DARK MATTER SEARCHES AT ATLAS: RUN 1 RESULTS AND RUN 2 PLANS

Caterina Doglioni, University of Geneva

ATLAS Collaboration

25/03/2015 – MITP "Effective Theories for Dark Matter"

Dark Matter at ATLAS
past and near future searches

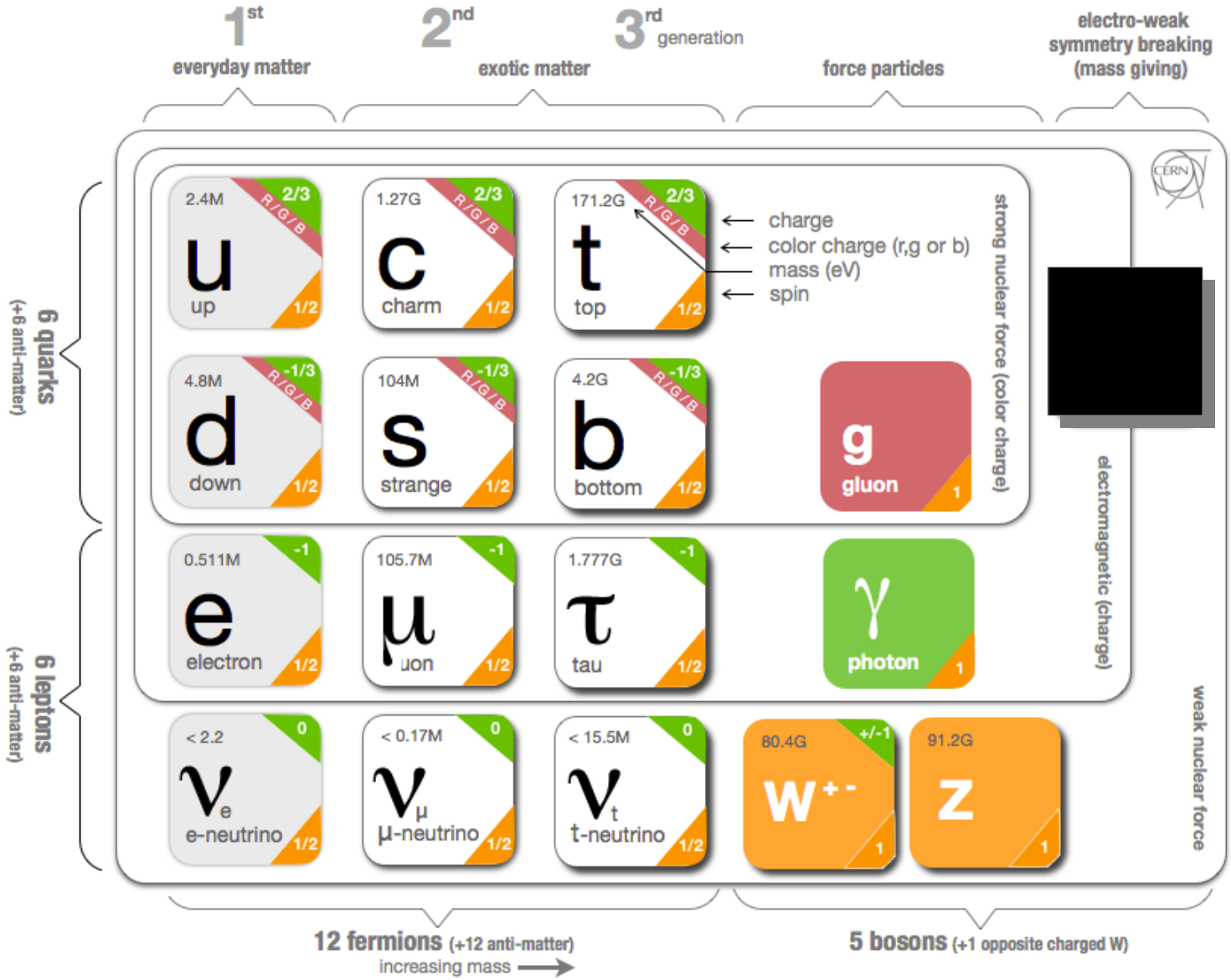
1. The heart of the (dark) matter: WIMPs

2. MET+X searches and Effective Field Theories:
(jet+MET, W+MET, heavy flavors+MET, dijet CI search)

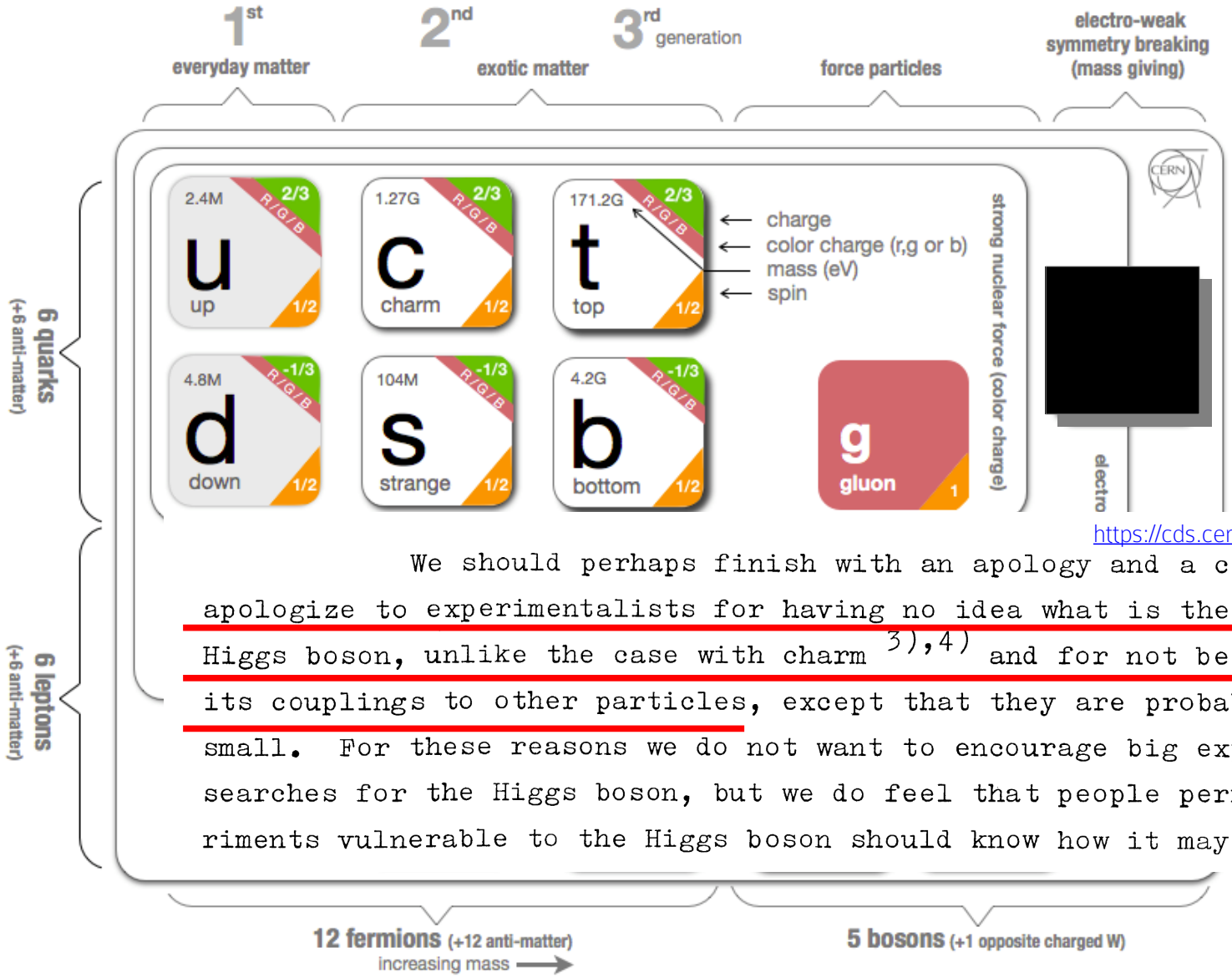
3. The case for simplified models and specific examples
(photon+MET, Z+MET,t+MET, Higgs→MET, dijet/dilepton)

