First searches for physics beyond the Standard Model at CMS

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Outline

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1. Introduction
2. Dijet searches
   - Dijet mass spectrum
   - Dijet centrality ratio
3. Heavy long-lived Particles
   - Heavy Stable Charged Particles
   - Stopped Gluinos
4. Commisioning of SUSY Searches
5. Outlook

Beyond the Standard Model at CMS

Standard Model

The SM has been very succesful, but it leaves many questions unsolved, which many other theories try to answer.

New Physics Searches

Final states with jets

- Dijets centrality ratio, resonances in the dijet mass distribution
- Black Holes, Multi-jet Resonance, Mono-jet, high mass resonances

Long lived particles

- Stopped gluinos, Heavy Stable Charged Particles
- GMSB SUSY decays to non-prompt photons

High mass dilepton and diphoton resonances

- Z' bosons, RS gravitons, excited leptons

High mass non resonant signals

- W' bosons, extra dimensions, contact interactions

Leptoquarks (CMS-PAS-EXO-10-005, see M. Kirsanov's talk)

Fourth generation

Supersymmetry

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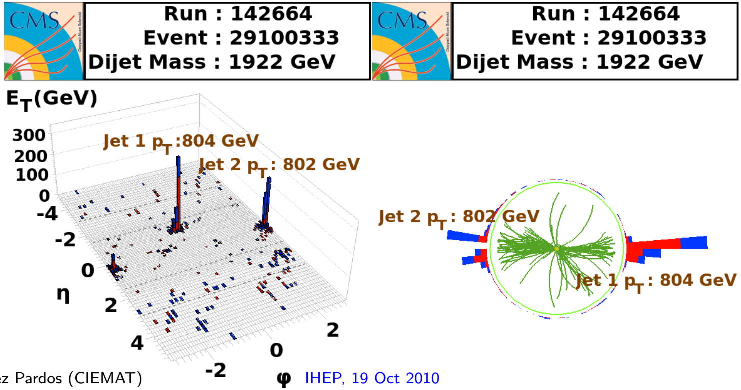
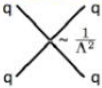
New Physics searches with Dijet Events

- Study the inclusive dijet final state using the observables:
  - Dijet mass spectrum:
    $M_{jj} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$
  - Dijet centrality ratio: $R = \frac{N(|\eta|<0.7)}{N(0.7<|\eta|<1.3)}$, both jets in the same η region



New Physics searches with Dijet Events

- Provide both a test of QCD and sensitivity to physics beyond the Standard Model.

	Mass Spectrum	Centrality Ratio
QCD 	simple test of cross section vs dijet mass from QCD and PDFs	detailed measure of QCD dynamics from angular distribution
Dijet Resonance 	provide most sensitive "bump" hunt for new particles decaying to dijets	less sensitive to dijet resonances, but important confirmation that "bump" is not QCD fluctuation
Contact Interaction 	because of experimental uncertainties, less sensitive to quark compositeness	sensitive search for quark compositeness

Dijet mass spectrum

- Resonances decaying to dijet are predicted by different theory models:

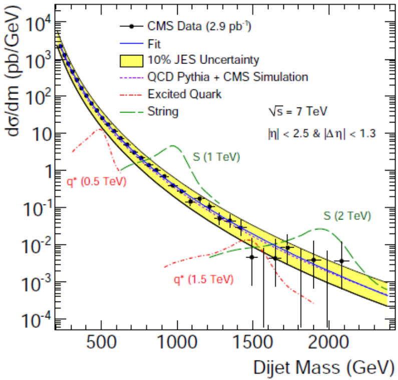
- String resonances: Regge excitations of quark and gluons, model with largest cross-section.
- Mass-degenerate excited quarks
- Axigluons: axial vector particles
- Colorons
- Scalar diquark
- Randall-Sundrum (RS) gravitons
- New gauge bosons (W', Z')

