SUSY @ CMS PTDR for the Flavor in the Era of LHC Worshop

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CERN-PH

October 9, 2006

Outline

Introduction

Comments pertaining to this workshop

Search, Discovery & Characterization

Canonical SUSY program as a function of luminosity
Interplay of inclusive and exclusive measurements
Results from inclusive measurements
Reconstruction
Prospects for Dark Matter

Preparation For First Data

From Detector Projects and Pieces to Physics Data
History

Outline

Comments pertaining to this workshop

This talk

is a downsized version of the SUSY at LHC talk in “Physics at LHC” 2006, Krakow, contains highlights of the CMS PTDR II SUSY analyses

Models according to how they affect flavor physics

- Constrained Minimal Flavor Violating [CMFV], e.g mSUGRA with low or moderate tan β, UEDs. the only source of quark flavor violation is the CMK
- Minimal Flavor Violation [MFV], same as CMFV with some new relevant operators that contribute to flavor transitions, e.g SUSY models with large tan β
- Next-to-MVF, new operators involving third generation quarks. they help solve problems in little Higgs, topcolor and RS models
- General Flavor Violation, e.g. most of MSSM before you worry about flavor contraints

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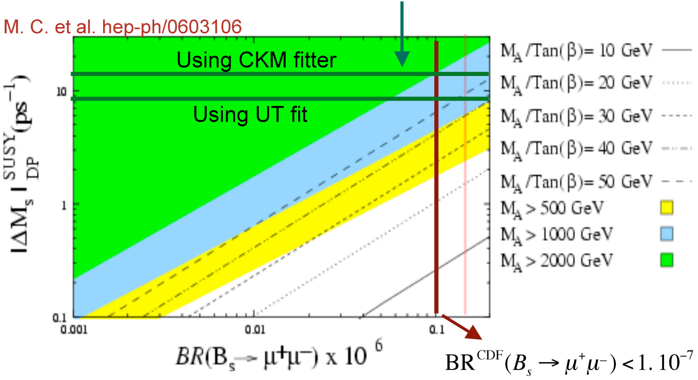
CMS PTDR framework

CMVF[mSUGRA], all results with detailed Geant-4 based CMS simulation - N.B. In the context of this workshop and in collaboration with the theory people we try to also move towards MVF e.g. Example tomorrow at WG2 Michael Schmitt, Rick Cavanaugh, Oliver Buchmüller.

Comments pertaining to this workshop

on the constraints front

M. C. et al. hep-ph/0603106



MVF SUSY models outside of the thick solid lines are excluded.

Comments pertaining to this workshop

measurements/theory data assisted calculations

- slightly high SM value for ΔM_s [used to be lower]
- slightly high SM value for BR($B_u \rightarrow \tau\nu$)
- large tan β SUSY gives negative contributions to the above in the correct ballpark [but then $B_s \rightarrow \mu\mu$ must be observed now!]
- The SM values are changing ... e.g ΔM_s used to be 18 ps^{-1} and became 21.5 ps^{-1}
- a very recent example of a new change in the theory calculation of the Br($B \rightarrow X_s\gamma$) [NNLO, hep-ph/0610067, Becher/Neubert] is showing slightly low SM calcualtion and "open a window for significant new physics contributions in rare radiative B decays", e.g charged Higgs of 500 GeV is back

Comments pertaining to this workshop

basics

Since the squarks and sleptons can have significant flavor changing vertices and be complex the connection to collider physics can be subtle indeed– but the main inplication is that the superpartners cannot be too heavy and that tan β is larger [which has no direct signature in general].

side remark

there is new tolerance in SM cosmology [e.g. Baremboim hep-ph/0608265] and the WMAP retranslated constraints are opening up the allowed space

remark

For the CMS studies of the past year we were signature driven in anticipation of first data. The analyses can be re-applied and repoptimized for SO(10) or MSSM models...Example tomorrow at WG2 Michael Schmitt, Rick Cavanaugh, Oliver Buchmüller.

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Outline

The SUSY Search Path

Discovery

Inclusive canonical searches

Characterization

Which other channels show excesses? multileptons? photons (GMSB perhaps) ? third generation particles ? spin analysis?

