Probing the higgsinos at the LHC

Chengcheng Han **(APCTP)**

Based on arXiv: 1502.03734

Collaborate with

M. Park, S. Munir, D. Kim

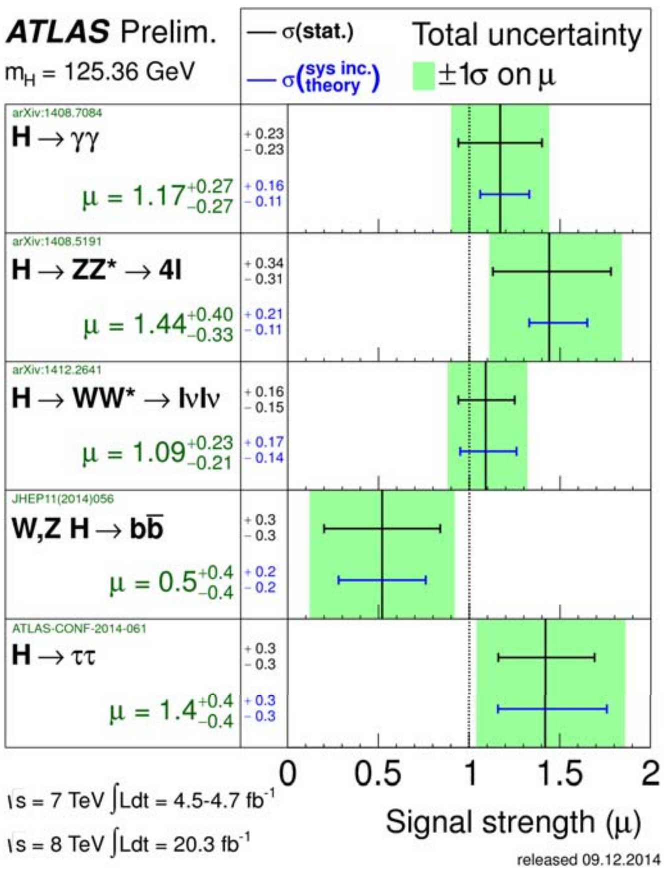
KIAS workshop: Exploring the Dark Sector

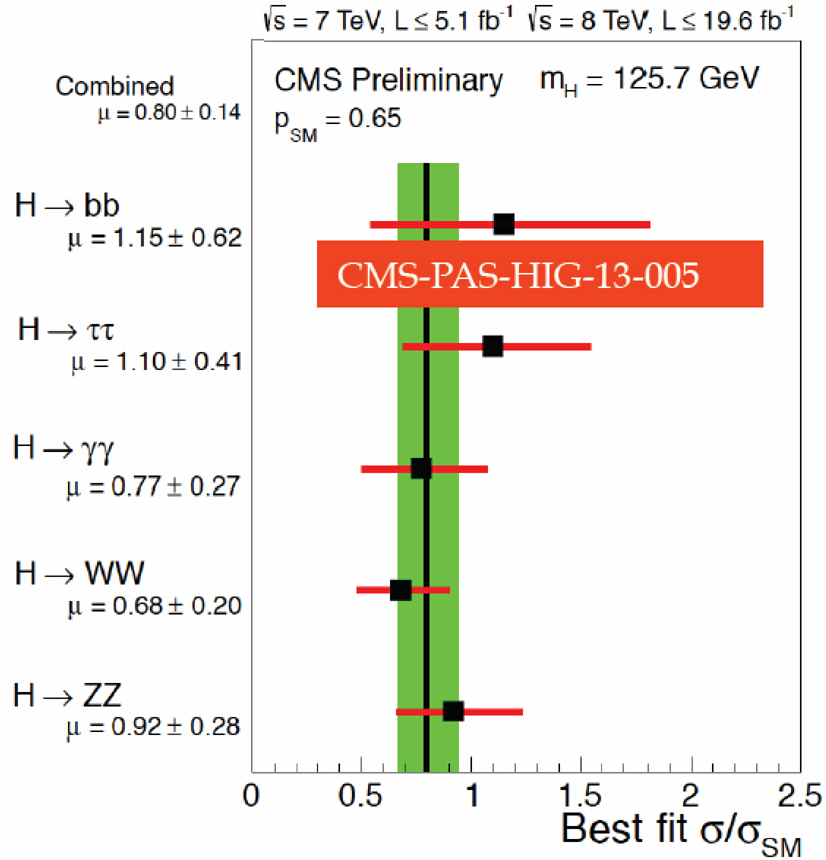
Outline

- Naturalness and Supersymmetry;

- Higgsinos search at LHC.

