Characterization of new physics at the LHC - II

Sanjay Padhi

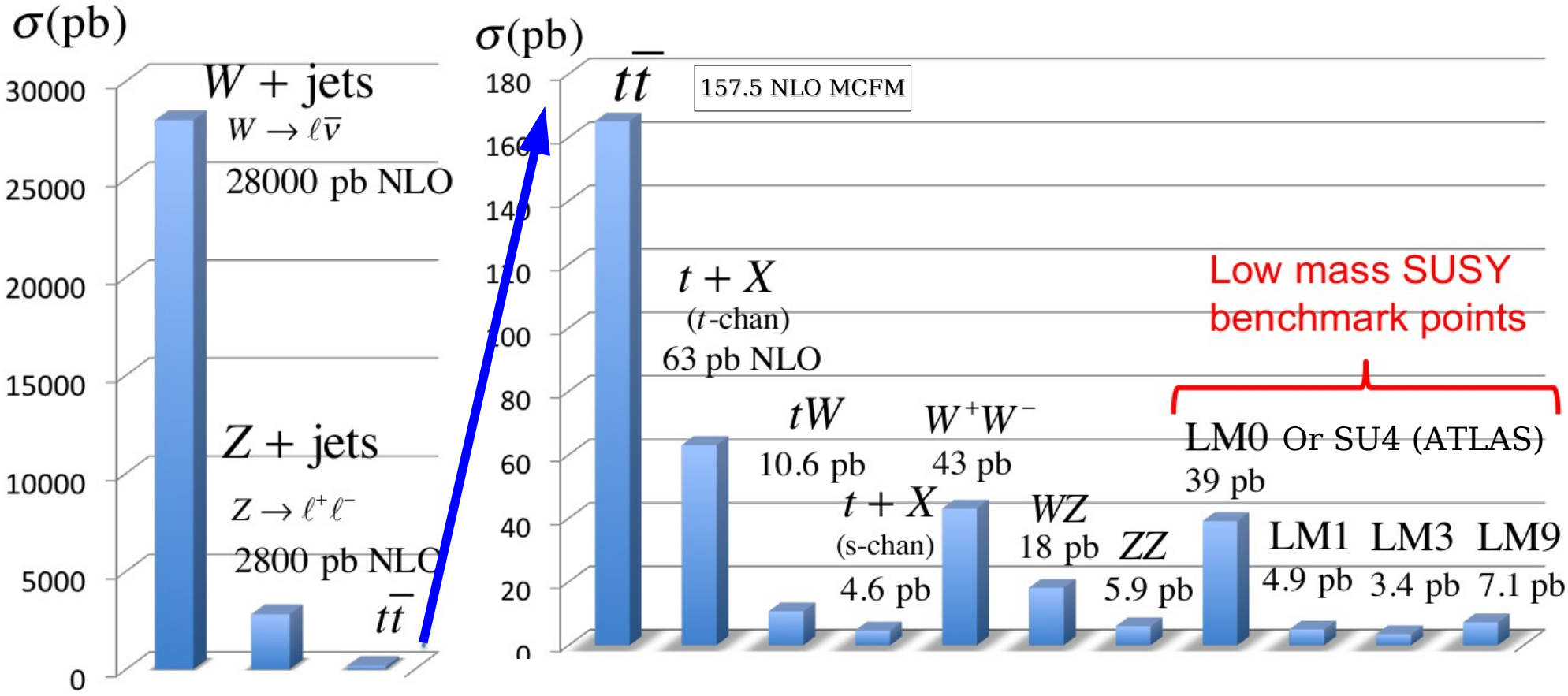
University of California, San Diego

Thanks to J. Incandela, P. Schuster, S. Somalwar, N. Toro, S. Thomas

Outline

- Introduction
- CMS Reference Analyses Structure
- Generic approaches used for data representation
  - mSUGRA/MSSM planes
- Physics interpretation of results
- Examples of Simplified Models for early searches
  - All hadronic searches
  - Photons + Jets + MET
  - Single and Multi-lepton searches
- Summary and Outlook

Introduction - A Tour of the cross sections @ 7 TeV



Latest news: ttbar cross section has been measured @ LHC (arXiv:1010.5994v1)

Several of the di-bosons (see later) and Single Top candidates have been seen

It is now time to focus on physics beyond the SM

- if no new physics is observed: represent the data in "model independent way"

Introduction

Main focus is to use a few selected topologies:

- which can provide a clear message of the physics scale we probe
- representation of data with maximum information needed for the theory community
- scope/prospects to generalize the search
- model-independent sensitivity
- characterization of a signal in case of enhancements

Disclaimer:

- Opinions expressed herein are my own
- What CMS will do with the 2010/11 data remains to be seen

CMS -SUSY Reference Analyses Structure

- Focus on robust and simple signatures (Reference Analyses)

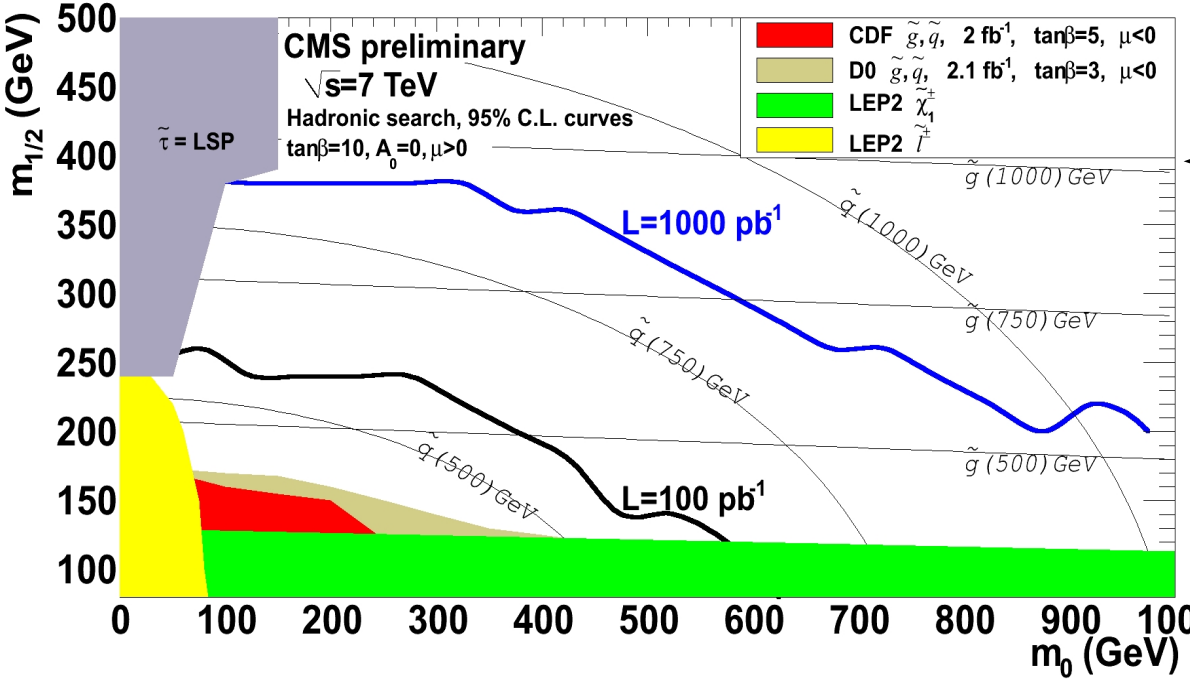
RA1/RA2	RA3	RA4	RA5	RA6	RA7
Jets + MET - inclusive - exclusive	Di-photon + MET	Single lepton + Jets + MET	Like-sign di-lepton + MET	Opposite-sign di-lepton + MET	Multi-lepton

- Signatures common to wide variety of models
- Use data-driven methods to estimate the Standard Model backgrounds
- Let Standard Model background and detector performance define searches
- Minimal set - also plan to add b-tags, top, taus in each analysis

