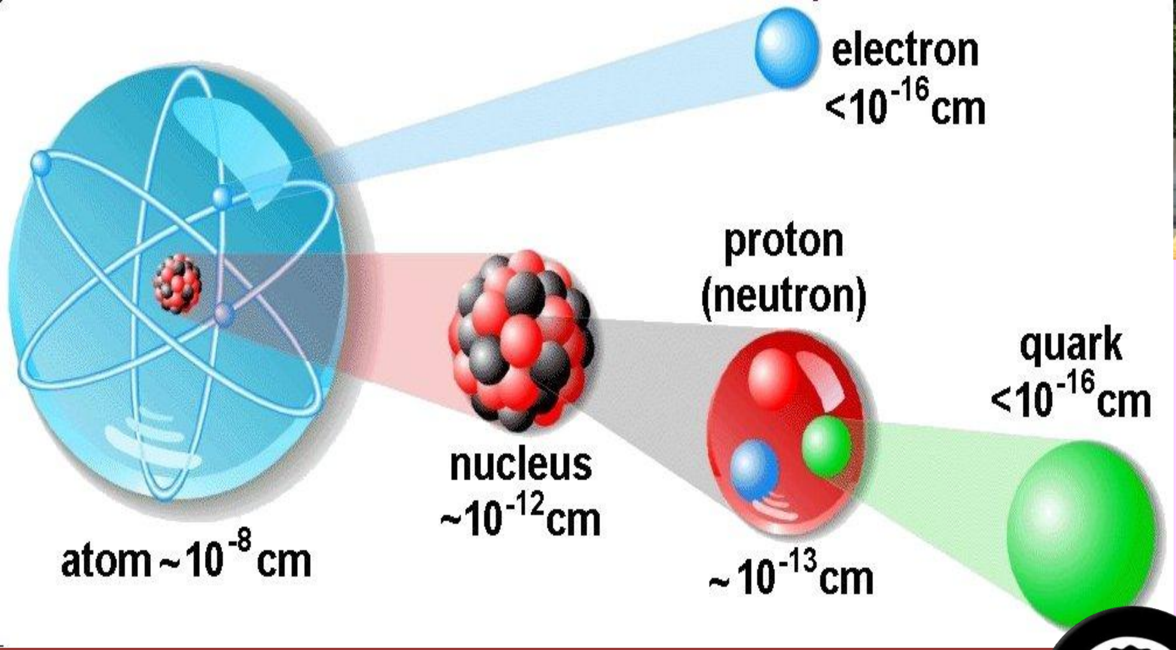

Search for Quark Compositeness

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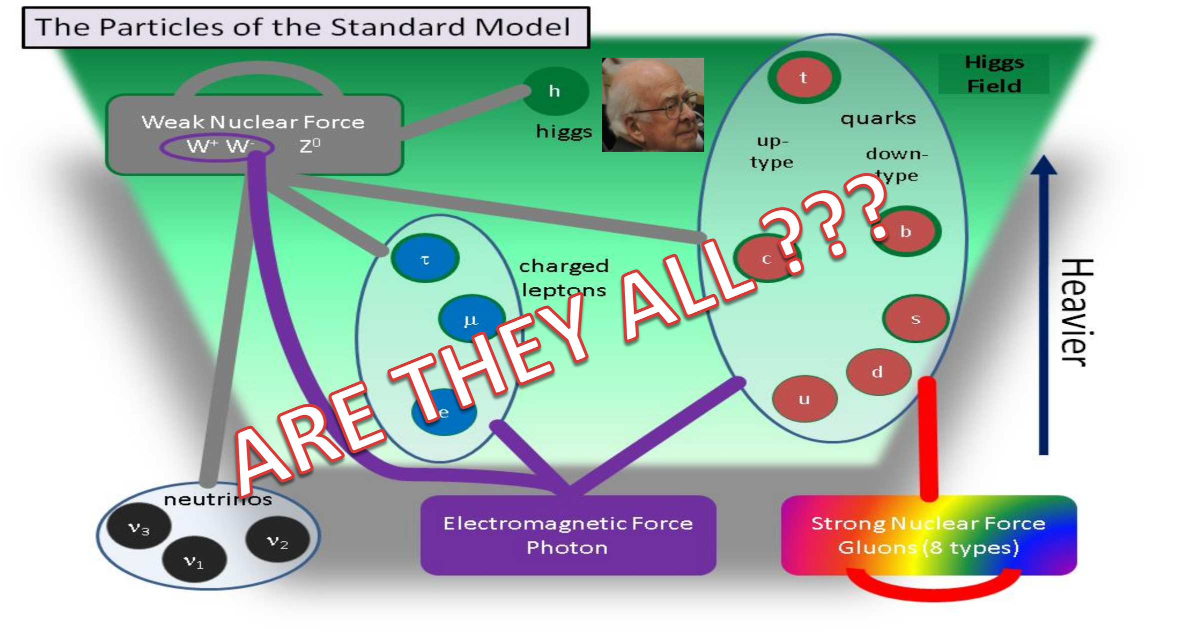

