NMSSM in disguise:

singlino dark matter with soft leptons at the LHC

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arXiv:0811.0011
with A.R. Raklev and M. White, Cambridge

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Overview

- Next-to-minimal model: MSSM + singlet superfield S:

$$\lambda \hat{S}(\hat{H}_d \cdot \hat{H}_u) + \frac{1}{3}\kappa \hat{S}^3$$

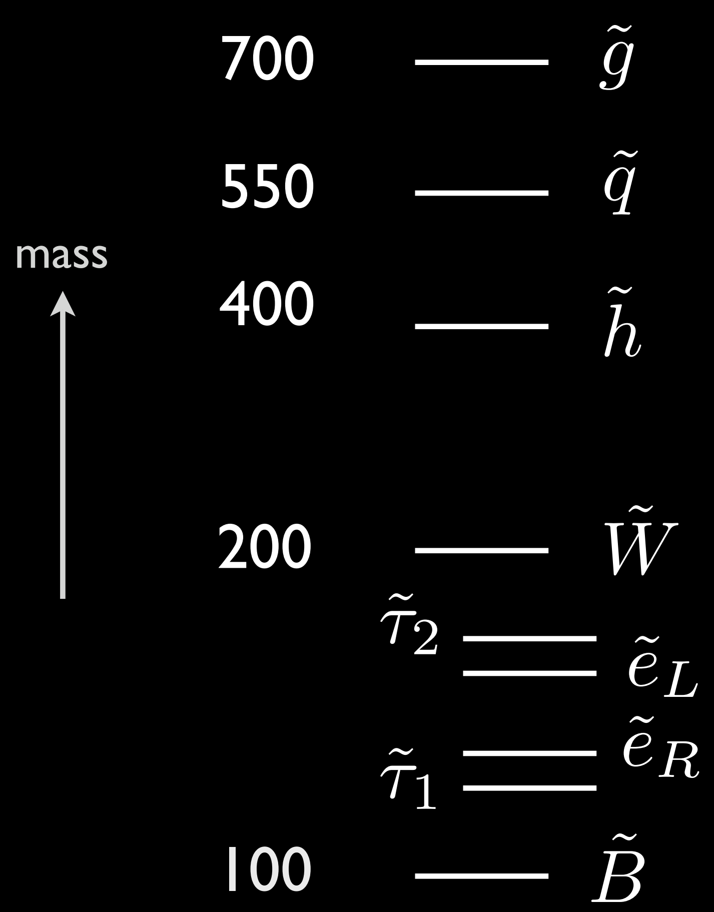
- Has two extra neutral (singlet) Higgs fields as well as an extra neutralino: the singlino
- Consider a SPS1a-like scenario supplemented by a singlino LSP. $\Omega h^2 \sim 0.1$ → small bino−singlino mass difference, max a few GeV
- Conventional cascade decays into the bino, followed by

$$\tilde{B} \to l^+ l^- \tilde{S}$$

- NB: each cascade has this bino-to-singlino decay as last step. However, resulting leptons are (very) soft.
- If missed, looks like ordinary MSSM with bino LSP, Ωh^2 too high.

Setup

- Consider a SPS1a-like scenario



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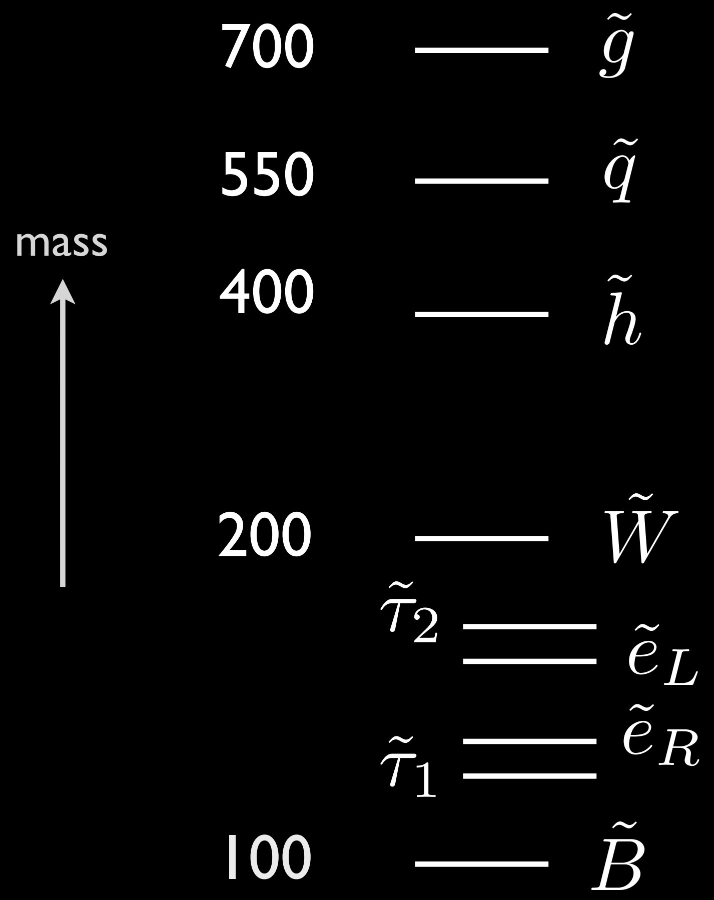
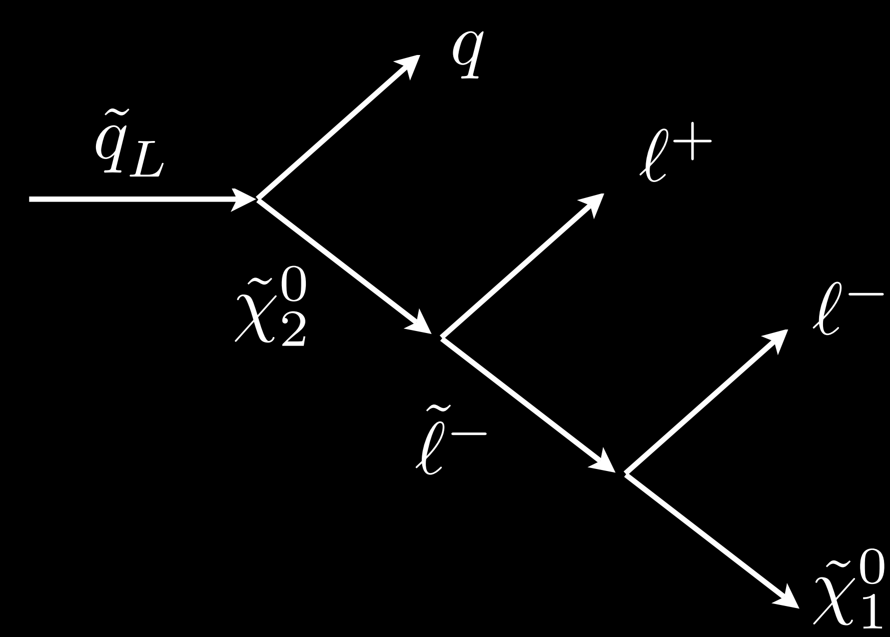
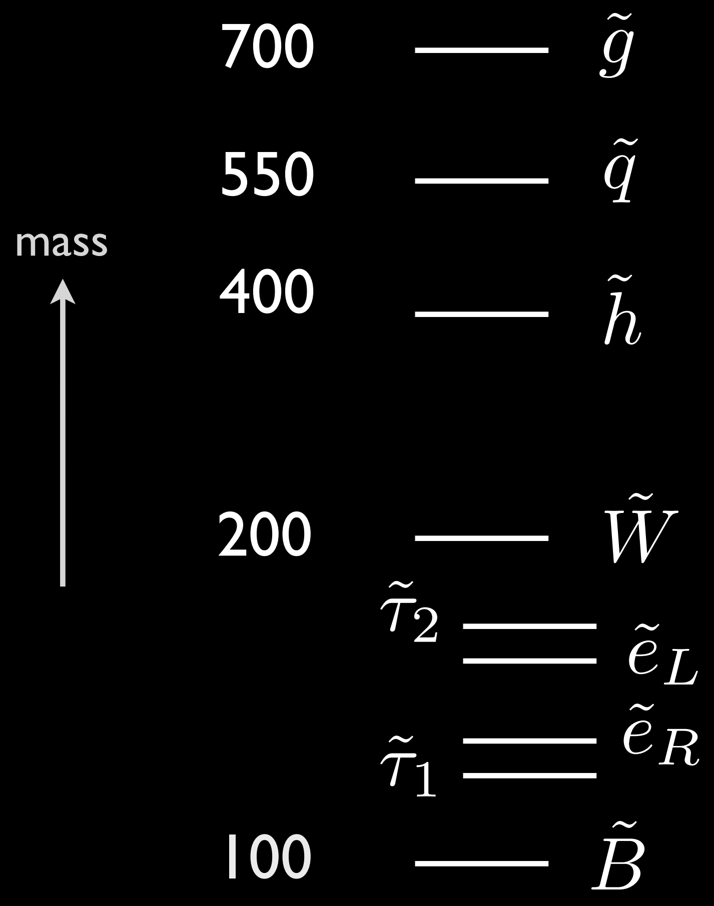


