



Physics Highlights at CMS

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on behalf the

CMS Collaboration

SLHC-PP open event 8. March 2011

Content

- QCD and related searches:
 - x-sections, angular distributions
 - composite quarks, resonances
- EWK and related searches:
 - W,WW,Z,t x-sextions
 - Anamolous gauge couplings, Higgs with 4th generation
- Exotic Physics Searches:
 - LeptoQuarks (LQ), W', Z', Blackholes (BH)
- Supersymmetry Searches:
 - Jet + MET, dilepton, di-photon+Met, stopped gluinos

20 min talk ~ 1/100 [min]/[physicist]

QCD and related searches

Inclusive jet production

- Cross section: huge.
 Spectra available with ~10² nb⁻¹
- Very good agreement with NLO QCD over nine orders of magnitude
 - P_T extending from 20 to 500 GeV
- Main uncertainty: Jet Energy Scale (5% in this example)



Jets: angular correlations





arXiv:1101.5029

Dijet mass (and search)

Very early search for numerous 1.099 TeV Jet 1 p = resonances **BSM**: string resonance, excited quarks, axigluons, colorons, E6 diquarks, W' & Z', RS gravitons Run 144112 Event 1189490855 Jet 2 $p_{T} = 935$ GeV M_{ii}~2.05 TeV da/dm (pb/GeV arXiv:1010.0203 104 CMS Data (2.9 pb⁻¹) **Four-parameter** 10% JES Uncertainty fit to describe <u>ද</u> ම_10් QCD Pythia + CMS Simulation Resonance Models CMS Data (2.9 pb" 0^2 Excited Quark String ◄ **QCD** shape $\sqrt{s} = 7 \text{ TeV}$ Excited Quark √s = 7 TeV × String 10' hl < 2.5 & l∆ nl < 1.3 Axigluon/Coloron 띪 E, Diquark 10 hl < 2.5 & I∆ηI < 1.3 W. × 10³ 7 (1 TeV) RS Graviton a* (0.5 TeV) $d\sigma$ 10^{-1} S (2 TeV) p_0 dm 10^{-2} m 10⁻³ a* (1.5 TeV) 10⁻² Ouark-Ouar 10-4 $B = p_2 + p_3 (m/\sqrt{s})$ 500 1000 1500 2000 2500 500 1000 1500 2000 Resonance Mass (GeV) Dijet Mass (GeV)

Contact interactions arXiv:1102.2020

- The χ distributions do not exhibit any excess at low χ. Good description by QCD.
- Lower limit on scale of contact interaction A=5.6 TeV (95% CL) Most stringent limit to date.





No sign of Compositeness of quark

EWK and related searches

W/Z production at 7 TeV



W, Z Cross Section vs \sqrt{s}

Baseline measured. Next: need high stats arXiv:1012.2466



top quark candidates: dilepton



Top in dileptons+jets

Full selection applied;

- Z-bosonVeto, |M(II)-M_z|>15 GeV
- ME_T >30 (20) GeV in ee,µµ,(eµ); N(jets)≥2



arXiv:1010.5994

WW production

- Last SM measurement before getting to the level needed for the Higgs search
 - Also probe for physics BSM (VVV vertex)
- Two high-P_T (20 GeV, |η|<2.4/2.5) isolated leptons (*ee*, *eμ*, μμ)
 - Bkgs: top, Drell-Yan (mainly Z)
 - Z-mass veto (15 GeV around Z)
 - M(II)>12 GeV (low-M resonances)
 - No 3rd lepton (P_T>10)
 - Jets counted: P_T>25, |η|<5.0

WW production arXiv:1102.5429

(H?) \rightarrow ZZ \rightarrow $\mu^+\mu^-\mu^+\mu^-$

CMS has a spectacular (and very rare indeed) event

Muons (p_τ[GeV], η, φ [rad])

 $\begin{array}{l} \mu_0^-(48.1422, -0.412532, -1.92555) \\ \mu_1^+(43.4421, 0.204654, 1.79493) \\ \mu_2^+(25.8769, -0.782084, 0.774588) \\ \mu_3^-(19.5646, 2.01112, -0.980597) \end{array}$

Invariant Masses

 $\mu_0 + \mu_1$: 92.15 GeV (total(Z) p_T 26.5 GeV, ϕ -3.03), $\mu_2 + \mu_3$: 92.24 GeV (total(Z) p_T 29.4 GeV, ϕ +.06), $\mu_0 + \mu_2$: 70.12 GeV (total p_T 27 GeV), $\mu_3 + \mu_1$: 83.1 GeV (total p_T 26.1 GeV).

