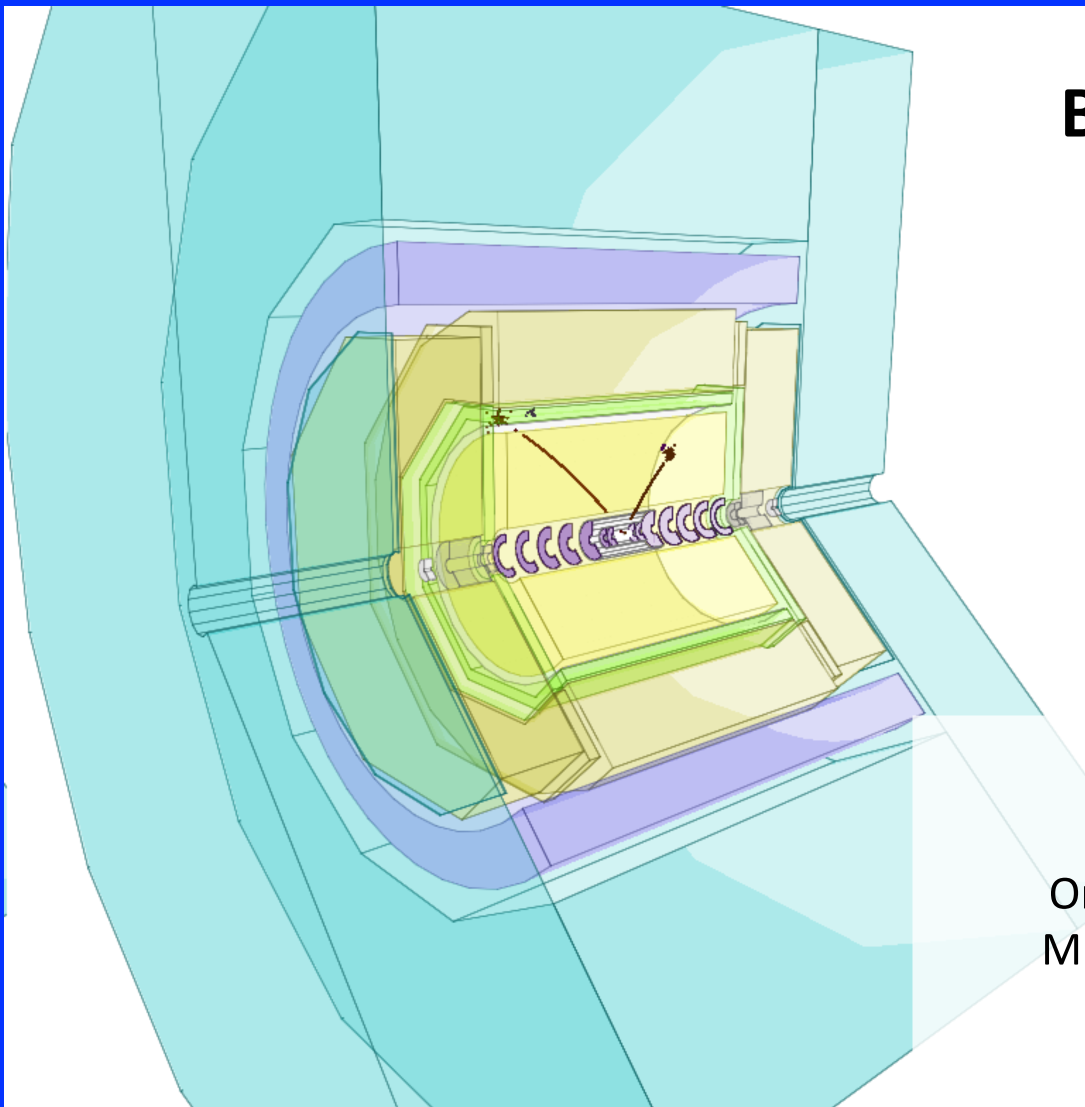
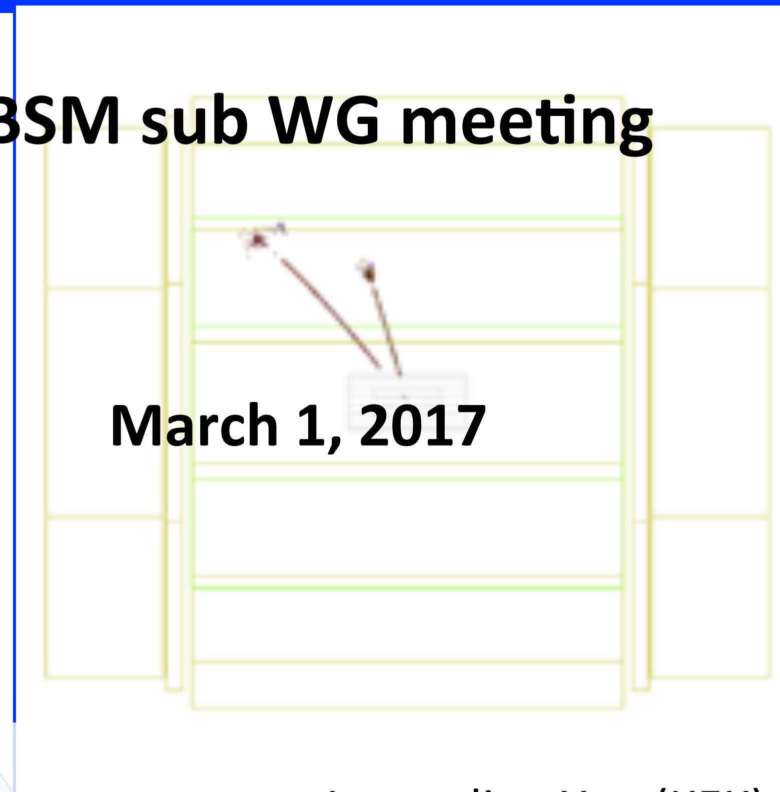
Characterizing Light Higgsinos from Natural SUSY at ILC $\sqrt{s}$ = 500 GeV