Note: A more up-to date picture also includes photons + leptons + Jets/MET

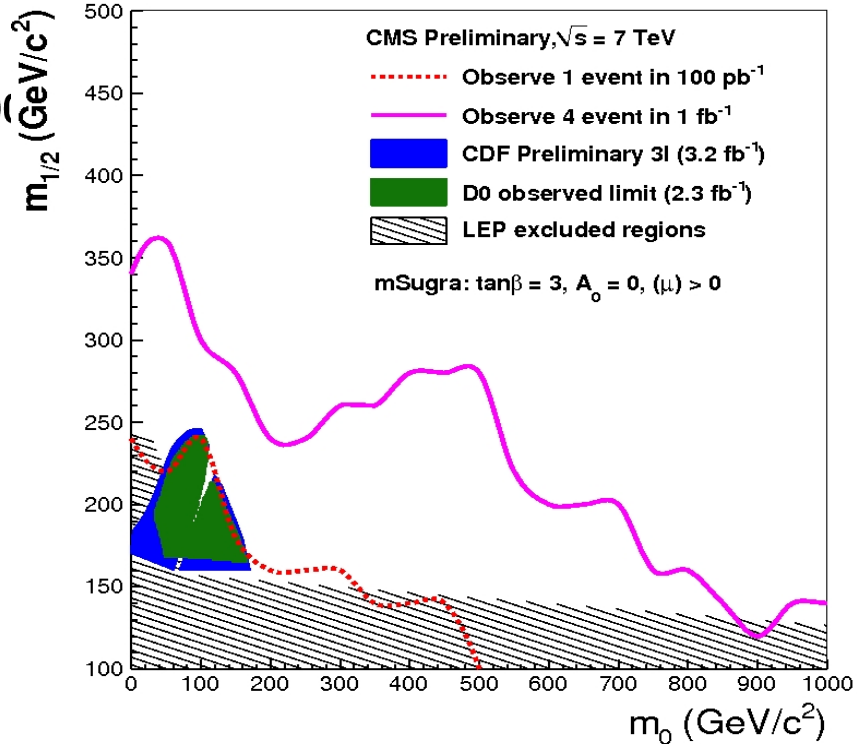
Generic approach used for data representation

mSUGRA/MSSM planes – MC exercise



All hadronic

Same Sign dileptons

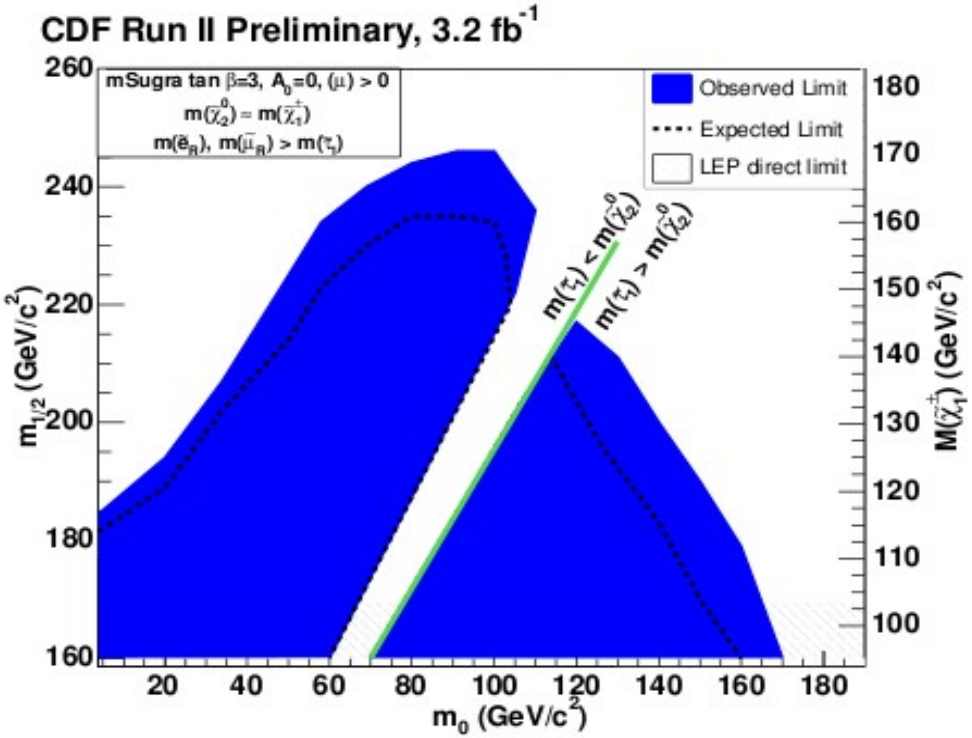


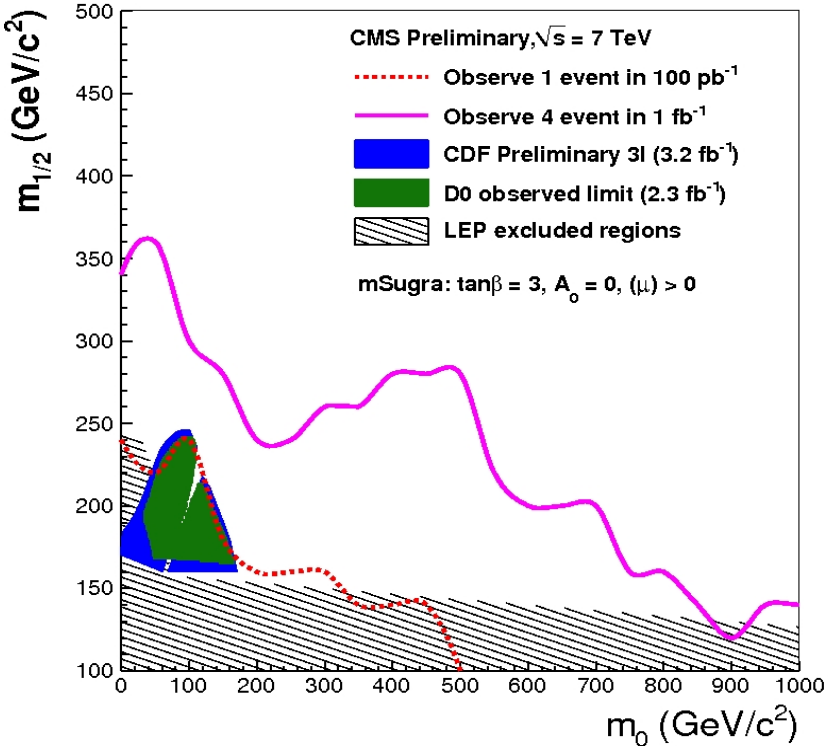
For details – CMS Note 2010/008

Both of these are MC projections:

predicting that ~100 pb^{-1} is sufficient to probe new territory in mSUGRA

mSUGRA/MSSM planes





Pros:

- Relatively small number of free parameters in mSUGRA space
- Easy to compare with other experiments such as Tevatron, LEP, etc

Cons:

- At any point in the parameter space, there are model dependent correlations
- This maps σ x Br responses in multiple channels/sub-processes

→ This information is lost!

Physics interpretation of results

Factorize data and the considered topology:

$$(\sigma \times Br) \sim \frac{N_{\text{Max Sig}}}{\epsilon}$$

Model/Topology after simulation

Based on expected and observed background in data:

- We measure the event yield in data
- We take the efficiency from the topology based MC simulations
- We express the results in terms of (σ x Br) upper limit

Represent the measured upper limit in a plane of particle masses

Possible to combine multiple topologies + multiple channels

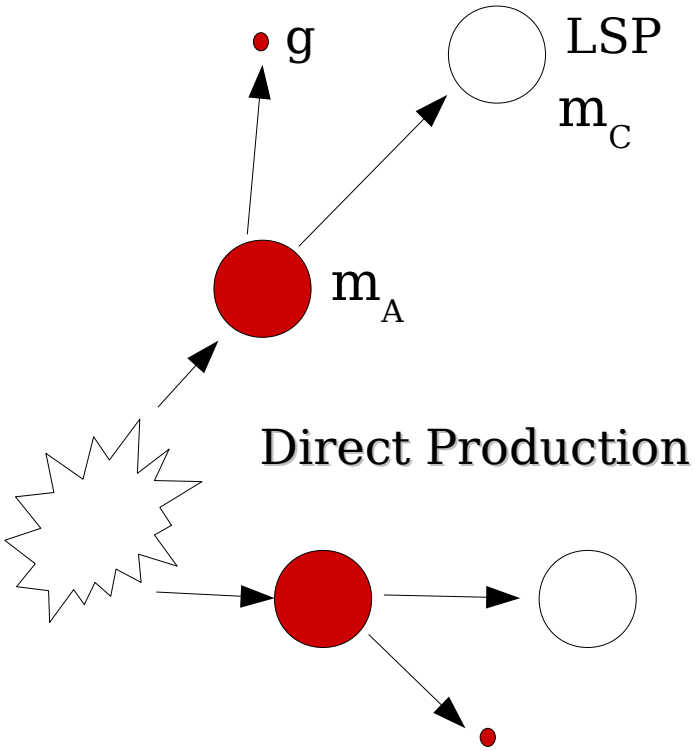
- arXiv:0808.1605 [hep-ph], See talk by Scott Thomas, Sunil Somalwar

