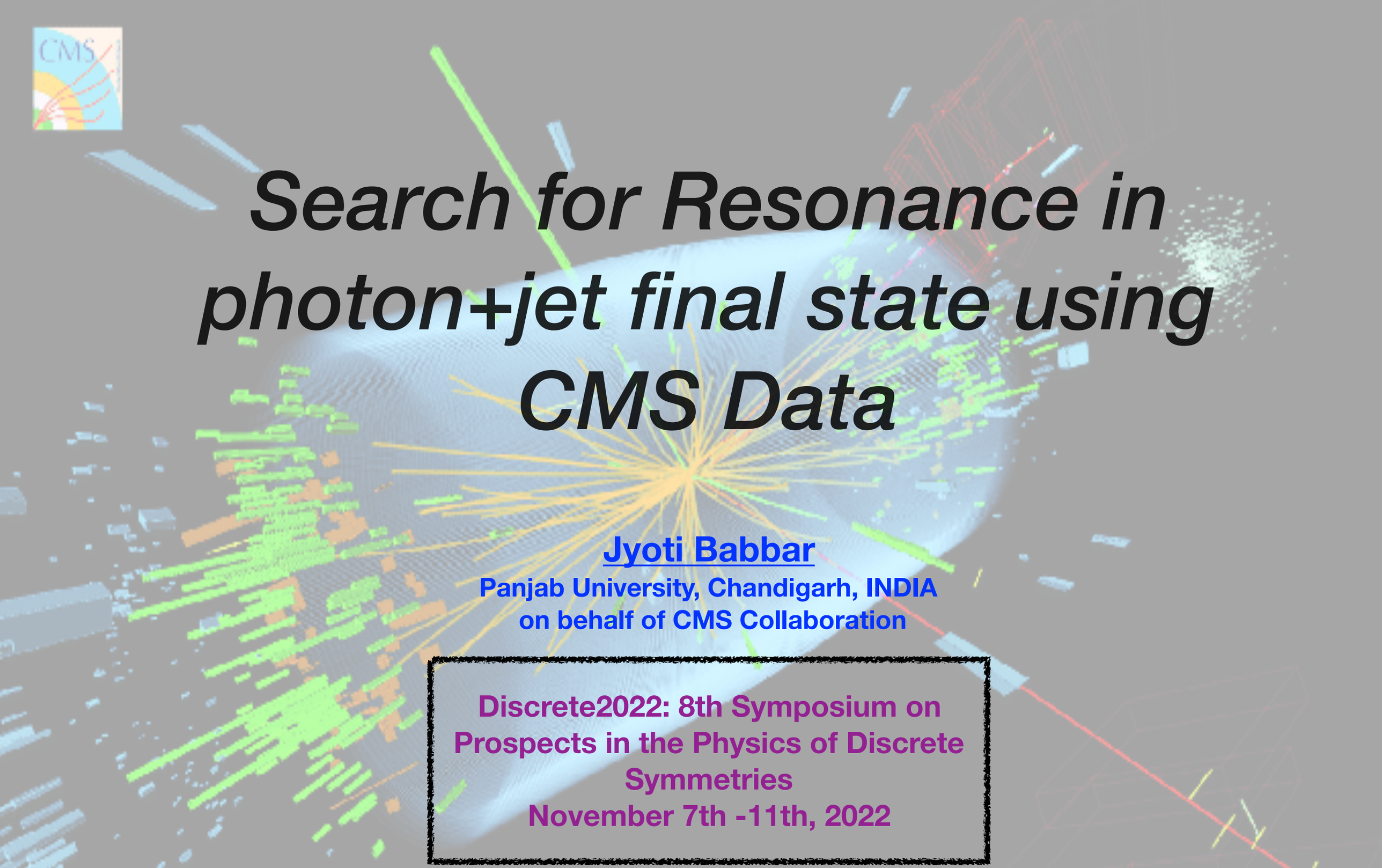

Search for Resonance in photon+jet final state using CMS Data

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on behalf of CMS Collaboration

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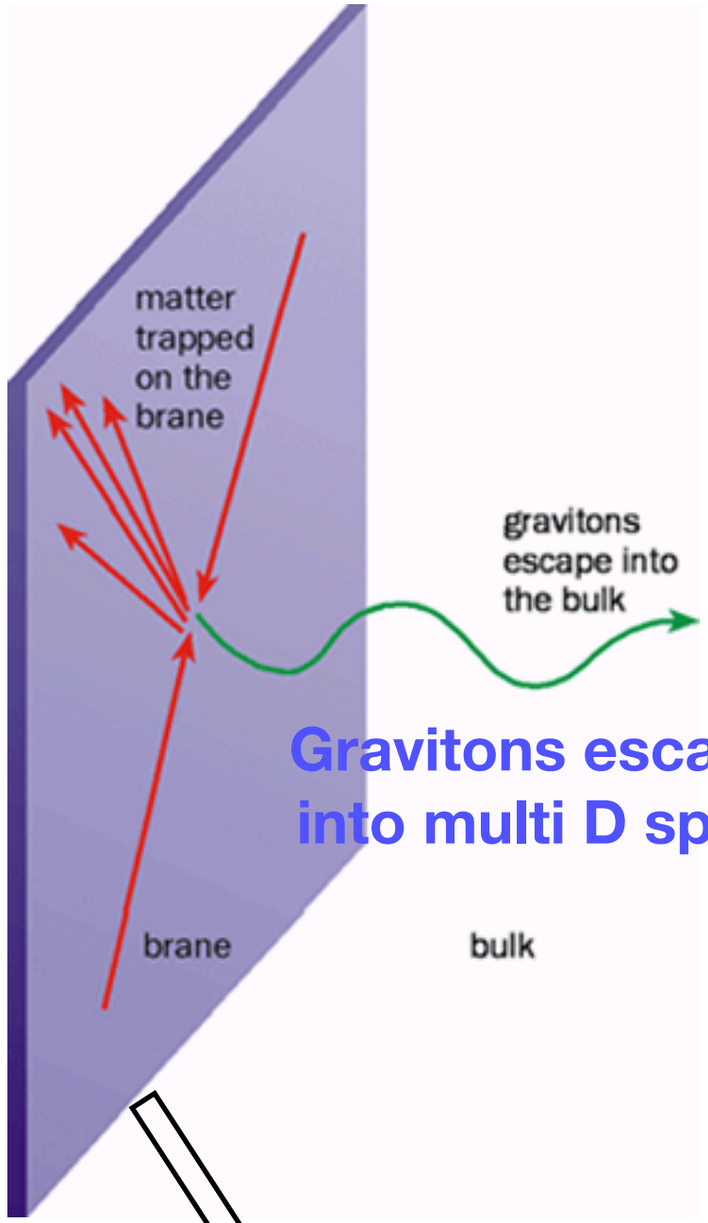
Introduction

