



# Searches and new limits with CMS (Non-SUSY searches)

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# Outline

- New physics searches in di-jet
  - di-jet mass resonance
  - quark compositeness
- New physics searches in lepton+jet
  - first generation leptoquark
- New physics searches in heavy stable charged particles
  - stopped gluino
  - slowly moving gluino/stop/stau
- Conclusions

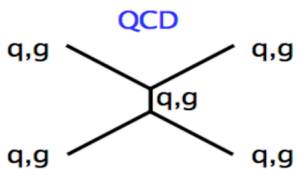
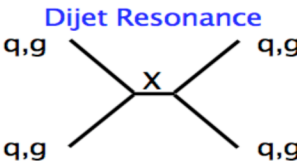
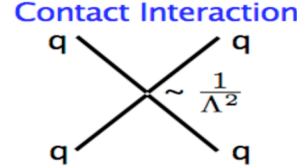


# Searches in di-jet



# Searches in di-jet

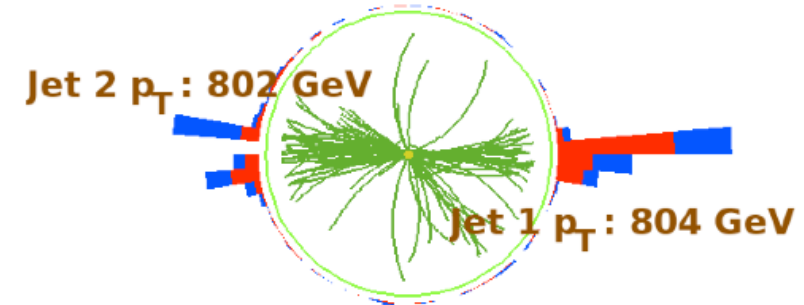
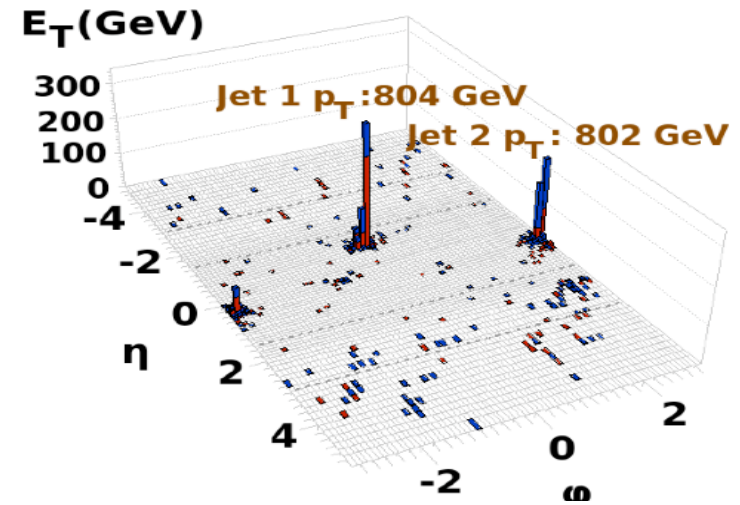
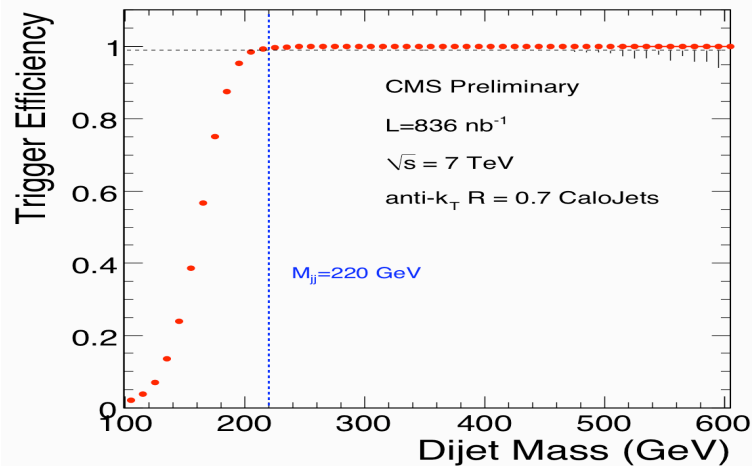
Di-jet events provide both a test of QCD and sensitivity to physics beyond the standard model, CMS studied di-jet mass spectrum and centrality ratio ( $R=N(|\eta|<0.7) / N(0.7<|\eta|<1.3)$ )

	Mass Spectrum	Centrality Ratio
	Test of QCD and PDFs through differential cross section $d\sigma/dm$	Test of QCD dynamics via angular distribution measurements
	Direct evidence for new particles decaying to jets	Some sensitivity through centrality ratio vs. di-jet mass distribution
	Lower sensitivity due to experimental uncertainties	C. I. produces more isotropic angular distribution than QCD



# Dijet mass spectrum

- Data used  $2.9 \text{ pb}^{-1}$  @ 7TeV
- Event selection based on a single-jet trigger with  $E_T > 50 \text{ GeV}$
- Trigger fully efficient for  $M_{jj} > 220 \text{ GeV}$
- At least two anti-kt calo-jets (distance parameter  $R=0.7$ ) with  $|\eta| < 2.5$ ,  $|\Delta\eta| < 1.3$
- Jet energy corrected as a function of  $\eta$  and  $P_T$  for detector response

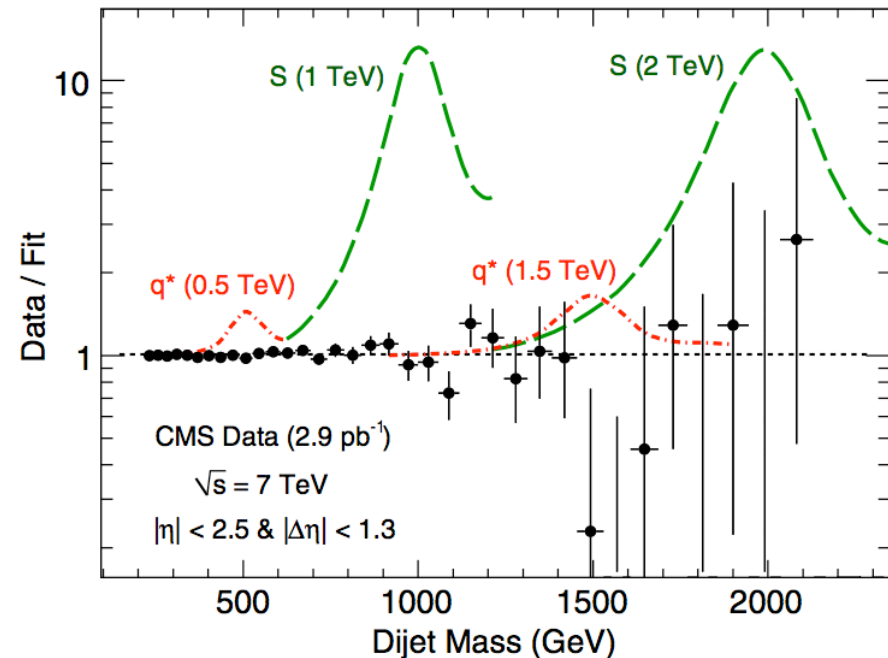
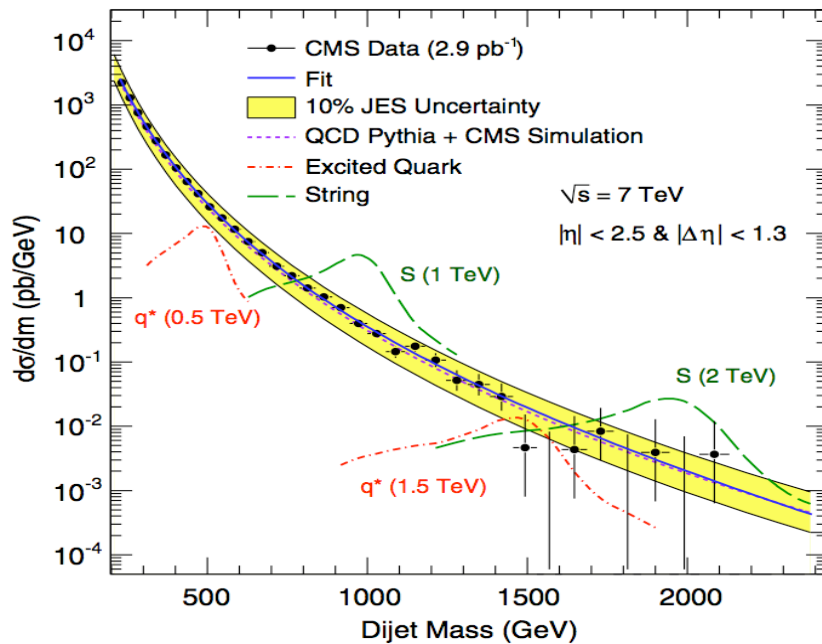