BSM sub WG meeting



March 1, 2017

Jacqueline Yan (KEK)

On behalf of H. Baer (Univ of Oklahoma), M. Berggren, S.-L. Lehtinen, J. List (DESY), K. Fujii (KEK), T. Tanabe (Univ of Tokyo)

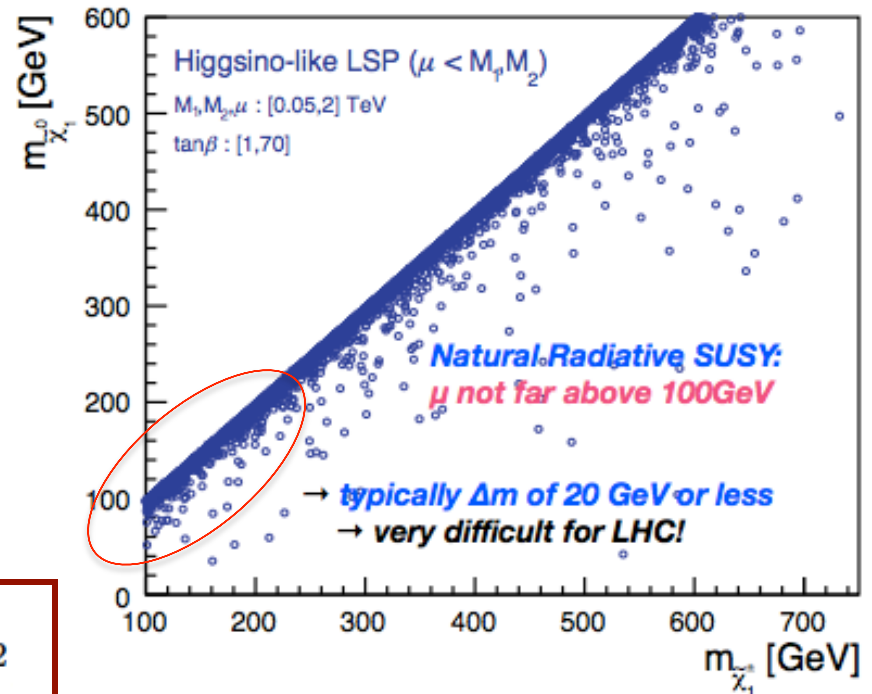
Outline

- Motivation of study
- Status and Plan
- Sample requests and others

Motivation for Searching Light Higgsinos with Small ΔM

❖ From experimental point of view:

- LHC already excluded large regions with large ΔM = M(NLSP) – M(LSP)
- Remaining region with compressed spectrum
  very small visible energy release,
  near impossible to probe at LHC
  ➔ **ILC is essential**



❖ From theoretical point of view:

Compressed Higgsino spectra related to naturalness [e.g. arXiv:1212.2655, arXiv:1404.7510]

$$\frac{M_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

- To maintain **small electroweak fine tuning ΔEW (<∼3%)**, all contributions on right-hand-side should be comparable to M(Z) ➔ requires **μ ∼ 100–300 GeV**
  top and bottom squarks in the few TeV regime, gluino mass 2−4 TeV,
  1st, 2nd generation squarks and sleptons in the 5−30 TeV regime