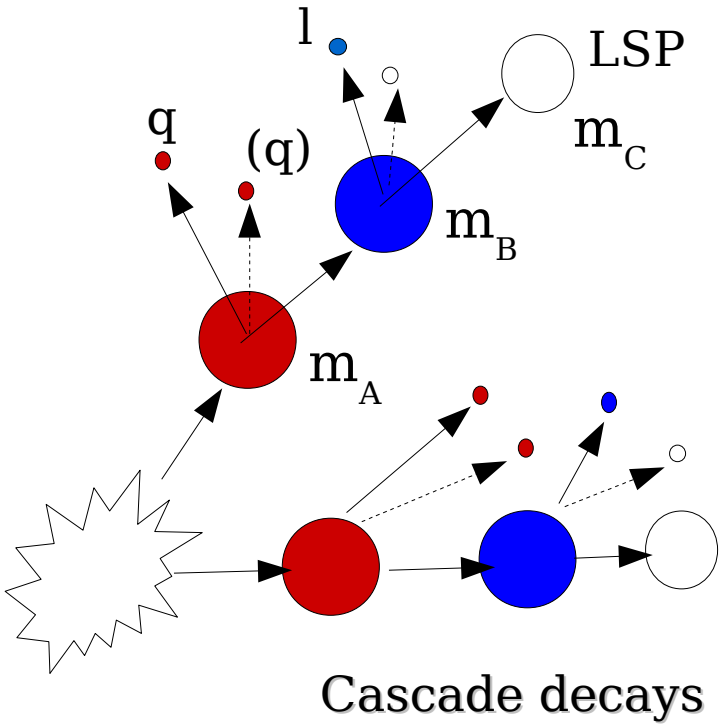
Choice of axis depends on the scale and kinematics of the processes

⇒ See next

Simplified Models for early searches

Simplified Models for early searches





assume LSP

- LSP (m_C): 1st mass scale (expect MET)

assume production via QCD

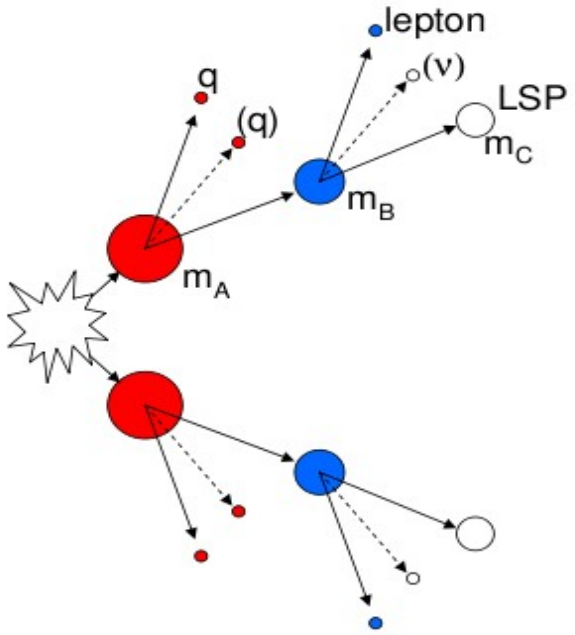
- squarks/gluinos (m_A): 2nd mass scale
- large cross sections

Two mass scales for direct production with 2 or 3 body decays

assume charged EWK particle coupling to quarks/squarks

- if chargino mass is in between gluino/squarks & LSP (m_B): 3rd mass scale

Simplified Models for early searches



m_A drives cross section

Δm_{AB} drives HT

Δm_{BC} drives lepton's p_T

MET is large as long as Δm_{AC} is large

Represent limits based on:

- m_A Vs m_c - Sensitive to strong production scale
- m_A Vs m_B - Sensitive to strong (m_A) and electroweak (m_B) scales
- m_A Vs Δm_{AB} – Sensitive to reconstructed quantities like HT (SumJetPT)
- m_A Vs Δm_{BC} – Sensitive to reconstructed quantities like lepton(s) p_T(s)

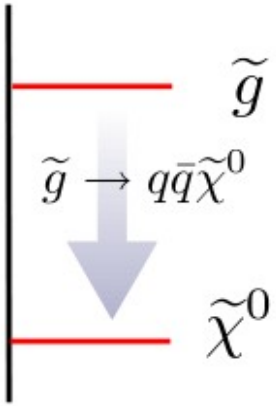
All hadronic searches – direct production

Alwall, Le, Lisanti, Wacker.
arXiv:0809.3264, arXiv0803.0019
Alwall, Schuster, Toro.
arXiv:0810.3921

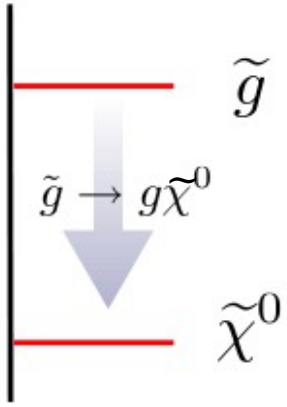
Two Simplified Models

$$pp \to \tilde{g}\tilde{g}$$

"Gluino" Directly Decaying to LSP



3 body decay
(*e.g.* heavy squarks)



2 body decay
(*e.g.* gauge mediation w/ squarks)

Free parameters

$m_{\tilde{g}}$
Mass of produced particle

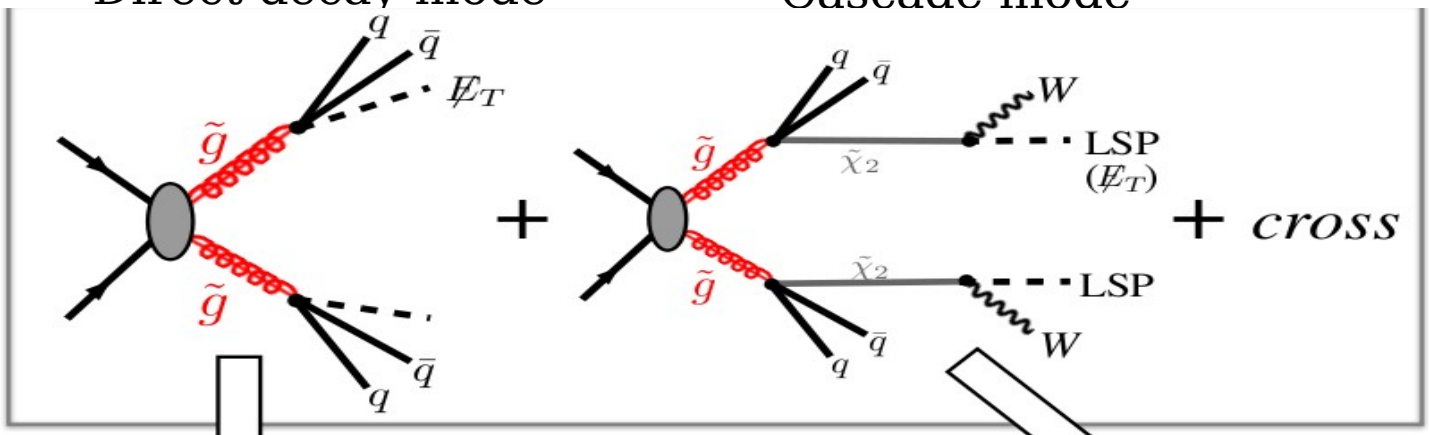
$m_{\tilde{\chi}^0}$
Mass of invisible particle

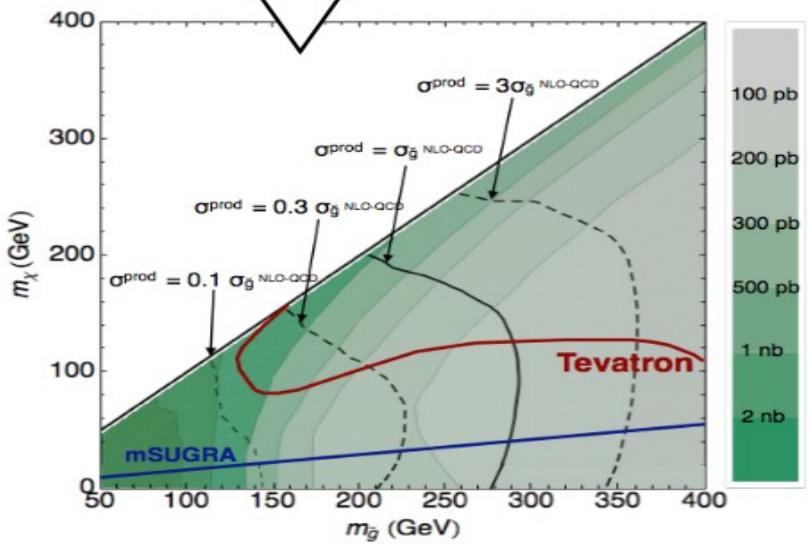
$\mathcal{B} \times \sigma_{pp \to \tilde{g}\tilde{g}}$
Cross section x Branching Ratio

