Science & Technology Facilities Council
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Search for boosted light Higgs bosons in NMSSM cascades

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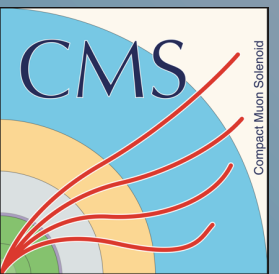


July 2024

Outline

- Introduction to NMSSM
- Signal Model
  - Event Selection
- Squark Mass reconstruction
  - Methods and Approaches
  - Squark Mass Binning
  - Performance comparison
- Summary and conclusion

Introduction

- ✓ Next-to-Minimal Supersymmetric Standard Model (NMSSM)
- ✓ Additional singlet super field
  - along with the typical MSSM contents
- ✓ Richer Higgs Sector:
  - By including the additional singlet
- ✓ It predicts a spectrum of

NMSSM

three CP-even Higgs bosons
two CP-odd Higgs bosons
two charged Higgs

MSSM

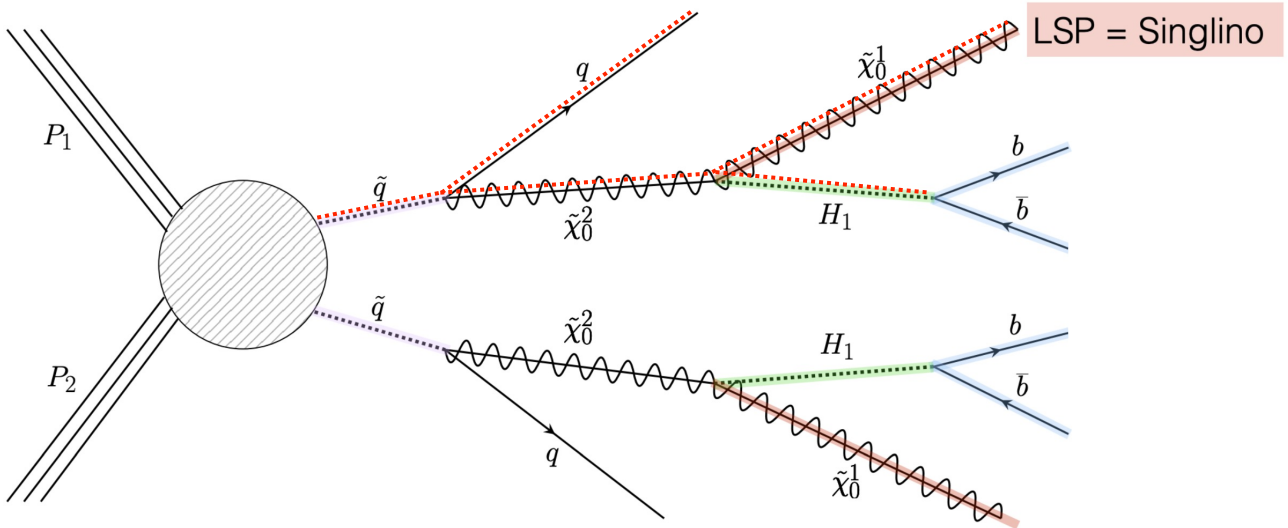
two CP-even Higgs bosons
one CP-odd Higgs bosons
a charged Higgs pair

- ✓ There are 7 Higgses in total
  - the lightest Higgs can be lighter than the SM Higgs!

Signal Model

LSP is Singlino-like

- cascade decays



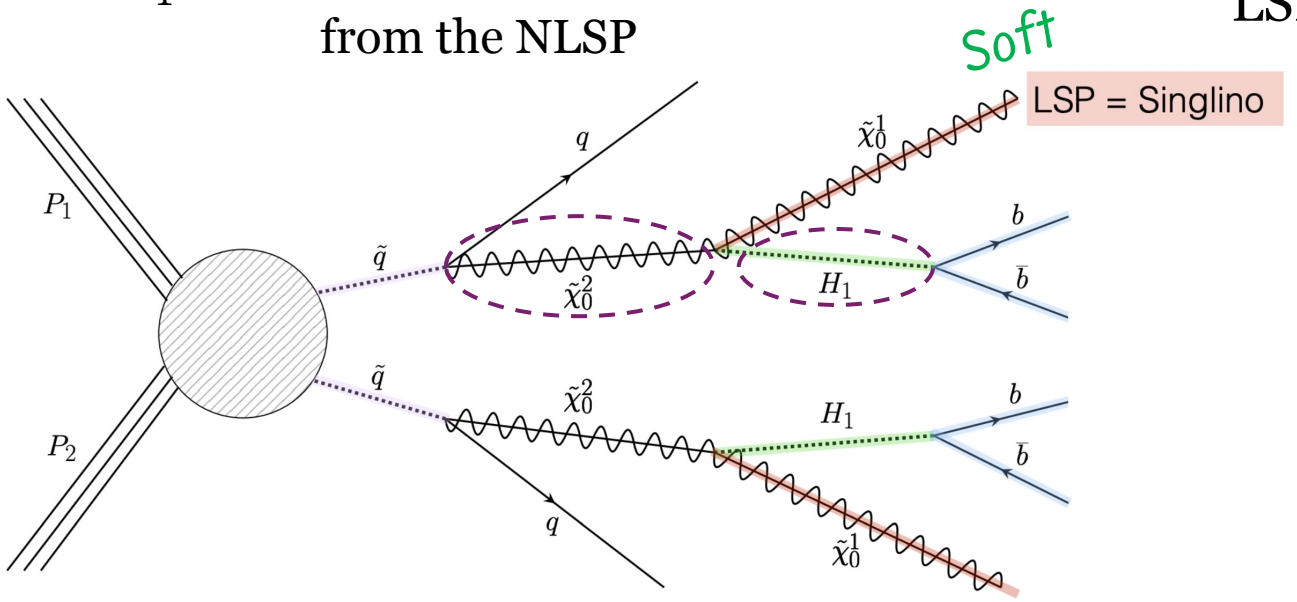
The decay arm also arises from gluino→squark+quark

$H_1 \neq H_{SM}$, it is one of the other CP even Higgs' in NMSSM.

