pMSSM Studies at a 100 TeV Collider

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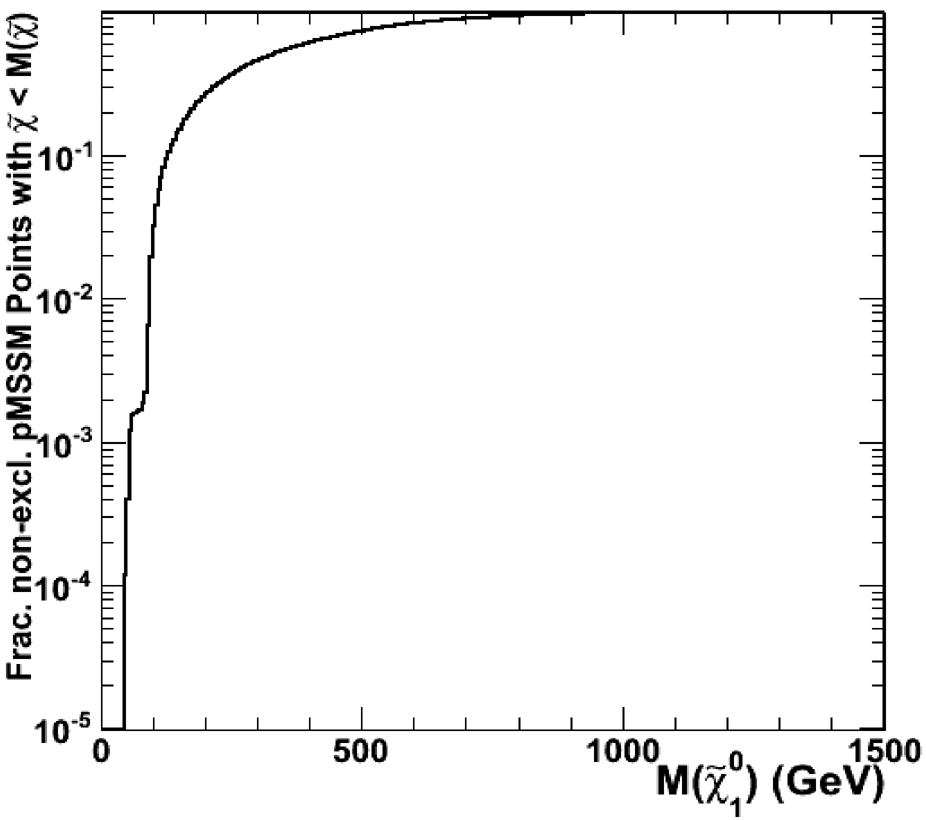
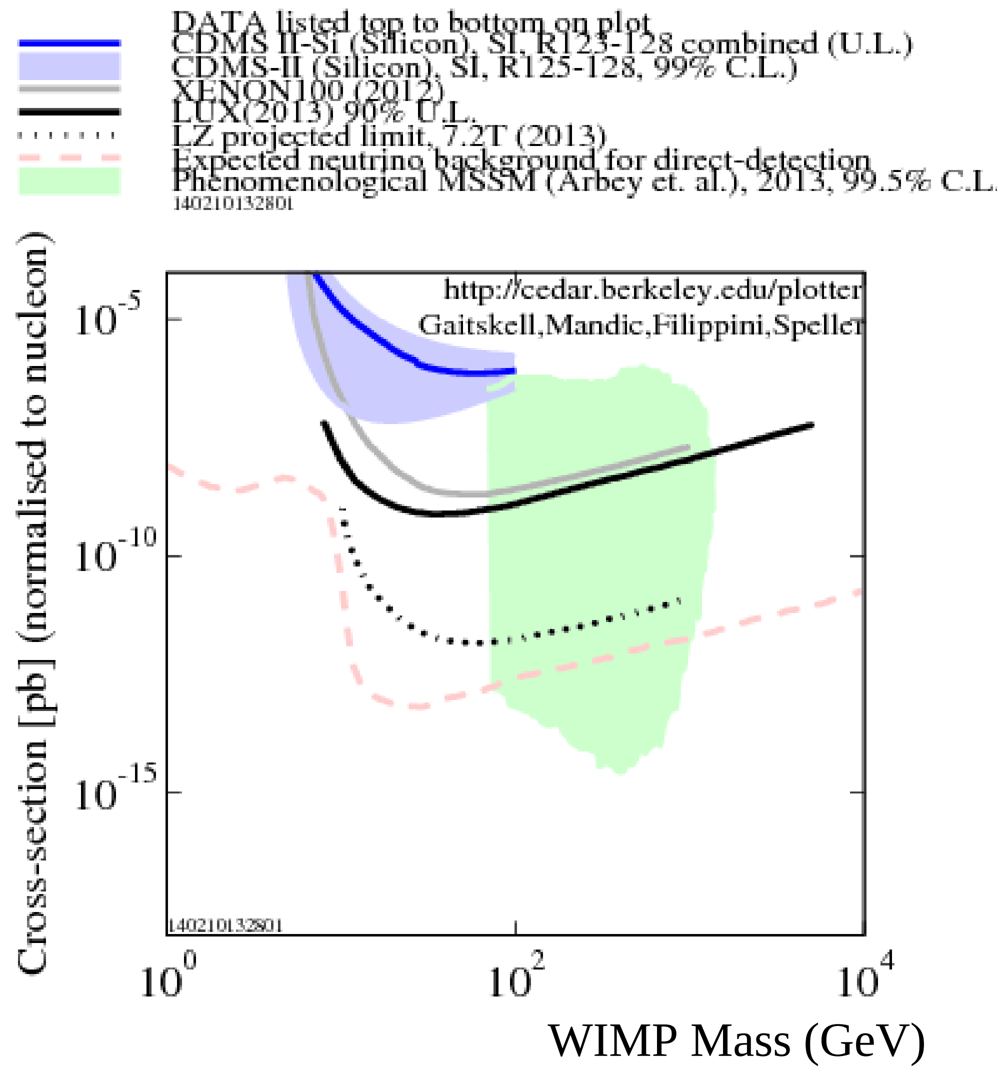
This study addresses the physics opportunites for a ~100 TeV collider for testing SUSY with special emphasis on the direct production of WIMPs, the complentarity with dark matter direct detection experiments and its role in the study of their nature;

ATLAS+CMS jets/leptons+MET
Searches 7+8 TeV

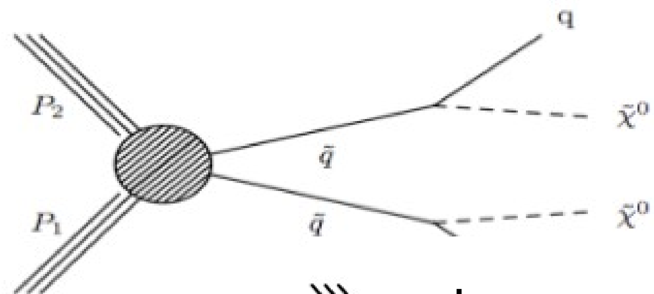


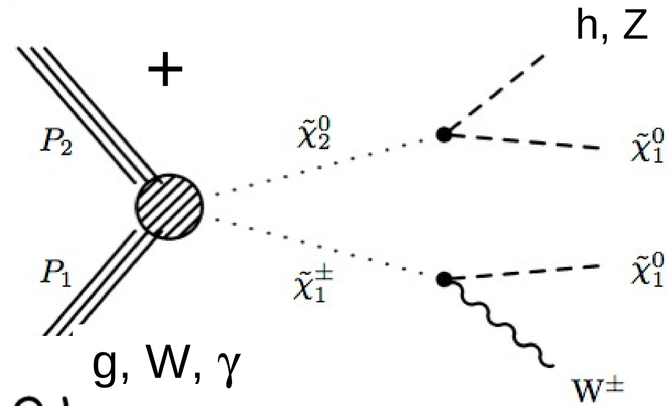


Can a 100 TeV collider say the definitive word on WIMPs at least in some well- defined models/theories (MSSM, …) ?

