

Dark Matter @ HL/HE-LHC

Experimental Overview

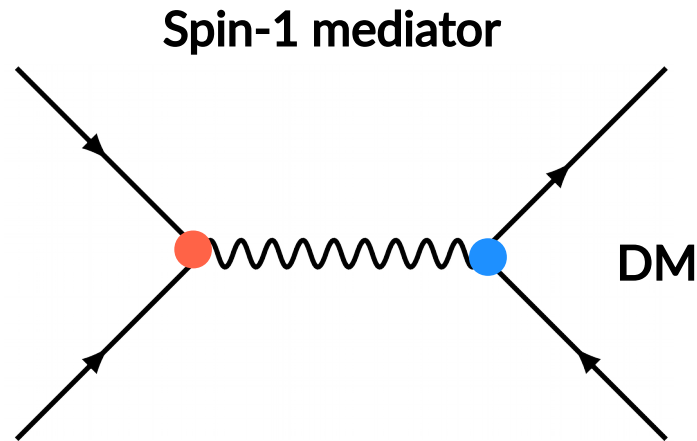
HL/HE-LHC workshop
CERN, June 18th, 2018

Andreas Albert

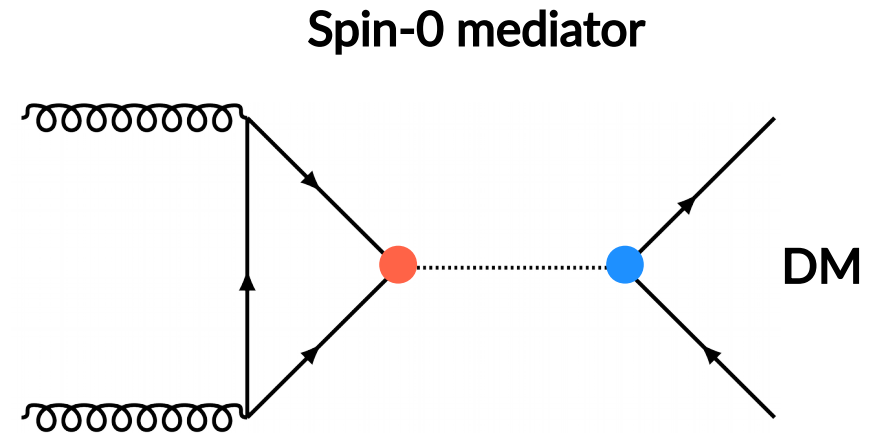
on behalf of the ATLAS, CMS and LHCb collaborations



Dark Matter at the LHC



Like Drell-Yan



Like Higgs (Yukawa!)

Simplified models with few free parameters:

m_{med} , m_{DM} , mediator-quark coupling, mediator-DM coupling

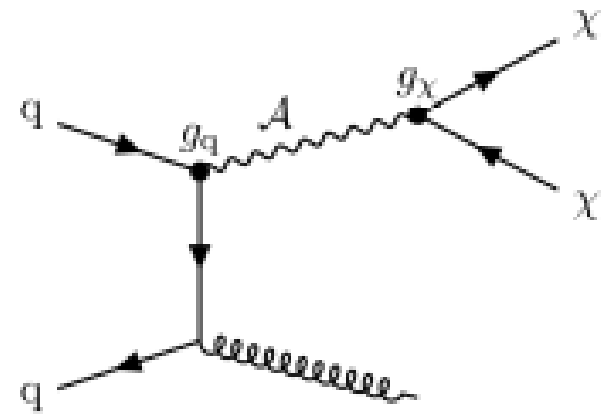
Search for associated production with one of many SM tags:

Jet, photon, Z, single/double top, b, H

Monojet

Monojet

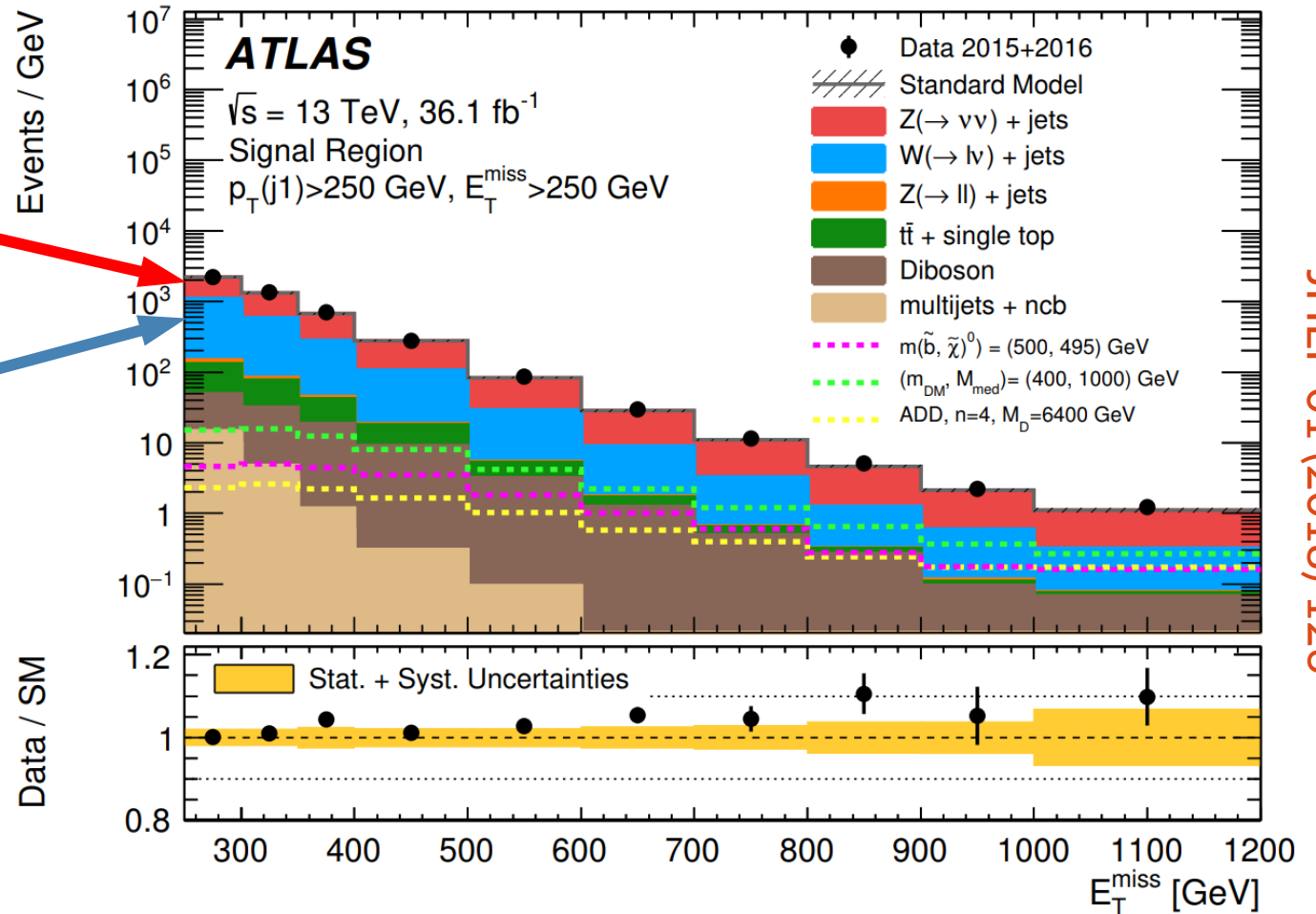
- At least one jet $p_T > 250$ GeV
- $\Delta\phi(\text{jet}, \text{MET}) > \sim 0.4$
- $\text{MET} > \sim 250$ GeV



$Z(\nu\nu)+j$ signal like

$W(l\nu)+j$, lepton lost

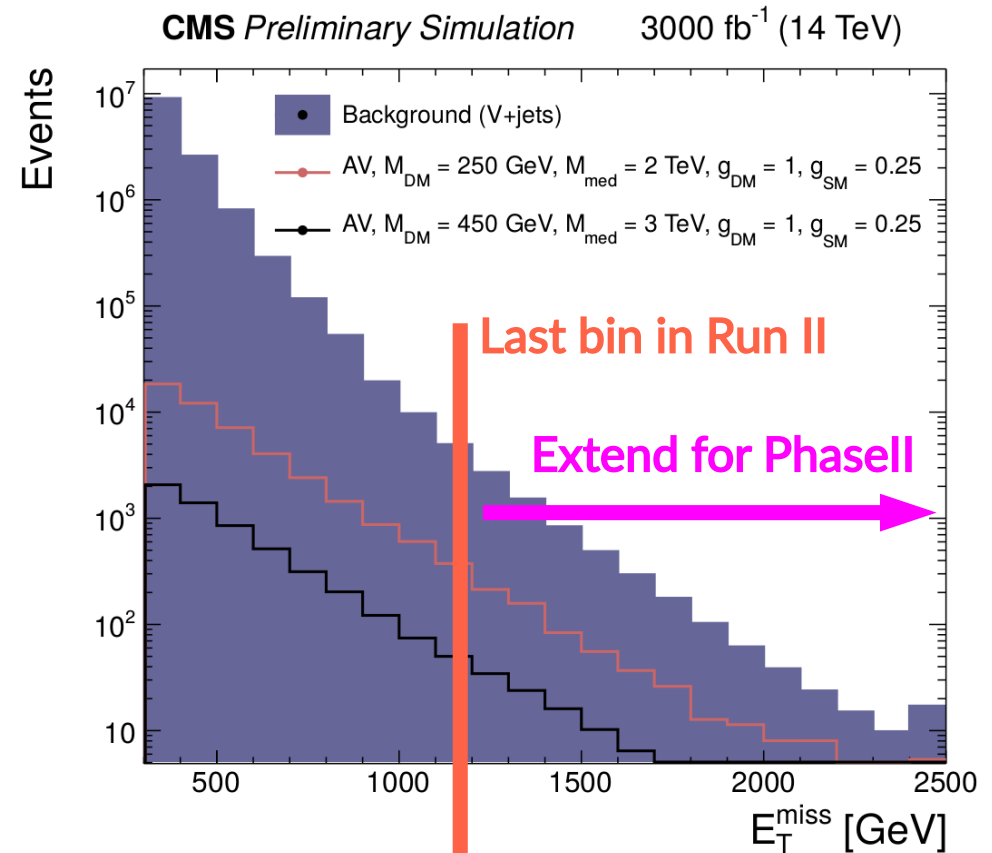
Low end of search region defined by trigger



