Status of Pre-CDR -- the cosmology working group

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2014-8-13

Outline

- dark matter
- EW baryogenesis

WIMPs at colliders

- First step: effective theory
  - most general and simplest case, only SM+DM
  - Signal: monojet, mono-gamma/Z, mono …
- Simplified model: SM+DM+mediator (s/t channel)
  - Signals: mono-jet/gamma/Z, mediator (Z'/squark)
- SUSY (Simplified DM)
- Other DM models
  -

Constrain the effective interaction @ CEPC

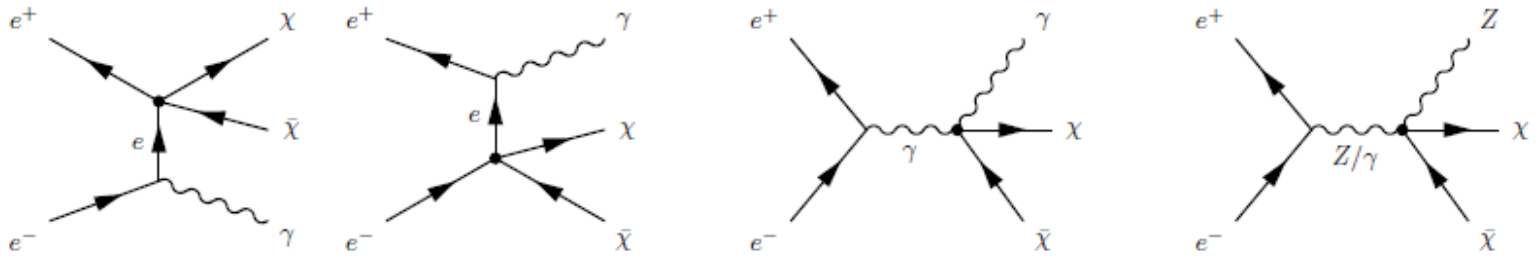
Bi, Yin, Yu, Yuan

We have given an study to constrain the interaction between DM and SM particle with effective operators.

Operators: $\mathcal{O}_e = \frac{1}{\Lambda^2}\bar{\chi}\Gamma_\chi\chi\bar{e}\Gamma_e e, \quad \Gamma_\chi, \Gamma_e \in \{1, \gamma_5, \gamma^\mu, \gamma^\mu\gamma_5, \sigma^{\mu\nu}\}$

$$\mathcal{O}_Z = \frac{1}{\Lambda_1^3}\bar{\chi}\chi B_{\mu\nu}B^{\mu\nu} + \frac{1}{\Lambda_2^3}\bar{\chi}\chi W^a_{\mu\nu}W^{a\mu\nu},$$

Signals: mono-gamma, mono-Z



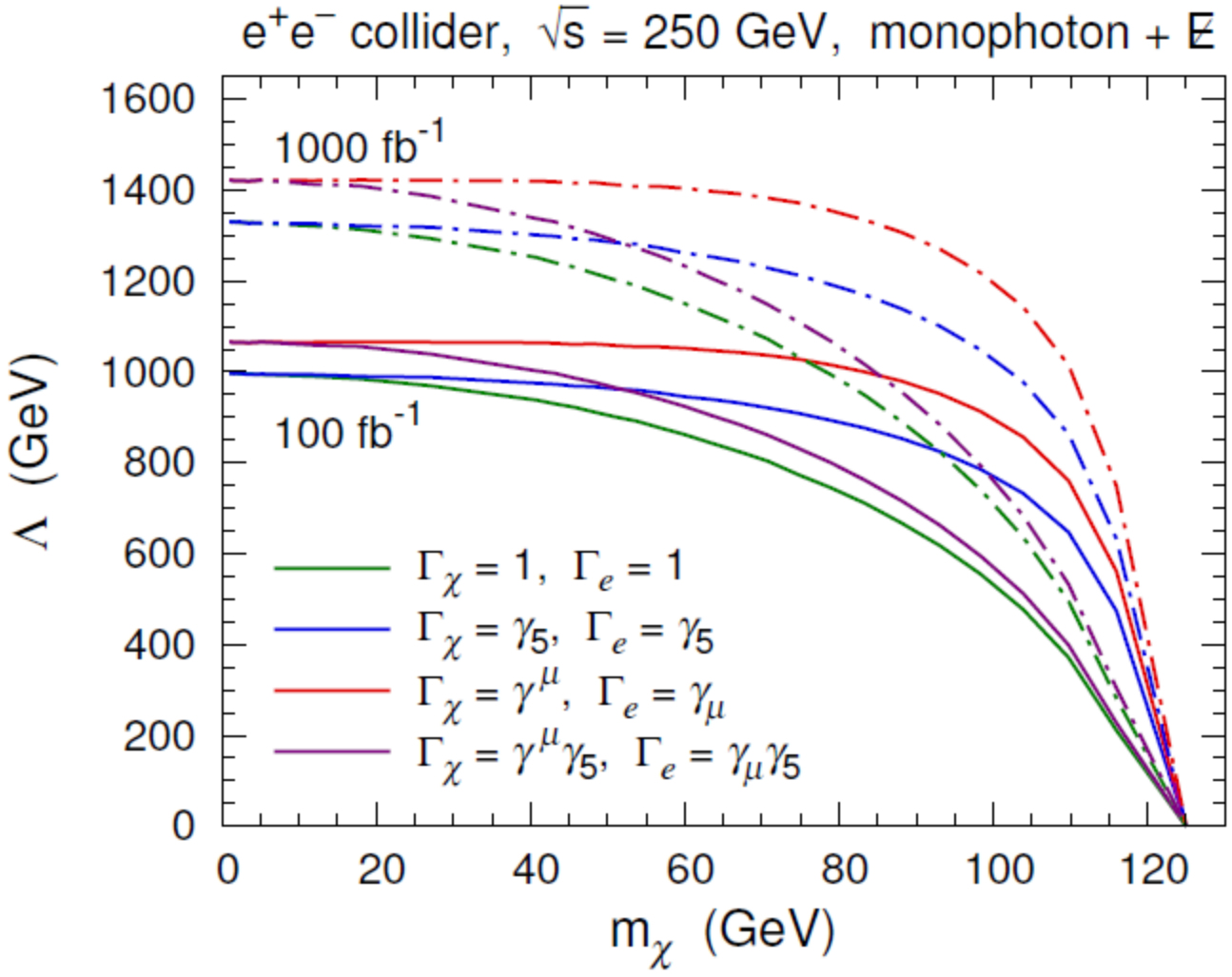
(a) DM coupled to electrons.

(b) DM coupled to photons.

