Searches for SUSY and other exotica at the LHC

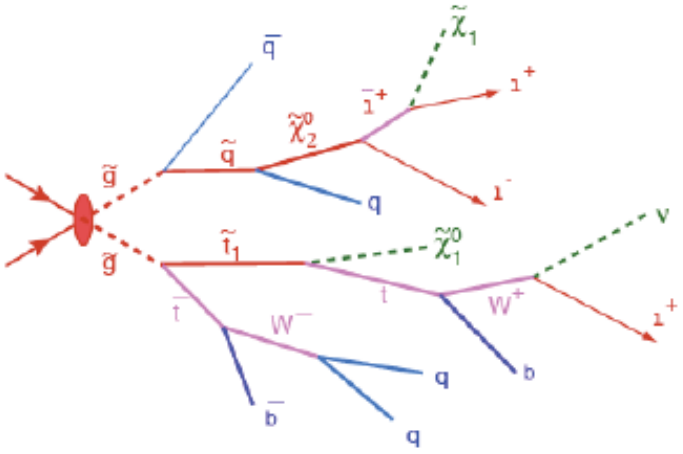
David Milstead
Stockholms Universitet

Motivation and outline

- Solutions to the hierarchy problem imply new physics at TeV energies
- Strategy to measure range of observables and where appropriate interpret within parameters of an exotic model.

Signature	Examples of model
Decay chain to WIMP candidate. Missing E_T + high p_T lepton, jets	MSUGRA
Missing E_T + high p_T leptons	String balls
Resonance production	RS- warped ED
Slow decay chain leading to delayed non-pointing photons	GMSB
Massive stable particles	Split-SUSY
Massive long-lived particles decaying in empty bunches	Split-SUSY

Inclusive SUSY searches



Production

Strong production cross section

Squark and gluino production

Mass-scale dependent, scenario-independent

Decay

R-parity conservation assumed

Heavy squark and gluino and long decay chains

Signatures

MET from LSPs, high E_T jets and lepton multiplicity.

Supersymmetry

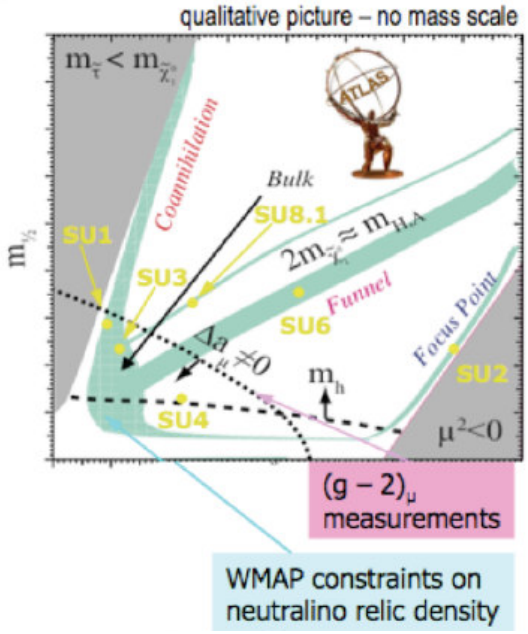
MSSM has >100 free parameters

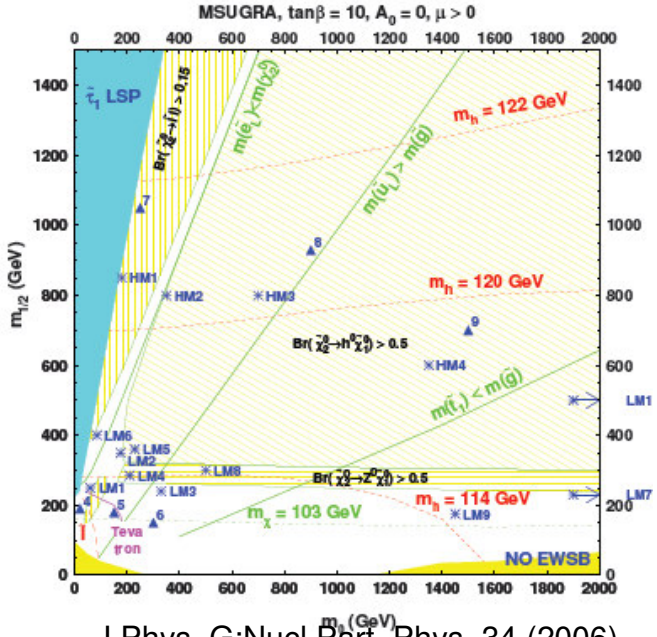
Need constrained models and benchmark points

- MSUGRA
- GMSB
- AMSB
- Split SUSY

- Low mass Msugra
  - SU4 (ATLAS)
  - LM0/LM1 (CMS)

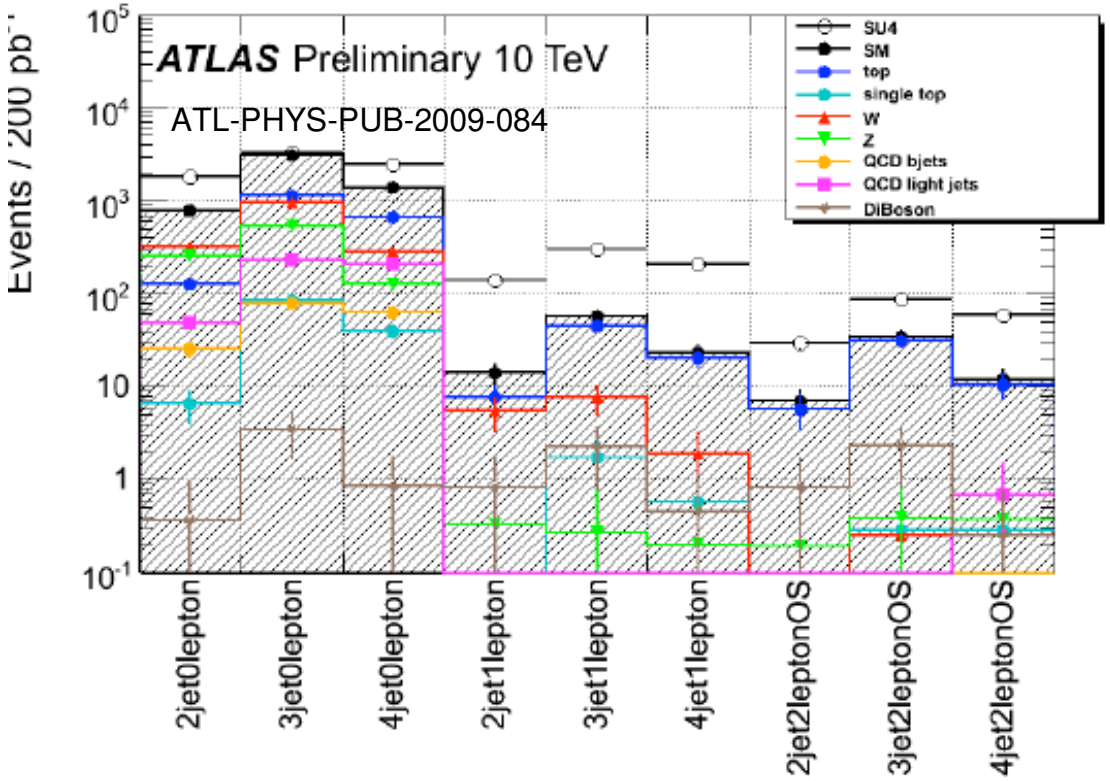
Search sensitivity:
1fb^{-1}@7 TeV ~ 200pb^{-1}@10 TeV





