Minimal Dark Matter at Colliders

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based on

arXiv:1504.03402 with

Keisuke Harigaya, Koji Ichikawa, Anirban Kund and Shigeki Matsumoto

and arXiv:1711.05449 with

Shigeki Matsumoto and Michihisa Takeuchi

Plan

1. Minimal Dark Matter

2. Indirect Search @Lepton Collider

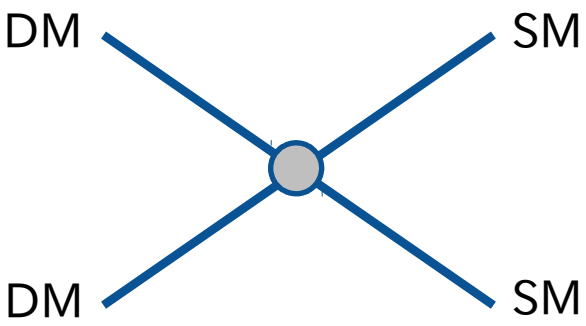
   Electroweak precision @LEP

   Drell-Yan process @ILC250

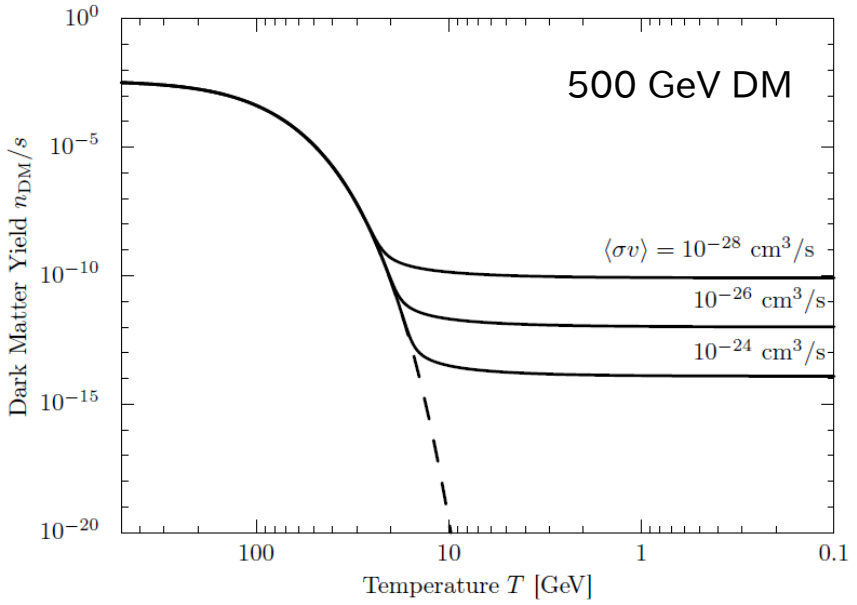
3. Indirect Search @LHC

WIMP Dark Matter

Weakly Interacting Massive Particle



DM abundance



Time

Concrete WIMP Model

WIMP: Weakly Interacting Massive Particle

SM gauge interaction

Minimal Dark Matter

Minimal Dark Matter (MDM)

- Well known interaction: concrete prediction
- Collider, direct detection, indirect detection
- Many new physics models include MDM
- …

Gauge interacting DM

DM's nature depends on SU(2)xU(1) charge

SU(2)

U(1)

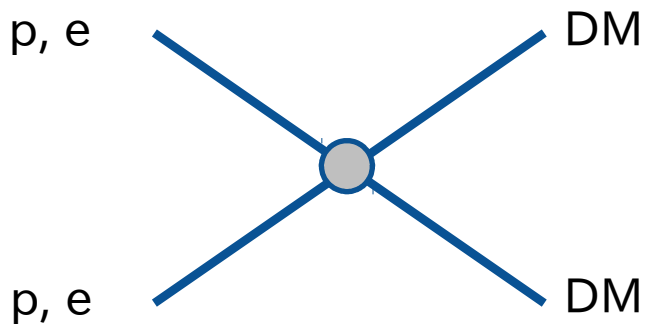
Y \ n	1	2	3	4	5
0		C	wino	C	5plet
1/2	C	higgsino	C		C
1	C	C		C	
3/2	C	C	C		C
2	C	C	C	C	
…	C	C	C	C	C

Example: Higgsino

Higgsino is

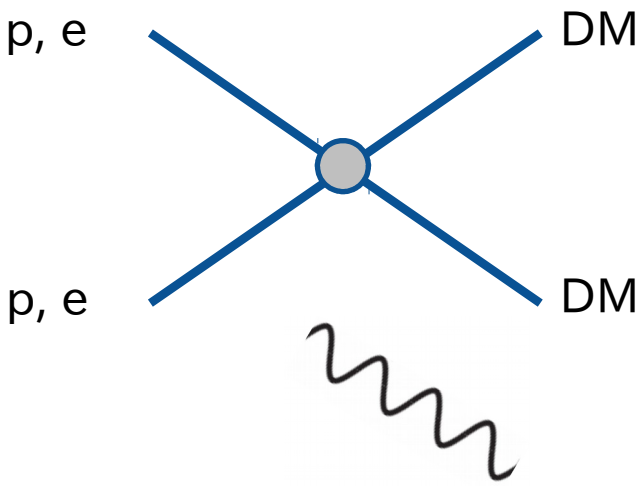
- (pseudo)Dirac fermion
- Hypercharge |Y|=1/2
- SU(2)doublet $\begin{pmatrix} \widetilde{H}_u^+ \\ \widetilde{H}_u^0 \end{pmatrix}, \begin{pmatrix} \widetilde{H}_d^0 \\ \widetilde{H}_d^- \end{pmatrix}$
- <1 TeV $\Omega h^2 \simeq 0.1 \left(\frac{m_{\widetilde{H}}}{1.1 \text{ TeV}} \right)^2$

Collider Signals of DM



DM is invisible

Collider Signals of DM

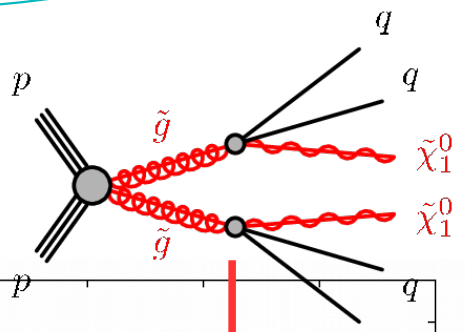


DM is invisible

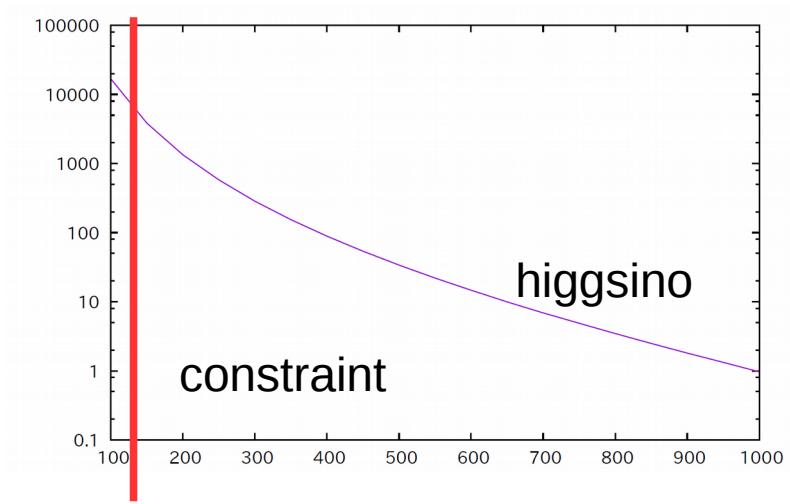
Additional objects are needed to see DM.
Missing energy (MET) search

