ZHEJIANG UNIVERSITY

对撞机的新进展 @ LHC and Tevatron

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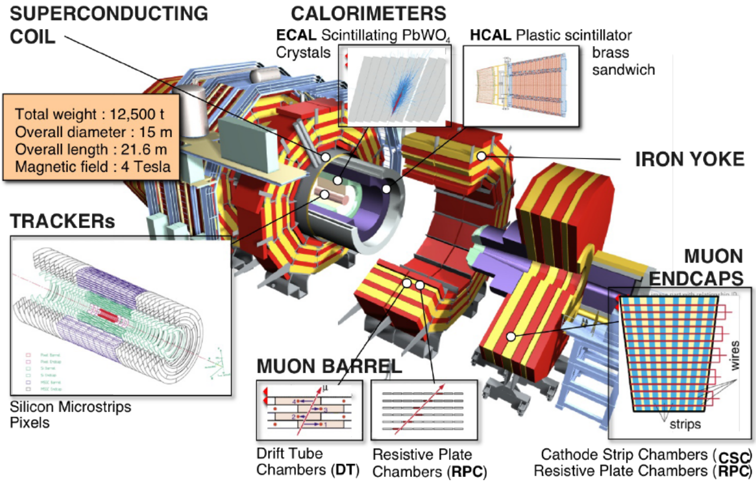
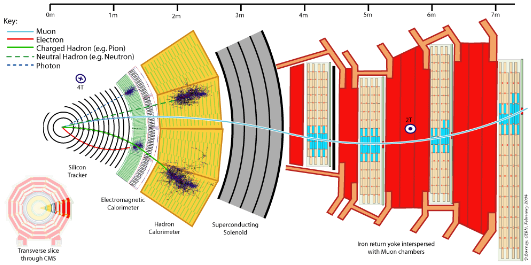
浙江大学浙江近代物理中心

探测器的组成


SUPERCONDUCTING COIL
CALORIMETERS
ECAL Scintillating $PbWO_4$ Crystals
HCAL Plastic scintillator brass sandwich
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
IRON YOKE
TRACKERs
Silicon Microstrips
Pixels
MUON ENDCAPS
wires
strips
MUON BARREL
Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

探测器中的粒子



- 电子，光子在电磁量能器中产生EM Shower。（tracking系统区分带电与不带电的粒子）
- τ子衰变: $c\tau_{\tau^\pm} \sim 80\ \mu$m$(\tau \sim 10^{-13}$ s): $\tau^+ \to \pi^+\bar{\nu}_\tau$ isolated pion. $\tau^\pm$ is not lepton in collider but can be distinguished from jet.
- μ子: $c\tau_{\mu^\pm} \sim 600$ m$(\tau \sim 10^{-6}$ s): $\mu^\pm$ is stable in collider.
- B介子次稳定: $c\tau_{B^\pm} \sim 500\ \mu$m$(\tau \sim 10^{-12}$ s): secondary vertex for b-tagging

大型强子对撞机是一个QCD machine!

Digging signal out of QCD: 1 out of 10^8

- high p_T object of $p_T > 120$ GeV: large mass difference
- large missing transverse energy: $\not{E}_T > 100$ GeV: DM and right kinematics
- isolated hard leptons (electron or muon) or photon: $e^\pm, \mu^\pm, \gamma$: isolation is the key
- jet with displaced vertex: b-tagging: b is from gluon splitting third generation new physics

However, what we see may not be what we think we have seen.

- jet/lepton energy measurement
- $\pi^0 \to \gamma\gamma$: boosted pion may look like photon
- $D_s^{\pm}$ being faked as $B^{\pm}$ 10%.
- π^+ being faked as μ^+.
- μ^+ from B semi-leptonic decay.
- τ identification
- ..... A lot of more faking

结论： LHC的主要结果

- A robust exclusion interval for the SM Higgs. Essentially only a narrow window below 600 GeV: 122-128 GeV.
- Some indication for m_H 125 GeV
- No evidence of new physics, although a big chunk of new territory has been explored
- Important results on B and D decays from LHCb (also CMS)

Outline

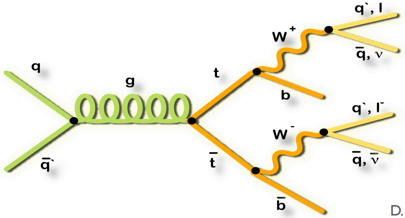
- Higgs
  - Cleanest: $\gamma\gamma$, 4ℓ
  - $b\bar{b}$+V
  - WW^*,τ
- Top Quark
- 共振态
- 低能超对称理论
  - $\not{E}_T$ 暗物质直接测量
  - 同号两轻子 $X+\ell^{\pm}\ell^{\pm}+\not{E}_T$
  - 第三代squark $X+b+\not{E}_T$
  - Photino NLSP in GMSB $X+\gamma+\not{E}_T$
  - R-parity violation: Three-jet resonance $\tilde{g}\rightarrow qqq$
- B/D介子物理