- 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**



Gravitons escapes into multi D space

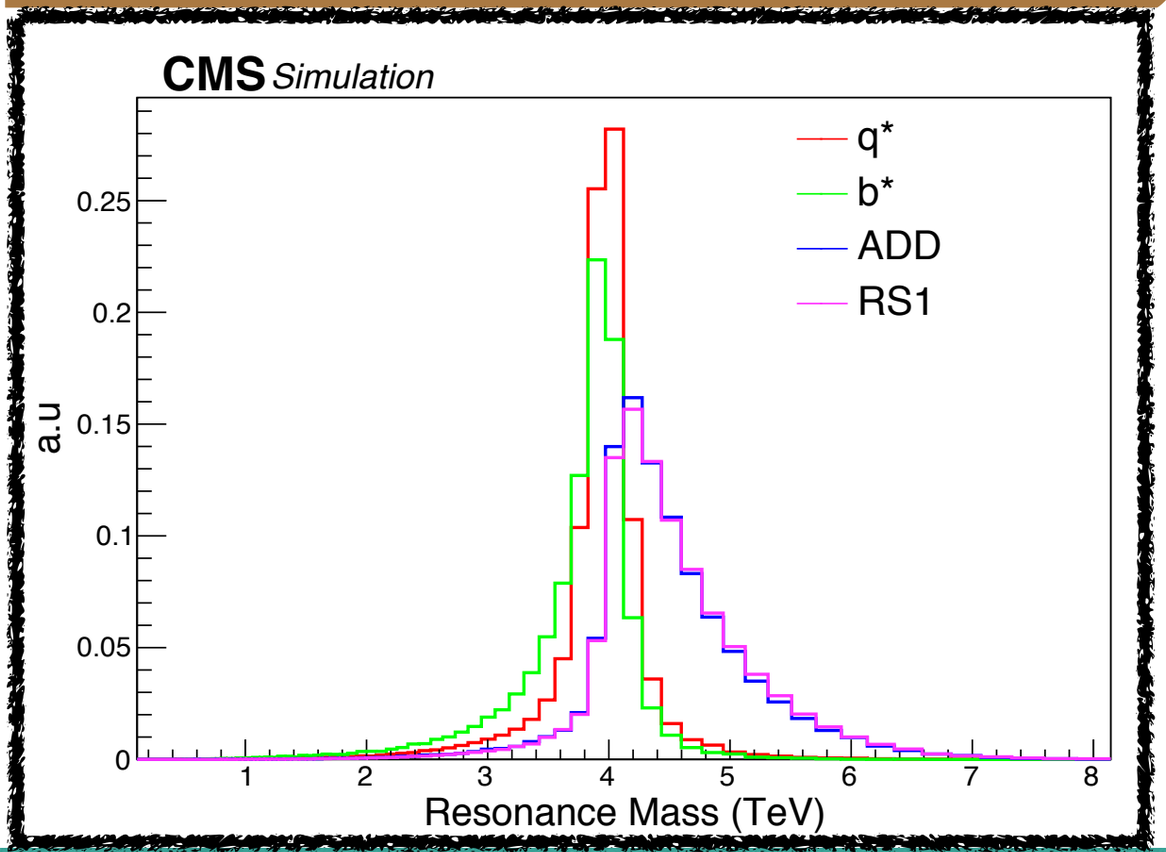
Standard Model exists in 3+1D space time

Previous Results

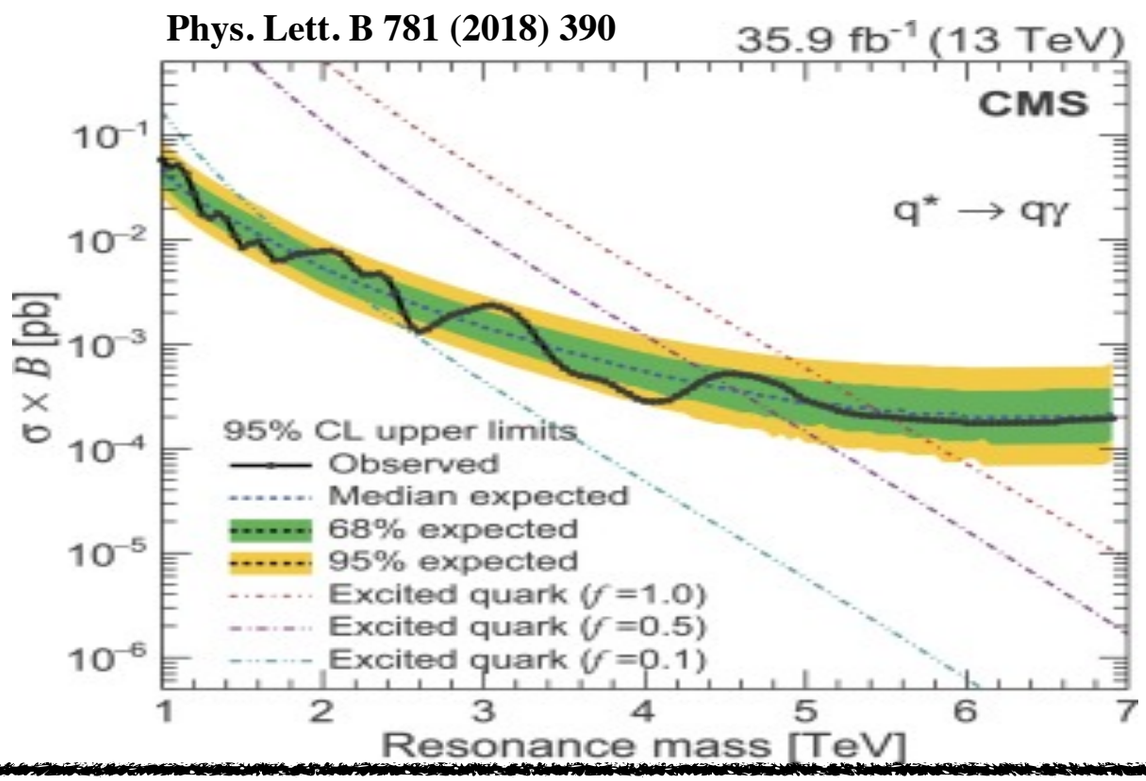
New !!

A search for new resonances decaying to photon+jet state with **luminosity 138fb^{-1} (2016-2018)**

- More data leads to more potential for new signals
- New techniques implemented
  - Wide jets are considered to include the FSR
  - Deep Neural network based tagger is used to tag the b-quark jets



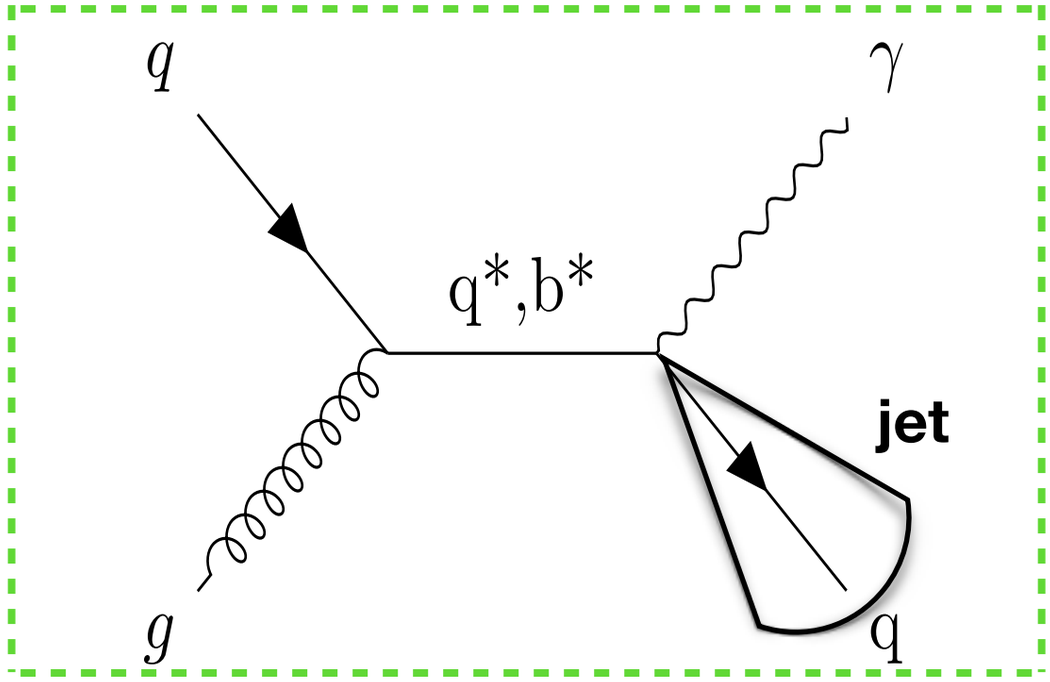
- **Existing results by CMS & ATLAS at √s = 13TeV decaying to photon + jet channel :**
  - q* and b* are excluded by CMS up to 5.5 TeV and 1.8 TeV with 35.8 fb^{-1} Phys. Lett. B 781 (2018) 390
  - q* excluded by ATLAS up to 5.3 TeV with 36.7fb^{-1} Eur. Phys. J. C (2018) 102
  - ADD and RS1 model of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



