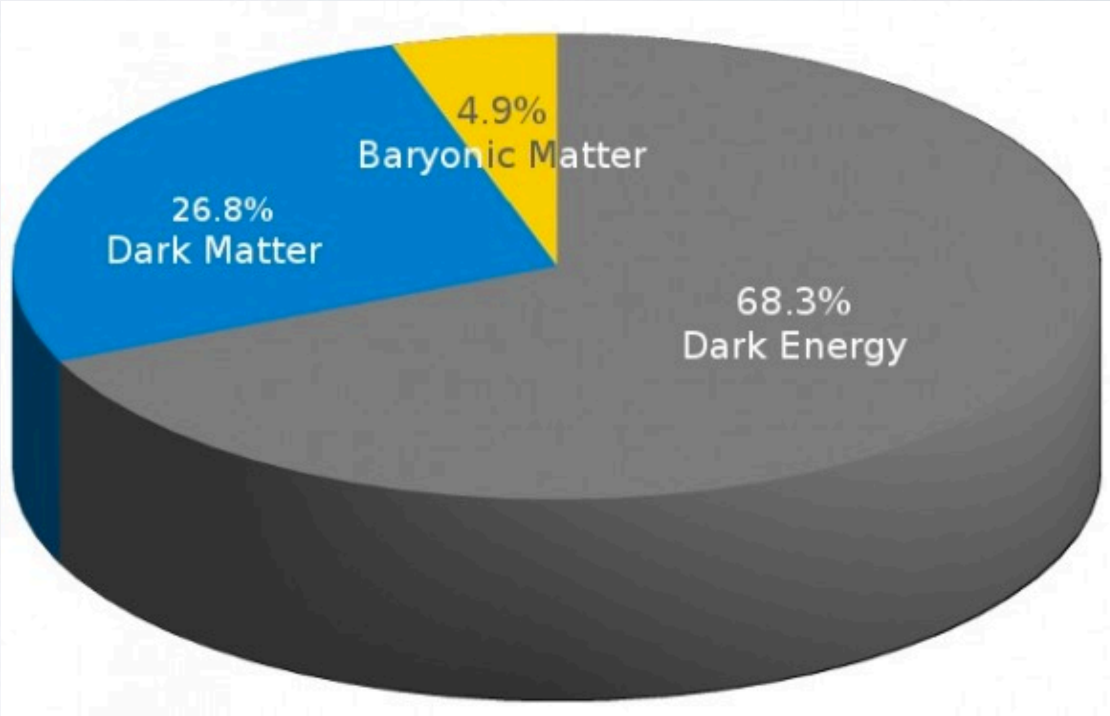
Electroweak Dark Matter at future hadron colliders

Xing Wang
University of Pittsburgh
HL/HE-LHC Meeting, Fermilab
April 6, 2018

PITTPACC
PITTSBURGH PARTICLE PHYSICS ASTROPHYSICS COSMOLOGY CENTER

INTRODUCTION

- Dark Matter and WIMP miracle
- SU(2) doublet $\tilde{H}$ or triplet $\tilde{W}$
- Only one free parameter: M_χ
- $\begin{cases} \text{DM relic abundance} \\ \text{thermal freeze-out} \end{cases} \Rightarrow \begin{cases} M_{\tilde{H}} \simeq 1 \text{ TeV} \\ \quad \text{or} \\ M_{\tilde{W}} \simeq 3 \text{ TeV} \end{cases}$



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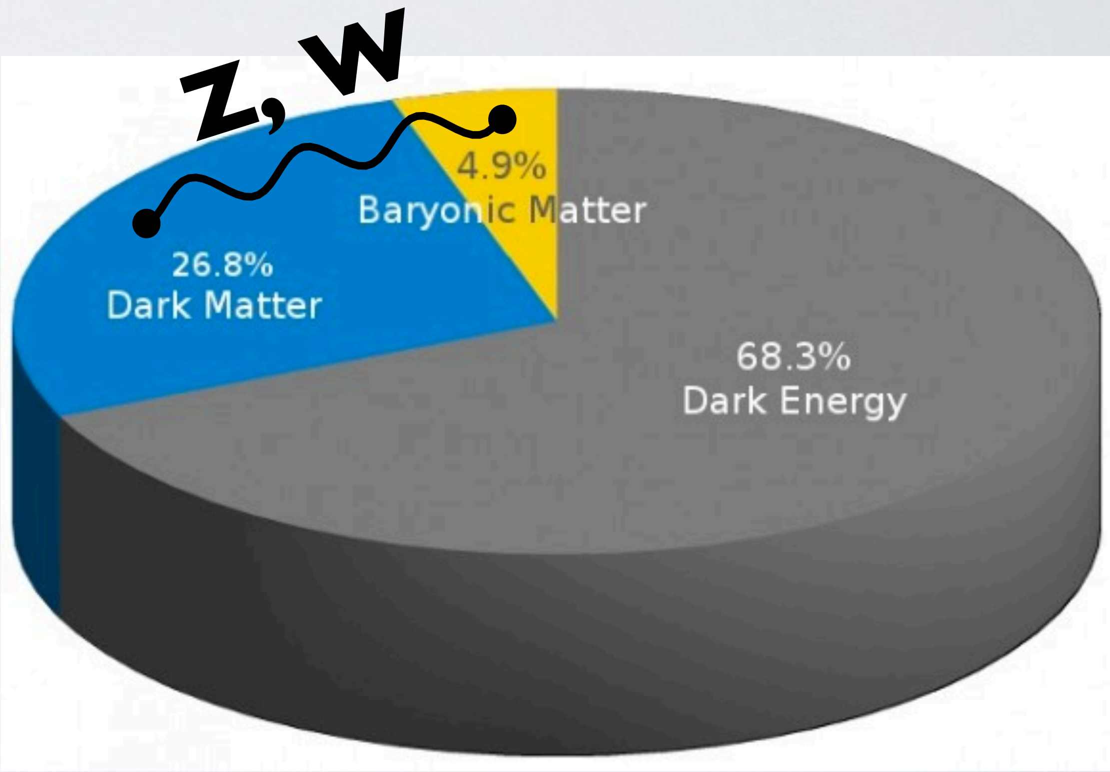
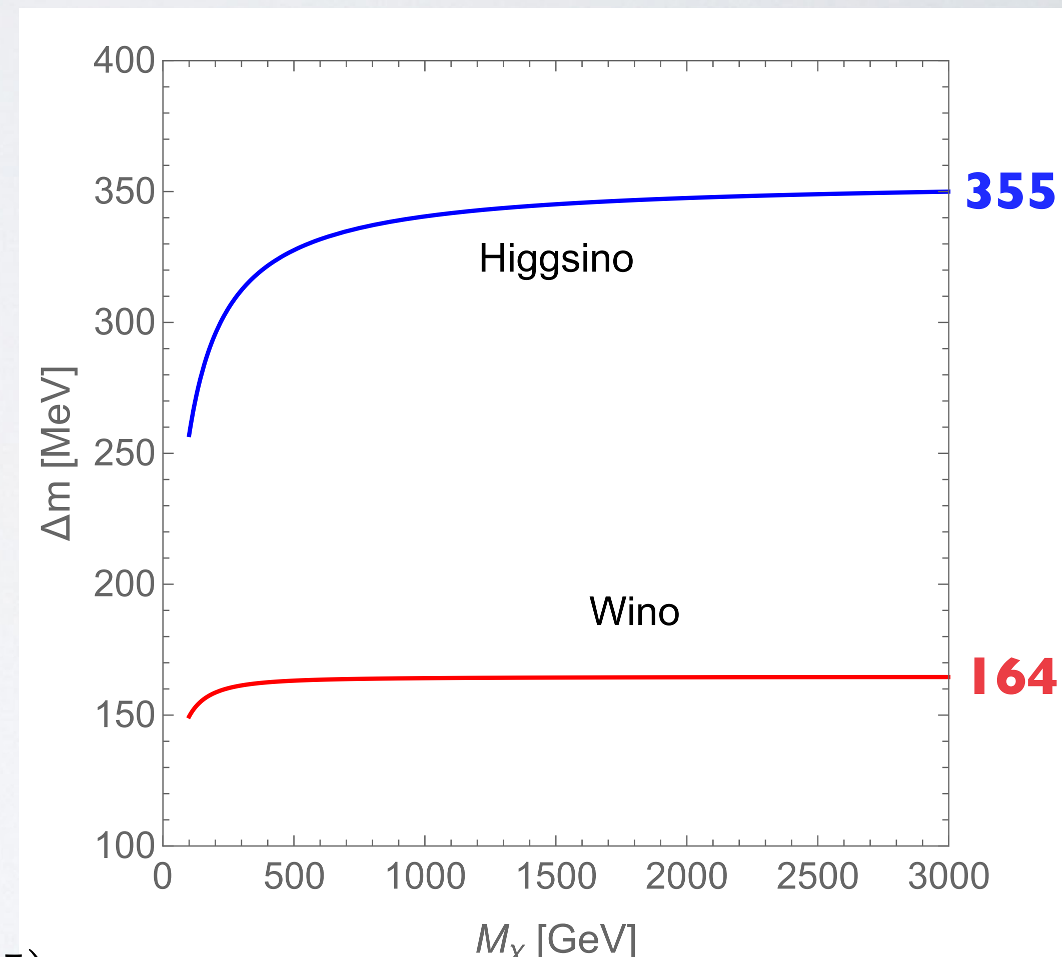
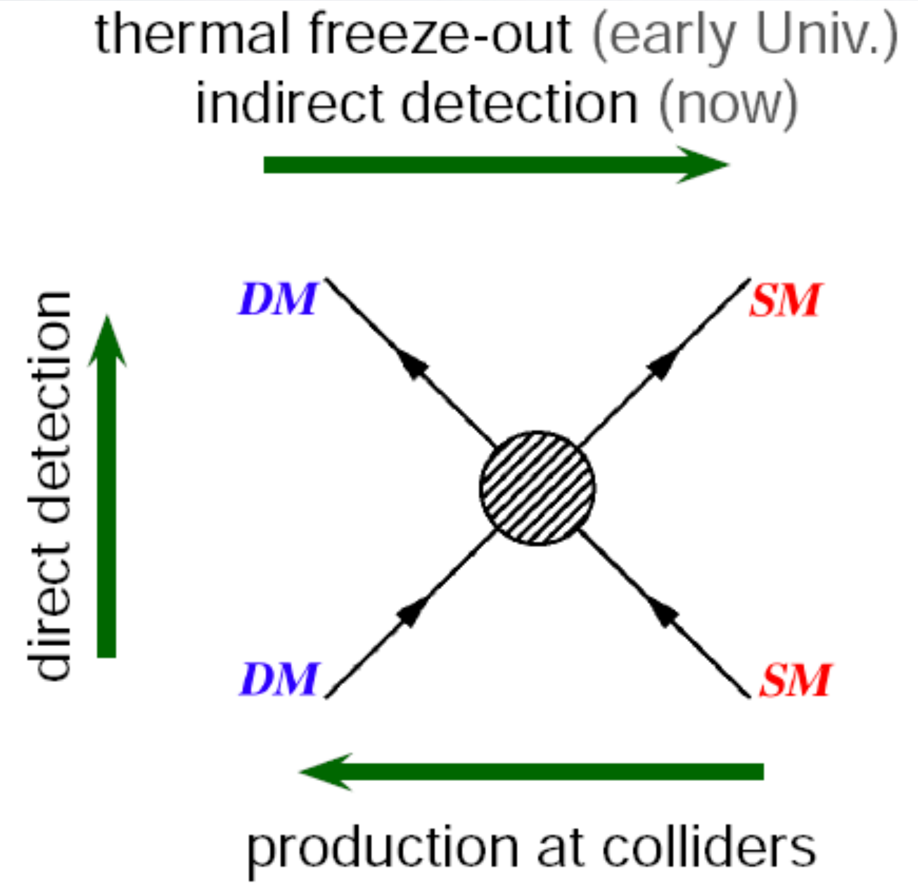