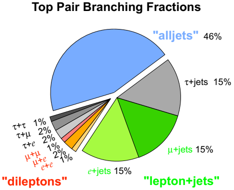
Higgs的典型信号

- 最clean的道：Higgs的四轻子($gg \to h \to ZZ^* \to 4\ell$)，双光子($gg \to h \to \gamma\gamma$)。
  背景清楚，高resolution
- 双轻子道 $gg \to h \to WW^* \to \ell\bar{\nu}\bar{\ell}\nu$
- $Wb\bar{b}$, $Zb\bar{b}$：Tevatron的最重要的道
- WBF产生h: $h \to \tau\tau$

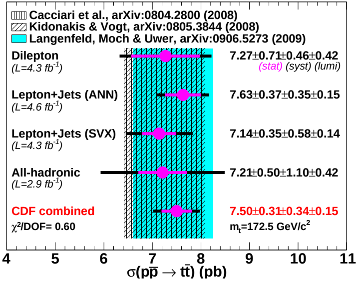
Measuring Top Properties

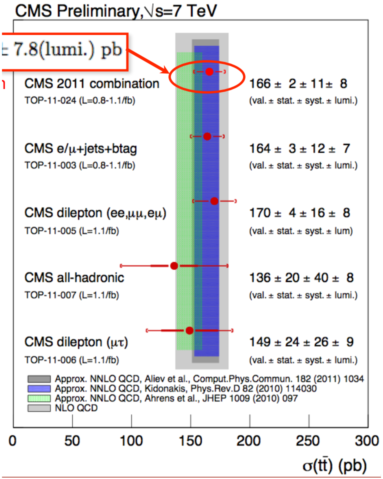
- Top almost always decays to *Wb*
  - Decay modes characterized by *W* decays
- Two main modes for top properties analyses:
  - Lepton+Jets: one *W* decays to quarks, one to e(μ) + ν
    - Moderate backgrounds, reasonable branching ratio; fully constrained kinematically
    - Usually require a *b*-tag to reduce backgrounds
  - Dilepton: both *W*'s decay to e(μ) + ν
    - Very low backgrounds, but small branching ratio; under-constrained kinematically

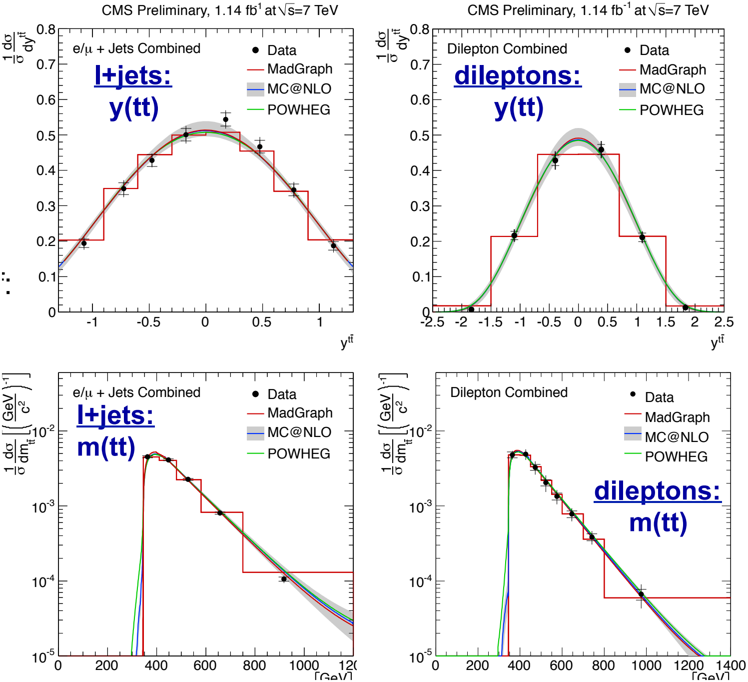




Top Cross Section






CMS Preliminary, 1.14 fb-1 at √s=7 TeV
e/μ + Jets Combined
l+jets:
y(tt)
Data
MadGraph
MC@NLO
POWHEG
CMS Preliminary, 1.14 fb-1 at √s=7 TeV
Dilepton Combined
dileptons:
y(tt)
Data
MadGraph
MC@NLO
POWHEG
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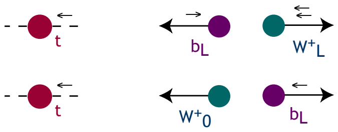
POWHEG
Dilepton Combined
dileptons:
m(tt)
Data
MadGraph
MC@NLO
POWHEG

Top Quark衰变的精细测量

m_t breaks electroweak gauge symmetry. Large m_t couples to symmetry breaking sector (“Goldstone” , longitudinal polarized W) strongly.

