Search for squarks and gluinos production in CDF

Monica D'Onofrio

IFAE-Barcelona

On behalf of the CDF collaborations

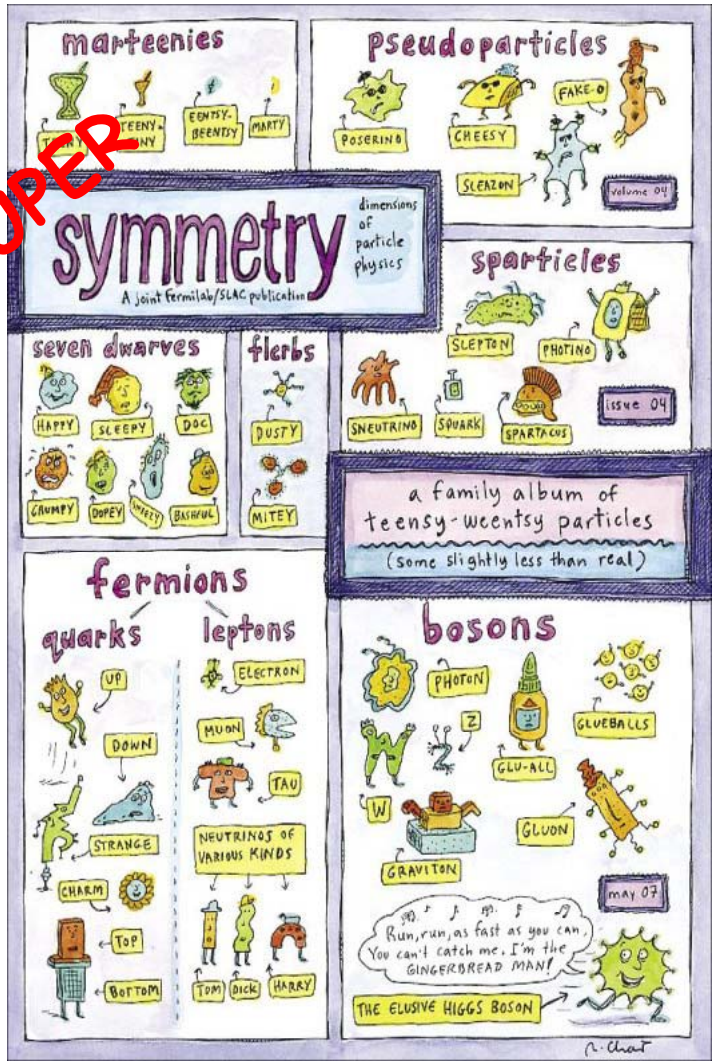
The 15th International Conference on Supersymmetry and the Unification of Fundamental Interactions

Karlsruhe, Germany

July 26 - August 1, 2007

Outline

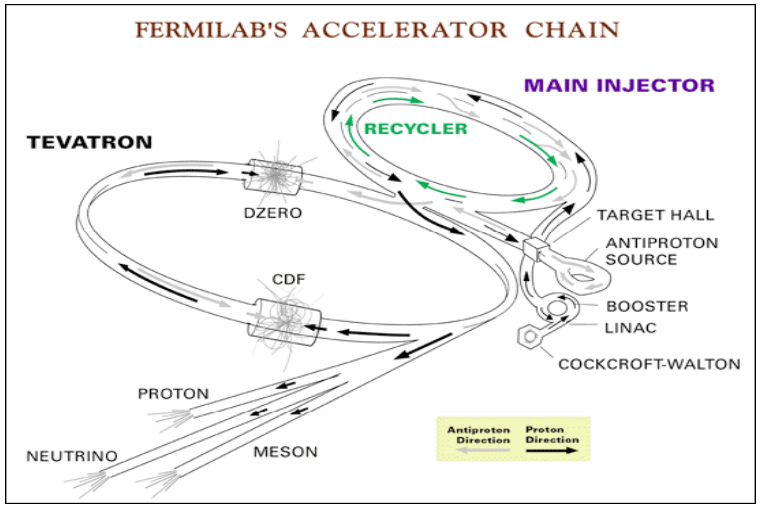
- Tevatron overview
- Supersymmetry in few words
- Squarks and Gluinos
- Background Processes
- Systematics
- Results
- Summary and Conclusions

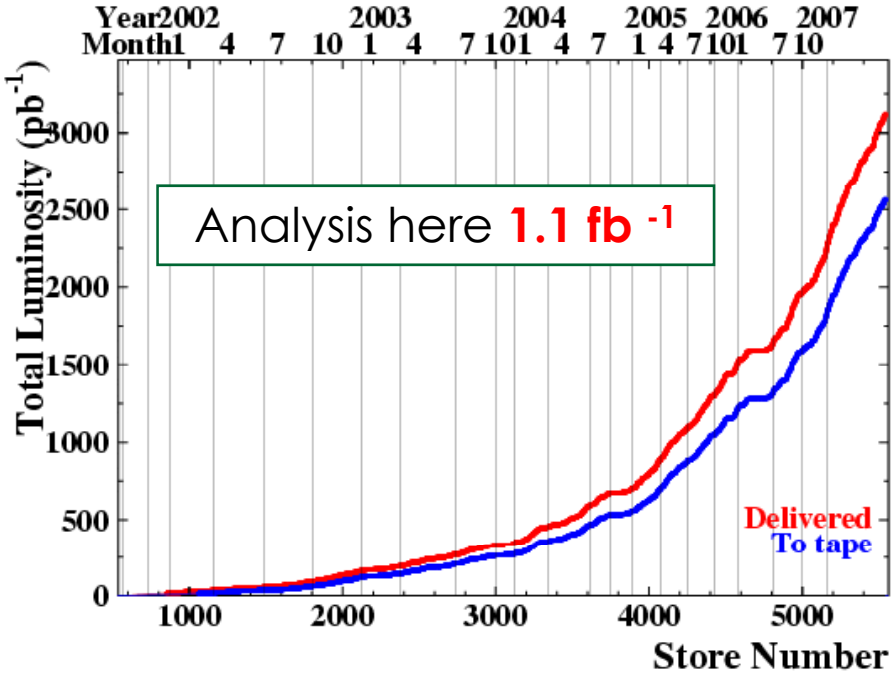


The Tevatron

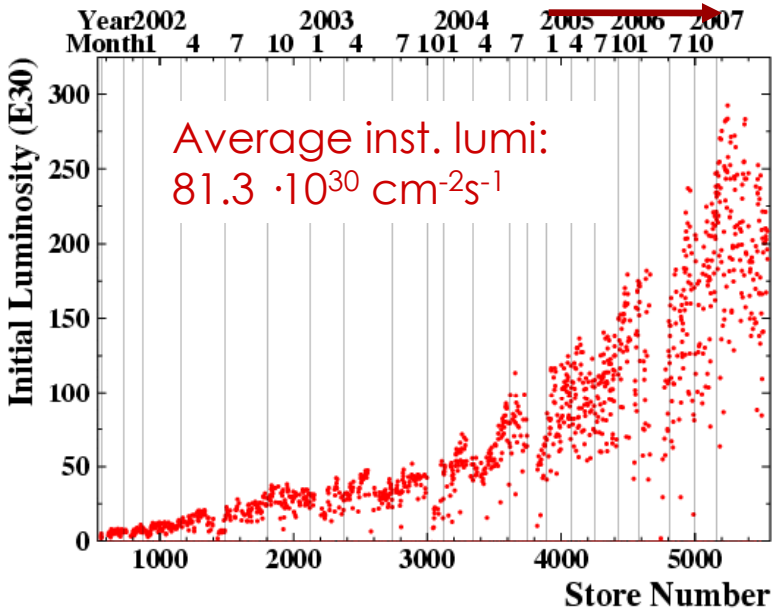
Highest-energy accelerator currently operational

Peak luminosity → **3 *10^{32} cm^{-2} s^{-1}**
Integrated luminosity/week → **~ 25 pb^{-1}**

