Search for Resonance in photon+jet final state using CMS Data

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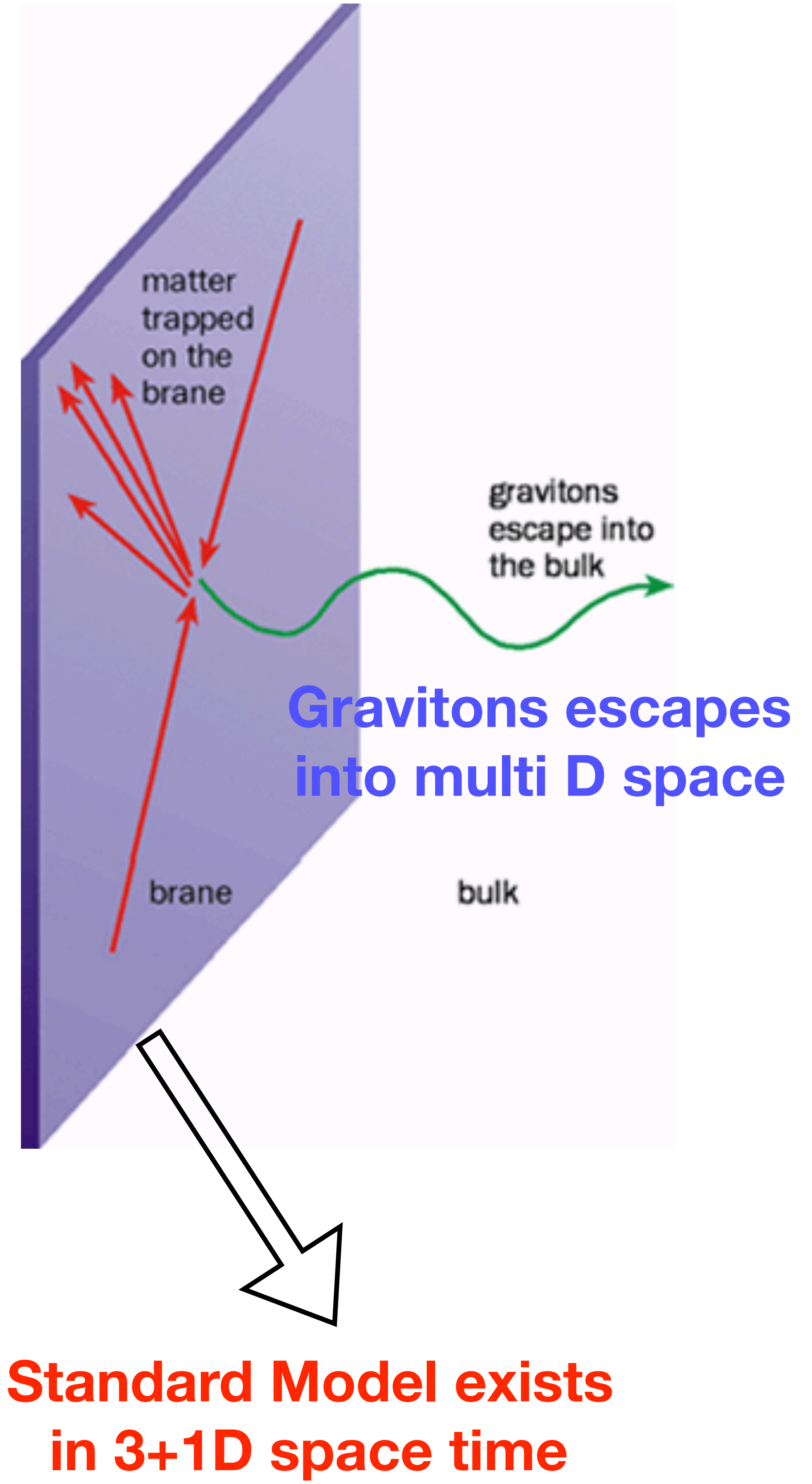
Introduction

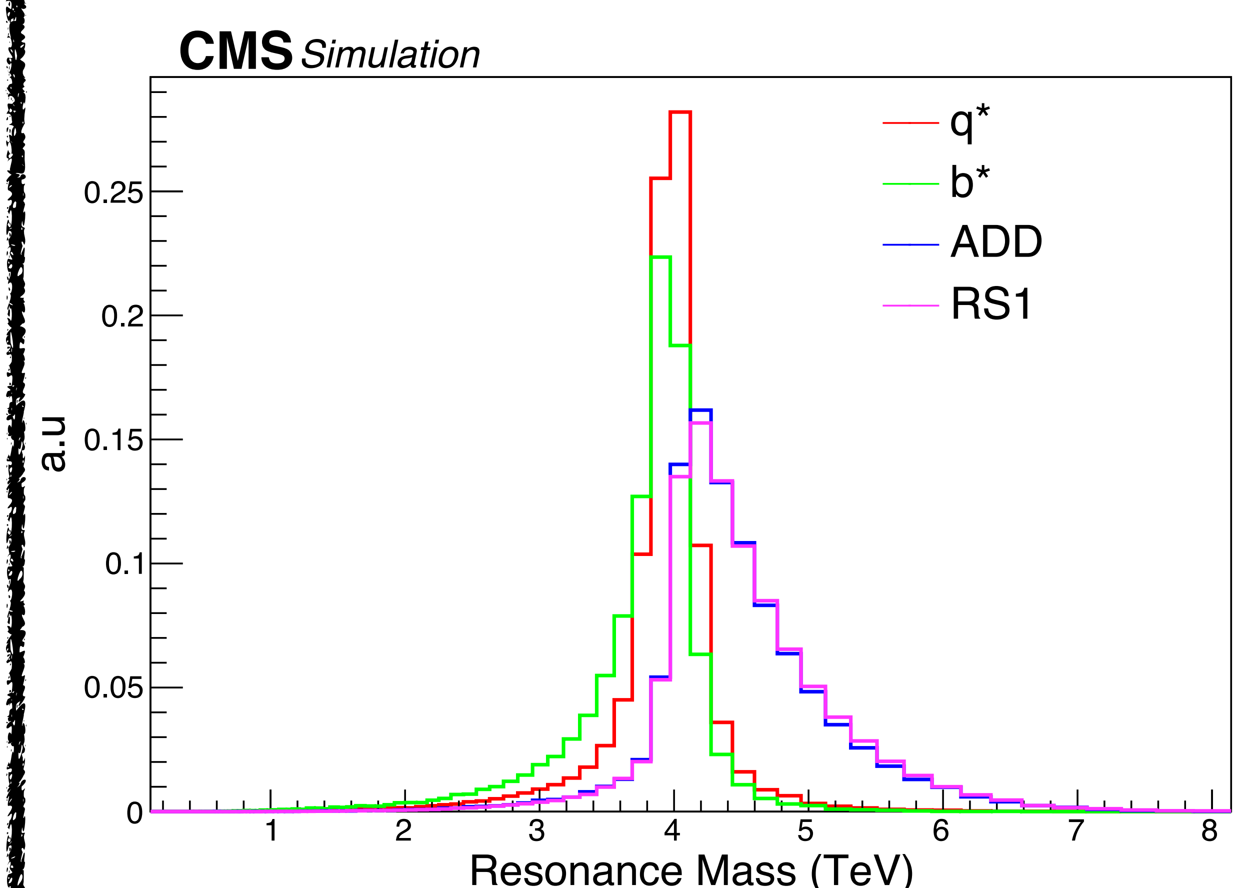
- Standard Model gives an extraordinary insight to fundamental nature of matter, but yet can not explain everything in the universe
- Beyond Standard Model searches : why only three generations of quarks and leptons??
  - ➡ **Models predict the quarks and leptons are not fundamental and there is an underlying structure for the fermions families.**
- Outstanding enigma of particle physics: the **hierarchy problem**, i.e. the large difference between the scale of electroweak and the Planck scale
  - ➡ **The existence of extra dimensions can explain such large difference. Standard Model confined to a 3-brane and only gravity propagates in extra dimensions**



