Photon signals of relic and compressed electroweakinos at a future circular collider

FCC BSM WG

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Based On Work With A. Delgado, F. Elahi, P. Fox, A. Martin, B. Ostdiek, T. Plehn, T. Schell, and M. Takeuchi

Relic neutralinos

- Consider (m = 0.2 - 3 TeV) winos, higgsinos, and binos which freeze out to the observed Ω_{DM}.

- Our motivation can be Split SUSY, but this is also the simplest example of EW-charged fermionic dark matter.

- TeV dark matter typically uses co-annihilation to decrease relic density (for example, higgsinos alone co-annihilate between their charged and neutral components). These mass splittings yield compressed decay byproducts at colliders.

- Compressed photons and leptons are highly boosted at 100 TeV, an excellent (and perhaps the only) complement to future direct and indirect detection experiments.

Freeze-out interpolation

- Pure Higgsinos freeze-out through annihilation and co-annihilation of 2 charged and 2 neutral states.

$$\Omega_{DM}h^2 = 0.12\left(\frac{\mu}{1.1\ \mathrm{TeV}}\right)^2$$

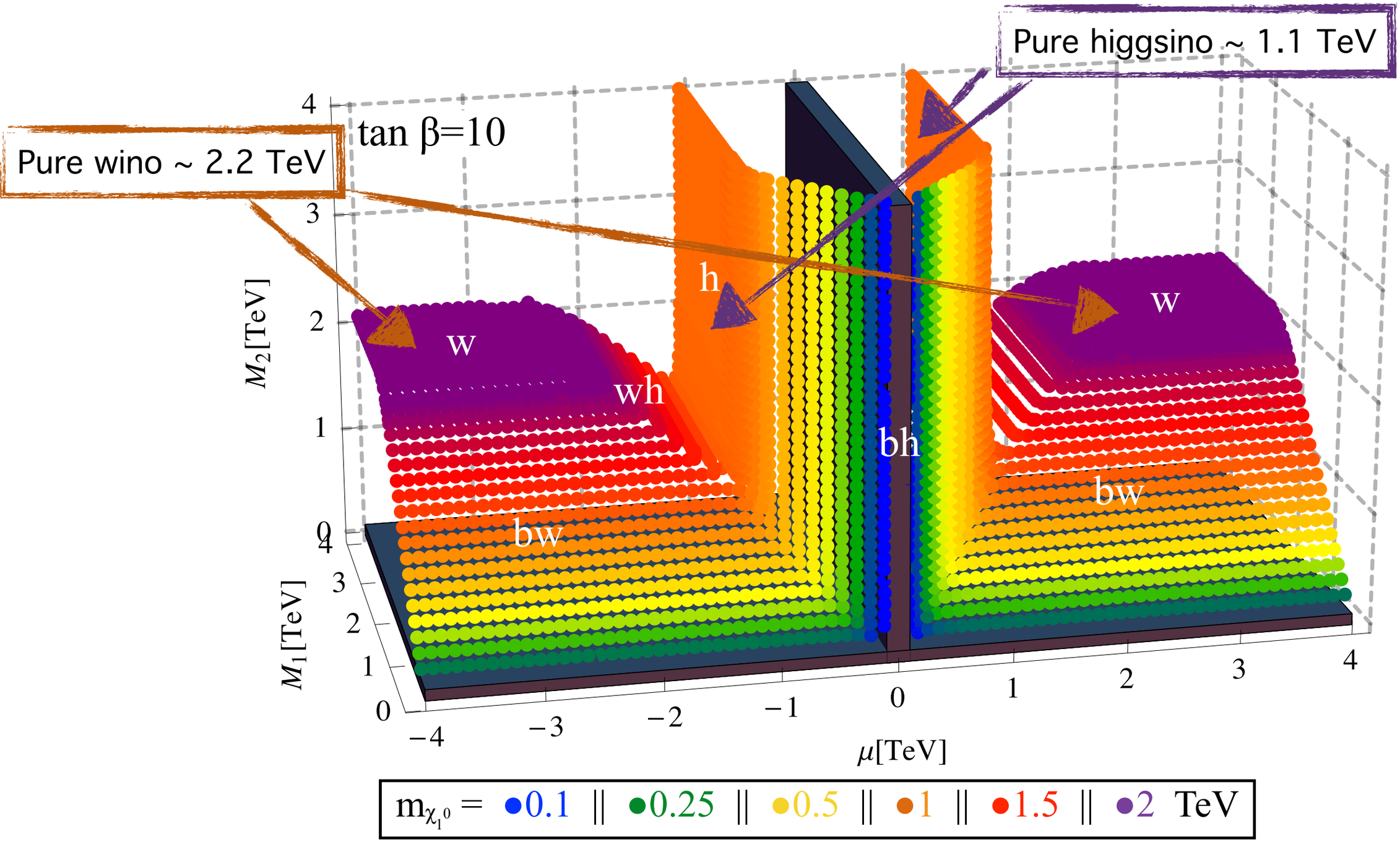
- Pure winos freeze-out through annihilation and co-annihilation of 2 charged states and one neutral states. Also, note Sommerfeld enhancements (on-shell W/Z exchange between initial annihilation states for m > 1.6 TeV).

$$\Omega_{DM}h^2 = 0.12\left(\frac{M_2}{2.6\ \mathrm{TeV}}\right)^2$$

- Pure binos overclose universe for m > GeV.

