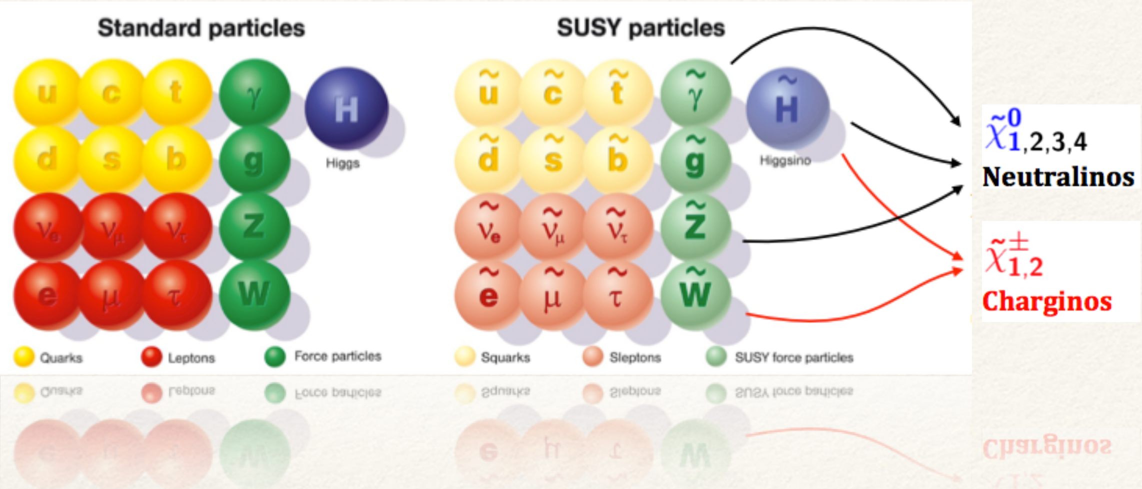
The 2023 International Workshop on CEPC @Oct 23 – 27, 2023 Nanjing

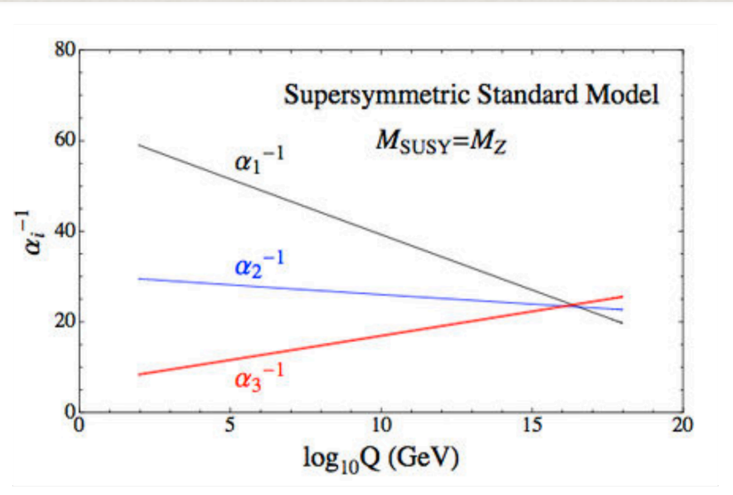
SUSY search prospects at CEPC

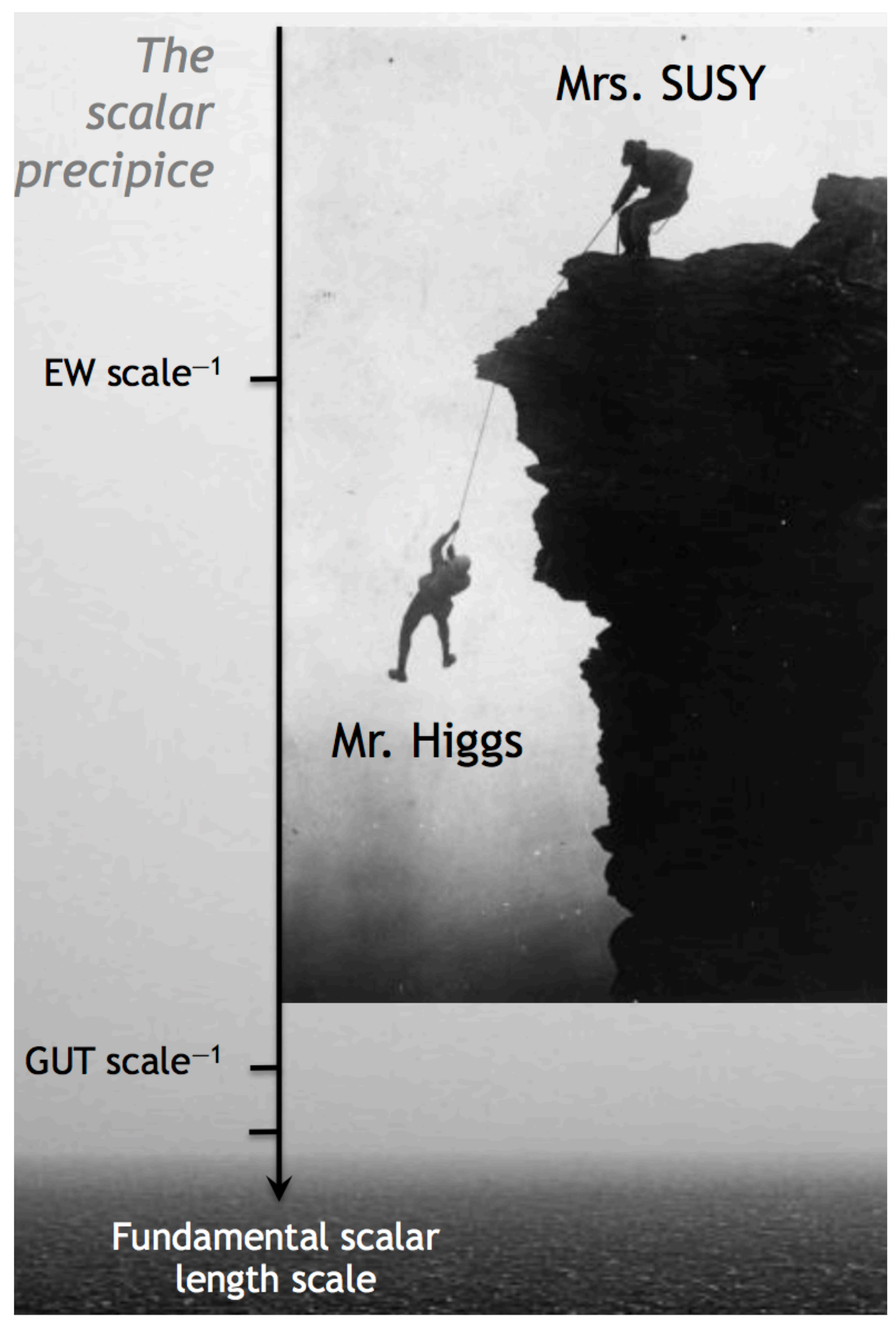
Da XU (IHEP, CAS)



Supersymmetry

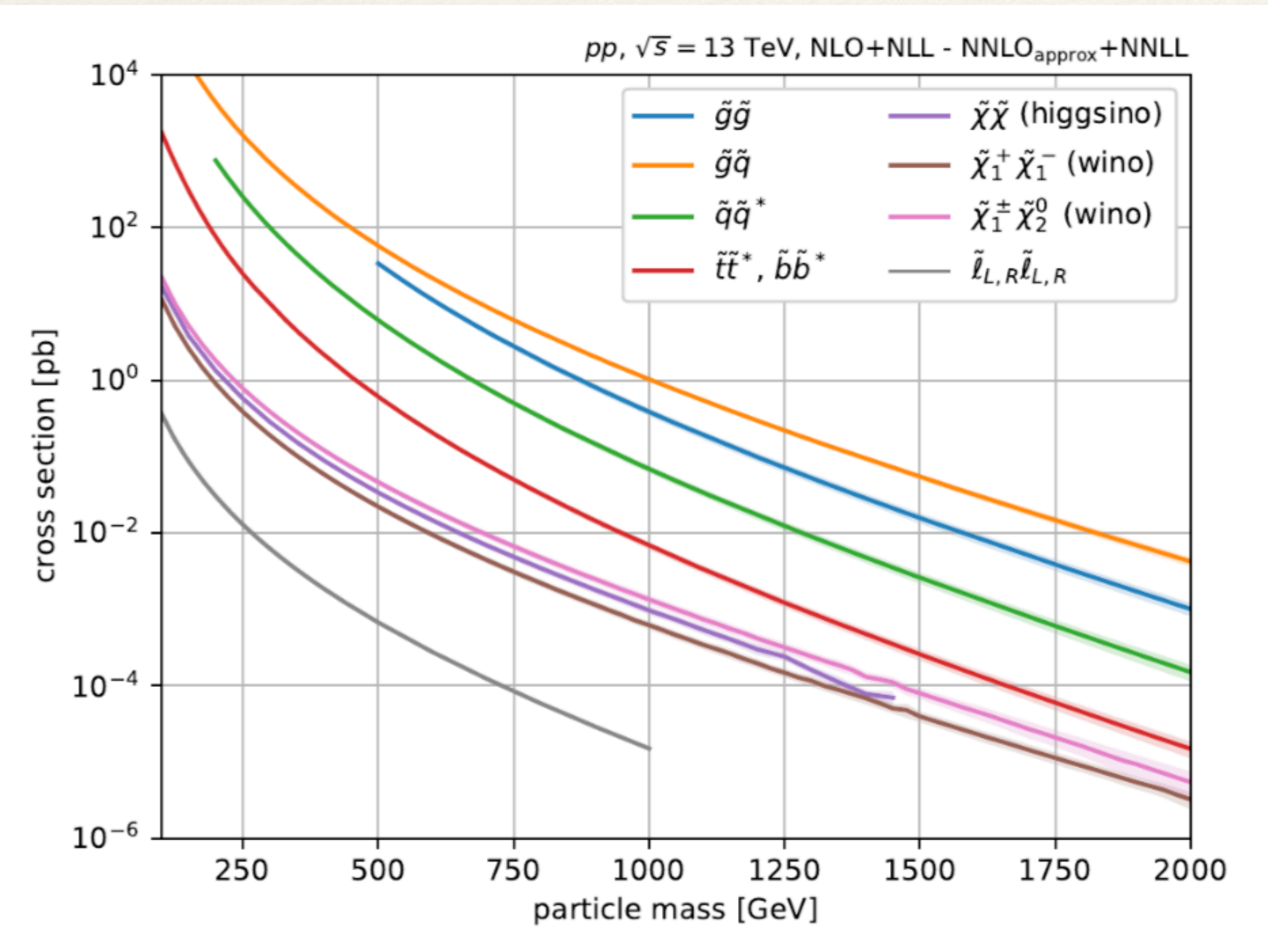
A fundamental theory which unifies fermions (matter) and bosons (forces)



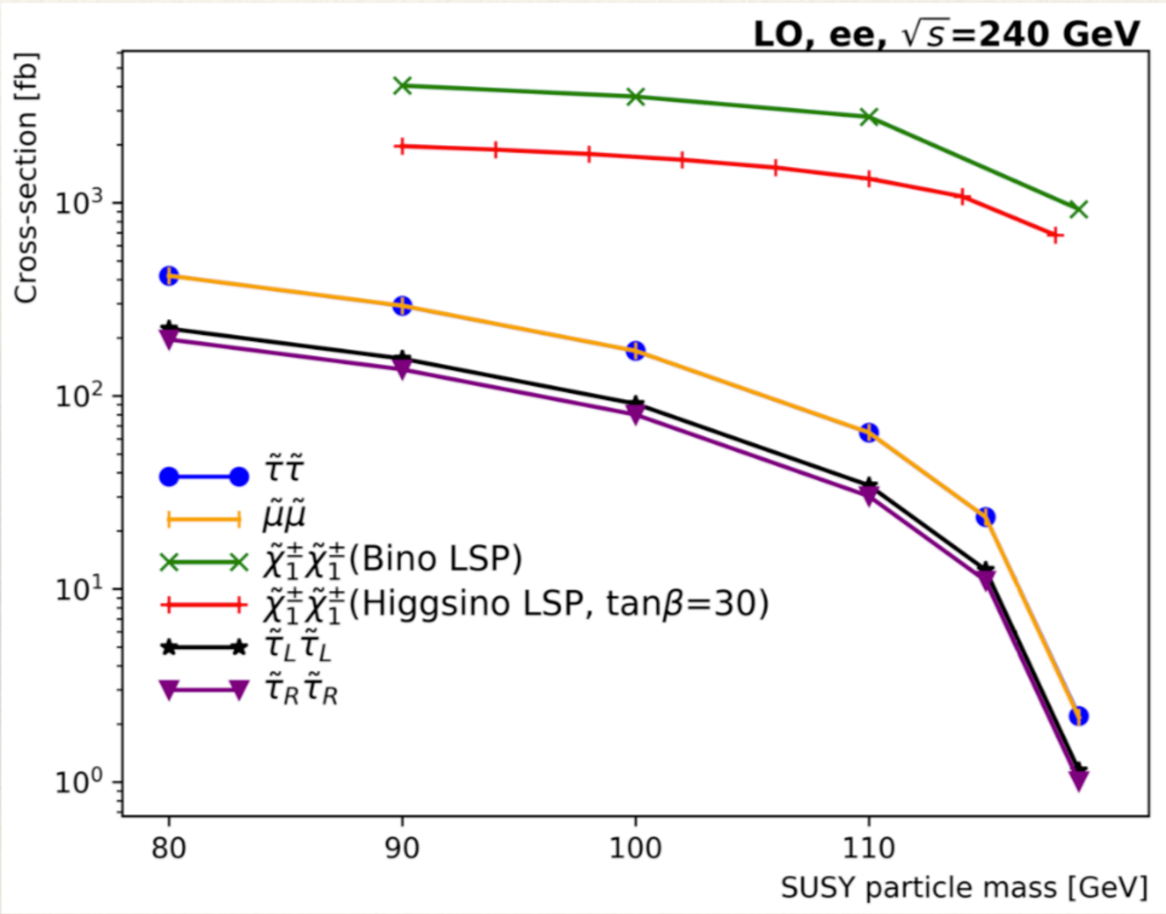


Where does SUSY hide?

