中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Prospects of electroweakino and slepton search at CEPC

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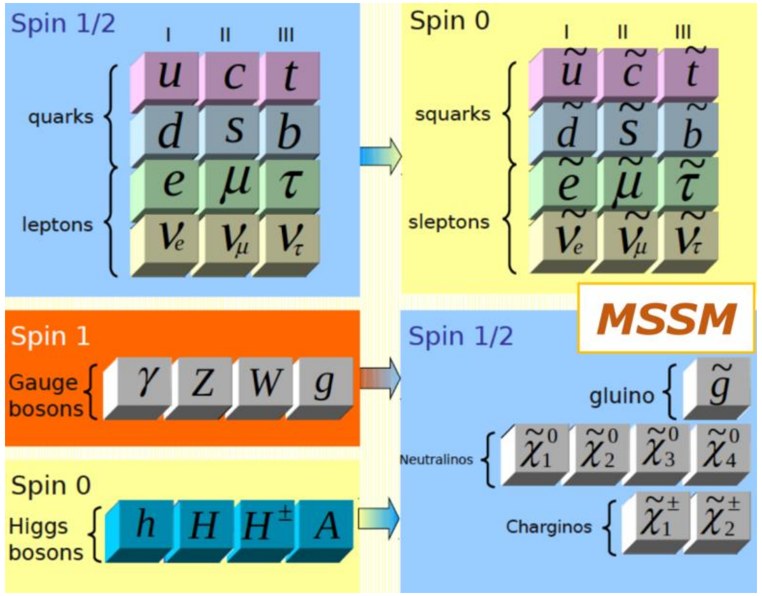
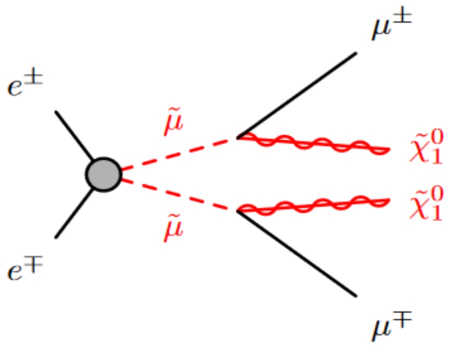
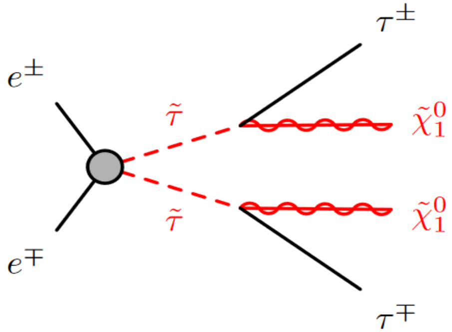
Supersymmetry

- Supersymmetry describes physics beyond Standard Model, with a symmetry between bosons and fermions.
  - Hierarchy problem
  - Grand unification of gauge couplings
  - Dark matter candidate
- R-parity: $P_R = (-1)^{3(B-L)+2S}$: Sparticles→negative P_R, SM particles→positive P_R.
  - R conserved: Sparticles are produced in pairs, Lightest SUSY particle (LSP) is stable as a dark matter candidate.
- Minimal Supersymmetric Standard Model (MSSM)
  - One superpartner for each SM particle

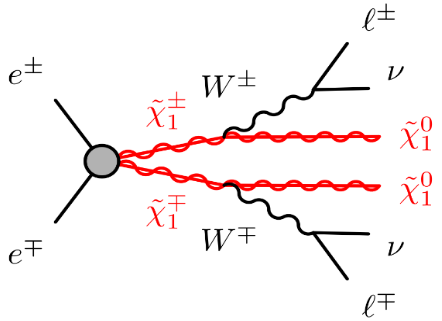




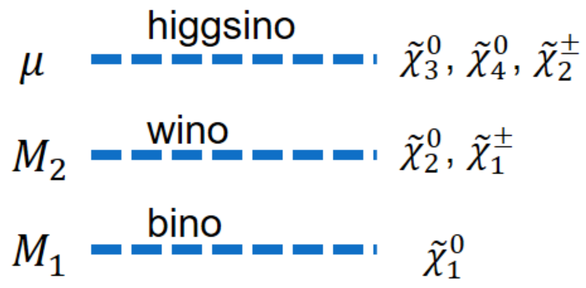
- Direct production of smuon pair
  - Final state: 2 opposite-sign(OS) muon and Missing transverse energy E_T^{miss}

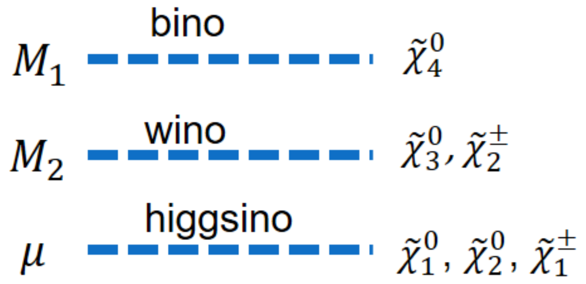


- Direct production of stau pair
  - Final state: 2 OS tau and E_T^{miss}



- Production of chargino pair
  - Bino LSP case
  - Higgsino LSP case
  - $W^{\pm}$ decays leptonically
  - Final state: 2 OS muon and E_T^{miss}

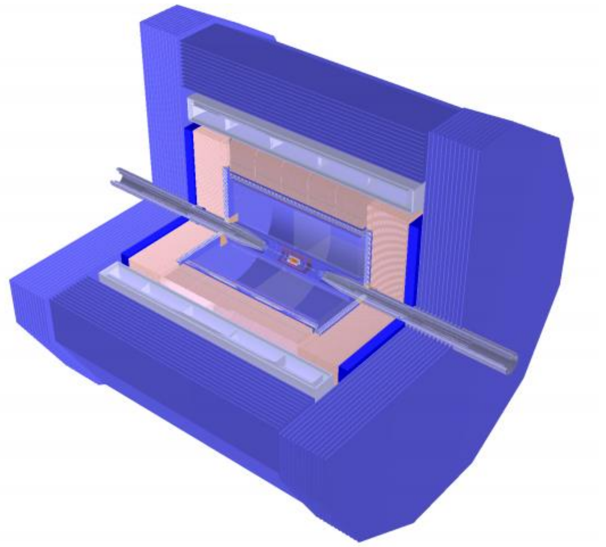




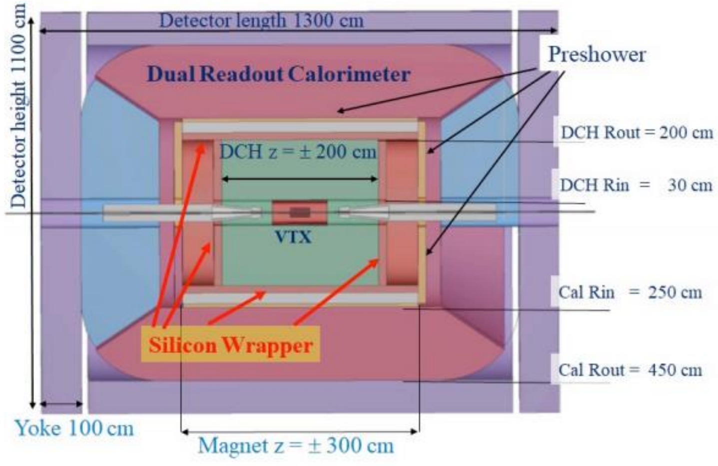
arXiv:2203.10580
Chinese Phys. C 46 013104

CEPC

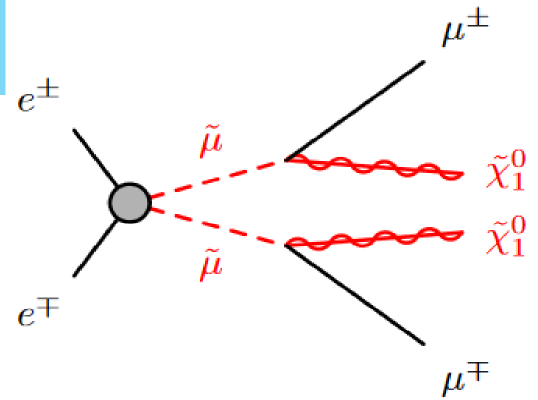
- CEPC(baseline)
  - A particle flow oriented detector uses an ultra high granularity calorimetry system, a low material silicon tracker and a 3 Tesla magnitude field.
  - E_{cm}: 240 GeV, Luminosity: 5050 fb^{-1}



