Can a high energy pp collider discover or exclude DM-motivated New Physics Models ?

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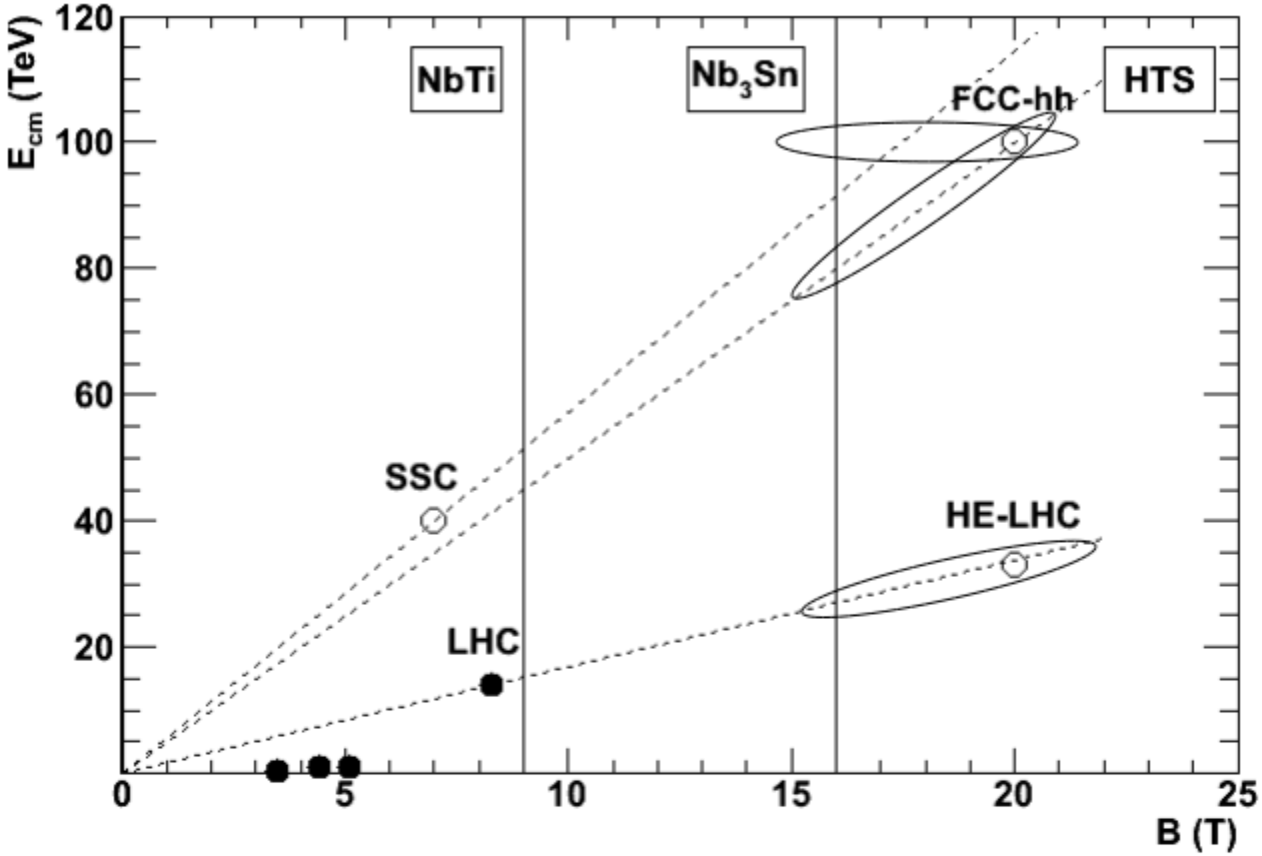
Dark Matter at a future hadron collider, FNAL December 4th 2015

Increasing beam energy pushes sensitivity to new physics processes;
but beam energy has important technological, design and cost implications



- for signal at fixed mass M, cross section grows with c.m. energy √s (at least as partonic luminosity L(x));

- for frontier mass reach luminosity must scale as s.

Beyond increasing our sensitivity and mass reach, will a high energy hadron collider provide us with some definitive answers on our most pressing questions ?

Can we discover or falsify DM-motivated models at LHC, HL-LHC, FCC ?

Is the mass scale of models of DM bound from from above so that the reach of a LHC and future hadron collider can be benchmarked against them ?

Full models: MSSM with neutralino or gravitino LSP

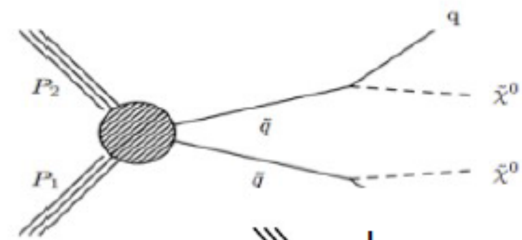
Effective Field Theories

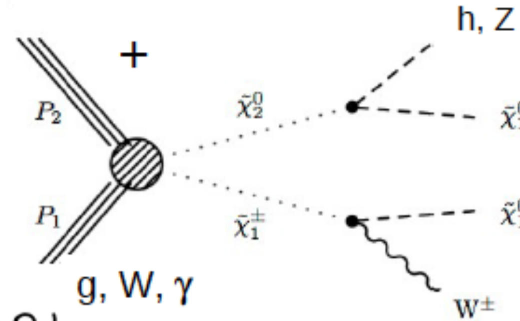
Collider analyses:

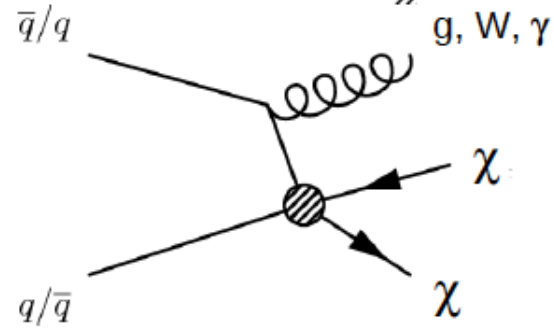
jets +MET

leptons + MET

mono-jets/gamma/V etc + MET







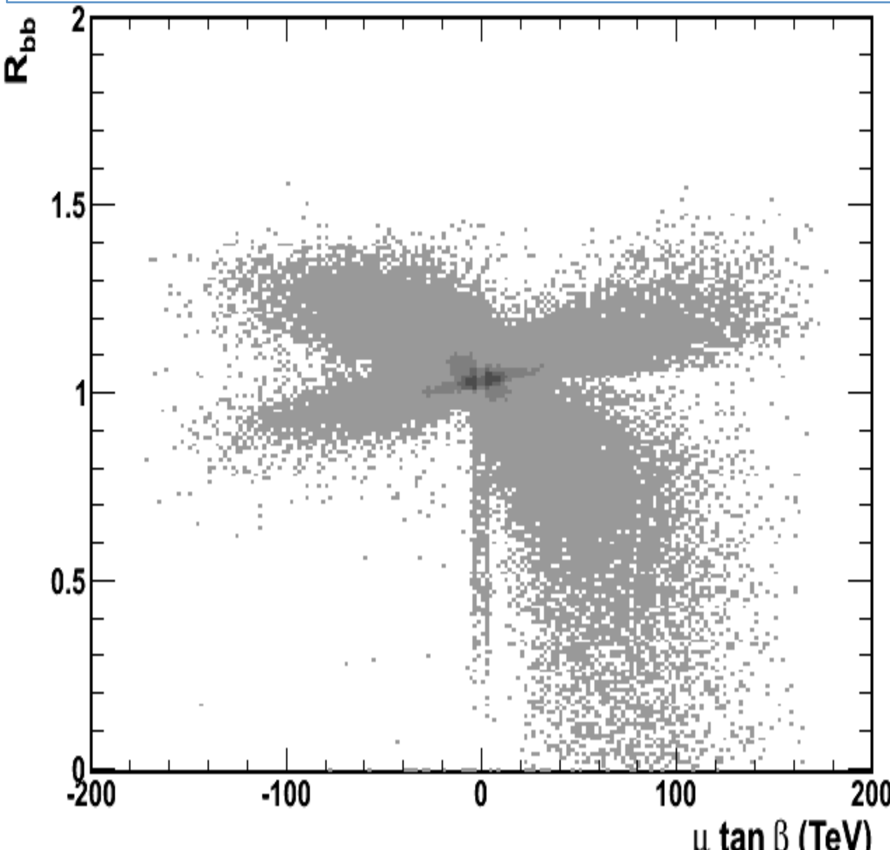
Jets+MET j0l+MET bb0l+MET (ATLAS)	EWK 2l+MET 3l+MET bb(h)l+MET (ATLAS)	mJ MonoJET+MET (ATLAS+CMS)	mW/Z monoW/Z+MET (ATLAS)

