$\tilde{\tau}$ co-annihilation models at LHC and ILC

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[1] DESY, Hamburg

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Outline

For all the details, see arXiv:1508.04383 (submitted to EPJC)

Studying SUSY in rich models

Remember, apart from stabilising the Higgs mass (naturalness) SUSY can address:

- Anomaly in $g-2$ of the μ: Would prefer a not-too-heavy smuon.
- Dark matter : A WIMP of ~ 100 GeV would be required. And a process not to over-produce it, eg. by co-anhiliation by a nearby NLSP.
- EW symmetry breaking, coupling constant unification: points to NP at or below 1 TeV
- Suppress the SUSY flavour problem (FCNC:s etc): Heavy 1:st & 2:nd generation squarks would be nice ...
- Other low-energy constrains : $b \to s\gamma$, $b \to \mu\mu$, ρ-parameter, $\Gamma(Z)$ ...

Can we still get all this with SUSY, without contradicting LHC limits ?!

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Example: The STCx models

STC4-10

- 11 parameters.
- Separate gluino
- Higgs, un-coloured, and coloured scalar parameters separate

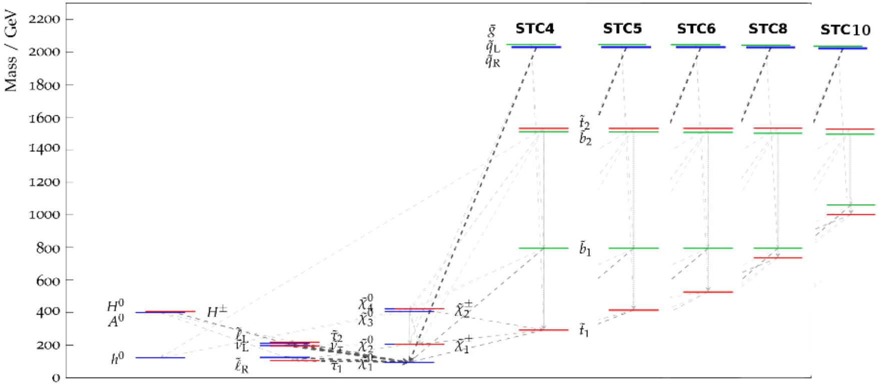
Parameters chosen to deliver all constraints (LHC, LEP, cosmology, low energy). In particular, the $\tilde{\tau}_1$ is the NLSP, with a mass-difference to the LSP $\sim$ 10 GeV $\Rightarrow$ Co-anhilitaion.
At E_{CMS} = 500 GeV:

- All sleptons available.
- No squarks.
- Lighter bosinos, up to $\tilde{\chi}^0_3$ (in $\mathrm{e^+e^-} \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_3$)

(See H. Baer, J. List, arXiv:1307:0782.)

Full STCx mass-spectrum

High mass squarks+gluino



Well-tempered higgs, bosino and slepton sector

Varying 3-gen squarks

STCx @ LHC14

- STC8 and STC10 studied by I. Melzer-Pellmann's group at DESY with fastsim (Delphes).
- Main features at LHC 14 TeV:
  - Cross-sections:
    - $\tilde{\chi}^0_k \tilde{\chi}^\pm_l > \tilde{\chi}^\pm_k \tilde{\chi}^\pm_l > \tilde{\tau}\tilde{\tau} > \tilde{\ell}\tilde{\ell} > \tilde{t}\tilde{t} > \tilde{b}\tilde{b} > \tilde{q}\tilde{q} > \tilde{\chi}^0_k \tilde{\chi}^0_l > \tilde{g}\tilde{g}$

    ranging from 1.5 pb to 1 fb. $M_{\tilde{t}}$ and $M_{\tilde{b}}$ is 200 GeV higher in STC10

    $\rightarrow$ Cross-sections for $\tilde{t}\tilde{t}$ and $\tilde{b}\tilde{b}$ 5 $\times$ smaller in STC10 wrt STC8.
  - $\tilde{\chi}$ cascade-decays to τ:s + the LSP in 75 % of the cases, often together with a boson (Z, W or h).
    - For $\tilde{\chi}^0$, the rest is either only bosons, or "nothing" (ie. neutrinos).
    - For $\tilde{\chi}^\pm$ the rest is other leptons.
  - The τ:s mostly come from $\tilde{\tau}_1 \rightarrow \tau \tilde{\chi}^0_0$, where the mass difference is only 10 $\mathrm{GeV} \Rightarrow$ little missing energy.
  - $\tilde{b}$ mostly decays to $b\tilde{\chi}^0$: > 50 % to $b\tilde{\chi}^0_1$. But also to $t\tilde{\chi}^\pm$ (20%)
  - $\tilde{t}$ always goes to $t\tilde{\chi}^0$, but rarely to $t\tilde{\chi}^0_1$ ($\sim$ 10%).
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⇒ LHC expectations

- Despite the high cross-section, the low amount of missing E_T and the long decay chains will make direct bosino and slepton observations hard.
- The simple decay-chains and very high missing E_T will make first- and second-generation squark production easy to detect. However, the cross-section is so low that it is still challenging.
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STCx @ LHC14: Full-hadronic search

- Select events with large amount of E_T in central, high E jets (HT) $\Rightarrow$ hard interaction.
- Further select large *missing* E_T (MHT) $\Rightarrow$ Partly invisible decay of heavy particle to a (much) lighter one.
- Avoid “signals” from bad measurements: Angle between any jet and the MHT direction large. Veto isolated leptons.
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- Same, but enhance in $\tilde{b}$ and $\tilde{t}$ by demanding two b-tagged jets.