$m_b/m_t \to 0$: “massless” b is left-handed polarized.



Longitudinal W polarization: $\epsilon_0 \sim k_\mu/m_W$

$$\epsilon_0^* \bar{u}_{bL} \gamma_\mu u_t \simeq \frac{m_t}{m_W} \bar{u}_{bL} u_t$$

$$f_0 = \frac{\Gamma(t \to bW_0^+)}{\Gamma(t \to bW_0^+) + \Gamma(t \to bW_+^+) + \Gamma(t \to bW_-^+)} \simeq 70\%$$

$f_- \simeq 30\%, f_+ \simeq 0$

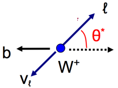
Confirmed by D0 and CDF and also CMS...

W polarization (2.2 fb^{-1})

CMS-PAS TOP-11-020

Feb'12

Anomalous contributions to the tWb vertex change the probabilities of the W helicity states

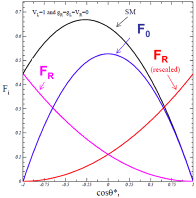


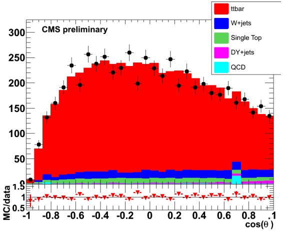
Angle between charged lepton and top direction in W rest frame

- In SM: 3 possible W helicity states:

F_0 (longitudinal) ~ 0.70, F_L (left) ~ 0.30, F_R (right) ~ 0

- Measure sensitive variable, cos(θ*), in **muon+jets** channel:
  - 1 isolated high-p_T μ, ≥ 4 jets, ≥ 1 b-tag
  - Kinematic fit to reconstruct ttbar system





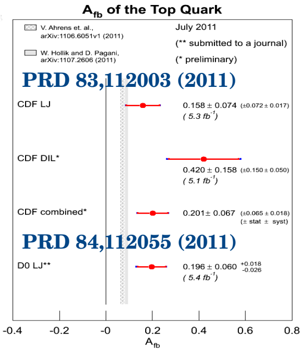
- Helicity fractions extracted from maximum likelihood fit:

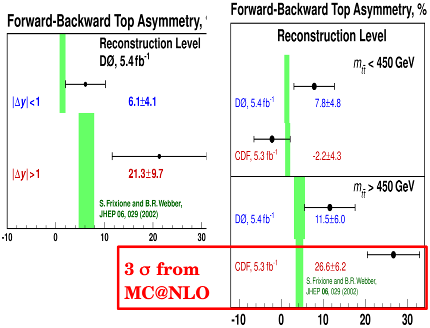
$$F_0 = 0.567 \pm 0.074(\text{stat.}) \pm 0.047(\text{syst.})$$
$$F_L = 0.393 \pm 0.045(\text{stat.}) \pm 0.029(\text{syst.})$$
$$F_R = 0.040 \pm 0.035(\text{stat.}) \pm 0.044(\text{syst.})$$

- Good agreement with SM
- Similar precision as previous measurements (Tevatron, ATLAS)

Great! but what does it tell us? Only EWSB occurs but not how EWSB take place... ...

pQCD在Top Pair系统的精细检验:A_{FB}





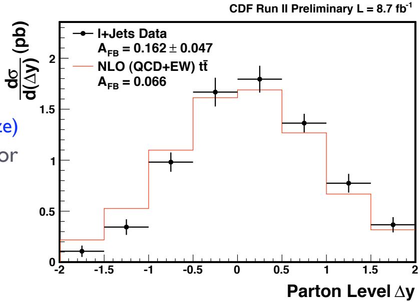
$$A_{FB}(M_{t\bar{t}} = 450 \text{ GeV}) = 0.475 \pm 0.112 \quad \text{Hollik:} 0.128$$

(A^l_{FB} at D0 is 5σ away from MCFM prediction but MCFM does not include spin correlation.)

