Dark Matter and LHC

From Strings to LHC II
19-23rd December,2007
FireFlies Ashram, Bangalore

Monoranjan Guchait
TIFR,Mumbai

22 December, 2006

Outline

- Dark Matter
- Models and Candidates
- Implications of Dark Matter at LHC
- Summary

Dark Matter

WMAP experiment extracted :

$$\Omega_m h^2 = 0.1265^{+0.0081}_{-0.0080}$$

$$\Omega_b h^2 = 0.0223 \pm 0.0007$$

Assuming the difference is due to the CDM:

$$\Omega_{cdm} h^2 = 0.1042^{+0.0081}_{-0.0080}$$

2σ: $0.0882 < \Omega_{cdm} h^2 < 0.1204$

The WIMP model

• They are stable, neutral, weakly interacting particles with interaction cross sections large enough that they were in thermal equilibrium for some periods in the early universe.

$$\Omega_{DM} \propto \frac{1}{. < \sigma v >}$$

$$< \sigma \mathrm{v} > \sim 1\mathrm{pb}$$

• The cross section results from an interaction mediated by a particle whose mass is of the order of $\sim$ 100 GeV.
• Masses are very close to the mass scale to the EW symetry breaking

Hints of new NP!

The WIMP:candidates

Supersymmetry offers LSP:

neutralino,

axino

Gravitino

sneutrino

The heavy Photon B_H in Little Higgs model.

The KK photon $B^{(1)}$ in Universal extra dimension(UED) model

....

Look for Dark Matter at colliders

A DM, is as weekly interacting as a neutrino, passes through the detector unobserved! Can be observed from the property of the particles produced in assocation with the WIMP. Most of the analysis is done the framework of SUSY.

Tevatron at $\sqrt{s} = 1960$ GeV, $m_{\tilde{q},\tilde{g}} \geq$ 300 GeV.

LHC $\sqrt{s} = 14000$ GeV, E_{eff} ~2000 GeV.
Expected to produce lot of WIMPs.

`Detection is a challenge`

Supersymmetry and Dark Matter

Supersymmetry has many free parameters: soft and gaugino masses, μ, $\tan\beta$, huge number of flavour-mixing parameters and phases.

Models: mSUGRA, AMSB, GMSB....

Neutralinos($\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$):

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z \cos\beta s_W & m_Z \sin\beta s_W \\ 0 & M_2 & m_Z \cos\beta c_W & -m_Z \sin\beta c_W \\ -m_Z \cos\beta s_W & m_Z \cos\beta c_W & 0 & -\mu \\ m_Z \sin\beta s_W & -m_Z \sin\beta c_W & -\mu & 0 \end{pmatrix}$$

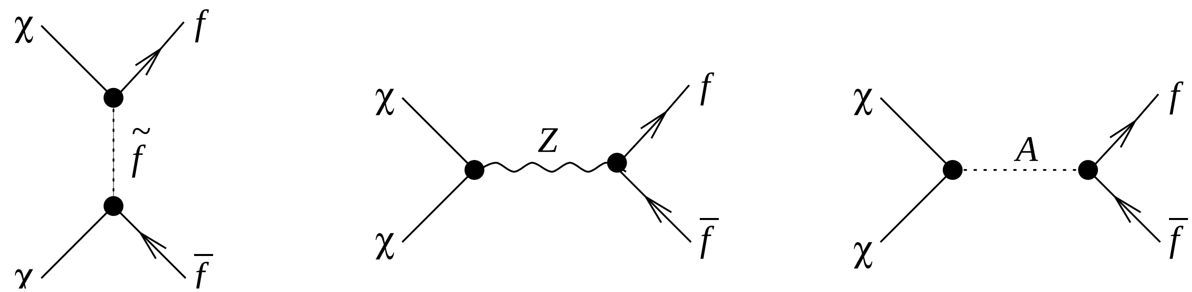
The $\tilde{\chi}$: $\tilde{\chi}^0 = a_w \tilde{W}^3 + a_B \tilde{B} + a_1 \tilde{H}_1^0 + a_2 \tilde{H}_2^0$

$|a_1|^2 + |a_2|^2 >> |a_W|^2 + |a_B|^2$ (Higgsino like)