Higgs couplings and signal strengths

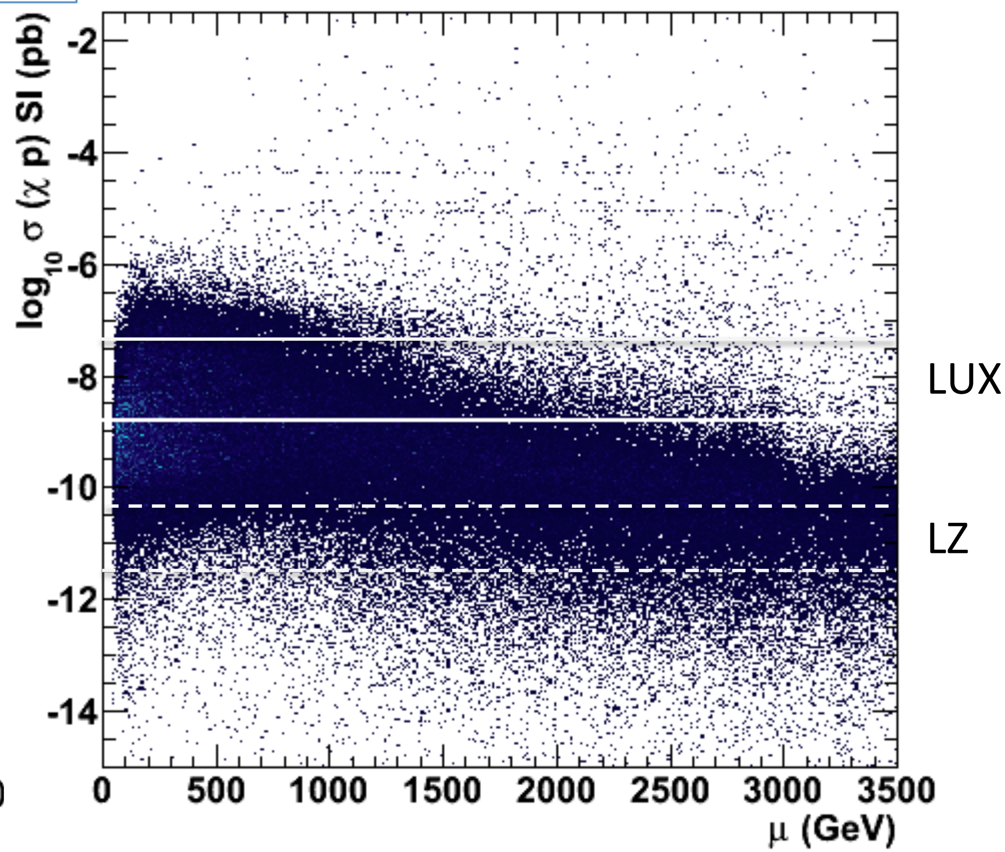
Colliders are not the only source of constraints: DM-motivated scenarios must fulfill relic DM density, DM searches and, possibly, other astrophysics bounds (or signals)

Complementarity between Higgs signal strength and DM direct detection

SUSY Δ_b correction to Higgs couplings scales as $\mu \tan\beta M_{\tilde{g}}/M^2_{\tilde{b},\tilde{t},\tilde{g}}$ and SUSY strongly interacting sector does not decouple



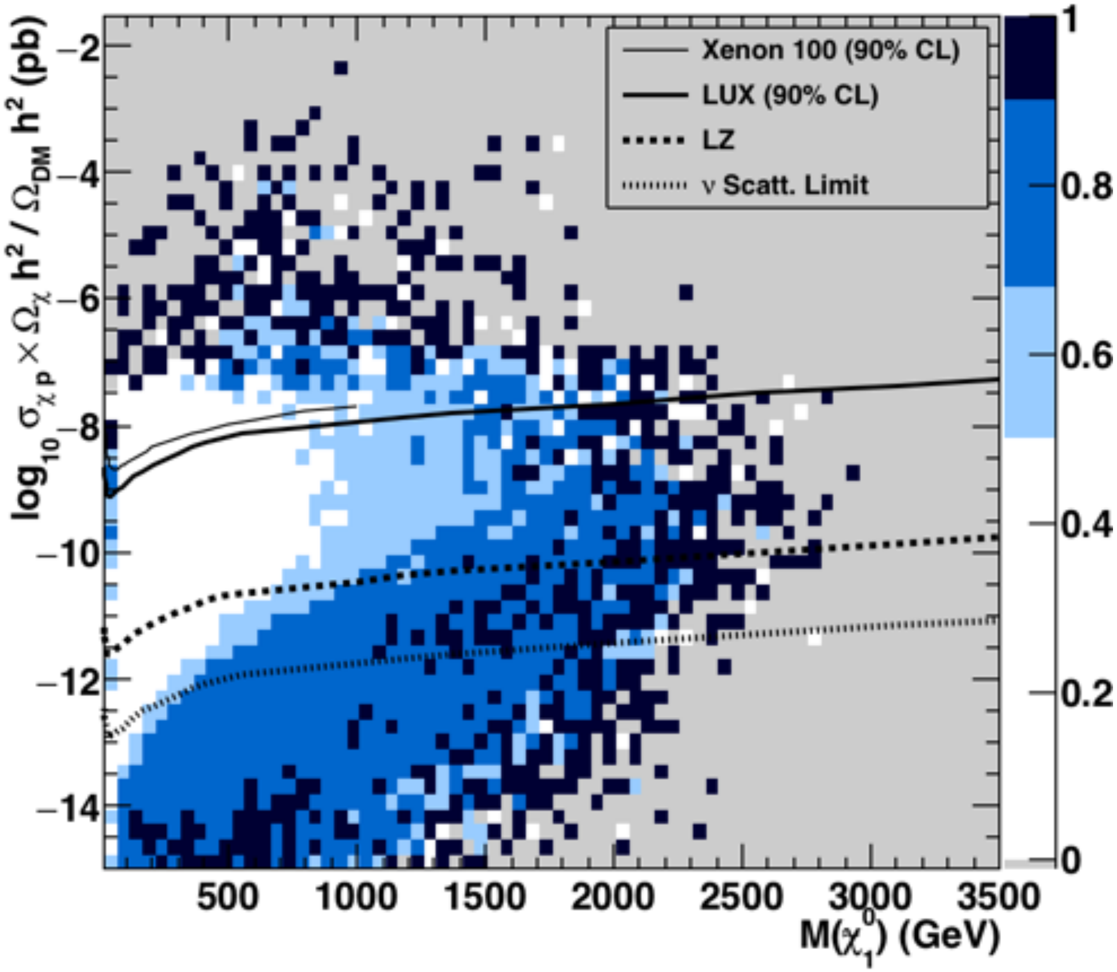
Arbey et al, Phys Lett B720 (2013)



