Studies for BDT and Multi-Bin based Signal Regions for the SUSY 0-lepton Analysis with the ATLAS Experiment

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11th Annual Meeting of the Helmholtz Alliance "Physics at the Terascale"

BMBF-Forschungsschwerpunkt ATLAS-EXPERIMENT

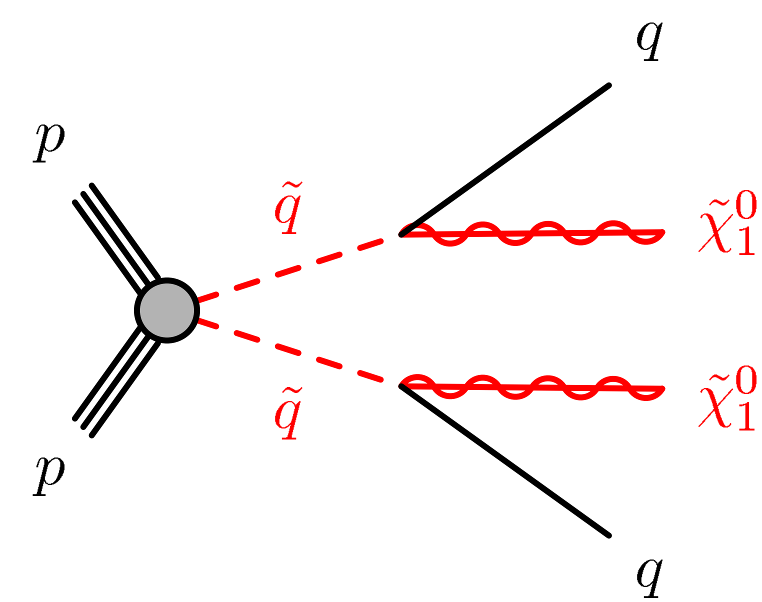
Physik bei höchsten Energien mit dem ATLAS-Experiment am LHC

FSP 103

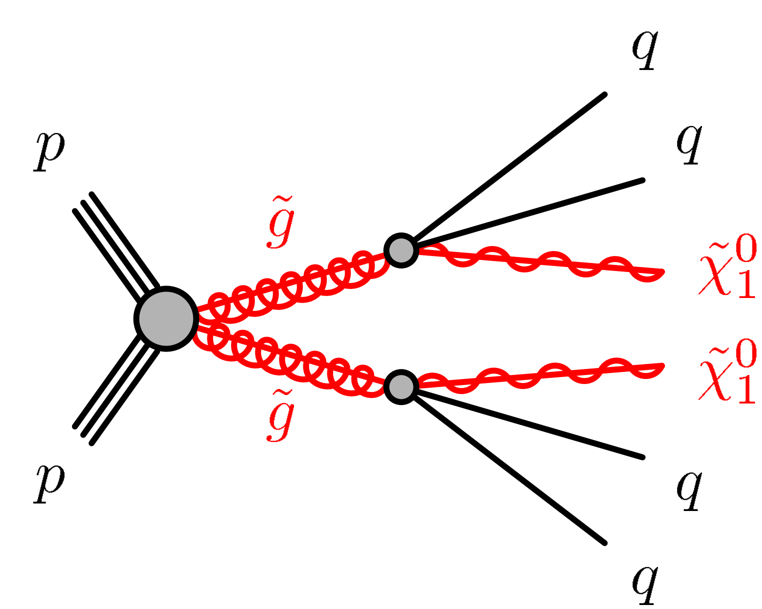
Bundesministerium für Bildung und Forschung

SUSY 0-lepton Analysis

- Strong SUSY production with focus on signature with
  - $E_{\mathrm{T}}^{\mathrm{miss}}$ from LSP (lightest supersymmetric particle)
  - Jets
  - No leptons

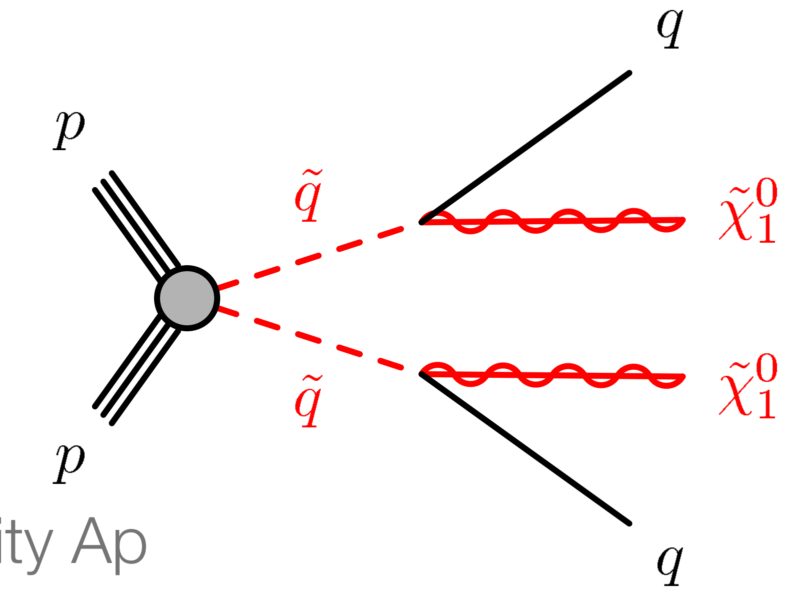


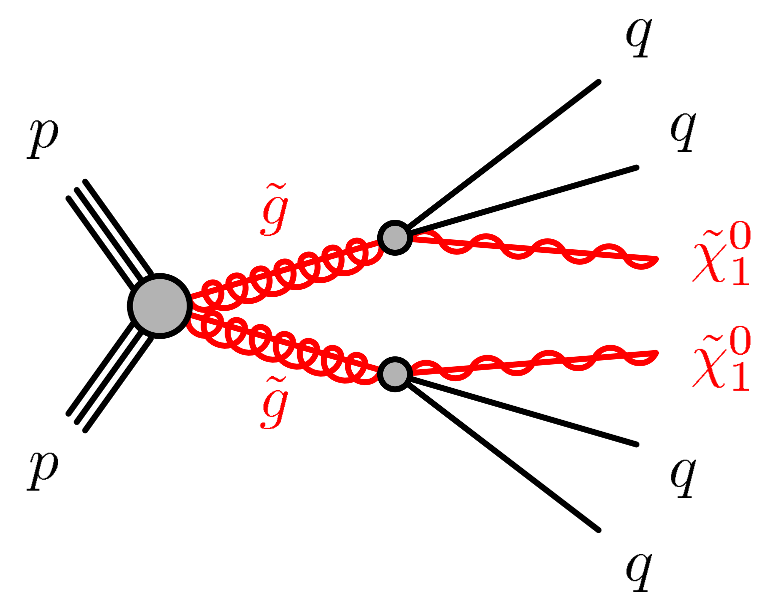
- ATLAS Note presented at Moriond 2017 (ATLAS-CONF-2017-022) with 36.1fb^{-1}
  - 8 signal regions for direct squark decay
  - 7 signal regions for direct gluino decay
  - Optimised for different mass regions



SUSY 0-lepton Analysis

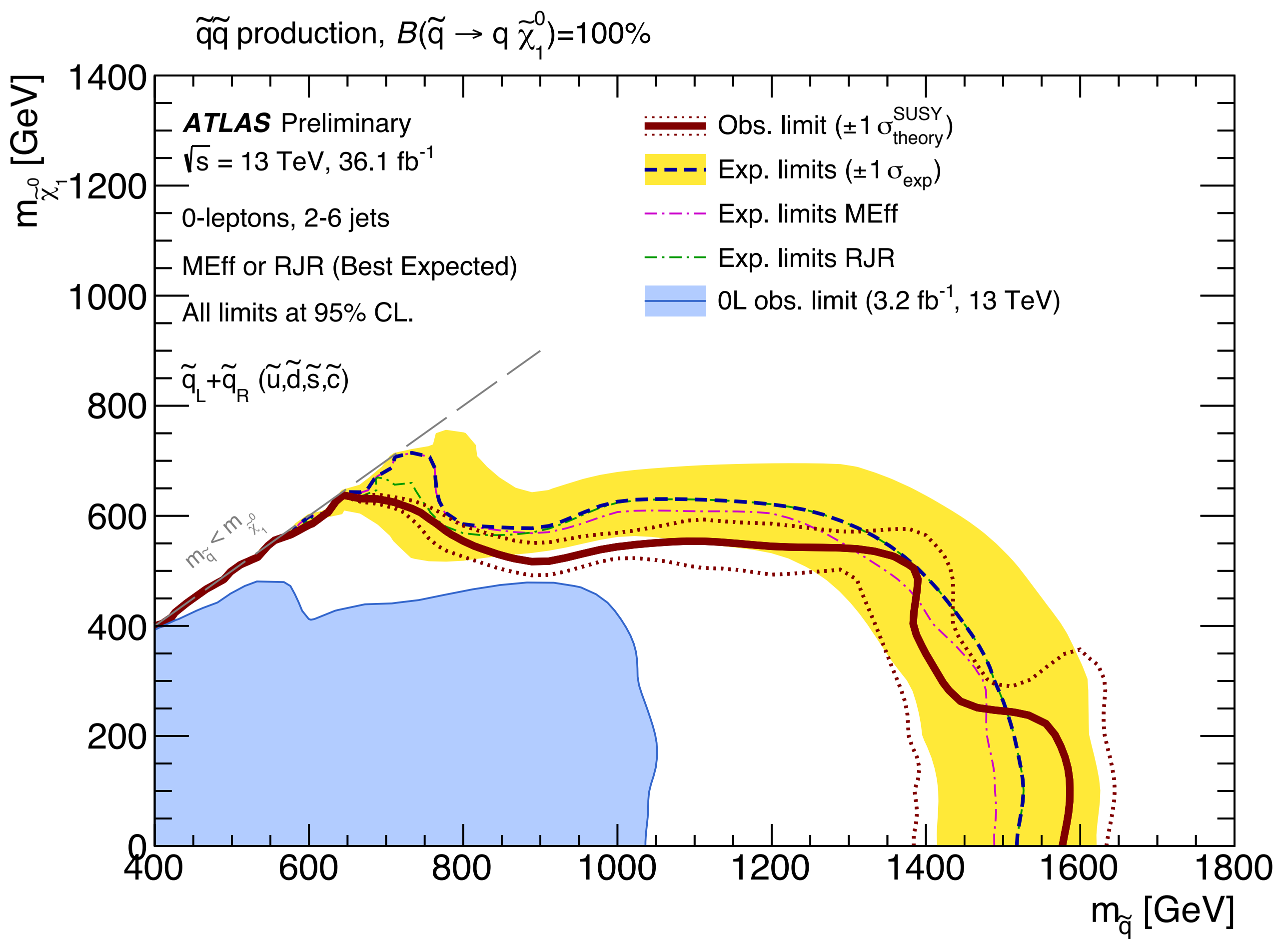
- Important variables which are used in current analysis ATLAS-CONF-2017-022:
  - Missing transverse energy $E_{\mathrm{T}}^{\mathrm{miss}}$ or MET
  - Effective mass $m_{\mathrm{eff}}(\mathrm{incl}) = \sum_{i=1}^{N_{\mathrm{Jet}}} |\mathbf{p}_{\mathrm{T}}^{(i)}| + E_{\mathrm{T}}^{\mathrm{miss}}$
  - $\mathrm{dPhi} = \Delta\phi(\mathrm{jet}_{1,2(3)}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$, P_T(jet), $|\eta|$(jet), Aplanarity Ap
  - $metSig = E_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{m_{\mathrm{eff}}(\mathrm{incl}) - E_{\mathrm{T}}^{\mathrm{miss}}}$
- Only Cut & Count analyses were implemented so far
- Signal Regions (SR) defined depending on number of jets and m_{eff}(incl) cut