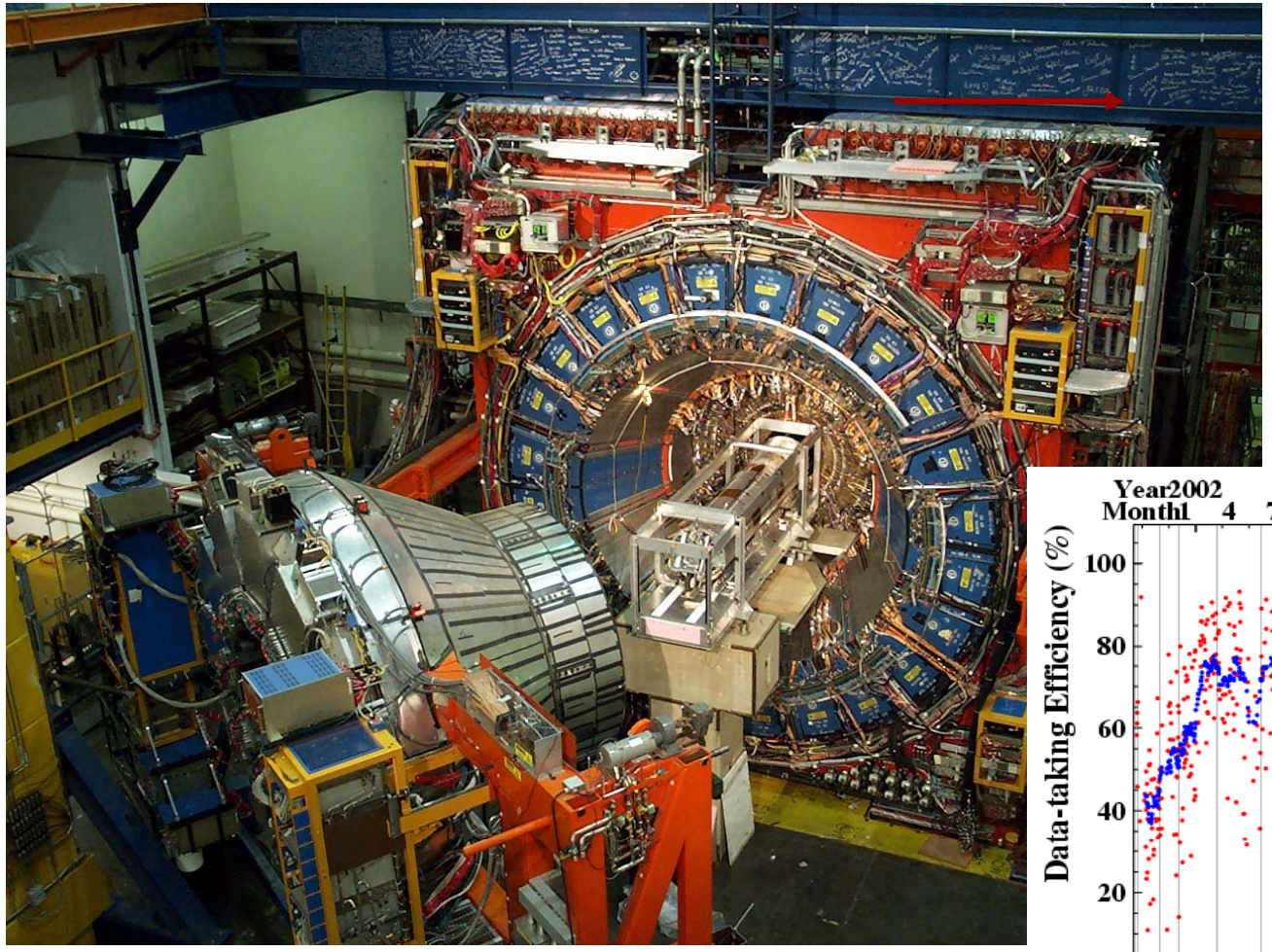




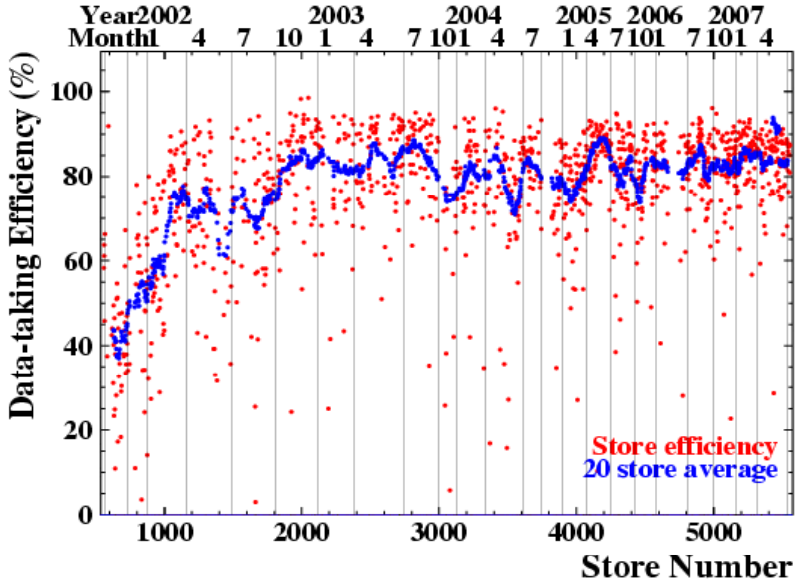
More than **2.5 fb^{-1}** recorded on tape



The CDF experiment



Recording data with high **efficiency (80-85%)** and making full use of detector capabilities.

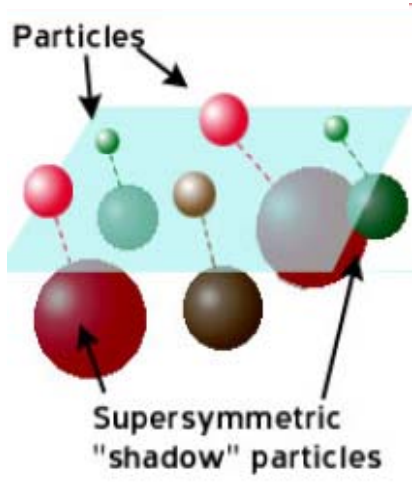


Supersymmetry

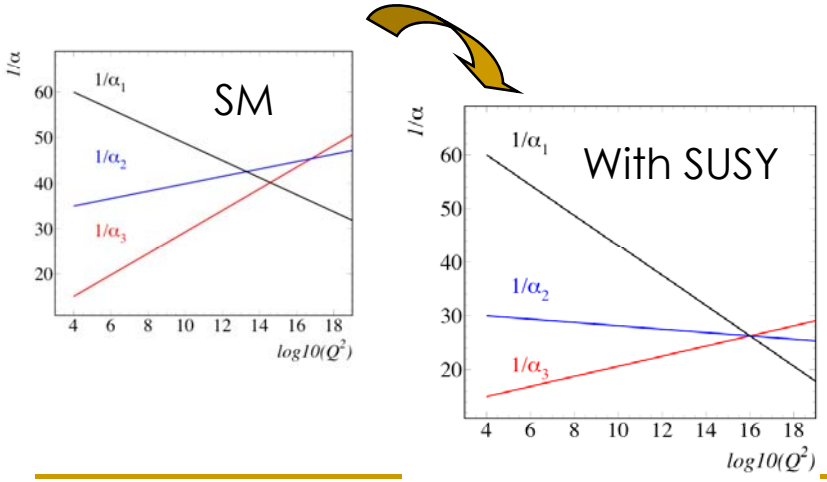
- New symmetry relating fermions and bosons to cancel out contributions to Δm^2_H : **Supersymmetry**

Q | Boson> = Fermion **Q | Fermion> = Boson**

- Minimal SuperSymmetric SM (MSSM):
  - Mirror spectrum of particles
  - Enlarged Higgs sector (two doublets with 5 physical states)
- Define R-parity = $(-1)^{3(B-L)+2s}$
  - R = 1 for SM particles, R = -1 for MSSM partners



→ if R-parity conserved, sparticles produced in pair, Lightest Supersymmetric Particle (LSP) stable



- Unifications of forces possible
- Dark matter candidate exists:
  - LSP stable if R-parity is conserved
  - Typically LSP is the lightest neutralino (χ_1^0)
  - Current mass limit $\chi^0_1 > 43$ GeV
  - Abundance of neutralino matches Dark Matter density in the Universe

Symmetry breaking

No SUSY particles found as yet:

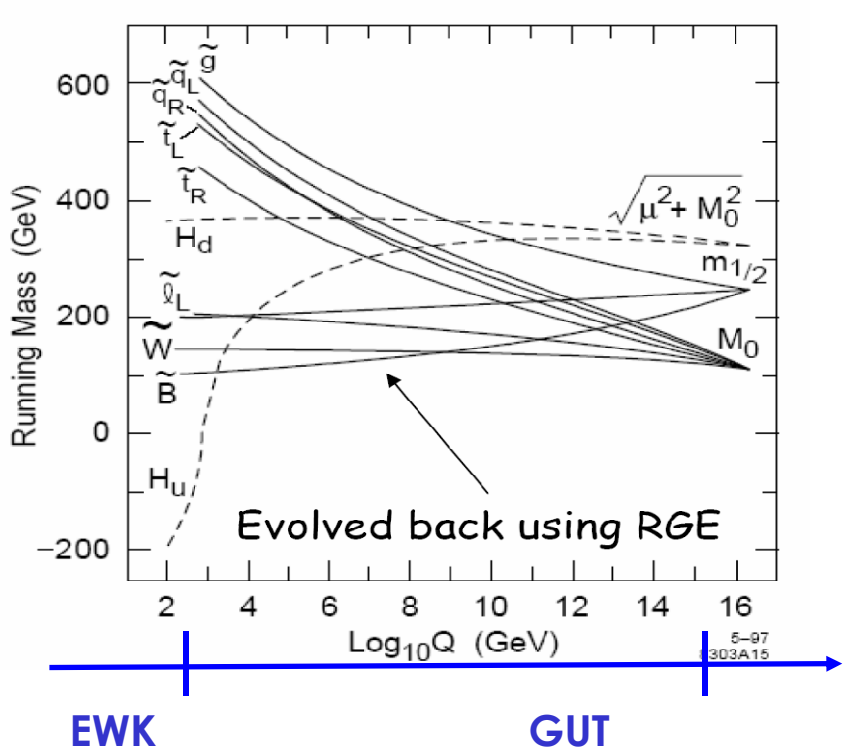
- SUSY must be broken: breaking mechanism determines phenomenology
- More than 100 parameters even in minimal (MSSM) models!

choose a model → mSUGRA

- New superfields in "hidden" sector
- Interact gravitationally with MSSM
- Soft SUSY breaking

5 parameters at GUT scale

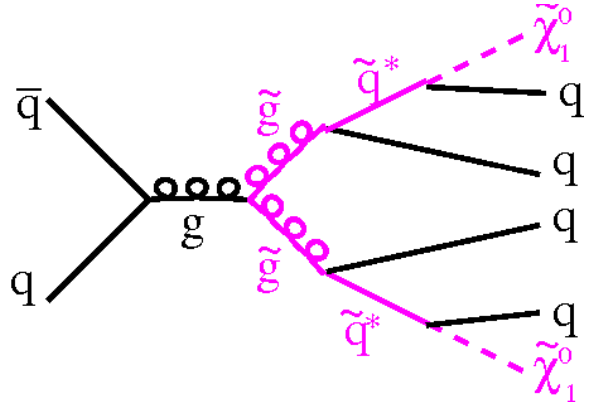
1. Unified gaugino mass $m_{1/2}$
2. Unified scalar mass m_0
3. Ratio of H_1, H_2 vevs tanβ
4. Trilinear coupling A_0
5. Higgs mass term sgn(μ)

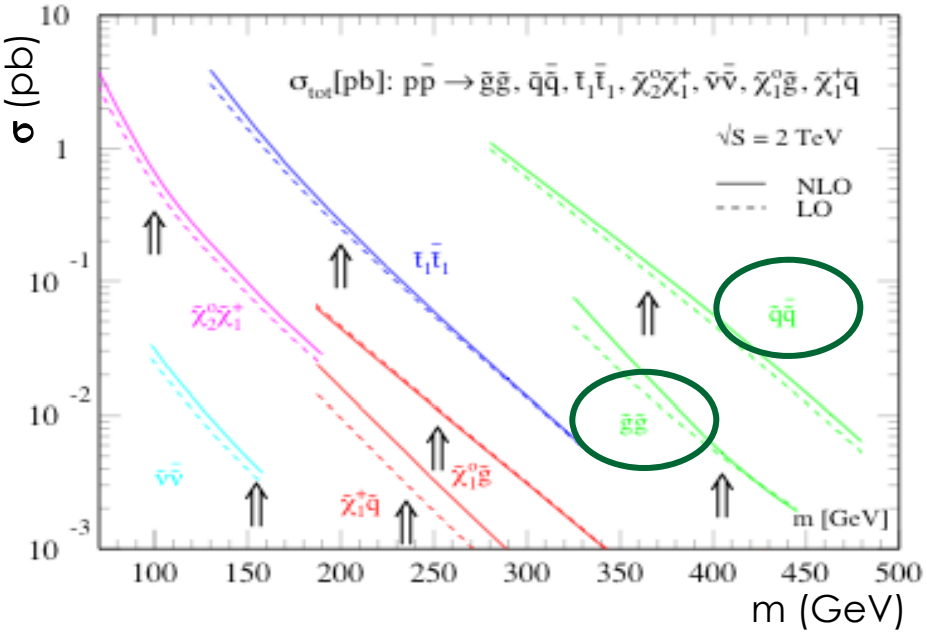


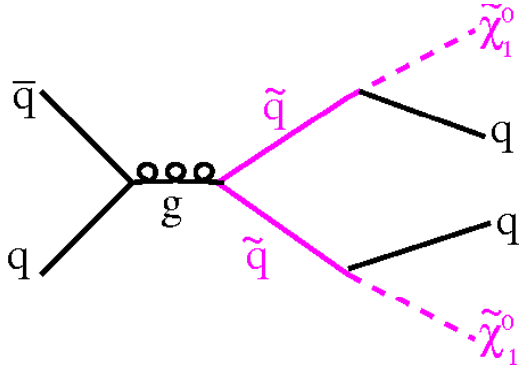
In R parity conservation scenario, the LSP is the neutralino → (χ_1^0)

Squark/gluino production

- R parity conserved: production in pairs
  - squark-antisquark
  - squark-squark (and c.c.)
  - gluino-gluino
  - squark-gluino (and c.c.)