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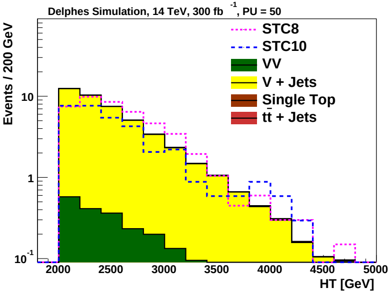

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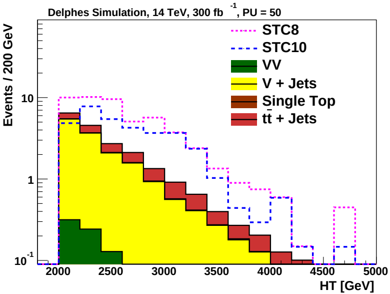

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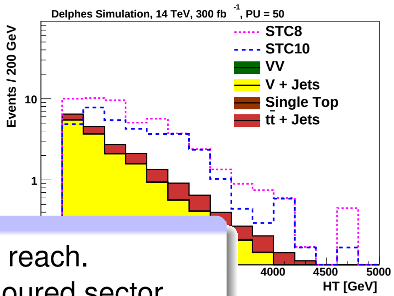

Good discovery reach.
Light on content of coloured sector.

STCx @ LHC14: Search for $\tilde{\mathrm{b}} \rightarrow b\tilde{\chi}_1^0$

- Select events with exactly two central, high E_T, b-tagged jets.
- No other jet with significant E_T allowed, veto leptons.
- Require high missing E_T and high transverse mass.
- The "contransverse mass" is an observable that is predicted to have an edge at $(M_{\tilde{\mathrm{b}}}{}^2 - M_{\tilde{\chi}_0^0}{}^2)/M_{\tilde{\mathrm{b}}} \approx M_{\tilde{\mathrm{b}}}$.

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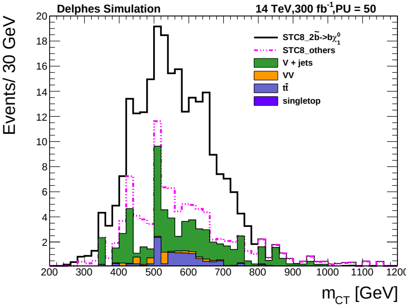

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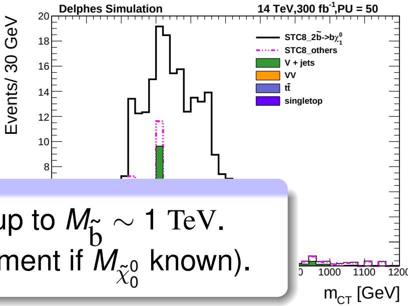

Good discovery reach, up to $M_{\tilde{\mathrm{b}}} \sim 1\ \mathrm{TeV}$.
Limits on $M_{\tilde{\mathrm{b}}}$ (or measurement if $M_{\tilde{\chi}_0^0}$ known).

STCx @ LHC14: Search for $\tilde{t}$ in single-lepton channel

- Low BR $\tilde{t} \to t\tilde{\chi}_1^0$ in the model. $\Rightarrow$ Look for $\tilde{t} \to t\tilde{\chi}_{2,3,4}^0$, with bosinos going to $W \to \ell\nu$ on one side, to $W \to qq'$ on the other.
- One (and only one) isolated lepton centraly + "Nothing"
- Many central jets (≥ 5), with one or two b-tagged.
- Transverse mass m_T of missing momentum and lepton > 260 GeV.
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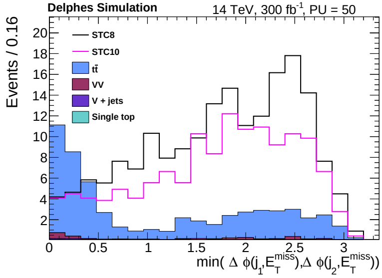

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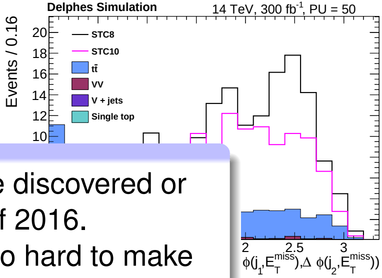

The discovery channel, will be discovered or excluded by the end of 2016.
Alas, purity is low (20-40 %), so hard to make further model determination.

STCx @ LHC14: Search for bosinos

- *Dominating* SUSY channel at LHC is $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ production: $>$ 1 pb.
- $\Rightarrow$ search for direct *un-colored* bosino prodution (“whiteinos”) !
- Golden channel: $\geq$ three leptons.
- Plethora of channels, and of backgrounds (WZ, $t\bar{t}$, Drell-Yan)
- $\Rightarrow$ 45 different searches binned in
  - $m_{\ell\ell}$, m_T, and E_T^{miss}
- No single bin highly significant, but together, $> 5\sigma$ @ < 200 fb^{-1}.
- Signal is a mainly $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$, followed by $\tilde{\chi}_2^\pm\chi_x$.

Ch	Total SM $\pm$ unc.	STC8	$Z_{\rm Bi}$	$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm\chi_x$	Other EWK	No EWK
$m_{\ell^+\ell^-} < 75$GeV							
1	10900 $\pm$ 3300	88	<0.5	76	7	3	2
2	5900 $\pm$ 960	130	<0.5	110	10	10	0
3	1390 $\pm$ 340	140	<0.5	110	20	10	10
4	1290 $\pm$ 210	26	<0.5	16	7	2	2
5	348 $\pm$ 121	19	<0.5	10	6	2	1
6	45.1 $\pm$ 32.4	8.5	<0.5	2.3	4.5	0.5	1.2
7	469 $\pm$ 125	26	<0.5	9	12	4	2
8	29.6 $\pm$ 6.8	9.6	0.9	2.5	5.7	0.6	0.8
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12	0.0262 $\pm$ 0.0095	0.3	<0.5	0.0	0.15	0.15	0.0
13	1.06 $\pm$ 0.19	1.1	0.6	0.0	0.4	0.6	0.0
14	0.89 $\pm$ 0.263	0.3	<0.5	0.0	0.3	0.0	0.0
15	0.0137 $\pm$ 0.0048	0	<0.5	0	0	0	0
75GeV$< m_{\ell^+\ell^-} < 105$GeV							
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12	0.058 $\pm$ 0.0176	0.12	<0.5	0.0	0.0	0.0	0.12
13	1.77 $\pm$ 0.2	0.15	<0.5	0.0	0.15	0.0	0.0
14	2.32 $\pm$ 0.35	0.31	<0.5	0.0	0.31	0.0	0.0
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Good discovery reach, directly related to ILC reach.
ILC-LHC synergy: precice masses from ILC into LHC long decay-chains $\Rightarrow$ detrmine properties of heavier bosinos .