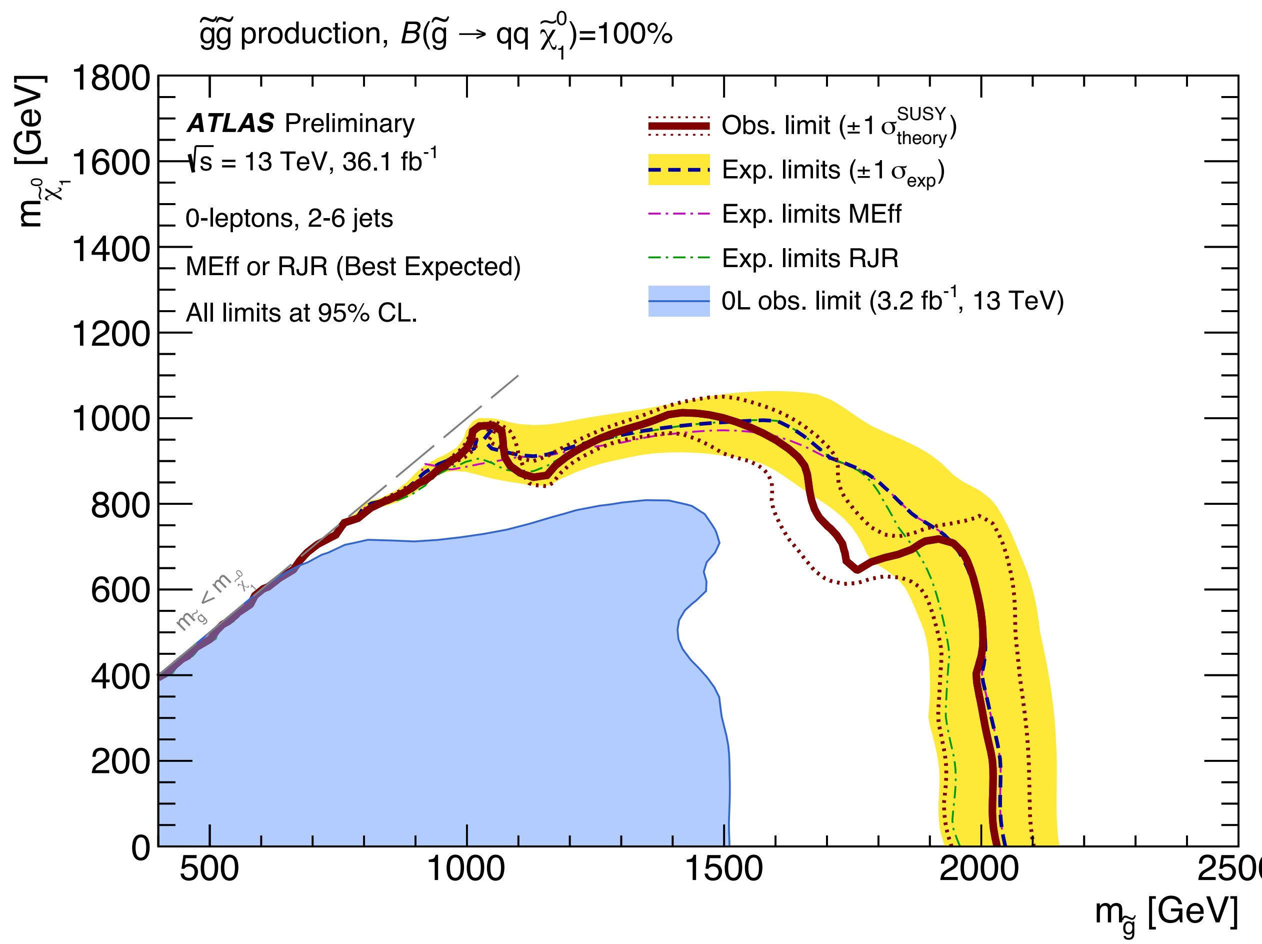


Current Status SUSY 0-lepton analysis

Squark Production



Gluino Production

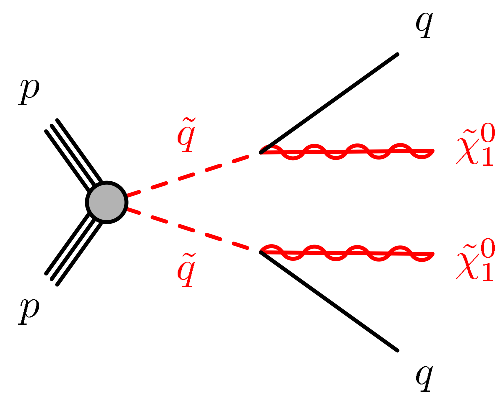


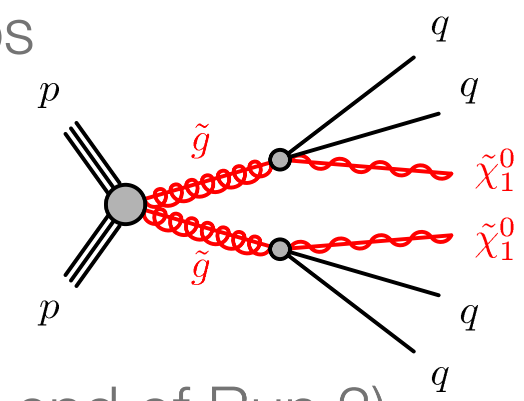
ATLAS-CONF-2017-022

What could be the improvement by using BDT or multi-bin analyses?

General Idea

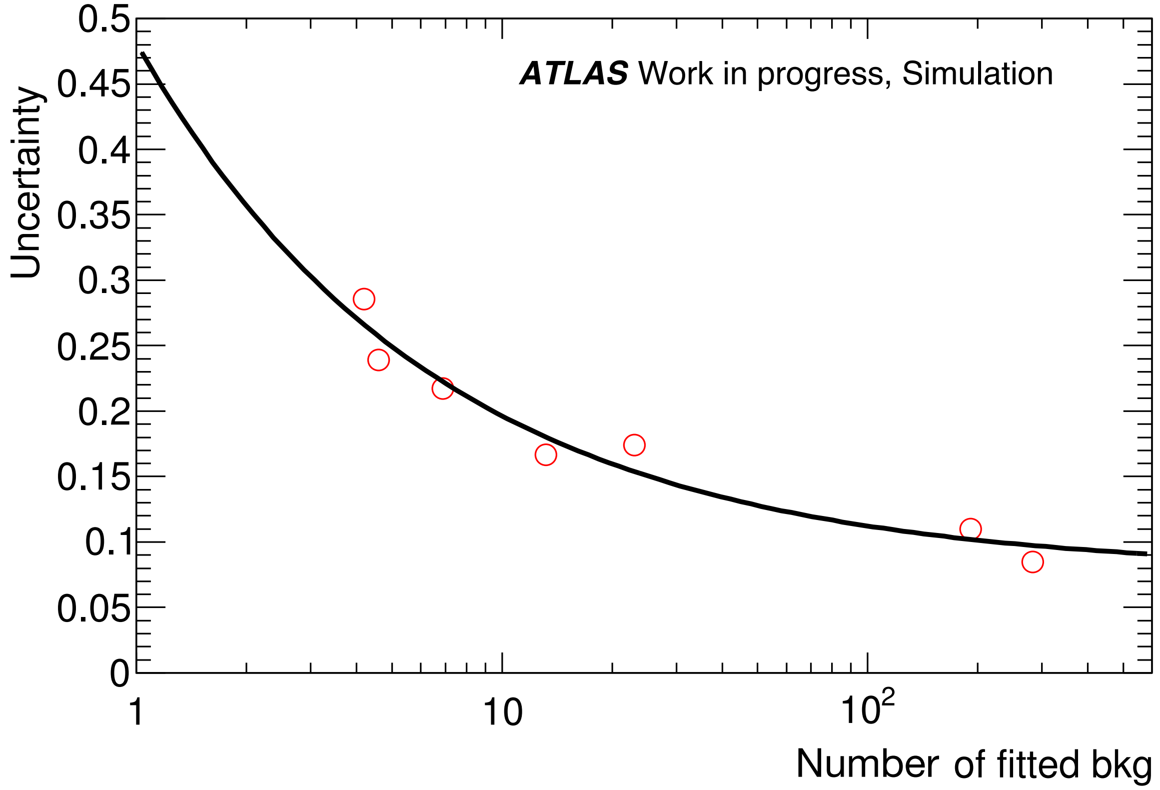
- Using BDT and multi-bin analysis to optimise significance in different signal regions (SR)
- Multi-bin: slicing data sample into different orthogonal bins
- Retrieving new cut definitions from machine learning techniques
- Comparison with reoptimised Cut & Count
- Signal: Squark and Gluino production with direct decays to neutralinos
    - Background: W, Z, Top, Diboson, QCD negligible
- Working with luminosity of 100 fb^{-1} for squarks & 120fb^{-1} for gluinos (~end of Run 2)