Monojet projections CMS

CMS-PAS-FTR-16-005

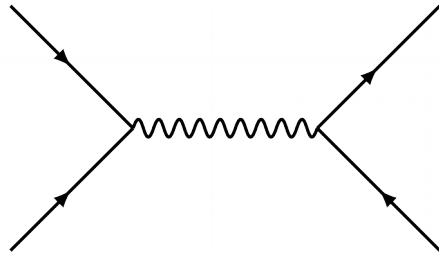
- Analysis on **DELPHES** 14 TeV samples, PU0
- Thresholds, selection like Run-II
- Background processes like Run II \rightarrow Z and W
- Extended binning



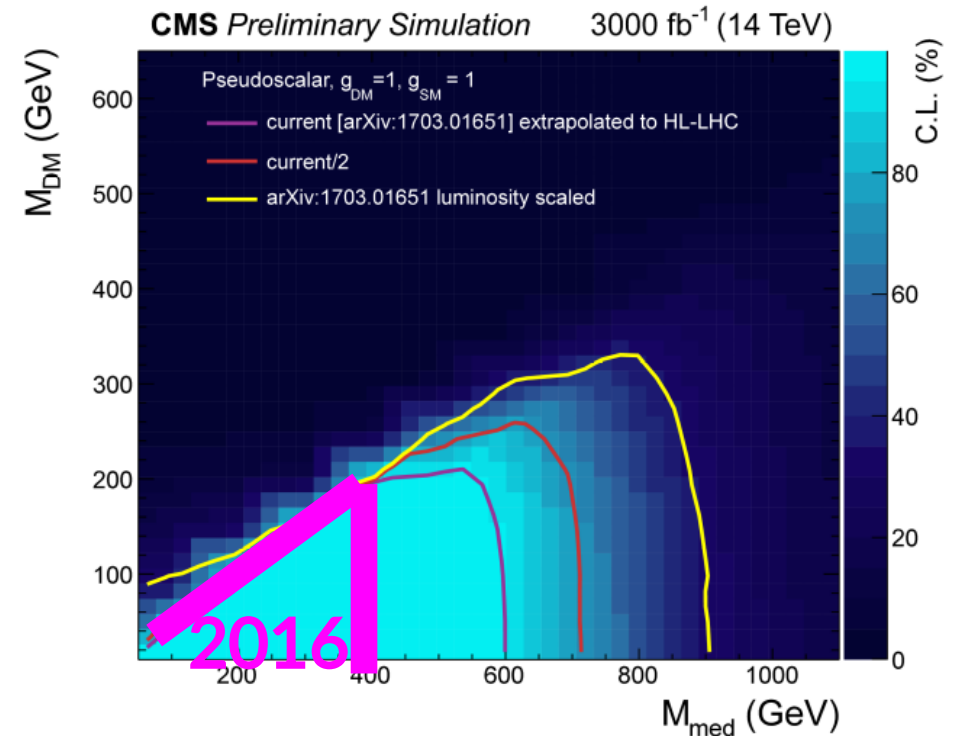
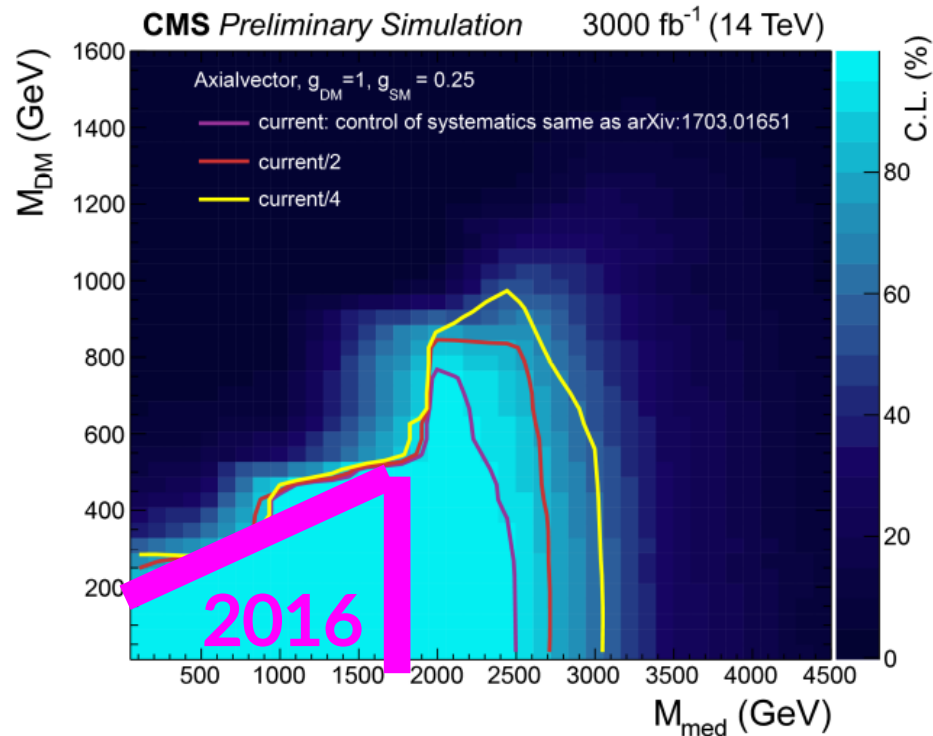
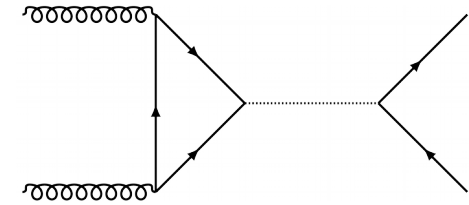
Monojet projections CMS

CMS-PAS-FTR-16-005

Axial-
vector

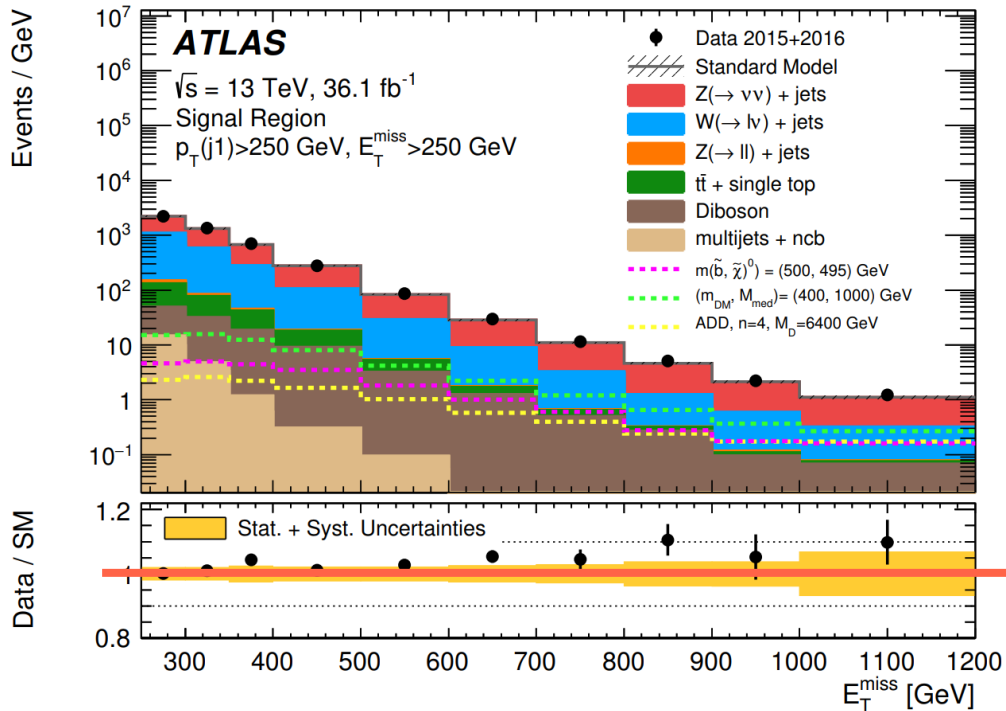


Pseudo
scalar



- Standard DMWG coupling scenarios
- Bottom line: Systematics matter for mass exclusion
- (Already significantly reduced during RunII wrt to “current”)

Monojet projections: ATLAS



- Rescale full 2016 result
- Use extended binning
- Validate with truth+smear approach
- Great opportunity for **cross-comparison!**

Extend

DM + Heavy flavour

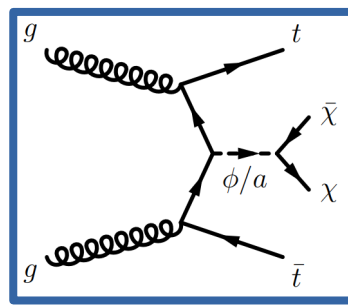
DM+TTbar

Higher BR

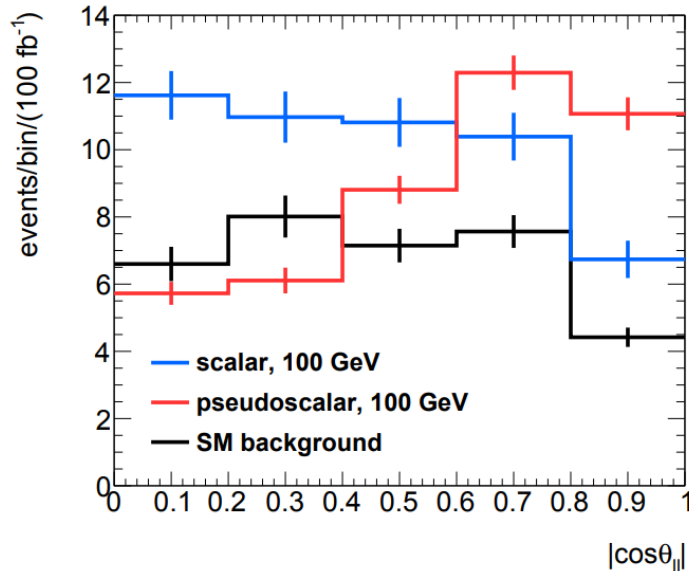
Cleaner

SM ttbar modes:

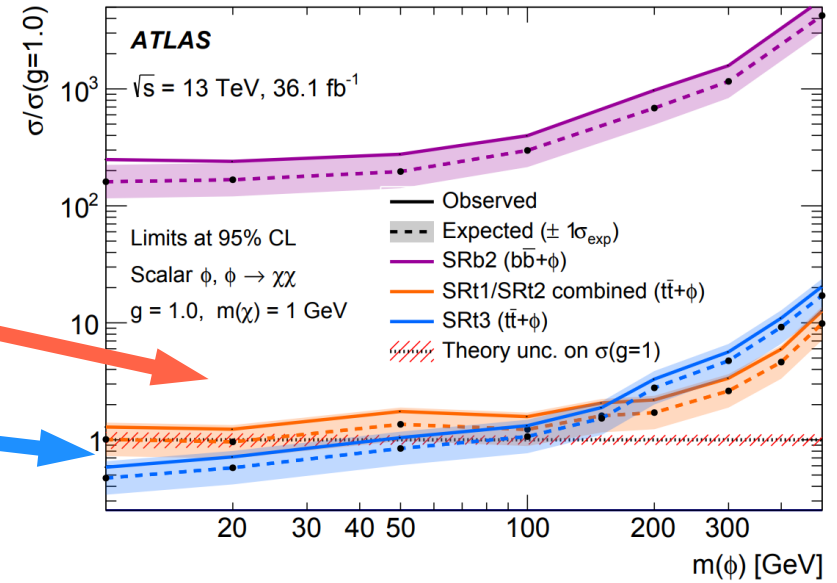
- Fully hadronic
- Semi-leptonic
- Leptonic



Post-discovery: CP properties?