# Fit to dijet mass spectrum

- Data fitted to a 4 parameter smooth function
- Obtained  $\chi^2/\text{ndf} = 32/31$
- No indication of new physics

$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

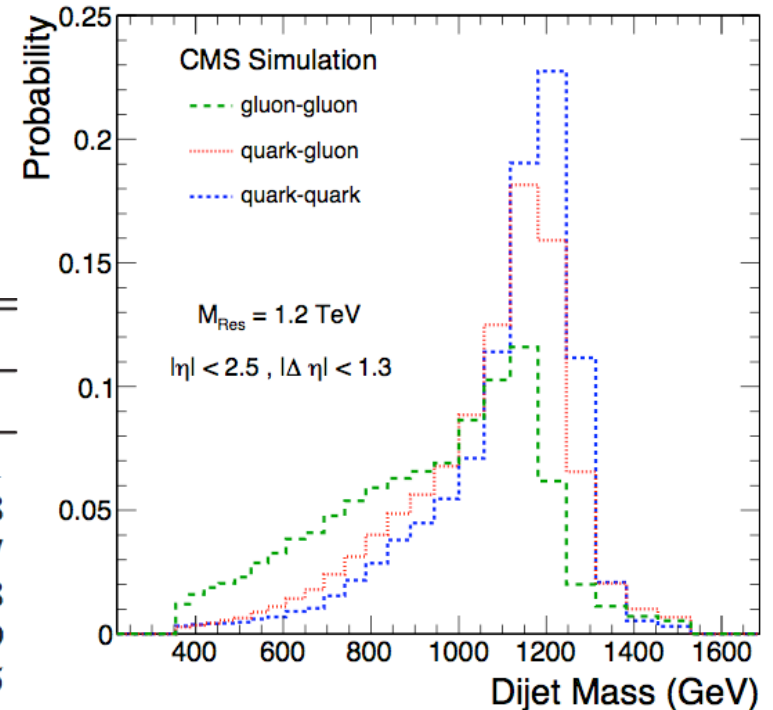




# Model independent Limits

- Generic upper limits on  $\sigma \cdot \text{Br}$   
Acceptance for gg, qg and qq resonance respectively, because of different dijet mass behavior.

Upper limit ( $pb$ )			Upper limit ( $pb$ )				
Mass (TeV)	qq	qg	gg	Mass (TeV)	qq	qg	gg
0.5	118	134	206	1.6	3.05	3.72	6.71
0.6	182	229	339	1.7	3.13	3.64	5.88
0.7	90.7	134	281	1.8	2.92	3.41	5.37
0.8	70.8	93.5	177	1.9	2.73	3.15	4.78
0.9	52.7	71.6	142	2.0	2.71	3.02	4.39
1.0	20.3	29.0	71.4	2.1	2.50	2.84	4.15
1.1	17.0	20.1	35.1	2.2	2.20	2.55	3.69
1.2	17.0	20.4	32.5	2.3	1.96	2.28	3.32
1.3	10.5	12.9	22.8	2.4	1.79	2.08	2.94
1.4	6.77	8.71	16.4	2.5	1.67	1.93	2.74
1.5	3.71	5.02	10.3	2.6	1.55	1.80	2.50

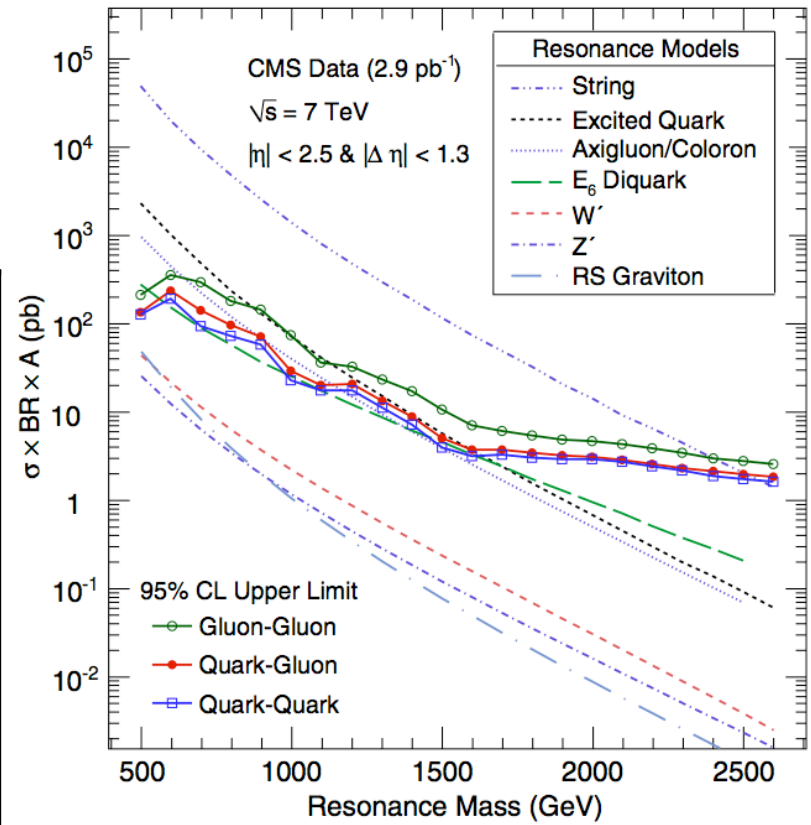




# Specific model limits

- No limits on  $W'$ ,  $Z'$ , RS graviton
- Extended previous limits for below 4 models