Arbey et al, Ann Phys (2015) arXiv:1504.05091

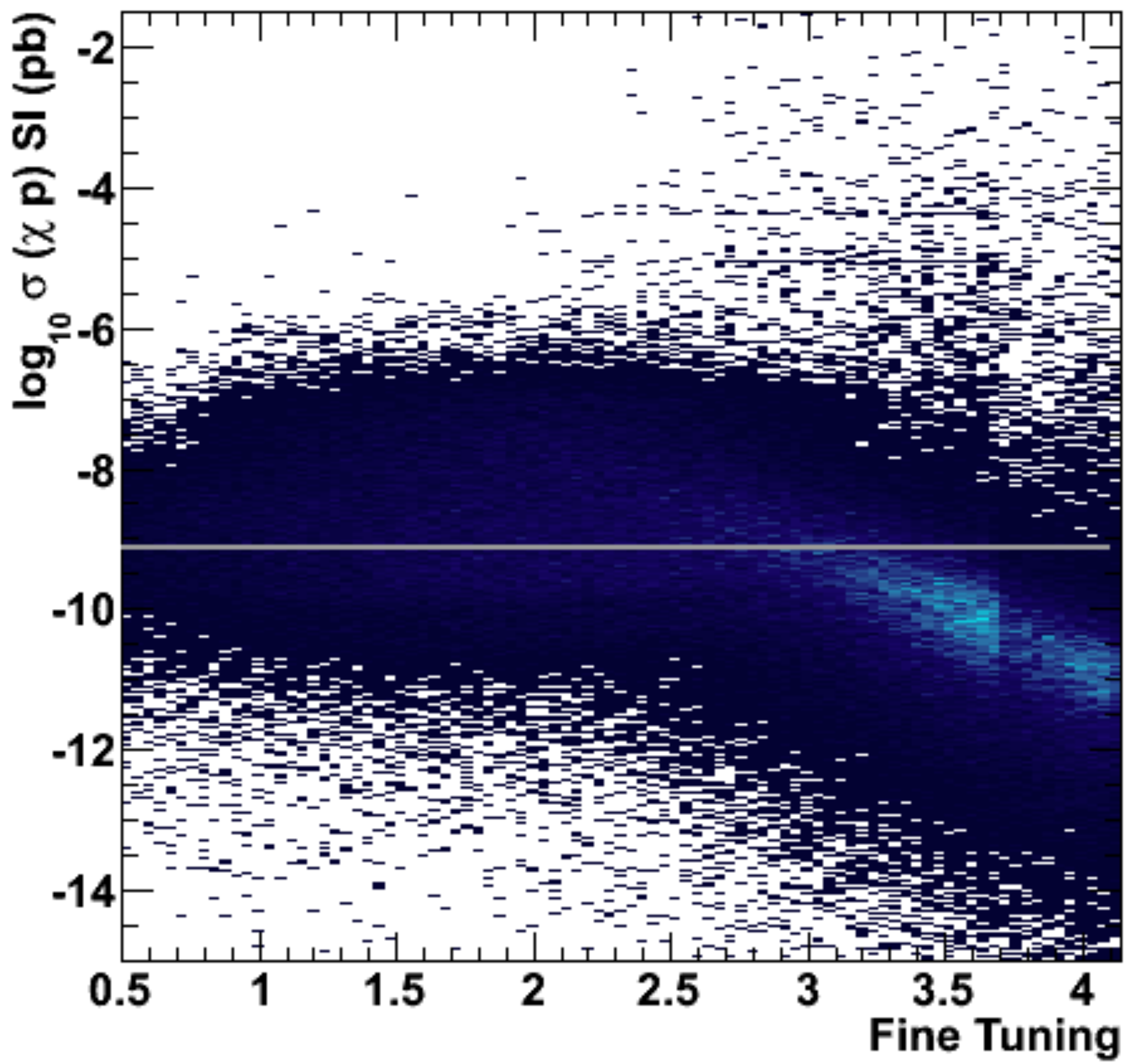
Complementarity between Higgs signal strength and DM direct detection

Fraction of pMSSM points (SUSY Masses < 5 TeV) not excluded at LHC Run 1
and excluded by Higgs coupling analysis (ILC 1 TeV)