ABSTRACT: The study for excited states of quarks in the **$pp \rightarrow q^* \rightarrow \gamma$ + jet** channel at the CMS experiment at the LHC is presented. Basic motivation for the search comes from the fact that we have always found something more fundamental when probed at higher energies. LHC opens large frontiers for new physics, compositeness being one of them.

Motivation

✓ Standard Model : Most successful theory of particle physics, thoroughly tested at the experimental level. But still it has some open questions :

- ➢ Hierarchy problem
- ➢ Lots of free parameters & many more.

✓ Definition of Fundamental stays tentative ~ Energy Scale

✓ TeV Scale→Structure of Quarks & Leptons.

✓ LHC colliding pp@8TeV can always surprise us with some new particles.

Model

✓Search for the structure of matter has resulted in various theoretical speculations.

✓Additional colored fermions is one of those-

➢ Can result in Kaluza-Klein excitations, or

➢ As excited states in wherein the quarks themselves are composites, or

➢ Theories with extended gauge symmetry.

The presence of such fermions (q*) can be manifested in γ+jet final state at the LHC.

Effective Lagrangian

$$\mathcal{L}_{int} = \frac{1}{2\Lambda}\bar{q}^*_R\left[\sum_i g_i b_i T^a_i G^a_{i\mu\nu}\right] q_L + h.c.$$

$$\left.\frac{d\sigma}{d\hat{t}}\right|_{qg\to q\gamma} = \frac{-\pi\alpha\alpha_s e_q^2}{3\hat{s}^2}\left[C_{sm} + 2\frac{f_1 f_3}{\Lambda^2}C_I + \frac{f_1^2 f_3^2}{\Lambda^4}C_Q\right]$$

$$C_{sm} \equiv \frac{\hat{u}}{\hat{s}} + \frac{\hat{s}}{\hat{u}}$$

$$C_I \equiv \frac{\hat{s}^2(\hat{s}-M_{q^*}^2)}{(\hat{s}-M_{q^*}^2)^2+\Gamma^2 M_{q^*}^2}\left(1+\frac{\hat{s}}{\Lambda^2}\right)^{-(n_1+n_3)} + \frac{\hat{u}^2}{\hat{u}-M_{q^*}^2}\left(1-\frac{\hat{u}}{\Lambda^2}\right)^{-(n_1+n_3)}$$

$$C_Q \equiv (\hat{s}\hat{u}+M_{q^*}^2 t)\left[\frac{\hat{s}^2}{(\hat{s}-M_{q^*}^2)^2+\Gamma^2 M_{q^*}^2}\left(1+\frac{\hat{s}}{\Lambda^2}\right)^{-2(n_1+n_3)} + \frac{\hat{u}^2}{(\hat{u}-M_{q^*}^2)^2}\left(1-\frac{\hat{u}}{\Lambda^2}\right)^{-2(n_1+n_3)}\right] + 2M_{q^*}^2\frac{\hat{s}\hat{t}\hat{u}}{\hat{u}-M_{q^*}^2}\frac{(\hat{s}-M_{q^*}^2)}{(\hat{s}-M_{q^*}^2)^2+\Gamma^2M_{q^*}^2}\left[\left(1+\frac{\hat{s}}{\Lambda^2}\right)\left(1-\frac{\hat{u}}{\Lambda^2}\right)\right]^{-(n_1+n_3)}$$

$$\left.\frac{d\sigma}{d\hat{t}}\right|_{q\bar{q}\to g\gamma} = \frac{8\pi\alpha\alpha_s e_q^2}{9\hat{s}^2}\left[B_{sm} - 2\frac{f_1 f_3}{\Lambda^2}B_I + \frac{f_1^2 f_3^2}{\Lambda^4}B_Q\right]$$

