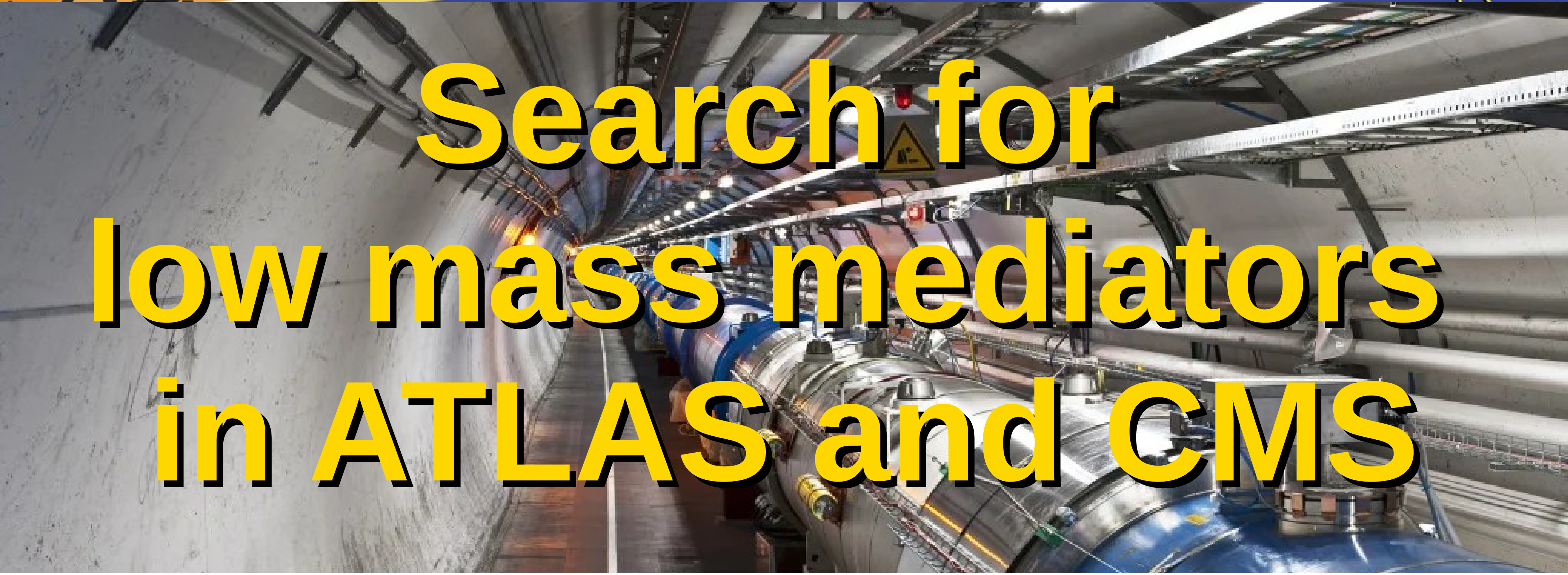
LHCP2021

Online

The Ninth Annual Conference on Large Hadron Collider Physics



Search for low mass mediators in ATLAS and CMS

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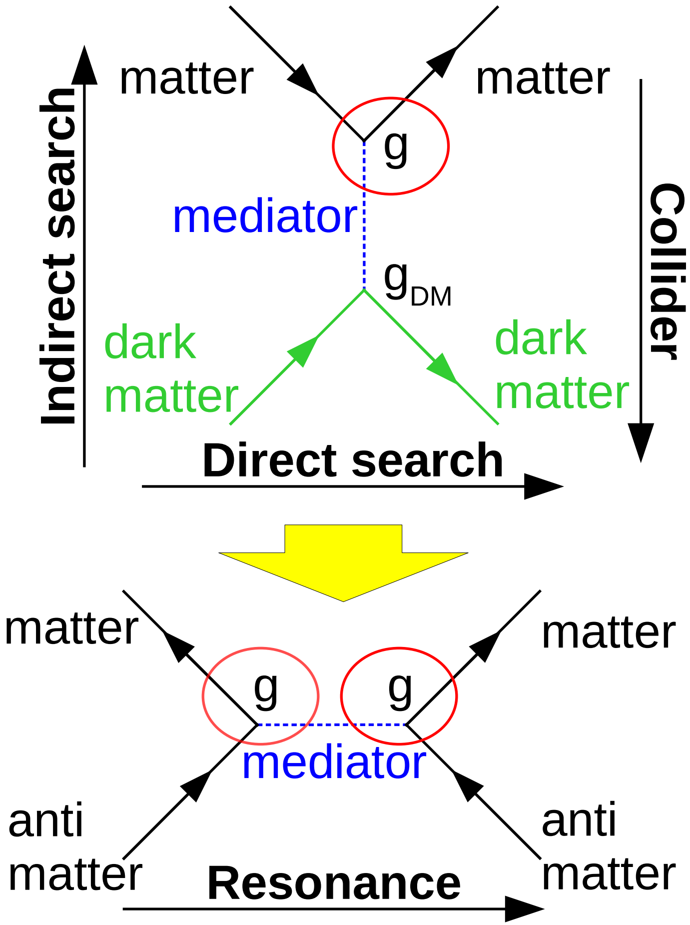
on behalf of the ATLAS and CMS Collaborations

