Searching for exotic BSM physics:

Extrapolation Until the End of Run-3

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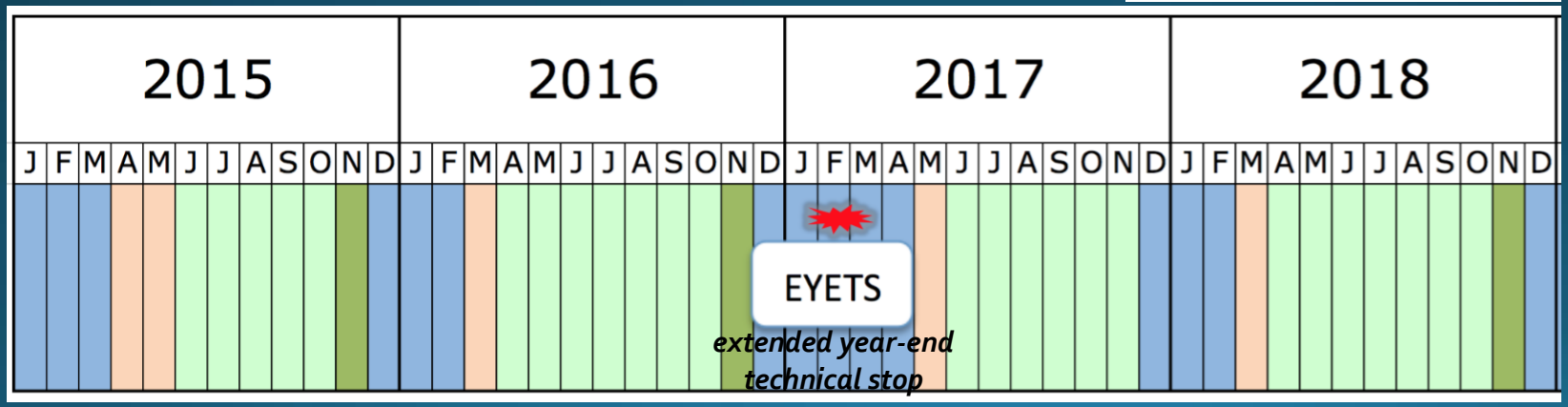
cnrs IN2P3 Les deux infinis

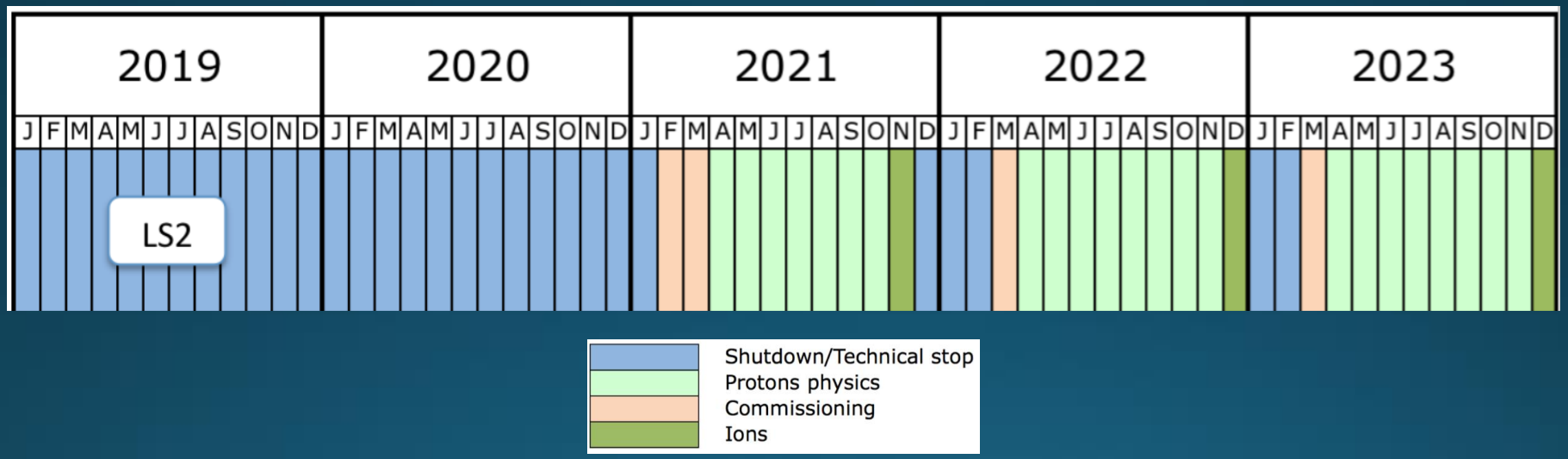
LHC Schedule: Run-2

- No change of beam energy in the current Run-2
  - The goal will be to prepare the LHC to run at 14 TeV during Run-3
- Already ~45 fb^{-1} delivered in 2015-2016
- Plan for this year:
  - 45 fb^{-1}
  - Should reach ~1.9 x 10^{34} $cm^{2}s^{-1}$
- Run-2 goal: > 120 fb^{-1} @ 13 TeV

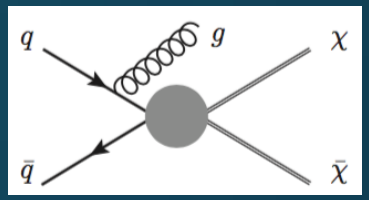


LHC Schedule: Run-3

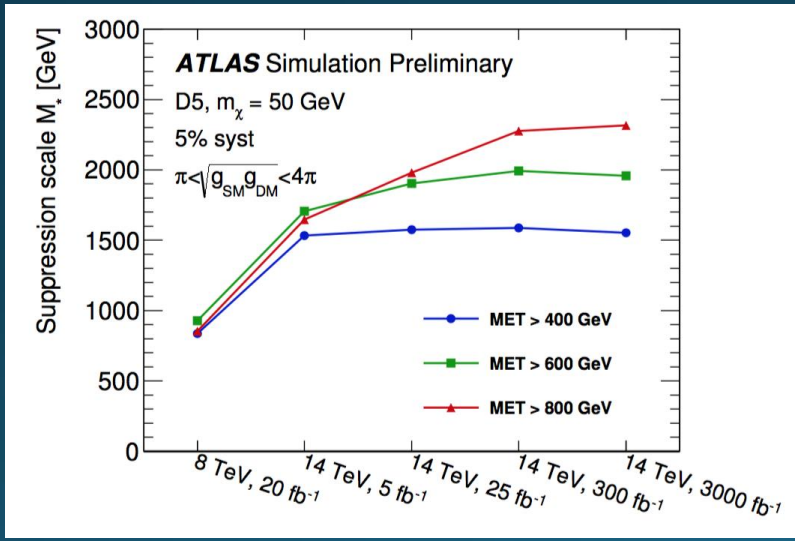
- Run-3 @ 14 TeV (?)
- Goal: 300 fb^{-1} accumulated by the end of 2023

