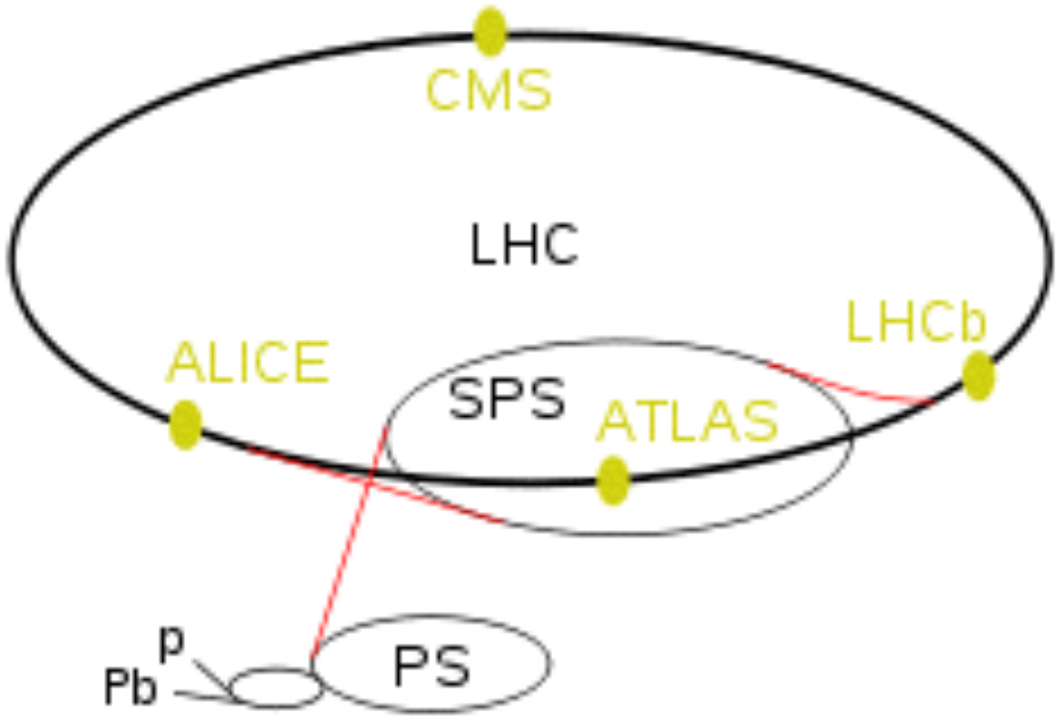


Searches for resonant signatures of Dark Matter production at the LHC

Jose Benitez (ATLAS, University of Iowa, U.S.)
on behalf of the ATLAS and CMS collaborations

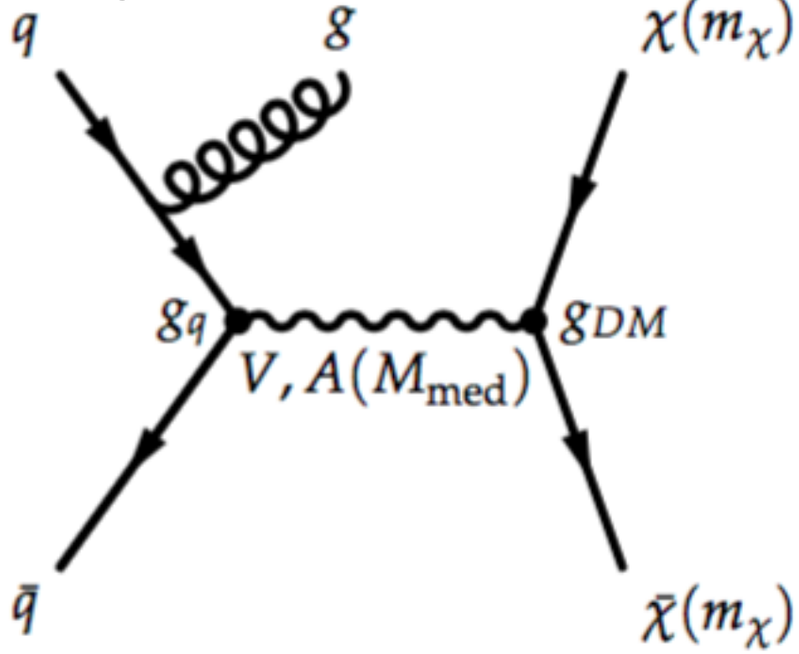
13th Recontres du Vietnam
Exploring the Dark Universe
Quy Nhon, Vietnam
July 23-29, 2017

introduction

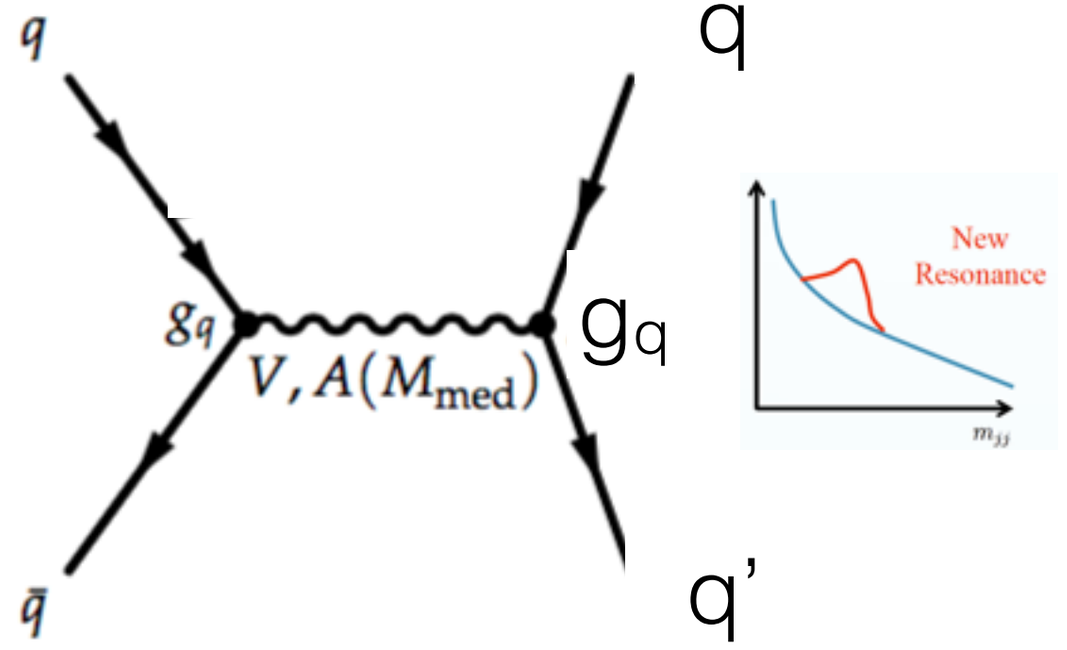
Possible searches at the LHC:

missing energy search

see talk by M. Queitsch

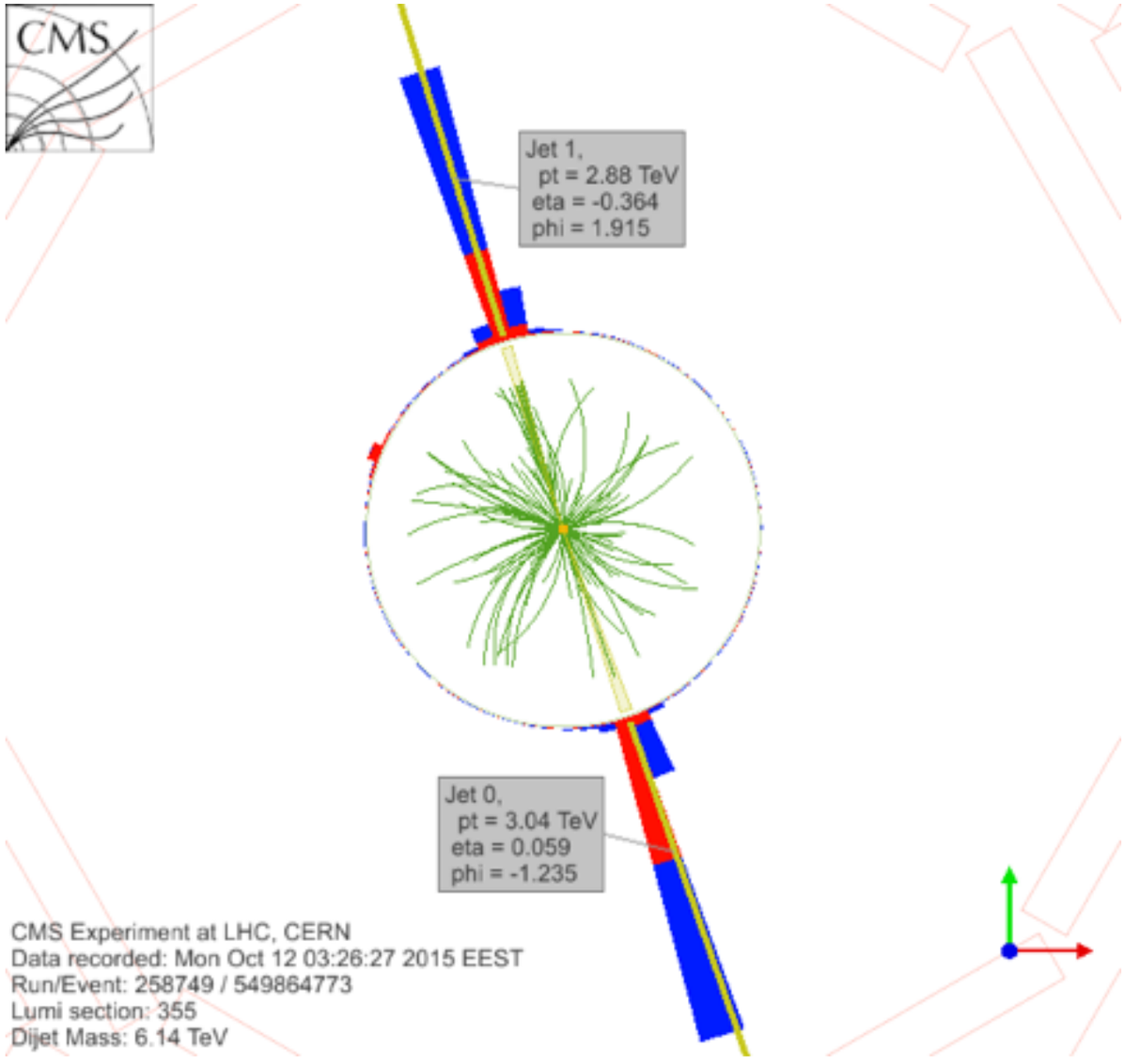


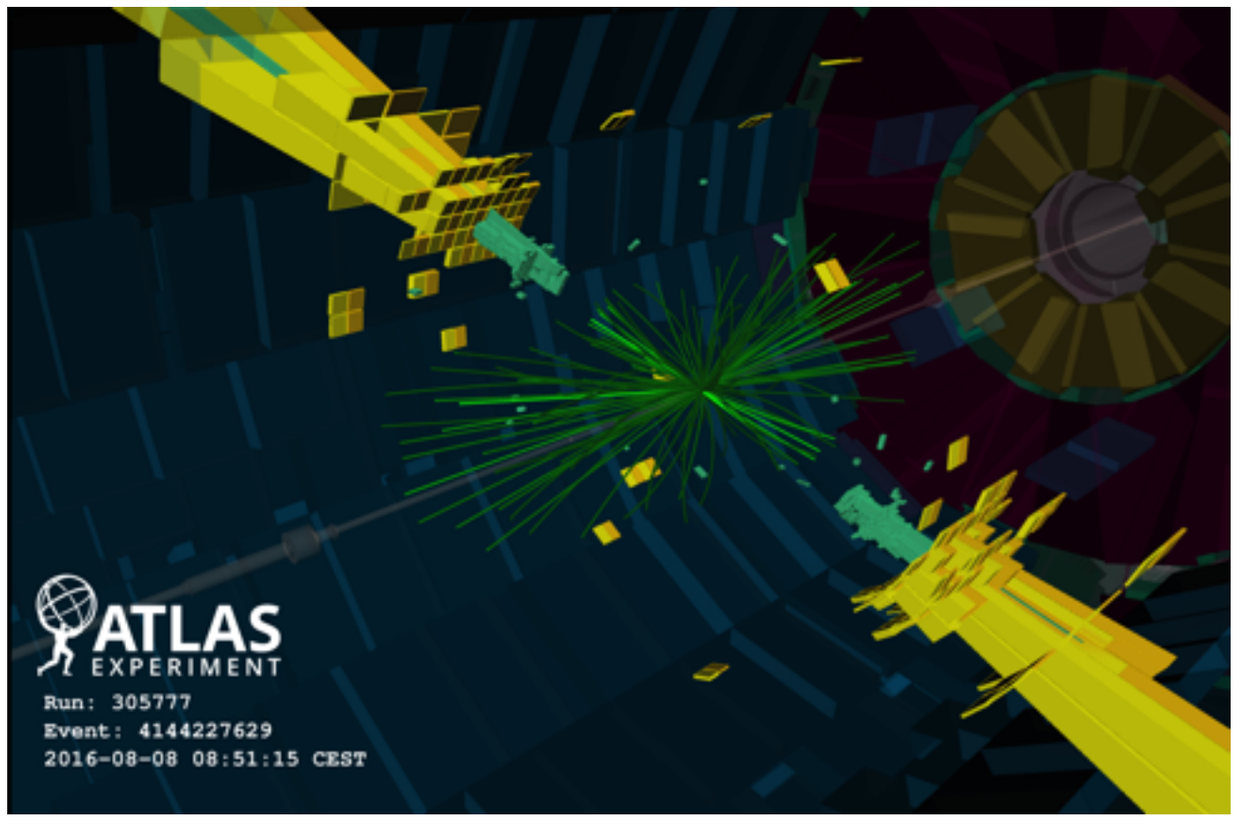
mediator search



- This talk focuses on the searches for the mediator in decays to quarks or leptons.
- Interpretations use generic models and benchmark scenarios [arXiv:1507.00966, arXiv:1703.05703]:
  - dijet searches: $g_q = 0.25$, $g_l = 0$, $g_{DM} = 1$
  - dijet + dilepton searches:
    - $g_q = 0.1$, $g_l = 0.1$, and $g_{DM} = 1$ (Axial-Vector)
    - $g_q = 0.1$, $g_l = 0.01$, and $g_{DM} = 1$ (Vector)
  - Choices lead to small widths ($\Gamma/M < 10\%$) needed for interpretations of the mass distributions.

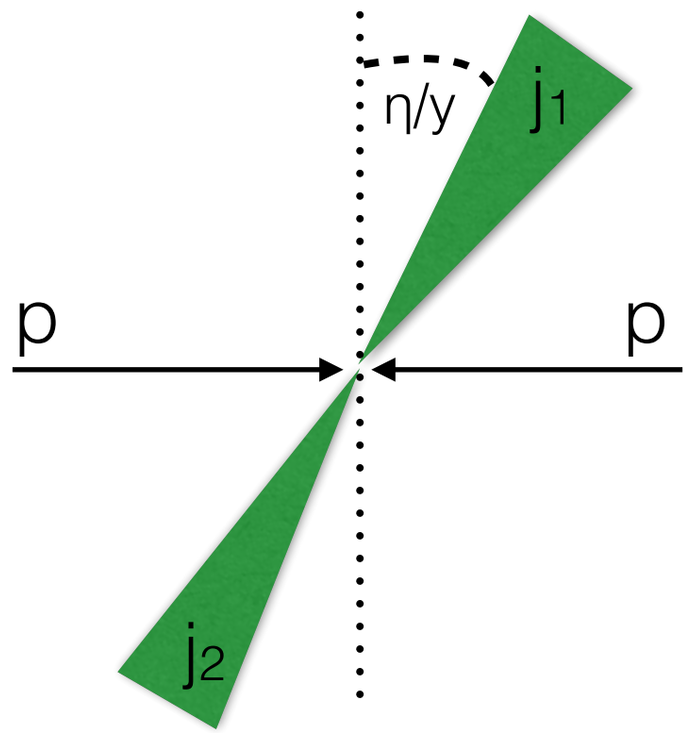
Dijet searches



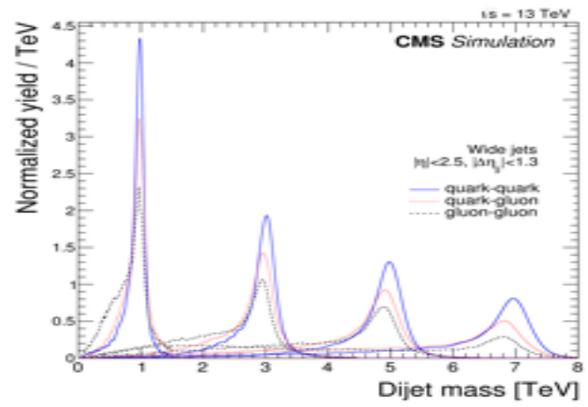


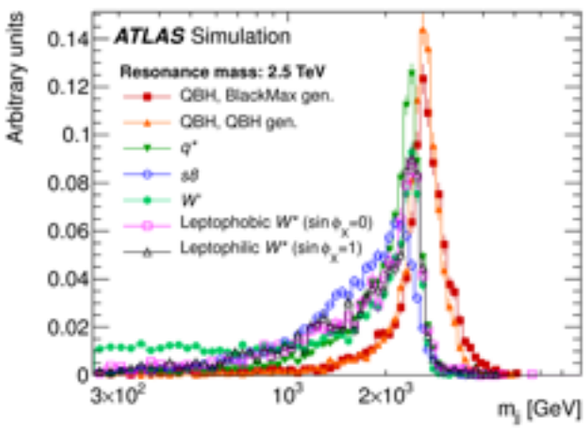
Displays of dijet events recorded with real data by CMS and ATLAS

