QUANTUM BLACK HOLE PRODUCTION AND DECAY TO THE DI-TOP FINAL STATE AT THE LHC WITH THE ATLAS DETECTOR

Sina Safarabadi Farahani

Supervisor: Douglas M. Gingrich*

Department of Physics
University of Alberta

Also at TRIUMF, Vancouver, British Columbia

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UNIVERSITY OF ALBERTA

INTRODUCTION

- ✓ Quantum Black Holes (QBH) are interesting possibilities at the LHC under low-scale gravity models, such as the ADD model (also known as large extra dimensions).
- ✓ They could decay to the signature of ditop (any combination of top and anti-top) final states. We will present the discovery potential for this production and decay.
- ✓ We will use Monte Carlo (MC) simulations of signal and background.
  - ✓ The data from the dijet analysis is also used for normalizing MC background to data.

QUANTUM BLACK HOLE

- QBHs are assumed to be produced from particle collisions at energies close to the Planck Scale (10^{19} GeV)
- Models with Large Extra Dimensions (ADD or LED model), proposed to solve the hierarchy problem, can reduce the Planck scale (M_D) to order of few TeV
- Production of QBH at energies accessible on Earth becomes a possibility (like the LHC)
- The "QBH" generator simulates black hole production and decay

ASSUMPTIONS AND NOTES

i. Validity of QBH (mass range):
   - $M_{min} = M_D$: 4-9 TeV in 1 TeV steps, 9.5 and 10 TeV → Threshold mass (M_{th})
   - M_{max} = min (center-of-mass energy, $3 \times M_{min}$) → Maximum allowed mass

ii. $M_{min} = M_D$ and M_{max} are our choice

iii. Number of extra dimensions: $n = 6$

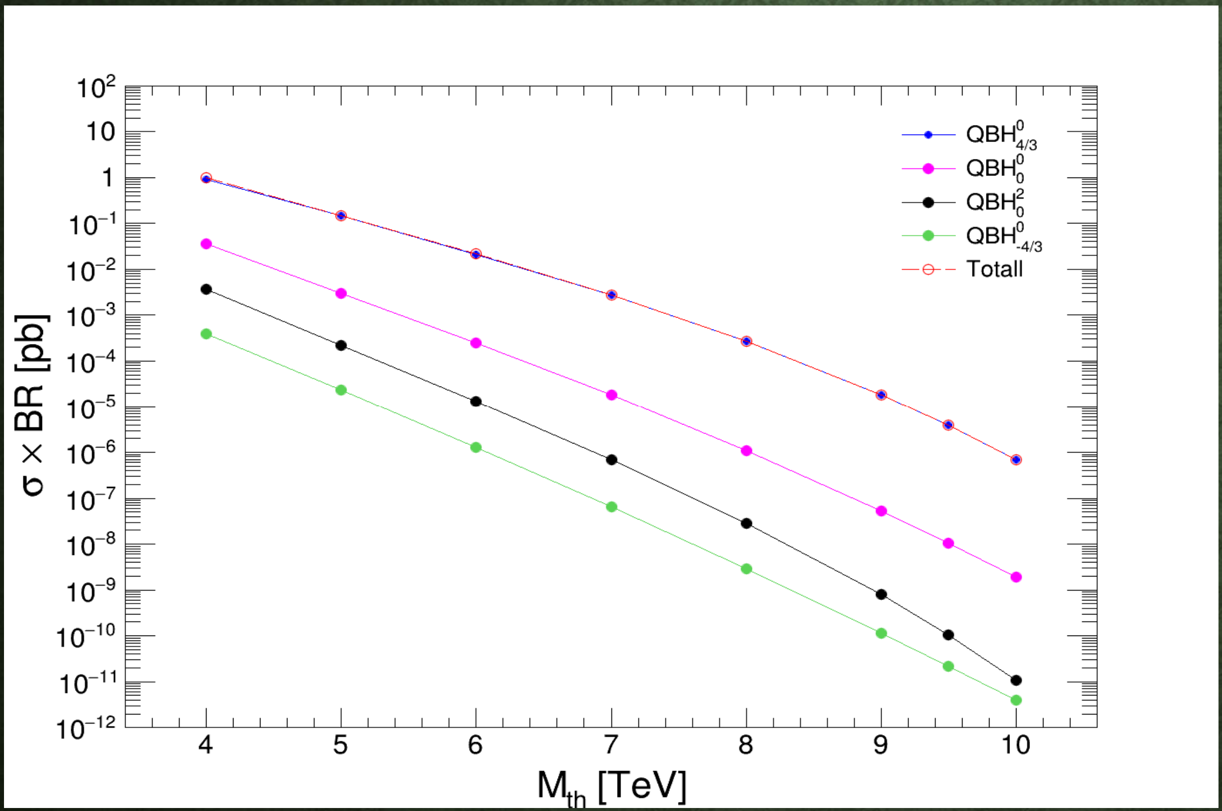
iv. Only QBH decays to two-body particle final states are considered which is the most dominant state over all n (The QBH can decay to as many as 6 particles)

