Disappearing tracks at FCC

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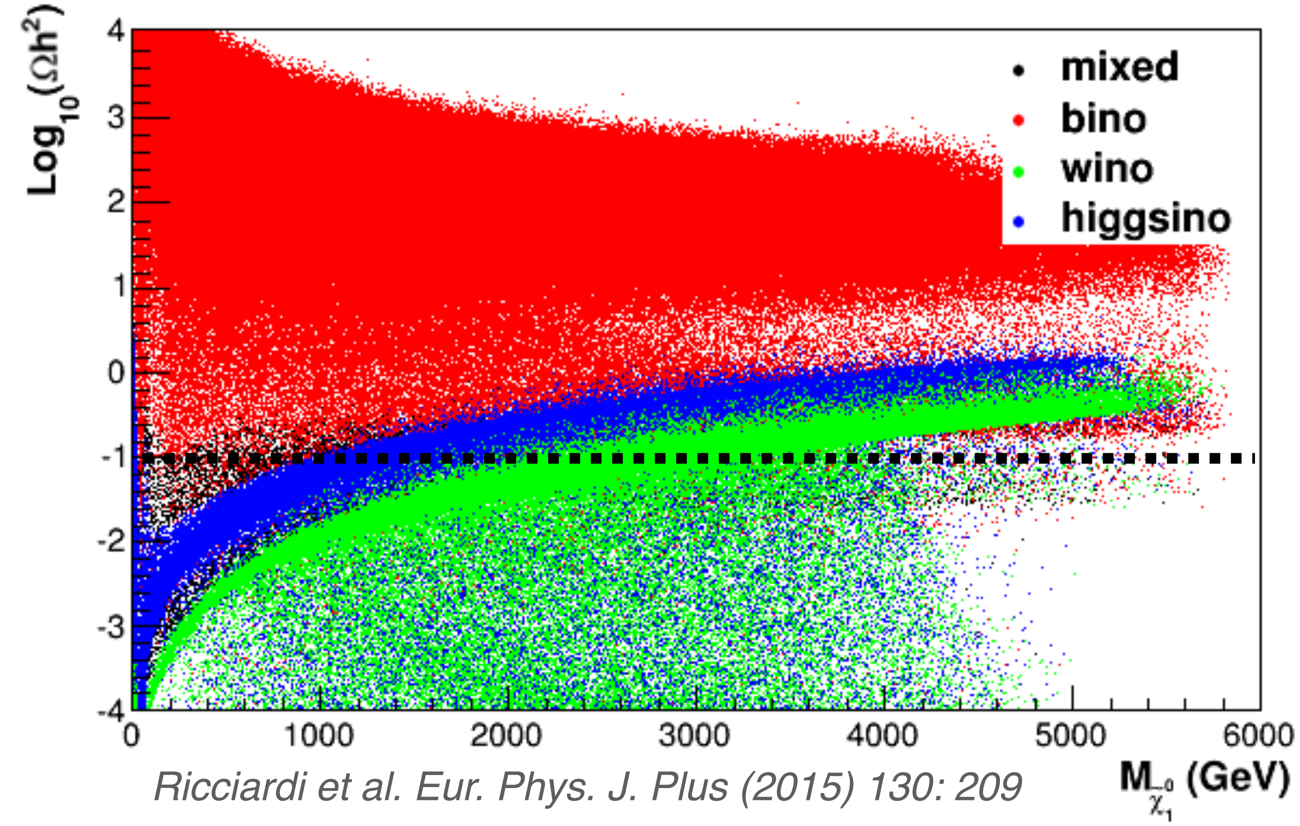
ICEPP
The University of Tokyo

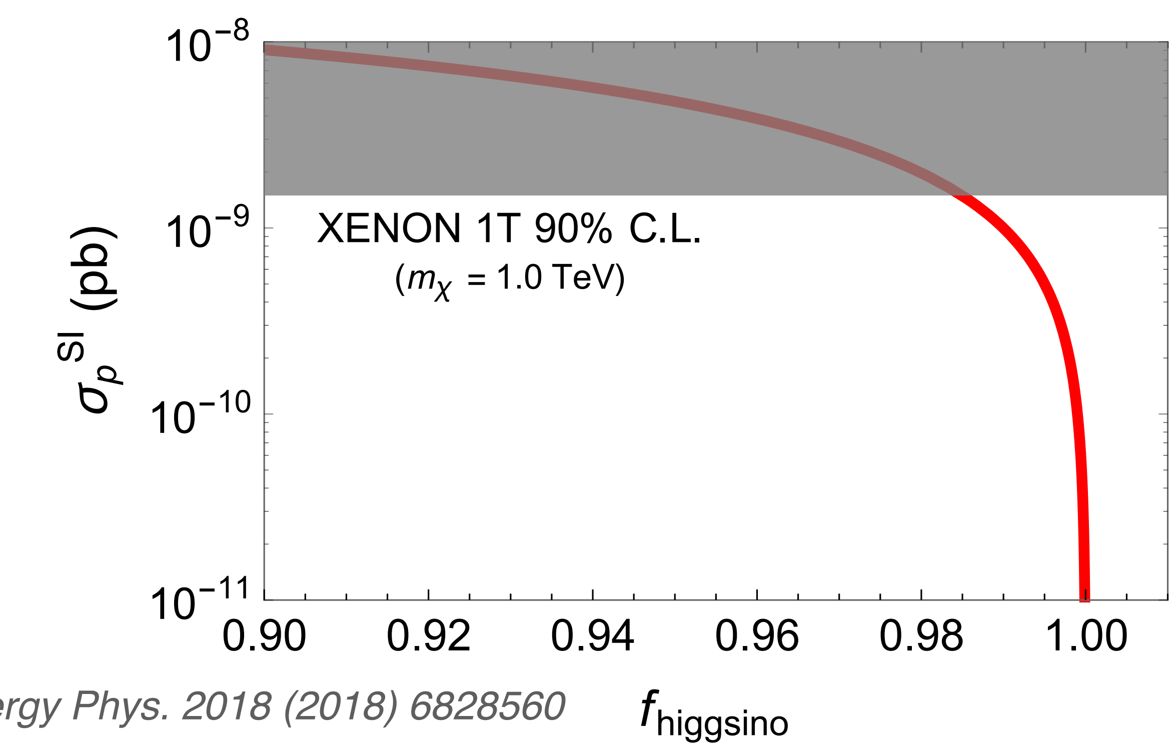
arXiv:1901.02987
arXiv:1901.10389

Neutralino dark matter

- The lightest neutralino is a good candidate of dark matter.
- Bino DM would be overproduced, while **Wino** and **Higgsino** would give the correct relic density.
- If thermally produced, the dark matter mass should be **~1 TeV for Higgsino** and **3 TeV for Wino** scenarios.
- “Mixed” LSP models are strongly constrained by underground direct-searches.



