Probing bino NLSP at lepton colliders

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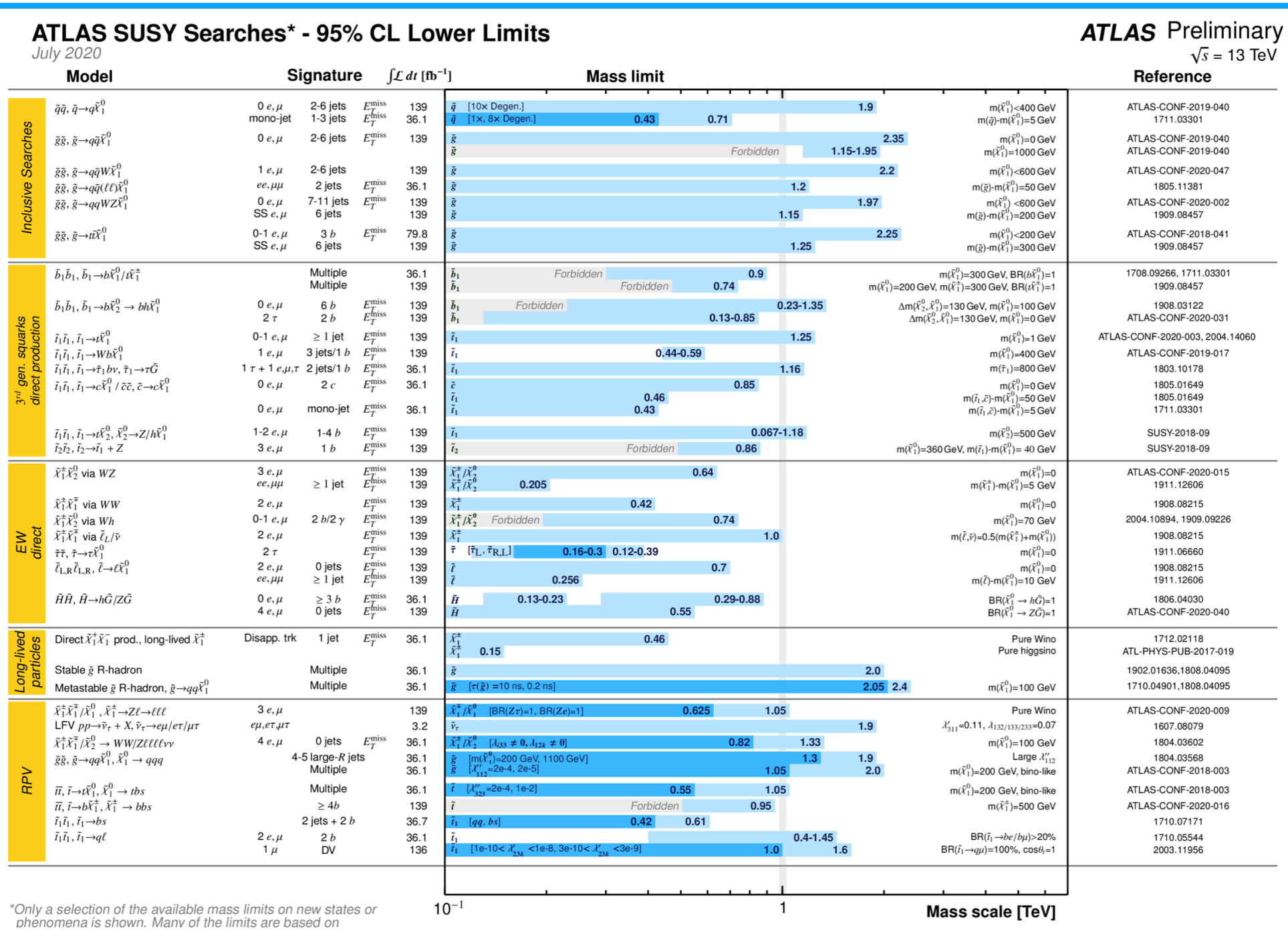
Why SUSY?