Reconstruction

(some) masses and decays: two LSP's in the final state $\rightarrow$ no mass peak. But kinematic endpoints (e.g. di-lepton edges) can provide masses of the particles involved.

"Measurement" of the underlying theory

We take more mass combinations, more decay chains, mass peaks once the LSP mass is known, determine the mass hierarchies, spins, &tc model parameters. How many simple measurements do we need to "nail" the theory?

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The SUSY Search Path

Inclusive

Inclusive canonical searches : large jet multiplicity, isolated leptons, large missing energy $\longrightarrow$ counting, identifying an excess.

Exclusive

specific decay processes $\longrightarrow$ [modulo reasonable assumptions] measure object combination of invariant masses and determine susy masses and parameters.

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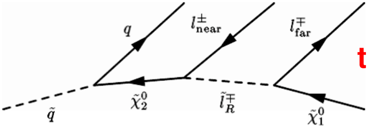

traps and pitfalls?

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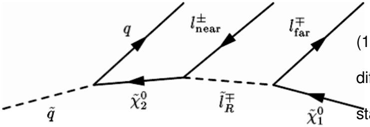

(1) is decay open? (2) kinematic edges are sensitive to mass differences (3) what other decay chains have the same final state [as the data analysis selection is designed for]? could be higher mass neutralinos or left-hand sleptons involved...

Attempts to Map Measurements to the Parameter Space

Inclusive+Exclusive

Inclusive [counting/cross section] and exclusive [end-point type] of measurements $\longrightarrow$ a-posteriori probabilities of mapping back to the parameter space (*cf* references last slide and "Olympics" series)

Attempts to Map Measurements to the Parameter Space

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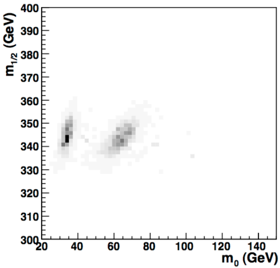
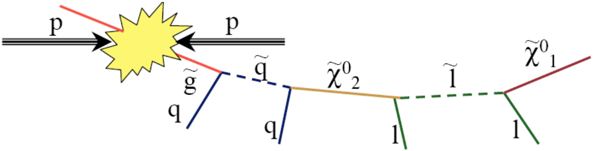
Example



[3] a-posteriori probability distribution of mSUGRA parameters using cross-section + end-point measurements in a Markov Chain Monte Carlo sampling of the parameter space. The two regions reflect the lack of knowledge of which slepton is involved in the decay chain.

Discovery: Inclusive Signatures



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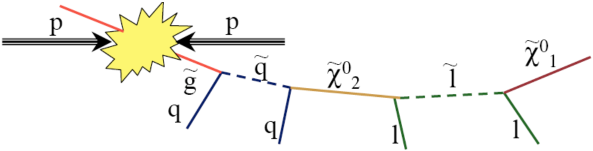
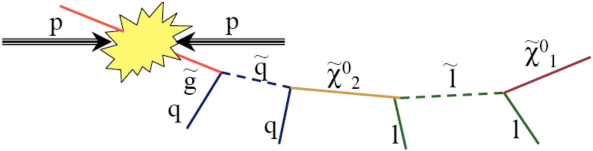


squarks and gluinos dominate production

Discovery: Inclusive Signatures



Example

- long decay chains possible
- many high P_T objects: leptons, jets, b-jets ...
- $R-$parity conservation $\longrightarrow$ LSP stable and weakly interacting $\longrightarrow$ large missing energy

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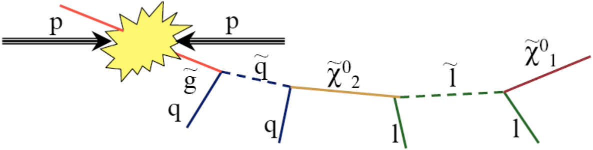
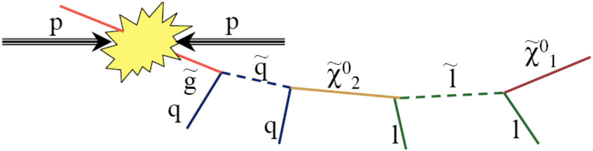