Exclusion Limits (TeV)	CMS (3 pb <sup>-1</sup> )	CDF (1.13 fb <sup>-1</sup> )	ATLAS (315 nb <sup>-1</sup> )
String	0.50-2.5	1.4	*
q*	0.50-1.58	0.87	1.26
Axigluon	0.50-1.17 1.47-1.52	1.25	*
E <sub>6</sub> diquark	0.50-0.58 0.97-1.08 1.45-1.60	0.63	*



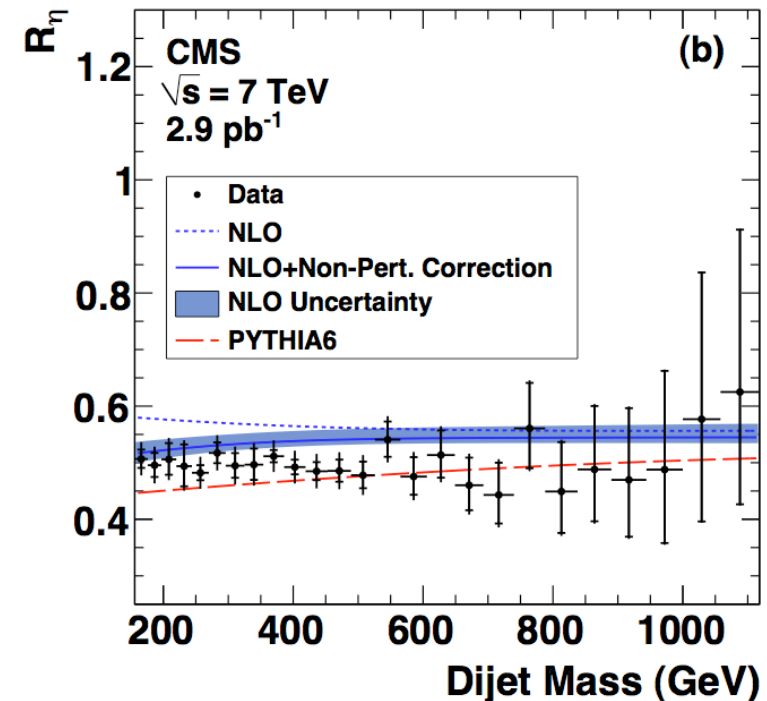
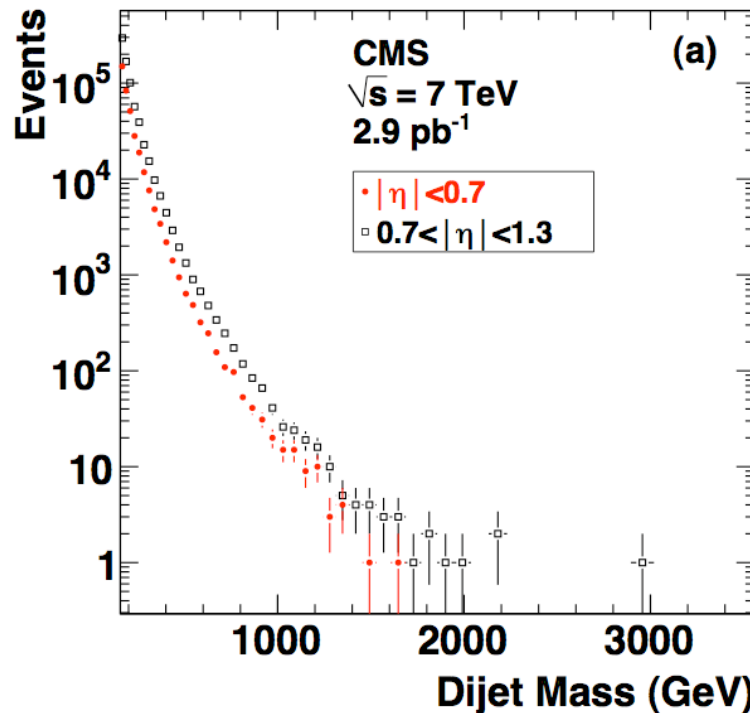
Published in Phys. Rev. Lett. 105. 211801





# Dijet centrality ratio

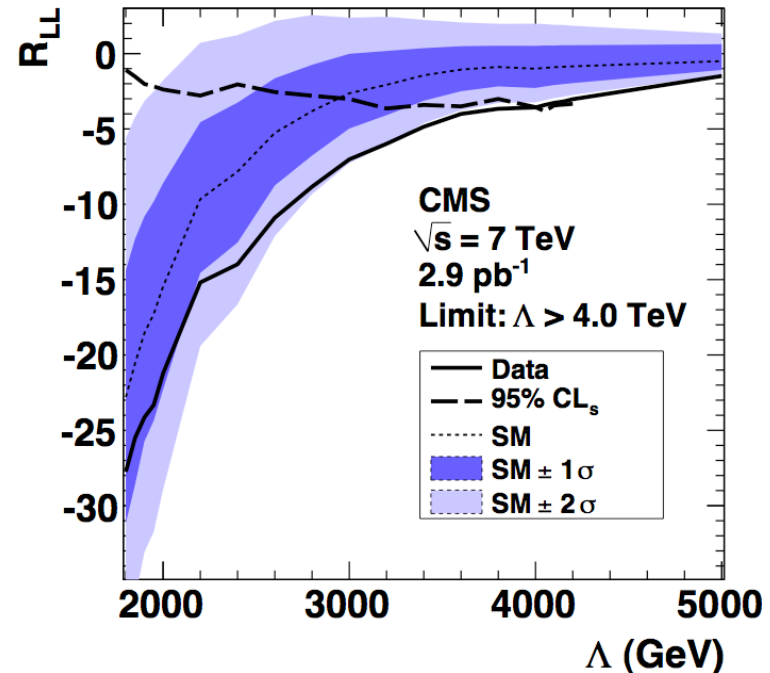
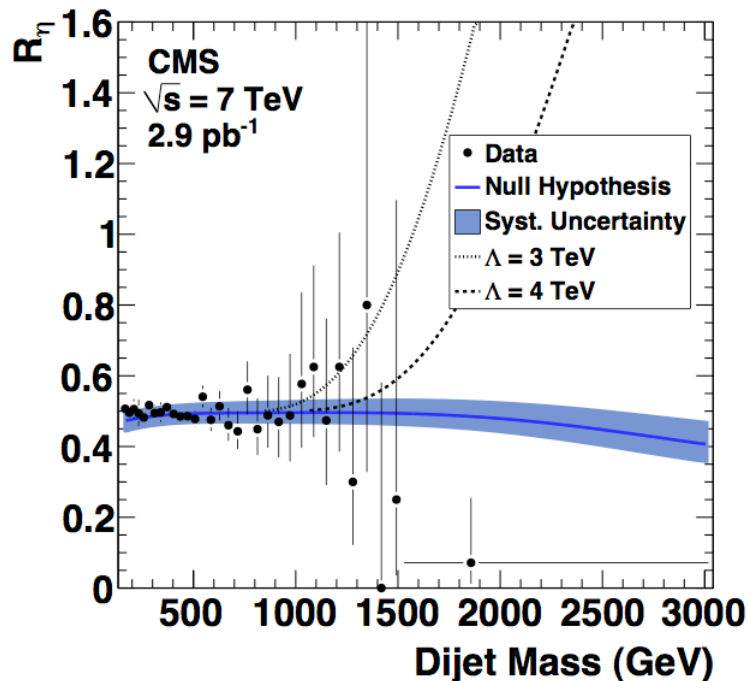
- $R = N(|\eta| < 0.7) / N(0.7 < |\eta| < 1.3)$
- Complimentary to the mass spectrum analysis
- Many experimental uncertainties cancel in the R (e.g. absolute jet energy scale, luminosity)