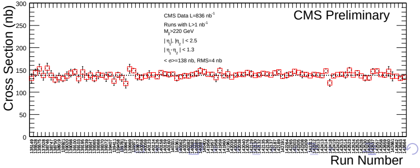
Model Name	X	Color	J^P	$\Gamma/(2M)$	Final-state Partons
String	S	mixed	mixed	0.003-0.037	qg, $q\bar{q}$, gg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W'	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z'	Singlet	1^-	0.01	$q\bar{q}$

Dijet mass spectrum

Results with 2.9 pb^{-1}, arXiv:1010.0203

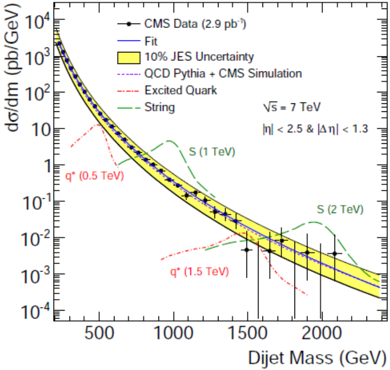
- Event selection based on a single-jet trigger. (One jet with E_T >50 GeV)
- Fully efficient for the selected events with M_{jj} >220GeV/c^2.
- No jet p_T requirements.
- Two jets reconstructed using the anti-k_T algorithm (R=0.7) with $|\eta|$ <2.5, $|\Delta\eta|$ <1.3 (leading jets).
- Spectrum extends to 2.1 TeV with 2.9 pb^{-1}.
- Data agree well with full QCD background simulation.
- Cross section vs. time: stable within 3%, indicates that JES stability is better than 0.5%.

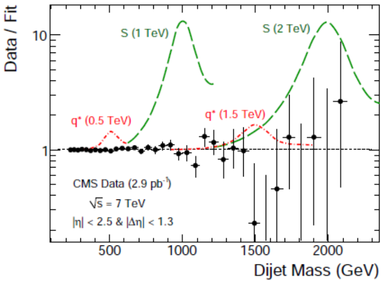




Dijet mass spectrum
Fit of mass spectrum

- Data fitted to $\frac{d\sigma}{dm} = \frac{P_0 \cdot (1-m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3 ln(m/\sqrt{s})}}$.
- Ratio beetween data points and the smooth fit is compared to simulated excited quarks and string resonance signals.
    - No indication of new physics with $\mathcal{L}= 2.9\ \mathrm{pb}^{-1}$.





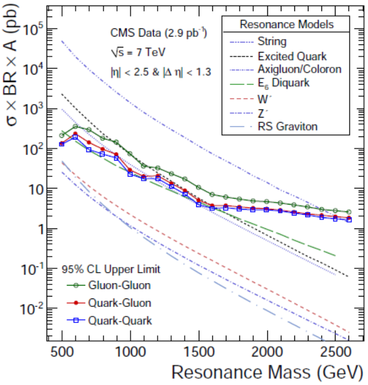
Model independent cross-section limits

- 95% CL upper limits on $\sigma \times \mathrm{BR} \times \mathrm{A}$ for dijet resonances of type gluon-gluon, quark-gluon and quark-quark.
- These upper limits are compared to the theoretical predictions for seven resonance models.

95% CL Mass Limit (TeV) using CTEQ6L

Model	CMS ($2.9\ \mathrm{pb}^{-1}$)	CDF ($1.13\ \mathrm{fb}^{-1}$)
String	2.5	1.4
q*	1.58	0.87
Axigluon	1.52	1.25
E_6 diquark	1.60	0.63

- Superseded Tevatron limits for string resonances, q*, E_6 diquark, axigluons. ATLAS: $M_{q*} > 1.26$ TeV ($315\ \mathrm{nb}^{-1}$), arXiv:1008.2461.

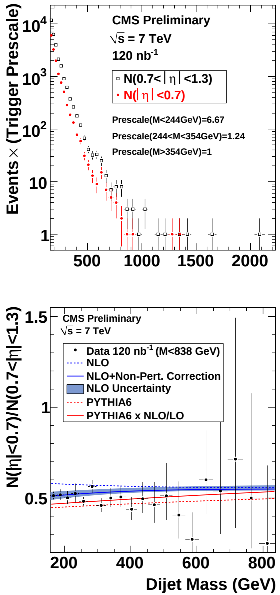


- Dominant sources of systematic uncertainty: JES, JER, integrated $\mathcal{L}$, BG parametrization.