INFN PISA

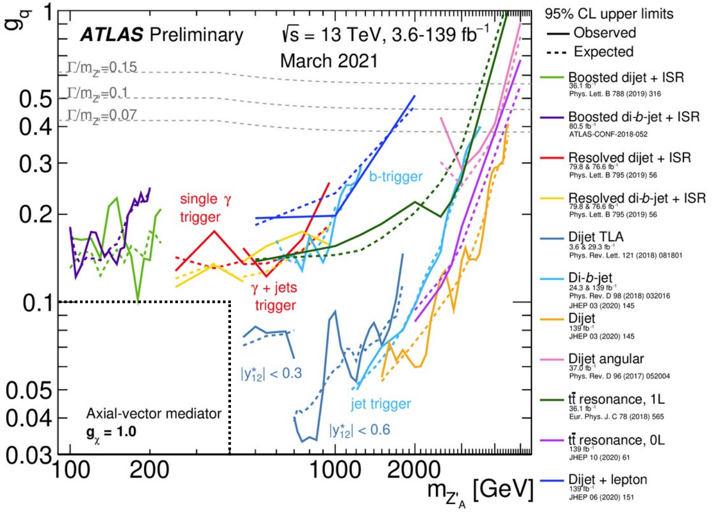
Introduction

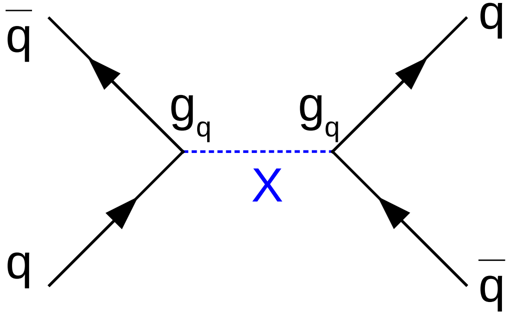
- Dark Matter can be detected in very different channels.
- If Dark Matter was produced by matter annihilation (s-channel), the dark matter mediator can be observed also in the decay to matter particles.
- Strong exclusion limits are set on the leptonic interaction (LEP, LHC, …)
- The search qq → X → qq is a good probe to look for low-mass dark-matter mediators.



Introduction

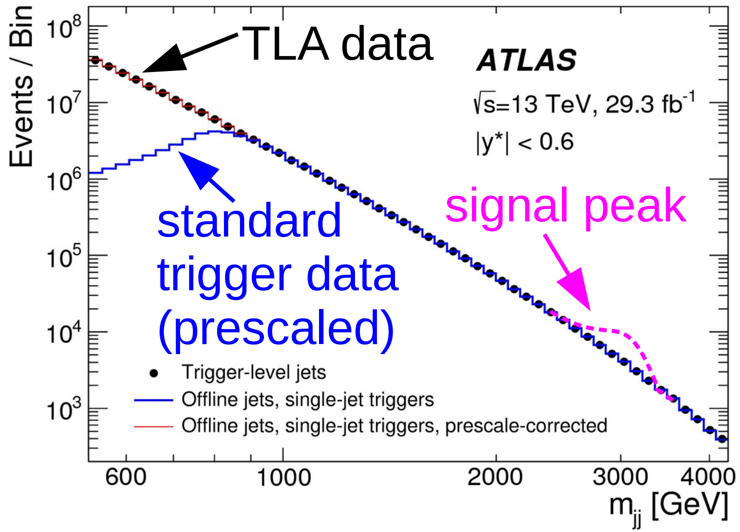
- The high energy and luminosity of the LHC pushed the exclusion limits towards larger mediators masses.
  - Dijet resonance search ($qq \to X \to qq$).
- The trigger rate limits make very challenging looking for low-mass resonances.
  - The 95% CL upper limit on the coupling (g) between quarks and the mediator is about 0.1 for $m_X < 400$ GeV.
- Special techniques are needed to explore the low-mass region.





Scouting & TLA

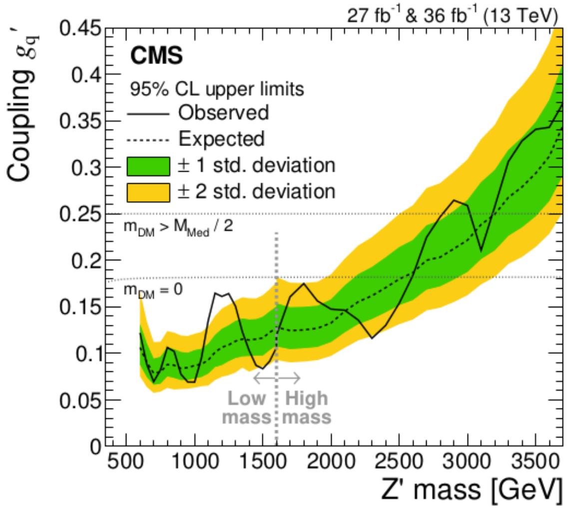
- **Way #1**: Data **Scouting** or **T**rigger **L**evel **A**nalysis: very high trigger rate saving only the jets reconstructed at trigger level instead of the full RAW event content
  - Eg. **10 Hz** x 1MB → **10 kHz** x 1kB.