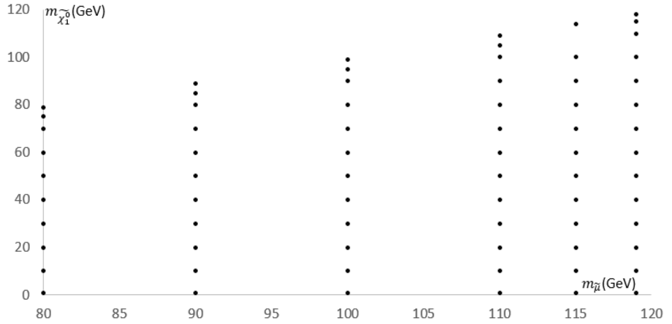
- Software Chain
  - Signal samples generation: MadGraph+Pythia
  - Standard Model sample generation: Whizard+Pythia
  - Simulation: MokkaC
  - Reconstruction tool: Marlin



Direct Smuon production



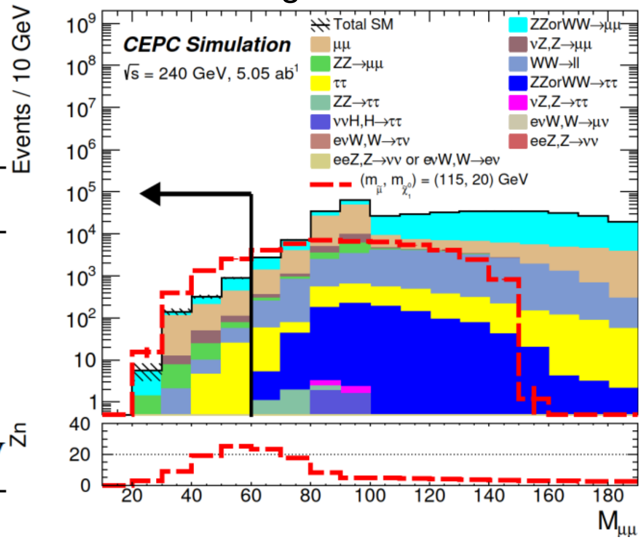
- The signal grid is in the $\tilde{\mu}$ and LSP mass phase space.
- The $\tilde{\mu}$ mass ranges from 80 GeV (LEP limit) to ~<120 GeV (CEPC $\sqrt{s}/2$), the LSP mass ranges from 1 GeV (nearly massless) to ~<$\tilde{\mu}$ mass.
- The kinematic distributions of signals are affected by $\Delta M(\tilde{\mu}, \tilde{\chi}_1^0)$.
- Performed a multi-dimension optimization, and defined 3 signal regions.
- Large DeltaM, high μ p_T, low M_{recoil}. Small DeltaM, low μ p_T, high M_{recoil}.
- Recoil system: All final state objects except the 2 OS leptons.
- For each signal point in the phase space, choose the signal region with highest Zn.



$$Zn = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+\sigma_b^2)}{b^2+(s+b)\sigma_b^2}\right] - \frac{b^2}{\sigma_b^2}\ln\left[1+\frac{\sigma_b^2 s}{b(b+\sigma_b^2)}\right]\right)\right]^{1/2}$$

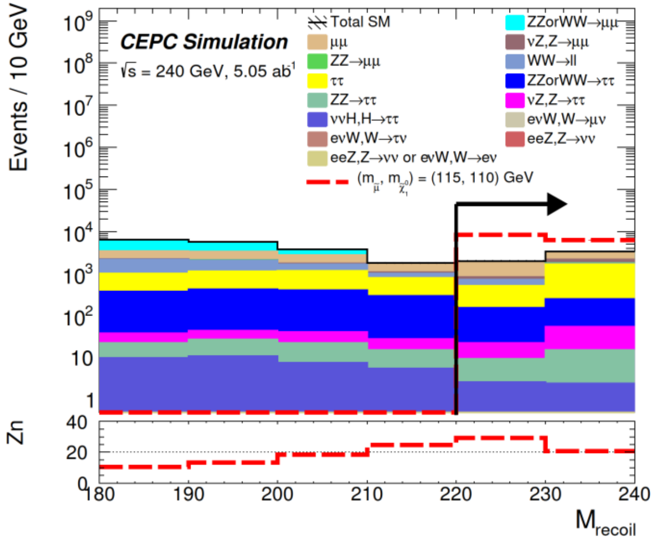
SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
== 2 muons (OS, both energy >0.5 GeV)		
$E_\mu > 40$ GeV	9 GeV$< E_\mu < 48$ GeV	-
$\Delta R(\mu, recoil) < 2.9$	$1.5 < \Delta R(\mu, recoil) < 2.8$	
$M_{\mu\mu} < 60$ GeV	$M_{\mu\mu} < 80$ GeV	-
$M_{recoil} > 40$ GeV	-	$M_{recoil} > 220$ GeV

highDeltaM



reject $\mu\mu$ from Z boson

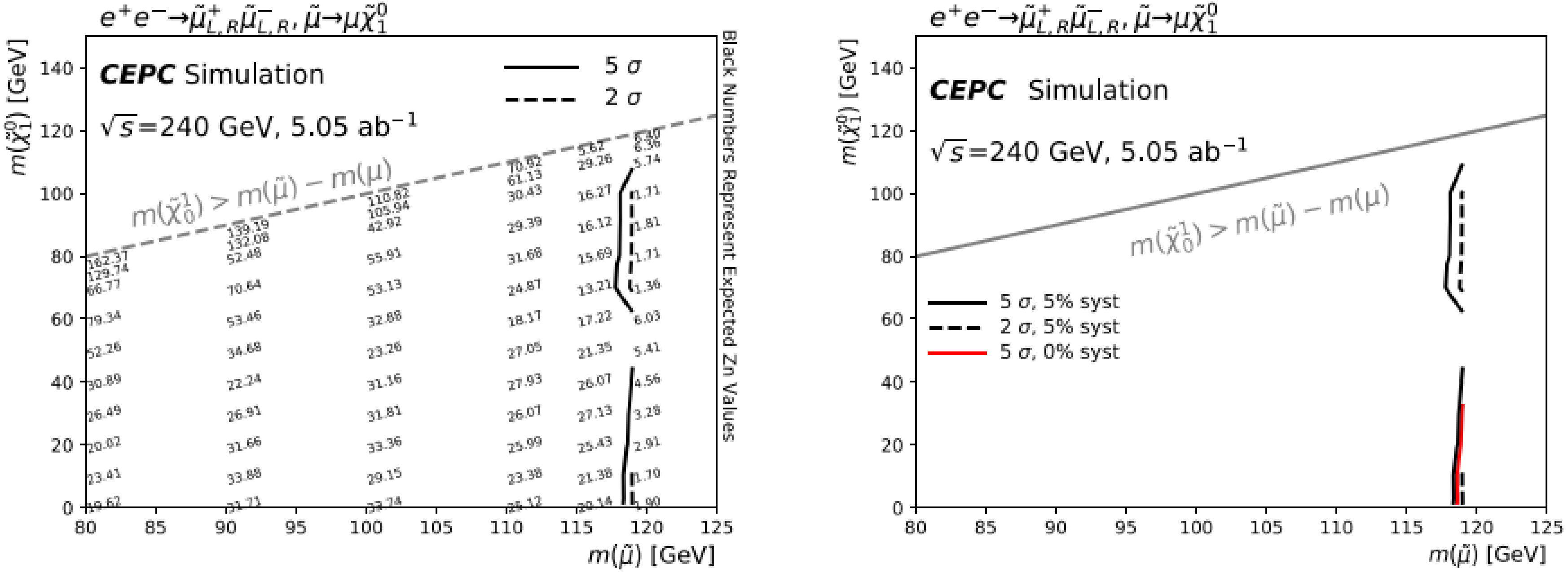
lowDeltaM



lowDeltaM → high M_{recoil}

Direct Smuon production

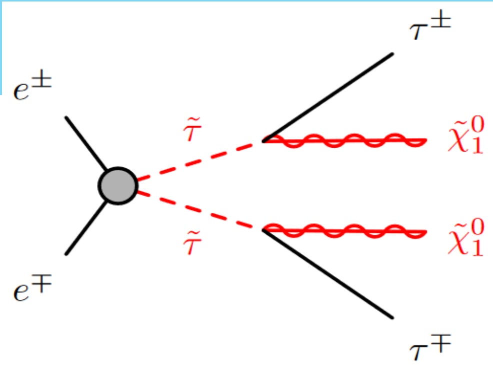
- For direct smuon production, assuming flat 5% systematic uncertainty, the discovery sensitivity can reach 117 GeV.
- Systematic uncertainty slightly affect the sensitivity.