high mass search strategy



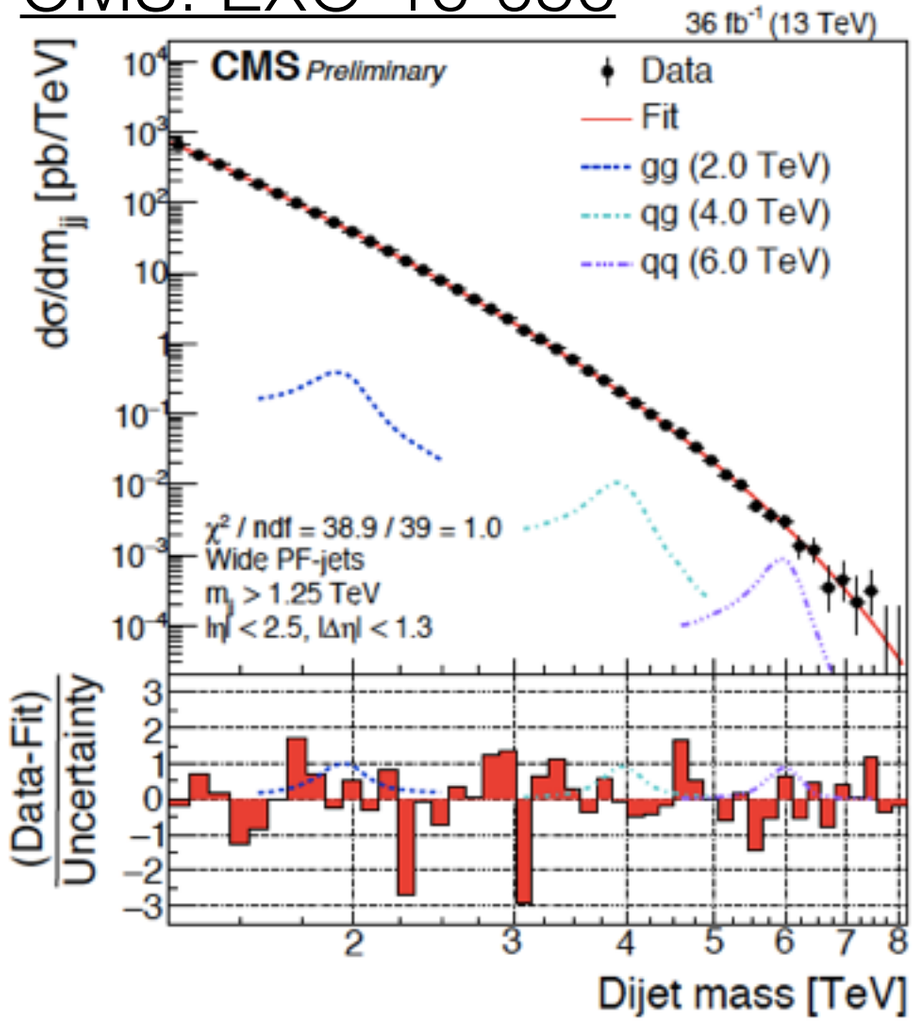
- **CMS Search:**
  - Particle flow jets (anti-kt R=0.4), p_T>30 GeV.
  - Trigger: sum p_T of jets>900 GeV
- **ATLAS search:**
  - Calorimeter jets (anti-kt R=0.4), p_T> 20 GeV.
  - Trigger: one high p_T jet > 380 GeV.
    Offline: p_T^{lead}> 440 GeV, $p_T^{sublead}$>60 GeV
- **Multijet background reduction with: $|\Delta\eta_{jj}| < \sim 1.3$**
- **Challenges calibrating jets with TeV momentum**
- **Detection resolution ~5% at high mass (qq')**



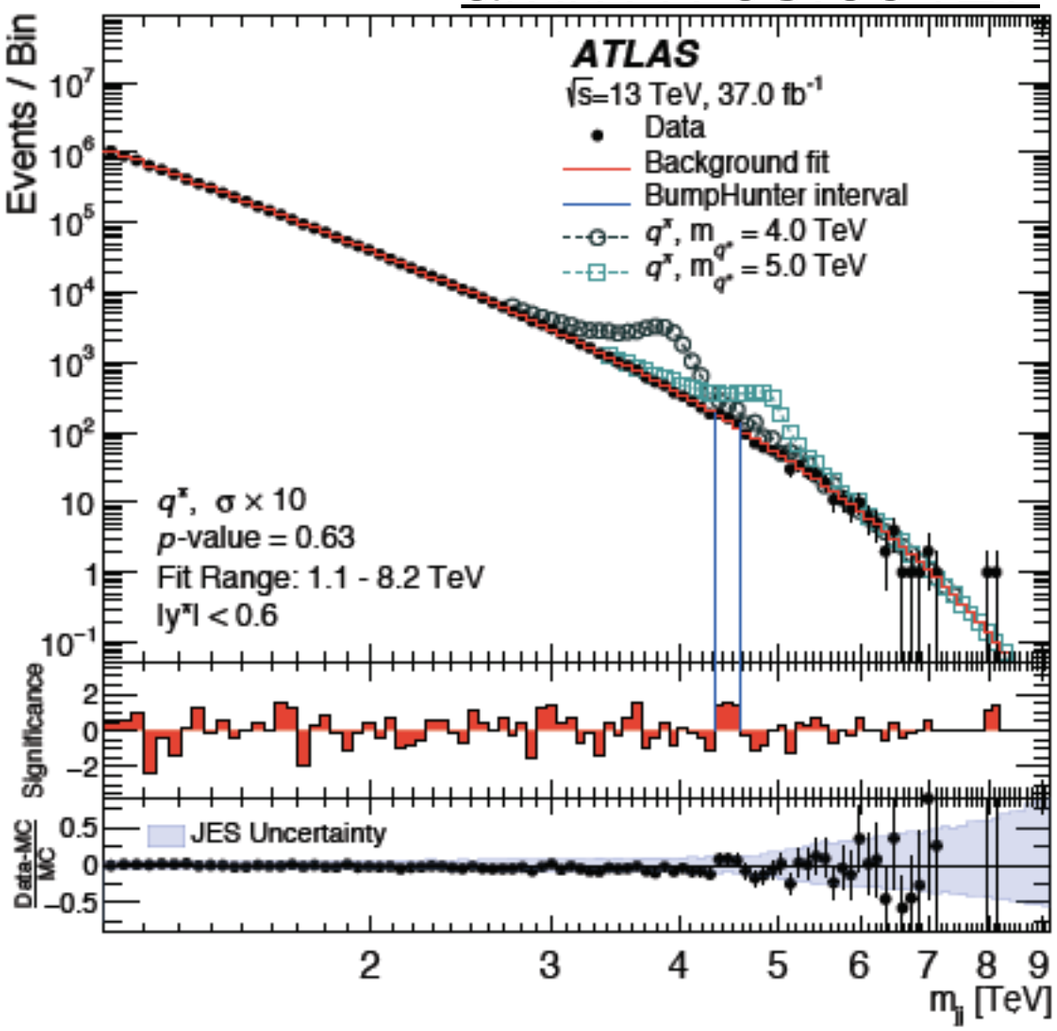


Dijet mass distributions

CMS: EXO-16-056



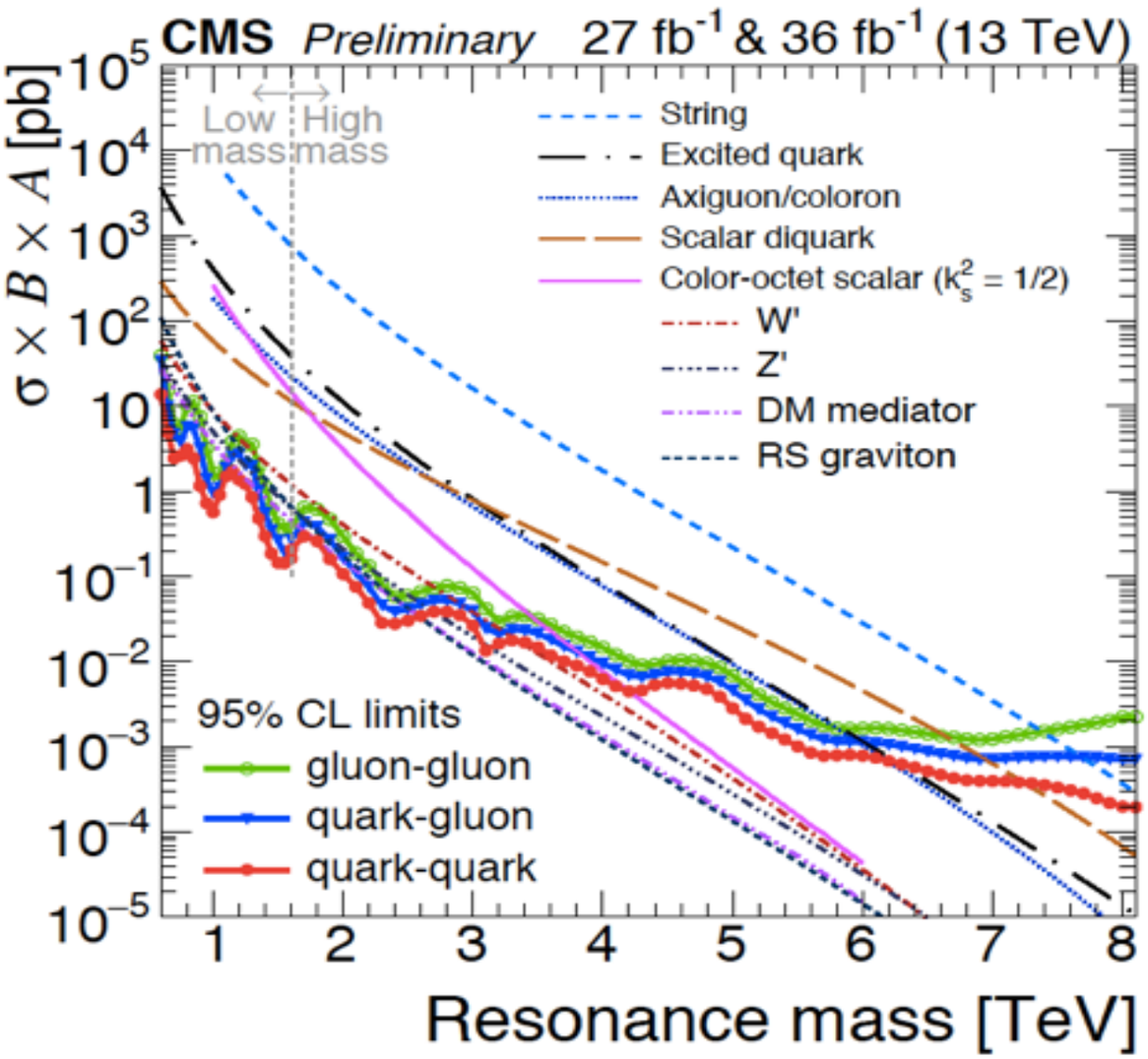
arxiv:1703.09127



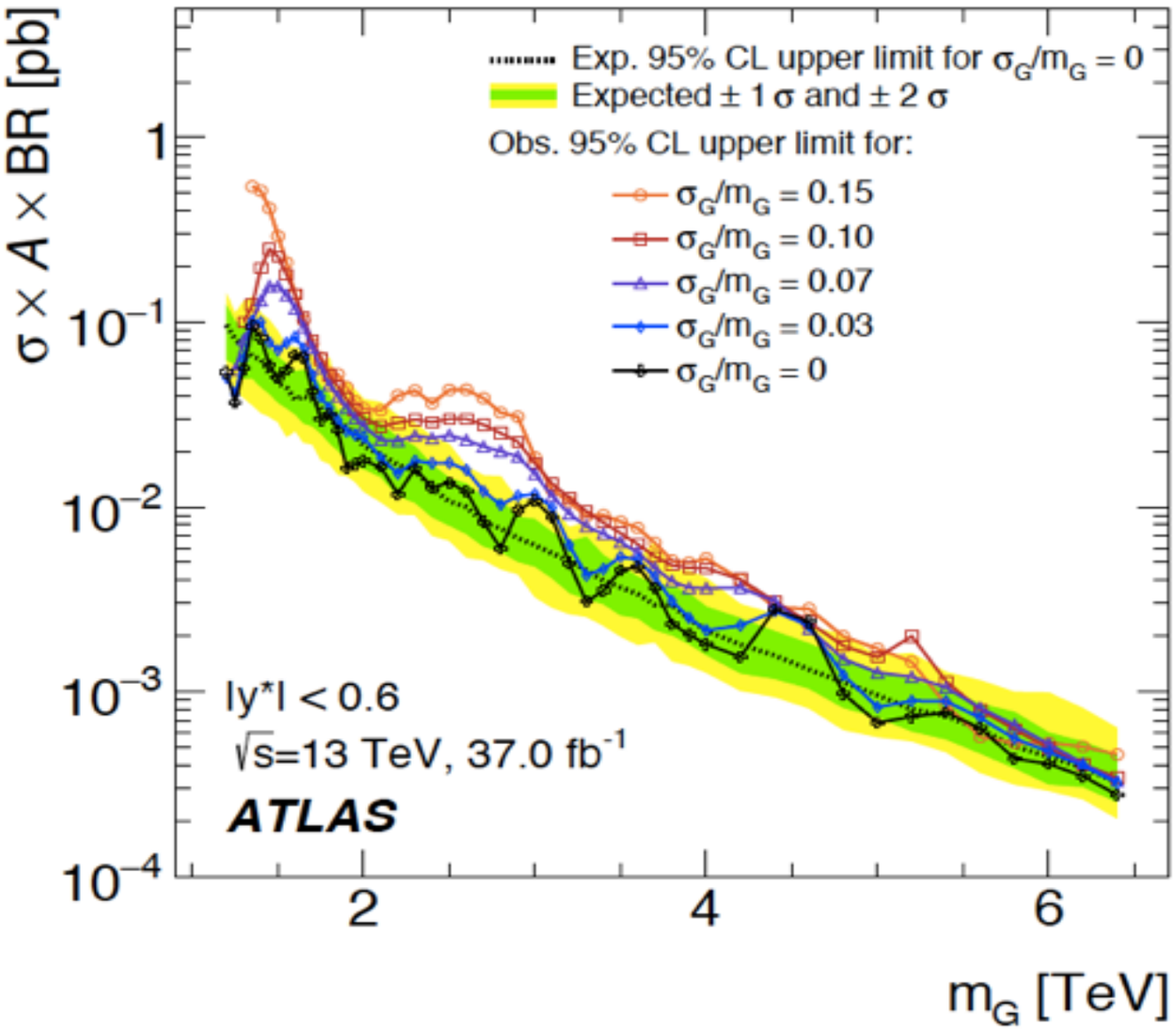
- Reconstructed masses up to ~9 TeV !
- Background fit using empirical power law models
- Model independent excess searches: multi-bin counting experiment in ~100 GeV steps (CMS) and sliding windows (ATLAS)

crossection limits

CMS: EXO-16-056



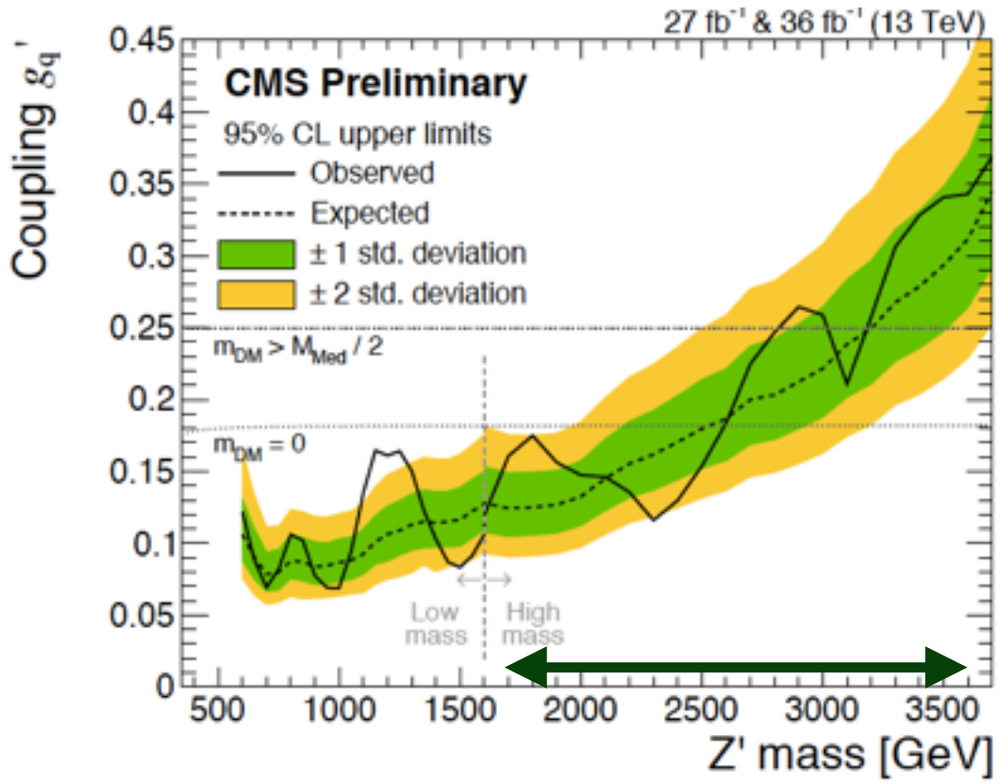
arxiv:1703.09127



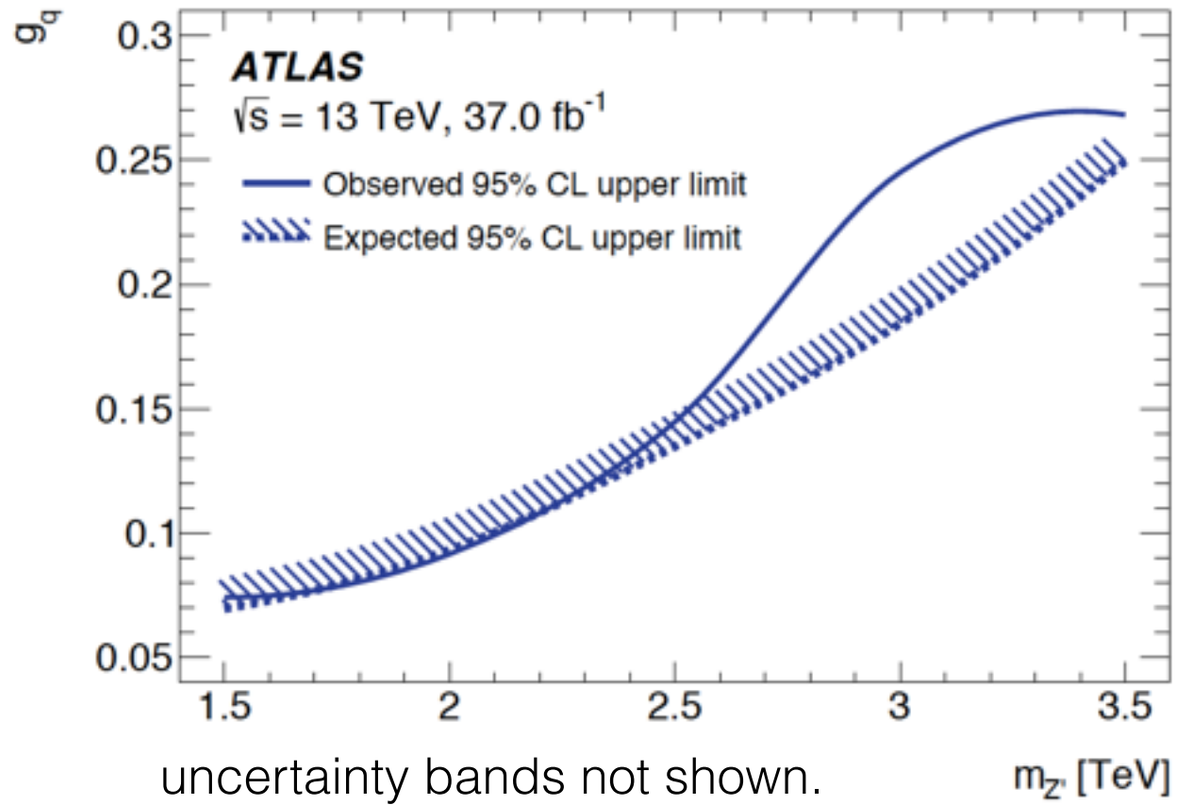
- Limits at 95 CL are computed on the σ x BR x Acceptance.
- Values range between ~10^{-3} pb @ 6 TeV and ~1pb @ 1 TeV
- ATLAS results computed for a “generic” model with Gaussian shape at particle level for easier model-independent interpretations.