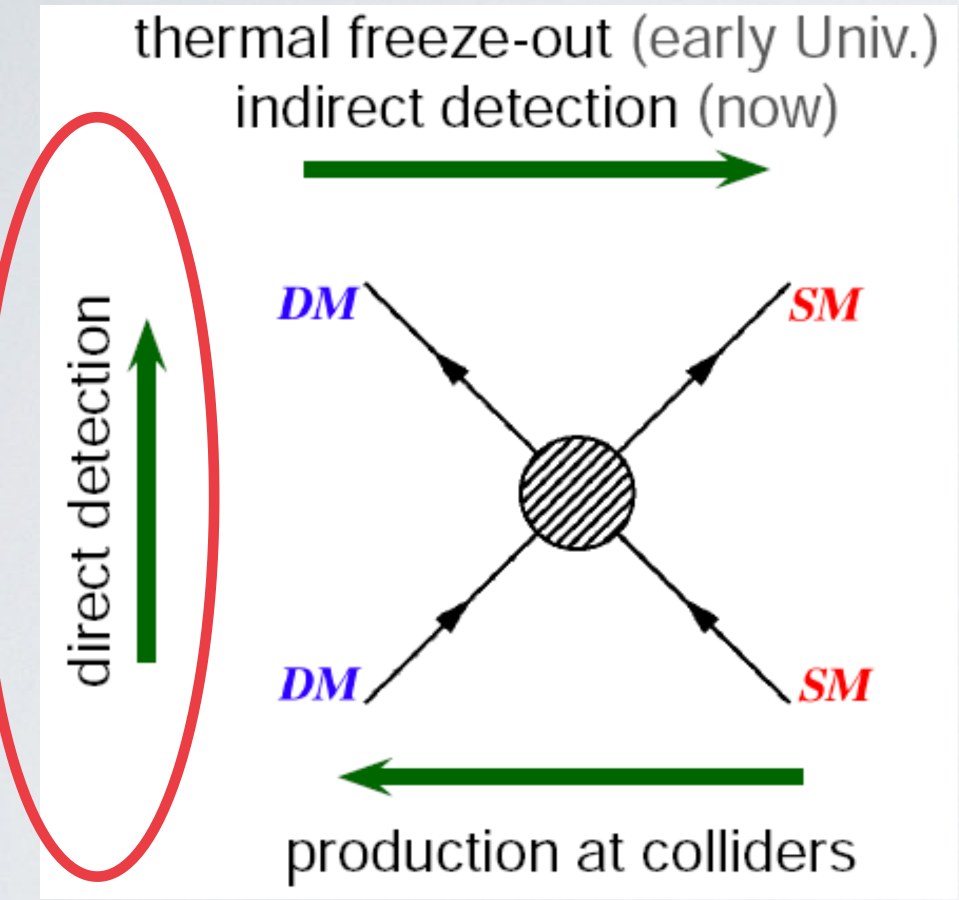
SPECTRUM

- Wino scenario
  - one Majorana neutralino + one chargino
- Higgsino scenario
  - one Dirac neutralino + one chargino
- 1-loop radiative mass splitting $\sim \mathcal{O}(100 \text{ MeV})$



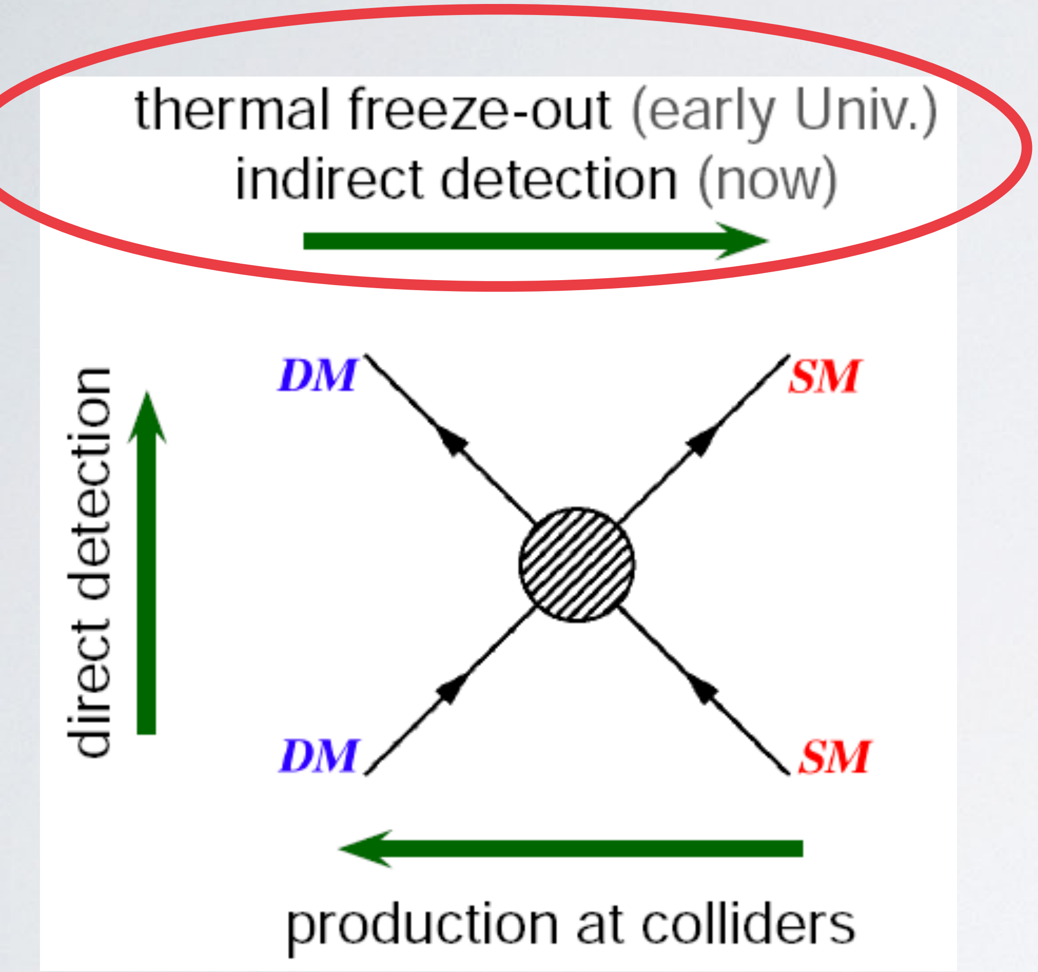

thermal freeze-out (early Univ.)
indirect detection (now)
direct detection
DM
SM
DM
SM
production at colliders

