Signal optimization of sbottom pair productions using MC simulations of $\sqrt{s} = 13 \div 14\, TeV$ pp collisions at ATLAS detector at LHC

Particle and Astroparticle Physics Autumn Programme

Marco Aparo

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Introduction: SM Issues

- **Some SM unsolved questions:**

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  - ✗ Coupling constants unification

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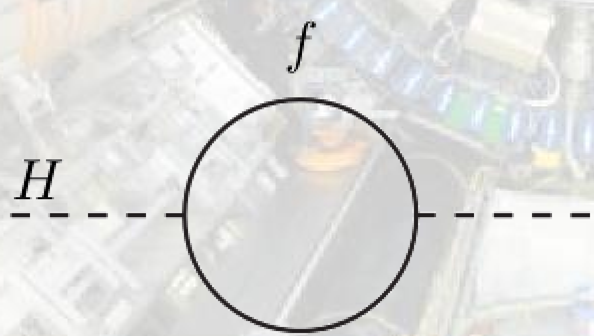
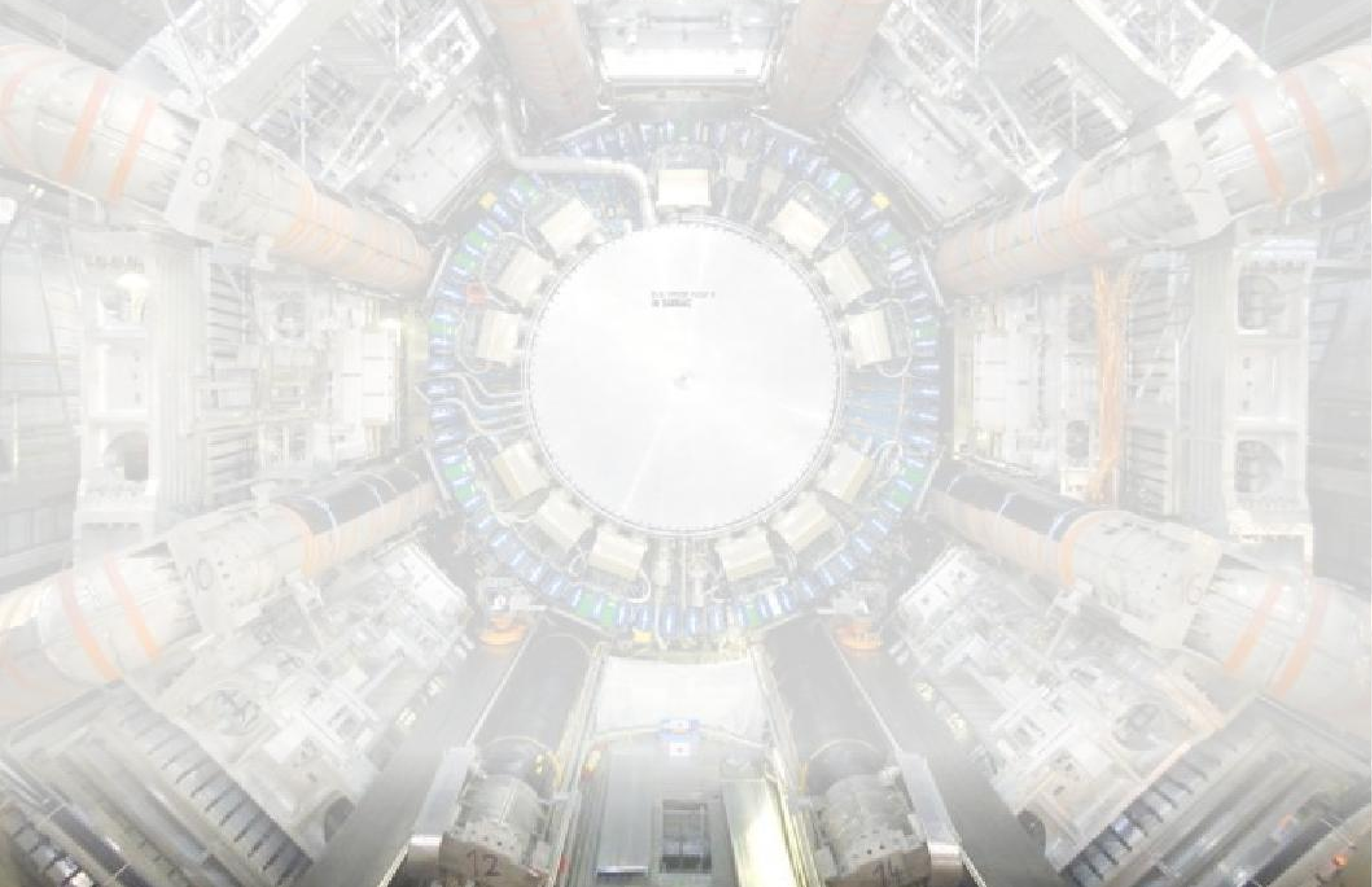
➔ **Some SM unsolved questions:**

- ✗ Coupling constants unification
- ✗ Higgs boson mass (loop corrections)
- ✗ Hierarchy problem



Introduction: SUper SYmmetry (SUSY)



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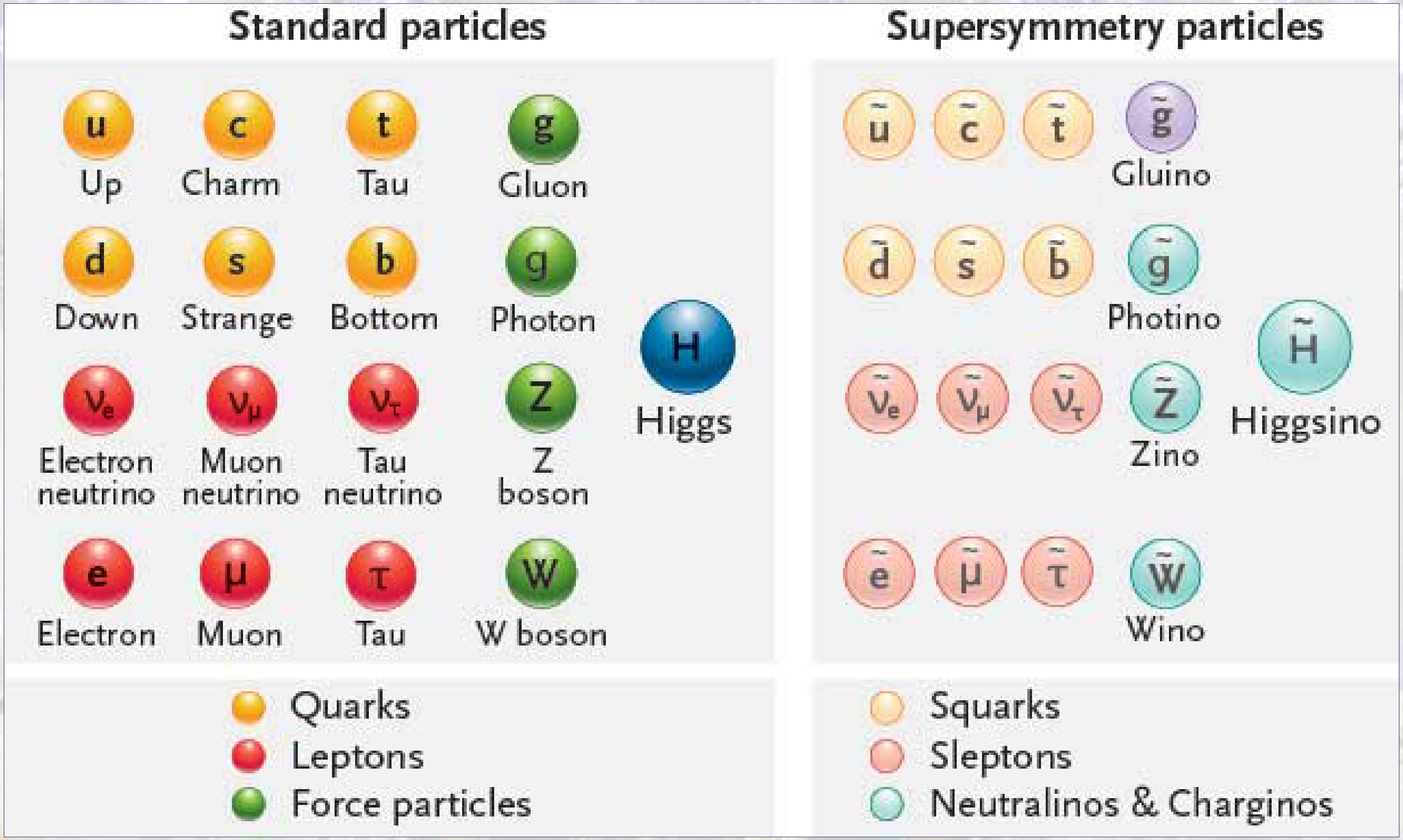

$$Q\,|Fermion\rangle = |Boson\rangle \qquad Q\,|Boson\rangle = |Fermion\rangle$$

$$Q = SUSY\ operator\ (carries\ spin\ 1/2)$$

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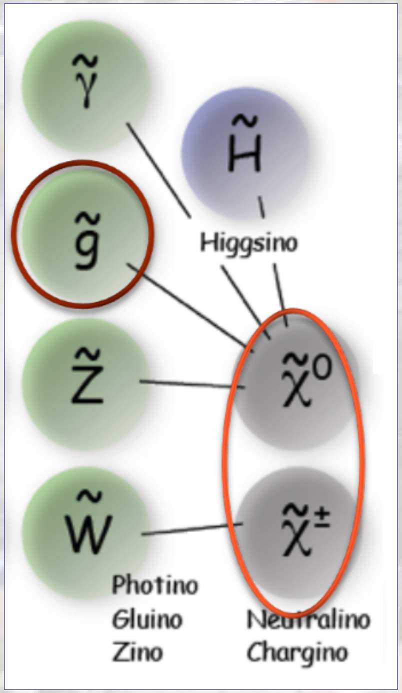

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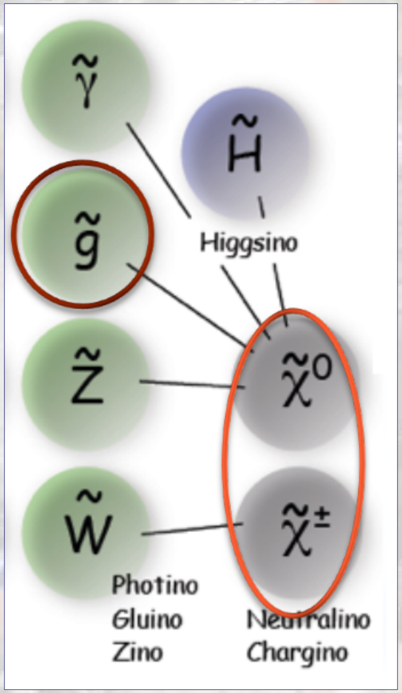
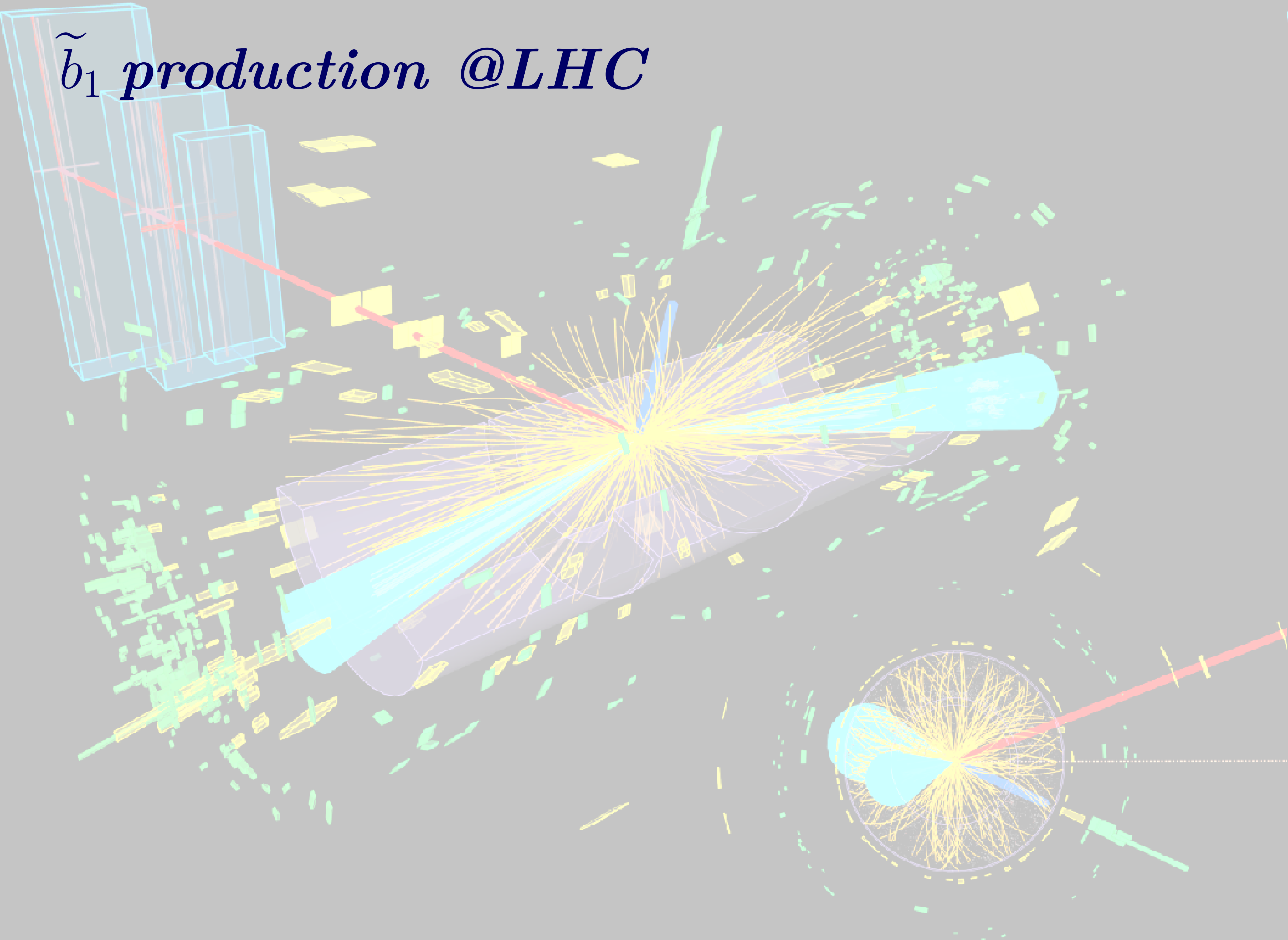
  - ✔ 3$^{\mathrm{RD}}$ generation squarks ($\widetilde{t}_1, \widetilde{t}_2, \widetilde{b}_1, \widetilde{b}_2$) and sleptons ($\widetilde{\tau}_1, \widetilde{\tau}_2$) are lighter than the other squarks/sleptons



$\widetilde{b}_1$ *production @LHC*



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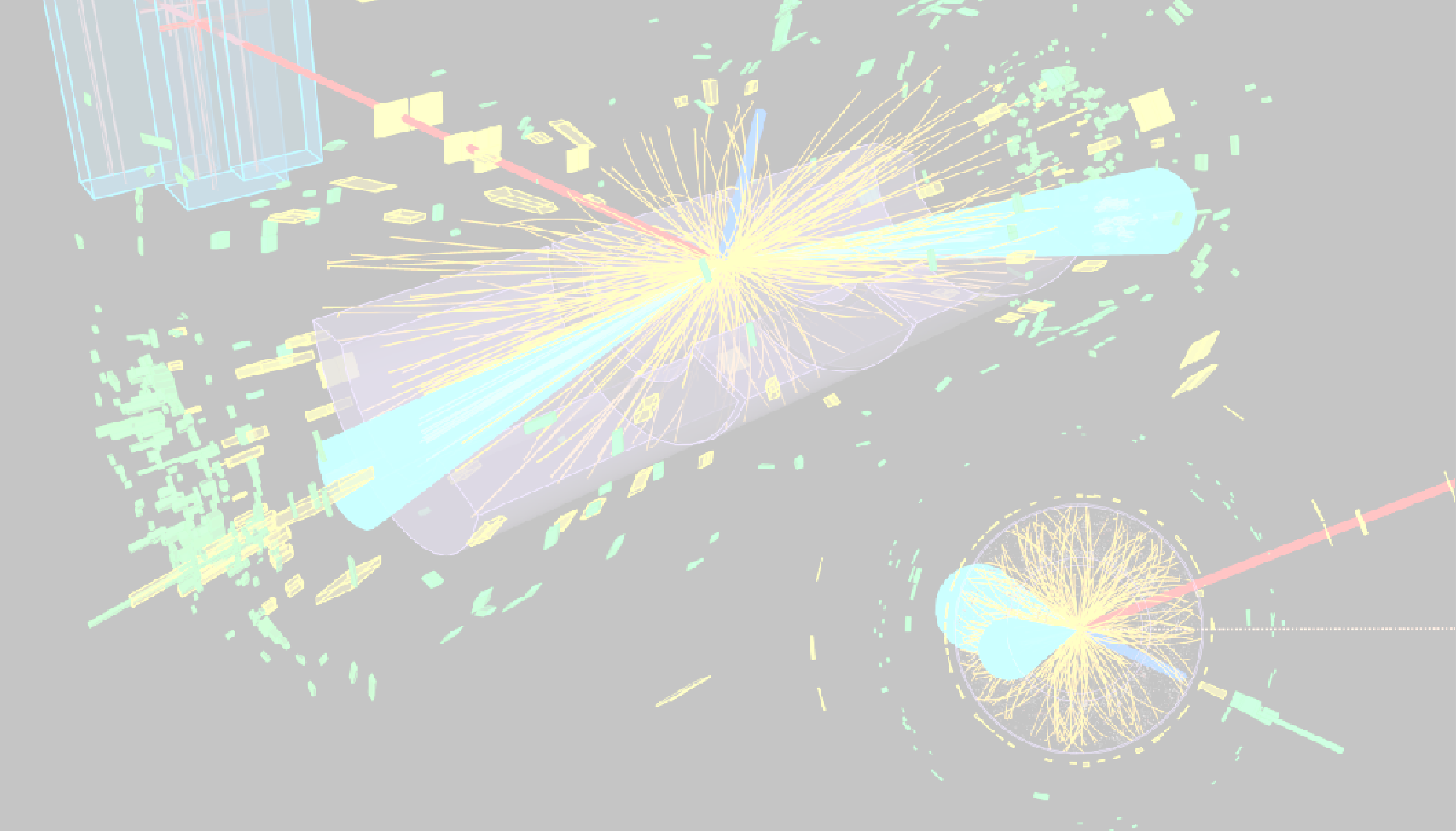

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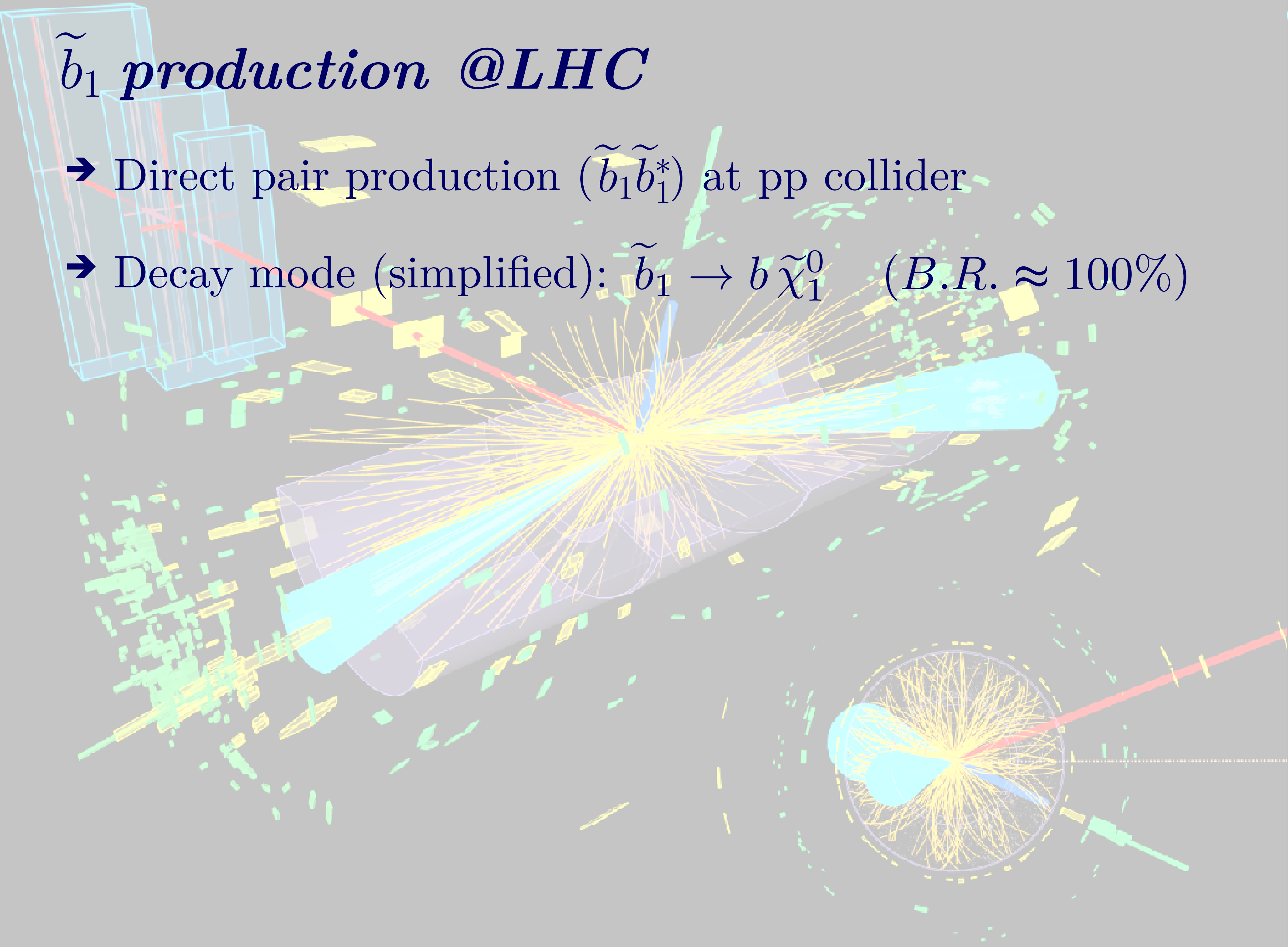

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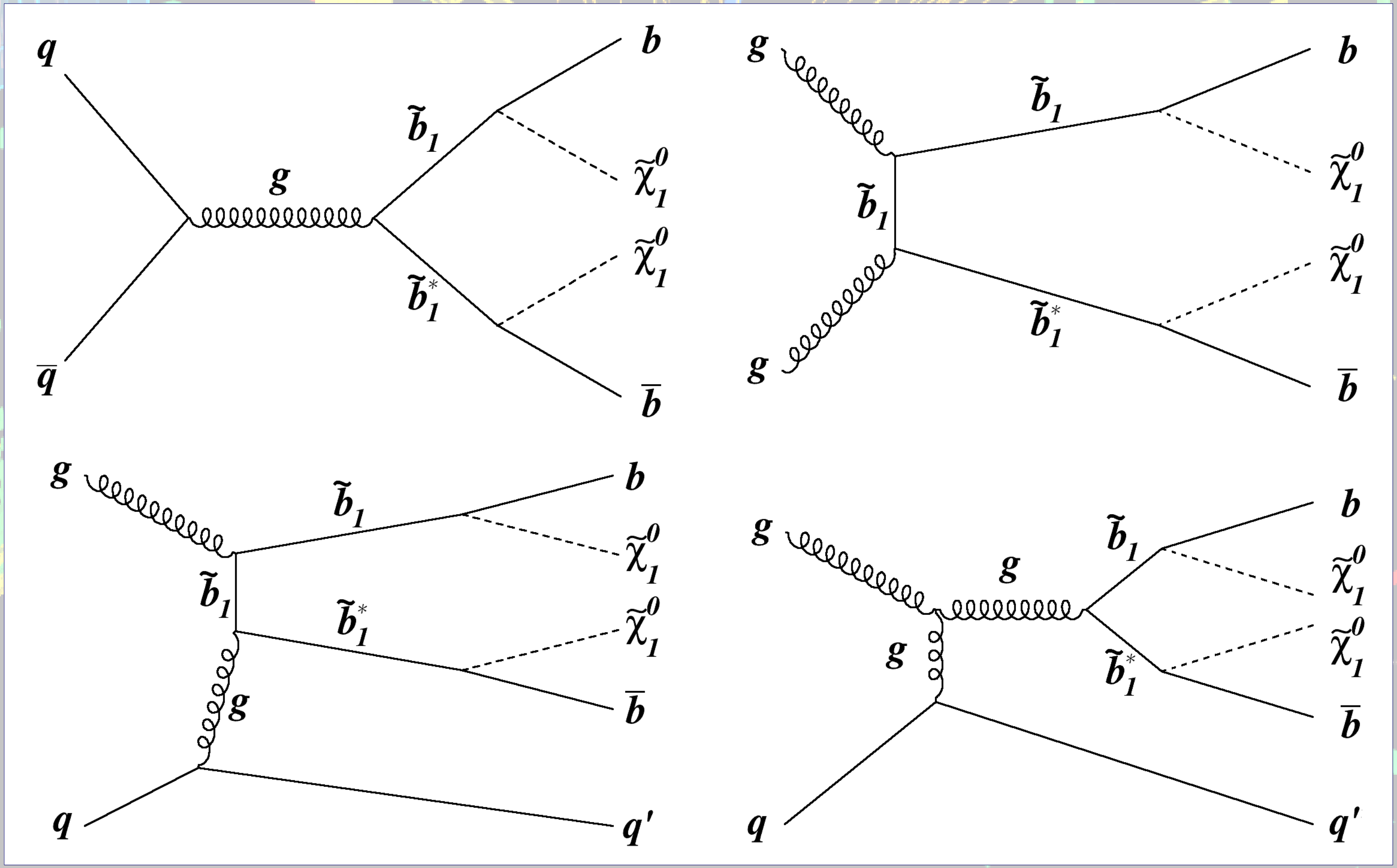
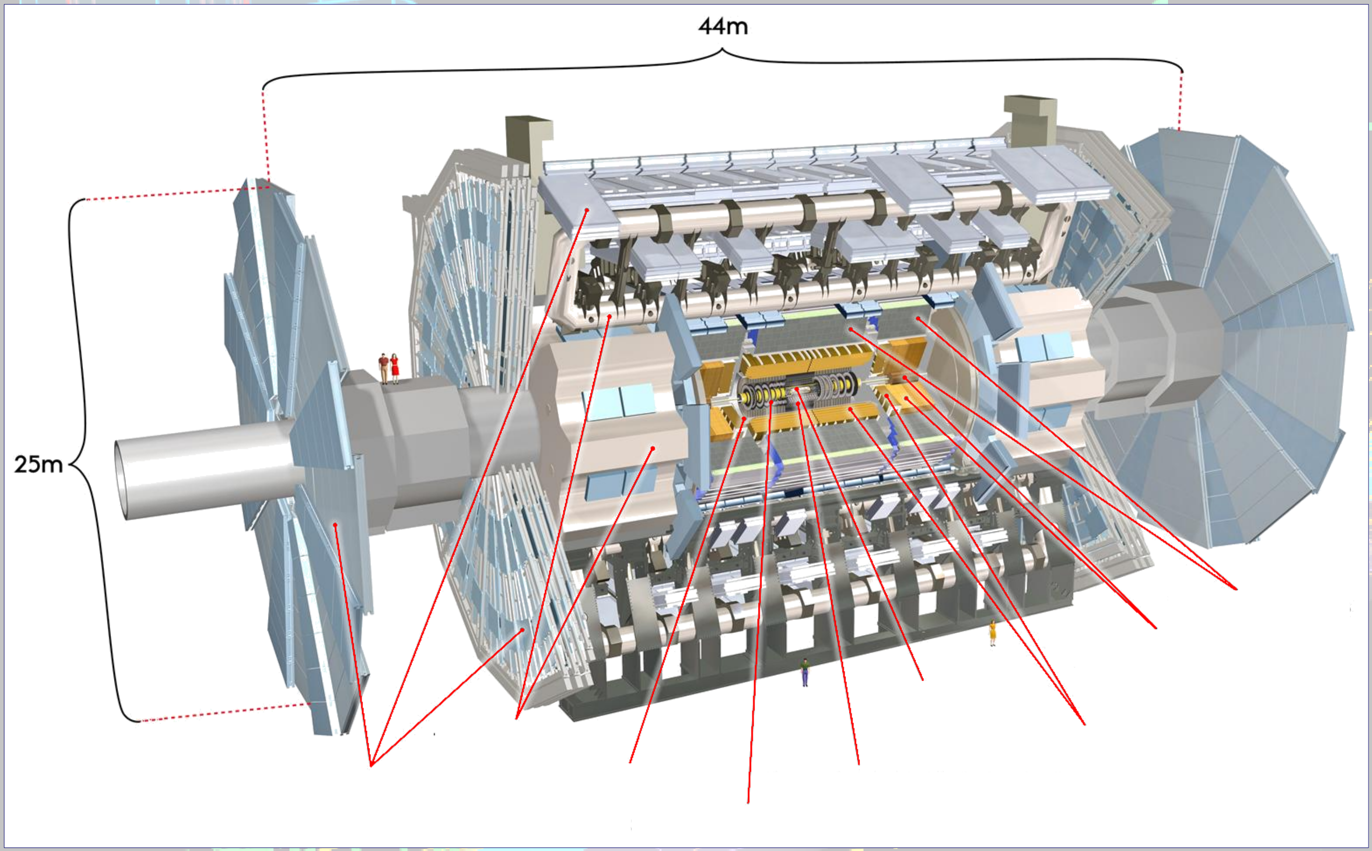