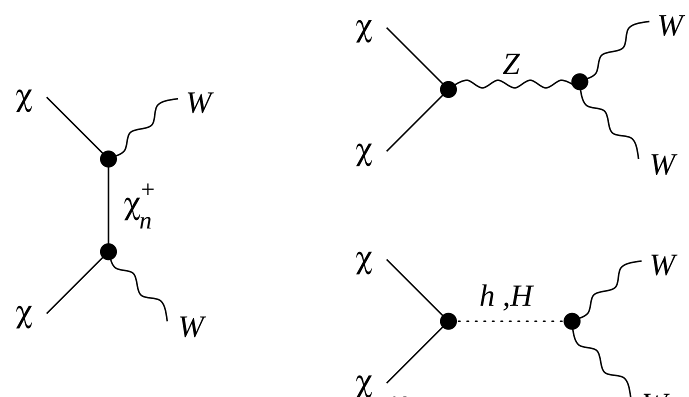
$|a_1|^2 + |a_2|^2 << |a_W|^2 + |a_B|^2$ (Bino like)

Neutralino Annhilation: $\tilde{\chi}\tilde{\chi} \to$ A+B

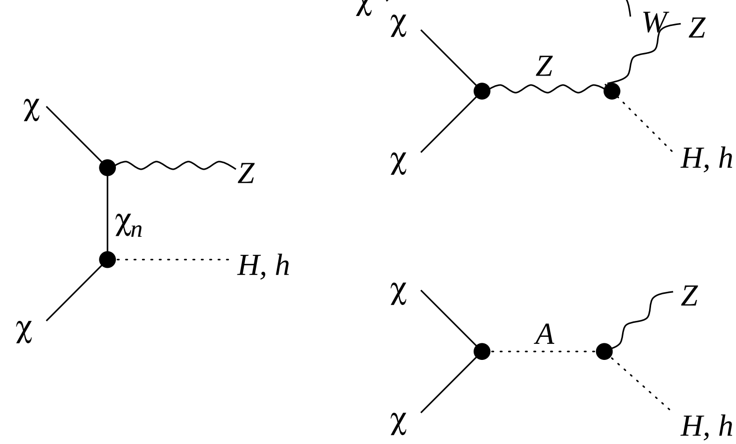
A, B $= q, \bar{q}, \ell\bar{\ell}$



A, B $= \mathrm{WW}, \mathrm{ZZ}$



A, B $= \mathrm{WH}, \mathrm{ZH}$



Model: mSUGRA

Parameters: $m_0, m_{1/2}, A_0, \tan\beta$, sgn($\mu$)

AT EW scale spectrum calculator:

ISASUGRA

SoftSUSY

SuSpect

Relic density calculations:

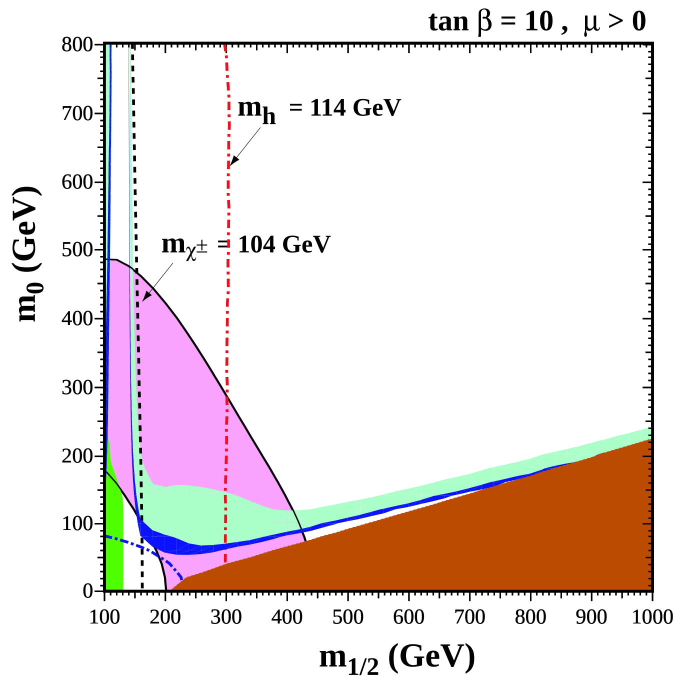
DarkSusy

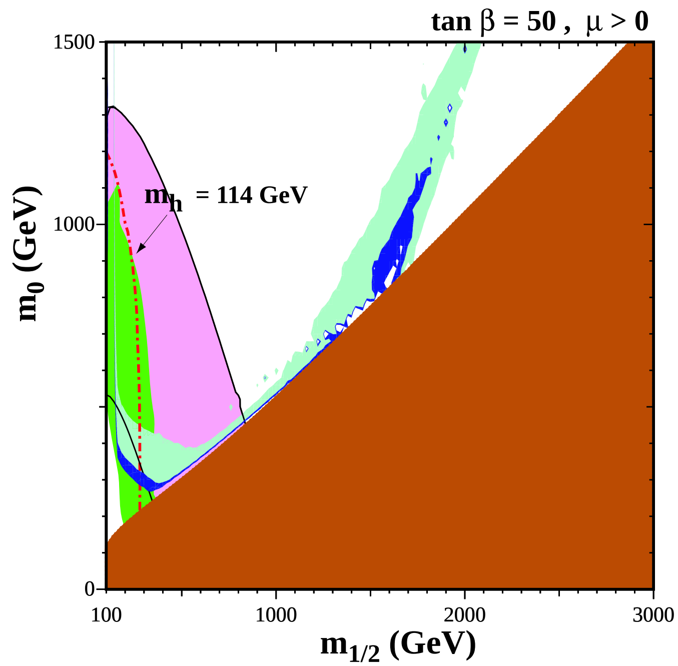
micrOMEGA

Constrained Parameter space

- The "funnel" region, $m_0 \sim m_{1/2}$, where neutralino rapidly annhilate via direct s-channel pseudoscalar Higgs poles, which opens up for large $\tan\beta$ region.
- "Co-annihilation" region, $m_{1/2} >> m_0$ it occurs $\tilde{\tau}_1 \tilde{\chi}_1^0 \to \tau\gamma$ or $\tilde{\tau}_1 \tilde{\tau}_1 \to \tau\bar{\tau}$. $\tilde{\tau}$ and $\tilde{\chi}_1^0$ is almost degenerate, making population of these two sparticles is almost the same, making NLSP $\tilde{\tau}$ thermally accessible. The ratio of population of these two particles depends on $\Delta M{=}(m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0})$ via Boltzman factor exp(-$\Delta M/T_f$). Bino like $\tilde{\chi}_1^0$
- The "Focus point" region $m_0(\sim$ few TeV)$>> m_{1/2}$, higgsino like $\tilde{\chi}_1^0$

mSUGRA constrained After WMAP





Parameter space dependent!!

- Can we verify if the DM particles in the neutralino expected to be produced at LHC?

- Can we look for a signal at the LHC that is reasonable direct consequences of the assumption that the neutralino is the DM particle?

SUSY particle production at Colliders

Squark and Gluino production:

$$\begin{aligned} pp &\rightarrow \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, ... \\ \tilde{g} &\rightarrow q\tilde{q} \\ \tilde{q} &\rightarrow q\tilde{\chi}_2^0 \\ \tilde{\chi}_2^0 &\rightarrow \mathrm{ff}\tilde{\chi}_1^0 \end{aligned}$$

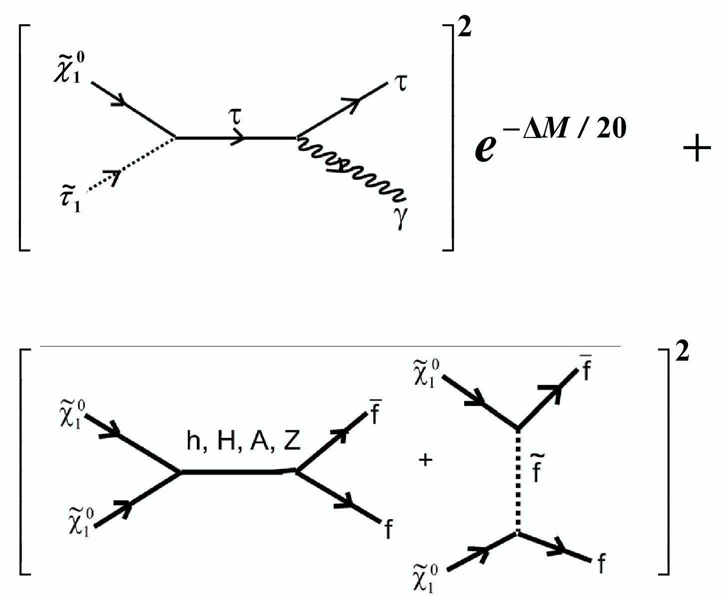
$\Rightarrow$ jets + leptons+ $\not{E}_T$