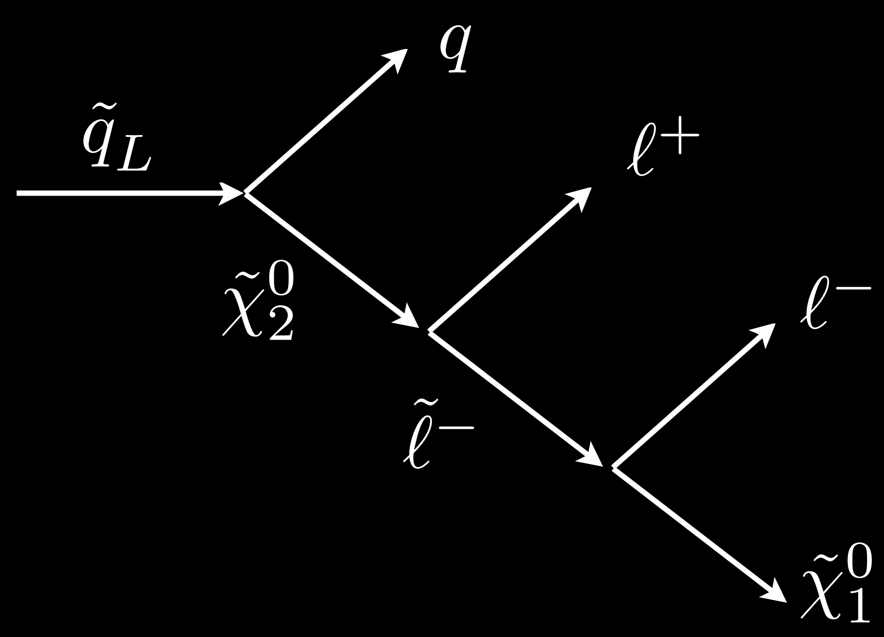


Setup

- Consider a SPS1a-like scenario

$$(m_{ll}^{max})^2 = (m^2_{\tilde\chi^0_2} - m^2_{\tilde l})(m^2_{\tilde l} - m^2_{\tilde\chi^0_1})/m^2_{\tilde l}$$





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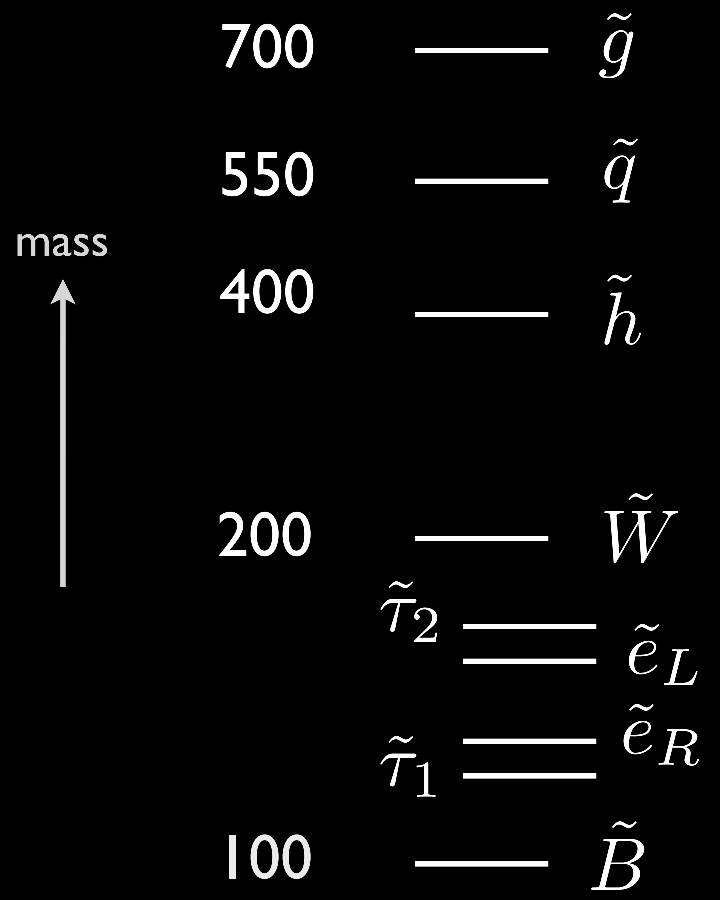

