LHC: from first data to SUSY

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Introduction

Focus of activity for ATLAS and CMS is to develop a strategy for making optimal use of the first data

- Complex detectors with tens of millions of channels and many different subsystems
- Ambitious performance goals driven by requirements from physics

Large amount of work (and time) required to control detector at desired level

Final understanding of detectors only with real collisions in LHC environment

Exploit time from now to collisions to achieve detector understanding adequate to fully take advantage of data from the first day

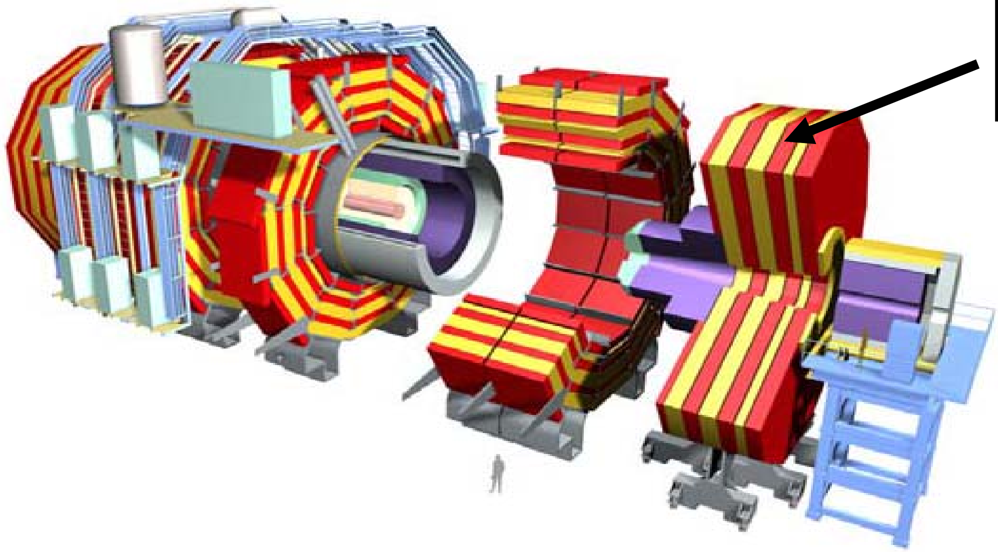
Main variables: readiness of detectors, time before LHC is running at full steam, building up of integrated luminosity

Recent announcement (from CMS mailing lists June 12)

Announced 7 June 2006 at a meeting among the 4 LHC experiments the machine, and DG

Experiments are requested to have the beam pipe in place, connected and ready by 1st September 2007 (instead of July 1st 2007).

Status of experiments at startup



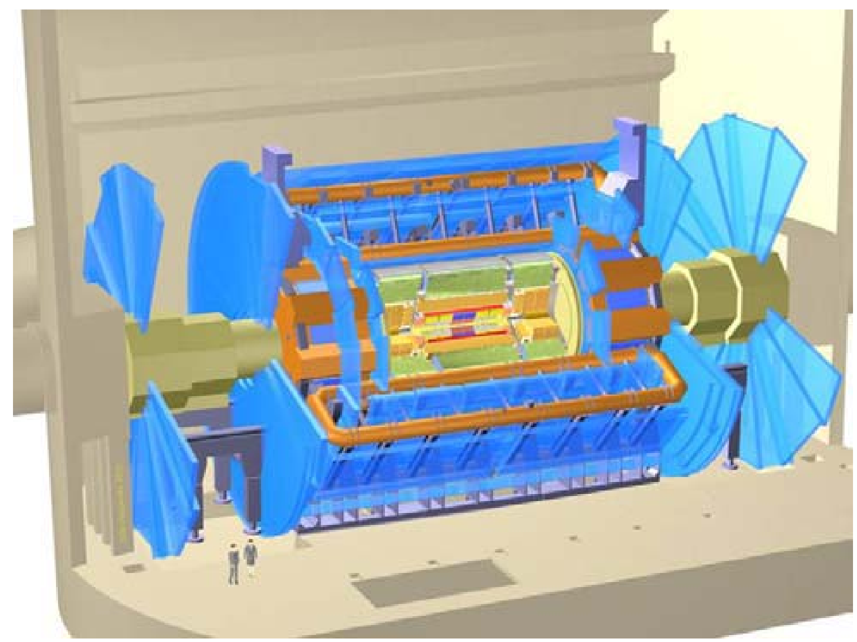
RPC over |η|<1.6 (instead of |η|< 2.1)
4th layer of end-cap chambers missing

Pixels and end-cap ECAL
installed during first shut-down

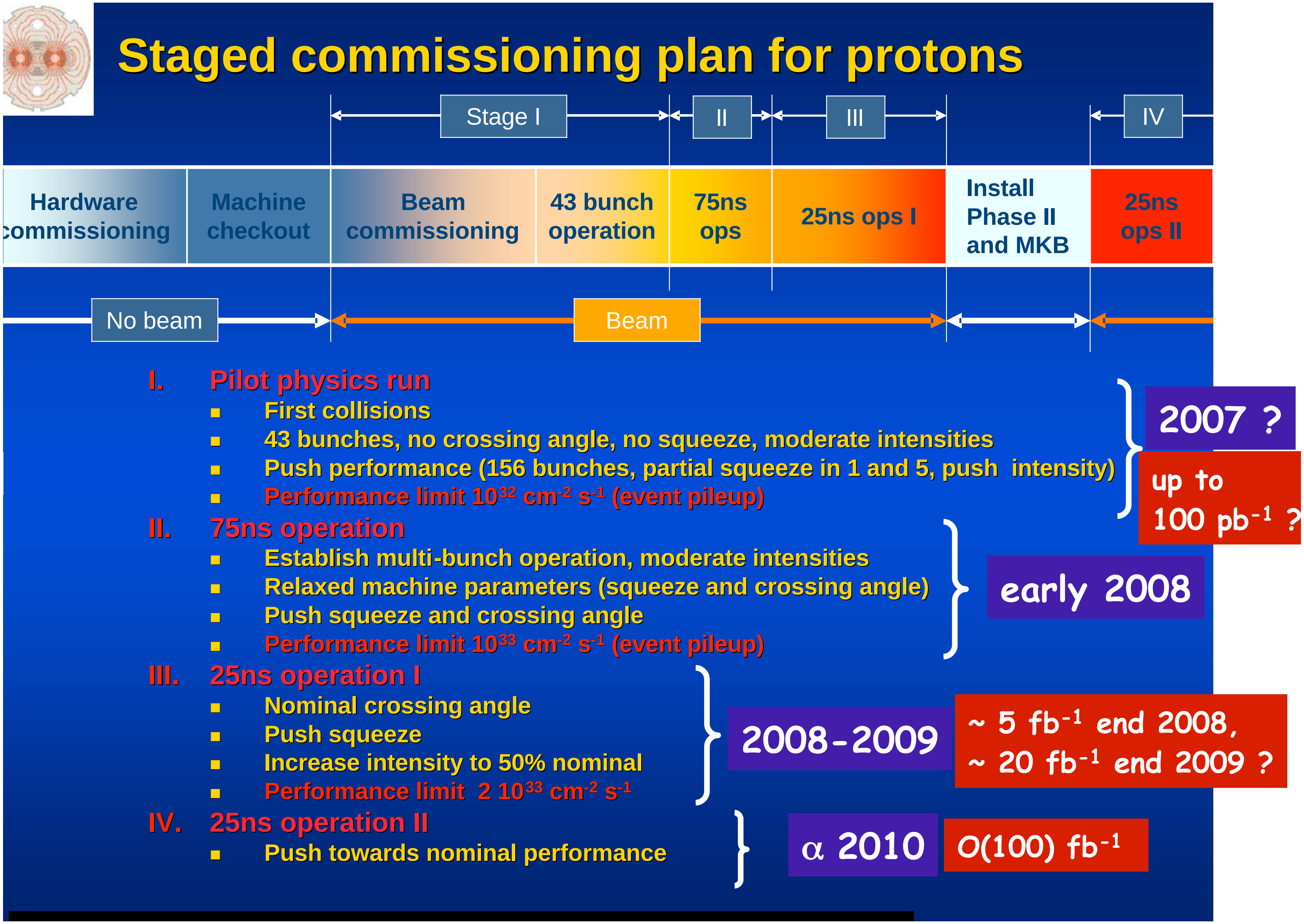
With delayed schedule of accelarator CMS will have one of End Cap in