The very SM-like Higgs

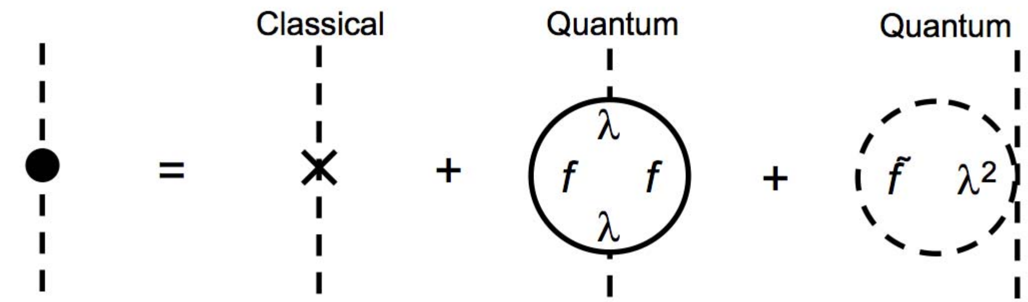




But still large room for new Physcis (2HDM,SUSY...).

Limited deviation of higgs coupling to other particles is still allowed

SUSY searches - naturalness



$$m_h^2 = (m_h^2)_0 - \underbrace{\frac{1}{16\pi^2}\lambda^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2}$$
$$+ \frac{1}{16\pi^2}\lambda^2(m_{\tilde{f}}^2 - m_f^2)\ln(\Lambda/m_h)$$

Supersymmetry can stabilize the Higgs mass

by

introducing the symmetry between fermions and bosons

In the MSSM,from the minimization of the higgs potential, for a moderate $\tan\beta$, we have

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

We can define a weak scale fine tuning parameter

$$\Delta_{EW} \equiv max_i|C_i|/(M_Z^2/2)$$

H. Baer, V. Barger, P. Huang, D. Michelson, A. Mustafayev, X. Tata arXiv 1212.2655

$|\mu| \lesssim$ 200-300 GeV

About 10-30 fine tuning

$m_{\tilde{t}} \lesssim$ 1-2 TeV

$m_{\tilde{g}} \lesssim$ 3-4 TeV

light Higgsinos are predicted in Natural supersymmetry

Feature of light higgsinos

In MSSM, the higgsinos will mix with the bino and wino. In the basis $(\widetilde{B}^0, \widetilde{W}^0, \widetilde{H}_d^0, \widetilde{H}_u^0)$, the tree level neutralino mass matrix:

$$\mathcal{M}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -m_W \tan\theta_W \cos\beta & m_W \tan\theta_W \sin\beta \\ & M_2 & m_W \cos\beta & -m_W \sin\beta \\ -m_W \tan\theta_W \cos\beta & m_W \cos\beta & 0 & -\mu \\ m_W \tan\theta_W \sin\beta & -m_W \sin\beta & -\mu & 0 \end{pmatrix}$$