Signal Model

LSP is light and mass splitting between Higgs and NLSP small

- LSP is soft
- H_1 inherits most of the momentum from the NLSP



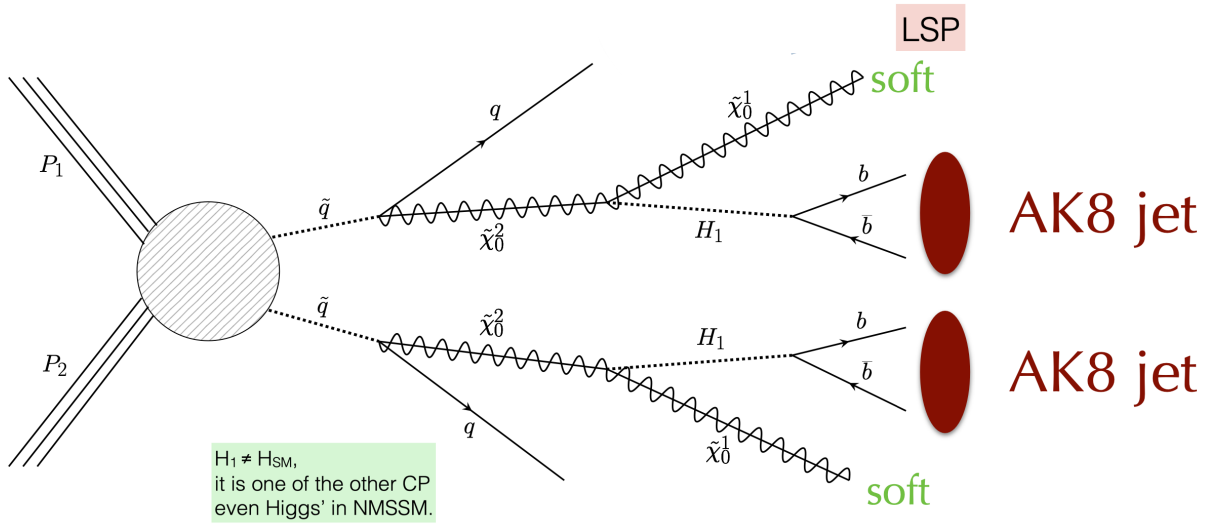
LSP is Singlino-like

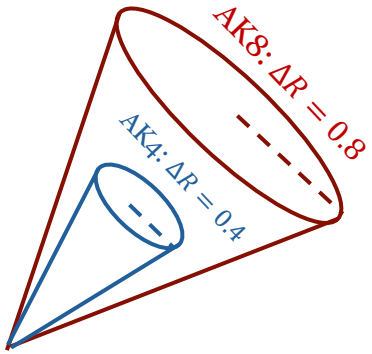
- cascade decays

Light Higgs is highly boosted and there is little MET

Signal Model

Light Higgs mainly decays to a pair of b-quarks, $b\bar{b}$, and is reconstructed as an AK8 Jet





Our previous published(HIG-20-018) analysis can be found here:
Search for light Higgs bosons from supersymmetric cascade decays in pp collisions at √s = 13TeV, arXiv:2204.13532

Ellwanger, U., Teixeira, A.M. NMSSM with a singlino LSP: possible challenges for searches for supersymmetry at the LHC. J. High Energ. Phys. 2014, 113 (2014). https://doi.org/10.1007/JHEP10(2014)113

Signal Model

- All the light-flavour Squarks are considered mass-degenerate at the mass called m_{SUSY}.
- Gluino-Squark mass splitting is set to 1%
  - All $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$ and $\tilde{g}\tilde{g}$ events have similar final states

The cross-sections for the SUSY mass $m_{SUSY} > 1200$ GeV

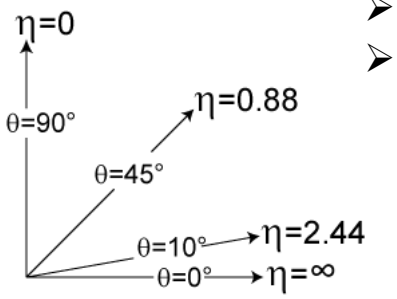
m_{SUSY}[GeV]	$\sigma(pp \to \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g})$[fb]	Uncertainty
1200	582.3	8%
1400	194.1	9%
1600	69.71	9%
1800	26.29	10%
2000	10.29	11%
2200	4.114	13%
2400	1.668	14%
2600	0.6792	16%
2800	0.2765	18%
3000	0.1117	21%
3200	0.04512	24%

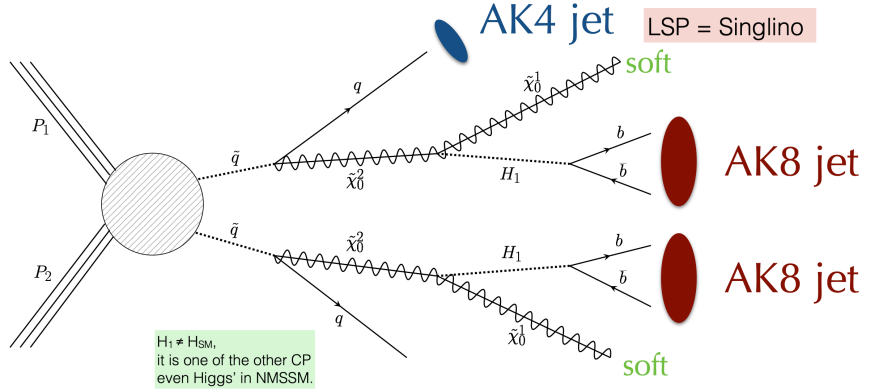
Event Selection

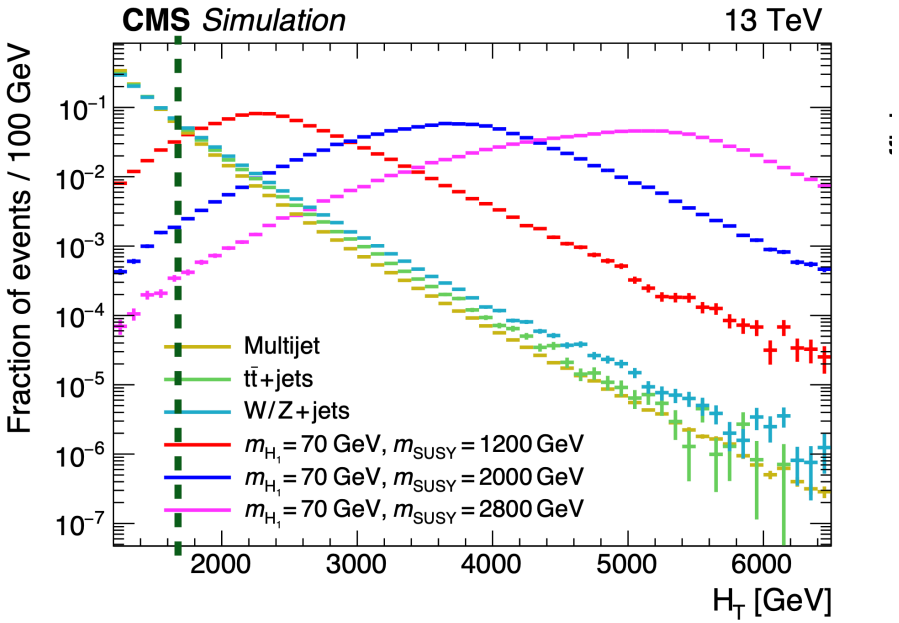
In the published analysis:

Requesting 3 Jets:

- Two AK8 Jets
  - $p_T > 300\ GeV$
  - $|\eta| < 2.4$
- At least one AK4 Jet (Jet radius 0.4)
  - $p_T > 300\ GeV$
  - $|\eta| < 2.4$
  - $\Delta R_{Ak4,Ak8} > 1.4$
- H_T (scalar sum of jet p_T) binning
- Further binning using AK8 Jet properties
  - Simple mass reconstruction based on Softdrop
  - Double b-tagging using BDT







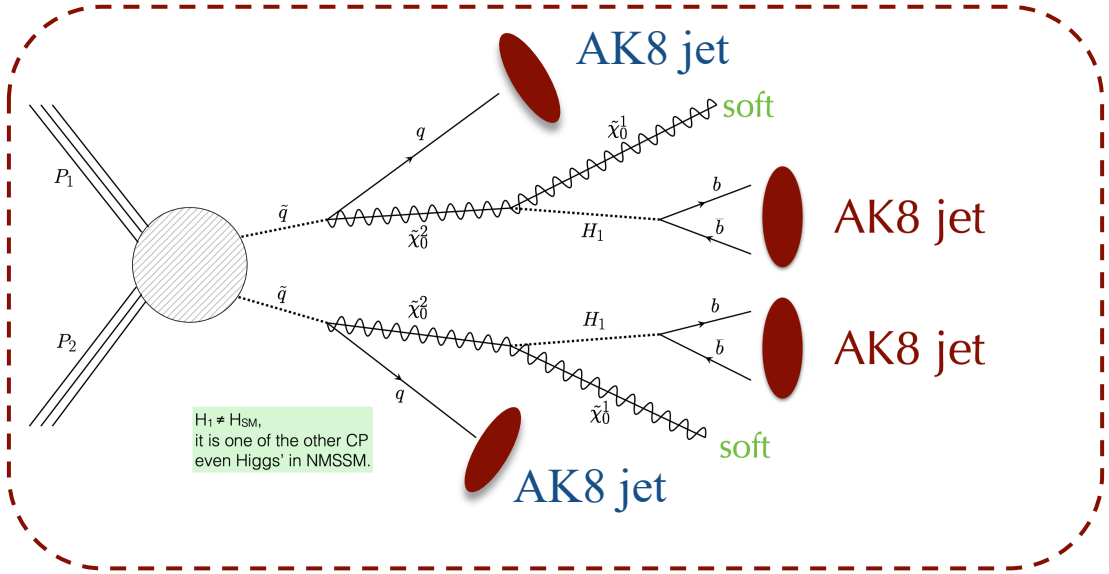
Event Selection

For Run3:

- Using ParticleNet for double-b-tagging and FatJet mass regression
- Introducing Squark mass reconstruction

Requesting 4 Jets:

2 Jets for Higgs & 2 Jet for Quarks



BUT we use Run2 Monte-Carlo simulation for now

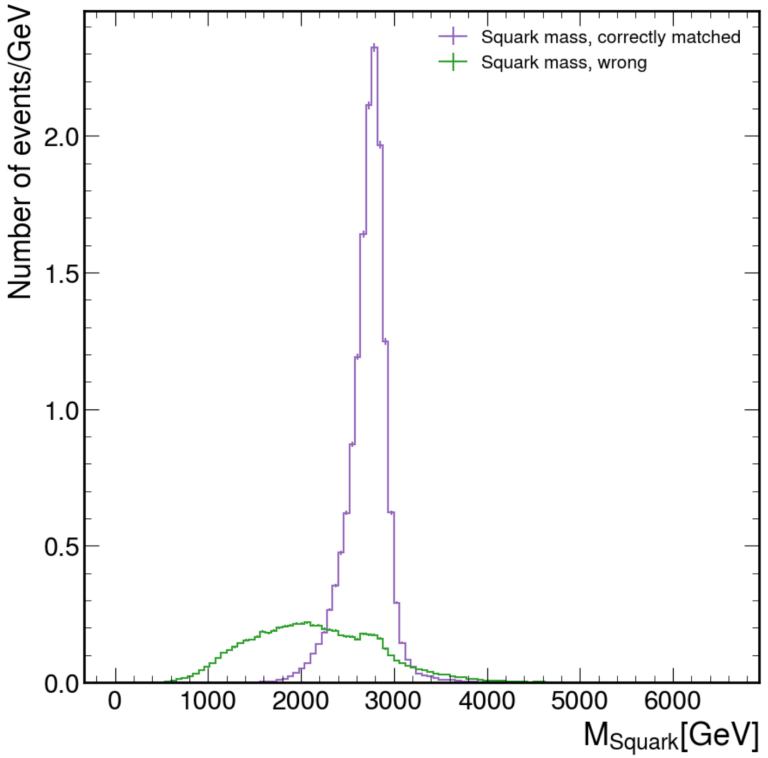
Background

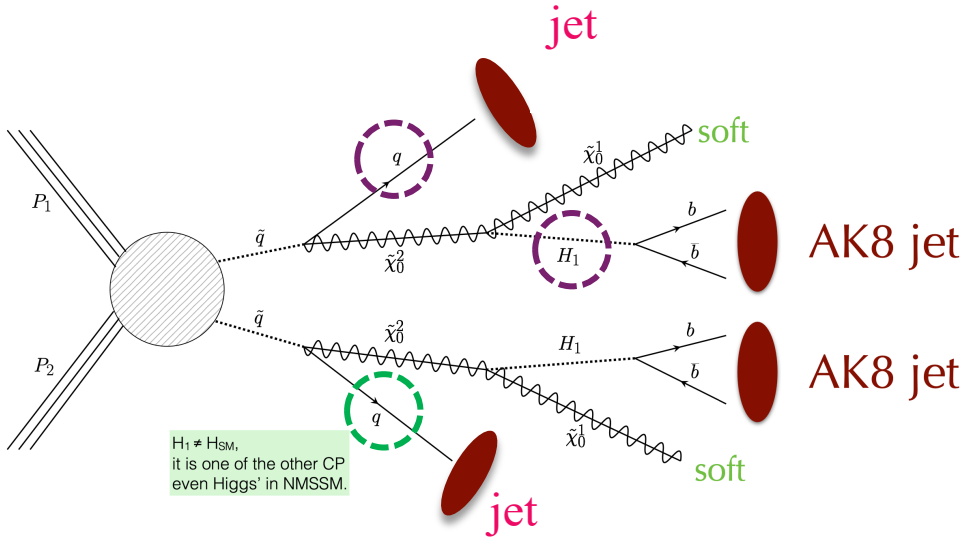
- In the published analysis: QCD >> $t\bar{t}$
- After using ParticleNet double-b-tag on QCD: QCD ~ $t\bar{t}$
- After applying new selections on $t\bar{t}$: QCD >> $t\bar{t}$

Squark Mass

Squark Mass

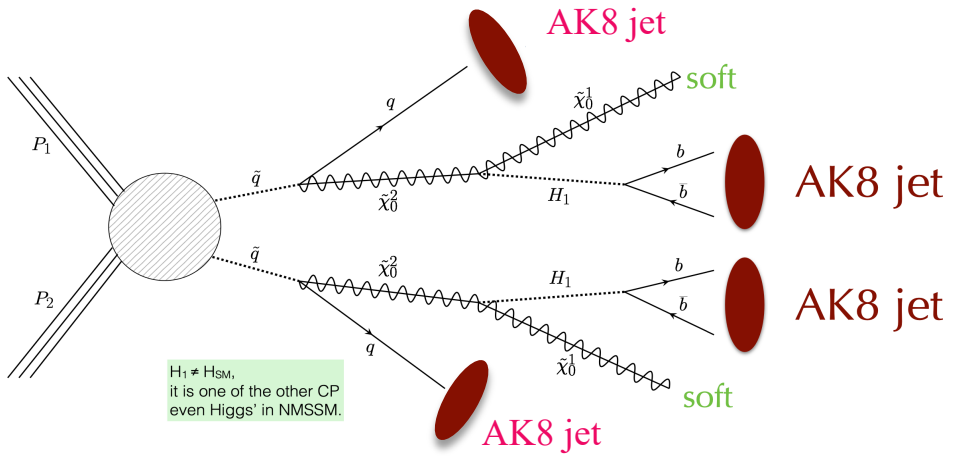
Since LSP is soft, the Squark can be reconstructed as *Quark + Higgs*

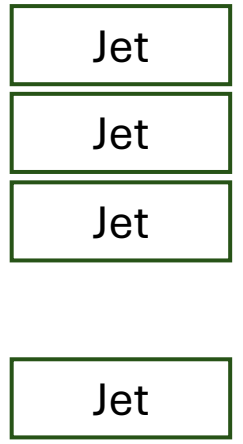




Mass Reconstruction: Method

- Sort Jets based on the b-tag score and take the first two as Higgs
- Sort the remaining Jets based on p_T and take the first two as Quark