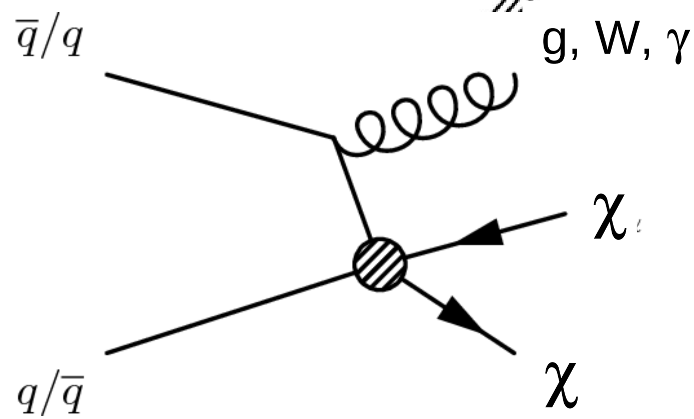
Combination of constraints from:

Jets/Leptons + MET Searches





Mono-jet/W/Z/g/l Searches

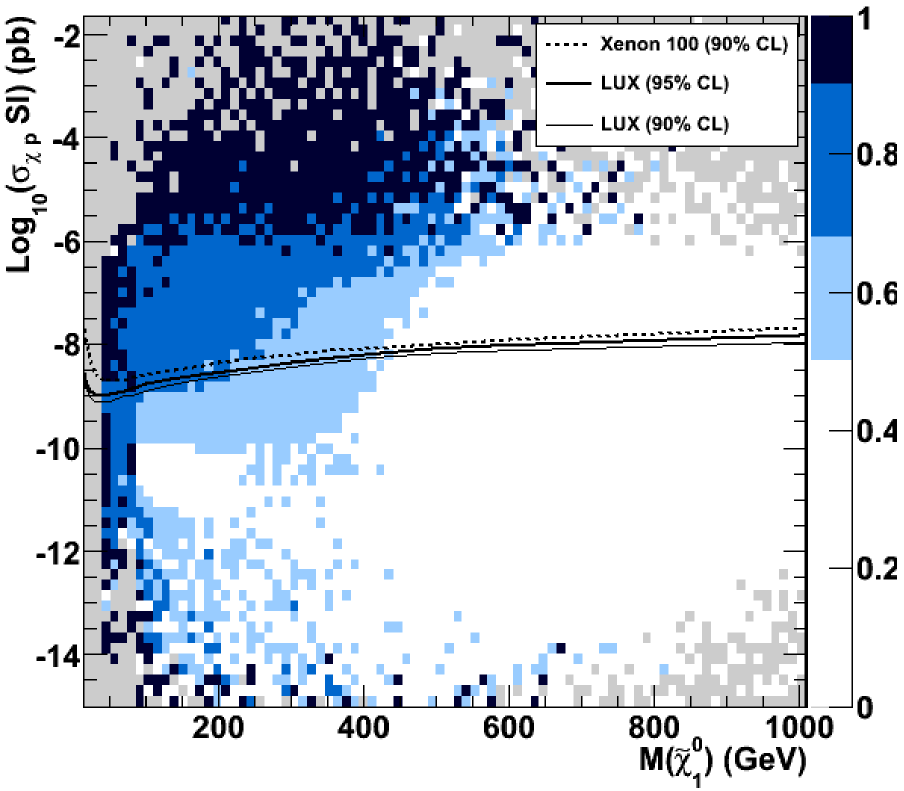


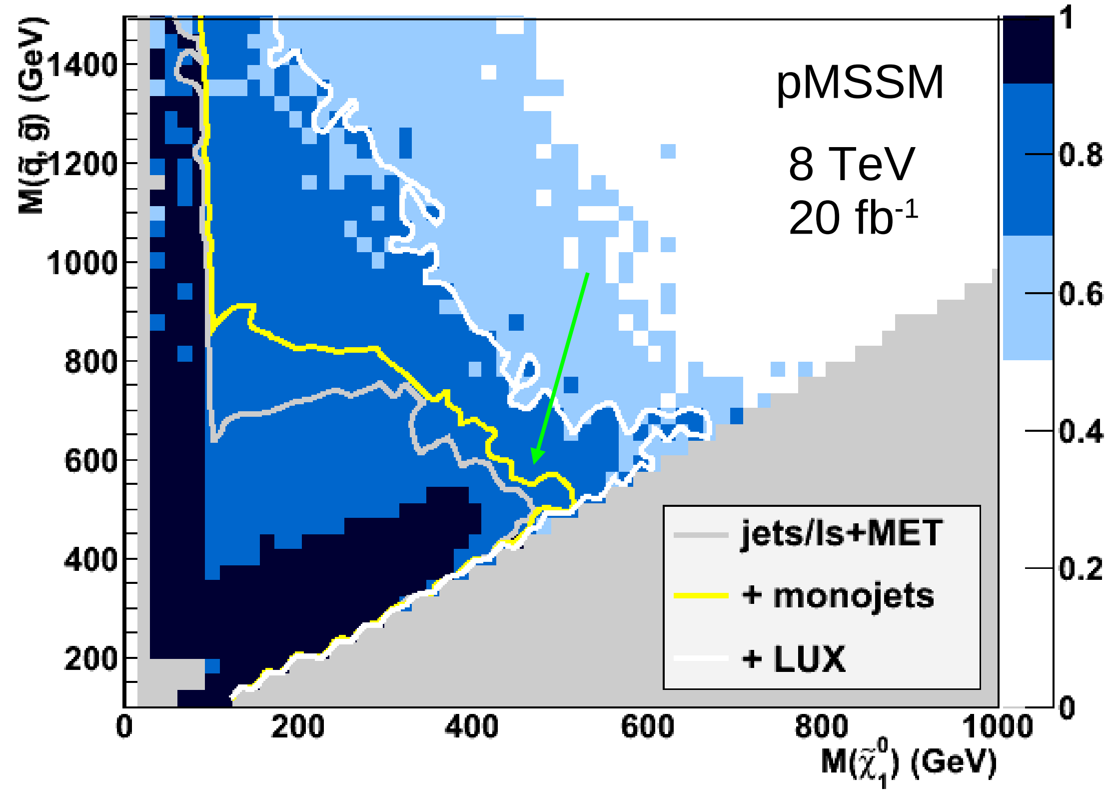
Dark Matter Direct Detection Underground Experiments:
LUX+Xenon+CDMS, LZ, 3rd generation experiments