# Limits on contact interaction

- Ratio flat for SM, rising for contact interaction.
- Log-likelihood ratio  $R_{LL}$  to test contact interaction vs. SM hypothesis
- **Contact interaction scale  $\Lambda < 4.0$  TeV is excluded @95% C.L.**
  - Tevatron and ATLAS limits are 2.8 TeV and 3.4 TeV respectively.



arXiv: 1010.4439 [hep-ex], accepted by PRL



# Searches in lepton+jet



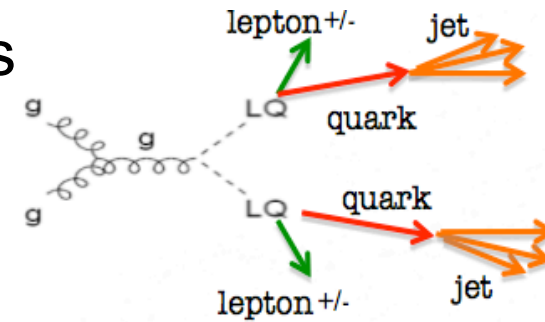
# Searches in lepton+jet

- Leptoquark: hypothetical particles carrying both lepton and baryon numbers

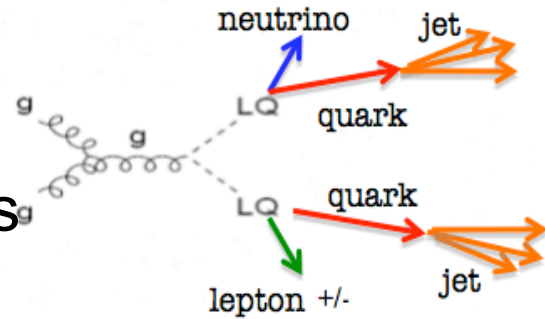
- Grand Unified Theories
- Technicolor, SUSY
- Composite models of leptons and quarks

- Three generations of leptoquarks

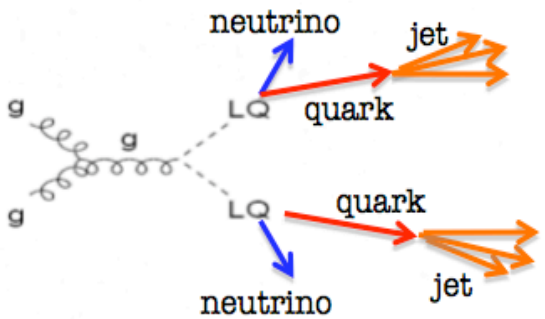
- Couple only to same generation.
- Decay to lepton + quark
  - $\beta = \text{Br}(LQ \rightarrow \text{lepton} +/ - + q)$
  - $1 - \beta = \text{Br}(LQ \rightarrow \text{neutrino} + q)$



$$\begin{matrix} lljj \\ \beta^2 \end{matrix}$$



$$\begin{matrix} lvjj \\ 2(1-\beta)\beta \end{matrix}$$



$$\begin{matrix} vvjj \\ (1-\beta)^2 \end{matrix}$$

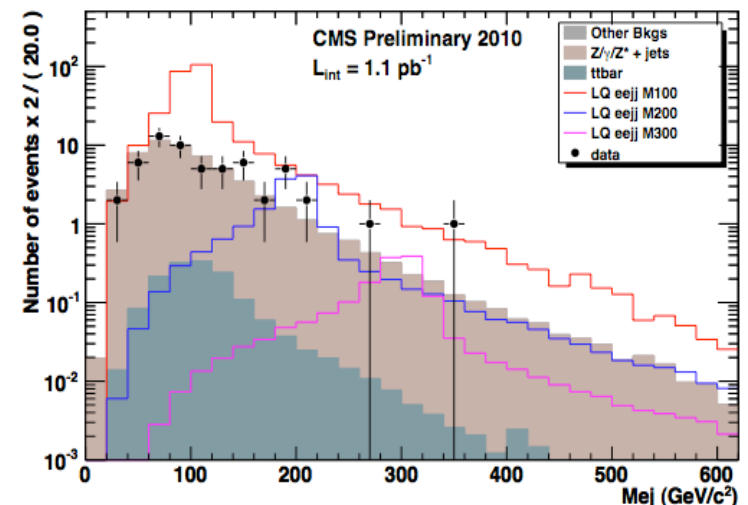
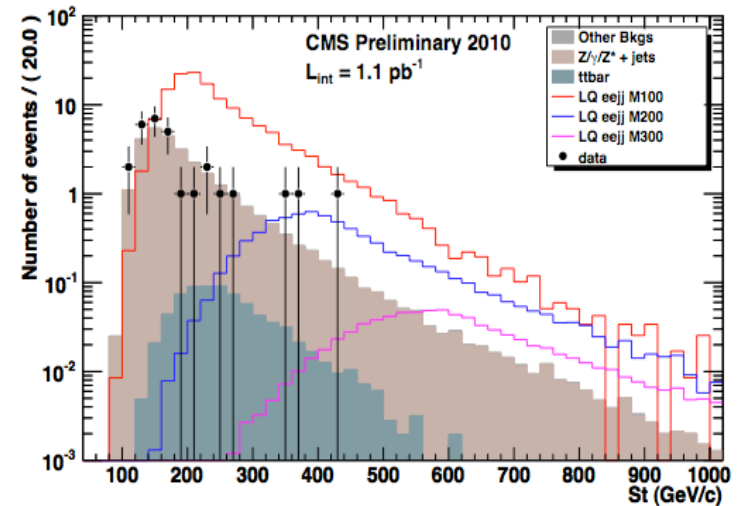