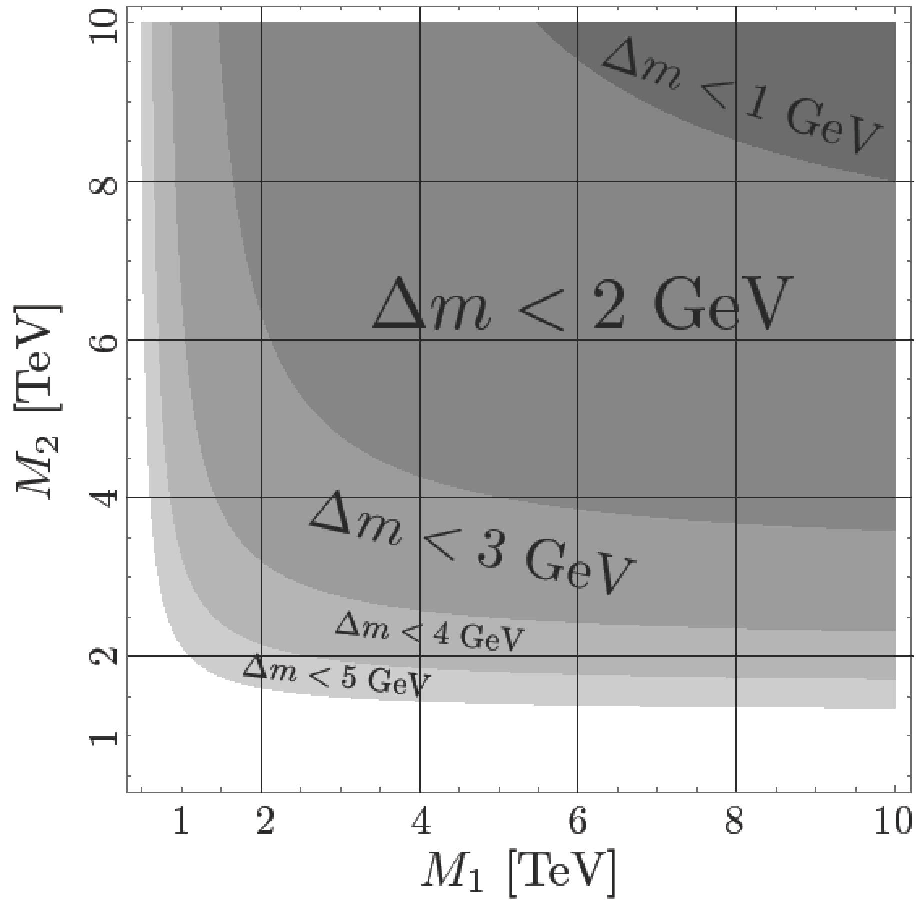
For $M_1, M_2 \gg |\mu|$

$$\Delta m = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} \simeq \frac{m_W^2}{M_2} + \frac{m_W^2 \tan^2\theta_W}{M_1}$$

Similarly $\quad m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \simeq \frac{1}{2}\Delta m$

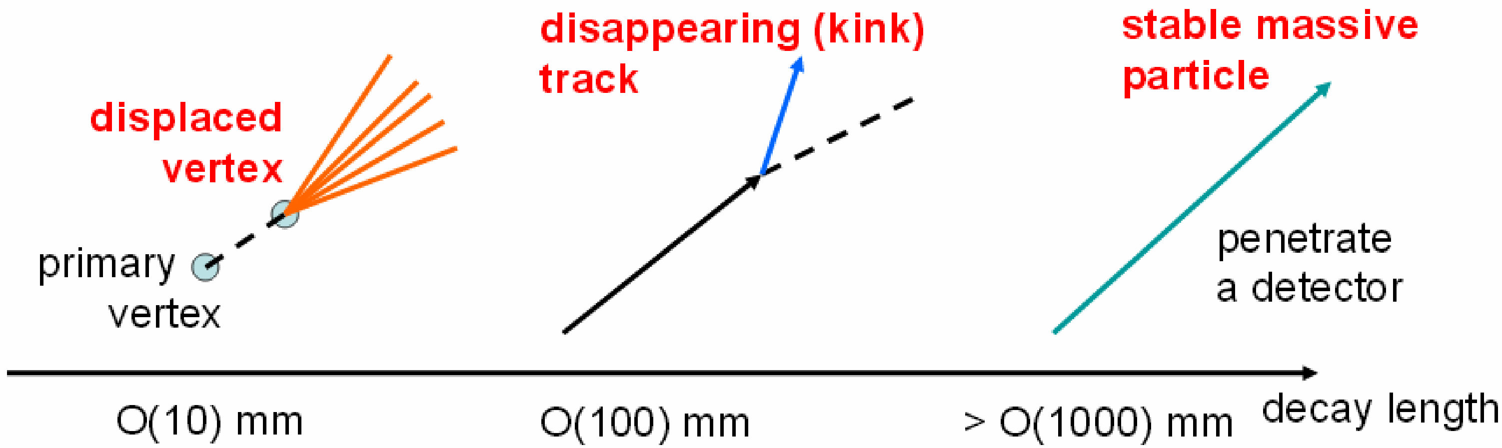
Small splitting between $\tilde{\chi}_1^\pm$ $(\tilde{\chi}_2^0)$ and $\tilde{\chi}_1^0$

Comment: Higgsino LSP is under abundance

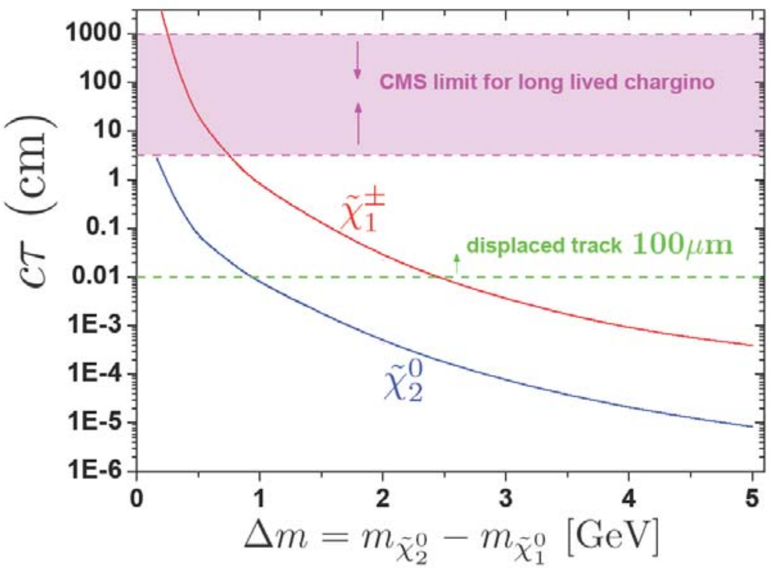


for the $M_1, M_2 > 1.5$ TeV (μ=150 GeV, $\tan\beta$=30) the mass splitting between these two neutralinos would be less than 5 GeV. The products of $\tilde{\chi}_1^{\pm}$ ($\tilde{\chi}_2^0$) decay would be very soft.

