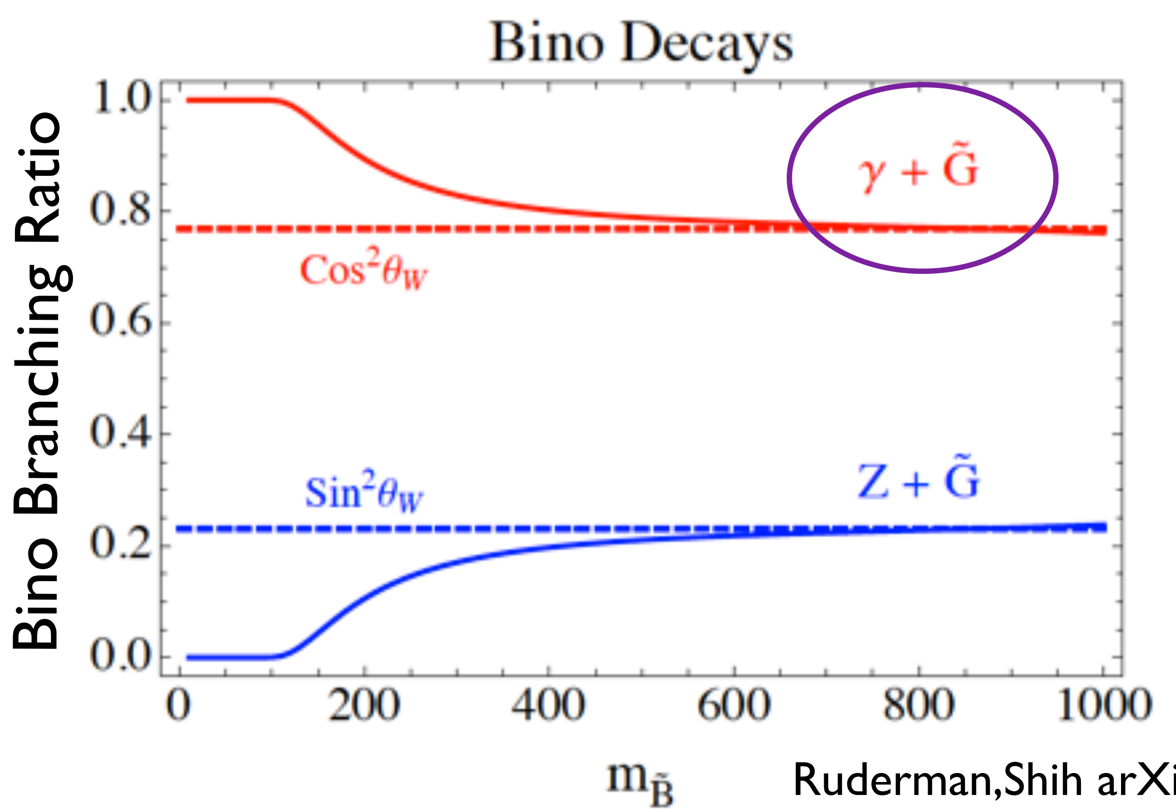
(SUSY) Photon + X searches at CMS

D. Mason for the CMS Collaboration

Why Photons?

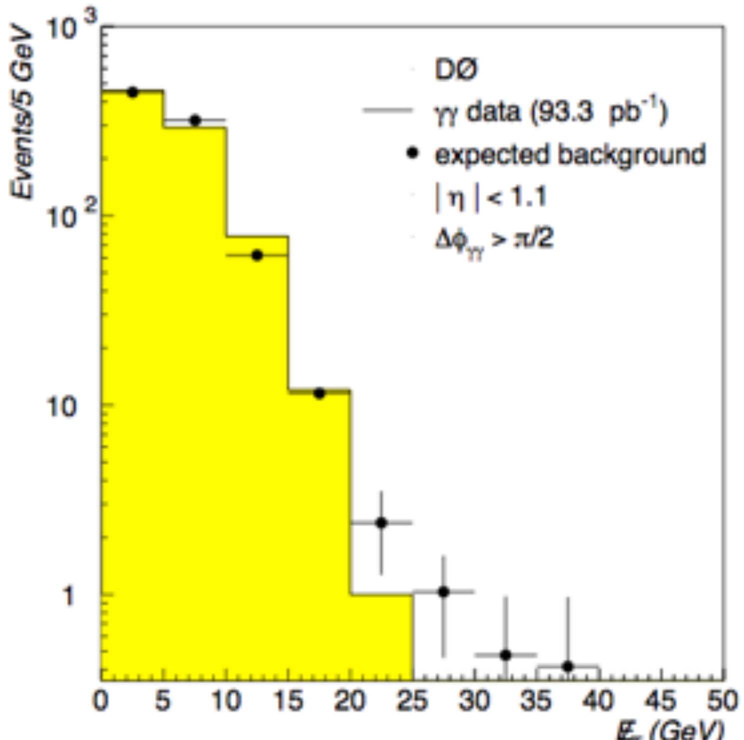
- We will discuss two CMS searches utilizing photons in the final state, motivated by General Gauge Mediated SUSY and Universal Extra Dimensions
  - In GGM SUSY the lightest SUSY particle is the gravitino
  - If the NLSP is a neutralino, especially if bino like:



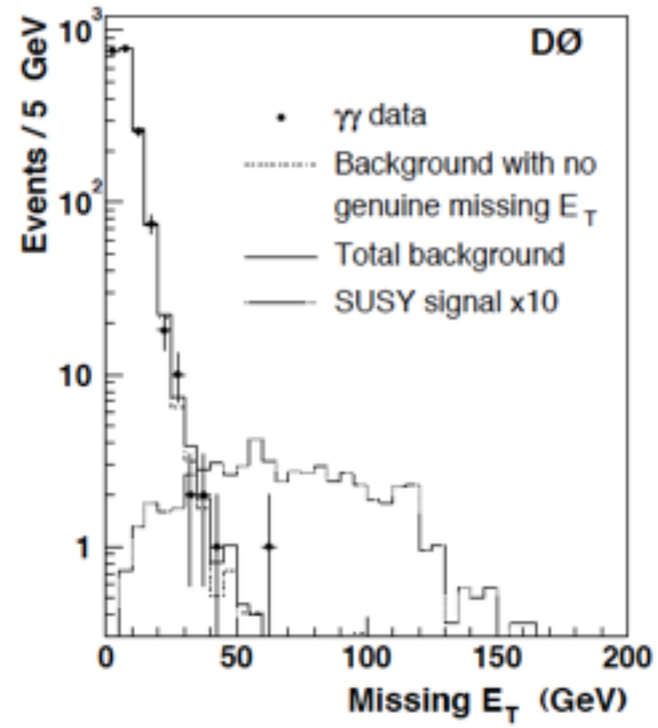
Ruderman,Shih arXiv:1103.6083

  - We would expect SUSY production to result in signatures containing photons + missing E_T

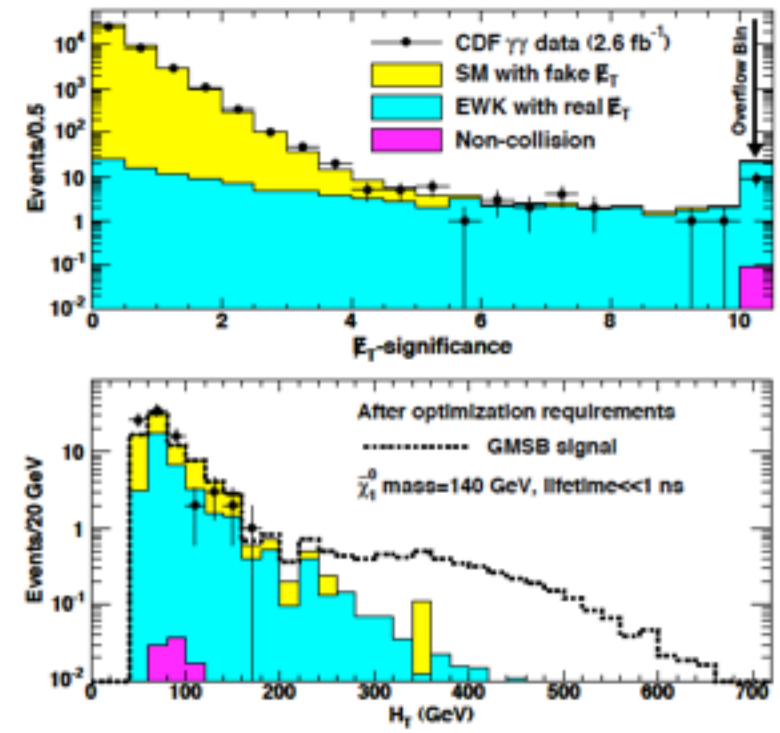
And Here “We” is not just CMS...