Dijet high mass limits

CMS: EXO-16-056



arxiv:1703.09127



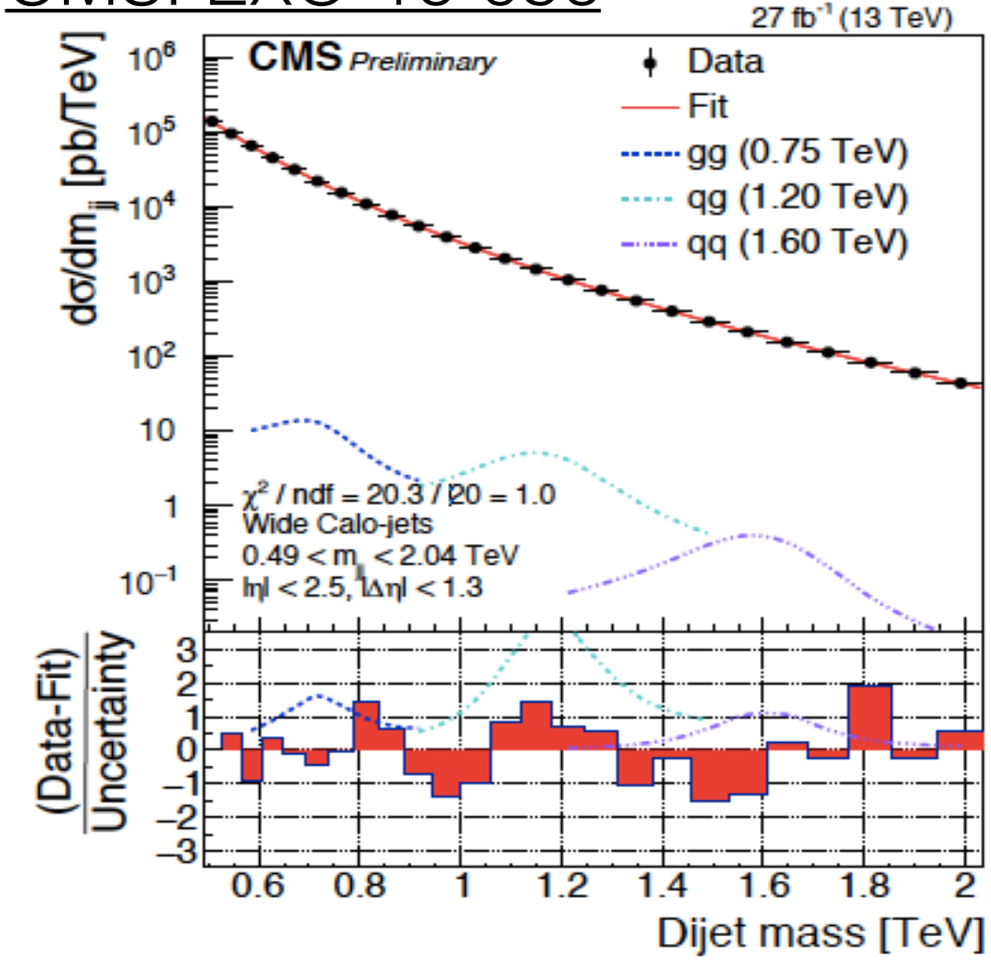
uncertainty bands not shown.

- No significant excess is observed.
- Limits on the σ x A x BR available in the references.
- Limits on resonances coupling *only* to quarks (assuming ~zero decay to DM) placed up to 3.5 TeV.
- Above 3.5 TeV and above g_q~0.5 the natural width of the resonance is larger than ~10%, narrow width model not valid.

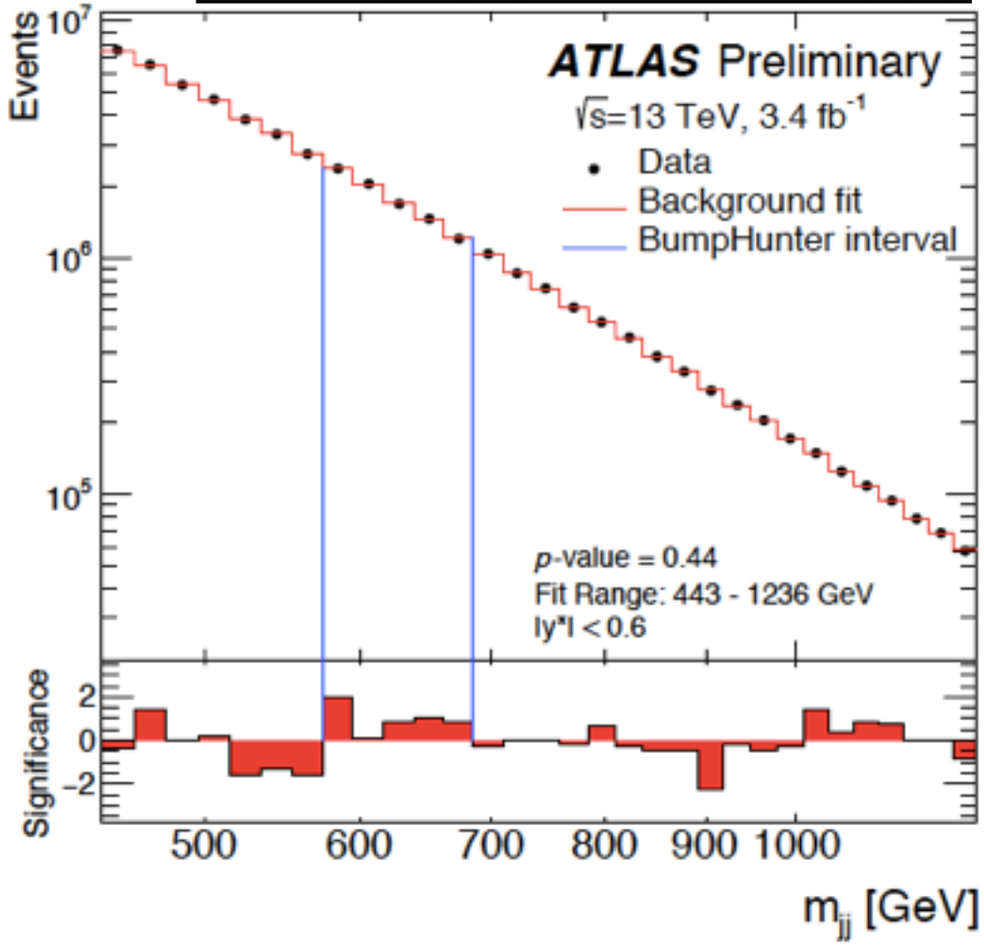
Going lower in mass: Trigger level analysis

- Dijet events with low mass cannot be recorded due to high rates from SM processes.
- Both ATLAS and CMS implemented a special readout at trigger level recording a compact data format for these events.
- Challenging jet calibration given less detector information. Also, difficult to model the background given the huge amount of events.

CMS: EXO-16-056

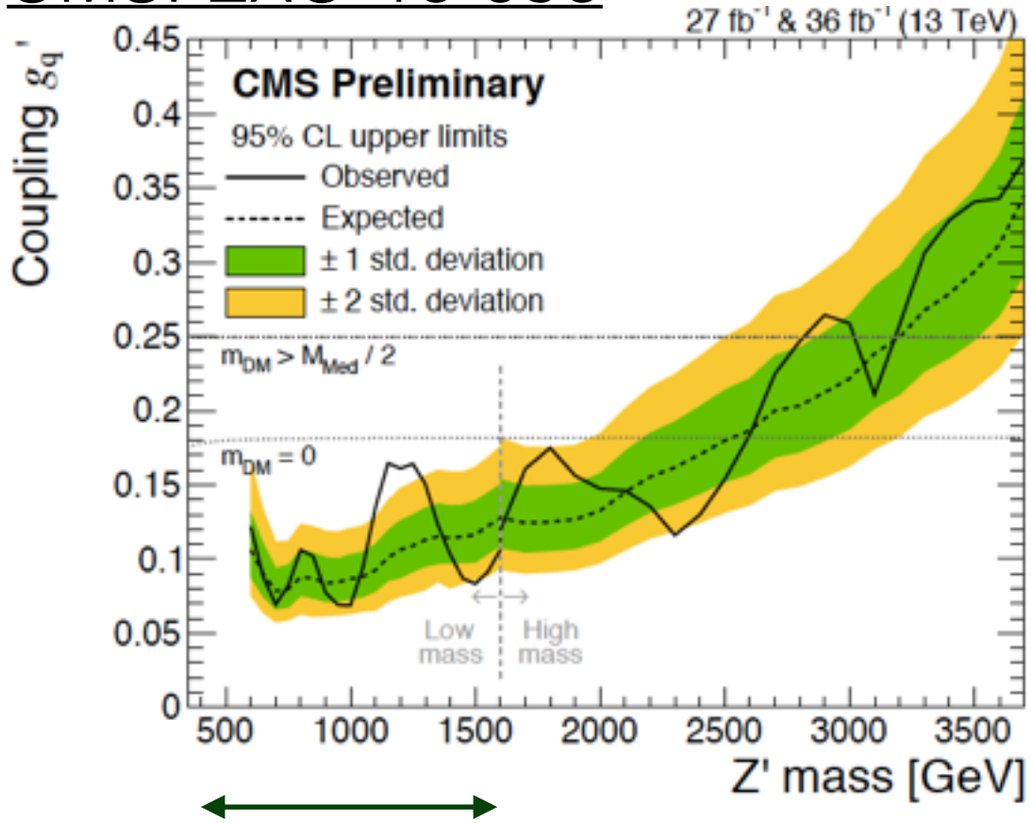


ATLAS-CONF-2016-030

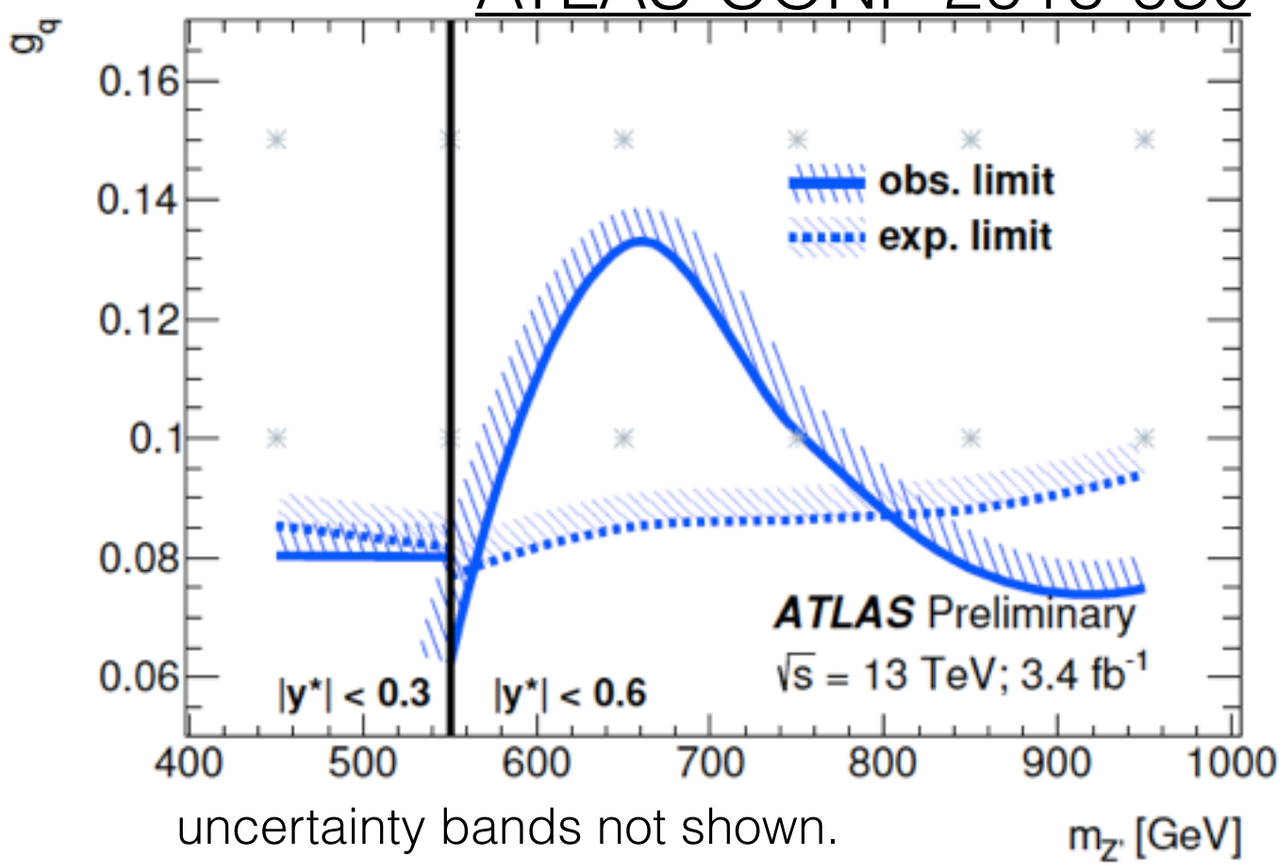


Trigger level analysis limits

CMS: EXO-16-056



ATLAS-CONF-2016-030

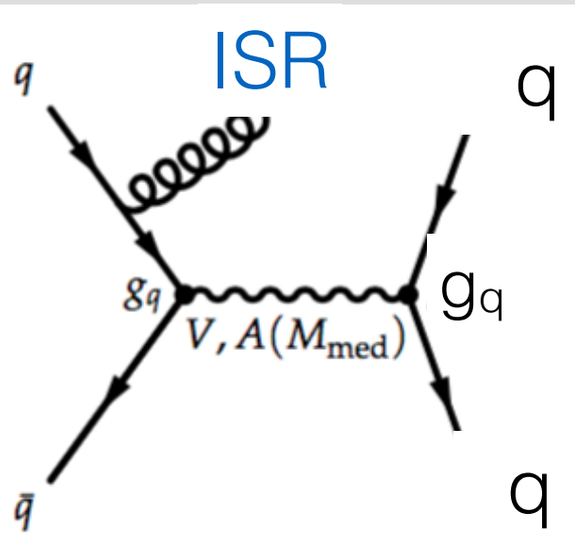


uncertainty bands not shown.