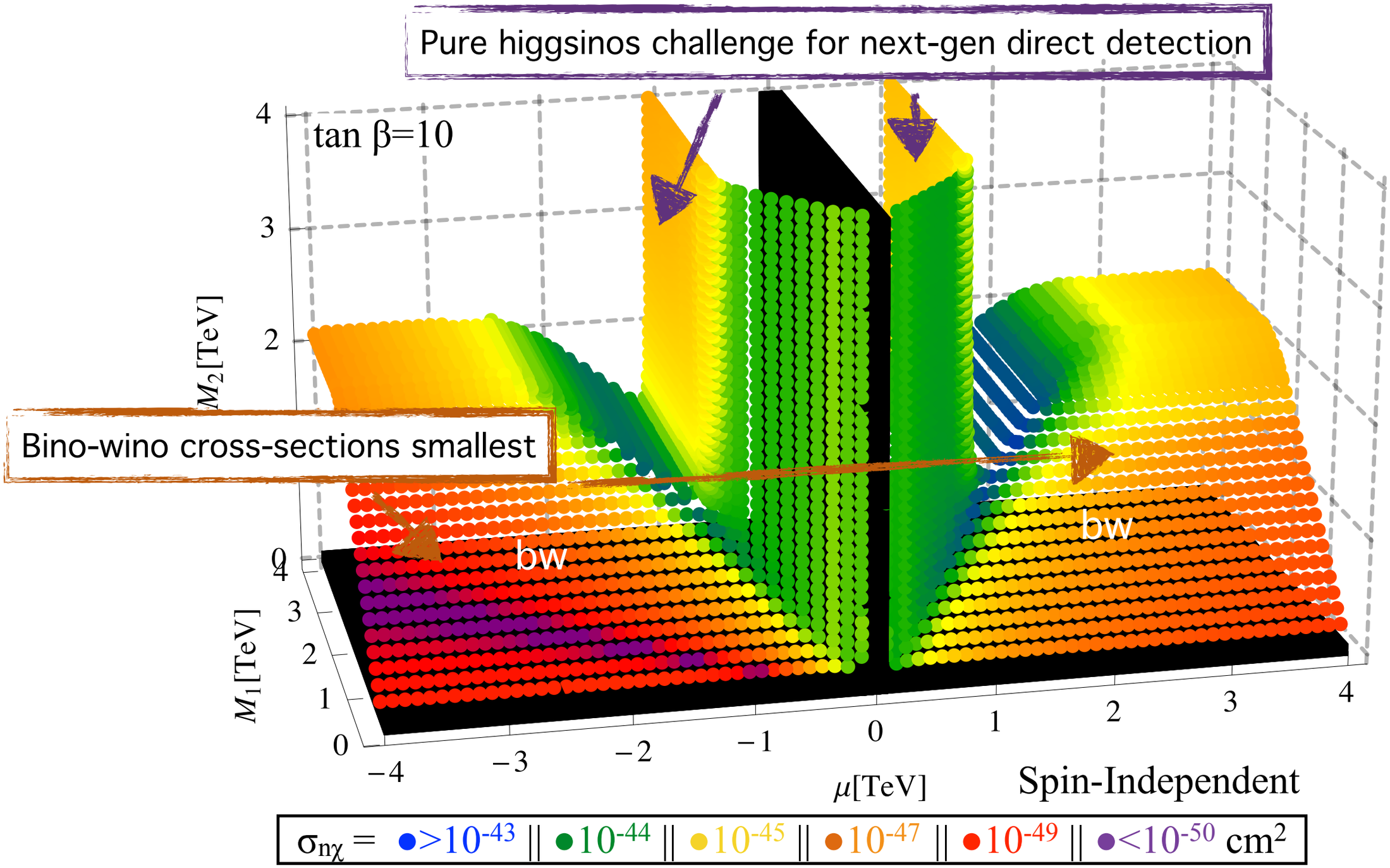
- LSP mixtures of bino-higgsino, wino-higgsino, and bino-wino, and coannihilations in the case of near-mass-degenerate μ, M_1, and M_2 can result in correct relic abundance.

Relic neutralino parameter space for tan β = 10



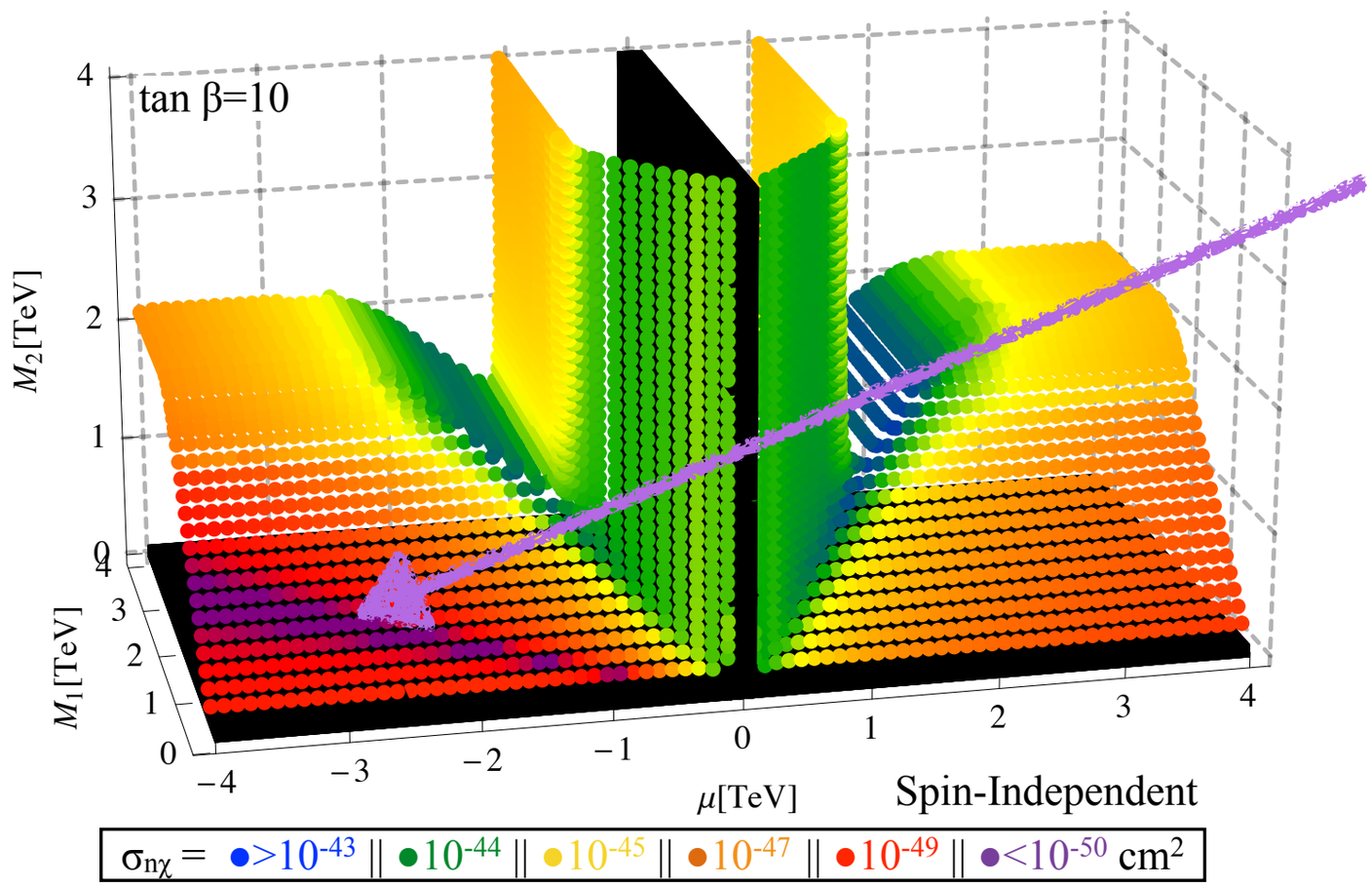
Relic dark matter for all params decoupled except Higgs doublet vevs (μ,tan β) and the bino and wino majorana masses (M_1,M_2)

Spin-independent direct detection complementarity



- Notice that the bino-winos are beyond the reach of next-generation Xenon 1T, LZ, Darkside experiments.