ATLAS: because of staging TRT coverage over $|\eta| > 2.0$ instead of $|\eta| > 2.4$

For both detectors: reduced trigger bandwidth due to deferrals on HLT processors



Possible scenario for machine startup (machine presentation)

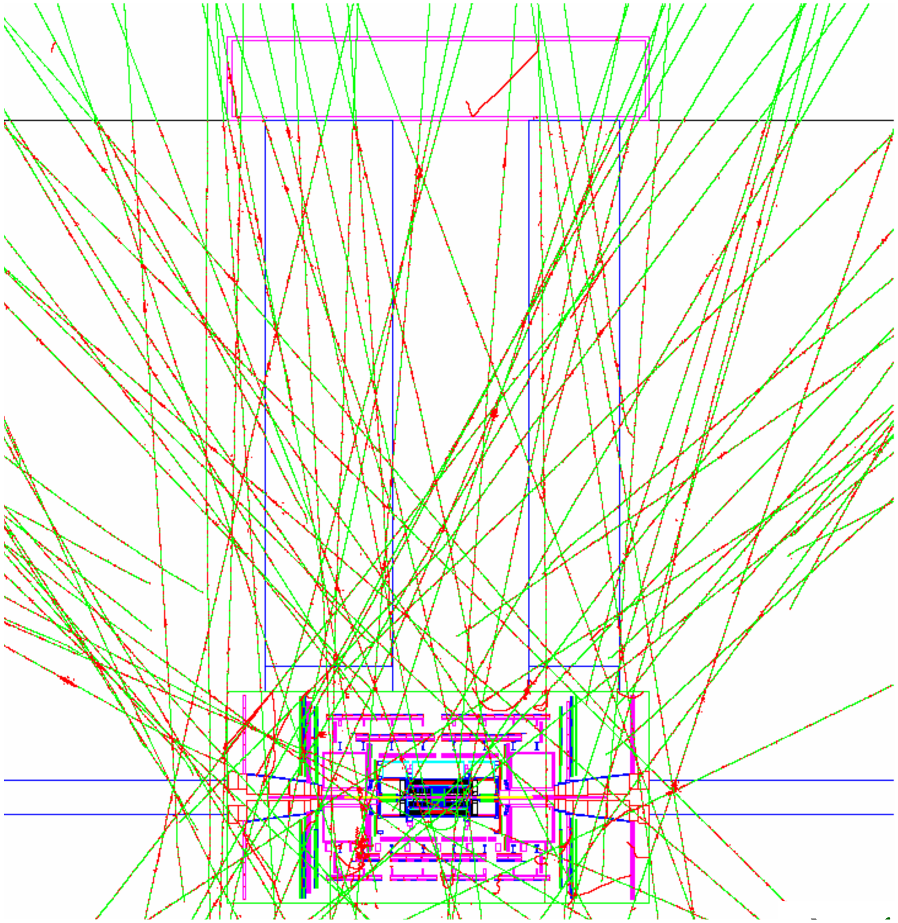


Integrated luminosities and dates: guesses by F. Gianotti

Based on this information develop start-up strategy

- Last few years: extensive test-beam activities with final detector components to achieve basic calibration. Notably: ATLAS combined test-beam of full slice of detector/CMS magnet and cosmics test challenge
- Now, extending up to most of 2007: Cosmics data taking. Detector timing and alignment
- From first injections: beam-halo and beam-gas interactions. More specialised alignment work
- First interactions:
  - Understand and calibrate detector and trigger in situ using well-known physics samples:
    - $Z \to ee, \mu\mu$: tracker, ECAL, muons system
    - $tt \to b\ell\nu bjj$: Jets scale, b-tag performance, $\not{E}_T$
  - Understand basic SM physics at 14 TeV: first checks of MonteCarlo
    - jets and W, Z cross-section/ratios top mass and cross-section
    - Event features: Min. bias, jet distributions, PDF constraints
  - Prepare road to discovery: background to discovery from tt, W/Z + jets.

Cosmic running



Work already ongoing for ATLAS and CMS

Data taking with assembled detectors in the pit in early 2007

- Initial alignment of detector with particles
- Timing-in of detectors
- Debugging of sub-systems, mapping of dead channels, etc.

0.01 seconds of cosmics in ATLAS shown in figure

Expect rate of $\sim$ 5000 Hz for ATLAS and $\sim$ 1800 Hz for CMS over full detector