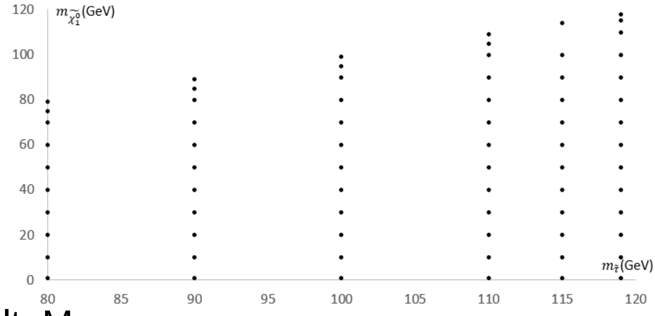


(a) systematic uncertainty = 5% (b) comparison between systematic uncertainty = 0% and 5%

Direct Stau production

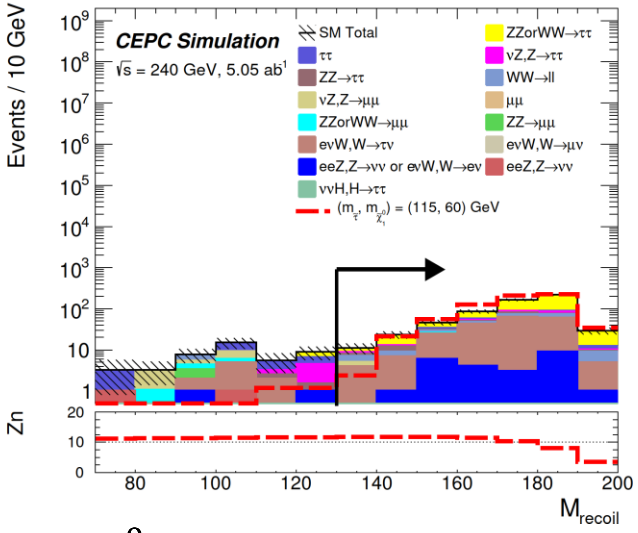
- The signal grid is in the $\tilde{\tau}$ and LSP mass phase space.
- The $\tilde{\tau}$ mass ranges from 80 GeV (LEP limit) to ~<120 GeV(CEPC $\sqrt{s}/2$), LSP mass ranges from 1 GeV(nearly massless) to ~< $\tilde{\tau}$ mass.
- The kinematic distributions of signals are influenced by $\Delta M(\tilde{\tau}, \tilde{\chi}_1^0)$, so we define 3 signal regions.
- For each signal point, use the signal region with highest Zn.
- Use the minus(positive) charged leading track to represent the $\tau^-(\tau^+)$ for simplicity.





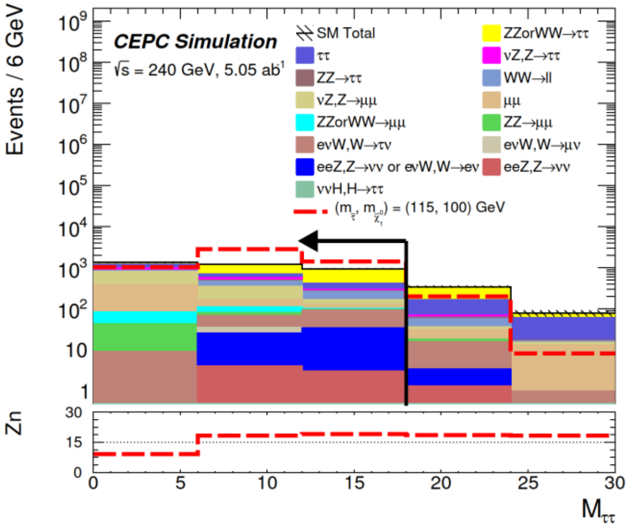
SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$E_{\tau^{\pm}}$ <34 GeV	$E_{\tau^{\pm}}$ <15 GeV	
sumP_T >70 GeV	sumP_T >40 GeV	-
-	$0.2 < \lvert\Delta\phi(\tau,\tau)\rvert < 1.2$	$\lvert\Delta\phi(\tau,\tau)\rvert > 0.6$
$2.4 < \lvert\Delta\phi(\tau^{\pm},recoil)\rvert < 3$		$\lvert\Delta\phi(\tau^{\pm},recoil)\rvert > 2.3$
$0.4 < \Delta R(\tau,\tau) < 1$	$0.4 < \Delta R(\tau,\tau) < 1.6$	-
$\Delta R(\tau^{\pm},recoil) < 3.1$		$\Delta R(\tau^{\pm},recoil) < 2.9$
$M_{\tau\tau}$ <50 GeV	$M_{\tau\tau}$ <40 GeV	$M_{\tau\tau}$ <18 GeV
M_{recoil} >90 GeV	M_{recoil} >130 GeV	M_{recoil} >210 GeV

midDeltaM



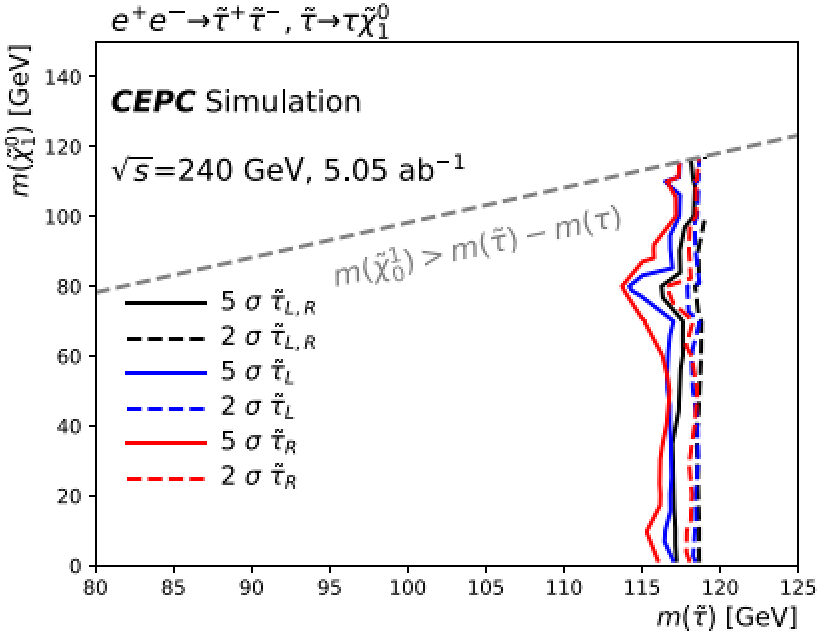
$\tilde{\chi}_1^0$ and not used particle from tau → M_{recoil}

lowDeltaM

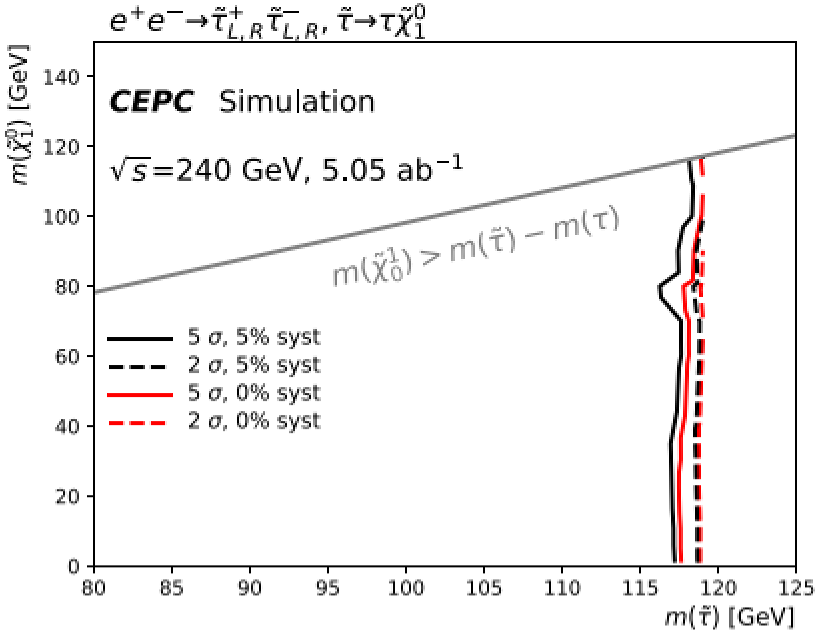


Soft τ → low $M_{\tau\tau}$

- For direct stau production, with left/right-handed combined(only) stau, assuming flat 5% systematic uncertainty, the discovery sensitivity can reach 116(113) GeV.
- Systematic uncertainty slightly affect the sensitivity.

