



Recent Exotics and beyond the SM results in ATLAS and CMS

Simone Pigazzini  

on behalf of the ATLAS and CMS collaborations

Corfù, 08/09/2017

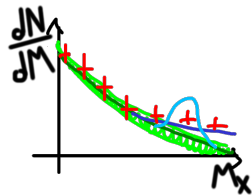
- **Test BSM models searching for new phenomena**
 - Dark Matter
 - Heavy gauge bosons
 - Leptoquarks
 - Heavy quarks
 - Excited fermions
 - Extra dimensions

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- **Broad physics scope: many models and vast phase-space.**

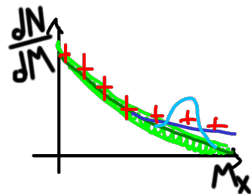
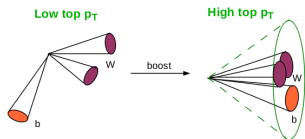
Exotica experimental tools

- Search for high mass (TeV) resonances is a large part of the program



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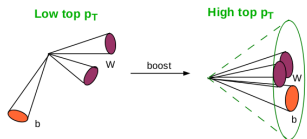
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 - **Tag hadronic decay of boosted H/Z/W or t/b quarks.**

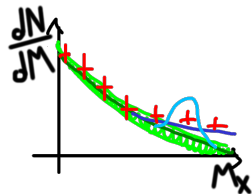
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- Plenty final states. extensive use of jet structure analysis:
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- **Uncommon signatures:** long lived particles.



Dark matter

Dark matter at collider experiment

- **DM is:** Mediator + stable WIMP → **Missing E_T signatures.**

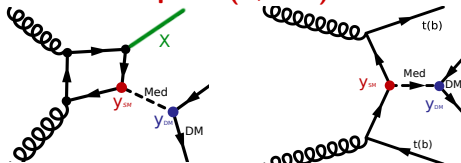
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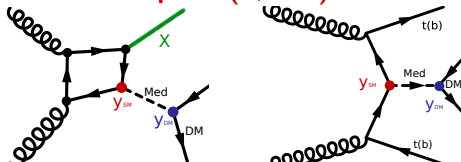
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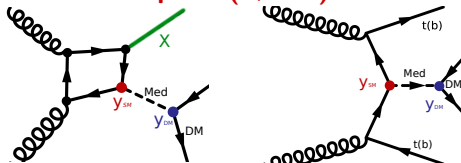


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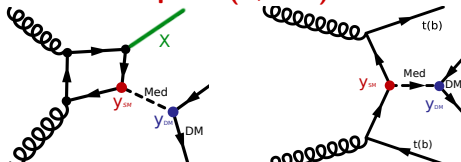
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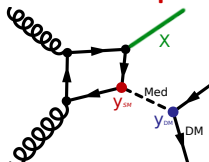
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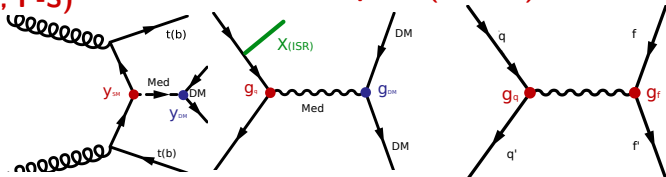


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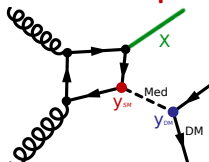


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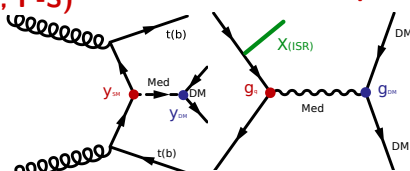


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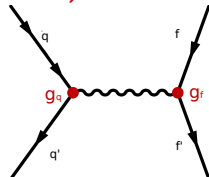
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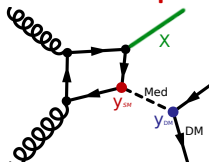
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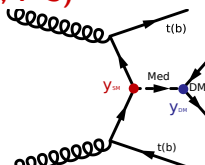
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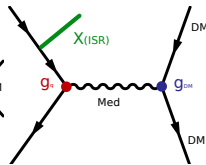
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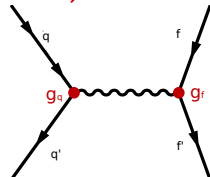
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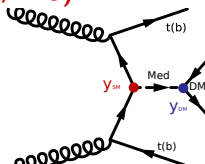
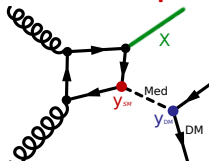
\rightarrow Mediator direct search: jj, e^+e^- and $\mu^+\mu^-$ final states.