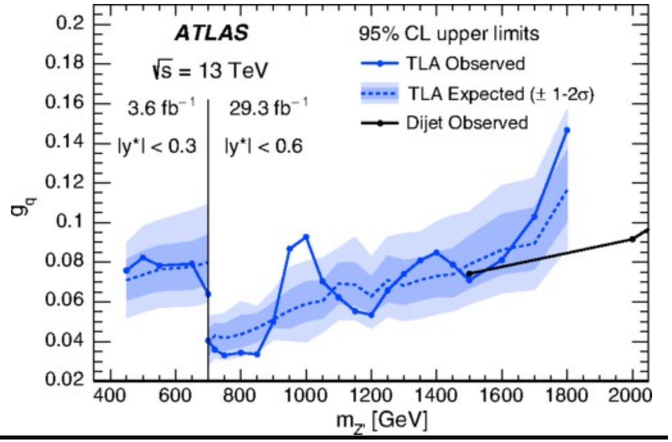


- **Pro**: lower trigger thresholds, no offline reconstruction.
- **Cons**: reprocessing not possible, poorer jet energy resolution.

Scouting & TLA

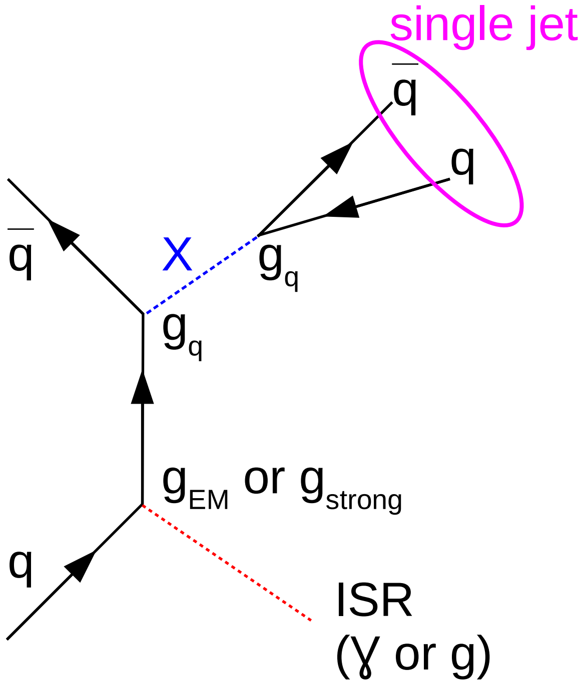
- The scouting & TLA allowed CMS and ATLAS to extend the dijet resonance search to lower mass.
  - CMS: 1.6 TeV → 600 GeV
  - ATLAS: 1.5 TeV → 700 GeV (450 GeV for low lumi data).





Boosted resonance

- **Way #2**: low-mass boosted resonance are reconstructed as a single energetic jet.
- The resonance is produced in association to a strong Initial State Radiation (ISR).
- The ISR can be either a photon or a jet and can be used to trigger the event.

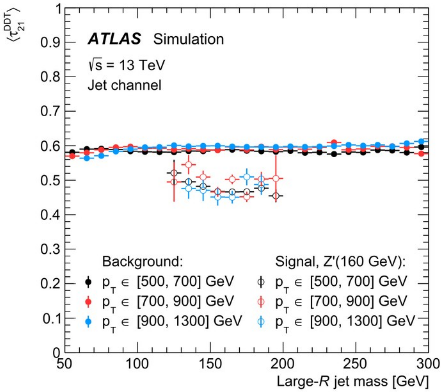


Boosted resonance (ATLAS)

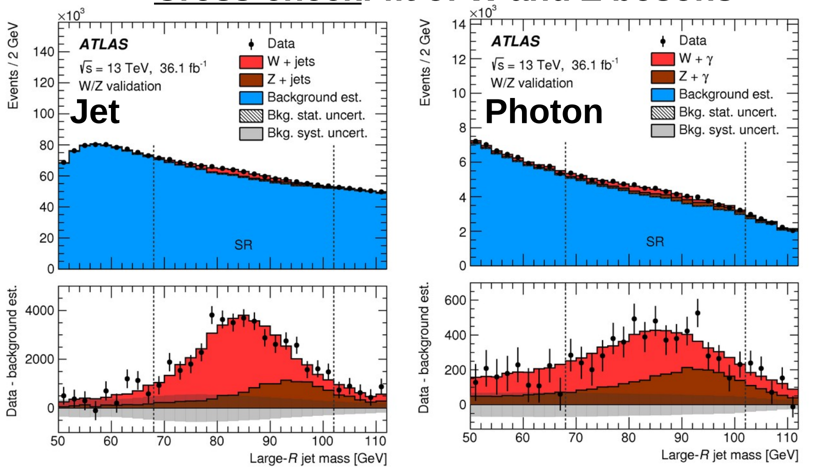
Phys. Lett. B 788 (2019) 316

- Data collected using a high p_T ISR:
  - Trigger: single photon p_T>140 GeV or jet p_T>380 GeV (offline selection photon p_T>155 GeV or jet p_T>420 GeV).
- Boosted resonance reconstructed as a jet with R=1.
  - Trimming against pile-up and soft radiation (k_T subjet R=0.2 and less of 5% p_T are dropped)
  - Main variable: τ_{21} , defined as the ratio τ_2/τ_1.
  - Designed decorrelated tagger (DDT) method
    - τ^{DTT}_{21} < 0.50 used to reduce background.
- Background:
  - V+jets/photon → simulation (NLO correction k-factor)
  - Multijet production → data driven from control region
    - Control region: τ^{DTT}_{21} > 0.50
    - Transfer factors obtained from side bands.