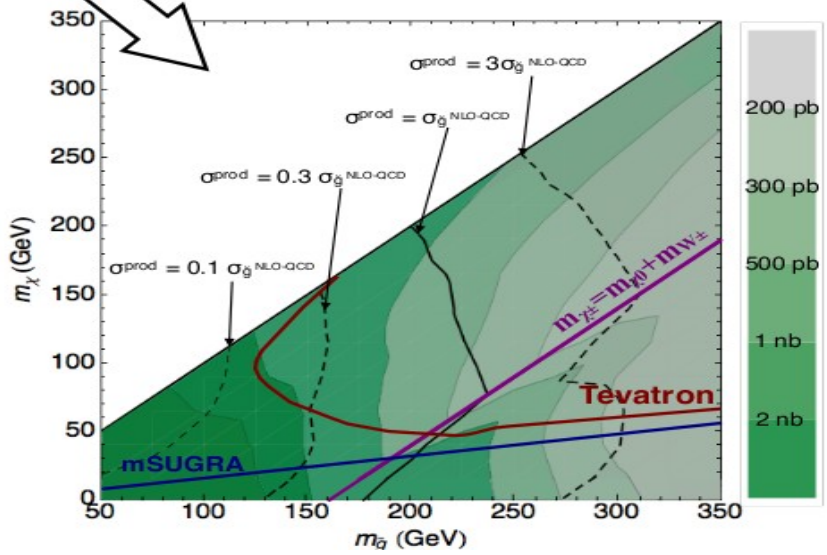
All hadronic searches

Direct decay mode

Cascade mode







- Shaded contours represent the maximum allowed cross section
- See talk by Sue Ann and Mariarosaria for the CMS study

http://www.lhcnewphysics.org/wiki/index.php?title=SimplifiedModels:GluinoOneStage

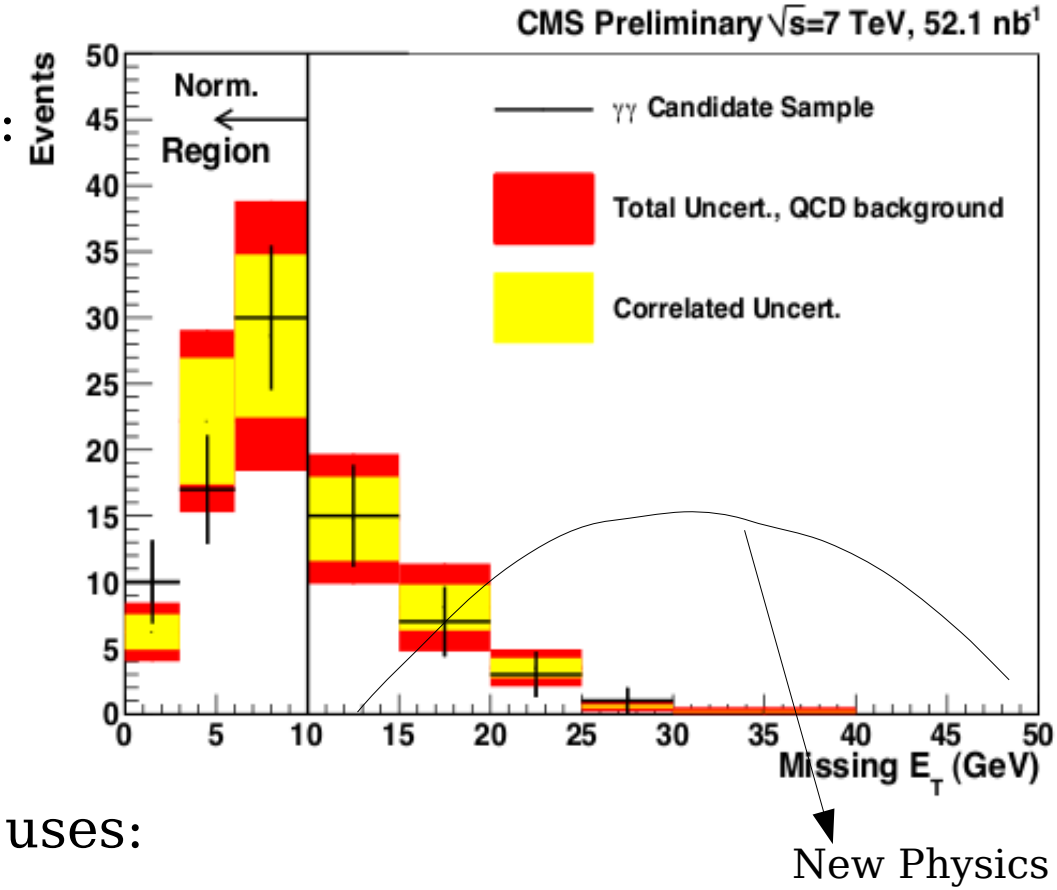
Photons + Jets + MET searches

Diphotons + MET signature:

Two major background components:

- W + $\gamma \Rightarrow \nu$ e γ
- QCD, direct photon events

In first case lepton is mis-identified as a photon.



MET > X, is the signal region

Data driven background estimation uses:

a) Use electron + photon sample with well identified electrons

b) For 2nd control sample where “fake-fake” region is selected

– dominated by QCD with non-isolated photons

Topologies for Photons + Jets + MET searches

Neutralino/Bino is the NLSP (GGM):

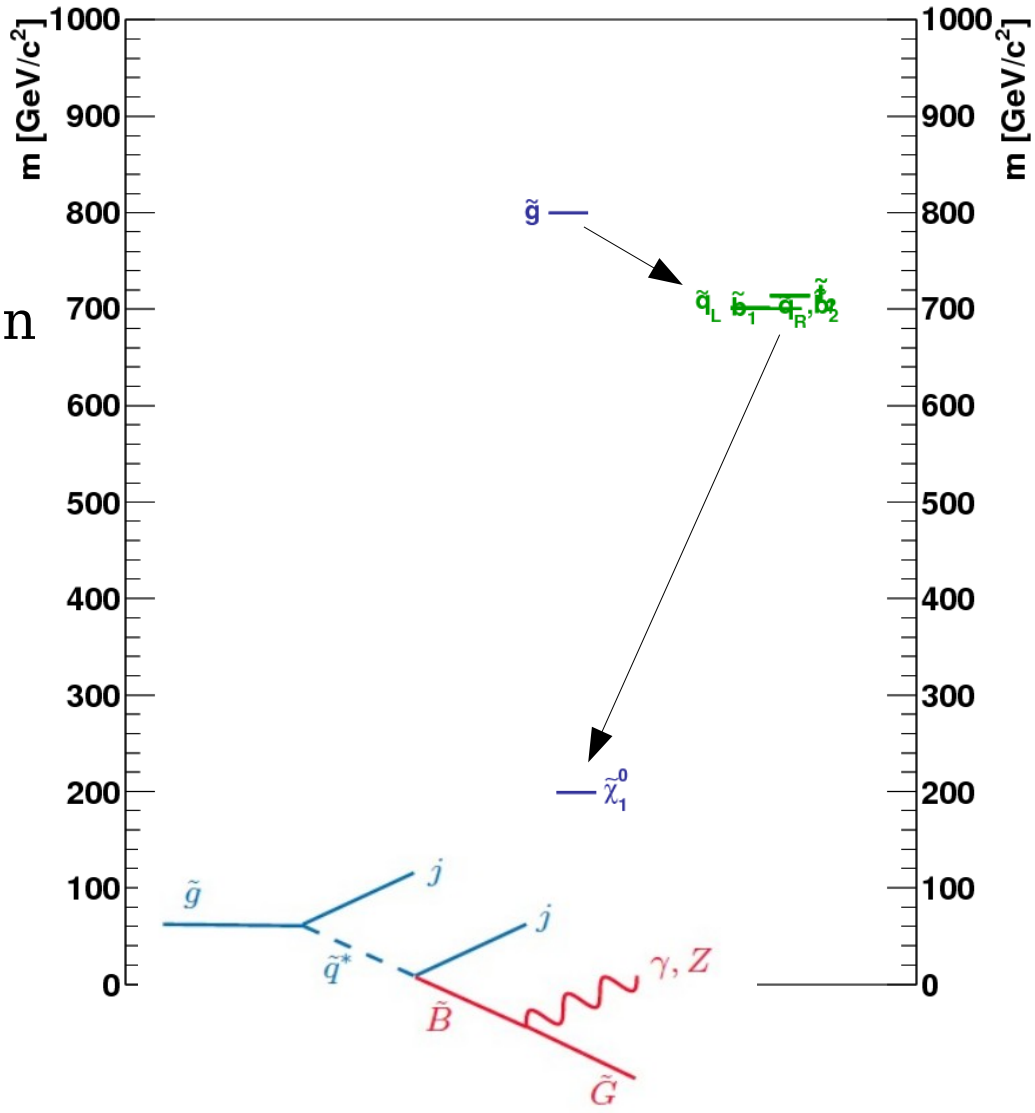
$$\chi_1^0 \rightarrow (\gamma , Z , h) + \tilde{G}$$

