Gaugino Masses at 100 TeV

Based on
Eur. Phys. J. C 79, 469 (2019), arXiv:1901.02987
JHEP 05, 179 (2019), arXiv:1901:10389

by
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Supersymmetry at 100 TeV

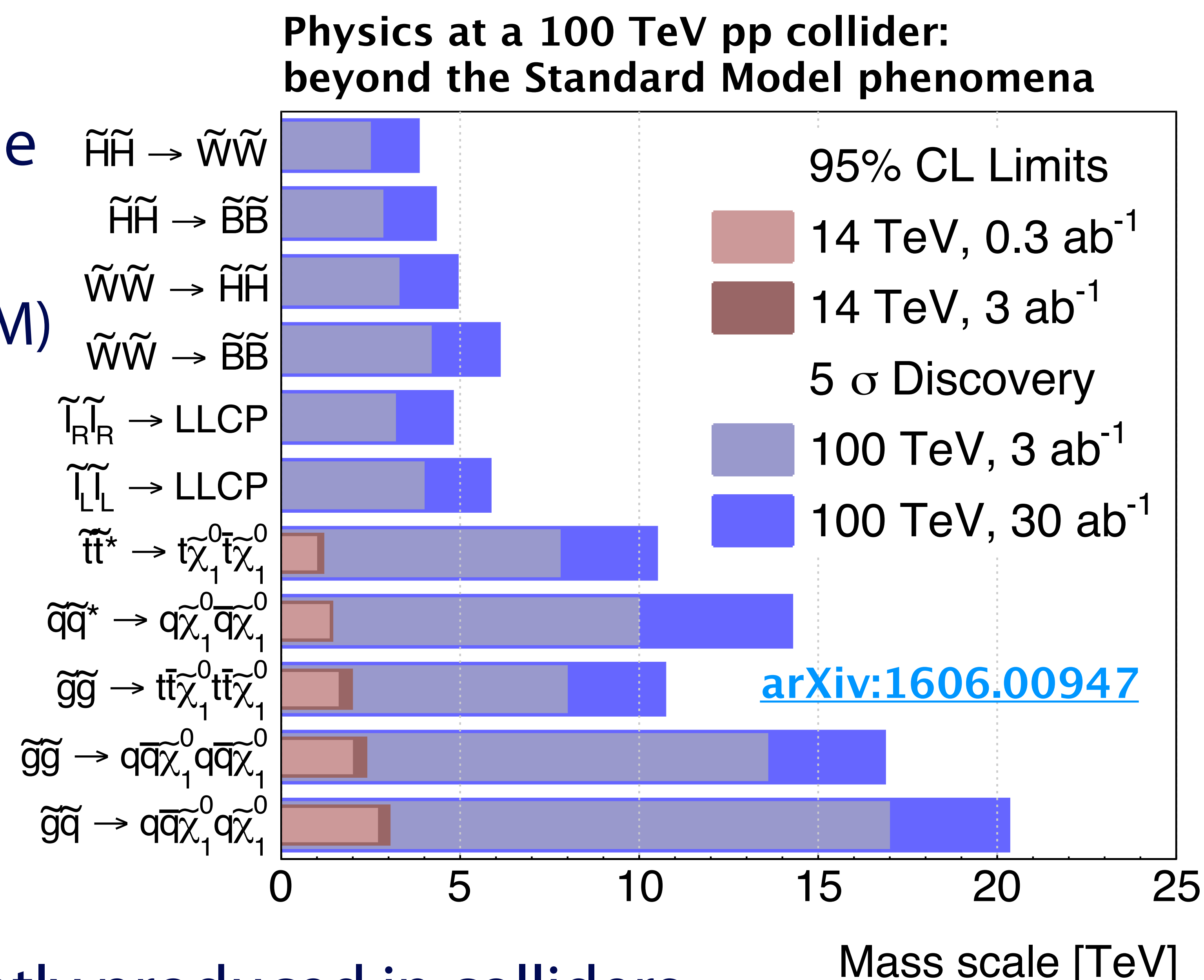
A big leap in BSM sensitivity at 100 TeV collider

Potential to explore strongly produced SUSY particles in10-20 TeV range

SUSY still well-motivated if some level of fine tuning allowed

e.g, **Pure Gravity Mediation** (PGM)

- 125 GeV Higgs mass
- Neutral Wino as DM candidate
- GUT around ~10^{16} GeV
- Heavy scalars; Light gauginos



Gauginos could be predominantly produced in colliders

➡ Study prospects for O(TeV) Wino/Higgsino at 100 TeV collider

Neutralino Dark Matter

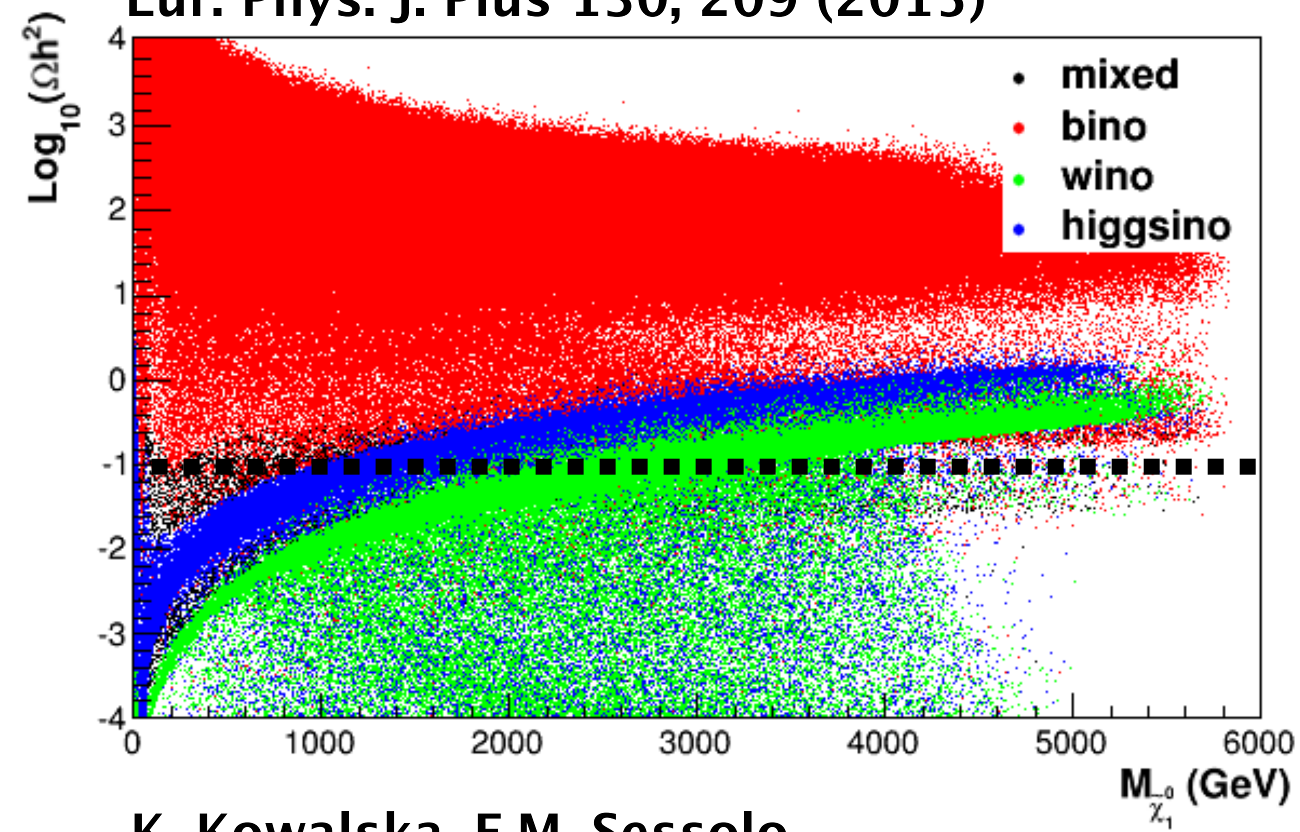
Lightest neutralino as DM candidate

- Bino DM typically over-produced
- Mixed states strongly constrained by direct detection experiments

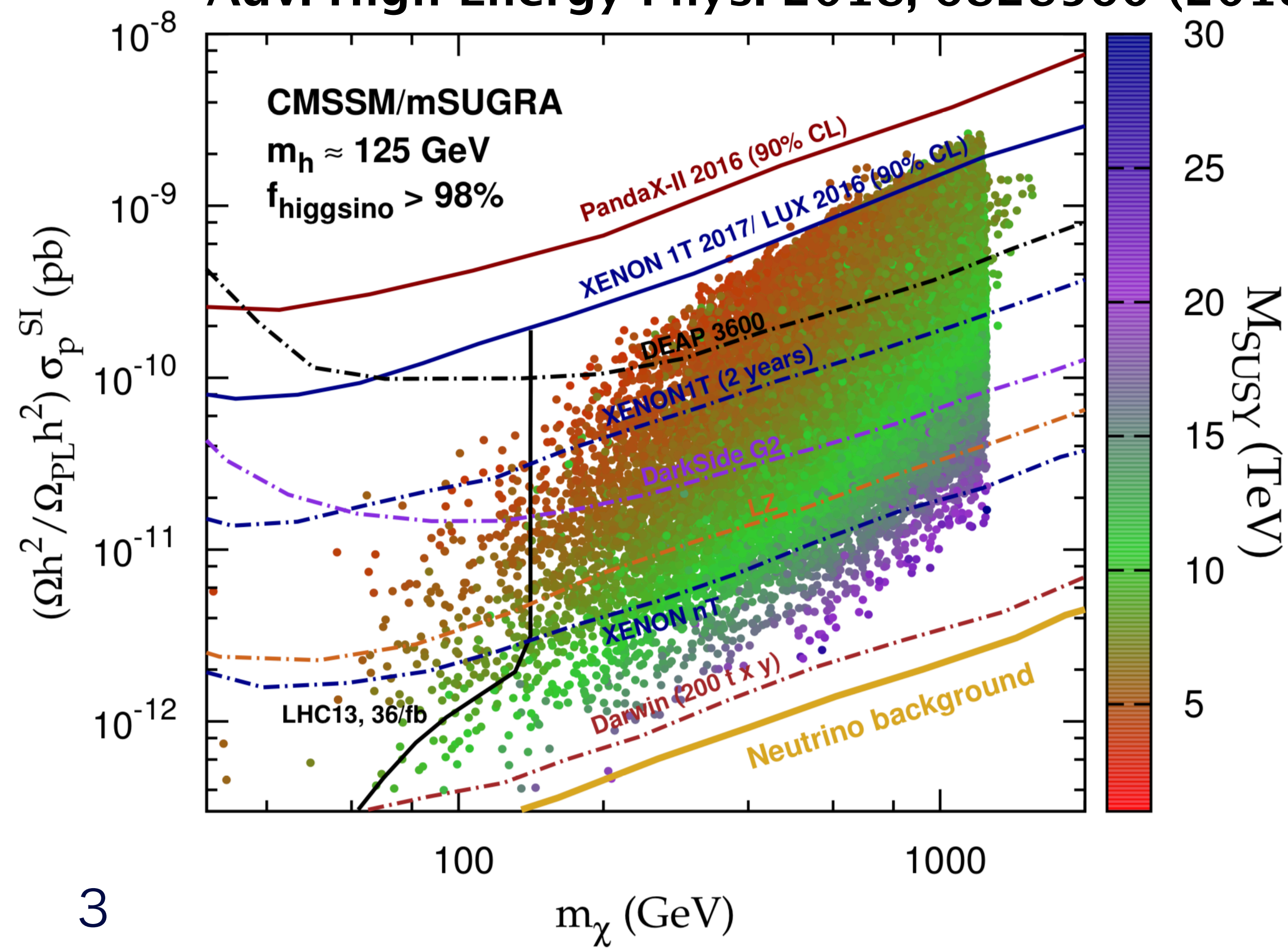
If thermally produced, the DM mass to be below **~3(1) TeV for pure Wino(Higgsino)**