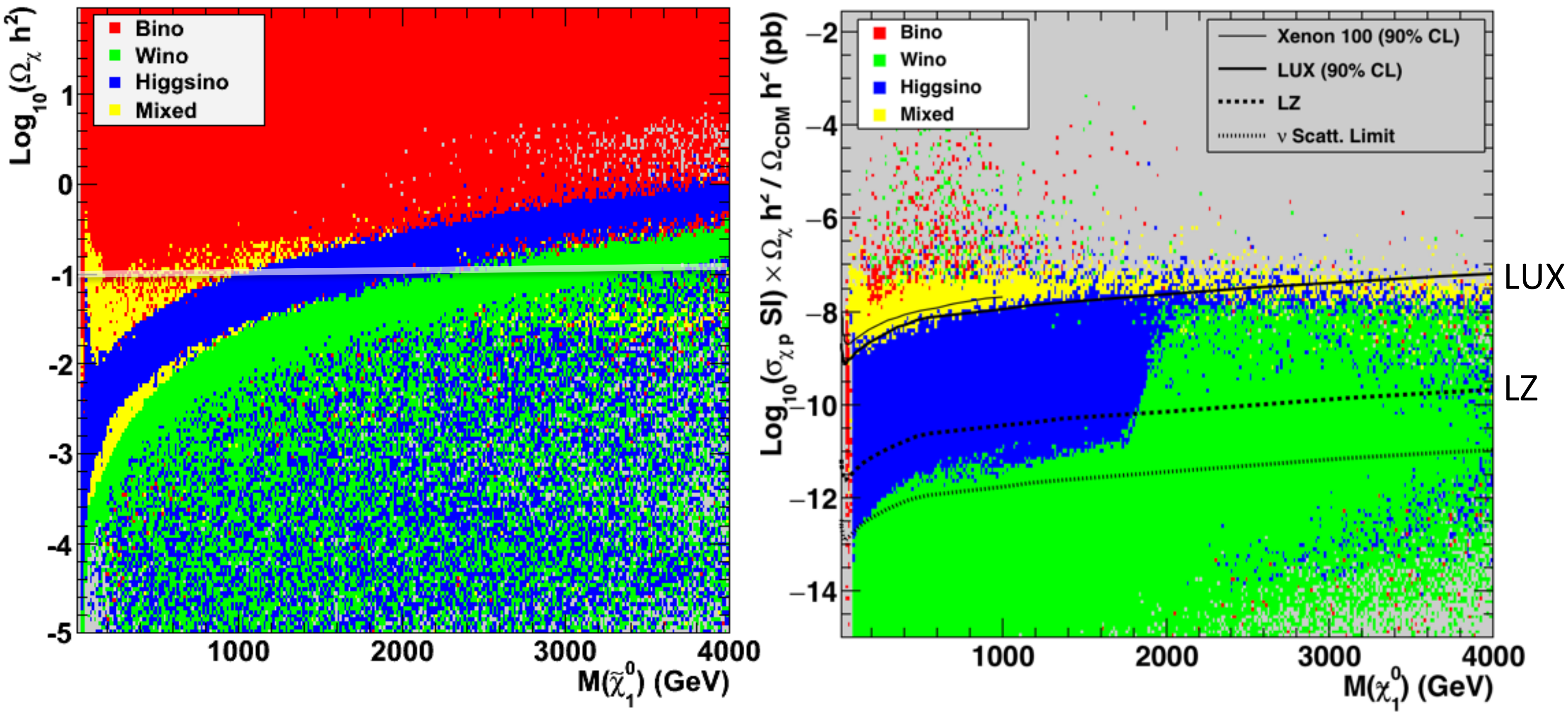


Arbey et al, to appear on Ann Phys (2015) arXiv:1504.05091

DM direct detection and SUSY Fine Tuning



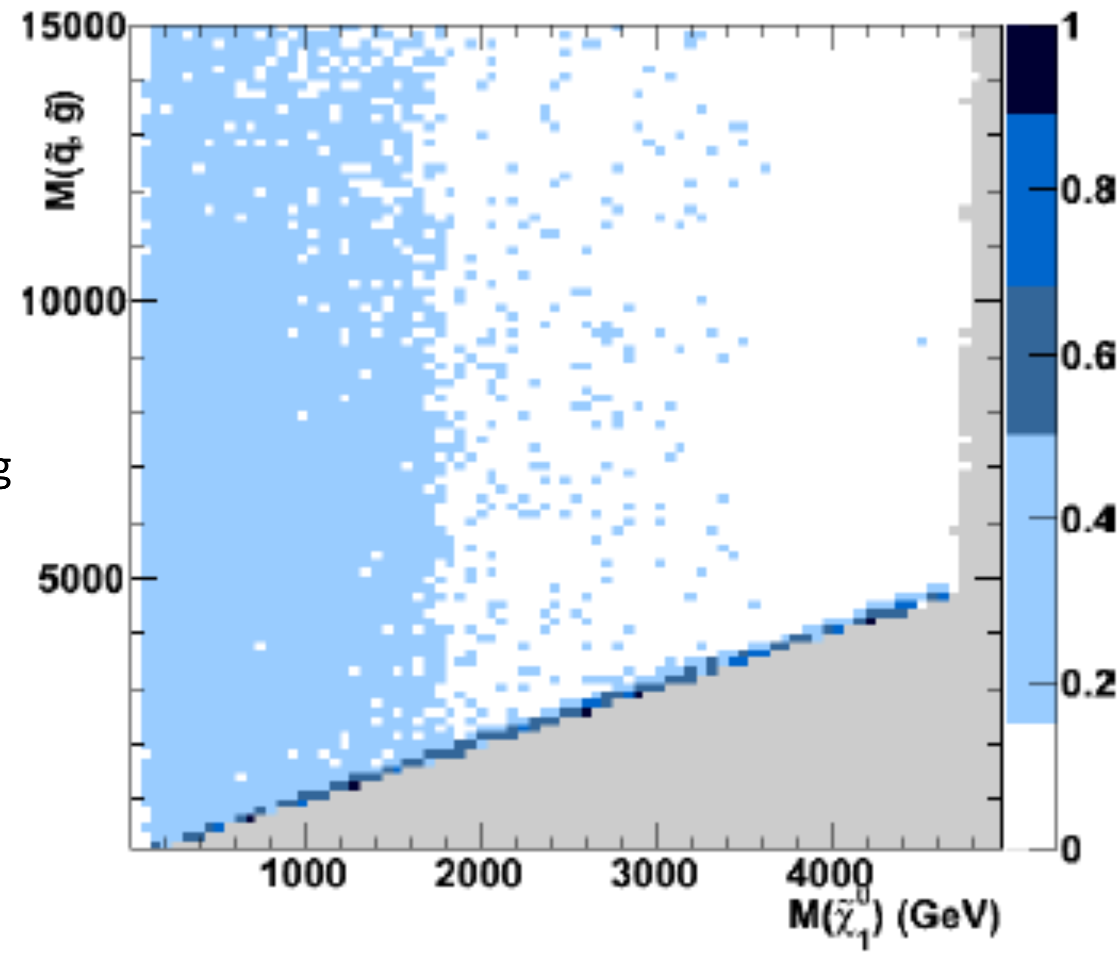
Mass upper bounds in Neutralino DM pMSSM: Neutralino Mass and DM Relic Density



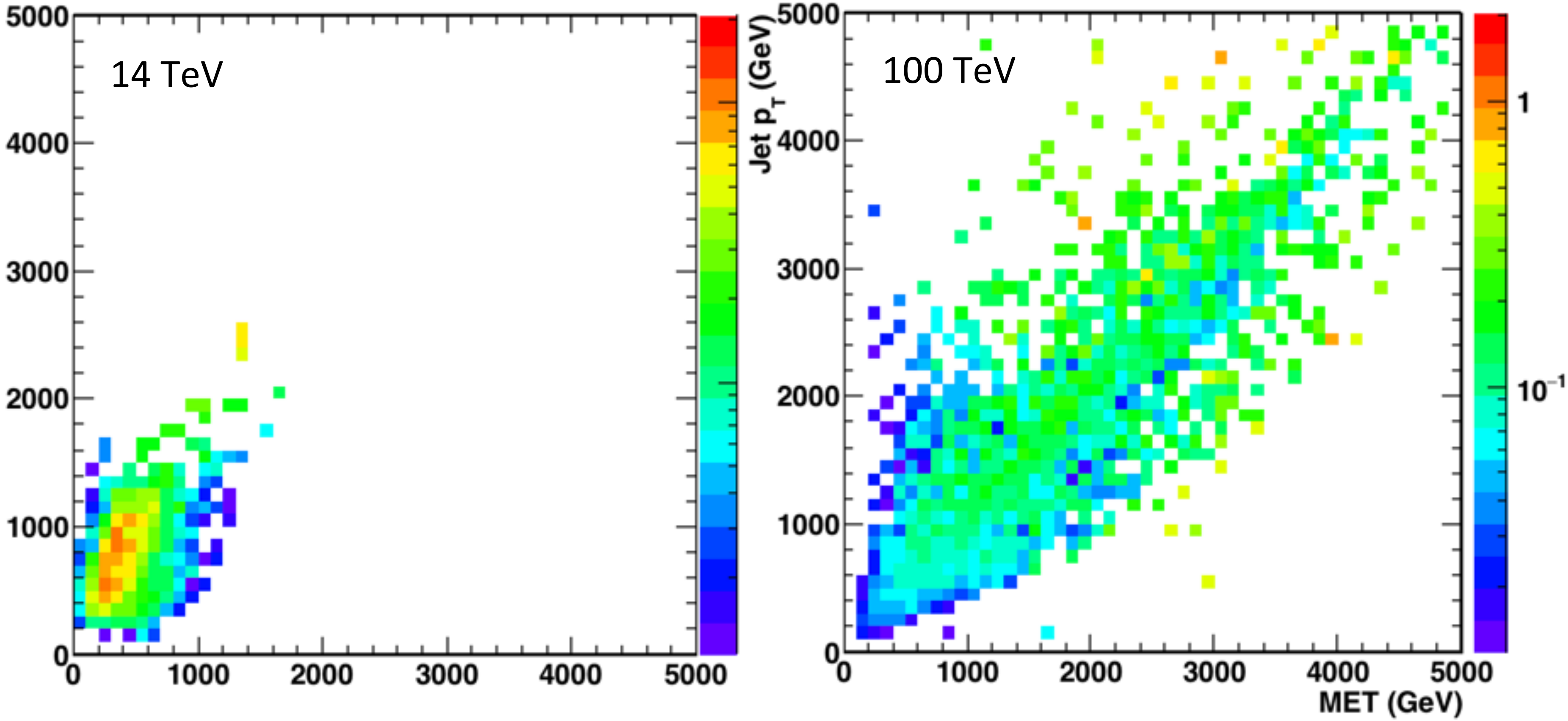
Arbey et al, to appear on Ann Phys (2015) arXiv:1504.05091

Fraction of pMSSM points
(SUSY Masses < 20 TeV)
with $\Omega_\chi h^2$ < PLANCK upper limit

Mono-jets offer access to small mass splitting scenarios where $M_1 \sim M_3$ (or $M_{\sim q}$) << M2, μ, $\Omega_\chi h^2$ is reduced by co-annihilation and monojet cross section boosted by production of strongly interacting SUSY particles giving small hadronic activity.