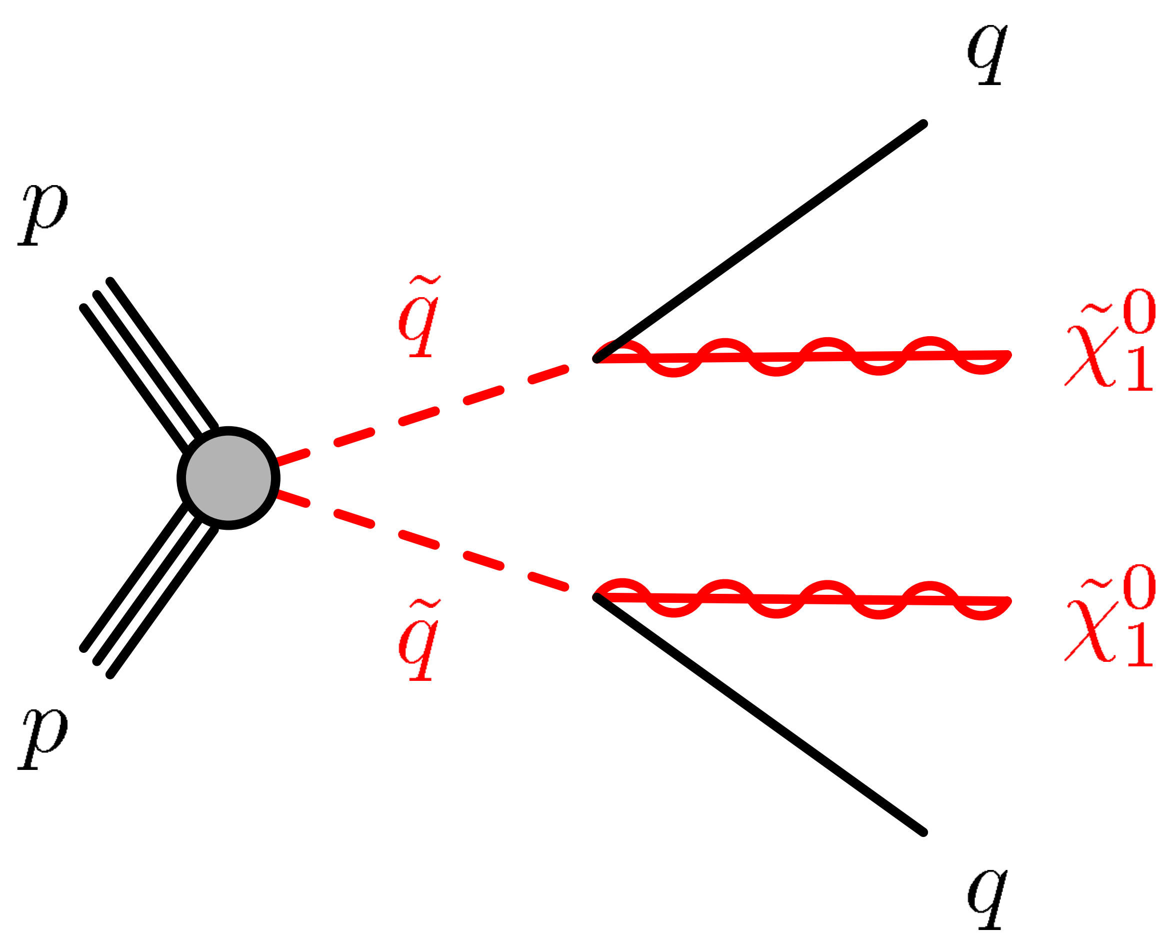


Working Point and Significance

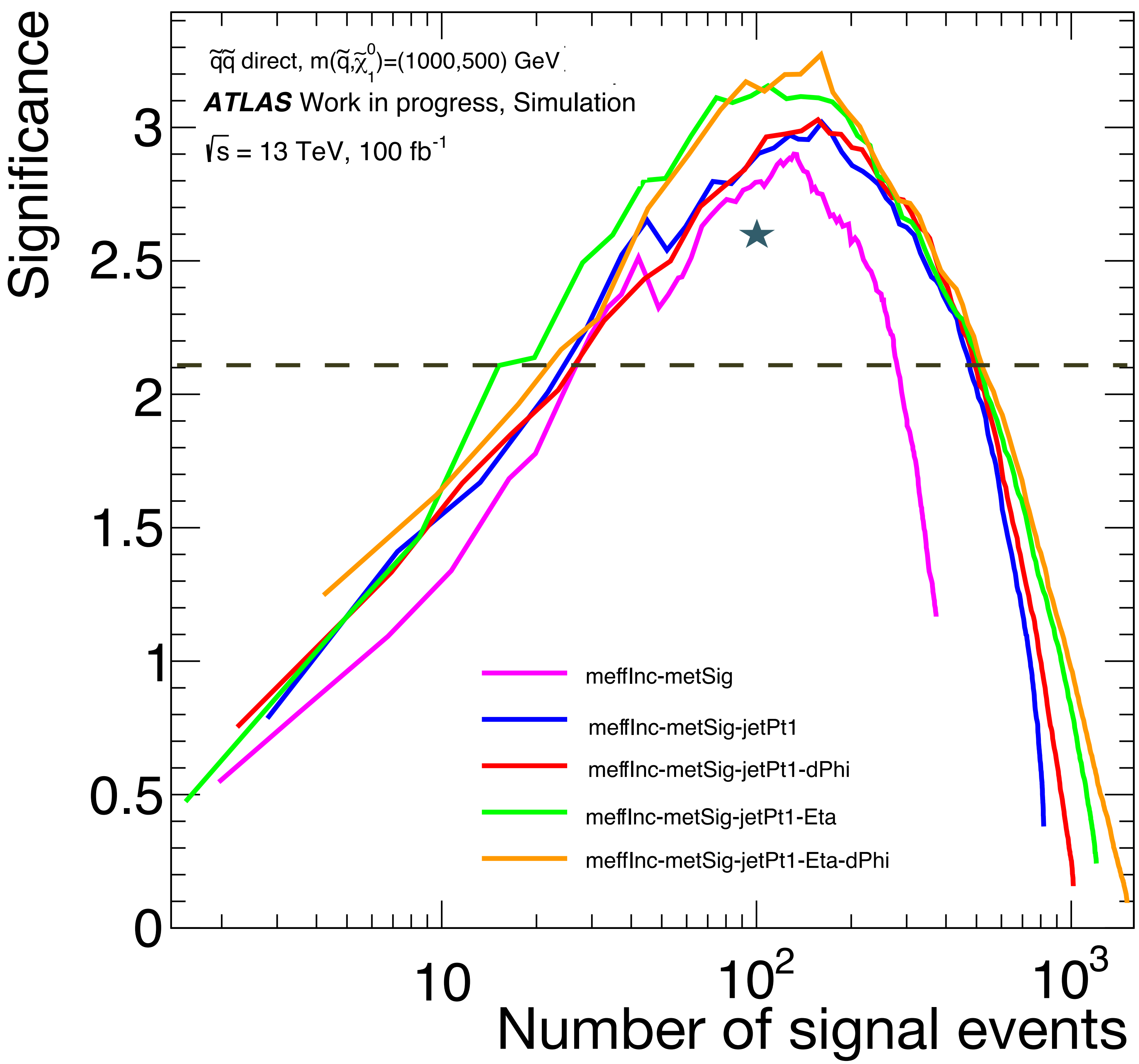
- Scanning whole range of BDT scores and choose point with highest significance
- Significance calculated with
    - RooStats.NumberCountingUtils.BinomialExpZ()-function
    - Uncertainty calculated depending on number of background events (function from SUSY 0-lepton discovery prospects analysis)