Pure Wino/Higgsino DM constrained by (in)direct detection experiments while still viable if some fine tuning allowed

G. Ricciardi et al.
Eur. Phys. J. Plus 130, 209 (2015)



K. Kowalska, E.M. Sessolo,
Adv. High Energy Phys. 2018, 6828560 (2018)



Wino/Higgsino Signatures at Collider

Nearly pure Wino/Higgsino as LSP :

~mass degenerate for $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ when other SUSY particles are heavy

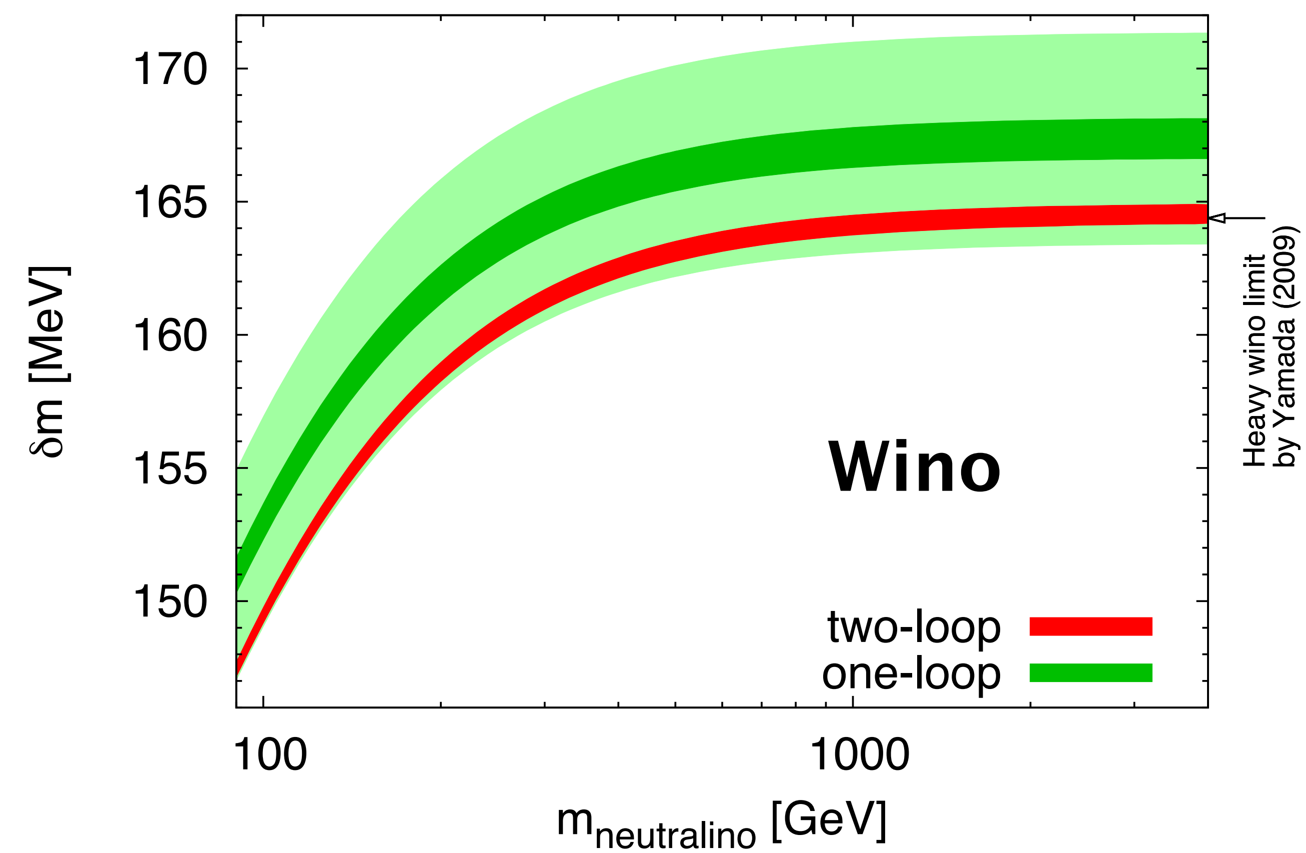
➡ ~160(350) MeV for Wino(Higgsino)

Non-negligible lifetime of $\tilde{\chi}_1^{\pm}$ due to small mass difference:

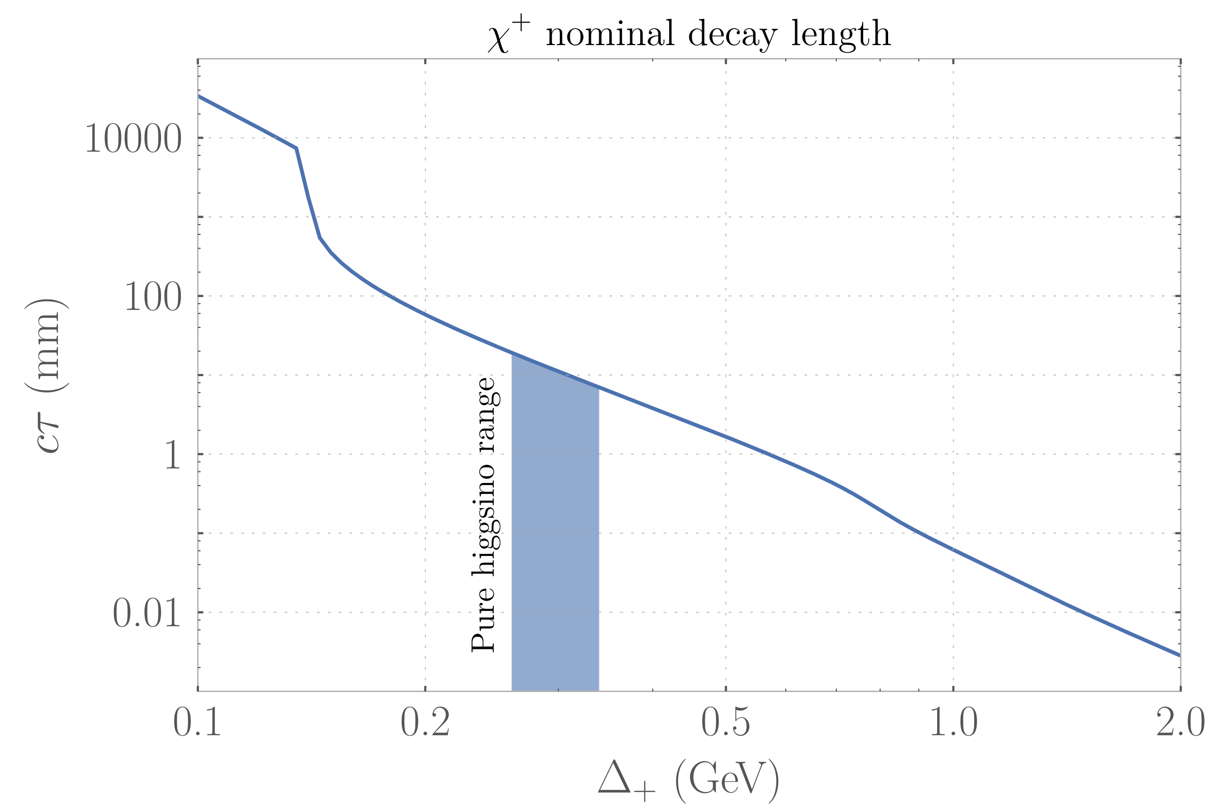
$c\tau$ ~ 6 cm (1.5 cm) for 3 TeV Wino (1 TeV Higgsino)