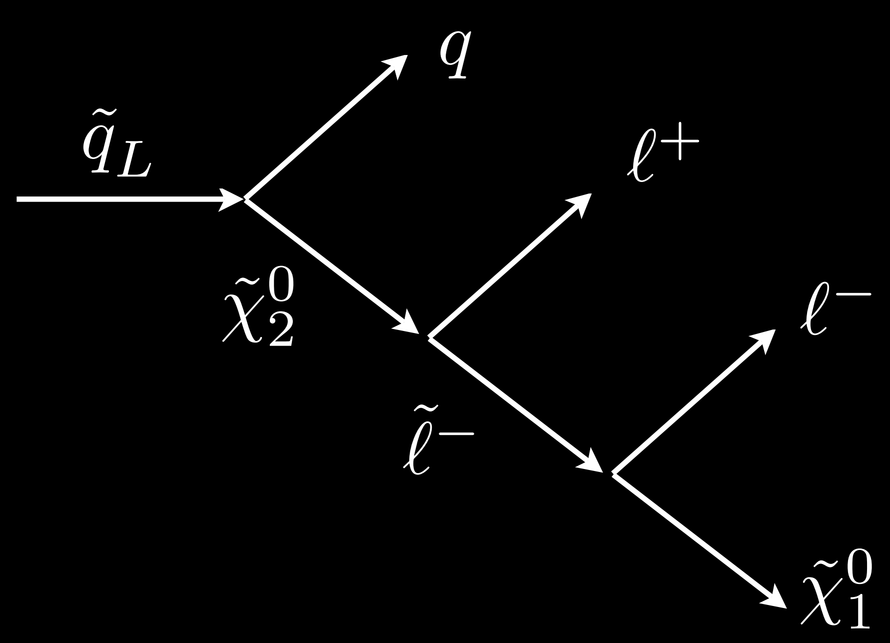

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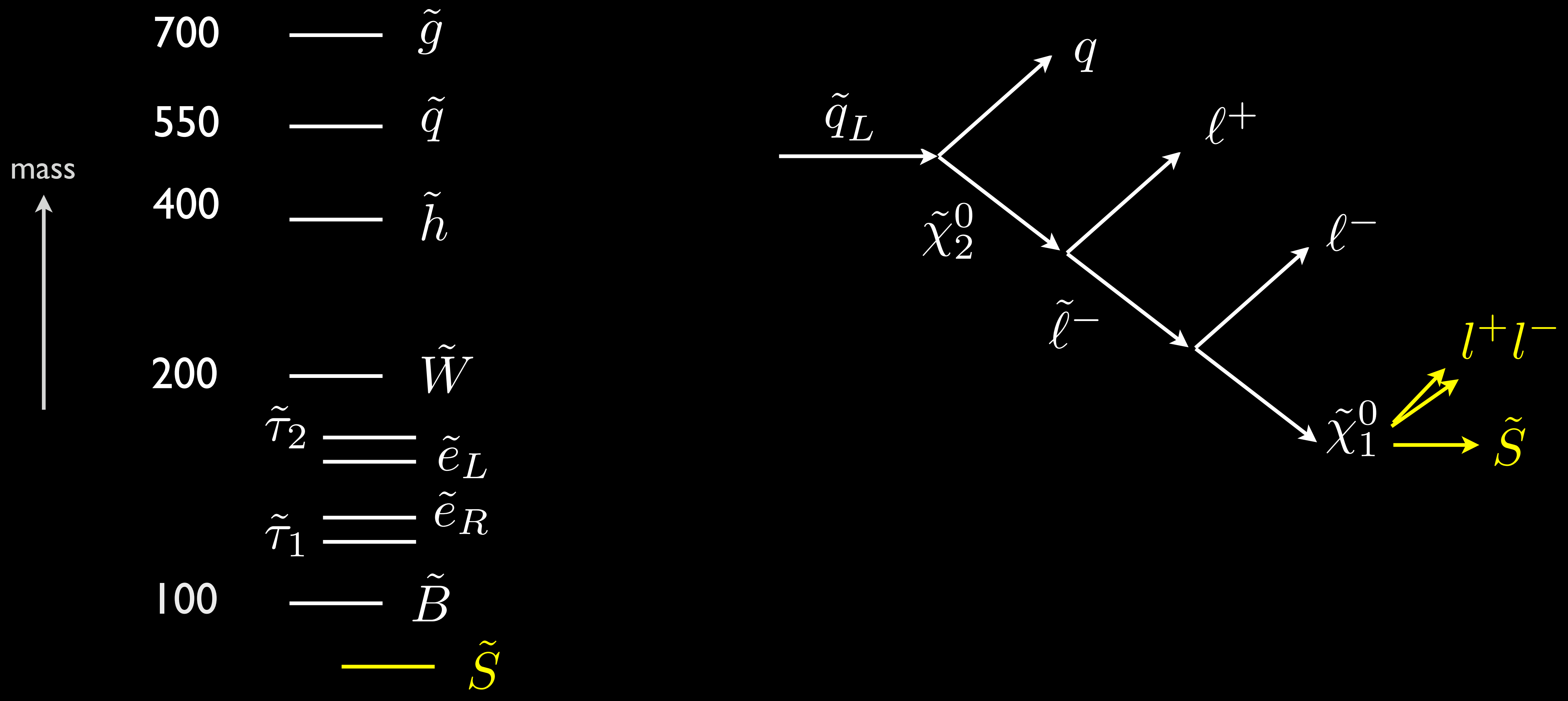


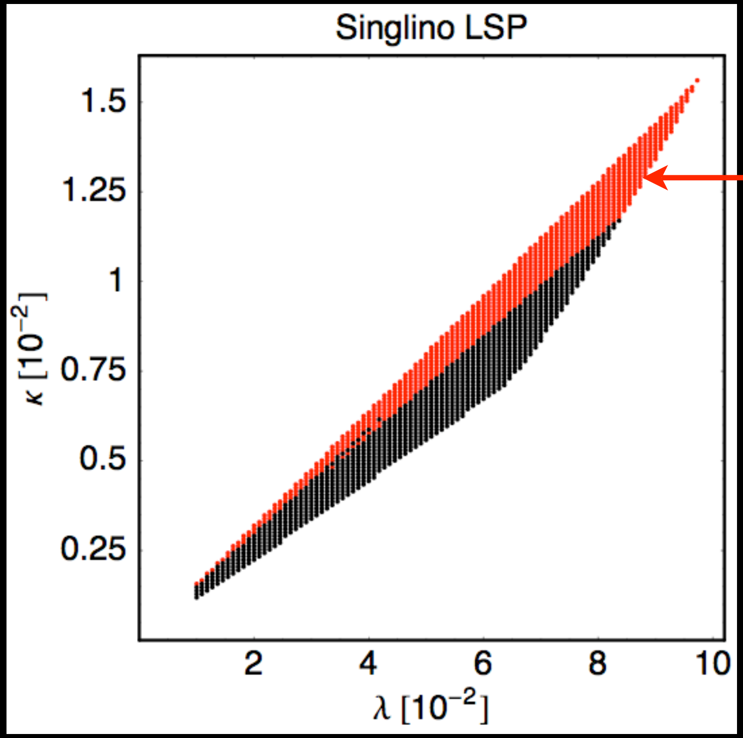
now supplement this by a NMSSM singlino LSP

Parameter space

- normal MSSM part:

Parameter	M_1	M_2	M_3	$\mu_{\rm eff}$	$M_{\tilde{L}_{1,3}}$	$M_{\tilde{E}_1}$	$M_{\tilde{E}_3}$	$M_{\tilde{Q}_1}$	$M_{\tilde{U}_1}$	$M_{\tilde{D}_1}$	$M_{\tilde{Q}_3}$	$M_{\tilde{U}_3}$	$M_{\tilde{D}_3}$
Value [GeV]	120	240	720	360	195	136	133	544	526	524	496	420	521

- scan over NMSSM parameters to obtain singlino LSP



relic density: $\Omega h^2 < 0.135$

$$\lambda \sim 0.01 - 0.1$$
$$\kappa \sim 0.1\lambda$$

[NMSSMTools]

