New results from SEARCHES FOR NEW physics AT cms

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Tuesday, February 26, 13

THE NEWCOMER

- A Higgs-like boson was found, close to the lower bound of the Higgs allowed mass range
- Not too heavy (eg for SUSY), but not that light
- Quite a special value. Do we live in a metastable vacuum? Is the quartic coupling zero @Plank

top and bottom Yukawa couplings (yt, yb), and of the Higgs quartic coupling . All couplings are Figure 5: *Regions of absolute stability, meta-stability and instability of the SM vacuum in the Mt–* Tuesday, February 26, 13

GO NATURAL?

the Higgs couplings (signal strength & BRs) could deviate from SM

If New Physics has something to do with making the Higgs light, we expect it @ TeV scale

Natural SUSY

light stop & sbottom, direct or via gluino decays

Extra dimensions (ADD, RS++)

high-mass KK partners (eg RS graviton to VV, $\ell\ell$, top pairs, etc)

Compositeness

exotic top partners lighter than 1 TeV 3

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Or living unnatural?

5

the Higgs couplings (signal strength & BRs) are SM-like

If New Physics has nothing to do with making the Higgs light, we still expect it to give a DM candidate, and possibly unification

Split SUSY

long-living particles, stopping gluinos, displaced vertices

Standard Model

We will keep setting limits on new physics for a while

Or living unnatural?

6

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Discussed Today
cles, stopping day **Split SUSY** long-living particles, stopping gluinos, displaced vertices

Standard Model

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Natural SUSY SEARCH: Multi(b)jet+MET

19 fb-1 MULTI(B)JET+MET SUS-12-024 **∑ E 6.0 2.0 1.0 1.0 1.0 1.0 1.7 ±** 0.71 **±** 0.7 **±** 0.71 **±** 0.7 **±** 0.7 **±** 1.0 1.7 **±** 0.7 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 **±** 0.17 jets, the *E*miss ^T distributions of events in the 1BL, 2BT, and 3B samples are shown in Fig. 3. The perpendicular to jet *i*, denoted *Ti*, is shown by the dotted (red) line. *sTi* is the uncertainty on *Ti*. $+$ \mathcal{M} \vdash Γ *SUS-12-02* Our method to evaluate the QCD background is based on the D*f*ˆmin variable. This method

Hadronic search for SUSY in multijet+MET events with btags \mathbf{MET} a modified version of the commonly used \mathbf{MET} (*i* = 1, 2, 3), the minimum azimuthal opening angle between the *E*miss **6 4 The D***f***ˆmin variable**

seen to be far less dependent on *E*miss

Event Selection

 ≥ 3 jets with $pT > 50$ GeV and $|\eta| < 2.4$, ≥ 1 bjet, i is the situation of α_j ≥2 jets with pT>70GeV Muon & Electron veto (pT > 10 GeV) Isolated track veto ($pT > 15$ GeV) $\Delta \dot{\varphi}$ ^{min} > 4.0 (sideband used for QCD) λ λ λ α (sideband used for Ω) Figure 4: Illustration of variables used to calculate D*f*ˆmin for the case of an event with exactly three jets with *p*^T *>* 30 GeV. The light-shaded (light gray) solid arrows show the true *p*^T values in this expression; we use arctan(*sTi* being equivalent for the small angles of interest here.] For the jet *p*^T resolution, it suffices to use \overline{P} $\overline{$ /*E*miss the simple linear parametrization *sp*^T

of the three jets *i*, *j*, and *k*. The dark-shaded (black) solid arrows show the reconstructed jet *p*^T

values. The angles of jets *j* and *k* with respect to the direction opposite to jet *i* are denoted *a^j*

three highest-*p*^T jets in an event. Misreconstruction of a jet primarily affects the modulus of its

^T than that based on D*f*min. Figure 5(c) shows the result

transverse momentum but not its direction. Thus QCD background events are characterized

W+jets 80.0 *±* 1.0 2.8 *±* 0.2 7.7 *±* 0.3 2.2 *±* 0.2 0.38 *±* 0.05

Z ! *nn* 104 *±* 2 5.3 *±* 0.4 13.8 *±* 0.7 3.5 *±* 0.3 0.80 *±* 0.10

^T for the event is shown by the dotted (red) arrow. The component of *E*miss

^T in a QCD event arises from the *p*^T mismeasurement of a single jet.