Decorrelated τ_{21} vs mass



Cross-check: fit of W and Z bosons



Boosted resonance (ATLAS)

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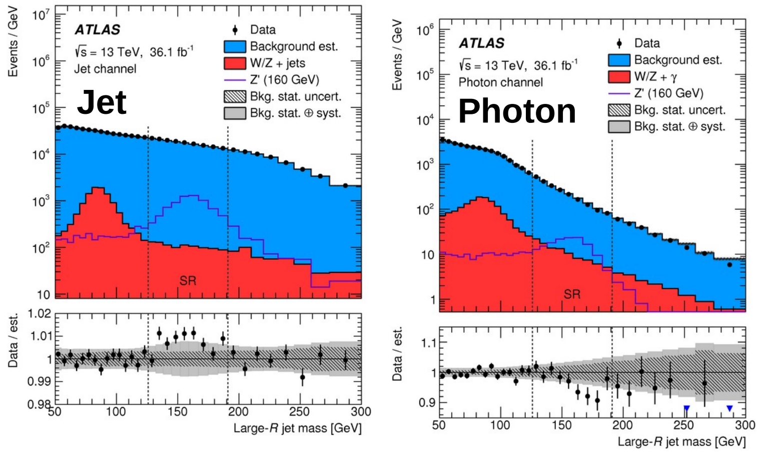
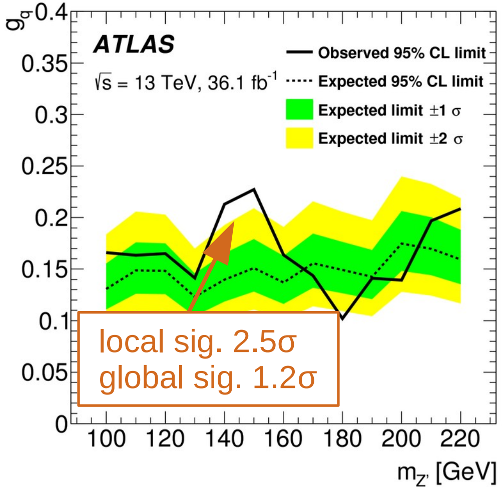
- Cross check, fit W/Z:
  - $\mu = 0.93 \pm 0.03\ (\text{stat}) \pm 0.24\ (\text{syst})$
  - $\mu = 1.07 \pm 0.13\ (\text{stat}) \pm 0.35\ (\text{syst})$
- Jet channel has the larger sensitivity.
- 95% CL upper limits set in the range 100 – 220 GeV.
  - No significant excess observed.

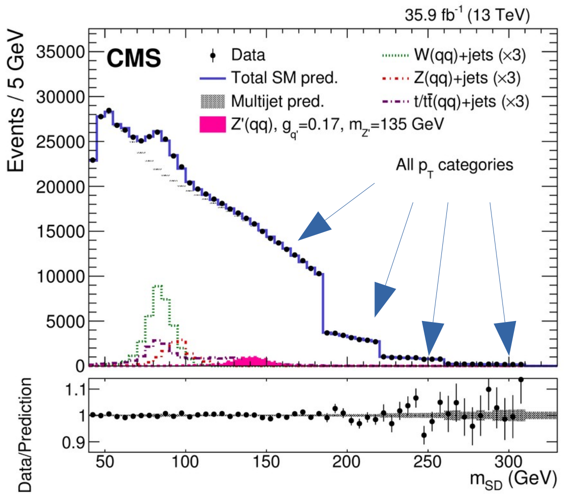


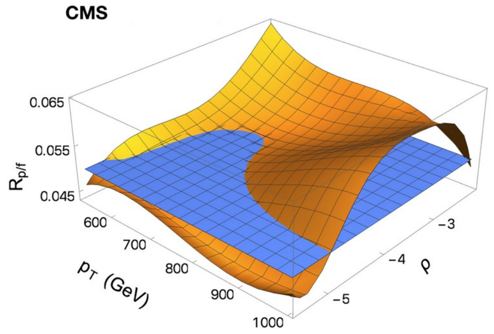


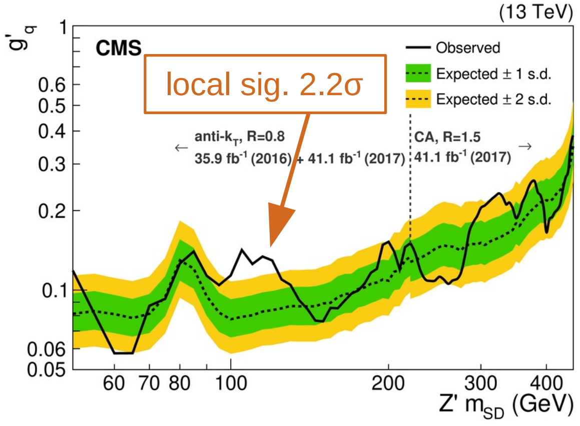
Boosted resonance + jet (CMS)

Phys. Rev. D 100, 112007 (2019)

- Trigger based on the (trimmed) boosted resonance or HT.
- Boosted resonance (p_T>525 GeV)
  - Jet AK8 (m>175 GeV) and CA15 (m<175 GeV);
  - Soft drop, trimming, and PUPPI to reduce QCD background;
  - Signal region: N_{12} < 0 (95% QCD rejection, by design)
    - use of designed decorrelated tagger;
    - select a range in $\rho = \ln(m^2 / p^2_T)$.
- EWK background taken from simulation ($t\bar{t}$, Z/W+ jets).
- QCD multijet is estimated from control region (N_{12}>0)
  - Corrected by pass-to-fail ratios, binned in ρ and p_T
    - Fitted with a Bernestein polynomial.
- Fit performed is several p_T categories.
- Combination 2017 data analysis + 2016.
  - No excess found