Run-II sensitive to $m_\phi \approx 100$ GeV



Projections ongoing

Dilepton final state

ATLAS: Truth + smear

CMS: DELPHES-based

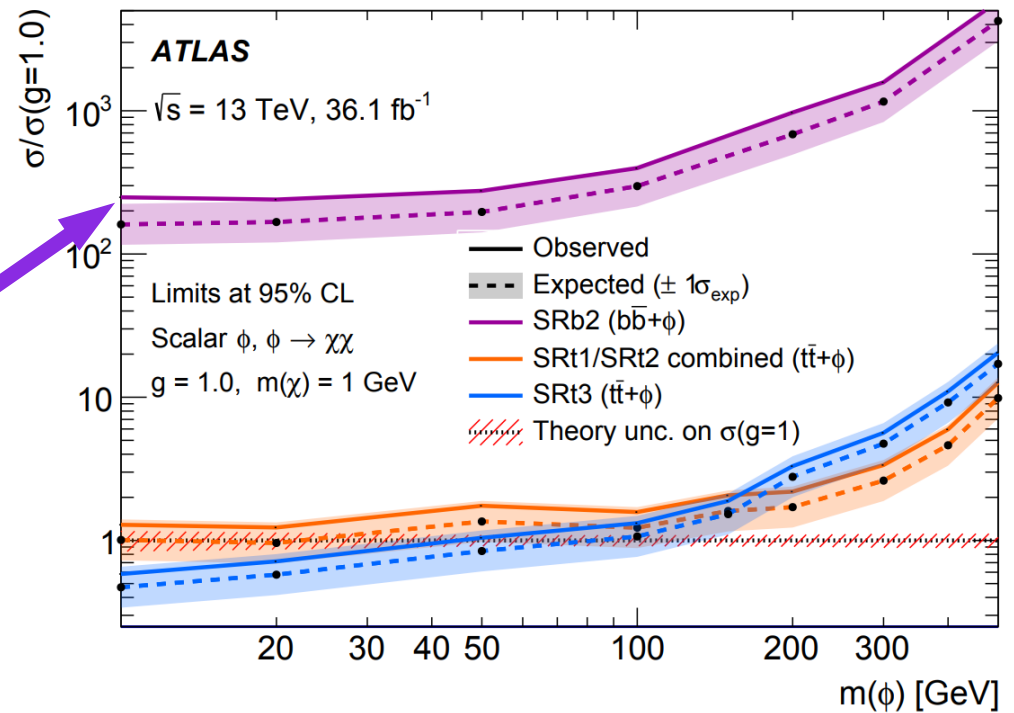
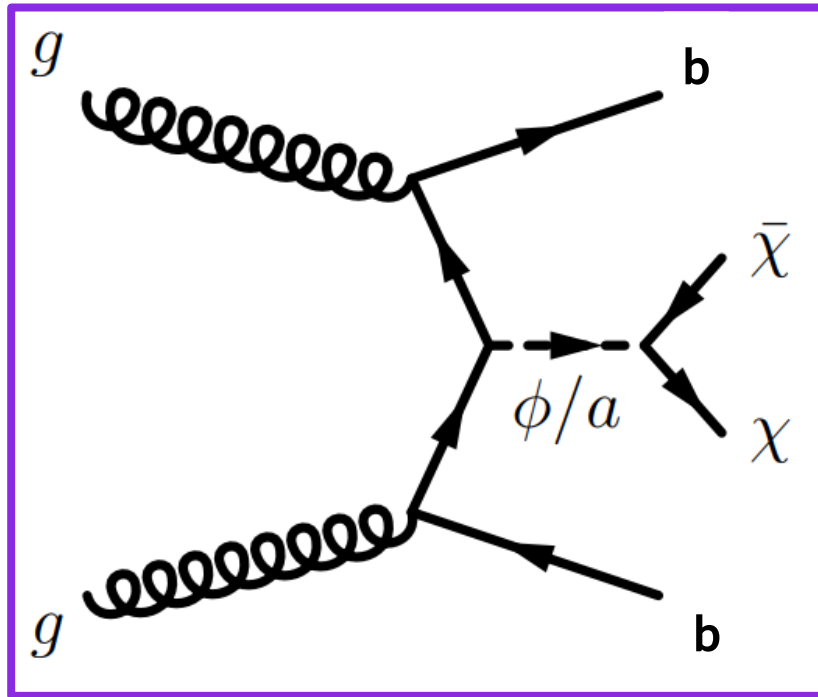
Analyzers coordinate in

- technicalities (generators etc)
- interpretation (a+2HDM?)

arxiv:1611.09841

Eur. Phys. J. C 78 (2018) 18

DM+BBbar



Eur. Phys. J. C 78 (2018) 18

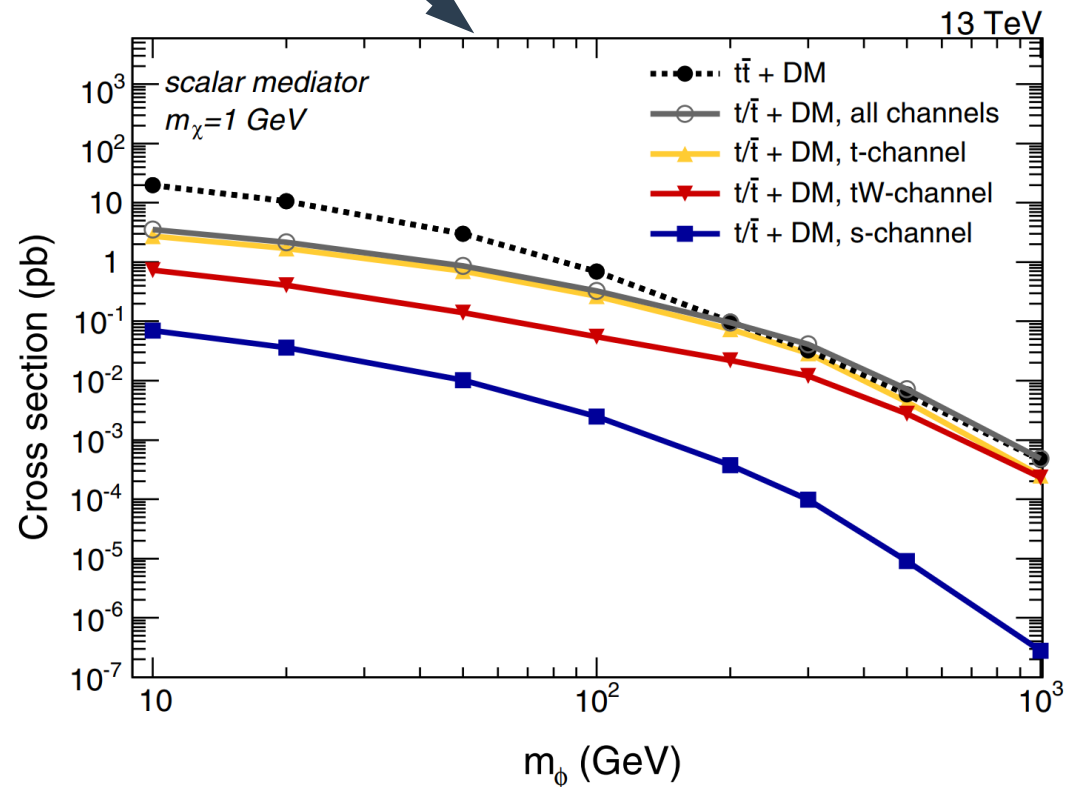
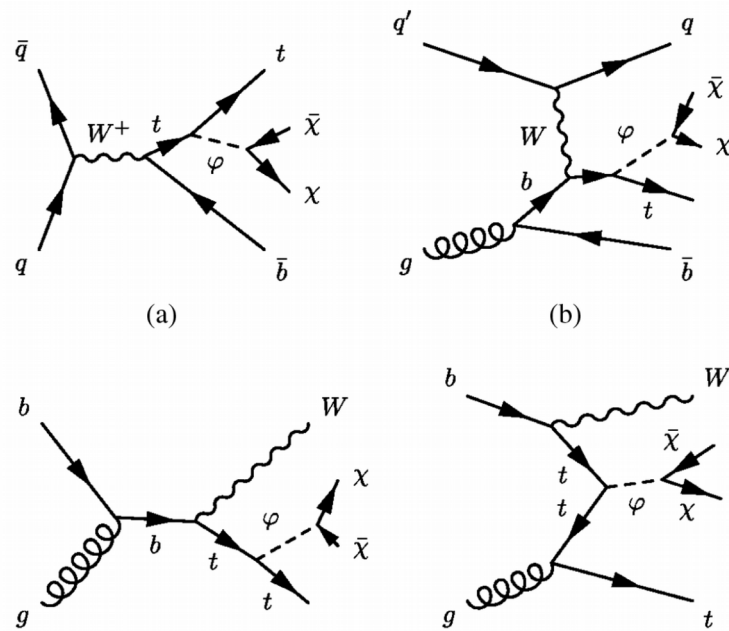
- Enhanced in a+2HDM at high $\tan(\beta)$
- B jets can be forward
- What can be gained from extended tracking?