Strong interaction, large rates, eg. for $m_{\tilde{g}}$ =500 GeV, 1 event/fb

Co-annhilation region

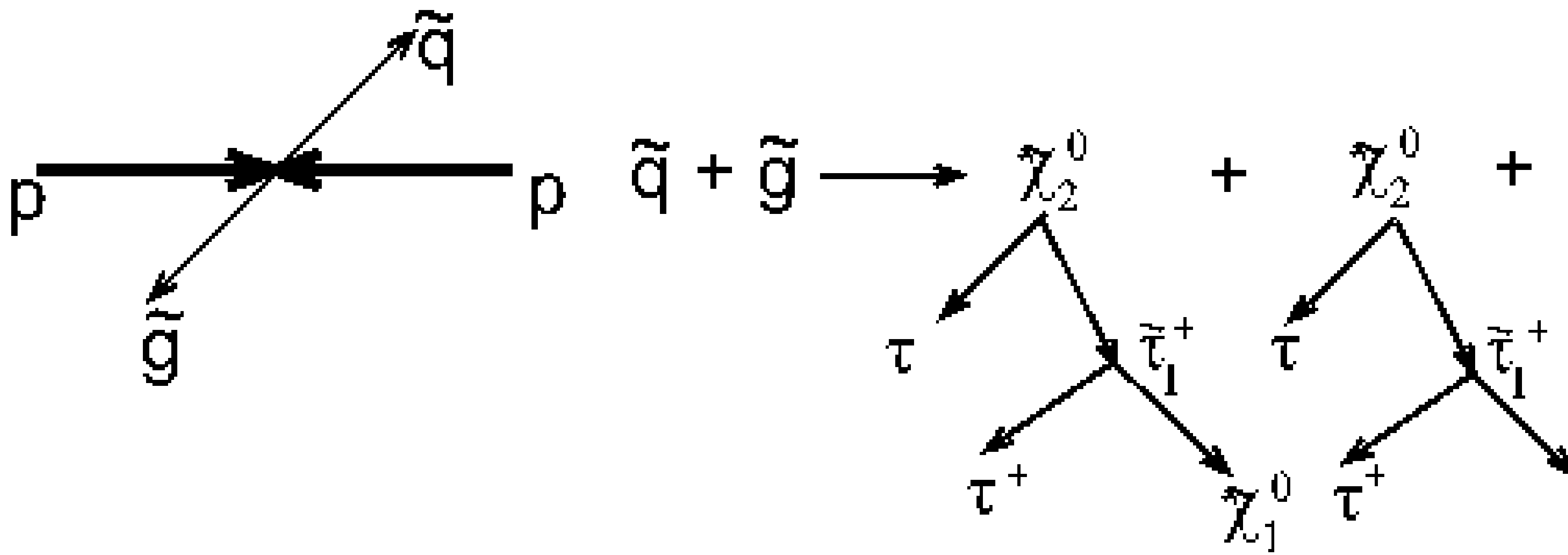
- m_0 small and $m_{1/2}$ $\leq$1.5 TeV

ΔM $\sim$5-15 GeV.



- Is it possible to have such low ΔM?
- At collider it is Experimentaly challenging