J.Phys. G:Nucl.Part. Phys. 34 (2006)

Inclusive searches



Jet $E_T > 100$ (40) GeV

$\Delta\Phi(\text{jet}_i, \text{MET}) > 0.2$ rad

Lepton $E_T > 20$ (10) GeV

MET > 80 GeV

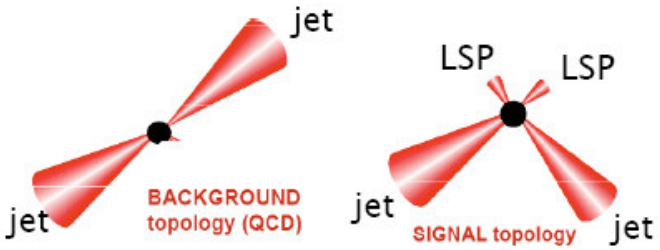
$M_{eff} = \sum E_T^{jet} + \sum E_T^{lep} + \text{MET}$

$S_T > 0.2$

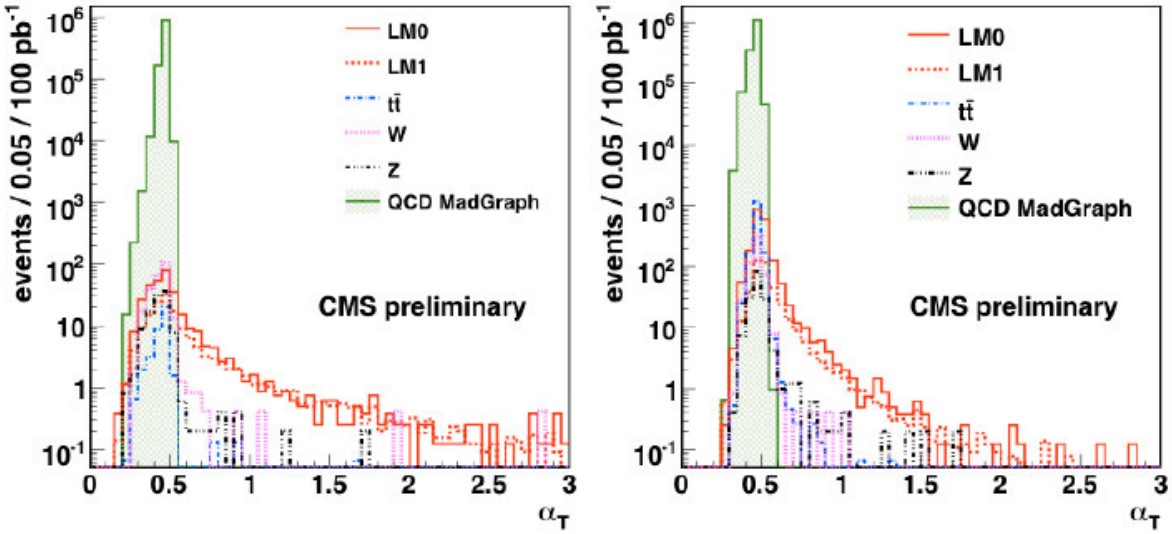
$M_T > 100$ GeV.

Good S/B for 200pb^{-1} at 10 TeV for a range of different topologies.

All hadronic searches



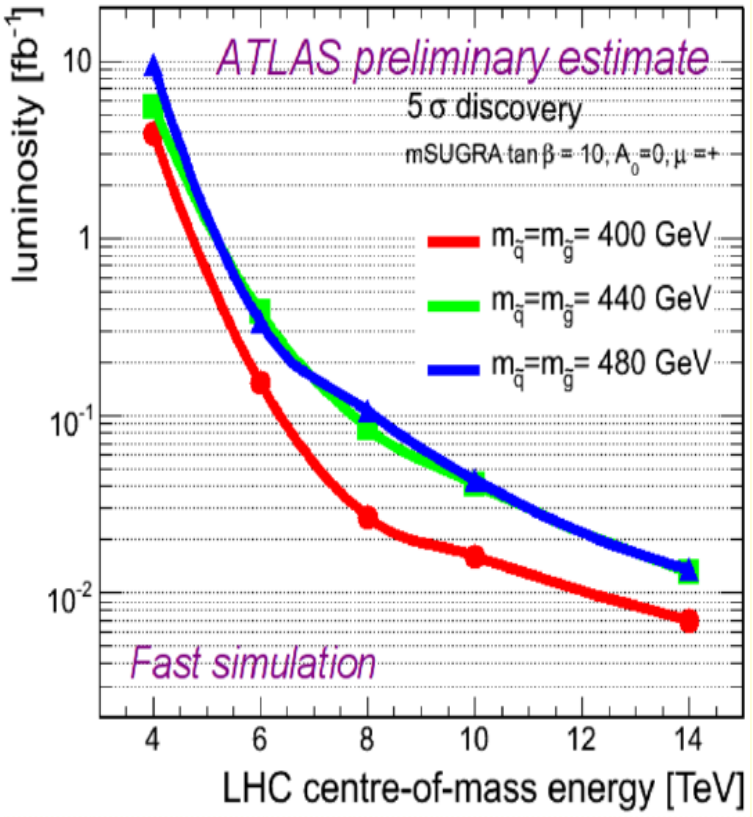
$$\alpha_T = \frac{E_{T\,j2}}{M_{T\,j1\,j2}}$$

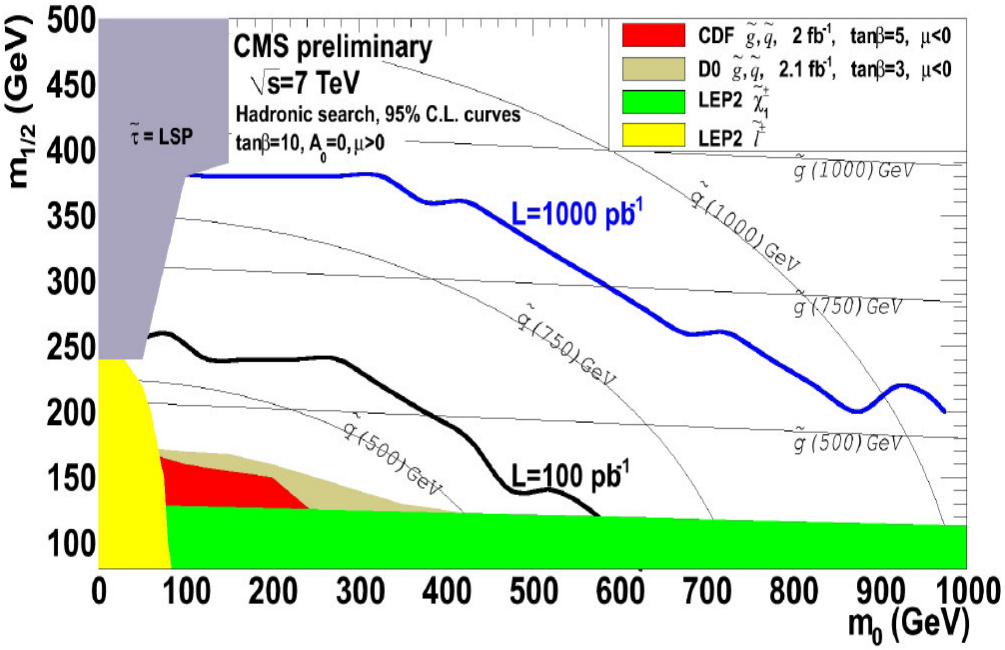


PRL101:221803 (2008), CMS-PAS-SUS-09-001

- Combine angular and energy info
- No dependence on MET
- Balanced events have α_T =0.5
- Lower values from jet mismeasurement.
  - Randall and Tucker-Smith:arXiv:0806.1049
  - Barr and Gwenlan arXiv:0907.2713.

