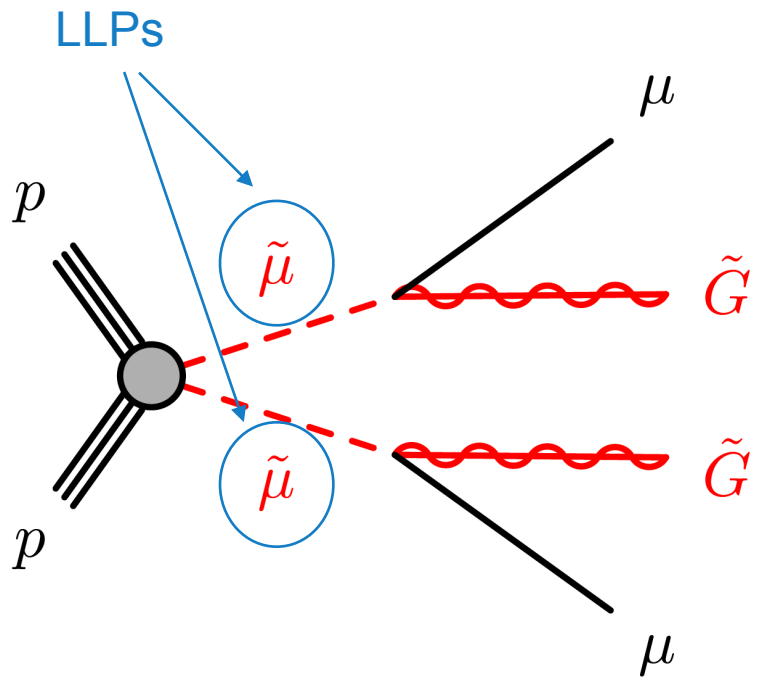
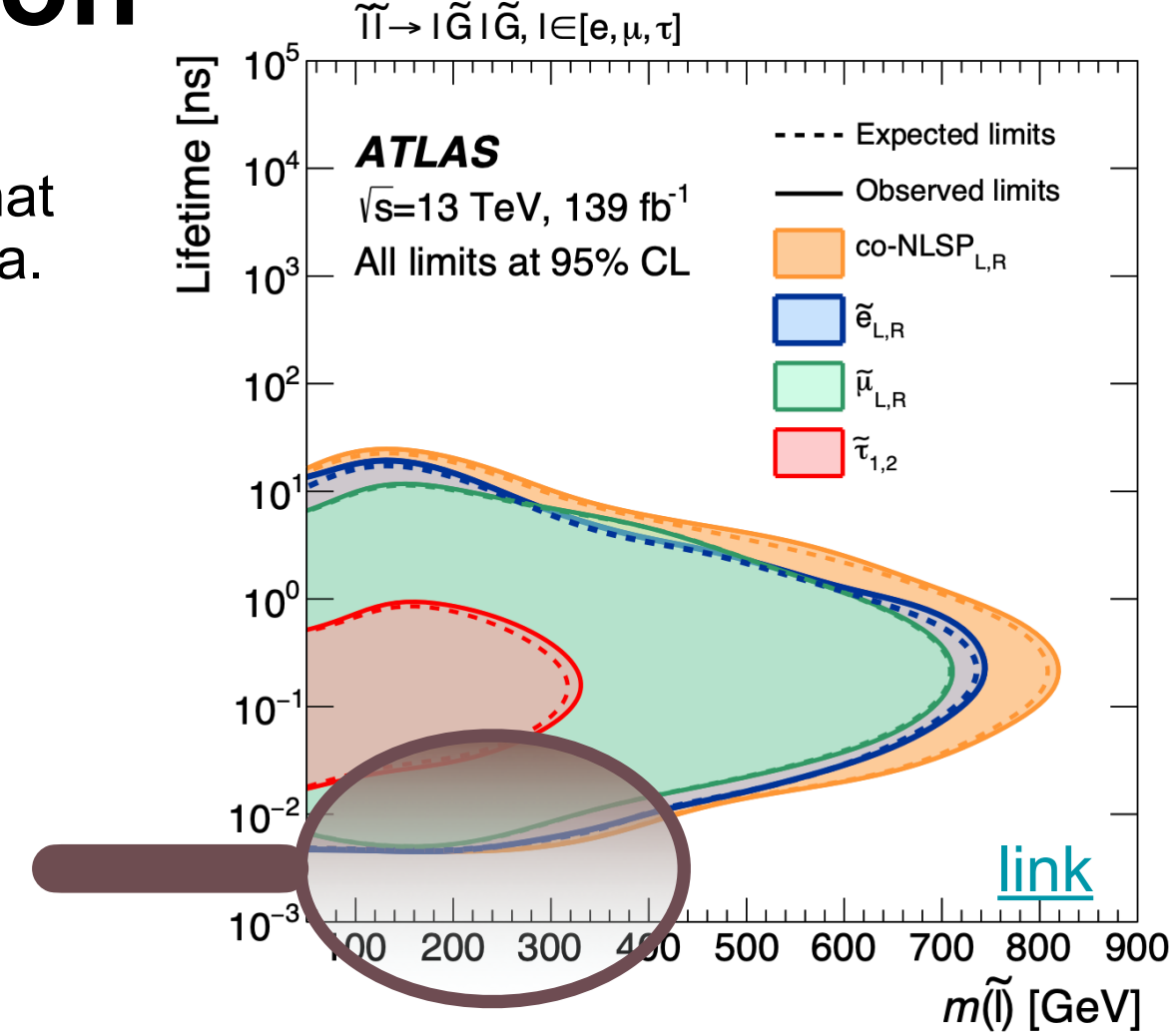
Search for pairs of muons with small displacements in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

13th LLP workshop arXiv:2305.02005 Melissa Yexley - m.yexley@cern.ch

Introduction & motivation

Search for **isolated**, **opposite sign muon pairs** that have **0.6 < |d0| < 3 mm** using all ATLAS Run 2 data.