Complementarity of Mono-jet and Jets/leptons +MET searches in MSSM

In the case of SUSY χ^0_1 WIMP, results are affected by the availability of multiple propagators and presence of other particles at small mass splitting, still mono-jets add to the LHC sensitivity, notably in the kinematically difficult small ΔM region;

An example at 8 TeV (pMSSM masses limited at 3 TeV):





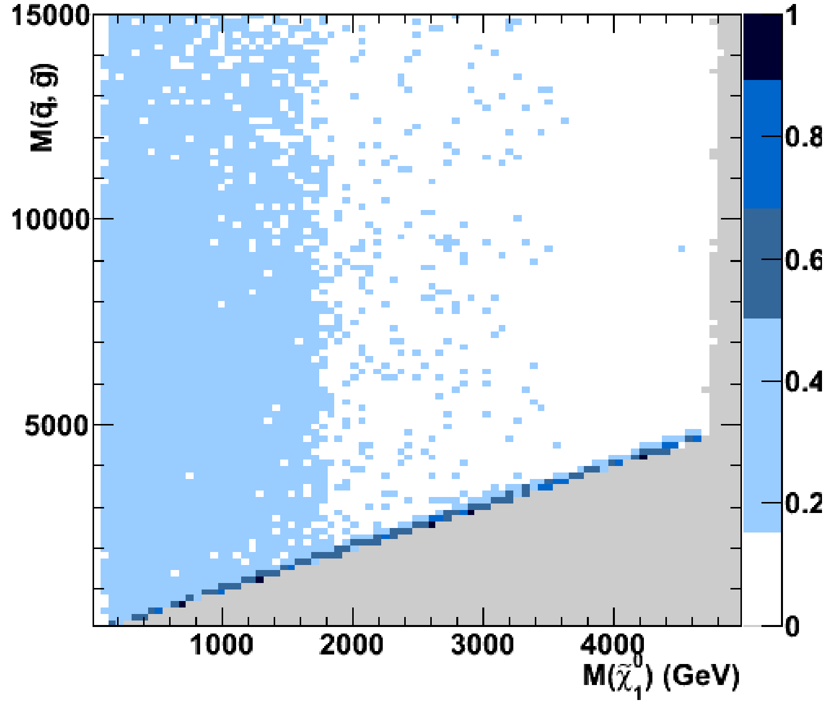
Arbey, MB, Mahmoudi, PRD 89 (2014) 077701

Main regions of interest for mono-jets et al.:

Large mass splitting scenarios where other particles are too heavy to be detected

$M_1 << M_2, M_3, \mu \rightarrow \chi$ WIMP must be bino-like, cross section drops but Ωh^2 is too large

Fraction of pMSSM points compatible with PLANCK $\Omega_\chi h^2$ upper limit (+syst)



Small mass splitting scenarios where kinematics reduces efficiency of jets/leptions+MET searches

$M_1 \sim M_3$ (or M~q) $<< M_2, \mu$: Ωh^2 brought down by co-annihilation, mono-jet xsec boosted by production of strongly-interacting sparticles

$M_1 \sim M_2$ or $\mu << M_3$ monoW/Z best suited for detection

pMSSM Scans for 100 TeV physics

Perform broad pMSSM scan
with sparticle masses up to 20-25 TeV:

Impose Ωh^2 flavour, LEP and LHC constraints:

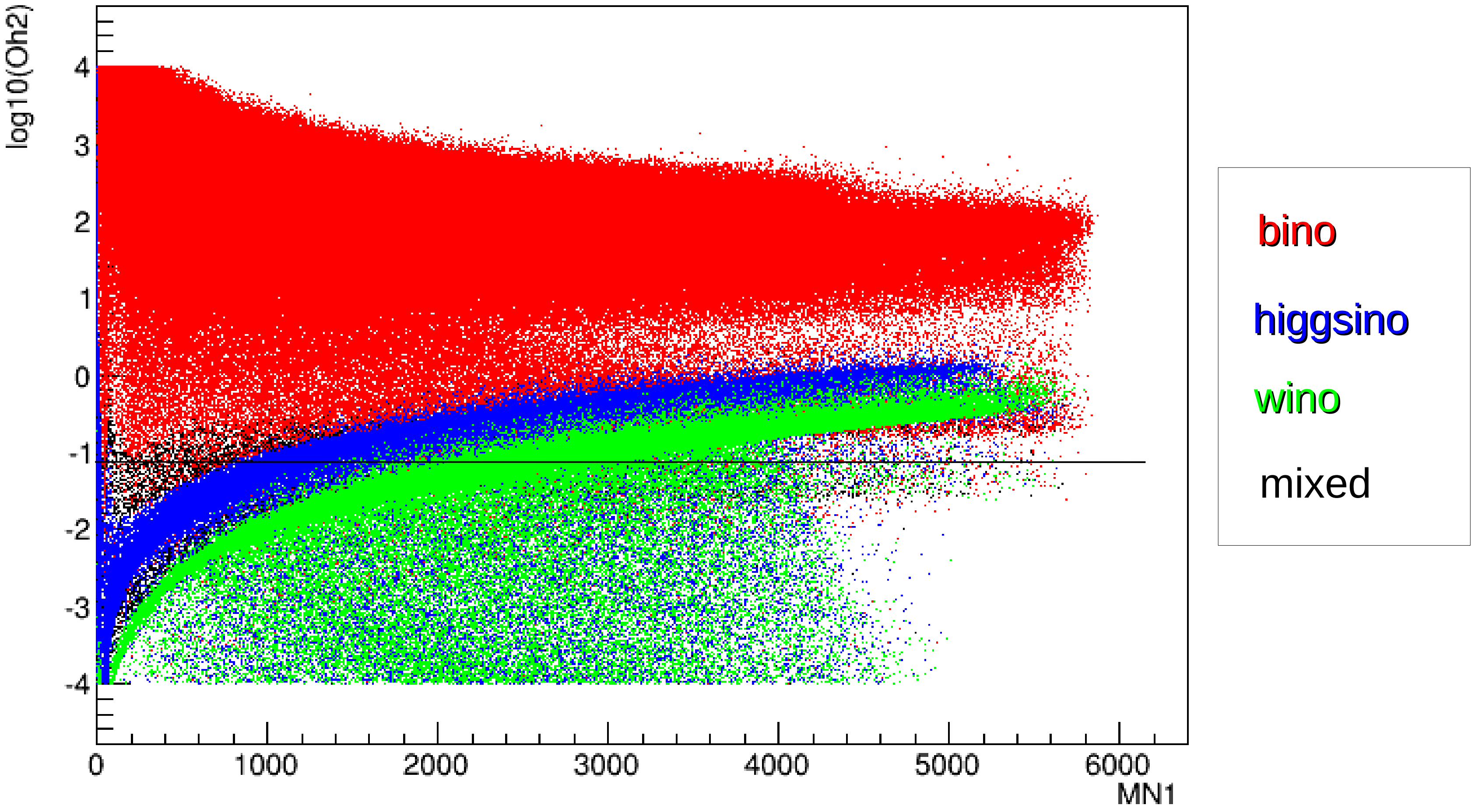
$$10^{-4} < \Omega_\chi h^2 < 0.163$$

$$1.1 \times 10^{-9} < \mathrm{BR}(B_s \to \mu^+\mu^-) < 6.4 \times 10^{-9}$$

$$123 < M_h < 129 \text{ GeV}$$

Parameter	Range
$\tan\beta$	[1, 60]
M_A	[50, 10000]
M_1	[-6000, 6000]
M_2	[-8500, 8500]
M_3	[50, 28000]
$A_d = A_s = A_b$	[-20000, 20000]
$A_u = A_c = A_t$	[-20000, 20000]
$A_e = A_\mu = A_\tau$	[-20000, 20000]
μ	[-12000, 12000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 12000]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 12000]
$M_{\tilde{\tau}_L}$	[50, 12000]
$M_{\tilde{\tau}_R}$	[50, 12000]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$M_{\tilde{q}_{3L}}$	[50, 25000]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 25000]
$M_{\tilde{t}_R}$	[50, 25000]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 25000]
$M_{\tilde{b}_R}$	[50, 25000]

Neutralino Mass and Relic Density

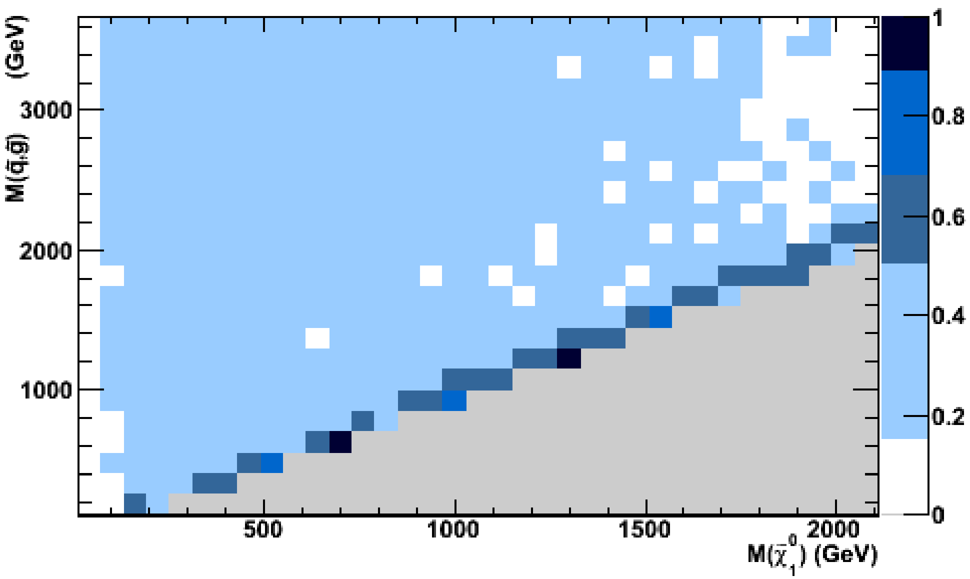


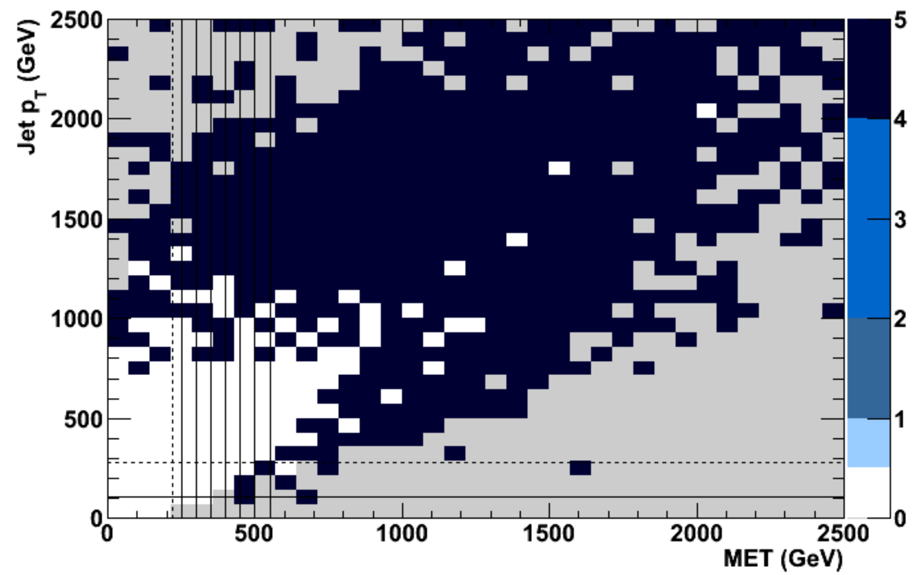
In absence of efficient annihilation mechanism, neutralino masses above ~3.5 TeV are incompatible with CMB Planck and WMAP data, co-annihilation with squarks brings their masses below 4 TeV and enhances both collider and scattering cross sections.

pMSSM Scans for 100 TeV physics

Take analyses as performed at 8 TeV, no cut optimisation (yet),
use SM bkg from ATLAS/CMS analyses and scale it up by appropriate factor to describe increase of rate in signal regions (MadGraph):
14 TeV 3 ab^{-1}, 80 & 100 TeV 1-10 ab^{-1}

Study S/B in jet pT vs MET plane for points along small mass splitting region at 14, 80 and 100 TeV





Assess if the points can be excluded at 95%CL by LHC-style search;

Study M(~q,~g) vs M(χ) and σ(χp) SI vs M(χ).

pp collider channels from LHC Run 1

Signal event generation with Madgraph & Pythia from scan points;
Physics objects reconstruction with Delphes & FastJet;
Test exclusion against scaled bkg using CLs.

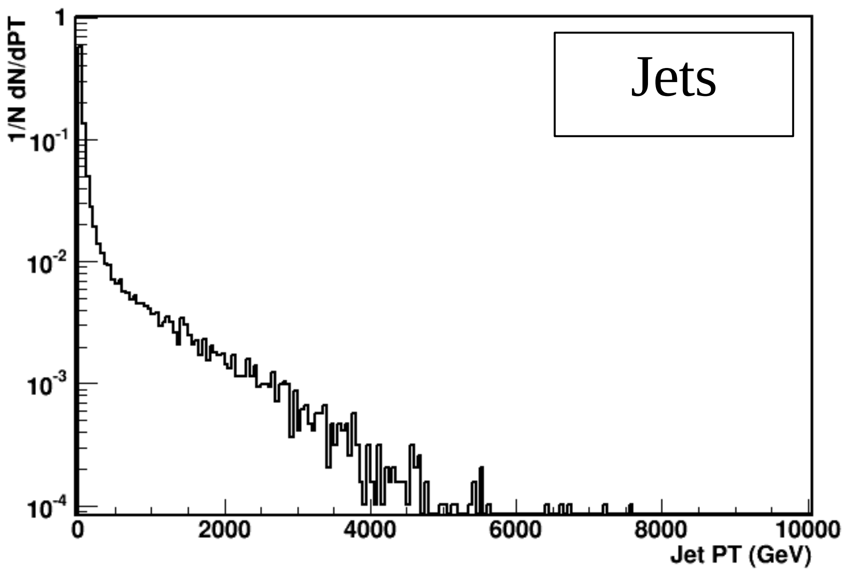
Jets+MET	EWK	mJ	mW/Z
j0l+MET bb0l+MET (ATLAS)	2l+MET 3l+MET bb(h)l+MET (ATLAS)	MonoJET+MET (ATLAS+CMS)	monoW/Z+MET (ATLAS)