^T greater than about 30 GeV, the distribution based on D*f*ˆmin is

numbers of events in the different signal regions are listed in Table 2 for data and simulation.

The simulated results are for guidance only and are not used in the analysis.

presumes that most *E*miss

and *ak*. The *E*miss

HT vs MET vs btag multiplicity 3D space binned $\Delta \text{WLE I} = \sum \text{ET}$ Control samples used to predict backgrounds **EMIST MISS ENGINEER** with data + MC scale factors $\text{MET} = \sum \text{E}_\text{T}$ $HT = \sum |p_T|$ ^{et} | \cdots the event of \cdots of \cdots D*fⁱ* is the angle between *E*miss ^T and jet *i*. The ^D*f*ˆmin variable is a modified version of the commonly used quantity ^D*f*min ⌘ min(D*fi*) (*i* = 1, 2, 3), the minimum azimuthal opening angle between the *E*miss ^T vector and each of the iplicity 3D space binned ¹ $\text{NLE I} = \sum \text{E I}$ $HT = \sum |\mathbf{p}_T|^2$ samples used to predict backgrounds **EXPERT PRESETE** 1
Fore ^T is evident. The corresponding result based on D*f*ˆmin is shown in Fig. 5(b). For the latter figure we choose D*f*ˆmin = 4.0 in place of D*f*min = 0.3, which yields a similar selection D*f*min *<* 0.3 as a function of *E*miss $T_{\rm t}$ and ϵ sample selected with $\rm MET = \Sigma E_{\rm T}$ IET vs btag multiplicity 3D space binned $\mathcal{L}^{\text{full}}$ latter figure we choose D*f*ˆmin = 4.0 in place of D*f*min = 0.3, which yields a similar selection efficiency. For $E = F \cup E$ **EXECUTE** ^T greater than about 30 GeV, the distribution based on ^D*f*ˆmin is

the simple linear parametrization *sp*^T

= 0.10 *p*^T [21].

Figure 5(a) shows the ratio of the number of events with D*f*min *>* 0.3 to the number with

8

efficiency. For values of *E*miss

seen to be far less dependent on *E*miss

 σ for events with the sponding to σ , σ is σ , σ is a jets. σ is an operating figure of σ is and σ

19 fb-1 Multi(b)jet+MET **SUS-12-024**

Kinematic plane binned in 4x4 regions in slices of btag multiplicity

19 fb-1 Multi(b)jet+MET **SUS-12-024**

The Environment Challenge

Hadronic analyses in hadronic environment are challenging

No signal selection (e.g. photon, leptons) comes at rescue

Any possible detector effect is a potential signal (e.g. calorimeter spikes look like jet&MET to first sight)

And the high PU environment does not help

PARTICLE FLOW

Combine the information from all detectors to reconstruct single particles

Provides lists of particles (e,m,g, charged and neutral hadrons)

Improves HCAL resolution with tracker

Replace the HCAL granularity with tracker granularity $($ important for jet substructure $)$

PU Correction with PF

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- We have a wonderful tracker and a 4T magnetic field
- Jets are clustered from PF candidates (e, µ, y, charged and neutral hadrons)
- Only the charged particles from the primary vertex are clustered. This removes the PU contribution from charged particles
	- The neutral contribution is subtracted in average, using FASTJET

19 fb-1 Multi(b)jet+MET **SUS-12-024**

Observed distributions agree with **MC** prediction

Prediction not used in the analysis (illustration only)

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$19 fb⁻¹$ 24 ULTI(B) $FT + \mathcal{M}FT$ SUS-12-024 ²²⁶ points in the bottom row, indicating a shape discrepancy between the two samples. The shape Multi(b)jet+MET **SUS-12-024**

19 fb-1 Multi(b)jet+MET **SUS-12-024**

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UNNatural SUSY SEARCH: heavy stabLe charged PARTICLES

Split SUSY & HSCP

- Split SUSY predicts a large mass gap between fermion (light) and scalar (heavy) sparticles
- The gluino travels through the detector as a Rhadron (hadronizig or interacting with the mateial), with or without electric charge
- We expect a slow particles traveling across the detector
	- Could start charged and become neutral (or vice versa) or stay charged all the way through (depending on what the gluon picks when hadronizing) $\tilde{\sigma}$