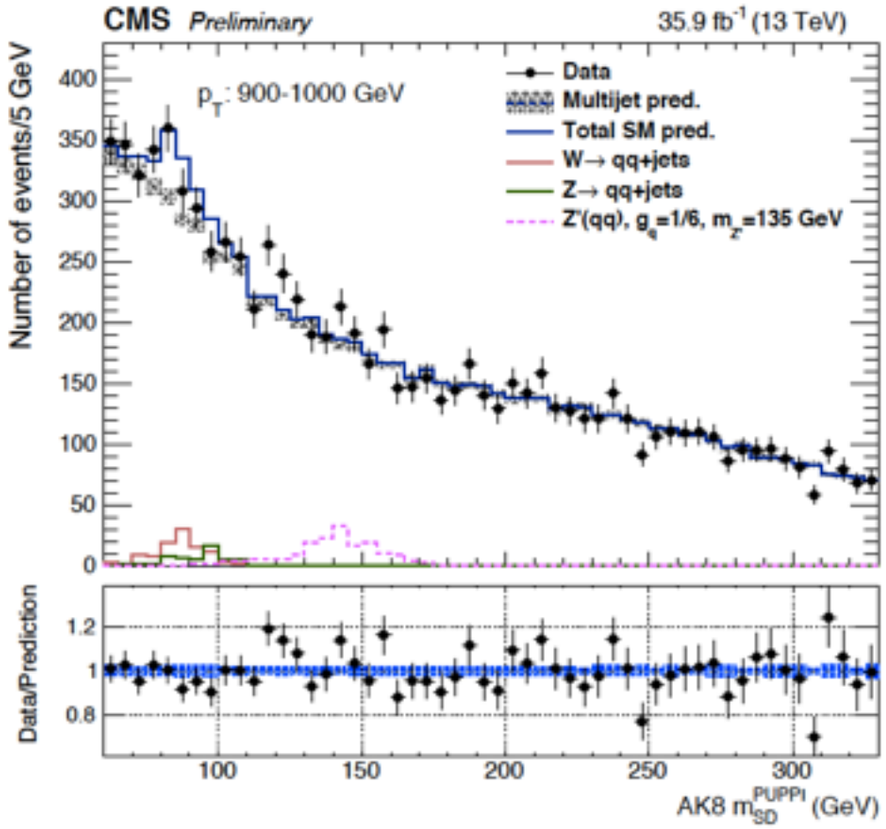
- Limits placed on the quark-coupling for masses from
  - 600 GeV up to 1600 GeV by CMS
  - 450 GeV up to 950 GeV by ATLAS , limits extend to low mass using tigher |y*| <0.3 category.
- No significant excess is found

Low mass search: boosted dijets

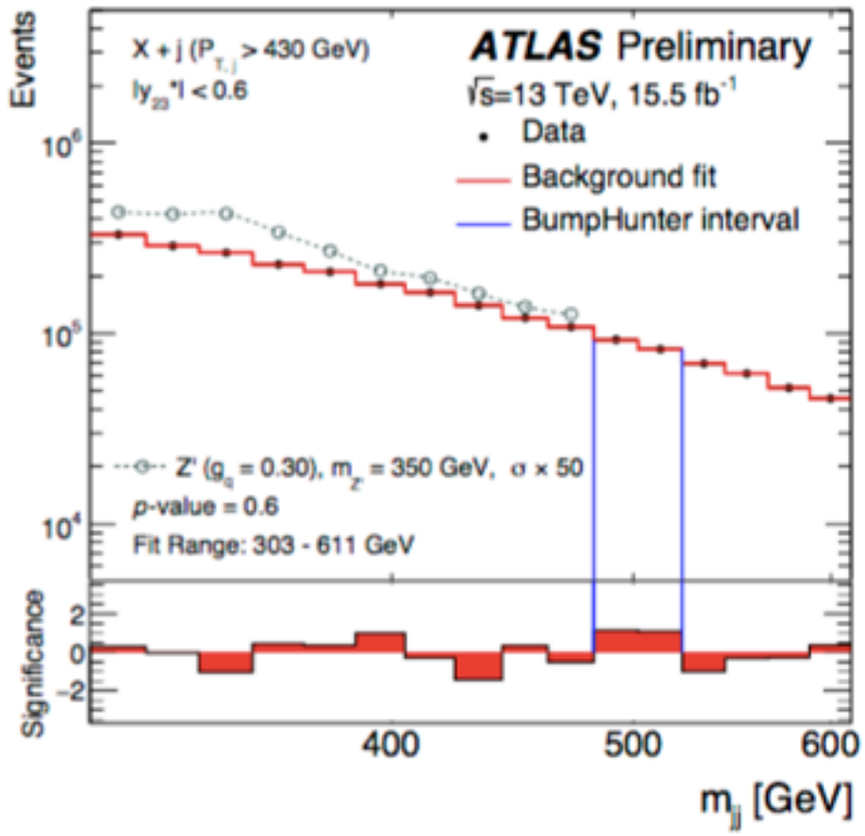
- Search for very low mass resonances is difficult to trigger due to large SM background. Boosted topologies from events with initial state radiation (jet or photon) reduce the rate of events.
- Resonance reconstruction using a single large radius jet with substructure and large transverse momentum by CMS or two R=0.4 calorimeter jets by ATLAS.



CMS: EXO-17-001



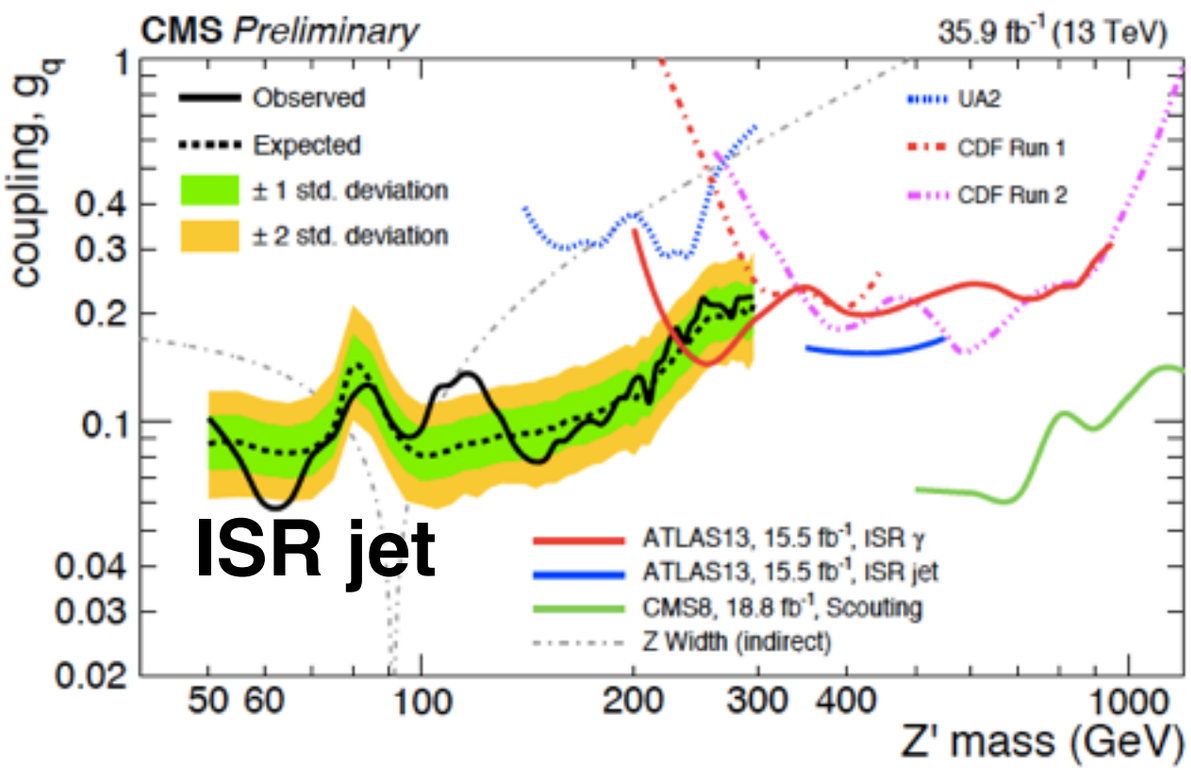
ATLAS-CONF-2016-070/



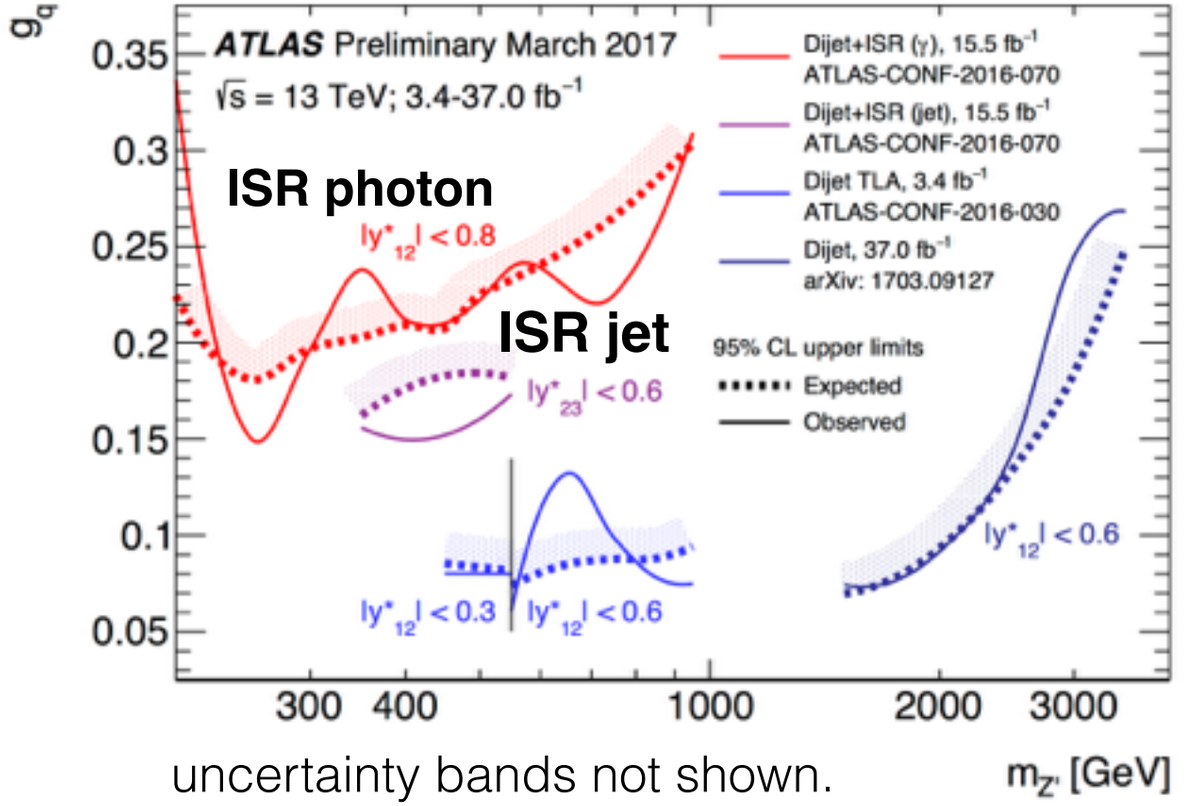
Difference in mass ranges due to difference in resonance reconstruction (merged vs resolved jets).

Boosted dijet search limits

CMS: EXO-17-001



ATLAS-CONF-2016-070



uncertainty bands not shown.

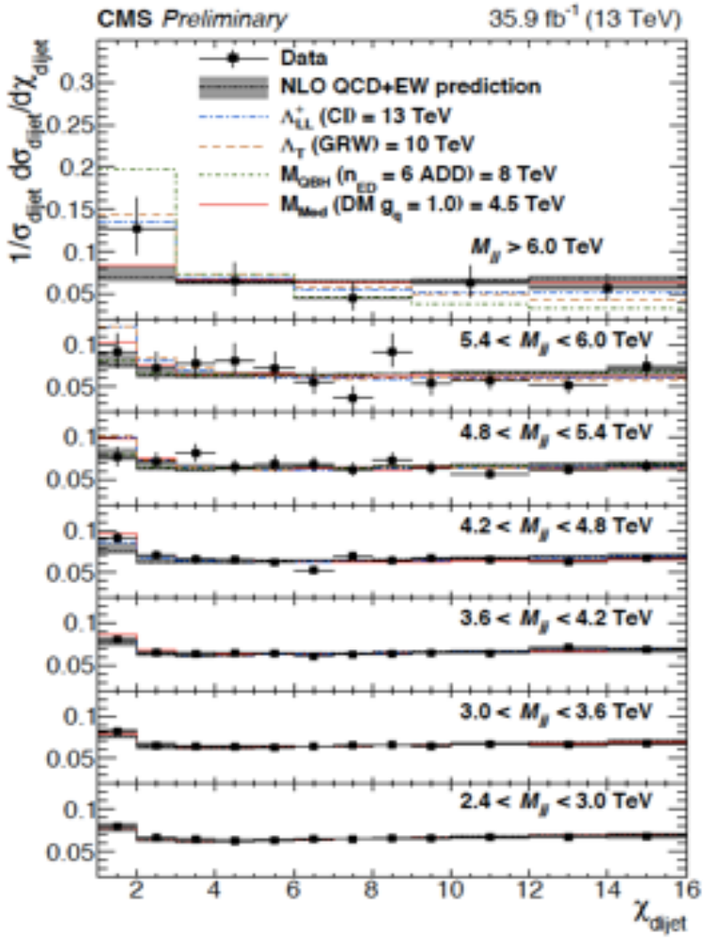
- CMS uses ISR jets and search extends from 50-300 GeV. First time limits in the range 50-100 GeV
- ATLAS uses both ISR photons and jets, and complements up to ~900 GeV.
- CMS: small excess at 115 GeV (2.9σ local, 2.2σ global)

wide resonance search

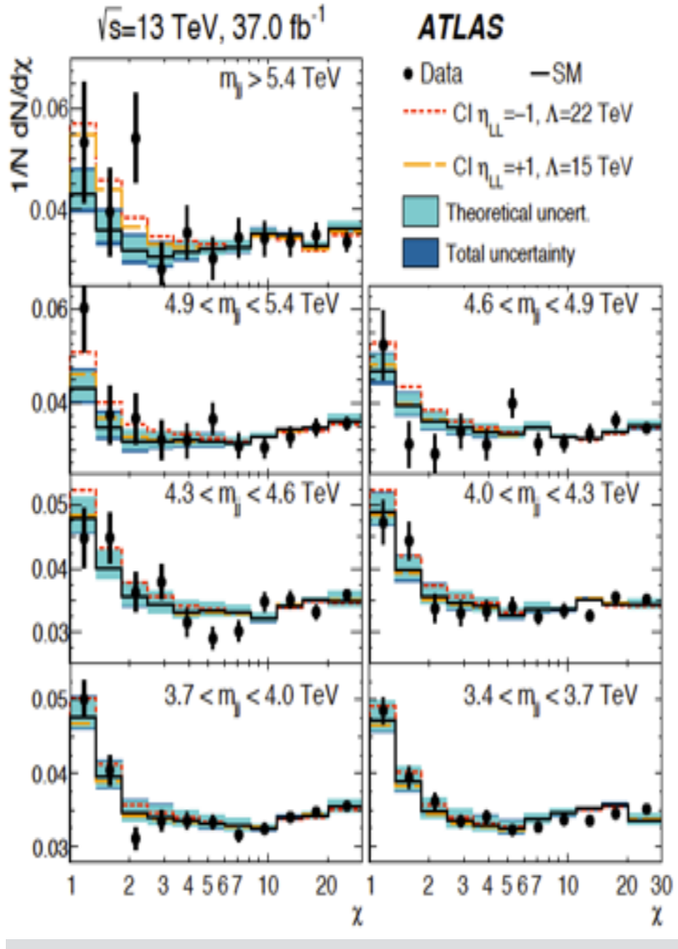
- At large coupling values (g_q~0.5) the resonance becomes very wide and the narrow-width approximation is not valid.
- Angular distribution (χ_{dijet}) can still reveal excess of events over the SM background.

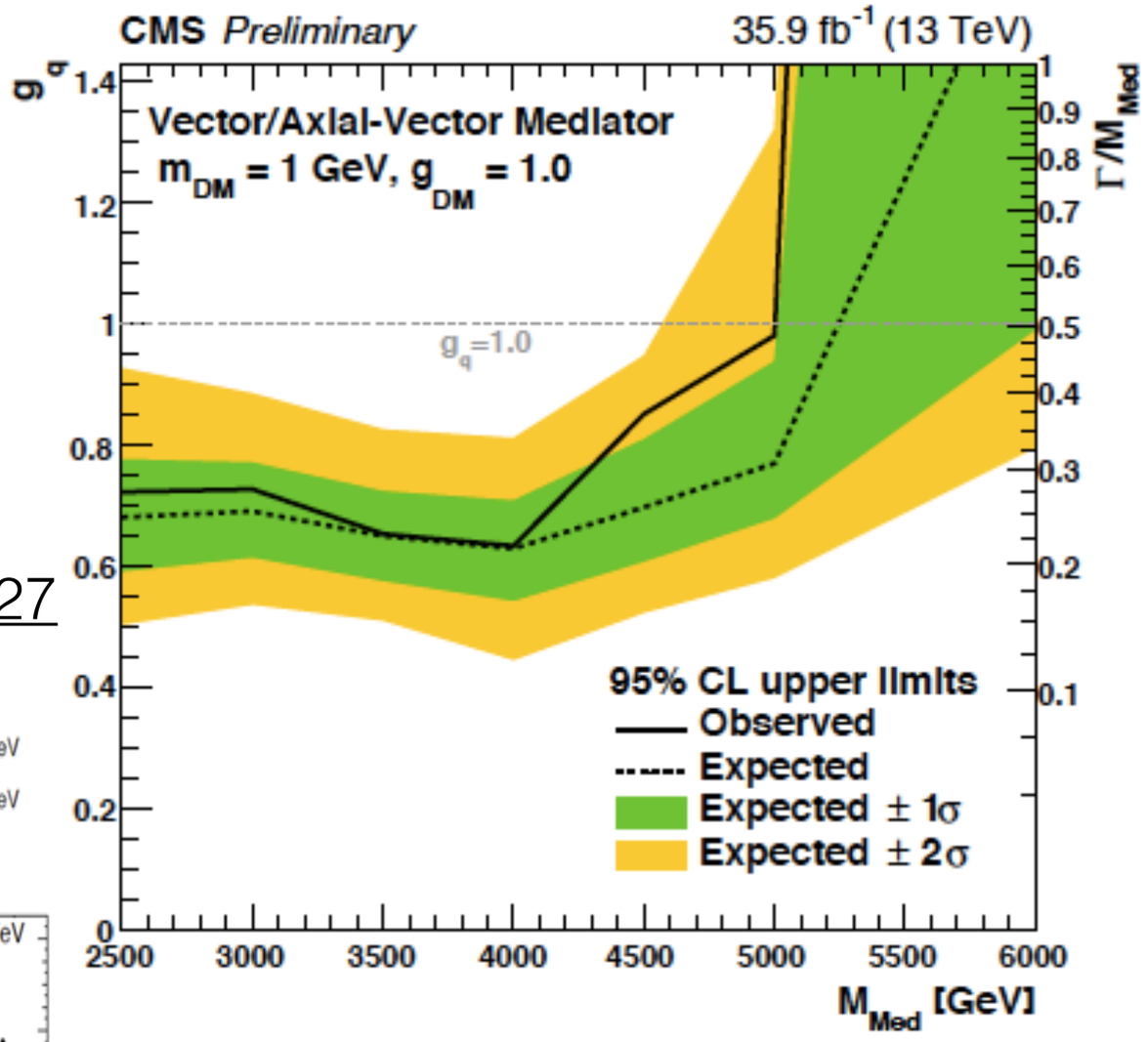
$$\chi_{\text{dijet}} = \exp(|(y_1 - y_2)|) \sim \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$