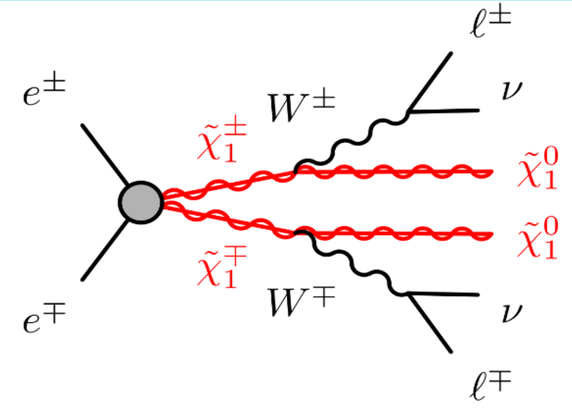


(a) systematic uncertainty = 5%

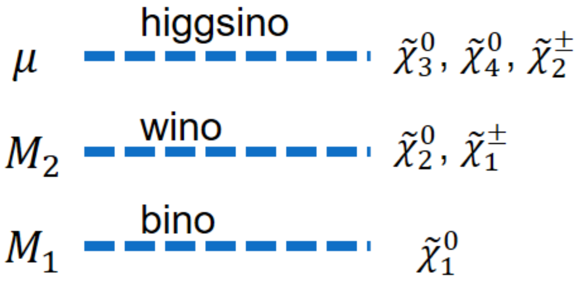


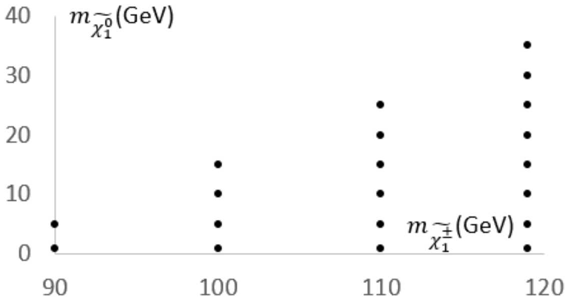
(b) comparison between systematic uncertainty = 0% and 5 %

Chargino pair production(Bino LSP)

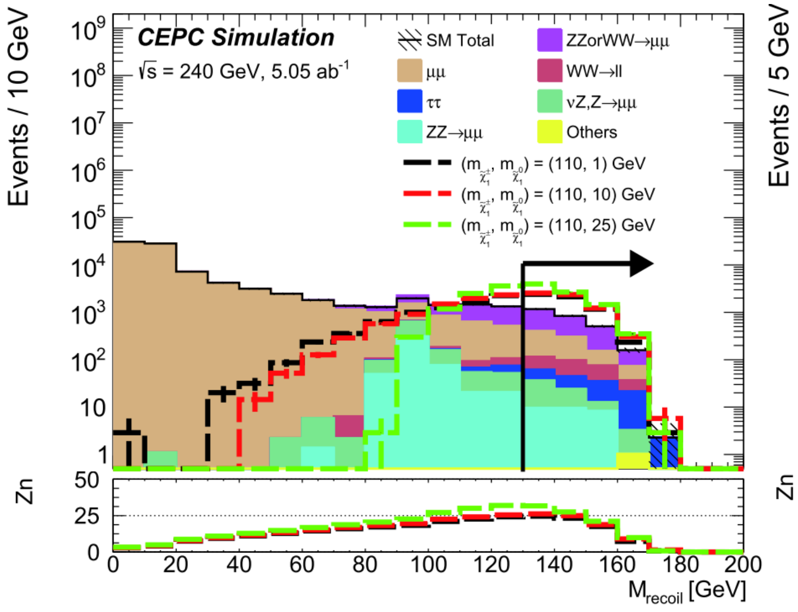


- The signal grid is in the wino($\tilde{\chi}_1^{\pm}$) and bino($\tilde{\chi}_1^0$) mass phase space.
- The wino mass is bounded by LEP ans CEPC limits, bino mass is bounded by wino mass – $W^{\pm}$ mass.
- Consider final states with 2 OS μ with energy larger than 10 GeV.

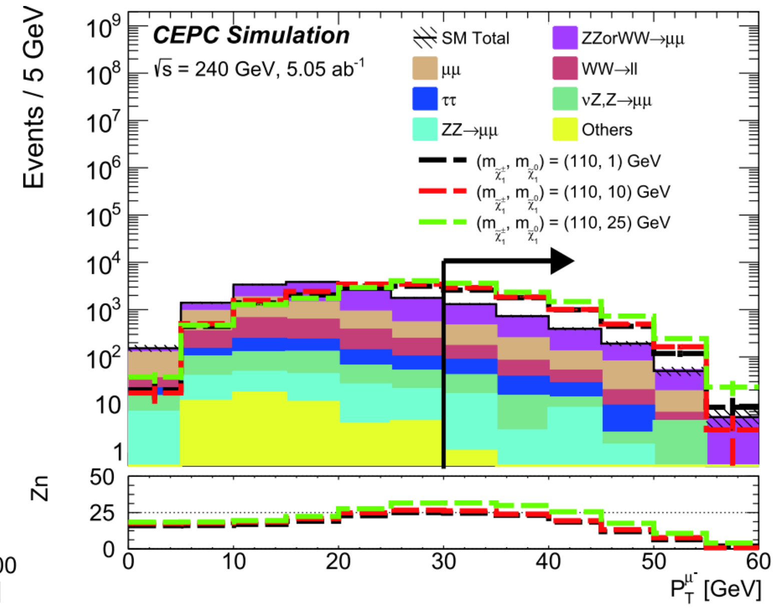




Signal regions
== 2 muons (OS)
$E_{\mu^{\pm}} > 10$ GeV
$0.4 < \Delta R(\mu^+, \mu^-) < 1.6$
$P_T^{\mu^{\pm}} > 30$ GeV
$M_{\text{recoil}} > 130$ GeV



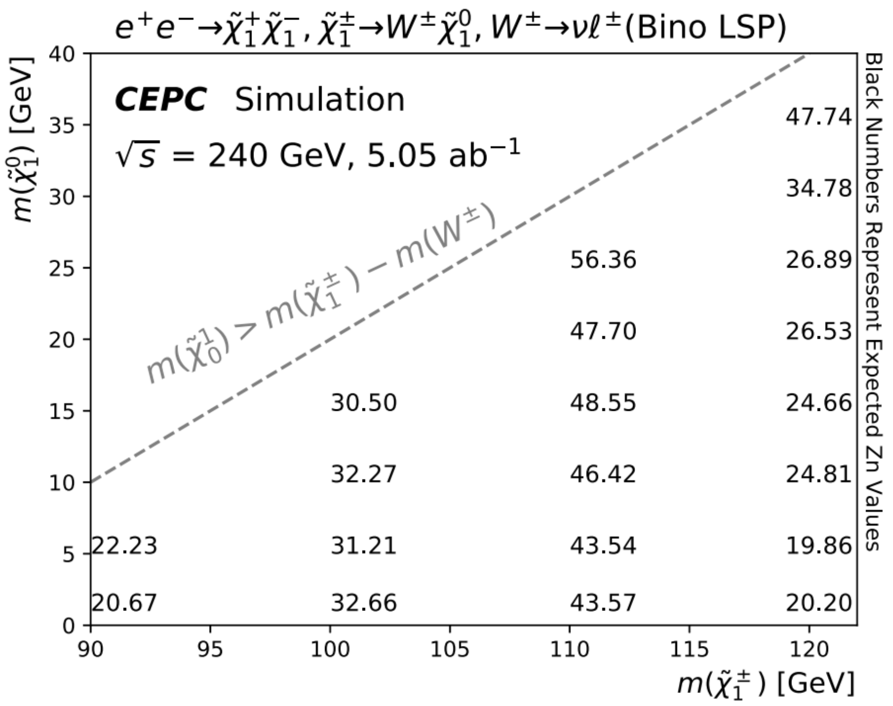
ν and $\tilde{\chi}_1^0 \rightarrow M_{recoil}$



