

# SUSY overview and new directions for Run3



ROBERTO FRANCESCHINI - ROME 3 U. - SEPT.11TH 2023



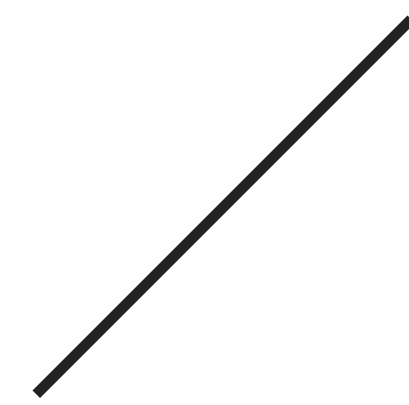
# What to learn from SUSY searches in 2023 (not a click-bait)

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# Why theorists like SUSY

- SUSY is the most complete microscopic theory conceived so far to go beyond the SM



When I say “complete” I mean that it is a theory that

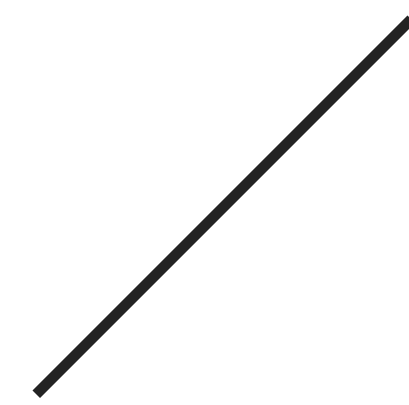
- in principle can be used to compute any\* observable quantity (famously the mass of the Higgs boson can be computed in SUSY,  $m_h < m_Z$  at tree-level in the MSSM ... )
- in principle contains the ingredients to deal with all/most issues that the SM cannot address (e.g. can give/accommodate Dark Matter, can give/accommodate/not-disturb flavor, has something to say on gravity)
- its main role and motivation for collider studies has been in the solution of the “weak/gravity hierarchy problem”

**Supersymmetric models are extremely compelling theoretically**



# What is to be liked in SUSY as an experimentalist?

- SUSY is the most complete “ATLAS” of experimental signals conceived so far to go beyond the SM



When I say “complete” I mean that

- it is quite hard to find an experimental signature that can be attained in another model and cannot be attained in SUSY (including possible R-parity breaking)
- the model also comes with “some” way to judge how likely it is the particular signal at hand (how much do I have to sweat to get this signal in a particular model)
- the model allows to derive the experimental implications of observing such signal (what other signals should I see besides this?)

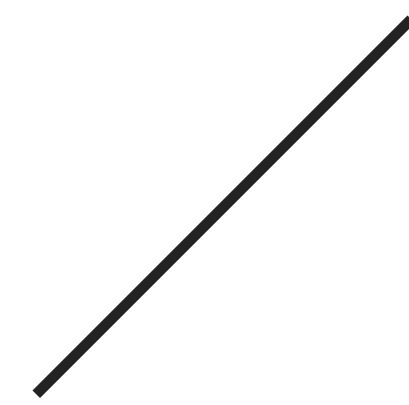
Being “complete” in the theory and experimental sense

- you can use it to stress-test the capability of your present (or future) accelerator+experiment
- create a solid ground for *th*  $\leftrightarrow$  *exp* exchange about reinterpretation/preservation of the searches

**Searches for supersymmetric models are extremely useful (even if SUSY is not realized in Nature)**

# Why SUSY in 2023 is as relevant as before

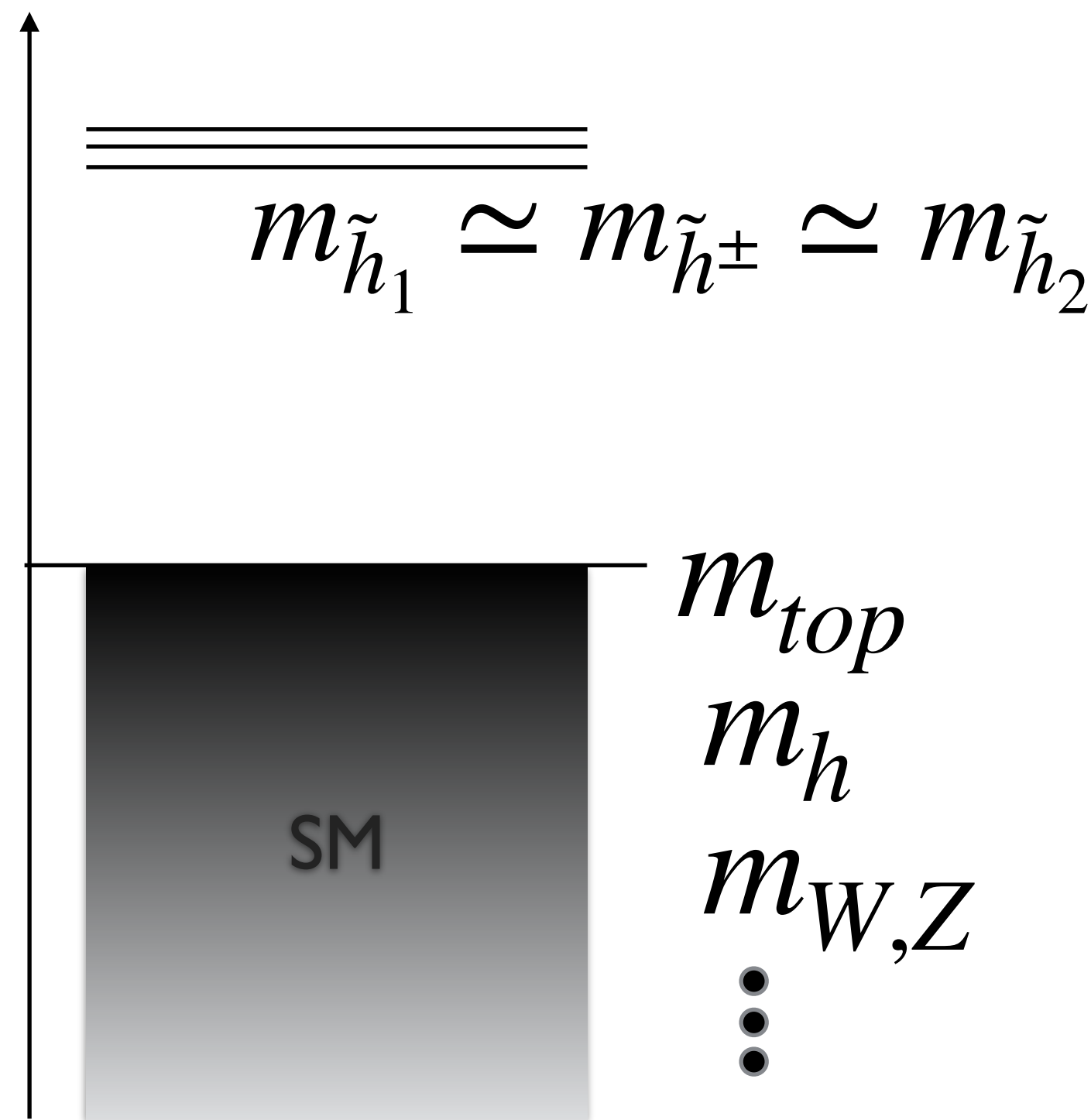
- because lots of things have not yet been tested



SUSY models have posed a number of challenges in search

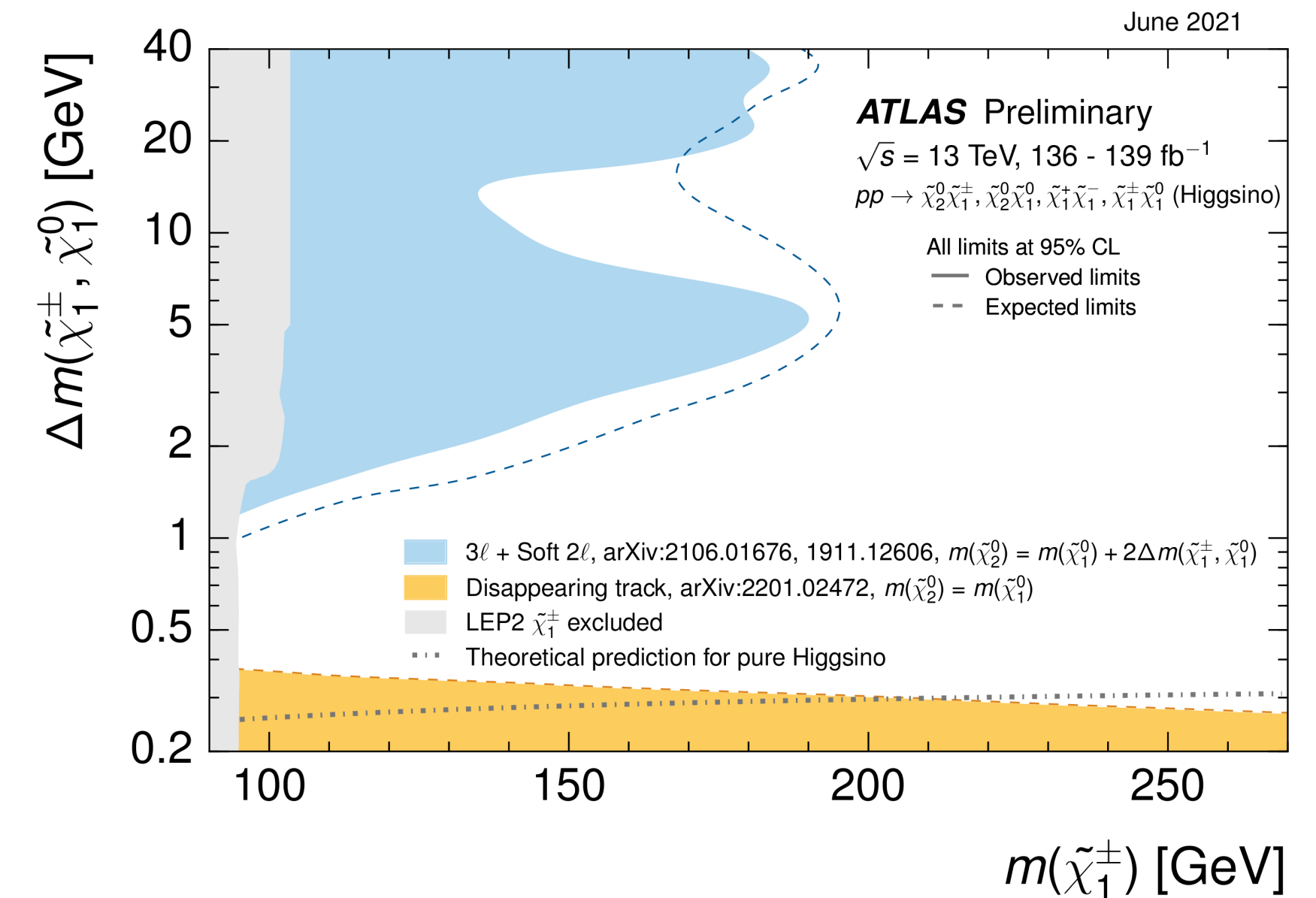
- it poses challenges that are open since the beginning of LHC and are not yet fully resolved
  - are we covering the entire space of signals that the NP can give?
  - are we communicating/presenting the results in a (re)usable way?
  - can we expect these result to remain usable after the end of LHC?

# ARE WE COVERING THE ENTIRE SPACE OF SIGNALS THAT THE NP CAN GIVE?



can appear to be a “perverse” setting for new-physics

far from being perverse, it is a very effective and reasonable way to not have seen particle dark matter so far ...

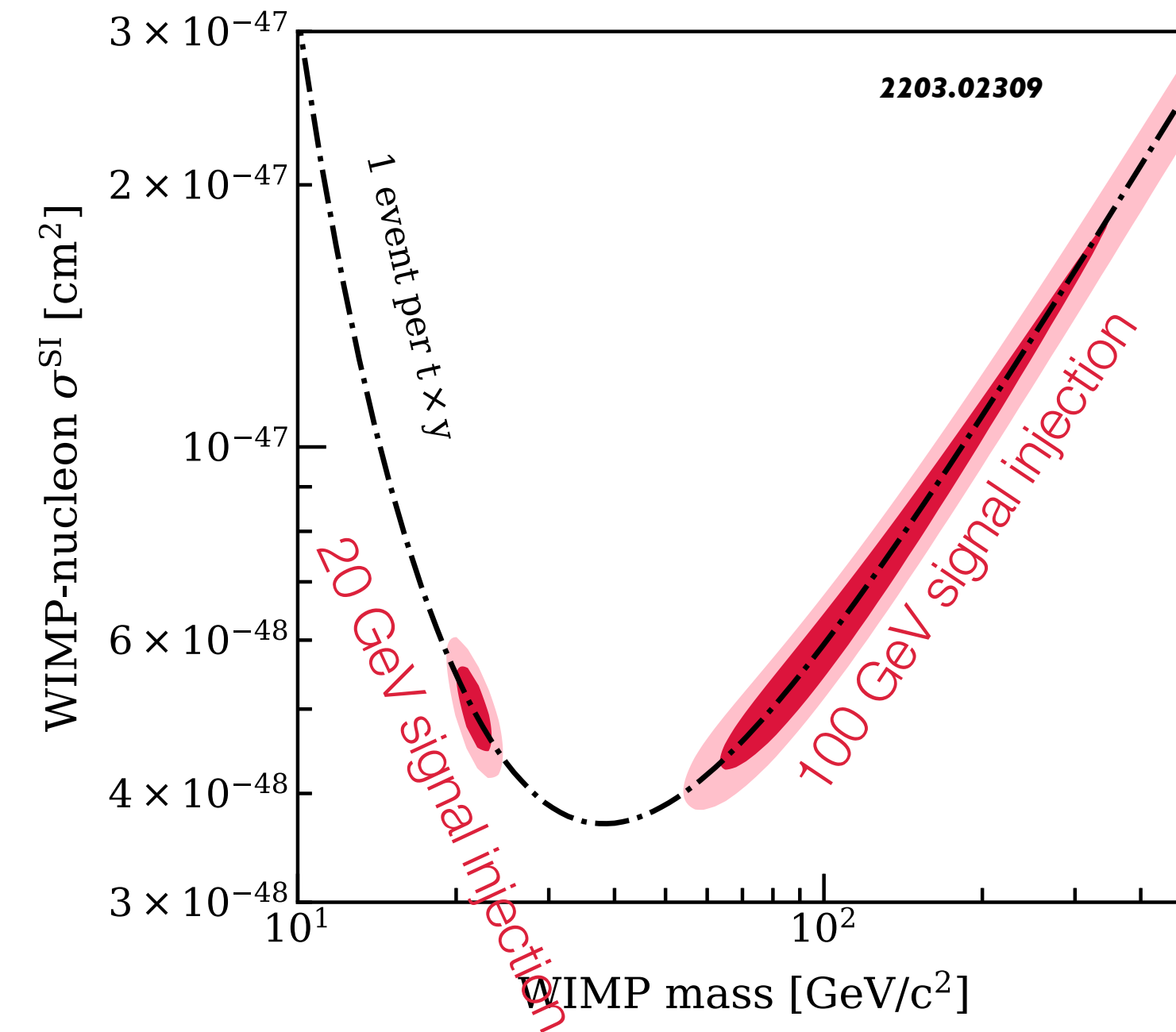
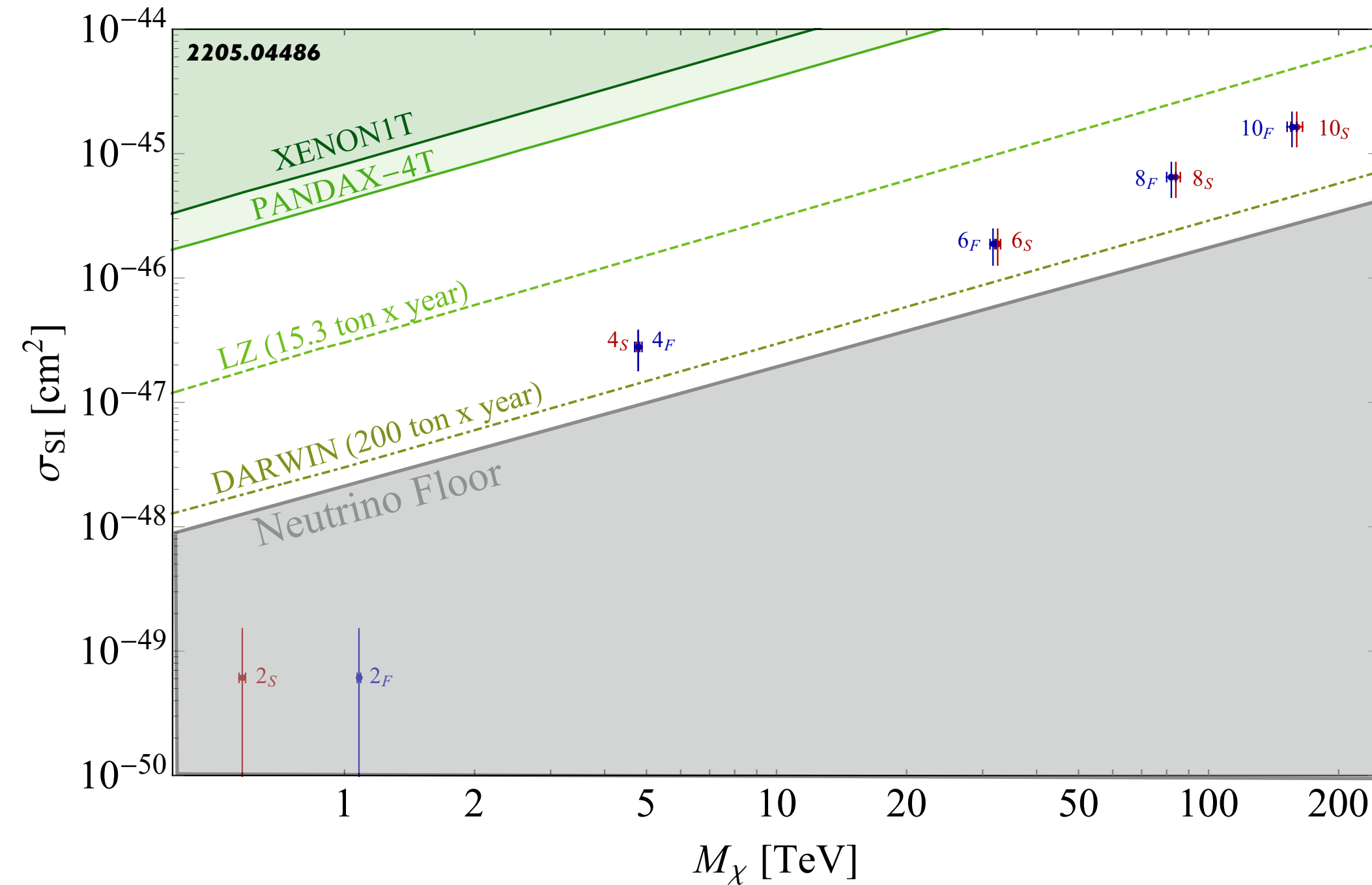


# ARE WE COVERING THE ENTIRE SPACE OF SIGNALS THAT THE NP CAN GIVE?

$$m_{\tilde{h}_1} \simeq m_{\tilde{h}^\pm} \simeq m_{\tilde{h}_2}$$

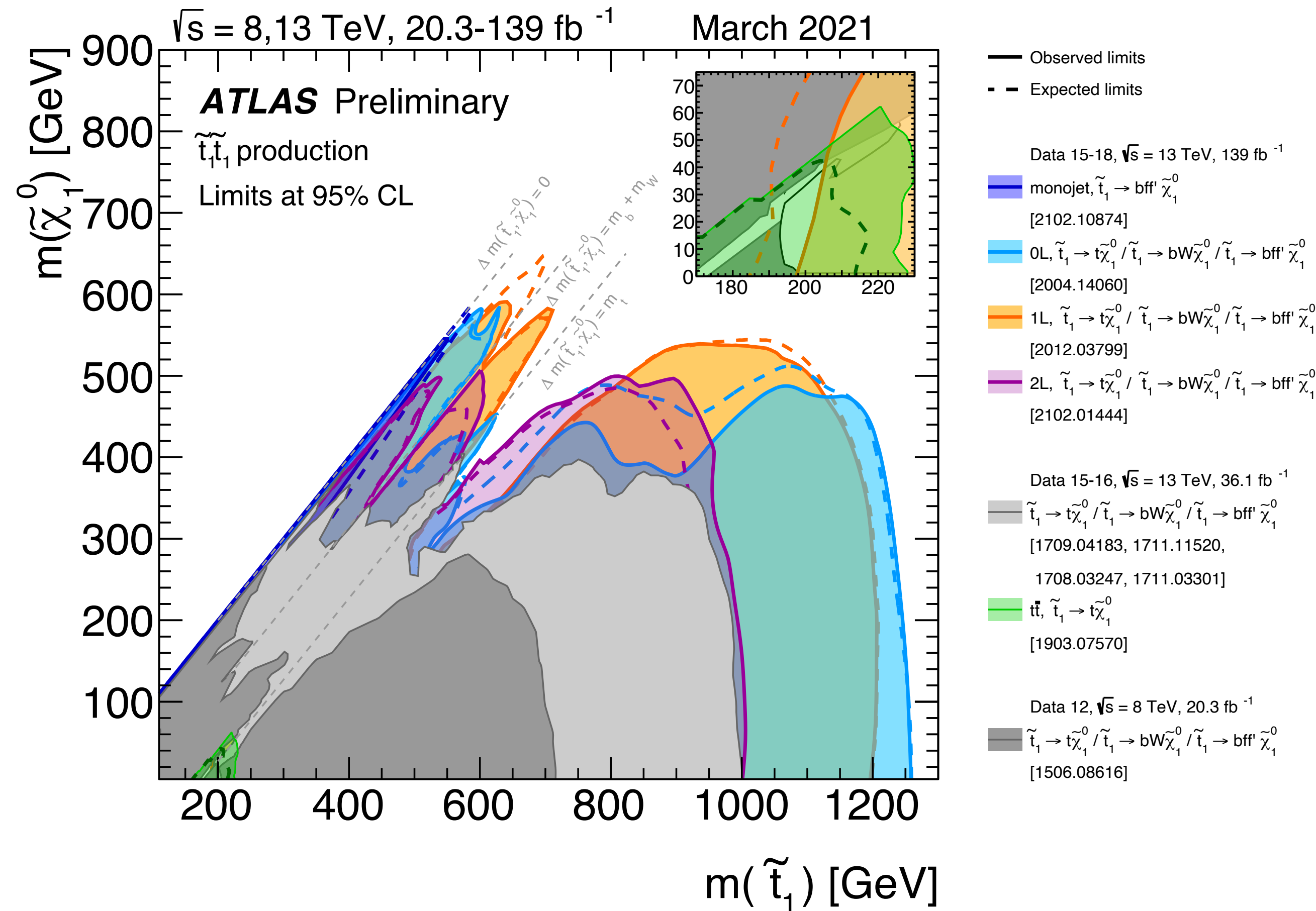
$m_{top}$   
 $m_h$   
 $m_{W,Z}$   
 $\vdots$

SM





# ARE WE COMMUNICATING/PRESENTING THE RESULTS IN A (RE)USABLE WAY?



results need to be obtained in some specific setting, e.g. assume  $\tilde{t} \rightarrow t\chi^0$

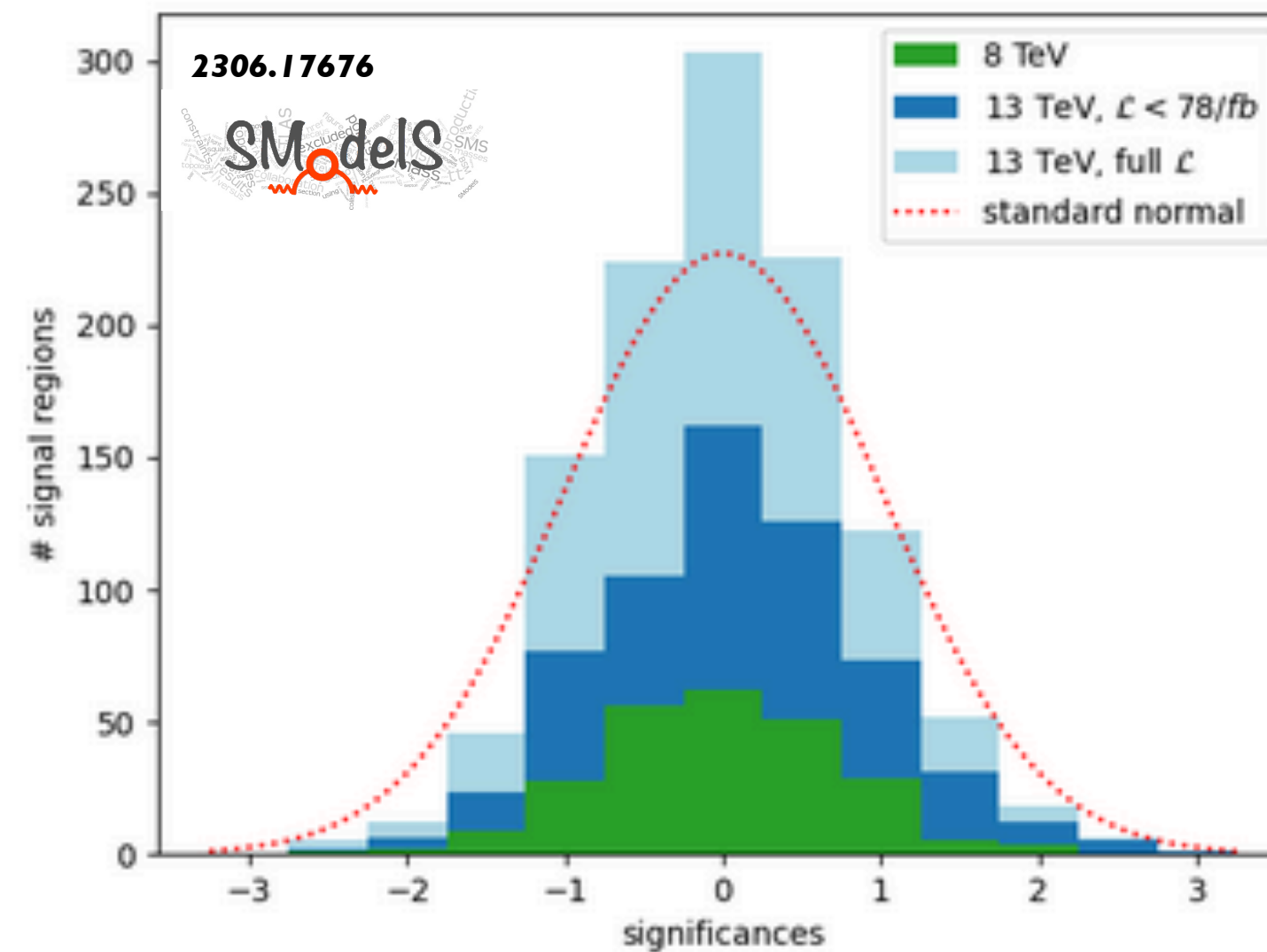
lots of work goes into extracting that specific bound (think about background estimate)

results must be re-usable

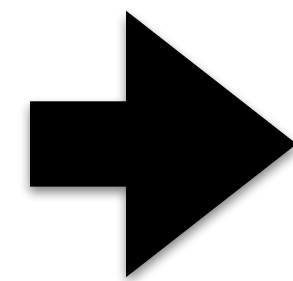


# AN EXAMPLE OF REUSE WITH **SModels**

List of analyses and topologies in the SMS results database, comprising 5744 individual maps from 1152 distinct signal regions, 100 different SMS topologies, from a total of 111 analyses. The list has been created from the database version **2.3.0**. There is also an [sms dictionary](#) and a [validation page](#). Link to list of results [including superseded and fastlim results](#).



plenty of other tools for “reuse”



(Re)interpretation of the LHC results for new physics

August 29, 2023 to September 1, 2023  
Durham University  
Europe/London timezone

# ANOTHER EXAMPLE OF REUSE ...



normal theorist working to recast



inconclusive recast  
result due to too  
many options, too  
many models not  
overlapping



outright wrong  
results



# ANOTHER EXAMPLE OF REUSE ...



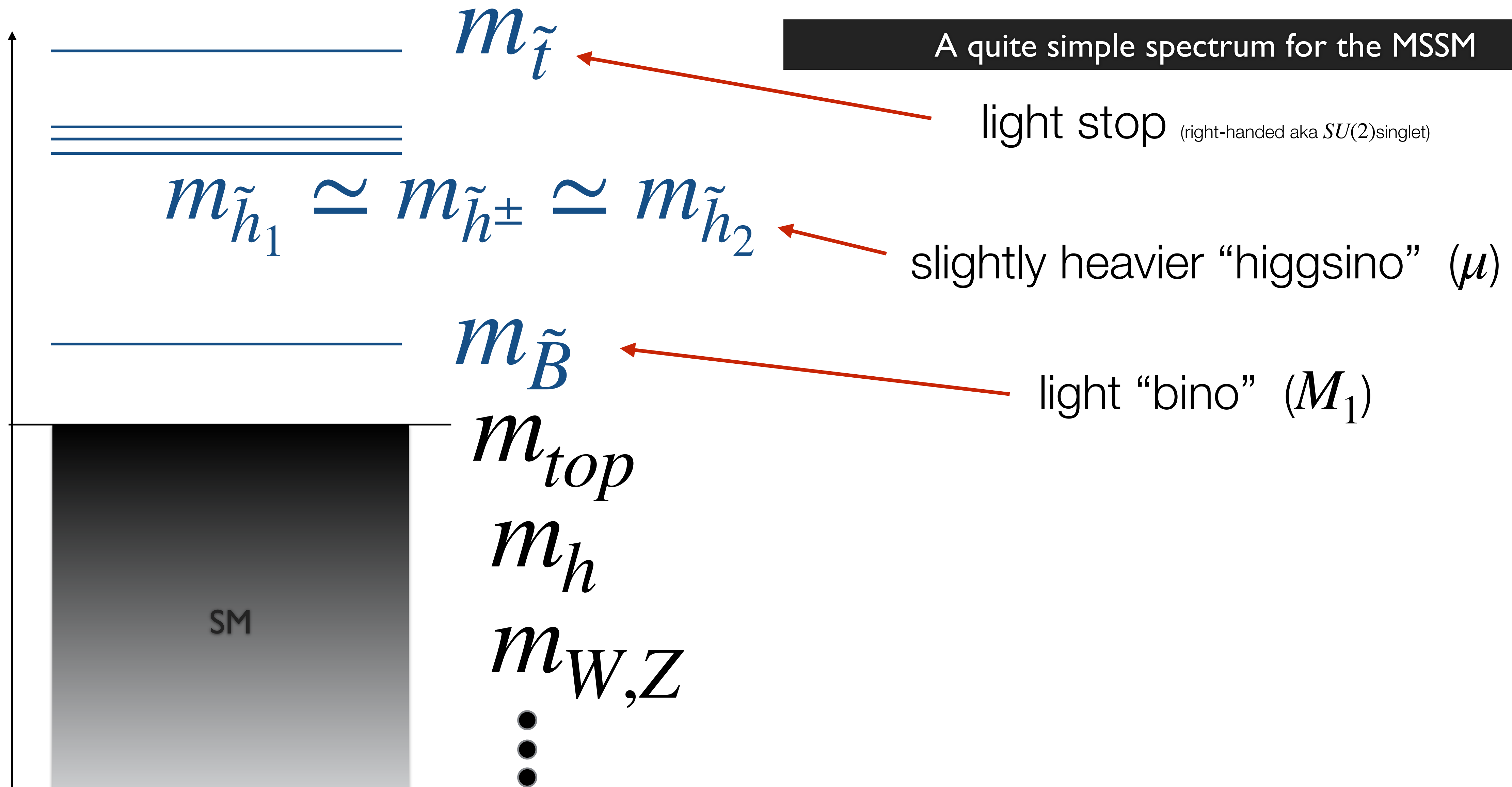
normal theorist working to recast



faithful recast

new interesting  
searches inspired  
by that

# ANOTHER EXAMPLE OF REUSE ...



Make everything a bit lighter now ...