More ATLAS results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

THE HEART OF THE MATTER, PRE-LHC



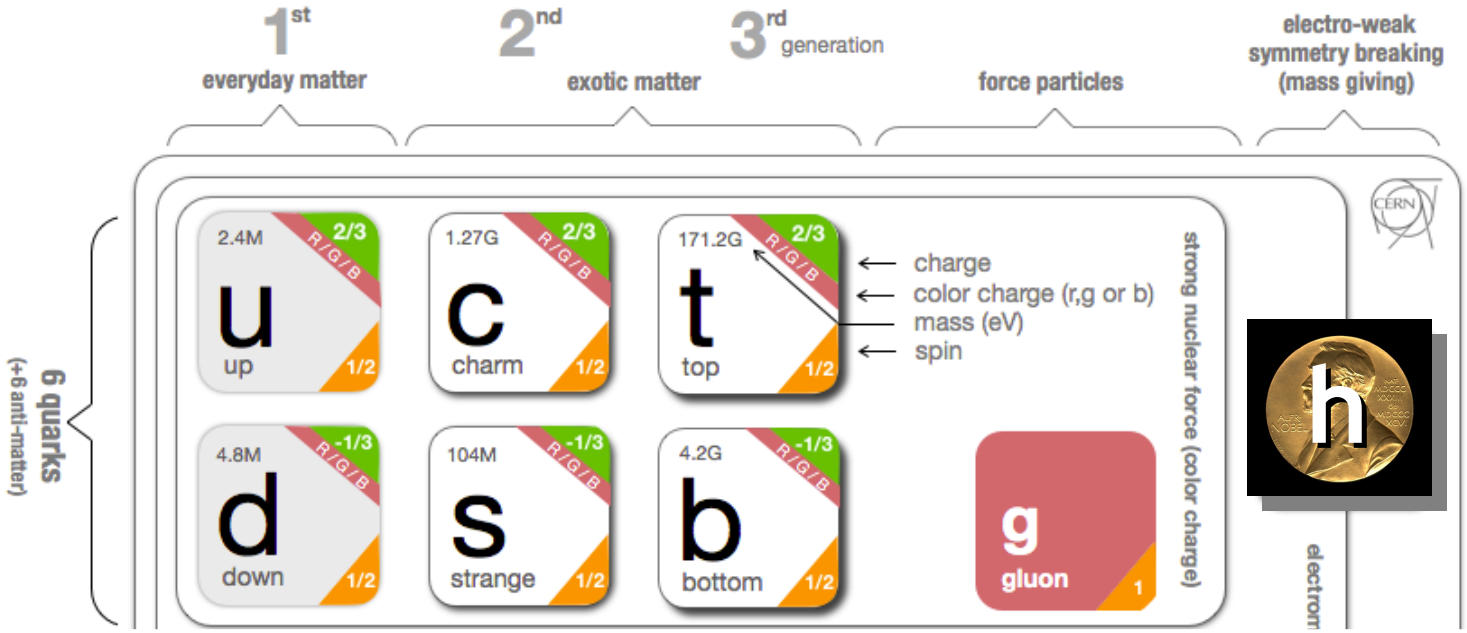
THE HEART OF THE MATTER, PRE-LHC

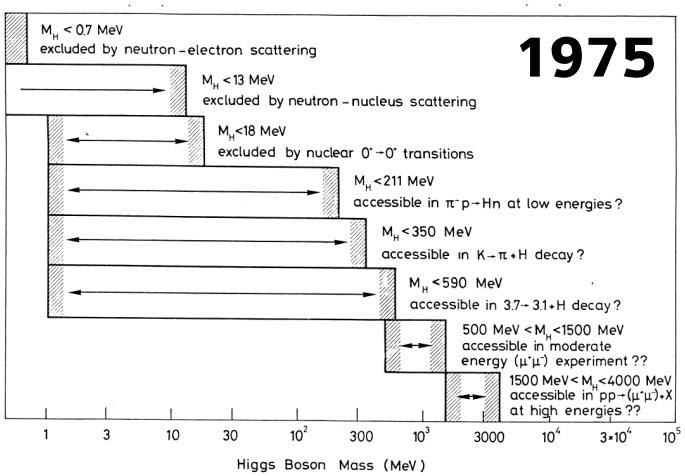


https://cds.cern.ch/record/874049

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3),4)] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

THE HEART OF THE MATTER, POST LHC RUN-1





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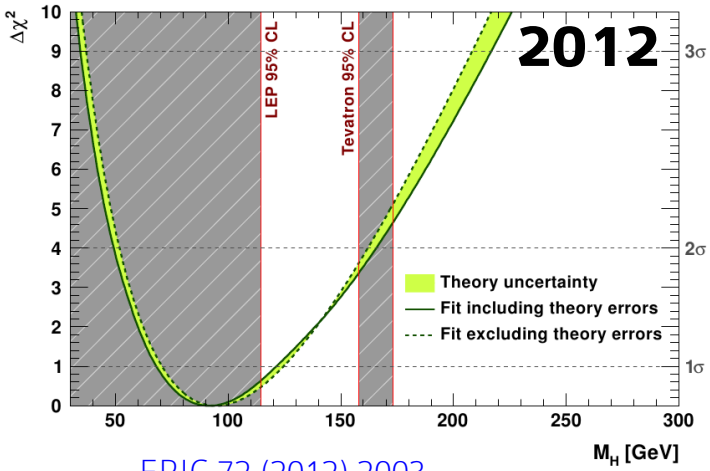
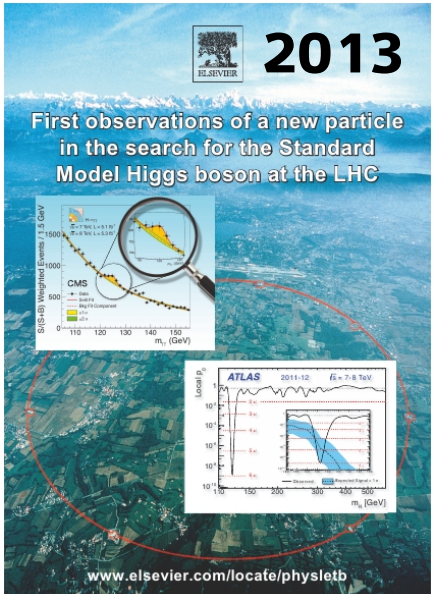


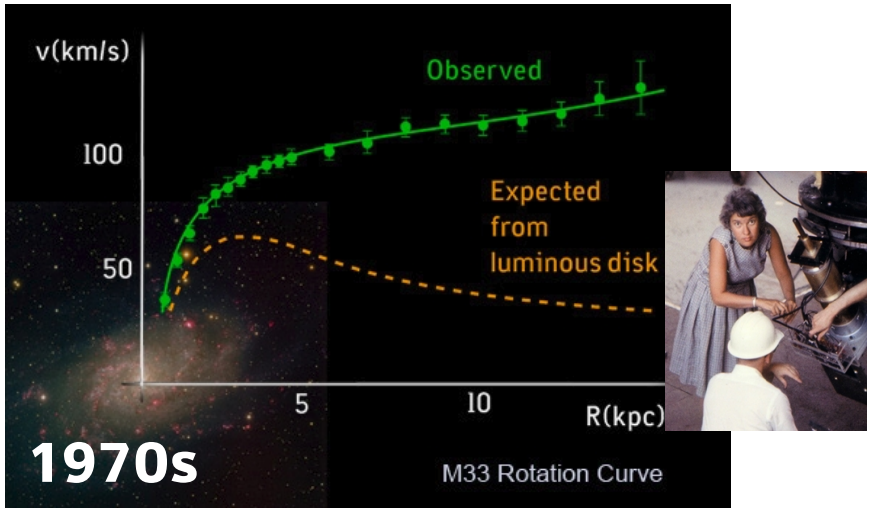
EPJC 72 (2012) 2003



AN EMPIRICAL PROBLEM OF THE SM: DARK MATTER

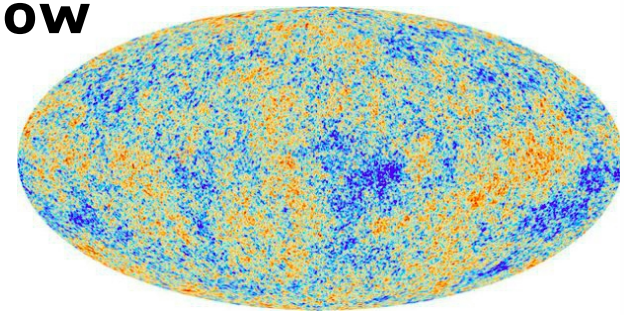
F. Zwicky – Coma cluster: mass vs light output

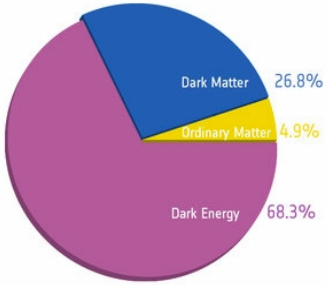
V. Rubin – Velocity of gas near Andromeda galaxy



Planck – Dark matter vs standard matter composition using CMB (temperature) fluctuations

