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Midterm Talk

Parameter determination for dark matter scenarios in the MSSM

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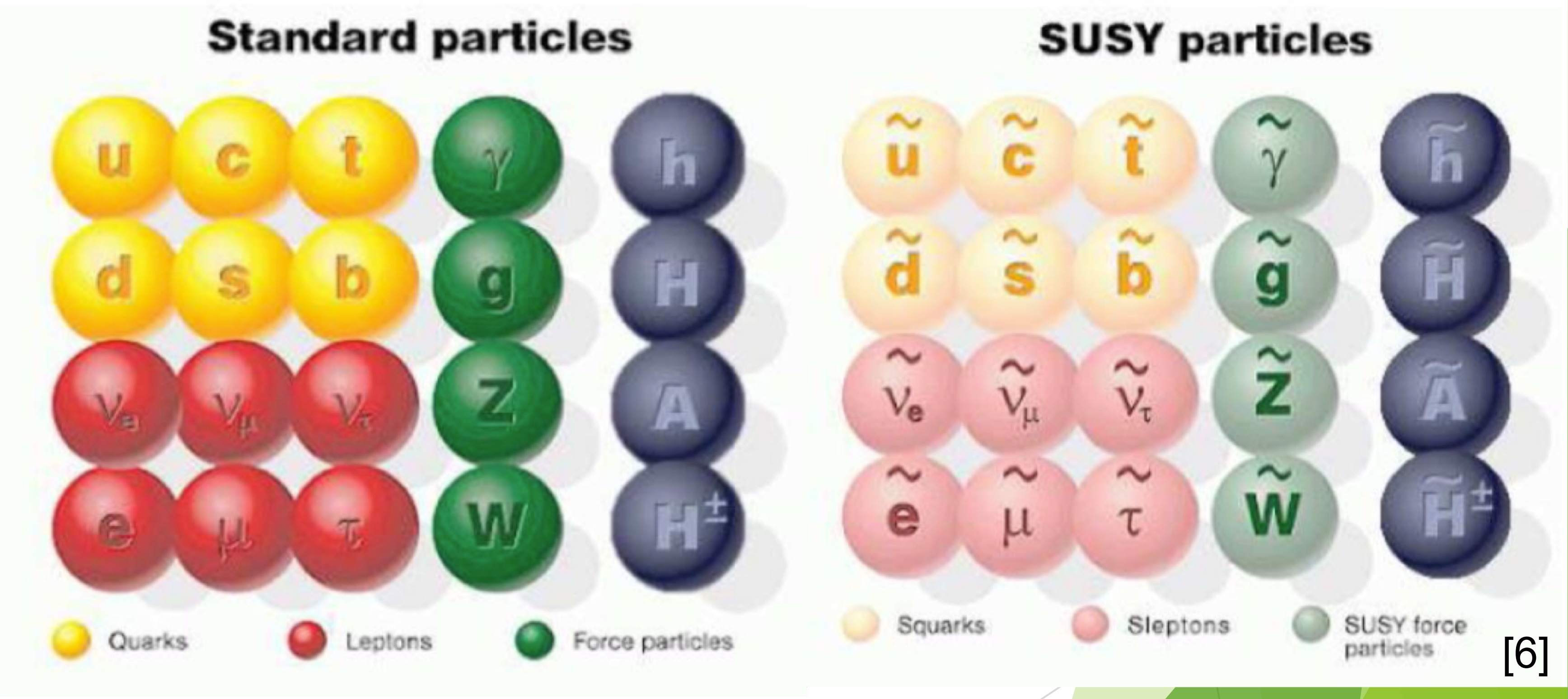
MSSM

- SM-particles get supersymmetric partners
- Additionally:
  - Neutralinos: $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
  - Charginos: $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$



[6]

Mass matrices in the MSSM

- Chargino and neutralino mass matrices
- We use the Bino-Wino basis $\{\tilde{B}, \widetilde{W}^0, \widetilde{H}_1^0, \widetilde{H}_2^0\}$
- Parameters:
  - M_1: Bino mass parameter
  - M_2: Wino mass parameter
  - μ: Higgsino mass parameter
  - $\tan\beta = \frac{v_2}{v_1}$

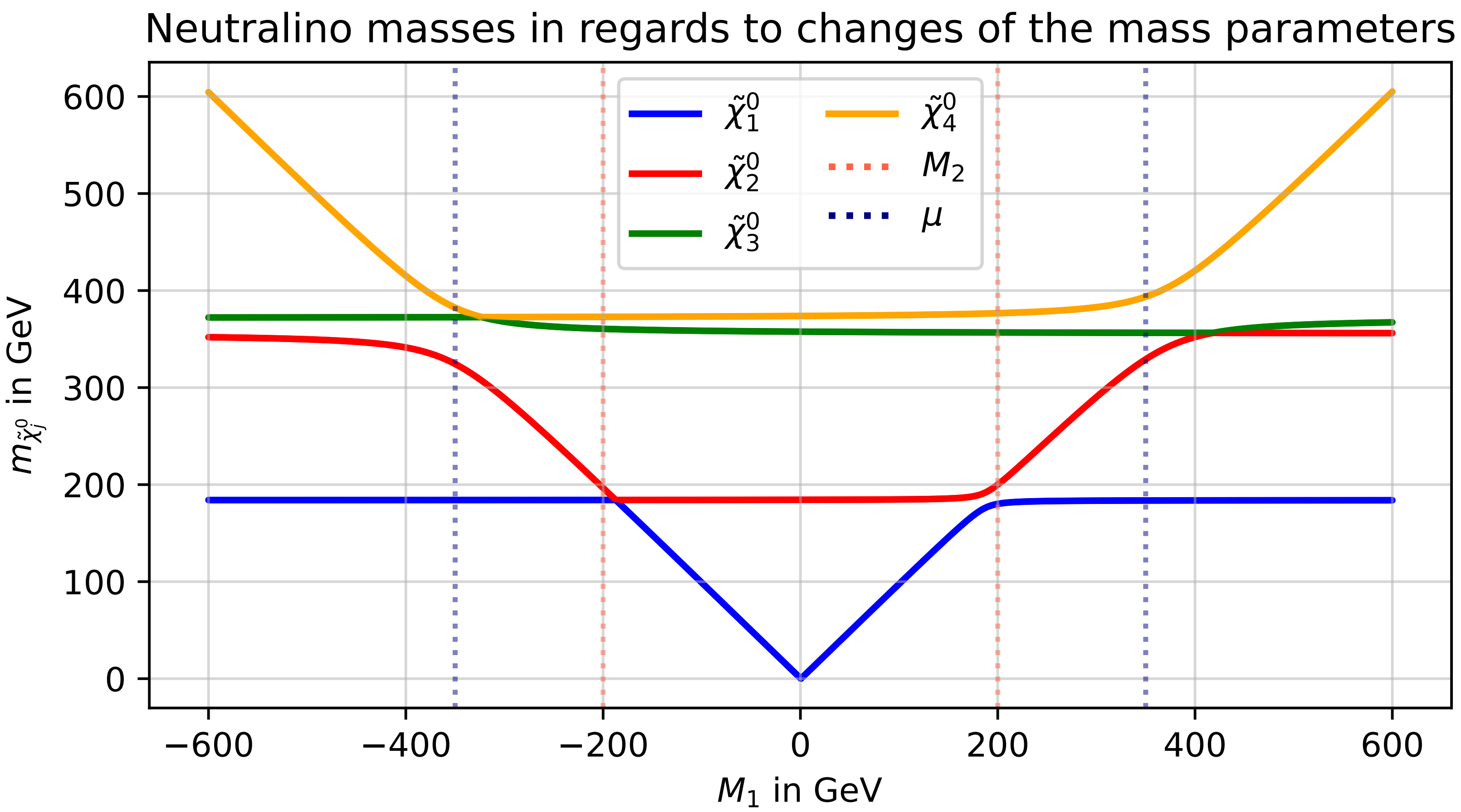
$$M_C = \begin{pmatrix} M_2 & m_W\sqrt{2}\sin\beta \\ m_W\sqrt{2}\cos\beta & \mu \end{pmatrix}$$

$$M_N = \begin{pmatrix} M_1 & 0 & -m_Z\cos\beta\sin\theta_W & m_Z\sin\beta\sin\theta_W \\ 0 & M_2 & m_Z\cos\beta\cos\theta_W & -m_Z\sin\beta\cos\theta_W \\ -m_Z\cos\beta\sin\theta_W & m_Z\cos\beta\cos\theta_W & 0 & -\mu \\ m_Z\sin\beta\sin\theta_W & -m_Z\sin\beta\cos\theta_W & -\mu & 0 \end{pmatrix}$$

[1]

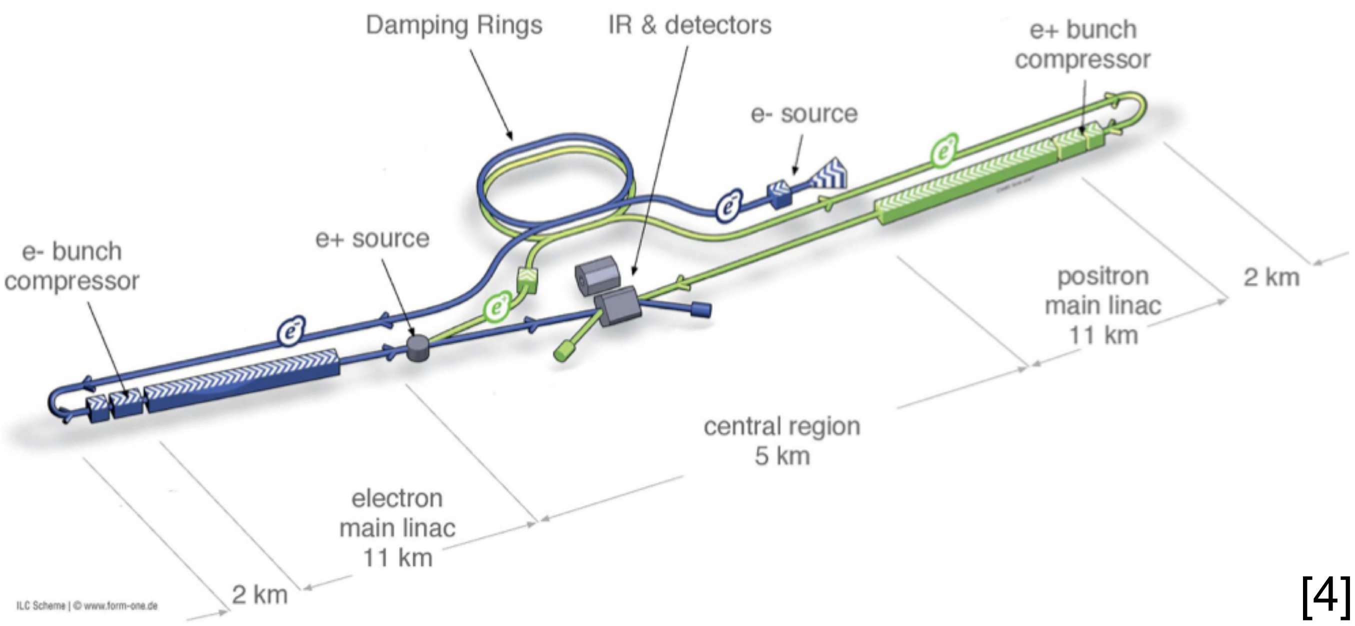
Mass hierarchy

- Particles are assigned by mass hierarchy
- Hierarchy determines sensitivity
- $\tilde{\chi}_1^0$ is a good candidate for DM



International Linear Collider

- Future e^+e^- linear collider with spin polarised beams
- Searches for signs of physics beyond the Standard Model
- Possible experiment:
  - $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$
  - Luminosity $L = 500\ \mathrm{fb}^{-1}$
  - $\sqrt{S} = 500\ \mathrm{GeV}$