Inclusive SUSY discovery potential





CMS NOTE-2010/008

Possible within ~100pb^{-1} at 7 TeV

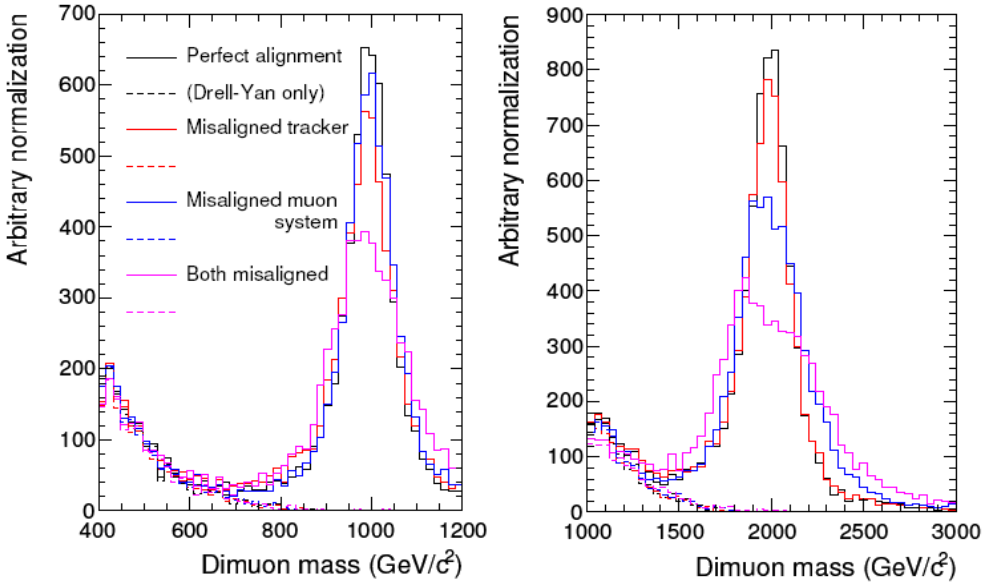
Resonances

- Eg Z'-like state at TeV scale mass
  - Extended SUSY-GUT groups
  - Sneutrinos in RPV SUSY
  - Little Higgs
  - Hidden Valley
  - Extra dimensions: gauge and graviton KK
  - ….

Dilepton resonances

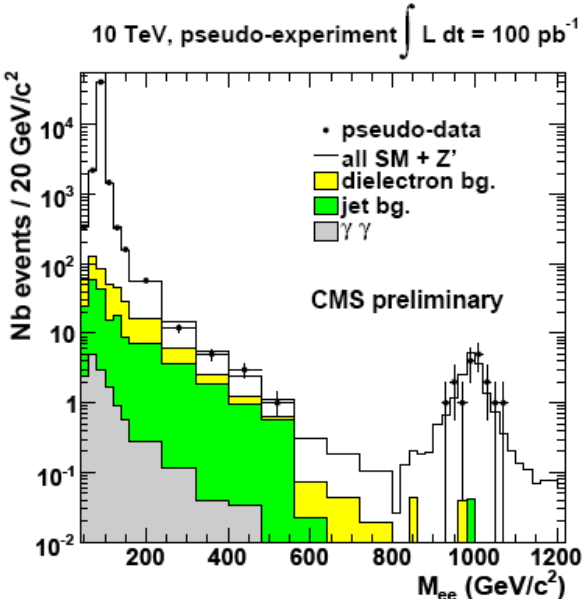
$Z_{SSM} \rightarrow \mu\mu$

CMS PAS SBM-07-002

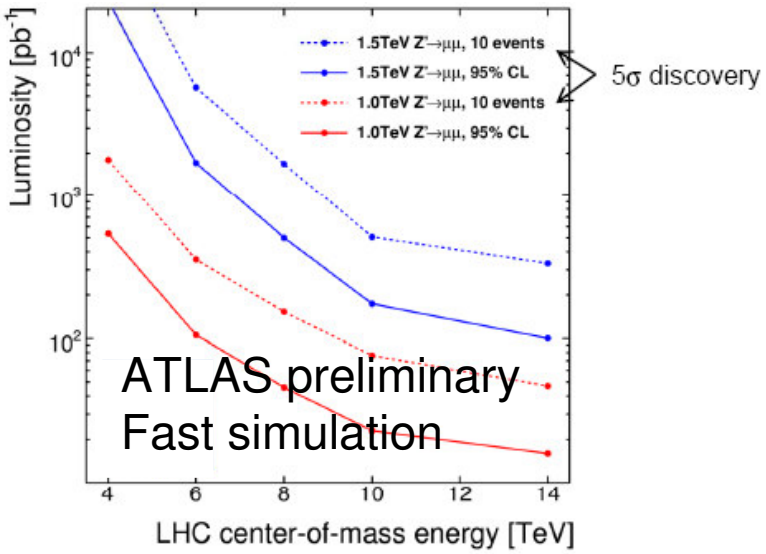


$Z_{SSM} \rightarrow ee$

CMS PAS EXO-09-006

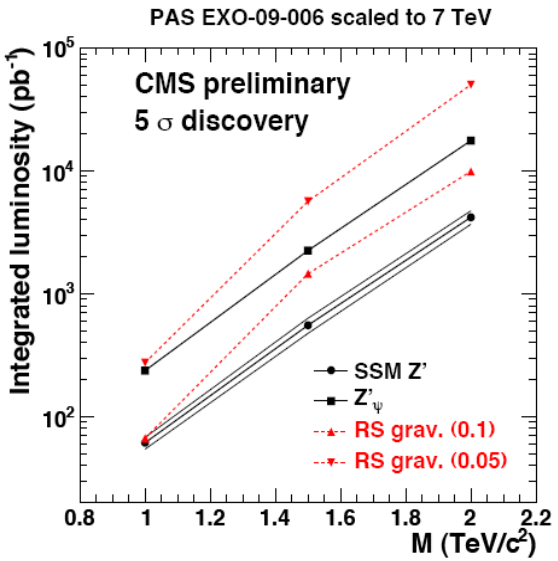


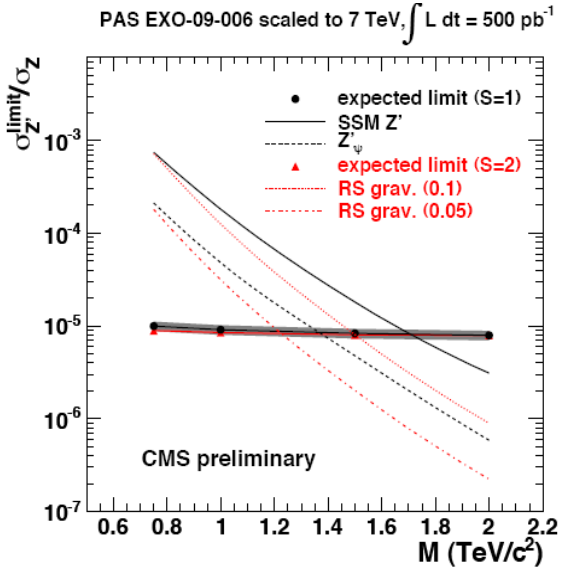
Discovery Potential



Z' Model	Indirect Searches (GeV)	Direct Searches (GeV)	
		e^+e^- Colliders	p^+p^- Colliders
Z'_χ	680	781	864
Z'_ψ	481	366	853
Z'_η	619	515	933
Z'_{LRSM}	804	518	–
Z'_{SSM}	1787	1018	966

Z_ψ, Z_{SSM} represent the exreme cases in sensitivity.