Dijet centrality ratio

$$R = \frac{N(|\eta|<0.7)}{N(0.7<|\eta|<1.3)}$$

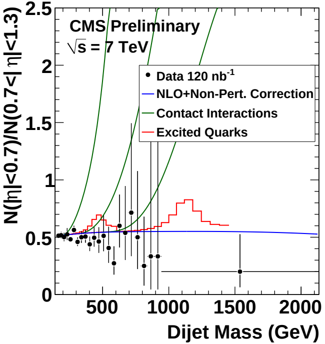
- Quantifies the centrality of the dijet system at a given dijet mass.
- New Physics predict higher dijet production at lower values of $|\eta|$.
- In SM: ratio roughly flat for the dominant t-channel scattering QCD (value 0.5-0.6).
- Two models considered, motivated by the possibility that q are composite particles: contact interactions and dijet resonances coming from q*.
- Rises rapidly with contact interactions.
- Peaks near the mass of the resonance for excited quarks (q*→qg).

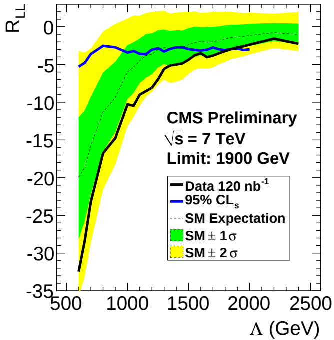


Dijet centrality ratio

Limits to contact interaction scale

- Ratio flat: no new physics.
- Contact interaction scale excluded for $\Lambda < 1.9$ TeV at 95% CL. with $\mathcal{L}=0.12\ pb^{-1}$ (Log-likelihood ratio statistic.)

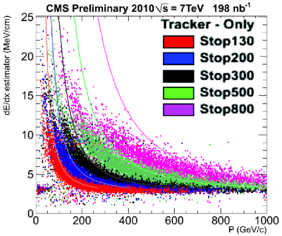


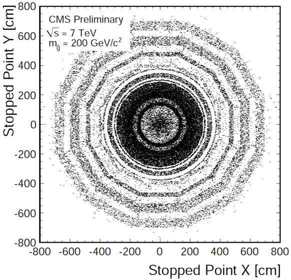


- ATLAS limit excludes $\Lambda < 3.4$ TeV with $\mathcal{L}=3.1pb^{-1}$, arXiv:1009.5069v1.

Outline

Heavy long-lived Particles

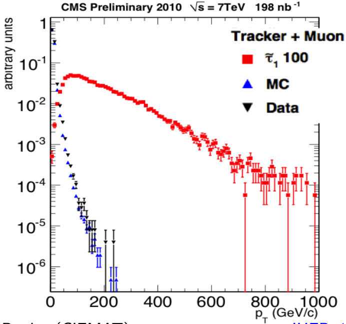


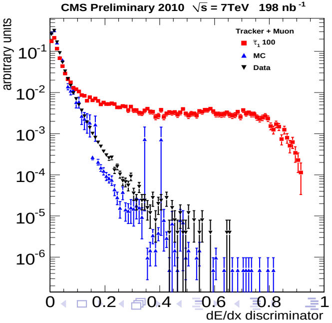


- Predicted by many new physics scenarios
  - Some flavours of SUSY
  - Hidden valley models
  - GUT's
  - Split SUSY
- Charged heavy particles: Slow moving particles will lose E at a higher rate than MIP. If hadron-like, can stop in the detector.
- Two complementary methods:
  - High momentum tracks with high dE/dX (sensitive to $\beta > 0.3$).
  - Stopped particles, decay product signals out-of-synch. w.r.t. bunch crossing ($\beta < 0.3$).