- Naturalness problem

- Unification of gauge couplings

- dark matter candidate

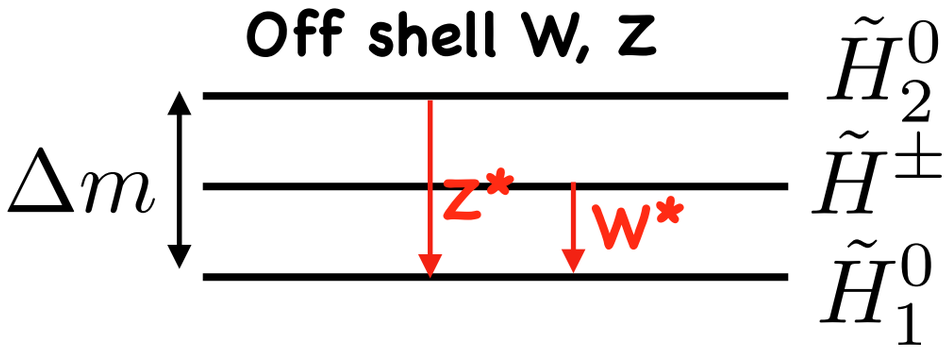
LHC searches

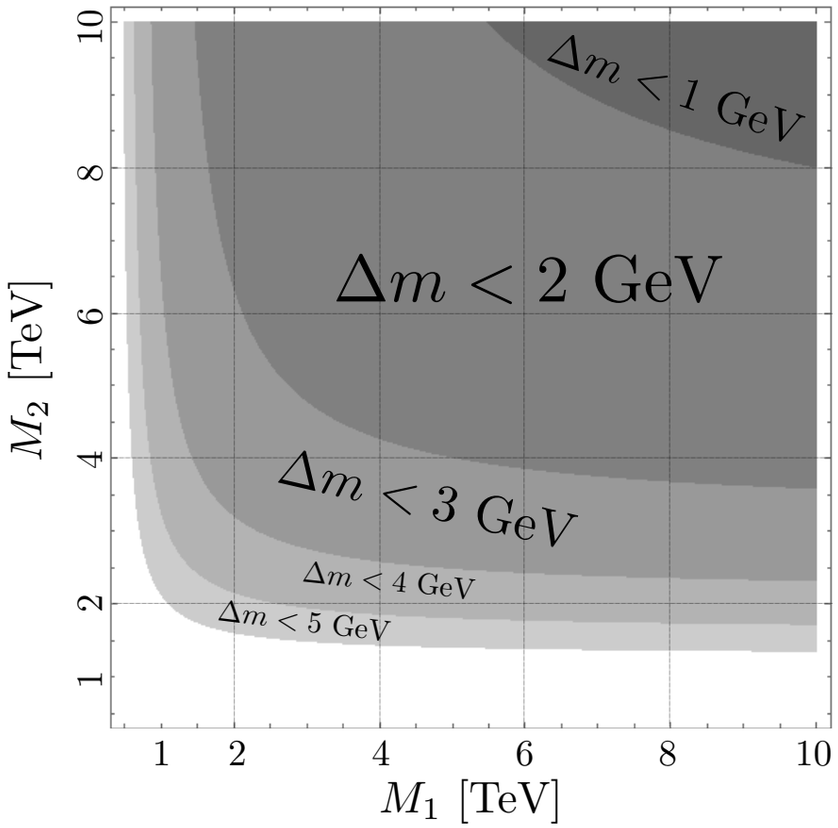


squark 1-2TeV, electroweakino and slepton few hundred GeV

Electroweakino

Higgsino



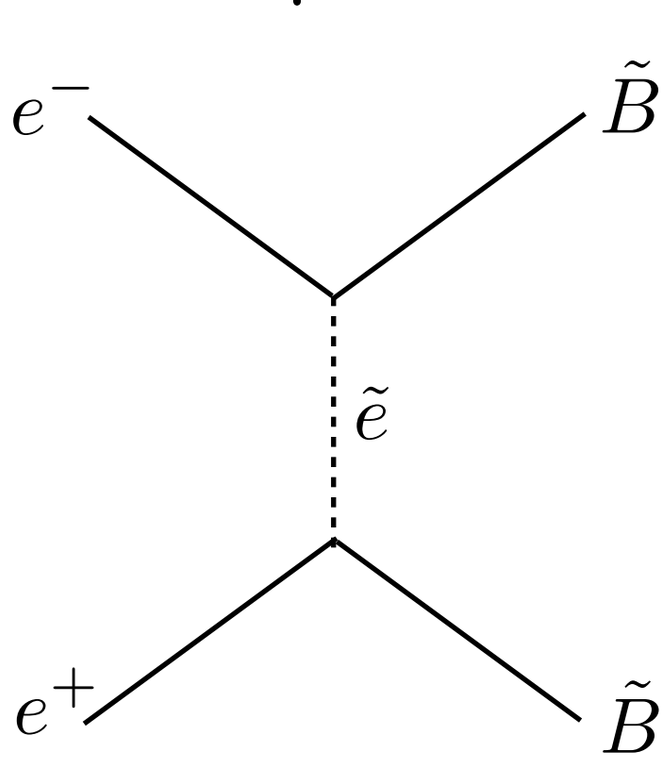


LEP limit around hundred GeV for chargino searches

Only one SUSY partner could be light

Names	spin 1/2	spin 1	$SU(3)_C,\ SU(2)_L,\ U(1)_Y$
gluino, gluon	$\widetilde{g}$	g	$(\mathbf{8},\ \mathbf{1}\ ,\ 0)$
winos, W bosons	$\widetilde{W}^{\pm}\ \ \widetilde{W}^{0}$	$W^{\pm}\ \ W^{0}$	$(\mathbf{1},\ \mathbf{3}\ ,\ 0)$
bino, B boson	$\widetilde{B}^{0}$	B^{0}	$(\mathbf{1},\ \mathbf{1}\ ,\ 0)$

Can be pair produced at lepton collider



Good opportunity at lepton colliders for light bino

Bino LSP(DM candidate)

- Bino dark matter is over-abundant due to small annihilation cross section(assume squark/ slepton heavy)

- Co-annihilation: can not be too light and constraint from dark matter direct searches

Bino NLSP

LSP candiate:

Gravitino: spin 3/2, supersymmetric partner of graviton

$$m_{3/2} \sim \frac{F}{m_{pl}}$$

Could be very light for low SUSY breaking models

Axino: supersymmetric partner of axion

Singlino: NMSSM, supersymmetric partner of singlet

Bino NLSP

Bino decay

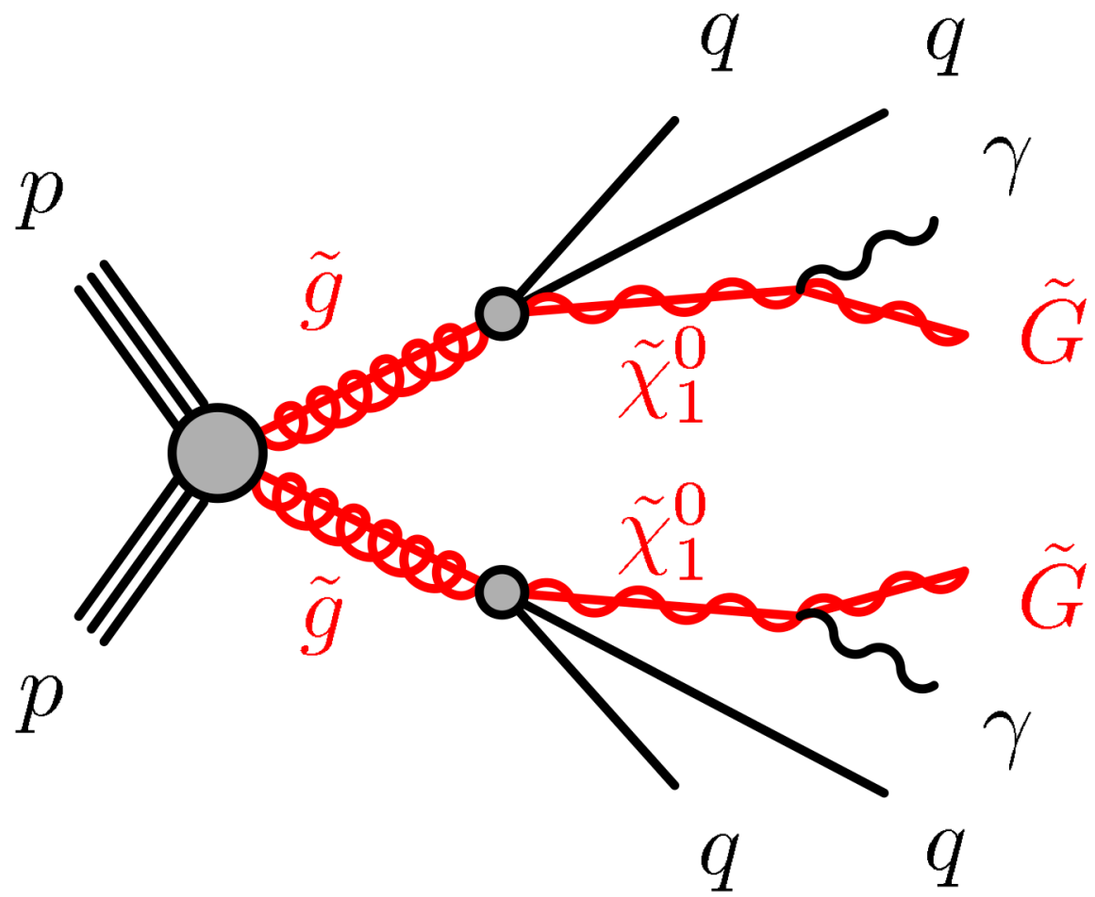
$$\tilde{B} \to \tilde{G} + h/Z/\gamma$$

Bino mass around or less than hundred GeV

Photon channel dominates

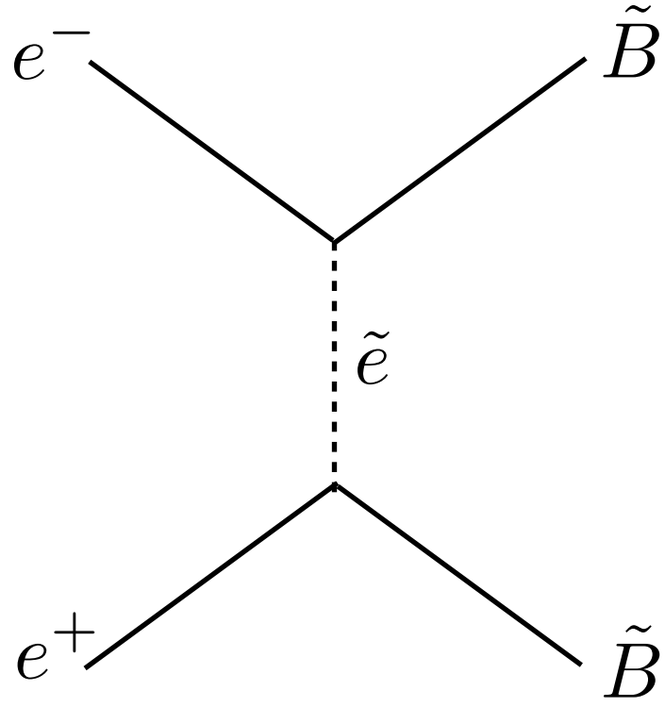
Similar searches at LHC

Search for supersymmetry in a final state containing two photons and missing transverse momentum in $\sqrt{s}$ = 13 TeV pp collisions at the LHC using the ATLAS detector