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

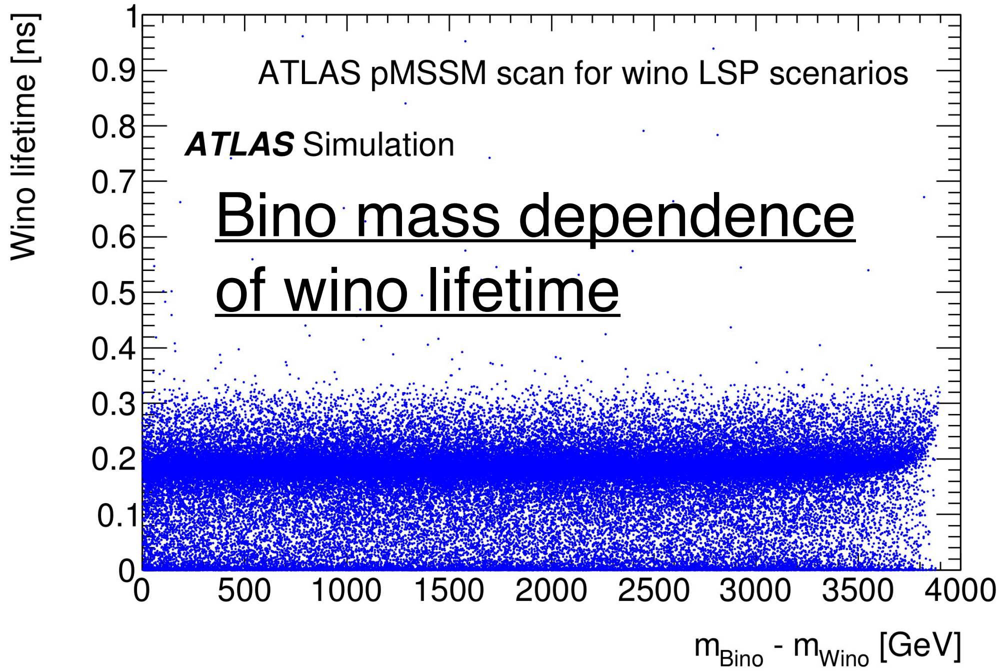


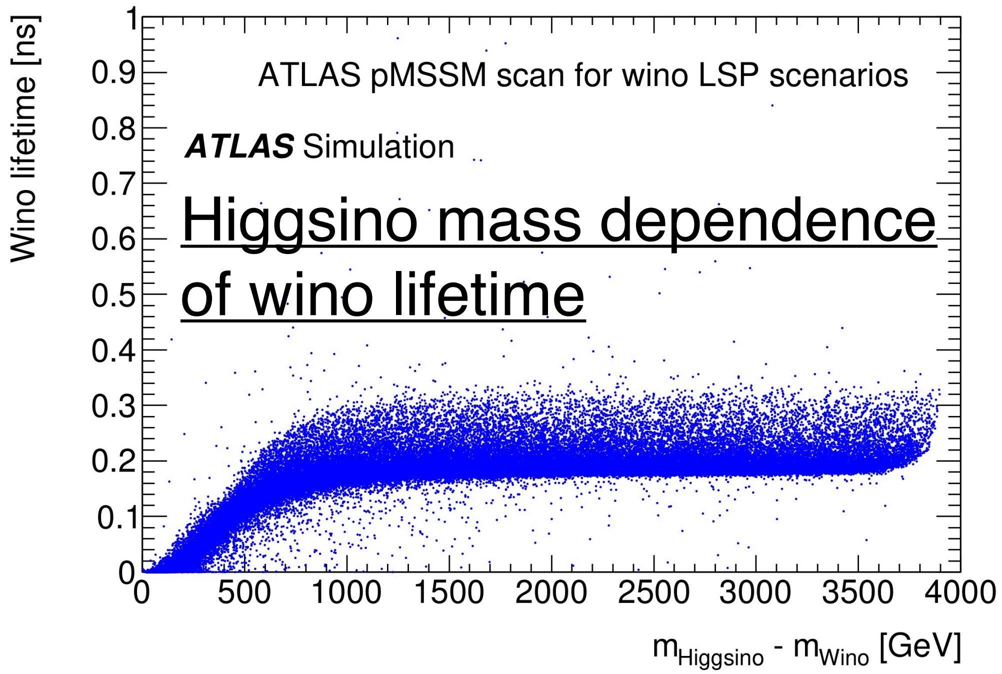
Adv.High Energy Phys. 2018 (2018) 6828560

Wino and higgsino at collider

- If the LSP is almost pure higgsino or wino, the **mass difference** between the neutral and the charged states is tiny (**$\mathcal{O}$(100 MeV)**) as a function of the LSP mass (nearly independent of other SUSY particle masses)

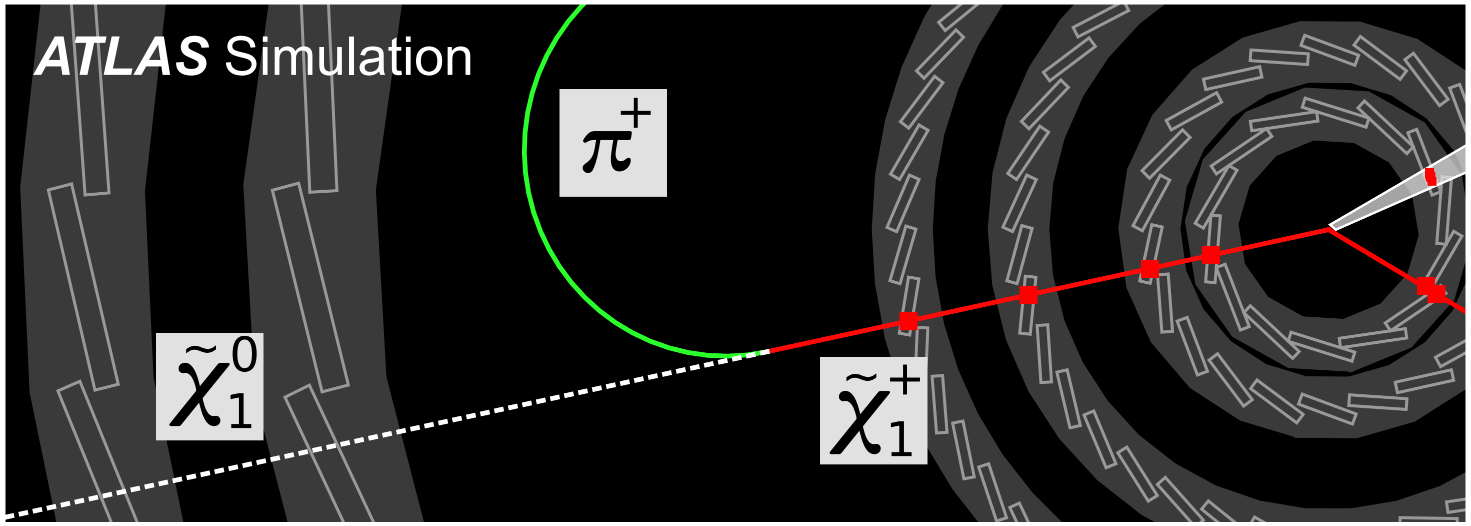
- Due to the small mass difference, the lifetime of chargino is macroscopic,
  - **Wino : *cτ* ~ 6 cm**
  - **Higgsino : *cτ* ~ 1–2 cm**





ATLAS SUSY-2016-06

Disappearing track search @ LHC



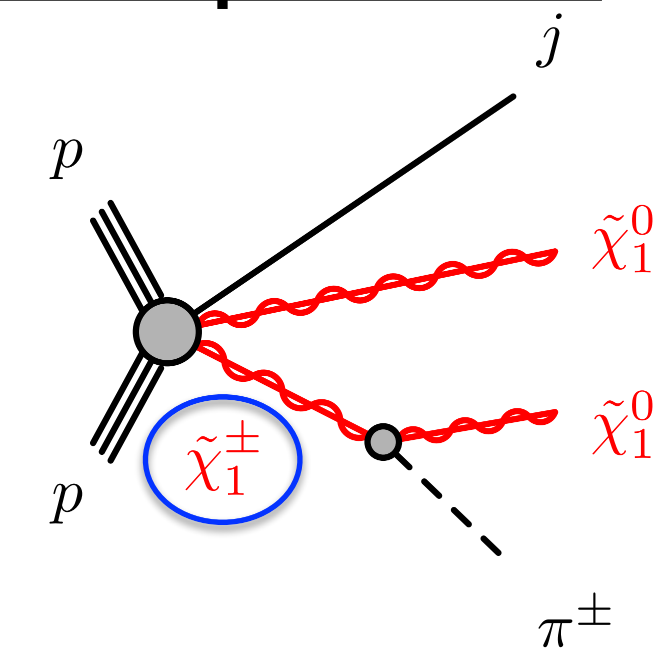
- Long lived chargino searches using **disappearing track**
  - Short tracks which do not have associated hits in the outer part of the tracker and calorimeters.
- ATLAS (36 fb^{-1} results)

  JHEP 06 (2018) 022
  - **Wino** excluded below **460 GeV** (cτ = 0.2 ns)
  - **Higgsino** excluded below **152 GeV**.