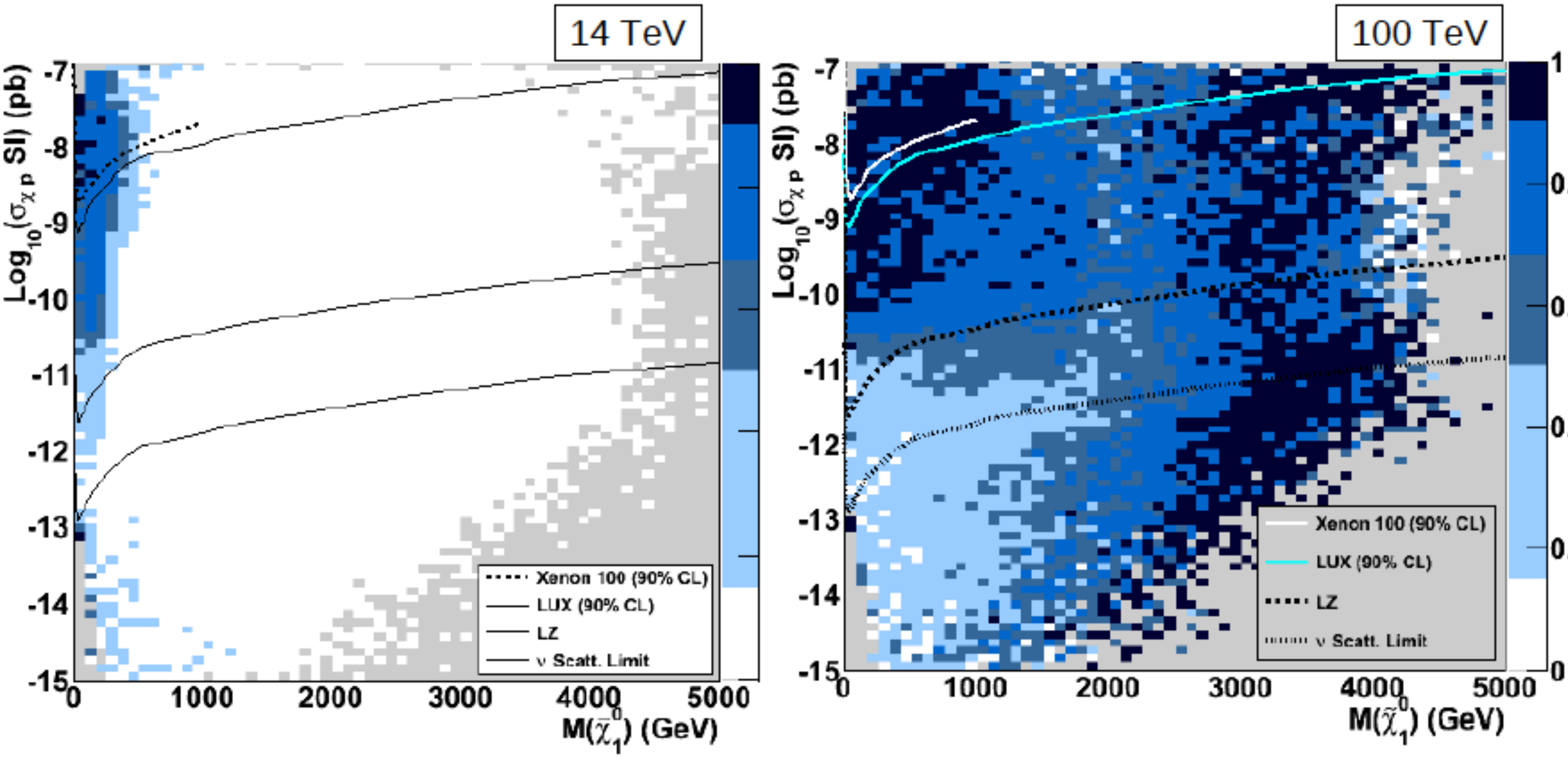


Mono-jet signal and SM background from LHC to 100 TeV



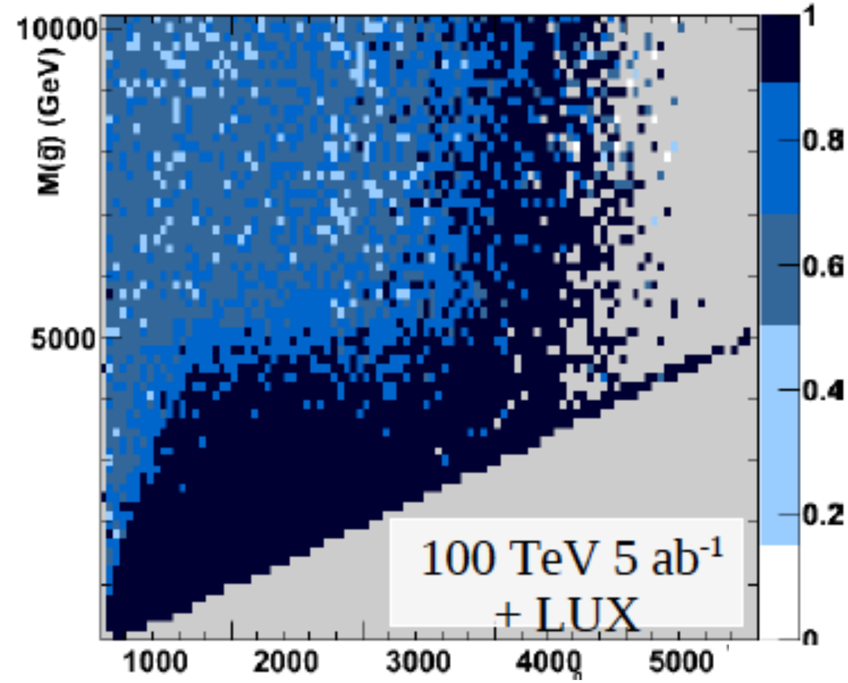
Scattering Cross Section vs M_χ

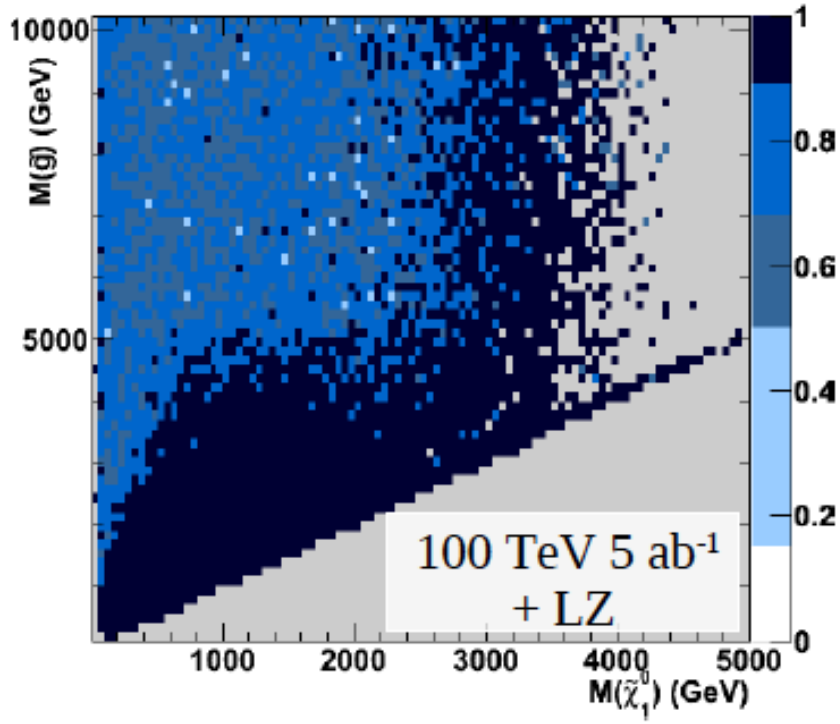
Fraction of pMSSM points (SUSY Masses < 20 TeV) excluded at 95% C.L. by 14 TeV and 100 TeV collider

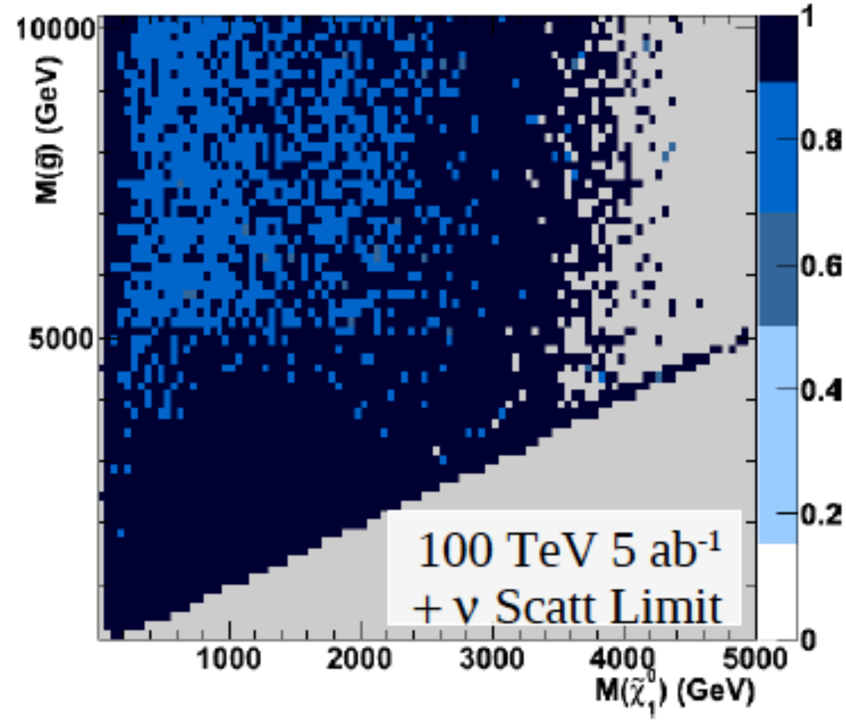


Fraction of excluded χ LSP pMSSM points (SUSY Masses < 20 TeV) for Collider and DM searches