- μ feeds mass to both SM (W, Z, h) and SUSY particles (Higgsinos)
- Higgsino masses not too far from masses of W, Z, h (∼100 GeV)

Goal of Light Higgsino Study

This study

Demonstrate measurement precision of Higgsino masses and production cross sections

Serve as a basis for future discussions of ILC run scenario in the case of new particles being discovered

Results of masses and cross sections (= “observables”) as input

S.-L. Lehtinen (DESY) et al

determine SUSY parameters

e.g. M_1, M_2, μ, $\tan\beta$

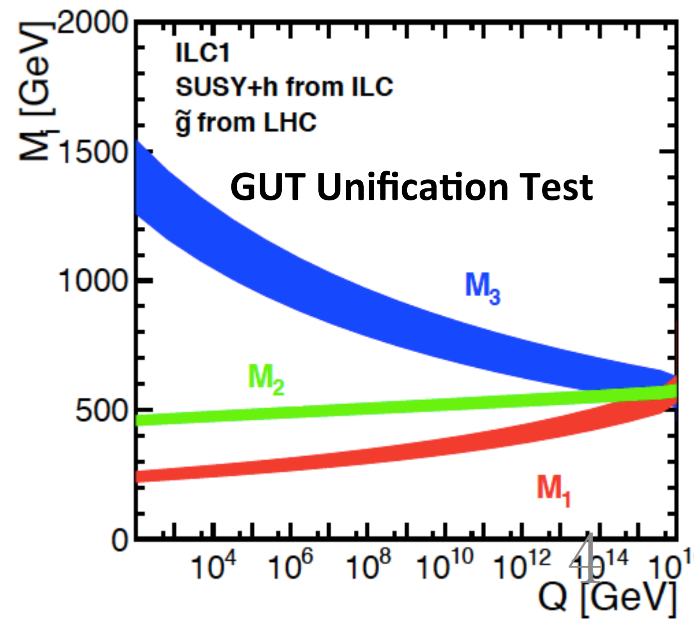
Why?

- **To get info about unobserved sparticles**
- **To test GUT-scale models**

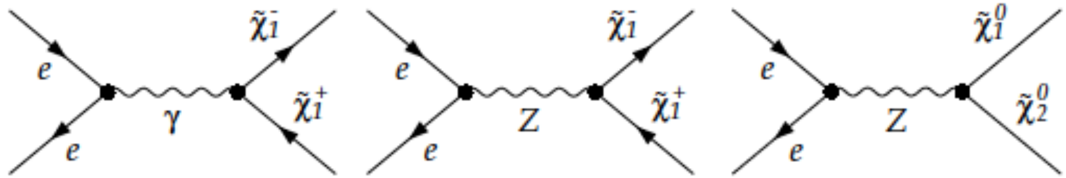
How?

- **Global χ^2 fit of to observables**

Study required input parameters and precisions;
interplay with Higgs precision measurements



Benchmarks in this Study



neutralino mixed production ($\chi_1^0 \chi_2^0$) and **chargino pair production ($\chi_1^+ \chi_1^-$)**

√s = 500 GeV, full ILD detector simulation , (Pe-, Pe+) = (-0.8,+0.3), (+0.8, -0.3)

RNS model (Radiatively-driven natural SUSY)

- **4 light Higgsinos:** $\tilde{\chi}_1^0$ (LSP) $\tilde{\chi}_2^0$ $\tilde{\chi}_1^+$ $\tilde{\chi}_1^-$
- **ΔM complies with naturalness** (no need for ISR tag)

Benchmarks with smaller ΔM are drawing attention ,
as ILC1 is (almost) excluded by LHC
ILC1 results (and some ILC2) shown at LCWS 2016, http://agenda.linearcollider.org/event/7371/contributions/37853/.
and in https://arxiv.org/pdf/1702.05333.pdf

- Recently produced preliminary results for **Mirage Mediation (nGMM1) (ΔM as small as 4.5 GeV)**
- Will show at next BSM-focused ILD meeting (Mar 8)
- Now finishing analysis and reconfirming results , in preparation for publication

NUHM2 model parameters [arXiv:1404.7510]

Benchmark	ILC1	ILC2
M_0 [GeV]	7025	5000
$M_{1/2}$ [GeV]	568.3	1200
A_0 [GeV]	-10427	-8000
tanβ	10	15
μ [GeV]	115	150
M_A [GeV]	1000	1000
$M(\chi_1^0)$ [GeV]	102.7	148.1
$M(\chi_1^\pm)$ [GeV]	117.3	158.3
$\Delta M(N_2,N_1)$	**21.3**	**9.7**
$M(\chi_2^0)$ [GeV]	124.0	157.8
$\Delta M(C_1,N_1)$	**14.6**	**10.2**