# 1st generation leptoquark

Search for LQ1 in two electron+ two jets channel,  $1.1\text{pb}^{-1}$  data

## Selection:

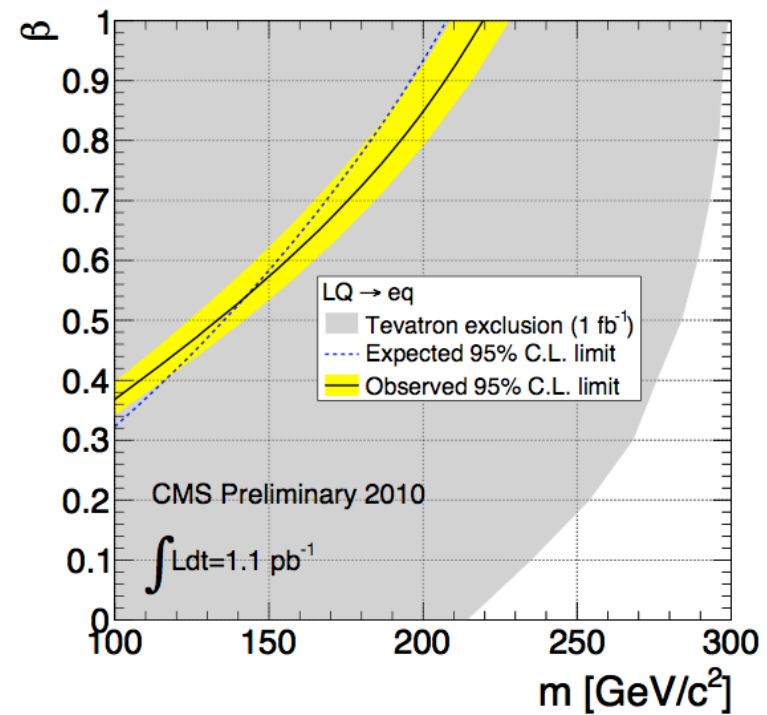
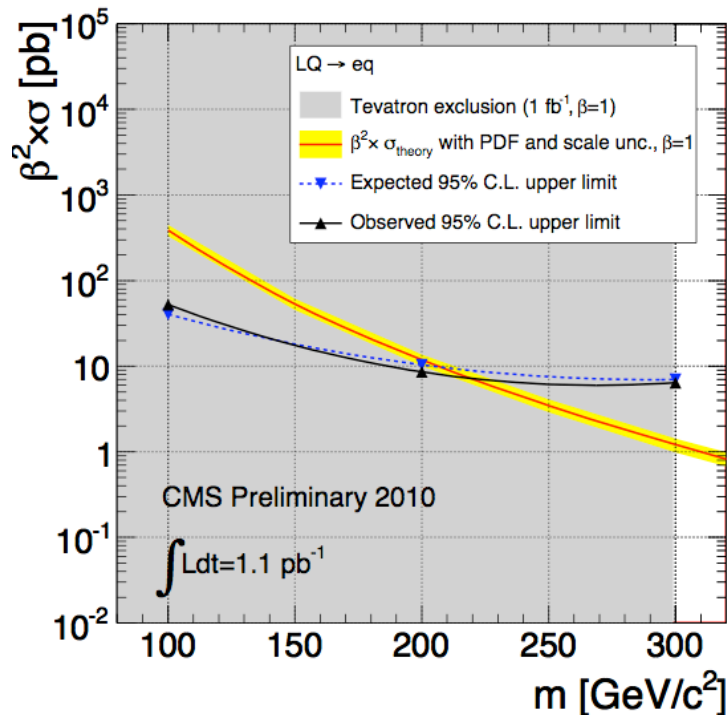
- At least two electrons with  $p_T > 30$  GeV, at least two jets with  $p_T > 30$  GeV
- Minimum  $\Delta R$  between any of the selected electrons and jets greater than 0.7
- $M_{ee} > 100$  GeV
- $S_t = p_T(e_1) + p_T(e_2) + p_T(\text{jet}_1) + p_T(\text{jet}_2) > 140\text{-}380$  GeV, optimized for different LQ1 mass hypotheses
- Two ways to combine the two leading electrons and the two leading jets to make two candidate LQ1's. The pair of  $M_{ej}$  with minimum difference is used





# 1st generation leptoquark

- In absence of discernable signal, set upper limit on  $\sigma(pp \rightarrow LQ1LQ1+X) \cdot \beta^2$ , 220 GeV 1st generation LQ1 is excluded for  $\beta=1$
- Results are in PAS EXO-10-005, available at <http://cdsweb.cern.ch/record/1289514>





# Searches for long-lived charged particle



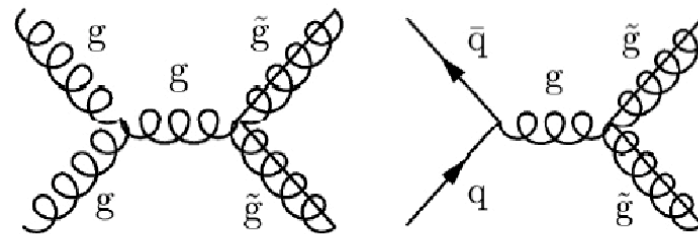
# Long-lived charged particle

Heavy Stable Charged Particle (HSCP), CHAMP/CMSP @ CDF/D0

- Small coupling/mass splitting between Next-to-Lightest Stable Particle (NLSP) and LSP, or some new confinement force  $\rightarrow$  NLSP long-lived (doesn't decay promptly inside detector)
- **Clean detector signature independent of BSM models.**

Production Mechanism:

- Pair production
- Cascade decay
- Resonance production
- **Lepton-like HSCP**
  - GMSB stau, UED KK tau
- **R-hadron** (strongly produced HSCPs picking up SM quarks)
  - Split Supersymmetry  $\rightarrow$  gluino (hadronized to gluinoball, R-meson, R-baryon)
  - Baryogenesis motivated Minimal Supersymmetric Standard Model  $\rightarrow$  stop







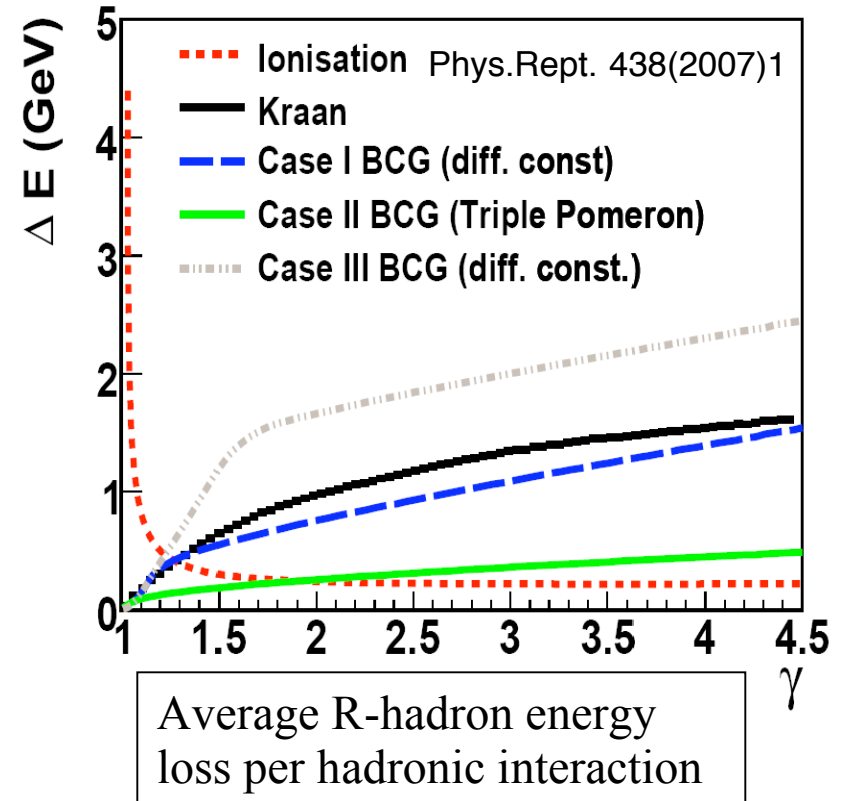
# Signatures in detector

## Slower time of flight

- Non-relativistic  $\rightarrow$  slower speed than SM particles

## Higher energy loss inside detector

- Lepton-like HSCPs, behave like (heavy) muons
  - Non-relativistic  $\rightarrow$  large ionization energy loss
- R-Hadron, also has hadronic interactions from different models
  - Few GeV per interaction  $\rightarrow$  no showering in calorimeters
  - heavy parton acts as spectator
  - Conversion to a different R-hadron species possible
  - New **neutral R-baryon** interaction model: all R-baryons become neutral after calorimeter arXiv:0908.1868 [hep-ph]