SUSY signal:Co-annhilation region



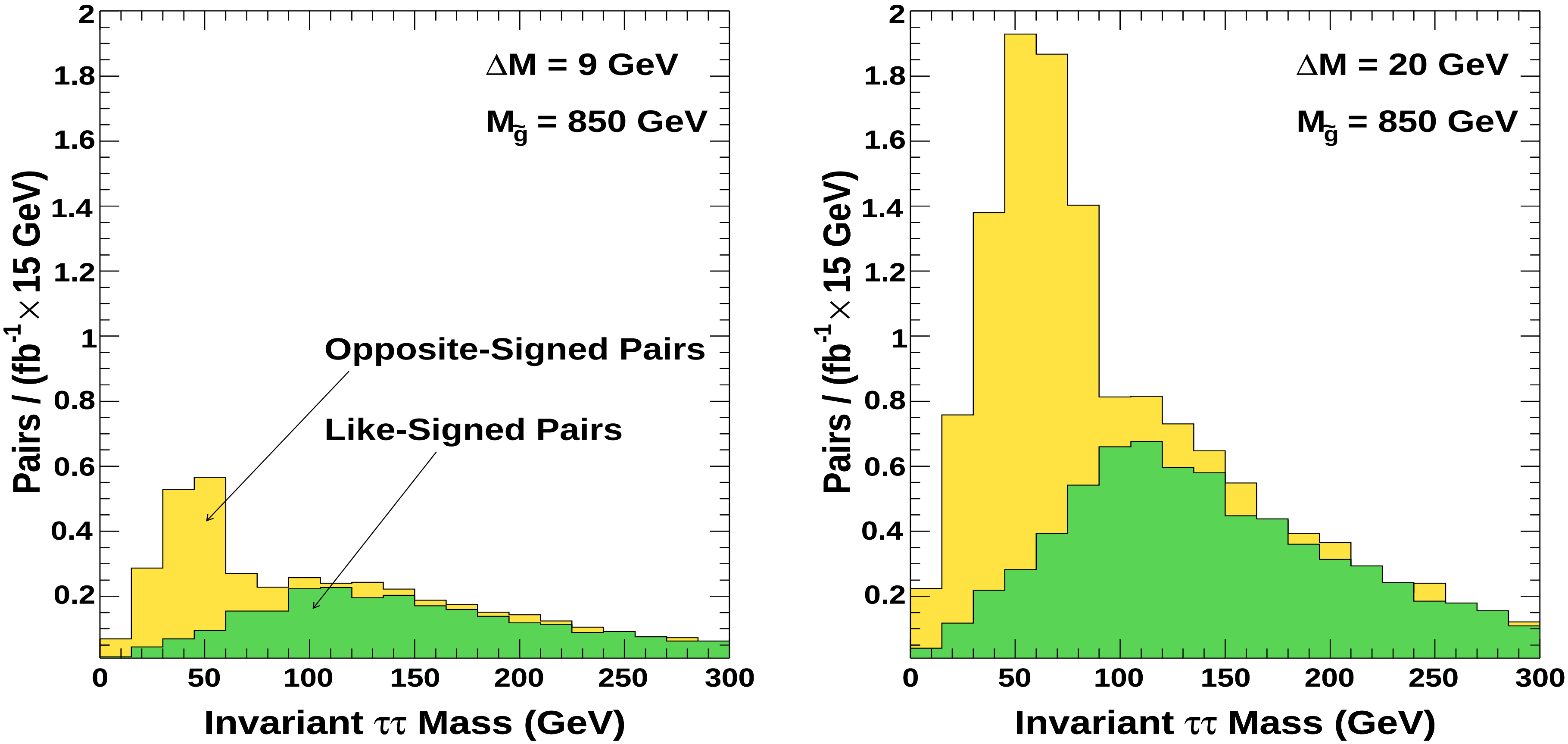
$\Delta M = m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$= 5-15 GeV

two “softer” and two harder τs in the final states

Signal: jets + $\not{E}_T$ + 4 τ (OS + SS)

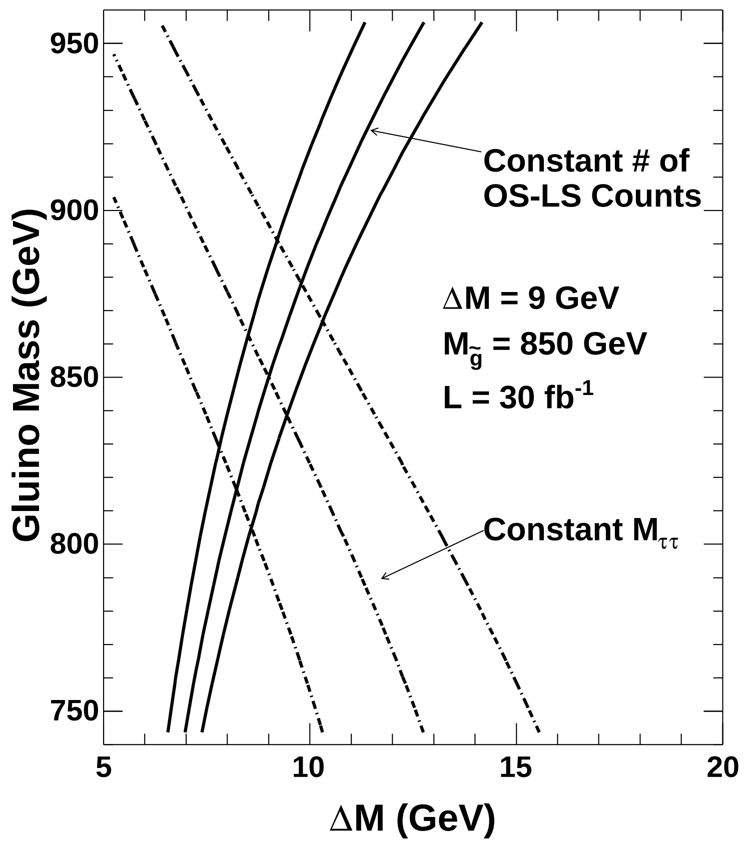
Arnowitt et. al. ’06

SUSY signal:Co-annhilation region



Arnowitt et. al. '06

SUSY signal:Co-annhilation region



$$\delta \Delta M / \Delta M \simeq 15\%; \ \delta M_{\tilde{g}} / M_{\tilde{g}} = 6\%$$