2013 -now



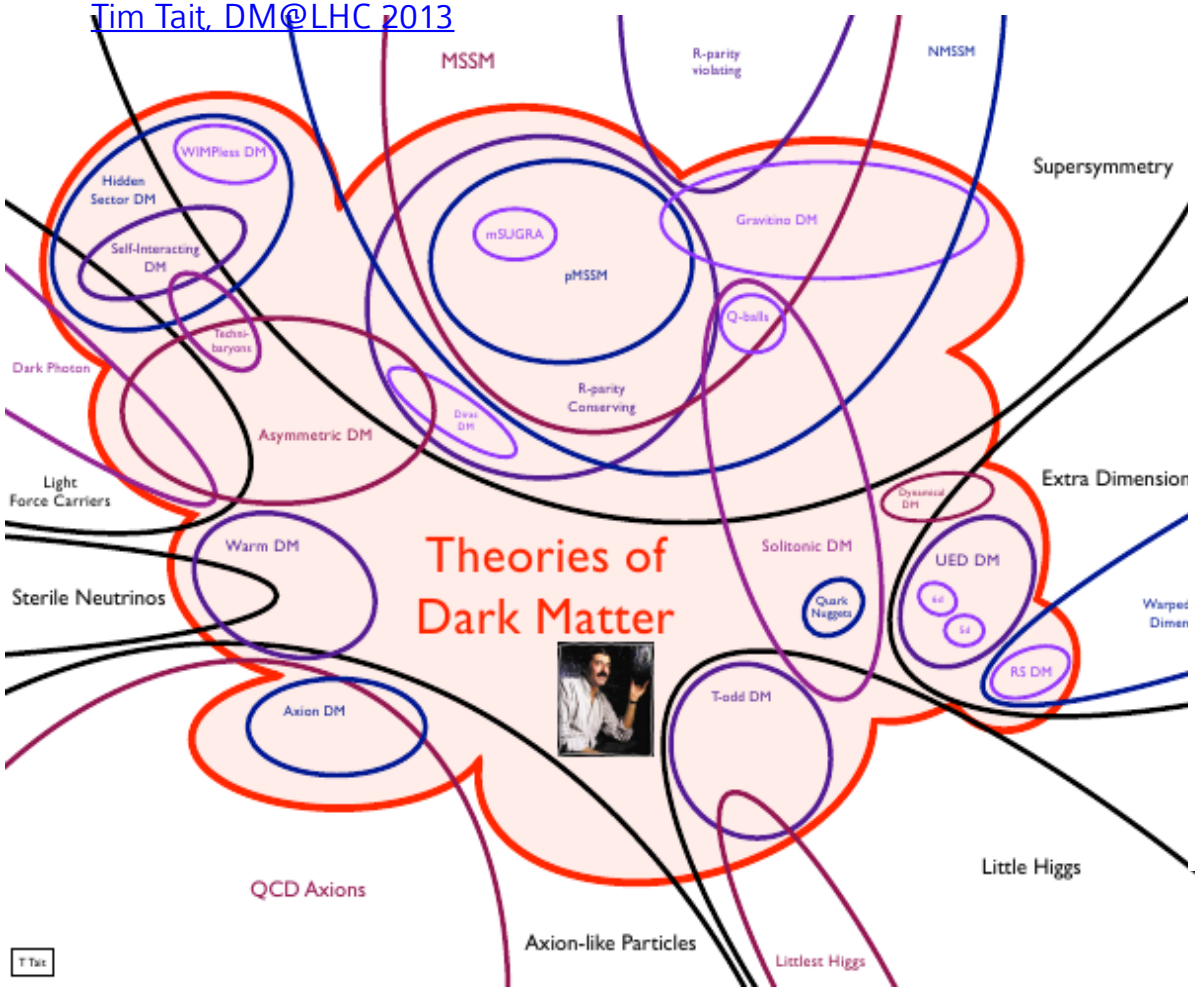


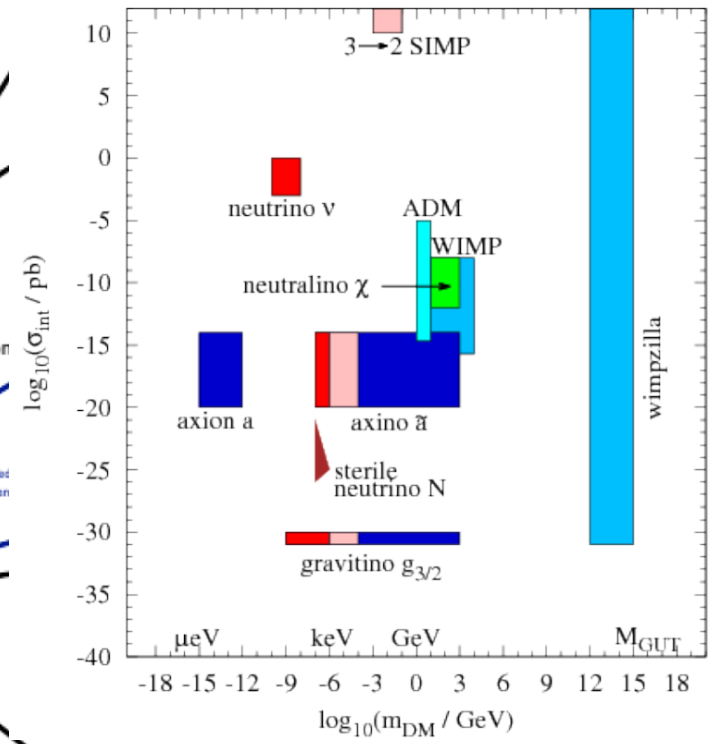
After Planck

Chandra/Hubble (NASA) – Visible mass of bullet cluster vs dark mass inferred from gravitational lensing

DARK MATTER IS THERE, BUT WHERE?

Tim Tait, DM@LHC 2013





DARK MATTER IS THERE, BUT WHERE?

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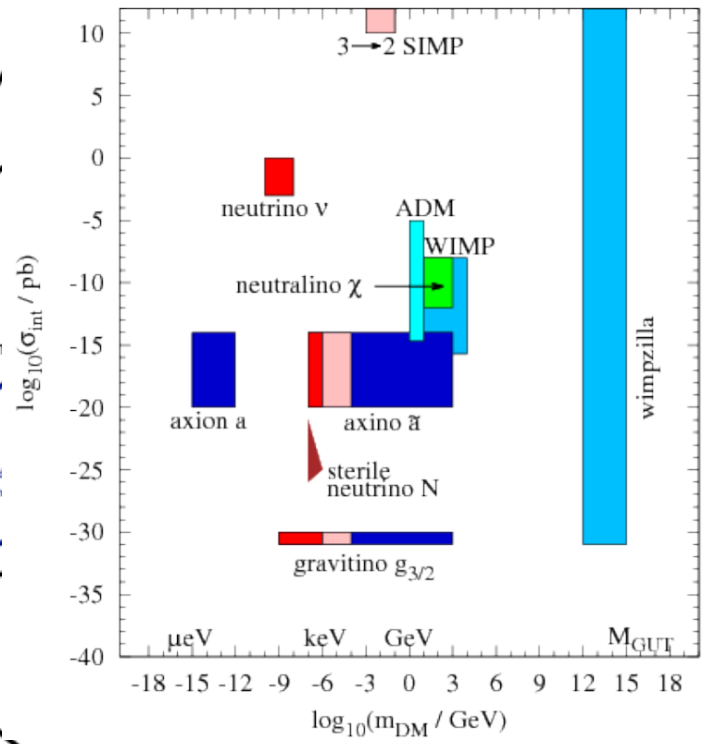
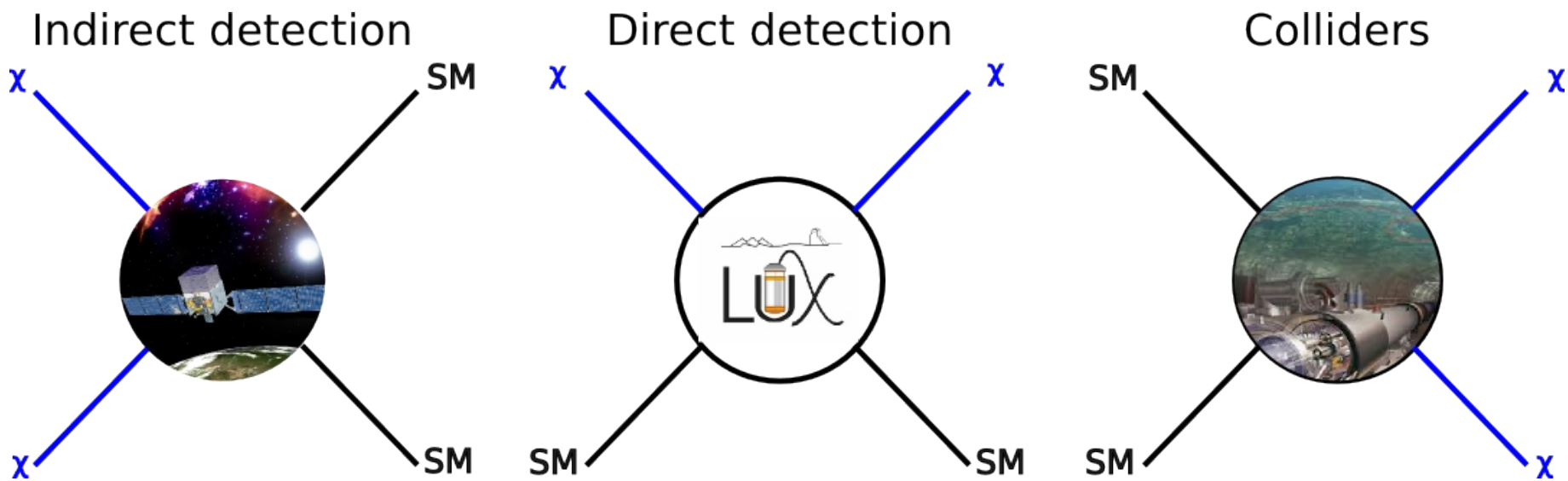


This talk: mostly focus on "model-independent" (i.e. non-SUSY) searches, but **still searches for WIMPs**

