Electroweak dark matter at future hadron colliders

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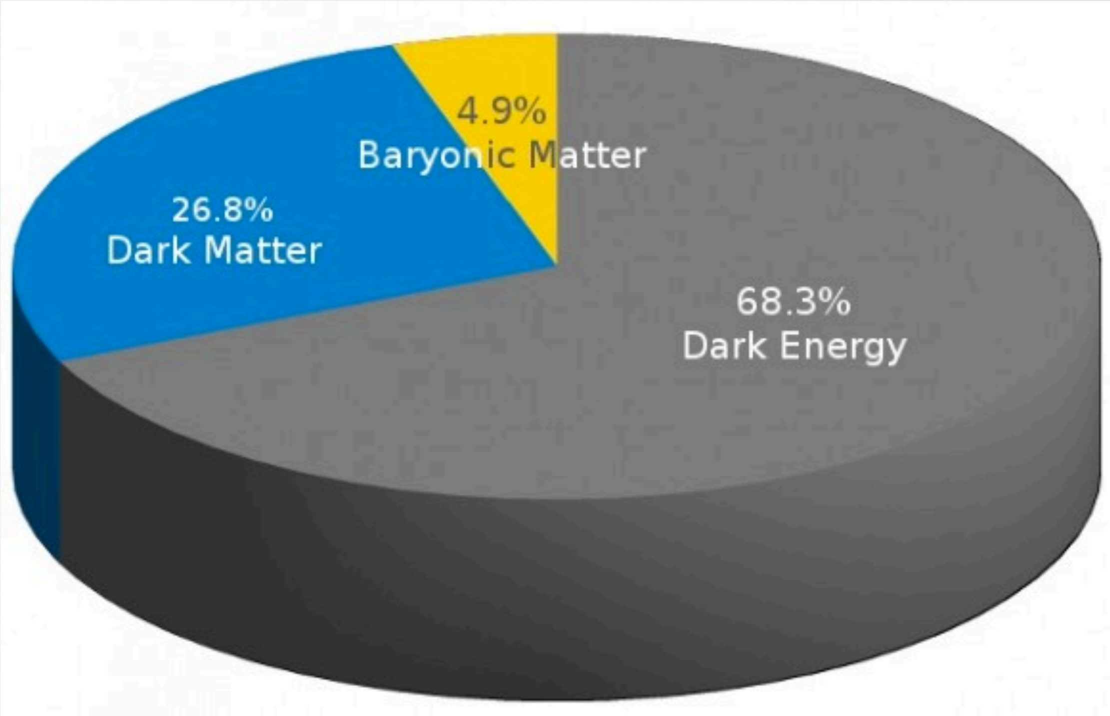
Introduction

- 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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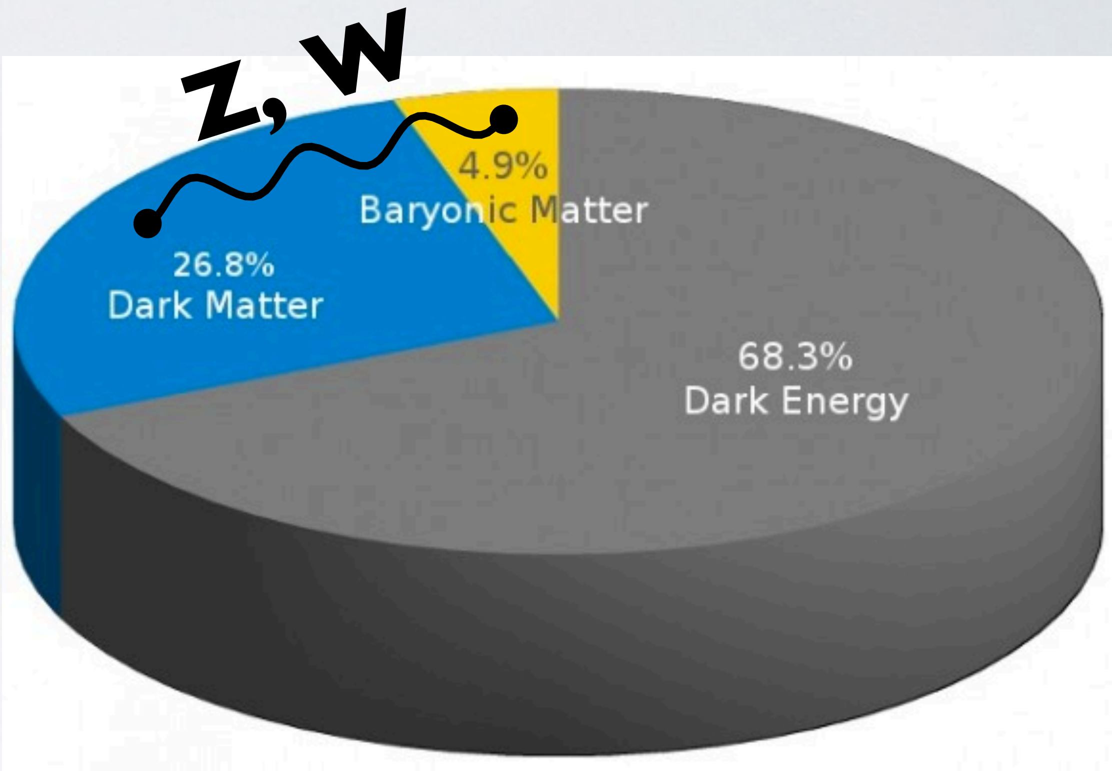
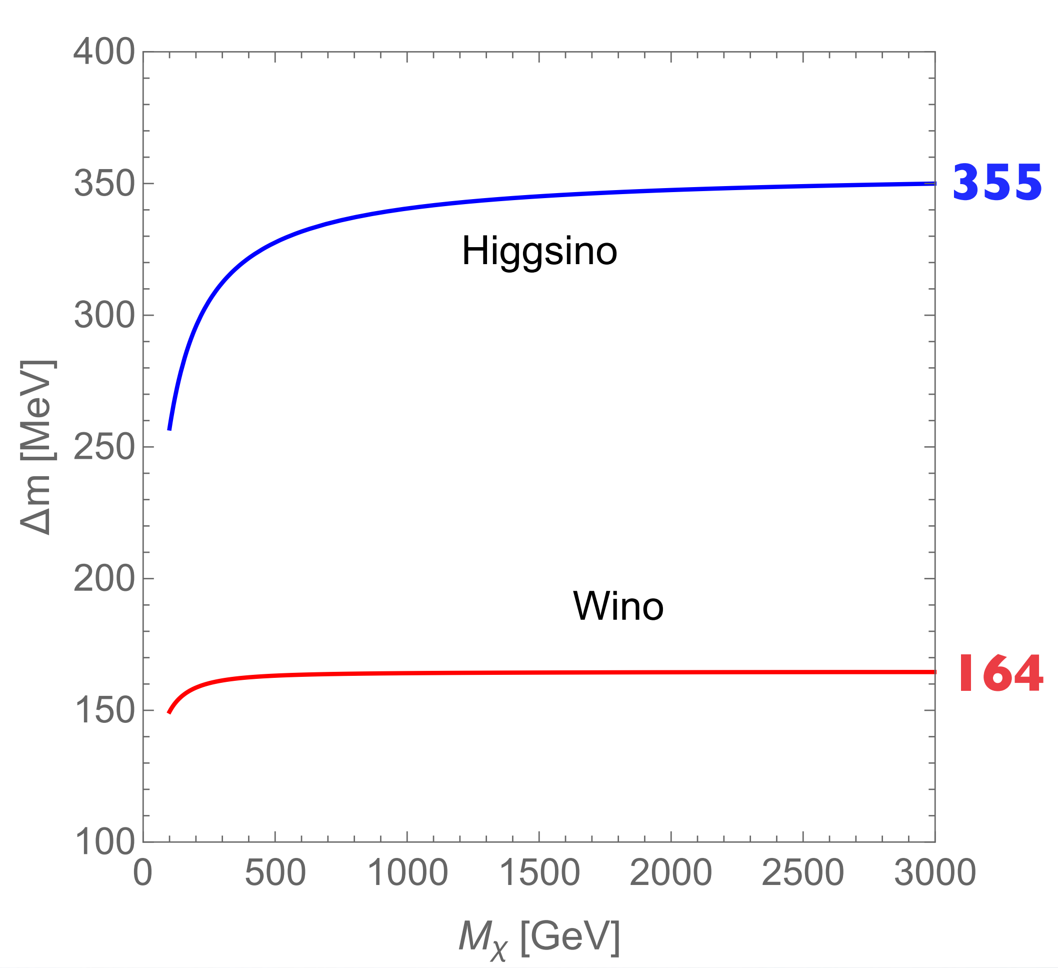
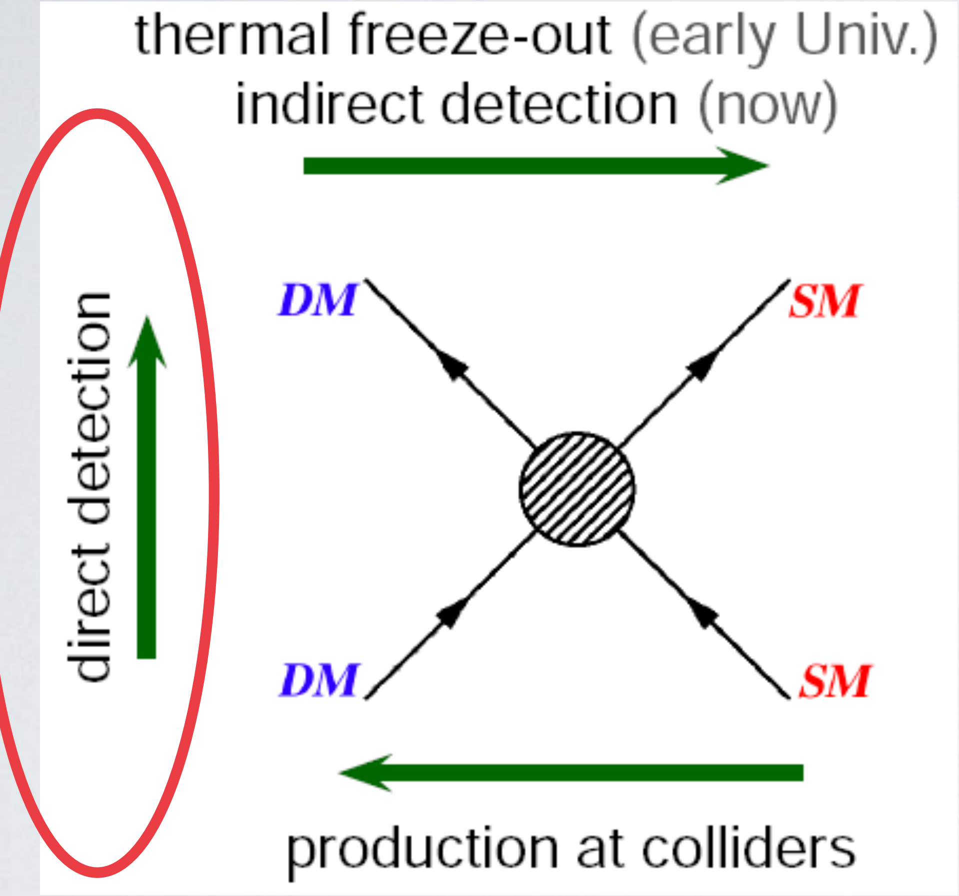