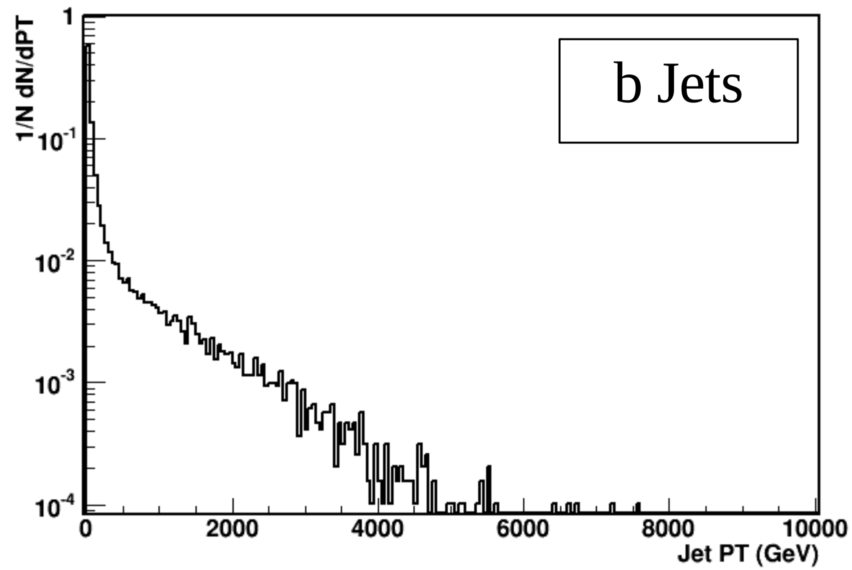
Fraction of pMSSM points excluded at 95%CL

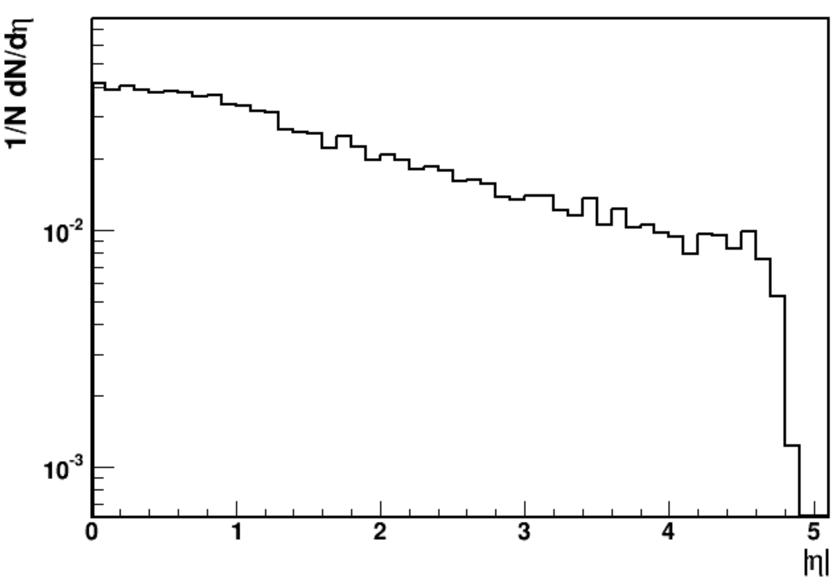
	Jets+MET	EWK	mJ	mW/Z
14 TeV $3\ ab^{-1}$	0.08	0.02	0.01	0.001
100 TeV $5\ ab^{-1}$	0.65	0.08	0.16	0.02

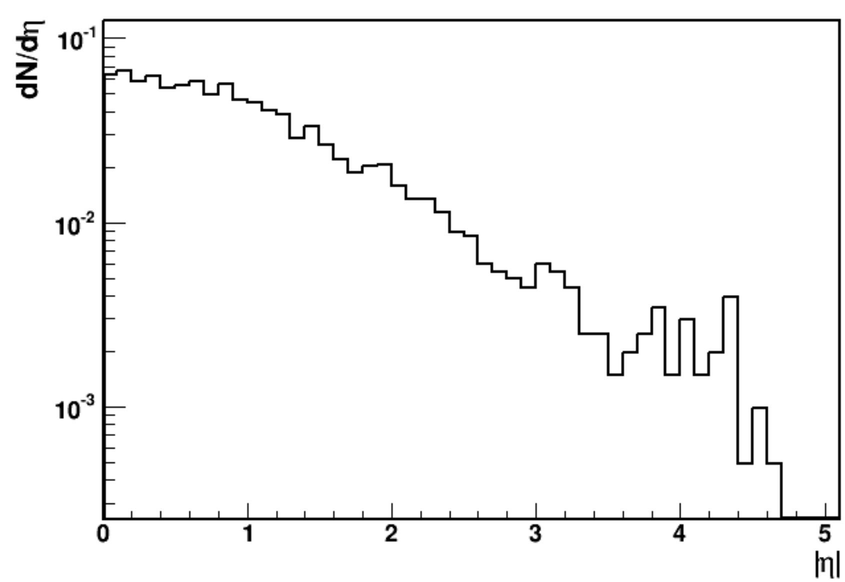
Signal Characterisation at 100 TeV

Distributions of PT and Rapidity of SUSY events for a "typical" accepted (and excluded) pMSSM point at 100 TeV (one entry/event)