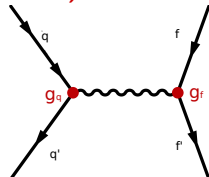
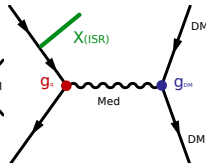
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- Analysis are model independent.

- **Results depend on assumptions/parameters choice.**

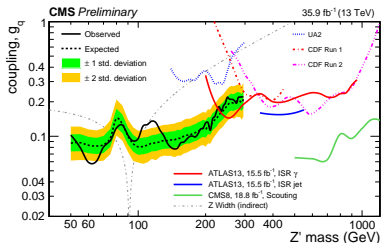
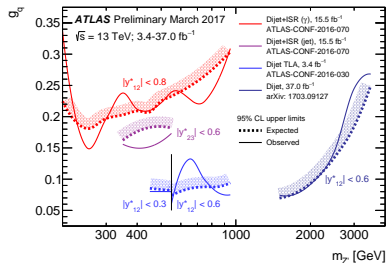
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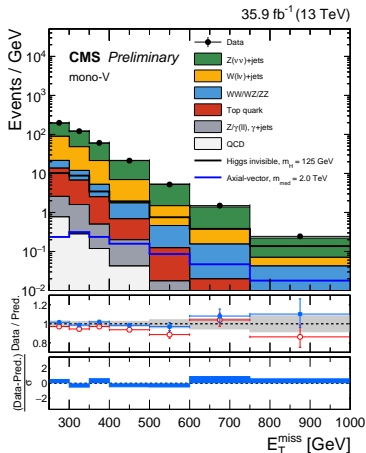
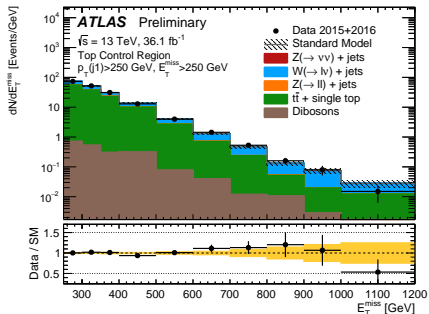
Experimental insight: jj final state

- **Di-jet production from QCD overwhelming at LHC.**
- Standard analysis only for m_{jj} in the TeV range.
- Lower mass region accessed through:
 - **Trigger level analysis**
 - **Boosted topology**
- CMS: Extensive use of fast developing techniques
 - **Pile-up mitigation.**
 - **Jet structure analysis.**
- Reaches $m_{Z'} = 50$ GeV: best result from SpS days.



Experimental insight: MET + X final state

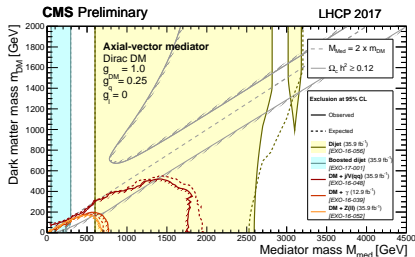
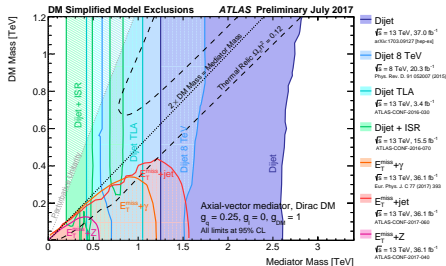
- All **MET + X** ($j/V, \gamma, Z \rightarrow \ell\ell$) extensively use data to constrain backgrounds contribution to E_T^{miss} spectrum.
 - Expected SM spectrum from simultaneous fit of several control regions.