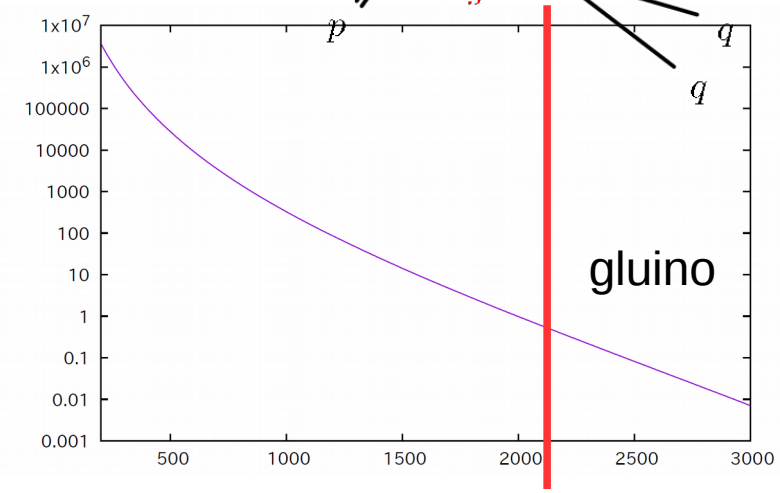
gluon photon, …

MDM is hard target



cross section [fb]





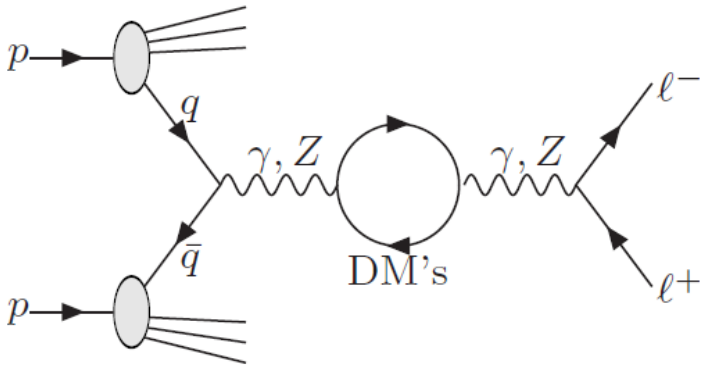
mass [GeV]

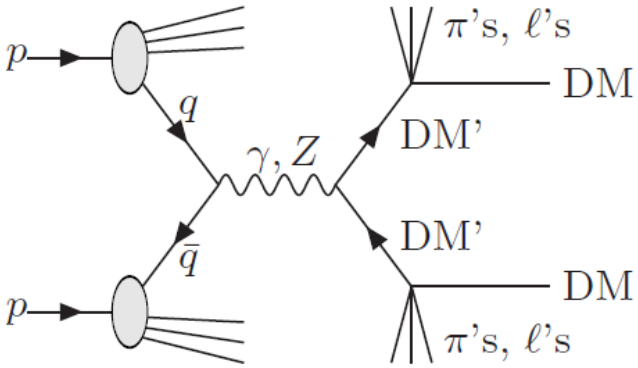
O(10^5) particle production

O(10) particle production

Efficient BG reduction and/or new observable are needed

MDM Search





Indirect Search from SM precision

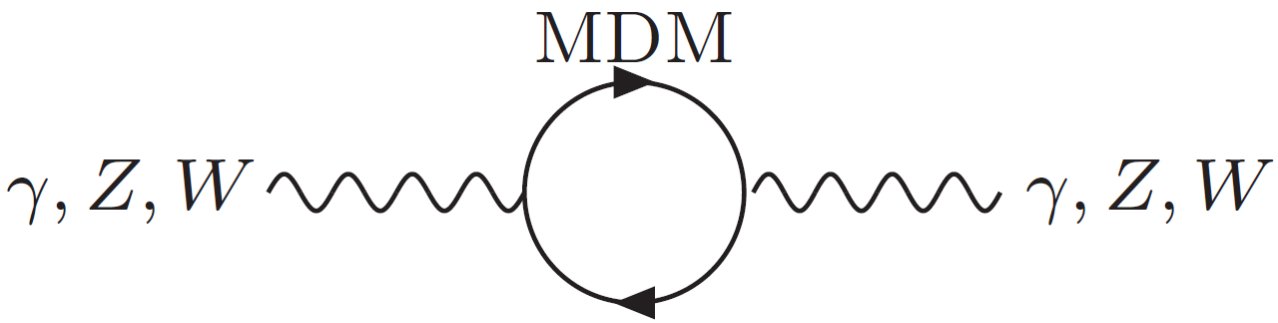
Exotic tracks:

- Disappearing track
- Displaced soft track

Indirect Search @ Lepton Collider

On-Z Observables

Heavy DM cannot be produced at collider, but affects SM processes

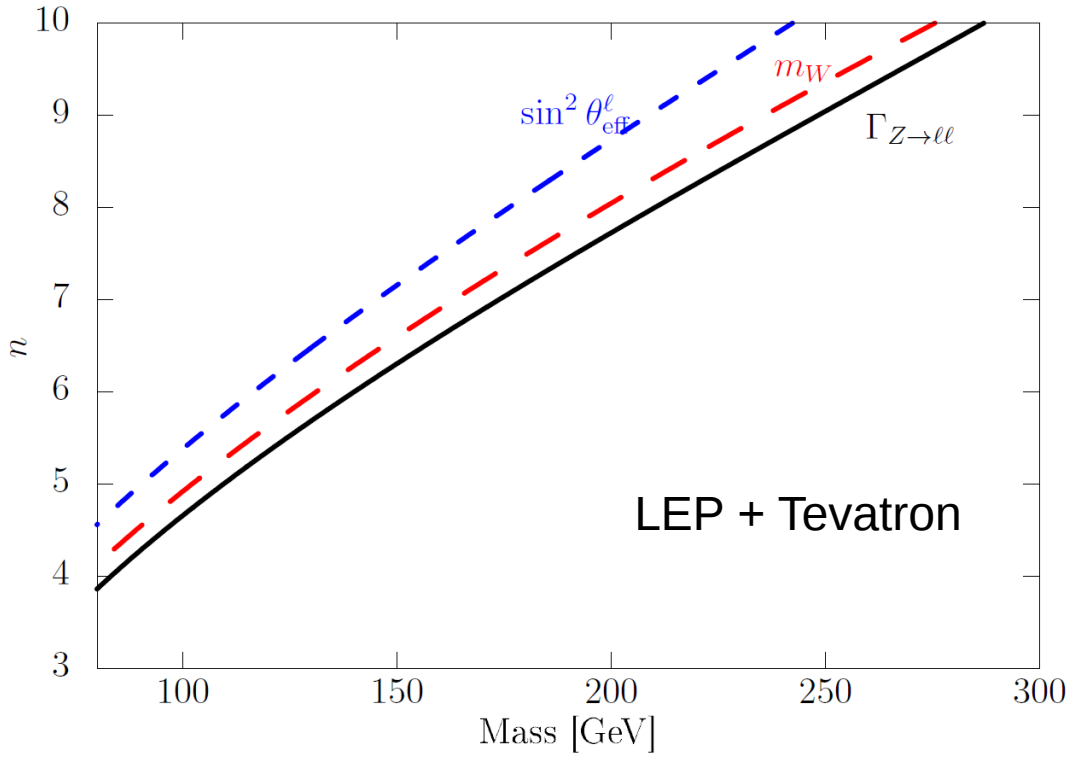


Case 1: Oblique correction to electoweak precision observables(EWPO)
weak boson mass and so on