Direct Squark Production



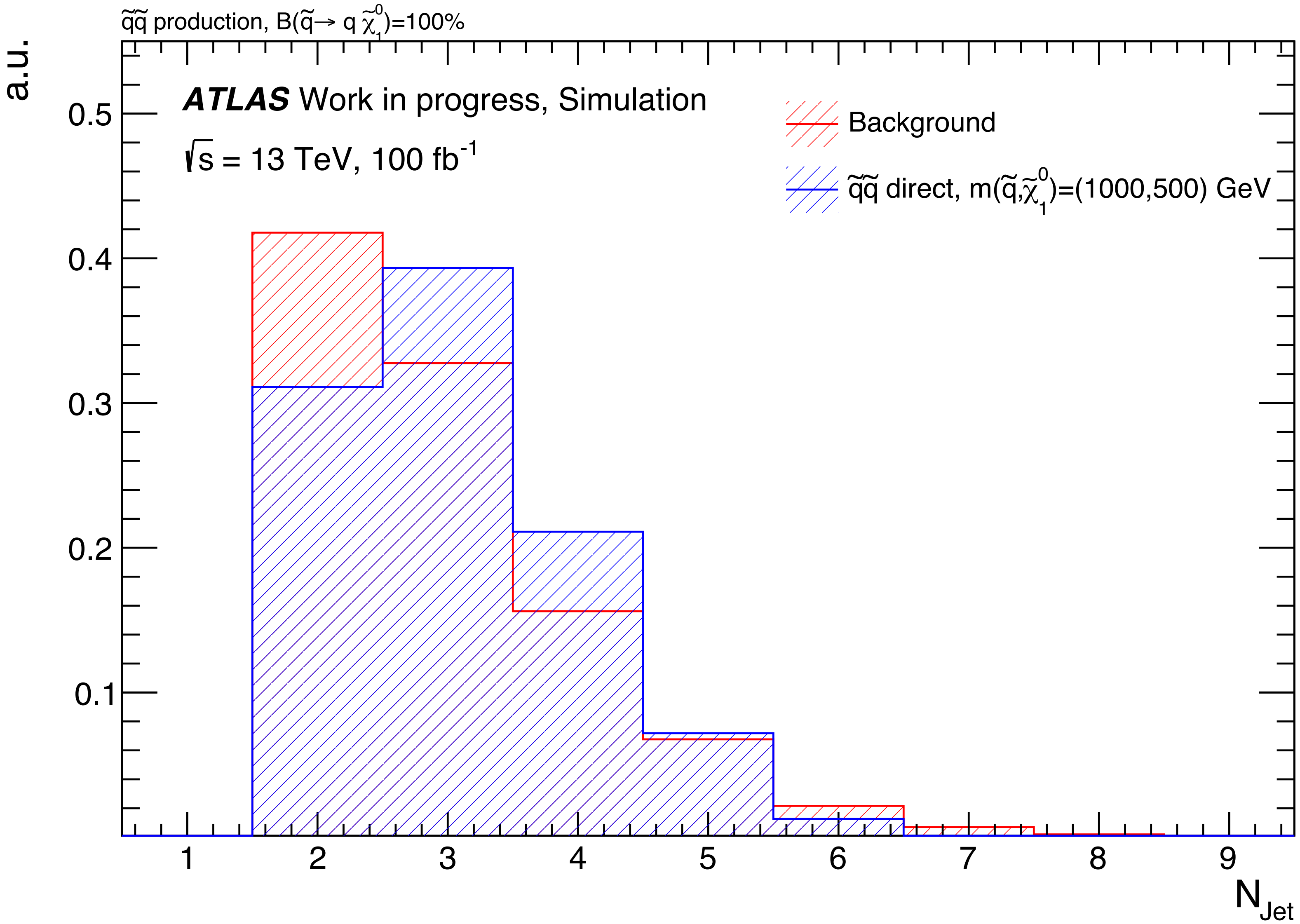
Finding Variable Combination



- Samples splitted into training and testing samples for BDT (EventNumber)
- Cuts for non trained variables are set to default from current analysis (here SR with 2j and m_{eff}(incl) cut of 1600 GeV)
- Significance
  - Default analysis: 2.11 – – –
  - Reoptimised Cut & Count: 2.61★

By adding variables ⇨significance improves

Separation in nJet slices

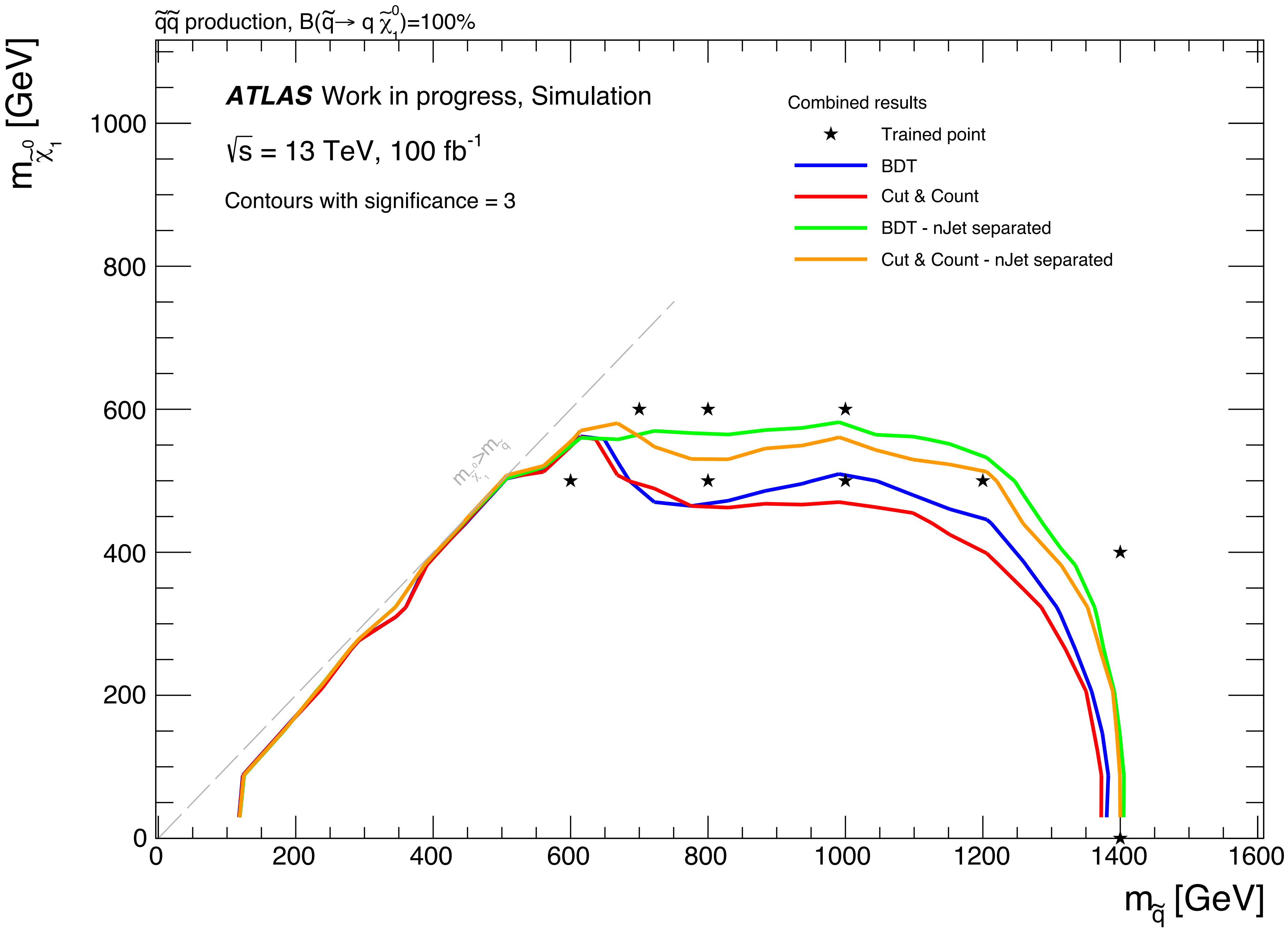


N_{Jet}	Significance BDT	Significance Cut	quad. sum BDT	quad. sum Cut
≥2	3.20	2.61		
==2	2.40	1.84		
==3	2.71	2.52	4.59	4.0
==4	2.18	1.79		
≥5	1.80	1.77		

$\tilde{q}\tilde{q}$ direct, m($\tilde{q}$,$\tilde{\chi}_1^0$)=(1000,500) GeV

- ISR & FSR increase number of jets → "different physics"
    - Mostly gluon jets and softer
- Division of training in different N_{jet} slices → improvement of ~50%

Contour Plots - Direct Squark Production



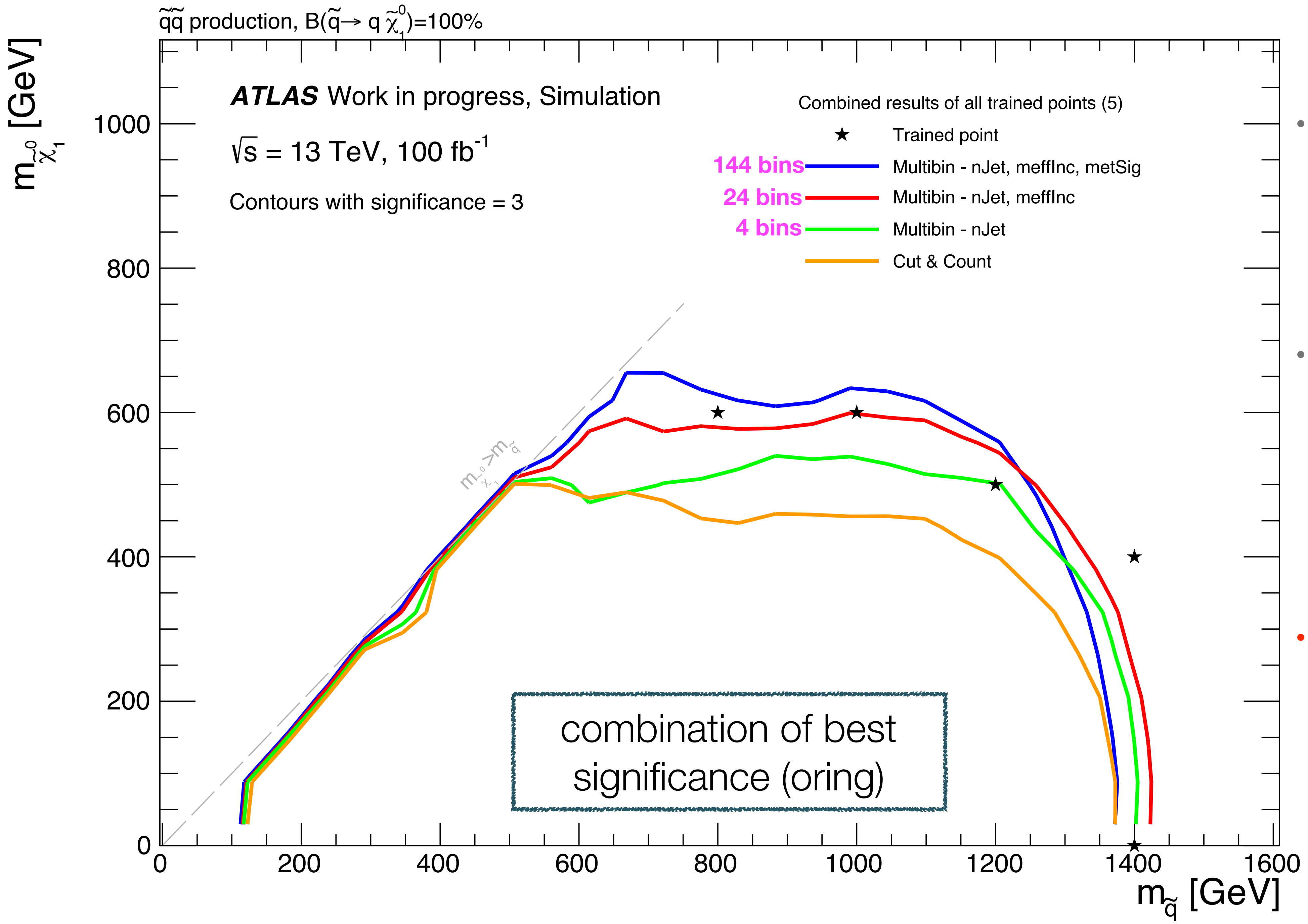
- BDT shows better results than Cut & Count
- <u>**Improvement with nJet separation**</u>
- Combination of both BDT and N_{jet} separation gives best result
- Using more variables for multi-bin analysis can improve results