Spectrum



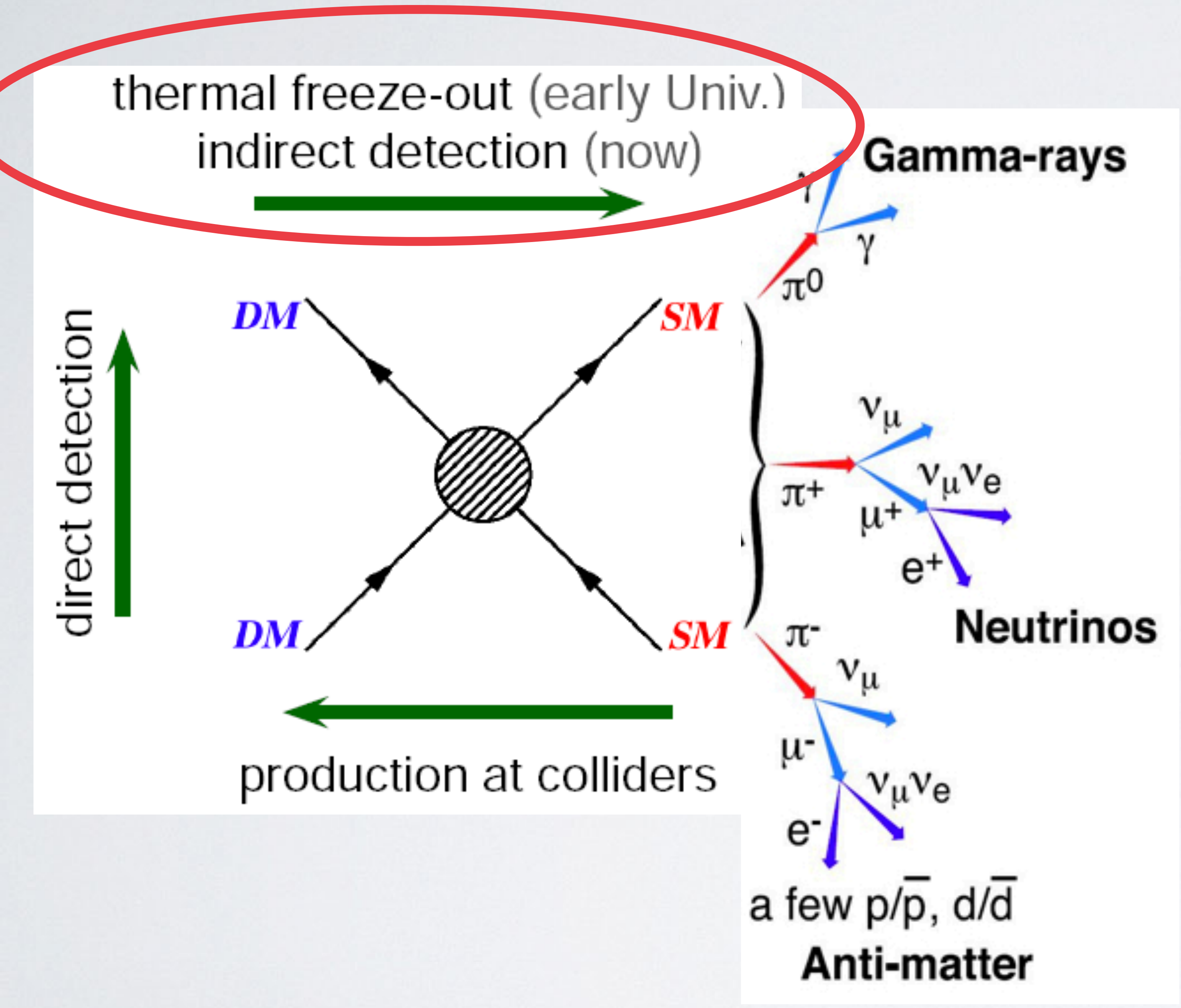
- Wino scenario
  - one Majorana neutralino + one chargino
- Higgsino scenario
  - one (pseudo-)Dirac neutralino + one chargino
- 1-loop radiative mass splitting $\sim \mathcal{O}(100 \text{ MeV})$