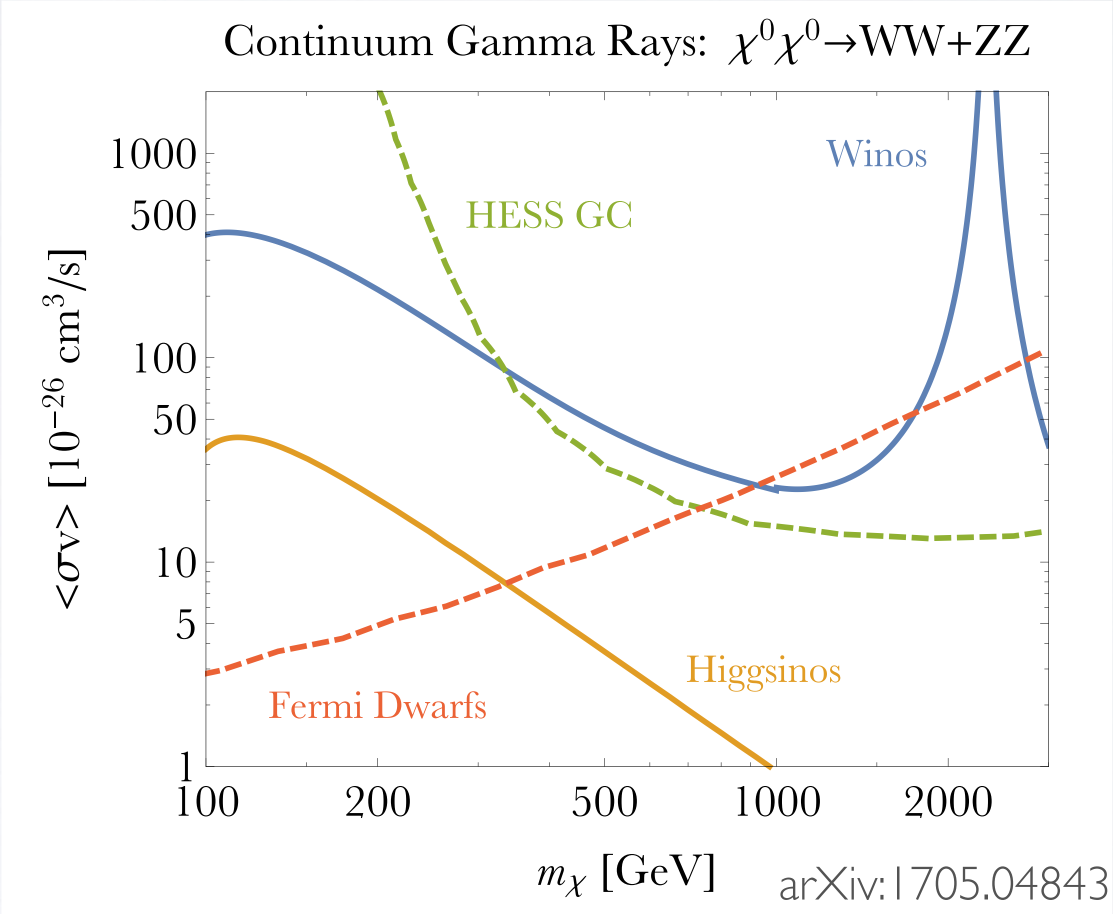
DIRECT DETECTION



- Direct detection loop-suppressed for pure states.
    - No tree-level SI interaction for Wino/Higgisno.
    - No tree-level SD interaction for Wino.
- Large SD cross section for Higgsino, already excluded.
    - Pseudo-Dirac Higgsino. $\Delta m_{12} \gtrsim \mathcal{O}(100 \text{ keV})$