➡ Disappearing track signature

M. Ibe, S. Matsumoto, R. Sato
PLB 721, 252 (2013)



R. Mahbubani, P. Schwaller, J. Zurita
JHEP 1706, 119 (2017)

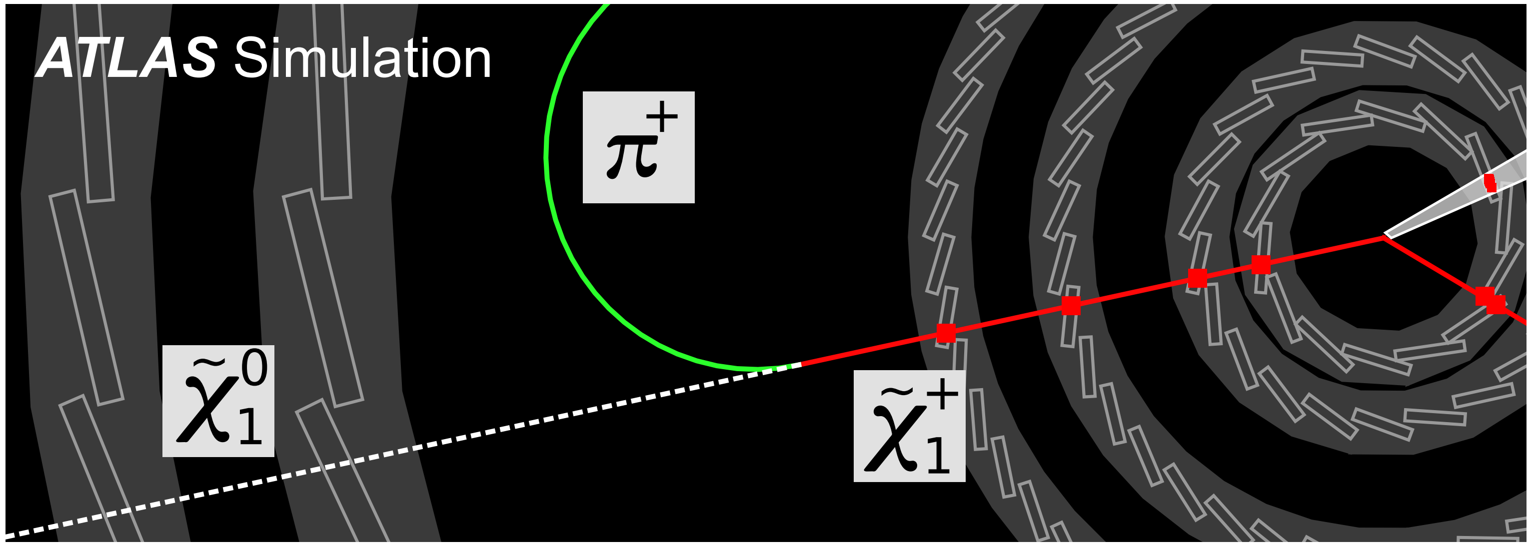


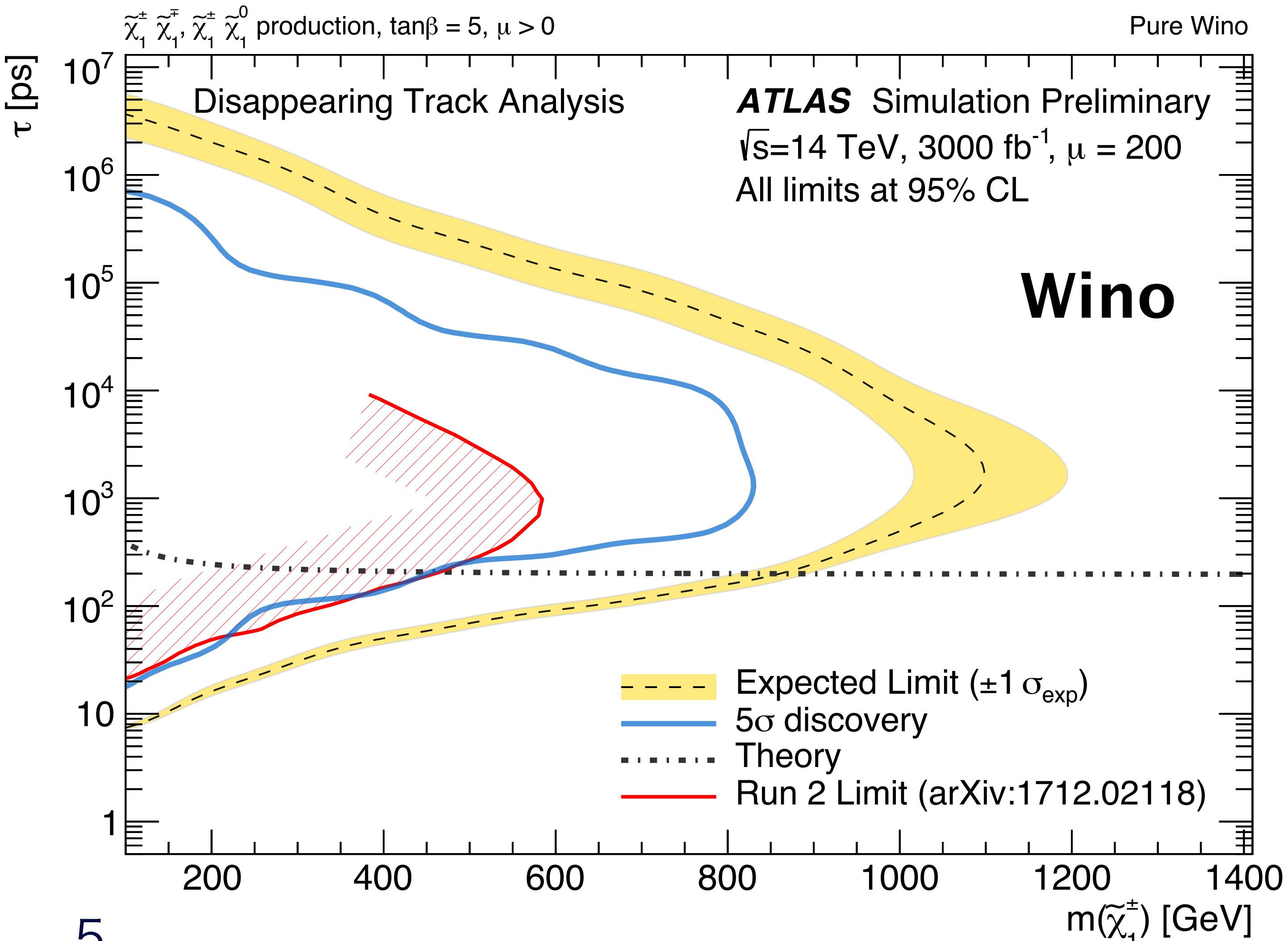
Disappearing Track

Long-lived $\tilde{\chi}_1^{\pm}$ decays into a soft pion and a $\tilde{\chi}_1^0$

- soft pion not reconstructable
- short track with no associated activity in outer tracker or calorimeter

➡ **Disappearing track inside detector**



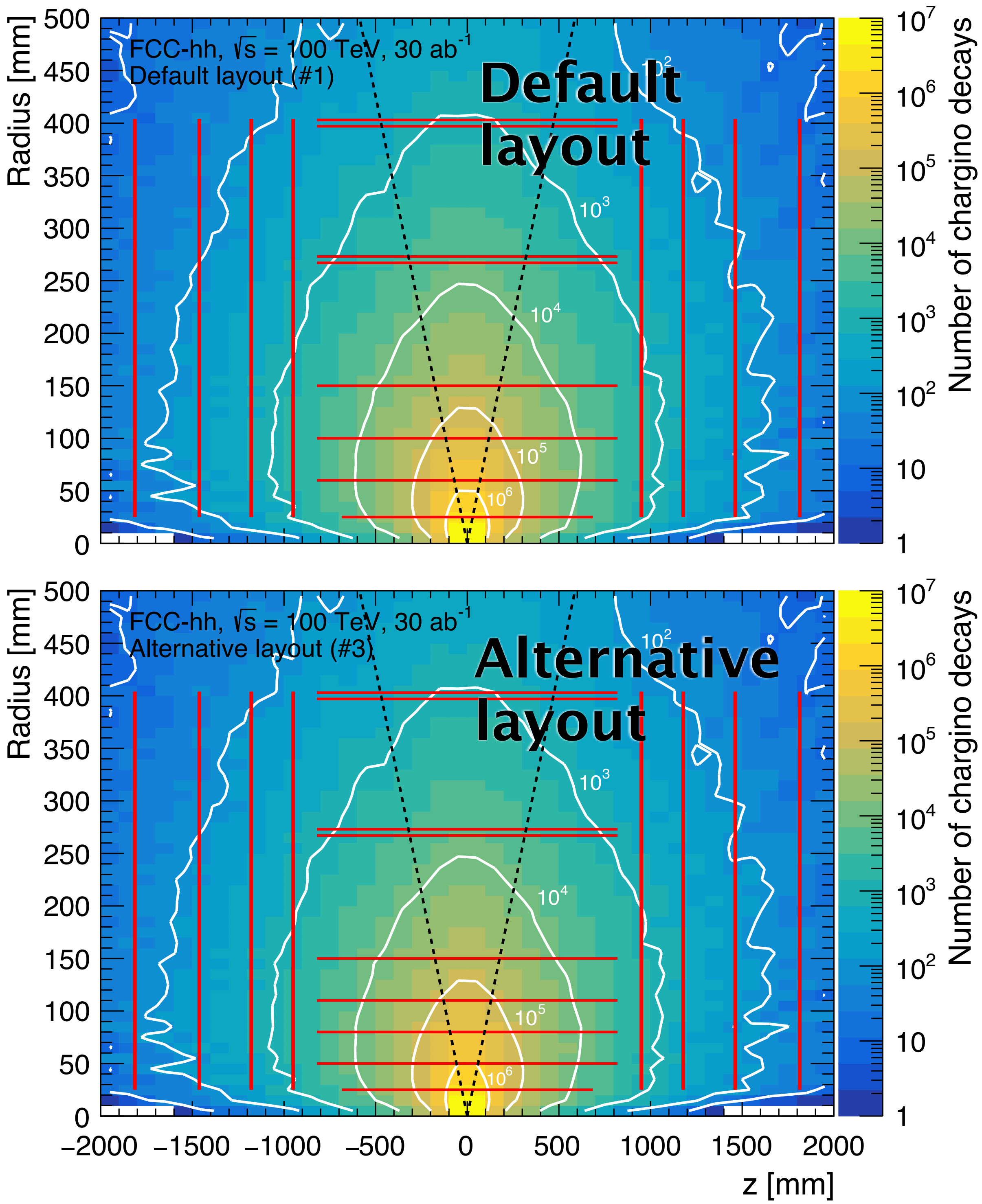


LHC results/prospects:

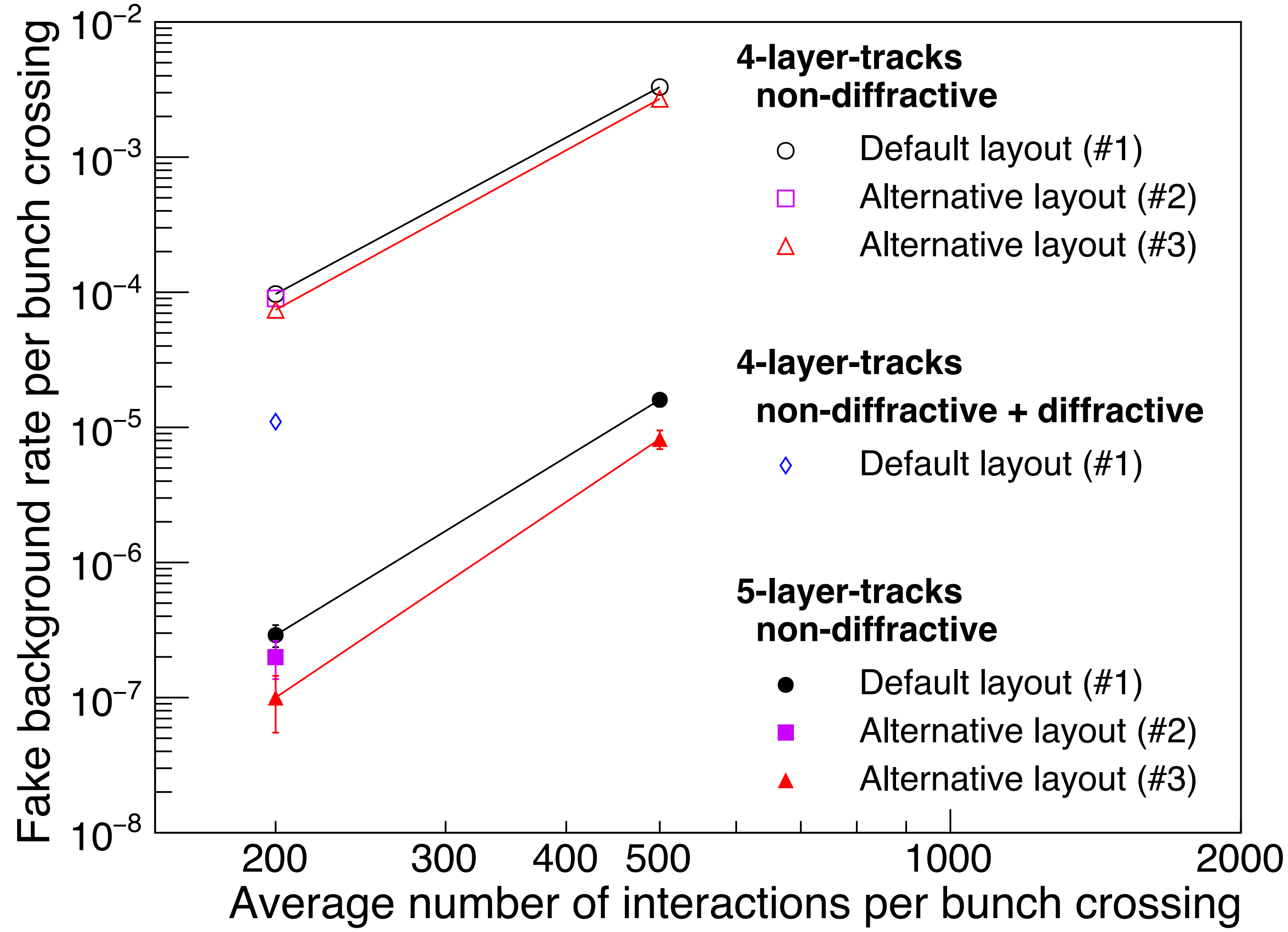
- Excluded up to 460(152) GeV for Wino(Higgsino)
- Expected to exclude up to ~850(250) GeV at 14 TeV, 3 ab^{-1}