Previous Results

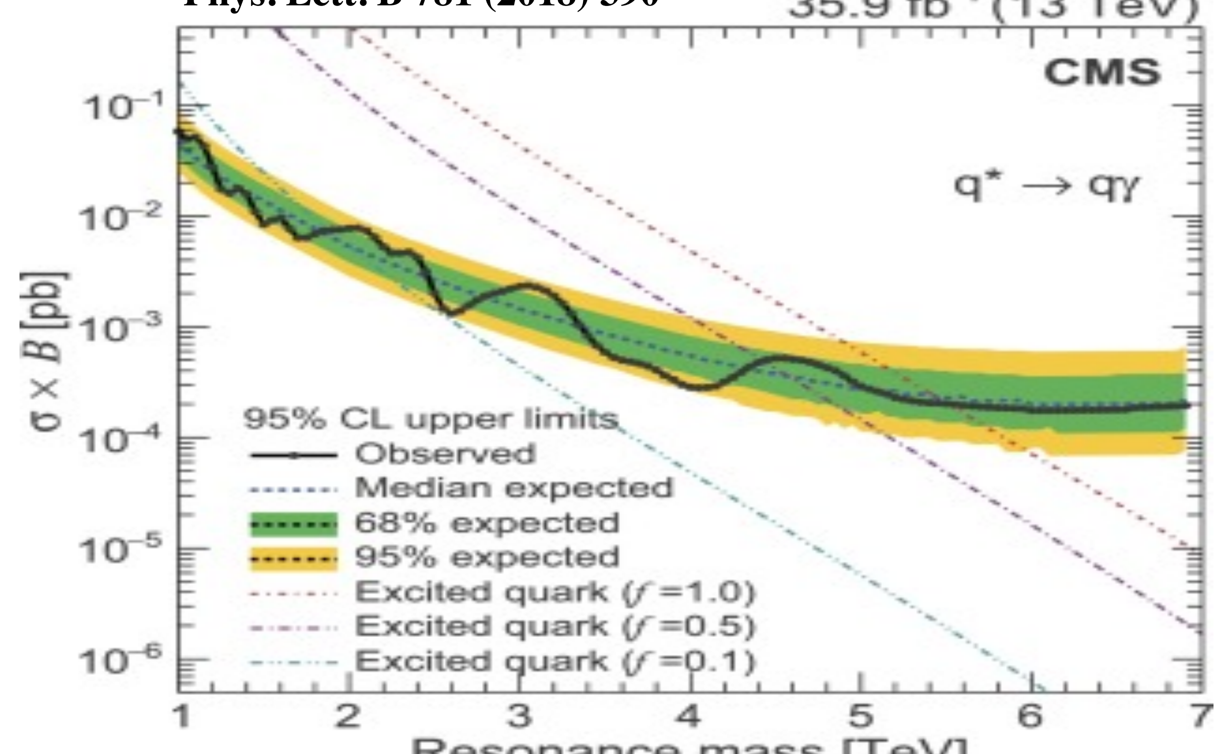
A search for new resonances decaying to photon+jet state with **luminosity 137fb^{-1} (2016-2018)**

- More data leads to more potential for new signals
- New techniques implemented



- **Existing results by CMS & ATLAS at $\sqrt{s}$ = 13TeV decaying to photon + jet channel :**
  - q* and b* are excluded by CMS up to 5.5 TeV and 1.8 TeV with 35.8 fb^{-1} Phys. Lett. B 781 (2018) 390
  - q* excluded by ATLAS up to 5.3 TeV with 36.7fb^{-1} Eur. Phys. J. C (2018) 102
  - ADD and RS1 model of the QBH upto 7.1 TeV and 4.4 TeV by ATLAS with luminosity 36.7fb^{-1} Eur. Phys. J. C (2018) 102