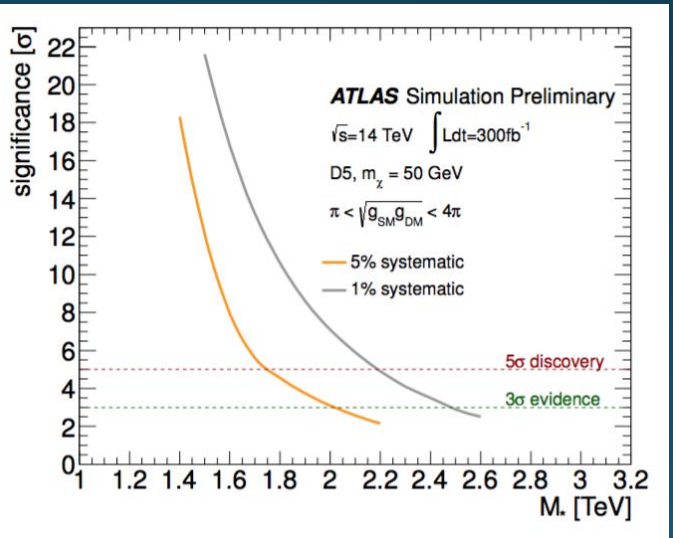


Dark Matter in jet+E_T^{miss} events



- High-p_T jet, large E_T^{miss} well separated from jets, veto on leptons and too many extra jets
- Estimate the main Z(νν)+jets BG using a W(μν)+jet CR and/or a γ+jets CR
- Projection studies done ***before the start on Run-2***, based on the model used at that time: EFT (vector type) with suppression scale M_*
  - *Increase in sensitivity was also confirmed with simplified models.*

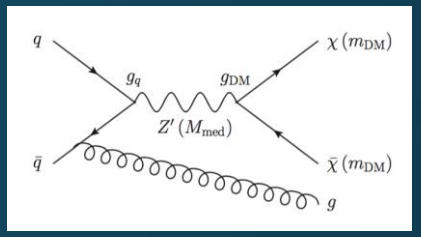




ATL-PHYS-PUB-2014-007

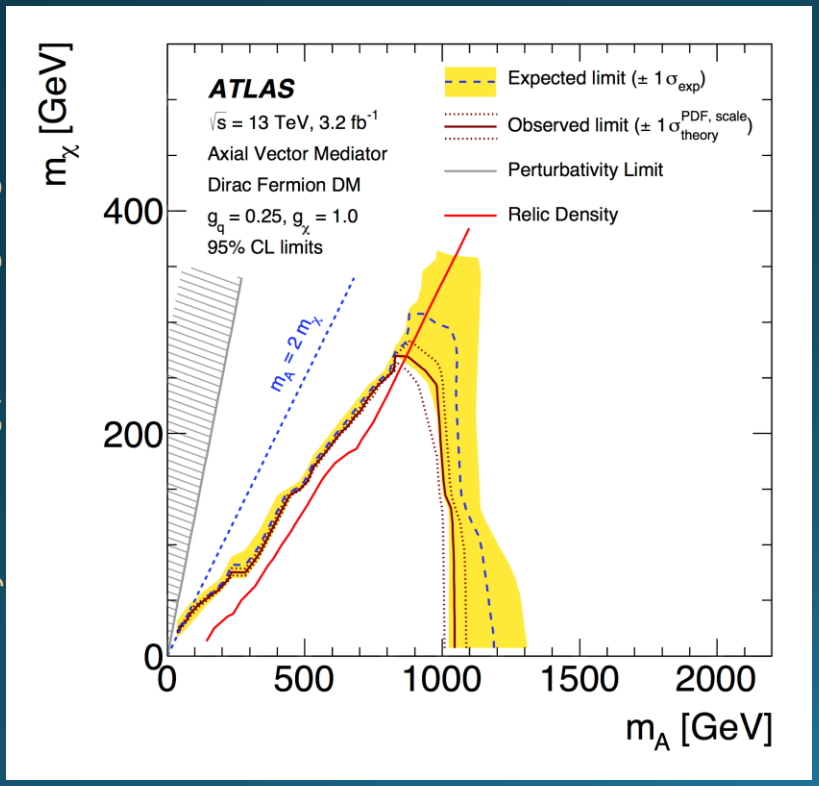
- Important to have tighter signal regions in E_T^{miss} to keep improving with data
  - Up to >800 GeV in the study, but could possibly gain further with larger dataset
- Optimistic scenario: if one could reduce the systematic uncertainty to 1% at the end of Run-3, could gain 0.5 TeV more

Dark Matter in jet+E_T^{miss} events



Where are we now (2015 data analysis)?

- Multiple signal regions with increasing E_T^{miss} cuts, up to E_T^{miss}> 700 GeV
- Present limit on a simplified model of dark matter and not on EFTs anymore:



Phys. Rev. D 94 (2016) 032005

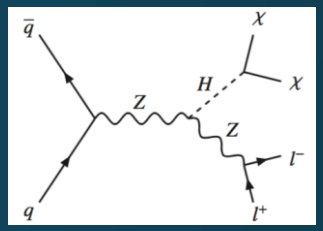
Largest uncertainty in the highest E_T^{miss} bin:

- Statistical (data in CR): 10%
- Total: 12.0%

Important systematic from Z+jet/W+jet ratio :

- EW radiative NLO correction differences in W+jets and Z+jets increase with boson p_T
  - Up to 4% in the highest E_T^{miss} SR
  - Could become a limiting factor… especially as it increases with tighter cuts
- Discussions / work in progress in the LHC DM WG

Dark Matter in H→invisible

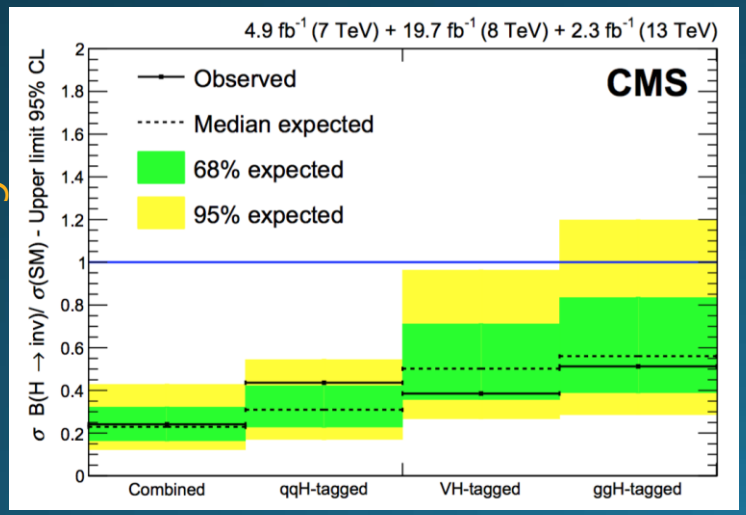


- Predictions done before Run-2 for 300 fb^{-1} in the Z(ll)H(inv) channel :