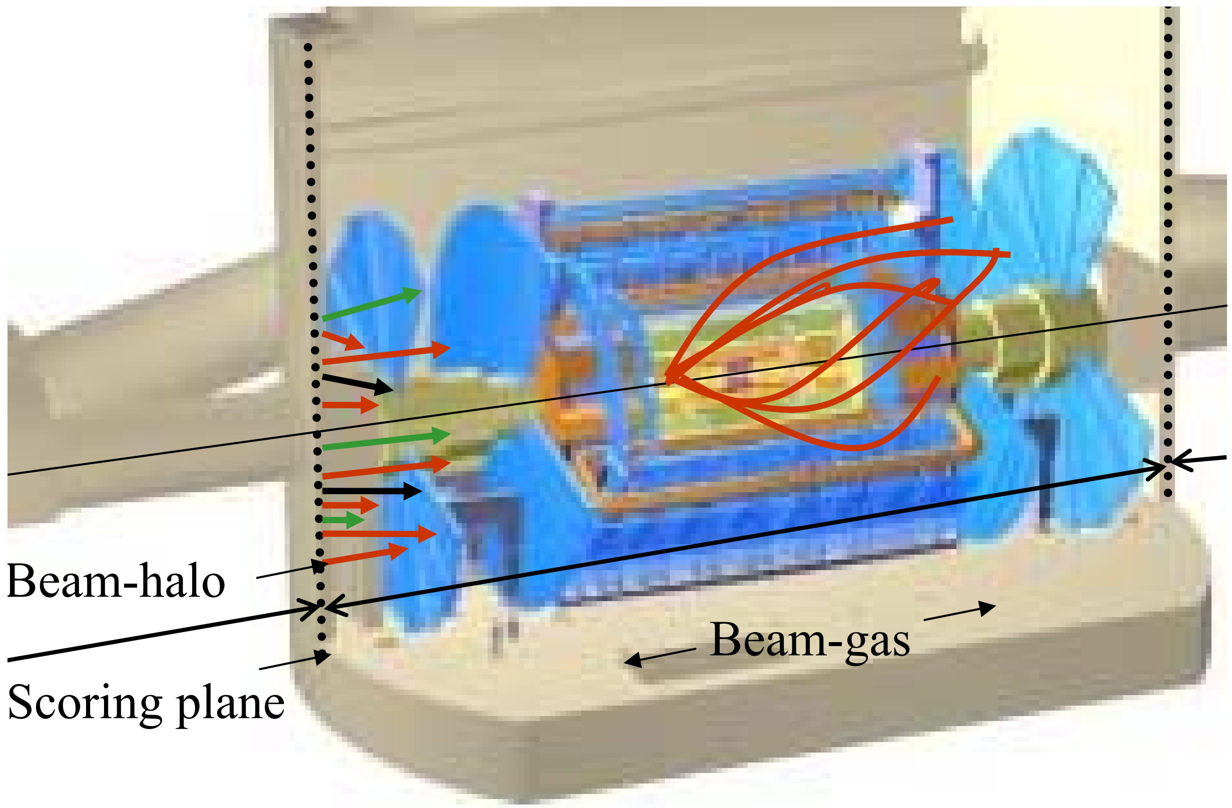
Single beam period

Beam halo:

- Low p_T muons particles from the machine
- Particles crossing the detectors parallel to the beam line: complementary to cosmics
- Use for alignment and calibration in endcap regions

Beam-gas

- Vacuum not perfect 3×10^{-8} Torr
- Proton-nucleon p(7 TeV)+p(rest)
- Resemble collision events but with soft spectrum
- Improve alignment of inner detector from survey values



Physics with early data

Realistic approach: assume low selection efficiency for interesting events

Process	$\sigma \times BR$		Events selected for 100 pb^{-1}
$W \to \ell\nu$	20 nb	$\sim 20\%$	~ 400000
$Z \to \mu\mu$	2 nb	$\sim 20\%$	~ 40000
$\bar{t}t$ (semileptonic)	370 pb	$\sim 1.5\%$	< 1000

Jets and minimum bias statistics only limited by allocated trigger bandwidth

Even from pilot run expect significant statistics from interesting physics processes

Many possible uses for early physics events:

- Calibrate/understand the detector
- Perform SM physics measurements
- Start understanding SM processes as background for new physics

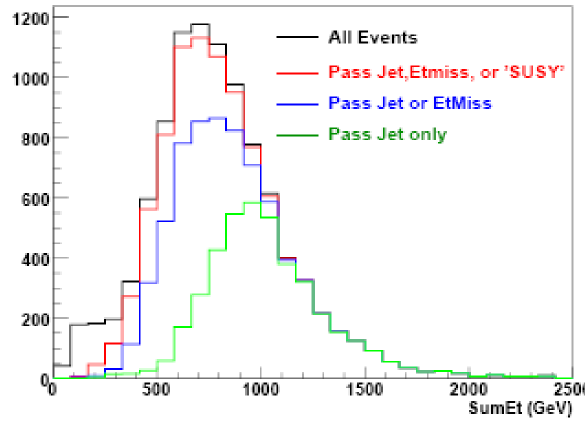
It is mandatory to demonstrate that we understand LHC physics through SM measurement before going for discovery physics

SUSY triggering. Example: efficiency for specific SUSY model

Focus on mSUGRA point with $m(\tilde{g}) \sim m(\tilde{q}) \sim 600$ GeV

Evaluate efficiency for different components of jet trigger menu

trigger	Efficiency (%)
J400	34
2J350	12
3J165	13
4J110	7
xE200	63
SUSY xE70+J70	90
Only jets	43
Jet or xE	73
Anything	92



Using only jet triggers gives low efficiency

missEt and 'SUSY' trigger do most of the job!

No lepton/tau trigger included in this study.

SUSY discovery: basic strategy

SUSY covers very broad range of phenomenologies. Try to go for simple signatures which appear in most models

Basic assumption: discovery from squark/gluinos cascading to undetectable LSP

Most important features of SUSY events used for discovery:

- $\not{E}_T$: from LSP escaping detection
- High E_T jets: variables: N_{jets}, $P_T(jet_1)$, $P_T(jet_2)$ $\Sigma_i |p_{T(i)}|$ $\Delta\phi(jet - \not{E}_T)$