Arnowitt et. al. '06

Co-annhilation: Does Polarization of τ help?

$$\tilde{\chi}_2^0 \to \tau \tilde{\tau}_1; \tilde{\tau}_1 \to \tau \tilde{\chi}_1^0$$

$$\tau^+ \to \pi^+ \nu_\tau (12.5\%), \rho^+ \nu_\tau \to \pi^+ \pi^0 (24\%), a_1 \nu_\tau \to \pi^+ \pi^0 \pi^0 \nu_\tau ($$

$\Rightarrow$ "1-prong" decay For 1-prong decay: $\mathrm{R} = \frac{\mathrm{E}_\pi}{\mathrm{E}_{\tau-\mathrm{jet}}}$

- For positive Polarization: $\mathrm{R} \sim 1$ or R $\sim$ 0
- For negative polarization $\mathrm{R} \sim 0.5$
- Select softest τ jets with a cut on "R"(> 0.75),

mainly from $\tilde{\tau}_1$ decay, p_T depends on ΔM.
From the slope of p_T, possible to determine ΔM

R.M.Godbole, MG, D.P.Roy in preparation

SUSY signal: Focus point(FP) region

- Focus point scenario, large scalar masses,low values of μ is possible.
- $\tilde{\chi}_1^0$ is mostly higgsino like
- Avoid problem FCNC,
- Help to cancel EDM in CPX scenario.

FP:signal and Background

Squark and Gluino production:

$$\begin{aligned} pp &\rightarrow \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, ... \\ \tilde{g} &\rightarrow tt\tilde{\chi}, tb\tilde{\chi} \\ \tilde{\chi} &\rightarrow f\bar{f}\tilde{\chi}_1^0 \end{aligned}$$

$\tilde{\chi}_1^0$ Higgsino like : $\mathrm{t}-\bar{\mathrm{t}}-\tilde{\chi}_1^0, \mathrm{t}-\bar{\mathrm{b}}-\tilde{\chi}_1^0$ favoured

Generic signal: jet multiplicity is high, b-tagged jets + large $\not{E}_T$.

Backgrounds: $t\bar{t}$, $t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$, QCD..

Tools: PYTHIA for signals, ALPGEN for Bg(4 fermions)(results cross checked with CalcHep,MadGraph)