Search for Heavy Stable Charged Particles

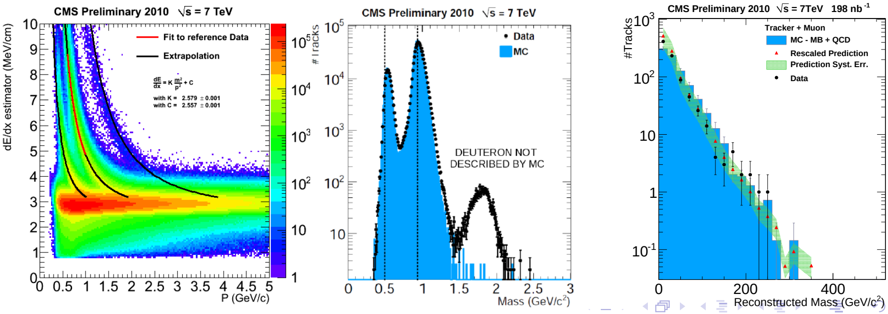
- Signature based search:
  - Tracker + muon (e.g. mGMSB $\tilde{\tau}$, m$\sim$100-300 GeV)
  - Tracker only (e.g. $\tilde{t}$, $\tilde{g}$ m$\sim$130-900 GeV)
- Select tracks with high p_T, dE/dx
  - Use discriminator for dE/dx based on measured energy loss for MIPs.
  - Good discrimination, MC-data agreement in both variables.
- Selection optimised in bins of η and number of hits to increase sensitivity.





Mass determination

- Mass estimate: Approximate Bethe-Bloch formula before minimum $I_h = K\frac{m^2}{p^2} + C$.
- Parameters K, C extracted by fitting proton line.
- Reverse to compute higher masses.
- Good agreement between data and MC in event counts and mass distribution. (right plot)

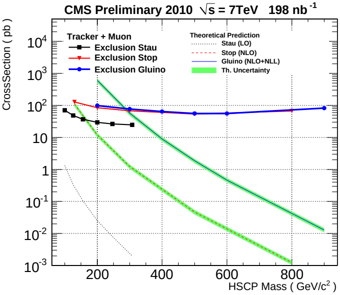


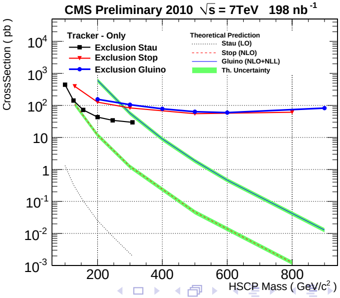
Results: Limits on HSCP Production

- Null result in search region and full mass spectrum.

	Exp.	Obs.	Exp. in full spectrum	Obs. in full spectrum
Muon-like	0.153 $\pm$ 0.061	0	0.249 $\pm$ 0.050	0
Tracker-like	0.060 $\pm$ 0.021	0	0.060 $\pm$ 0.011	0

- Set 95% CL limits on the production cross-section for **stau**, stop and gluino.
  - Tracker-only analysis: exclusion $m_{\tilde{g}} < 271$ GeV/c^2.
  - Tracker + muon: exclusion $m_{\tilde{g}} < 284$ GeV/c^2.

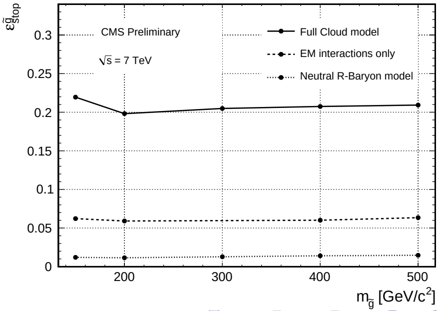




Search for Stopped Gluinos

- If long-lived gluinos are produced at CMS will hadronise into 'R-hadrons' ($\tilde{g}g$, $\tilde{g}q\bar{q}$, $\tilde{g}qqq$ states).
- These stopped R-hadrons may decay during time intervals when there are no pp collisions.
- Complements HSCP searches because it's sensitive to β <0.3.

- Event selection:
  - Jet trigger + veto beam presence.
  - Veto events with muons (cosmic BG).
  - Noise rejection.
- Up to ∼20% probability to stop somewhere in CMS, model dependent.