Defined at GUT scale ,
Defined at weak scale **Observables**

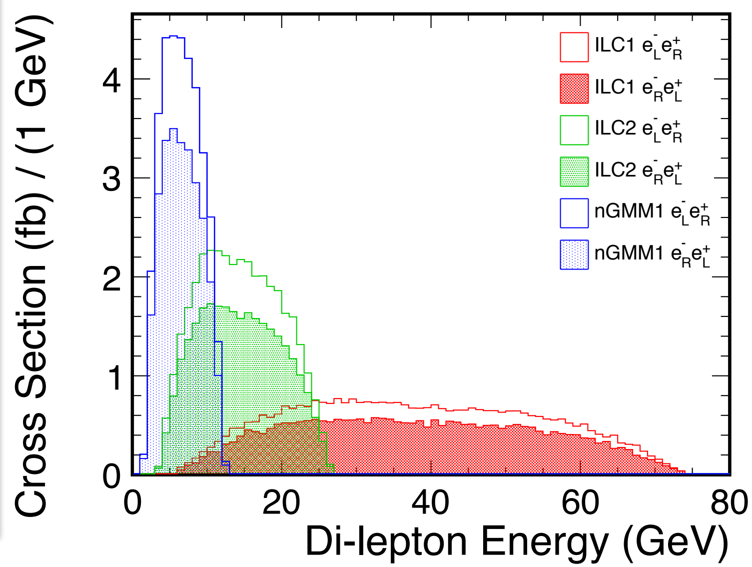
Analyzing challenging benchmarks with smaller ΔM

Despite reduced visible energy, doable without large change in analysis strategies

Showed that Higgsino mass precisions ＜～1% (H20) should be achievable

Masses [GeV] from LHA files:

	ILC1	ILC2	nGMM1
M(N1)	102.7	148.1	151.4
M(N2)	124.0	157.8	155.8
ΔM(N2,N1)	**21.3**	**9.7**	**4.4**
M(C1)	117.3	158.3	158.7
ΔM(C1,N1)	**14.6**	**10.2**	**7.3**



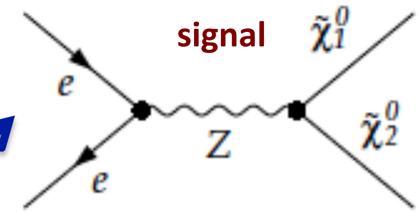
Cross sections [fb] for $\sqrt{s}$=500 GeV with TDR beam parameters ,
Event Generator: WHIZARD v1.95, DBD setup)

Process (Pe-,Pe+)	ILC1	ILC2	nGMM1
C1C1 (-1,+1)	1799.9	1530.5	1520.6
C1C1 (+1,-1)	334.5	307.2	309.5
N1N2 (-1,+1)	490.9	458.9	463.5
N1N2 (+1,-1)	378.5	353.8	357.3

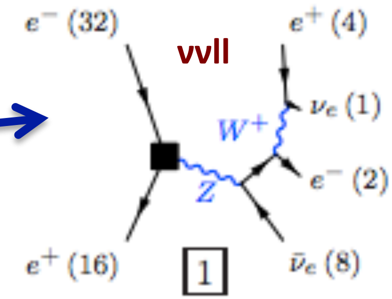
Event Selection

Neutralino mixed production with leptonic decay

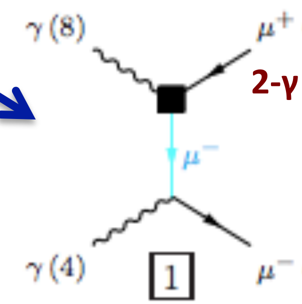
$$e^+e^- \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$$



- Reconstruct **two leptons (ee or μμ) which originate from Z^* emission in decay of χ_2^0 to χ_1^0**
- Major residual bkg. are 4f processes accompanied by large missing energy (ννll)



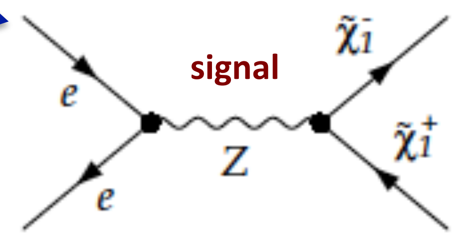
- 2-γ processes are removed by BeamCal veto, cuts on lepton track p_T, and coplanarity



Chargino pair production with semileptonic decay

$$e^+e^- \rightarrow \tilde{\chi}_1^+\,\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_1^0 qq'\ell\nu$$

- Reconstruct **two jets which originate from W^* emission in decay of $\chi_1^\pm$ to χ_1^0**



- Use lepton (e or μ) from the other chargino as tag
- BeamCal veto, cuts on missing p_T, # of tracks, # of leptons, and coplanarity remove almost all bkg.