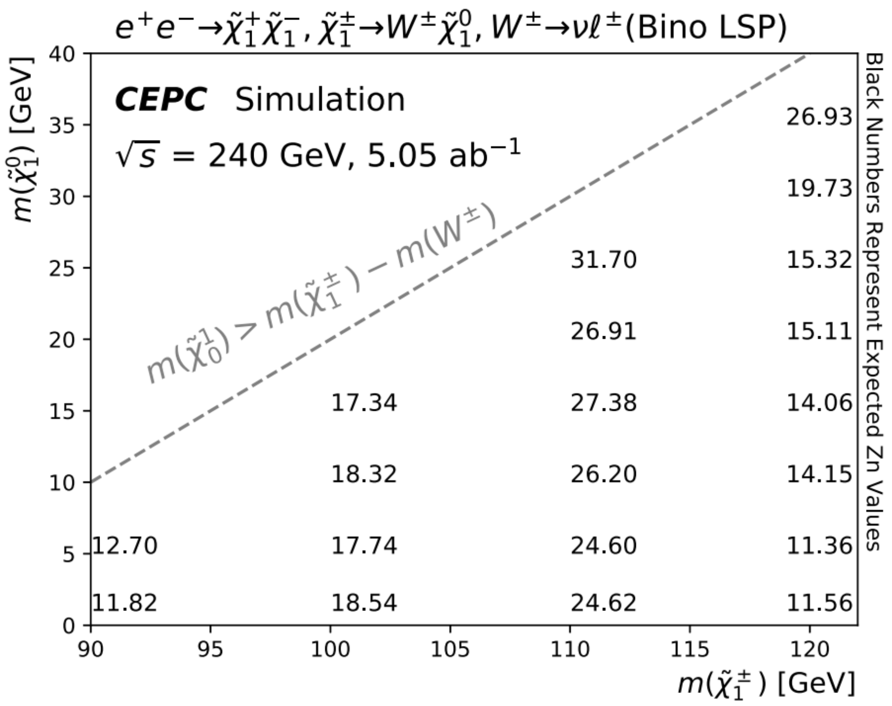
μ from on-shell W isn't very soft

Chargino pair production(Bino LSP)

- The discovery potential can reach the kinematic limit $\sqrt{s}/2$ and isn't sensitive to systematic uncertainties.



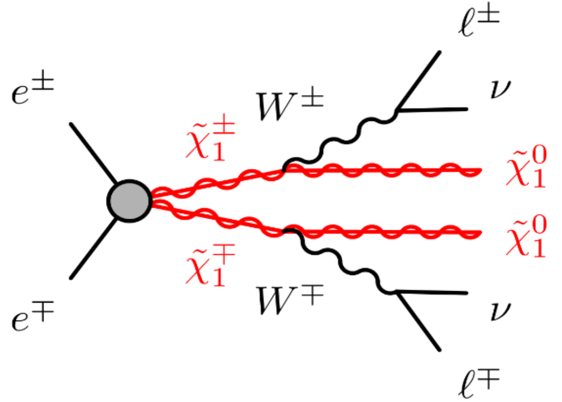
(a) systematic uncertainty = 0%

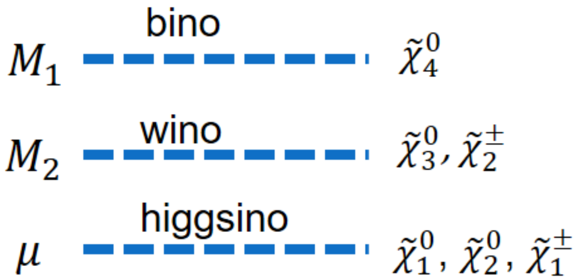


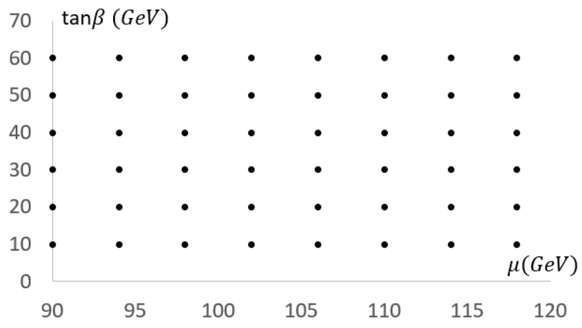
(b) systematic uncertainty = 5%

Chargino pair production(Higgsino LSP)

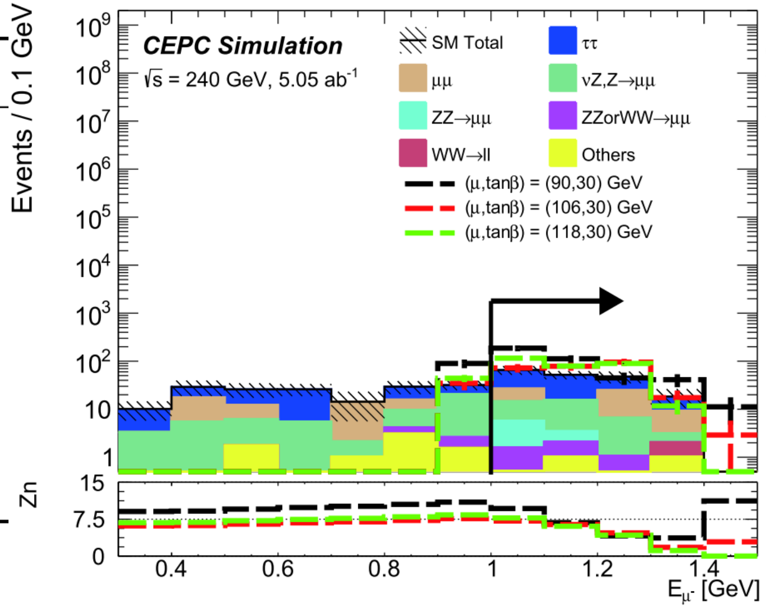
- The signal grid is in μ and $\tan\beta$ phase space.
- $|\Delta\phi(\mu^{\pm}, recoil)| < 2.9$ suppresses muon and recoil system back to back.
- $|\Delta\phi(\mu^{+}, \mu^{-})| < 1.4$ rejects 2 muons back to back
- small $\Delta M(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{0}) < 2$ GeV → soft muon, large M_{recoil}