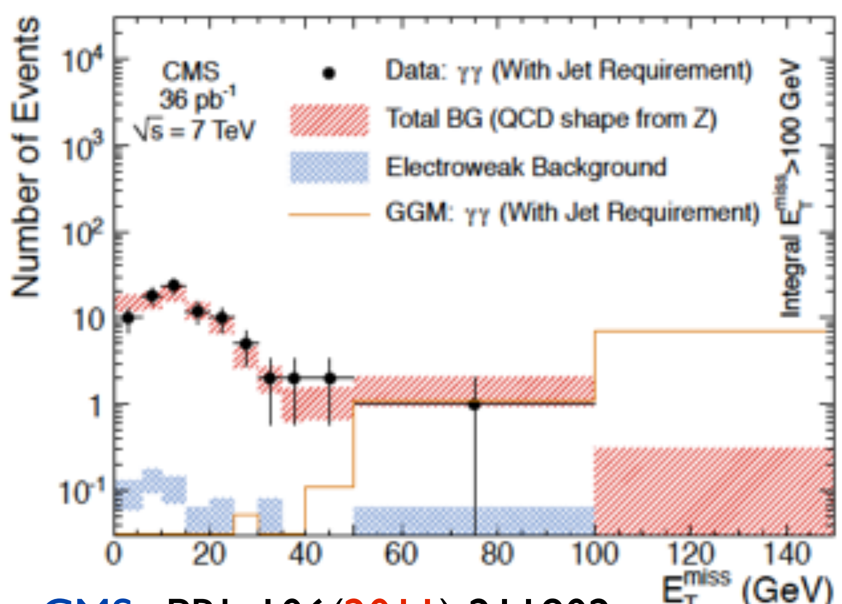
D0: PRL 78(1997) 2070-2074



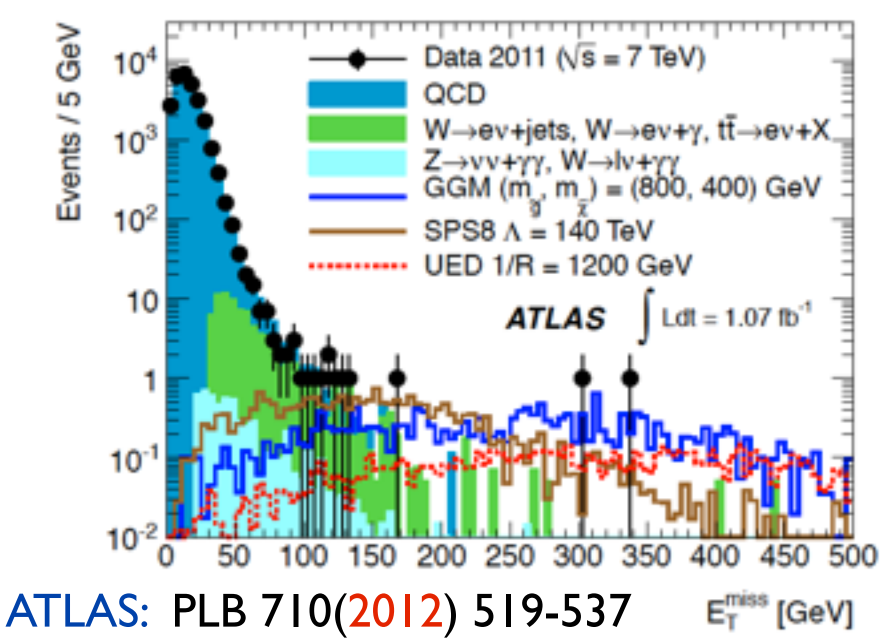
D0: PRL 94(2005) 040801



CDF: PRL 104(2010) 011801



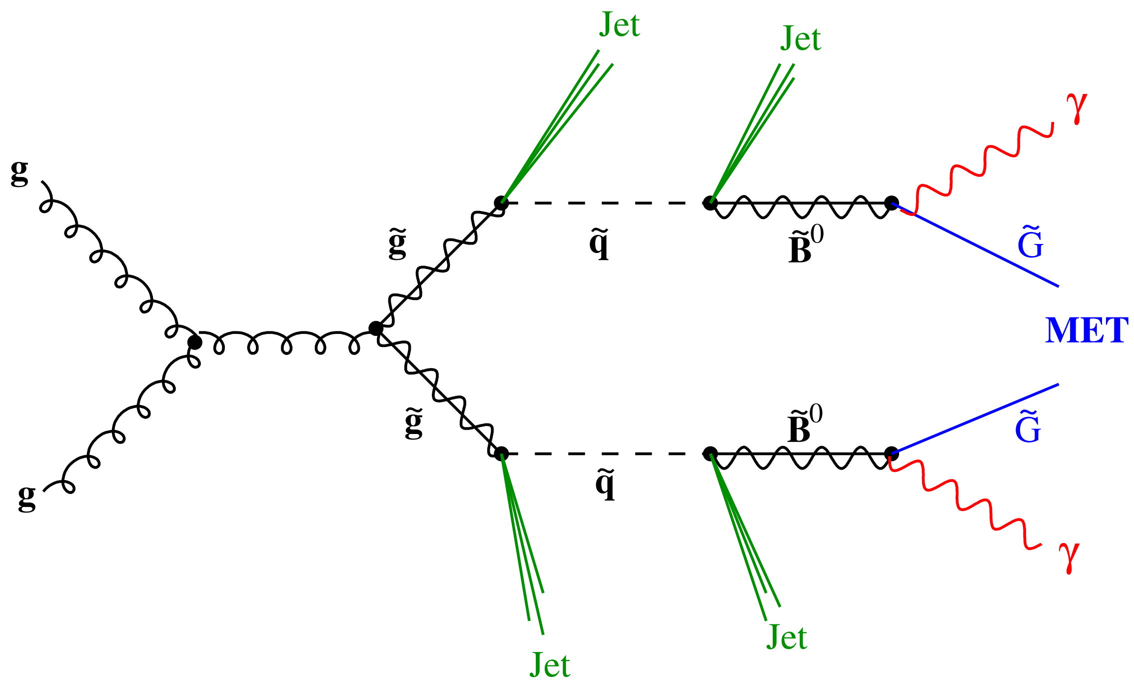
CMS: PRL 106(2011) 211802

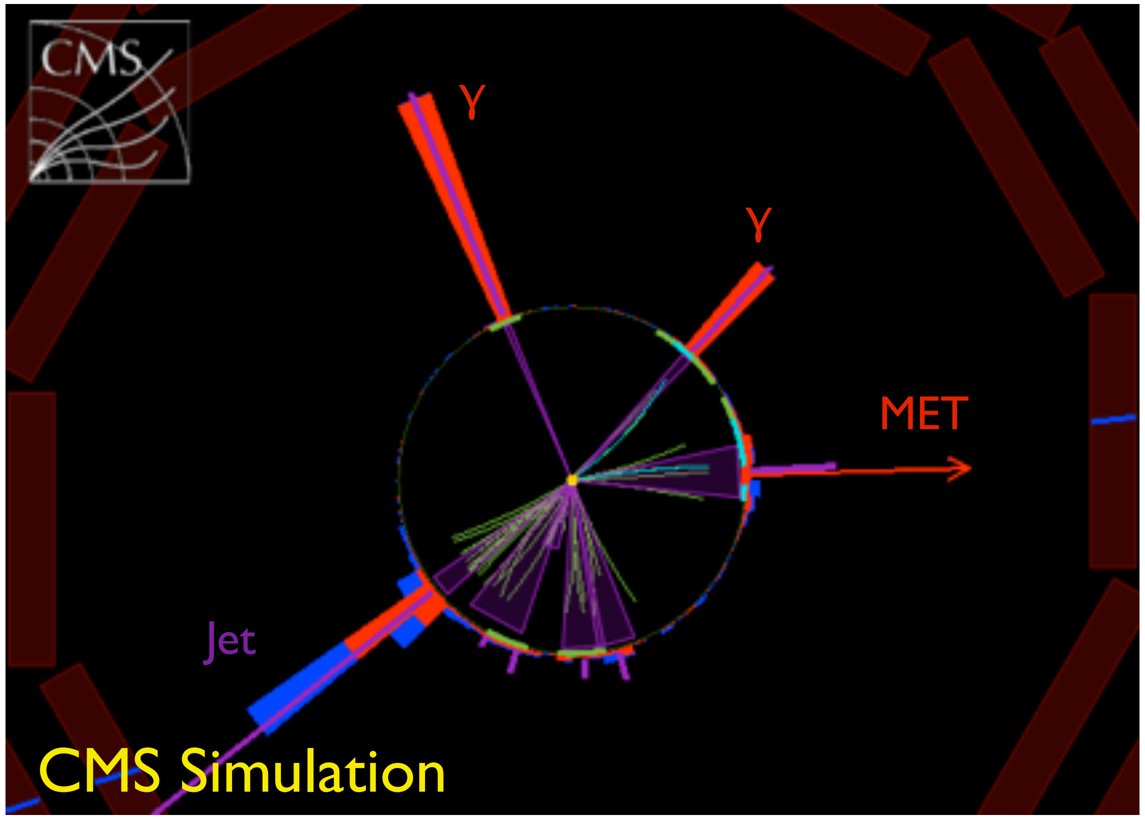


ATLAS: PLB 710(2012) 519-537

Now we look at CMS after 5 /fb

Diphoton + Jets + ME_T

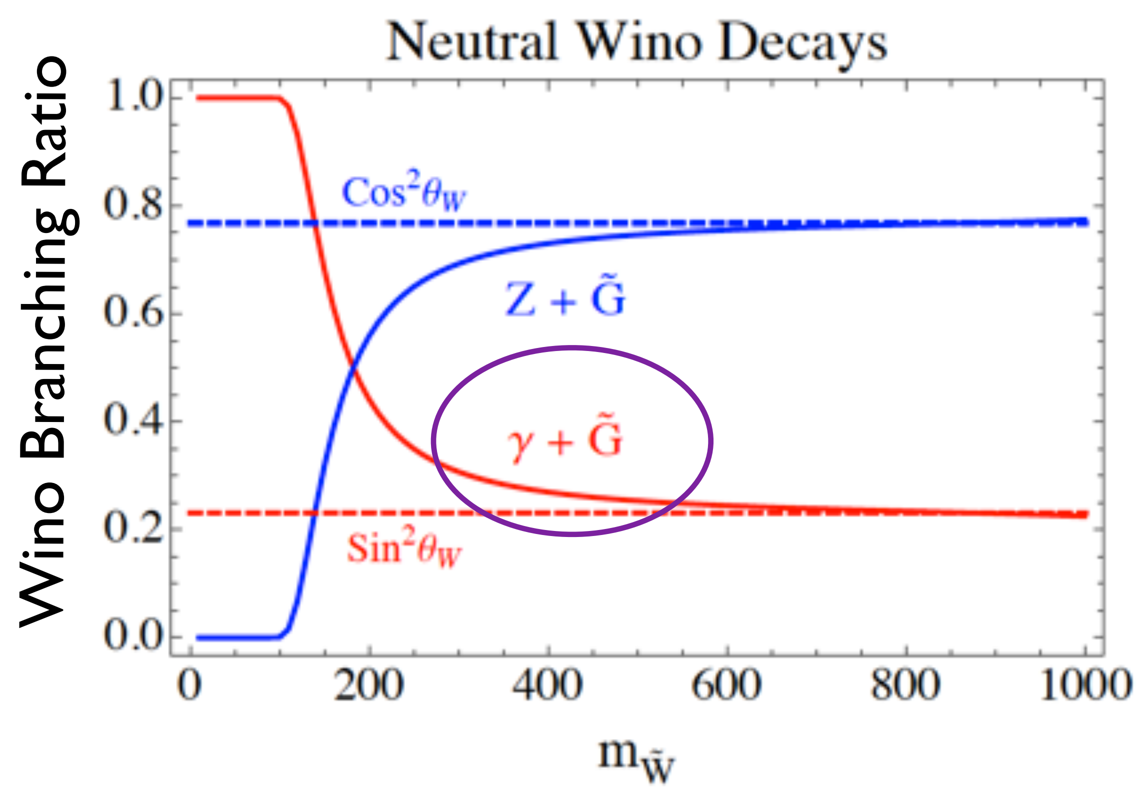




- At the LHC strong production is expected to dominate.
  - This results in decay chains providing jets, ending in the NLSP and LSP.
  - R parity conservation ⇒ 2 binos ⇒ two photons + missing E_T from gravitinos
  - Jetty signal, but number of jets can vary, depending on initial production of gluinos or squarks, and their relative masses.
- Diphoton + ME_T SM backgrounds are small

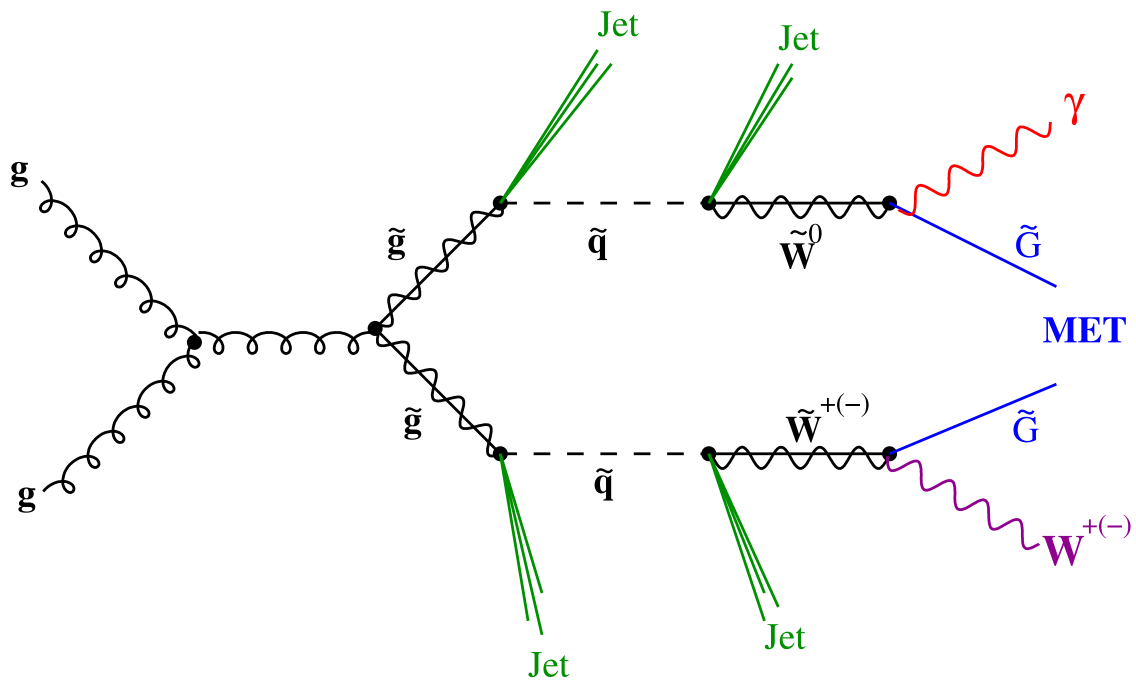
But this is not all...

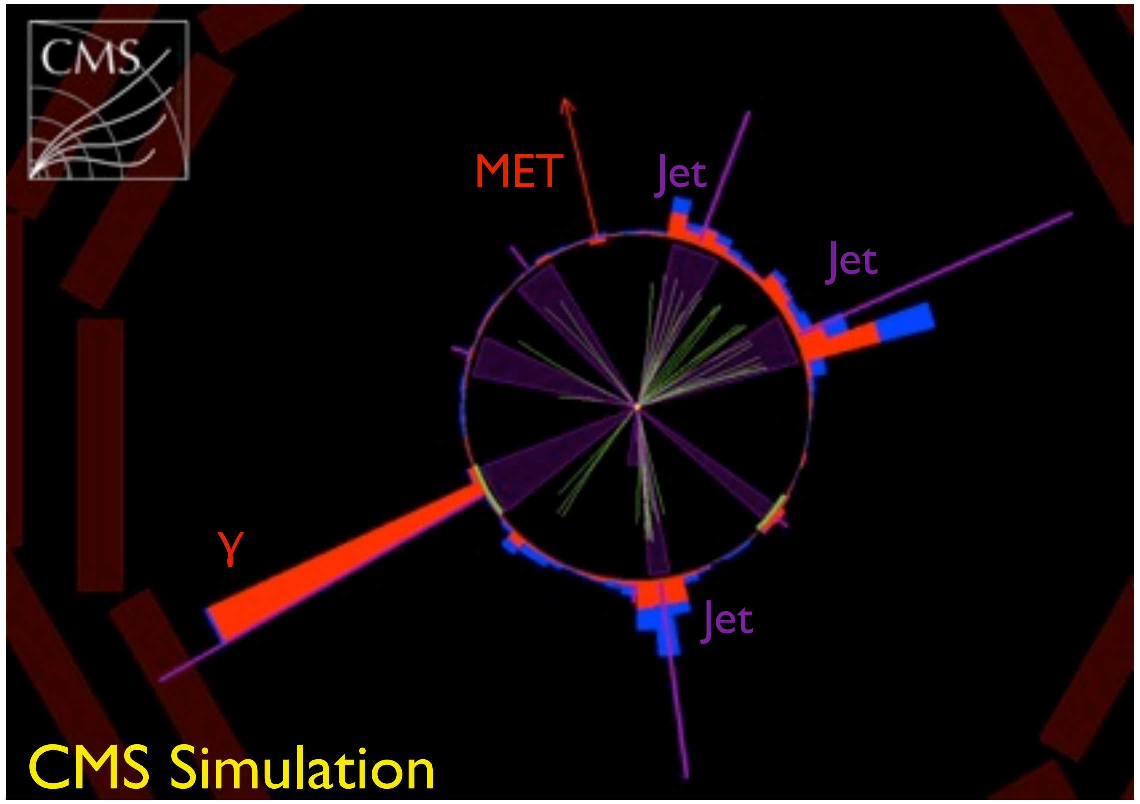
- Although not dominant, wino-like neutralino NLSP's have a fair shot at decaying to photons as well:



- Here a diphoton search would not be ideal
- Instead we search for at least one photon, some jets and ME_T

Photon + Jets + ME_T





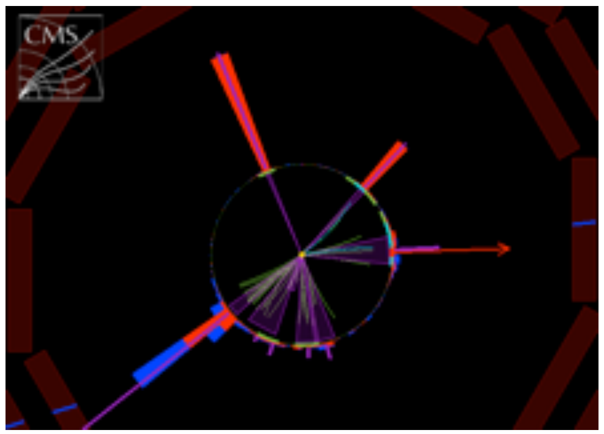
- Wino-like neutralino/chargino co-NLSP.
    - Branching ratio favors EW bosons over photons -- search for at least one photon with several jets. (though this is inclusive I will be calling this the "single photon" search)
    - SM backgrounds are larger, suppress by increasing energy thresholds and requiring more jets.
- CMS first to extend SUSY photon based searches to winos!