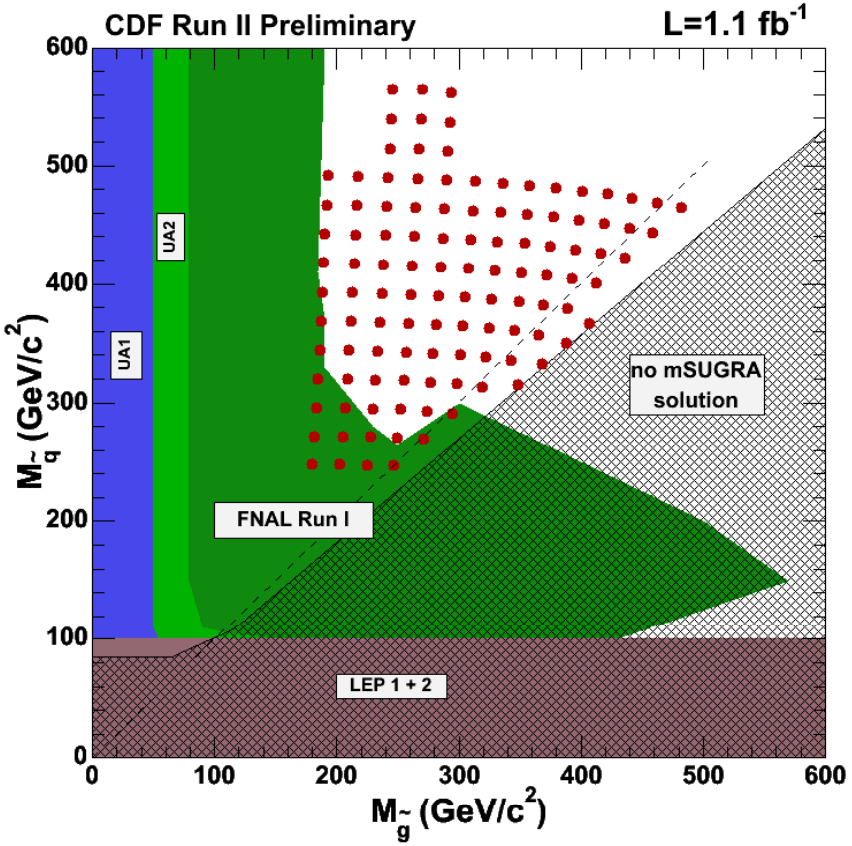


Signature:

multi jets + Missing Transverse Energy (from the undetected LSP)

mSUGRA samples generation

PYTHIA Tune A generation on the squark-gluino mass plane
(stop/sbottom removed from 2→2 processes):



$\tan\beta = 5$
$A_0 = 0$
Sign(μ) = -1
$M_0 \in [0,500\ \text{GeV}/c^2]$
$m_{1/2} \in [50,200\ \text{GeV}/c^2]$

mSUGRA parameters

Different sub-processes normalized to PROSPINO NLO σ calculation (5 flavors):

- Input masses, mixing and couplings generated using ISASUSY 7.74
- Use CTEQ6.1M PDF
- Renormalization and factorization scales:

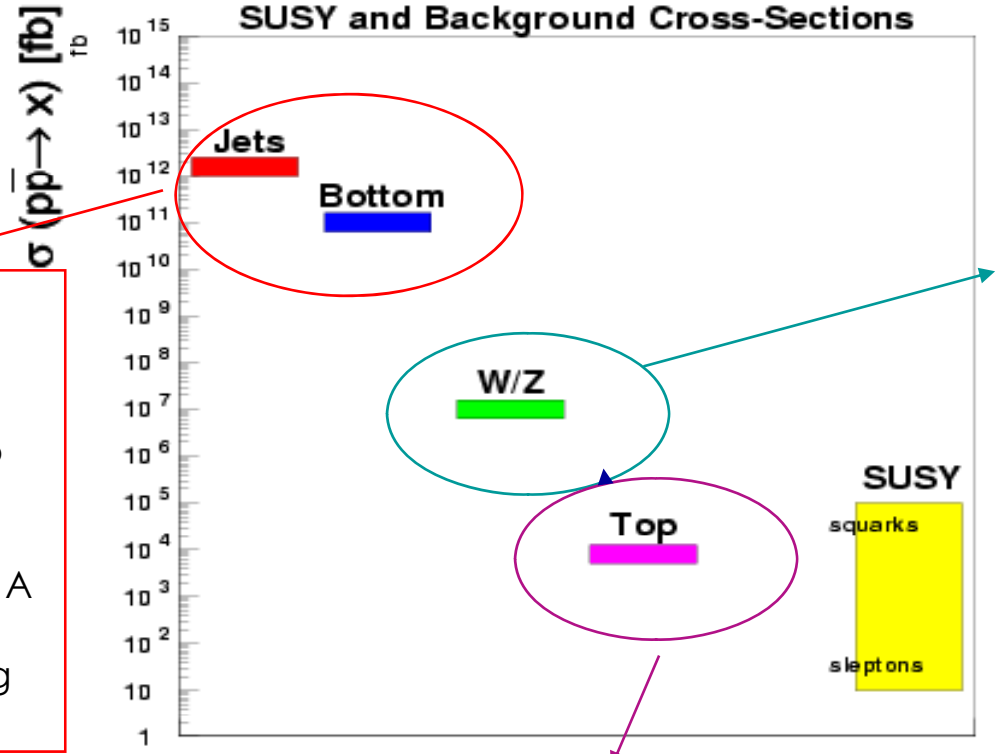
$\mu \rightarrow M_g$ or M_q or $\frac{1}{2}(M_g+M_q)$

Background

Background processes dominate

→ Need to be specifically rejected

Signatures very similar to SUSY



QCD multijets production dominates:
→Missing E_T due to jet energy mismeasurements
→ use Pythia Tune A MC normalized to data in low-missing E_T region

W→lν+jets, Z→ll+jets and Z→νν+jets:

- exclusive n-parton samples generated with ALPGEN; parton shower from PYTHIA.
- samples matched with MLM method and normalized to the inclusive D/Y cross section

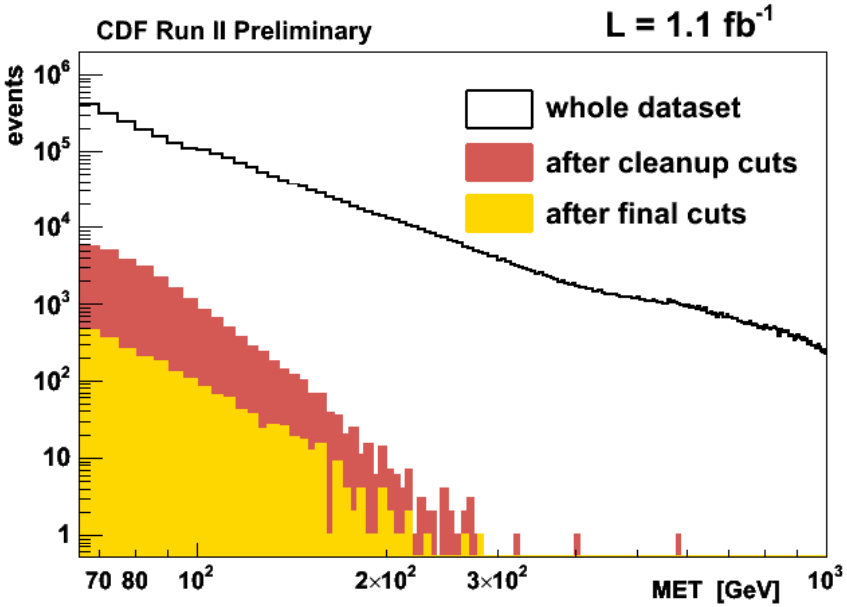
DiBoson (use MC normalized to MCFM NLO cross section)

- m_t = 172 GeV/c^2
- use Pythia MC samples normalized to the theoretical cross section σ_{ttbar}= 7.3 pb

Background rejection

Cleanup Cuts

- at least one central jet with $|\eta|<1.1$
- minimum missing E_T of 70 GeV
- **beam-related backgrounds** and **cosmics**. Removed using vertex information and combining calorimeter and tracking information



QCD rejection

- $|\Delta\phi$ (missingE_T-jets)$| > 0.7$ to remove events with missing E_T aligned to the direction of one of the jets in the final state.

W/Z+jets and diboson rejection

- Electromagnetic fraction (EMF) of the jets less than 90% to reject electrons mis-identified as jets
- $|\Delta\phi$ (missingE_T-isolated track)$| > 0.7$ to reject events with missing E_T due to undetected muons
- Z veto applied

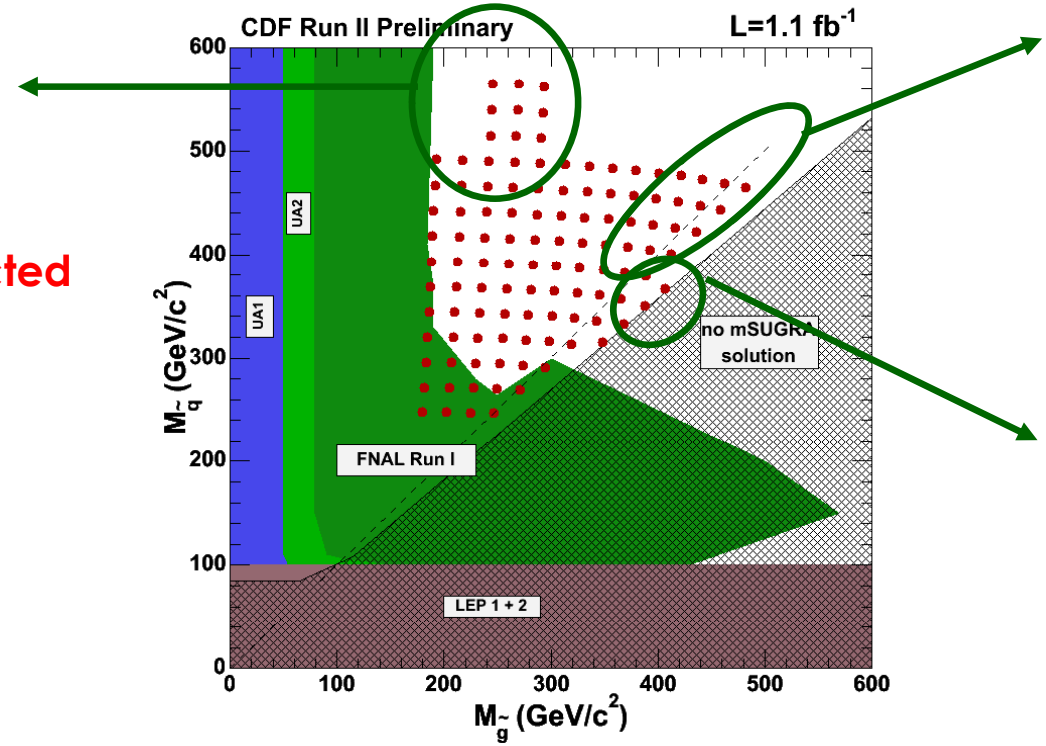
Optimization

- Missing E_T,$H_T = \Sigma E_T j_{(j=1..4)}$, E_T of the leading jets considered to further discriminate signal from background
- Different topologies expected throughout the squark-gluino plane