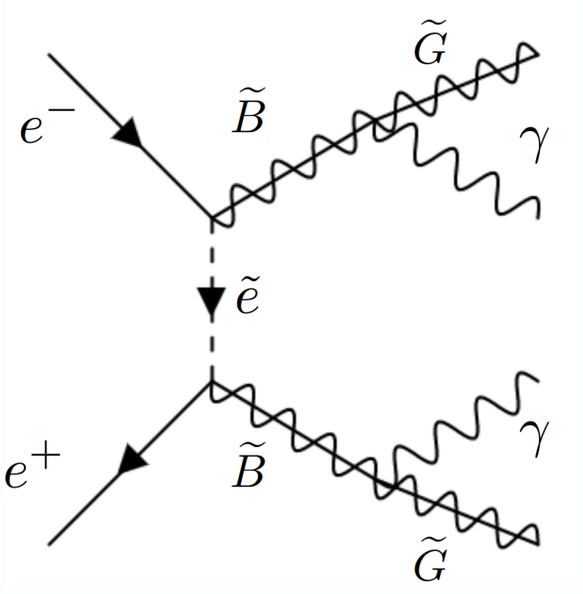
Large production due to gluino

Bino production

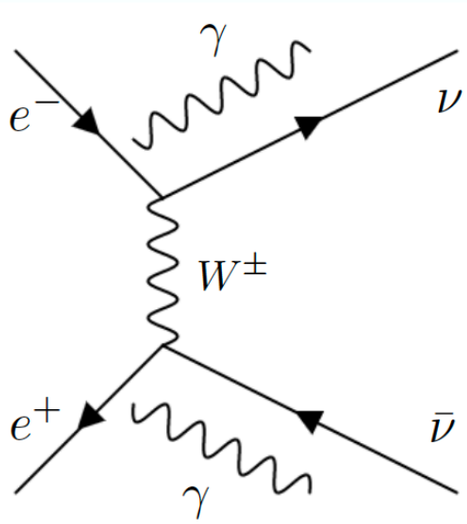


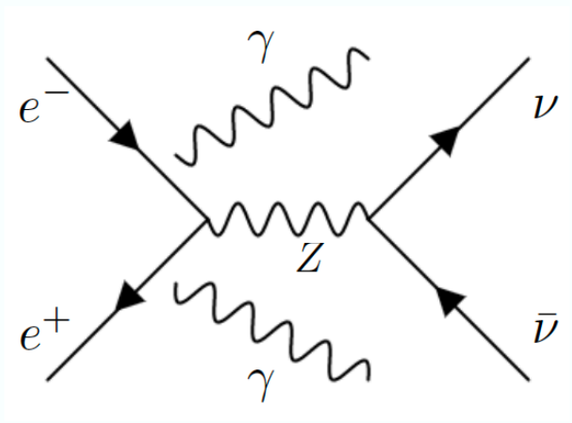
$$\sigma_{\rm tot}(e^+e^- \to \tilde{B}\tilde{B}) \approx \frac{g_1^4}{48\pi}\left(Y_{e_L}^4 + Y_{e_R}^4\right)\frac{s}{m_{\tilde{e}}^4}\left[1-\left(\frac{2m_{\tilde{B}}}{s}\right)^2\right]^{3/2}$$