(Di)photon + Jet(s) + ME_T Searches

- Should be noted that as the mass of the gravitino increases, so does the NLSP lifetime.
- The searches I will now discuss assume prompt neutralino decay
- To learn about CMS's "long lived" searches stay tuned to Jie Chen's talk this afternoon!
- Until then, we will discuss CMS's "single" and diphoton search results
  - Both searches have results from the full 2011 CMS dataset!
  - http://cdsweb.cern.ch/record/1436111

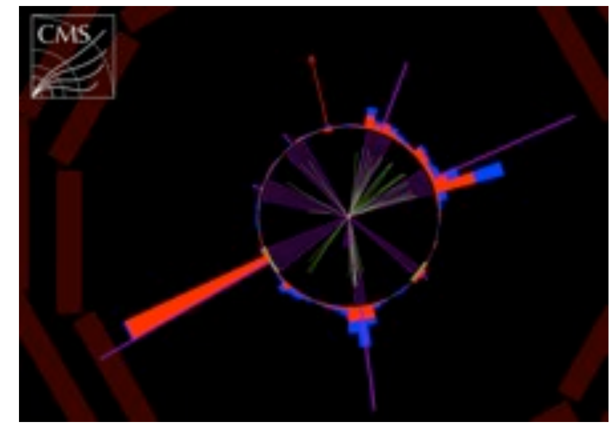
Candidate Selection

Diphoton



- At least two candidate photons
- Leading photon p_T>40 GeV
- Trailing photon p_T>25 GeV
- both photons in barrel ($|\eta|<1.4$)
- At least 1 Jet, p_T>30 GeV, $|\eta|<2.6$

Single Photon



- At least one candidate photon
- photon p_T > 80 GeV, in barrel
- H_T > 450 GeV*
- NJets $\geq$ 2, $|\eta|<2.6$

* H_T is the scalar sum of transverse energies of the photon, and the jets with p_T>30 GeV, $|\eta|<2.6$ that have ΔR>0.3 from the photon or an isolated lepton

Backgrounds

- Dominant backgrounds estimated from the data, minor irreducible backgrounds from MC:
  - "Non Intrinsic ME_T" backgrounds -- ME_T acquired through mis-reconstruction & resolution effects.
    - i.e. QCD, where highly EM rich jets become "fake" photons.
    - Measure from data in orthogonal samples selected to as closely as possible mimic the hadronic environment of the candidate sample
  - "Intrinsic ME_T" backgrounds -- those with actual ME_T which enter into the sample via electron mis-id as a photon, etc.
    - i.e. EWK backgrounds like Wgamma, W+jet where $W \rightarrow e\nu$
    - Measure from data, use measured $e \rightarrow \gamma$ fake rate to normalize.
  - A third class, smaller than the other two, enters into the single photon search. ISR/FSR can produce real photons and have real MET, this must be determined from MC

Larger

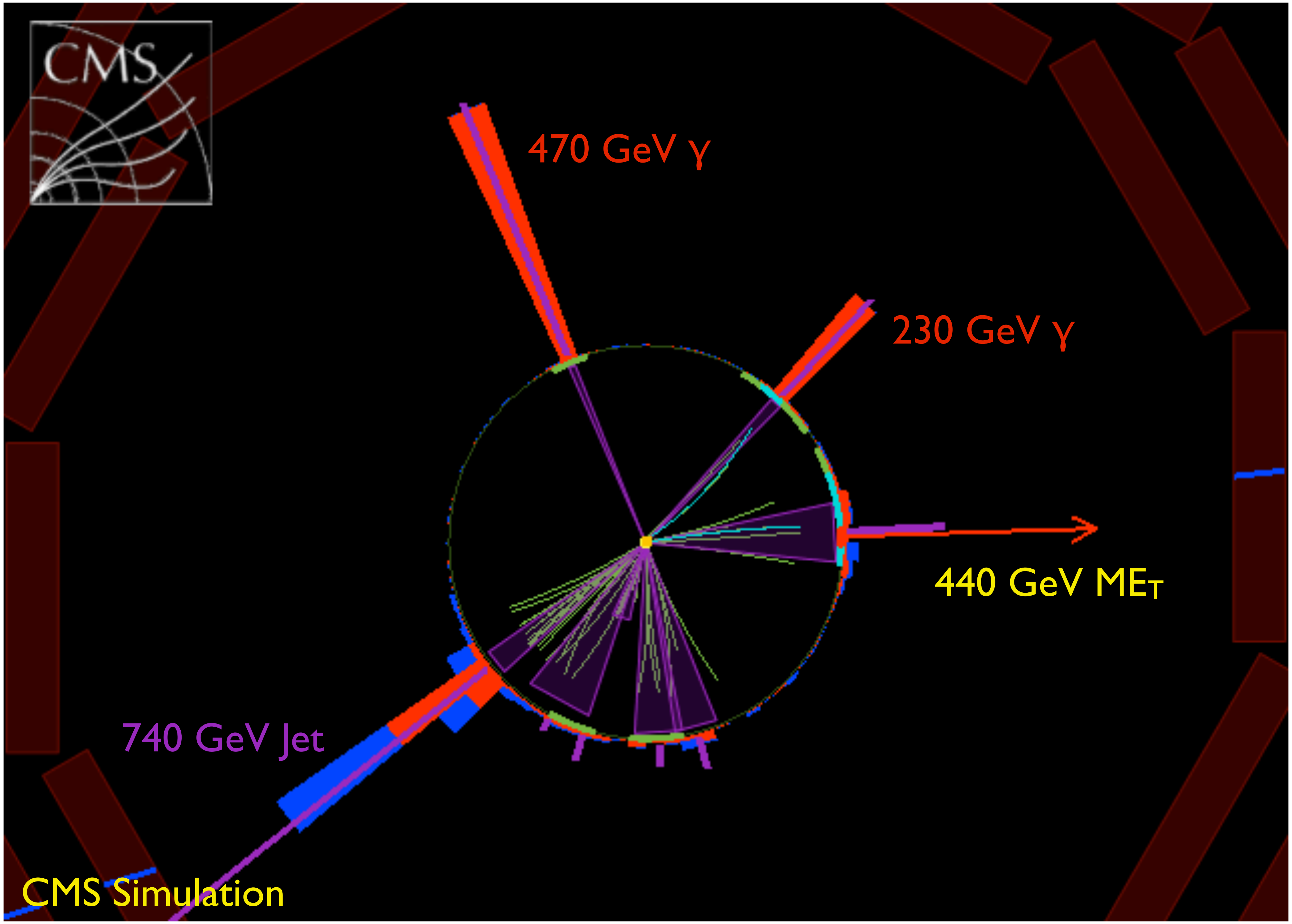
Smaller

- Finally with candidates and backgrounds in hand, look for evidence of an excess at high ME_T

Event Types

- We begin with requiring one or more EM objects, which are used in either the candidate selection or for background estimates.
  - We use shower shape and the energy sum in a hollow cone around the EM object to differentiate between candidate photons and "fake" photons.
    - Candidate photons are required to have a narrow shower shape, with energy within a hollow cone ($\Delta R=0.3$) summed between the tracker, Ecal and Hcal less than 6 GeV (called the "isolation sum"). ($\Delta R^2=\Delta\eta^2+\Delta\varphi^2$)
      - Isolation sums are compensated for pile-up based on the measured transverse energy density of each event.
    - "Fake" photons invert the shower shape or isolation sum requirement
      - In both cases only up to a point however -- the trigger imposes limit on the shower shape, and we limit the isolation sum to 20 GeV. We do not want our fake photons to be grossly different from our candidates.
    - Both photons and "fake" photons require a veto on hits in the pixel tracker.
      - An electron is defined as a photon with pixel tracker hits required

Diphoton Search Specifics



A simulated m_{gluino}=1200 GeV, m_{squark}=1250 GeV, m_{bino}=225 GeV signal event

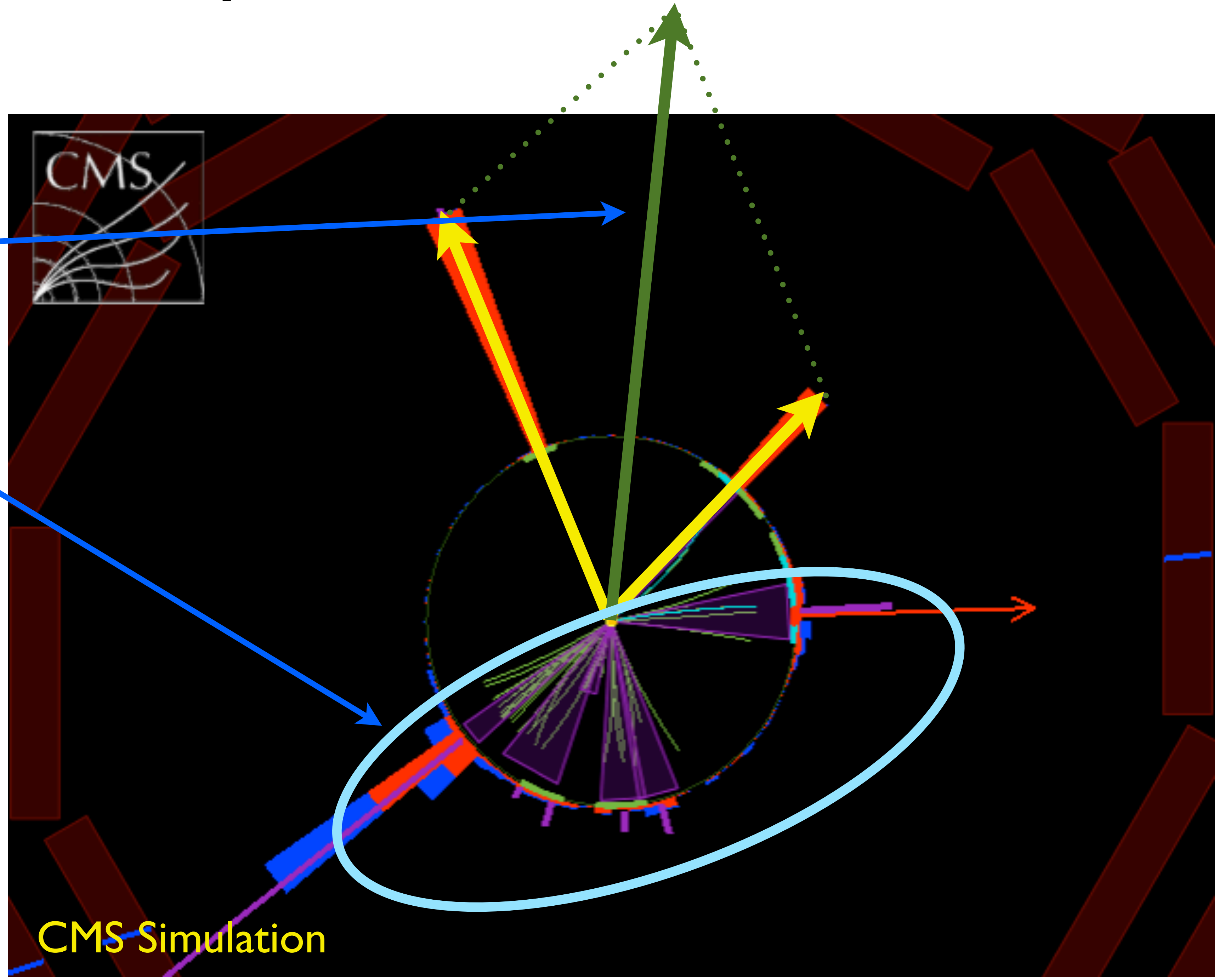
Diphoton Non Intrinsic ME_T Background

- Resolution effects and instrumental mis-measurement can create ME_T in the hadronic environment
  - Dominant background -- thanks to plentiful EM enriched QCD dijets
- Our goal is to find an orthogonal sample which mimics the hadronic environment of our candidate sample.
- We measure the ME_T shape due to this background from a sample of di-"fake" photons.
  - We also use the ME_T shape from $Z\rightarrow ee$ events for a systematic estimate.
- Because we are selecting less isolated objects we can have slightly worse ME_T resolution.
- We correct for this effect by re-weighting the di-"fake" events by the ratio of the distributions of the vector sums of the two EM objects (diphoton or di-"fake").
  - Corresponds to recoil of the hadronic system
- queue the cartoon:

Di-EM p_T cartoon

The pT of the diphoton system

acts as a proxy for the hadronic system

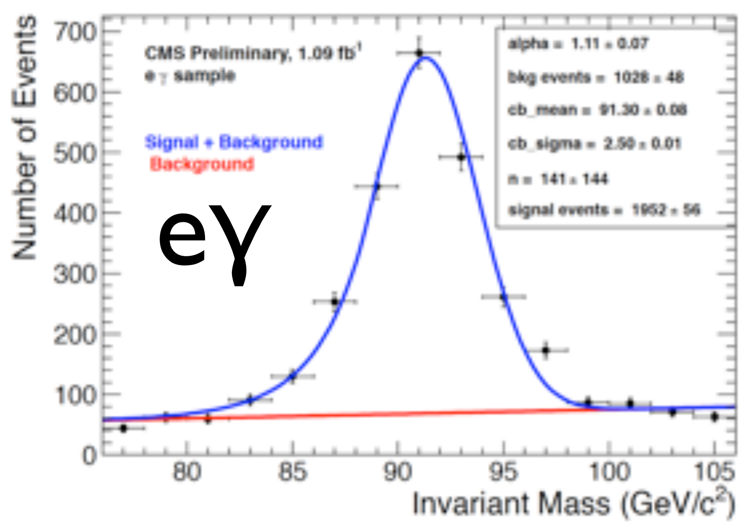


- Reweighting factors from the di-fake sample shape to diphoton sample shape are very small -- low single digit %

- We then normalize the reweighted di-"fake" sample to the diphoton candidate sample in the region where diphoton ME_T < 20 GeV.

Diphoton Intrinsic ME_T Background

- This subdominant background comes from EW processes where an electron is mistaken for a photon. (at low ME_T around 1%, but at high ME_T closer to 10% of the Non-Intrinsic MET bkg.)
- We measure this from our data as well, measuring the $e \rightarrow \gamma$ fake rate, then applying that to the ME_T background measured from a sample of electron-photon events.
- We measure the rate that an electron is mis-reconstructed as a photon from fits in invariant mass at the Z peak in di-electron events and electron-photon events.