CMS:EXO-16-046



ATLAS: arxiv:1703.09127

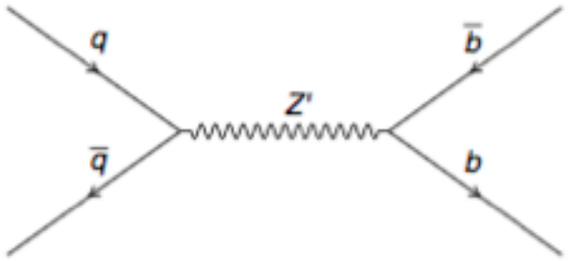




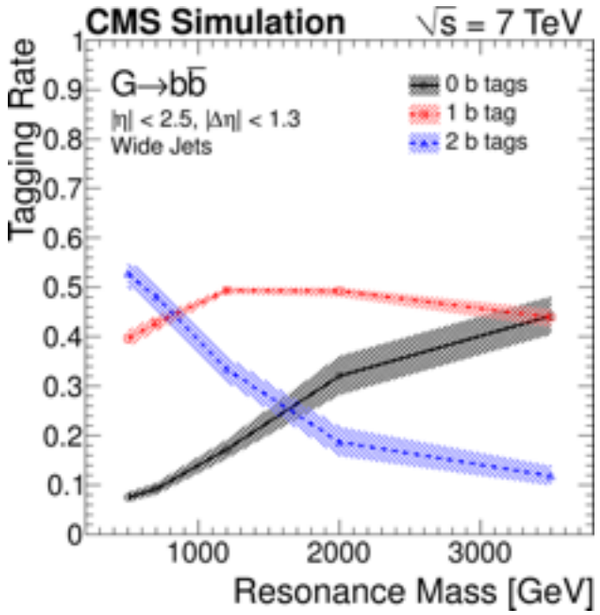
- Couplings excluded above g_q~0.7 for masses up to ~5 TeV for case of m_{DM}~0.

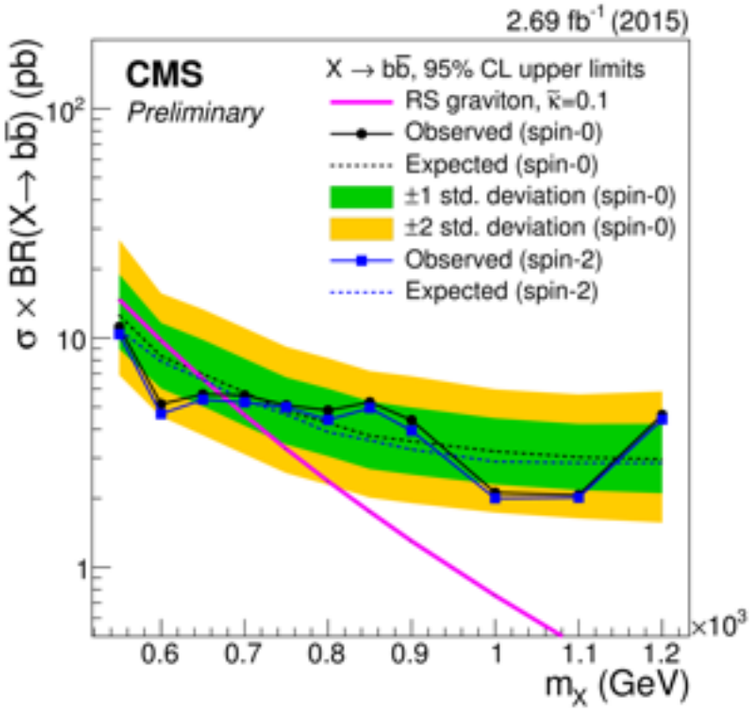
bb resonances

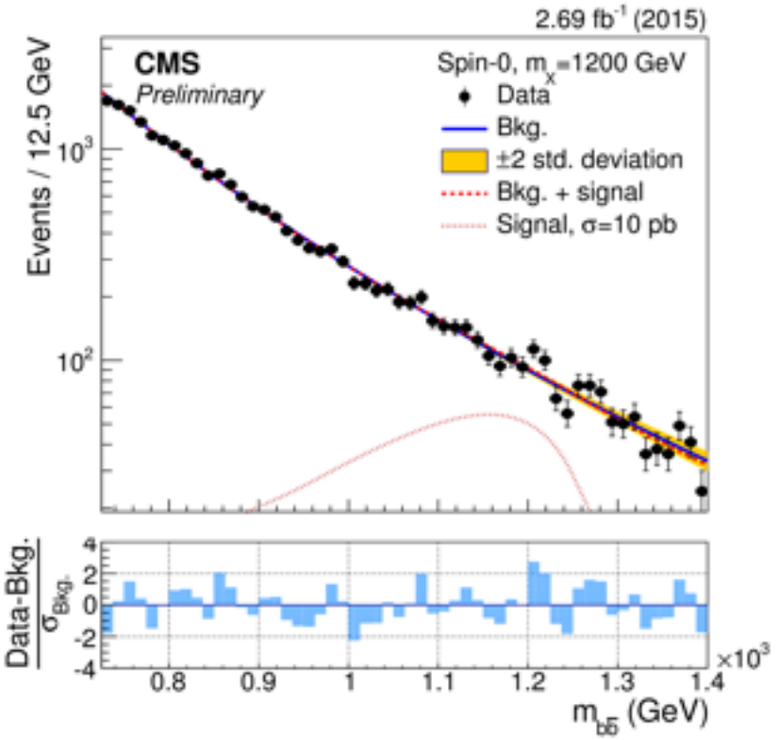
- Searches performed using b-tagged dijets test possible flavor dependent coupling
- b-tagging of high p_T jets is challenging for high mass resonances
- Complementary searches by CMS and ATLAS (low vs high mass)
- No excess found in searches up to ~5 TeV.