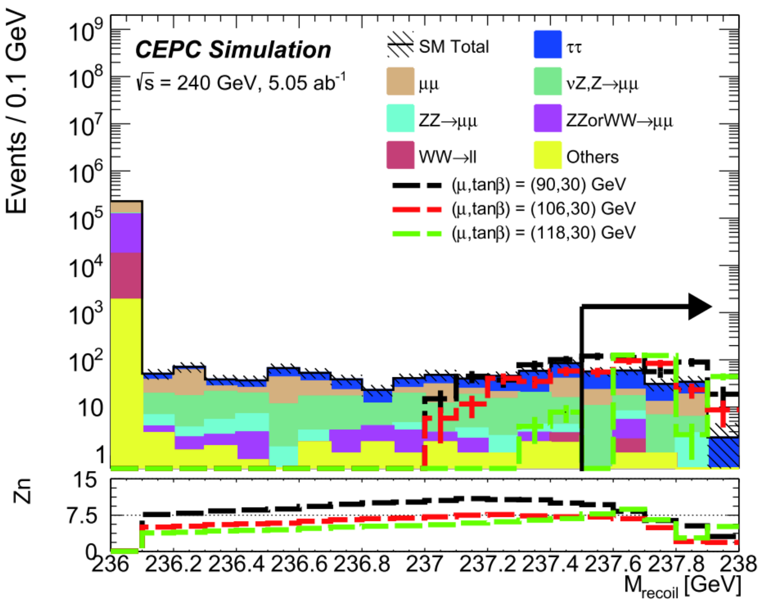




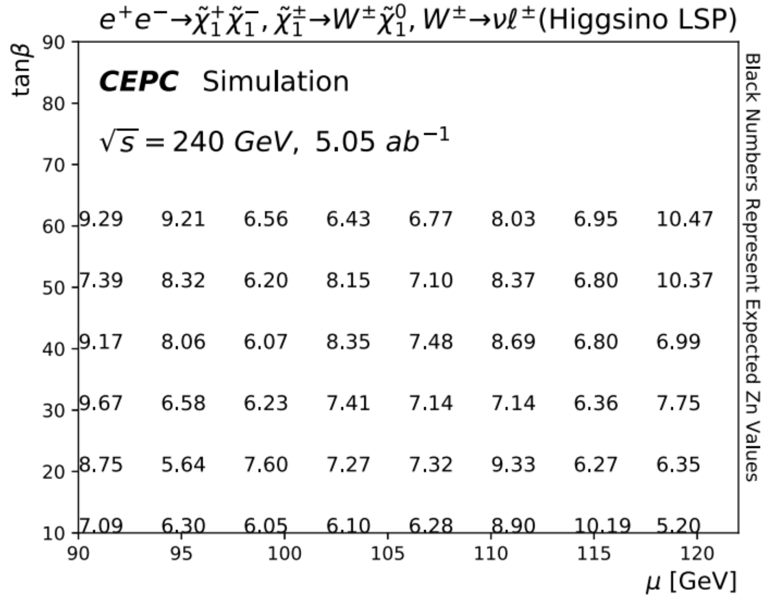


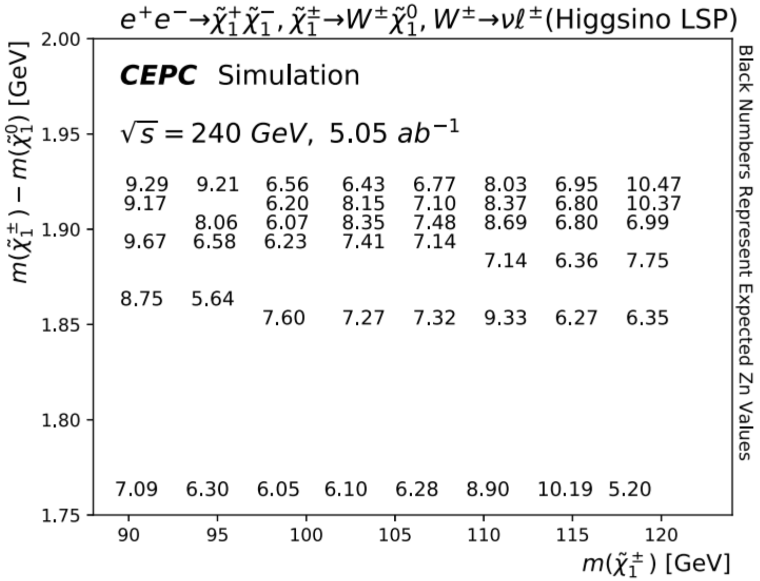
Signal regions
== 2 muons (OS)
$E_{\mu^{\pm}} > 1.0$ GeV
$3.2 < \Delta R(\mu^{\pm}, \text{recoil}) < 4.6$
$\lvert\Delta\phi(\mu^{\pm}, \text{recoil})\rvert < 2.9$
$\lvert\Delta\phi(\mu^{+}, \mu^{-})\rvert < 1.4$
$M_{\text{recoil}} > 237.5$ GeV





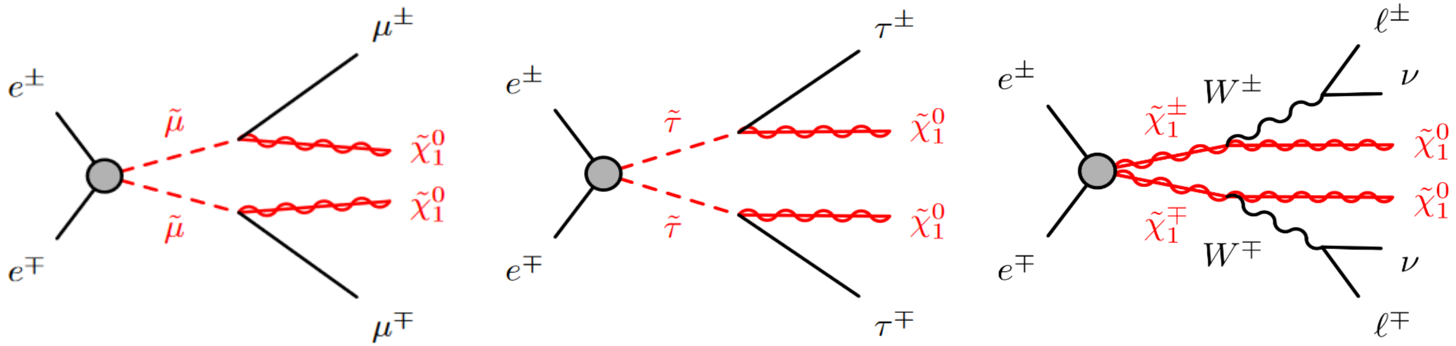
The discovery sensitivity can again reach the kinematic limit $\sqrt{s}/2$ and isn't sensitive to systematic uncertainties and mass splitting between $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$.



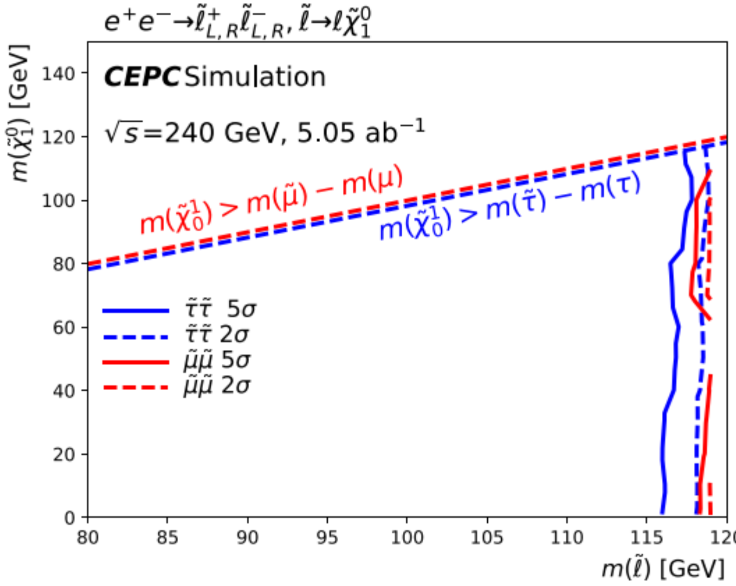


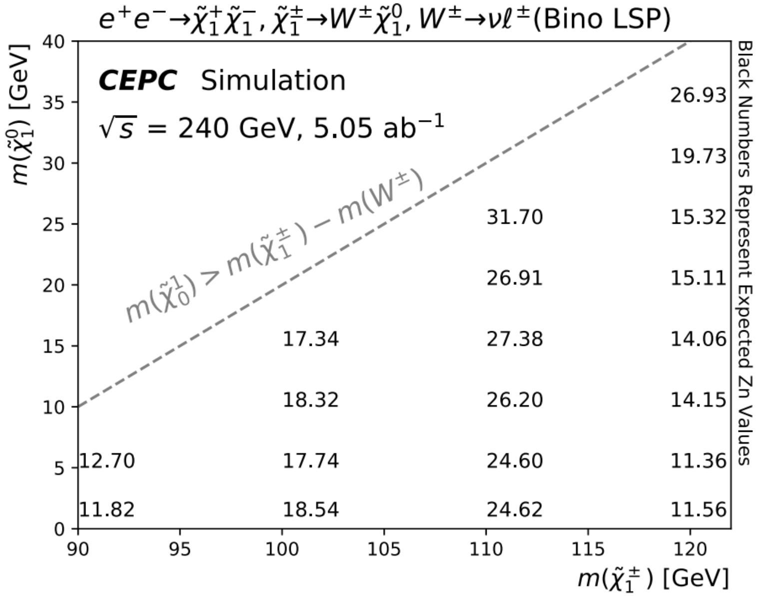
Summary

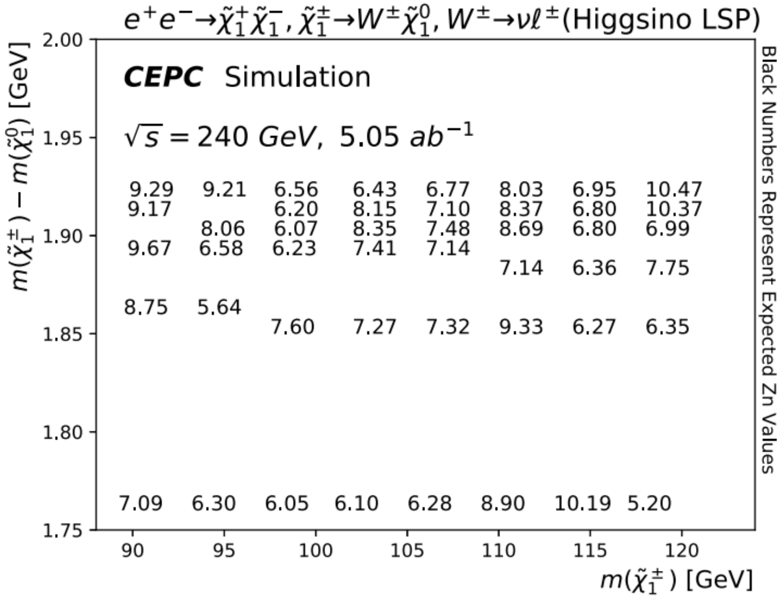
- Several searches for electroweakino and slepton are performed at CEPC.



- The discovery potential is close to kinematic limit $\sqrt{s}/2$.