Disappearing Track at FCC

Disappearing track analysis for Wino/Higgsino at FCC-hh in CDR



Alternative inner-tracker layouts to study impact on the sensitivity



- Estimate of fake background (random crossings) with GEANT4
- Contribution from pile-up interactions taken into account

Timing Measurement

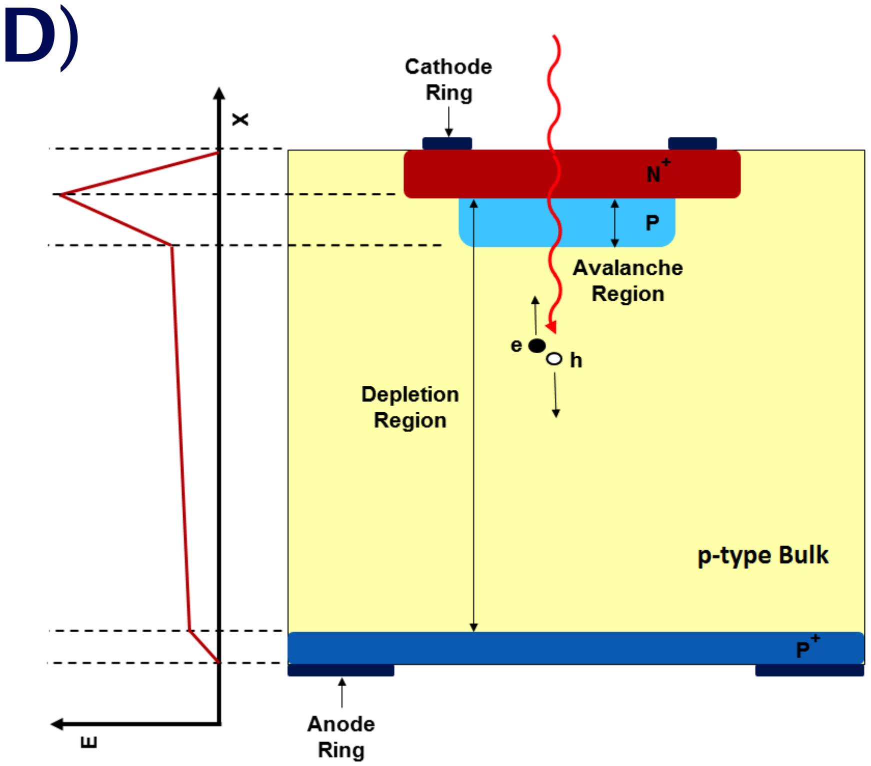
Timing measurement for track is crucial for background rejection as well as the measurement of chargino velocity

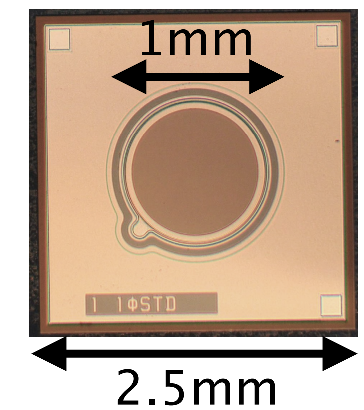
Low–**G**ain **A**valanche **D**etector (**LGAD**)

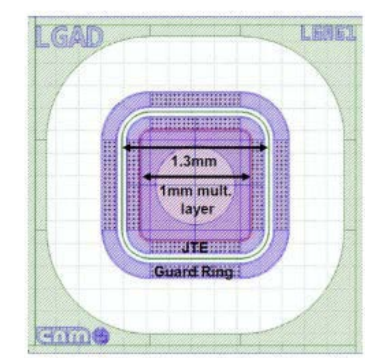
- $\lesssim$ 30 ps time resolution feasible
- ongoing study for radiation hardness

Assumed in this study that 30~50 ps time resolution can be achieved for the inner-pixel tracker at FCC

ATLAS HGTD





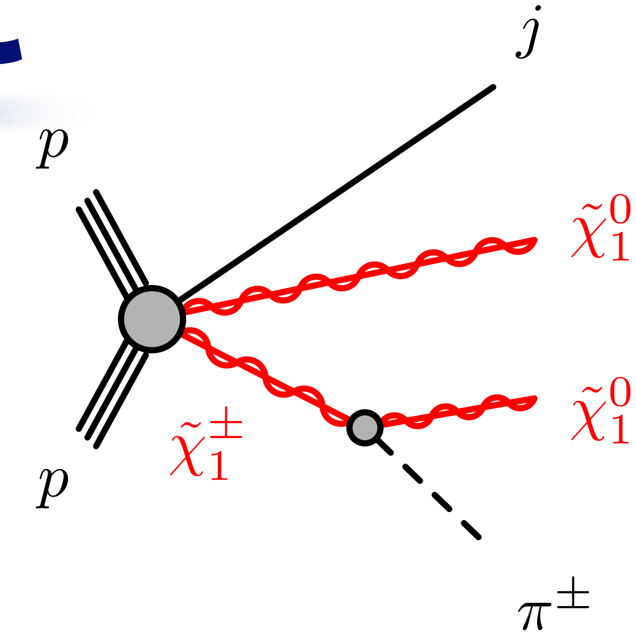


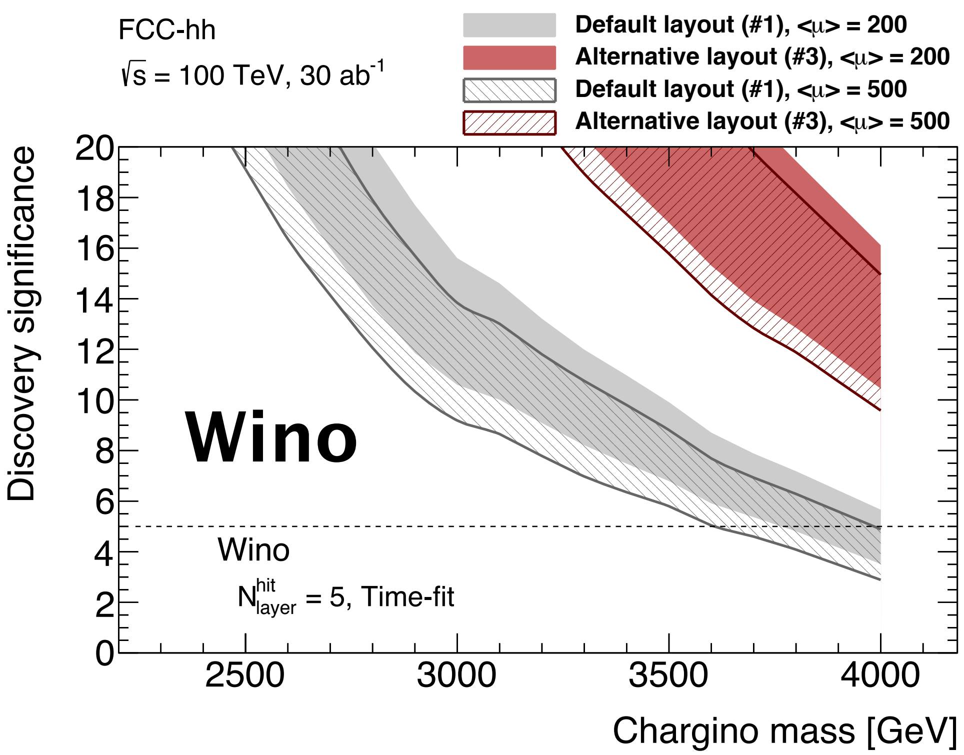
- >95% of fake tracks (random crossings) can be removed with 50 ps hit-level time resolution
- Wino velocity β can be measured with an accuracy of ~6% at $\beta < 0.8$

