# Resonance Search for Quark Excitation with the CMS Experiment

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The poster presents a search for excited quarks (q*) decaying into a γ + jet final state in pp collisions at √s = 8 TeV. The search is done with the data taken by the CMS experiment at the LHC corresponding to an integrated luminosity of 19.7 $fb^{-1}$. We find no deviation from the Standard Model predictions and evaluate the 95% CL upper limits on cross section times branching fraction as a function of excited quark mass ($M_{q^*}$). Limits on excited quarks are presented as a function of their mass and coupling strength; masses below 3.5 TeV are excluded at 95% CL for unit couplings to their standard model partners.

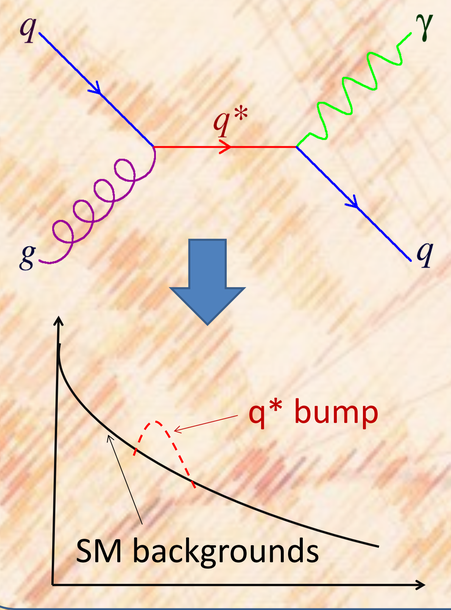
## Introduction

- Compositeness models : Possible explanation to mass hierarchy in quarks and leptons.
- Excited states → Signal of composite structure.
- The interaction of excited states with SM partners is given by Lagrangian,

$$\mathcal{L}_{\text{int}} = \frac{1}{2\Lambda}\overline{q_R^*}\sigma^{\mu\nu}\left[\sum_i g_i b_i T_i^a G_{i\mu\nu}^a\right]q_L + h.c.$$

- Λ - Compositeness scale .
- $f_s$, $f$, $f'$ – Coupling multipliers to SU(3), SU(2) and U(1) gauge field-strength tensors.

## What do we expect ?



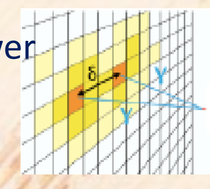

**Signal**
- ✓ Excited quarks (q* → γ + jet)
- ✓ Assumptions : Compositeness scale, Λ = $M_{q^*}$
- ✓ $f_s = f = f'$
- ✓ Considered $f$ = 0.5 and 1.0 scenarios
- ✓ Studied LO PYTHIA samples

**Backgrounds**
- ✘ Standard model γ + jet (PYTHIA × 1.3*).
- ✘ Di-jet final state : jet faking photon (PYTHIA × 1.3*).
- ✘ γ + W/Z : W/Z decays to a pair of jets.

*k-factor = 1.3

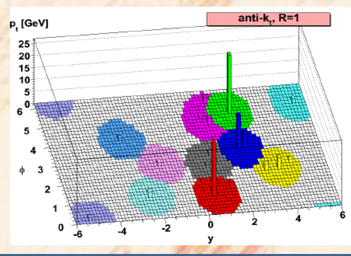
## What events do we select ?

- Single photon trigger with $p_T^\gamma$ > 150 GeV
- A good primary vertex
  - |z| < 24 cm from the center of the detector
  - Tranverse distance from z-axis < 2cm
  - Number of degree of freedom > 4
- Photon identification
  - Ratio of the single closest HCAL tower energy to the ECAL energy < 0.05
  - $\sigma_{i\eta i\eta}$ < 0.011
- Photon isolation
  Requiremnt on $\Sigma p_T$ of photons, charged and neutral hadrons in hollow cone around photon candidate




$\sigma_{i\eta i\eta}$ : energy weighted width of crystals in eta. Distinguishes photons from jets