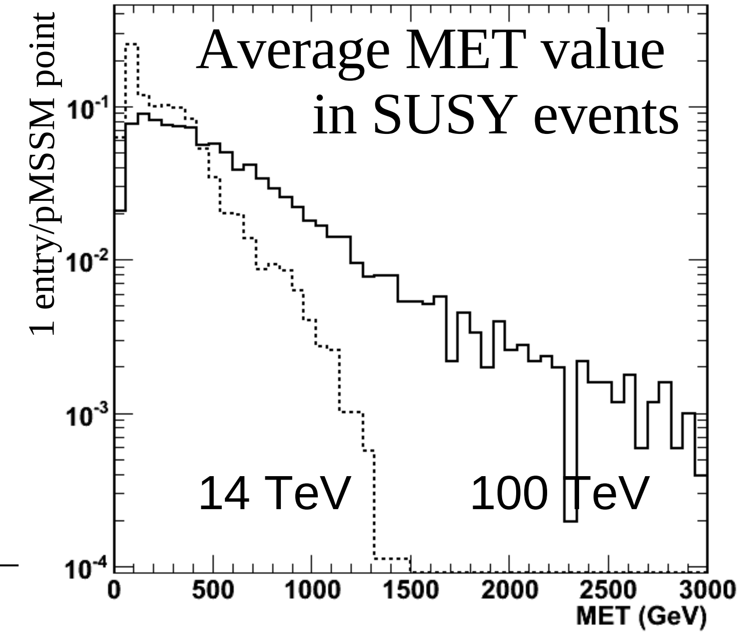




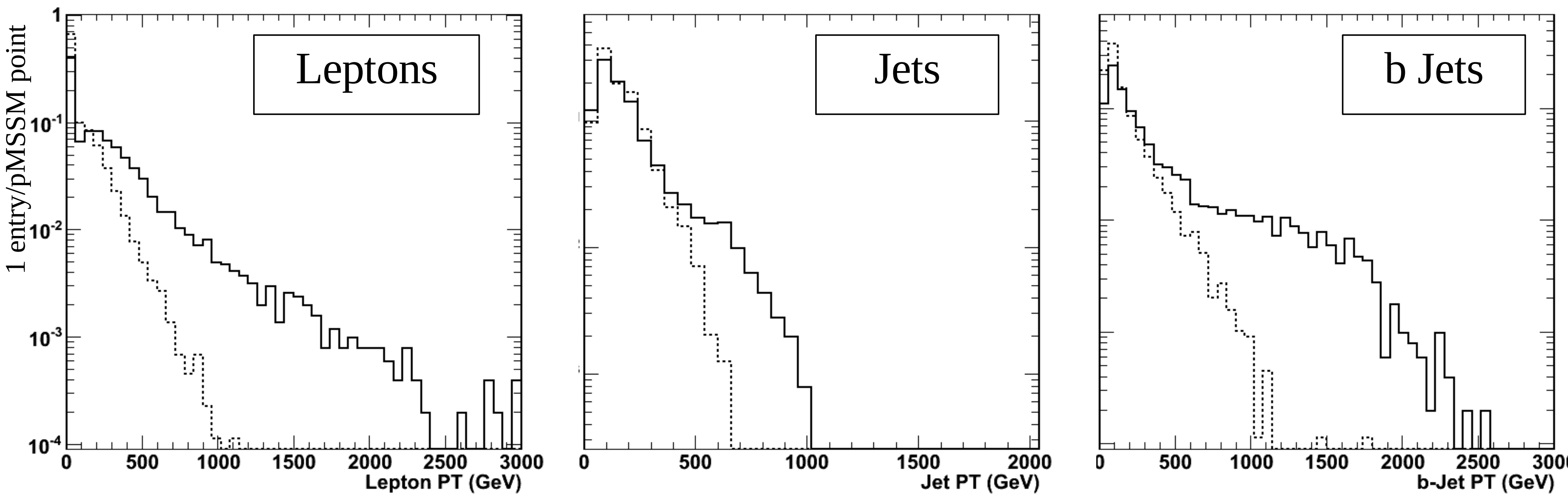


Signal Characterisation at 14 and 100 TeV

Distributions of average values in SUSY events
for a set of accepted pMSSM points
(one entry/pMSSM point)