Signature



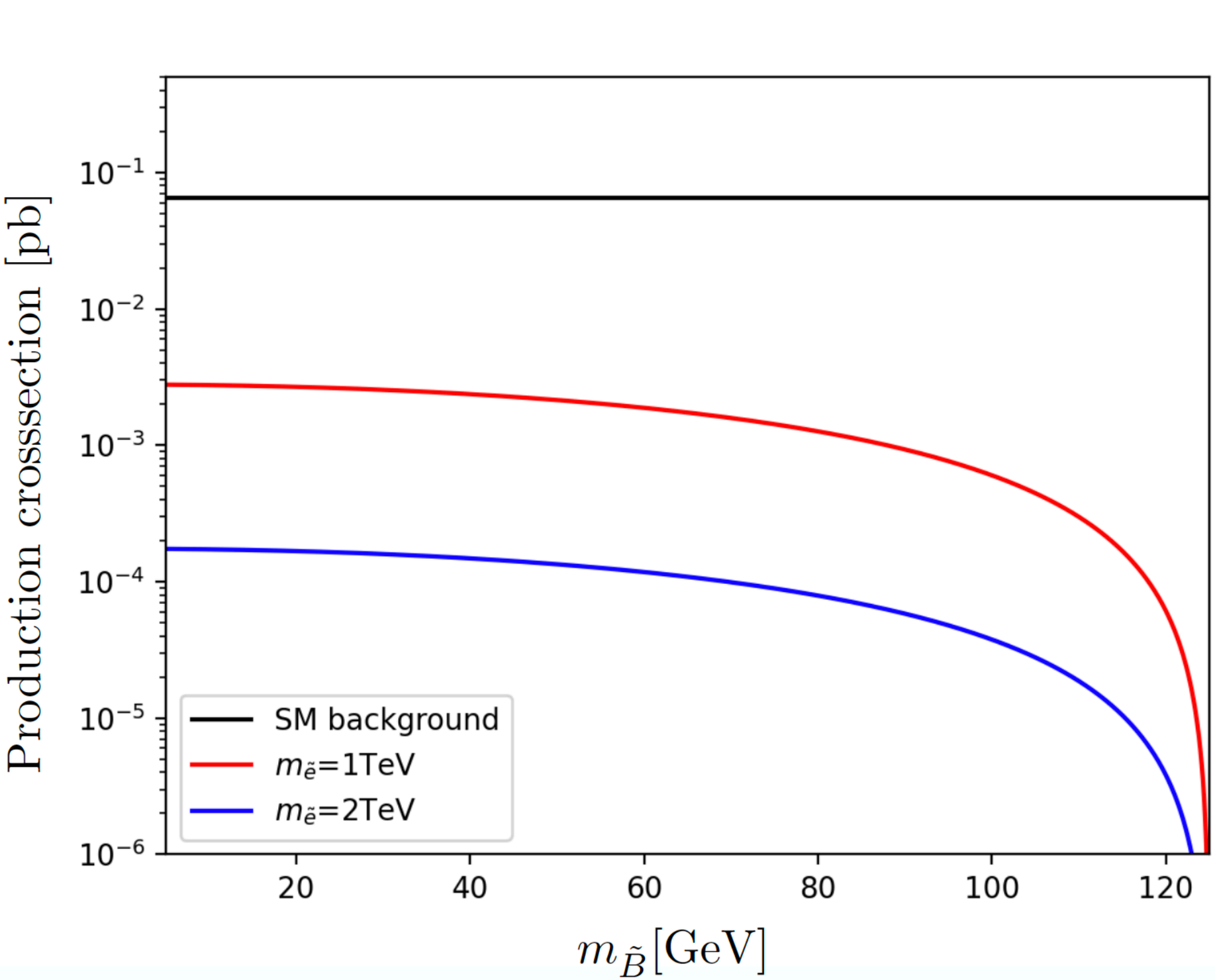
2 gamma+ missing energy





Backgrounds

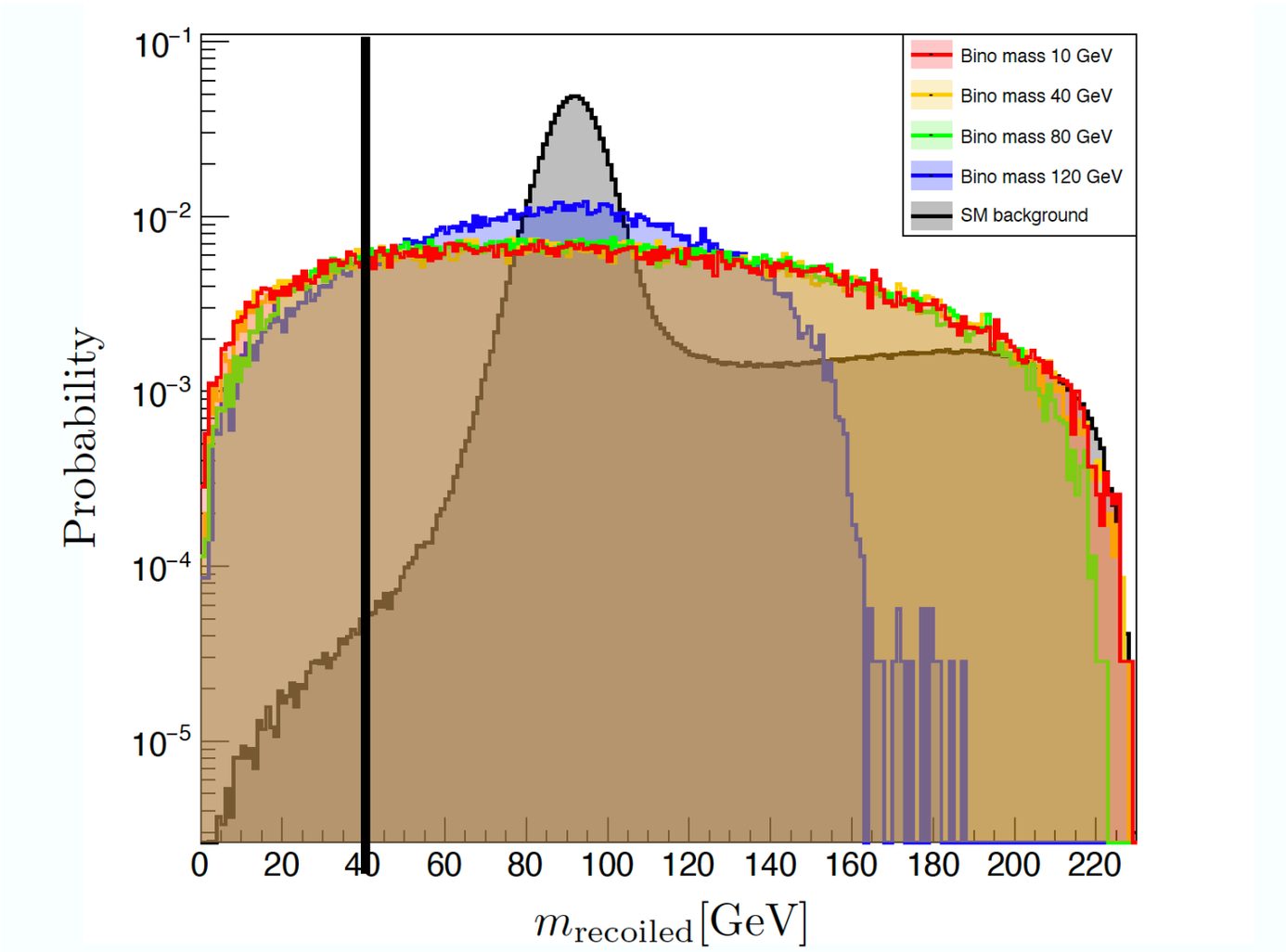
Bg vs signal


Production crosssection [pb]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
SM background
$m_{\tilde{e}}$=1TeV
$m_{\tilde{e}}$=2TeV
20
40
60
80
100
120
$m_{\tilde{B}}$[GeV]

Variable-1: recoiled mass

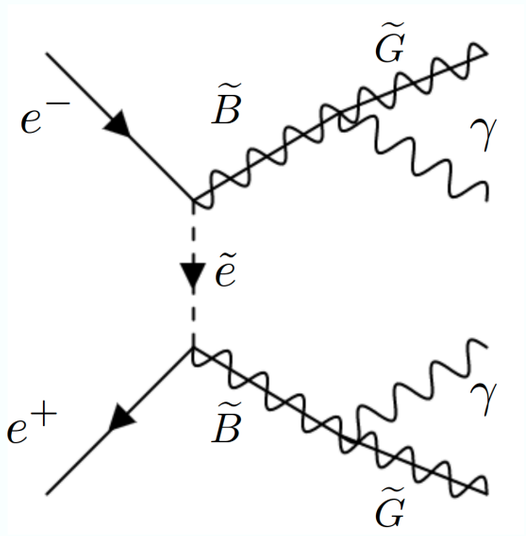
$$(\sqrt{s},0,0,0) = p^{\gamma 1} + p^{\gamma 2} + \not{p}$$