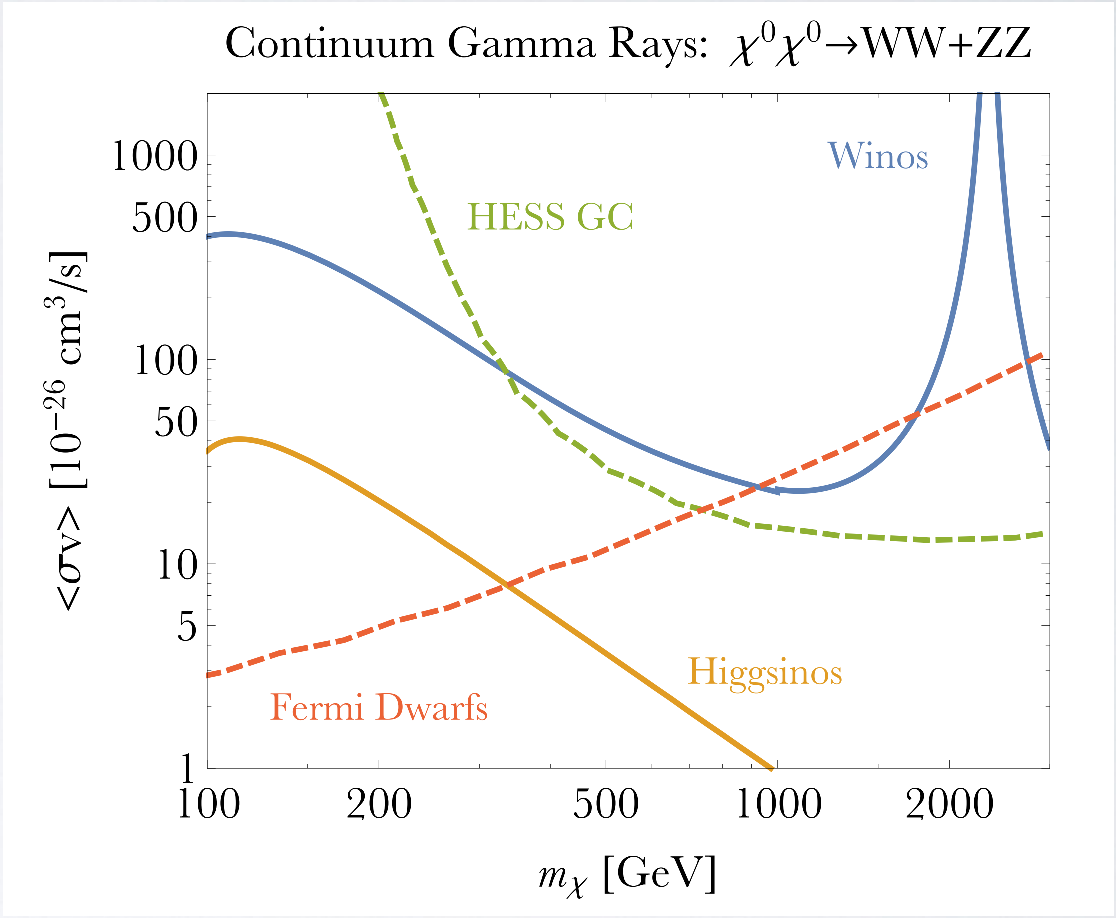
Direct Detection



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

Indirect Detection



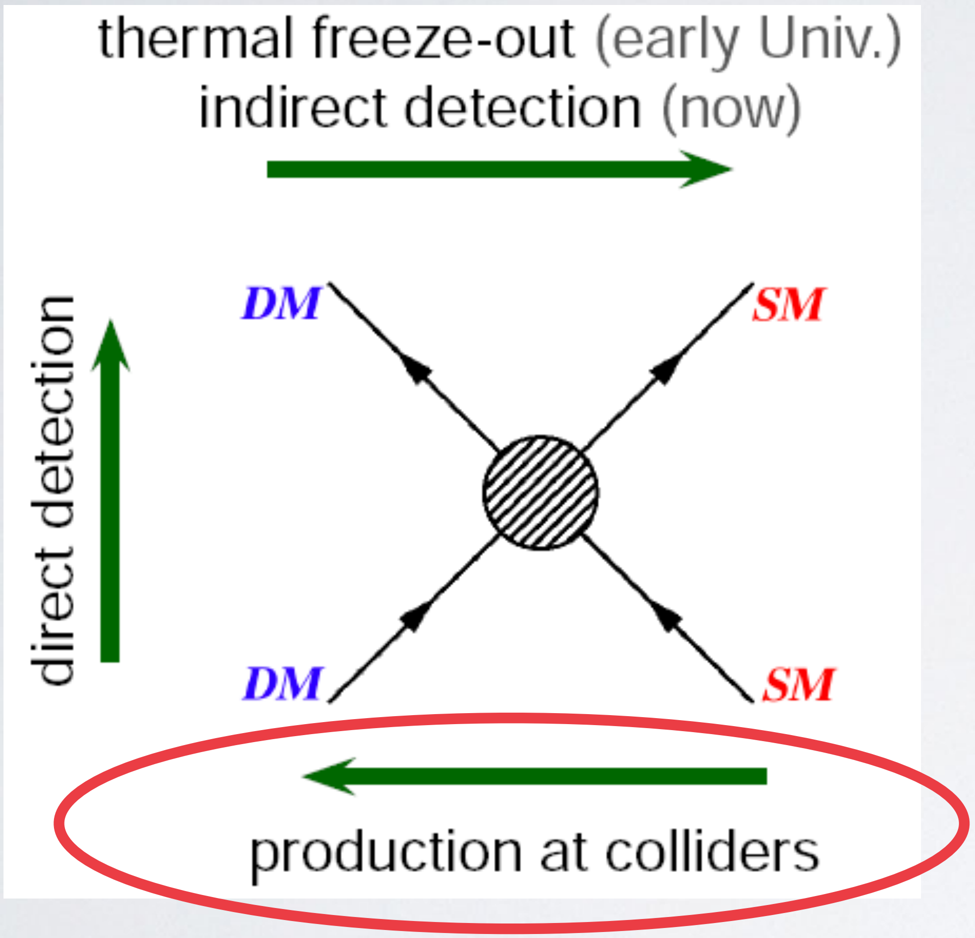


R. Krall, M. Reece arXiv:1705.04843

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

Collider Searches

T. Han, S. Mukhopadhyay, XW, arXiv: 1805.00015



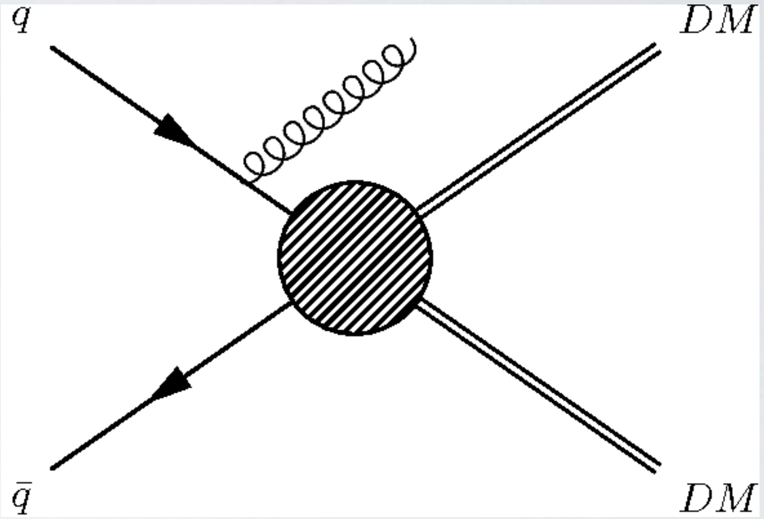
- Future hadron colliders
  - HL-LHC 14 TeV with $3\ \mathrm{ab}^{-1}$
  - HE-LHC 27 TeV with $15\ \mathrm{ab}^{-1}$
  - FCC/SppC 100 TeV $30\ \mathrm{ab}^{-1}$