$$B_{sm} \equiv \frac{\hat{u}}{\hat{t}} + \frac{\hat{t}}{\hat{u}}$$

$$B_I \equiv \frac{\hat{t}^2}{\hat{t}-M_{q^*}^2}\left(1-\frac{\hat{t}}{\Lambda^2}\right)^{-(n_1+n_3)} + \frac{\hat{u}^2}{\hat{u}-M_{q^*}^2}\left(1-\frac{\hat{u}}{\Lambda^2}\right)^{-(n_1+n_3)}$$

$$B_Q \equiv \hat{t}\hat{u}\left[\frac{\hat{t}^2}{(\hat{t}-M_{q^*}^2)^2}\left(1-\frac{\hat{t}}{\Lambda^2}\right)^{-2(n_1+n_3)} + \frac{\hat{u}^2}{(\hat{u}-M_{q^*}^2)^2}\left(1+\frac{\hat{s}}{\Lambda^2}\right)^{-2(n_1+n_3)}\right] + M_{q^*}^2\hat{s}\left[\frac{\hat{t}}{\hat{t}-M_{q^*}^2}\left(1-\frac{\hat{t}}{\Lambda^2}\right)^{-(n_1+n_3)} + \frac{\hat{u}}{\hat{u}-M_{q^*}^2}\left(1+\frac{\hat{s}}{\Lambda^2}\right)^{-(n_1+n_3)}\right]^2$$

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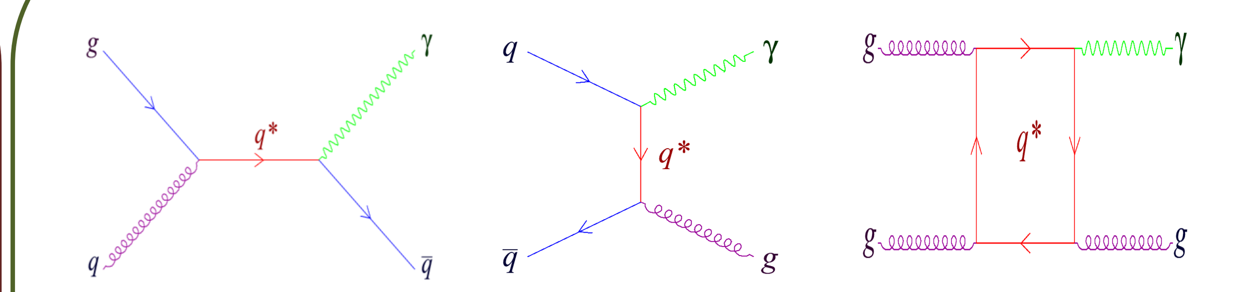
q* Signal