SUSY states not well separated from SM states

mass-differences between SUSY states comparable to SM masses

final states similar to SM processes

$$\chi^+ \rightarrow W\chi^0 \rightarrow \ell + \text{mET} \simeq W \rightarrow \ell\nu$$

$m_{\tilde{t}_{top}}$

$m_{\tilde{h}^\pm} \simeq m_{\tilde{h}_2}$

$m_{W,Z}$

$m_{\tilde{B}}$

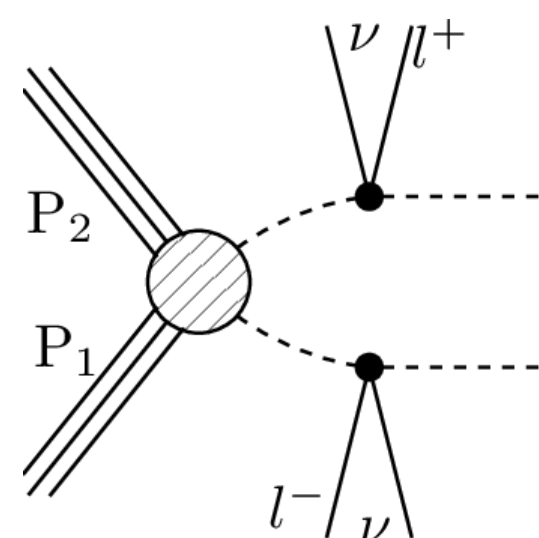
$m_{\tilde{h}_1}$   
SM



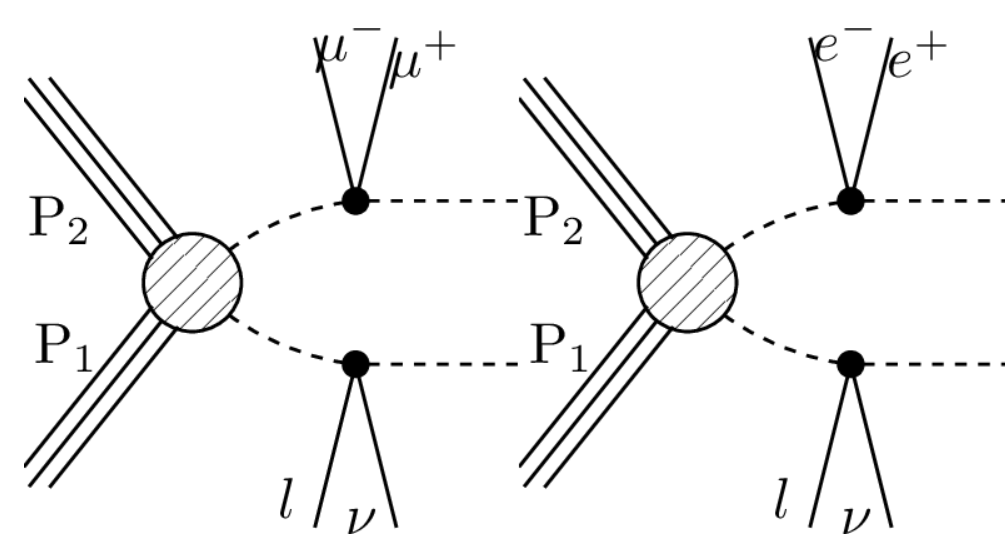
# MODELS MAYBE COVERED MAYBE NOT

Searches and signal regions identified by SModelS include

TChiWWoff

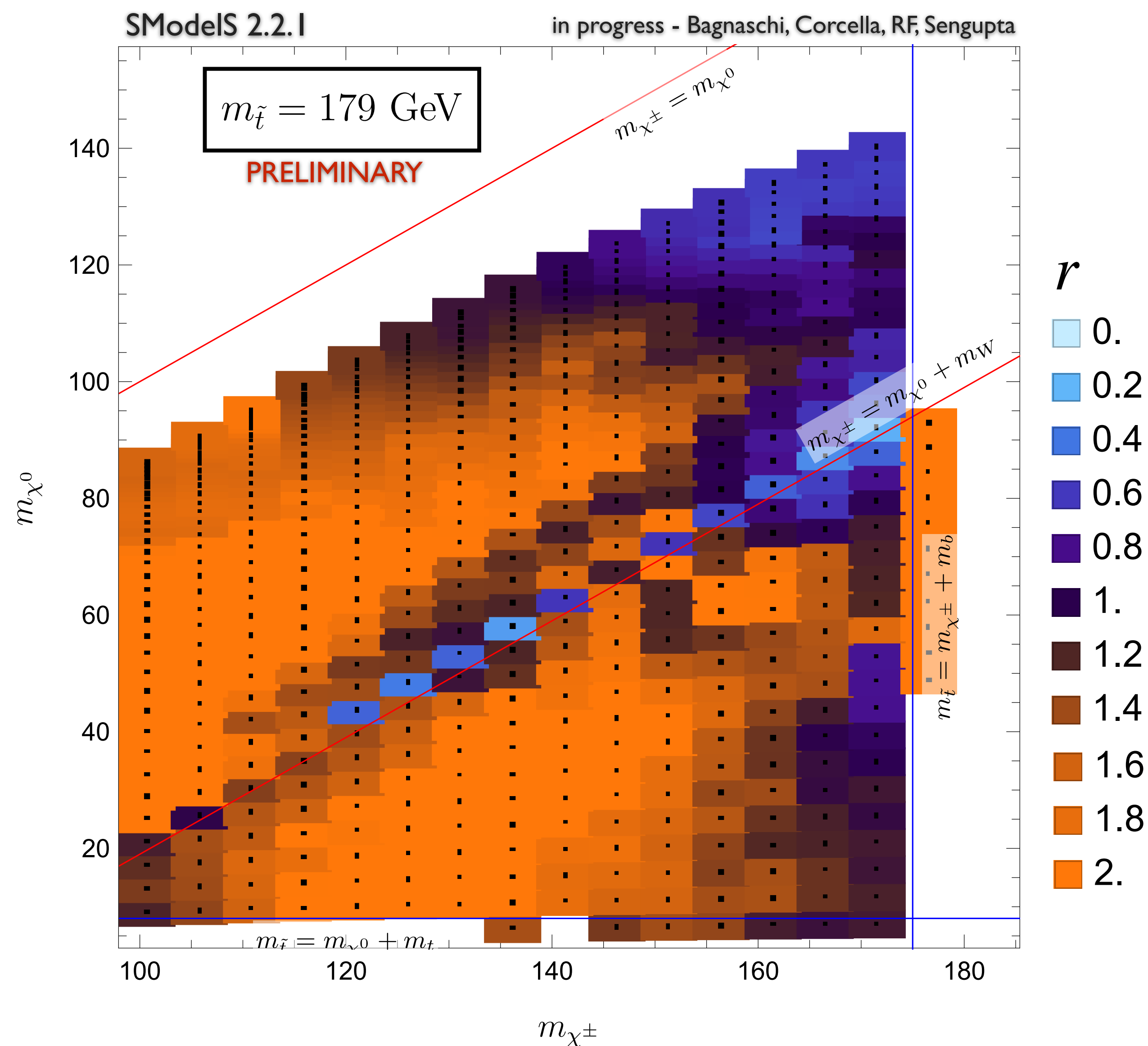


TChiWZoff



$r > 1$  (black-to-orange scale)  
the model is excluded by  
present searches

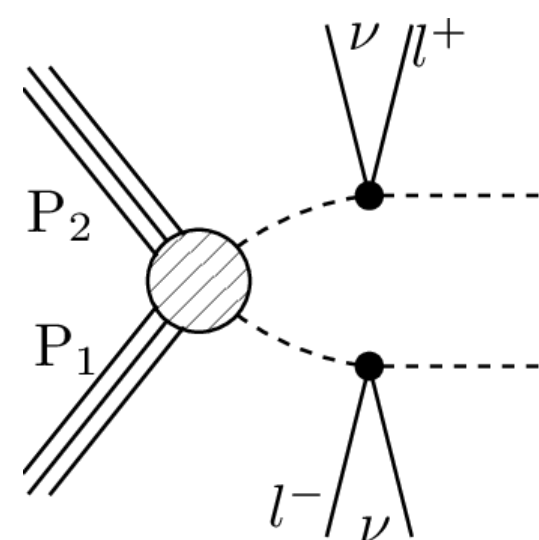
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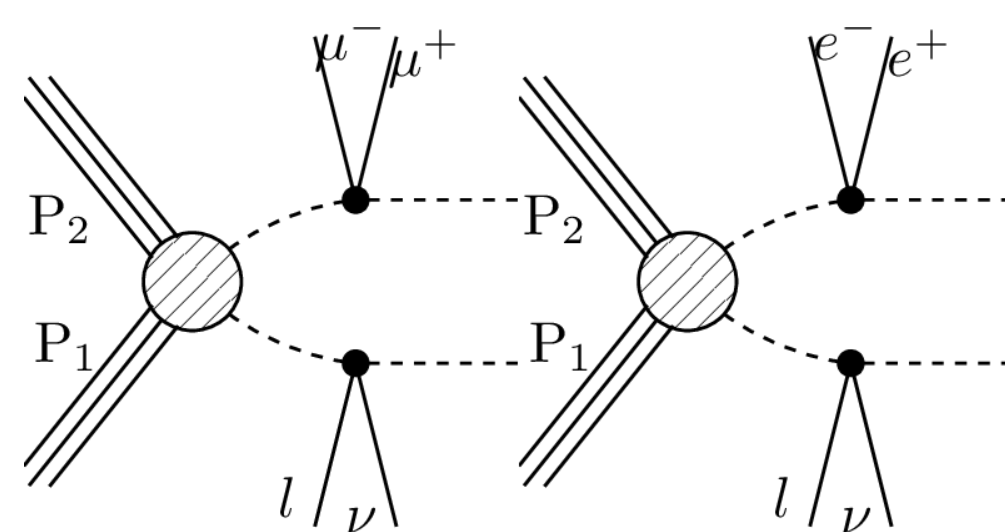
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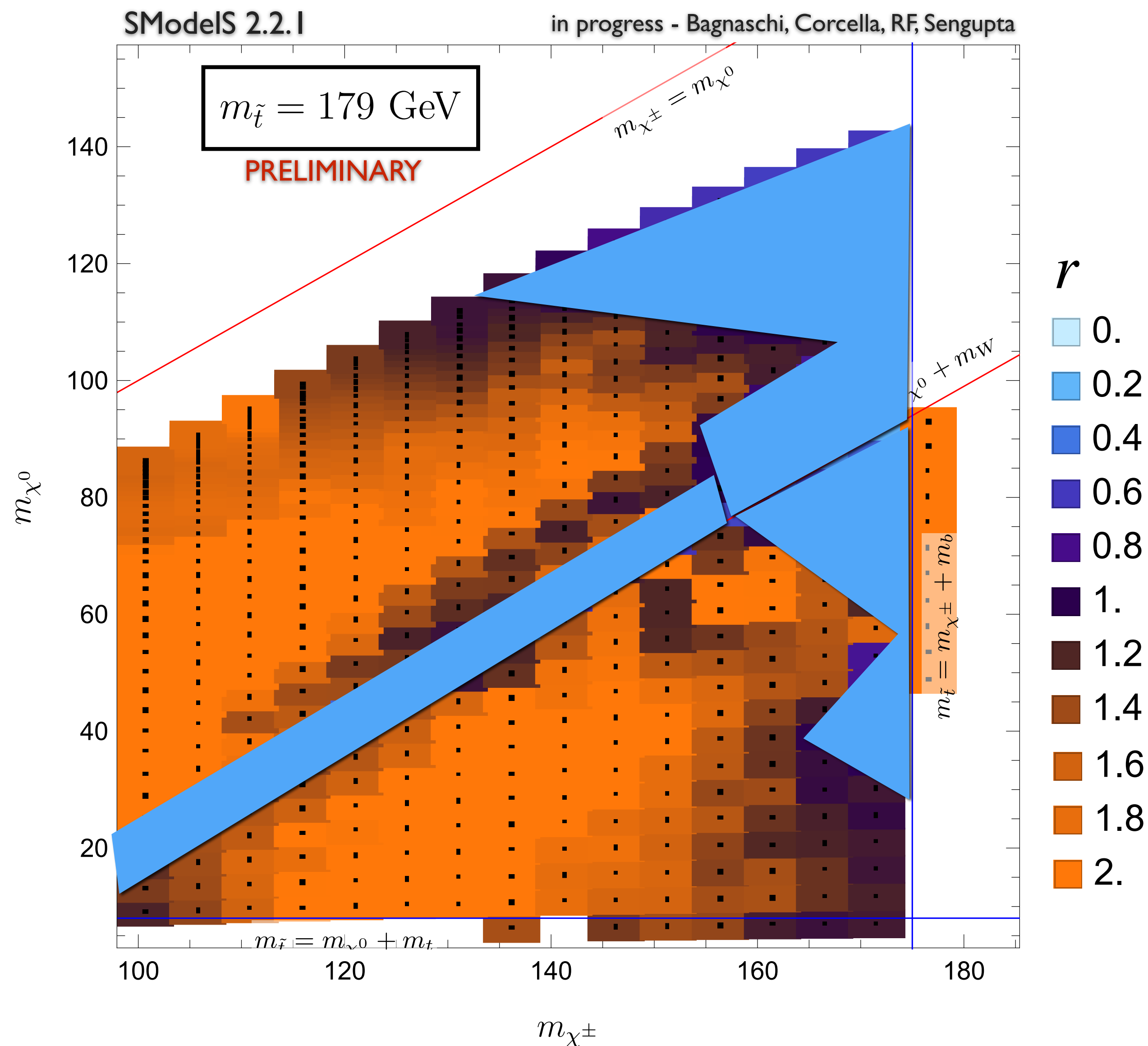
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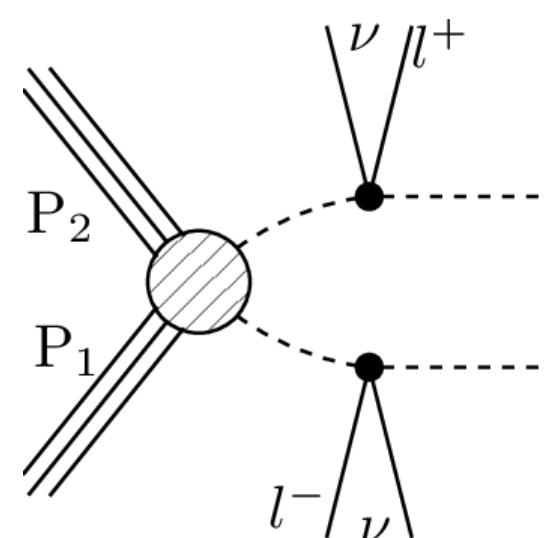
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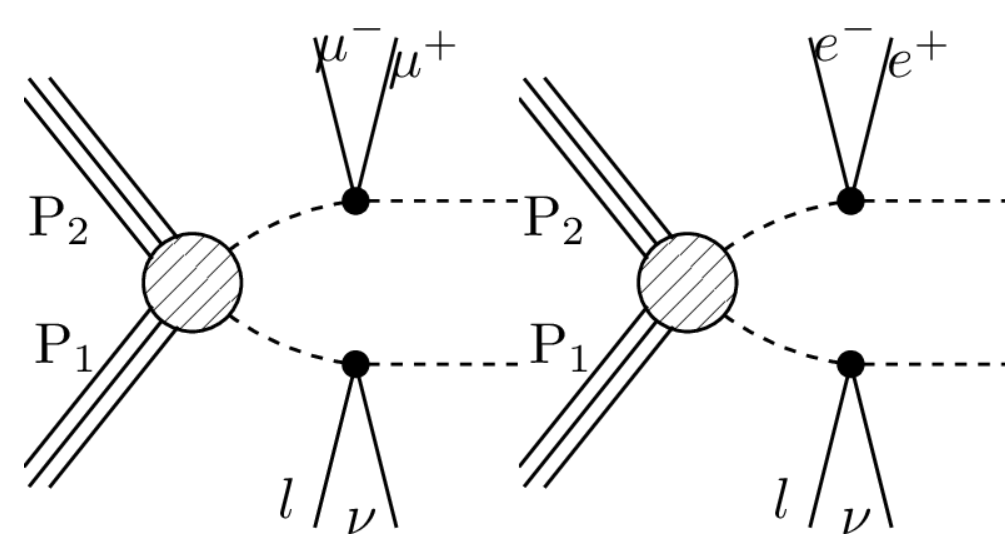
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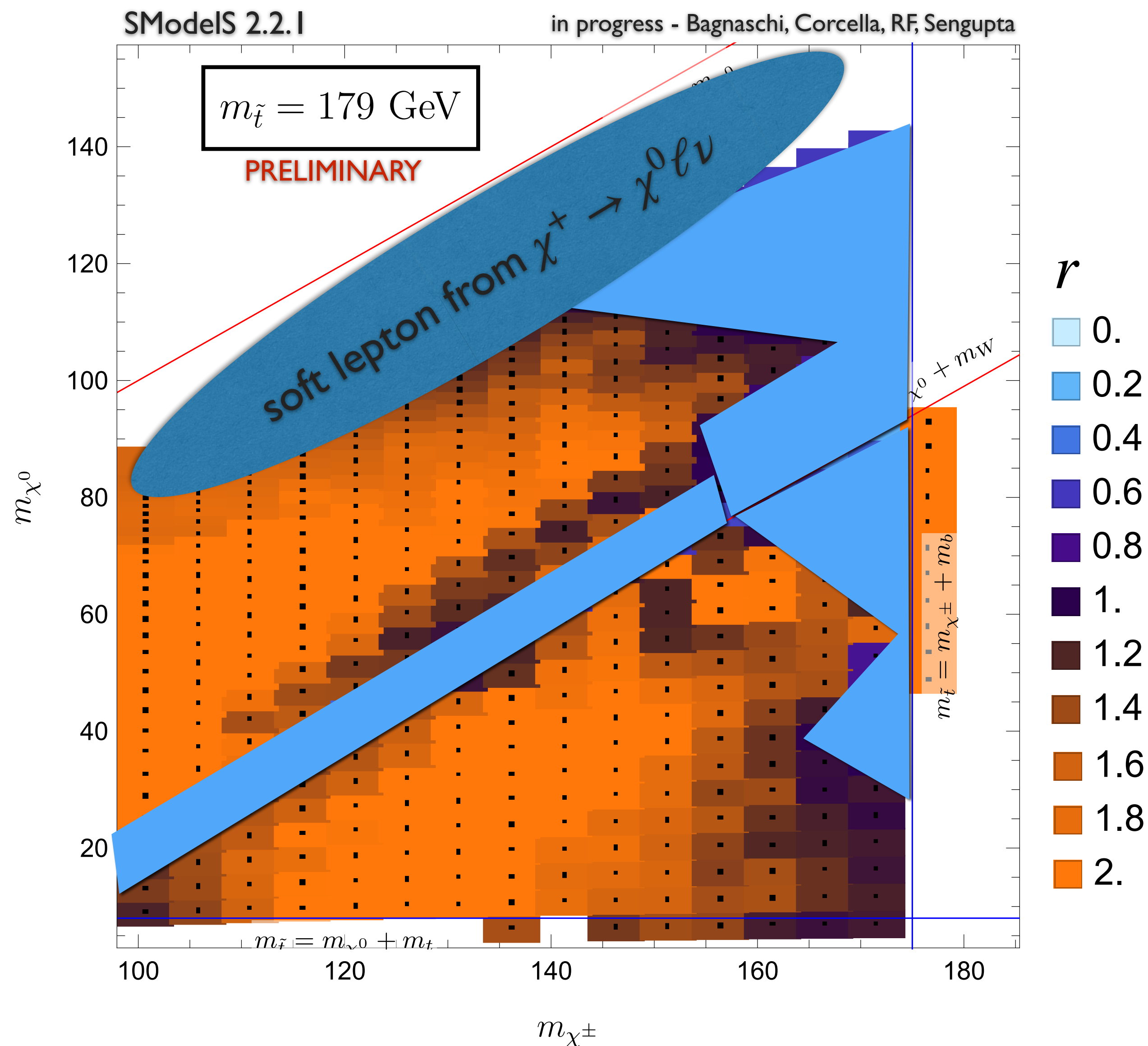
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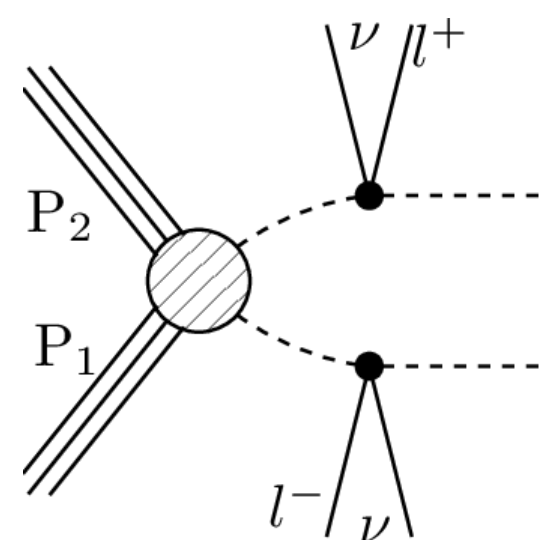




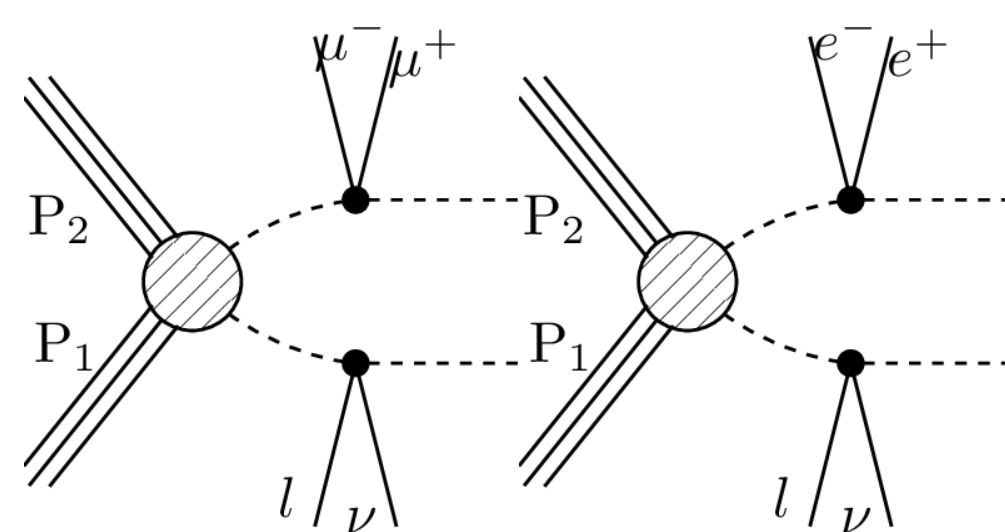
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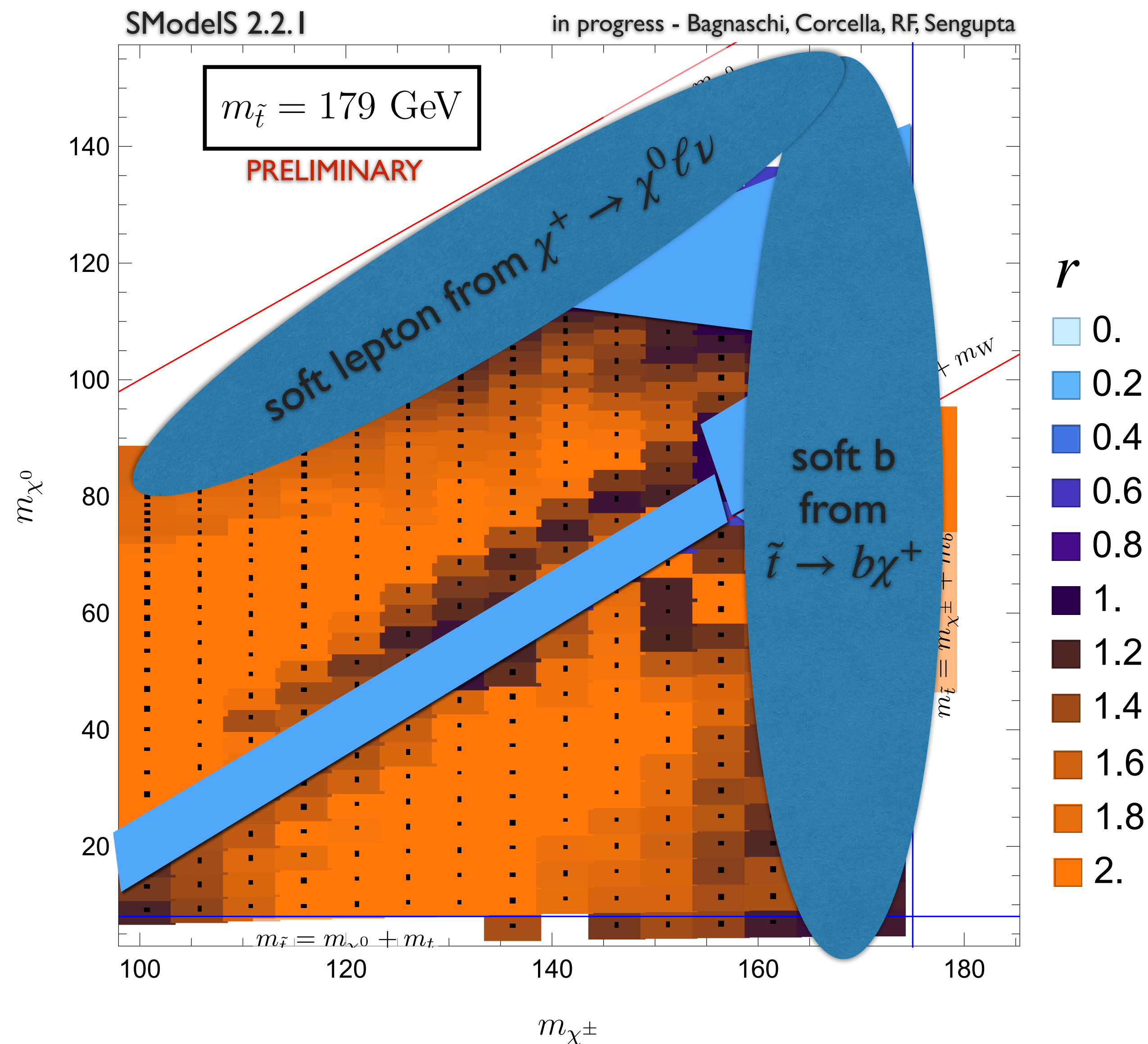


