NEW PROBES FOR BINO DARK MATTER WITH COANNIHILATION AT THE LHC

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ARXIV:1504.00504 N.NAGATA, H.O AND S.SATOSHI

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ARXIV:1506.08206 N.NAGATA, H.O AND S.SATOSHI

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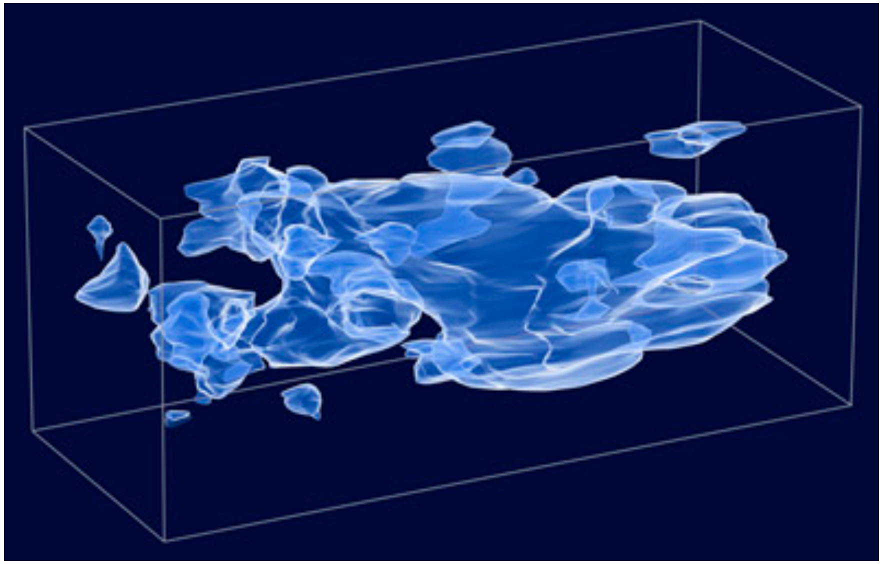
DARK MATTER

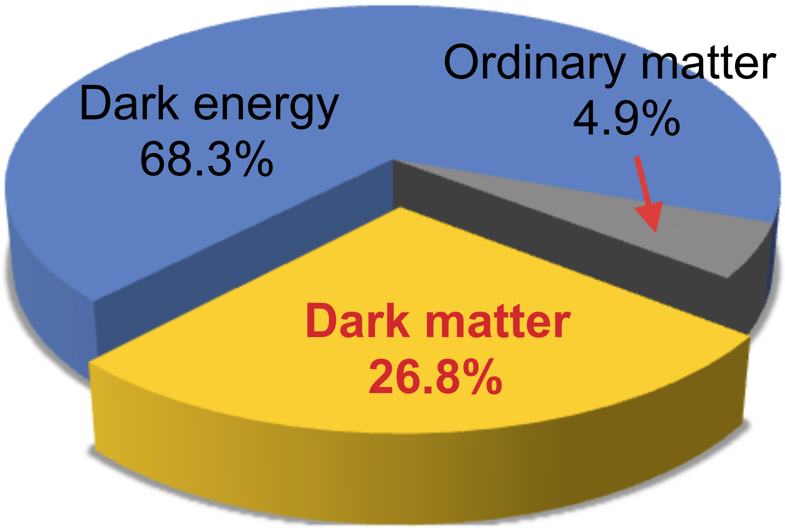
Regardless of the evidence of the dark matter, we don't have any particles for DM in the standard model.

The candidates should be neutral, non-baryonic and non-relativistic particles. SUSY particles could satisfy the requirements for DM.

- **Other possibilities – sterile neutrino, axion and so on..**



3-D Distribution of Dark Matter by Hubble



Universe mass composition by Planck

SUPER SYMMETRY

Introduction of partners for all particles in standard model:

- **The spin differs by a half-integer.**
- **R-parity conservation makes the lightest SUSY particle stable.**
  - Dark matter candidates – neutral, non-baryonic, non-relativistic

S = 0	S = 1/2			S = 3/2
sneutrino	Bino	Wino	Higgsino	Gravitino

Ruled out by the observation.
Phys.Lett.B 339, 248(1994)

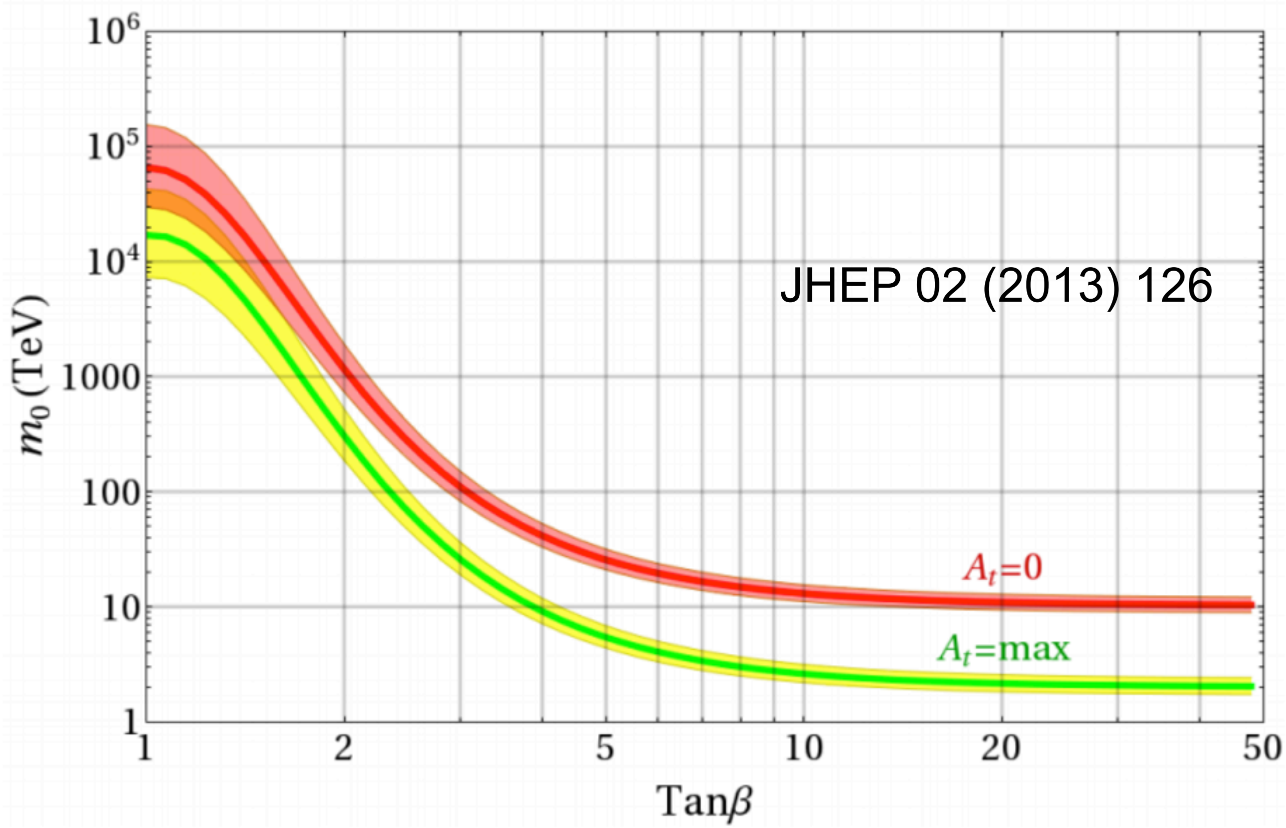
Induce "Gravitino" problem,
but several solutions exist.