Muon selection cuts

Trigger: 2 muon objects with $p_T > 14$ GeV

$p_T > 20$ GeV

$|\eta| < 2.5$

$0.1 < |d_0| < 3$ mm

Isolated

$m_{\mu+\mu-} > 110$ GeV

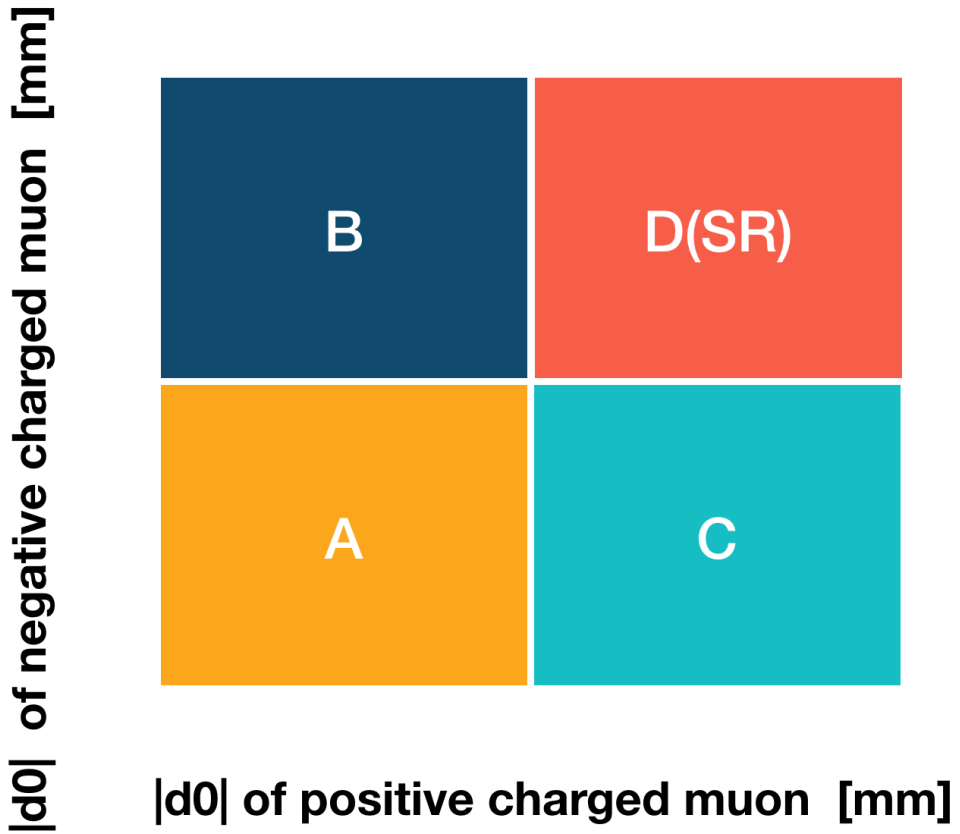
Muons are of opposite sign

After selection cuts **bb → μμ** is the dominant background. **Data driven** method to estimate the expected number of background events in the signal regions.

Background estimation

- Use the **data driven** ABCD method to estimate the background in the signal region.

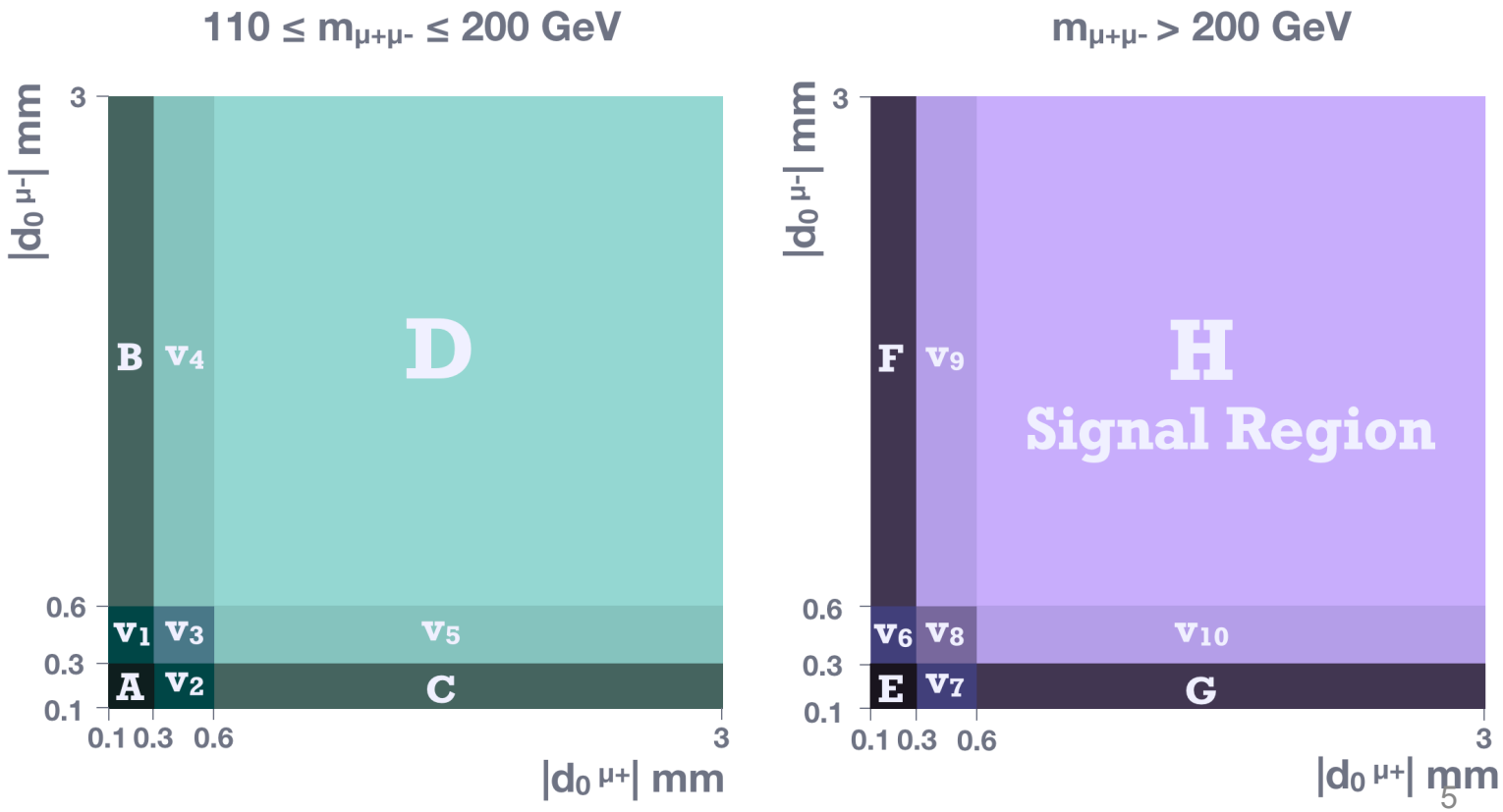
$$N_D^{\text{pred. bkg}} = \frac{N_B^{\text{data}} \times N_C^{\text{data}}}{N_A^{\text{data}}}$$