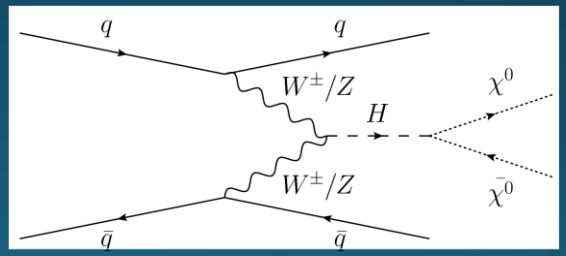
BR(H→inv.) limits at 95%CL	CMS	ATLAS
Best scenario *Assumptions*	17% *Theo. uncert. halved, others scaling as 1/sqrt(L)*	23% *Uncert. on the main BG scales as 1/sqrt(L)*
Conservative scenario *Systematics as before*	28%	32%
Run-1 limit observed/expected in this channel	81% / 83% *Eur. Phys. J. C* **74** (2014) 2980	75% / 62% *Phys. Rev. Lett.* **112** (2014) 201802

ATL-PHYS-PUB-2013-014
CMS NOTE-13-002

- Nice improvement foreseen, but VBF is the most sensitive channel:



arXiv:1610.09218



As for the jet+MET analysis, the Z(νν)+jets main BG is constrained using W(μν) control regions

- *Important to reduce the Z / W ratio uncertainty*

Di-jet resonances

- Smoothly falling di-jet BG: functional form fit:

$$f_4(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x} \qquad x \equiv \frac{m_{jj}}{\sqrt{s}}$$

- Predicted limit evolution with data (14 TeV) for two benchmarks (excited quarks and ADD quantum black hole with n_D=6):

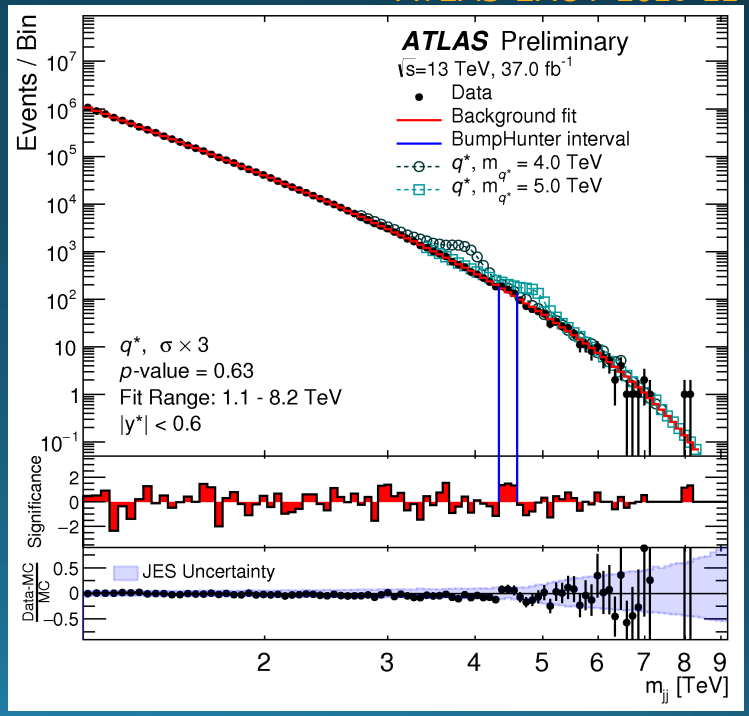
integrated luminosity [fb^{-1}]	m_{q^*} [TeV]	m_{QBH} [TeV]
0.1	4.0	8.2
1	5.0	8.9
5	5.9	9.2
25	6.6	9.7
300	7.4	10.0
3000	8.0	10.1

ATL-PHYS-PUB-2015-004

- Current limit with 37.0 fb^{-1} of **13 TeV data**:
  - q*> 6 TeV (5.8 TeV) observed (expected)
  - m_{QBH}> 8.9 TeV (obs & exp)]

Still some gain to be had at high mass by the end of Run-3

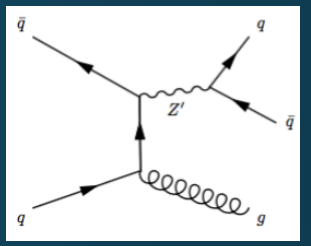
ATLAS-EXOT-2016-21



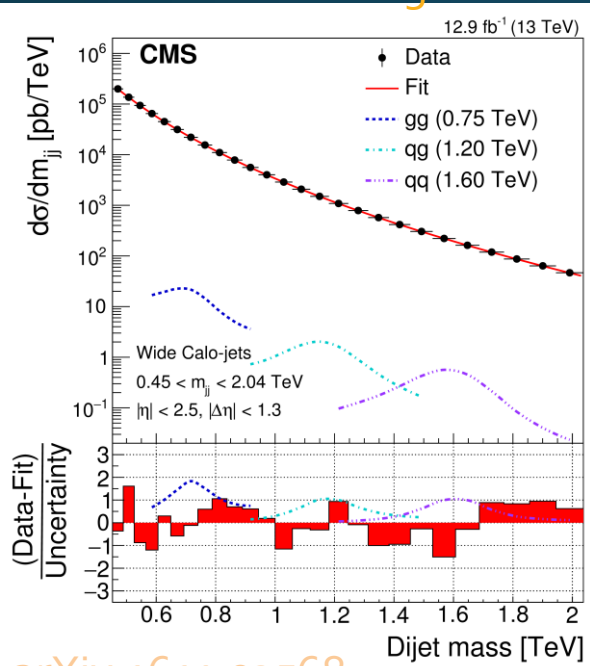
Low-mass di-jet resonances

An interesting recent development of di-jet searches

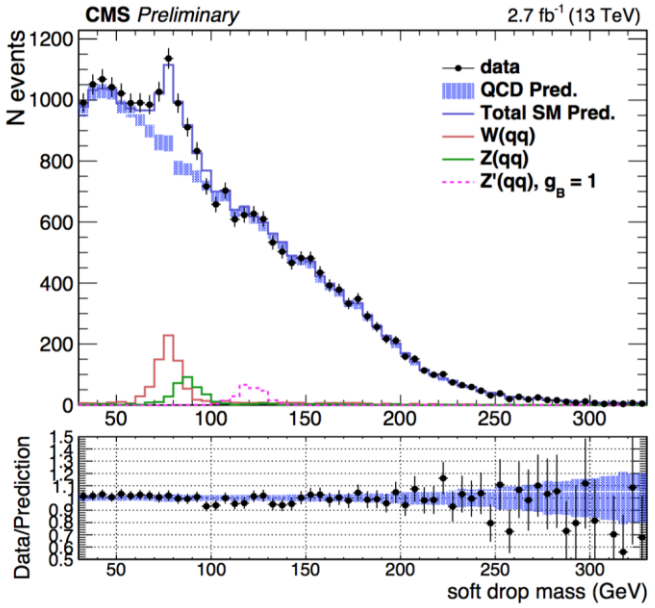
- Need to by-pass the huge trigger-rate wall:
  - Bandwith = rate x size
    - reduce the size: data scouting
  - Trigger on an ISR object (e.g. a high-p_T jet)
    - Can use boosted techniques at very low masses