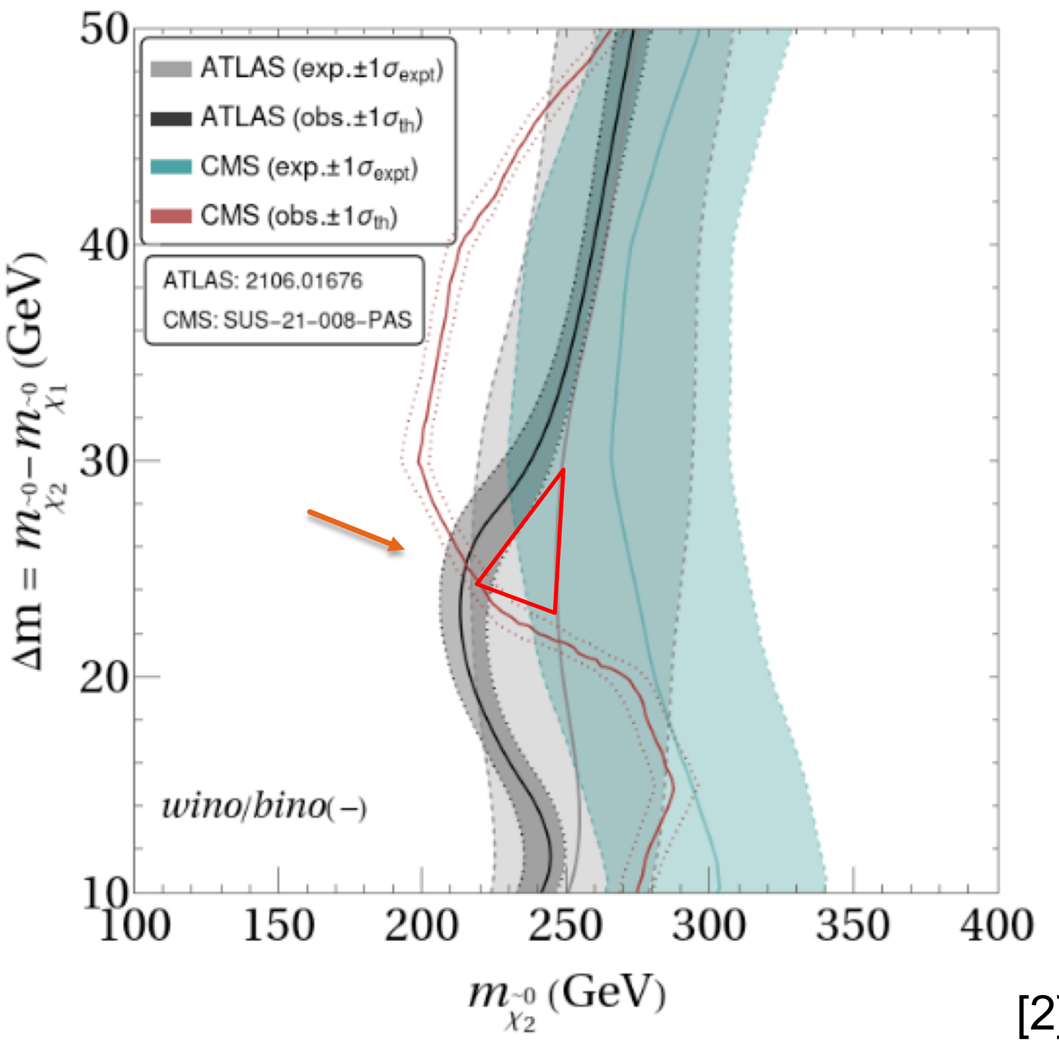
[4]

Scenario

- Bino/Wino(–): Bino-wino DM with $\mu \times M_1 < 0$

$$100\ \text{GeV} \leq -M_1 \leq 400\ \text{GeV}\ , \quad |M_1| \leq M_2 \leq 1.4\,|M_1|$$
$$1.2\,|M_1| \leq \mu \leq 2\ \text{TeV}\ , \quad 2 \leq \tan\beta \leq 60$$
$$100\ \text{GeV} \leq m_{\tilde{l}_L} = m_{\tilde{l}_R} \leq 1.5\ \text{TeV}\ , \quad M_A = 3\ \text{TeV}$$

- Some excess of events → Search for points in this excess



[2]

Data

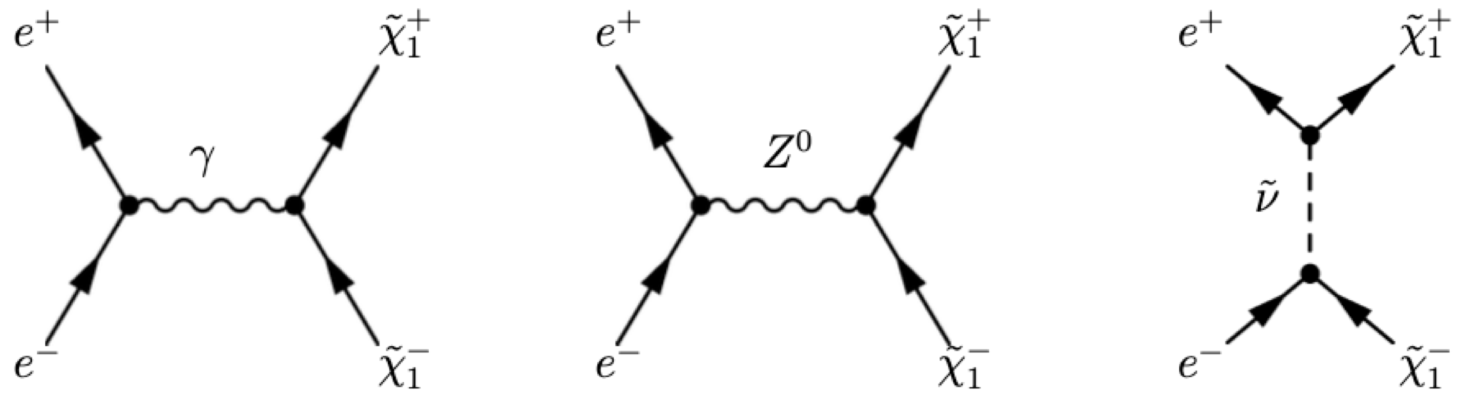
- SLHA files are taken from „Consistent Excesses in the Search for $\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$: Wino/bino vs. Higgsino Dark Matter“[2]
  - Florian Lika did the same analysis before but with other data
- Constraints:
  - Muon g-2 contribution
  - Vacuum stability constraints
  - DM relic density constraints
  - Constraints from LHC measurements
  - DM direct detection constraints

Steps of the analysis

- Chargino production crosssection $\sigma(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-)$ and chargino and neutralino masses $(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0})$ are measured
- Left and right chargino mixing angles $\phi_{L,R}$ are determined
- The parameters (M_1, M_2, μ) are reconstructed with uncertainties via a scan over the parameter space
- DM relic density $(\Omega\hbar^2)$ is calculated and compared to the relic density gained from the true values

Chargino pair production

- Contributing first order Feynman diagrams for chargino pair production:

[1] 

- Crosssection calculated with mixing angles

$$\sigma^{\pm}\{ij\} = c_1 \cos^2 2\Phi_L + c_2 \cos 2\Phi_L + c_3 \cos^2 2\Phi_R + c_4 \cos 2\Phi_R + c_5 \cos 2\Phi_L \cos 2\Phi_R + c_6$$

[5]

Configurations

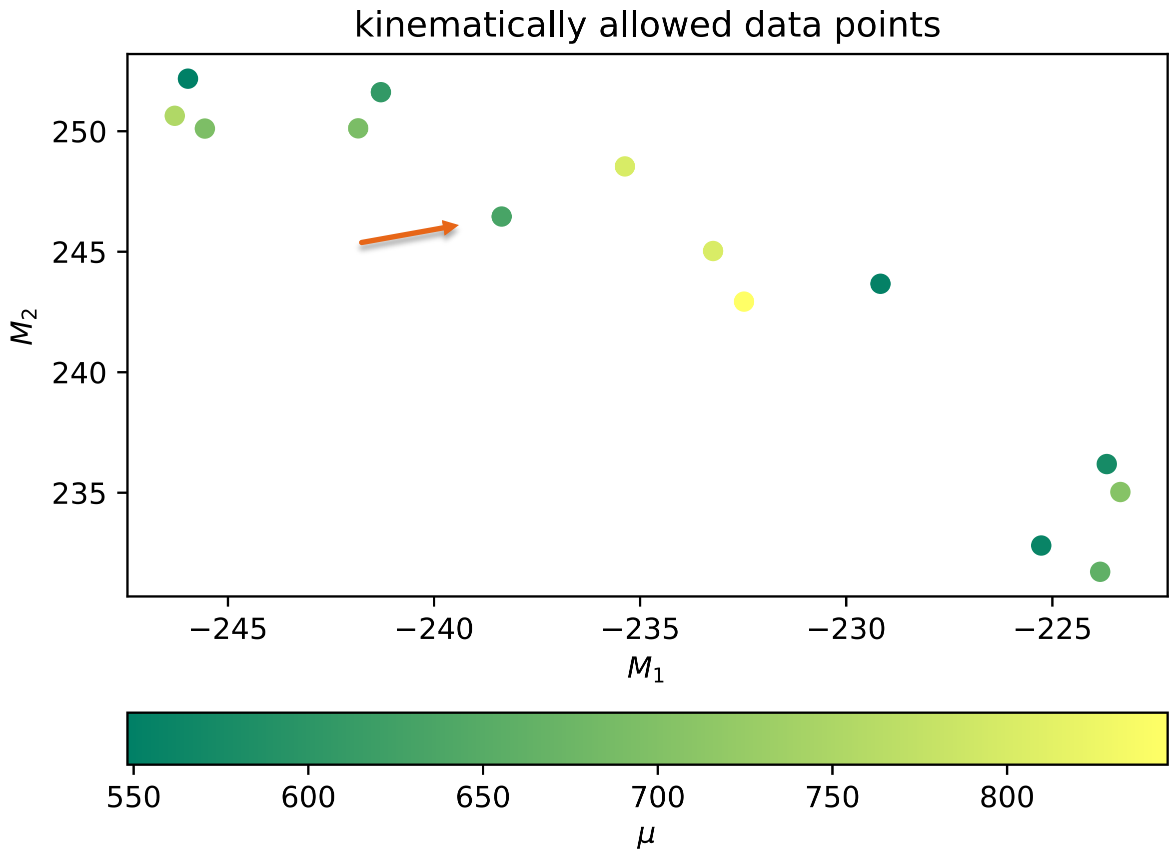
- We use four beam configurations to increase precision
- Consider the following uncertainties:

statistical uncertainty	$\sigma_{\text{stat}} = \frac{\sqrt{\sigma L}}{L}$
polarisation uncertainty	$P_{e^-} = \pm 0.804,\ P_{e^+} = \mp 0.603$ $P_{e^-} = \pm 0.796,\ P_{e^+} = \mp 0.597$
mass uncertainty	$\delta m_{\tilde{\chi}_1^\pm} = 0.005 m_{\tilde{\chi}_1^\pm}$

$\sqrt{s}$	P_{e^-}	P_{e^+}
500 GeV	-0.8	+0.6
500 GeV	+0.8	-0.6
550 GeV	-0.8	+0.6
550 GeV	+0.8	-0.6