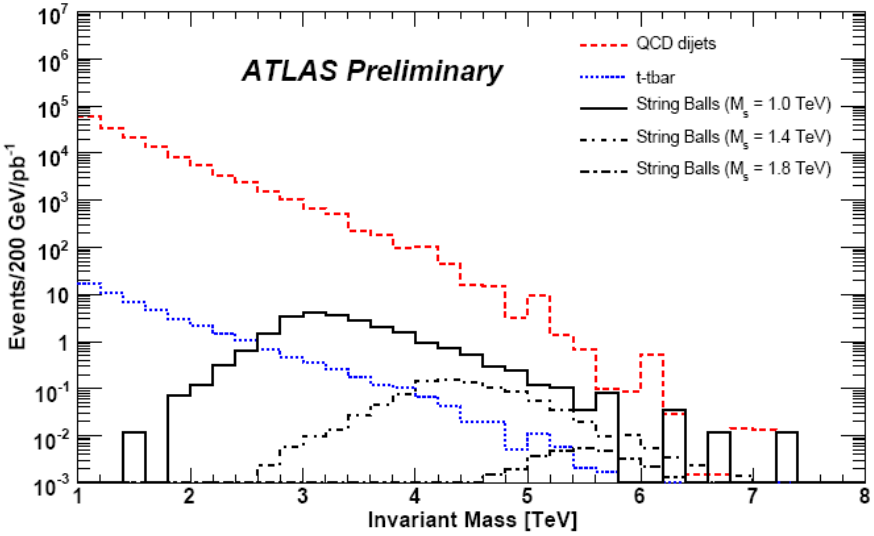


CMS NOTE-2010/008

String balls

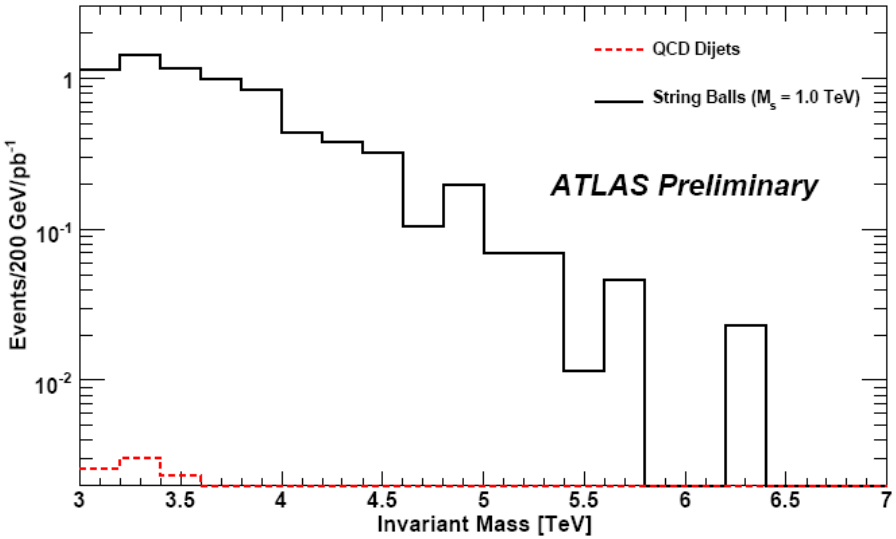
- Embed TeV-scale gravity in string models
  - Perturbative string theory with weak coupling
- String balls are high entropy string states
  - New form matter involving gravity + string theory
- String balls produced below Black hole mass threshold
  - Black holes@LHC will evolve into these states
- Excited string states of SM with TeV masses

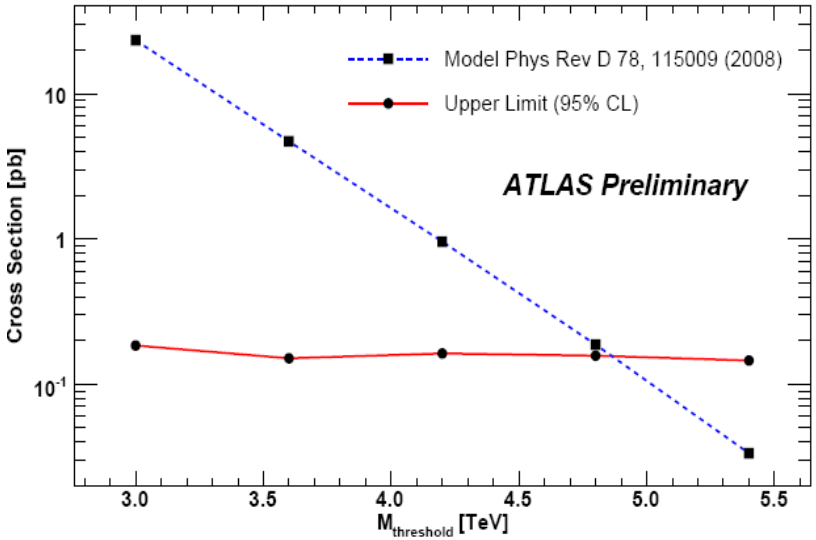
String ball observables



$\sum |\vec{p}_T| + E_T > 2.4$ TeV

Lepton $p_T > 100$ GeV





Luminosity = 100pb^{-1}

$\sqrt{s} = 10$ TeV

Possible exclusion limits well below a wide range of mass threshold values.

String scale $M_S < 1.6$ TeV

Long-lived particles

- Long-lived particles features of many BSM models.
- Observe and extract quantum numbers.
- Decay in flight and stable

Particle	Signature
Lepton-like	Penetrating
Gluon-like	Penetrating R-hadron + charge exchange
Quark-like	Penetrating R-hadron + charge exchange

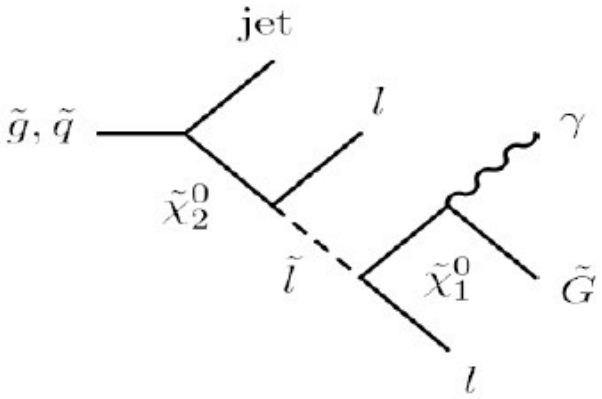
$Q_{\rm em}$	$C_{\rm QCD}$	S	Model(s)
0	**8**	1	Universal Extra Dimensions (KK gluon)
± 1	**1**	$\frac{1}{2}$	Universal Extra Dimensions (KK lepton)
			Fat Higgs with a fat top (ψ fermions)
			4th generation (chiral) fermions
			Mirror and/or vector-like fermions
		0	Fat Higgs with a fat top (ψ scalars)
$\pm\frac{4}{3}$	**3**	$\frac{1}{2}$	Warped Extra Dimensions with GUT parity (XY gaugino)
		0	5D Dynamical SUSY-breaking (xyon)
$-\frac{1}{3},\frac{2}{3}$	**3**	$\frac{1}{2}$	Universal Extra Dimensions (KK down, KK up)
			4th generation (chiral) fermions
			Mirror and/or vector-like fermions
			Warped Extra Dimensions with GUT parity (XY gaugino)
$\epsilon < 1$	**1**	$\frac{1}{2}$	GUT with $U(1) - U(1)'$ mixing
			Extra singlets with hypercharge $Y = 2\epsilon$
			Millicharged neutrinos
?	?	$0/\frac{1}{2}/1$	"Technibaryons"