v. The effects of a detector are not simulated, but their effects are included

vi. An Integrated luminosity of $L = 150\ \text{fb}^{-1}$ is used

vii. The anti-k_t jet algorithm with the R parameter of $R = 0.4$ is used

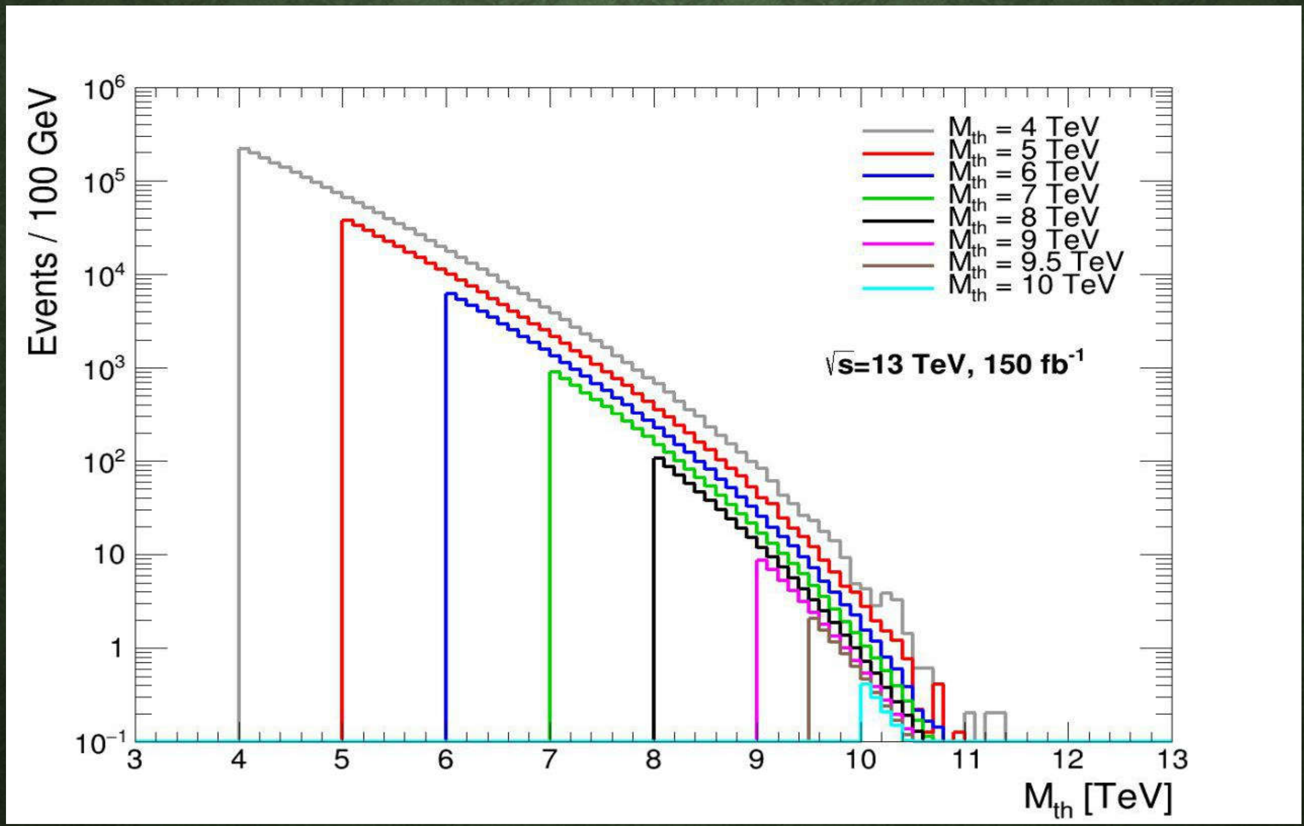
CROSS-SECTION × BRANCHING RATIO (QBH generator level)