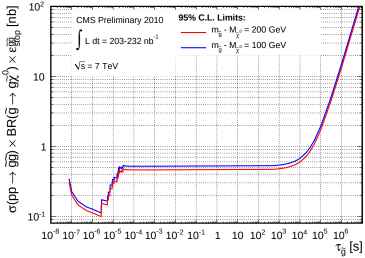


Limits on gluino stopping probability

Counting and time profile results

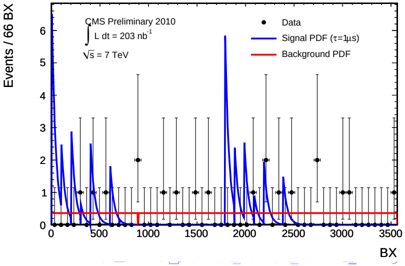
Counting experiment

- Hypothesis on $\tau_{\tilde{g}}$ from 75ns to 10^7s: set limits on $\sigma \times \mathrm{BR} \times \epsilon_{\tilde{g}\tilde{g}}$ over 14 orders of magnitude in $\tau_{\tilde{g}}$.
- No excess above expected BG.
- Result independent of models of R-hadron formation and nuclear int.



Time profile analysis

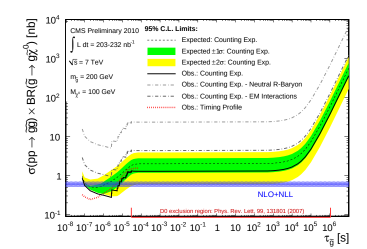
- Expected timing profile of gluino decays is correlated with the timing profile of the delivered $\mathcal{L}$, while BG is not, it's flat with time.
- Range limited to 100 μs (gluino lifetime smaller than orbit period to be distinguishable from BG.)



Model dependent results

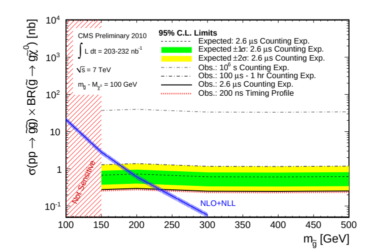
Gluino cross-section limit

- Use stopping probability to obtain a limit (e.g. $m_{\tilde{g}} = 200$ GeV, $M_{\tilde{\chi}^0} = 100$ GeV) employing the R-hadrons models.
- For $m_{\tilde{g}} = 200$ GeV excluded 75 ns $< \tau_{\tilde{g}} < 6\mu$s.
- Extends Tevatron results below 30μs.



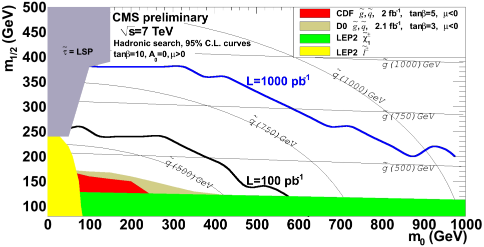
Gluino mass limit

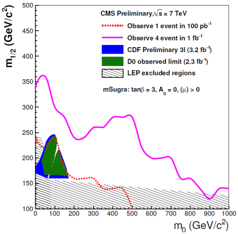
- For a mass difference $m_{\tilde{g}} - M_{\tilde{\chi}^0} > 100$ GeV, exclusion:
- Time profile analysis: $m_{\tilde{g}} < 229$ GeV (τ=200 ns)
- Counting experiment: $m_{\tilde{g}} < 225$ GeV (τ=2.6 μs)



Outline

SUSY searches





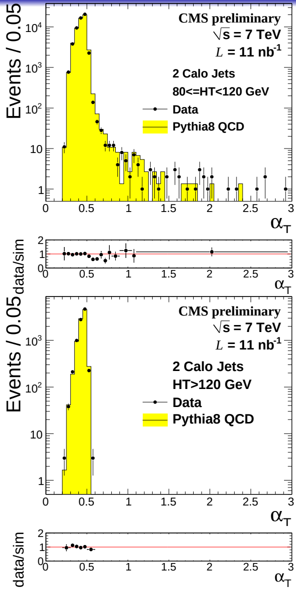
- 100 pb^{-1} 7 TeV data should provide sensitivity to SUSY parameter space well beyond current Tevatron limits and in several analyses it should be enough with the 2010 dataset to surpass Tevatron.
- Searches in SUSY involve a broad range of signatures with jets, leptons, γ and MET: require a careful control of BG.
- Currently efforts to test strategies to supress and estimate SM backgrounds with data, validate data-driven methods, ie. supressing QCD contributions to MET and predicting QCD contribution to lepton samples.