The Asymmetry at CDF in the Full Dataset

- Updates from CDF's 5.3 fb^{-1} lepton+jets analysis:
  - Add new data stream and increase luminosity to 8.7 fb^{-1}
    - 2498 events (double sample size)
  - Use NLO generator Powheg for signal modeling
  - Parton level shape corrections use regularized unfolding algorithm
    - Proper multi-binned measurement of rapidity and mass dependence
- Parton Level A_{FB}: 16.2 ± 4.7 %

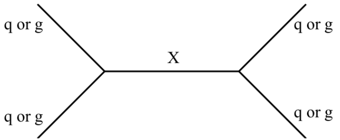
  (NLO: 6.6%)



CDF Conf. Note 10807

Dijet Resonances

- QCD predicts a smooth, steeply falling dijet mass spectrum
- Many extensions of the SM predict new massive objects producing resonant structures ("bumps") in the dijet mass spectrum



- The following specific models of *s*-channel resonances considered:
  - String resonances (S), E_6 diquarks (D), excited quarks (q*), axigluons (A), colorons (C), heavy gauge bosons (W' and Z'), RS gravitons (G)
- The main background for this search is the SM jet production

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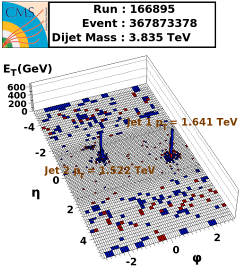
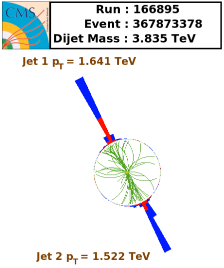
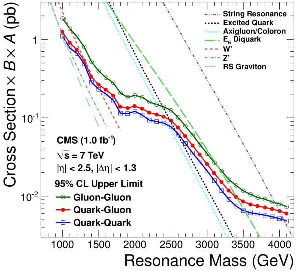
Dijet Resonances (cont'd)

- Generic 95% CL upper limits are set on σ×BR×A
  - Acceptance A refers to kinematic requirements |η|<2.5 and |Δη|<1.3 (for isotropic decays, A≈0.6)
- These limits can be compared to predictions of σ×BR×A at the parton level of any model of dijet resonance production





Highest dijet mass event

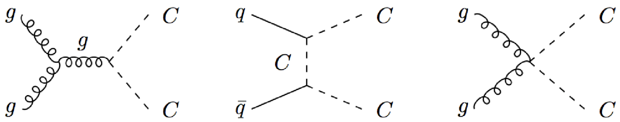


Mass limits for some of the benchmark models considered

Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40

Pair-Produced Dijet Resonances

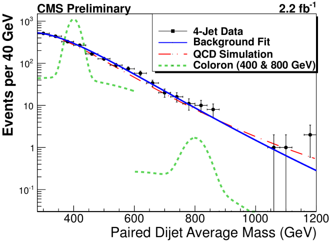
- Dijet resonance searches generally more sensitive to singly-produced new particles
- This search focuses on narrow colored resonances produced strongly in pairs and each decaying into a pair of jets
  - Search performed in a paired dijet mass spectrum in events with at least 4 jets
  - Paired dijet mass defined as the average of the two dijet masses
- Search results compared with a specific coloron model



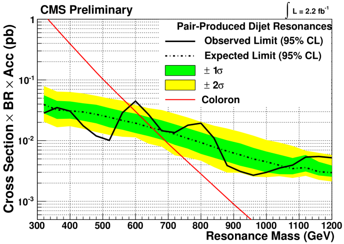
- As with the dijet resonances, the main background is the SM multijet production

Pair-Produced Dijet Resonances (cont'd)

- Signal and background modeling:
  - Signal samples produced using MadGraph with colorons modeled as narrow dijet resonances
  - Signal shape modeled by a double Gaussian
  - Background modeled by the same smooth function as in the dijet resonance search
- Dominant sources of systematic uncertainty:
  - Jet energy scale, jet energy resolution, integrated luminosity, statistical uncertainty on the background fit



Smoothly falling distribution.
No evidence for new particle production



Results:

- Pair production of colorons with 320<M(C)<580 GeV (320<M(C)<650 GeV expected) excluded at 95% CL

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超对称的典型信号

- 暗物质？jet+$\not{E}_T$ (also in all other channels except R-parity violation.)
- 第三代squark: lots of b-jets
- Majorana Gluino: 同号双轻子
- Photino in GMSB: $\gamma + \not{E}_T$

SUSY in Jets+MET

This talk presents searches which were thought having SUSY in mind:

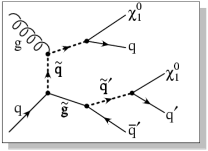
- High rate of gluino, squark production

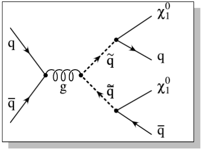
This is translated into the topology:

- Final states with jets, invisible energy due to LSP (ME_T)

These searches are sensitive to processes which:

- Are strongly produced
- Have a massive, weakly interactive, stable colorless particle