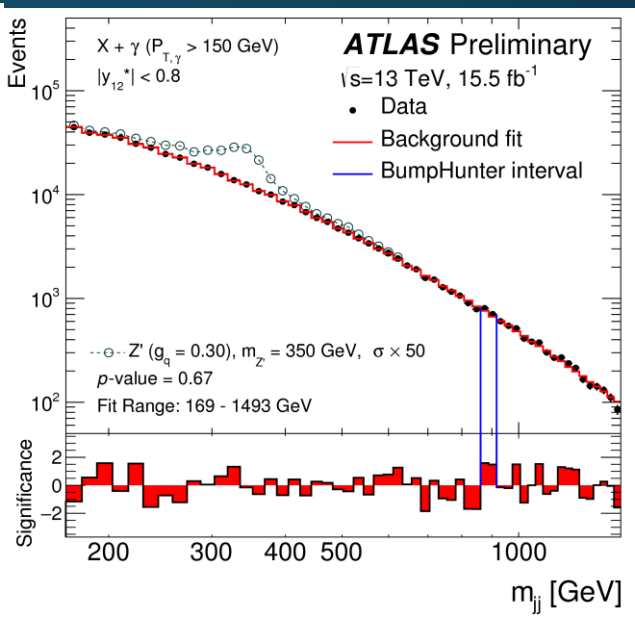
Data scouting



With ISR: boosted



With ISR: resolved



CMS-PAS-EXO-16-030

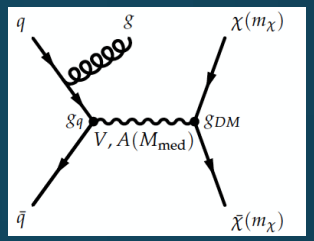
ATLAS-CONF 2016-070

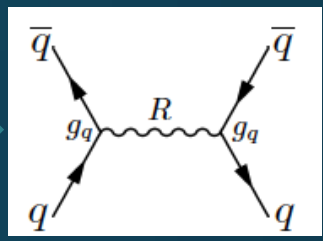
arXiv:1611.03568

Di-jet resonances: DM searches

Another interesting recent development of di-jet searches

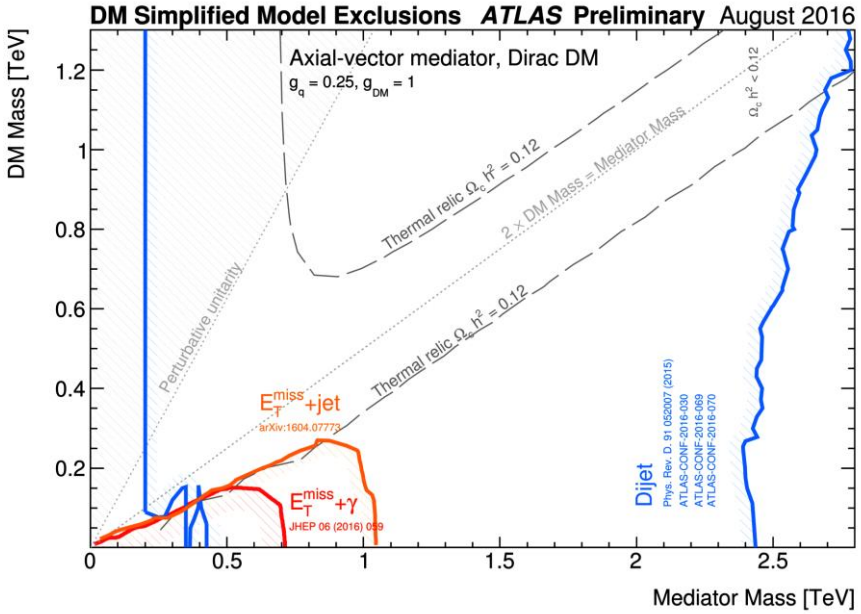
- Search directly for the DM mediator…



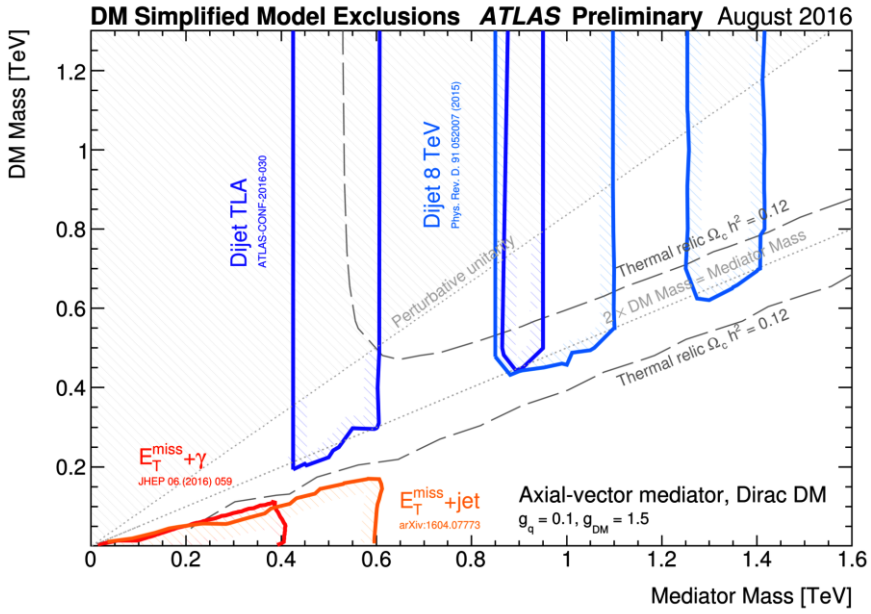


- New interpretation of the di-jet searches:

g_q=0.25, g_{DM}=1



g_q=0.1, g_{DM}=1.5

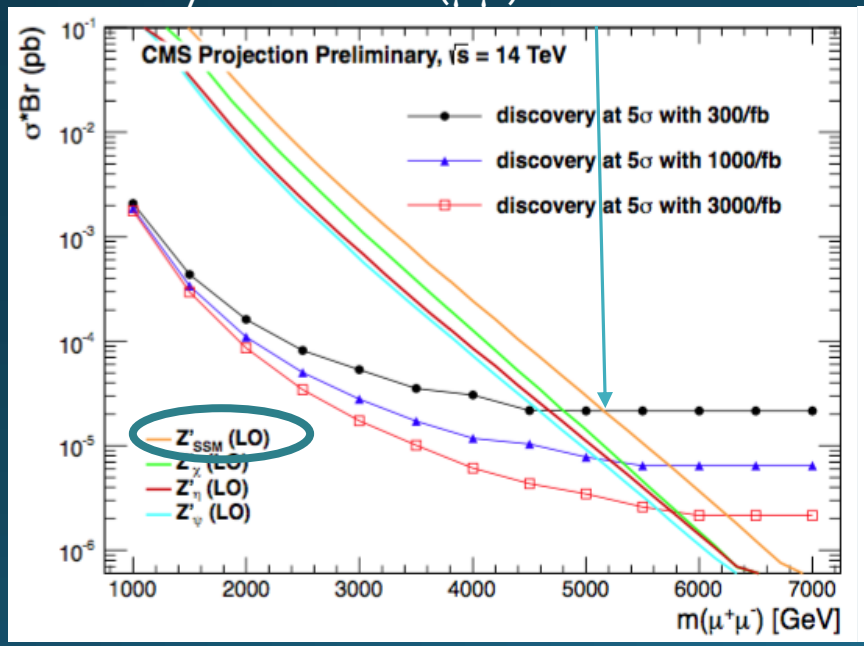


Interplay with searches of type X+E_T^{miss} depends on the couplings…

Di-lepton resonances

- Benchmark: Sequential Standard Model Z' (same fermionic couplings as the SM Z)
- Main Z BG from Monte Carlo, normalised in low m_{ll} region

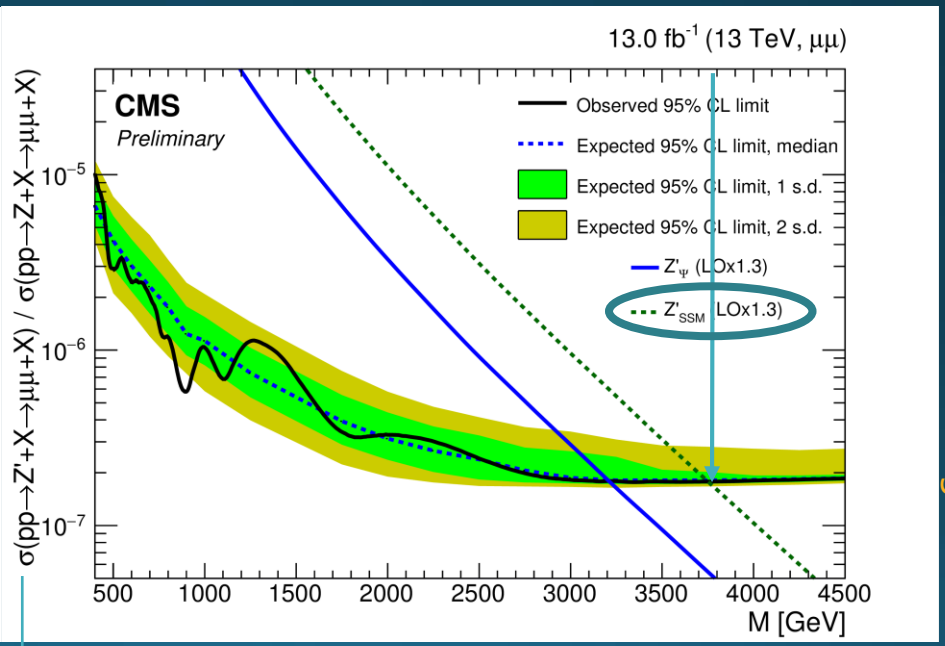
Discovery reach CMS (μμ):



CMS NOTE-13-002

(similar in ee)

Current limit:

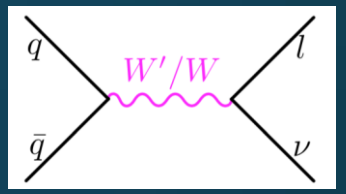


CMS-PAS-EXO-16-031

Limit on the ratio Z'/Z : cancellation of some uncertainties

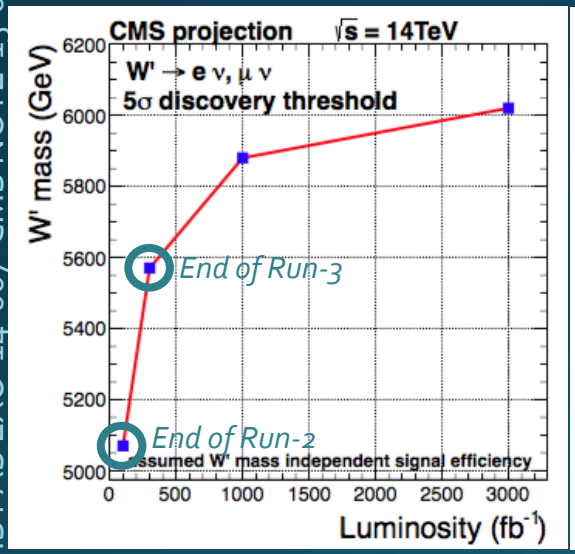
Still room for searching until the end of Run-2/3
Also exploring interplay with dark matter searches now…

Search for a W'→lν

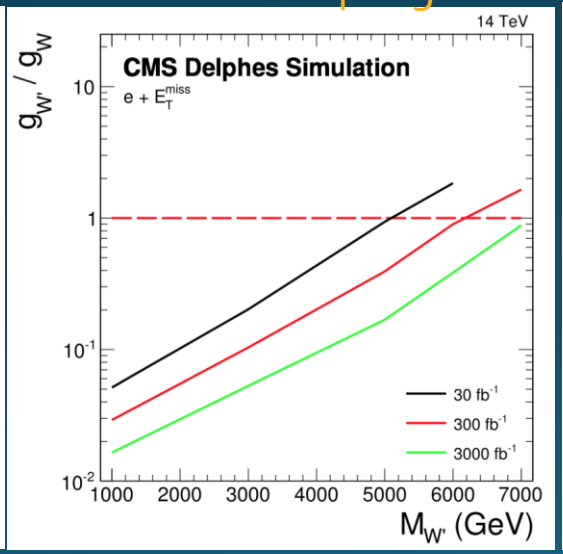


- Looking for an excess in the m_T(lep, E_T^{miss}) tail
- ***Discovery reach*** for a W' @ 14 TeV (assuming constant reconstruction and isolation efficiency for leptons):