Mixed with each other,
resulting in four neutralino.
The LSP mass of O(100) GeV ~ O(1) TeV is favored.

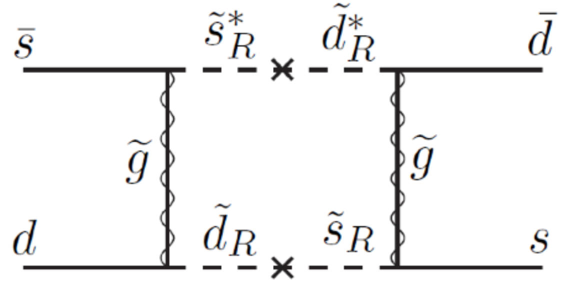
SUSY AND HIGGS MASS

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3g^2 m_t^4}{8\pi^2 m_W^2} \ln\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right)$$

In the minimal SUSY model, Higgs should be lighter than Z boson. 125 GeV higgs implies heavy sfermion, say more than 100 TeV.

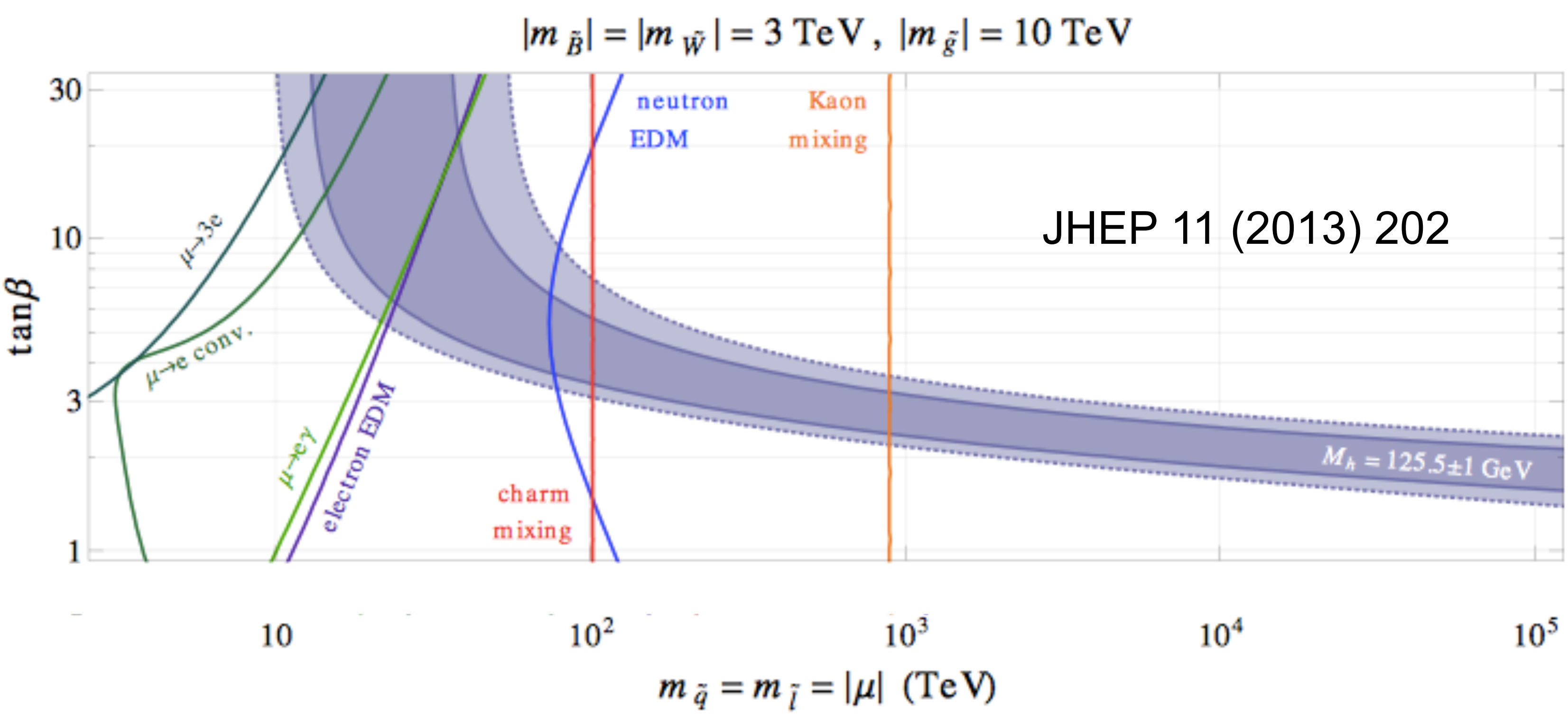


FLAVOR / CP PROBLEM



The terms inducing Flavor/CP violation exist in the SUSY model.

- **No evidence of new physics in low energy experiments require un-natural tuning of the terms, mitigated by heavy sfermion.**



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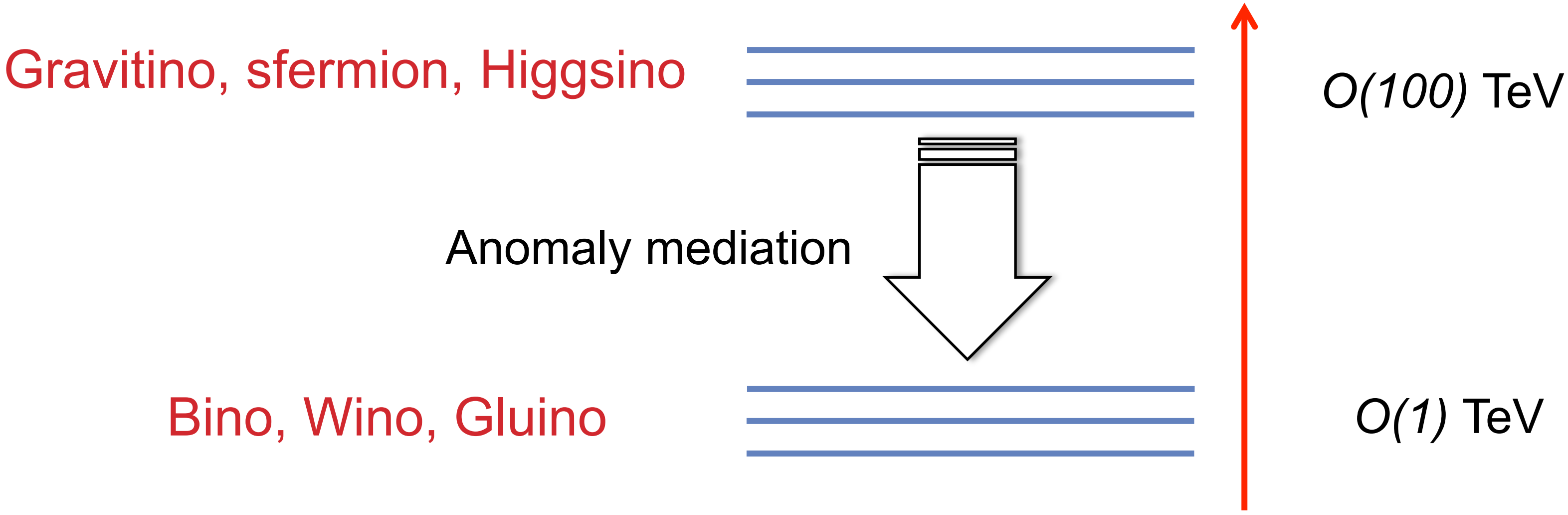
MASS SPECTRUM IN SPLIT SUSY