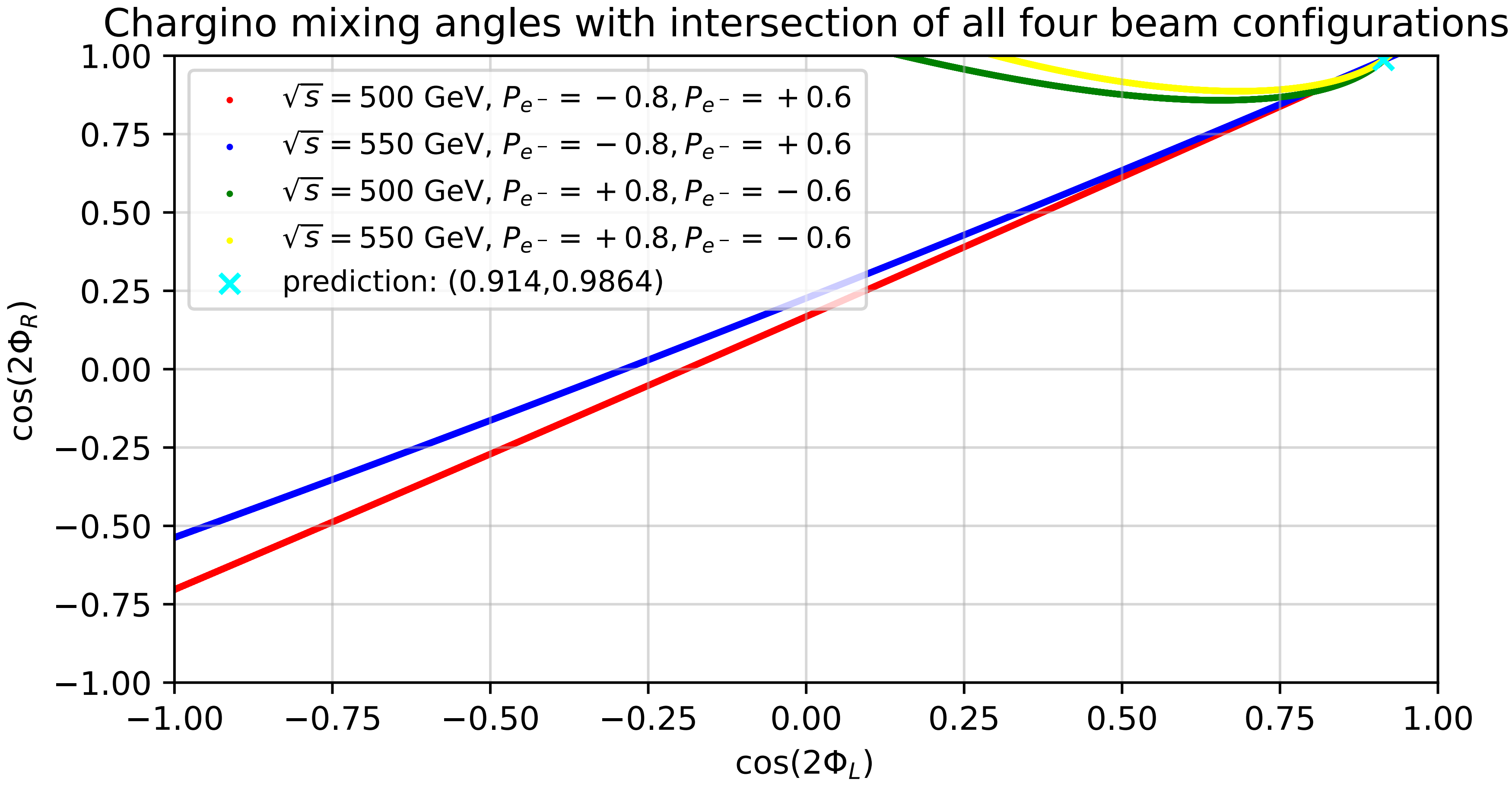
Example point

- Out of 14 kinematically allowed data points, one is taken as example point for following explanations



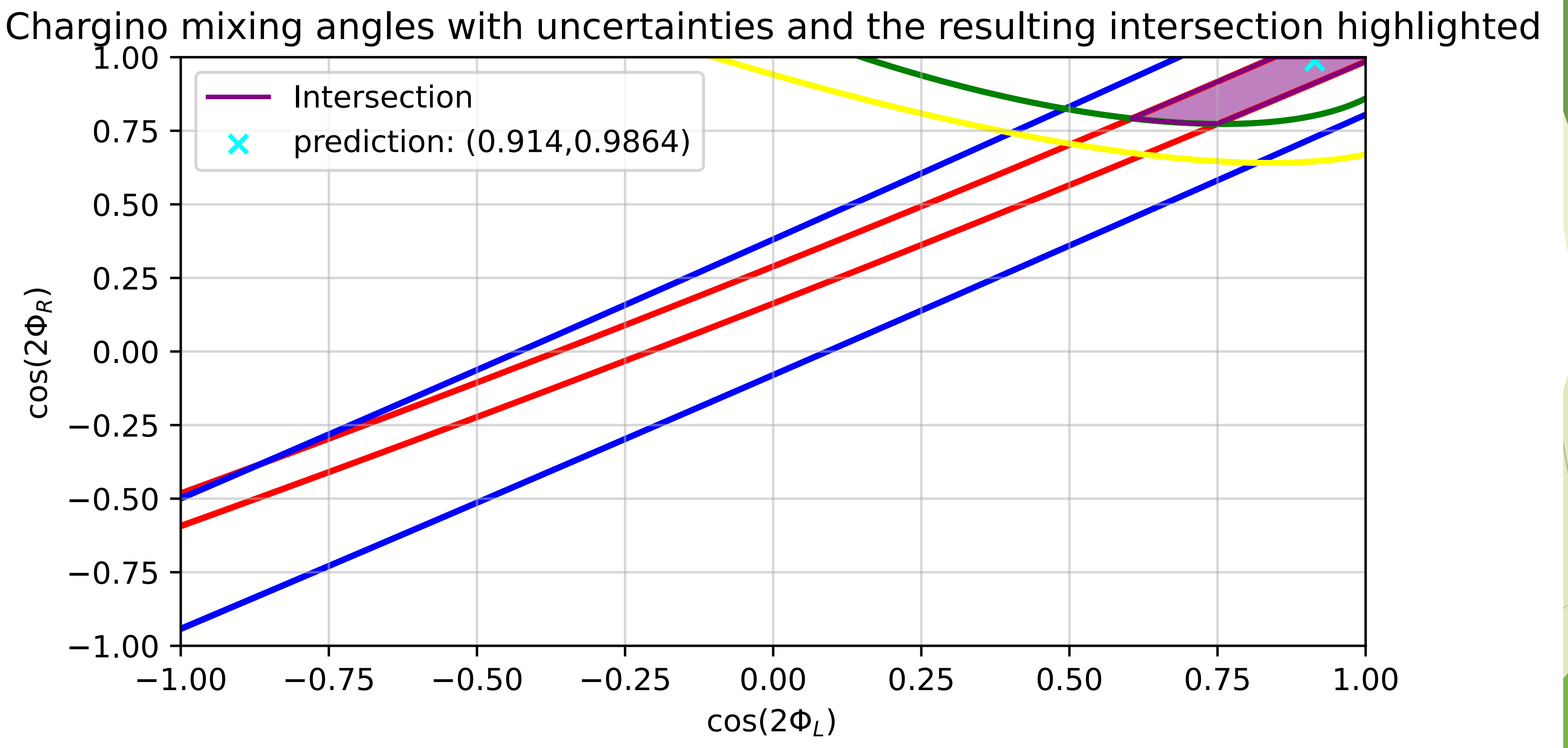
M_1	-238.36 GeV	$\sigma^{500}_{-.8,+.6}$	394.9612 fb
M_2	246.46 GeV	$\sigma^{500}_{+.8,-.6}$	11.0373 fb
μ	632.64 GeV	$\sigma^{550}_{-.8,+.6}$	519.8185 fb
$\tan\beta$	51.97	$\sigma^{550}_{+.8,-.6}$	14.4873 fb
$M_{\tilde{\nu}}$	496.78 GeV	$m_{\tilde{\chi}^{\pm}_1}$	241.48 GeV

Mixing angles without uncertainties



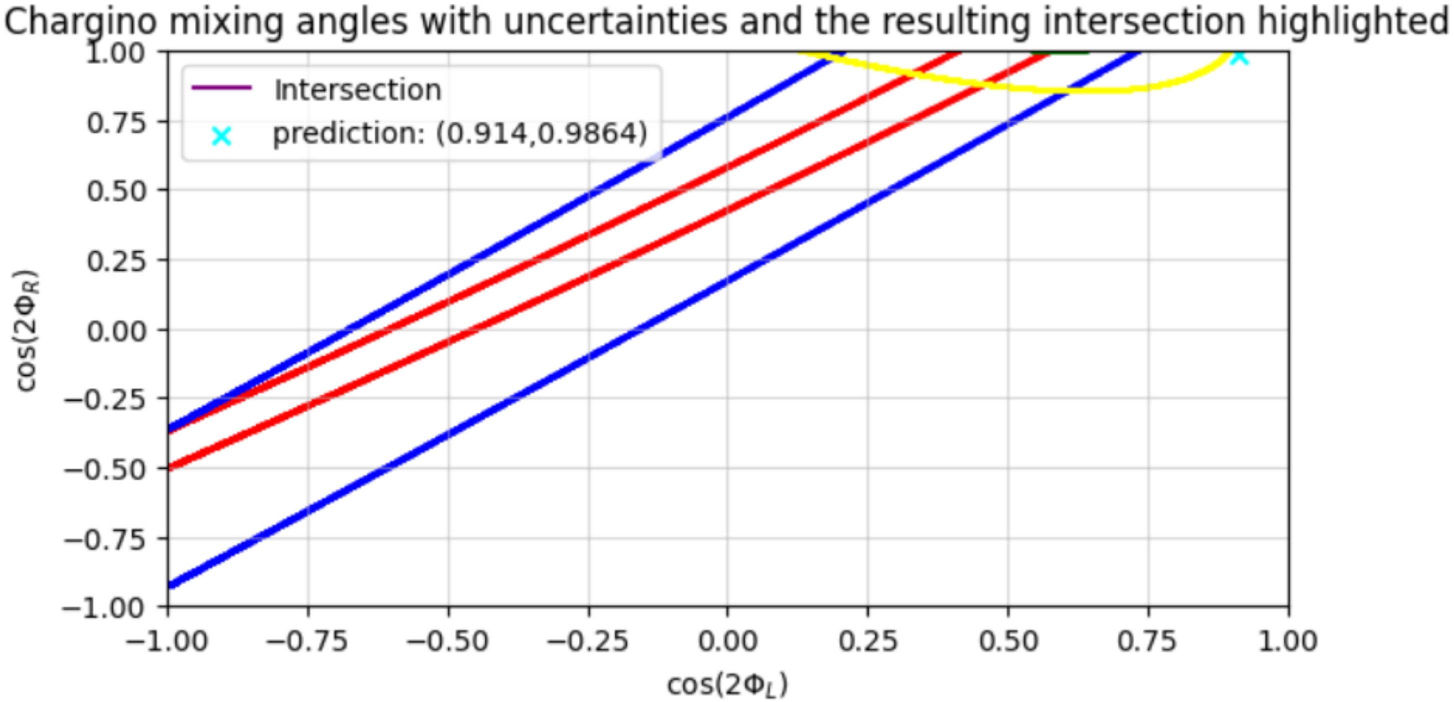
$$\sigma^{\pm}\{ij\} = c_1 \cos^2 2\Phi_L + c_2 \cos 2\Phi_L + c_3 \cos^2 2\Phi_R + c_4 \cos 2\Phi_R + c_5 \cos 2\Phi_L \cos 2\Phi_R + c_6$$