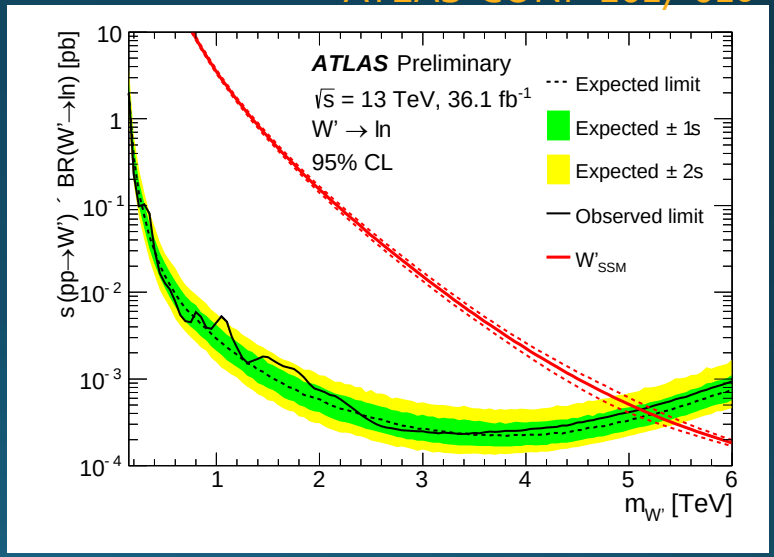
SSM



Various couplings



ATLAS-CONF-2017-016



- Current limit with 36.1 fb^{-1} @ 13 TeV: 5.11 TeV (expected: 5.24 TeV)

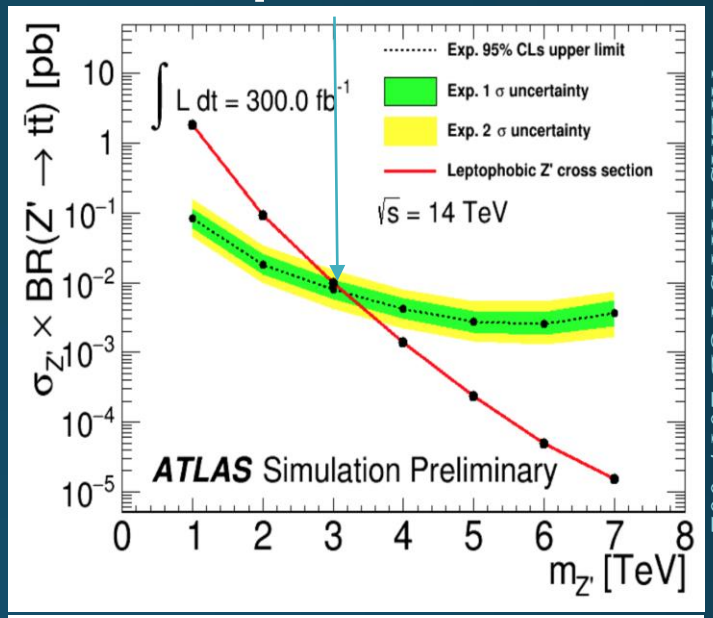
Main W BG from MC with NNLO corrections

CMS PAS EXO-14-007 CMS NOTE-13-002

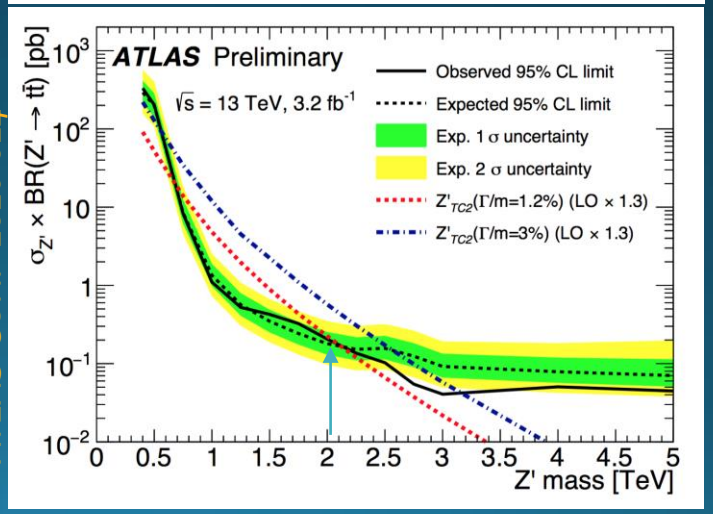
Di-top resonance (semi-leptonic)

- Benchmark: Z′ boson in the TopColour model
- Main tt BG from MC
- Boosted channel at high mass
- Expect a 3 TeV limit at the end of Run-3
- Main uncertainties:
  - tt BG normalisation
  - Large-jet uncertainties
  - **Taken as is for the extrapolation**
    - *conservative scenario*