Invariant Mass of 4µ: 201 GeV

Around the standard model in 7 months

Exotic Physics Searches

Leptoquarks (I)

- As name implies, they are both "leptons" and "quarks":
 i.e. carry baryon and lepton number & color (large σ!)
 - GUT-inspired models, with (hypothetical) proton decay acting as one of the main motivations
 - Decay: into ℓq (branching ratio β) and vq (BR=1- β)
 - A leptoquark for each generation; cross-couplings FCNC constraints.
 - In general: assume decays to one lepton only; searches usually carried out independently for each generation
 - ➡ Easier searches (e/µ): first two generations, LQ1 and LQ2
- Pair-produced (gluon fusion) final state: dileptons & jets look for: peak in mass(*lq*)

Leptoquarks (II)

Main irreducible bkg: DY+jets; 2nd: top production

 In situ Z+jets measurement + measured top cross section in the dilepton channel to estimate both bkgs

 DY+jets normalized to Z+jets (control region) anti-Z cut optimize Sum P_{T} cut (S_T cut LQ massdependent)

Leptoquarks: limits

LQ1: S_T> 340-660 GeV for M_{LQ1} = 200-500 GeV, 2-0 events observed; consistent with bkg estimate

Search for W' arXiv:1103.0030 muon arXiv:1012.4945 electron

Main bkgs: W* (high-mass tail of B-W) and QCD; estimated via template method

- Mass-dependent selection:
 - M_⊤ > 400-675 GeV for M(W') = 0.6-2.0 TeV; 2-0 events observed
- M(W') > 1.58 TeV (electrons&muon) well beyond Tevatron limit: 1.12 TeV [CDF@5.3 fb⁻¹, arXiv:1012.5145]

Search for Z'

arXiv:1103.0981v1

Coherent ee and μμ analyses
Require +/– for muons; not for elecs

SUSY Searches

SUSY: what we know

Several high-P_T jets; high MET (R_p conservation); possibly lepton and b-rich

SUSY: what we don't know (breaking)

Huge number of theoretical models

- Very complex analysis; MSSM-124. Hard work to study particular scenario
 - assuming it is available in an event generator (!)
- To reduce complexity we have to choose some "reasonable", "typical" models; use a theory of dynamical SYSY breaking
 - mSUGRA (gravity-mediated)
 - GMSB (gauge-mediated)
- Model determines phenomenology

CMSSM (mSUGRA) 5 parameters:

- Common scalar masses (m₀)
- Common gaugino masses (m_{1/2})
- All tri-linear Higgs-sfermion-sfermion couplings *A*₀
- tanβ and sign(µ)

SUSY: signatures and bkgs

Searches distinguished by the number of leptons

- In all cases, demand "(high-P_T) jets + (high) ME_T"
- 0l (all-hadronic); 1l; 2l (and break down into OS and SS)

SUSY: 2010 jets+ME_T "early search"

- Strongly-produced squarks and gluinos with M>400 GeV
 - Decaying into SM particles (e.g. quarks) plus LSP; either directly or after a long chain
 - Huge background from QCD (several orders of magnitude).
 - Strategy: use kinematics (α_T) to reduced it to negligible level, then tackle next bkg
 - Veto leptons to avoid EWK backgrounds with MET arising from neutrinos
 - Largest remaining bkgs: $Z(\rightarrow vv)$ +jets, $W(\rightarrow \ell v)$ +jets and t-tbar

For remaining bkgs (estimate): data-driven methods

- Direct estimate of EWK bkg using W+jets (for W & top) and γ +jet (for Z(→vv)+jets)
- Inclusive estimate using extrapolation from lower-H_T (where SUSY is negligible)

SUSY: jets+ME_T "early search"

• Apply a cut at α_T >0.55, QCD \rightarrow negligible

SUSY: jets+ME_T arXiv:1101.1628v1

13 events observed, consistent with bkg estimates of

- Already with 35 pb⁻¹: significant extension of previous (Tevatron+LEP) reach
- Updated "later" hadronic result in approval for Moriond

10.5

SUSY GMSB search: diphotons

- GMSB: just as good a SUSY; solves all issues that SUSY is good for: hierarchy; unification at GUT scales; also (for very longlived LSP, also DM)
- Very small Bkgs: jets; γ+jet; W+γ; W+jet (and jet → γ; "fake")
- Two data-driven bkg estimates to get ME_T tail (dominated by hadronic recoil):
 - Z→ee events (not applying tracking to e's)
 - Loose photon-ID (so picking up jets); gives "fake-fake" bkg. Normalize to diEM p_T; spectrum to data (at low p_T)

No excess over bkg estimate → limits

For equal squark and gluino masses the limits are 740, 800 GeV, and 780 GeV

Summary

- Many Standard Model "standards" done such as xsections and detector/theory performance validated:
 - Overall good agreement with this "fresh data" from a new detector!
- Even the 2010 data had significant physics reach beyond previous experiments
 - Many new exclusion limits, no discoveries yet
- 2011 will reach far beyond previous experiments, hopefully uncover new physics!