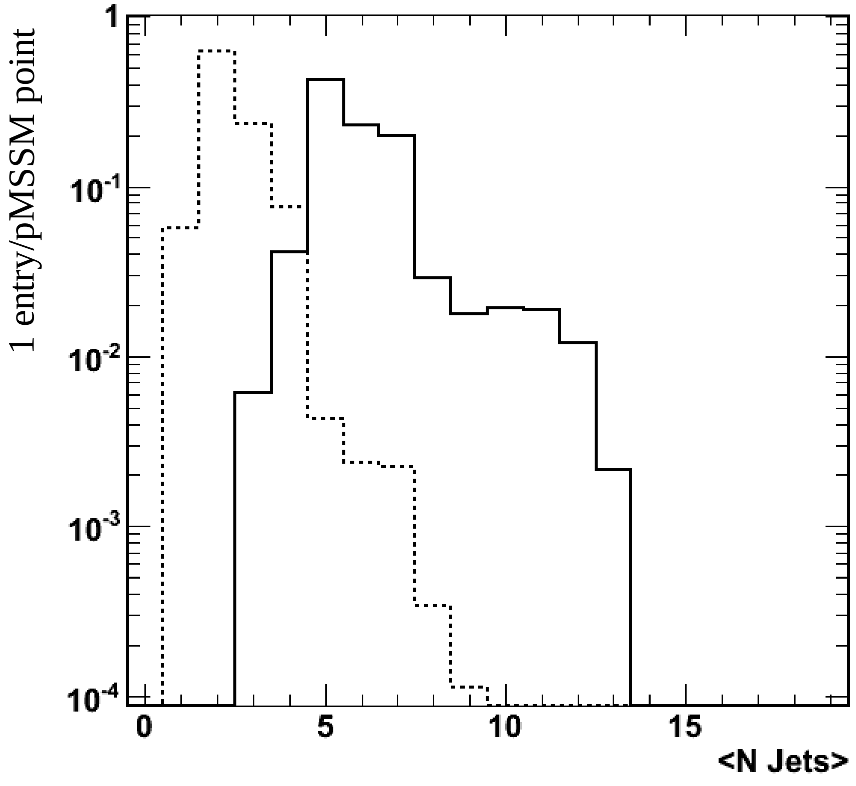


Average PT value in SUSY events

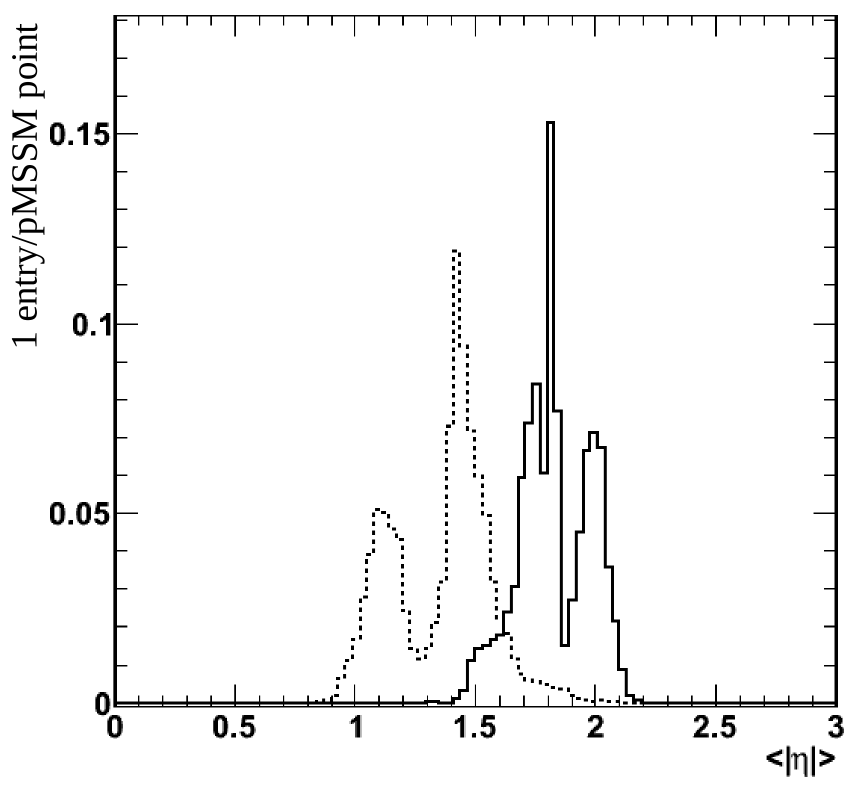


Signal Characterisation at 14 and 100 TeV

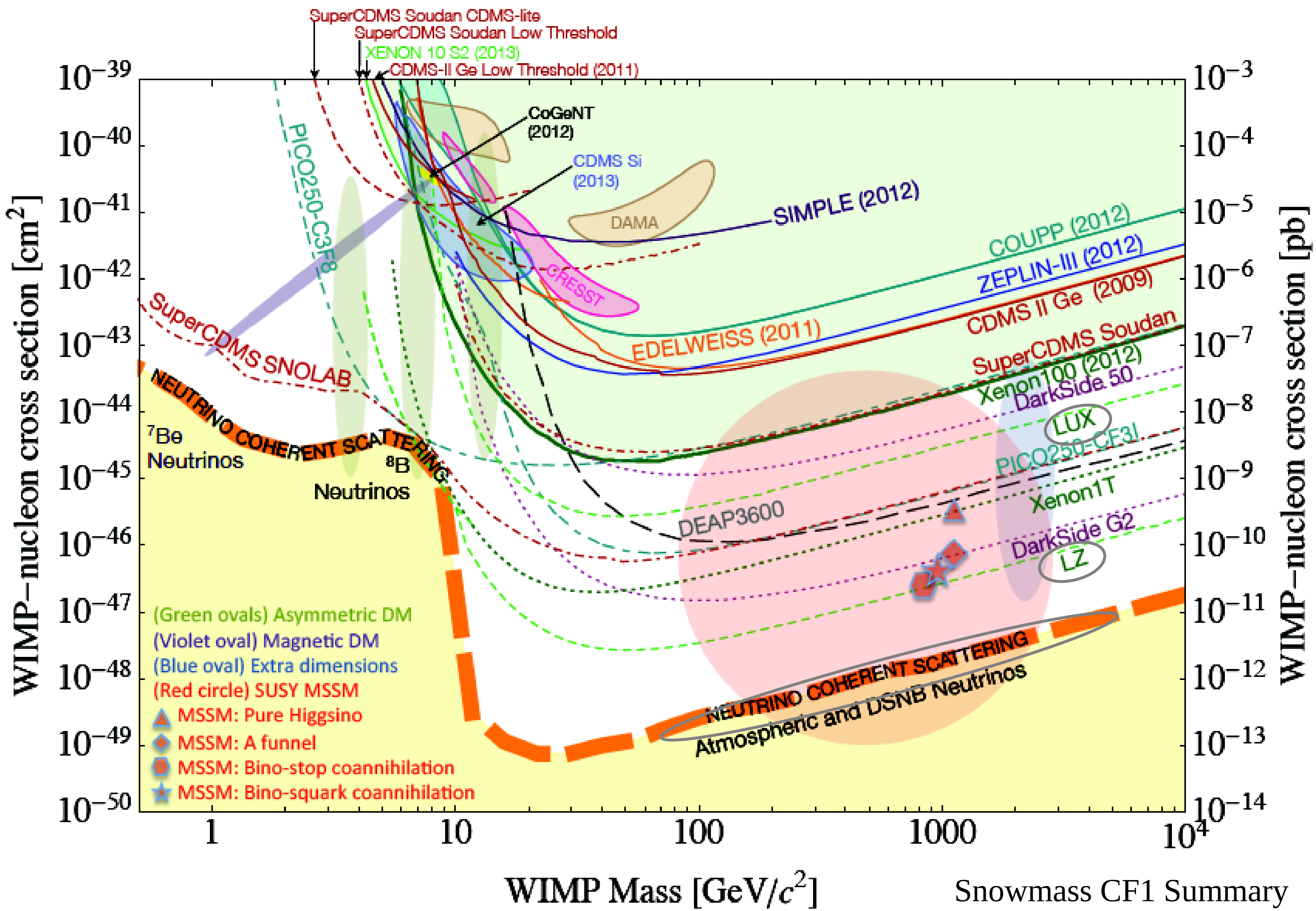
Average Jet Multiplicity in SUSY events



Average Jet Rapidity in SUSY events



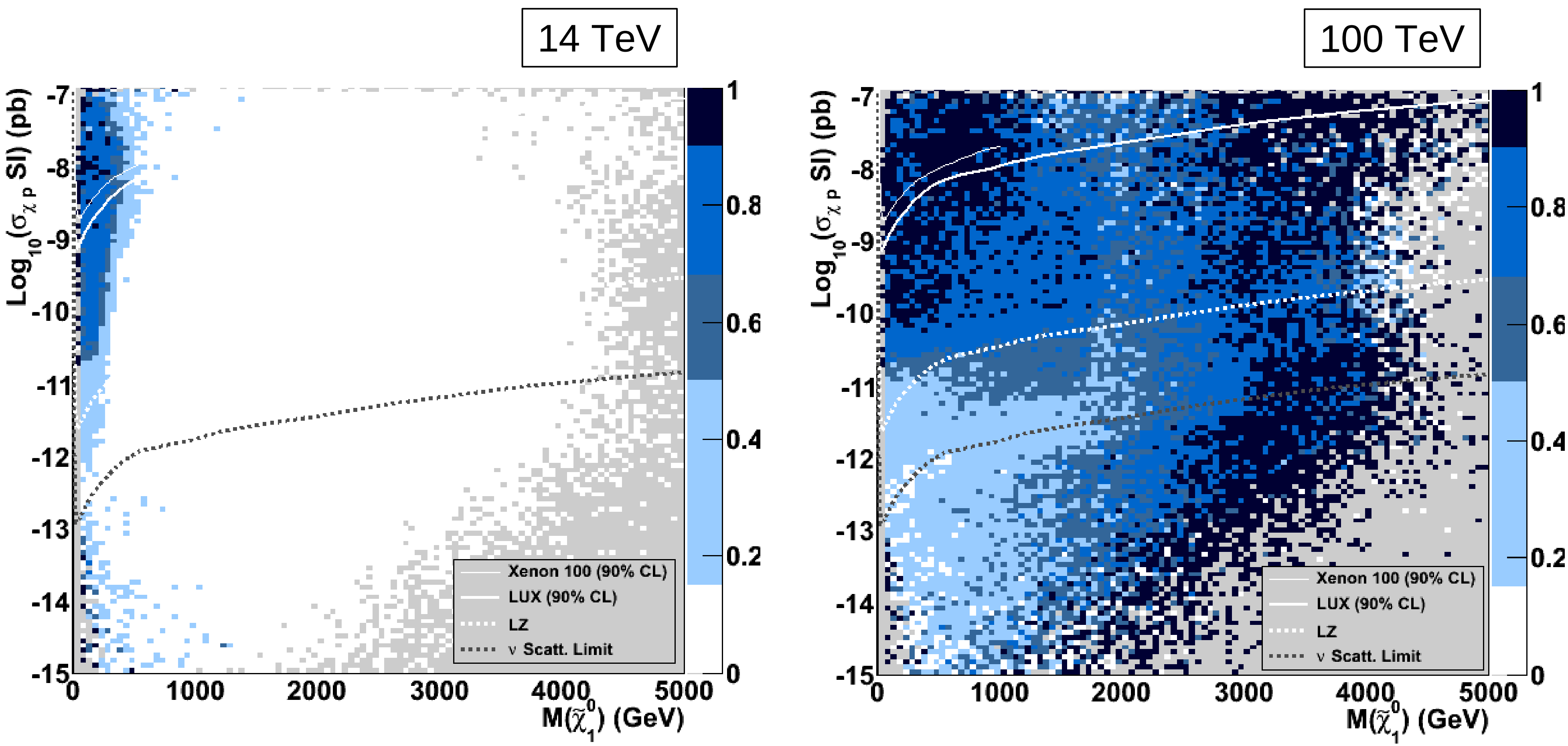
Dark Matter Direct Detection Experiments: Limits and Future Sensitivity