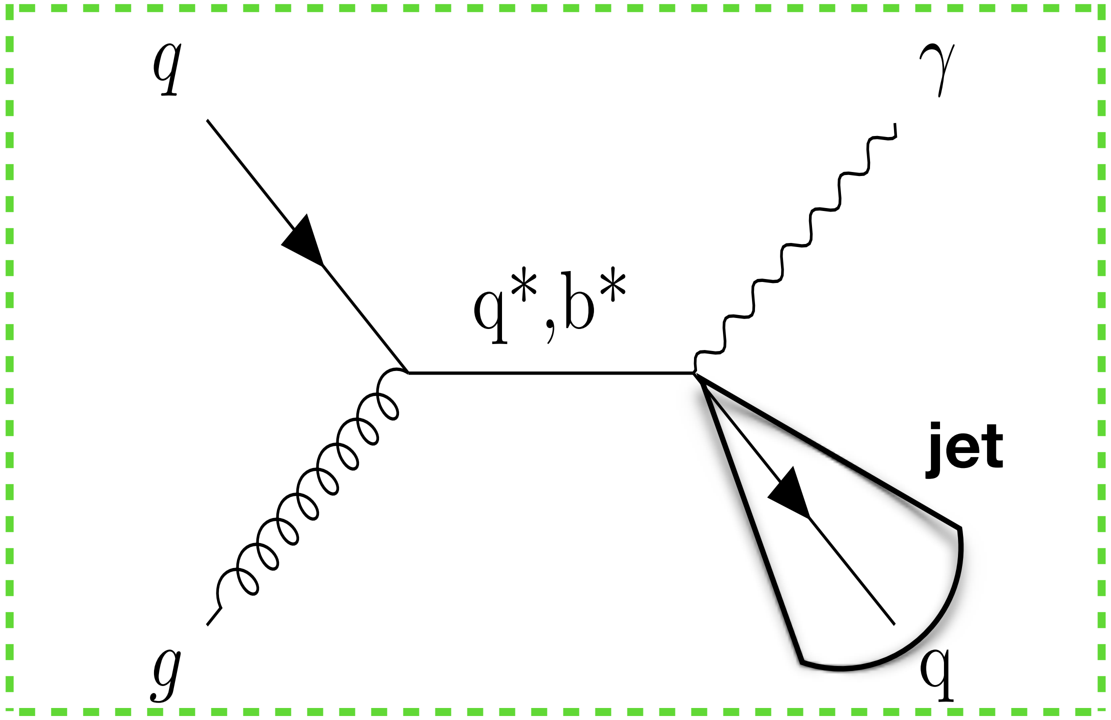
Phys. Lett. B 781 (2018) 390



Signal Modelling

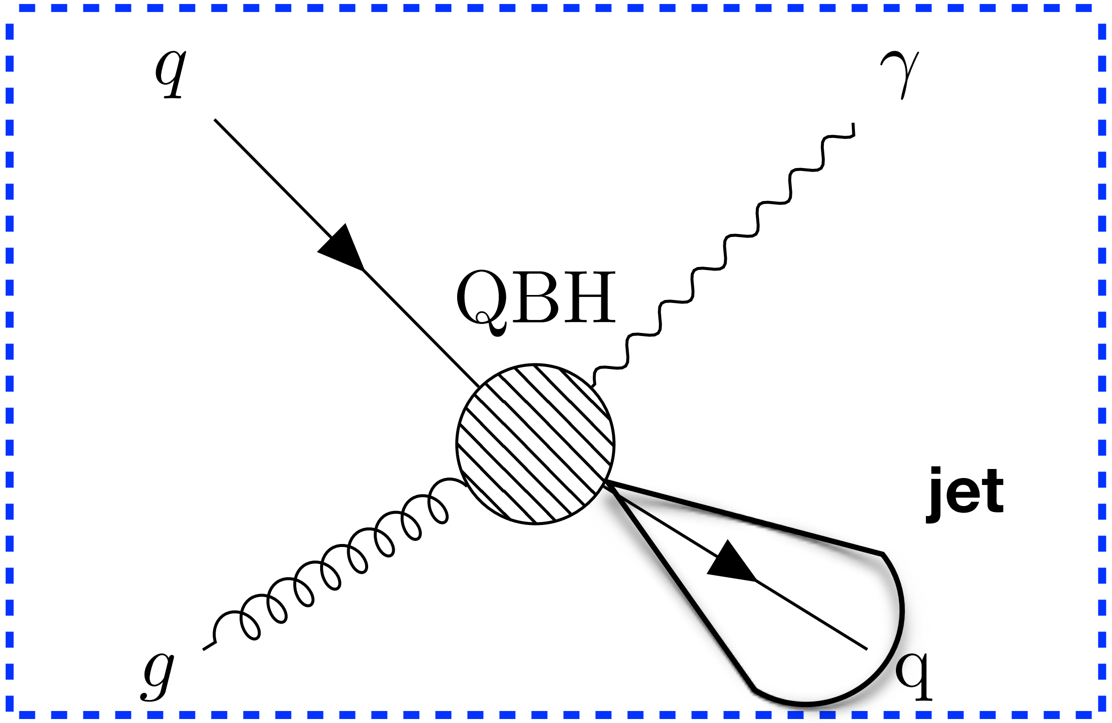
Composite models

- Composite models predicts the substructure of the quarks (light flavor quarks q* and heavy flavor quarks b*)
    - ➡ The search for excited light and heavy quarks signals with coupling multipliers to Standard Model f = 1.0, 0.5 and 0.1 is performed



Quantum Black Hole models

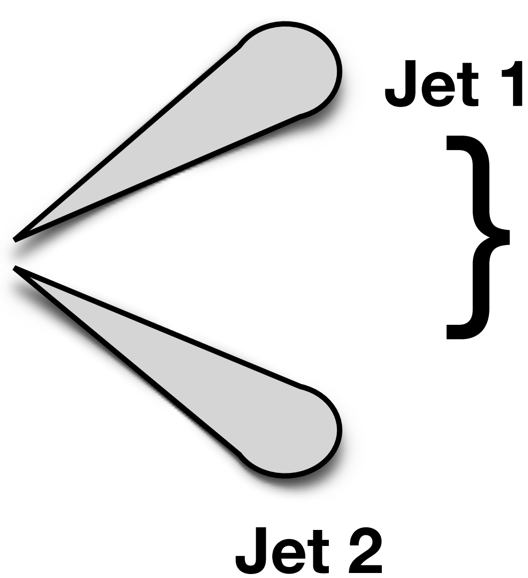
- The Quantum Black Holes (QBH) which are the quantum analogs of the black holes can be produced at the LHC. Due to radiation and experimental effects it appears as a resonance.
- QBHs are non thermal objects, expected to decay predominantly to pairs of particles
- Two well known models of QBH are studied :
    - ➡ ADD (with n=6 extra dimensions) and
    - ➡ RS1 (with n=1 extra dimension)