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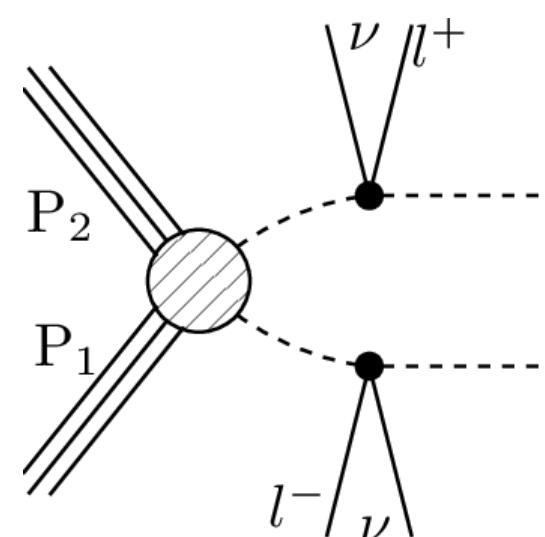




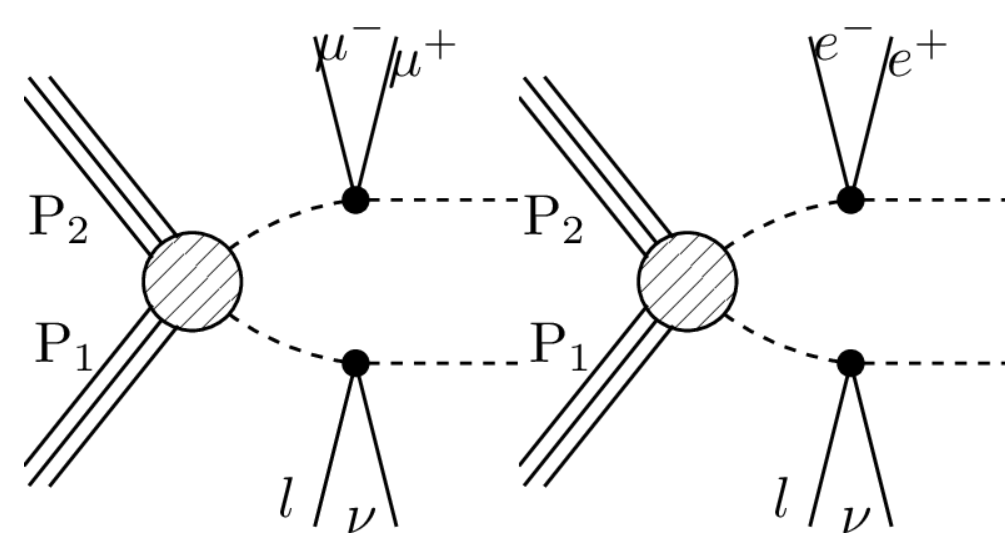
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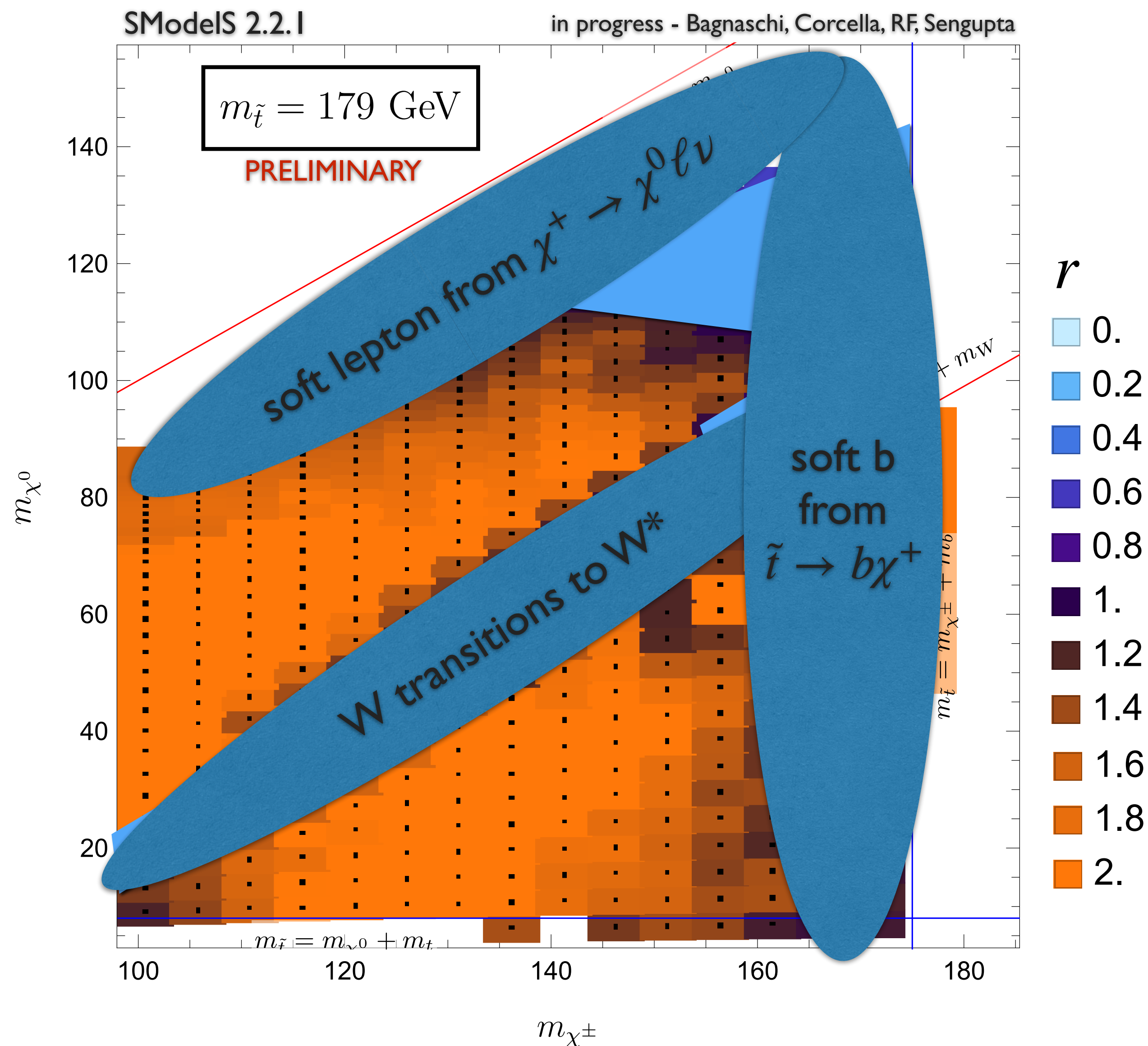
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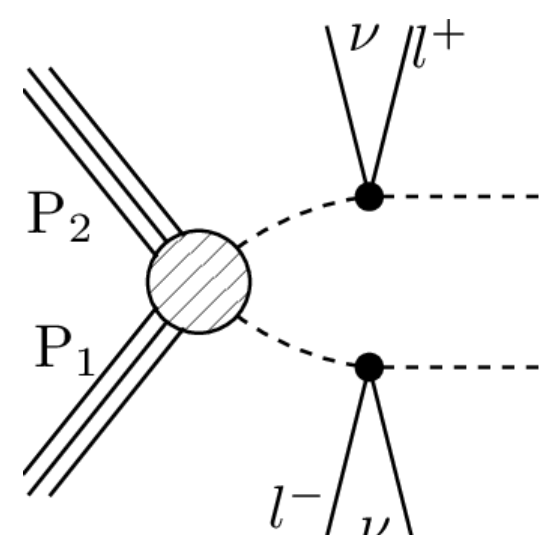




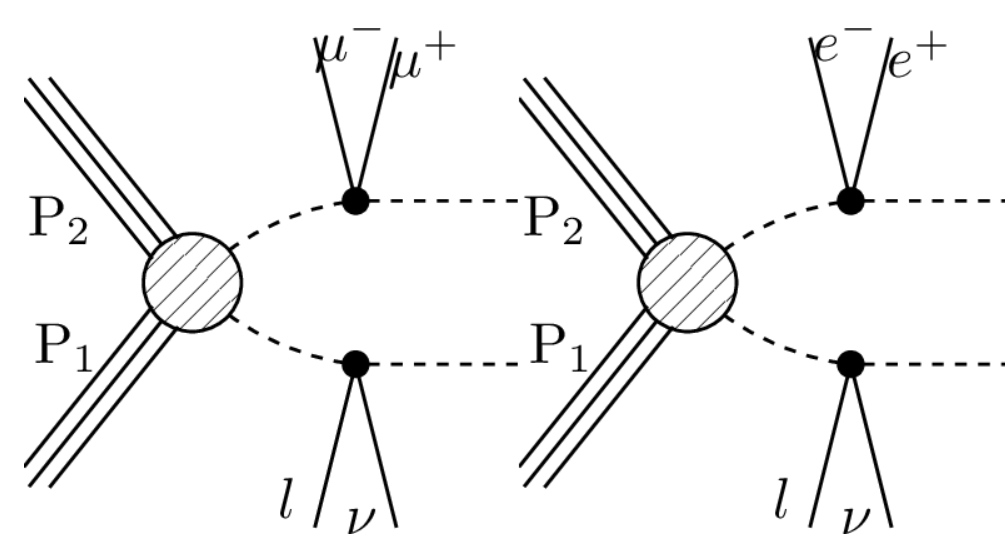
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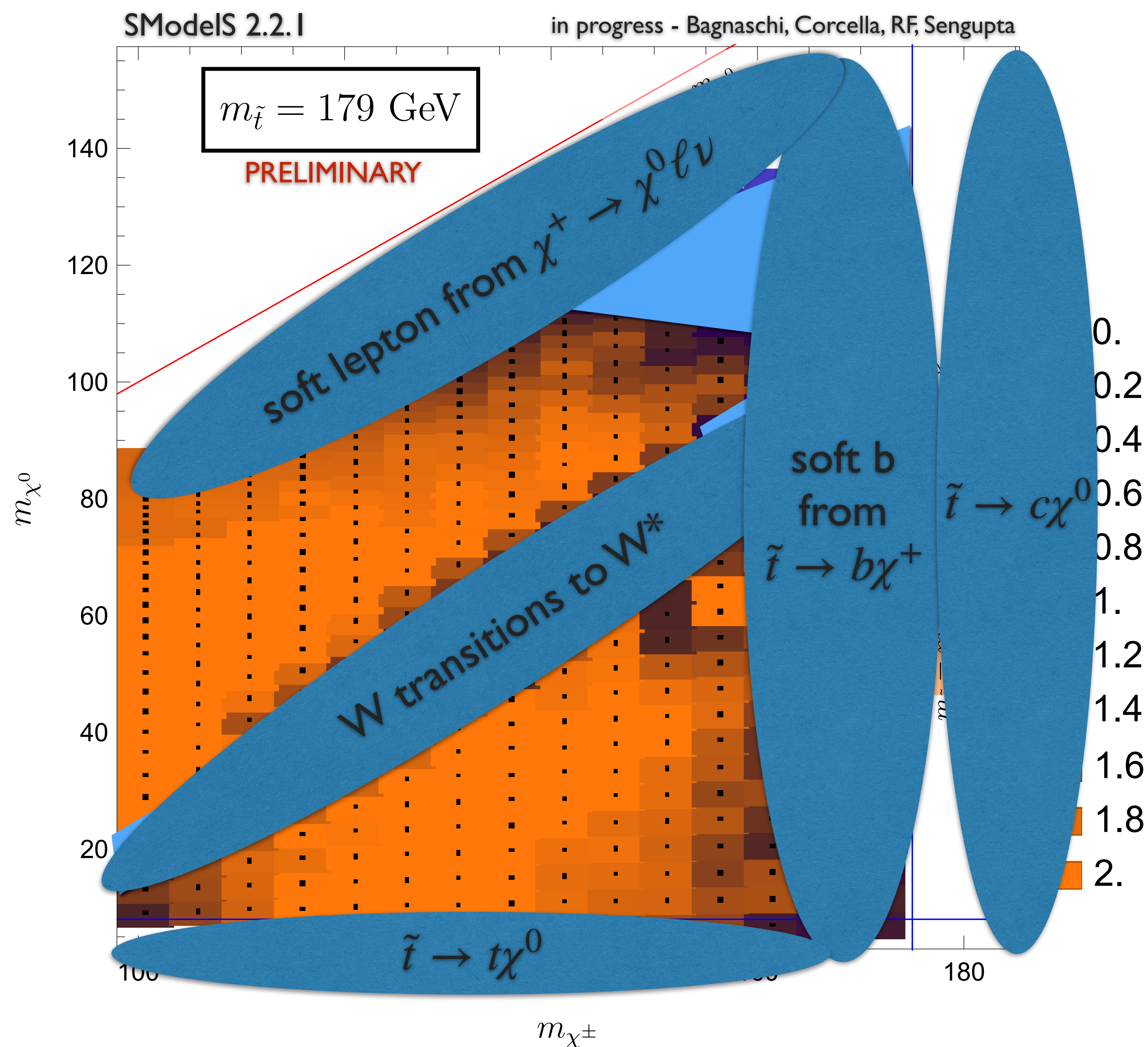


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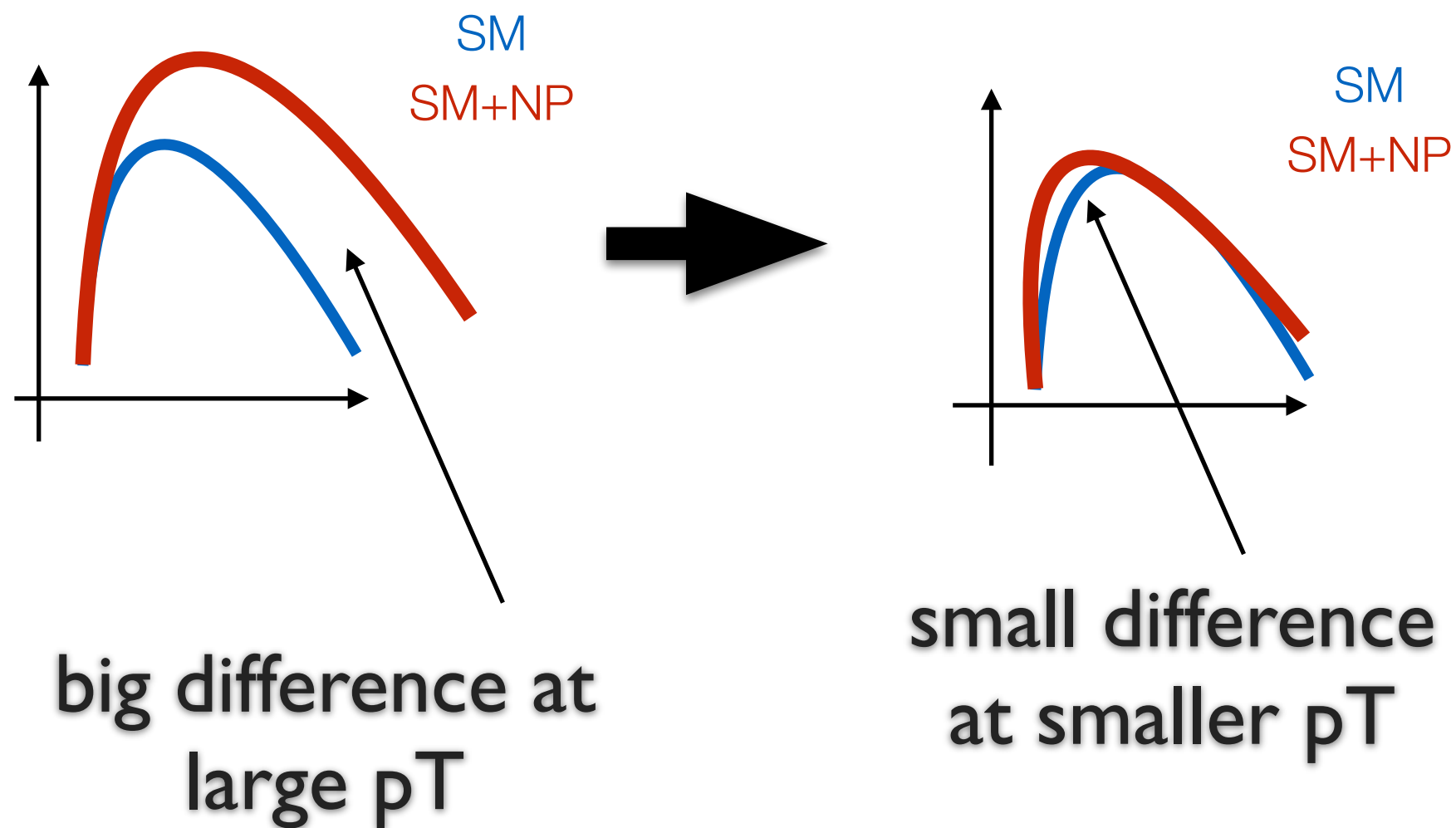
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# WHAT TO DO TO COVER THESE MODELS

Measure  $pp \rightarrow t\bar{t}$  as precise as you can!

turn the search into a  
SM measurement

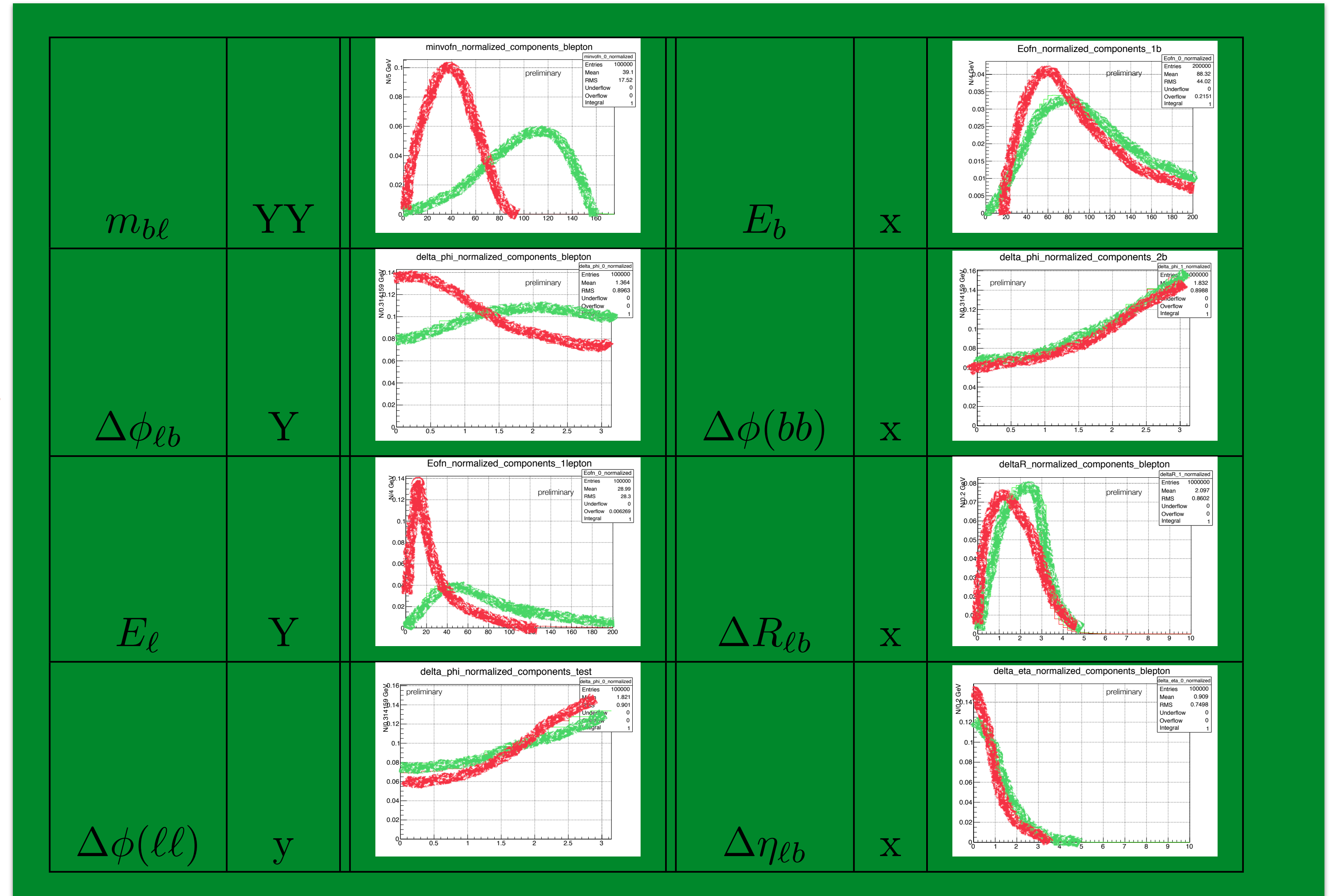
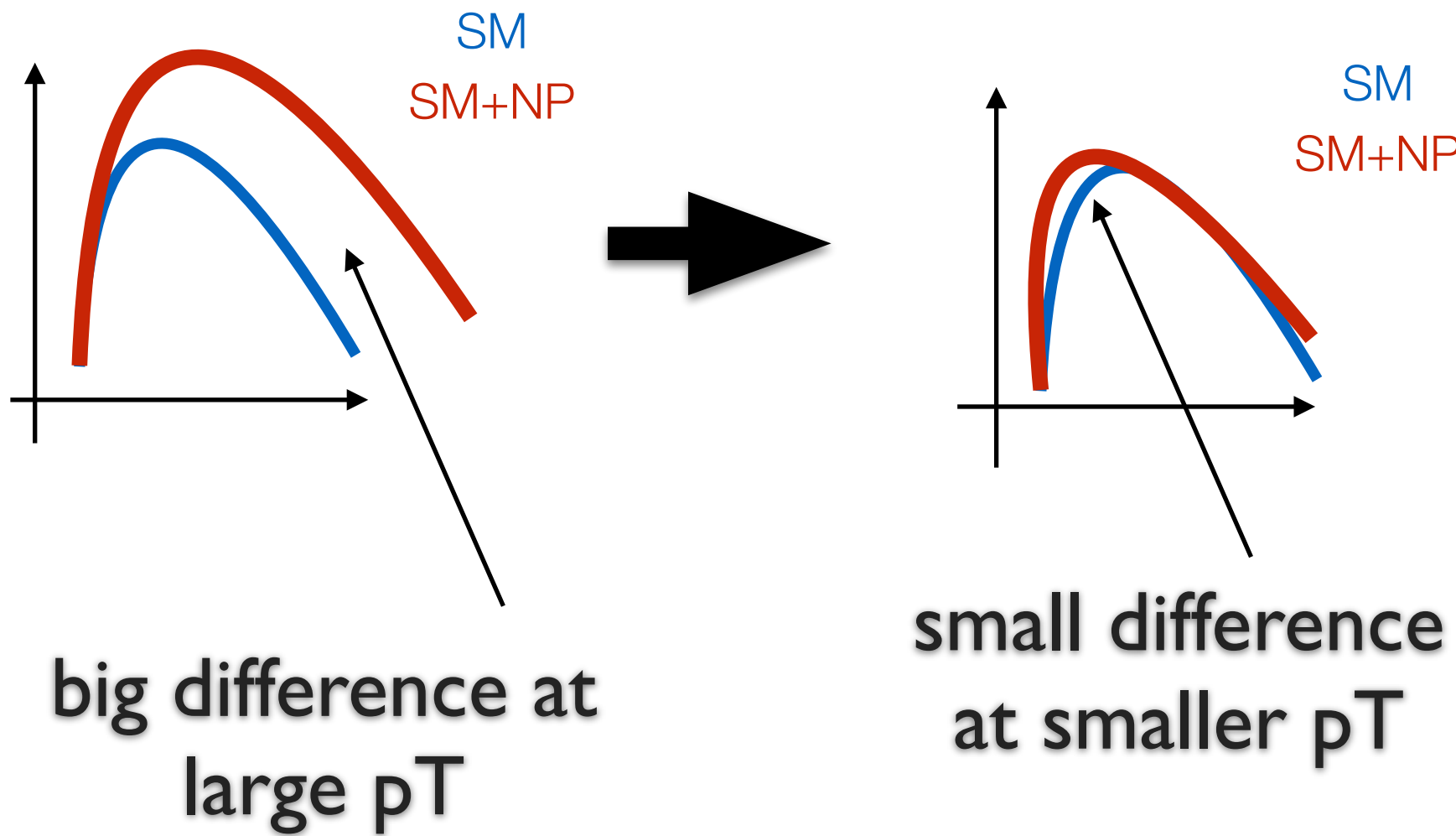