ATLAS projections ongoing

DM + Single Top (I)

Same simplified model also gives us DM + 1 top + W, q, b

- XS can be \approx same or greater than $t\bar{t}$
- Signature very similar to DM+ $t\bar{t}$



DM + Single Top (II)

- 30% sensitivity improvement w/o analysis optimization
- Gain with more lumi!

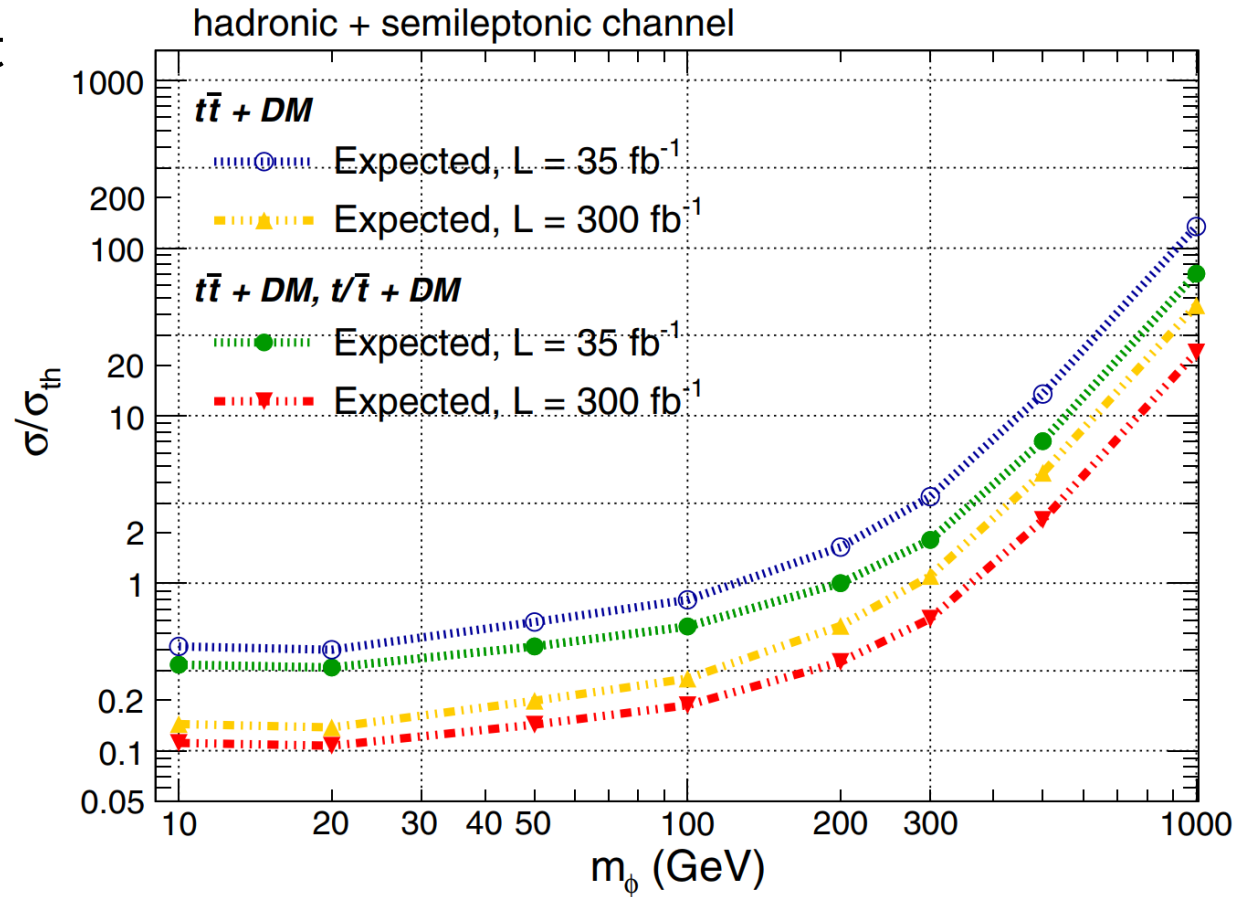
Projections ongoing

ATLAS:

- 2L final state
- Exploit angular correlations
- Truth + smear

CMS

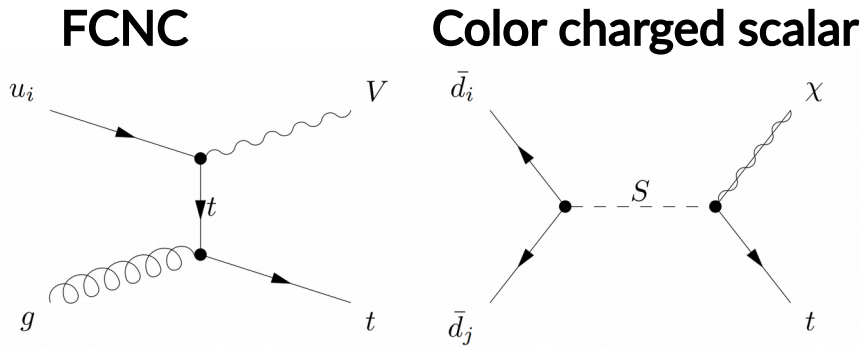
- Hadronic final state
- ttbar analysis strategy
- DELPHES



DM + Single Top (III)

Single top signatures also from more exotic models

arxiv:1311.6478

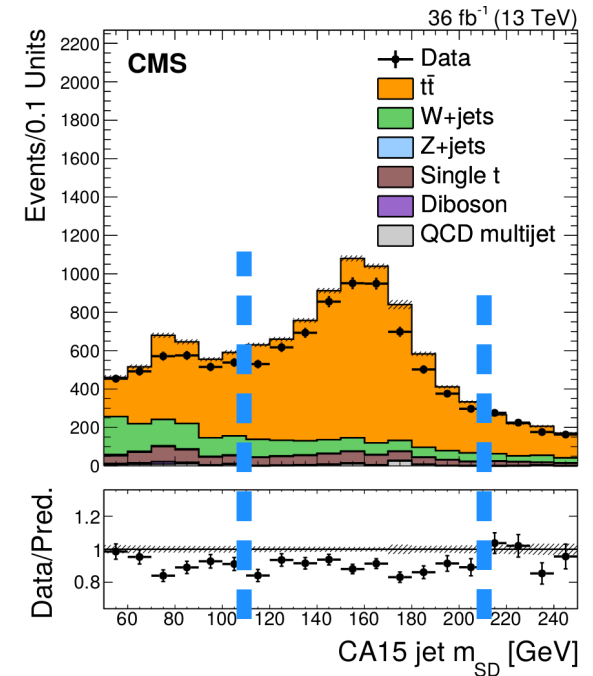
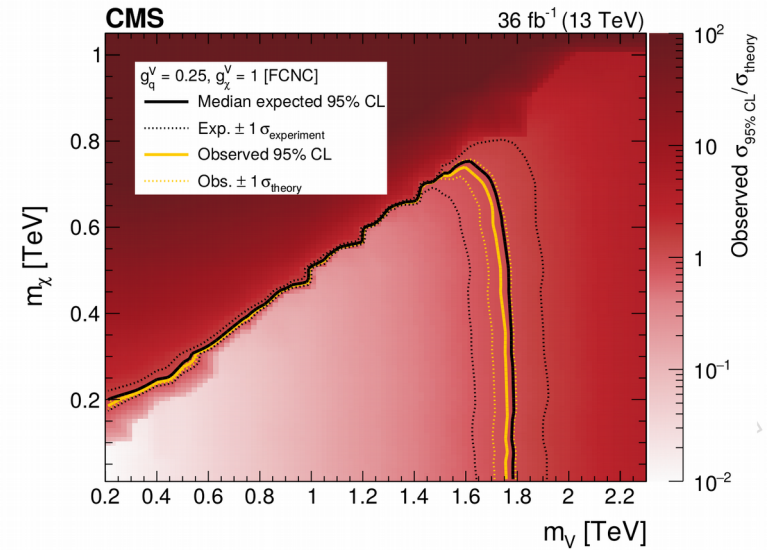


Really "single" top \rightarrow high boost \rightarrow top jets? \rightarrow

ATLAS projection ongoing

- truth + smear method
- Hadronic and leptonic channels
- HL and HE scenarios

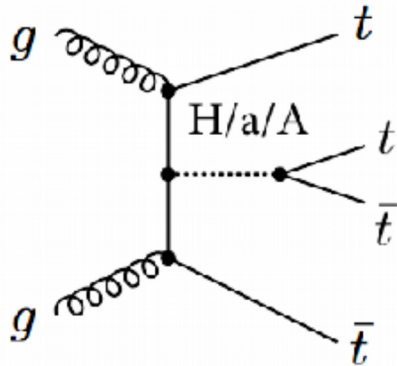
Run-II



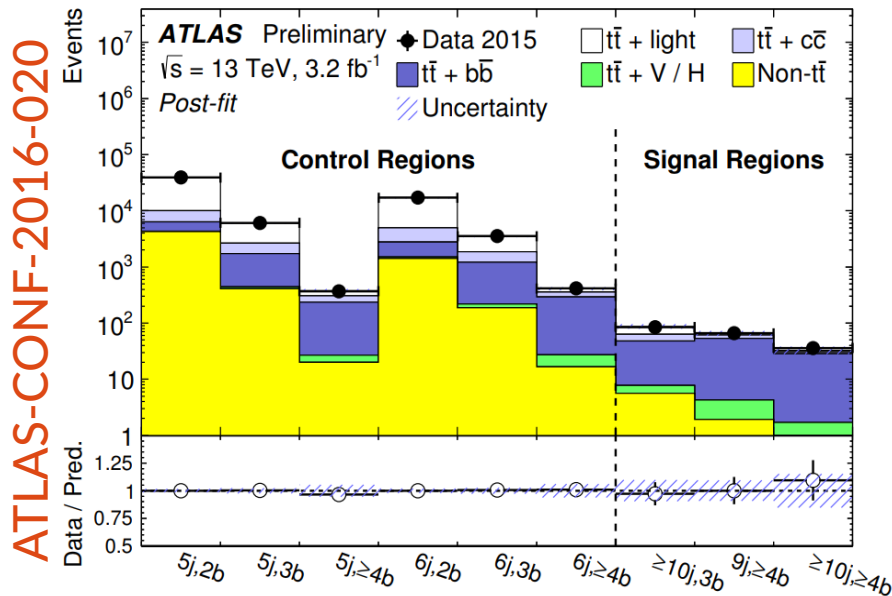
JHEP06(2018)027

Quadruple top: Find the mediator

Four tops: High multiplicities!

