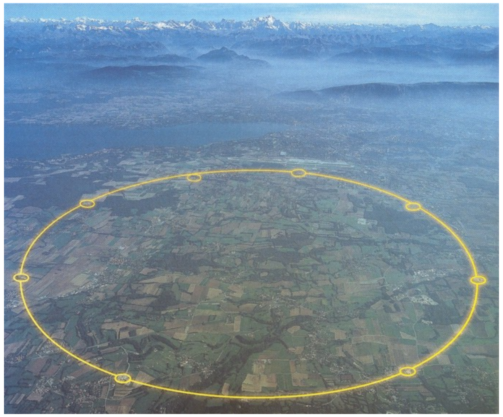
Results from the First Run of the Large Hadron Collider and the Last Run of the Tevatron



Scott Thomas
Rutgers University

High Energy Experiment at Rutgers

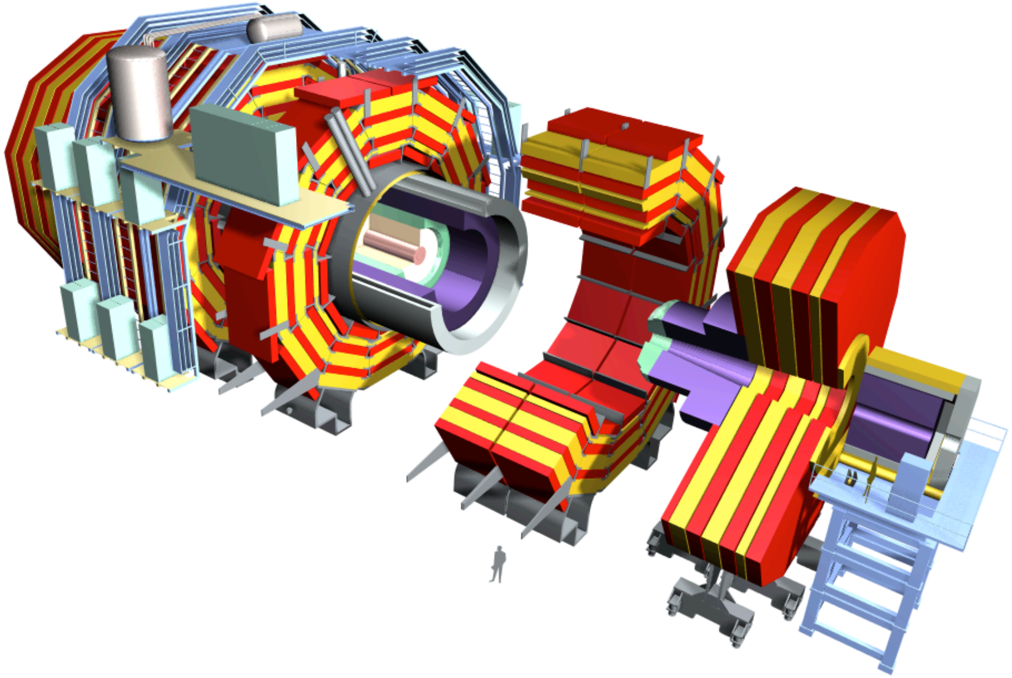
Faculty: John Paul Chou, Yuri Gershtein, Eva Halkiadakis, Amit Lath, Steve Schnetzer, Sunil Somalwar, Scott Thomas

Physicists: Bob Stone, John Doroshenko, Pieter Jacques

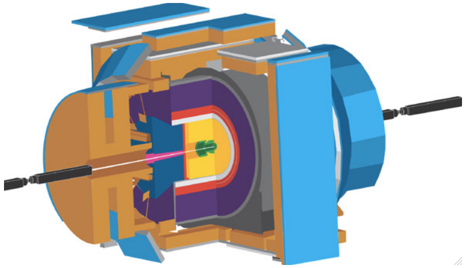
Postdocs: Karen Andeen, Richard Gray, Dan Dugan, Dean Hidas, + 2-3 Can Kilic

Students: Keith Rose, Dmitry Hits, Anthony Barker, Shruti Panwalkar, Rishi Patel, Claudia Seitz, Daryl Hare, Lindsay Winter, Gautam Jain, David DeMair, Ed Ronan, Richard Bavier, Jorge Chavez, Ian LaFlotte, Emmanuel Contreras, Christian Contreras , Sean Yeager, Eric Williams, Yue Zhao, Michael Park

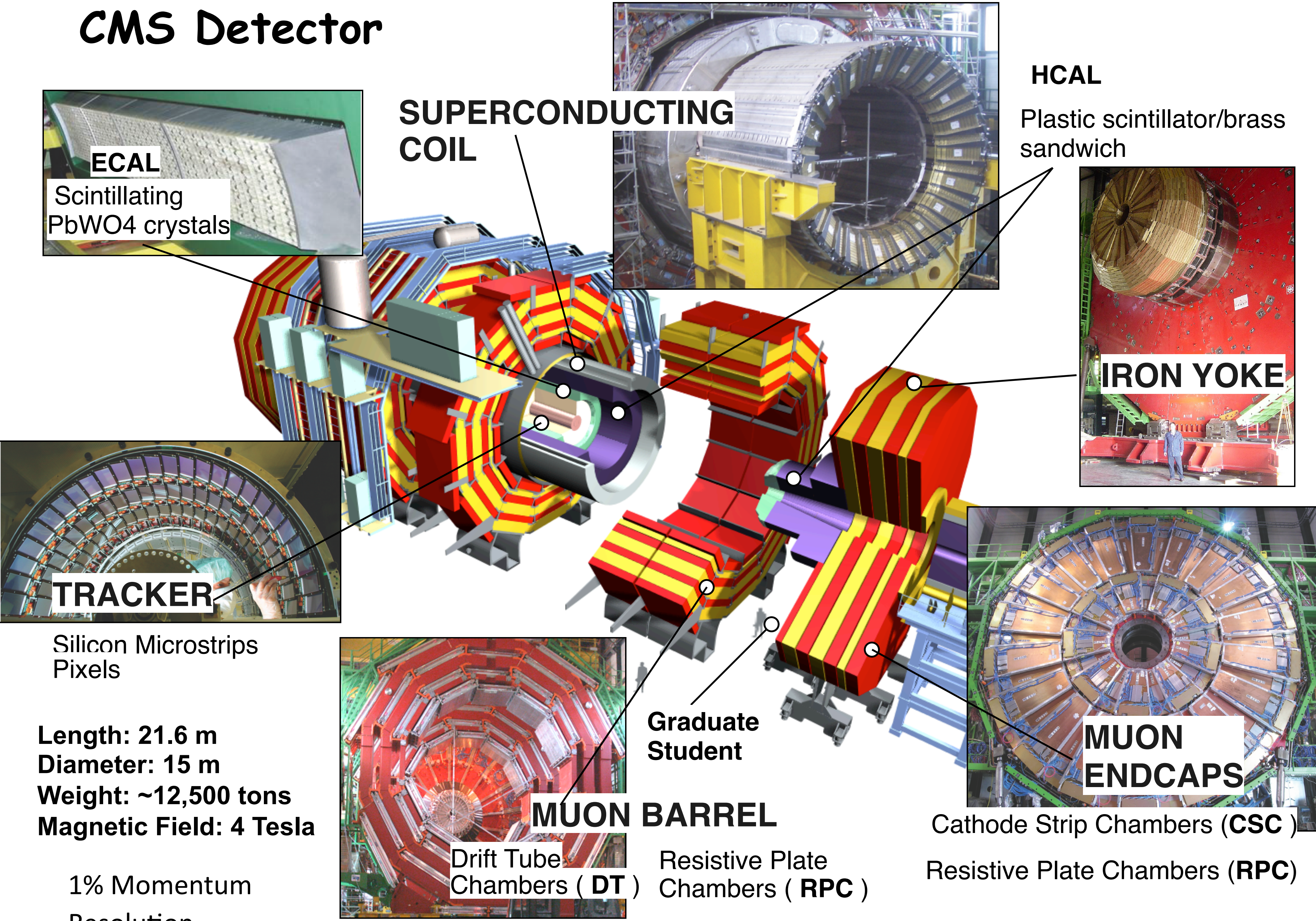
CMS



CDF



CMS Detector



ECAL
Scintillating
PbWO4 crystals

**SUPERCONDUCTING
COIL**

HCAL

Plastic scintillator/brass
sandwich

IRON YOKE

TRACKER

Silicon Microstrips
Pixels

**Graduate
Student**

**MUON
ENDCAPS**

Cathode Strip Chambers (**CSC**)

Resistive Plate Chambers (**RPC**)

MUON BARREL

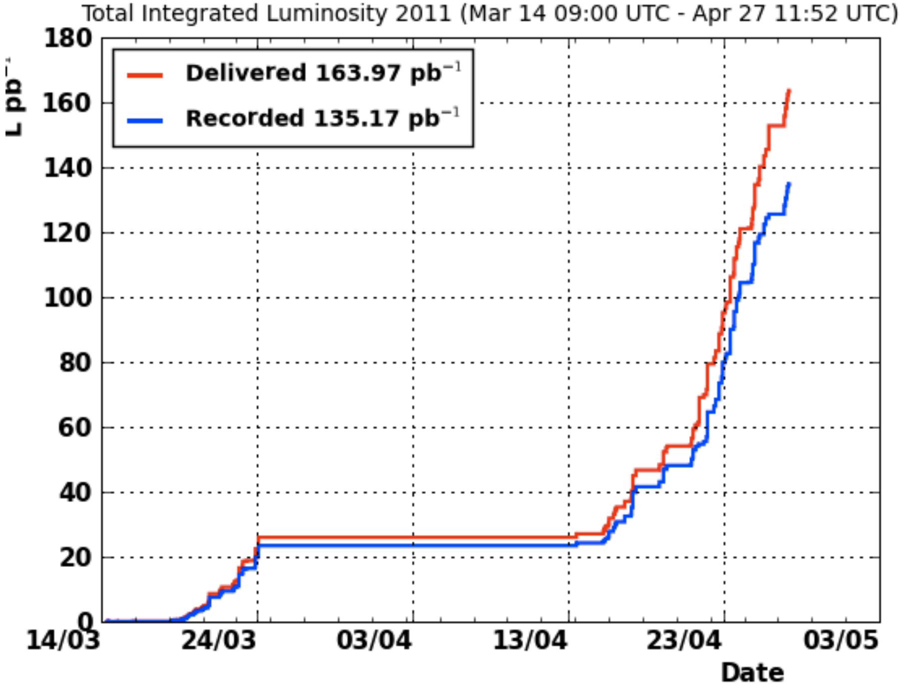
Drift Tube
Chambers (**DT**)

Resistive Plate
Chambers (**RPC**)

Length: 21.6 m
Diameter: 15 m
Weight: ~12,500 tons
Magnetic Field: 4 Tesla

1% Momentum
Resolution

Integrated Luminosity 2011

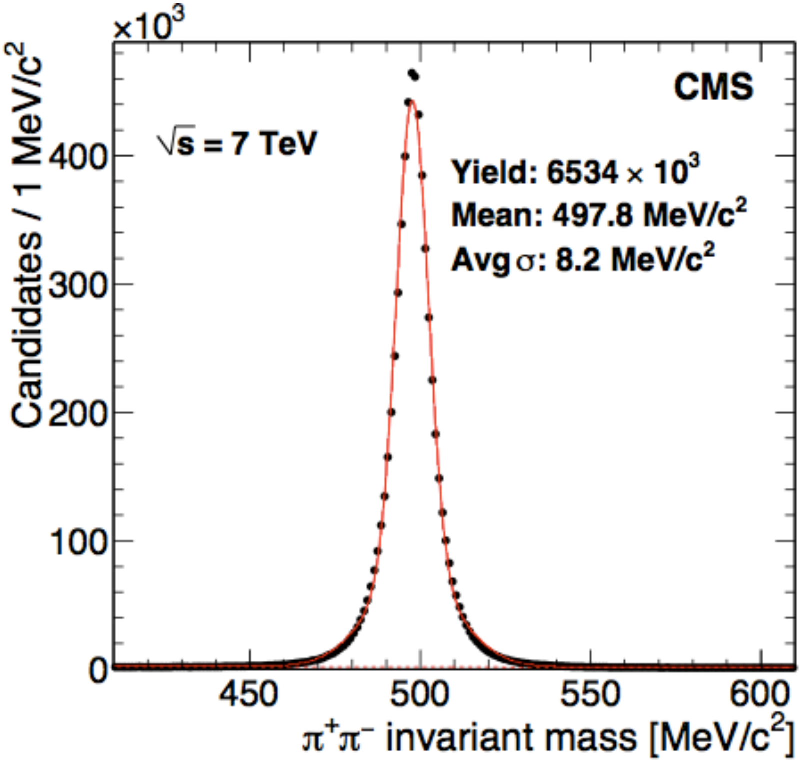


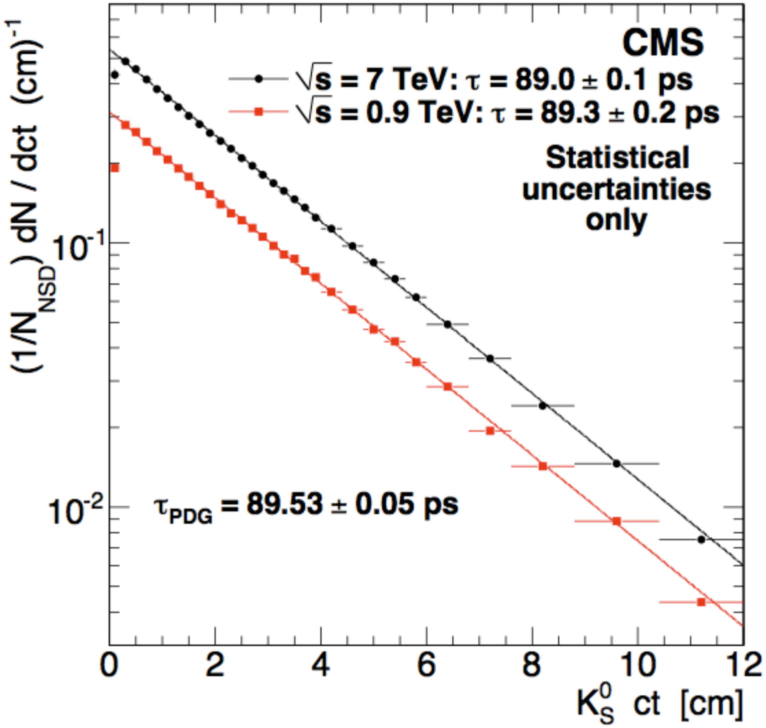
Last Week:
O(100) pb^{-1} / week

This Talk: CMS Fall 2010 Data Set 35 pb^{-1}

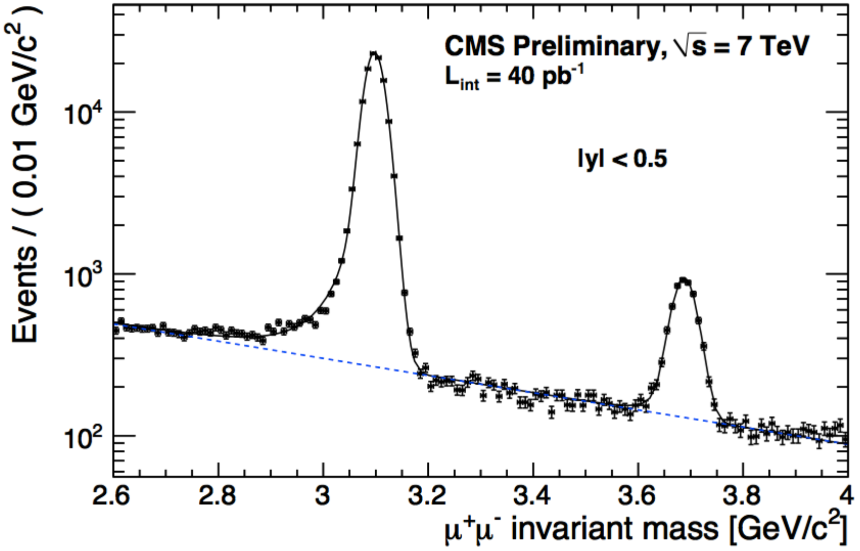
CDF Fall 2010 Data Set 3 fb^{-1}

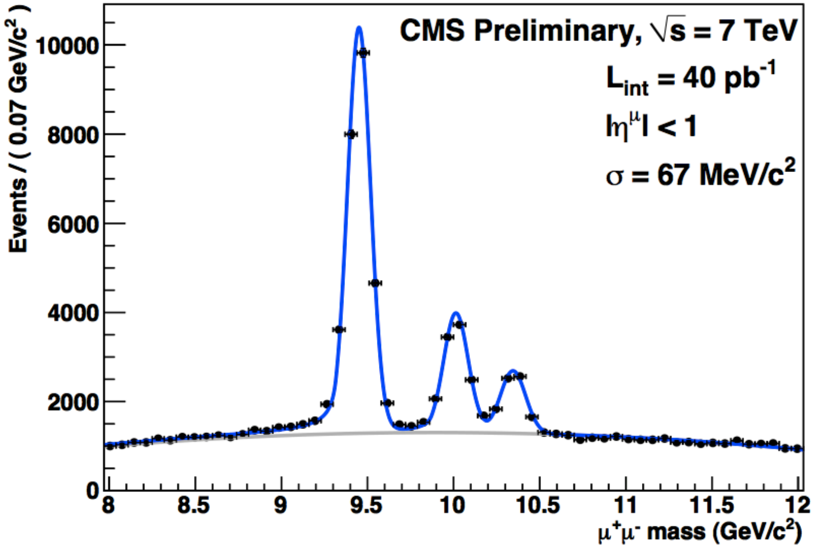
K_S -> π^+ π^-


×10³
CMS
√s = 7 TeV
Yield: 6534 × 10³
Mean: 497.8 MeV/c²
Avg σ: 8.2 MeV/c²
Candidates / 1 MeV/c²
0
100
200
300
400
450
500
550
600
π⁺π⁻ invariant mass [MeV/c²]

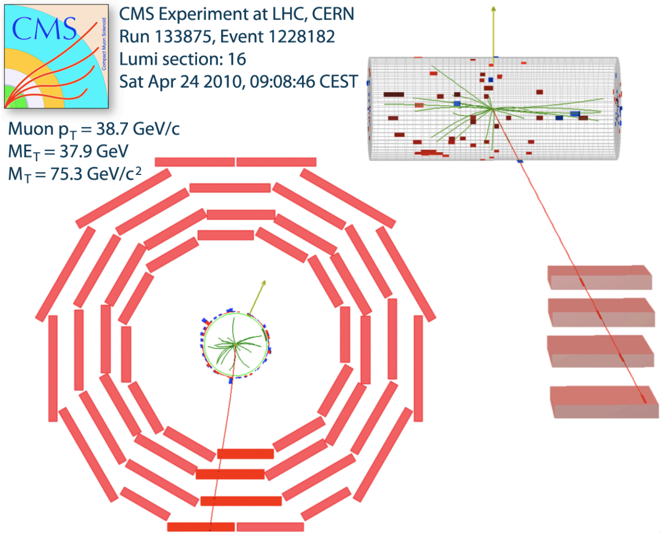

CMS
√s = 7 TeV: τ = 89.0 ± 0.1 ps
√s = 0.9 TeV: τ = 89.3 ± 0.2 ps
Statistical uncertainties only
τPDG = 89.53 ± 0.05 ps
(1/NNSD) dN / dct (cm)⁻¹
10⁻¹
10⁻²
0
2
4
6
8
10
12
K⁰S ct [cm]