QBH (RS1) ⟶ photon+jet studied first time in the CMS

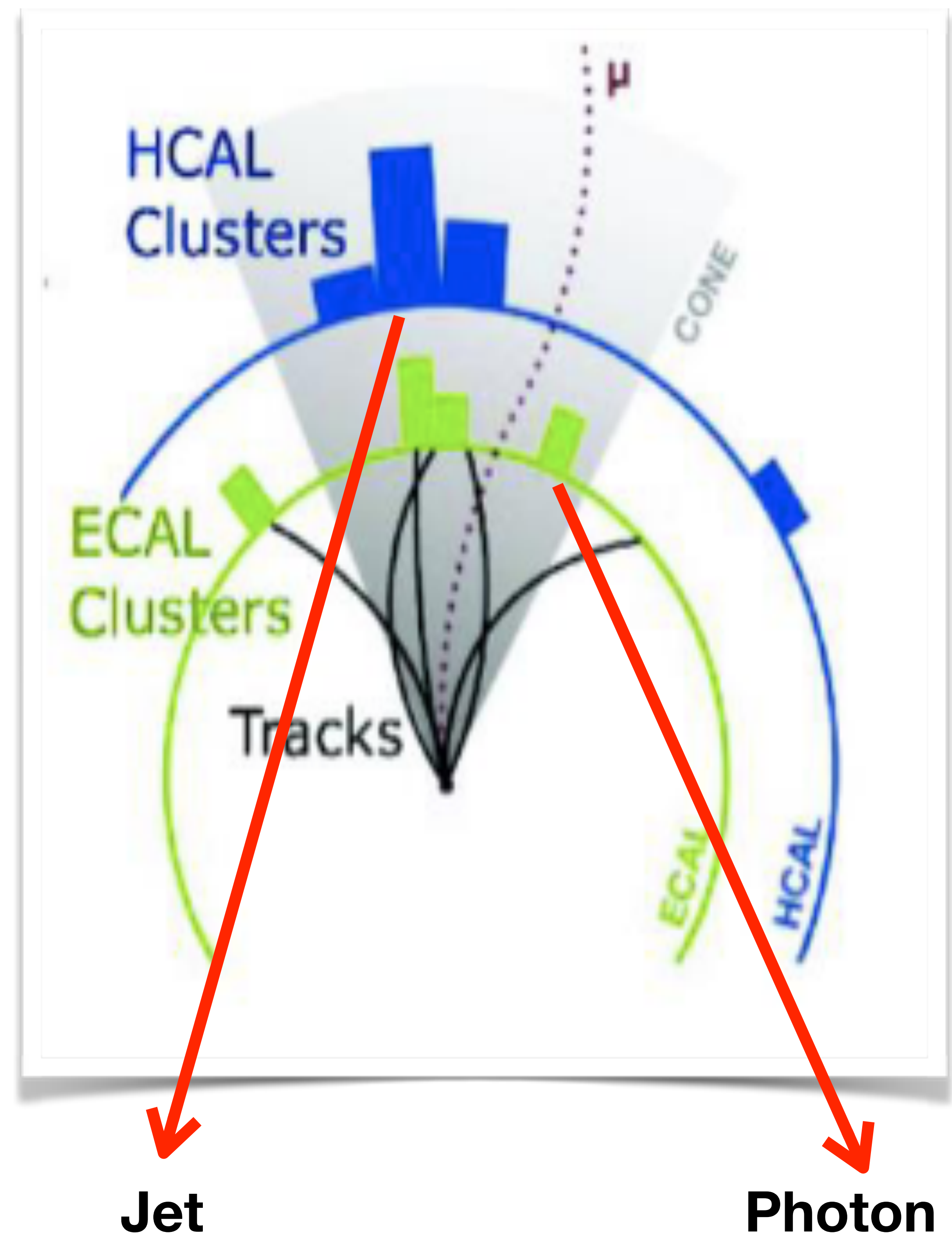
CMS Detector

- Photons energy are calibrated in the electromagnetic calorimeter of CMS detector with no tracks associated with it.
- Jets are reconstructed in Hadron Calorimeter of the detector
  - Jets with $\Delta R < 1.1$ between them are merged together to form **wide jets to account for the final state radiation.**



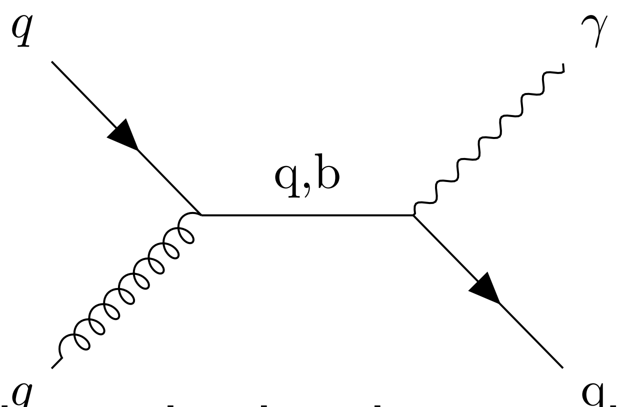
If $\Delta R < 1.1$ merged together

Wide jet



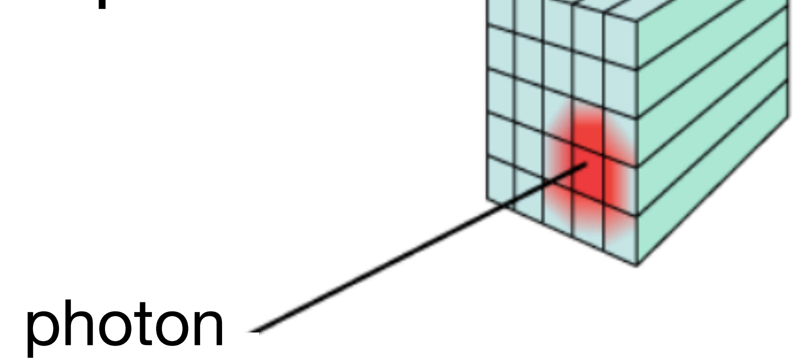
SM Backgrounds

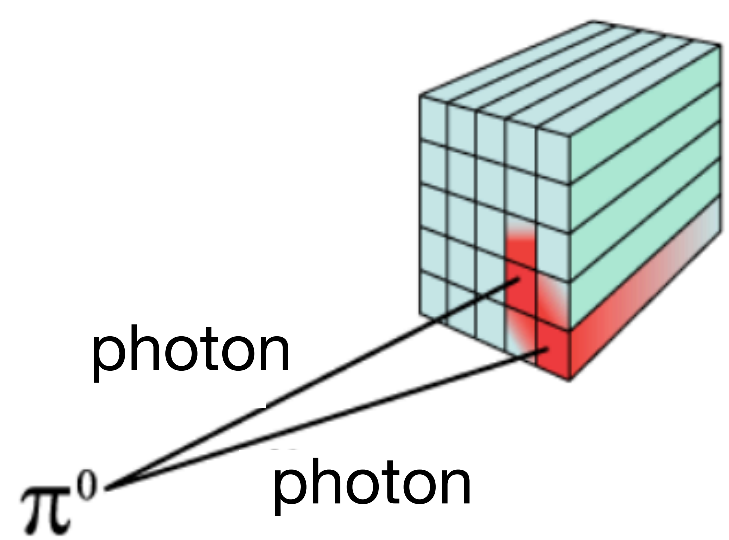
- The major background to the study is the standard model photon+jet background, with small contribution from QCD and electroweak background.