As bino has a small direct production cross section, dominant production is via gluino-gluino:

$$\tilde{g} \rightarrow q\tilde{q} \rightarrow qq\chi_1^0 \rightarrow \gamma + \tilde{G}$$

$$\rightarrow \gamma + X + MET$$

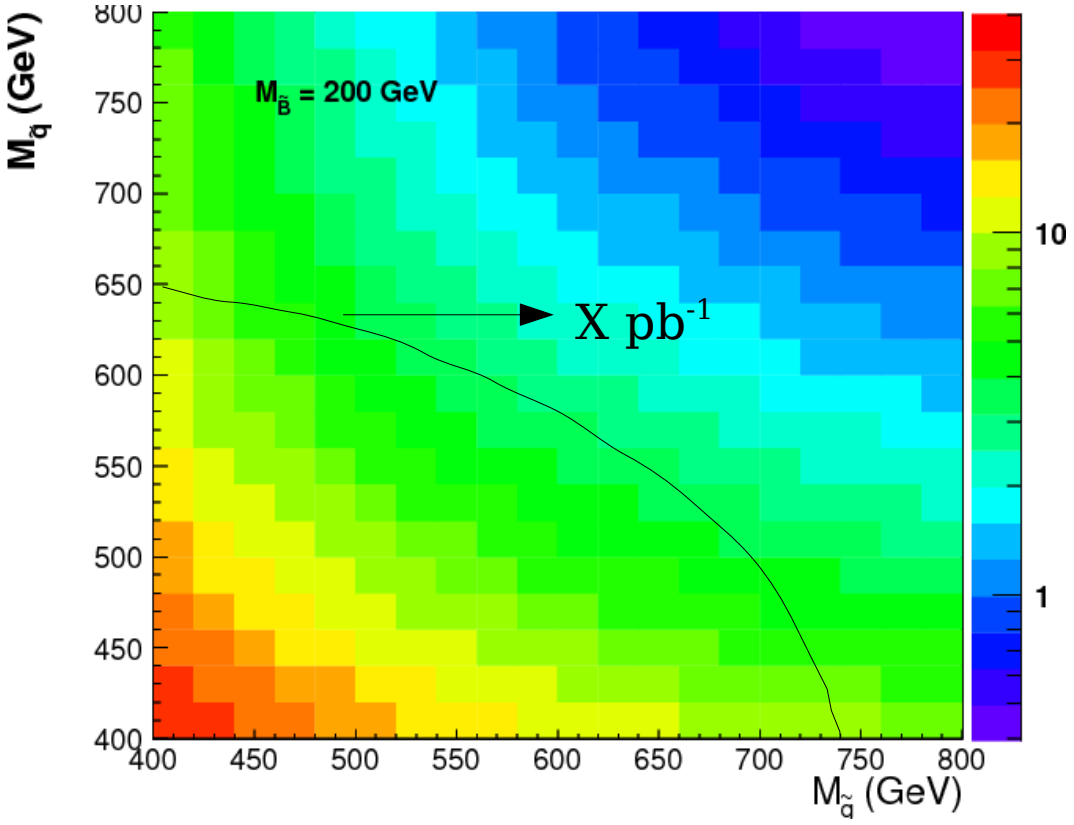
The pt of the photon and the amount of MET is determined by the neutralino/Bino mass

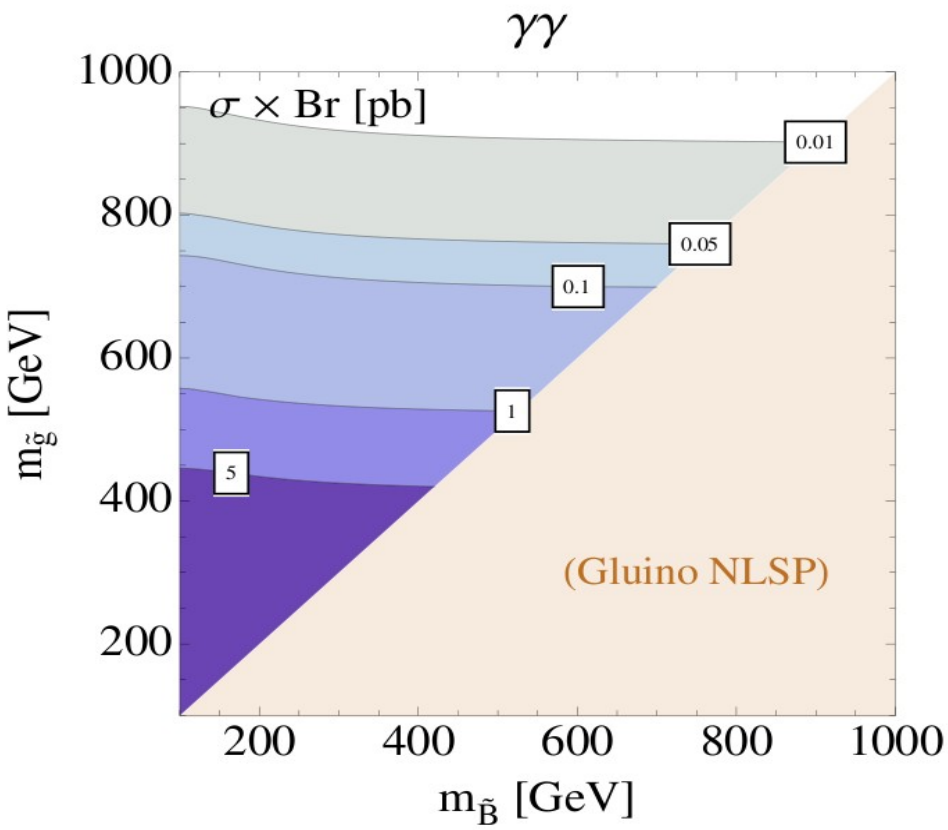


Yuri Gershtein, Michael Park, Josh Ruderman, David Shih, Scott Thomas, Yue Zhao:

http://www.lhcnewphysics.org/wiki/index.php?title=SimplifiedModels:General_Neutralino_NLSP

Photons + Jets + MET searches





Most interesting is the (σ x Br) sensitivity plot:

- the maximum cross section limit is driven by the gluino mass
- the contours are expected to reflect the hardness of the photon and MET with increase in mass of the Bino

Search involving: Single and dileptons

There are several interesting topologies involving:

- Neutralino and Chargino decays
  - **Mode 2** $G \rightarrow jjN_2^0 \rightarrow jj\ (Z^{0(*)}N_1^0)$
  - **Mode 3** $G \rightarrow jjC_1^{\pm} \rightarrow jj\ (W^{\pm(*)}N_1^0)$

Schuster, Toro, Wacker, Izaguirre:

http://www.lhcnewphysics.org/wiki/index.php?title=SimplifiedModels:GluinoOneStage

- Stops and sbottoms from the cascade:

1. Model A
   1. T → t chi0
   2. T → b chi0 (invisible chip)
   3. Parameters: m_T, m_{chi0}, BR(t chi0)/BR(b chi0)
2. Model B
   1. T → t Z/W chi0
   2. T → b Z/W chi0
   3. Parameters: m_T, m_{chi0}, BR(t Z chi0)/BR(b W chi0)

Kaplan, Fox, Toro, Kuflik, Lu, Mrenna:

http://www.lhcnewphysics.org/wiki/index.php?title=SimplifiedModels:StopSbottom

Searches involving multi-leptons

It is a complex number counting experiment (Several channels)