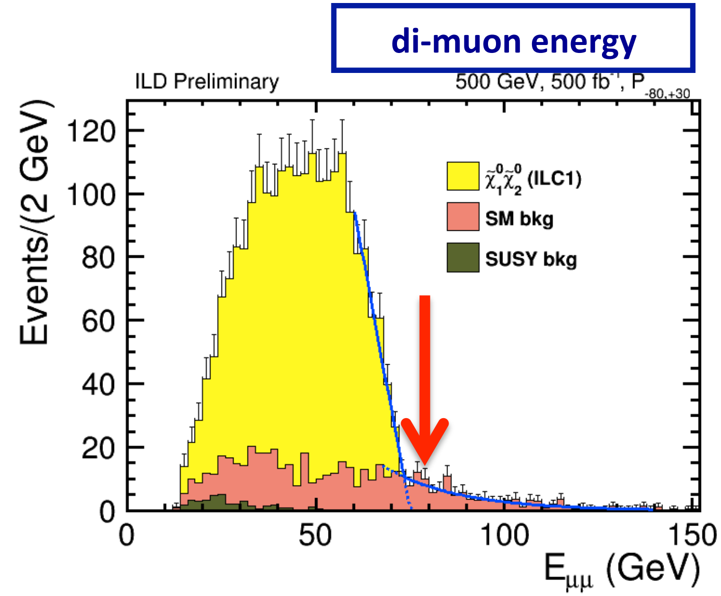
  (signal significance > 100)

Extraction of Higgsino Mass and Cross Section

Mass :

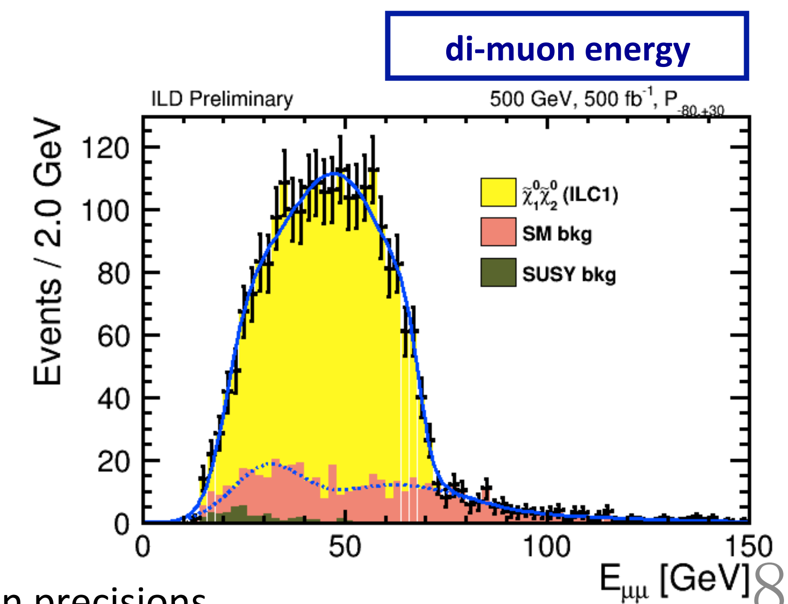
- Kinematic edges of dilepton/dijet energy and invariant mass are functions of $\sqrt{s}$ and Higgsino masses
- **Extract kinematic edges by a fit to distributions ➔ calculate masses**

(requires correction for detector resolution)



Cross section:

Count number of events under dilepton / dijet energy



- Use Toy Monte Carlo to obtain mass and cross section precisions

Status

made **progress in analysis of benchmarks with smaller ΔM** *some channels still in progress*

Currently obtained statistical precisions: **Assuming H20**

- Mass : < ~ 0.5% (ILC1, ILC2) <~1.5% (nGMM1)
- Cross section : 1–1.5% (ILC1, ILC2)

- Pessimistic limit for case of overlay in Higgsino signal : "a factor of 2 worse"

Plans

- Requests sent to Mikael for **production of extra SGV samples for aa2f and ae/ea3f processes** (currently not enough statistics to ensure they are gone from higher kinematic edge)