Backgrounds

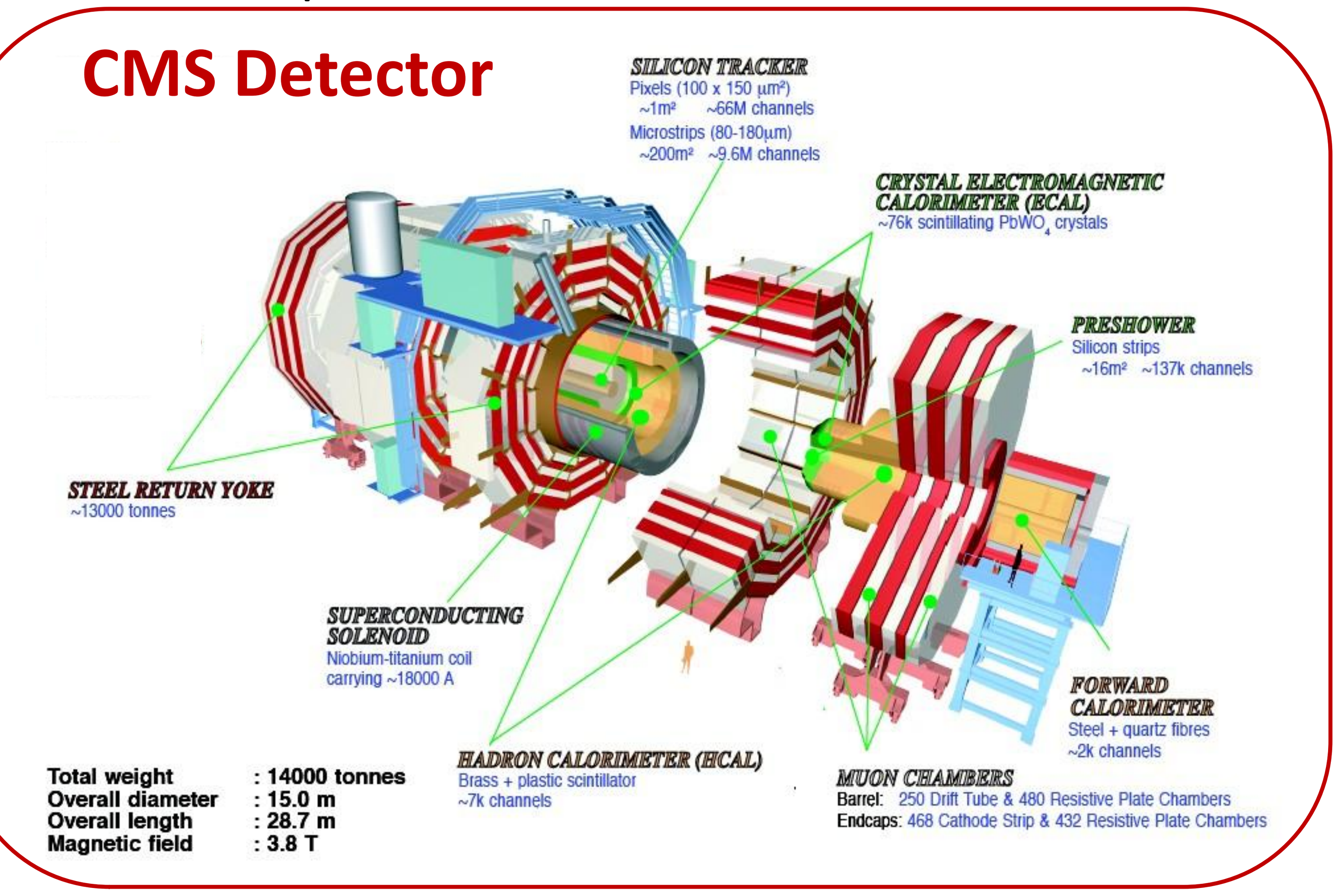
✓ SM γ+jet

✓ Dijet final state: Jet faking photon.

✓ γ+W/Z where W/Z decays to a pair of jets

✓ γ+Dijet : one of the jet is either lost or mismeasured.

CMS Detector



Sub-Detectors Resolutions

$\|\eta\|$ < 2.5 : Tracker
$\sigma/p_T \approx 10^{-4}\ p_T \oplus 0.005$ (TeV)
$\|\eta\|$ < 4.9 : EM Calorimeter
$\sigma/E \approx 0.03/\surd E \oplus 0.003$ (GeV)
$\|\eta\|$ < 4.9 : Had Calorimeter
$\sigma/E \approx 1.0/\surd E \oplus 0.050$ (GeV)
$\|\eta\|$ < 2.6 : Muon Spectrometer
$\sigma/p_T \approx 0.10$ (GeV)(1 TeV Muons)

Search

✓ We define the model by one parameter, the excited-quark mass M_{q^*}.

✓If the compositeness scale, $\Lambda = M_{q^*}$, then SU(3), SU(2), and U(1) coupling multiplier $f_s = f = f' = 1$.

✓Used Pythia simulated signal and background samples.

✓Generated signal with different mass points (M_{q^*} = 1, 1.2, 1.5, 2, 2.5, 3, 3.5 TeV).

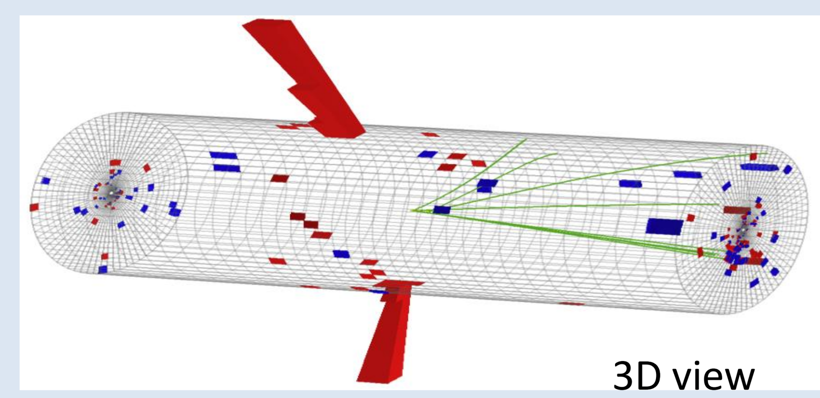
✓Considered dominant backgrounds(γ+jet & Dijet)