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						5	3
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						2	1
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						0.8	0.4
						0.0	0.8
						0.0	0.12
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Summary of LHC

If STCx is realised in nature

- LHC will discover something non-SM:
  - Central $t\bar{t} \rightarrow$ *hadrons* events with lots of of missing ET and one isolated lepton.
  - Central $b\bar{b}$ events with lots of missing ET, and a tell-tale contraverse mass distribution.
  - Insignificant (3 σ) excess in celtral, fully hadronic events with high missing ET.
  - A diffuse, highly significant, excess of three-lepton, transversly unbalanced events.
  - Largely systematics limited.
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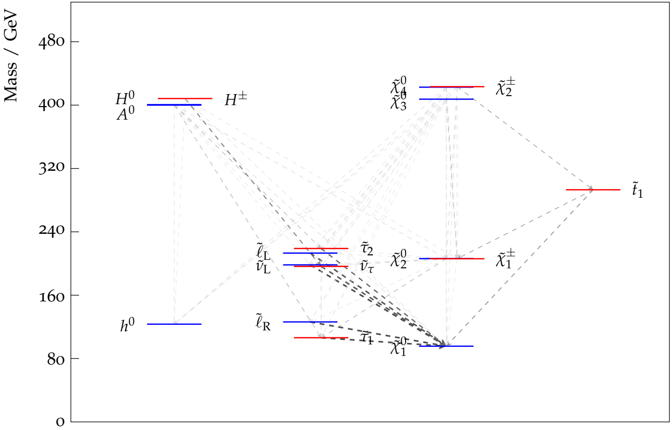
What is it ?
Is it SUSY?

The STCx benchmark @ ILC

Zoomed STCx mass-spectrum



Observables:

Observable	Gives	If
Edges (or average and width)	Masses	... not too far from threshold
Shape of spectrum	Spin	
Angular distributions	Mass, Spin	
Invariant mass distributions from full reconstruction	Mass	... cascade decays
Angular distributions from full reconstruction	Spin, CP,	... masses known
Un-polarised Cross-section in continuum	Mass, coupling	
Polarised Cross-section in continuum	Mass, coupling, mixing	
Decay product polarisation	Mixing	... $\tilde{\tau}$ decays
Threshold-scan	Mass(es), Spin	

Channels and observables at 250, 350 and 500 GeV

Channel	Threshold	Available at	Can give
$\tilde{\tau}_1\tilde{\tau}_1$	212	250	$M_{\tilde{\tau}_1}$, $\tilde{\tau}_1$ nature, τ polarisation
$\tilde{\mu}_R\tilde{\mu}_R$	252	250+	+ $M_{\tilde{\mu}_R}$, $M_{\tilde{\chi}^0_1}$, $\tilde{\mu}_R$ nature
$\tilde{e}_R\tilde{e}_R$	252	250+	+ $M_{\tilde{e}_R}$, $M_{\tilde{\chi}^0_1}$, $\tilde{e}_R$ nature
$\tilde{\chi}^0_1\tilde{\chi}^0_2$ *)	302	350	+ $M_{\tilde{\chi}^0_2}$, $M_{\tilde{\chi}^0_1}$, nature of $\tilde{\chi}^0_1, \tilde{\chi}^0_2$
$\tilde{\tau}_1\tilde{\tau}_2$ *)	325	350	+ $M_{\tilde{\tau}_2}\theta_{mix}$ $\tilde{\tau}$
$\tilde{e}_R\tilde{e}_L$ *)	339	350	+ $M_{\tilde{e}_L}$, $\tilde{\chi}^0_1$ mixing, $\tilde{e}_L$ nature
$\tilde{\nu}_{\tilde{\tau}}\tilde{\nu}_{\tilde{\tau}}$	392	500	7 % visible BR ($\rightarrow \tilde{\tau}_1 W$)
$\tilde{\chi}^{\pm}_1\tilde{\chi}^{\pm}_1$ *)	412	500	+ $M_{\tilde{\chi}^{\pm}_1}$, nature of $\tilde{\chi}^{\pm}_1$
$\tilde{e}_L\tilde{e}_L$ *)	416	500	+ $M_{\tilde{e}_L}$, $M_{\tilde{\chi}^0_1}$, $\tilde{e}_L$ nature
$\tilde{\mu}_L\tilde{\mu}_L$ *)	416	500	+ $M_{\tilde{\mu}_R}$, $M_{\tilde{\chi}^0_1}$, $\tilde{\mu}_R$ nature
$\tilde{\tau}_2\tilde{\tau}_2$ *)	438	500	+ $M_{\tilde{\tau}_2}$, $M_{\tilde{\chi}^0_1}$, $\tilde{\tau}_2$ nature, θ_{mix} $\tilde{\tau}$
$\tilde{\chi}^0_1\tilde{\chi}^0_3$ *)	503	500+	+ $M_{\tilde{\chi}^0_3}$, $M_{\tilde{\chi}^0_1}$, nature of $\tilde{\chi}^0_1, \tilde{\chi}^0_3$

*): Cascade decays.

+ invisible $\tilde{\chi}^0_1\tilde{\chi}^0_1$, $\tilde{\nu}_{\tilde{e},\tilde{\mu}}\tilde{\nu}_{\tilde{e},\tilde{\mu}}$.