Blind spot interlude

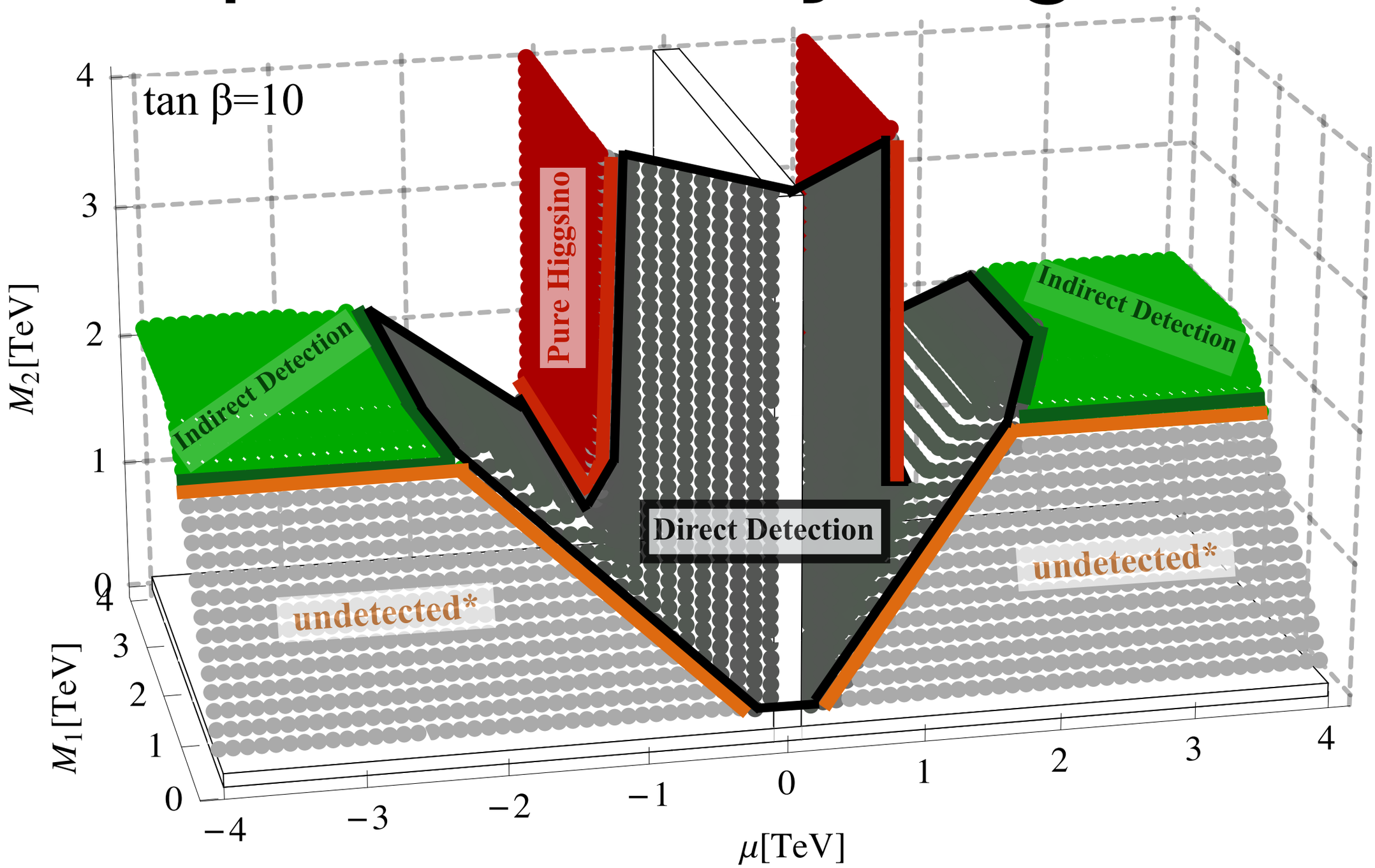


Differentiating the neutralino mass eigenstate equation with respect to v, and setting the neutralino-higgs coupling $c_{h\chi\chi}$=0 yields conditions for null higgs-neutralino couplings.

$$M_1 + \mu \sin 2\beta = 0$$
$$M_2 + \mu \sin 2\beta = 0$$

- There is a ray of spin-independent "blind spots" where the coupling of the higgs to neutralinos vanishes.

Complementarity in general



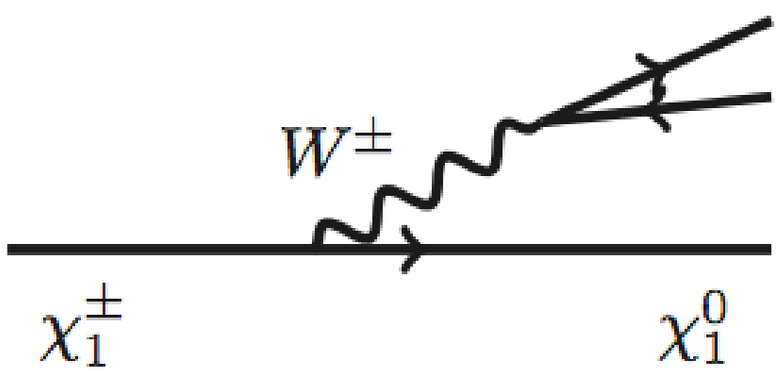
*Some of bottom row accessible at LHC 3/ab

- In fact, the bino-winos are relatively unreachable with non-collider methods.