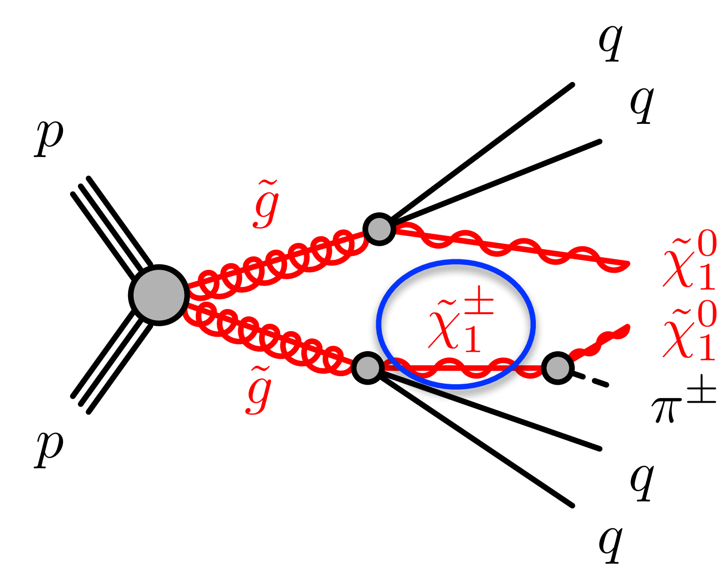
  ATL-PHYS-PUB-2017-019
- CMS
  - **Direct production** (38 fb^{-1}) *JHEP 08 (2018) 016*
  - **Full Run 2 result** for gluino-decay channel.

  CMS-PAS-SUS-19-005

Direct production

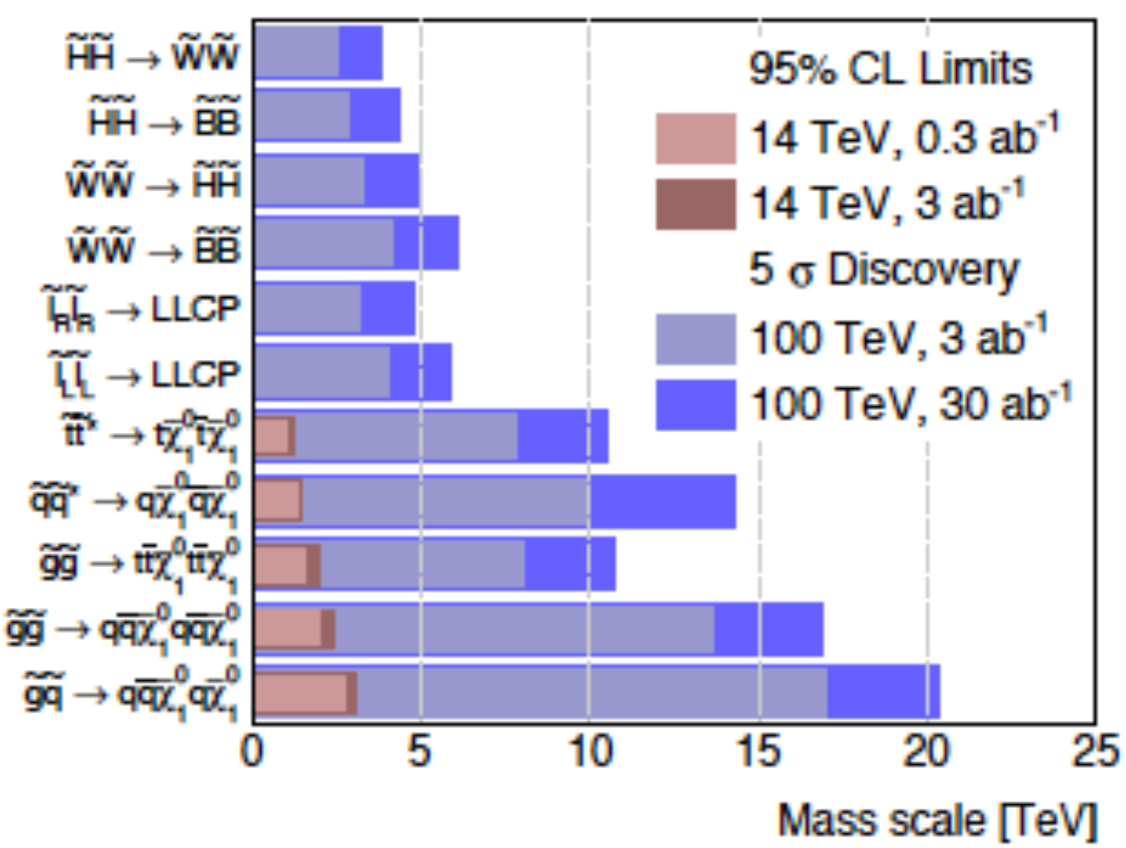


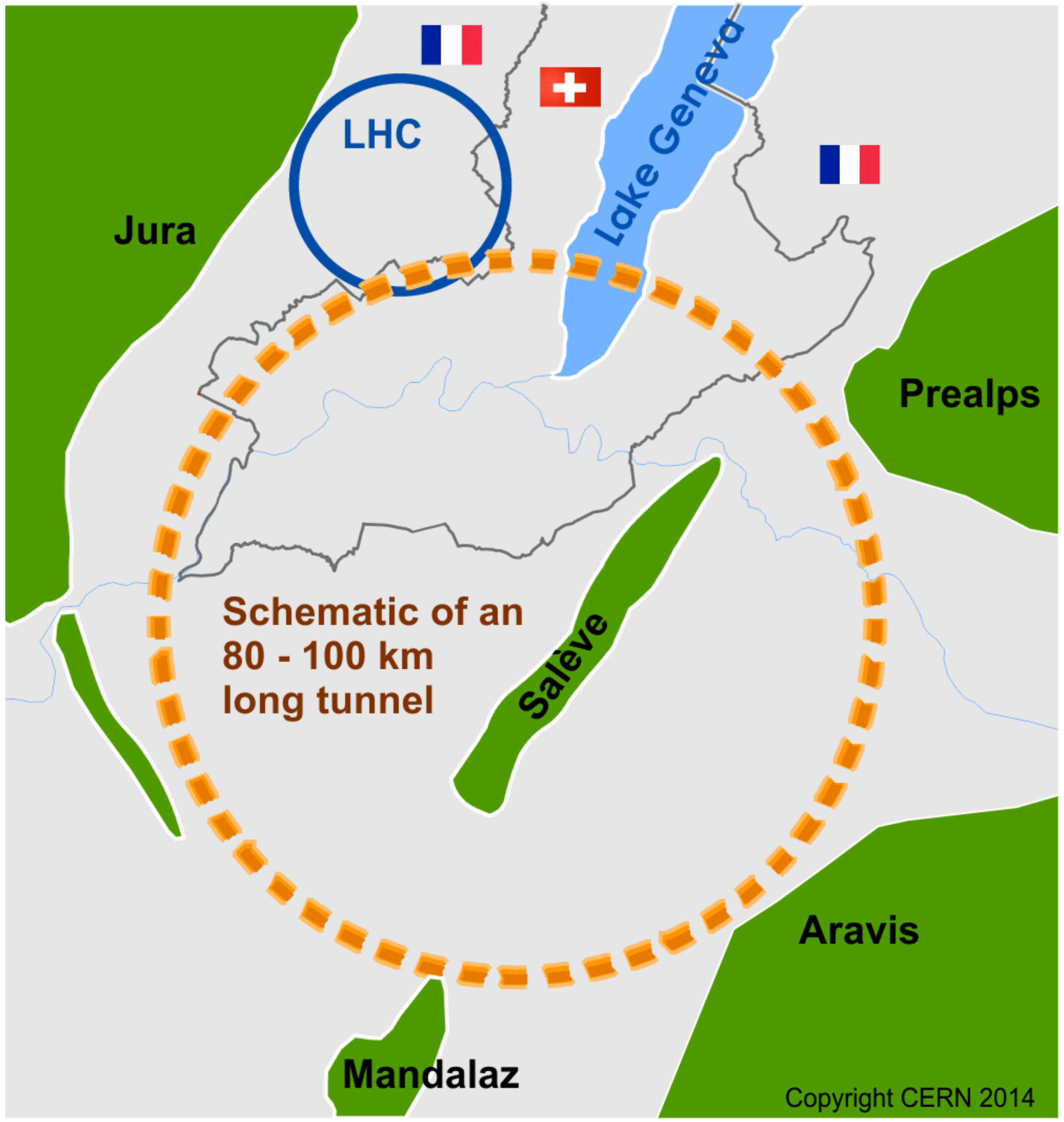
From gluino decay



Future Circular Collider (FCC-hh)