hep-ph/0611040

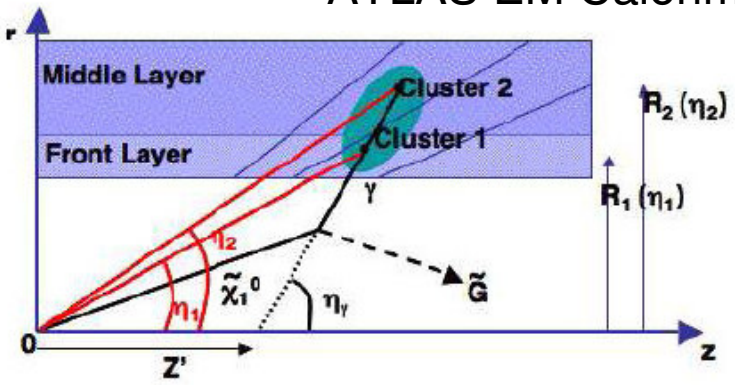
Non-pointing photons

GMSB scenarios - neutralino NLSP.

name	NLO (LO) σ [pb]	Λ [TeV]	M_m [TeV]	C_G	$c\tau$ [mm]	$M_{\tilde{\chi}_1^0}$ [GeV]
GMSB1	7.8 (5.1)	90	500	1.0	1.1	118.8
GMSB2	7.8 (5.1)	90	500	30.0	$9.5 \cdot 10^2$	118.8
GMSB3	7.8 (5.1)	90	500	55.0	$3.2 \cdot 10^3$	118.8



ATLAS EM Calorimeter

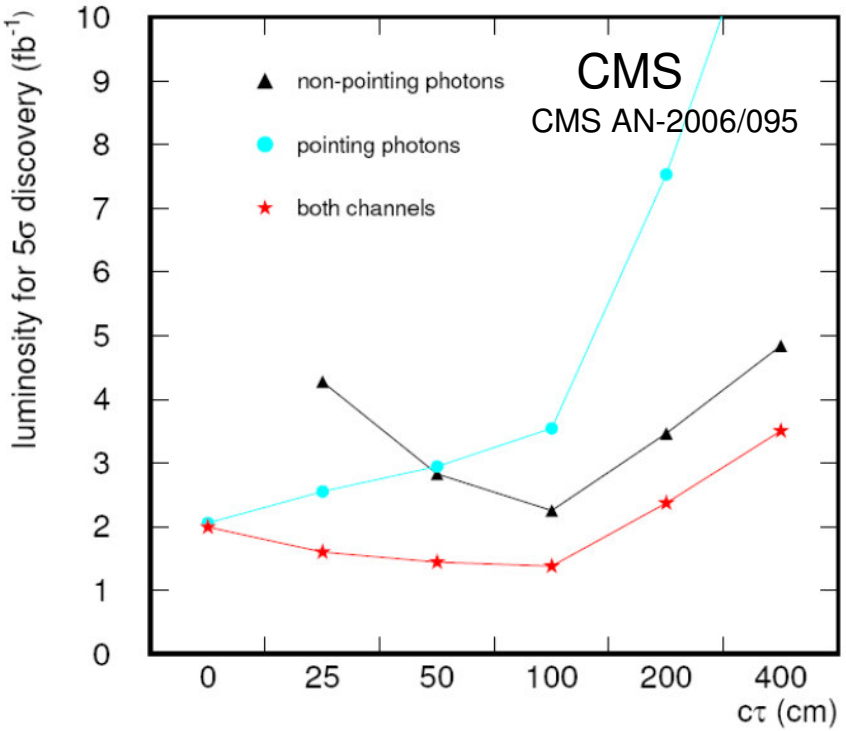


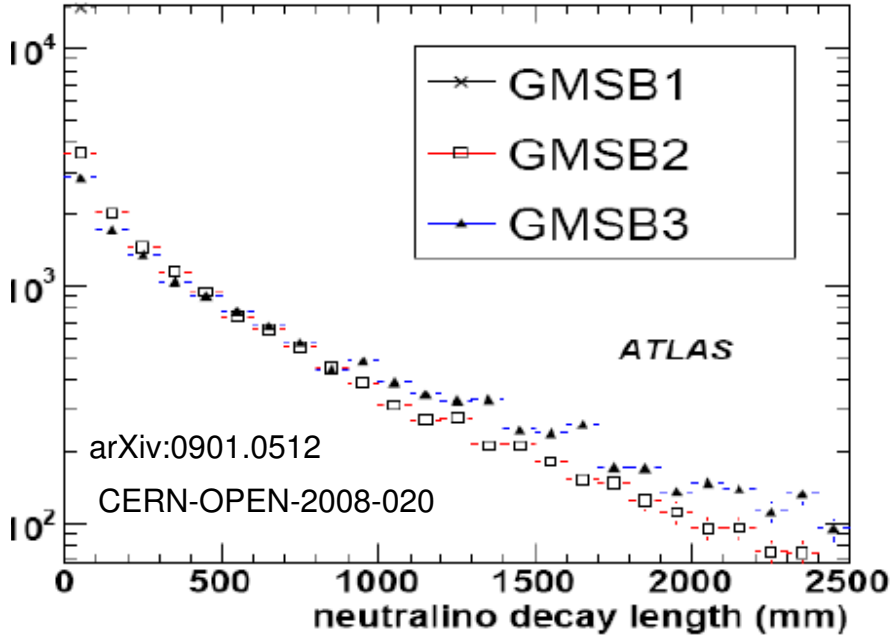
$C_{grav} > 1$

$\Rightarrow$ neutralino decays away from IP.

$\Rightarrow$ non-pointing high p_T photon.

Non-pointing photons





Criteria:

Decay within inner tracking detector

$p_T > 20$ GeV ; $|\eta| < 2.5$

Lepton pairs of opposite and same sign (OSSF).

N_γ	N_{OSSF}	Signal	$\sum$ Background	Sig	N_W	N_Z	$N_{t\bar{t}}$
0	0	825.2	929.6	27.1	274.4	21.0	632.8
0	1	265.2	73.0	33.2	8.7	1.4	63.0
1	0	255.8	51.7	35.7	19.5	2.0	30.1
1	1	68.6	1.4	58.6	0.2	0.0	1.2
2	0	12.5	0.1	12.5	0.0	0.0	0.1
2	1	4.7	0.0	4.7	0.0	0.0	0.0