Higgsino mass could be similar to the heavy sfermion mass.

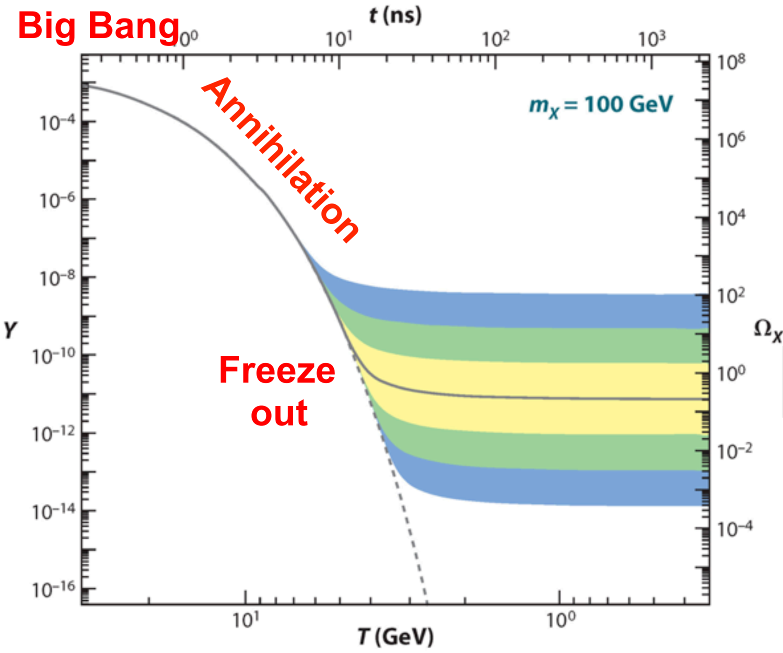
Relatively light Gauginos can be realized by Anomaly mediation.

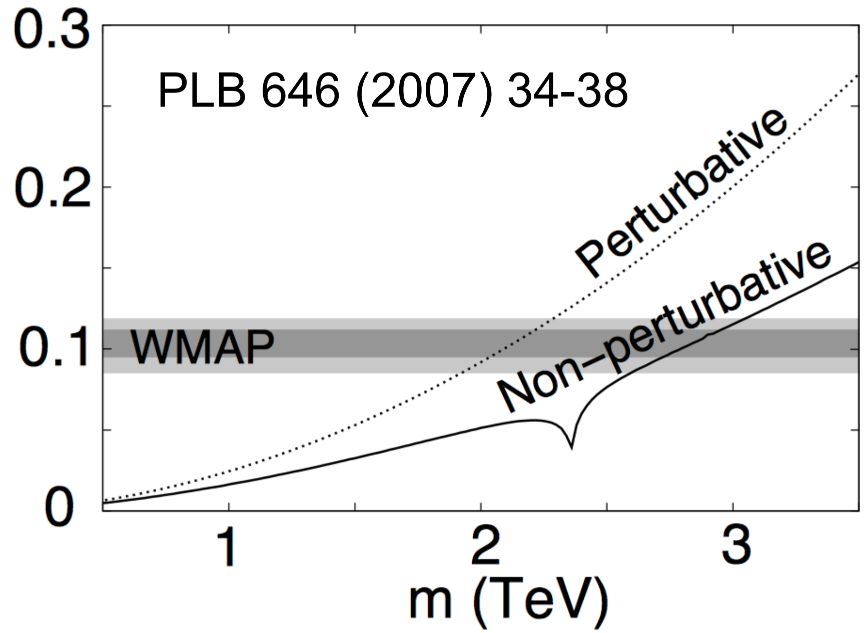
- **Four neutralinos consist of**
  - Two Higgsino-like neutralino with *O(100)* TeV
  - Bino-like and Wino-like neutralino with *O(1)* TeV



WINO DARK MATTER

Wino DM is required to be 2 ~ 3 TeV to explain whole abundance.





- **Unique signature at the LHC : M_W > 270 GeV**
- **Direct interaction with nucleus underground**
- **Indirect detection through cosmic γ-rays observation**

BINO DM AND CO-ANNIHILATION

Bino DM is quite sterile compare to the Wino DM

- **Direct and indirect detection is challenging**

Bino DM suffers from over-production compared to observation.

- **Bino-Bino annihilation cross section is too small.**
- **Co-annihilation helps this situation very well.**

If Bino DM is compressed with NLSP such as Gluino or Wino,

- **Bino and NLSP are in chemical equilibrium.**
  - Bino ⇔ NLSP
- **NLSP has larger annihilation cross section than Bino.**
  - NLSP + NLSP → SM particles
- **Before freeze out, Bino LSP can be suppressed sufficiently.**

PROPOSED SEARCHES

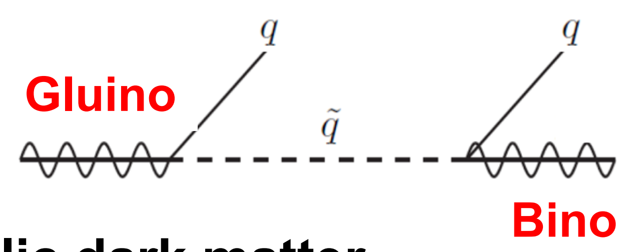
Two searches for Bino dark matter;

- **Bino – Gluino co-annihilation (arXiv:1504.00504)**
  - LSP : Bino
  - NLSP : Gluino
- **Bino – Wino co-annihilation (arXiv:1506.08206)**
  - LSP : Bino
  - NLSP : Wino