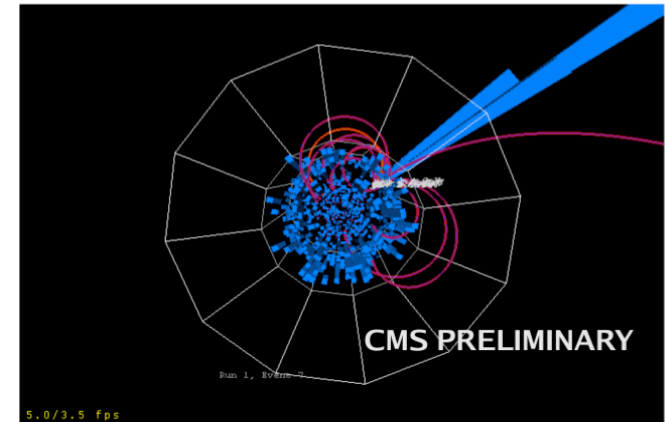
# HSCP detection

HSCPs can possibly stop inside ( $\beta < 0.3$ ) or slowly escape ( $0.4 < \beta < 0.9$ ) detector

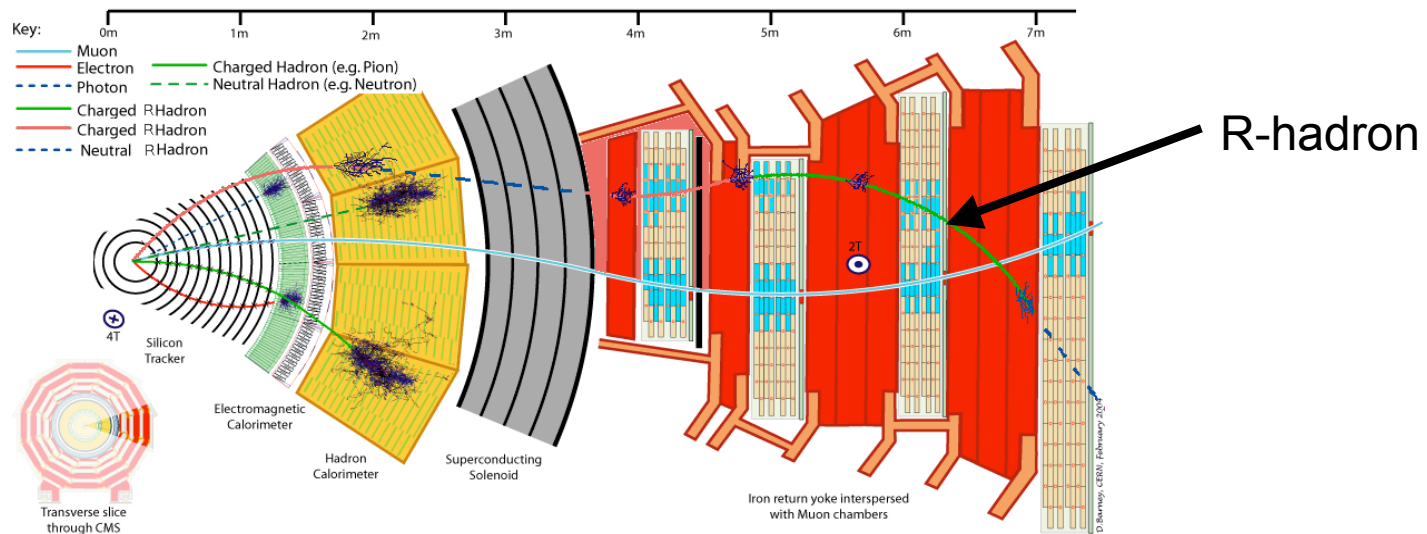
**Stopped HSCP:** look for energetic hadronic jet from HSCPs decaying during beams OFF or collision intervals

**Slowly moving HSCP:** measure  $\beta$  from delayed time of flight (T.O.F) and tracker  $dE/dx$  (ionization energy loss per path length)

- Can measure mass from  $p/(\beta\gamma c)$



CMS-PAS-EXO-09-001





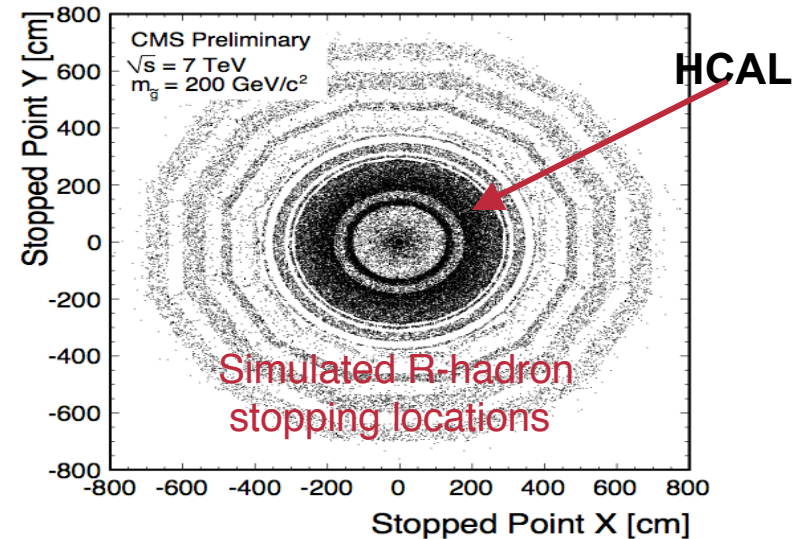
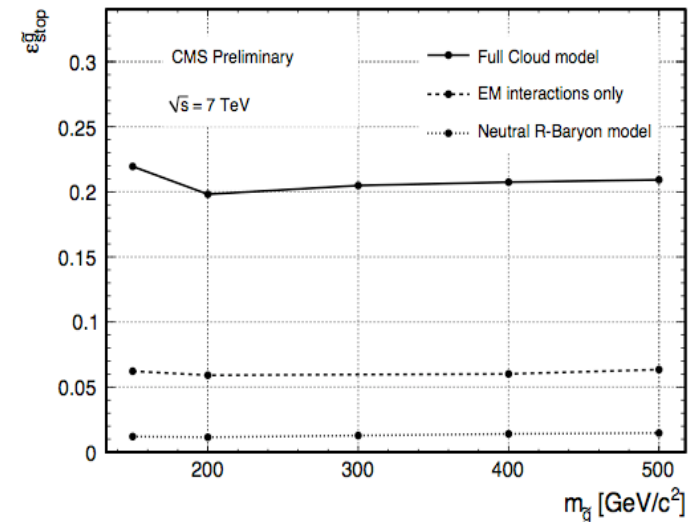
# Stopped gluino