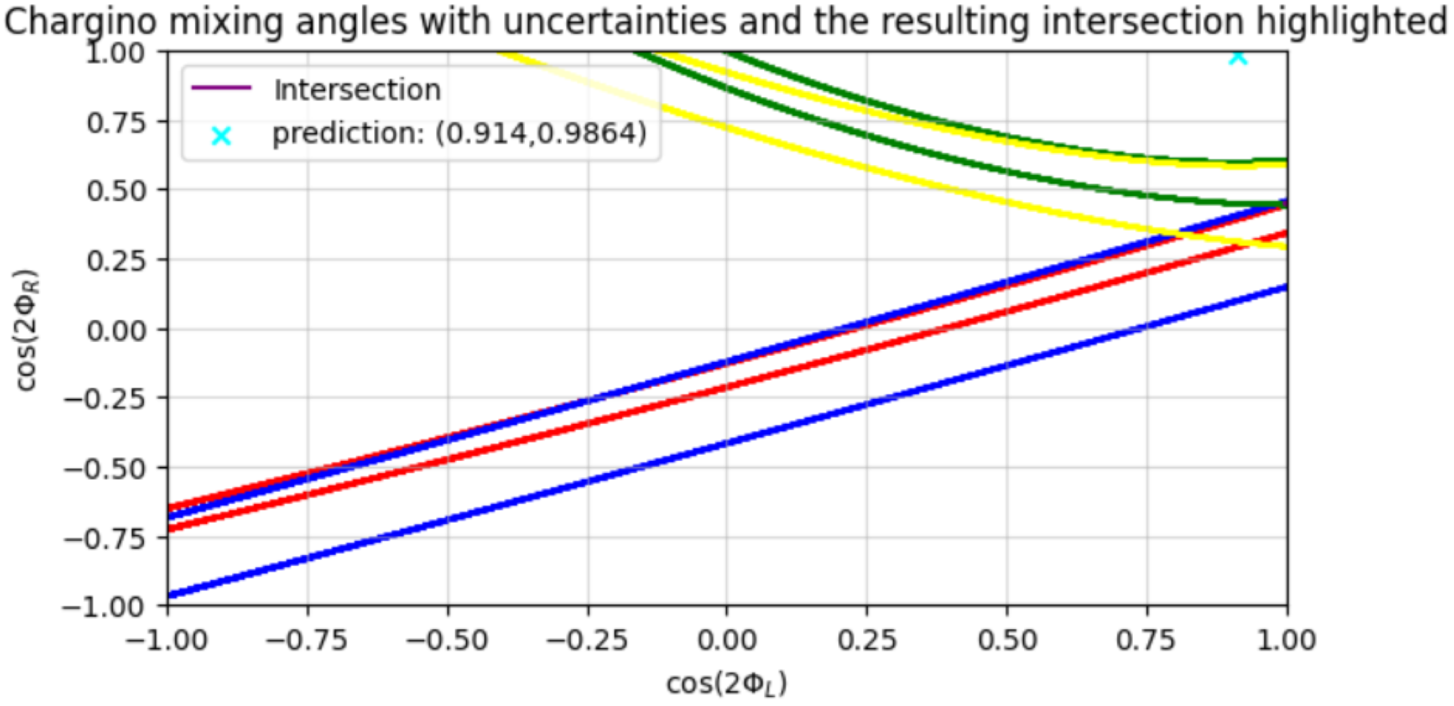
Valid mixing angles



Variation of $M_{\tilde{\nu}}$

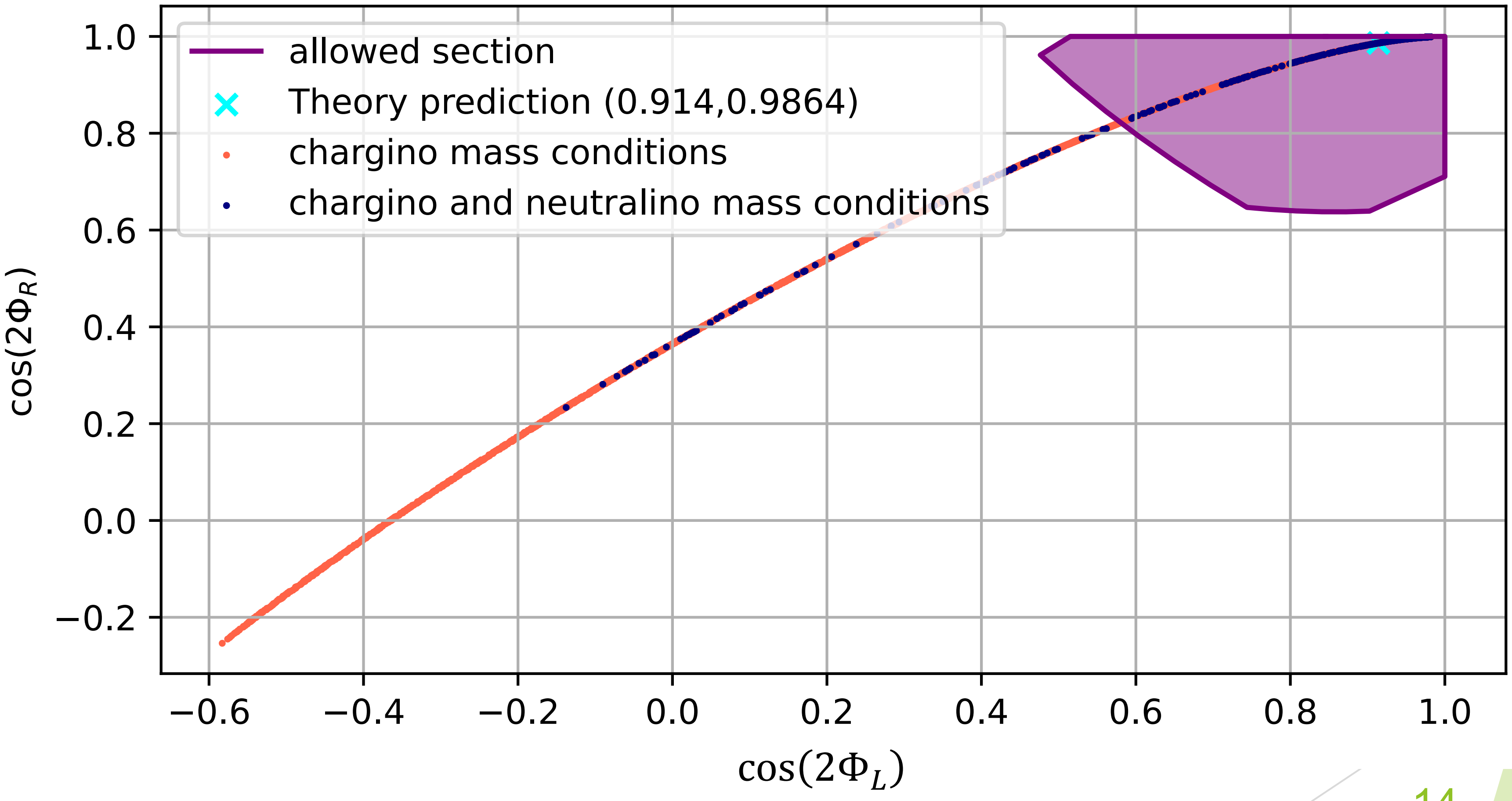
- In steps of 10 GeV
- Variation for the whole data set: -140 to +110 GeV
- Variation for this point: -40 to +80 GeV



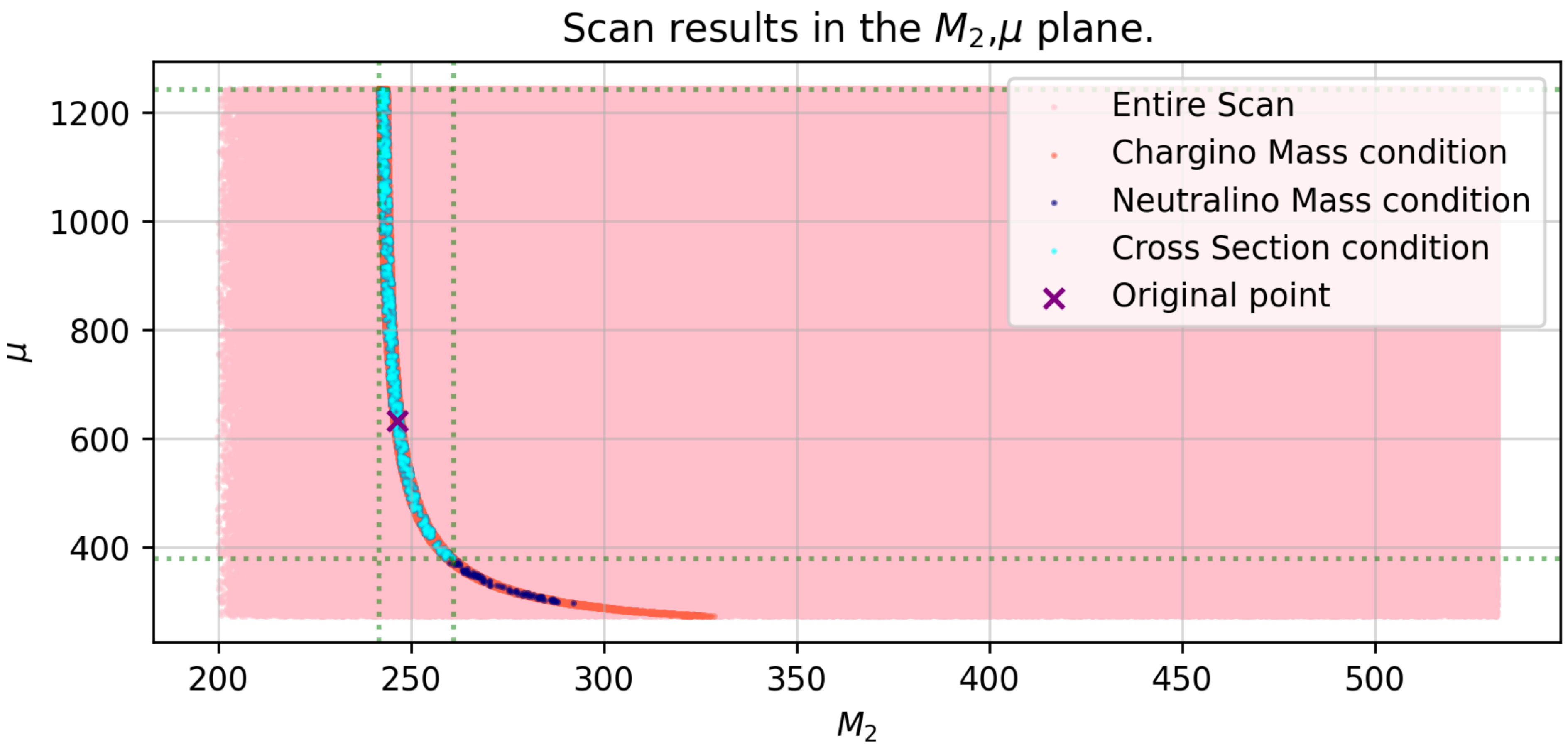


Scanning for valid points

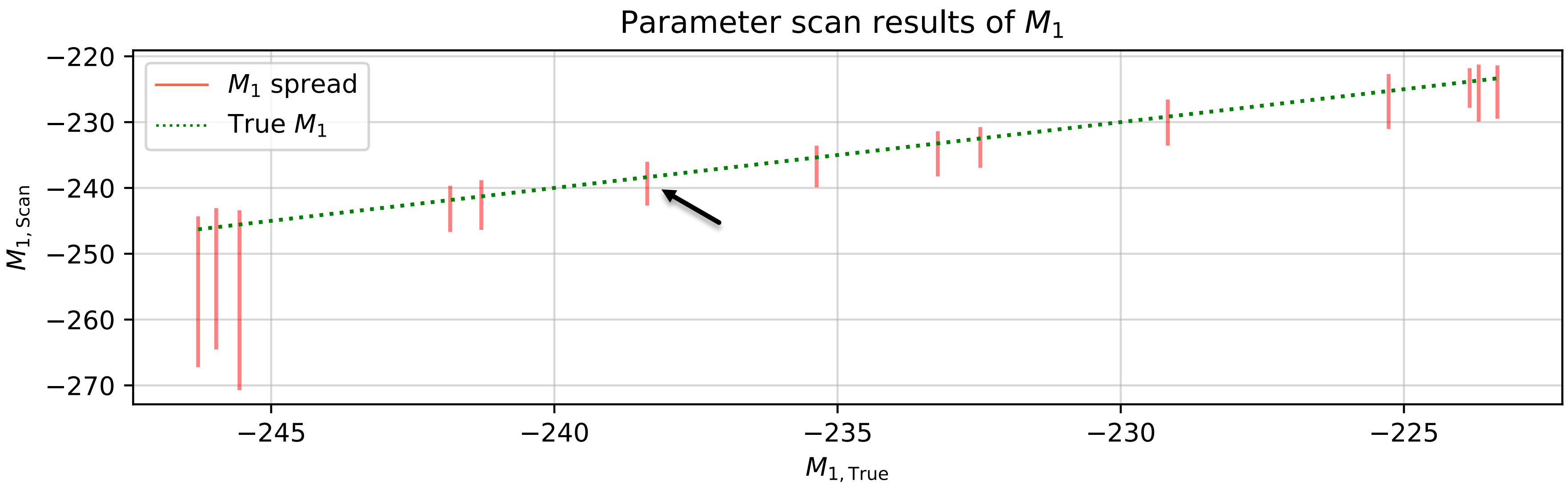
Scan results with cross-section condition visualised using the intersection surface.