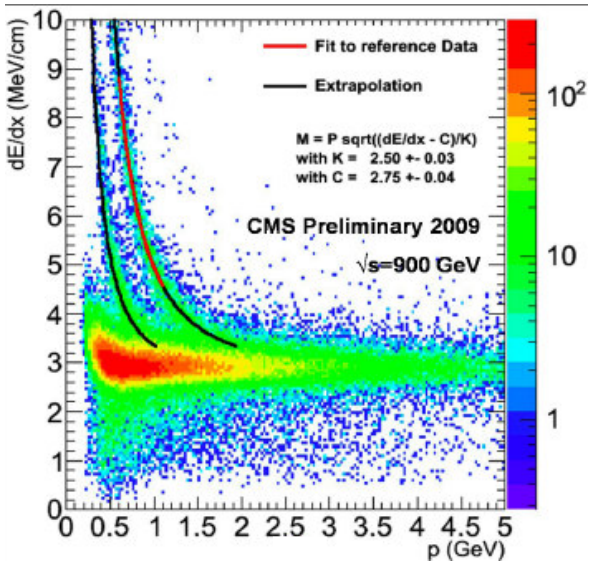
$1fb^{-1}$

ATLAS

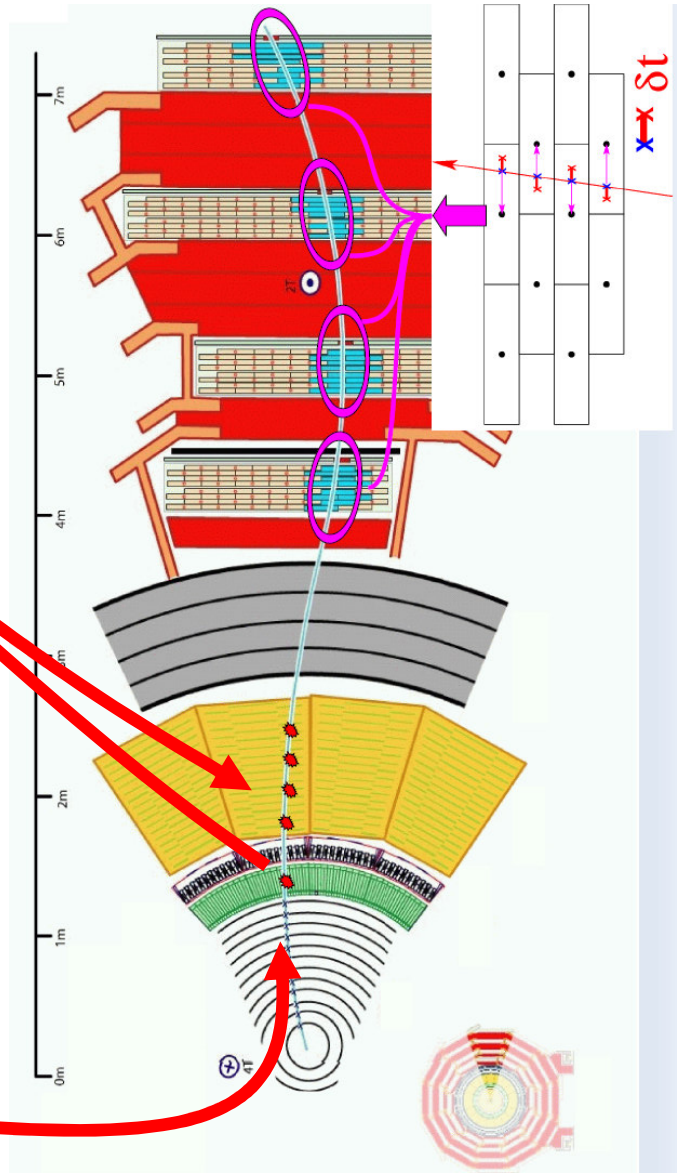
Stable massive particles at CMS

Time delay from hits in DT

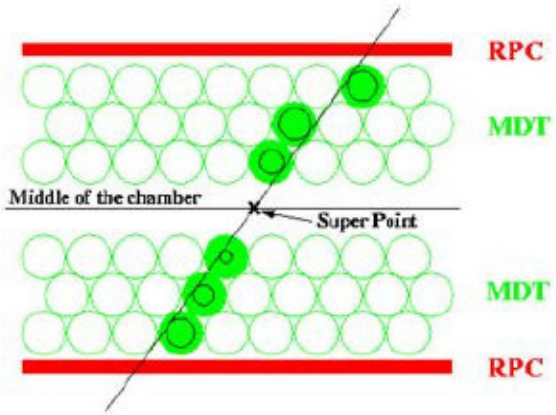
Time delay from pulse shape in ECAL, HCAL, CSC.