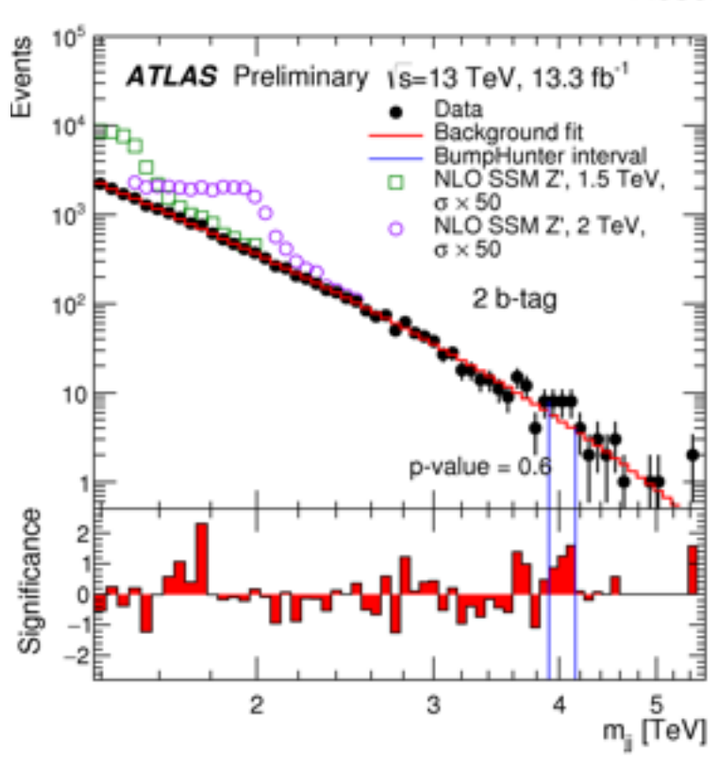


CMS: HIG-16-025

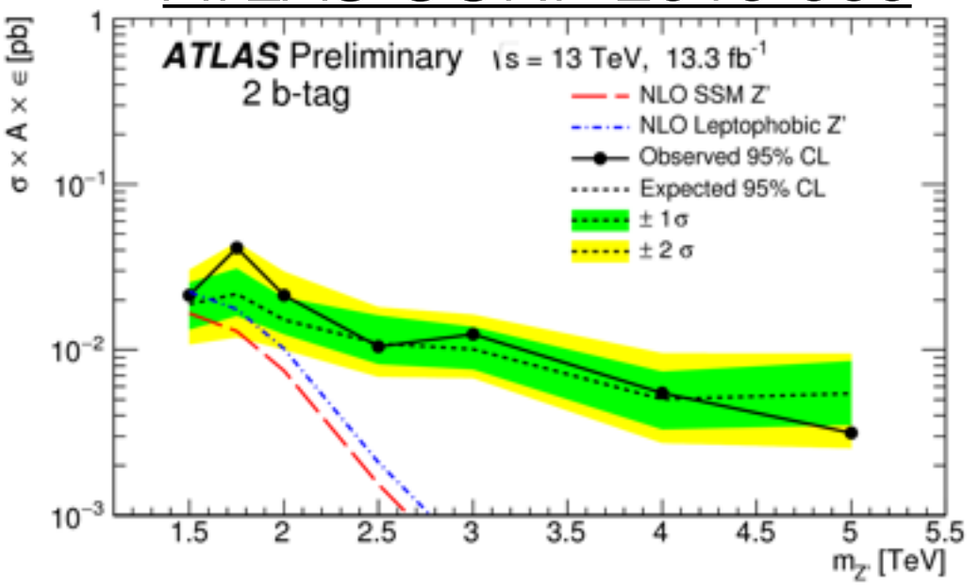






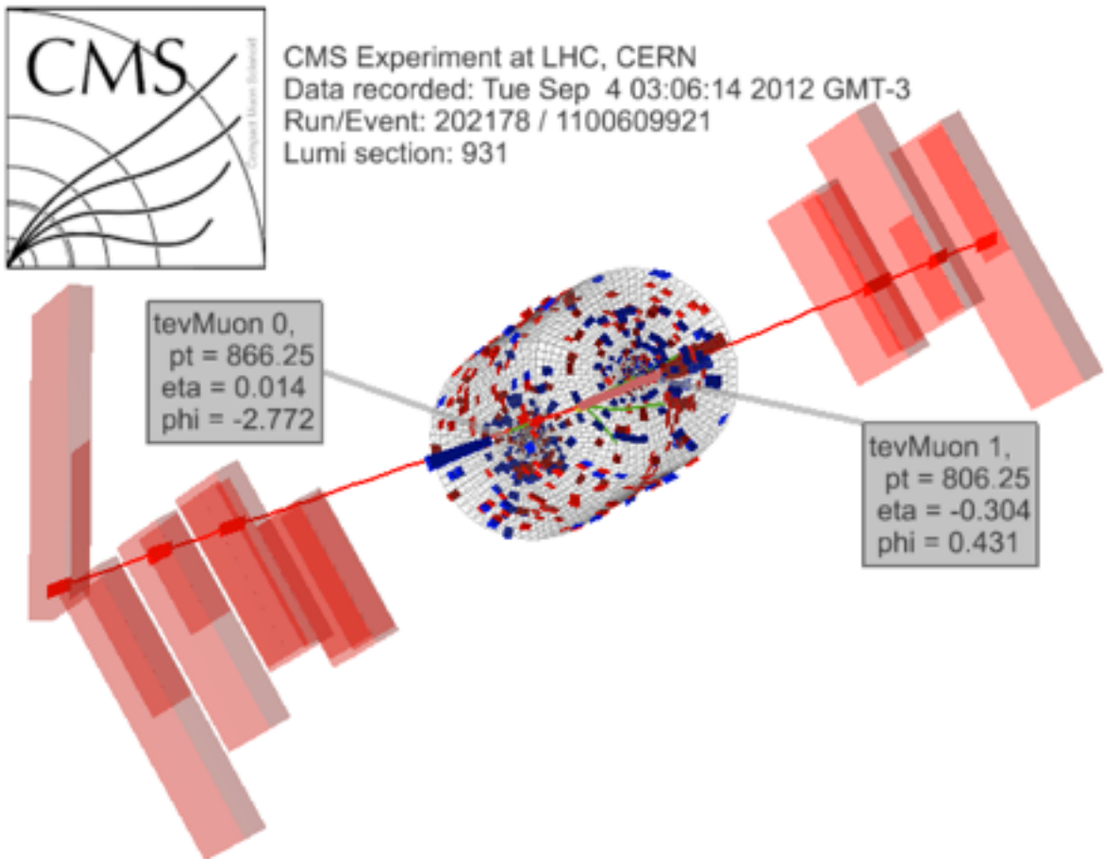


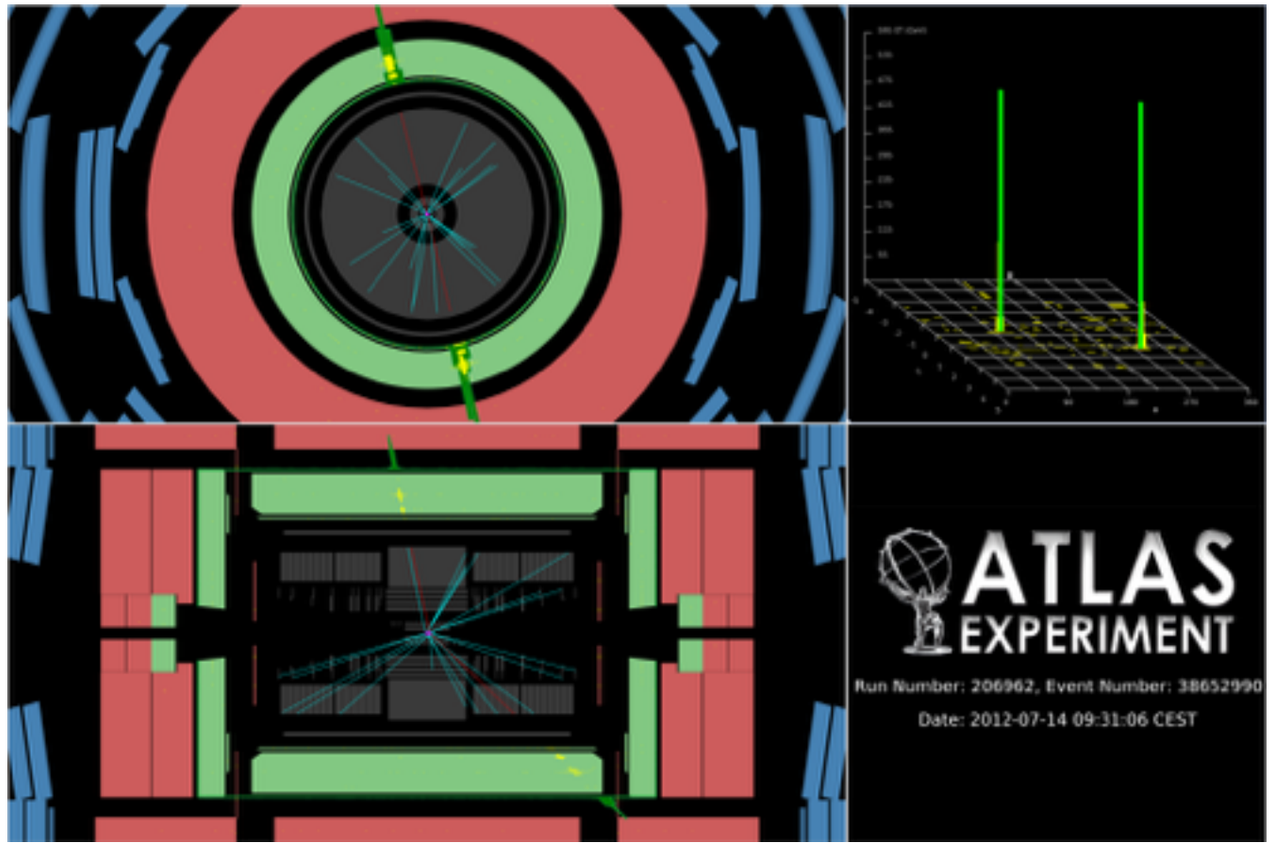
ATLAS-CONF-2016-060



Dilepton searches

Dilepton event displays



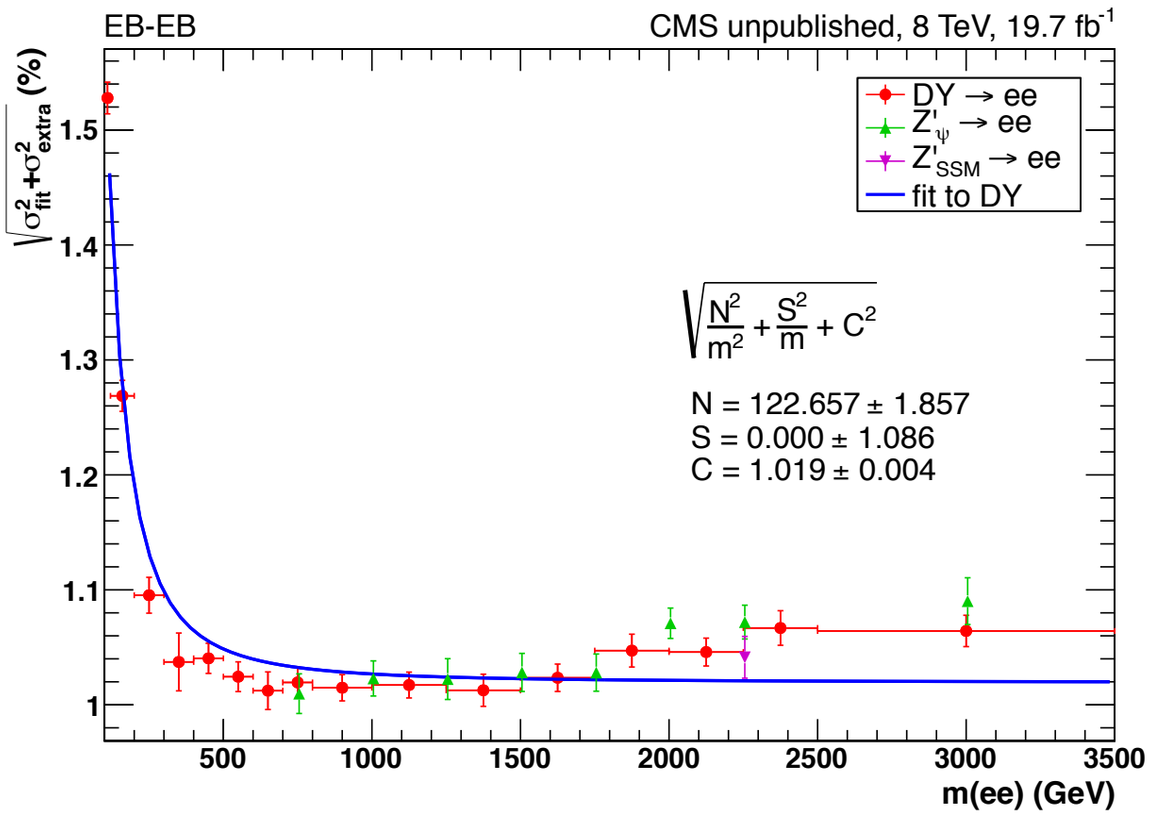


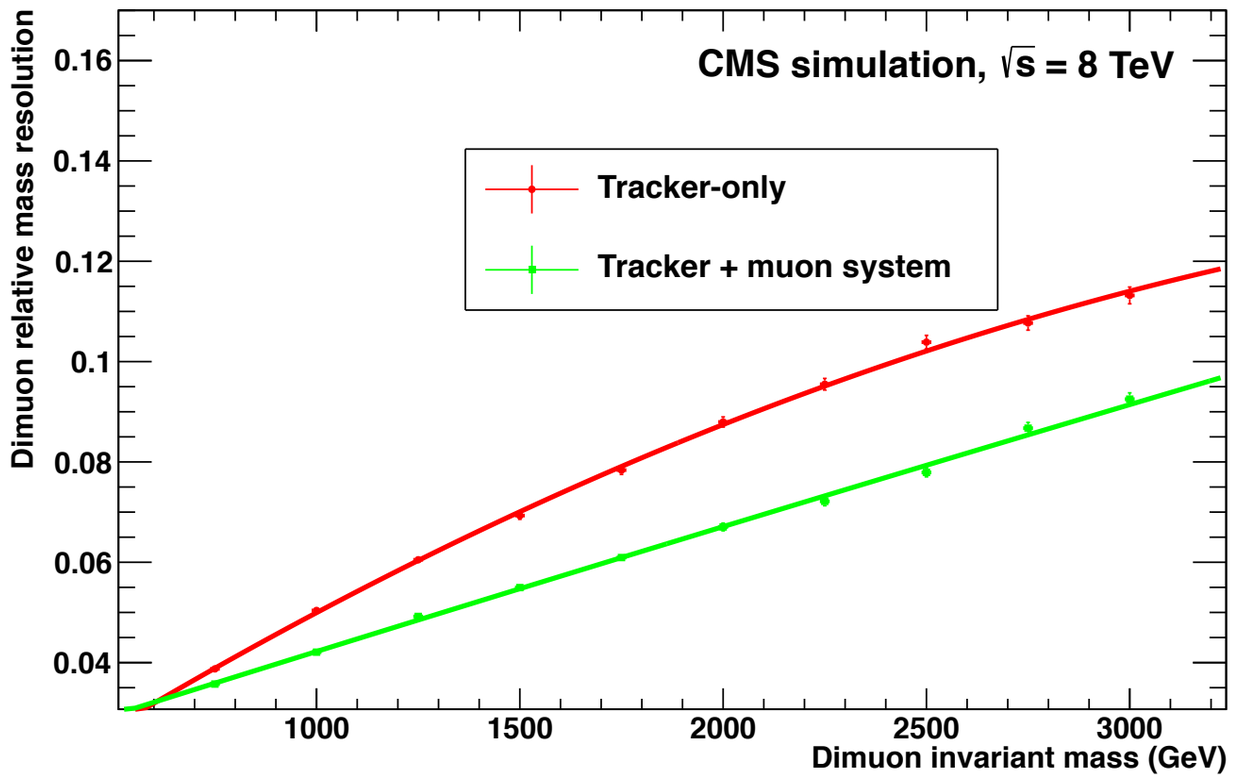
Left: display of a data event where a dimuon event is reconstructed by CMS with an invariant mas of 1.7 TeV

Right: display of a dielectron data event reconstructed by ATLAS with an invariant mass of 1.5 TeV

mass resolution

CMS- EXO12061

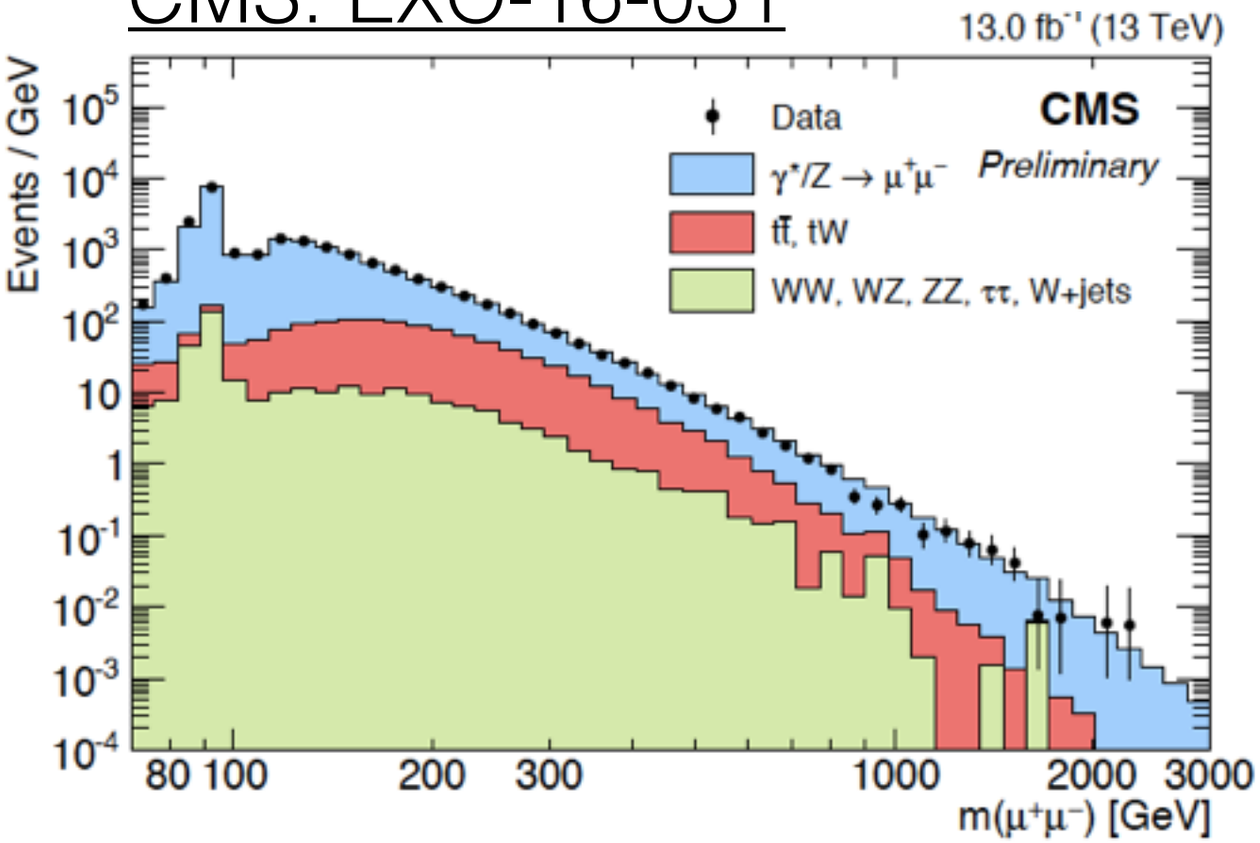




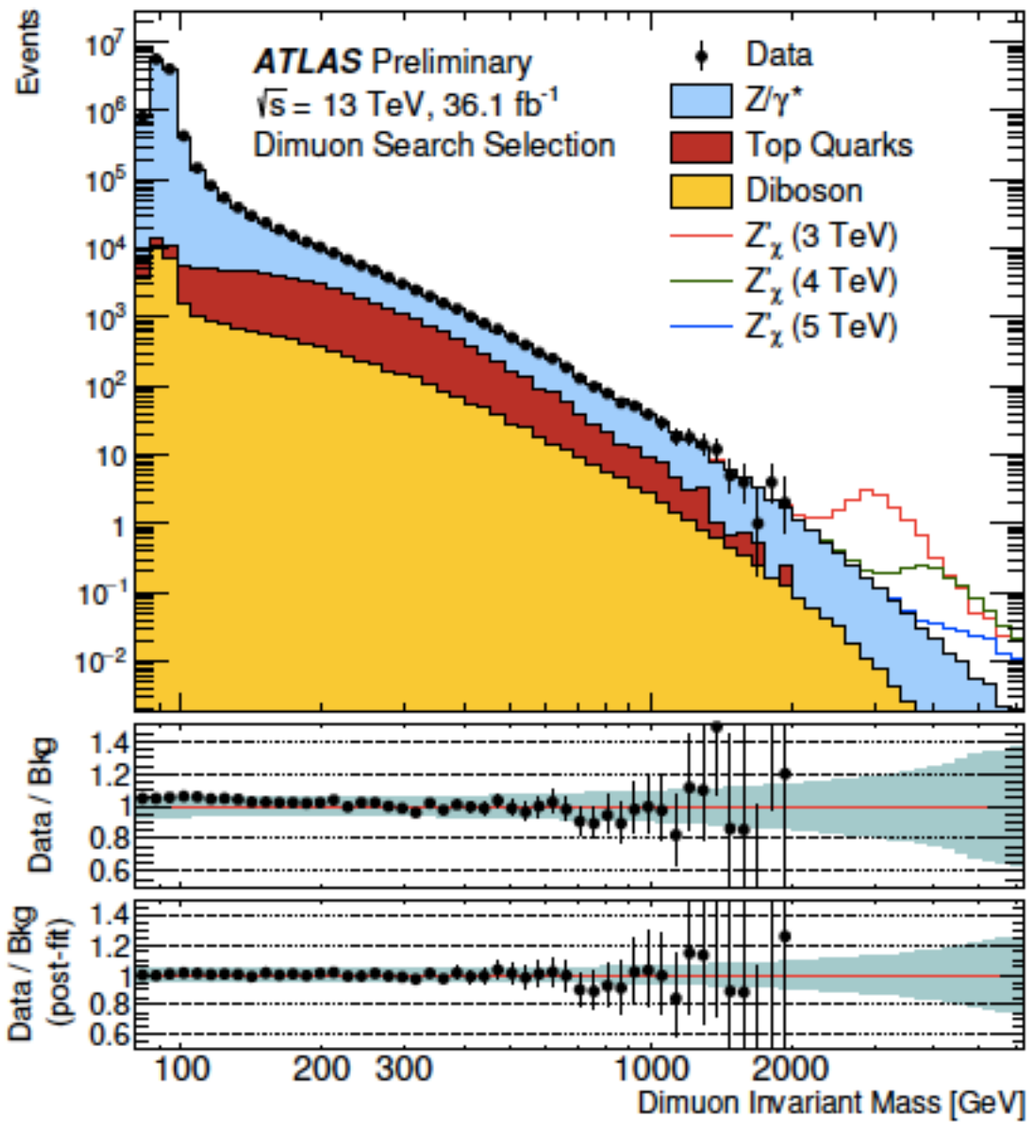
- Resolution on the invariant mass of dielectron (left) and dimuons (right) reconstructed by CMS up to ~3.5 TeV.
- The resolution for electrons is worse at low mass due to low energy electrons, but remains ~1% at high mass.
- For dimuons, the resolution degrades up to ~10% at high mass due to the worse muon momentum resolution.
- Similar performance with ATLAS

$\mu^+\mu^-$ final state

CMS: EXO-16-031



ATLAS-CONF-2017-027

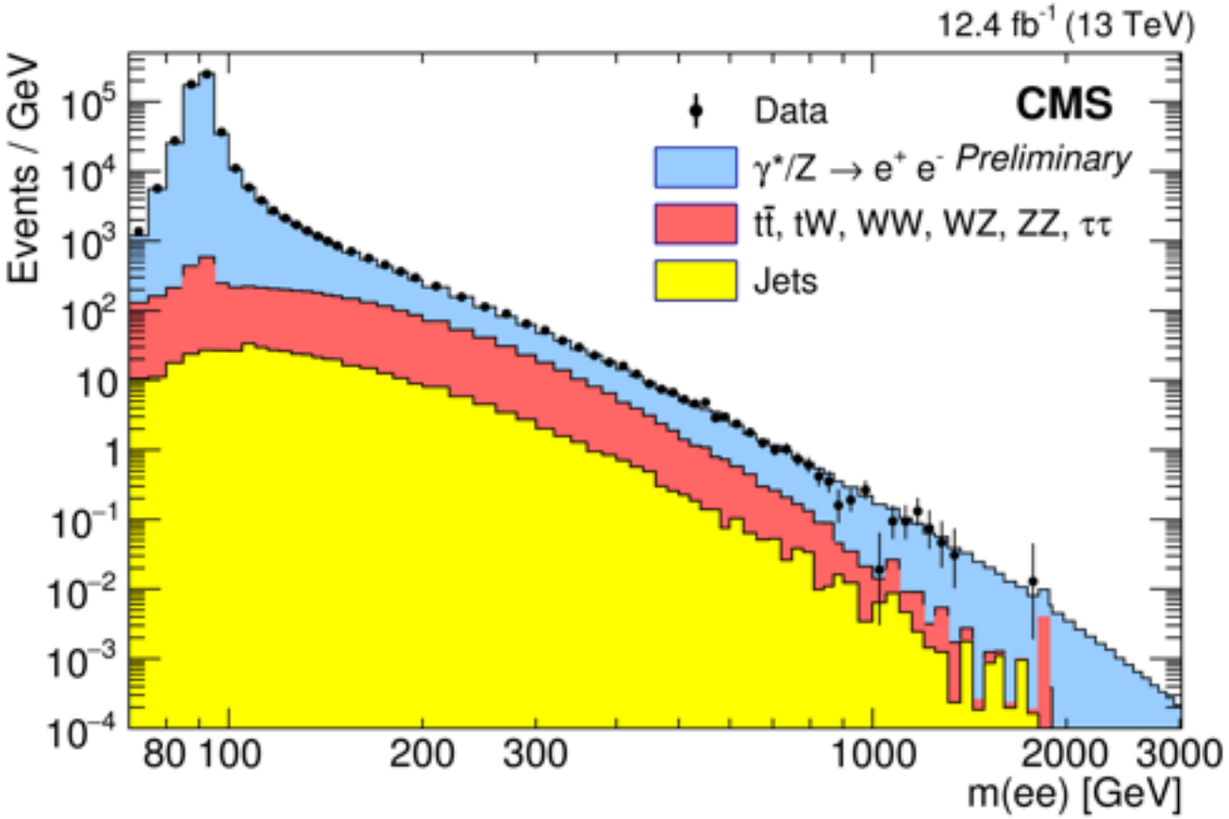


Background mainly from SM Z—>$\mu^+\mu^-$.