- 100 km tunnel in Geneva area
- *pp* collider with $\sqrt{s}$ = 100 TeV
- 200—1000 collisions per bunch crossing
- Total integrated lumi. ~ 20 ab^{-1}
- Much higher sensitivities to various new physics than LHC



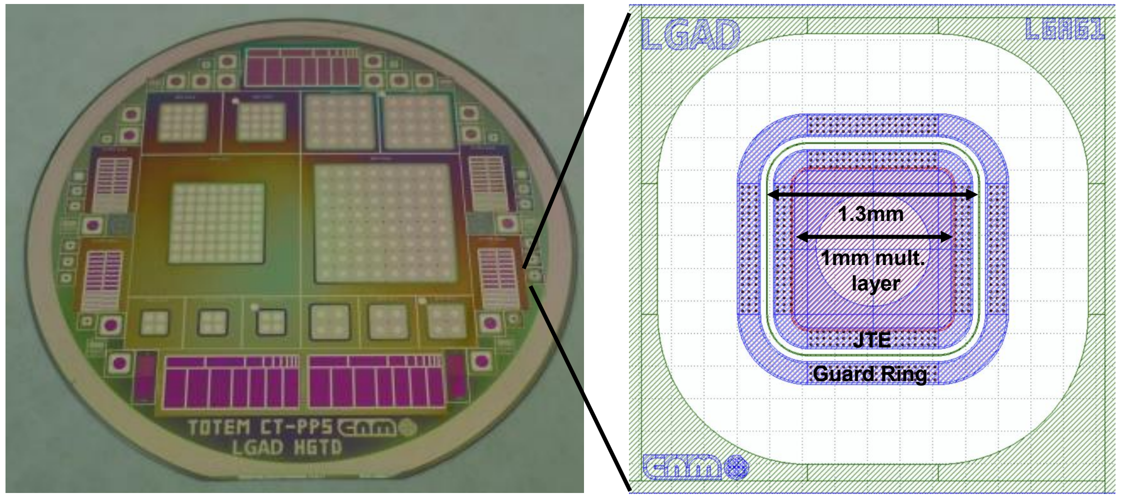


Details in Filip's talk

Future Circular Collider Study. Volume 3, CERN-ACC-2018-0058. Submitted to Eur. Phys. J. ST.

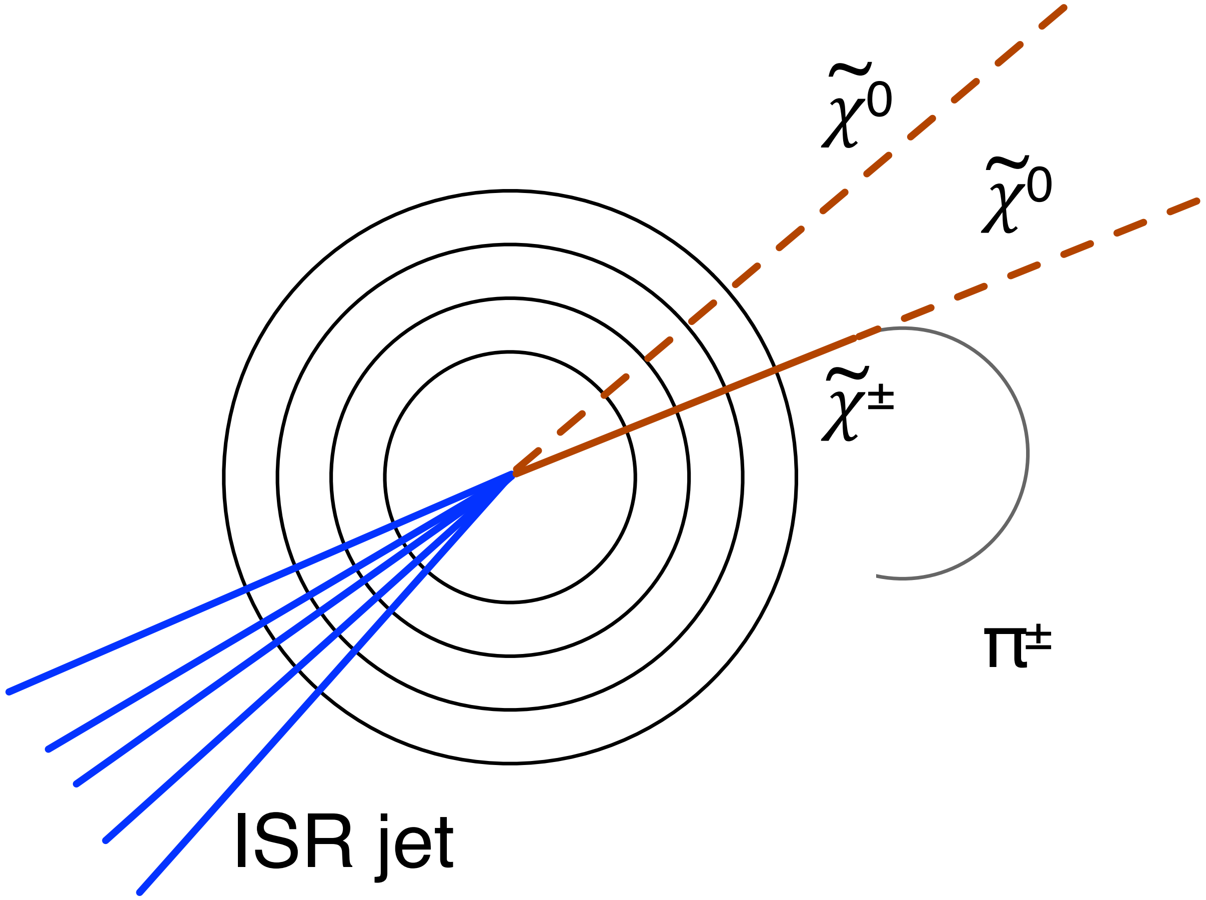
DT + Hit-time information

- **Low Gain Avalanche Detectors** (LGAD) have time resolution of **10—30 ps**
- We assume here that the detector can be used in FCC as the inner pixel-detector (not at an additional timing-layer).



2017 JINST 12 P05003

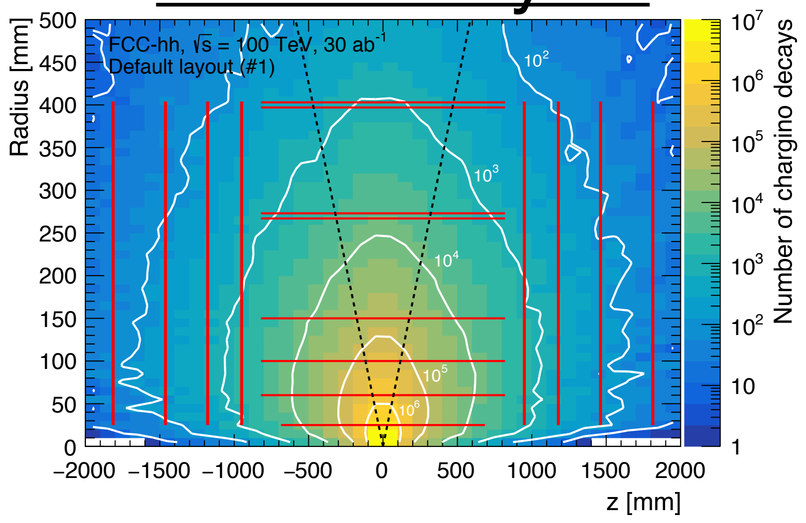
- We can use the hit-time for two purpose
  1. **BG fake tracks** (random-combination) decrease by requiring consistent time of pixel-hits on track.
  2. Measure **the velocity of a particle**.
     - Vertex time can be determined by ISR jets
     - If hit-time resolution is 20 ps, velocity resolution for charginos could be ~6%.