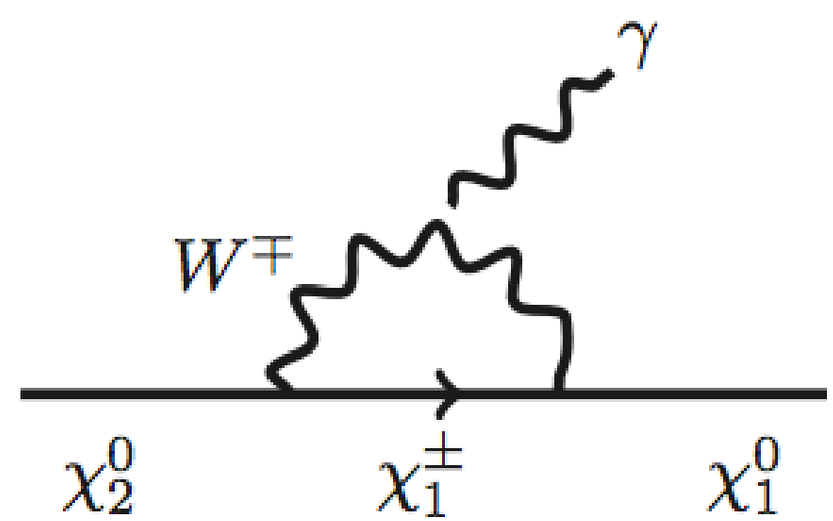
[Schwaller Zurita 1312.7350, Han Kribs Martin Menon 1401.1235, Baer Mustafayev Tata 1409.7058, JB Delgado Elahi Martin Ostdiek 1408.6530, Han Wu Yang Zhang Zhang 1409.4533]

Compressed electroweakinos at colliders

- Use the jets + MET dark matter search, but also..
- Cut out typical backgrounds ($Z \to \nu\nu$) by exploiting decays between relic co-annihilators. This provides additional soft leptons and photons in signal events ($W^* \to \ell\nu$, $Z^* \to \ell\ell$, $W^{loop} \to \gamma$).