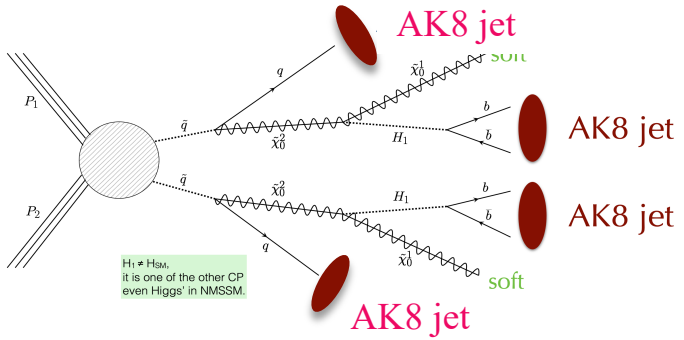




Mass Reconstruction: Method

- Reconstruct SquarkA with AK8 with the highest b-tag score (JetA)
- Reconstruct SquarkB with AK8 with the second-highest b-tag score (JetB)

There are only two combinations:



Pair One

SquarkA = (JetA + Jet1).mass
SquarkB = (JetB + Jet2).mass

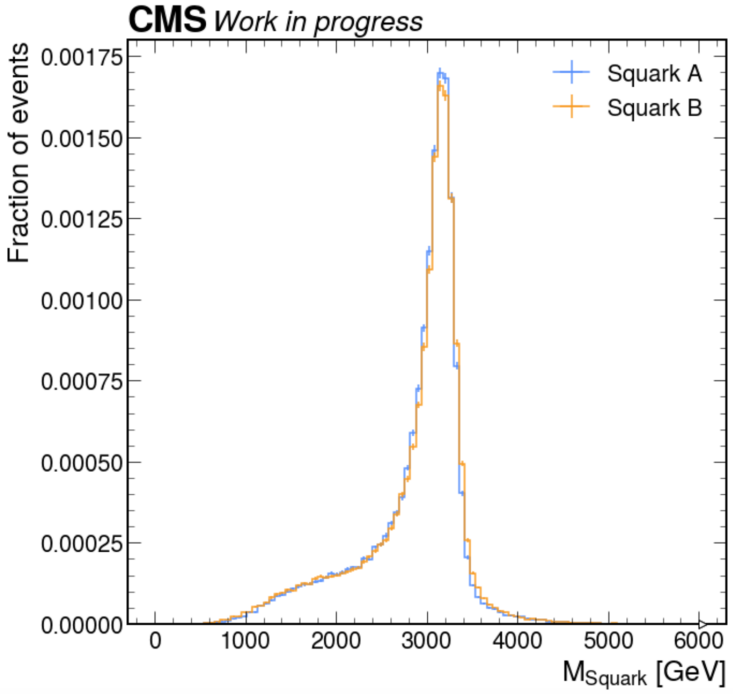
Pair Two

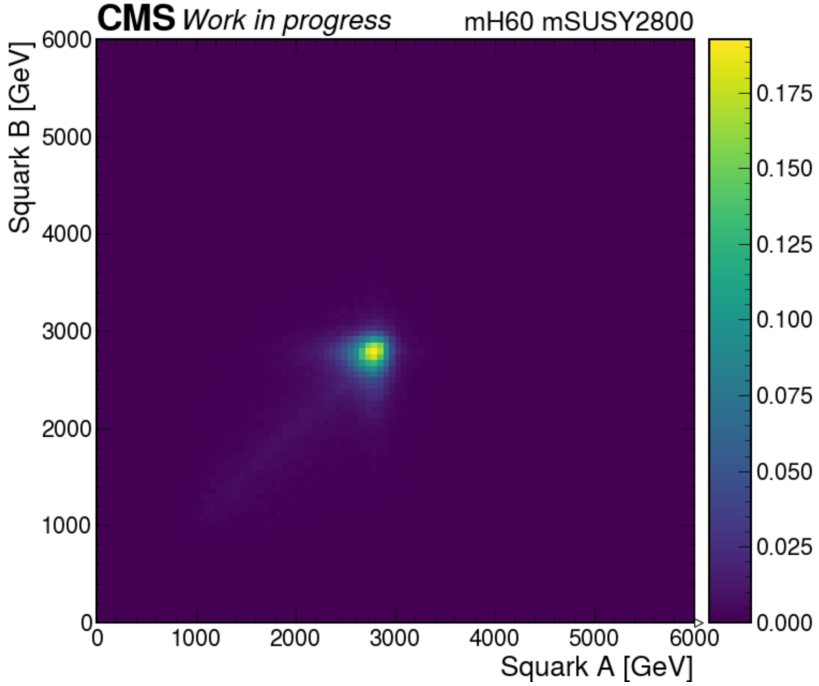
SquarkA = (JetA + Jet2).mass
SquarkB = (JetB + Jet1).mass

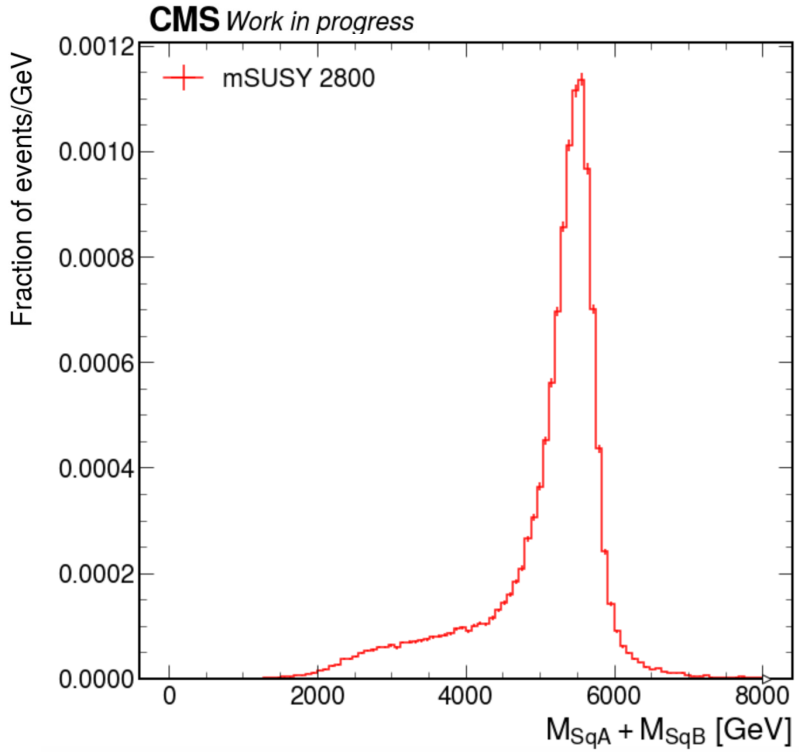
Always choose the pair with Squark mass more similar to each other i.e:
Choose the pair with the minimum $|mass_{SquarkA} - mass_{SquarkB}|$