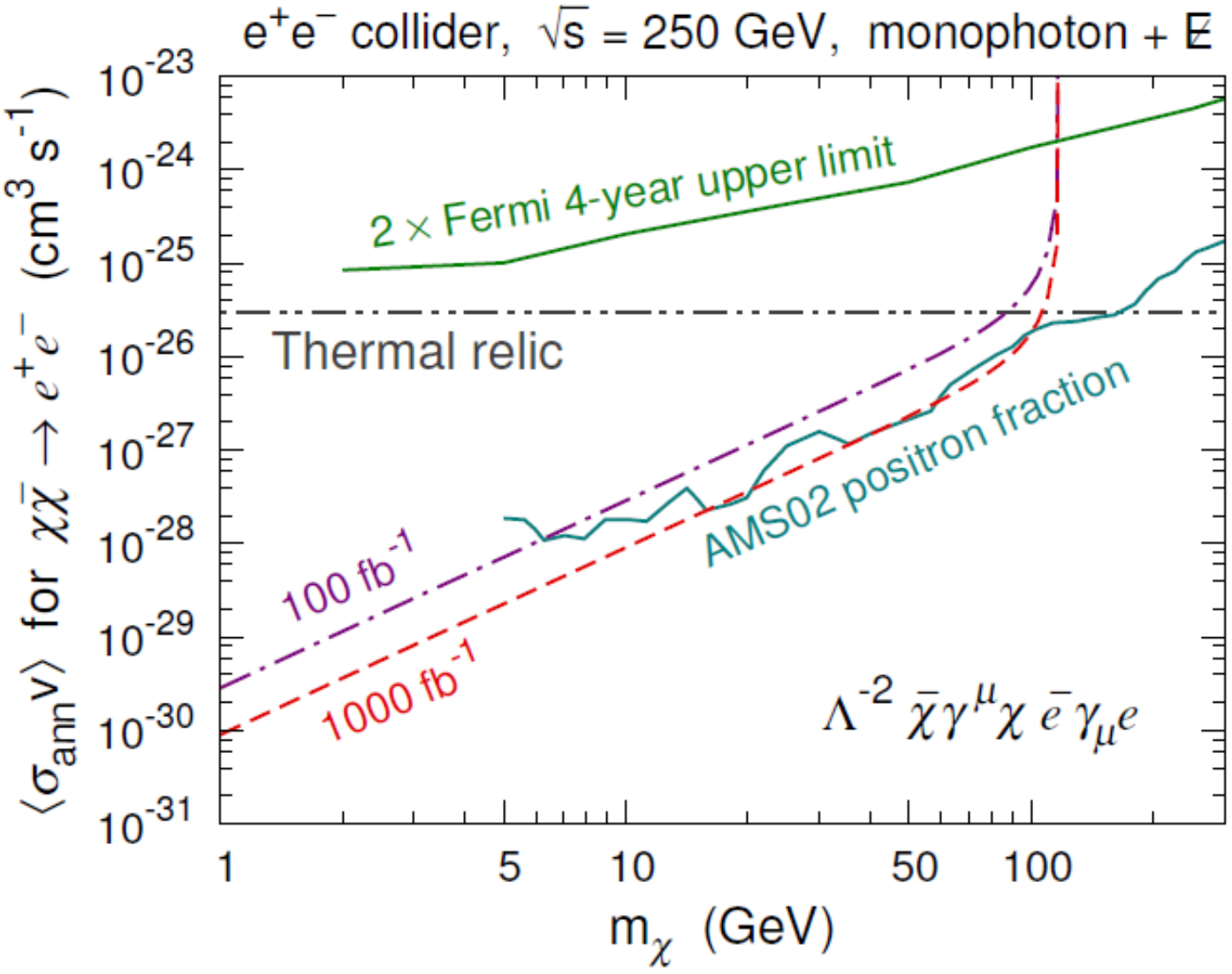
(c) DM coupled to Z bosons.

Figure 1. DM production processes $e^+e^- \to \chi\bar{\chi}\gamma$ and $e^+e^- \to \chi\bar{\chi}Z$.