Signal Modelling

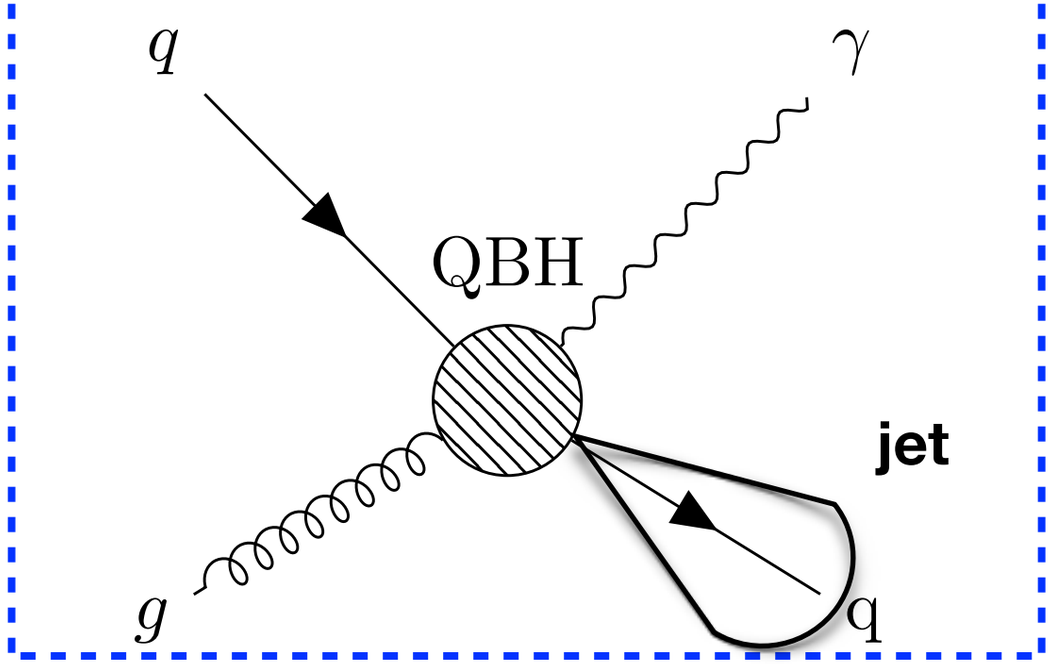
Composite models

- 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

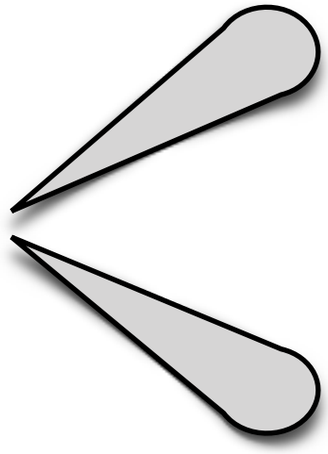
- The Quantum Black Holes (QBH) which are the quantum analogs of the black holes can be produced at the LHC. Due to radiation and experimental effects it appears as a resonance.
- QBHs are non thermal objects, expected to decay predominantly to pairs of particles
- Two well known models of QBH are studied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