PREJUDICE: WIMP DARK MATTER

(Our) **preferred DM candidate**
matches cosmological observations (e.g. thermal relic density):
dark, stable, cold, weakly interacting with SM particles,
mass of up to a few TeV → a **WIMP**

Good News! **Complementary** Dark Matter experiments

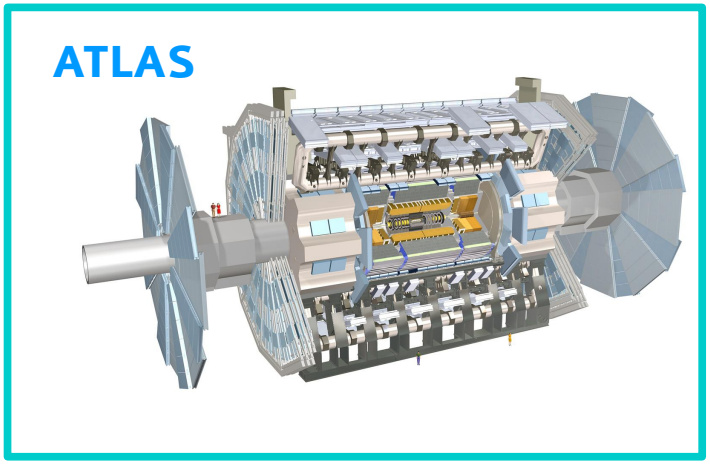


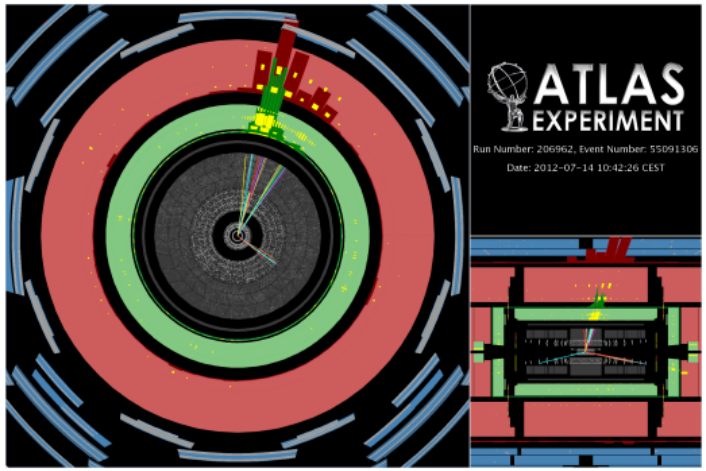
COLLIDER EXPERIMENTS: ATLAS AND CMS

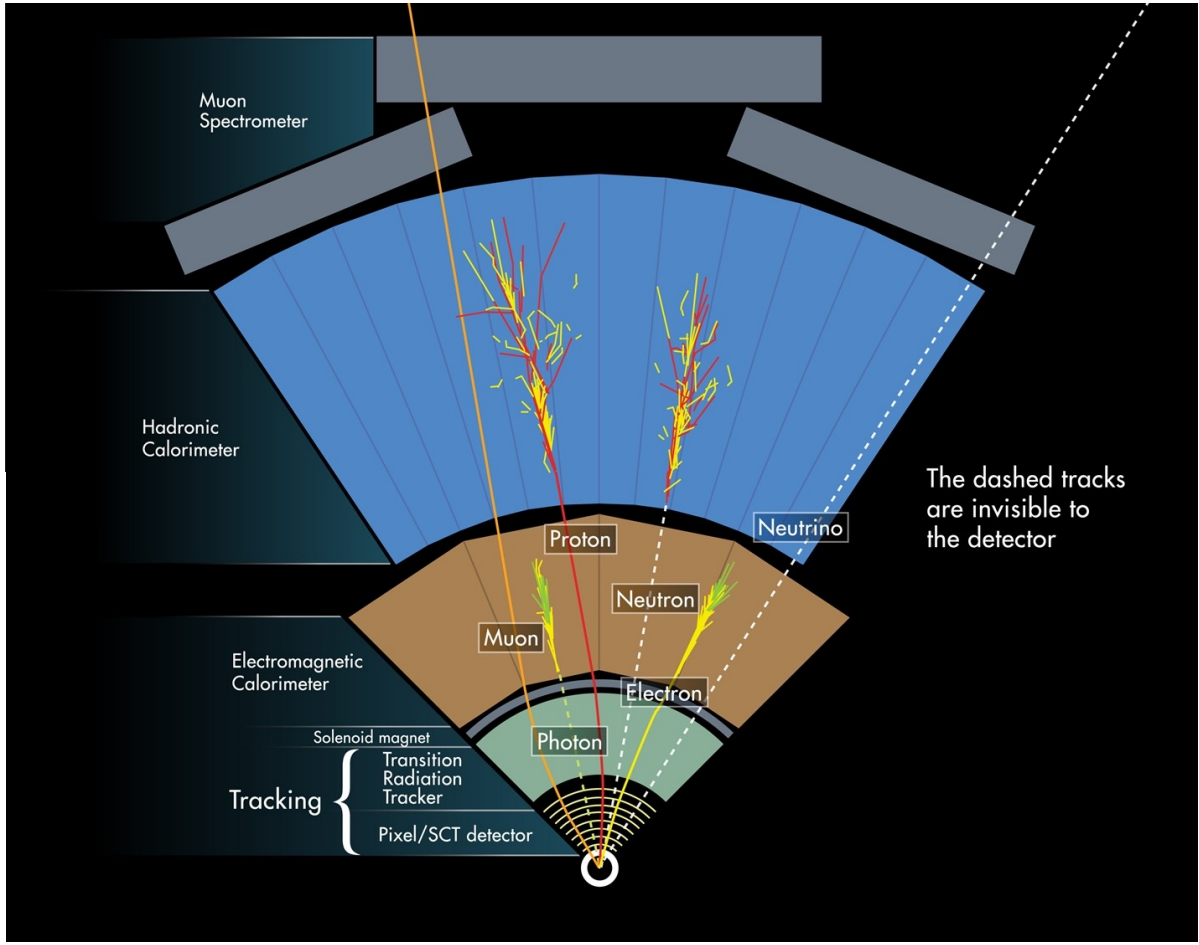
- ATLAS and CMS ➞ physics with jets, leptons, photons
  - General-purpose experiments, covering ~ full solid angle
  - Excellent tracking, calorimetry, muon spectrometer

THE ATLAS EXPERIMENT IN A NUTSHELL

Key point in searches for invisible particles: **hermetic detector**



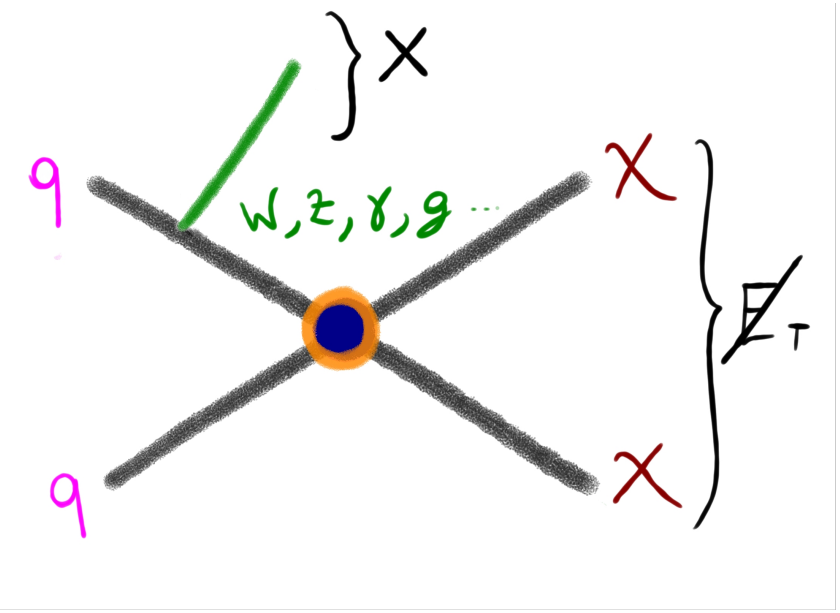


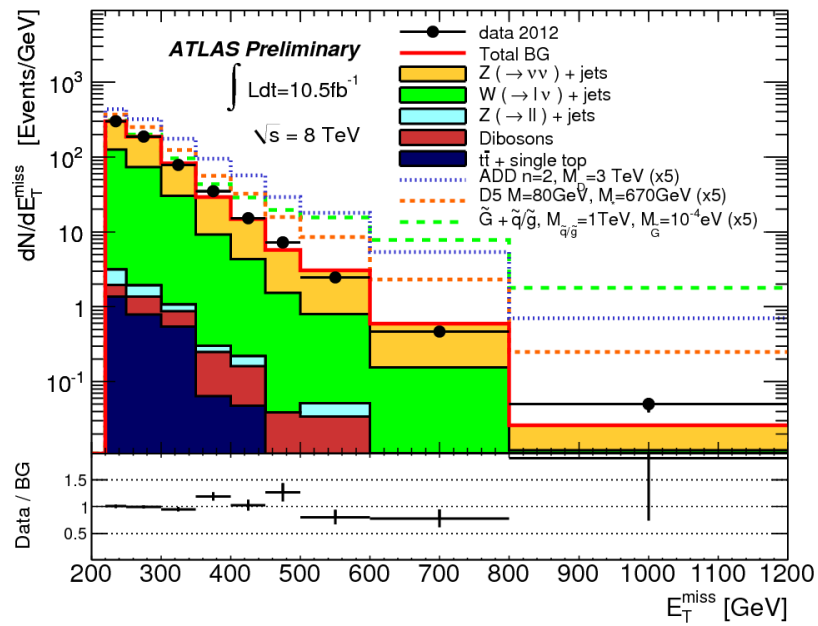


How a WIMP event (but also: $Z \rightarrow \nu\nu$ + jet) would look like in ATLAS

