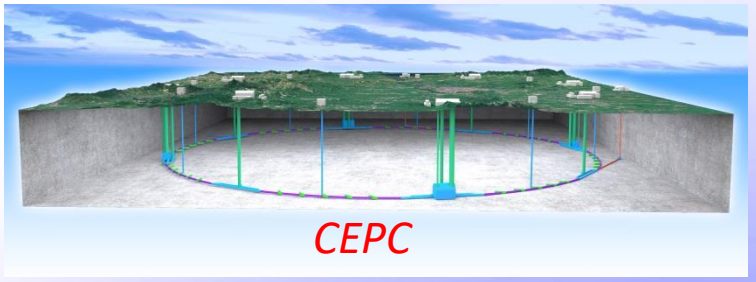

Prospect on slepton search at CEPC@360 GeV

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吕峰

第十四届全国粒子物理学术会议

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Institute of High Energy Physics
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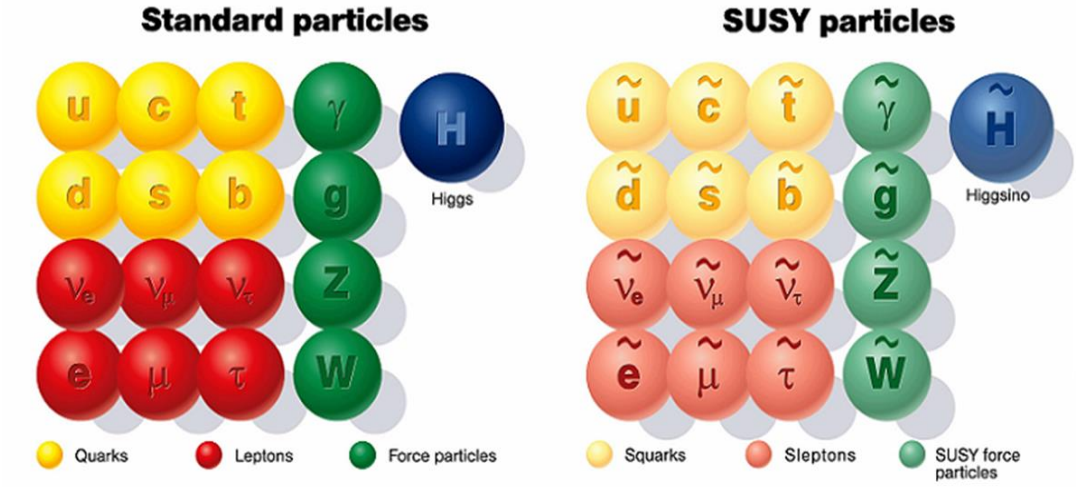
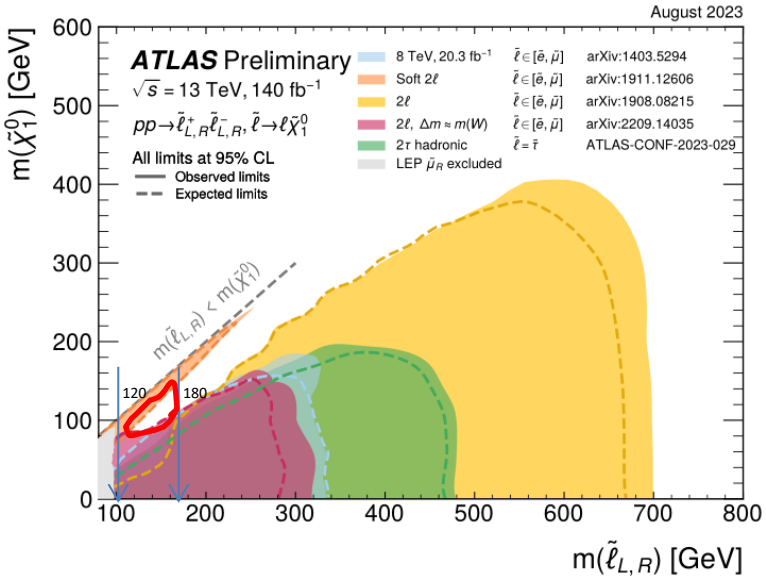
Introduction

SUSY reveals an unique symmetry relates matter and forces particles (fermions and bosons) together, may deeply solve current SM puzzles, such as dark matter ; dark energy; matter /anti-matter asymmetry; neutrino masses/mixing ; hierarchy problem; gravity in gauge theory and its unification . Sleptons masses may be lighter than squarks （~100 GeV）.

CEPC provides good chance to hunt it !

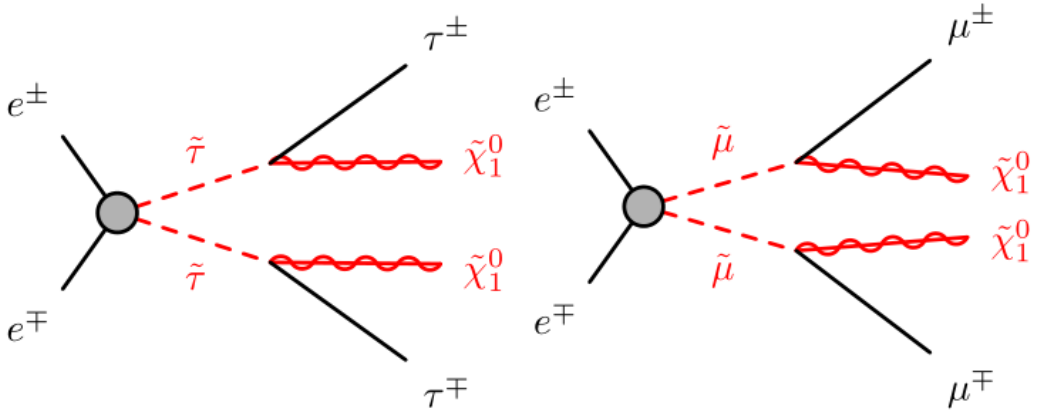




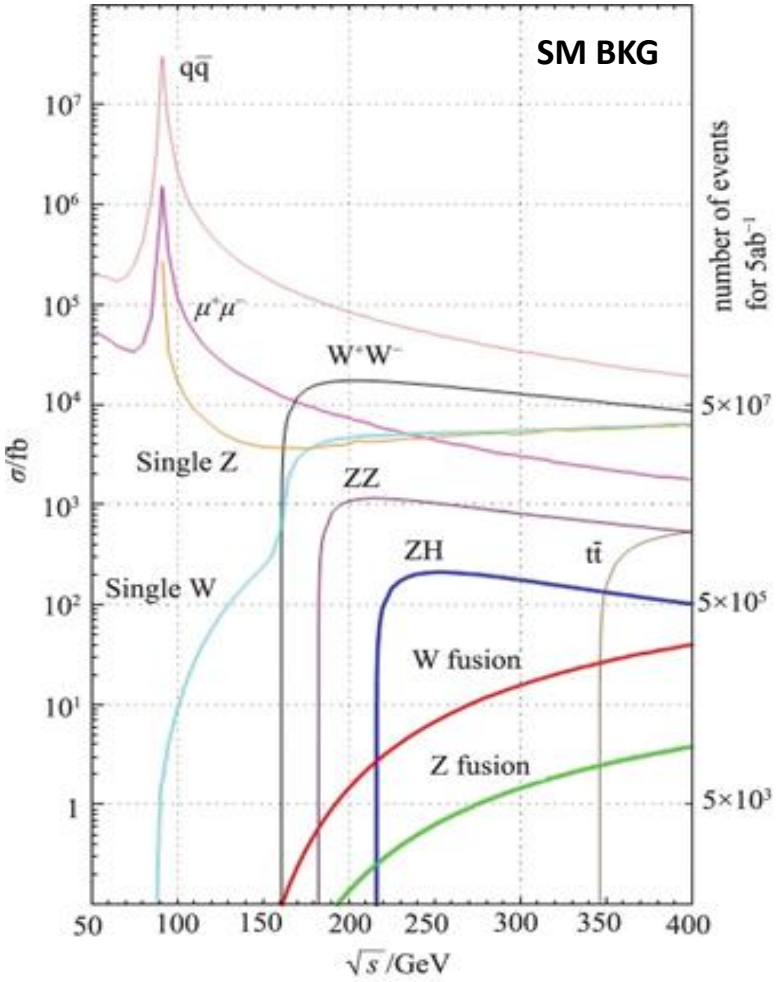
PDG@2024 : LHC exclusion limits on slepton masses

Slepton search at CEPC@360GeV

- Signal sample designed in slepton and LSP mass phase space;
- Slepton mass is bounded by LEP/CEPC limit; LSP is bounded by the slepton mass
- Slepton decays into a lepton and a LSP with 100% BR
- Signal cross-section (LO) :