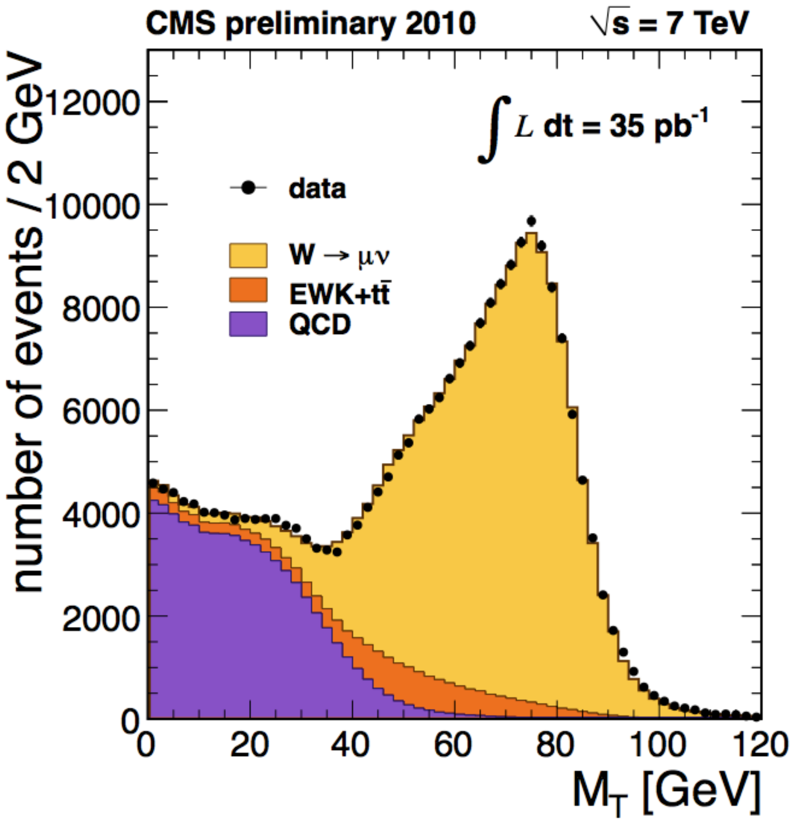
J/ψ and Upsilon -> $\mu^+ \mu^-$

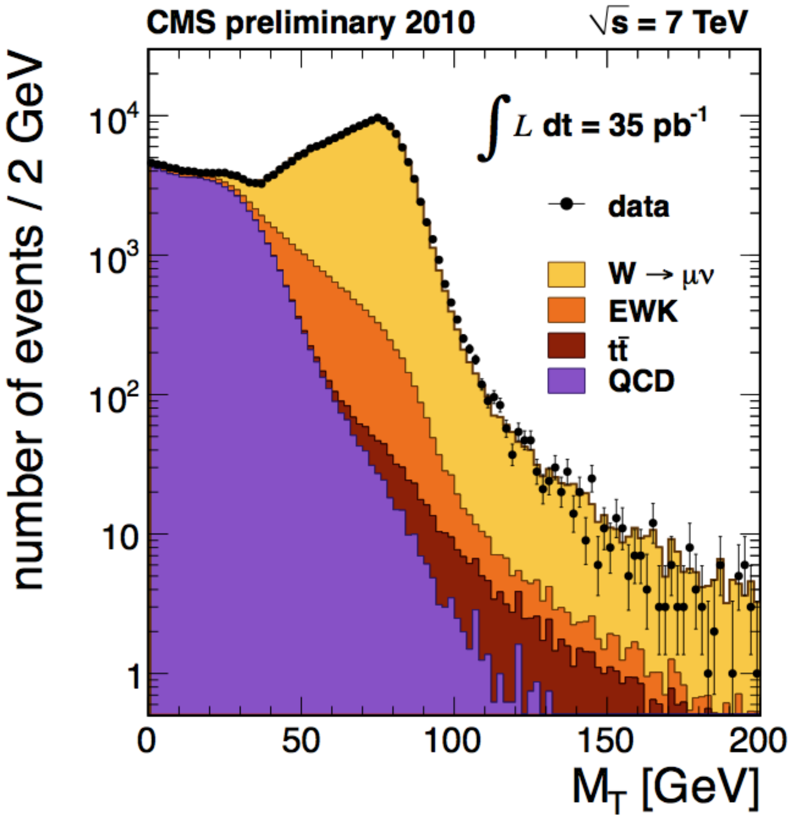




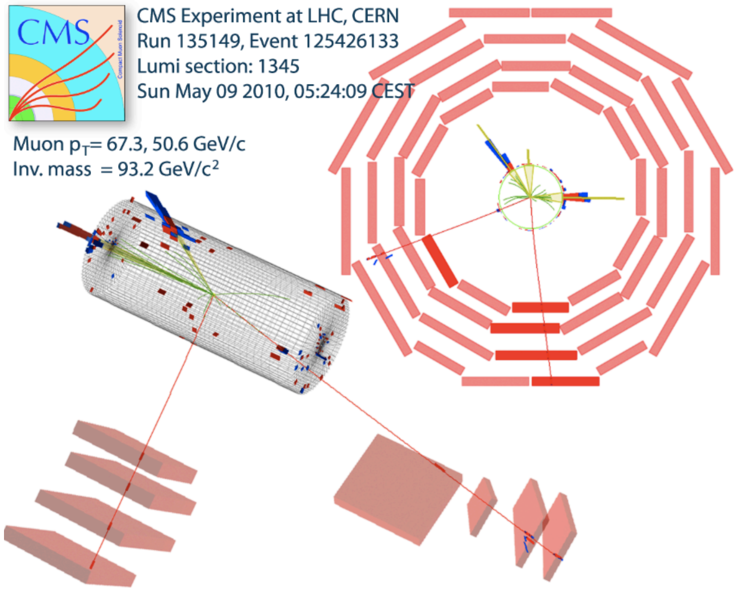
W -> μ ν

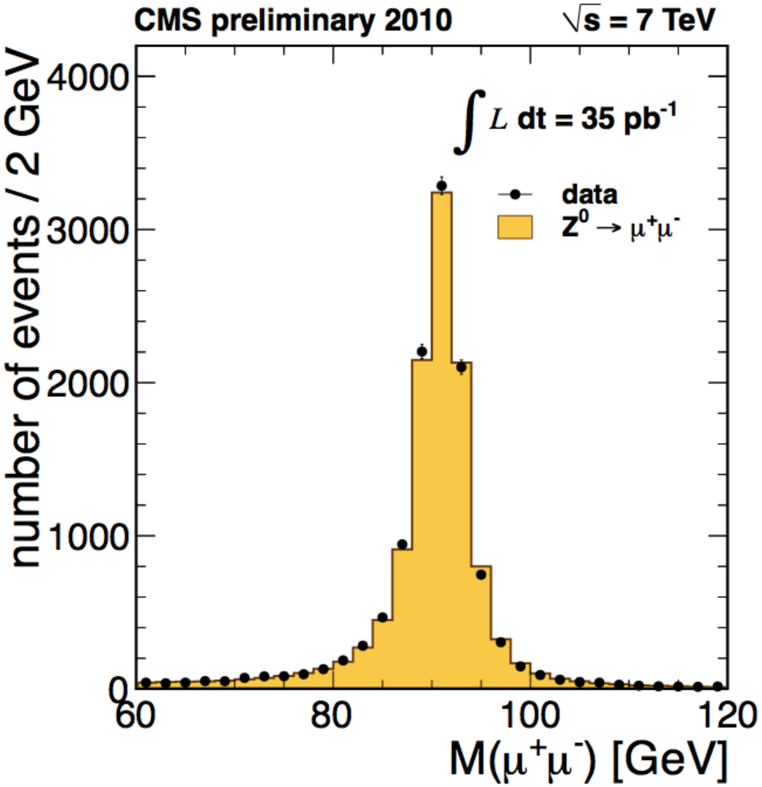

CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST
Muon p_T = 38.7 GeV/c
ME_T = 37.9 GeV
M_T = 75.3 GeV/c²

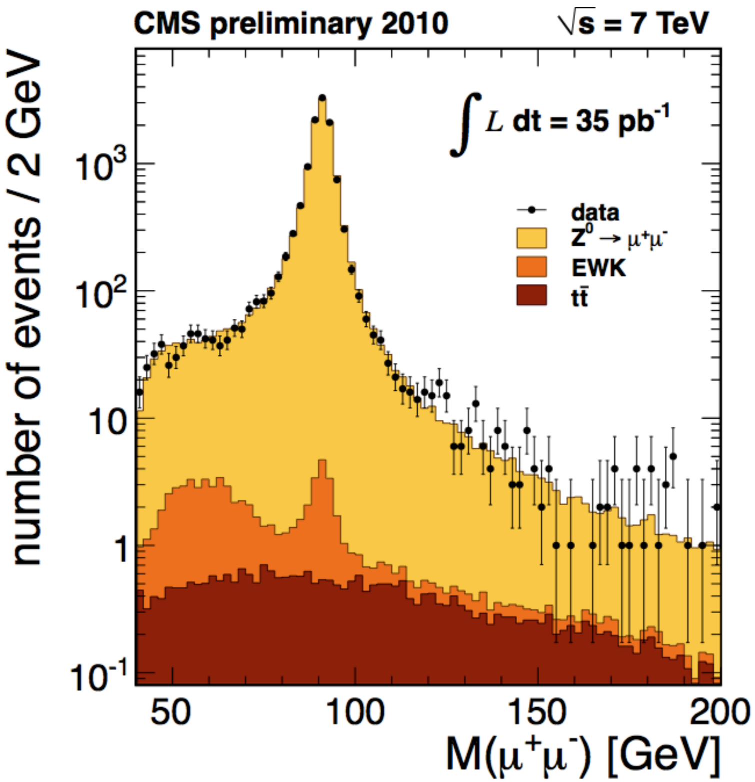

CMS preliminary 2010
√s = 7 TeV
∫L dt = 35 pb⁻¹
data
W → μν
EWK+tt̄
QCD
number of events / 2 GeV
0
2000
4000
6000
8000
10000
12000
0
20
40
60
80
100
120
M_T [GeV]


CMS preliminary 2010
√s = 7 TeV
∫L dt = 35 pb⁻¹
data
W → μν
EWK
tt̄
QCD
number of events / 2 GeV
1
10
10²
10³
10⁴
0
50
100
150
200
M_T [GeV]

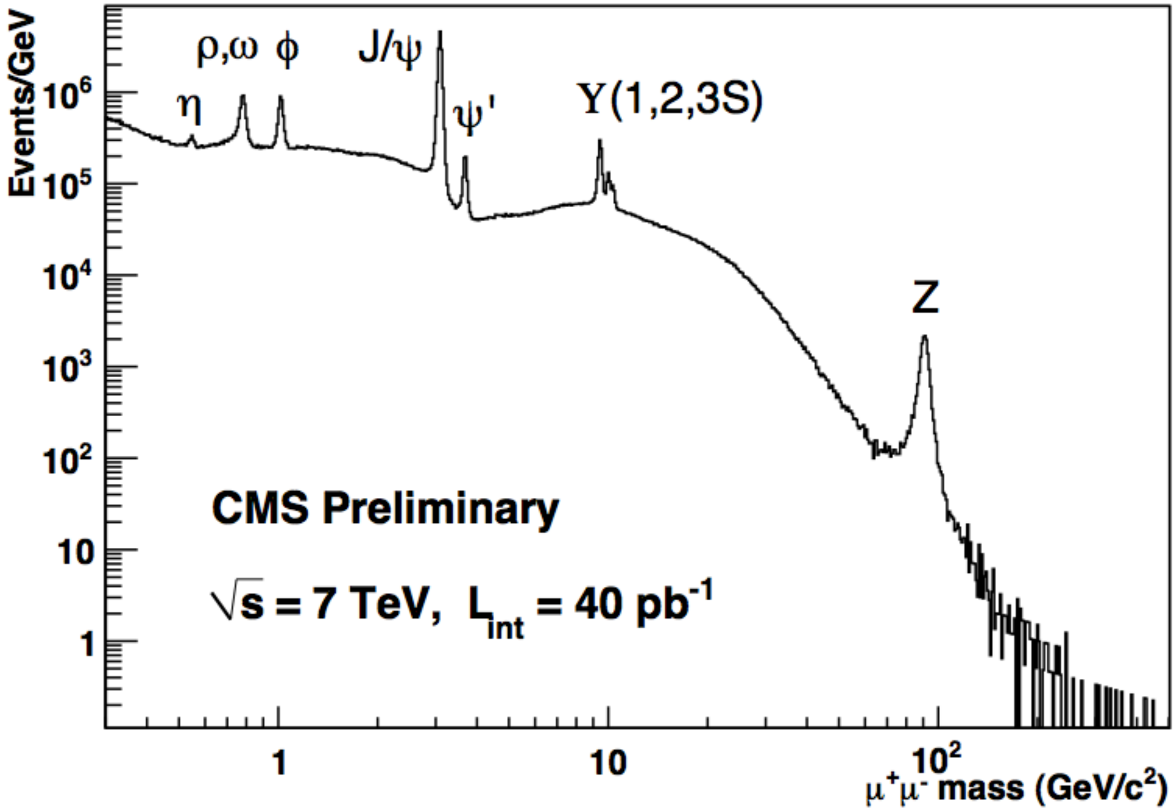
Z -> μ^+ μ^-


CMS
CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST
Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c²


CMS preliminary 2010
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 35\ pb^{-1}$
data
$Z^0 \to \mu^+\mu^-$
number of events / 2 GeV
0
1000
2000
3000
4000
60
80
100
120
$M(\mu^+\mu^-)$ [GeV]


CMS preliminary 2010
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 35\ pb^{-1}$
data
$Z^0 \to \mu^+\mu^-$
EWK
$t\bar{t}$
number of events / 2 GeV
10^{-1}
1
10
10^2
10^3
50
100
150
200
$M(\mu^+\mu^-)$ [GeV]

μ^+ μ^- Spectrum



Physics Outline:

String Di-jet Regge Resonances

SUSY

- SS Di-Leptons + MET - Sneutrino LSP
- Multi-leptons - Slepton Co-NLSP (GMSB), Leptonic RPV
- Di-photon + MET - Bino NLSP (GMSB)
- Multi-jet Resonances - Hadronic RPV
  CDF + CMS

Factorized Mapping from Data -> Theory through Topologies

Consistent On-Shell Effective Theory

High Multiplicity + S_T Signatures (Black Holes)

...

Other CMS Searches:

SUSY

Stable Heavy Charged Particles - Sleptons, R-Hadrons

Stopped Gluinos - R-Hadrons

Jets (b) + MET - Neutralino LSP

Mono-Lepton + MET - Neutralino LSP

OS Di-Leptons + MET - Neutralino LSP

Lepton + Photon + MET - Wino LSP

Z-Bosons + MET - Higgsino LSP

… …

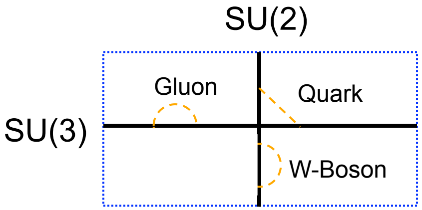
High Multiplicity + S_T Signatures Inclusive
(Black Holes)

Search First for
What You Can
Discover First

Open String Di-Jet Regge Resonances

- High p_T: $\sigma(pp \rightarrow jj)$ Largest – First Place to Look for New Physics
- String Scale $\alpha_0{}^{-1} = m_s{}^2$ Could be O(TeV)

Quarks, Gluons = Open String
Modes on D-Branes



$g_2 \neq g_3$

Open String Regge Excitations - Any Realization String Theory -

Observable for m_s = O(TeV) - Significant Modification of QCD

Tower of Excitations for Gluon, All Quarks, … g^* , q^*

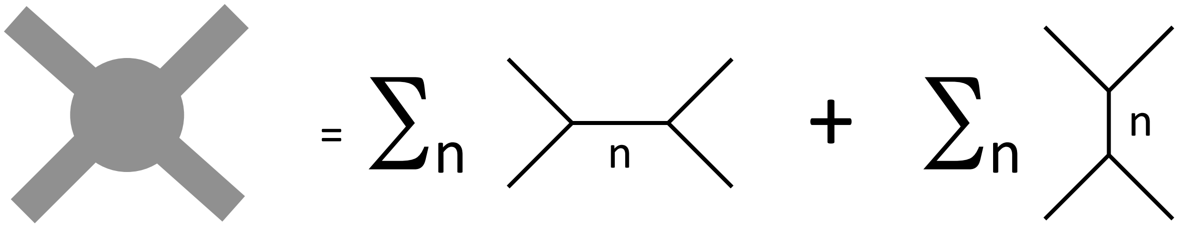
$m_n{}^2 = n\, m_s{}^2$ n=0,1,2,3,… Equally Spaced in m^2

Degenerate (up to small finite corrections)

Regge Excitation Spins ΔJ = 1,…,n

Open String Di-Jet Regge Resonances

String-String Scattering



Veneziano Form Factor

Regge Level

Spin

$$V(x,y) = \frac{\Gamma(1-x)\Gamma(1-y)}{\Gamma(1-x-y)} = \frac{x}{x+y} \sum_{n=0}^{\infty} \frac{1}{n!(x-n)} \sum_{j=0}^{n} |s(n,j)| y^{j+1}$$

$$x, y = s, t, u$$

Crossing Symmetry: x <-> y

s-Channel Resonances for Entire |Matrix Element|^2 in "All" Channels

m_s = O(TeV) - Significant Modification of Di-Jets

Open String Di-Jet Regge Resonances

2 -> 2 Scattering Amplitudes with Veneziano Form Factors

All Spin and Color Channels … $1 + 3 + 6 + 8_S + 8_A + 15 + 27$

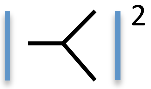
$$
\begin{aligned}
\mathcal{M}(g_a^{\pm} g_b^{\pm} \to g_c^{\pm} g_d^{\pm}) &= g^2 \frac{s^2}{stu} \Big[2sV(t,u)\, \mathbf{P}_{27}{}^{ab}{}_{cd} + 3\,(tV(s,u) - uV(s,t))\, \mathbf{P}_{8_A}{}^{ab}{}_{cd} \\
&+ \frac{5}{3} \left(tV(s,u) + uV(s,t) - \frac{4}{5} sV(t,u) \right) \mathbf{P}_{8_S}{}^{ab}{}_{cd} \\
&+ \frac{16}{3} \left(tV(s,u) + uV(s,t) - \frac{1}{8} sV(t,u) \right) \mathbf{P}_{1}{}^{ab}{}_{cd} \Big] \\
\mathcal{M}(g_a^{\pm} g_b^{\mp} \to g_c^{\pm} g_d^{\mp}) &= g^2 \frac{u^2}{stu} \Big[2sV(t,u)\, \mathbf{P}_{27}{}^{ab}{}_{cd} + 3\,(tV(s,u) - uV(s,t))\, \mathbf{P}_{8_A}{}^{ab}{}_{cd} \\
&+ \frac{5}{3} \left(tV(s,u) + uV(s,t) - \frac{4}{5} sV(t,u) \right) \mathbf{P}_{8_S}{}^{ab}{}_{cd} \\
&+ \frac{16}{3} \left(tV(s,u) + uV(s,t) - \frac{1}{8} sV(t,u) \right) \mathbf{P}_{1}{}^{ab}{}_{cd} \Big] \\
\mathcal{M}(g_a^{\pm} g_b^{\mp} \to g_c^{\mp} g_d^{\pm}) &= g^2 \frac{t^2}{stu} \Big[2sV(t,u)\, \mathbf{P}_{27}{}^{ab}{}_{cd} + 3\,(tV(s,u) - uV(s,t))\, \mathbf{P}_{8_A}{}^{ab}{}_{cd} \\
&+ \frac{5}{3} \left(tV(s,u) + uV(s,t) - \frac{4}{5} sV(t,u) \right) \mathbf{P}_{8_S}{}^{ab}{}_{cd} \\
&+ \frac{16}{3} \left(tV(s,u) + uV(s,t) - \frac{1}{8} sV(t,u) \right) \mathbf{P}_{1}{}^{ab}{}_{cd} \Big] \\
\mathcal{M}(g_a^{\pm} g_b^{\mp} \to \bar{q}_{\bar{i}}^{\mp} q_j^{\pm}) &= g^2 \frac{u}{s} \Big[\left(\sqrt{\frac{u}{t}} V(s,t) + \sqrt{\frac{t}{u}} V(s,u) \right) \left(\sqrt{\frac{5}{6}}\, \mathbf{P}_{8_S}{}^{ab}{}_{\bar{i}j} + \sqrt{\frac{8}{3}}\, \mathbf{P}_{1}{}^{ab}{}_{\bar{i}j} \right)
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{M}(g_a^{\pm} g_b^{\mp} \to \bar{q}_{\bar{i}}^{\mp} q_j^{\pm}) &= g^2 \frac{u}{s} \Big[\left(\sqrt{\frac{u}{t}} V(s,t) + \sqrt{\frac{t}{u}} V(s,u) \right) \left(\sqrt{\frac{5}{6}}\, \mathbf{P}_{8_S}{}^{ab}{}_{\bar{i}j} + \sqrt{\frac{8}{3}}\, \mathbf{P}_{1}{}^{ab}{}_{\bar{i}j} \right) \\
&+ \left(\sqrt{\frac{u}{t}} V(s,t) - \sqrt{\frac{t}{u}} V(s,u) \right) \sqrt{\frac{3}{2}}\, \mathbf{P}_{8_A}{}^{ab}{}_{\bar{i}j} \Big] \\
\mathcal{M}(g_a^{\pm} g_b^{\mp} \to \bar{q}_{\bar{i}}^{\pm} q_j^{\mp}) &= g^2 \frac{t}{s} \Big[\left(\sqrt{\frac{u}{t}} V(s,t) + \sqrt{\frac{t}{u}} V(s,u) \right) \left(\sqrt{\frac{5}{6}}\, \mathbf{P}_{8_S}{}^{ab}{}_{\bar{i}j} + \sqrt{\frac{8}{3}}\, \mathbf{P}_{1}{}^{ab}{}_{\bar{i}j} \right) \\
&+ \left(\sqrt{\frac{u}{t}} V(s,t) - \sqrt{\frac{t}{u}} V(s,u) \right) \sqrt{\frac{3}{2}}\, \mathbf{P}_{8_A}{}^{ab}{}_{\bar{i}j} \Big] \\
\mathcal{M}(q_i^{\pm} g_a^{\pm} \to q_j^{\pm} g_b^{\pm}) &= g^2 \frac{s}{t} \Big[\sqrt{-\frac{u}{s}} V(s,t) (\, \mathbf{P}_{15}{}^{ai}{}_{bj} - \, \mathbf{P}_{\bar{6}}{}^{ai}{}_{bj}) \\
&- \frac{1}{3} \left(\sqrt{-\frac{u}{s}} V(s,t) + 8 \sqrt{-\frac{s}{u}} V(t,u) \right) \mathbf{P}_{3}{}^{ai}{}_{bj} \Big] \\
\mathcal{M}(q_i^{\pm} g_a^{\mp} \to q_j^{\pm} g_b^{\mp}) &= g^2 \frac{u}{t} \Big[\sqrt{-\frac{u}{s}} V(s,t) (\, \mathbf{P}_{15}{}^{ai}{}_{bj} - \, \mathbf{P}_{\bar{6}}{}^{ai}{}_{bj}) \\
&- \frac{1}{3} \left(\sqrt{-\frac{u}{s}} V(s,t) + 8 \sqrt{-\frac{s}{u}} V(t,u) \right) \mathbf{P}_{3}{}^{ai}{}_{bj} \Big] \\
\mathcal{M}(q_i^{\pm} \bar{q}_{\bar{j}}^{\mp} \to q_k^{\pm} \bar{q}_{\bar{\ell}}^{\mp}) &= g^2 \Big[\left(\frac{u}{s} - \frac{u}{3t} \right) \mathbf{P}_{8}{}^{i\bar{j}}{}_{k\bar{\ell}} + \frac{8u}{3t}\, \mathbf{P}_{1}{}^{i\bar{j}}{}_{k\bar{\ell}} \Big] V(s,t)
\end{aligned}
$$

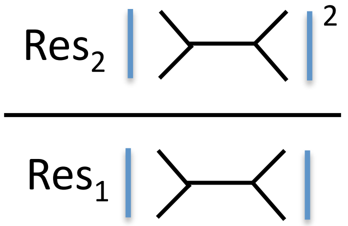
Open String Di-Jet Regge Resonances

Improve Scattering Amplitudes for Leading Re-scattering Effects - Finite Width of Resonances

Modified Optical Theorem:



$$= \frac{1}{m_s}\Gamma(\text{Initial} \rightarrow R^{(1)} \rightarrow \text{All}) = m_s^2\,\frac{\text{Res}_2[\sigma(\text{Initial} \rightarrow R^{(1)} \rightarrow \text{All})]}{\text{Res}_1[\mathcal{M}(\text{Initial} \rightarrow \text{Initial})]} =$$



$$\begin{aligned}
\frac{1}{m_s}\Gamma(q_i^{\pm} g_a^{\pm} \rightarrow R^{(1)} \rightarrow \text{All}) &= \alpha_s\left(\frac{1}{8}\,\mathbf{P_{15}}^{ai} + \frac{1}{8}\,\mathbf{P_{\bar{6}}}^{ai} + \frac{1}{24}\,\mathbf{P_{3}}^{ai}\right) \\
\frac{1}{m_s}\Gamma(q_i^{\pm} g_a^{\mp} \rightarrow R^{(1)} \rightarrow \text{All}) &= \alpha_s\left(\frac{1}{16}\,\mathbf{P_{15}}^{ai} + \frac{1}{16}\,\mathbf{P_{\bar{6}}}^{ai} + \frac{1}{48}\,\mathbf{P_{3}}^{ai}\right) \\
\frac{1}{m_s}\Gamma(g_a^{\pm} g_b^{\mp} \rightarrow R^{(1)} \rightarrow \text{All}) &= \alpha_s\left(\frac{19}{60}\,\mathbf{P_{8_S}}^{ab} + \frac{41}{60}\,\mathbf{P_{1}}^{ab}\right) \\
\frac{1}{m_s}\Gamma(q_i^{\pm} \bar{q}_{\bar{j}}^{\mp} \rightarrow R^{(n)} \rightarrow \text{All}) &= \alpha_s\left(\frac{79}{360}\,\mathbf{P_{8}}^{i\bar{j}} + \frac{49}{180}\,\mathbf{P_{1}}^{i\bar{j}}\right)
\end{aligned}$$