If a model does not predict hadronically rich events, with invisible energy

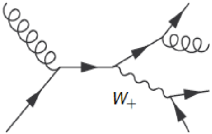
- This is the wrong place to look at ;)

SM in Jets+MET

Standard Model processes can be divided in **two broad categories**:

"Reducible":

- QCD:
  - ✗ Huge cross section, potential jet fluctuations create *fake* ME_T
  - ✓ Generally, reduced to negligible amount with topological cuts
- W+Jets, Top:
  - ✗ They have genuine ME_T
  - ✓ But also a lepton → *lepton veto*



"Irreducible":

- Z(νν)+Jets:
  - ✗ Same topology, real ME_T
  - ✓ Cannot be reduced (at least efficiently), must be estimated

MHT (1.1/fb): definition

Multibinned analysis based on:

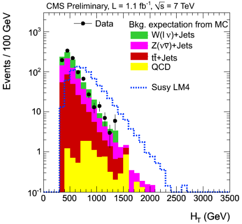
- **H_T**: scalar sum of jets p_T>50 GeV, |η|<2.5
- **MH_T**: vector sum of jets p_T>30 GeV, |η|<5

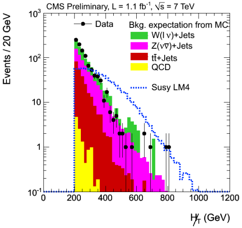
Event Selection:

- N^{jets}(pT>50 GeV, |η|<2.5)>=3
- H_T>350 GeV, MH_T>200 GeV → reduces QCD
- Δφ(jet_N,MH_T) > 0.5 (n=1,2) && Δφ(jet_3,MH_T) > 0.3
  →protects against MH_T due to jet mismeasurement
- Veto on isolated electrons/muons (loose cuts), pT>10 GeV, |η|<2.5 (2.4) for electrons (muons) → reduces W+jets, Top

Search Regions:

- *Medium H_T/MH_T*: H_T>500 GeV, MH_T > 350 GeV
- *High H_T*: H_T > 800 GeV, MH_T > 200 GeV
- *High MH_T*: H_T>800 GeV, MH_T > 500 GeV





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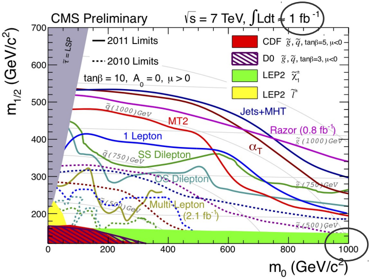
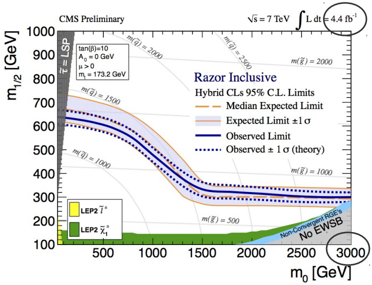
Exclusion Limits



Caveat: *M_{T2} limit is a combination of "M_{T2}" (low m_0) and "$M_{T2}b$" (high m_0)*

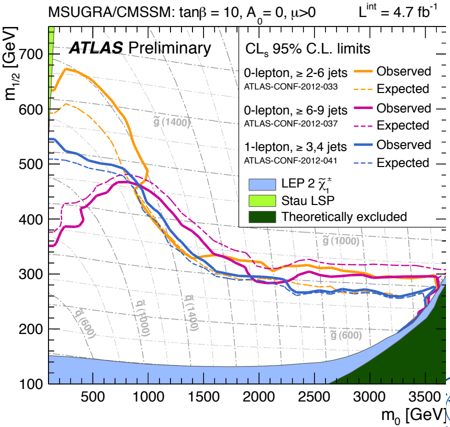
Msugra/CMSSM:

- tanβ=10
- A_0=0
- μ>0

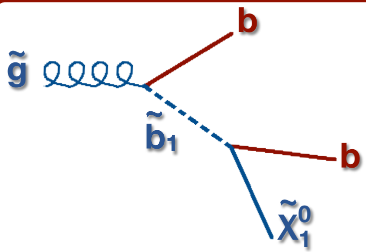


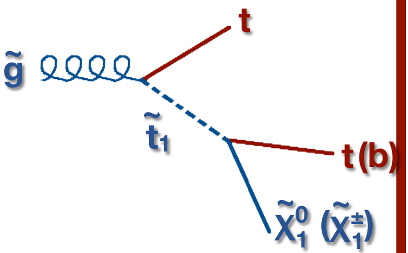
Conclusions

- Three analyses have been presented.
- All use 4.7fb^{-1} of 7 TeV data.
- No excess above the Standard Model expectation was observed.
- Limits were set in MSUGRA/CMSSM and some simplified models.
- Searches designed to be generic
  $\rightarrow$ should cover many other models.
- Other analyses are in the process of being updated to the full dataset.
- We look forward to 8 TeV running this year.
- Are there any questions?