$M_{\tilde{q}} > M_{\tilde{g}}$

$\tilde{g}\tilde{g}$ process dominates

≥ 4 jets expected



$M_{\tilde{q}} \sim M_{\tilde{g}}$

$\tilde{q}\tilde{g}$ process dominates

≥ 3 jets expected

$M_{\tilde{q}} < M_{\tilde{g}}$

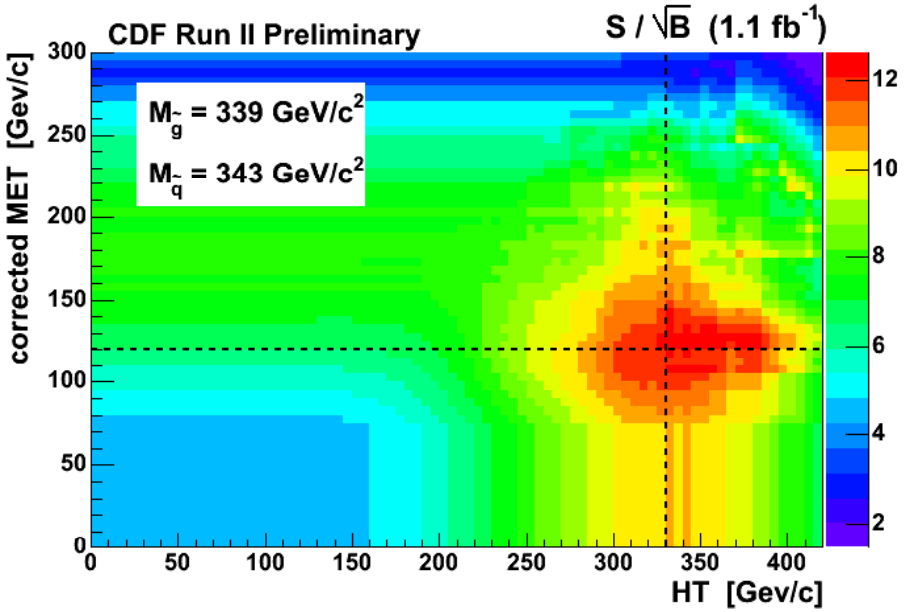
$\tilde{q}\tilde{q}$ process dominates

≥ 2 jets expected

Use different jet multiplicities to maximize signal sensitivity and background rejection

Optimization (2)

- 5 different set of selections and jet multiplicities employed to maximize S/√B across the squark/gluino mass plane.

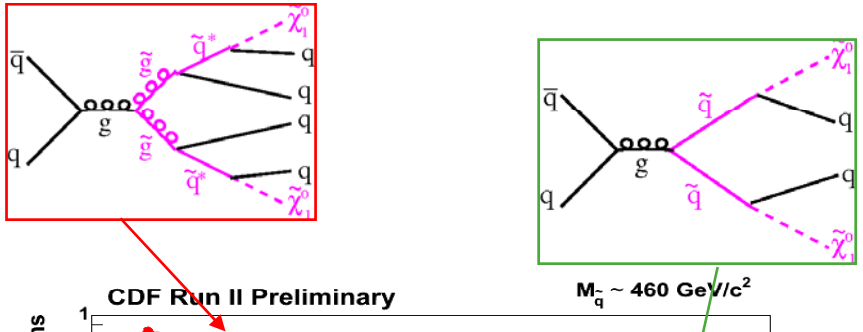


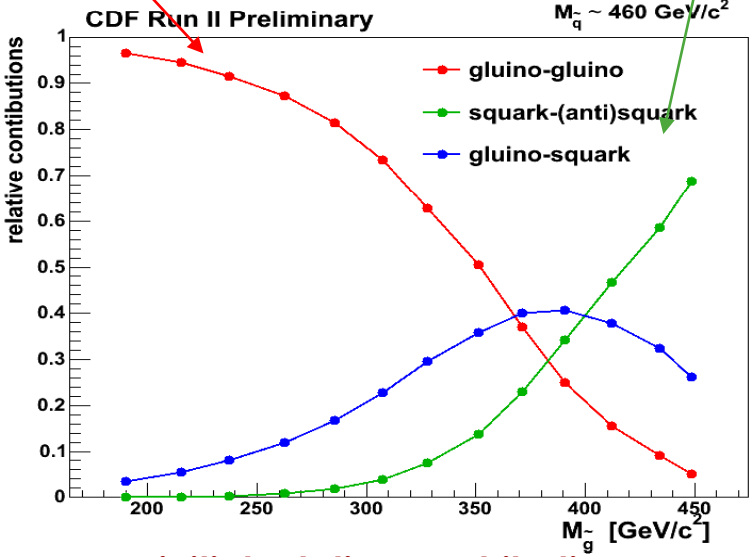
Definition of the signal regions

[GeV]	**4 jets**	**3 jets (A)**	**3 jets (B)**	**3 jets (C)**	**2 jets**
H_T	280	230	280	330	330
missing E_T	90	75	90	120	180
E_T(jet1)	95	95	120	140	165
E_T(jet2)	55	55	70	100	100
E_T(jet3)	55	25	25	25	--
E_T(jet4)	25	--	--	--	--

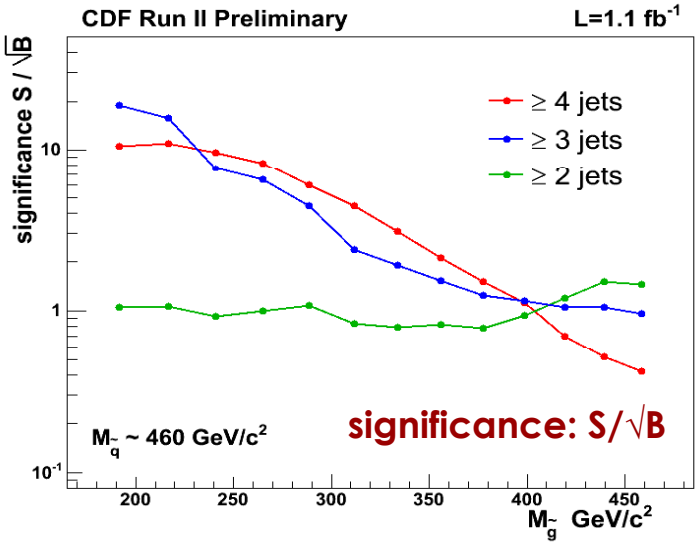
$S/\sqrt{B}$ and relative contributions

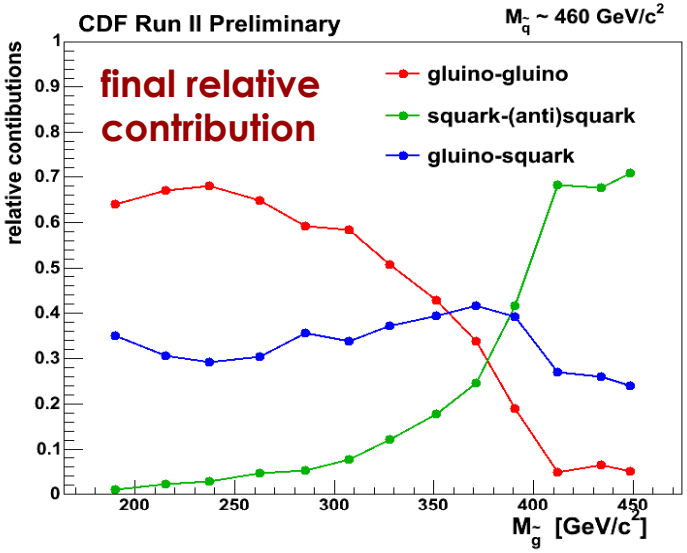
- 4-jet, 3-jet(A,B,C combined) and 2-jet optimization performed to maximize sensitivity to different sub-processes





initial relative contribution





Control Regions

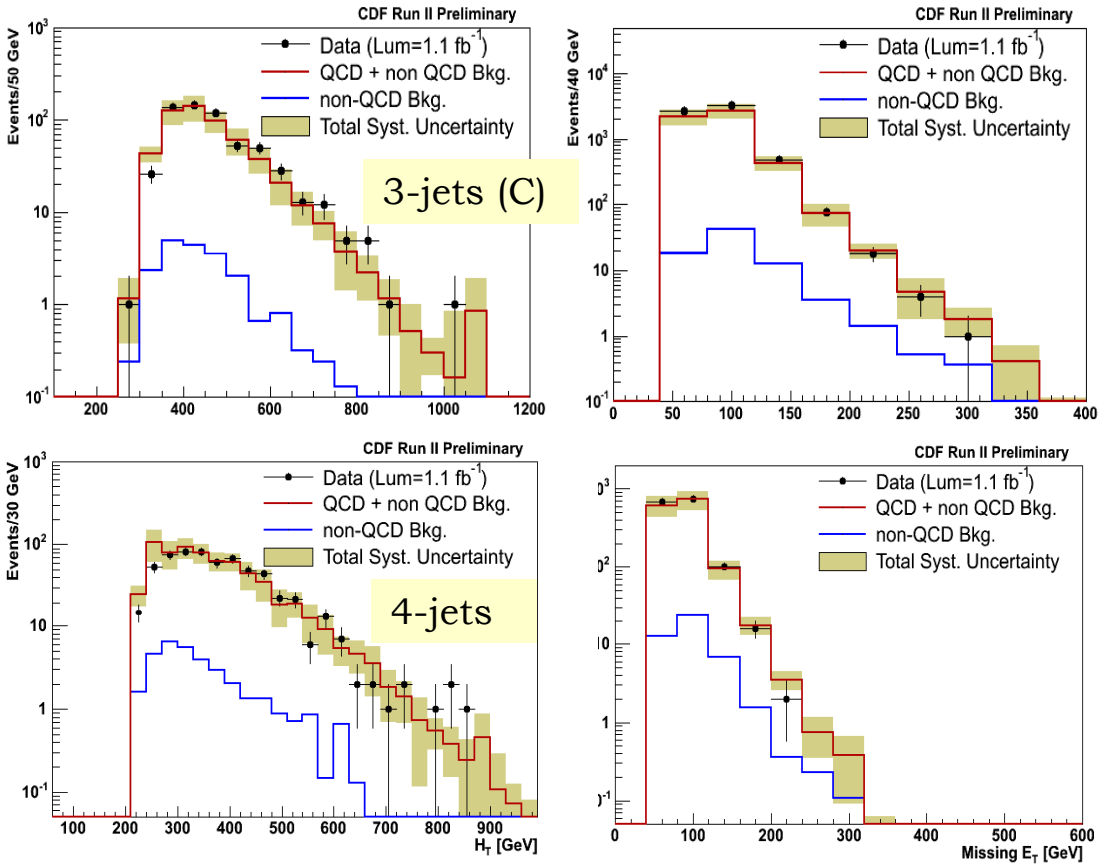
- Control regions defined by reversing selection requirements defined to suppress specific background processes
- As example:

  $|\Delta\phi$ **(missingE_T-jets)**$|$ selection reversed for at least one of the leading jets

→ **Enhance QCD contribution**

- Reversing requirements on EMF of leading jets or on Isolated tracks in the event, enhance Boson+jets or top background contributions

- Missing E_T and H_T distributions



good agreement between data and SM MonteCarlo

Systematic uncertainties

Signal & Background → 3% variation in Jet Energy Scale
→ 6% uncertainty on luminosity

- **PDF**: CTEQ6.1M. Use Hessian method to determine systematic uncertainties.
- **Renormalization scale**:
  Default:
  - $\tilde{g}\tilde{g}$: $\mu = M_{\tilde{g}}$
  - $\tilde{q}\tilde{g}$: $\mu = 0.5[M_{\tilde{g}}+M_{\tilde{q}}]$
  - $\tilde{q}\tilde{q}$ and $\tilde{q}\tilde{\tilde{q}}$: $\mu = M_{\tilde{q}}$

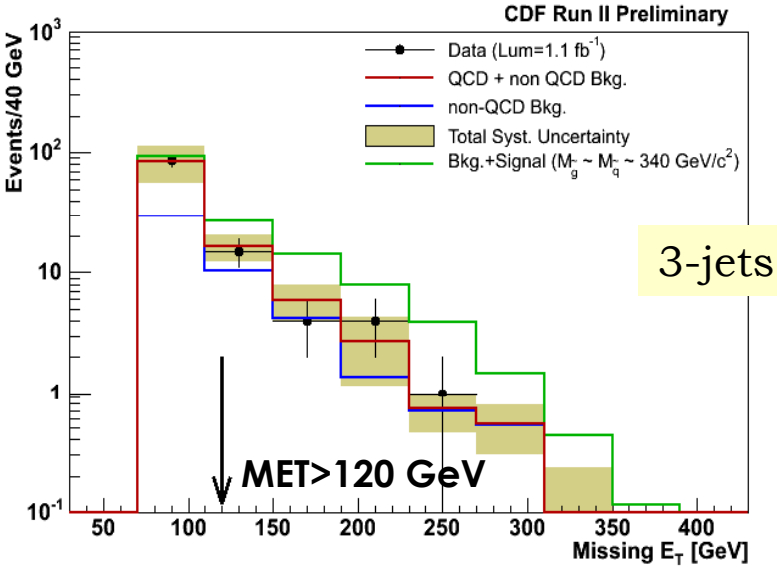
  Nominal PROSPINO scale shifted to ½ and 2 μ.
- **Initial/Final state radiation (ISR/FSR)**:
  - increased/decreased via variation of Λ_{QCD}

- **ISR/FSR** in top and Boson+jets production
- 2% global uncertainty on inclusive W/Z cross section used to normalize W/Z+jets cross section
- 10% **PDF + Renormalization** uncertainty on diboson and top cross section
- Uncertainty on QCD normalization negligible (< 1%)

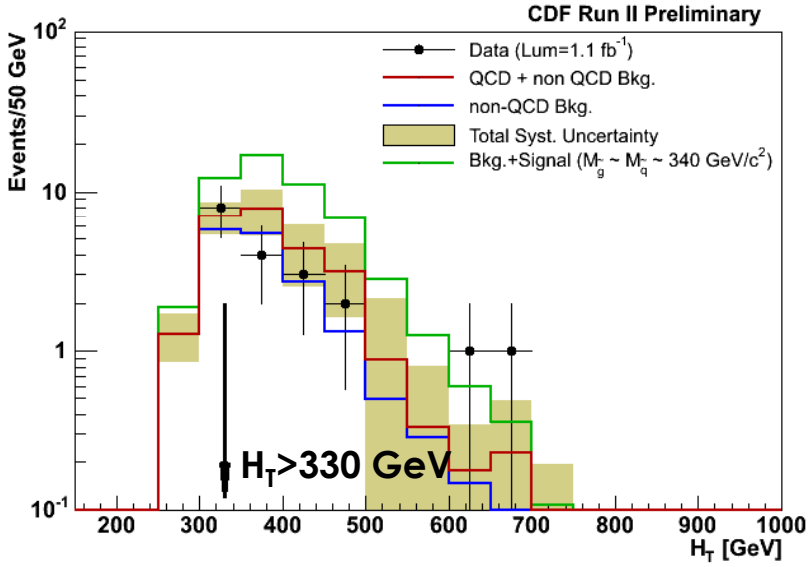
DATA vs SM predictions

Events in 1.1 fb^{-1}	DATA	SM Expected
4-jets	**22**	22 ± 2(stat.) ± 7(syst.)
3-jets (A)	**494**	484 ± 14 (stat.) ± 117 (syst.)
3-jets (B)	**136**	123 ± 6 (stat.) ± 35 (syst.)
3-jets (C)	**17**	20 ± 2 (stat.) ± 6 (syst.)
2-jets	**9**	9 ± 1 (stat.) ± 2 (syst.)

Good agreement between Observed and Expected events



3-jets (C)



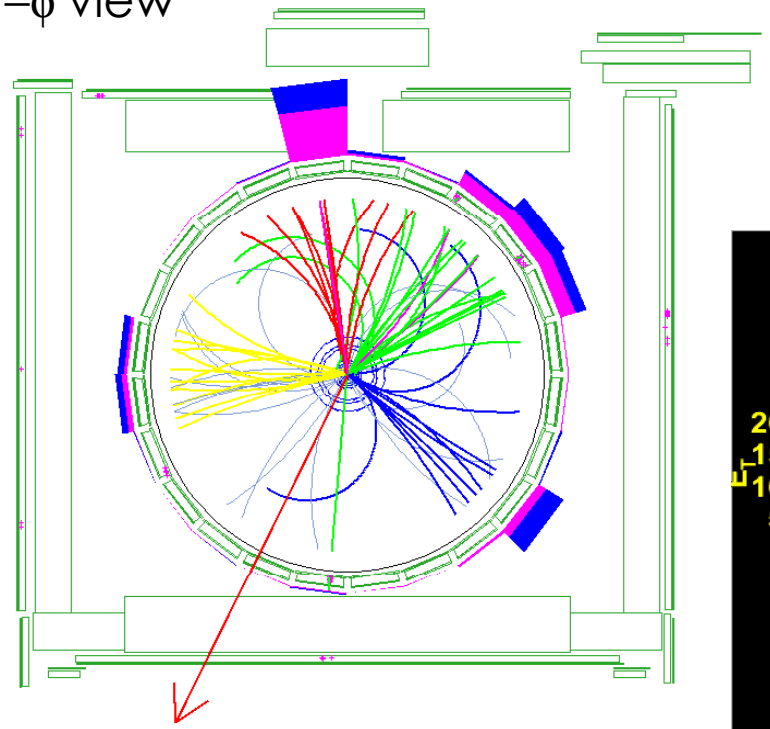
no evidence of SUSY has been found → **extract EXCLUSION LIMIT**

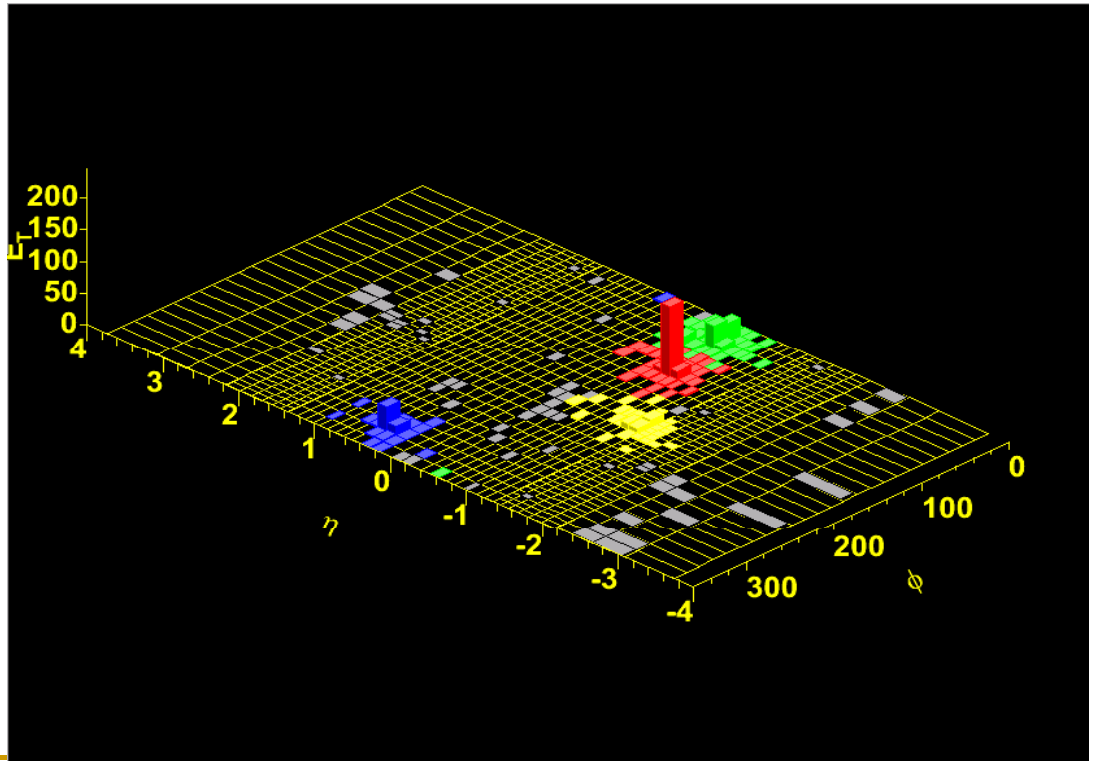
one selected event

- missing E_T = 196GeV
- E_T(jet1) = 236GeV,
  E_T(jet2) = 150GeV,
  E_T(jet3) = 84GeV
- H_T (3-jets) = 470GeV