$\sqrt{s}$ (TeV)	L (ab^{-1})	Collider (MET)	+LUX DM	+LX DM	+3rd Gen. DM
100	1.0	0.63	0.65	0.73	0.90
100	3.0	0.67	0.69	0.75	0.91
100	5.0	0.69	0.72	0.76	0.92



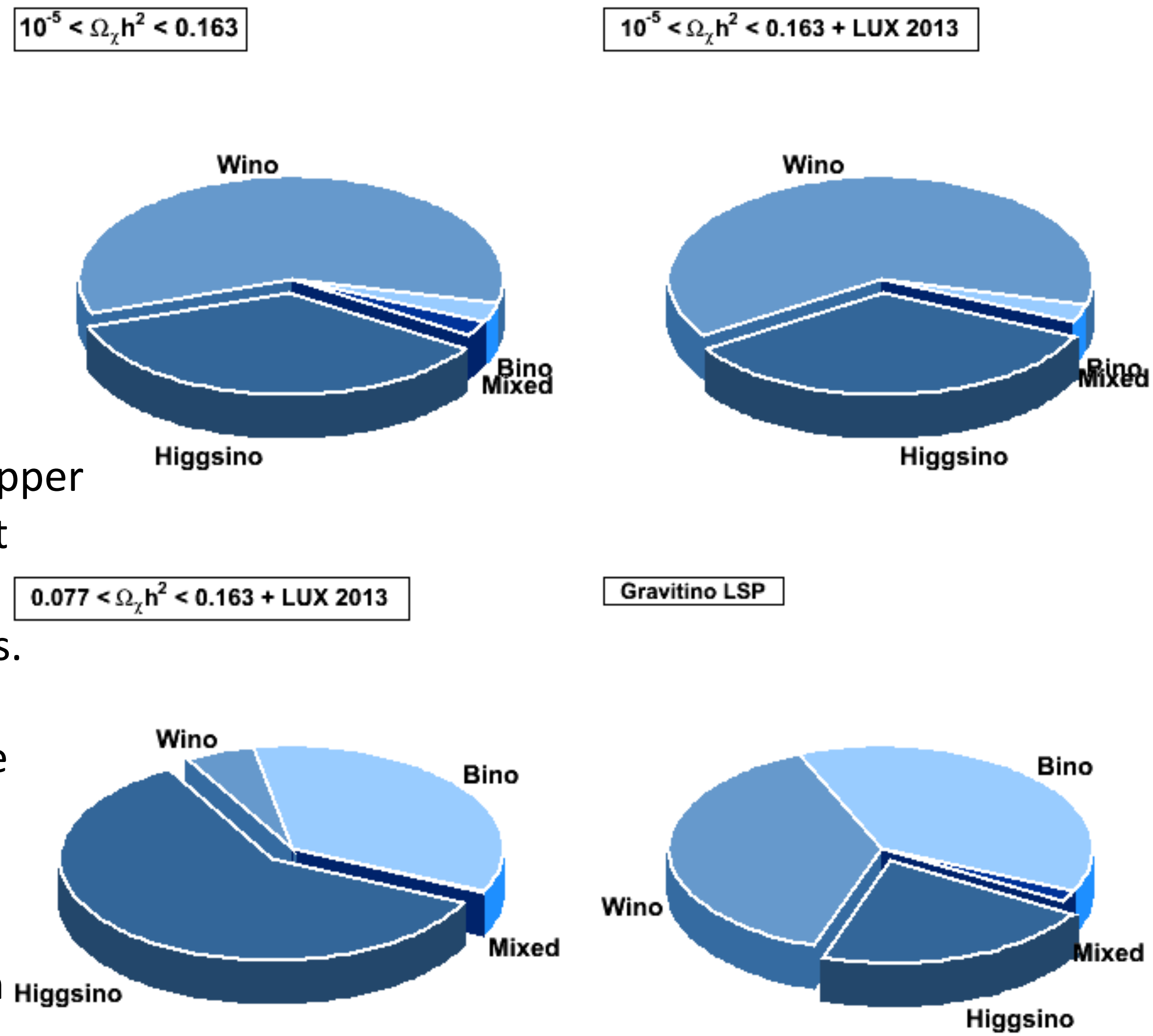




Gravitino DM in pMSSM

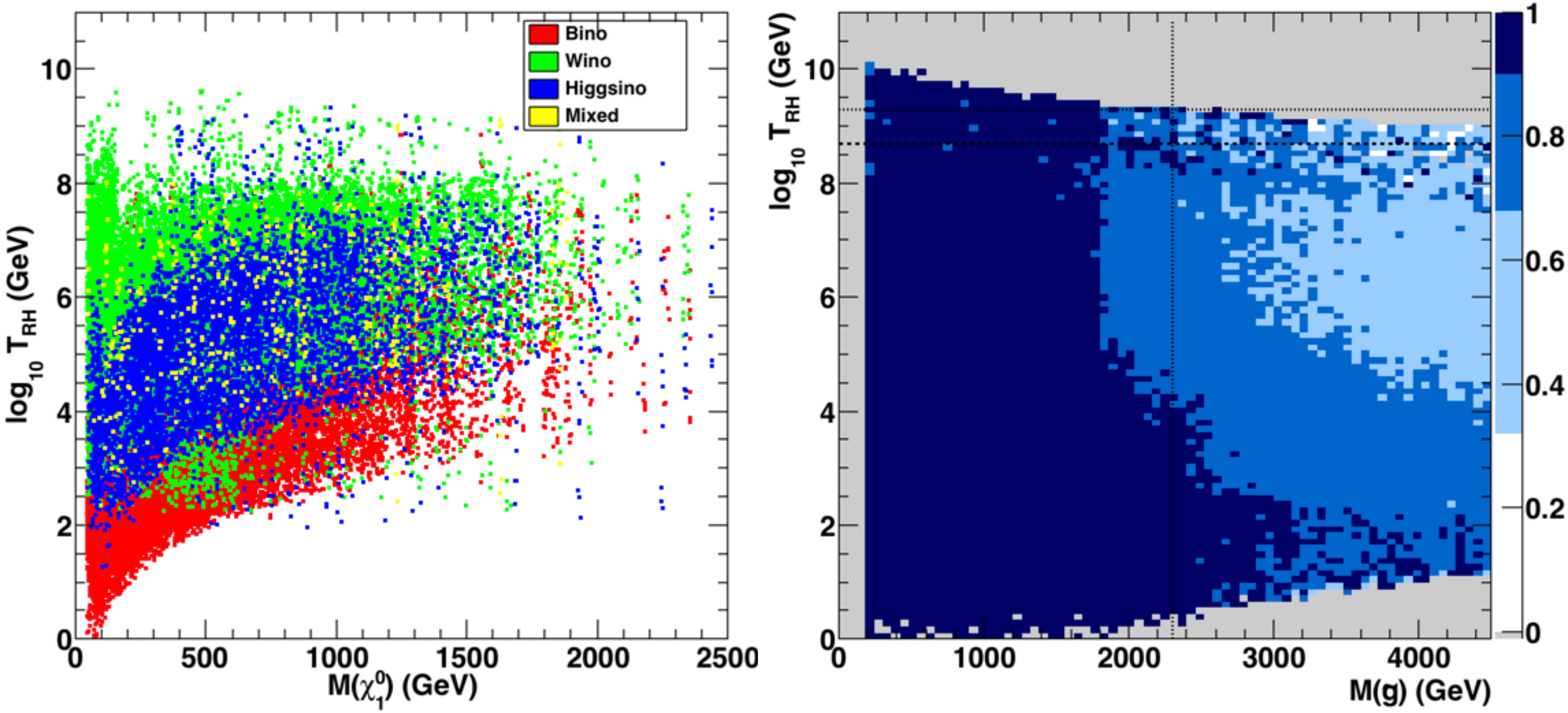
Neutralino LSP and gravitino LSP models differ mostly for their sensitivity to DM relic density constraint that severely restricts MSSM parameter space for neutralino LSP, modifies the occurrence of χ of different nature and favours mass degeneracy in the spectrum. This implies some upper mass bounds on SUSY particles but has important consequences on detectability at hadron colliders.