The closest SM process is $t \to Wb$

Discovery: Inclusive Signatures



Example

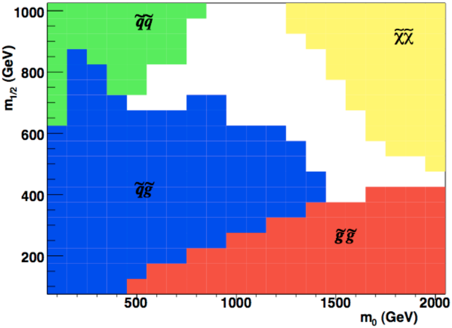
- assuming 600 GeV gluino and MSSM-like SUSY:
- large cross-section [QCD couplings] and coloured particles in the final state (jets)
- Majorana new particles $\longrightarrow$ excess of same-sign lepton pairs
- decay of neutral particle into two particles with lepton quantum numbers $\longrightarrow$ excess of opposite-sign same-flavor lepton pairs

Inclusive Signatures CMS PTDR2:LCHCC-2006/021

- canonical inclusive
  - jets+ E_T^{miss} (*)includes strategies for beam halo/noise, first data
  - jets+ μ+ E_T^{miss}
  - same-sign dimuon
  - opposite-sign same flavor dielectron and dimuon
  - opposite-sign same flavor hadronic ditau
  - trileptons at high m_0
- higher reco object inclusive
  - Z + E_T^{miss}
  - t hadronic + E_T^{miss}
  - $h^0(b\bar{b})$ + E_T^{miss} (*) includes strategies for decay chain separation aka "hemispheres"
- flavor violating
  - opposite-sign different flavor $e\mu$ for FV neutralino decays [next talk]

SUSY maps

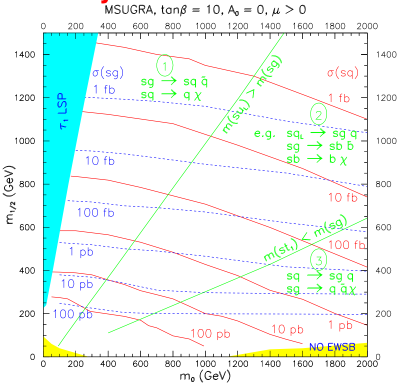
production



- major production mechanisms in parameter space

SUSY maps

decays



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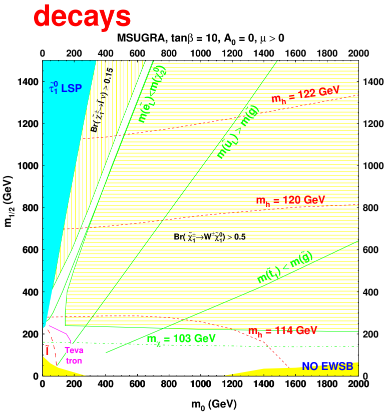

- major decays in parameter space

SUSY maps

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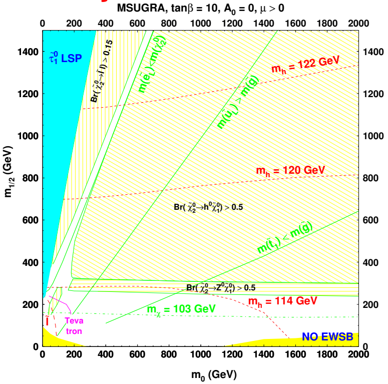

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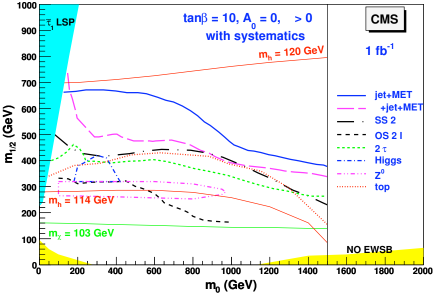
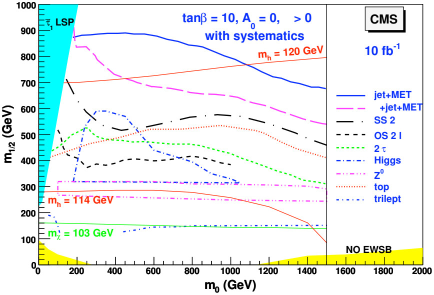
Inclusive Signatures CMS PTDR2:LCHCC-2006/021