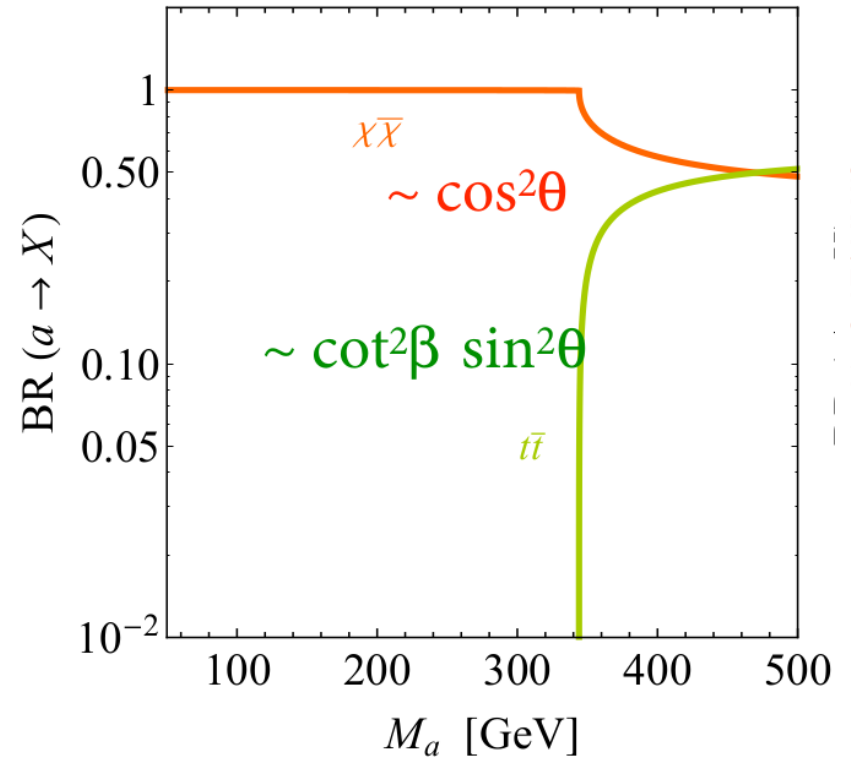


RunII: 1lep + jets



ATLAS-CONF-2016-020

$$\sin\theta = 1/\sqrt{2}, m_\chi = 1 \text{ GeV}$$



arxiv:1701.07427

ATLAS projection

- truth + smear
- 1 lepton or 2 SS leptons
- Focus on a+2HDM

Mono-Z, γ , VBF DM

Mono-Z

Search for back-to-back Z and MET

Cleaner final state than monojet → cut tigher on topology

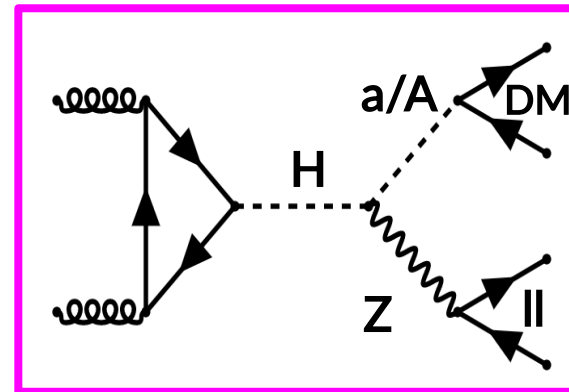
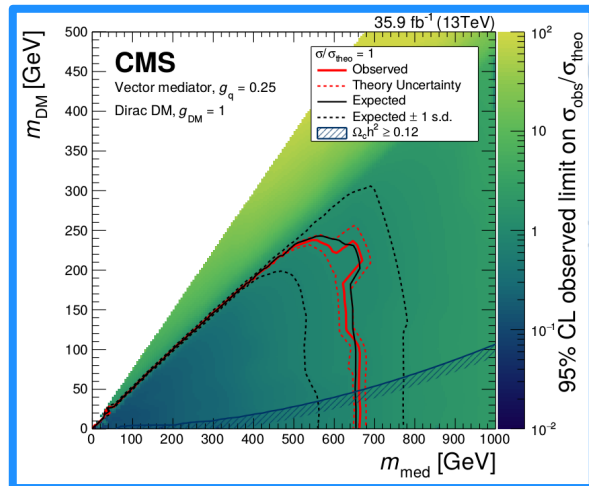
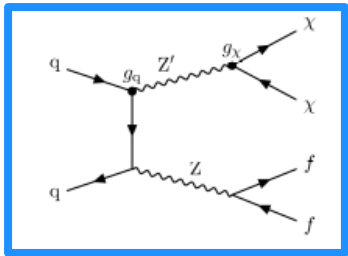
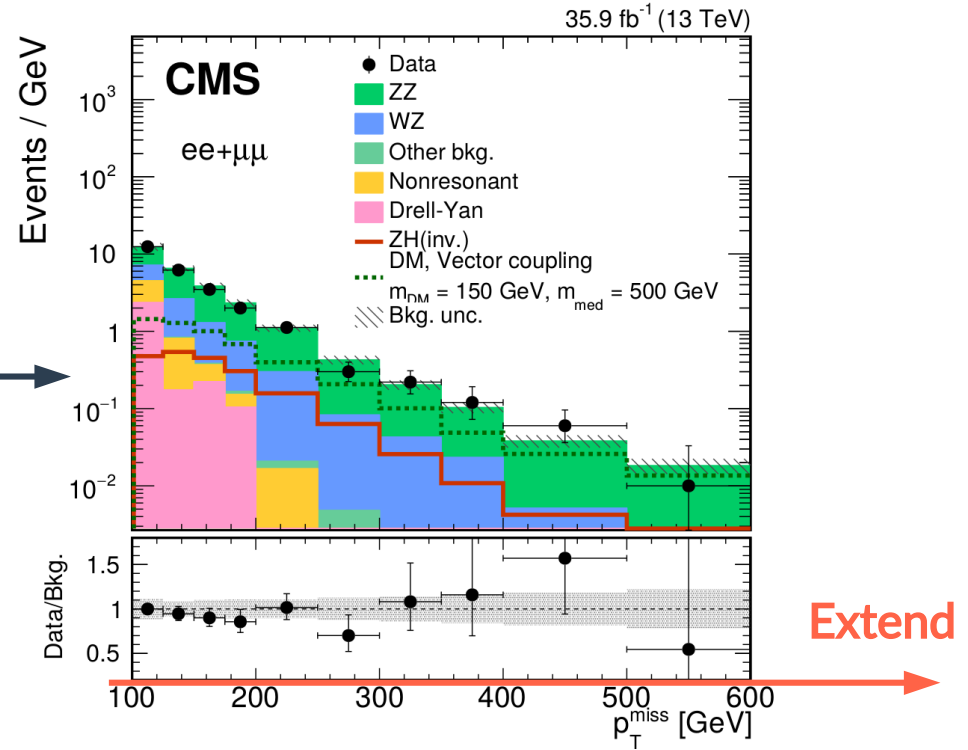
$$E_{T,miss} > 100 \text{ GeV}$$

$$|p_{T,Z} / E_{T,miss} - 1| < 0.4$$

$$\Delta\phi(Z, E_{T,miss}) > 2.6$$

CMS Projection

- Rescale Run-II result
 - Interpretation:
 - Standard spin-1 mediator
 - 2HDM+pseudoscalar
- arxiv:1701.07427

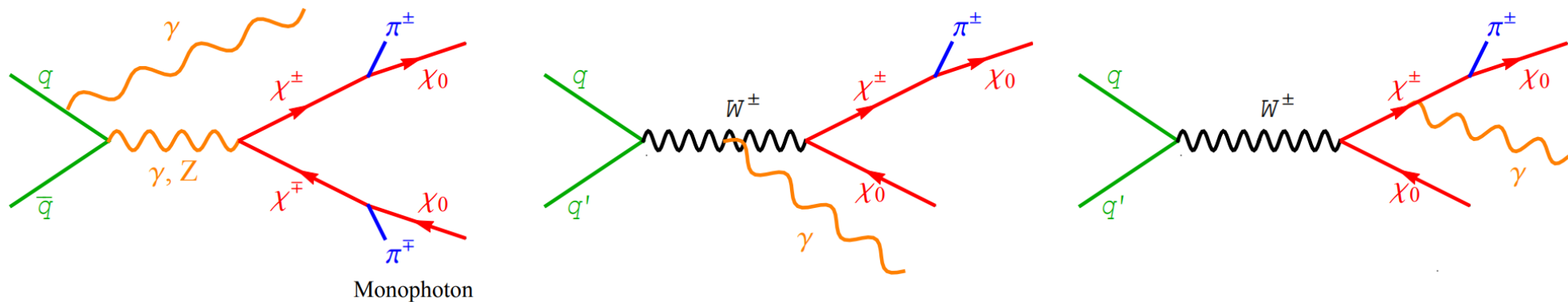


Monophoton and VBF: SU(2) Triplet DM

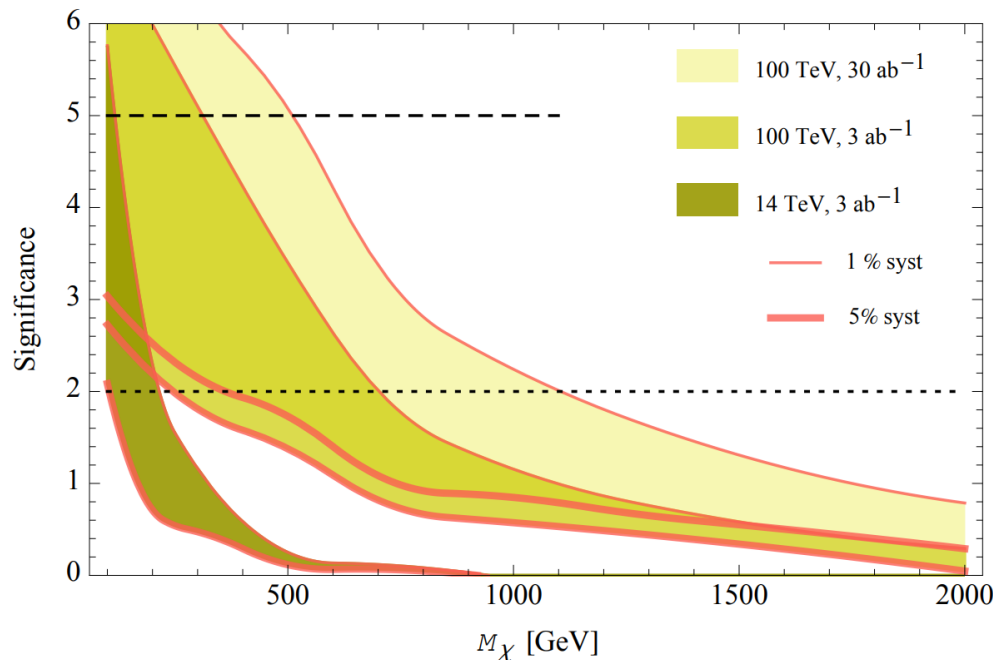
arxiv:1407.7058

Looks just like Wino production

- Small mass gap between $\chi^\pm, \chi^0 \rightarrow$ pion lost
- Constraints from disappearing tracks!