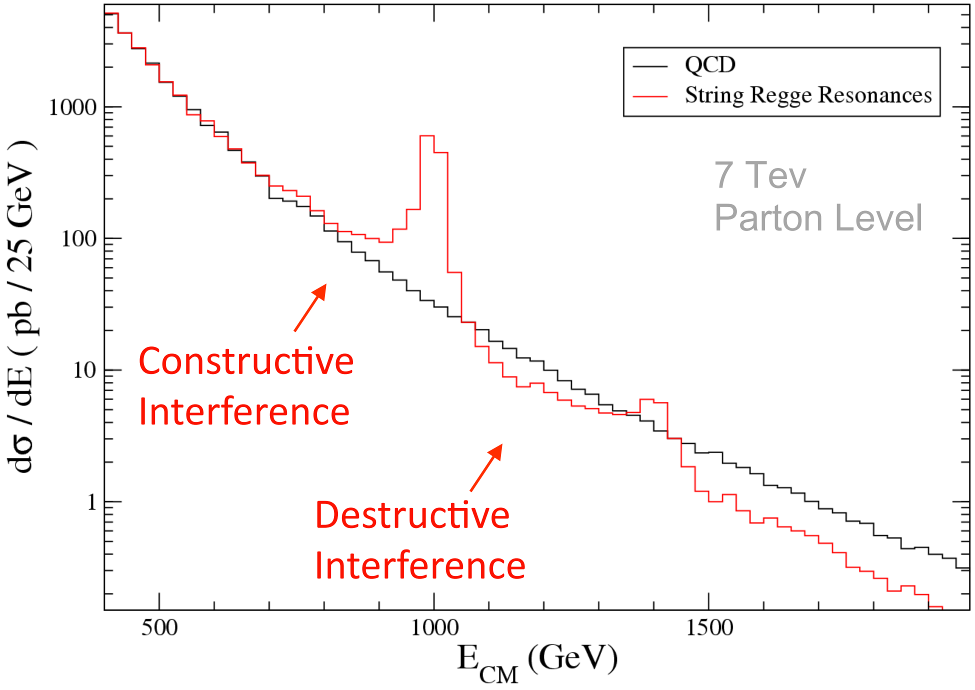
$$\frac{|V(s,y)|^2}{y^2} \simeq \frac{1}{(s - m_s^2)^2 + m_s^2\Gamma^2}$$

Includes Effects of Coherence Quantum Interference Among Regge Resonances of Different Spin and Intereference with Continuum

Open String Di-Jet Regge Resonances

Incorporate Improved Veneziano Amplitudes into Veneziano Monte Carlo (VMC)
(non-trivial Hack of Pythia – Reduces to Pythia 2->2 Scattering for m_s -> large)

(Can Kilic)



Constructive Interference

Destructive Interference

1st Resonance BIG –

“All” Color and Kinematic Channels
Gluon, All Quarks
Multiple Spins – Add Coherently

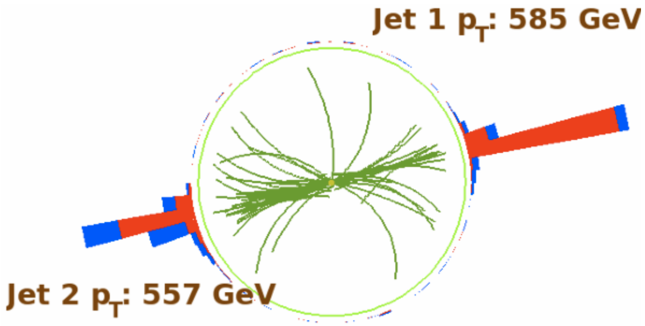
m_n^2 Spacing

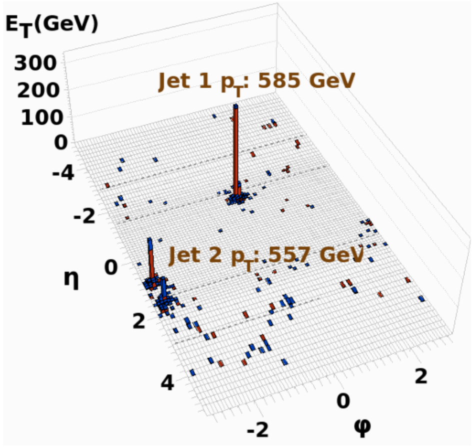
Γ_n Grow Rapidly with n

Constructive-Destructive .
Opposite Standard g^*, q^*

Essentially Model Independent Probe of String Theory

Open String Di-Jet Regge Resonances

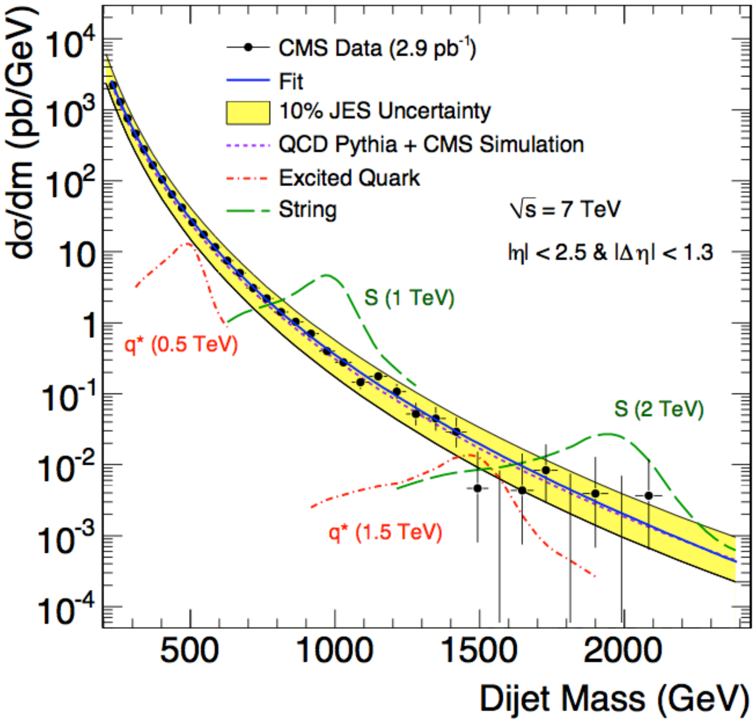


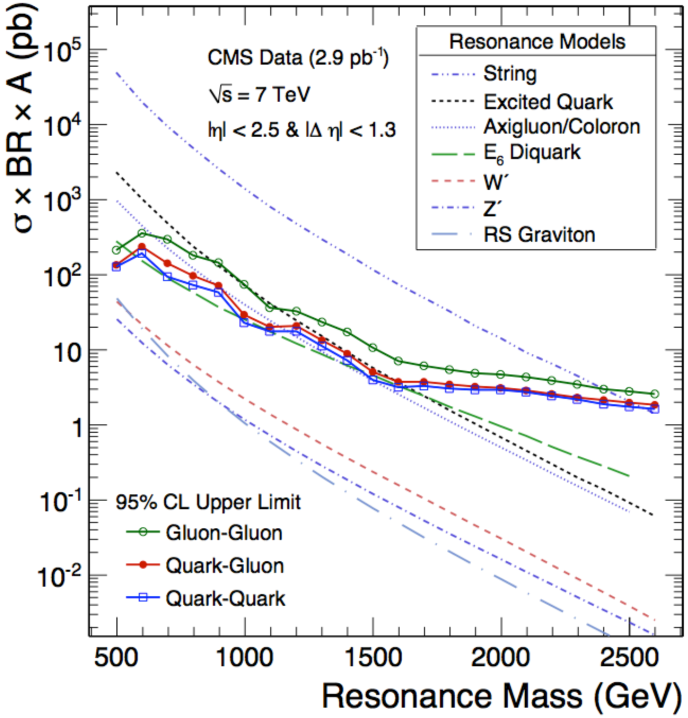


Direct Test of String Theory

$m_s > 2.4$ TeV

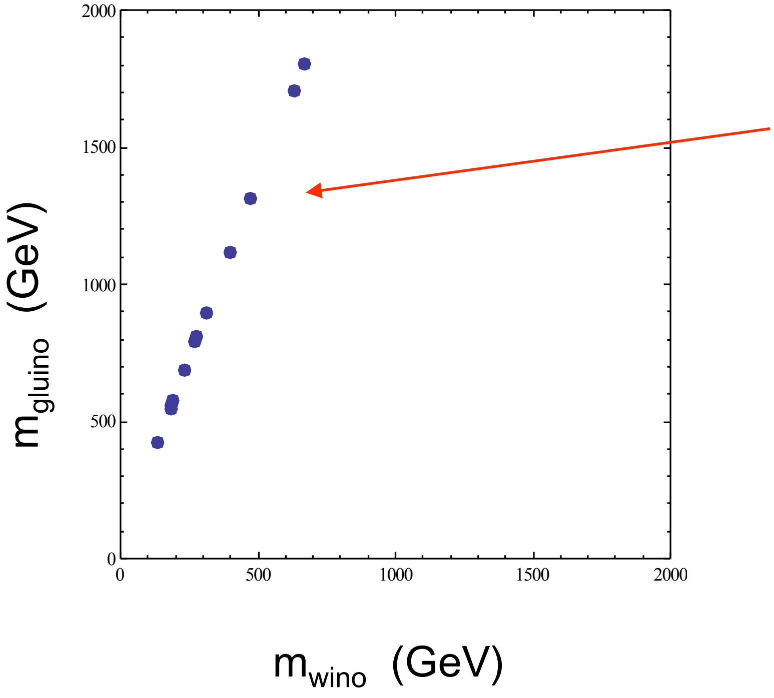
(Eventually - Contact Interaction)





SUSY: Search First for What You Can Discover First

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

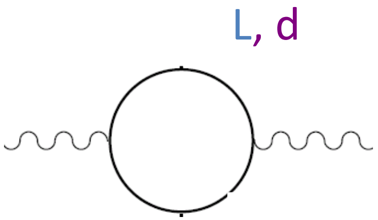
(Gaugino Unification)

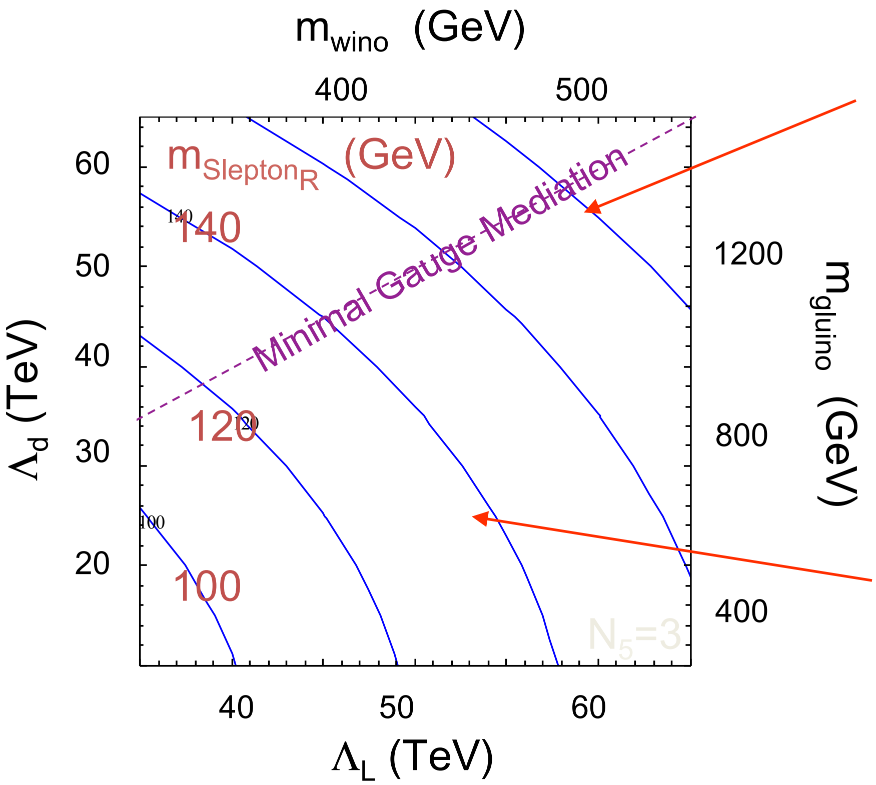
SUSY: Search First for What You Can Discover First

- Strong Production -> Relatively Low Background Final States
- Parameterize with Simple Production and Decay Topologies
  (Details at end of talk)

Gauge Mediation with Split Messegners

Independent SUSY Breaking for Minimal Messengers



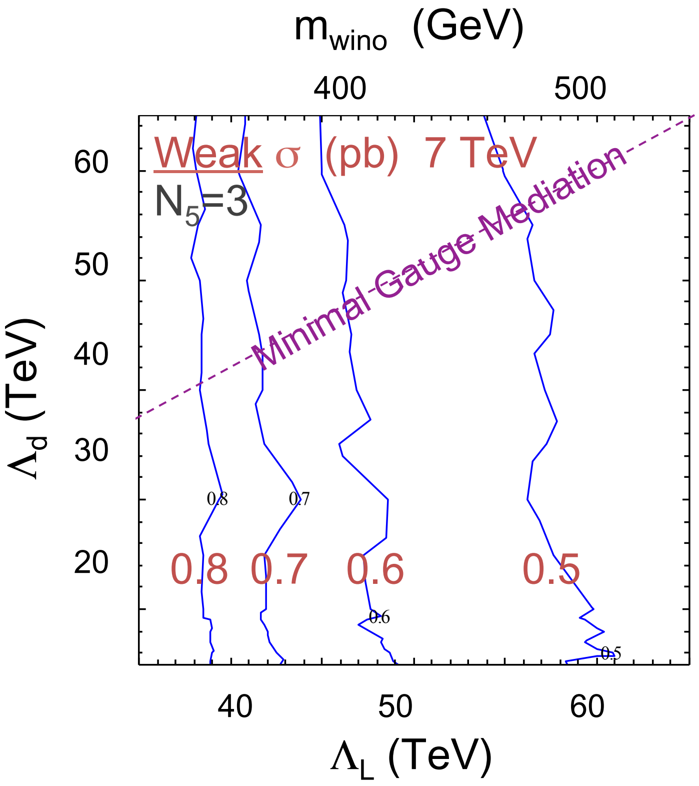


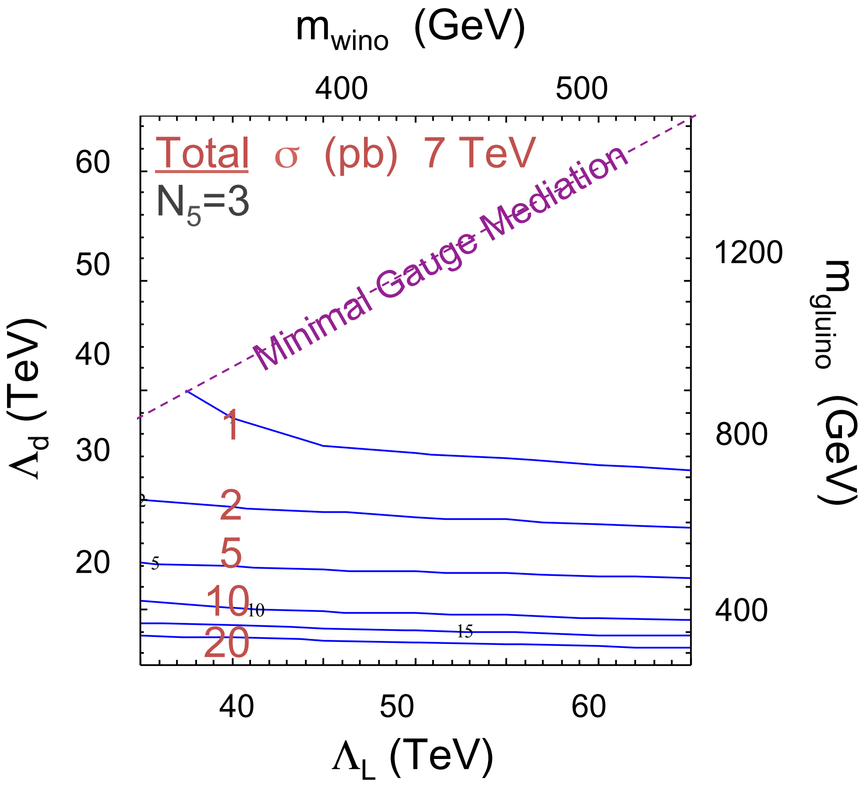
Stretched Gauge Ordered Spectra

Compressed Gauge Ordered Spectra

Benchmark Points, .
Lines/Slopes, .
Manifolds

Gauge Mediation with Split Messegners



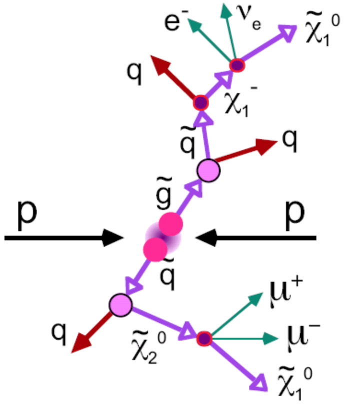


(Most of Plane Not Excluded by Tevatron)

General New Physics (SUSY) Searches

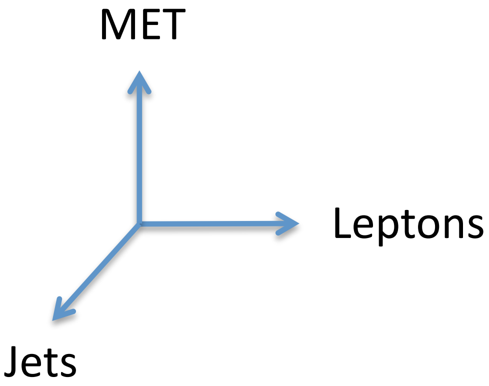
Far Too Many Scenarios –
Mass Orderings, …

Organize by Signatures
(Dictated by Backgrounds)



High p_T Isolated Objects:

Jets
b-Jets
Electrons
Muons
Taus
Z-Bosons
Photons
MET
Top Quarks



MET

Leptons

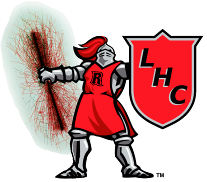
Jets

Non-Isolated Interesting Also …

CMS SUSY Matrix

	Multi-Jet	Hadronic	Single Lepton	OS di-Lepton	SS di-Lepton	Lepton-Photon	Di-Photon	Multi-Lepton
No MET	X							X
With MET		X				X	X	X
With HT					(X)			X
With MET +HT			X	X	X			

X = Rutgers =

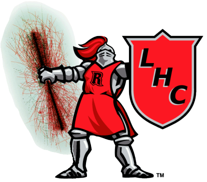


CMS SUSY Matrix

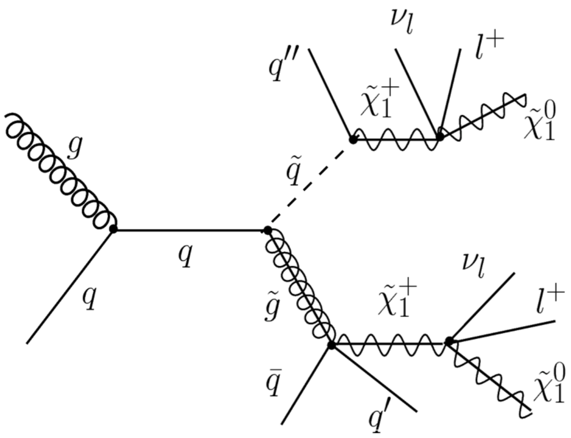
	Multi-Jet	Hadronic	Single Lepton	OS di-Lepton	SS di-Lepton	Lepton-Photon	Di-Photon	Multi-Lepton
No MET	Ⓧ							Ⓧ
With MET		X			Ⓧ	X	Ⓧ	Ⓧ
With HT					(X)			Ⓧ
With MET +HT			X	X	Ⓧ			