INDIRECT DETECTION

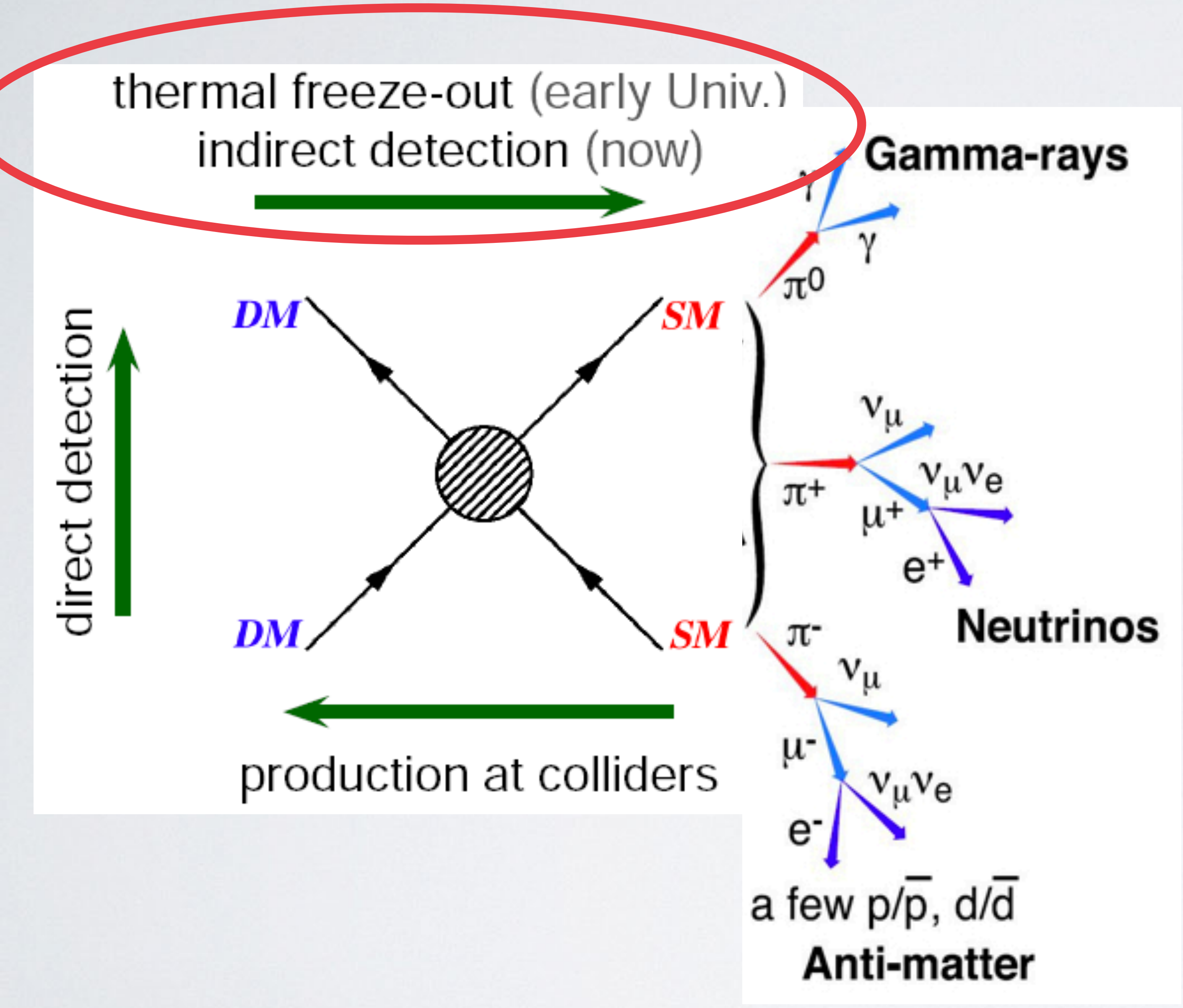


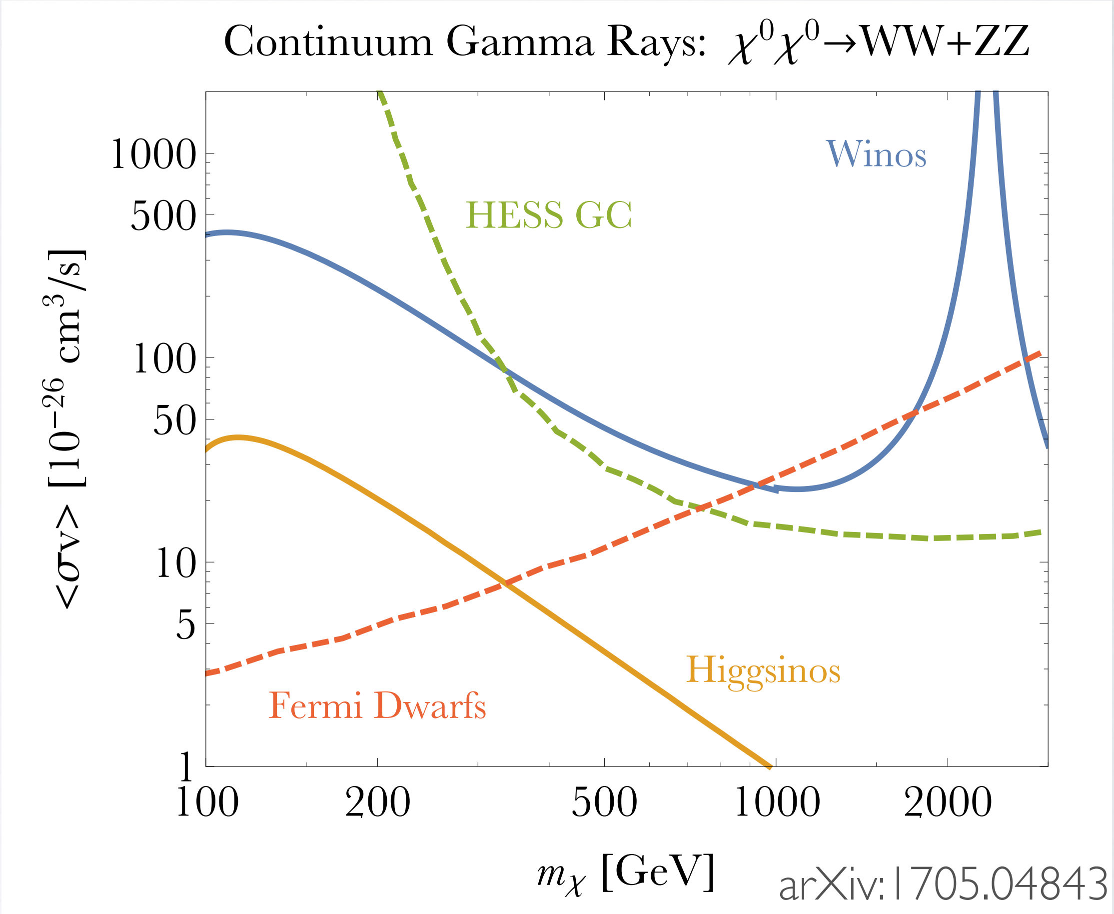


arXiv:1705.04843

- Sensitive to the astro uncertainties (e.g. DM profile, propagation model)
- Complementary to collider searches.

INDIRECT DETECTION





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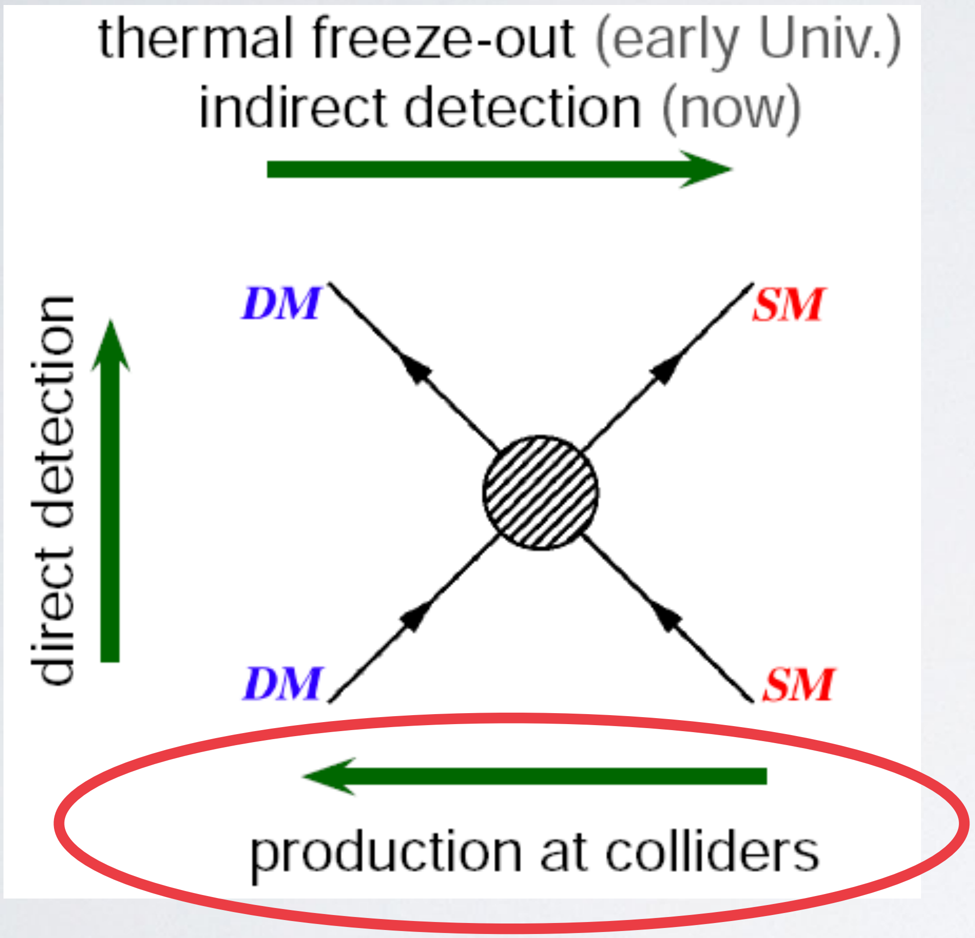
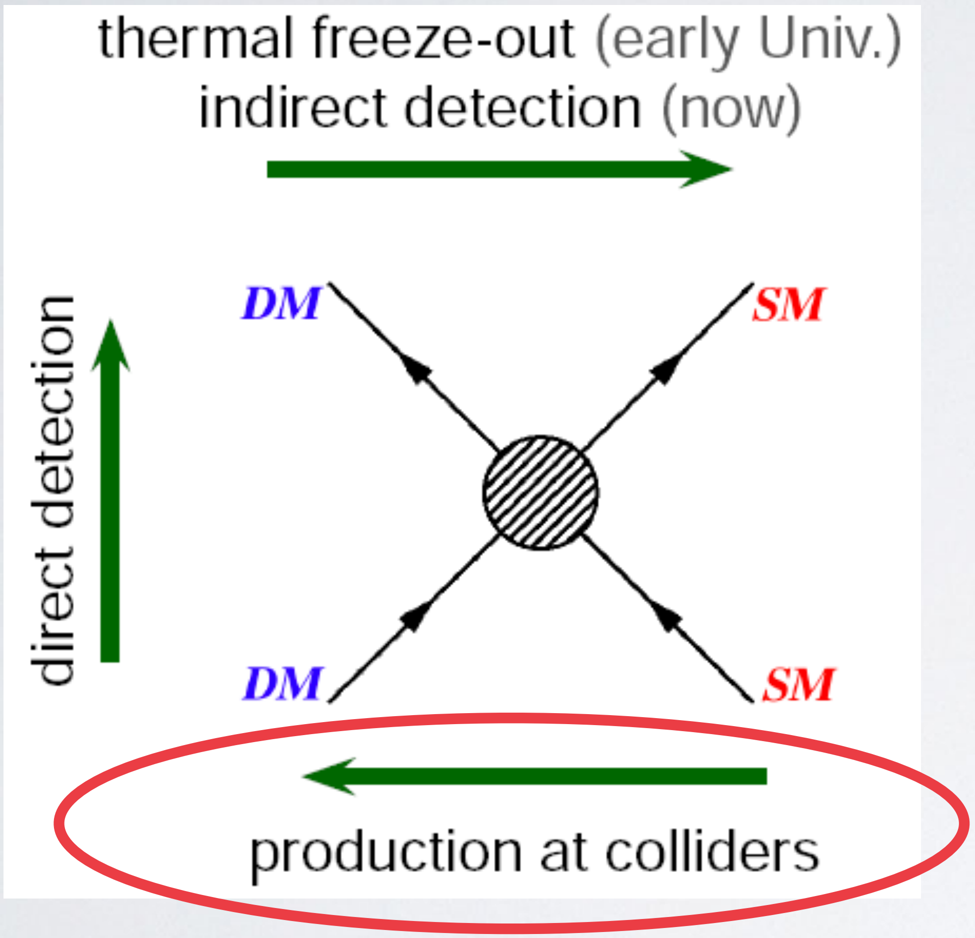
COLLIDER SEARCHES



- Future hadron colliders
  - HL-LHC 14 TeV with 3 ab^{-1}
  - HE-LHC 27 TeV with 15 ab^{-1}
  - FCC/SppC 100 TeV arXiv: 1404.0682 arXiv: 1407.7058
- Monojets
- Disappearing tracks

COLLIDER SEARCHES



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  - HL-LHC 14 TeV with 3 ab^{-1}
  - HE-LHC 27 TeV with 15 ab^{-1} — T. Han, S. Mukhopadhyay, XW coming soon
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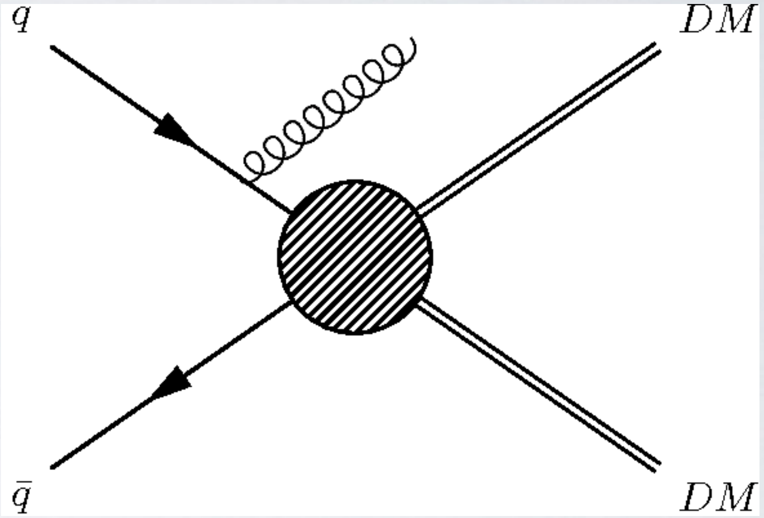
MONO-JETS

- One hard jet recoils against MET.