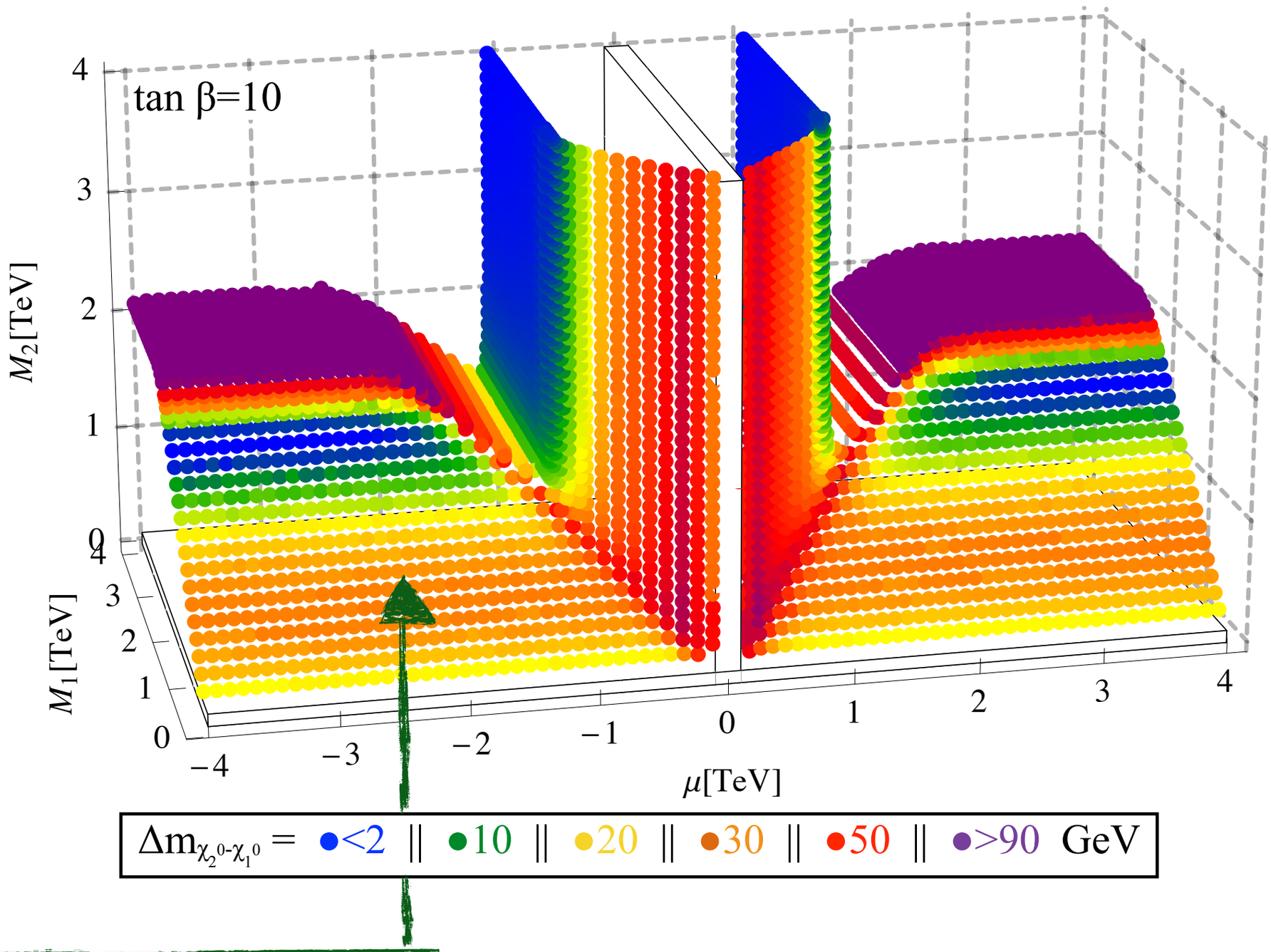


Δm = 10-50 GeV



Δm = 5-30 GeV

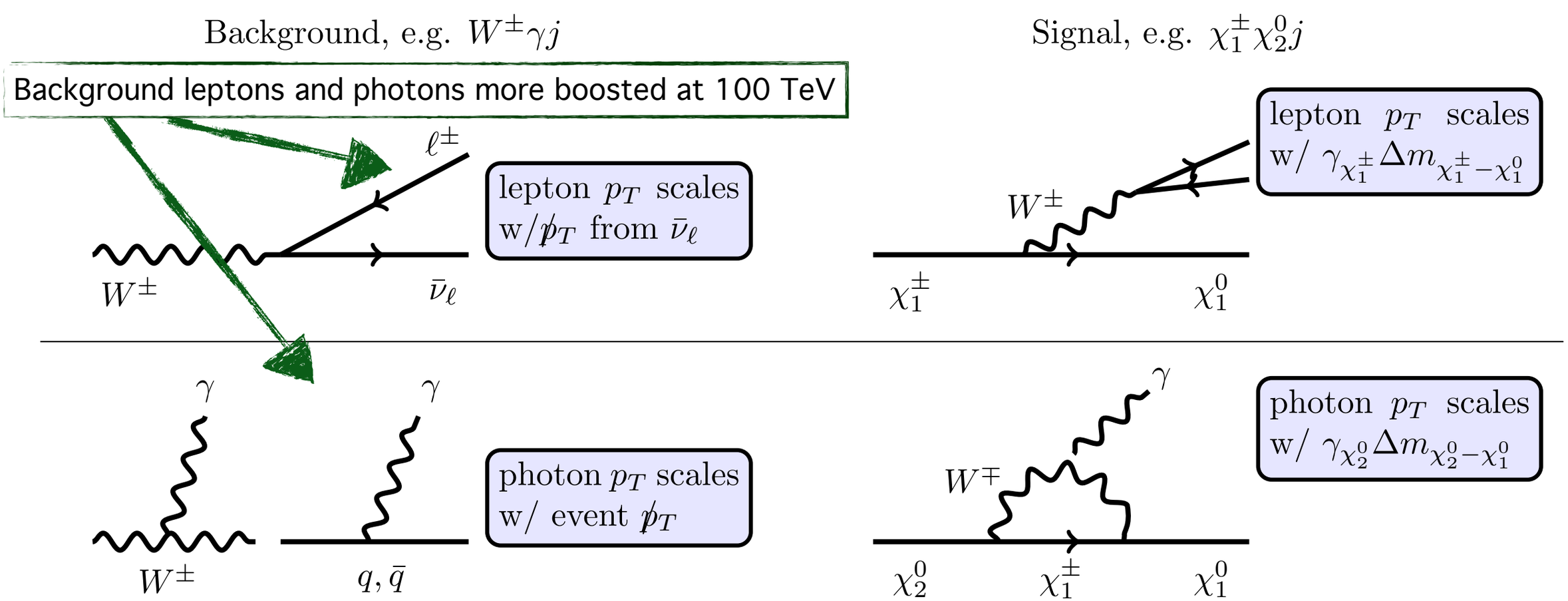
Neutral NLSP-LSP mass splitting



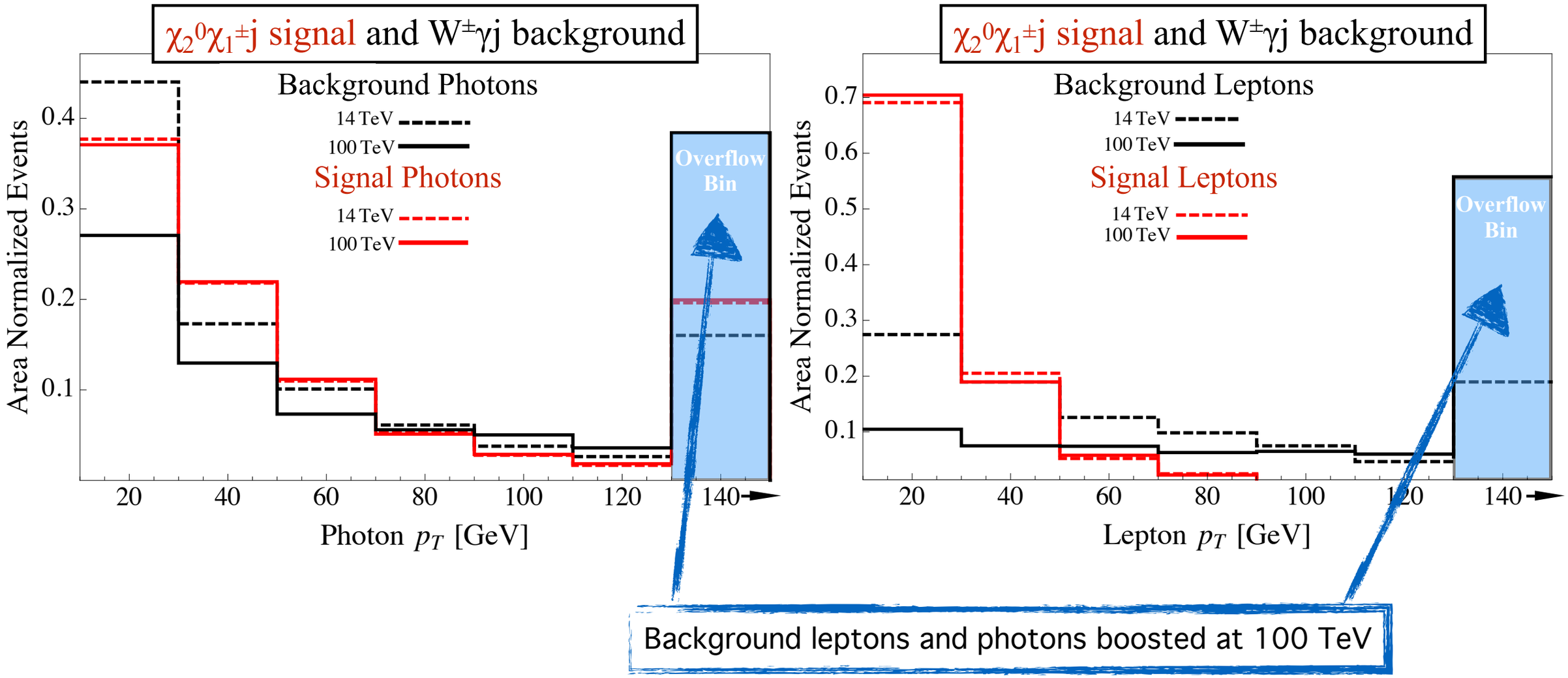
- The bino-wino surface has neutral NLSP-LSP mass splittings of between 2 and 30 GeV (compressed collider searches apply).

Compressed bino-wino search strategy

- Search for signal events $pp \to \chi_2^0 \chi_1^\pm j \to \left(\gamma \chi_1^0\right) \left(\ell^\pm \nu \chi_1^0\right) j$
- Major background is jet plus photon with W→ℓv.
- Signal/background grows as 14→100 TeV.