○ Discuss today

X = Rutgers =



Same Sign Di-Leptons



SS Di-Leptons

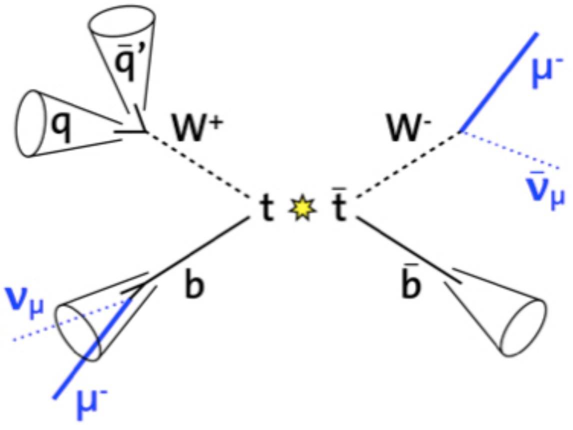
+ MET

or + JET

Relatively Low SM Backgrounds

Same Sign Di-Leptons

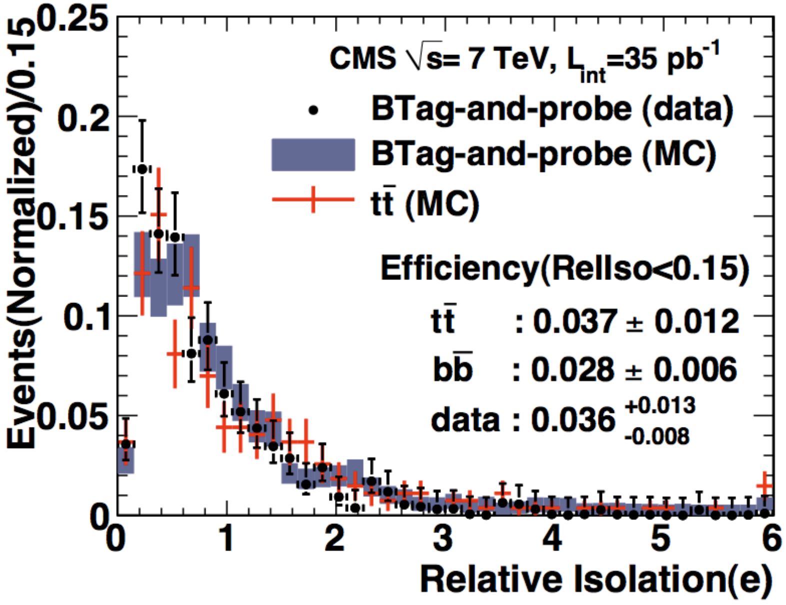
Dominant Physics Background ttbar

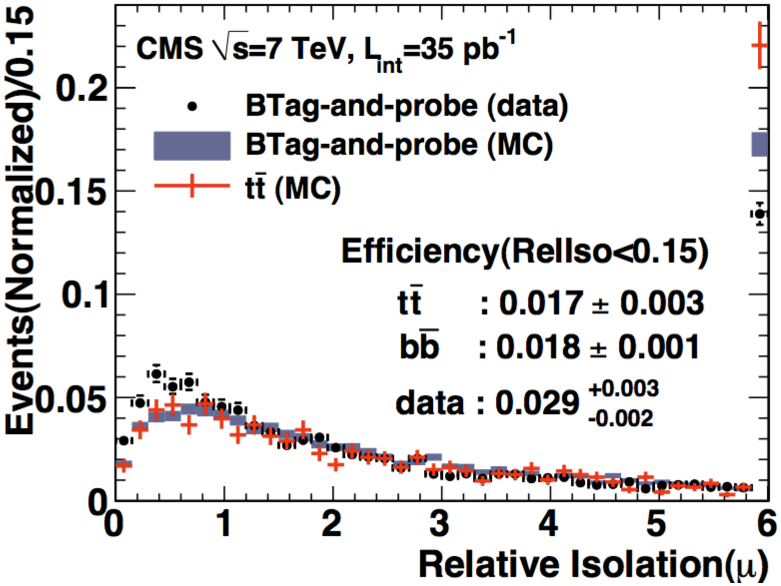


Measure Rel Isolation - Tag+Probe

Extrapolate in Isolation

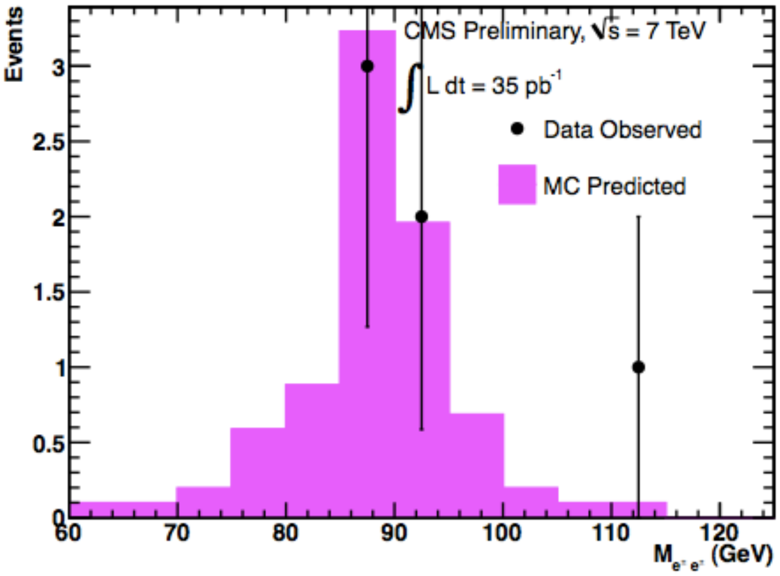
Control Region -> Signal Region



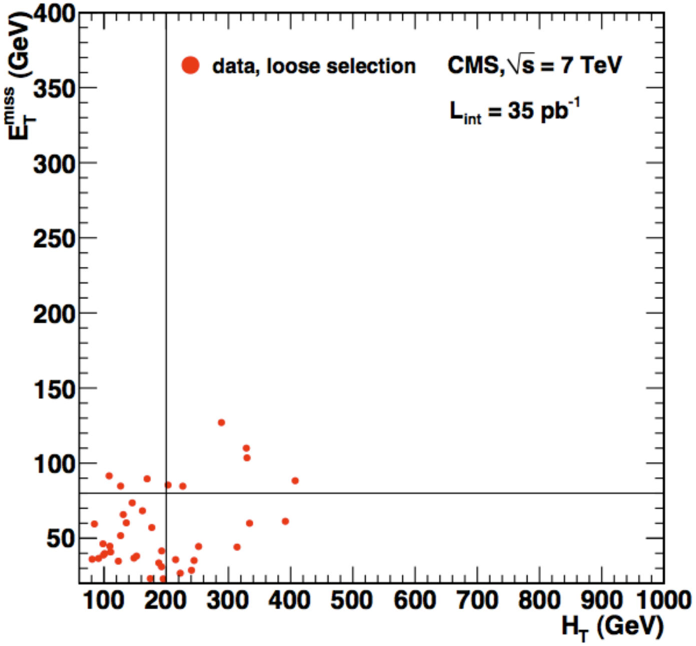


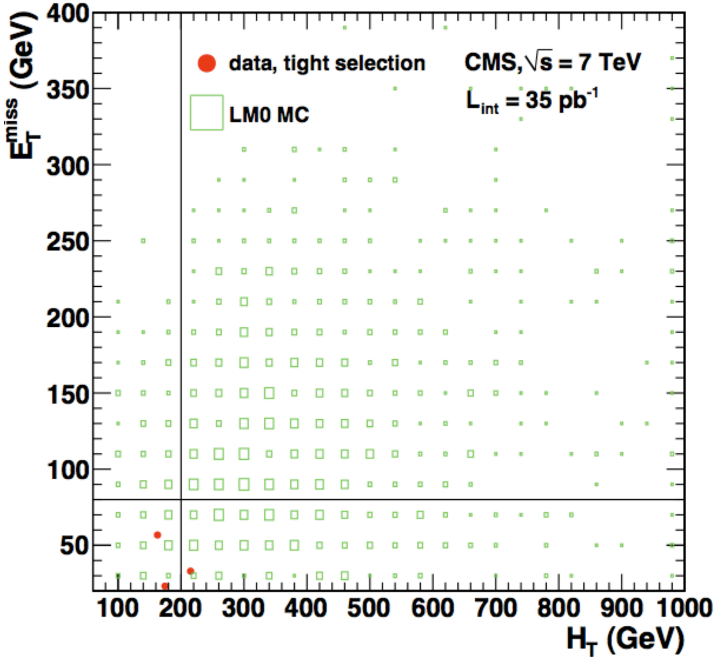
Same Sign Di-Leptons

Electron Charge Mis-Identification Rate



Same Sign Di-Leptons

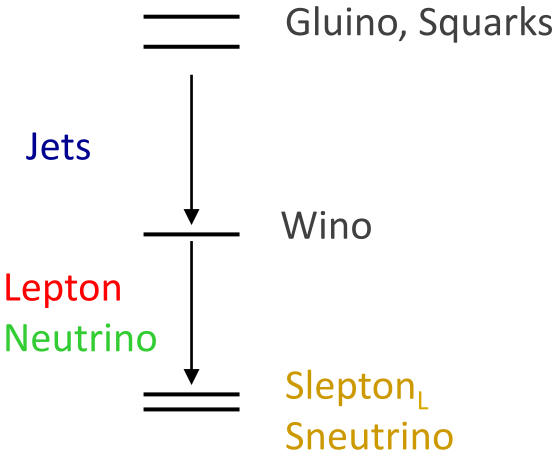




Search Region	ee	$\mu\mu$	$e\mu$	total	95% CL UL Yield
Lepton Trigger					
$E_T^{miss} > 80$ GeV					
MC	0.05	0.07	0.23	0.35	
predicted BG	$\mathbf{0.23^{+0.35}_{-0.23}}$	$\mathbf{0.23^{+0.26}_{-0.23}}$	**0.74 ± 0.55**	**1.2 ± 0.8**	
observed	**0**	**0**	**0**	**0**	**3.1**
$H_T > 200$ GeV					
MC	0.04	0.10	0.17	0.32	
predicted BG	**0.71 ± 0.58**	$\mathbf{0.01^{+0.24}_{-0.01}}$	$\mathbf{0.25^{+0.27}_{-0.25}}$	**0.97 ± 0.74**	
observed	**0**	**0**	**1**	**1**	**4.3**

Same Sign Di-Leptons

Production + Decay Topology:



Gluino, Squarks

Jets

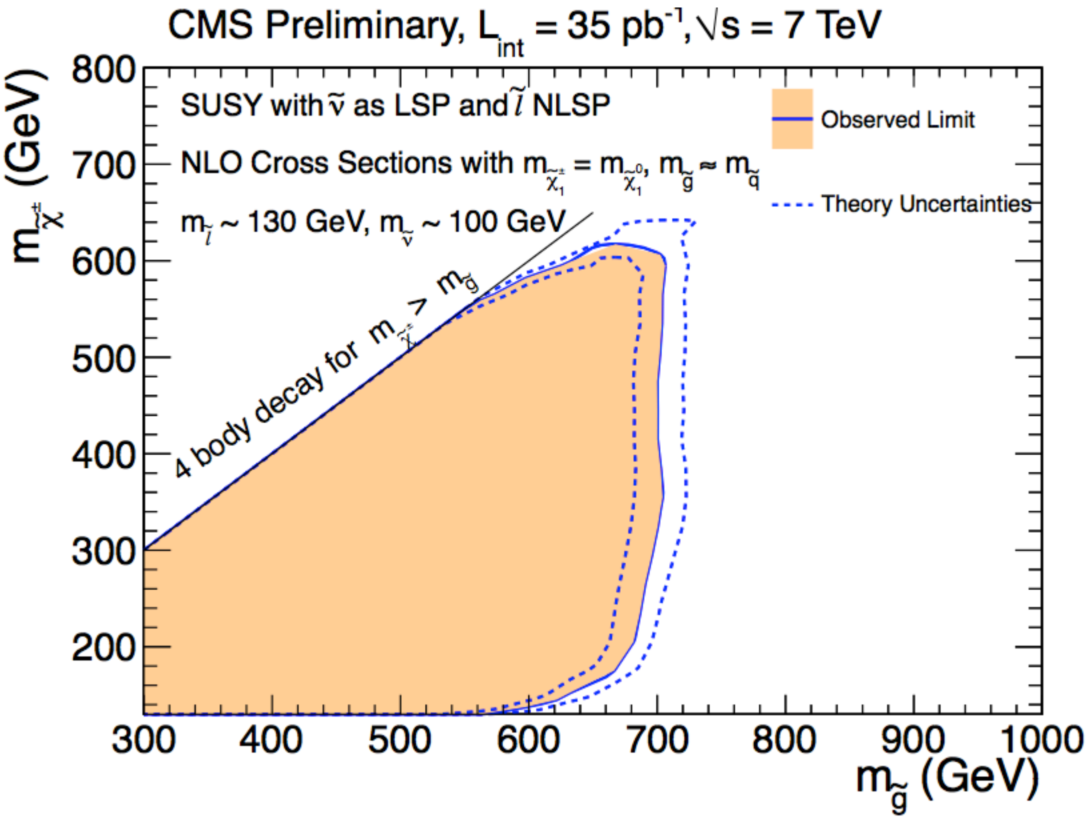
Wino

Lepton

Neutrino

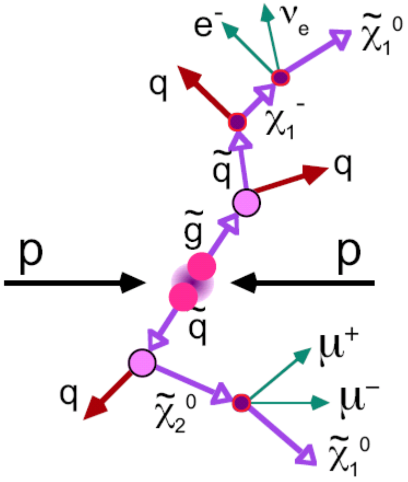
Slepton$_L$

Sneutrino



Br(All -> SS) = 1/8

Multi-Leptons



3 or 4 or more Leptons

+ MET

or + JET

Relatively Low SM Backgrounds

Classic Tri-Lepton Signature – CMS Considerably Expanded Scope

(Tevatron Searches Narrowly Focussed – mSUGRA signature)

Multi-Leptons

Backgrounds Depend to a Large Degree on Di-Lepton Pairs Type within Multi-leptons:

	DY	Correlated $Q = 0$ CC Decays	Uncorrelated CC Decays
OSSF	×	×	×
OSOF		×	×
SSSF			×
SSOF			×

$$\begin{aligned} \text{OSSF} &\equiv \ell^{\pm}\ell^{\mp} \\ \text{OSOF} &\equiv \ell^{\pm}\ell'^{\mp} \\ \text{SSSF} &\equiv \ell^{\pm}\ell^{\pm} \\ \text{SSOF} &\equiv \ell^{\pm}\ell'^{\pm} \end{aligned}$$

$$(N_X, N_Y)_{\text{min}Z} \equiv \ \{ \ (N_{(\ell_a\ell_b)|X}, N_{(\ell_a\ell_b)|Y}) \ \ \forall \ \ (\ell_i\ell_j)(\ell_k\ell_\ell)\cdots\ell_p \ \in \ \ell_1\ell_2\cdots\ell_n$$

$$| \ \min \ N_{(\ell_a\ell_b)|X,Y\neq Z} \ | \ \min \ N_{(\ell_a\ell_b)|Z} \ \} \quad \text{for } X, Y, Z = \text{SS}, \text{OSOF}$$

$$\mathcal{N}_{\text{OSSF}} \equiv \sum_{\substack{(\ell_i\ell_j)(\ell_k\ell_\ell)\cdots\ell_p \\ \in \ \ell_1\ell_2\cdots\ell_n}} N_{(\ell_a\ell_b)|\text{OSSF}}$$

$$N_{\text{DY}} \equiv \ \{ \ \max \ N_{(\ell_a\ell_b)|\text{OSSF}} \ \ \forall \ \ (\ell_i\ell_j)(\ell_k\ell_\ell)\cdots\ell_p \ \in \ \ell_1\ell_2\cdots\ell_n \ \}$$

Multi-Leptons

Classify All Multi-Leptons Channels:

Hierarchy of Backgrounds

	$\lvert Q\rvert$	$N_{\rm DY}$	$\mathcal{N}_{\rm OSSF}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minSS}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minOSOF}$
$\ell^\pm\ell^\pm\ell^\pm\ell^\pm$	4	0	0	(2 , 0)	(2 , 0)
$\ell^\pm\ell^\pm\ell^\pm\ell'^\pm$	4	0	0	(2 , 0)	(2 , 0)
$\ell^\pm\ell^\pm\ell'^\pm\ell'^\pm$	4	0	0	(2 , 0)	(2 , 0)
$\ell^\pm\ell^\pm\ell^\pm\ell'^\mp$	2	0	0	(1 , 1)	(1 , 1)
$\ell^+\ell^+\ell'^-\ell'^-$	0	0	0	(0 , 2)	(2 , 0)
$\ell^\pm\ell^\pm\ell'^+\ell'^-$	2	1	1	(1 , 0)	(1 , 0)
$\ell^+\ell^-\ell^\pm\ell'^\pm$	2	1	2	(1 , 0)	(1 , 0)
$\ell^+\ell^-\ell^\pm\ell^\pm$	2	1	3	(1 , 0)	(1 , 0)
$\ell^+\ell^-\ell^\pm\ell'^\mp$	0	1	2	(0 , 1)	(2 , 0)
$\ell^+\ell^-\ell'^+\ell'^-$	0	2	2	(0 , 0)	(0 , 0)
$\ell^+\ell^-\ell^+\ell^-$	0	2	4	(0 , 0)	(0 , 0)

Multi-Leptons

Classify All Multi-Leptons Channels:

Hierarchy of Backgrounds

	$\lvert Q\rvert$	$N_{\rm DY}$	$\mathcal{N}_{\rm OSSF}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minSS}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minOSOF}$
$\ell^\pm\ell^\pm\ell^\pm$	3	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell^\pm\ell'^\pm$	3	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell^\pm\ell'^\mp$	1	0	0	(0 , 1)	(1 , 0)
$\ell^+\ell^-\ell'^\pm$	1	1	1	(0 , 0)	(0 , 0)
$\ell^+\ell^-\ell^\pm$	1	1	2	(0 , 0)	(0 , 0)
$\ell^\pm\ell^\pm$	2	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell'^\pm$	2	0	0	(1 , 0)	(1 , 0)
$\ell^+\ell'^-$	0	0	0	(0 , 1)	(0 , 1)
$\ell^+\ell^-$	0	1	1	(0 , 0)	(0 , 0)

Multi-Leptons

Classify All Multi-Leptons Channels:

Hierarchy of Backgrounds

	$\|Q\|$	$N_{\rm DY}$	$\mathcal{N}_{\rm OSSF}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minSS}$	$(N_{\rm SS}, N_{\rm OSOF})_{\rm minOSOF}$
$\ell^\pm\ell^\pm\ell^\pm\tau_h^\pm$	4	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell^\pm\ell'^\pm\tau_h^\pm$	4	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell^\pm\ell^\pm\tau_h^\mp$	2	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell^\pm\ell'^\pm\tau_h^\mp$	2	0	0	(1 , 0)	(1 , 0)
$\ell^\pm\ell^\pm\ell'^\mp\tau_h^\pm$	2	0	0	(0 , 1)	(1 , 0)
$\ell^\pm\ell^\pm\ell'^\mp\tau_h^\mp$	0	0	0	(0 , 1)	(1 , 0)
$\ell^+\ell^-\ell'^\pm\tau_h^\pm$	2	1	1	(0 , 0)	(0 , 0)
$\ell^+\ell^-\ell^\pm\tau_h^\pm$	2	1	2	(0 , 0)	(0 , 0)
$\ell^+\ell^-\ell'^\pm\tau_h^\mp$	0	1	1	(0 , 0)	(0 , 0)
$\ell^+\ell^-\ell^\pm\tau_h^\mp$	0	1	2	(0 , 0)	(0 , 0)

Multi-Leptons

Classify All Multi-Leptons Channels:

Hierarchy of Backgrounds

Make Hierarchical Ordering of Multi-Lepton Channels according to Background

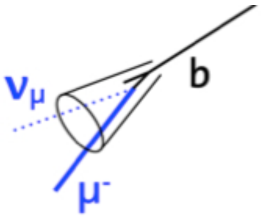
Events -> Channels Lowest to Highest Background Exclusively

Exclusive Combination of All Channels

Multi-Leptons

Backgrounds for Many Chananels

fake leptons +
leptons from heavy flavor



Semi-Automated Combined Fakeable Object
Using d_{xy} impact parameter as probe of heavy flavor content

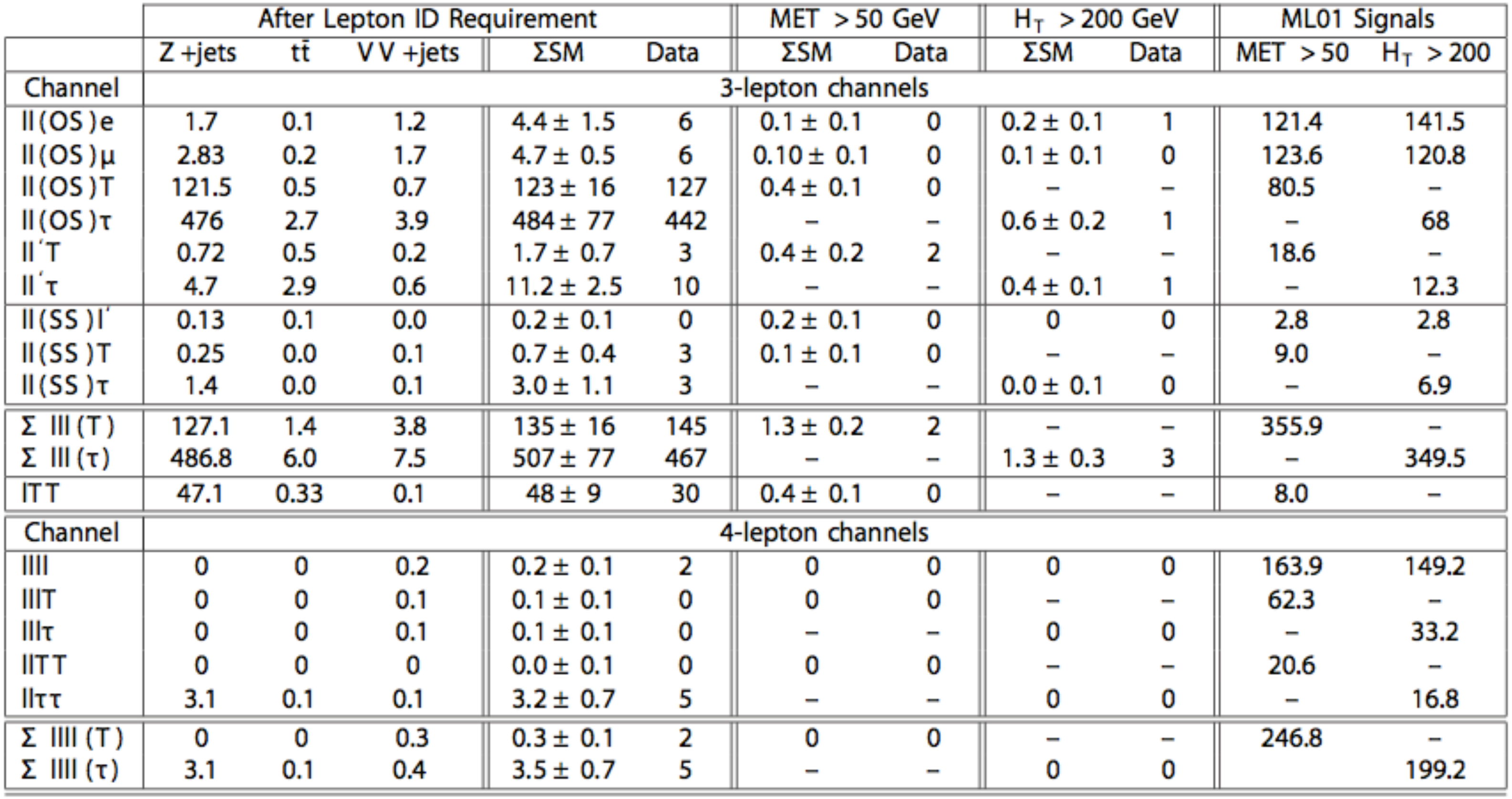
Utilizes moderate to high statistics of QCD control

$$f_\mu = \frac{N_\mu^{\mathrm{ISO}}}{N_T^{\mathrm{ISO}}} = \frac{N_\mu}{N_T} \cdot \frac{\epsilon_{\mathrm{ISO}}^{\mu}}{\epsilon_{\mathrm{ISO}}^{T}}$$

Multi-Leptons

Data:

157 Exclusive Channels ->

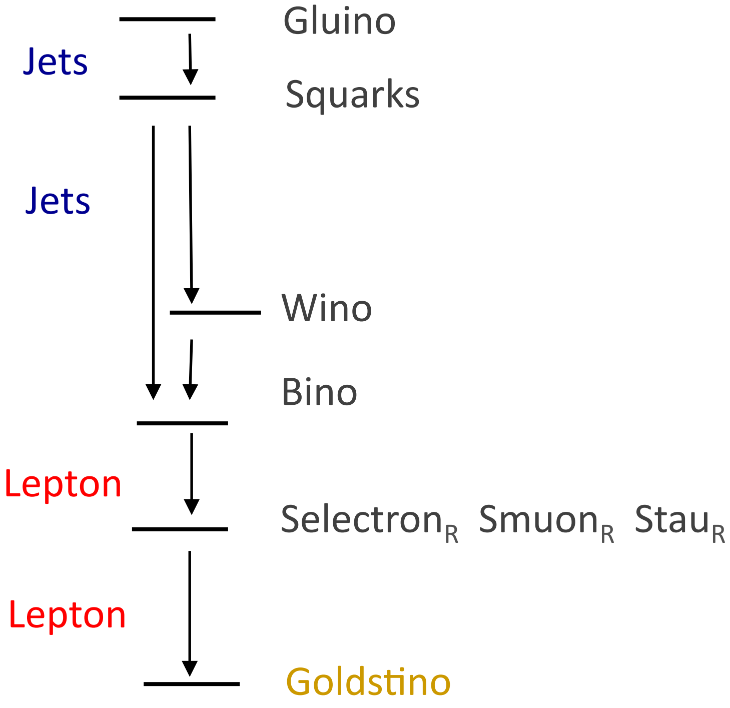


	After Lepton ID Requirement					MET > 50 GeV		H_T > 200 GeV		ML01 Signals	
	Z +jets	$t\bar{t}$	V V +jets	ΣSM	Data	ΣSM	Data	ΣSM	Data	MET > 50	H_T > 200
Channel	3-lepton channels										
ll(OS)e	1.7	0.1	1.2	4.4 ± 1.5	6	0.1 ± 0.1	0	0.2 ± 0.1	1	121.4	141.5
ll(OS)μ	2.83	0.2	1.7	4.7 ± 0.5	6	0.10 ± 0.1	0	0.1 ± 0.1	0	123.6	120.8
ll(OS)T	121.5	0.5	0.7	123 ± 16	127	0.4 ± 0.1	0	–	–	80.5	–
ll(OS)τ	476	2.7	3.9	484 ± 77	442	–	–	0.6 ± 0.2	1	–	68
ll′T	0.72	0.5	0.2	1.7 ± 0.7	3	0.4 ± 0.2	2	–	–	18.6	–
ll′τ	4.7	2.9	0.6	11.2 ± 2.5	10	–	–	0.4 ± 0.1	1	–	12.3
ll(SS)l′	0.13	0.1	0.0	0.2 ± 0.1	0	0.2 ± 0.1	0	0	0	2.8	2.8
ll(SS)T	0.25	0.0	0.1	0.7 ± 0.4	3	0.1 ± 0.1	0	–	–	9.0	–
ll(SS)τ	1.4	0.0	0.1	3.0 ± 1.1	3	–	–	0.0 ± 0.1	0	–	6.9
Σ lll(T)	127.1	1.4	3.8	135 ± 16	145	1.3 ± 0.2	2	–	–	355.9	–
Σ lll(τ)	486.8	6.0	7.5	507 ± 77	467	–	–	1.3 ± 0.3	3	–	349.5
lTT	47.1	0.33	0.1	48 ± 9	30	0.4 ± 0.1	0	–	–	8.0	–
Channel	4-lepton channels										
llll	0	0	0.2	0.2 ± 0.1	2	0	0	0	0	163.9	149.2
lllT	0	0	0.1	0.1 ± 0.1	0	0	0	–	–	62.3	–
lllτ	0	0	0.1	0.1 ± 0.1	0	–	–	0	0	–	33.2
llTT	0	0	0	0.0 ± 0.1	0	0	0	–	–	20.6	–
llττ	3.1	0.1	0.1	3.2 ± 0.7	5	–	–	0	0	–	16.8
Σ llll(T)	0	0	0.3	0.3 ± 0.1	2	0	0	–	–	246.8	–
Σ llll(τ)	3.1	0.1	0.4	3.5 ± 0.7	5	–	–	0	0		199.2