- Signal

$$\chi^0\chi^0/\chi^{\pm}\chi^0/\chi^{\pm}\chi^{\mp} + \text{jets}$$

- Dominant background:

$$Z(\nu\nu) + \text{jets}, \quad W(\ell\nu) + \text{jets}$$

- Subdominant:

$$t\bar{t}, \;\; Z(\ell\ell) + \text{jets}, \;\; \text{diboson}, \;\; \text{multi-jets}$$

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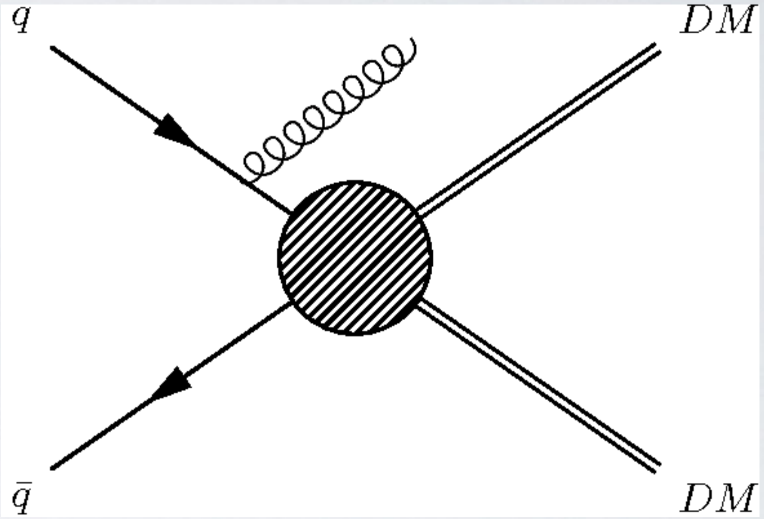

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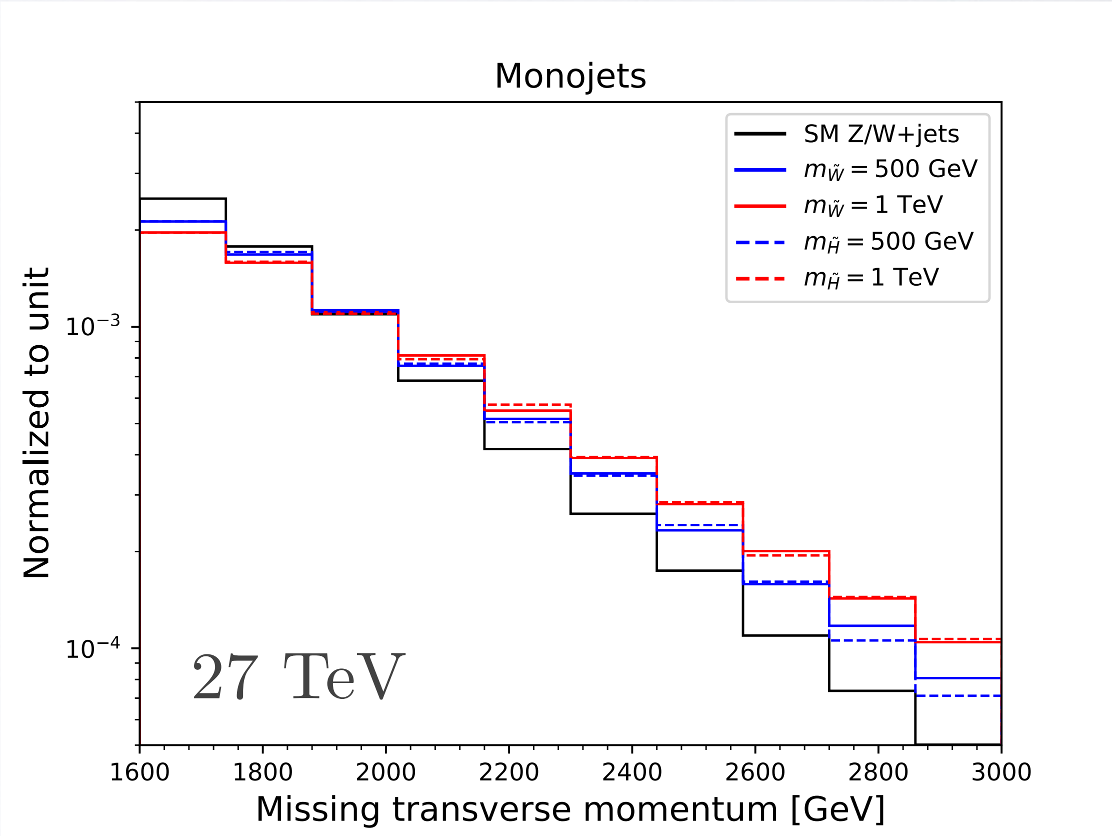
SIMULATION

- Madgraph 5 + Pythia 6.4.28 + Delphes 3
- MLM matching up to 2 jets
- Selection cuts:
  - MET, p_{T,j_1}, p_{T,j_2}
  - $N_{\text{jets}} \leq 2, \quad \Delta\phi_{j_1 j_2} < 2.5$
  - Lepton veto

$\sqrt{s}$	MET [GeV]	p_{T,j_1} [GeV]	p_{T,j_2} [GeV]
14 TeV	650	300	30
100 TeV	3500	1200	300
27 TeV	1800 - 2700	400	60 - 160

arXiv: 1404.0682



SIGNIFICANCE

- $$\text{Significance} = \frac{S}{\delta B} = \frac{S}{\sqrt{B + \lambda^2 B^2 + \gamma^2 S^2}}$$

- We assume

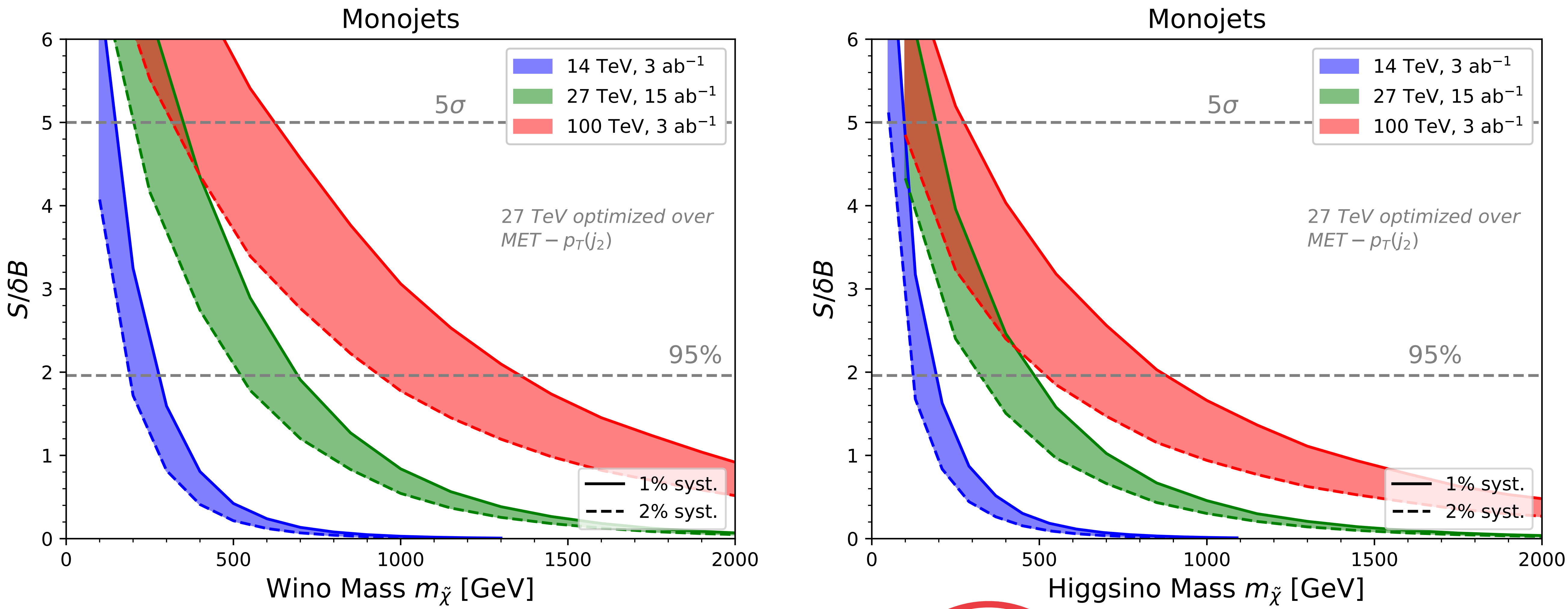
$$\lambda = 1 - 2\%,\ \gamma = 10\%$$

- Theoretical error for W/Z+jets has been reduced to $\mathcal{O}(1\%)$, using NNLO QCD + nNLO EW calculation. arXiv: 1705.04664