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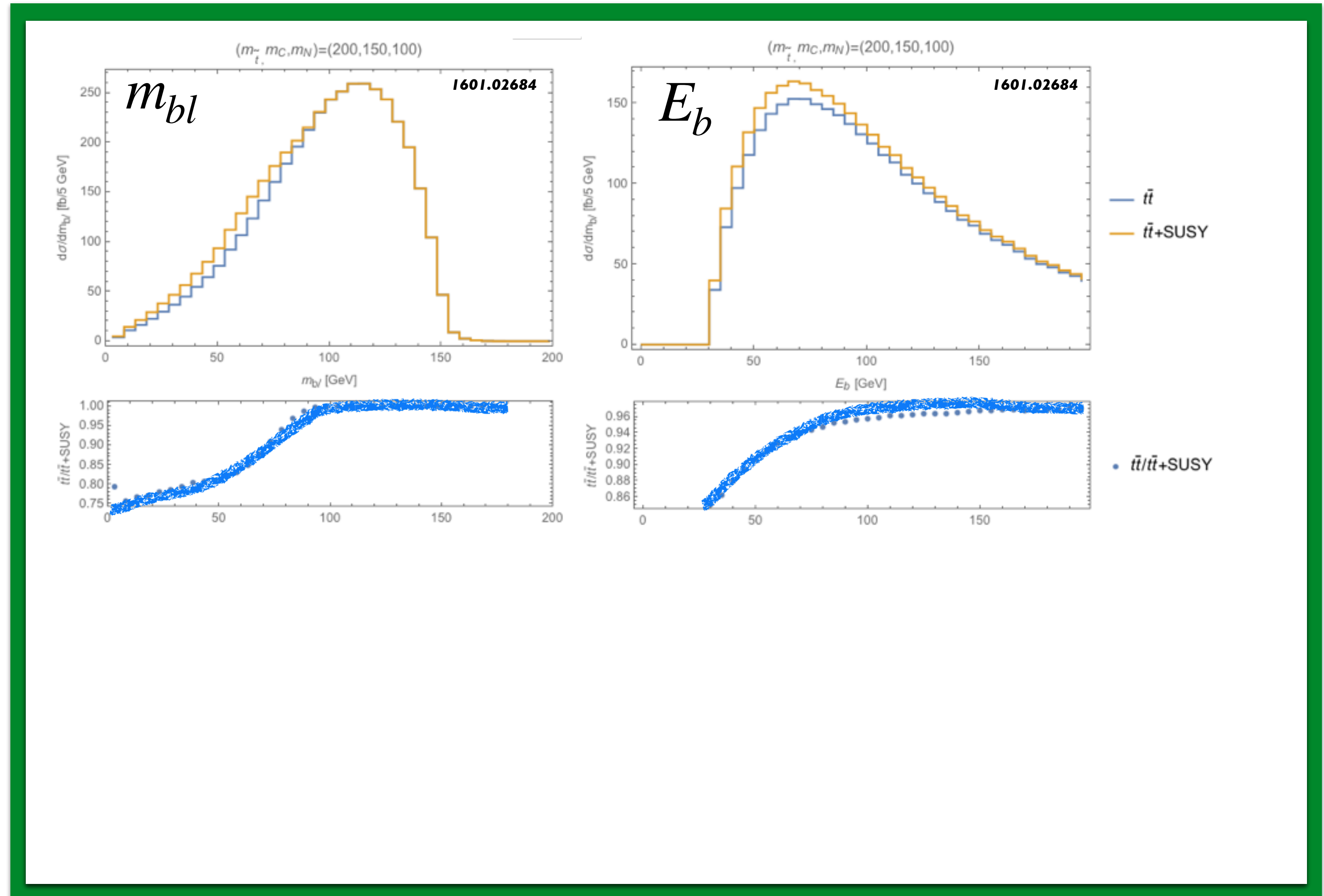
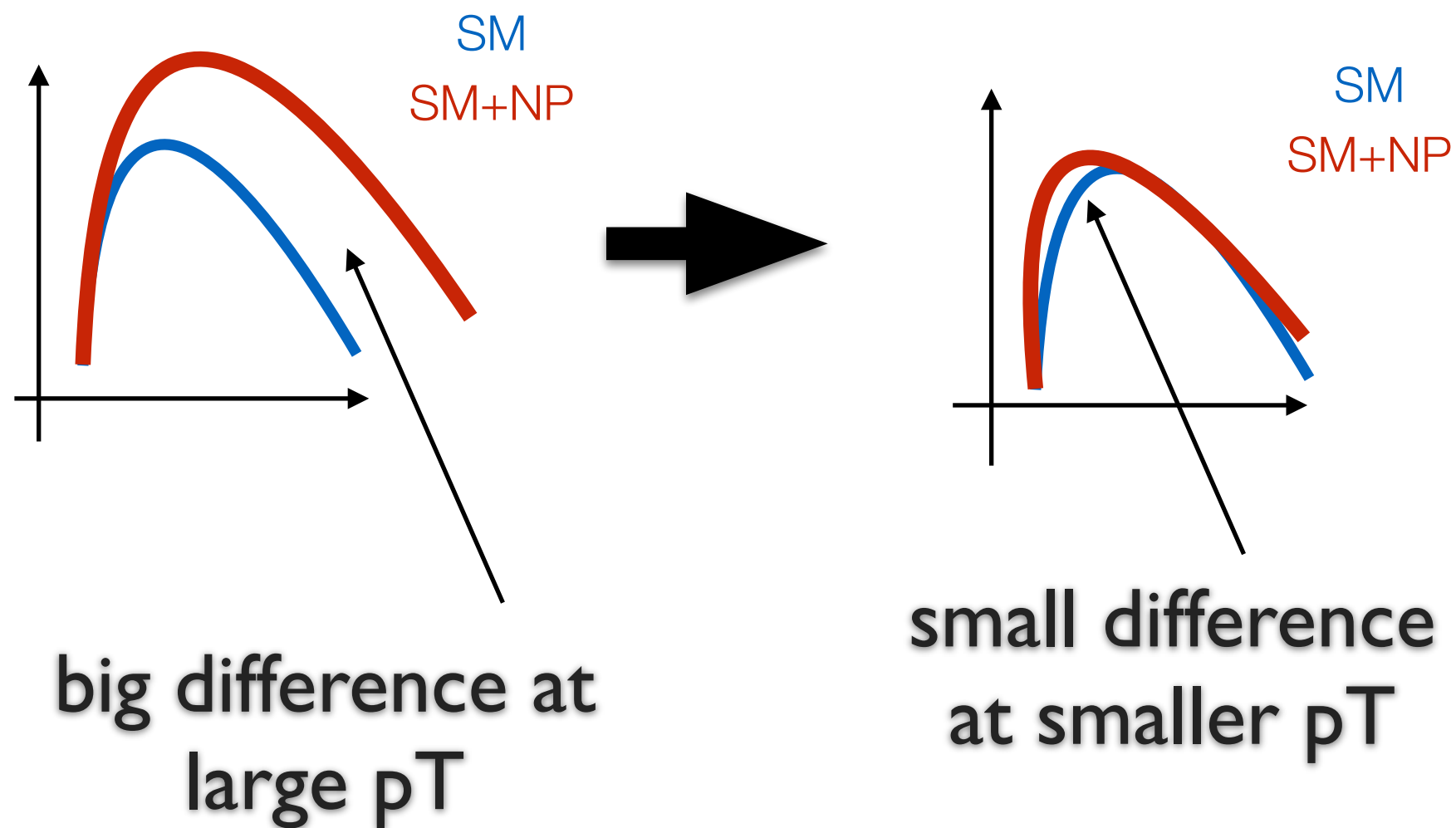
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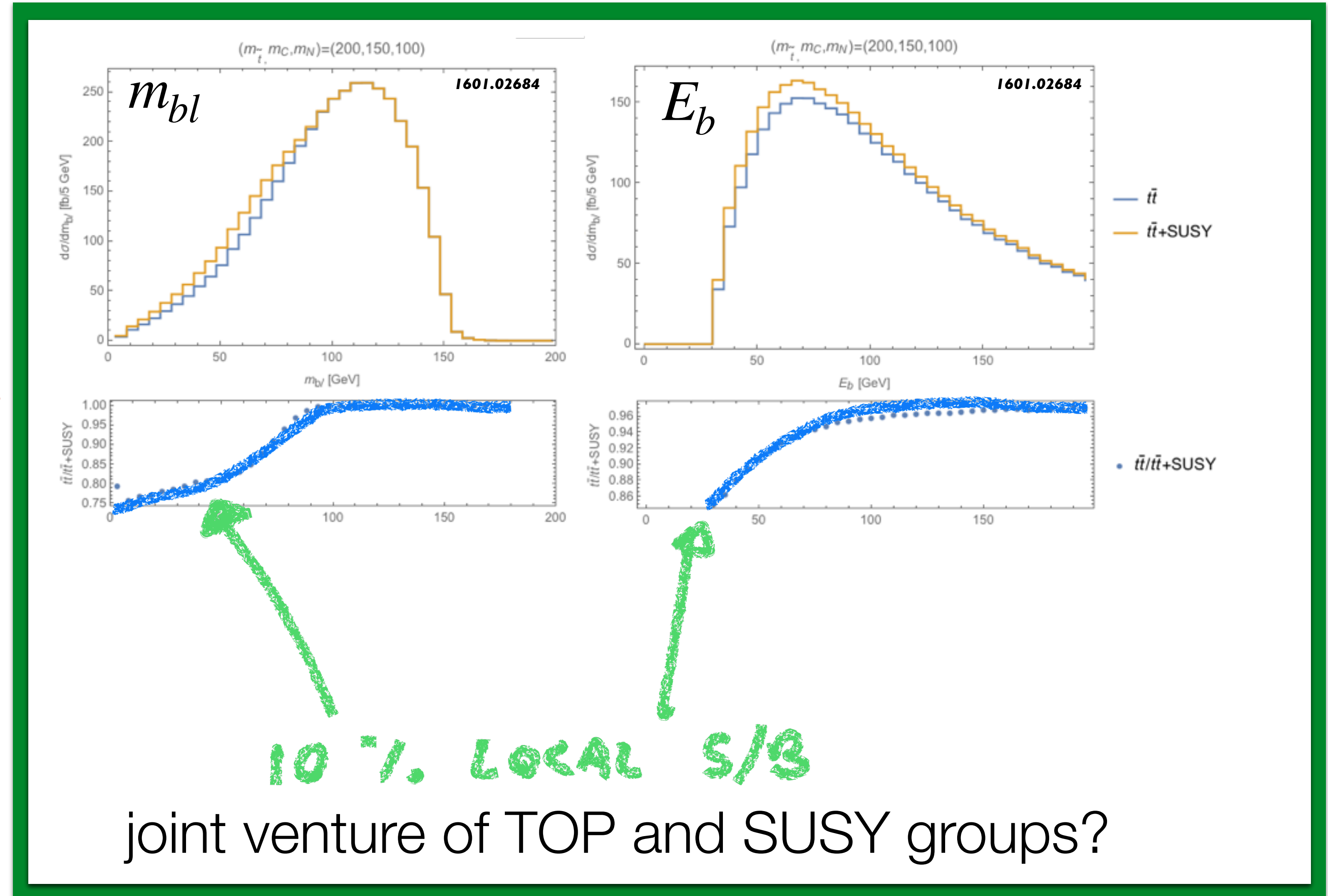
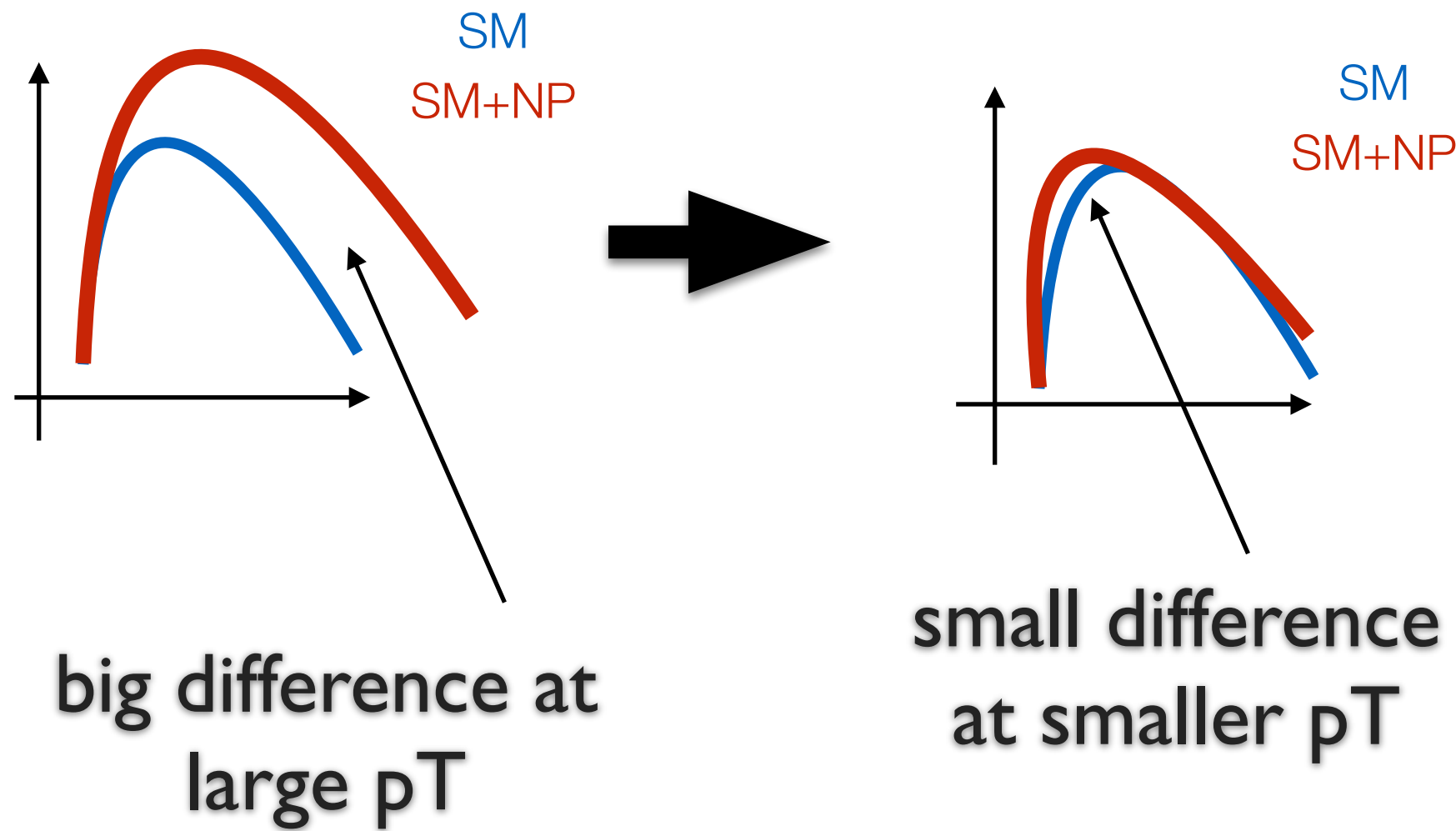
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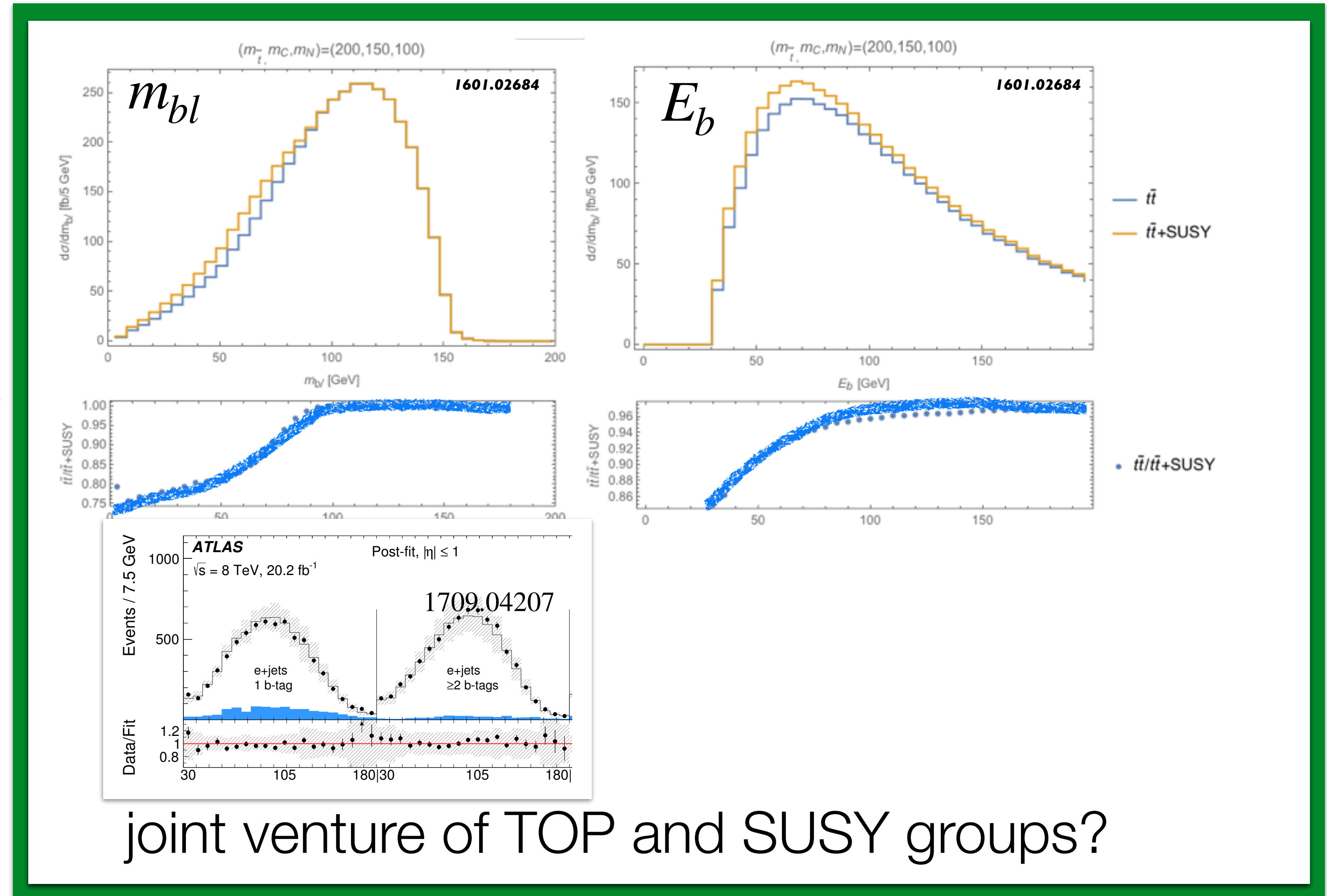
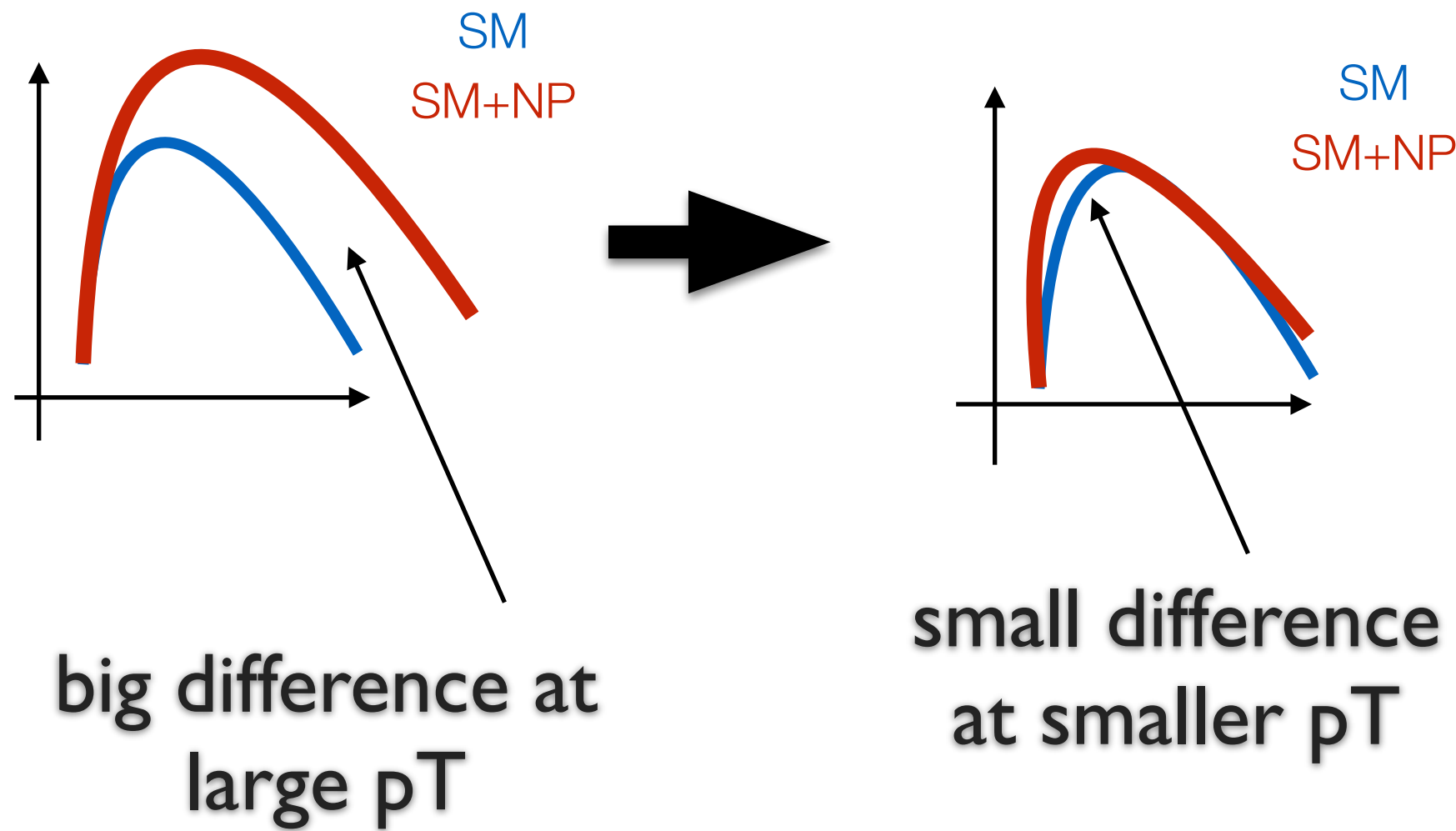




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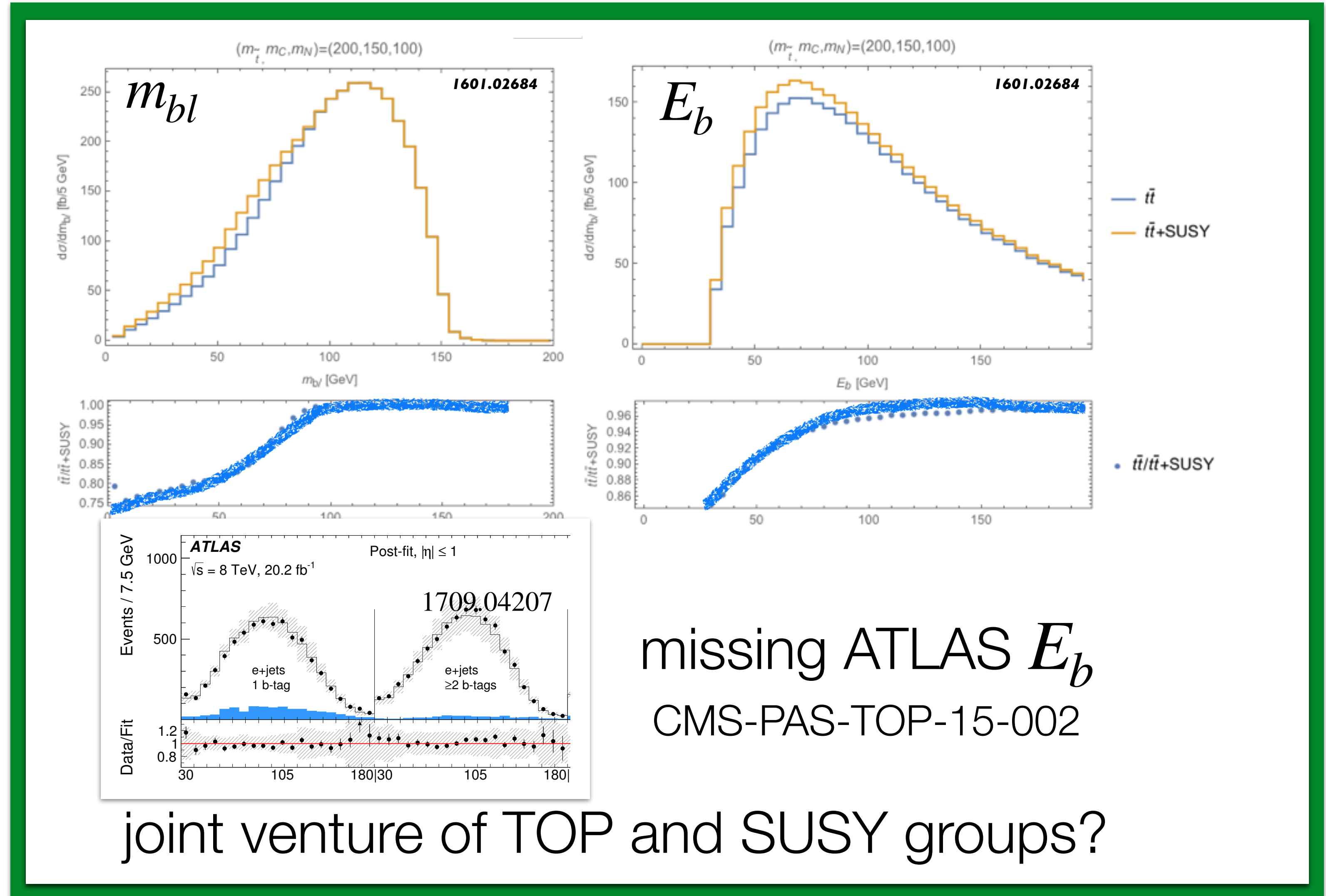
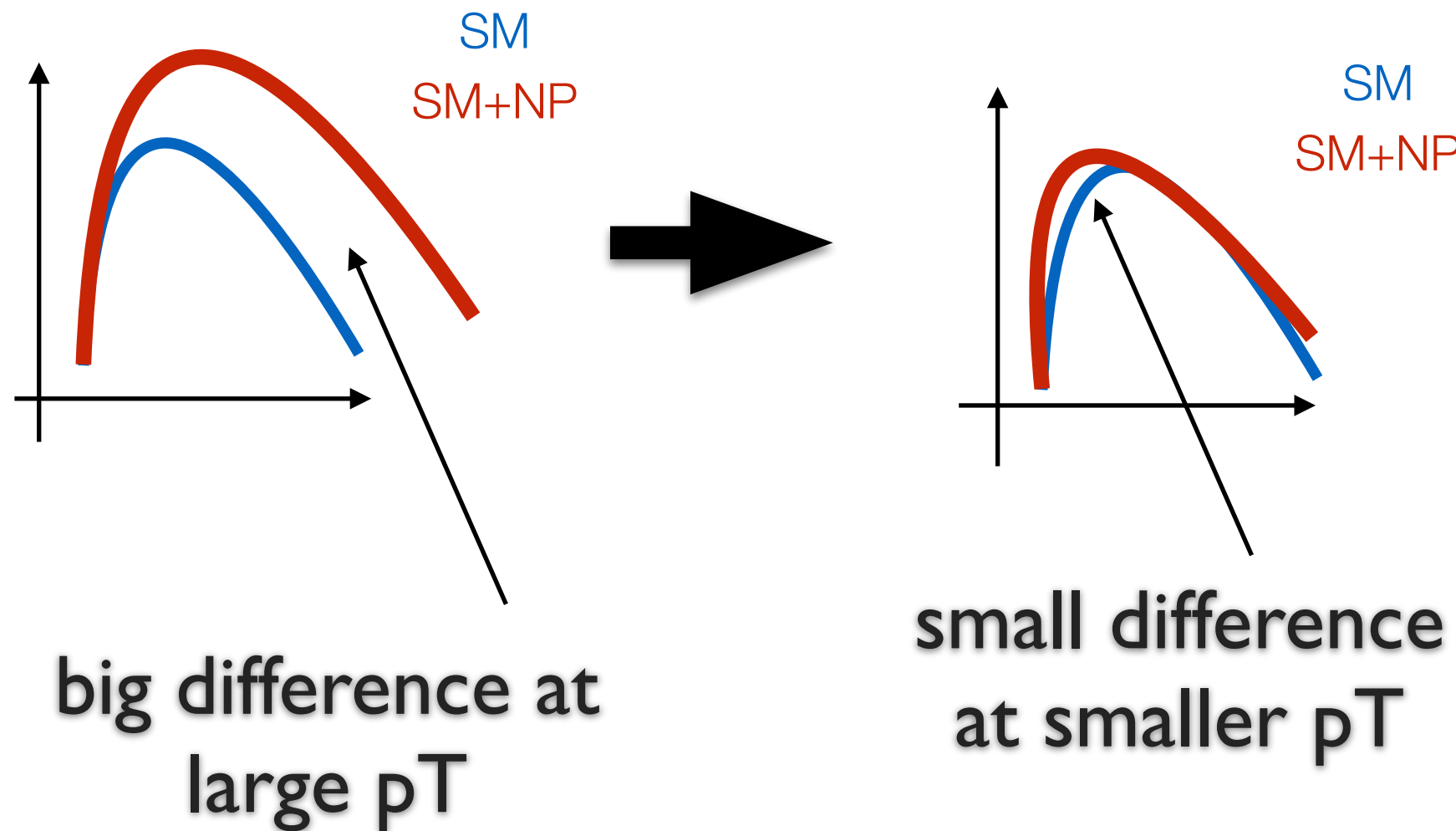
joint venture of TOP and SUSY groups?