Constraints on the 4-fermion operators @CEPC

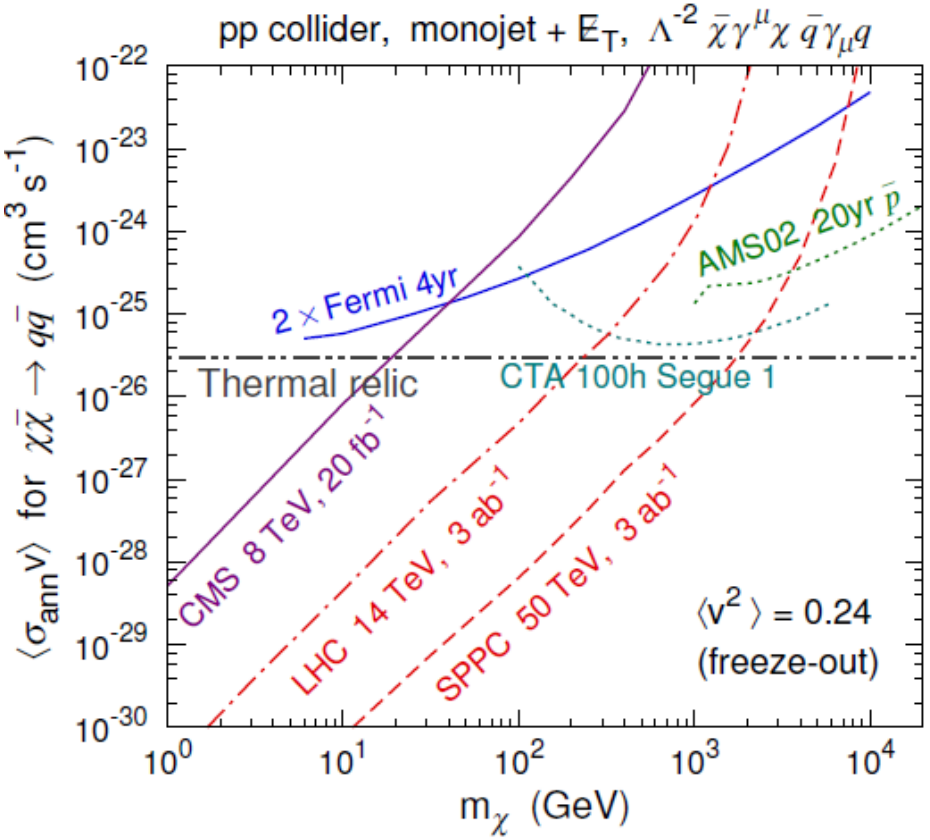


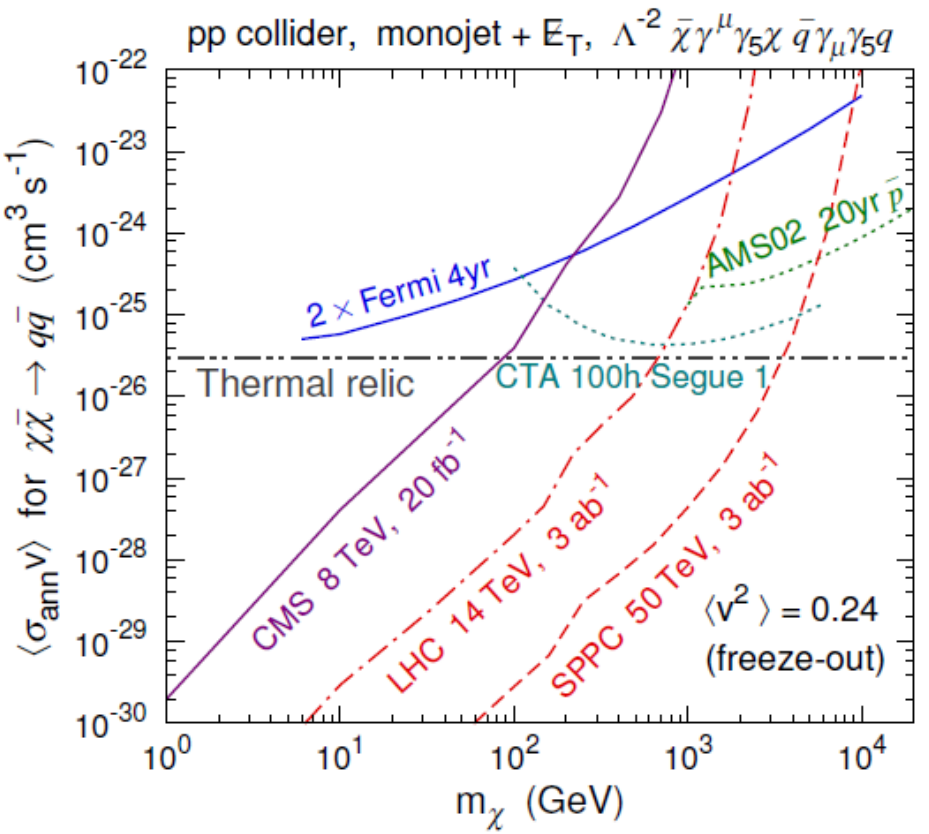
Comparison with the sensitivities of indirect DM detection by Fermi, AMS-02



Simulation of LHC and SPPC (@50TeV)

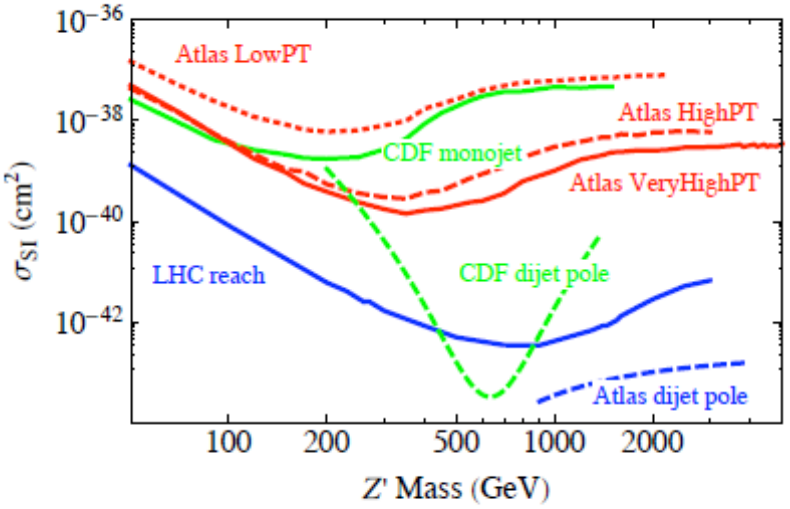
Comparison with the indirect detection by Fermi, CTA and AMS-02 (20yrs)



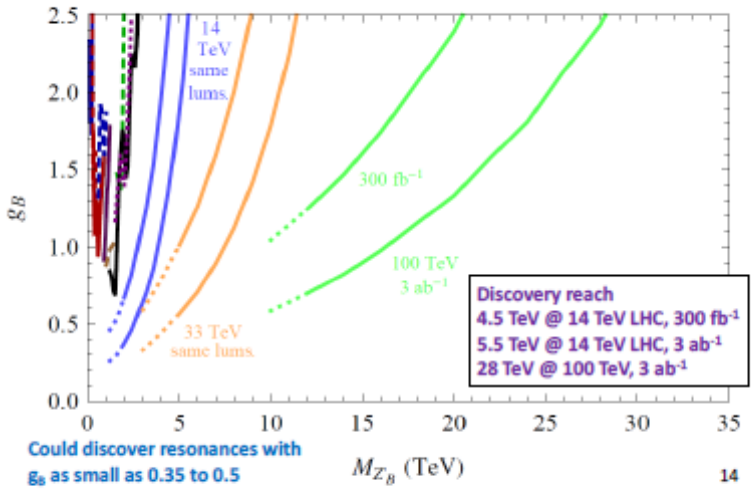


Simplified mediator models

Possible to discover the mediator first!