SPS1a-like benchmark points with a singlino LSP

- normal MSSM part:

Particle	$\tilde{\chi}_2^0$	$\tilde{\tau}_1$	$\tilde{e}_R$	$\tilde{e}_L$	$\tilde{\tau}_2$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{\chi}_5^0$	$\tilde{t}_1$	$\tilde{q}_{L,R}$	$\tilde{g}$
Mass [GeV]	115	132	143	201	205	222	365	390	397	550–570	721

- in addition:

Point	$\lambda\,[10^{-2}]$	$\kappa\,[10^{-3}]$	A_λ	A_κ	$m_{\tilde{\chi}_1^0}$	m_{A_1}	m_{A_2}	m_{S_1}	Ωh^2	$\Gamma(\tilde{\chi}_2^0)$
A	1.49	2.19	−37.4	−49.0	105.4	88	239	89	0.101	7×10^{-11}
B	1.12	1.75	−42.4	−33.6	112.1	75	226	100	0.094	9×10^{-13}
C	1.20	1.90	−39.2	−53.1	113.8	95	256	97	0.094	1×10^{-13}
D	1.47	2.34	−39.2	−68.9	114.5	109	259	92	0.112	4×10^{-14}
E	1.22	1.95	−44.8	−59.1	114.8	101	219	96	0.096	8×10^{-15}

NMSSMTools

- conventional cascade decays into the bino, then $\tilde{B} \to l^+ l^- \tilde{S}$

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note small mass difference of 10 to 0.2 GeV

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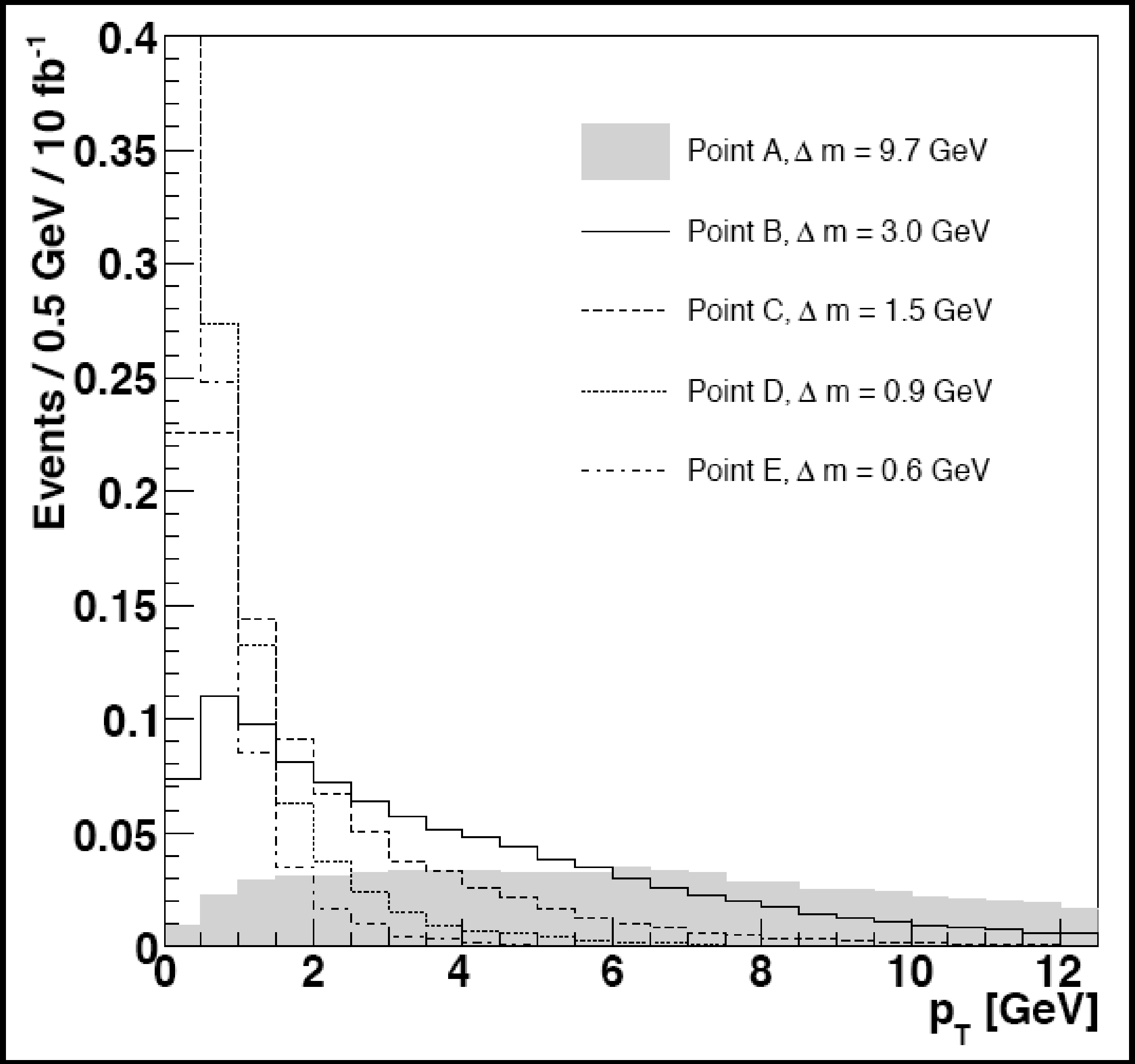
Soft leptons in LHC cascade decays



p_T distributions for leptons from the decay $\tilde{\chi}_2^0 \rightarrow l^+ l^- \tilde{\chi}_1^0$

(normalized to 1)

Monte Carlo analysis

- 10 fb^{-1} for each benchmark point.
- SUSY signal generated with PYTHIA 6.413.
- SM backgrounds: HERWIG 6.510 interfaced to ALPGEN 2.13 for prod. of high jet multiplicities and JIMMY 4.31 for multiple int's.
- AcerDET-1.0 for a fast simulation of a generic LHC detector.