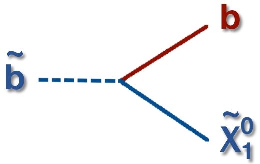


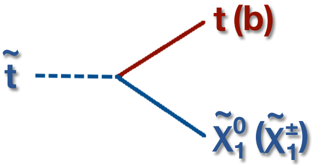
through gluino decays





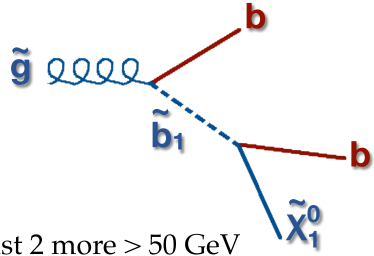
direct production





Gluino Mediated Sbottom

- **Analysis signature:**
  b-tagged jets + E_T^{miss}
- **Trigger:**
  1 high p_T jet + E_T^{miss}
- **Selection:**
  first jet > 130 GeV; at least 2 more > 50 GeV
  E_T^{miss} > 130 GeV
  1-2 jets must be b-tagged
  veto electrons & muons
  E_T^{miss} / m_{eff} > 0.25



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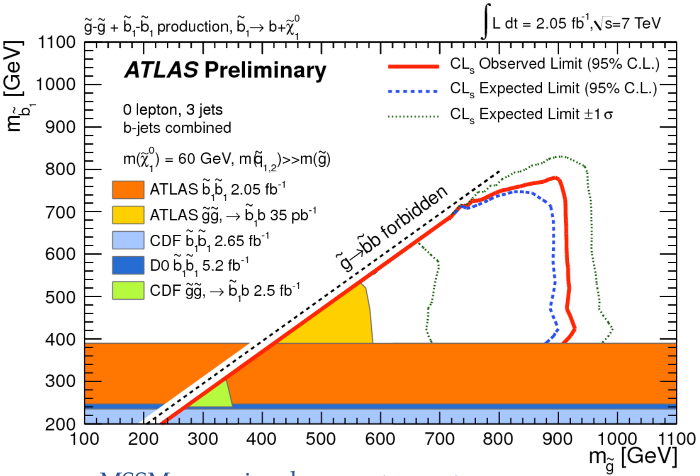
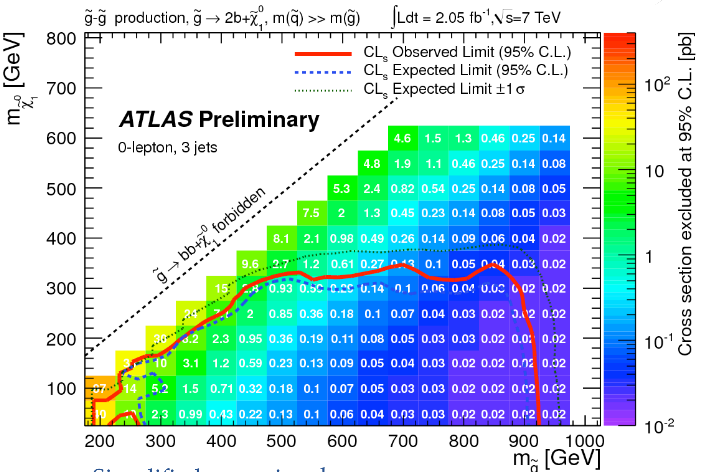


MSSM scenario where $m_{\tilde{g}} > m_{\tilde{b}_1} > m_{\tilde{\chi}_1^0}$

$\mathcal{B}(\tilde{g} \to \tilde{b}_1 b) = 100\%$ (other squarks heavy)

$\mathcal{B}(\tilde{b}_1 \to b\tilde{\chi}_1^0) = 100\%$

ATLAS-CONF-2012-003



Simplified scenario where $m_{\tilde{g}} < m_{\tilde{b}_1}$

$\mathcal{B}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0) = 100\%$ (other squarks heavy)

(off-shell sbottom)

ATLAS-CONF-2012-003

Summary

- Broad program of 3rd generation squark searches underway on ATLAS
  - **Gluino-mediated sbottom:** *b*-jets + E_T^{miss}
  - **Gluino-mediated stop:** 1 lepton + 4 jets + E_T^{miss}, same-sign dilepton + E_T^{miss}, multijets + E_T^{miss}
  - **Direct sbottom:** 2 *b*-jets + E_T^{miss} (m_{CT})
  - **Direct stop (GMSB):** 2 leptons + jets + E_T^{miss}
- No significant excesses; limits set on stop and sbottom masses ($m_{\tilde{b}} > 800$ GeV for $m_{\tilde{g}} < 920$ GeV [MSSM], $m_{\tilde{t}} > 450$ GeV for $m_{\tilde{g}} < 650$ GeV [MSSM])
- Still analyzing 5 fb^{-1} @ 7 TeV and looking forward to 8 TeV data in 2012!