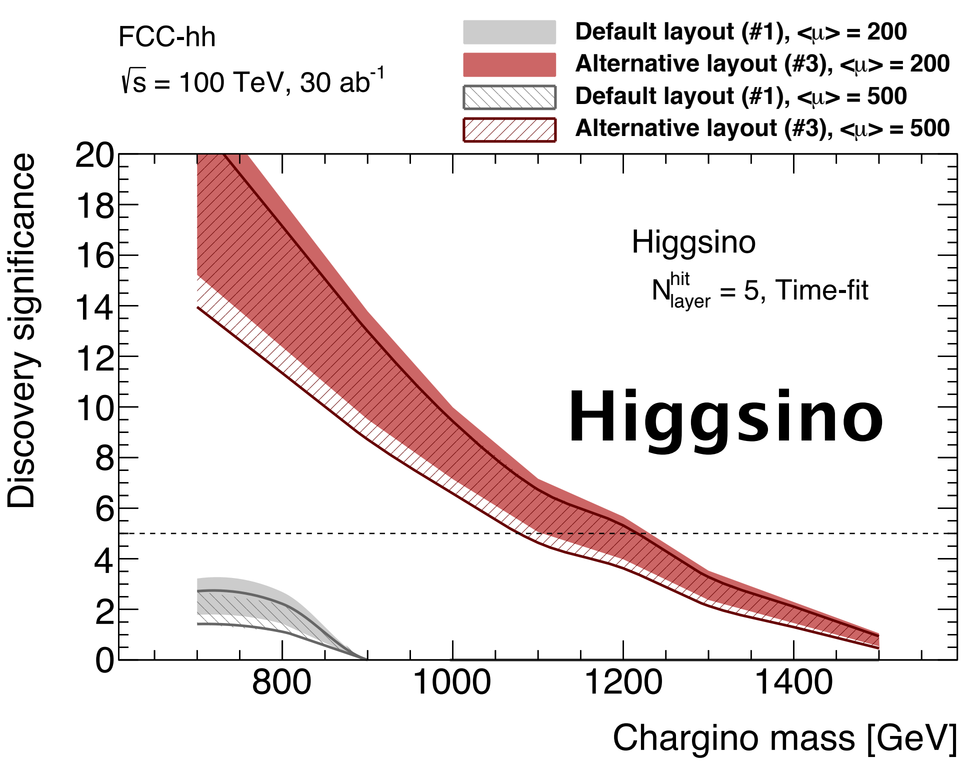
Disappearing Track at FCC

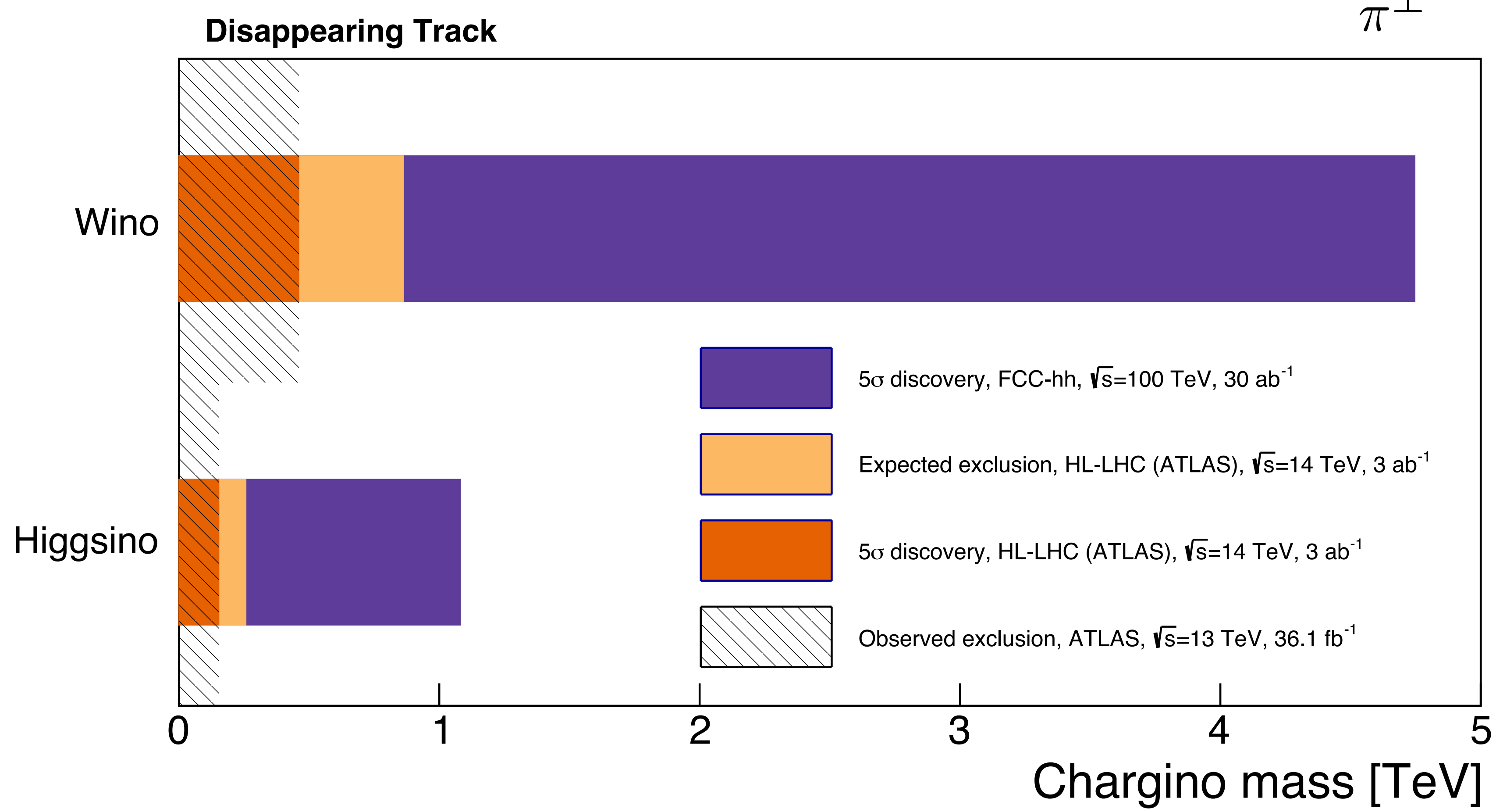
ISR jet + E_T^{miss} + single disappearing track signature

- 5 layers within 15 cm from beam line
- Timing information used to suppress background









➡ FCC can cover the full mass range for discovery of thermal Wino/Higgsino DM

Gaugino Masses

Can we determine gaugino masses if they are within FCC reach?

Consider the case where Wino is lighter than other gauginos:

- Neutral Wino as LSP (→ disappearing track)
- Wino mass assumed to be 2.9 TeV (full DM density accounted for by Wino)
- Pair production of gluinos considered as main production mode

PGM as possible SUSY breaking scenario

Fundamental parameters in PGM ($m_{3/2}$, L, ϕ_L) can be derived from gaugino masses

	Point 1	Point 2	Point 3
$m_{3/2}$ [TeV]	250	302	350
L [TeV]	800	756	709
$m_{\tilde{B}}$ [GeV]	3660	4060	4470
$m_{\tilde{W}}$ [GeV]	2900	2900	2900
$m_{\tilde{g}}$ [GeV]	6000	7000	8000
$\sigma(pp \to \tilde{g}\tilde{g})$ [fb]	7.9	2.7	1.0

➡ Implication to SUSY breaking mechanism

Information about masses of heavy Higgses and Higgsinos

Gaugino Signals

Pair production of gluinos

$$\tilde{g} \to q\bar{q}\tilde{B}, q\bar{q}\tilde{W}$$

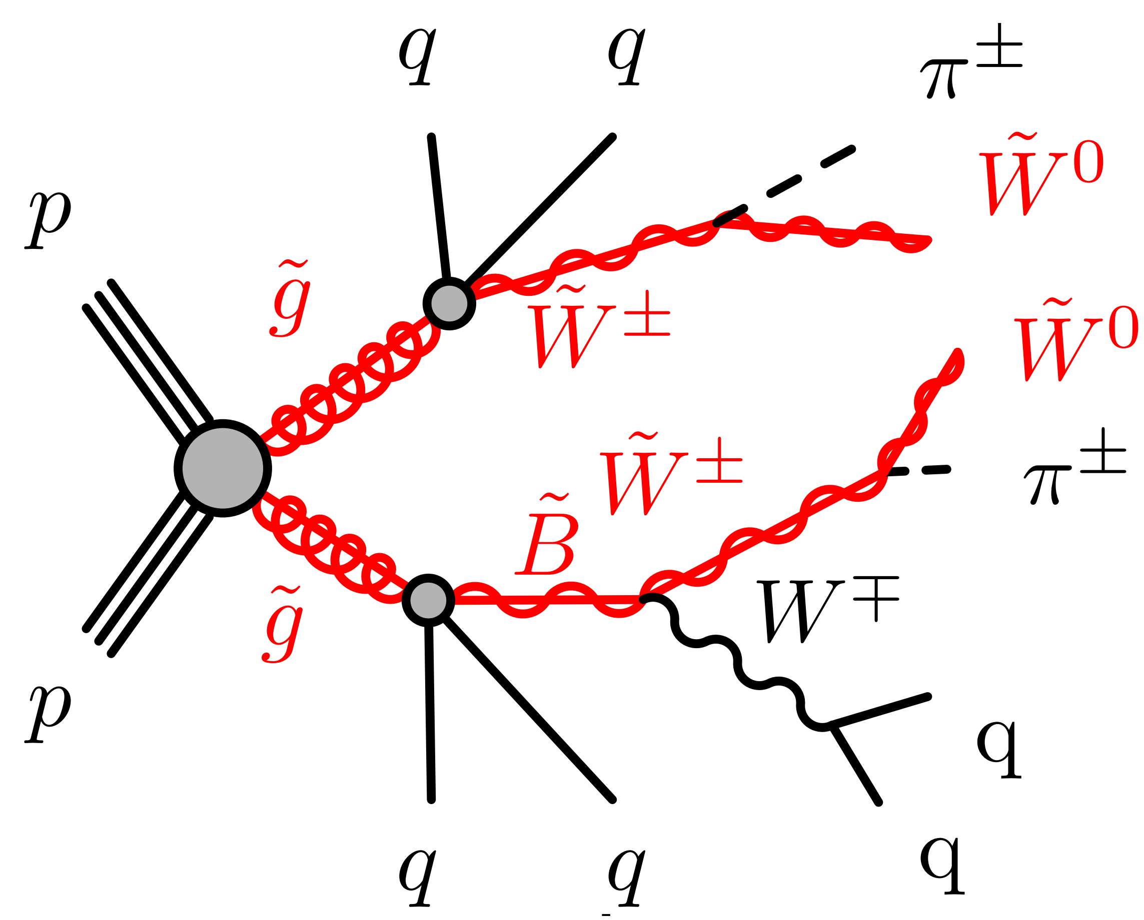
$$\mathrm{BR}(\tilde{g} \to q\bar{q}\tilde{B}) = \mathrm{BR}(\tilde{g} \to q\bar{q}\tilde{W}) = 0.5$$

Bino decays to Wino + *W*/Higgs -boson

$$\tilde{B} \to \tilde{W}^{\pm}W^{\mp}, \tilde{W}^{0}h$$

$$\tilde{W}^{\pm} \to \pi^{\pm} + \tilde{W}^{0}$$

→ *Disappearing track*



Event selection:

- 2 disappearing tracks :
  - *1st track = r > 10 cm, |η| < 1.5*
  - *2nd track = r > 10 or 5 cm, |η| < 1.5*
- $E_T^{miss} > 1$ TeV

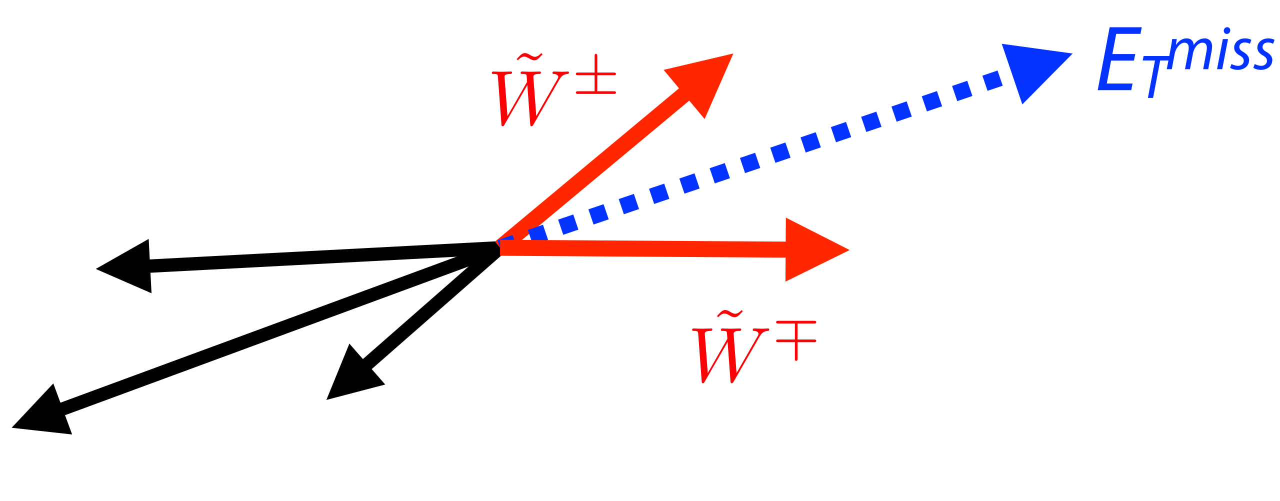
Only disappearing tracks with *r* > 10 cm used for mass determination (→ next slides)