Monophoton: γ radiation not just ISR



ATLAS projections ongoing

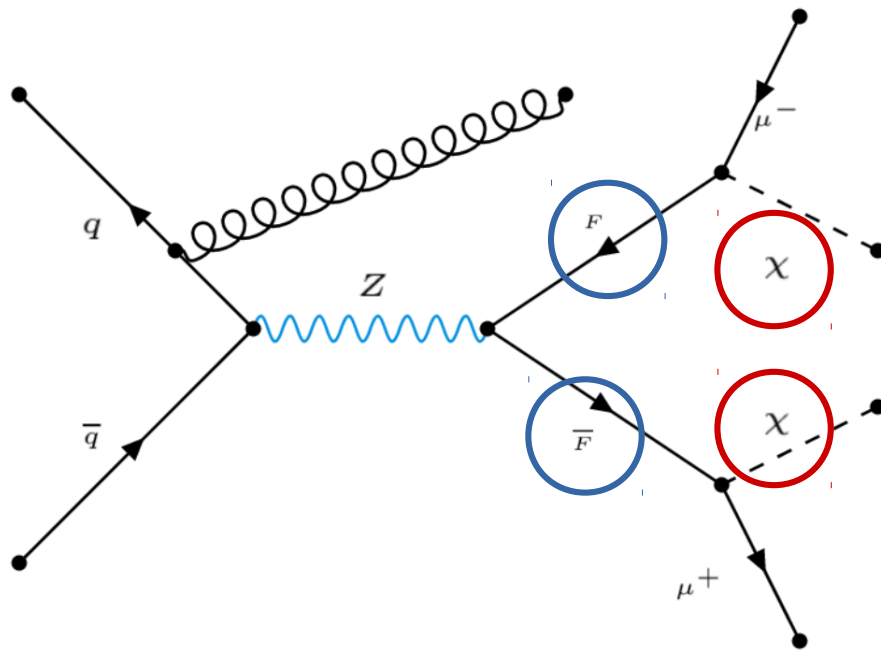
Rescaling Run-II results

Monophoton: ≈ 300 GeV reach if syst small

VBF: ≈ 100 -150 GeV reach

arxiv:1407.7058

Vector-like fermions



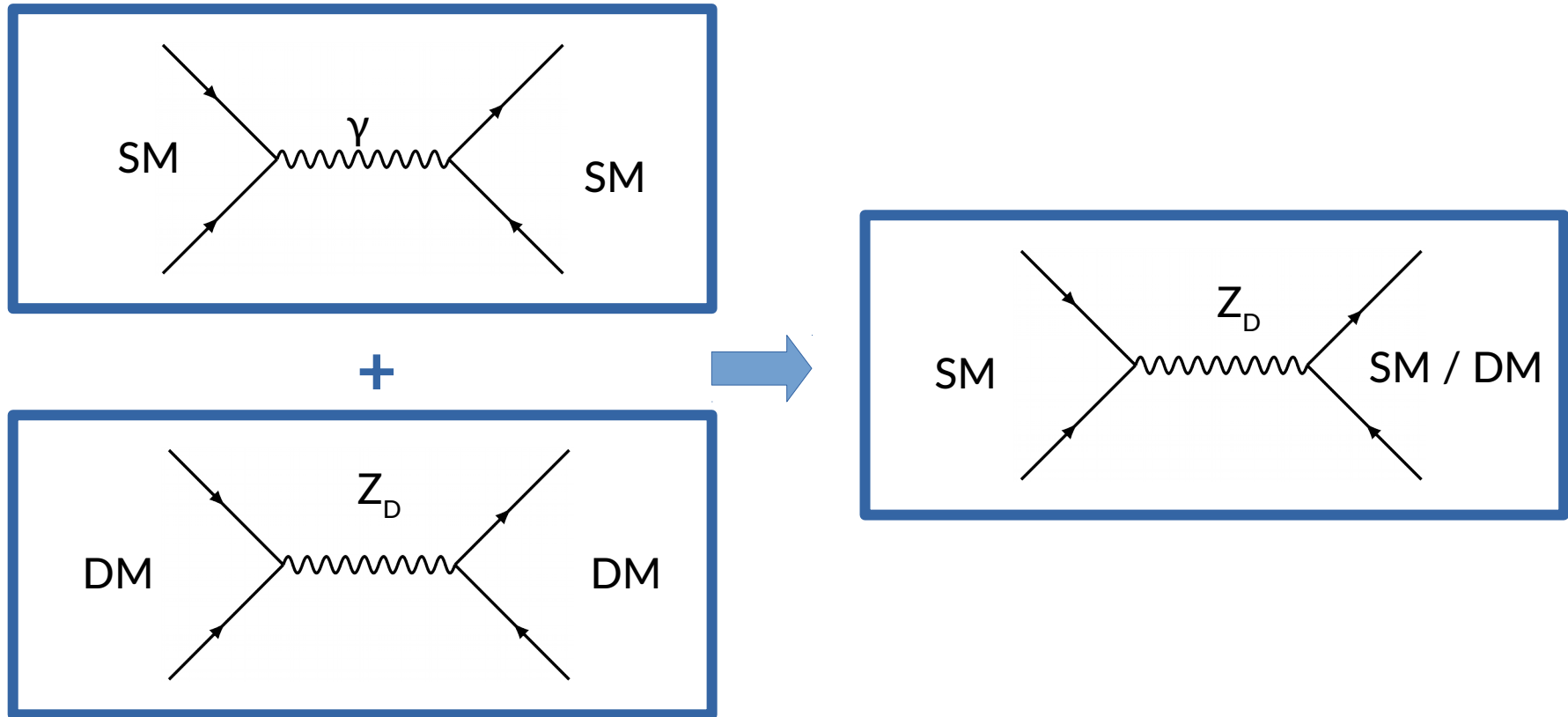
Heavy fermions + scalar DM

\approx Monojet with soft leptons

CMS projection ongoing
DELPHES
1 or 2 soft leptons

Dark photons

Dark Photons

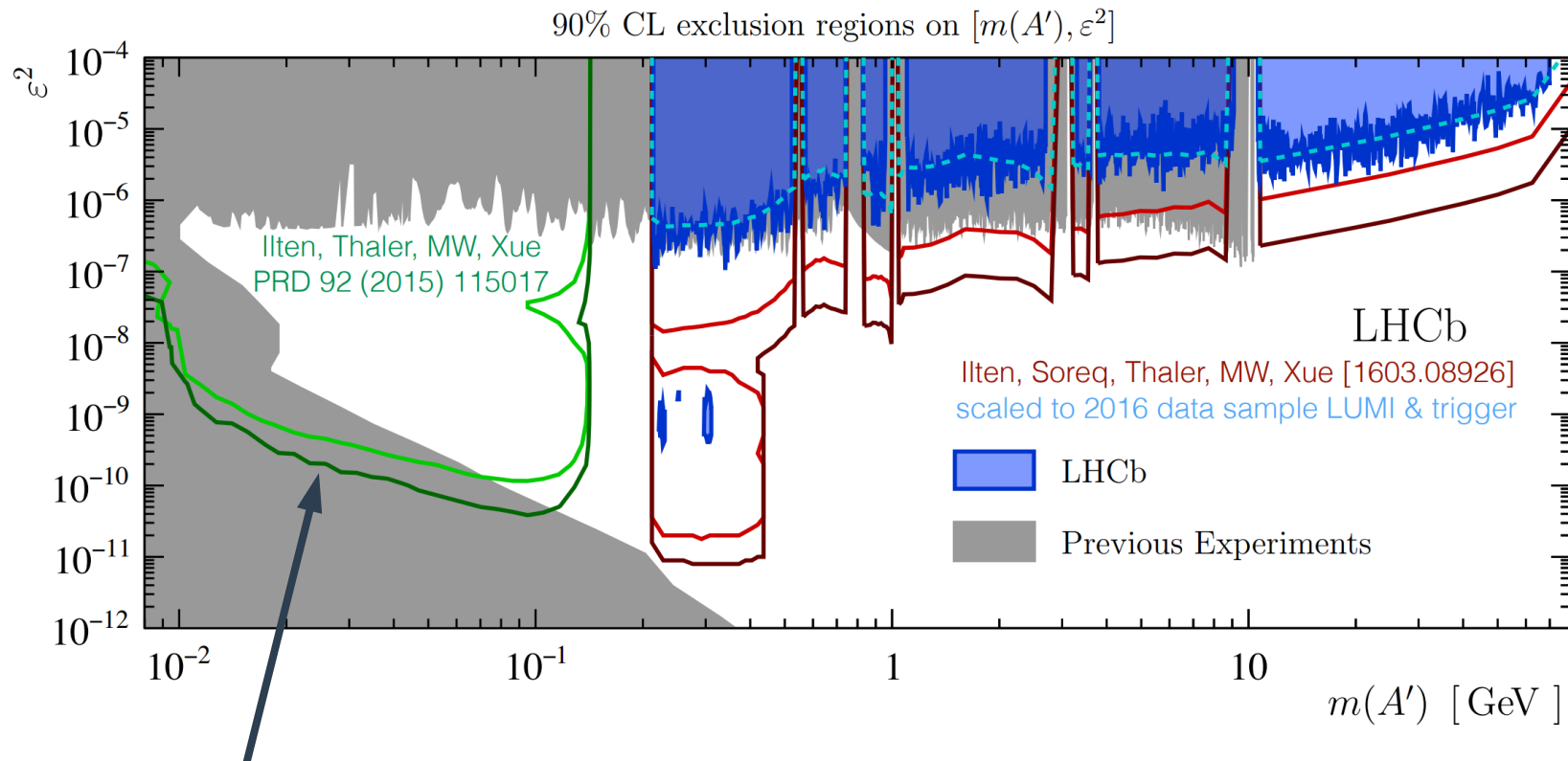


Dark photon mixes with SM photon

$$\mathcal{L} \supset -\frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{1}{2} m_{A'}^2 A'_\mu A'^\mu + \epsilon e A'_\mu J_{\text{EM}}^\mu$$

