CMS

DM@CMS

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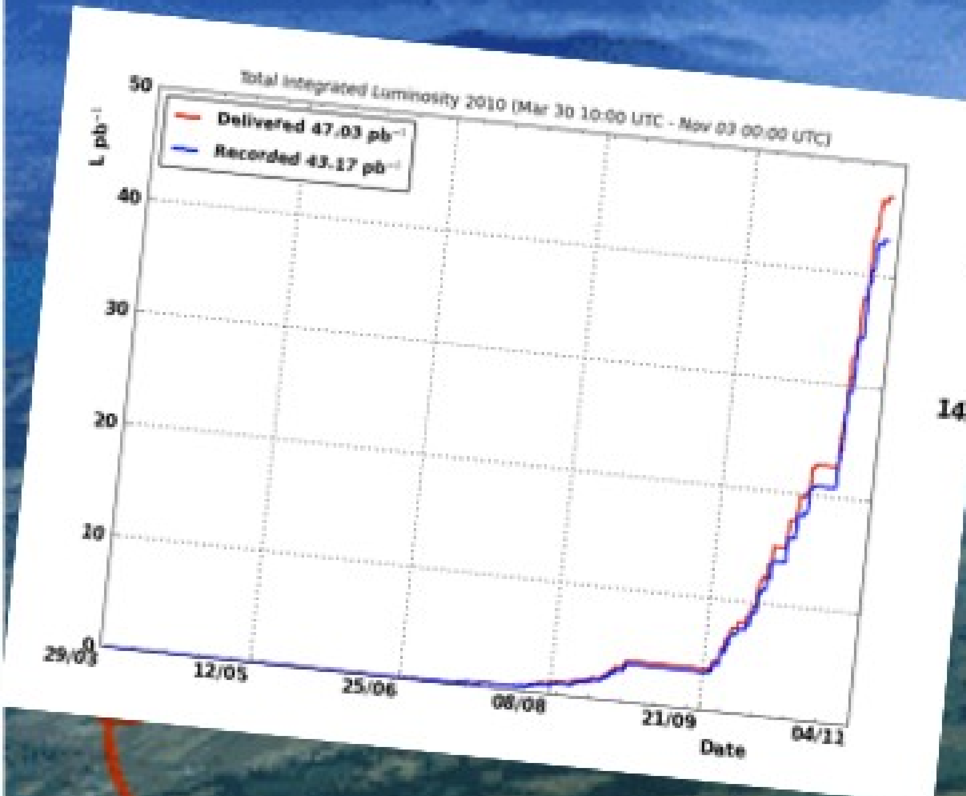
on behalf of CMS collaboration

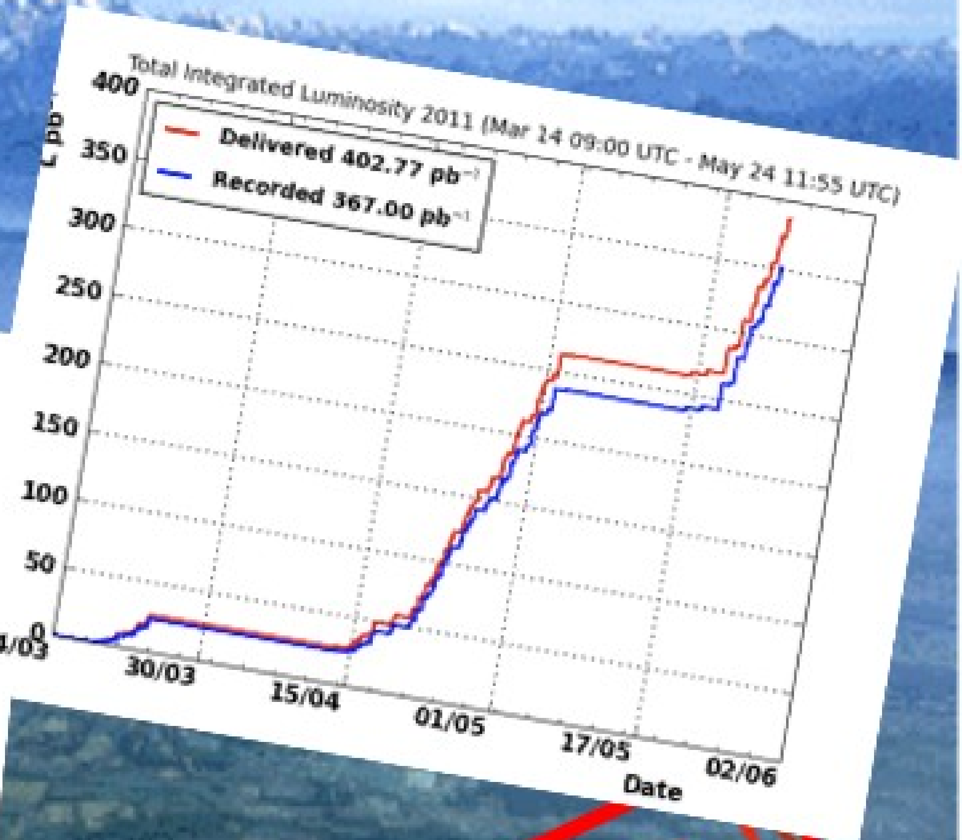
RICAP 2011, ROME
25-27 May 2011

In this talk:

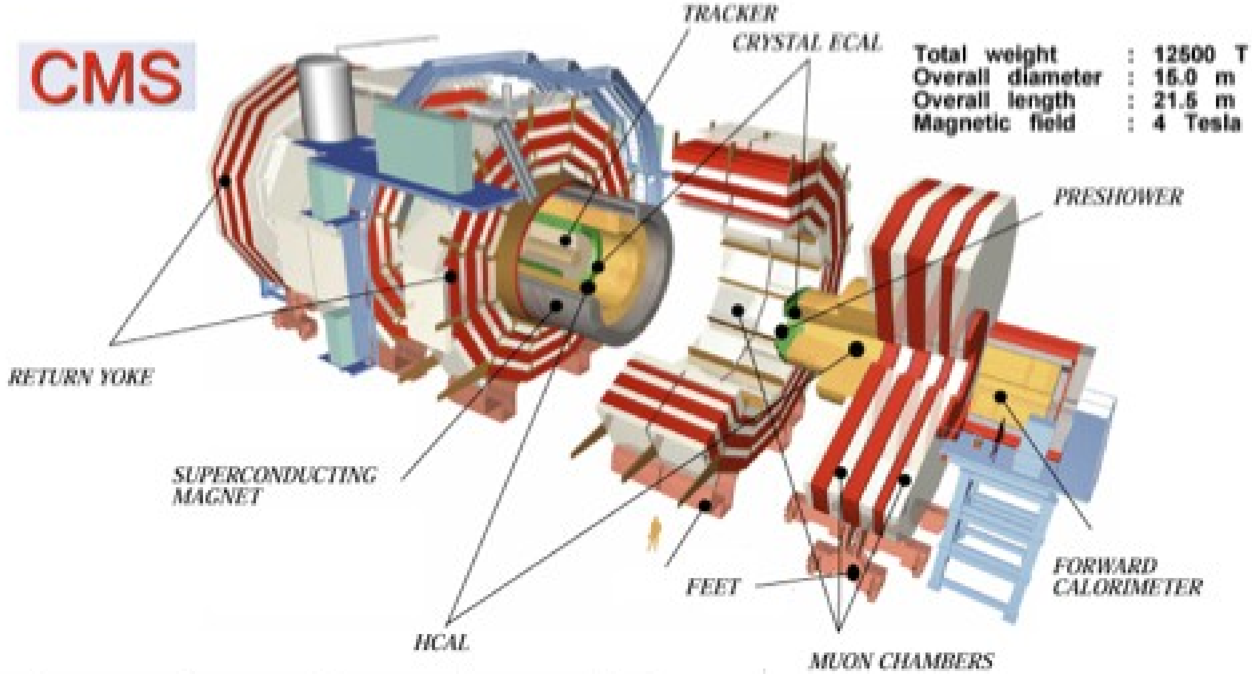
- The experiment
- Dark matter searches
  - Searches with missing energy
  - Searches for long lived particles
  - Searches with lepton jets
  - Exercising mass reconstruction