Dark matter spin-1: results

- Analysis set limits on $\mu = \sigma_{obs}/\sigma_{theo}$ scanning the parameters set $M_{med}, M_{DM}, g_{DM}, g_{SM}$
- Excluded region in the $M_{DM} - M_{med}$ plane strongly depend on the coupling choice.**

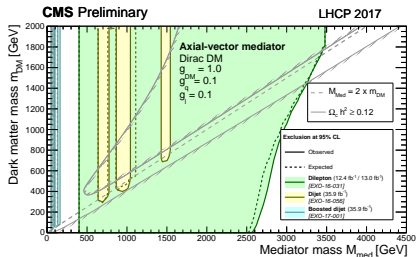
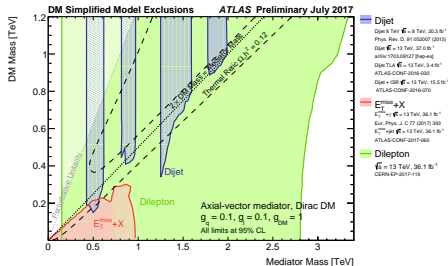
Leptophobic scenario, spin-1



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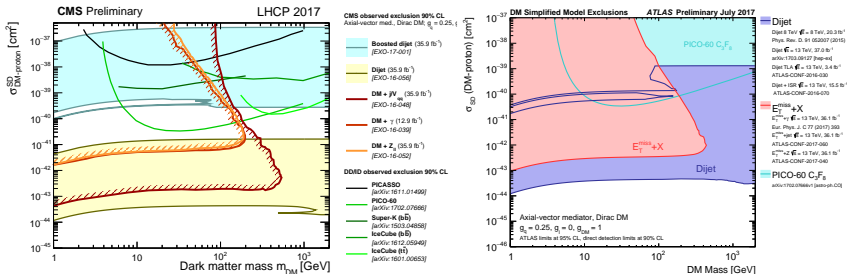
$g_l > 0$ scenario, spin-1



- If coupling to leptons allowed, $Z \rightarrow \ell\bar{\ell}$ final state very powerful probe.**

Dark matter: collider vs direct detection experiments

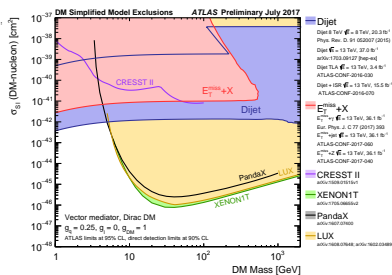
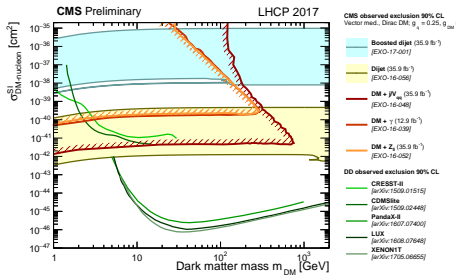
- Direct detection experiments have low sensitivity for low DM masses.
 - **Collider results can cover this part of the phase space.**



- DD cross section derived from collider results assuming $g_q = 0.25$, $g_{DM} = 1$ and Dirac DM.

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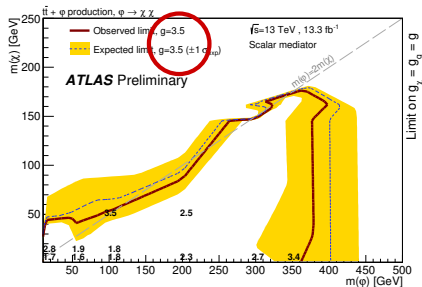
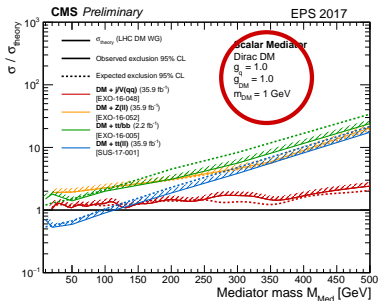


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Dark Matter spin-0: results

- DM + heavy flavour competitive especially at low mass (scalar mediator)

Scalar mediator

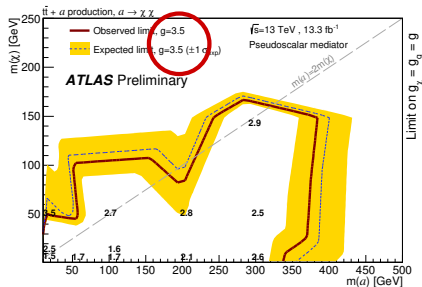
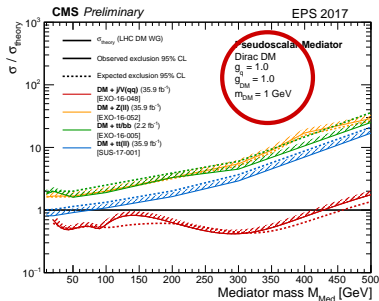


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- ATLAS analysis slightly less sensitive: coupling lower limit $1.5 < g < 2.0$, $M_{\text{med}} < 100 \text{ GeV}$.

