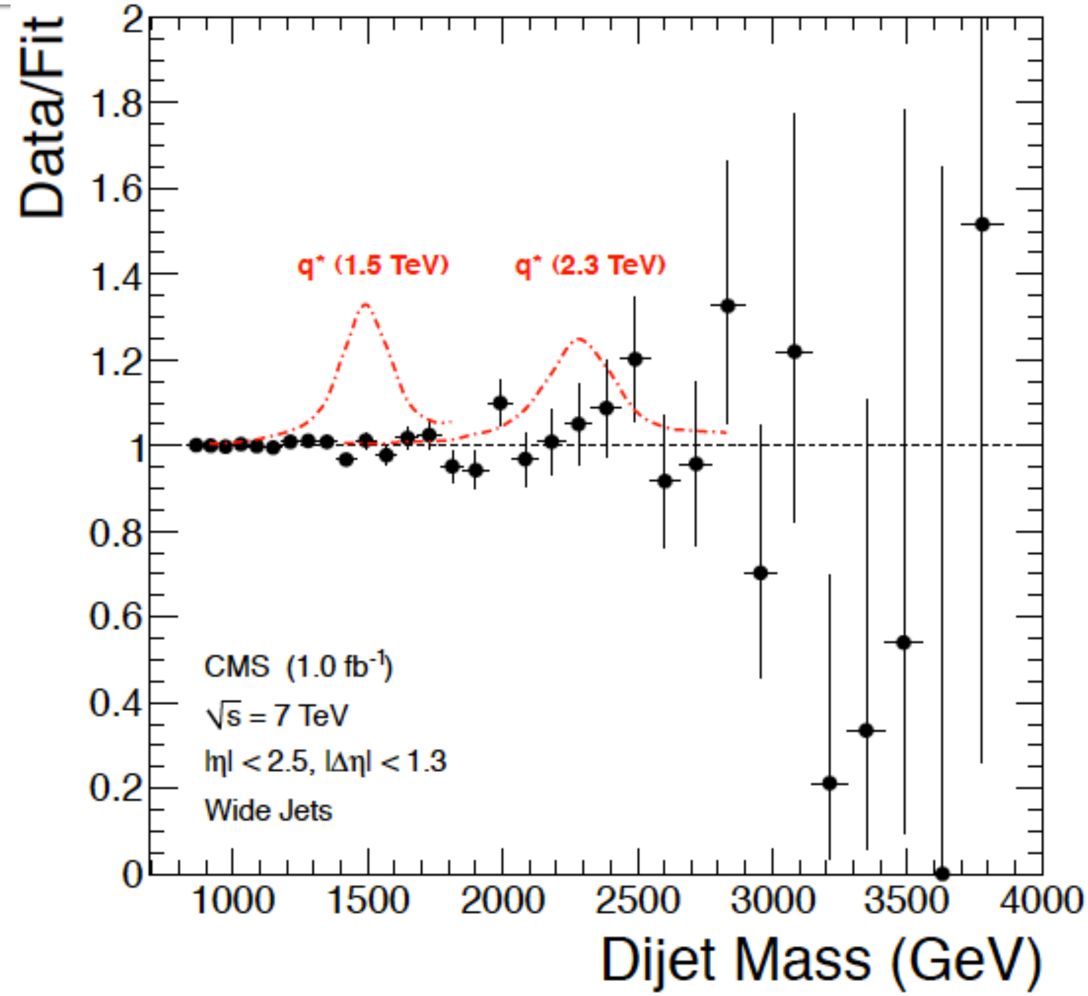
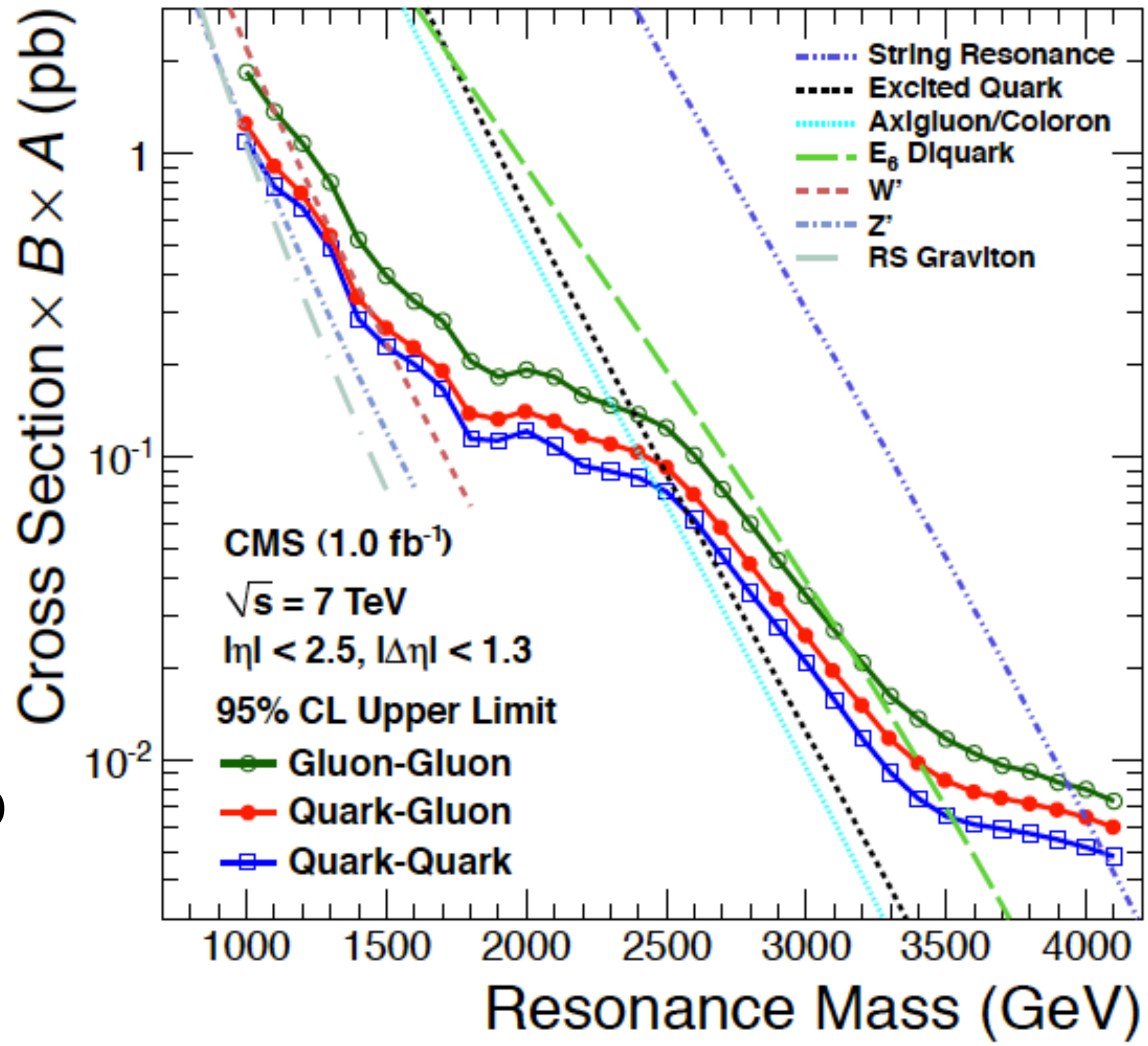


$$\frac{d\sigma}{dm} = \frac{P_0(1-m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3\ln(m/\sqrt{s})}}$$

Limits:

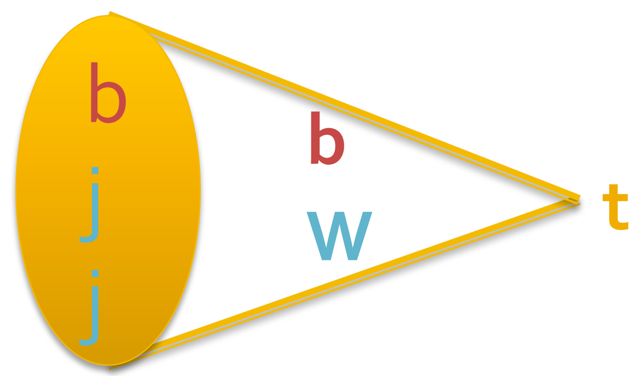
- Note different upper limits depending on decay.
- All of these are resonances with natural widths small compared to detector resolution.



arXiv:1107.4771 , our first 1 fb^{-1} paper!

Z′→di-top

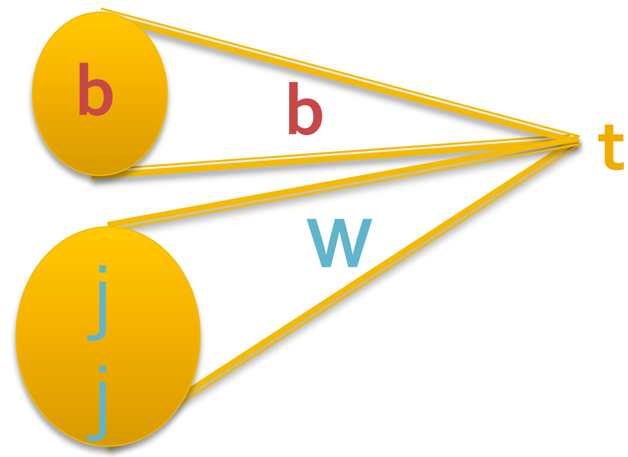
- If one has a very heavy boson that decays to top-quark pairs, then the decay of the top could all be boosted into one "top-jet".
- Look for two topologies, one with two type one "top-jets", in opposite hemispheres.



Type 1, one top quark reconstructed as one big ($\Delta R<0.8$) jet.

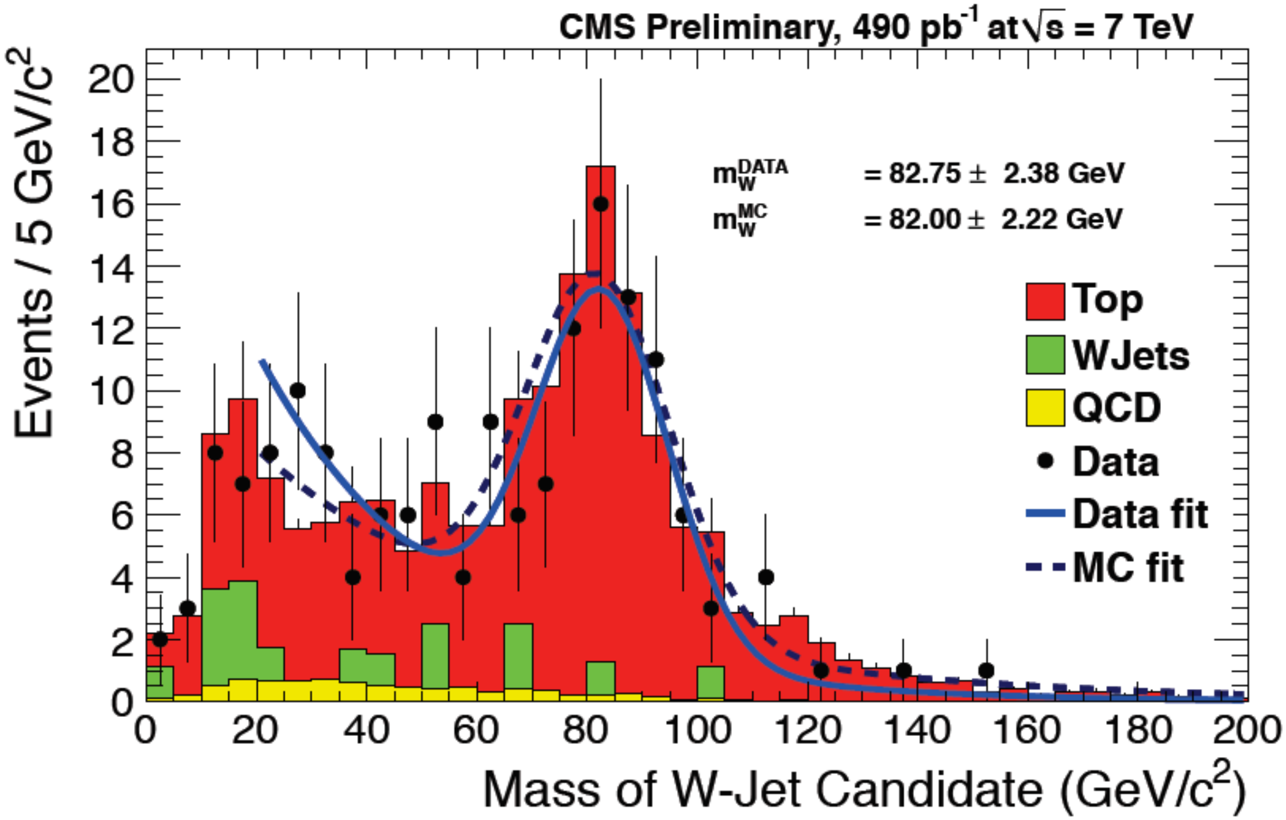
Z'->di-top

- If one has a very heavy boson that decays to top-quark pairs, then the decay of the top could all be boosted into one "top-jet".
- A second topology is where one top is type 1 and a second is of this second type (in the opposite hemisphere).