Standard cuts for SUSY analysis

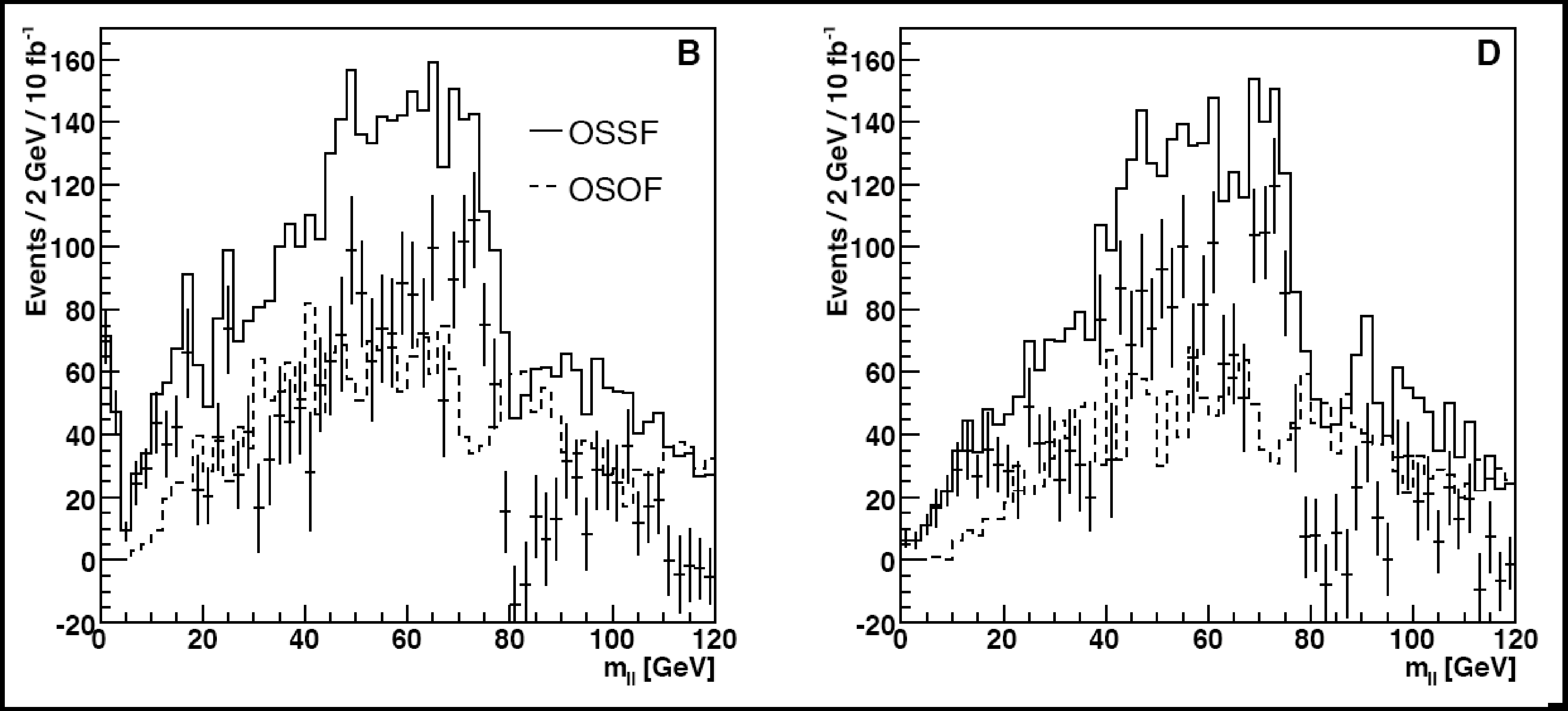
- Require at least three jets with p_T > 150, 100, 50 GeV.
- Require missing transverse energy $\not{E}_T > \max(100\ \mathrm{GeV}, 0.2 M_{\mathrm{eff}})$
- Require two opposite-sign same-flavour (OSSF) leptons with p_T > 20, 10 GeV.

NB: Efficiencies+resolutions from G. Aad et al., ATLAS Collab., JINST 2008

Standard lepton p_T cuts

(p_T > 20, 10 GeV)

ΔM = 3 GeV ΔM = 0.9 GeV



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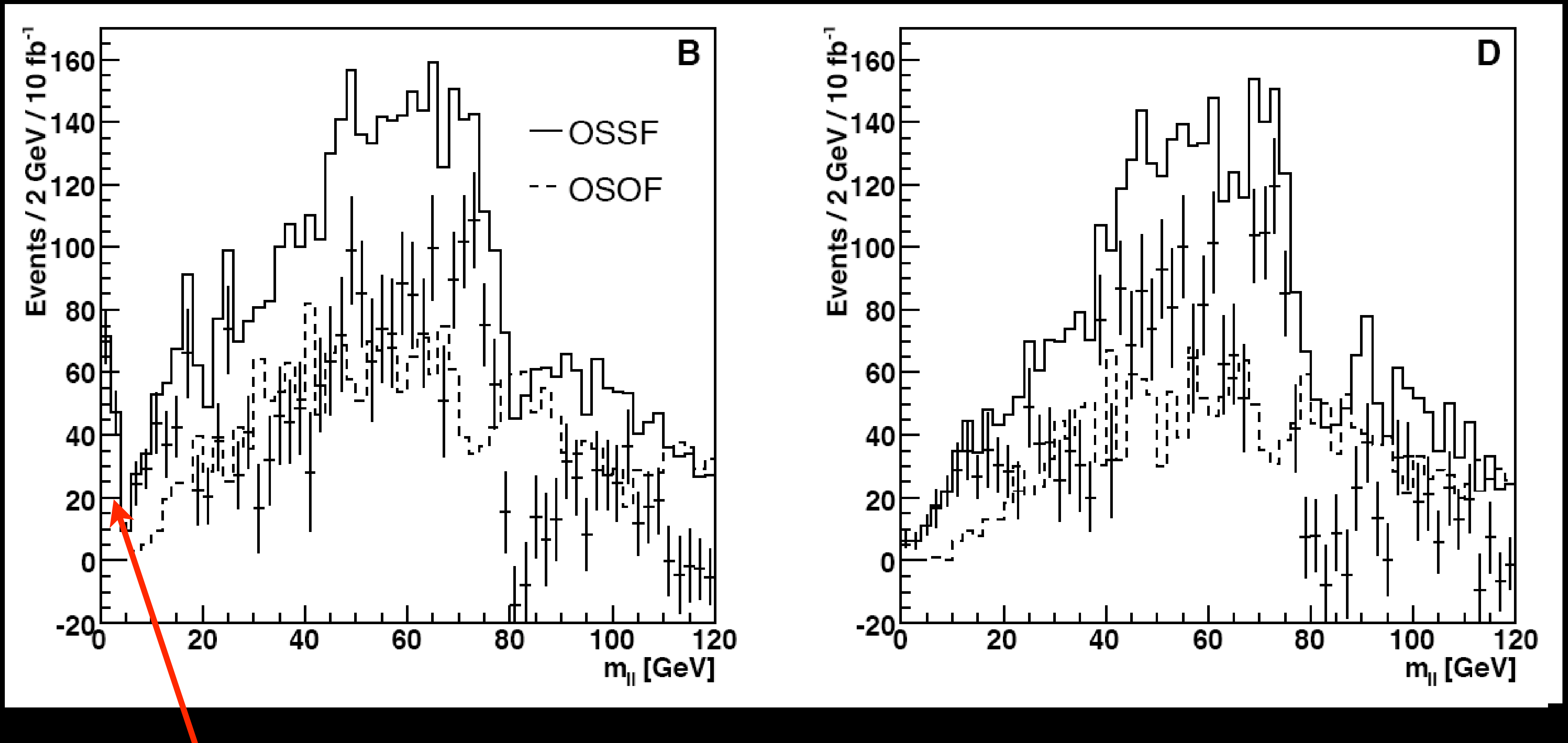