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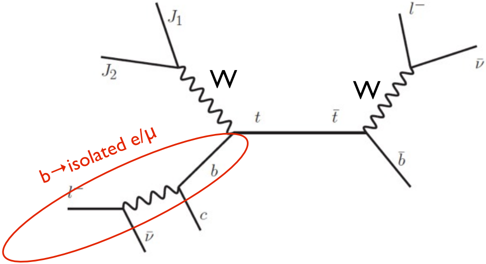
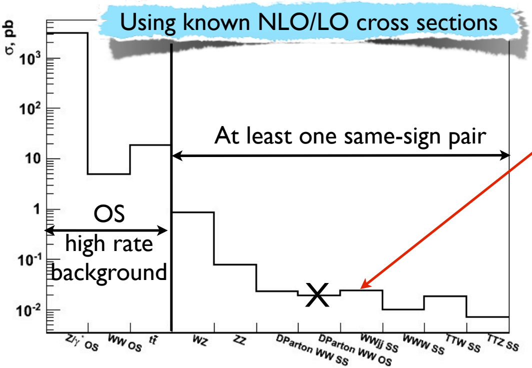
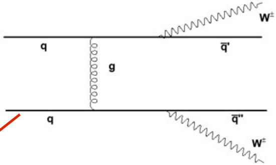
top-pair backgrounds: jet→ leptons

- Important background for all analyses with leptons
- Most of this background is from top-pair events
  - ✓ Note, not all is from b->e/μ, some can come from charm in W, or just light flavor
  - ✓ Muons are almost all from b, so says simulation !



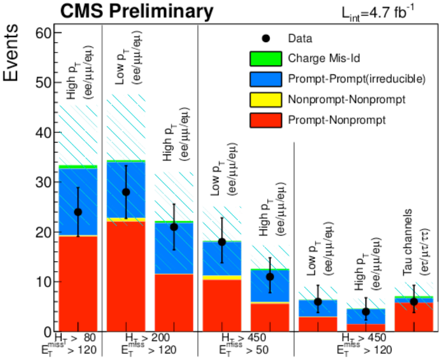
Same-sign dileptons in SM





- In SM only W and Z boson decays are of any interest
- WZ and ZZ above have extra lepton ==> extra Z rejected for SS analysis
- TTW and TTZ
  - ✓ Note, these naturally have 2 b-quarks

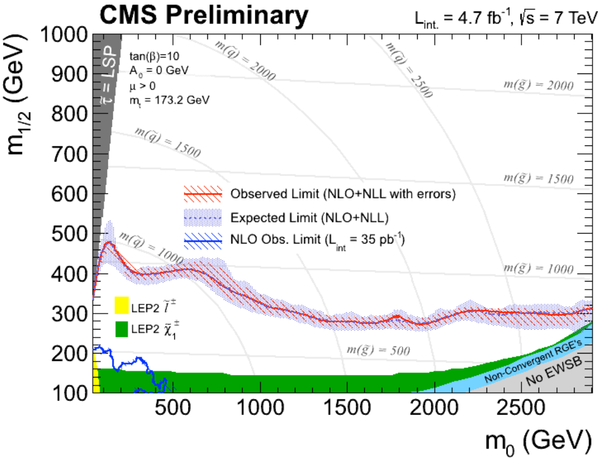
SS dileptons: results (1)



Region	Mode or p_T threshold			Total	UL 95% CL
	$p_T^{\ell 1,\ell 2} > 20, 10$ GeV				
	ee	$\mu\mu$	$e\mu$		
1	6.7 ± 2.7	8.3 ± 3.1	18.3 ± 6.9	33.2 ± 12.0	
	5	7	12	24	14.0
2	4.2 ± 1.7	5.9 ± 2.3	11.9 ± 4.5	22.1 ± 9.8	
	4	6	11	21	16.3
3	3.7 ± 1.5	3.0 ± 1.2	5.8 ± 2.3	12.5 ± 4.7	
	4	2	5	11	9.9
4	1.1 ± 0.8	1.1 ± 0.6	2.5 ± 1.1	4.6 ± 2.0	
	1	0	3	4	6.1
	$p_T^{e,\mu} > 10, 5$ GeV				
	ee	$\mu\mu$	$e\mu$		
2	4.3 ± 1.7	13.9 ± 6.0	16.1 ± 6.2	34.3 ± 13.2	
	4	10	14	28	17.4
3	3.3 ± 1.5	6.3 ± 2.8	8.6 ± 3.5	18.2 ± 6.9	
	4	6	8	18	14.3
4	1.0 ± 0.8	2.3 ± 1.2	3.1 ± 1.4	6.4 ± 2.6	
	1	2	3	6	7.4
	$p_T^{\tau,e,\mu} > 15, 10, 5$ GeV				
	$e\tau$	$\mu\tau$	$\tau\tau$		
4	2.6 ± 1.0	4.4 ± 2.2	0.0 ± 0.1	7.1 ± 2.8	
	1	5	0	6	7.1