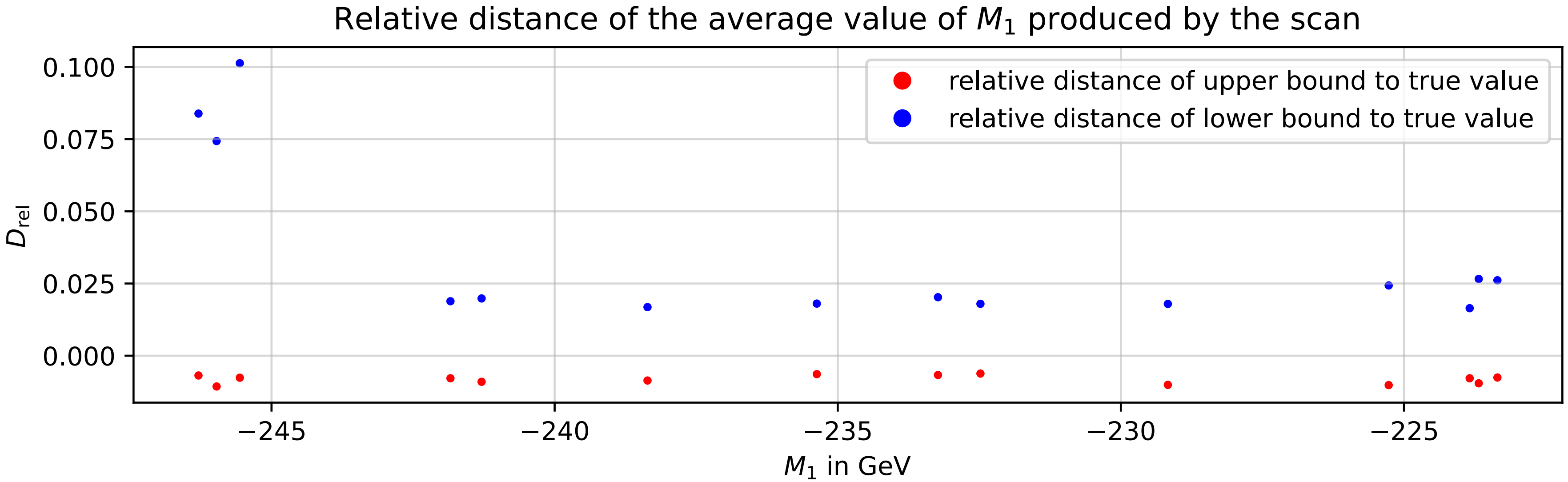


Scanning for valid points



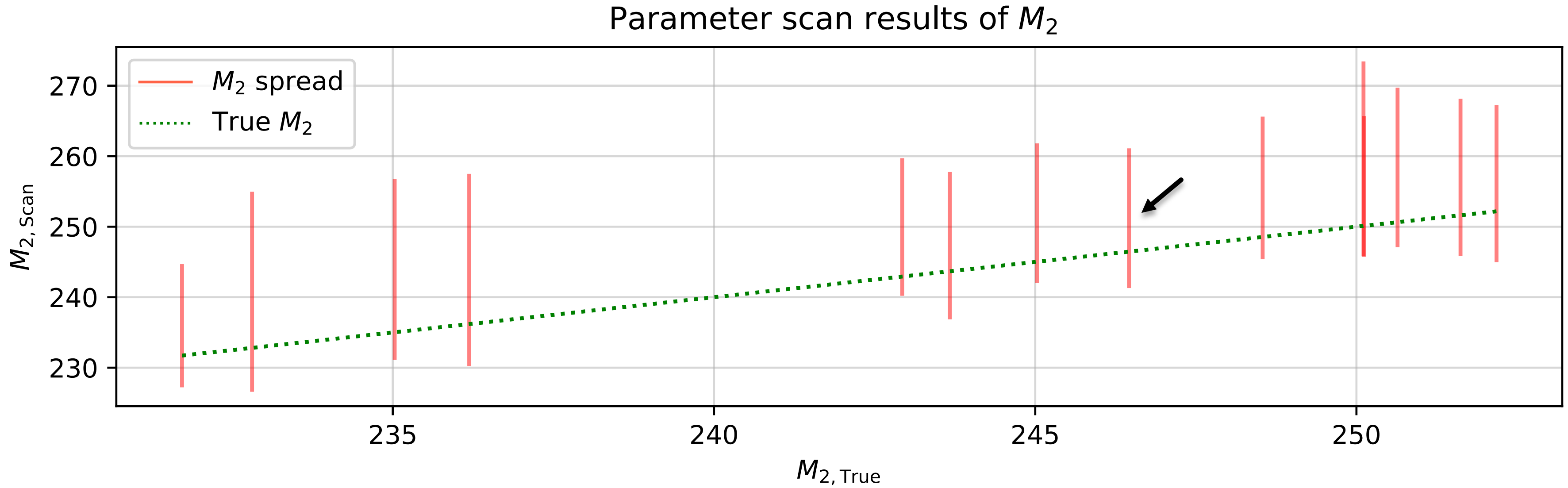
Results for M_1

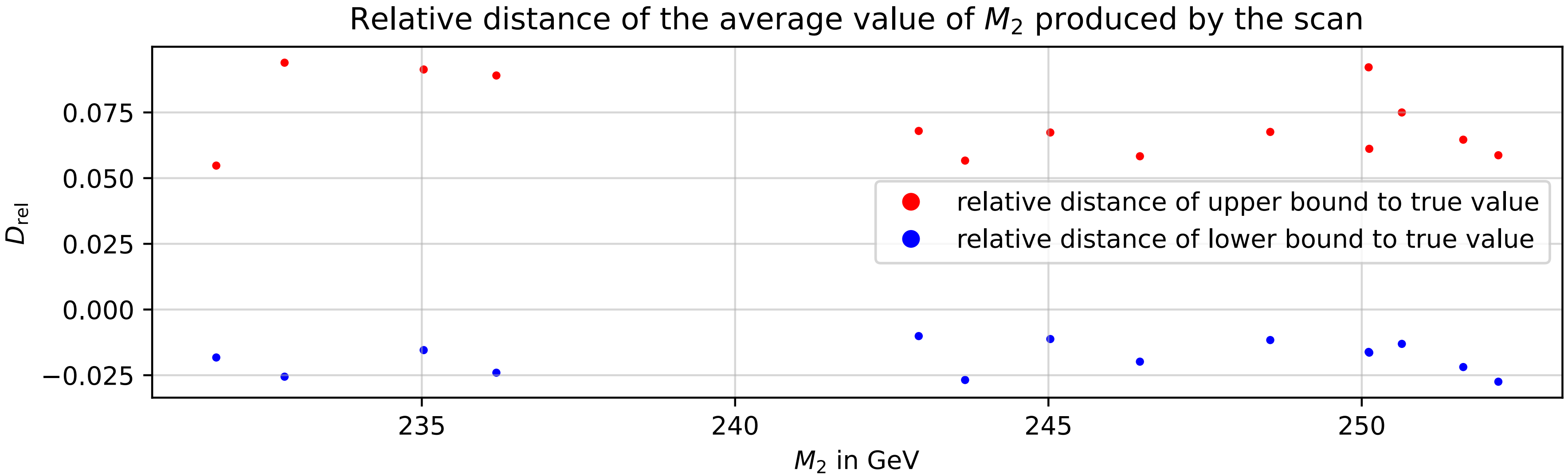




$$D_{rel} = \frac{M_{1,scan} - M_{1,true}}{M_{1,true}}$$

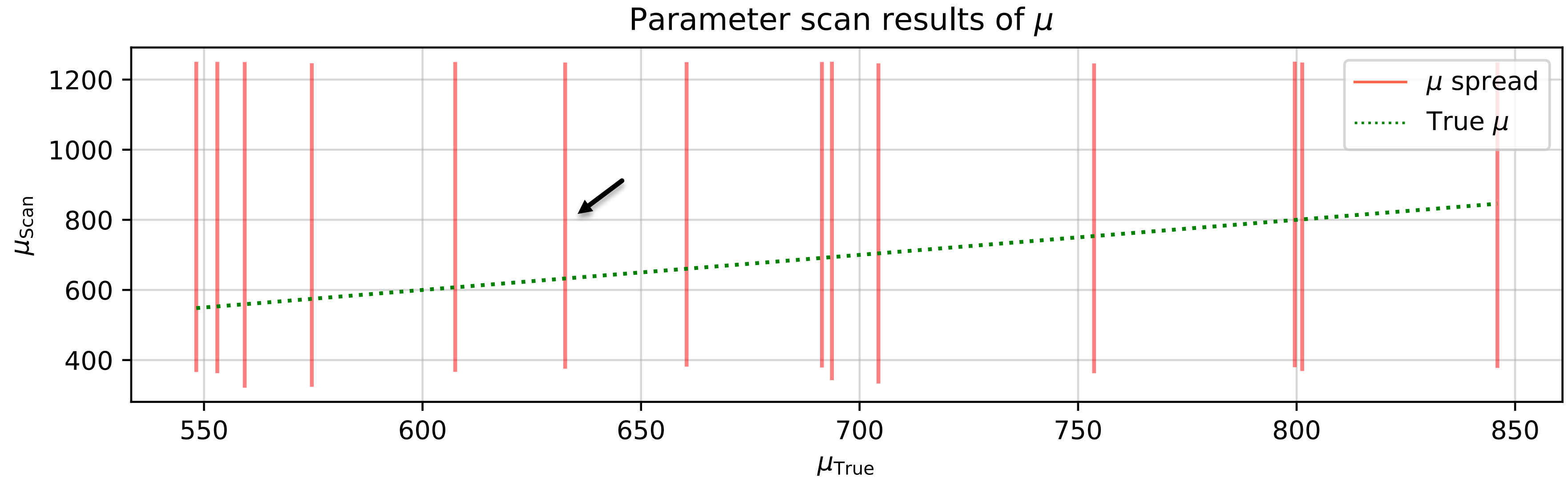
Results for M_2

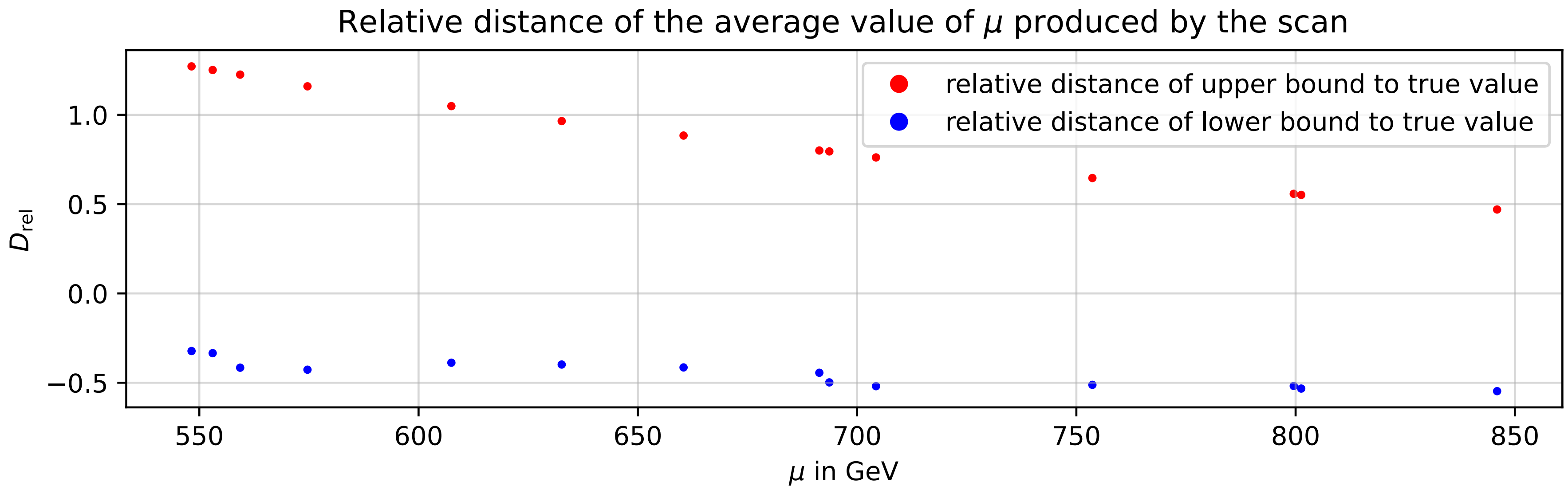




$$D_{rel} = \frac{M_{2,scan} - M_{2,true}}{M_{2,true}}$$