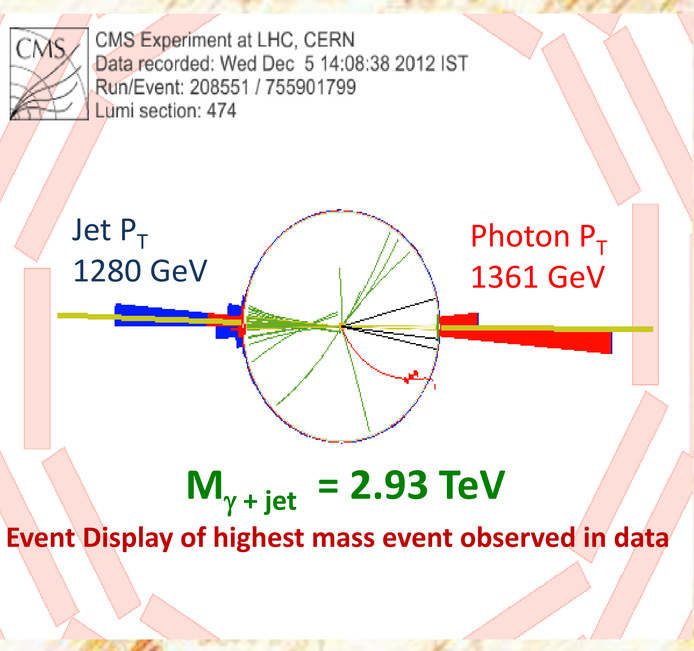
- Photon $p_T$ > 170 GeV & |η| < 1.44
- Jet selection
  - Anti-kt5 Particle flow jets
  - ΔR(γ, jet) > 0.5; ΔR = $\sqrt{(\Delta\eta^2 + \Delta\varphi^2)}$
  - Jet $p_T$ > 170 GeV
  - Jet |η| < 3.0
- Δφ (γ, jet) > 1.5
- Δη (γ, jet) < 2.0
- $M_{\gamma + jet}$ > 560 GeV




**Efficiency for q* signal**

| Selection | q* = 1 TeV |
|---|---|
| Photon ID | 70.2 % |
| $P_T^\gamma$ > 170 GeV | 67.2 % |
| $\|\eta^\gamma\|$ < 1.44 | 65.0 % |
| $P_T^{jet}$ > 170 GeV | 63.6 % |
| $\|\eta^{jet}\|$ < 3.0 | 63.4 % |
| Δφ(γ, jet) > 1.5 | 63.3 % |
| Δη(γ,jet) < 2.0 | 54.6 % |
| $M_{\gamma+jet}$ > 560 GeV | 54.2 % |

## What do we observe ?



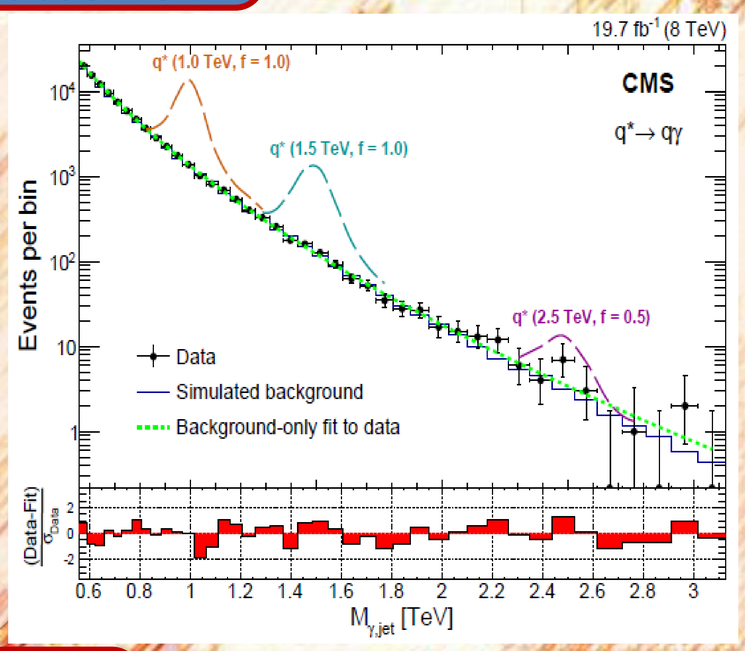

**$M_{\gamma + jet}$ = 2.93 TeV**

**Event Display of highest mass event observed in data**

- ✓ Invariant mass distribution of the γ + jet events in data – compared to MC simulations after final selection
- ✓ Background modelling from data.
- ✓ Fit to a standard parameterization