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

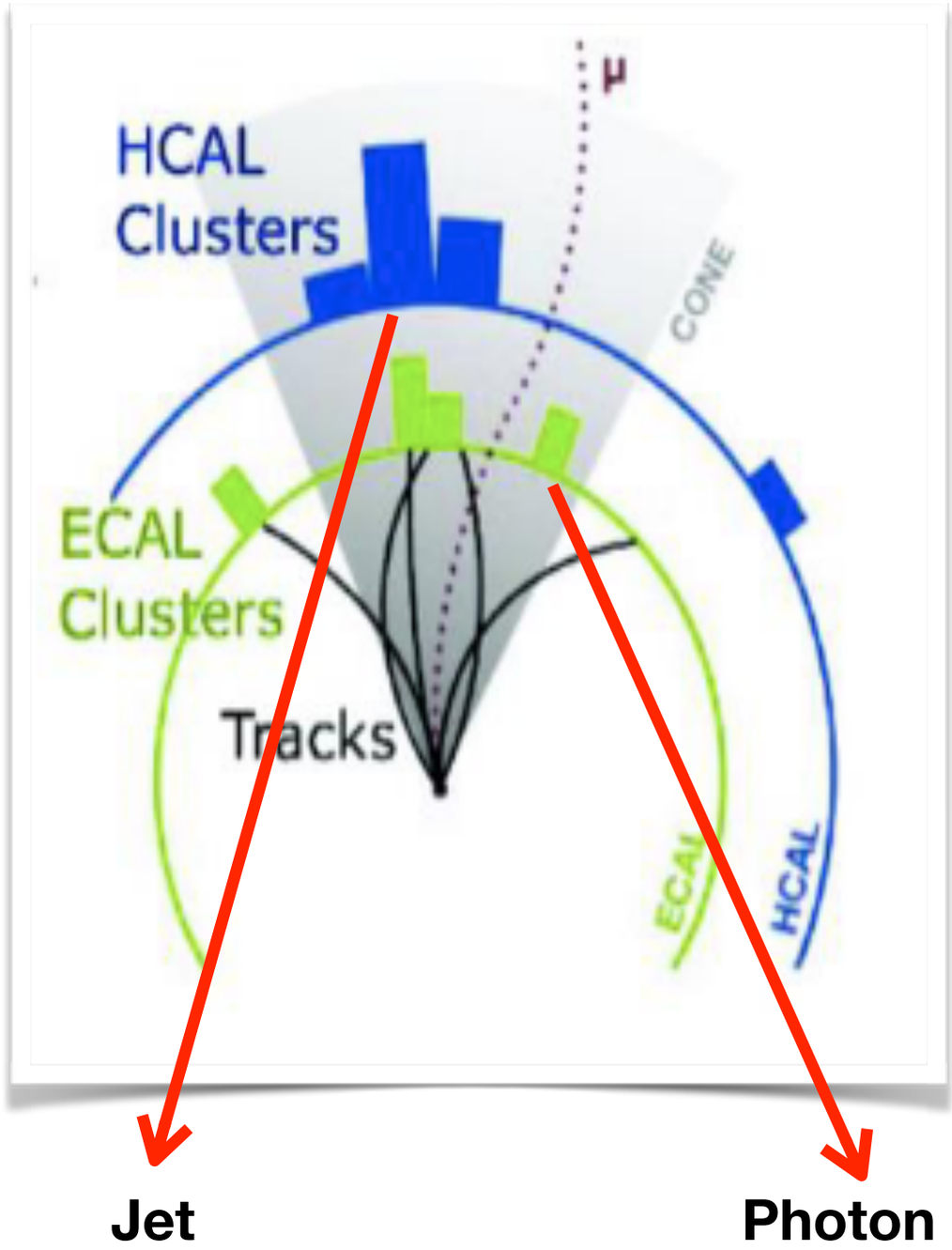
CMS Detector

- 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.**



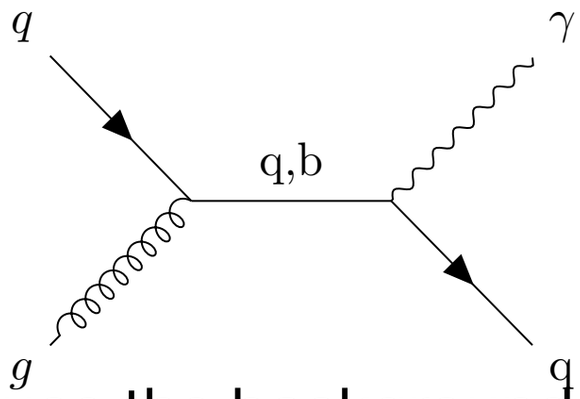
If $\Delta R < 1.1$ merged together

Wide jet



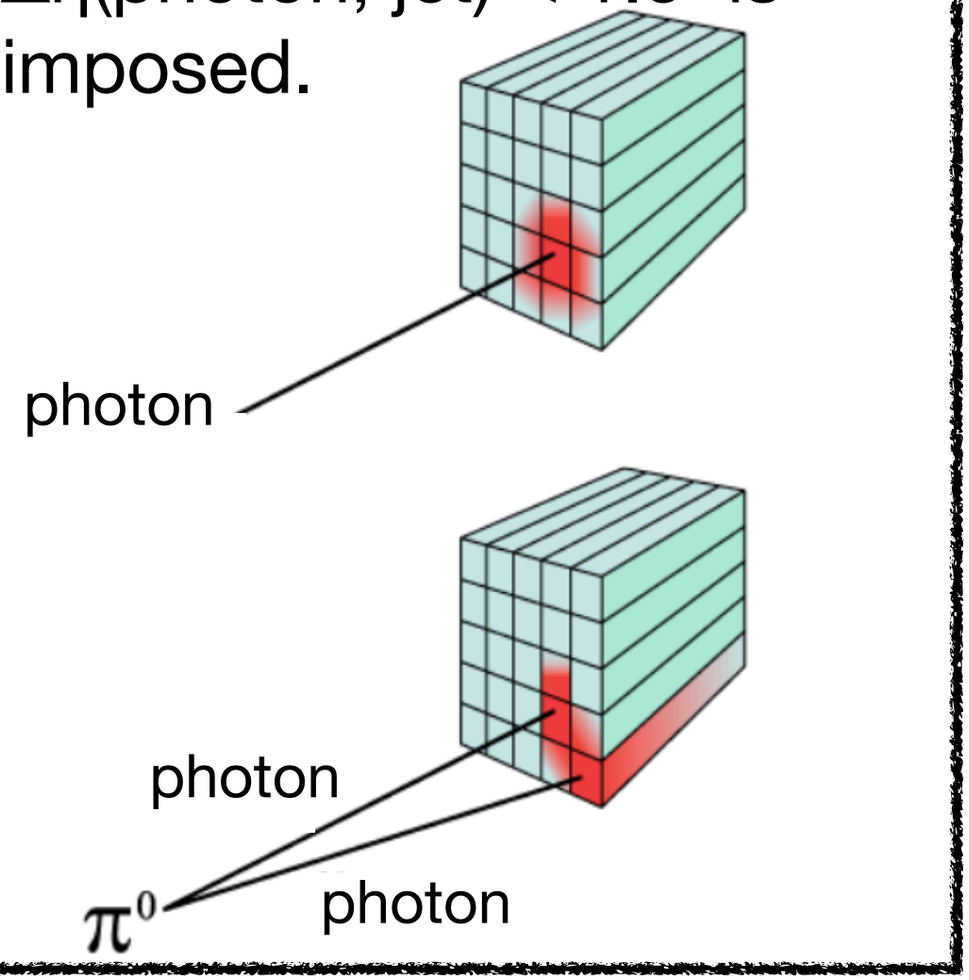
SM Backgrounds

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



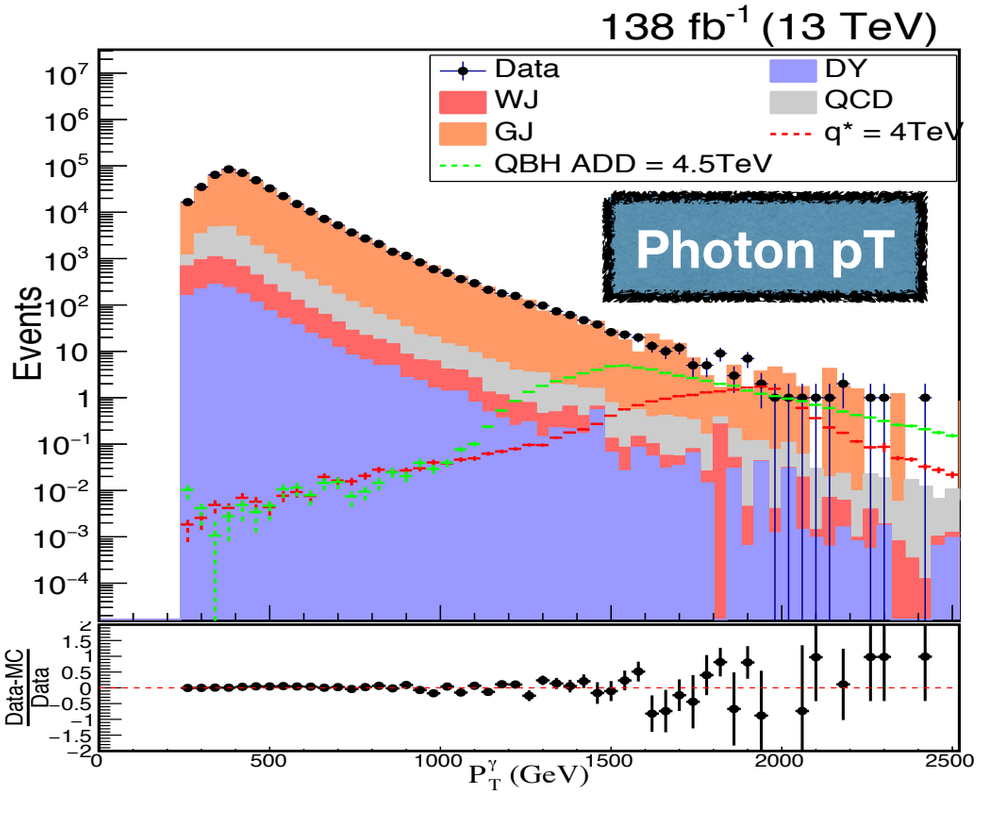
- To reduce the background and improve the signal efficiency, selections are applied:
  - **A high pT photon in the barrel region of the detector ($|\eta|^{\gamma} < 1.44$)**
  - **A high pT wide-jet in the central region of the detector**
  - **For resonance to exist, photon and jet produced via hard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