Mass Reconstruction: binning

- Sum of masses: $mass_{SquarkA} + mass_{SquarkB}$

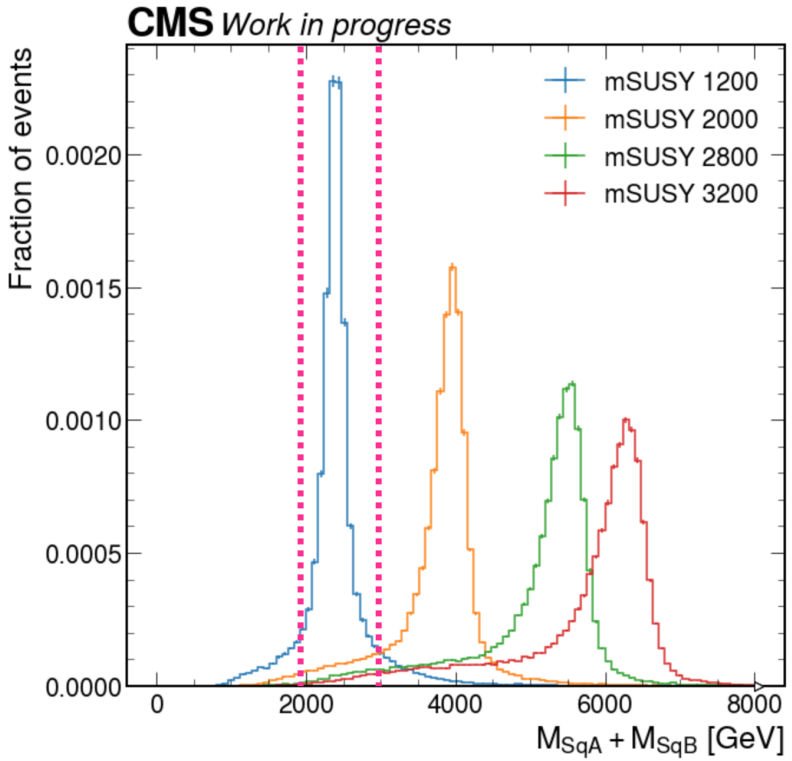






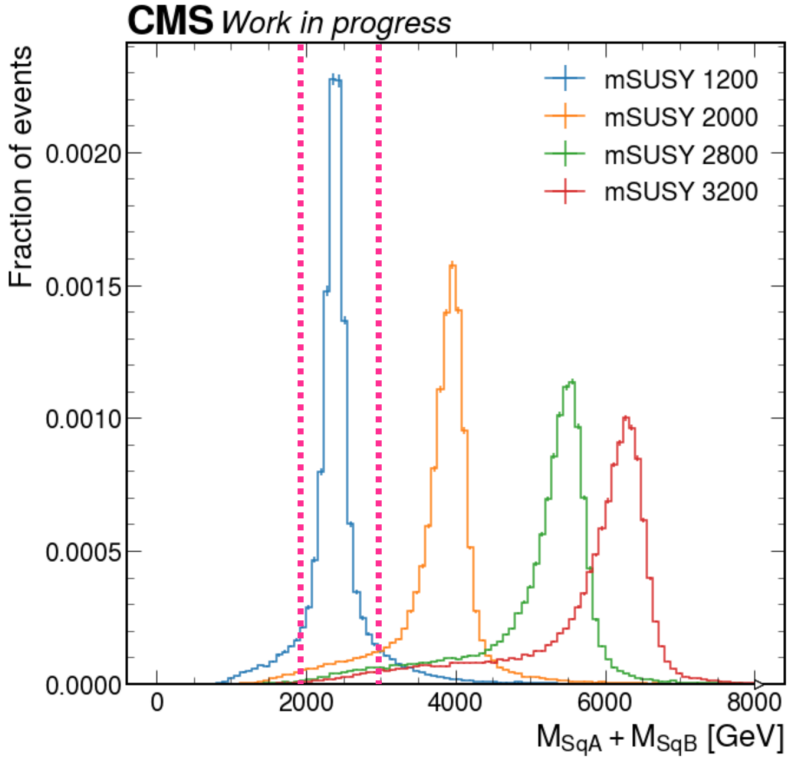
Mass Reconstruction: binning

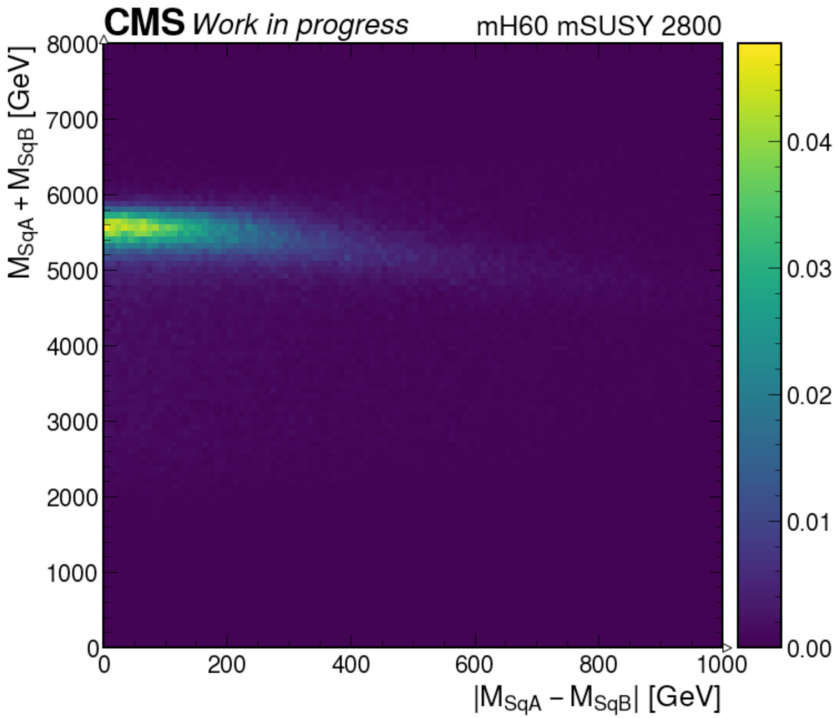
- Each mSUSY has its own narrow peak
- Use binning on the total mass

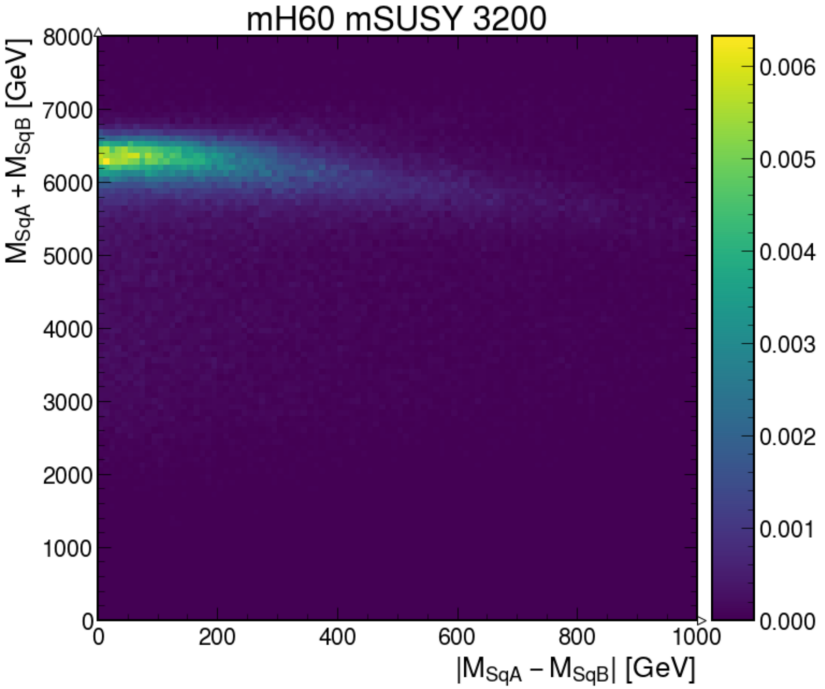


Mass Reconstruction: binning

- Each mSUSY has its own narrow peak
- Use binning on the total mass
- Difference of masses: $|mass_{SquarkA} - mass_{SquarkB}|$