(a) direct stau production (b) direct smuon production



MadGraph LO

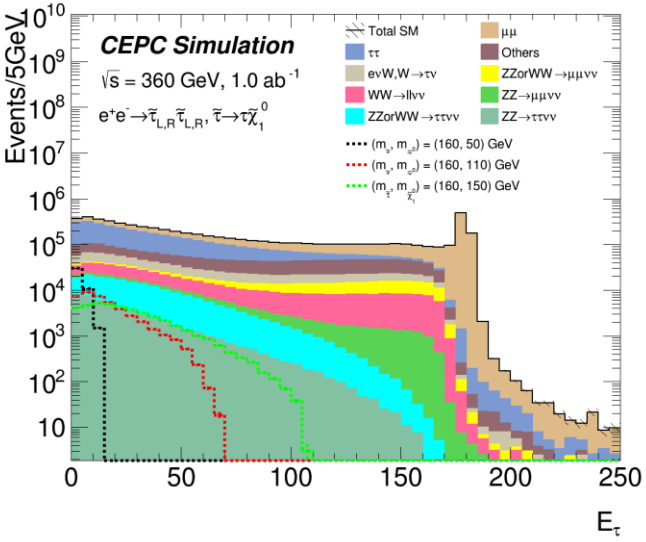
Signal xsection: $M_{\tau\sim}$ = 160 GeV 42.2 fb

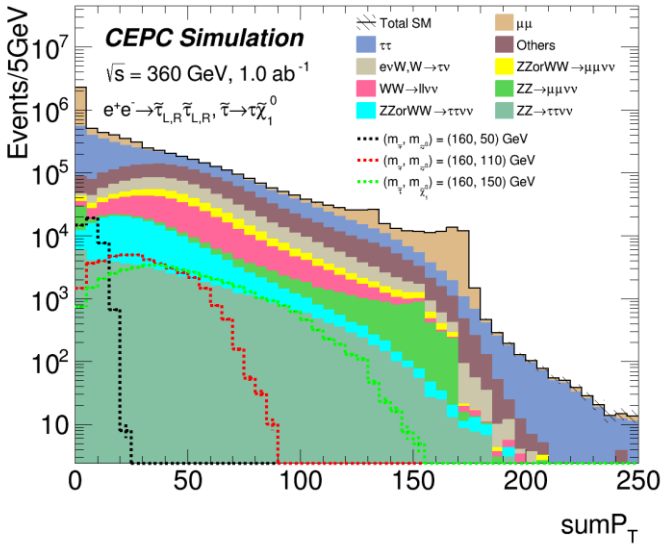
$M_{\mu\sim}$ = 170 GeV 22.3 fb

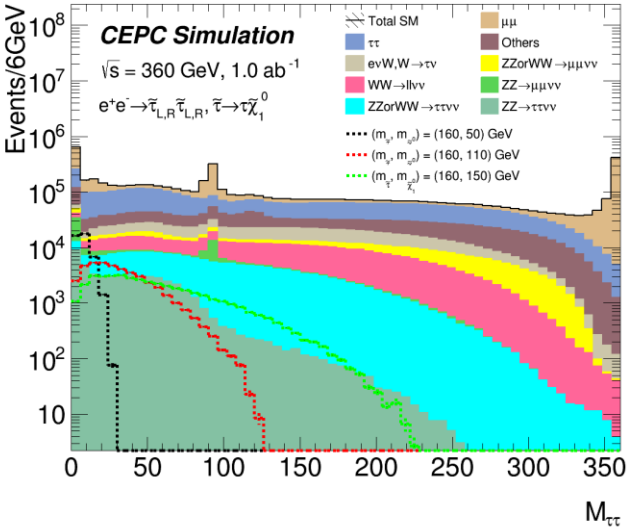
SM BKG includes all final states with two leptons (electrons, muons or taus) and large recoil mass.

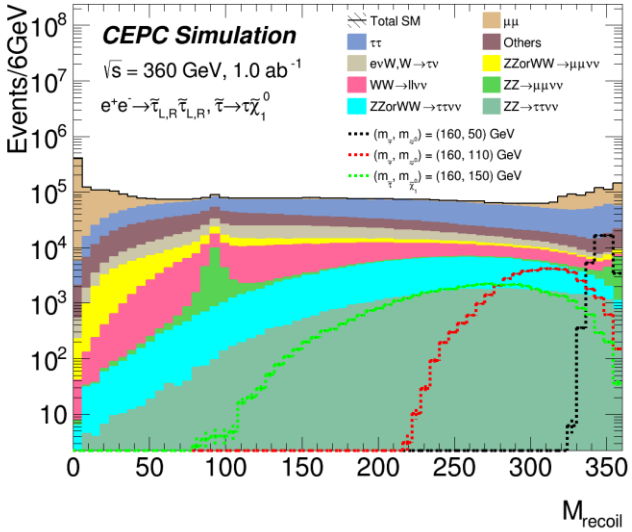
360GeV 1ab stau Analysis: preselection

FulSim









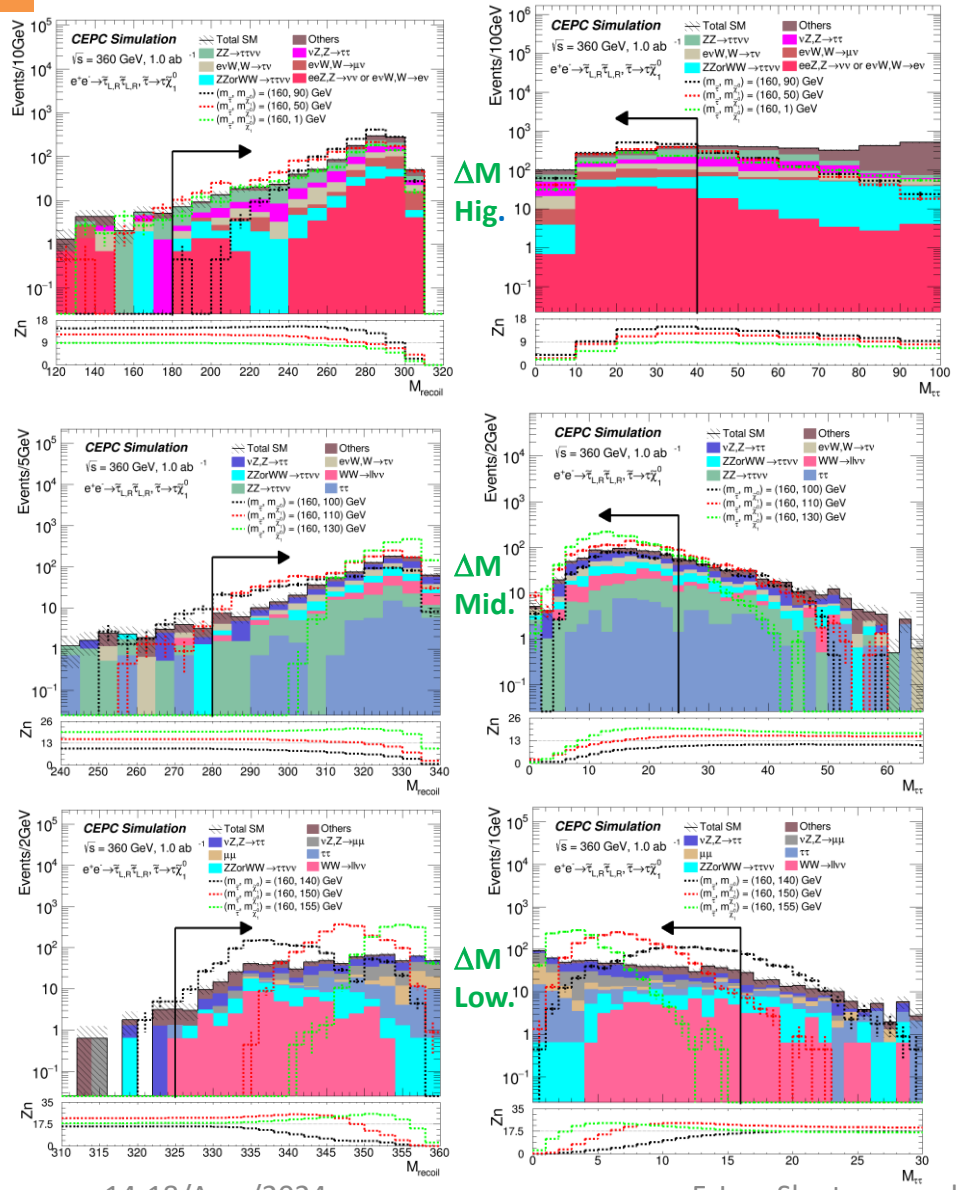
Preselection:

- ✓ No tau ID
- ✓ Select two most energetic tracks (E>0.5GeV) as tau candidates
- ✓ OS

Three signal Regions

M_{stau}, M_{LSP}	ΔM
160, 50 GeV	High
160, 110	Middle
160, 150	Low

360GeV 1ab stau Analysis: N-1 plots



FulSim

- ✓ ”N-1” distributions after signal region requirements for the direct stau pair production.
- ✓ All signal region requirements are applied except on the variable shown.
- ✓ The stacked histograms show the expected SM backgrounds.
- ✓ To illustrate, the distributions from SUSY reference points are shown as dashed line.
- ✓ The lower pad is the sensitivity Zn calculated with a statistical uncertainty and a 5% flat systematic uncertainty

Good optimized !

