Search for High-Mass Dilepton Resonances Using 139 fb^{-1} of pp Collision Data Collected at $\sqrt{s}$ = 13 TeV with the ATLAS Detector

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Resonant Dilepton Analysis

Motivation

BSM Models

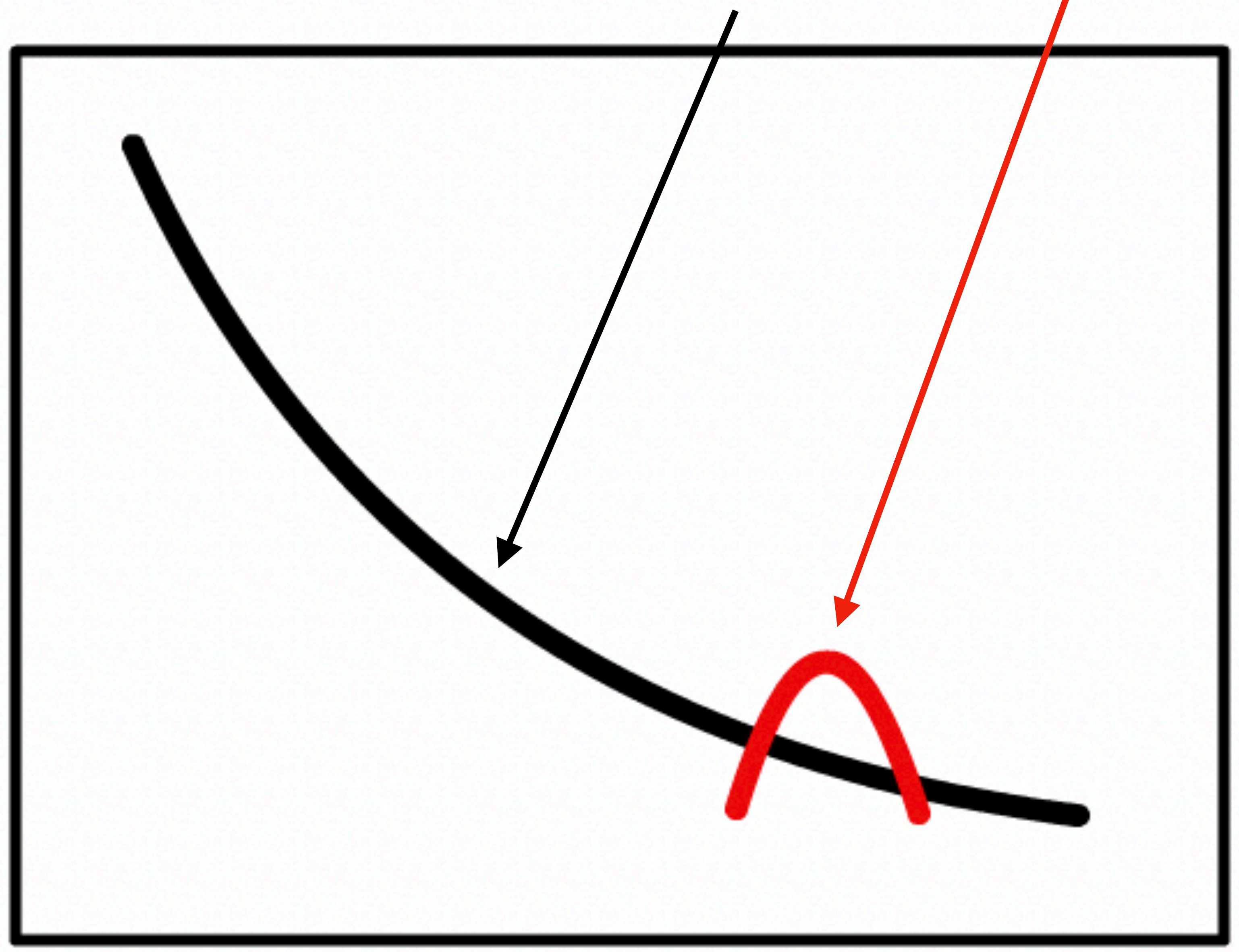
- New U(1) symmetry
  - E_6 symmetry GUT
  - Z'_{SSM} used as benchmark
- Heavy Vector Triplet HVT - SU(2)
- RS gravitons
- MSSM Higgs
- Any other spin 0,1 or 2 resonance

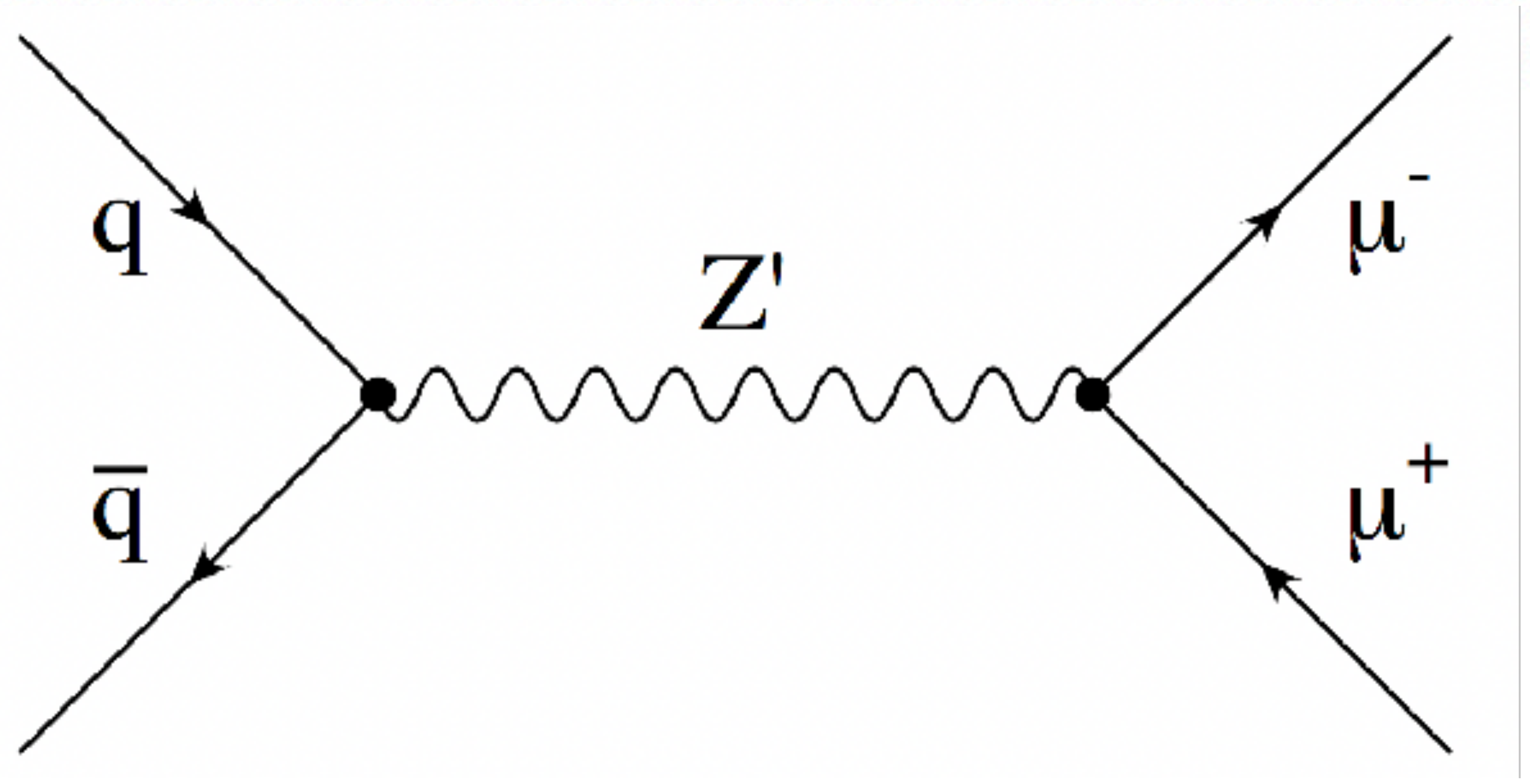
$$E_6 \rightarrow SO(10) \times U(1)_\psi \rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$$

Results presented here are from arXiv:1903.06248v3 [hep-ex] (link) Using full LHC run 2 data (139 fb^{-1})

Also showing some plots from previous analysis iteration for comparison arXiv:1707.02424 [hep-ex] (link)

These models would all manifest as **narrow resonances** above the **SM dilepton background**.





Analysis Strategy

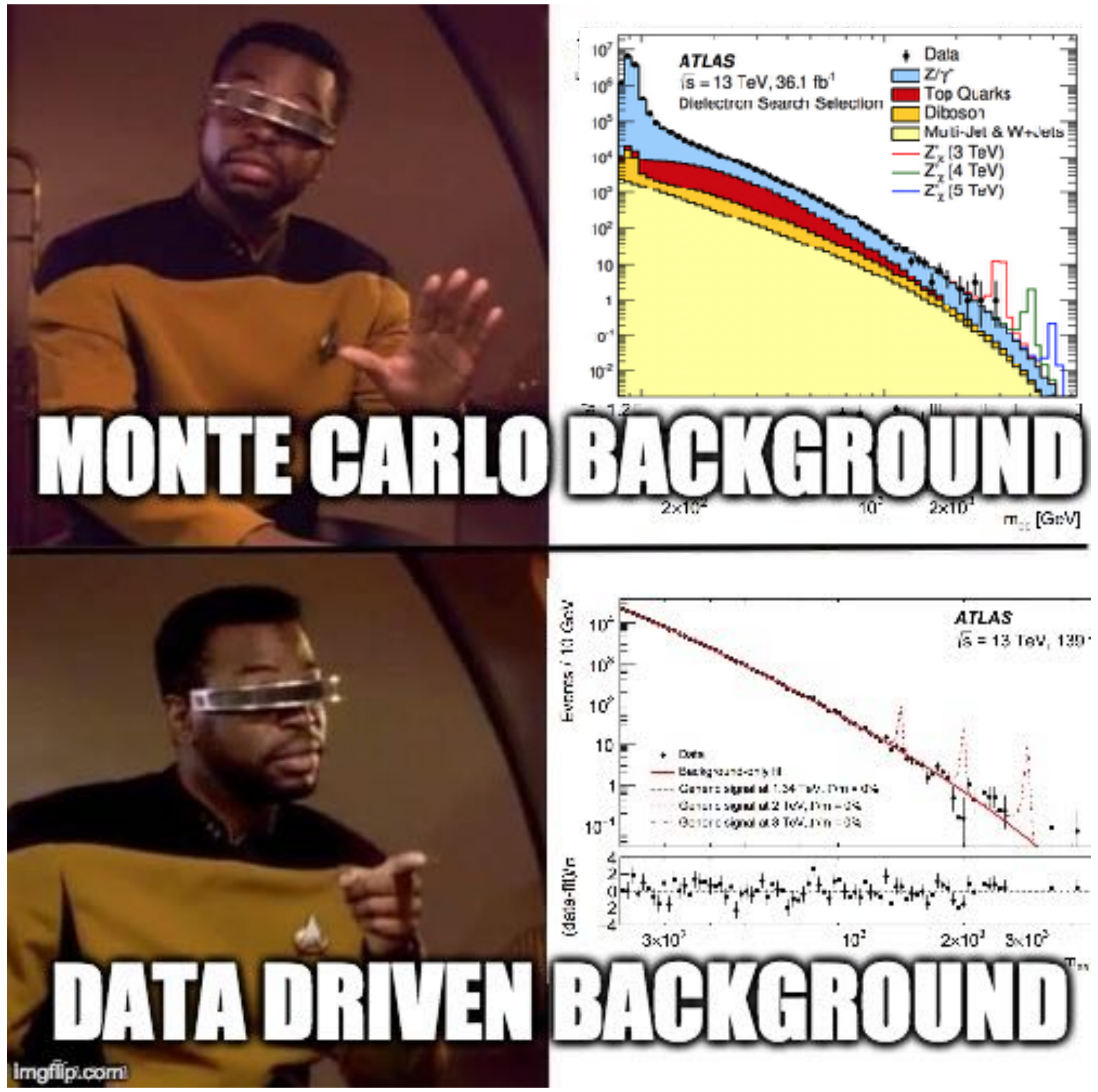
Analysis Stragegy

- Select two leptons
- Calculate their invariant mass m_{ll}
- Look for deviation over background expectation
- If no deviation found, set limits on BSM models