## Data Samples:

- 95 hours of trigger live-time during LHC fills, peak luminosity  $2\text{-}7 \cdot 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ , as control sample for background estimation
- 62 hours of trigger live-time during LHC fills with a peak luminosity of  $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ , an integrated luminosity of  $10 \text{ pb}^{-1}$

## Selection:

- dedicated 20 GeV jet trigger with no coincidence of signals from beam position and timing (BPTX) monitors
- 50 GeV jet energy requirement, beam-related, cosmic and instrumental background rejection





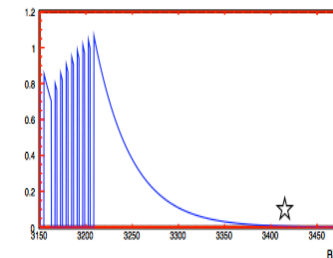
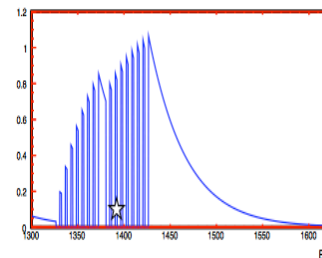
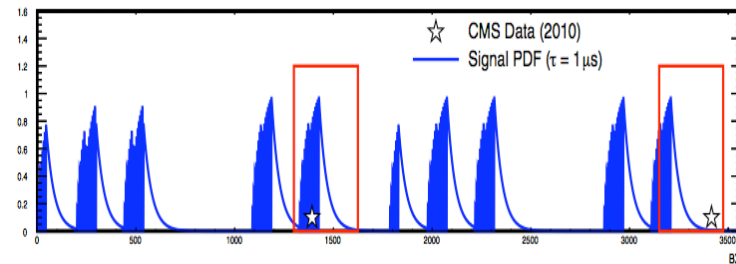
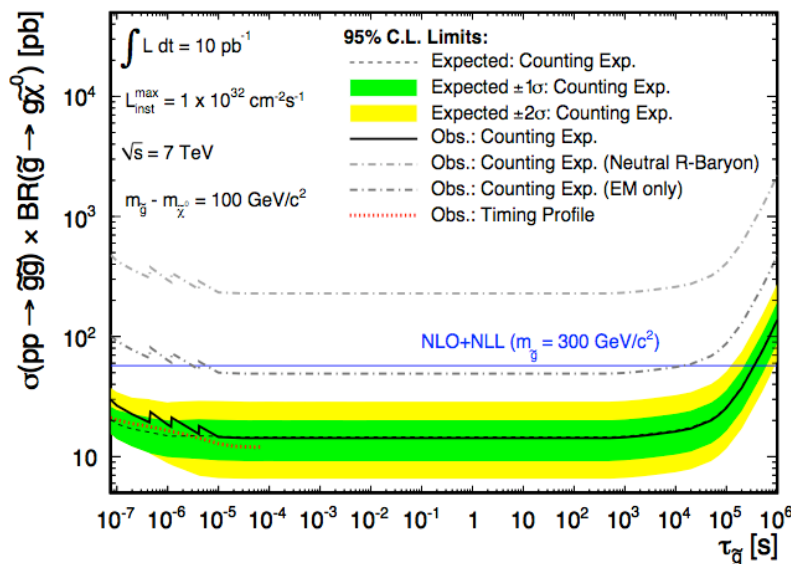
# Stopped gluino

Counting experiment: as a function of expected gluino lifetime  $\tau$

- for  $\tau < T_{\text{LHCorbit}} (89 \mu\text{s})$  select events in a window of  $1.26 \tau$  after the closest collision

Time-profile analysis: look at observed event timing distribution

- Signal peaks at bunch crossing
- Distinguishable from flat background for lifetimes  $\tau < T_{\text{LHCorbit}}$
- Construct signal pdf and fit the data  $\rightarrow$  set 95% C.L. on the signal





# Stopped gluino

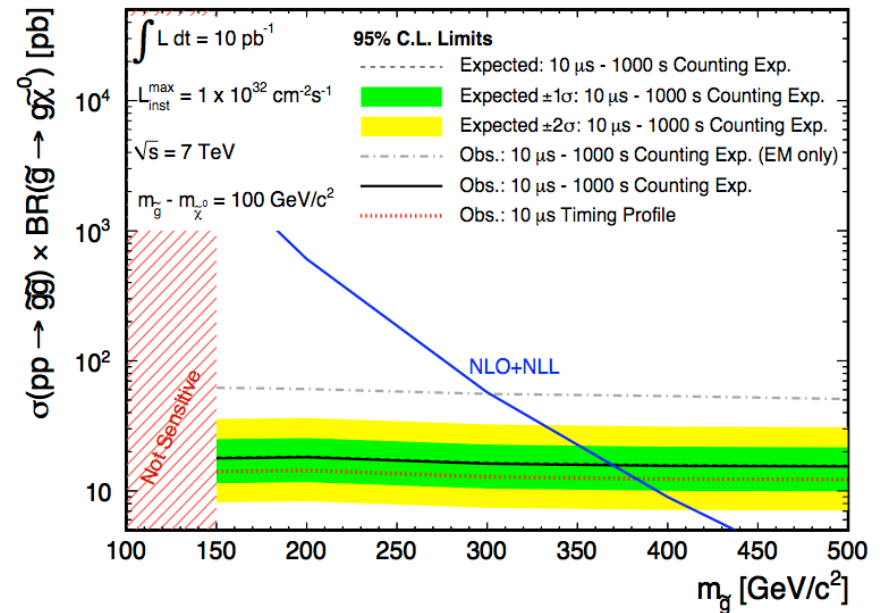
## Counting experiment:

- For mass difference between gluino and neutralino  $> 100$  GeV,  $\text{Br}(\text{gluino} \rightarrow g + \text{neutralino}) = 100\%$ ,  $m_{\text{gluino}} < 370$  GeV are excluded for lifetimes from  $10 \mu\text{s}$  to  $1000$  s from counting experiment

## Time-profile analysis:

- $m_{\text{gluino}} < 382$  GeV are excluded for a lifetime of  $10 \mu\text{s}$