- Current limit with 3.2 fb^{-1} of 13 TeV data
  - boosted channel only

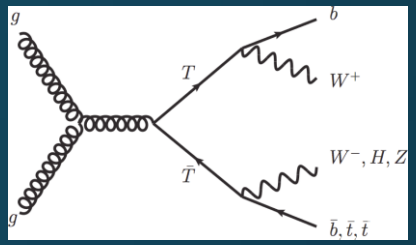


ATLAS-PHYS-PUB-2017-002



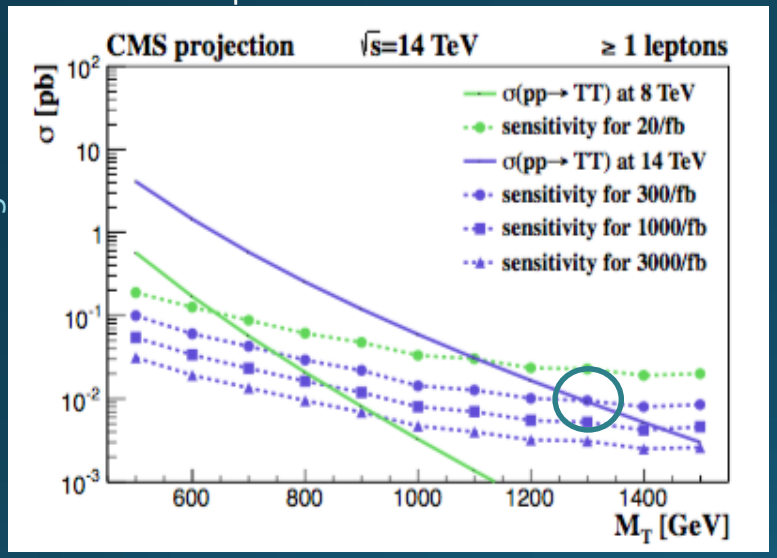
ATLAS-CONF-2016-014

Heavy vector-like T quark

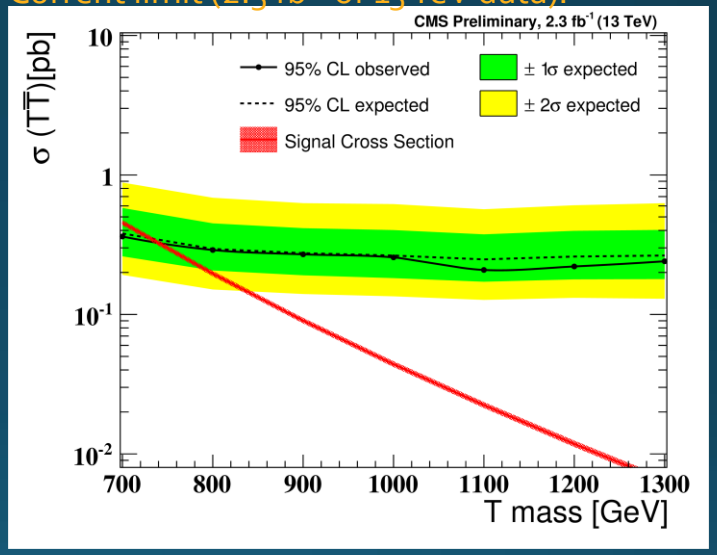


- Predicted e.g. in some Higgs compositness models
- Extrapolation based on the Run-1 8 TeV search:
  - 8 signal regions : at least one electron or muon + a number of jets identified as originating from a b-quark or a boosted W or Z

CMS NOTE-13-002

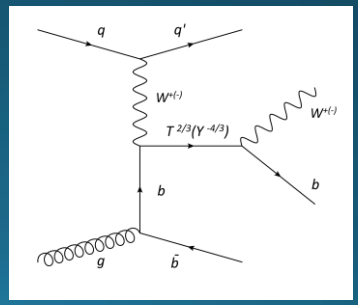


Current limit (2.3 fb^{-1} of 13 TeV data):

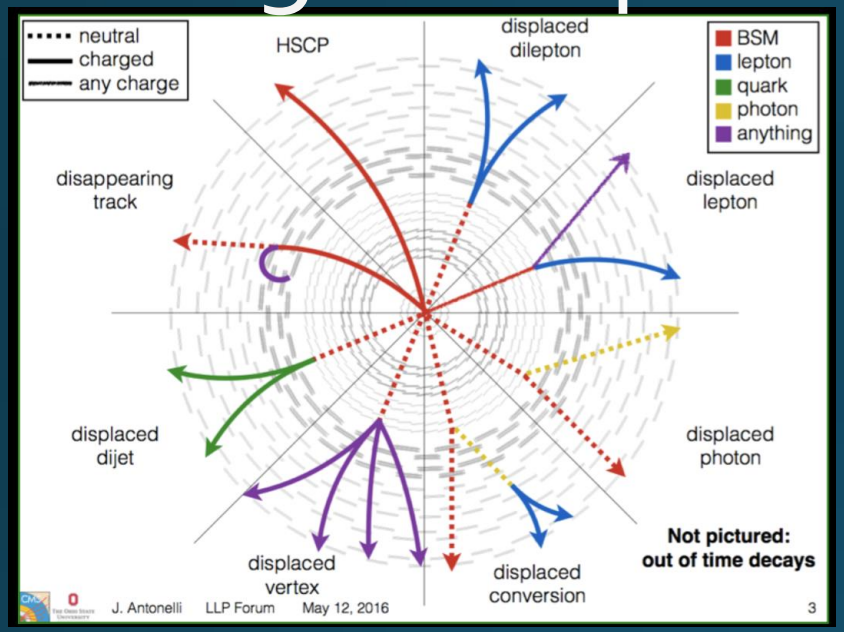


CMS-PAS-B2G-16-002

- *Mass limit could still increase by ~1.7*
- Many searches now also searching for single-production:
  - More model-dependent (as production depends on the coupling)
  - Can reach higher masses
  - Limits on σ x BR in the T→Wb (arXiv:1701.08328), T→Zt (arXiv:1701.07409) and T→Ht (arXiv:1612.00999) channels already set using the 2015 dataset



Long-lived particles



Challenging as often need special triggers, custom reconstruction, etc
→ these searches often take more time

- Effort ongoing between the LHC experiments and theorists to produce a **white paper**
  - How do we best ensure that we don't miss BSM LLP signatures for the remainder of the LHC program?
    - Identify the gaps in coverage (e.g. higgs portals?)
      - Especially important if new triggers need to be set
      - New search ideas?
    - Identify some benchmarks / ways to present results?
  - Next workshop: 24-26 April at CERN

Conclusions

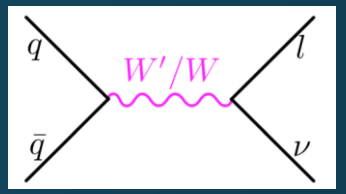
- The 13 TeV dataset should increase by a factor ~3 by the end of Run-2 in 2018
- After LS2, data taking should resume in 2021 with Run-3 lasting until the end of 2023, possibly at 14 TeV
  - By then, expect ~300 fb^{-1} of data to analyse
- Searches for BSM physics will continue to explore uncharted territories
  - as more data will populate the tails we're after…
  - as we will be able to probe smaller couplings in the bulk of the distributions…

Conclusions

- Improvements will come from:
  - Continuing to improve selection of existing analyses as data is taken
    - e.g. going to higher MET in the jet+MET searches, developments in boosted techniques,…
  - Maintaining excellent performance in an increasingly challenging environment
    - Both experiments have shown very good resilience against increasing pileup
  - Including theoretical improvements on SM predictions
  - Developing new analyses
    - Searching for smaller couplings at low masses, like recent low-mass dijet searches …
    - Covering more extensively long-lived signatures
    - …