An, Ji, LTW, 1202.2894 Assume $g_{Z'} = g_D$

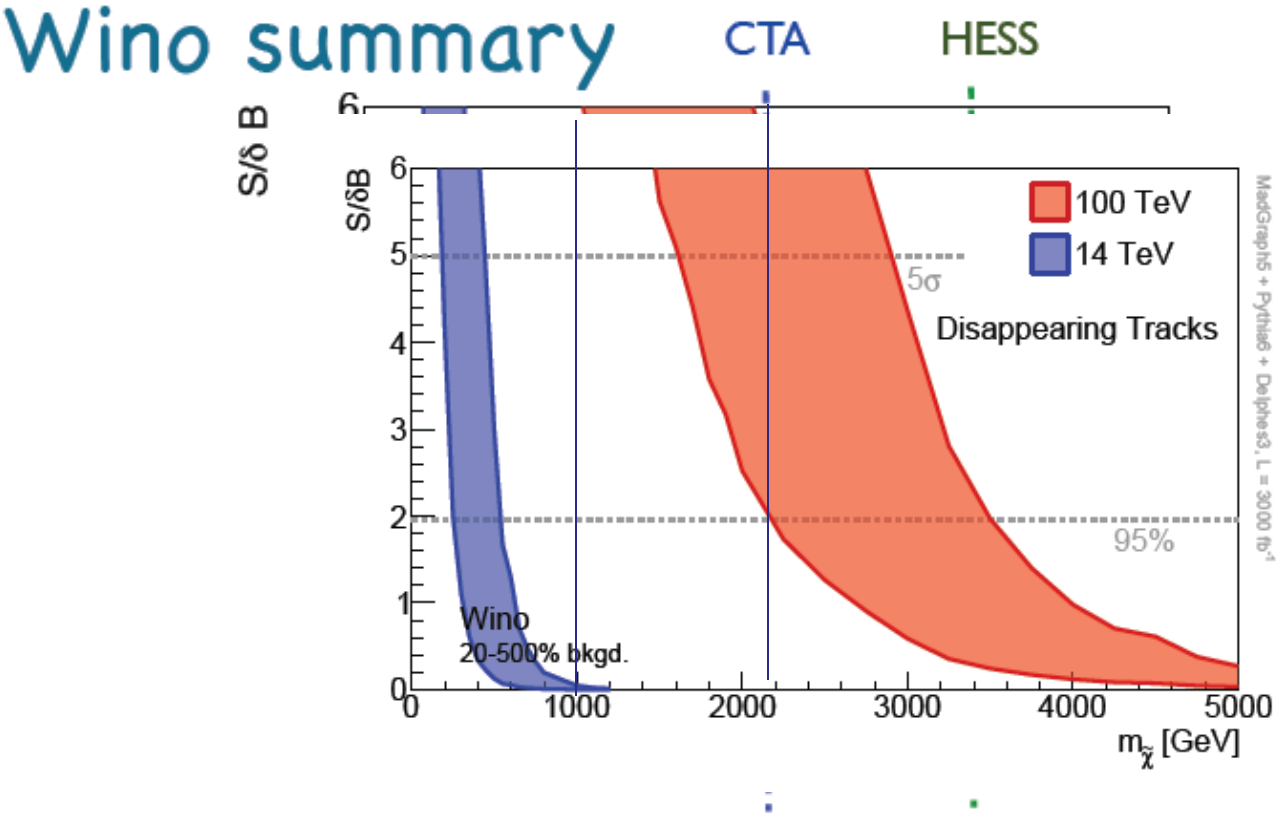


Felix Yu, talk at LPC Jan. 31

For t-channel mediator, squark like searches

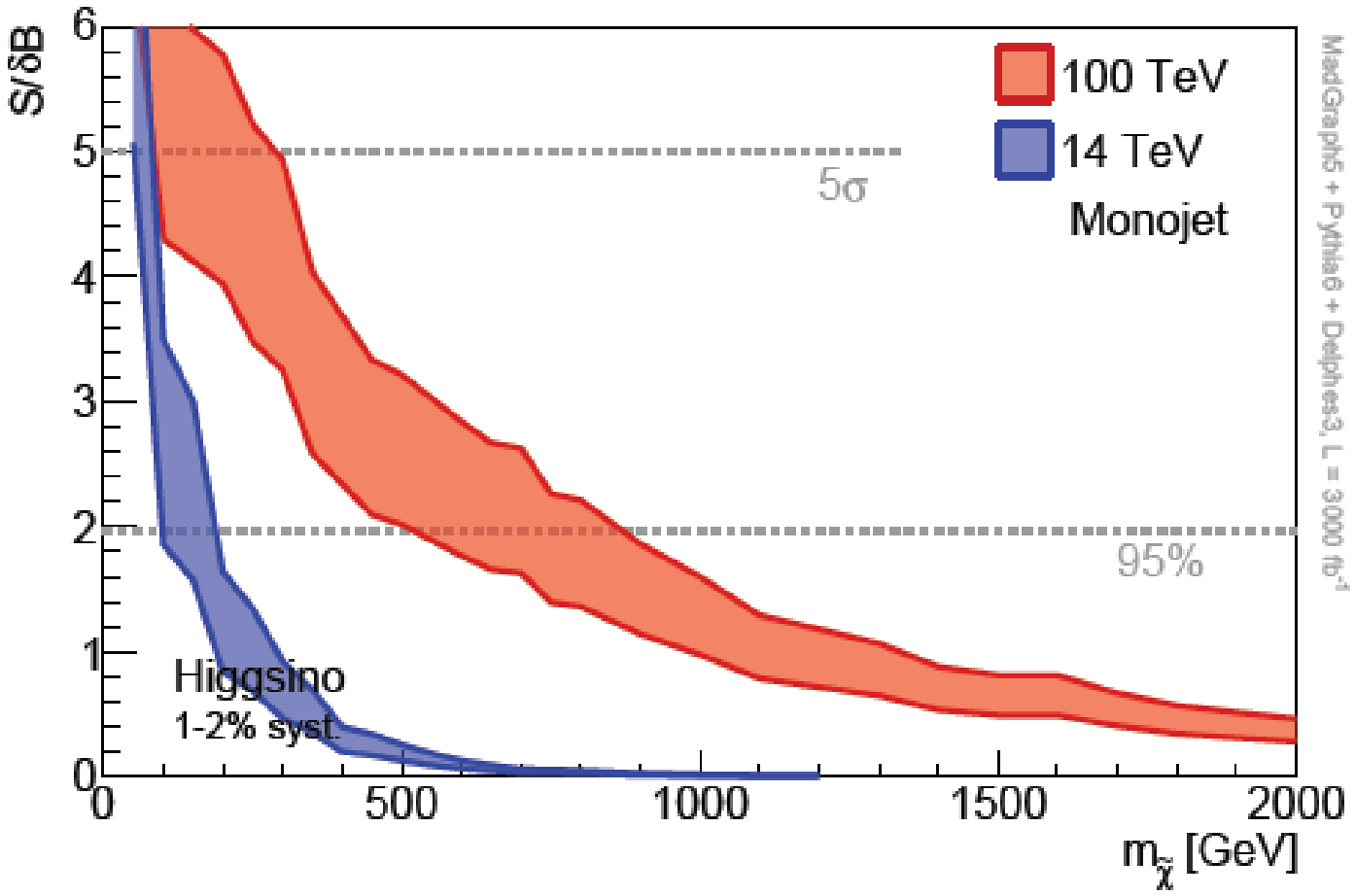
Widely studied at LHC. Still missing at SppC.

Back to SUSY (simplified) (LT is working)

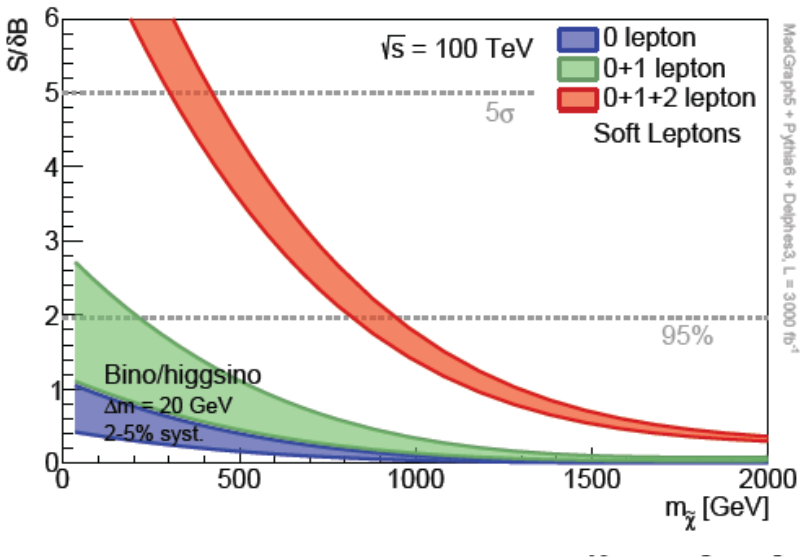


- In combination with indirect detection, there is hope to "completely cover" the wino parameter space.