The ATLAS detector



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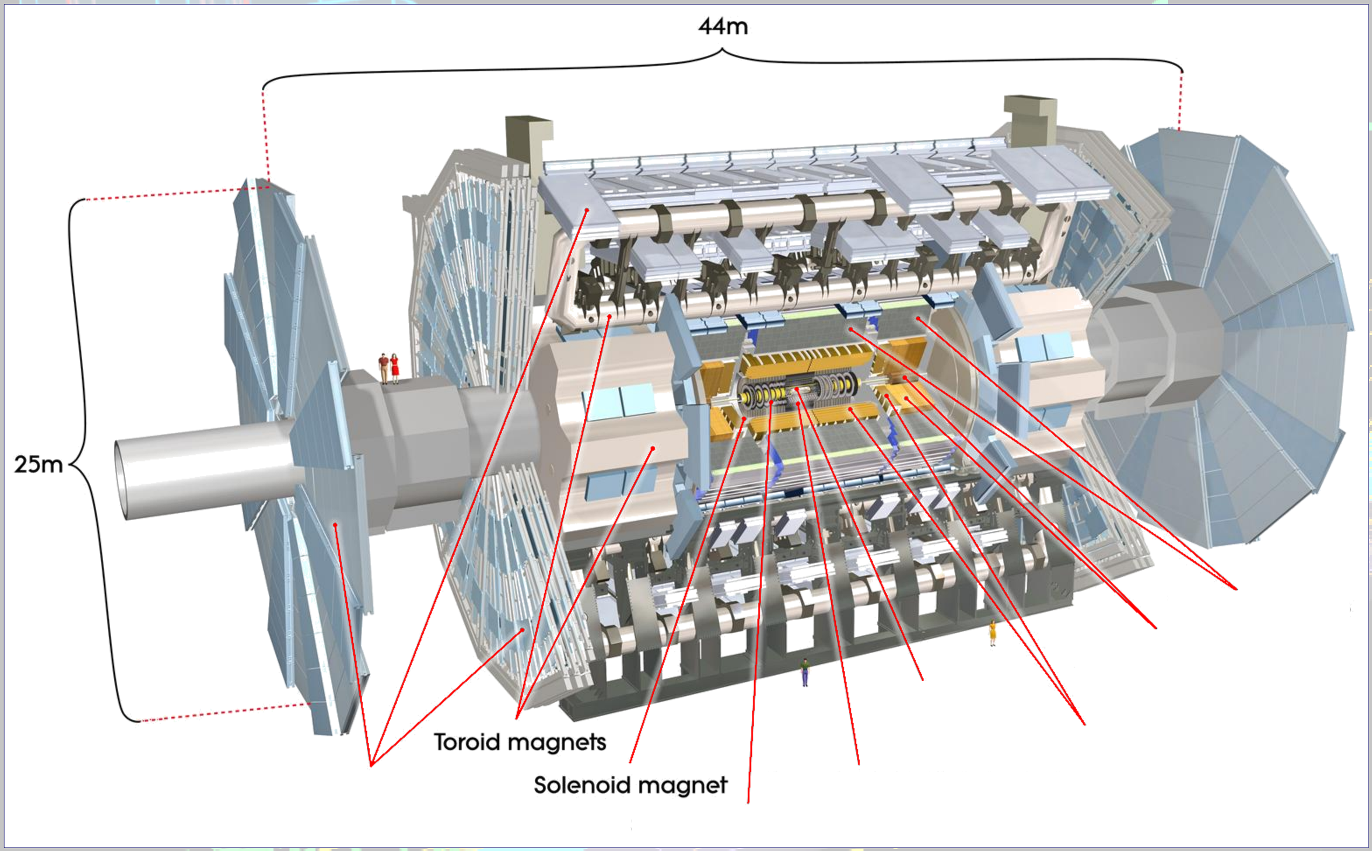

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- Toroid

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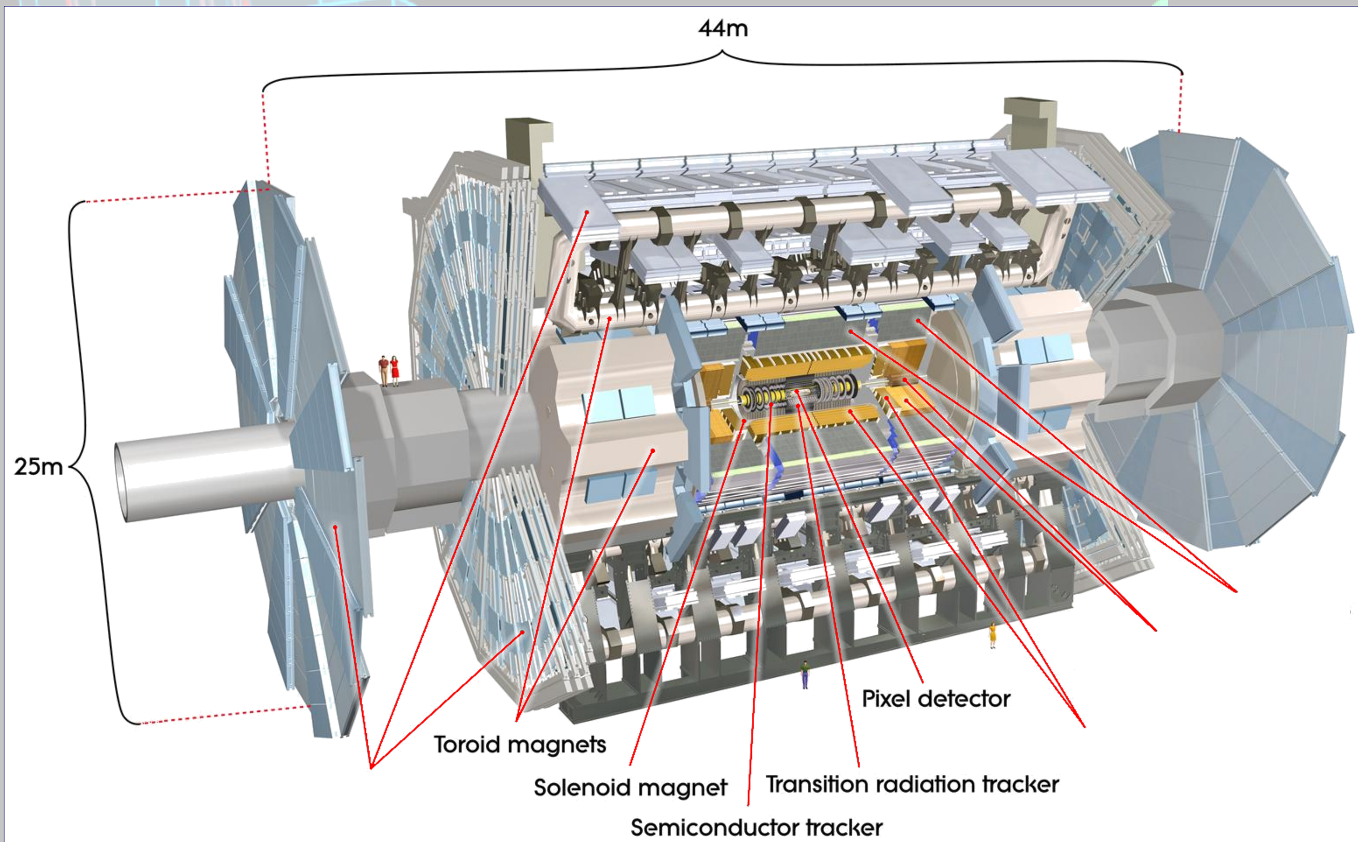

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- Inner Detector:
  - Pixel
  - Microstrip
  - Transition Radiation

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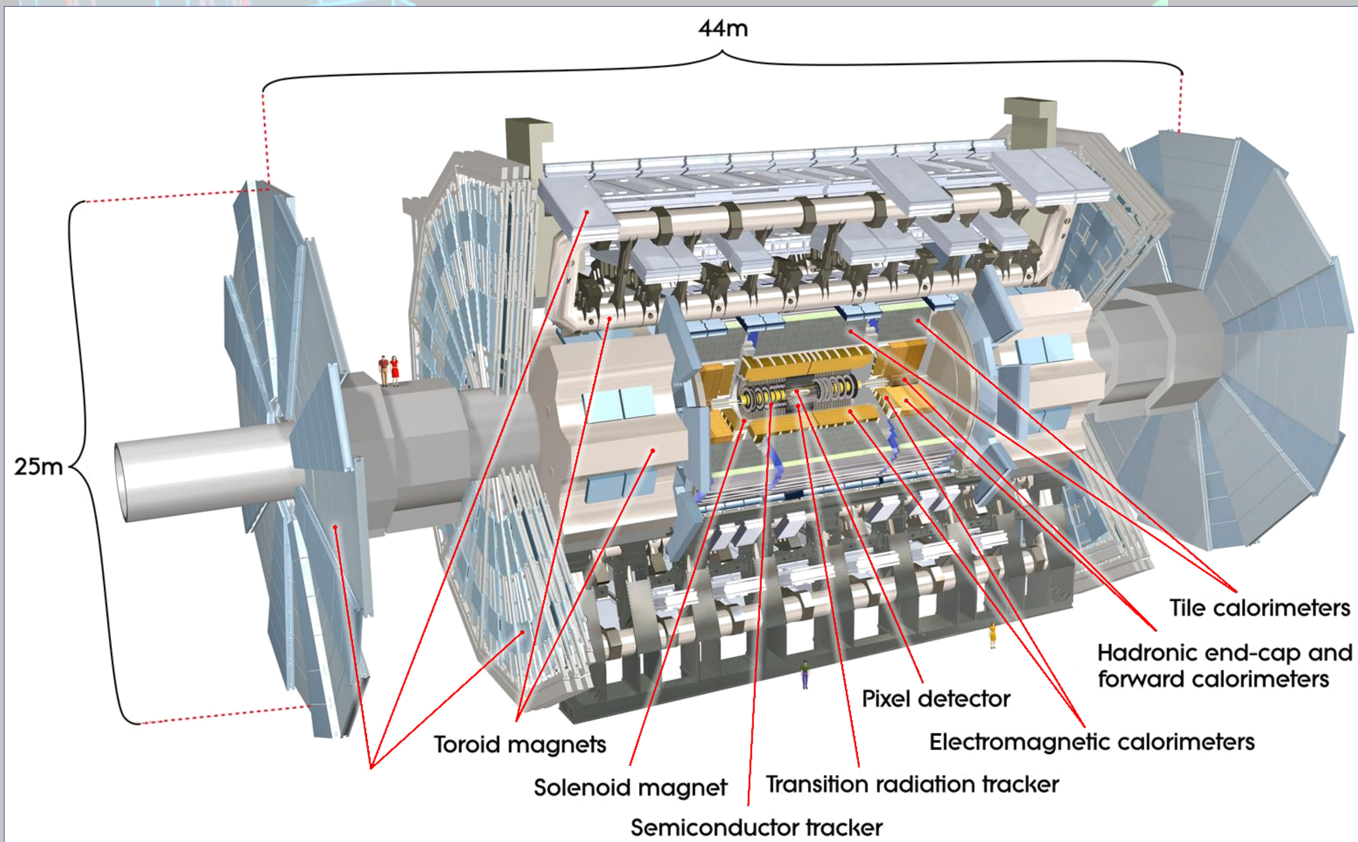

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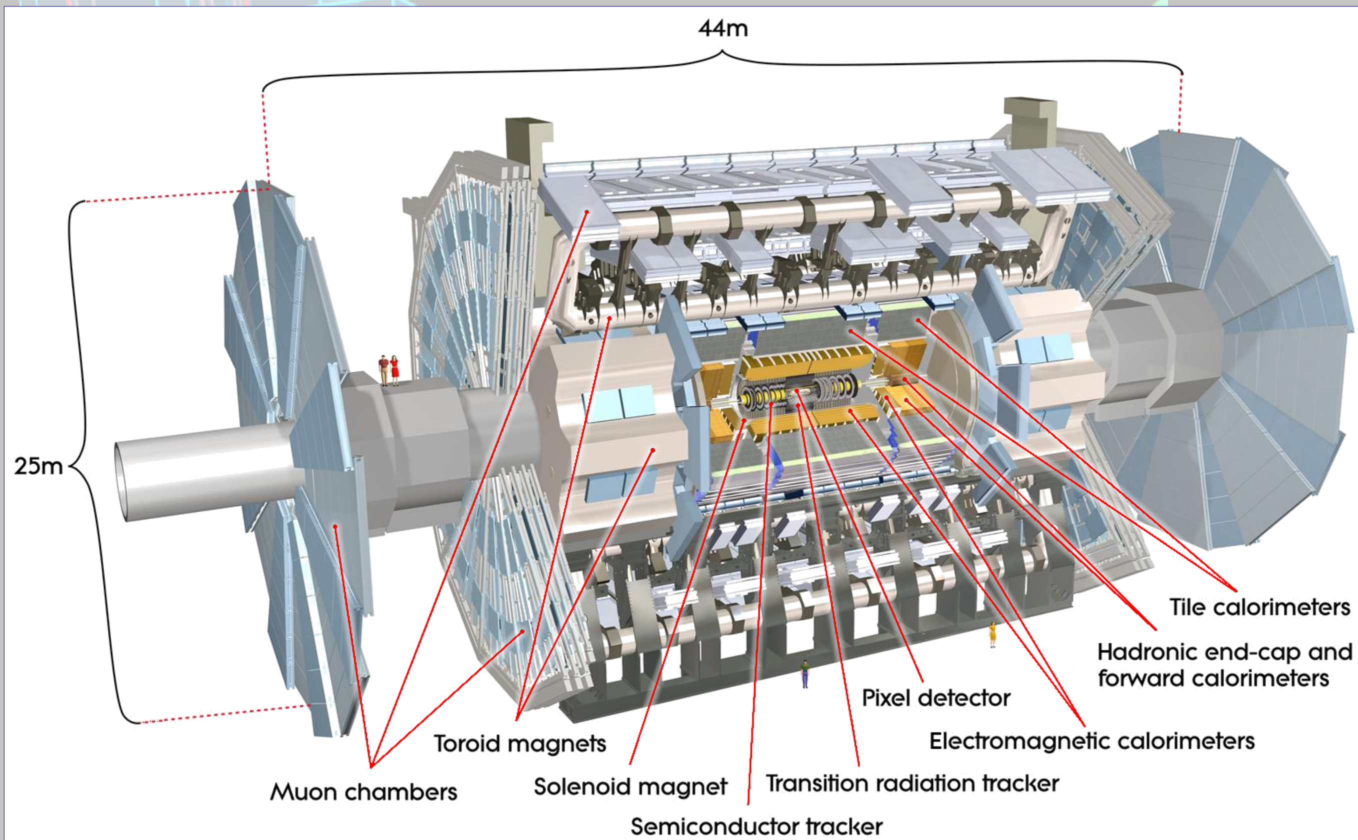

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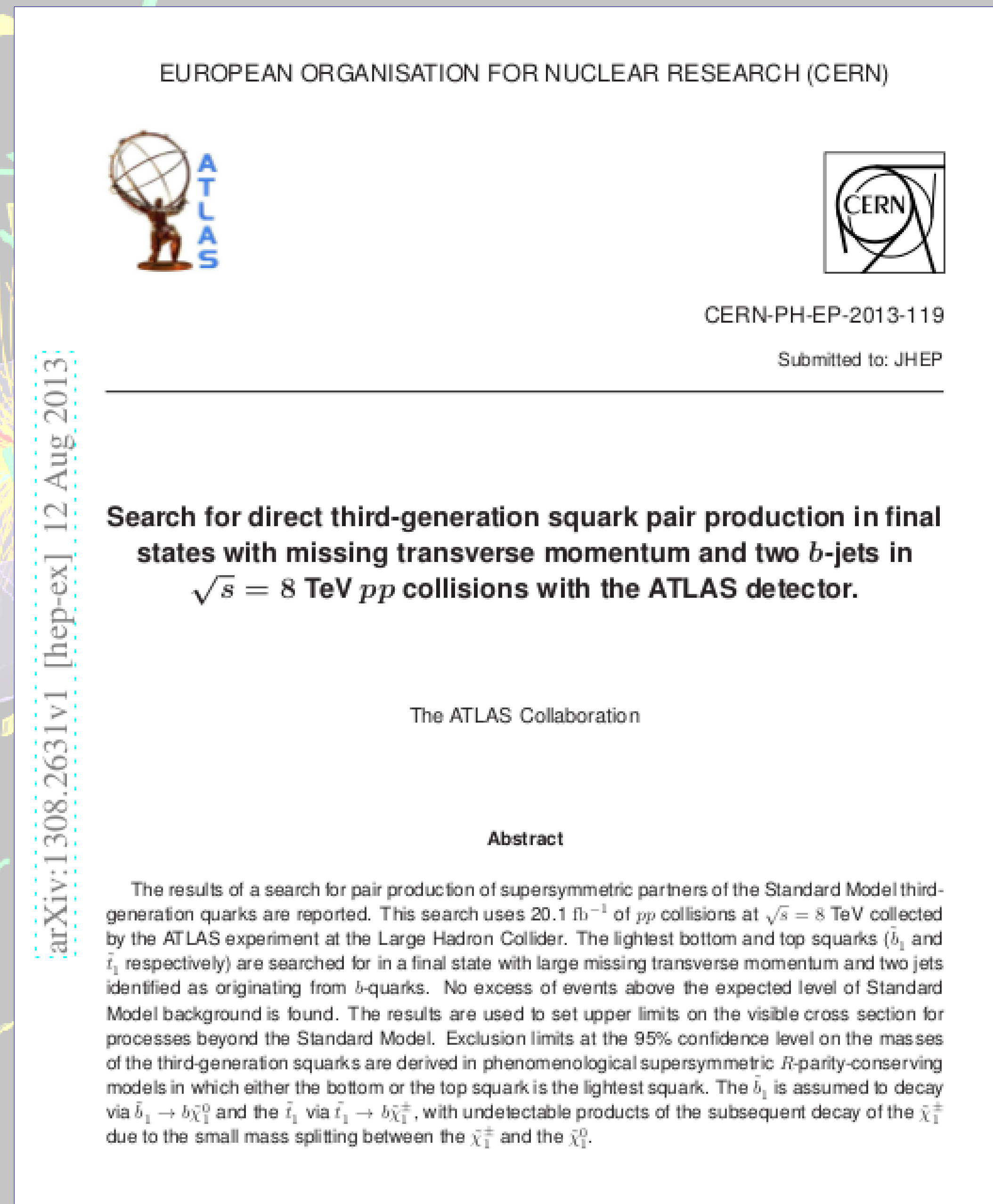
➔ Replicate the same analysis described in the reference article, using:


EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2013-119

Submitted to: JHEP

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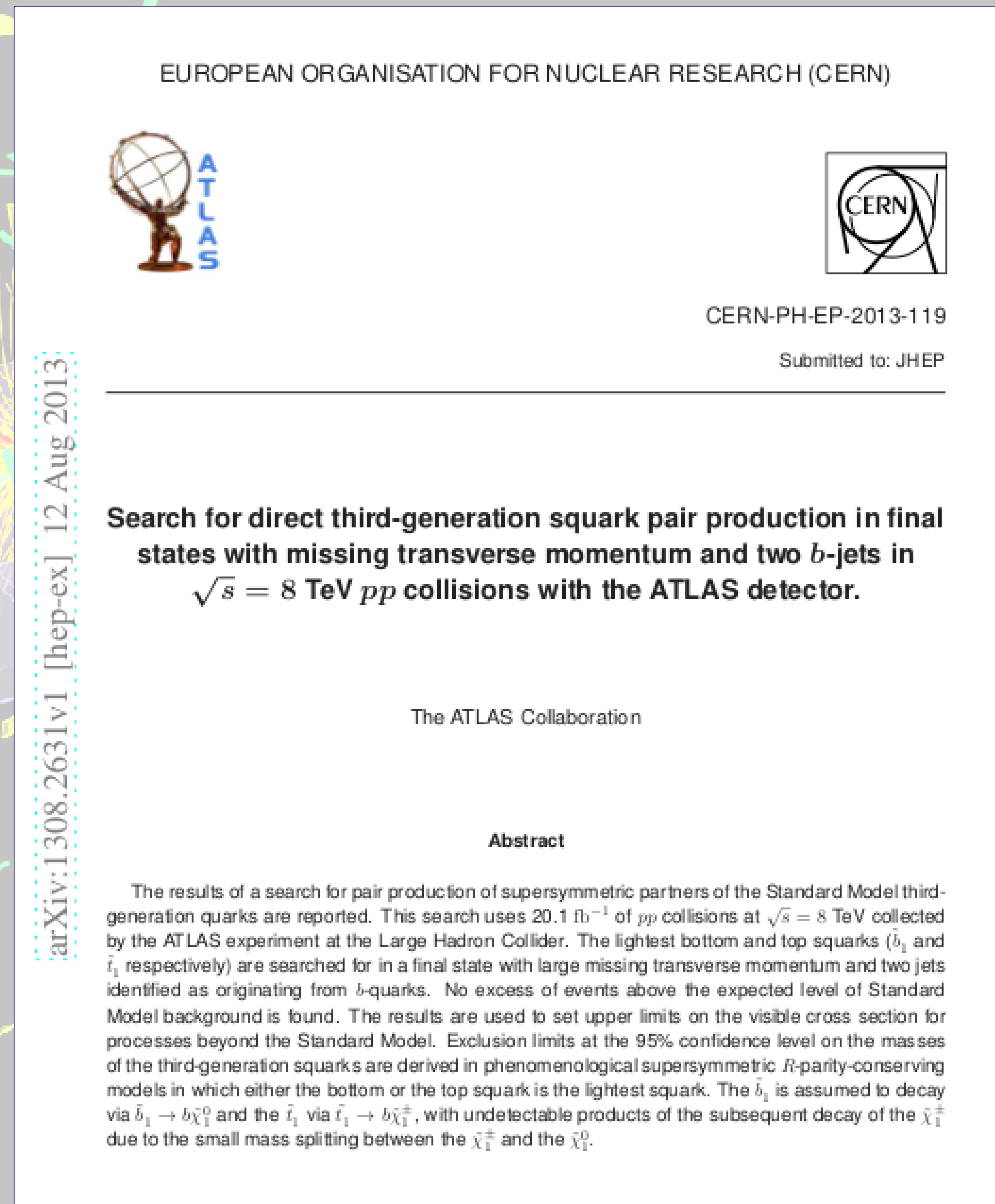

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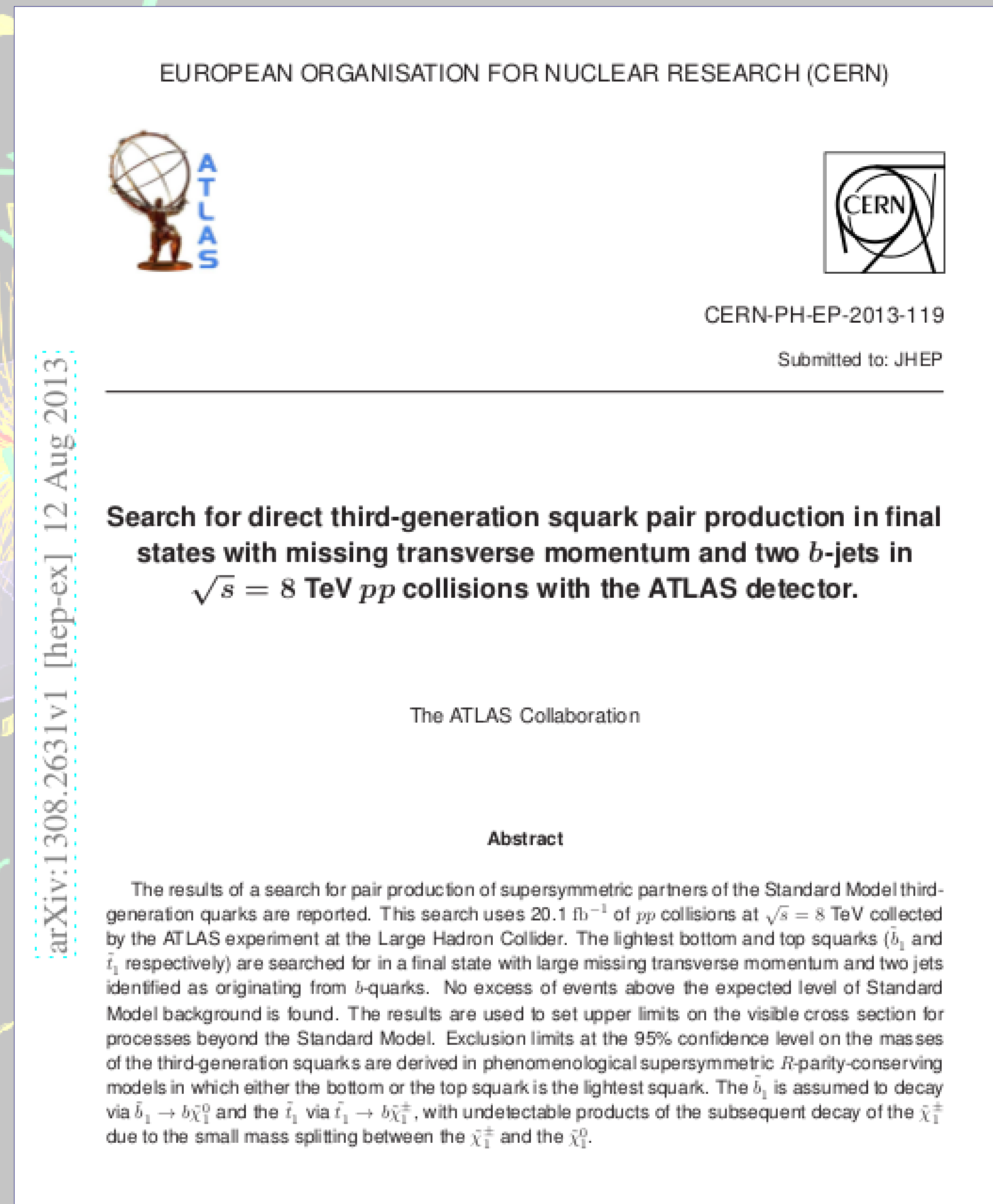
➔ Then try to optimize the signal-to-background ratio...