Photons at CMS

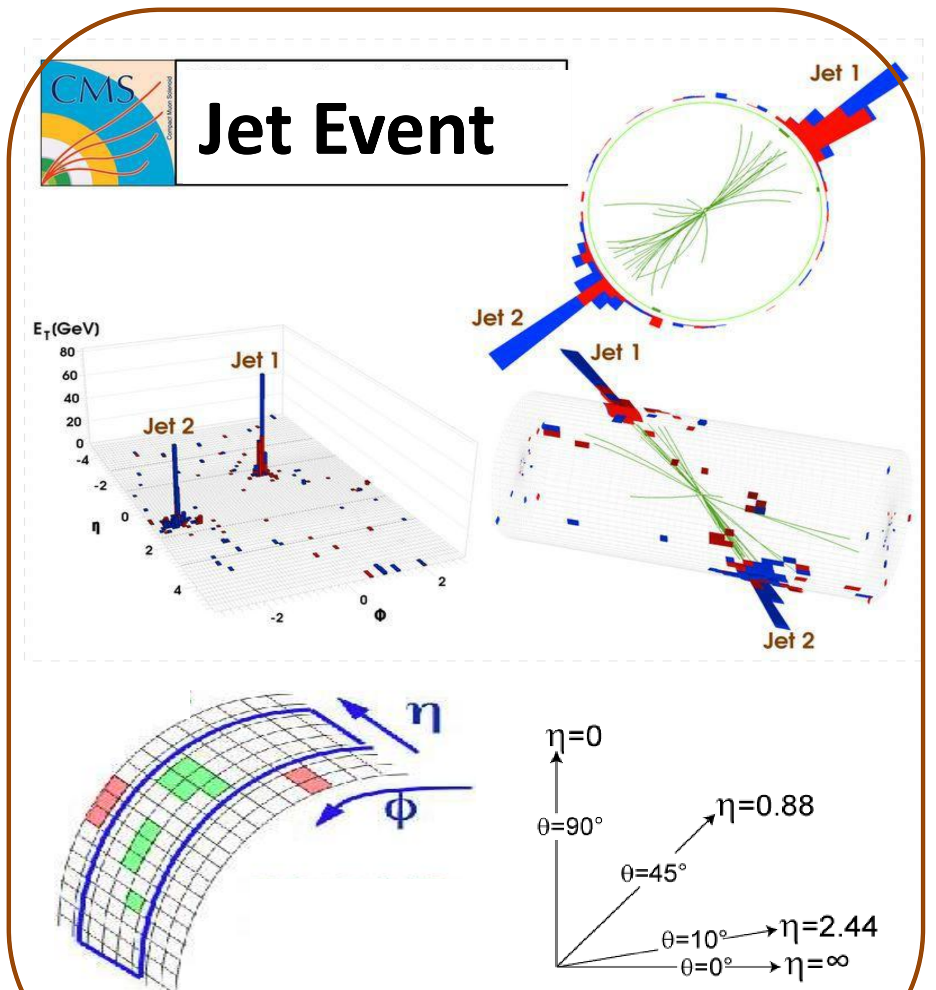
✓ Photons deposit almost all of their energy in ECAL.

✓Are NOT expected to leave any track.

✓ Converted photons spread energy in φ-plane due to magnetic field.