Event Selection

- Two same sign leptons (*ee* or *μμ*)
- Highest E_T lepton pair selected (favouring *ee*)
- 225 GeV < m_{ll} < 6 TeV

New strategy for background estimation



Background and Signal Modelling

- MC statistics becoming an issue in low mass region
- PDF uncertainty very large in high mass region
- Move to data-driven method of background estimation

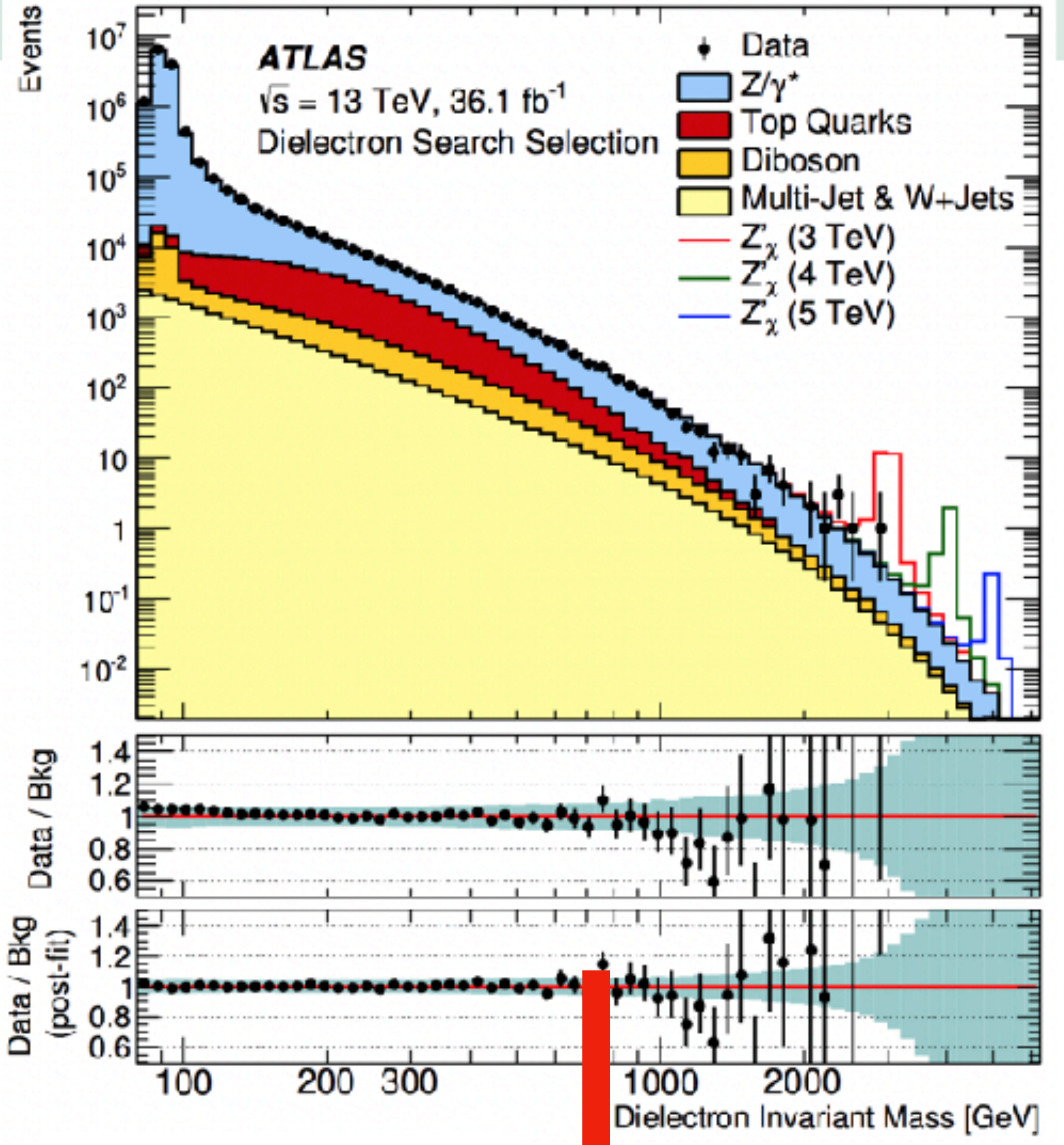
$$f_{\ell\ell}(m_{\ell\ell}) = f_{\mathrm{BW},Z}(m_{\ell\ell}) \cdot (1 - x^c)^b \cdot x^{\sum_{i=0}^{3} p_i \log(x)^i}$$

$f_{BW,Z}$ Is a Breit Wigner modelling the Z boson peak $x = \frac{m_{ll}}{\sqrt{s}}$

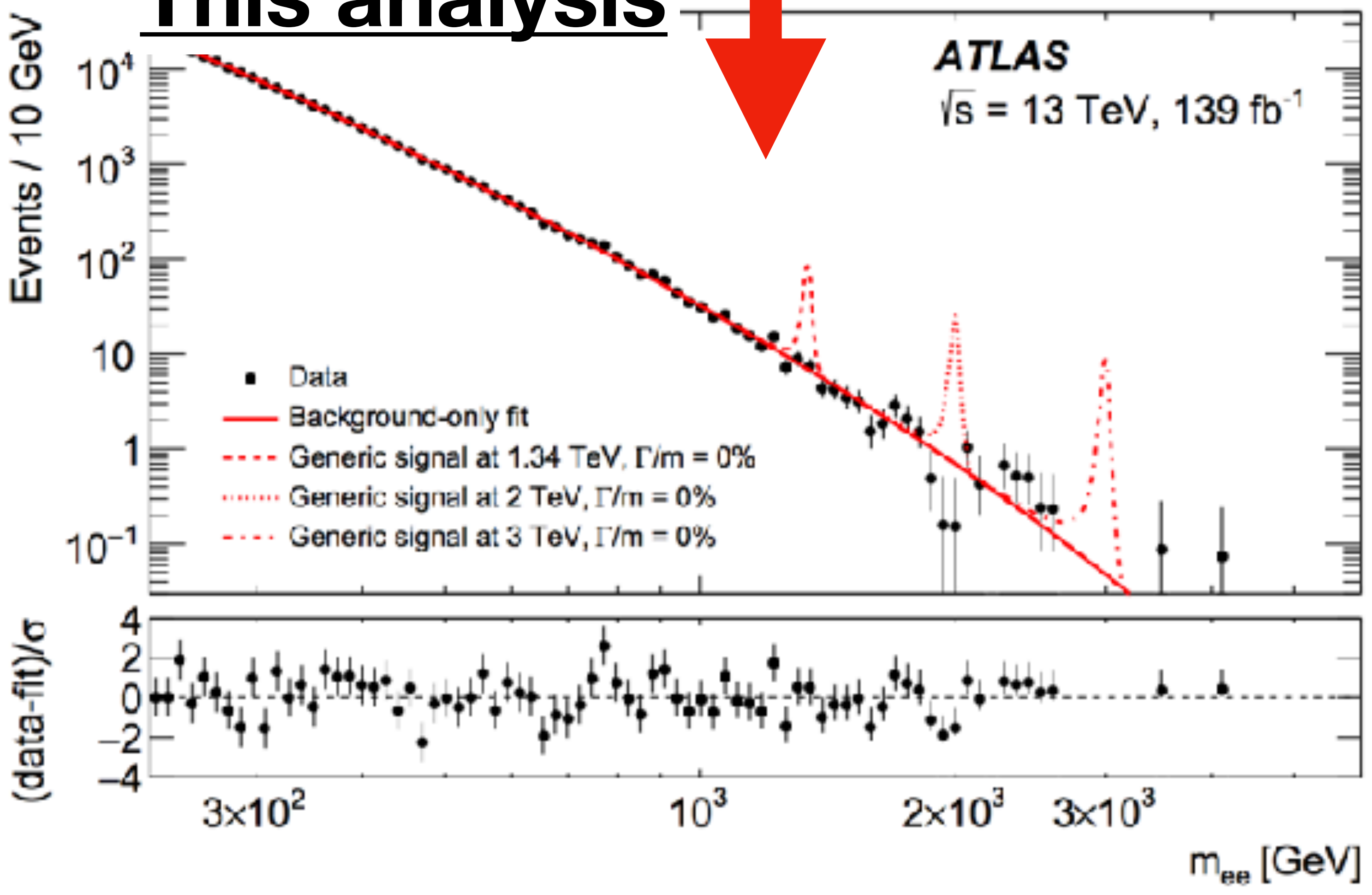
- Still use MC for:
  - Background validation and optimisation
  - Determining resolution and acceptance etc.

- Use truth MC smeared by detector resolution using so-called *transfer functions*
- Signal: Non-relativistic Breit Wigner distribution convoluted with sum of gaussian and Crystal Ball distribution (detector resolution and response)

Previous analysis



This analysis

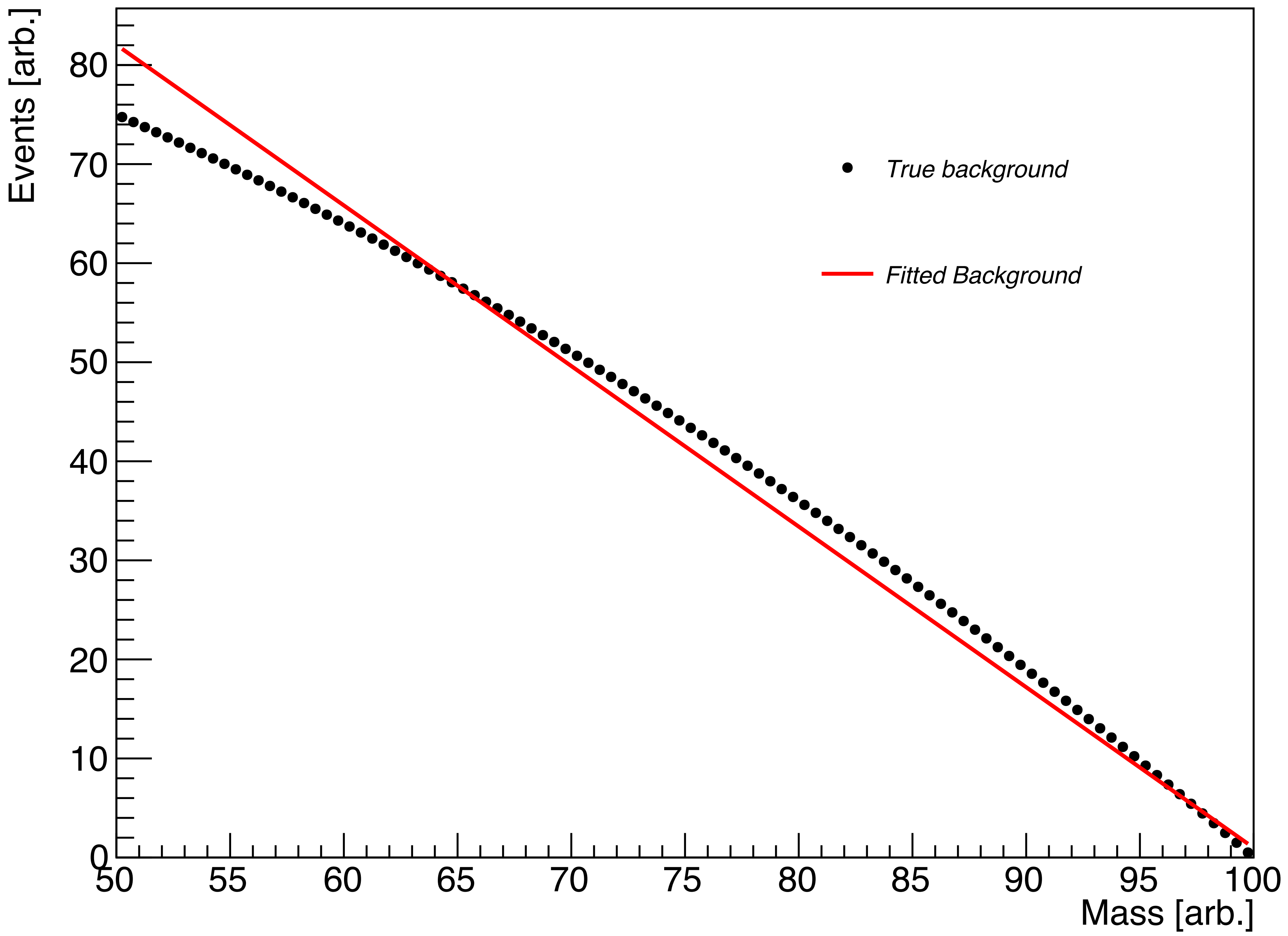


Spurious Signal

Parametric function needs to be:

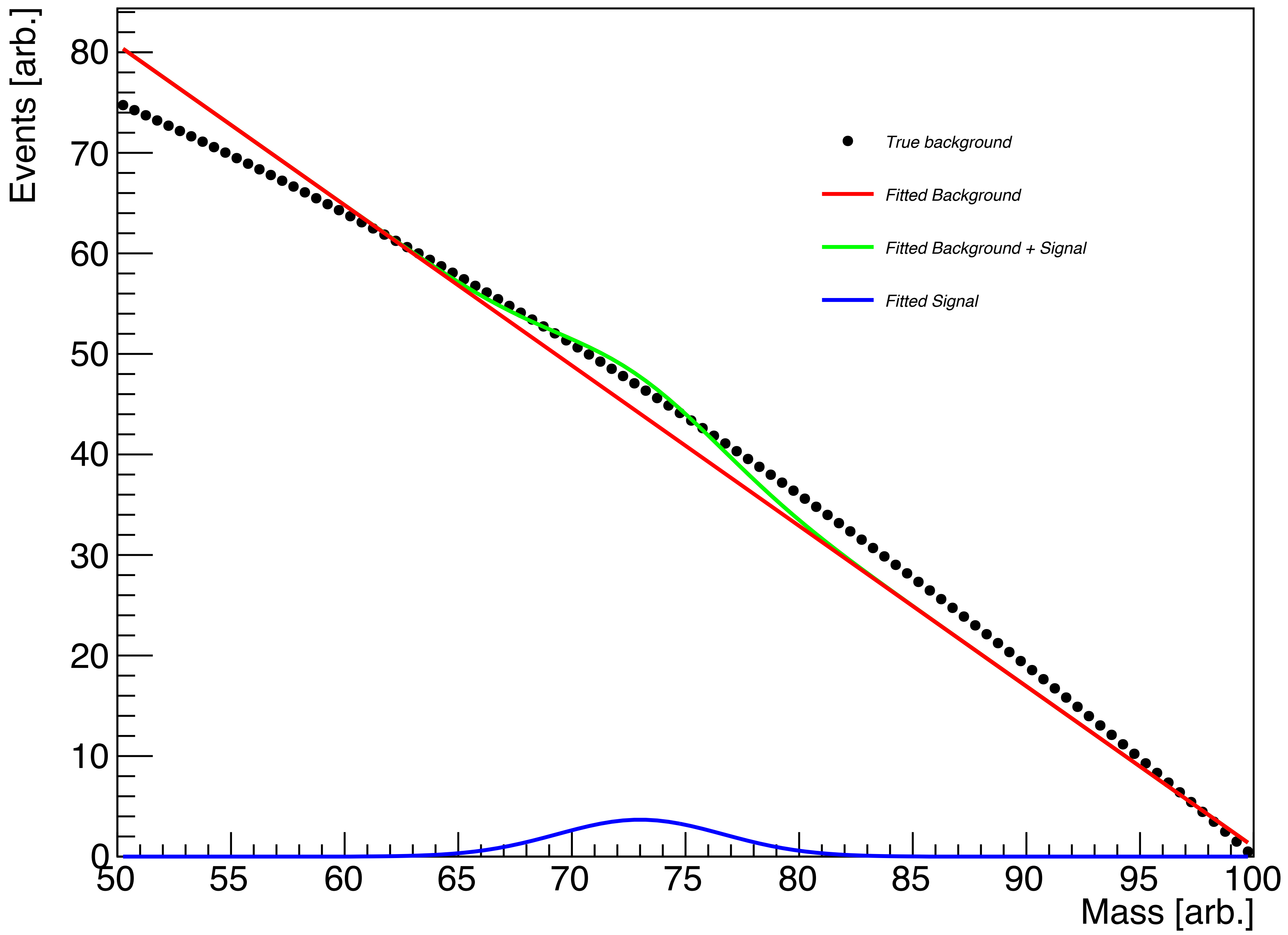
- Flexible enough to accurately describe background
  - Spurious signal test
- Not too flexible. May swallow a potential signal
  - Injection test

Mismodelled background…



…give rise to…

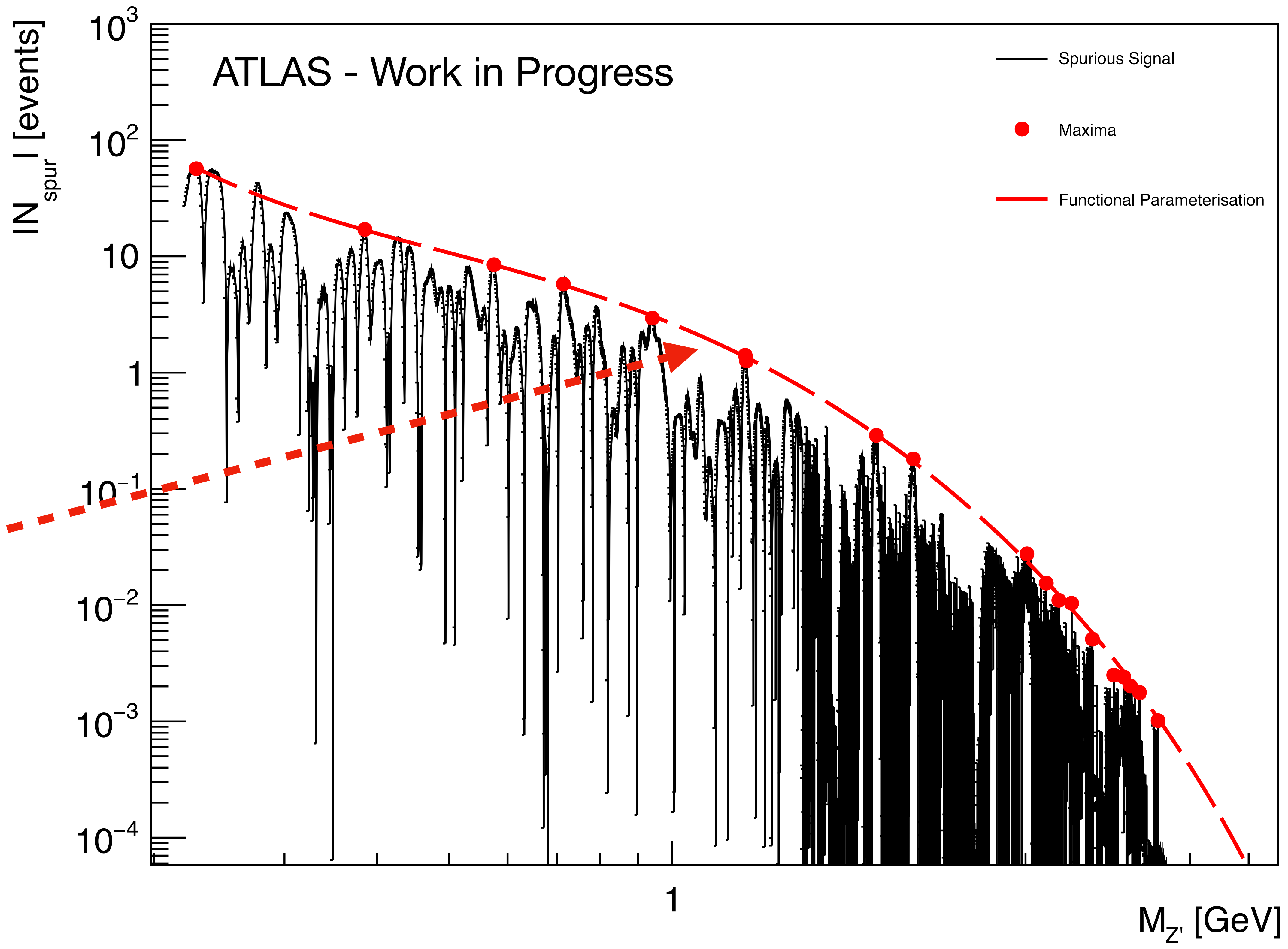
…spurious signal



Spurious signal

Procedure

- Sig+bgr fit on MC template (no signal expected)
- N_{sig} measure of background mismodelling
- N_{sig} varies as a function of invariant mass
    - Fit a **smooth function** to the envelope of the resulting distribution (see figure)



Spurious Signal

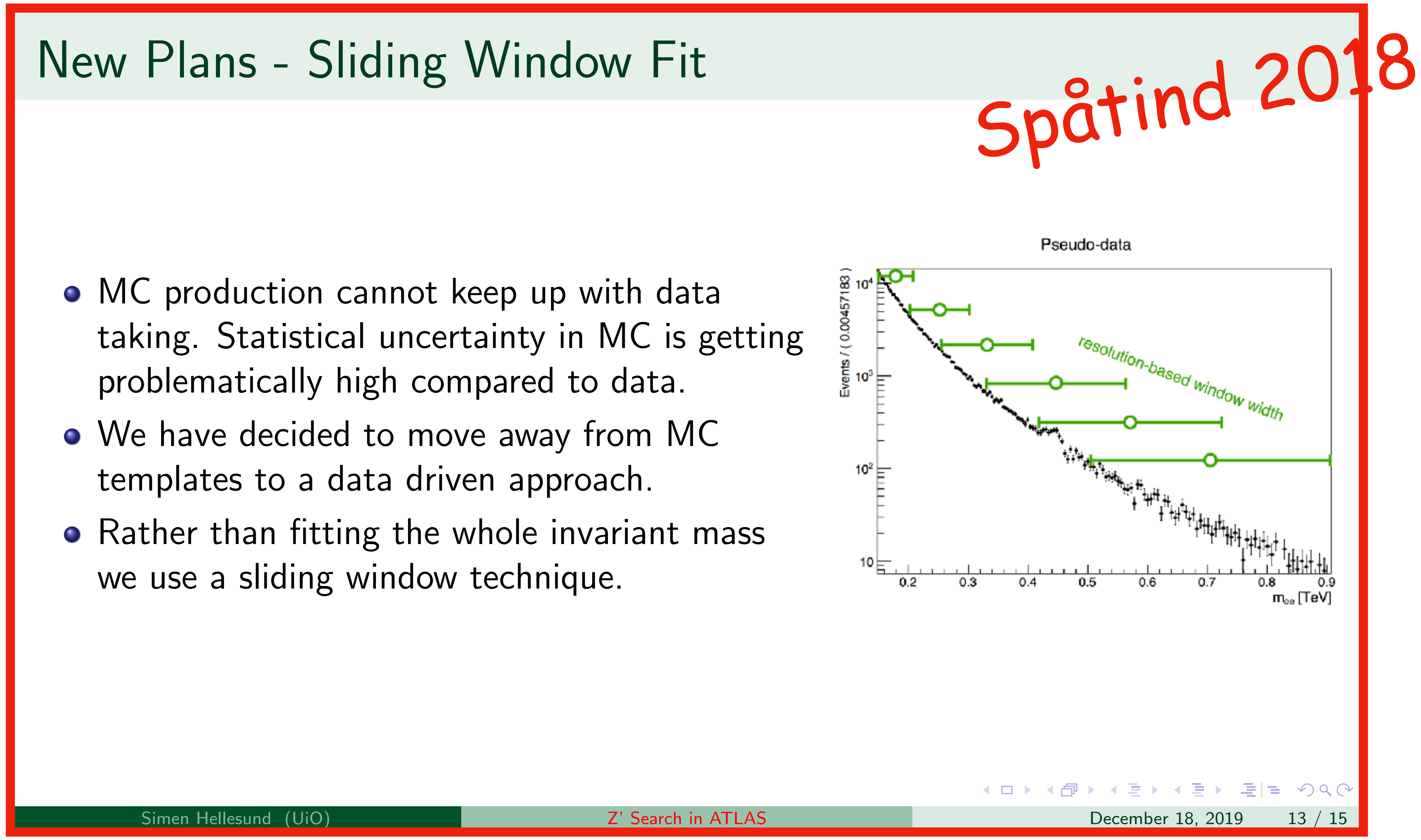
For Background Optimisation

- Selected background fit function must have "small enough" N_{sig}
  - Typically require N_{sig} / σ_{bgr} < 50% (smaller than statistical fluctuations)
- If more than one function satisfies above requirement, use the one with fewer free parameters