Current Constraints from EWPO

of SU(2) representation

Majorana Fermion

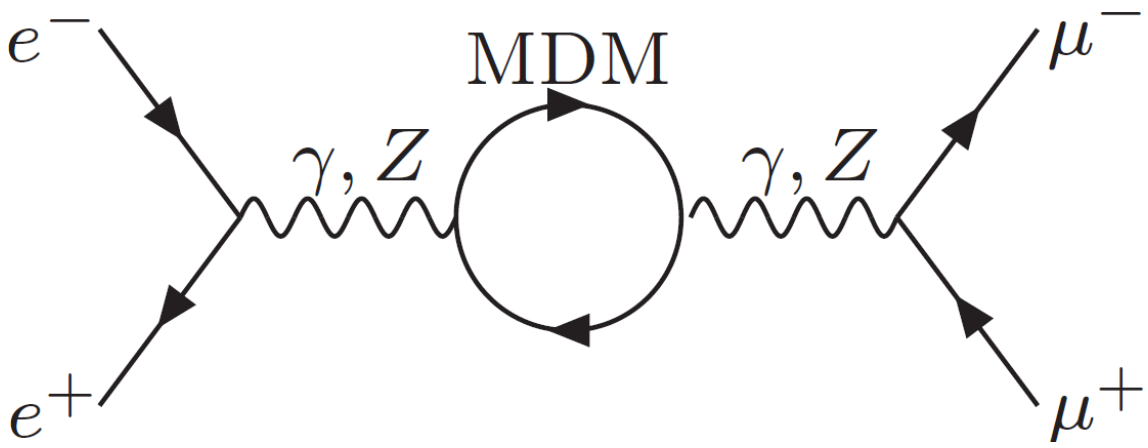


Corrections are roughly proportional to n^3 / m^2

[Harigaya+, 1504.03402]