Hadron collider



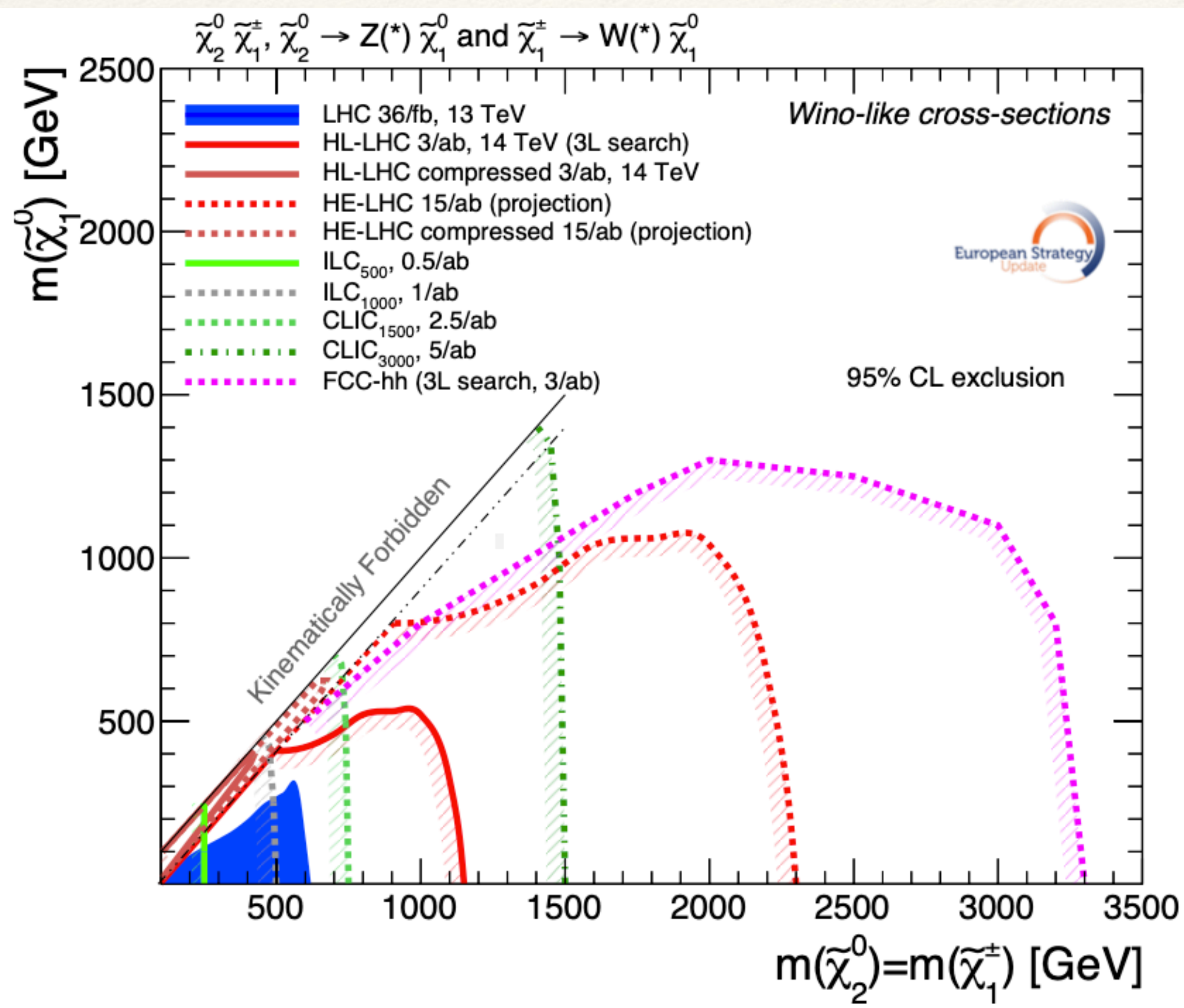
Lepton collider

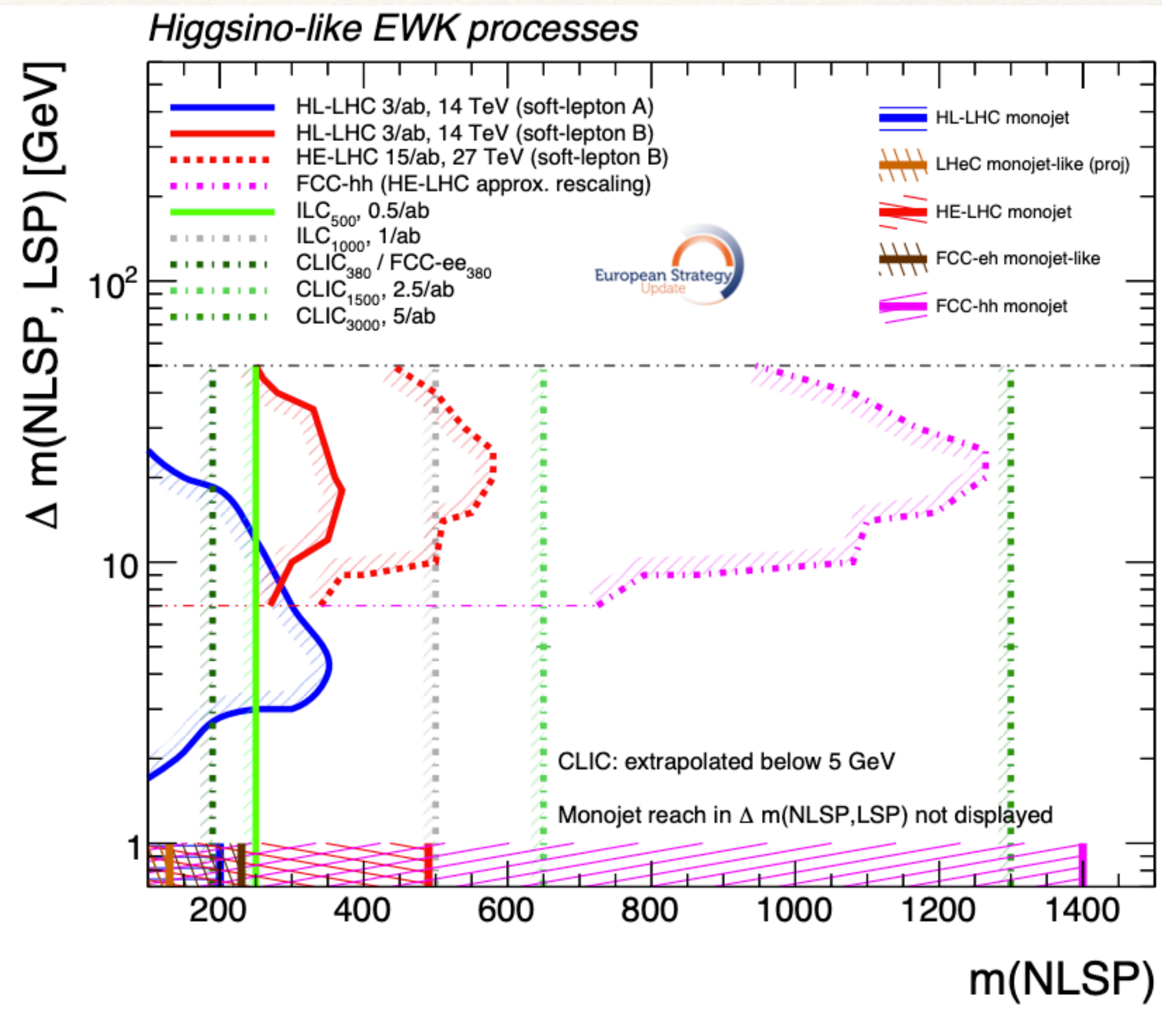


- For slepton prod. of 100 GeV, the production rates at both the LHC and CEPC are on a similar scale (~10^-1 pb); in this context, lepton collider demonstrates comparable or even significant potential for exploring the low mass region.

In EU strategy

CERN-ESU-004



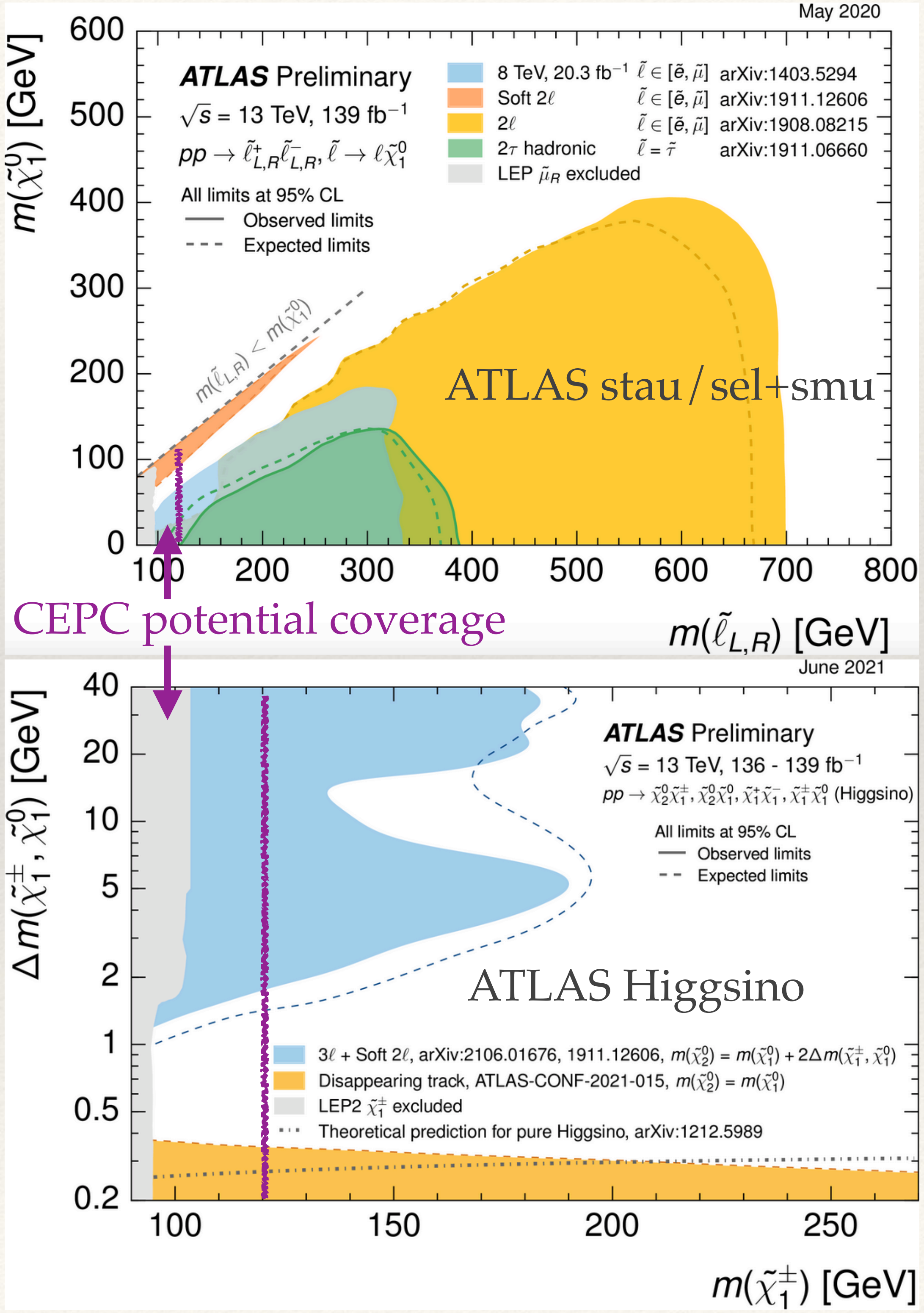


- Typically, the discovery power is constrained by the detector kinematic limit: $\sqrt{s}/2$.
- Still uncovered phase space for HL-LHC..

SUSY search @LHC vs CEPC

- The electroweak SUSY search is of great interest at CEPC: the generic searches for wino / higgsino / bino / slepton, as well as the relevant dark matter searches.