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Pseudo-scalar mediator



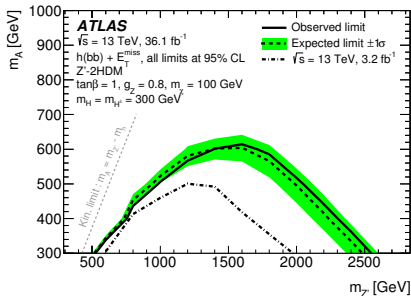
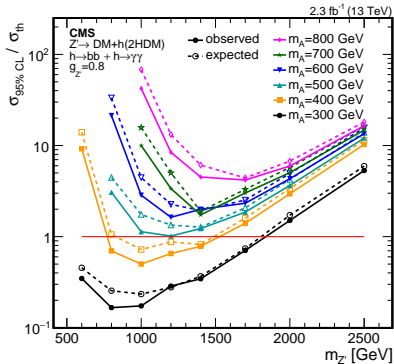
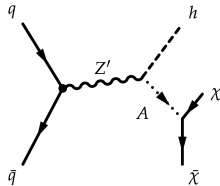
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Dark matter: summary

- Mono-j/V
 - Mono- γ
 - Di-jet
 - Mono-Z(ll)
 - Di-leptons (e, μ)
 - $t\bar{t}(b\bar{b})$
 - **Mono-H**
- dominated by systematic uncertainties.
- dominated by statistical uncertainty.

Dark matter: DM + Higgs

- Sensitivity still statistically limited.
- **Probe alternative models:** Higgs emitted by mediator since ISR suppressed.
- **$H \rightarrow b\bar{b}$ channel dominates** (but other final states are being investigated).



Bump hunting

Di-bosons final state

- Di-photons
- WW, ZZ, (HH)
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Di-bosons final state

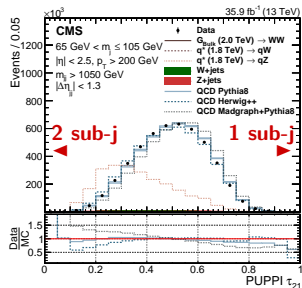
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between x4-x10 sensitivity gain from 8 to 13 TeV (2012 → 2015/2016)

Slower gain from now on.

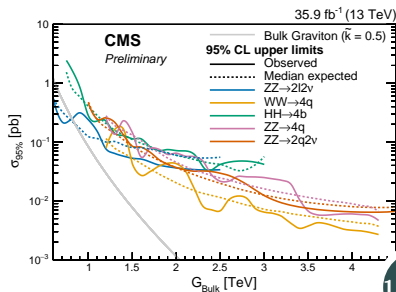
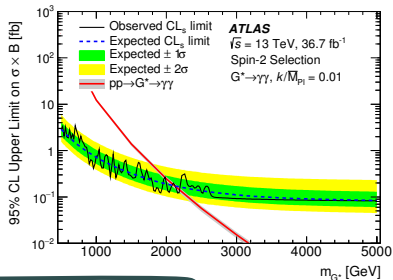
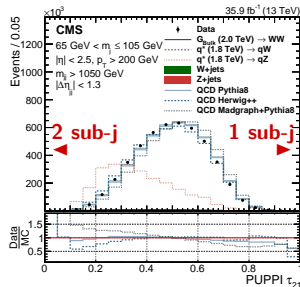
KK gravitons

- Graviton coupling to heavy bosons is favoured in the Bulk scenario while $G \rightarrow \gamma\gamma$ is non-negligible in the RS1 scenario.
- **Boson-jet tagging techniques** heavily used to extend search region up to 4 TeV.