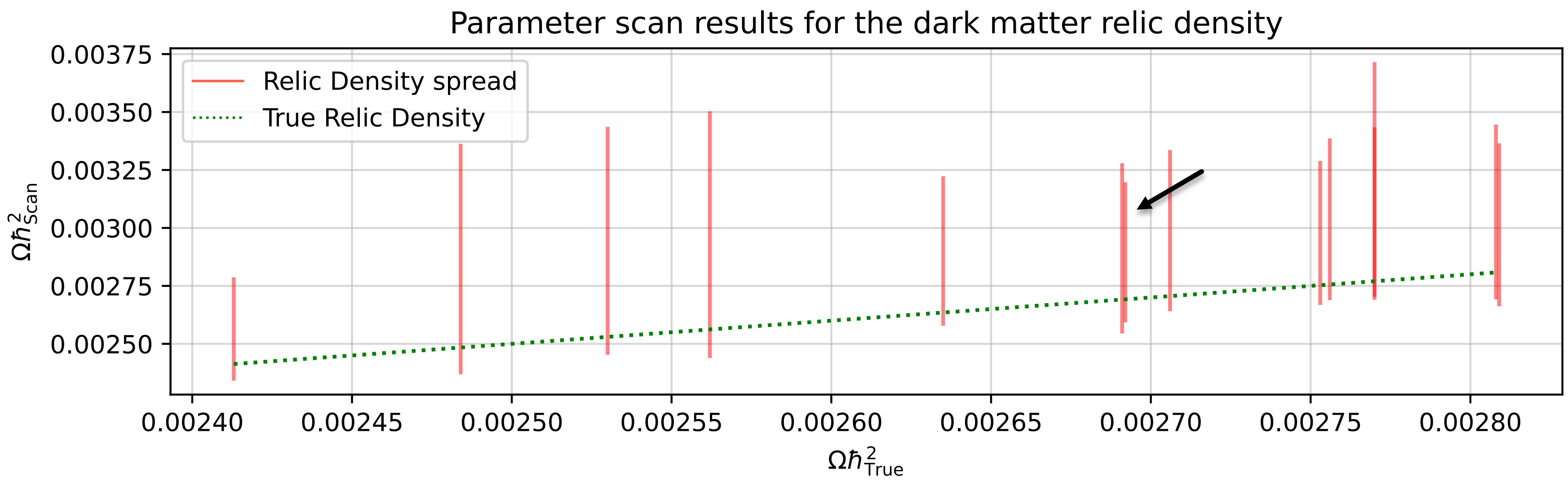
Results for μ

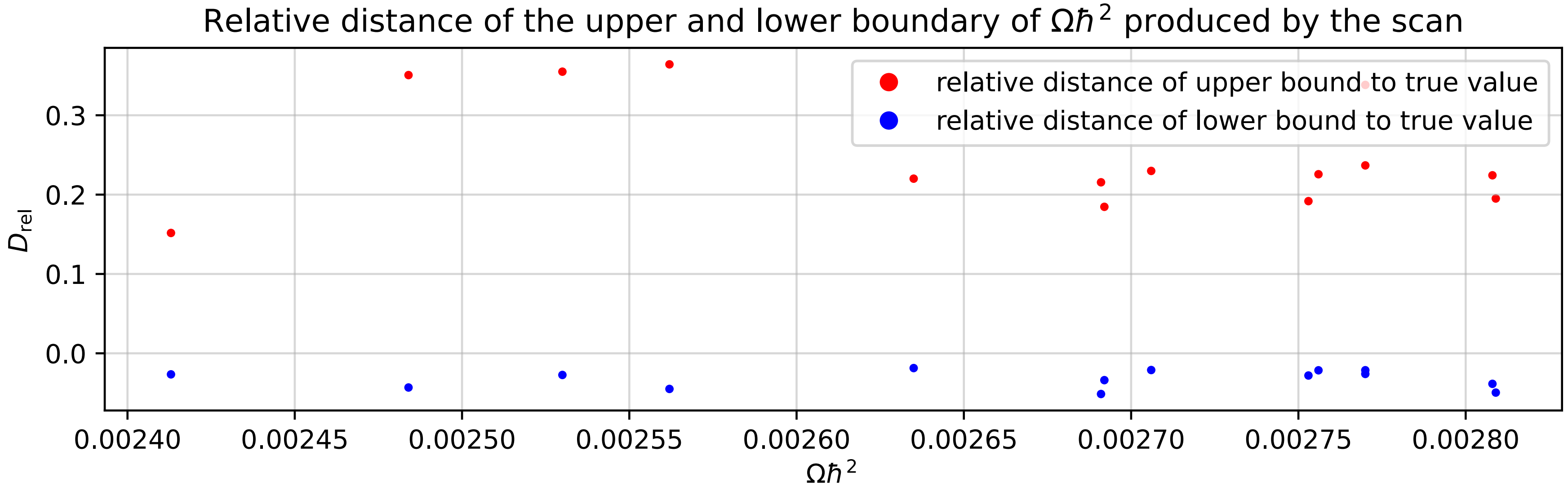




$$D_{rel} = \frac{\mu_{scan} - \mu_{true}}{\mu_{true}}$$

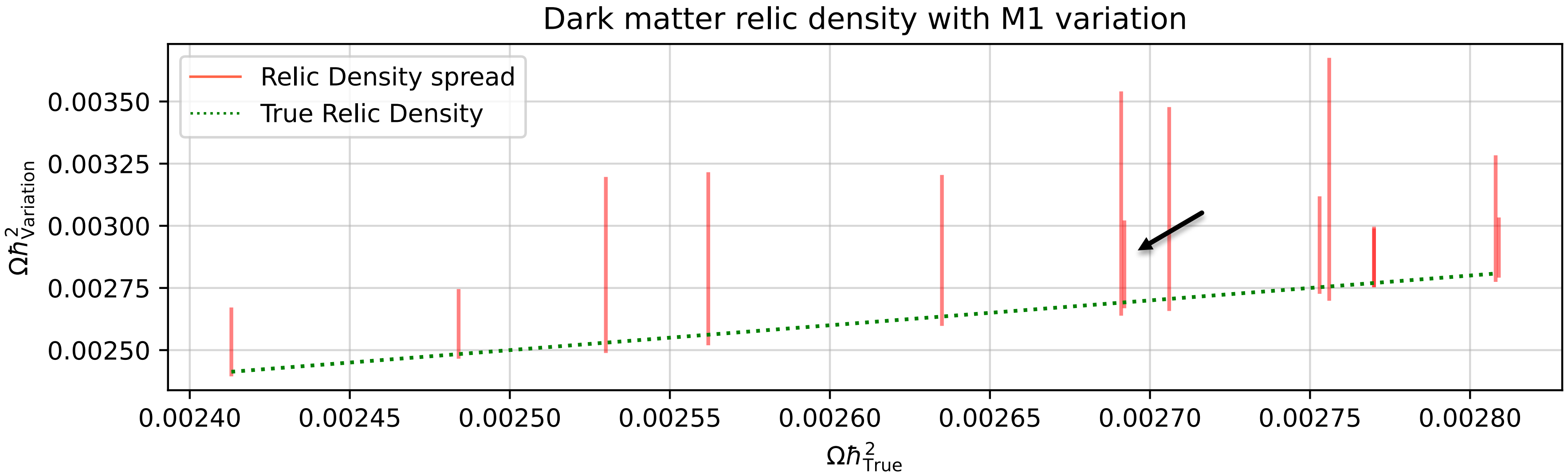
Results for DM relic density

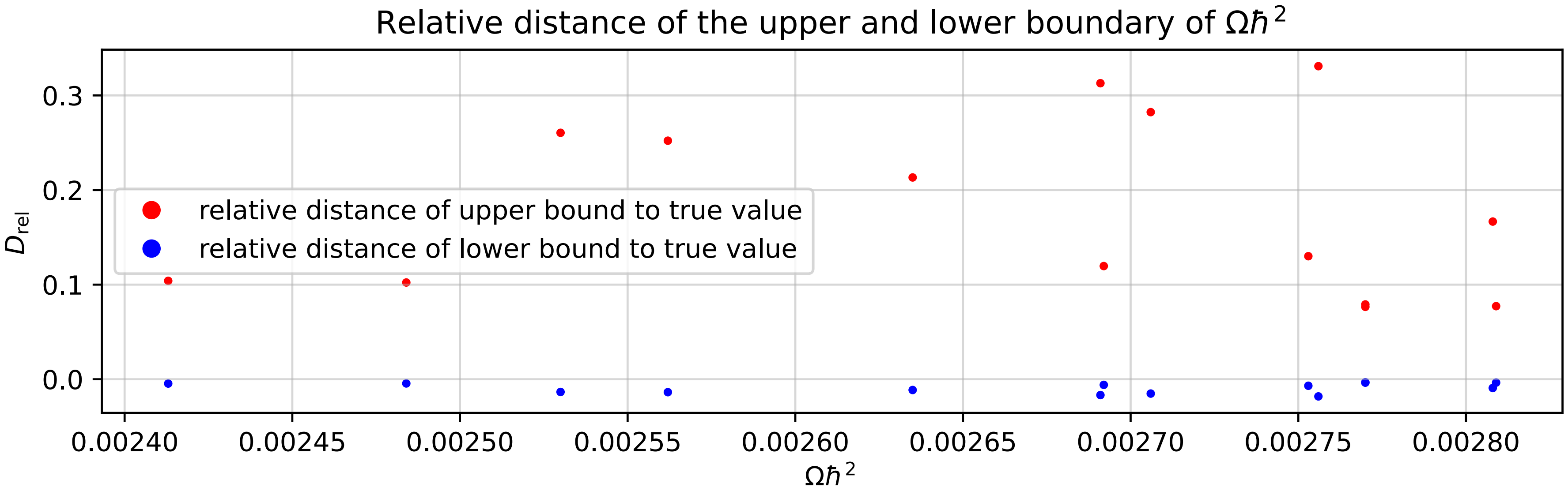




$$D_{rel} = \frac{\Omega\hbar^2{}_{scan} - \Omega\hbar^2{}_{true}}{\Omega\hbar^2{}_{true}}$$