- To reduce the background and improve the signal efficiency, selections are applied:
  - **A high pT photon in the barrel region of the detector ($|\eta|^{photon} < 1.44$)**
  - **A high pT wide-jet in the central region of the detector**
  - **For resonance to exist, photon and jet produced via hard scattering would decay mostly back to back**

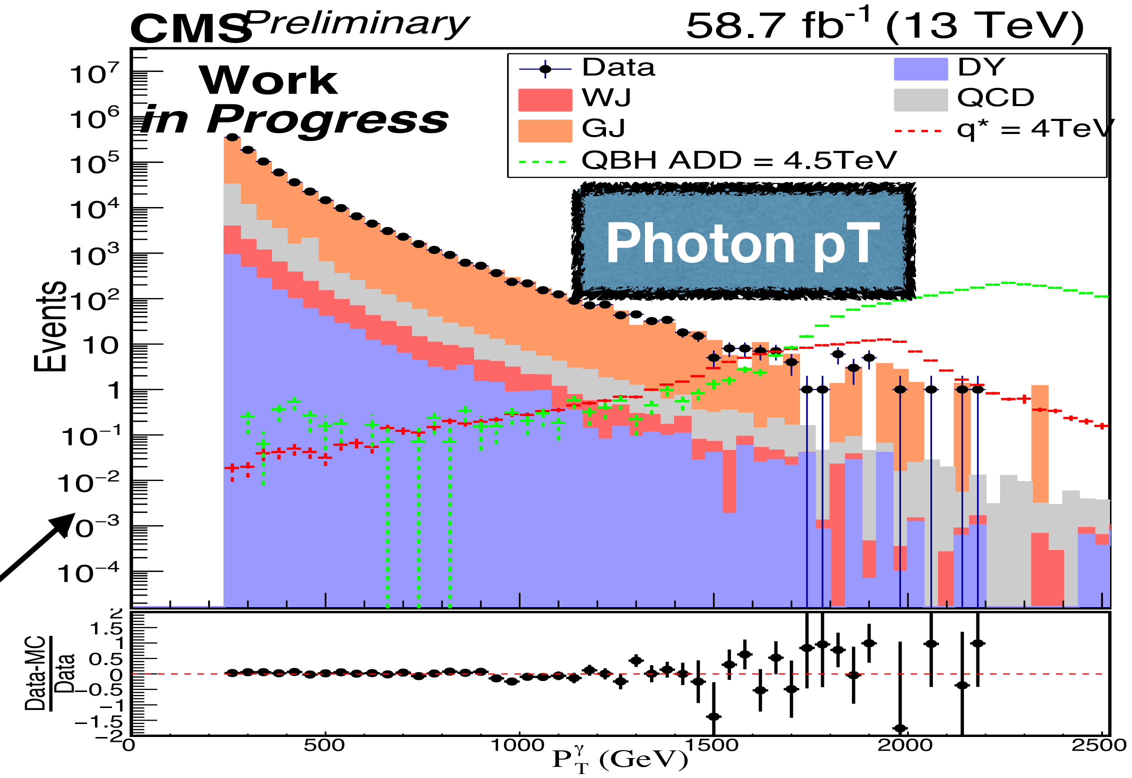
- The multi-jet backgrounds also contributes when π^0 decays to two overlapping photons
  - To reduce the QCD background further, $\Delta\eta$(photon, jet) < 1.5 is imposed.



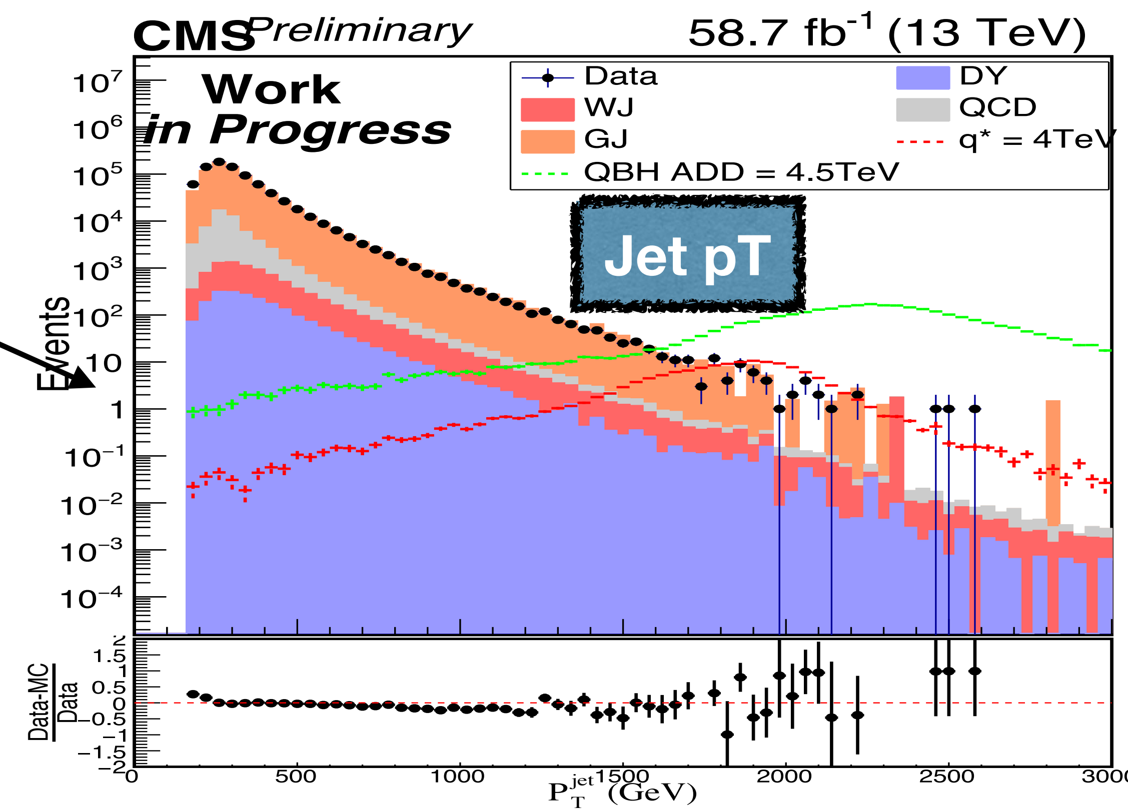


Analysis Strategy

- **The search for resonance is performed by looking for a bump in the invariant mass distribution of the final state particles**
- **Background estimation is done from data**
- **MC is used for optimizing the selections and validation with data**



- Distribution after selection
- Data/Background agreement for different year (2016-2018) distributions
- Similar distribution with 35.8fb^{-1} and 41.7 fb^{-1} is observed
- **Data is consistent with SM expectations**