Combine Exclusive Channels

Multi-Leptons: Slepton Co-NLSP (GMSB)

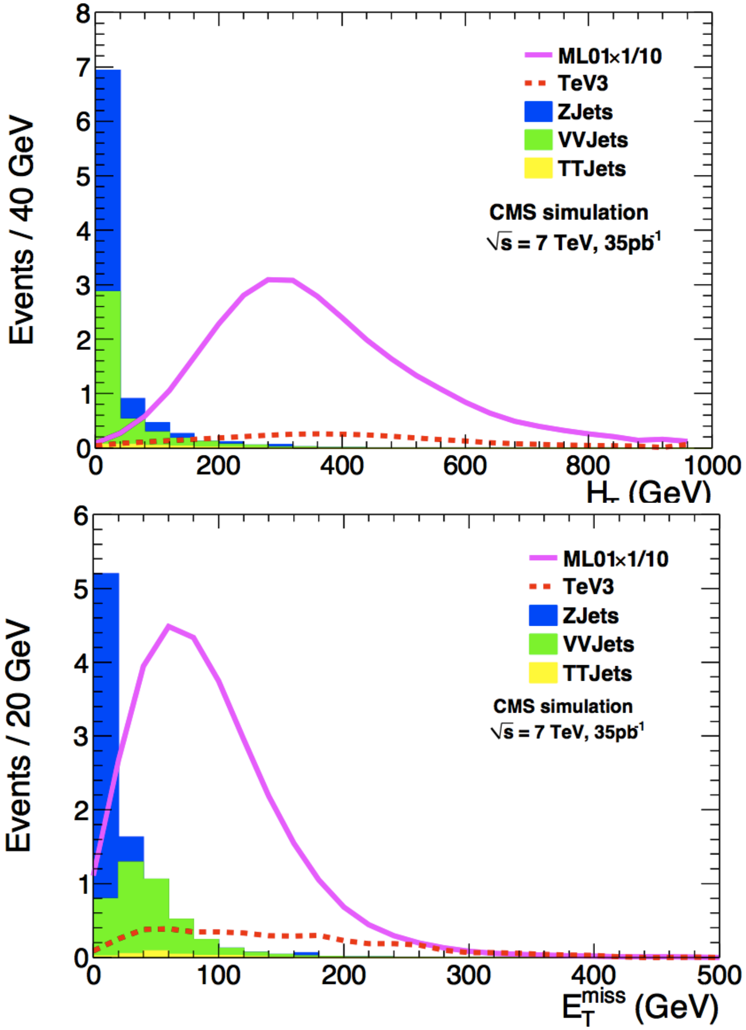
Production + Decay Topology:



Br(All -> 4 Leptons) = 1

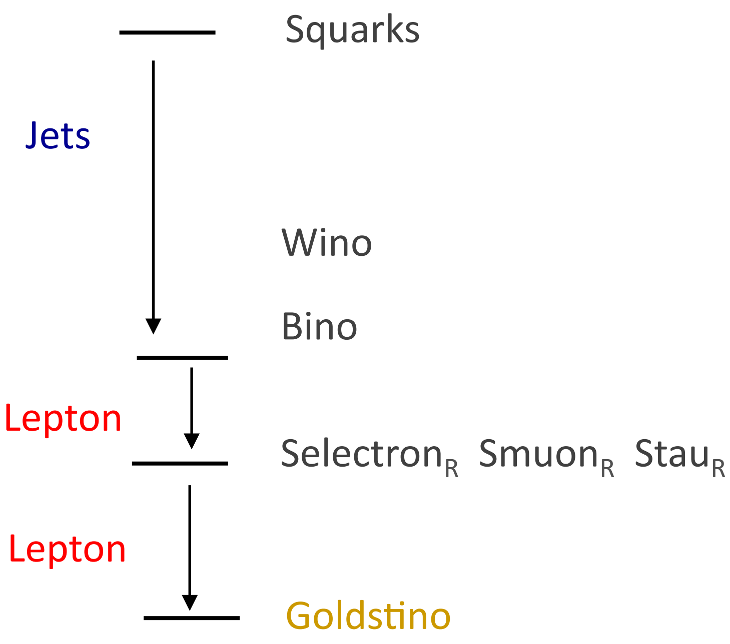
New Territory – First few pb^{-1}

m_{gluino} = 450 GeV
m_{squark} = 360 GeV



Multi-Leptons: Slepton Co-NLSP (GMSB)

Production + Decay Topology:


Squarks

Jets

Wino

Bino

Lepton

Selectron_R Smuon_R Stau_R

Lepton

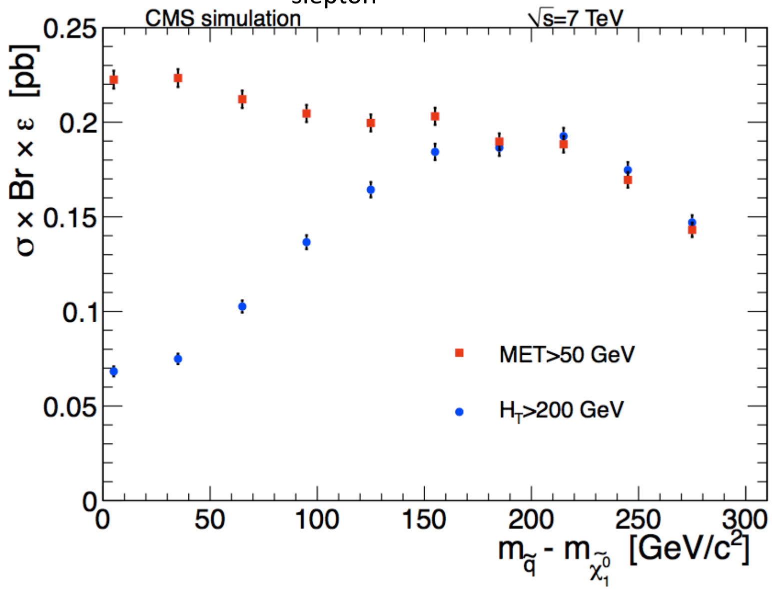
Goldstino

Br(All -> 4 Leptons) = 1

Require MET or HT if necessary
in Given Lepton Channel

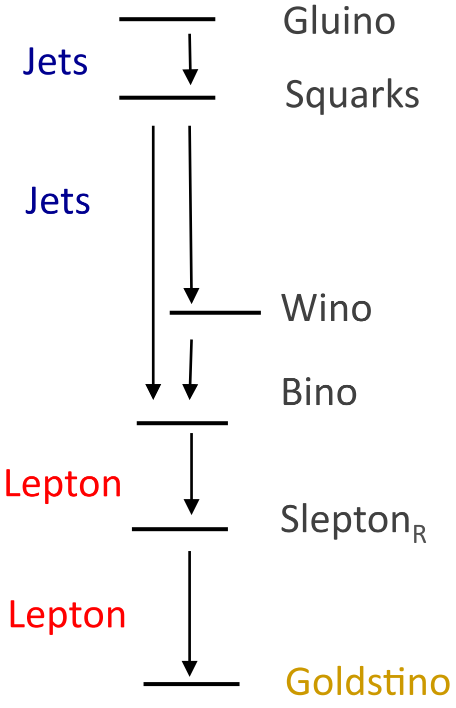
But Not Both

m_{squark} = 500 GeV
$m_{slepton}$ = 185 GeV



Multi-Leptons: Slepton Co-NLSP (GMSB)

Production + Decay Topology:



Gluino

Jets

Squarks

Jets

Wino

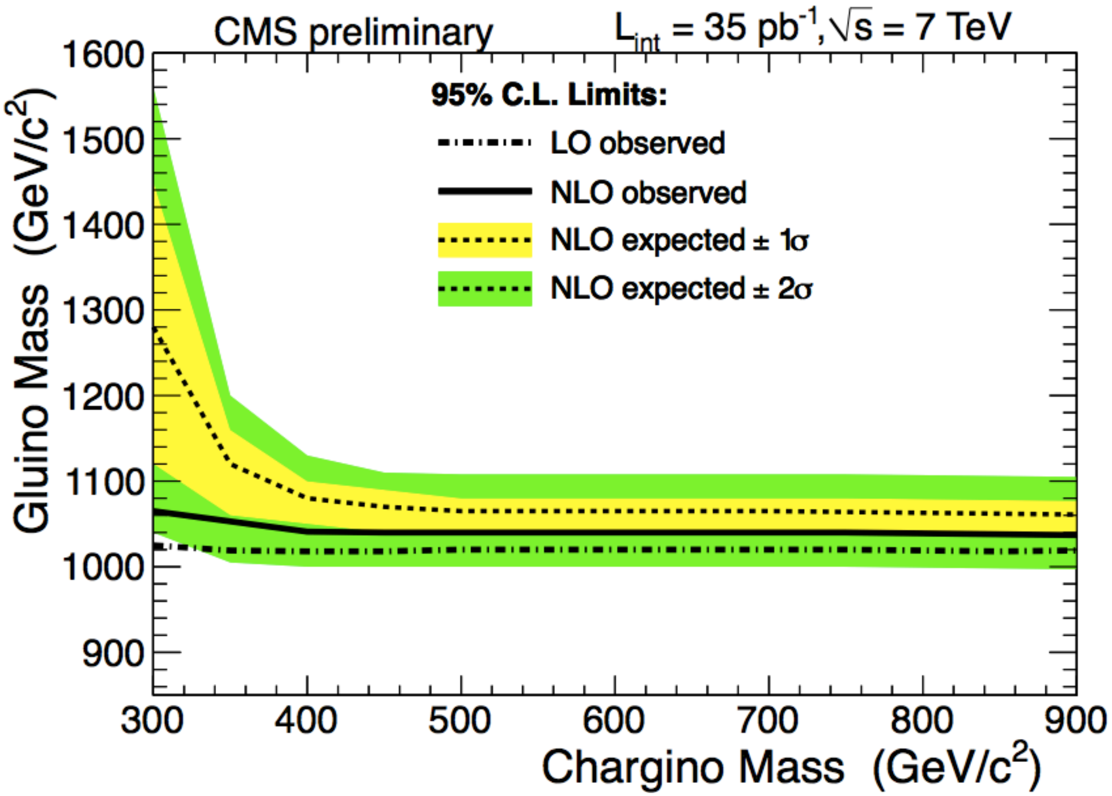
Bino

Lepton

Slepton$_R$

Lepton

Goldstino

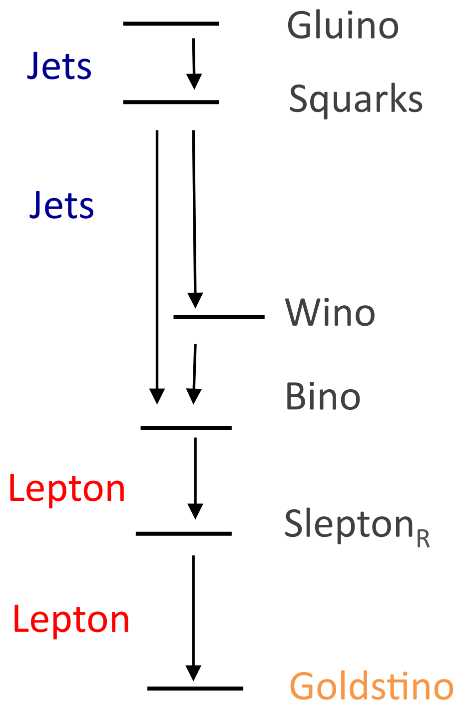


Br(All -> 4 Leptons) = 1

New Territory – First few pb^{-1}

Multi-Leptons: Slepton Co-NLSP (GMSB)

Production + Decay Topology:



Gluino

Jets

Squarks

Jets

Wino

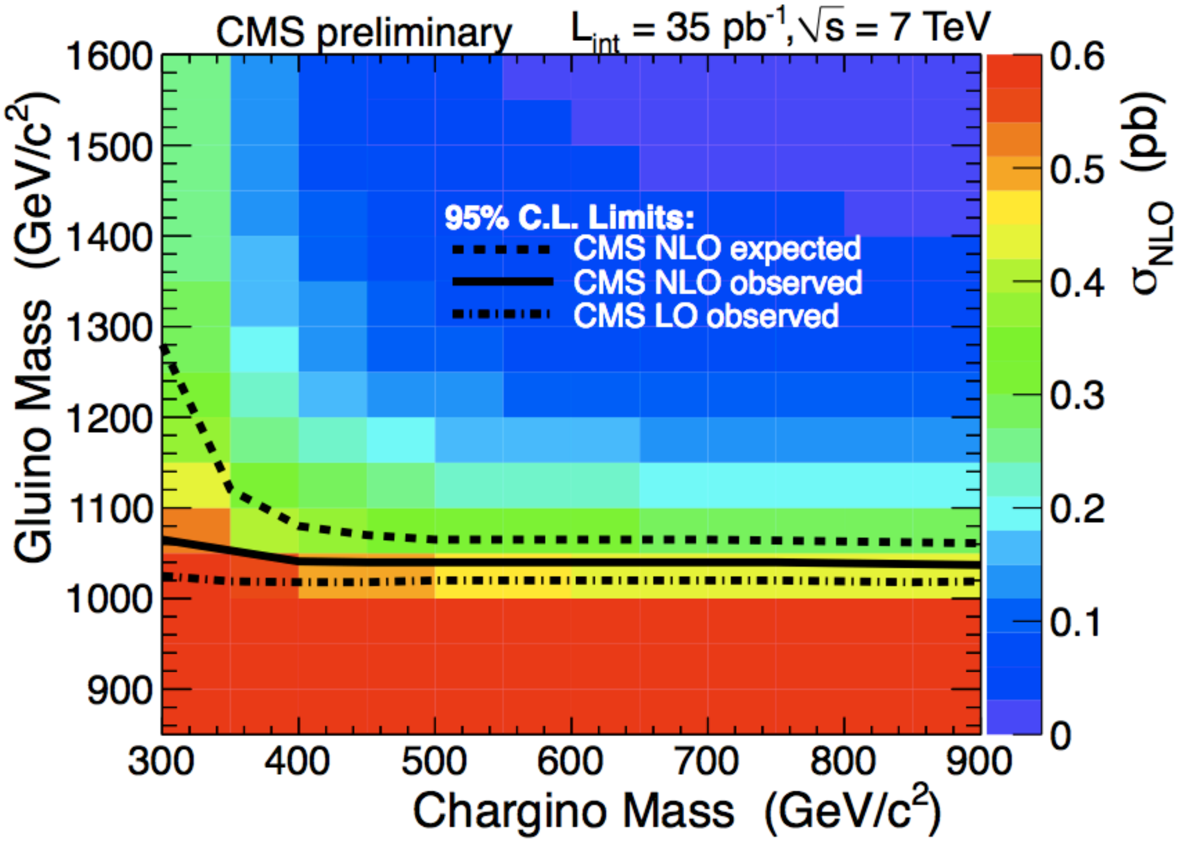
Bino

Lepton

Slepton_R

Lepton

Goldstino



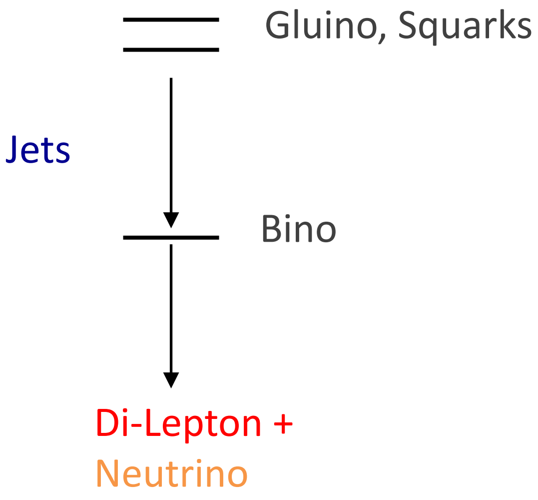
Br(All -> 4 Leptons) = 1

New Territory – First few pb^{-1}

Multi-Leptons: Leptonic R-Parity Violation

Production + Decay Topology:

$W = \lambda_{ijk} L_i L_j e_k$

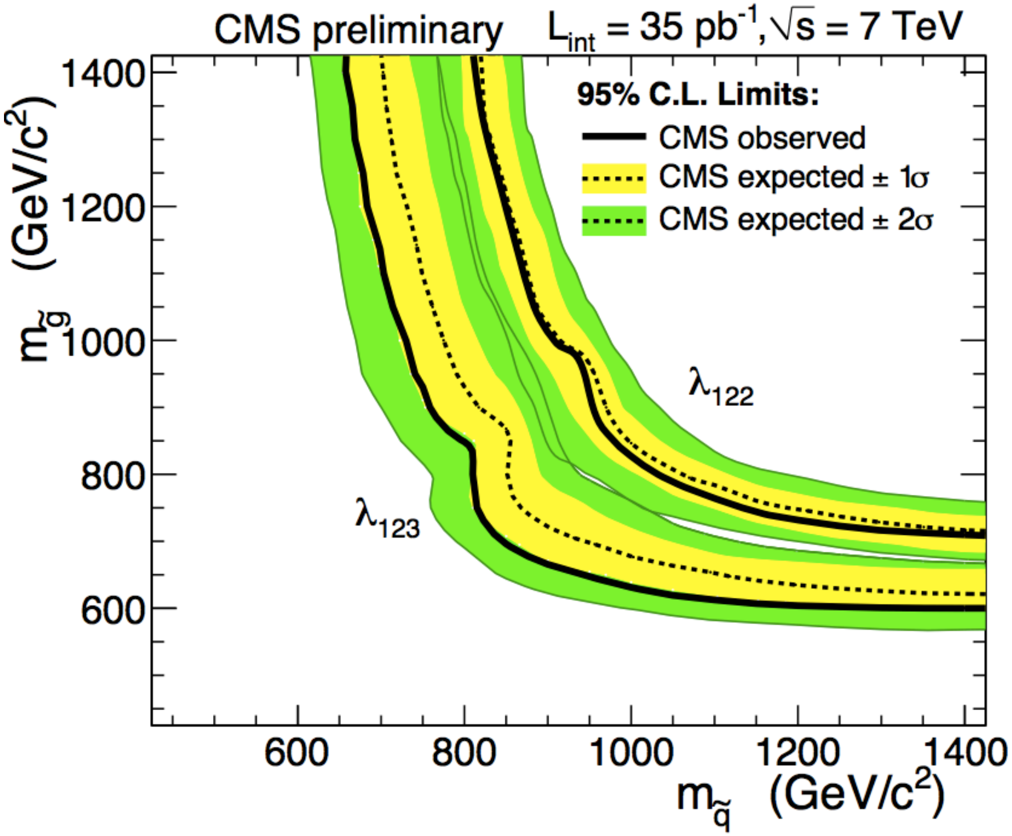


Gluino, Squarks

Jets

Bino

Di-Lepton +
Neutrino

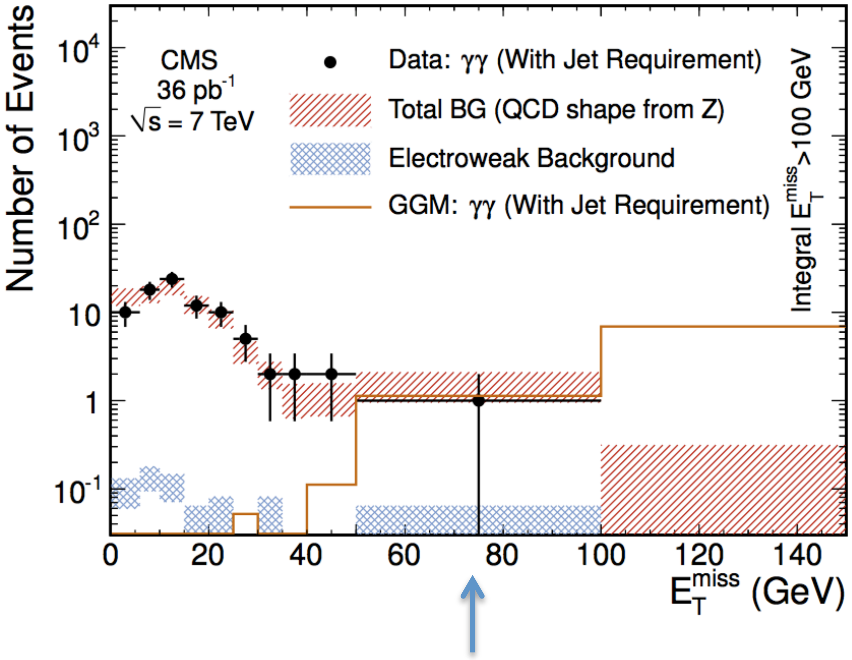


Di-Photon + MET

N_γ >= 2	$E_{T\gamma}$ > 30 GeV	$\|\eta\|$ < 1.4
N_j >= 1	E_{Tj} > 30 GeV	$\|\eta\|$ < 2.6
MET	MET > 50 GeV	

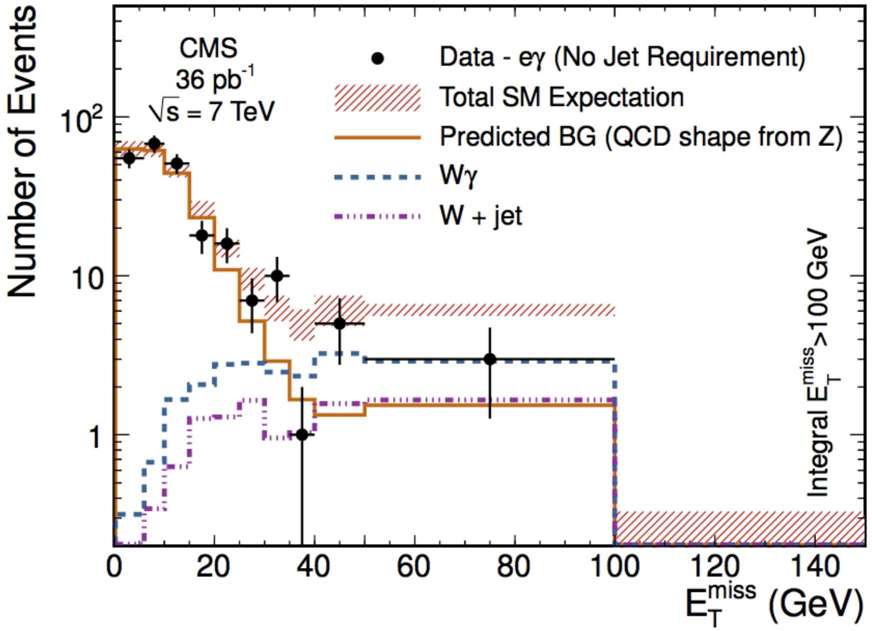
Dominant Backgrounds from MET mis-measurement