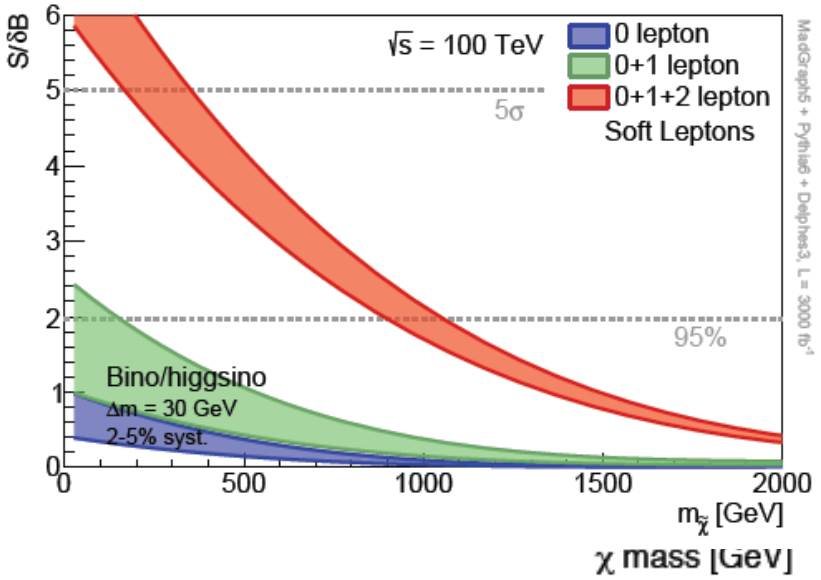
Higgsino (monojet)



Well-tempered, mono-jet + soft lepton



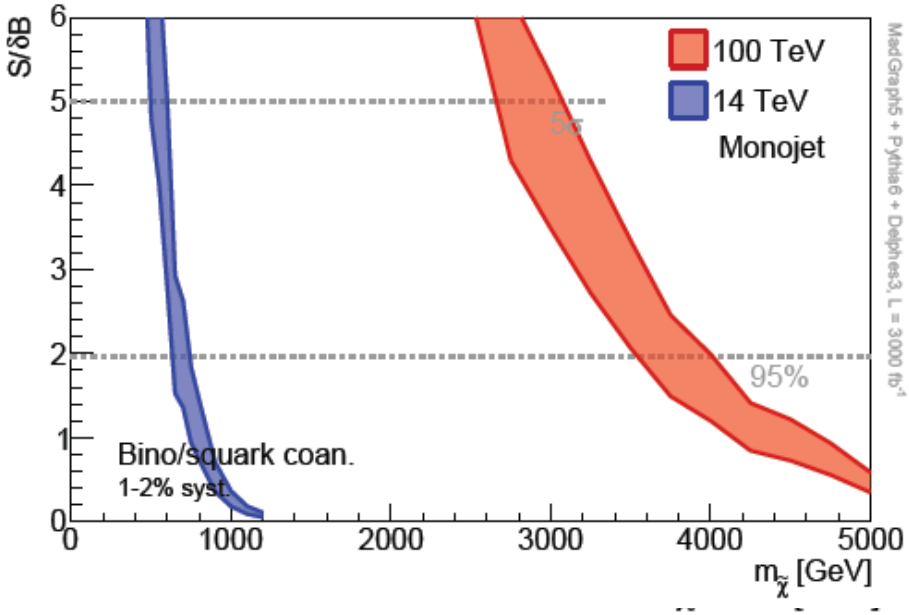
20 GeV < pT lepton < 40 GeV

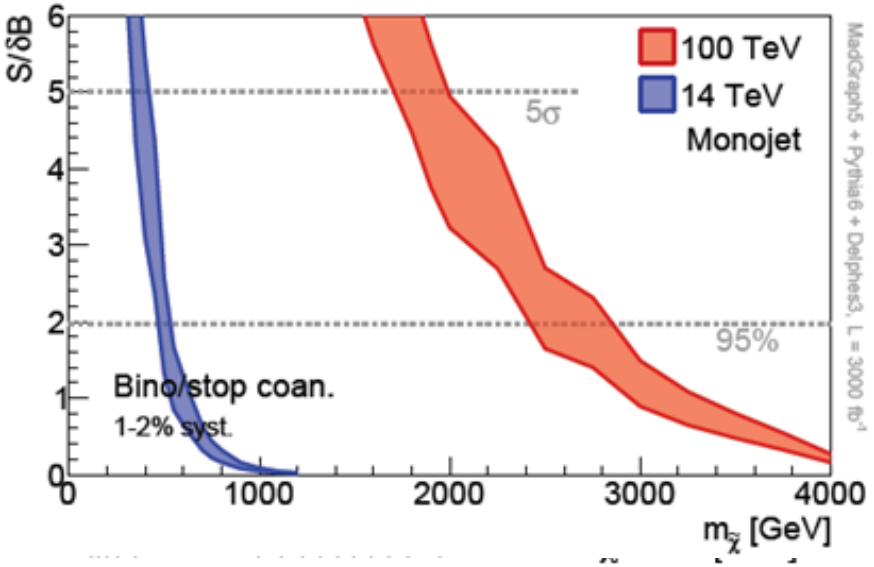


10 GeV < pT lepton < 30 GeV

- Adding soft lepton. S/B is O(1).
- Mitigating factor: Higher lepton threshold at 100 TeV.

Co-annihilation, monojet





- Driven by stop/squark production.
- Impressive reach from mono-jet.
- Could consider soft lepton in the stop case.