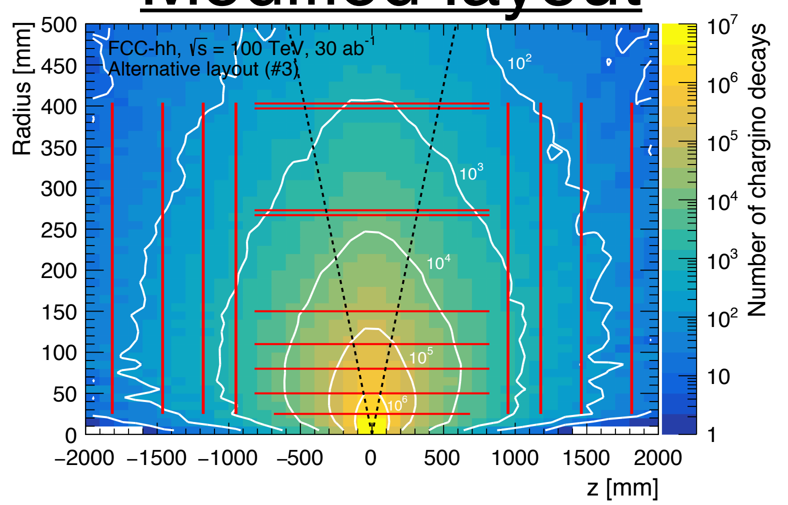
Expected reach at FCC

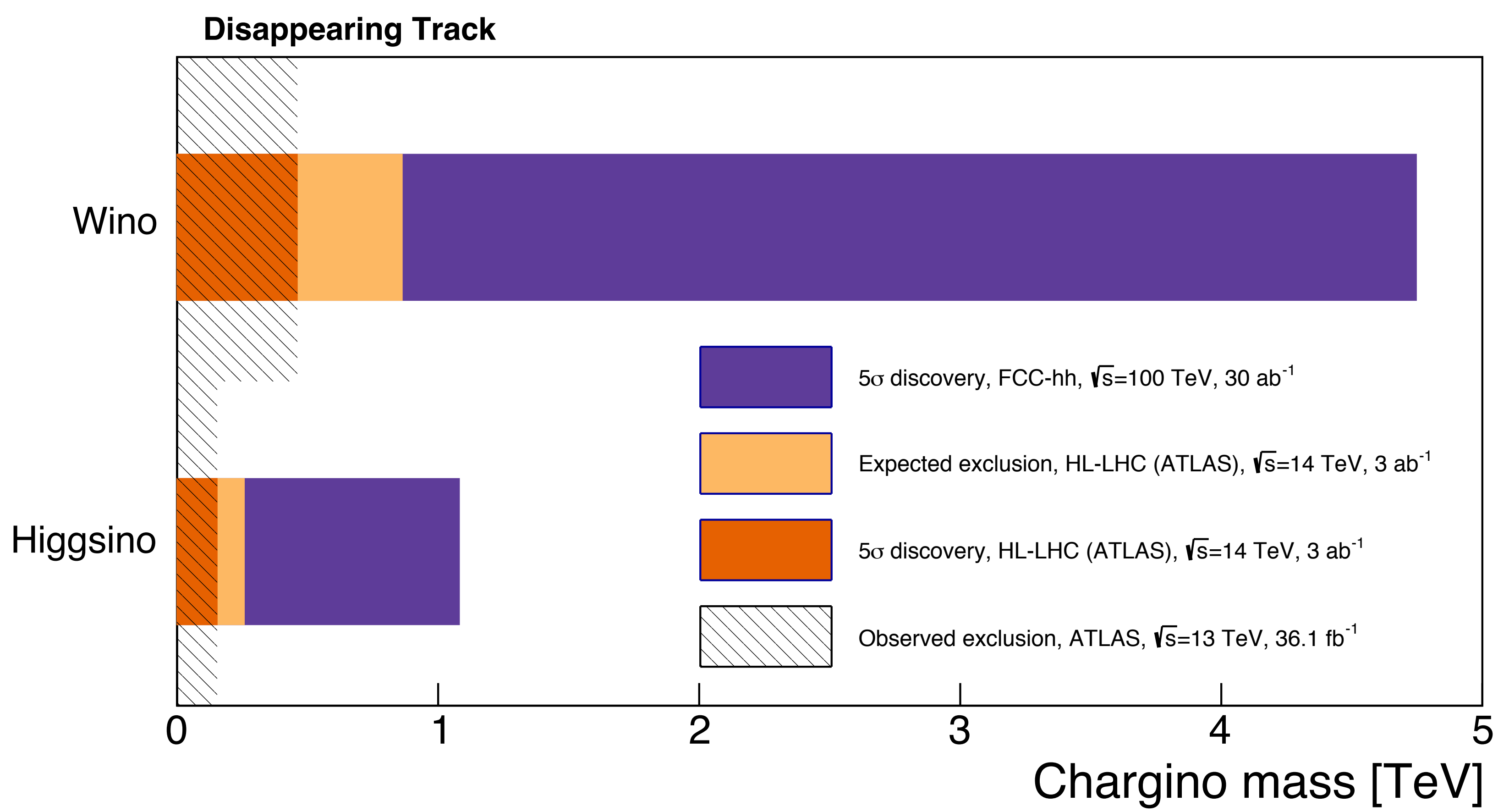
- Signal and signature : direct production, ISR jet + MET + a disappearing track
- Modified pixel-detector layout (5 layers within 15cm from the beamline)
- BG rejection using time information (χ^2/ndf in the fit)
- Fake track BG estimated using Geant4 simulation

Nominal layout



Modified layout





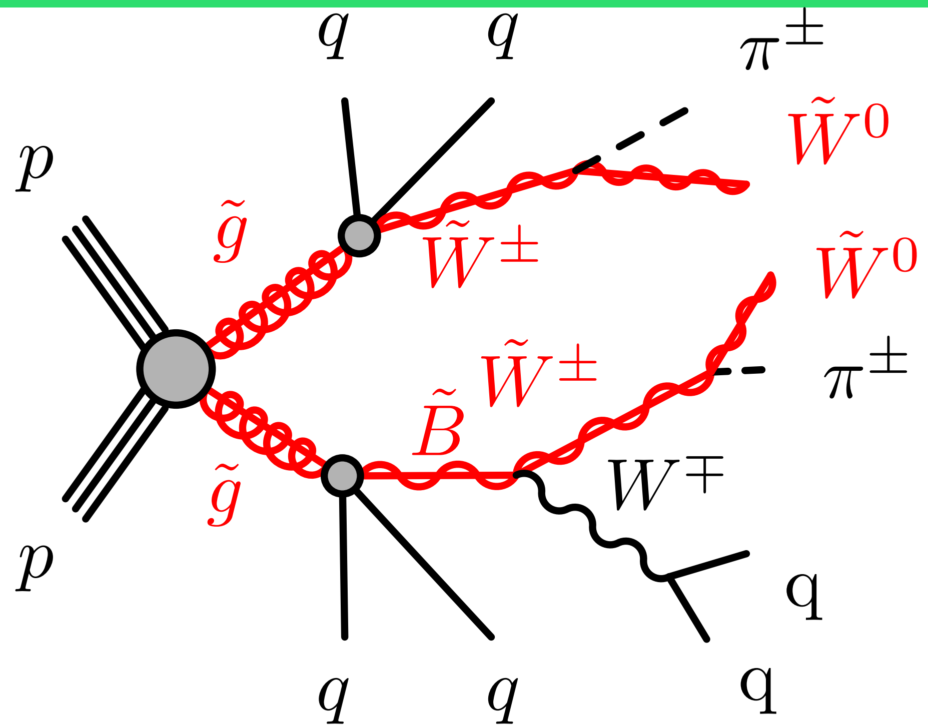
We can discover 3 TeV wino or 1 TeV higgsino

Strong production of wino

$$\tilde{g} \to \bar{q}q^{(\prime)}\tilde{W}$$

$$\tilde{g} \to \bar{q}q\tilde{B},\ \tilde{B} \to \tilde{W}^{\pm}W^{\mp},\quad \tilde{W}^0 h$$

$$\mathrm{Br}\,(\tilde{g} \to \bar{q}q\tilde{B}) = \mathrm{Br}\,(\tilde{g} \to \bar{q}q^{(\prime)}\tilde{W}) = 0.5$$