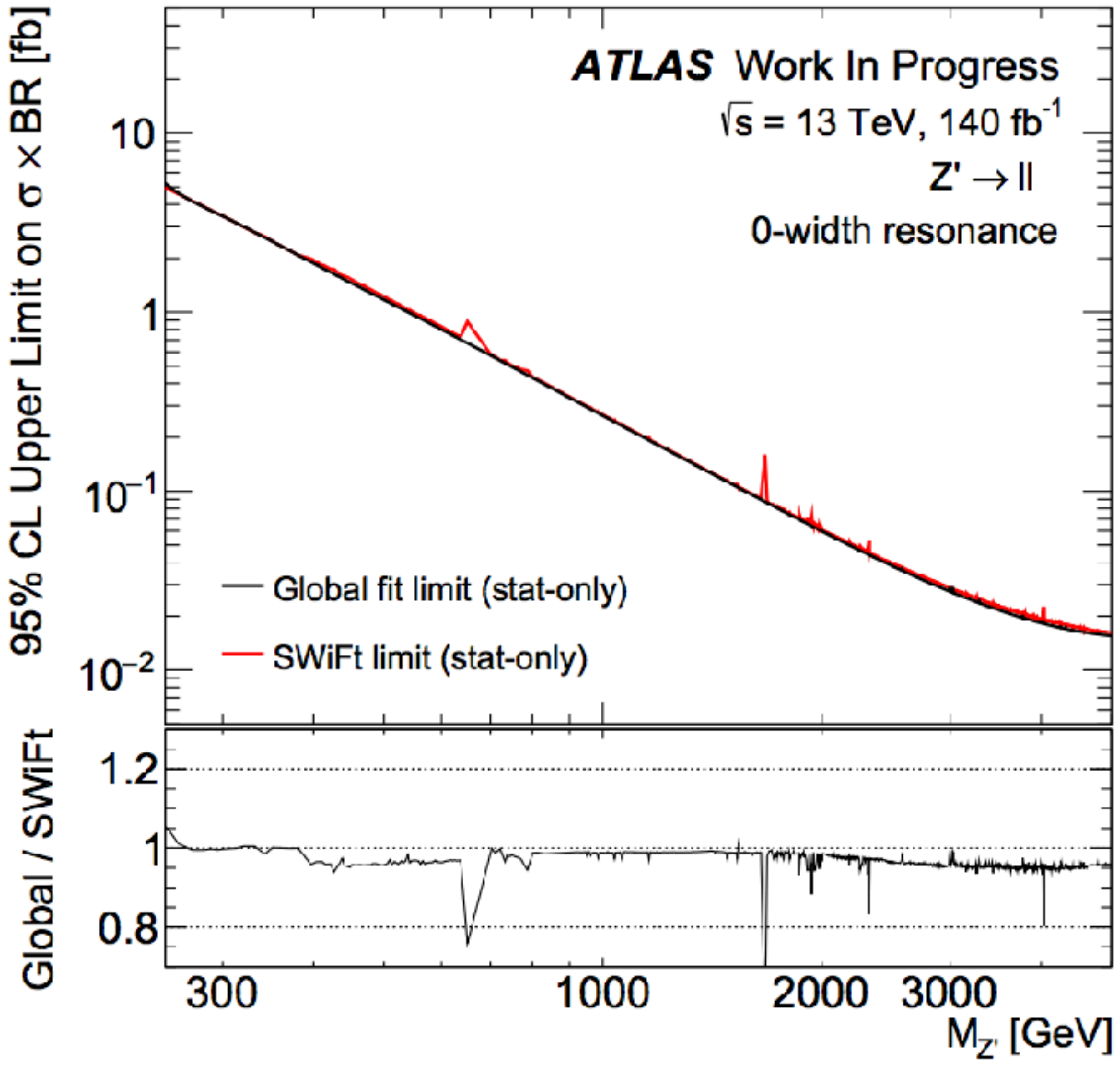
As systematic uncertainty

- Add spurious signal as a penalty in the signal shape normalisation
- Worst case scenario - background mismodelling same shape as signal hypothesis
- Other background uncertainties propagated into spurious signal systematic uncertainty

Background



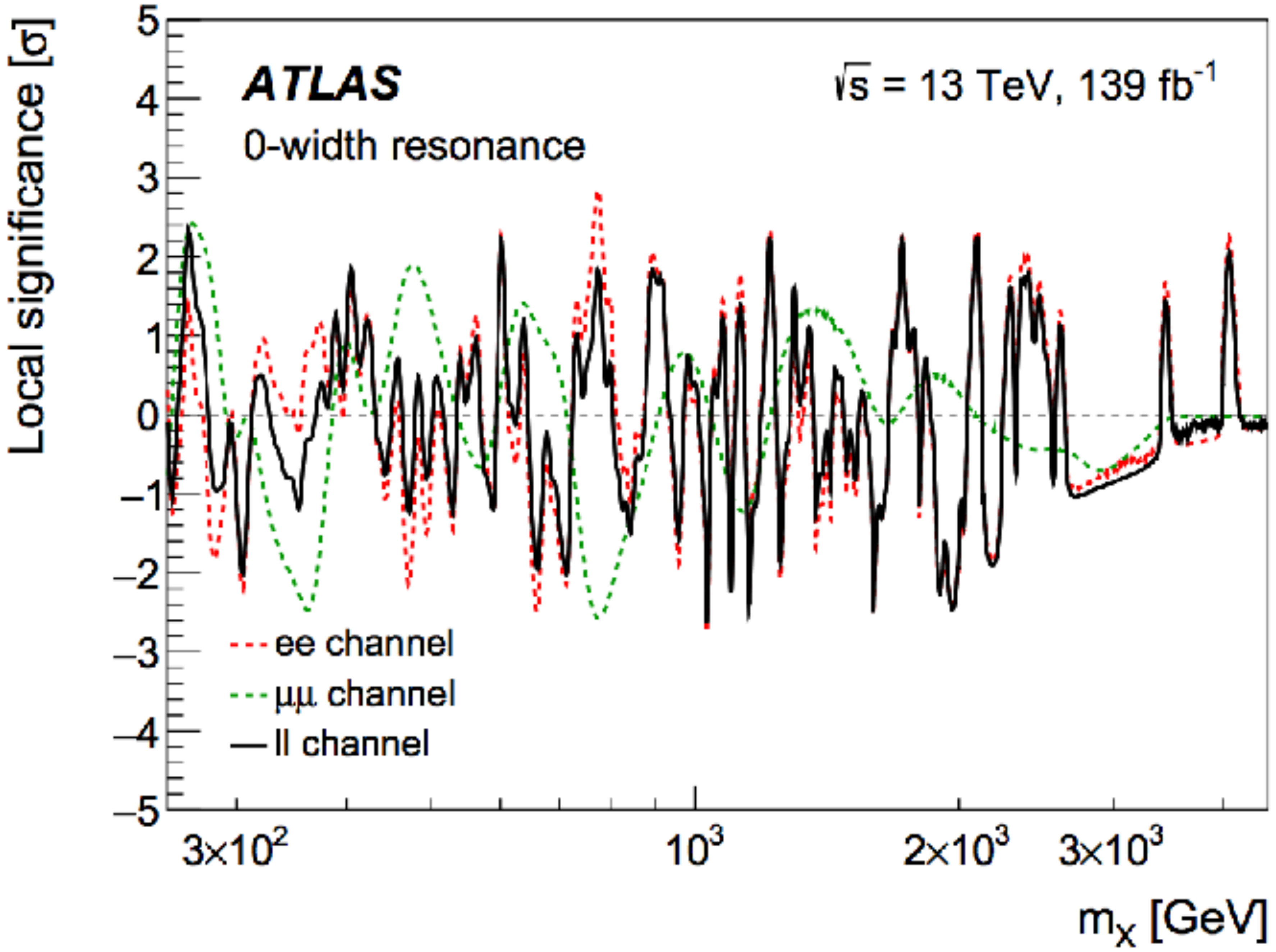
Global fit vs sliding window fit (SWiFt)