- Finish/finalize analysis for all benchmarks

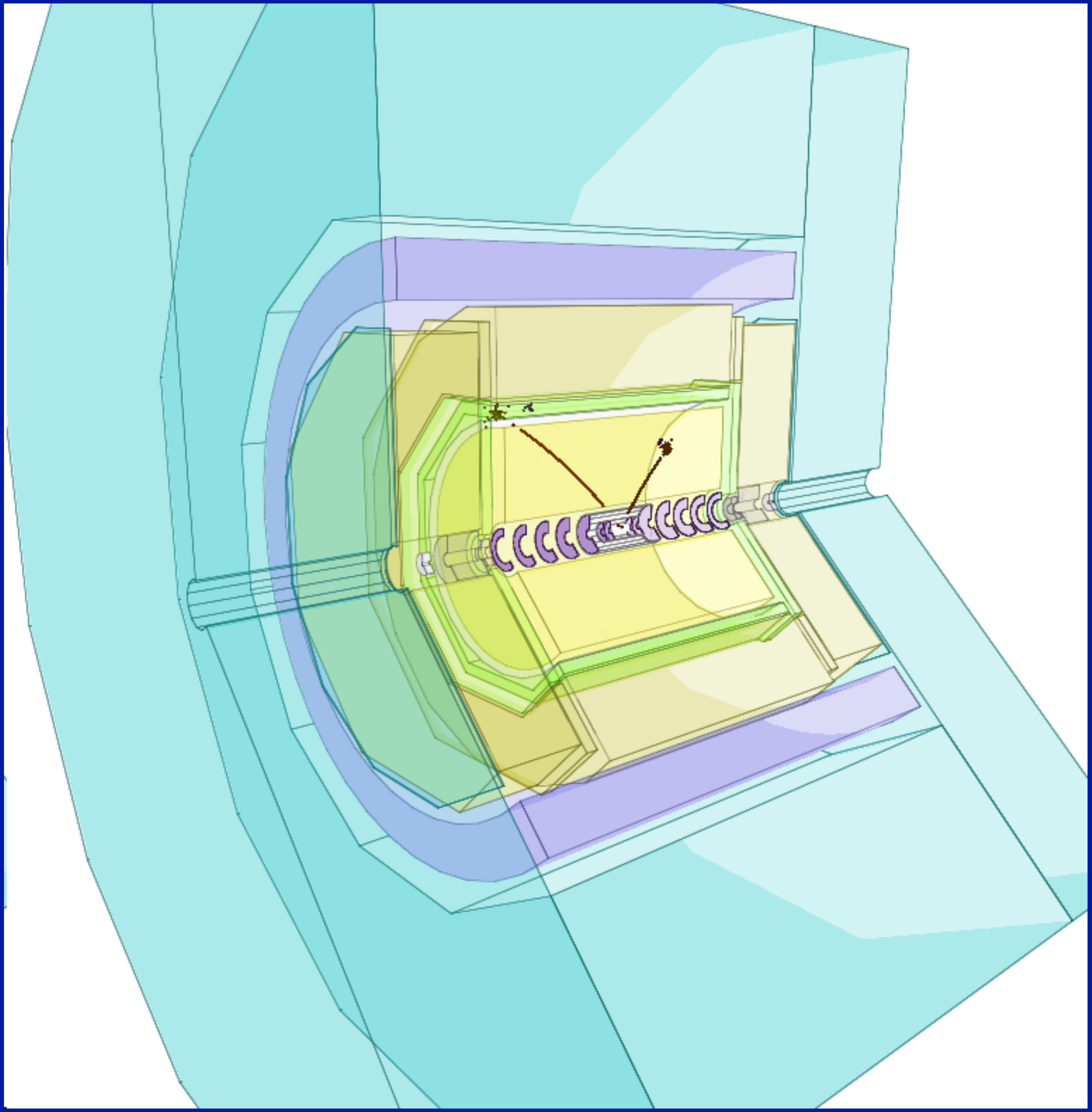
➔ move towards publication of a **paper including all 3 benchmarks**

theory, analysis, and SUSY parameter extraction

- Study potential for treating overlay bkg
- Study new tools for low pt tracking → improve **lepton tagging efficiency**