Snowmass CF1 Summary
arXiv:1310.8327

Spin-independent Scattering Cross Section vs M_{WIMP}:
14 vs 100 TeV

Fraction of pMSSM points excluded at 95%CL

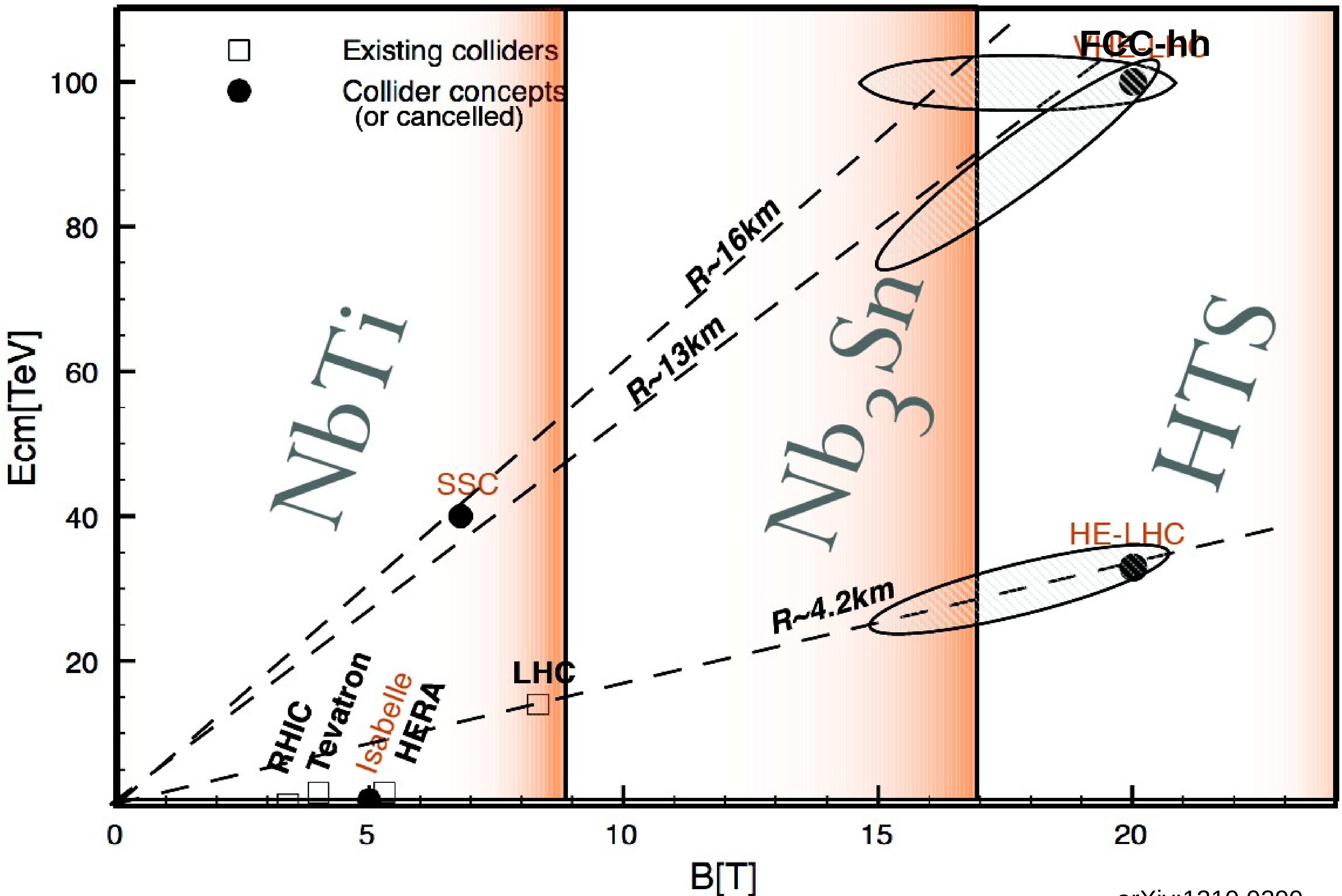


Summary of fractions of excluded pMSSM points: Combination of Collider and DM Searches

(Preliminary)	Jets+MET+EWK +mJ +mW/Z	+LUX DM	+LZ DM	+3rd Gen. DM
14TeV 3 ab^{-1}	0.09	0.19	**0.50**	0.76
100 TeV 1 ab^{-1}	0.63	0.65	0.73	0.90
100 TeV 3 ab^{-1}	0.67	0.69	0.75	0.91
100 TeV 5 ab^{-1}	0.69	0.72	0.76	**0.92**

Interpretations of DM limits depend on local DM density which is subject to uncertainties; interpretation of collider results has reduced systematics;

Role of the superconductor in energy reach at hadron colliders



arXiv:1310.0290

Summary of fractions of excluded pMSSM points: Reach vs Collider Energy and Luminosity

(Preliminary)	80 TeV	80 TeV+ 3G DM	100 TeV	100 TeV +3G DM
1 ab^{-1}	0.57	0.88	0.63	0.90
3 ab^{-1}	0.63	0.89	0.67	0.91
5 ab^{-1}	0.65	0.89	0.69	0.92
10 ab^{-1}	0.66	0.90	0.69	0.92

Study Plans

Develop study along two main lines:

i) Assess collider energy (80 → 120 TeV)/ & luminosity (1-10 ab^{-1}) requirements to achieve full coverage of pMSSM parameter space when combined with 3G DM search
ii) Characterise event features and probe detector requirements;

Include more SUSY search channels and optimise cuts: probe reach of 100 TeV;

Identify and characterise points escaping exclusion;

After setting exclusion limits, focus on observation what would be learned at various energies and luminosities.