Conclusion: Very similar results, keep global fit approach

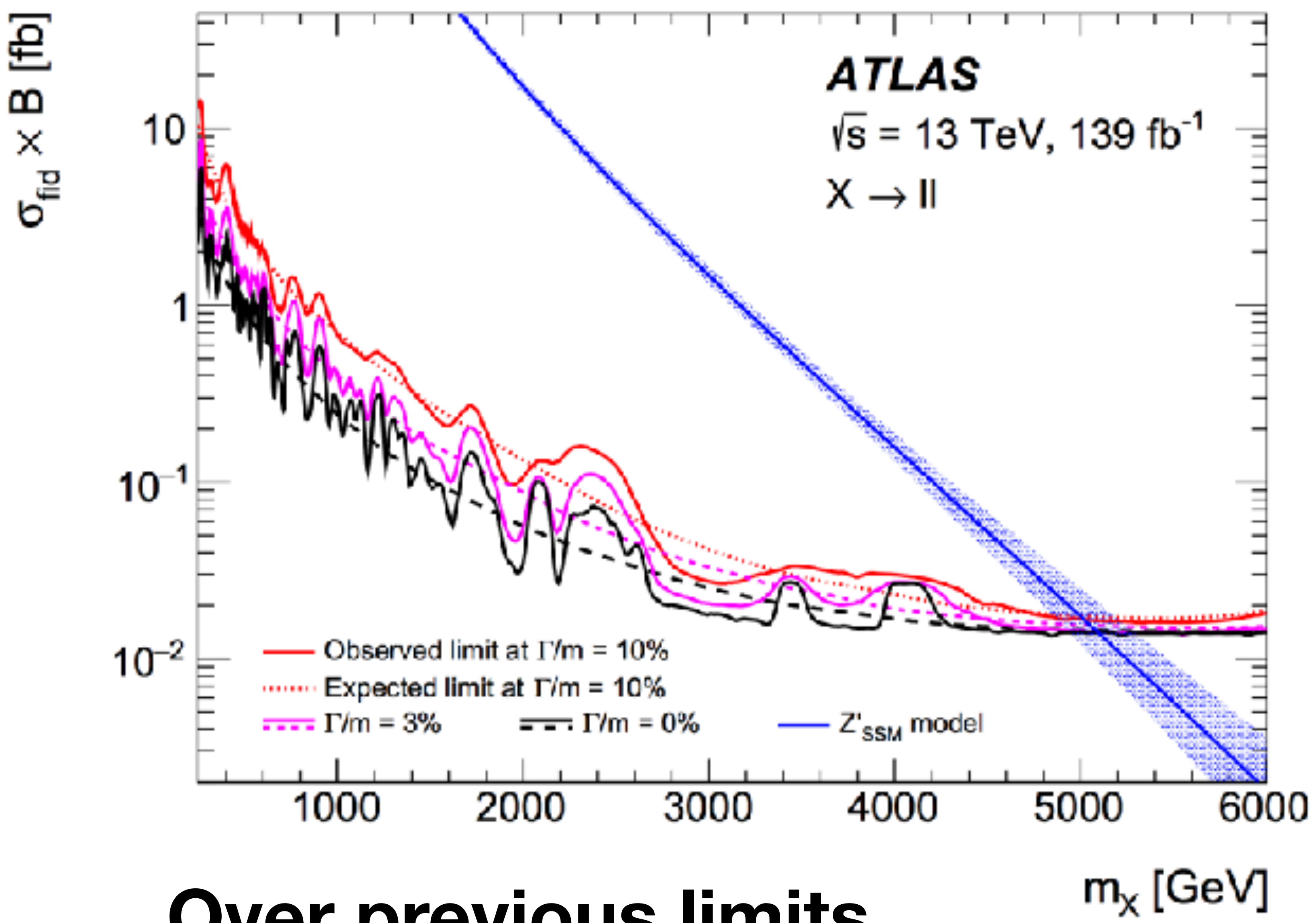
Results and Limits

Significances for a "zero width" (resolution only) signal

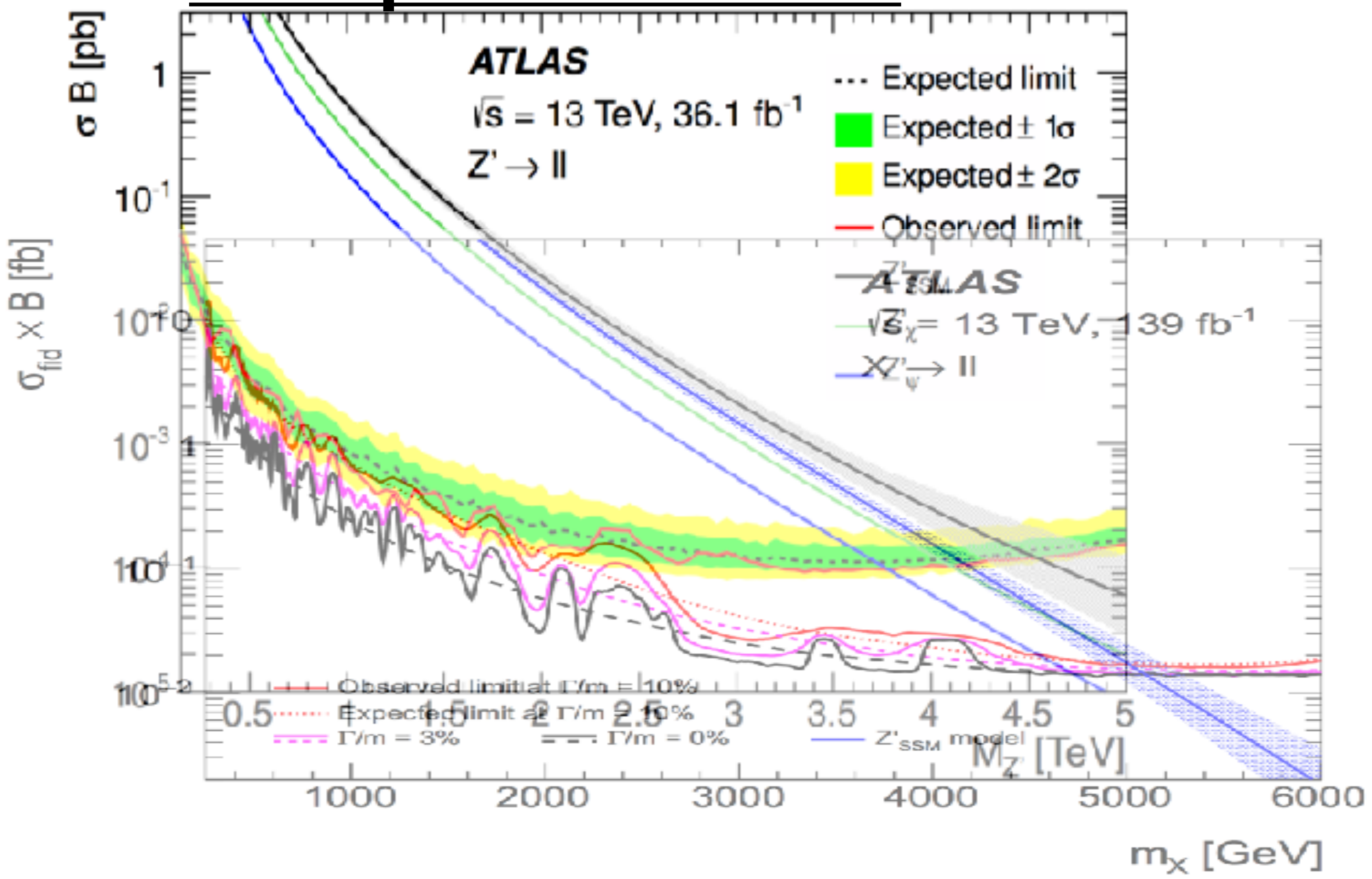


Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		$\ell\ell$	
	obs	exp	obs	exp	obs	exp
Z'_ψ	4.1	4.3	4.0	4.0	4.5	4.5
Z'_χ	4.6	4.6	4.2	4.2	4.8	4.8
Z'_{SSM}	4.9	4.9	4.5	4.5	5.1	5.1