- All possible combination of lepton flavours and charges are considered

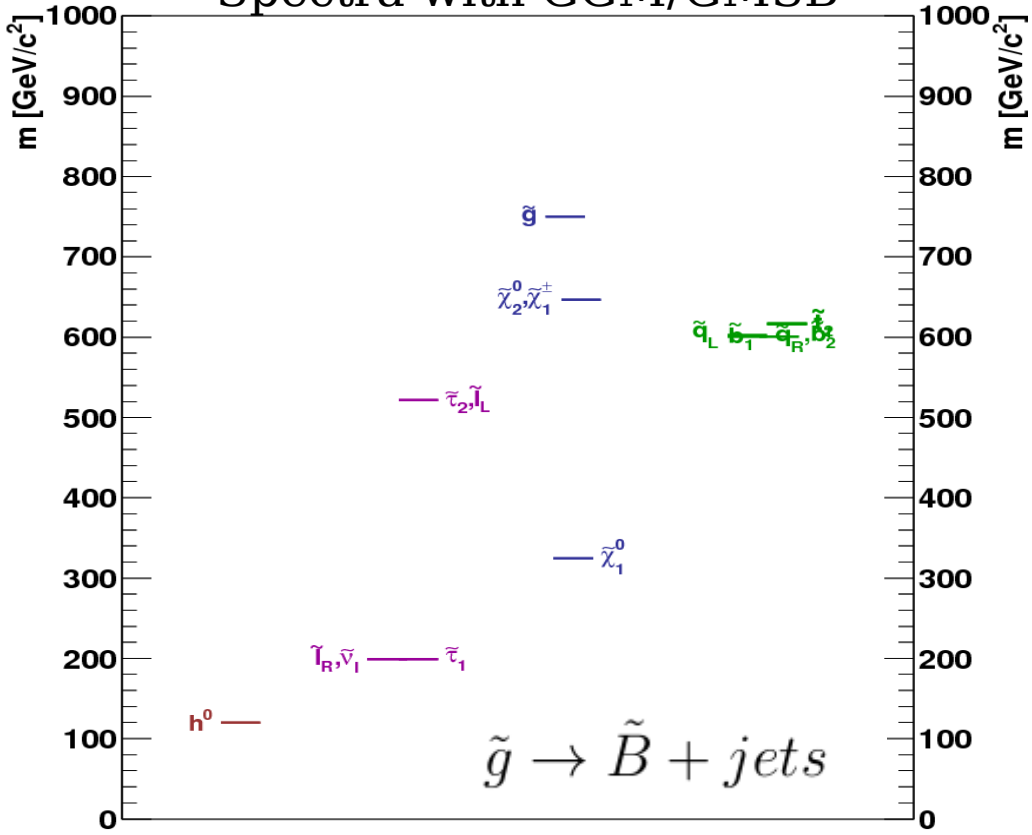
- Multileptons (e,μ,τ) along with Jets

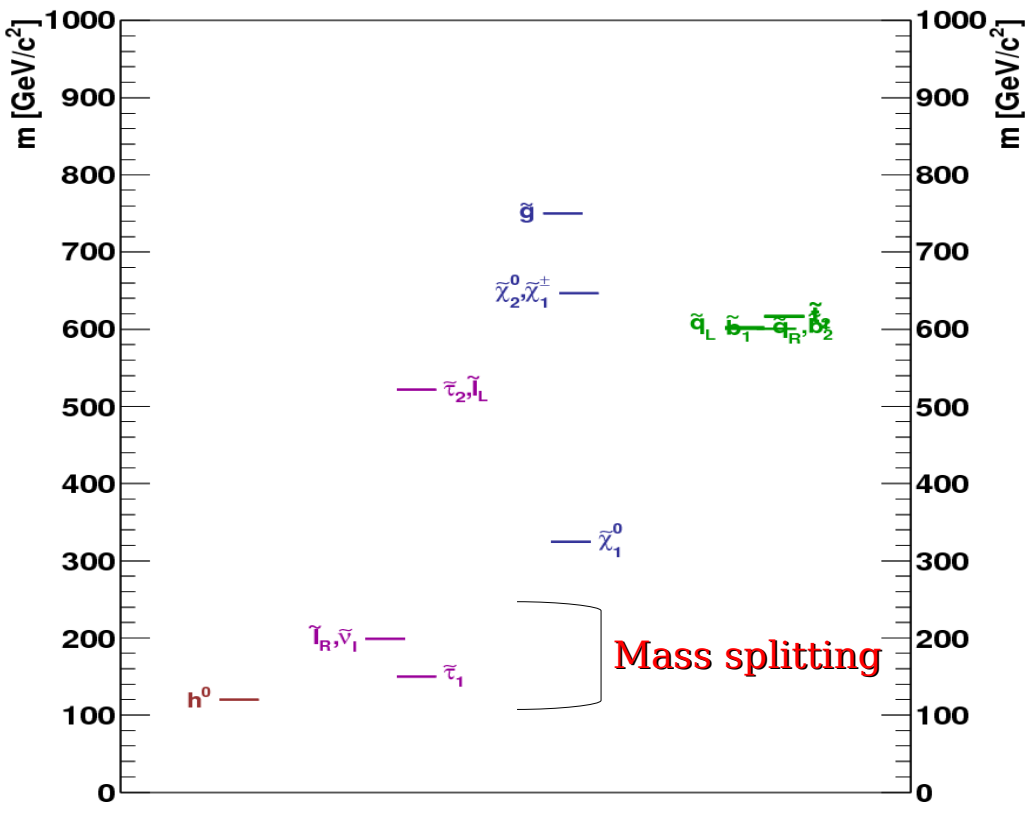
- Multileptons (e,μ,τ) + MET

– Multileptons (e,μ,τ) + MET + Jets

Searches involving multi-leptons

Spectra with GGM/GMSB





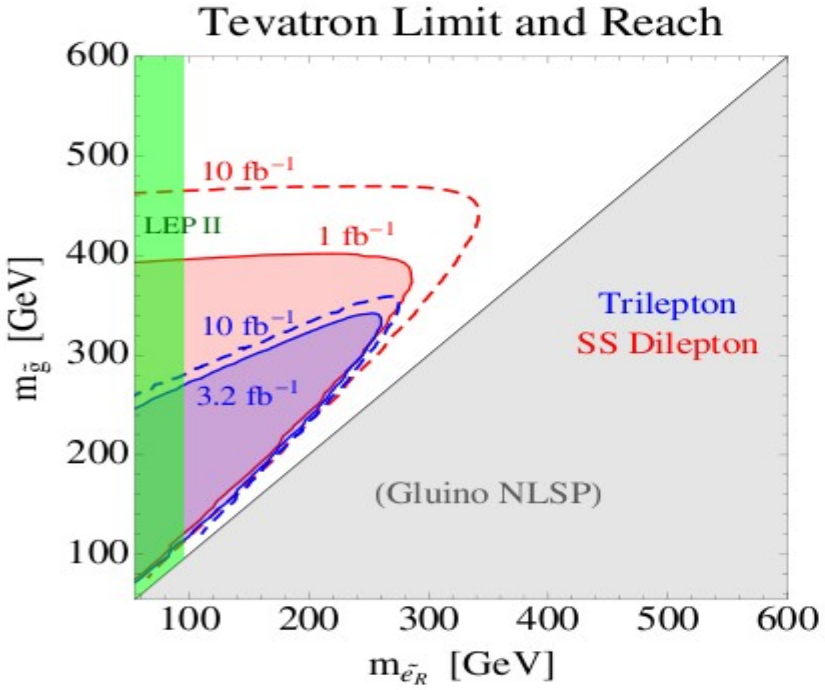
$$\tilde{B} \rightarrow (\tilde{e}_R^\pm, e^\mp), \ (\tilde{\mu}_R^\pm, \mu^\mp), \ (\tilde{\tau}_1^\pm, \tau^\mp) \ ; \quad \tilde{\ell}_R^\pm \rightarrow \ell^\pm + \tilde{G}$$