In Split SUSY, long-lived NLSPs (Gluino and Wino) could be naturally appeared

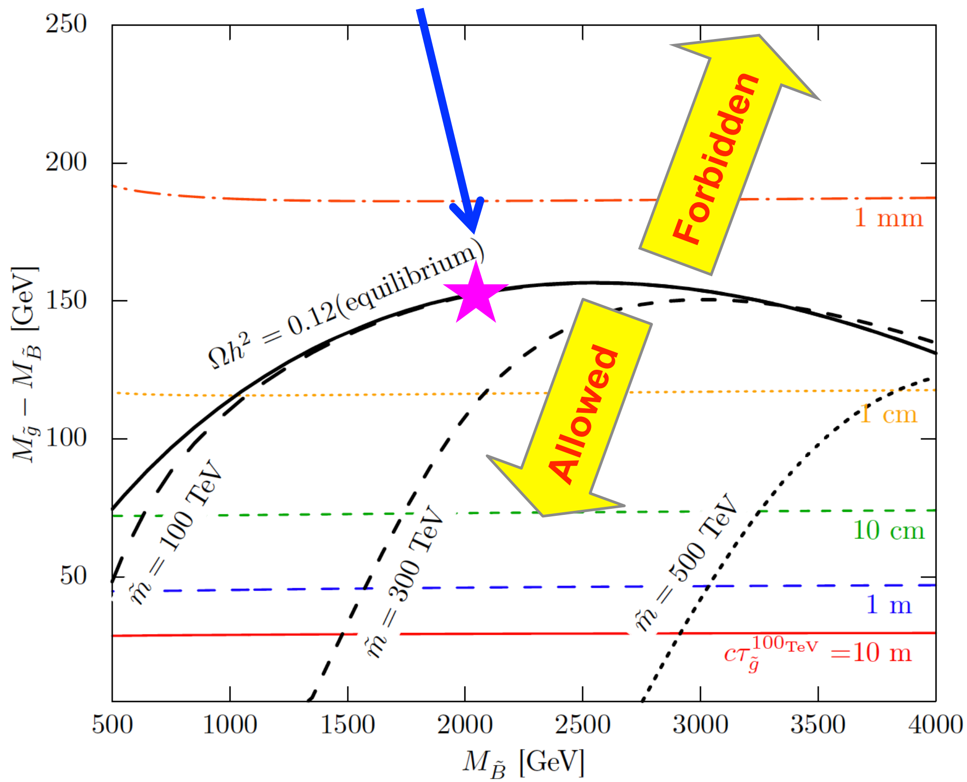
- **Resulting in ~100 GeV displaced vertex at the LHC.**

BINO-GLUINO CO-ANNIHILATION



The mass difference is constrained by relic dark matter

- **Depending on Bino mass and squark mass**
  - e.g. 2000 GeV Bino, 2150 GeV Gluino and 100 TeV squark



Due to the small mass difference, Gluino becomes long-lived.

$$c\tau_{\tilde{g}} = \mathcal{O}(1) \times \left(\frac{\Delta M}{100\ \mathrm{GeV}}\right)^{-5} \left(\frac{\widetilde{m}}{100\ \mathrm{TeV}}\right)^{4}\ \mathrm{cm}$$

Also suppressed by heavy squark.

~ 100 GeV displaced vertex

LONG-LIVED PARTICLE SEARCH AT THE LHC

Taken from Nick Barlow's talk yesterday

https://indico.cern.ch/event/356420/session/4/contribution/554

	Multi-track displaced vertices	Displaced dileptons	Kinked/ Disappearing tracks	Non-pointing photons	Non-pointing leptons	Slow/highly-ionizing charged particles	Decays in empty bunch crossings
RPV SUSY, neutralino LSP	[1],[10]	[1],[9]					
RPV SUSY, squark LSP					[14]	[3],[12]	[6],[8]
Gauge-mediation, neutralino NLSP	[1]	[1]		[4],[13]			
Gauge-mediation, slepton NLSP						[3],[12]	
Anomaly-mediated SUSY breaking			[5],[11]			[2],[3]	
Split / mini-split SUSY	[1]					[2],[3],[12]	[6],[8]

= Search should be possible in principle.

= Model is unlikely to give rise to this signature.

Note 1: These lists are not exhaustive! Other models are available..
Note 2: Many searches also have non-SUSY interpretations.

[n],[m] = ATLAS, CMS publication.
Refs shown on final slide.

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LONG-LIVED PARTICLE SEARCH AT ATLAS

arXiv:1504.05162

ATLAS summarized the searches for long-lived gluino with LSP of 100 GeV, resulting in O(100) GeV displaced vertex.

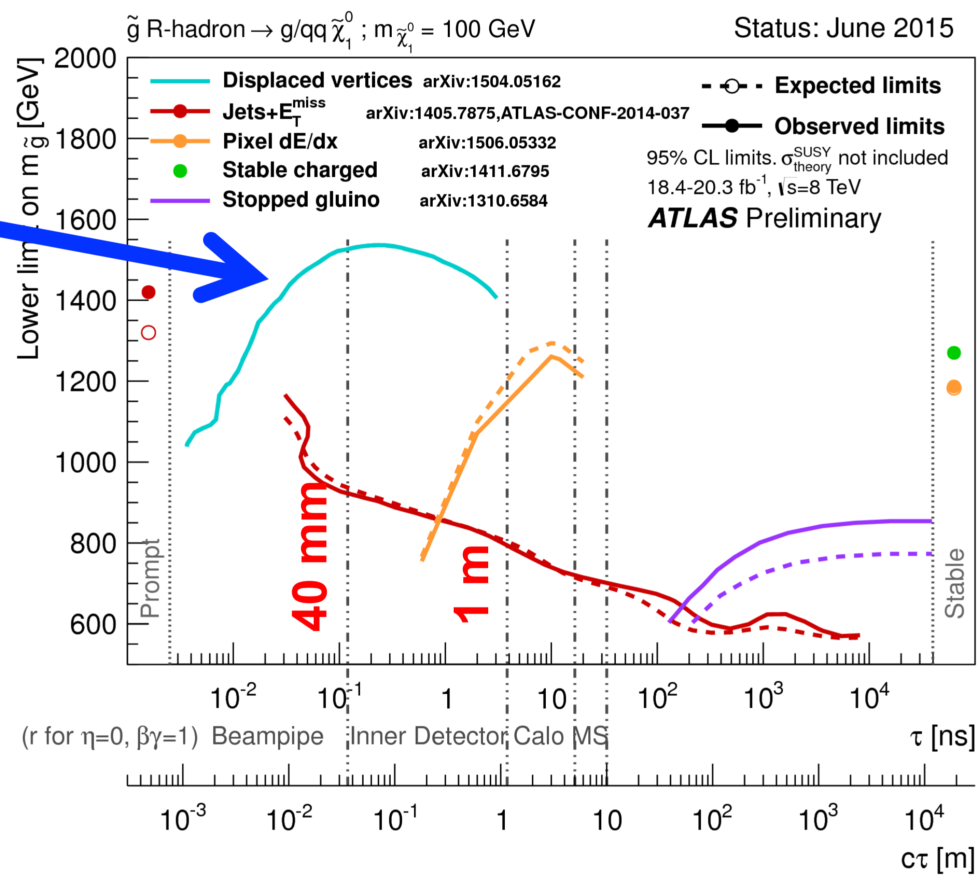
Dedicated displaced vertex search in ATLAS inner detector