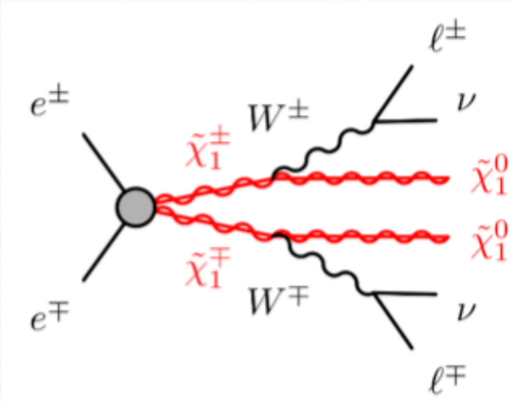
- Comparing to LHC, CEPC has
  - Well-defined energy, momentum and polarization
  - High-precision measurements
  - Clean environment
  - Superior sensitivity for electroweak stats, especially in probing super compressed scenarios which is extremely challenge in hadron collider



Today's menu

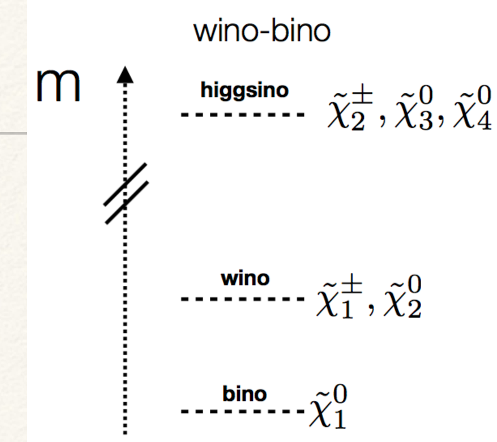
- A substantial amount of ongoing research and activity focused on SUSY in CEPC

Wino/bino	
Higgsino	arxiv:2105.06135
Smuon	
Stau	arxiv:2203.10580
Off-shell Smuon	arxiv:2211.08132
Right-handed *off-shell* selectron	arxiv:2202.11011
Bino NLSP	arxiv:2101.12131

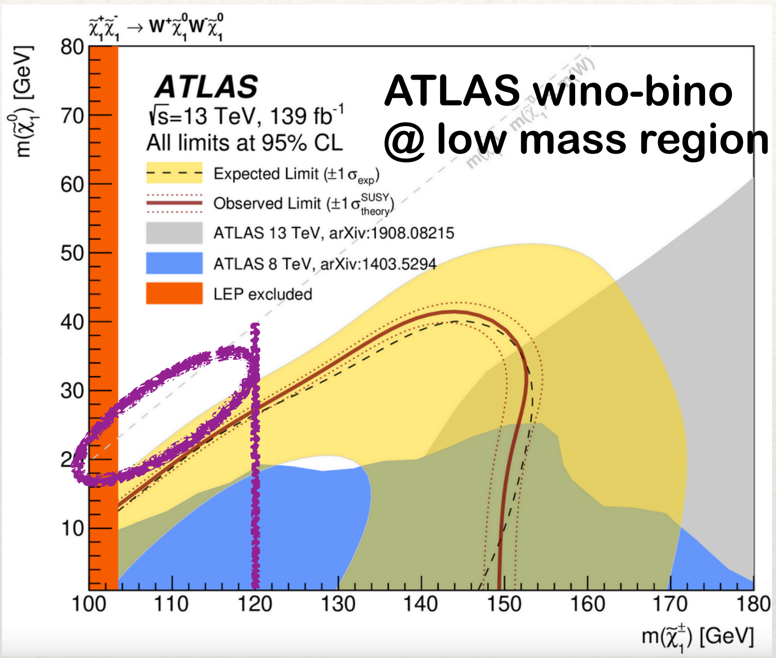


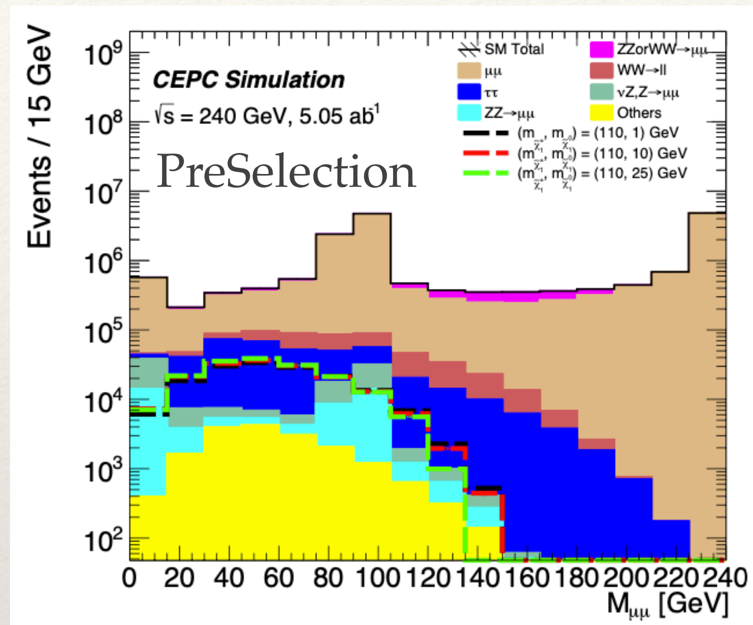
arxiv:2105.06135

Wino-bino search

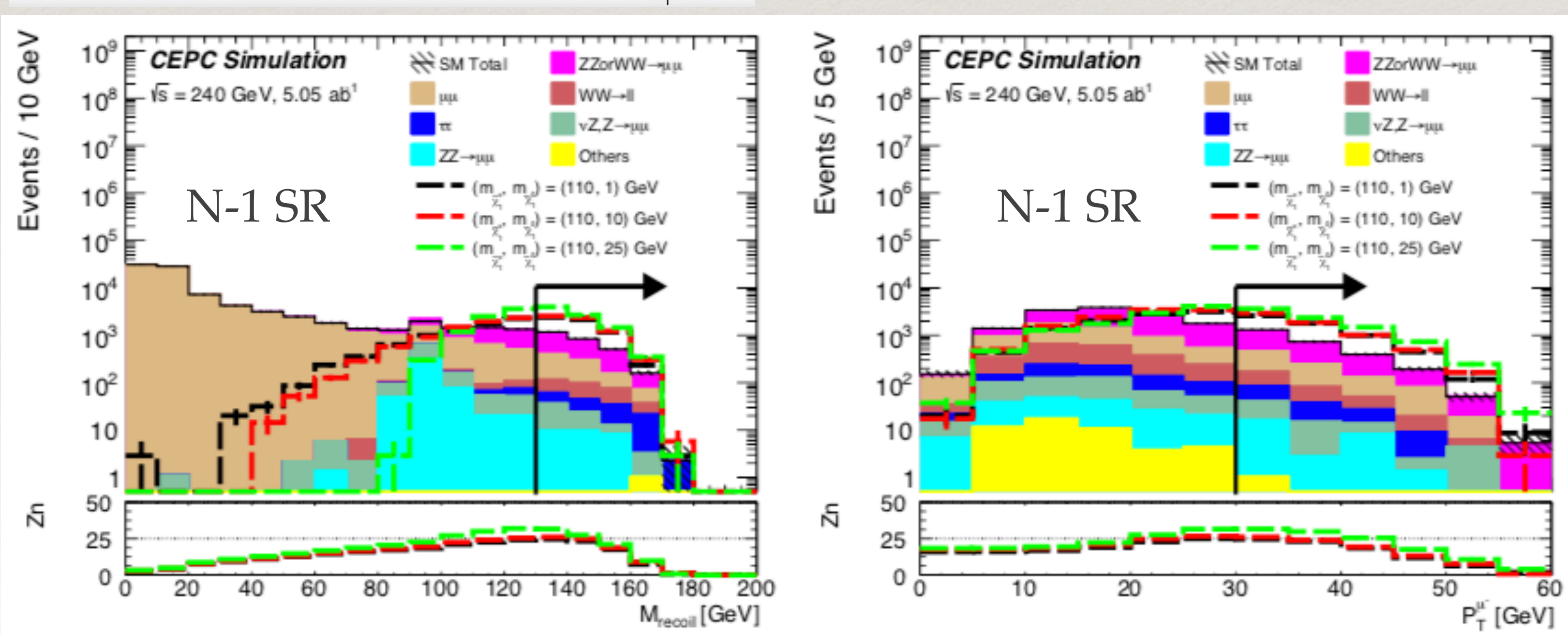


- A challenge scenario for LHC experiment in the low mass region!





- Background after preSel: peak ~ Z(->mumu) mass region and tend to have large deltaR
- Recoil system is then defined as all particles except two OS muons
- Mrecoil: high in signal case due to large missing energy -> most powerful cut

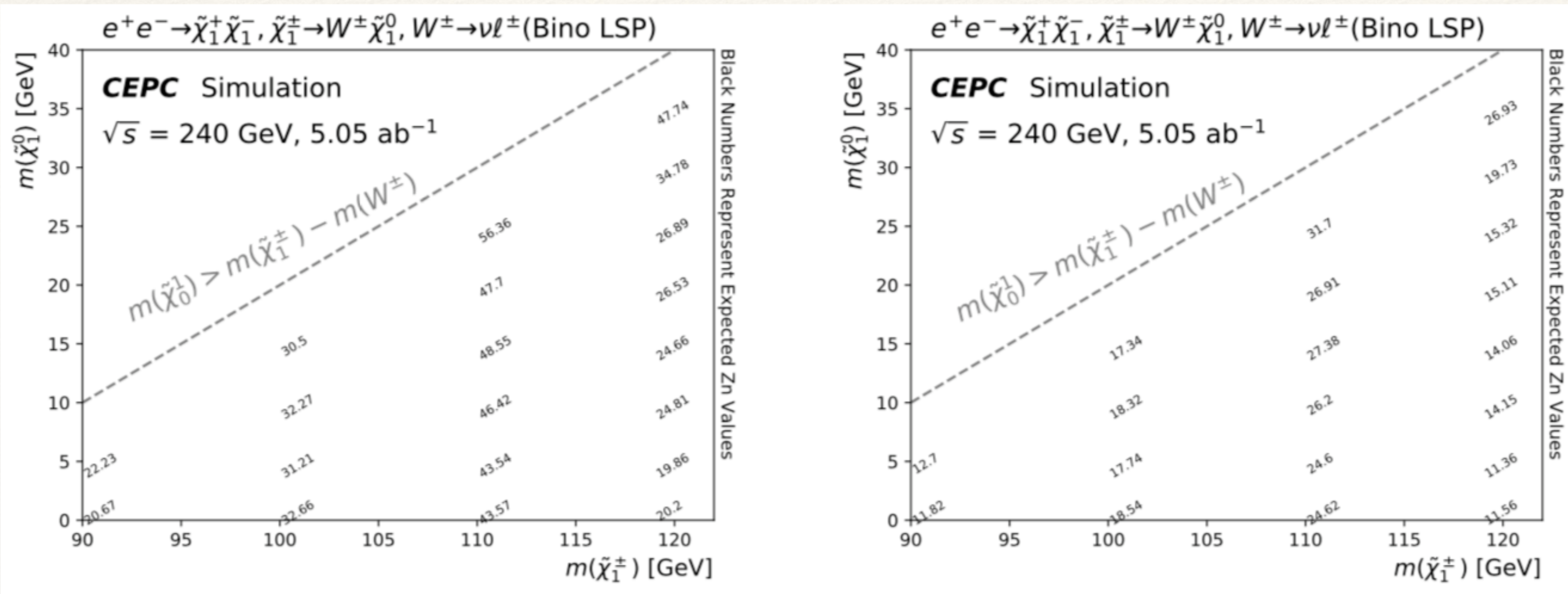


(a) M_{recoil} (M_{recoil} >130 GeV) (b) $P_T^{\mu^-}$ ($P_T^{\mu^-}$ >30 GeV)

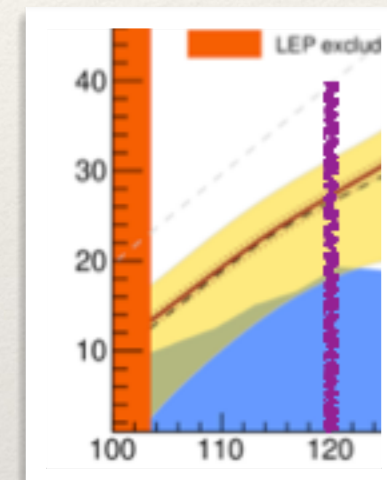
- $P^{\mu\pm}$ > 30 GeV: suppress soft background muon processes
- Dominant background in SR: ZZ or $WW \to \mu\mu\nu\nu$ and $\mu\mu$

Signal Region
== 2 muons (OS, both energy > 10 GeV)
$0.4 < \Delta R(\mu^+, \mu^-) < 1.6$
$P_T^{\mu^{\pm}} > 30$ GeV
$M_{recoil} > 130$ GeV

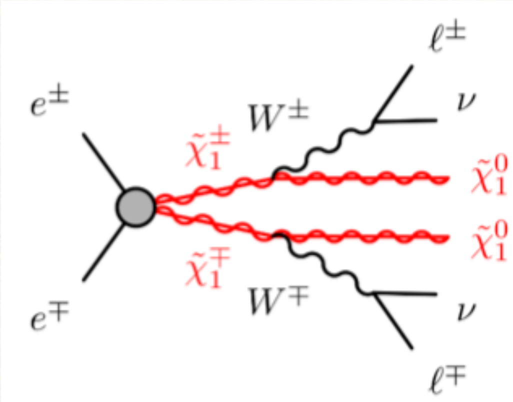
Wino-bino search



(a) systematic uncertainty = 0%   (b) systematic uncertainty = 5%

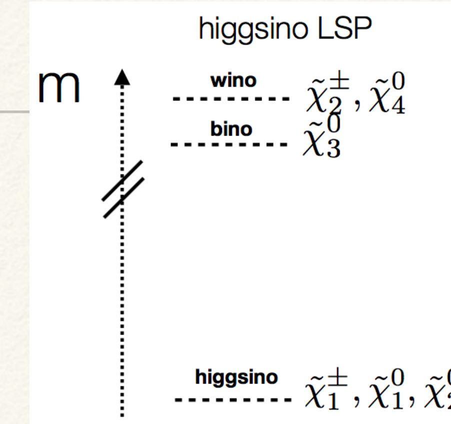


- Great discovery sensitivity coverage, up to the detector constraint.
- Perfectly fill in the full ATLAS gap region. No large impact from the uncertainty on the discovery sensitivity.