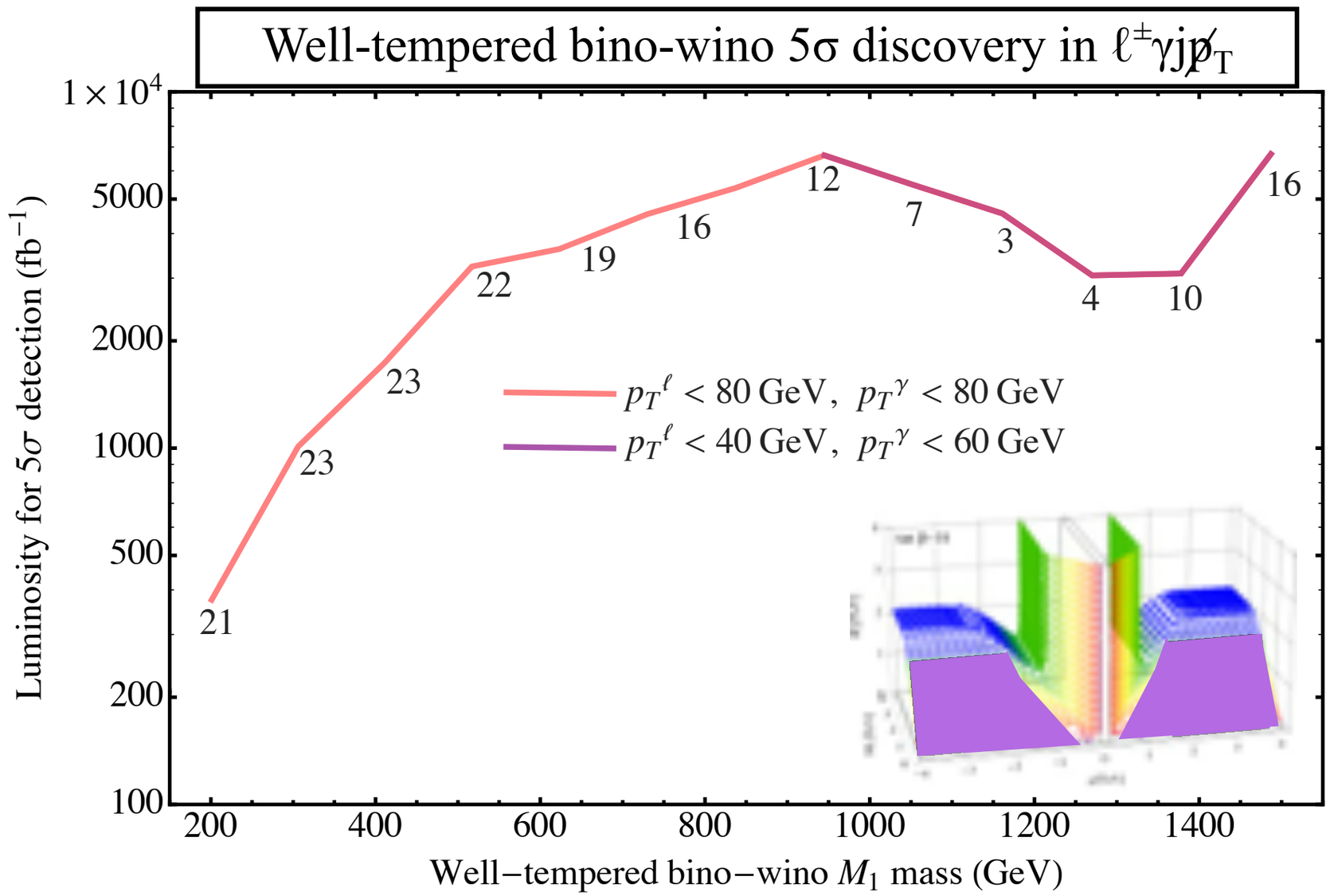
Signal/background grows as 14→100 TeV



- In the case of leptons, W→ℓv must be highly boosted at a 100 TeV collider for a Wγj event to produce 1.5 TeV missing transverse momentum (compared to MET = 300 GeV at a 14 TeV collider).

- For photons, more boosted background events mean larger fraction of boosted photons.

Bino-wino search significance



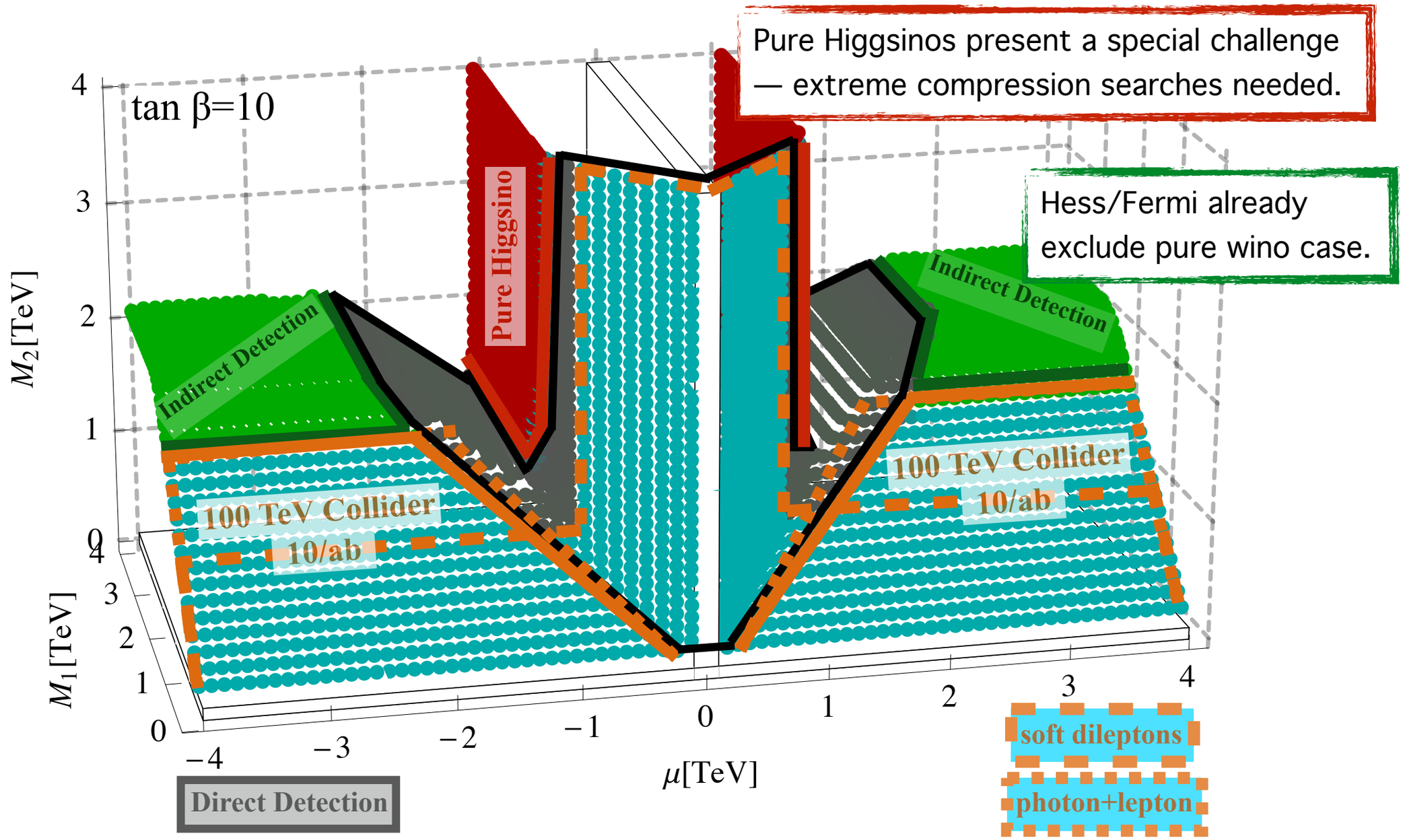
$$p_{T,\ell} = \begin{cases} [5, 80] \text{ GeV} & (M_1 < 900 \text{ GeV}) \\ [5, 40] \text{ GeV} & (M_1 \geq 900 \text{ GeV}) \end{cases} \qquad |\eta_\ell| < 2.5$$