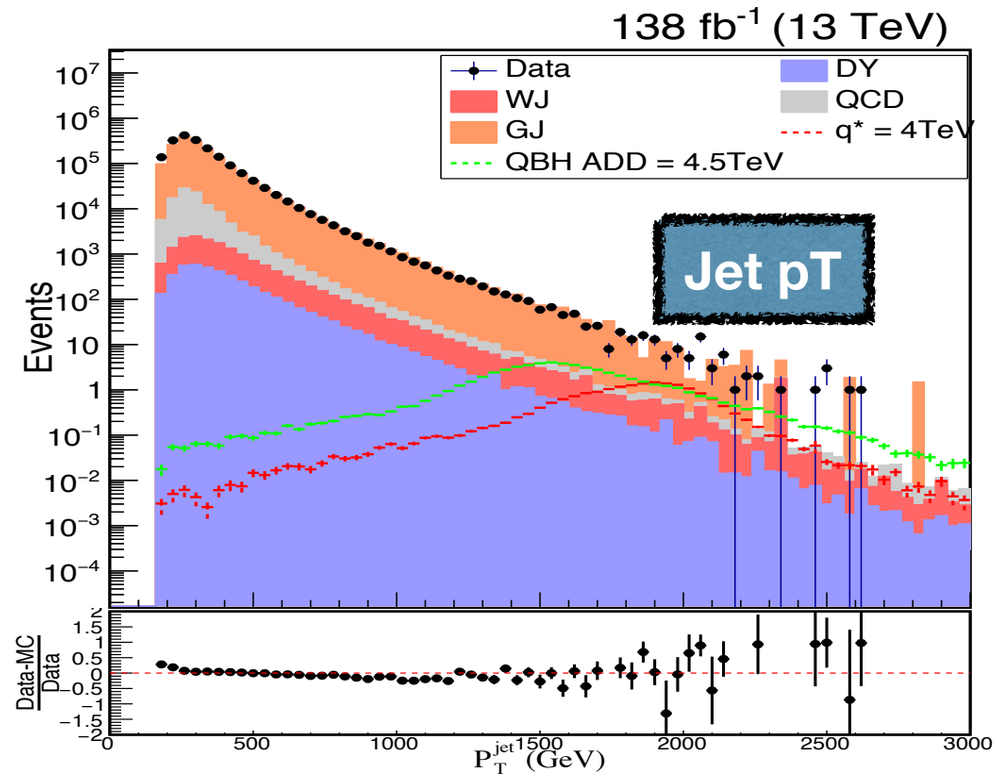


Analysis Strategy

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



- Distribution after selection
- Data/Background agreement for RunII distributions
- The kinematics distributions are well in agreement.



Background Modelling

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

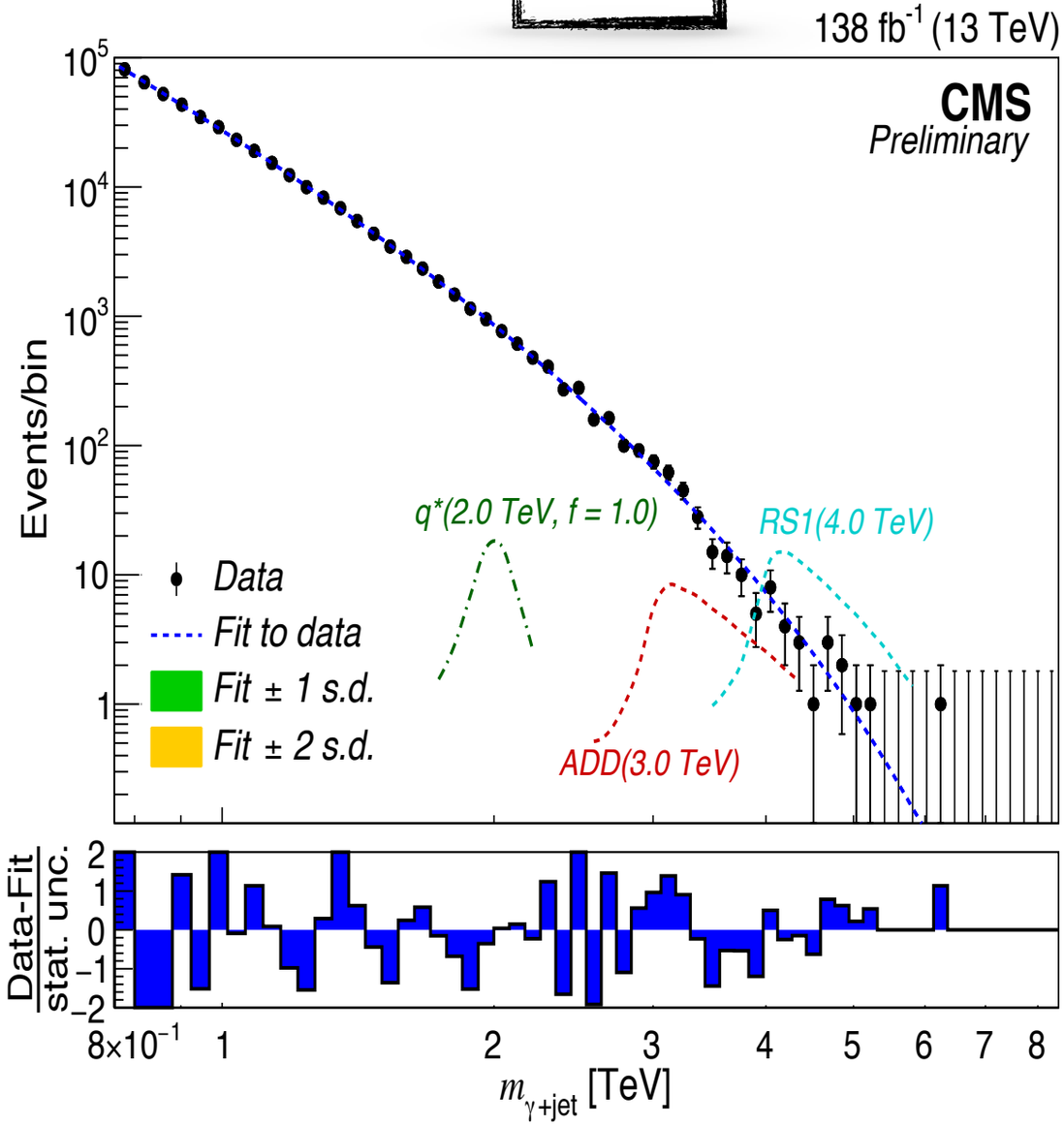
$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 ln(m/\sqrt{s})}}$$

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 ($M_{\gamma+jet}$ = 2TeV)
  - QBH (ADD $M_{\gamma+jet}$ = 3TeV and RS1 $M_{\gamma+jet}$ = 4TeV)

New!!



Systematic Uncertainties

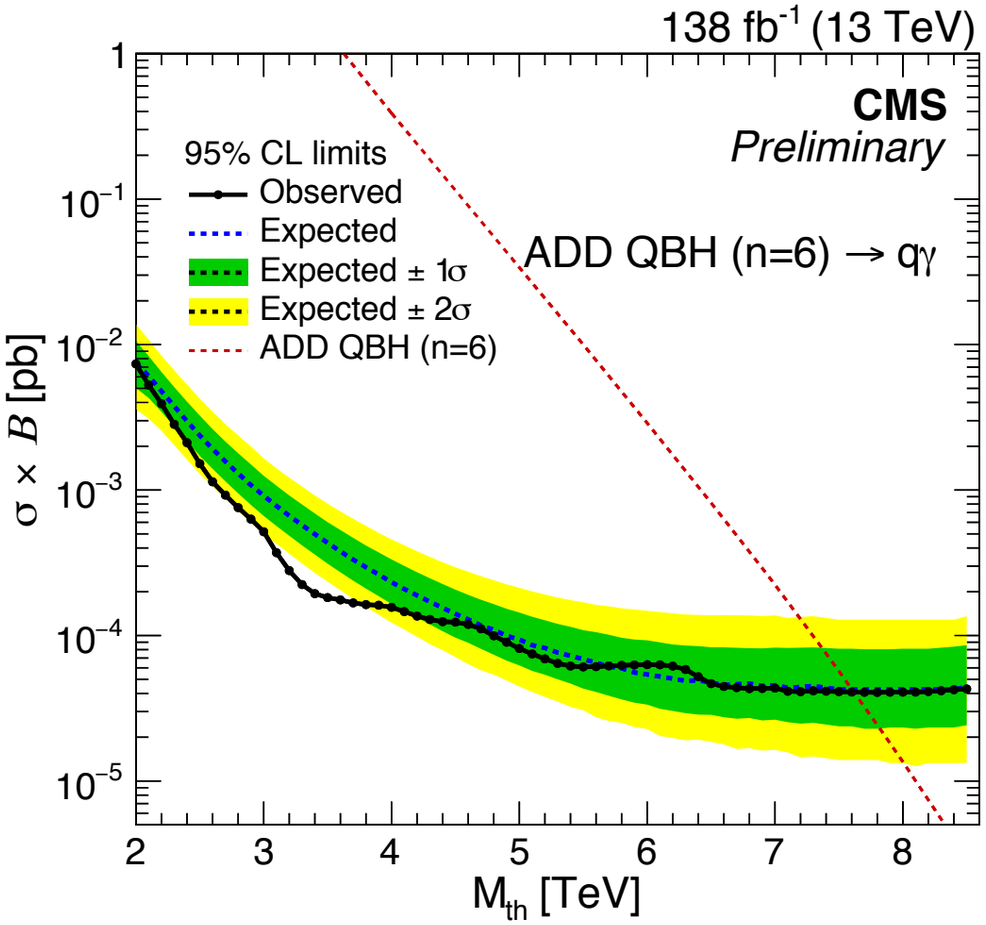
- The major systematics contribution comes from the uncertainties on the parameters in the background functional form.
- Bias study is also performed to account for the possible bias due to the choice of the functional form chosen
  - ➡ The systematic due to bias is negligible, compared to the statistical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