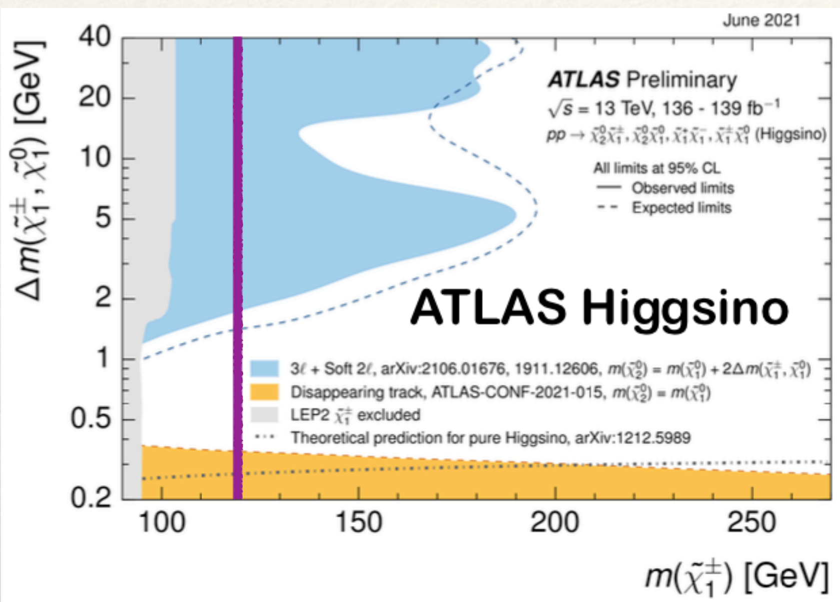


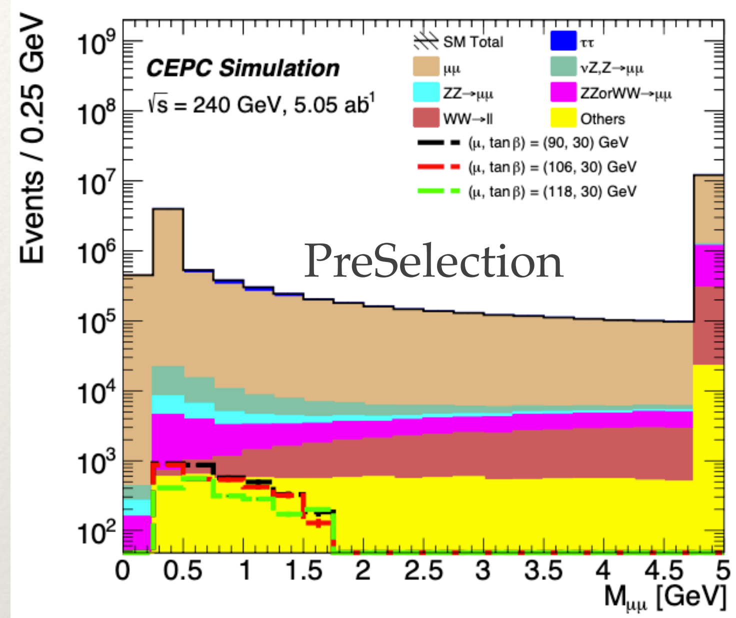
arxiv:2105.06135

Higgsino search

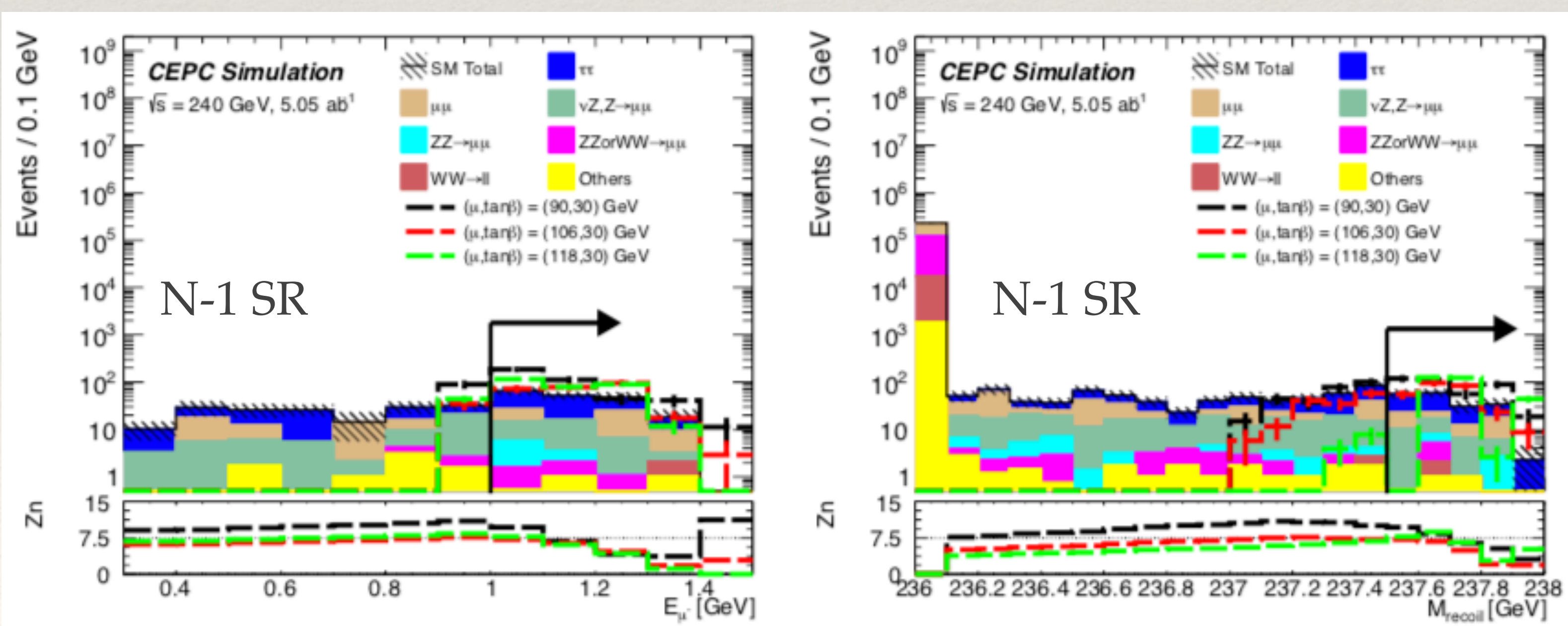


- Motivated by Naturalness; challenge in compressed region.





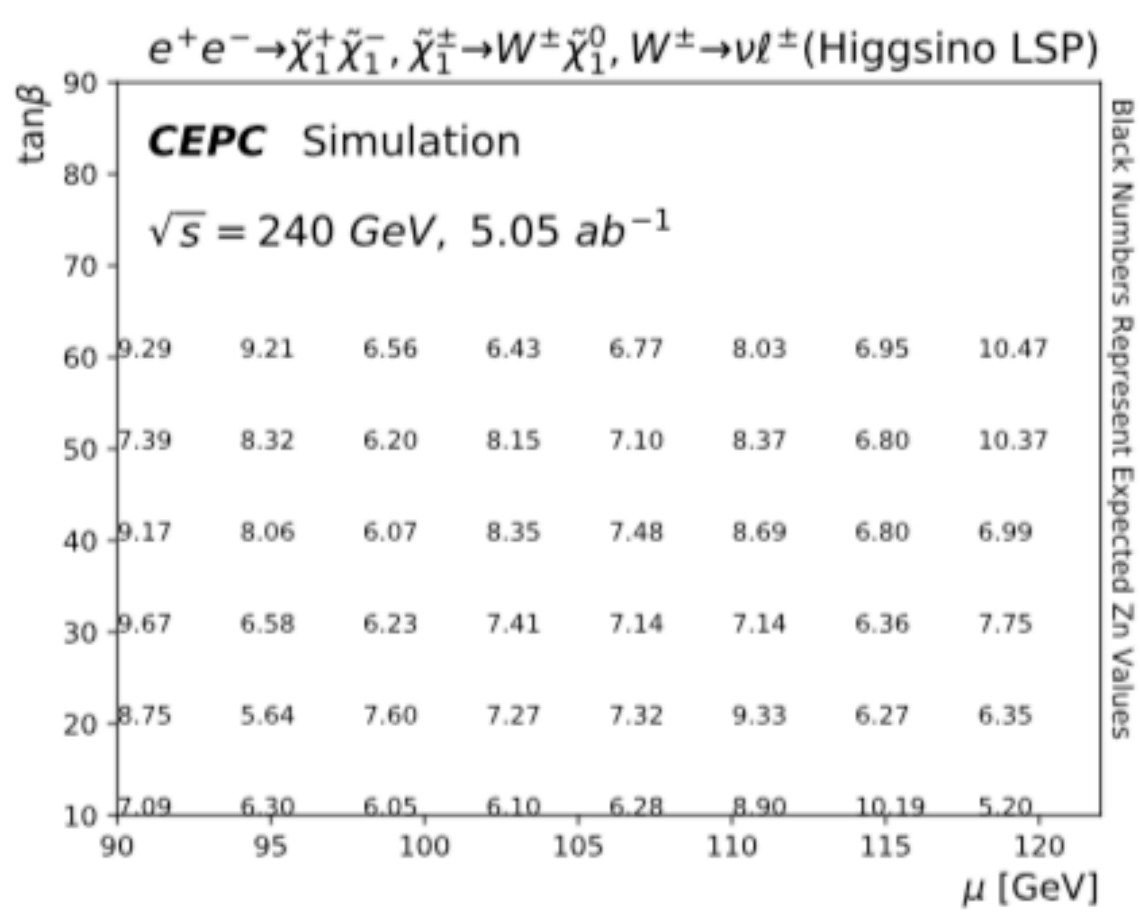
- Unlike wino-bino, the higgsino signal has much softer muons due to small signal mass splitting -> low Eμ
- Mrecoil: much significant for signal
- A list of angle discriminants: i.e. |Δφ(μ+,μ-)|: suppress the back-to-back di-muon events
- Dominant background: $\tau\tau$



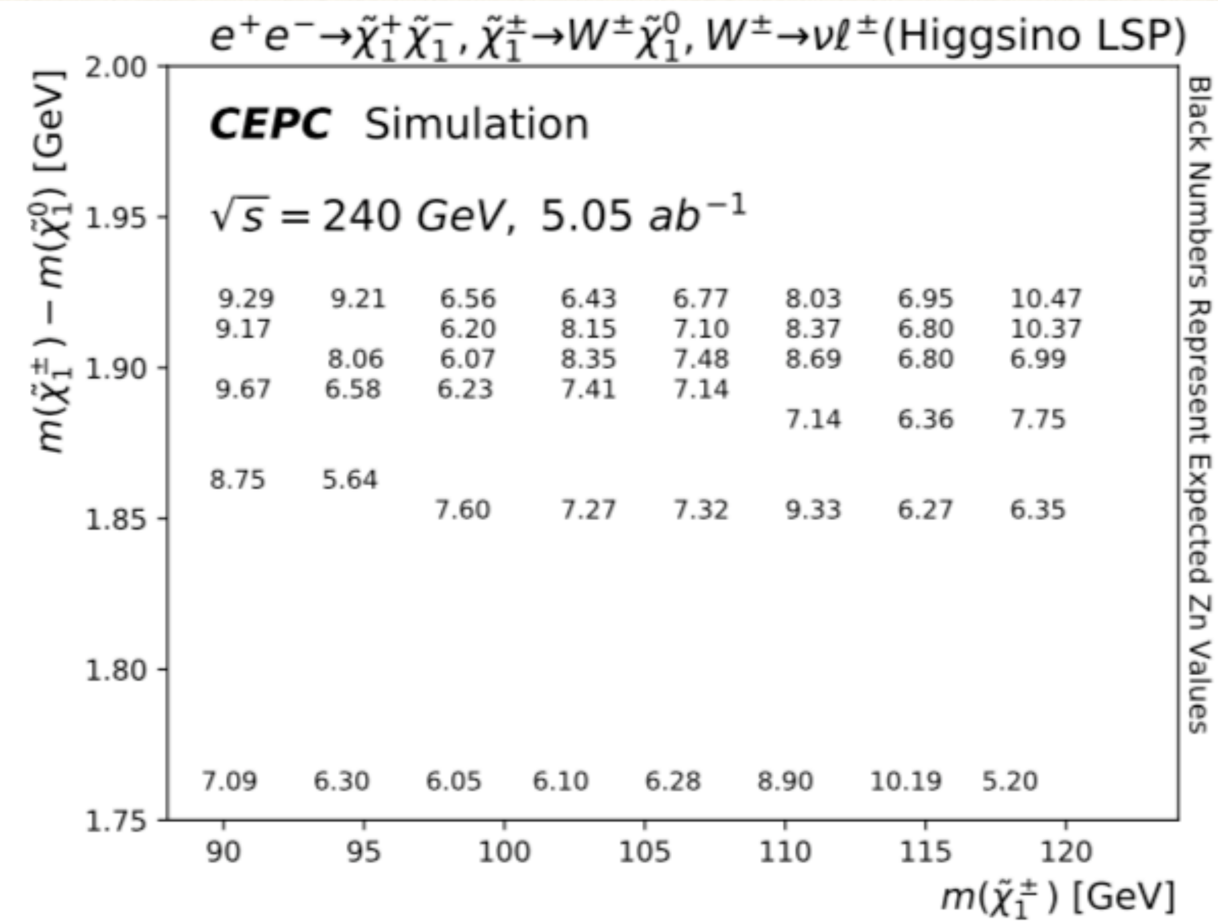
(a) E_{μ^-} ($E_{\mu^-} > 1.0$ GeV) (b) M_{recoil} ($M_{recoil} > 237.5$ GeV)

Signal Region
== 2 muons (OS)
$E_{\mu^{\pm}} > 1.0$ GeV
$3.2 < \Delta R(\mu^{\pm}, recoil) < 4.6$
$\lvert\Delta\phi(\mu^{\pm}, recoil)\rvert < 2.9$
$\lvert\Delta\phi(\mu^{+}, \mu^{-})\rvert < 1.4$
$M_{recoil} > 237.5$ GeV