QBH State
$uu \to QBH^0_{4/3} \to tt$
$\bar{u}\bar{u} \to QBH^0{}_{-4/3} \to \overline{tt}$
$q\bar{q} \to QBH^0_0 \to t\bar{t}$
$gg \to QBH^2_0 \to t\bar{t}$

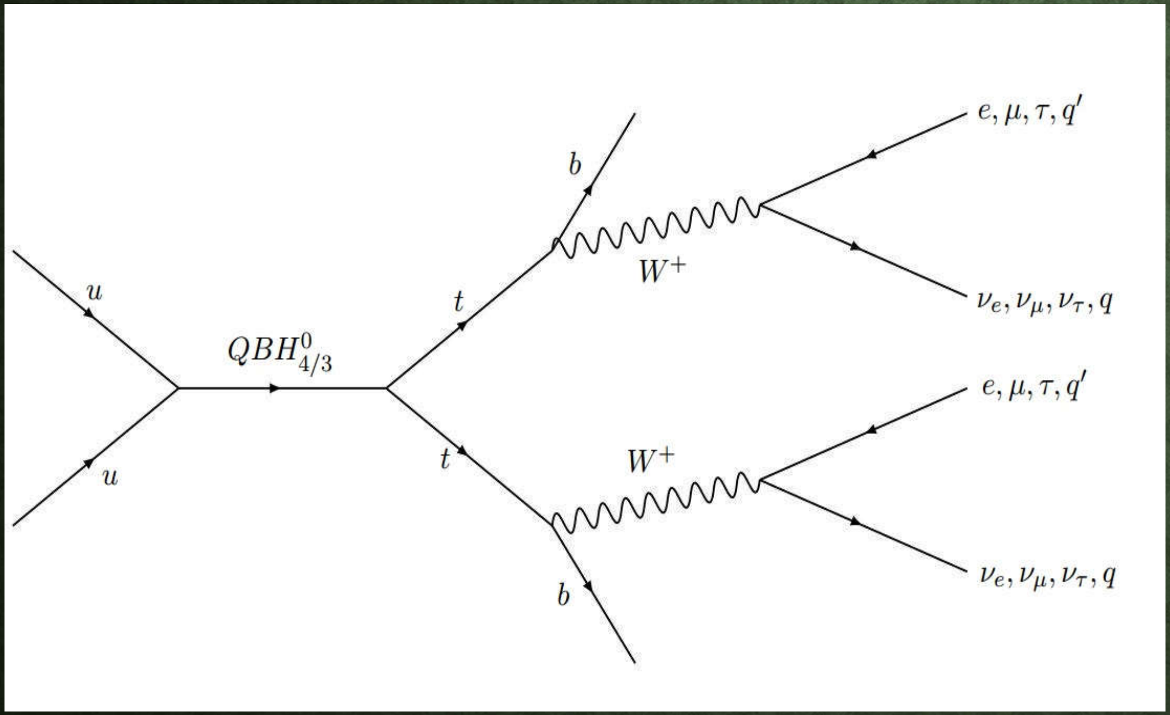
Since the total cross-section almost overlaps with the $QBH_{4/3} \to t\,t$ state, this is the only state we will consider.

MASS DISTRIBUTION (QBH generator level)



Normalized to cross-section × Luminosity

QBH DECAY



W-boson Decay modes:
Hadronic: 68.3%
Leptonic: 31.7%

~1/3 of leptonic decays are tau leptons which are not directly detected by a detector.