Type 2, one top quark split into two jets, one of which is the two jets from the W decay.

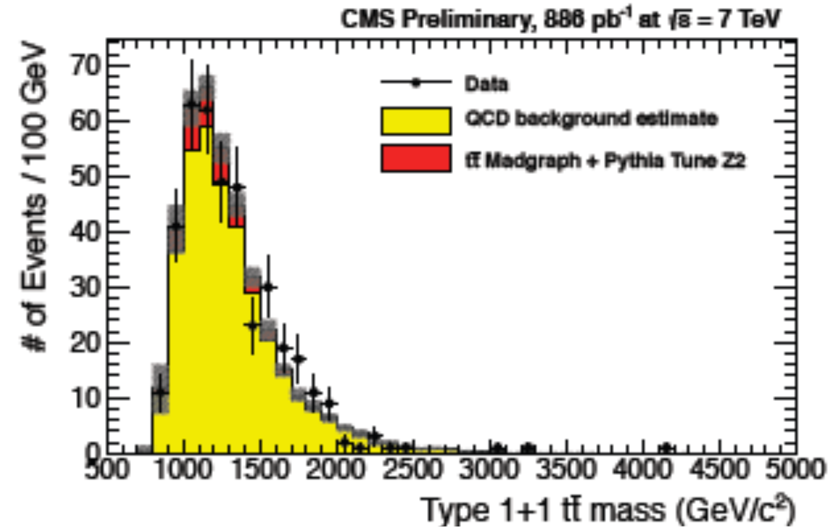
Check Subjet energy scale:

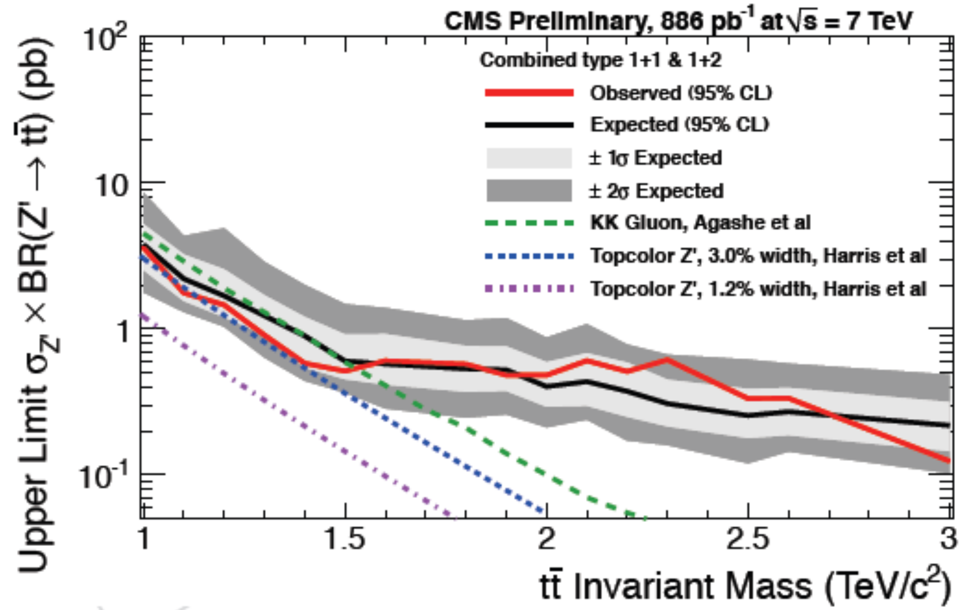


- Appeal to a separate semileptonic top candidate sample where "W-jets" are identified, and check the subjet mass.

Mass and Limits:

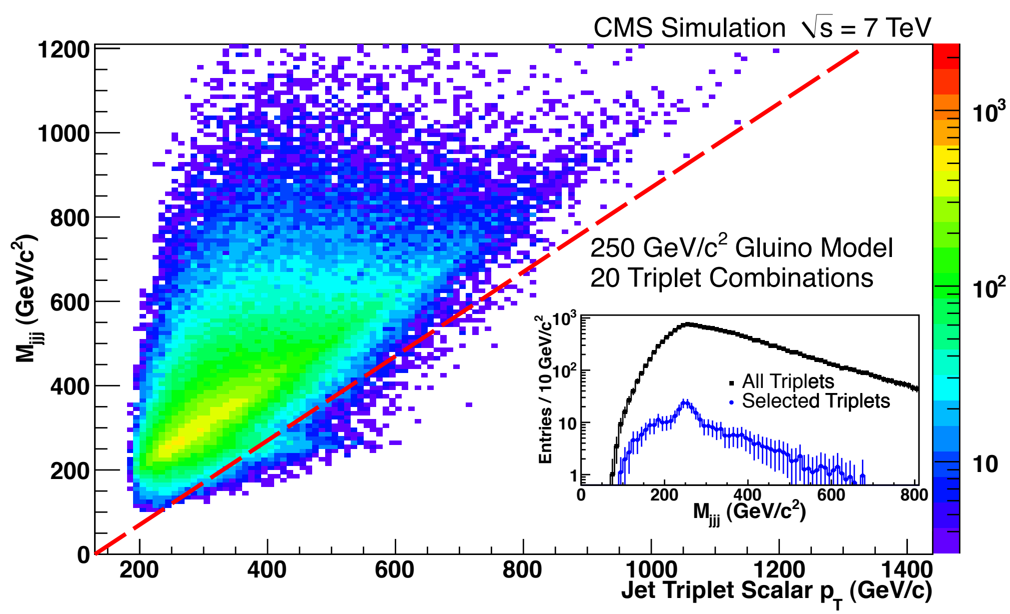
- Top is the mass plot for type one, as expected, far from the top-pair threshold (high H_T required), mainly QCD.
- Bottom: Combined Type1-1, Type1-2, limits on various heavy resonances.





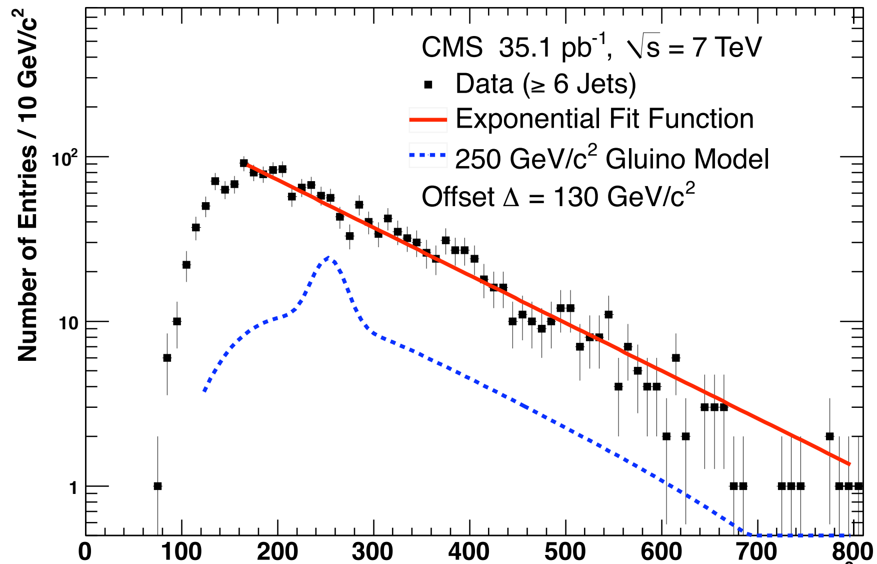
More inclusively:

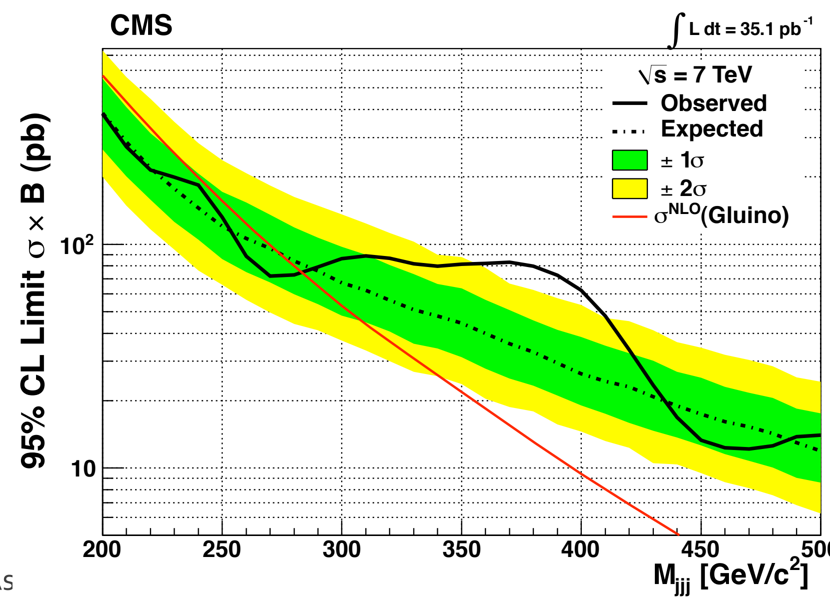
- One can take a different tack on searching for hadronic exotic signatures.
- Look for a heavy resonance decaying to triplets of jets.
- Boost of the three jet system makes the proper combination of jets stand out.



Background shape:

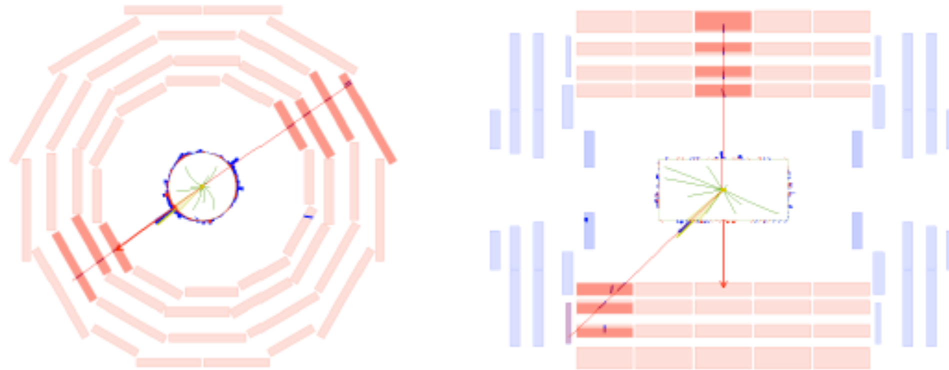
- We fit the lower jet multiplicity events (which won't be populated by our six-jet signal) to get a shape for the background distribution, and then scale that for our candidates.
- This analysis is recently submitted, but used last year's data, so expect more soon!



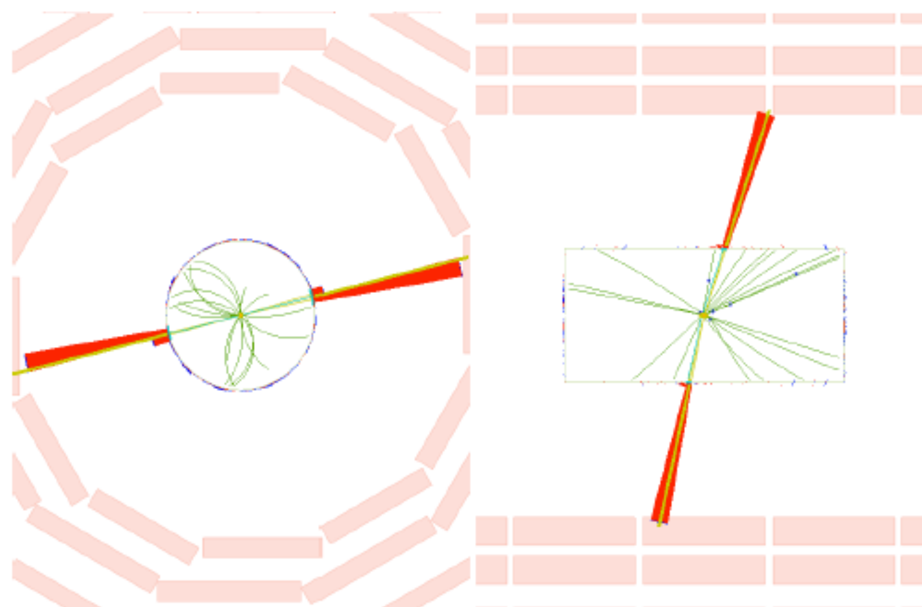


$Z' \rightarrow ee,\mu\mu$

- Similarly, but with far better resolution, one can look for dilepton resonances.
- Muon mass resolution varies from 4% at 500 GeV, to 7% at 1 TeV.
- Electron mass resolution is more or less flat above 500 GeV, at 1.3(2.4)% for EBEB(EBEE).