Gravitino LSP models relaxes these constraints while retaining upper mass bounds through contribution of heavy gluinos to gravitino production after inflation and if leptogenesis is considered.



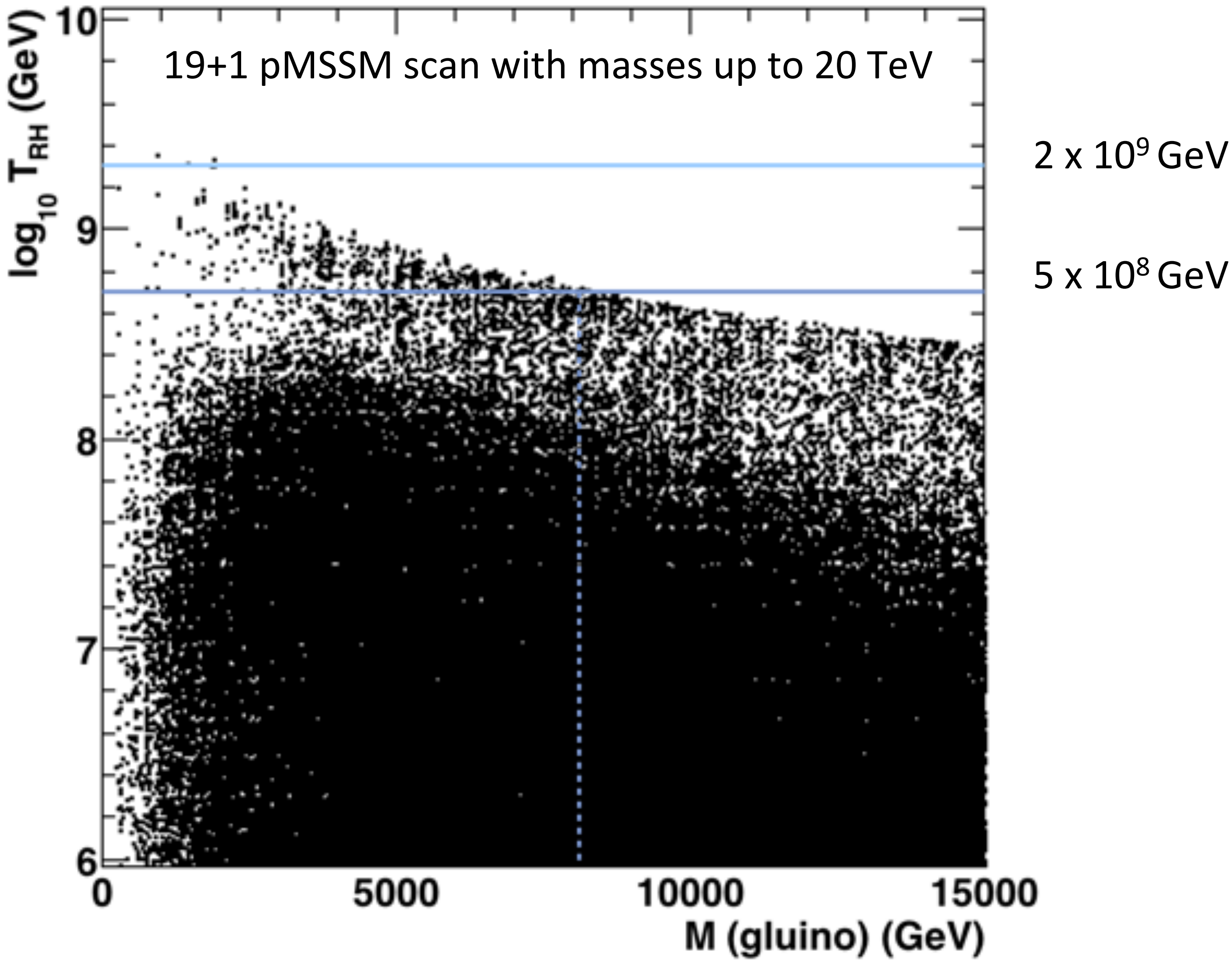
Mass upper bounds in Gravitino DM pMSSM:
Gluino Mass and Re-heating Temperature

Thermal leptogenesis can produce observed baryon number provided re-heating temperature after inflation T_{RH} is sufficiently high. MSSM Gravitino LSP with wino χ gives solutions at high T_{RH} near the bound of $\Omega_G h^2$ overclosure:



Arbey et al, to appear on Phys Rev D92 (2015) arXiv:1505.04595

Interplay of $\Omega_G h^2$, T_{RH} and gluino mass determine an upper bound on M_{gluino} in Gravitino LSP MSSM with thermal leptogenesis relevant to HL-LHC and high energy hadron collider.

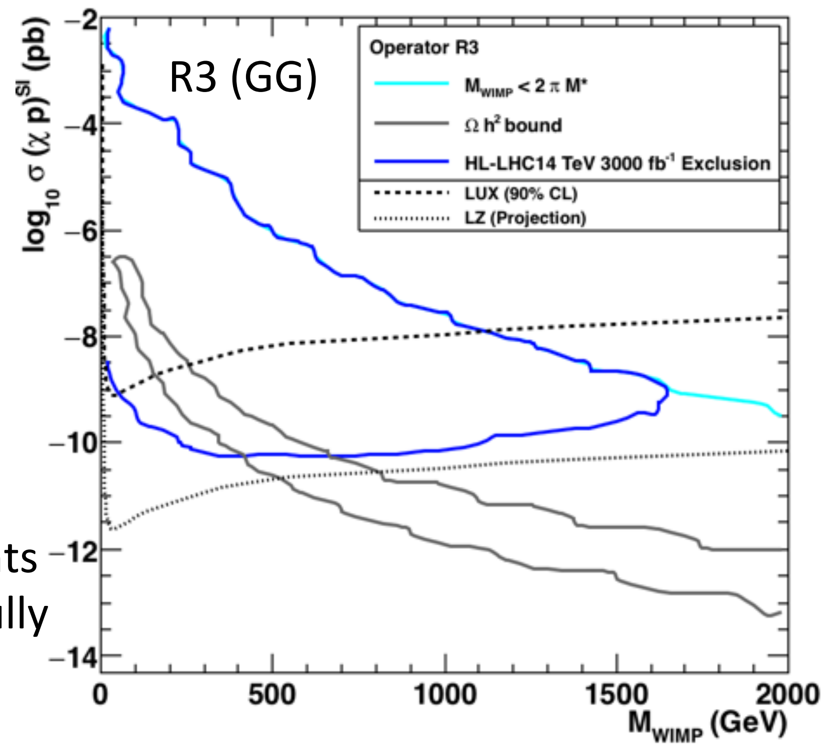


Dark Matter in Effective Field Theories

Assume DM couples to SM through unspecified NP with dynamic becoming relevant only above effective suppression scale M*