Tau lepton decays:
Hadronic: 64.8% (τ_q)
Leptonic: 35.2% (τ_l)

QBH DECAY MODES

- Fully-hadronic: 56.4% → Both W-bosons decay hadronically.
- Semi-hadronic: 37.2% → One of the W-bosons decay hadronically and the other one leptonically.
- Leptonic: 6.4% → Both W-bosons decay leptonically.

✓ We will be reconstructing the QBH state in the fully- and semi-hadronic topologies

✓ leptonic decays are ignored for three main reasons:

1. Small fraction of the sample (less signal events)
2. Hard separation of leptonic decays from the other two
3. Not a well reconstructed mass (specially for having two high energy neutrinos produced)

DETECTOR EFFECTS

Although no detector simulation was performed, ATLAS detector effects are included (ATLAS results):

- ❖Detector acceptance for different objects (e, μ, jets)
- ❖Lepton (e, μ) efficiency (detection probability)
- ❖p_T resolution of leptons and jets
- ❖p_T scale of jets
- ❖p_T resolution of Missing Transverse Energy (MET)
  - ➢ p_T resolution of MET is calculated from the p_T resolution of other objects (calculated by ourselves)

EVENT SELECTION

The cuts are applied in the order appeared in the table

Event type	Selection criteria
Leptonic	well separated leptons, $p_{T_{lepton_{1,2}}} > 350$ GeV
Fully-hadronic	well separated jets, $p_{T_{\text{jet}1,2}} > 1$ TeV, $M_{jet_{1,2}} > 100$ GeV, $\frac{p_{T_{\text{jet}1}}}{p_{T_{\text{jet}2}}} < 1.25$
Semi-hadronic	well separated jets, $\frac{p_{T_{\text{jet}1}}}{p_{T_{\text{jet}2}}} > 1.25$, $p_{T_{\text{jet}1}} > 1.2$ TeV, $M_{jet1} > 120$ GeV, MET > 150 GeV, $p_{T_{\text{lepton}}} > 75$ GeV

For the 9 TeV sample:
77% of Hadronic events &
63% of Mixed events are reconstructed

71% of the whole sample with less than 5.0% fake events

Fake events ≡ misidentification of the decay modes

SELECTION ALGORITHM

- Hadronic: Each of the two highest p_T jets are considered the top quark candidates

- Mixed:
  - The highest p_T jet is considered as one of the top quark candidates
  - The other top quark is "reconstructed" from the W-boson ($W \rightarrow l\ \nu$) and the second highest p_T jet which is the b-quark candidate

BACKGROUND

- QCD dijet (PYTHIA8, HERWIG++)
- ttbar production (Powheg) (expected number of events $\sim$10 events in the mass range 4-4.5 TeV with $L = 150\ \mathrm{fb}^{-1}$)
- W/Z + jets (Powheg) (expected number of events $\sim$0 events in the mass range above 3 TeV with $L = 150\ \mathrm{fb}^{-1}$)