More Highlights

Search for BHs

- THE signature of low-scale quantum gravity (M_D << M_{Pl})
 - BH formation when the two colliding partons have distance smaller than R_s, the Schwarzschild radius corresponding to their invariant mass
 - Cross section from geometry: $\sigma = \pi R_s^2 \sim \text{TeV}^{-2}$ (up to ~100 pb!)
- BHs decay instantaneously via Hawking evaporation emitting "democratically" a large number of energetic quarks, gluons, leptons, photons, W/Z, h, etc.
 - Contrary to SUSY, expect ~ small MET (this: model-dependent)
- In practice: CHARYBDIS 2 and BlackMax generators
 - Original papers [Dimopoulos & Landsberg, PRL 87, 161602 (2001); Giddings & Thomas, PRD 65, 050610 (2002)],
 - Plus: [partial] grey-body factors, spinning Kerr black holes, formation of a stable non-interacting remnant, etc.
 - Caveat: semi-classical approximation; expected to be modified for BH masses <~ 5M_D

Search for BHs

- Expect lots of activity in the event, so
 - Use $S_T = Sum E_T$ of all objects (including ME_T) with $E_T > 50$ GeV.
 - Great for avoiding pileup (in the future as well)
- Key observation for search: S_T-invariance of final state multiplicity. Expecteded for Mass, but ST?
 - A posteriori wisdom: FSR/ISR collinear do not affect ST a lot

Search for BHs

Use N=2 shape (with uncertainties) to fit higher multiplicities – where signal more prominent

Heavy Stable Charged Particles

They appear in numerous SM extensions:

- SUSY (split SUSY: gluinos much lighter than squarks → long lifetime; GMSG models: stau NLSP, decaying via gravitational coupling only; light stop with only a limited number of decay modes)
- Other: hidden valleys; GUTs; ...

Two types of signatures:

- MIP: HSCP passes through tracker & muon chambers
- Strongly interacting: R-hadrons traversing material can flip Q or become neutral (for example in gluino hadronization). Majority would not reach muon chambers

Analyses

- dE/dx: Massive, charged particles traversing detector: highly ionizing tracks in tracker and possibly muon systems
- (Out-of-time) Jet: particles stopping in the detector and decaying possibly out-of-time with the collisions

 Complementary signatures: jet analysis sensitive to slow particles; dE/dx search needs higher β (min-P_T requirement)

Heavily ionizing tracks

Stopped gluinos (I)

Slow (β < 0.4) long-lived gluinos hadronize into and then stop in the dense material of the CMS detector

Their number builds up with luminosity:

Stopped gluinos (II)

- Special trigger: no-beam .AND. BPTX (anticoincidence)
 - Was run also after the end of fills (to reach long lifetimes)
- Main background: cosmic rays, beam halo, HCAL noise

 Select against them (e.g. HCAL noise: jets not at same phi). Finally: signal shape (electronics): use ratio of energy in BX+1/ BX and BX+2/BX+1

Stopped gluinos (III)

Search carried out for different lifetimes (Δt=1.26 τ_σ) <u>β</u> [

•	51	
Lifetime [s]	Expected Background (\pm stat. \pm syst.)	Observed
1×10^{-7}	$0.8 \pm 0.2 \pm 0.2$	2
$1 imes 10^{-6}$	$1.9 \pm 0.4 \pm 0.5$	3
$1 imes 10^{-5}$	$4.9 \pm 1.0 \pm 1.3$	5
1×10^{6}	$4.9\pm1.0\pm1.3$	5

Also look at time structure (τ<100μs)</p>

Given T hypothesis: calculate PDF for signal evt time, using lumi profile; bkg: flat

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8

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d 10²

103

10

100

√s = 7 TeV

m_a - m_e = 100 GeV/c²

150

200

250

Fix m[~]_g-M[~]_{x0}=100 GeV (efficient trig/jet)

Counting experiment: exclude m^w_g < 370 GeV</p>

450 50 m_x [GeV/c²]

Obs.: 10 µs - 1000 s Counting Exp. (EM only) Obs.: 10 µs - 1000 s Counting Exp.

Obs.: 10 µs Timing Profile

350

400

NLO+NLL

300