Invisible DM particles **escape detection**:

LHC experiment strategy: **tag** events using **recoiling** object(s), measure **missing transverse momentum (Missing E_T)**



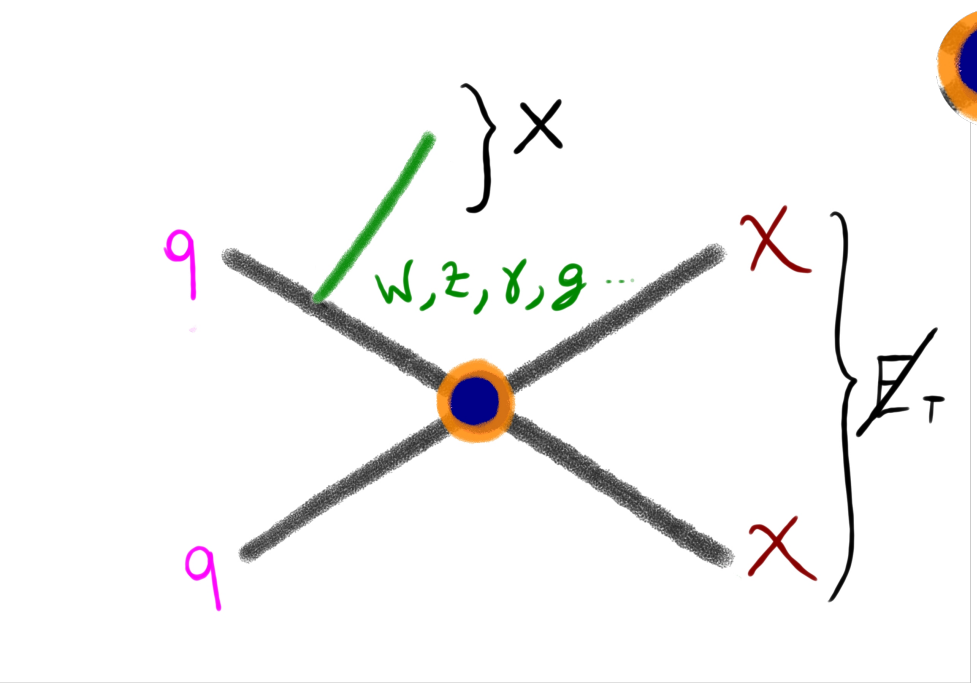


WIMP signature: excess in **tails of MET distribution**

(searches for also sensitive to other models)

Commonly used benchmark at colliders:

Contact Interaction (Effective Field Theories)



arxiv:1008.1783

= **EFT Operators** representing types of DM-SM interactions with DM particles

Advantages:
Limited number of degrees of freedom: scale of interaction (M* or Λ), DM mass

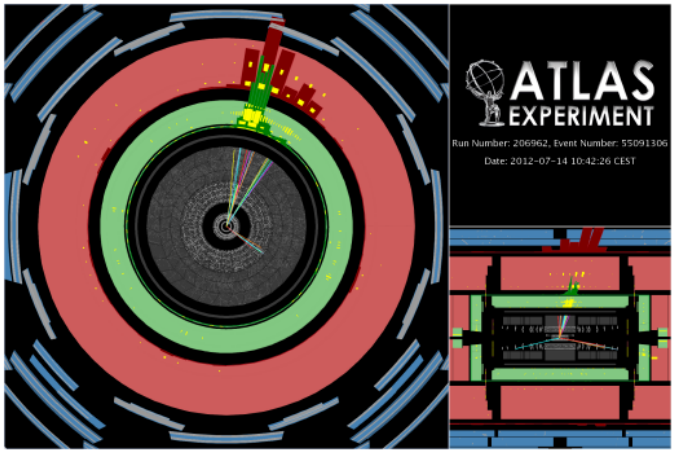
Disadvantages:
Only applicable at **low momentum transfer**

Question for later discussion:
Is this EFT/CI still a **viable/useful benchmark** for colliders?
Can/should we do something about its **validity**?

JET+MET SEARCHES

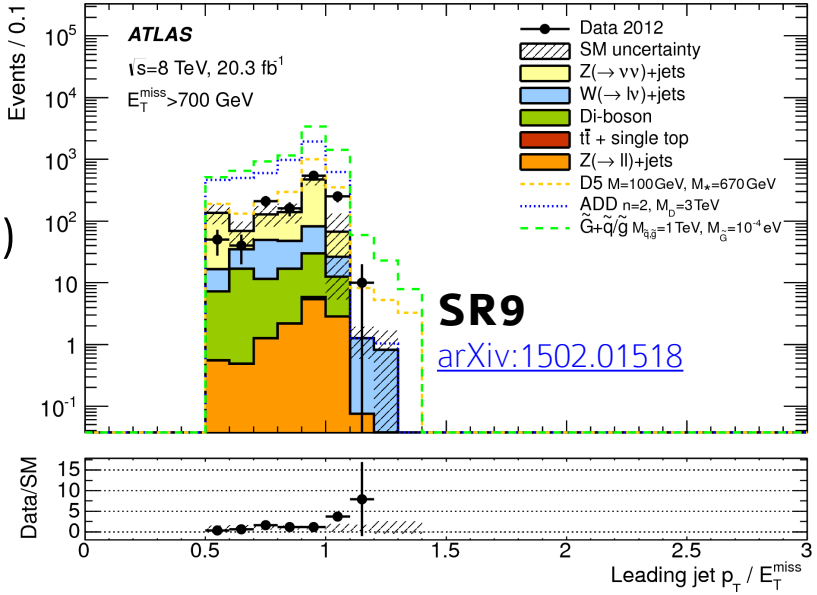
ATLAS: arXiv:1502.01518
CMS: arXiv:1408.3583

Jet+MET: look for excess of events with high pT jet(s), high missing transverse momentum

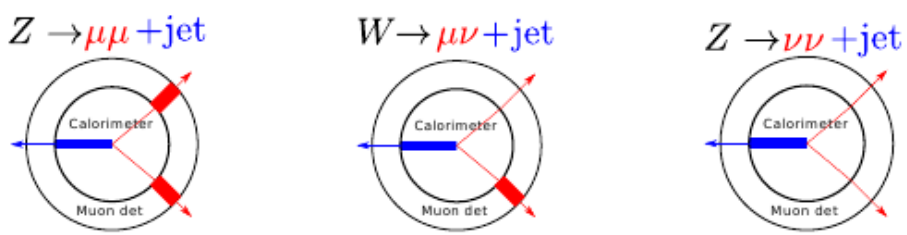


Signal regions (SR):
Cut and count analysis,
varying jet pT and MET thresholds

Dominant background uncertainties:
W/Z backgrounds (theory, CR stat.)
Object reconstruction (jet/MET)
e.g. SR9: pT > 700 GeV, MET > 700 GeV:
total background uncertainties: 14%

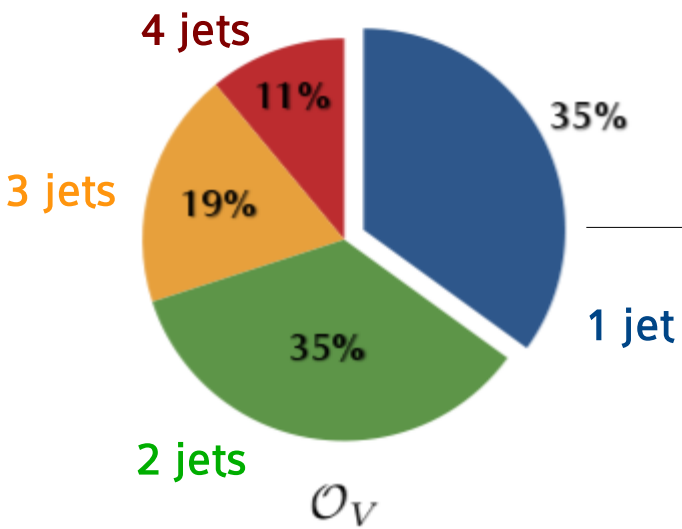


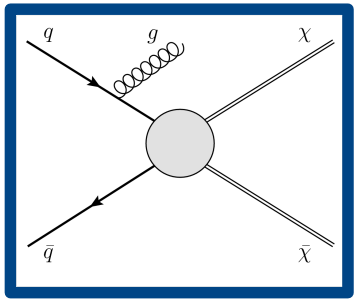
Background estimation (main: Zνν+jets):
use transfer factors from W/Z control regions (CR)