M. Low, L.T. Wang, arXiv: 1404.0682
M. Cirelli, *et al.* Xiv: 1407.7058

- Monojet
- Disappearing track
- Higher energies are very advantageous.

Mono-Jet

- 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:

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

Mono-Jet

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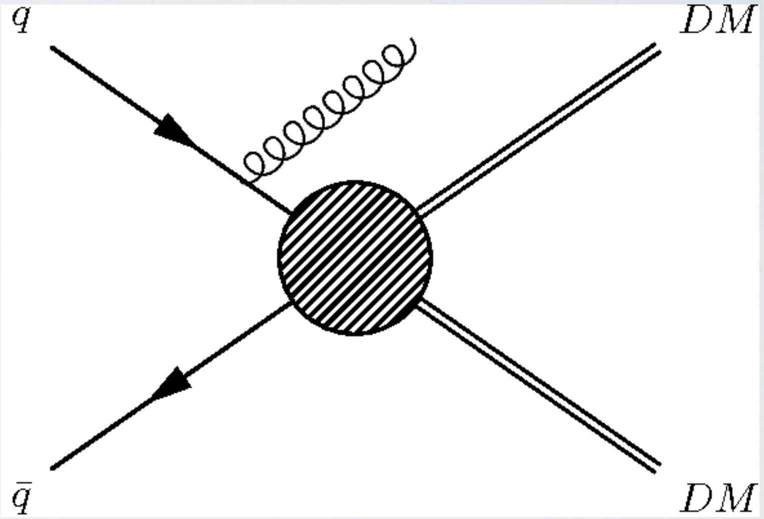

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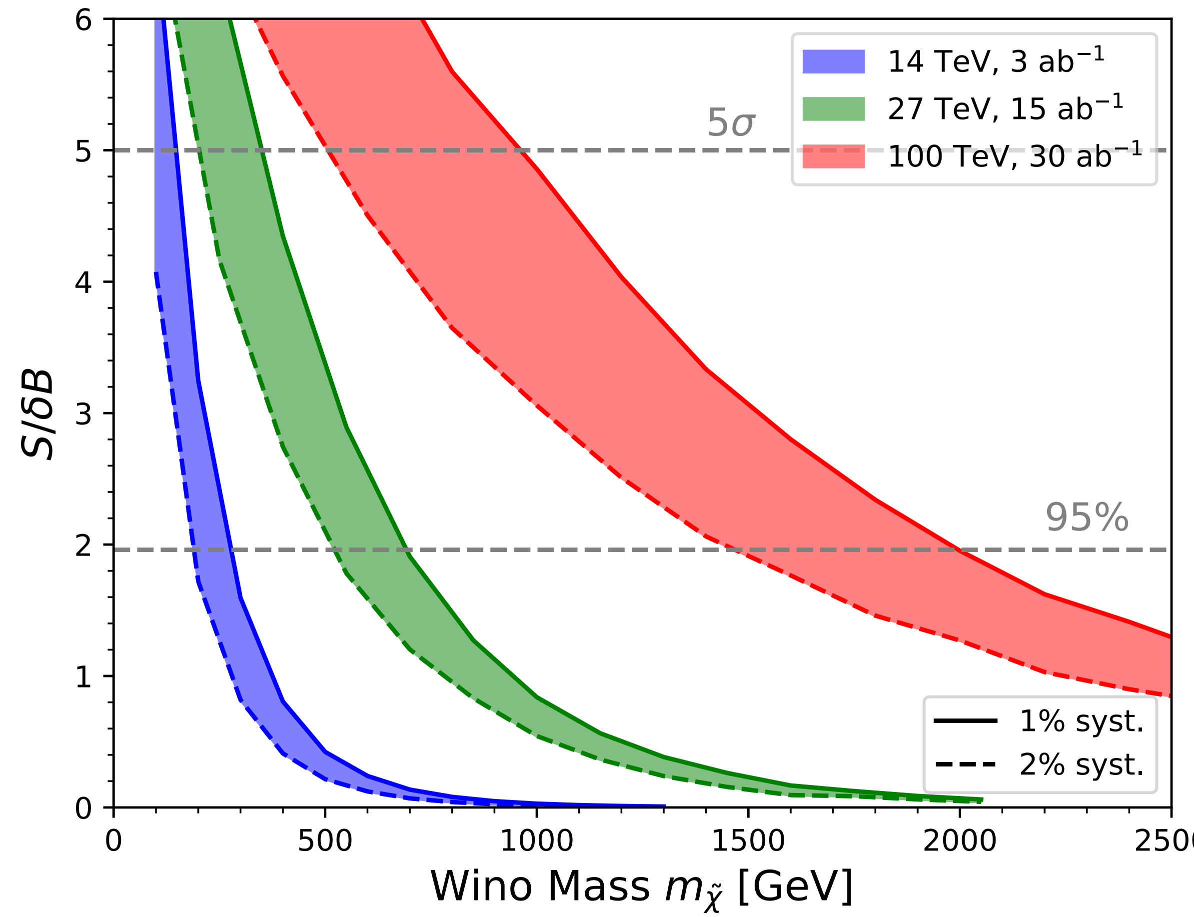
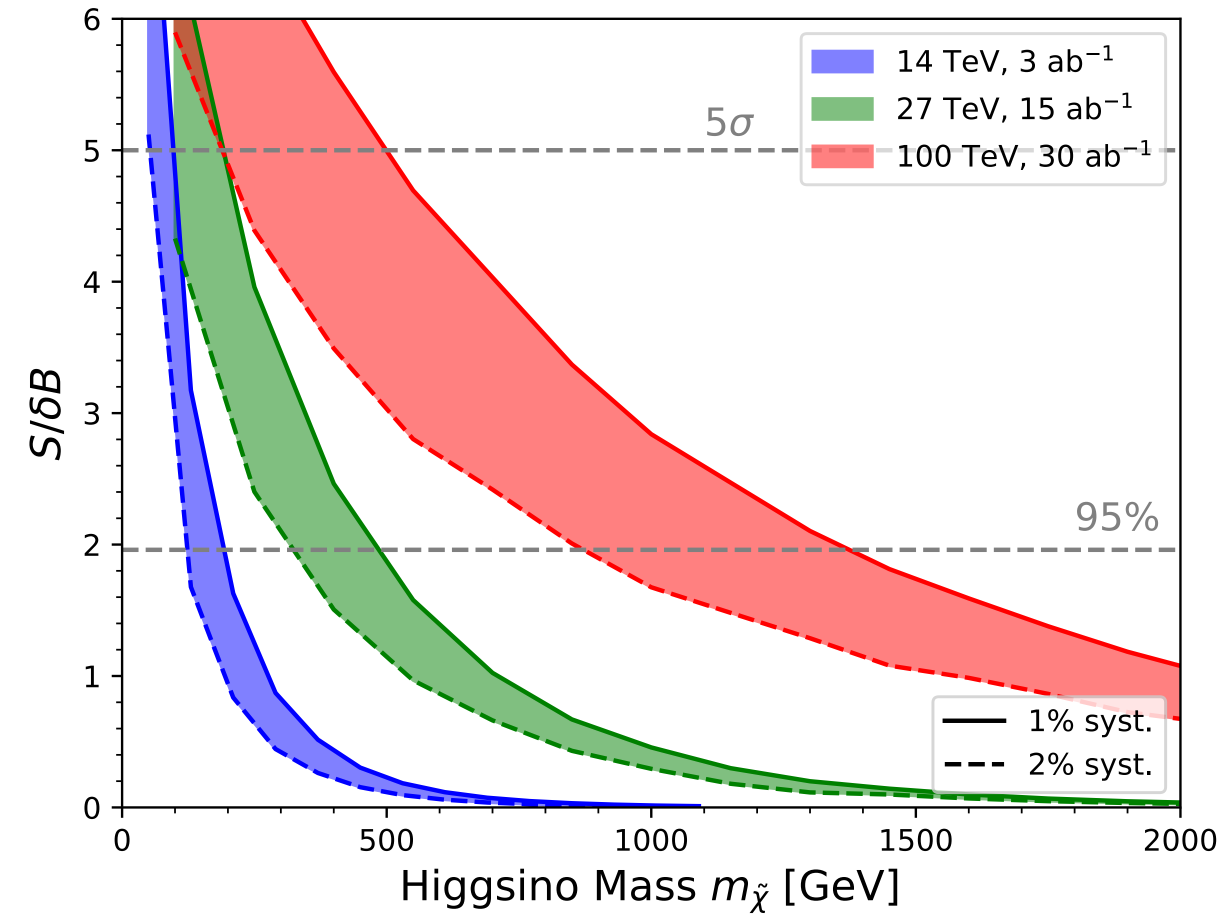
- $\lambda = 1 - 2\%, \ \gamma = 10\%$