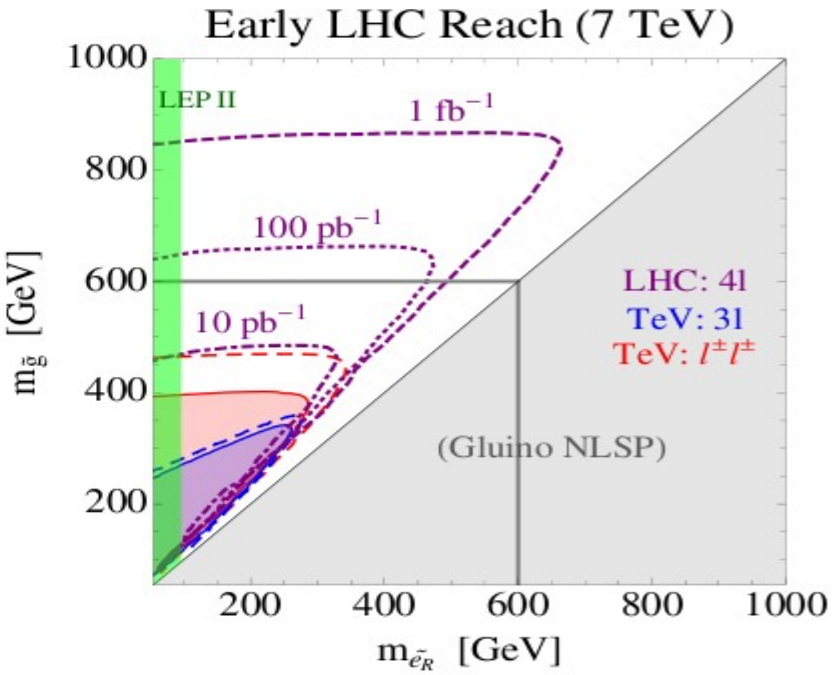
Bino decays with equal branching ratio per family to the leptons

This gives rise to : Multilepton signature

Note: If mass splitting between staus and sleptons = 0; slepton co-NLSP

Searches involving multi-leptons





Tevatron limits are based on CDF SameSign and trilepton analysis

→ See S. Somalwar's talk

LHC estimation is based on lepton pt > 10 GeV, $|\eta| < 2$, MET > 60 GeV

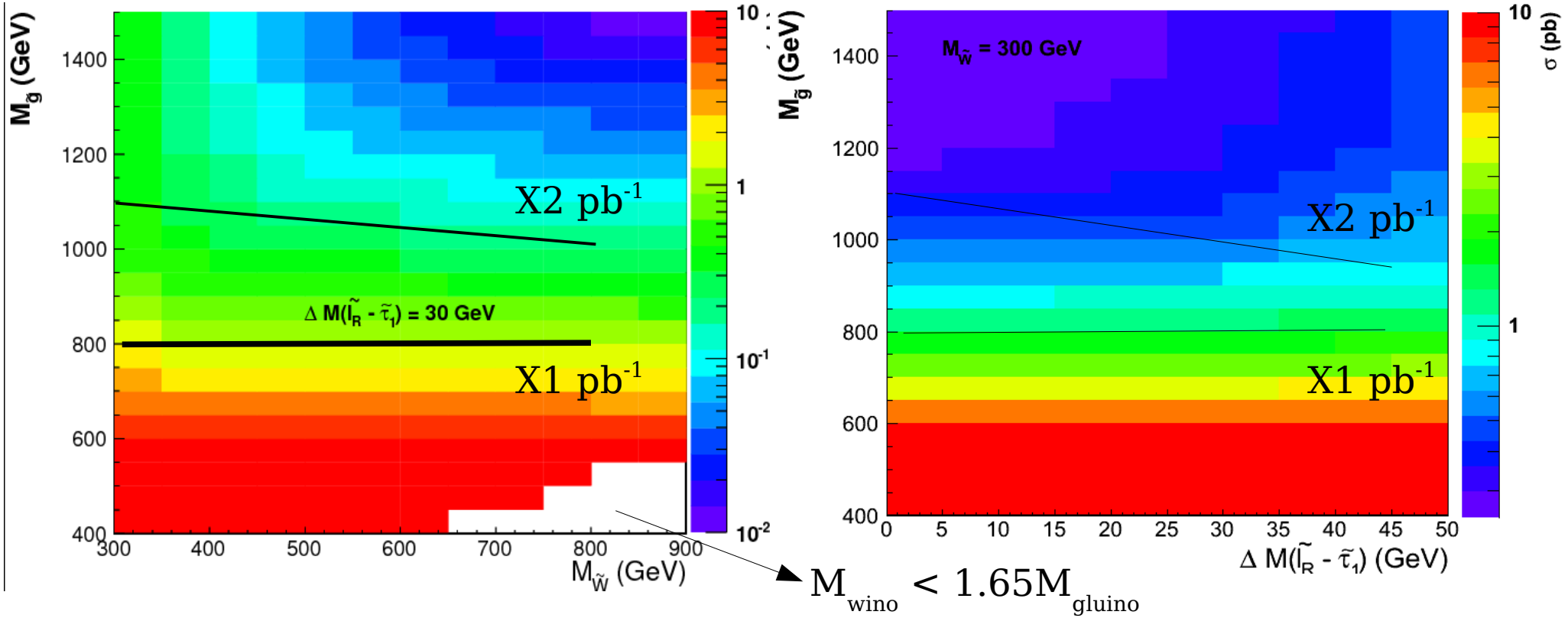
Cross section is driven by the gluino mass

LHC can provide better sensitivity with few 10s of pb^{-1}

Richard Gray, Michael Park, Josh Ruderman, David Shih, Sunil Somalwar, Scott Thomas, Yue Zhao :

http://www.lhcnewphysics.org/wiki/index.php?title=SimplifiedModels:Multi-Lepton_GMSB

Searches involving multi-leptons + MET/Jets



Cross section is driven by the gluino mass

Plot probes the strong (gluino mass) and electroweak (Wino mass) scale

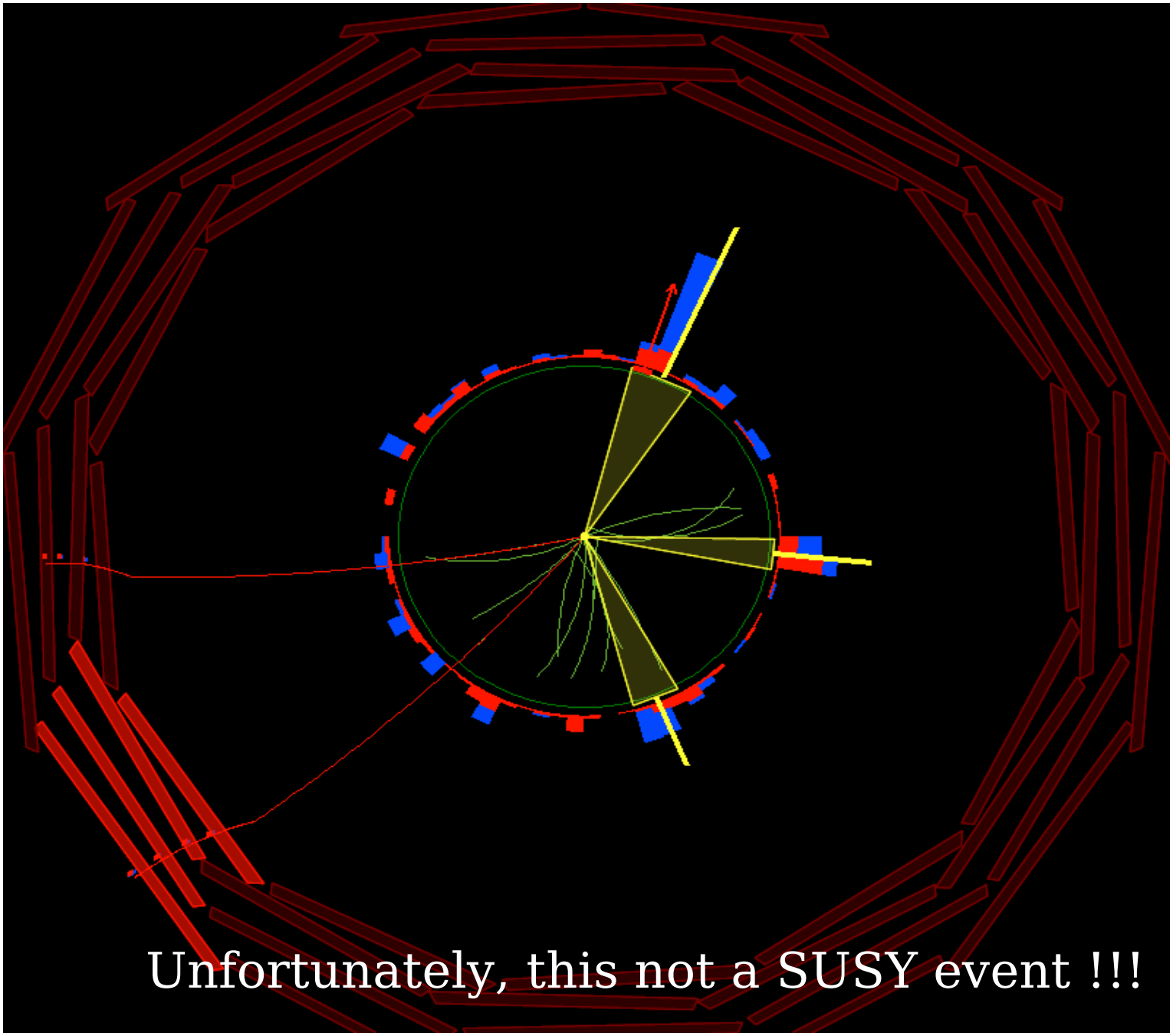
Mass difference between M_{gluino} and (M_{bino} α M_{wino}) drives the HT or SumJetPt