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$$\mathrm{S}{=}\sigma_S \cdot \mathcal{L} \cdot \varepsilon_S \qquad B = \sum_i B_i = \sum_i \sigma_{B_i} \cdot \mathcal{L} \cdot \varepsilon_{B_i}$$

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- Search for sensitivity regions in the sbottom-nautralino masses plane, considering statistical (and systematical) fluctuations in the SM background.

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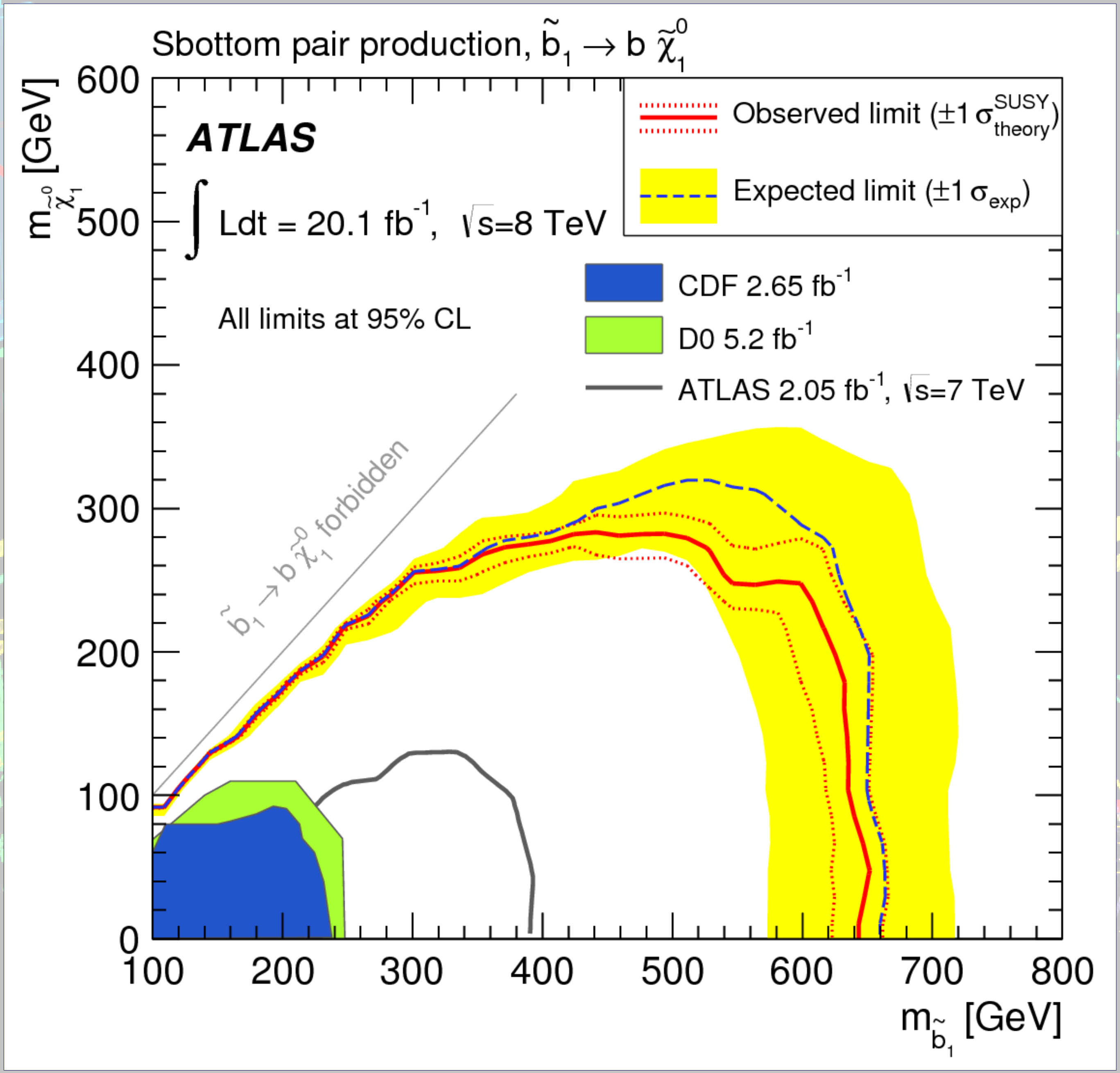
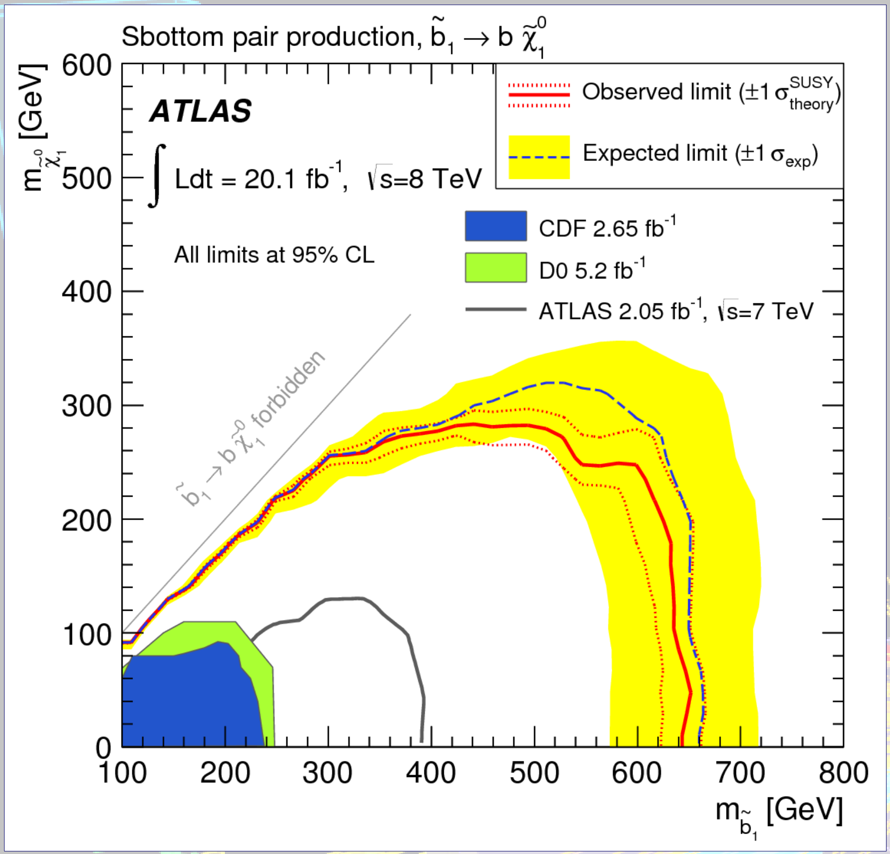
- Verify the signal-background compatibility for each set of cuts.

Sensitivity Plot!



Signal Region A (SRA)



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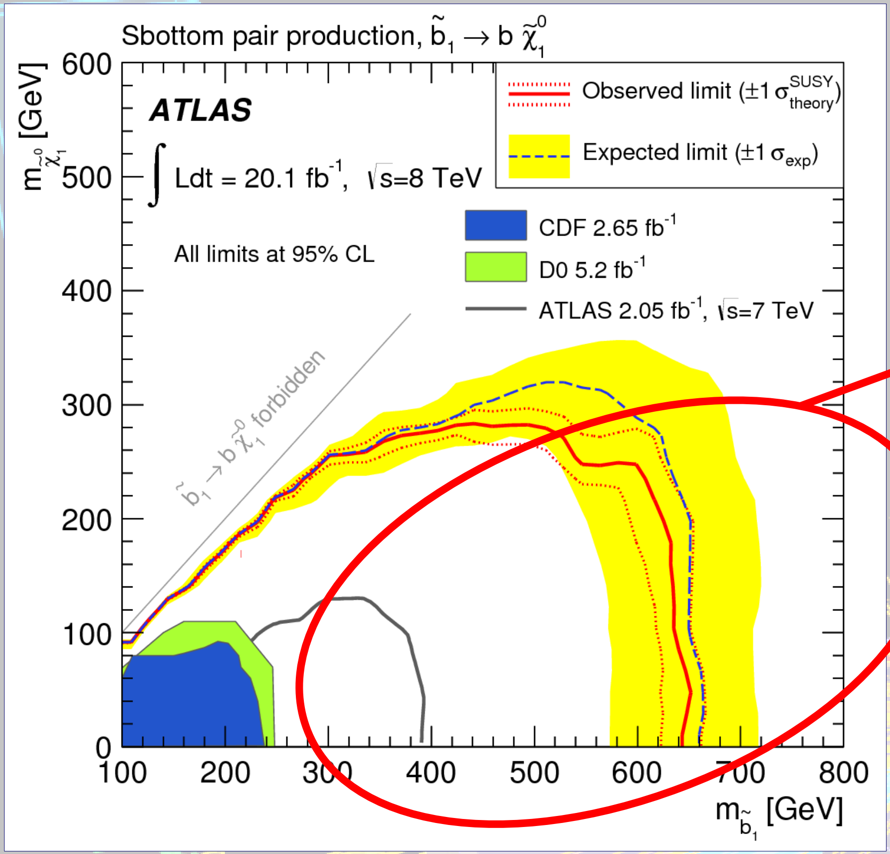

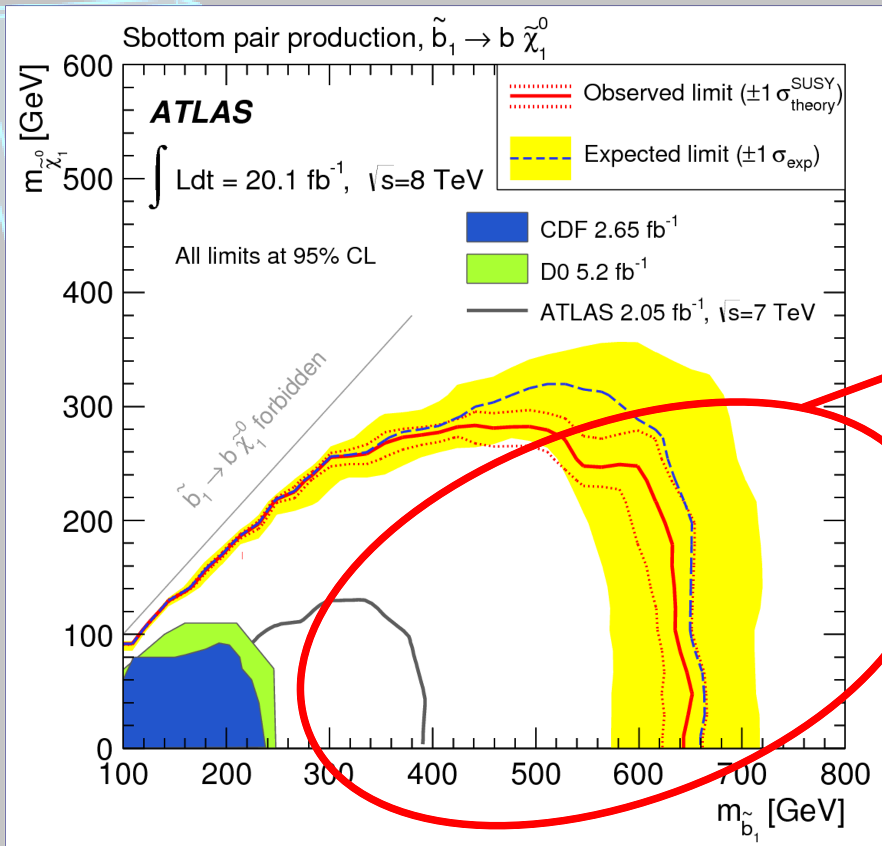

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$$m(\widetilde{b}_1) - m(\widetilde{\chi}_1^0) - m(b) \simeq m(\widetilde{b}_1)$$

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- ➔ Large "energy" available for the reaction (decay)

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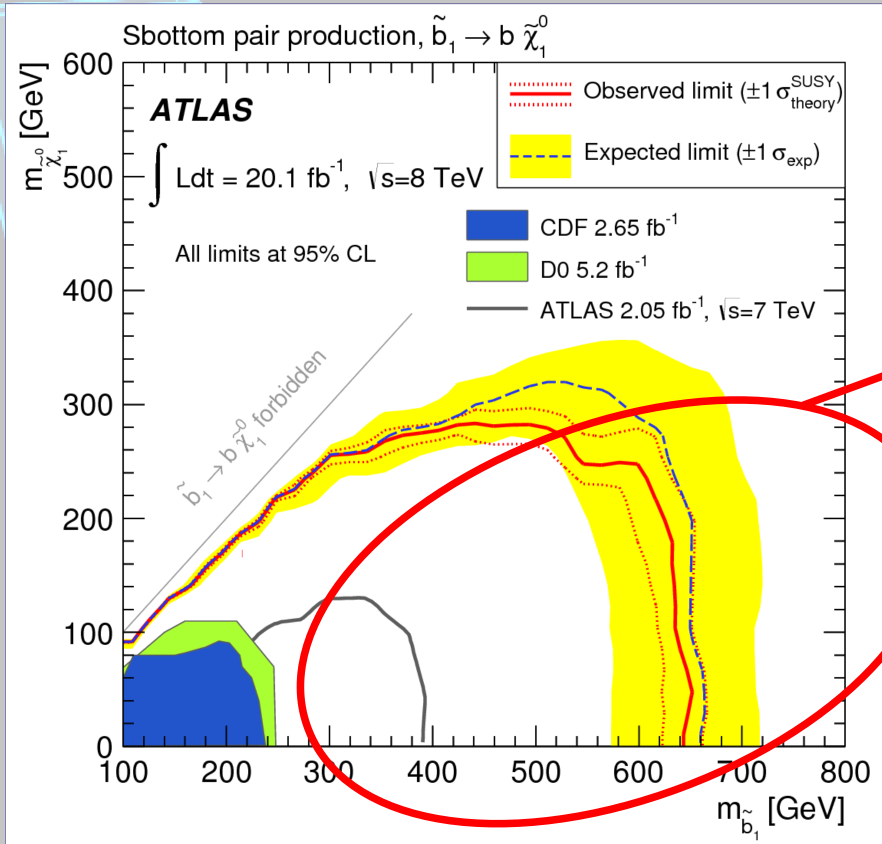

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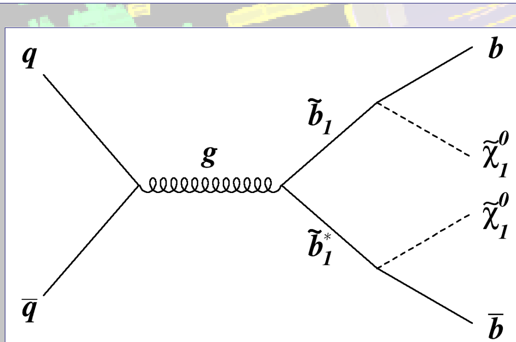
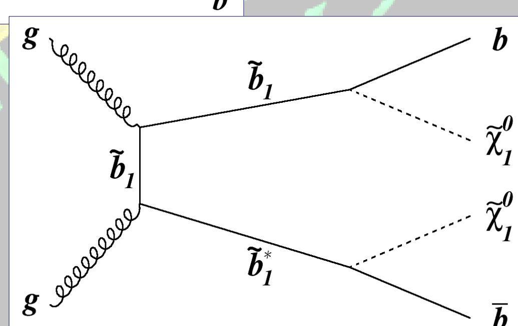
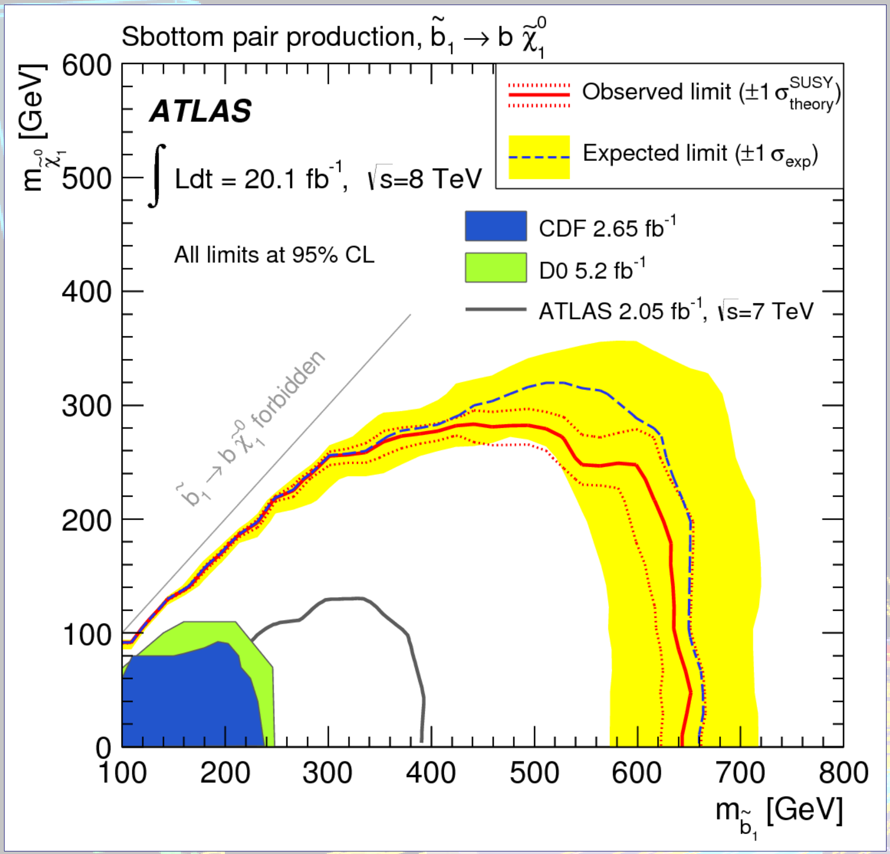
- ➔ Large mass splitting between squark and neutralino
- ➔ Large “energy” available for the reaction (decay)
- ➔ <u>*FINAL STATE*</u>:
  - 2 b-tagged, high-p_T leading jets
  - Missing Energy (E_T^{miss})







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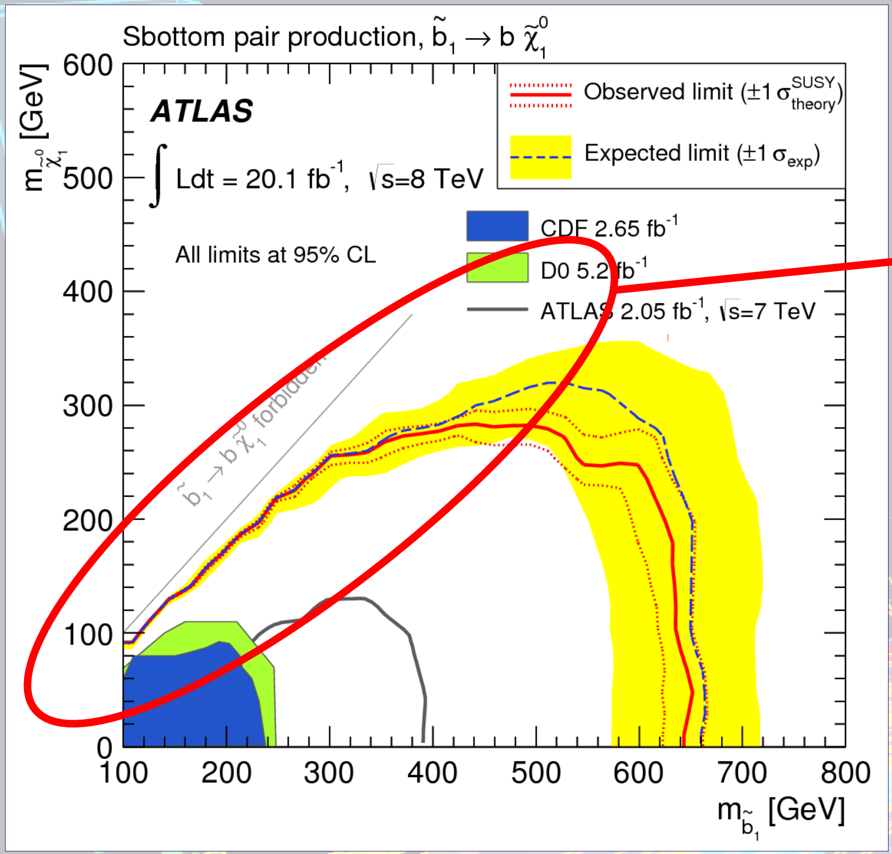

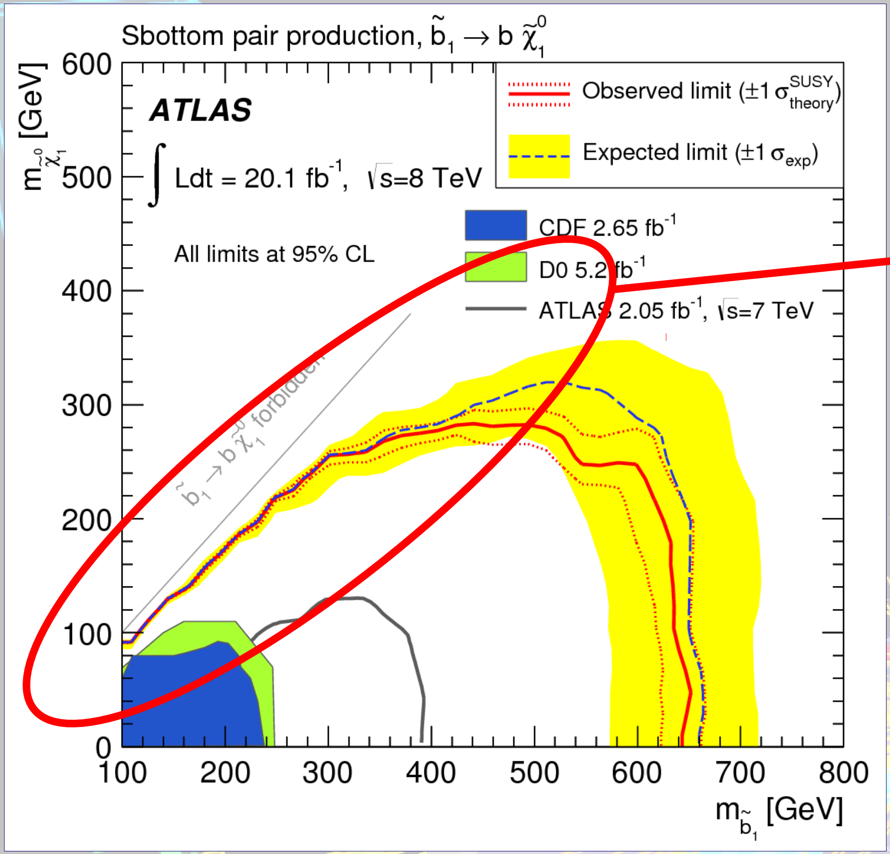

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➔ To enhance sensitivity for:

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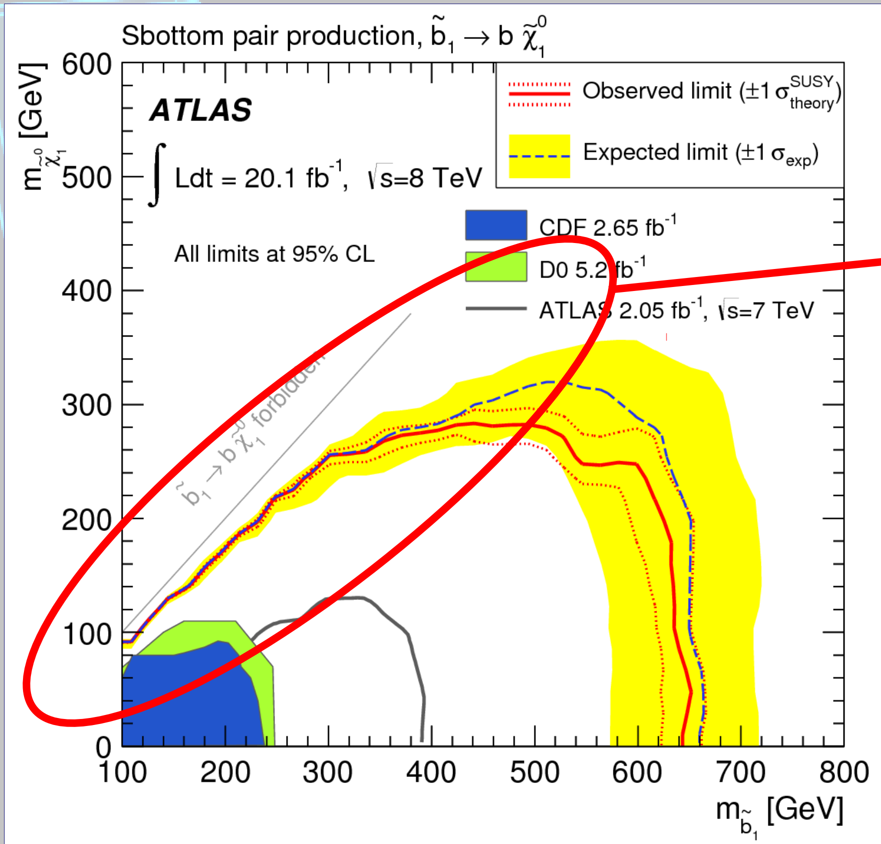
- Small "energy" available for the reaction (decay)
- High-p_T, not-b-tagged leading jet recoiling against the squark-pair system (ISR)



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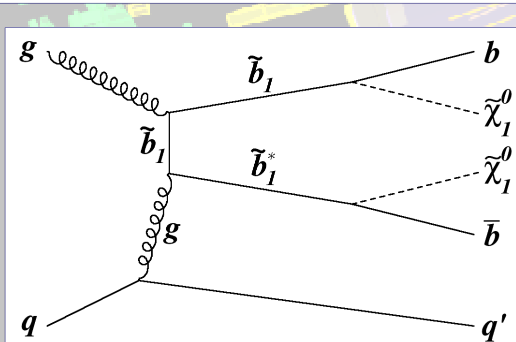
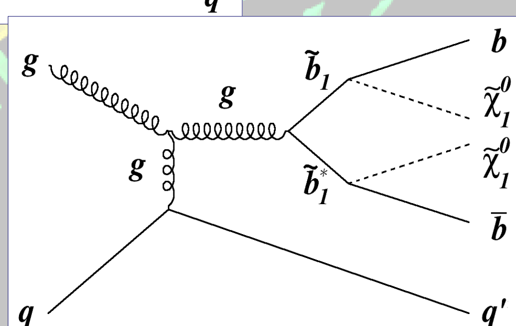


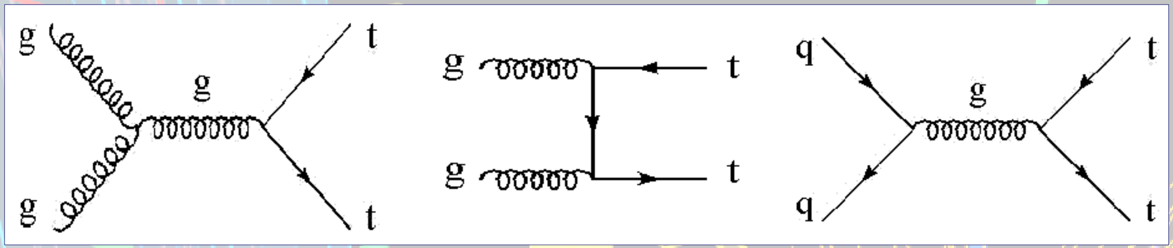


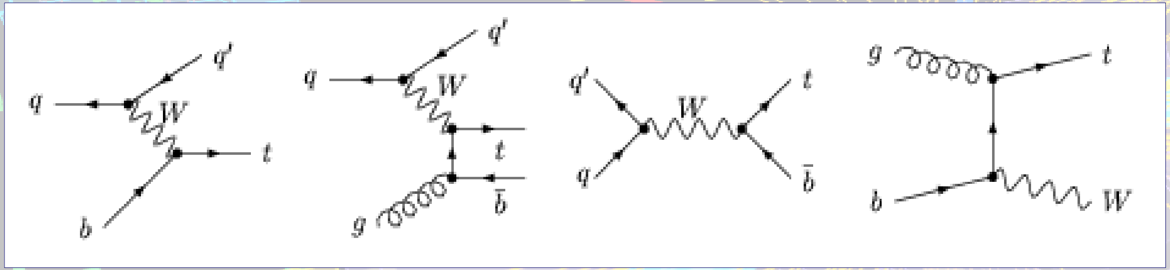
➔ *FINAL STATE*:

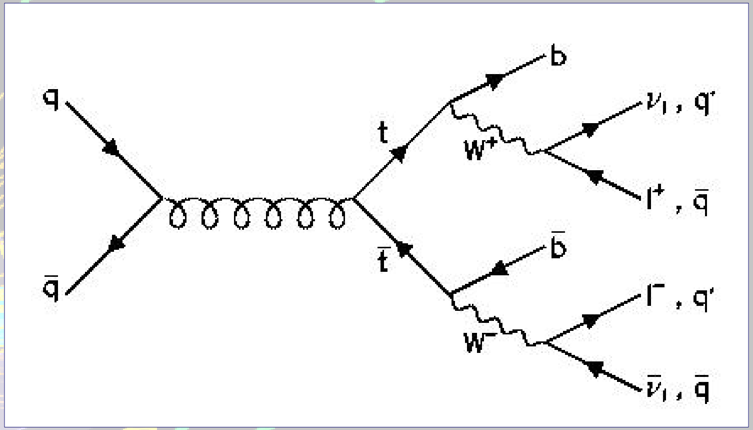
- 1 not b-tagged, high-p_T leading jet
- 2 b-tagged, high-p_T sub-leading jets
- High Missing Energy (E_T^{miss})

Expected SM background

- ➔ $t\bar{t}$ and *Single-top* productions:







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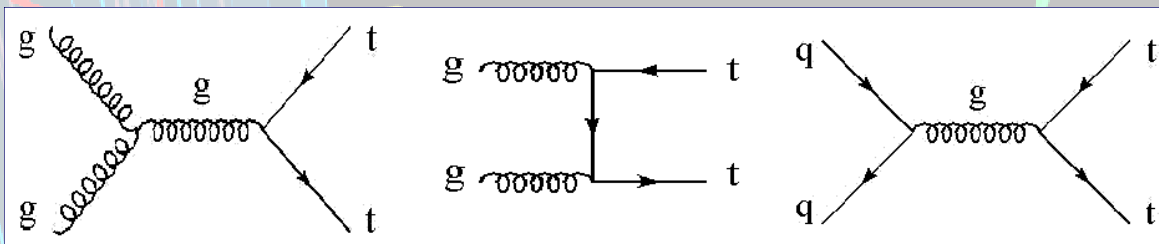
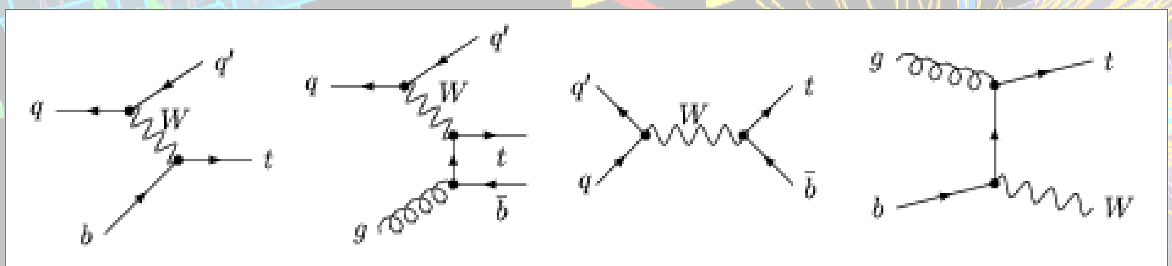
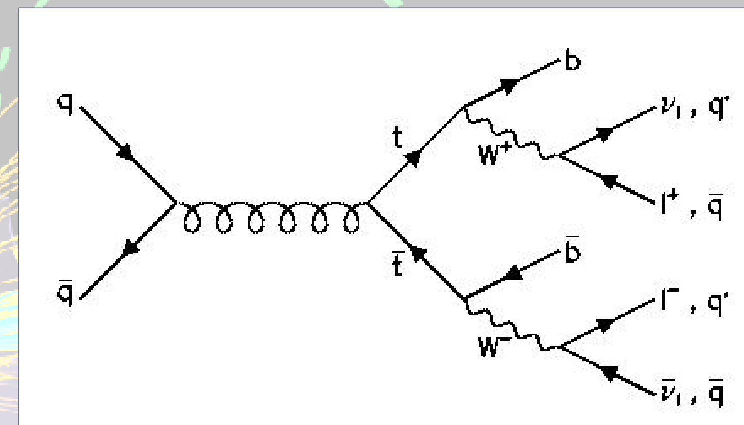
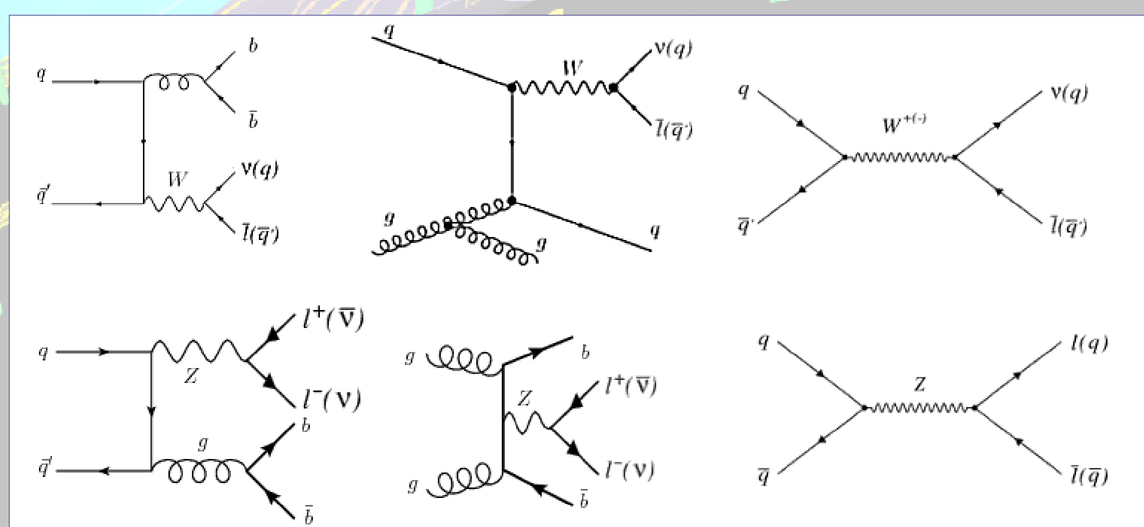






- *W* and *Z bosons* productions (*DY*, *W+jet*, *Z+jet*, ...):



Used Variables

$$\mathrm{p}_T\ ,\eta\ \ ,\phi\ ,E_T^{miss},\ m_{bb}$$

$$\Delta\phi_{min} = \min\left(\left|\phi_1 - \phi_{p_T^{miss}}\right|, \left|\phi_2 - \phi_{p_T^{miss}}\right|, \left|\phi_3 - \phi_{p_T^{miss}}\right|\right)$$

$$\mathrm{m}_{eff}\,(k) = \sum_{i=1}^{k}\left(p_T^{jet}\right)_i + E_T^{miss}$$

$$\mathrm{H}_{T,3} = \sum_{i=4}^{n}\left(p_T^{jet}\right)_i$$

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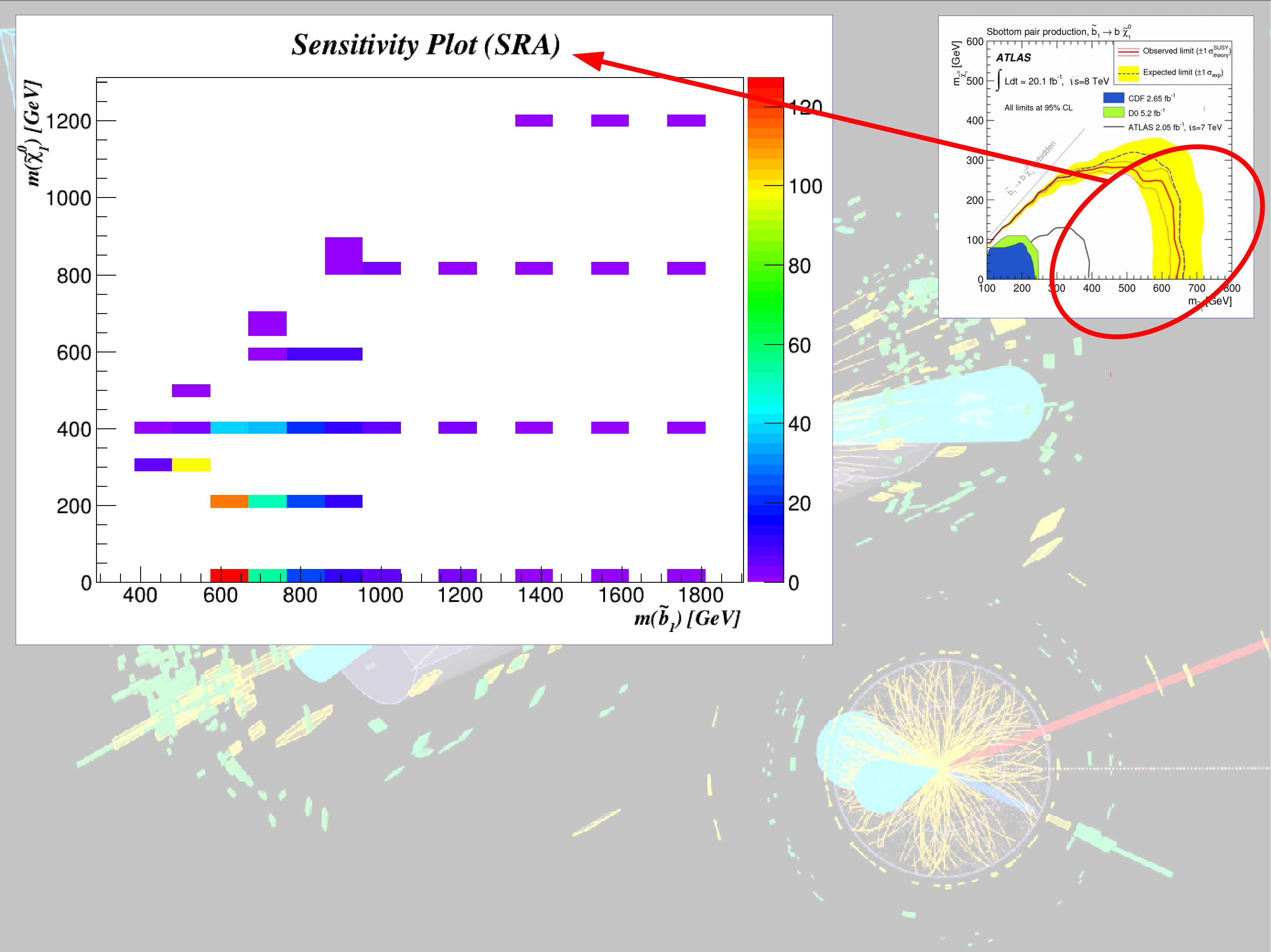
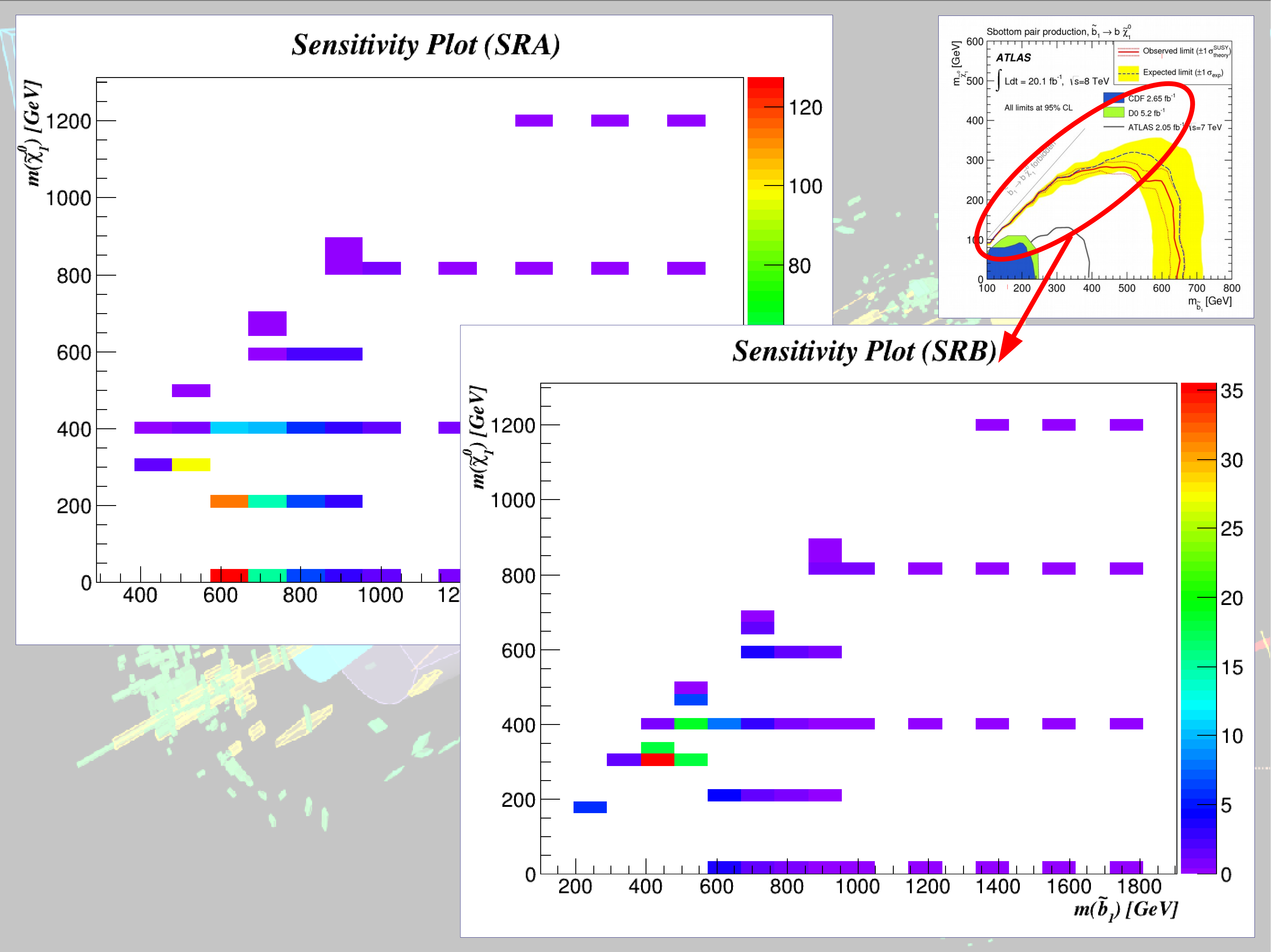
$$\mathrm{m}_{CT}^2\left(j_1^b, j_2^b\right) = \left[E_T\left(j_1^b\right) + E_T\left(j_2^b\right)\right]^2 - \left[\overrightarrow{p_T}\left(j_1^b\right) - \overrightarrow{p_T}\left(j_2^b\right)\right]^2$$

$$\mathrm{m}_{CT}^{max} = \frac{m^2\left(\widetilde{b}\right) - m^2\left(\widetilde{\chi}_1^0\right)}{m^2\left(\widetilde{b}\right)}$$

Selection cuts (article)

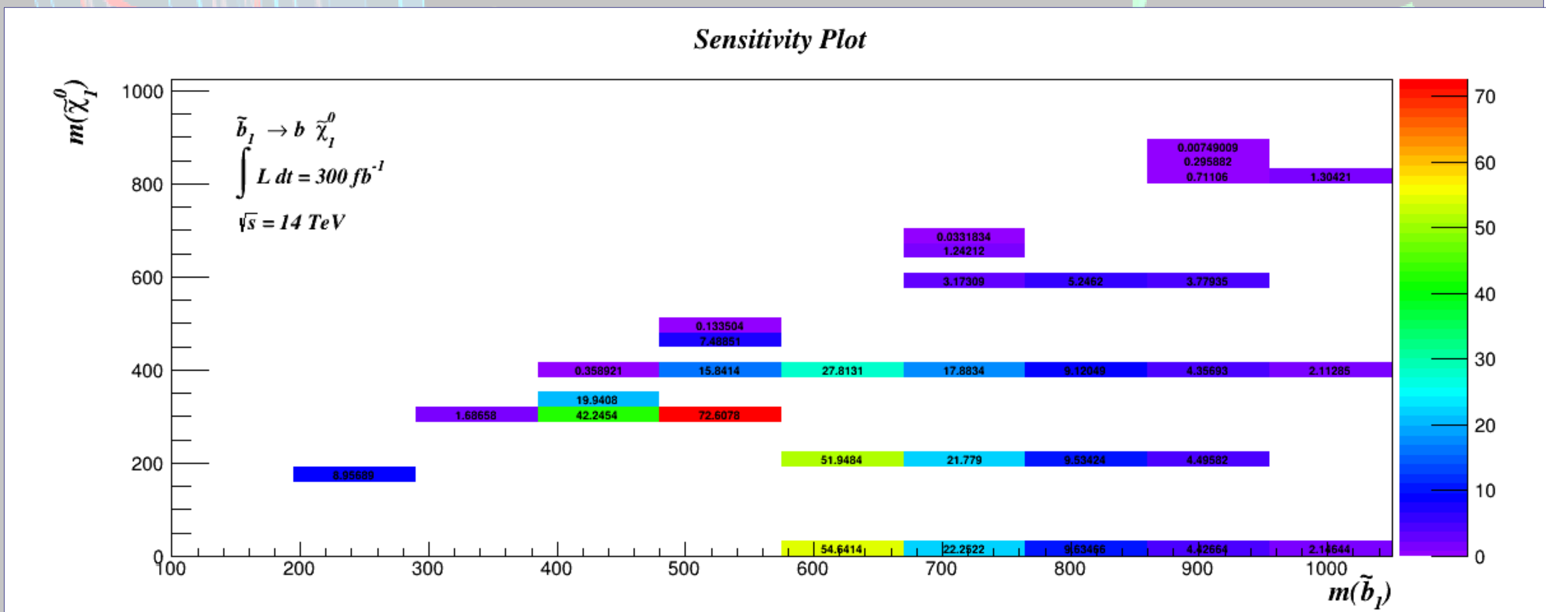
Description	*Signal Regions*	
	SRA	*SRB*
Lepton Veto	if p_T (e or μ) > 6 GeV	
E_T^{miss}	$> 150\,GeV$	$> 250\,GeV$
1^{st} jet $p_T(j_1)$	$> 130\,GeV$	$> 150\,GeV$
2^{nd} jet $p_T(j_2)$	$> 50\,GeV$	$> 30\,GeV$
3^{rd} jet $p_T(j_3)$	veto if $> 50\,GeV$	$> 30\,GeV$
$\Delta\phi\,(p_T^{miss},\, j_1)$	-	> 2.5
b-tagging	leading 2 jets ($p_T > 50$ GeV, $\lvert\eta\rvert < 2.5$)	2^{nd} and 3^{rd} leading jets ($p_T > 30$ GeV, $\lvert\eta\rvert < 2.5$)
	$n_{b-jets} = 2$	
$\Delta\phi_{min}$	> 0.4	
$E_T^{miss}/m_{eff}(k)$	$E_T^{miss}/m_{eff}(2) > 0.25$	$E_T^{miss}/m_{eff}(3) > 0.25$
m_{CT}	$> 150\,(200, 250, 300, 350)$ GeV	-
$H_{T,3}$	-	< 50 GeV
m_{bb}	> 200 GeV	-

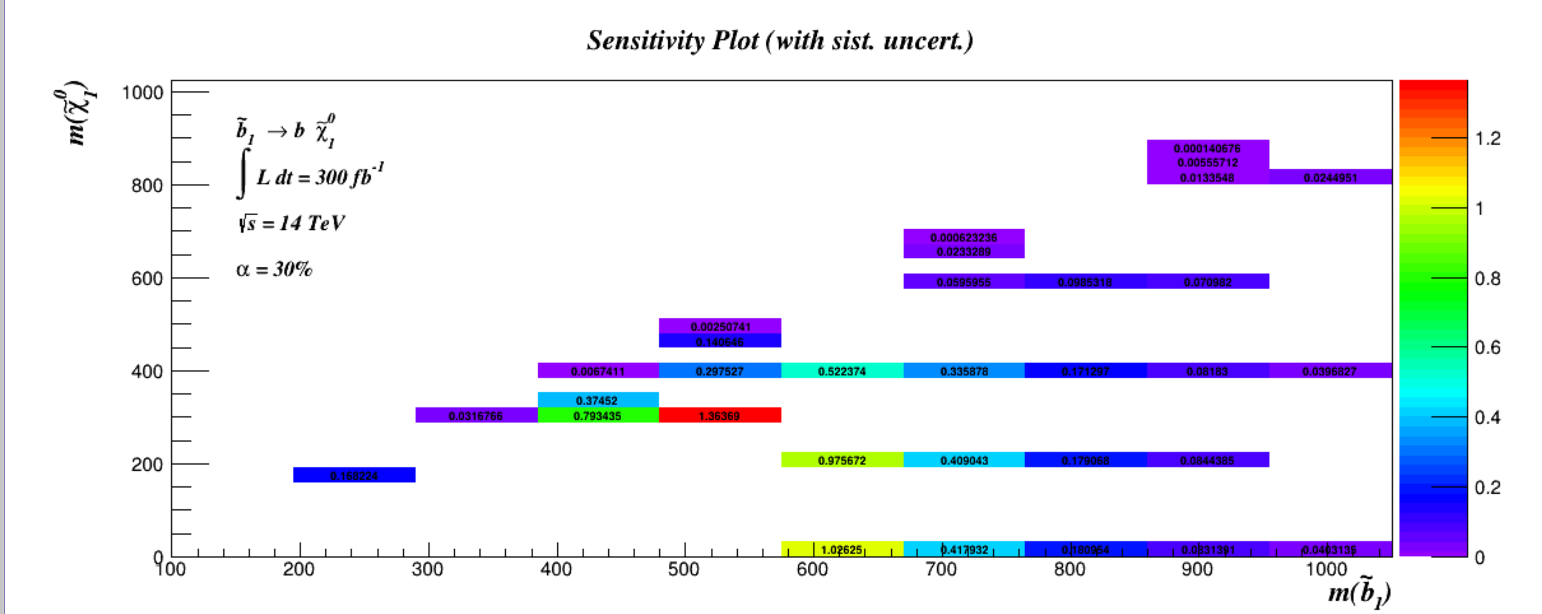

Sensitivity Plot (SRA)
m(χ̃₁⁰) [GeV]
m(b̃₁) [GeV]
0
200
400
600
800
1000
1200
1400
1600
1800
20
40
60
80
100
120
Sbottom pair production, b̃₁ → b χ̃₁⁰
ATLAS
∫ Ldt = 20.1 fb⁻¹, √s=8 TeV
All limits at 95% CL
Observed limit (±1 σ theory SUSY)
Expected limit (±1 σexp)
CDF 2.65 fb⁻¹
D0 5.2 fb⁻¹
ATLAS 2.05 fb⁻¹, √s=7 TeV
m χ̃₁⁰ [GeV]
m b̃₁ [GeV]

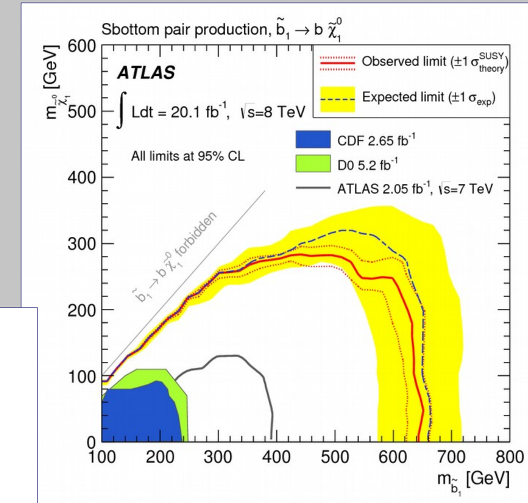


Sensitivity Plot (SRA)
m(χ̃₁⁰) [GeV]
Sensitivity Plot (SRB)
m(b̃₁) [GeV]
Sbottom pair production, b̃₁ → b χ̃₁⁰
ATLAS
∫ Ldt = 20.1 fb⁻¹, √s=8 TeV
All limits at 95% CL
Observed limit (±1 σ theory SUSY)
Expected limit (±1 σ exp)
CDF 2.65 fb⁻¹
D0 5.2 fb⁻¹
ATLAS 2.05 fb⁻¹ √s=7 TeV
b̃₁ → b χ̃₁⁰ forbidden
m_χ̃₁⁰ [GeV]
m_b̃₁ [GeV]