✓ QCD dijet is the dominant background and will neglect the other two

Background Uncertainties

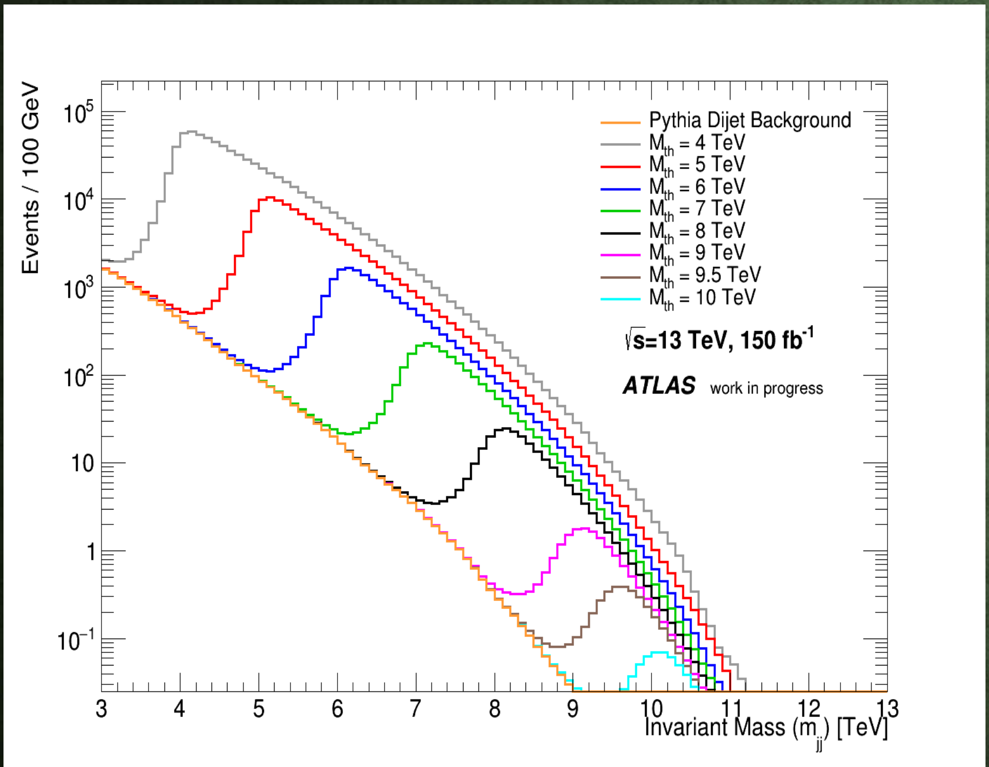
i. Statistical

ii. Theory modeling (generator difference)