Results

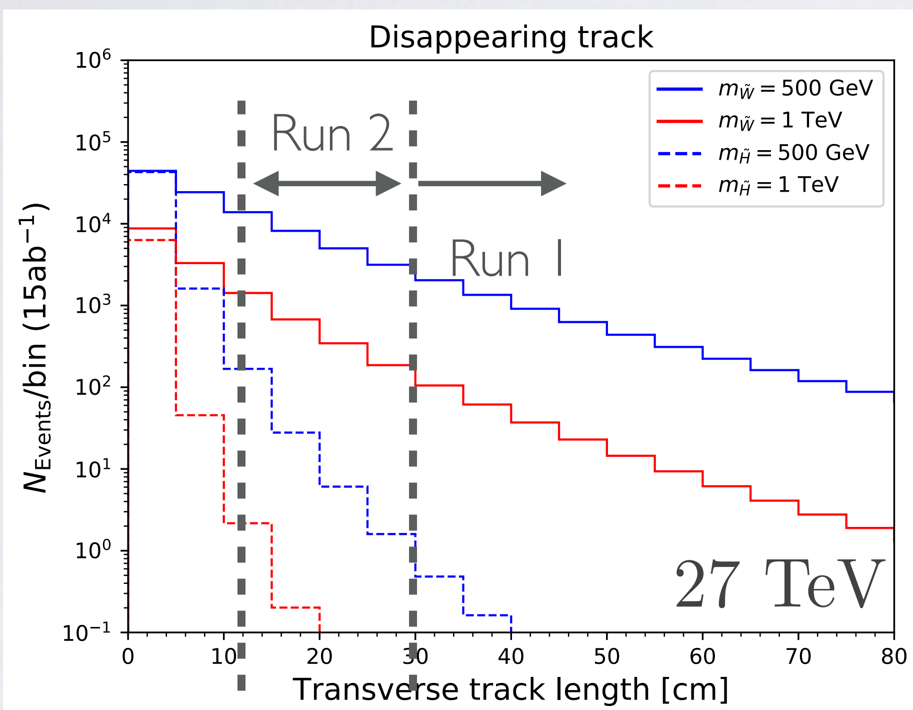




95% CL limit [GeV]	14 TeV	27 TeV	100 TeV
Wino	190 – 280	530 – 700	1500 – 2000
Higgsino	130 – 200	330 – 490	900 – 1370

Disappearing Track

- Long-lived chargino decays inside the tracker



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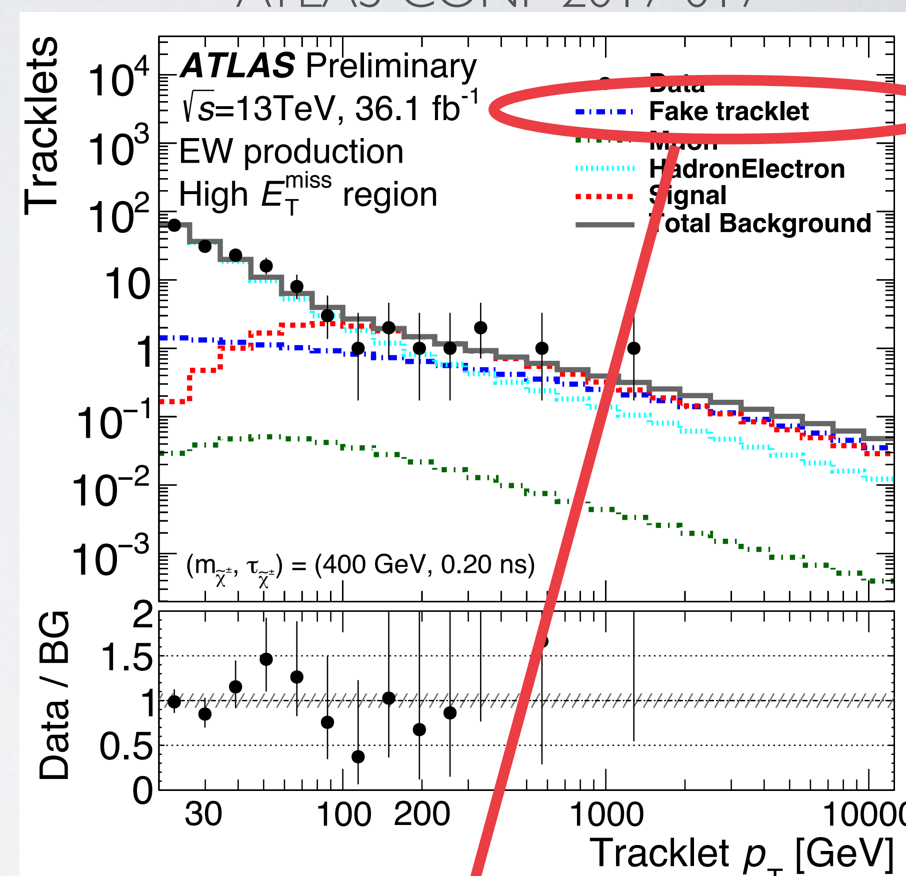
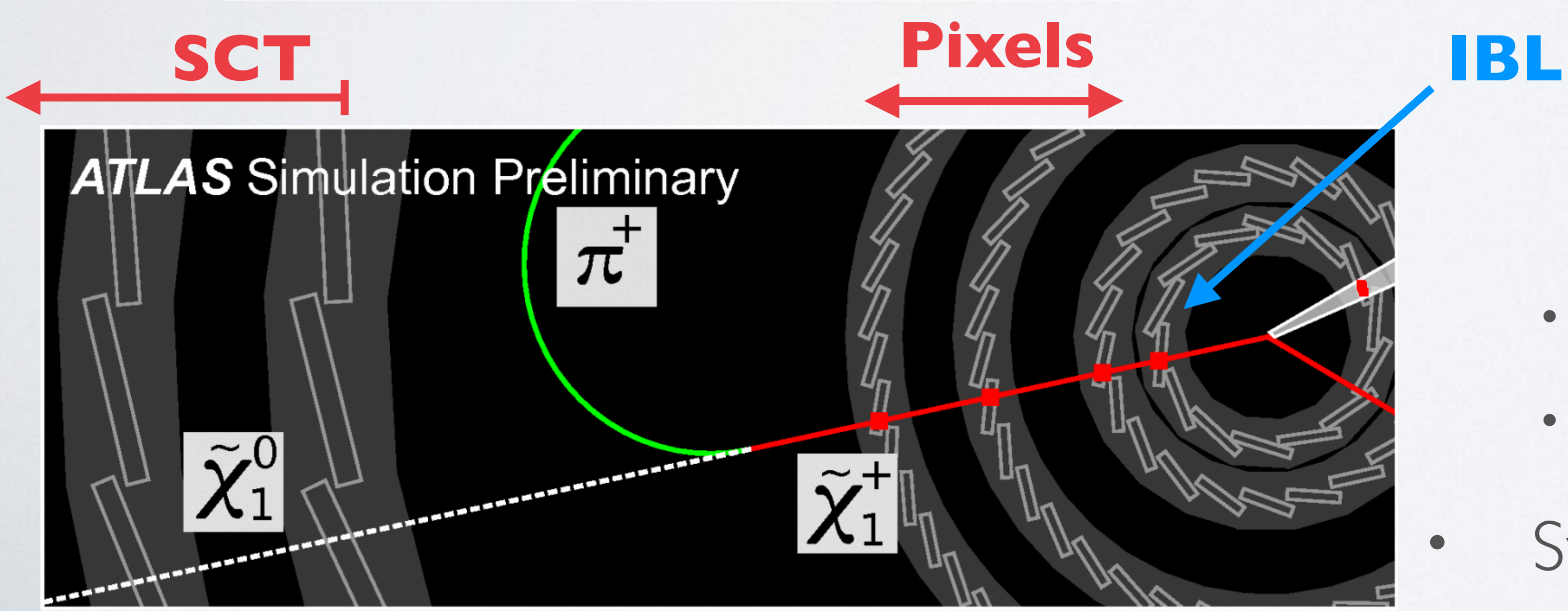