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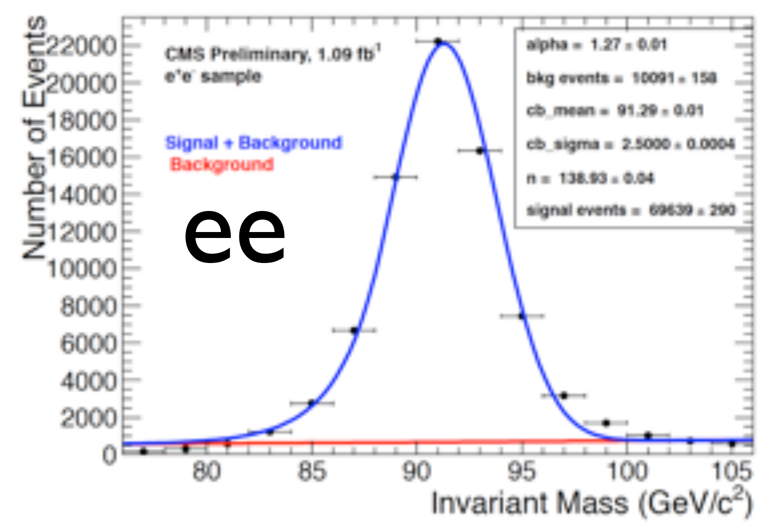
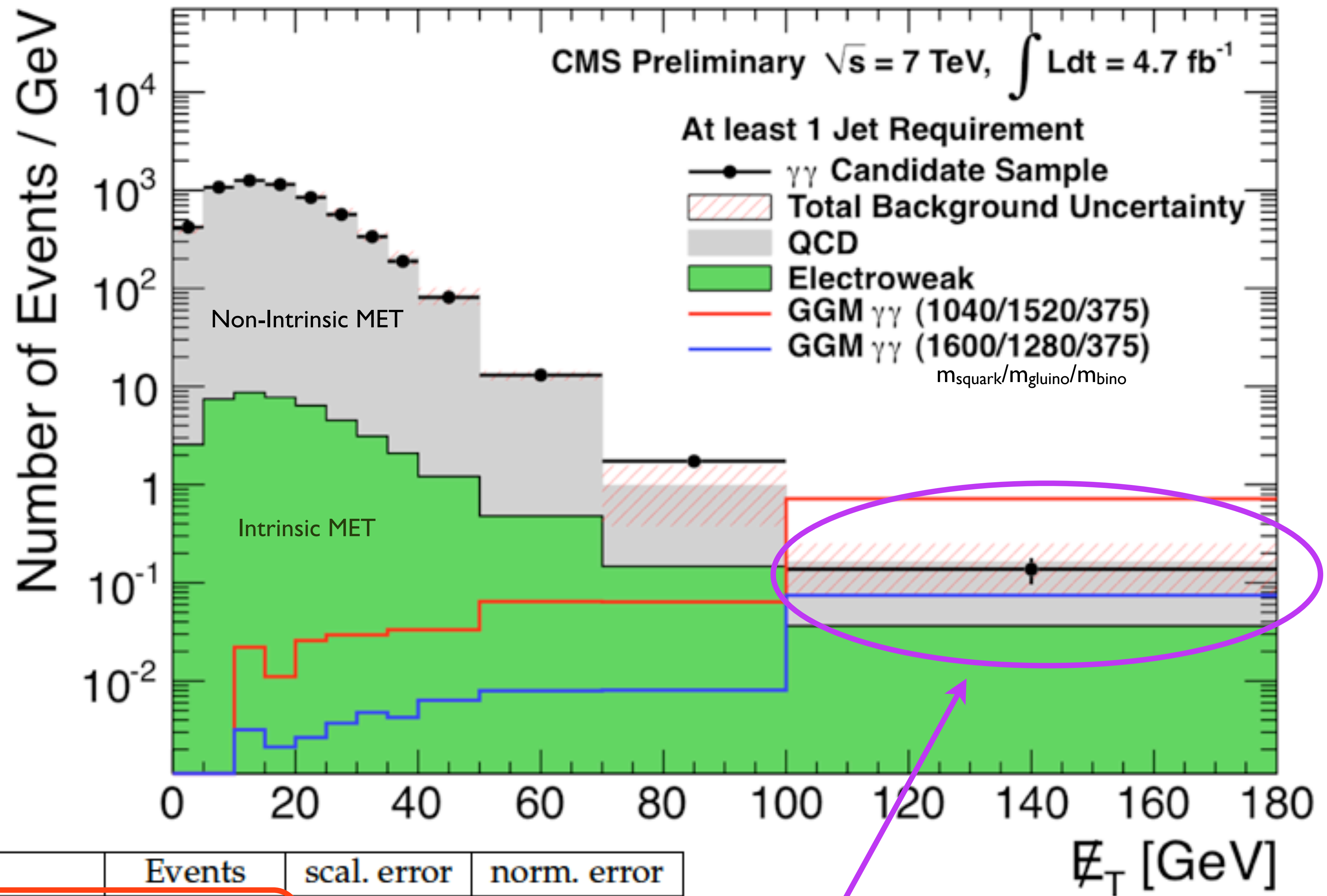


$\simeq 1.5\%$

  - Different shape assumptions tried, difference becomes a systematic.

- This measured $e\gamma$ fake rate is used to normalize the ME_T shape obtained from the full electron-photon sample to the diphoton candidate ME_T distribution.

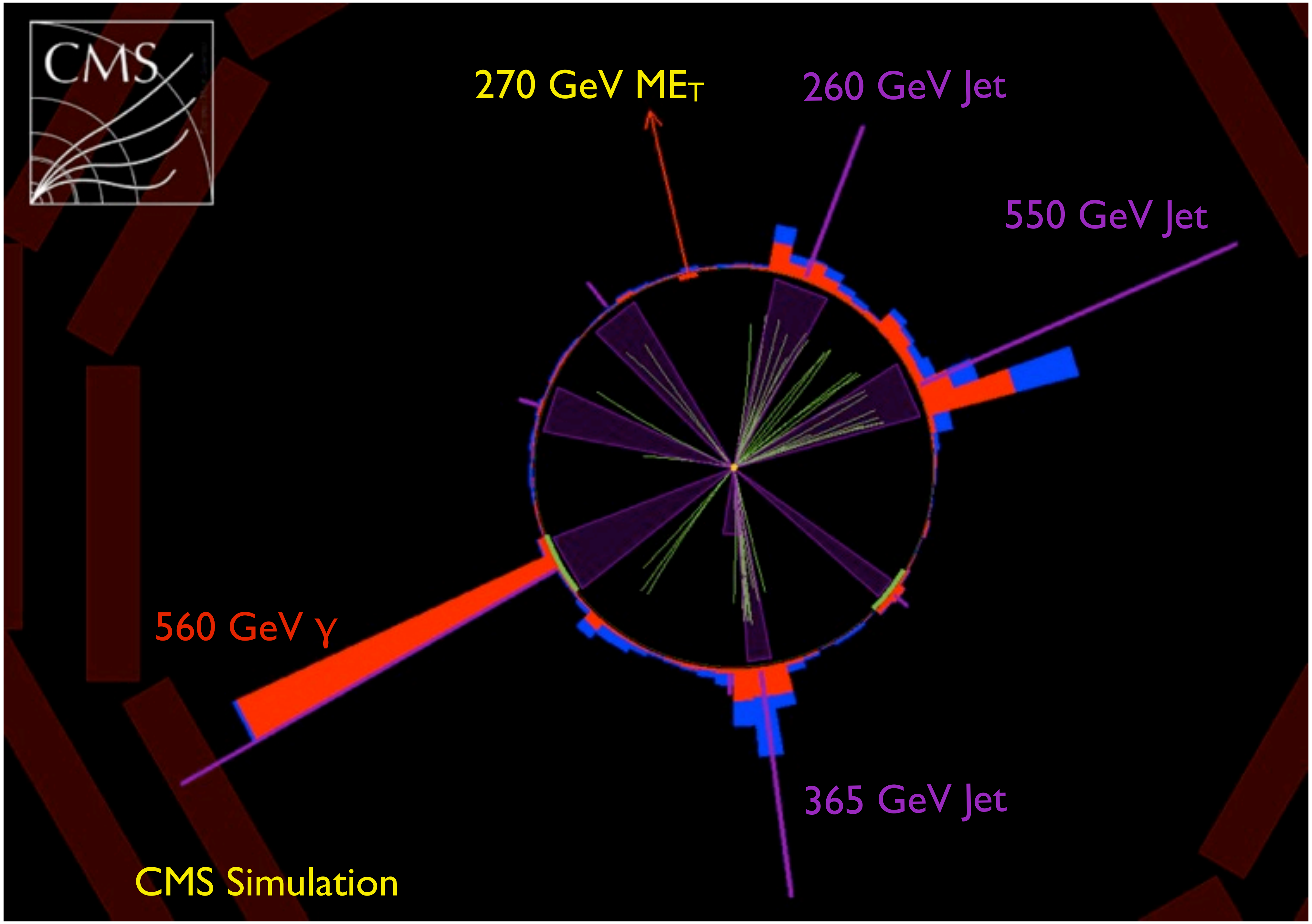
Putting this together -- The Measurement!



Type	Events	scal. error	norm. error
$\gamma\gamma$ candidates	11		
ff QCD background	10.1 ± 4.2	± 0.3	± 0.03
ee QCD background	14.7 ± 3.1	± 0.1	± 0.03
EWK background	2.9 ± 1.0	± 0.0	± 0.9
Total background (ff)	13.0 ± 4.3		

Good agreement between diphotons and background estimates !

Single Photon Search Specifics



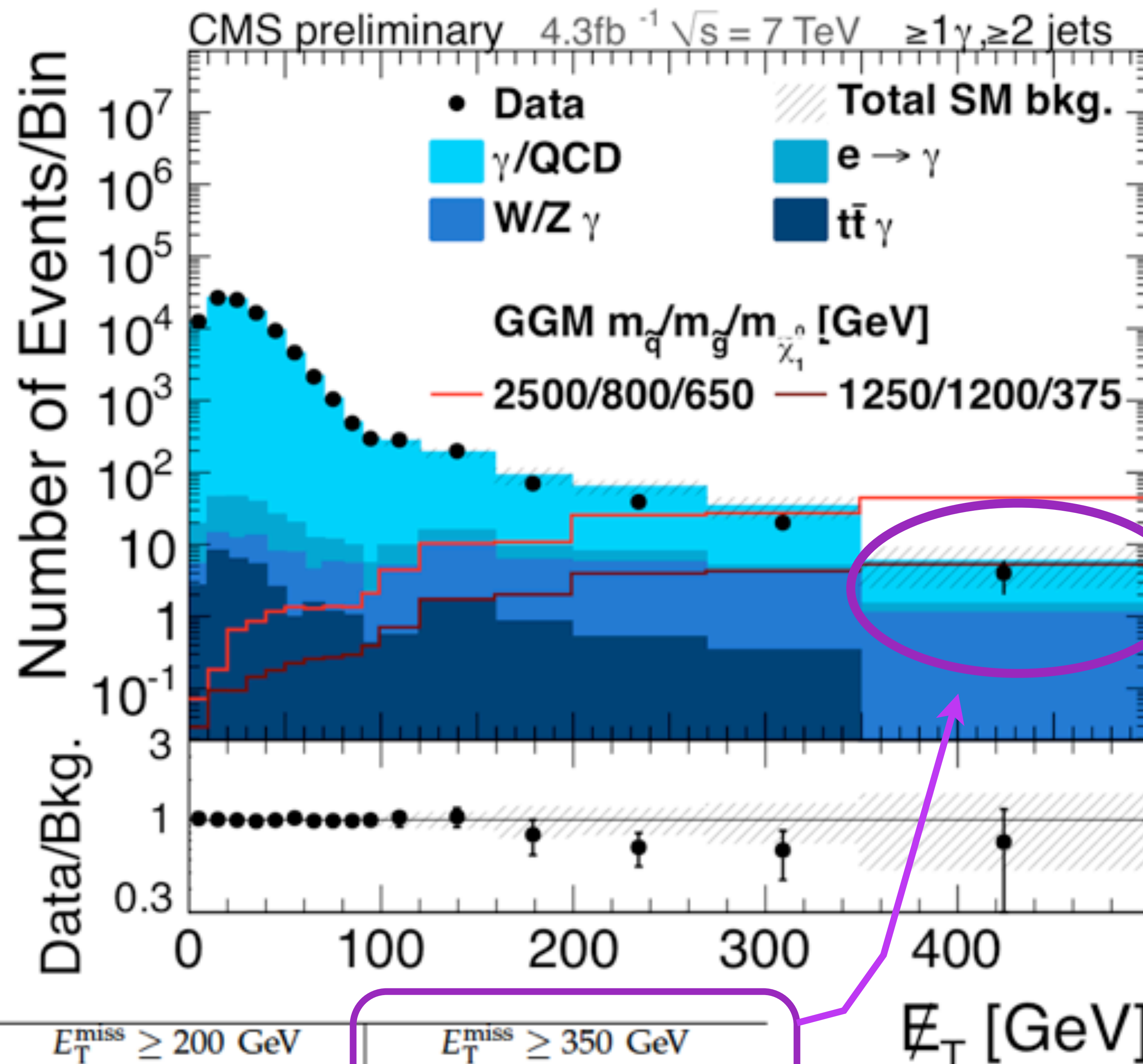
A simulated m_{gluino}=1200 GeV, m_{squark}=1250 GeV, m_{bino}=225 GeV signal event

"Single" Photon Background Estimates

- Dominant background from multijets where jet "fakes" a photon, and QCD photon + jets. Non-intrinsic MET
- Analogous to the diphoton analysis, use the "fake" photon + jet sample
  - Reweight by photon p_T, using ratio in shapes between candidates and fakes in ME_T<100 GeV region. (Here shape and scaling magnitude are the same step)
    - Individual shape ratios for jet multiplicities =2 jets and ≥ 3 jets
- Intrinsic ME_T also analogous to diphoton -- electron-jet sample scaled by fake rate.
  - For photon p_T>80 GeV fake rate is determined to be 0.6 ± 0.25%
- Irreducible background due to ISR/FSR estimated from W+Jets and ttbar MC
  - Very small, and take 100% systematic

"Single" Photon Measurement

Observations in excellent agreement with background predictions



≥ 1γ, ≥ 2 jets	$E_T^{miss} \geq 100$ GeV	(stat.)	(syst.)	$E_T^{miss} \geq 200$ GeV	(stat.)	(syst.)	$E_T^{miss} \geq 350$ GeV	(stat.)	(syst.)
QCD (from data)	607.7	±46.7	±54.0	90.7	±16.4	±9.9	6.8	±4.1	±0.8
$e \to \gamma$ (from data)	17.2	±0.3	±7.2	3.5	±0.2	±1.5	0.4	±0.01	±0.2
FSR/ISR(W, Z)	27.6	±3.2	±27.6	10.4	±2.0	±10.4	1.6	±0.8	±1.6
FSR/ISR($t\bar{t}$)	3.8	±0.9	±3.8	0.8	±0.4	±0.8	< 0.01	< 0.01	< 0.01
total SM estimate	656.4	±46.9	±92.7	105.5	±16.5	±22.6	8.7	±4.2	±2.5
Data	615			63			4		

GGM Interpretation

- In both the single and diphoton searches our candidates are in good agreement with our background estimates -- we observe no excess.
- We then provide CLs limits in the context of GGM SUSY by performing counting experiments (individually within the diphoton and single photon analyses) in 6 bins at high ME_T.
  - 2-D scans performed across pairs of model parameters (masses)
    - squark vs gluino mass (with neutralino mass at 375 GeV)
    - gluino vs neutralino (bino) mass (squarks at 2500 GeV)
  - Squarks assumed ~degenerate
  - All other masses decoupled (3500 GeV)
  - Prospino cross sections and PDF uncertainties according to PDF4LHC