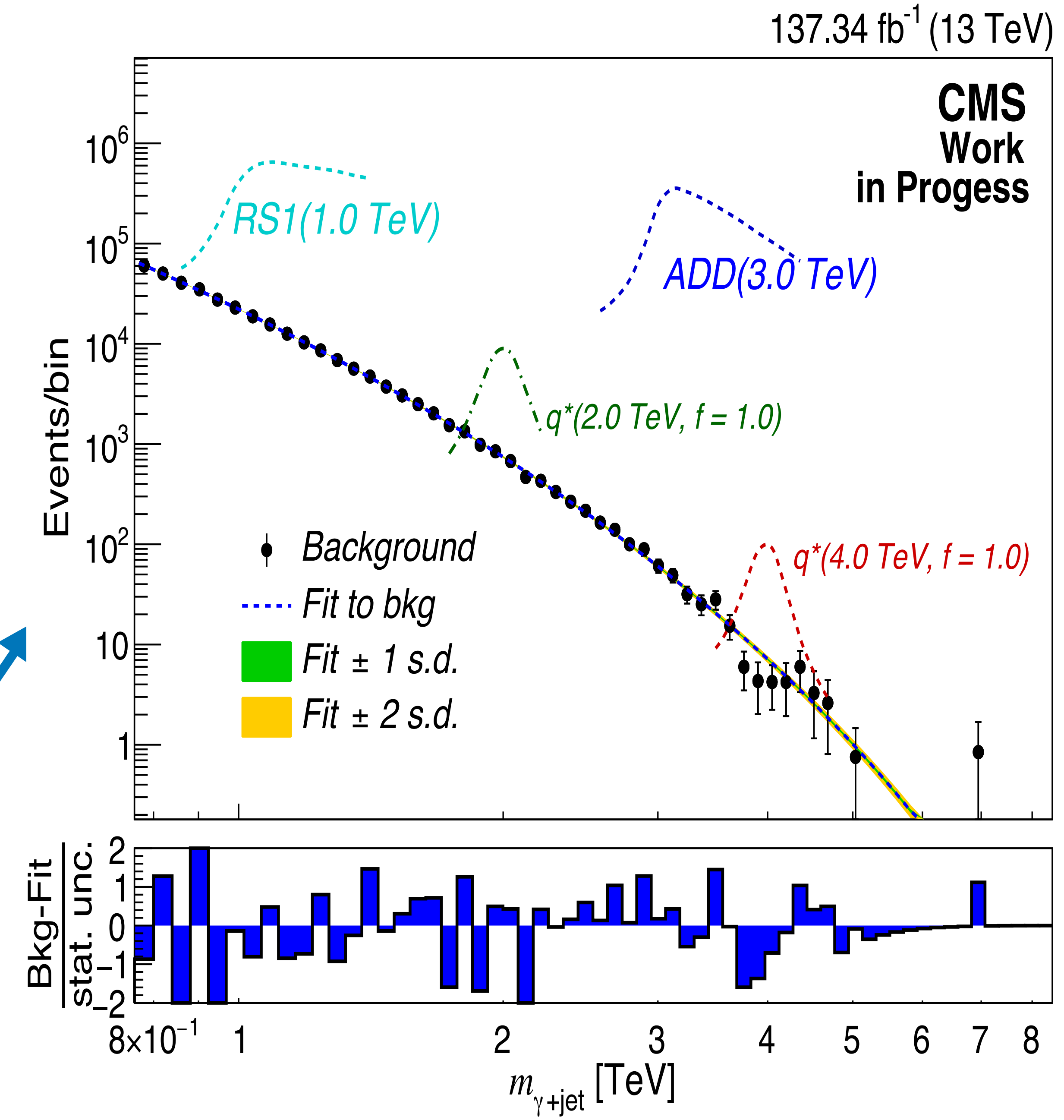
Background Modelling

- To look for any excess of events, the invariant distribution of photon+jet is fitted with functional form

$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3 ln(m/\sqrt{s})}}$$

Functional form :

- ➡ Numerator represents the mass dependence of parton distributions
- ➡ Denominator refers to mass dependence of QCD matrix element.



- The function is chosen on the basis of fisher test and Goodness of fit test with p values significance > 0.05
- Expected signals mass points shapes :
  - ◉ Light quarks ($M_{\gamma+jet}$ = 1TeV and $M_{\gamma+jet}$ = 4TeV)
  - ◉ QBH (ADD $M_{\gamma+jet}$ = 3TeV and RS1 $M_{\gamma+jet}$ = 1TeV)

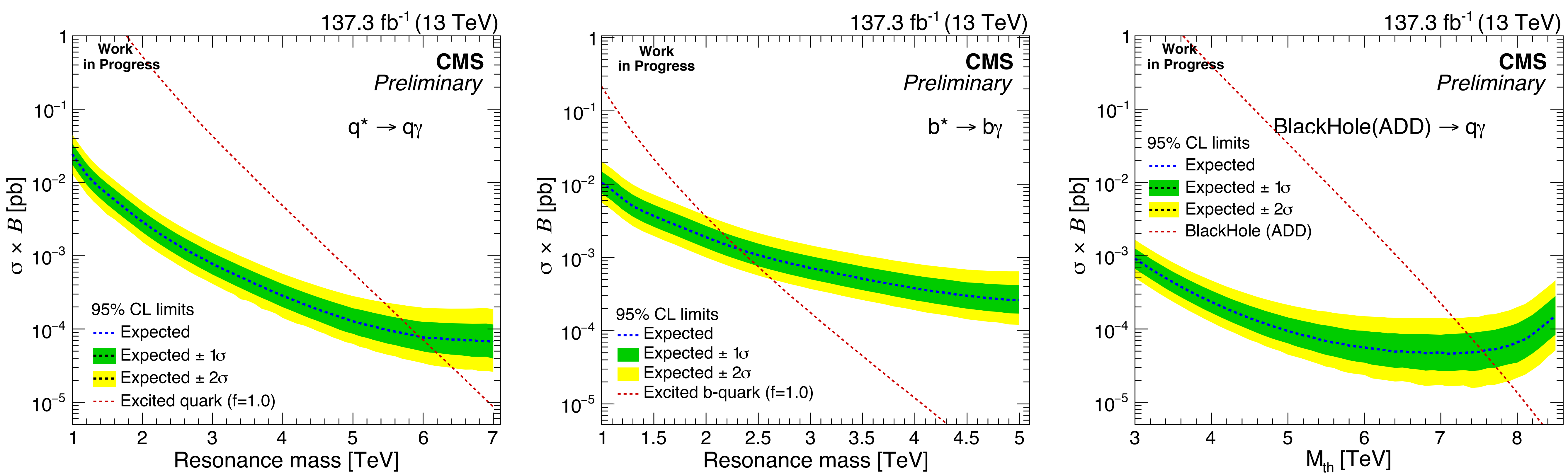
Data is blinded,
and MC simulations are used as proxy for Data

Systematic Uncertainties

- The major systematics contribution comes from the uncertainties on the parameters in the background functional form.
- Bias study is also performed to account for the possible bias due to the choice of the functional form chosen
  - The systematic due to bias is negligible, compared to the statistical uncertainty of the fit of invariant mass distribution
- Other Signal uncertainty dominated by photon ID inefficiency (10%) and b quark tagging (14%)

Results

- The expected limits with MC are calculated.
- Expected Upper limits on cross section is measured and :
  - **q* is excluded up to 6.0 TeV**
  - **b* is excluded up to 2.3 TeV**
  - **ADD is excluded up to 7.6 TeV**