 \widetilde{g} and \widetilde{g} and \widetilde{g} $rac{\mathbf{v}}{\mathbf{v}^2}$ $\widetilde{\chi}{}^{\scriptscriptstyle 0}$ **effective coupling** suppressed by squark **virtuality**

 $\overline{\mathsf{q}}$

q

HSCP in CMS

Tracker only

Sensitive to any HSCP produced prompt (irrespective of what happens after) Uses dE/dX in tracker to separate signal from BKG

Muon Only

Sensitive to any HSCP crossing muon detector (irrespective of what happens before)

Uses TOF to separate signal from BKG

Tracker + TOF

uses both (for HSCP crossing the detector)

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dE/dX IN THE TRACKER ⁹⁴ The CMS experiment uses a right-handed coordinate system, with the origin at the nominal ⁹⁵ interaction point, the *x* axis pointing to the center of the LHC ring, the *y* axis pointing up ⁹⁶ (perpendicular to the plane of the LHC ring), and the *z* axis along the counterclockwise beam

- Measure the charge released in the tracker ⁹⁷ direction. The polar angle *q* is measured from the positive *z* axis and the azimuthal angle in the • Measure the charge released in the tracker
	- Compute ionization, which gives a measurement of p/m through charge-dependent empirical coefficients

	Also can be calculated by \sim $\frac{1}{2}$

20

 18

Pi ⇥

discrimination

Pi ²*ⁱ* ¹

2*N*

20

 $p^2 + C$ $\frac{16}{14}$ $\frac{16}{12}$ $\frac{16}{12}$ $\frac{16}{10^3}$ 12 *as a company of the compa* 10 provides S vs B $\frac{4}{2}$ 500 , \mathbf{P} , \mathbf{Q} The time of the muon system can be used to the muon system can be used to discriminate between speed-of-light par-
The sday February 26, 13

Data (Vs=8 TeV)

 $MC: Q=3$ 400 GeV/ c^2

 $MC: Q=1$ 400 GeV/ c^2

 $10⁴$

1
108 **3.2 Times-of-fluid Measurements**

dE/dX IN THE $\frac{10^{10}}{10^{22}}$ ⁹⁸ *x*-*y* plane. The pseudorapidity is given by *h* = ln[tan(*q*/2)].

c

Figure 2: Observed and predicted mass spectra for candidates entering the tracker-only (left

Additional discrimination from pvalue of MIP-ionization pdf (for data-driven BKG determination) As in Ref. [23], *dE*/*dx* for a track is calculated as: $\ddot{}$ $\text{onization pdf (for} \quad \quad \text{or} \quad \frac{1}{2}$ ◆1/*^k*

probability MIP to produce <= 10° $\sum_{\text{observed ionization}}$ $I_{as} =$ 3 *N* ⇥ $\sqrt{ }$ 1 $\frac{1}{12N} +$ *N* \sum *i*=1 \overline{r} $P_i \times$ $\left(P_i\right)$ $\frac{2i-1}{2N}$ 2*N* $\binom{2}{ }$ **observed ionization**

• Measurement of mass from the 10^{-1} $\begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$ or the detector, and the sum is over the track measurement in the track measurement in the track measurement in the track measurement is over the track measurement in the sum is over the track measu sure of I_N in the *I*² *a*² data sideband] **P**₀ **P**₀ *B***₀** measurement. The *Ias* and *I*⁰ knowledge of Ih(p) [measured on

⁹⁹ **3.1 dE/dx Measurements**

$TIME OFEIICHT$ ¹⁰⁷ are determined from data using a sample of low-momentum protons. *^p*² ⁺ *^C*. (3) where the empirical parameters *^K* ⁼ 2.559*±*0.001 MeV cm¹ *^c*² and *^C* ⁼ 2.772*±*0.001 MeV cm¹ ¹⁰⁶ *b*¹ = 1 + *cd^t ^L* (4) Time of flight