$$m_{\mathrm{rec}} = \sqrt{((\sqrt{s},0,0,0) - p^{\gamma 1} - p^{\gamma 2})^2}$$

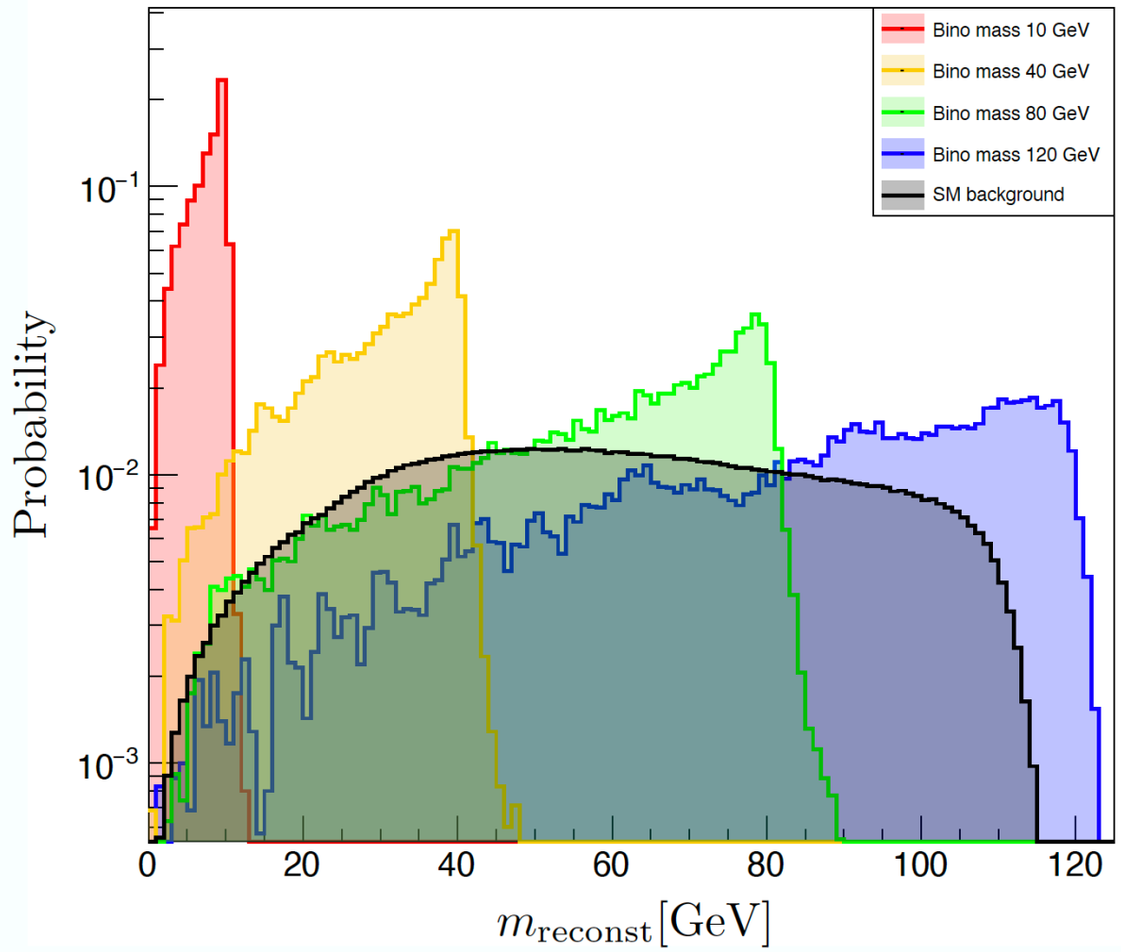


Z-peak in Bg

Variable-2: reconstructed mass



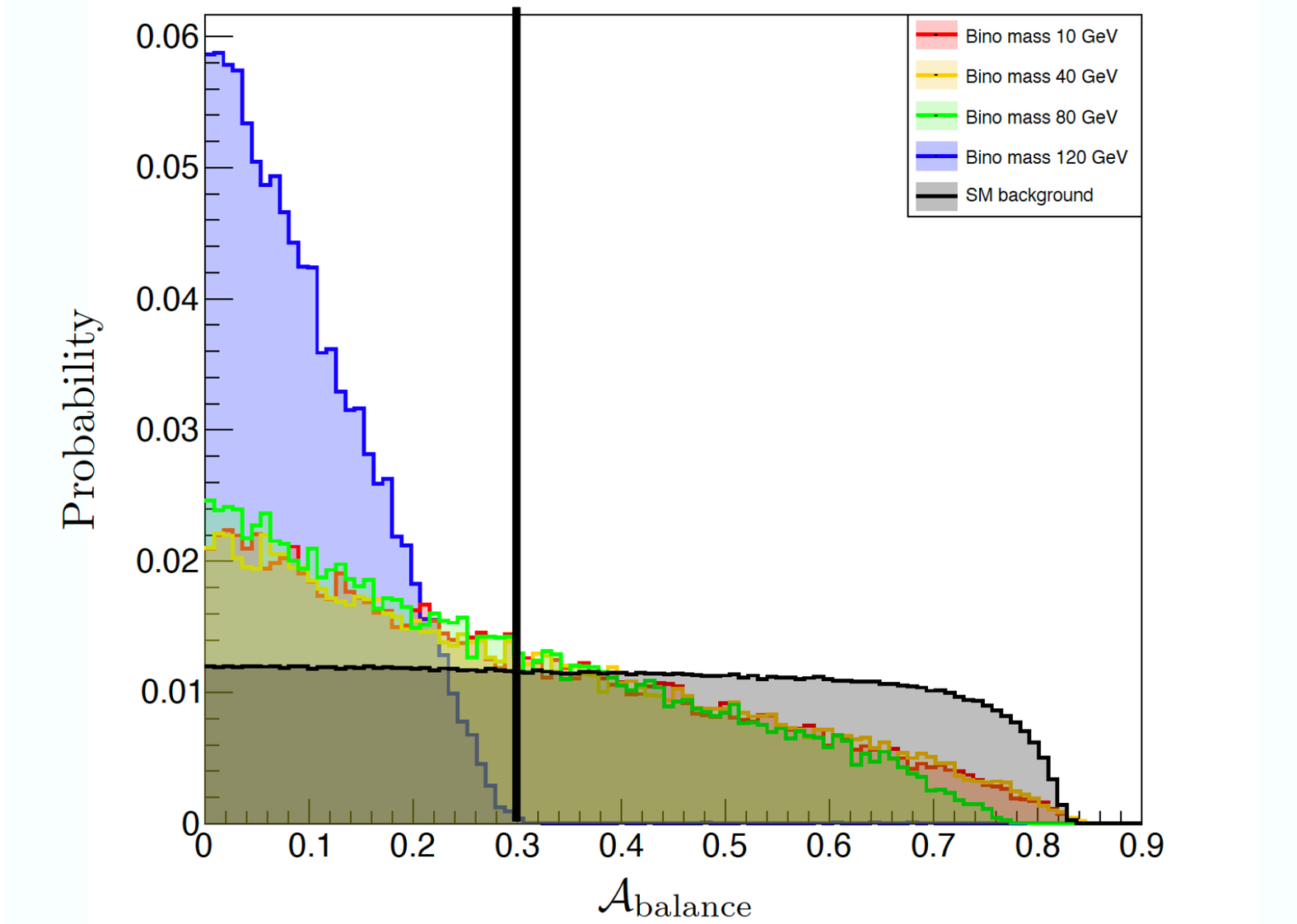
2 missing energy:
still possible to reconstruct mass
see the paper for details