3D view



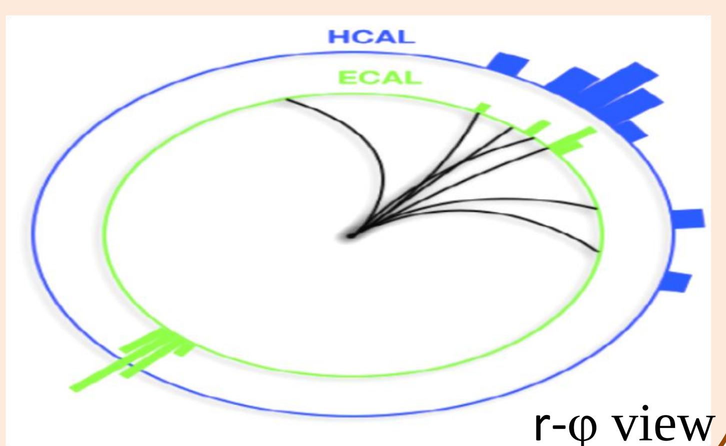
Coordinate system

Photon+Jet

✓ High P_T photons & jets are selected.

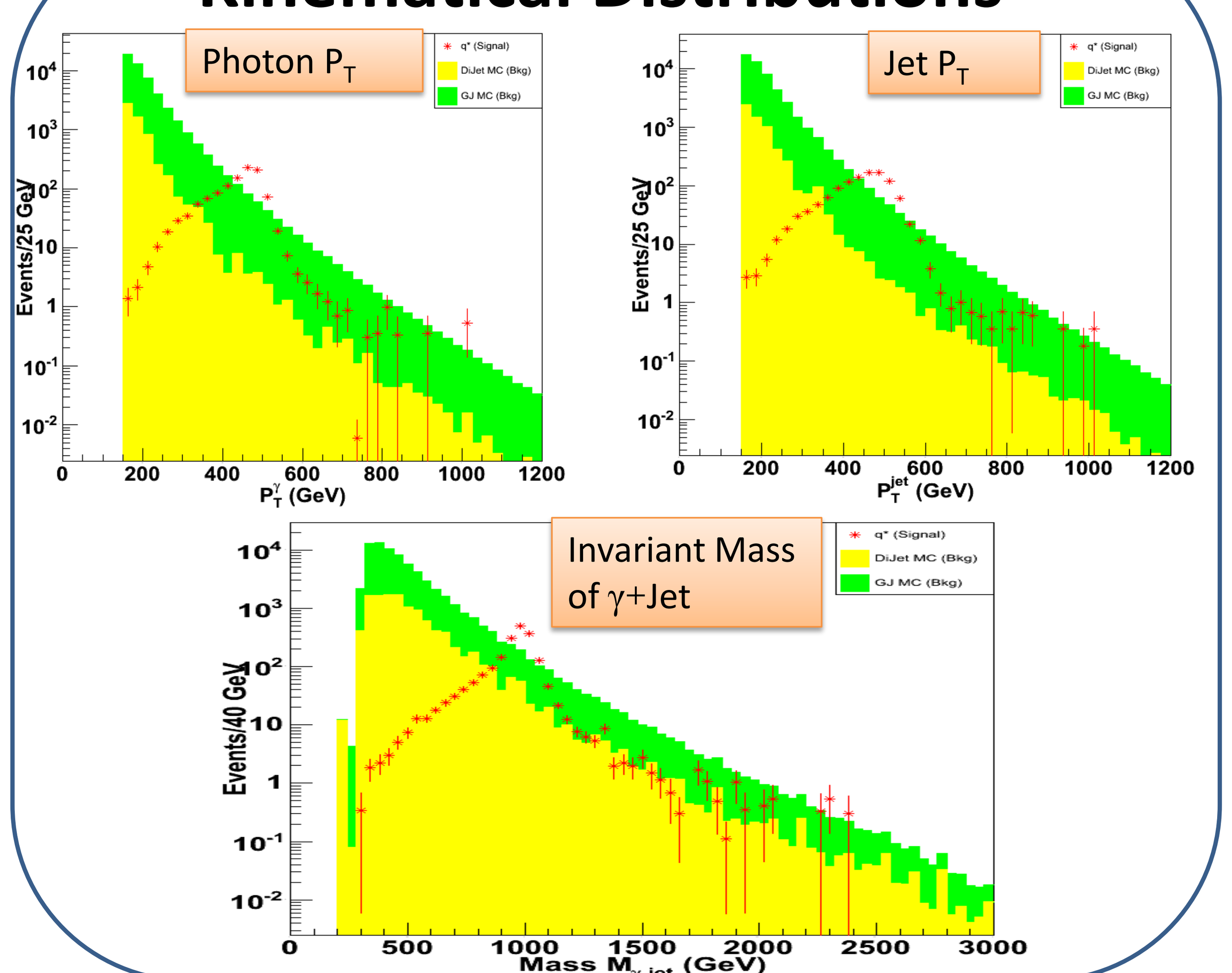
✓ Expected mostly in Barrel.