Background estimation

- The ABCD method is extended to further **separate** background and signal regions and allow for **validation regions**

$$N_H^{\text{pred. bkg}} = \frac{N_B^{\text{data}} \times N_C^{\text{data}} \times N_E^{\text{data}}}{(N_A^{\text{data}})^2}$$

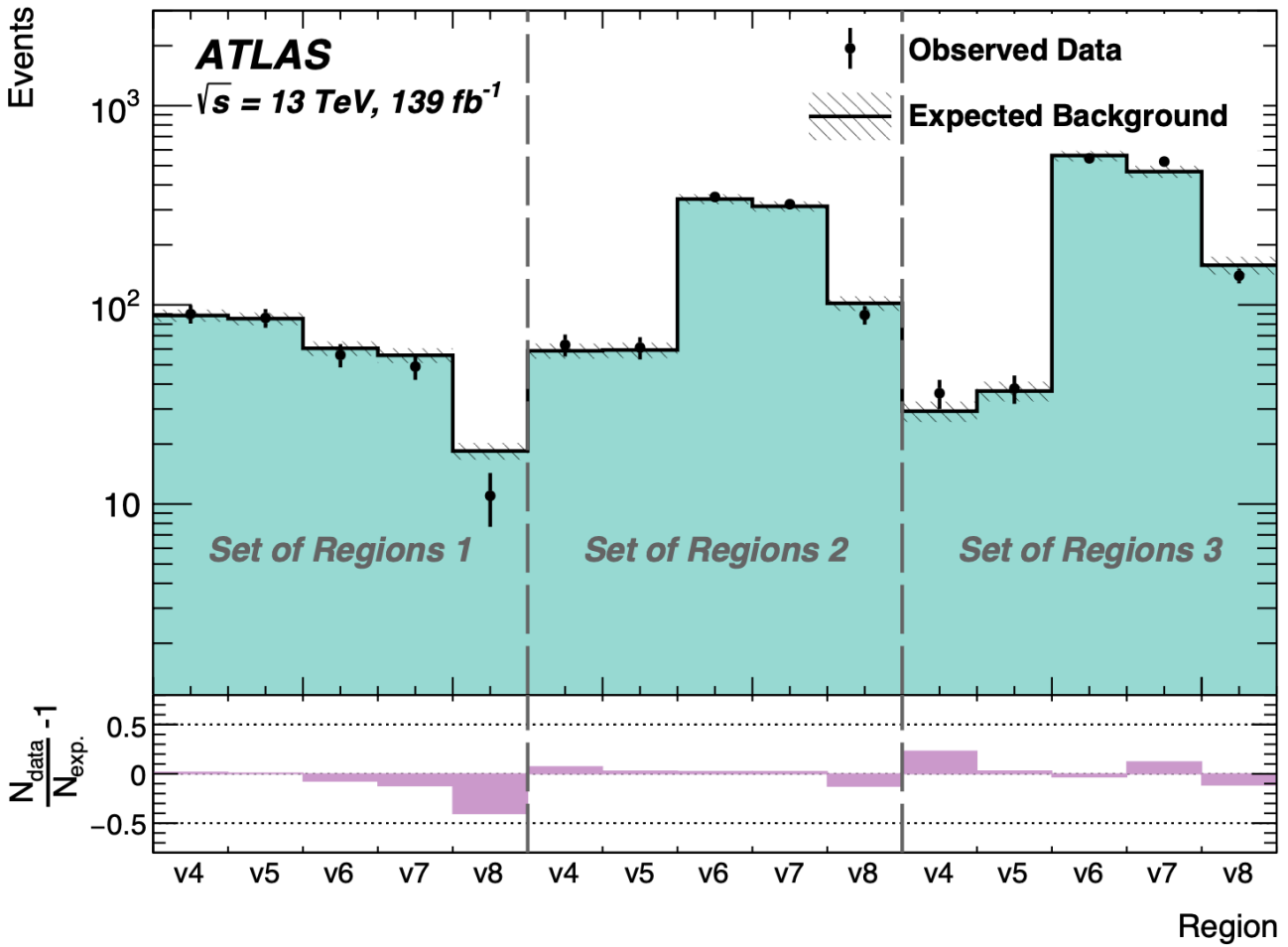


Background estimate continued

- Three sets of overlapping regions are used to provide control and validation regions with **low signal contamination**
- Set of Regions 1 has low signal contamination for smuon masses ≥ 300 GeV
- Set of Regions 2 " " " " " " " of 200 GeV
- Set of Regions 3 " " " " " " " < 200 GeV

Set of Regions	Lower displacement region	Higher displacement region	Threshold $m_{\mu^+\mu^-}$	Additional cut
1	$0.1 \leq \lvert d_0 \rvert < 0.3$	$0.6 \leq \lvert d_0 \rvert < 3$ mm	200 GeV	-
2	$0.1 \leq \lvert d_0 \rvert < 0.3$	$0.6 \leq \lvert d_0 \rvert < 3$ mm	140 GeV	-
3	$0.1 \leq \lvert d_0 \rvert < 0.3$	$0.6 \leq \lvert d_0 \rvert < 1.3$ mm	125 GeV	$\Delta R_{\mu^+\mu^-} > 3$ rad.

Validation



A conservative **uncertainty of 40%** is assigned as non-closure systematic uncertainty in the three signal regions.