- exclude 1600 GeV gluino with around 10 cm flight length

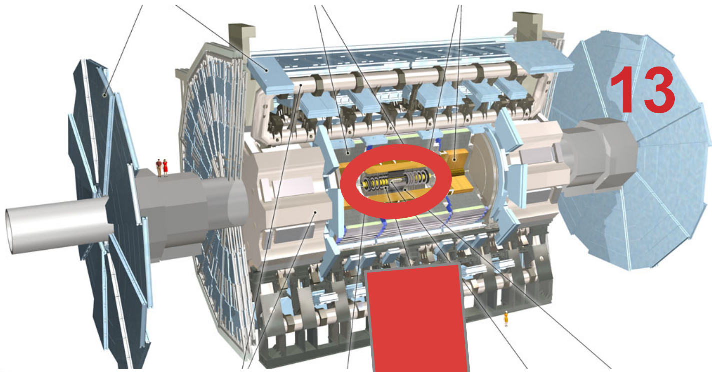
Madgraph5 and Pythia6
Delphes3

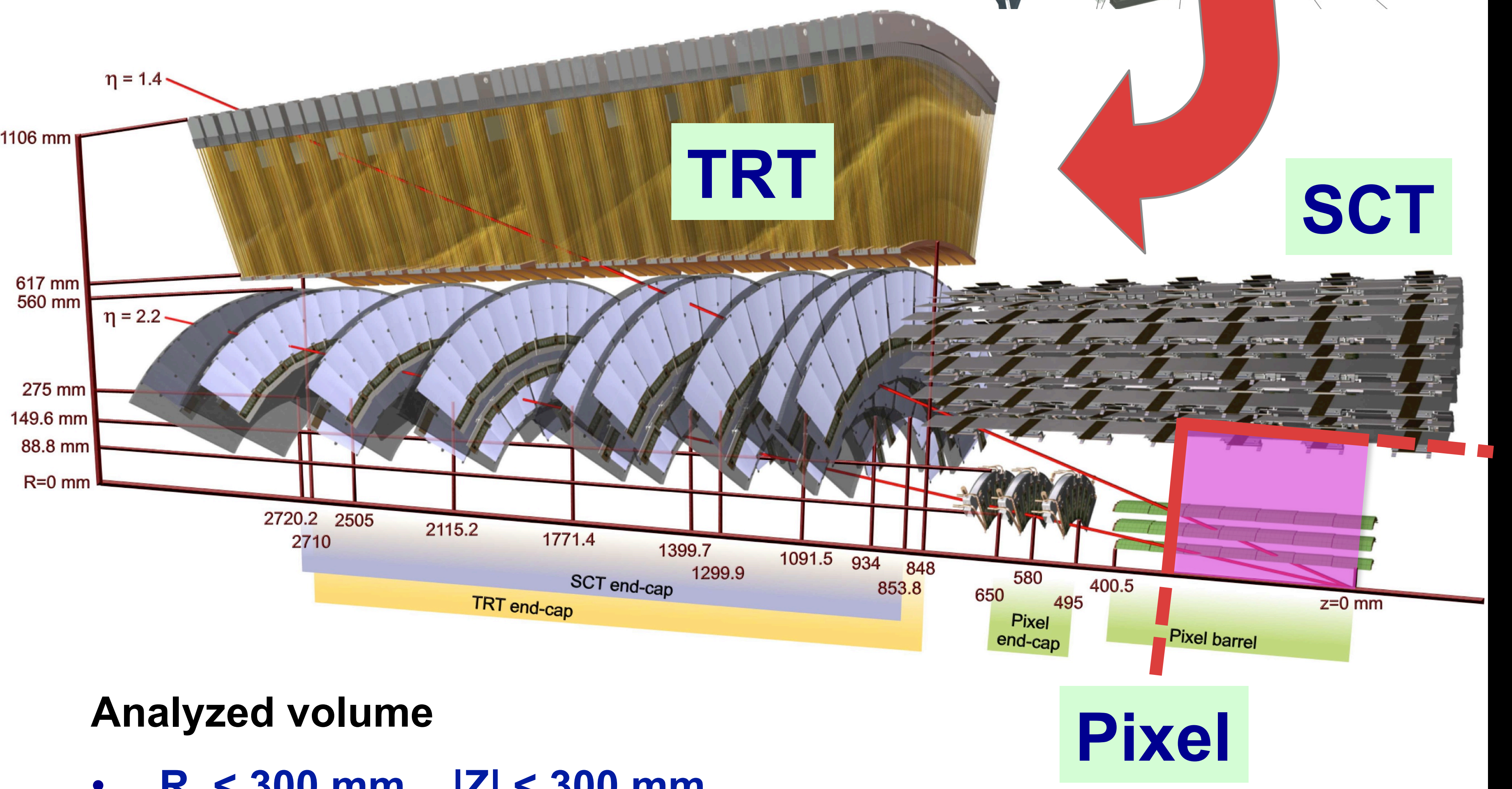
The result can be interpreted for 100 GeV displaced vertex with