Substantially extends D0 limits 270 GeV



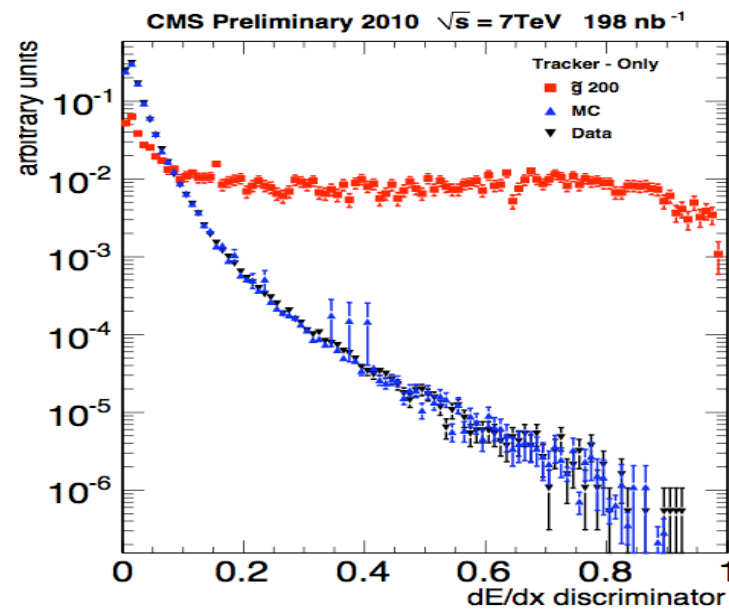
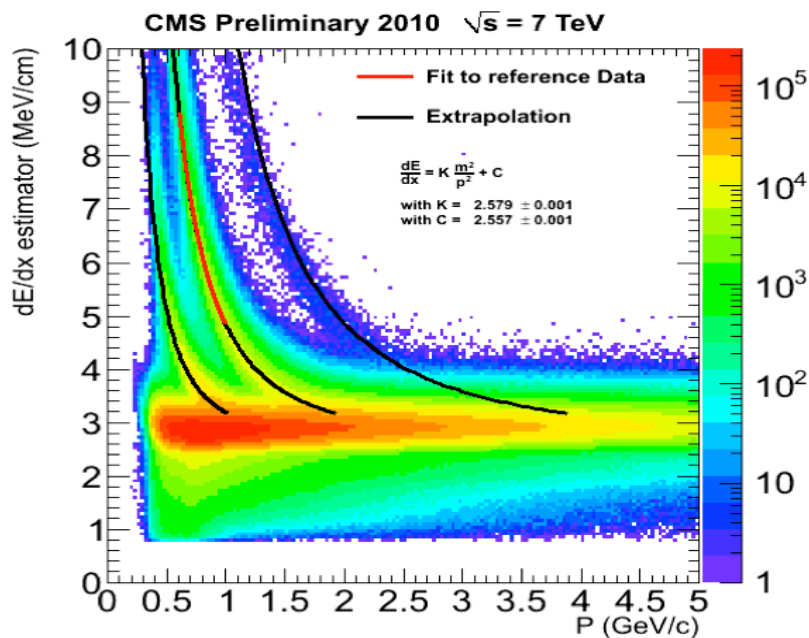
arXiv:1011.5861 [hep-ex], submitted to PRL



# Slowly moving HSCP

Track based analysis: select tracks with high pt and dE/dx

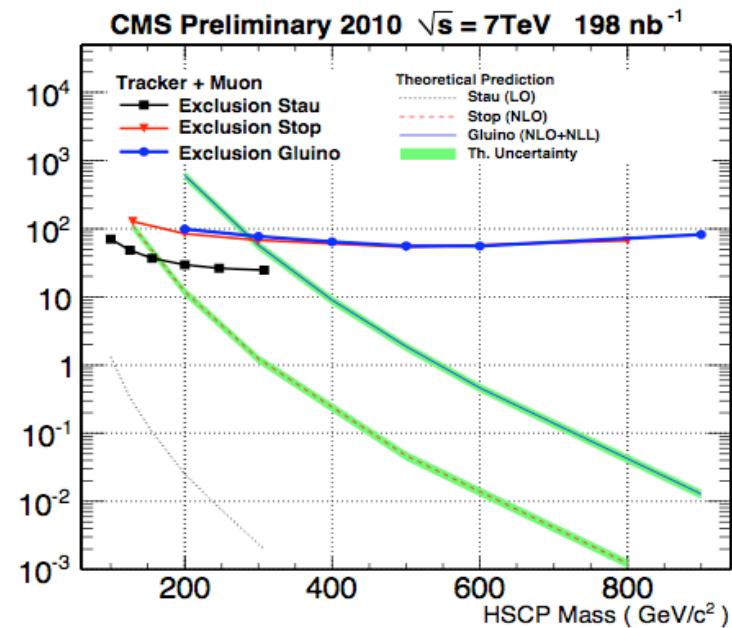
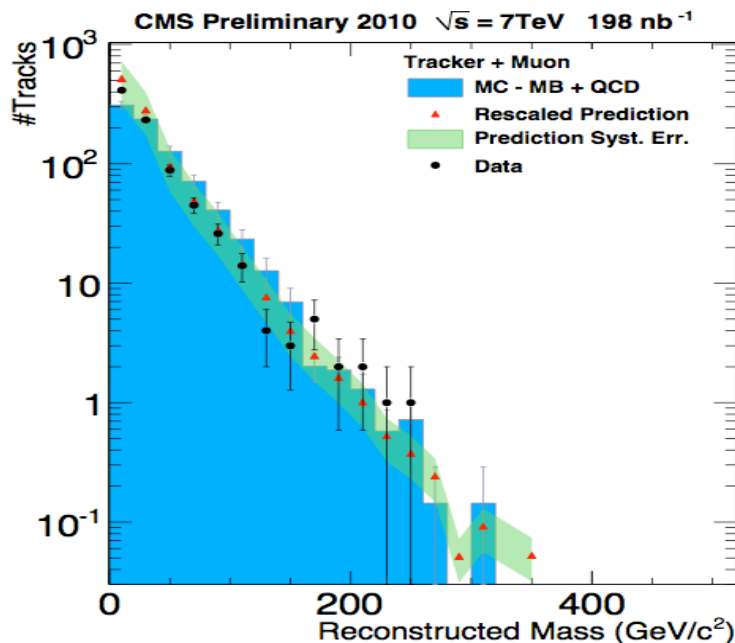
- Two analysis methods
  - ✓ Tracker standalone
  - ✓ Tracker+Muon (matching with Muon system candidates)
- Analysis uses a discriminator for tracker dE/dx in bins of  $\eta$  and number of dE/dx hits.
- Look for enhancement in high dE/dx region





# Slowly moving HSCP

- Data is consistent with expected background (data-driven estimation)
- Gluino mass  $< 284$  GeV is excluded, no limits for stop and GMSB stau yet with  $0.2 \text{ pb}^{-1}$  data
- Estimated CDF gluino limit: 322 GeV, from arXiv:1011.2964 [hep-ph]
- Results are in PAS EXO-10-004, available at <http://cdsweb.cern.ch/record/1280690>





# Summary

- The most recent results from CMS with 0.2 - 10 pb<sup>-1</sup> of integrated luminosity are presented
  - Di-jet resonance (published in PRL105.211801)
  - Contact interaction (accepted by PRL)
  - Leptoquark
  - Heavy stable charged particles (stopped gluino search submitted to PRL)
  - No new physics is observed yet
  - Limits obtained have exceeded or become near to Tevatron results
- Stay tuned for more exciting exotica searches on 40 pb<sup>-1</sup> data collected in 2010  
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>





# Back Up