(c) Electroweak channel high-E_T^{miss} region

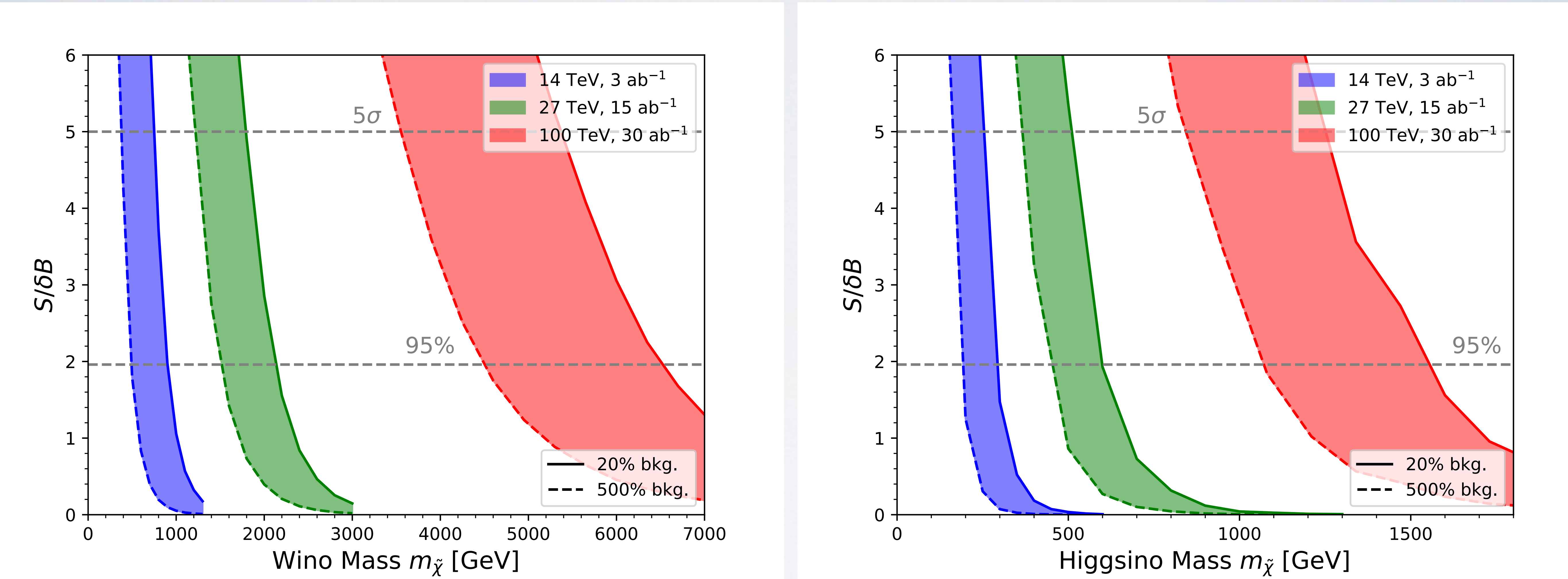


$$f\,(p_T) = \exp\left(-p_0 \cdot \log(p_T) - p_1 \cdot (\log(p_T))^2\right)$$

- Scale according to $Z(\nu\nu) + \text{jets}$
- Vary background from 20% to 500%.

- Systematics: $\lambda = 20\%, \quad \gamma = 10\%$

Result



95% CL limit [GeV]	14 TeV	27 TeV	100 TeV
Wino	500 – 900	1500 – 2100	4500 – 6500
Higgsino	200 – 300	450 – 600	1100 – 1550

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-jet and disappearing track are powerful channels.
- The possible LHC high energy upgrade would significantly extend the reach of wino/Higgsino searches.