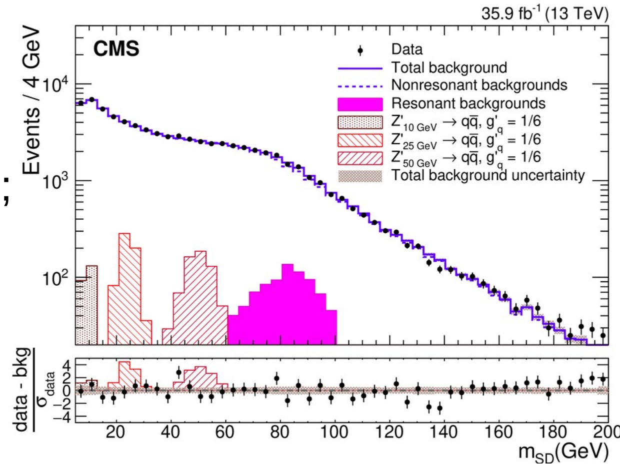


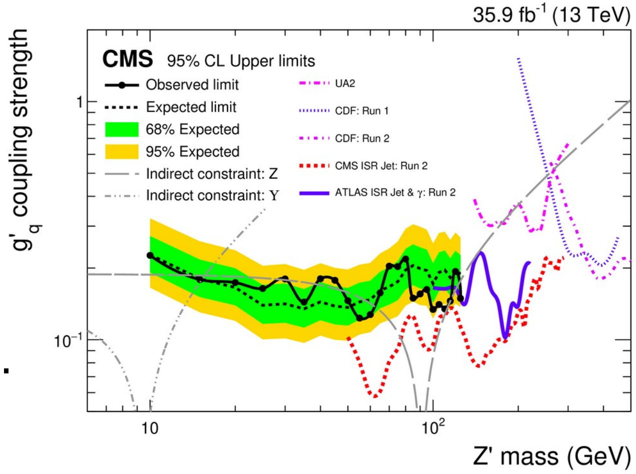


Boosted resonance + photon (CMS)

Phys. Rev. Lett. 123 (2019) 231803

- Triggered by single photon p_T > 175 GeV (offline p_T > 200 GeV).
- Main backgrounds:
  - Resonant: W/Z + γ, $t\bar{t}$ (e → γ misid.) (simulation + data driven correction);
  - Non-resonant: multijet (jet → γ misid.) (data driven).
- Boosted resonance (AK8 jet, p_T > 200 GeV),
  - soft drop mass algorithm, validated down to 10 GeV.
- Selection:
  - large angle photon-jet, b-tag veto (against $t\bar{t}$);
  - DDT N_{12}<0 (90% rejection by definition).
- Non resonant background estimated from control region (N_{12}>0).
  - pass-to-fail ratio fitted in (ρ, p_T) bins, using a simultaneous fit;
  - data-to-simulation efficiency scale factor for resonant bkg (0.909±0.046).
- Data is in agreement with the background-only prediction.

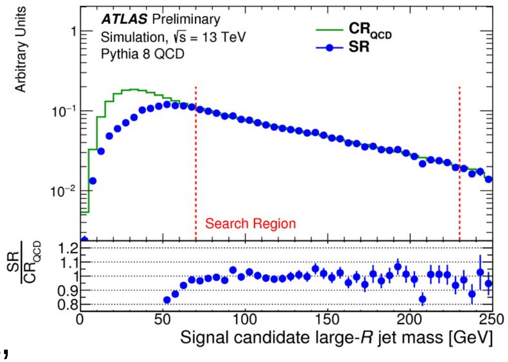


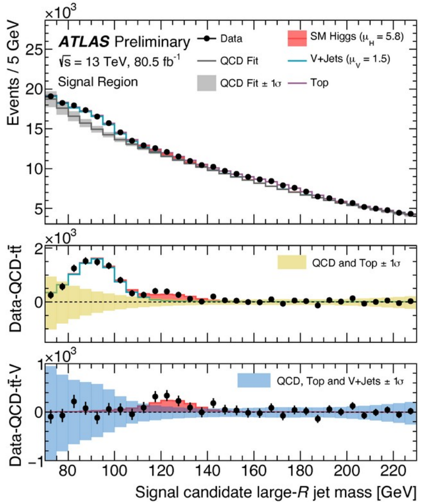


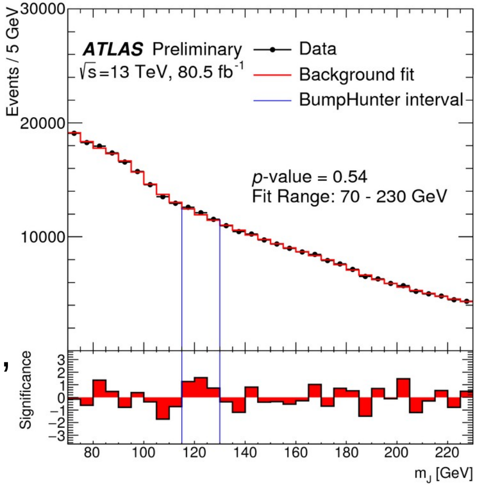
Boosted b-quark resonance (ATLAS)