- In future : light Higgsino analysis at lower ECM (350 GeV ?) *staging*

Thank you for listening



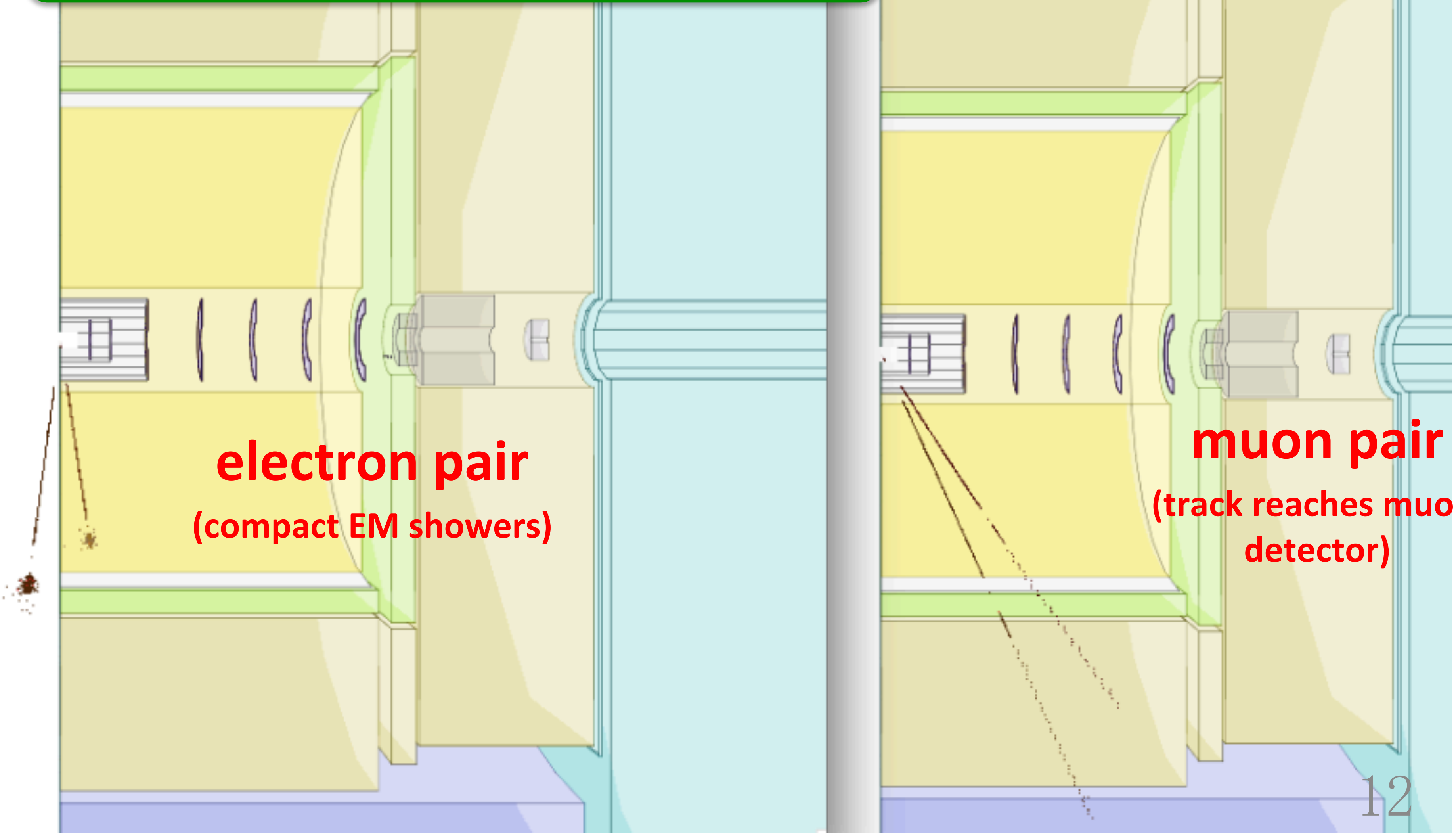
Additional Material

How do these signals look in the detector? (1)

√s =500 GeV

Neutralino mixed production with leptonic decay

$$e^+e^- \rightarrow \widetilde{\chi}_1^0\, \widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0 \widetilde{\chi}_1^0 \ell^+ \ell^-$$