this is the singlino signal

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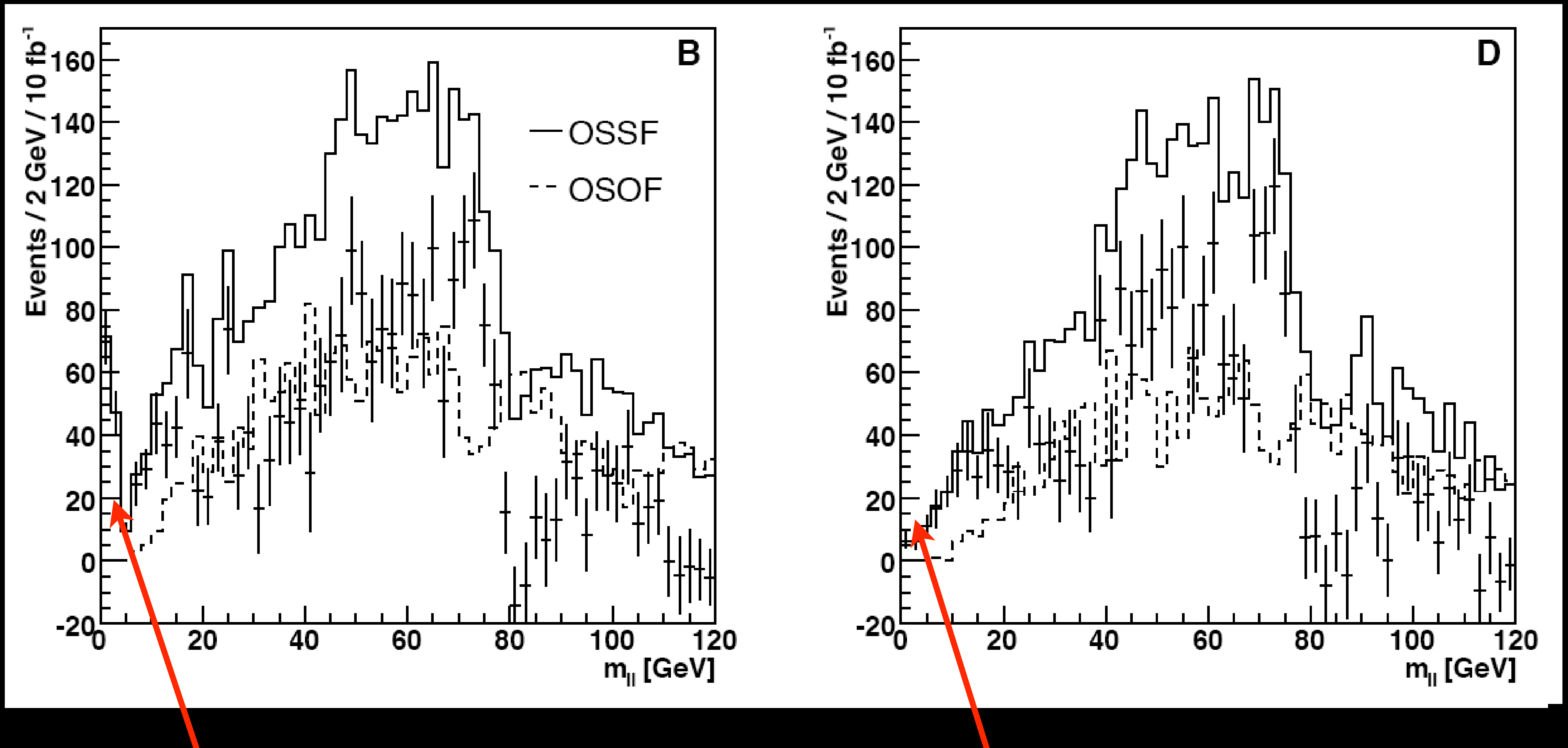
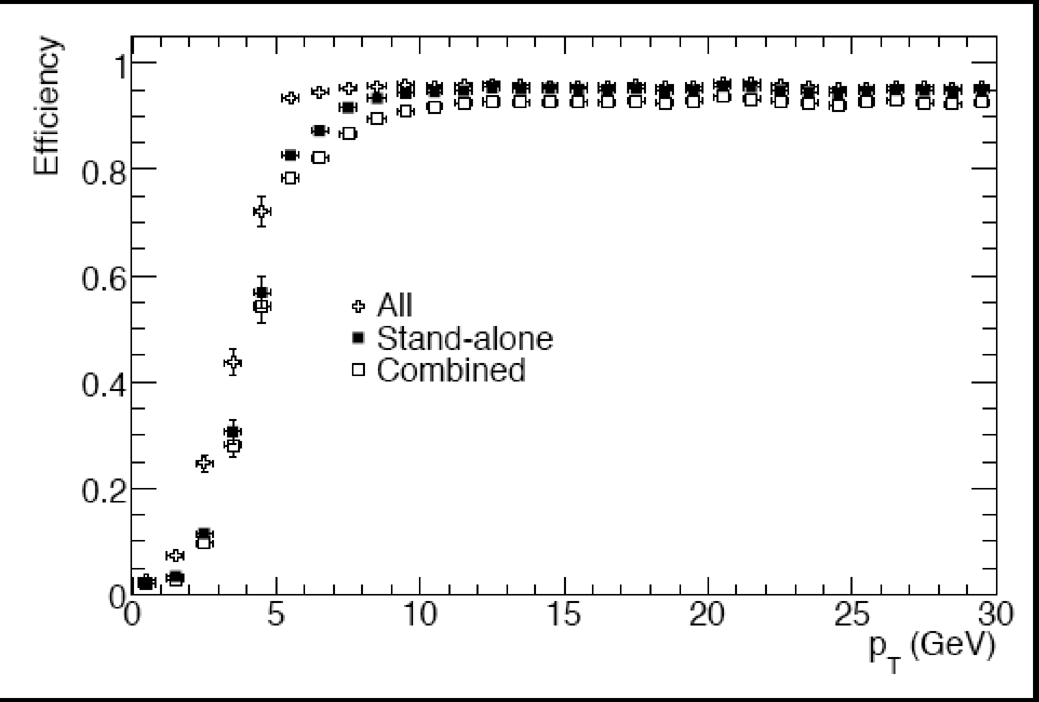


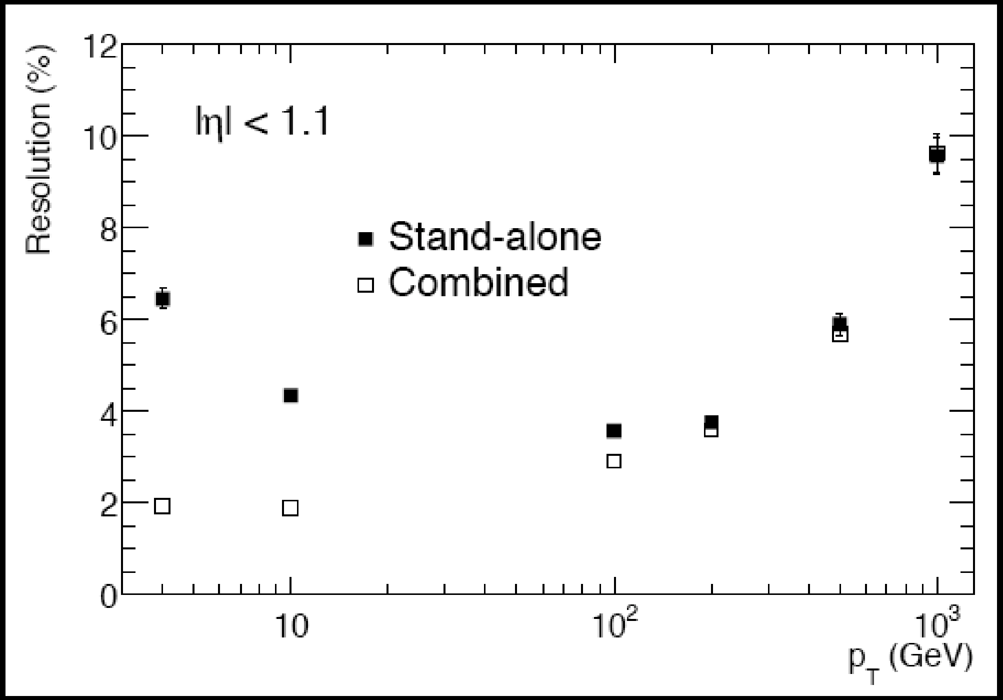
this is the singlino signal

here the singlino is lost!
want to lower lepton p_T cut

How low can we go?