- Experimental errors are also currently at percentage level already.

arXiv:1711.03301

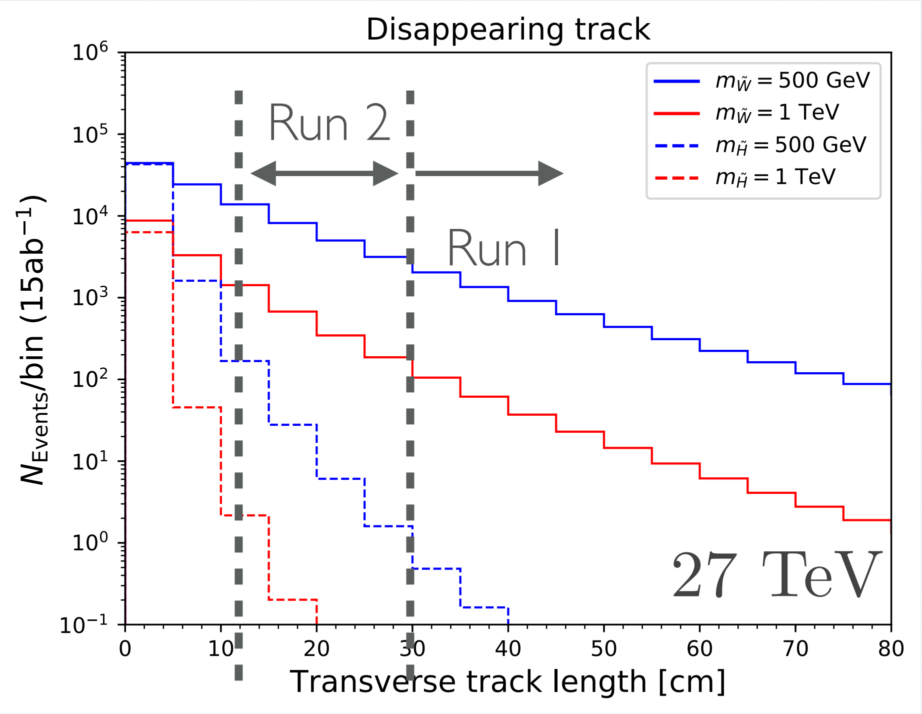
RESULTS

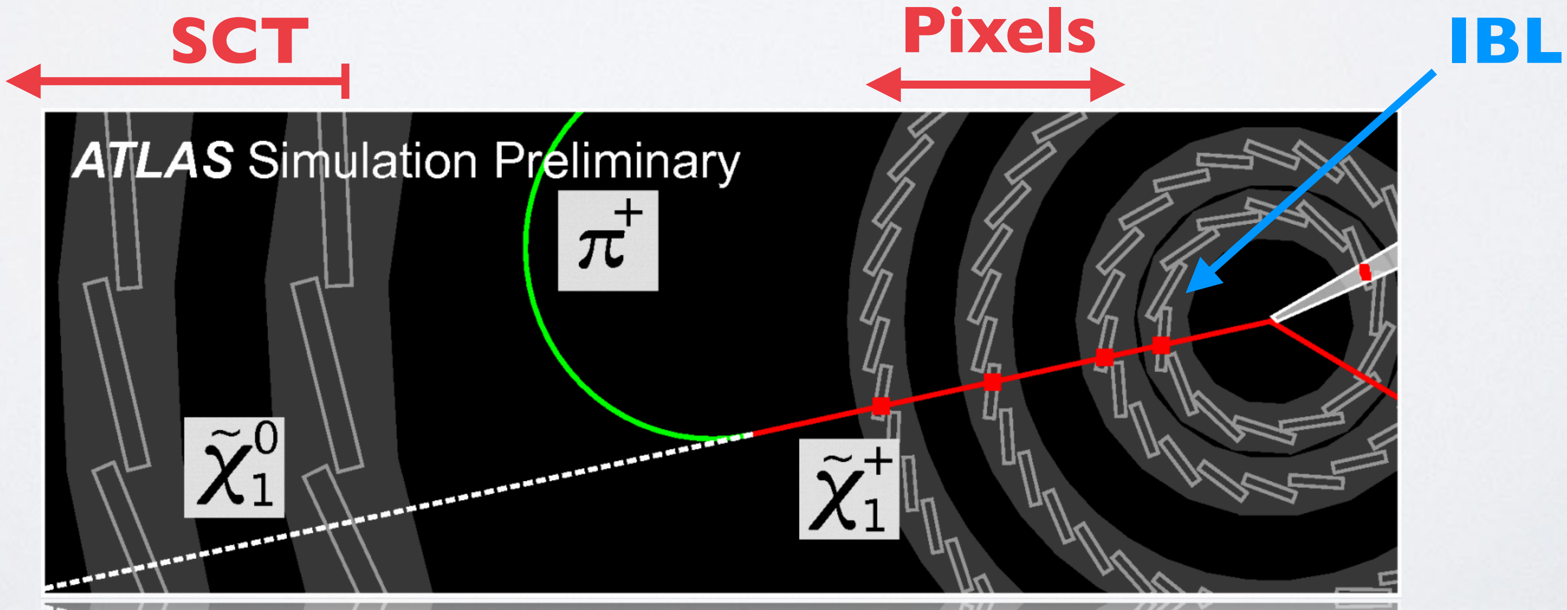


95% CL limit [GeV]	14 TeV	27 TeV	100 TeV
Wino	190 – 280	530 – 700	940 – 1360
Higgsino	130 – 200	330 – 490	520 – 880