360GeV 1ab stau Analysis:Event criteria,yields

Table 1 Summary of selection requirements for the direct stau production signal region. DeltaM means difference of mass between $\tilde{\tau}$ and LSP

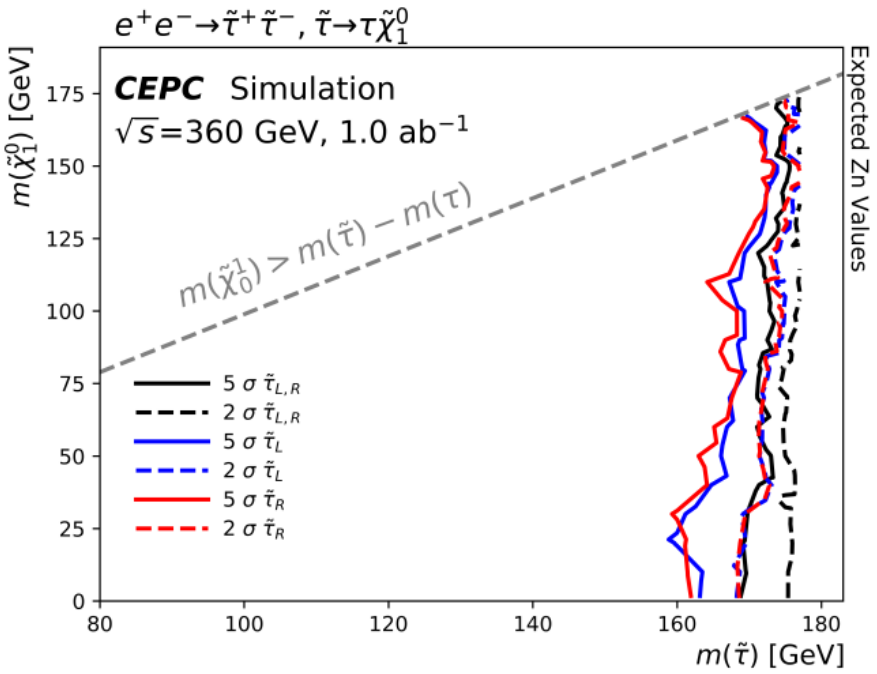
SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$E_{\tau^\pm}$ <40 GeV	$E_{\tau^\pm}$ <15 GeV	
sumP_T >50 GeV	sumP_T >20 GeV	-
2.55 <$\|\Delta\phi(\tau^\pm, recoil)\|$ <3.1	$\|\Delta\phi(\tau^\pm, recoil)\|$ <3.1	$\|\Delta\phi(\tau^\pm, recoil)\|$ >2.3
-	0.45<$\Delta R(\tau,\tau)$ <1.7	$\Delta R(\tau,\tau)$ >0.45
$\Delta R(\tau^\pm, recoil)$ <3.2	$\Delta R(\tau^\pm, recoil)$ <3.15	$\Delta R(\tau^\pm, recoil)$ <2.9
$M_{\tau\tau}$ <40 GeV	$M_{\tau\tau}$ <25 GeV	$M_{\tau\tau}$ <16 GeV
M_{recoil} >180 GeV	M_{recoil} >280 GeV	M_{recoil} >325 GeV

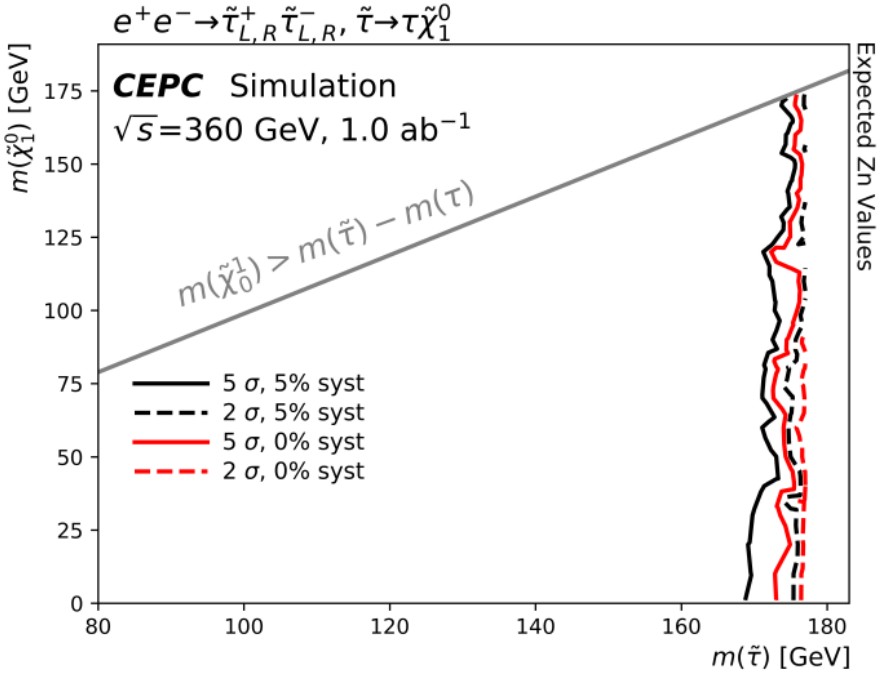
Table 2 The number of events in the signal regions for signal and SM backgrounds with statistical uncertainty for direct stau production

Process	SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
ZZ or $WW \to \tau\tau\nu\nu$	79±7	111±8	59±6
$\tau\tau$	16±4	55±7	91±9
$\nu Z, Z \to \tau\tau$	169±10	173±10	170±10
$ZZ \to \tau\tau\nu\nu$	246±11	97±7	42±5
$WW \to \ell\ell\nu\nu$	75±7	91±7	52±6
$\nu Z, Z \to \mu\mu$	30±4	34±5	163±10
$\mu\mu$	-	14±3	81±7
ZZ or $WW \to \mu\mu\nu\nu$	37±5	5.9±1.9	8.2±2.2
$ZZ \to \mu\mu\nu\nu$	10±3	4.4±1.7	22±4
$e\nu W, W \to \tau\nu$	118±9	112±8	41±5
$e\nu W, W \to \mu\nu$	115±9	20±4	11±3
$eeZ, Z \to \nu\nu$ or $e\nu W, W \to e\nu$	104±8	25±4	15±3
$eeZ, Z \to \nu\nu$	4.6±1.3	0.4±0.4	-
$\nu\nu H, H \to$ anything	51±6	18±3	6.5±2.0
Total SM	1053±25	760±22	761±22
m($\tilde{\tau}$,$\tilde{\chi}_1^0$) = (160,50) GeV	1028±21	157±8	9.4±2.0
m($\tilde{\tau}$,$\tilde{\chi}_1^0$) = (160,110) GeV	984±21	1053±22	151±8
m($\tilde{\tau}$,$\tilde{\chi}_1^0$) = (160,150) GeV	-	3.1±1.2	1690±27

360GeV 1ab stau Analysis: Zn map

FulSim



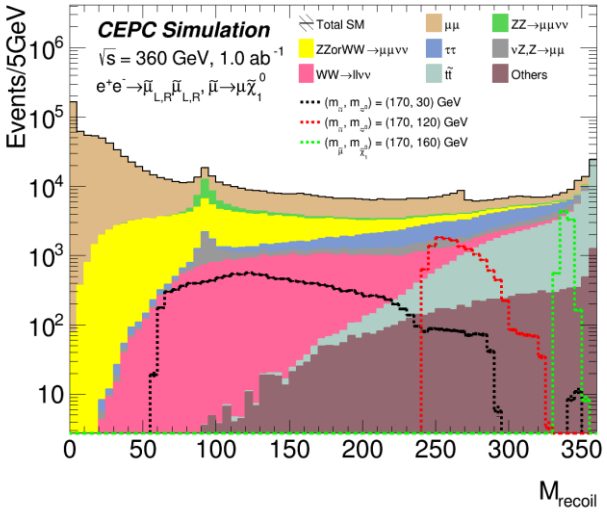


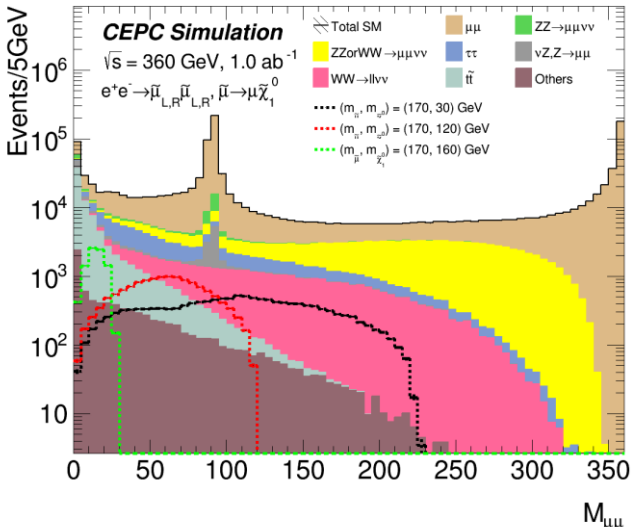
Effects on Zn contour from stau sources (left) or sys. errors (right)