Limit scan



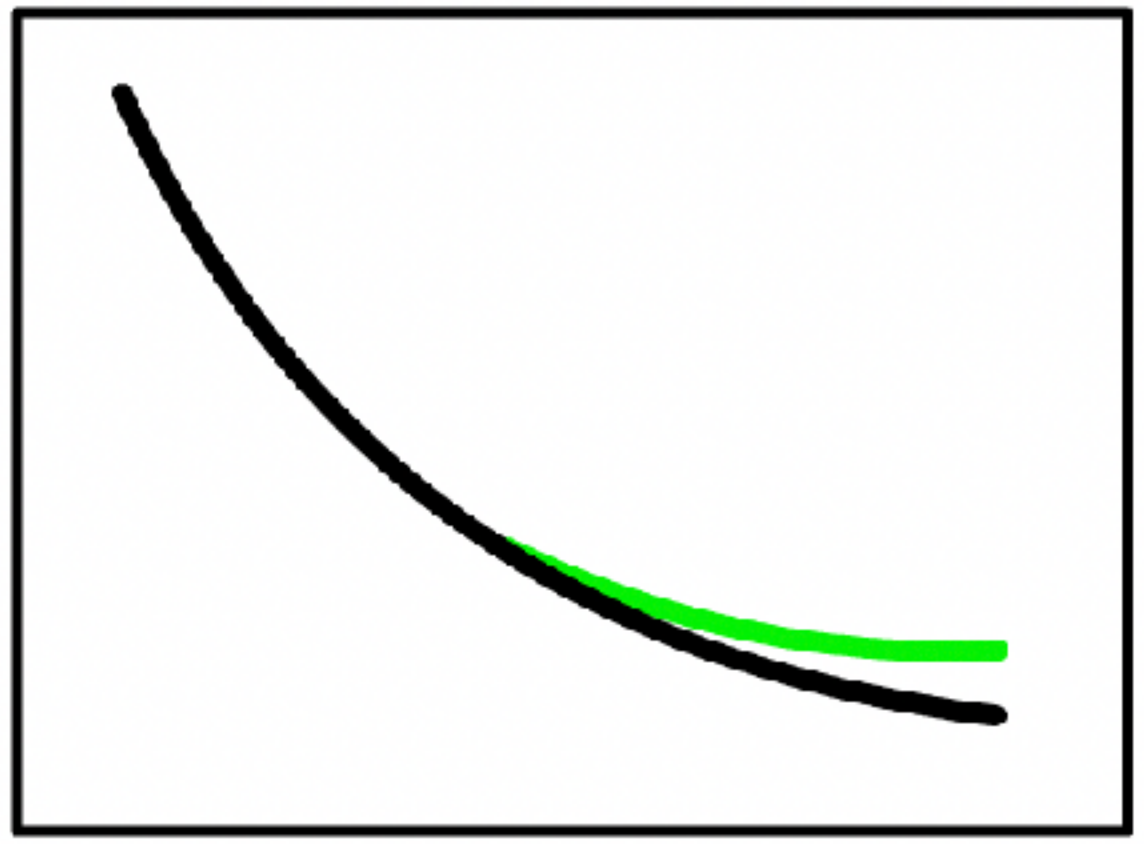
Over previous limits

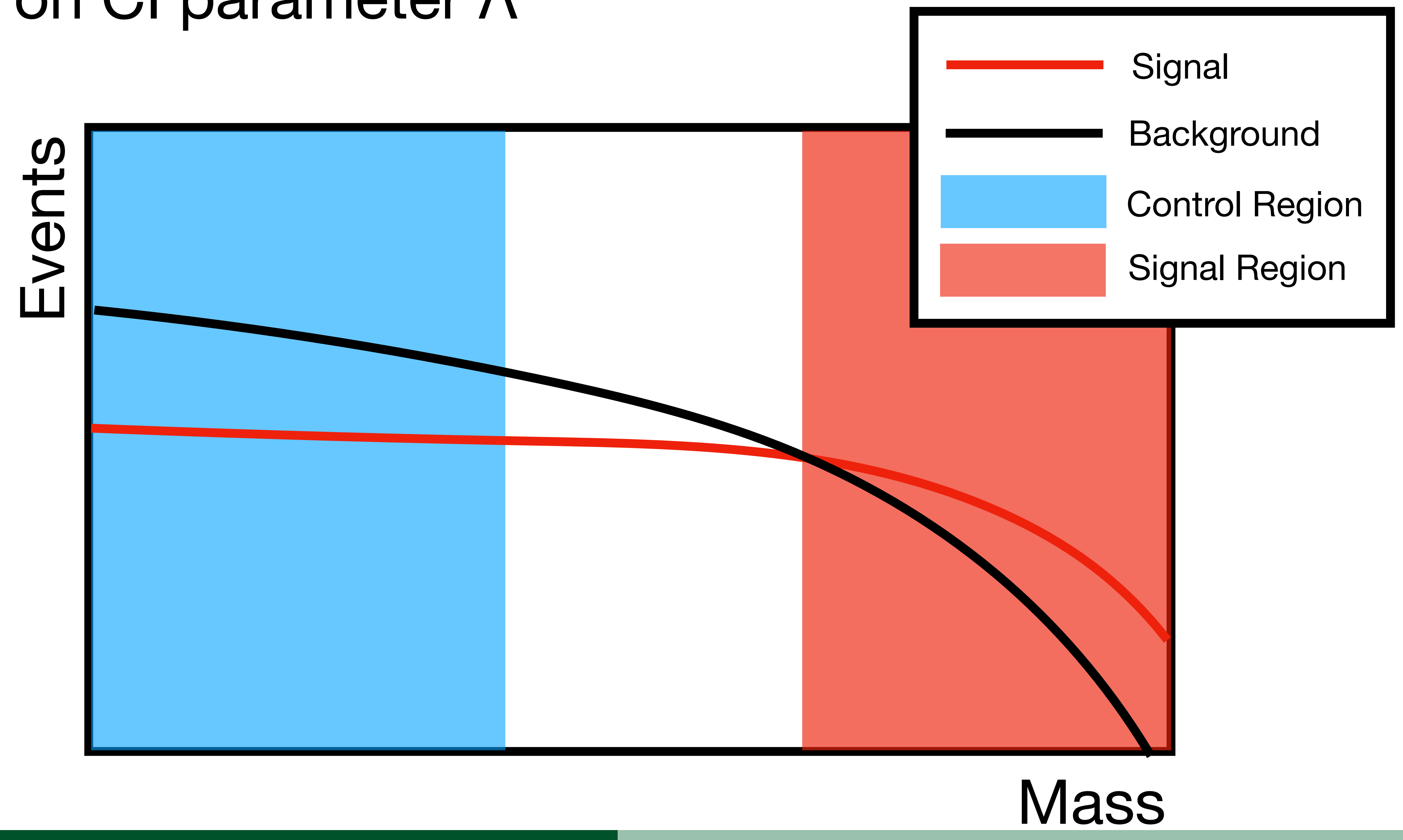


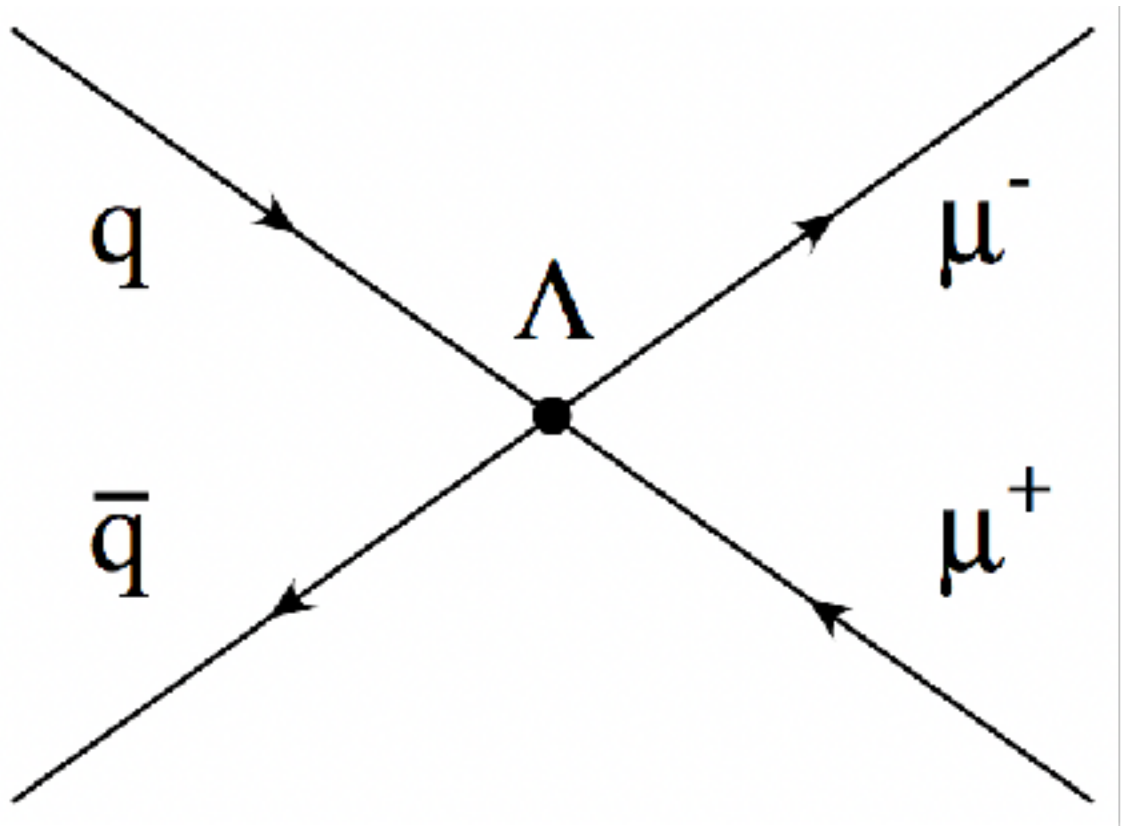
ADD Graviton Non-Resonant Analysis

Non-Resonant Dilepton Analysis

- Ongoing analysis, complementary to resonant search
- Same object and event selection
- Looking for broad excesses in high mass region. (resonant background strategy not suitable)
- Models such as contact interactions (CI)
- Data driven background extrapolation strategy
- Setting limit on CI parameter Λ







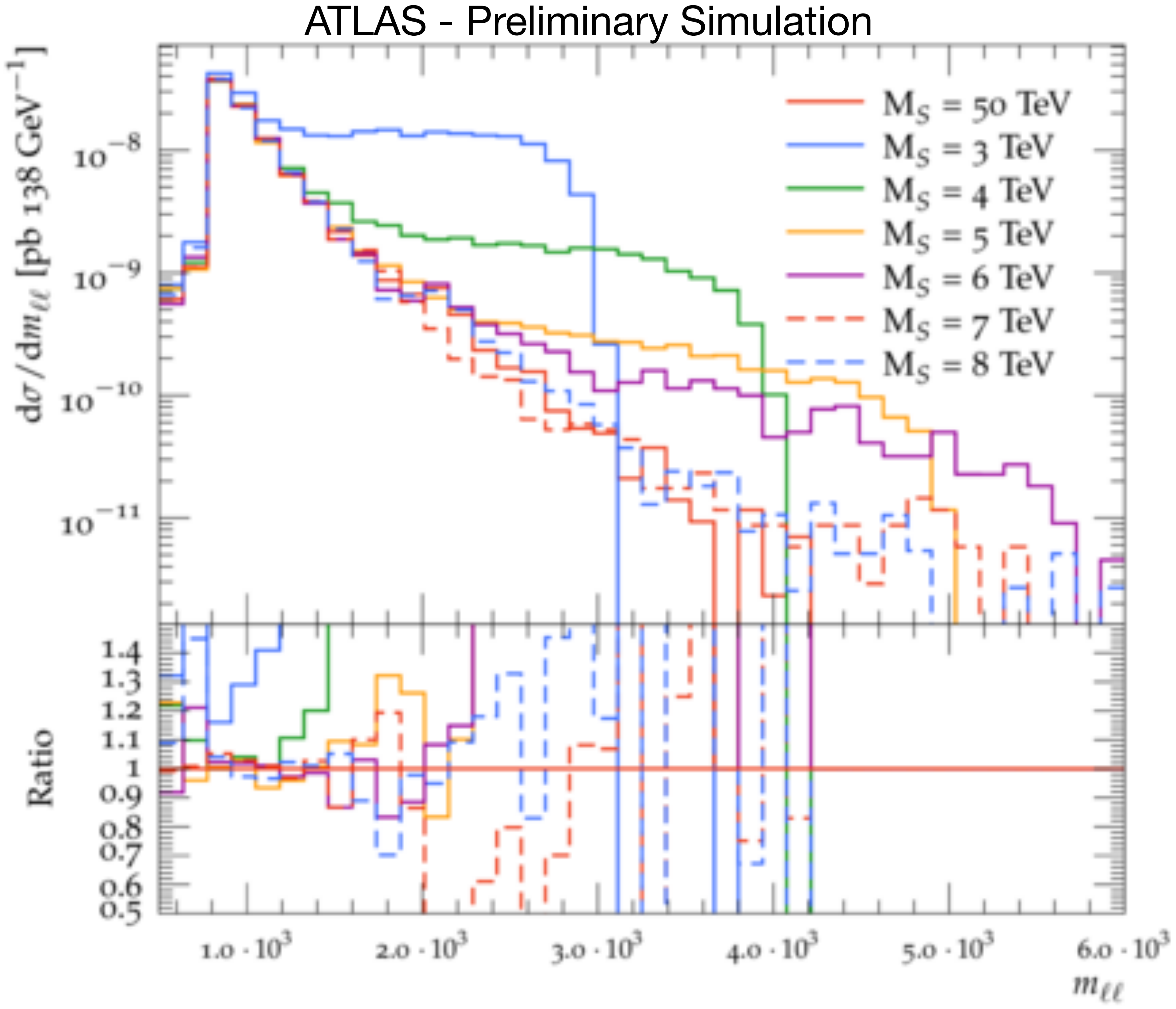
ADD Graviton Model - Motivation

- Problem: Why is gravity so weak?
- Possible solution: Gravitons propagate in higher dimensions
- Strength of gravity related to size of extra dimensions.
- Gives rise to so-called *Kaluza-Klein* (KK) graviton modes.
- KK spacing inversely proportional to size of extra dimensions
  - TeV scale means graviton spectrum essentially continuous - signature similar to CI

ADD Graviton Model - Plan

- Aim: set limit on string scale M_S (UV cutoff) for different number of extra dimensions (n=2,3,4,…) and conventions

- *ee* channel truth MC (Sherpa)
- Convoluted with a DY distribution
- Deviates from DY distribution at different points depending on M_S

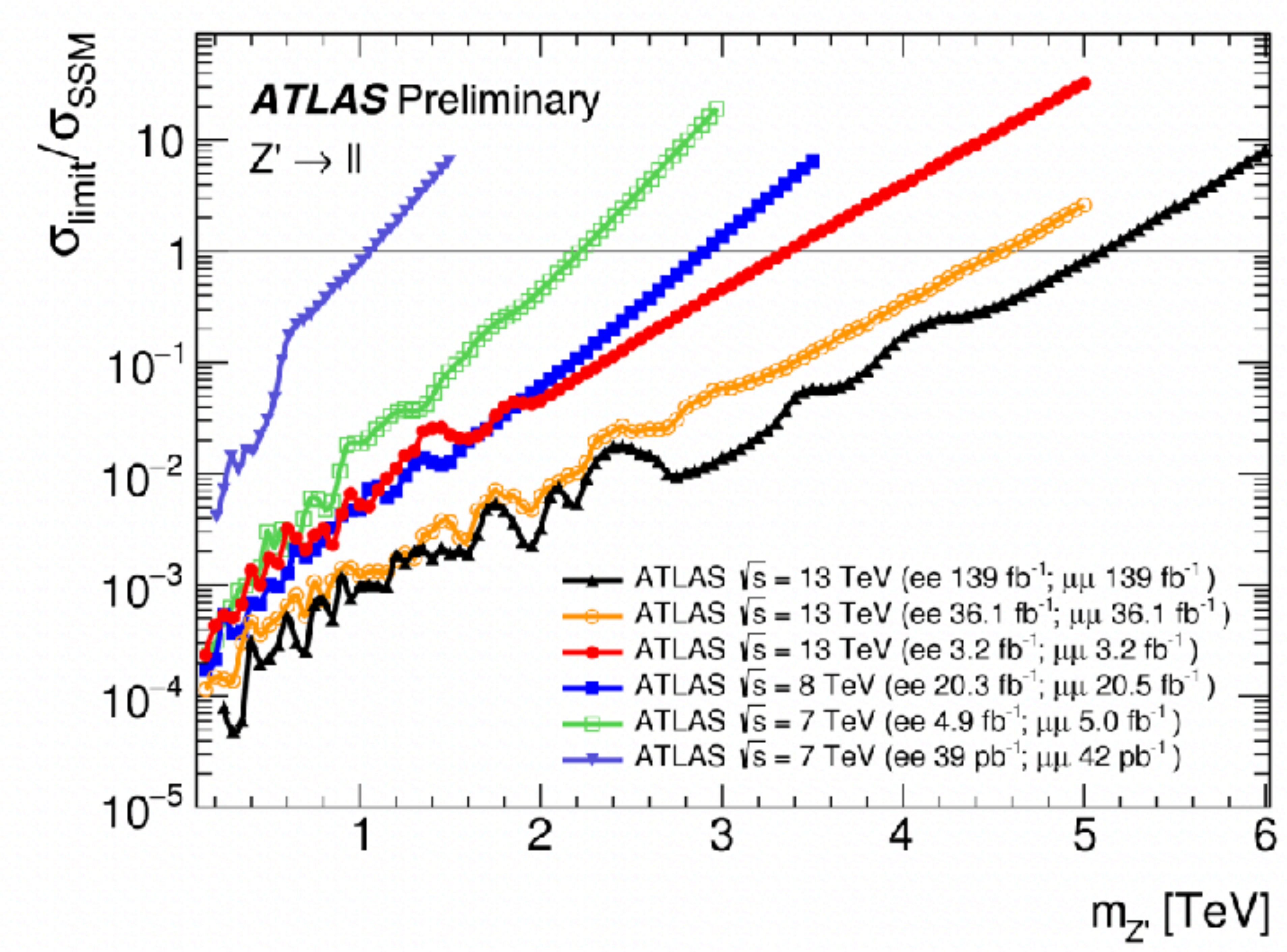


Summary and Conclusions

Summary and Conclusions

- Search conducted for new phenomena in dilepton final states using 139 fb^{-1} of data collected at the ATLAS detector
- No deviation from SM expectation observed
- Limits set on various BSM models
  - Limit improvement shown on the right.