3-jets (C)

r–ϕ view

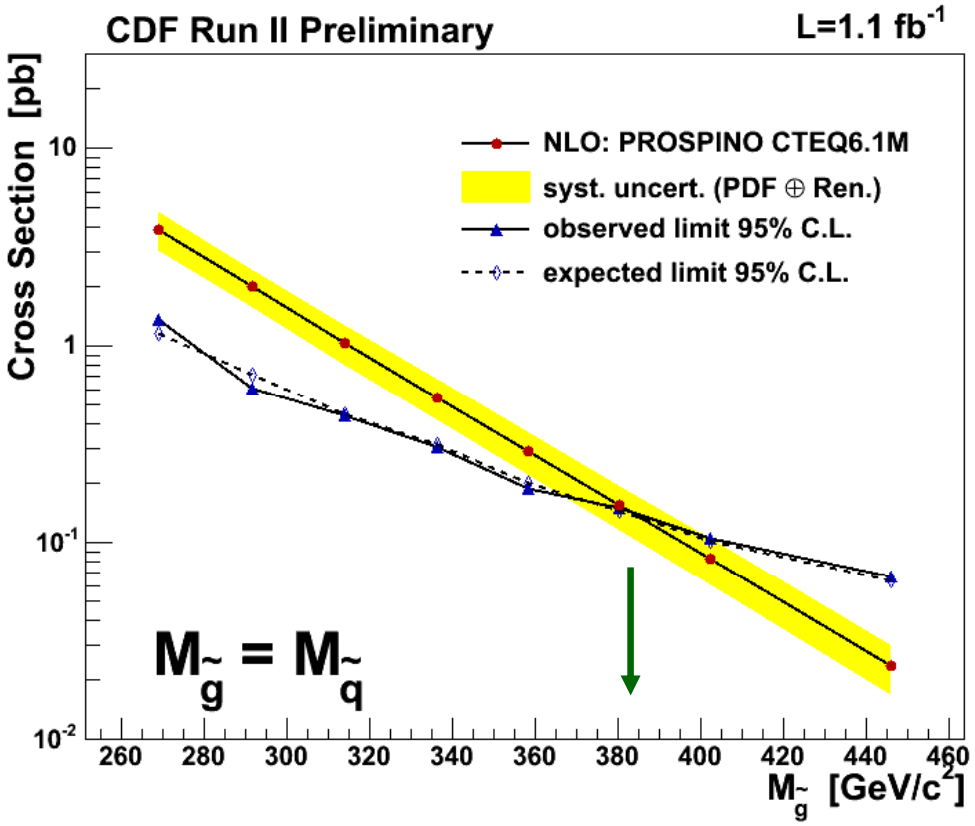




Limit on signal cross sections (1)

- Bayesian approach: curves at 95% C.L.
- Include correlations between signal and background systematic uncertainties
- Systematic uncertainties on signal cross section included in the limit calculation (15-50% from PDF+Renormalization scale)
- Mass limit quoted as the cross point with the nominal NLO prediction.

- Cross sections along the diagonal

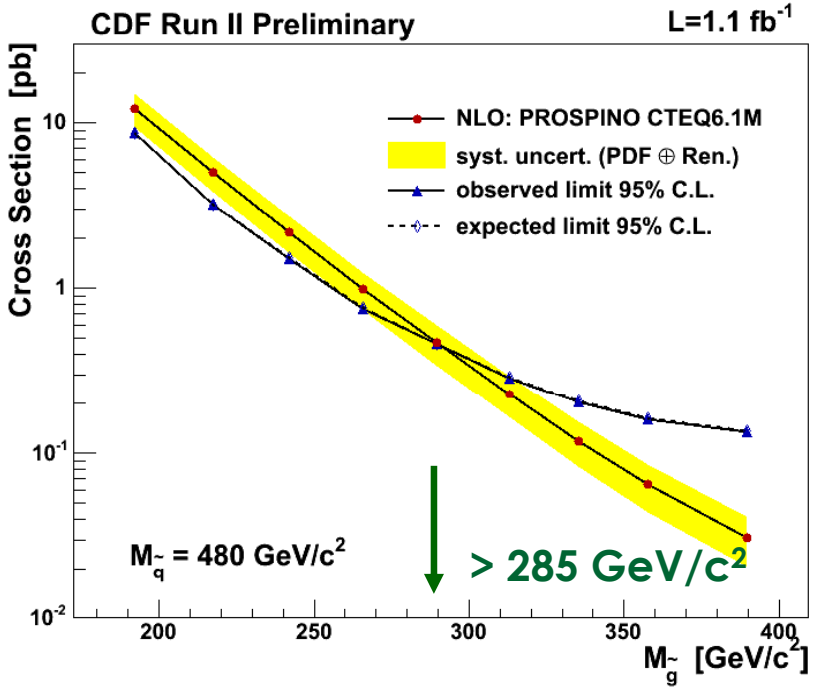


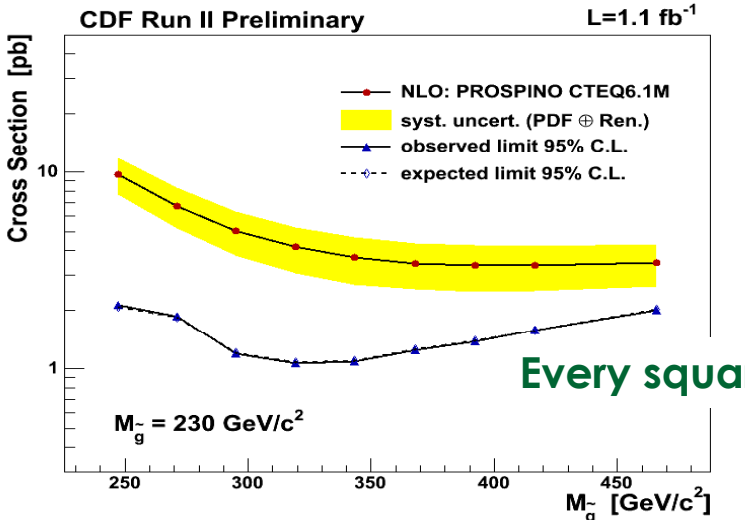
For $M_{\tilde{g}} \sim M_{\tilde{q}}$:

masses excluded up to 385 GeV/c^2.

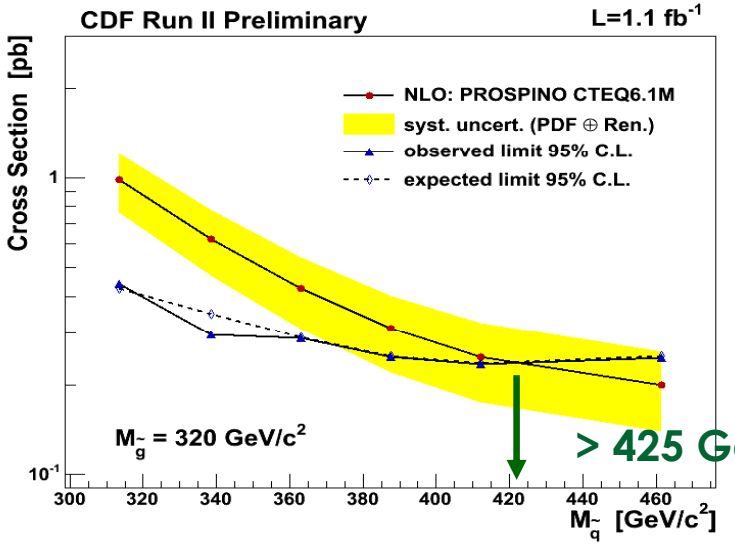
Limit on signal cross sections (2)

- Cross sections for fixed values of squark / gluino masses

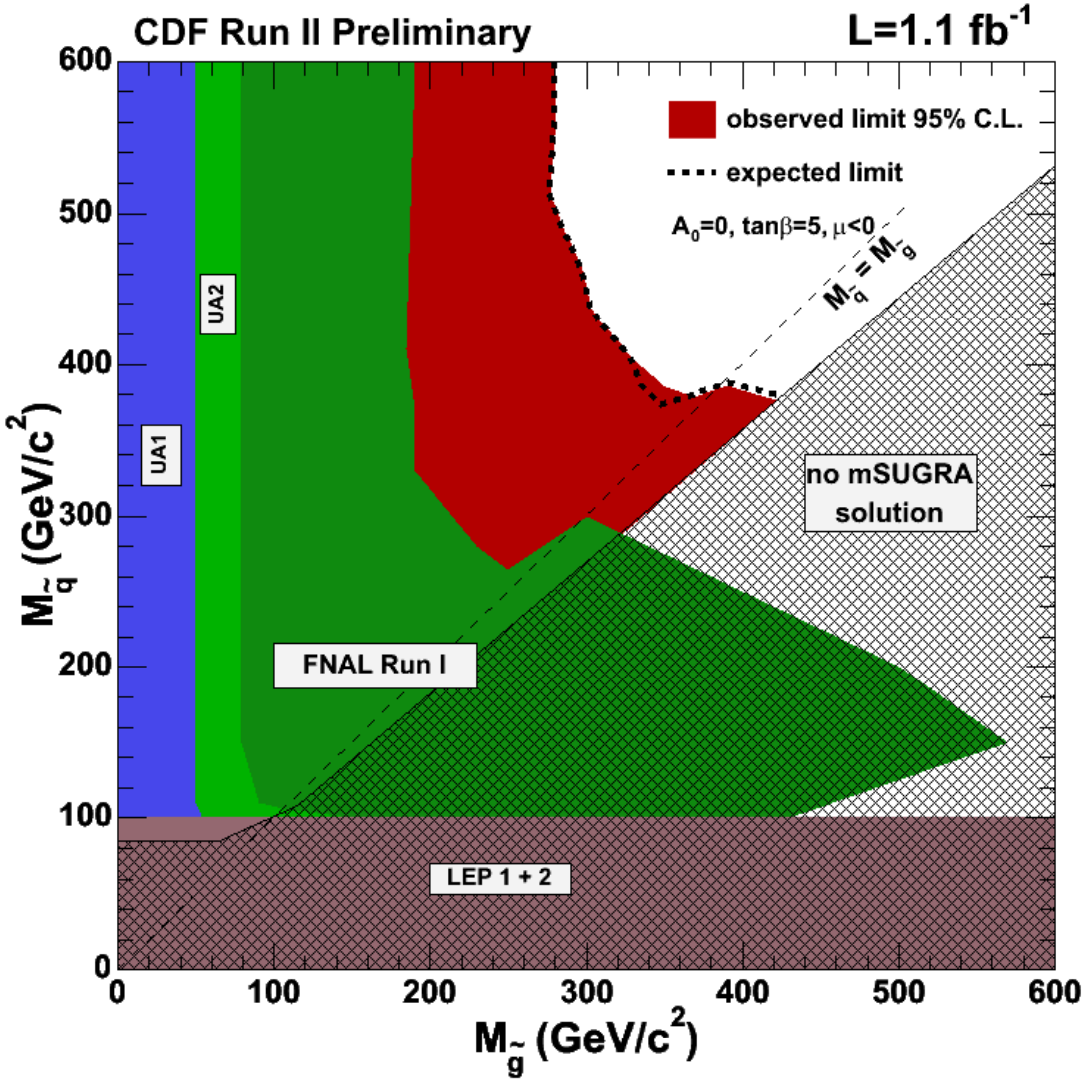




Every squark mass



Exclusion Limit (gluino-squark mass plane)