- trigger efficiency
- DV reconstruction efficiency



ATLAS
INNER DETECTOR

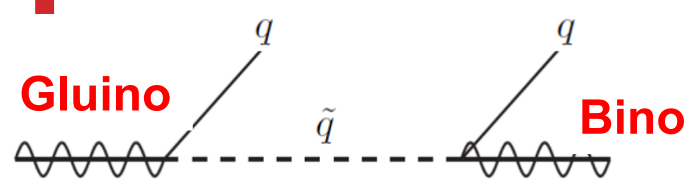


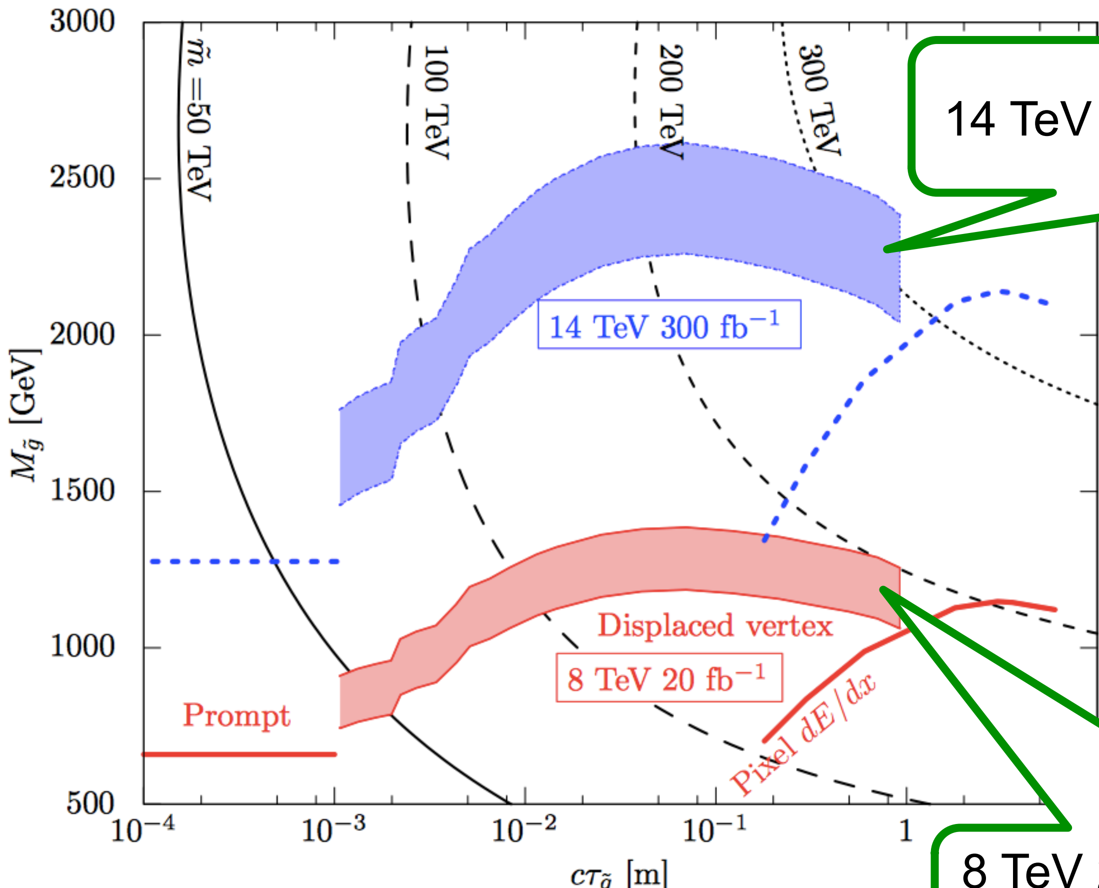


Analyzed volume

- R < 300 mm , |Z| < 300 mm

EXPECTED SENSITIVITY FOR BINO-GLUINO



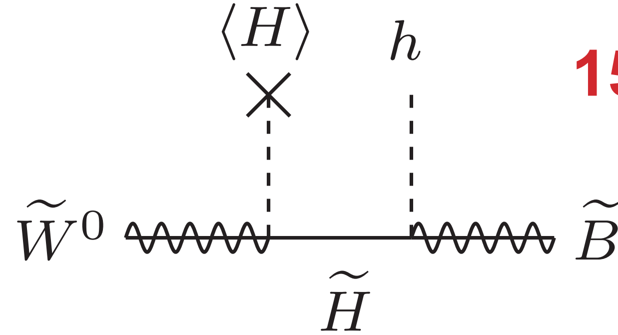


14 TeV 300 fb^{-1} : **2200 GeV @ 10 cm**

8 TeV 20 fb^{-1} : **1200 GeV @ 10 cm**

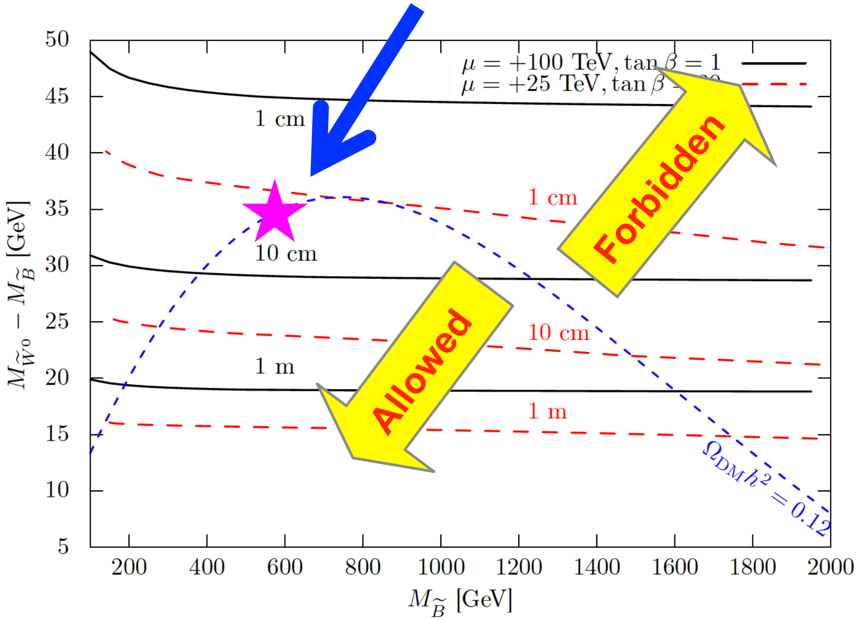
e.g. 1600 GeV for 100 GeV LSP

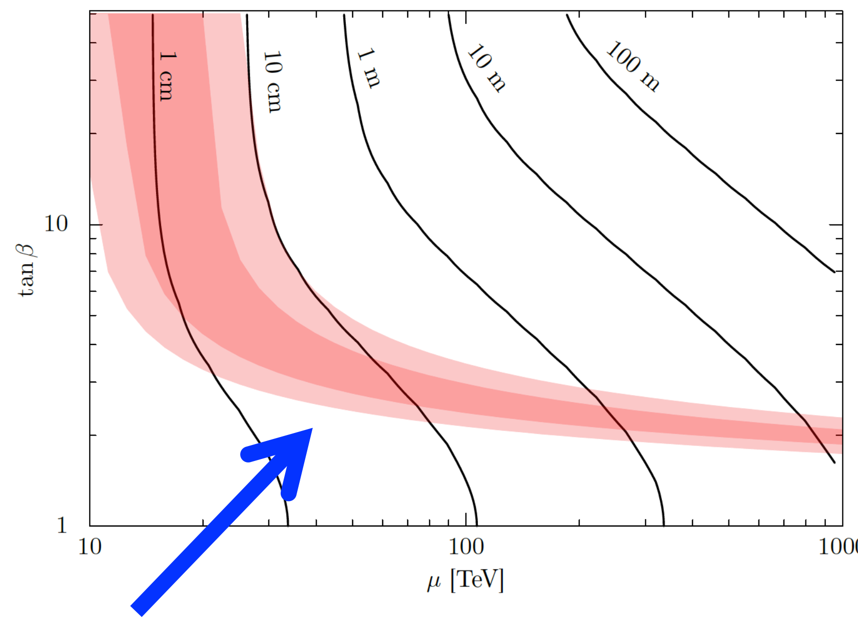
BINO-WINO CO-ANNIHILATION



The mass difference is constrained by relic dark matter.