	ll Invariant Mass Limit [TeV]	
	36 fb^-1	139 fb^-1
Z'_SSM	4.5	5.1
Z'_psi	3.8	4.5
Z'_chi	4.1	4.8



- Currently involved with non-resonant search
- Focussing on ADD graviton model

Backup

Object and Event Selection

Satisfy Good Run List, event cleaning and have a least two el

Electron selection	
Feature	*Criteria*
Pseudorapidity range	$(\lvert\eta\rvert < 1.37) \quad \lvert\rvert \quad (1.52 < \lvert\eta\rvert < 2.47)$
Energy calibration	es2017_R21_v1 (ESModel)
Transverse momentum	$p_T > 30$ GeV
Object quality	Not from a bad calorimeter cluster (BADCLUSELECTRON)
	Remove clusters from regions with EMEC bad HV (2016 data only)
Track to vertex association	$\lvert d_0^{BL}(\sigma)\rvert < 5$
	$\lvert\Delta z_0^{BL} \sin\theta\rvert < 0.5$ mm
Identification	LooseAndBLayerLLH (QCD fakes), MediumLLH (main selection)
Isolation	Gradient

Electron Triggers:

- 2015: 2e12_lhloose_L12EM10VH
- 2016: 2e17_lhvloose_nod0
- 2017 and 2018: 2e24_lhvloose_nod0

Muon Triggers:

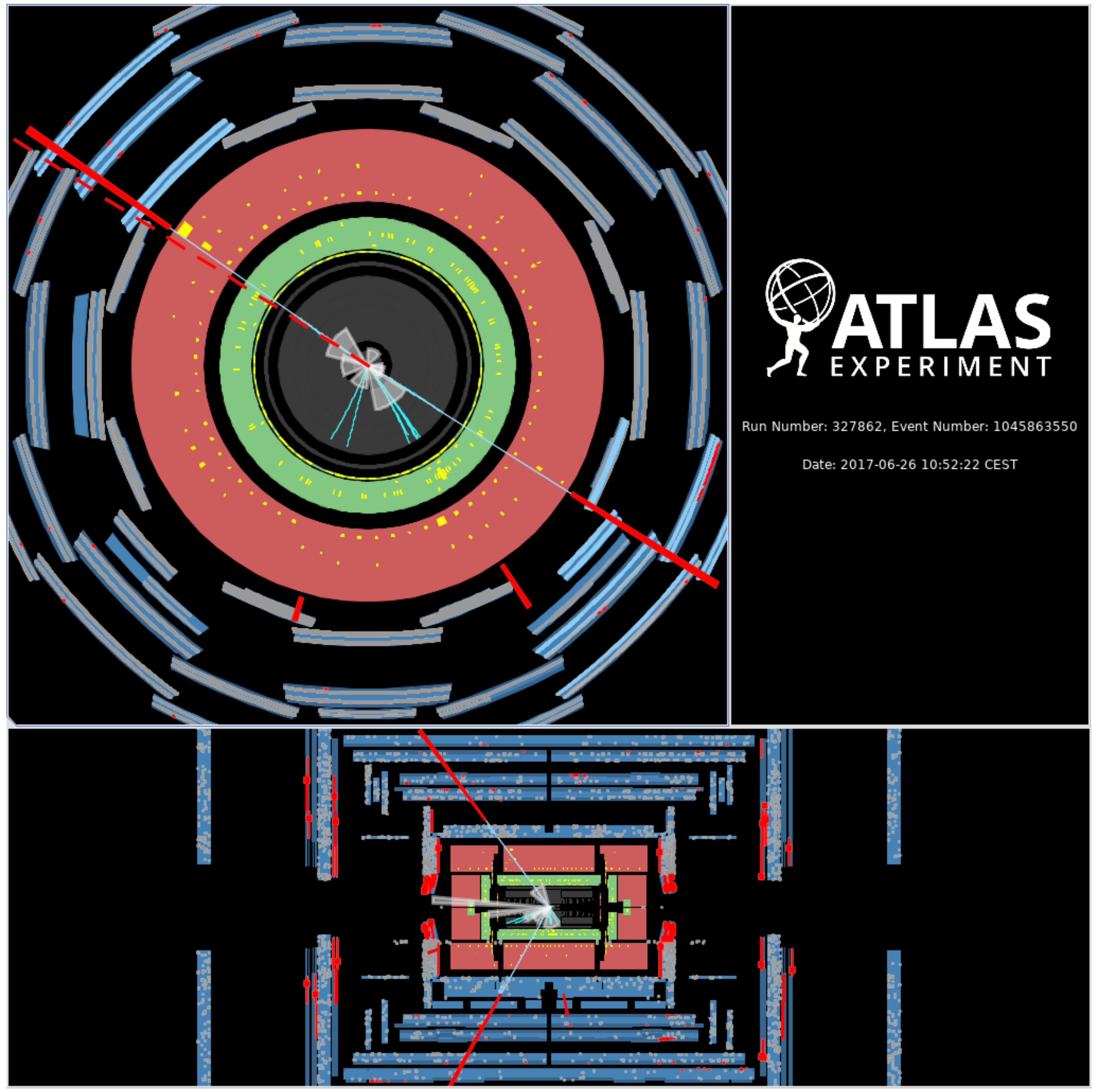
- 2015: mu26_imedium or mu50
- 2016, 2017 and 2018: mu26_ivarmedium or mu50

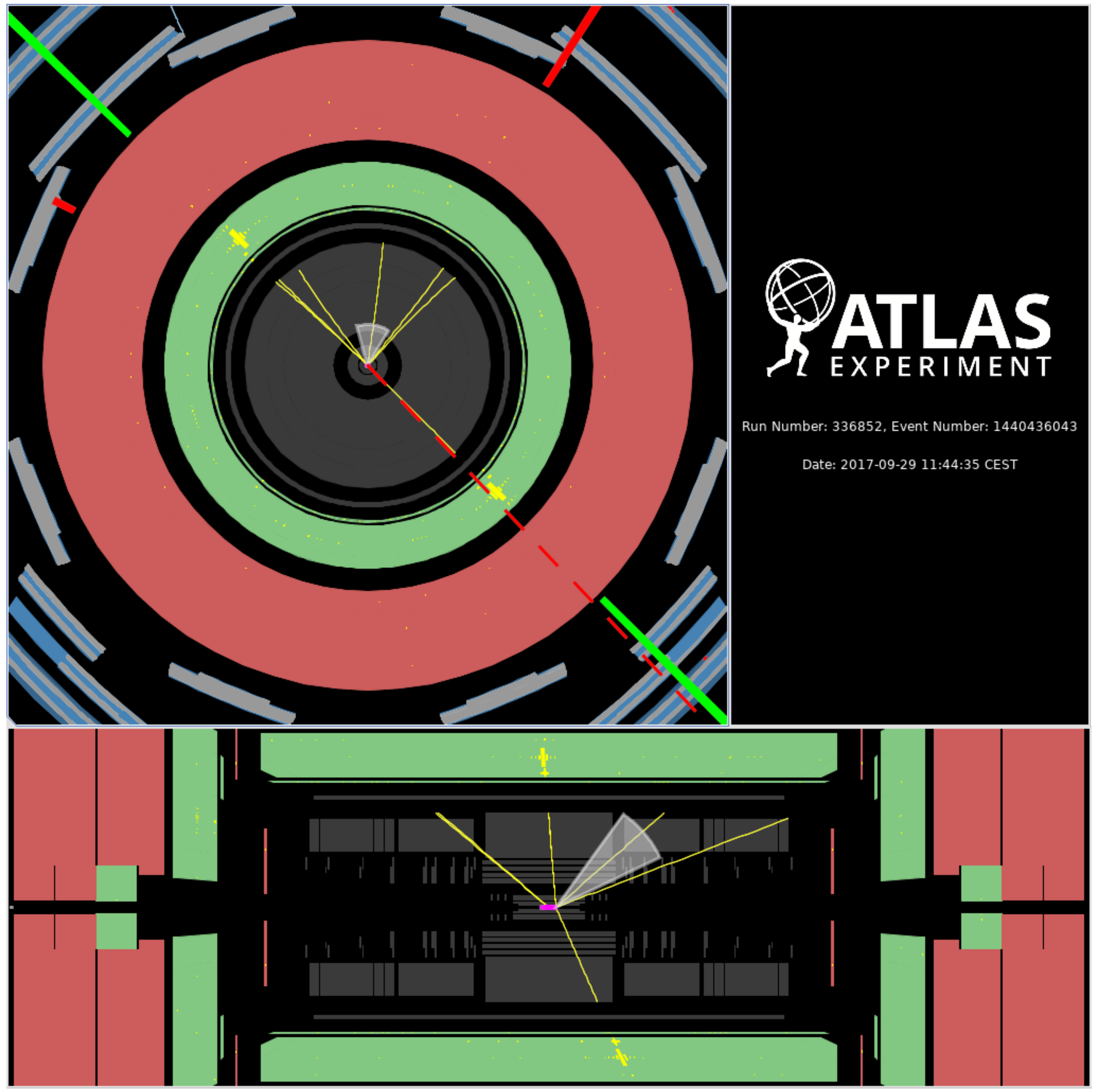
Muon selection	
Criteria	Value
Selection Working Point	High-pT
Isolation Working Point	FCTightTrackOnly
Momentum Calibration	Sagitta bias correction not applied to data
p_T Cut	$p_T > 30$ GeV
η Cut	$\lvert\eta\rvert < 2.5$
d0 Significance Cut	$3\,\sigma$
z0 Cut	0.5 mm

Systematics Table

Uncertainty source for m_X [GeV]	Dielectron 300	Dielectron 2000	Dielectron 5000	Dimuon 300	Dimuon 2000	Dimuon 5000
Spurious signal	± 12.5 (12.0)	± 4.6 (10.8)	± 0.1 (1.0)	± 11.7 (11.0)	± 3.8 (3.5)	± 2.1 (2.2)
Lepton identification	± 1.6 (1.6)	± 5.6 (5.6)	± 5.6 (5.6)	± 1.8 (1.8)	$^{+12}_{-10}\left(^{+12}_{-10}\right)$	$^{+25}_{-20}\left(^{+25}_{-20}\right)$
Isolation	± 0.3 (0.3)	± 1.1 (1.2)	± 1.1 (1.1)	± 0.4 (0.4)	± 0.4 (0.4)	± 0.4 (0.5)
Luminosity	± 1.7 (1.7)	± 1.7 (1.7)	± 1.7 (1.7)	± 1.7 (1.7)	± 1.7 (1.7)	± 1.7 (1.7)
Electron energy scale	$^{-1.7}_{-4.0}\left(^{+1.0}_{-1.8}\right)$	$^{-1.9}_{-6.0}\left(^{+1.7}_{-2.9}\right)$	$^{+0.1}_{-0.4}$ (± 0.8)	-	-	-
Electron energy resolution	$^{+7.9}_{-8.3}\left(^{+1.1}_{-0.9}\right)$	$^{+9.0}_{-11.8}\left(^{+0.7}_{-0.5}\right)$	$^{+0.4}_{-0.9}$ (± 0.1)	-	-	-
Muon ID resolution	-	-	-	$^{+0.8}_{-2.3}\left(^{+0.3}_{-0.8}\right)$	$^{+0.9}_{-1.3}\left(^{+0.7}_{-1.1}\right)$	$^{+0.6}_{-0.4}\left(^{+0.5}_{-0.3}\right)$
Muon MS resolution	-	-	-	$^{+2.8}_{-3.8}\left(^{+1.0}_{-1.3}\right)$	$^{+3.2}_{-3.0}\left(^{+2.6}_{-2.4}\right)$	± 2.4 (2.1)
‘Good muon’ requirement	-	-	-	± 0.6 (0.6)	$^{+9.0}_{-8.2}\left(^{+9.0}_{-8.2}\right)$	$^{+55}_{-35}\left(^{+55}_{-35}\right)$