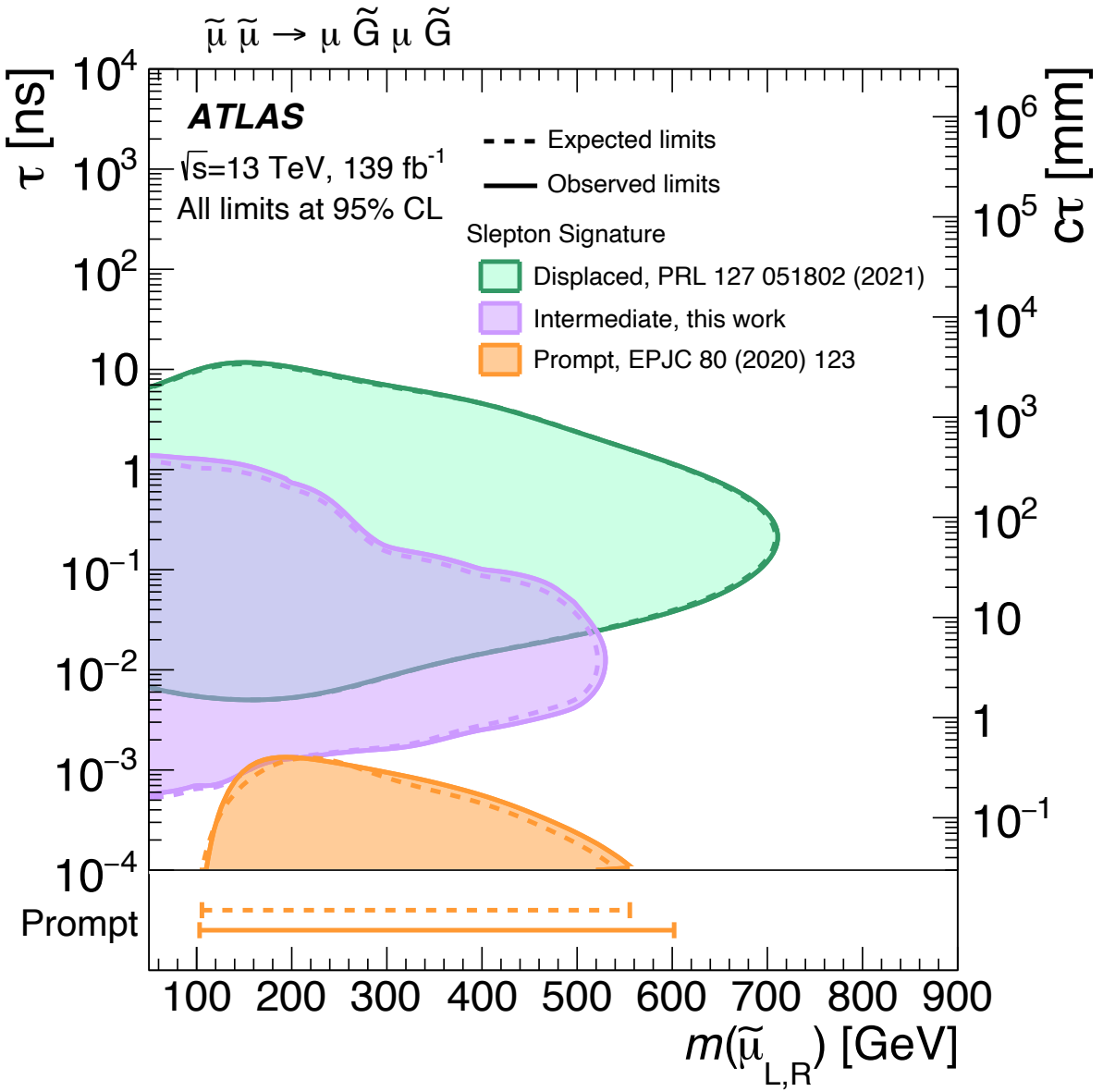
Results

- The observed number of events in all signal regions is found to be **compatible** with the **background expectation** within statistical and systematic uncertainties.
- The results are used to set **model-independent limits** on the contribution of generic BSM signals in each of the SRs defined by the three sets of regions, assuming no signal contamination in the CRs.

Set of Regions	Expected N_H^{bkg}	Observed N_H^{data}	$\langle A\epsilon\sigma \rangle_{\text{obs}}^{95}$ [fb]
1	2.1 ± 0.8	1	0.02
2	12.5 ± 5.2	7	0.04
3	17.2 ± 7.4	14	0.06

Interpretation

- A combined likelihood fit is performed in regions A, B, C, E, and H, **including** the possible **signal contribution** in the **control regions**.
- As the Set of Regions 1 provides the best expected sensitivity across all the plane and therefore is the **only** set of regions used in the fit.
- A search for direct slepton production with prompt decay, link. is reinterpreted using the RECAST framework.
- **This is the first explicit reinterpretation of prompt lepton searches in the long-lived regime in ATLAS.**



Reinterpretation

Hep data and RECAST for this analysis:

COMING SOON!


Thank you for listening!
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Systematics

- Uncertainties on a multiplicative factor that corrects for differences in **trigger efficiency** between data and MC are found to be **within 5%** for all signal samples and are applied as a systematic uncertainty to the number of expected signal events.
- Remaining uncertainties that may arise due to the differences between MC and data include muon reconstruction efficiency, the scale and resolution of the momentum of the muon and are found to be **negligible, < 1%**, across all analysis regions and no systematic uncertainties are added in these categories.

Systematics continued

- **Statistical uncertainties** associated with the simulated **MC** samples are accounted for.
- Theoretical uncertainties include **cross section uncertainties** of **1.6–3.9%**.
- **Modelling uncertainties** for the signal process, e.g. effects of varying the factorisation and renormalisation scales, initial and final state radiation, and underlying effects were found to be **negligible** and are not included as systematics.
- In order for the exclusion fit to interpolate between the generated lifetimes and extrapolate above the generated **lifetimes** a **re-weighting procedure** is applied to the generated signal MC samples to provide smuon lifetimes between the generated lifetimes. A **12%** uncertainty is applied when the lifetime is re-weighted to a higher lifetime.