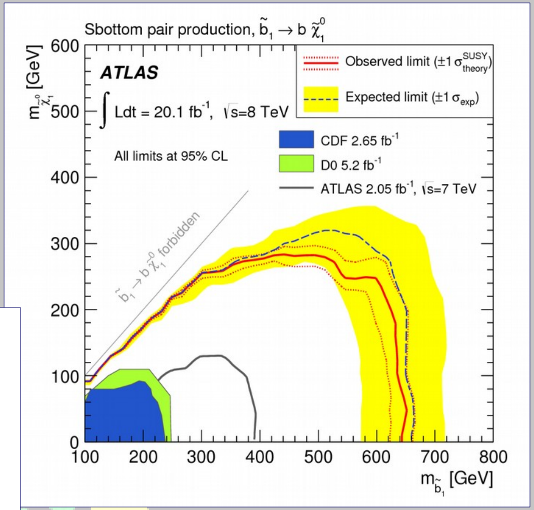
With the article's cuts

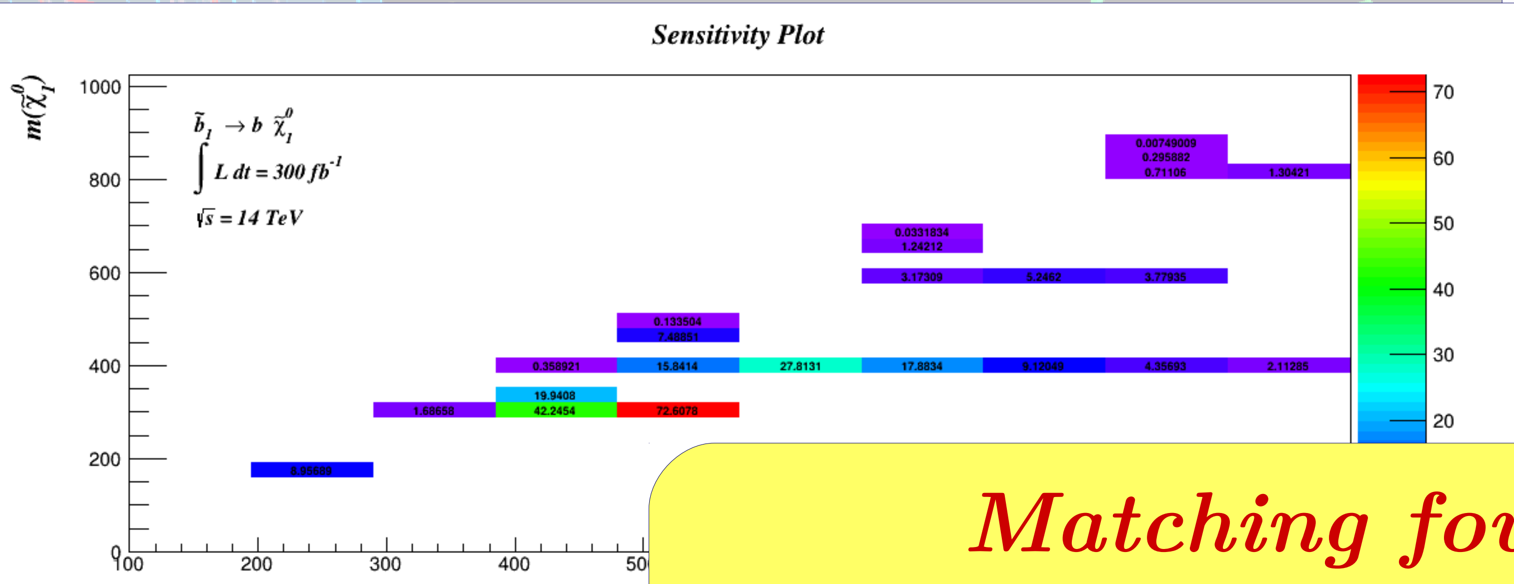


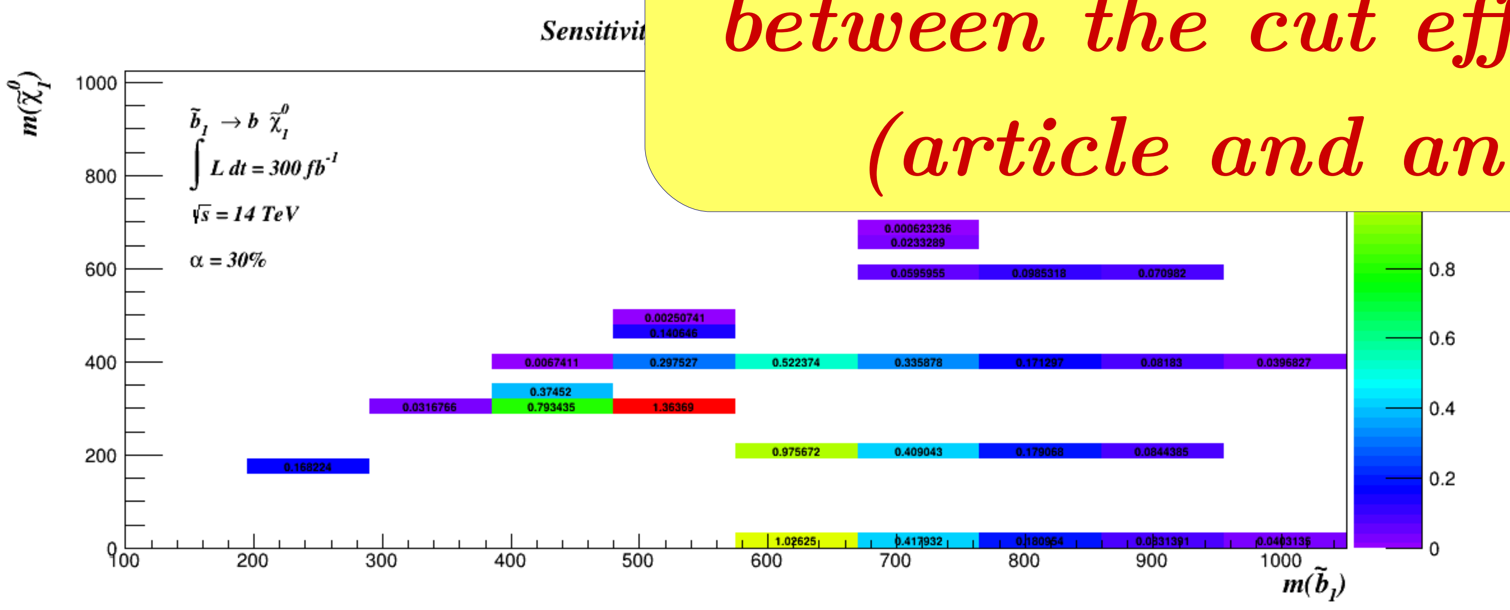




With the article's cuts

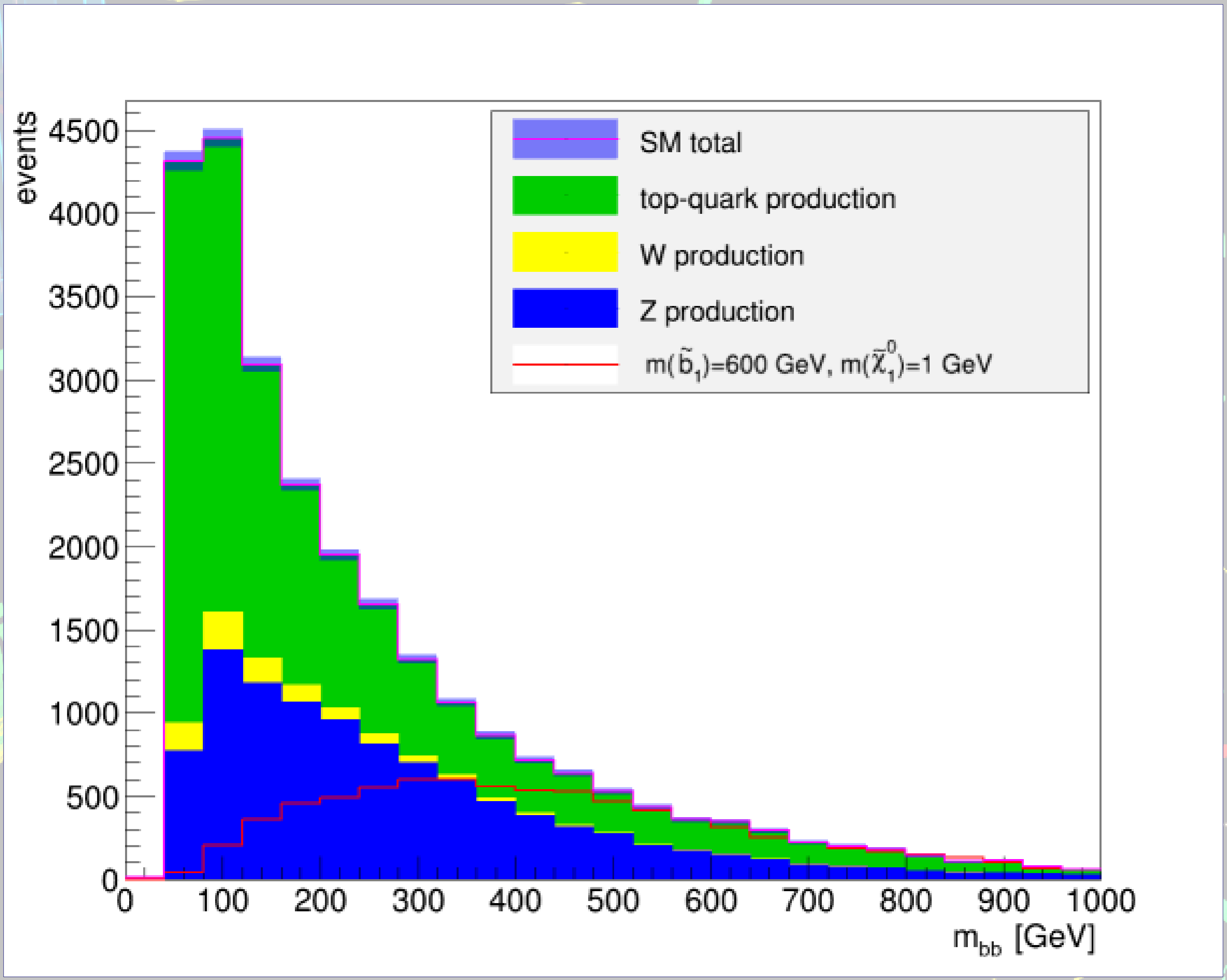




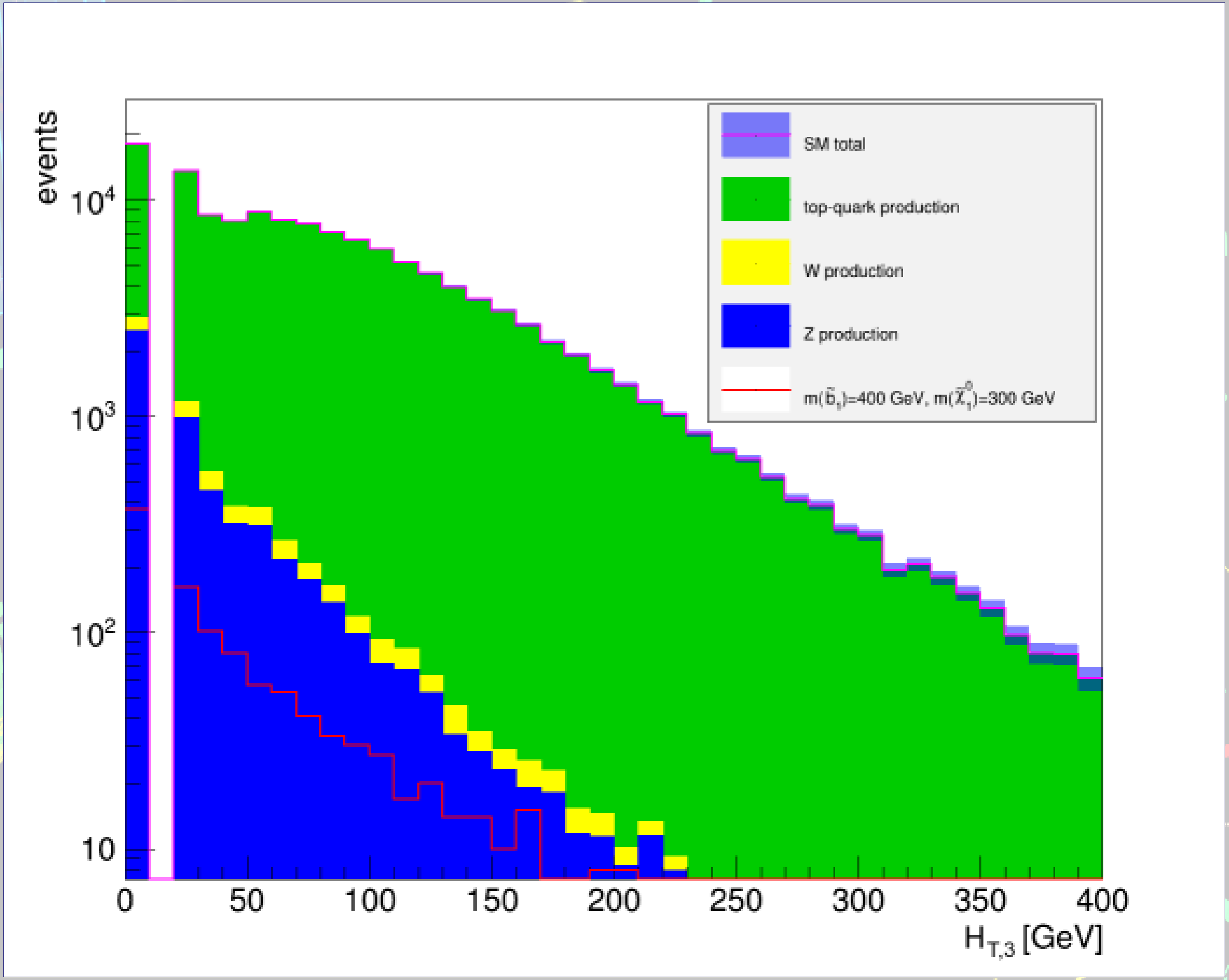


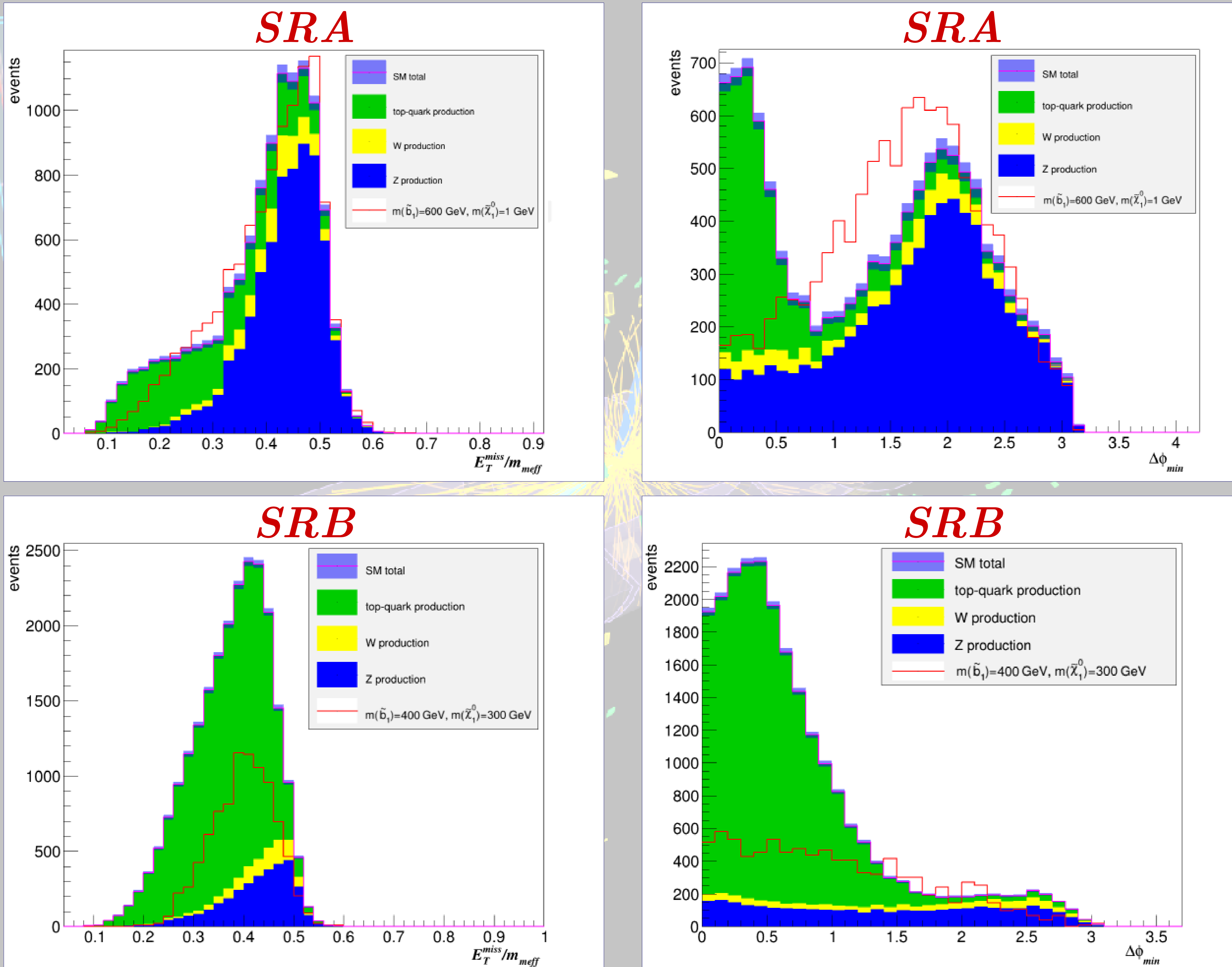
Matching found between the cut efficiencies (article and analysis)

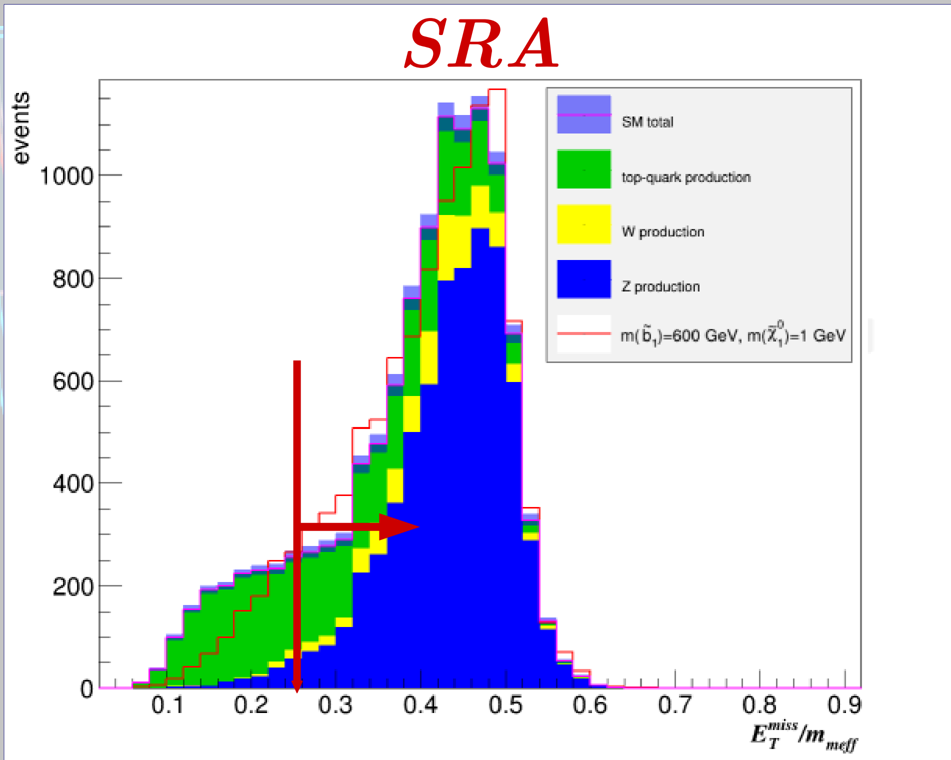
SRA signal optimization



SRB signal optimization




SRA
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=600 GeV, m($\tilde{\chi}_1^0$)=1 GeV
E_T^{miss}/m_{meff}
SRA
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=600 GeV, m($\tilde{\chi}_1^0$)=1 GeV
$\Delta\phi_{min}$
SRB
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=400 GeV, m($\tilde{\chi}_1^0$)=300 GeV
E_T^{miss}/m_{meff}
SRB
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=400 GeV, m($\tilde{\chi}_1^0$)=300 GeV
$\Delta\phi_{min}$



SRA
events
SM total
top-quark production
W production
Z production
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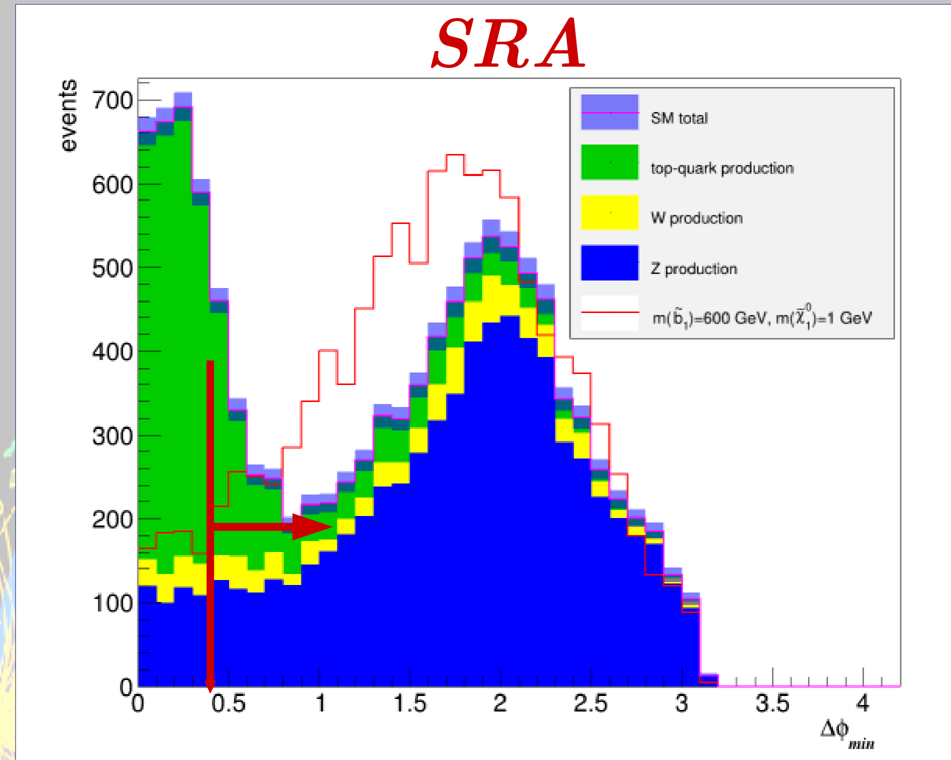
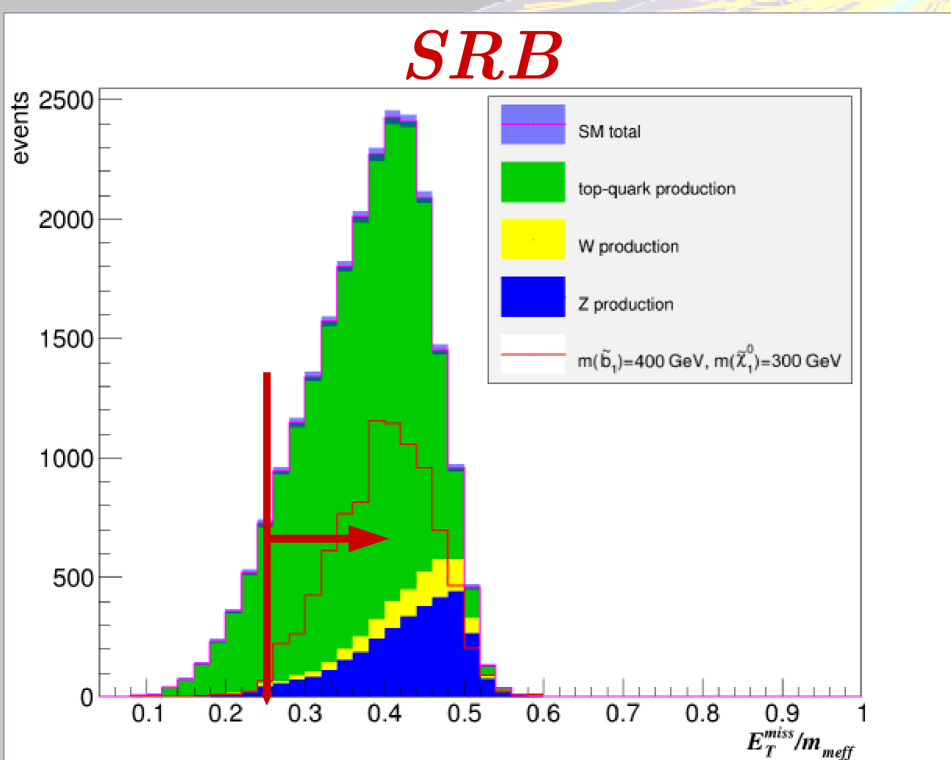
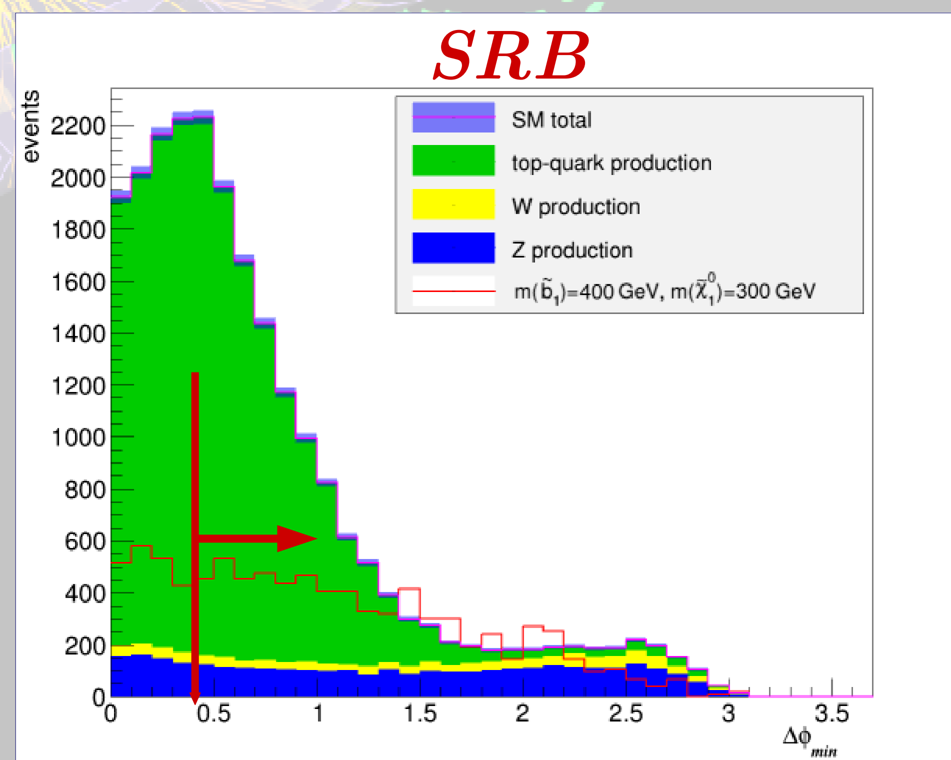
E_T^{miss}/m_{meff}



SRA
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=600 GeV, m($\tilde{\chi}_1^0$)=1 GeV
$\Delta\phi_{min}$