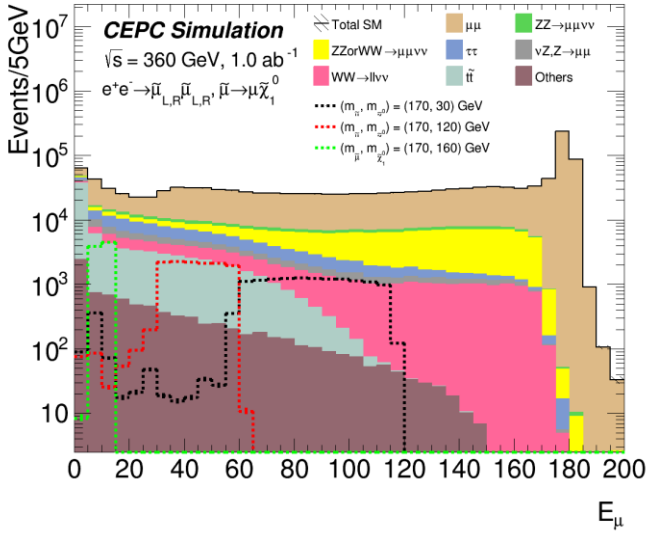
1ab 5% sys. , Left/Right-hand up to 159 GeV ; Combined up to 168.5 GeV

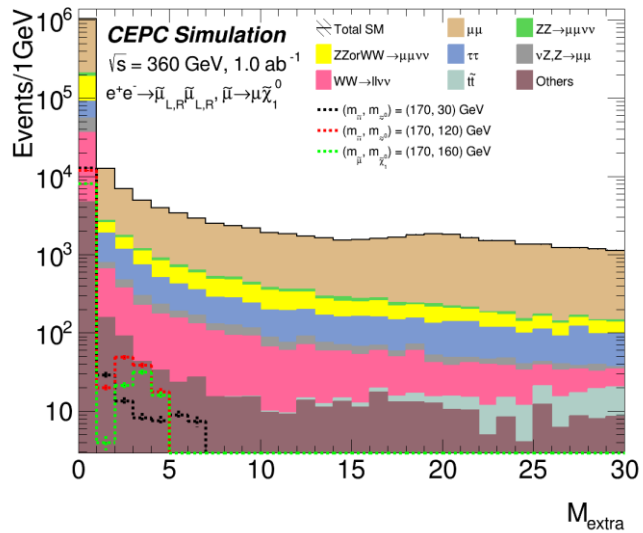
360GeV 1ab smu Analysis: Preselection

FulSim









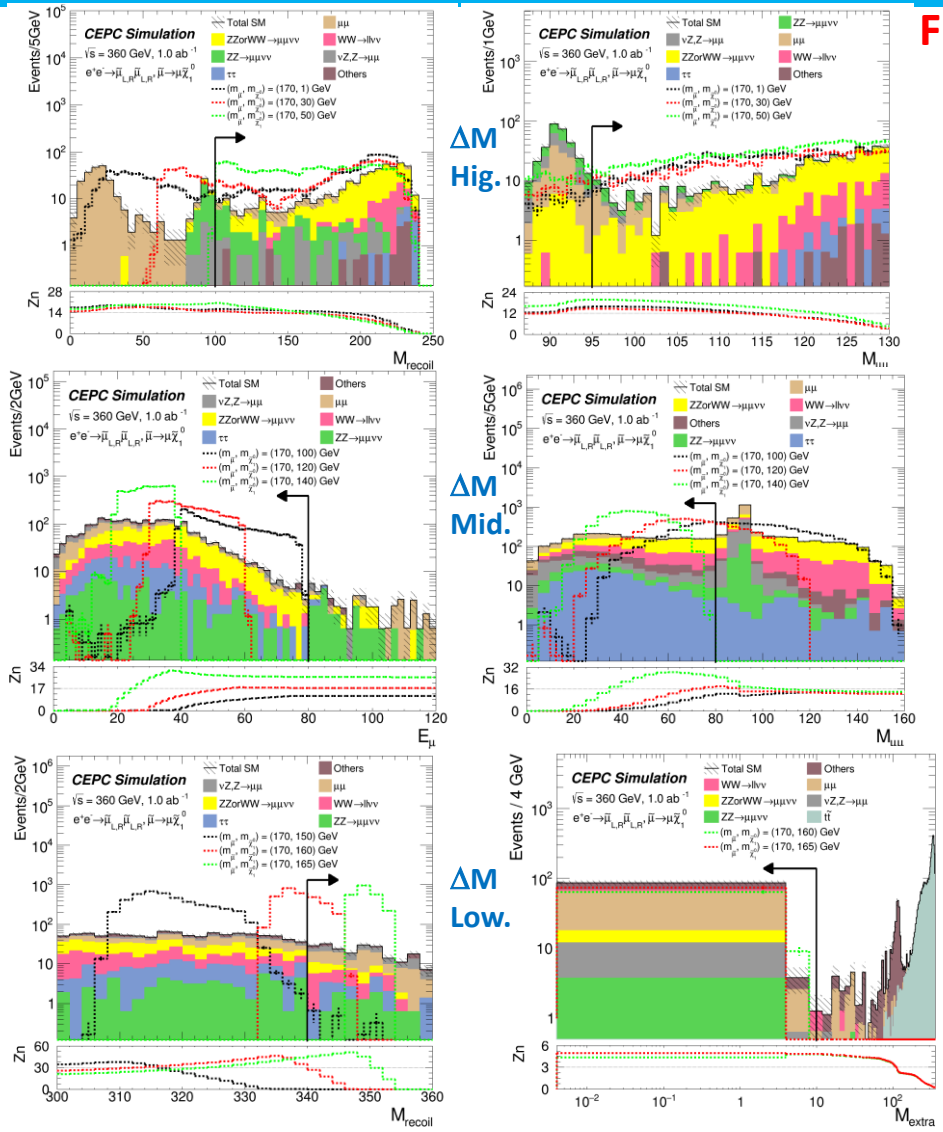
Preselection:

- ✓ No muon ID
- ✓ Select two most energetic tracks (E>0.5GeV) as muon candidate s
- ✓ OS

Three signal Regions

M_{stau}, M_{LSP}	ΔM
170, 30 GeV	High
170, 120	Middle
170, 160	Low

360GeV 1ab smu Analysis: N-1 plots



FulSim

- ✓ ”N-1” distributions after signal region requirements for the direct smu pair production.
- ✓ All signal region requirements are applied except on the variable shown.
- ✓ The stacked histograms show the expected SM backgrounds.
- ✓ To illustrate, the distributions from SUSY reference points are shown as dashed line.
- ✓ The lower pad is the sensitivity Zn calculated with a statistical uncertainty and a 5% flat systematic uncertainty

Good optimized !

360GeV 1ab smu Analysis: Criteria, Yields

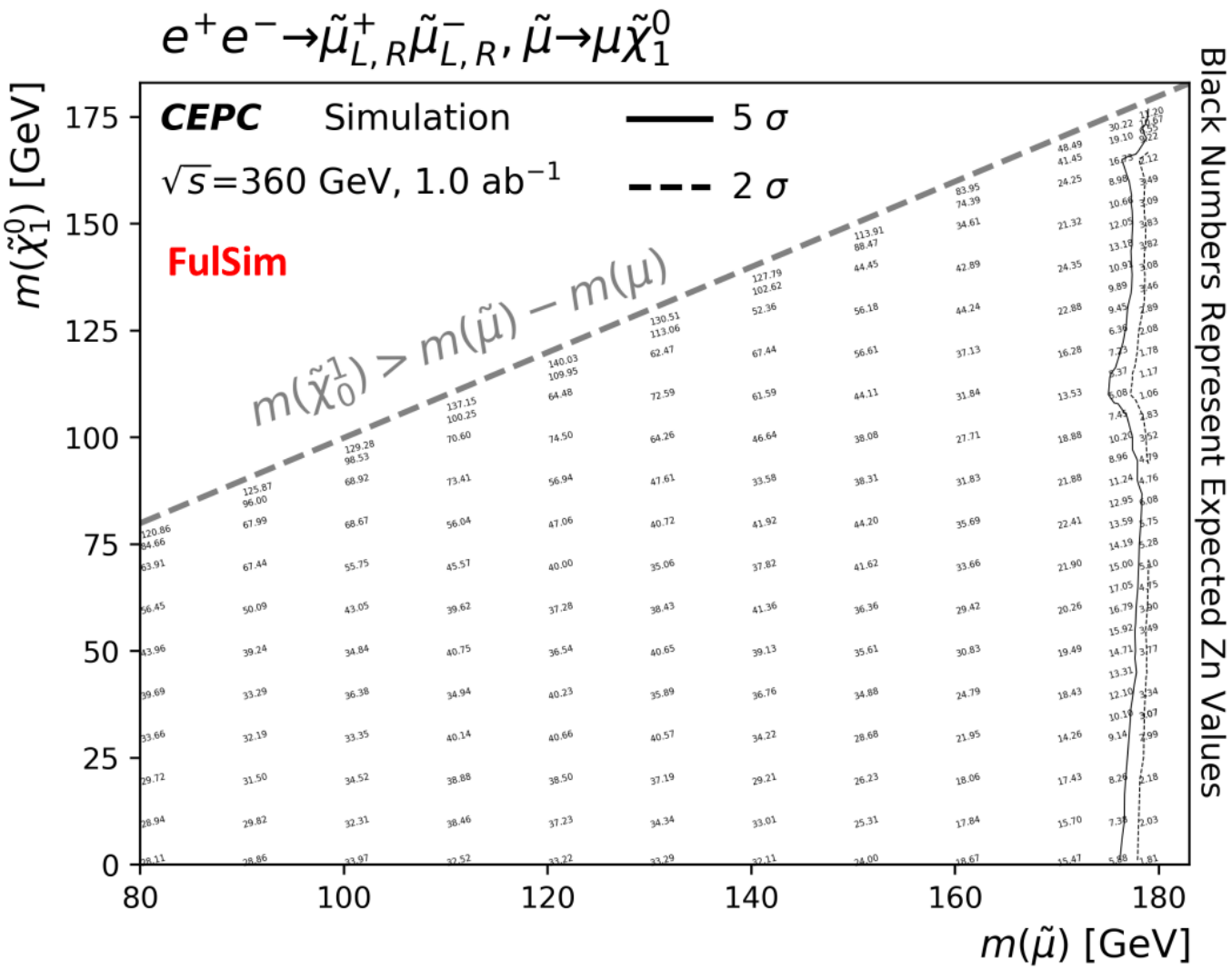
Table 3 Summary of selection requirements for the direct smuon production signal region. DeltaM means difference of mass between $\tilde{\mu}$ and LSP

SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$E_\mu > 60$ GeV	$E_\mu < 80$ GeV	-
$\Delta R(\mu, recoil) < 2.8$	$1.9 < \Delta R(\mu, recoil) < 2.9$	
$M_{\mu\mu}$ <87 GeV || GeV 95 $< M_{\mu\mu} <$ 130 GeV	$M_{\mu\mu} < 80$ GeV	-
$M_{recoil} > 100$ GeV	-	$M_{recoil} > 340$ GeV
M_{extra} <15 GeV	M_{extra} <10 GeV	M_{extra} <10 GeV

Table 4 The number of events in the signal regions for signal and SM backgrounds with statistical uncertainty for direct smuon production

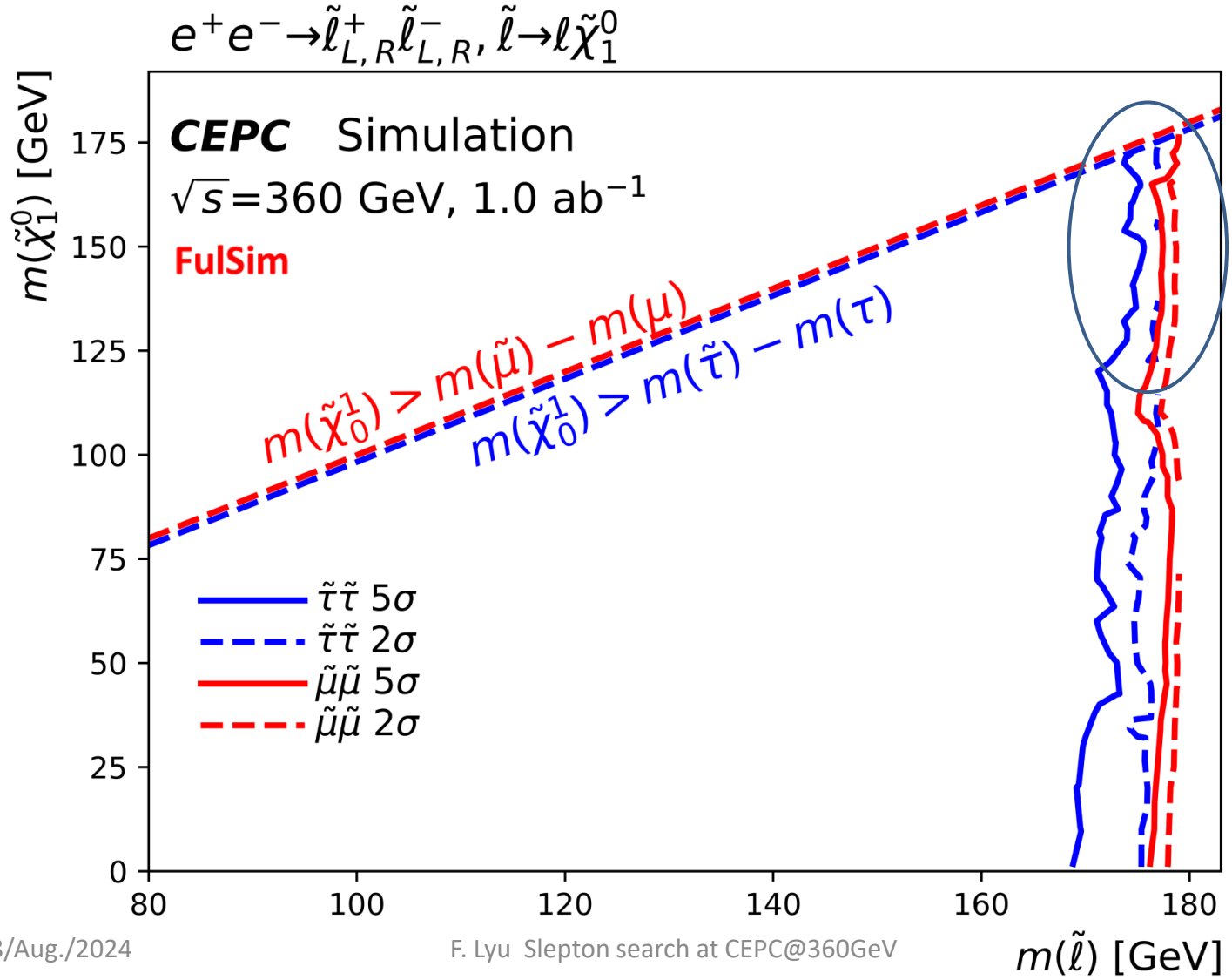
Process	SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$ZZorWW \to \mu\mu\nu\nu$	333±14	869±23	19.4±3.4
$\mu\mu$	64±6	441±17	78±7
$\nu Z, Z \to \mu\mu$	19±4	204±11	48±6
$ZZ \to \mu\mu\nu\nu$	44±5	104±8	8.8±2.3
$WW \to \ell\ell\nu\nu$	64±6	444±17	22±4
$\tau\tau$	11.0±2.8	209±12	12±3
$ZZorWW \to \tau\tau\nu\nu$	7.6±2.2	98±8	3.8±1.6
$ZZ \to \tau\tau\nu\nu$	1.0±0.7	41±5	6.0±1.7
$\nu Z, Z \to \tau\tau$	-	67±7	12.5±2.8
$\nu\nu H, H \to$ anything	1.7±1.2	25±5	-
ttbar	0.07±0.07	0.14±0.10	-
$e\nu W, W \to \mu\nu$	-	-	-
$e\nu W, W \to \tau\nu$	-	-	-
$eeZ, Z \to \nu\nu$	-	-	-
$eeZ, Z \to \nu\nu$ or $e\nu W, W \to e\nu$	-	-	-
Total SM	524±18	2503±39	210±12
m($\tilde{\mu}$,$\tilde{\chi}_1^0$) = (170,30) GeV	775±11	82±4	7.4±1.1
m($\tilde{\mu}$,$\tilde{\chi}_1^0$) = (170,100) GeV	1111±14	1927±18	2.5±0.6
m($\tilde{\mu}$,$\tilde{\chi}_1^0$) = (170,165) GeV	-	2310±20	2310±20

360GeV 1ab smu Analysis: Zn map (5% sys.)



Up to 175GeV

360GeV 1ab slepton search (5% sys.)