DISAPPEARING TRACKS

- Long-lived chargino decays inside the tracker





BACKGROUND

- Various backgrounds
- Hard to estimate

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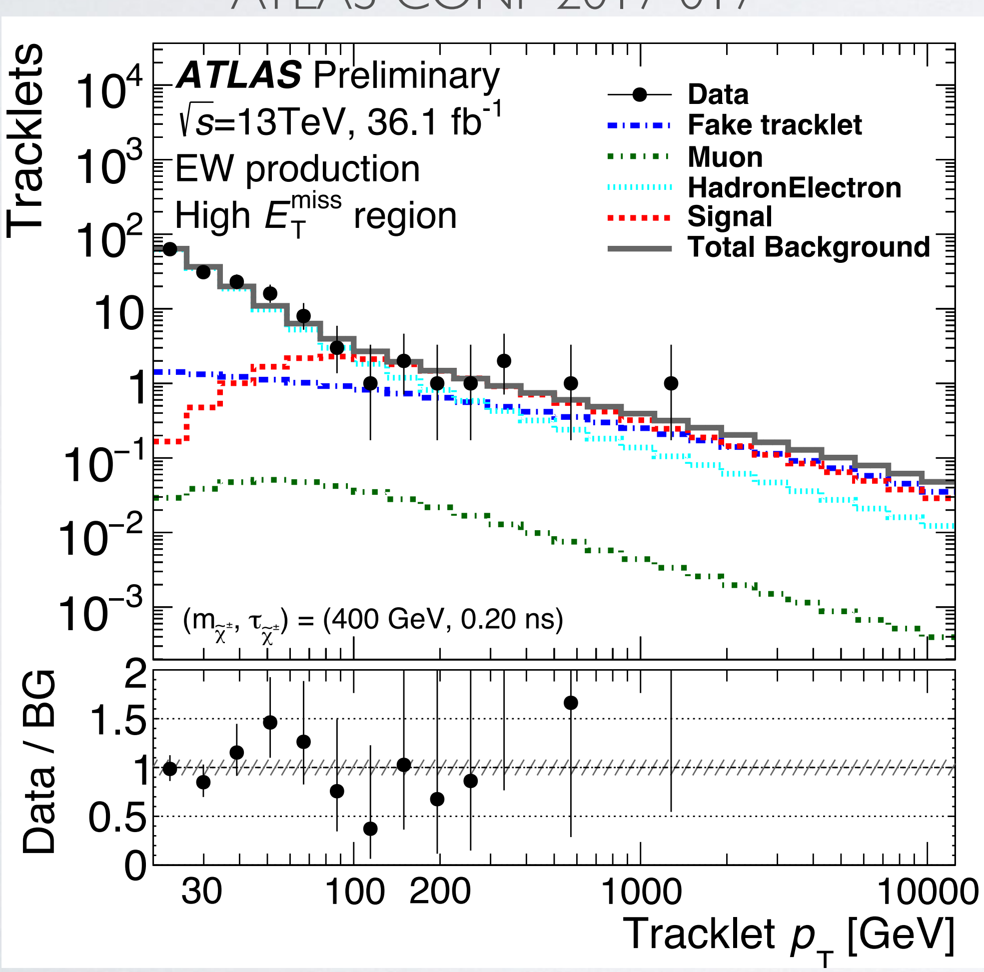
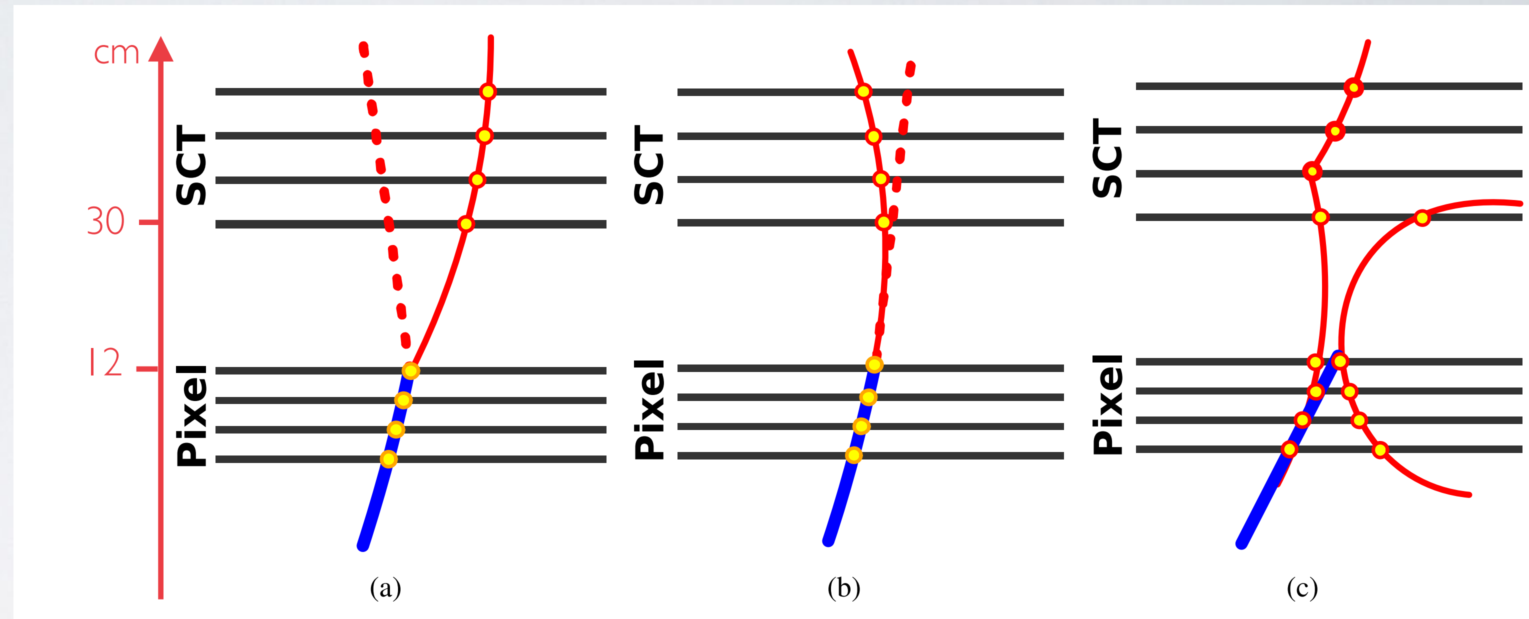


(c) Electroweak channel high-E_T^{miss} region



- We do a naive estimation
  - $f\,(p_T) = \exp\left(-p_0 \cdot \log(p_T) - p_1 \cdot (\log(p_T))^2\right)$
  - Scale according to $Z(\nu\nu) + \text{jets}$
  - Vary background from 20% to 500%.

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- Hard to estimate

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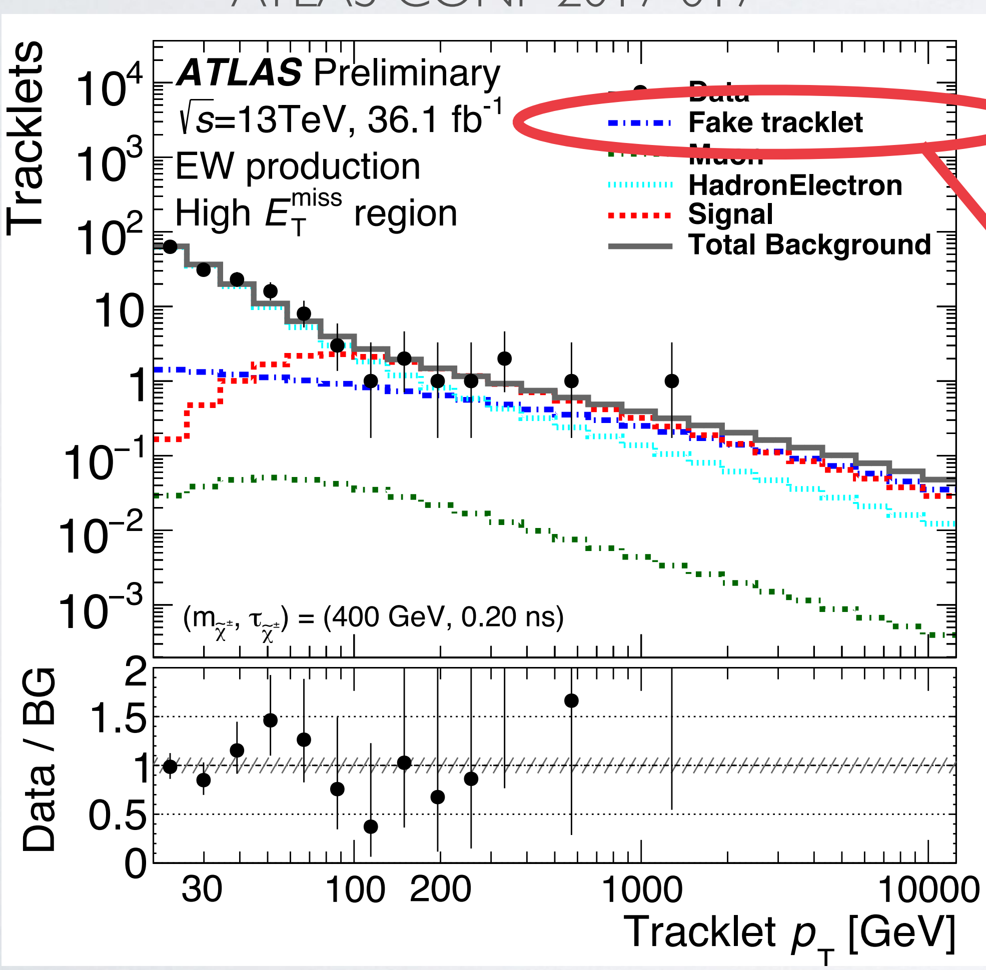

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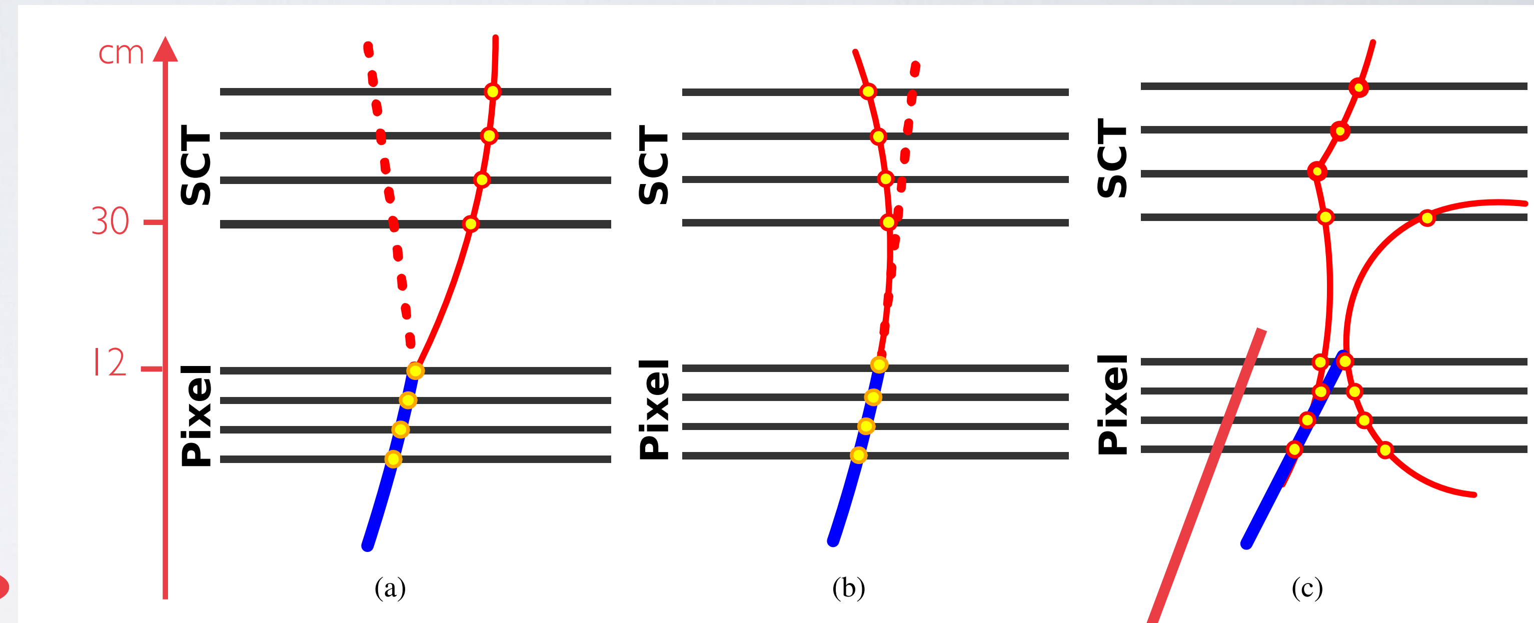

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  - Vary background from 20% to 500%.