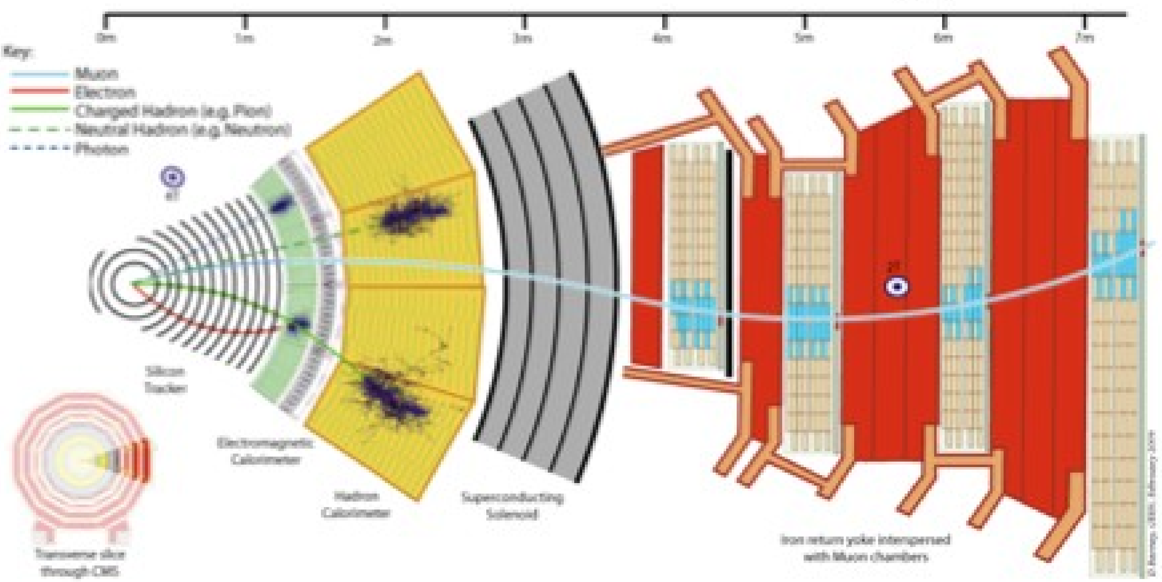
Center of mass energy: 7 TeV



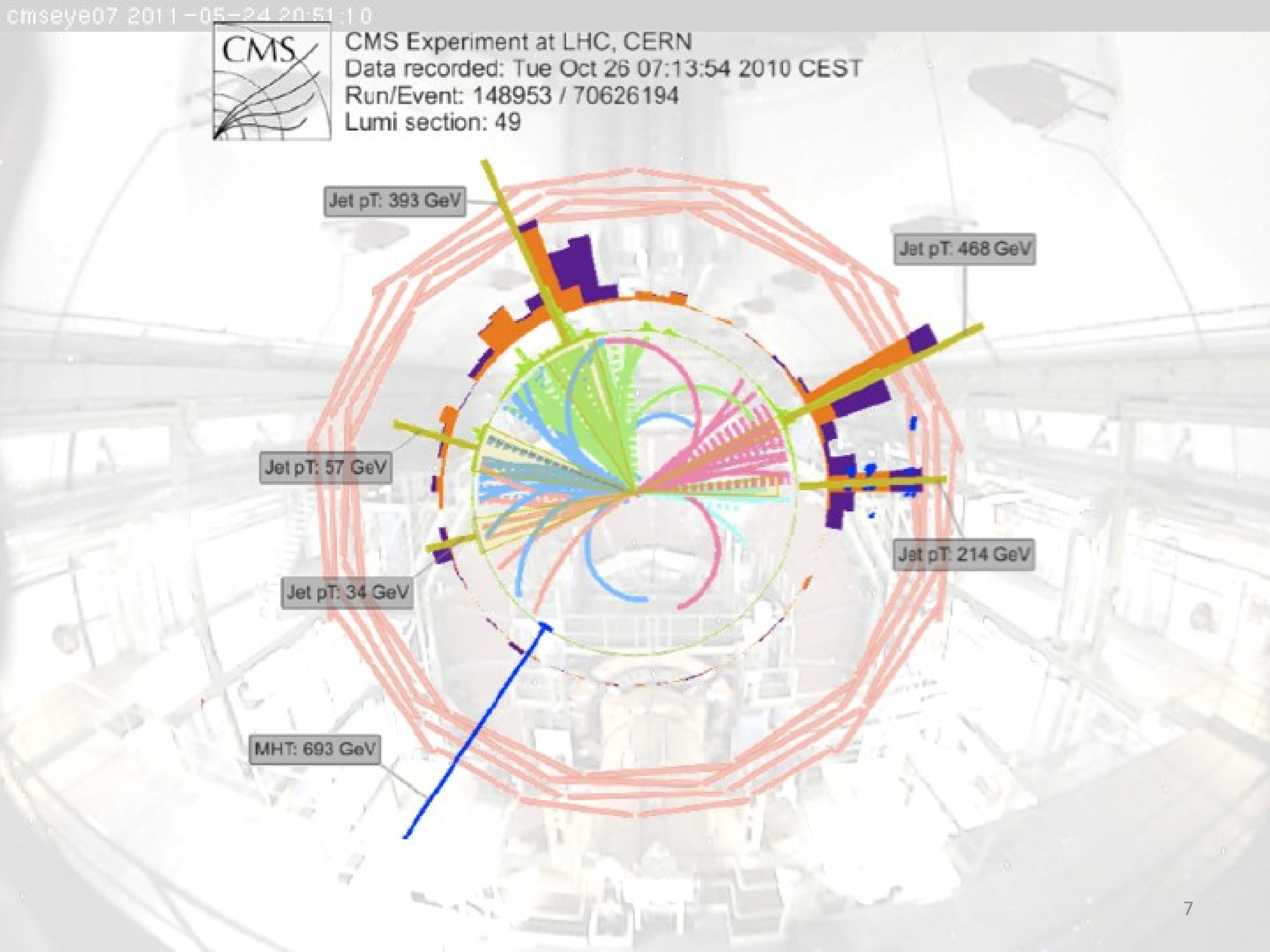


The Compact Muon Solenoid detector






cmseye07 2011-05-24 20:51:10


cmseye07 2011-05-24 20:51:10
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 07:13:54 2010 CEST
Run/Event: 148953 / 70626194
Lumi section: 49
Jet pT: 393 GeV
Jet pT: 468 GeV
Jet pT: 57 GeV
Jet pT: 214 GeV
Jet pT: 34 GeV
MHT: 693 GeV

What CMS has found out about dark matter so far…

...but


www.wallpapersite.net

Disclaimer

The essential task of CMS is to look for new physics at TeV scale, and present the actual experimental observations (e.g. event counts after a selection, etc.).

However sometimes CMS interprets results for illustrative purposes, in terms of example models (regardless of their theoretical motivation).

For practical reasons, all current CMS interpretations that can be related to dark matter are within the framework of supersymmetry.

Which DM can CMS look for?