FP:Signal and Background cross sections

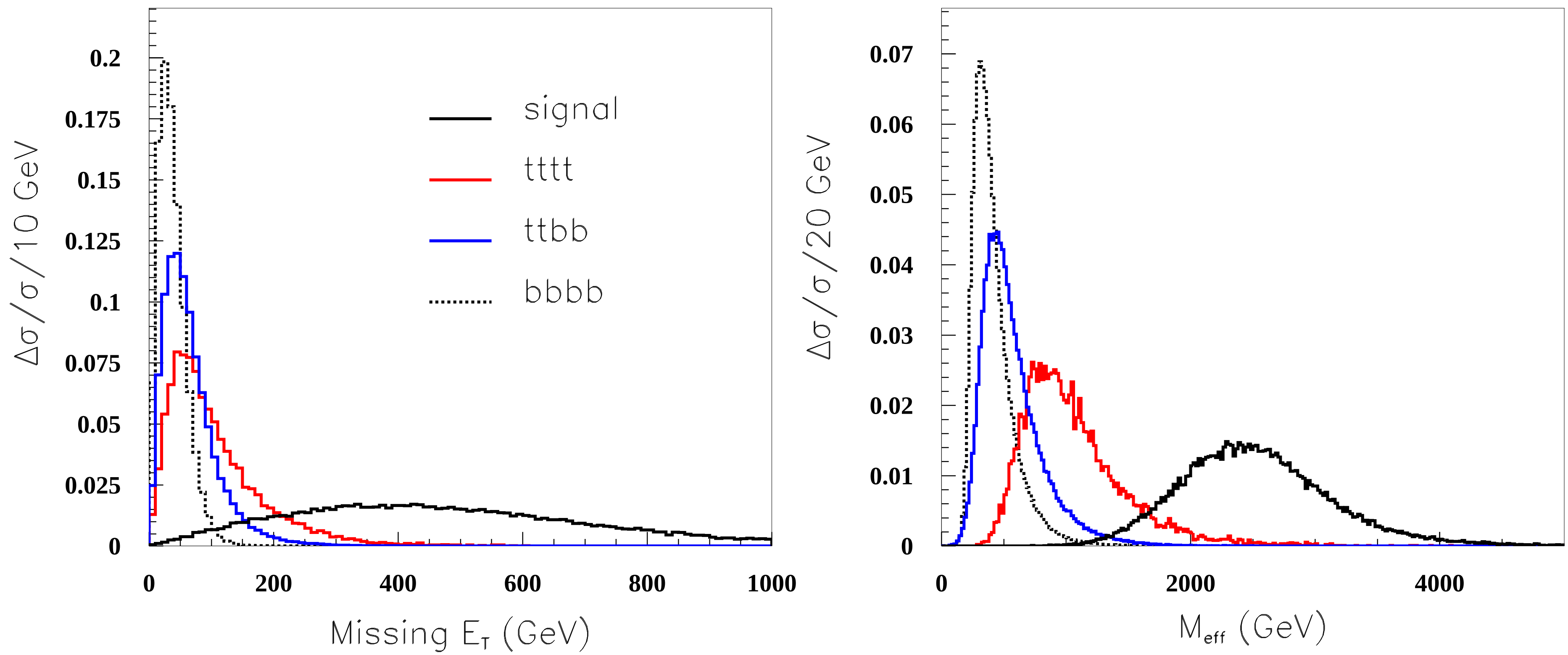
FP point ($\mathrm{m_0}$, $\mathrm{m_{1/2}}$)	$\mathrm{m_{\tilde{g}}}$	$\sigma(fb), Q = \sqrt{\hat{\mathrm{s}}}$
FP1 (3700.0, 700.0)	1751.3	1.18
FP2 (3975.0, 730.0)	1824.7	0.81
FP3 (3975.0, 790.0)	1950.0	0.39
FP4 (4130.0, 833.0)	2047.4	0.24
FP5 (4235.0, 866.0)	2119.8	0.16
$t\bar{t}t\bar{t}$		2.82
$t\bar{t}b\bar{b}(\hat{p}_T^b > 20GeV)$		1.76 $\times 10^3$
$b\bar{b}b\bar{b}(\hat{p}_T^b > 20GeV)$		7.61 $\times 10^3$
$t\bar{t}$		5$\times 10^5$
QCD$(\hat{p}_T > 500GeV)$		1.81 $\times 10^5$

For $\mathcal{L}$ =100/fb, signal events $\sim$ 100
Background events $\sim 10^3 - 10^6$ expected.