Benchmark points in PGM model of SUSY

	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

Detector assumption

- 5 pixel layers in 10 cm from beamline

Analysis pre-selection

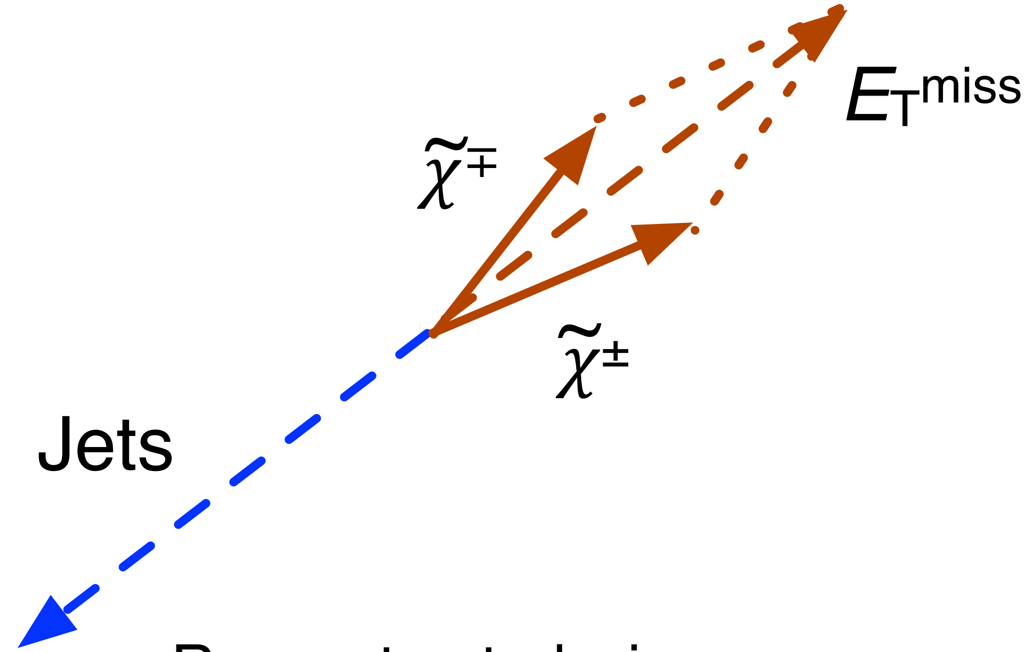
- $E_T^{miss} > 1$ TeV
- Two disappearing tracks
  - 1st : r > 10 cm
  - 2nd : r > (5* or)10 cm

** these results are in the paper*

Wino mass measurement

$$\text{mass} = \text{momentum}/\beta \cdot \sqrt{(1-\beta^2)}\ ,$$

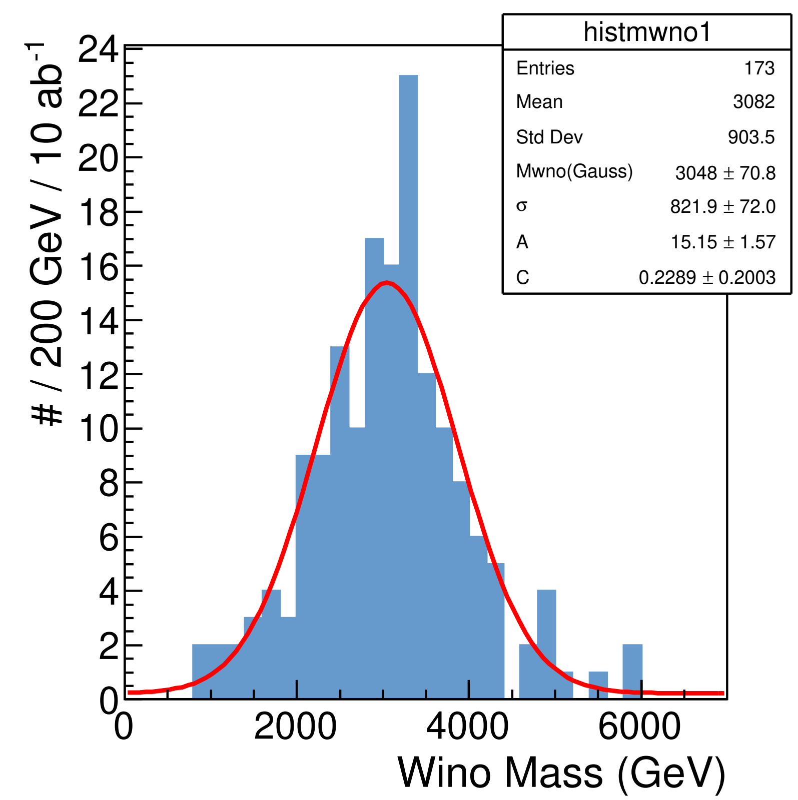
$$\beta = v/c$$



- **Velocity** is measured by the tracker using **time information**
- How to measure the **momentum** ?
  - We can not use the momentum of charged-wino tracks because of the **too poor resolution**; the track length is too short (< 10cm) !
  - Instead, we can reconstruct from ***E_T^{miss}* and direction of charged winos**, because pion carry little momentum (O(100 MeV))