γγ Signal Region



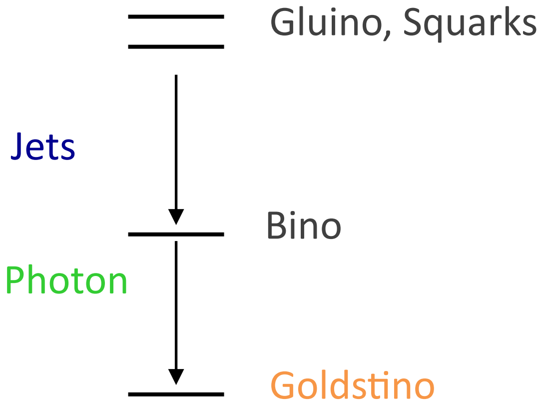
1 Event

eγ Control Region



Di-Photon + MET: Bino NLSP (GMSB)

Production + Decay Topology:



Gluino, Squarks

Jets

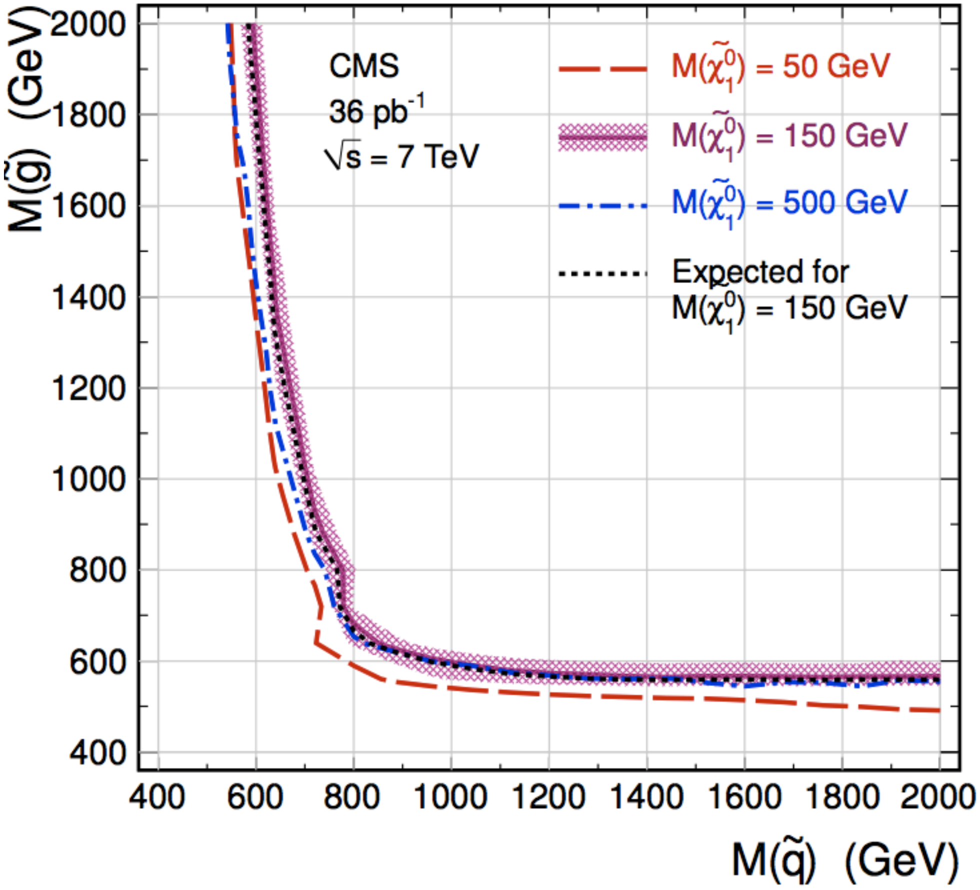
Bino

Photon

Goldstino

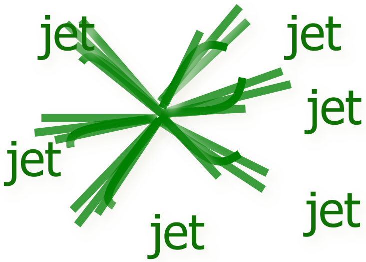
Br(All -> $\gamma\gamma$ + Jets) = $\cos^4 \theta_W$

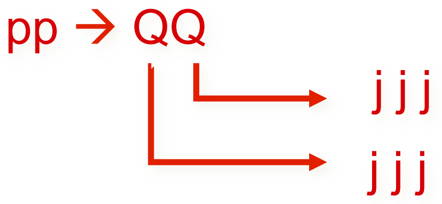
Note: Associated Jets
from Strong Production



Extracting Boosted Hadronic Resonances Using Jet Ensemble Correlations

Purely Hadronic Final States Very Difficult
- Great Discovery Potential …

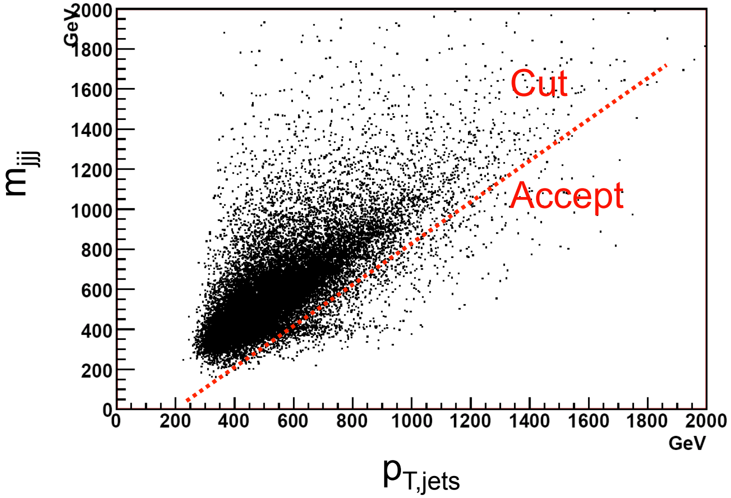



pp → QQ

j j j

j j j

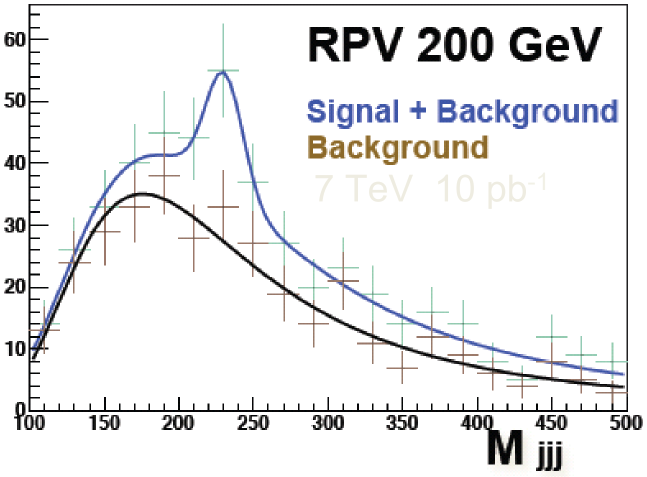
SUSY – Hadronic RPV $Q = \tilde{g}$



Standard Techniques Fail on
High Multiplicity Final States

QCD Fills Up Phase Space !!

Accept Combinatoric Confusion
Form Ensemble of Permutations
Invariant- Non-Invariant Correlation

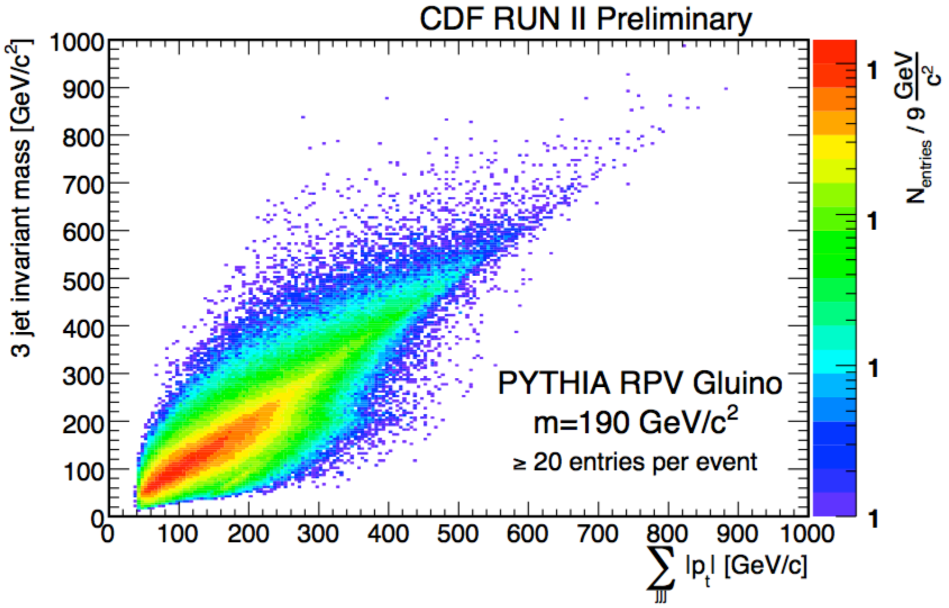


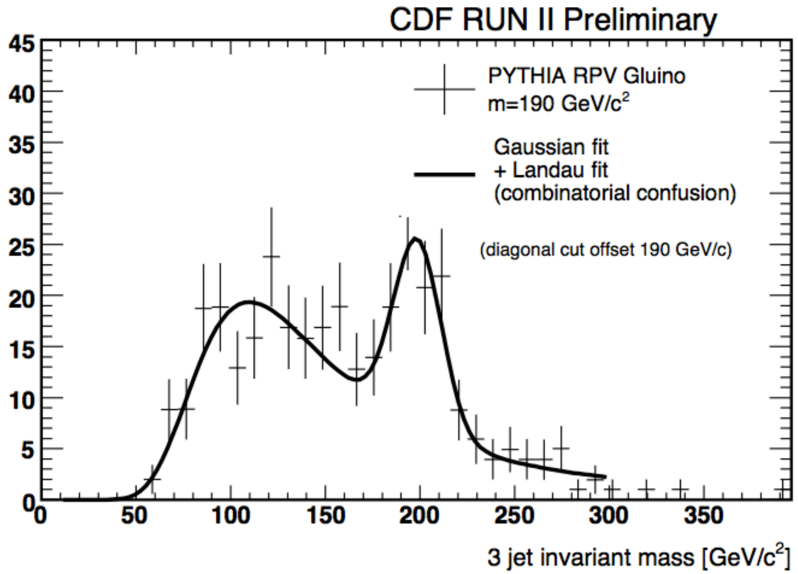
Extend to Other Signatures …

Boosted Tri-Jet Resonance: CDF

Signal Monte Carlo:

Combinatoric Confusion + Boosted Tri-jet Resonance



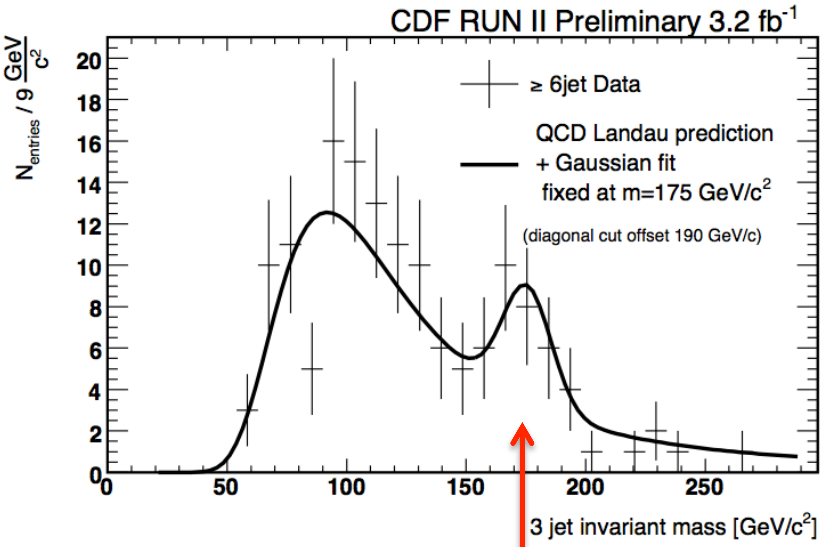


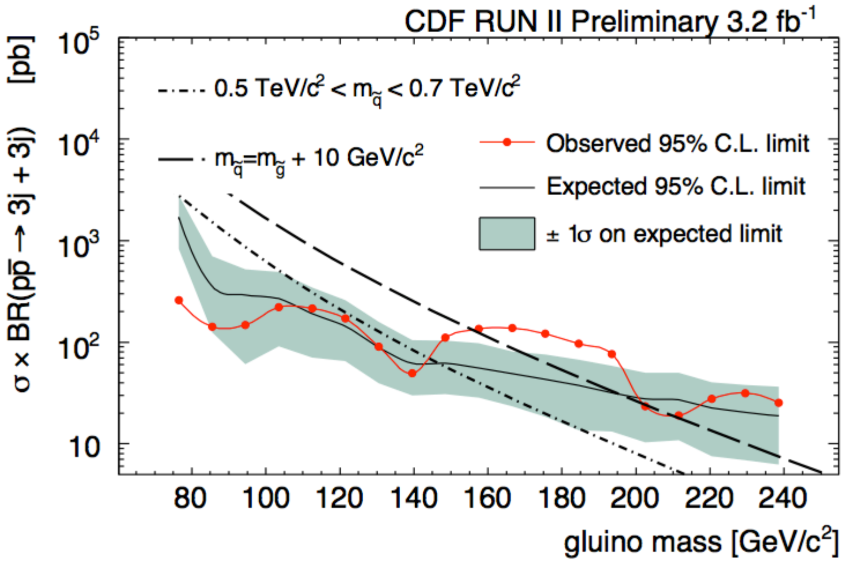
Boosted Tri-Jet Resonance: CDF

Gluino Pair Production +
Hadronic R-Parity Violation

Data:

$W = \lambda_{ijk} \; u_i \, d_j \, d_k$





Excess - Consistent with Boosted Hadronic Top Quarks

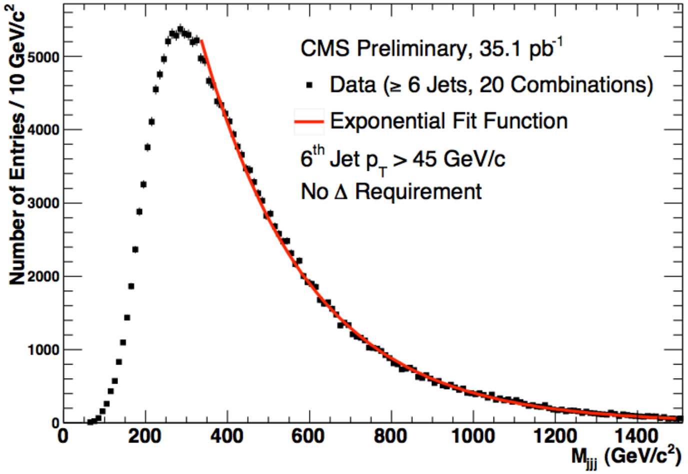
11 Events in Peak, 8 Background Events Under Peak

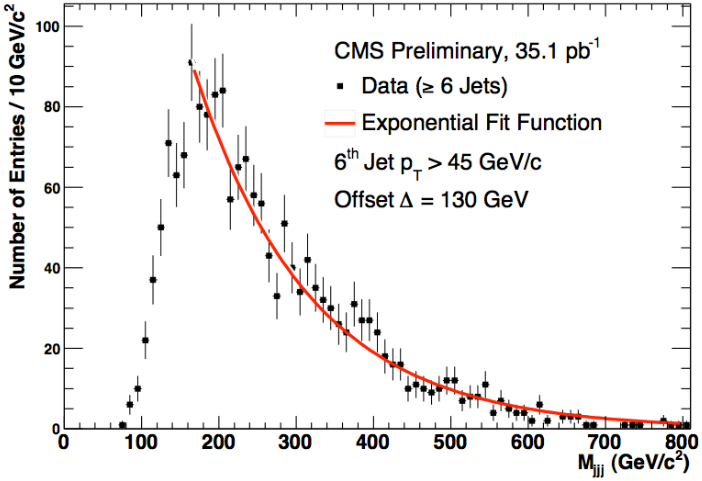
1 Boosted Top Quark Event Expected in Peak (MC)

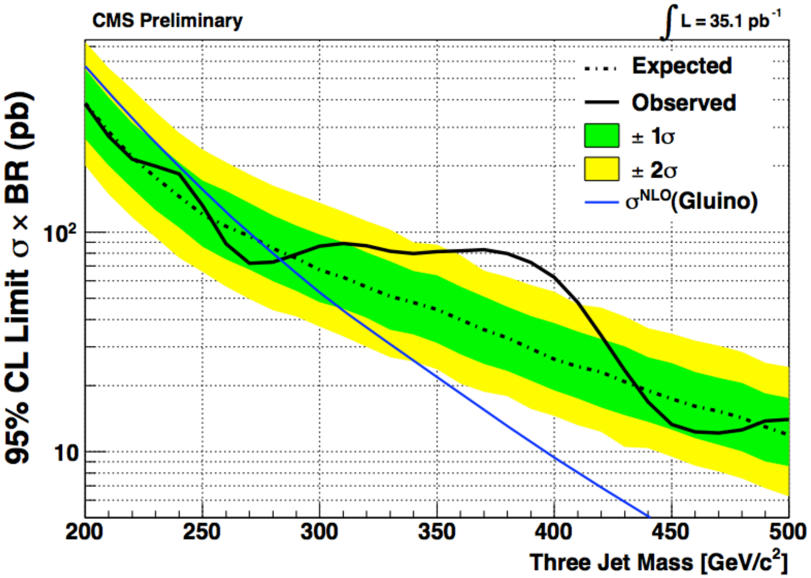
Boosted Tri-Jet Resonance: CMS

Not Sensitive to Boosted Hadronic Top Quarks

Data:





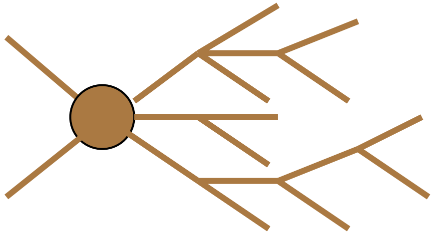


Gluino Pair Produtino + Hadronic R-Parity Violation

$$W = \lambda_{ijk}\ u_i\, d_j\, d_k$$

Mapping from Data → Theory

Data → Underlying Theoretical Framework



Production + Decay Through Relatively Narrow Intermediate States

$\Gamma / m \ll 1$

Production+Decay Trees = Topologies = COSET = SMS ; OSET …

Specified by m_i , J_i , Quantum Numbers,
(some cases $d\Gamma / dm_{ij}$ decay functions)

Monte Carlo Specification: (Isotropic Decays)

- 2→1 or 2→2 Production – Pythia, Madgraph. …..
  Spectrum + Cascade Decay Tree – SLHA Input file
- Pythia 6.4.24, Marmoset, …

Experimental Results

Triggers + Cuts + Analysis Procedure → **Sensitivity from N_{excess} in Given Final States**

↓

$(\sigma.Br.A)_f \qquad f = 1,\ldots,N_f$

Acceptance *A* Includes Effects of

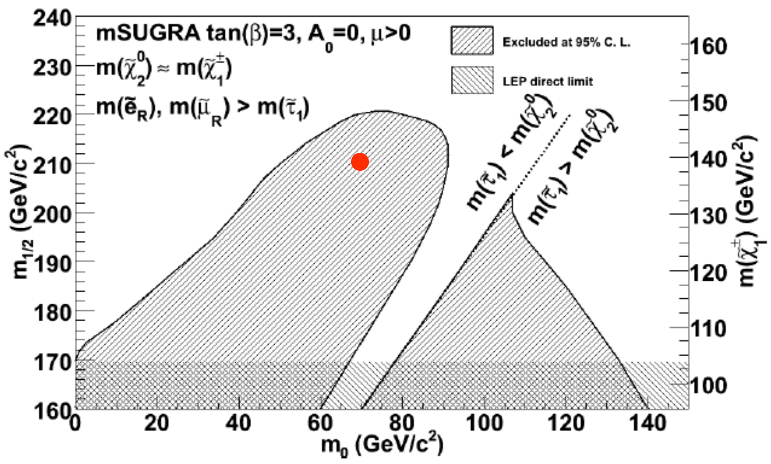
1. *Triggers + Cuts + Analysis Procedure*
2. Detector Response

For Map Onto Theoretical Framework *A* Also Includes

3. Mass Spectrum, Spins, Quantum Numbers, Decay Distributions

Model Space Interpretation of Results

- Example – Tevatron Tri-Lepton Searches



mSUGRA parameter space

Presentation of Search Results:

Mapping from σ.Br.A Results in Multiple Channels Onto Model Space n =0,1,2,3 τ

Any Point in Model Space -
Model Dependent Correlations
Among Spectrum, σ, and Br’s, and A

Information Lost !