1st & 2nd phase transition - EWBG

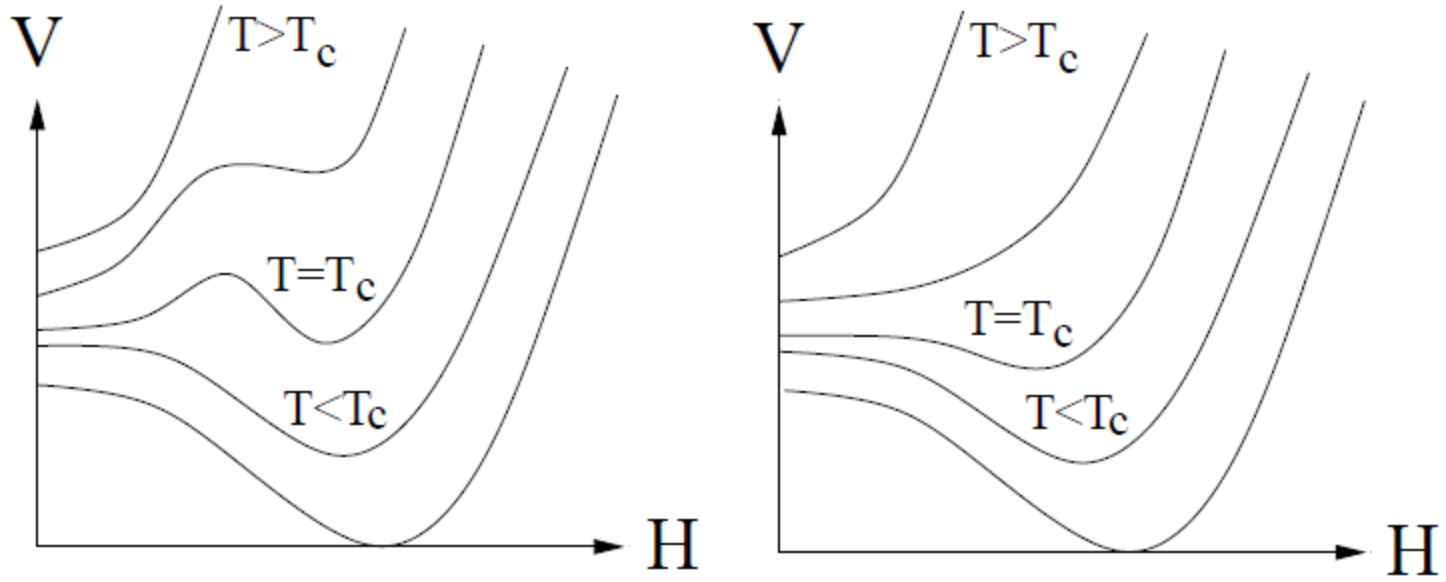


Fig. 10. Schematic illustration of Higgs potential evolution with temperature for first (left) and second (right) order phase transition.

Successful EWBG requires a strongly first-order electroweak phase transition. The generated baryon asymmetry is kept without washout. The phase transition proceeds when bubbles of the broken phase nucleate and expand within the surrounding symmetric phase.

• SM electroweak phase transition is first-order only if the mass of the Higgs boson $m_h < 75$ GeV

• Even if the phase transition is first order, the CP violation by CKM phase is not large enough to generate sufficient asymmetries

• All viable realizations of EWBG needs new physics beyond the SM. The new physics must couple to the SM Higgs quite strongly and new particle masses not too far above the electroweak scale.

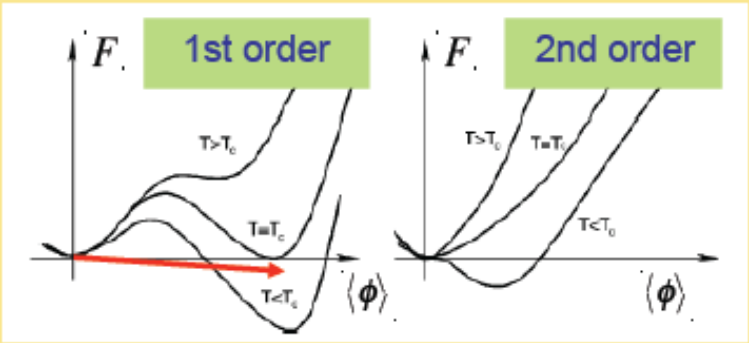
• **A generic prediction of EWBG is that new phenomena should be discovered (severely constrained) at LHC-HL, CEPC (SPPC).**

1st order phase transition

- Class1 -- New scalars couple to the Higgs field and modify the Higgs effective potential by running in loops (e.g. MSSM)
- Class 2 -- New scalar fields coupling to the Higgs that develop VEV in the early Universe, which can influence the effective Higgs potential at tree level (e.g. NMSSM)
- Class 3 -- New particles that couple to Higgs field are heavy and induce effective operator at the Higgs potential
- Those coupling inevitably induce 1, deviation of Higgs potential and its couplings with SM particles 2, mixing with a hidden sector 3, exotic(invisible) decays
- High precision measurement of Higgs properties are essential to test those scenarios

M. Ramsey-Musof, J. Shu, T. Liu are working on the part. MR is responsible for EW part. The present version focus on the Higgs portal models.

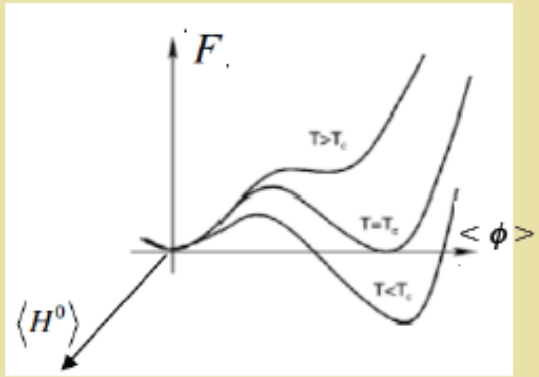
EW Phase Transition: Higgs Portal



Increasing m_h →

← *New scalars*

$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$



- *Renormalizable*
- *ϕ : singlet or charged under $SU(2)_L \times U(1)_Y$*
- *Generic features of full theory (NMSSM, GUTS…)*
- *More robust vacuum stability*
- *Novel patterns of SSB*

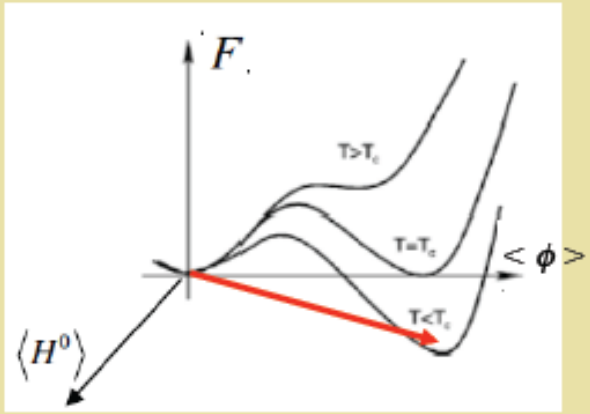
EW Phase Transition: Singlets

$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$

Tree-level barrier

Modify T_C

- *Two Higgs-like mixed states*
- *Modified SM-like Higgs self-coupling*
- *Reduced SM-like Higgs signal strength*
- *Resonant di-Higgs production*
- *Exotic decays*