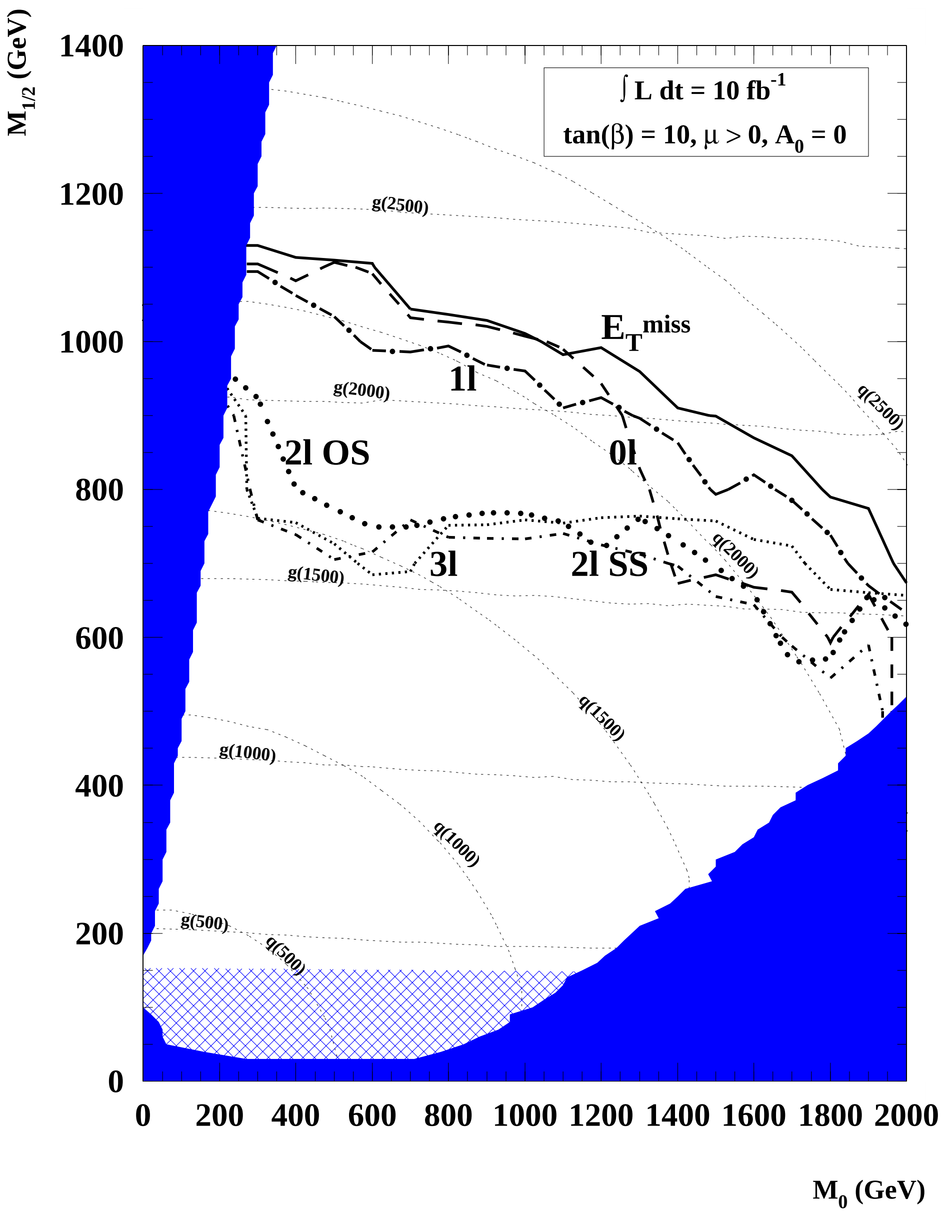
  guaranteed if unification of gaugino masses assumed, otherwise can devise degenerate models where jets are very soft. Variables:
- Spherical events: variable S_T

  From Tevatron limits squarks/gluinos must be heavy ($\gtrsim$ 400 GeV).
- Multiple leptons: from decays of Charginos/neutralinos typically present in cascade

Focus on sets of basic inclusive signatures for RPC SUSY $\tilde{\chi}_1^0$ LSP

Specialised signatures (e.g. photons and CHAMPS from GMSB) not to be neglected (trigger!!), need theory input on this

Inclusive SUSY signatures

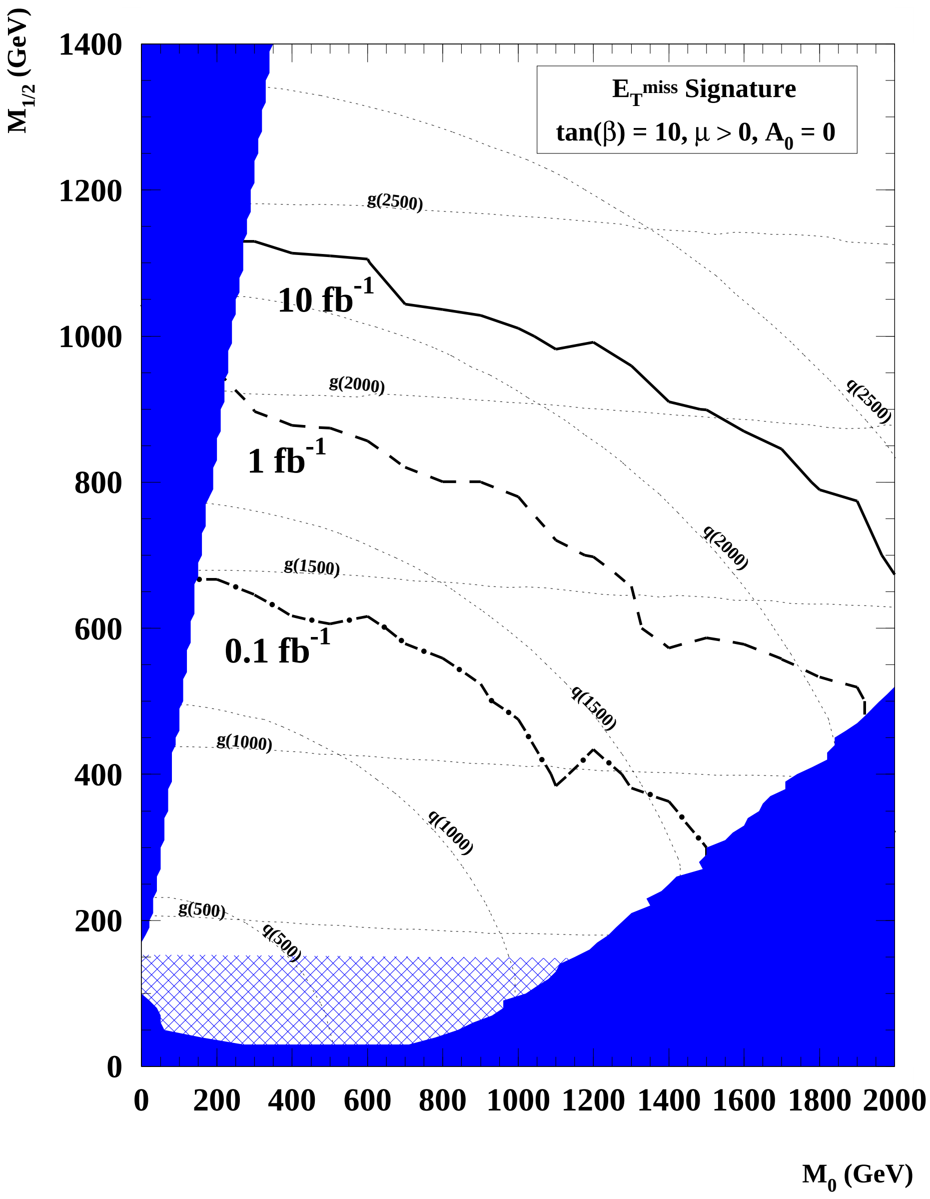


Multiple signatures on most of parameter space

- $\not{E}_T \Leftarrow$ Dominant signature
- $\not{E}_T$ with lepton veto
- One lepton
- Two leptons Same Sign (SS)
- Two leptons Opposite Sign (OS)

When first signal observed with a signature, look for it also in other channels

Discovery reach as a function of luminosity



- $\sim$1300 GeV in 100 pb^{-1}
- $\sim$1800 GeV in 1 fb^{-1}
- $\sim$2200 GeV in 10 fb^{-1}