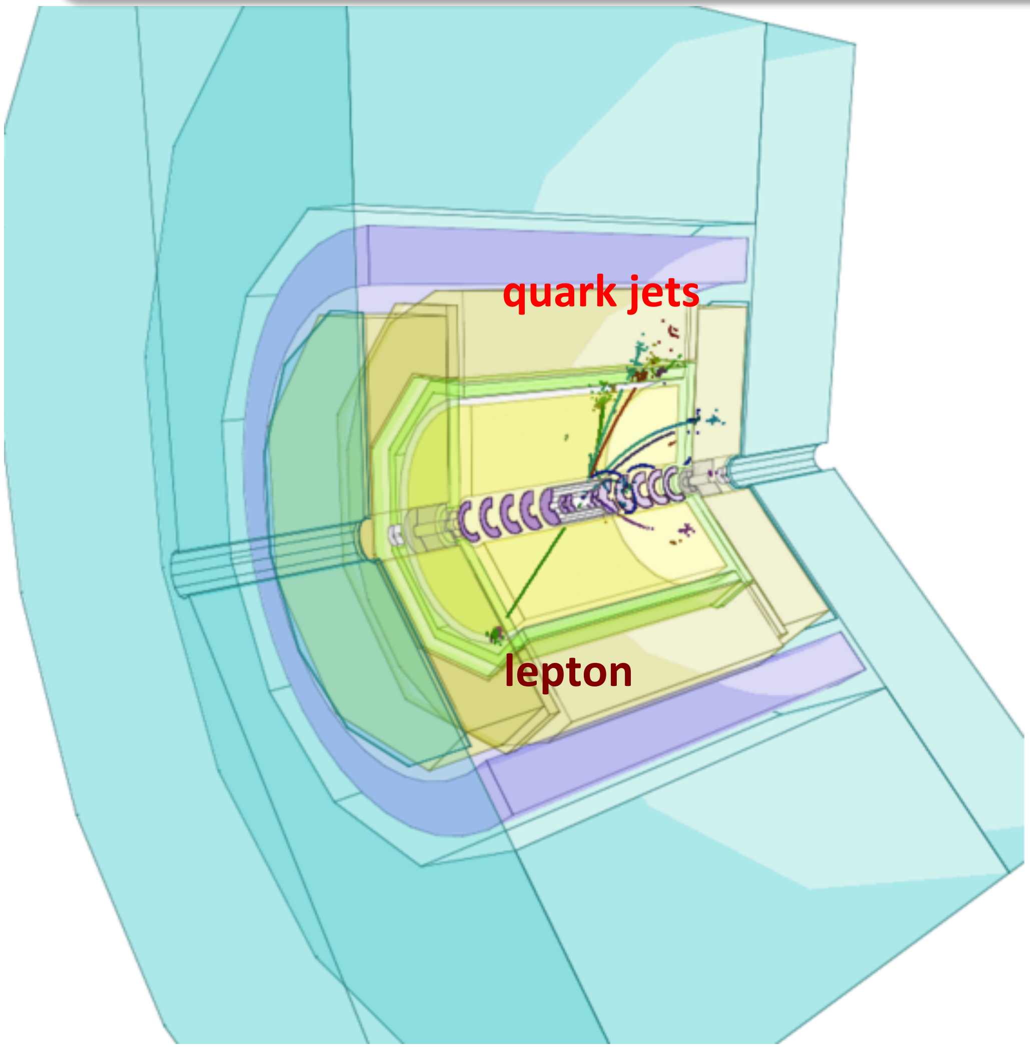


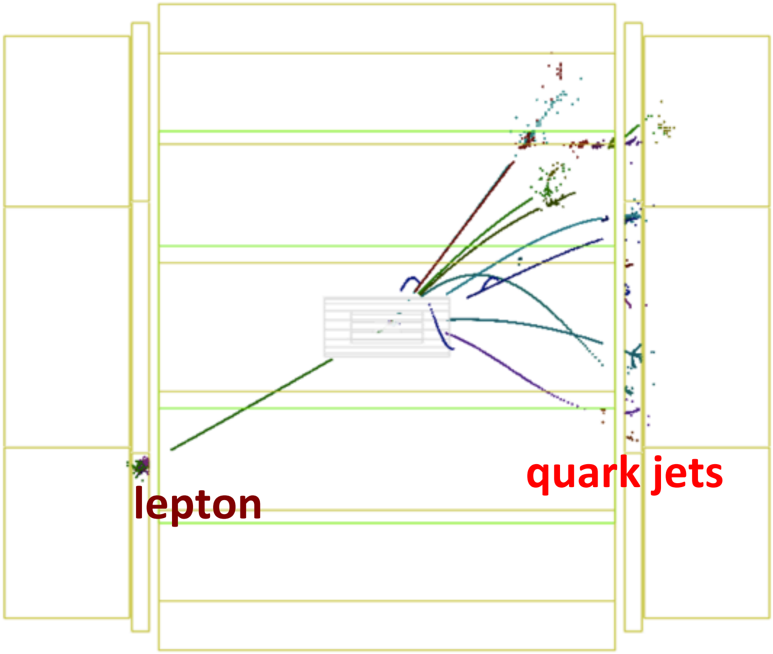
How do these signals look in the detector? (2)

√s =500 GeV

Chargino pair production with semileptonic decay

$$e^+e^- \to \widetilde{\chi}_1^+ \widetilde{\chi}_1^- \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0 q q' \ell \nu$$





Chargino Search