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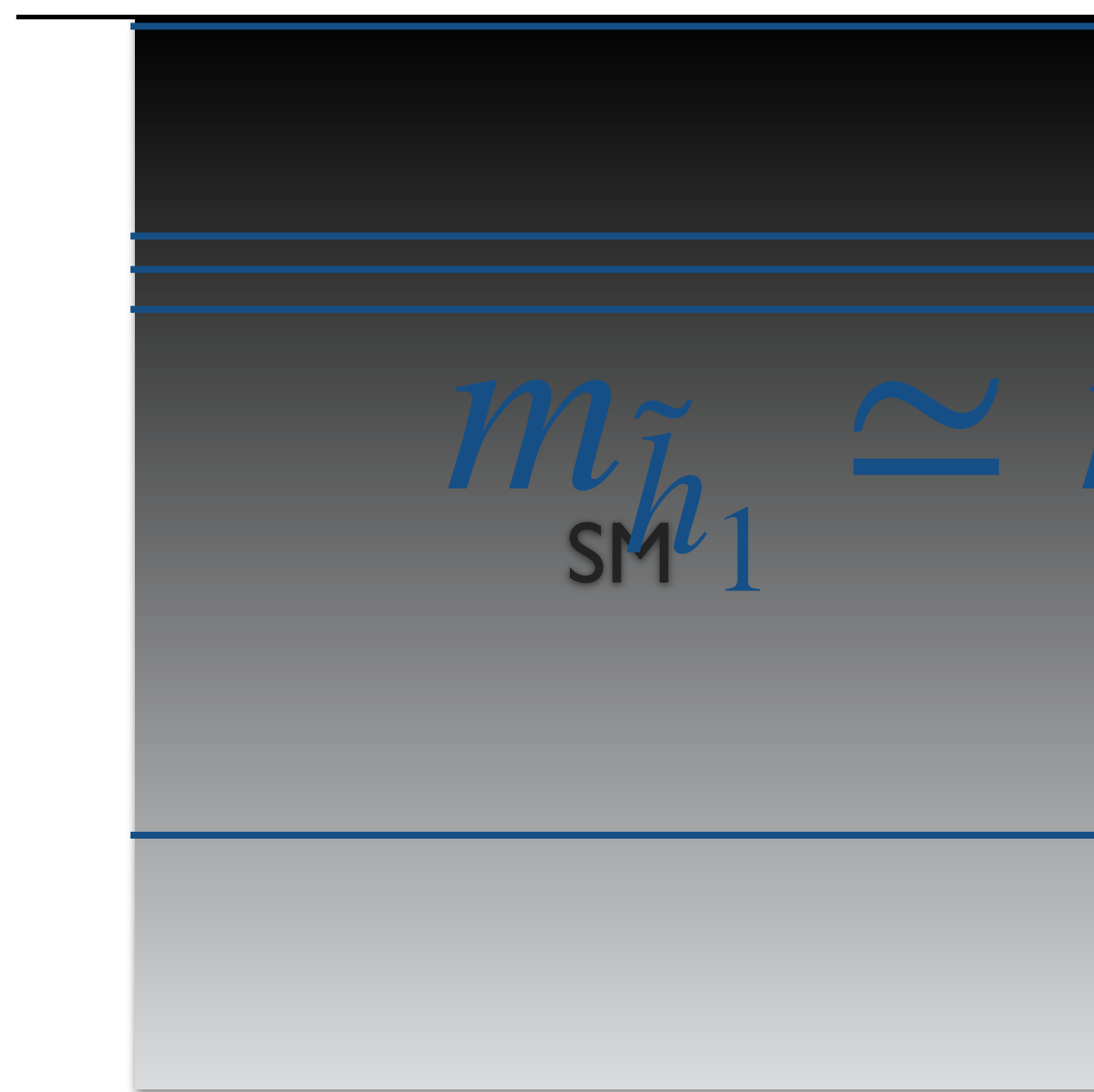
Measure  $pp \rightarrow t\bar{t}$  as precise as you can!

turn the search into a SM measurement

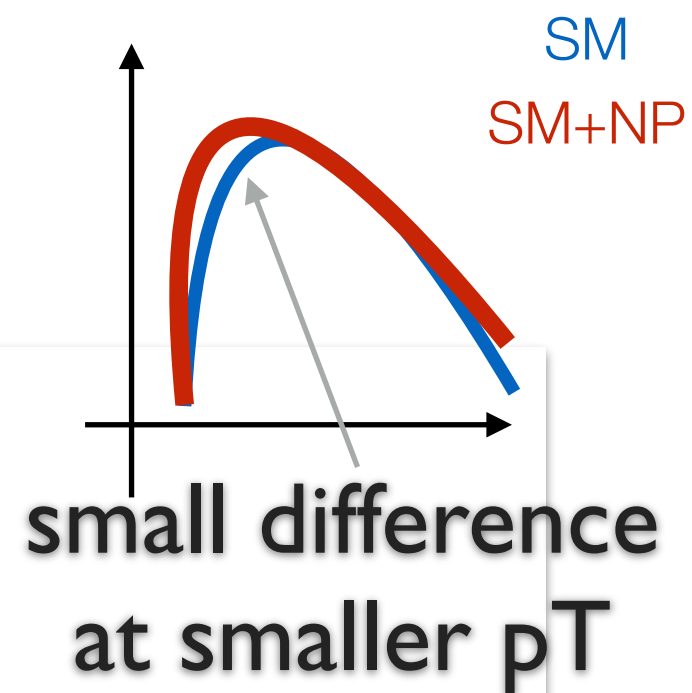


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turn the search into a SM measurement

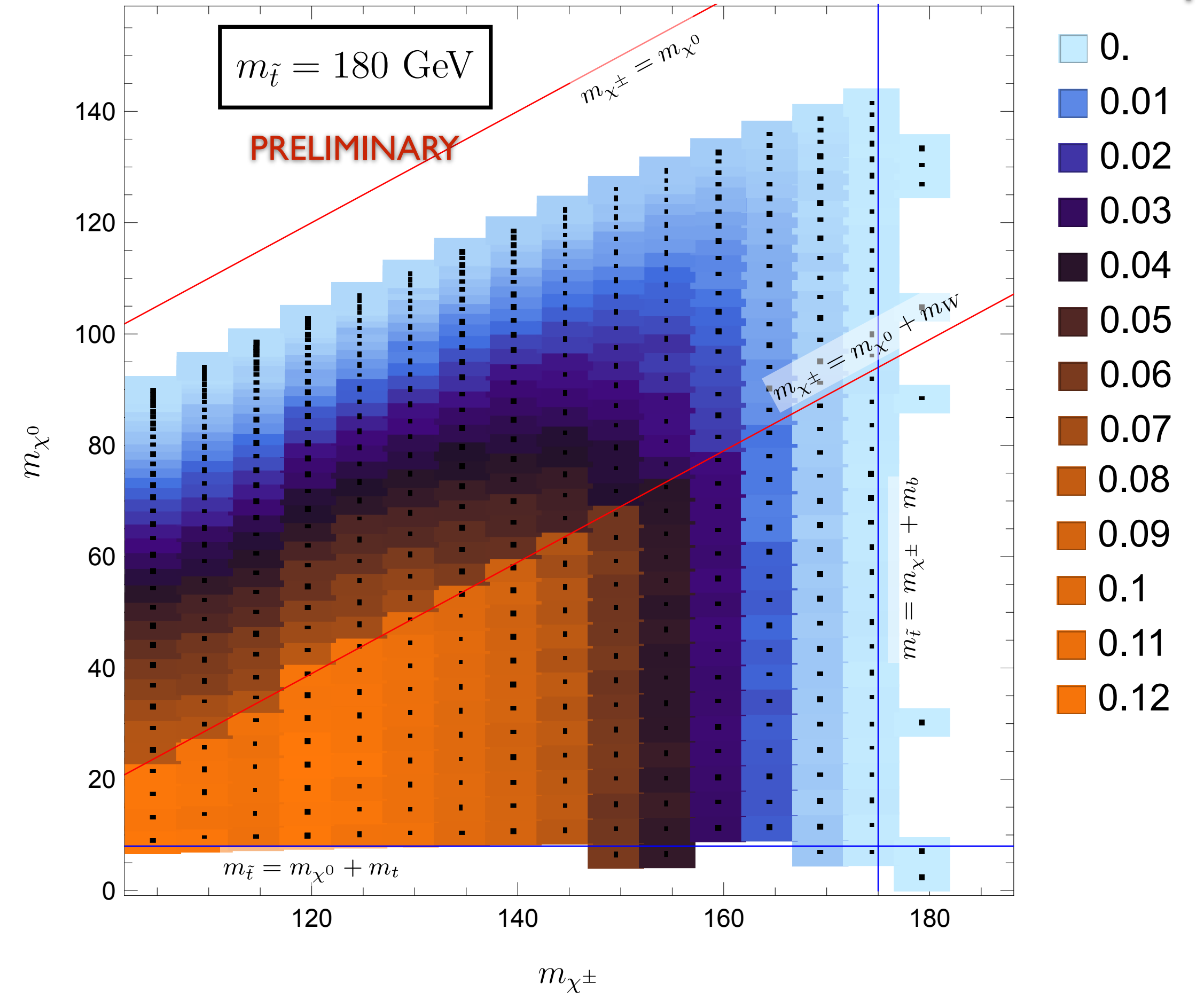


$m_{\tilde{t}_{top}}$   
 $m_{\tilde{h}_1} \approx m_{\tilde{h}_\pm} \approx m_{\tilde{h}_2}$   
 $m_{W,Z}$   
 $m_{\tilde{B}}$



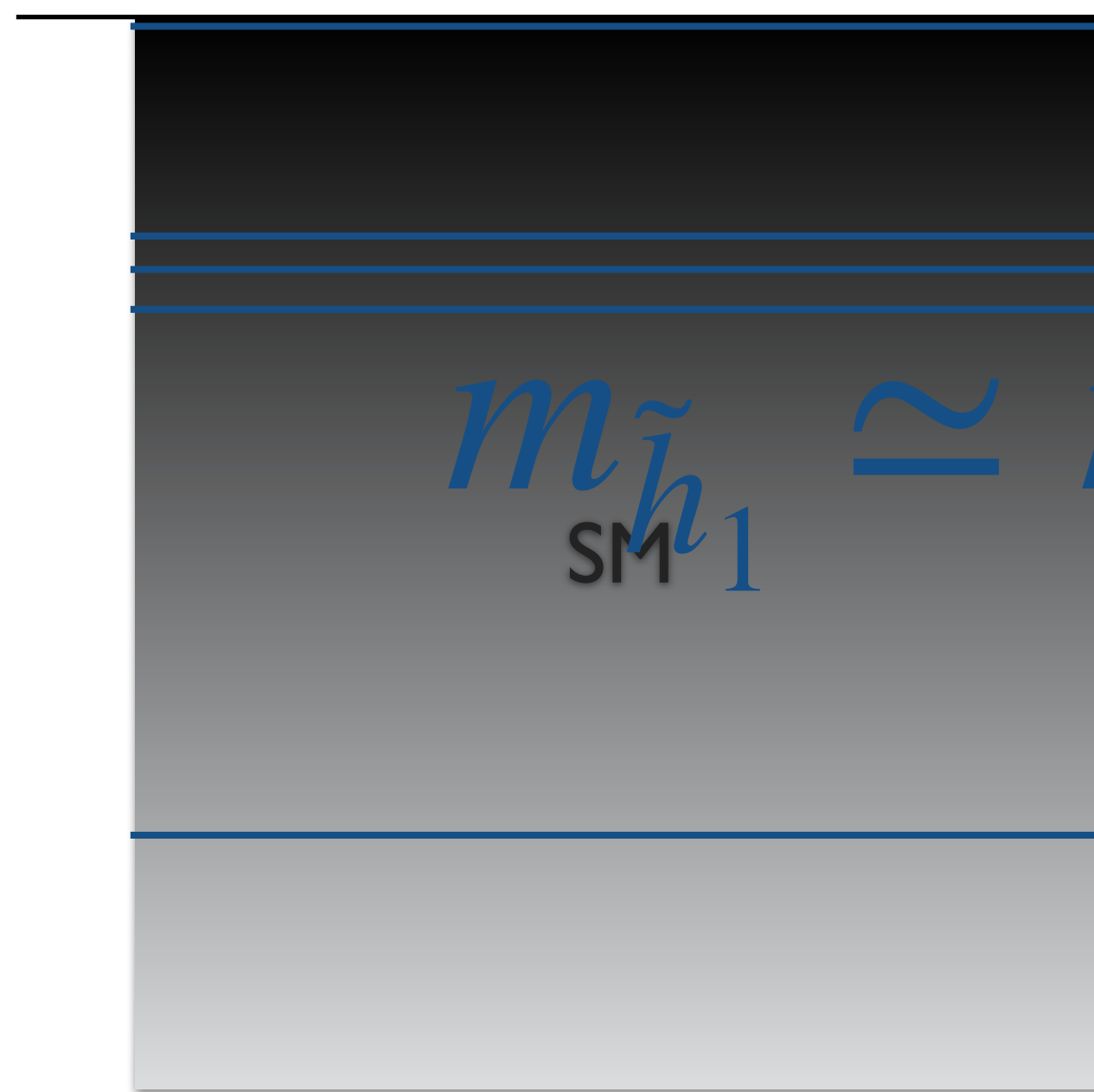
in progress - Bagnaschi, Corcella, RF, Sengupta

total  $S/B$  in  $d\sigma/dm_{b\ell}$

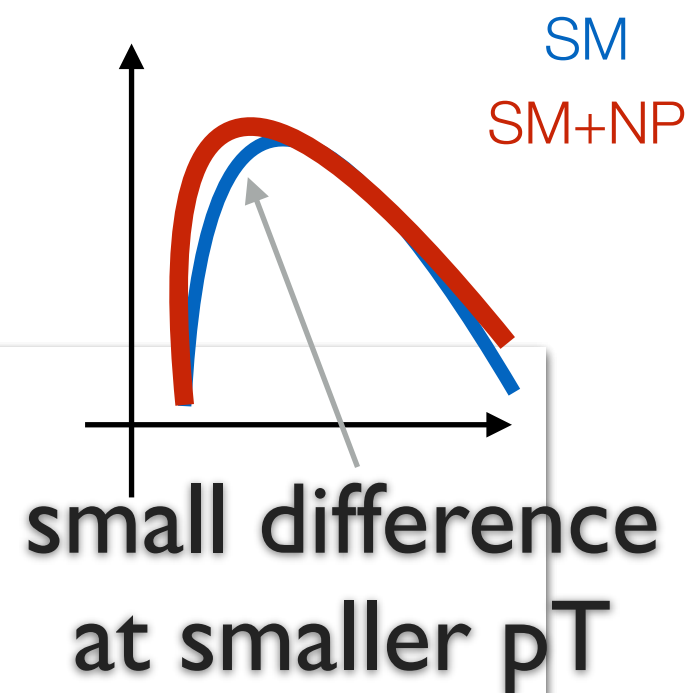


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turn the search into a SM measurement

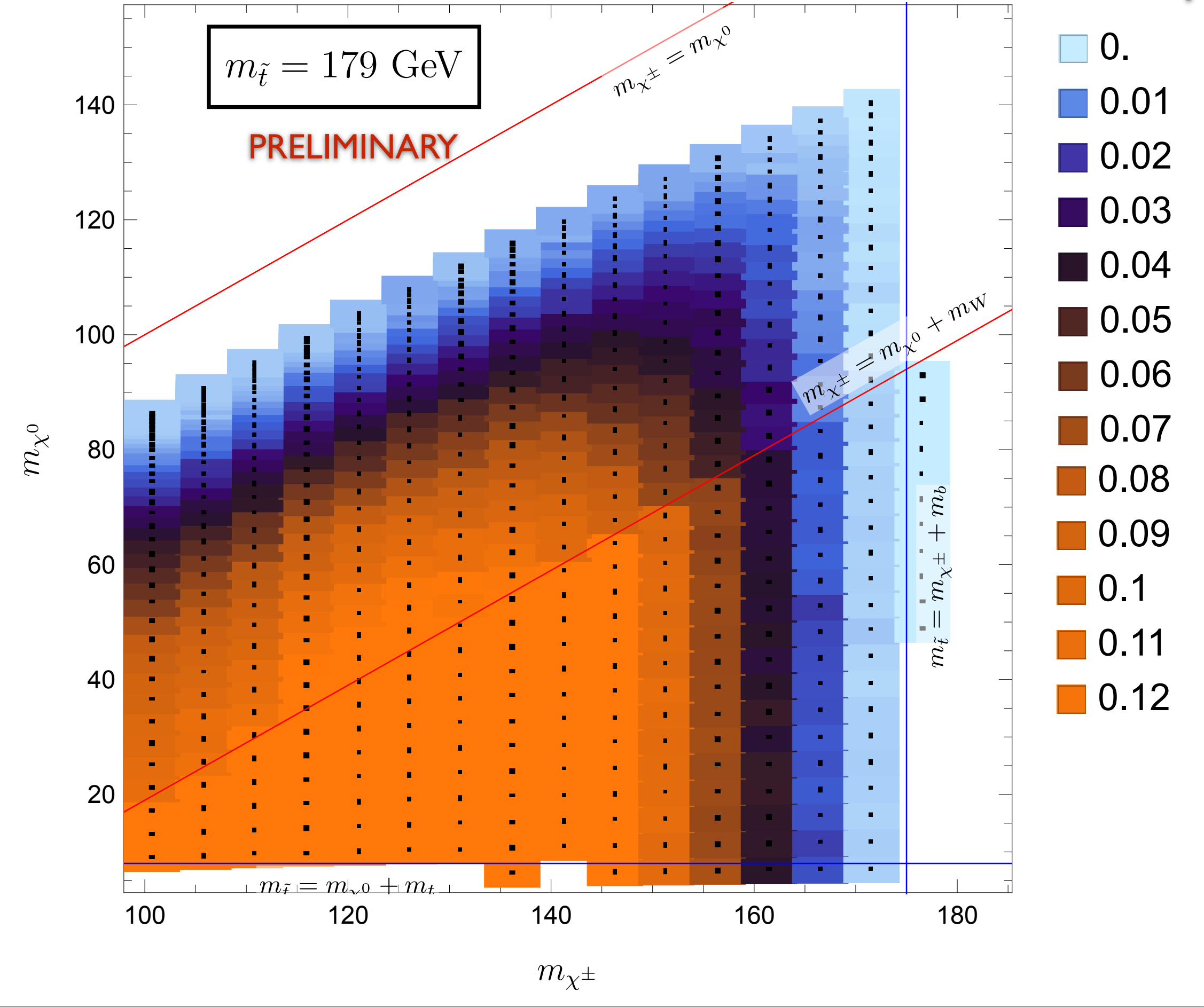


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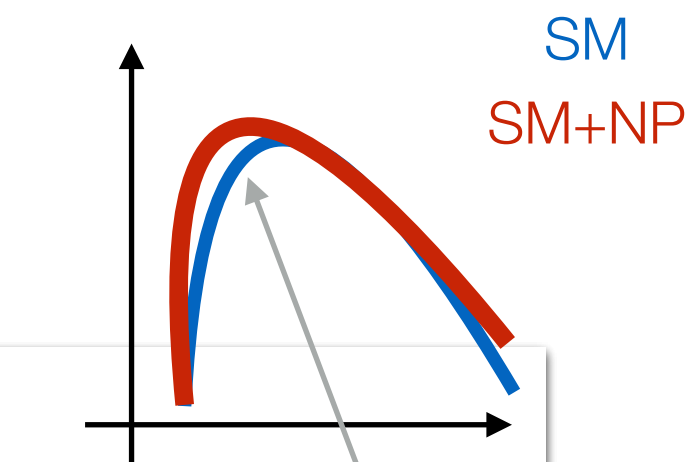


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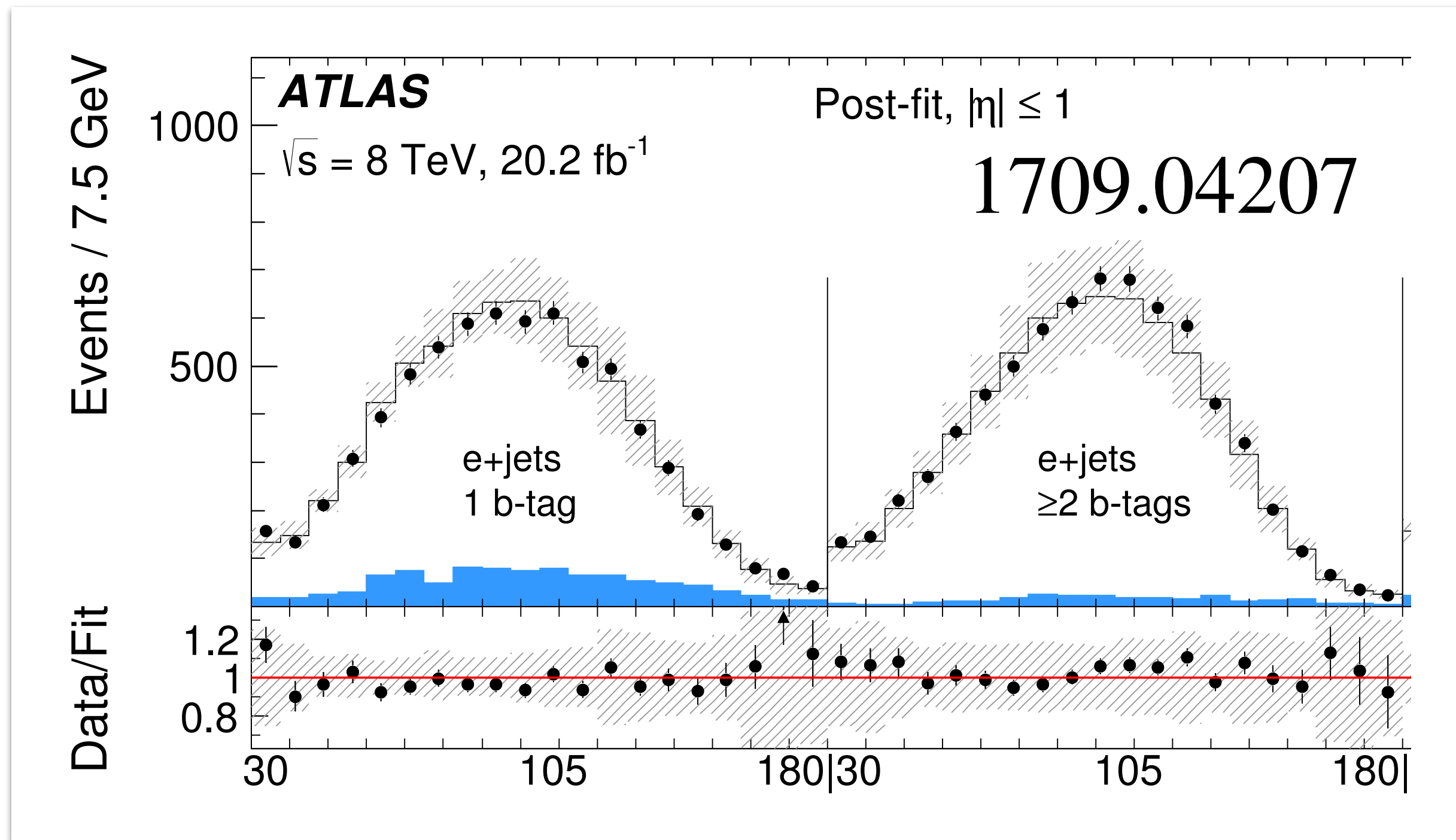
$m_{bl} \in [20, 100] \text{ GeV}$  *S/B* in  $d\sigma/dm_{bl}$



# WHAT TO DO TO COVER THESE MODELS



turn the search into a SM measurement

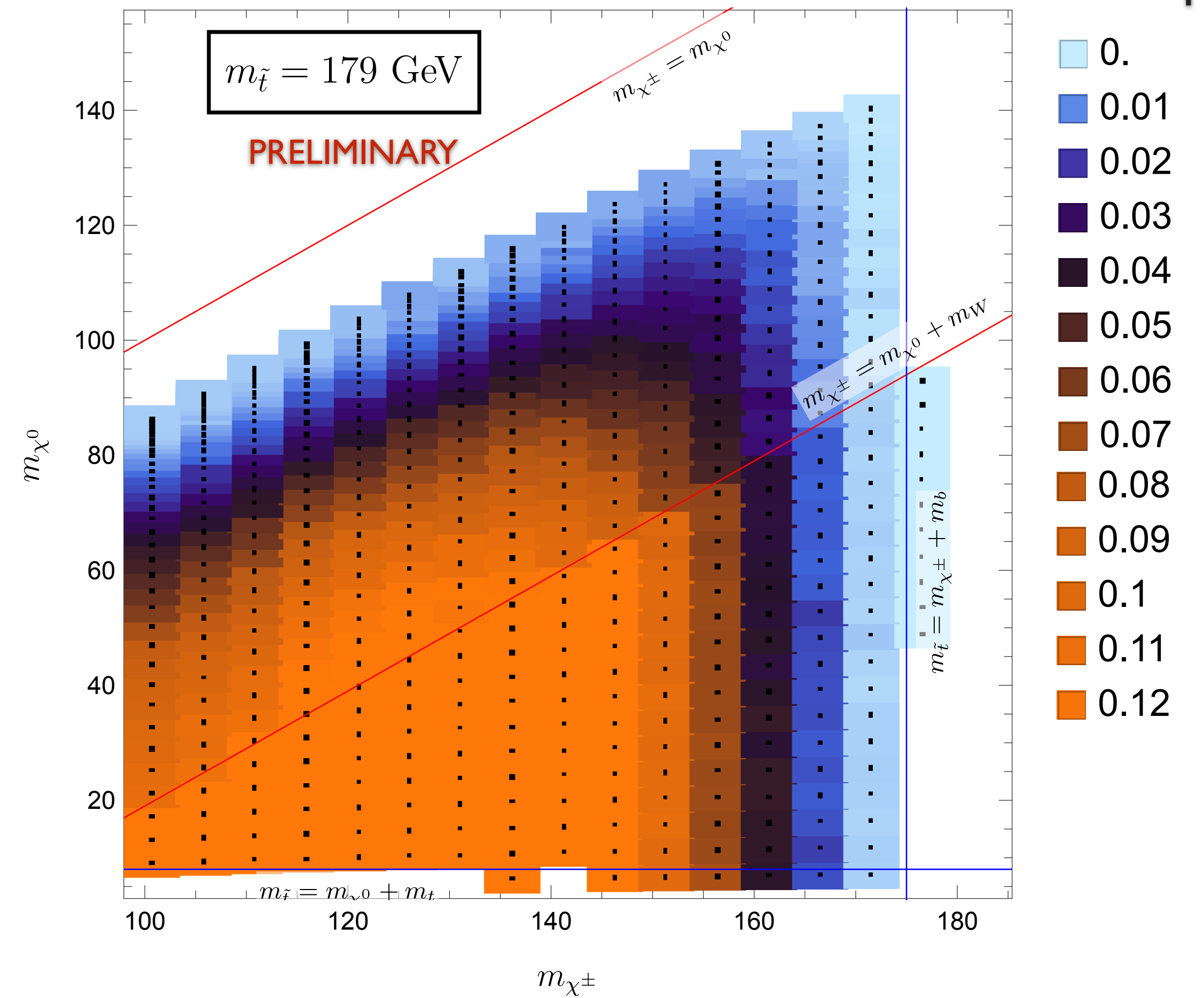


turn a measurement into a search

in progress - Bagnaschi, Corcella, RF, Sengupta

$m_{bl} \in [20, 100] \text{ GeV}$  *S/B* in  $d\sigma/dm_{bl}$

small difference at smaller  $p_T$



# CONCLUSION #1

Colored Light SUSY  Not everything covered, and can be fixed

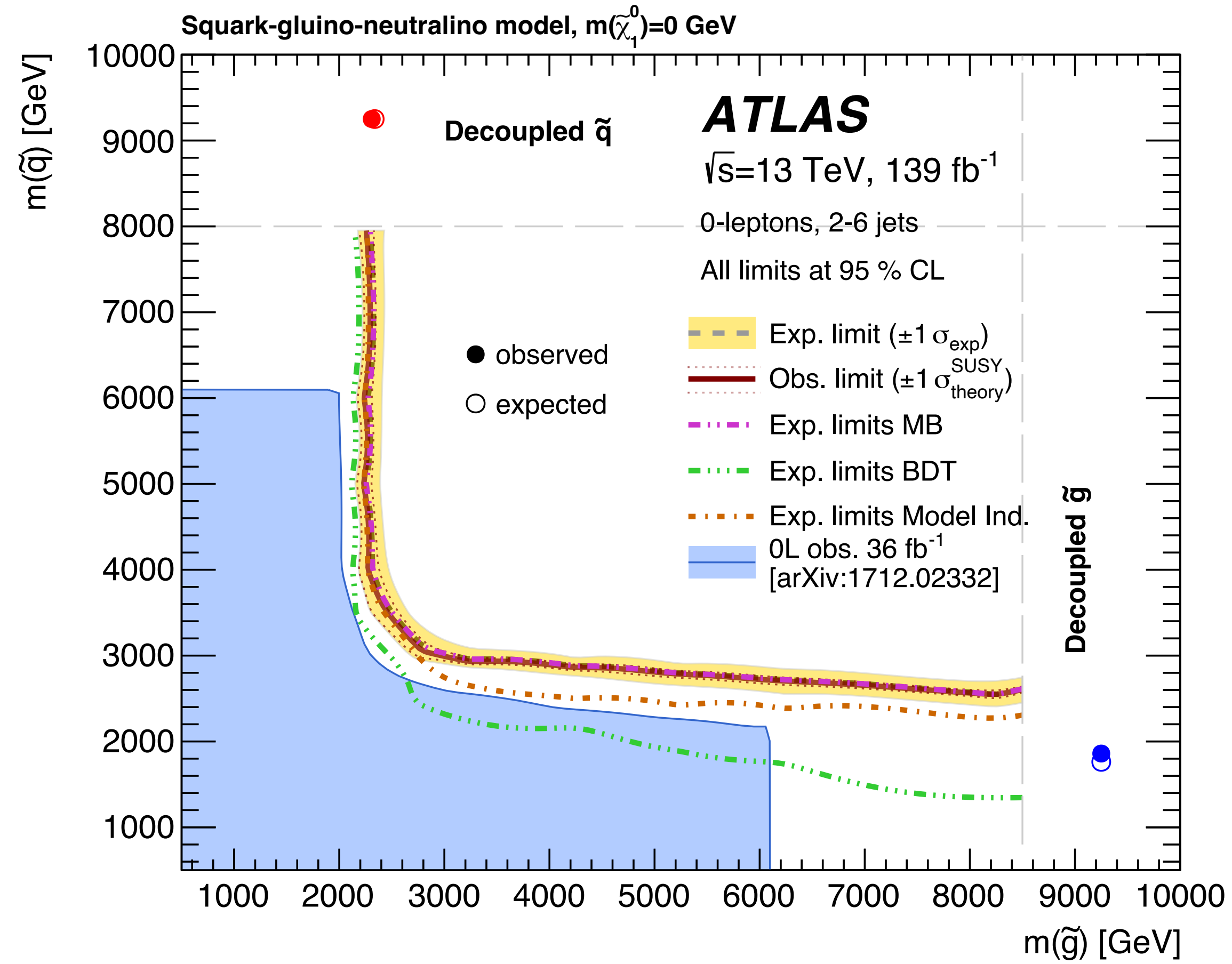
measurements of top quark properties can give searches as spin-off  
or

searches can be inspired by these measurements

it is necessary to strike a balance between effort to attain precision  
and search reach