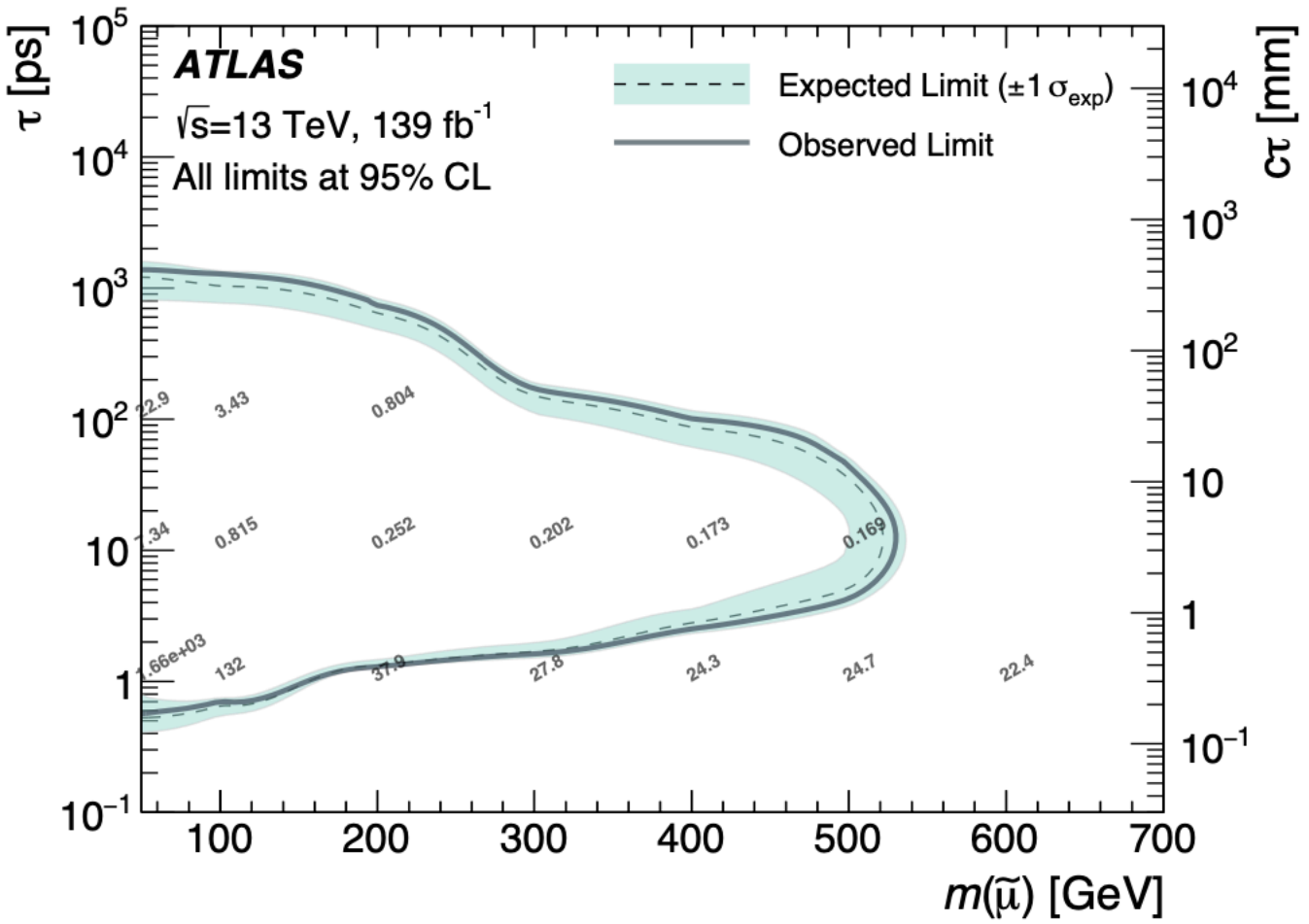


Figure 5: Expected (dashed) and observed (solid) exclusion contours for $\tilde{\mu}$ NLSP production as a function of the left- and right-handed smuons, $\tilde{\mu}_{L,R}$, mass and lifetime at 95% CLs. The upper limit on the visible cross section in fb is overlaid.