$$m_{\tilde{B}} - 10\ \mathrm{GeV} \leqslant m_{\mathrm{reconst}} \leqslant m_{\tilde{B}} + 3\ \mathrm{GeV}$$

Variable-3: energy balance

$$\mathcal{A}_{\text{balance}} = \frac{|E^{\gamma 1} - E^{\gamma 2}|}{|E^{\gamma 1} + E^{\gamma 2}|}$$

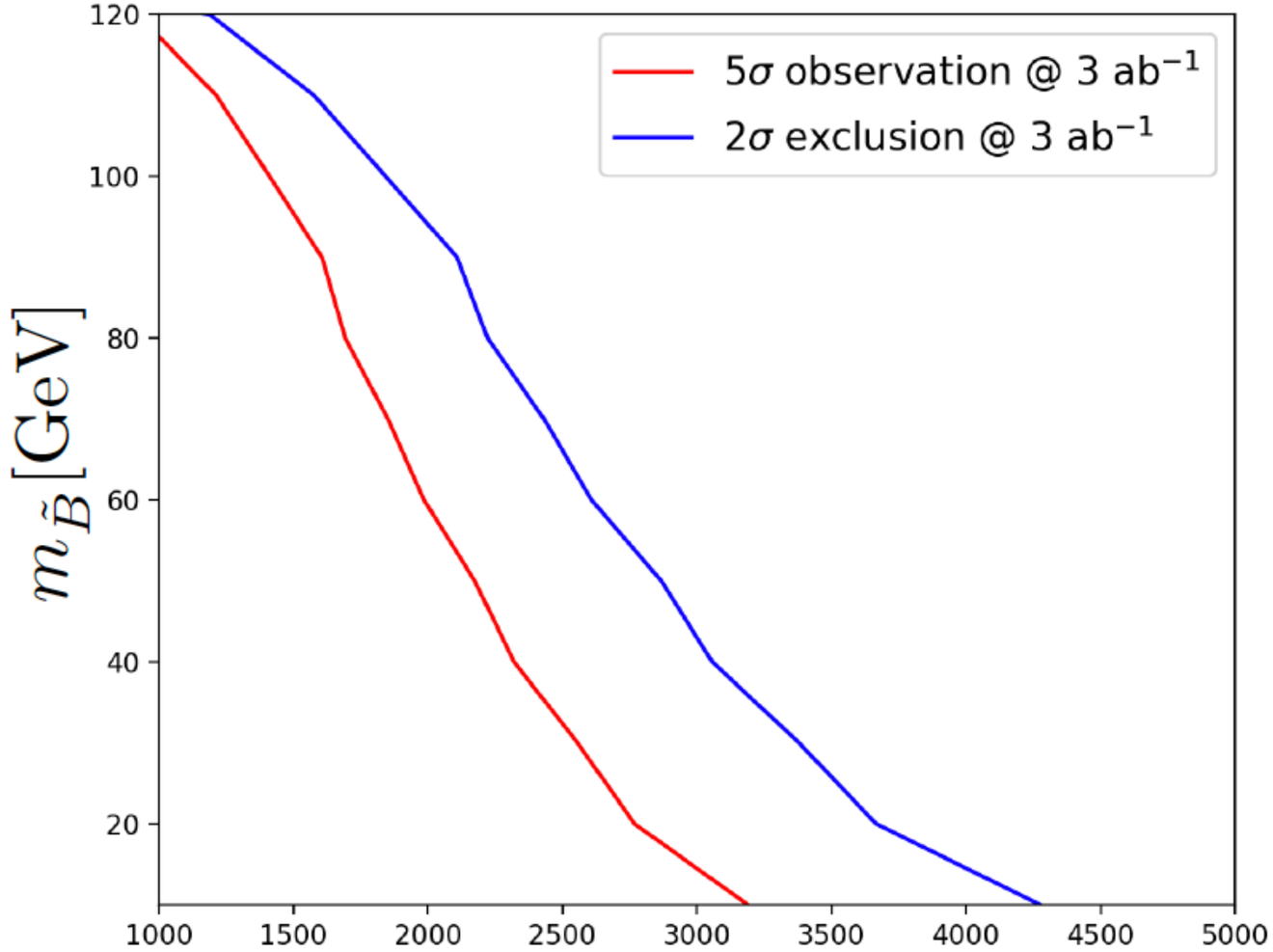


Cut-flow

Assuming 3 ab-1, slepton 1 TeV

	BKG	$m_{\tilde{B}}$=10 GeV	$m_{\tilde{B}}$=40 GeV	$m_{\tilde{B}}$=80 GeV	$m_{\tilde{B}}$=120 GeV
photon $p_{\mathrm{T}} > 10$ GeV	194,100	6,193	5,539	3,458	173
$m_{\mathrm{recoiled}} < 40$ GeV	147	912	785	439	18.6
$\mathcal{A}_{\mathrm{balance}} < 0.3$	40.4	661	553	317	18.6
$m_{\mathrm{reconst}} \in [0, 13]$ GeV	1.1	651	-	-	-
$m_{\mathrm{reconst}} \in [30, 43]$ GeV	2.8	-	269	-	-
$m_{\mathrm{reconst}} \in [70, 83]$ GeV	3.5	-	-	96.8	-
$m_{\mathrm{reconst}} \in [110, 123]$ GeV	13.1	-	-	-	14.8
$\mathcal{S}/\mathcal{B}$	-	633.2	96.6	27.7	1.13
Significance	-	83.8	44.1	21.9	3.5