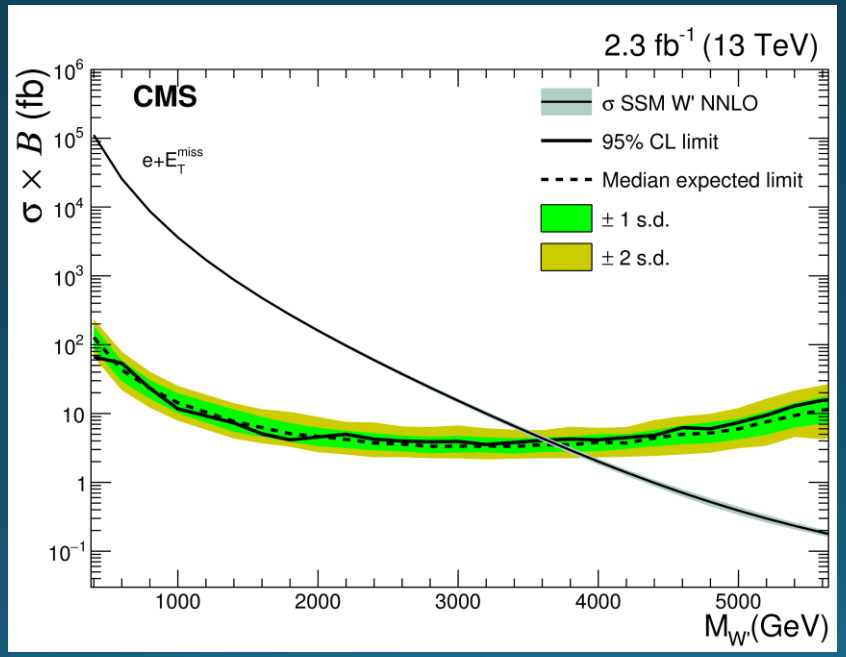
Further info

Search for a W'→lν



- CMS limit with 2.3 fb^{-1} @ 13 TeV:

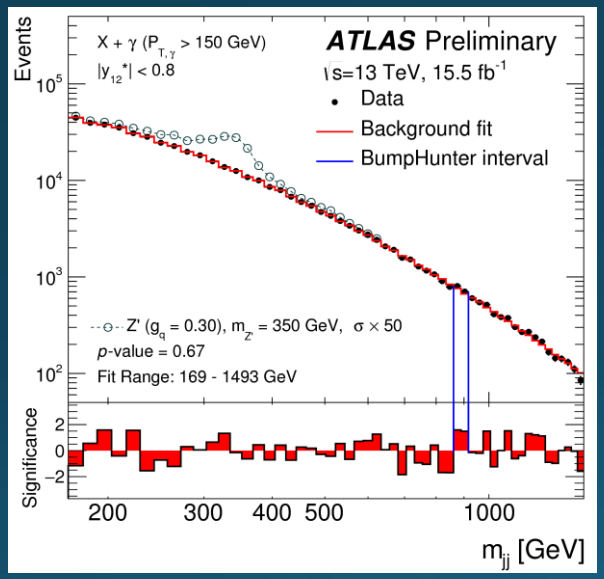
main W BG from MC with mass-dependent NNLO corrections

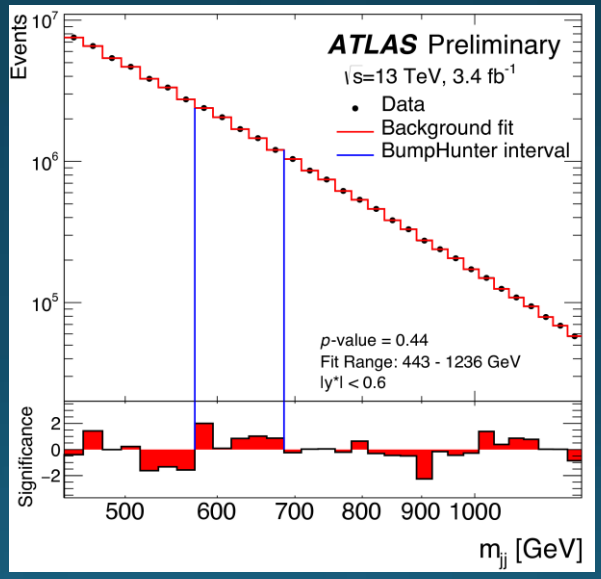


arXiv:1612.09274

Di-jet resonances

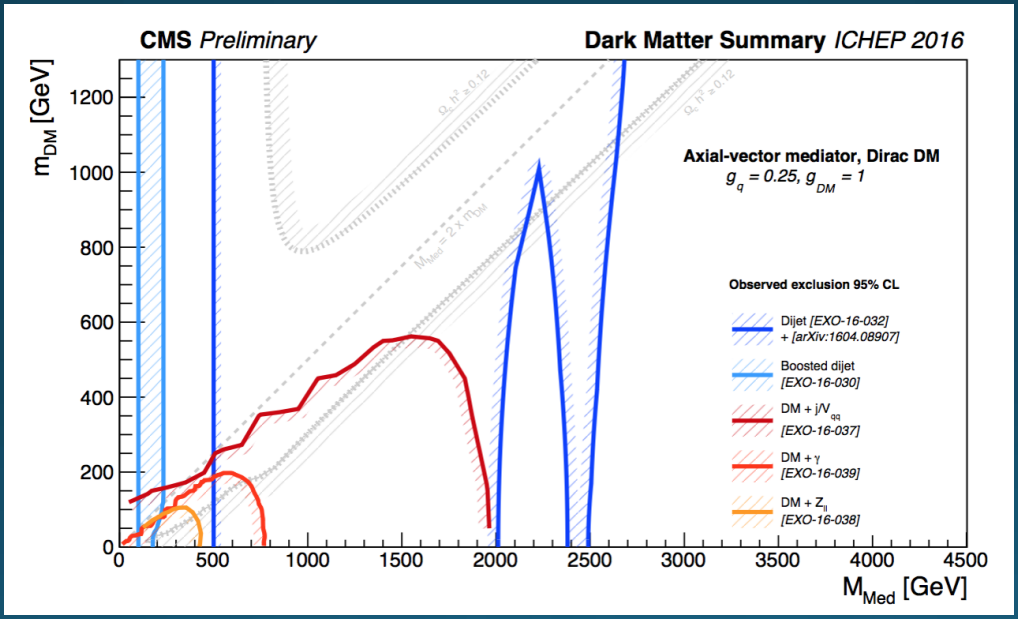
- Low-mass searches in ATLAS:





Di-jet resonances

- Interplay with DM searches in CMS:



Dilepton resonances

- Limits predicted for 14 TeV data:

model	300 fb^{-1}
$Z'_{SSM} \rightarrow ee$	6.5
$Z'_{SSM} \rightarrow \mu\mu$	6.4

- Current limits with 13.3 fb^{-1} of 13 TeV data:

Model	Width [%]	θ_{E_6} [Rad]	Lower limits on $m_{Z'}$ [TeV]					
			ee		$\mu\mu$		$\ell\ell$	
			Obs	Exp	Obs	Exp	Obs	Exp
Z'_{SSM}	3.0	-	3.85	3.86	3.49	3.53	4.05	4.06

ATLAS-CONF-2016-045