- These signals depend on the lifetime of the particles



From Yuya Azuma(ATLAS)



μ=150 GeV

$\tan\beta$=30

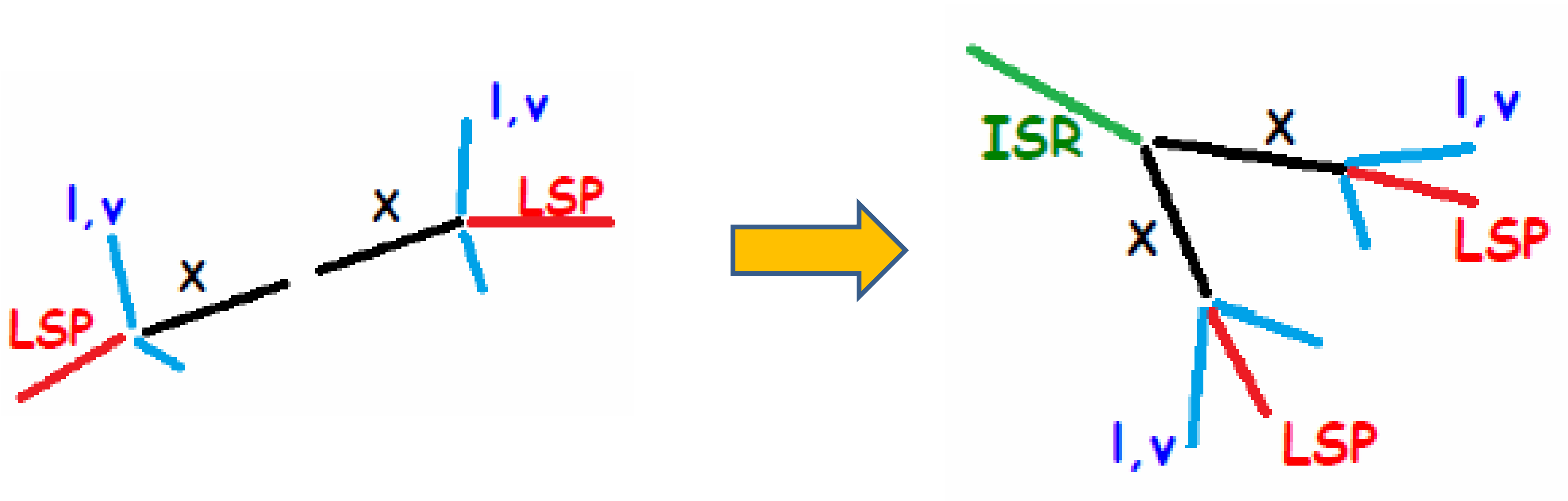
Chargino gives a disappering (kink) track

Neutralino decay gives displaced vertex

We focus on the few GeV splitting region

Monojet for light higgsinos

- Small-splitting region is generally less sensitive because visible particles are soft
- To improve, ISR jets or photons would be very helpful.



JHEP 1042(2014) 049 Chengcheng Han, Kobakhidze, Liu, Saavedra, Wu, Yang

Results from previous monojet study (14 TeV 100 fb^{-1})

cut	$Z(\nu\bar{\nu})+j$	$W(\ell\nu_\ell)+j$	$W(\tau\nu_\tau)+j$	$t\bar{t}$	Signal (μ = 100 GeV)	Signal (μ = 200 GeV)
$p_T(j_1) > 500$GeV	69322	241740	119078	210943	1242	415
$\not{E}_T > 500$GeV	26304	28209	16513	2786	950	335
veto on $p_T(j_2) > 100$, $p_T(j_3) > 30$	16988	12194	7577	306	602	223
veto on e, μ, τ	16557	3963	3088	102	597	220
veto on $b-$jets	16303	3867	3046	56	576	214

Although we can get a good $S/\sqrt{B}$ to increase luminosity,we have S/B less than 5%. It is challengeable for experiment.

Sys. error for CMS or ATLAS monojet search now is around 5% – 10%

The VBF search for such higgsinos are studied recently.
To get good significance, a Sys. $< 5\%$ is also needed

arXiv:1502.05044. A. Berlin, T. Lin, M. Low, Lian-Tao Wang.