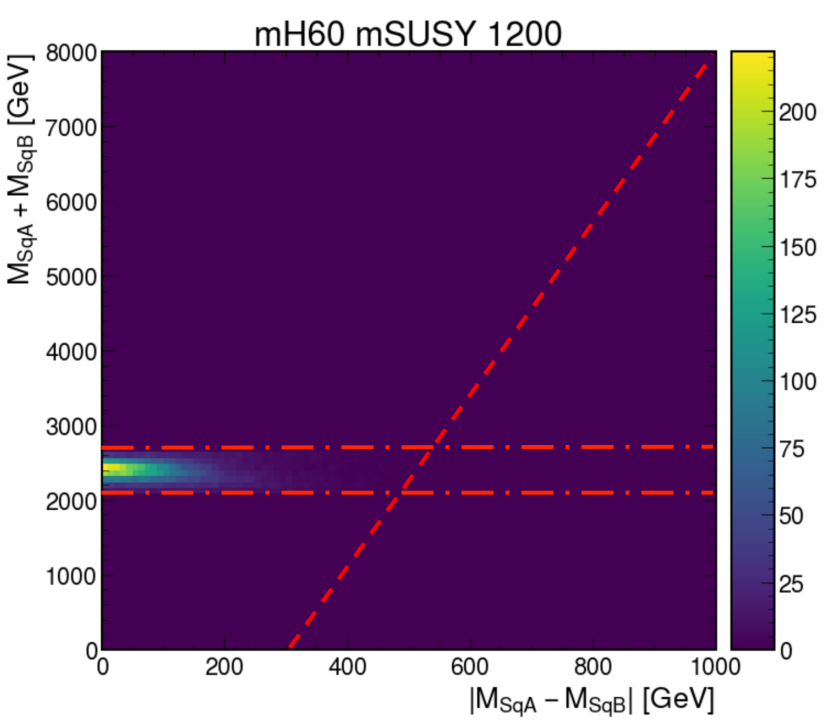


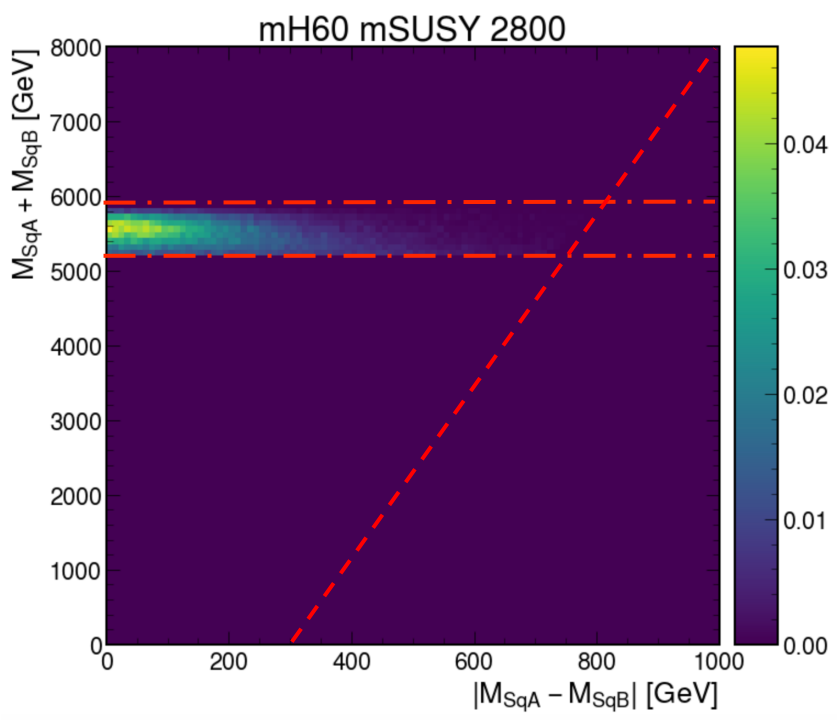


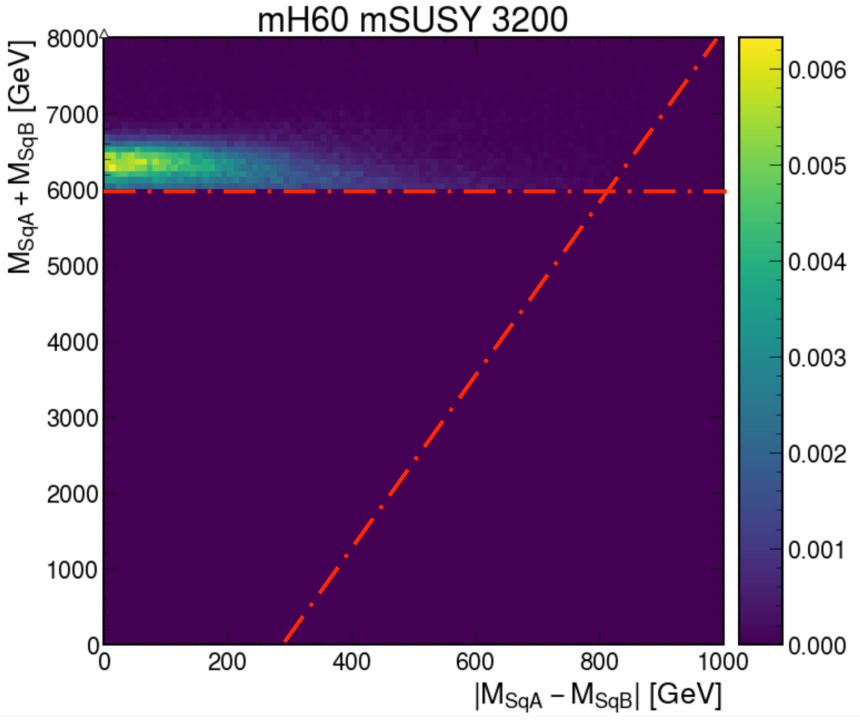


Mass Grid

- Define a mass grid for different mSUSY mass
- Based on mass resolution we propose 7 different mass bins