Fast discovery from signal statistics

Time for discovery determined by:

- Time to understand detector performance ($\not\!\!E_T$ tails, lepton id, jet scale)
- Time to collect sufficient statistics of SM control samples: W, Z+jets, $\bar{t}t$

Two main background classes:

- Instrumental $\not\!\!E_T$
- Real $\not\!\!E_T$ from neutrinos

Backgrounds to $\not\!\!E_T+$ jets analysis

Instrumental $\not\!\!E_T$ from mismeasured multi-jet events:

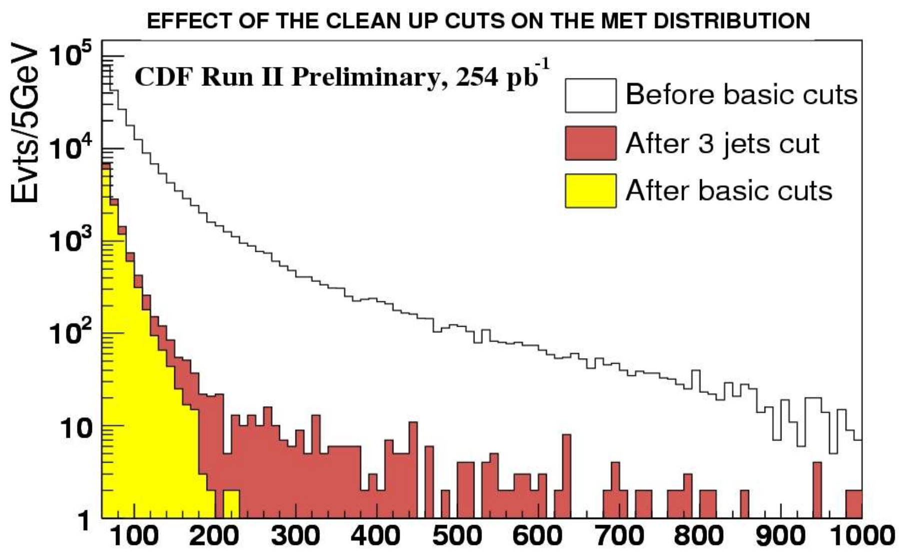
Many sources: gaps in acceptance, dead/hot cells, non-gaussian tails, etc.

Require detailed understanding of tails of detector performance.

Reject events where fake $\not\!\!E_T$ likely.

- beam-gas and machine backgrounds
- displaced vertexes
- hot cells
- $\not\!\!E_T$ pointing along jets
- jets in regions of poor response

See effect of $\not\!\!E_T$ cleaning in CDF



All detector and machine garbage will end up in $\not\!\!E_T$ trigger

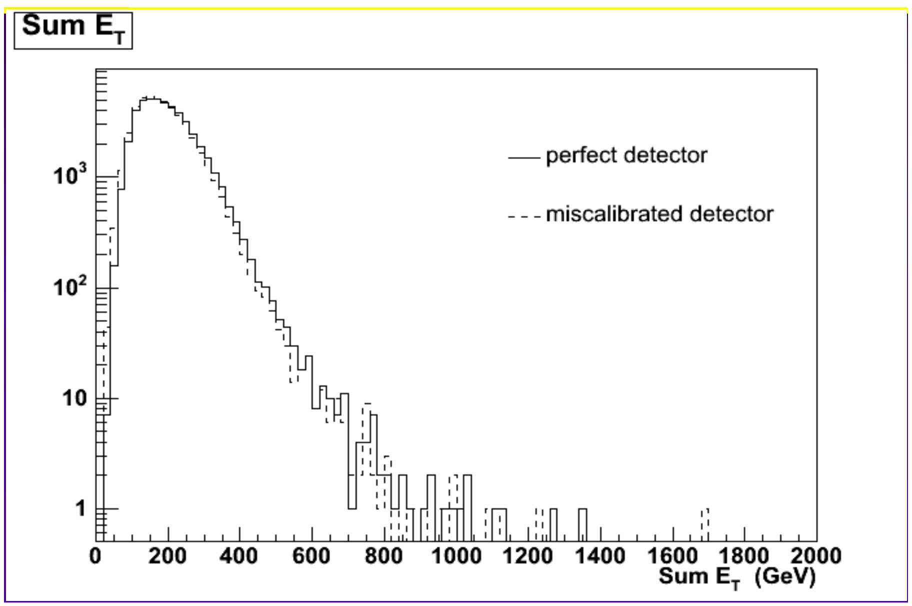
Long and painstaking work before all the sources of instrumental $\not\!\!E_T$ are correctly identified

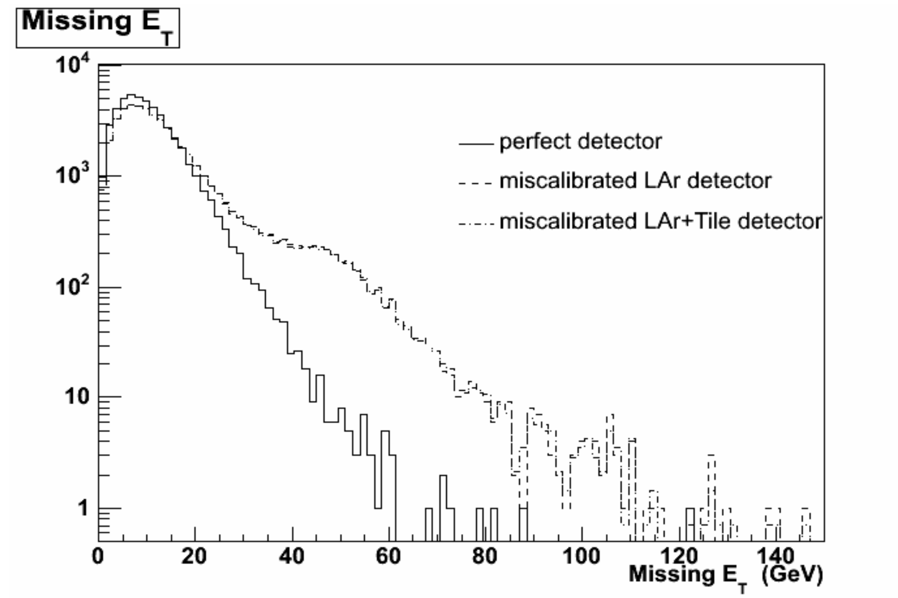
Example: effect of dead cells

Preliminary ATLAS study (R. Mc.Pherson, K. Voss)

Assume readout of a certain number of calo cells not working. Evaluate effect on $\not{E}_T$

Apply to $Z \to ee$ sample





Aim of the exercise: evaluate sensitivity of $Z \to \ell\ell$ as a diagnostic of detector imperfections affecting $\not{E}_T$ studies