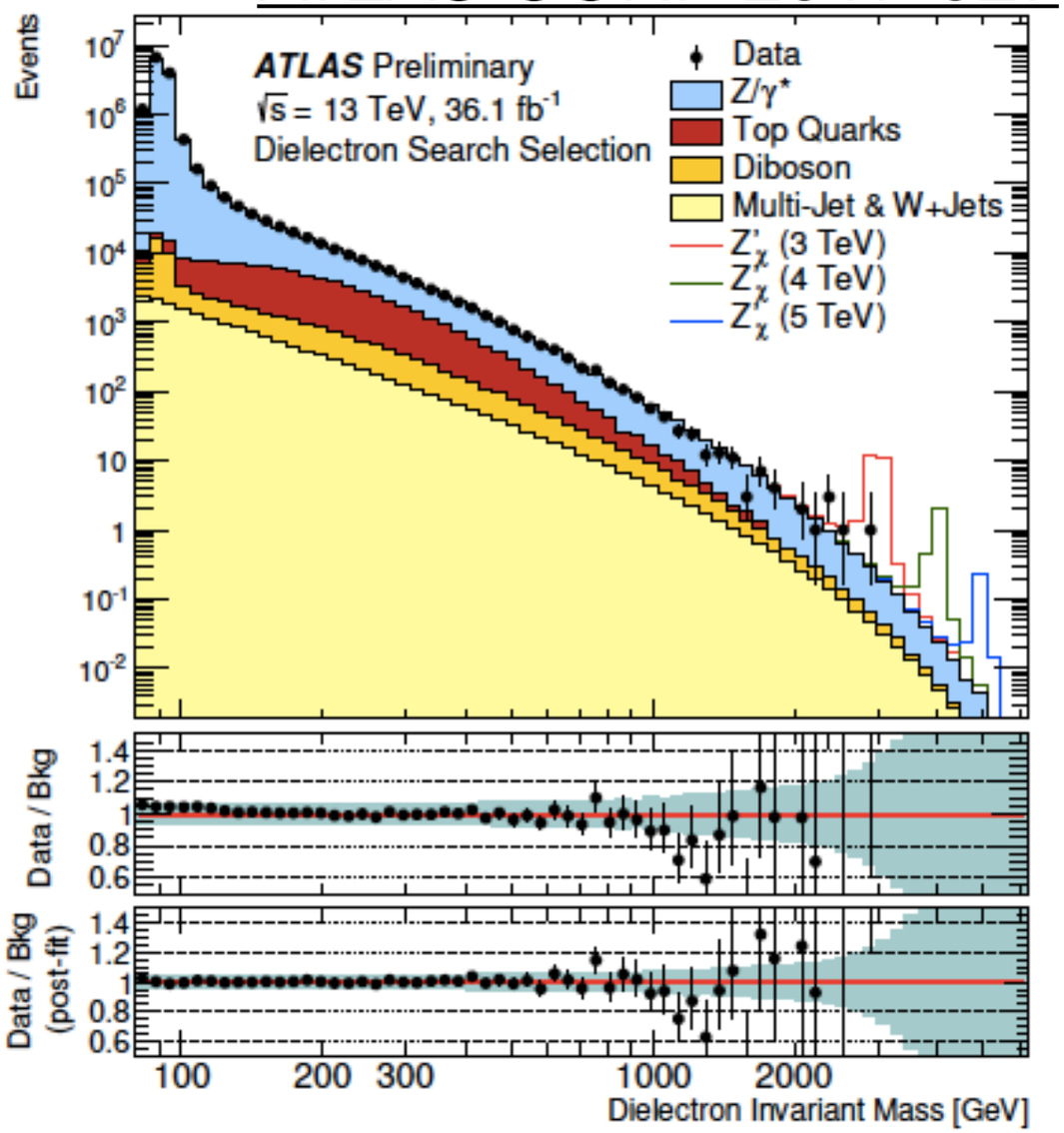
- Analysis selections:
  - muon p_T>53 GeV (CMS) , p_T>30 GeV (ATLAS)
  - isolation requirement,
  - opposite charge.

e^+e^- final state

CMS: EXO-16-031



ATLAS-CONF-2017-027

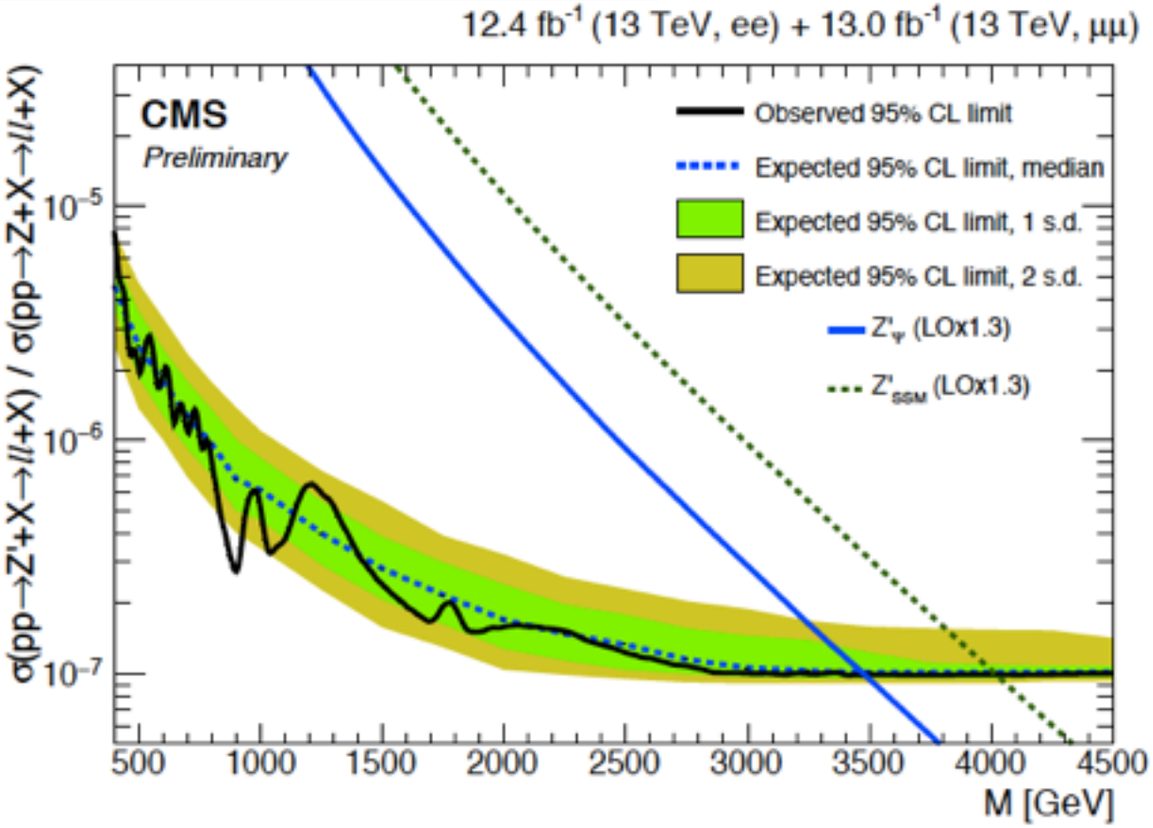


Background mainly from SM Z—>e^+e^-.

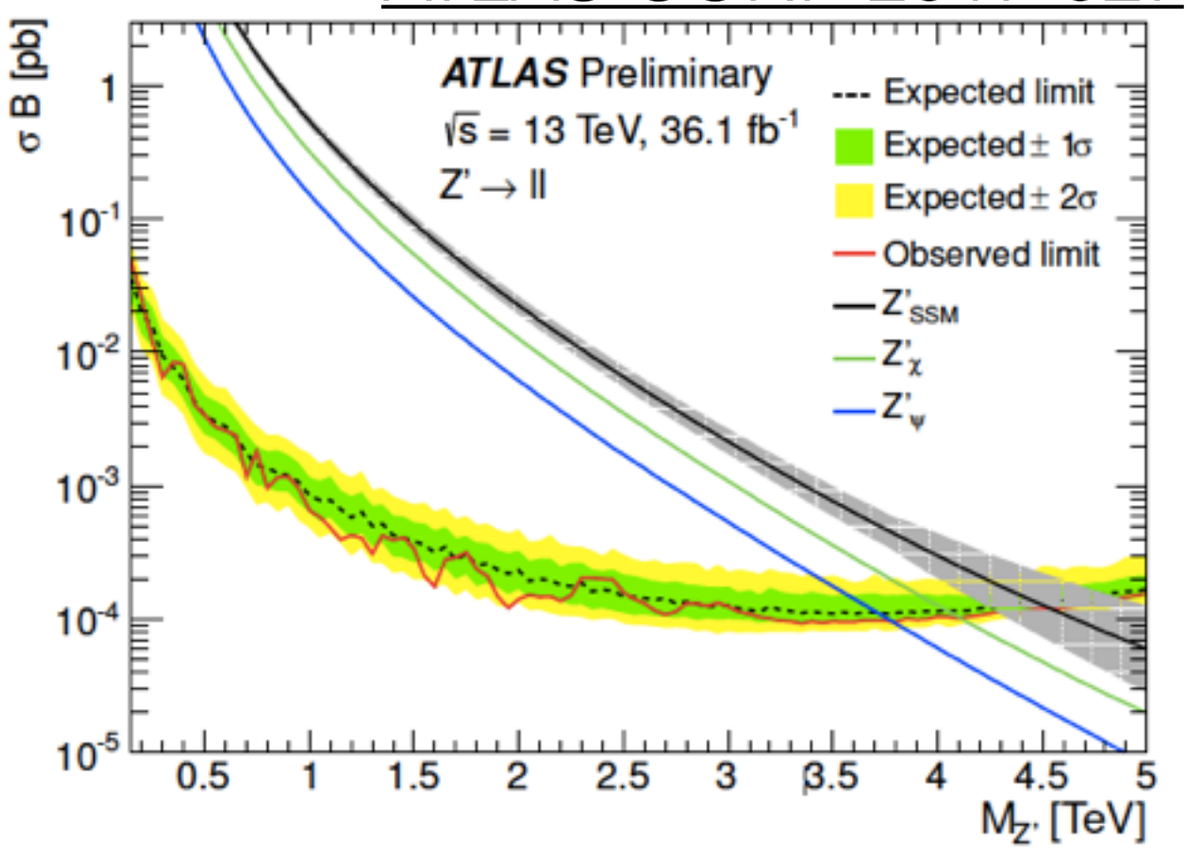
- Analysis selections:
  - electron transverse energy >35 GeV (CMS), >30 GeV (ATLAS)
  - sophisticated electron identification algorithms
  - isolation w.r.t. tracks and calorimeter deposits

crossection limits

CMS: EXO-16-031



ATLAS-CONF-2017-027



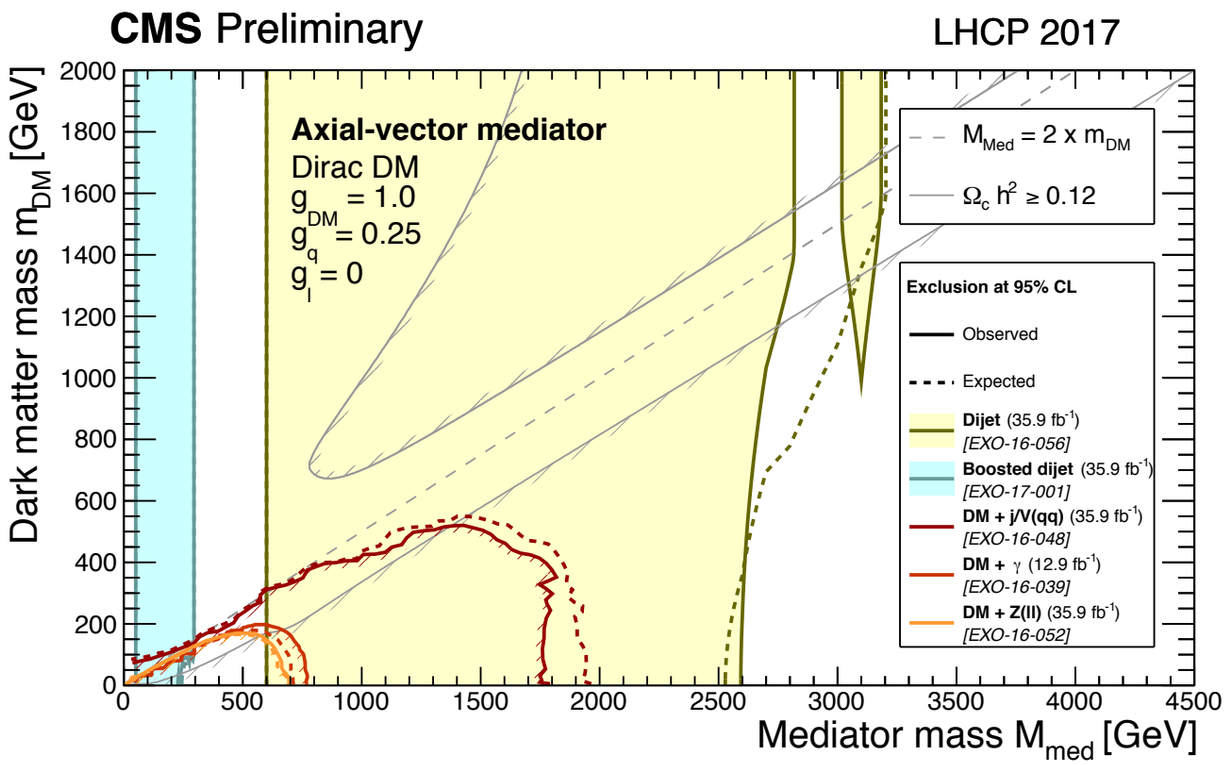
- Very clean search, but no excess observed above the SM background
- Limits combine both electron and muon channels
- Cross section x BR limits between 10^{-4} and 10^{-3} pb for TeV resonances
- Limits similar for both experiments,

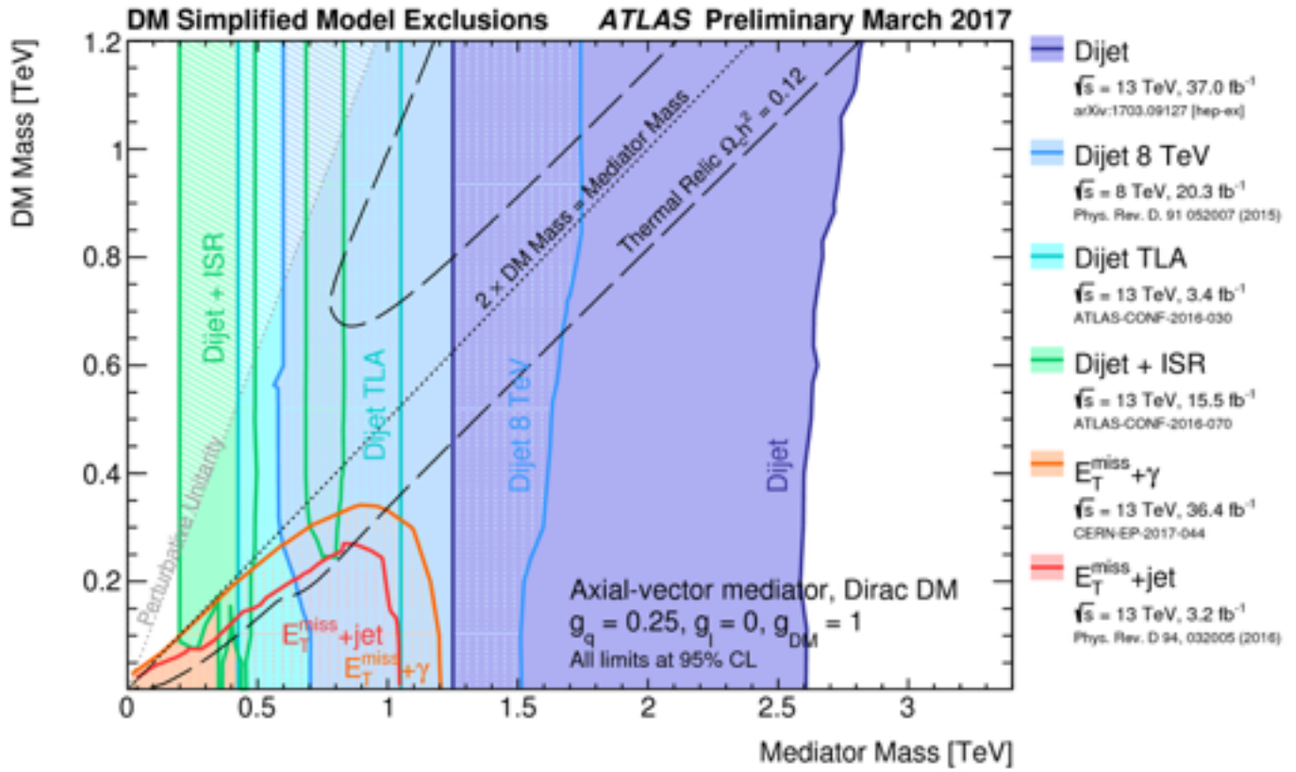
Summary plots for mediator exclusions

Computed for benchmark scenarios:

- dijet searches: $g_q = 0.25$, $g_l = 0$, $g_{DM} = 1$
- dijet + dilepton searches:
  - $g_q = 0.1$, $g_l = 0.1$, and $g_{DM} = 1$ (Axial-Vector)
  - $g_q = 0.1$, $g_l = 0.01$, and $g_{DM} = 1$ (Vector)

AV mediator exclusions (dijet)