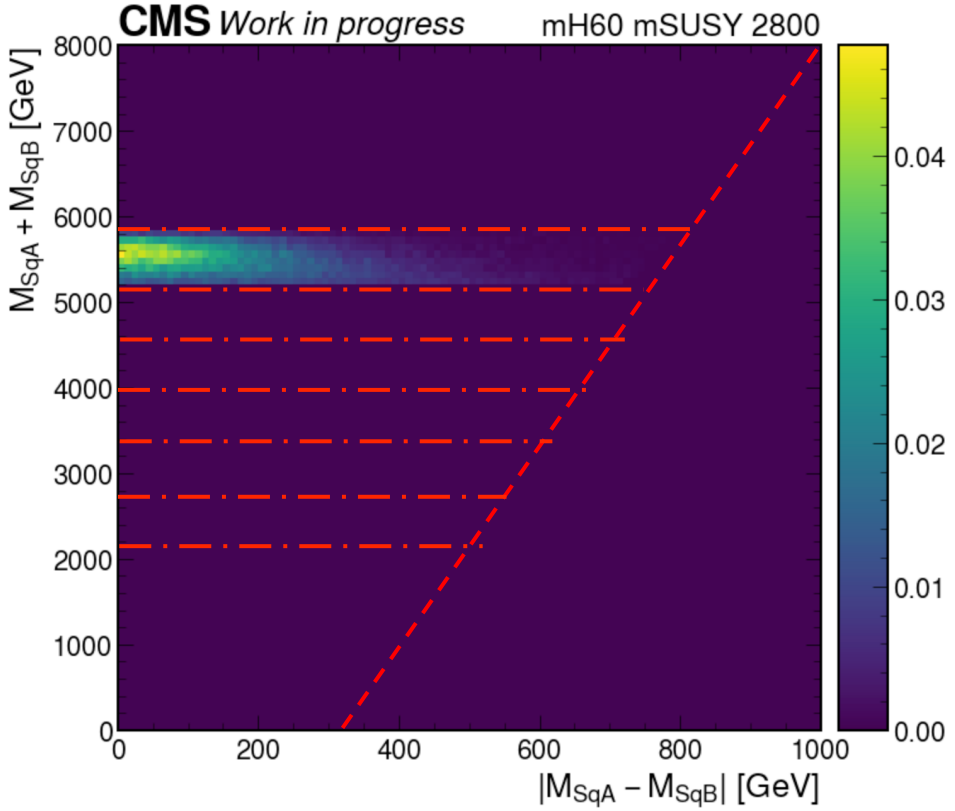


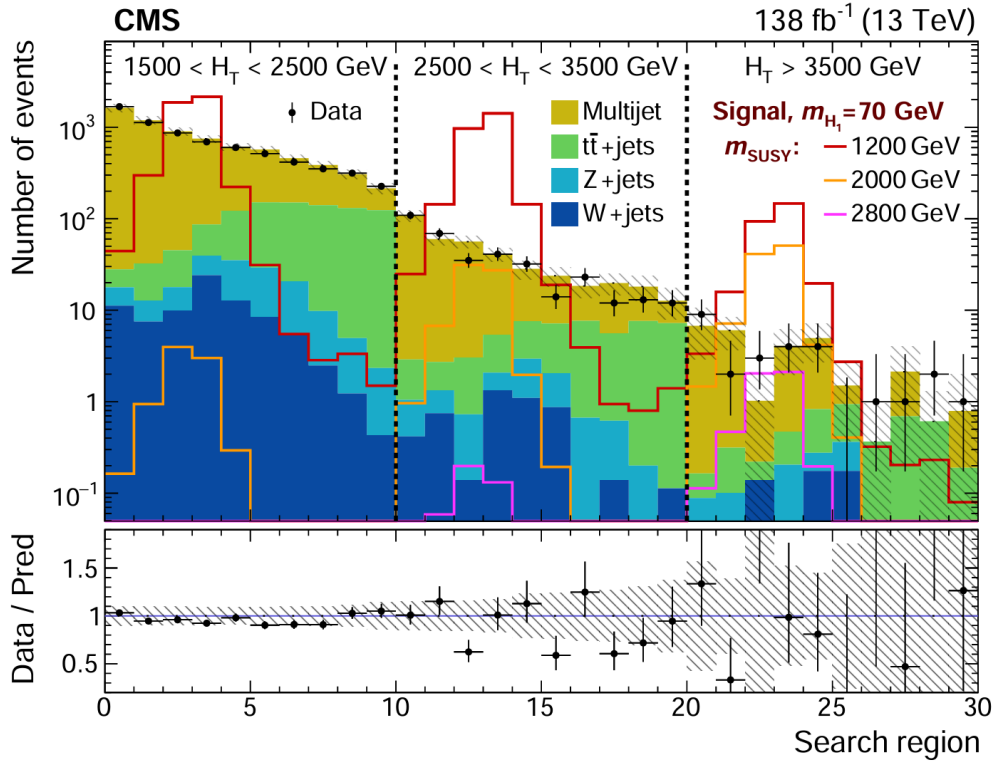




H_T Binning VS Mass Binning

Squark mass is a more powerful variable for binning compared to H_T binning





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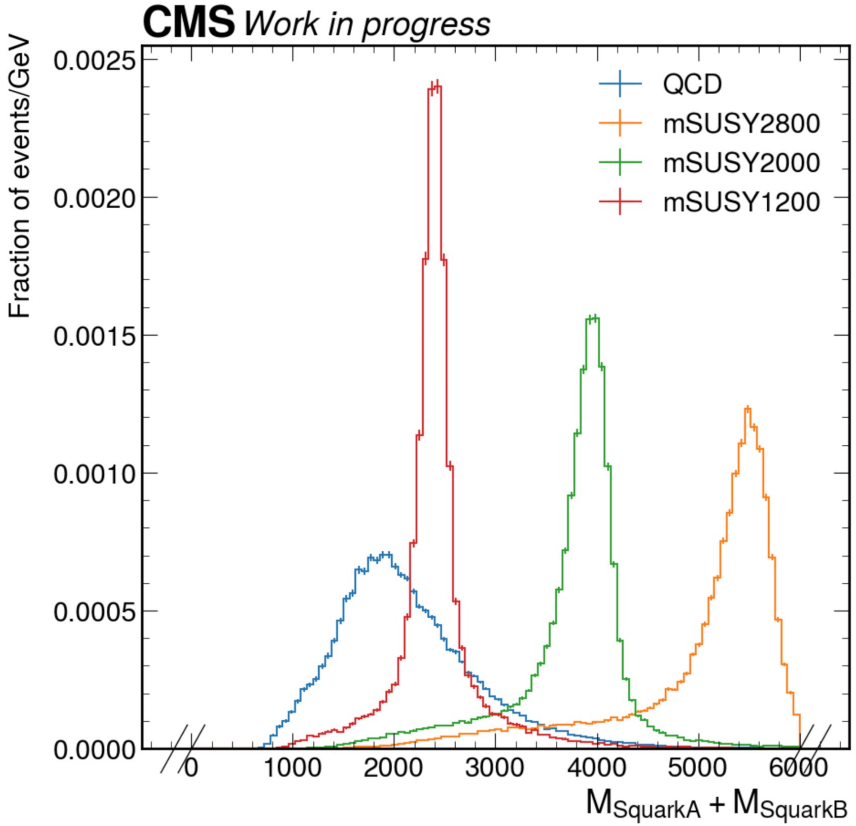
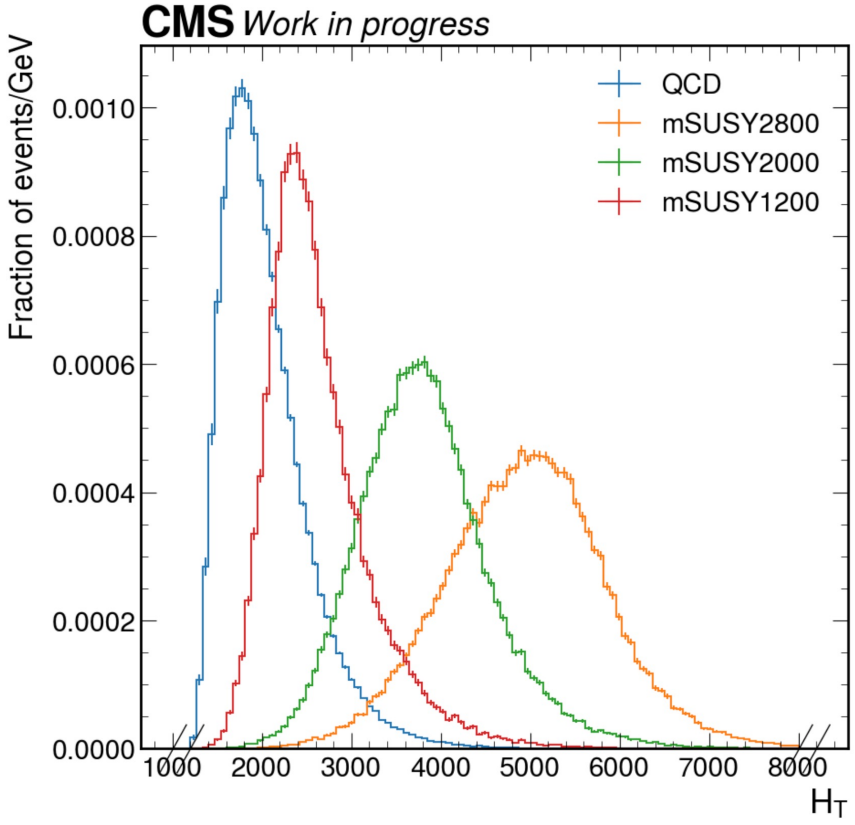