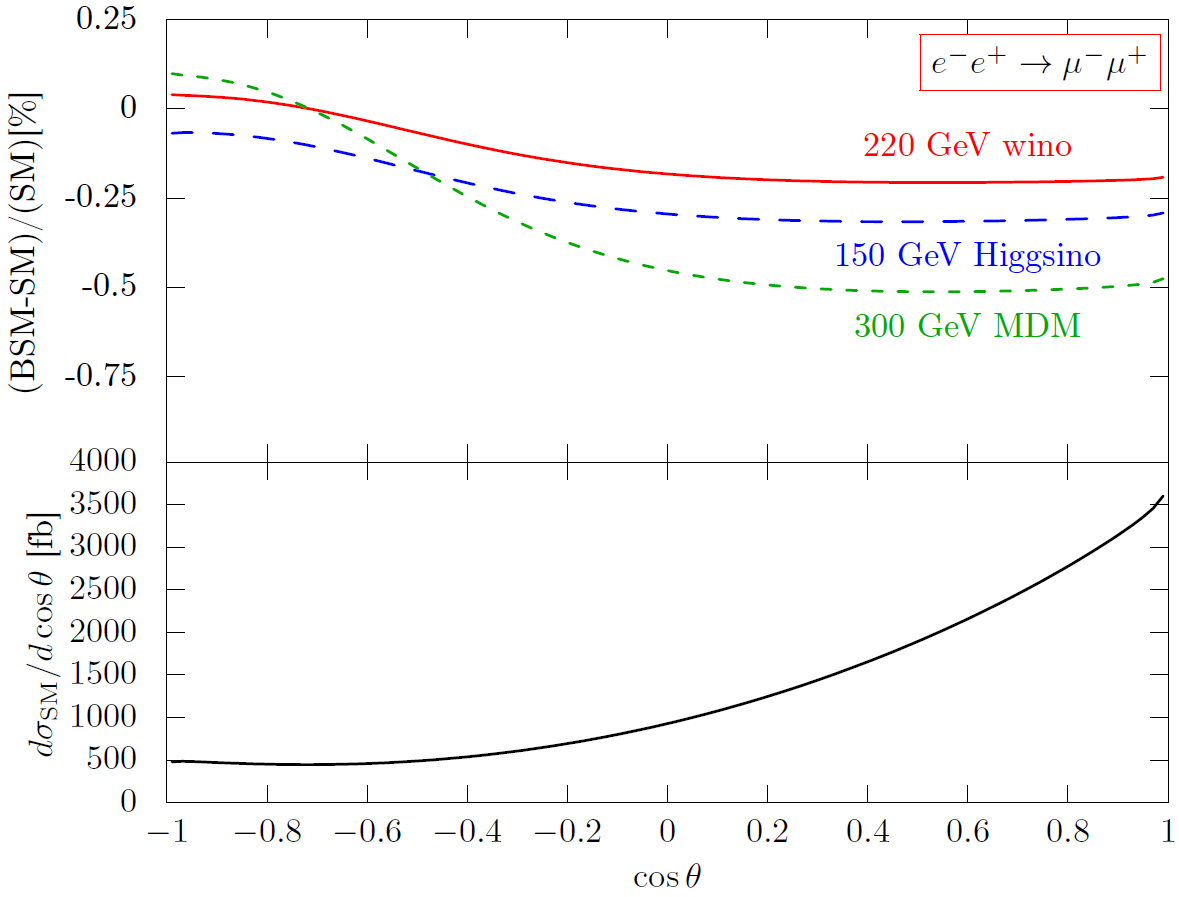
ILC250 for MDM

Heavy DM cannot be produced at collider, but affects SM processes

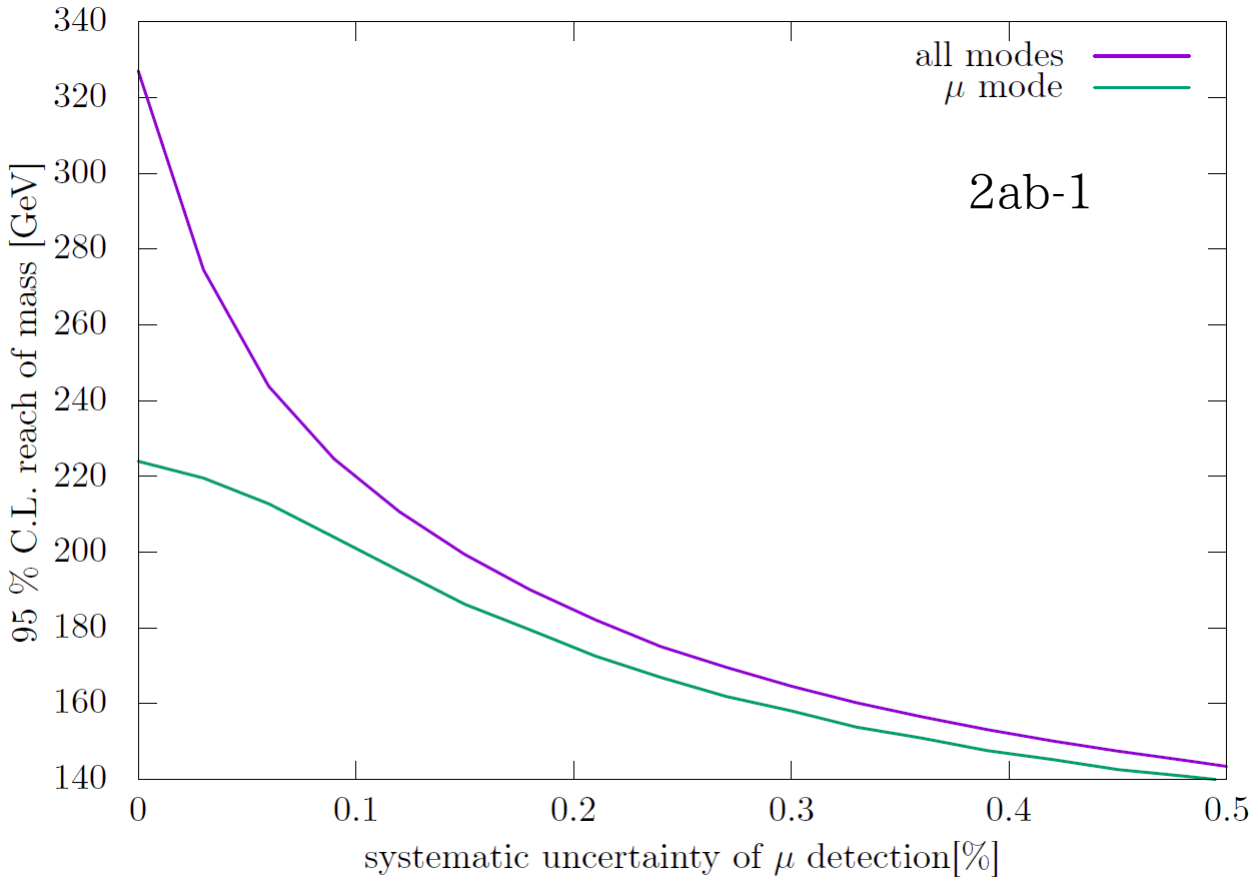


Case 2: Correction to SM process at ILC.

ILC250 for Heavy MDM



Reach of ILC250 for Higgsino



mu, e, b, c sys. Ratios: 2 : 1.5 : 5 : 10 assumed

Effective Operator

Mz and LEP energy < 2 x mass.
Integrating out of MDM leads effective operators

$$-\frac{1}{\Lambda_{2W}^2}(D_\mu W_{\mu\nu}^a)^2 - \frac{1}{\Lambda_{2B}^2}(\partial_\mu B_{\mu\nu})^2 + \cdots$$

$$\frac{1}{\Lambda_{2W}^2} = \frac{g^2}{16\pi^2}\frac{1}{15m^2}\frac{n(n-1)(n+1)}{6}$$

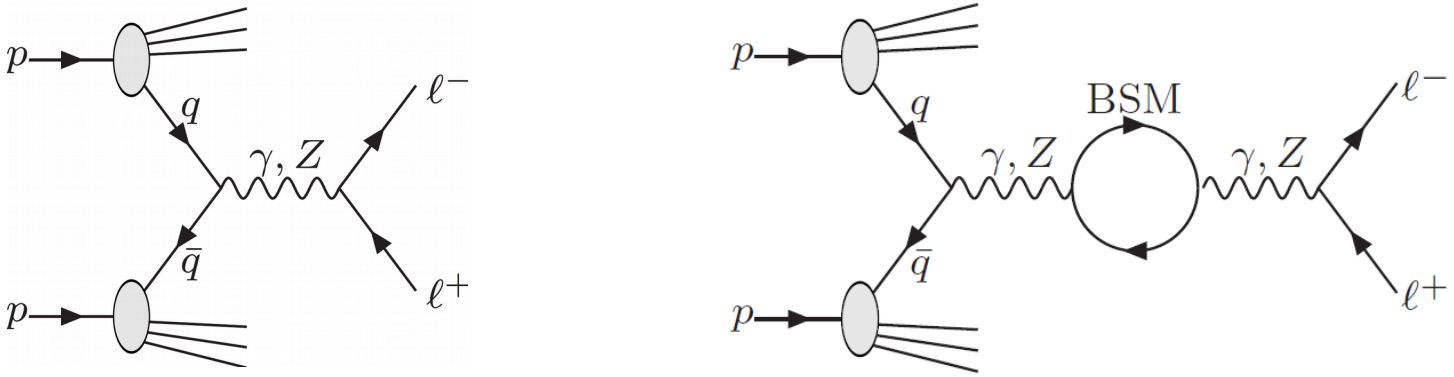
$$\frac{1}{\Lambda_{2B}^2} = \frac{g'^2}{16\pi^2}\frac{2nY^2}{15m^2}$$

(Dirac Fermion)

Indirect Search @ LHC

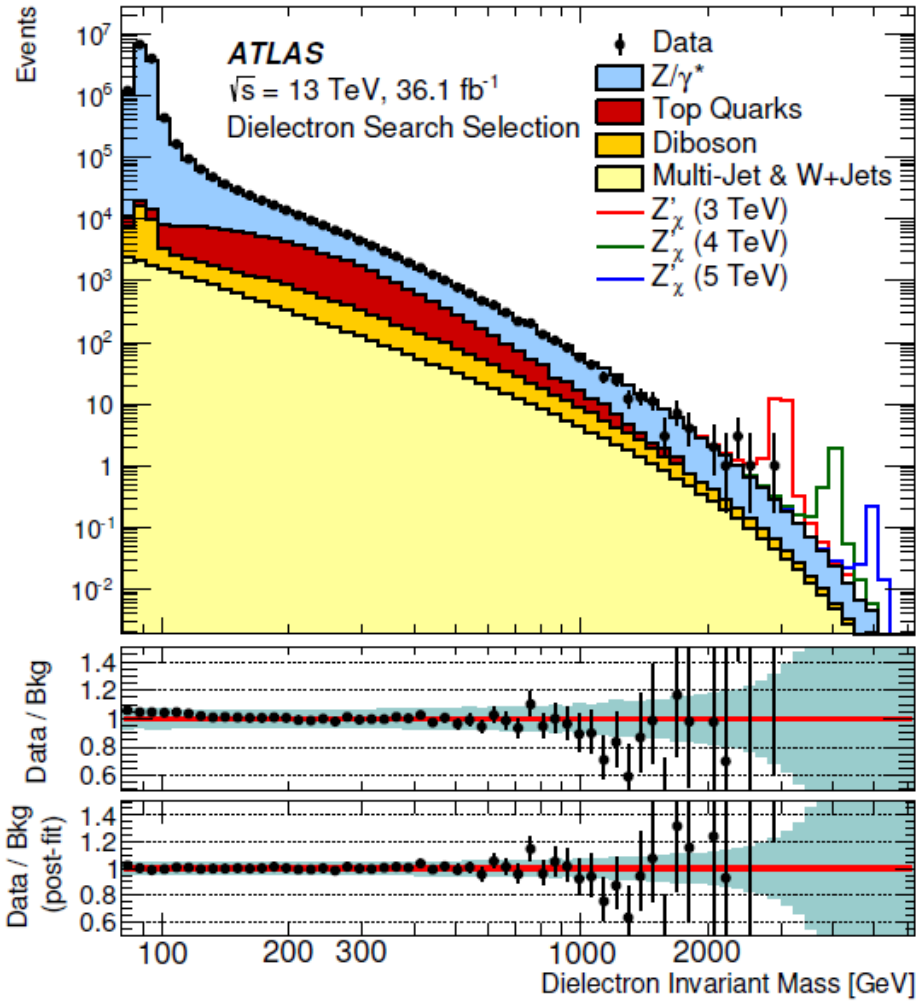
[Matsumoto, SS, Takeuchi, 1711.05449]