Isolated lepton-veto is also applied

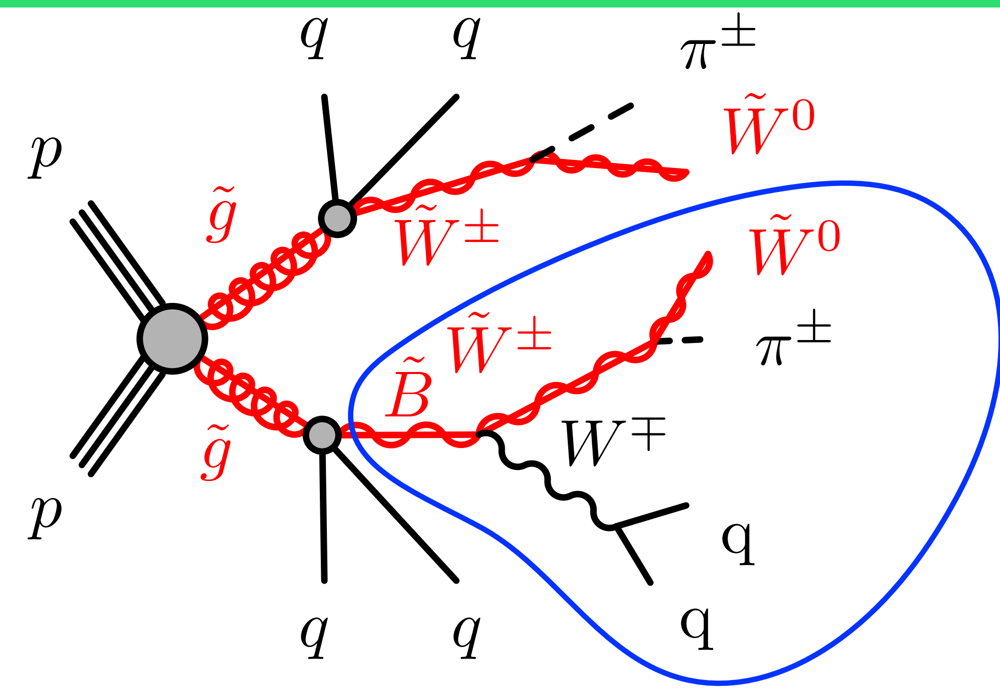
Reconstructed wino mass



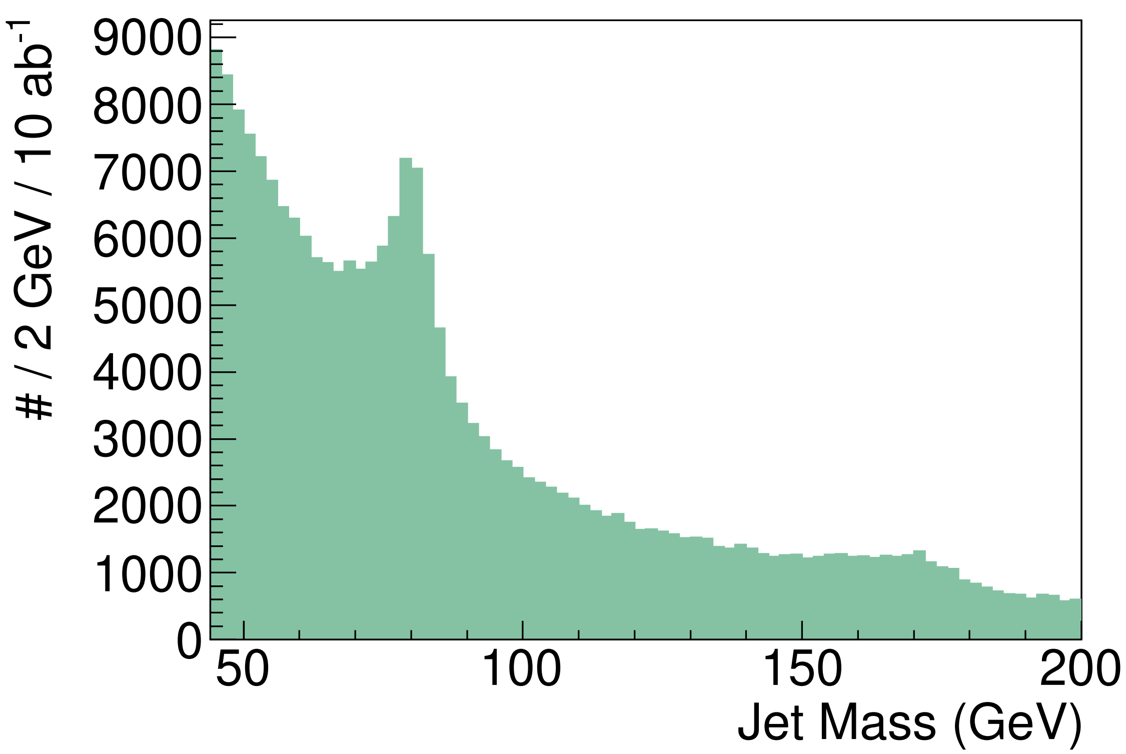
2% precision @ 2.9 TeV

Bino mass measurement

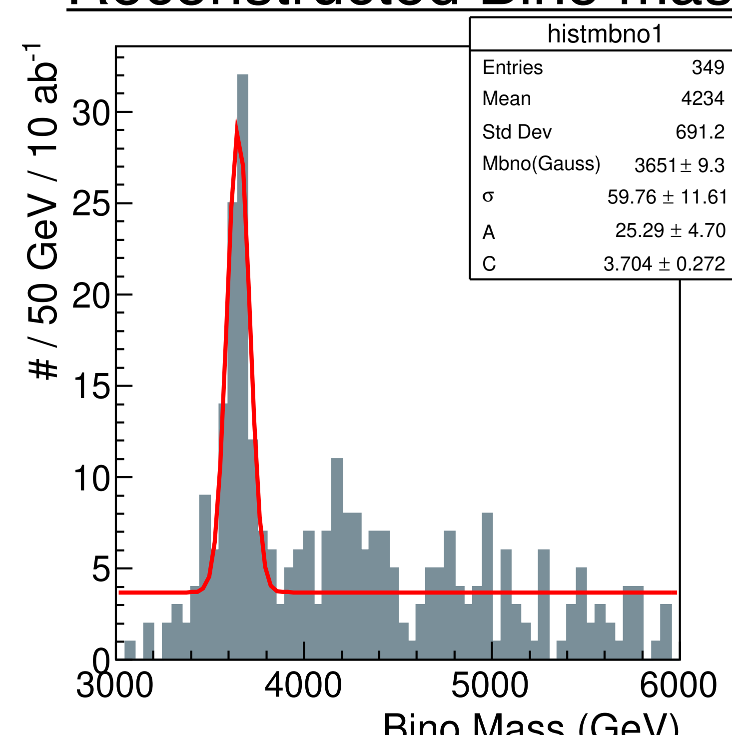
- Reconstruct **Bino mass** from **Wino and W momentum**
  - **Wino momentum** : reconstruct from the measured **velocity** and Wino **mass**.
  - **W momentum** : reconstruct using **fat jets**.



Fat jet mass



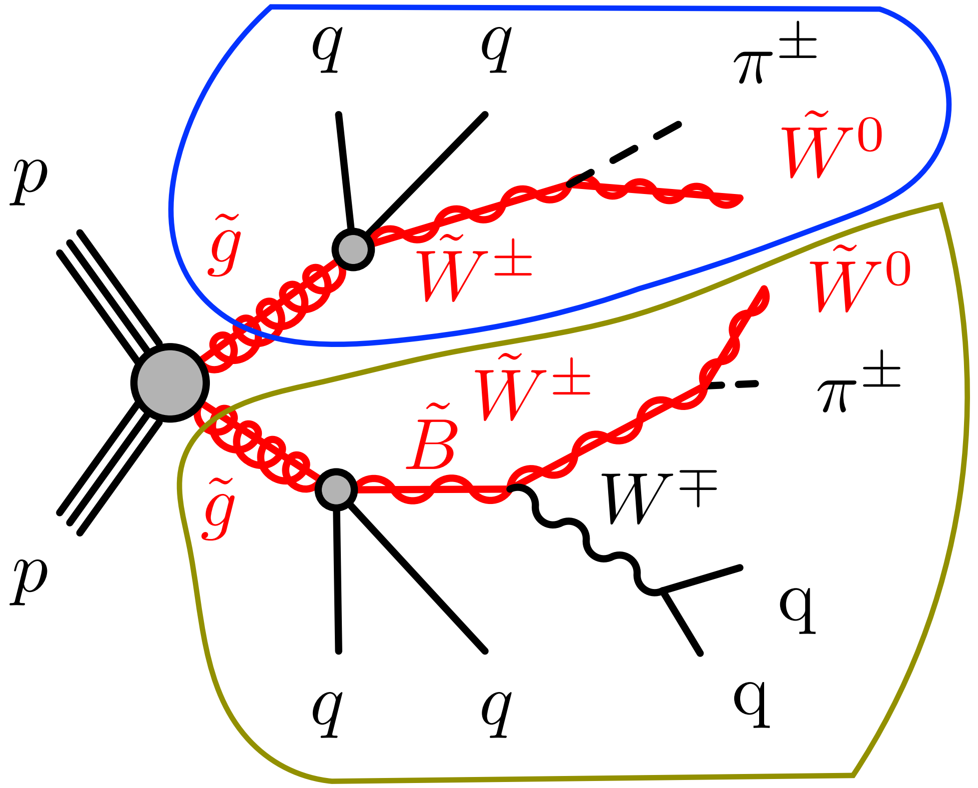
Reconstructed Bino mass



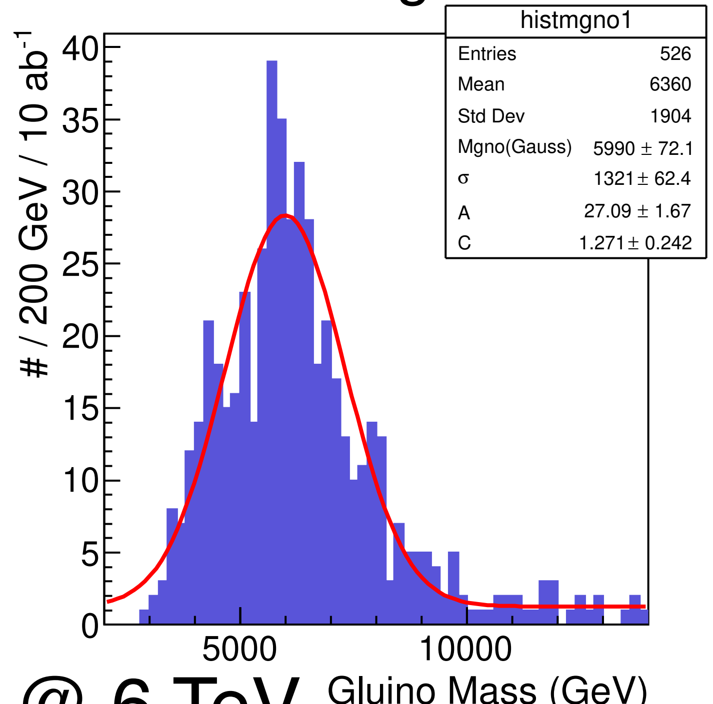
<2% precision @ 3.7 TeV

Gluino mass measurement

- **Gluino mass** is reconstructed by **"hemi-sphere" analysis**
  1. Define two hemi-spheres using two disappearing-track directions
  2. Iteratively assign jets to each hemi-sphere and update the directions
  3. Reconstruct the gluino mass from jets and Winos.