Experimentalists:
Please Always Give
this Information

Unnecessary Assumption

Interpretation of Results

- **Simplified Topologies**

  Benchmarks

  * Probe All Relevant Corners of Signature Space

- **Present Results in Simple Model Spaces**
- **Forum for Submitting Models to Collaborations**
- **General Problem of Mapping Data → Theory**

  1. Useful Both Pre- and Post-Discovery
  2. Include Multiple Experimental Channels
  3. Include Arbitrary Combinations of Multiple Topologies with Arbitrary σ + Mass Spectra + Br's
  4. Useful in Archival Form in Future

Mapping Data → Theory

Given Experimental Sensitivities in Multiple Final State Channels

$(\sigma.Br.A)_f$ $f = 1,\ldots,N_f$ ← Start From This Data

Map onto Any Theoretical Framework
Defined by a General Set of
Production + Decay Tree Topologies with
General Spectrum, Cascade Decay Br's, and σ's

Factorized Mapping Data → Theory

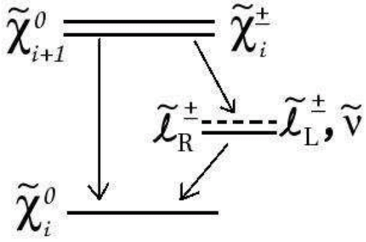
(Dube, Glatzer, Somalwar, Sood, ST arXiv:0808.1605)

Model Independent Method for Presenting and Interpreting Multi-Channel Results

Data → Multiple Topologies or Directly into Model Space

- Form Hypothesis for Production + Decay Tree Topologies – Test Hypothesis

Can Include
Multiple Topologies and
Multiple Final State Channels



Factorized Mapping Data → Theory

(Dube, Glatzer, Somalwar, Sood, ST arXiv:0808.1605)

Trees

Decays in Each Tree

$$(\sigma \cdot \mathrm{Br} \cdot \mathcal{A})_f = f(\sigma_t, \mathrm{Br}_{\alpha_t}, m_{i_t}) = \sum_{t=1}^{N_t} \sigma_t \cdot \prod_{\alpha_t=1}^{N_{\mathrm{Br}_t}} \mathrm{Br}_{\alpha_t} \cdot \mathcal{A}_{f,t}(m_{i_t})$$

Acceptance for Tree t in Final State f

- **Factorized Parameterization of $(\sigma.\mathrm{BR}.A)_f$ for <u>Any</u> Incoherent Combination of Production+Decay Tree Topologies**

- **Provides a Mapping Theory → Data**

  $\mathrm{Dim} = N_t \,.\, N_{BR,t} \,.\, N_{mt} \rightarrow \mathrm{Dim} = N_f$

- **Acceptance $A_{f,t}(m_i)$ function in Mass Spectrum Space Only**

- **Free to Impose (Model Dependent) Relations among**
  σ_t , $\mathrm{Br}_{\alpha t}$, m_{it}

Factorized Mapping Data → Theory

(Dube, Glatzer, Somalwar, Sood, ST arXiv:0808.1605)

The Acceptance in Spectrum Space

$$A_{f,t}(m_i) \approx A \,.\, \varepsilon$$

Resolution, Reconstruction, Material, Conversions, Isolation Criteria, Fakes

Geometry
Kinematics

$$\mathcal{A}_{f,t}(m_i) \simeq \int d\widetilde{\Phi}_f(m_i) \prod_{i=1}^{N_p,f} \mathcal{P}_i(\eta_i, p_{T,i}; \eta_j, p_{T,j}) \cdot \varepsilon_i(\eta_i, p_{T,i})$$

Dimensionless
Phase Space

Geometric + Kinematic
Acceptance Including
Inter-Object Isolation

Intra-Object
Efficiency

Easily Simulated
Monte Carlo Tools
Object Reconstruction

Parameterize

Theory Detector Simulator (TDS)

β-Version Testing

Simulate Geometric + Kinematic $A_{f,t}(m_i)$ <u>Only</u>

- **Form Objects from MC Stable Particle Information**

e , μ , γ , jets

→ Fast-Jet on Tracks or All Hadrons (Anti-Kt)

τ_h Derived Object from 1,3 Prong jets
(b-tagging) from MC matching to jet Parent

- **Very Straightforward Simulation Tool – Easily Reproduced**

Detector Response from $\varepsilon_i(\eta_i , p_{Ti})$ – Input from Full Simulation

PGS Alone Doesn't do a Great Quantitative Job on $A_{CMS,ATLAS}$
$A_{CMS,ATLAS} = (A_{PGS} \cdot \varepsilon_{PGS})\, \varepsilon^{-1}{}_{PGS} \cdot \varepsilon_{CMS,ATLAS}$ Not Practical / Painful

Factorized Mapping Data → Theory

(Dube, Glatzer, Somalwar, Sood, ST arXiv:0808.1605)

- Parameterize Factorized $A_{f,t}(m_i)$ for Each Hypothesis Topology Using TDS and Parameterized Detector Efficiencies; Br's=1
- Validate **Both** $A_{f,t}(m_i)$ and $\varepsilon_{f,t}$(m_i) Against Full Detector Simulation on Benchmark Topologies

Defines Mapping

$(\sigma.Br.A)_f|_{THEORY} = f(\sigma_t, Br_{\alpha t}, m_{it})$ ←→ $(\sigma.Br.A)_f|_{EXP}$

- Form Likelihood Entropy $L=L(\sigma_t, Br_{\alpha t}, m_{it})$ on Theory Space Based on Pulls for Sensitivity in Each Final State Channel

(Can Also Form Composite σ function Weighted by Experimental Sensitivity in Each Final State Channel)

(Initially Can/Should Impose Relations Among $\sigma_t, Br_{\alpha t}, m_{it}$ to Limit Dimensionality of Theory Space)

Factorized Mapping Data → Theory

(Dube, Glatzer, Somalwar, Sood, ST arXiv:0808.1605)

Likelihood or Composite σ Functions –
Uncorrelated Across Final State Channels Requires
Exclusive Search in These Channels
(Events fall in Only Single Channel)

Background Hierarchically Ordered Exclusive Combination
of Channels Always Provides Better Sensitivity Anyway
(Tri-leptons CDF, Multi-leptons CMS, …)

Experimentalist:

1. Report Exclusive Sensitivities in All Channels $(\sigma.Br.A)_f$
   (Please Always do This Anyway)

2. Provide Both $A_{f,t}(m_i)$ and $\varepsilon_{f,t}(m_i)$ Information from
   Full Simulation for Appropriate Benchmark Topologies
   Including SM Processes Validated in Data

Factorized Mapping Data → Theory

Features:

- Production σ's Factor Out of Problem
- Cascade Br's Factor Out of Problem
- Multiple Topologies + Multiple Channels Easily Combined
- "Model Independent" Within Specified
  Topology Set Spectrum Space –
  No Relation Among $\sigma_t, Br_{\alpha t}, m_{it}$ Need be Specified
- Only Requires Simulating Factorized form of Acceptance
  $A = \mathrm{A} \,.\, \varepsilon$ in Spectrum Space of Relevant Toplogies
- Can Add More Topologies Later
  (Since Don't Simulate Combinations of Topologies)

Applicable to:

- Null Results – Exclusion Contours in Spectrum + Br + σ
  Space or Directly in Model Space
- Positive Result – Likelihood Function in Spectrum + Br + σ
  Space or Directly in Model Space
- Archival Presentation and Usage of Results

Tractable Simplified Model Topologies

1. Only Few/One Topologies

2. Very Few States

3. Numerous States –
   Subspace of General Spectrum Space

↑

- Best Simplified Models Probe All Relevant Corners of Signature Space

Solved or Solvable Mappings Data → Theory

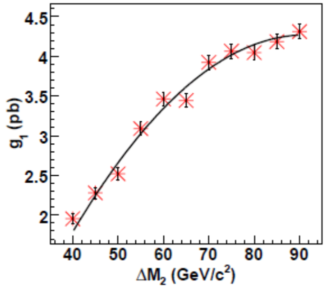
1. Tevatron Tri-lepton Wino→Slepton→Bino

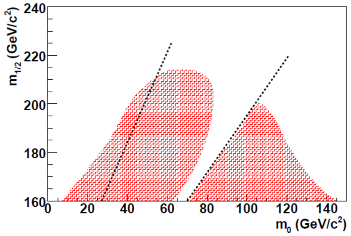
(Dube, Glatzer, Somalwar, Sood, ST arXiv:0808.1605)

Full Parameterization of $A_{f,t}(m_i)$ in Spectrum Space Tractable

Sunil will Describe on Saturday …

Private Simulation Tools for $A_{f,t}(m_i)$. ε Test - Results Mapped onto mSUGRA Space Agree Well with Full Simulation



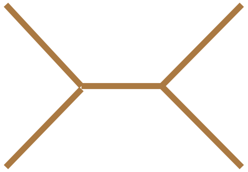


Solved or Solvable Mappings Data → Theory

2. CMS Same-Sign Di-Leptons
3. CMS Multi-Leptons
4. CMS Di-Photons + MET
5. CMS Jets + MET
6. Di-Jet Resonances

Simplest Topology

Parameterized by Single σ, Single m,
for 3 final states qq, qg, gg



Di-Jet Resonance Mapping Data → Theory

$A = A\ .\ \varepsilon$

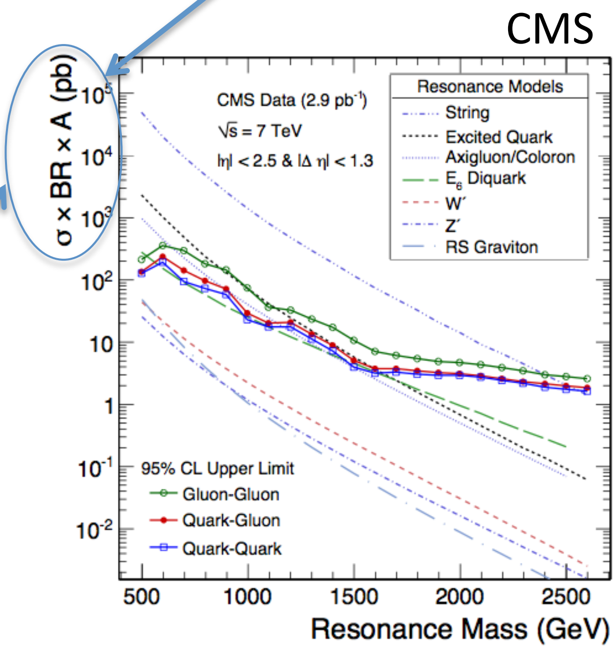
Geometry Resolution

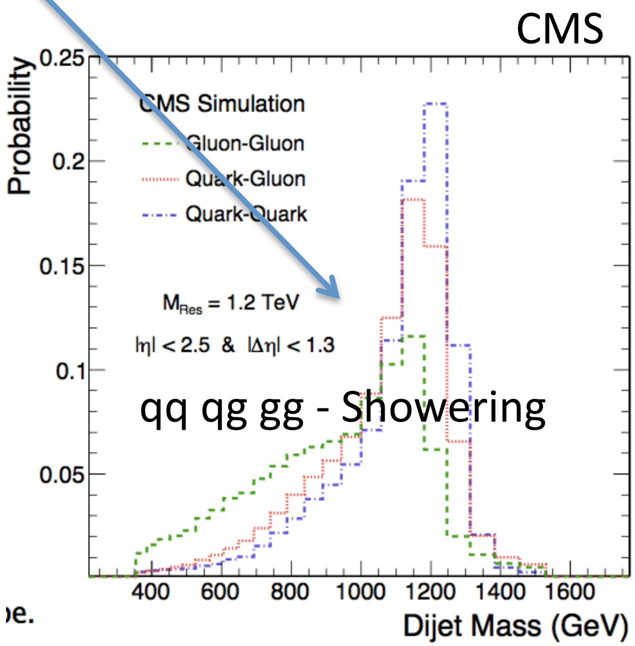
$A = A(m)$ $\varepsilon = \varepsilon(m)$

Sensitivity $\sigma.Br.A = (\sigma.Br.A)\ \varepsilon$

Model Independent

Experimentalists Have Factored Resolution out of Sensitivity





qq qg gg - Showering

Di-Jet Resonance Mapping Data → "All" Theory

- Narrow Width – Perturbative Showering

(Kats, Kilic, ST ;
Mangano, Mrenna, ...)

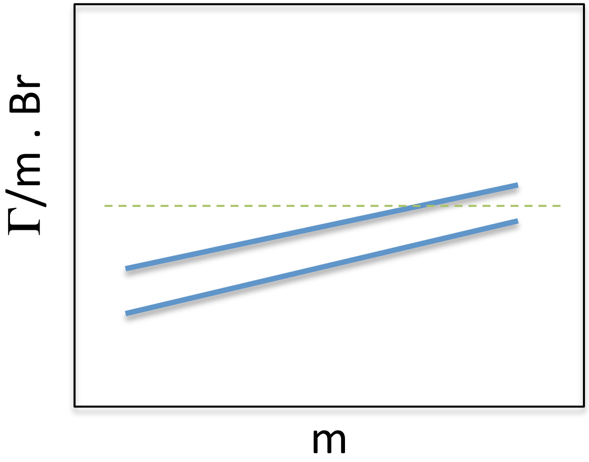
$$\frac{d\sigma(12 \to 3)}{d\cos\theta} = 16\pi^2 \frac{(2J_3+1)\dim(R_3)\ S\ \mathrm{Br}(3 \to 12)}{(2J_1+1)(2J_2+1)\dim(R_1)\dim(R_2)} f_{J_3}(\cos\theta)\frac{\Gamma_3}{m}\delta(s-m^2)$$

Spin + Color, Angular Distribution, Strength *All* Factorize

Table of A(m) – Minimal Couplings
(Subcategories)

	J = 0	1/2	1	3/2	....
qq					
qg					
gg					

Mapping → "All" Models



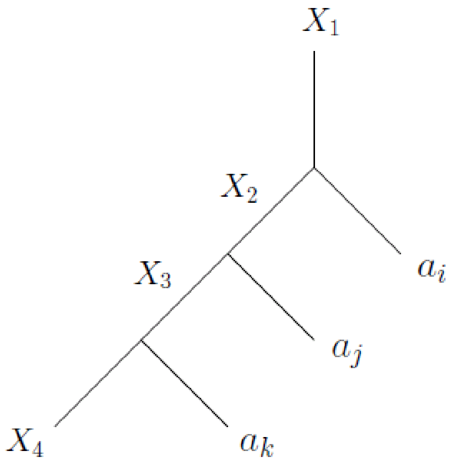
Consistent On-Shell Effective Theory for Cascade Decay Correlations (COSET)

- Develop Effective Field Theory -

Calculate Cascade Decay Correlations

Systematic Expansion in Γ/m , m/M

Provides Framework to Consider Wide Range Standard Model + New Physics Processes Correlations in Generalized Multi-Dimensional Dalitz Spaces of Invariants



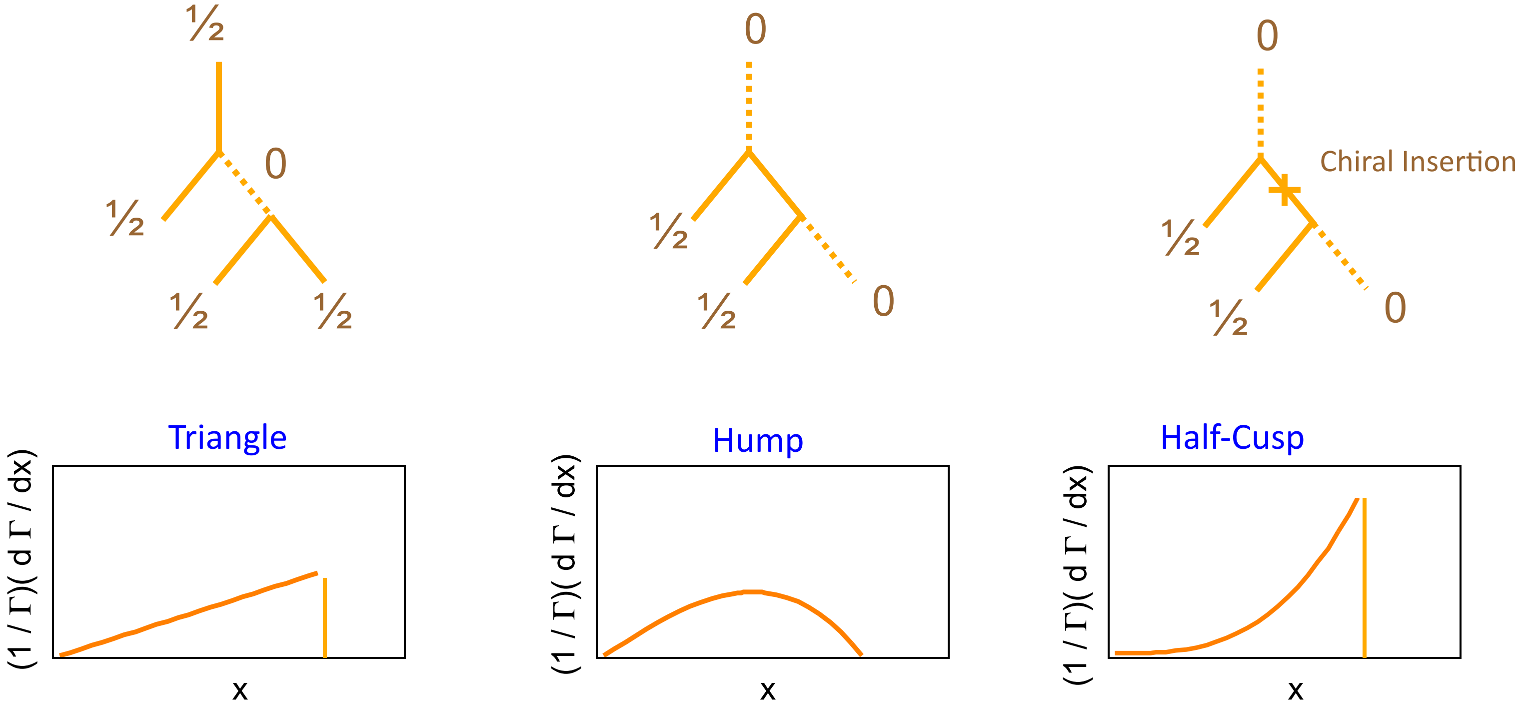
$$\frac{d\Gamma_{X_1\to a_1\ldots a_{n-1}X_n}}{\Gamma_{X_1\to a_1\ldots a_{n-1}X_n}} = |\widetilde{T}_{a_1\ldots a_{n-1}X_n\leftarrow X_1}|^2 \prod_{k=2}^{n-1} \prod_{\omega^{(k)}=\theta^{(k)},\phi^{(k\neq 2)}} J_{\omega_{ij}^{(k)}\ell mpq}(m^2_{a_\ell a_m}, m^2_{X_p}, m^2_{a_q}) \frac{dm^2_{a_i a_j}}{m^{2\ \max}_{a_i a_j}}$$

Leading Order in COSET Expansion:

Invariant Mass Distributions in Generalized Dalitz Space – Uniquely Determined by Masses and Spins

(No Arbitrary Couplings)

COSET - Sequential Two-Body Cascade Decay Correlations



Chiral Structure Unique - Independent of Majorana/Weyl, Dirac, PseudoDirac, …

Only Possibilities for Adjacent Branch Correlations with J=0, ½

(Almost) Complete List of Correlations - Three Sequential Decays J <= 1

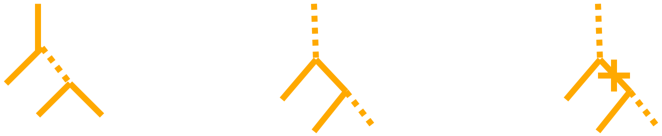
Discerning SUSY In Cascade Decay Correlations

Limited Set of Possible Adjacent Branch Correlations : J=0, ½

Adjacent Di-Lepton Distributions – All Possible SUSY Spectra

	Triangle	Hump	Half-Cusp
Opposite-Sign Same-Flavor	$\chi_i^0 \to \tilde{\ell}^\mp_{L,R}\ell^\pm$ $\hookrightarrow \chi_i^0\ell^\mp\ell^\pm$		$\tilde{\ell}^\pm_{L,R} \to \chi_i^0\ell^\pm$ $\hookrightarrow \tilde{\ell}^\pm_{R,L}\ell^\mp\ell^\pm$
Opposite-Sign Opposite-Flavor			$\tilde{\ell}^\pm_{L,R} \to \chi_i^0\ell^\pm$ $\hookrightarrow \tilde{\ell}'^\pm_{R,L}\ell'^\mp\ell^\pm$
Same-Sign Same-Flavor		$\tilde{\ell}^\pm_{L,R} \to \chi_i^0\ell^\pm$ $\hookrightarrow \tilde{\ell}^\mp_{R,L}\ell^\pm\ell^\pm$	
Same-Sign Opposite-Flavor		$\tilde{\ell}^\pm_{L,R} \to \chi_i^0\ell^\pm$ $\hookrightarrow \tilde{\ell}'^\mp_{R,L}\ell'^\pm\ell^\pm$	

SUSY → Distinctive Patterns



(Template) Search for Correlations in Data

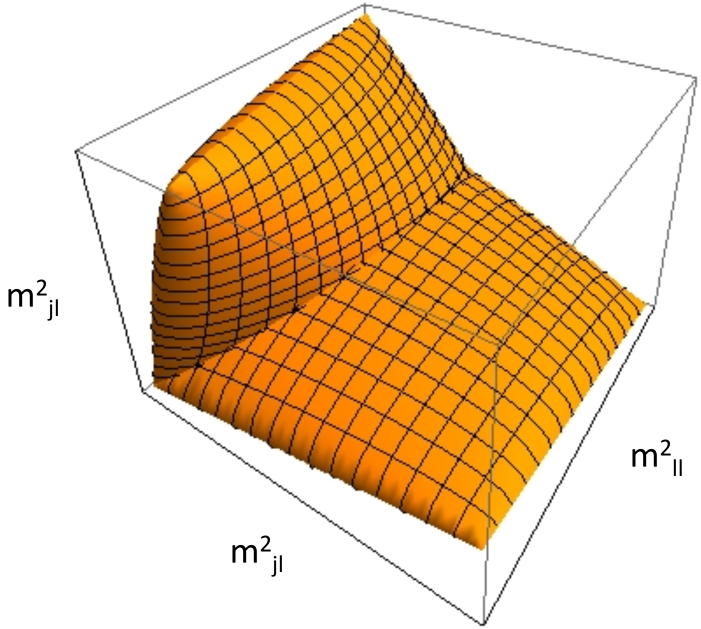
Next To Nearest OnShell Mass Extraction Technique (NNOMET)

Correlations Uniquely Determined by Masses and Spins

(SUSY) Three Sequential Cascade Decays

$$\tilde{q} \to \chi_2^0 + q$$
$$\hookrightarrow \tilde{\ell}^\pm + \ell^\mp$$
$$\hookrightarrow \chi_1^0 + \ell^\pm$$

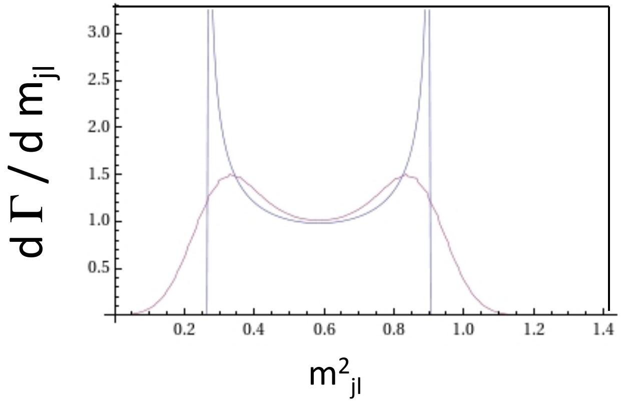
Jets+
Leptons
+MET



Distribution In 3D Dalitz Space Uniquely Determined in Terms of 4 Mass Parameters → 4 Sparticle Masses in Cascade Decay Tree

Includes Combinatoric "Non-Confusion" for $\text{Lepton}_{1,2}$

Does Not Use Measurent of MET



Next To Nearest OnShell Mass Extraction Technique (NNOMET)