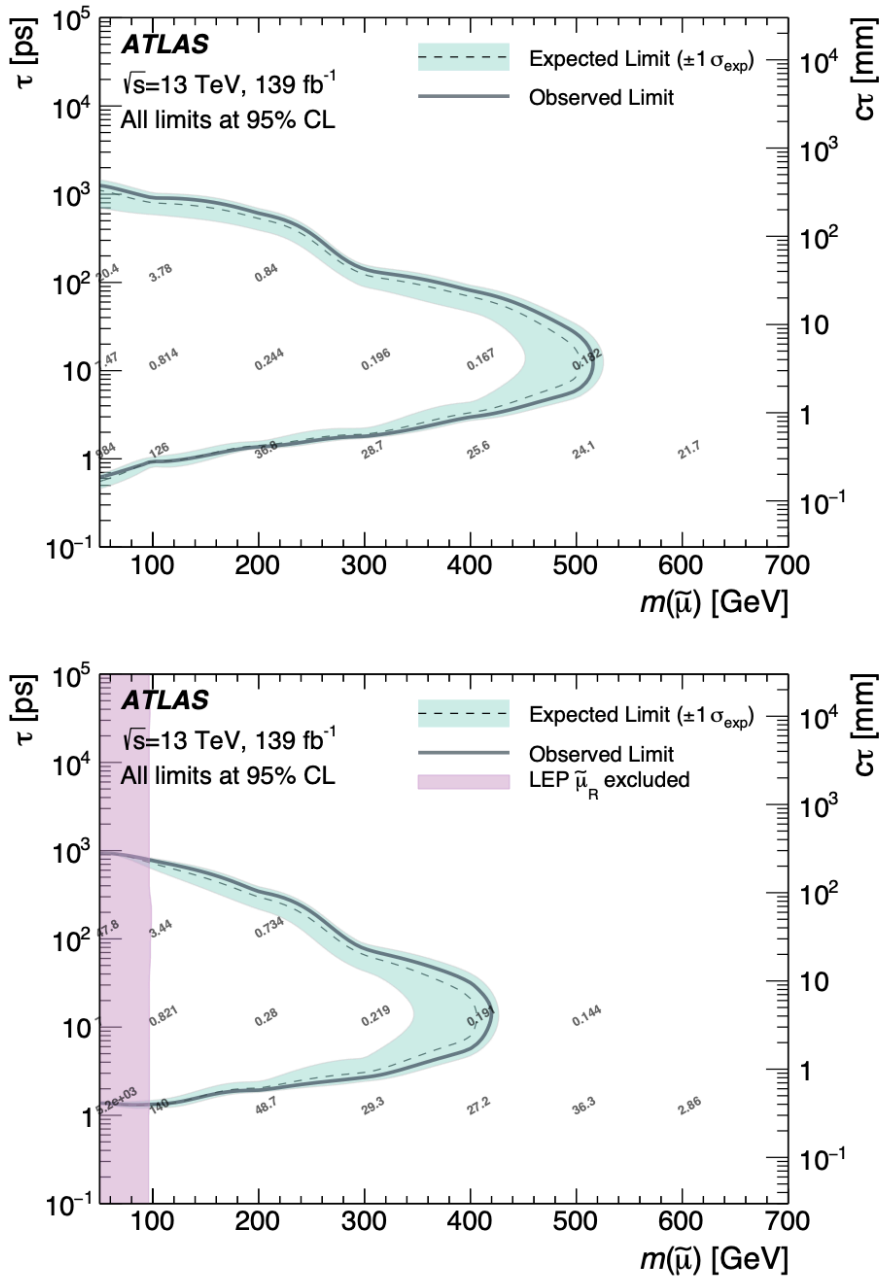


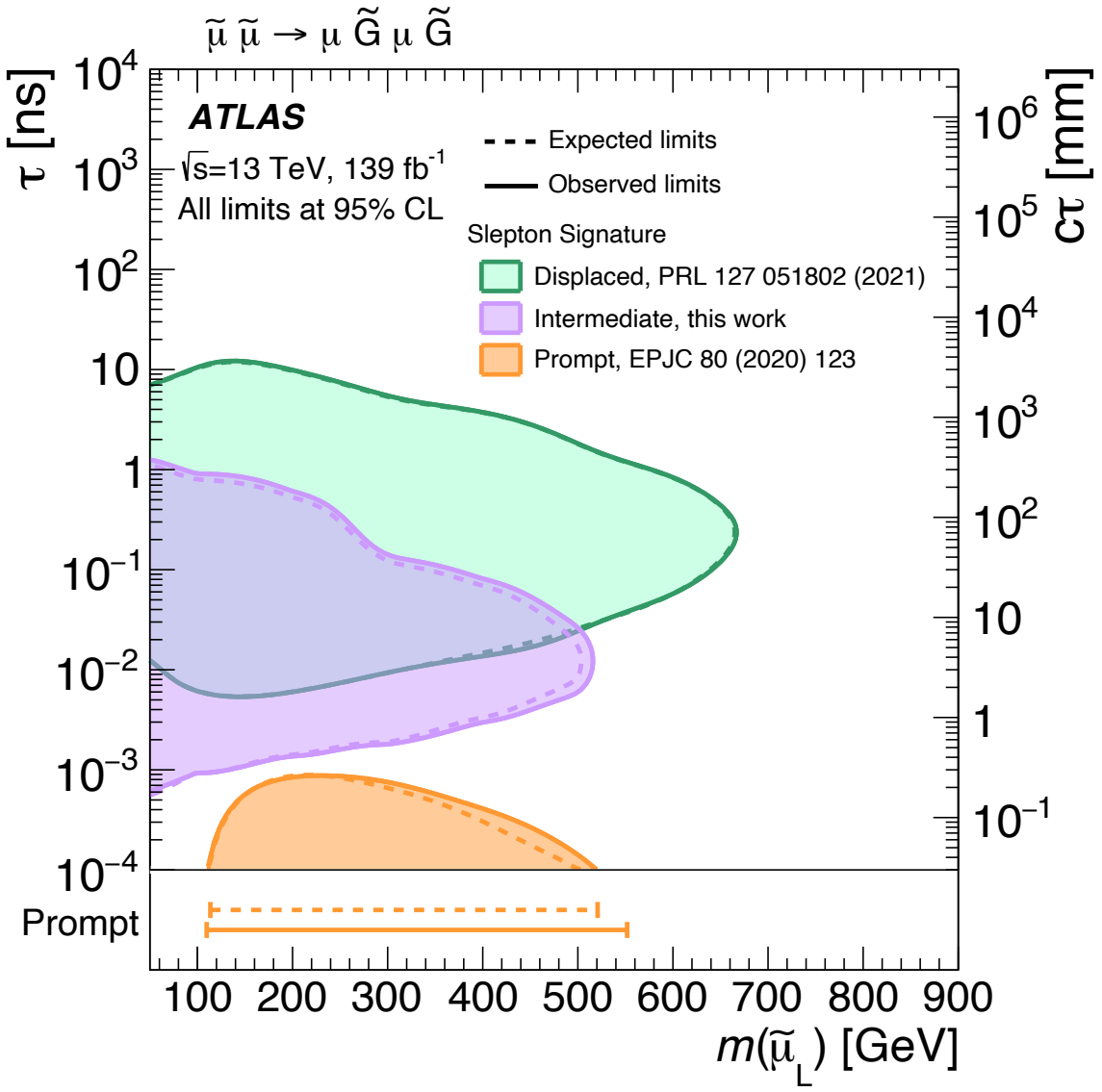
Figure 6: Expected (dashed) and observed (solid) exclusion contours for $\tilde{\mu}$ NLSP production as a function of the left-handed smuon, $\tilde{\mu}_L$, (top) and right-handed smuon, $\tilde{\mu}_R$, (bottom) mass and lifetime at 95% CLs where the shaded region shows the region excluded by LEP [23]. The upper limit on the visible cross section in fb is overlaid.

Selection cuts	$\tilde{\mu}$ (mass [GeV], lifetime [ps])		
	(200 GeV, 1ps)	(200 GeV, 10ps)	(200 GeV, 100ps)
Inital number of events ($\mathcal{L} \times \sigma$)	4,212.0	4,212.0	4,212.0
Pass trigger, both muons: $\|\eta\| < 2.5$ and medium quality	2,127.0	2,062.8	684.3
Both muons $p_t > 20$ GeV	2,092.0	2,026.2	677.5
Both muons are isolated	2,075.3	2,007.1	673.0
Invariant mass of the two muons > 200 GeV	1,279.7	1,249.3	456.0
Both muons $0.6 < \|d_0\| < 3$ mm	1.4	202.6	63.6

Table 3: Cutflow for the signal region H for smuon masses of 200 GeV and smuon lifetimes of 1 ps, 10 ps and 100 ps. For the following $\tilde{\mu}$ mass and lifetime points, the number of Monte Carlo events generated are: 70,000 for (200 GeV, 1 ps), 36,000 for (200 GeV, 10 ps), and 36,000 for (200 GeV, 100 ps).

Selection cuts	$\tilde{\mu}$ (mass [GeV], lifetime [ps]) (300 GeV, 10ps)	(400 GeV, 10ps)	(500 GeV, 10ps)
Inital number of events ($\mathcal{L} \times \sigma$)	869.1	258.3	93.6
Pass trigger, both muons: $\|\eta\| < 2.5$ and medium quality	439.2	134.6	48.2
Both muons $p_t > 20$ GeV	436.2	134.4	48.1
Both muons are isolated	433.5	133.8	48.0
Invariant mass of the two muons > 200 GeV	335.2	115.4	43.7
Both muons $0.6 < \|d_0\| < 3$ mm	52.2	18.1	6.7

Table 4: Cutflow for the signal region H for smuon masses of 300, 400, and 500 GeV and smuon lifetime 10 ps. For the following $\tilde{\mu}$ mass and lifetime points, the number of Monte Carlo events generated are: 24,000 for (300 GeV, 10 ps), 36,000 for (400 GeV, 10 ps), and 12,000 for (500 GeV, 10 ps).