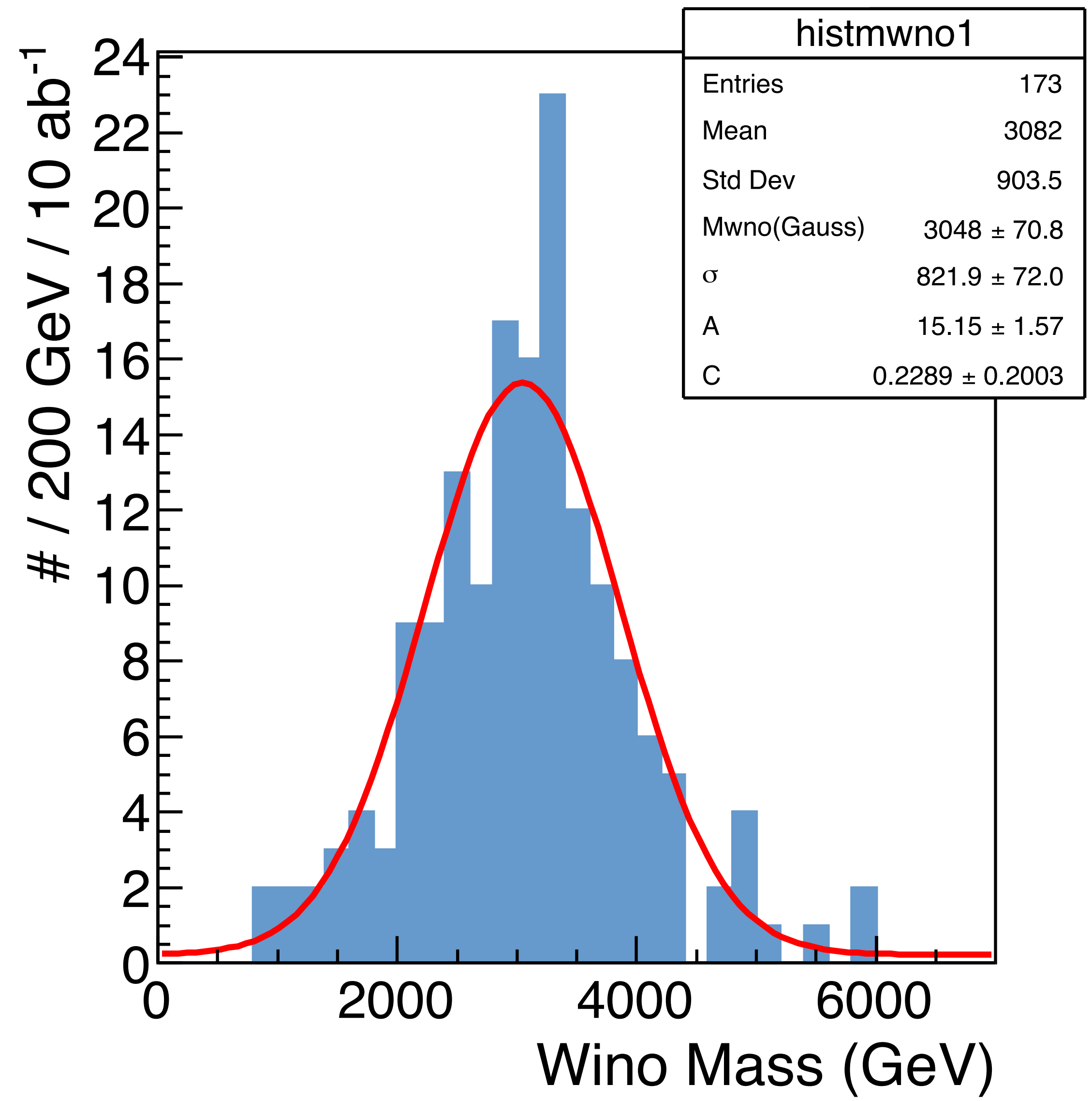
Wino Mass Measurement

Wino mass determined by measuring velocity (β) and momentum

$$m_{\tilde{W}} = p_{\tilde{W}} \cdot \frac{\sqrt{1-\beta^2}}{\beta}$$

- β measured using timing information:
  β resolution ~ 6% with at r > 10cm, β < 0.8
- momentum reconstructed by splitting E_T^{miss} into Wino directions (determined from disappearing tracks)