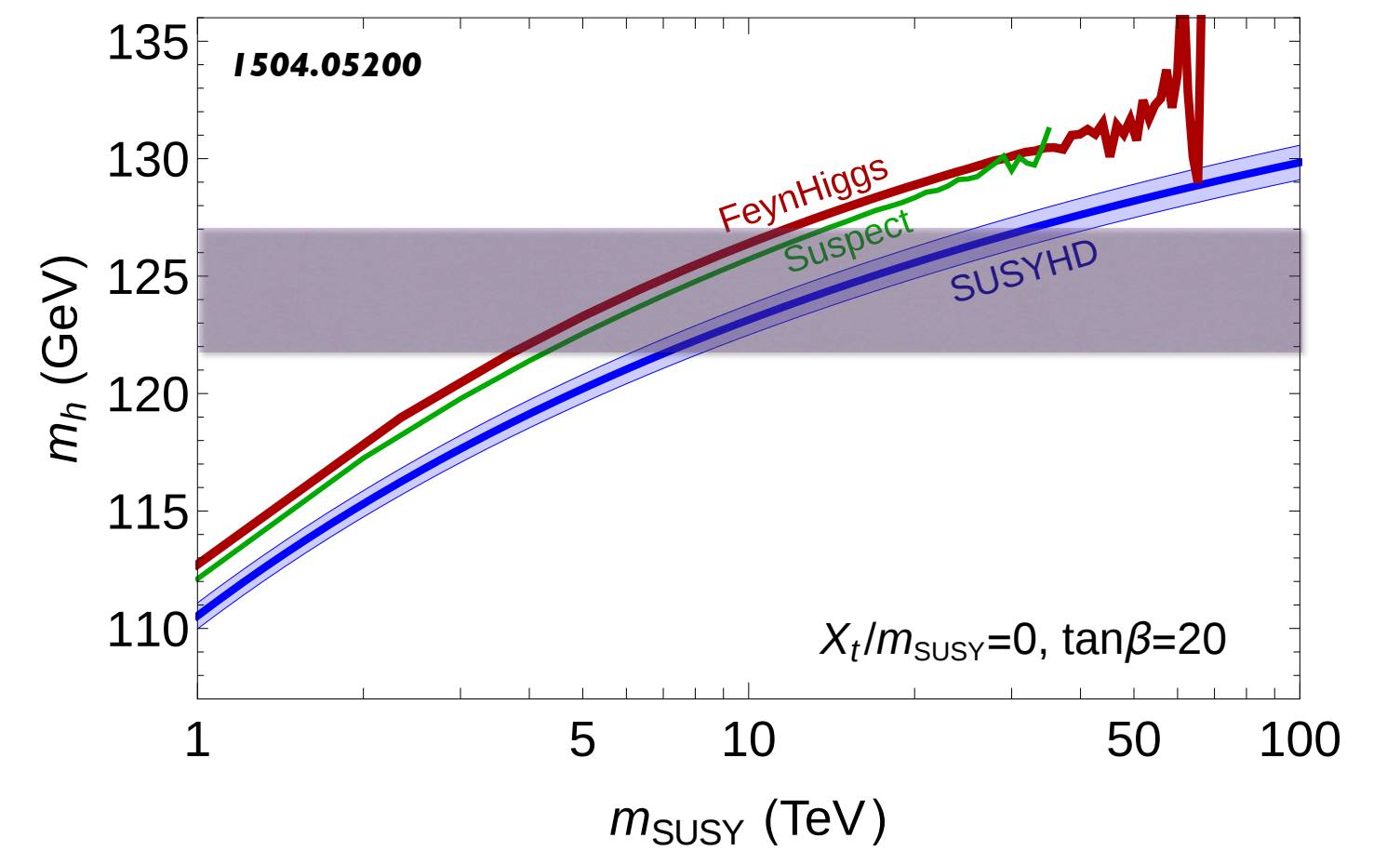
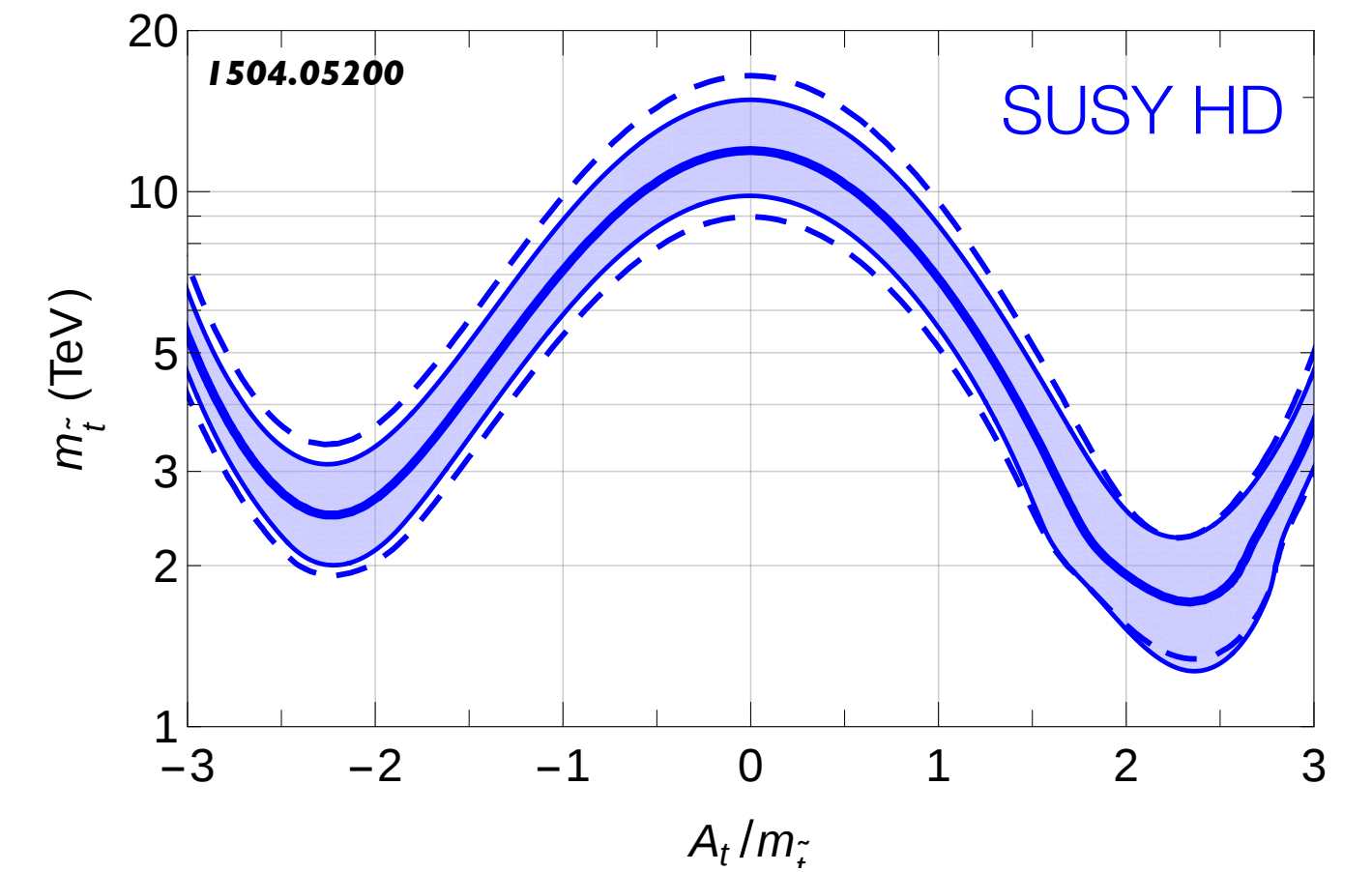
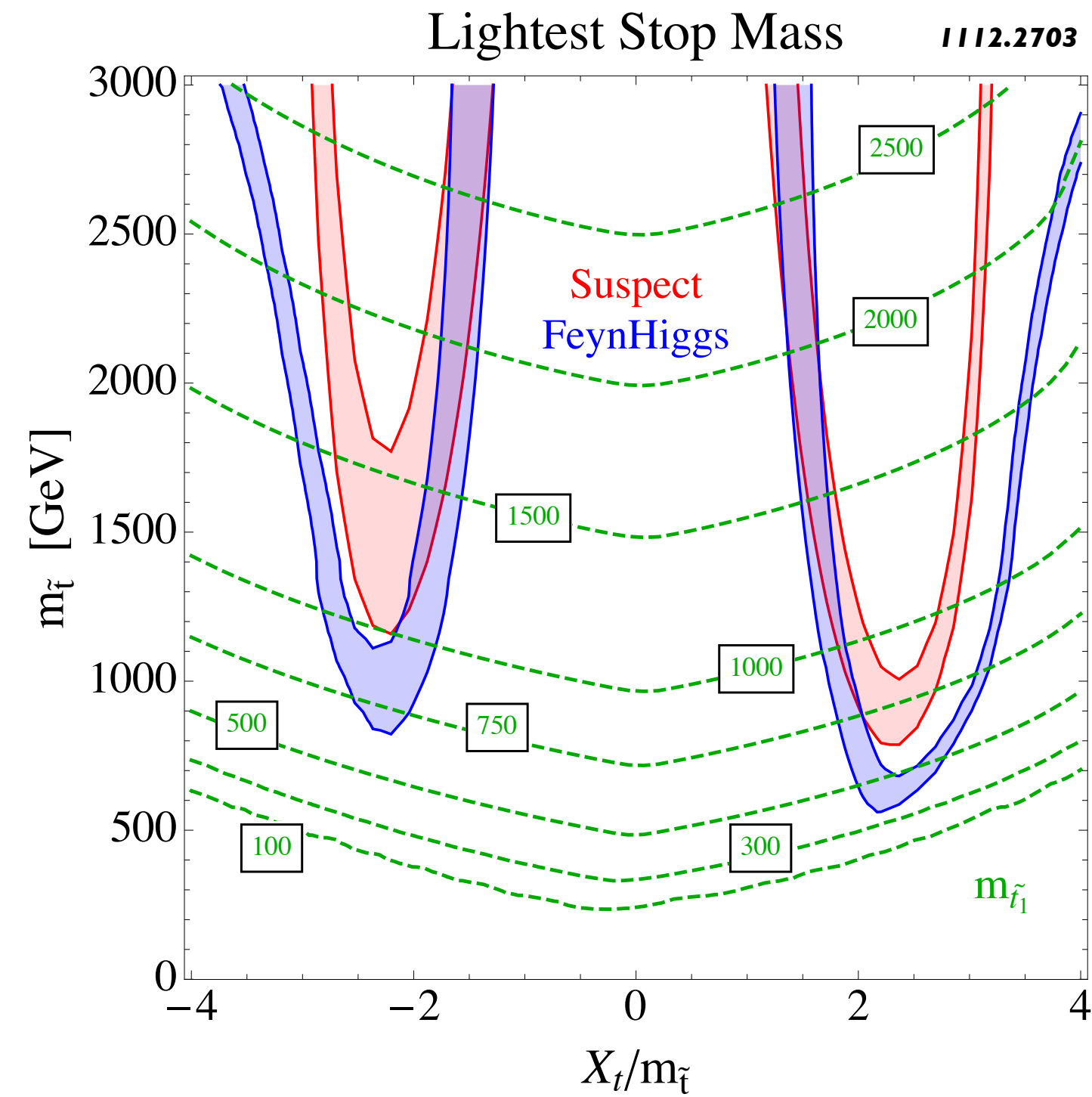
# WHAT ABOUT HEAVY COLORED SUSY?



# THE IMPORTANCE OF KEEPING PUSHING

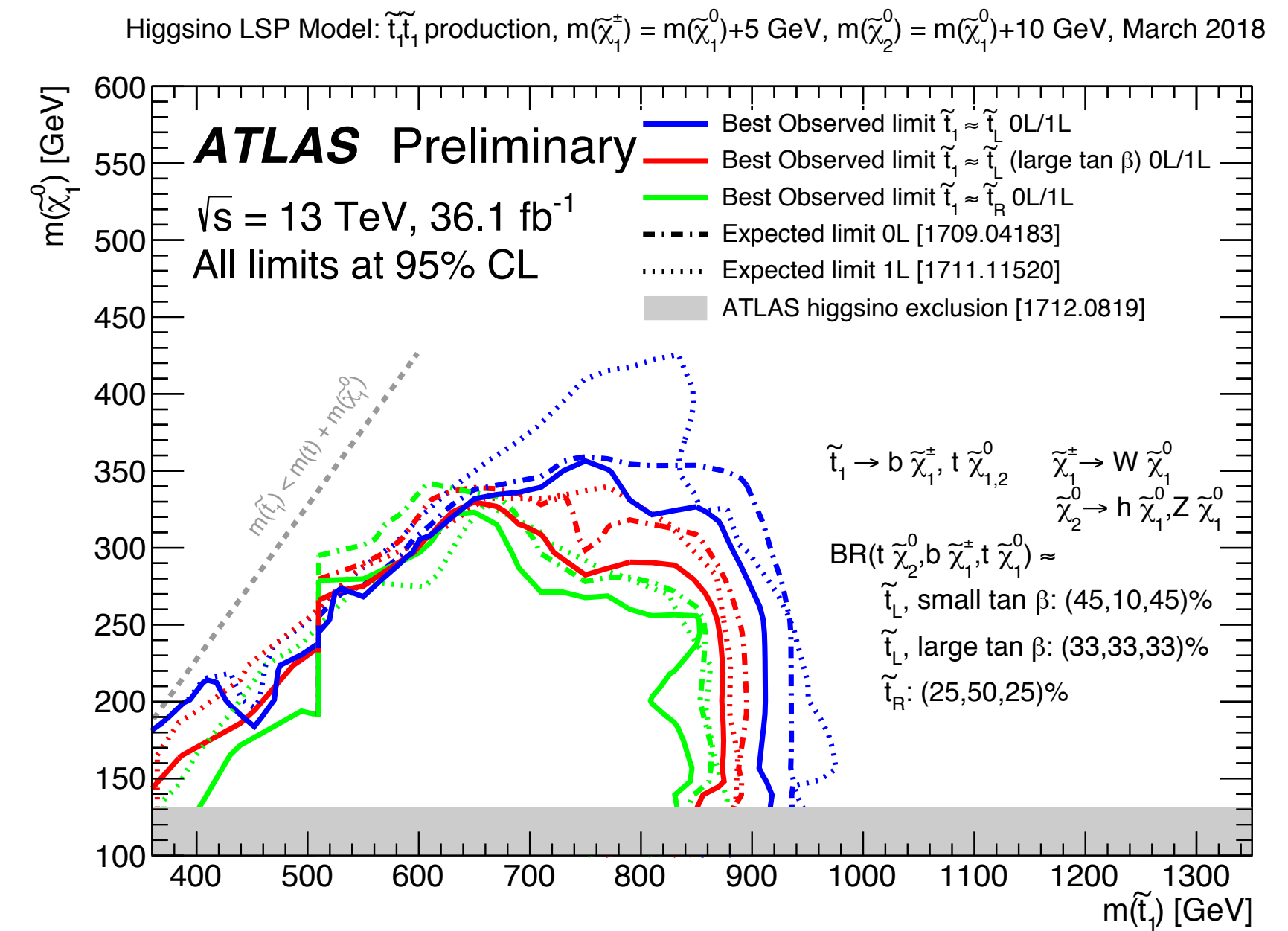
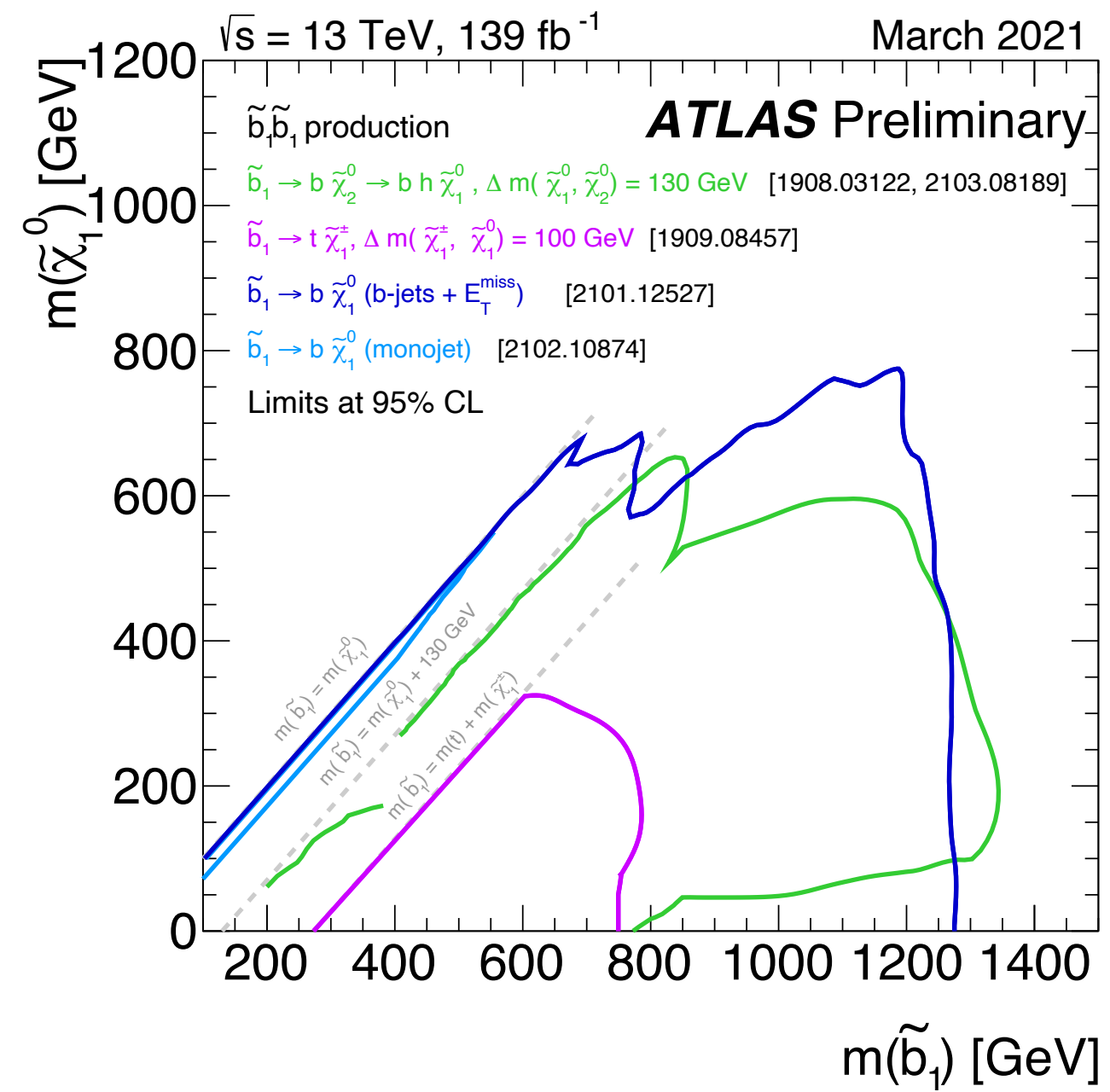
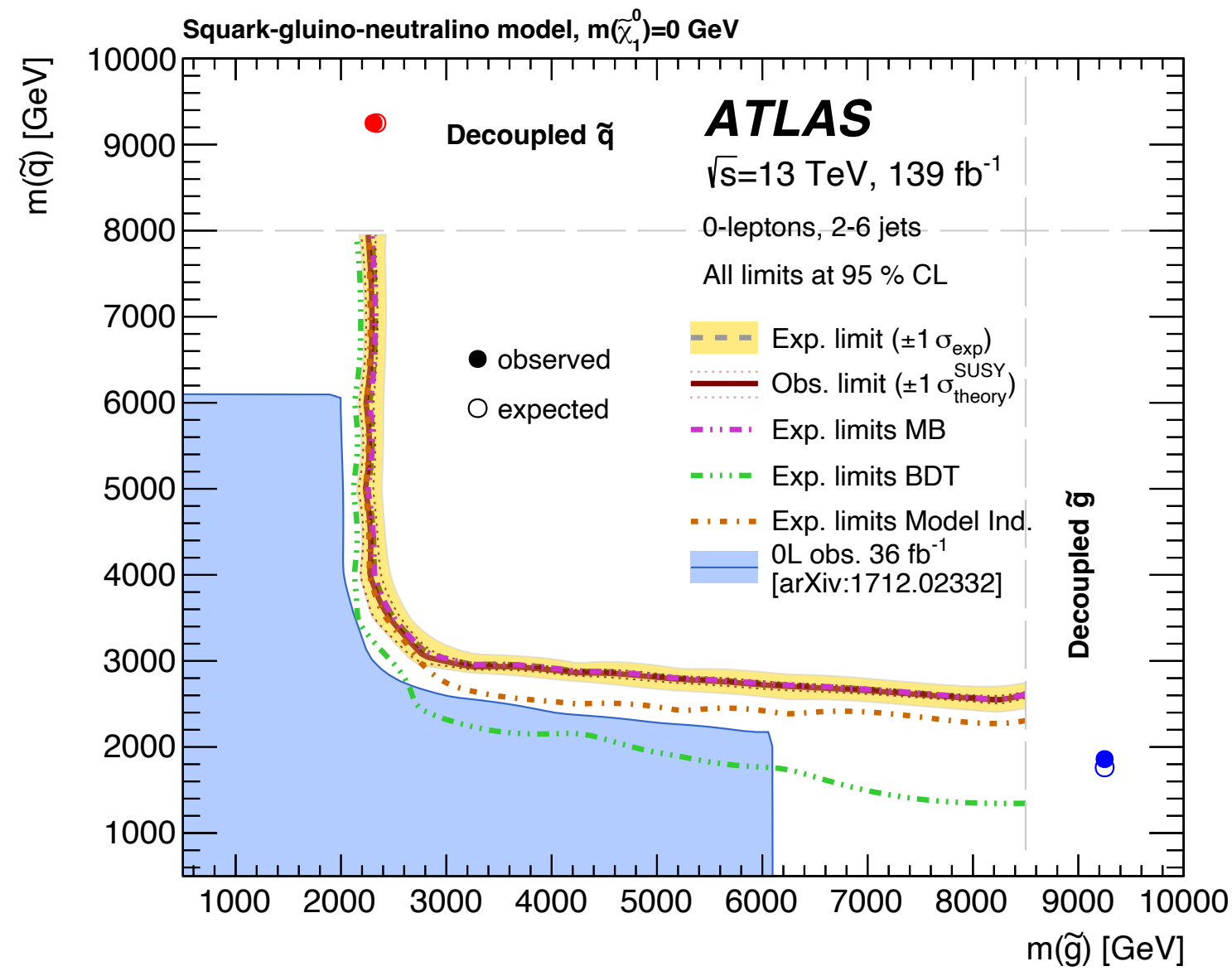
Heavy SUSY is not at all a bad thing! 1212.6971

The computation of  $m_h$   
in the MSSM points  
towards heavy SUSY



# CONCLUSION #2

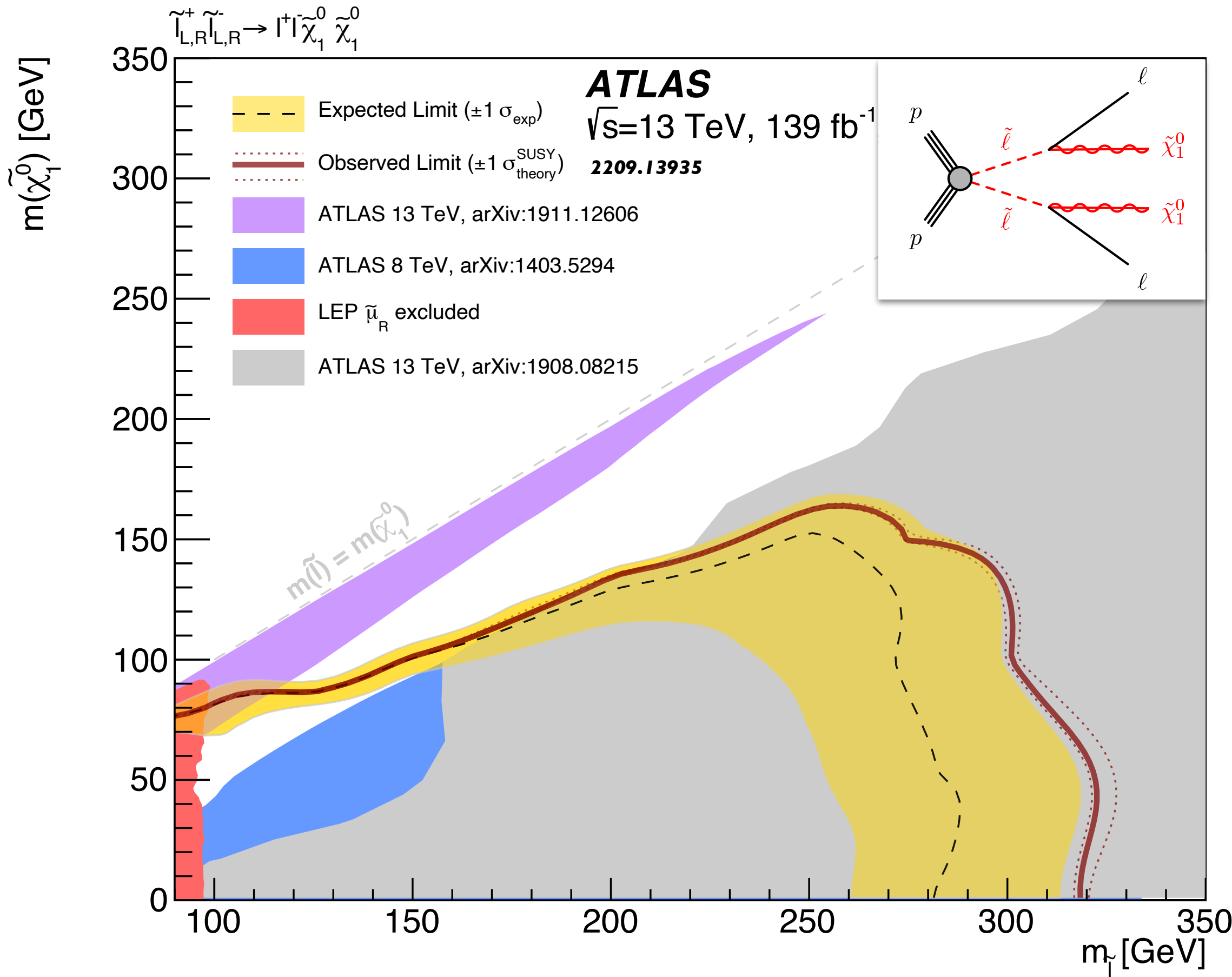
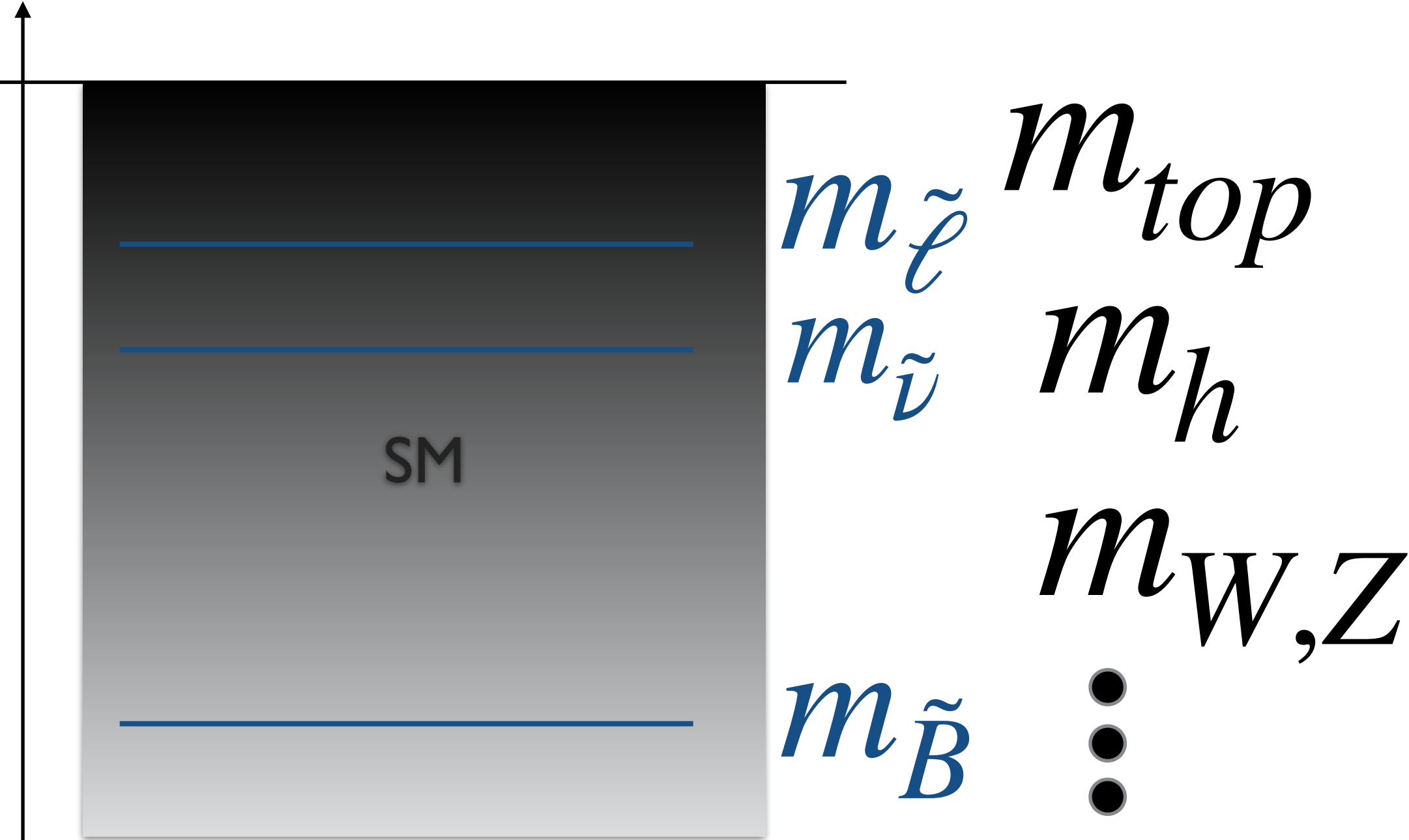
SUSY  $\gg$  TeV matters  $\Rightarrow$  Keep it up!