Use arrival time in the muon chambers to measure the TOF **108** To measure the $I\cup F$ brift tubes (DT) ¹⁰⁸ **3.2 Time-of-flight Measurements** Let I use arrival time in the muon chambers **b** be announced the B and Construction of the DT and Construction of the with $\frac{1}{2}$

ticles and slower candidates. A single *d^t* measurement can be used to determine the track *b*¹

For a single hit determines β ⁻¹ \bullet For a single hit determines β ¹ (*n* 2) *n* β ⁻¹

> $\beta^{-1} = 1 \ +$ $c\delta_t$ $\beta^{-1} =$ *cd^t*

• For a track, weighted average of the \Box single hits **b**1 measurements from the DT and CSC single hits from the track of the track of the track. The track of the track. The track of the track of the track of the track of th b1 measurements from the DT and CSC systems associated with the track of the track. The track of the track. The track of the track of the track of the track (minimal number of hits in a given DT chamber that allows for at least one residual calculation is *n* = 3). The weight for the *i th* CSC measurement is given by:

$$
w_i = \frac{(n-2)}{n} \frac{L_i^2}{\sigma_{DT}^2}
$$

Ih = *K*

¹⁰⁷ are determined from data using a sample of low-momentum protons.

via the equation:

 DTs ($\sigma \sim 3$ ns)

 $DTs (\sigma \sim 3 \text{ ns})$ CSCs ($\sigma \sim 7 \text{ ns}$ for measurement contains and *s*
D_T is the domestic of the DT measurements of the DT m $CSCs$ ($\sigma \sim 7$ ns for

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For both $\sigma(\beta^{-1})$ ~ 0.07 measured value of 3 ns is used. The factor (*n* 2)/*n* acounts for the fact that residuals are Γ_{α} both For both $\sigma(\beta^{-1})$ ~0.07

Tev HEAVY ST $+8\text{TeV}$ **10² EXPLEM EXAMPLE 10² EXAMPLE 1000 EXAMPLE 10² EXAMPLE 10² EXAMPLE 1000 EXAMPLE 100 12 6 Systematic Uncertainties** Table 1: Results of the final selections of predicted background and observed number of predicted \mathbb{R} of uncorrelated variable $\frac{1}{10^{2}}$ \bullet Use ionization and TC at large m with data Data driven ABCD me $Mass (GeV/c²)$ 0 500 1000 10^{-2} 10^{-1}) Mass (GeV/*c*² 0 500 1000 10^{-2} 10^{-1} 2*c* Tracks / 40 GeV/ 10^{-1} 1 10 Observed Data-based SM prediction Gluino (M=1000 GeV/ c^2) Tracker - Only CMS Preliminary $\sqrt{s}=8$ TeV, L=18.8 fb⁻¹ 2*c* Tracks / 40 GeV/ 10^{-1} 1 10 Observed Data-based SM prediction Stau (M=308 GeV/ c^2) Tracker + TOF CMS Preliminary \sqrt{s} =8 TeV, L=18.8 fb⁻¹ Tight Selection

 10^{-2} ₀

 $Mass (GeV/c²)$

 10^{-2} ₀

) Mass (GeV/*c*²

0 500 1000

0 500 1000

-1 10 -1 10 Heavy StabLE Charged PARTICLES **7Tev +8TeV EXO-12-026**

Q=1e (LO)

Q=2e/3 (LO)

Heavy StabLE Charged PARTICLES **7Tev +8TeV EXO-12-026**

Final limit obtained combining 7TeV and 8TeV data

NEW RESONANCES

21 fb Dilepton searches**EXO-12-061 -1**

Pair of high-pT isolated leptons with same flavor (e,μ)

Selection tuned to maximize significance. S vs B discrimination from $m_{\ell\ell}$ shape

Bkg shape taken from MC and normalized to data in the mass sideband [60,120] GeV

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HIGH-PT LEPTONS Efficiency
|
| 1 **CMS Preliminary, s = 8 TeV,** $\int L dt = 19.6$ **fb⁻¹**

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Leptons at high pT are different than standard leptons

pT resolution worse (better) for muons (electrons)

Energy deposits in the hadronic calorimeter could spoil isolation

Reconstruction and identification tuned differently

The effects are well model by the MC, as Leptons at high pT are different than
standard leptons
pT resolution worse (better) for muons
(electrons)
Energy deposits in the hadronic
calorimeter could spoil isolation
Reconstruction and identification tuned
differentl