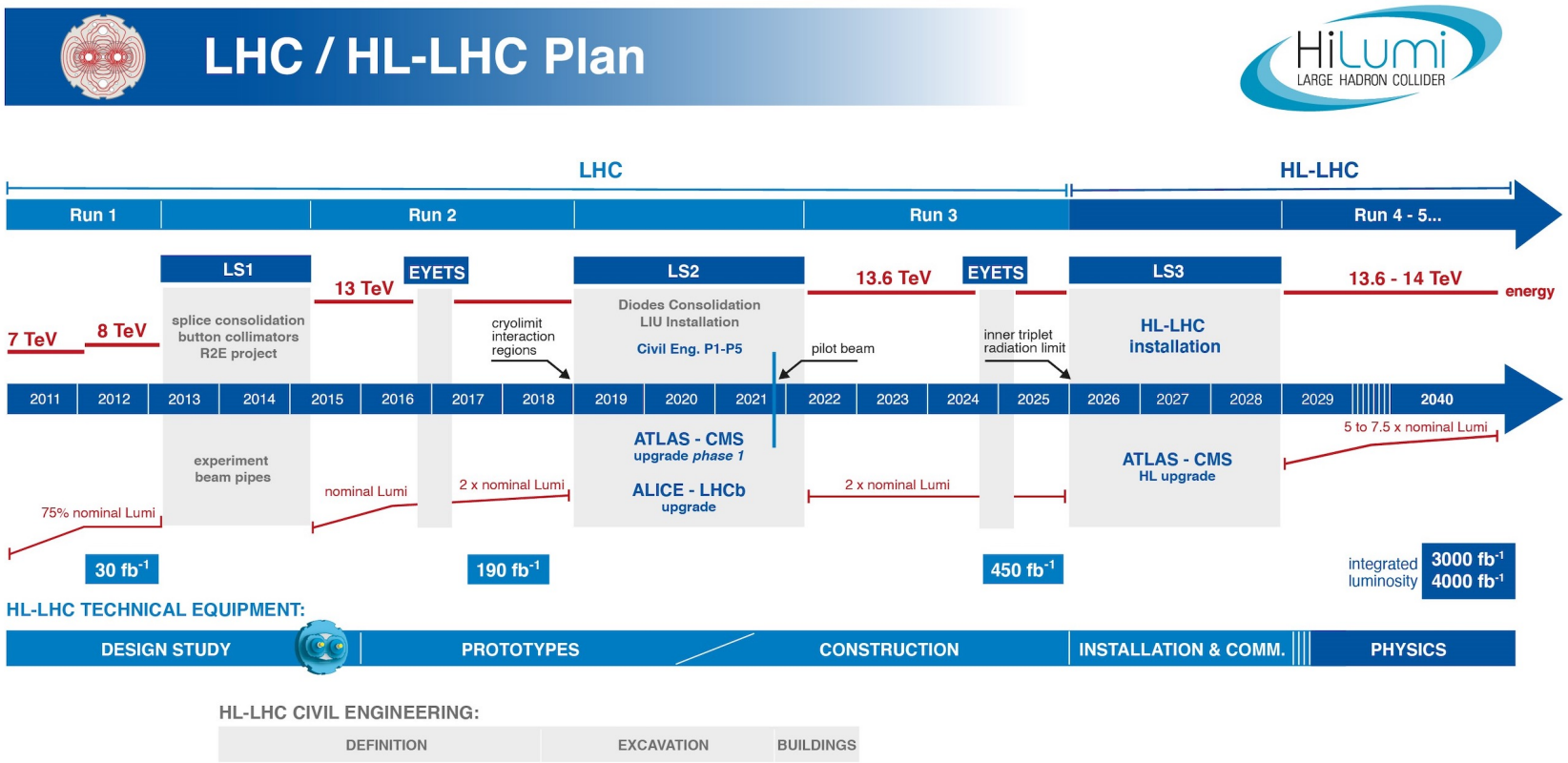


Summary and Conclusion

- ✓ Introduce Squark mass reconstruction
- ✓ Add mass grid for Squark
- ✓ Retain H_T binning in parallel for general interpretation (less model-dependent)
- ✓ Using Mass binning for model-dependent interpretation
  - Expect improvement in mass reach

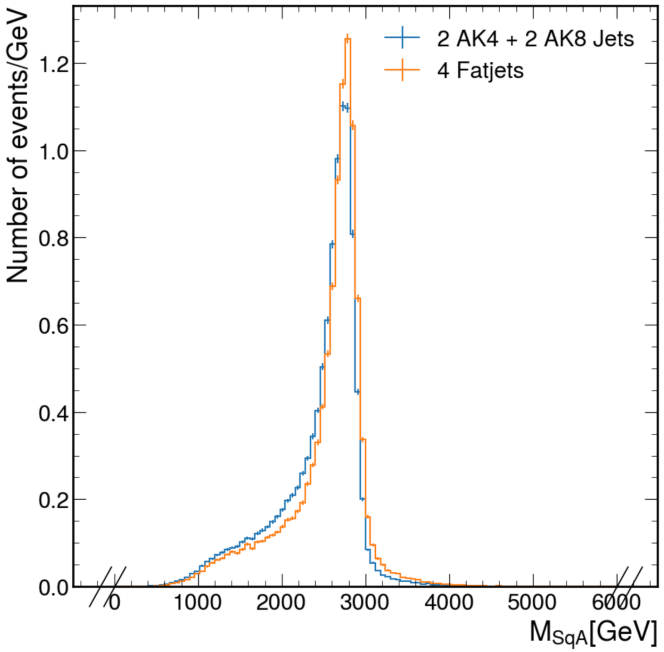
Backups

CERN Plan

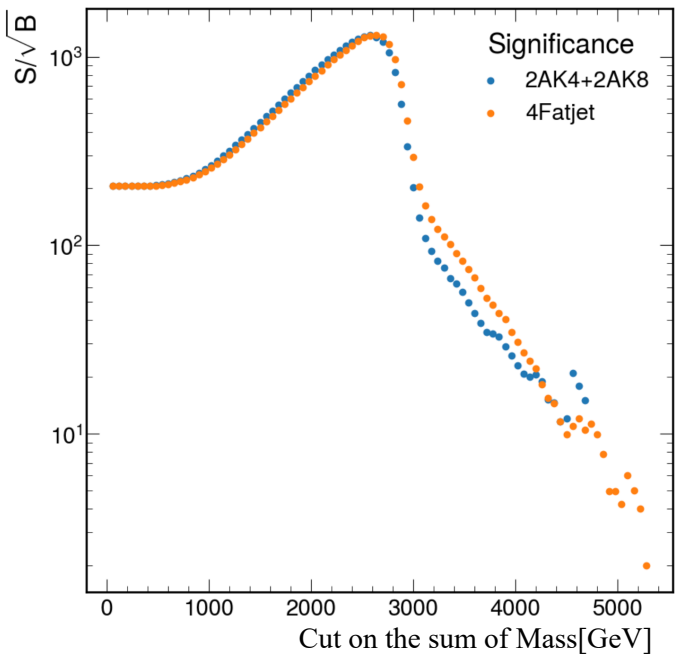

LHC / HL-LHC Plan
HiLumi
LARGE HADRON COLLIDER
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
pilot beam
inner triplet
radiation limit
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
5 to 7.5 x nominal Lumi
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1
HL-LHC TECHNICAL EQUIPMENT:
DESIGN STUDY
PROTOTYPES
CONSTRUCTION
INSTALLATION & COMM.
PHYSICS
HL-LHC CIVIL ENGINEERING:
DEFINITION
EXCAVATION
BUILDINGS

Mass Reconstruction: 4Fatjets VS 2AK4+2AK8

- Comparing the first and second approach for Squark mass reconstruction
- Calculated significance for Squark mass after only applying kinematic selections



Squark mass for mH60 mSUSY3200



4 Fatjets method gives better Squark mass resolution!

Still using Run2: using AK4chs VS AK8Puppi