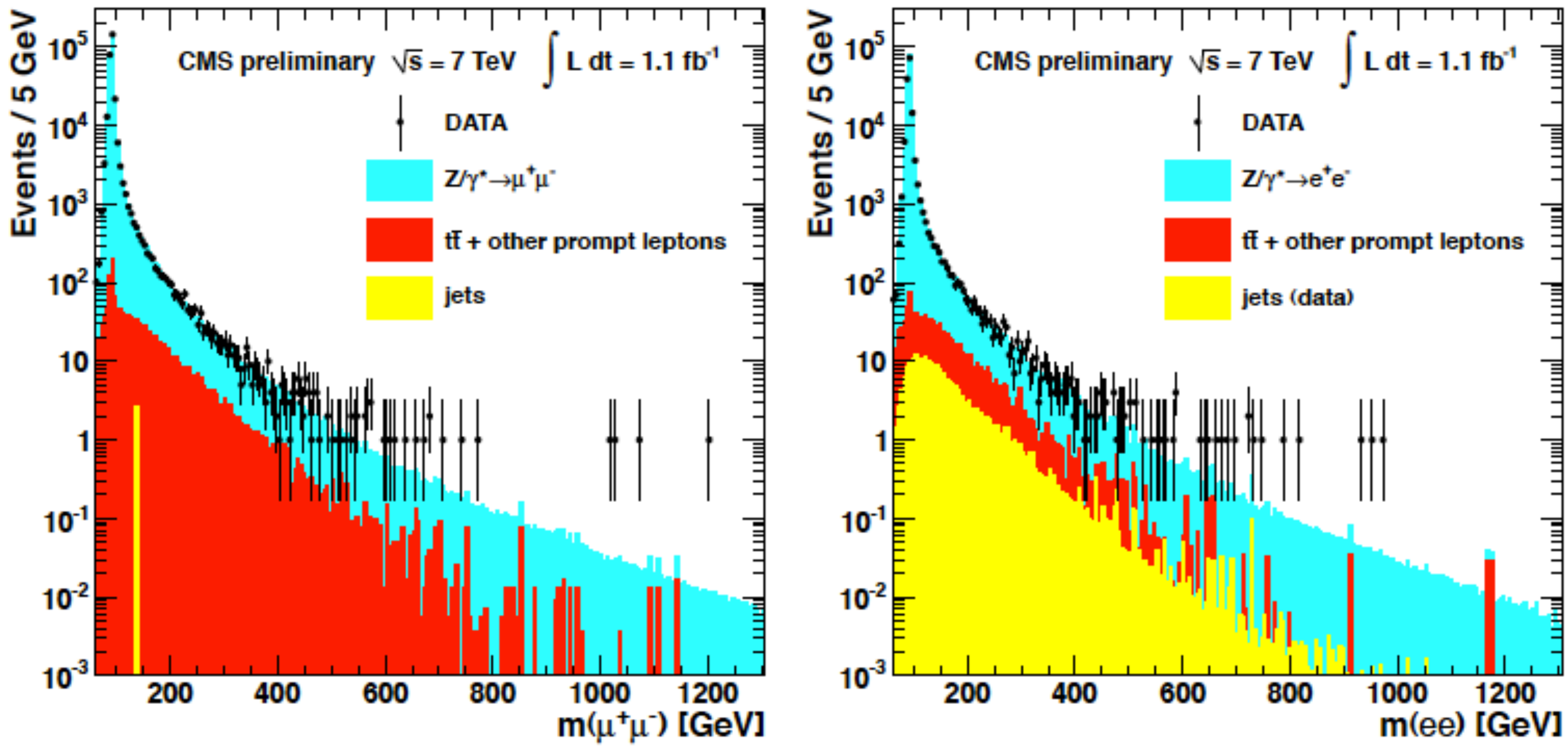


High mass $\mu\mu$ event



High mass ee event

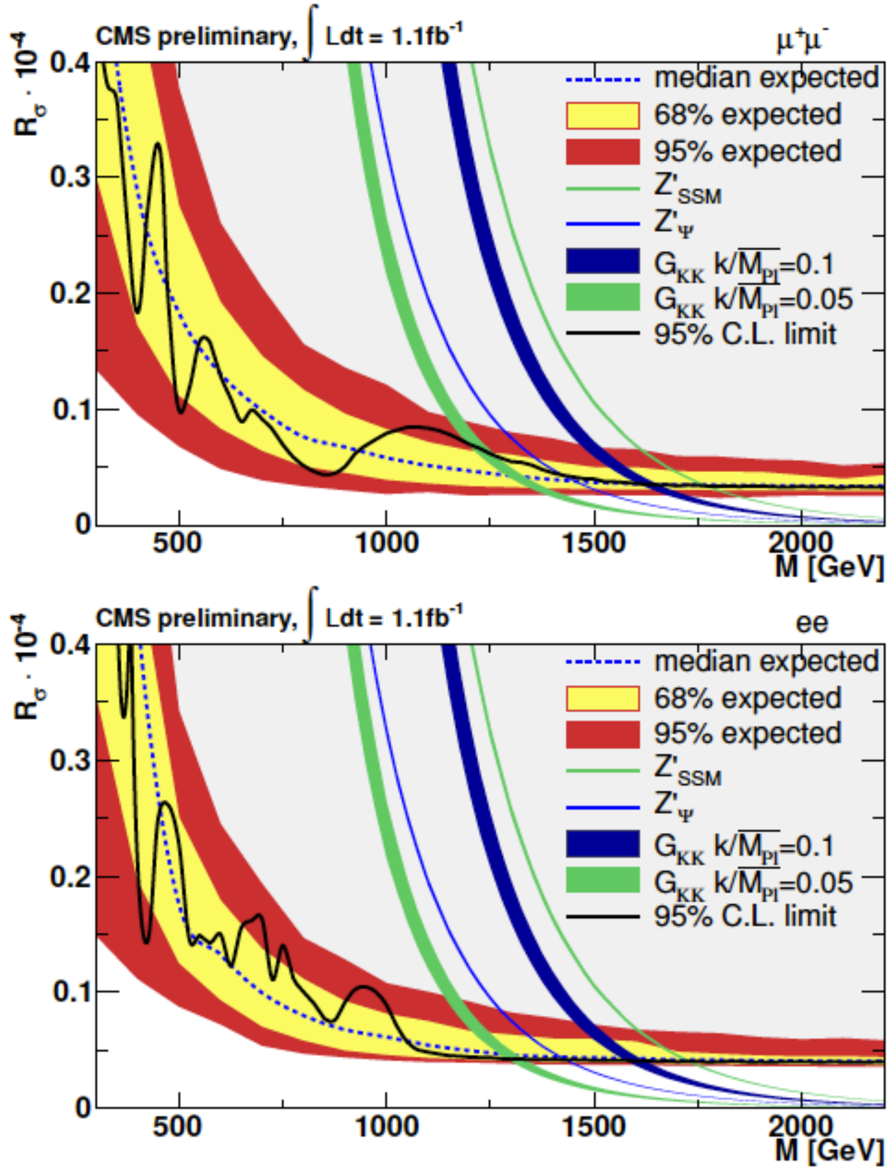
Spectra:



- The actual spectra themselves, MC for DY normalized to 60-120 GeV, NNLO shape taken for DY.
- Top backgrounds, QCD backgrounds taken from data.

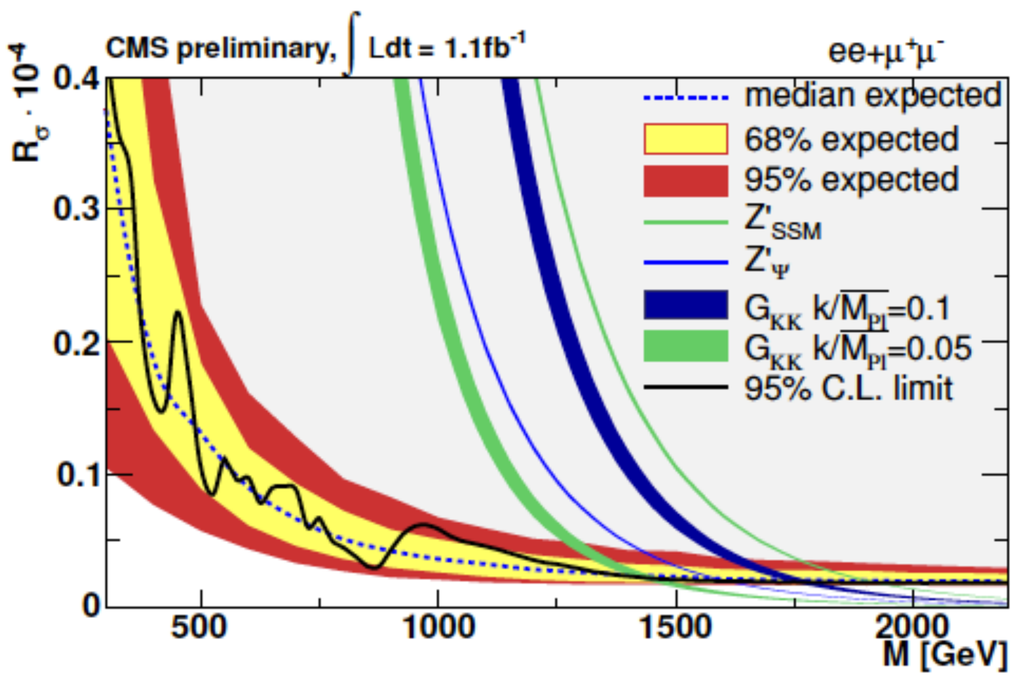
Limits:

- Individual observed limits bobble around a bit due to the slightly choppy spectra of the dilepton mass.



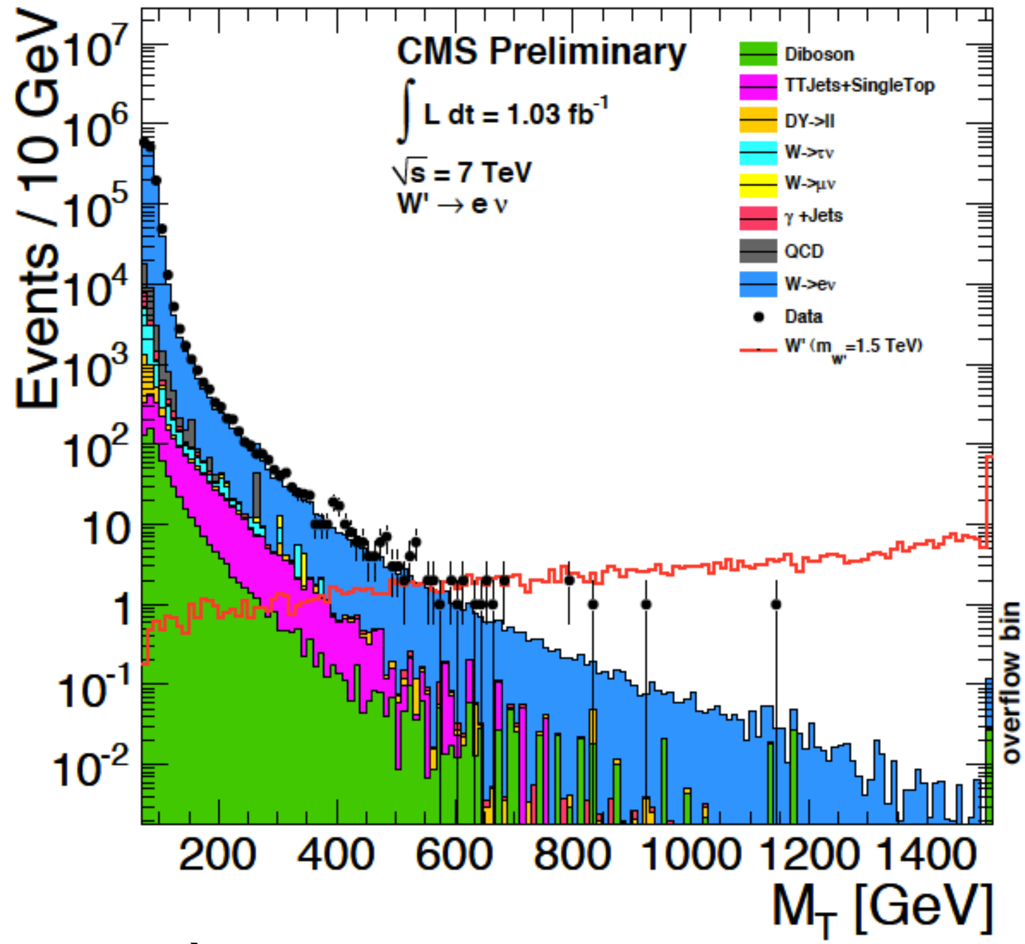
Limits:

- Individual observed limits bobble around a bit due to the slightly choppy spectra of the dilepton mass.
- Combining them smoothes this out considerably.