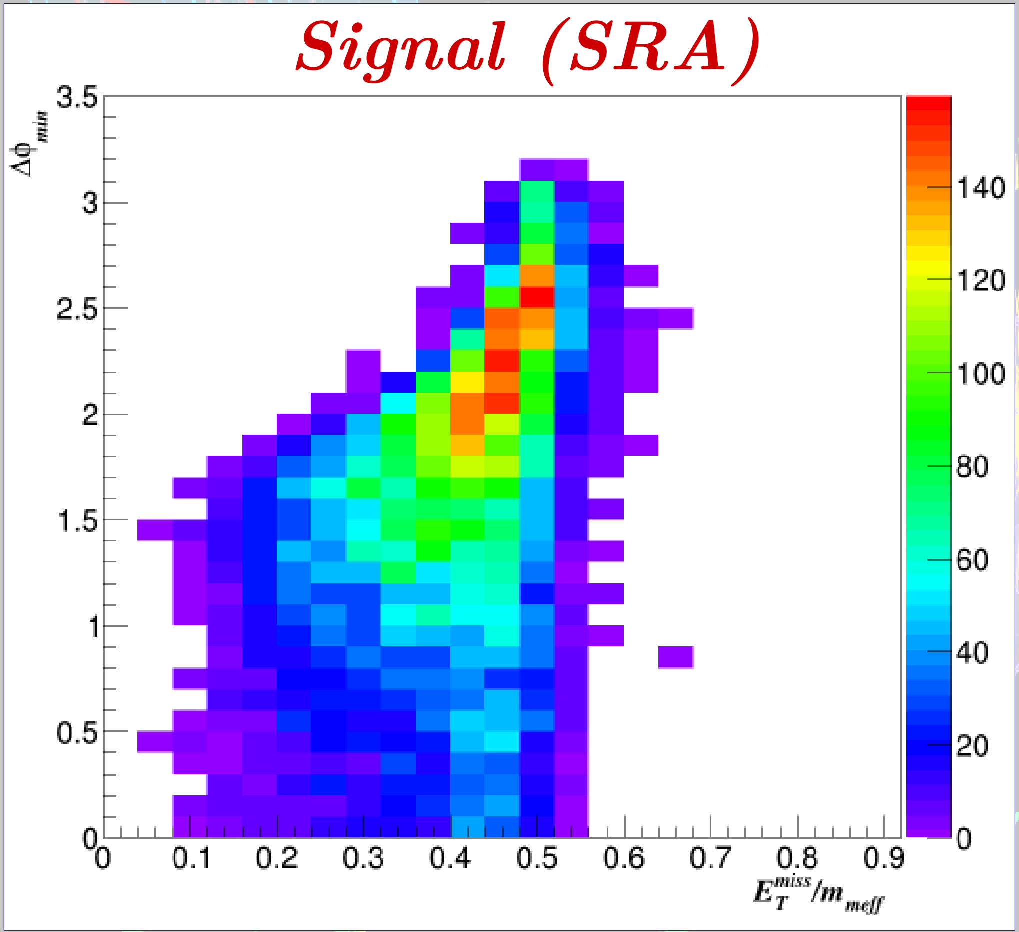


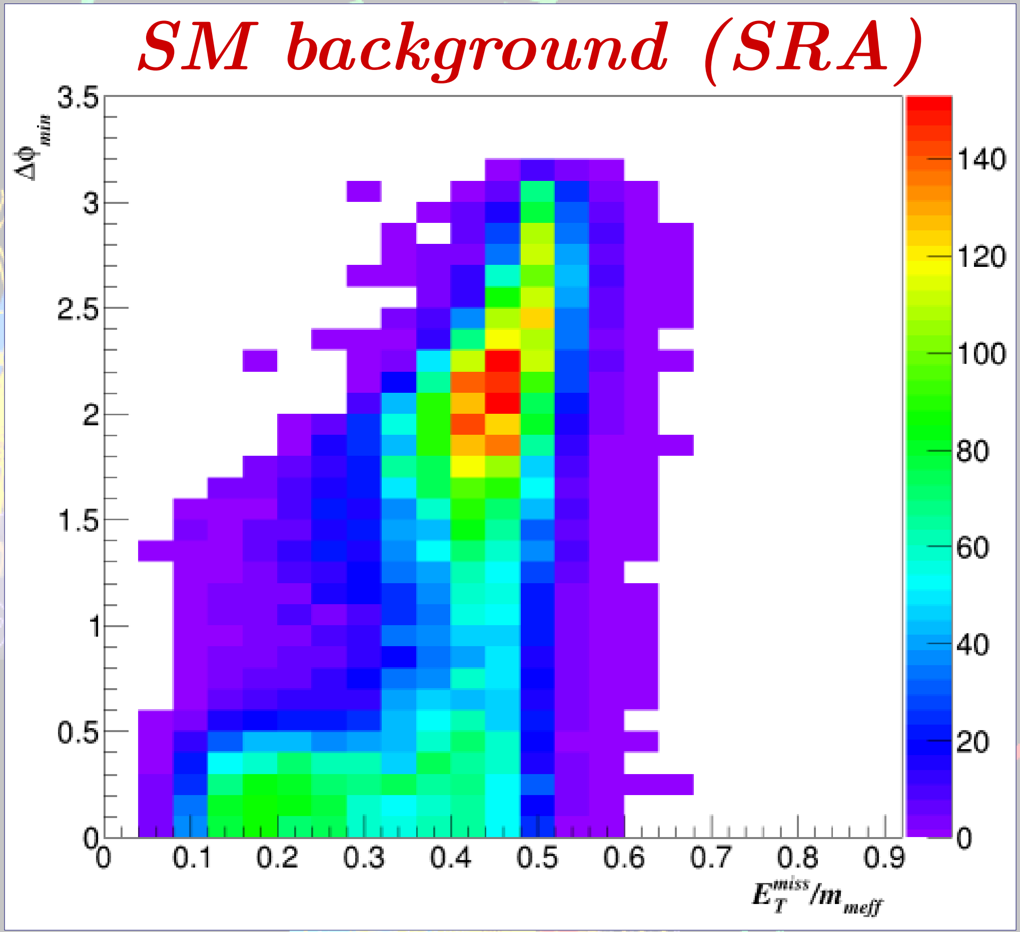
SRB
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=400 GeV, m($\tilde{\chi}_1^0$)=300 GeV
E_T^{miss}/m_{meff}



SRB
events
SM total
top-quark production
W production
Z production
m($\tilde{b}_1$)=400 GeV, m($\tilde{\chi}_1^0$)=300 GeV
$\Delta\phi_{min}$

Variables correlation and optimization





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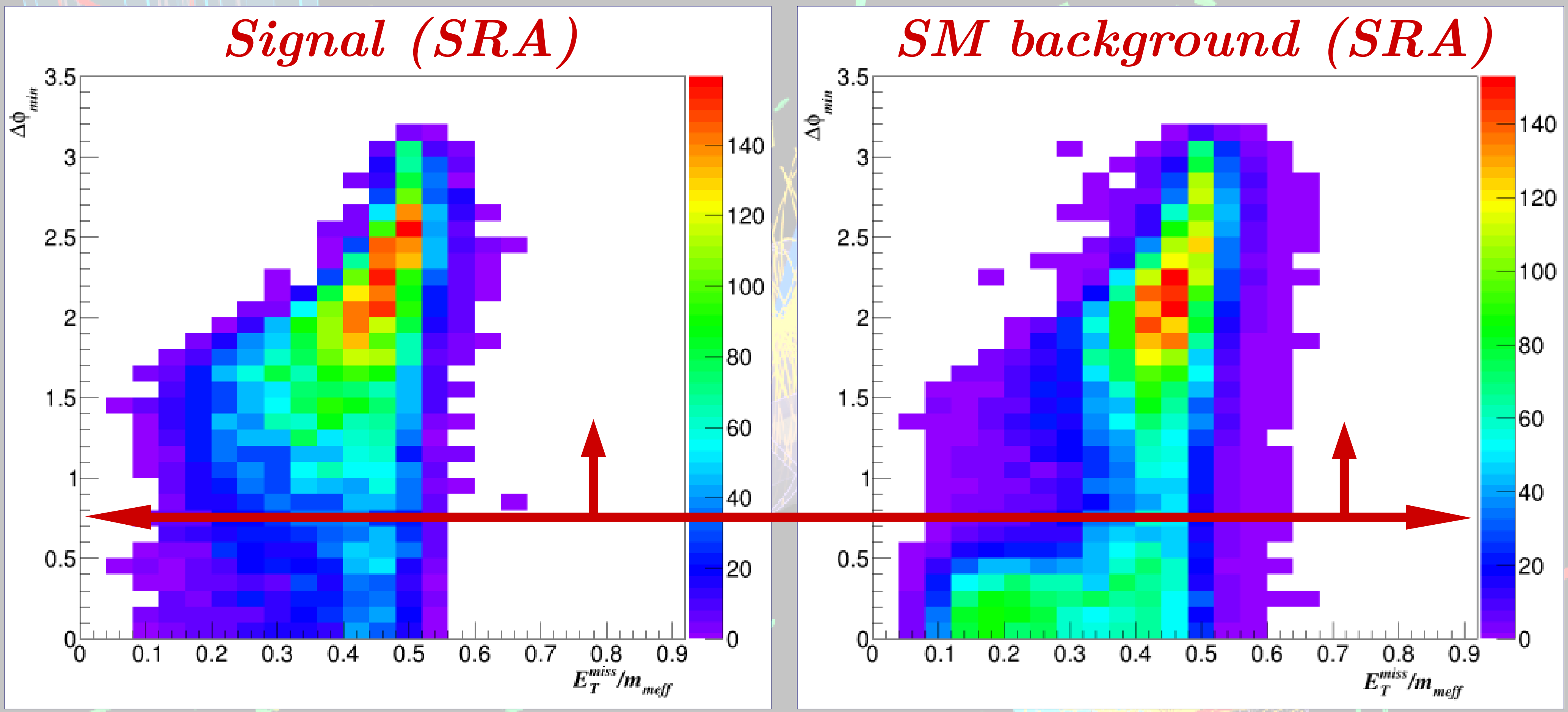
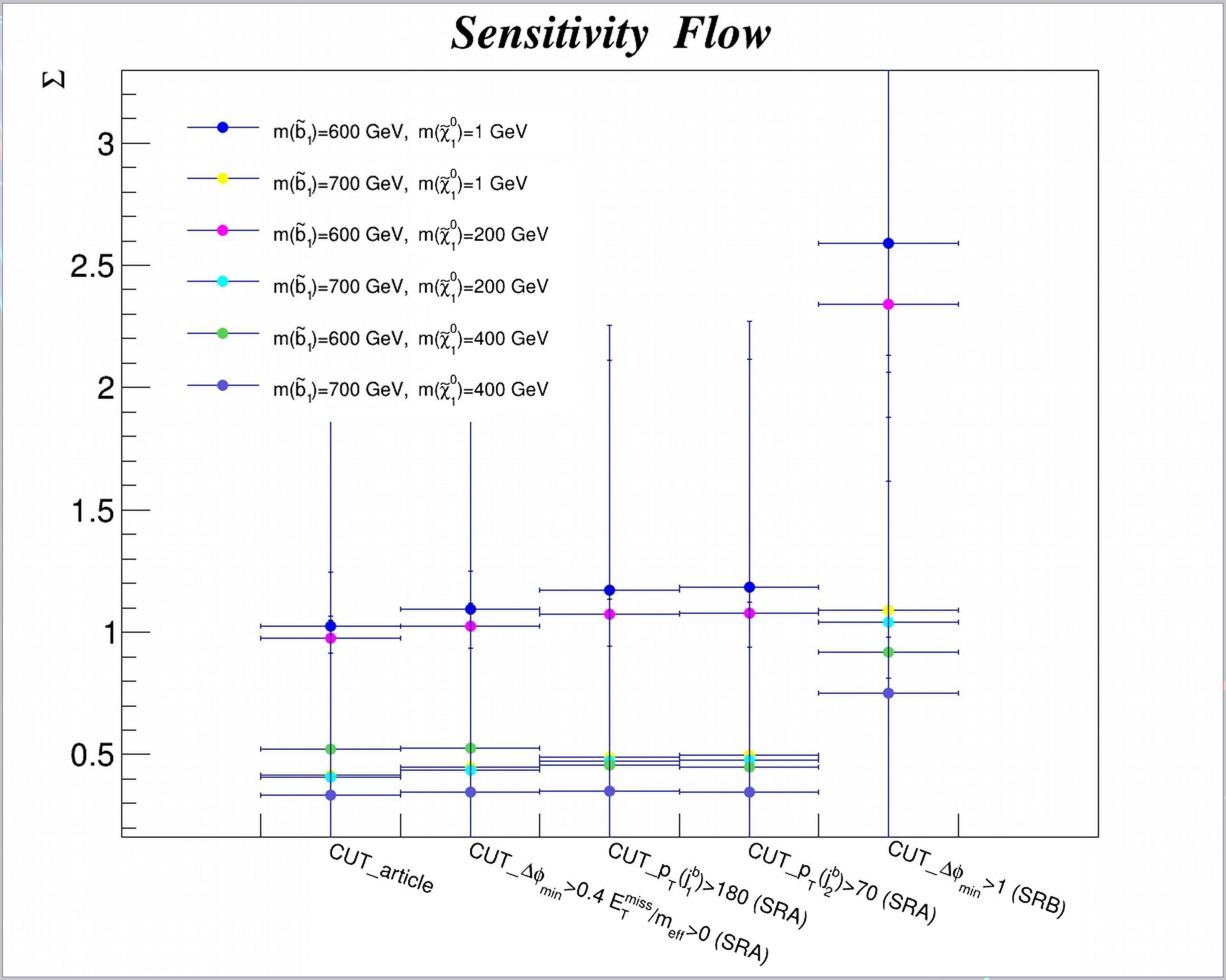
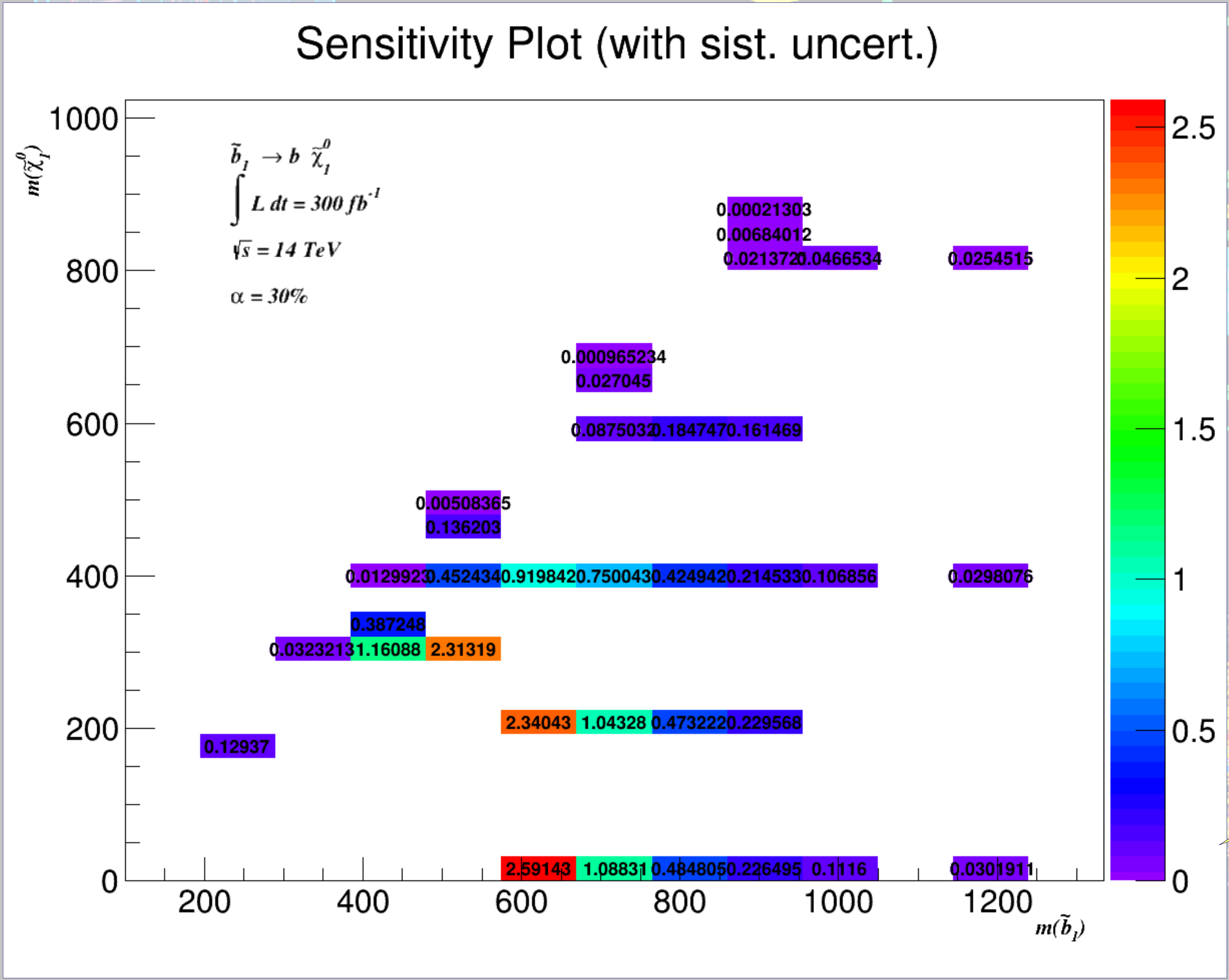
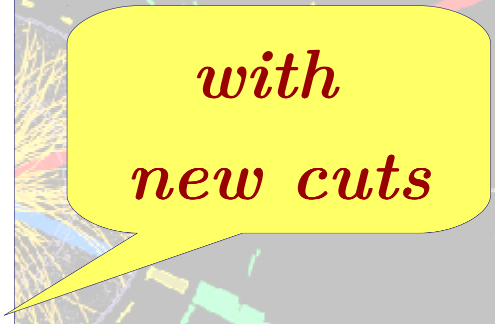




Sensitivity Flow
Σ
3
2.5
2
1.5
1
0.5
m($\tilde{b}_1$)=600 GeV, m($\tilde{\chi}_1^0$)=1 GeV
m($\tilde{b}_1$)=700 GeV, m($\tilde{\chi}_1^0$)=1 GeV
m($\tilde{b}_1$)=600 GeV, m($\tilde{\chi}_1^0$)=200 GeV
m($\tilde{b}_1$)=700 GeV, m($\tilde{\chi}_1^0$)=200 GeV
m($\tilde{b}_1$)=600 GeV, m($\tilde{\chi}_1^0$)=400 GeV
m($\tilde{b}_1$)=700 GeV, m($\tilde{\chi}_1^0$)=400 GeV
CUT_article
CUT_$\Delta\phi_{min}$>0.4 E_T^{miss}/m_{eff}>0 (SRA)
CUT_$p_T(j_1^b)$>180 (SRA)
CUT_$p_T(j_2^b)$>70 (SRA)
CUT_$\Delta\phi_{min}$>1 (SRB)

After 1^{ST} optimization





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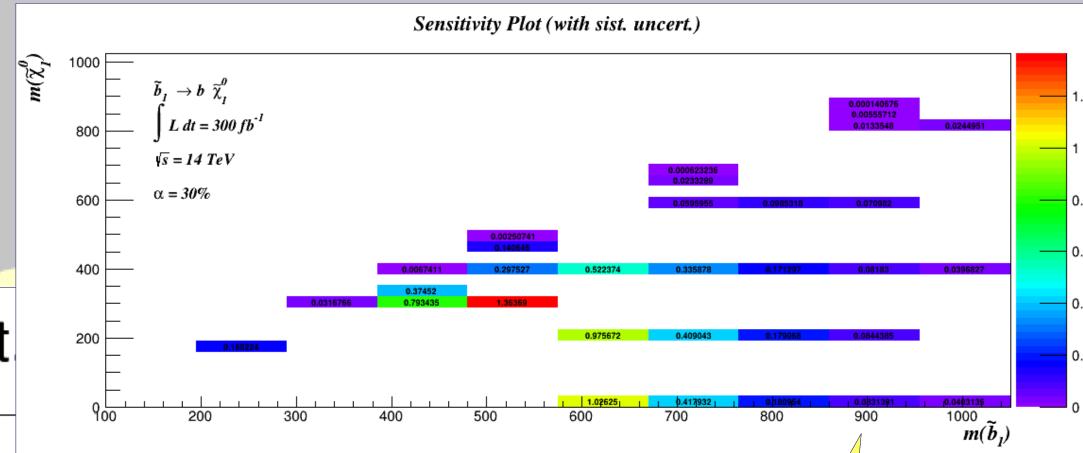
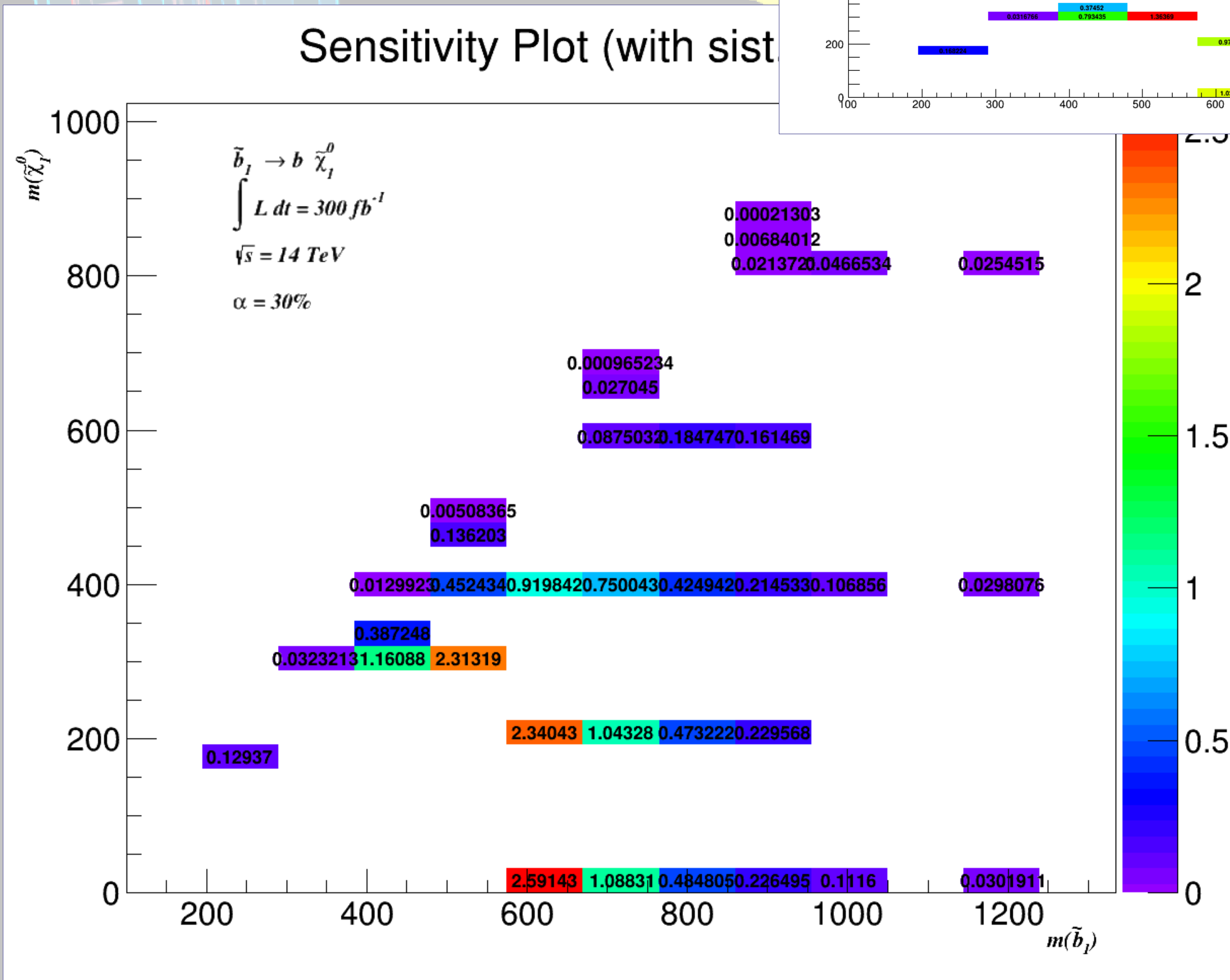
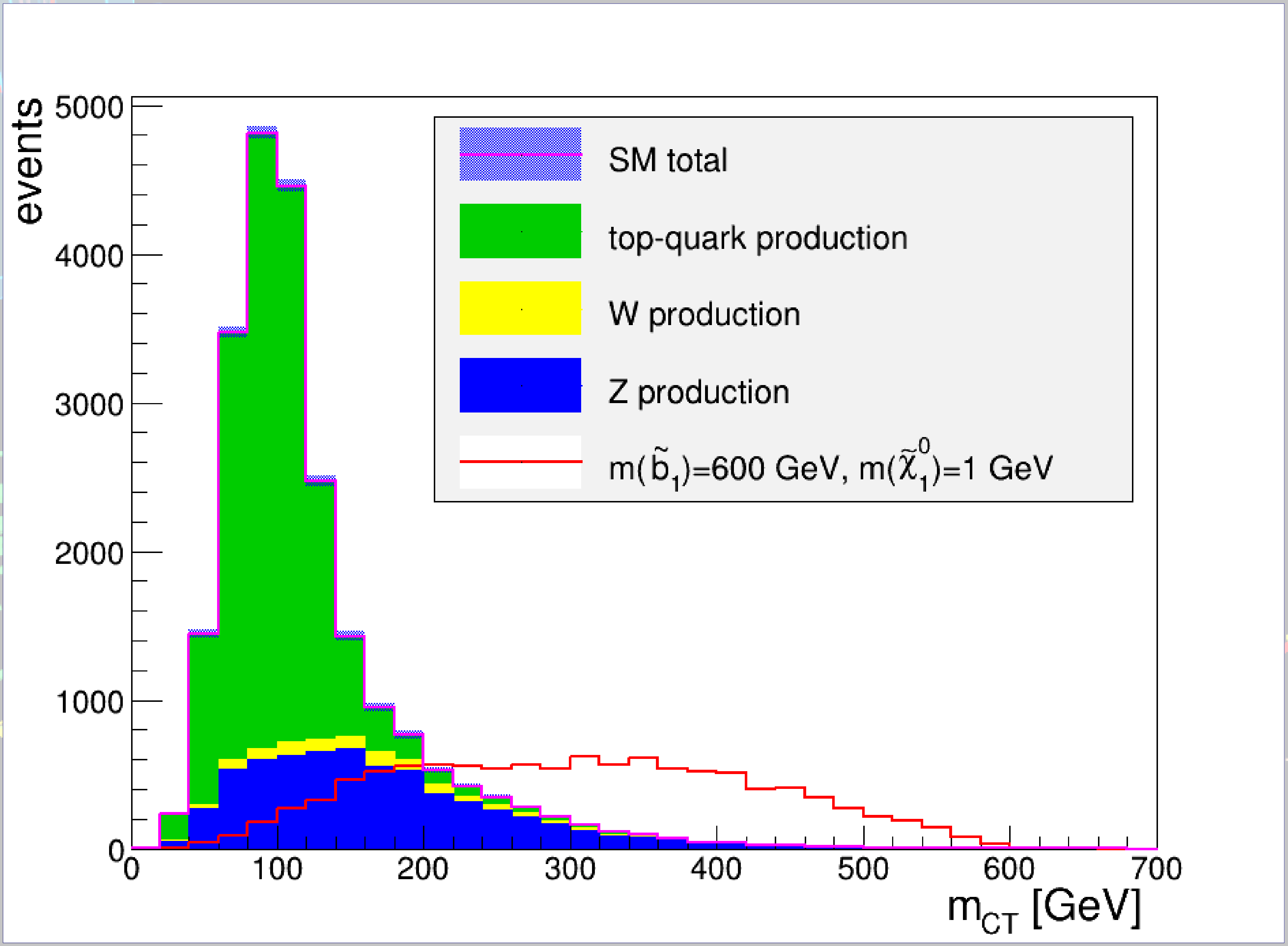