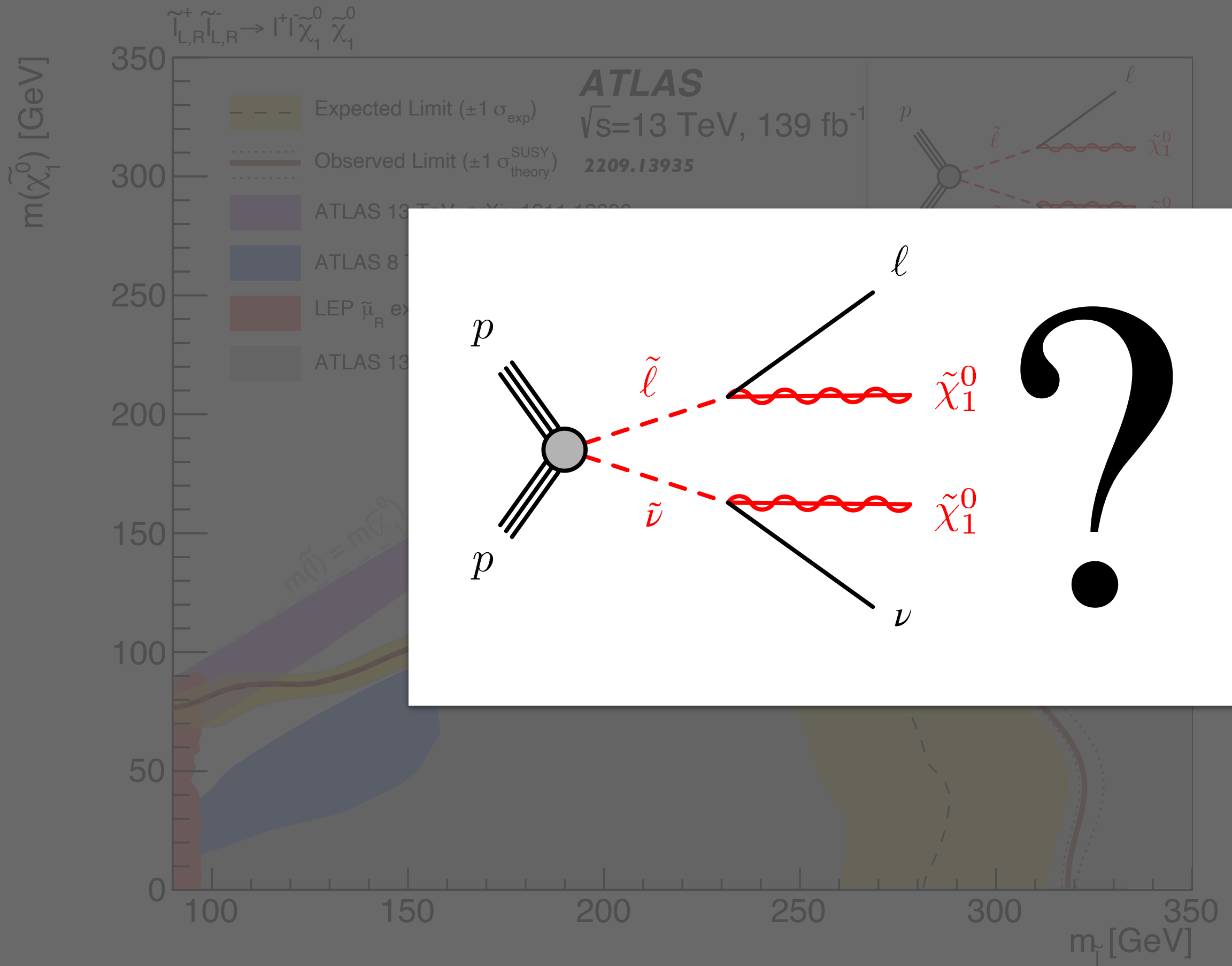
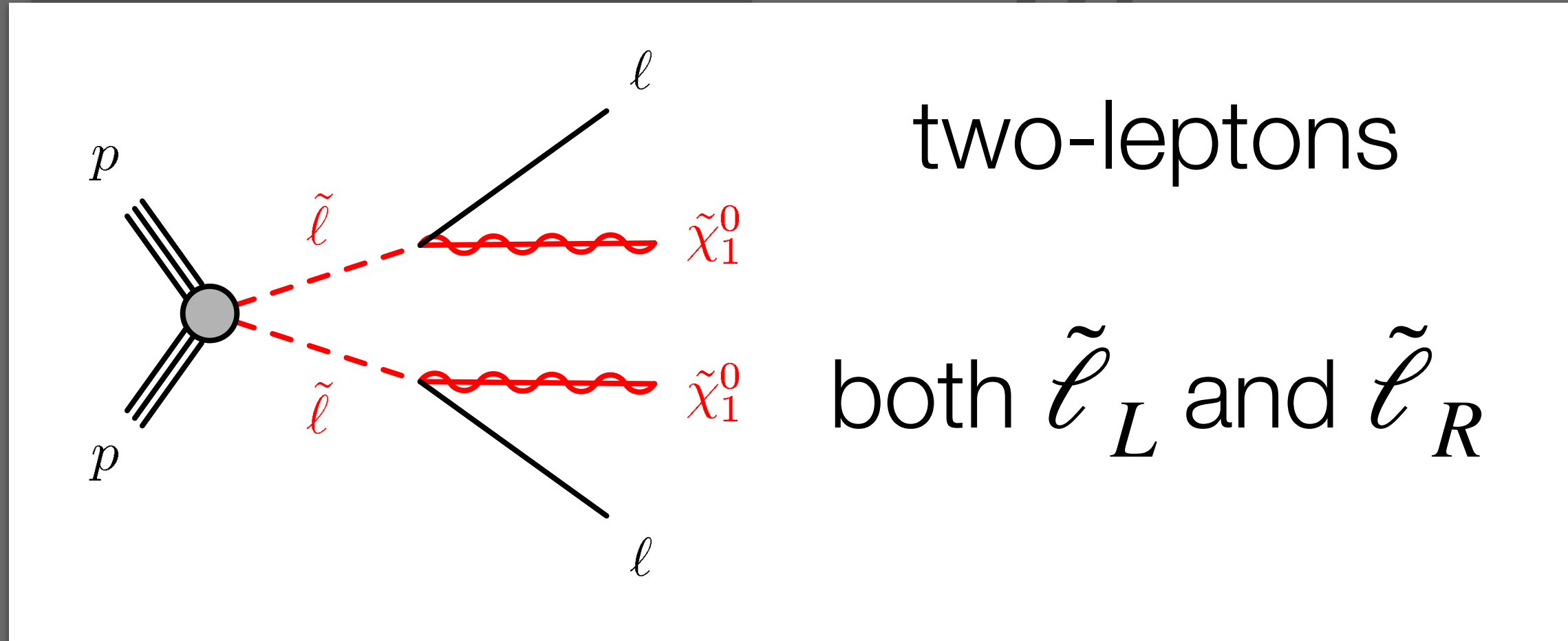
# THE FAINTEST ELECTROWEAK SUSY SIGNALS

Run3 and HL-LHC material!



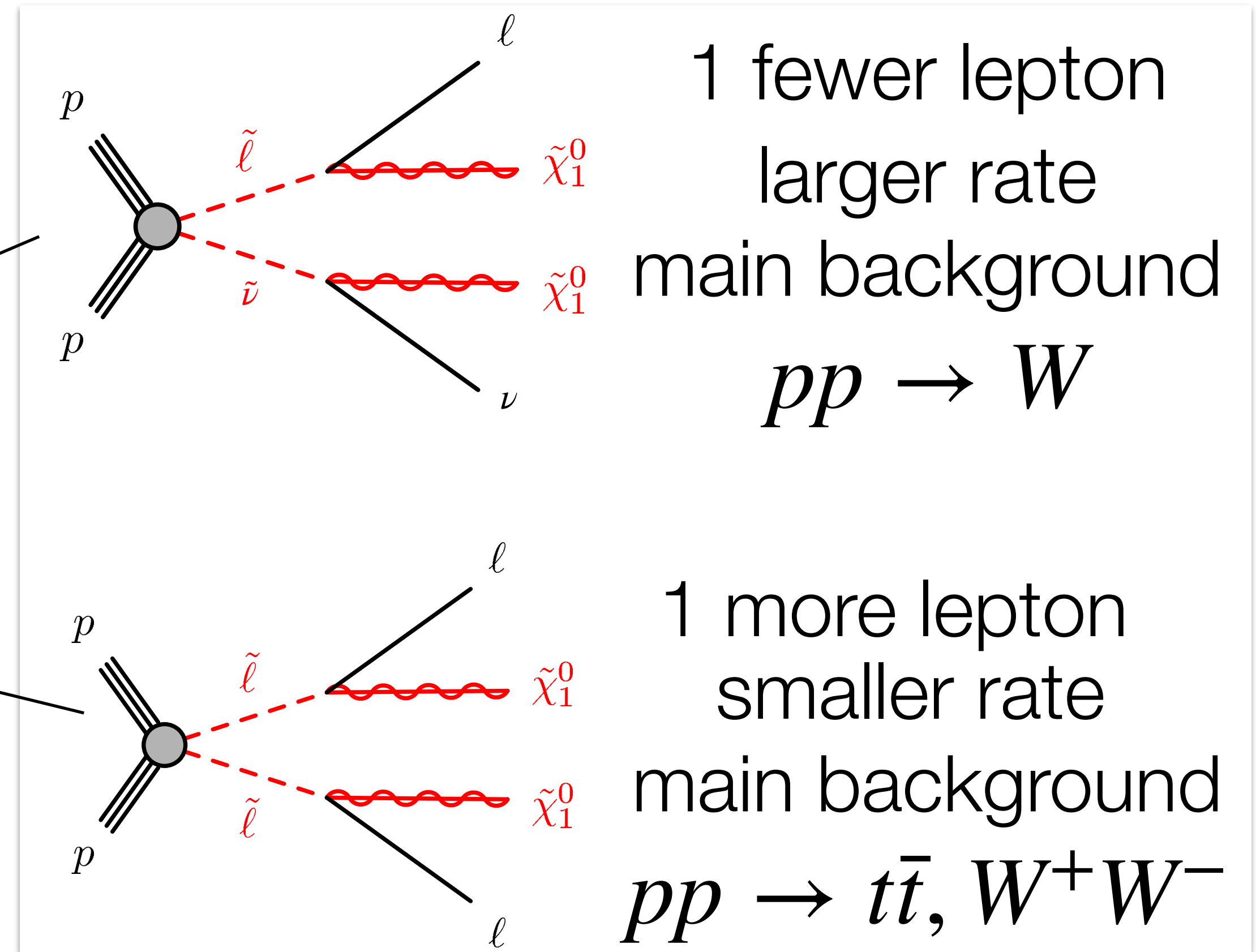
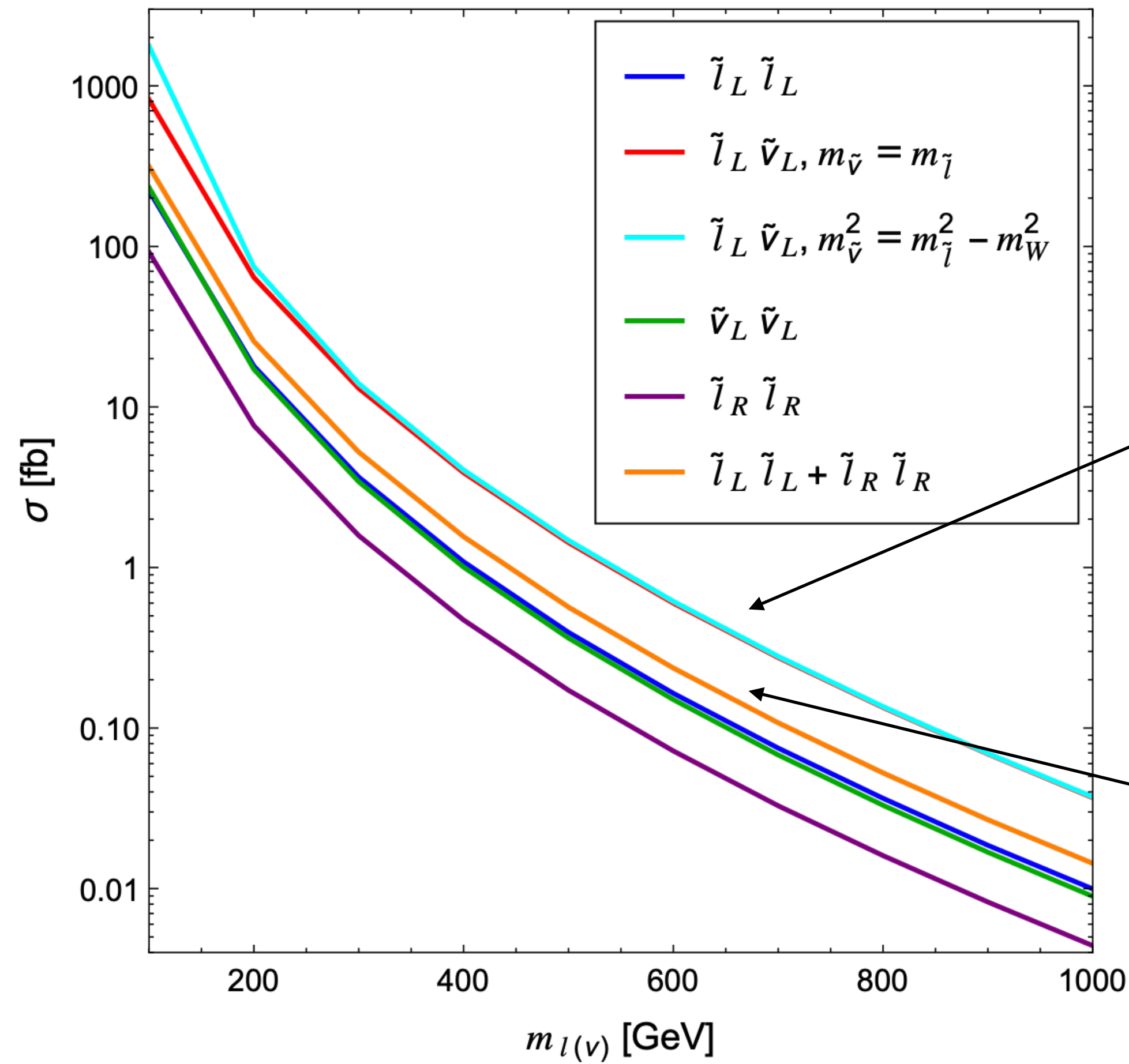
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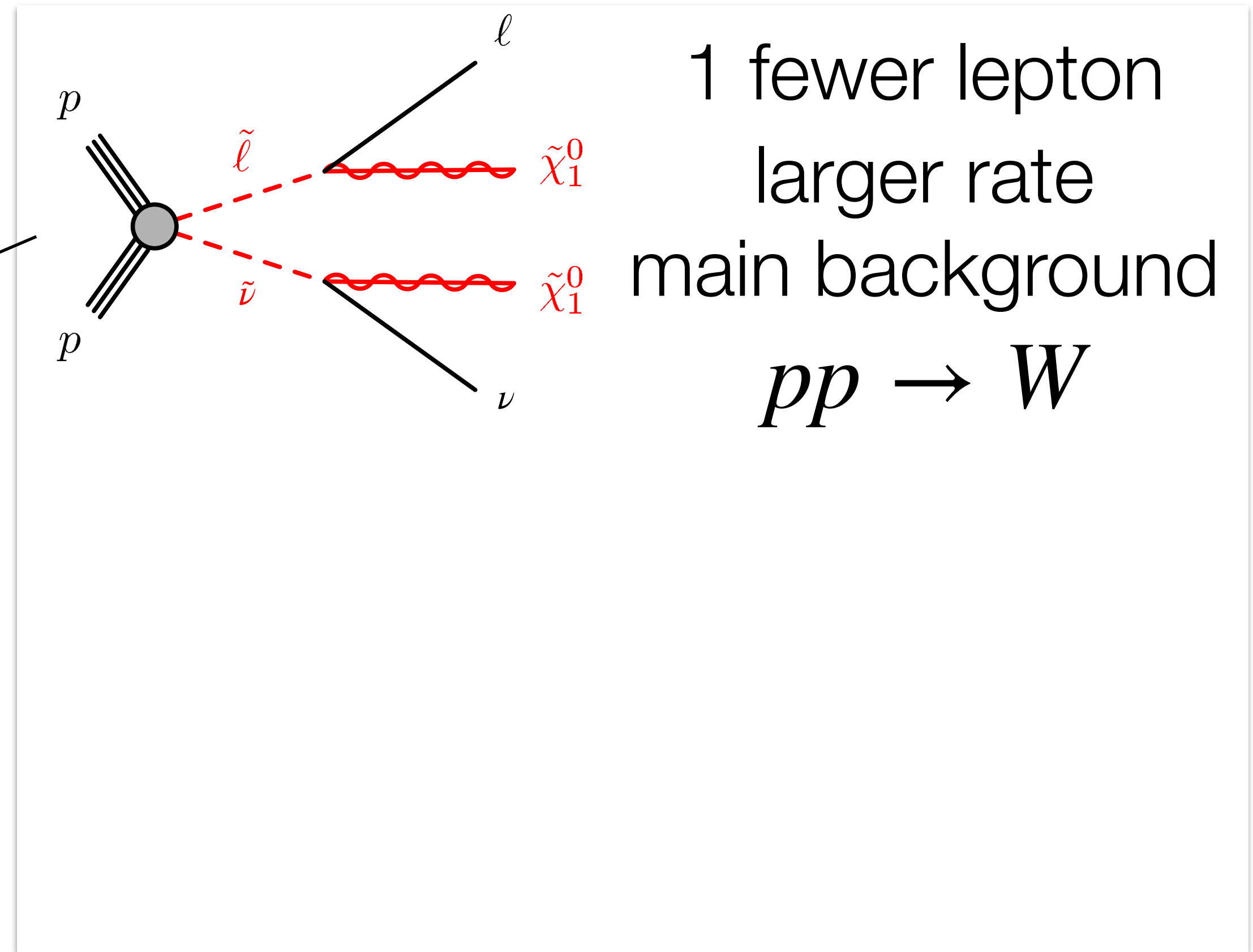
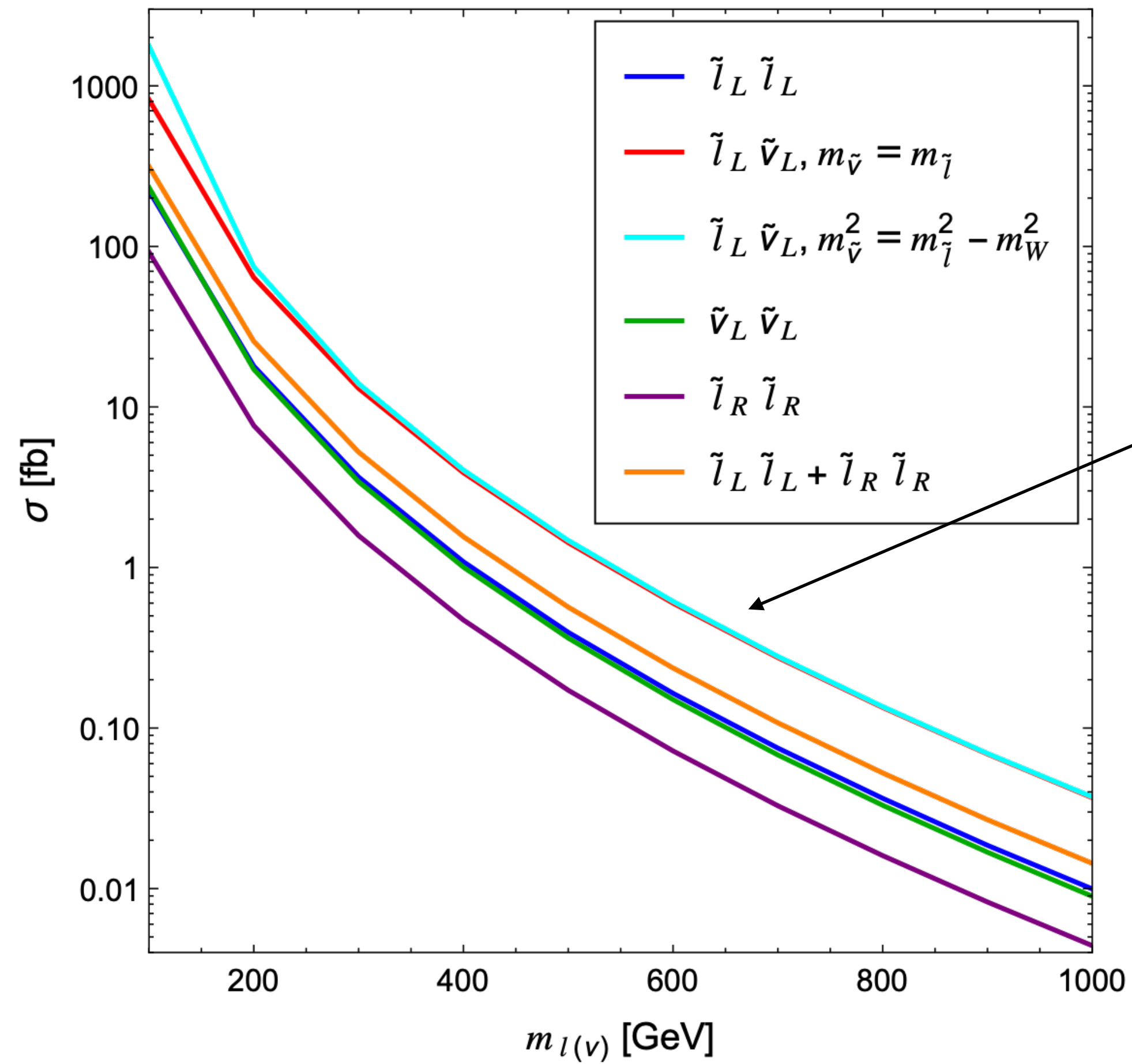
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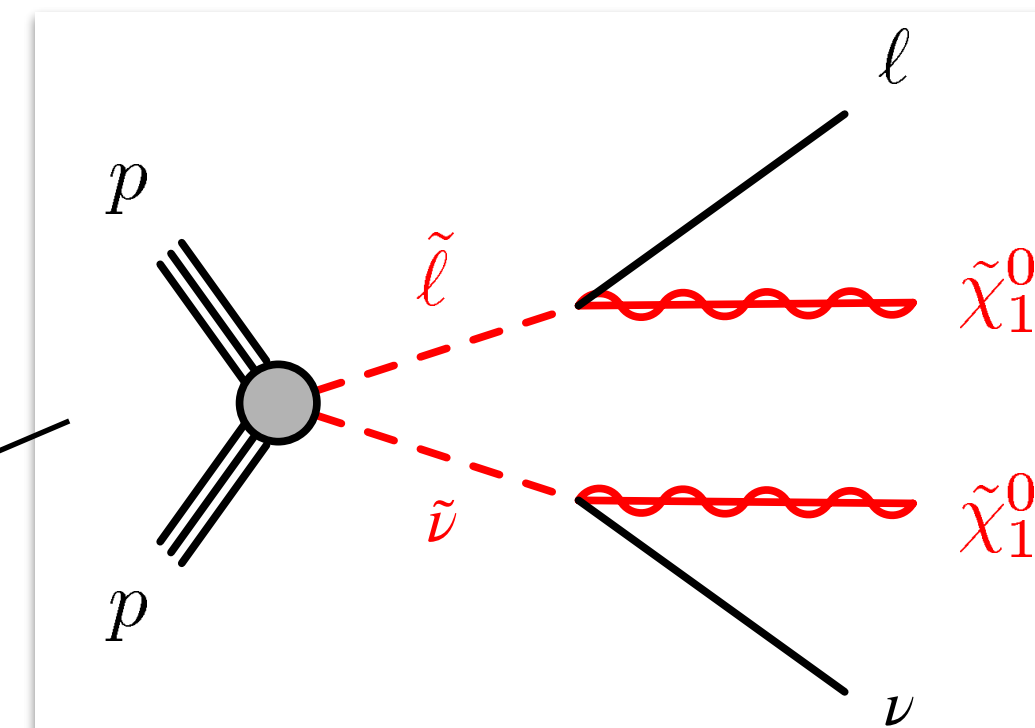
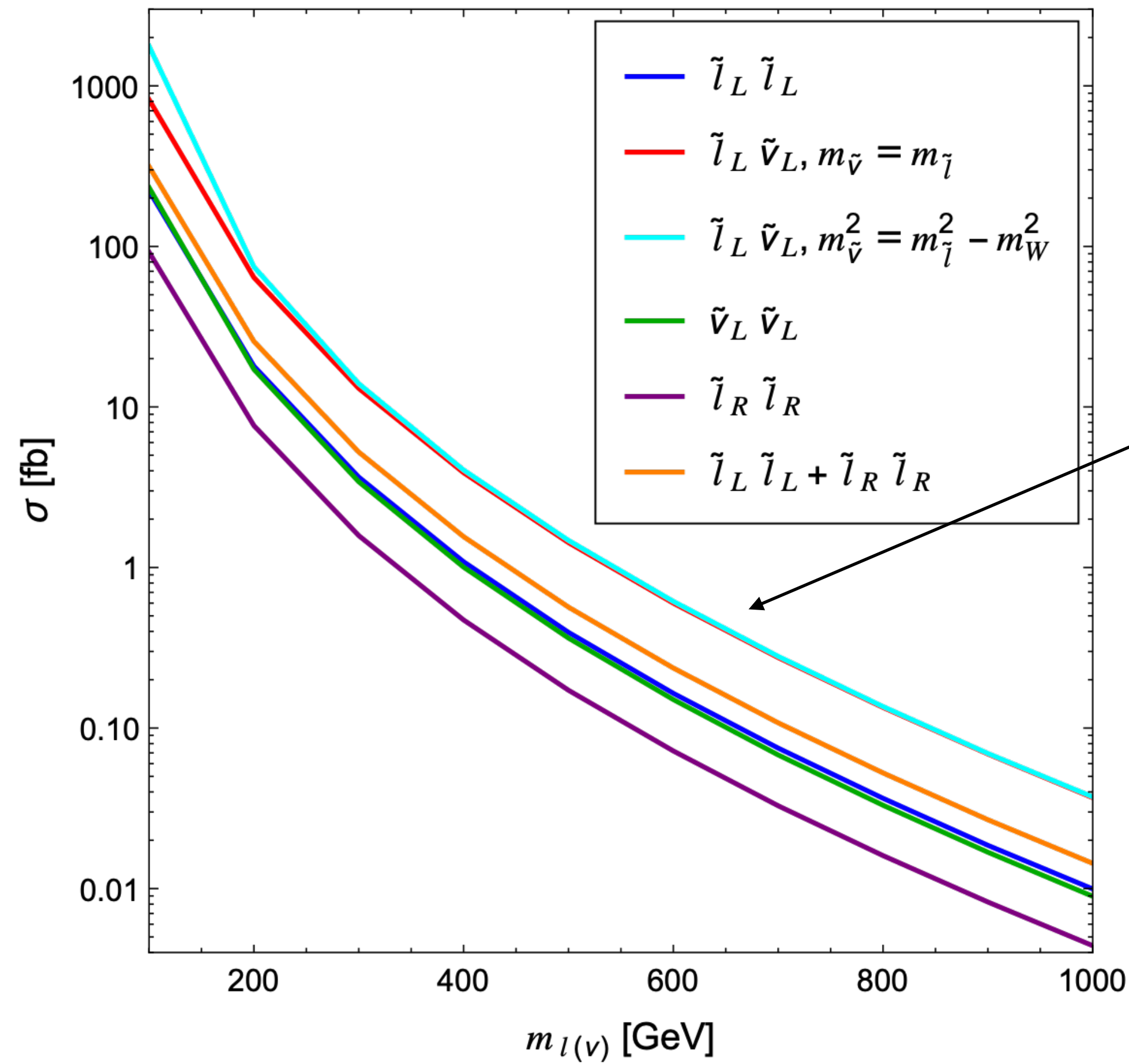
Run3 and HL-LHC material!