Discovery map including background systematics





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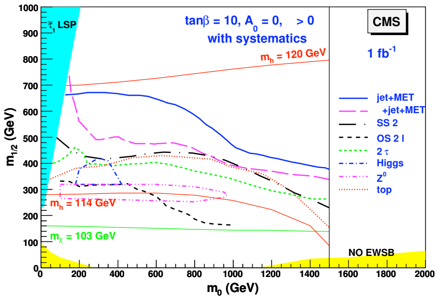
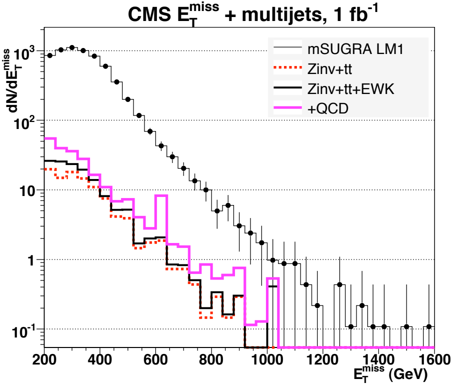


- interplay of signatures in the parameter space
- including excess of t's, τ's, b's, Z's and W's
- for fast orientation need to understand very fast and very well lepton efficiencies and E_T^{miss} tails

Inclusive Signatures CMS PTDR2:LCHCC-2006/021

E_T^{miss} +jets, $m_0 = 60$, $m_{1/2}$ = 250, A_0 = 0, $\tan(\beta)$ = 10, $sgn(\mu)$ = +1 [CMS LM1 test-point]

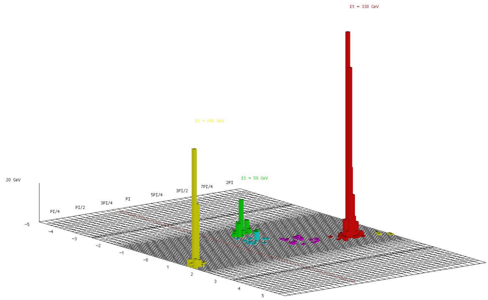


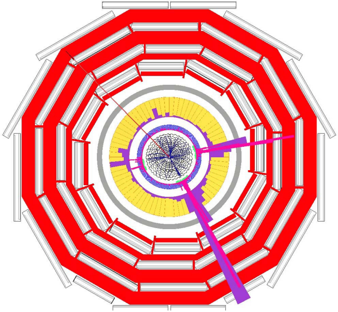
- fast-track to discovery of low mass SUSY $\mathcal{O}(10)$ pb^{-1} b/c of signal cross section – control of systematics using SM processes (e.g. Z+jets, top)
- BUT $\sim$ fb^{-1} needed to reliably do this: the time between $\mathcal{O}(10)$ and $\mathcal{O}(100)$ pb^{-1} of well understood data will be critical for the discovery and characterization of SUSY

Inclusive Signatures CMS PTDR2:LCHCC-2006/021

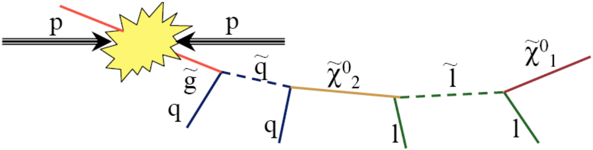
E_T^{miss} +jets candidate event display

E_T^{miss}=360 GeV, $E_T(1)$=330 GeV, $E_T(2)$=140 GeV, $E_T(3)$=60 GeV





First Mass Clues (dileptons)