Cut & Count Multi-Bin Analysis

- nJet separation improved results
  - ➡ Adding more variables might provide further improvements
- Additional binning in m_{eff}(incl) and metSig
- Cut & Count training of remaining variables for each possible bin combination
- Looking for technique to reduce number of bins
  - Currently up to 144 bins (4x6x6)

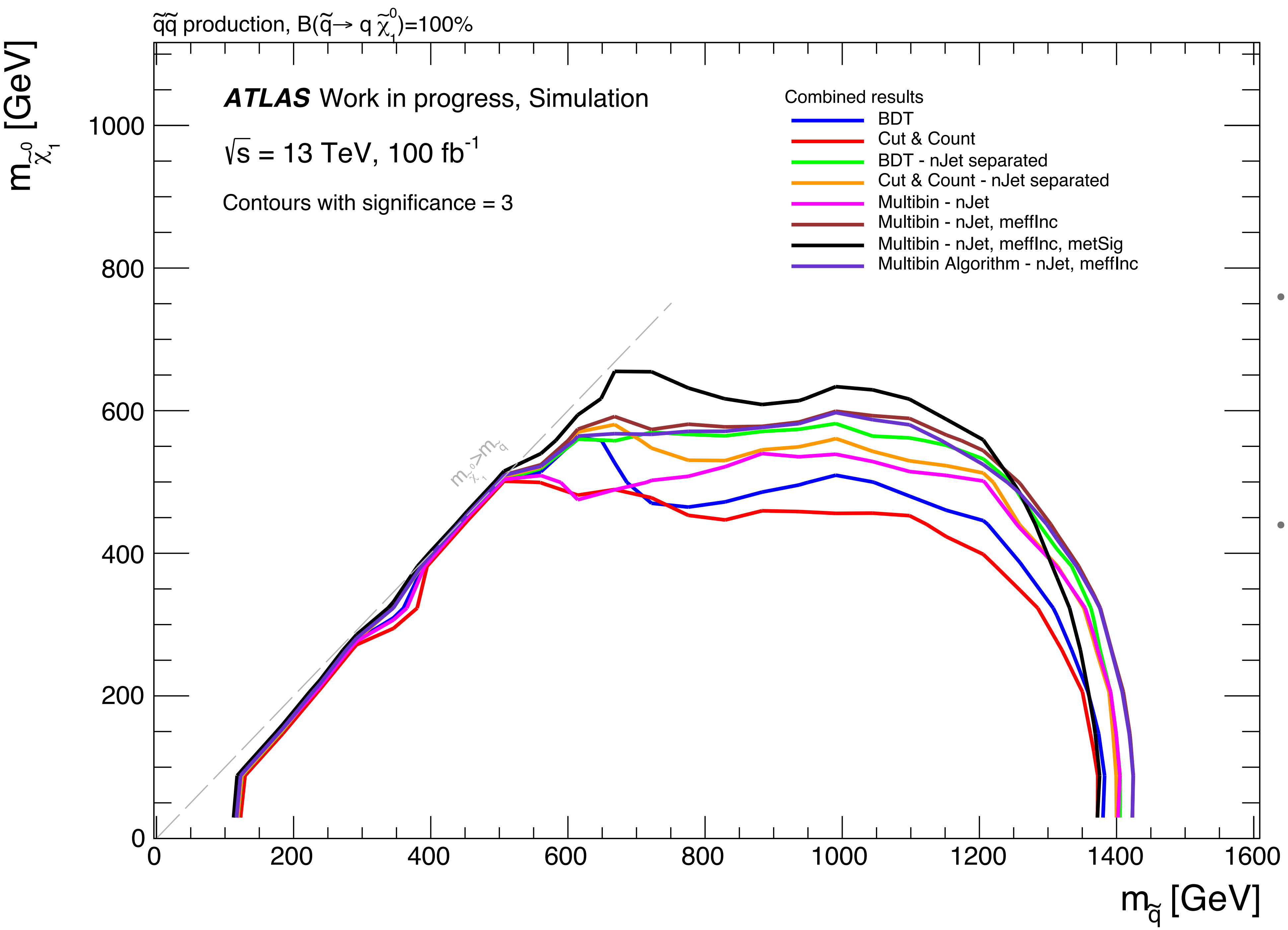
	N_{Jet}	m_{eff}(incl) [GeV]	metSig
1	==2	1200 - 1600	12 - 16
2	==3	1600 - 2000	16 - 20
3	==4	2000 - 2400	20 - 24
4	≥5	2400 - 2800	24 - 28
5		2800 - 3200	28 - 32
6		≥3200	≥32

Cut & Count Multi-Bin Analysis



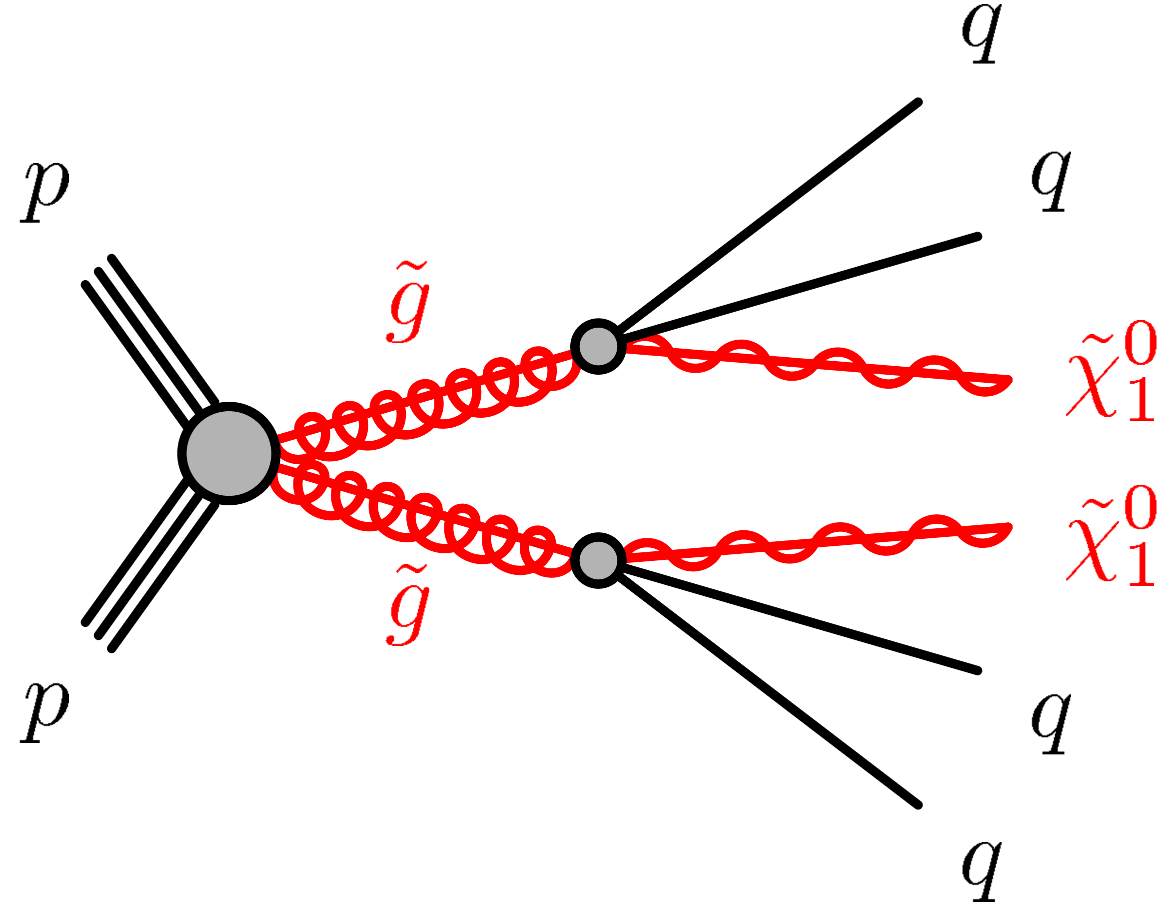
- Adding m_{eff}(incl) binning yields to significant improvement
- Additional metSig bins improve the low Δm regions but shows decrease in high Δm
- Finding compromise between complexity and gain
  ⇨ Multi-bin with nJet & m_{eff}(incl) bins