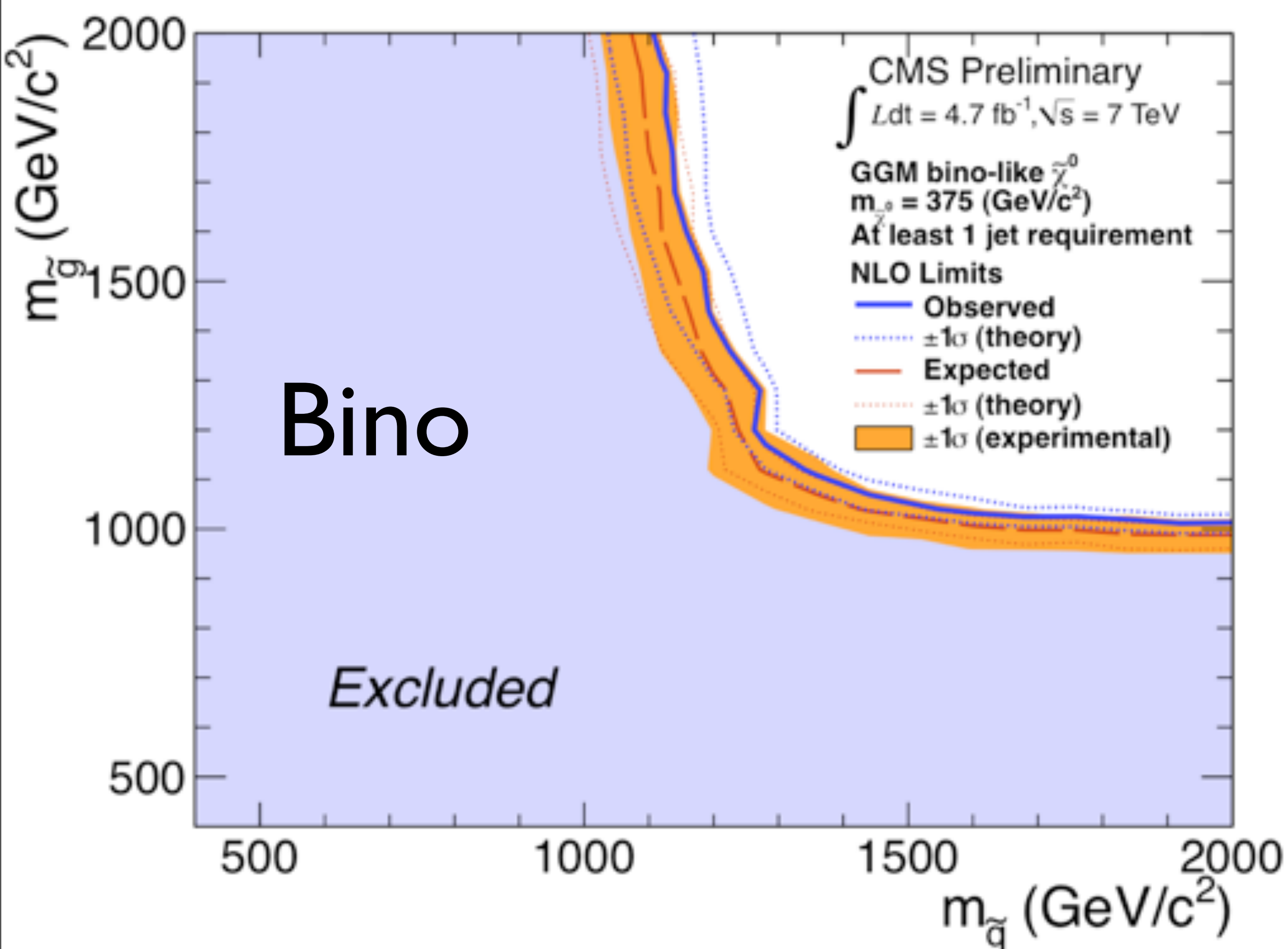
Systematics included in Limit Setting

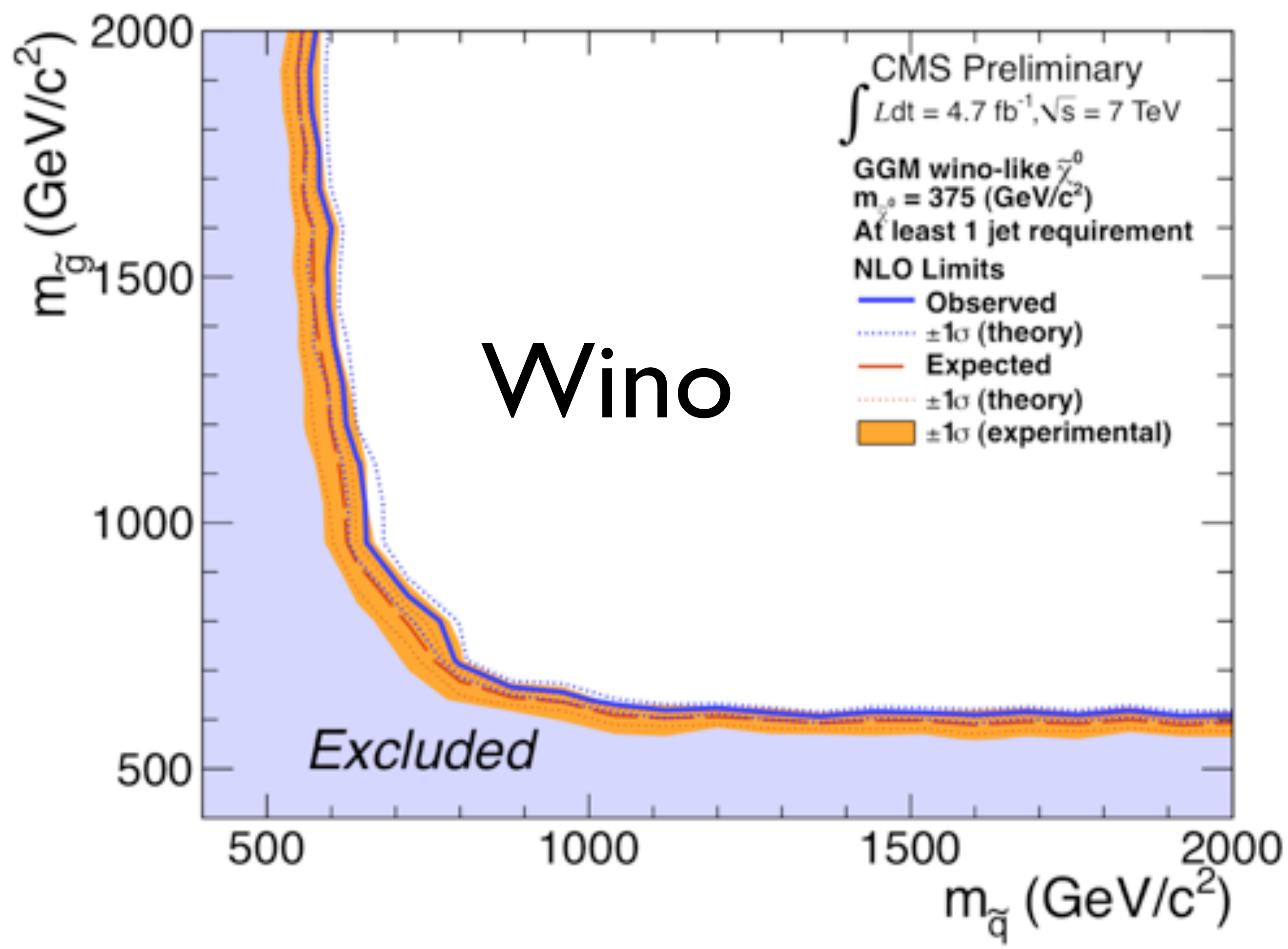
Systematic	Value (%)
PDF uncertainty on xsec	4-66
Renormalization scale (MC)	4-28
PDF uncertainty to acceptance	0.1-9
Integrated Luminosity	4.5
Photon Data/MC scale	2.6
Non-Intrinsic ME_T bkg. estimate	45
Intrinsic ME_T bkg. estimate	34
Pile-up on photon ID	2.4
Jet energy scale on acceptance	2.0

- Separated this into theory, data/MC scales, and measurement uncertainties
- PDF and renormalization scale uncertainties are small for lower masses in scans but become large when squark and gluino masses reach toward 2 TeV
- The large % uncertainties for the background estimates are at highest ME_T, where statistics are low...

Diphoton in squark/gluino plane

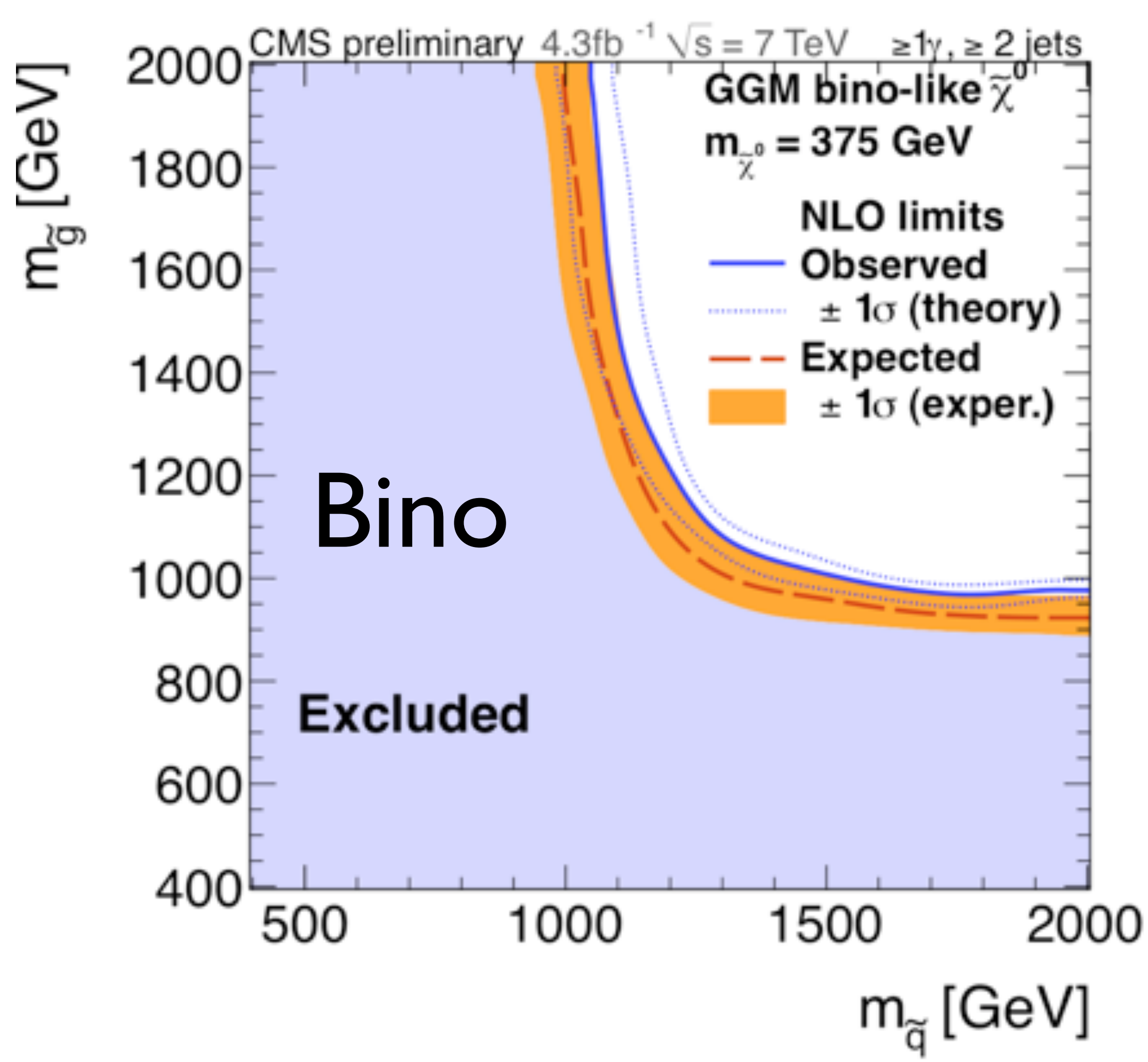
- Neutralino mass fixed at 375 GeV (i.e. for "bino-like" wino decoupled at 3.5TeV, "wino-like", bino decoupled at 3.5 TeV)
- Bino limit (at left) is most exclusive, Wino (right) less exclusive than single photon result