Higgsino search



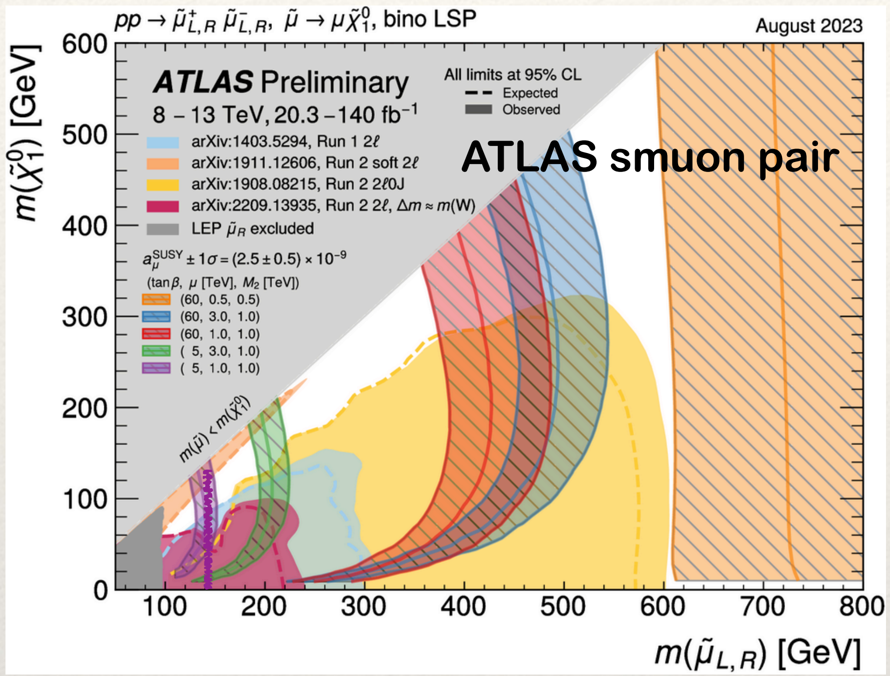
(b) systematic uncertainty =5%

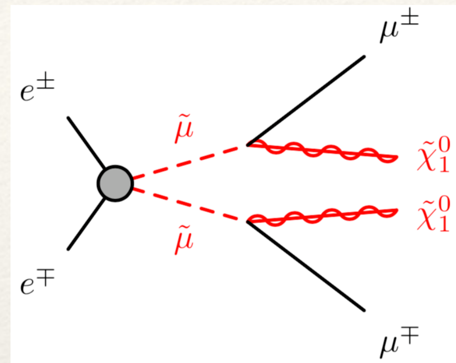


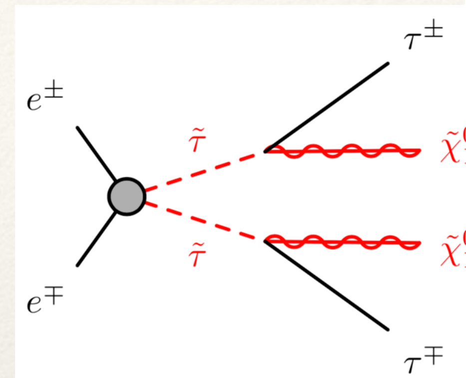
(d) systematic uncertainty =5%

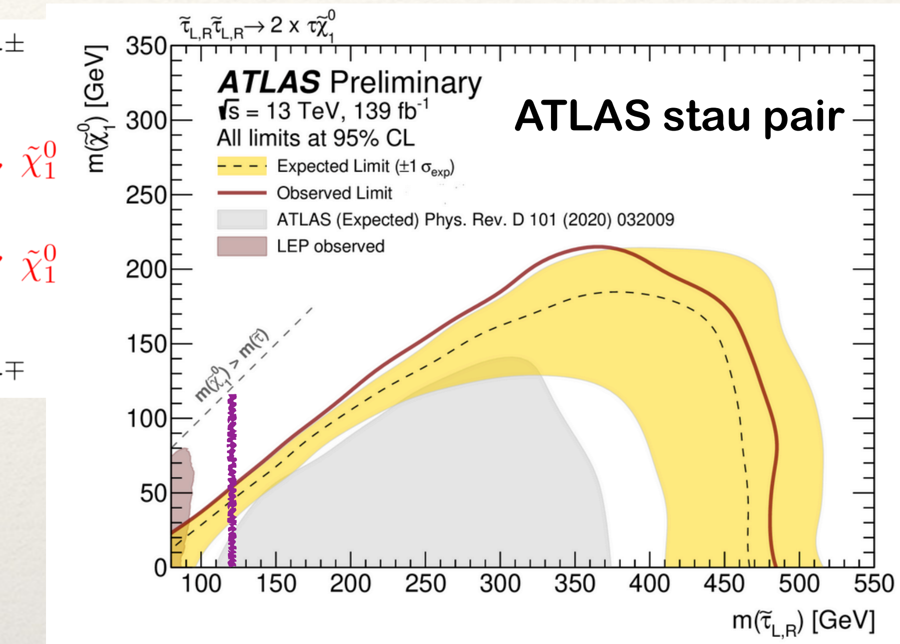
- Nice discovery sensitivity coverage, up to the detector constraint.
- Interpreted in both μ-tanβ and C1-dM scenarios. According to the current result, there are large potential to explore to even compressed region.

Smuon/Stau search



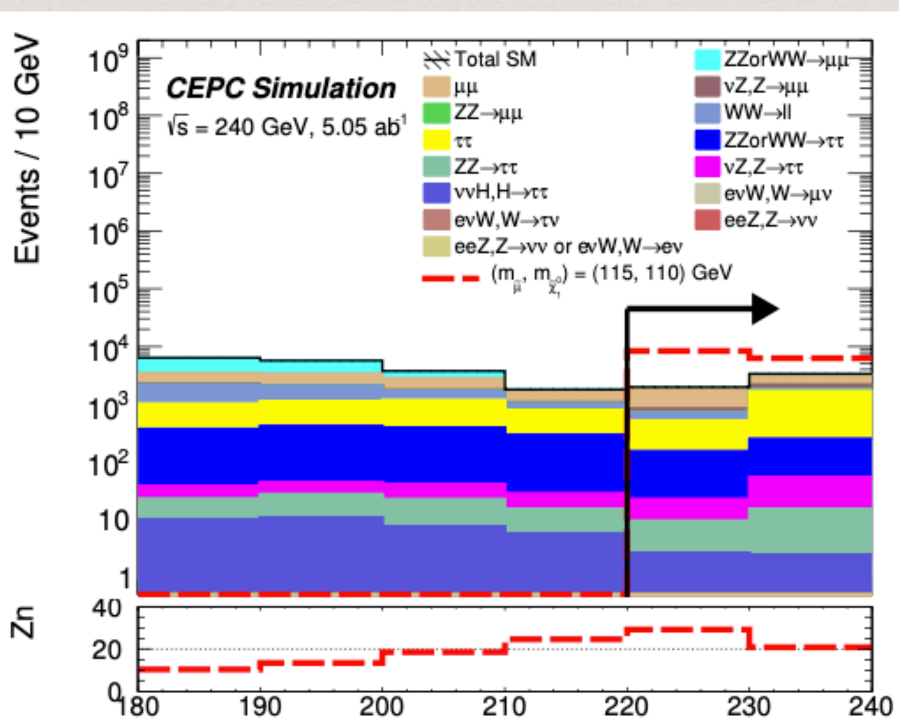




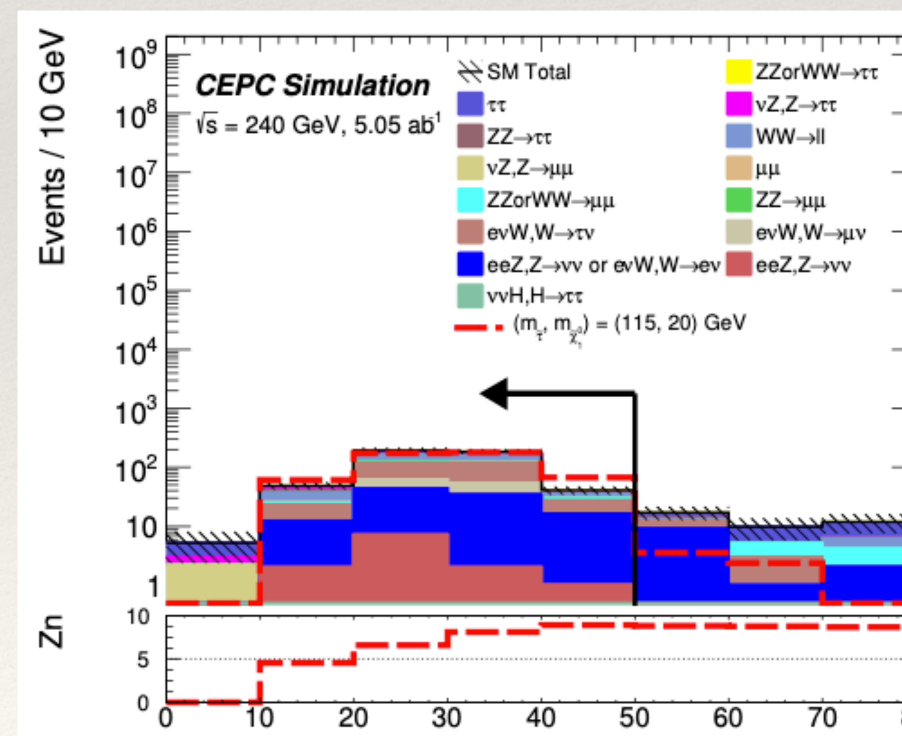


- Smuon is favored by muon g-2 excess; Stau is favored by dark matter relic density measurement.
- Explore soft smuon/stau in CEPC.
- For each case, 3 SR categories according to different mass splitting.
- For high dM, high μ/τ energy; For low dM, high Mrecoil

SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
== 2 muons (OS, both energy >0.5 GeV)		
$E_\mu > 40$ GeV	9 GeV$< E_\mu < 48$ GeV	-
$\Delta R(\mu, recoil) < 2.9$	$1.5 < \Delta R(\mu, recoil) < 2.8$	
$M_{\mu\mu} < 60$ GeV	$M_{\mu\mu} < 80$ GeV	-
$M_{recoil} > 40$ GeV	-	$M_{recoil} > 220$ GeV

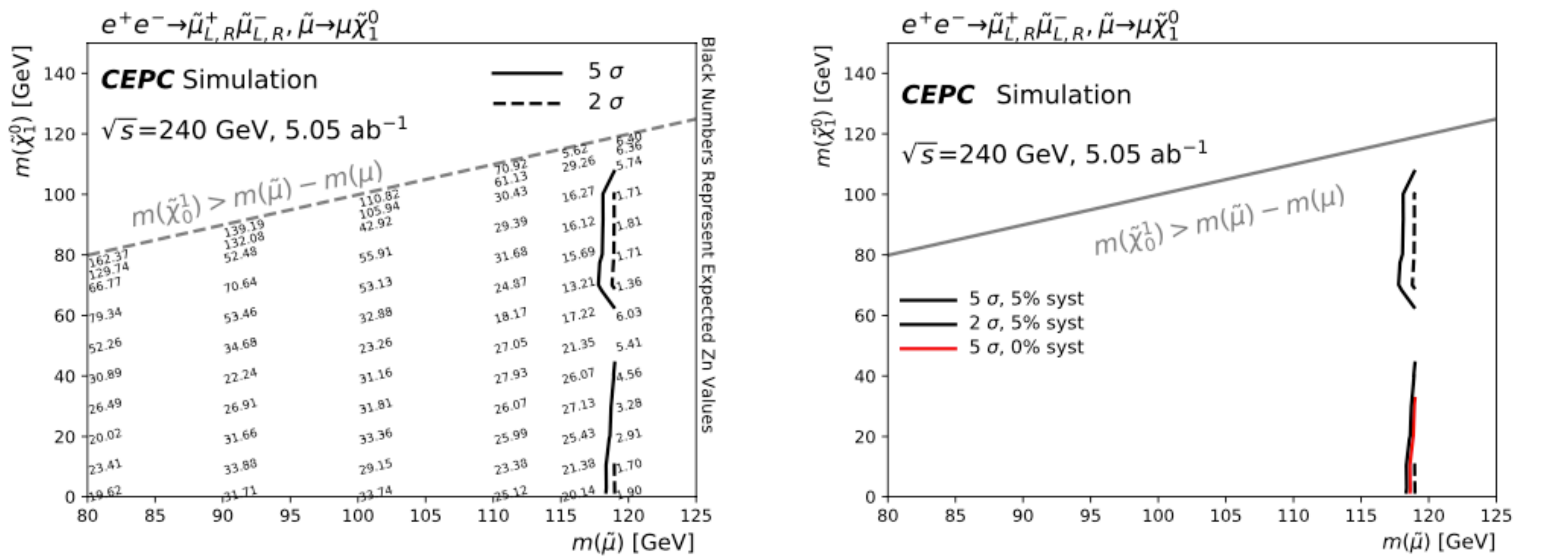


SR-lowDeltaM



SR-highDeltaM

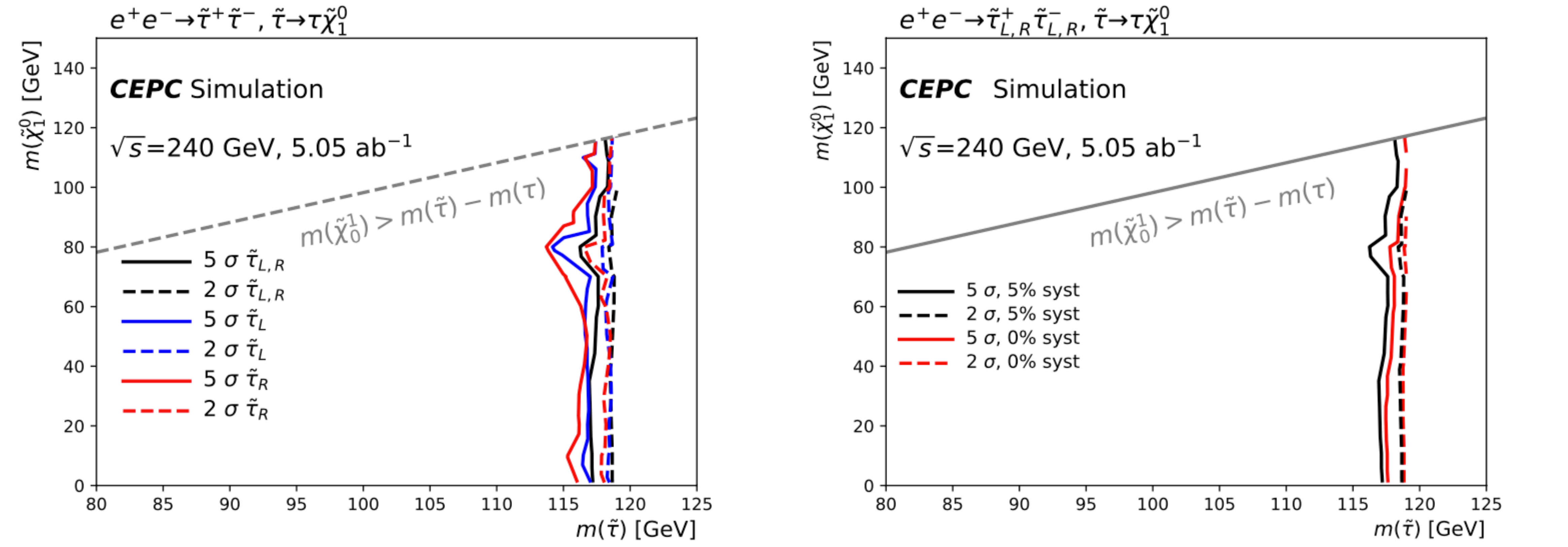
Smuon search



(a) systematic uncertainty = 5% (b) comparison between systematic uncertainty = 0% and 5%

- With flat 5% systematic, the discovery sensitivity can reach up to <u>117 GeV</u> in smuon mass. Fill in the LHC challenge region. No large impact from the uncertainty.