- Take realistic lepton efficiencies & resolutions from ATLAS:
  G. Aad et al., Journal of Instrumentation 3, S08003 (2008)



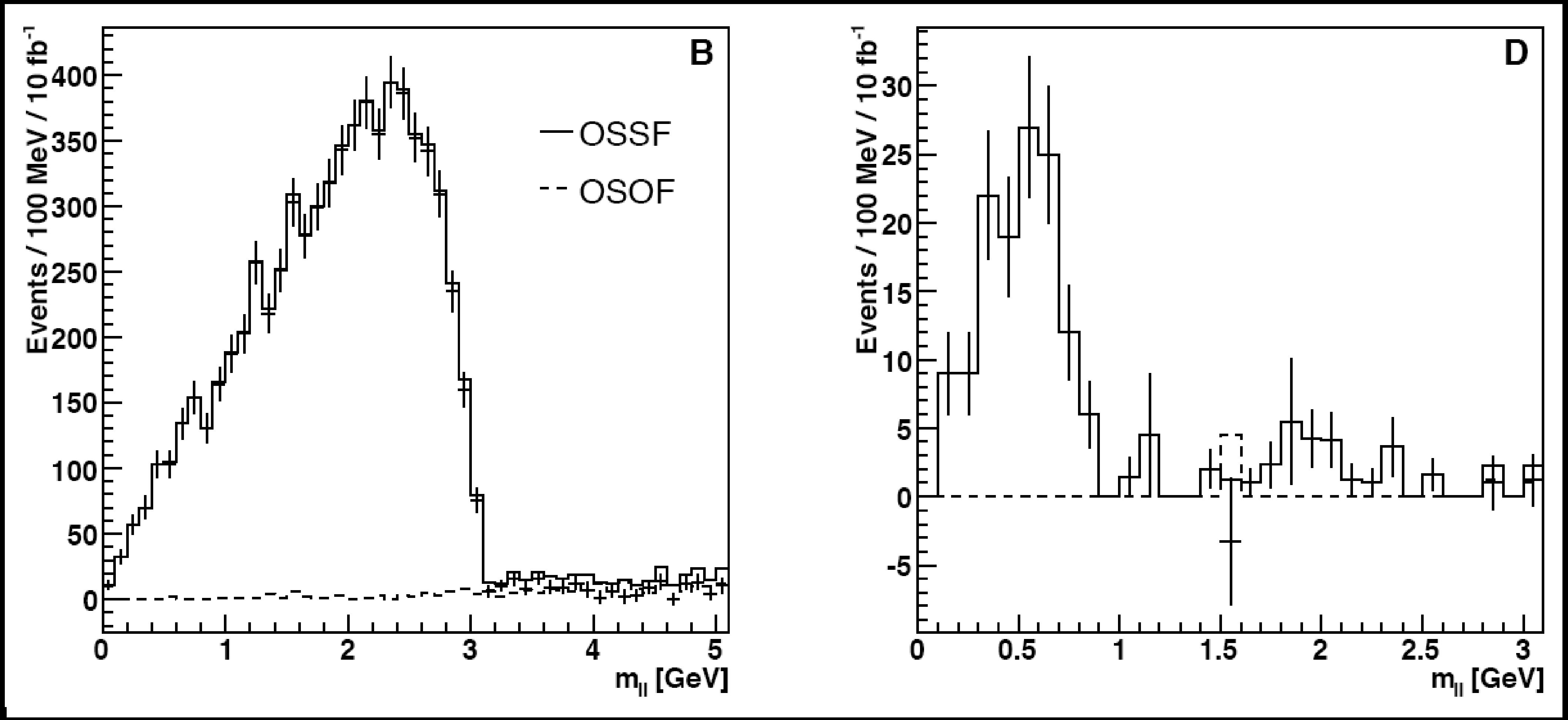


Ex: Efficiency for reconstructing muons (left) and fractional momentum resolution (right)

Lowering lepton p_T cuts to 2 GeV

ΔM = 3 GeV

ΔM = 0.9 GeV



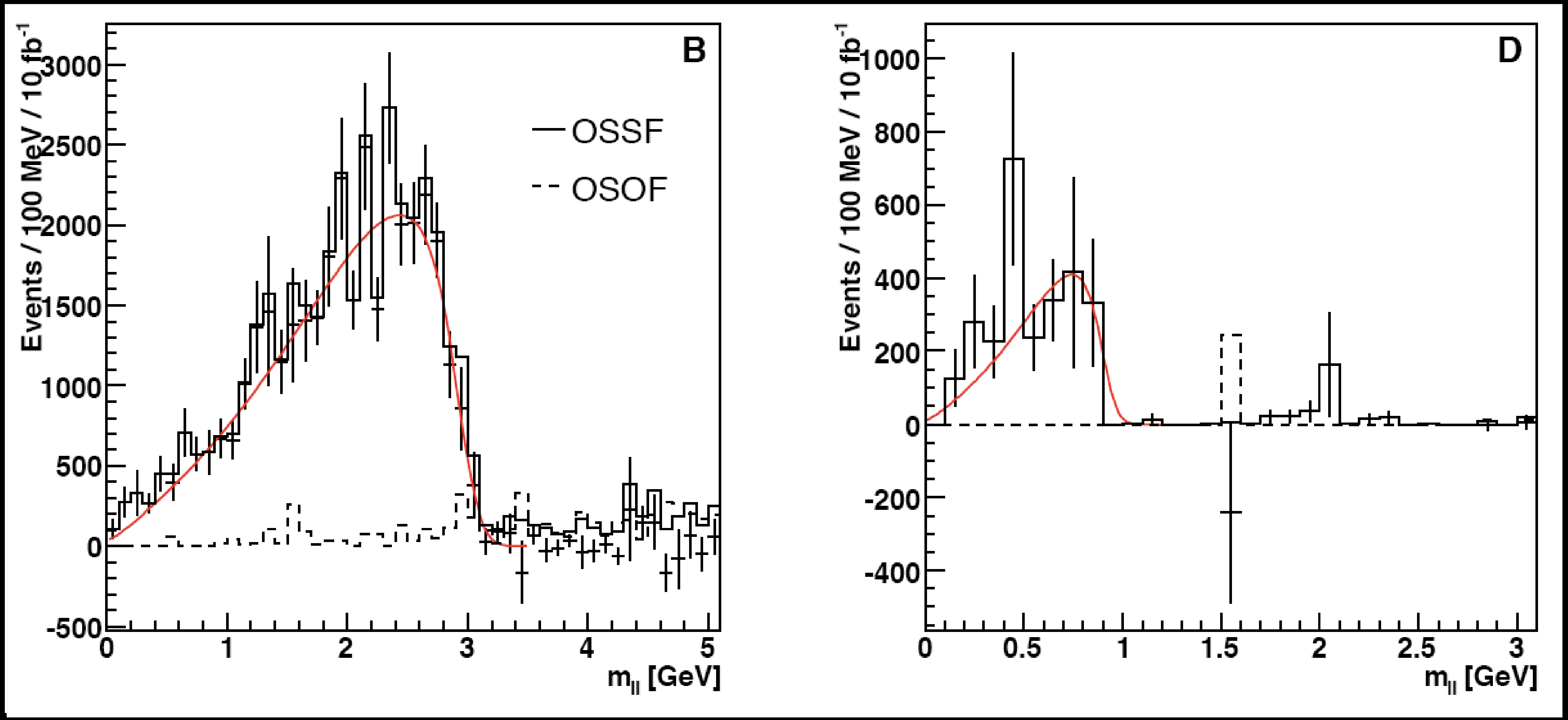
Very good precision on kinematic endpoint.