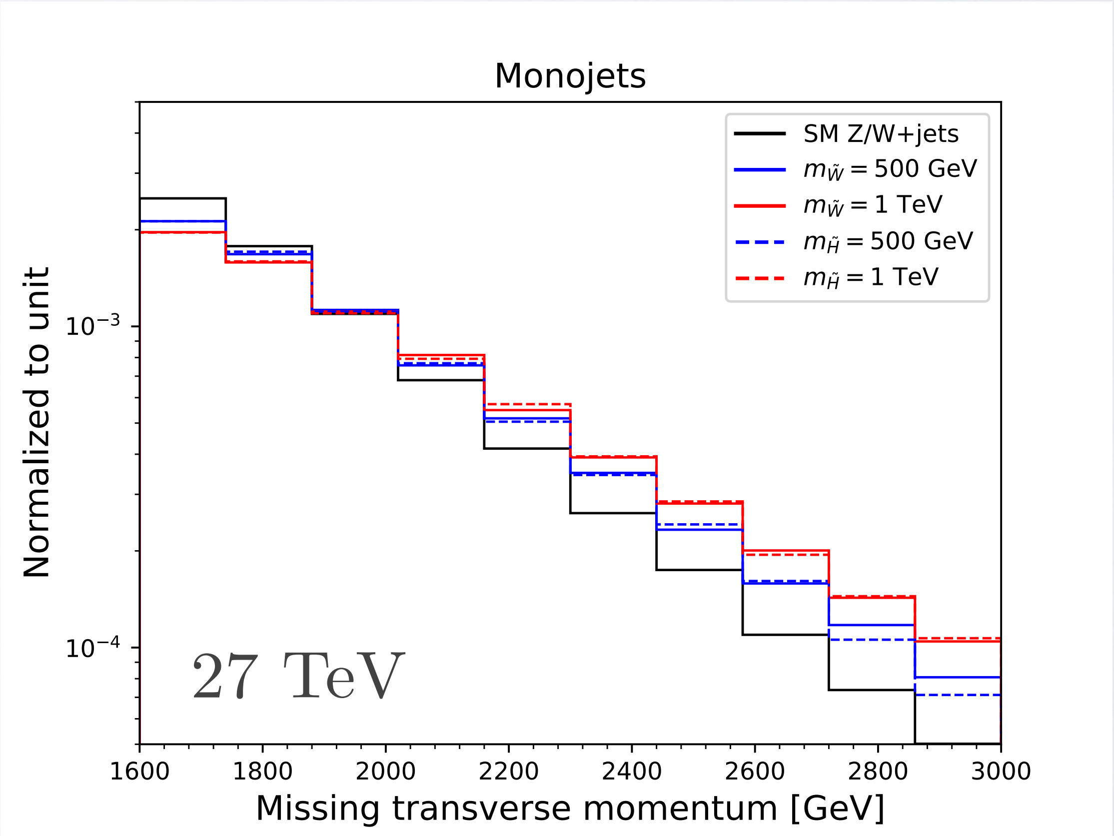
95% C.L.	Wino Monojet	Wino Disappearing Track	Higgsino Monojet	Higgsino Disappearing Track
14 TeV	280 GeV	900 GeV	200 GeV	300 GeV
27 TeV	700 GeV	2.1 TeV	490 GeV	600 GeV
100 TeV	2 TeV	6.5 TeV	1.4 TeV	1.5 TeV

Back-ups

Monojet

- 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

$\sqrt{s}$	$\not{E}_T^{\text{min}}$ [GeV]	p_{T,j_1} [GeV]	p_{T,j_2} [GeV]	$p_{T,\tau}$ [GeV]
14 TeV	650	300	30	30
27 TeV	1800–2700	400	60–160	30
100 TeV	4800–7000	1200	250–450	40



Background

- Various backgrounds
- Hard to estimate

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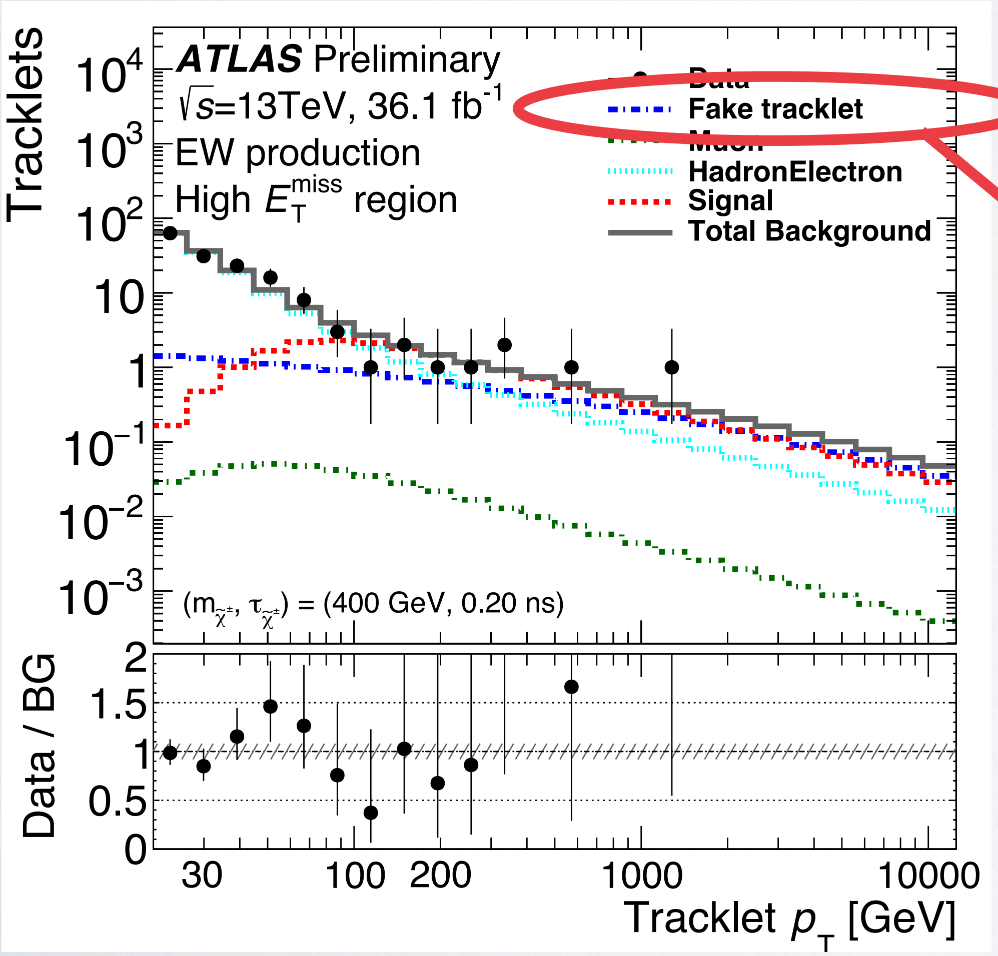

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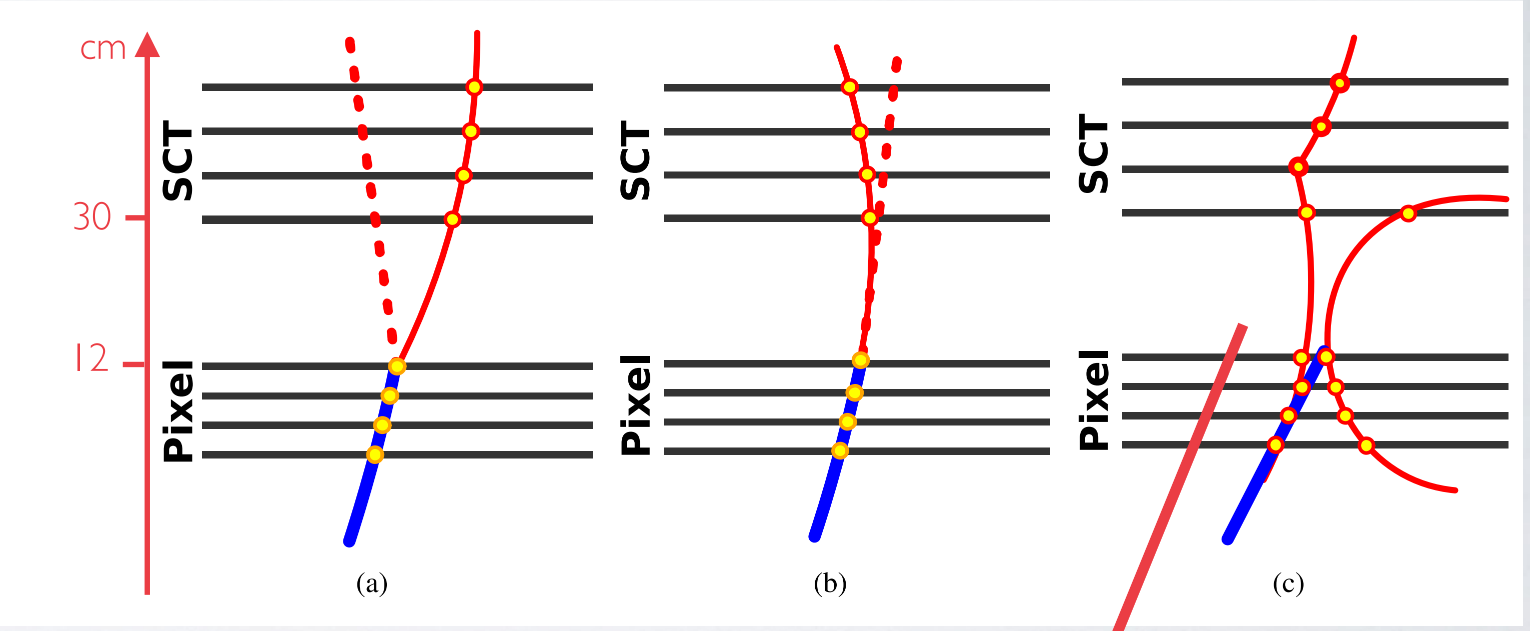