W'

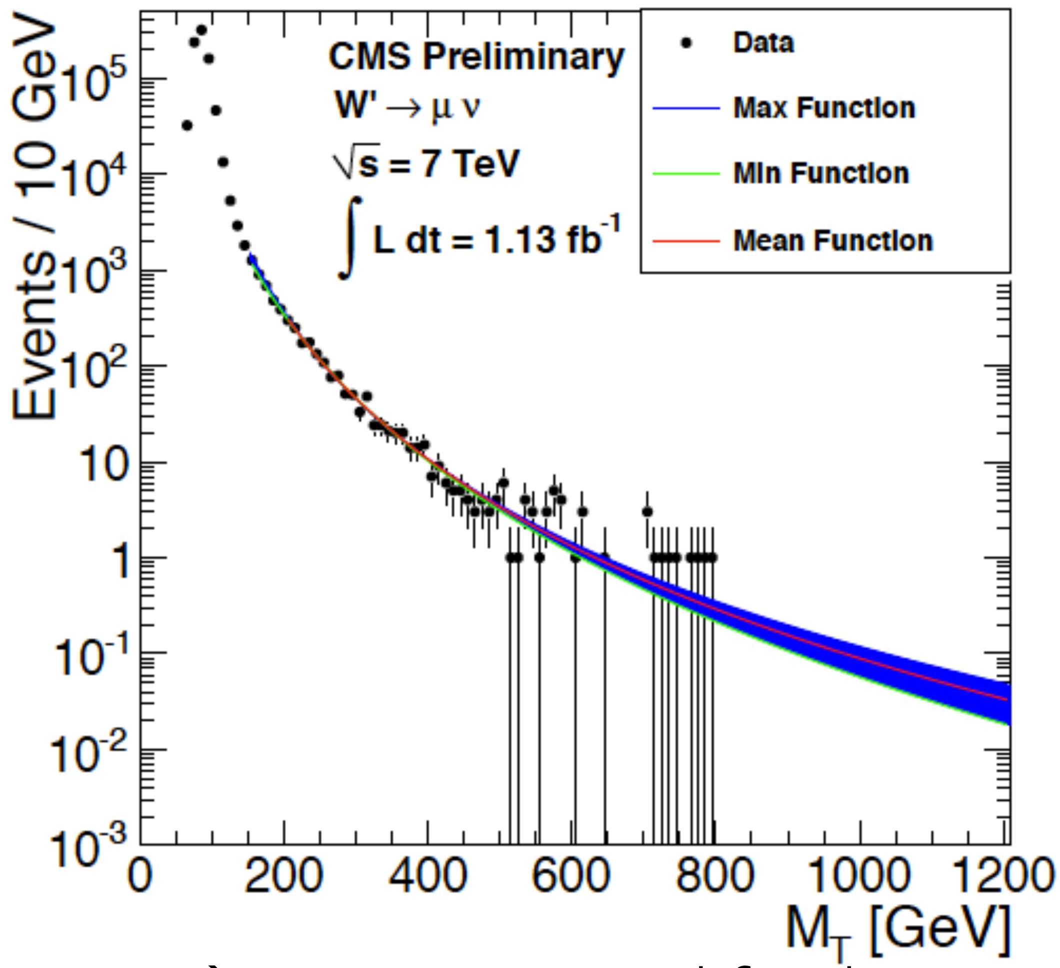
- Like Z', many models which extend the SM have additional heavier counterparts to the SM W boson.
- In some scenarios, the W' decays similarly to it's SM counterpart, e.g. to lepton and neutrino.



W→eν transverse mass distribution and expected background.

W'

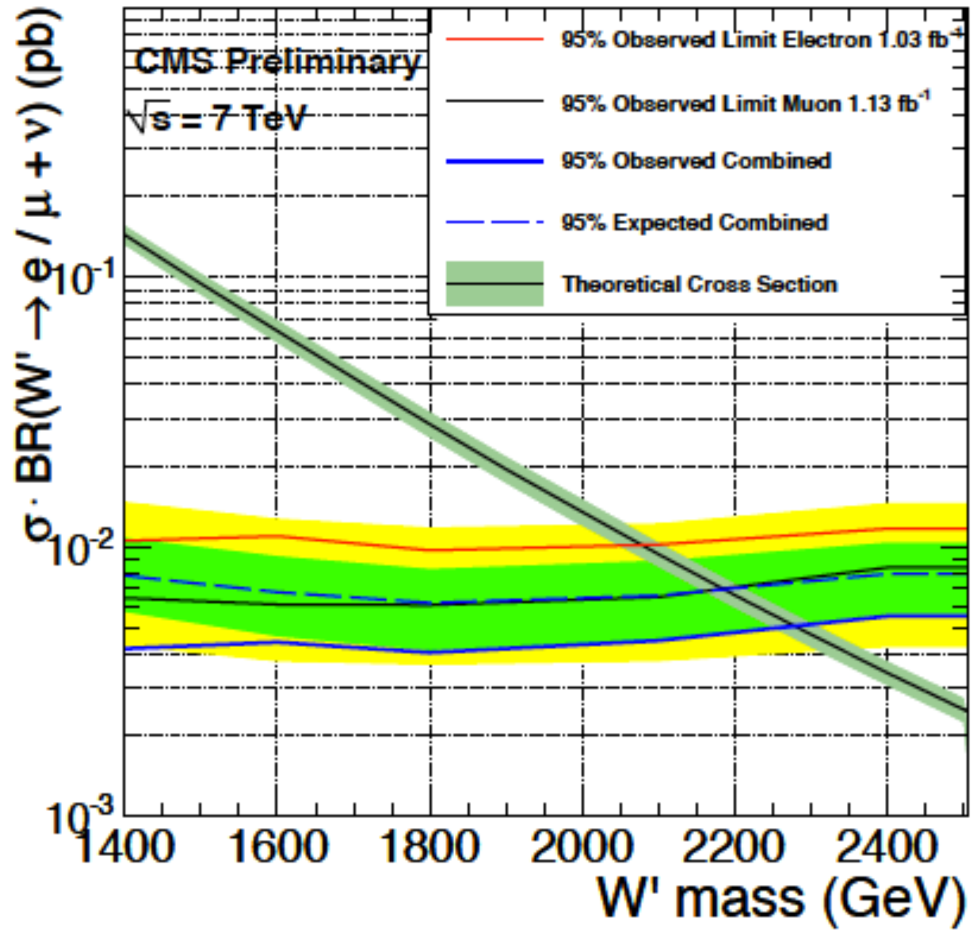
- Like Z', many models which extend the SM have additional heavier counterparts to the SM W boson.
- In some scenarios, the W' decays similarly to it's SM counterpart, e.g. to lepton and neutrino.



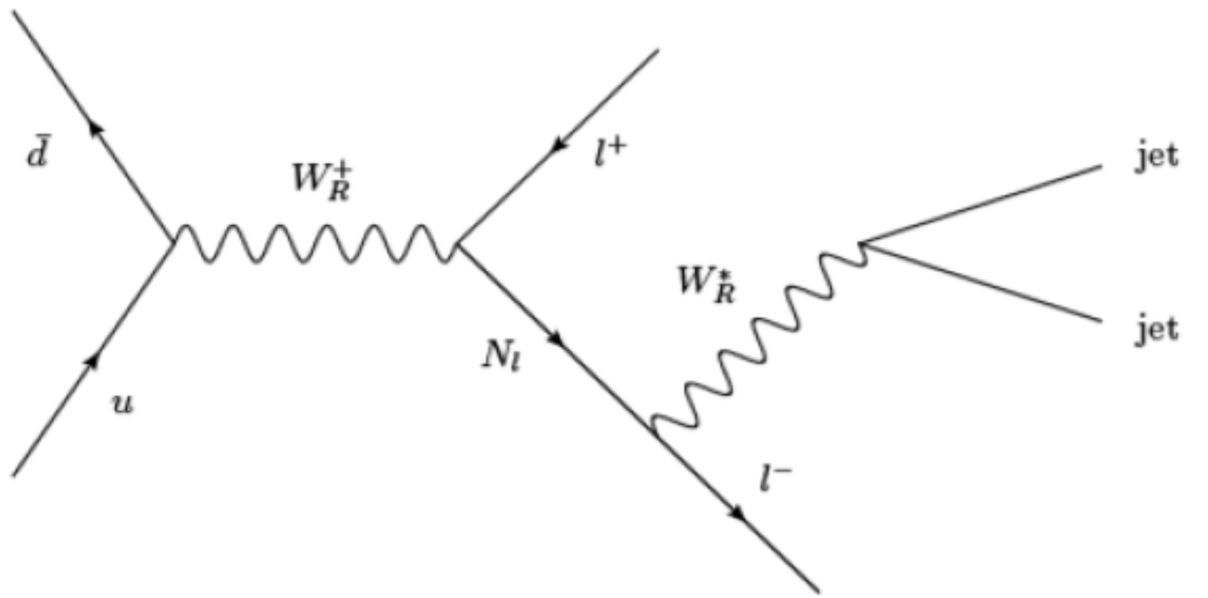
W→μν transverse mass, with fit in the low M_T region, extrapolated to high M_T.

Limits:

- No excess is observed, thus limits are placed on the cross section for a W'.
- Theoretical model on right assumes identical coupling as SM W.