$$m_{ll}^{max} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$

After re-weighting with lepton efficiencies

ΔM = 3 GeV

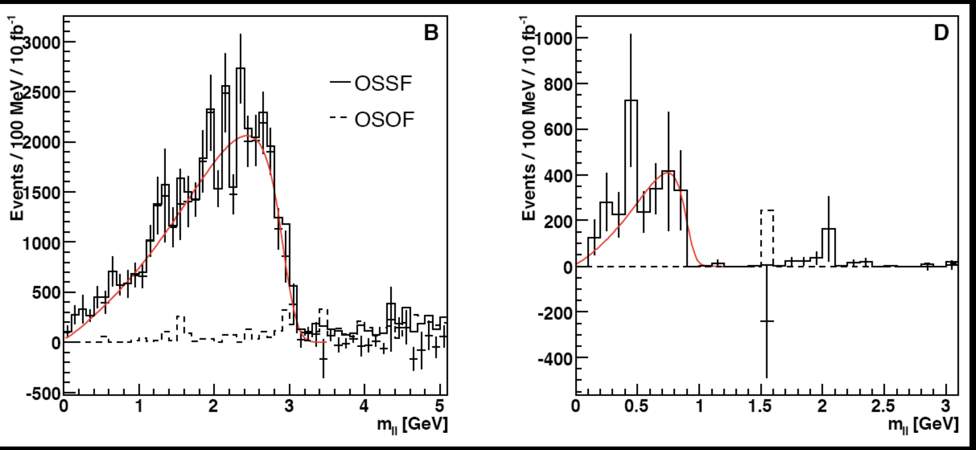
ΔM = 0.9 GeV



Very good precision on kinematic endpoint.
Red line: fit to full m_{ll} distribution

Mass constraints

ΔM = 3 GeV　　　　ΔM = 0.9 GeV



$$m_{ll}^{max} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$

Fit to m_{ll} distribution using full matrix of Bartl, Fraas Majerotto, 1986

Benchmark point	A	B	C	D
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	9.77 ± 0.03	2.98 ± 0.02	1.39 ± 0.03	0.92 ± 0.02
$m_{\tilde{l}} - m_{\tilde{\chi}_1^0}$	46.5 ± 12.7	52.7 ± 21.9	69.0 ± 53.6	57.2 ± 95.8
χ^2/ndf	1.20	1.29	2.06	0.90

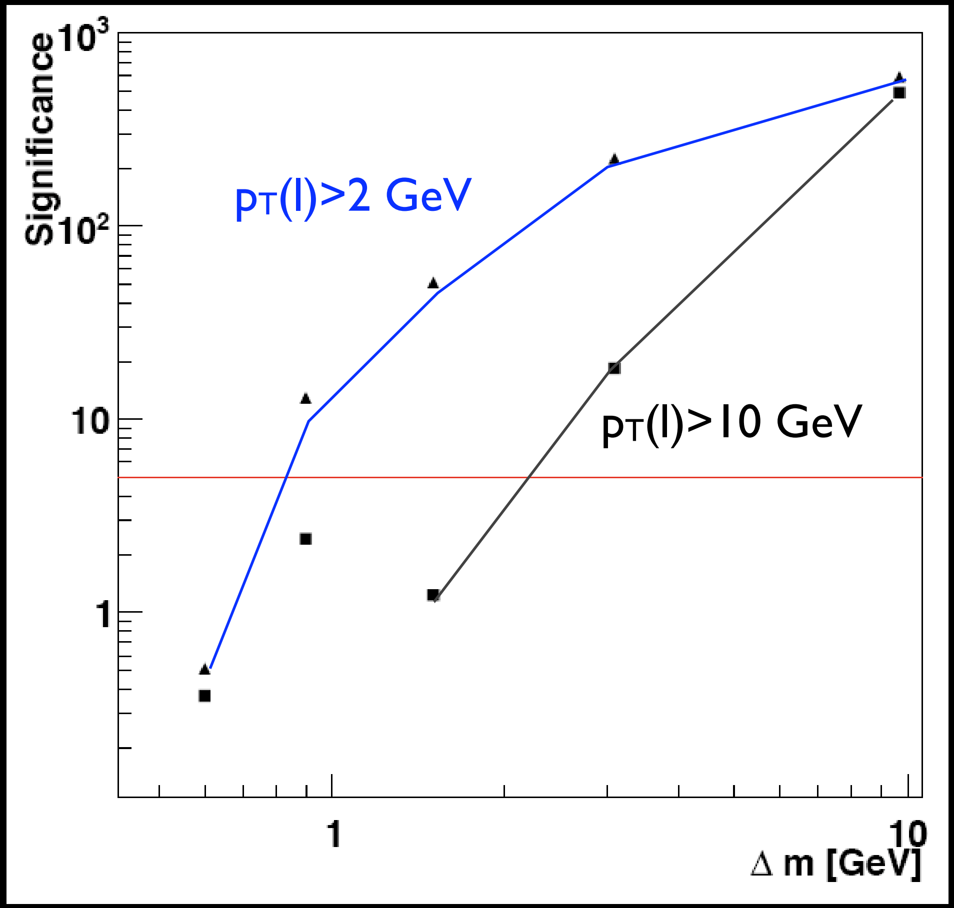
Can determine bino-singlino mass difference to ~30 MeV acurracy!

Conclusions

- Considered a SPS1a-like NMSSM scenario with a singlino LSP; characterized by small bino-singlino mass difference.
- Virtually all SUSY events contain two decays $\tilde{B} \to l^+ l^- \tilde{S}$ leading to soft OSSF di-leptons.
- With standard lepton p_T requirements, lower edge in the di-lepton invariant mass distribution visible down to ΔM~3 GeV. For smaller mass differences need to lower cuts.
- Very good determination of bino-singlino mass difference possible.
- Lower edge in the di-lepton distribution may appear much earlier than that of the `standard' wino→bino decay.
- May even be an early discovery channel for SUSY

-- provided that the soft leptons are searched for

Signal significance



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