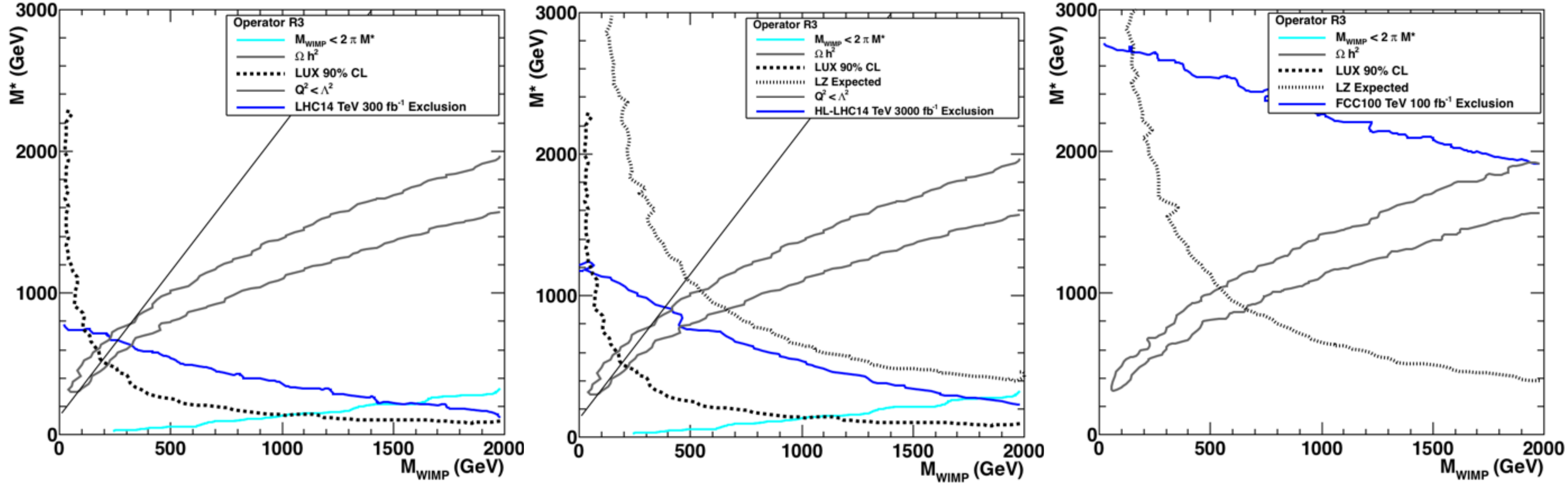
Interactions of DM pairs with gluon and quark pairs described by Langrangian characterised by effective operator and coupling depending on fermionic or scalar (real or complex) nature of DM particle

Limitations of validity of EFT to be carefully considered given the high energies of colliders under consideration at which the particle mediating the DM-SM interaction may be produced on-shell.

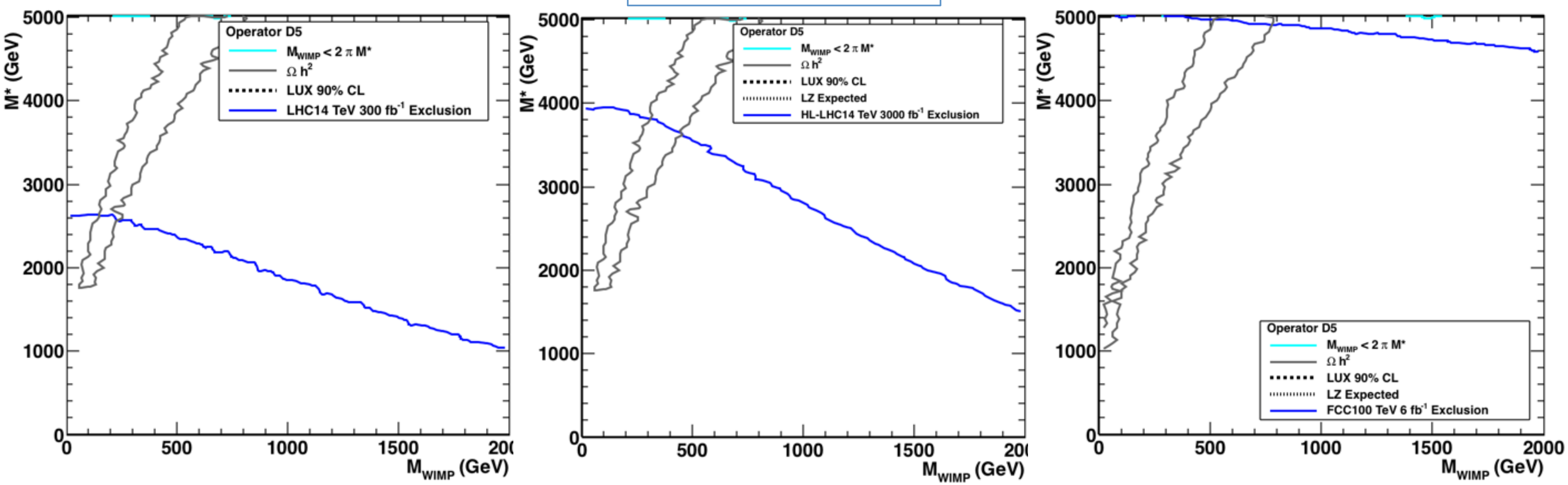


Collider constraints (here for monojet searches) probe parameter space along M*- M_{WIMP} but can be complemented by relic density constraints and DM direct detection limits (if relevant) to fully probe DM-motivated parameter space.

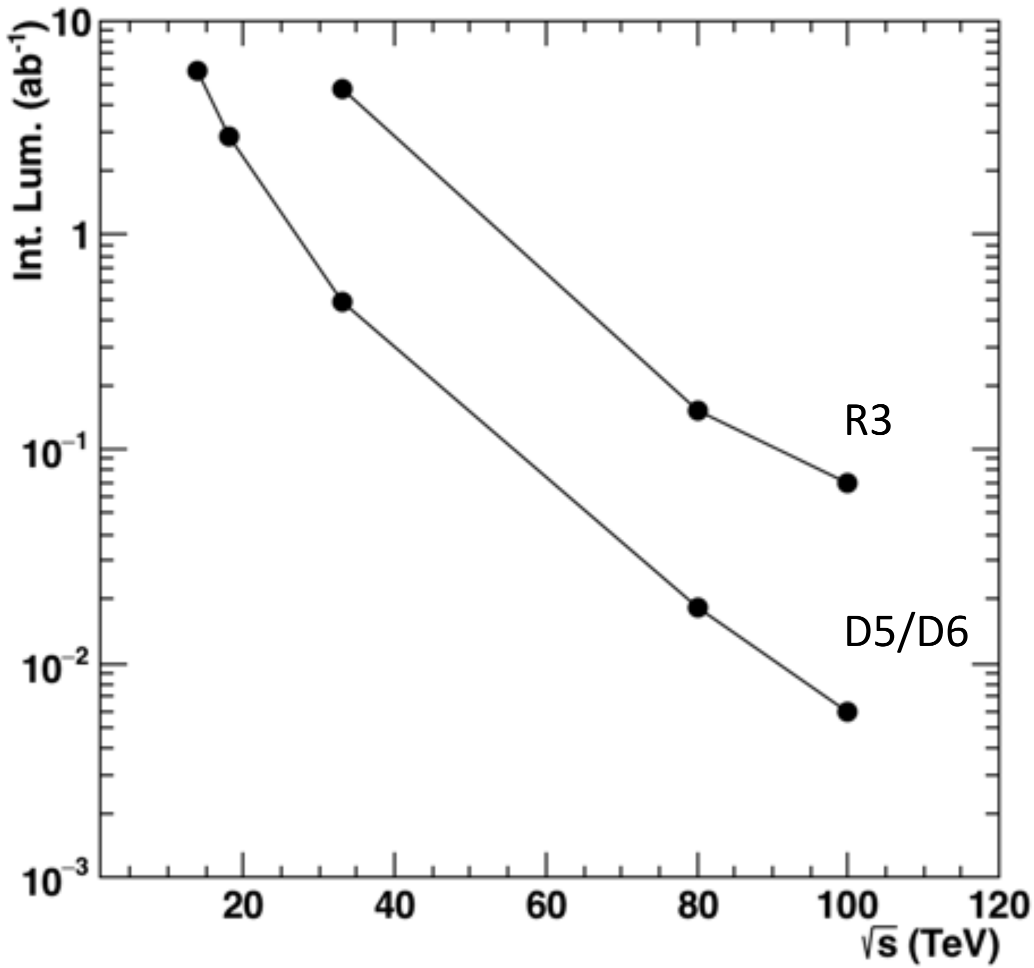
Operator R3 (GG)



Operator D5 (qq)



Integrated luminosity vs pp Collision Energy
to exclude DM-compatible parameter space (EFT D5 operator with M* < 5 TeV)



Perspectives

SUSY (χ and G LSP) and EFTs provide DM-motivated scenarios where mass scale of new particles is bound by Ωh^2;

Within these models interesting to investigate how an high energy pp collider can discover signal or fully exclude parameter space as function of energy and luminosity;

Combination of collider and dark matter direct detection experiments appears crucial for ensuring coverage of parameter space (and identify nature of WIMP if signal is observed);

Optimise 100 TeV analyses and examine in details characteristics of points escaping detection;