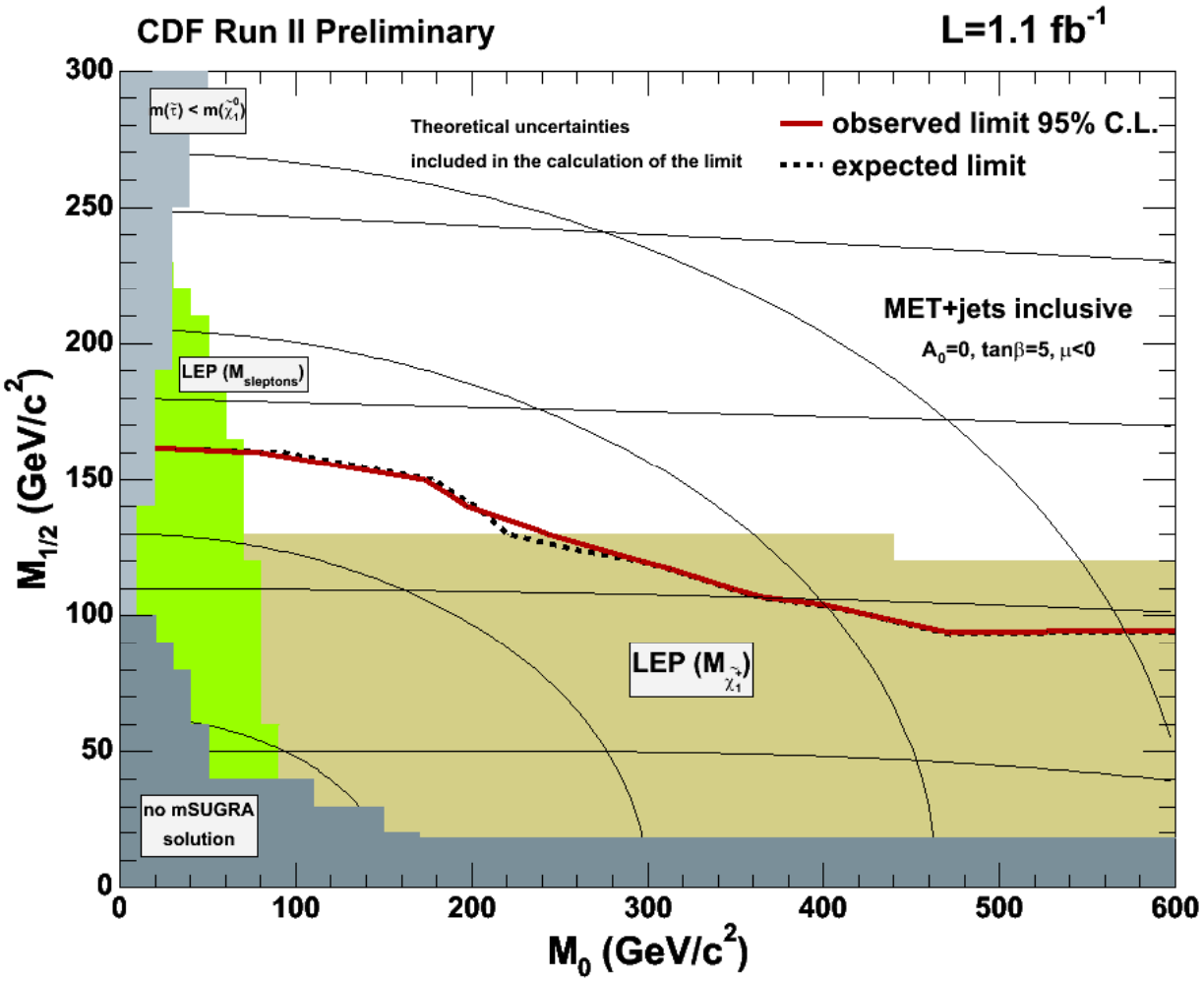


For nominal cross section: observed limit of ~ **385 GeV/c^2 when $M_{gl} \sim M_{sq}$** .

$M_{gl} \sim 280$ GeV/c^2 in any case.

M_{gl} excluded < 410 GeV/c^2 for squark masses < 380 GeV/c^2

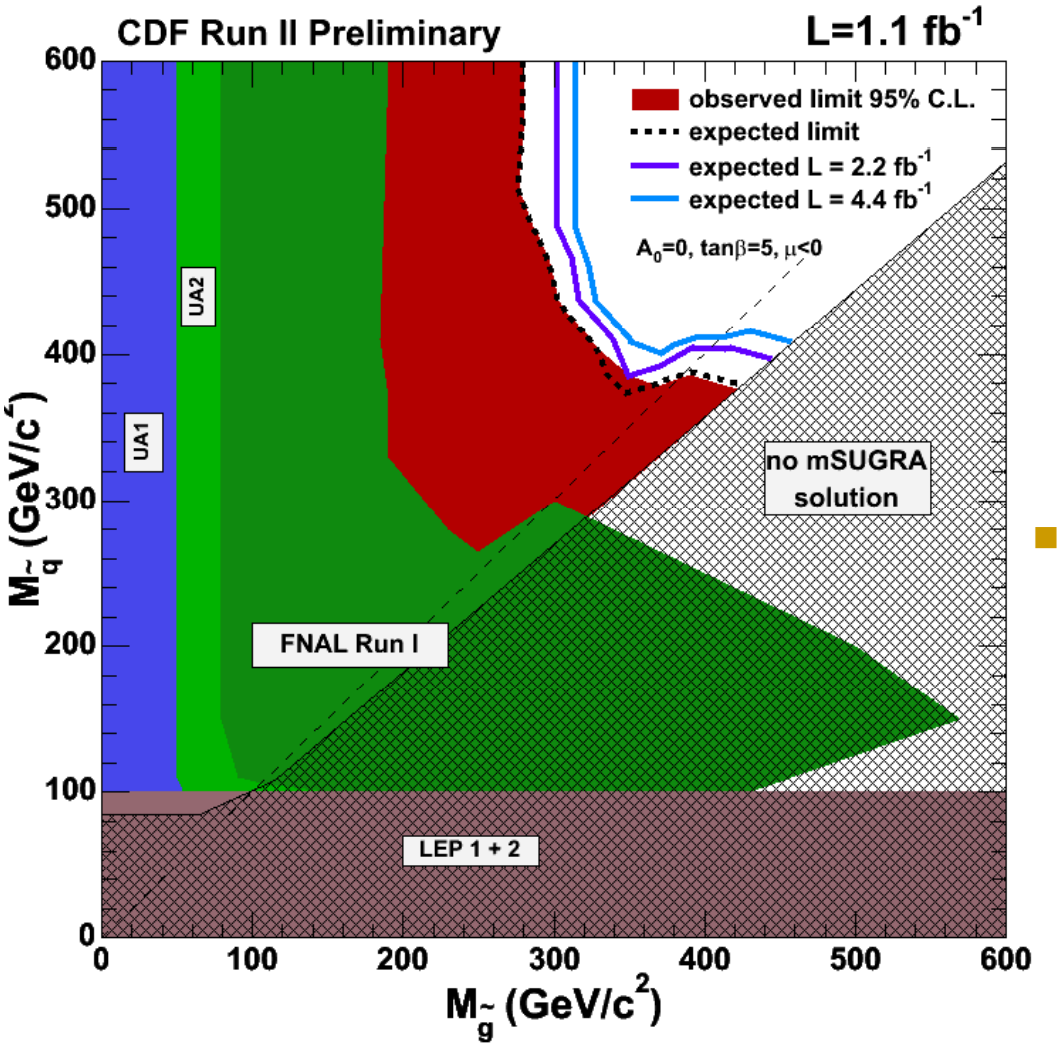
Exclusion Limit (m_0 vs $m_{1/2}$ plane)

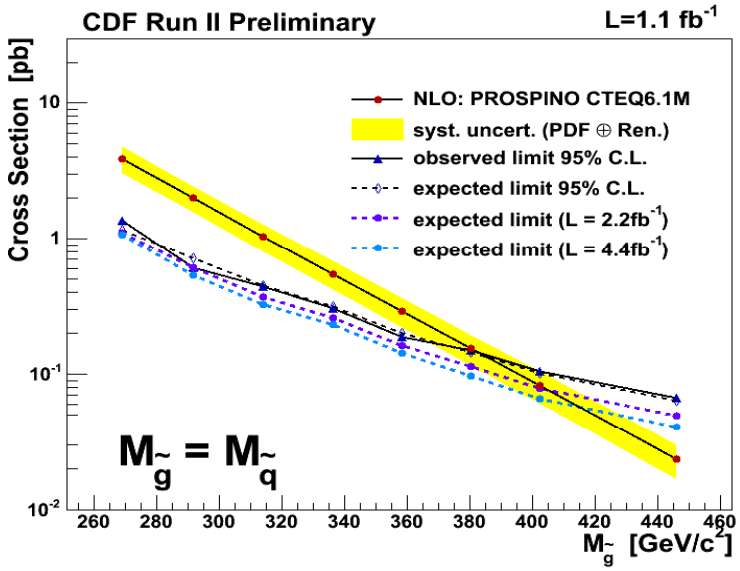


Exclusion limit on the mSUGRA parameters at the GUT scale

Better limit respect to LEP chargino and sleptons searches in the region **$75<M_0<250$** and **$130<M_{1/2}<165$ GeV/c^2**

The future





- Expected limits with ×2 and ×4 luminosity, assuming no further improvements in the analysis:

  when $M\tilde{g} \sim M\tilde{q}$, $M\tilde{g}$ excluded up to

  405 GeV/c^2 (2.2 fb^{-1}) and
  420 GeV/c^2 (4.4 fb^{-1})

Summary

- No evidence of Squarks and Gluinos in 1.1 fb^{-1} of data has been found in CDF dedicated analysis.
- Complex analysis considering different final states with the aim to maximize sensitivity across the squark/gluino mass plane, and followed by a careful evaluation of background contributions and systematic uncertainties.
  - $M_{\tilde{g}}$ below 280 GeV/c^2 is excluded at 95% C.L in the mSUGRA scenario ($A_0 = 0$, $\tan\beta = 5$, $\mu < 0$).
  - When $M_{\tilde{g}} \sim M_{\tilde{q}}$, masses below 385 GeV/$c^2$ are excluded at 95% C.L.
  - For $M_{\tilde{q}} < 380$ GeV/c^2, $M_{\tilde{g}}$ below 410 GeV/c^2 excluded at 95% C.L.
- Ready to double the amount of data used here

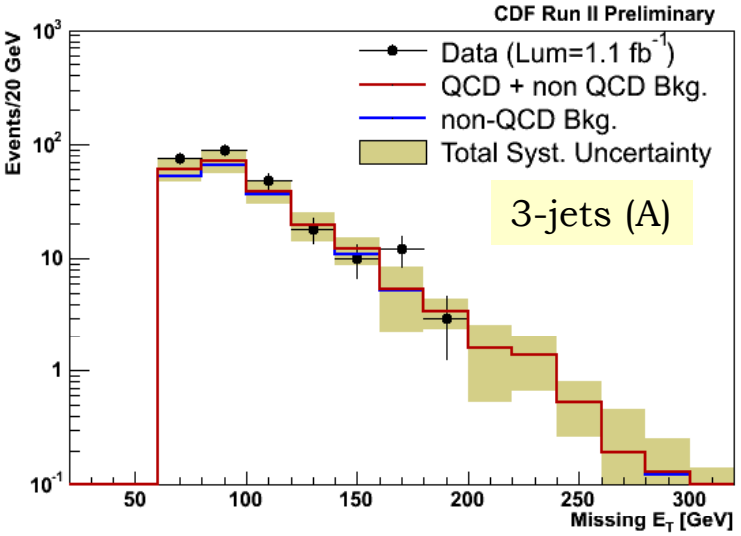
It may be that the first SUSY hint is just around the corner…


Back up

Control Regions (2)