Suppressing QCD contribution to MET

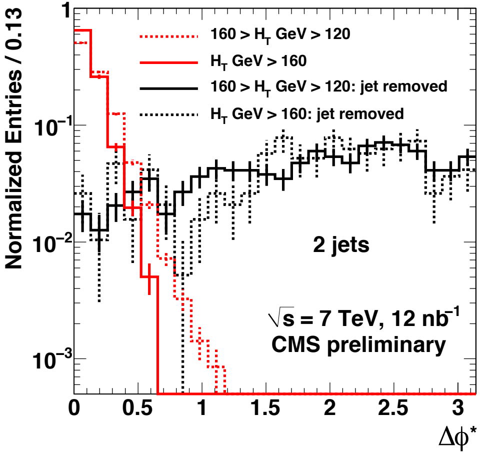
- QCD events where hadronic activity is mismeasured would produce artificial MET: key BG that must be carefully controled.

Suppressing QCD with α_T in dijet and multijet channels.

- α_T characterises the overall transverse momentum balance of the event:
  $$\alpha_T = \frac{p_{T2}}{M_T} = \frac{\sqrt{p_{T2}/p_{T1}}}{\sqrt{2(1-cos\Delta\phi)}},$$
  powerful discriminator against QCD.
- QCD BG confined to α_T <0.5.
- α_T rejection power increases with $H_T = \sum p_T(jet)$, observed for 2-jet, $\geq$3 jets (SUSY: H_T >350 GeV).



Suppressing QCD contribution to MET



Suppressing QCD with $\Delta\phi$

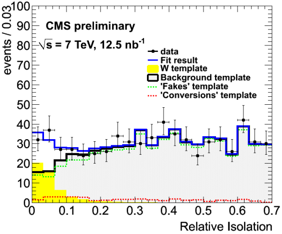
- $\Delta\phi^*$(jet,MET) tests whether one jet rescaled could balance the event.
- Small for QCD (cut at 0.5 suppress it efficiently), larger values if there is MET.

QCD background prediction for leptons

- BG from non-prompt leptons and hadrons misidentified as leptons are important in SUSY signatures with isolated leptons, and particularly in tighter signatures as like-sign di/tri-leptons.
- Discriminating variable: Isolation

e+jet+MET

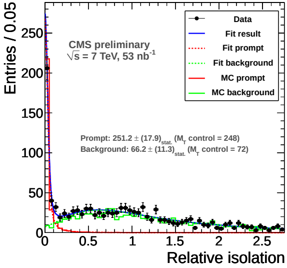
- Model isolation behaviour for BG in control samples, selected inverting certain selection cuts.



- Events well modeled.

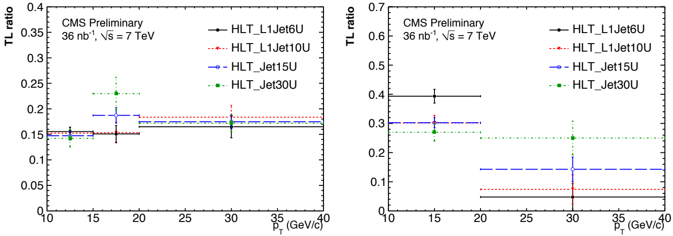
muon+jet+MET

- Direct fit to isolation distribution to determine the BG from non-prompt muons to prompt muon signal.



Same signed dilepton background prediction

- Main BG is expected from $t\bar{t}$ where both W decay leptonically and one is charge mis-identified or one lepton comes from b/c decay or mis-id. light quark jet.
- Use jet-triggered control sample (loose lepton-ID + iso) to measure selection efficiency in terms of tight (signal)/loose (BG enriched) selection ratio (TL ratio).