Graphics by S. Schramm

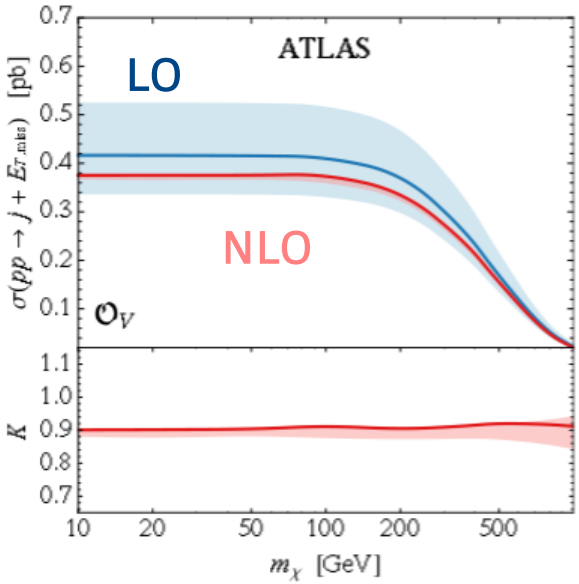
arXiv:1310.4491, Emanuele Re's talk





Naive monojet doesn't quite capture all QCD effects

NLO reduces uncertainties



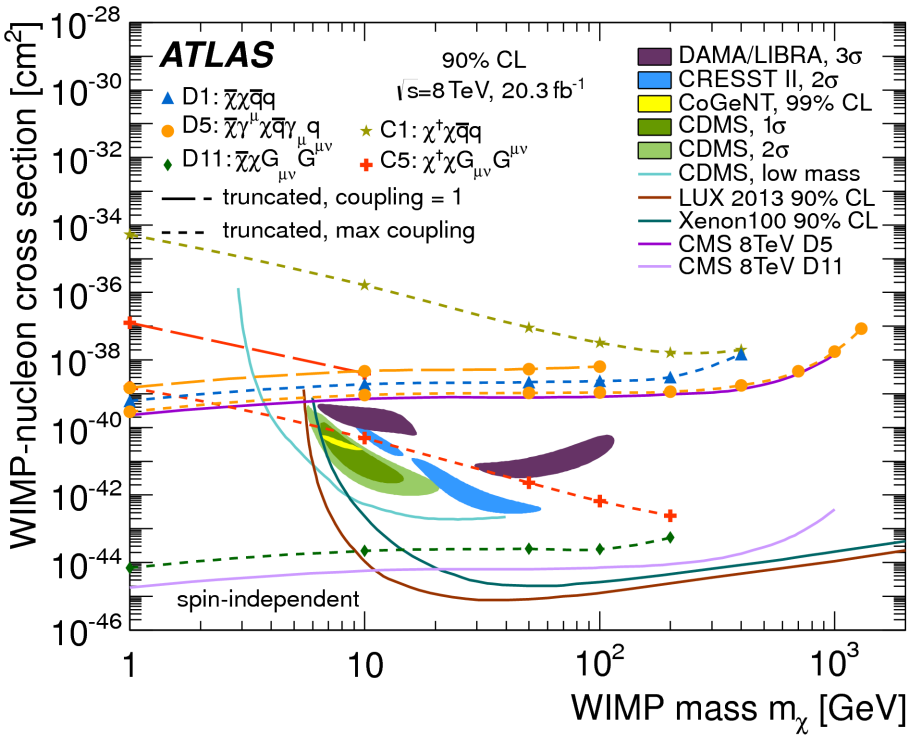
ATLAS 8 TeV analysis: ATLAS: arXiv:1502.01518

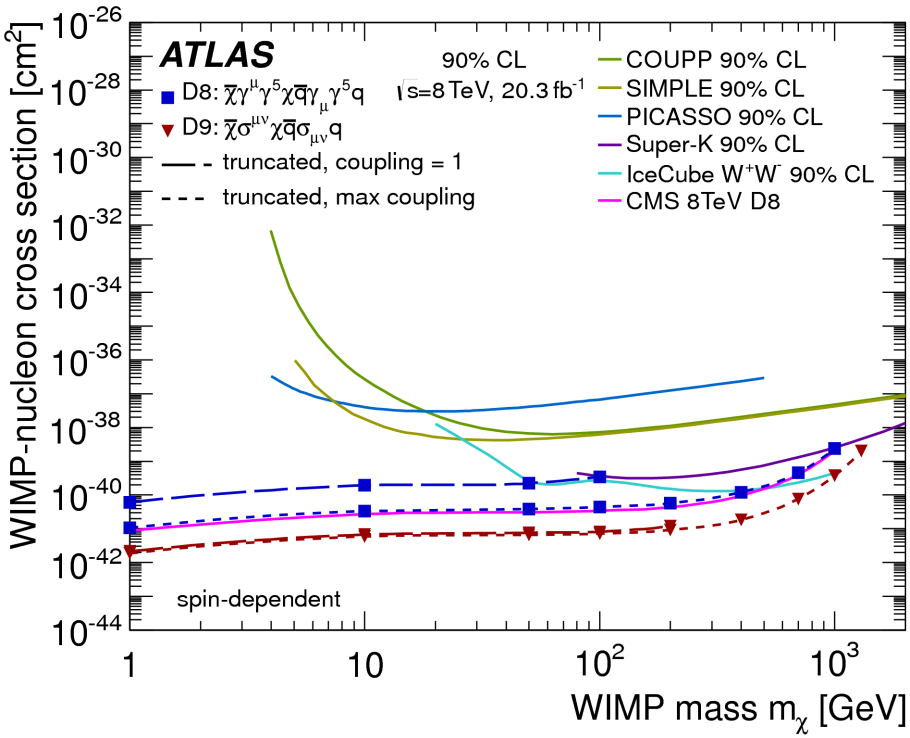
use **NLO signals**, **release jet veto** (but keep monojet-like topology)

→ improvements in EFT limits

RESULTS OF JET+MET SEARCHES

ATLAS: arXiv:1502.01518
CMS: arXiv:1408.3583





Model-dependent comparison

Needs **agreement** on benchmarks and assumptions

→ e.g. **truncation** procedure to ensure **EFT validity**

Complementarity of DD/ID and colliders:

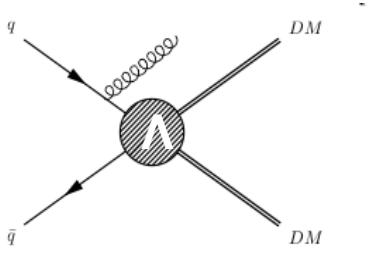
outlines strengths of each of the experiments

Question for later discussion:

is a comparison on this plane reasonable?

EFT VALIDITY: IS TRUNCATING A SOLUTION?