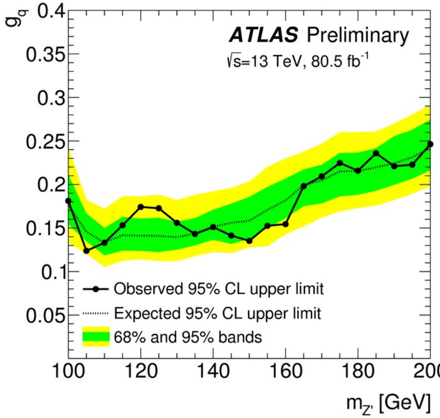
ATLAS-CONF-2018-052

- Trigger requires a single jet (R=1 p_T > 480 GeV).
- Boosted resonance (p_T > 480 GeV);
  - trimming to reduce background,
  - track subjets used for b-tagging.
- Backgrounds:
  - V+jets and H+jets based on MC, normalization fitted to data,
    - $\mu_V = 1.5 \pm 0.22$ (stat.) ± 0.29 (syst.) ± 0.18 (th.) [obs. 5 σ],
    - $\mu_H = 5.8 \pm 3.1$ (stat.) ± 1.9 (syst.) ± 1.7 (th.) [obs. 1.6 σ].
  - $t\bar{t}$ based on MC,
    - normalization fitted in a specific $CR_{t\bar{t}}$ (muon + b-tag).
  - Multijet fitted using an analytic function.
- Analytic function fitted using a CR QCD (0 b-tag),
  - Data split in ~60 slices of data having the same stat of the SR,
  - Function: exponential polynomial. #parameters: Fisher test.
- No signal excess found.





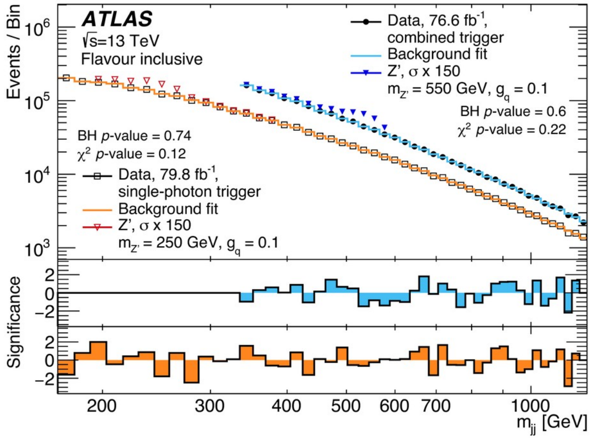


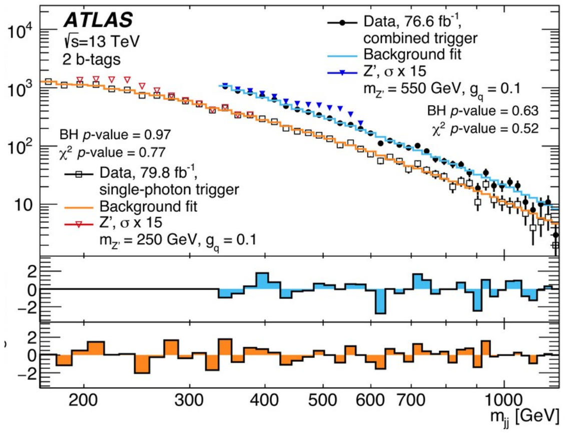


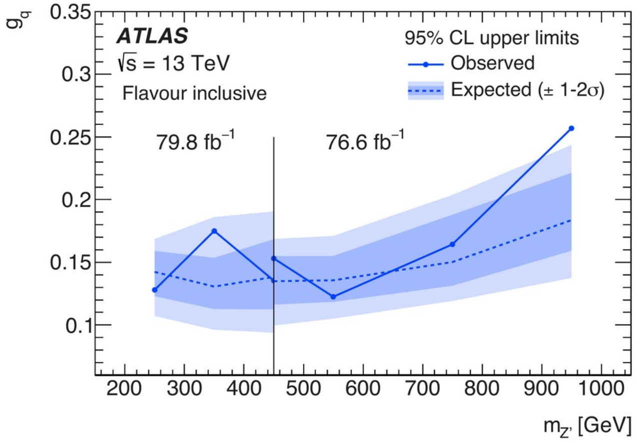
Di-jet resonance + photon (ATLAS)

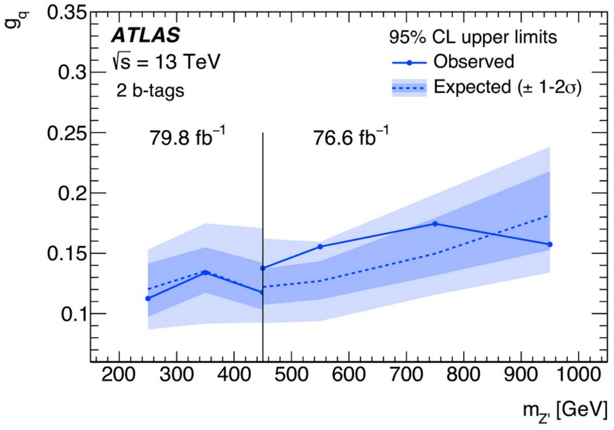
Phys. Lett. B 795 (2019) 56

- **Way #3**: Resolved dijet produced with ISR (photon).
- Trigger photon (140 GeV) or photon & two jets (85 GeV & 50 GeV)
- Two analyses: flavour inc. and double b-tags,
  - similar expected sensitivity.
- Multijet backgound fitted with an analytic function using sliding windows.
- No excess reported
  - p-value >= 0.6.