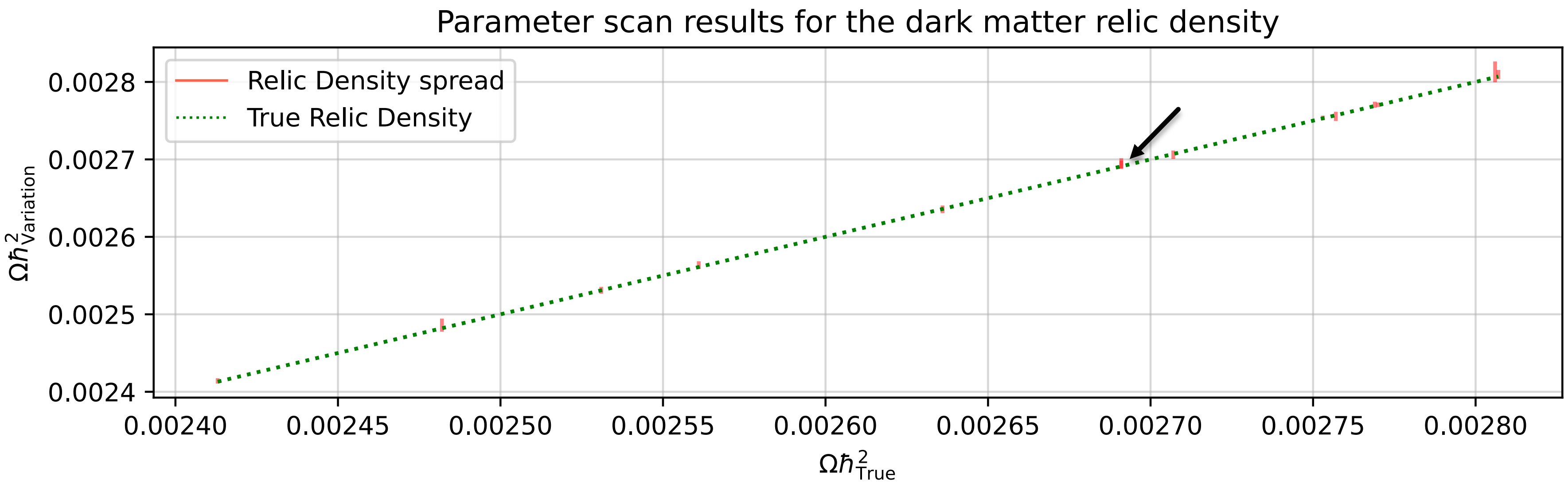
Variation of M_1

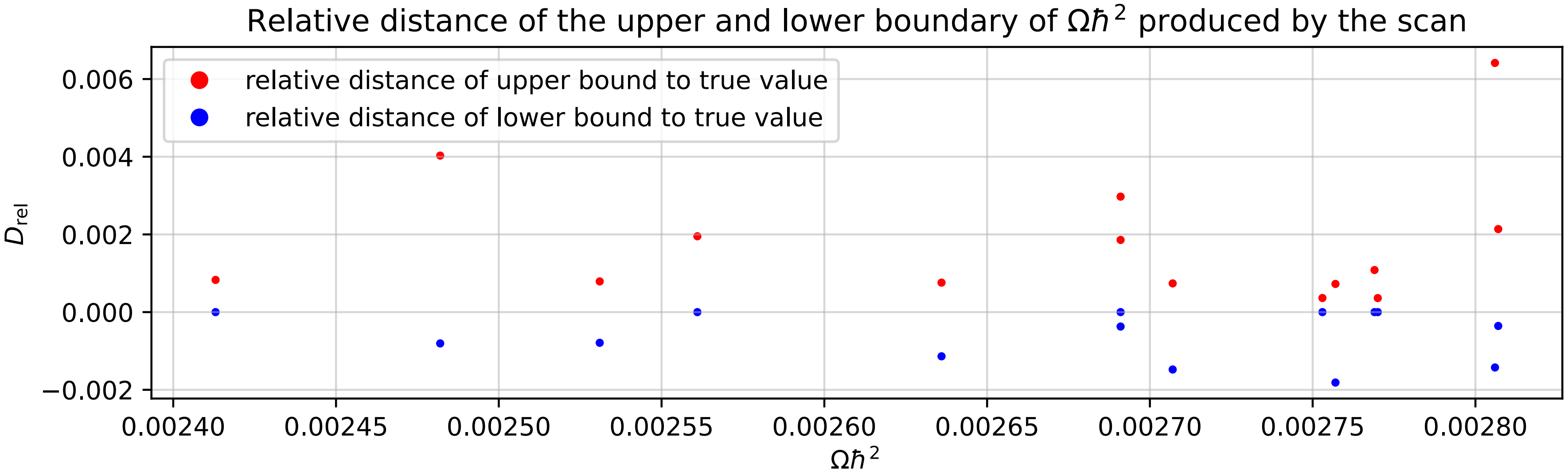




$$D_{rel} = \frac{M_{1,var} - M_{1,true}}{M_{1,true}}$$

Variation of μ





$$D_{rel} = \frac{\mu_{var} - \mu_{true}}{\mu_{true}}$$

Conclusion & Outloock

- Florians code was debugged and improved
- Different data set was studied
- Next steps:
  - Include forward-backward asymmetry (A_{FB}) as additional parameter to improve accuracy
  - Find alternative method of getting $M_{\tilde{\nu}}$ (via A_{FB}) to get a more reliable uncertainty and thus improve the accuracy
  - Optimize beam energy to get higher crosssections and better accuracy

Thank you for your attention! ☺

Questions?

Sources

- [1] Combined LHC/ILC analysis of a SUSY scenario with heavy sfermions, 2018, arXiv:hep-ph/0607104v2
- [2] Consistent Excesses in the Search for $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$: Wino/bino vs. Higgsino Dark Matter, 2024, arXiv:2403.14759v1
- [3] Master thesis of Florian Lika: SUSY Parameter determination within Dark Matter Phenomenology at future e+e− Colliders, 2023
- [4] On the physics potential of ILC and CLIC, A.F.Zarnecki, 2020
- [5] SUSY Parameter Determination in Combined Analyses at LHC/LC, 2003, arXiv:hep-ph/0312069v1
- [6] Beyond the standard model seraches at the LHC, 2016, https://indico.cern.ch/event/555909/contributions/2265363/attachments/1325399/1989408/deroeck_Islamabad2016_2_v1.pdf

Backup

- Coefficients from crosssection formula:

$$c_1 = \int_C |Z|^2\{c_{LR}L^2 f_2 + c_{RL}R^2 f_1\}$$

$$c_2 = \int_C |Z|^2\{c_{LR}L^2(1-4L)(2f_2+f_3) + c_{RL}R^2(1-4R)(2f_1+f_3)\} - \int_C G\tilde{N}4\{c_{LR}L(2f_2+f_3)+c_{RL}R(2f_1+f_3)\} - \int_C Re(Z)\tilde{N}c_{LR}Lf_3$$

$$c_3 = \int_C |Z|^2(c_{LR}L^2 f_1 + c_{RL}R^2 f_2) - \int_C Z\tilde{N}2c_{LR}Lf_1 + \int_C \tilde{N}^2 c_{LR} f_1$$

$$c_4 = \int_C |Z|^2(1-4L)\{c_{LR}L^2(2f_1+f_3) + c_{RL}R^2(2f_2+f_3)\} + \int_C \tilde{N}^2 2c_{LR}f_1 + \int_C Re(Z)\tilde{N}c_{LR}L\{-4f_1 - f_3 + 4L(2f_1+f_3)\} + \int_C G\tilde{N}4c_{LR}(2f_1+f_3) - \int_C GRe(Z)4\{c_{LR}L(2f_1+f_3)+c_{RL}R(2f_2+f_3)\}$$

$$c_5 = \int_C |Z|^2(c_{LR}L^2 + c_{RL}R^2)f_3 - \int_C Re(Z)\tilde{N}c_{LR}Lf_3$$

$$c_6 = \int_C |Z|^2\{c_{LR}L^2(1-8L) + c_{RL}R^2(1-8L) + 16L^2(c_{LR}L^2+c_{RL}R^2)\}(f_1+f_2+f_3) - \int_C Re(Z)\tilde{N}c_{LR}L(1-4L)(2f_1+f_3) + \int_C G^2(c_{LR}+c_{RL})(f_1+f_2+f_3) - \int_C Re(Z)G8\{c_{RL}R + c_{LR}L(1-4L)\}(f_1+f_2+f_3) + \int_C \tilde{N}^2 c_{LR} f_1 + \int_C G\tilde{N}4c_{LR}(2f_1+f_3)$$

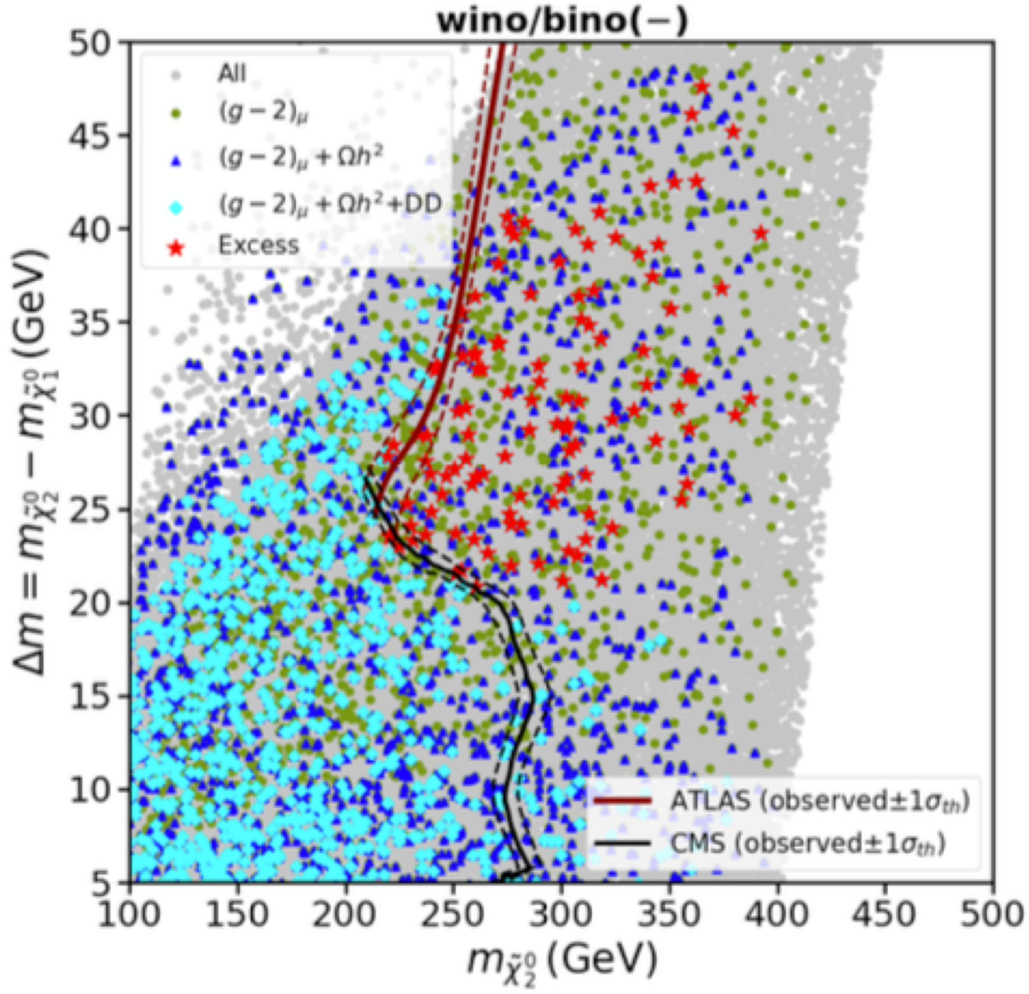
[5]

Backup

$$m^2_{\tilde{\chi}^{\pm}_{1,2}} = \frac{1}{2}(M_2^2 + \mu^2 + 2m_W^2 \mp \Delta_C)$$

$$\Delta c = \left[(M_2^2 - \mu^2)^2 + 4m_W^4 \cos^2 2\beta + 4m_W^2(M_2^2 + \mu^2) + 8m_W^2 M_2 \mu \sin 2\beta\right]^{\frac{1}{2}}$$