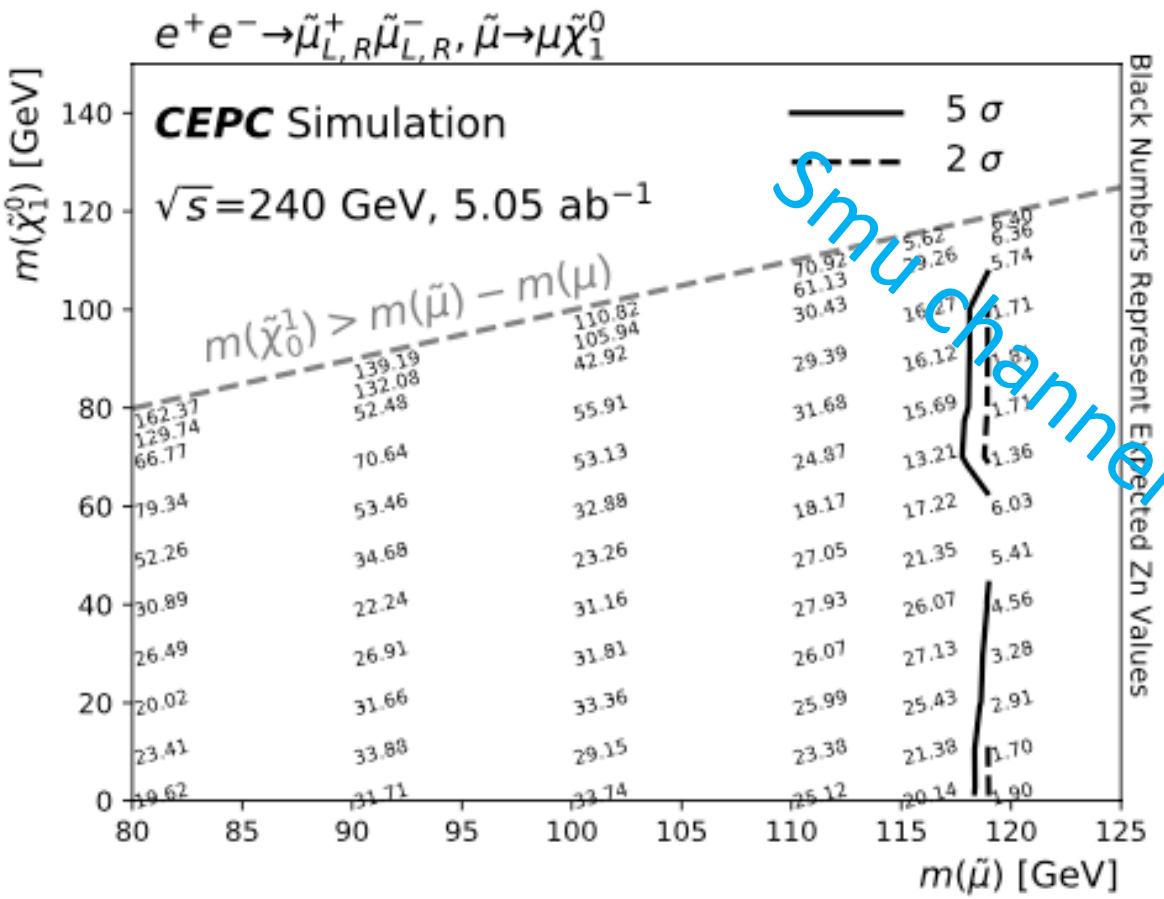
Summary

- Slepton search at CEPC@360GeV 1ab 5% sys. is investigated
- The potential to discover the production of combined left-handed and right-handed stau up to 168.5 GeV if exists, or up to 159 GeV for the production of pure left-handed or right-handed stau; the discovery potential of direct smuon reaches up to 175 GeV
- Increase 82.5 (79) GeV for stau (smu) channels relative to LEP's, and 42.5 (58) GeV relative to CEPC@240GeV case, will be one motivation to raise CEPC@240GeV to 360GeV for new physics search

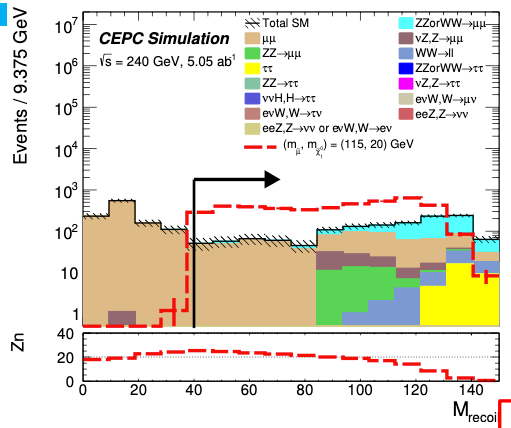
Thanks for your attention !

Backup

CEPC@240GeV 5.05ab with 5% sys.

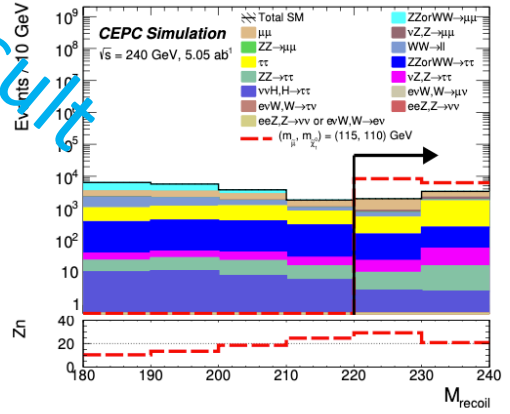


Smu channel Result



(a) SR-highDeltaM:M_{recoil}

N-1 plot



(e) SR-lowDeltaM:M_{recoil}

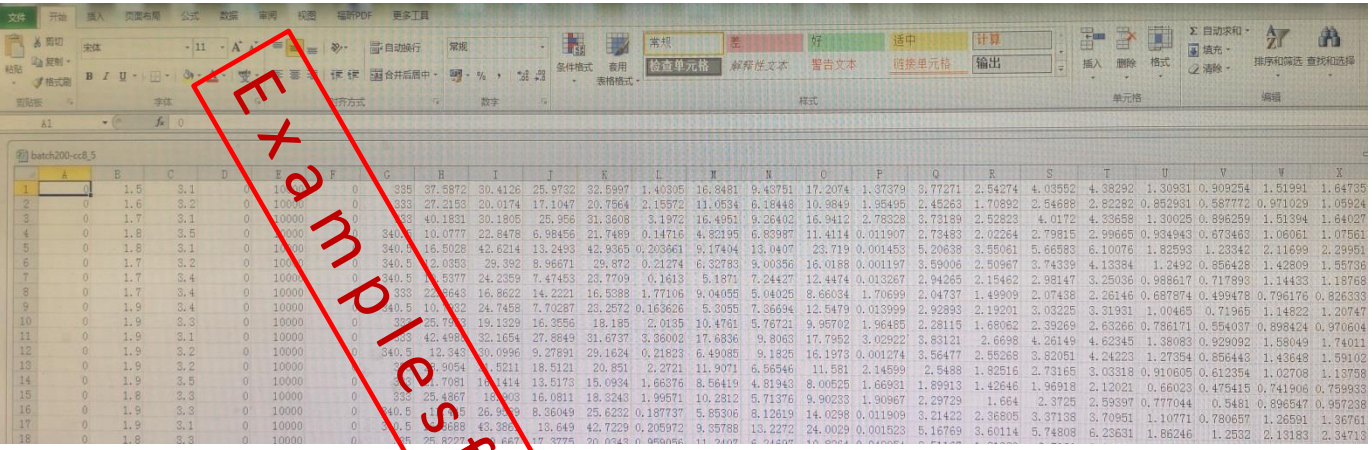
CEPC@240GeV has the potential to discover the production of combined left-handed and right-handed stau up to 116 GeV if exists, or up to 113 GeV for the production of pure left-handed or right-handed stau; the discovery potential of direct smuon reaches up to 117 GeV with the same assumption

CEPC@360GeV 1ab Analysis:

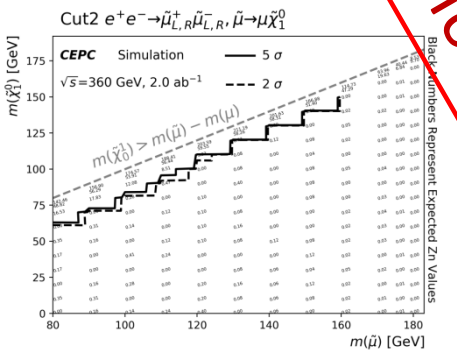
Chanllenge at CEPC@360GeV slepton Analysis:

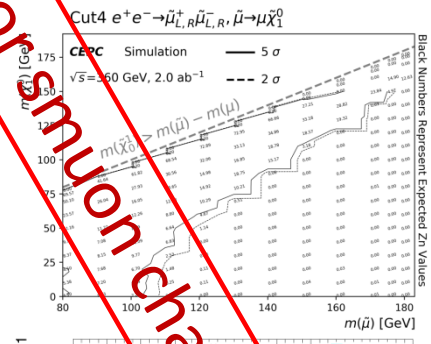
- ✓ Have to generate all related CEPC@360GeV SM full simulation samples for the first time
- ✓ Luminosity is decreased to 1ab $^{-1}$, which is only 1/5 of the 240GeV's
- ✓ Slepton@360 GeV x-sections are much smaller. Such as 360GeV xsection for 175GeV smuon mass is one order of magnitude lower than 240GeV x-section for 115GeV
- ✓ The phase space of 360GeV case (slepton mass: 80-179 GeV) is 150% wider than that of 240GeV (slepton mass: 80-119), so the signal distribution is significantly broadened, which greatly introduce much more SM background, to make more hard to suppress BKG
- ✓ 360GeV introduces new ttbar BKG which is none for 240GeV

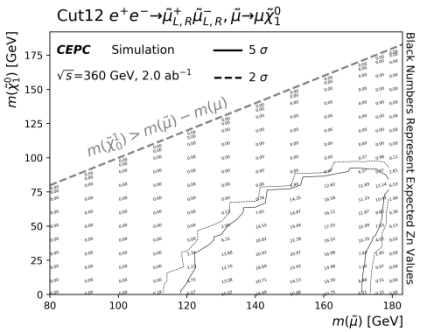
360GeV 1ab Analysis: Three key processes

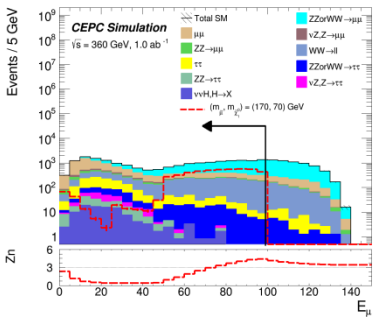


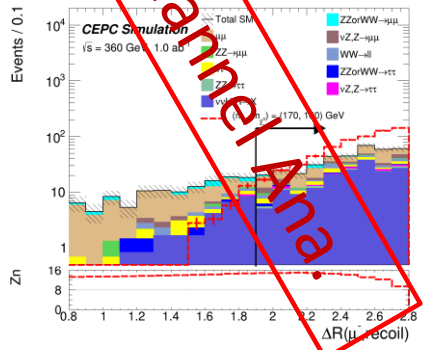
Examples for smuon channel Ana.