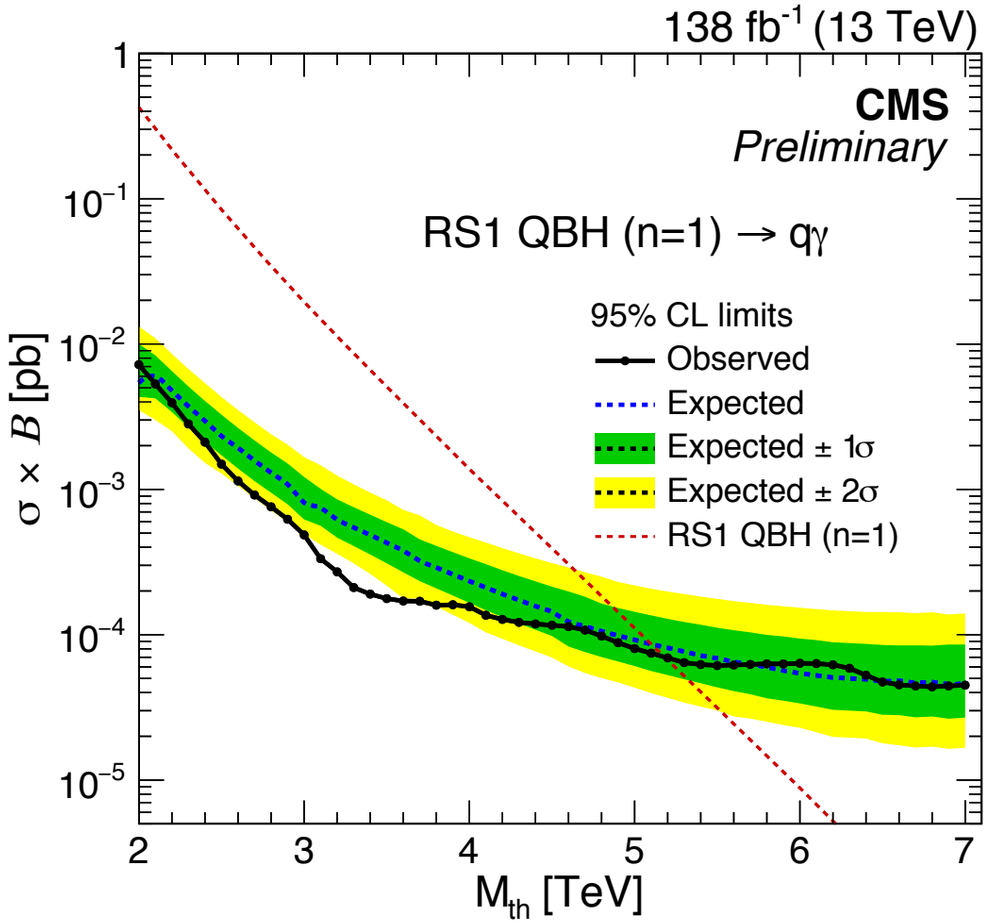
Results : QBH

- 95% upper limits on cross section and mass is measured and :

New!!

- **ADD model with 6 extra dimensions is excluded upto 7.5 TeV**
- **RS1 model with 1 extra dimension is excluded upto 5.2 TeV**