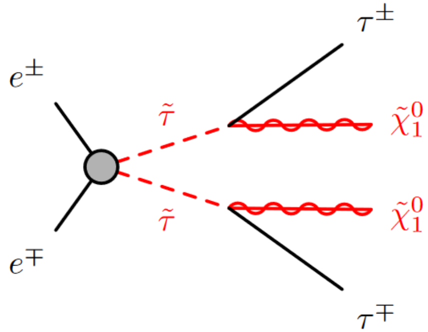
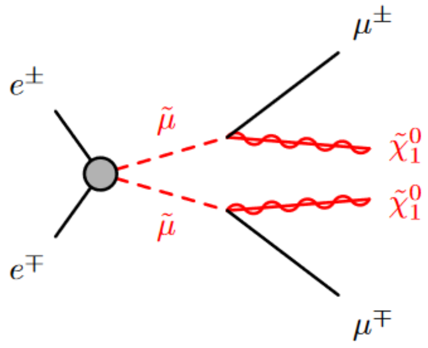
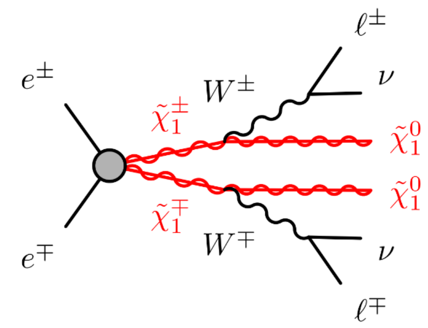
The End

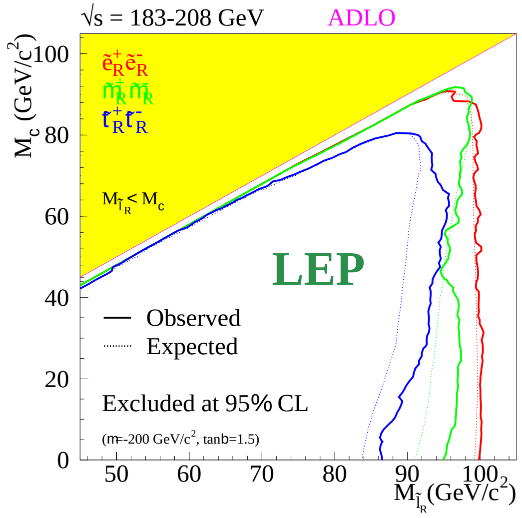
Backup

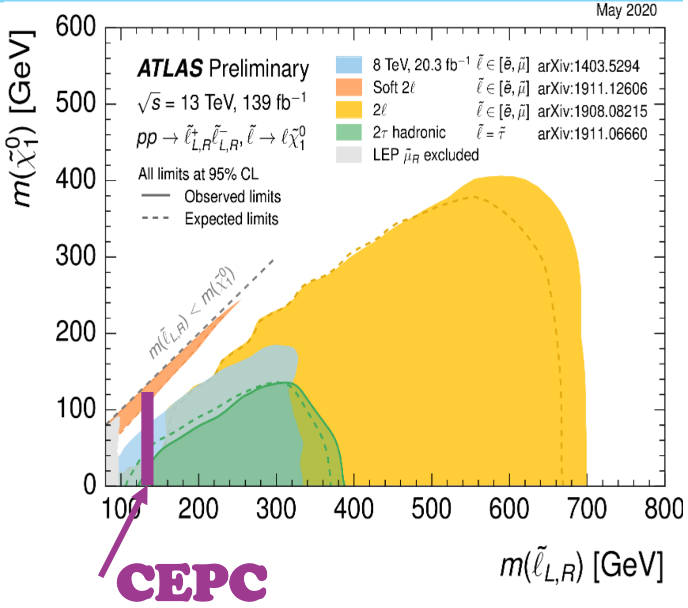
Motivation

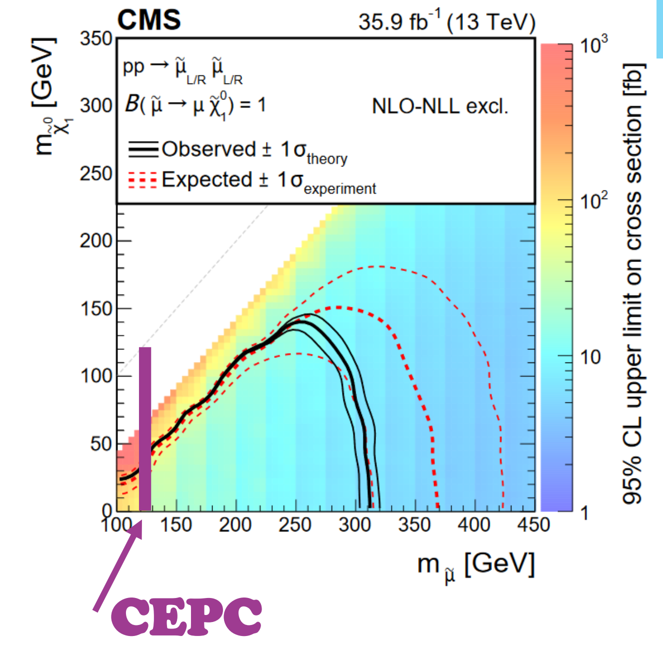
- Signal scenarios
  - Direct production of stau pairs
    - DM relic density consistent with cosmology observation
  - Direct production of smuon pairs
    - can explain g-2 excess
  - Production of chargino pairs decaying via W bosons
    - Bino LSP, large cross section, dark matter arguments
    - Higgsino LSP, interesting related with higgs, naturalness considerations.