# THE FAINTEST ELECTROWEAK SUSY SIGNALS

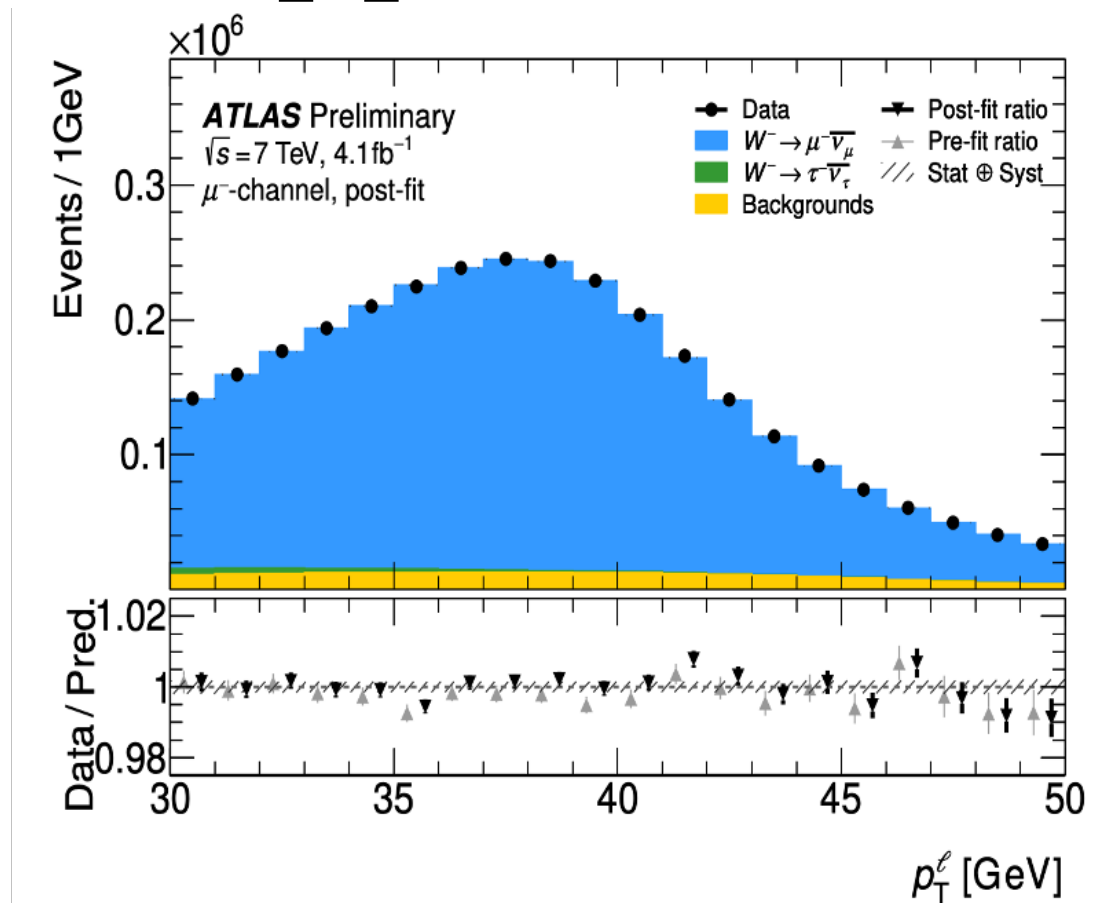
Run3 and HL-LHC material!



turn the  $m_W$  measurement into a search

1 fewer lepton  
larger rate  
main background

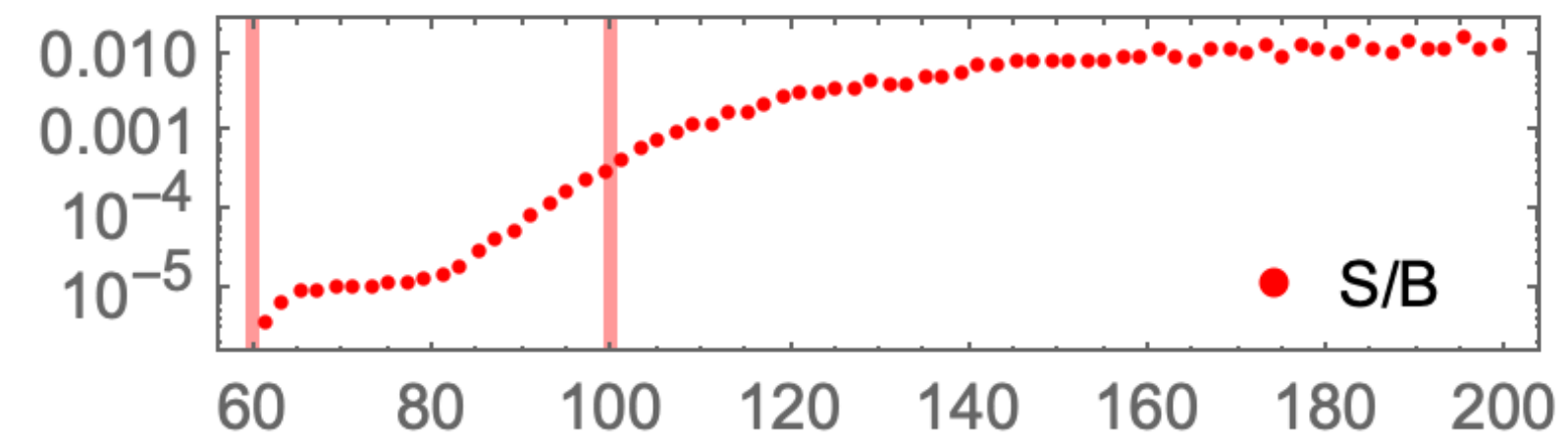
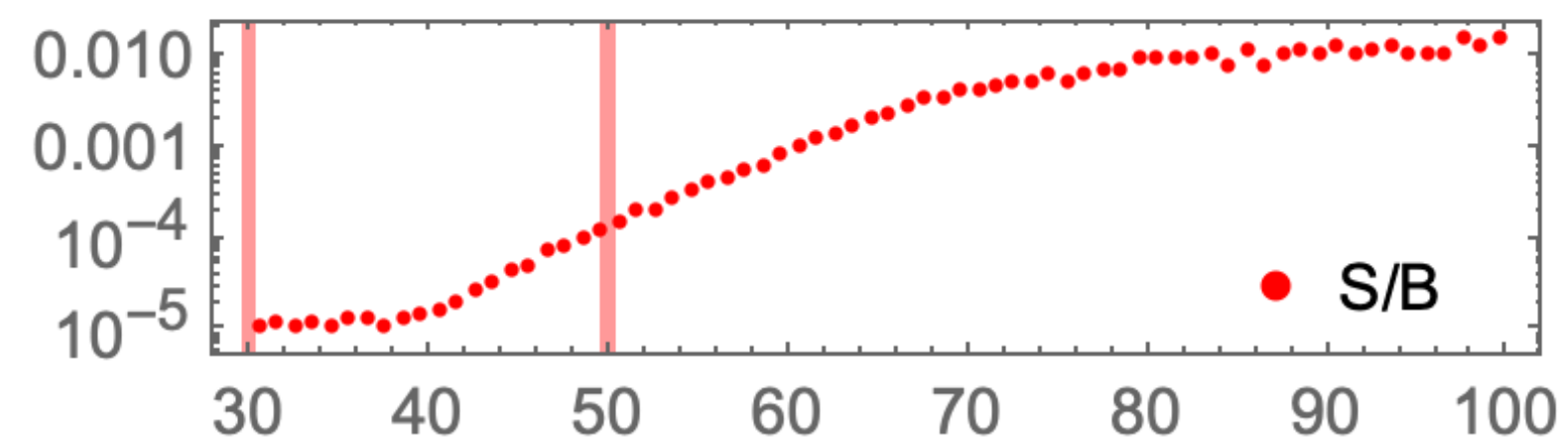
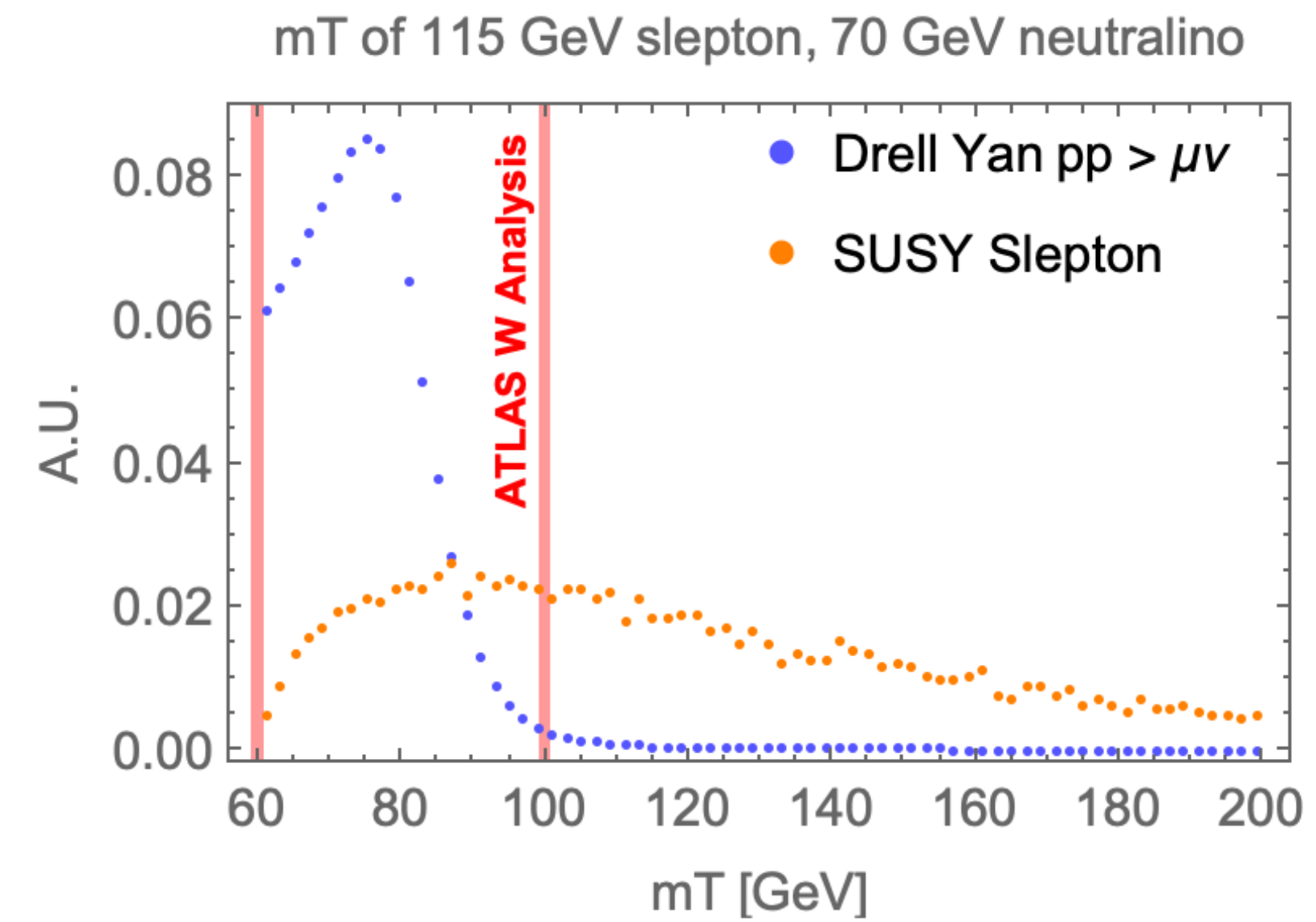
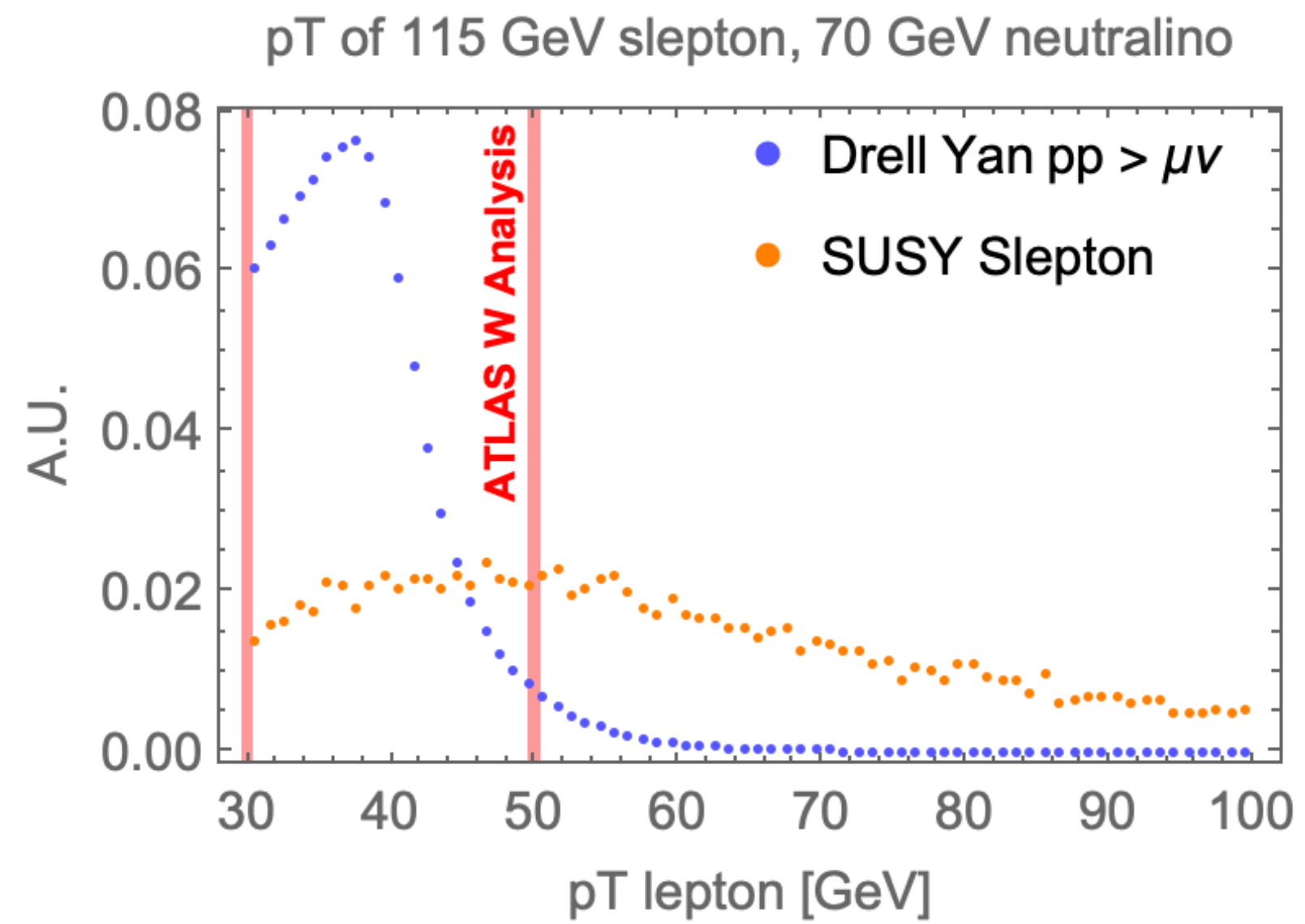
$$pp \rightarrow W$$



# THE FAINTEST ELECTROWEAK SUSY SIGNALS

Run3 and HL-LHC material!

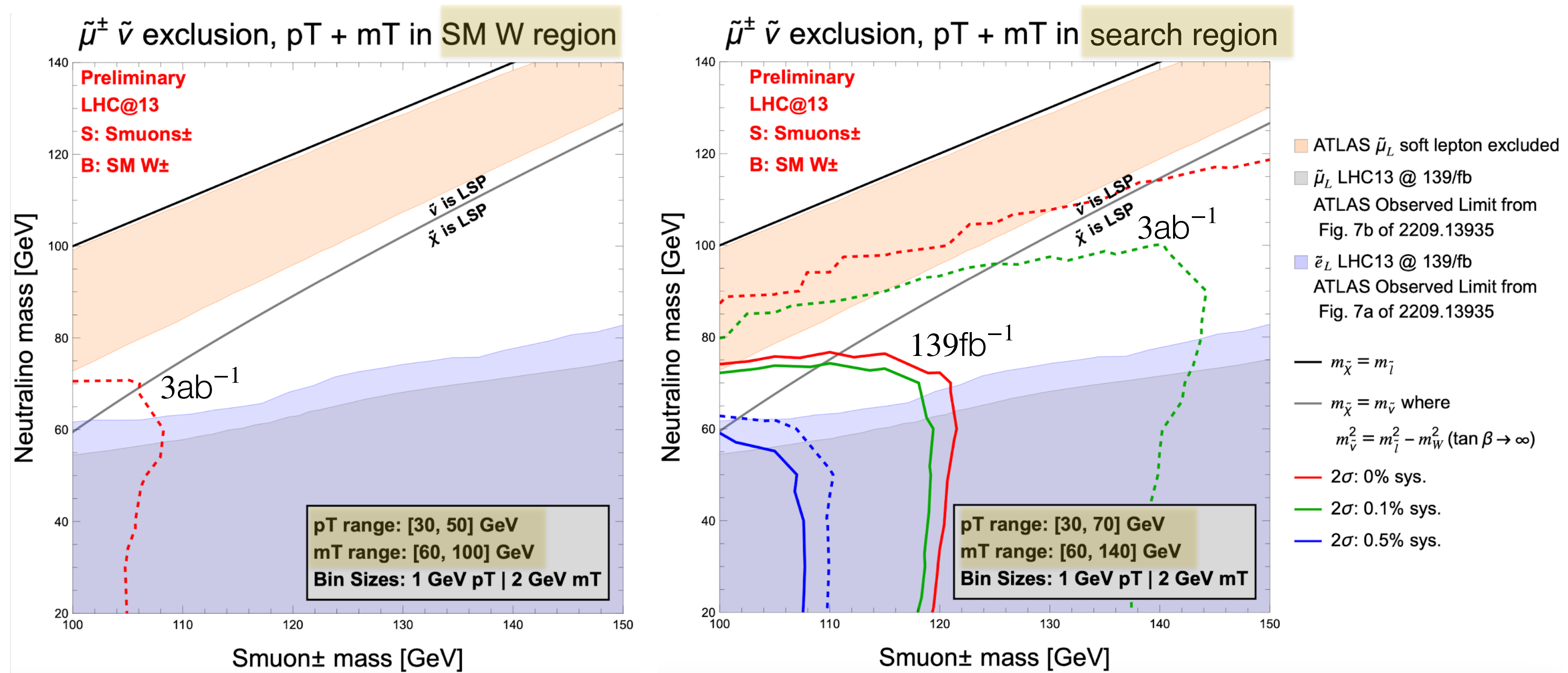
in preparation Agashe, Airen, RF, Kim, Ricci, and Sathyan



# THE FAINTEST ELECTROWEAK SUSY SIGNALS

## Run3 and HL-LHC material!

in preparation Agashe, Airen, RF, Kim, Ricci, and Sathyan



# CONCLUSION #3

EW Light SUSY  Not everything covered, and can be fixed

measurements of weak boson properties,  $m_W$ , can give searches as spin-off

or

searches can be inspired by these measurements

it is necessary to strike a balance between effort to attain precision  
and search reach

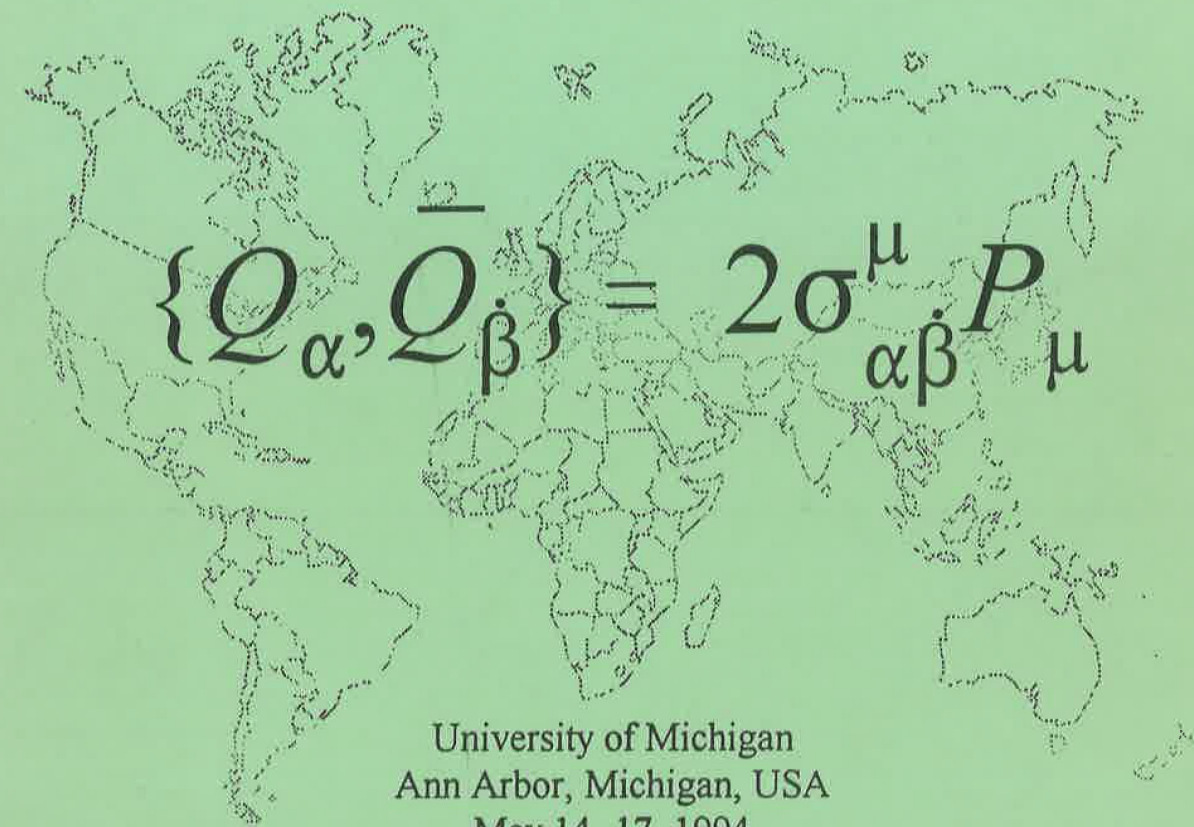


# CONCLUSIONS AND OUTLOOK

UM-TH-94-35  
September 1994

International Workshop on  
Supersymmetry and Unification of  
Fundamental Interactions

*SUSY 94*



University of Michigan  
Ann Arbor, Michigan, USA  
May 14 -17, 1994

Editors

Christopher Kolda & James D. Wells  
University of Michigan

SUSY has ruled the world of  
phenomenology for long time

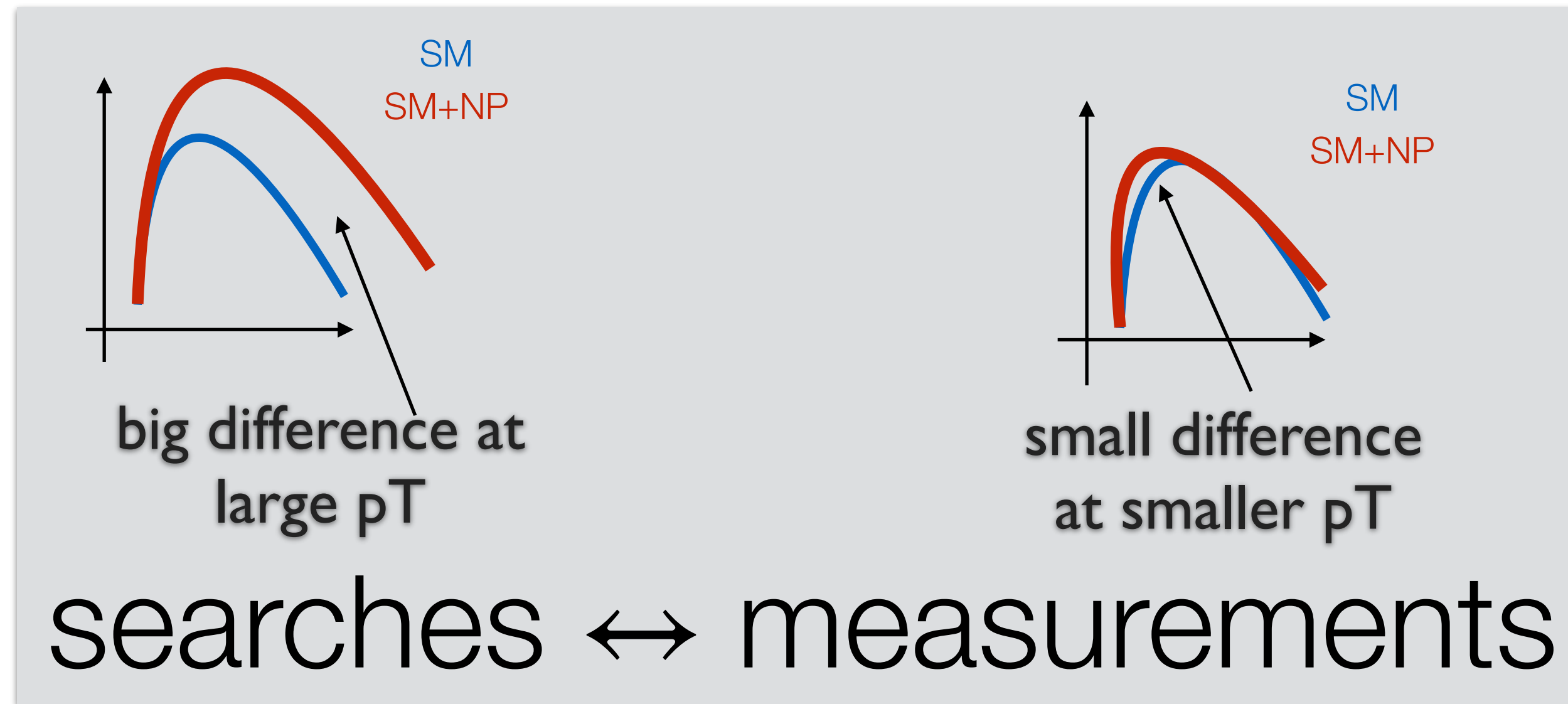
its phenomenology keeps providing very  
hard challenges with which to confront  
in the experimental practice

Run3 and beyond may give the  
opportunity to face long standing issues

# CONCLUSIONS AND OUTLOOK

RUN3 AND BEYOND MAY GIVE THE OPPORTUNITY TO FACE LONG STANDING ISSUES

BSM signals (of all sorts) that look too much like the SM are difficult at LHC



SUSY searches are a very established compartment of the physics program.

- Can lead the way on “precision searches”
- Can lead the way on the preservation and reinterpretation

For “outside SUSY”: Do we trust the methods that we use in measurements?

Do we trust them so much that we can use them (possibly extended) to perform searches?

In my opinion this makes a test of these methods, that are otherwise tested “only” by confronting

measurements from other experiments (e.g.  $m_W$  and  $top$  quark properties from ATLAS and from CMS or CDF)





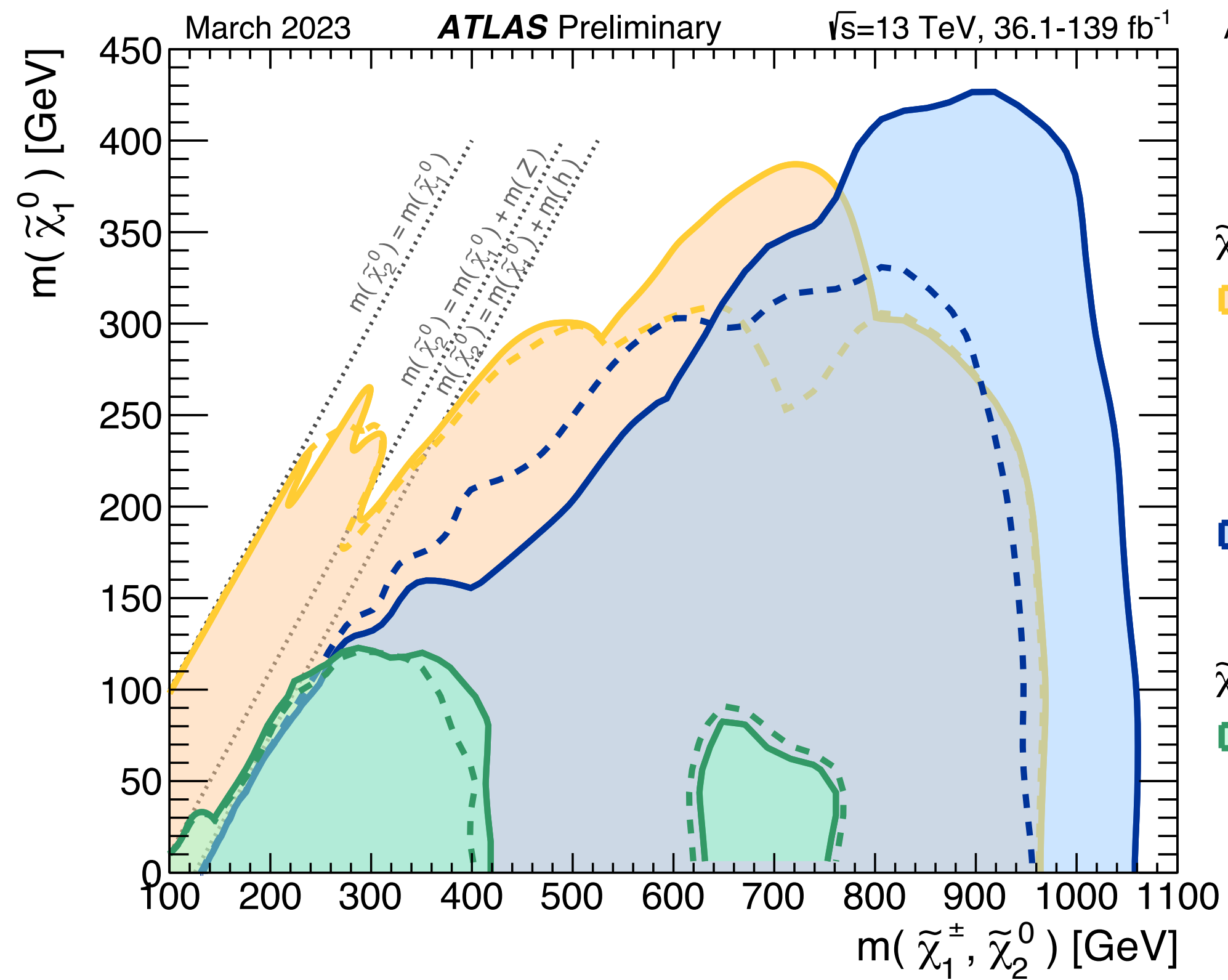
Keep it steady



explore new (joint) approaches



Thank you!



The 95% CL exclusion limits on  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  and  $\tilde{\chi}_1^+ \tilde{\chi}_2^0$  production with SM-boson-mediated decays, as a function of the  $\tilde{\chi}_1^\pm$ ,  $\tilde{\chi}_2^0$  and  $\tilde{\chi}_1^0$  masses. The production cross-section is for pure wino  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  and  $\tilde{\chi}_1^+ \tilde{\chi}_2^0$ . Each individual exclusion contour represents a union of the excluded regions of one or more analyses.