Summary Plot - Direct Squark Production

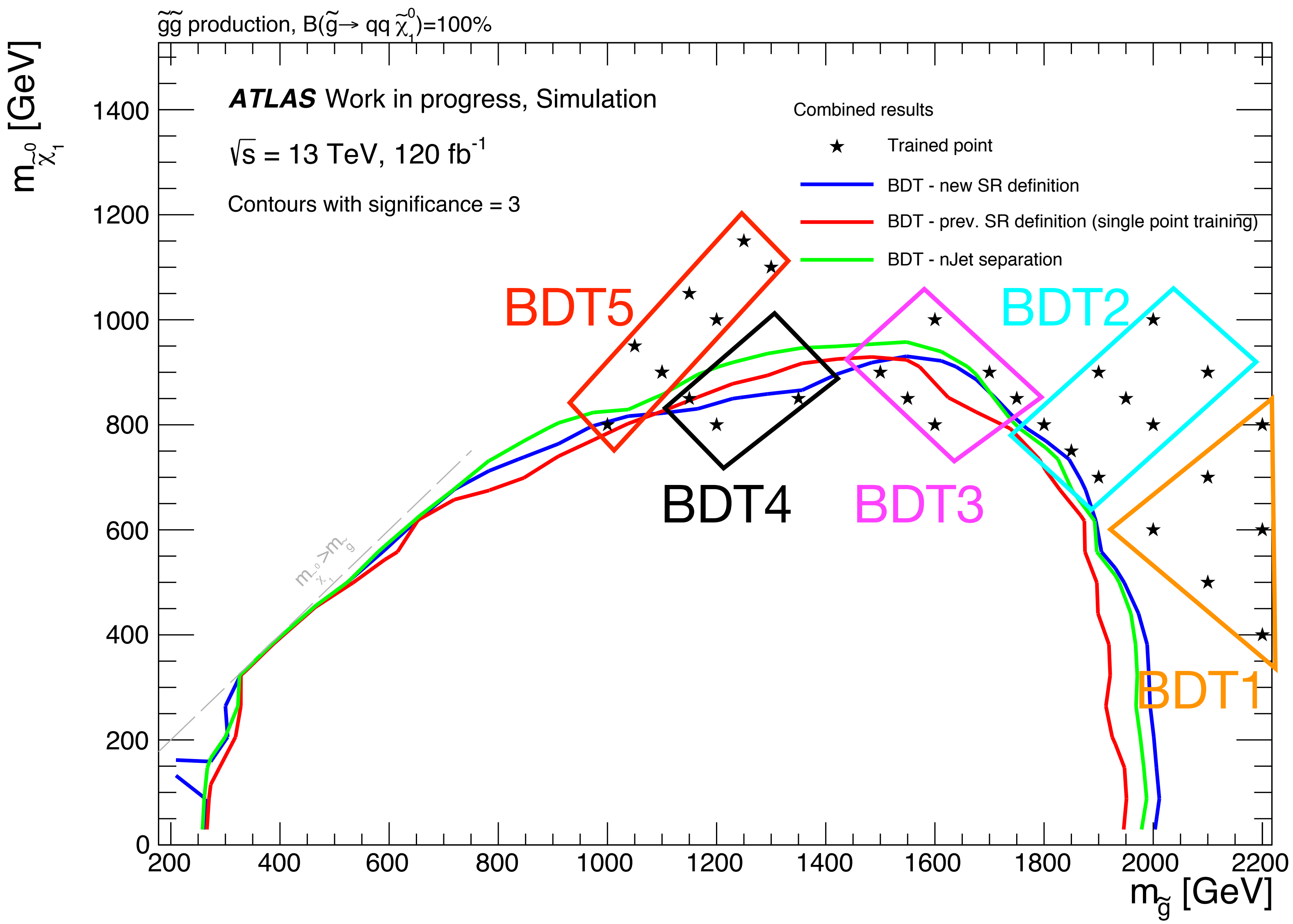


- BDT results similar to multi-bin with N_{jet} & m_{eff}(incl)
- **Main increase due to binning into different variables**

Direct Gluino Production



Direct Gluino Production



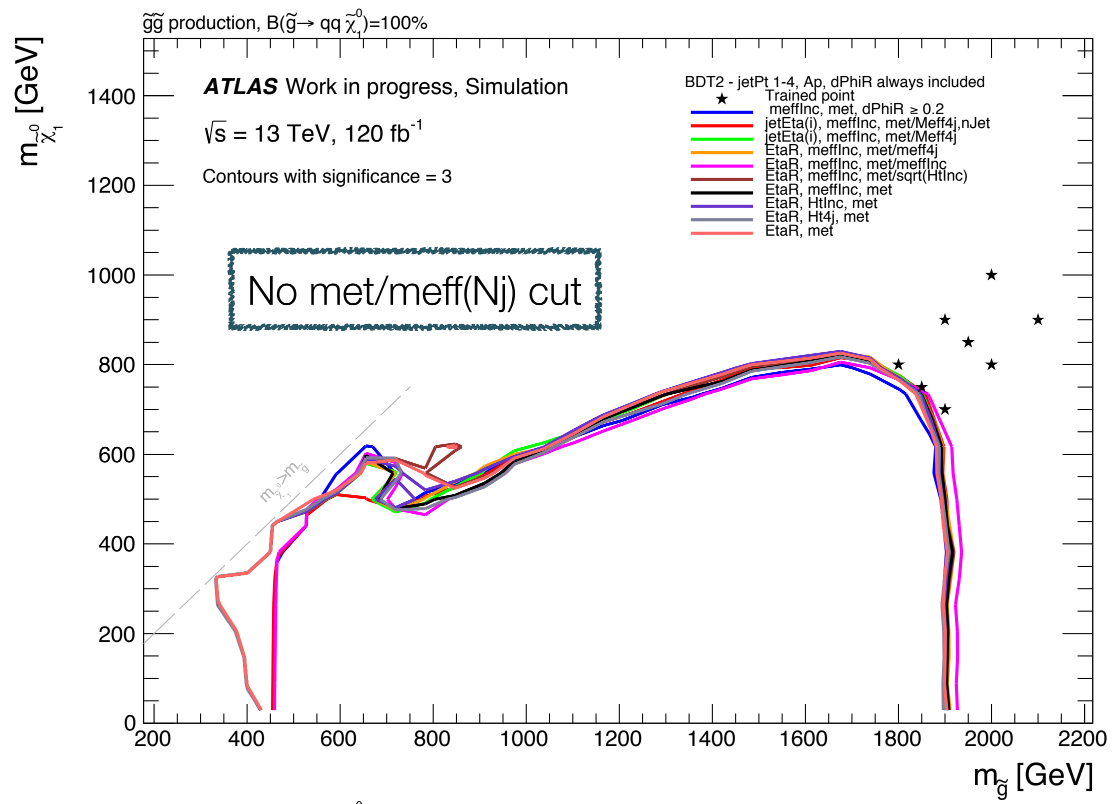
- Switched to 120 fb^{-1}
- Using Signal Regions with similar kinematics instead of single points
- Almost no gain with N_{jet} separation
- 13 Input variables
- **Can we reduce number of input variables without loosing much sensitivity?**

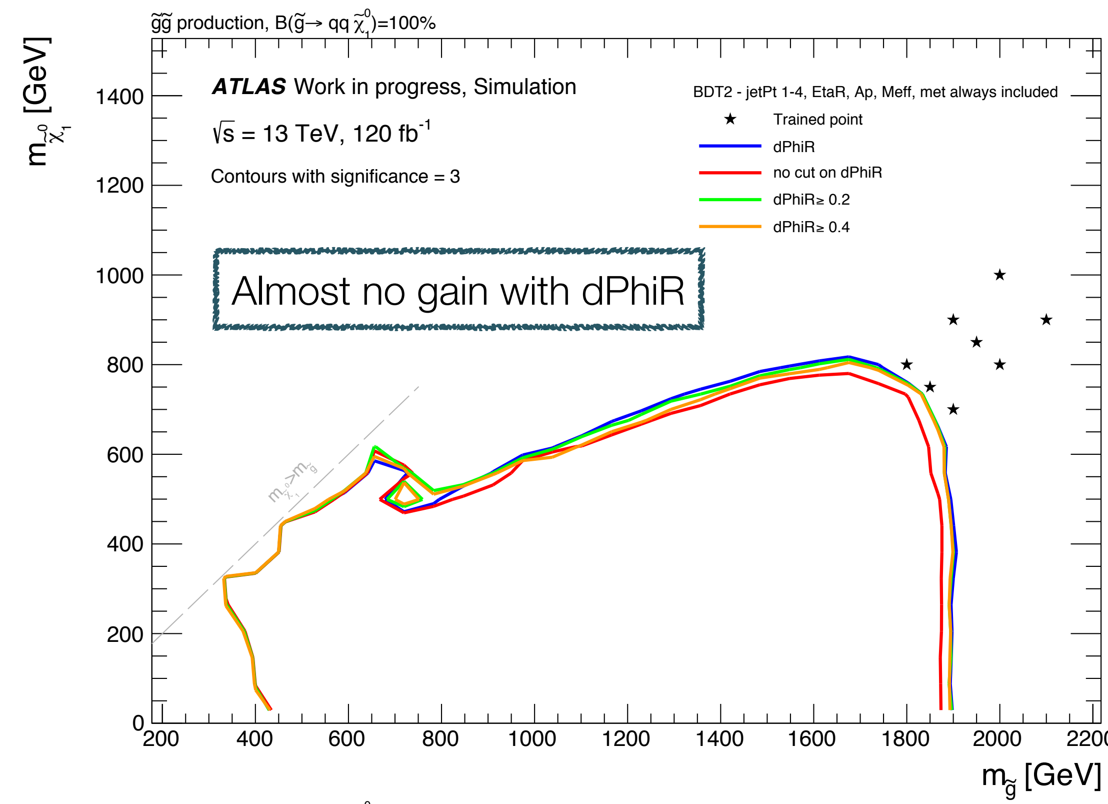
Input Variables BDT1-4

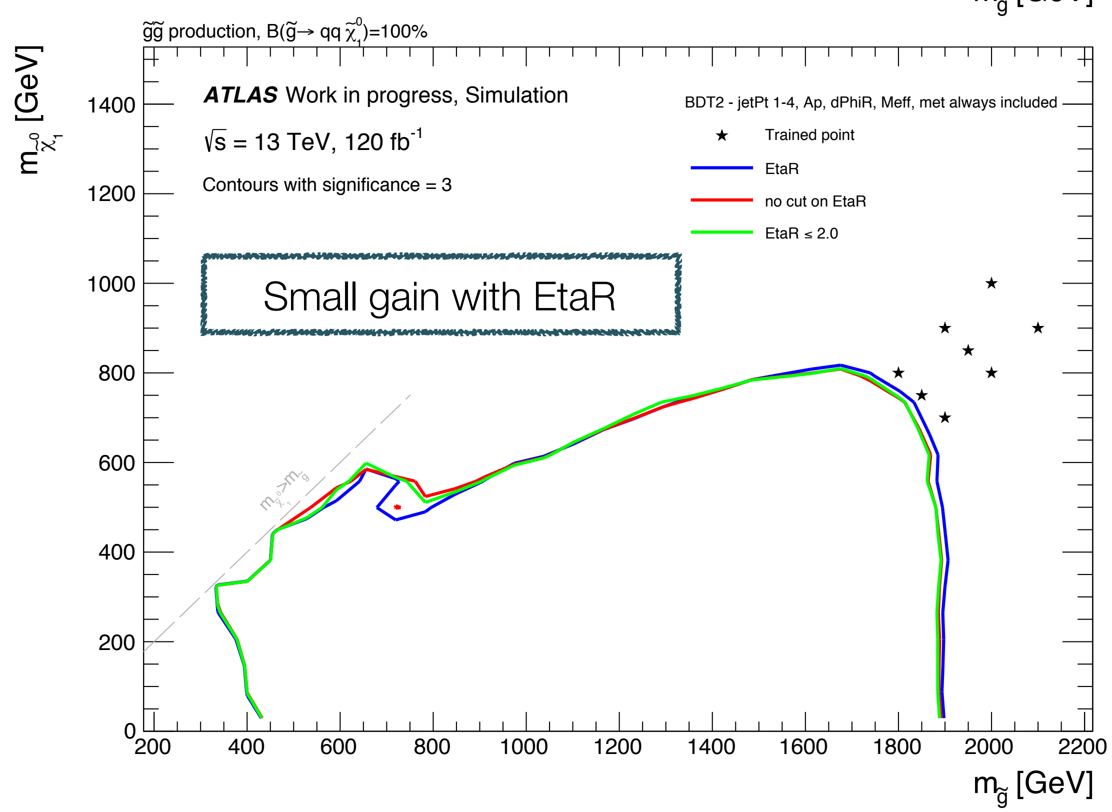
$N_{\mathrm{jet}},\ m_{\mathrm{eff}}(\mathrm{incl}),\ E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(\mathrm{incl}),\ \Delta\phi(\mathrm{jet}_{I>3}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$