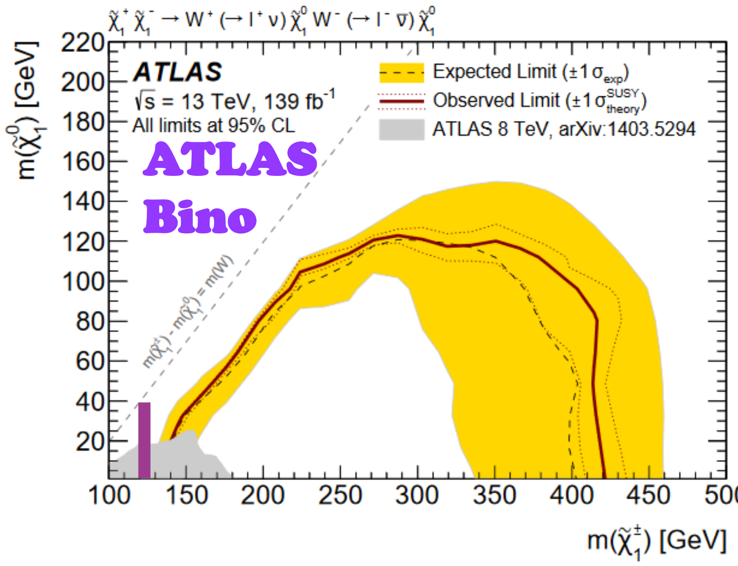
Current status from LEP and LHC

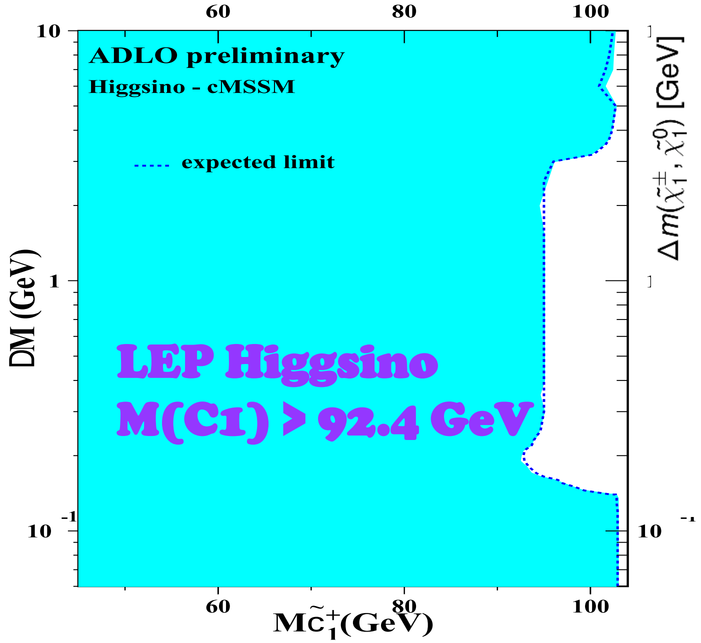




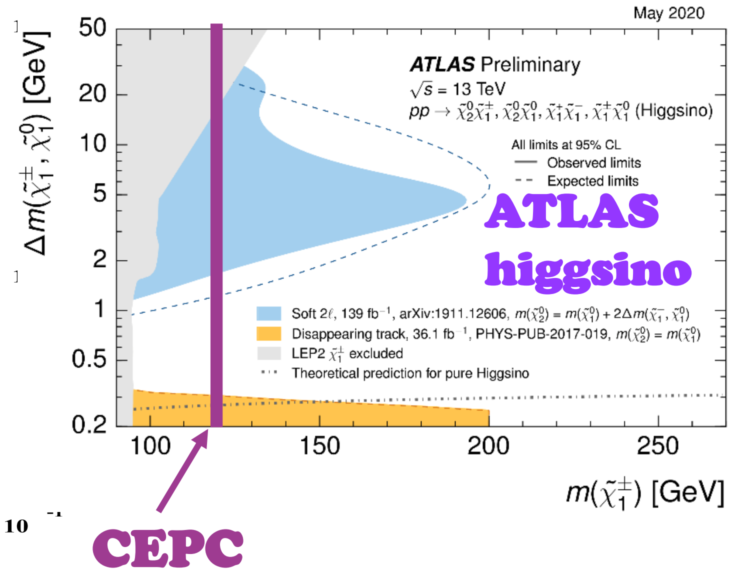


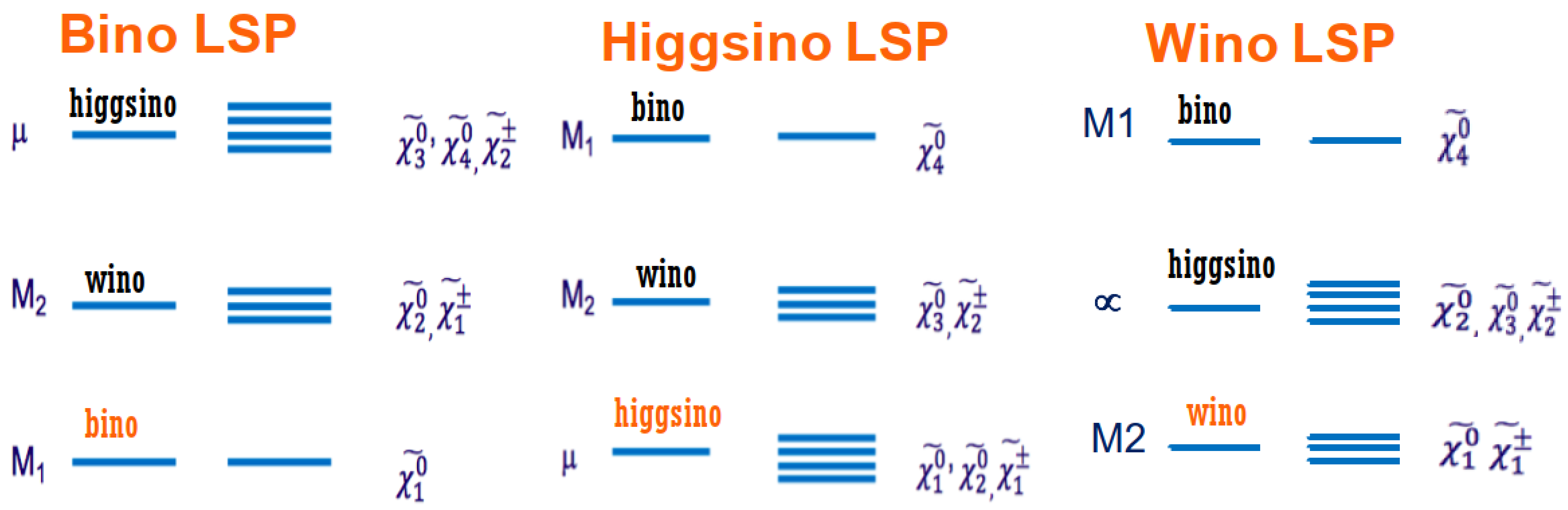











Bino LSP
μ
higgsino
$\tilde{\chi}_3^0, \tilde{\chi}_4^0, \tilde{\chi}_2^\pm$
M_2
wino
$\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$
M_1
bino
$\tilde{\chi}_1^0$
Higgsino LSP
M_1
bino
$\tilde{\chi}_4^0$
M_2
wino
$\tilde{\chi}_3^0, \tilde{\chi}_2^\pm$
μ
higgsino
$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$
Wino LSP
M1
bino
$\tilde{\chi}_4^0$
∝
higgsino
$\tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_2^\pm$
M2
wino
$\tilde{\chi}_1^0\ \tilde{\chi}_1^\pm$

Reconstruction

- Tracking

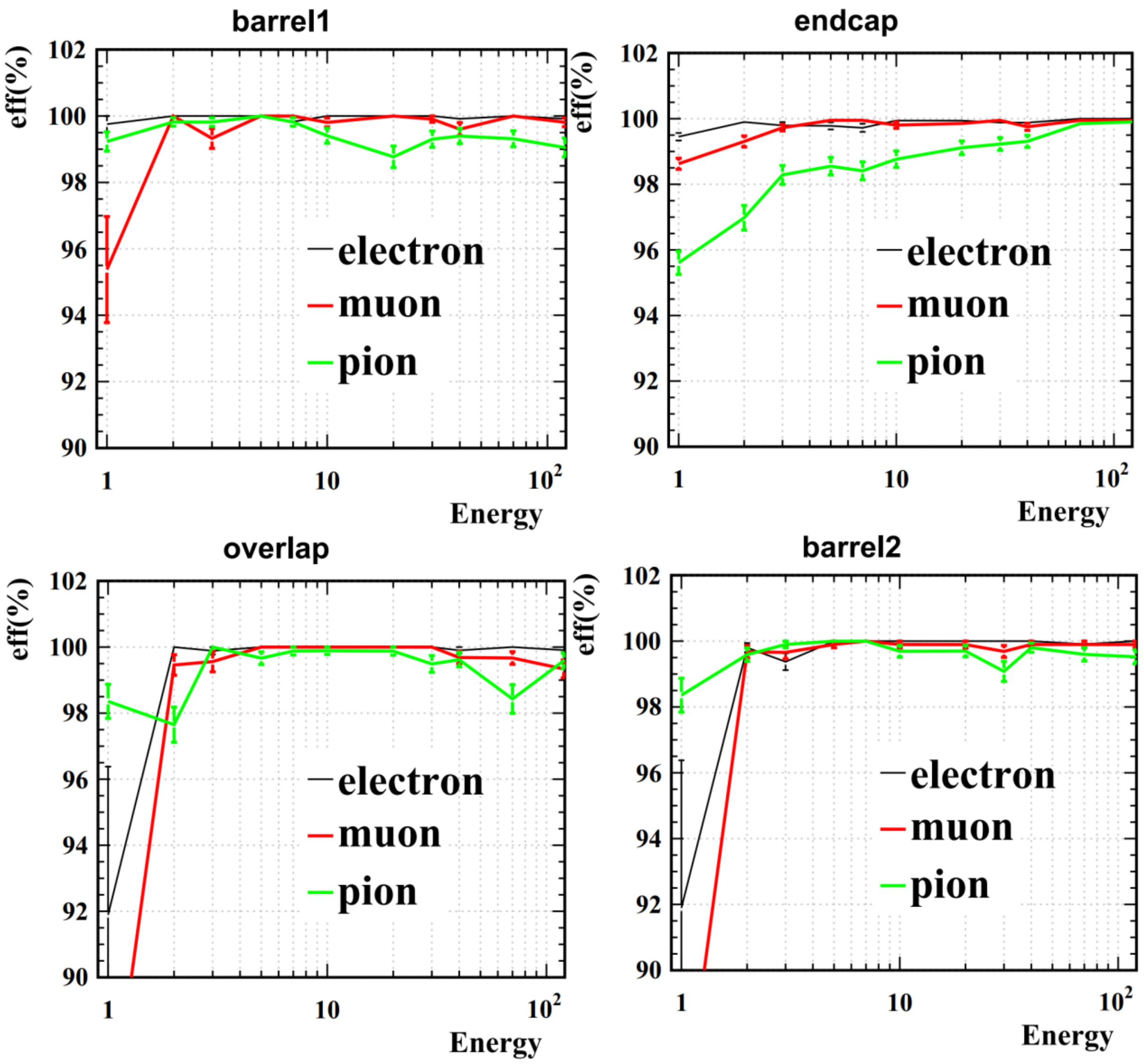
	Tracking software
TPC	Clupatra
VTX	SiliconTracking
SIT	
FTD	ForwardTracking
Merging	FullLDCTracking

- Particle Flow Object reconstruction: Particle Flow Algorithm Arbor
- Lepton identification: LICH based on Multivariate Data Analysis (TMVA)

Muon ID efficiency

Eur. Phys. J. C (2017) 77:591

- The efficiency of lepton identification for e^-, μ^- and π^+ as function of particle energy in the four regions.



- **barrel 1**: middle of barrel ($|\cos\theta| < 0.3$),
- **barrel 2**: edge of barrel ($0.3 < |\cos\theta| < 0.7$),
- **overlap**: overlap region of barrel and endcap ($0.7 < |\cos\theta| < 0.8$),
- **endcap**: ($0.8 < |\cos\theta| < 0.98$).