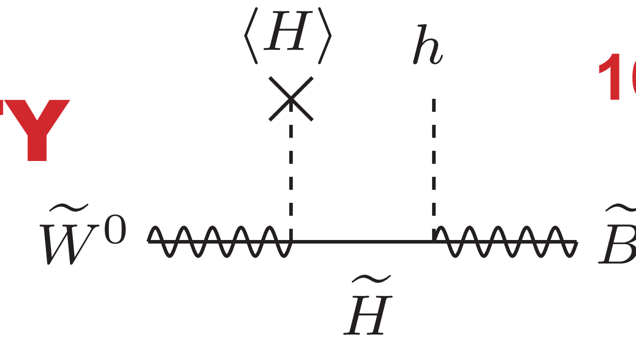
- **Depending on Bino mass**
  - e.g. 600 GeV Bino and 635 GeV Wino





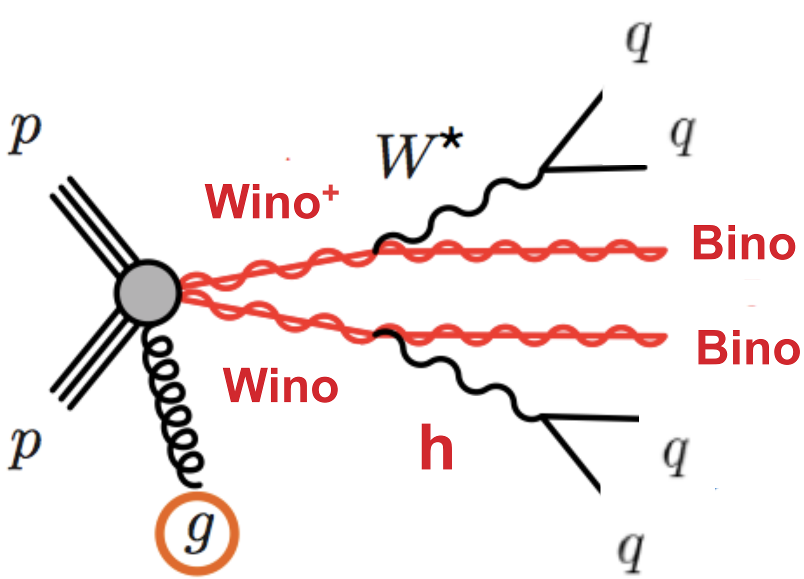
- **Due to heavy Higgsino, Wino could become long-lived.**
  - ~30 GeV displaced vertex at the LHC

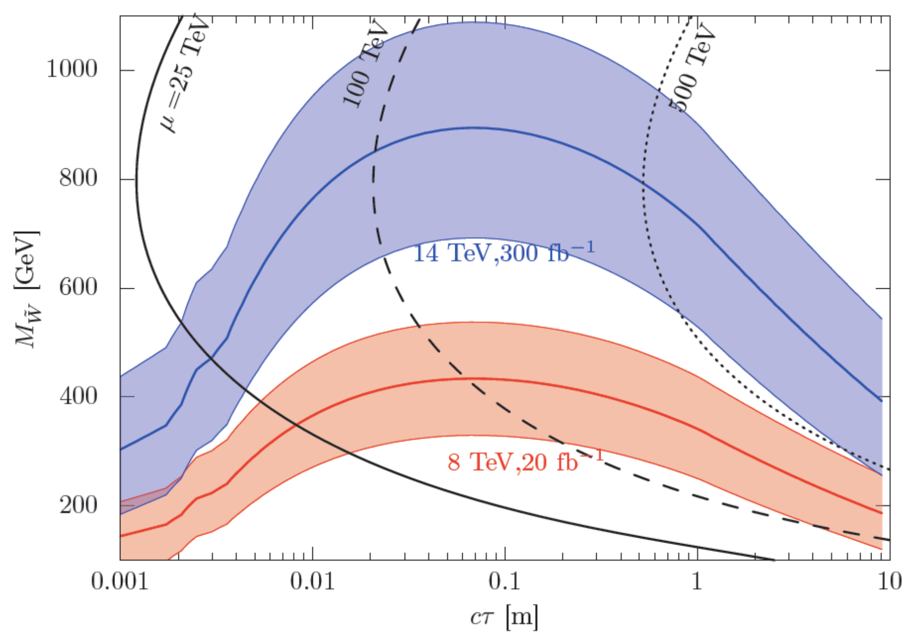
EXPECTED SENSITIVITY FOR BINO-WINO



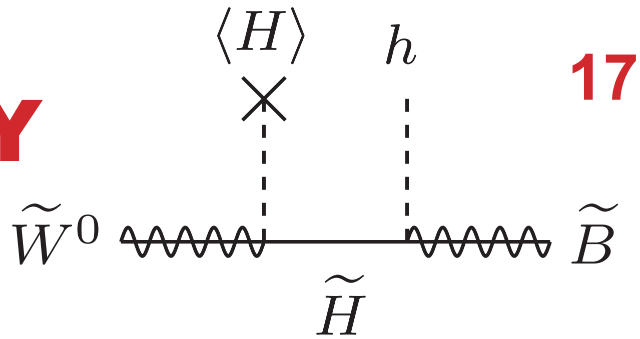
ElectroWeaKino pair production with initial state radiation (ISR)

- **MET > 200 GeV can trigger O(1)% of the production.**
- **All hadronic decay of displaced Higgs and W can be searched.**
  - Search for EWK decay at the collision point needs to require leptons.