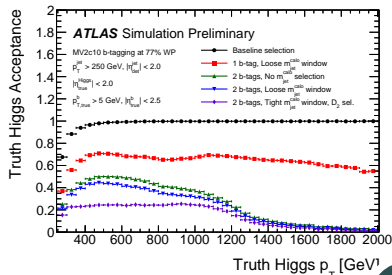
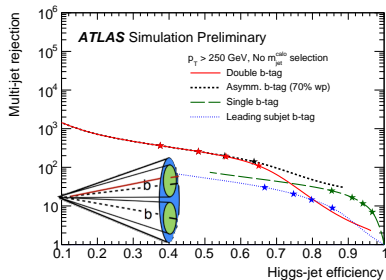
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Experimental insight: boosted $H \rightarrow \bar{b}b$ signature

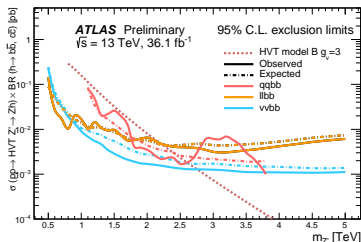
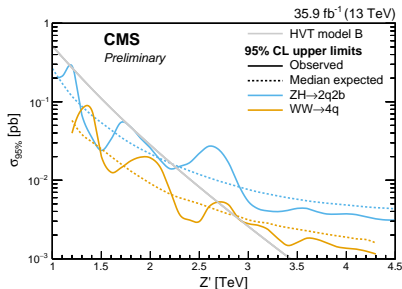
- Z/W and H coming from HVT decay has large boost:
 - **Hadronic Z/W and H decay product are collimated into one single jet.**
- A dedicated $H \rightarrow \bar{b}b$ tagger has been developed
- Very good performance in the 250 - 1200 GeV p_T range.**



Heavy vector triplet

- Larger limits ($\sim 4 - 5$ TeV) are set on W' and Z' masses in the fermion decay channels, **but these channel are complementary** (fermionophobic models).

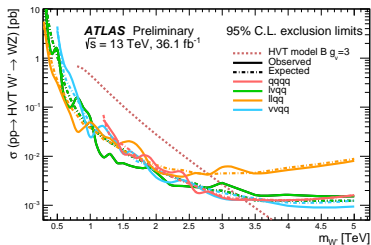
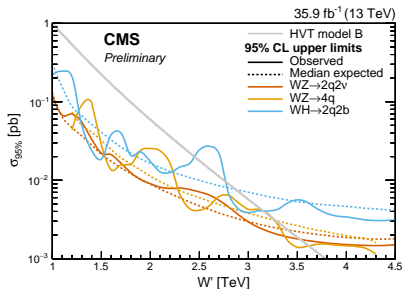
Heavy Z'



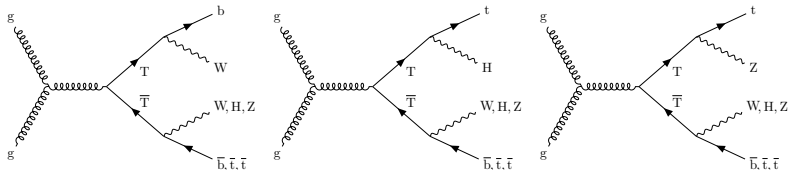
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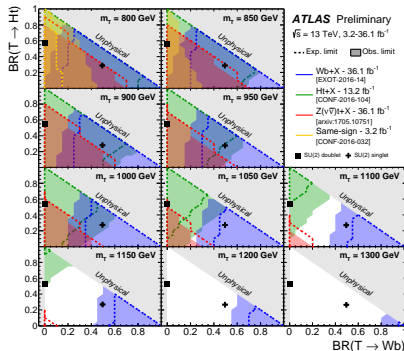
Heavy W'



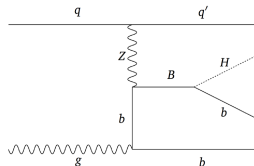
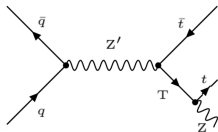
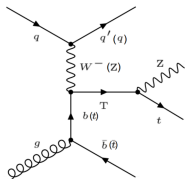
Fermion resonances: VLQ pair production