Backup


wino/bino(−)
All
$(g-2)_\mu$
$(g-2)_\mu+\Omega h^2$
$(g-2)_\mu+\Omega h^2$+DD
Excess
ATLAS (observed$\pm1\sigma_{th}$)
CMS (observed$\pm1\sigma_{th}$)
$\Delta m = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$ (GeV)
$m_{\tilde{\chi}_2^0}$ (GeV)
50
45
40
35
30
25
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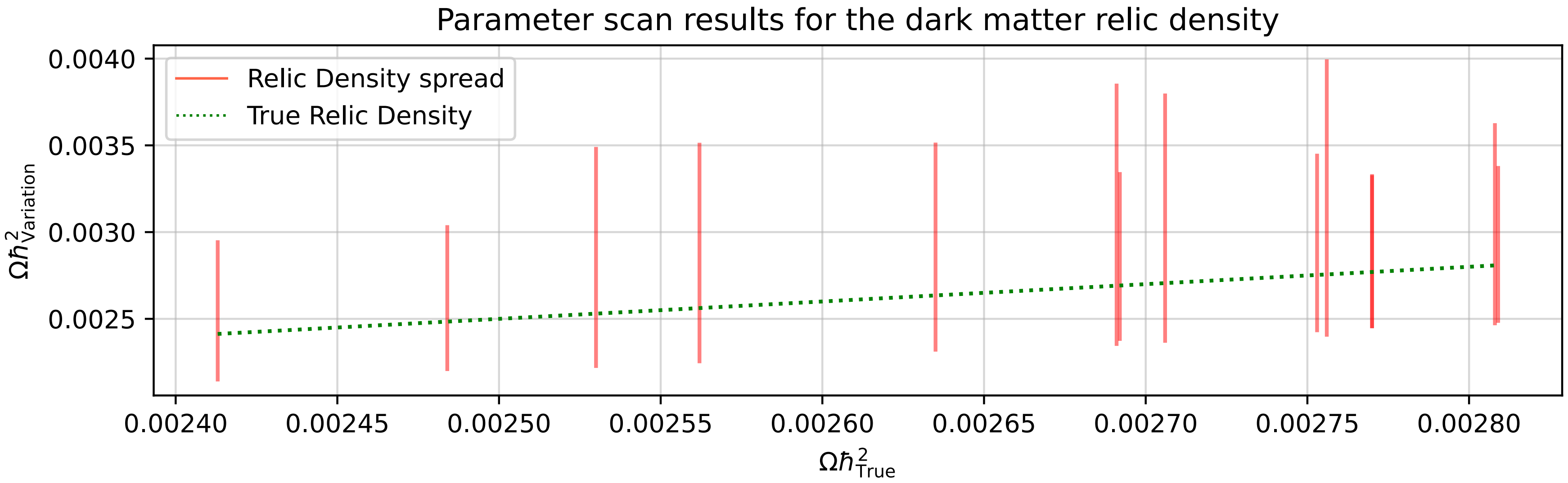
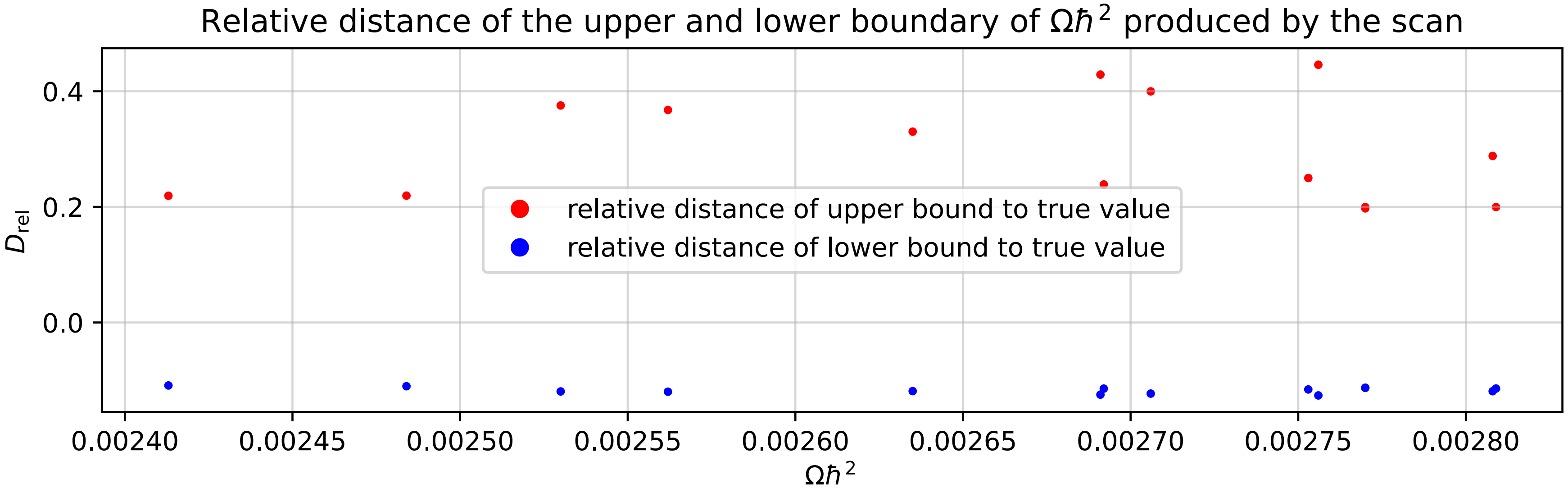
15
10
5
100
150
200
250
300
350
400
450
500

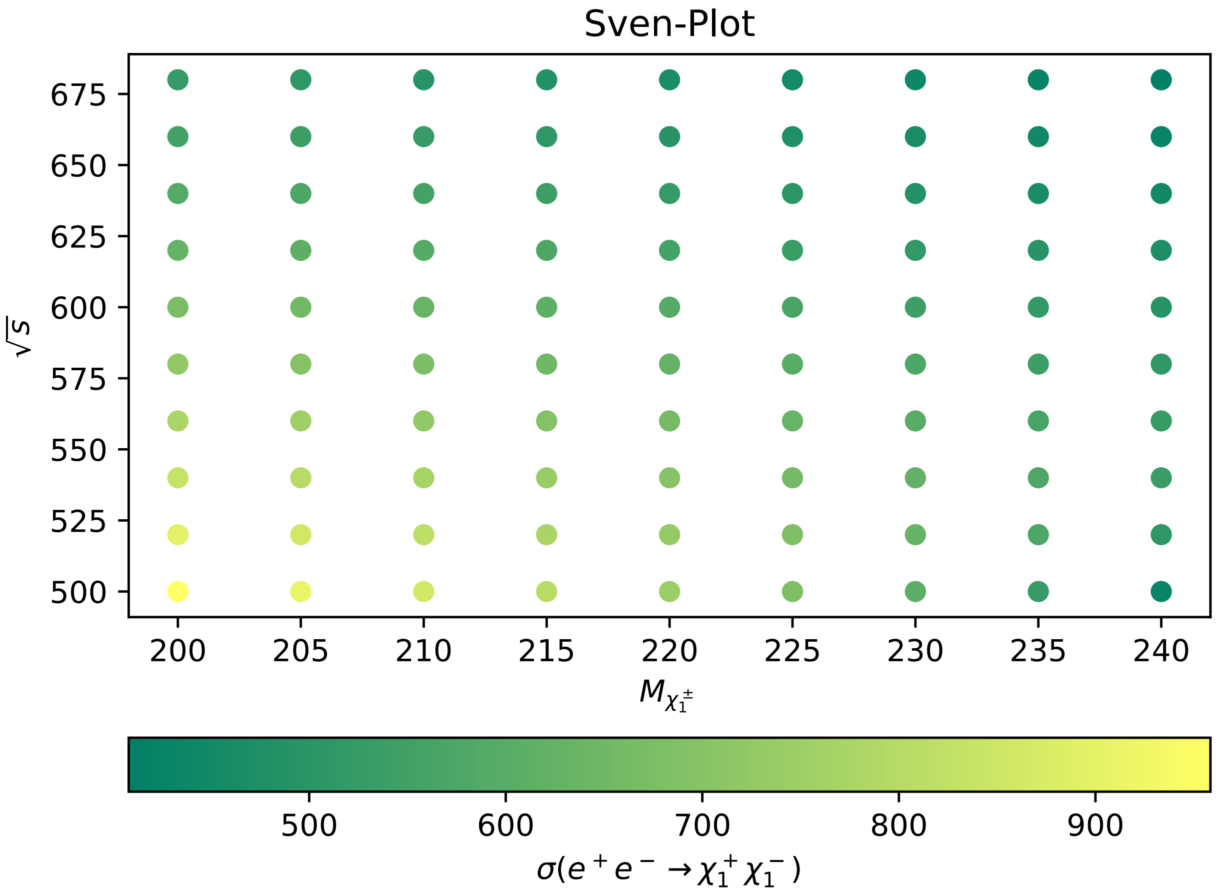
Variation of M_2





$$D_{rel} = \frac{M_{2,var} - M_{2,true}}{M_{2,true}}$$

Backup


Sven-Plot
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210
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$M_{\chi_1^\pm}$
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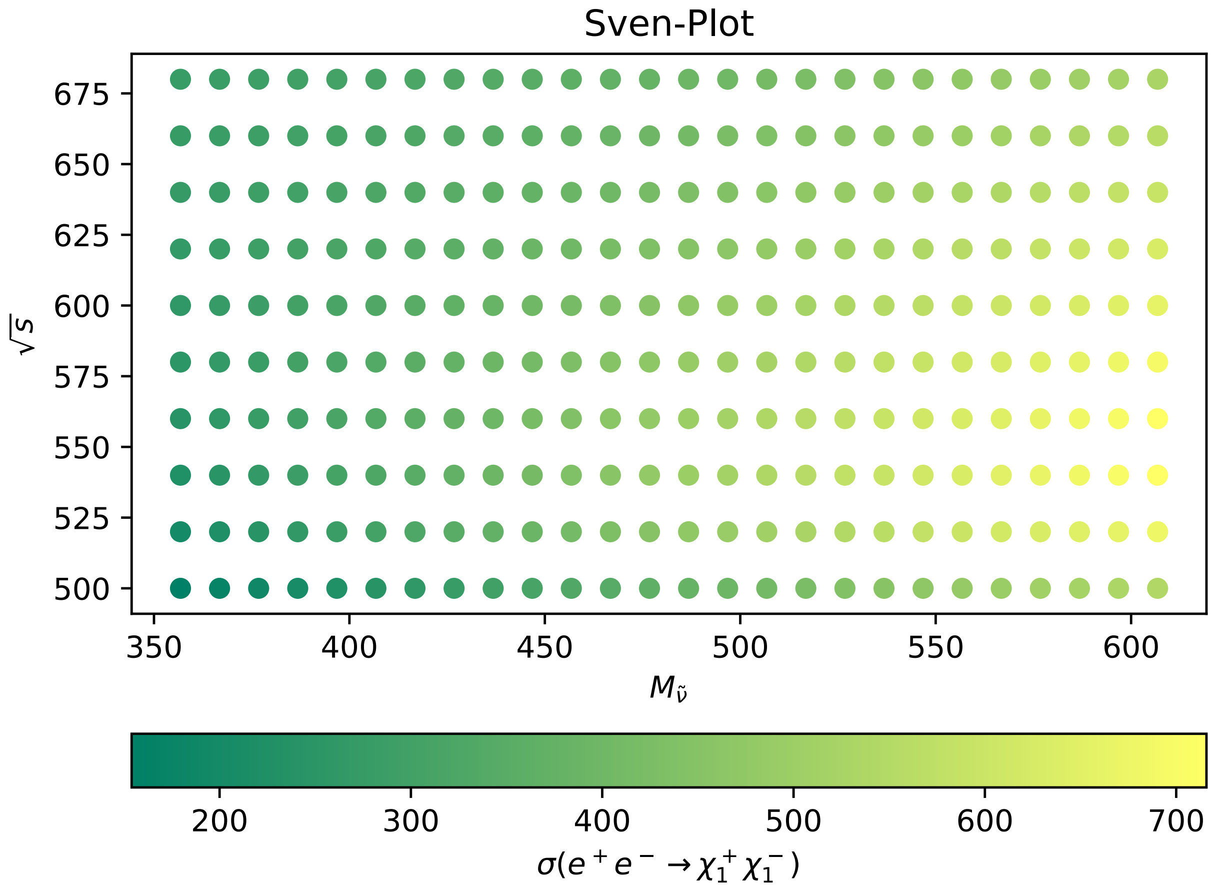
900
$\sigma(e^+e^- \to \chi_1^+\chi_1^-)$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$M_{\tilde{\nu}}$
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$\sigma(e^+e^- \to \chi_1^+\chi_1^-)$

Muster

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