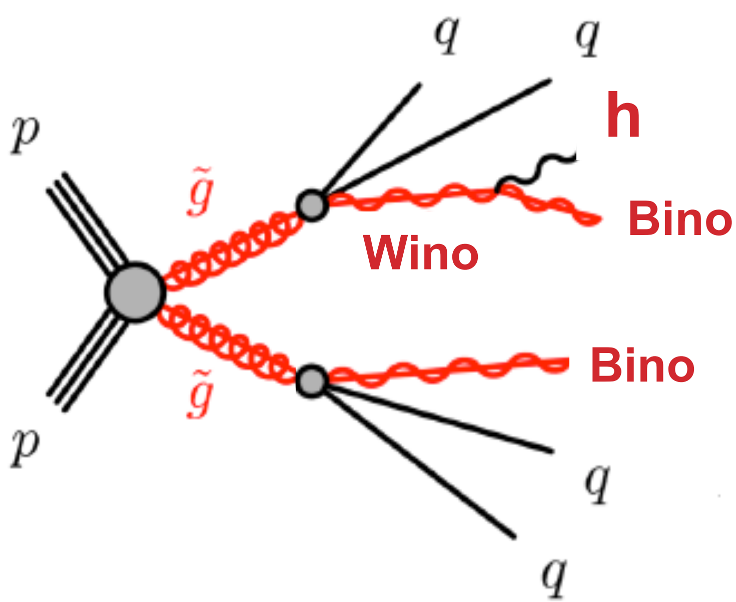


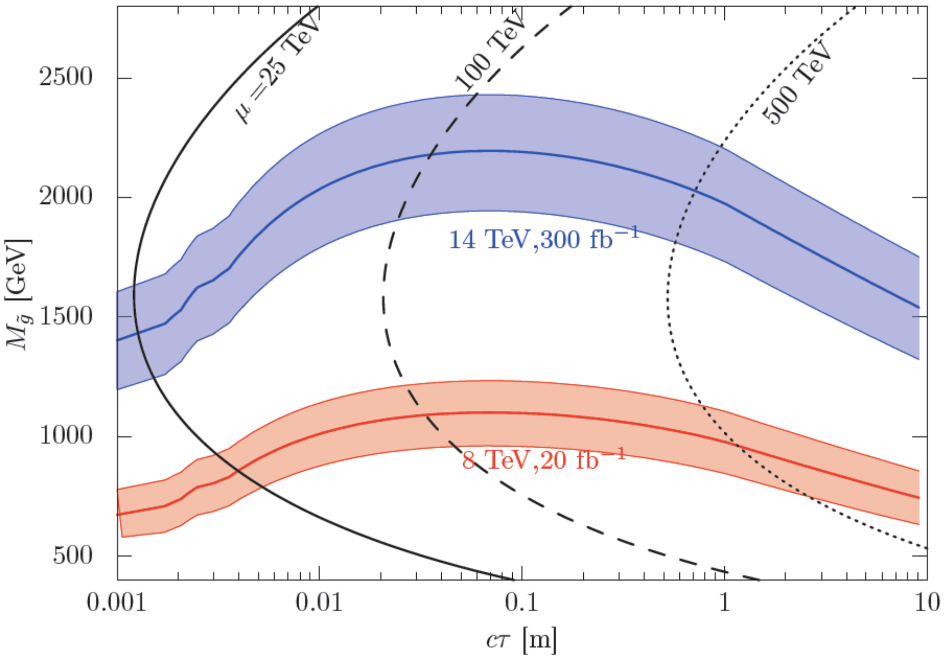
EXPECTED SENSITIVITY FOR BINO-WINO



Gluino pair production

- **High trigger efficiency**
- **Another approach to inclusive jet + MET search**





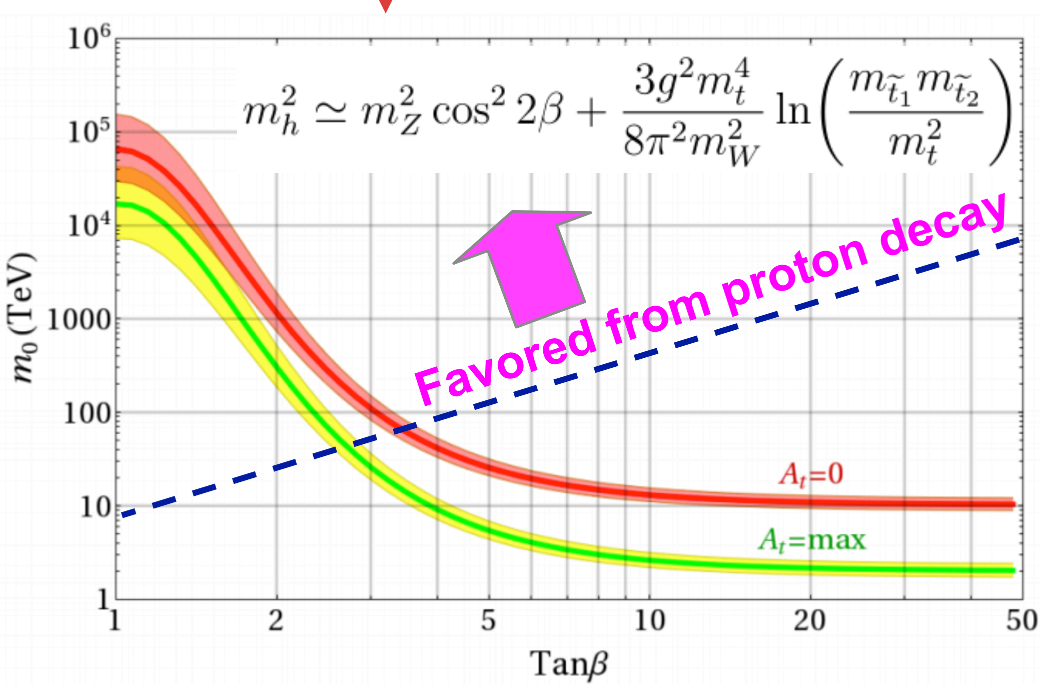
CONCLUSION

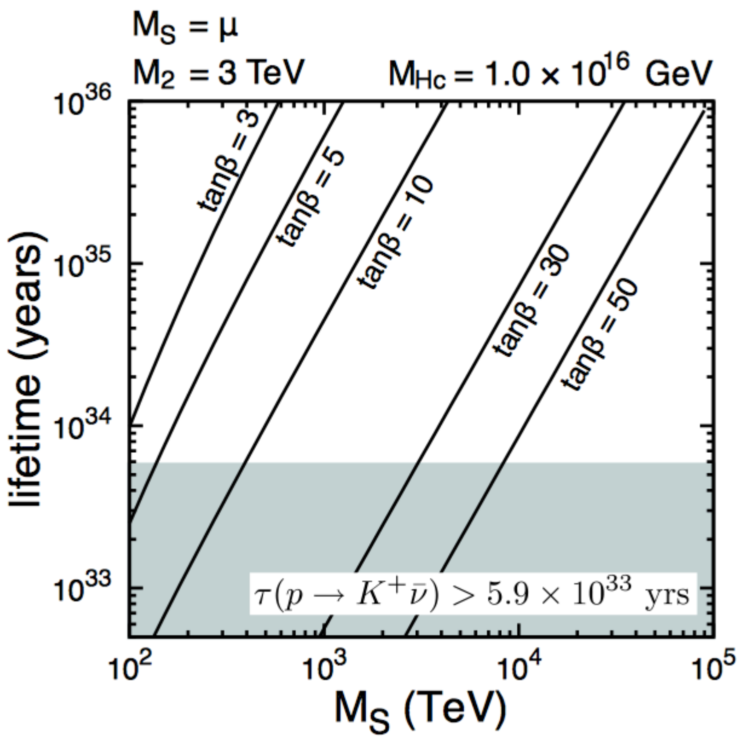
Dark matter is the missing piece in the Standard Model.

- **The lightest O(1) TeV SUSY particle satisfies the DM properties.**
  - Higgs mass and Flavor/CP problem implies O(100) TeV squark
  - Two mass scales can be realized by AMSB
  - Fine tuning for the higgs mass would be $10^{-4} – 10^{-6}$
- **Pure Bino with co-annihilation with other gauginos could be DM.**
  - Bino search by underground/cosmic observation would be difficult.
  - No unique signature such as pure Wino -- disappearing track.
- **Long-lived gauginos with Bino LSP could be naturally appeared.**
  - Three processes for long-live Gluino and Wino are proposed.
  - No similar search so far -- we have big possibility for discovery !

HEAVY SFERMION?

More than 100 TeV of sfermion mass are compatible to 125 GeV higgs and proton decay lifetime.





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RECONSTRUCTION OF DISPLACED VERTEX

	Standard	DV
d_0	< 10 mm	< 300 mm
Z_0	< 320 mm	< 1500 mm

Loosen the standard selection and improve the efficiency