Summary

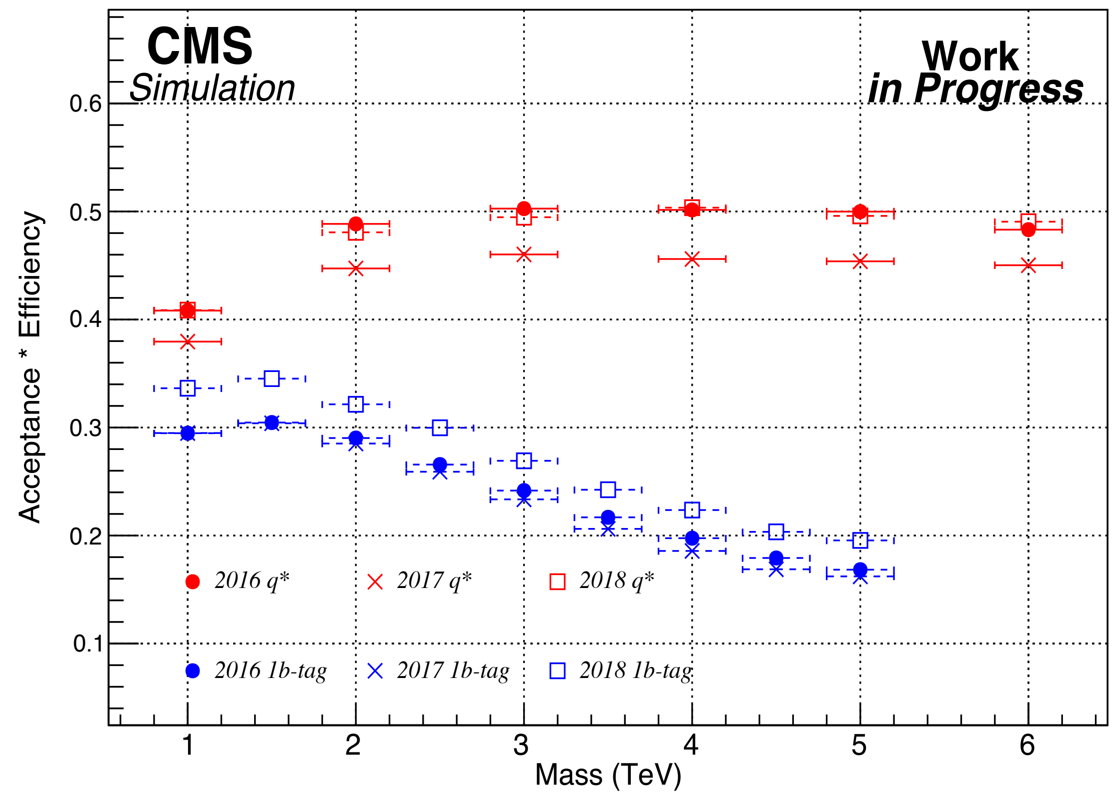
- The search for excited state of light and heavy flavor of quarks is performed using CMS data
- The possibility of Quantum Black hole at the LHC and decaying to two particle state is also considered.
- The expected exclusion limits on signals are calculated, since the Data is blinded till the selections are optimized from simulations.

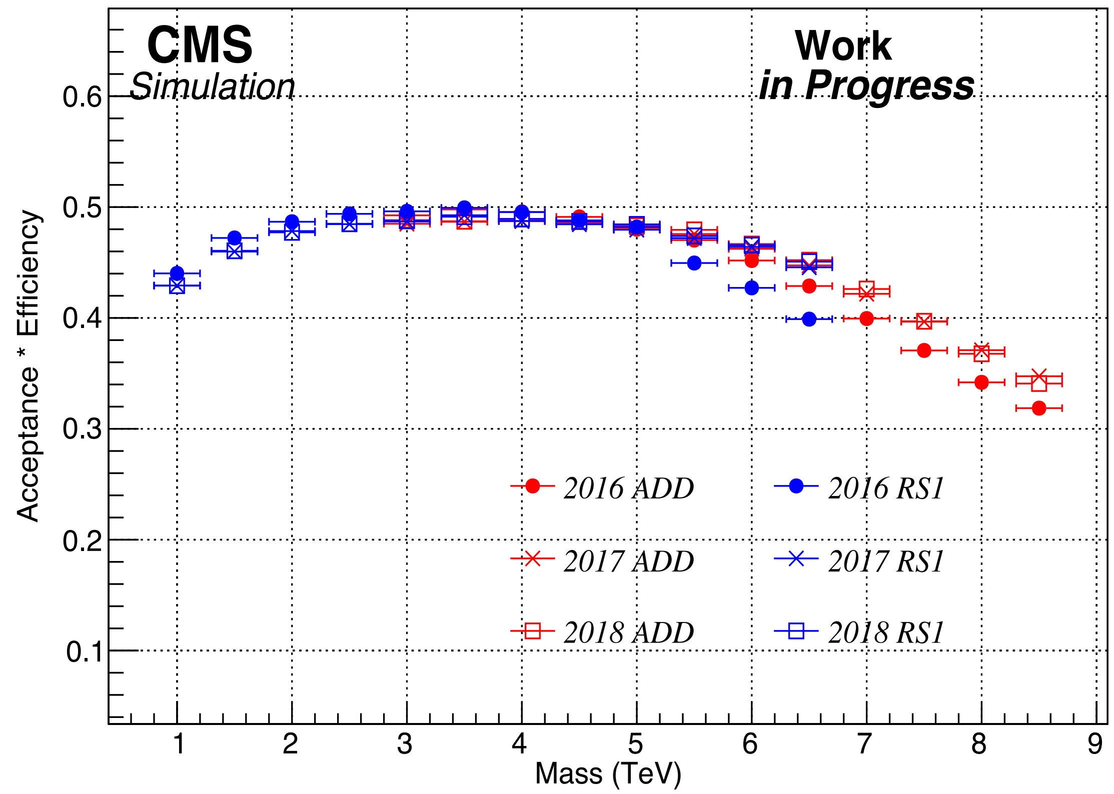
Thank you!!!

Additional Material

Efficiency Tables

- The efficiency of the signals after the selections applied normalized to 2016 data, 2017 data and 2018 data, corresponding to the luminosity 35.8 fb^{-1}, 41.7 fb^{-1} and 58.7 fb^{-1} respectively.