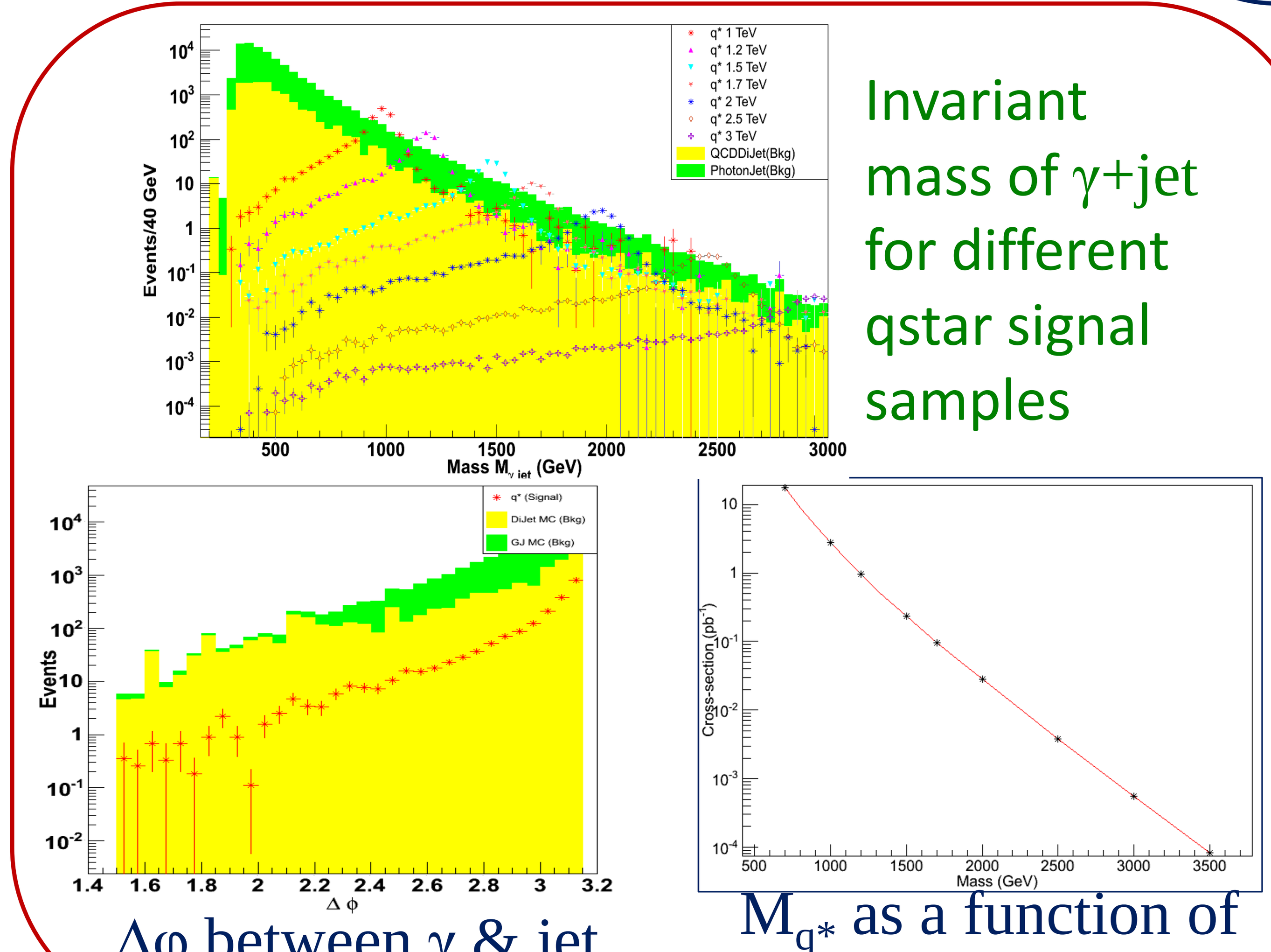
✓ Both must be back-to-back.



r-φ view

Kinematical Distributions





Invariant mass of γ+jet for different qstar signal samples

$\Delta\varphi$ between γ & jet

M_{q^*} as a function of cross section

References :

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