- WIMP dark matter (neutralinos, sneutrinos, lightest KK particles, lightest T-odd parity particles…): DM that shows up as missing energy in the colliders. But all such candidates come with similar signatures – in many cases LHC is not sufficient to distinguish between them.
- Gravitinos (very indirect hints from heavy charged stable particles - HCSB)
- Axions/axinos (very indirect hints from discovery of neutralino with excess relic abundance, or discovery of HCSP)
- Candidates from the dark sector, by possible observation of dark photons
- …

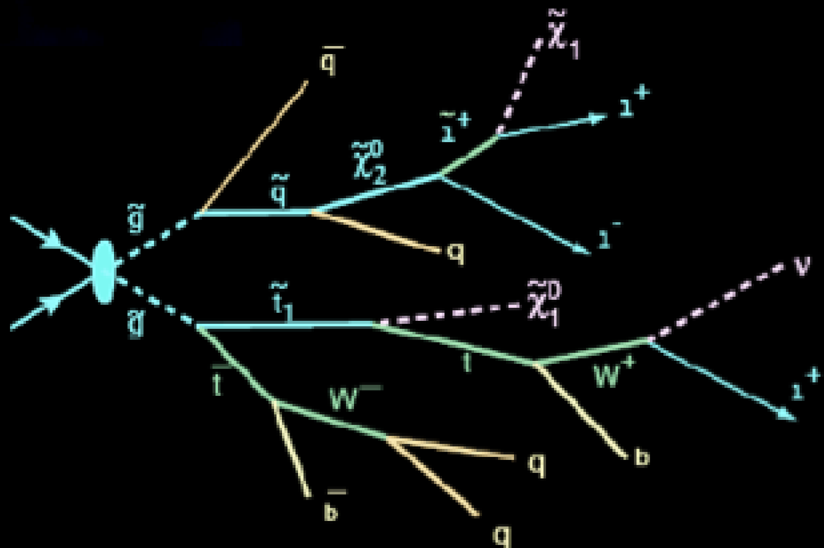
CMS (and ATLAS) can find valuable hints, however they cannot reveal the exact nature of dark matter alone. Need complementary results from direct/ indirect detection experiments.

DM discovery strategy

- Discover a deviation from the SM in E_T^{miss} + X channel, or in searches for long lived particles, or any other channel.
- Investigate if discovered signal points to a DM candidate. Possibly first rough evaluation of the DM candidate mass
- Make first mass measurements based on kinematics of high-BR decays. Model-independent calculation of the DM particle mass, comparison with direct detection experiments
- Model estimation: Precision measurements involving cross sections, BRs, angular distributions, rare decays, etc. Need 14TeV and O(10fb^{-1}) of integrated luminosity. Model-independent calculation of relic density, interaction cross section, etc.

Searches with missing energy (neutralinos, gravitinos, axinos…)

WIMP hunting in CMS



Strong production followed by cascade decays involving leptons and jets into a pair of heavy, neutral, stable particle.

Explore all possible E_T^{miss} + X signatures!

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

(and their t/b/tau enriched variants)

Hadronic example: Multijets + MHT

CMS-PAS-SUS-10-005

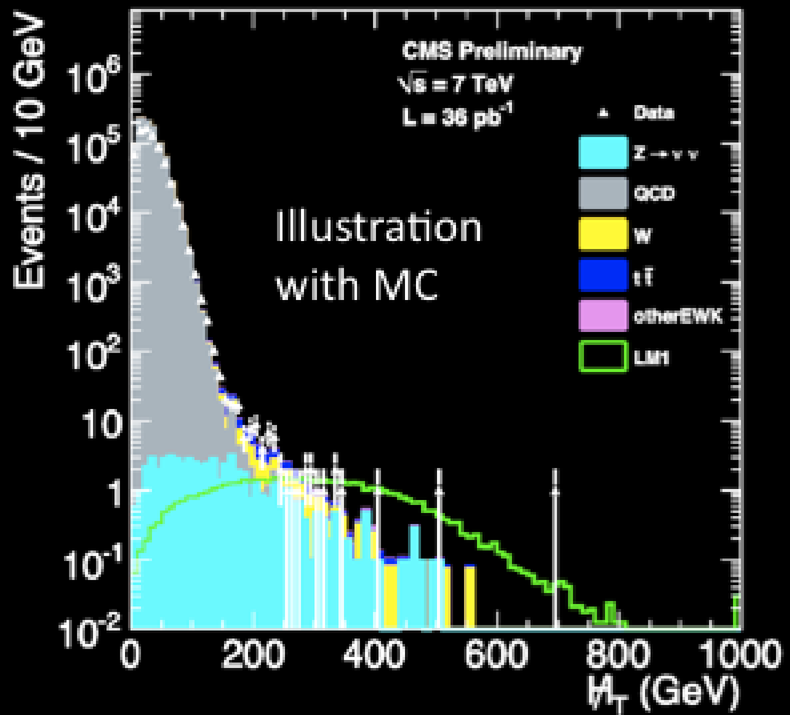
Baseline selection:

- ≥ 3 jets with E_T > 50 GeV and |η| < 2.5
- HT > 300 GeV and MHT > 150 GeV

where

$$HT = \sum_{jets} p_T, \quad M\vec{H}T = -\sum_{jets} \vec{p}_T$$

- Veto isolated electrons and muons



Backgrounds:

- Multijet QCD, Z->vv, W+jets, ttbar (estimated wth data-driven methods)

Results:

- MHT > 250 : Observed = 15, Expected SM BG = 18.8 ± 3.5
- HT > 500 : Observed = 40, Expected SM BG = 43.8 ± 9.2

CONSISTENT WITH SM !

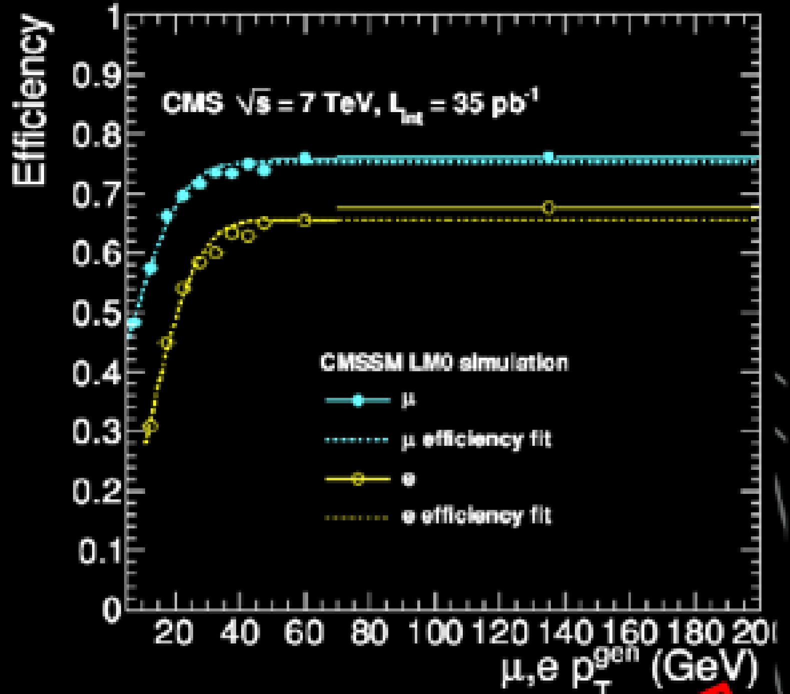
Leptonic example: Same sign dileptons

arXiv:1104.3168

Baseline selection:

- 2 same sign isolated leptons (e or μ)
  - $p_{T,1} > 20$ GeV, $p_{T,2} > 10$ GeV
- ≥ 2 jets
  - $p_T > 30$ GeV, $|\eta| < 2.5$
- E_T^{miss}:
  - > 30 GeV (ee and μμ)
  - > 20 GeV (eμ)

Analysis provides public lepton efficiency models.