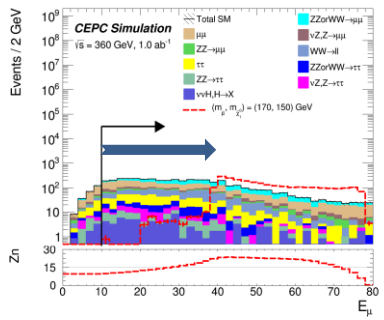












Process I

Sensitivity values **Execl** created by **several ten thousands** of combinations of distinguishing variables

Sorting & finding Better

Process II

Zn plot

~200 Global comparing & making Balance

Process III

N-1 plot

~100 Final check & best adjustment

CEPC@360GeV variables definition

- $|\Delta\phi(\ell^{\pm}, recoil)|$, the difference of azimuth between one lepton and the recoil system.
- $|\Delta\phi(\ell, \ell)|$, the difference of azimuth between two leptons.
- $\Delta R(\ell^{\pm}, recoil)$, the cone size between one lepton and the recoil system.
- $\Delta R(\ell, \ell)$, the cone size between two leptons.
- $E_{\ell^{\pm}}$, the energy of one lepton.
- sumP_T, the sum of the tranverse momentum of two leptons.
- $M_{\ell\ell}$, the invariant mass of two leptons.
- M_{recoil}, the invariant mass of the recoil system.

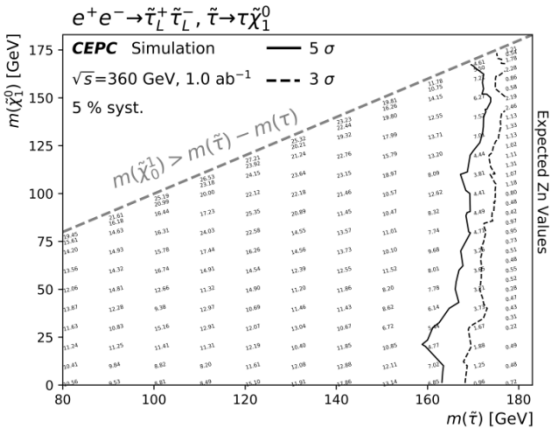
Distinguishing variables
in Signal Event Selection

– Mextra: the invariant mass of all extra reconstructed particles with their energy above 0.5 GeV except the two muon tracks. Only used for smuon channel ttbar suppression

Sensitive reference Zn:

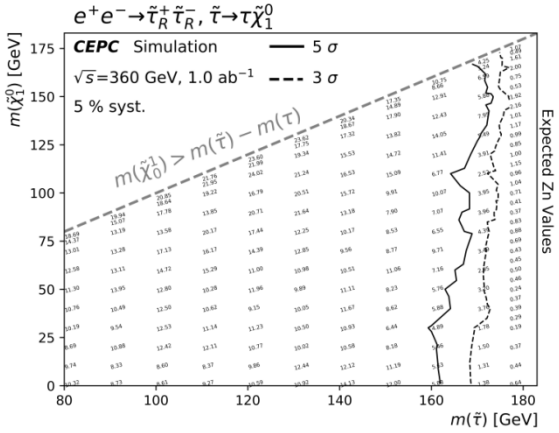
$$Zn = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+\sigma_b^2)}{b^2+(s+b)\sigma_b^2}\right] - \frac{b^2}{\sigma_b^2}\ln\left[1+\frac{\sigma_b^2 s}{b(b+\sigma_b^2)}\right]\right)\right]^{1/2}$$

360GeV 1ab stau Analysis: Zn map



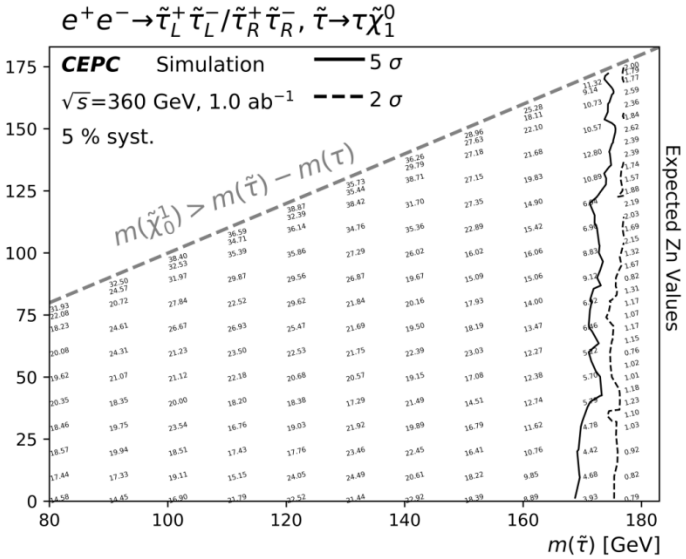
Stau pure Left-hand

Up to 159 GeV



Stau pure Right-hand

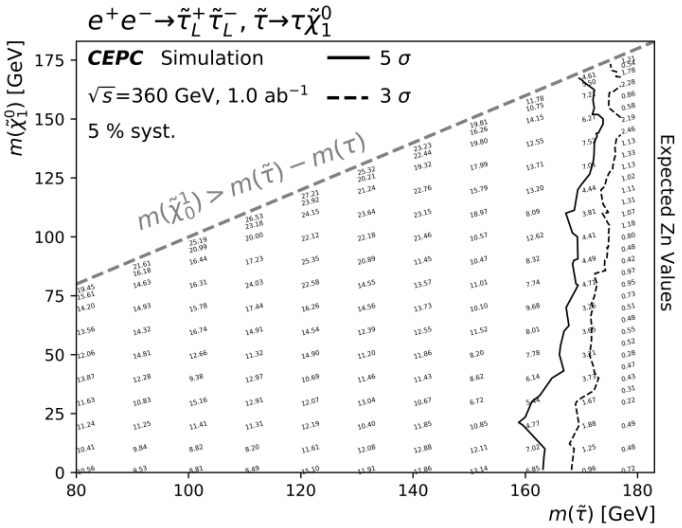
Up to 159 GeV



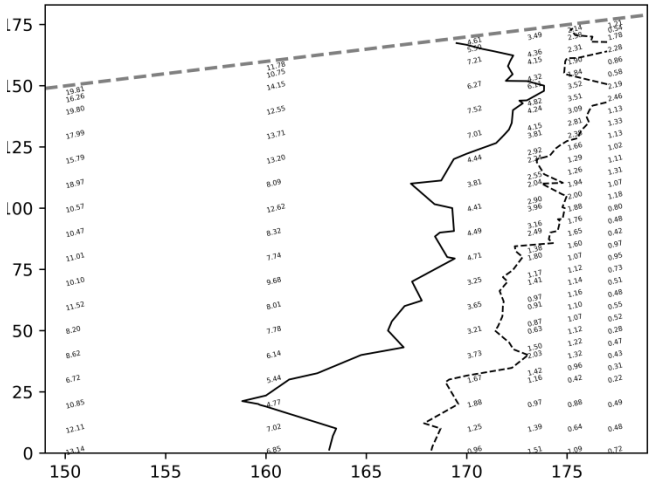
Stau combined Left-hand and right-hand together