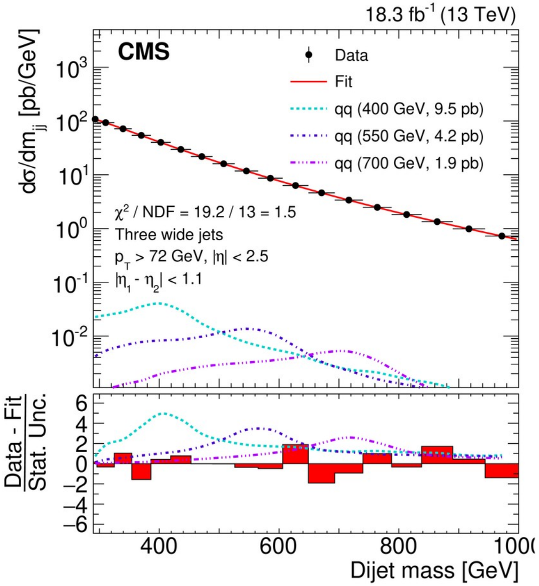


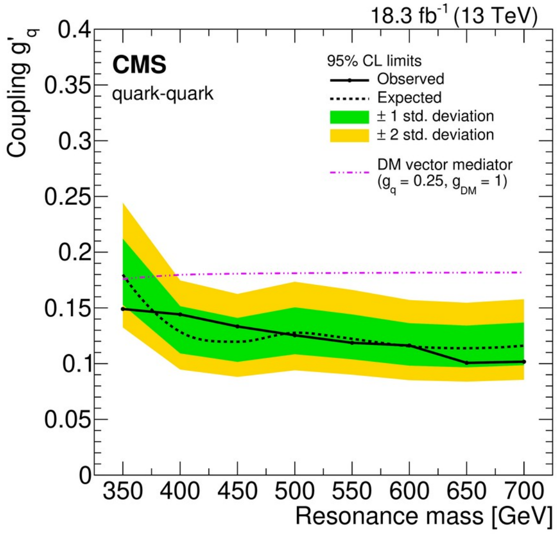


Di-jet resonance + jet, scouting (CMS)

Phys. Lett. B 805 (2020) 135448

- **Way #4:** Combine the resolved dijet produced in association with ISR (jet) with data scouting.
- Trigger requires sum jet p_T >250 GeV.
- Dijet defined as the pair of two leading jets.
- Multijet background fitted with an analytic function.
- Three jets with p_T > 72 GeV,
  - to minimize the lower mass limit.
- Data is in agreement with the background-only hypothesis.