Indirect Probe at LHC



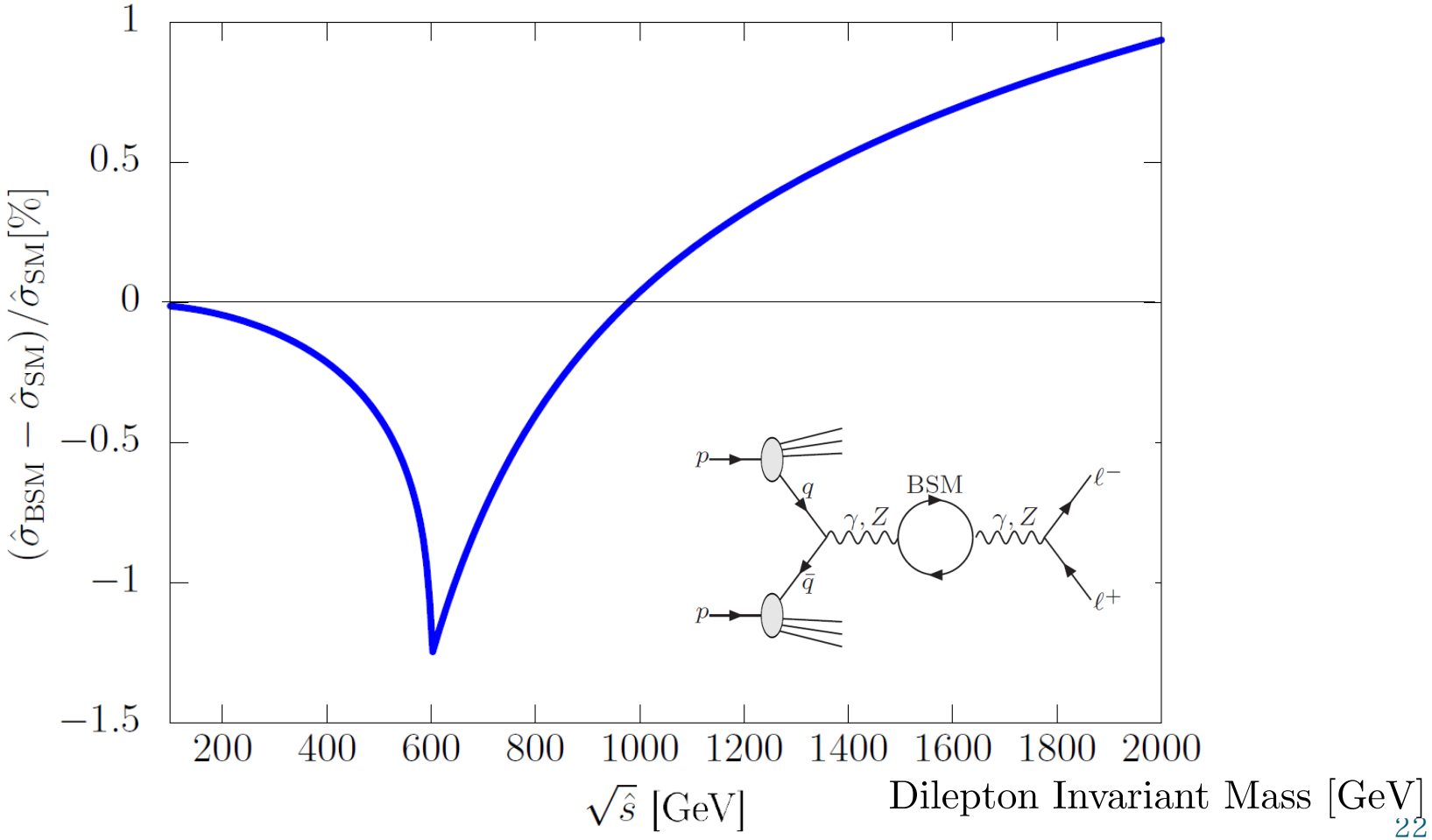
Interference between SM and BSM gives correction