Evaluate the possibility of applying event-by-event corrections

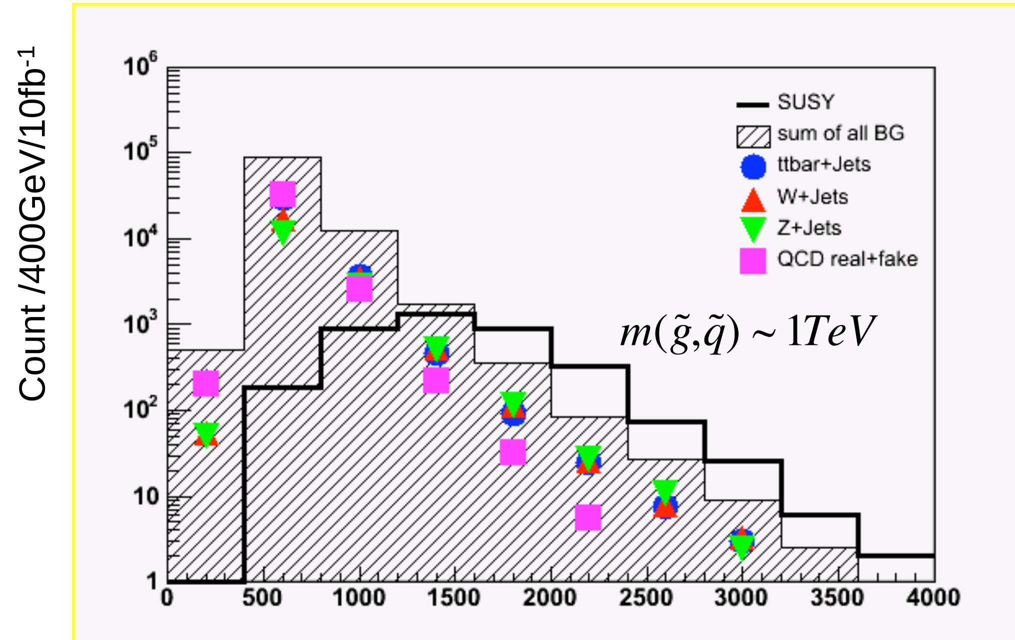
Control of $\not{E}_T$ from Standard Model processes

Real $\not{E}_T$ from ν production in SM:

SUSY selection:

- $\not{E}_T > 100$ GeV
- At least 1 jet with $p_T > 100$ GeV
- At least 4 jets with $p_T > 50$ GeV

Plot $M_{\text{eff}} = \Sigma_{i=1}^{4} |p_{T(jet_i)}| + E_T^{\text{miss}}$



Effective Mass(GeV) = mE_T + Σ P_T(4je

Comparable contributions from: • $\bar{t}t$+jets • W+jets • Z+jets

Counting experiment: need precise estimate of background processes in signal region

Complex multi-body final states: can not rely on MonteCarlo alone. Need both data and MonteCarlo

Need also SUSY generator with extra jet in. Is smadgraph enough, validated, etc.?

Example: statistics for control of $Z \to \nu\nu$+jets

Use $Z \to \ell\ell$ to model background

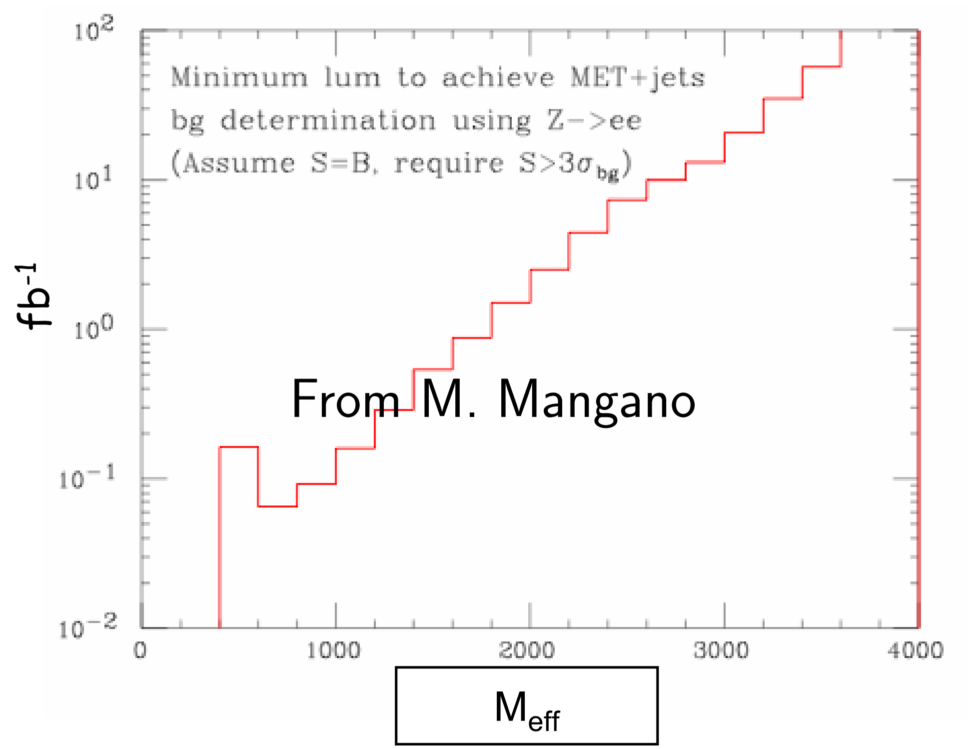
Normalisation needs to be multiplied by $BR(Z \to \nu\nu)/BR(Z \to ee) \sim 6$

Assuming SUSY signal $\sim Z \to \nu\nu$ bg, evaluate luminosity necessary for having $N_{SUSY} > 3 \times \sigma_{bg}$

Stat error on background:

$$\sigma_{bg} = \sqrt{N(Z \to ee)} \times \frac{BR(Z \to \nu\nu)}{BR(Z \to ee)}$$

For each bin where normalisation required, need ~ 10 reconstructed $Z \to \ell\ell$ events. Need to consider acceptance/efficiency factors as well



Several hundred pb^{-1} required. Sufficient if we believe in shape, and only need normalisation. Much more needed to perform bin-by-bin normalisation

What might we know after inclusive analyses?

Assume we have a MSSM-like SUSY model with $m_{\tilde{q}} \sim m_{tg} \sim 600$ GeV

Observe excesses in $\not{E}_T + jets$ inclusive, $+1$ lepton, $+2$ leptons

- Undetectable particles in the final state $\not{E}_T$
- Production of particles with mass∼600 GeV (M_{eff} study) and with couplings of ∼QCD strength (X-section)
- Some of the produced particles are coloured (jets in the final state)
- Some of the new particles are Majorana (excess of same-sign lepton pairs)
- Lepton flavour $\sim$ conserved in first two generations (same number of leptons and muons)
- Decays of neutral particle into two particles with lepton quantum numbers (excess of Opposite-Sign/Same-Flavour (OS-SF) leptons)
- ....