Two parameters: mixing strength ϵ + mass

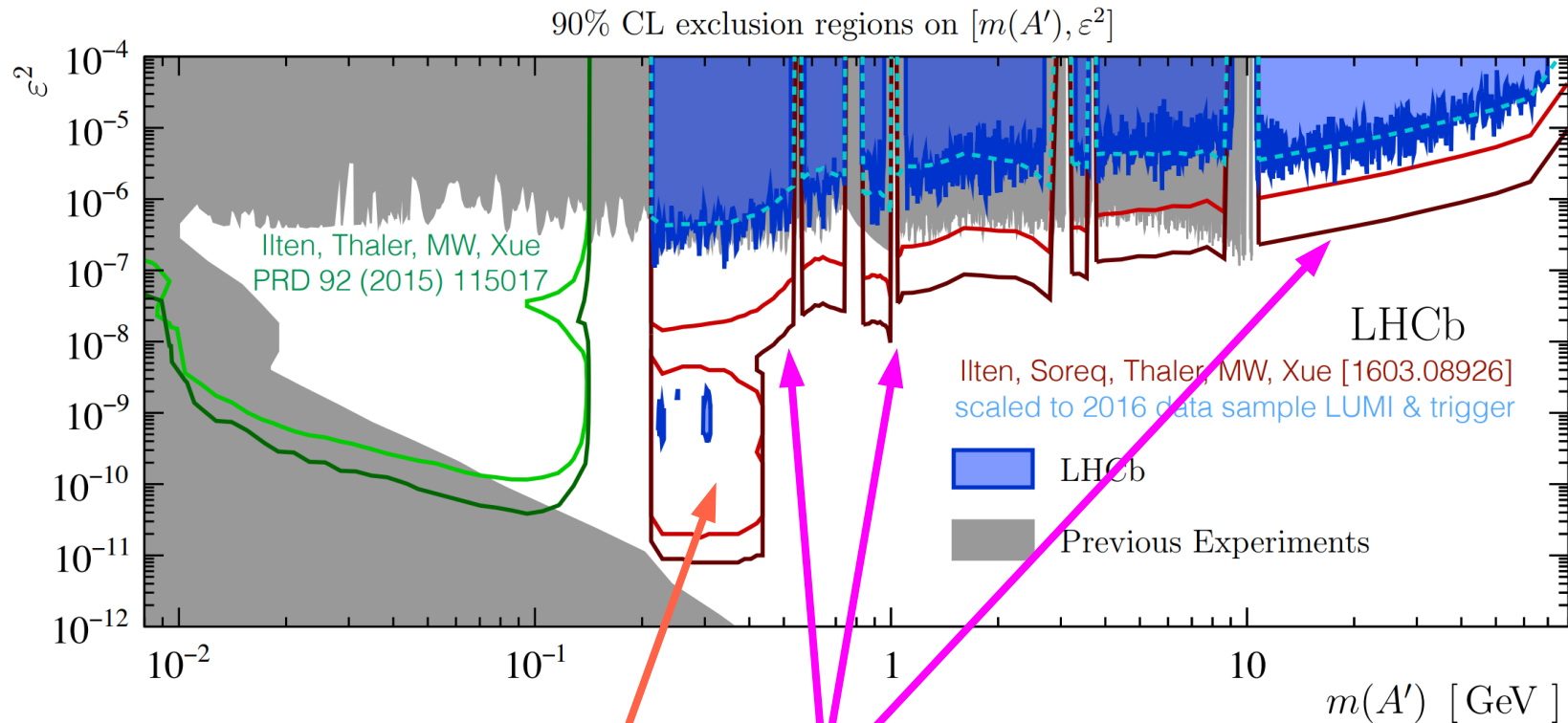
Dark Photons $\rightarrow \mu\mu$ @ LHCb



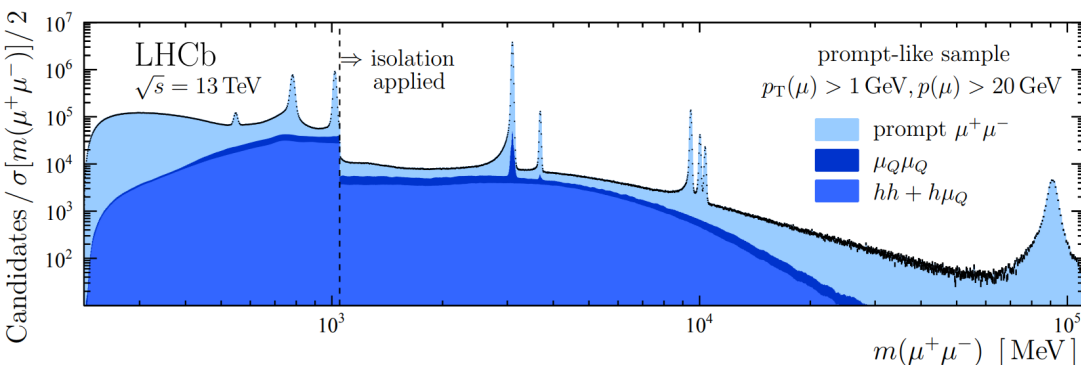
$D^{*0} \rightarrow D^0 + \text{dark photon} \rightarrow D^0 e^+e^-$
Relies on large D^{*0} sample in Run 3

$$\frac{\Gamma(D^{*0} \rightarrow D^0 A')}{\Gamma(D^{*0} \rightarrow D^0 \gamma)} = \epsilon^2 \left(1 - \frac{m_{A'}^2}{\Delta m_D^2} \right)^{3/2}$$

Dark Photons $\rightarrow \mu\mu$ @ LHCb



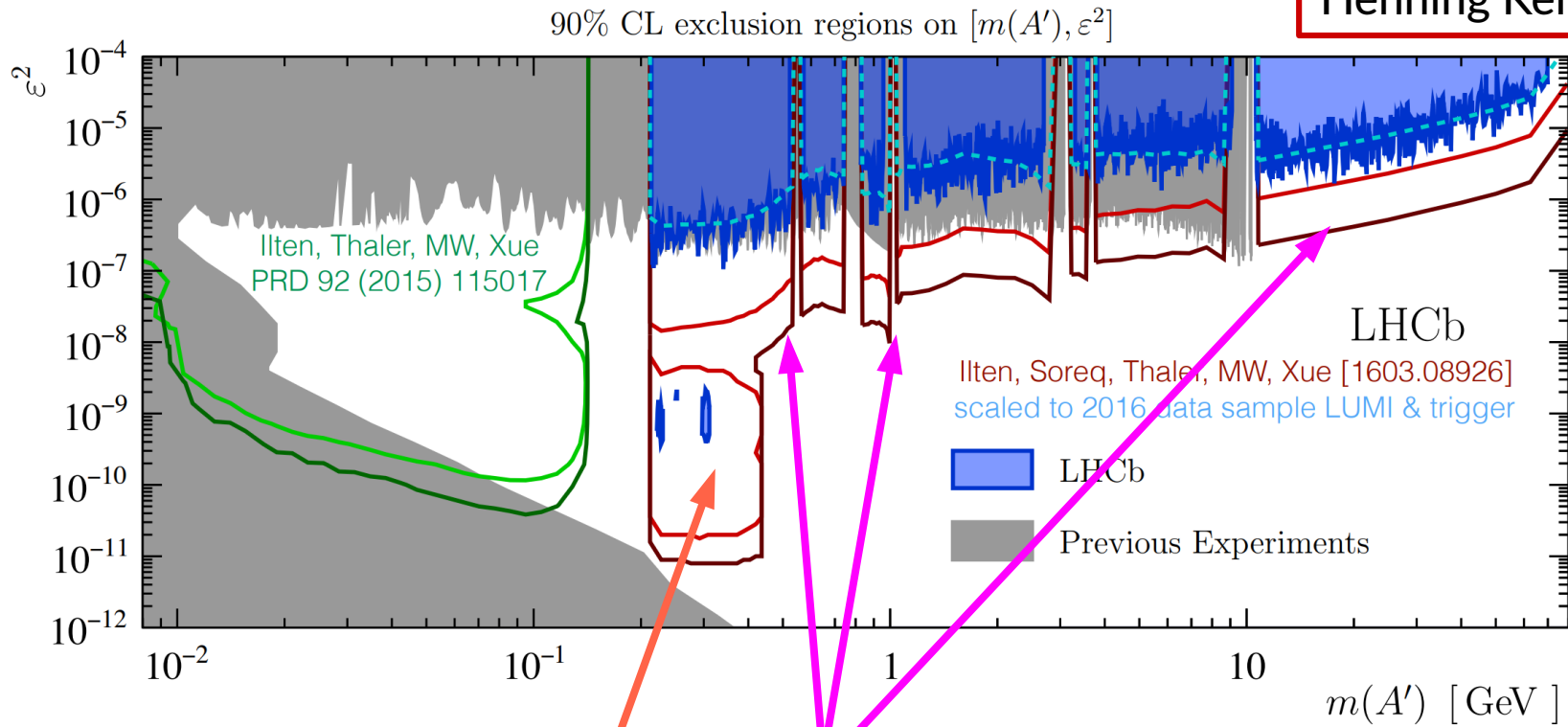
$A' \rightarrow \mu\mu$: Displaced and prompt