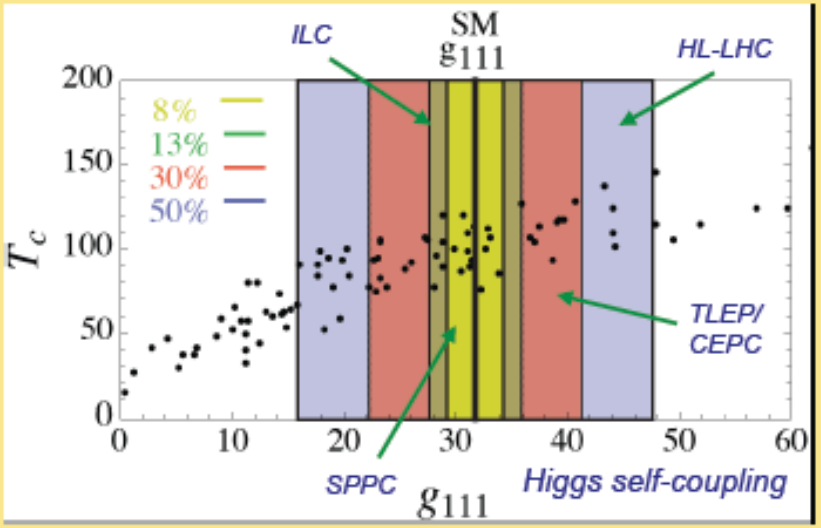
- *Tree-level barrier*
- *Possible lower T_C : better for baryogenesis*

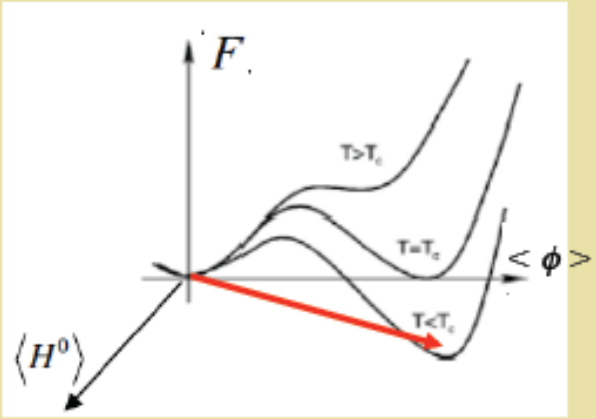
EWPT & Singlets: Higgs Self-Coupling

$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$

Tree-level barrier

Modify T_C





- *Tree-level barrier*
- *Possible lower T_C : better for baryogenesis*
  - *Black points: strong 1st order EWPT*
  - *Colored bands: prospective precision*

Thanks: P. Winslow

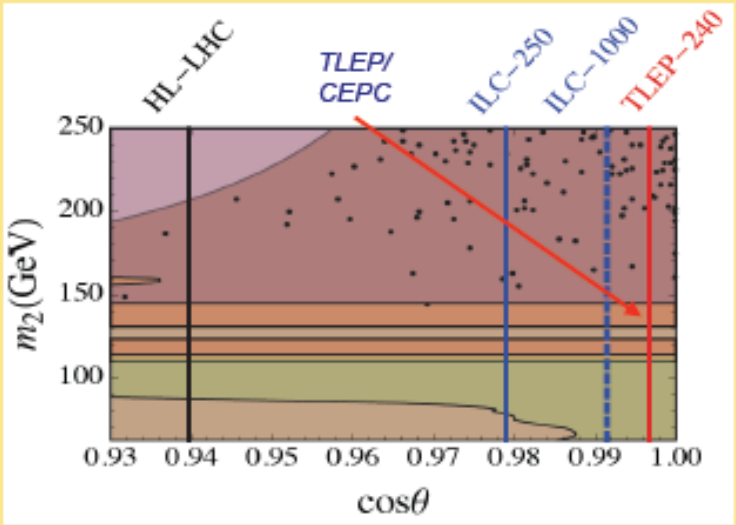
1407.5342

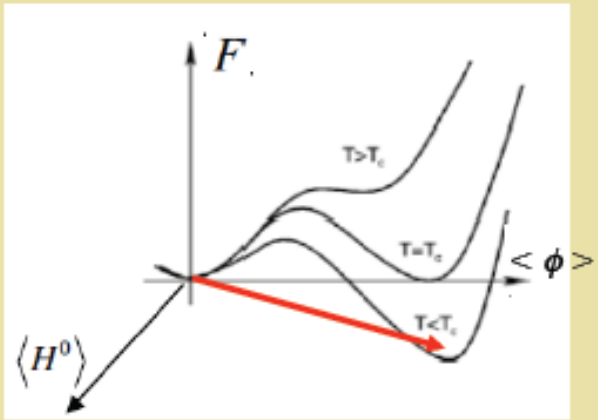
EWPT & Singlets: Mixing Angle

$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$

Tree-level barrier

Modify T_C





- *Tree-level barrier*
- *Possible lower T_C : better for baryogenesis*

- *Black points: strong 1st order EWPT*
- *Vertical lines: prospective precision*

Thanks: P. Winslow

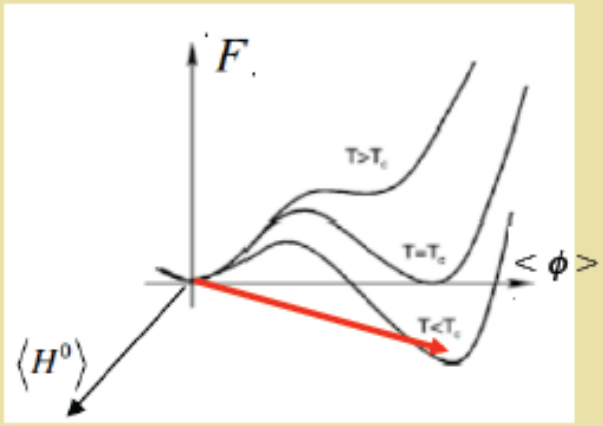
1407.5342

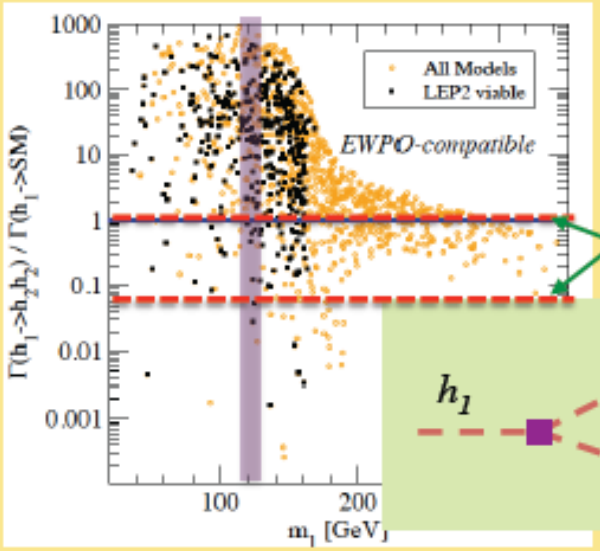
EWPT & Singlets: Exotic Decays

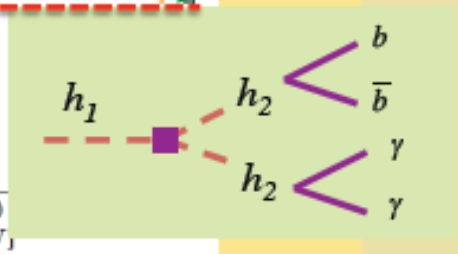
$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$