Highest Mass Event Displays

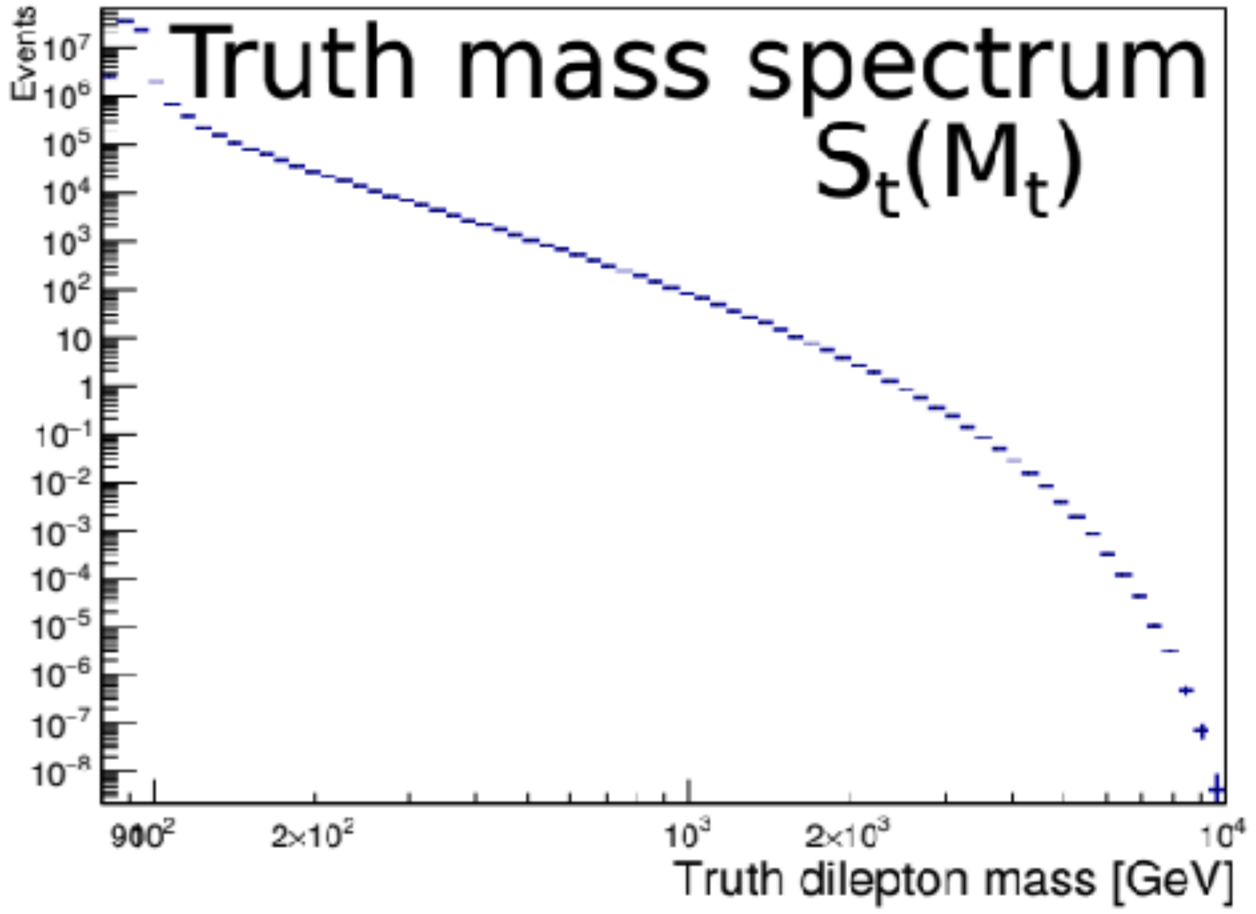




$m_{\mu\mu}$ =2.75 TeV

m_{ee} =4.06 TeV

Transfer Functions



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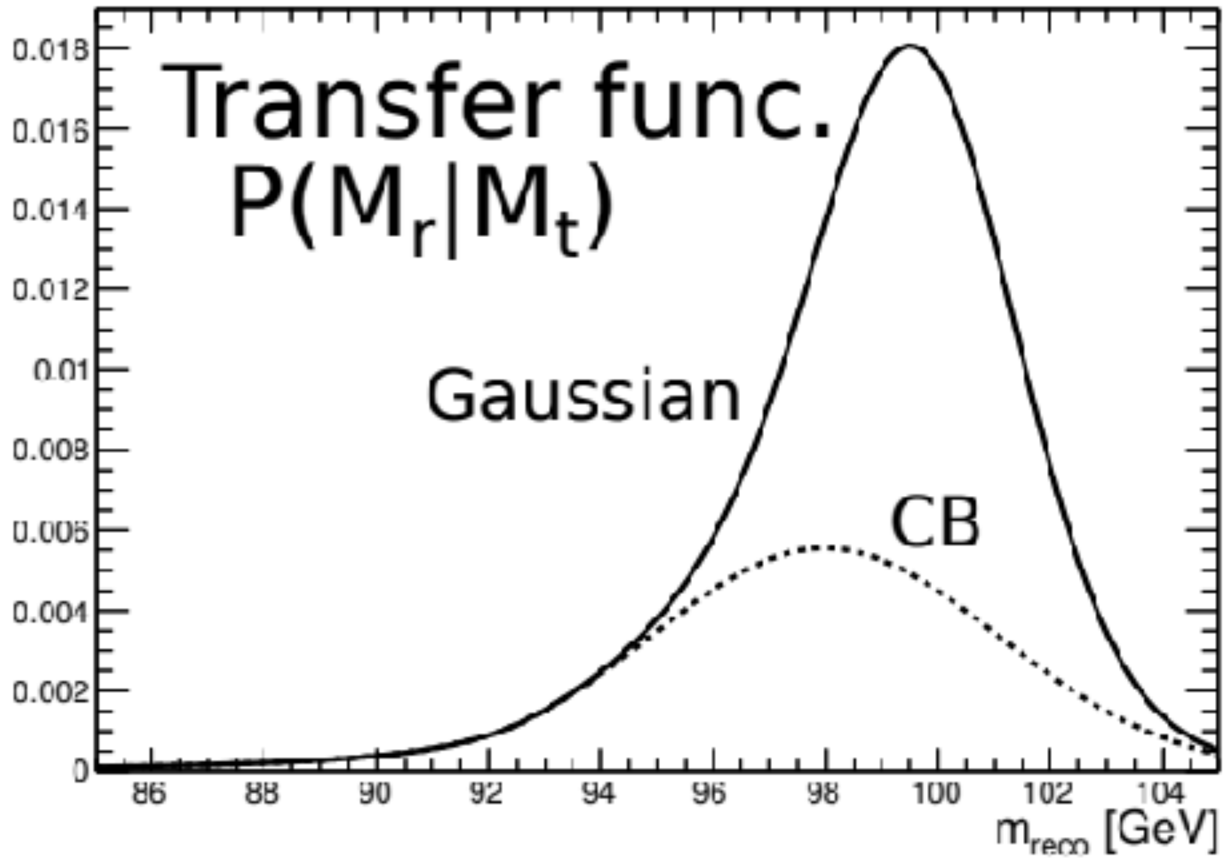

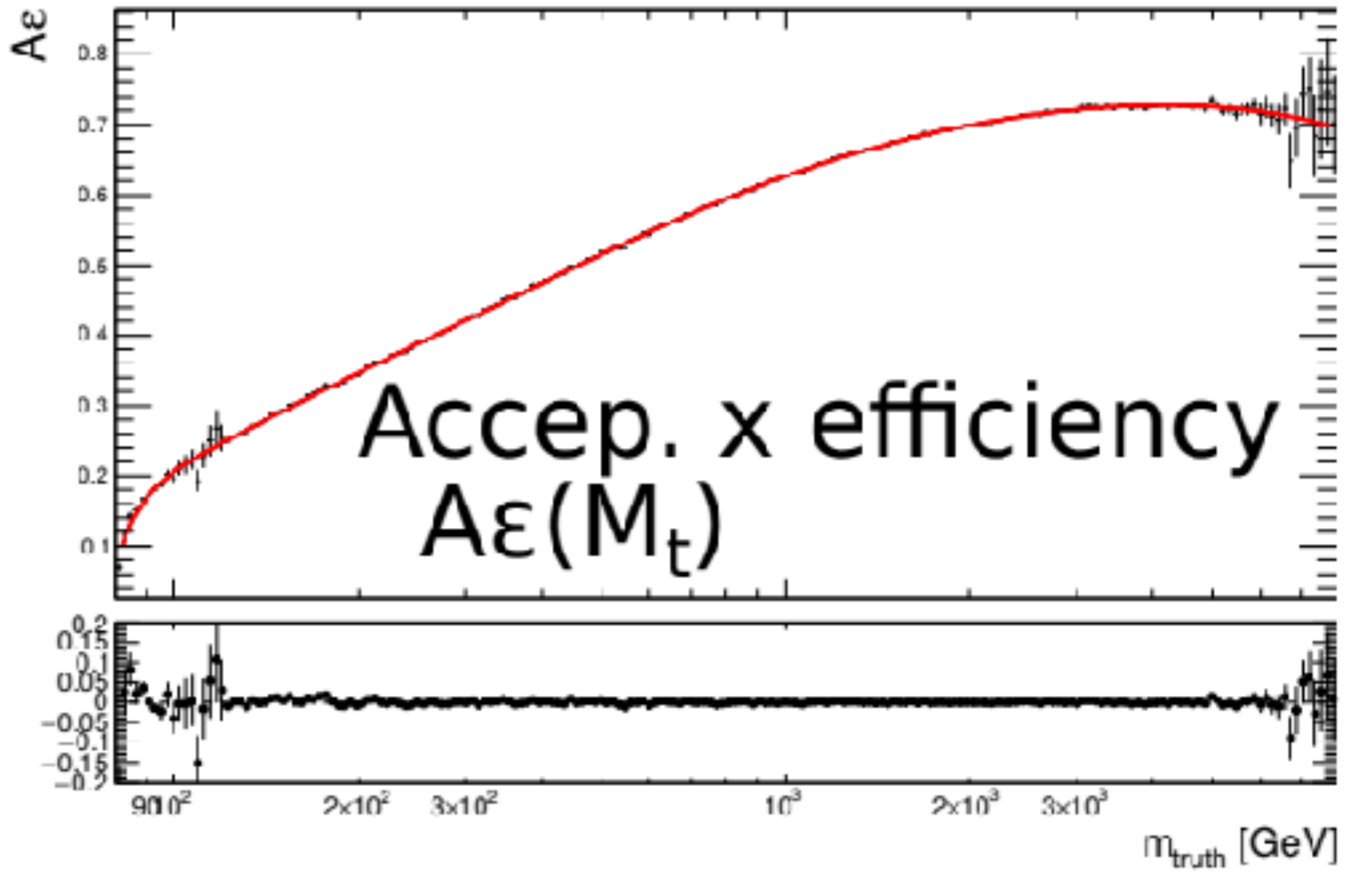

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