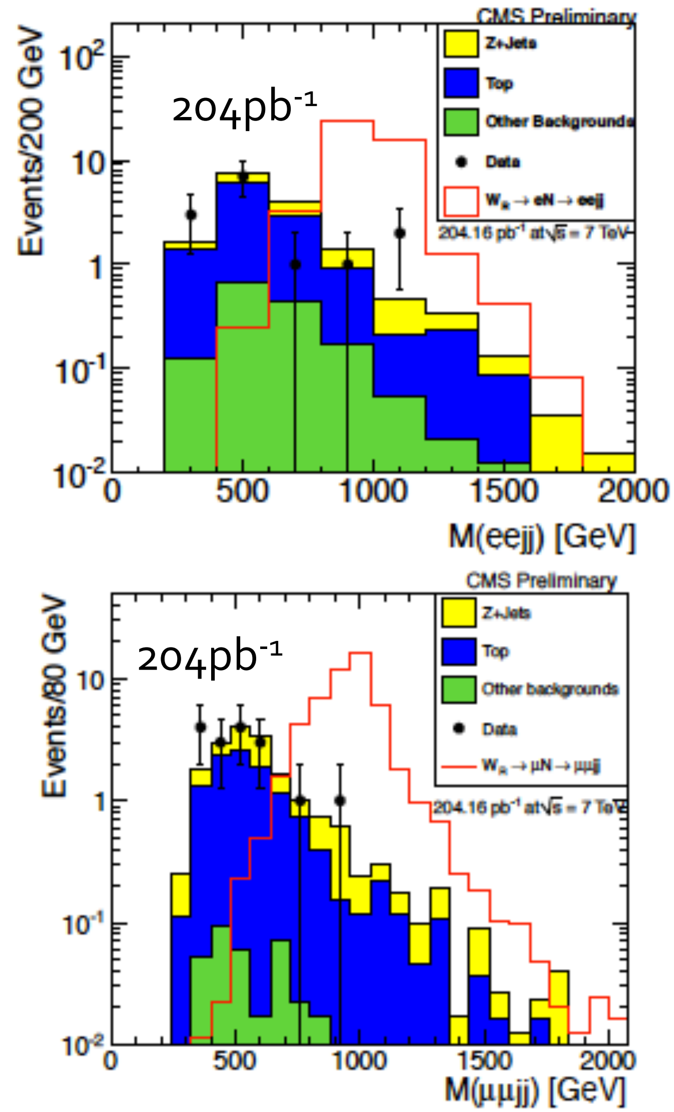
W_R



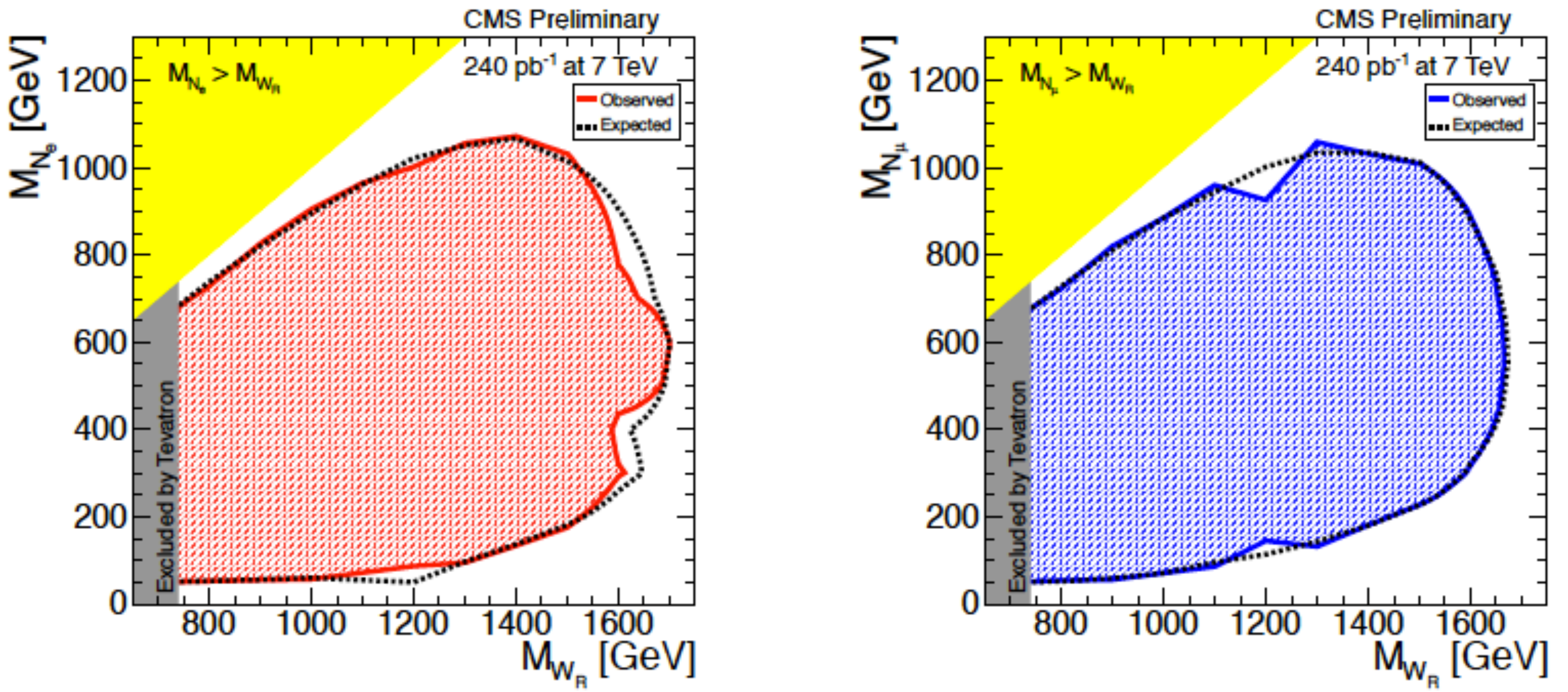
- Some models have quite different W bosons however. This W_R couples to a right handed (heavy neutrino), which subsequently decays through a virtual W_R.

Selection and Backgrounds:

- Require two leptons (ee,μμ), p_T>60/30 GeV, and M_{ll}>200 GeV
- Two jets, p_T > 40 GeV
- Backgrounds primarily DY and top production, DY normalized in data, top normalized to luminosity.



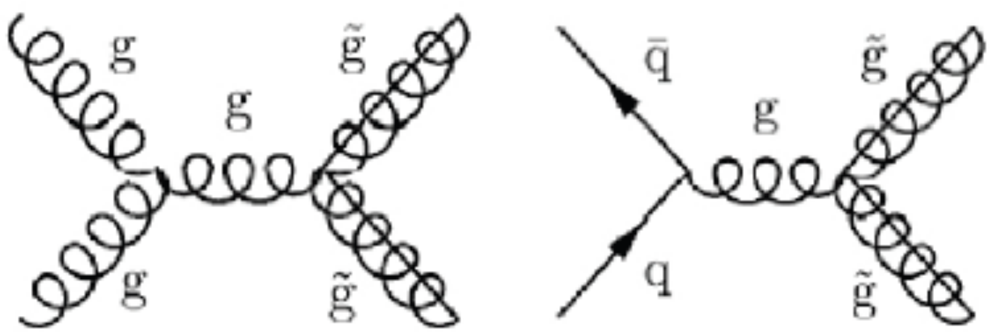
Limits:



- No excess observed over estimated background.
- Mass limits as a function of M_N and M_{W_R} (for electron (red) and muon (blue).

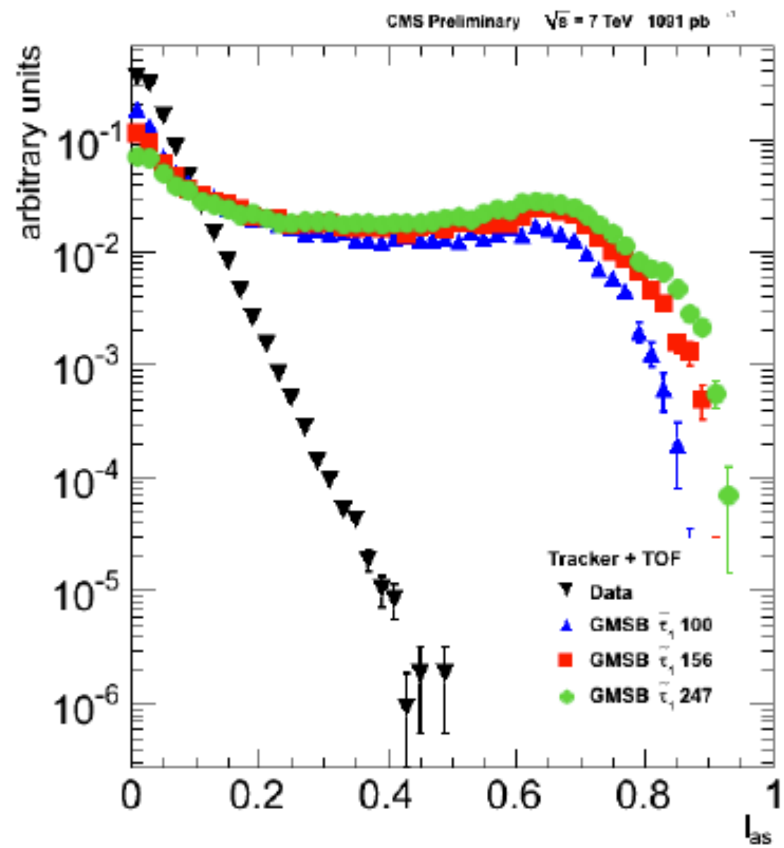
HSCP:

- "Stable" here just means stable with respect to transit in the detector.
- Two Main varieties:
  - Slow: ($0.4 < \beta < 0.9$)
  - Stopped: ($\beta < 0.3$)
- A number of different models, pair vs. singly produced, hadron-like vs. lepton-like, etc.

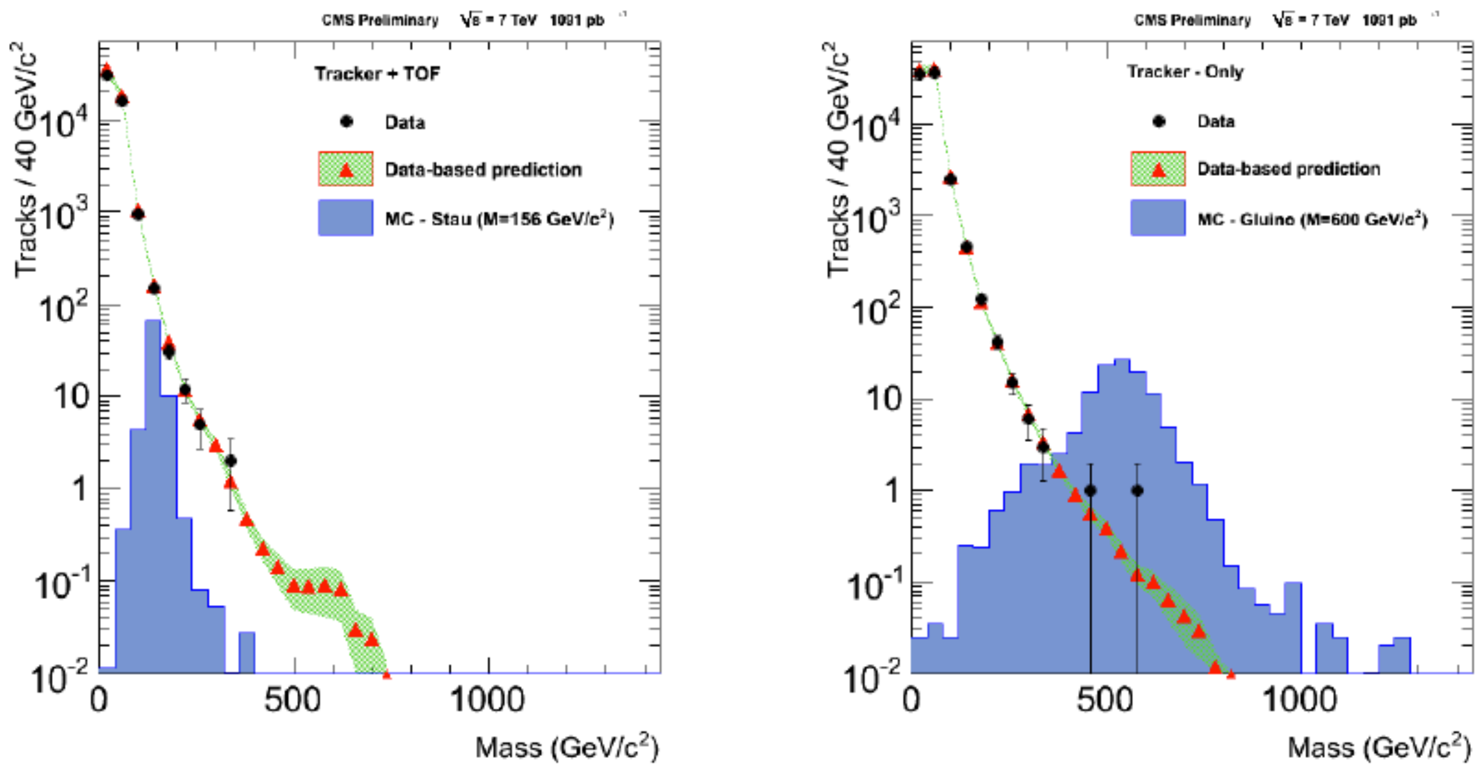


Slow:

- Use tracker energy loss measurements, with lower β comes higher energy loss.
- For "heavy muon" style HSCP, use time of flight from the muon system.