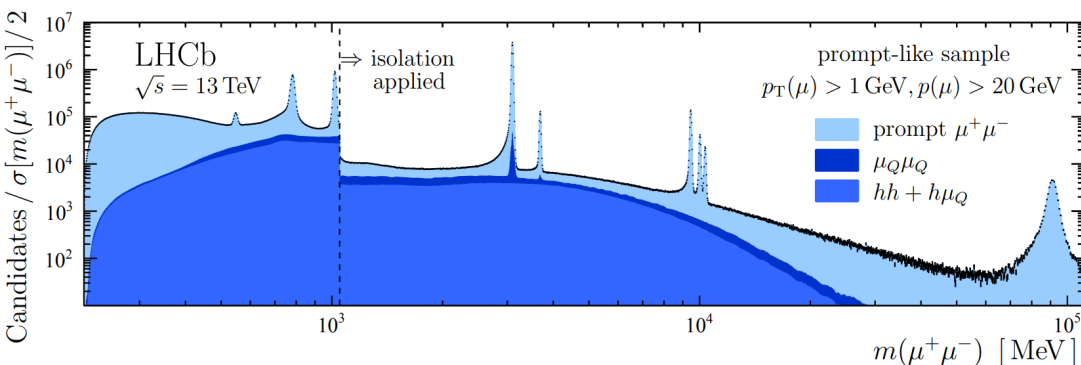
- Systematics cancel relative to SM γ BG (modulo lifetime effects)
- Trigger upgrade before Run 3
→ Large gains expected

Dark Photons $\rightarrow \mu\mu$ @ LHCb

Displaced: Talks by Carlos Vazquez Sierra Henning Keller



$A' \rightarrow \mu\mu$: Displaced and prompt



- Systematics cancel relative to SM γ BG (modulo lifetime effects)
- Trigger upgrade before Run 3 \rightarrow Large gains expected

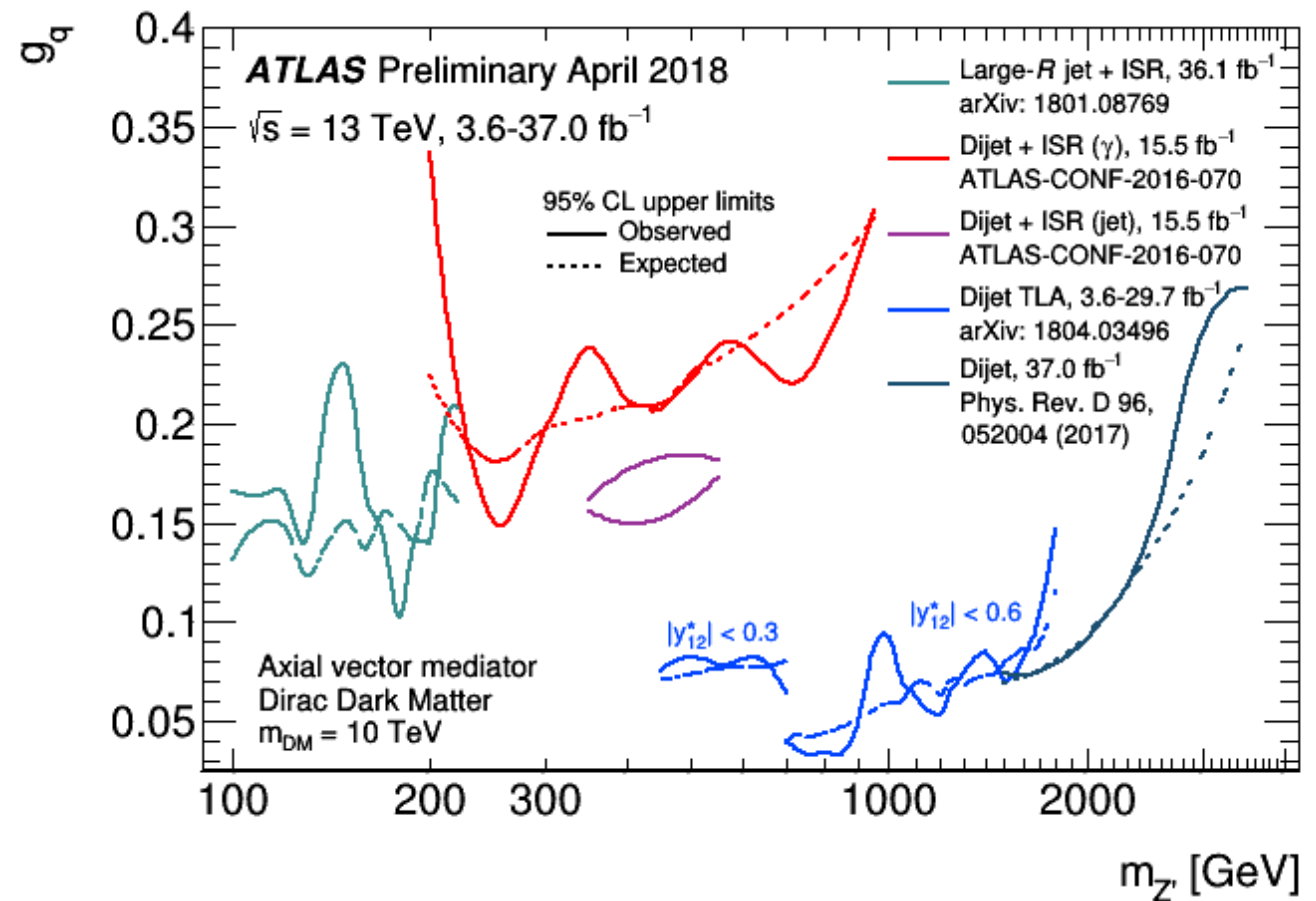
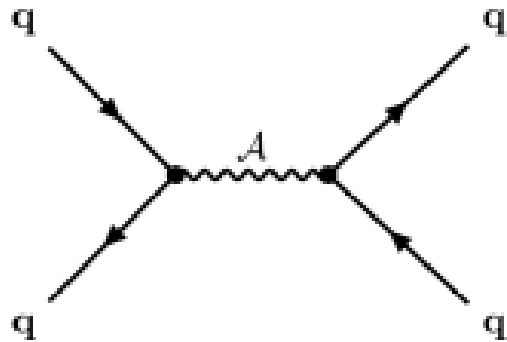
Summary

- Rich DM program in Run-II is being mirrored in projection studies
- Lots of opportunity for comparison between final states, methods, experiments
- Focus at this time on the upcoming yellow report: Many ongoing studies on track!

Backup

Mediators

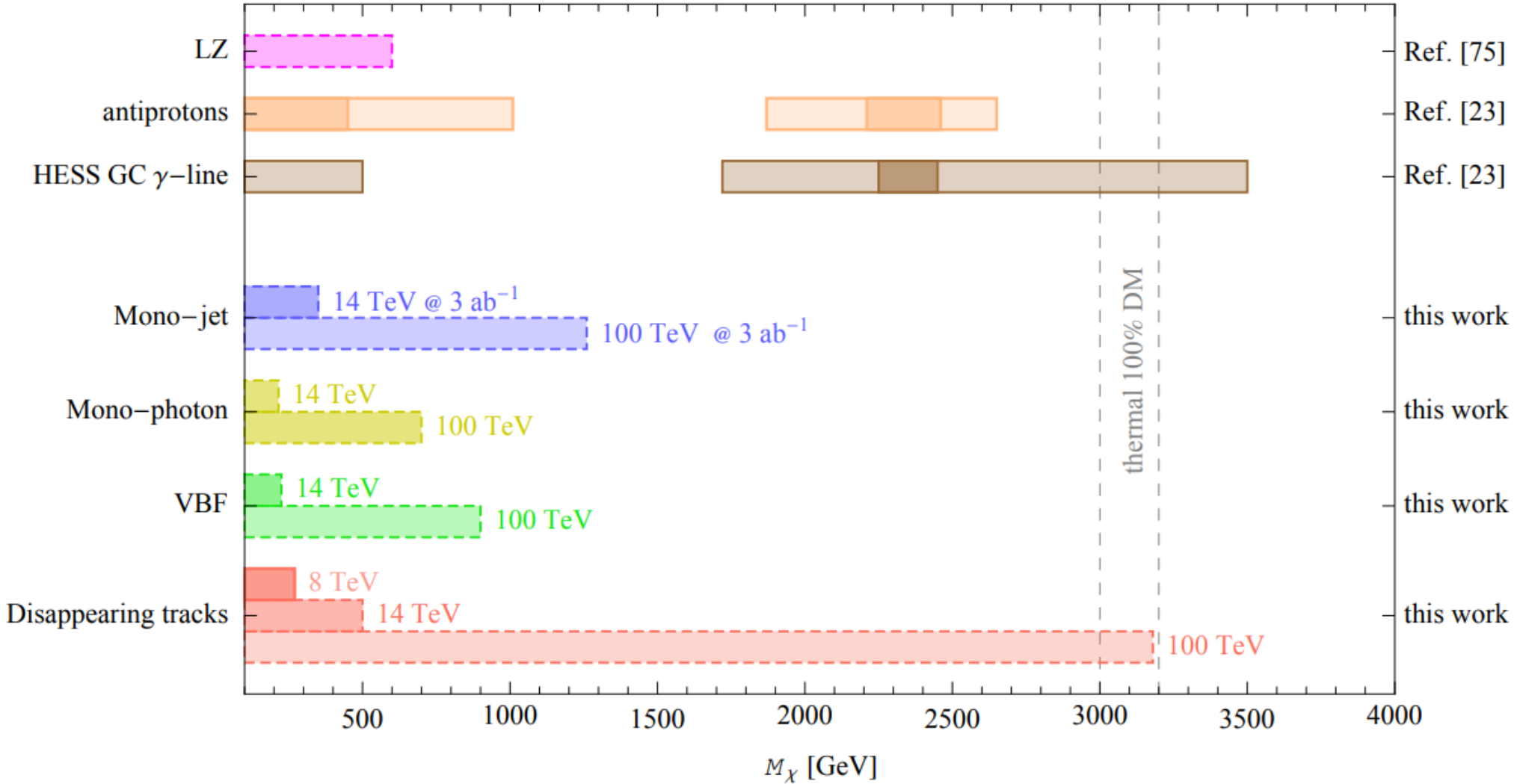
Mediator searches: Dijet, dilepton?



- What is the coupling reach?
- Open!

Triplet DM

Summary of constraints (solid edge) and reaches (dashed edge)



FTR-16-005

Table 3: Summary of the event selection criteria used to select monojet events for this analysis.

Event selection	
AK4 jets	$p_T(j_1) > 250$ for AV (200 for PS), $ \eta < 2.5$
$\Delta\phi(\text{jet}, E_T^{\text{miss}})$	$\Delta\phi > 0.5$
veto electrons	$p_T > 10, \eta < 2.4$
veto muons	$p_T > 10, \eta < 2.5$
veto taus	$p_T > 18, \eta < 2.3$
b-jet veto	'Loose', $p_T > 15, \eta < 2.5$
E_T^{miss}	$E_T^{\text{miss}} > 200$ GeV