Backgrounds:

- Mainly ttbar (due to leptons from bs)

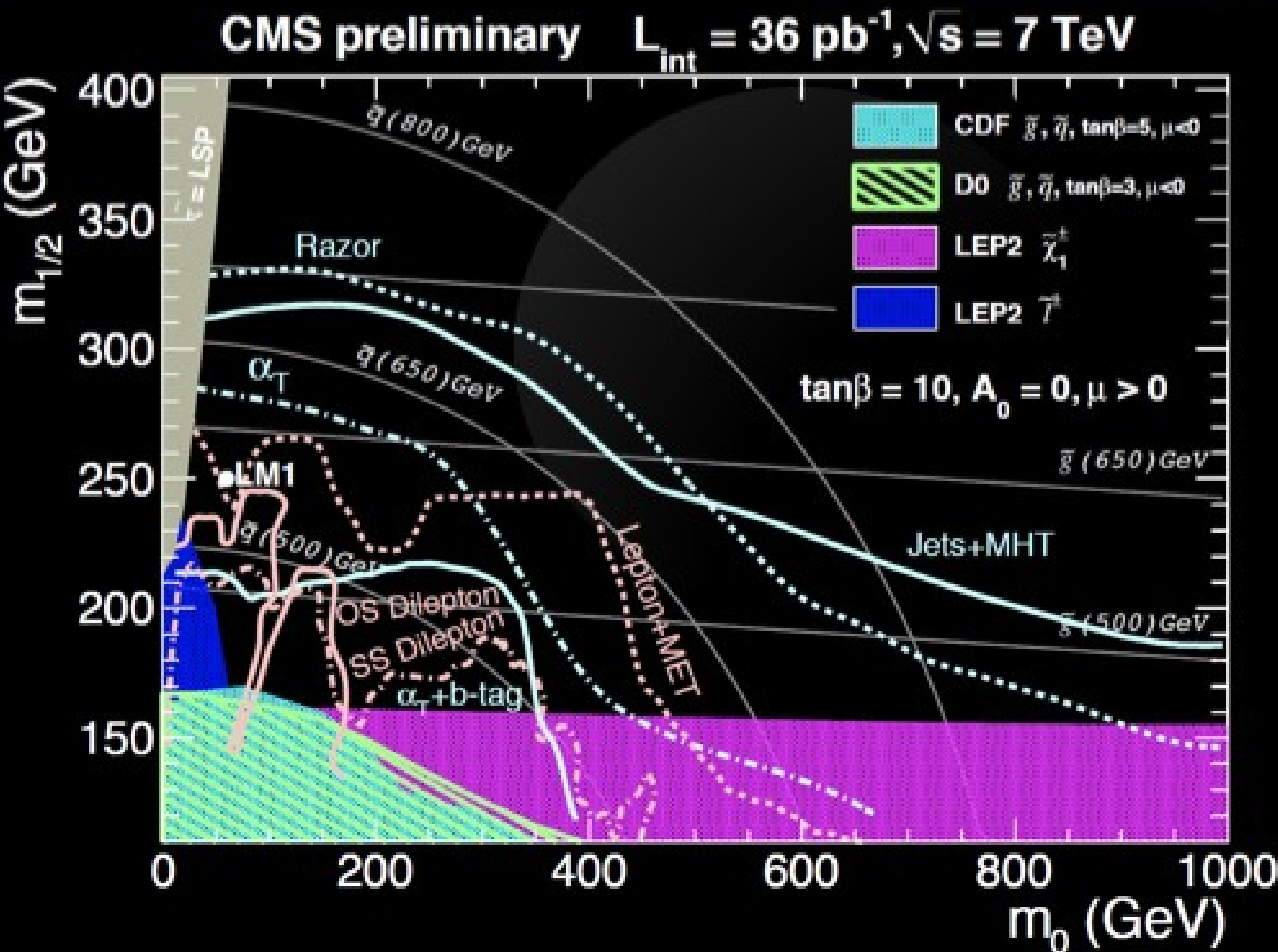
Results:

- MET > 80 : Observed = 0, Expected SM BG = 1.2 ± 0.8
- HT > 200 : Observed = 1, Expected SM BG = 0.97 ± 0.74

CONSISTENT WITH SM !

mSUGRA interpretation: neutralino DM

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS



This plane predicts neutralino dark matter – however current results are not sufficient to put a limit on the neutralino relic density.

MSSM+ν_R interpretation: sneutrino DM

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS10004_sneutrino

Sneutrino DM problem solved by introducing right-handed neutrinos with vanishing or small Majorana masses.

N. Arkani-Hamed et.al, Phys. Rev. D64:115011,2001; Z. Thomas et.al, Phys.Rev.D77:115015,2008; A.Katz, B.Tweedle, Phys. Rev. D 81, 035012 (2010), G. Belanger et.al, JCAP 1101:017,2010

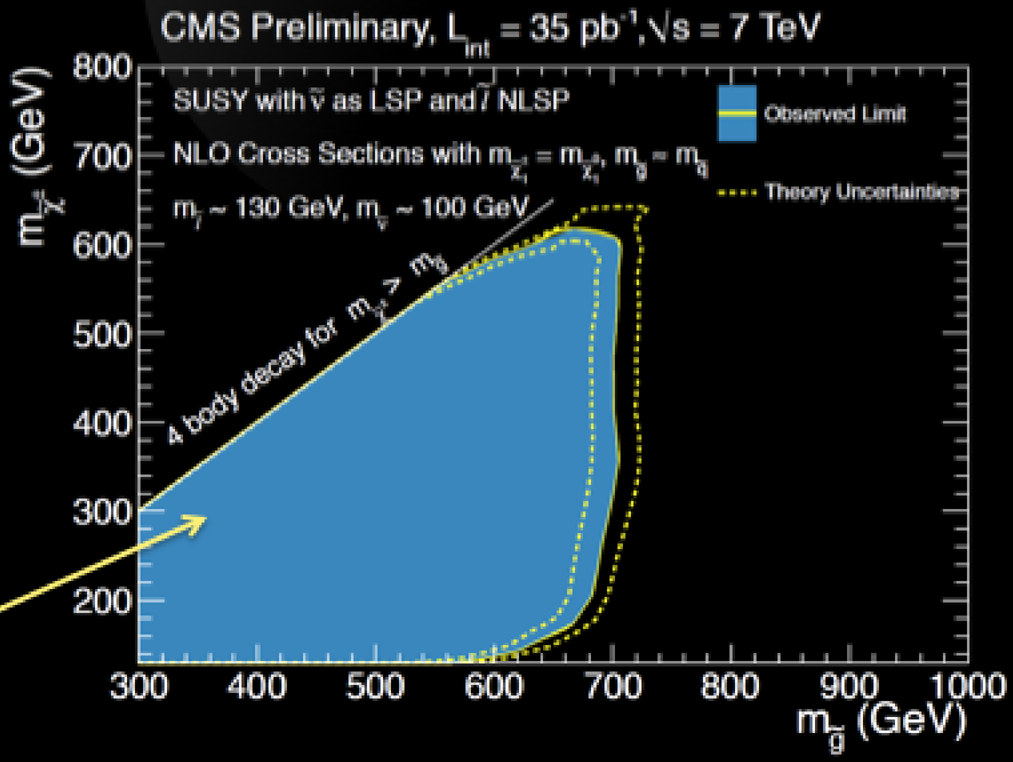
Mass relations:

$$m_{\tilde{q}} \sim m_{\tilde{g}}; \quad m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm}$$

Typical decay chain:

$$\tilde{g} \rightarrow qq\tilde{\chi}_1^\pm \rightarrow qq\ell^\pm\tilde{\nu}_1$$