Systematics table

Source	Type	Relative Size(%)	Signal Model
Luminosity	Normalization	1.6	$q^*/b^*/QBH$
Jet energy scale	Shape	~ 1.0	$q^*/b^*/QBH$
	Normalization	< 0.002	$q^*/b^*/QBH$
Jet energy resolution	Shape	0.6-1.9	$q^*/b^*/QBH$
Photon energy scale	shape	~ 1.0	$q^*/b^*/QBH$
	Normalization	< 0.002	$q^*/b^*/QBH$
Photon energy resolution	Shape	0.4-1.2	$q^*/b^*/QBH$
Pileup	Normaliation	0.1	$q^*/b^*/QBH$
High pT Photon ID inefficiency	Normalization	~ 10.0	$q^*/b^*/QBH$
HLT Trigger inefficiency	Normalization	5.0	$q^*/b^*/QBH$
Signal shape interpolation	Shape	<1.0	$q^*/b^*/QBH$
b-tag SF uncertainty	Shape	0.2-3.0	b^*
	Normalization	7.9-14.3	b^*

Table 1: Effect of various systematic uncertainties on signal.

Signal, Data and Background

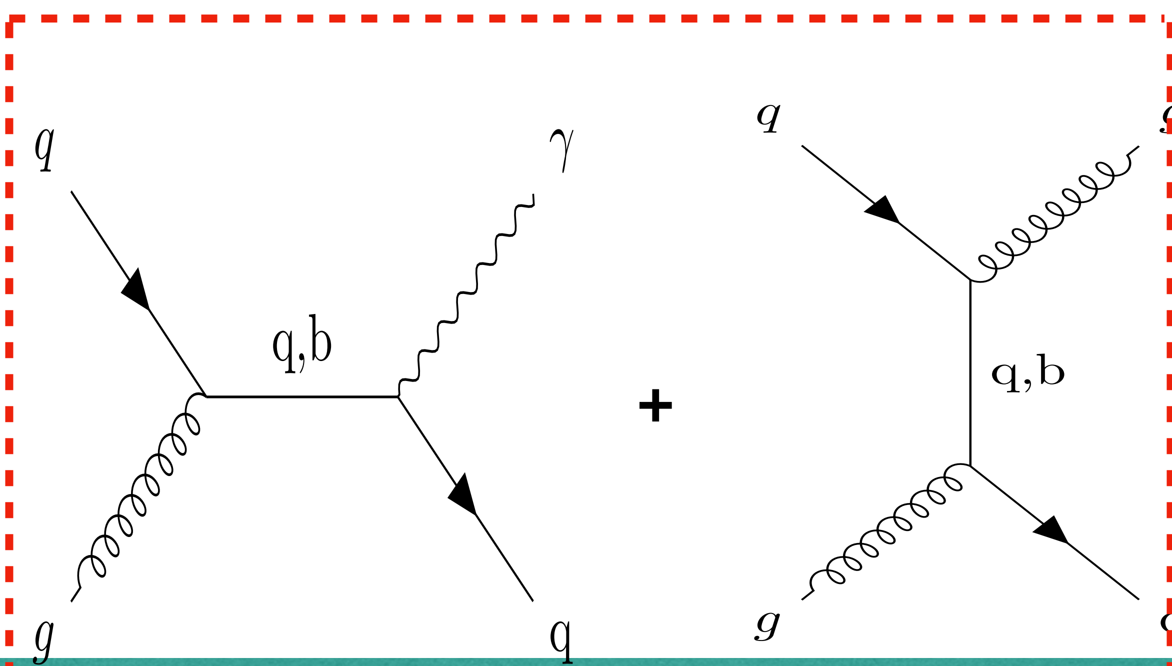
Data : CMS full RunII data corresponding to luminosity 137.4 fb-1

Background : Standard Model photon+jet background is the major background, with small contribution from QCD and Electroweak processes.

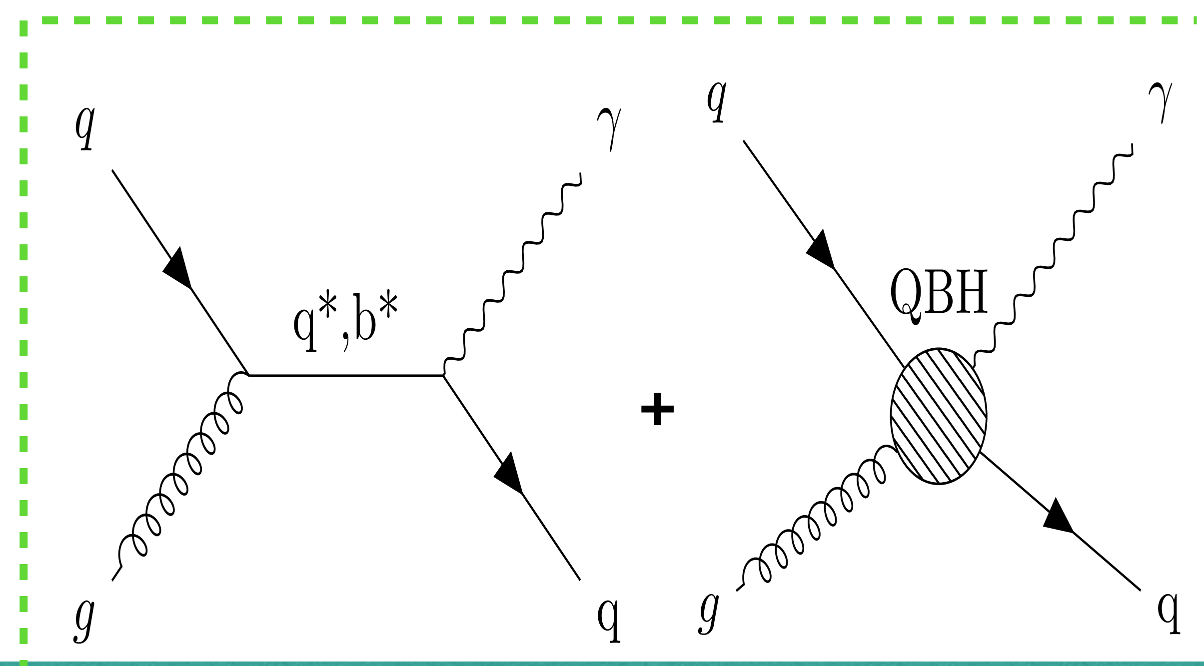
Signals :

- q* and b* stimulated with Pythia8 generator at the leading order (LO)
- QBH: generated with QBHv3.0 generator

SM



BSM



Event Selection

The search for resonance is performed by looking for a bump in the invariant mass distribution of the final state particles

Photons :

- Photon pT > 240 GeV
- $|\eta|^{\gamma} < 1.44$

Jets :

- Jet pT > 170 GeV
- $|\eta|^{jet} < 2.4$
- Heavy flavor quarks (b*) passes the neural based discriminator

Photon + jet selection :

- ΔR(photon, jet) > 1.1
- $\Delta\eta$(photon, jet) < 1.5
- Invariant Mass(photon, jet) > 761 GeV