21 fb Dilepton searches**EXO-12-061 -1**

$mZ'_{SSM} > 2960$ GeV $mZ'_{\Psi} > 2600$ GeV

 20 fb⁻¹ W'→ ev SEARCHES EXO-12-060 **5** ¹⁵⁹ tt, and Drell–Yan events. Di-bosons (WW, WZ, ZZ) decaying to electrons, muons, or taus were ¹⁵⁸ of the standard model W ! `*n* decays. Other important backgrounds arise from QCD multijet, ¹⁶⁰ also considered. The event samples for the electroweak background processes *W* ! `*n* and ¹⁶¹ Z ! `` (` = e, *µ*, *t*) were produced using PYTHIA. For the W, a transverse-mass dependent

W-> e ν **QCD W-> e** ν **QCD**

500 1000 1500 2000 2500

2000

 $\int^2 L \, dt = 20 \, fb^{-1}$ $\sqrt{s} = 8 \, \text{TeV}$

• one muon (electron) with $p_T > 45$ GeV (E_T>100 GeV) ¹⁶³ QCD K-factors, ranging from 1.28 to 1.23 are applied to the *Z* background distribution. The

 0^7 $\rm _{\bar{E}}$

 10^{7}

- Muon track-based isolation <15% for Δ R<0.3 and Δ p_T/p_T < 0.3 ¹⁶⁵ MADGRAPH in combination with PYTHIA, and the newly-calculated NNLL (next-to-leading-
- Electron from isolated ECAL deposits matched to track. E_T from ECAL **4 3 Event selection** 169° which the Nuovemberg sections sections sections $\frac{1}{2}$ and $\frac{1}{2}$

CMS Preliminary $\int L dt = 20$ fb⁻¹ $\sqrt{s} = 8$ TeV

W' → **e**ν **M=2500 GeV**

W' → **e**ν **M=2500 GeV**

 $\sim 10^{7}$ is a largely suppressed by the event selection requirements. The simulation of pile-up is included by $\sim 10^{7}$ $\overline{O}10^6$ in the event samples by $\overline{O}10^6$ \overline{C} minimum bias \overline{C} munimum background by \overline{W} \vert bkg on the tail Fit MT distribution with empirical

157 The primary source of the primary source of the primary source of the peak, high transverse mass tail the original to the primary source of the peak, high transverse mass tail the peak, high transverse mass tail to the

¹⁶² K-factor is calculated to account for NLO QCD and electro-weak corrections. Mass-dependent

¹⁶⁷ event samples were normalized to the integrated luminosity of the recorded data, using cal-

 $\begin{array}{ccc} 0^7 & \rightarrow & \cdots & \cdots & \cdots \ 0^7 & \rightarrow & \cdots & \cdots & \cdots & \cdots \end{array}$ W $\rightarrow \mu \vee$

 10^7 $\left[\frac{1}{2} \right]$ $\left[\$

CMS Preliminary $\int L dt = 20$ fb⁻¹ $\sqrt{s} = 8$ TeV

50500 10000 150500 201000 251500

10000

5

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 20 fb⁻¹ W'→ ev SEARCHES EXO-1 $2096 - 111$ which corresponds to the statistics, the statistics, the statistics, the statistics, the statistical statistic at p ²¹¹ *^s* = 7 TeV the exclusion limit was at 2.5 TeV when combining both channels [4]. Figure 5 20.20 than 2.20 in the expected limit of 3.25 TeV) in the electron and 3.15 TeV (com- $200-10$ and $200-10$, as shown in Fig. 4. Combining both channels, as shown in Fig. 4. Combined, as shown in Fig. 4. Combined, and 20 which corresponds to the statistics, the statistics, the statistics, the limit is 3.3 **EXO-12-060**

²⁰⁷ with SM-like couplings of masses less

at 95% confidence level (CL) the existence of a SSM W⁰

displays the excluded W⁰

displays the exclusive control of the exclusive

cross section times branching ratio as a function of the W0 \sim T 213 and 2.13 corresponding values are summarized in Table 2.5 corresponding in Table 2.5 corresponding in Table 2.5 corresponding values are summarized in Table 2.5 corresponding values are summarized in Table 2.5 correspo $TATL$ as $TATL$ as $TATL$ as a function of the WO TAT $mW'_{SSM} > 3350$ GeV