Using results from the same sign dilepton search with $E_T^{miss} > 80$

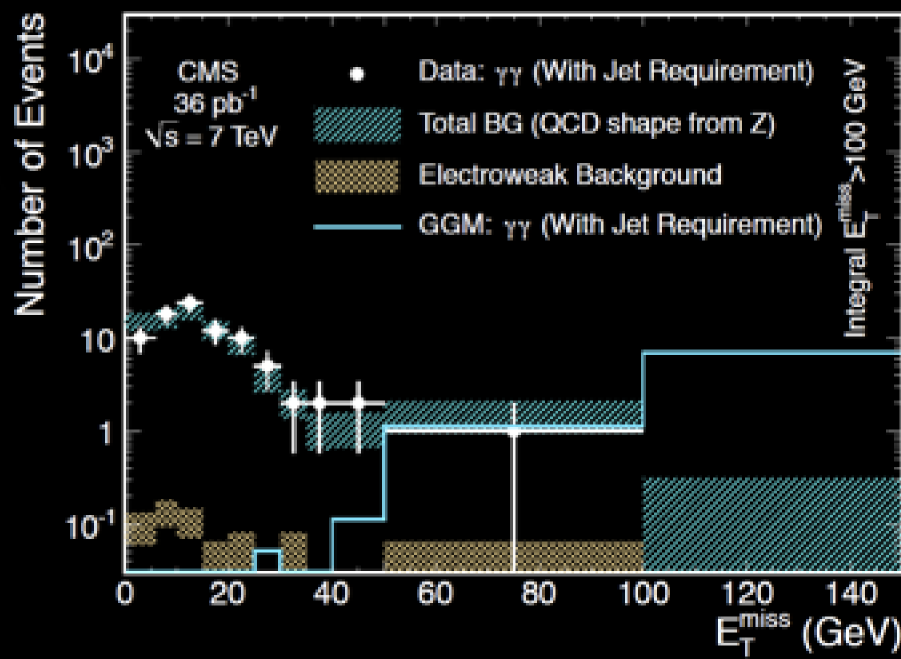


Photon example: 2γ+jets+E_T^{miss}

arXiv:1103.0953

Baseline selection:

- ≥2 photons
  - p_T > 30 GeV and |η| < 1.4
  - special photon identification
- ≥1 jet with E_T > 30 GeV
- E_T^{miss} ≥ 50 GeV



Backgrounds:

- Mainly QCD (photon + jets with fakes)

Results:

Observed = 1, Expected SM BG = 1.2 ± 0.8

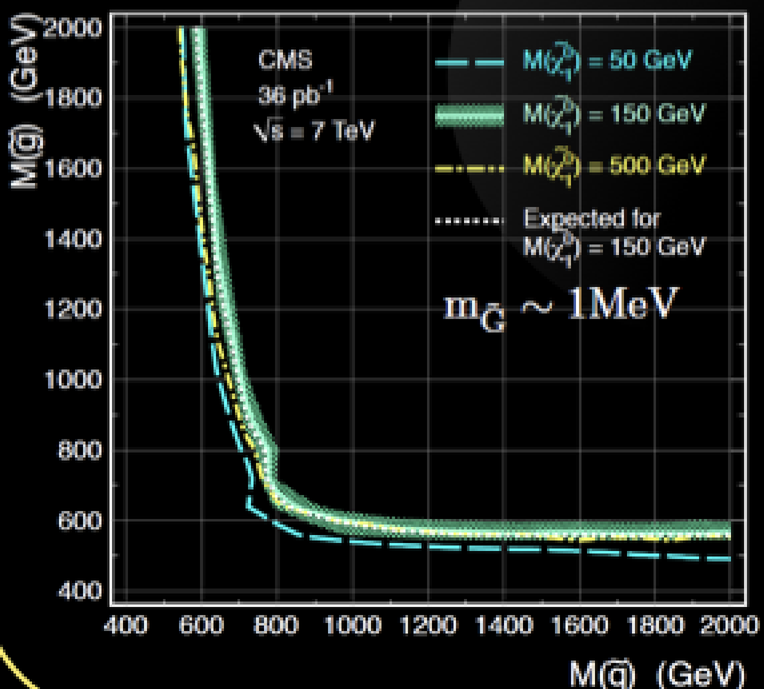
CONSISTENT WITH SM !

GGM interpretation: gravitino DM

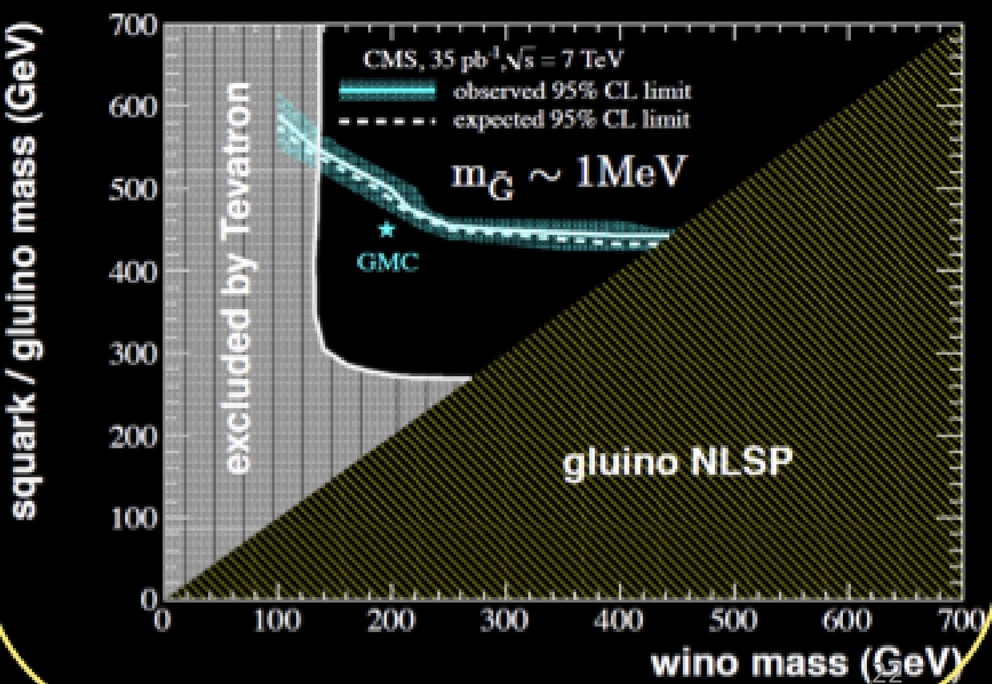
arXiv:1103.0953, arXiv:1105.3152

Model: SUSY with general gauge mediation (GGM). Gravitino LSP, neutralino NLSP. Neutralino decays promptly to photon + gravitino. Investigated different NNLSPs:

Gluino/squark NNLSP, decaying to quarks + NLSP. Put mass limits using γ + jets + E_T^{miss} results.



Chargino NNLSP, decaying to lepton + NLSP. Put mass limits using γ + jets + E_T^{miss} results.