dE/dx in tracker ECAL and HCAL

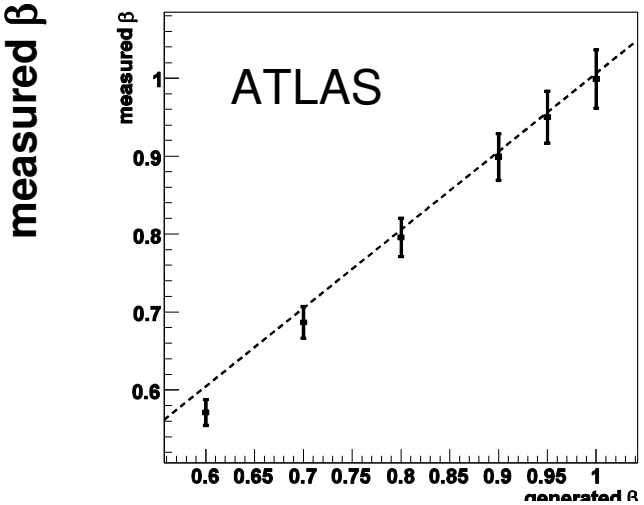


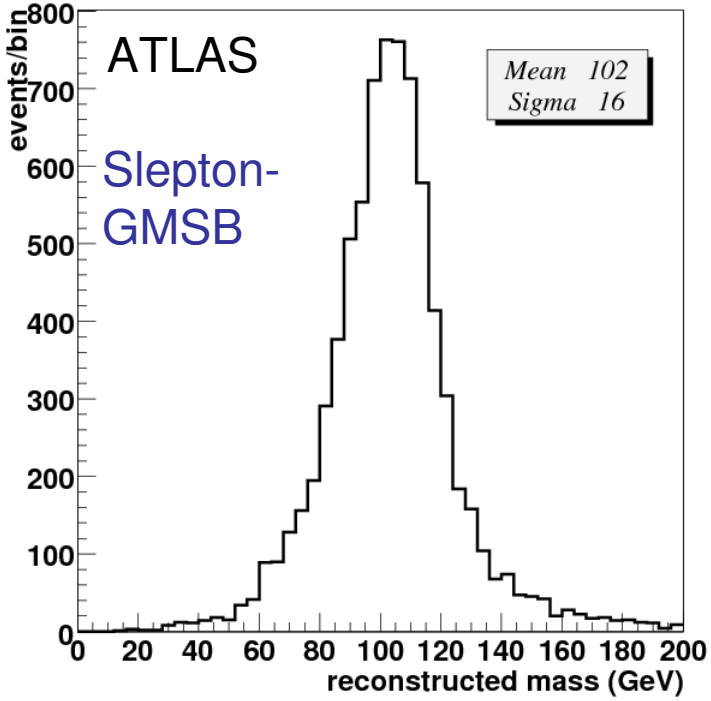
Reconstructed mass

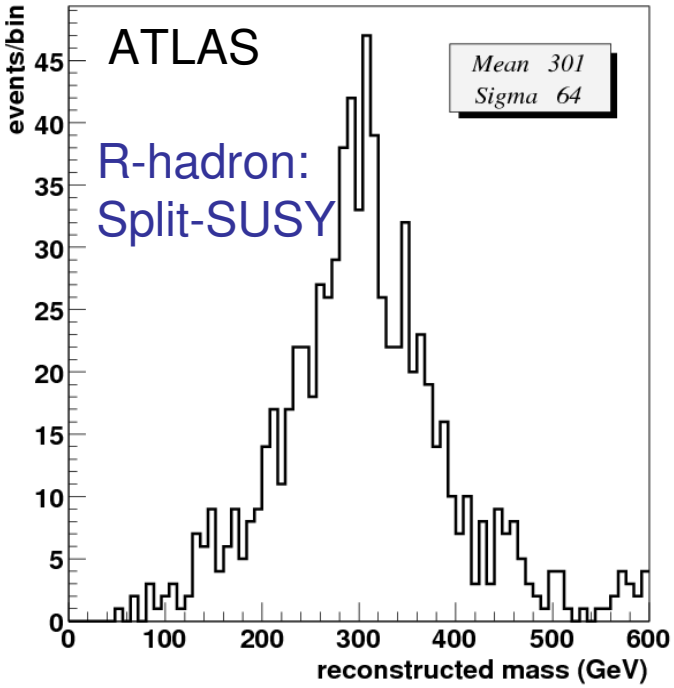


β from RPC, and MDT track fit

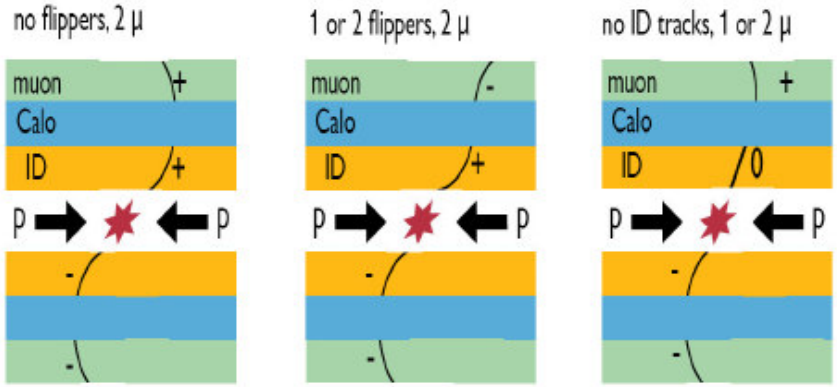
EPJC62 (2009), 281



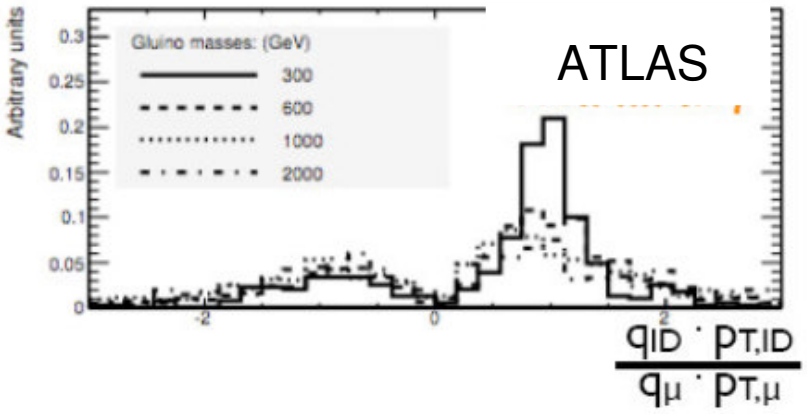




R-hadron selections



Cuts
One hard muon track with no inner tracking link.
Two back-to-back ID tracks with TRT hits satisfying high threshold/low threshold < 0.05
Two back-to-back like-sign muons
At least one hard muon track with hard matching inner track with opposite charge



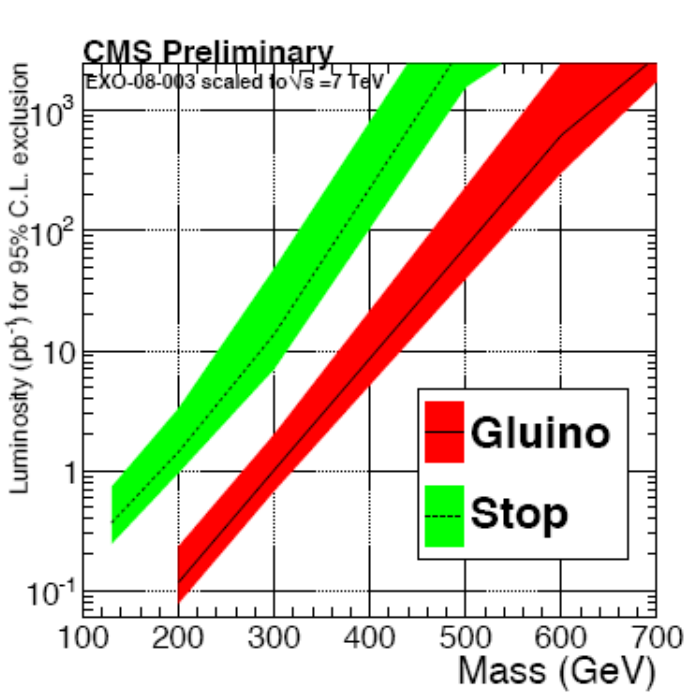
Sample	Rate (Events/fb^{-1})
300 GeV gluino	6.44×10^3
600 GeV guino	2.70×10^3
1000 GeV guino	10.7
1300 GeV guino	1.20
1600 GeV guino	0.147
2000 GeV guino	1.26×10^{-2}
300 GeV stop	70.0
600 GeV stop	3.9
1000 GeV stop	0.1
J5	0.893
J8	2.26×10^{-3}
$Z \rightarrow \mu\mu$	0.776