$\tilde{\mu}\,\tilde{\mu} \rightarrow \mu\,\tilde{G}\,\mu\,\tilde{G}$
ATLAS
$\sqrt{s}$=13 TeV, 139 fb^{-1}
All limits at 95% CL
Expected limits
Observed limits
Slepton Signature
Displaced, PRL 127 051802 (2021)
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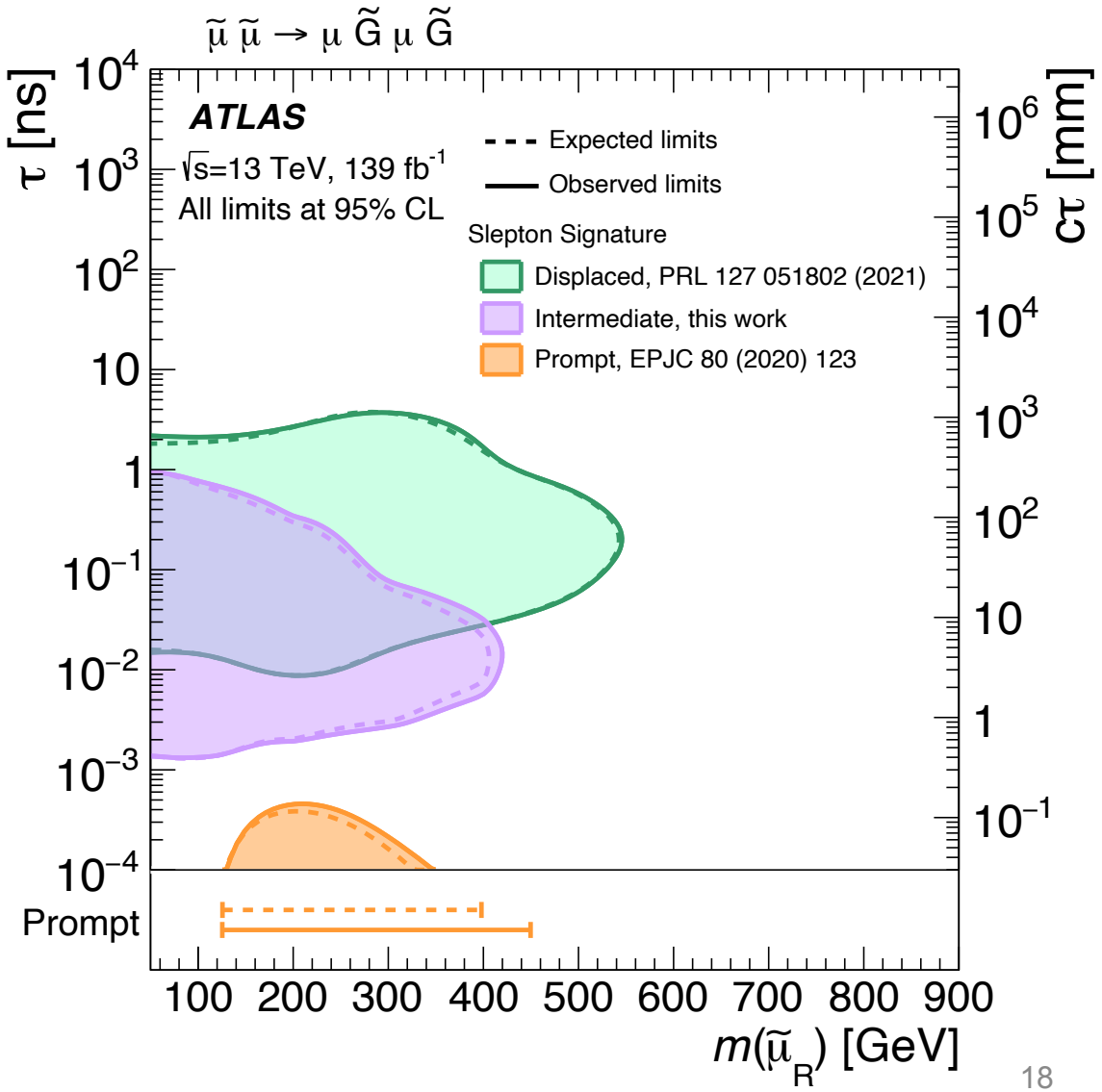
τ [ns]
$c\tau$ [mm]
Prompt
$m(\tilde{\mu}_L)$ [GeV]


$\tilde{\mu}\,\tilde{\mu} \rightarrow \mu\,\tilde{G}\,\mu\,\tilde{G}$
ATLAS
$\sqrt{s}$=13 TeV, 139 fb^{-1}
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τ [ns]
$c\tau$ [mm]
Prompt
$m(\tilde{\mu}_R)$ [GeV]