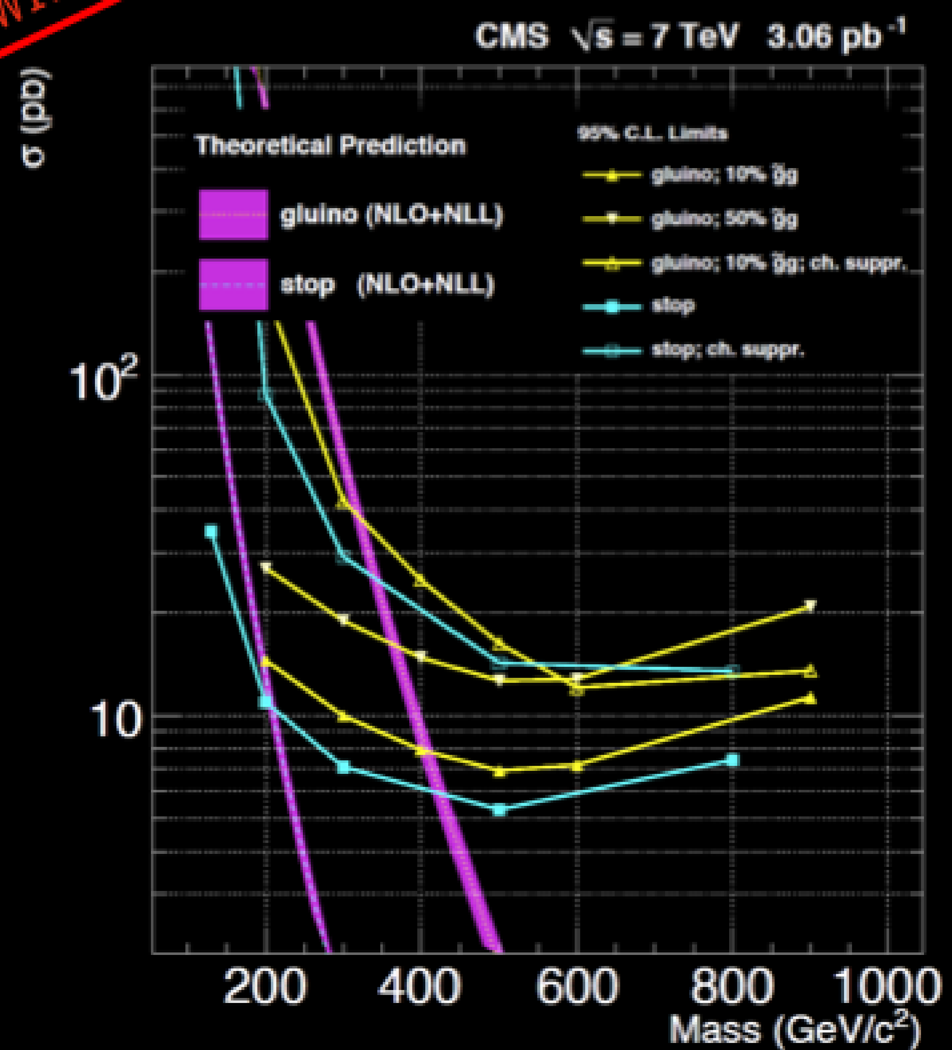
Heavy Stable Charged Particles (neutralinos, gravitinos, axinos, …)

Heavy charged stable particles

arXiv:1101.1645

CONSISTENT WITH SM !

- Heavy, charged particles with long lifetimes hint non-WIMP dark matter such as gravitinos or axinos.
- Heavy charged "stable" particles (HCSP) have muon like signature – but they have low velocity (non-relativistic).
- Measure β using tracker dE/dx and muon time of flight (check delayed hits), then calculate the mass.
- Negligible backgrounds.

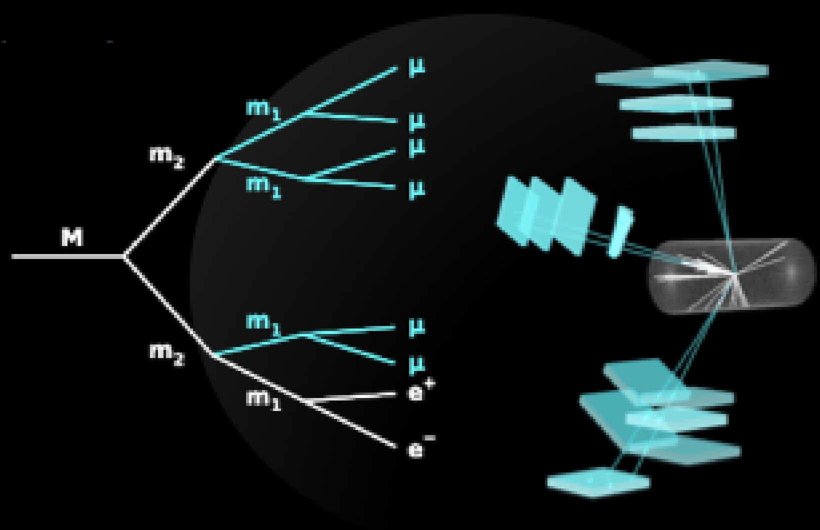


Lepton jets
(TeV scale fermions)

Lepton jets - I

CMS-PAS-EXO-11-013

- High energy positron excess in cosmic ray spectrum motivated new models that associate the excess with annihilation of new TeV scale DM particles.
- Such models typically have an extra U(1) symmetry with weak coupling to the SM. Breaking of the U(1) results in a vector boson, a "dark photon" with mass ~ O(1GeV). Weak coupling to the SM allows dark photons to decay to collimated lepton pairs (lepton jets) or occasionally, to hadrons.
- In the supersymmetric extensions of such models, dark photons can be produced at the SUSY cascade decays.

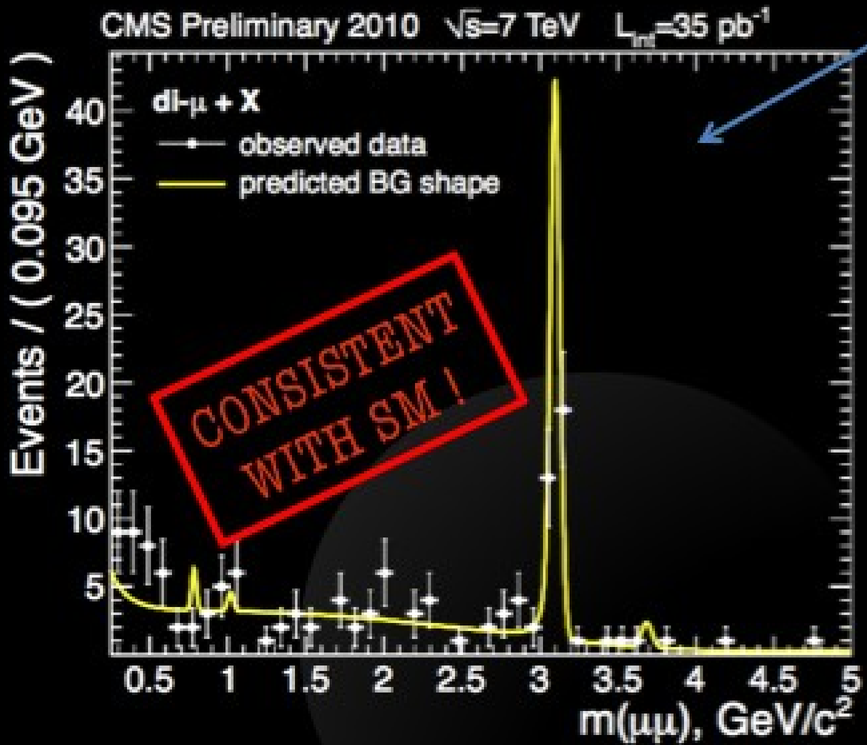


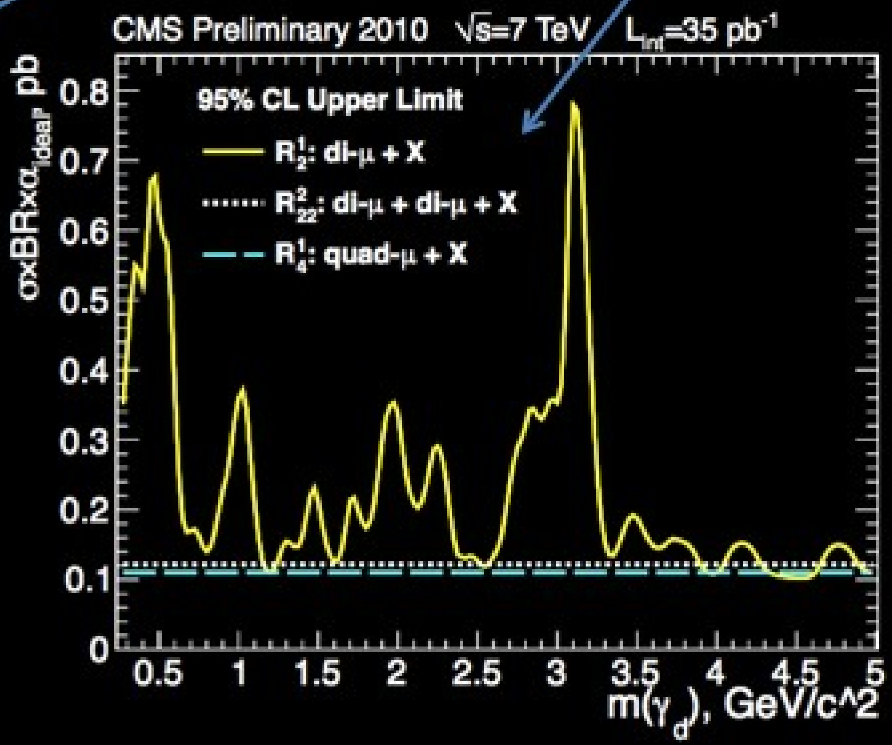
Observing the lepton jets coming from a dark photon in CMS could hint to models with TeV scale dark matter.