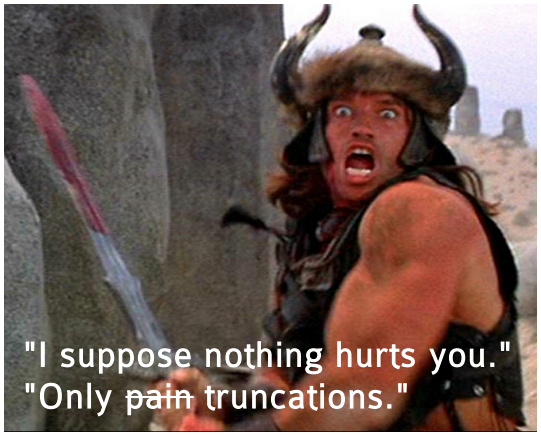
ATLAS: arXiv:1502.01518



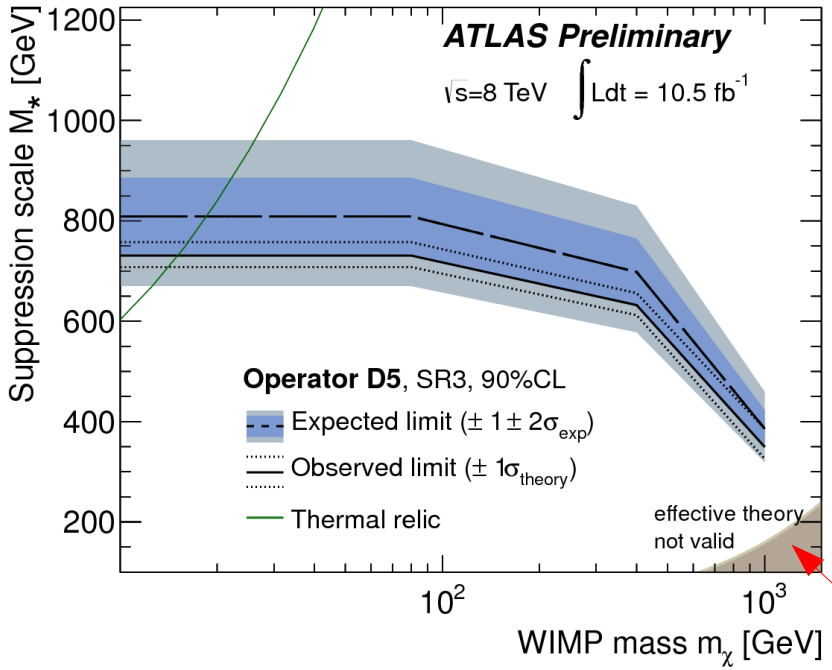
CI approximation valid if

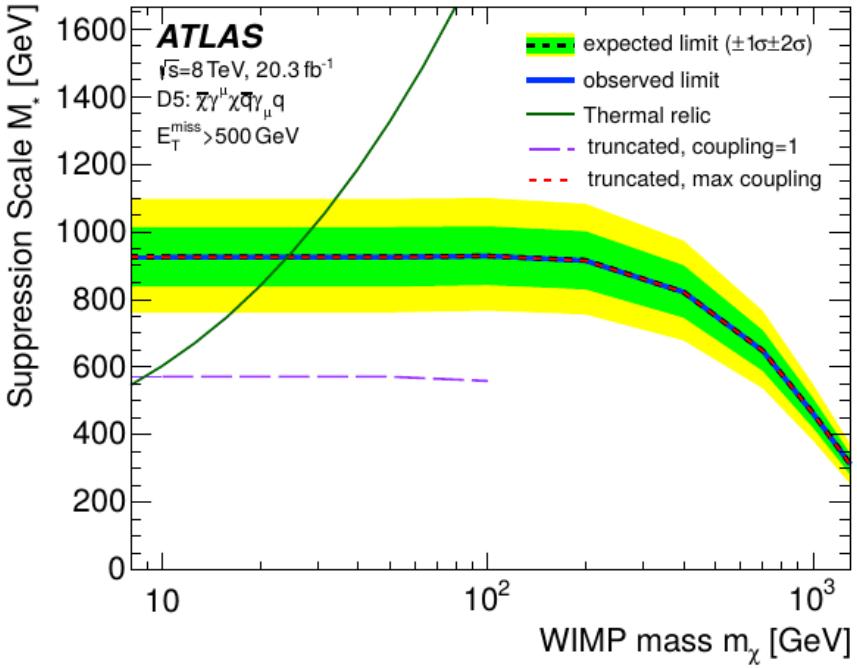
$$Q_{tr} < M_{med}$$

(minimal constraint)



Can we simply remove invalid events and have **conservative** limits at all times?

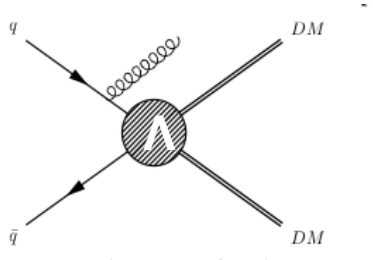




Coupling perturbativity + s-channel mediator

EFT VALIDITY TRUNCATION PROPOSAL (ATLAS)

ATLAS: arXiv:1502.01518



Valid if

$$Q_{tr} < M_{med}$$

(minimal constraint)

Connect **mediator mass and EFT scale Λ**: need information on **theory completion** → coupling-dependent condition, **precise and well-defined** within choices

Operator(s)	Relation between M_{med} and M_*	Coupling term range
D1	$M_{med} = \sqrt{y_q g_\chi}\ \sqrt{M_*^3/m_q}$	$0 < \sqrt{y_q g_\chi} < 4\pi$
C1	$M_{med} = y_q \lambda_\chi \zeta_\lambda\ M_*^2/m_q$	$0 < y_q \lambda_\chi \zeta_\lambda < (4\pi)^2 \zeta_\lambda$
D5, D8, D9	$M_{med} = \sqrt{g_q g_\chi}\ M_*$	$0 < \sqrt{g_q g_\chi} < 4\pi$
D11	$M_{med} = \sqrt[3]{a g_\chi}\ M_*$	$0 < \sqrt[3]{a g_\chi} < \sqrt[3]{16\pi}$
C5	$M_{med} = \sqrt{a \lambda_\chi \zeta_\lambda}\ M_*$	$0 < \sqrt{a \lambda_\chi \zeta_\lambda} < 4\sqrt{\pi \zeta_\lambda}$

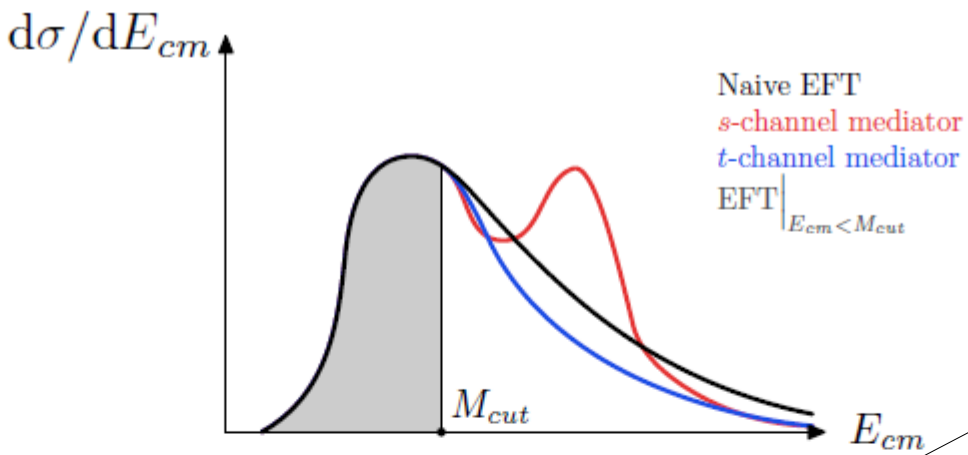
Key parameter for truncation: $R^{tot}_{M_{med}}$ = fraction of events passing $Q_{tr} < M_{med}$

Two equivalent procedures:

cross-section truncation, corresponding only to valid events(used in 8 TeV papers)

iterative rescaling of M* limits after determining R (used in 14 TeV studies)

ALTERNATIVE EFT VALIDITY TRUNCATION PROPOSAL arXiv:1502.01518



$$\mathcal{L}_{\text{EFT}} = -\frac{1}{M_*^2}\left(\overline{X}\gamma^\mu\gamma^5 X\right)\left(\sum_{\text{flavours}} \overline{q}\gamma_\mu\gamma^5 q\right)$$

- We restrict the signal to the events for which

$$\boxed{E_{\text{cm}} < M_{\text{cut}}},$$

where E_{cm} is the total invariant mass of the hard final states of the reaction:

$$E_{\text{cm}} = \sqrt{\hat{s}} = \sqrt{\left(p^\mu(\text{DM}_1) + p^\mu(\text{DM}_2) + p^\mu(\text{jet})\right)^2}.$$

- Indeed, the following *always* holds:

$$\sigma^{\text{signal}}_{\text{true model}} > \sigma^{\text{signal}}_{\text{corresp. EFT}}\Big|_{E_{\text{cm}}<M_{\text{cut}}}.$$

Thus we obtain conservative but reliable limits.

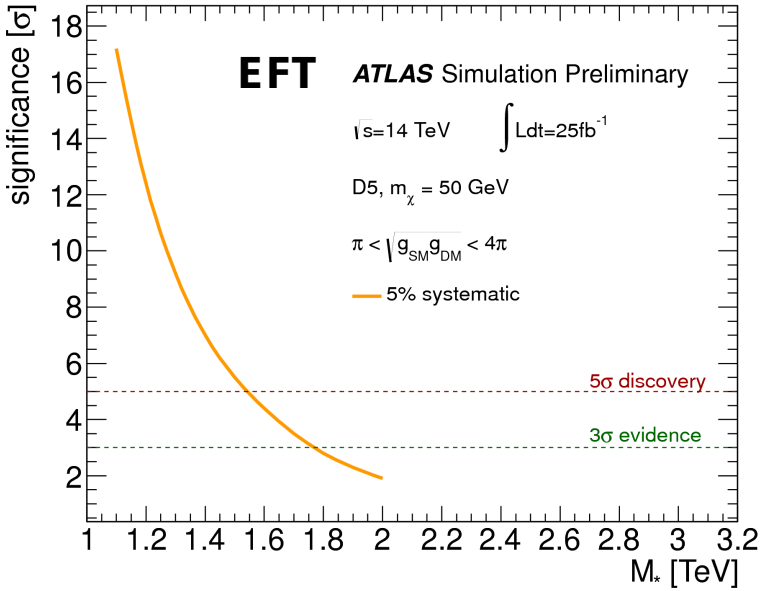
Mcut = g*M*

- only depends on parameters of the EFT as opposed to needing information on UV completion (still, physical interpretation requires assumptions)