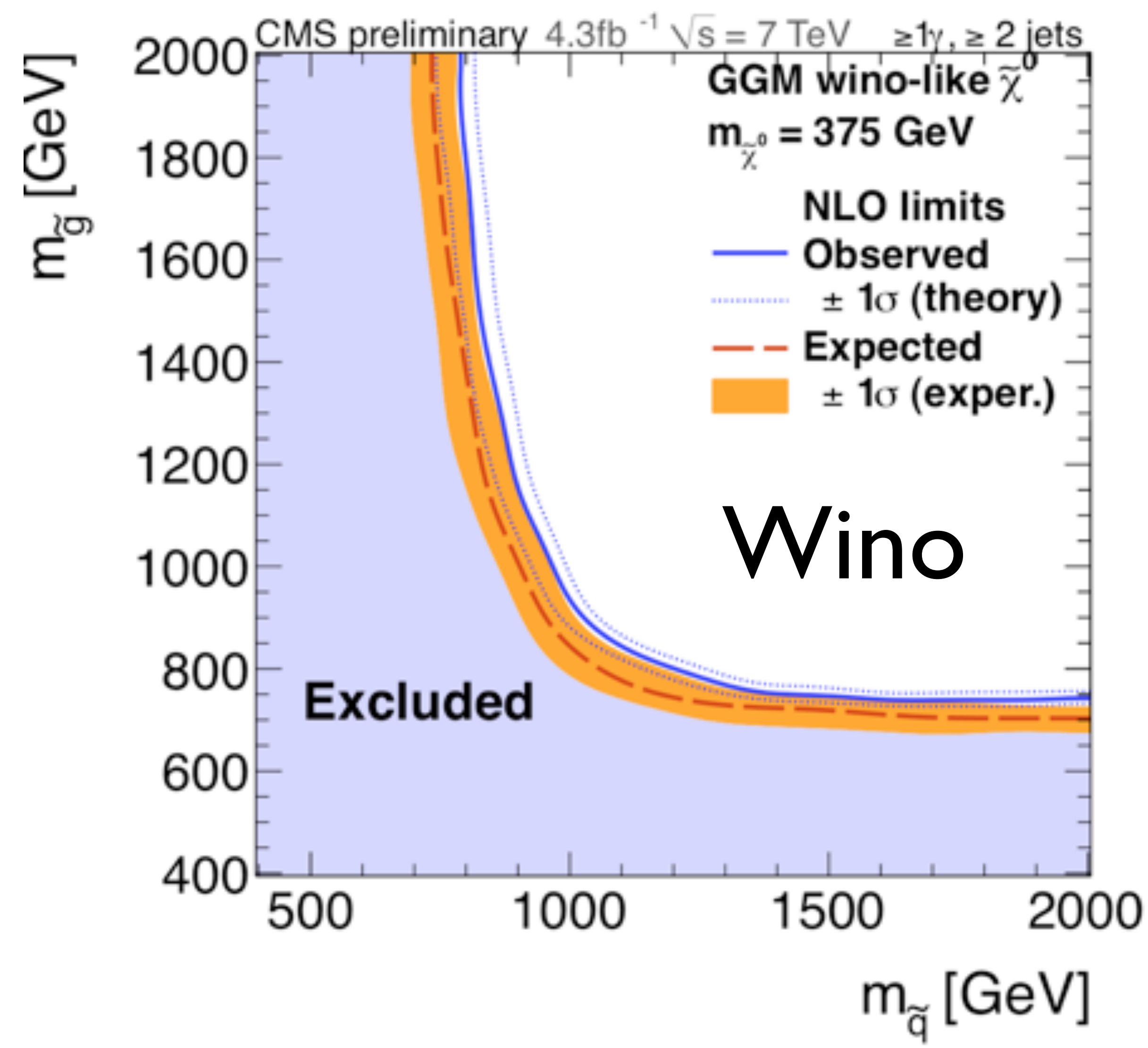




Single photon squark-gluino limits

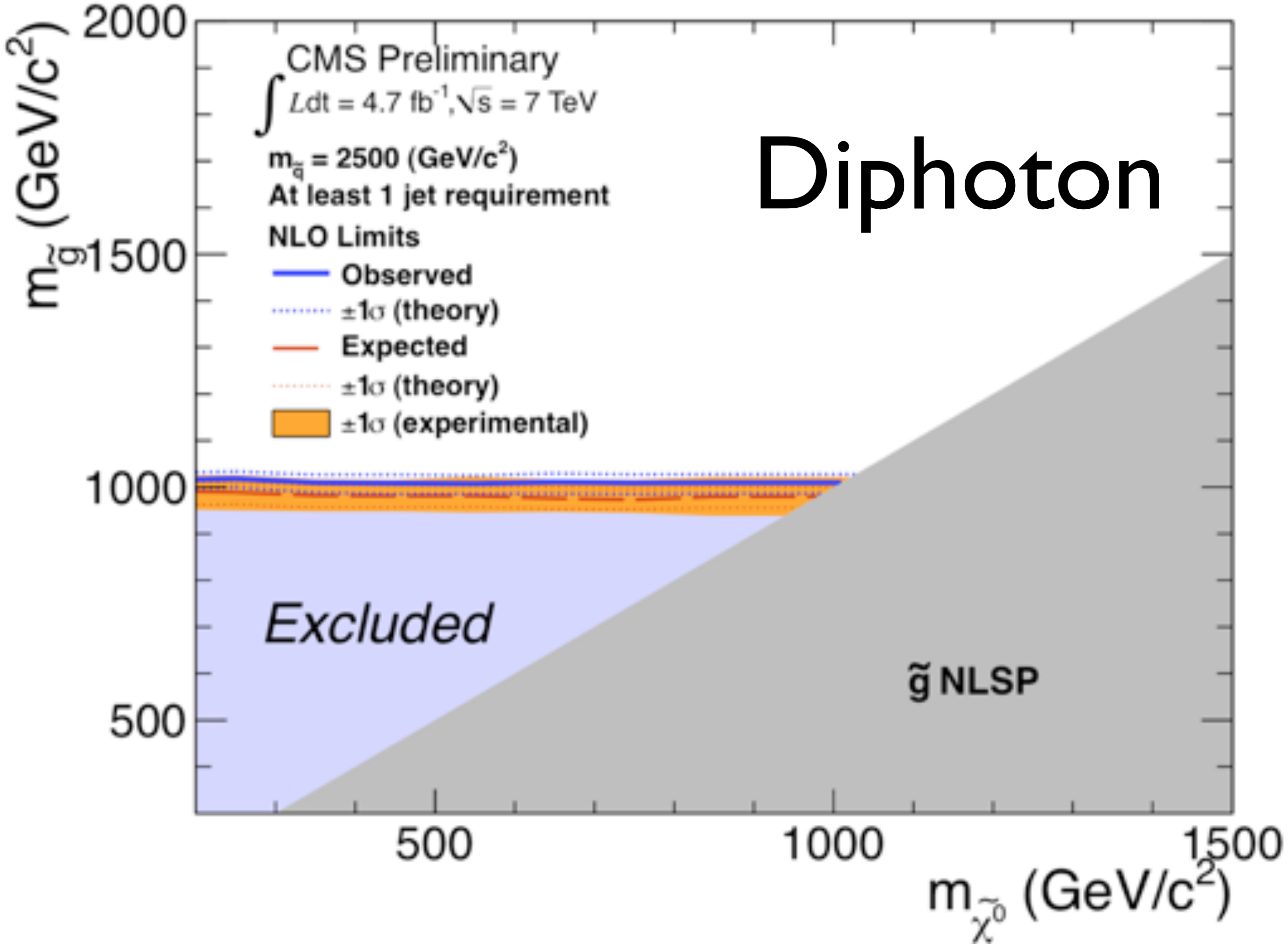
- Single Photon exclusion contours in squark/gluino plane. Neutralino again fixed at 375 GeV.
- Single photon provides best limits for Wino-like neutralino.

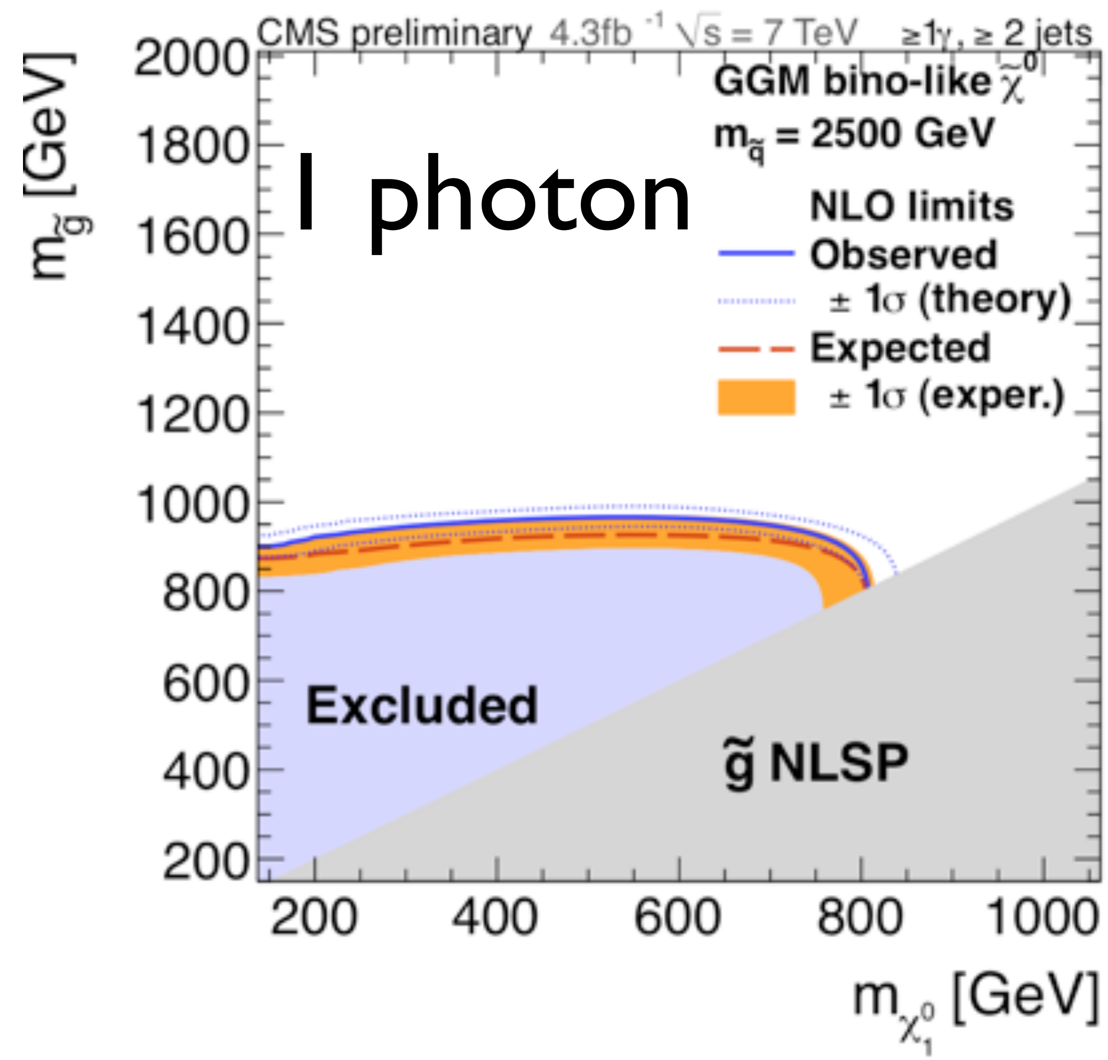




Both analyses, gluino-bino plane

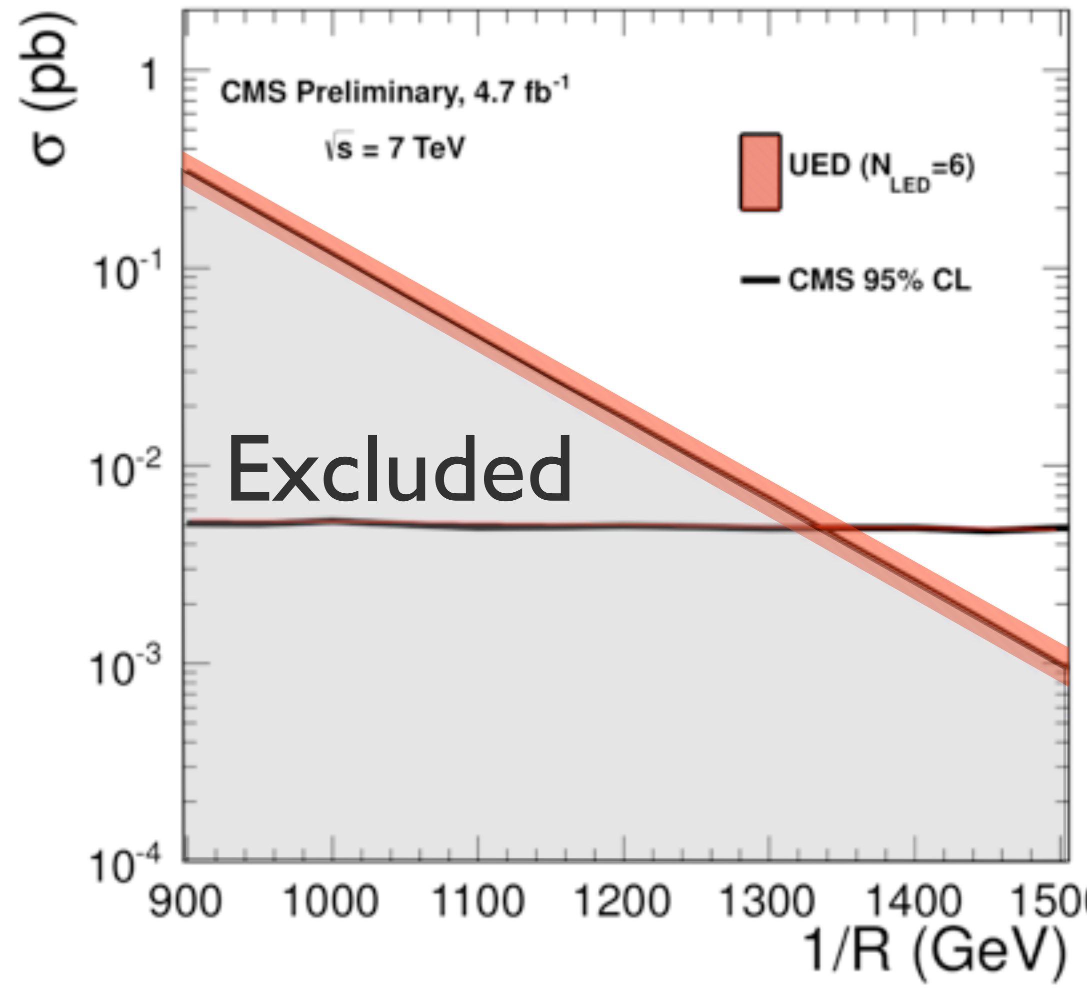
- Diphoton result at left is most exclusive
- Single photon result shows effects of H_T cut in contour curve.





Universal Extra Dimensions Interpretation

- One can construct similar event topologies as GGM SUSY through Universal Extra Dimensions
  - Kaluza-Klein excited states ("towers") are produced, at LHC predominantly through strong interactions
  - These excitations decay, producing particles and jets, not entirely unlike a SUSY cascade, leading down to the lightest Kaluza-Klein particle, in this case a photon.
  - The UED space is embedded a space with N Large Extra Dimensions (LEDs) where only a graviton may propagate.
  - The KK photon then decays gravitationally to a photon + graviton, which then results in ME_T.