SUSY backgrounds at the ILC

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  - $e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^- f\bar{f}$, with both e^+e^- un-detected.
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- Real missing energy + pair of SM-particles = di-boson production, with neutrinos:
  - $WW \rightarrow \ell\nu\ell\nu$
  - $ZZ \rightarrow f\bar{f}\nu\nu$
- Fake missing energy + pair of SM-particles = $\gamma\gamma$ processes, ISR, single IVB.
  - $\mathrm{e}^+\mathrm{e}^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-f\bar{f}$, with both e^+e^- un-detected.
  - $\mathrm{e}^+\mathrm{e}^- \rightarrow f\bar{f}\gamma$, with γ un-detected.

Features of STC4 @ 500 GeV

- The $\tilde{\tau}_1$ is the NLSP.
- For $\tilde{\tau}_1$: $E_{\tau,min} = 2.3\ \mathrm{GeV}$, $E_{\tau,max} = 45.5\ \mathrm{GeV}$: $\gamma\gamma$ *– background* $\Leftrightarrow$ *pairs – background*.
- For $\tilde{\tau}_2$: :$E_{\tau,min} = 52.4\ \mathrm{GeV}$, $E_{\tau,max} = 150.0\ \mathrm{GeV}$: *WW* $\rightarrow$ *lνlν – background* $\Leftrightarrow$ *Polarisation*.
- For $\tilde{\mathrm{e}}_\mathrm{R}$or $\tilde{\mu}_\mathrm{R}$: :$E_{l,min} = 7.3\ \mathrm{GeV}$, $E_{l,max} = 99.2\ \mathrm{GeV}$: Neither $\gamma\gamma$ nor *WW* $\rightarrow$ *lνlν* background severe.
- For pol=(1,-1): $\sigma(\tilde{\mathrm{e}}_\mathrm{R}\tilde{\mathrm{e}}_\mathrm{R})$ = 1.3 pb !
- $\tilde{\tau}$ NLSP $\rightarrow$ τ:s in most SUSY decays $\rightarrow$ SUSY is background to SUSY.
- For pol=(-1,1): $\sigma(\tilde{\chi}^0_2\tilde{\chi}^0_2)$ and $\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1)$ = several hundred fb and BR(X$\rightarrow\tilde{\tau}$) $>$ 70 %. For pol=(1,-1): $\sigma(\tilde{\chi}^0_2\tilde{\chi}^0_2)$ and $\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1) \approx 0$.

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STC4 @ 500 GeV

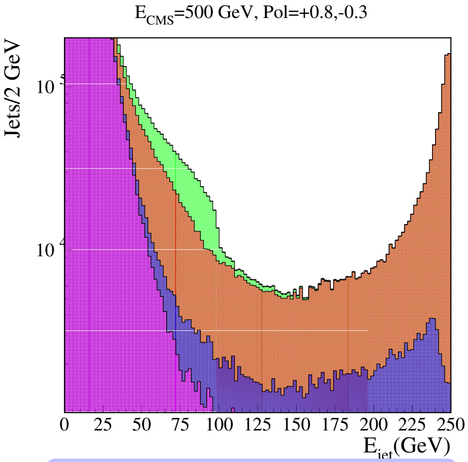
Strategy:

- Global preselection to reduce SM, while efficiency for all signals stays above $\sim$ 90 %.
- The further select for all sleptons ($\tilde{e}_R, \tilde{e}_L, \tilde{\mu}_R, \tilde{\mu}_L, \tilde{\tau}_1$).
- Next step: specific selections for $\tilde{e}_R$ and $\tilde{\mu}_R$, for $\tilde{e}_L$ and $\tilde{\mu}_L$, and for $\tilde{\tau}_1$.
- Last step: add particle id to separate $\tilde{e}$ and $\tilde{\mu}$, special cuts for $\tilde{\tau}_1$.
- Check results both for RL and LR beam-polarisation.

STC4 global

After a few very general cuts:

- Missing energy > 100
- Less than 10 charged tracks
- $|\cos\theta_{Ptot}| < 0.95$
- Exactly two τ-jets
- Visible mass < 300 GeV
- θ_{acop} between 0.15 and 3.1



Magenta: $\gamma\gamma$, Blue: 3f,
Red: Rest of SM, Green: SUSY.

STC4 sleptons @ 500 GeV:$\tilde{e}$, $\tilde{\mu}$

- Selections for $\tilde{\mu}$ and $\tilde{e}$:
  - Correct charge.
  - P_T wrt. beam and one ℓ wrt the other.
  - Tag and probe, ie. accept one jet if the other is "in the box".
- Further selections for R:
  - Cuts on polar angle and angle between leptons.
- E_{jet}, beam-pol 80%,-30%...
- Determine masses from edge-possitions.

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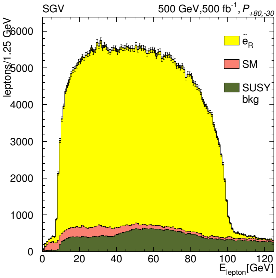

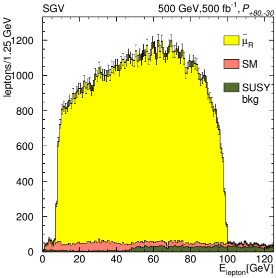

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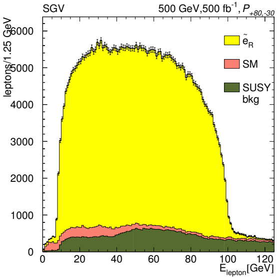
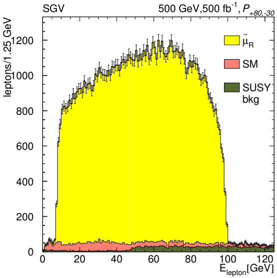




STC4 sleptons @ 500 GeV: $\tilde{e}$, $\tilde{\mu}$

Results from edges (E_{CMS}=500, 500 fb^{-1} @ [+0.8,-0.3])

selectrons:

$$M_{\tilde{e}_R} = 126.20 \pm 0.21 \text{ GeV}/c^2$$
$$M_{\tilde{\chi}^0_1} = 95.47 \pm 0.16 \text{ GeV}/c^2$$

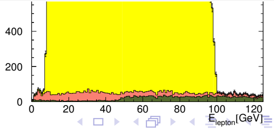
smuons:

$$M_{\tilde{\mu}_R} = 126.01 \pm 0.51 \text{ GeV}/c^2$$
$$M_{\tilde{\chi}^0_1} = 95.47 \pm 0.38 \text{ GeV}/c^2$$

combined:

$$\sigma_{M_{\tilde{\chi}^0_0}} = 147 \text{ MeV}/c^2 \qquad \sigma_{M_{\tilde{\ell}_R}} = 194 \text{ MeV}/c^2$$

- Determine masses from edge-possitions.