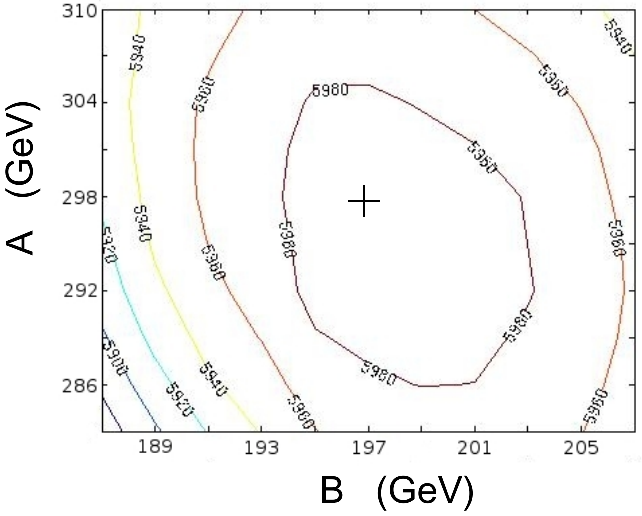
- LM1 Benchmark

TDR Cuts 14 TeV , 100 pb^{-1}

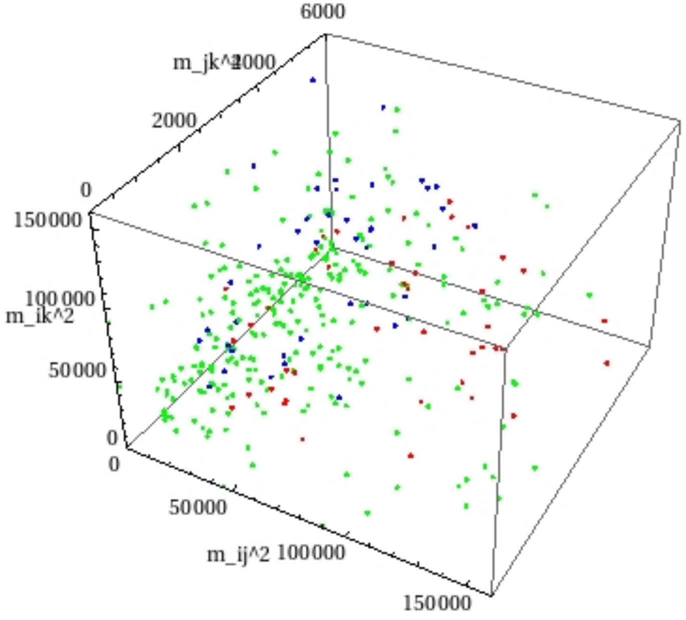
O(50) SUSY Events

Likelihood Entropy

Kinematic Mass Parameters



Working to Extend to Discovery Level …



Red – SUSY Decay Sequence

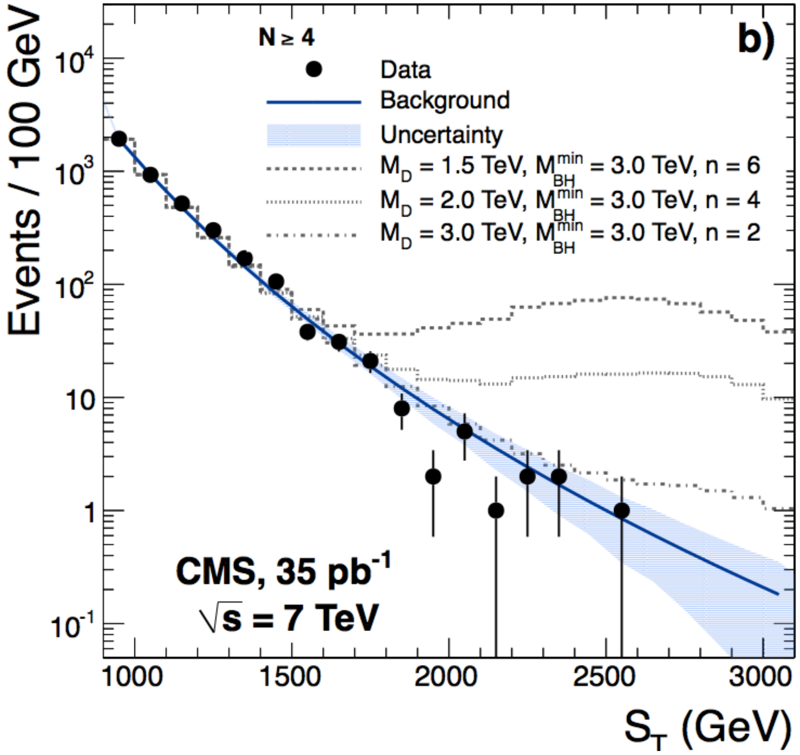
Blue – SUSY "Combinatoric" Decay Sequence

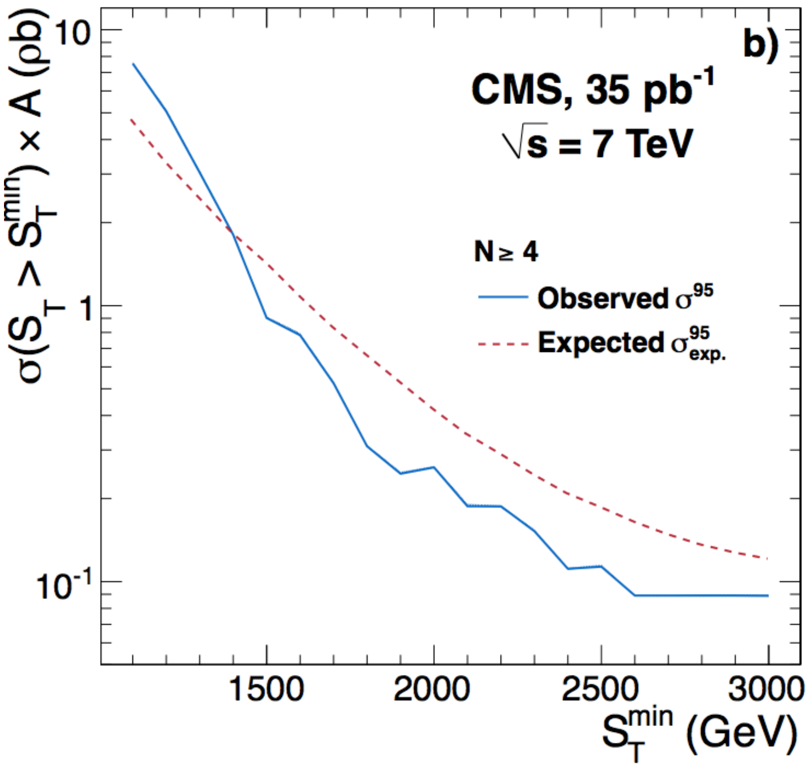
Green – Top Background

Form an Ensemble of All Jets p_T > 60 GeV + 2 Leptons Multiple Entries per Event

(S+S)/B = 1/3

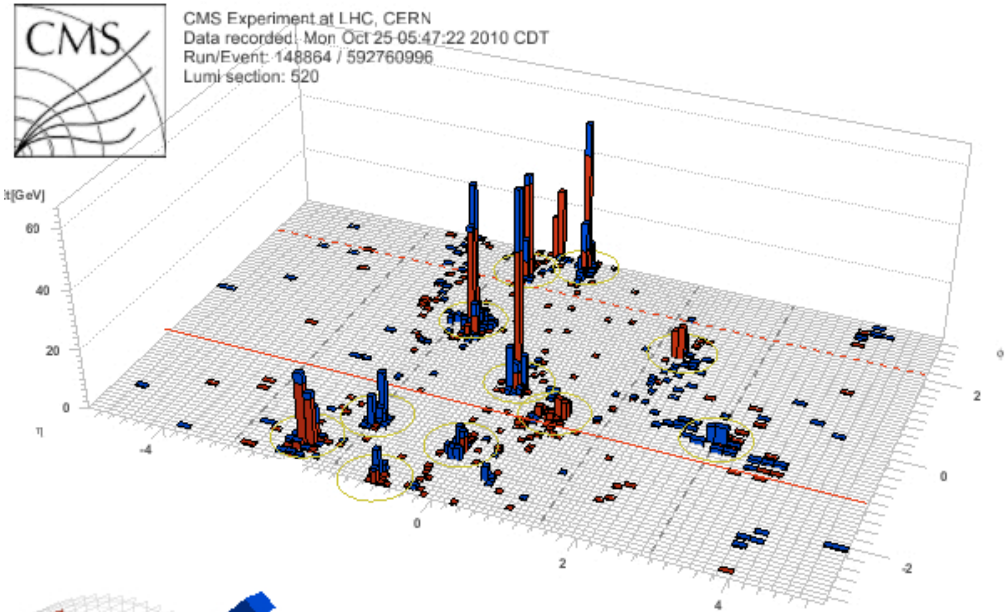
High Multiplicity + S_T (Black Holes):

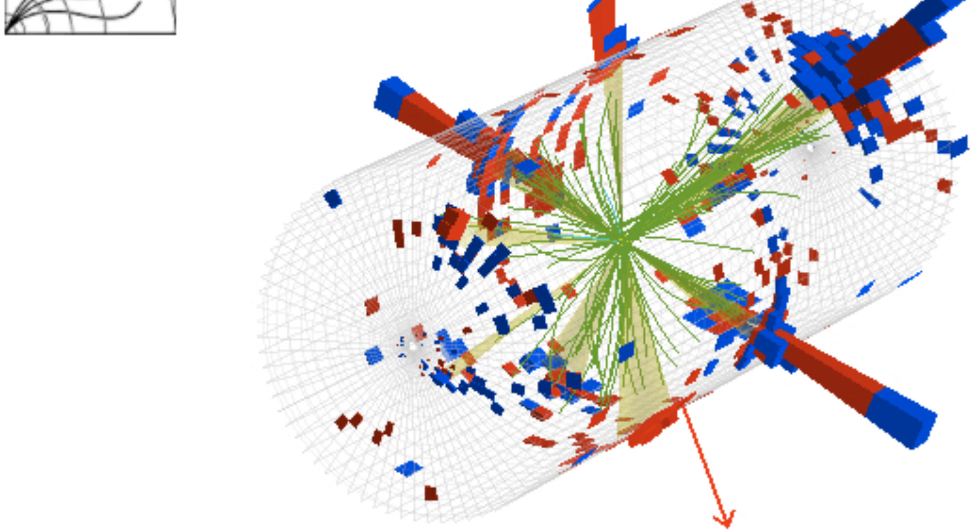




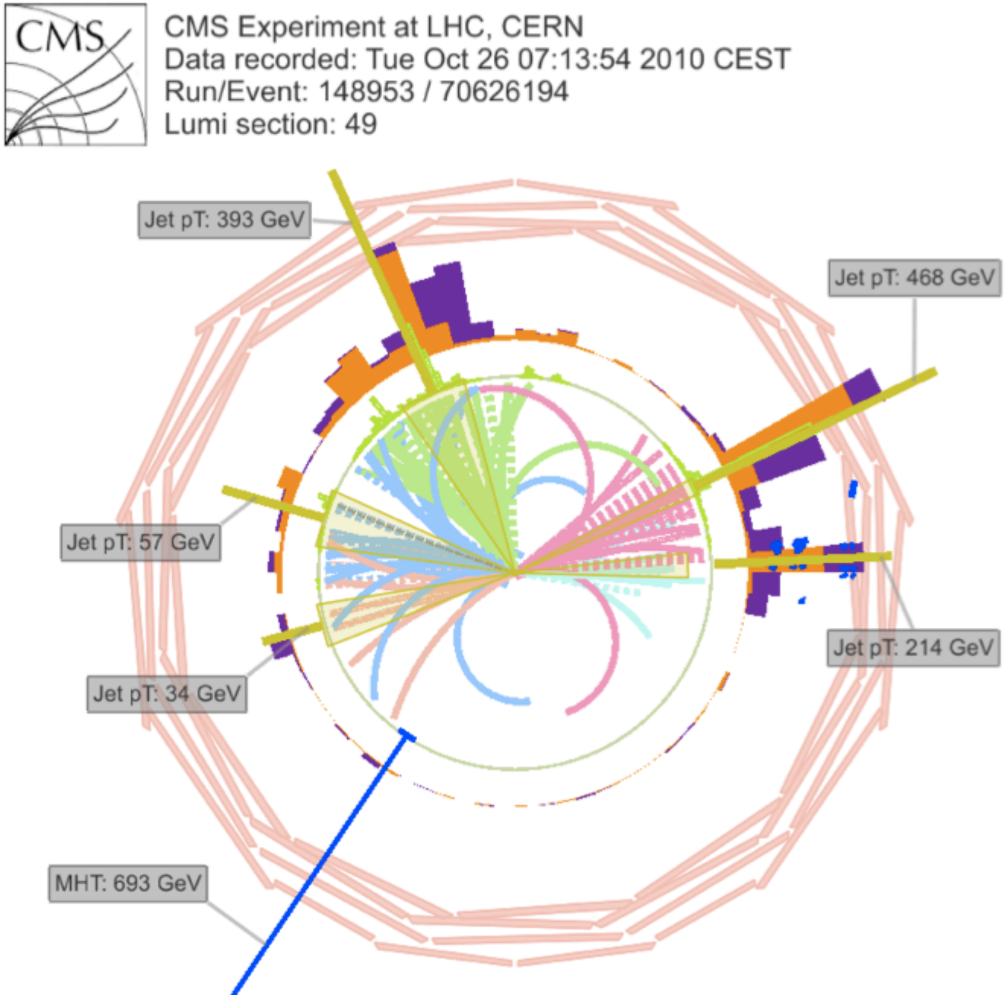
High Multiplicity + S_T (Black Holes): 10 Jet Event

S_T = 1.3 TeV





Jets + MET: Highest MH_T Event



MH_T = 1.83 TeV

No Indications of
Obvious Instrumental
Mis-Measurement

Announce Discovery

Recent BBC Report on the LHC :

… “ Physicists May Discover that Time Travel is Possible at the LHC “ …

Time Travel Searches Belong in the Exotics Group :

Signature – We should Already Know Some Results from the LHC

Evidence for Time Travel in the CMS SUSY Group …

Available on CMS information server

CMS NOTE 2011 / 112

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

6 December 2011

Evidence for squark and gluino production in pp collisions at $\sqrt{s}$ = 7 TeV

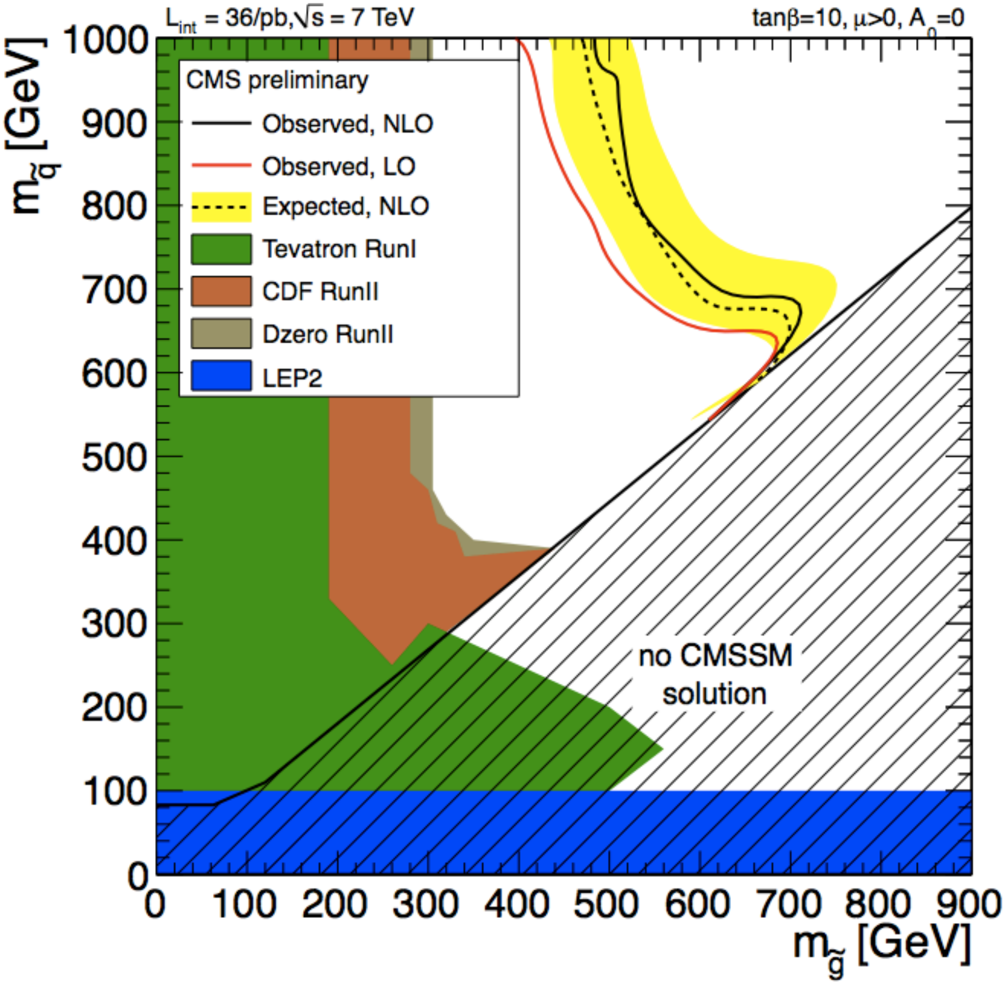
CMS collaboration

Abstract

Experimental evidence for squark and gluino production in pp collisions $\sqrt{s}$ = . 7 TeV with an integrated luminosity of 97 pb^{-1} at the Large Hadron Collider at CERN is reported. The CMS experiment has collected 320 events of events with several high $\mathrm{E_T}$ jets and large missing $\mathrm{E_T}$, and the measured effective mass, i.e. the scalar sum of the four highest $\mathrm{P_T}$ jets and the event $\not{\mathrm{E}}_{\mathrm{T}}$, is consistent with squark and gluino masses of the order of 650 GeV/c^2. The probability that the measured yield is consistent with the background is 0.26%.

Submitted to *European Journal of Physics*

2011 Promises to be an Interesting Year !

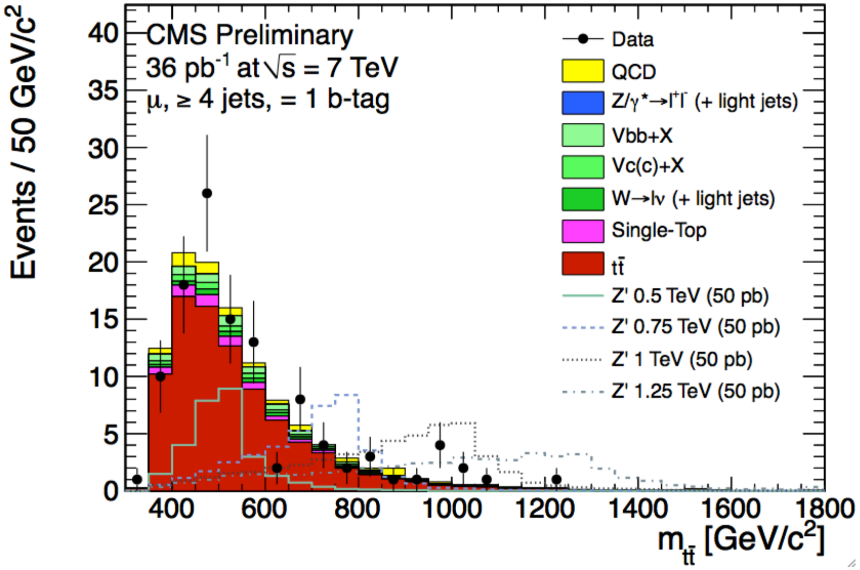

L_{int} = 36/pb, $\sqrt{s}$ = 7 TeV
tanβ=10, μ>0, A_0=0
CMS preliminary
Observed, NLO
Observed, LO
Expected, NLO
Tevatron RunI
CDF RunII
Dzero RunII
LEP2
no CMSSM solution
$m_{\tilde{q}}$ [GeV]
$m_{\tilde{g}}$ [GeV]
0
100
200
300
400
500
600
700
800
900
1000

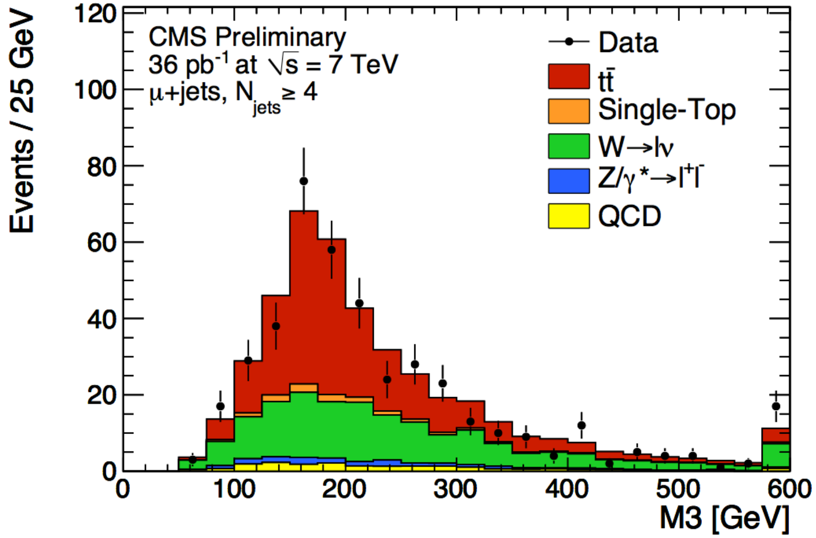
Top Quarks

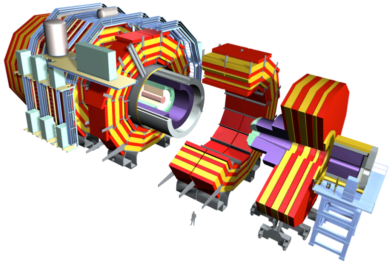
$$pp \to t\bar{t} \to Wb\,Wb \to \mu\nu j\;jjj$$

Yesterday's Discovery
Today's Background
Today' s Calibration
Tomorrow's Key to Discovery

Top Quarks Couple Strongly to Higgs Condensate - Search for New Physics





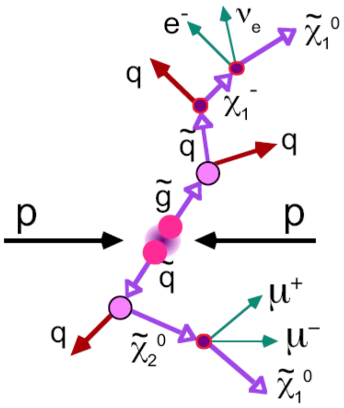


Purely Hadronic	**Single Lepton**	**Di-Lepton (OS/SS)**	**Multi-Lepton**	**Di-Photon**	**Photon & Lepton**
• *QCD* • *Z->nunu* • *W+jets/ ttbar*	• *W+jets* • *ttbar*	• *W/Z+jets* • *ttbar* • *(WW/WZ/ZZ)*	• *WW/WZ/ZZ* • *ttbar*	• *QCD*	• *W gamma* • *W/γ+jets*

Main Backgrounds

Super-Space Signatures

Depend on Ordering in Superpartner Mass Spectrum … . (Too Many to Search All Individually)



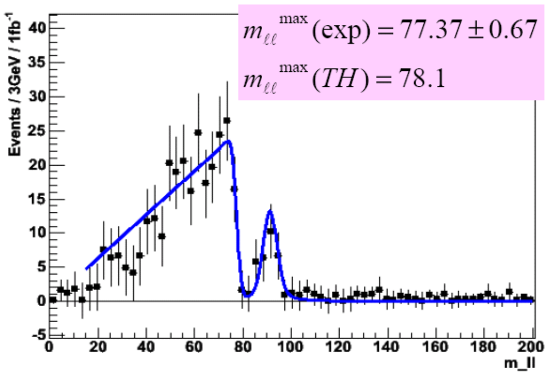
Organize by Signatures =

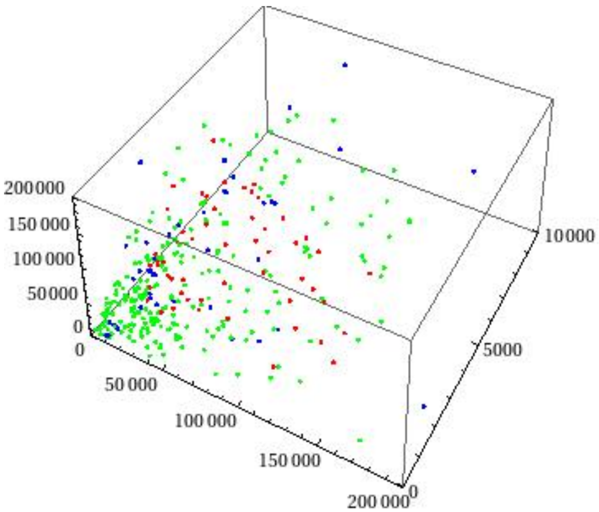
{ Missing Energy, Leptons, Jets, Photons, Z-Bosons, Top Quarks, … }

Comprehensive Search - Formidable Task

Search for …

1. Simple Excess
2. Distinctive Correlations





(Much more in Tuesday Seminar)