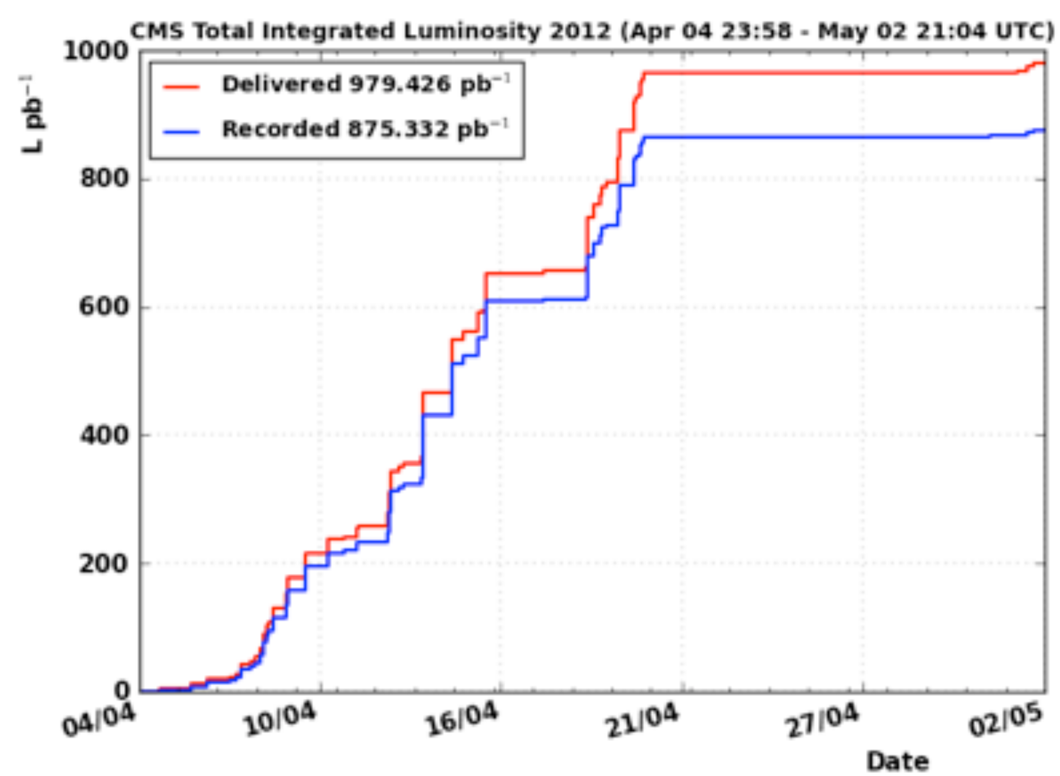


UED cross section upper limit for 6 Large Extra Dimensions. R is the radius of compactification, the UV cutoff, Λ, is ΛR=20, M_D, (N+1) dimensional Planck scale = 5 TeV, #KK excitation quark flavors = 5

1/R < 1335 GeV excluded

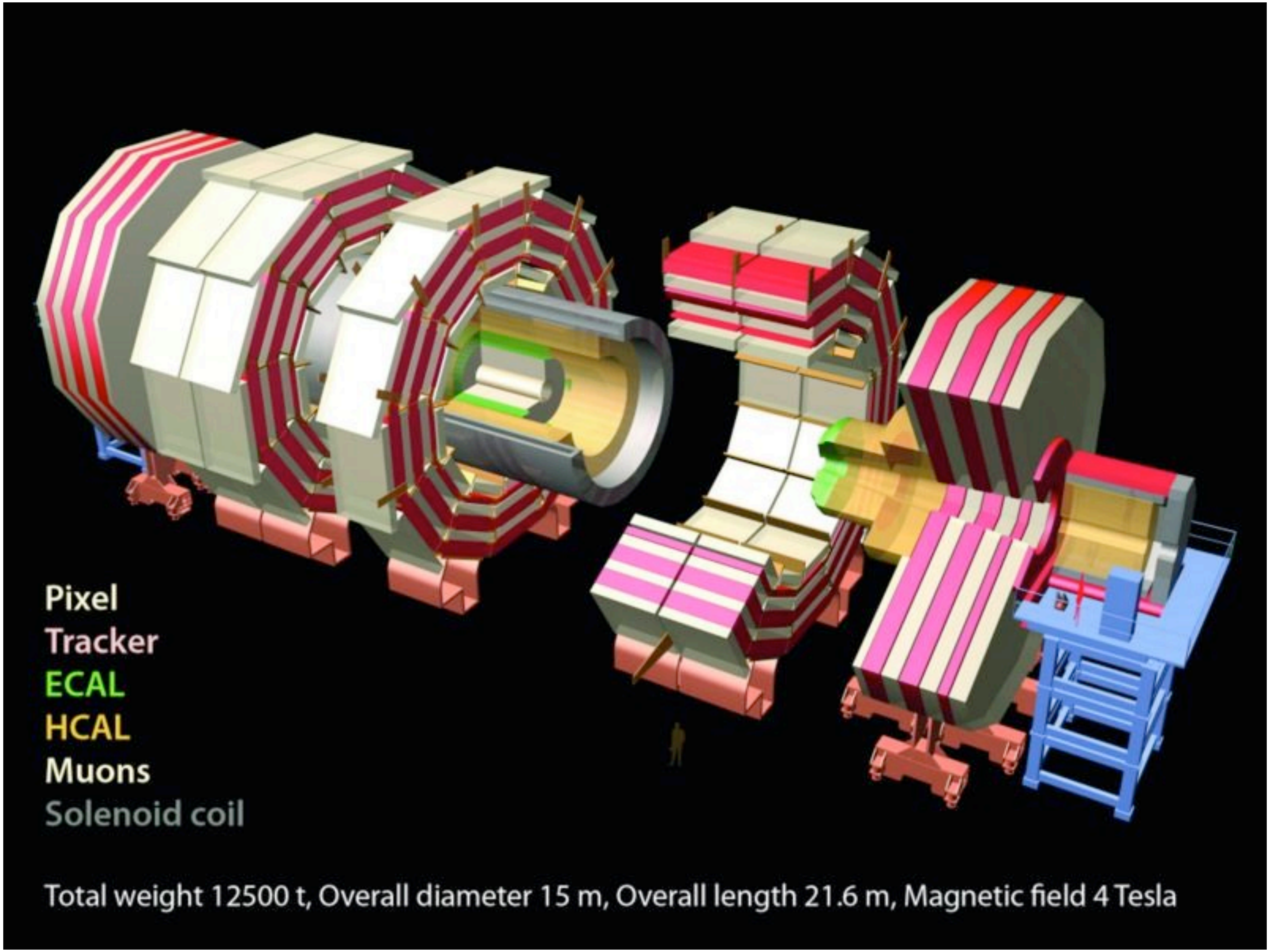
Summary

- We have seen the results of two CMS SUSY searches utilizing photons in the final state.
- No excess seen, and competitive limits in the context of GGM SUSY and Universal Extra Dimensions have been extracted.
- These results are currently being finalized and along with additional interpretation (Simplified Models and different planes in GGM mass space) will be headed for publication soon.
- The LHC has gotten off to an amazing start for 2012, already delivering close to 1/fb!
- We are hard at work analyzing this new data, and will soon show you what 8 TeV brings!