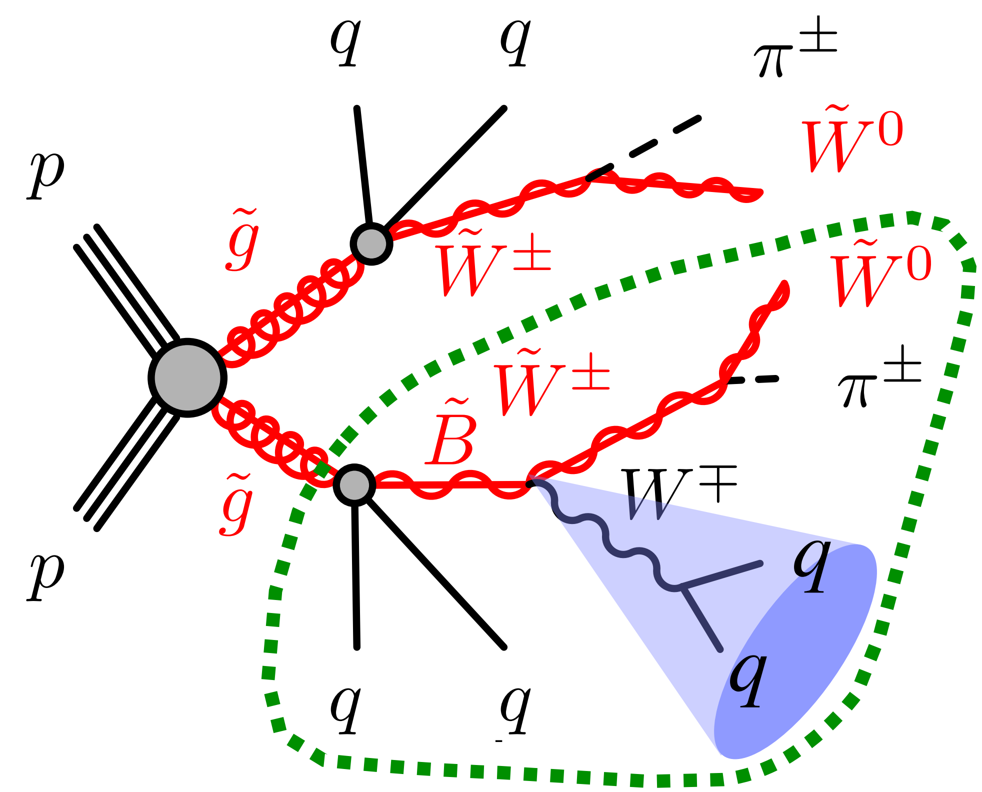
- 2-3% precision at 2.9 TeV

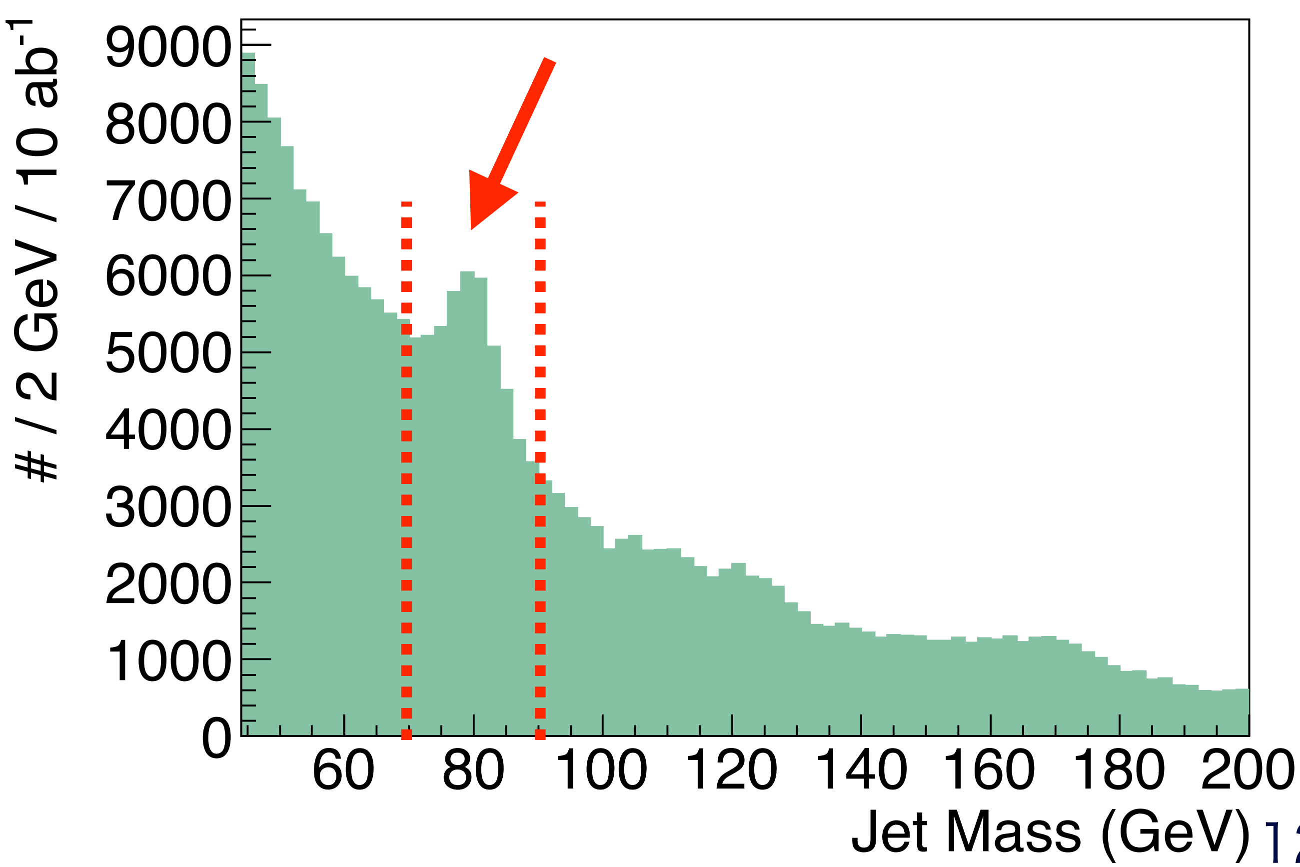
Bino Mass Measurement

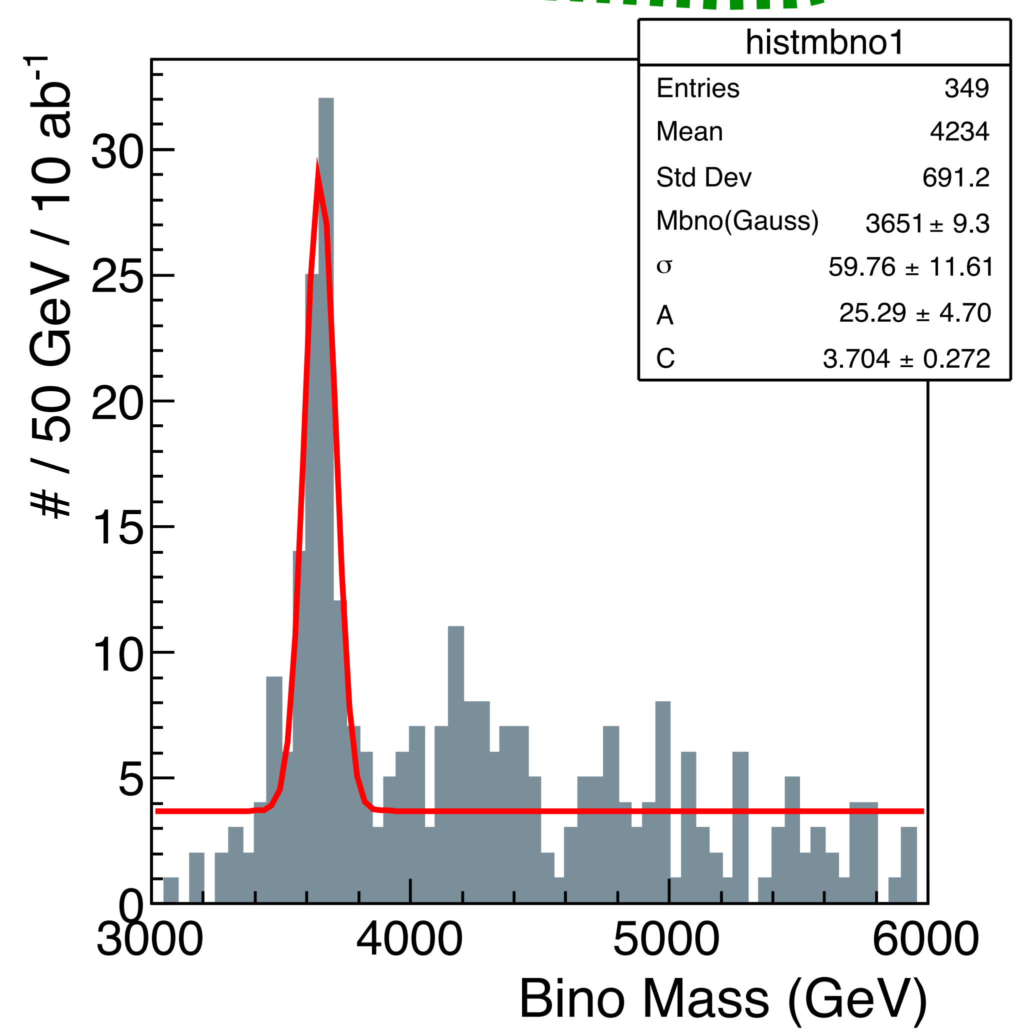
Bino mass reconstructed from Wino momentum and *W*-boson:

$$m_{\tilde{B}} = \sqrt{(m_{\tilde{W}} v_{\tilde{W}} + p_{W^{\pm}})^2}$$

- Wino momentum obtained from measured mass and velocity
- *W*-boson momentum from fat-jet





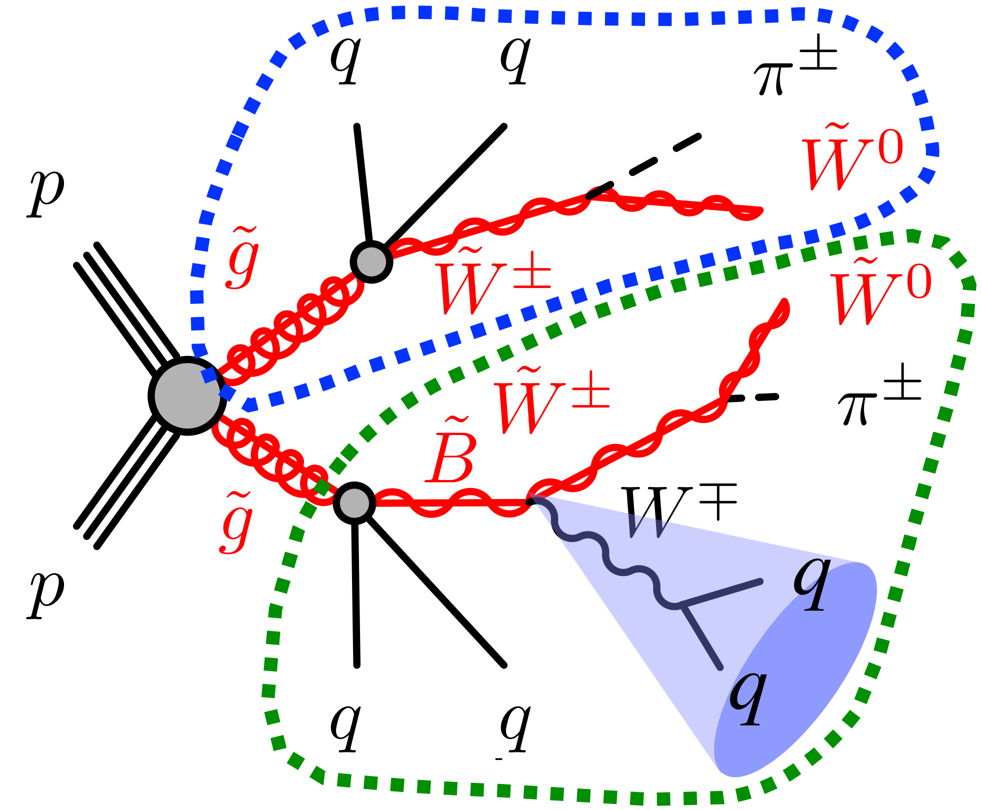


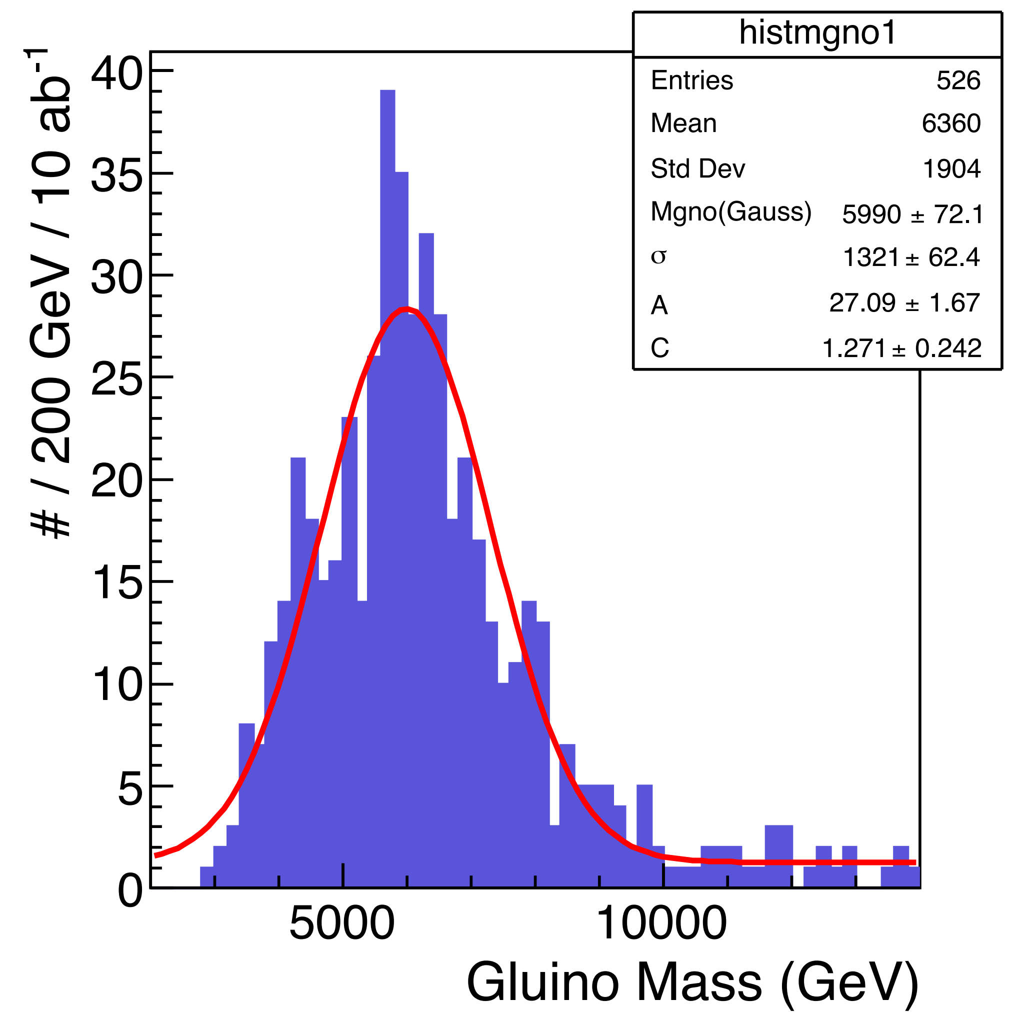
- 2-3% precision at ~4 TeV
  (dominated by $\sigma_{m\tilde{W}}$)