FP:Signal and Backgrounds

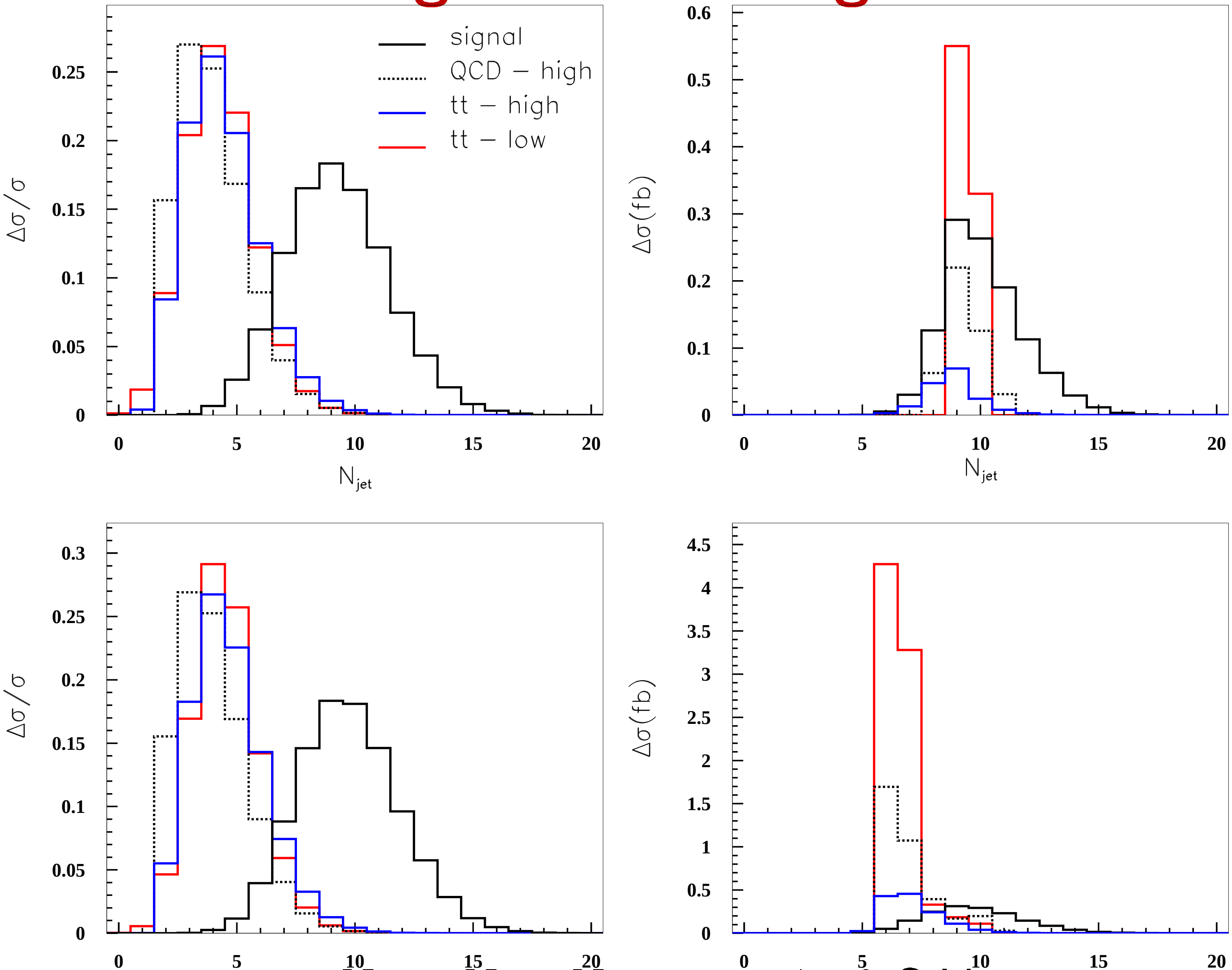
$$M_{\rm eff} = \not{E}_T + \sum_{\rm obj} E_T$$

$m_{\tilde{g}}$=1750 GeV;



M. Guchait
TIFR, Mumbai

FP:Signal and Backgrounds



$N_{\rm obj}=N_\ell + N_{jets}$; $m_{\tilde{g}}$=1750 GeV;

M. Guchait
TIFR, Mumbai

FP:Signal and Backgrounds cross section after cuts

Process	$N_{jet} \geq$ 6	$N_{obj} \geq$ 9	$N_{btag} \geq$ 2	$P_T^{b1} \geq$ GeV 300 GeV	$\not{E}_T \geq$ GeV 300 GeV	$M_{eff} \geq$ G 2000Ge
Signal	0.9674	0.7116	0.7899	0.6275	0.7416	0.8173
QCD - high	0.1490	0.0074	0.0177	0.0599	**0.0018**	0.1033
QCD - low	0.0151	0.0001	0.0052	0.0003	**0.0000**	1.9×10
$t\bar{t}$ - high	0.2318	**0.0188**	0.4567	0.5853	0.1799	0.0963
$t\bar{t}$ - low	0.1984	0.0083	0.1490	0.0074	0.0023	**0.0014**
$t\bar{t}t\bar{t}$	0.9304	0.5457	0.5946	0.1014	**0.0316**	**0.0340**
$t\bar{t}b\bar{b}$	0.5792	0.0831	0.4509	0.0265	0.0033	**0.0018**
$b\bar{b}b\bar{b}$	0.2186	0.0064	0.5854	0.0120	**0.00004**	0.0002

$S/\sqrt{(B)} \sim 10$ for $\mathcal{L}$ =300/fb for $m_{\tilde{g}}$ =1750 GeV.
Properties of $\tilde{\chi}_1^0$ need to be determined to make it ensure candidate for dark matter.

A.Datta, S.P.Das,MG, M. Maity,0708.2048

Summary

• Neutarlino is a DM candidate and WMAP data constrins the parameter space

• Co-annhilation region can be probed and possibly ΔM can be measured

• For Co-annhilation region, polarization f τ can be exploited

• Focus point scenario can also be probed, expected to probe $m_{\tilde{g}}$ upto 1.8 TeV. 3 b tag may be useful.

• Properties of $\tilde{\chi}_1^0$ need to be studied