- sensitive to reconstructed Jets, Jet energy scales, etc

Mass difference between the sleptons can lead to staus as NLSP or sleptons as co-NLSP:

- lepton reconstruction (both soft and hard)
- sensitive to fake leptons as we study “soft” pt leptons

Taking in the scenery – Same Sign dimuon event



Pt1 = 15.6 GeV

Pt2 = 15.0 GeV

Tracker & global

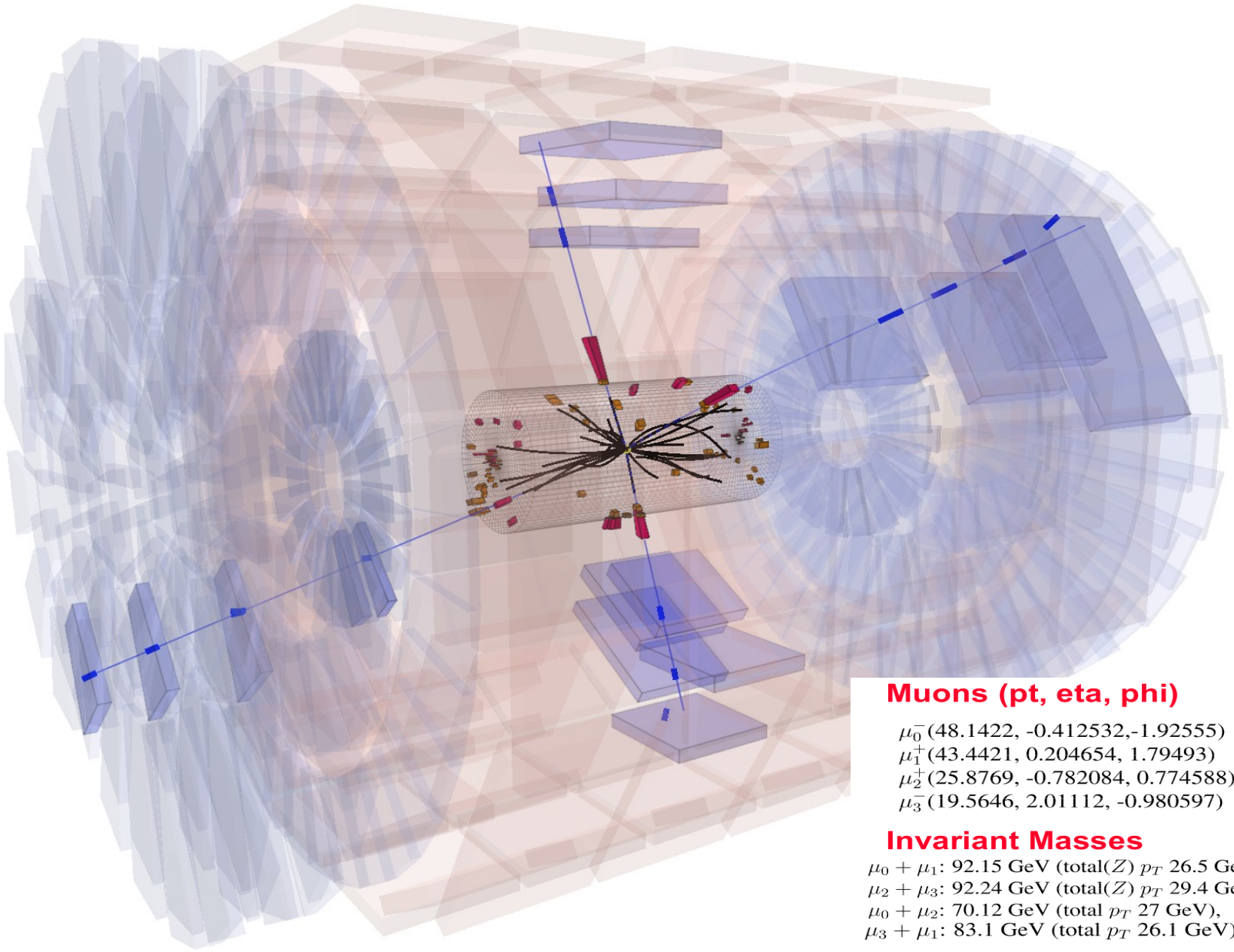
Jetpt1 = 23.9 GeV

Jetpt2 = 13.1 GeV

Jetpt3 = 10.4 GeV

MET = 13.1 GeV

Taking in the scenery: $ZZ \to 4$ muon event



Muons (pt, eta, phi)

μ_0^-(48.1422, -0.412532,-1.92555)
μ_1^+(43.4421, 0.204654, 1.79493)
μ_2^+(25.8769, -0.782084, 0.774588)
μ_3^-(19.5646, 2.01112, -0.980597)

Invariant Masses

$\mu_0 + \mu_1$: 92.15 GeV (total(Z) p_T 26.5 GeV, ϕ -3.03),
$\mu_2 + \mu_3$: 92.24 GeV (total(Z) p_T 29.4 GeV, ϕ +.06),
$\mu_0 + \mu_2$: 70.12 GeV (total p_T 27 GeV),
$\mu_3 + \mu_1$: 83.1 GeV (total p_T 26.1 GeV).

Invariant Mass of 4μ: 201 GeV

Outlook

CMS for the most part relies on data driven techniques to account for all major background in beyond the SM searches

Currently we are exploring a “few sets” of simplified topologies to:

- show the scales we can probe at the LHC
- data representation in “model independent” manner
- representation of data with maximum information needed for the theory community

CMS expects to pursue a balanced diet of:

– Targeted searches for well motivated models

– Generic searches based on signatures

References

CMS Physics results:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

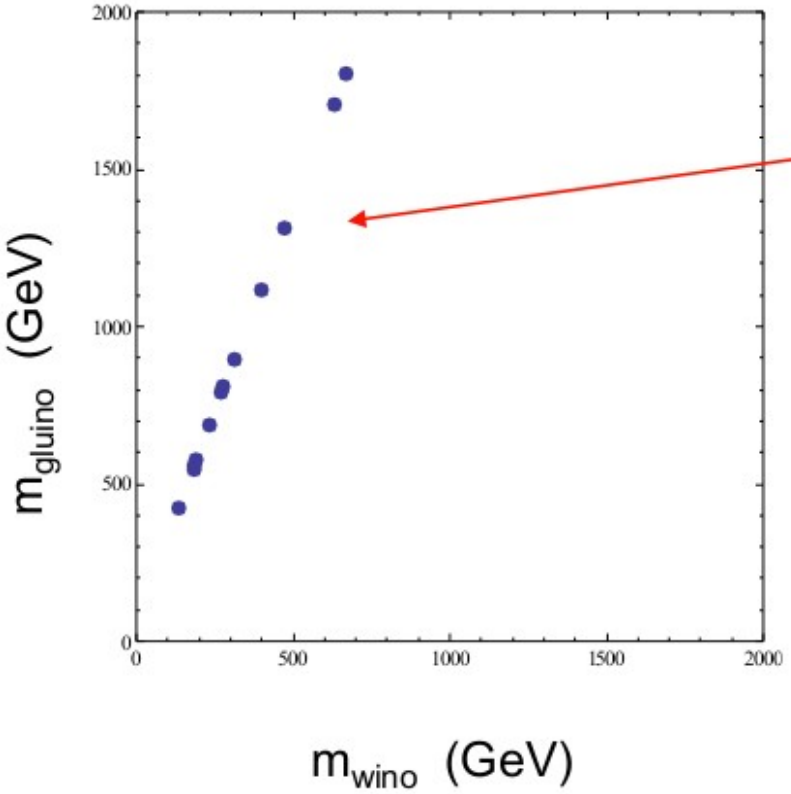
Topologies considered:

http://www.lhcnewphysics.org/wiki/index.php?title=Simplified_Models_By_Working_Group

Backup Slides

SUSY benchmark points

CMS (Public) SUSY Benchmarks - TDR (Atlas Similar)



Stretched Gauge Ordered Spectra

Relatively Low σ

Led to Expectation that Need O(100's) pb^{-1} to go Beyond Tevatron

(Gaugino Unification)