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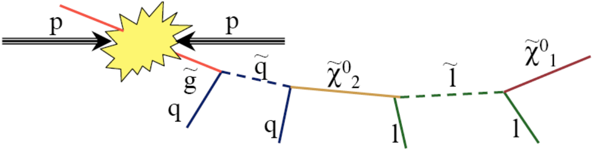
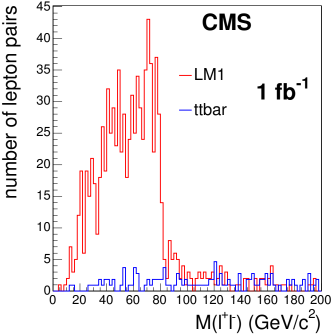
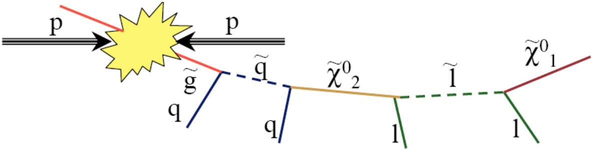
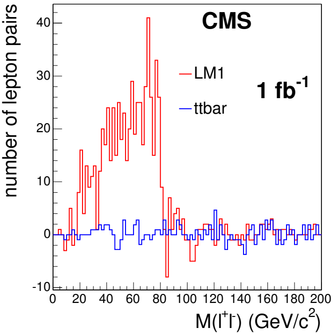




- SFOS dilepton+jets+E_T^{miss}
- $t\bar{t}$:WW+j:Z+j:other$\sim$ 6:1:1:1
- flavor subtraction ($e^-\mu^+ + e^+\mu^-$) to supress chargino, W, $t\bar{t}$, WW, "other"
- L1+HLT trigger path required
- overall systematic on the background 20% (JES dominated)
- 5σ discovery with $\sim$ 20 pb^{-1} (of data understood as expected with 1 fb^{-1}).

First Mass Clues (dileptons)





- $M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1 - \frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1 - \frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\ell}_R)}}$
- $M_{\ell\ell}^{max}$(meas)= 80.42 ± 0.48 GeV/c^2, *cfr* with
- expected $M_{\ell\ell}^{max}$= 81 GeV/c^2 [given $M(\tilde{\chi}_1^0)$ = 95, $M(\tilde{\chi}_2^0)$= 180 and $M(\tilde{\ell}_R)$ = 119 GeV/c^2]

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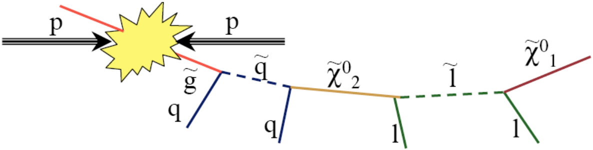
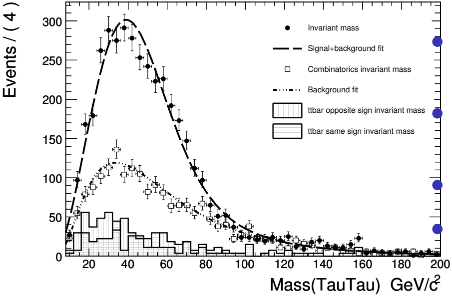
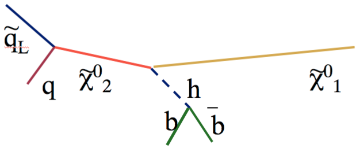




- $m_0 = 185$, $m_{1/2} = 350$,$A_0 = 0$, $\tan(\beta) = 35$ $sgn(\mu) = +1$ [CMS LM2 test-point]
- selection uses 1-prong/3-prong OS hadronic τ, two jets, E_T^{miss}
- $M_{\tau\tau}^{max}$(meas) 95±5 with 40 fb^{-1}
- difficult due to (soft) τ decays and energy scale

First Mass Clues ($b\bar{b}$)



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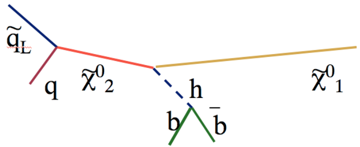

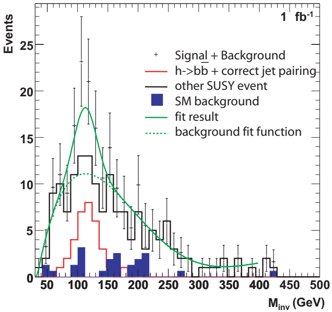

- $b\bar{b}$ width to be extracted from SM control processes
- 5σ excess with 1.5 fb^{-1}
- background here 5th order polynomial, signal Gaussian of fixed width
- cascade chain separation using 2 axis (aka "hemisphere")
- 2 b's required in the same hemisphere and closest in ΔR

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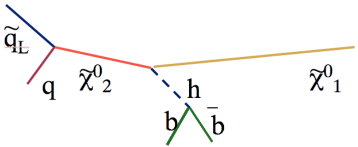