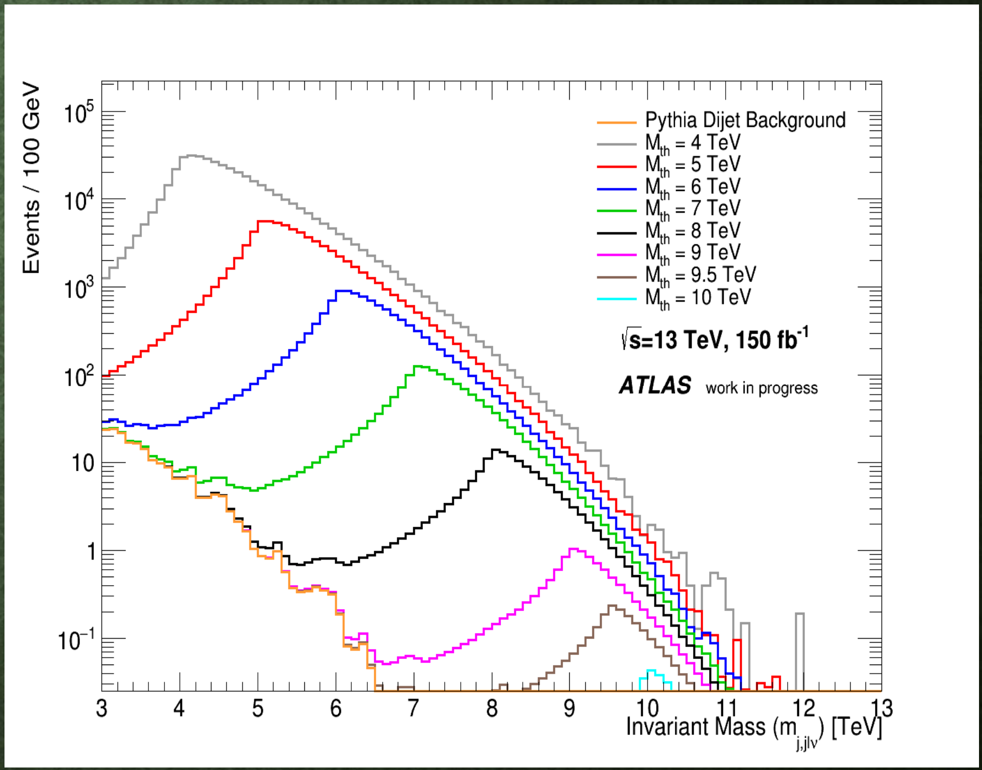
iii. Detector effects

MASS DISTRIBUTION

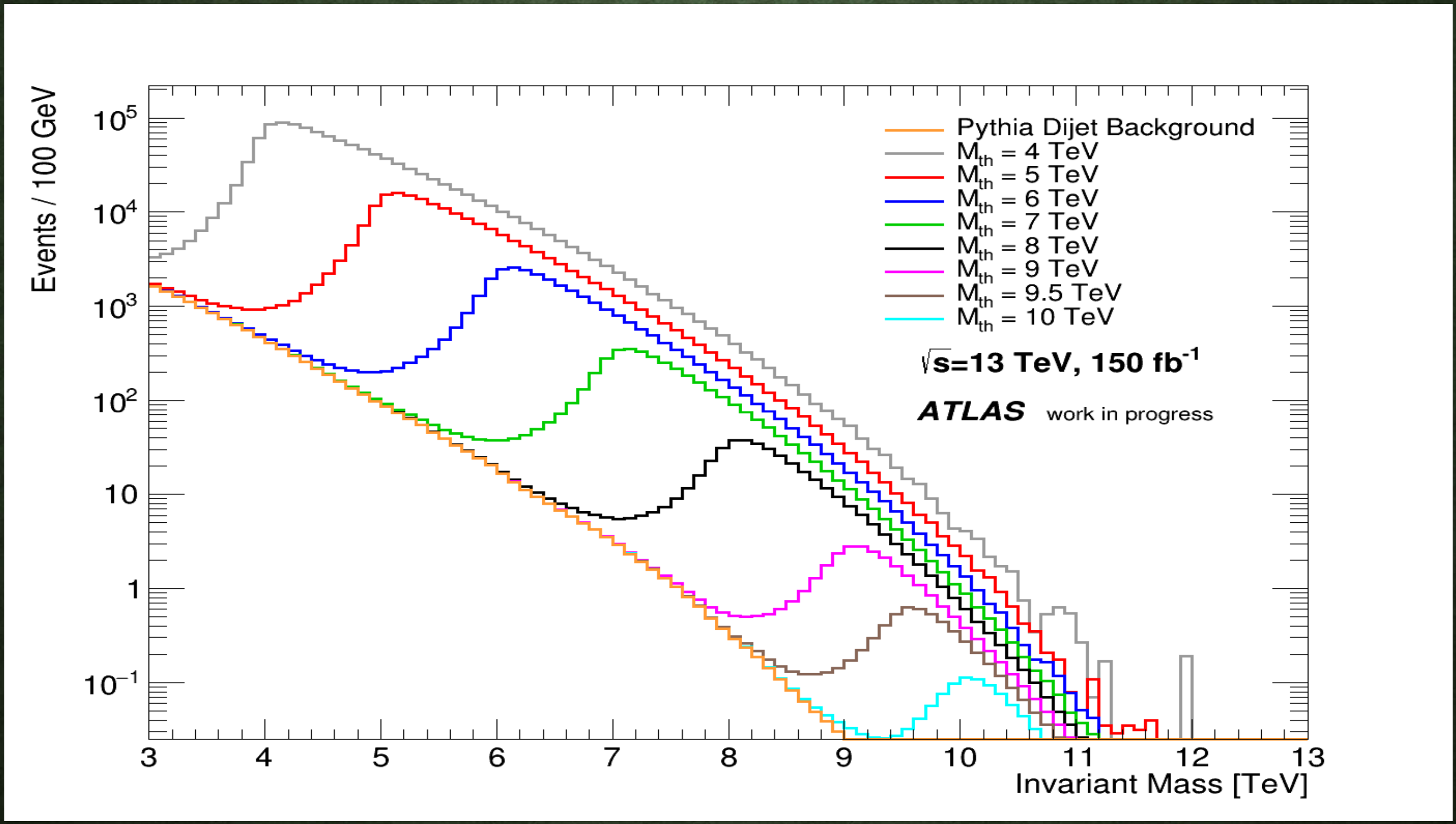
Fully-hadronic



Semi-hadronic



MASS DISTRIBUTION

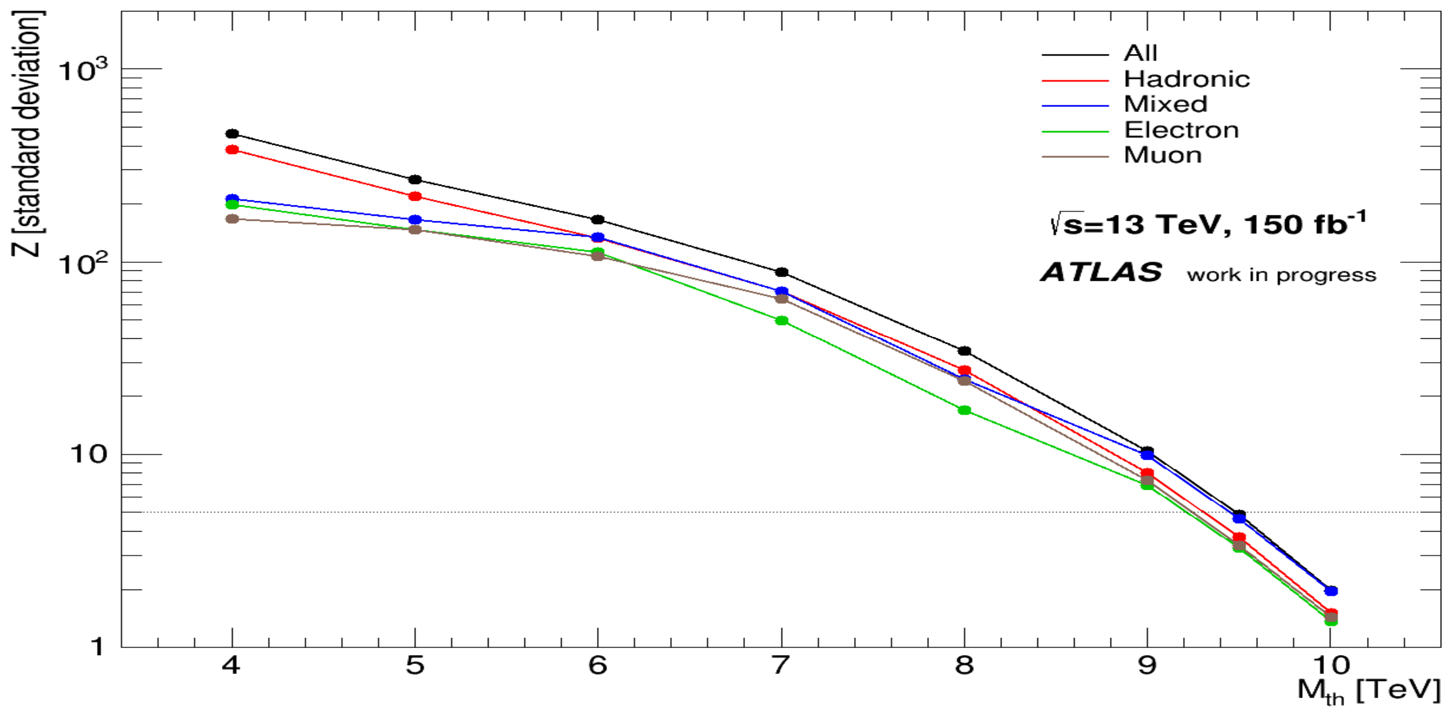


Fully- and semi-hadronic combined

DISCOVERY POTENTIAL

$$Z = \sqrt{2\left((s+b)\ln\left[\frac{(s+b)\,(b+\sigma_b^2)}{b^2+(s+b)\,\sigma_b^2}\right] - \frac{b^2}{\sigma_b^2}\ln\left[1+\frac{\sigma_b^2 s}{b\,(b+\sigma_b^2)}\right]\right)}$$