Observed Data

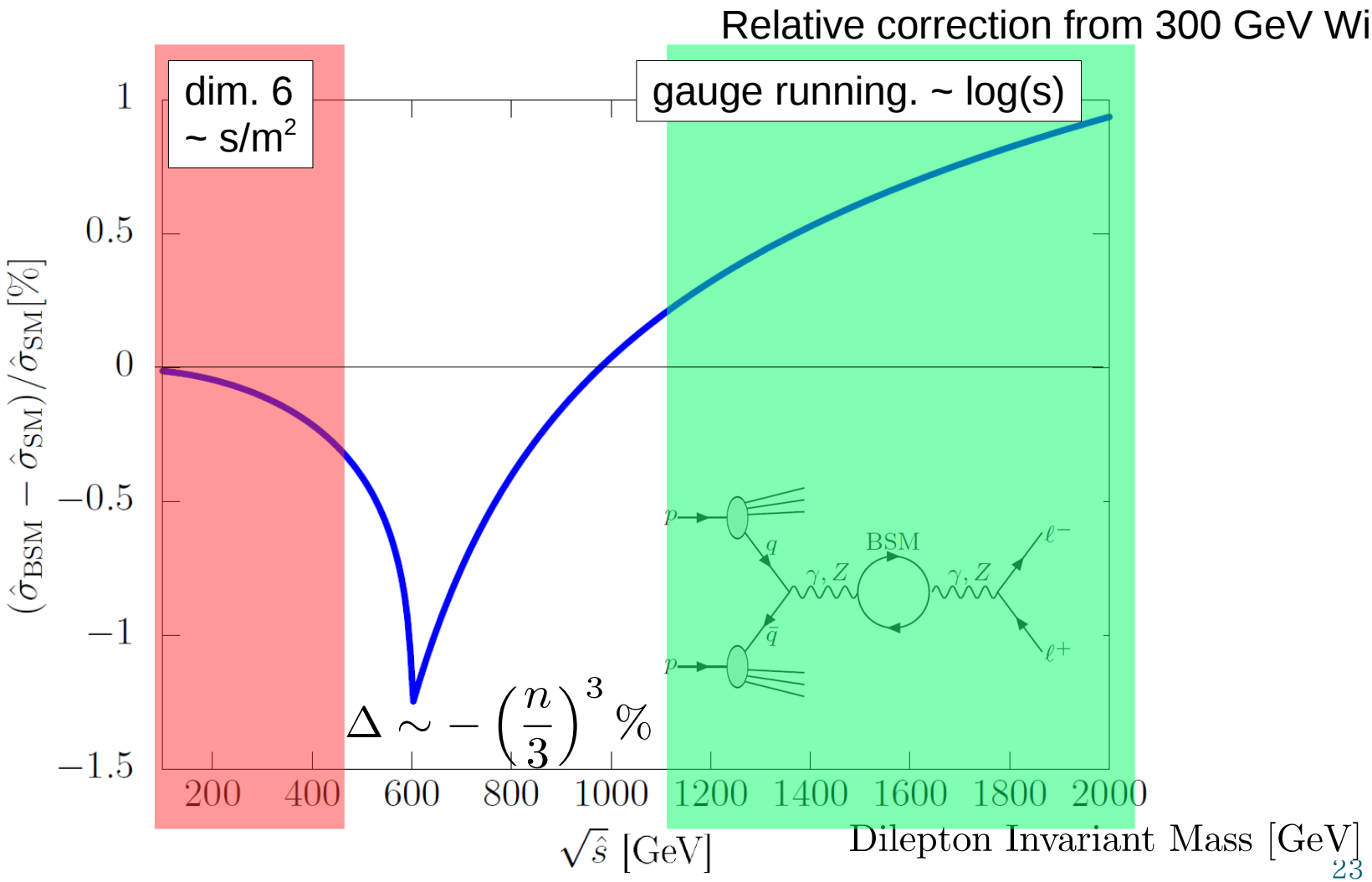


Correction from MDM

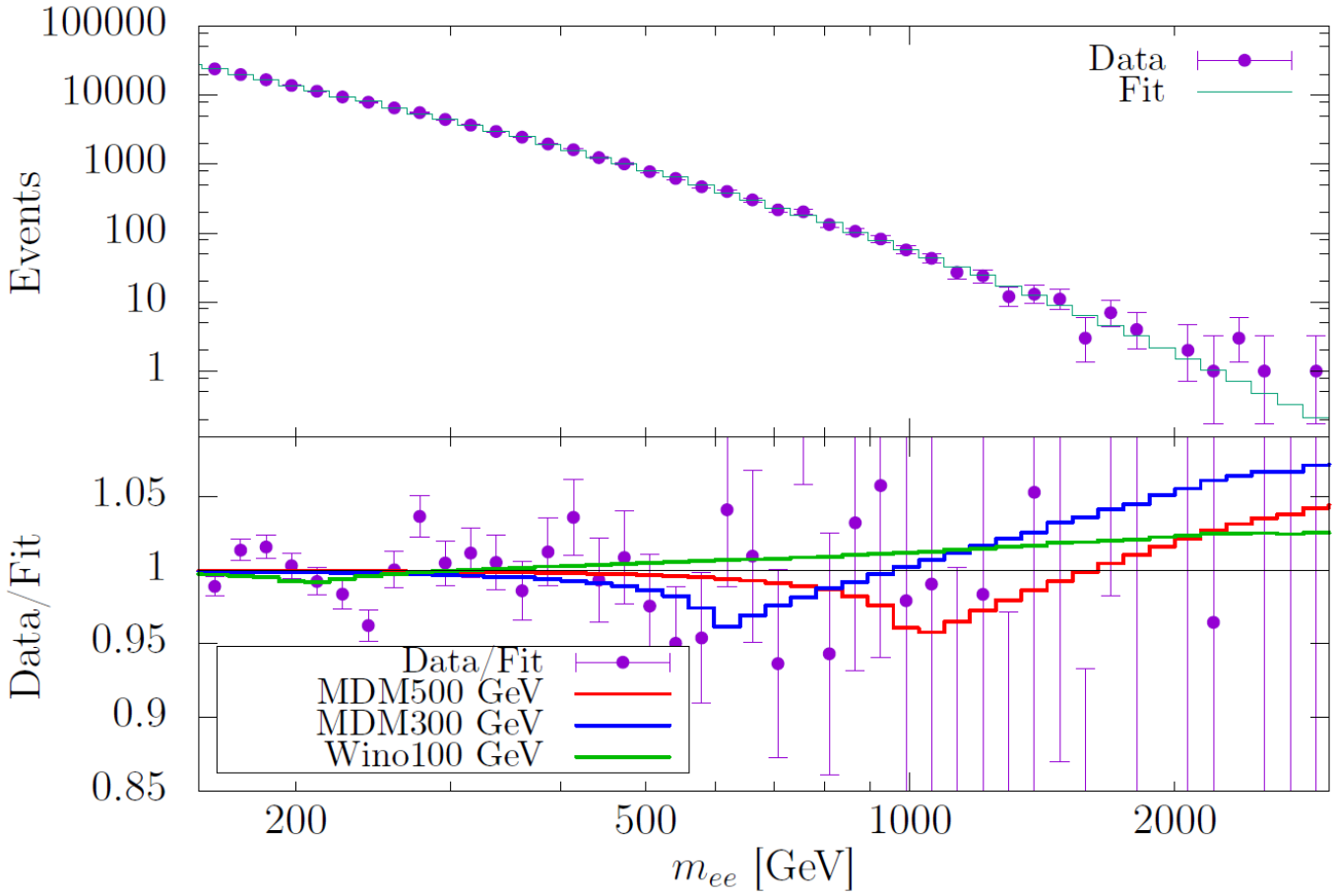
Relative correction from 300 GeV Wino



Correction from MDM

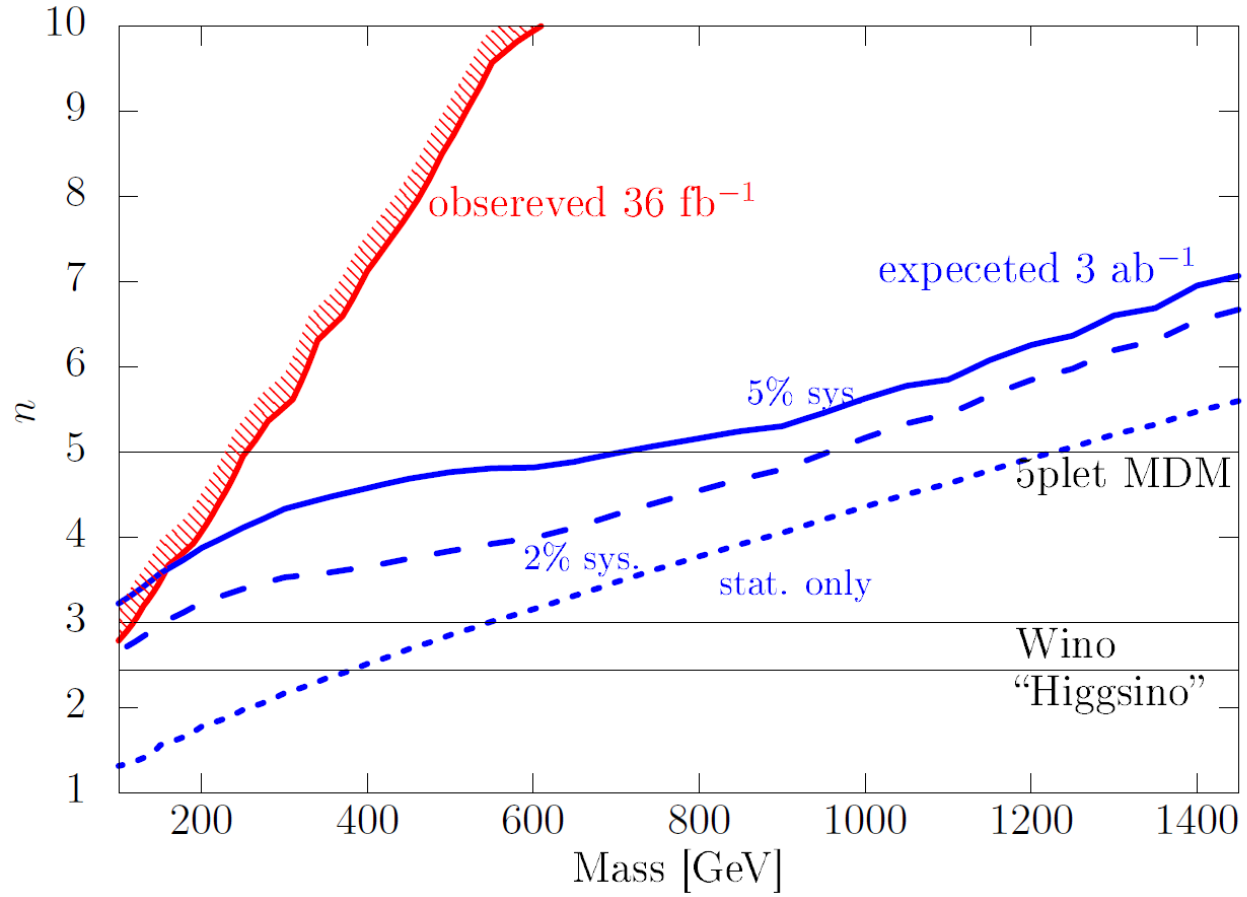


Indirect Probe at LHC



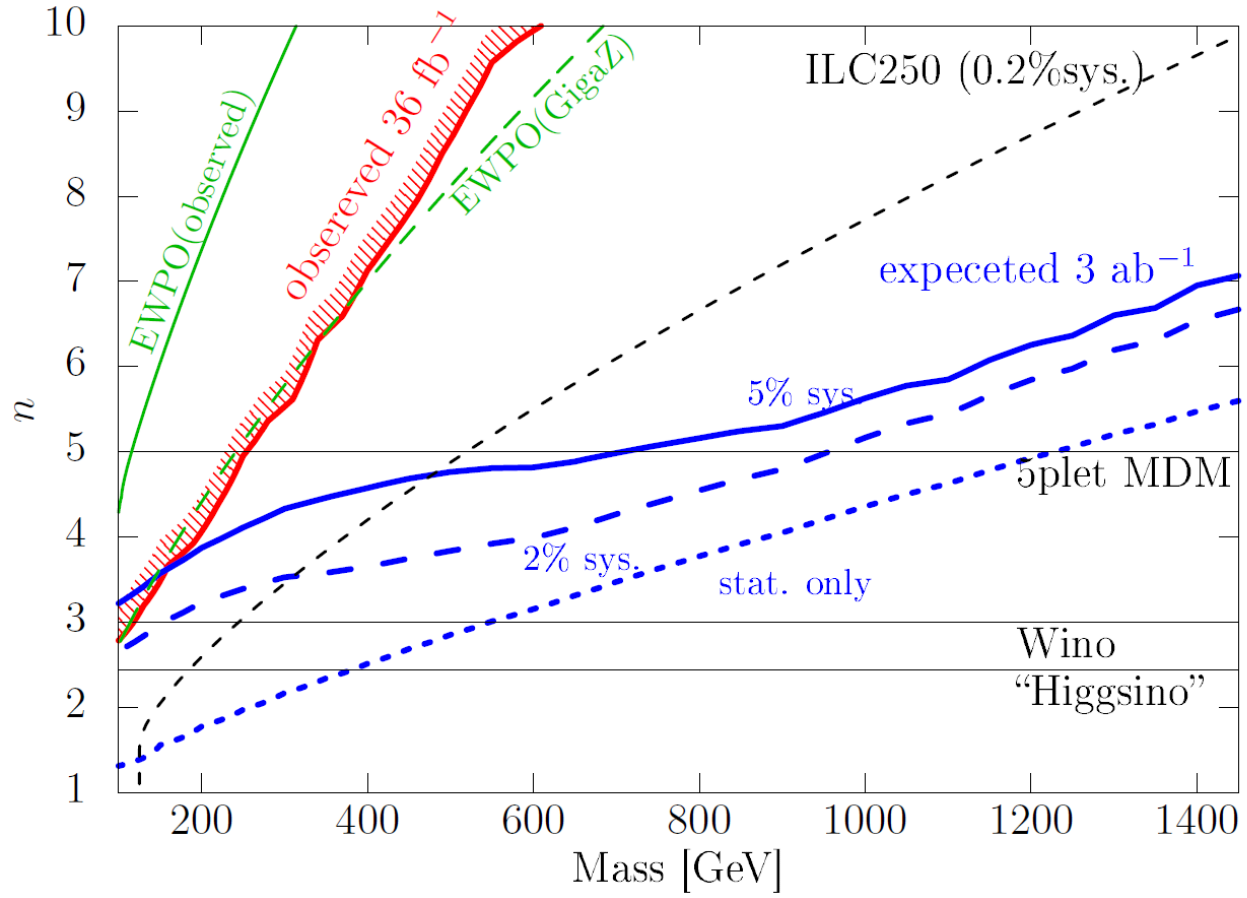
Indirect Probe at LHC

of SU(2) representation



Indirect Probe Summary

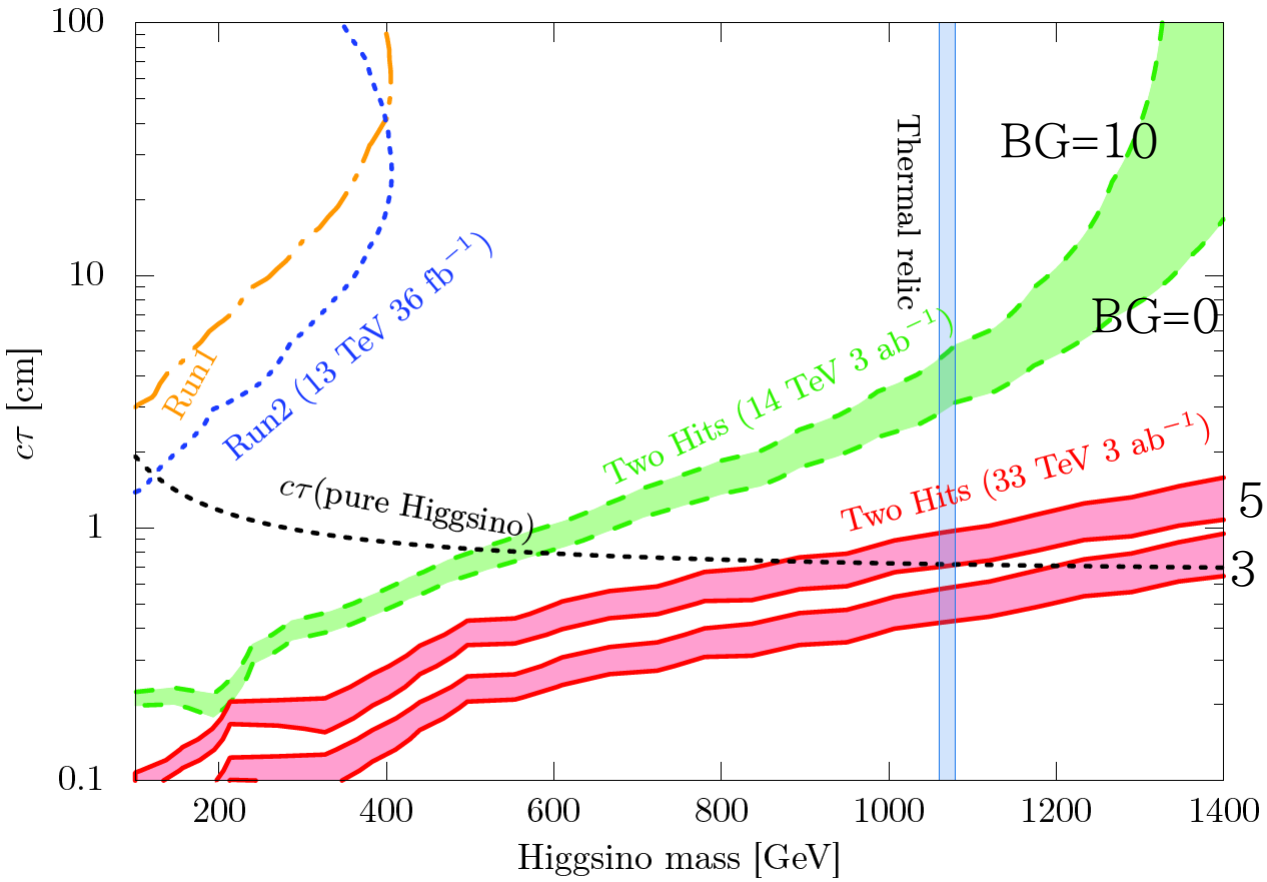
of SU(2) representation



Summary

- MDM can be indirectly tested at LHC and ILC