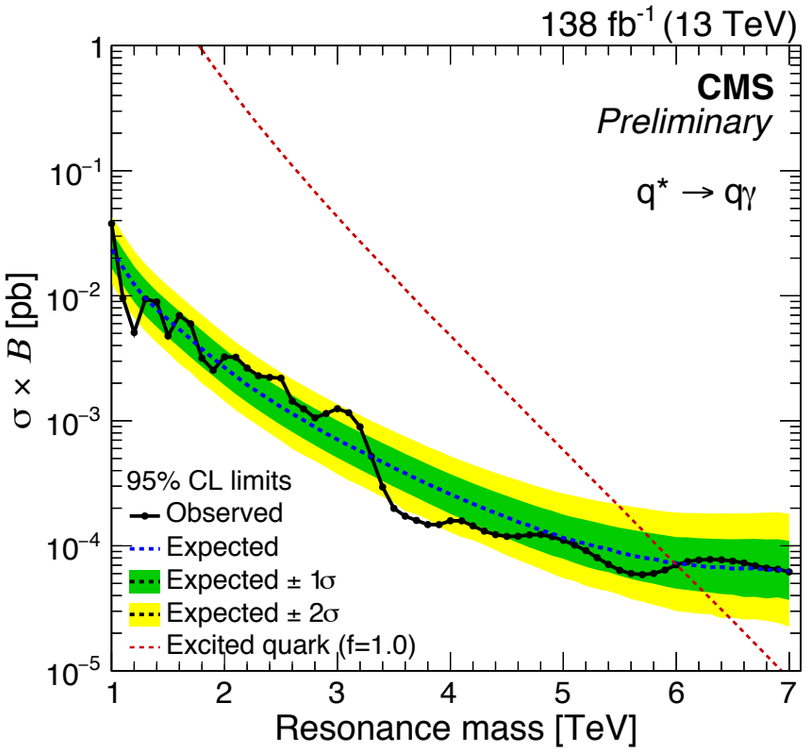


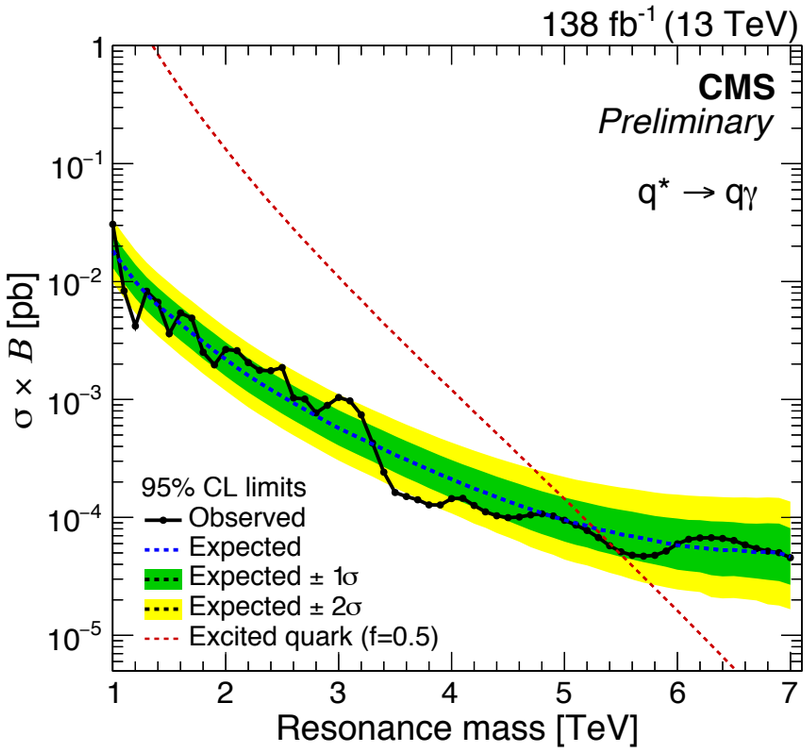


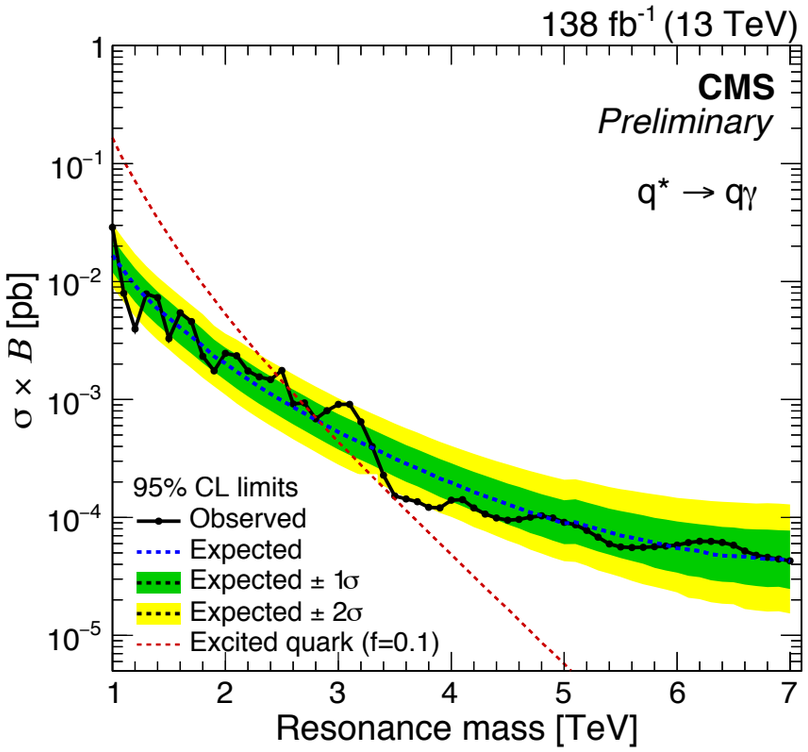
Results : q*

- 95% upper limits on cross section and mass for different coupling multiplier is measured and :
  - **q* for coupling f =1.0 is excluded upto 6.0 TeV**
  - **q* for coupling f =0.5 is excluded upto 5.4 TeV**
  - **q* for coupling f =0.1 is excluded upto 2.4 TeV**

New!!





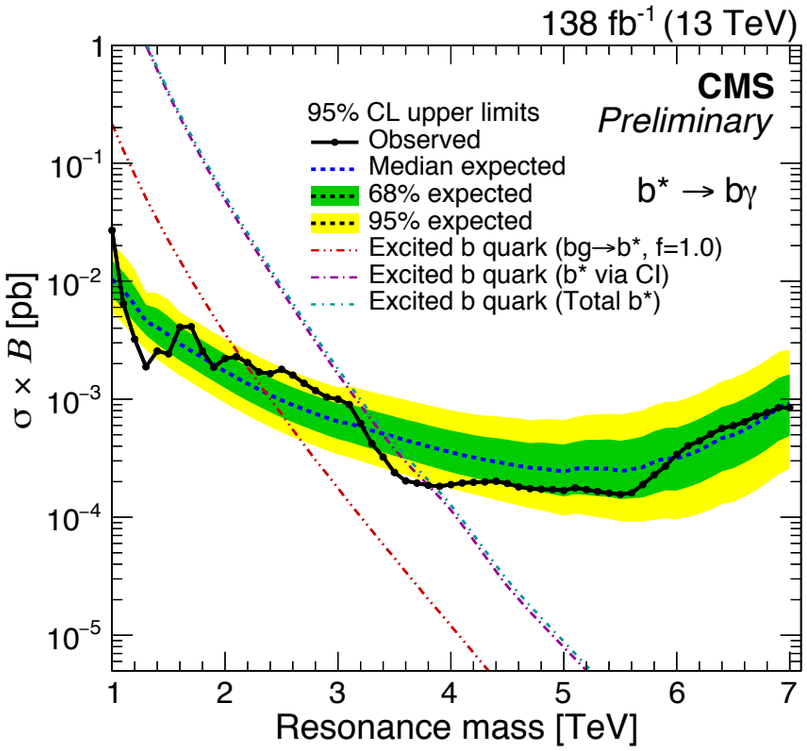


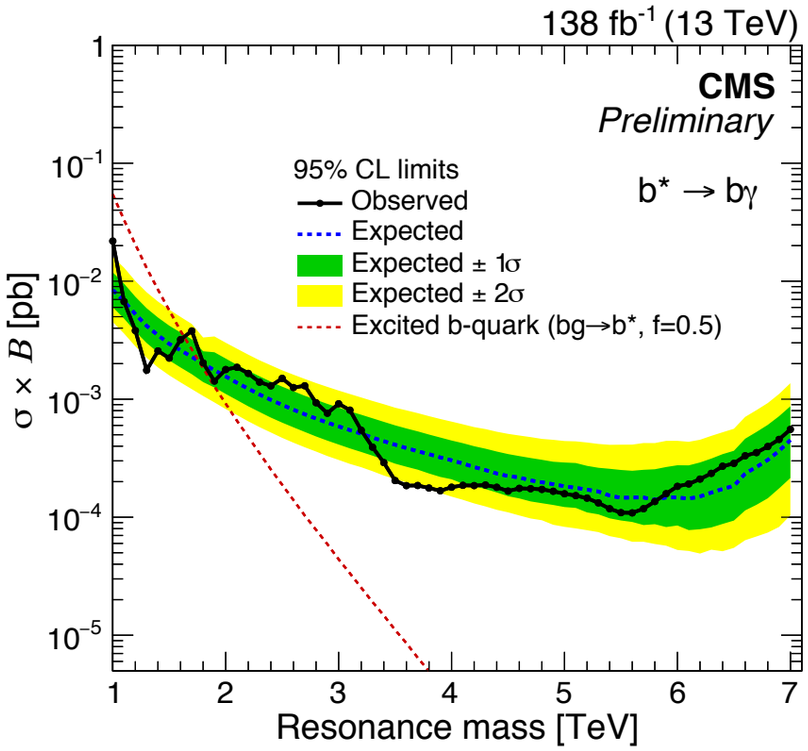
Results : b*

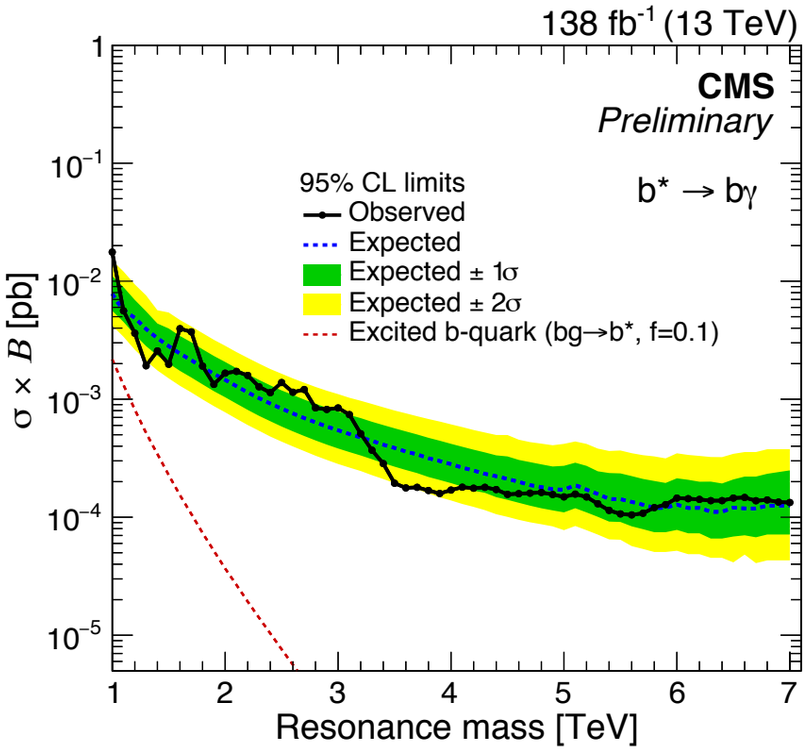
- 95% upper limits on cross section and mass for different coupling multiplier is measured and :
  - **b* for coupling f =1.0 is excluded upto 2.2 TeV**
  - **b* for coupling f =0.5 is excluded upto 1.6 TeV**
  - **b* for coupling f =0.1, the analysis could not reach the required sensitivity.**

New!!