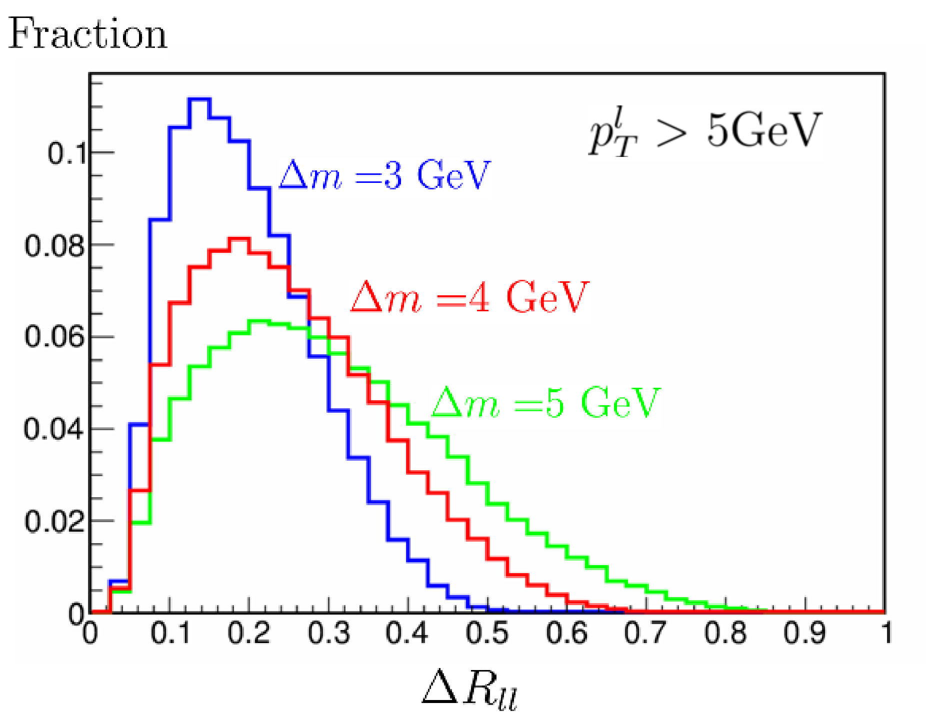
What we can do?

We should resort to the soft decay products

$$\chi_2^0 \to Z^* + \chi_1^0 \text{ or } \chi_1^\pm \to W^* + \chi_1^0$$

For $\chi_1^\pm \to W^* + \chi_1^0$, W+jets background is huge.

So we choose $\chi_2^0 \to Z^* + \chi_1^0 \to 2\mu + \chi_1^0$ Here we only choose muons which have clean backgrounds

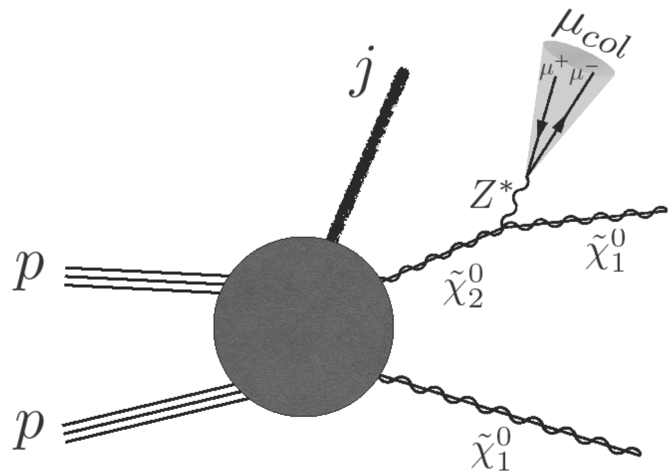


The two leptons are close to each other, we can not use two isolated leptons, the usual isolation criteria (ΔR=0.3) would remove a lot of signal events.