(old) with article cuts

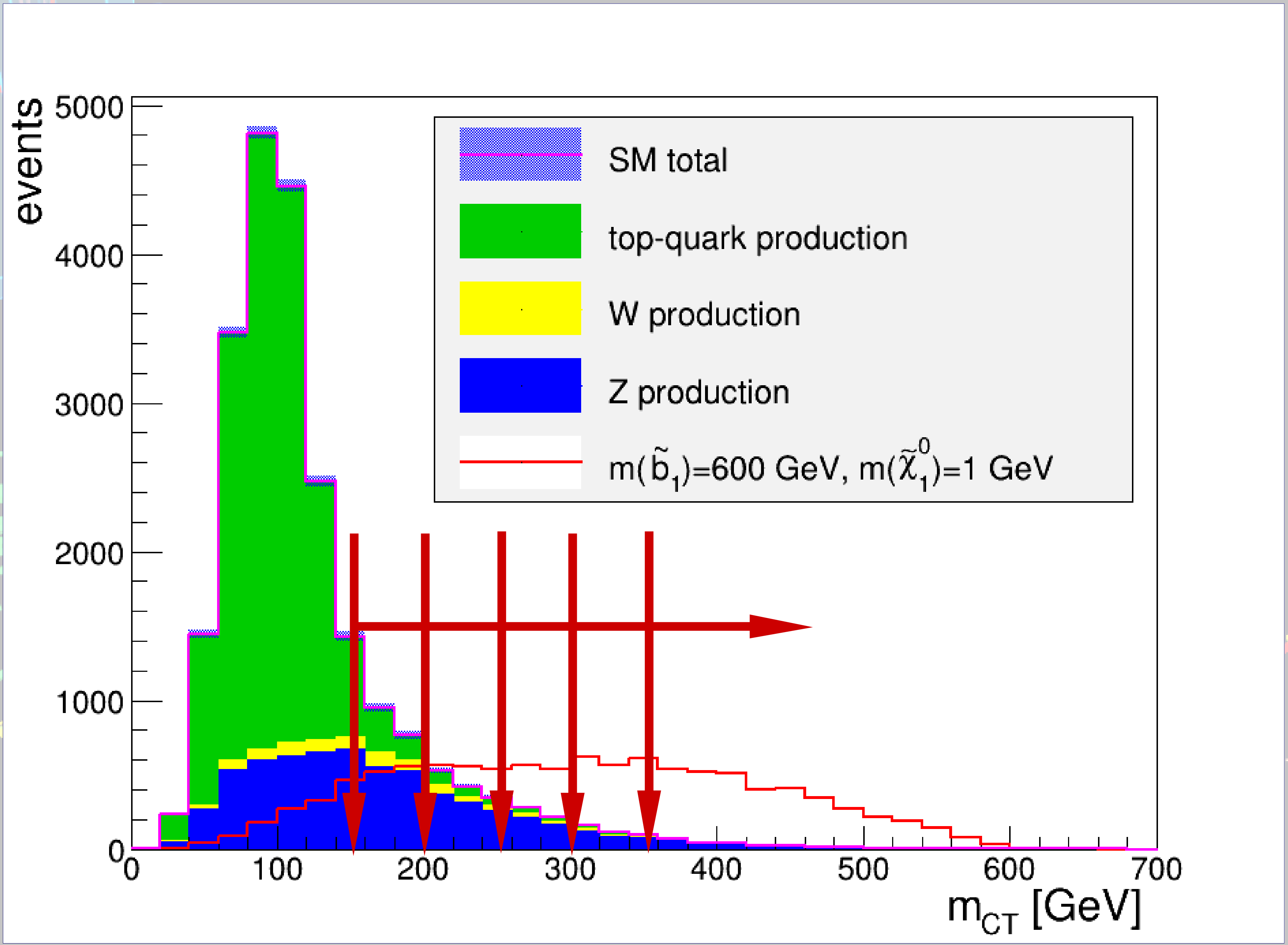
with new cuts

m_{CT} cut flow



events
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
m_CT [GeV]
SM total
top-quark production
W production
Z production
m(b̃_1)=600 GeV, m(χ̃^0_1)=1 GeV

m_{CT} cut flow



events
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
m_{CT} [GeV]
SM total
top-quark production
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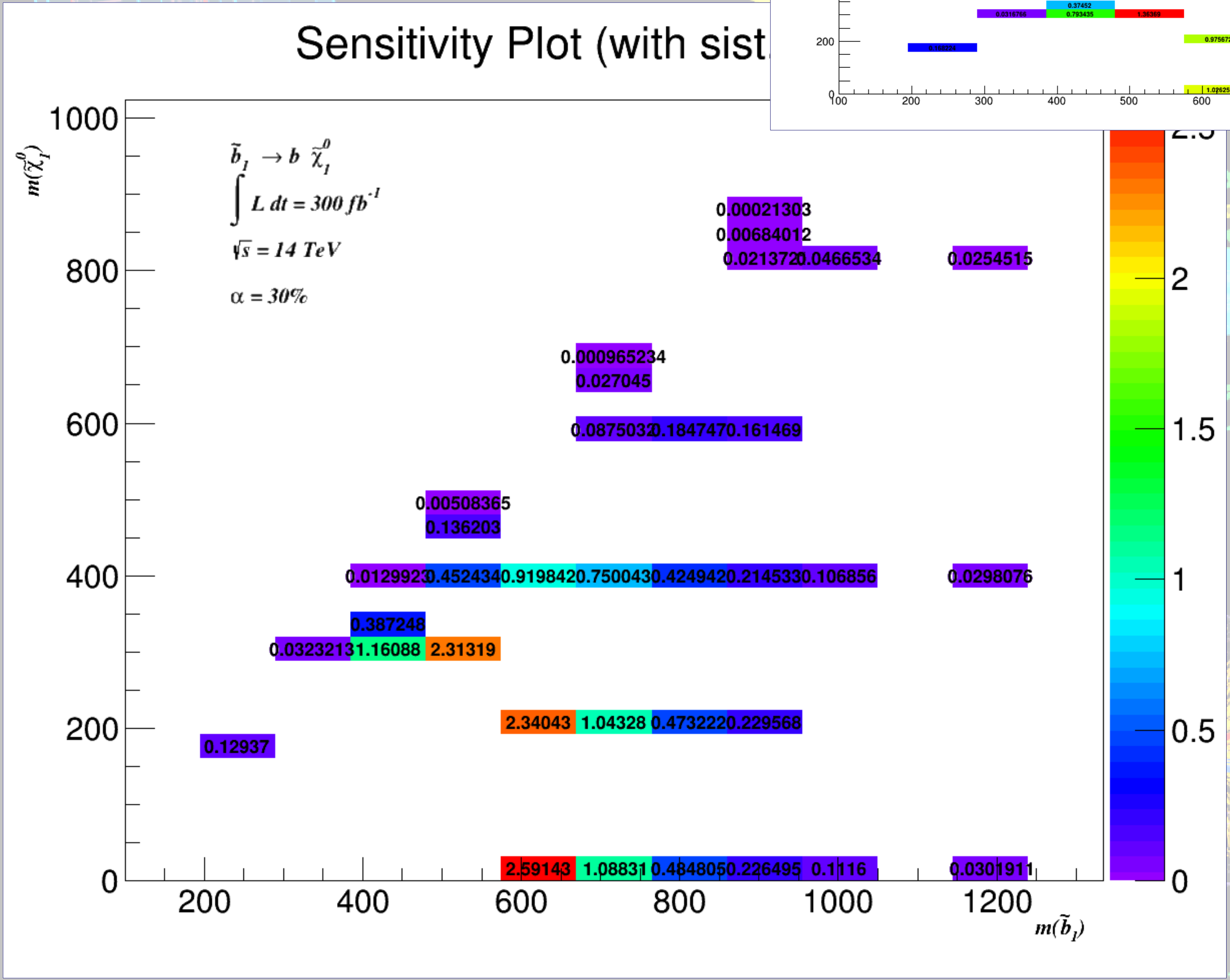
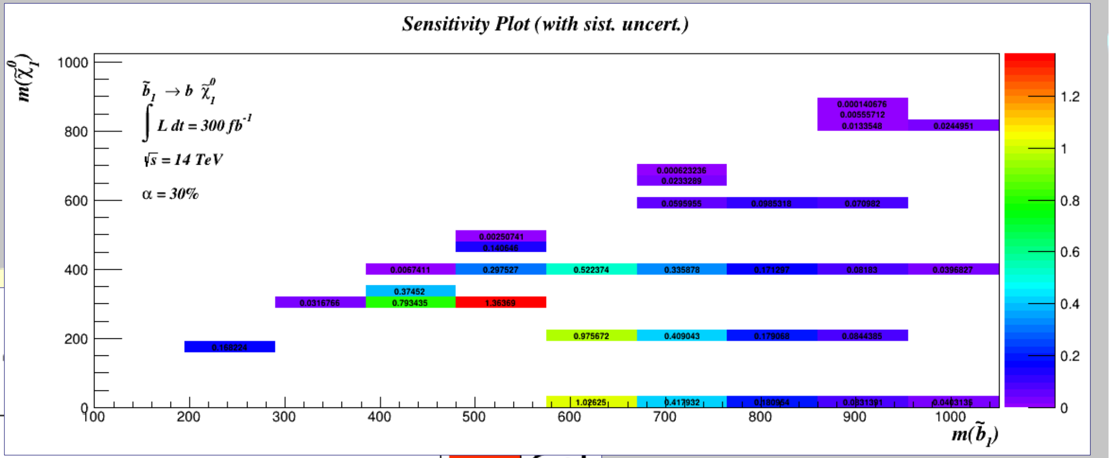
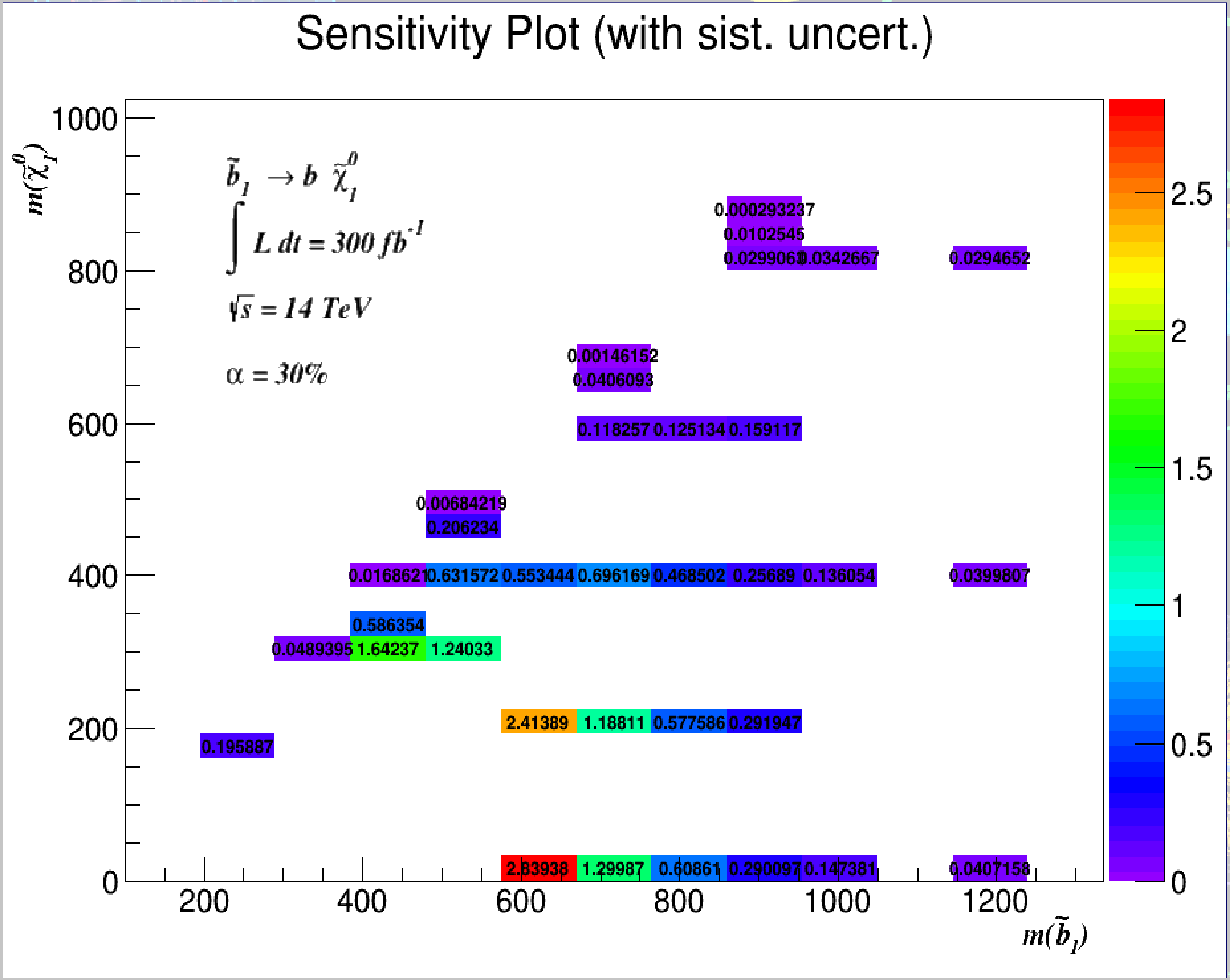
After 1ST optimization





After 2^{ND} optimization (with m_{CT} new selections)



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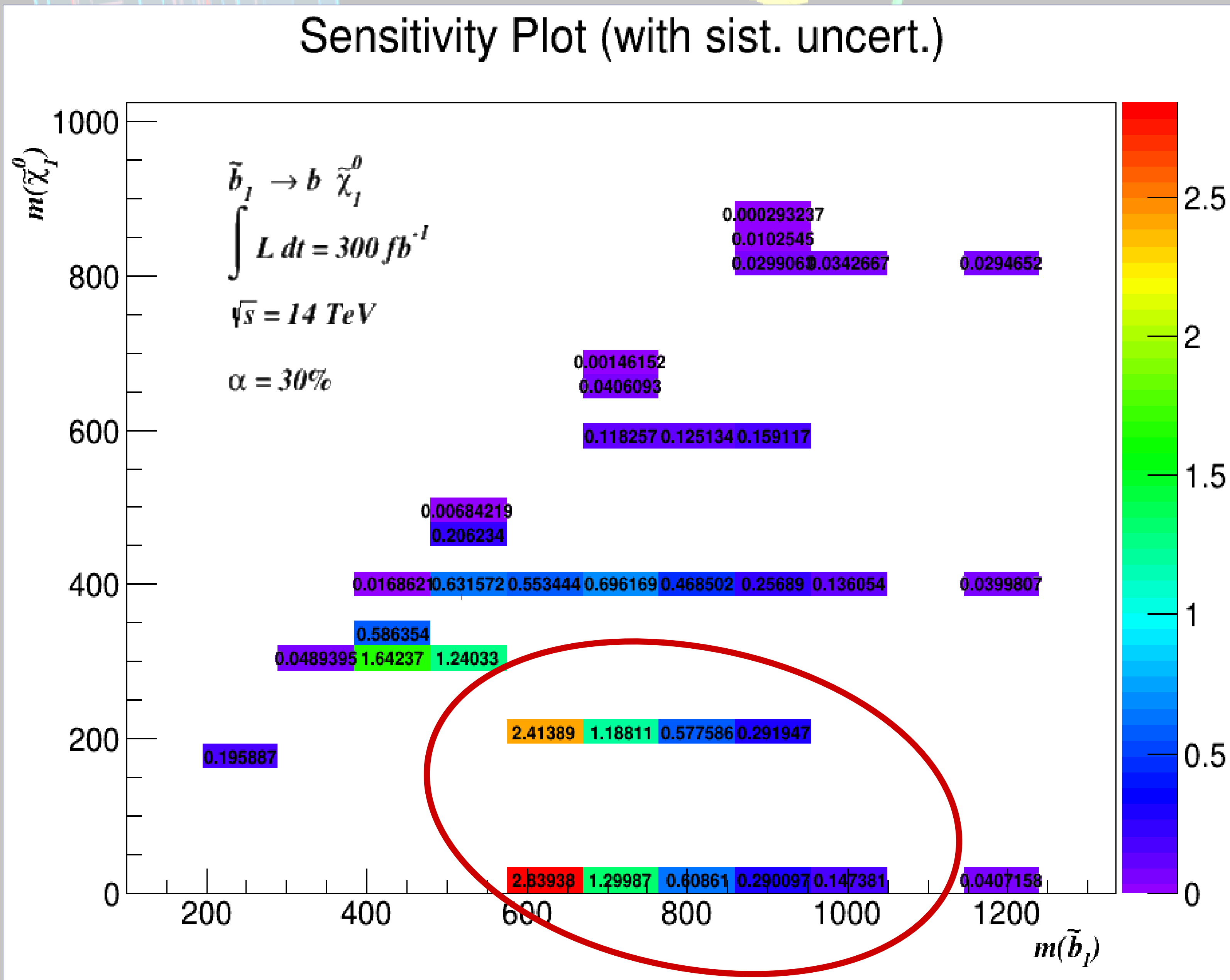
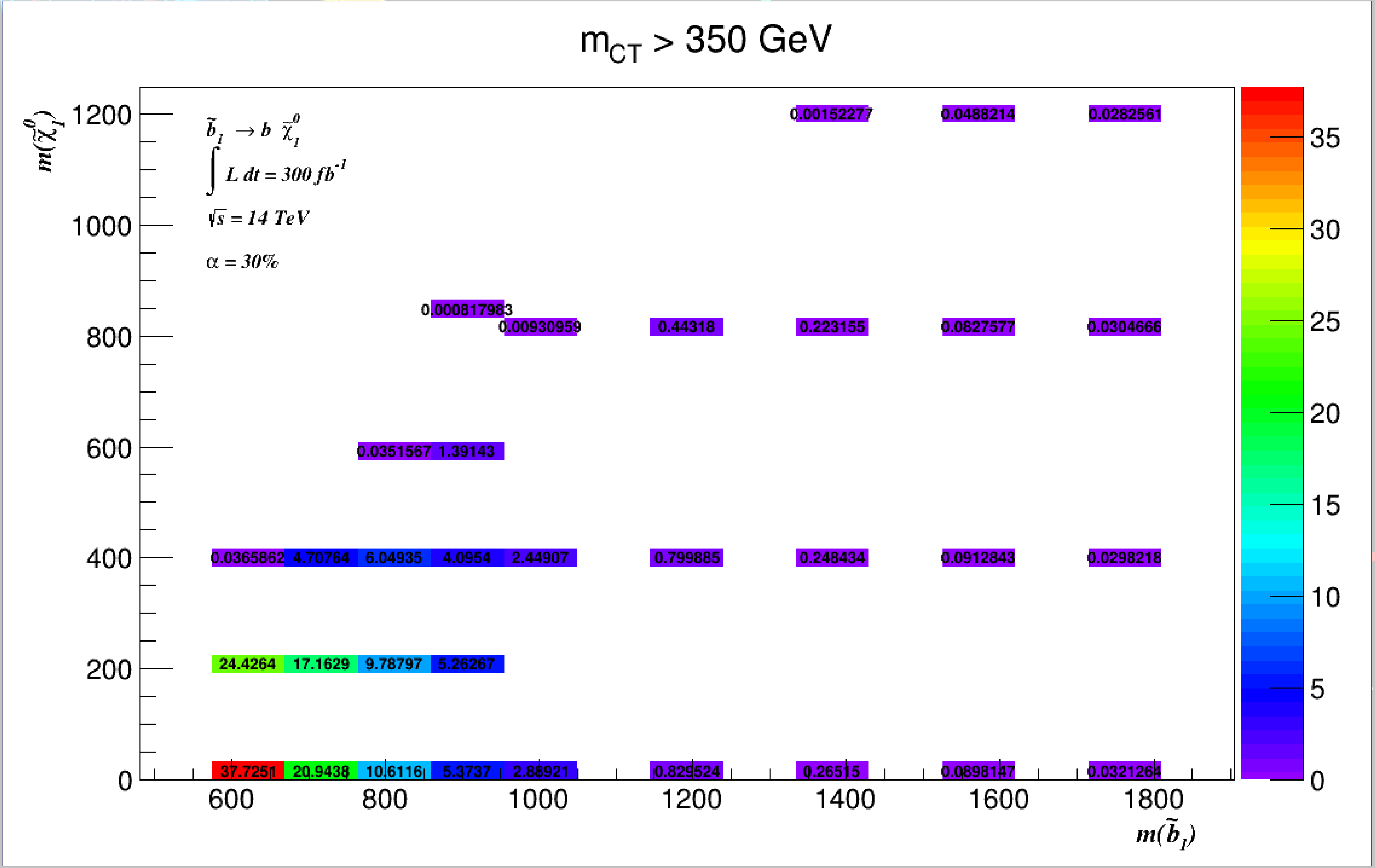


Final m_{CT} selections (SRA only)



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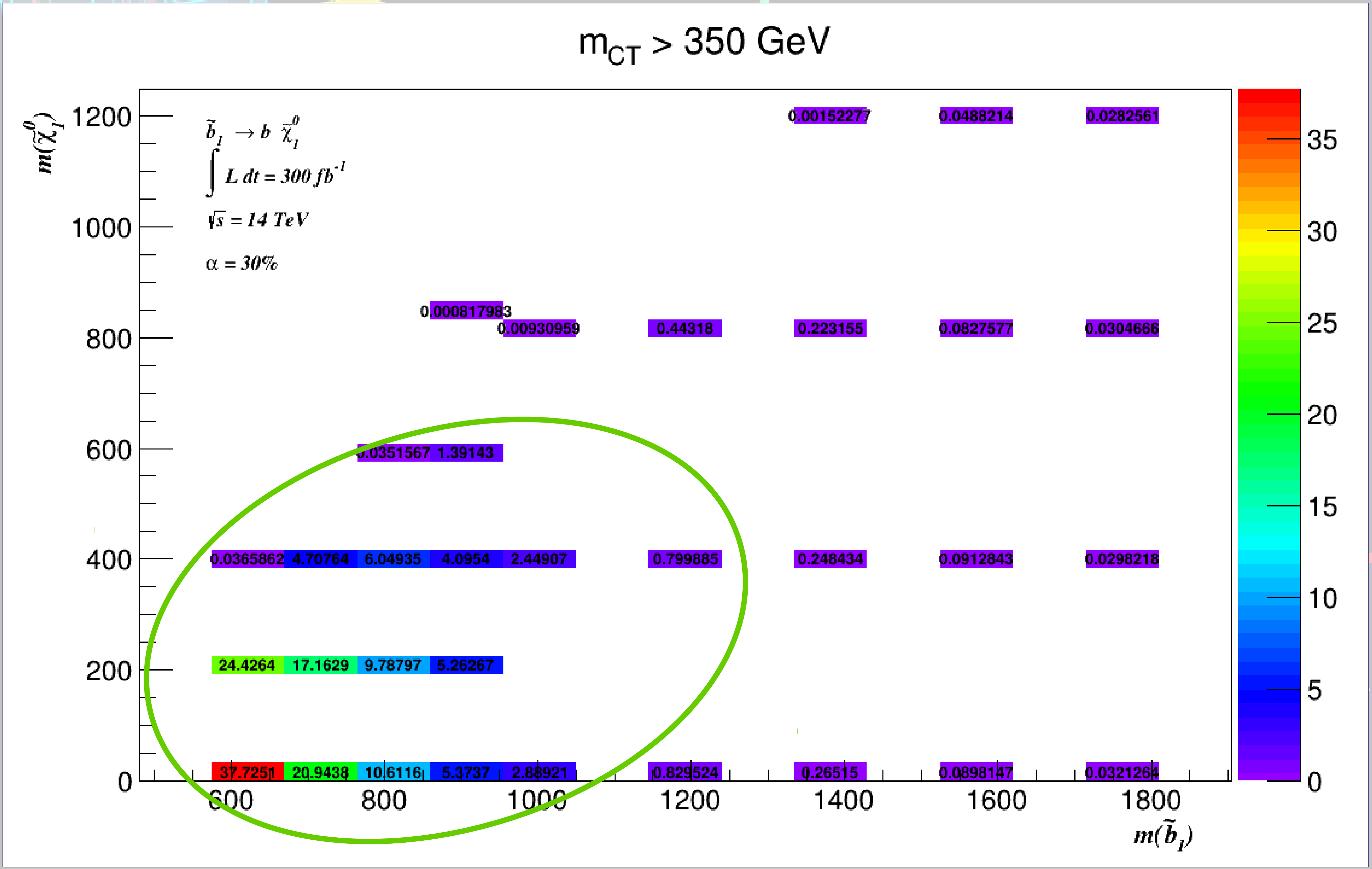

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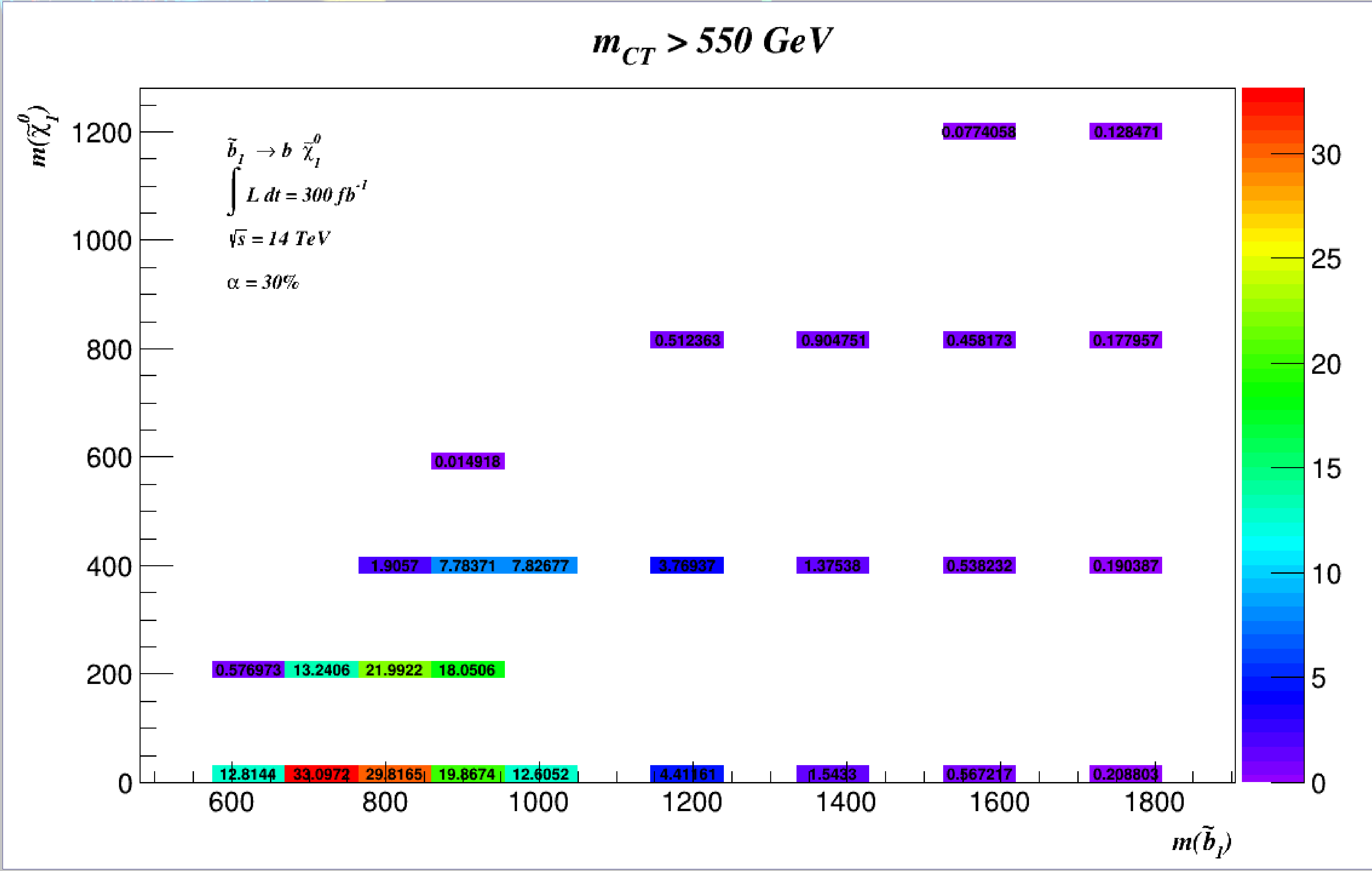