$$p_{T,\gamma} = \begin{cases} [5, 80] \text{ GeV} & (M_1 < 900 \text{ GeV}) \\ [5, 60] \text{ GeV} & (M_1 \geq 900 \text{ GeV}) \end{cases} \qquad |\eta_\gamma| < 2.5 \qquad \Delta R_{\ell-\gamma} > 0.5$$

$$p_{T,j} > 1 \text{ TeV} \qquad |\eta_j| < 4.5$$

$$\not{p}_T > 1.5 \text{ TeV}$$

Future complementarity



- Compressed searches at a future circular 100 TeV collider are necessary to discover TeV-scale bino-wino dark matter.

Prologue

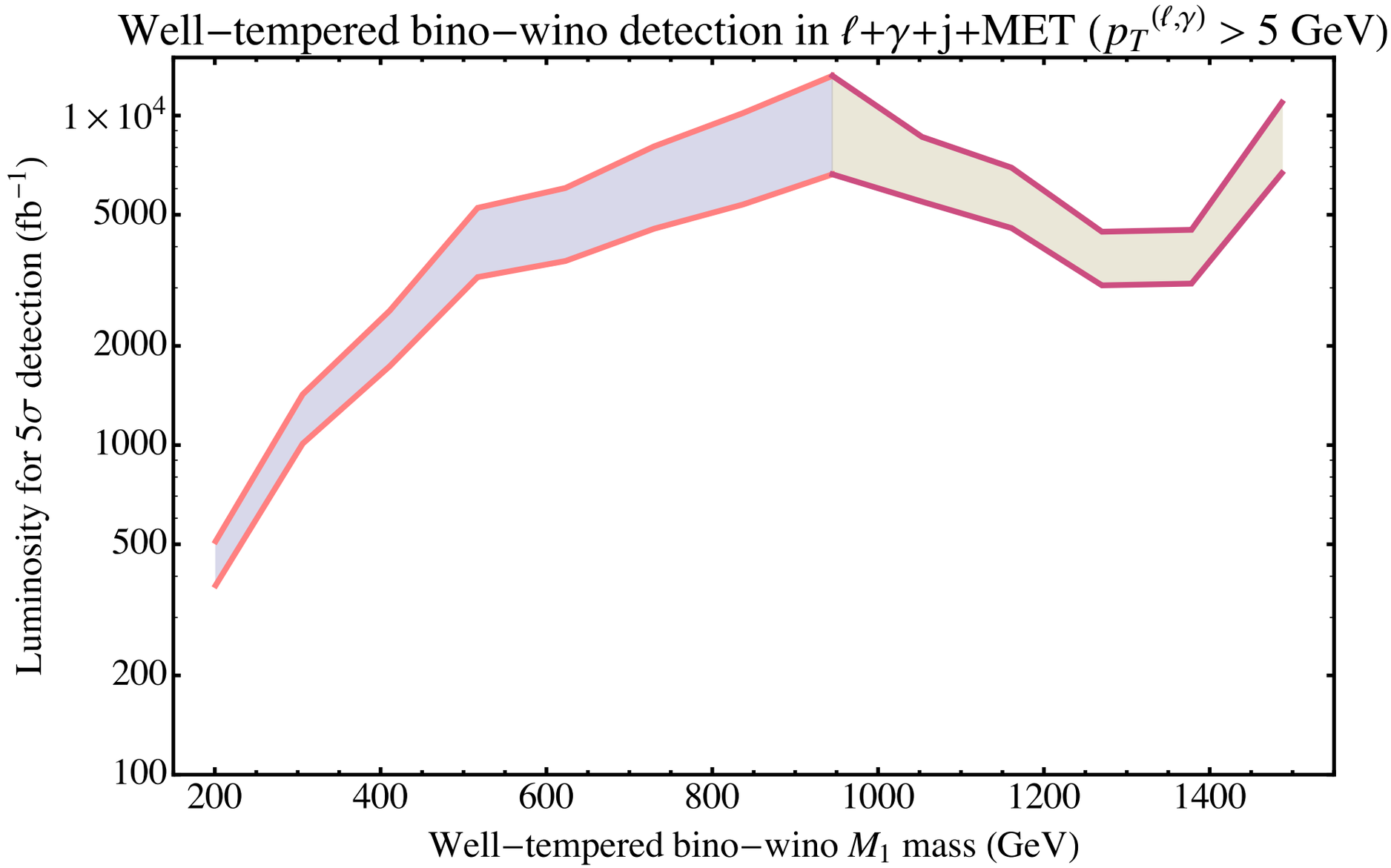
- TeV bino-wino dark matter, motivated especially in split SUSY and simplified triplet-singlet scenarios, can probably only be found with 100 TeV hadron collider compressed searches.

- EW sector co-annihilation generally leads to compressed signals at colliders: jet + MET + soft leptons and photons.

- Future work should target pure Higgsinos and more generally 1-4 GeV mass split dark matter.