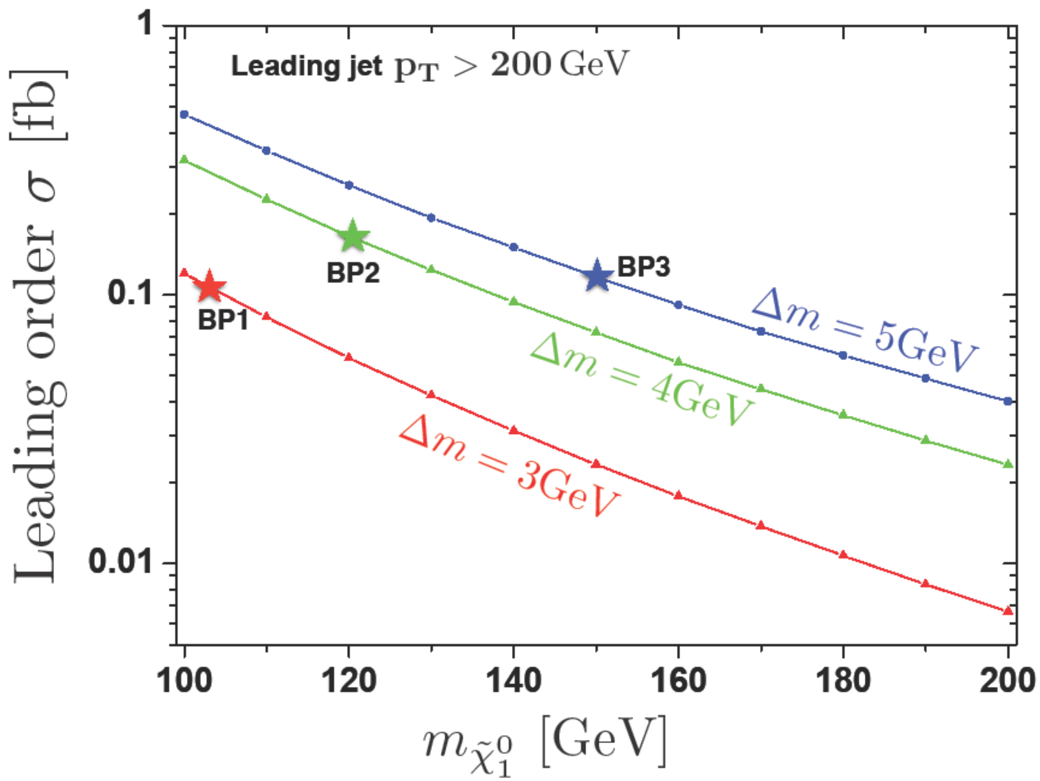
Our the dimuon criteria (μ_{col})

Two muon candidates satisfying $M_{\mu\mu} < 5$ GeV and $0.1 < \Delta R_{\mu\mu} < 0.5$. The dimuon are isolated by other objects. Using the criterion $I_{sum} < 3$ GeV, where the isolation parameter of the muon jet I_{sum} is defined as the scalar sum of the transverse momenta of all additional charged tracks with $p_T > 0.5$ GeV within a cone of size $\Delta R = 0.5$ centered on the momentum vector of the dimuon.

Our typical signal is: monojet + μ_{col} + missing energy



we show the production rate for different mass splitting. Here we include the $j\tilde{\chi}_1^0\tilde{\chi}_2^0, j\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production with $\tilde{\chi}_2^0$ decaying into $\tilde{\chi}_1^0 + \mu\mu$, here we also require the μ p_T larger than 5 GeV at parton level.



We find when mass splitting becomes smaller, the cross section reduce quickly. But even the mass splitting is 3GeV for 200 GeV neutralino for 14 TeV LHC $3000 fb^{-1}$, there are still more than 20 events of the signal.

From monojet search, we can easily find the main backgrounds:

$Z(\nu\bar{\nu}) + \gamma^*(\mu\bar{\mu}) + jets,$

$W(l\nu) + \gamma^*(\mu\bar{\mu}) + jets,$

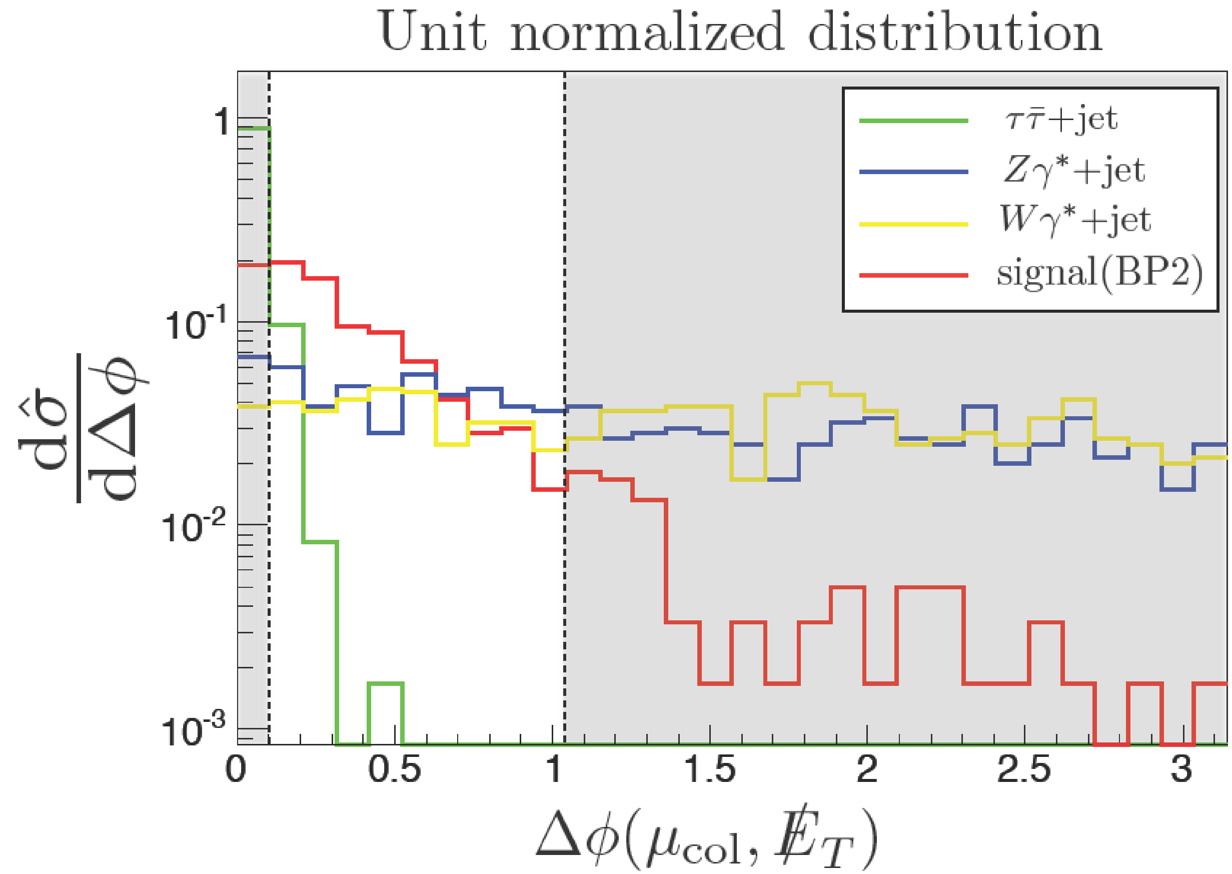
$\tau\bar{\tau} + jets$ (the two muons from the τs decay are also close to each other)

Backgrounds from bottom production which the bottom mistag as a dimuon events(order 10^{-4}) are highly suppressed

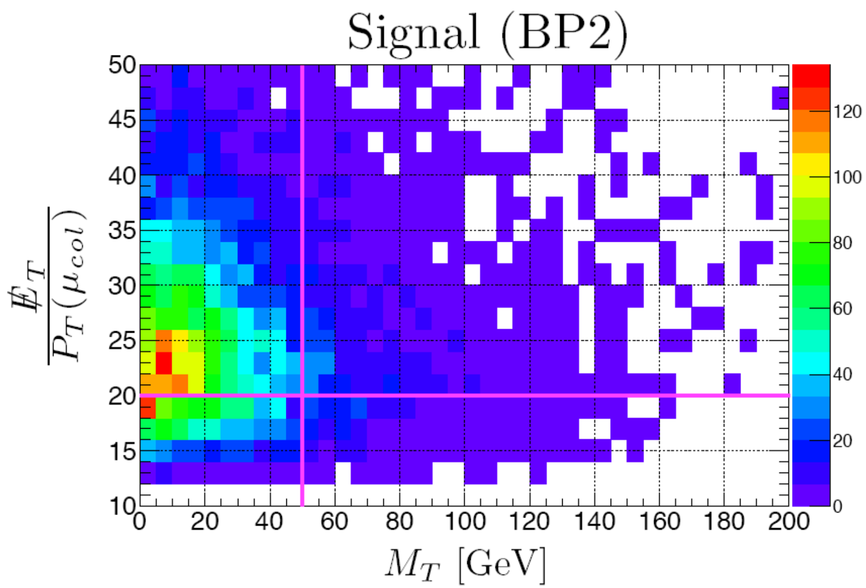
- Mono-jet cut: We require $p_T > 250\,\text{GeV}$ for the leading jet and veto events which have more than three jets with $p_T > 30\,\text{GeV}$. $\Delta\phi$ between the leading jet and the second jet should be larger than 0.4. All the jets are b- and τ-vetoed. Any events containing an electron with p_T larger than $10\,\text{GeV}$ are also vetoed. We additionally require $> 250\,\text{GeV}$ and demand exactly one pair of SF/OS muon candidates with each of these muons having $p_T > 5\,\text{GeV}$.