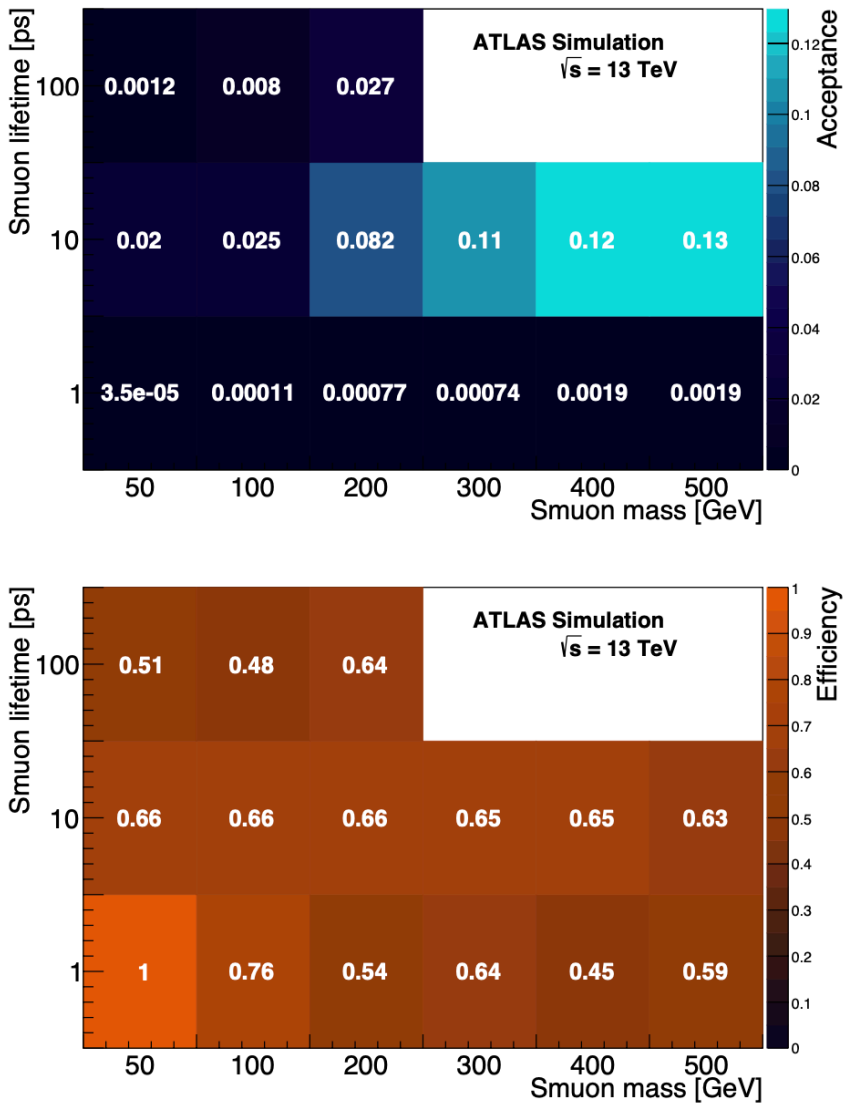
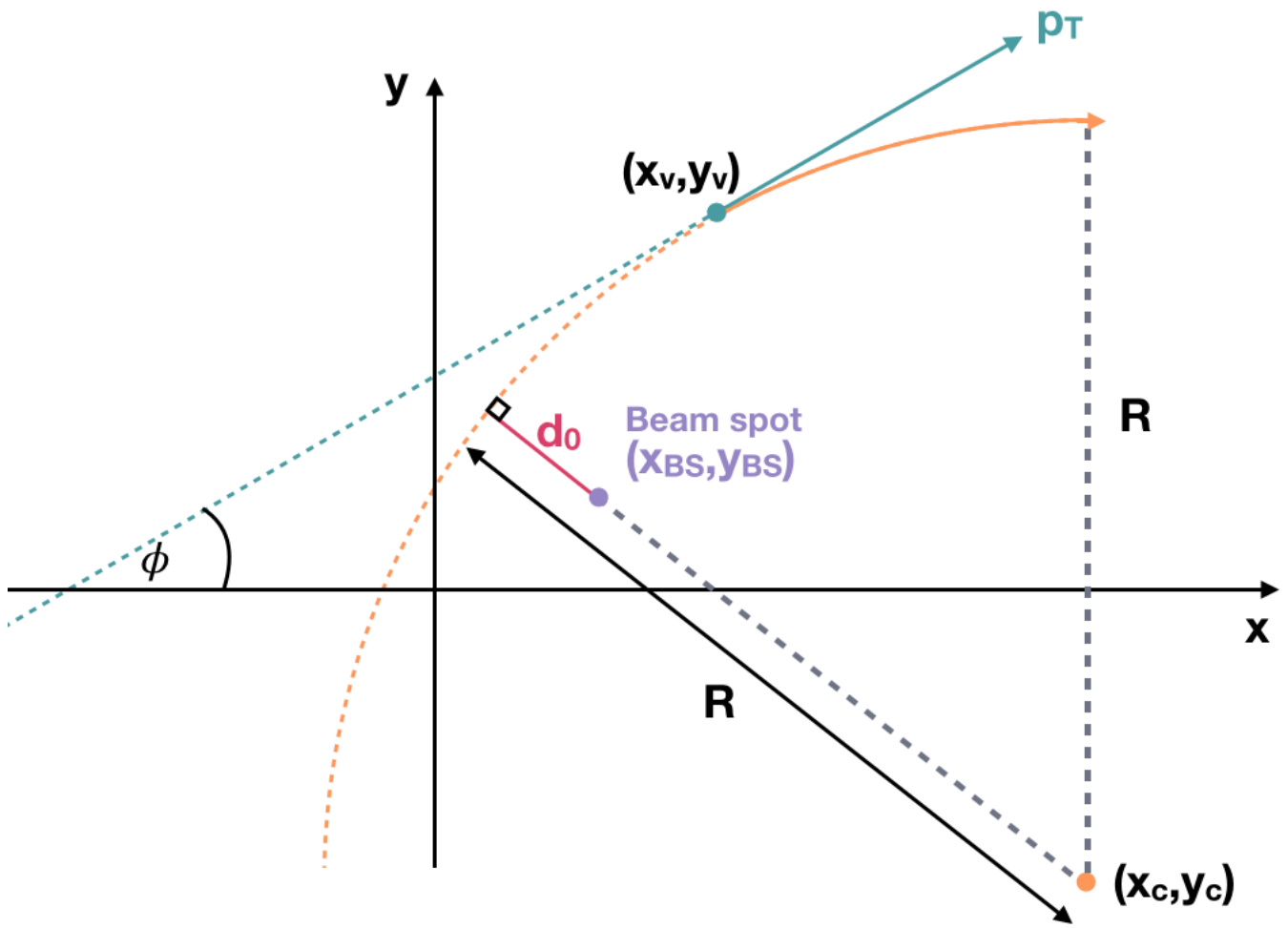


Figure 9: Acceptance (top) and efficiency (bottom) for smuon masses of 50–500 GeV and smuon mass of 1, 10, and 100 ps. Acceptance is defined as the number of accepted events at generator level in signal Monte Carlo simulation divided by the total number of events in the sample. Efficiency is defined as the number of selected reconstructed events in SR H divided by the number of events that were accepted. To be accepted, events are required to have at least 2 truth muons that have $p_T > 20$ GeV and $|\eta| < 2.5$, $m_{\mu^+\mu^-} > 200$ GeV and $0.6 < |d_0| < 3$ mm.

Definition of d_0



C = Centre of the detector