- b* signal provided via gauge interaction and resonance component of b* produced via contact interaction exclude the signal upto 3.8 TeV with both processes combined.







Summary

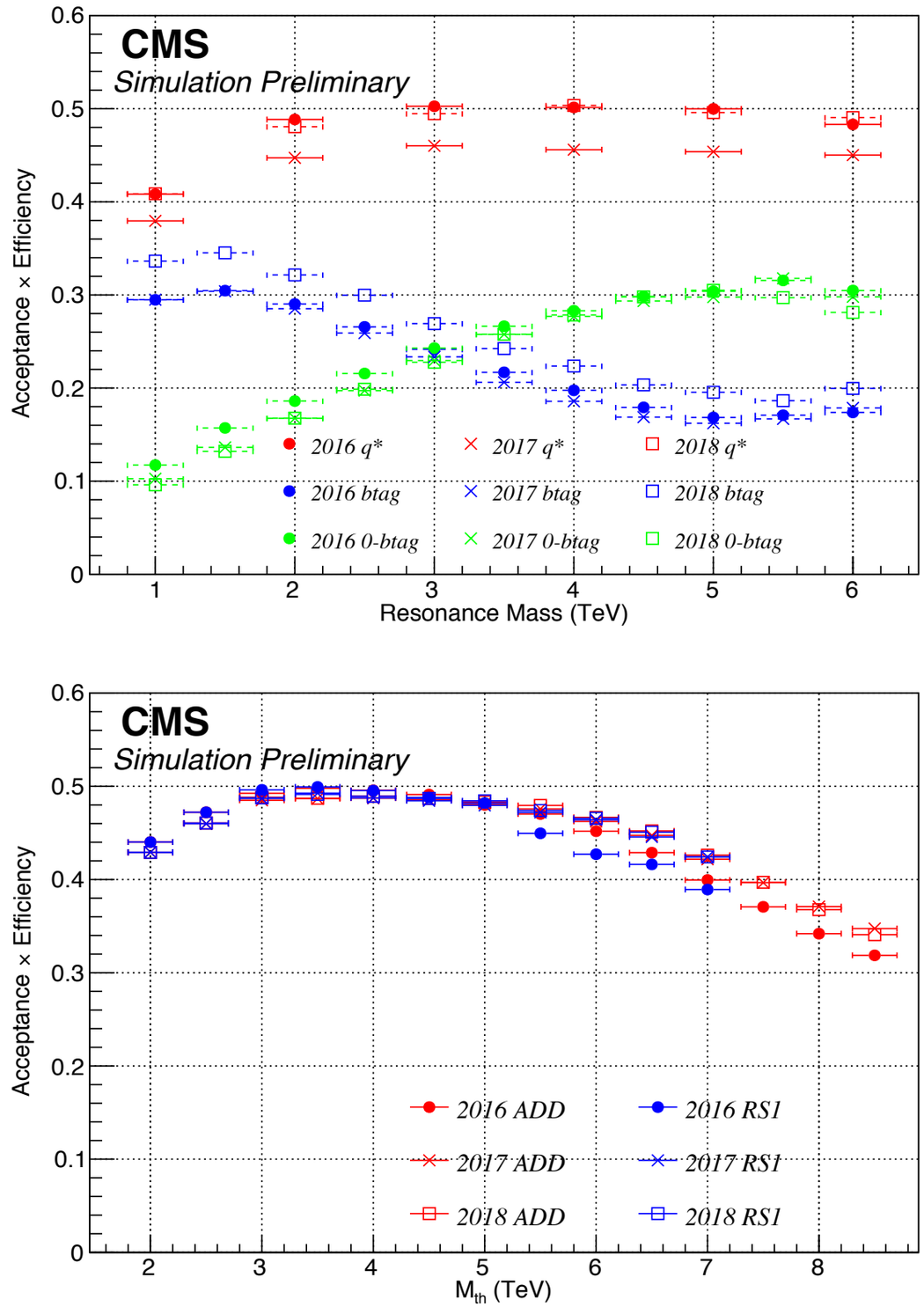
- The search for excited state of light and heavy flavor of quarks is performed using CMS data with full Run2 data.
- The possibility of Quantum Black hole at the LHC and decaying to two particle state is also considered.
- Results are consistent with the SM expectations. No significant deviation is observed.
- **All results are featured in the preliminary result PAS_EXO_20_012**

Thank you for attention !!!

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 36 fb^{-1}, 42 fb^{-1} and 59 fb^{-1} respectively.



Signal, Data and Background

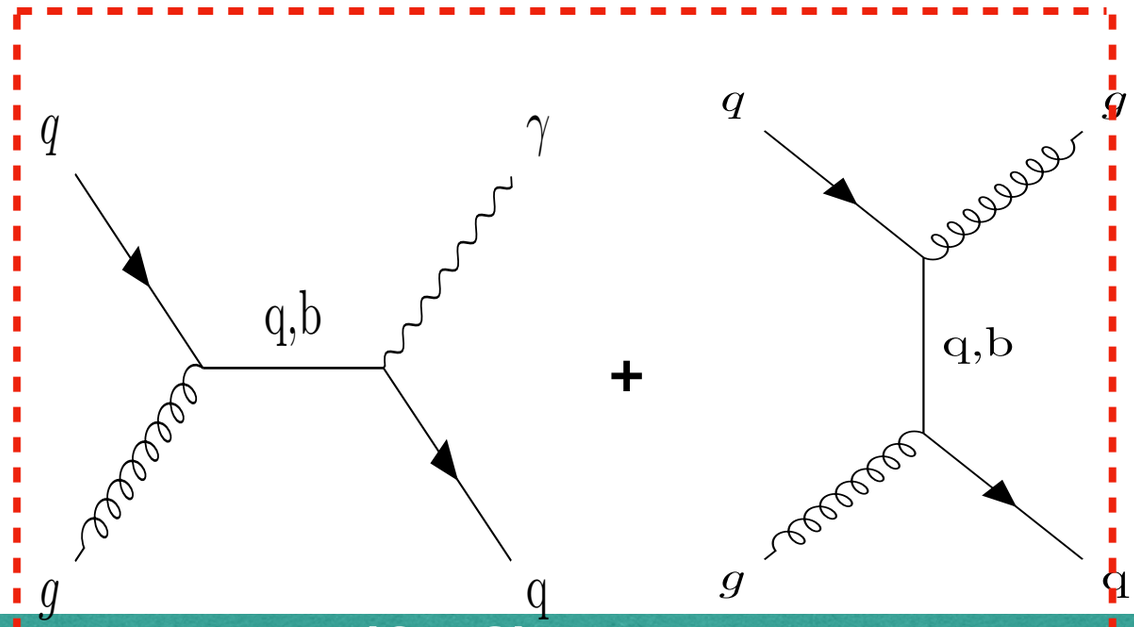
Data : CMS full RunII data corresponding to luminosity 138 fb^{-1}

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