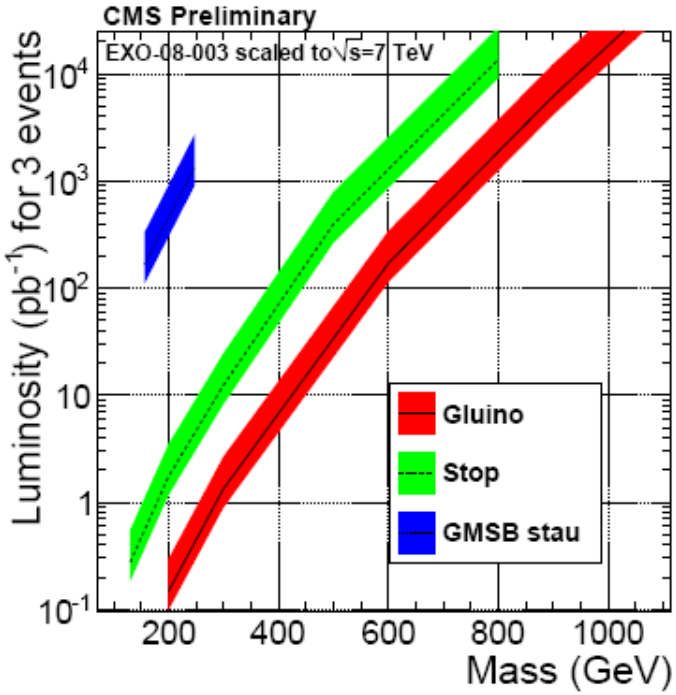
ATLAS arXiv:0901.0512

CERN-OPEN-2008-020

Discovery potential

CMS NOTE-2010/008

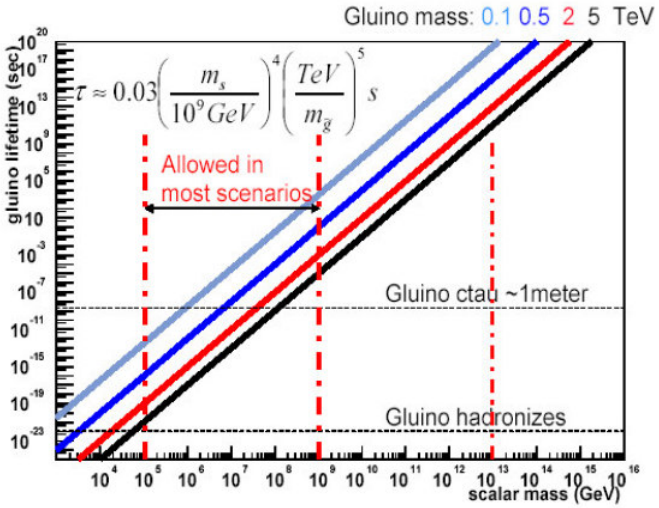


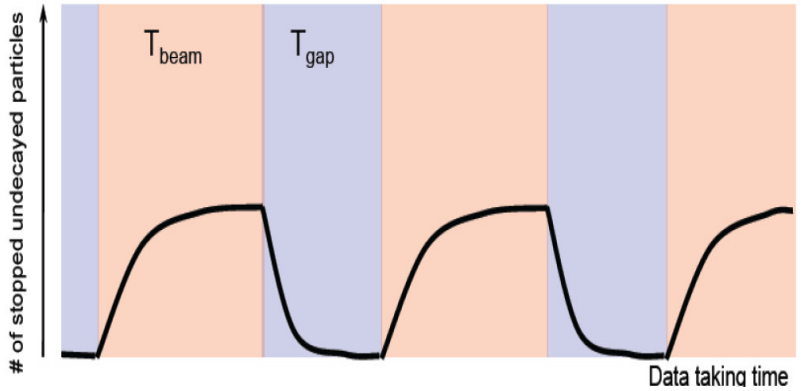


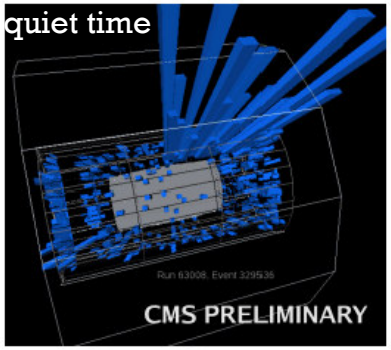
7 TeV centre-of-mass energy
Early discovery possible for low mass SMPs.

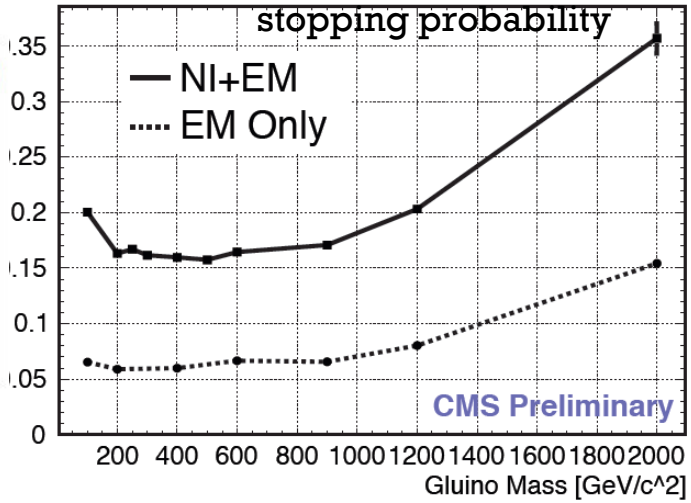
Stopped gluinos

Long-lived gluinos in Split-supersymmetry.
Tag them in no-beam intervals : beam gaps and interfill periods





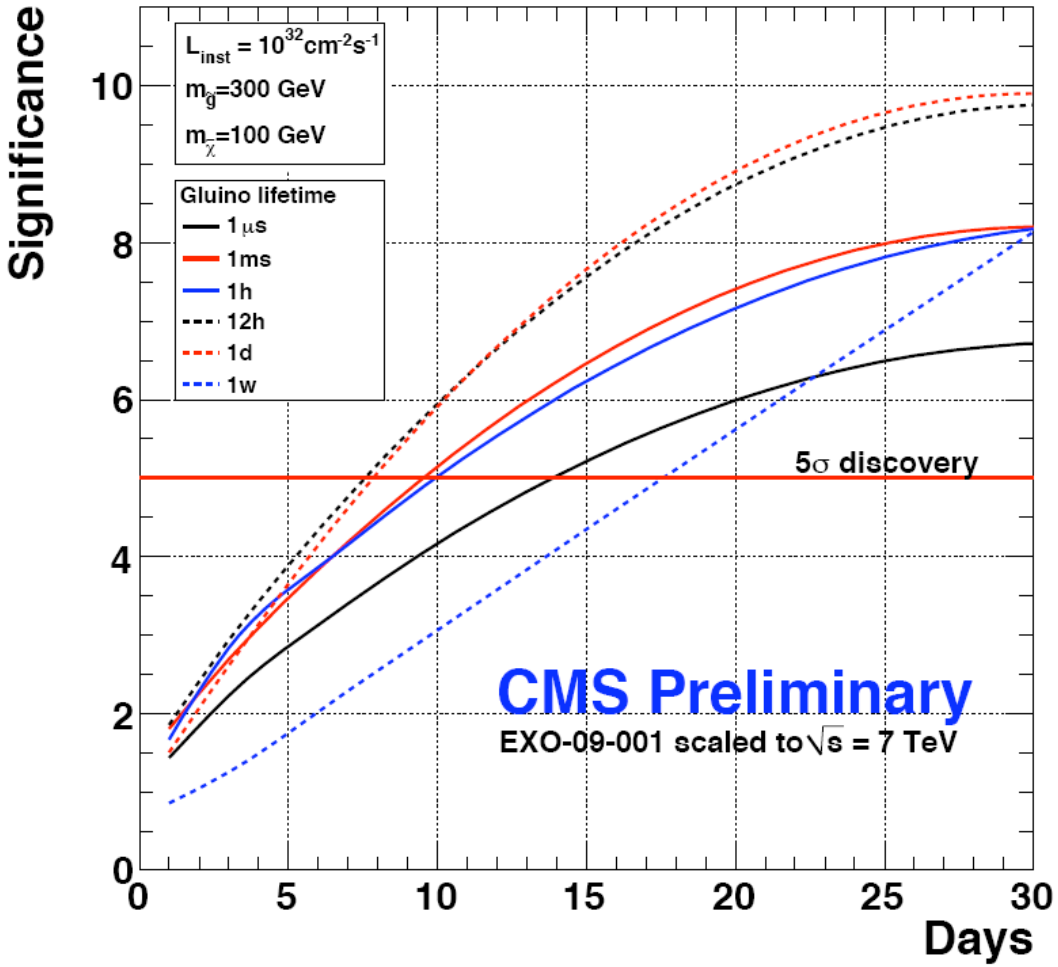




Selection	BG rate	Efficiency
Trigger	5Hz	31%
50 GeV jet	0.02 Hz	20%
Muon veto	0.005 Hz	19%
Cleaning cuts	0.4 mHz	16%

CMS PAS EXO-09-001

Stopped gluino – discovery potential



300 GeV stopped gluino
$L=10^{32} cm^{-2} s^{-1}$
Possible discovery within 30 days.

Uncertainties due to gluino production model and scattering effects.

Summary

- Dedicated program of searches for physics beyond the Standard Model at ATLAS and CMS
- Range of observables
  - Inclusive MET-based searches
  - Resonance
  - Searches for long-lived stable and decaying particles.