- We do a naive estimation
  - $f\left(p_{\mathrm{T}}\right) = \exp\left(-p_0 \cdot \log(p_{\mathrm{T}}) - p_1 \cdot (\log(p_{\mathrm{T}}))^2\right)$
  - Scale according to $Z(\nu\nu) + \text{jets}$
  - Vary background from 20% to 500%.
- Systematics: $\lambda = 20\%, \quad \gamma = 10\%$

Disappearing Track

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

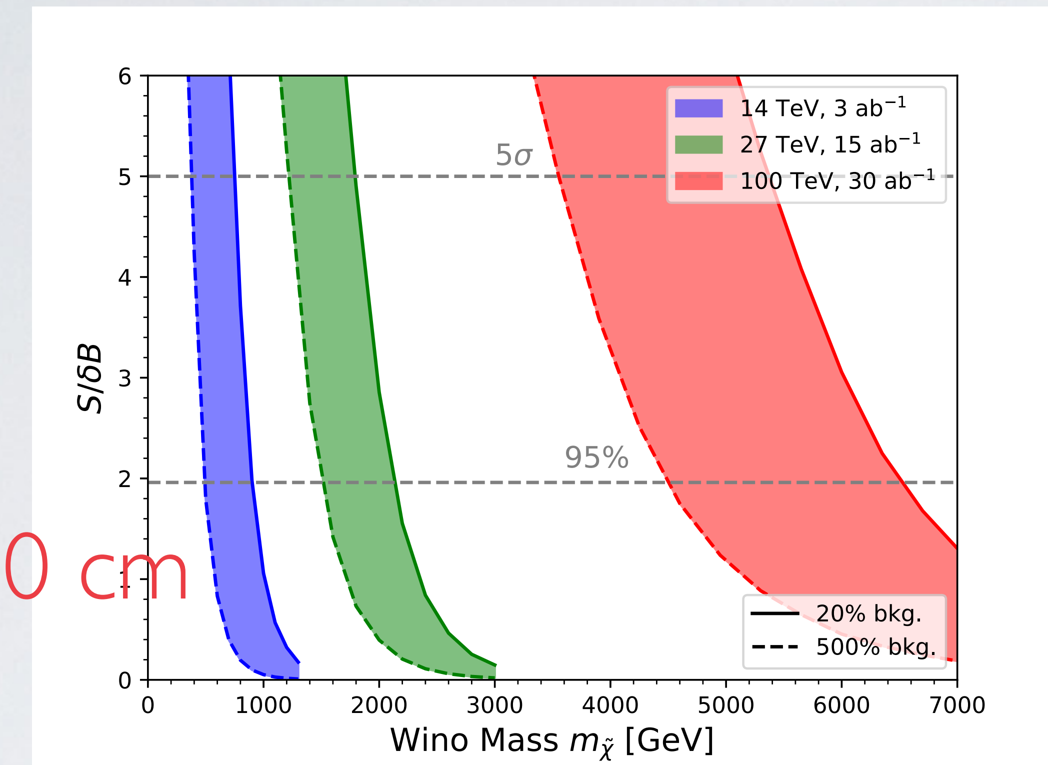
Systematics:

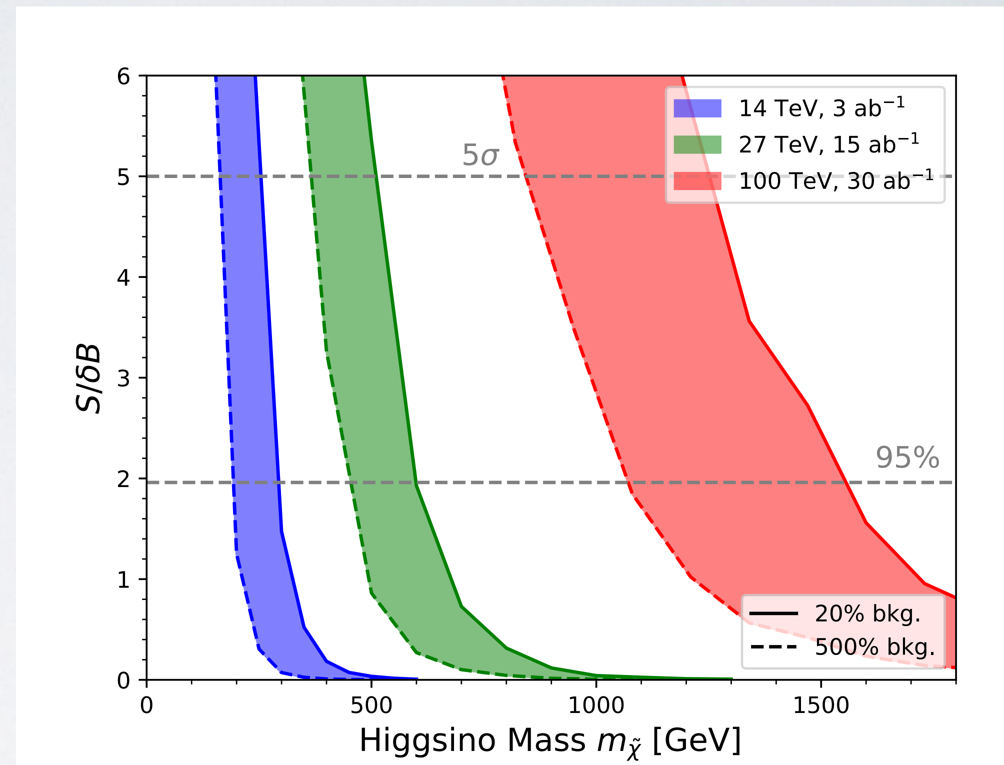
$$\lambda = 20\%, \quad \gamma = 10\%$$

$\sqrt{s}$	$\not{E}_T$ [GeV]	p_{T,j_1} [GeV]	p_{T,j_2} [GeV]	$p_{T,\text{track}}$ [GeV]
14 TeV	150	150	70	250
27 TeV	400 – 700	400 – 600	140	400 – 700
100 TeV	1000 – 1400	700 – 1400	500	1000 – 1400

Result

12<d<30 cm





30<d<80 cm