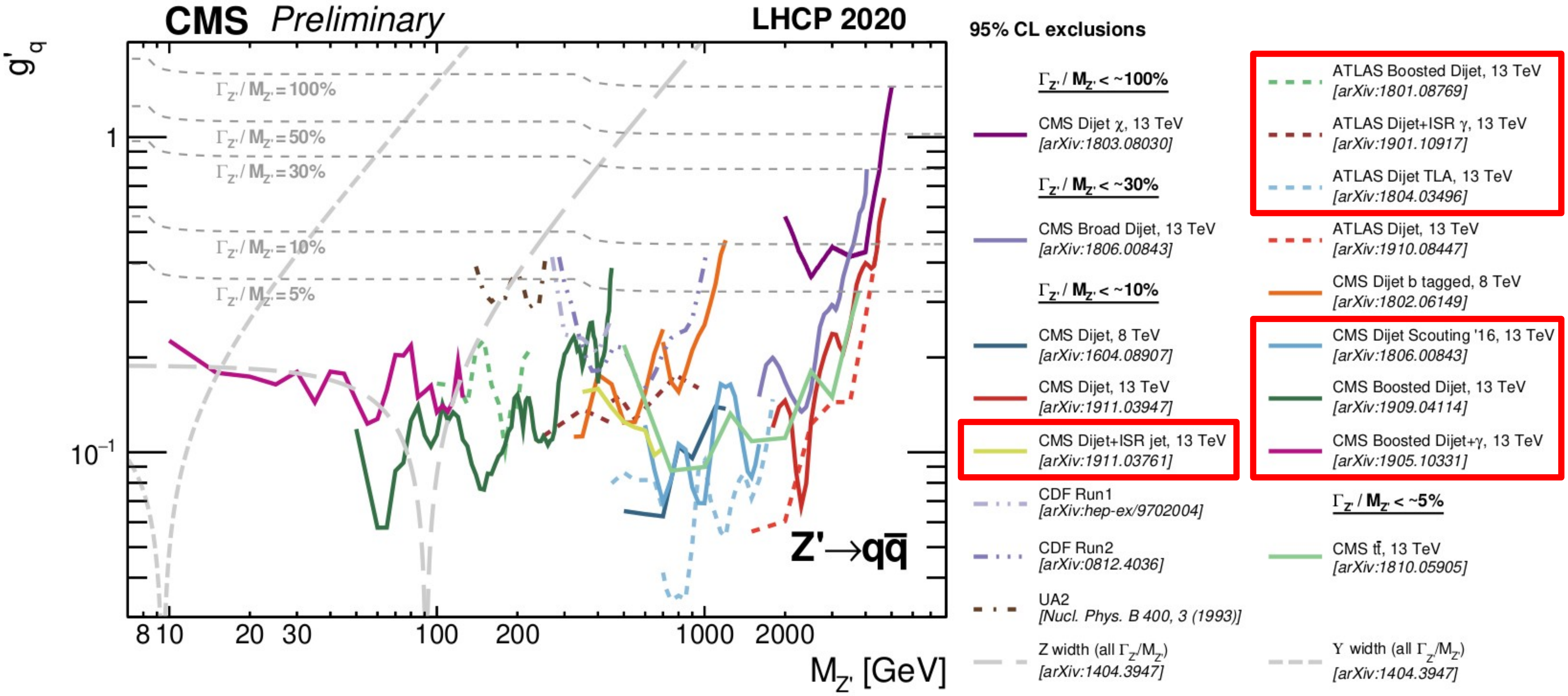




Conclusions

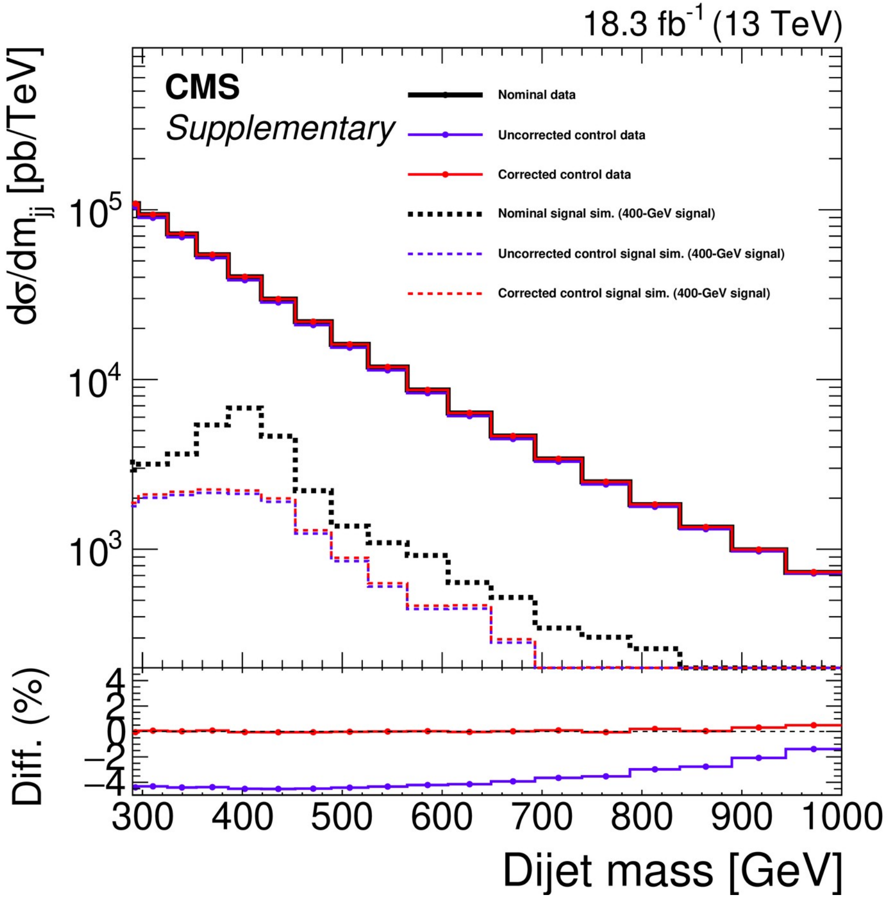
- Low-mass resonance is an interesting region,
  - Exclusion upper limit on coupling is around 0.1 below 400 GeV.
- Low-mass regions is challenging from many point of view:
  - Reconstruction (eg. boosted objects);
  - Trigger (eg. scouting, TLA, combined triggers);
  - Final states (eg. ISR, b-tagging, photons).
- Large improvements are expected:
  - New techniques (eg. improved boosted objects reconstruction);
  - Many analyses are still based on 2016 lumi → ~x4 lumi expected.

Conclusions



Backup

Backup


18.3 fb^{-1} (13 TeV)
CMS
Supplementary
Nominal data
Uncorrected control data
Corrected control data
Nominal signal sim. (400-GeV signal)
Uncorrected control signal sim. (400-GeV signal)
Corrected control signal sim. (400-GeV signal)
dσ/dm$_{jj}$ [pb/TeV]
Diff. (%)
Dijet mass [GeV]

g’q vs gq

couples to DM particles. We convert g_q into g'_q using the following relationship

$$g'_\mathrm{q} = \frac{g_\mathrm{q}}{\sqrt{1 + 1/\left(3N_\mathrm{q}(M_\mathrm{med})g_\mathrm{q}^2\right)}} \qquad (2)$$

where $N_\mathrm{q}(M_\mathrm{med})$ is the effective number of quarks

$$N_\mathrm{q}(M_\mathrm{med}) = \sum_q \left(1 - 4\frac{m_q^2}{M_\mathrm{med}^2}\right)^{1/2}\left(1 + 2\frac{m_q^2}{M_\mathrm{med}^2}\right) \qquad (3)$$

and the index q runs over the quark flavors (u, d, s, c, b, t) having $m_q < M_\mathrm{med}/2$ [11,60].