- Good agreement in all selections
  - ➡ Set upper limits on possible signal

SS dileptons: interpretation in cMSSM

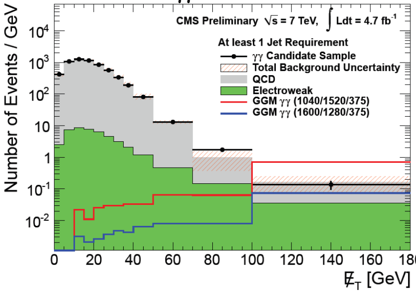


- Extend to about 1 TeV in gluino/squark masses

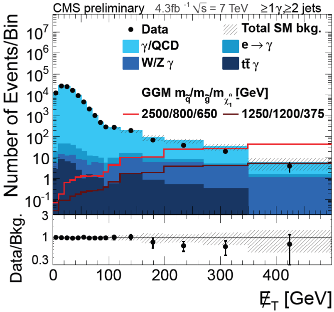
γ+MET: MET distributions

- Observed data in agreement with background predictions

γγ channel



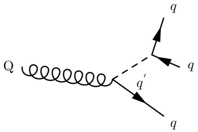
γ channel



Limits calculated by combining exclusive bins of MET
1γ: 6 bins starting at MET of 100 GeV
2γ: 6 bins starting at MET of 50 GeV

Three-Jet Resonances

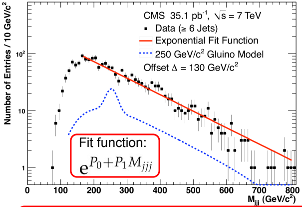
- New physics could be hiding in final states with more than 4 high-p_T jets
- This search focuses on a pair production of massive colored resonances, each decaying into 3 jets, resulting in a 6-jet final state ($pp \rightarrow QQ \rightarrow 3j\ 3j$)



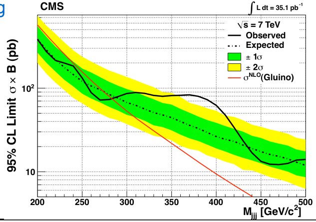
- One specific model of 3-jet resonances realized in RPV decays of supersymmetric gluinos to 3 quarks
  - Event selection criteria optimized in the context of this model but generic enough to provide a robust model-independent basis for searches for other models of new physics producing similar final states
- As in all cases up to now, the main background is the SM multijet production

Three-Jet Resonances (cont'd)

- Background modeling:
  - Shape of the triplet mass distribution largely unchanged between events with N_{jet}=4 (or N_{jet}=5) and $N_{jet}\geq 6$
  - $N_{jet}\geq 6$ triplet mass distribution described by an exponential function with the slope parameter P_1 constrained by the N_{jet}=4 triplet mass distribution
- Signal modeling:
  - Signal samples simulated using PYTHIA6
  - Gluinos modeled as narrow resonances and set to decay to 3 quarks through the λ_{uds} quark RPV coupling with BR(g~→qqq)=100%
- Dominant sources of systematic uncertainty:
  - Jet energy scale, ISR/FSR, pile-up, choice of PDFs, integrated luminosity

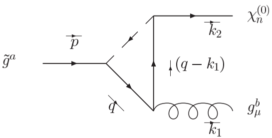


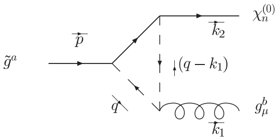
Data consistent with background expectation



Results:
- Gluino masses in the range 200 to 280 GeV (200 to 270 GeV expected) excluded at 95% CL

Is SUSY dead? Not at all.





- Gluino-bino coannihilation $\tilde{g} \to g\tilde{\chi}_1^0$
- Stop-bino coannihilation $\tilde{t} \to c\tilde{\chi}_1^0$
- Stau NLSP (favored by enhanced diphoton in MSSM of 125 GeV Higgs)

谢谢!