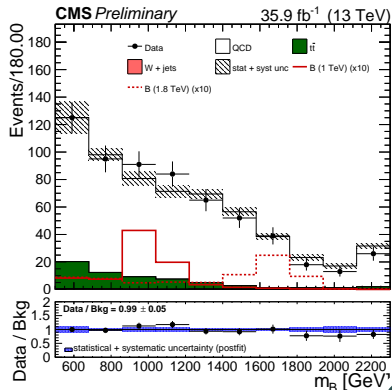
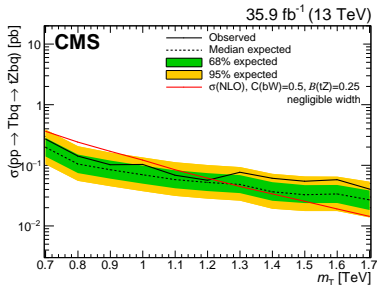
- Vector-like-quarks searches focus on 3rd generation.
 - **T, B decay restricted to H, Z, W + t, b.**
- **Events categories defined using jet structure and heavy flavour content.**



Fermion resonances: VLQ single production



- **Forward jets used to tag candidates VLQ events.**



Long lived particles

- **Search for exotic particles decaying into SM particles producing displaced vertex.**

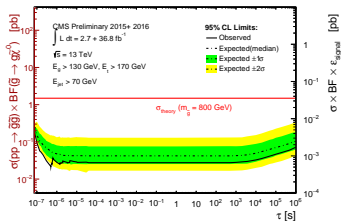
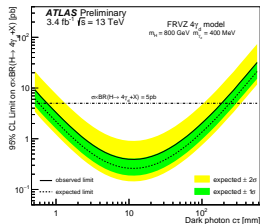
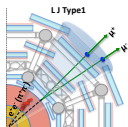
→ Heavy particles with high dE/dx .

→ Dark photons.

- Experimental signatures are very peculiar:

→ Hadronic jets not synchronized with LHC bunch crossings.

→ Leptonic jets.



Summary

- Challenging goal: **test a wide range of BSM models and phase space.**
 - Large part of the effort is still on searching for new resonances.
 - Novel experimental techniques used to explore TeV mass spectrum.
- Dark matter at colliders complementary to astronomical observation and direct detection experiments.
- Most of the analysis in a steady state after big gain from 8 to 13 TeV:
 - **New approaches being discussed withing the collaborations.**

Documentation

- **Dark matter**

- Di-jet low mass: [ATLAS-CONF-2016-070](#)
- Di-jet trigger level analysis: [ATLAS-CONF-2016-030](#)
- Di-jet high mass: [arXiv: 1703.09127](#)
- Mono-photon: *Eur. Phys. J. C* 77 (2017) 393
- Mono-jet: [ATLAS-CONF-2017-060](#)
- Mono-Z: [ATLAS-CONF-2017-040](#)
- $Z \rightarrow e^+e^-(\mu^+\mu^-)$: [CERN-EP-2017-119](#)
- $t\bar{t} + \text{DM}$: [ATLAS-CONF-2016-077](#)
- Mono-Higgs ($H \rightarrow \bar{b}b$): [arXiv: 1707.01302](#)

- **Di-bosons resonances**

- Di-photons: [arXiv: 1707.04147](#)
- Boosted $H \rightarrow \bar{b}b$ tagger: [ATLAS-CONF-2016-039](#)
- HVT: Z' [CERN-EP-2017-111](#), [ATLAS-CONF-2017-055](#)
- HVT: W' [CERN-EP-2017-147](#), [ATLAS-CONF-2017-051](#), [CERN-EP-2017-146](#)

- **Long lived particle**: [ATLAS-CONF-2016-042](#)

- **Dark matter**

- Di-jet low mass: EXO-17-001
- Di-jet high mass: EXO-16-056
- Mono-photon: EXO-16-039
- Mono-jet: EXO-16-048
- Mono-Z: EXO-16-052
- $Z \rightarrow e^+ e^- (\mu^+ \mu^-)$: EXO-16-031
- $b\bar{b}$ +DM : EXO-16-005
- $t\bar{t}$ +DM : SUS-17-001
- Mono-Higgs ($H \rightarrow \bar{b}b$): EXO-16-012

- **Di-bosons resonances**

- Bulk Graviton: CMS-PAS-B2G-16-023, CMS-PAS-B2G-16-026, CMS-PAS-B2G-17-001, CMS-PAS-B2G-17-001
- HVT: Z' B2G-17-002, CMS-PAS-B2G-17-001
- HVT: W' CMS-PAS-B2G-17-005, CMS-PAS-B2G-17-001, B2G-17-002

- **VLQ**: B2G-17-009, B2G-17-007

- **Long lived particle**: EXO-16-004