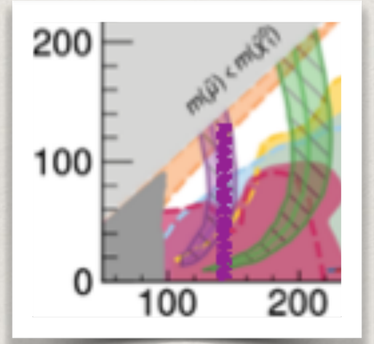
Stau search

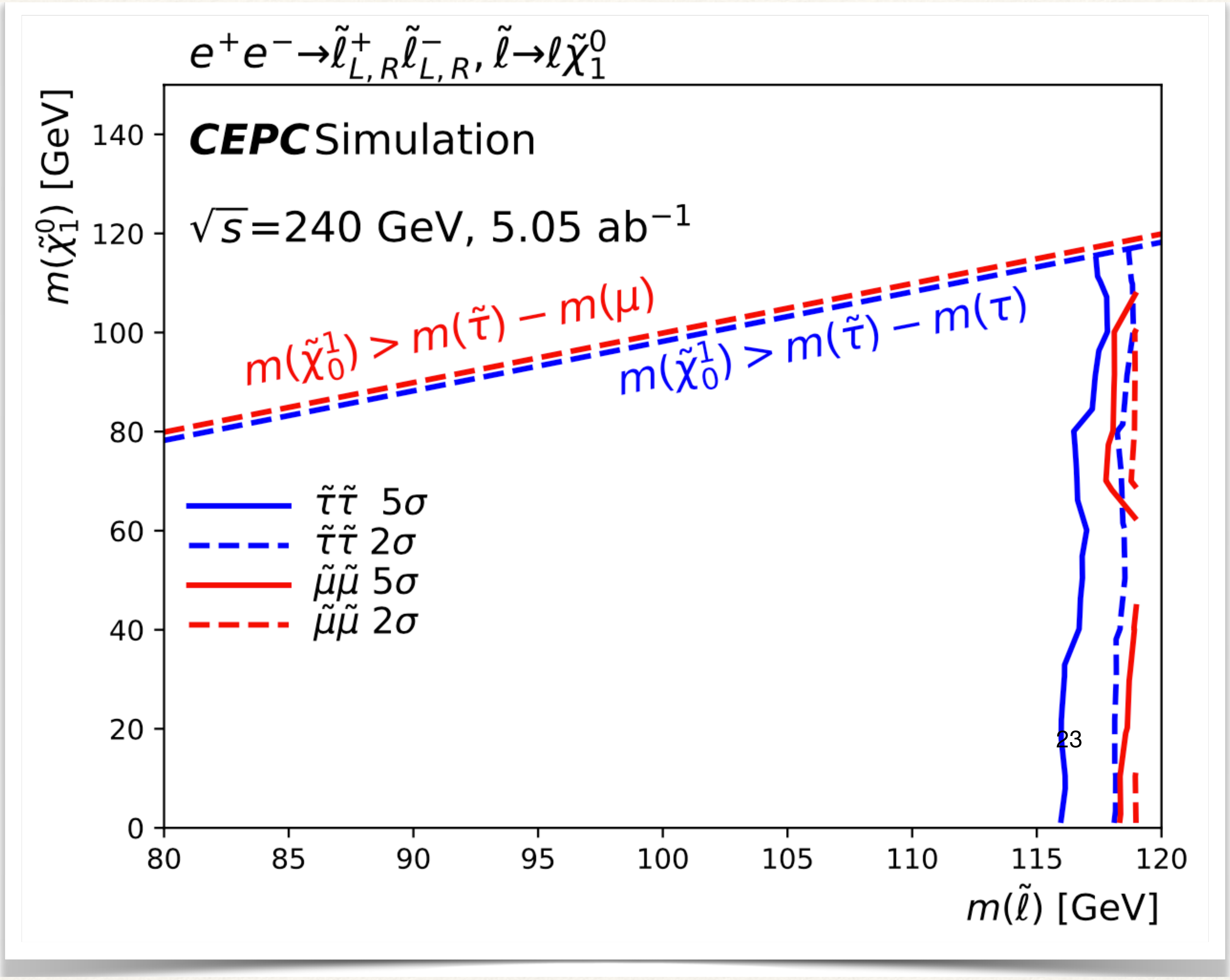


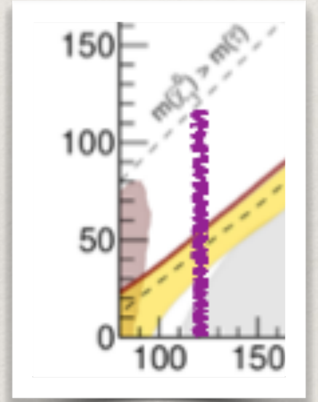
(a) systematic uncertainty = 5% (b) comparison between systematic uncertainty = 0% and 5 %

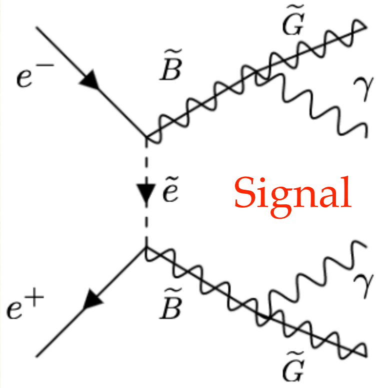
- For direct stau production with left-/right- combined(only) stau, assuming flat 5% systematic uncertainty, the discovery sensitivity can reach up to <u>116 GeV (113 GeV)</u> in stau mass. Great power to fill the LHC gap!

Smuon/Stau search



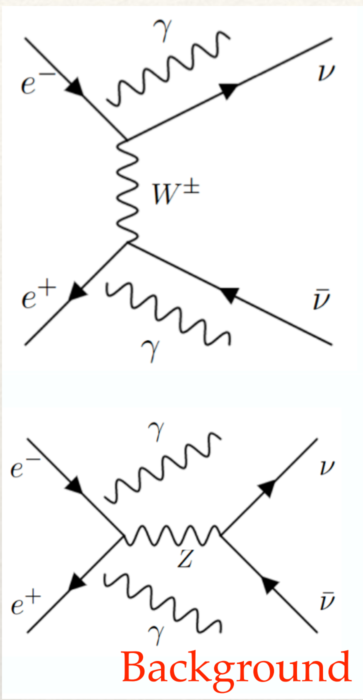




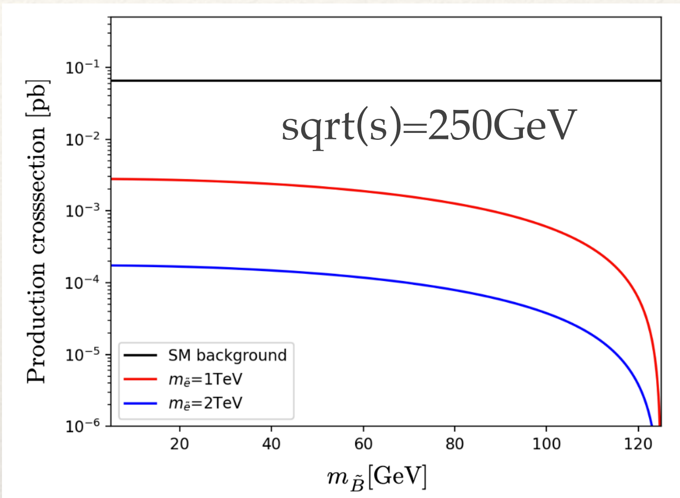


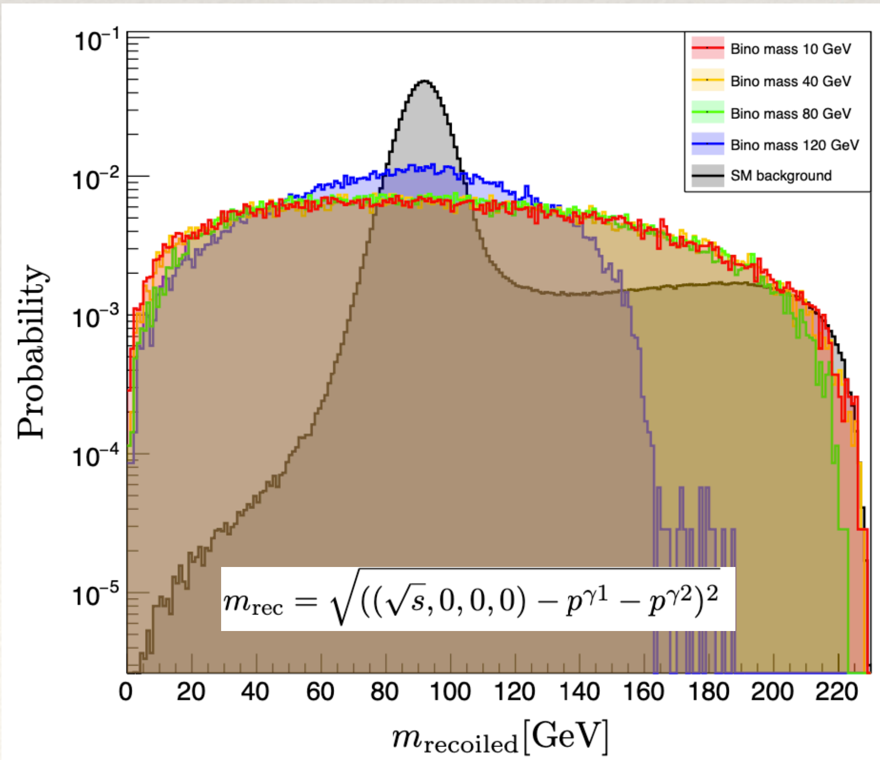
arxiv:2101.12131

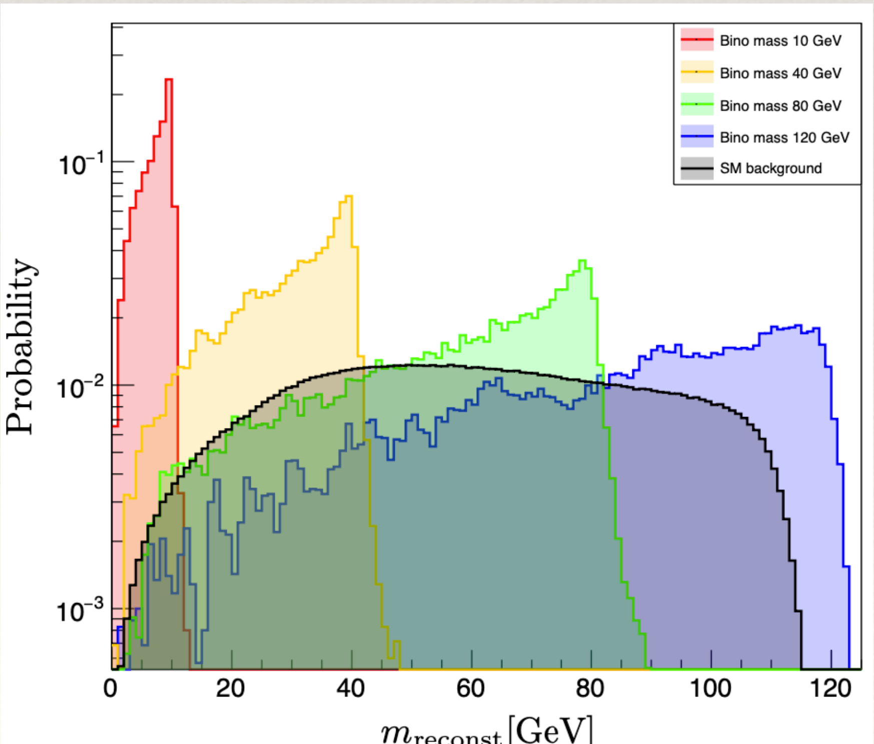
Bino-NLSP

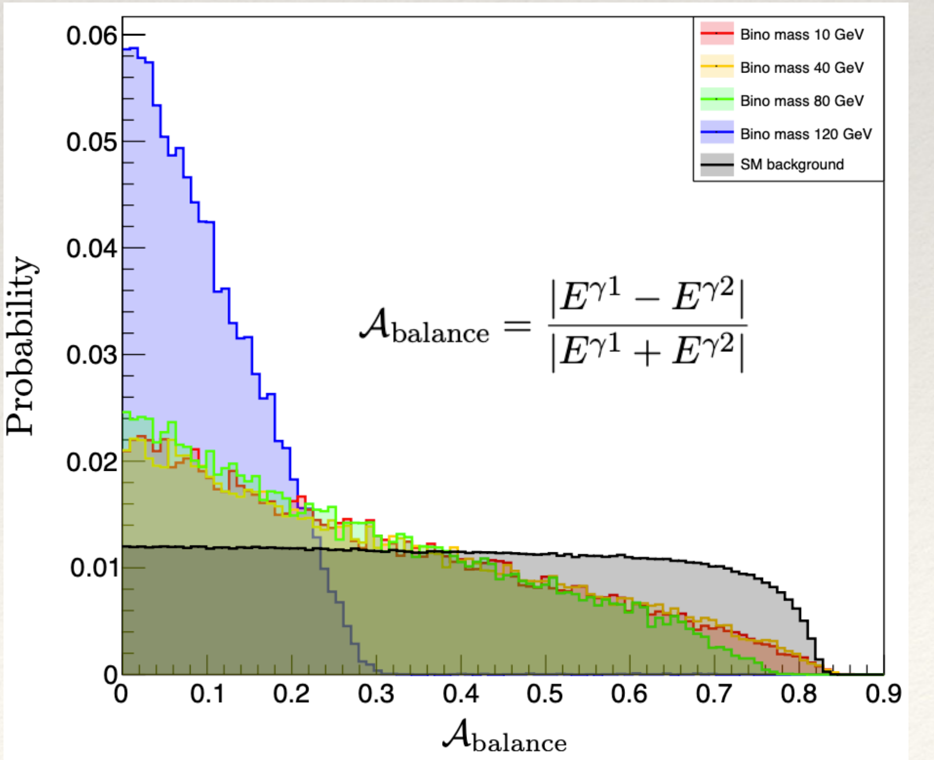


- Light bino pairs produced in lepton collider
- Scenario with gravitino as LSP and bino as NLSP
- Search for final states with 2photons+missing energy
- Background: SM t-channel W, s-channel Z
- Key discrimination: recoiled mass (reject Z), reconstructed bino mass, energy balance (small for heavy bino)