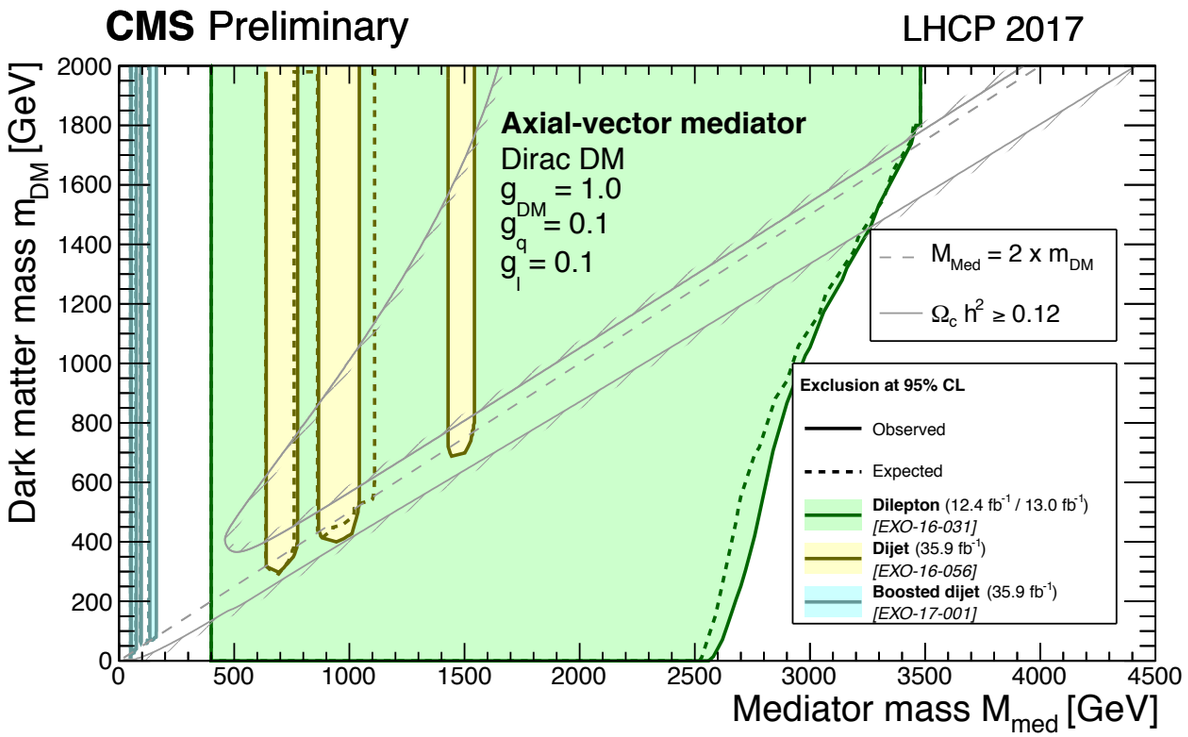


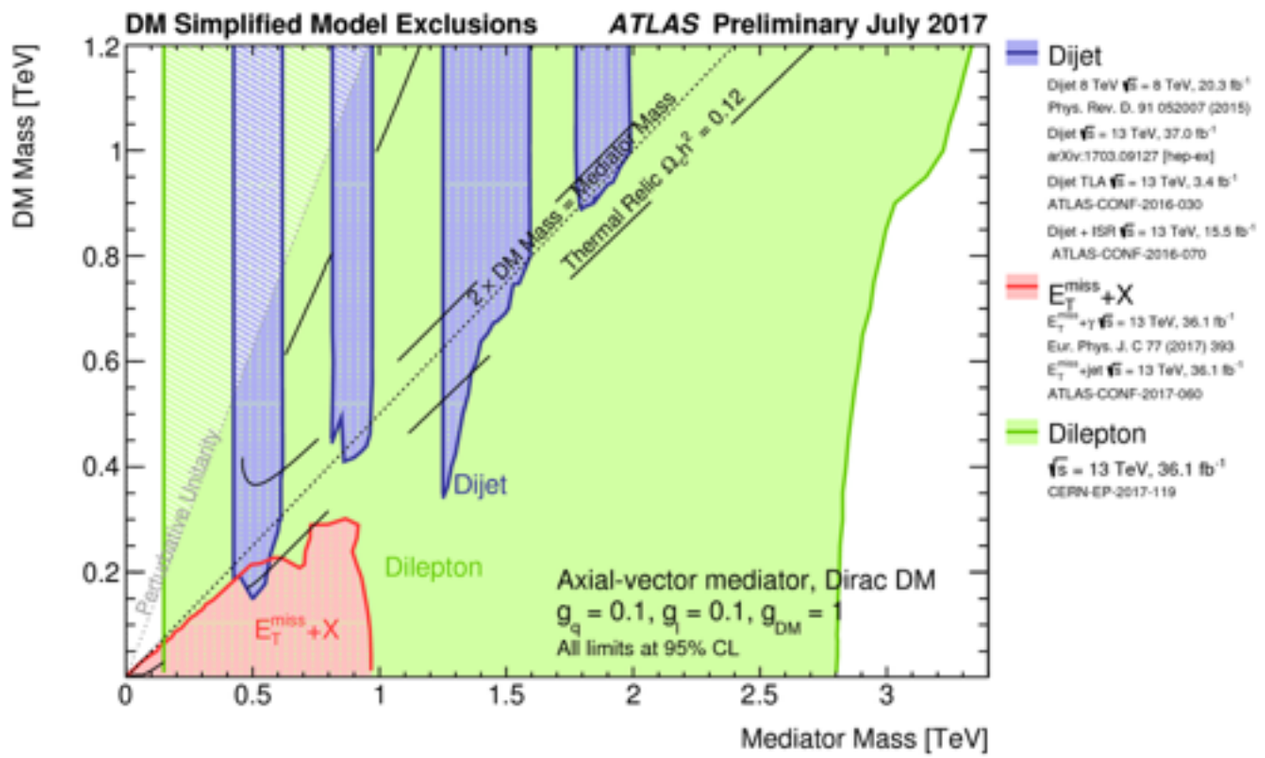


[https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/DM_summary_plots_LHCP_2017.pdf]
[https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/index.html]

- Limits on the m_{DM} vs mediator mass parameter plane with no coupling to leptons.
- Mediator mass exclusion slightly improves for high m_{DM} as the mediator has larger decay fraction to quarks.
- Nice complementarity to the exclusions from direct searches using missing energy signatures.

AV mediator exclusions (dijet+dilepton)

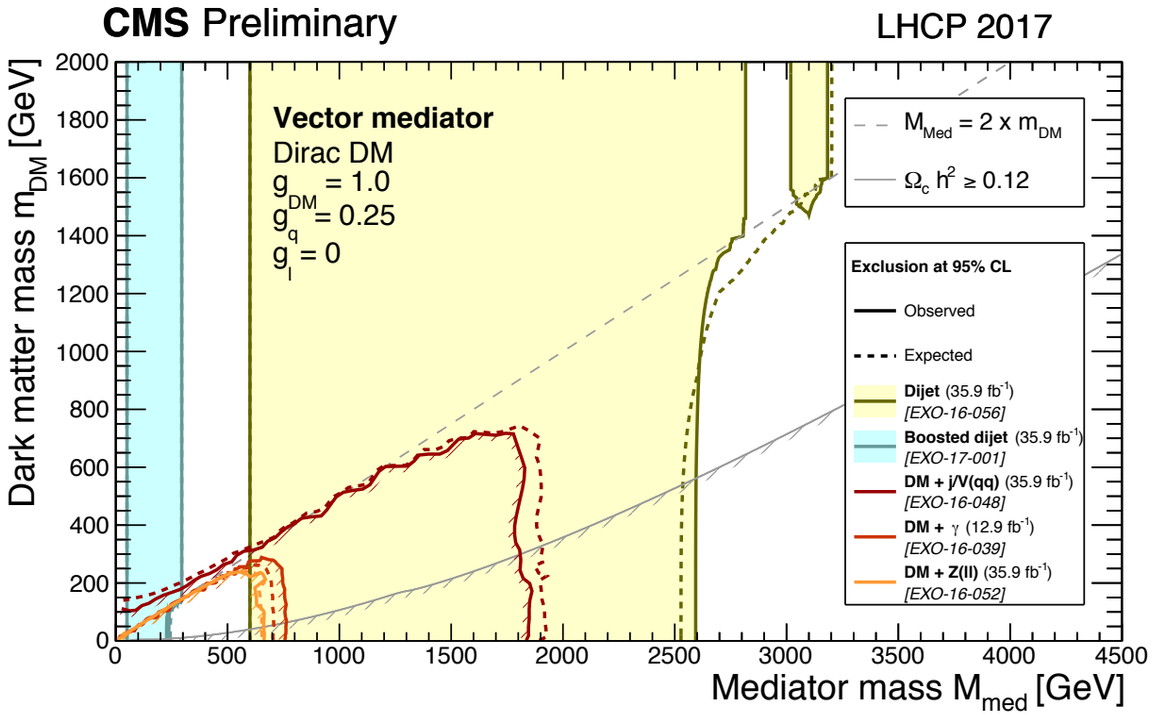


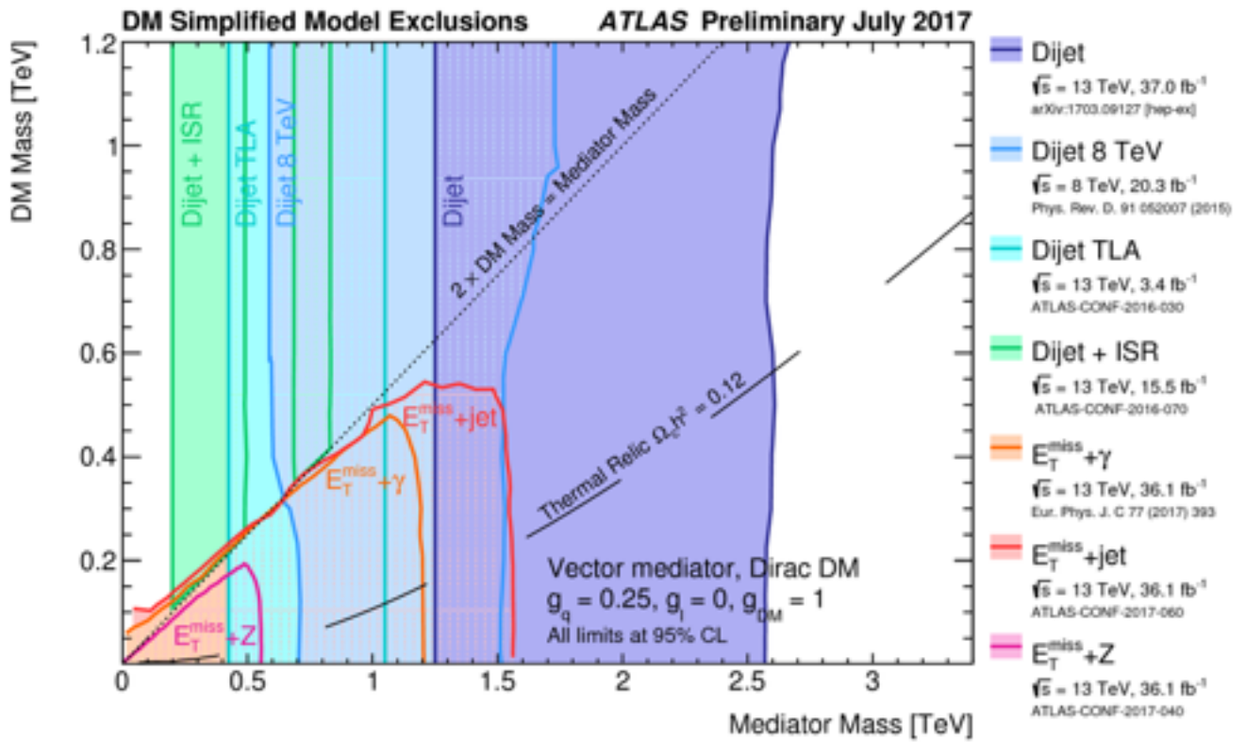


[https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/DM_summary_plots_LHCP_2017.pdf]
[https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/index.html]

- The exclusions are computed for a dark matter coupling g_{DM} = 1.0, a quark coupling g_q = 0.1 universal to all flavors, and lepton coupling g_l = 0.1 [arXiv:1703.05703].
- For these couplings the mass exclusions from dileptons are higher than from the dijets
- The vertical dijet bands correspond to different dijet analyzes, and fluctuations in the crossection limits.

Vector mediator exclusions (dijet)

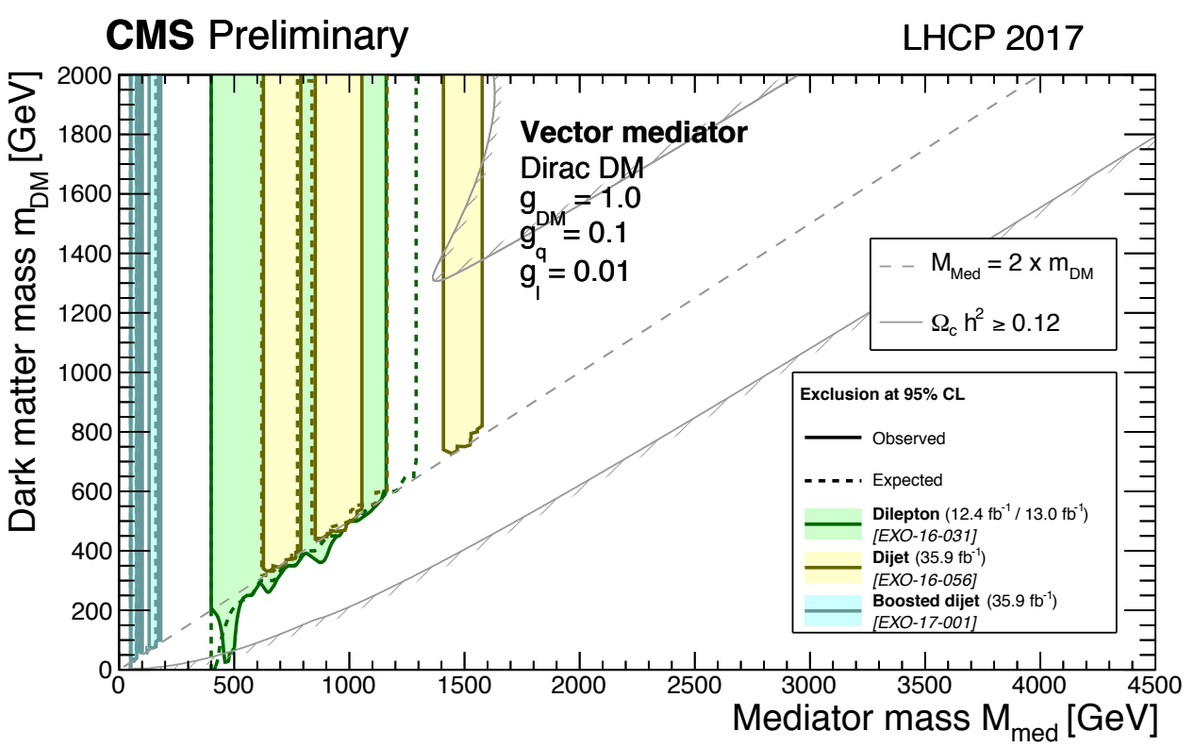


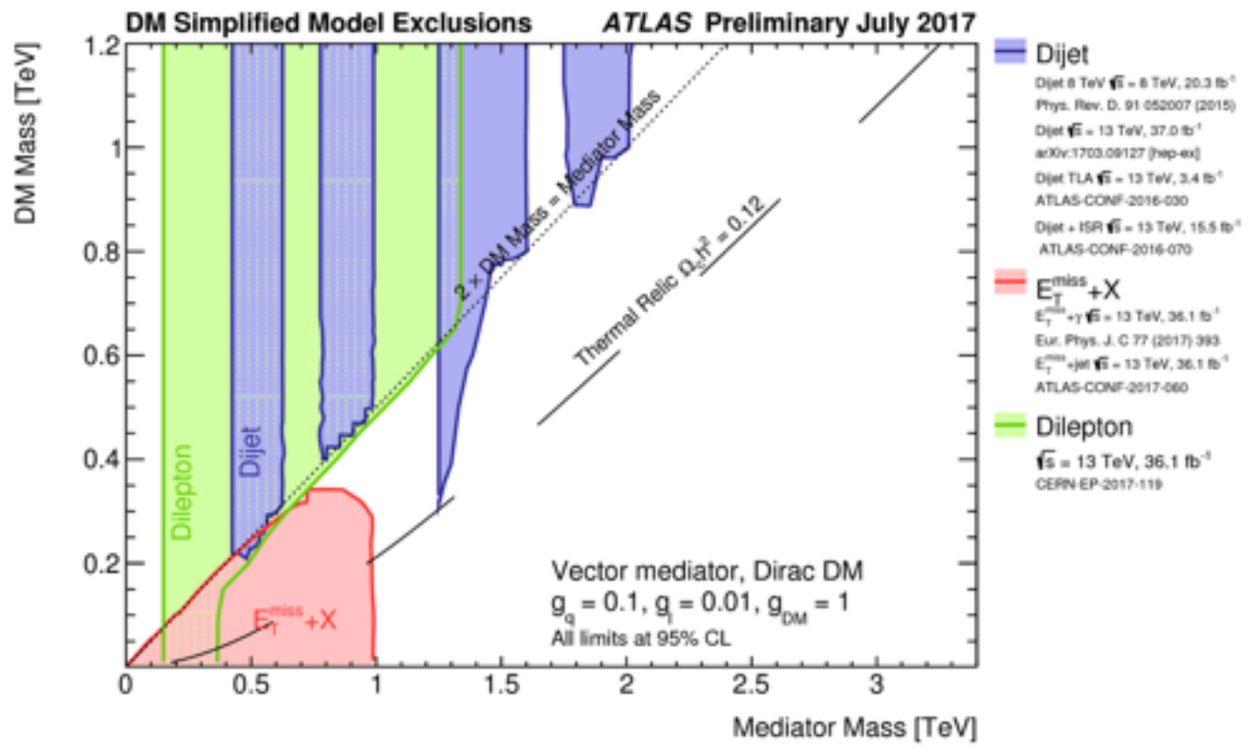


[https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/DM_summary_plots_LHCP_2017.pdf]
[https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/index.html]

- Similar exclusion for Vector resonances as for Axial-Vectors

Vector mediator exclusions (dijet+dilepton)

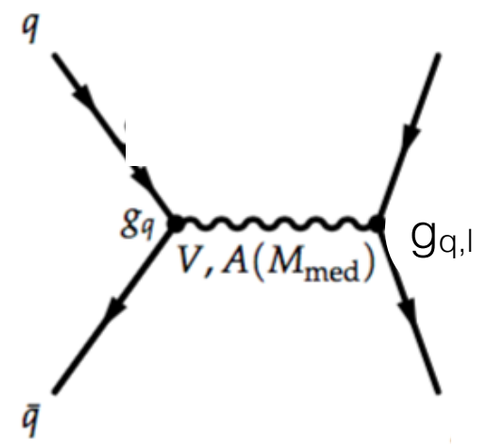




[https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/DM_summary_plots_LHCP_2017.pdf]
[https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/index.html]

- The exclusions are computed for a dark matter coupling g_{DM} = 1.0, a quark coupling g_q = 0.1 universal to all flavors, and lepton coupling g_l = 0.01[arXiv:1703.05703].
- With this choice of couplings, the Z' decays to leptons are reduced with respect to the decays to quarks.
- Exclusions start mainly above 2 x m_{DM} as the decays of the mediator to DM are then suppressed.
- The vertical dijet bands correspond to different dijet analyzes, and fluctuations in the crossection limits.

Summary



- Very exciting times with large amount of new data from the LHC
- Increased center-of-mass energy of 13 TeV increases possible production of new heavy particles.
- Searches in dijet and dilepton final states by ATLAS and CMS are sensitive to mediator signatures.
- Many analyses already performed with full 2016+2015 data, including standard high mass search, and new techniques used to search at low mass.
- Dilepton searches recently started to be interpreted in the context of mediator searches.
- Parameter exclusions from dijet and dilepton searches complement those of more direct searches for missing energy.
- So far no significant excess has been observed, but much more data will be collected this year and in 2018. Stay tuned !

Thanks.