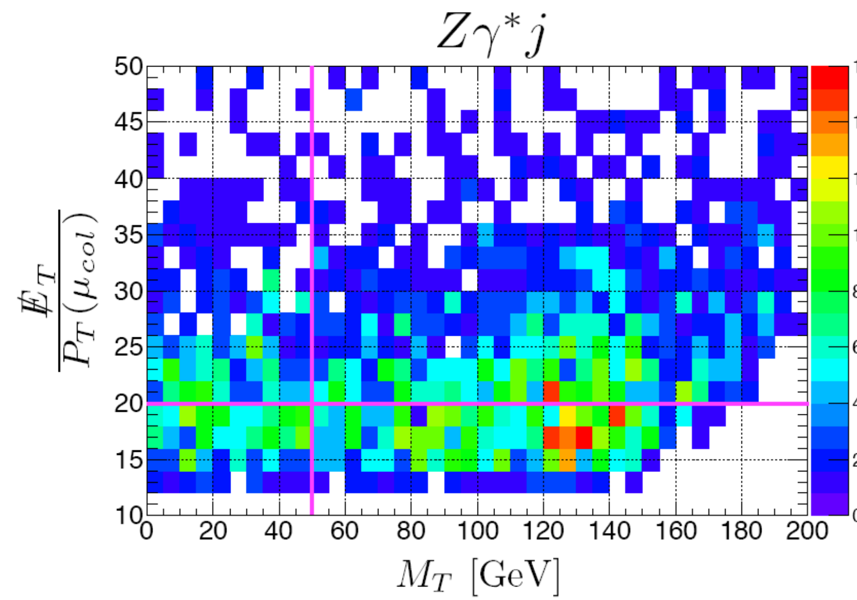
- Basic cuts on μ_{col}: $1\,\text{GeV} < m_{\mu\bar{\mu}} < 5\,\text{GeV}$ and $0.1 < \Delta R_{\mu\bar{\mu}} < 0.5$. Here the cut at the lower end of $\Delta R_{\mu\bar{\mu}}$ is to remove the main backgrounds where two muons emerge from a γ^*. The is required to be isolated with $I_{sum} < 3\,\text{GeV}$. The p_T of the in our signal usually tends to be small. We therefore apply the cut $p_T < 20\,\text{GeV}$ for the μ_{col}.

After these cuts, for the signal μ =120 GeV , Δm=4 GeV, we get a S/B ~ 2%



Cut on $0.1 < \Delta\phi(\mu_{col},\mathrm{E}_T^{miss}) < \pi/3$. We show the $\Delta\phi(\mu_{col}, E_T)$ distributions for the signal corresponding to our BP2 as well as the backgrounds. We note that imposing the lower cut of $\Delta\phi > 0.1$ removes much of the $\tau\bar{\tau} + jets$ background and the upper cut leaves only about a third of the $V + \gamma^* + jets$ background. As for the signal, these cuts only remove less than 30% of the events.





An upper cut of $M_T < 50$ GeV and a lower cut of $E_T/p_T(\mu_{\rm col}) > 20$ suppresses the background while allowing most of our signal events

we also require $1.5\,\mathrm{GeV} < m_{\mu_{\rm col}} < 4\,\mathrm{GeV}$, cutting off also the small window, $3.0\,\mathrm{GeV} < m_{\mu_{\rm col}} < 3.2\,\mathrm{GeV}$, corresponding to the mass of the J/Ψ resonance.

Cut-flow for our signal and background processes. The cross sections are in fb and the S/B and $S/\sqrt{B}$ given in the last two rows correspond to $\mathcal{L} = 3000\,\text{fb}^{-1}$ at the 14 TeV LHC.

cuts	$W\gamma^*$ j	$Z\gamma^*$ j	$j\tau\tau$	Total BKG	BP1	BP2	BP3
Mono-jet	8.057	8.82	6.674	23.0	0.052	0.072	0.056
basic μ_{col}	0.753	1.05	0.314	2.1	0.041	0.042	0.028
$\Delta\phi(\mu_{col}, \not{E}_T)$	0.288	0.324	0.035	0.65	0.028	0.030	0.020
$m_{\mu_{col}}$	0.106	0.118	0.024	0.248	0.017	0.023	0.015
M_T & $\frac{\not{E}_T}{p_T(\mu_{col})}$	0.037	0.044	0.011	0.092	0.013	0.016	0.010
S/B					0.14	0.17	0.11
$S/\sqrt{B}\,(\sigma)$					2.4	2.9	1.85

we can achieve a statistical significance $\sim 2.9\,\sigma$ as well as a $S/B \sim 17\%$ with an integrated luminosity of $3000\,\text{fb}^{-1}$ at the 14 TeV LHC, for the pair production of higgsinos with masses 124 GeV and 120 GeV.

Main systematic uncertainty analysis

The Muon transverse momentum resolution: 1%.

The collinear muons reconstruction effects: 3.5%.

Jet and missing energy scale and resolution: 0.7%.

Pile up corrections to the jet P_T: 1.5% (8TeV).

(ATLAS-CONF-2013-068, arXiv 1212.5409, 1210.7619)

We expect the Sys. error $\sqrt{1^2 + 3.5^2 + 0.7^2 + 1.5^2}\% \lesssim 5\%$

It is hopeful to search for the Higgsinos by using this method!


STEPHEN COVEY:
Begin with
the end in mind.