Some sparse pieces of a giant jigsaw puzzle. Proceed to try exclusive analyses to fill in some of the gaps

What next?

Assume an excess seen in inclusive analyses: how does one verify whether it is actually SUSY? Need to demonstrate that:

- Every particle has a superpartner
- Their spin differ by $1/2$
- Their gauge quantum numbers are the same
- Their couplings are identical
- Mass relations predicted by SUSY hold

This can only be performed through precise measurements of masses, BR, cross-sections, angular distributions

In last ten years developed a strategy for performing as many as possible of these measurements at the LHC

Measurement of model parameters

The problem is the presence of a very complex spectroscopy due to long decay chains, with crowded final states

Many concurrent signatures obscuring each other

General strategy:

- 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, SUSY or anything else
- Having adjusted template models to measurements, try to find additional signatures to discriminate different options

In order to develop this program need guidance from theory: interesting signatures defined by prejudices on models one considers good candidates for BSM physics

Need to establish a protocol for collaboration with theorists

Conclusions

ATLAS and CMS might be collecting the first LHC data towards end of next year

Focus of efforts of the two collaborations is getting ready for optimal use of these data

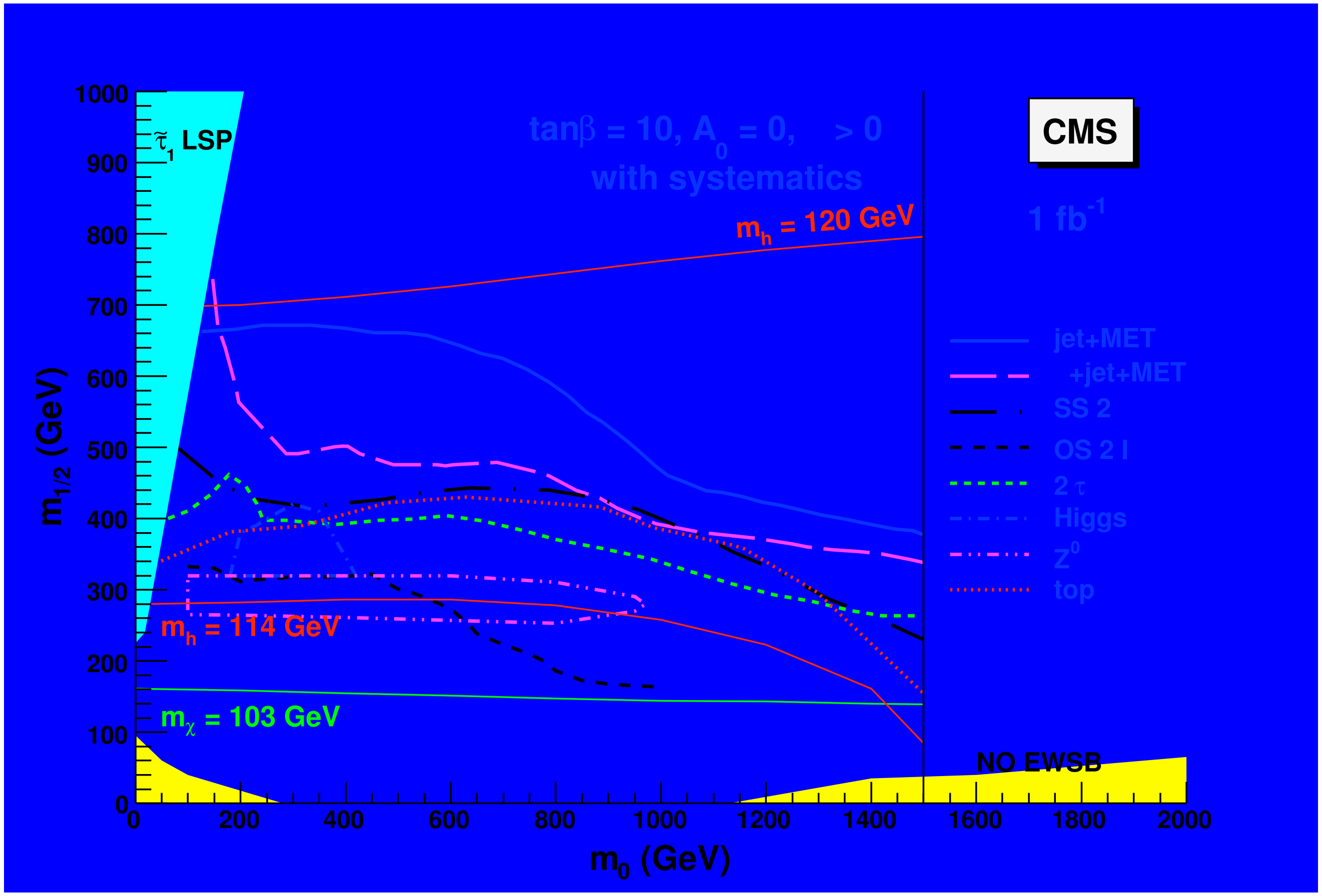
Main goals of early data taking:

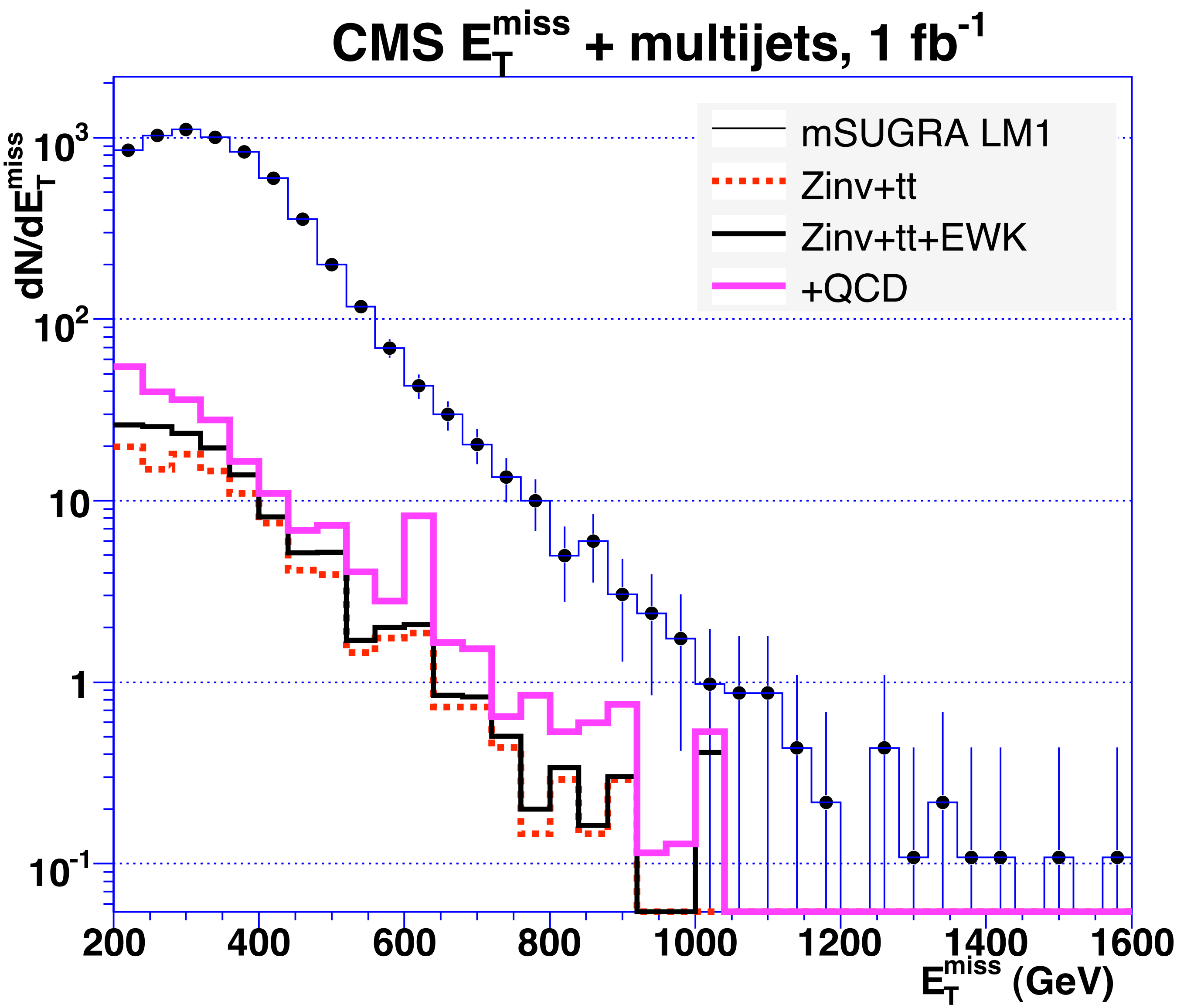
- Understanding detector
- Understanding Standard Model physics at 14 TeV

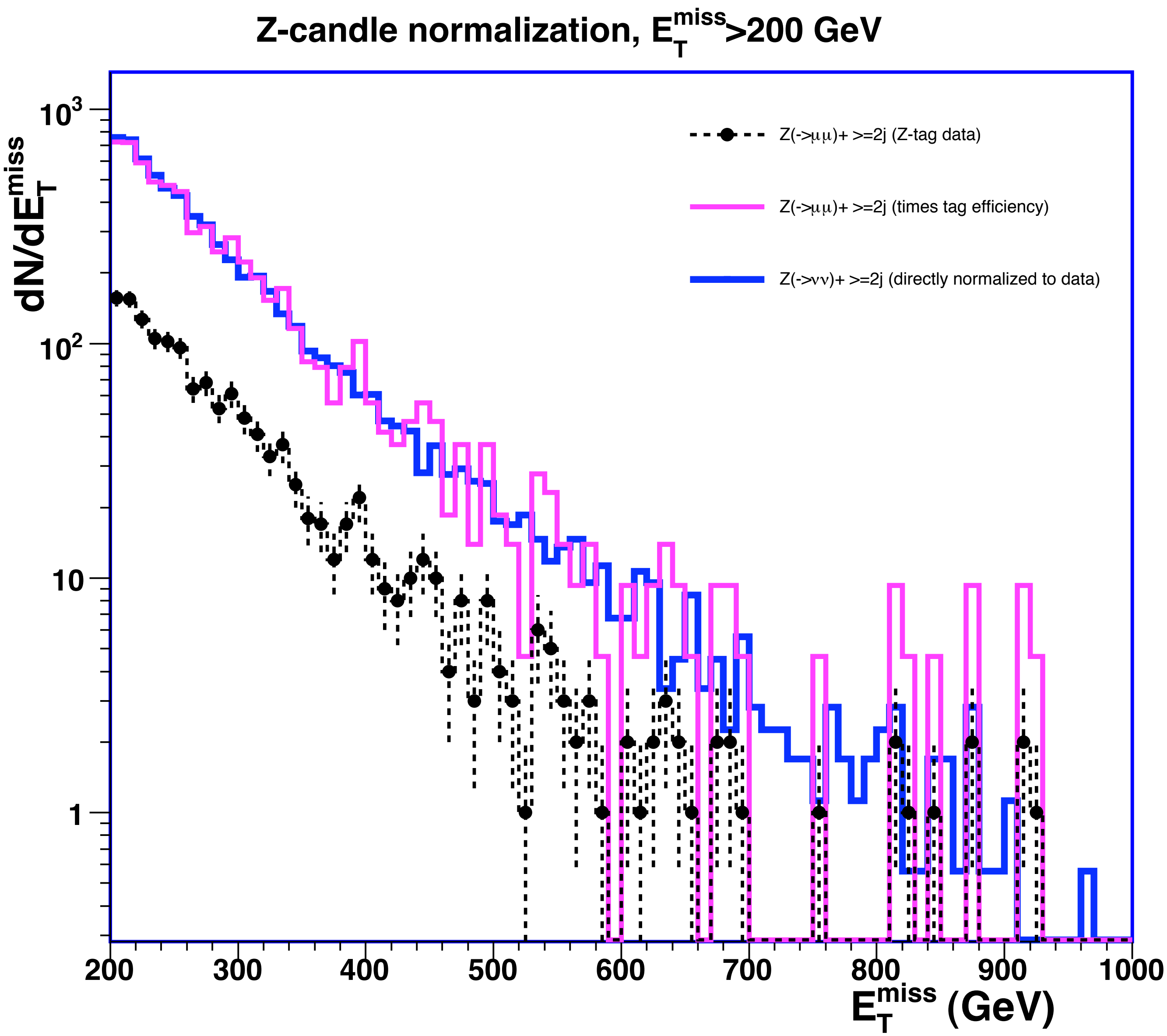
Achieving the two goals is pre-requisite for discovery physics

SUSY discovery time determined by time necessary to carry out this program. If all goes well need 1-2 years and a few fb^{-1} from when first good data are on mass storage to claim discovery

Inclusive reach (CMS)




CMS E_T^{miss} + multijets, 1 fb^{-1}
mSUGRA LM1
Zinv+tt
Zinv+tt+EWK
+QCD
dN/dE_T^{miss}
E_T^{miss} (GeV)
200
400
600
800
1000
1200
1400
1600
10^3
10^2
10
1
10^{-1}



Z-candle normalization, E_T^{miss}>200 GeV
dN/dE_T^{miss}
10^3
10^2
10
1
Z(->μμ)+ >=2j (Z-tag data)
Z(->μμ)+ >=2j (times tag efficiency)
Z(->νν)+ >=2j (directly normalized to data)
200
300
400
500
600
700
800
900
1000
E_T^{miss} (GeV)