Reconstructed gluino mass

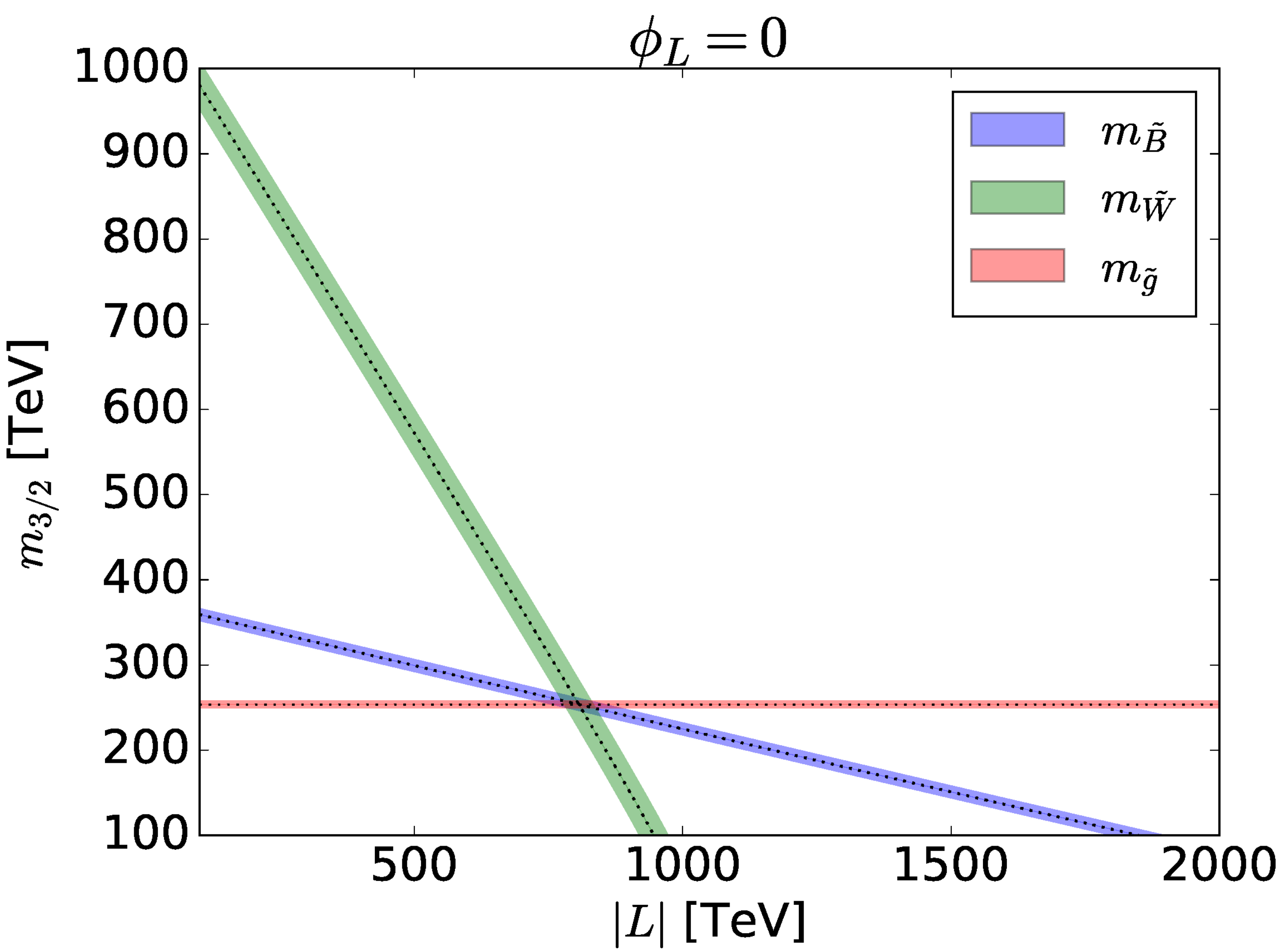


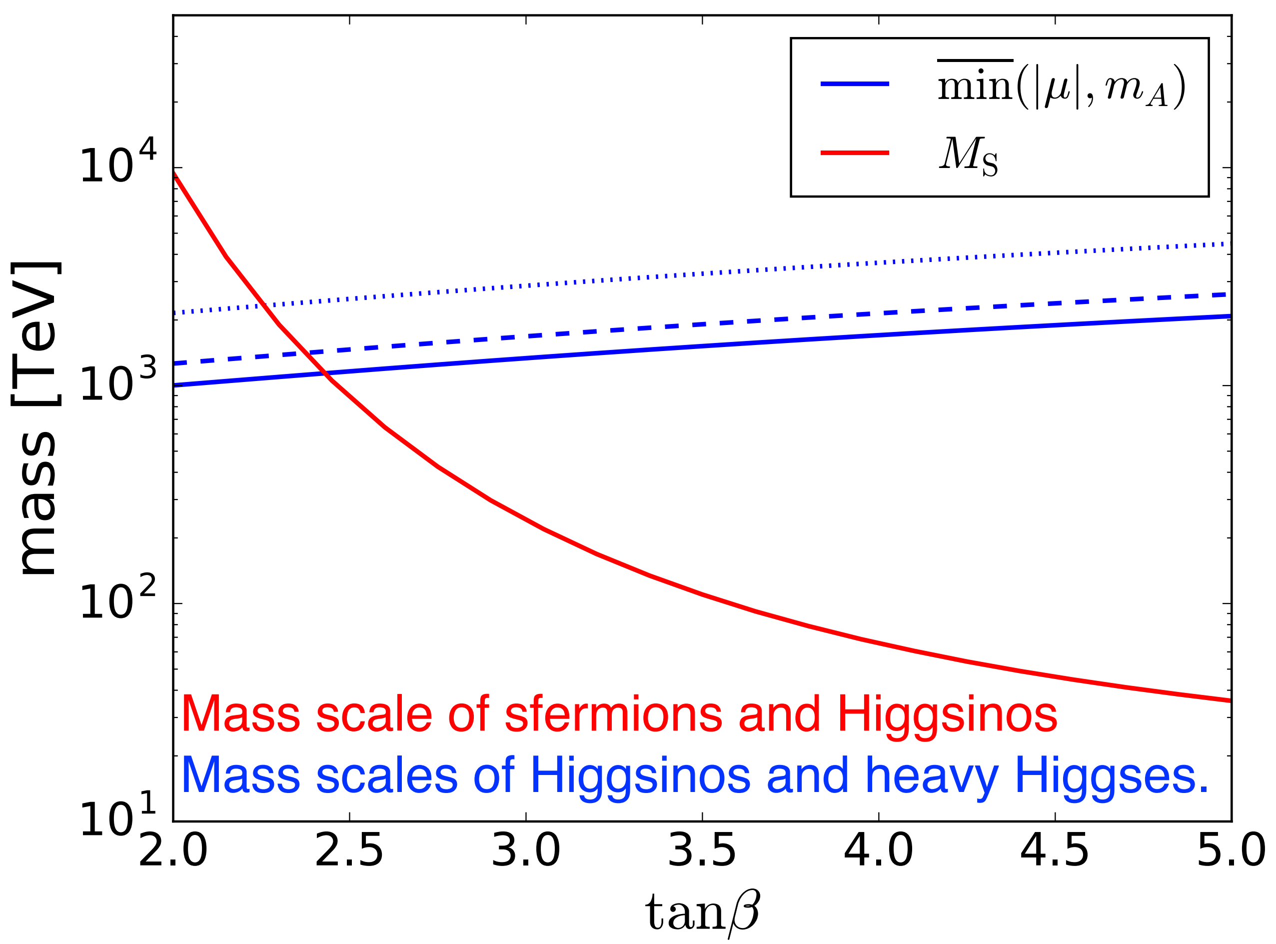
- Gluino mass can be estimated from the **cross-section**.
  - Comparing the two estimates would be **good test of SUSY hypothesis**.

Isolated lepton-veto is also applied

<2% precision @ 6 TeV

Implication





Three model parameters can be constrained by the gaugino mass measurements.

The gaugino mass measurements would imply also **the next particle-mass scale** (Higgsino, Higgses and sferimions)

Conclusion

- **Timing-capable inner-most detector** in collider experiments is very effective to reduce background.
  - This will enable to **discover higgsino or wino DM.**
- Using the velocity measurement of charginos, it becomes possible to **measure all gaugino masses**.
  - This will give understanding of **the next energy scale** (beyond FCC).
  - Can we do a similar search in **LHC or HL-LHC** using pixel *dE/dx*, instead of timing, to measure the velocity ?