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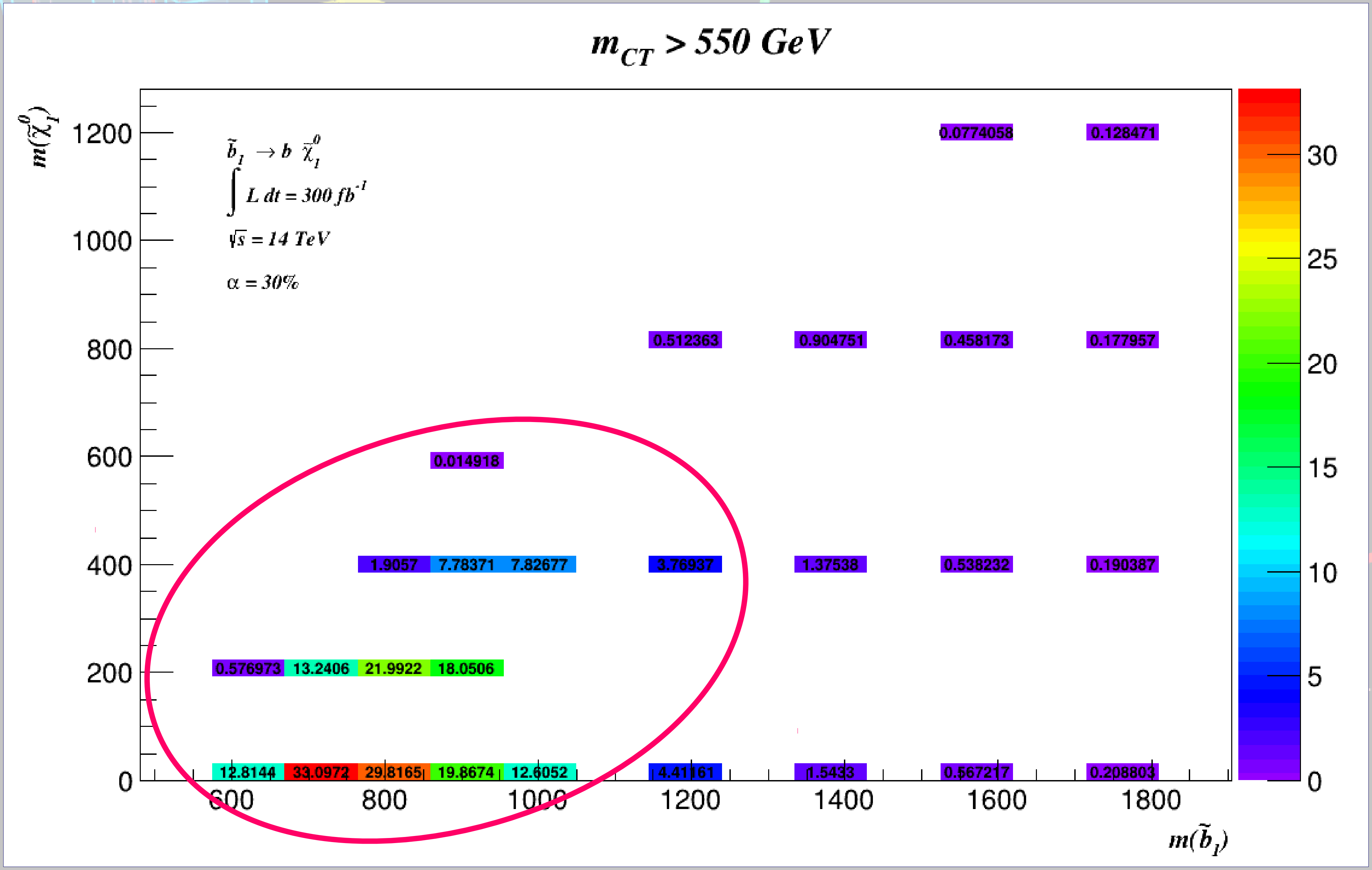
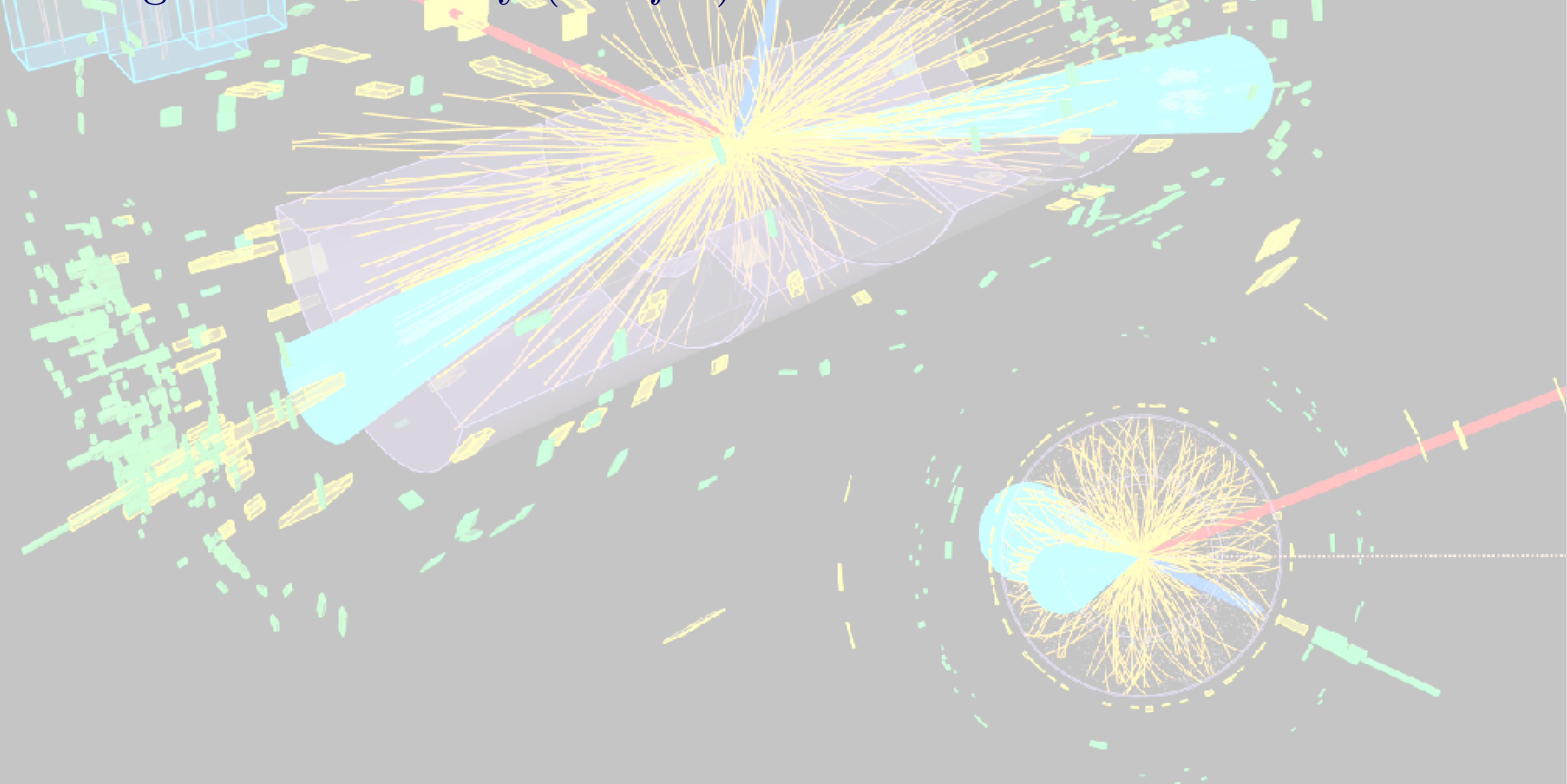


Summary

- Worked only with MC samples
- Replicate the analysis performed using 8 *TeV* datasets. Then, try to optimize the selections for the new energy (14 *TeV*) and integrated luminosity (300 fb^{-1})



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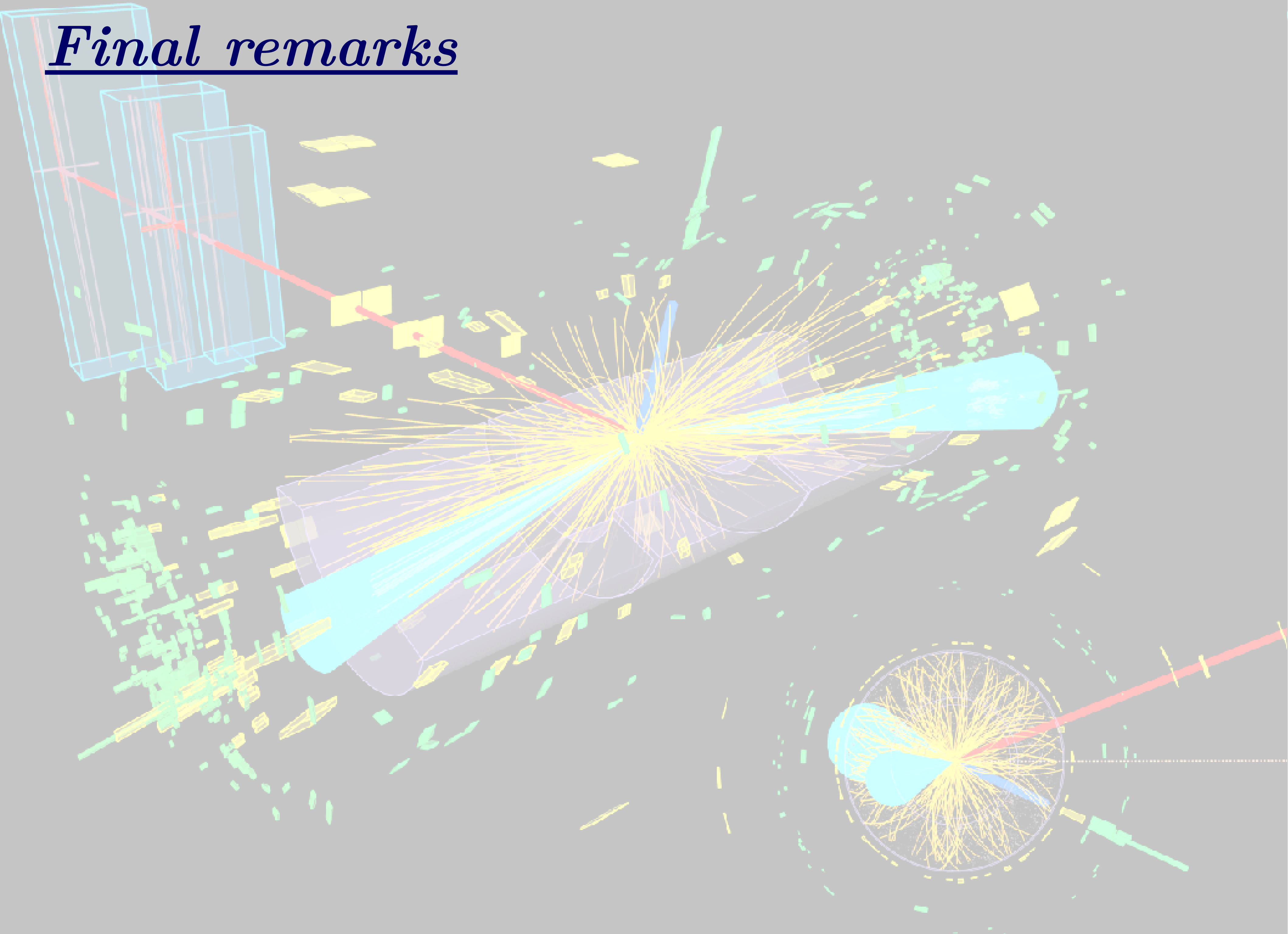
- ➔ With $m_{CT} > 350, 550\ GeV$, sensitivity increased substantially on signal points with high $m(\widetilde{b}_1)$ and low $m(\widetilde{\chi}_1^0)$ (large mass splitting)

Final remarks



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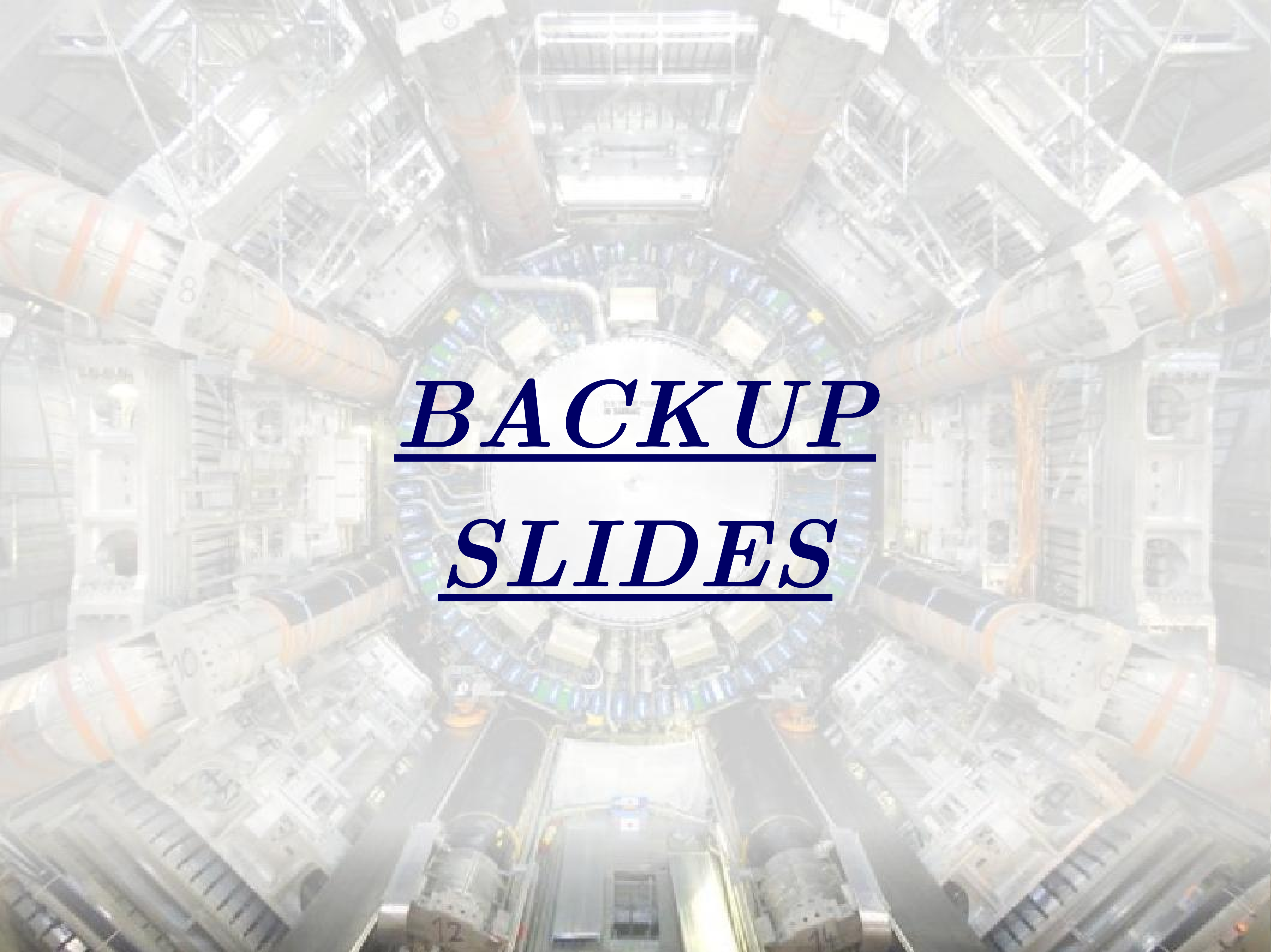
- Further optimizations needed in SRB

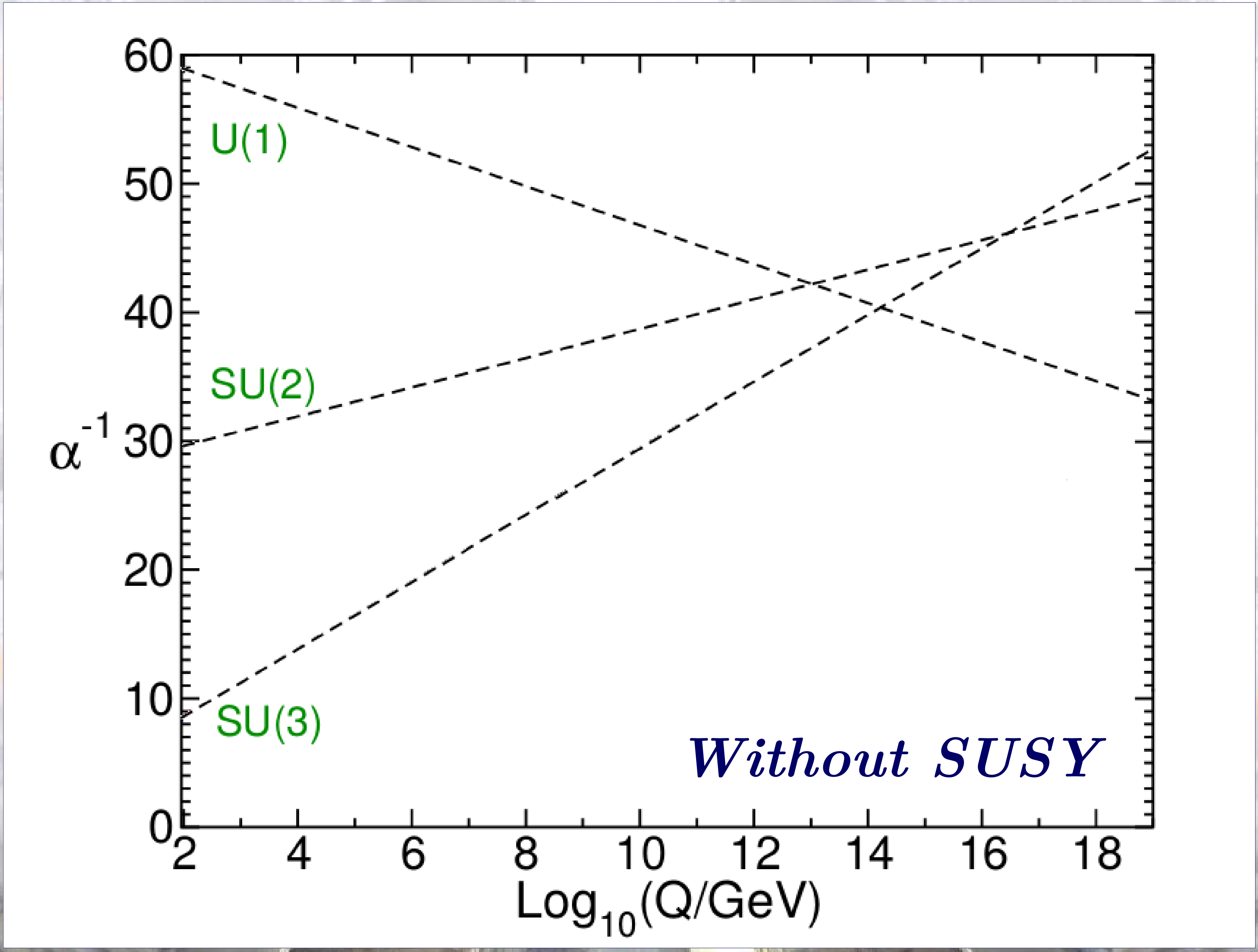
Thank you for the attention



BACKUP SLIDES

Introduction: SM Issues

➔ **Coupling constants unification**



Introduction: SM Issues

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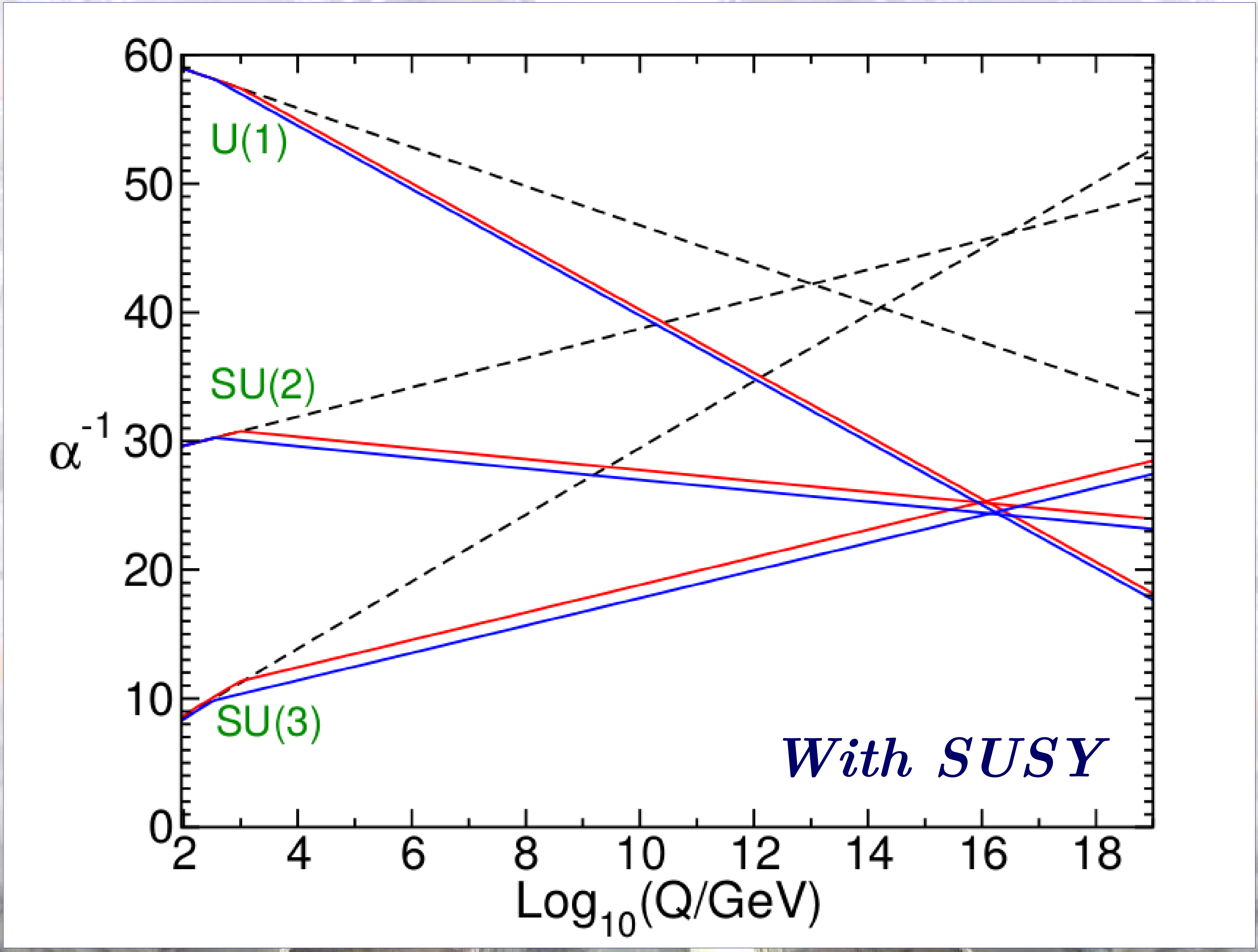

Introduction: SM Issues

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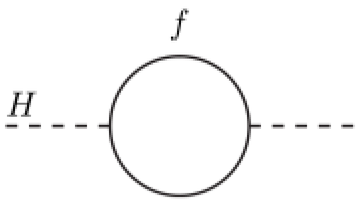

$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2 + \dots .$$

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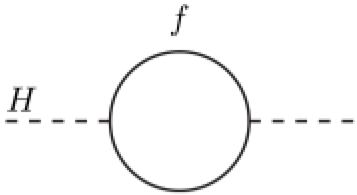

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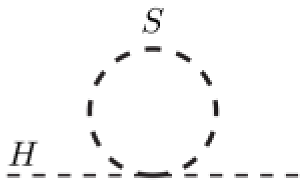

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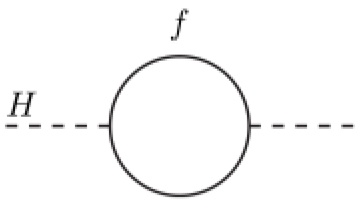

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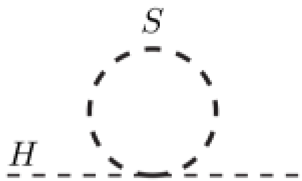

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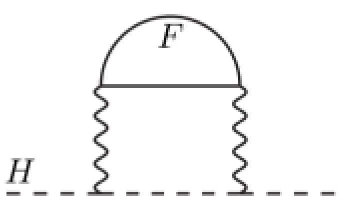
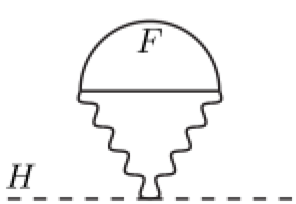


$$\Delta m_H^2 = C_H T_F \left(\frac{g^2}{16\pi^2}\right)^2 \left[a\Lambda_{\mathrm{UV}}^2 + 24m_F^2 \ln(\Lambda_{\mathrm{UV}}/m_F) + \ldots\right]$$



Introduction: SUper SYmmetry (SUSY)

➔ *MSSM (Minimal Supersymmetric Standard Model)*: minimal extension of the SM, with the lowest number of new particles and interactions, allowed by phenomenology.

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➔ *R-Parity* (P_R) or *Matter Parity* (P_M): symmetries added in MSSM, that restricts the allowed values of the *leptonic* (L) and *baryonic* (B) number.

$$P_M = (-1)^{3(B-L)} \qquad P_R = (-1)^{3(B-L)+2s}$$

(where s is the spin) equivalent in any interaction.

$$\begin{cases} P_R = 1 & \textbf{\textit{SM particles+higgs bosons}} \\ P_R = -1 & \textbf{\textit{MSSM particles+higgsinos}} \end{cases}$$

Introduction: SUper SYmmetry (SUSY)

If P_R is conserved in every MSSM interaction:

- The lightest sparticle ($P_R = -1$) or *LSP*, is *stable* (cannot decay into SM particles, since it would violate P_R). If it's electrically neutral, it can be a candidate for non-baryonic Dark Matter!

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- In *collider experiments* (i.e. LHC), sparticles are *always produced in even numbers* (usually in pairs).

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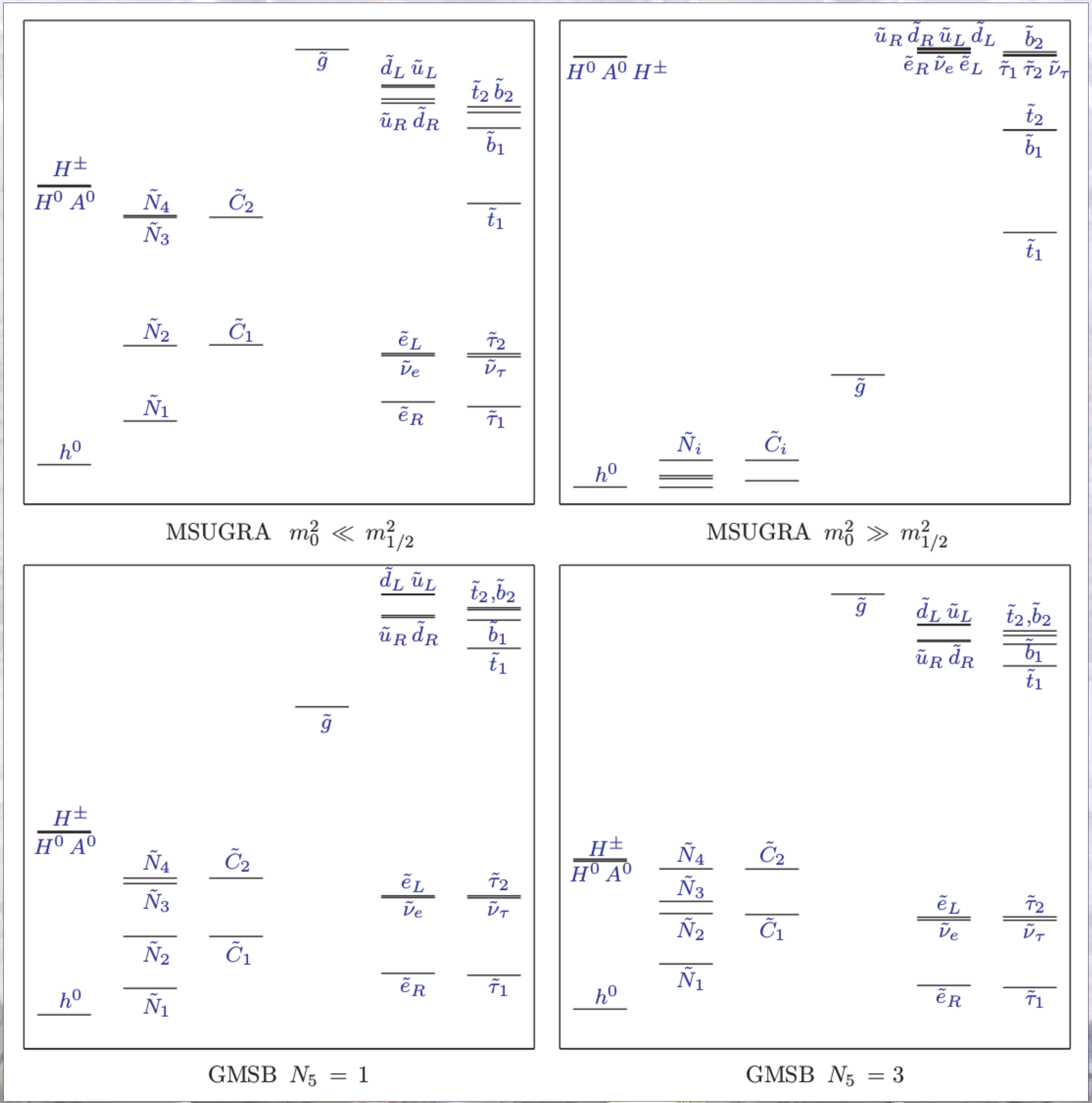
- ➔ There are some restrictions on the sparticles masses and mixing parameters. However, there is still a large number of free parameters in the theory. Assumptions on MSSM particle mass-spectrum are needed.

Introduction: SUSY mass-spectra



MSUGRA $m_0^2 \ll m_{1/2}^2$

MSUGRA $m_0^2 \gg m_{1/2}^2$

GMSB $N_5 = 1$

GMSB $N_5 = 3$