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

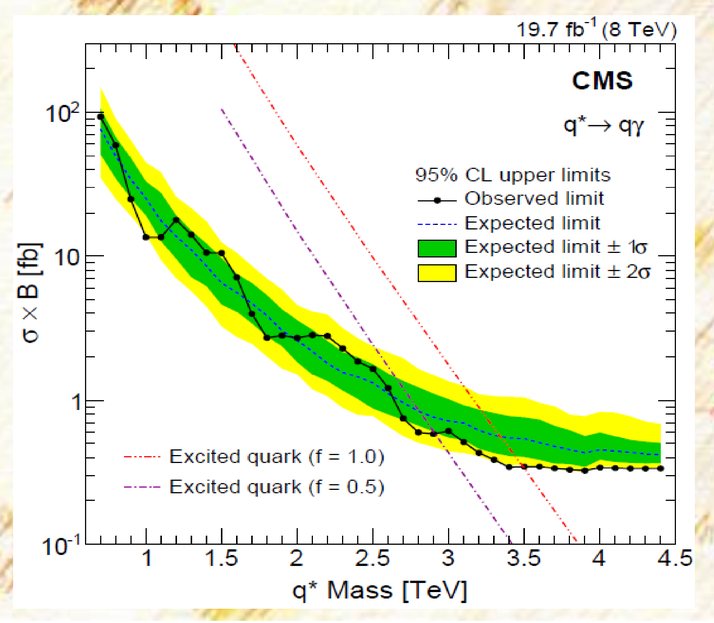
- No Excess observed → Set Limits
- Upper limits on cross section – evaluated using Bayesian formalism & binned likelihood.

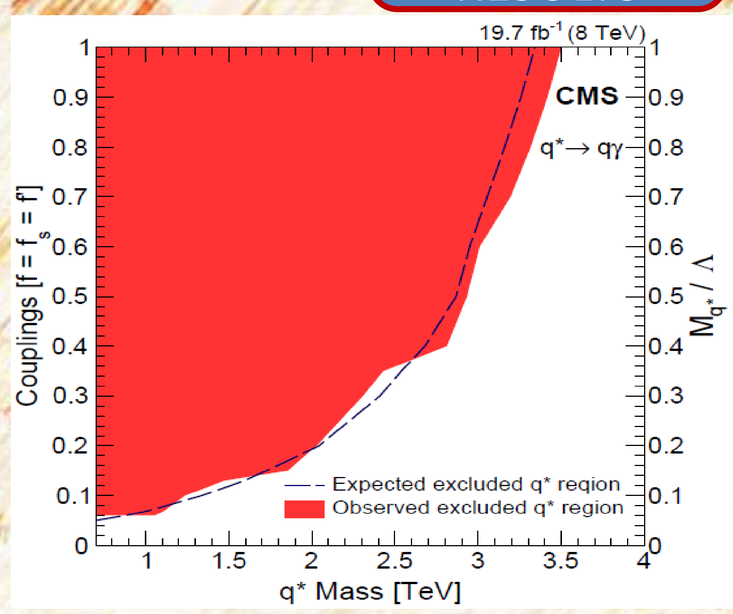



- ✓ Background shape uncertainty – evaluated by marginalizing the fit parameters with a flat prior
- ✓ Uncertainty on signal –

| Major Sources | Uncertainty |
|---|---|
| Jet energy resolution | 10% |
| Photon energy resolution | 0.5% |
| Jet energy scale | 0.5-0.7% |
| Photon energy scale | 0.7% |
| Photon ID | 3-4% |
| Luminosity | 2.6% |

## RESULTS




## Summary

- A search for excited quarks decaying to a photon and jet is presented.
- Set 95% CL upper limits on σ × BR for q* → γ+jet.
- We exclude **0.7 < $M_{q^*}$ < 3.5 TeV** for $f$ = 1.0.
- **For the first time at LHC, Search sensitivity has been investigated for coupling strength less than unity.**
- **Present exclusion at 95% CL as function of coupling strength and q* mass.**

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CMSPublicPhysicsResultsEXO-13-003

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