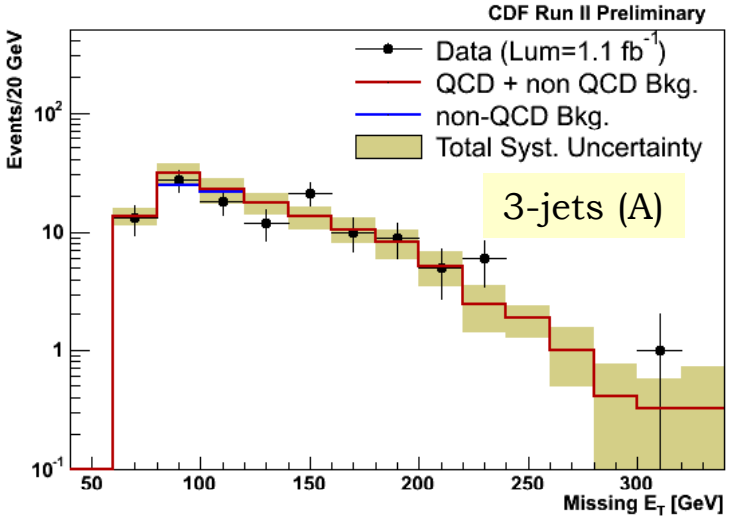
***electrons dominated sample*:**

EMF cut reversed to enhance the electron related contributions (mainly W+jets, DiBoson)



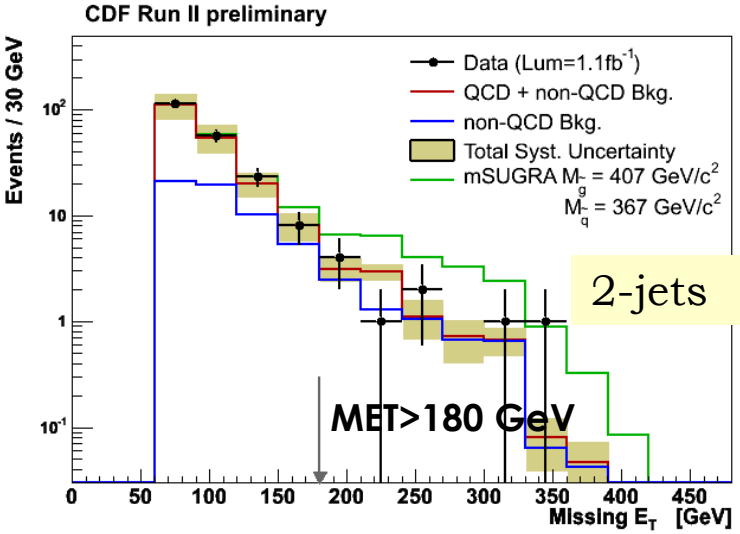
***muons dominated sample*:**

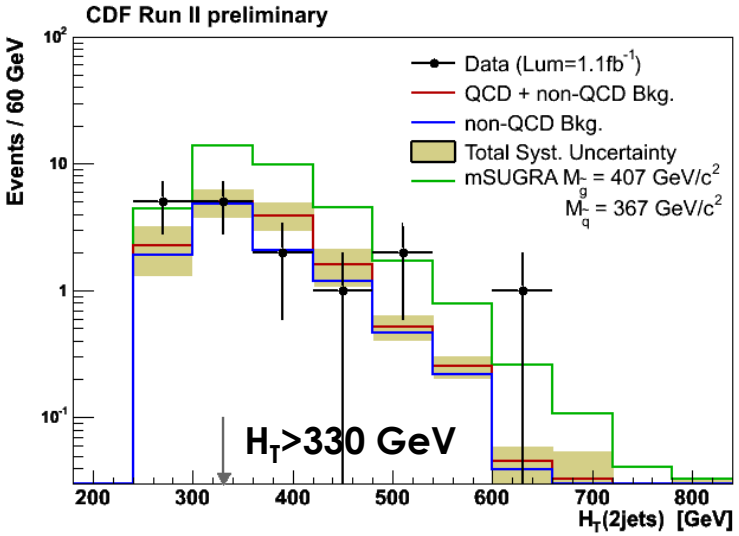
cut on the **isolated tracks** reversed to enhance muon related contributions (mainly W+jets and tt).

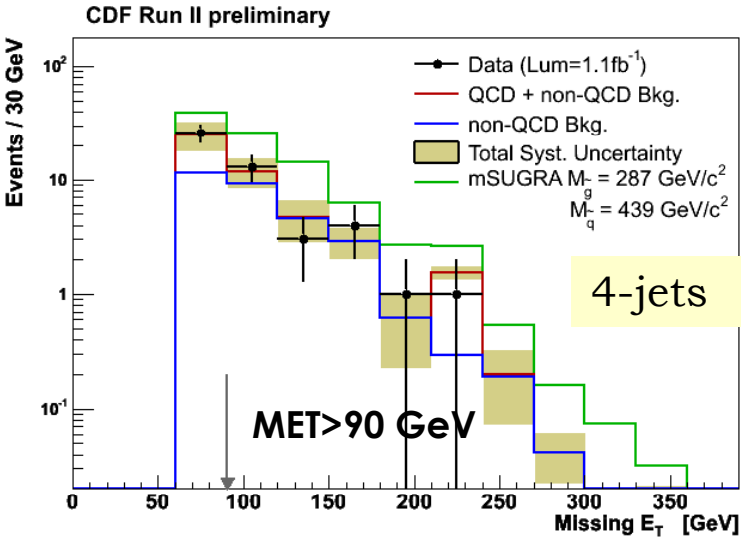


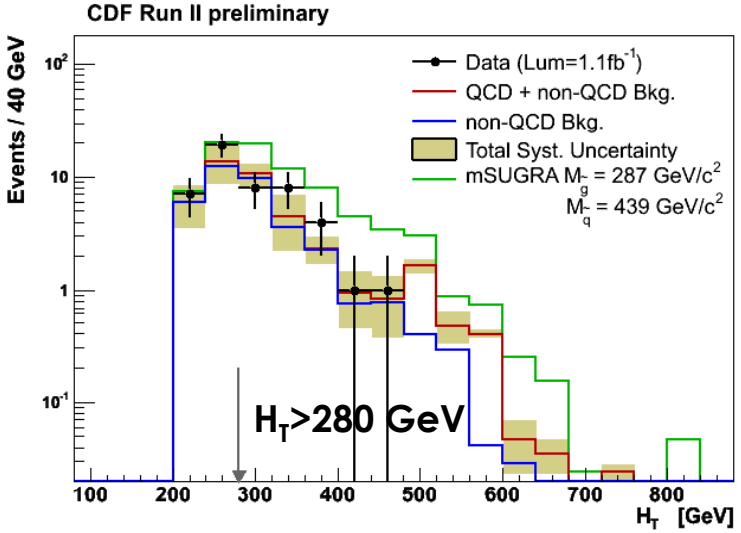
good agreement between data and SM MonteCarlo

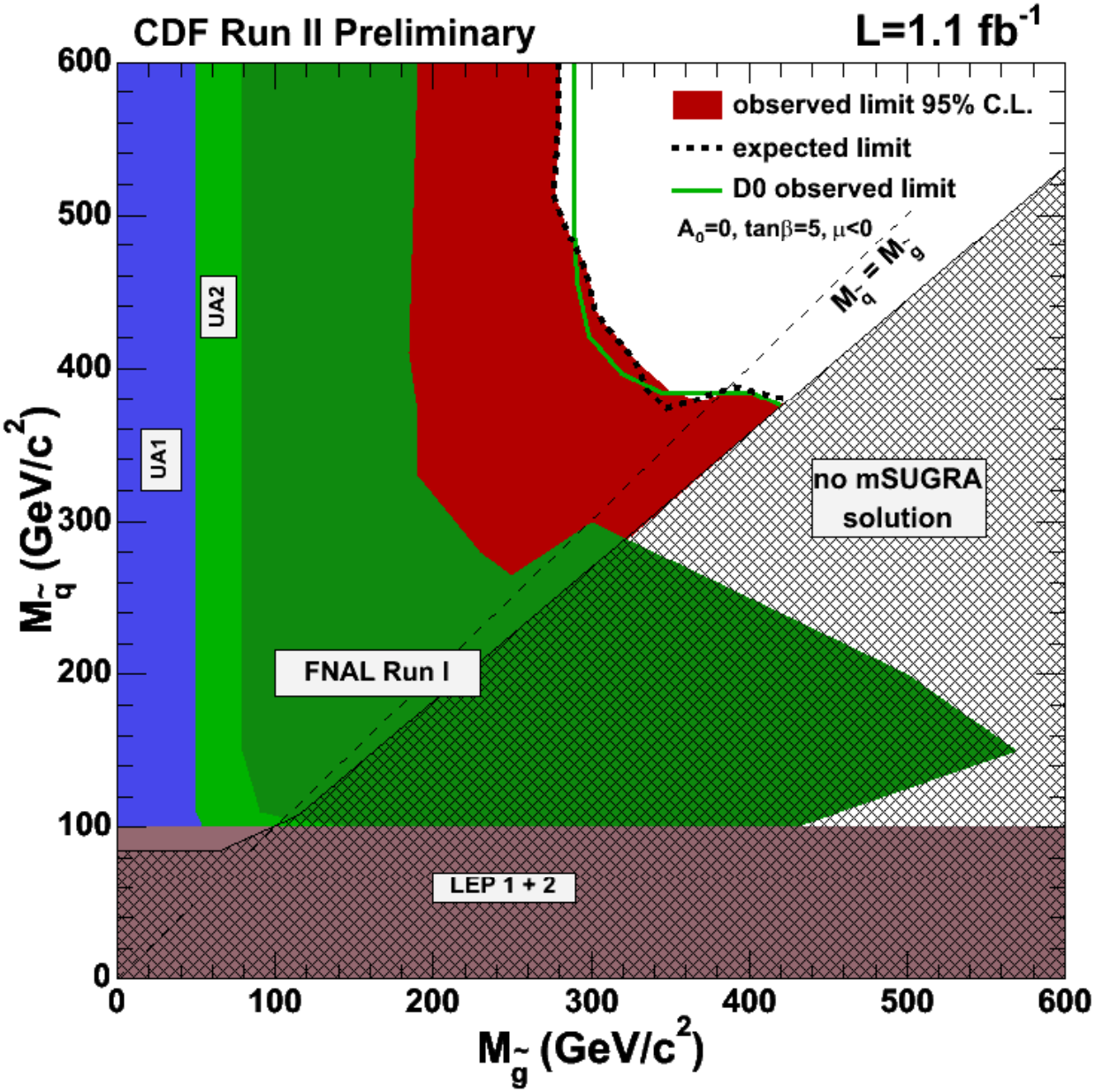
Data vs SM predictions (2)










CDF Run II Preliminary
L=1.1 fb-1
observed limit 95% C.L.
expected limit
D0 observed limit
A0=0, tanβ=5, μ<0
M~q = M~g
UA1
UA2
FNAL Run I
LEP 1 + 2
no mSUGRA solution
M~q (GeV/c2)
M~g (GeV/c2)
0
100
200
300
400
500
600