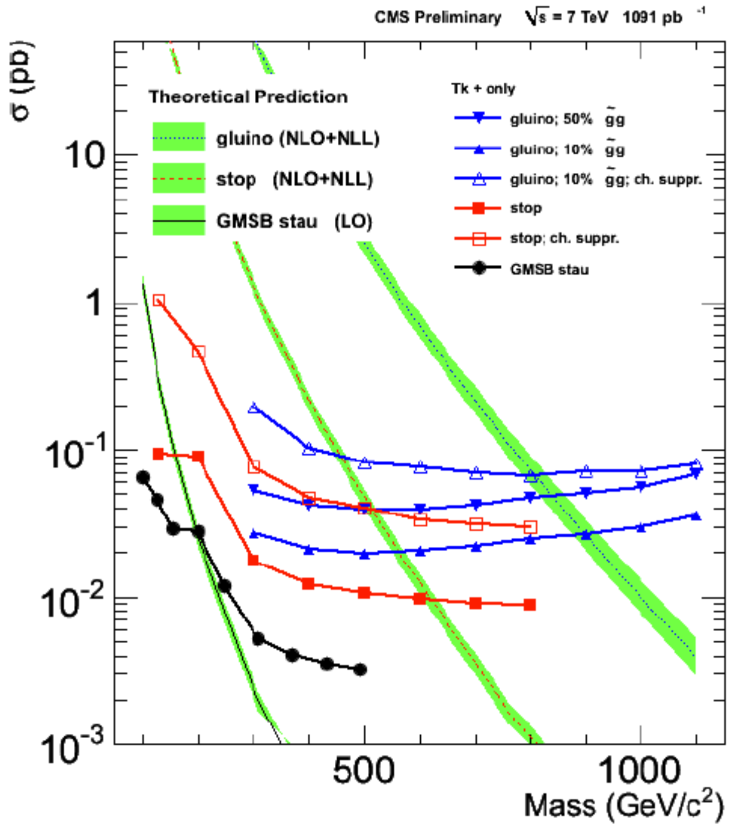


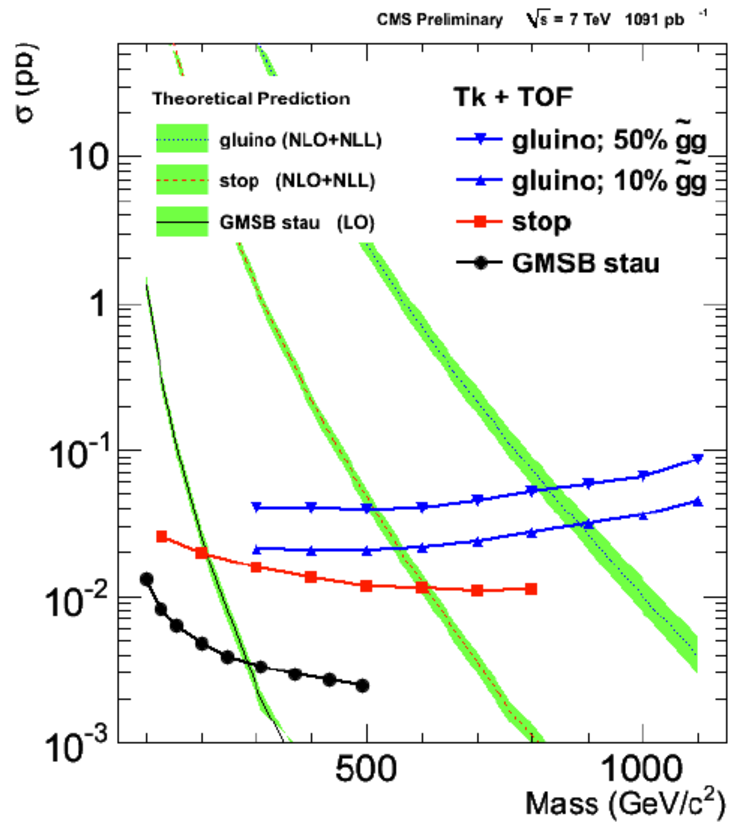
dE/dx and p, calculate mass:



- Using tracker only (right) and tracker+TOF on right.

Limits:

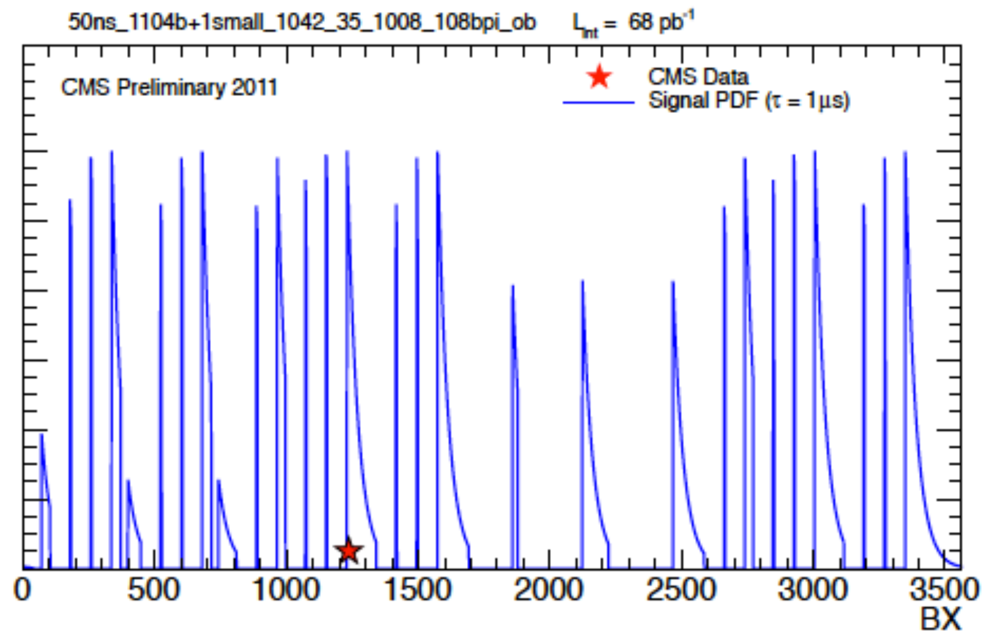




- Busy limit plot: Blue, black and red are observed cross section limits. Green bands are the theoretical cross section for benchmark HSCP.

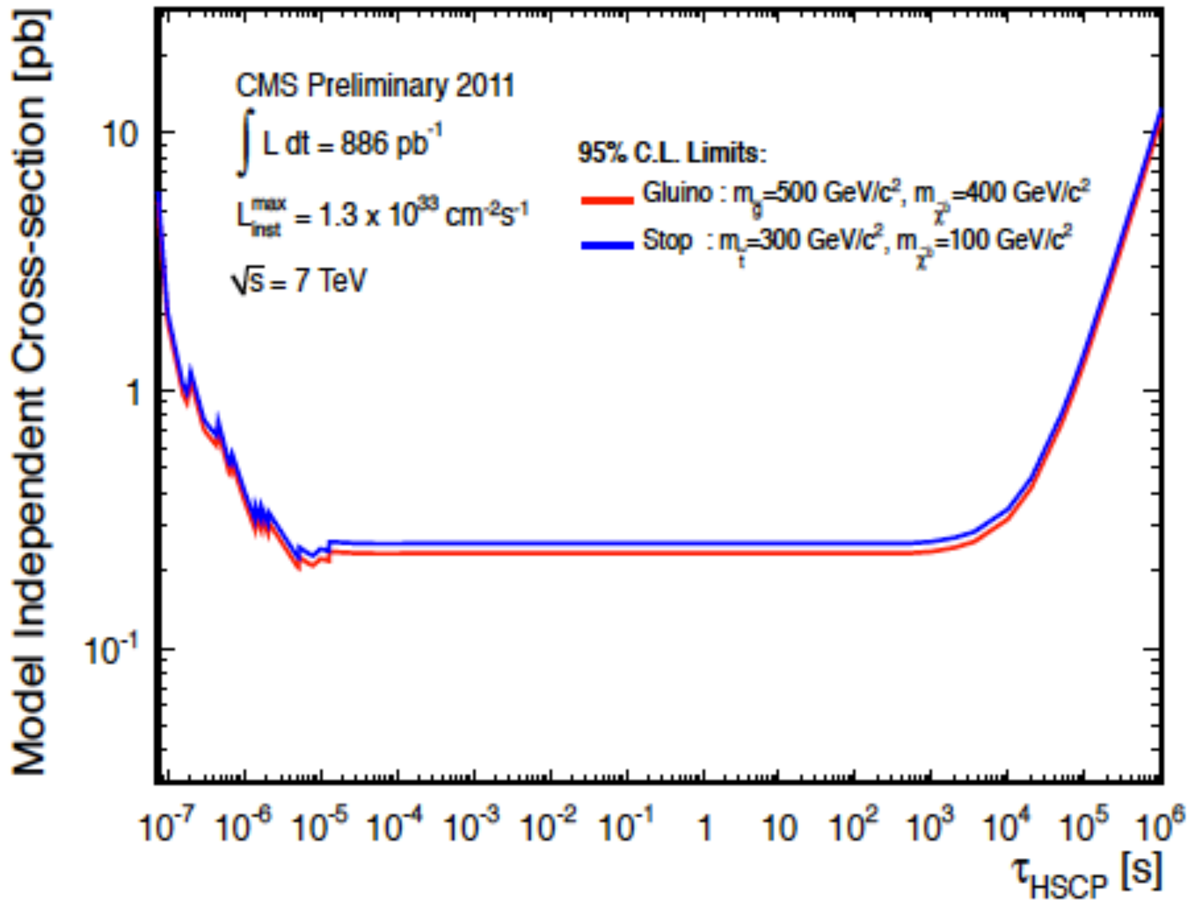
Stopped HSCP:

- Similar to previous models, “R-hadrons” could lose energy and finally stop within the CMS detector, and then decay seconds, minutes, or even hours later.



Look in “gaps” in LHC beam structure for energy depositions that are inconsistent with noise, and uncorrelated to collisions. Overlay is for 1μs decay time for particles produced in collisions.

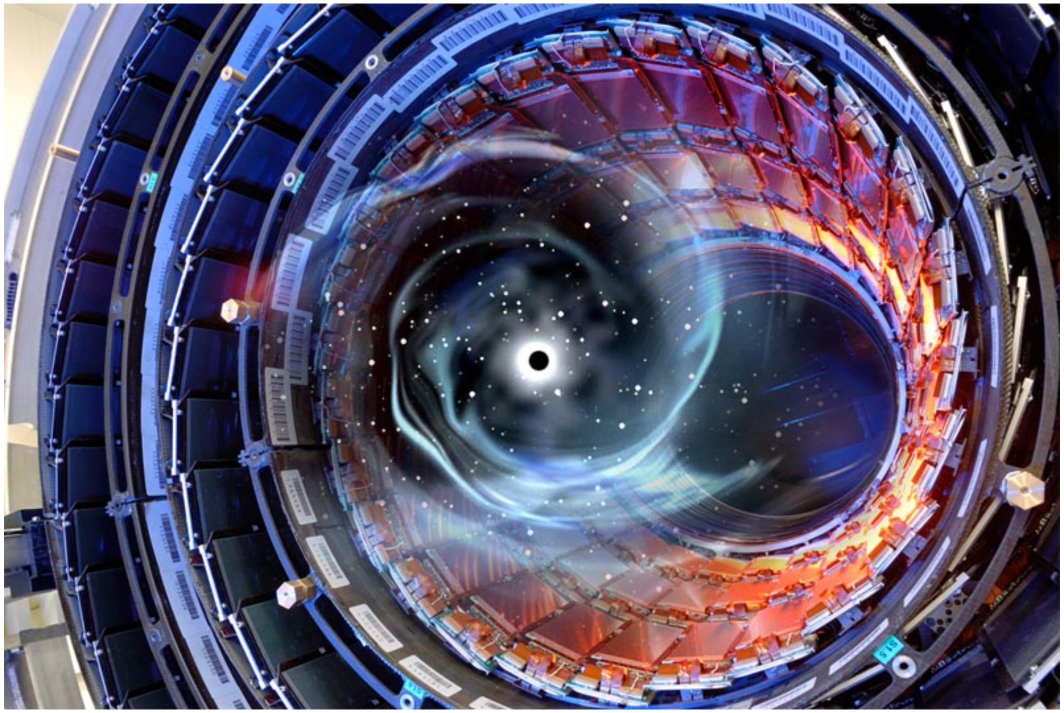
Limits:



- Model independent limit on energetic decay within detector, as a function of lifetime.

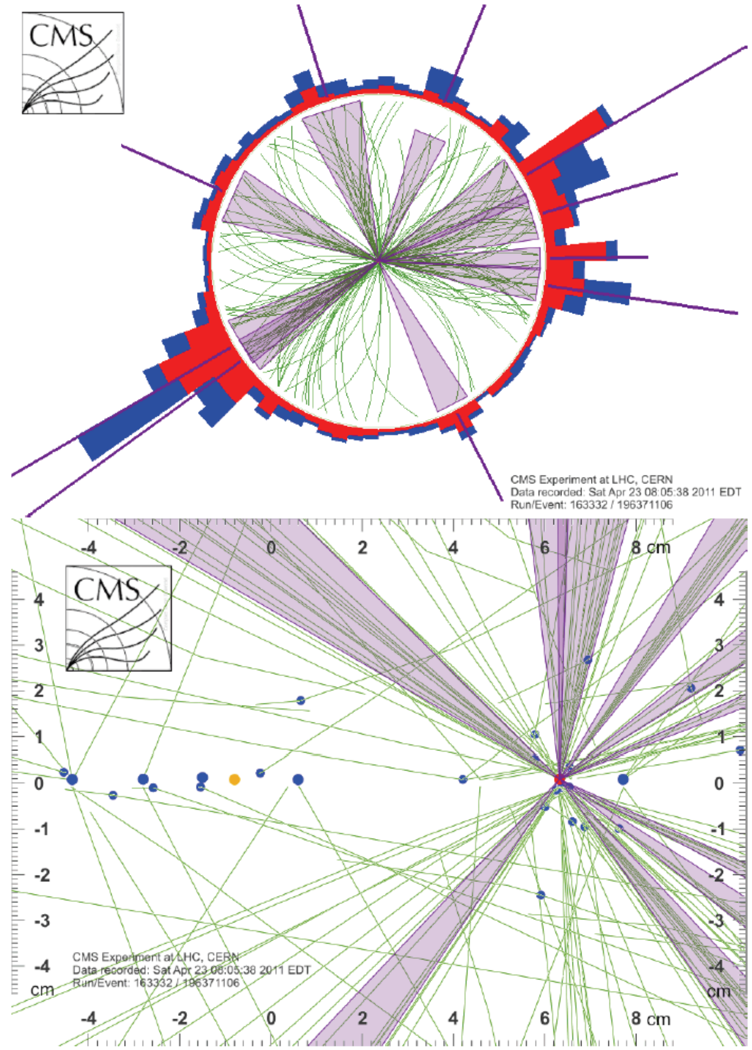
Black Holes

- In models with additional spatial dimensions, black hole production becomes possible (and even frequent).
- More remarkably, these black holes decay "democratically", leading to a large particle multiplicity of many different kinds (γ, e, μ, q…)