$\tilde{e}_R$ and $\tilde{\mu}_R$ threshold scans

From these spectra, we can estimate $M_{\tilde{e}_R}$, and $M_{\tilde{\chi}_1^0}$ to < 0.2 GeV, and $M_{\tilde{\mu}_R}$ to < 0.5 GeV.

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So: Next step is $M_{\tilde{\ell}}$ from threshold:

- 10 points, 10 fb^{-1}/point.
- Luminosity $\propto E_{CMS}$, so this is $\Leftrightarrow$ 170 fb^{-1} @ E_{CMS}=500 GeV.

- Error on $M_{\tilde{\mu}_R}$ and $M_{\tilde{e}_R}$ = 200 MeV.
- Fermion hypothesis excluded with fit-probabilities $< 10^{-5}$

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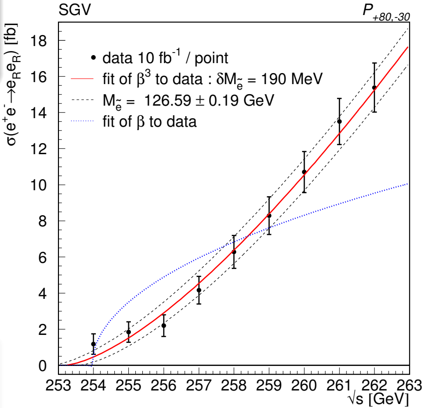

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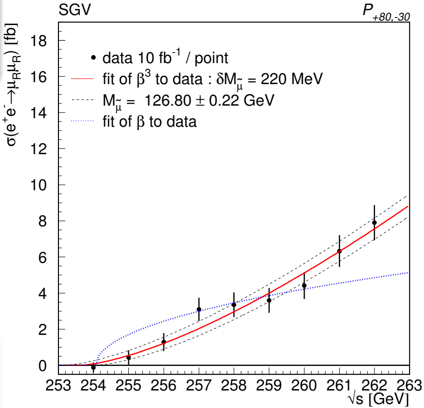

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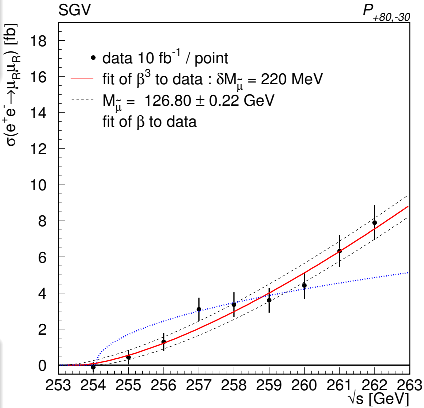

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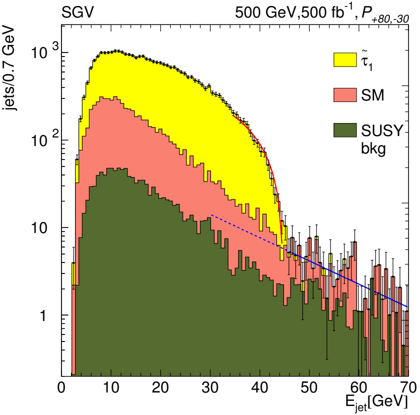
STC4 sleptons @ 500 GeV: $\tilde{\tau}_1$

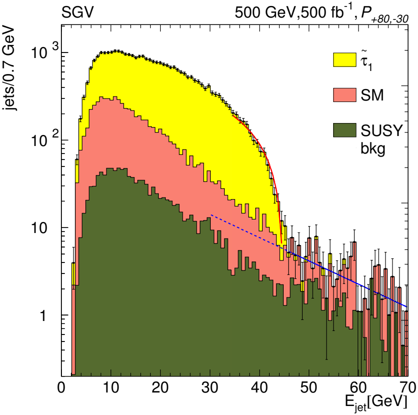
Selections for $\tilde{\tau}_1$:

- Correct charge.
- P_T wrt. beam and one τ wrt the other.
- $M_{jet} < M_\tau$
- $E_{vis} < 120$ GeV, $M_{vis} \in [20, 87]$ GeV.
- Cuts on polar angle and angle between leptons.
- Little energy below 30 deg, or not in τ-jet.
- At least one τ-jet should be hadronic.
- Anti-$\gamma\gamma$ likelihood.



Fitting the $\tilde{\tau}$ end-points

- Only the upper end-point is relevant.
- Background subtraction:
  - $\tilde{\tau}_1$: Important SUSY background, but region above 45 GeV is signal free. Fit exponential and extrapolate.
  - $\tilde{\tau}_2$: $\sim$ no SUSY background above 45 GeV. Take background from SM-only simulation and fit exponential.
- Fit line to (data-background fit).