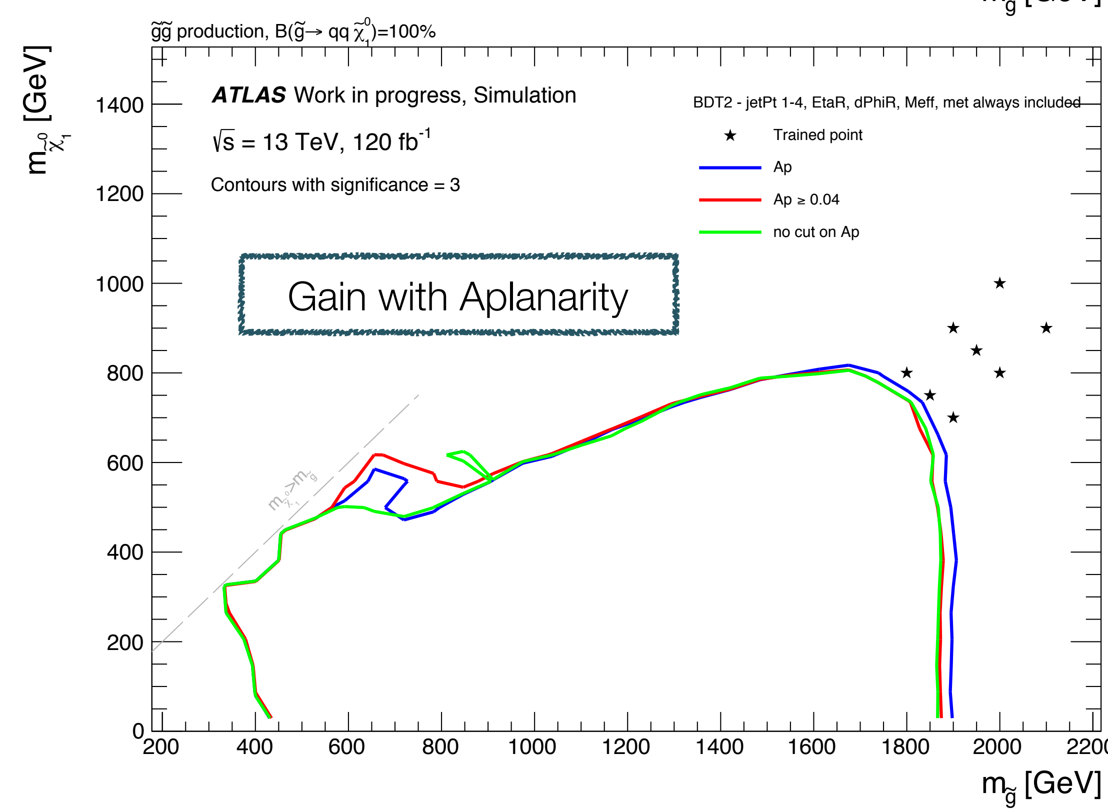
$\mathrm{Ap},\ 1^{\mathrm{st}} - 4^{\mathrm{th}}\mathrm{jetPt},\ 1^{\mathrm{st}} - 4^{\mathrm{th}}\mathrm{jet}\eta$

BDT Variable Study - for SR BDT2

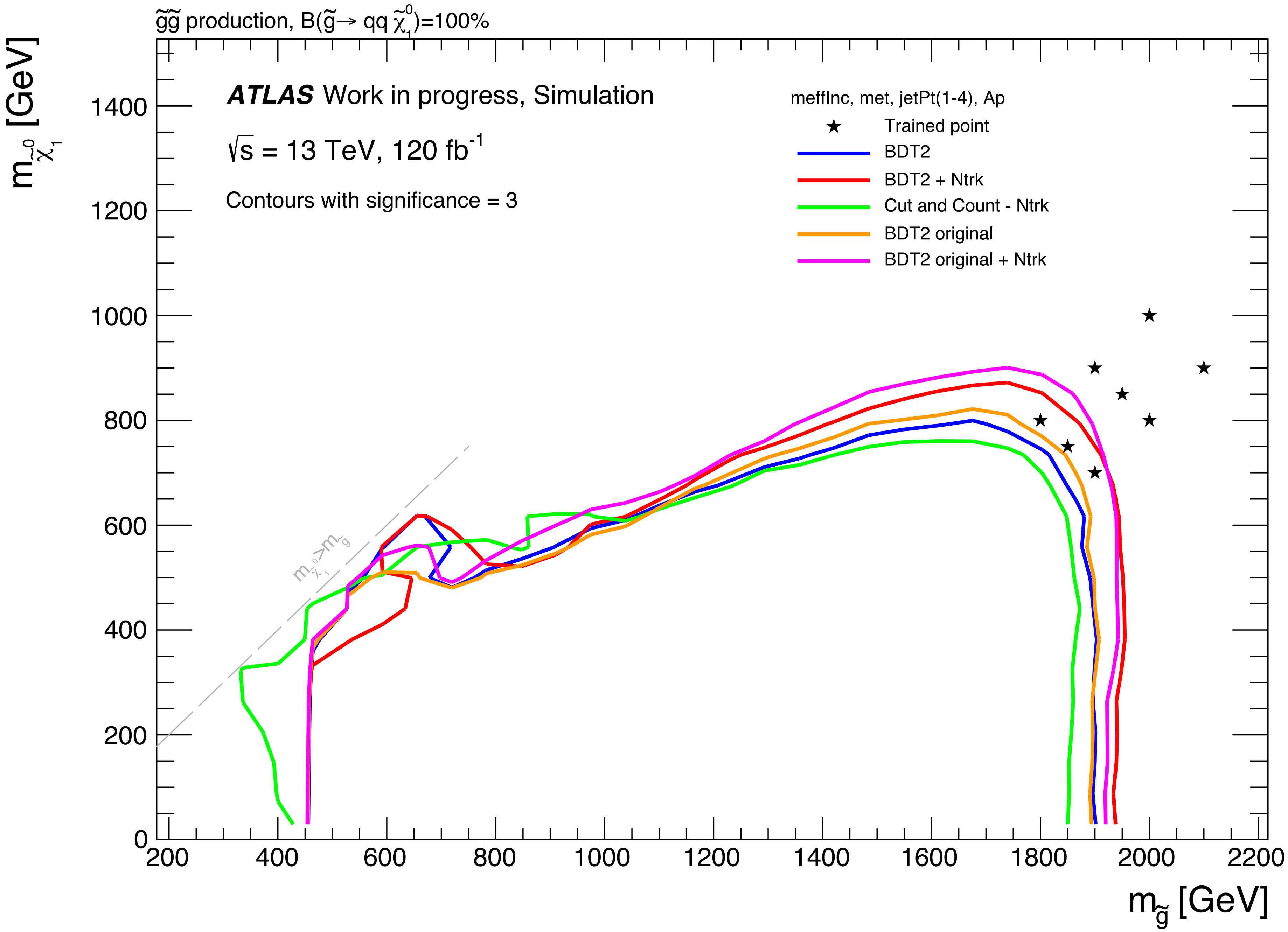








BDT Variable Study - for SR BDT2



Best results vs simplicity:
m_{eff}(incl), MET, jetPt(1-4), Ap

- New simplified variable combination slightly worse but simpler
- Significant improvement with N_{trk} variable
  - Gluon jets have more tracks than quark jets
    - background: gluon dominated
    - signal: quark dominated
- Further approach: trying to understand the gain and translate into new cut definitions

Summary

- Squark Study
  - BDT shows improvement with respect to Cut & Count
  - Regions with higher LSP (neutralino) masses show greater improvement than with high squark masses
  - Multibin analysis with more variables (m_{eff}(incl), metSig) shows large improvement better than BDT
  - Taking complexity of analysis into account, **multi-bin analysis with N_{Jet} and m_{eff}(incl) seems to be best**
- Gluino Study
  - Using new signal region definition (more statistics for training and better results)
  - Considering gain vs. simplicity in BDT2 SR: m_{eff}(incl), met, jetPt (1-4), Ap as input for BDT
  - **N_{trk} variable improves results significantly** (gain of ~75 GeV in $m_{\tilde{\chi}_1^0}$)
  - Further approach: Trying to extract new cuts from BDT or maybe also neural networks