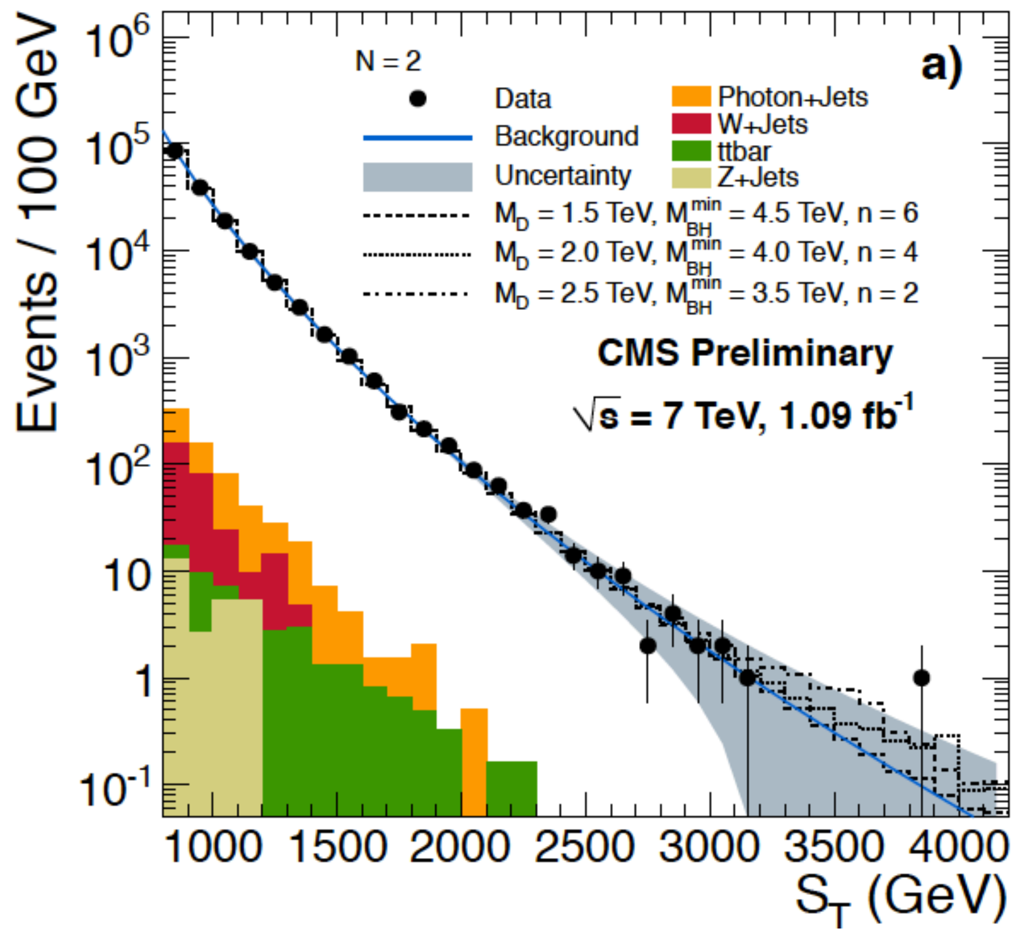
Explosive!

- One of our S_T>1 TeV events, this one with greater than nine jets, leptons or photons.
- You can see that this was only one of a few interactions in this crossing.



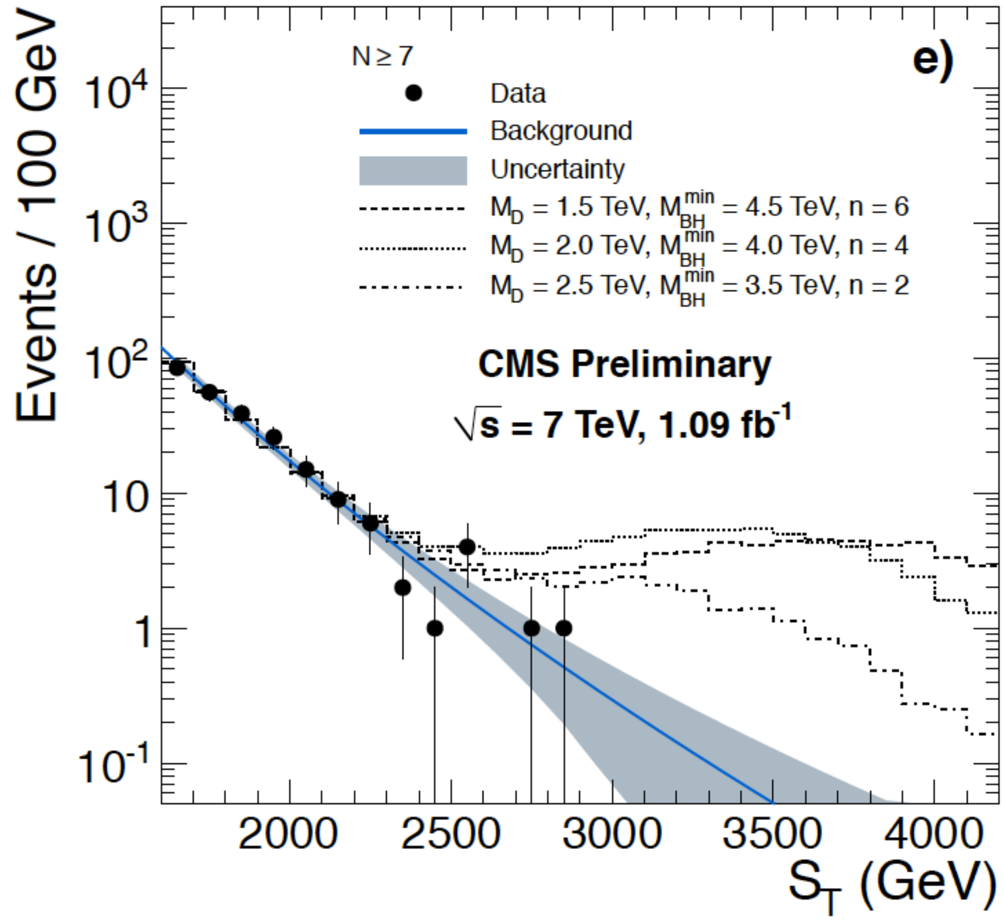
Background:

- We fit the S_T distribution for small values of N (number of "items" in the event), where SM dominates.



Black Holes

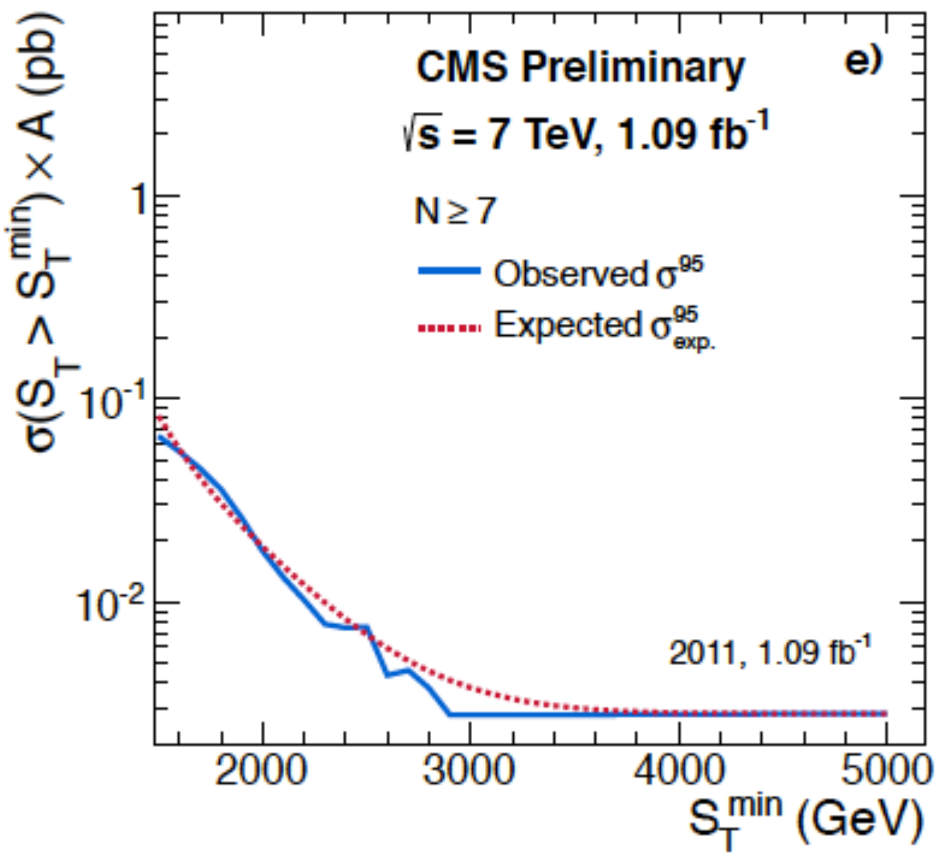
- We fit the S_T distribution for small values of N (number of "items" in the event), where SM dominates.
- We then use the same shape, and float the normalization for the high N bins.



New preliminary result.

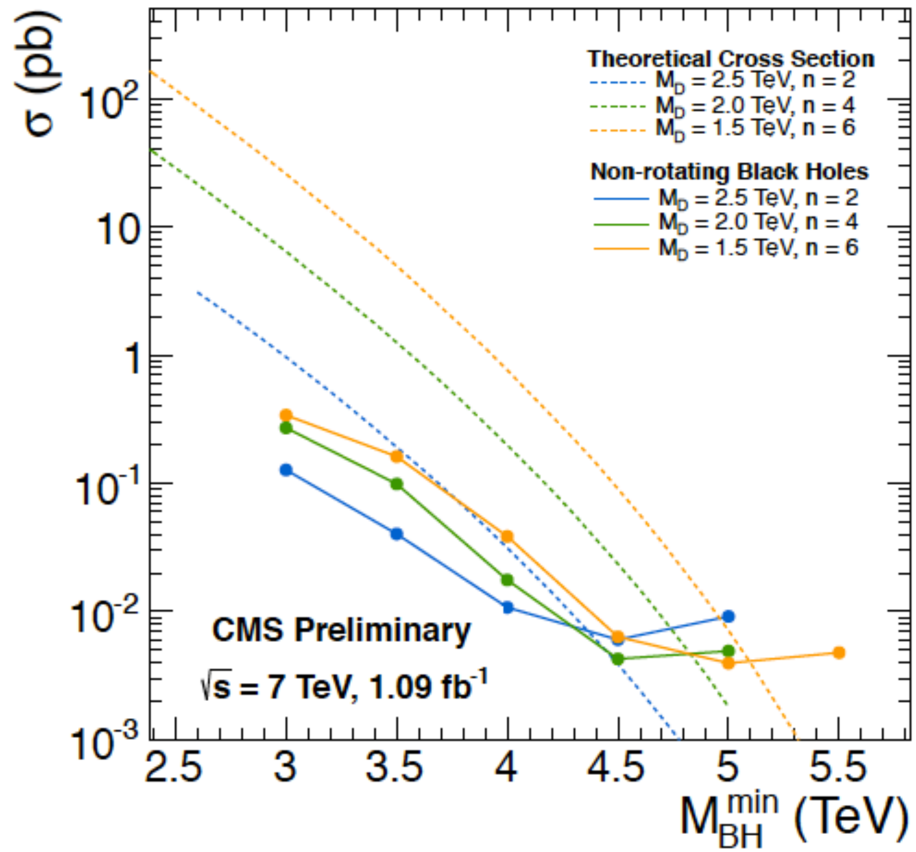
Limits:

- Using the fit to determine the expected number of events in the high S_T range, limits are set.