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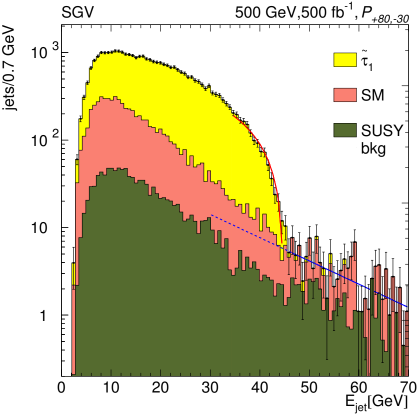

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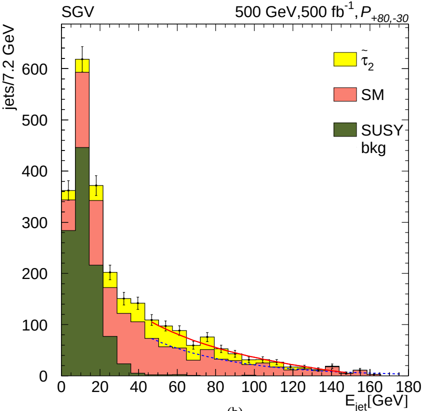

(b)

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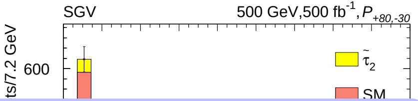
  - exponential



Results for $\tilde{\tau}_1$

$$E_{max,\tilde{\tau}_1} = 44.49^{+0.11}_{-0.09}\,\mathrm{GeV}$$

Translates to an error on the mass of 0.27 GeV/c^2, dominated by the error from $M_{\tilde{\chi}^0_1}$.

Results for $\tilde{\tau}_2$

$$E_{max,\tilde{\tau}_2} = 145.4^{+5.9}_{-4.4}\,\mathrm{GeV}$$

Translates to an error on the mass of 5 GeV/c^2, dominated by the error from the end-point.

Reminder: SPS1a' results (Phys.Rev.D82:055016,2010)

The previous $\tilde{\tau}$ study in the very similar model SPS1a' gave:

Results for $\tilde{\tau}_1$

$M_{\tilde{\tau}_1} = 107.73^{+0.03}_{-0.05}\mathrm{GeV}/c^2 \oplus 1.3\Delta(M_{\tilde{\chi}^0_1})$

The error from $M_{\tilde{\chi}^0_1}$ largely dominates

Results for $\tilde{\tau}_2$

$M_{\tilde{\tau}_2} = 183^{+11}_{-5}\mathrm{GeV}/c^2 \oplus 18\Delta(M_{\tilde{\chi}^0_1})$

The error from the endpoint largely dominates

Results from cross-section for $\tilde{\tau}_1$

$\Delta(N_{signal})/N_{signal} = 3.1\% \rightarrow \Delta(M_{\tilde{\tau}_1}) = 3.2\mathrm{GeV}/c^2$

Results from cross-section for $\tilde{\tau}_2$

$\Delta(N_{signal})/N_{signal} = 4.2\% \rightarrow \Delta(M_{\tilde{\tau}_2}) = 3.6\mathrm{GeV}/c^2$

End-point + Cross-section $\rightarrow \Delta(M_{\tilde{\chi}^0_1}) = 1.7\mathrm{GeV}/c^2$

Also: τ polarisation in $\tilde{\tau}_1$ decays

$\Delta(\mathcal{P}_\tau)/\mathcal{P}_\tau$ = 9 %.

Conclusions

We have done a combined ILC-LHC study of a SUSY model that fulfils all current constraints. The model has good visibility at *both* machines.

- At LHC: study
  - Methods for discovery
  - Control of systematics essential.
  - Insight in coloured sector, in synergy with ILC.
- The observations will discover BSM physics., both in the coloured and EW sectors.
- But had to say what physics it is.
- At ILC: Study best method to analyse spectra, eg
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ILC and LHC

Combining ILC precision with LHC reach the will allow to extend the model study to the colored sector and to the heavier bosinos, ie. to the full spectrum.

Thank You !

BACKUP

BACKUP SLIDES

Observables: Pair-production, two-body decay (less text)

- So, there are two SUSY parameters, and two independent observables in the spectrum.
- Any pair of observables can be chosen, edges, average, standard deviation, width, ...
- Which choice is the best depends on the situation.
- Just a bit of algebra to extract the two SUSY masses.
- Note that if $E_{beam} >> M_X$, there is just one observable (low edge becomes 0, width becomes average/2), so one should not operate too far above threshold !
- Note that there are two decays in each event: two measurements per event.
- Also note that there are not enough measurements to make a constrained fit, even assuming that the two SUSY particles in the two decays are the same: (2×4 unknown components of 4-momentum (=8)) - (total E and p conservation (=4) + 2

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Observables: Pair-production, two-body decay

However:

- If the masses are known from other measurements, there are enough constraints.
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- ... and the angular distributions both in production and decay can be measured.
- From this the spins can be determined, which is essential to determine that what we are seeing is SUSY.

Furthermore:

- Looking at more complicated decays, such as cascade decays, there are enough constraints if some (but not all) masses are known.
- Allows to reconstruct eg. the slepton mass in $\tilde{\chi}_2^0 \to \tilde{\ell}\ell \to \ell\ell\tilde{\chi}_1^0$ if chargino and LSP masses are known.
- Order-of-magnitude better mass resolution.

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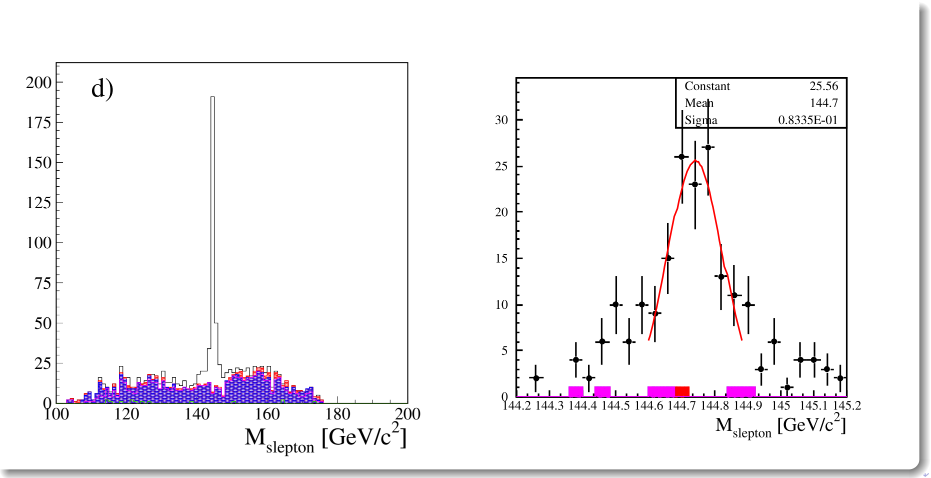
- Order-of-magnitude better mass resolution.