- As powerful as mono-jet + MET search
- This method uses only EW gauge interaction
  - Any EW interacting particle

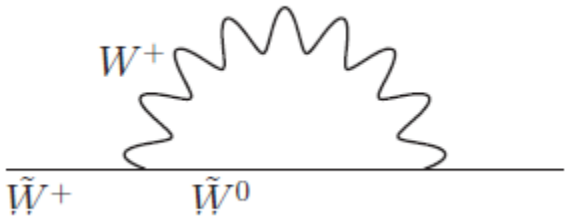
Prospects for Higgsino



MET>400 GeV

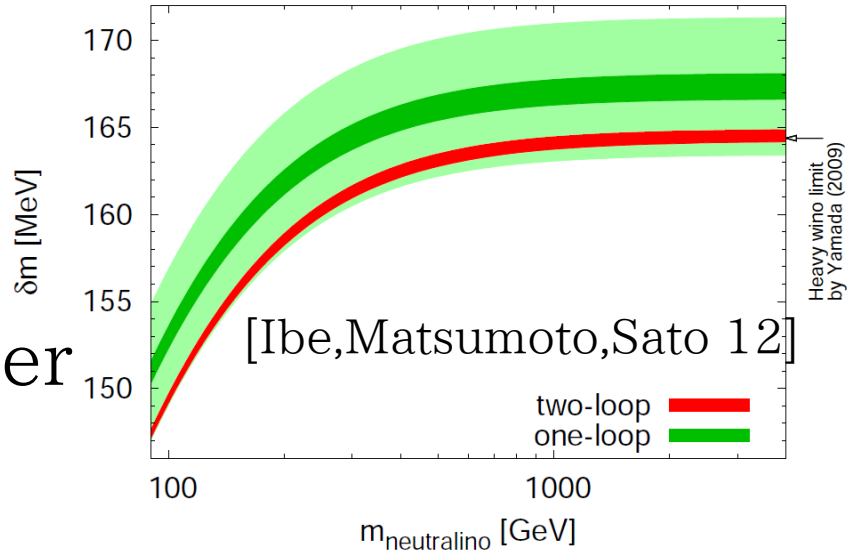
MET>600 GeV

Wino Spectrum



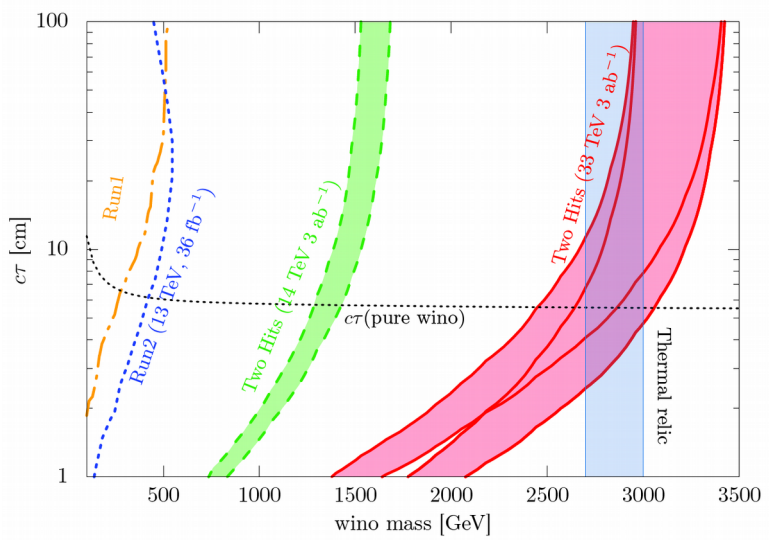
Radiative correction

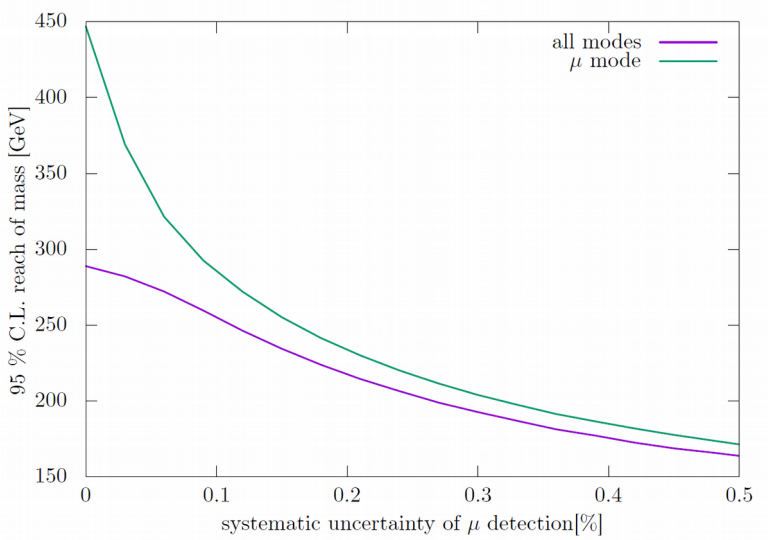
$$\begin{pmatrix} \widetilde{W}^+ \\ \widetilde{W}^0 \\ \widetilde{W}^- \end{pmatrix}$$ Charged slightly heavier



$$c\tau(\widetilde{W}^{\pm} \to \widetilde{W}^0 \pi^{\pm}) \simeq 7 \text{ cm} \left(\frac{\Delta m}{165 \text{ MeV}} \right)^{-3}$$

Wino Case


100
10
1
$c\tau$ [cm]
500
1000
1500
2000
2500
3000
3500
wino mass [GeV]
Run1
Run2 (13 TeV, 36 fb^{-1})
Two Hits (14 TeV 3 ab^{-1})
$c\tau$(pure wino)
Two Hits (33 TeV 3 ab^{-1})
Thermal relic


450
400
350
300
250
200
150
95 % C.L. reach of mass [GeV]
0
0.1
0.2
0.3
0.4
0.5
systematic uncertainty of μ detection[%]
all modes
μ mode

Higgsino DM is tough