Limits:

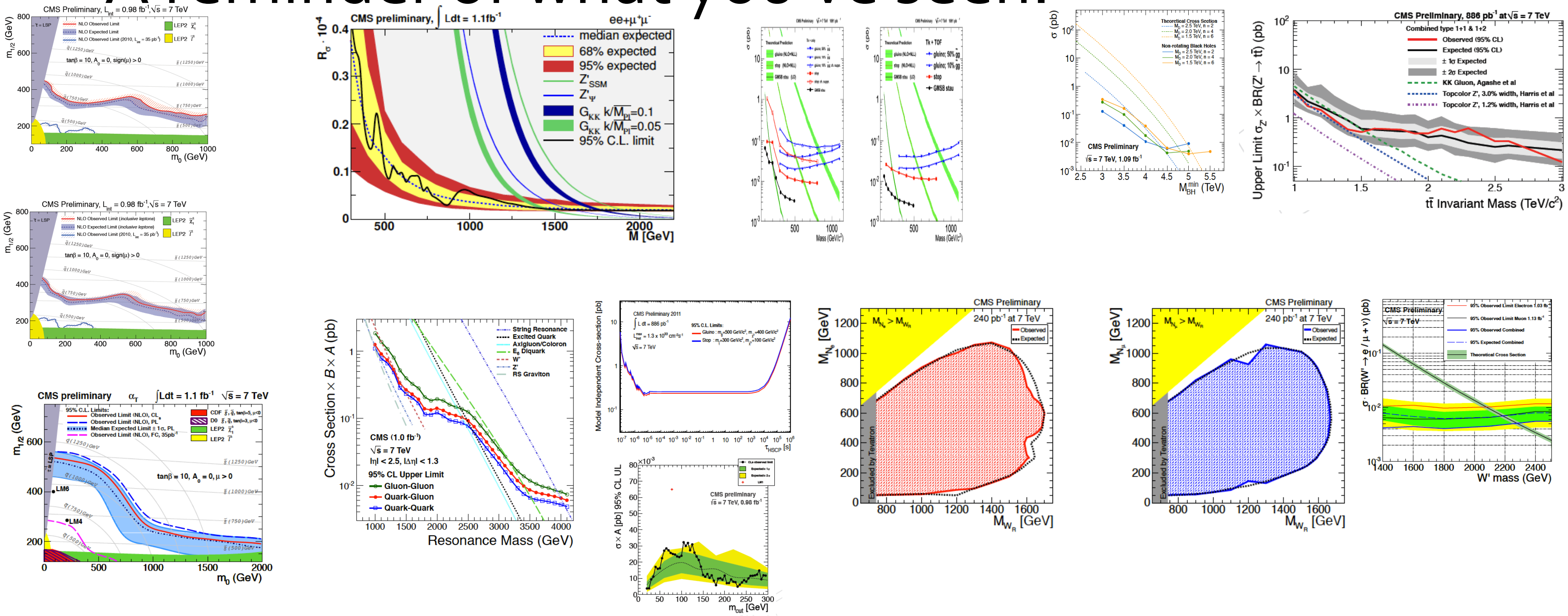
- Using the fit to determine the expected number of events in the high S_T range, limits are set.



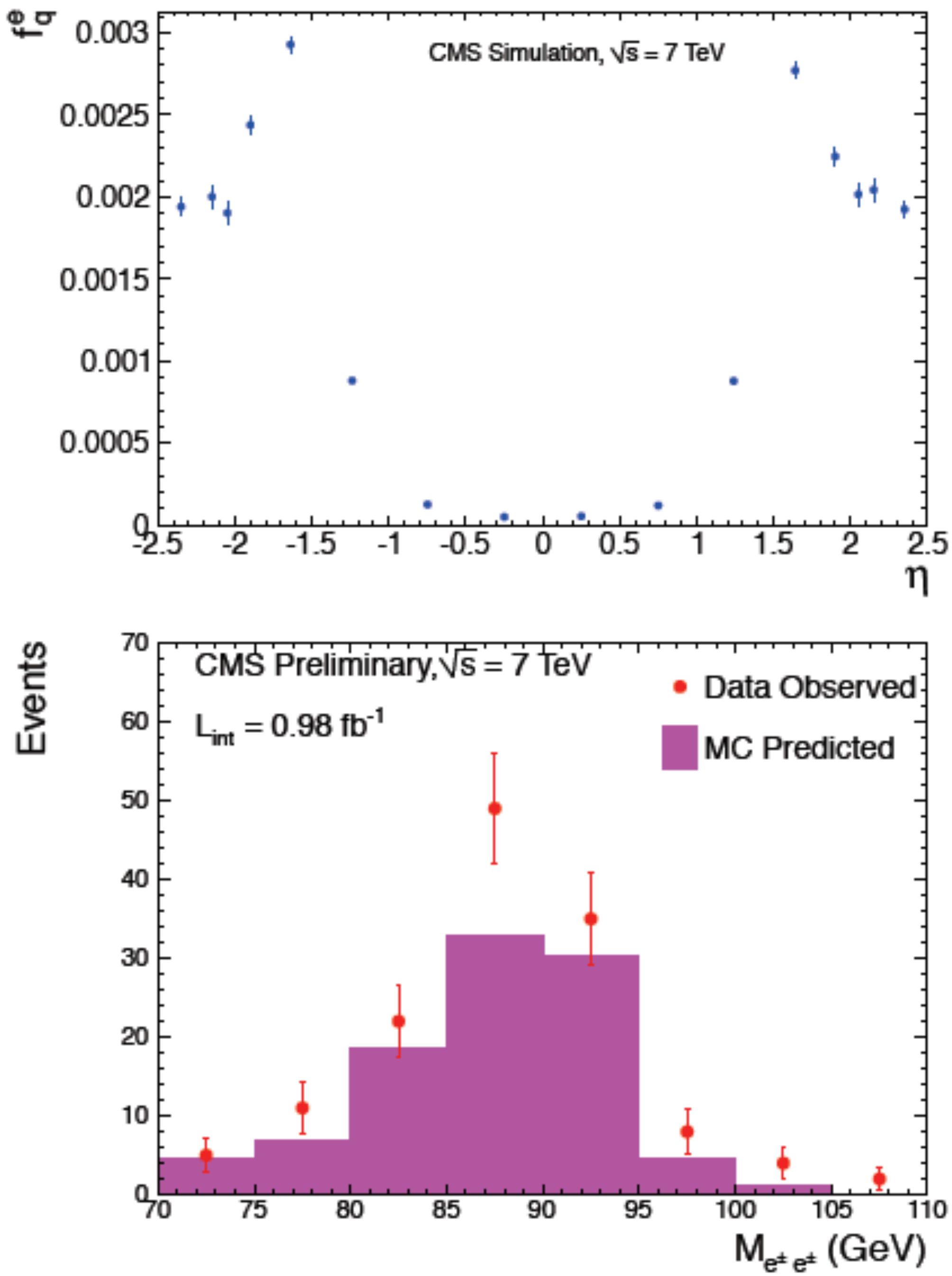
Conclusion

- I have concentrated on only some of the MOST recent analyses to come out of the CMS Experiment on the topic of BSM.
- Many more exist, and even more are still to come.
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

- I have concentrated on only some of the MOST recent analyses to come out of the CMS Experiment on the topic of BSM.
- A reminder of what you've seen:



BACKUPS

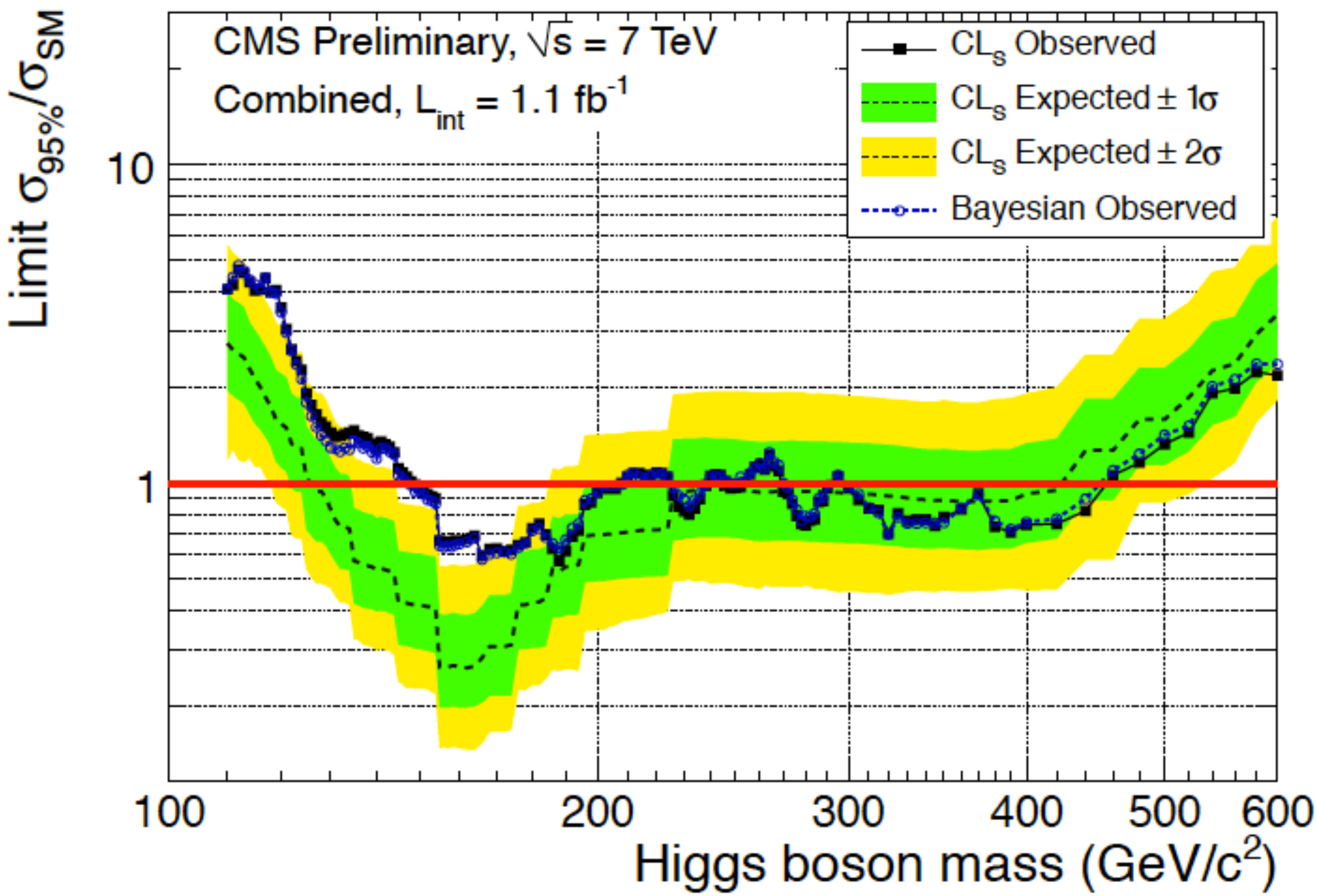


CMS Simulation, √s = 7 TeV
f_q^e
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
η
CMS Preliminary, √s = 7 TeV
L_{int} = 0.98 fb^{-1}
Data Observed
MC Predicted
Events
70 60 50 40 30 20 10 0
70 75 80 85 90 95 100 105 110
$M_{e^\pm e^\pm}$ (GeV)

$W' \to l\nu$

Table 1: Minimum M_T requirement for the search windows for different W' masses, expected number of signal and background events and number of observed events, along with expected and observed limit for each W' signal sample. The cross sections correspond to the $\sigma_{W'} \times \mathcal{B}(W' \to \ell\nu)$ process, with $\ell = e, \mu$. The exclusion limit is determined using a Bayesian method.

W' mass (GeV)	M_T (GeV)	N_{sig} (Events)	N_{bkg} (Events)	N_{data} (Events)	σ_{theory} (pb)	Exp. Limit (pb)	Obs. Limit (pb)
Electron channel							
1400	1000	53.838 ± 3.707	2.227 ± 1.124	1	0.144	0.014	0.011
1600	1100	23.681 ± 1.630	1.438 ± 0.798	1	0.063	0.013	0.011
1800	1100	12.021 ± 0.735	1.438 ± 0.798	1	0.029	0.011	0.010
2100	1100	3.764 ± 0.242	1.438 ± 0.798	1	0.009	0.012	0.010
2400	1100	1.193 ± 0.087	1.438 ± 0.798	1	0.003	0.013	0.012
Muon channel							
1400	1000	68.665 ± 7.320	2.014 ± 1.402	0	0.144	0.011	0.006
1600	1050	31.932 ± 3.403	1.621 ± 1.182	0	0.063	0.010	0.006
1800	1100	14.455 ± 1.540	1.316 ± 1.002	0	0.029	0.009	0.006
2100	1100	4.435 ± 0.473	1.316 ± 1.002	0	0.009	0.010	0.007
2400	1100	1.249 ± 0.133	1.316 ± 1.002	0	0.003	0.013	0.008



CMS Preliminary, √s = 7 TeV
Combined, L_int = 1.1 fb^-1
CL_s Observed
CL_s Expected ± 1σ
CL_s Expected ± 2σ
Bayesian Observed
Limit σ_95%/σ_SM
10
1
100
200
300
400
500
600
Higgs boson mass (GeV/c^2)