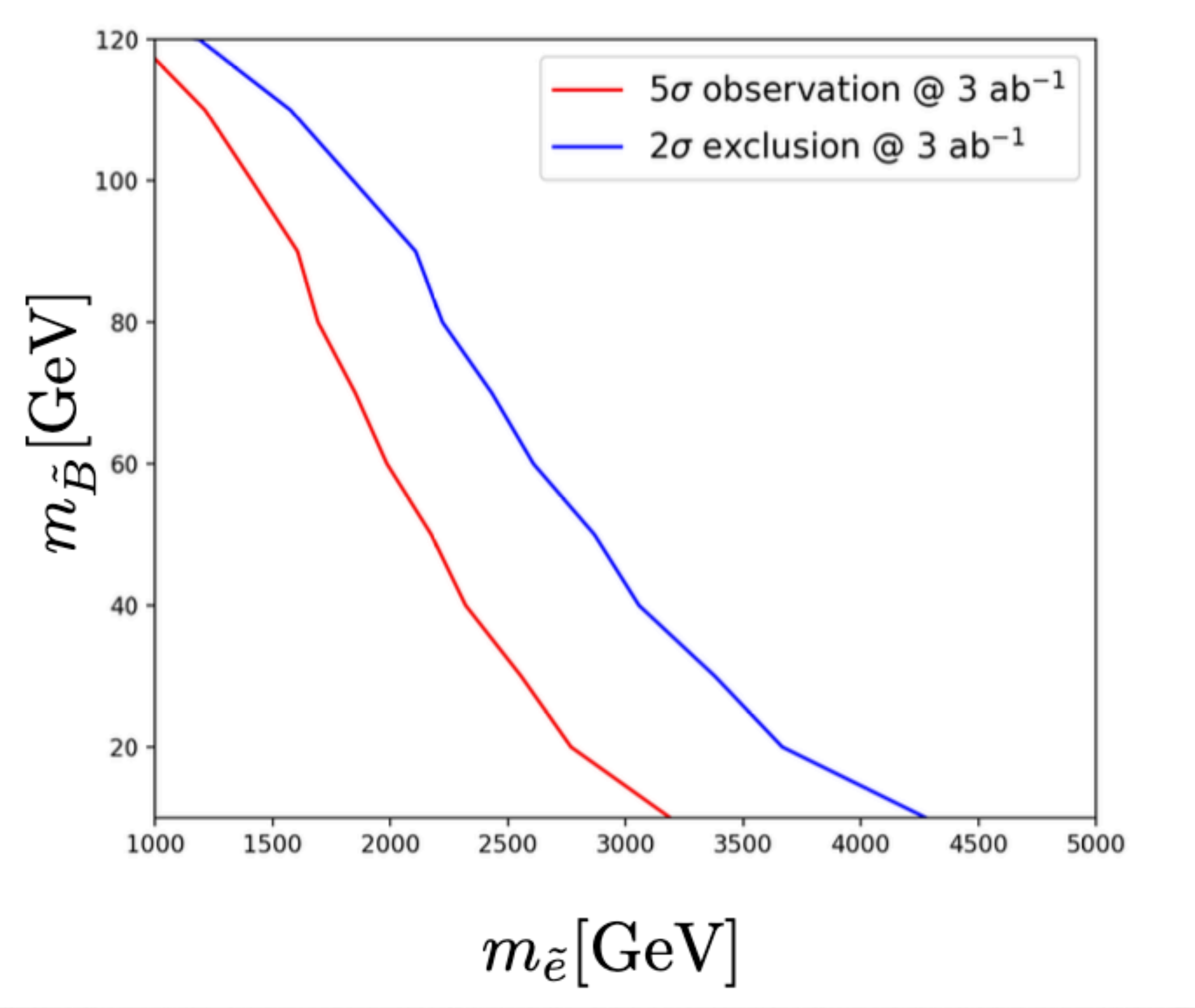






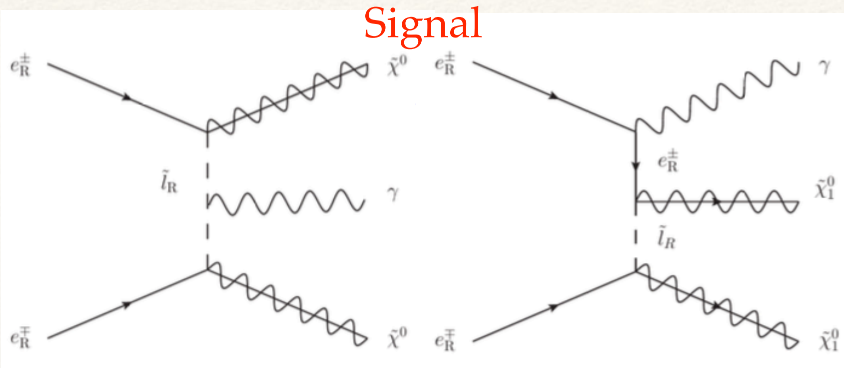


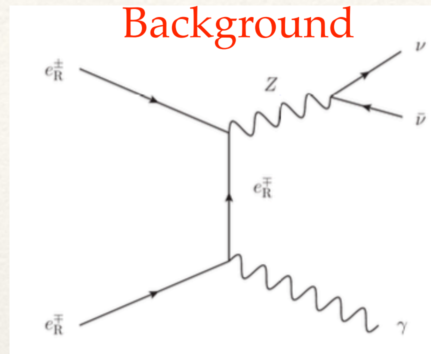
Bino-NLSP



- A bino mass around 100 GeV can be probed at the 5σ level for a slepton below 1.5 TeV.
- For a bino mass around 10 GeV, a slepton mass less than 3 TeV can be probed at the 5σ level, which is much beyond the LHC reach.

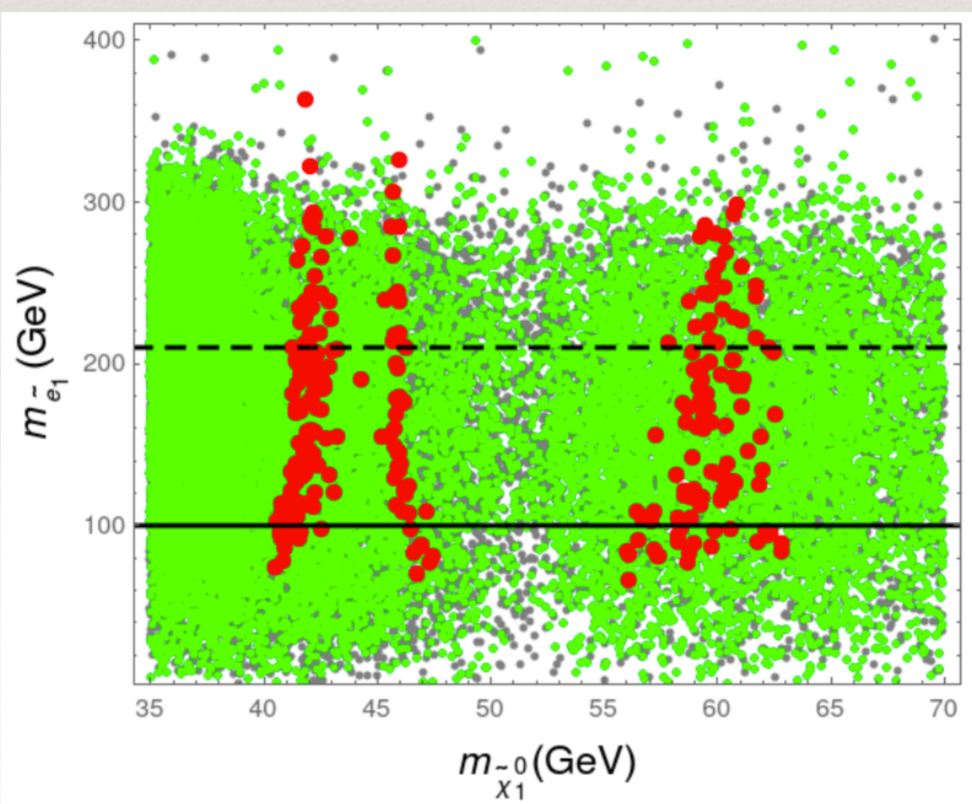
Right-handed *off-shell* selectron

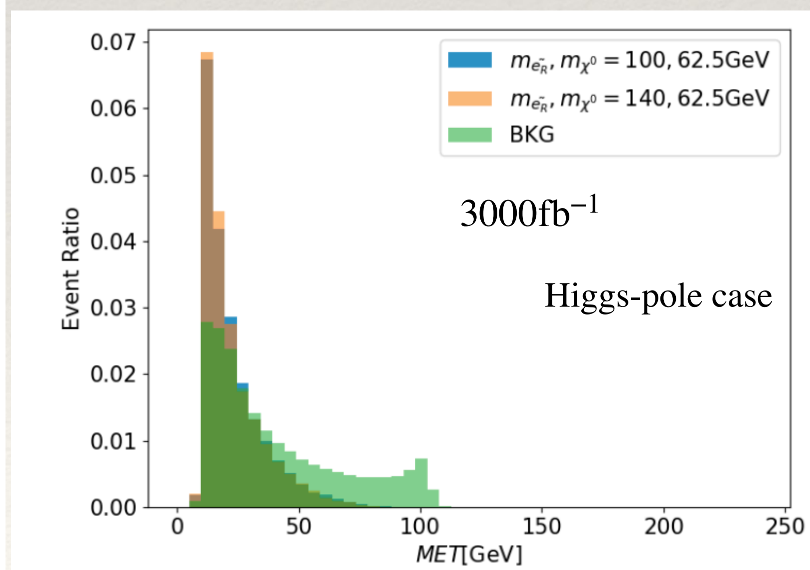


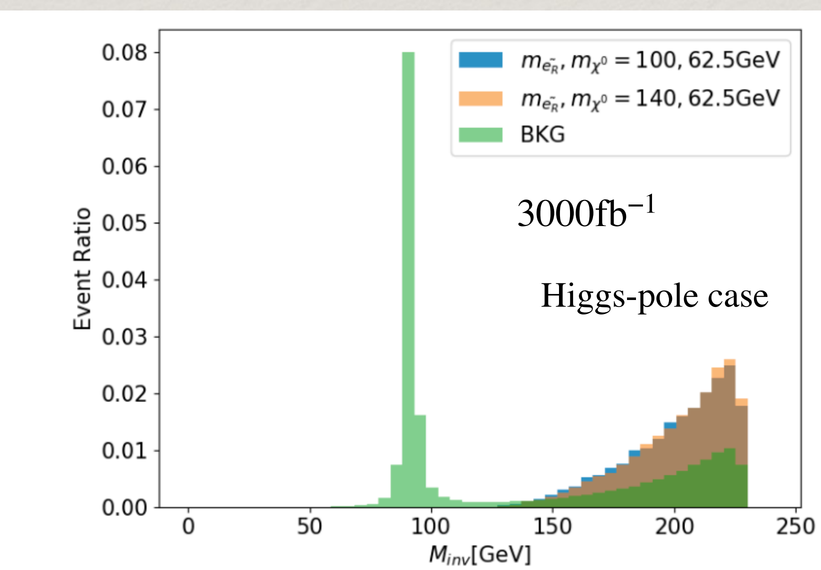


- Search for $e_R^+ e_R^- \to \tilde{\chi}^0_1$(bino) + $\tilde{\chi}^0_1$(bino) + γ with t-channel process mediated by an off-shell right-handed slepton
- Final states with missing transverse energy induced plus an emissive mono-photon
- Background: $Z(\nu\nu)\gamma$ (neglecting W as mediator)
- Photon isolation is applied