Observables: Pair-production, two-body decay

However:

- If the masses are known from other measurements, there are



- Order-of-magnitude better mass resolution.

Observables

But this is not all !

- The cross-section in $\mathrm{e}^{+}\mathrm{e}^{-} \rightarrow XX$ close to threshold depends both on coupling, spin and kinematics (= β).
- The distribution of the angle between the two SM-particles depends on β, in a complicated, but calculable way.
- The cross-section is different for L and R SUSY particles.
- So checking how much the cross-section changes when switching beam-polarisations measures mixing.
- Measure the helicity of the SM particle $\rightarrow$ properties of the particles in the decay, ie. in addition to the produced X, also the invisible U. In one case this is possible: In $\tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0 \rightarrow X\nu_\tau\tilde{\chi}_1^0$.

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Extracting the $\tilde{\tau}$ properties

See Phys.Rev.D82:055016,2010

Use polarisation (0.8,-0.22) to reduce bosino background.

From decay kinematics:

- $M_{\tilde{\tau}}$ from $M_{\tilde{\chi}_1^0}$ and end-point of spectrum = $E_{\tau,max}$.
- Other end-point hidden in $\gamma\gamma$ background:Must get $M_{\tilde{\chi}_1^0}$ from other sources. ($\tilde{\mu}$, $\tilde{e}$, ...)

From cross-section:

- $\sigma_{\tilde{\tau}} = A(\theta_{\tilde{\tau}}, \mathcal{P}_{beam}) \times \beta^3/s$, so
- $M_{\tilde{\tau}} = E_{beam}\sqrt{1-(\sigma s/A)^{2/3}}$: no $M_{\tilde{\chi}_1^0}$!

From decay spectra:

- $\mathcal{P}_\tau$ from exclusive decay-mode(s): handle on mixing angles $\theta_{\tilde{\tau}}$ and $\theta_{\tilde{\chi}_1^0}$

Topology selection

Take over SPS1a' $\tilde{\tau}$ analysis principle

$\tilde{\ell}$ properties:

- Only two particles (possibly τ:s:s) in the final state.
- Large missing energy and momentum.
- High Acolinearity, with little correlation to the energy of the τ decay-products.
- Central production.
- No forward-backward asymmetry.

+ anti $\gamma\gamma$ cuts.

Select this by:

- Exactly two jets.
- $N_{ch} < 10$
- Vanishing total charge.
- Charge of each jet = $\pm$ 1,
- $M_{jet} < 2.5\ \mathrm{GeV}/c^2$,
- E_{vis} significantly less than E_{CMS}.
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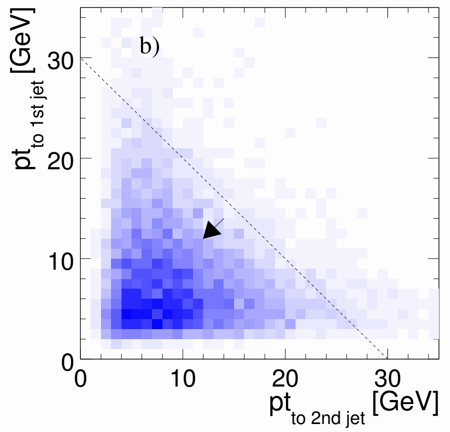
$\tilde{\tau}_1$ and $\tilde{\tau}_2$ further selections

- $\tilde{\tau}_1$:
  - $(E_{jet1} + E_{jet2}) \sin\theta_{acop} < 30$ GeV.
- $\tilde{\tau}_2$:
  - Other side jet not e or μ
  - Most energetic jet not e or μ
  - Cut on Signal-SM LR of $f(q_{jet1} \cos\theta_{jet1}, q_{jet2} \cos\theta_{jet2})$

Efficiency 15 (22) %



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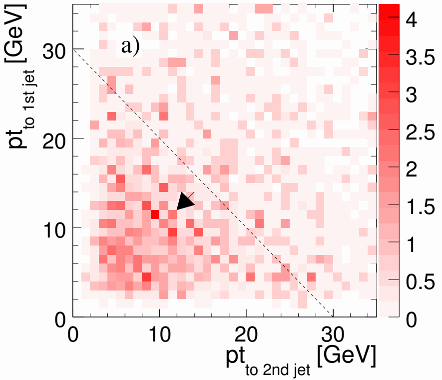

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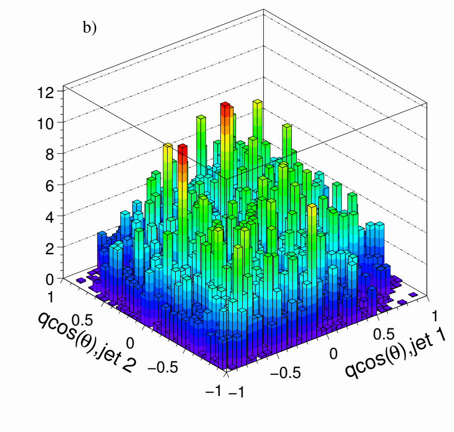

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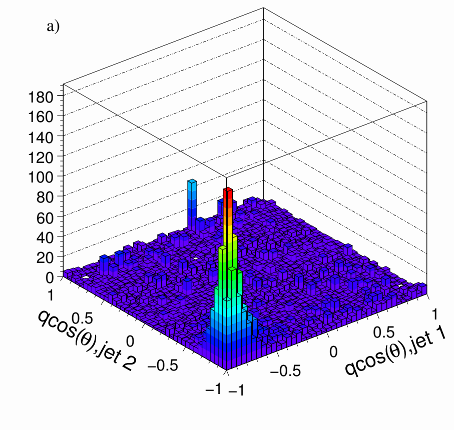