*M*W⁰ [GeV] 300 900 1500 2000 3000 3500 4000

1

0.22

FURTHER C+MET INTERPRETATIONS **20 fb-1** 226 and 226 and 226 in terms of 226 in terms of 226 in terms of 226 ²²⁷ Non-Conserving model), providing a limit on the binding energy scale L. The statistical in- 228 , using a uniform prior 228 requiring 229 requiring 229 requiring 229 **22-060** EXO-12-060

²²⁴ on the mass can be directly translated to bounds on the split-UED parameter space (1/*R*, *µ*) as

²⁴¹ observed limits are 3.20(3.15) TeV for the electron(muon) channel, with 3.25(3.10) TeV expected.

Build two **wide jets** of $\Delta R=1.1$ around the two highest-pT jets

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- AntiKt jets R=0.5 with pT>40 GeV - Look for secondary jets with ΔR <1.1 around the two leading jets

- Widejet selection $|\eta_{wi}|$ < 2.5, $|\Delta \eta_{wi}|$ <1.3
- Study the di-widejet mass spectrum: look for a bump on the falling QCD distribution
- No significant excess seen

- Model-independent xsec limit on generic qq, qg, and gg final states
- Limit compared to specific models to derive mass lower limits

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For the s8 color octet model the observed exclusion is 1.0 *< M*(s8) *<* 2.66 TeV in agreement

Flexibility @HLT

Hardware L1 trigger interfaced to the detector (standard)

No L2/L3 trigger. Instead, softwarebased trigger running on PC farm

Running online a faster version of the offline reconstruction

In principle (and in practice) one could run the analysis selection online

This is what we do to keep the analyses as efficient as possible

~ 350 Hz of physics taken and reconstructed ~ 600 taken and parked for next year (not enough CPU @T0)

Run for 16h at the end of 2011 run (7TeV) t_1 integrated luminosity (t_2 fb-1) fb-1) fb-1) fb-1) Figure 7: The observed 95% CL upper limits for the low-mass analysis on *s* ⇥ *B* ⇥ *A* for dijet Collected ~4 times the statistics we had in 2010 (35 pb-1) with equivalent trigger Improved the limit published in 2010 by one order of magnitude Similar results @8TeV by Summer

Trigger rate ~ kHz for one trigger writing a reduced event content (HLT jet list)

cannot
normally
record
on
tape
due
to
trigger

– possibility
to
extend
the
standard
trigger
setup

reconstructed
during
High
Level
Trigger
online

processing,
no
raw
data
from
CMS
detector,

NP Searches in the Higgs Era

- We started the run searching for anything The LHC is a discovery machine, and CMS a multipurpose experiment
- We found something, and we have a better view on the "right" questions natural NP vs unnatural scenarios becoming quantitative
- The run is over, but there is still a lot to learn from these data new searches for specific scenarios, suggested by the Higgs discovery
- The first LHC run was a successful warmup no matter what the new searches will tell us
- But let's all keep in mind that this is a ~14 TeV machine and the best might still have to come

BACKUP

events. **7Tev**

HSCP **EXO-12-026** $T_{\rm F}$ 1. Results of the final selections for $T_{\rm F}$ and $T_{\rm F}$ and $T_{\rm F}$ and $T_{\rm F}$

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Gluino signals at p*^s* = 7 TeV and 8 TeV as well as the ratio of the cross section limit to the **+8TeV**

Table 3: Signal effective (Eq.), expected (Exp.) and observed (Obs.) cross section limits for \mathcal{C} HSCP **EXO-12-026 7Tev**

the combination. The combination $\mathcal{L}_\mathcal{A}$ is used on the muon-only analysis uses uses uses uses uses uses

ABCD METHOD

x and y uncorrelated the observed yield in B,C, and D gives an estimate of A

 $N_A = N_B \times N_D/N_C$

MATERIAL BUDGET

HCAL: At eta=0 there is less than 6 interaction lengths of HCAL. ECAL provides an additional interaction length ECAL ~25 radiation length (23 cm crystals, 0.9 cm rad length)