Up to 168.5 GeV

360GeV 1ab stau Analysis: Zn map

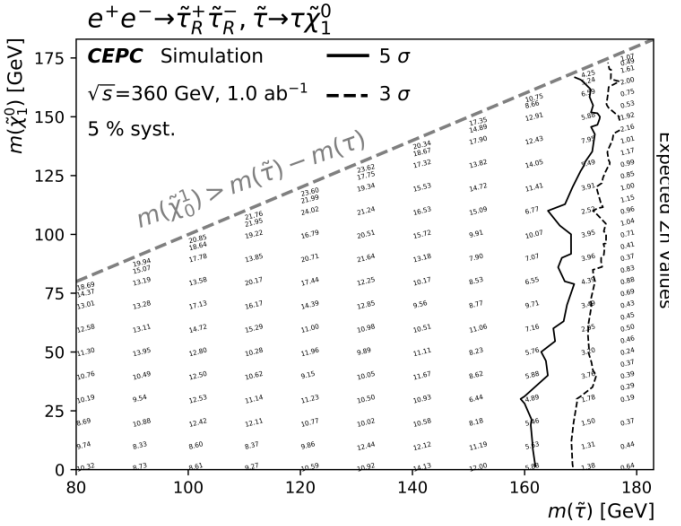


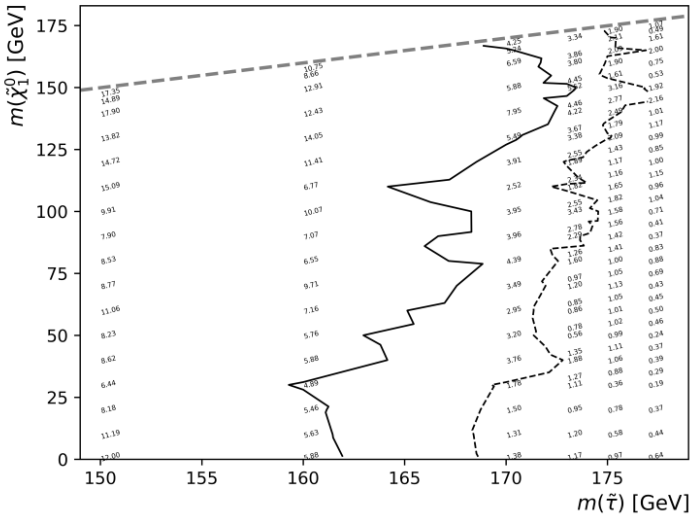
Enlarged at High mass



Stau pure Left-hand

Up to 159GeV

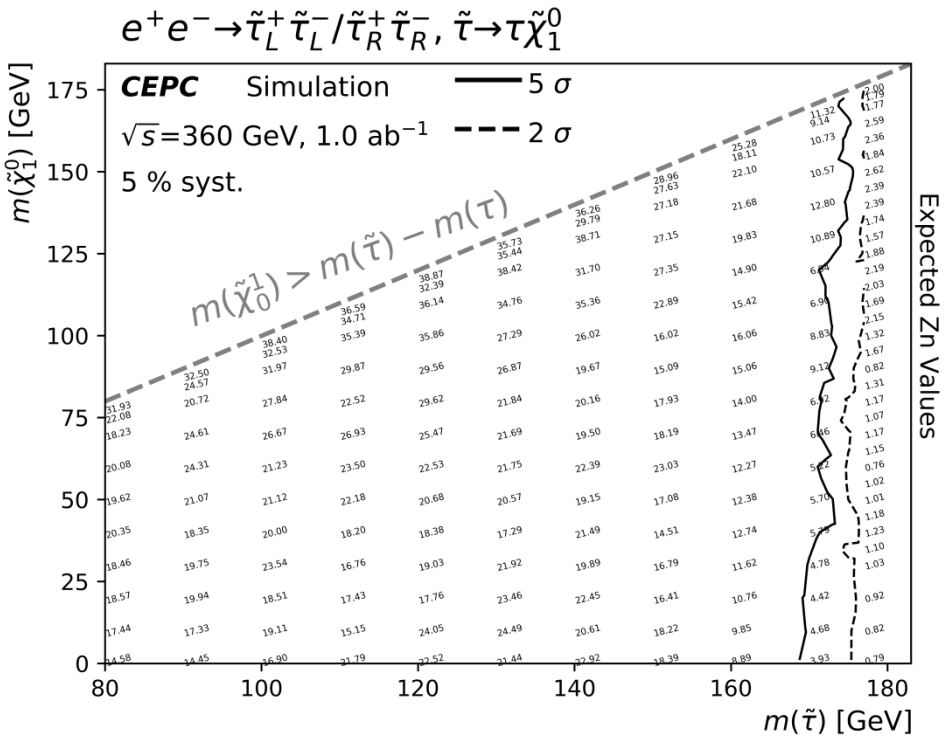




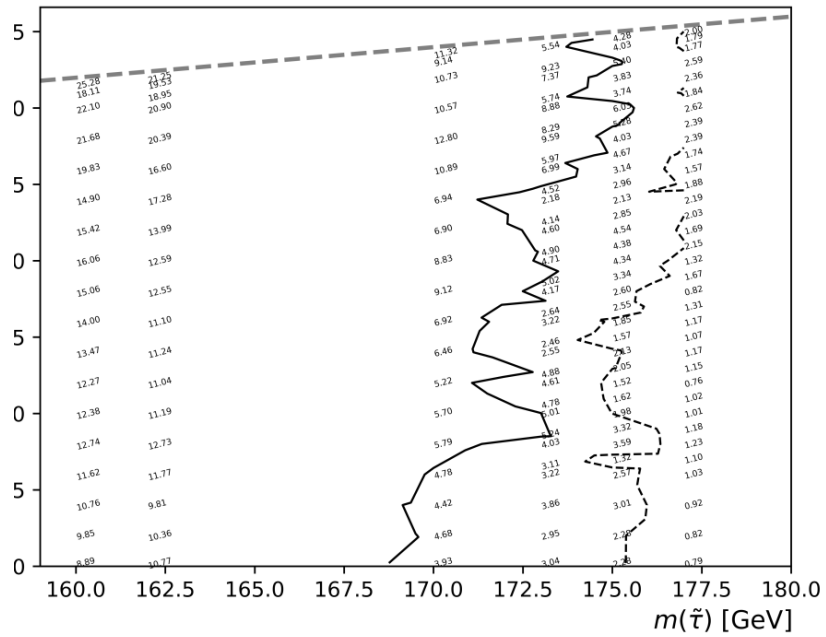
Stau pure Right-hand

Up to 159GeV

360GeV 1ab stau Analysis: Zn map



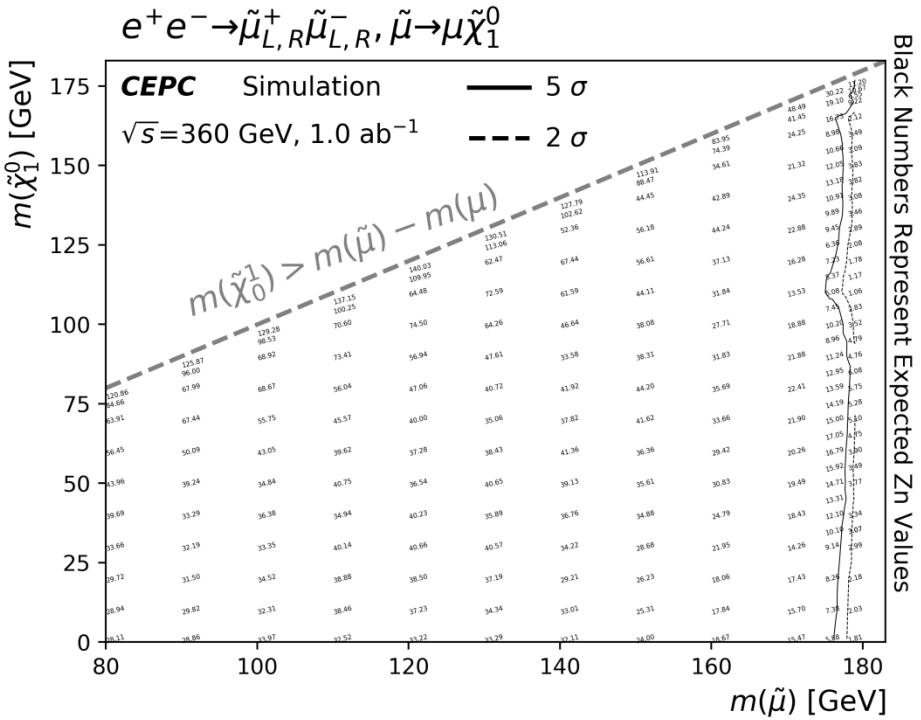
Enlarged at High mass



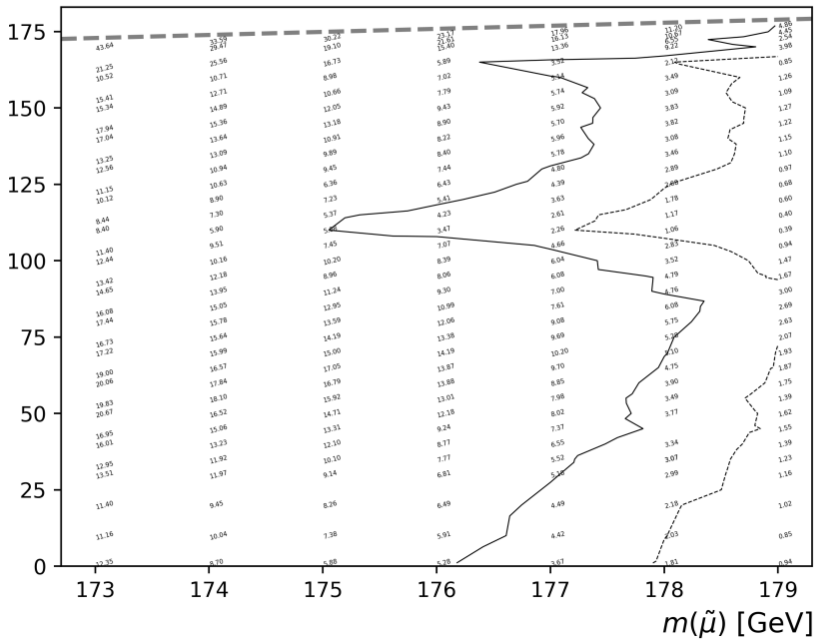
Stau combined Left-hand and right-hand together

Up to 168.5GeV

360GeV 1ab smu Analysis: Zn map



Enlarged at High mass



Up to 175GeV