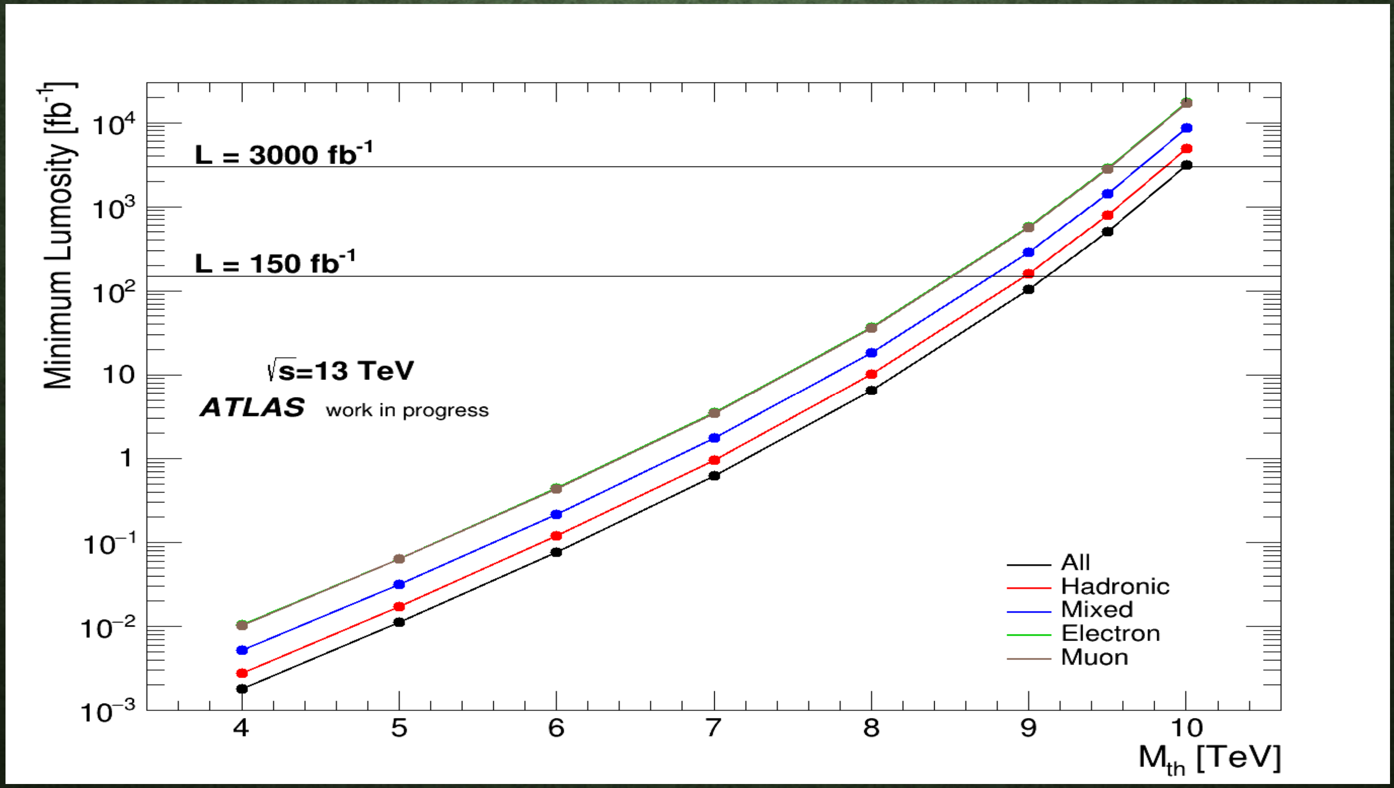
s $\equiv$ number of signal events only
b $\equiv$ number of background events only
σ_b $\equiv$ total background uncertainty



MINIMUM REQUIRED LUMINOSITY

Conditions for discovery potential:

- ✓signal significance (Z) ≥ 5 standard deviations
- ✓number of expected signal (s) ≥ 10



DISCOVERY POTENTIAL

Decay mode	M_{th} [TeV]	
	150 fb^{-1}	3000 fb^{-1}
Semi-hadronic (Electron)	8.5	9.5
Semi-hadronic (Muon)	8.5	9.5
Semi-hadronic	8.7	9.7
Fully-hadronic	9.0	9.9
Fully- and semi-hadronic	9.1	10.0

Maximum detectable mass using L = 150, 3000 fb^{-1} for each decay mode

SUMMARY

We:

- Simulate QBH production for different mass thresholds
- Estimate the background contributions with corresponding uncertainties
- Reconstruct the QBH state in fully- and semi-hadronic topologies
- Estimate the discovery potential assuming an integrated luminosity of 150 fb^{-1}

Thank You Very Much
For Your Attention!