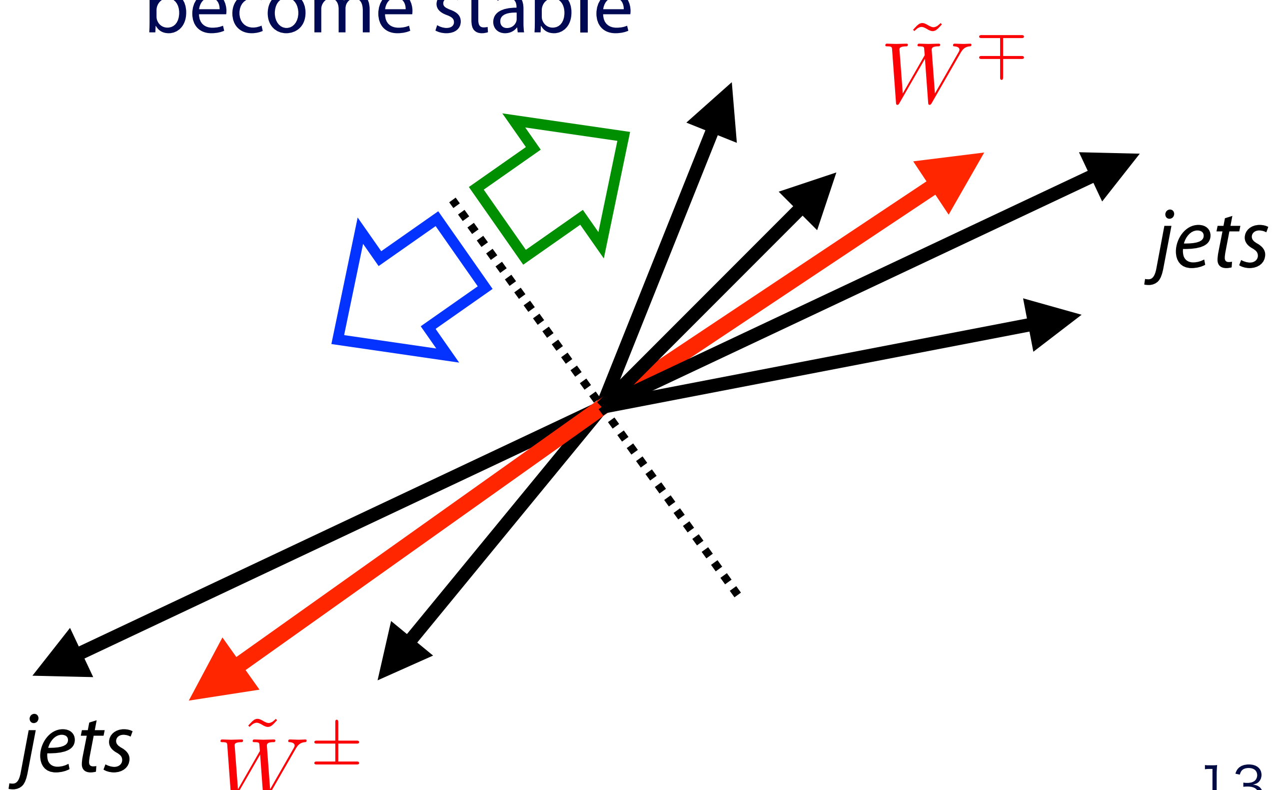
Gluino Mass Measurement

Gluino mass reconstructed using hemisphere analysis:

- Take Wino momenta as hemispheres
- Assign all jets to each hemisphere using distance metric and update hemisphere momenta
- Iterate until the hemispheres become stable



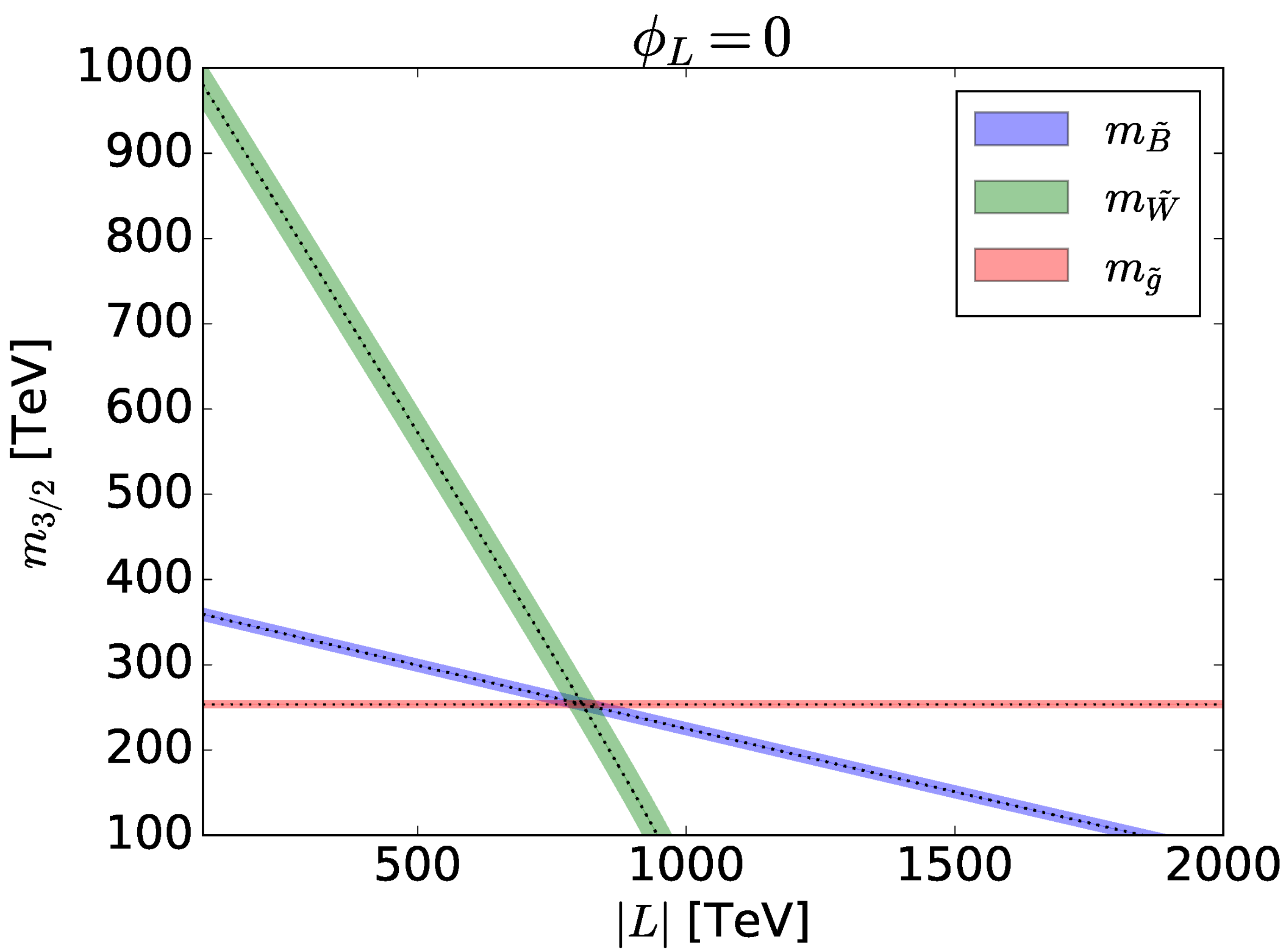


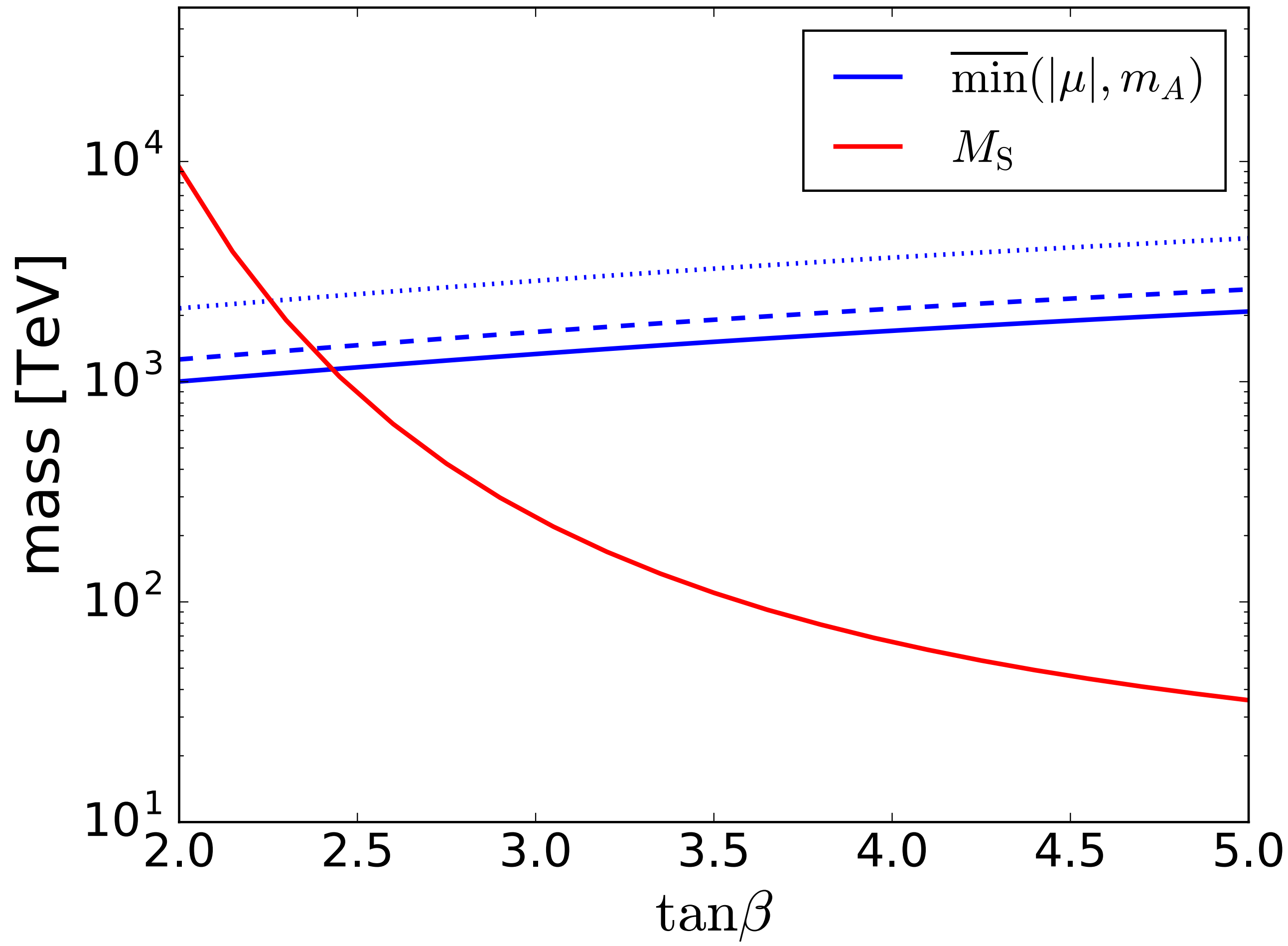


- 1-2% precision at 6-8 TeV (controlled by $\sigma_{m\tilde{W}}$ and stat. error)

Implication

(Upper bound on) heavy Higgs,
Higgsino mass scale
sfermion mass scale





PGM parameters ($m_{3/2}$, L, ϕ_L) can be constrained from gaugino masses

Information about mass scales of heavy Higgses, Higgsinos or sfermions can be extracted

Summary

- Presented prospect of gaugino searches with disappearing track analysis at 100 TeV collider
- **FCC-hh at 100 TeV can cover the full mass range for discovery of thermal Wino/Higgsino DM**

- Possible to determine Wino, Bino and Gluino masses if they are within FCC reach
  - *Crucial to have inner-detector with timing capability*

  ➡ Implication to SUSY breaking mechanism and mass scales of heavy SUSY particles