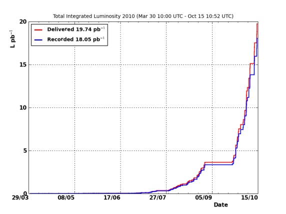


- Extrapolate this eff. to lepton-triggered samples to predict the yield of SS-dileptons passing tighter requirements.
- Predicted and observed number of same-signed dilepton events consistent.

Outline

Summary and outlook

- In this talk we presented results with 0.12 - 2.9 pb^{-1}.
- CMS is already exploring new territory in various physics channels.
- No signals of new physics observed yet.
- Understanding of the SM background is the first step towards BSM searches and the data collected by CMS at 7 TeV allowed to test some of methods to suppress and measure them.
- Both the LHC and CMS are performing very well, the luminosity collected is increasing fast, with more than 20 pb^{-1} recorded as of today.



- Stay tuned for updates, we are at the beginning of an exciting journey.

Bibliography

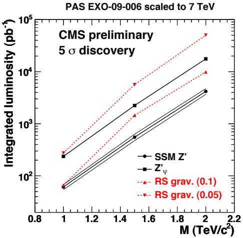
- Search for New Physics with the Dijet Centrality Ratio, CMS PAS EXO-10-002
- First Results on the Search for Stopped Gluinos in pp collisions at 7 TeV, CMS PAS EXO-10-003
- Search for Heavy Stable Charged Particles in pp collisions at 7 TeV, CMS PAS EXO-10-004
- Search for Dijet Resonances in the Dijet Mass Distribution in 7 TeV pp Collisions at CMS, CMS PAS EXO-10-010
- Performance of Methods for Data-Driven Background Estimation in SUSY searches, CMS PAS SUS-10-001
- Search for Dijet Resonances in 7 TeV pp Collisions at CMS, CMS Collaboration, arXiv:1010.0203
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

BACK UP

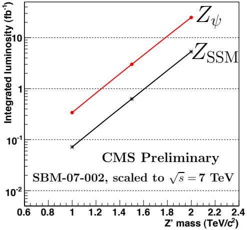
Prospects

Examples of dilepton and diphotons resonances

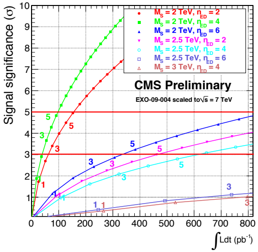
Z'→ee



Z'→ $\mu\mu$

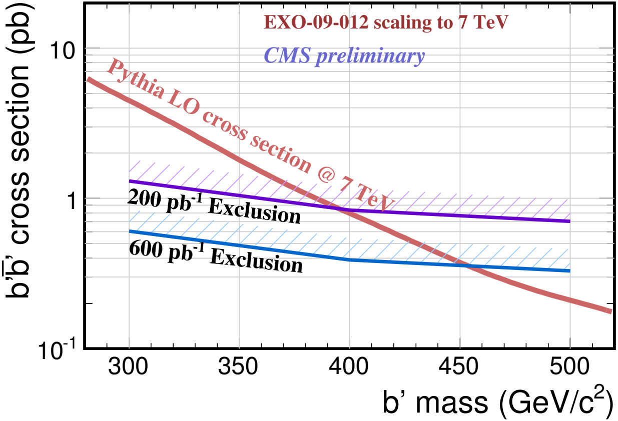


LED - diphotons



Prospects

Fourth generation b'



Jet reconstruction

- Anti-kT algorithm
  - $d_{ij} = min(\frac{1}{k_{T,i}^2}, \frac{1}{k_{T,j}^2})\frac{R_{ij}^2}{R^2}$
  - $\Delta R_{i,j}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$
  - Tends to cluster the energy around the hardest particles
  - Merging of 4-vector pairs based on transverse momentum weighted by the distance in the (y,ϕ) plane
  - Clustering terminates when that distance is greater than an specific value R (resolution parameter), of the order of unity
  - Infrared and collinear safe.