Lepton jets - II

CMS-PAS-EXO-11-013

CMS search for new μμ resonances in various event topologies like [μμ] and [μμ][μμ] with collimated groups of dimuns. No excess observed. Set model-independent limits on cross section × BR × acceptance.





What if we see an excess…

The trouble with E_t^{miss} signal

If the excess is in the E_T^{miss} channel, this possibly indicates double-sided contribution to E_T^{miss}, long, tangled chains, complicated signatures.

- No clear resonances over the background
- Not possible to reconstruct the complete event.
- Small kinematic sensitivity to mass of the invisible particle
- Difficult to measure absolute masses. Mass differences are easier to measure (using mass differences introduce correlations when extracting the absolute masses)
- Extra jets from QCD radiation complicate the jet signatures.

Also see J Alwall LBL RPM talk , March 4 2010

A looong shopping list …

mass/mass splitting	LCC1 Value		LHC	ILC 500	ILC 1000
$m(\tilde{\chi}_1^0)$	95.5	$\pm$	4.8	0.05	
$m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$	86.1	$\pm$	1.2	0.07	
$m(\tilde{\chi}_3^0) - m(\tilde{\chi}_1^0)$	261.2	$\pm$	@[a]	4.0	
$m(\tilde{\chi}_4^0) - m(\tilde{\chi}_1^0)$	280.1	$\pm$	2.2[a]	2.2	
$m(\tilde{\chi}_1^+)$	181.7	$\pm$	-	0.55	
$m(\tilde{\chi}_2^+)$	374.7	$\pm$	-	-	3.0
$m(\tilde{e}_R)$	143.1	$\pm$	-	0.05	
$m(\tilde{e}_R) - m(\tilde{\chi}_1^0)$	47.6	$\pm$	1.0	0.2	
$m(\tilde{\mu}_R) - m(\tilde{\chi}_1^0)$	47.5	$\pm$	1.0	0.2	
$m(\tilde{\tau}_1) - m(\tilde{\chi}_1^0)$	38.6	$\pm$	5.0	0.3	
$BR(\tilde{\chi}_2^0 \to \tilde{e}e)/BR(\tilde{\chi}_2^0 \to \tilde{\tau}\tau)$	0.077	$\pm$	0.008		
$m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$	109.1	$\pm$	1.2	0.2	
$m(\tilde{\mu}_L) - m(\tilde{\chi}_1^0)$	109.1	$\pm$	1.2	1.0	
$m(\tilde{\tau}_2) - m(\tilde{\chi}_1^0)$	112.3	$\pm$	-	1.1	
$m(\tilde{\nu}_e)$	186.2	$\pm$	-	1.2	
$m(h)$	113.68	$\pm$	0.25	0.05	
$m(A)$	394.4	$\pm$	*	(> 240)	1.5
$m(\tilde{u}_R)$, $m(\tilde{d}_R)$	548.	$\pm$	19.0	16.0	
$m(\tilde{s}_R)$, $m(\tilde{c}_R)$	548.	$\pm$	19.0	16.0	
$m(\tilde{u}_L)$, $m(\tilde{d}_L)$	564., 570.	$\pm$	17.4	9.8	
$m(\tilde{s}_L)$, $m(\tilde{c}_L)$	570., 564.	$\pm$	17.4	9.8	
$m(\tilde{b}_1)$	514.	$\pm$	7.5	5.7	
$m(\tilde{b}_2)$	539.	$\pm$	7.9	6.2	
$m(\tilde{t}_1)$	401.	$\pm$	(> 270)	-	2.0
$m(\tilde{g})$	611.	$\pm$	8.0	6.5	

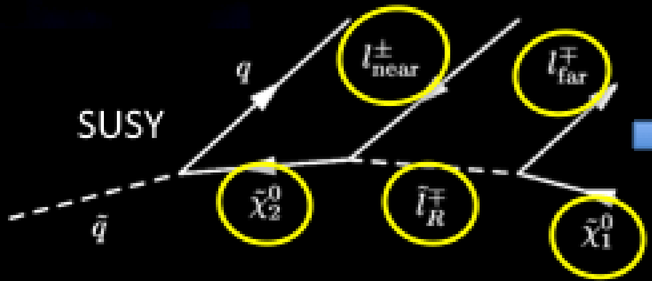
Example list for variable that can be reconstructed for a a low mass mSUGRA point.

Errors estimated based on LHC (mostly ATLAS) measurements.

Phenomenology study Baltz et. Al. Phys.Rev.D74:103521, 2006

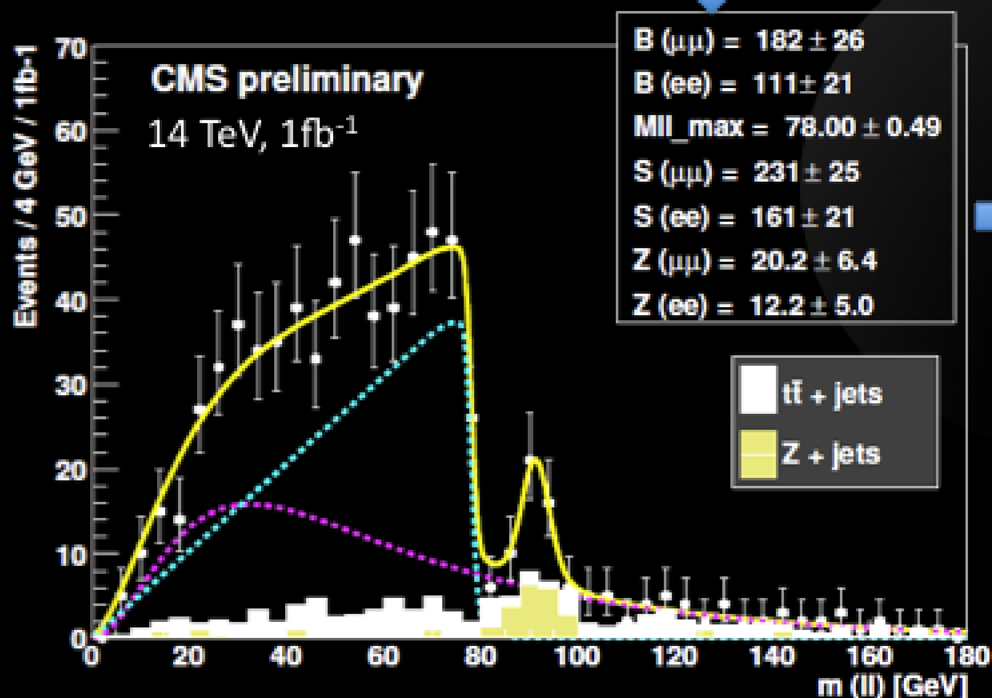
Most common exercise: the dilepton edge

CMS-SUS-08-001 Monte Carlo study



Baseline dileptons + jets + E_T^{miss} selection:

- ≥ 2 isolated OSSF leptons with $p_T > 10$ GeV, $|\eta| < 2.4$
- ≥ 3 jets $E_T > 30$ GeV, $|\eta| < 3$
- E_T(j1, j2) > 120, 80 GeV
- $E_T^{miss} > 200$ GeV



m(ll)^{max} TH: 78.15 GeV
m(ll)^{max} measured: 78.00 ± 0.49 GeV

For 2-body decays, upper endpoint corresponds to

$$m_{\ell\ell}^{max} = m_{\tilde{\chi}^0_2}\sqrt{1-\frac{m^2_{\tilde{l}_R}}{m^2_{\tilde{\chi}^0_2}}}\sqrt{1-\frac{m^2_{\tilde{\chi}^0_1}}{m^2_{\tilde{l}_R}}}$$

Simultaneous fit to

$$F(m) = N_{sig}\cdot S(m) + N_{bkg}\cdot B(m) + N_Z\cdot Z(m)$$

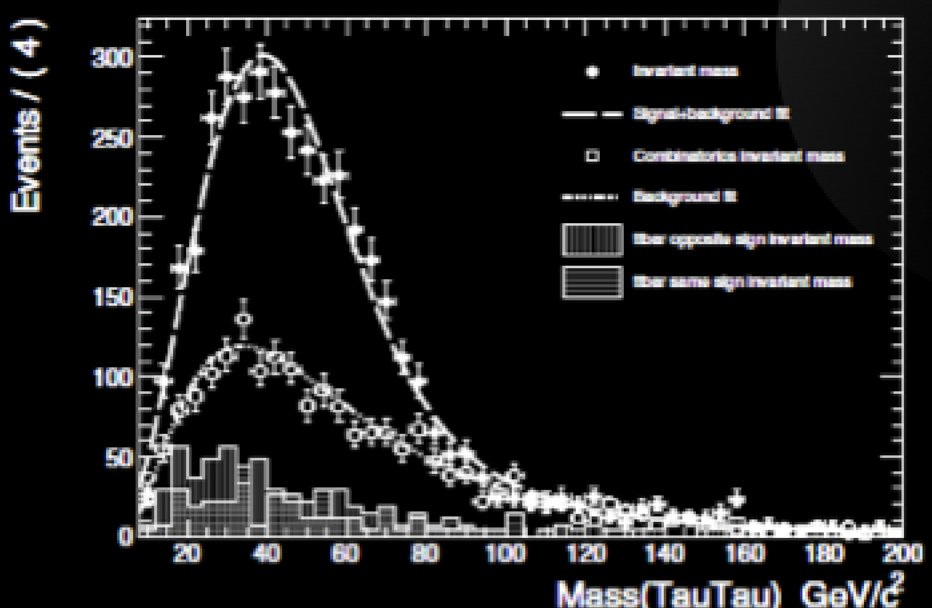
Ditau edge

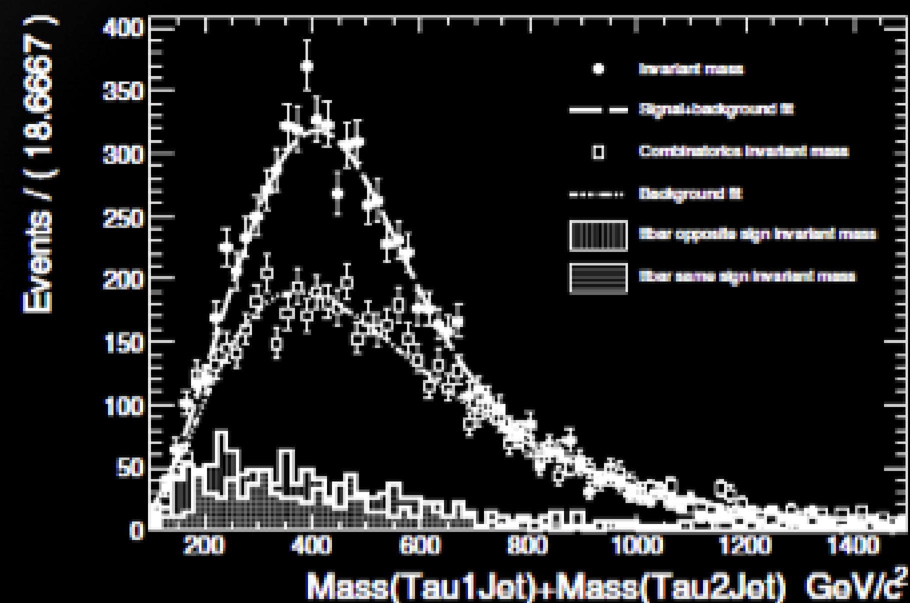
CMS TDR, J.Phys.G34:995-1579,2007 Monte Carlo study

Baseline ditau + jets + MET selection (14 TeV, 40fb^{-1}):

- ≥ 2 itau candidates (hadronic or leptonic) with $\Delta R(\tau\tau) > 2$
- ≥ 2 jets, E_T(j1, j2) > 150, 150 GeV
- E_T^{miss} > 150 GeV

Several invariant mass distributions were fitted to composite shapes, and endpoints were extracted from the fits.





Diltau edges: Results

CMS TDR, J.Phys.G34:995-1579,2007   Monte Carlo study

End-points (GeV)	case 1 (GeV)	case 2 (GeV)
$m(\tau_1\tau_2)^{\max} = 95 \pm 3$	$M(\tilde{\chi}_1^0) = 213 \pm 14$	$M(\tilde{\chi}_1^0) = 147 \pm 23$
$m(\tau_1 Q)^{\max} = 559 \pm 11$	$M(\tilde{\chi}_2^0) = 337 \pm 17$	$M(\tilde{\chi}_2^0) = 265 \pm 10$
$m(\tau_2 Q)^{\max} = 298 \pm 7$	$M(\tilde{\tau}) = 310 \pm 17$	$M(\tilde{\tau}) = 165 \pm 10$
$m(\tau_1\tau_2 Q)^{\max} = 596 \pm 12$	$M(\tilde{q}) = 839 \pm 19$	$M(\tilde{q}) = 763 \pm 33$
$E_5^{meas} = 780 \pm 20$	$E_5^{calc} = 815 \pm 26$	$E_5^{calc} = 765 \pm 30$

Solve 4 equations giving first 4 endpoints as a function of 4 sparticle masses.
Resolve ambiguities by matching to $E_5 = m(\tau_1 Q) + m(\tau_2 Q)$.

	LM2 benchmark point	
	measured	theory
$M(\tilde{\chi}_1^0)$ (GeV)	$147 \pm 23(\mathrm{stat}) \pm 19(\mathrm{sys})$	138.2
$M(\tilde{\chi}_2^0)$ (GeV)	$265 \pm 10(\mathrm{stat}) \pm 25(\mathrm{sys})$	265.5
$M(\tilde{\tau})$ (GeV)	$165 \pm 10(\mathrm{stat}) \pm 20(\mathrm{sys})$	153.9
$M(\tilde{q})$ (GeV)	$763 \pm 33(\mathrm{stat}) \pm 58(\mathrm{sys})$	753-783 (light $\tilde{q}$)

Summary

- LHC collected and CMS recorded >400pb^{-1}, 7TeV pp collision data.
- CMS detector is performing well, generally remarkable data-Monte Carlo agreement.
- Many new physics searches published with 35pb^{-1}. Many updates and new searches underway.
- All current CMS results are consistent with the Standard Model. Setting limits on illustrative new physics models ("SUSY" for DM-related searches)
- If an excess is found, CMS will try all possible mass, BR, cross section measurements, from which DM properties could be extracted.
- In case of discovery, CMS results need to be complemented with direct/indirect DM detection results to reveal the exact nature of DM.