SIMULATION

- We follow the 13 TeV ATLAS analysis to extract the signal efficiency.
- Selection cuts:
  - MET, p_{T,j_1}, p_{T,j_2}, $p_{T,\mathrm{track}}$
  - $\Delta\phi_{j,\mathrm{MET}} > 1.5$
  - $0.1 < |\eta^{\mathrm{track}}| < 1.9$
  - Track isolation $\Delta R = 0.4$
  - Track length $12 < d < 30$ cm

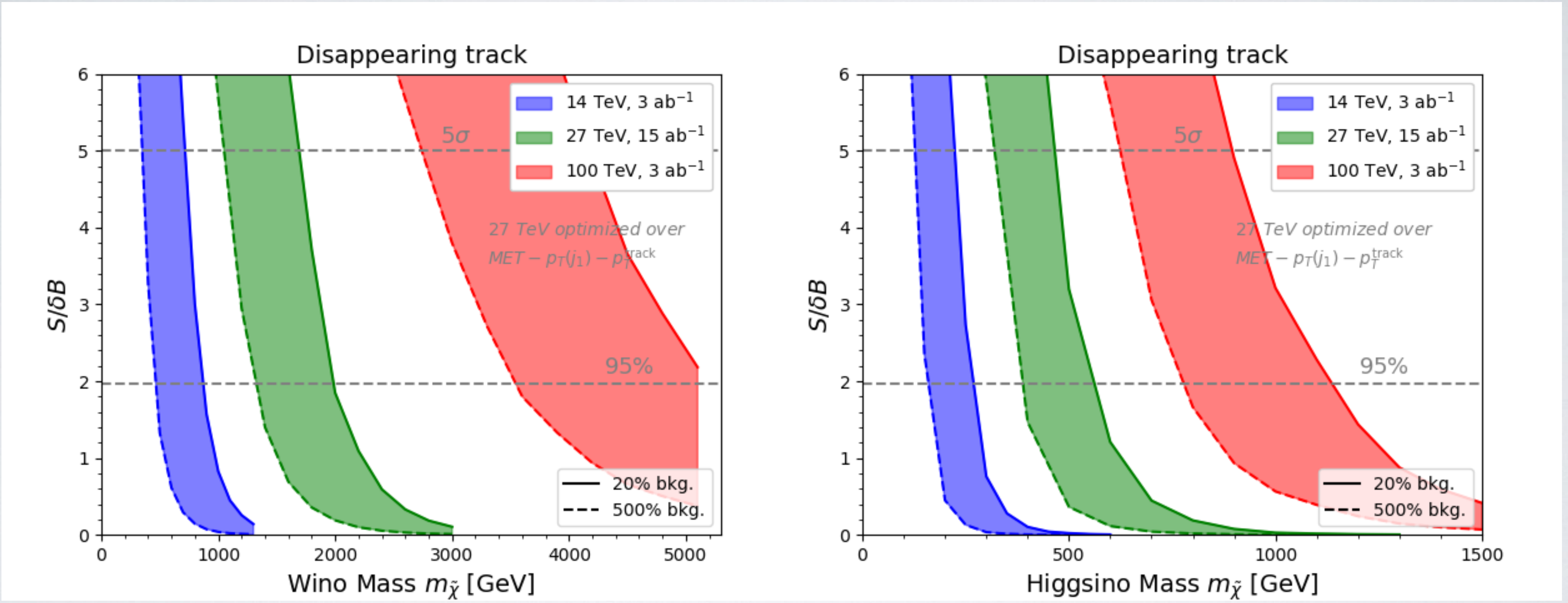
Systematics:

$\lambda = 20\%, \quad \gamma = 10\%$

$\sqrt{s}$	MET [GeV]	p_{T,j_1} [GeV]	p_{T,j_2} [GeV]	$p_{T,\mathrm{track}}$ [GeV]
14 TeV	130	130	70	250
100 TeV	975	975	500	1500
27 TeV	300 - 550	200 - 450	140	400 - 500

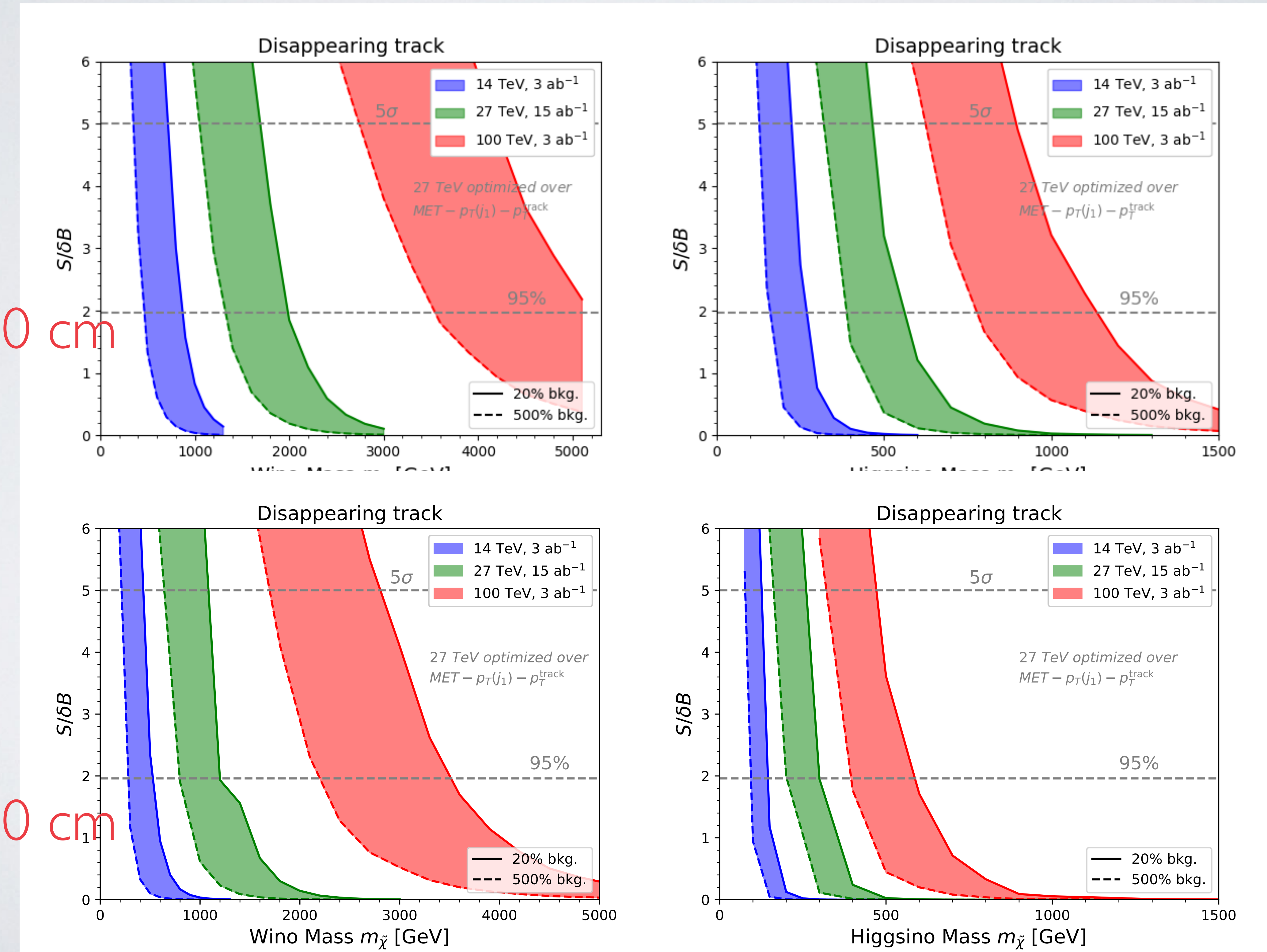
arXiv: 1404.0682

RESULT



95% CL limit [GeV]	14 TeV	27 TeV	100 TeV
Wino	480 – 880	1300 – 2000	3500 – 5300
Higgsino	160 – 270	390 – 560	780 – 1140

RESULT



12<d<30 cm

30<d<80 cm

SUMMARY

- Wino/Higgsino dark matter are simple but well-motivated models.
- Collider searches are important to cover the relevant parameter space, which is complementary to the indirect detection.
- Mono-jets and disappearing track are powerful channels.
- The possible LHC high energy upgrade would significantly extend the reach of wino/higgsino searches.