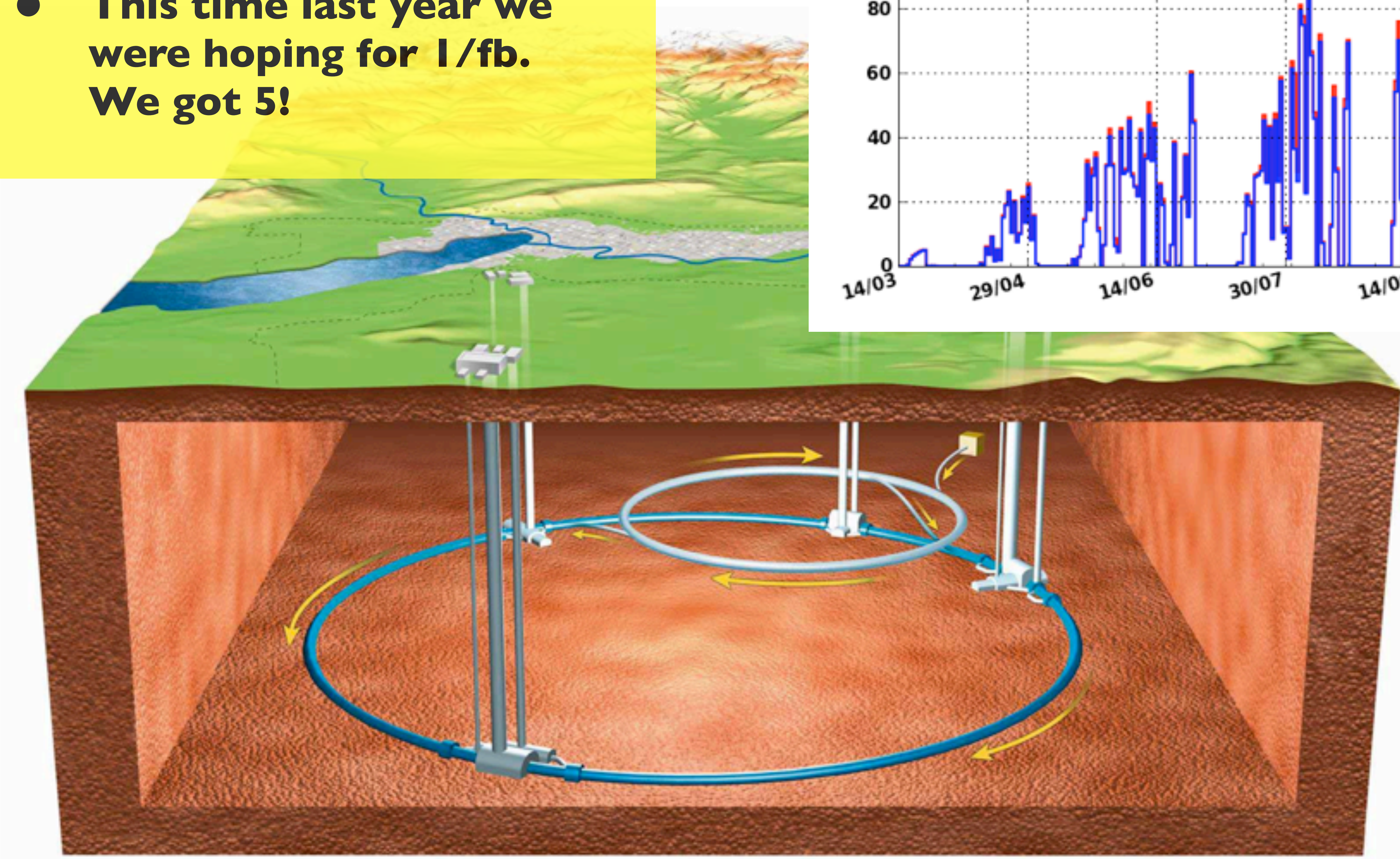
Backups

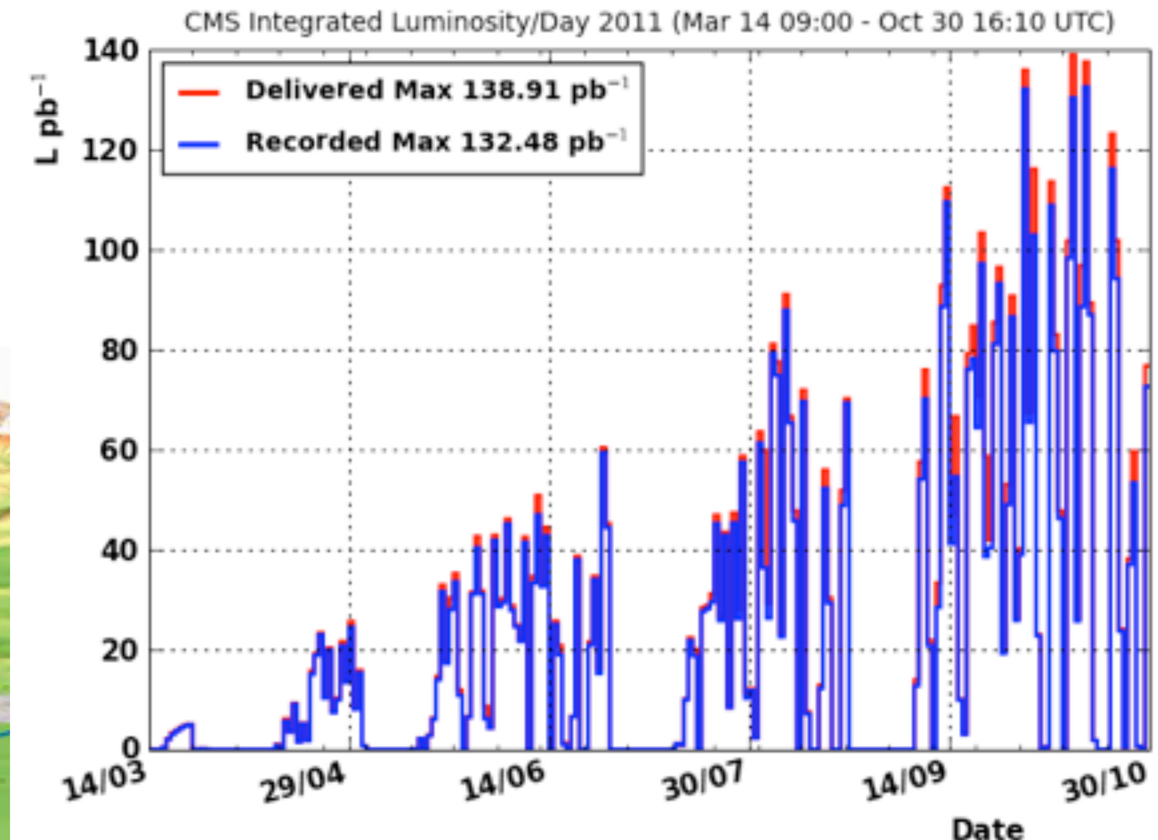
Compact Muon Solenoid



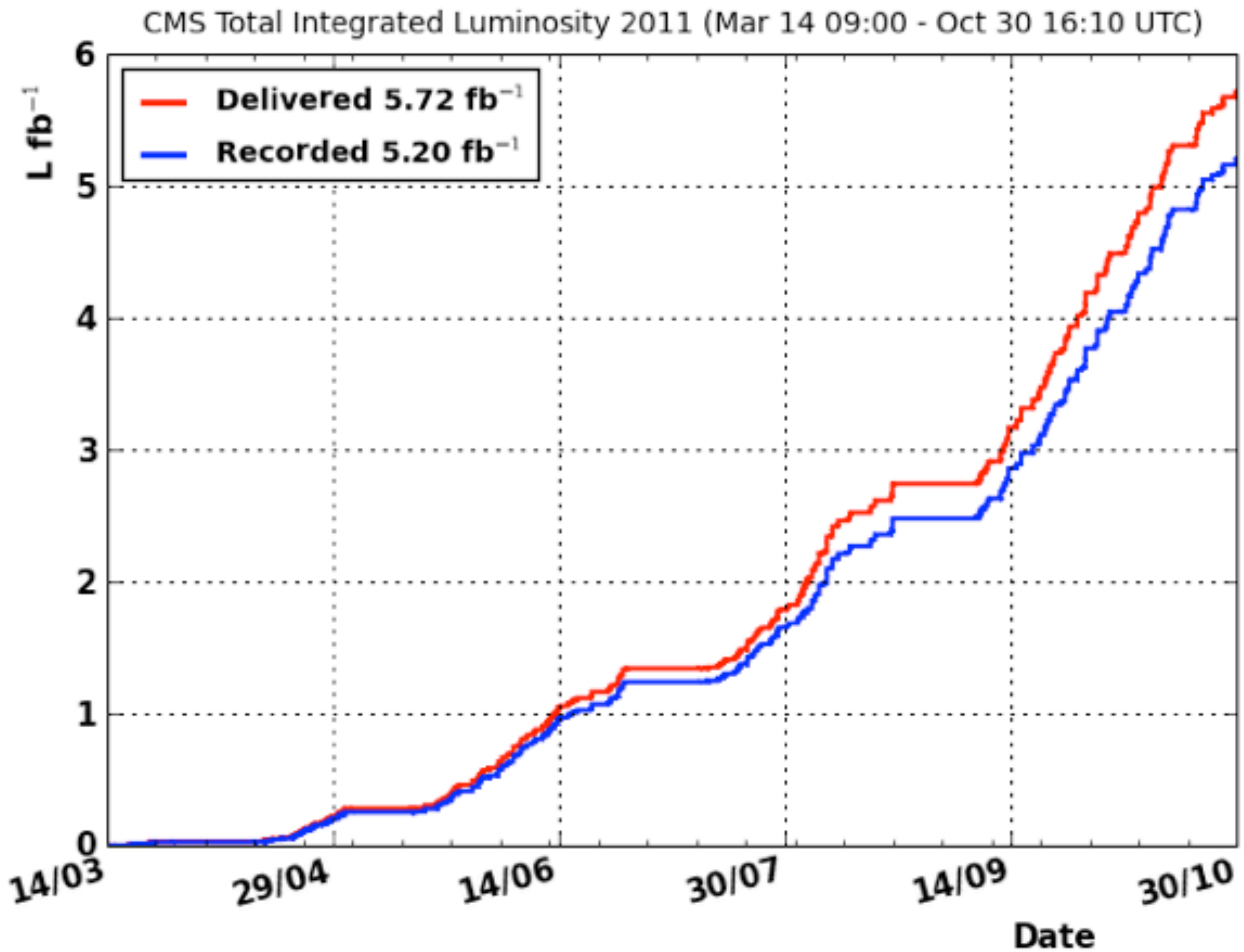
LHC 2011

- **This time last year we were hoping for 1/fb. We got 5!**



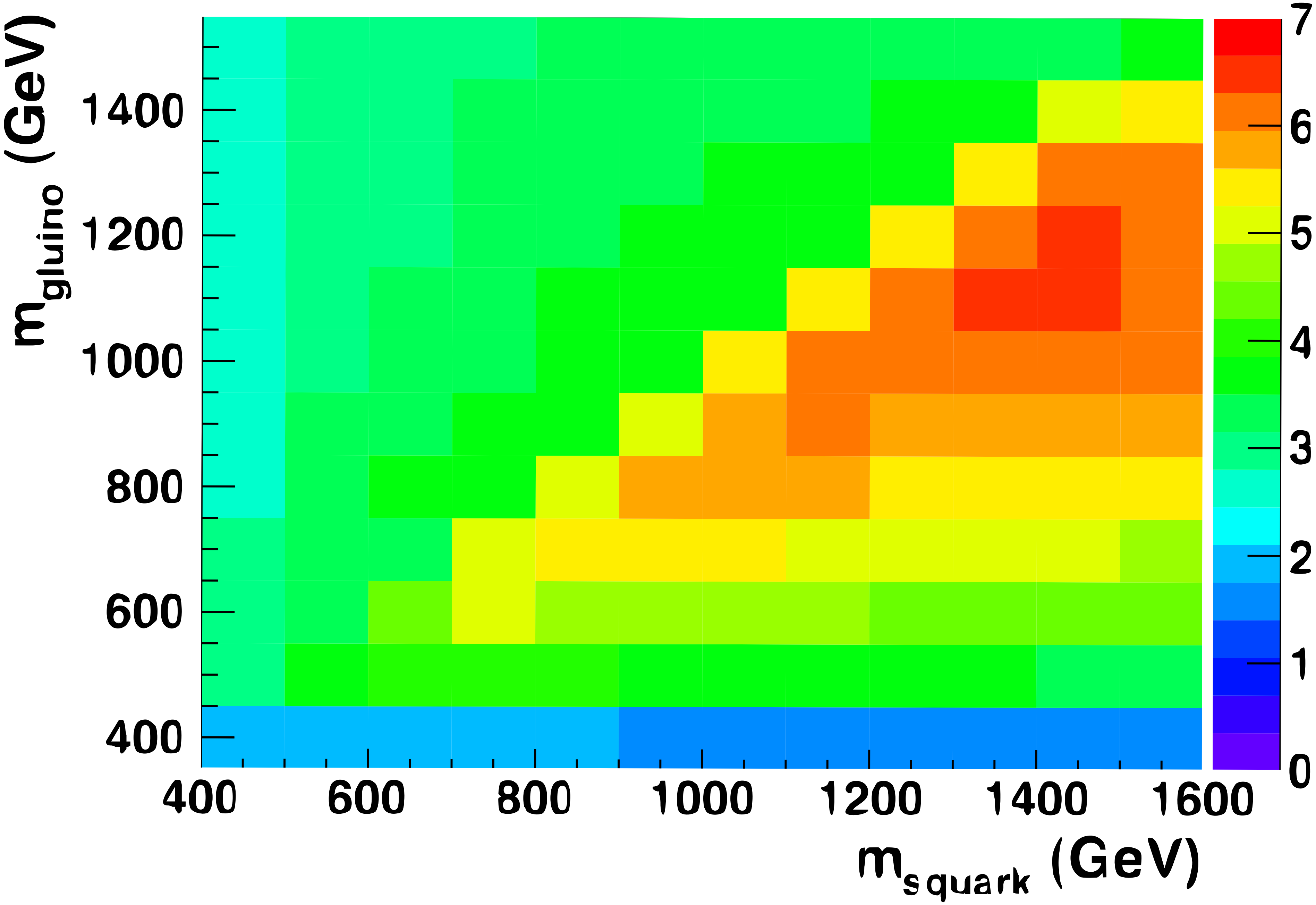


2011 Lumi



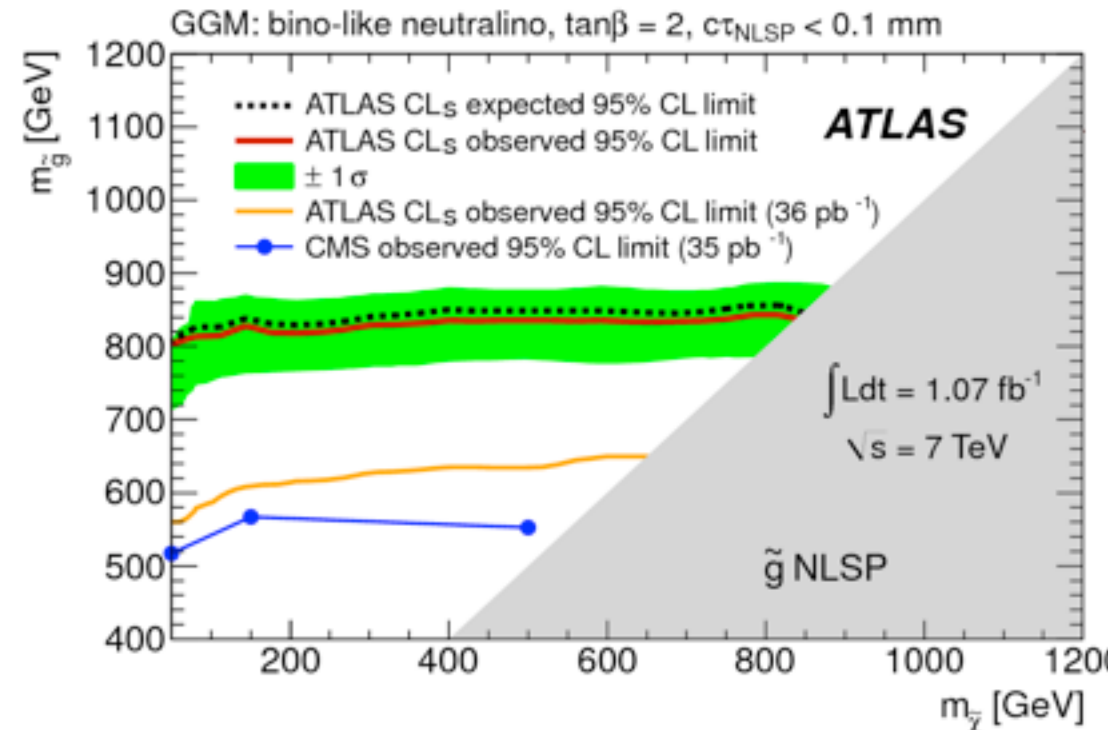
CMS Total Integrated Luminosity 2011 (Mar 14 09:00 - Oct 30 16:10 UTC)
Delivered 5.72 fb^{-1}
Recorded 5.20 fb^{-1}
L fb^{-1}
0
1
2
3
4
5
6
14/03
29/04
14/06
30/07
14/09
30/10
Date

Jets from MC

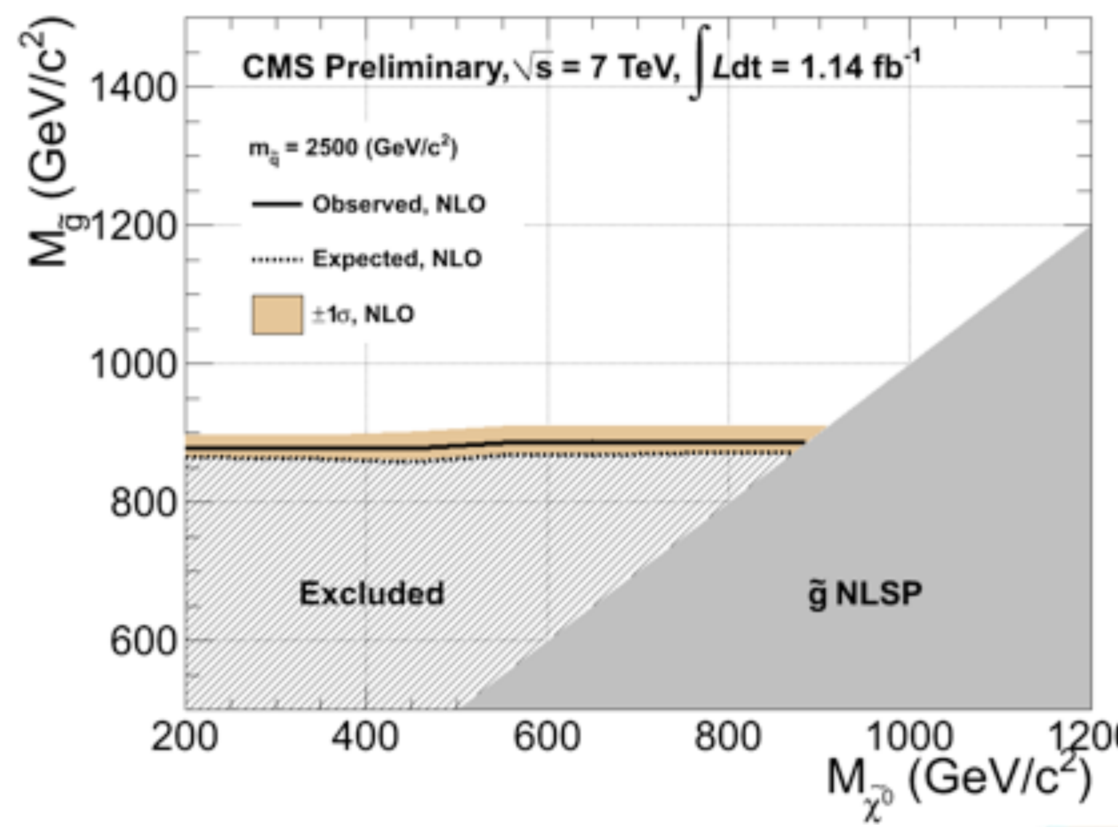


m_{gluino} (GeV)
1400
1200
1000
800
600
400
400
600
800
1000
1200
1400
1600
m_{squark} (GeV)
7
6
5
4
3
2
1
0

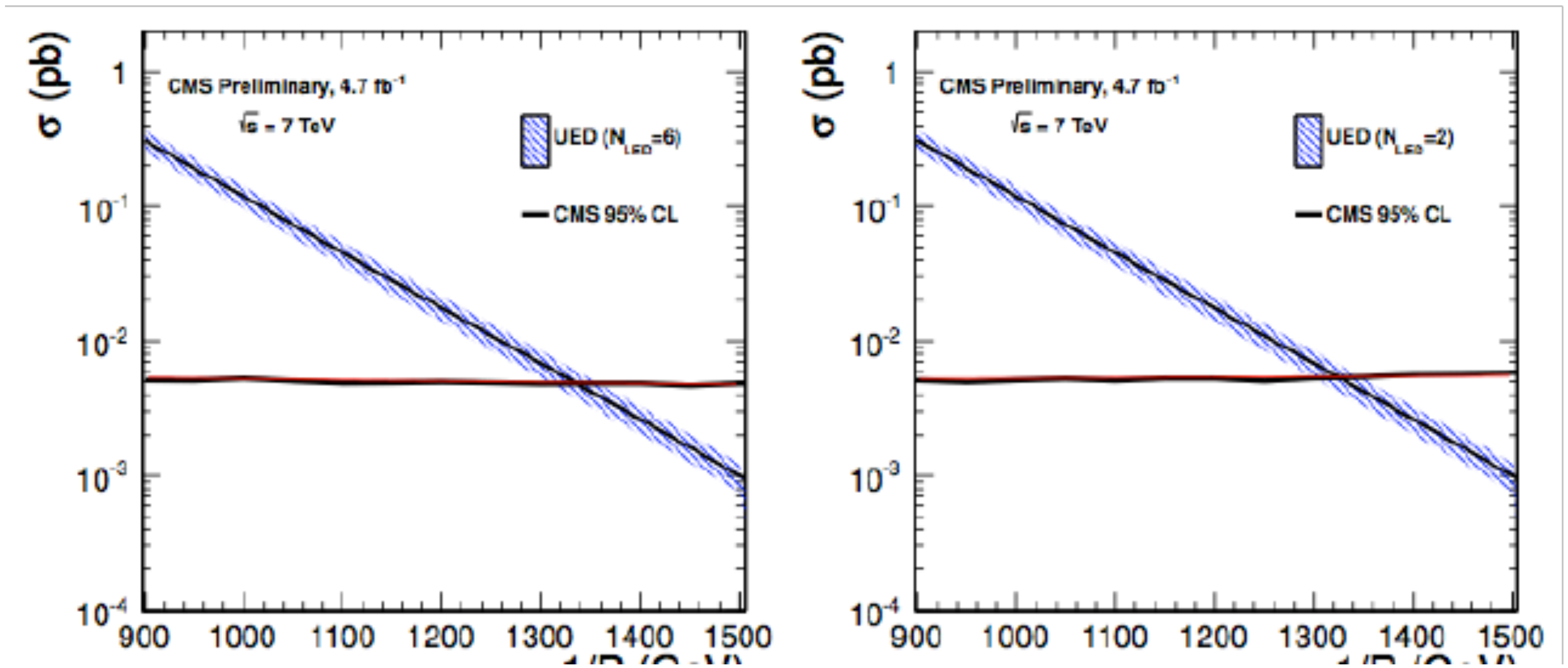
1/fb results



- ATLAS: PLB 710 (2012) 519 above,
- SUS-11-009 PAS below



UED results



- N_{LED}=6, (1/R<1335 GeV) excluded on the left, =2 on the right (1/R<1323 GeV excluded).