Tree-level barrier

Modify T_C







- *Tree-level barrier*
- *Possible lower T_C : better for baryogenesis*

- *Black points: strong 1st order EWPT*
- *Vertical axis: $\Gamma(h_1 \to h_2 h_2)/\Gamma(h_1 \to SM)$*

0705.24252

EW Phase Transition: Non-Singlet

Real Triplet $\Sigma \sim (1,3,0)$

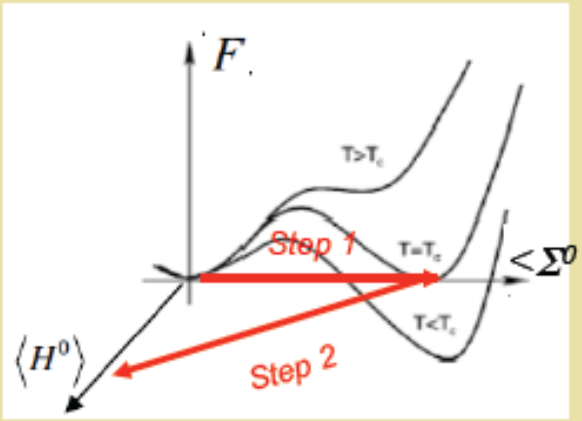
Two-step EWPT & dark matter

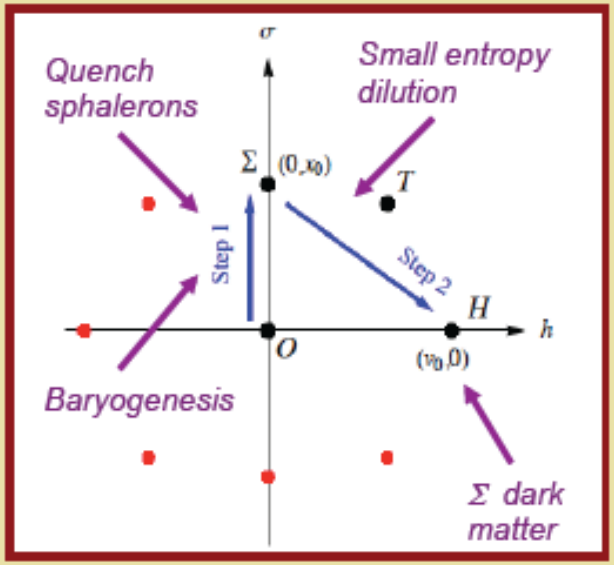
$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$

Small tree-level barrier (ρ param)

Controls 2nd step

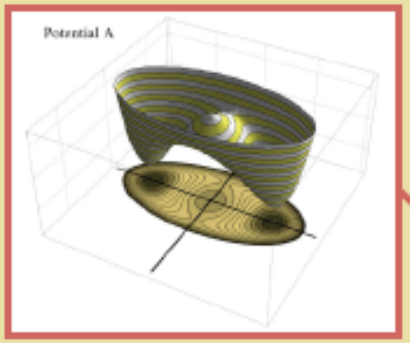
- *Modified $h \to \gamma\gamma$*
- *Direct production of new states*





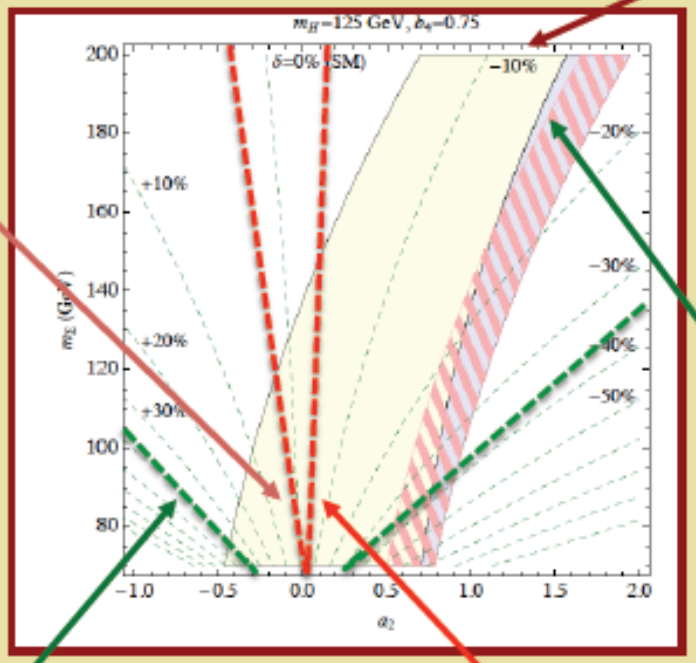
Patel, R-M: arXiv 1212.5652 ; Fileviez-Perez, Patel, RM, Wang

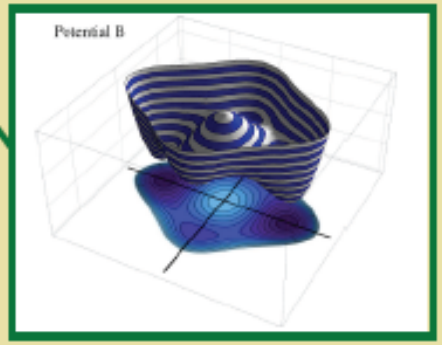
EW Phase Transition: Non-Singlet



One-step EWSB

% shift in $\Gamma(h\to\gamma\gamma)$





Two-step EWSB

ILC 250

CEPC

H. Patel & R-M, 1212.5652/hep-ph (2012)

Baryogenesis & EWPT: Other Topics

- *Direct searches for new states (electroweak multiplets or heavier strongly interacting multiplets) that may enable baryogenesis viable phase transitions (likely SppC) (in progress)*
- *Direct search for singlet-like scalar (in progress for LHC) at both CEPC and SppC*
- *Update studies of exotic Higgs decays as probes of EWPT*
- *Study direct and indirect signatures of new CPV interactions as needed for baryogenesis and compare with future EDM and heavy flavor sensitivities (in progress)*

- Class I models, loop induced 1st PT. Parameter space probed at CEPC/SppC.

- CP violation at CEPC/SppC.

Summary

- DM search at CEPC is studied at EFT.
- Study on DM @ SPPC has performed for EFT and simplified SUSY. A final version of this part is coming soon.

- EW baryogenesis is testable at the CEPC. Works on Higgs portal and other related topics are going on. A preliminary version is ready.