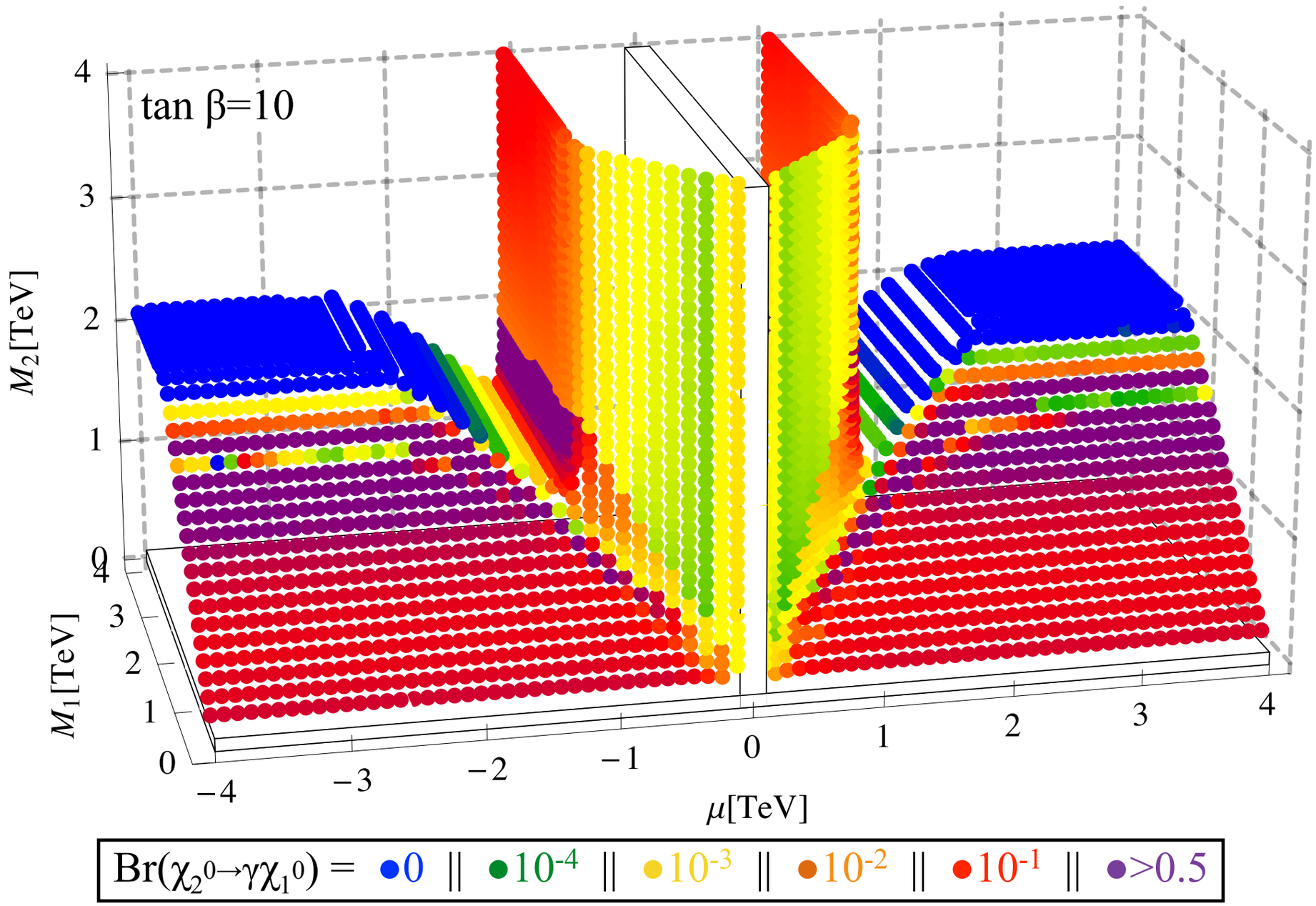
Backup slides

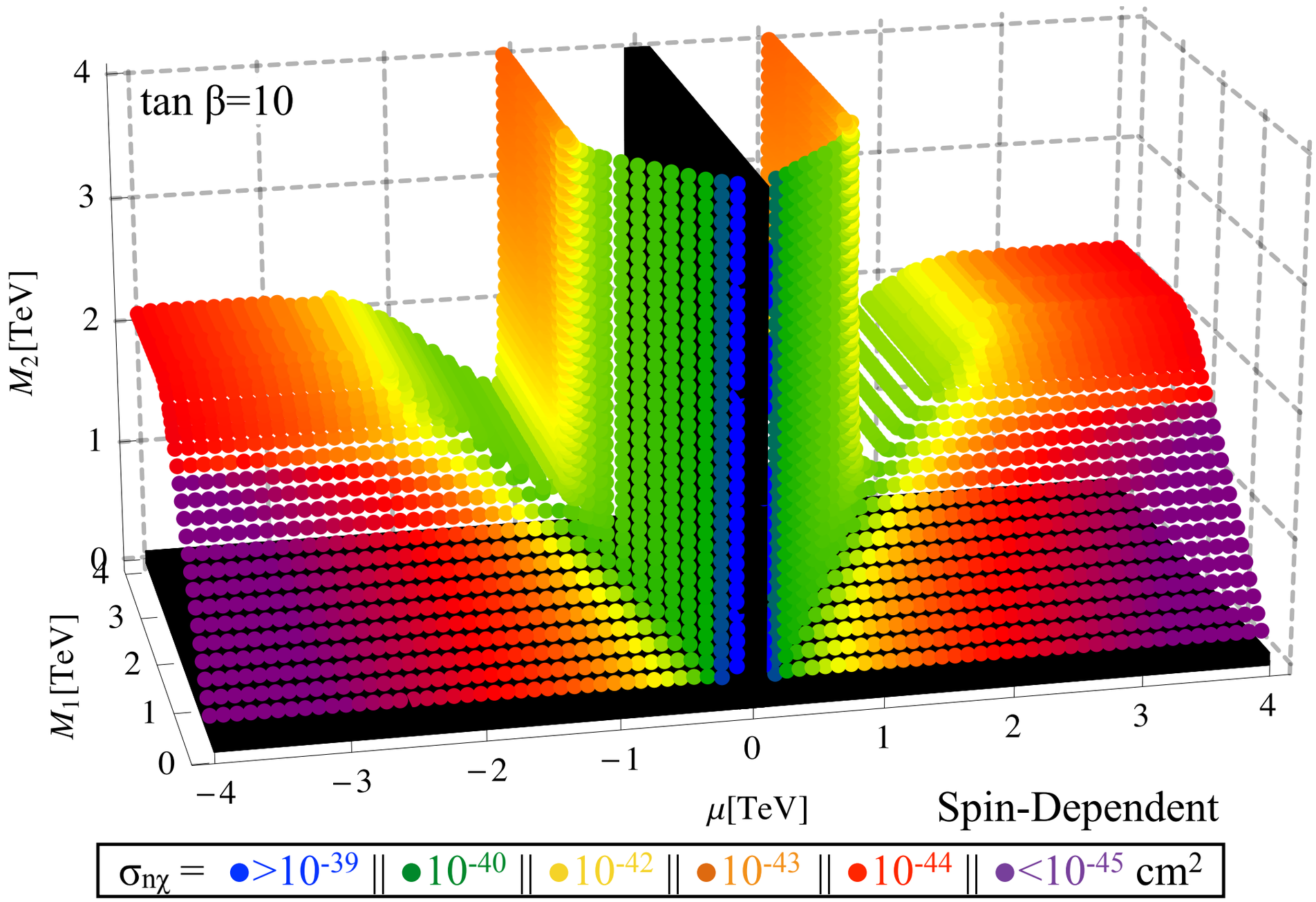
Bino-wino search with statistical errors



2% background and 10% background error assumed for upper curve in plot.

Branching to photons



Trade off between 3 body decays and 1 loop suppression of radiative decays.

Spin dependent direct detection