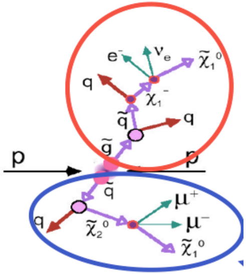

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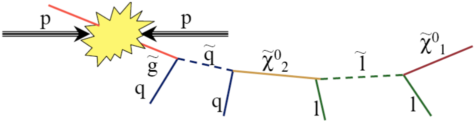
First Mass Clues (adding the jets)



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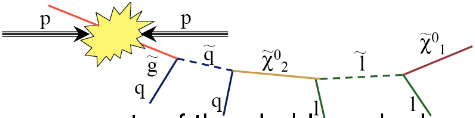
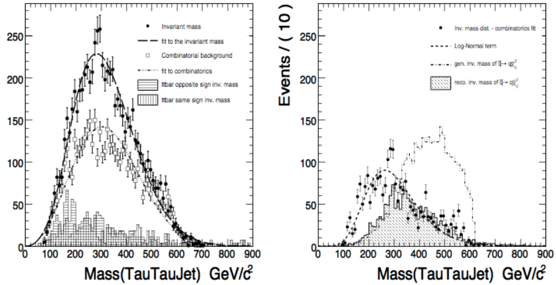


Combine measurements of thresholds and edges from different jet/lepton mass combinations to obtain mass measurements:



CMS PTDR [1]

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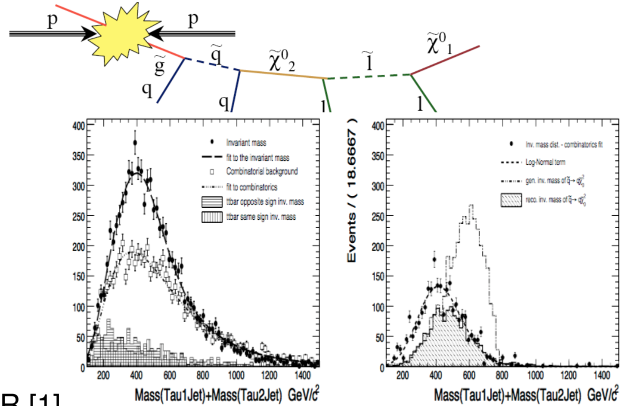

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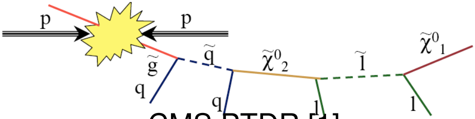
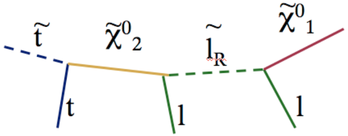


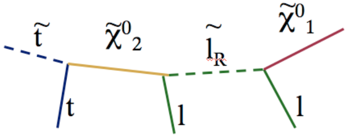
CMS PTDR [1]

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

stop: inclusive top excess



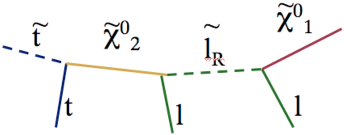
stop: inclusive top excess

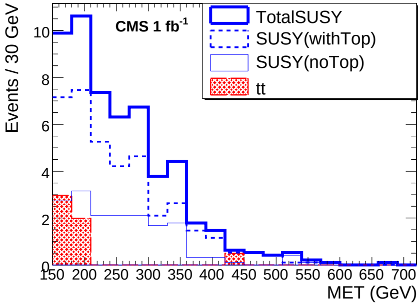


$\tilde{t}$ sources (LM1)