Backup

SUSY 0-lepton Analysis - Variables

- Missing transverse energy $E_{\mathrm{T}}^{\mathrm{miss}}$ or MET
- Effective mass $m_{\mathrm{eff}} \equiv \sum_{i=1}^{n} |\mathbf{p}_{\mathrm{T}}^{(i)}| + E_{\mathrm{T}}^{\mathrm{miss}}$ $\quad m_{\mathrm{eff}}(\mathrm{incl}) = \sum_{i=1}^{N_{\mathrm{Jet}}} |\mathbf{p}_{\mathrm{T}}^{(i)}| + E_{\mathrm{T}}^{\mathrm{miss}}$
- $\mathrm{dPhi} = \Delta\phi(\mathrm{jet}_{1,2(3)}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ $\quad \mathrm{dPhiR} = \Delta\phi(\mathrm{jet}_{i>3}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$
- jetPt
- jetEta, $\mathrm{Eta} = \max(\eta_1, \eta_2)$, $\mathrm{EtaR} = \max(\eta_1, \eta_2, \eta_3, \eta_4)$
- Aplanarity Ap = $3/2\lambda_3$, with λ_3 smallest eigenvalue of normalised momentum tensor

$$metSig = E_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{m_{\mathrm{eff}}(\mathrm{inc}) - E_{\mathrm{T}}^{\mathrm{miss}}}$$

Signal Region Definition Current Analysis

<table>
<tr><td>Targeted signal</td><td colspan="8">$\tilde{q}\tilde{q},\ \tilde{q} \rightarrow q\tilde{\chi}_1^0$</td></tr>
<tr><td rowspan="2">Requirement</td><td colspan="8">Signal Region [Meff-]</td></tr>
<tr><td>2j-1200</td><td>2j-1600</td><td>2j-2000</td><td>2j-2400</td><td>2j-2800</td><td>2j-3600</td><td>2j-2100</td><td>3j-1300</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] ></td><td colspan="8">250</td></tr>
<tr><td>$p_{\mathrm{T}}(j_1)$ [GeV] ></td><td>250</td><td>300</td><td colspan="4">350</td><td>600</td><td>700</td></tr>
<tr><td>$p_{\mathrm{T}}(j_2)$ [GeV] ></td><td>250</td><td>300</td><td colspan="4">350</td><td colspan="2">50</td></tr>
<tr><td>$p_{\mathrm{T}}(j_3)$ [GeV] ></td><td colspan="7">–</td><td>50</td></tr>
<tr><td>$|\eta(j_{1,2})|$ <</td><td>0.8</td><td colspan="4">1.2</td><td colspan="3">–</td></tr>
<tr><td>$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ ></td><td colspan="6">0.8</td><td colspan="2">0.4</td></tr>
<tr><td>$\Delta\phi(\mathrm{jet}_{\mathrm{i}>3}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ ></td><td colspan="6">0.4</td><td colspan="2">0.2</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] ></td><td>14</td><td colspan="5">18</td><td>26</td><td>16</td></tr>
<tr><td>m_{eff}(incl.) [GeV] ></td><td>1200</td><td>1600</td><td>2000</td><td>2400</td><td>2800</td><td>3600</td><td>2100</td><td>1300</td></tr>
</table>

<table>
<tr><td>Targeted signal</td><td colspan="7">$\tilde{g}\tilde{g},\ \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td></tr>
<tr><td rowspan="2">Requirement</td><td colspan="7">Signal Region [Meff-]</td></tr>
<tr><td>4j-1000</td><td>4j-1400</td><td>4j-1800</td><td>4j-2200</td><td>4j-2600</td><td>4j-3000</td><td>5j-1700</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] ></td><td colspan="7">250</td></tr>
<tr><td>$p_{\mathrm{T}}(j_1)$ [GeV] ></td><td colspan="6">200</td><td>700</td></tr>
<tr><td>$p_{\mathrm{T}}(j_4)$ [GeV] ></td><td colspan="4">100</td><td colspan="2">150</td><td>50</td></tr>
<tr><td>$p_{\mathrm{T}}(j_5)$ [GeV] ></td><td colspan="6">–</td><td>50</td></tr>
<tr><td>$|\eta(j_{1,2,3,4})|$ <</td><td>1.2</td><td colspan="5">2.0</td><td>–</td></tr>
<tr><td>$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ ></td><td colspan="7">0.4</td></tr>
<tr><td>$\Delta\phi(\mathrm{jet}_{\mathrm{i}>3}, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ ></td><td colspan="6">0.4</td><td>0.2</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}} / m_{\mathrm{eff}}(N_{\mathrm{j}})$ ></td><td>0.3</td><td colspan="3">0.25</td><td colspan="2">0.2</td><td>0.3</td></tr>
<tr><td>Aplanarity ></td><td colspan="6">0.04</td><td>–</td></tr>
<tr><td>m_{eff}(incl.) [GeV] ></td><td>1000</td><td>1400</td><td>1800</td><td>2200</td><td>2600</td><td>3000</td><td>1700</td></tr>
</table>

ATLAS-CONF-2017-022

BDT Signal Region Definitions - Original Definition

Preselection

BDT1, BDT2

nJet > 3, M_{eff}> 1400, E_T^{miss} > 300, 1st jet P_T > 200, E_T^{miss}/M_{eff} > 0.2, $\Delta\phi(E_T^{miss}, j_{1,2,3})$ > 0.4

BDT3, BDT4

nJet > 3, M_{eff}> 800, E_T^{miss} > 300, 1st jet P_T > 200, E_T^{miss}/M_{eff} > 0.2, $\Delta\phi(E_T^{miss}, j_{1,2,3})$ > 0.4

BDT5

nJet > 1, M_{eff}> 1400, E_T^{miss} > 300, 1st jet P_T > 200, $E_T^{miss}/\sqrt{H_T}$ > 12, $\Delta\phi(E_T^{miss}, j_{1,2,3})$ > 0.4

Input variable

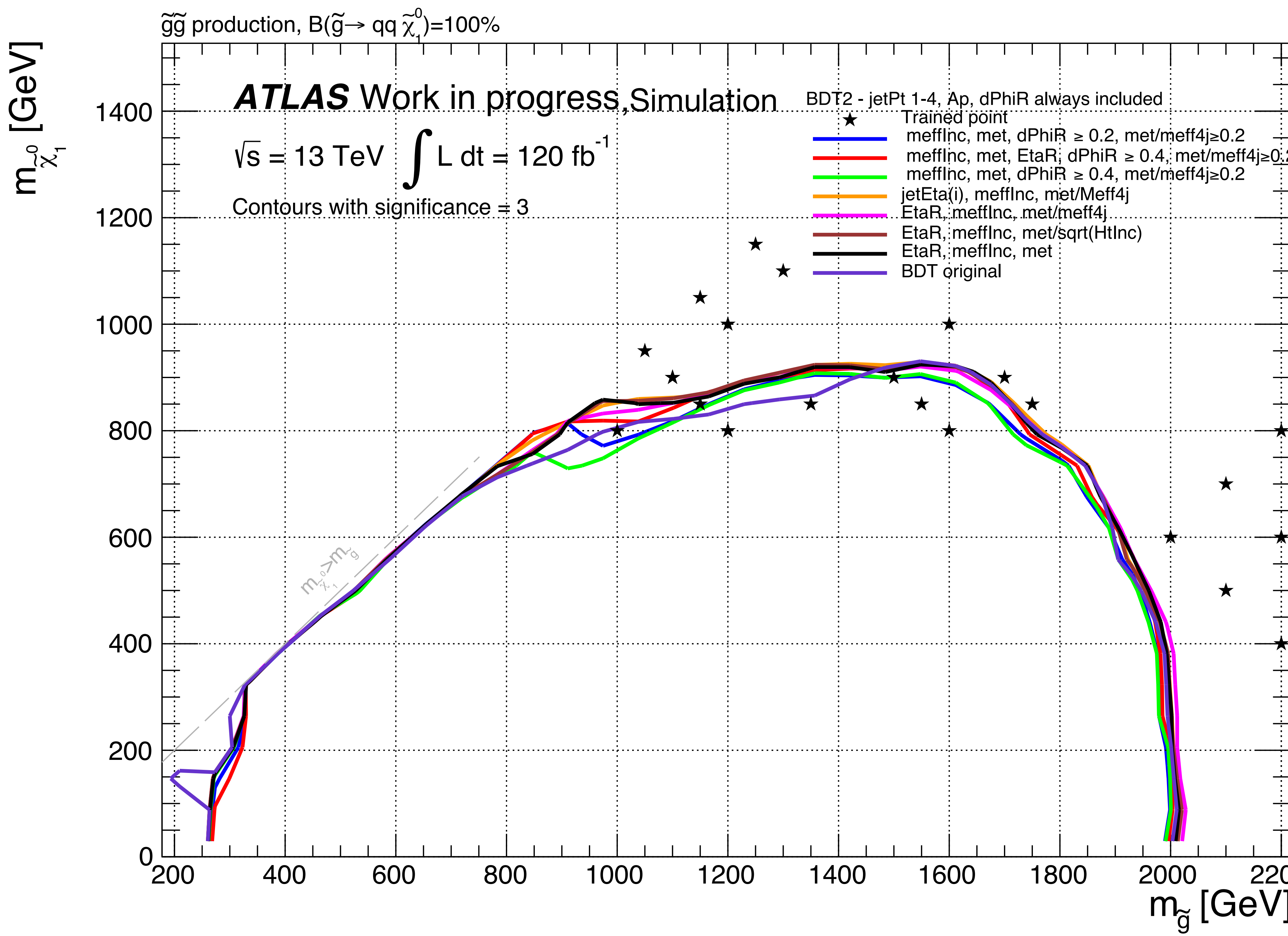
BDT1, BDT2, BDT3, BDT4

nJet, M_{eff}, E_T^{miss}/M_{eff}, $\Delta\phi(E_T^{miss}, j_{i>3})$,
Aplanarity, 1st - 4th jet P_T, 1st - 4th jet η

BDT5

nJet, M_{eff}, $E_T^{miss}/\sqrt{H_T}$, $\Delta\phi(E_T^{miss}, j_{1,2,3})$, $\Delta\phi(E_T^{miss}, j_{i>3})$,
Aplanarity, 1st -4th jet P_T, 1st-4th jet η

BDT Variable Study - Oring



Significance Function

```
f1 = ROOT.TF1("f1","[0]+[1]/pow(x,[2])",1,500.)
f1.SetParameter(0,0.077)
f1.SetParameter(1,0.40 )
f1.SetParameter(2,0.53 )
backgroundError=f1.Eval(nbBkg)
significance = RooStats.NumberCountingUtils.BinomialExpZ(nbSig, nbBkg, backgroundError)
```