Sensitivity

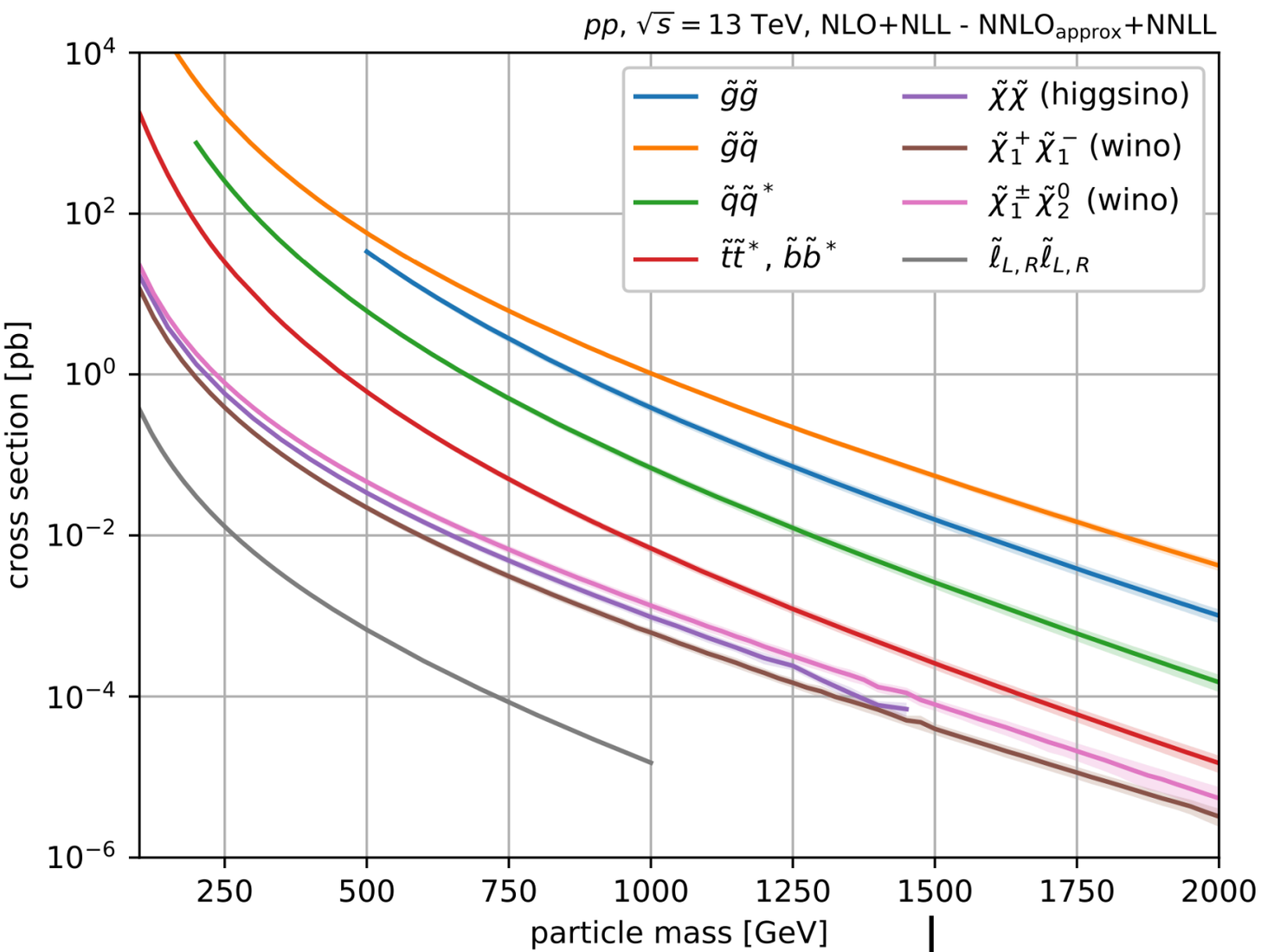


For 3 ab-1, bino mass 100 GeV, around 1.5 TeV 5sigma (2 TeV 2sigma)

For 3 ab-1, bino mass 20 GeV, around 3 TeV 5sigma (4 TeV 2sigma)

Comparing with LHC slepton direct searches

NLO-NLL $\tilde{\ell}^+_{L,R}\tilde{\ell}^-_{L,R}$: any single generation, sum of left- and right-handed sleptons



300	0.006254	-2.1 %	2.3 %
320	0.004802	-2.2 %	2.3 %
340	0.003732	-2.3 %	2.5 %
360	0.002931	-2.5 %	2.6 %
380	0.002325	-2.6 %	2.8 %
400	0.001859	-2.8 %	2.9 %
440	0.001216	-3.0 %	3.1 %
500	0.0006736	-3.2 %	3.3 %
600	0.0002763	-3.6 %	3.6 %
700	0.0001235	-3.8 %	3.8 %
800	5.863e-05	-4.2 %	4.2 %
900	2.918e-05	-4.6 %	4.6 %
1000	1.504e-05	-5.2 %	5.1 %

0.5*10-6 pb

LHC 3 ab-1, at most 1.5 TeV

Summary

- The only SM partner which could be light is Bino
- A light Bino prefers to be NLSP, not LSP
- Lepton collider is not only precision machine, but also a discovery machine. It can be much beyond LHC reach in some cases.