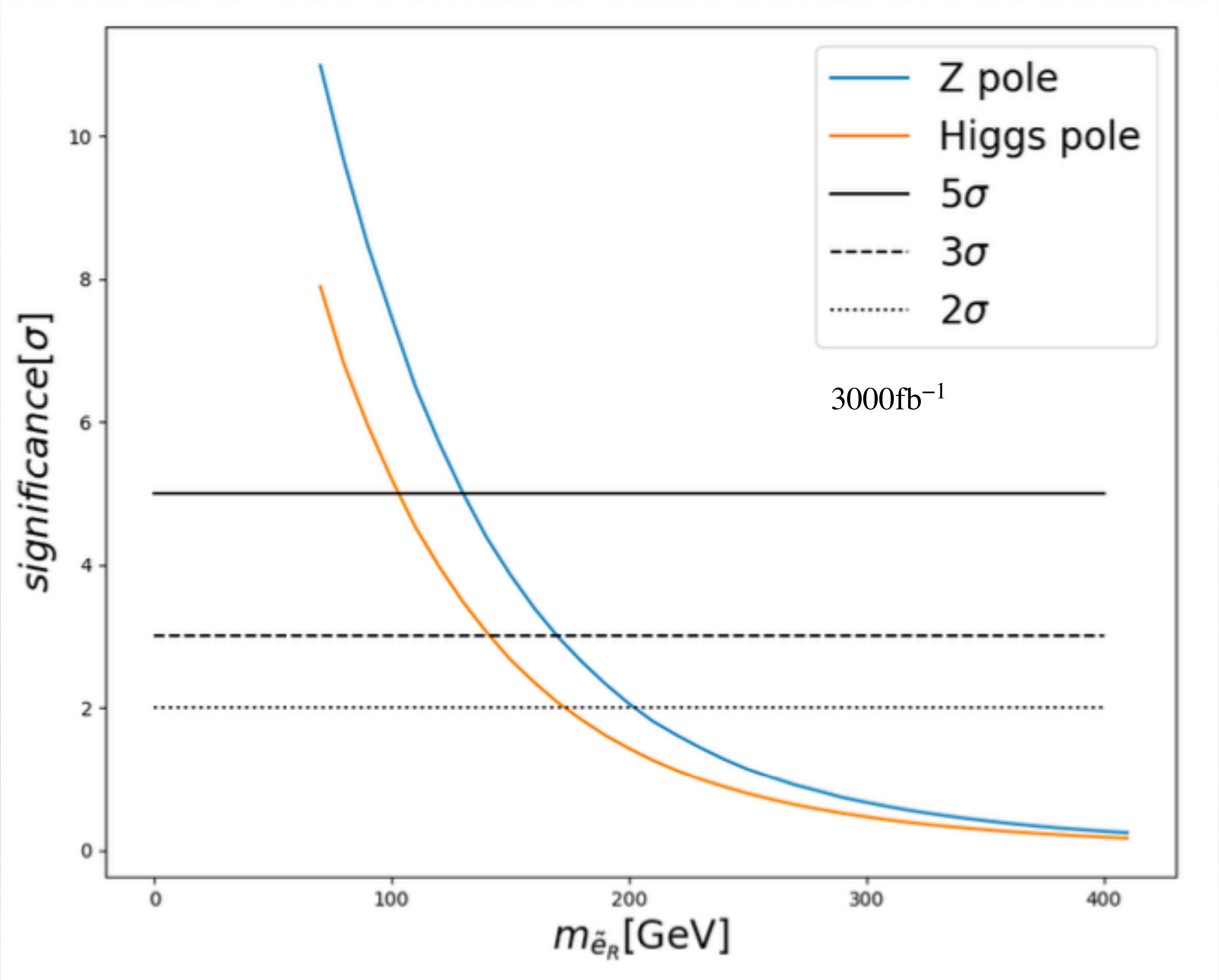
- Green: Higgs mass bounds and rare B-meson constraints
- Red: + dark matter relic density bound —> implies N1 mass matches Z-pole ($m_{\chi^0_1} \approx 1/2 m_Z$) and Higgs-pole ($m_{\chi^0_1} \approx 1/2 m_h$) .







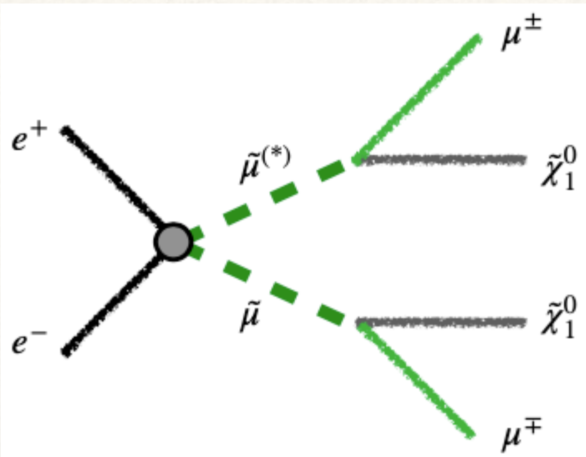
Right-handed *off-shell* selectron

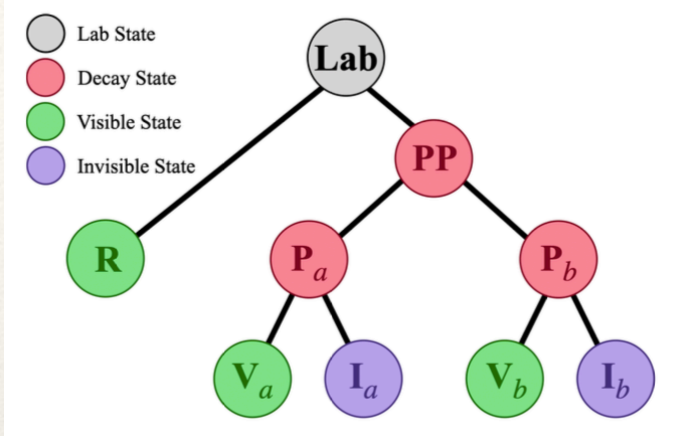


- For Z-pole (Higgs-pole) case, the right-handed selectron can be excluded up to 180 (140) GeV at 3σ.
- Nicely break through the collision energy and probe heavier selectrons.

arxiv:2211.08132

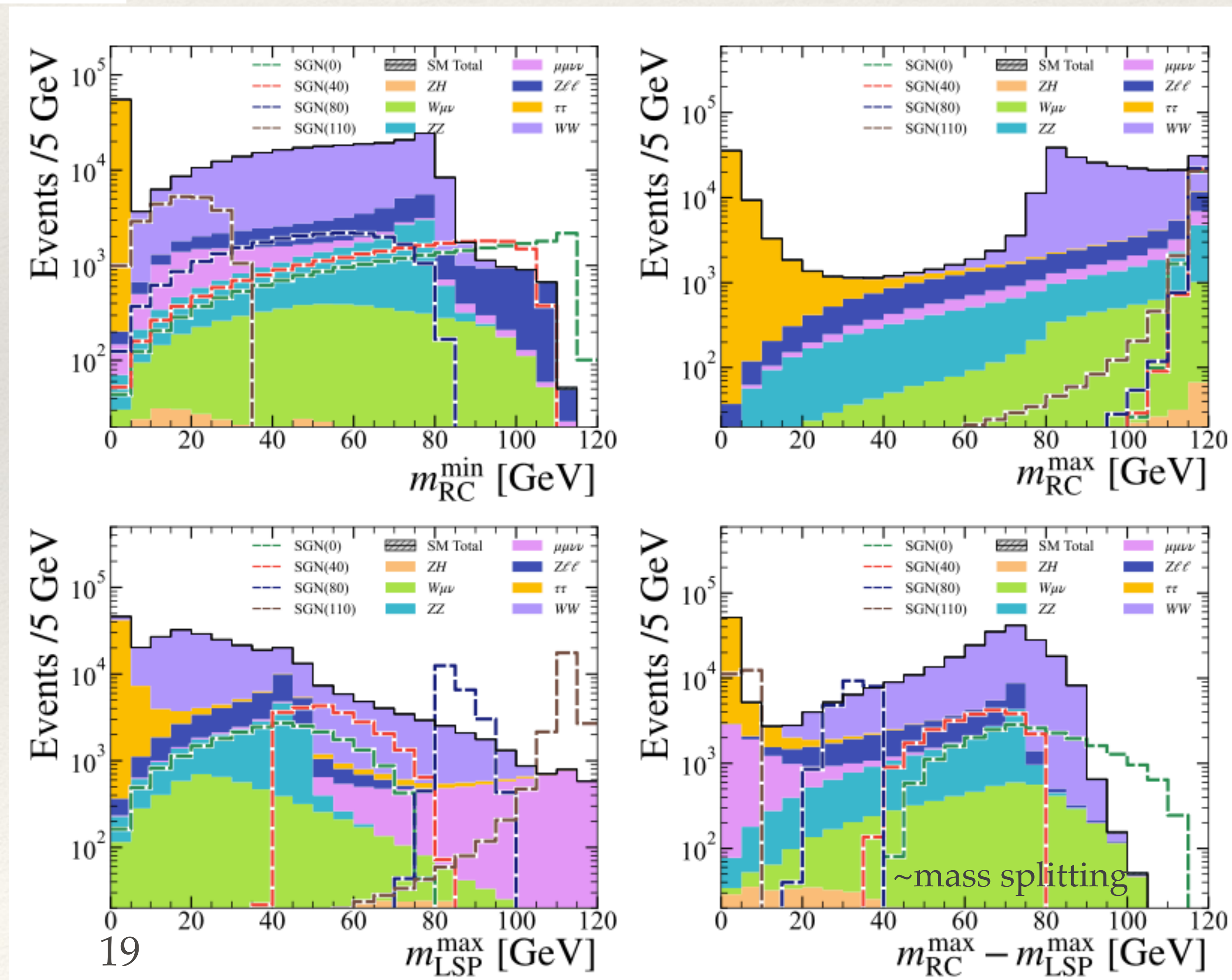
Off-shell Smuon



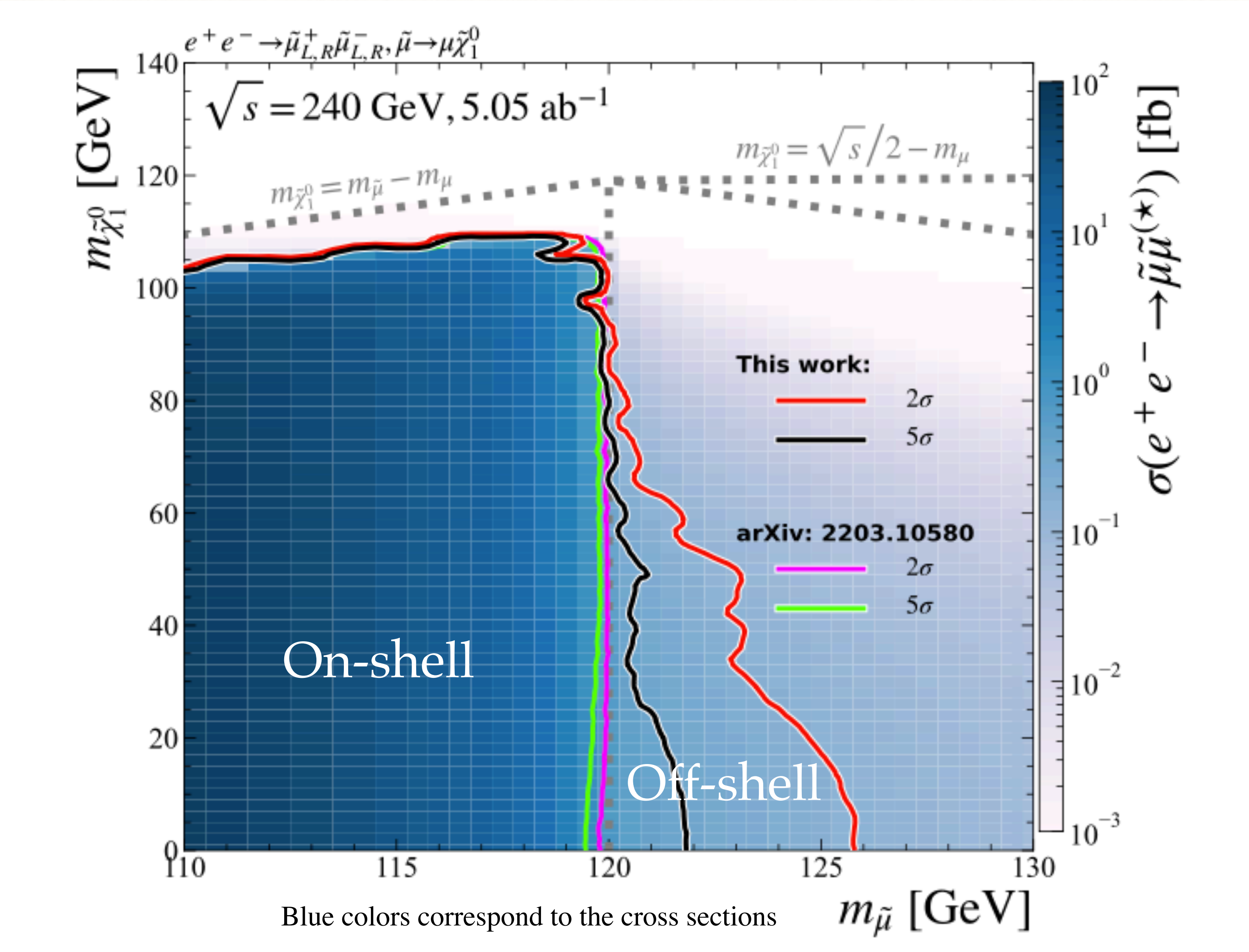


SR	SRL-01	SRL-02	SRM-01	SRM-02
	$m_{\mathrm{RC}}^{\mathrm{min}} > 85$	$m_{\mathrm{RC}}^{\mathrm{max}} > 117$ $m_{\mathrm{RC}}^{\mathrm{min}} > 95$ $E_{\mu^\pm} \in [50, 70]$	$m_{\mathrm{RC}}^{\mathrm{min}} > 85$ $m_{\mathrm{LSP}}^{\mathrm{max}} \in [40, 60]$ $m_{\mathrm{RC}}^{\mathrm{max}}(40) > 110$	$m_{\mathrm{LSP}}^{\mathrm{max}} \in [50, 70]$ $m_{\mathrm{RC}}^{\mathrm{max}}(40) > 110$ $m_{\mathrm{RC}}^{\mathrm{min}}(40) > 100$
SM total	7532 ± 86	900 ± 30	2079 ± 45	970 ± 31
SGN(0)	38900	10900	6360	2270
SGN(40)	23800	1410	22100	10200
SGN(80)	0	0	0	0
SGN(110)	0	0	0	0

- Study a specific decay topology: the system with a pair of massive particles P, each decaying into visible V and invisible particle(s) I: i.e. smuon pair production
- The recoil system R comprises all observable particles that are not assigned to the main system, i.e. ISR, imperfect object recon.
- This analysis is focusing on off-shell smuon region!
- A new set of kinematics are developed reconstruct the mass of semi-invisible decaying particles
- 12 SR bins are designed targeting various kinematic regions



Off-shell Smuon



- Large drop of cross-section when entering into the off-shell region.
- The detection (discovery) limit for a smuon can reach up to 126 GeV (122 GeV). The limit break through the line of $\sqrt{s}/2$ and go into the off-shell region.

Summary

- Various prospective searches for electroweakinos have been explored with CEPC experimental environment.
- The discovery potential is typically restricted by the detector's kinematic limitations. However, in-depth studies of off-shell or t-channel interactions can surpass these energy constraints and provide insights into heavier particles.
- These studies can serve as valuable references for other lepton colliders such as the ILC and FCC-ee etc.
- A lepton collider is not solely a precision-measurement machine; it possesses a unique advantage in exploring the challenging scenarios that may prove difficult for hadronic colliders.

Extra slides