$Mother \rightarrow Daughters$	B.R(%)	$Mother \rightarrow Daughters$	B.R(%)
$\tilde{g} \rightarrow \bar{t} + \tilde{t}_1$	6.16	$\tilde{g} \rightarrow \bar{b} + \tilde{b}_1$	18.09
$\tilde{g} \rightarrow \bar{b} + \tilde{b}_2$	12.67	$\tilde{t}_2 \rightarrow Z^0 + \tilde{t}_1$	12.17
$\tilde{t}_2 \rightarrow h_0 + \tilde{t}_1$	2.62	$\tilde{b}_2 \rightarrow W^- + \tilde{t}_1$	16.33
$\tilde{b}_1 \rightarrow W^- + \tilde{t}_1$	6.64	$\tilde{t}_1 \rightarrow \chi_2^0 + t$	12.53
$\tilde{t}_1 \rightarrow \chi_1^0 + t$	17.70	$\tilde{t}_2 \rightarrow \chi_{all}^0 + t$	40.58
$\tilde{b}_1 \rightarrow \chi_1^+ + t$	48.36	$\tilde{b}_2 \rightarrow \chi_1^+ + t$	23.85

stop: inclusive top excess

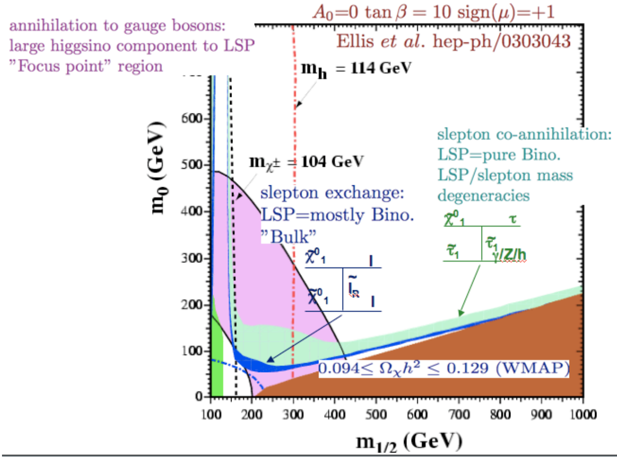




- excess of reconstructed hadronic top
- $m(jj)$ consistent with W mass and $m(jjb)$ consistent with top mass
- 2C kinematic fit
- additional b's can be used to start reconstruction
- excess of t's in LM1 used inclusively

Dark Matter

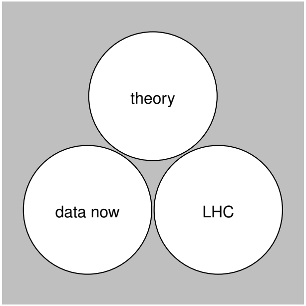
use extracted model parameters to estimate LSP DM properties (using Micromegas [8], DarkSUSY[9])



Case study

co-annihilation signatures

- m_0=70 $m_{1/2}$=350 A_0=0 tan β=10, sgn(μ)=+1
- $\chi_2^0 \longrightarrow \ell\tilde{\ell}_{L,R} \longrightarrow \ell\ell\chi_1^0 \longrightarrow$ double dilepton invariant mass edge
- small slepton-neutralino mass difference $\rightarrow$ one soft lepton
- large E_T^{miss}, 1 hard jet, dileptons (with flavor subtraction OSSF-OSOF)
- measure edges/thresholds in $q\ell\ell$, $q\ell$

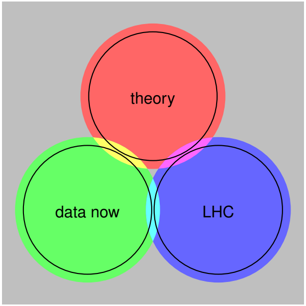


knowledge,ignorance,enlightenment and temptation

- we know something about dark/B matter
- we think we know something about SUSY
- we think we will measure it at the LHC

Note

Efforts to put all what we know, what we think we know and what we know we don't know, into one coherent picture: tough without the LHC data in hand but preparative value is huge.



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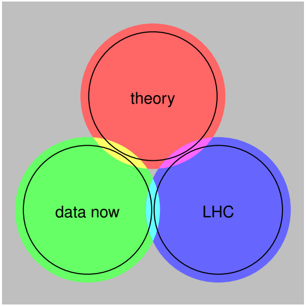

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Outline

Integration-Commissioning-Start-up Physics

test beams/cosmics/single beam/collisions

Definition (commissioning & physics)

test beams-cosmics-one beam-collisions:

1. commissioning data (alignment/calibration/synchronization)
2. commissioning data (trigger)
3. physics data
4. first analyses