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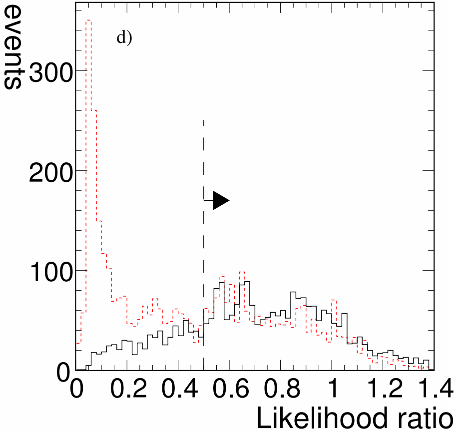

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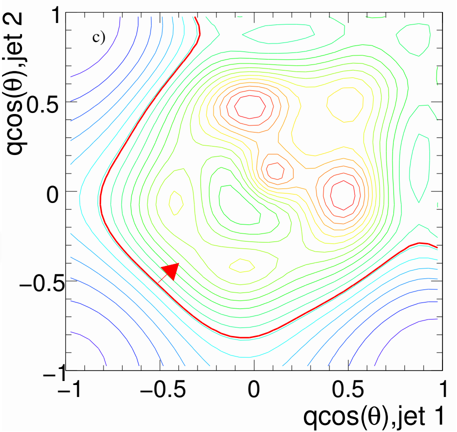

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$\tilde{\mu}$ channels

Use “normal” polarisation (-0.8,0.22).

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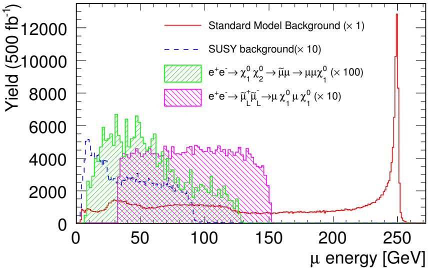
- $\tilde{\chi}^0_1\tilde{\chi}^0_2 \rightarrow \mu\tilde{\mu}_R\tilde{\chi}^0_1 \rightarrow \mu\mu\tilde{\chi}^0_1\tilde{\chi}^0_1$

- Momentum of μ:s
- E_{miss}
- $M_{\mu\mu}$



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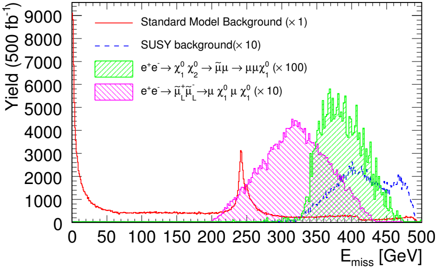

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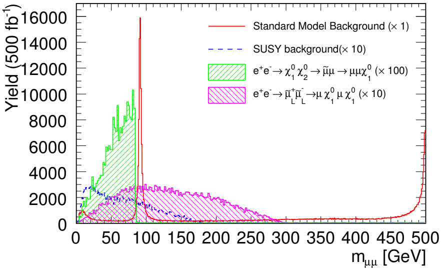


$\tilde{\mu}_L \tilde{\mu}_L$

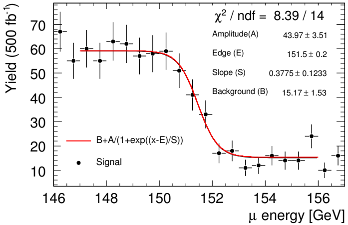
Selections

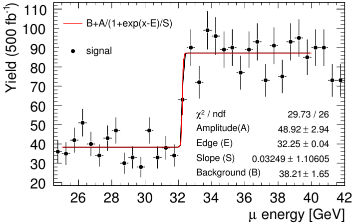
- $\theta_{missingp} \in [0.1\pi; 0.9\pi]$
- $E_{miss} \in [200, 430]\mathrm{GeV}$
- $M_{\mu\mu} \notin [80.100]\mathrm{GeV}$ and > 30 GeV/c^2

Masses from edges. Beam-energy spread dominates error.

$\Delta(M_{\tilde{\chi}_1^0}) = 920\mathrm{MeV}/c^2$

$\Delta(M_{\tilde{\mu}_L}) = 100\mathrm{MeV}/c^2$





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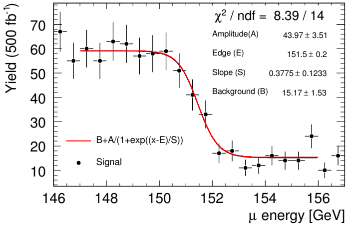
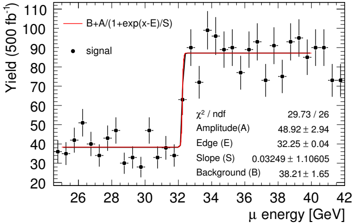




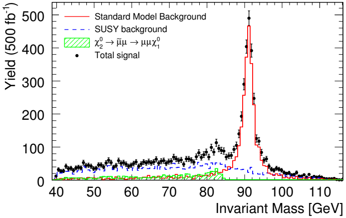
$\tilde{\chi}_1^0\ \tilde{\chi}_2^0$

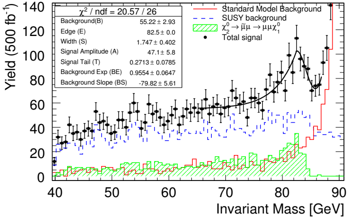
Selections

- $\theta_{missingp} \in [0.2\pi; 0.8\pi]$
- $p_{Tmiss} > 40\mathrm{GeV}/c$
- β of μ system > 0.6.
- $E_{miss} \in [355, 395]\mathrm{GeV}$

Masses from edges. Beam-energy spread dominates error.

$\Delta(M_{\tilde{\chi}_2^0}) = 1.38\mathrm{GeV}/c^2$





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