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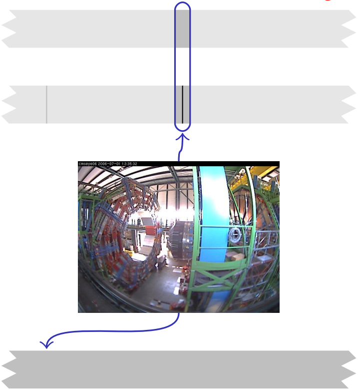

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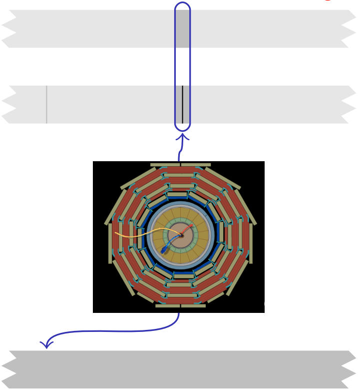

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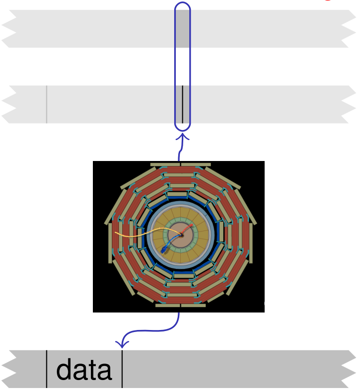

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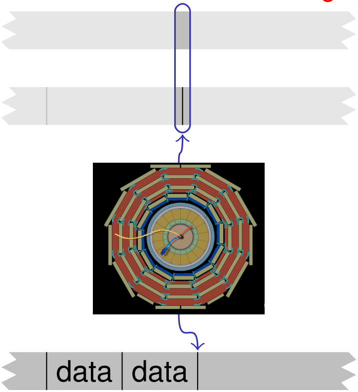

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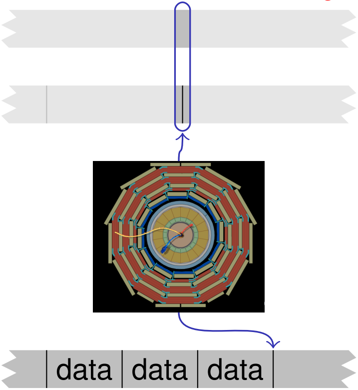

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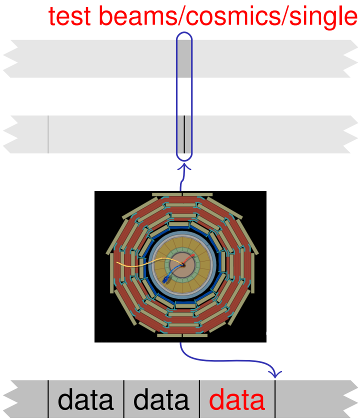

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Comparative History:First Papers from CDF

Minimum Bias

- P_T of charged particles 1988
- η distribution of charged particles 1990
- K_s production 1990

Jets

- Dijet angular distribution 1989
- Inclusive jet cross section 1989
- Two-jet inv-mass distributions 1990
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First Data and SUSY

At start-up

- understand detectors and SM backgrounds
- control/understand: trigger, initial calibrations, scales, resolutions, efficiencies...
- minimize poorly estimated standard model backgrounds
- use SM "candle"/control samples (W/Z/top) to estimate backgrounds as possible (this afternoon)
- adapt methods for background extraction as a function of luminosity
- have in place MC tools

First Data and SUSY

General Stategy

- Choose signatures identifying well defined decay chains
- Extract constraints on masses, couplings, spin from decay kinematics/rates (especially for spin, need clever ideas!)
- try to match emerging pattern to tentative template models
- having adjusted template models to measurements, try to find additional signatures to discriminate different options

- CMS PTDR, LHCC-2006-021
- ATLAS PTDR, LHCC-1999-015
- Lester *et al.* hep-ph/0508143 JHEP01,080 (2006)
- A.J.Barr, JHEP02, 042 (2006),hep-ph/0511115
- M.M. Nojiri, G. Polesello, D.R. Tovey JHEP03,063 (2006) hep-ph/0512204
- Allanach et al hep-ph/0507283
- Baltz et al hep-ph/0602187
- Belanger *et. al* hep-ph/0405253
- Gondolo *et. al* astro-ph/0406204