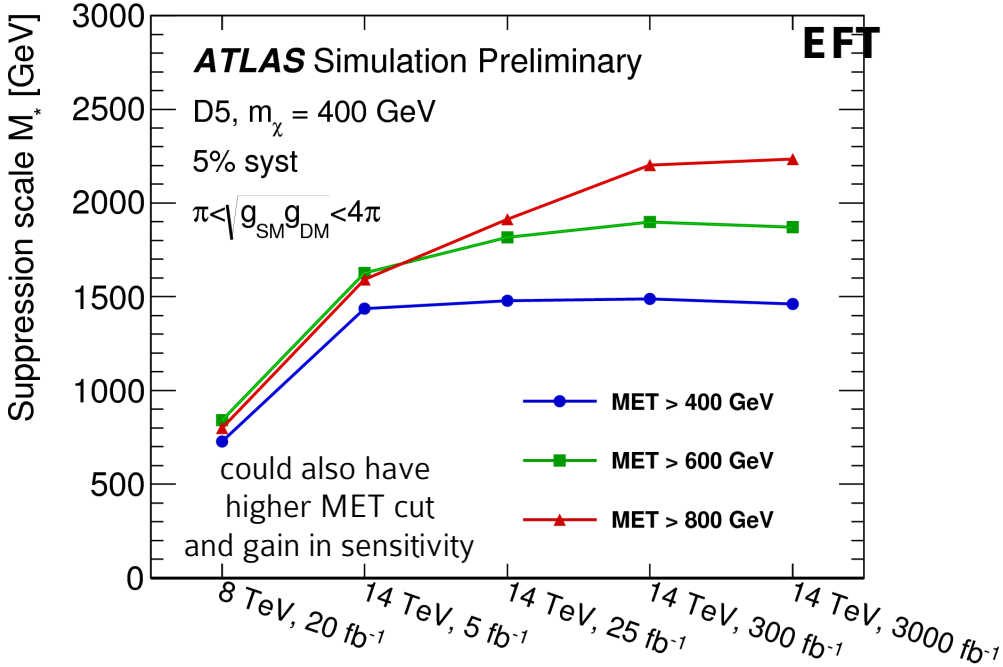
- can be **scanned**

PROSPECTS FOR JET+MET SEARCH AT 14 TEV ATLAS-PHYS-PUB-2014-007

Adopting similar **search strategy** as **8 TeV**
Generator-level backgrounds **+ smearing** for pile-up and detector conditions



	$\sqrt{s}$ [TeV]	μ	L [fb^{-1}]
	8	20	20
Phase 0 upgrade (2014-2015)	14	60	25
Phase 1 upgrade (2018)	14	60	300
Phase 2 upgrade (2022)	14	140	3000

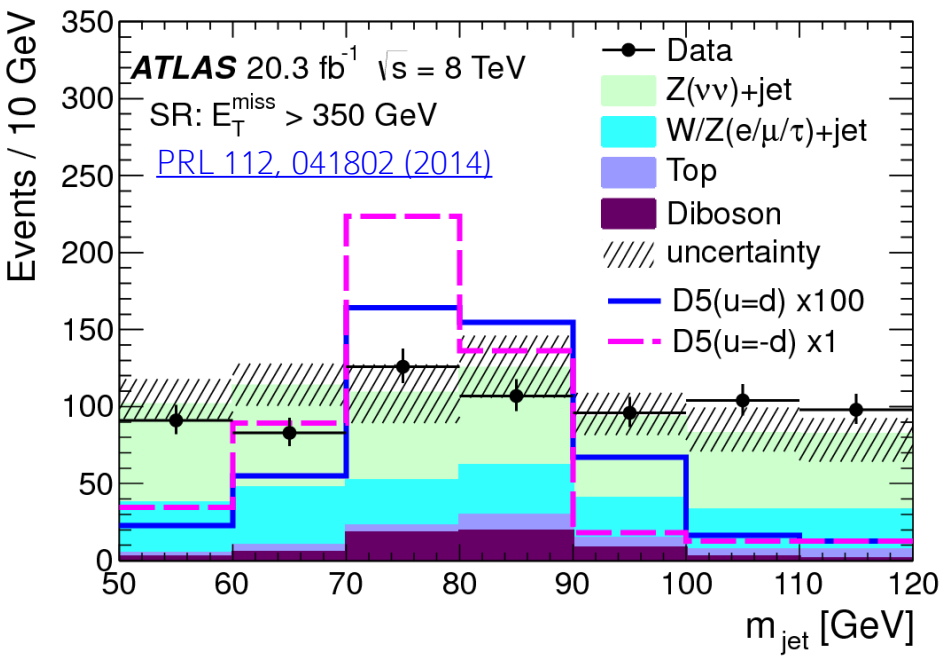


Surpassing previous limits within **1st year of data taking**

DARK MATTER WITH GAUGE BOSONS

MET+W/Z/γ: look for excess of events with high pT boson (decay products), high missing transverse momentum

W/Z → jj: use of single fat jet mass for W/Z tagging



ATLAS: CMS:

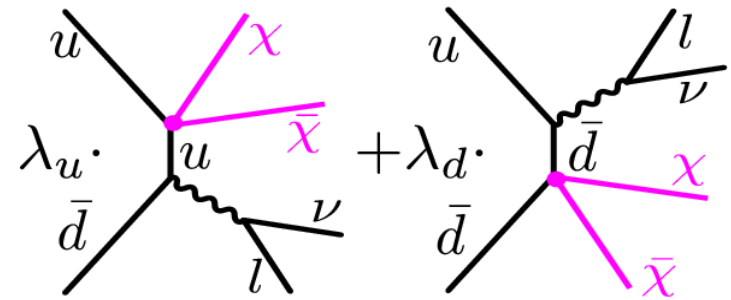
W/Z → jj: PRL 112, 041802 (2014) W → lnu: arXiv:1408.2745

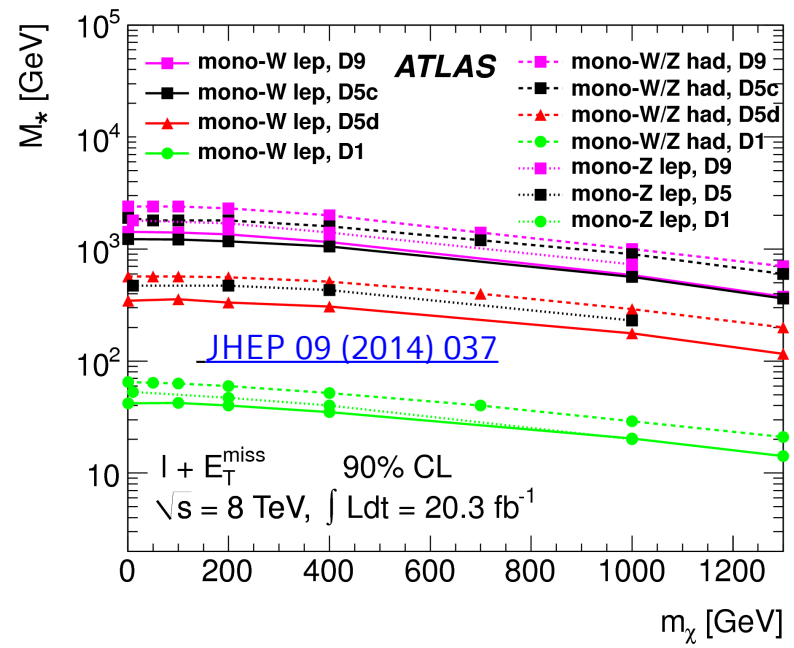
Z → ll: PRD 90, 012004 (2014) photon: arXiv:1410.8812

W → lν: JHEP 09 (2014) 037

photon: PRD 91, 012008 (2015)

Advantage for W: interference

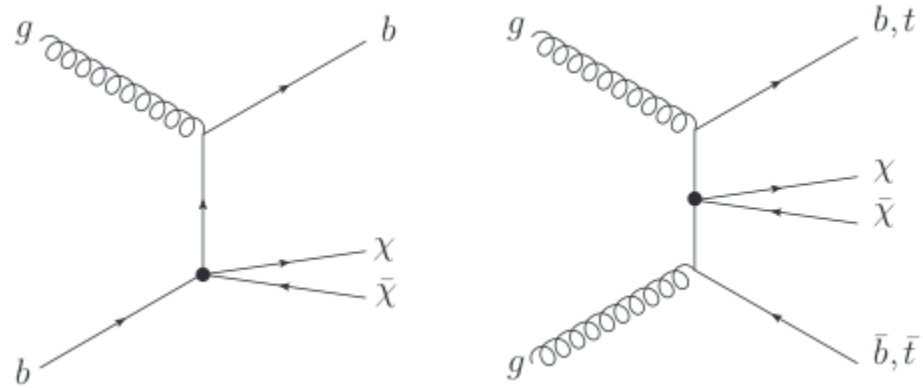




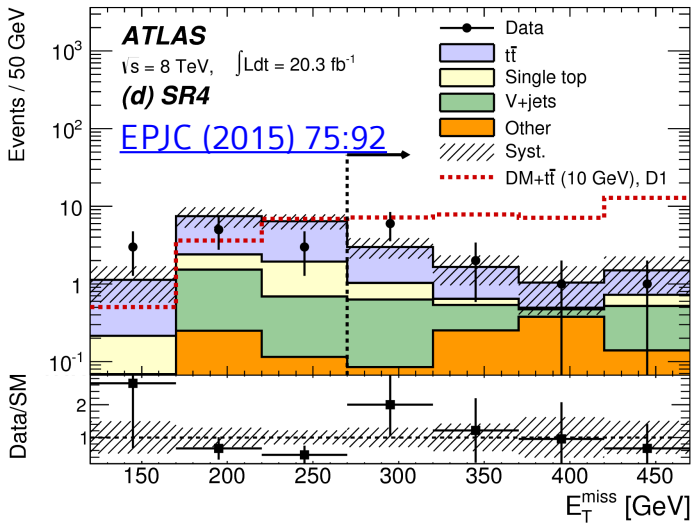
DARK MATTER WITH HEAVY QUARKS

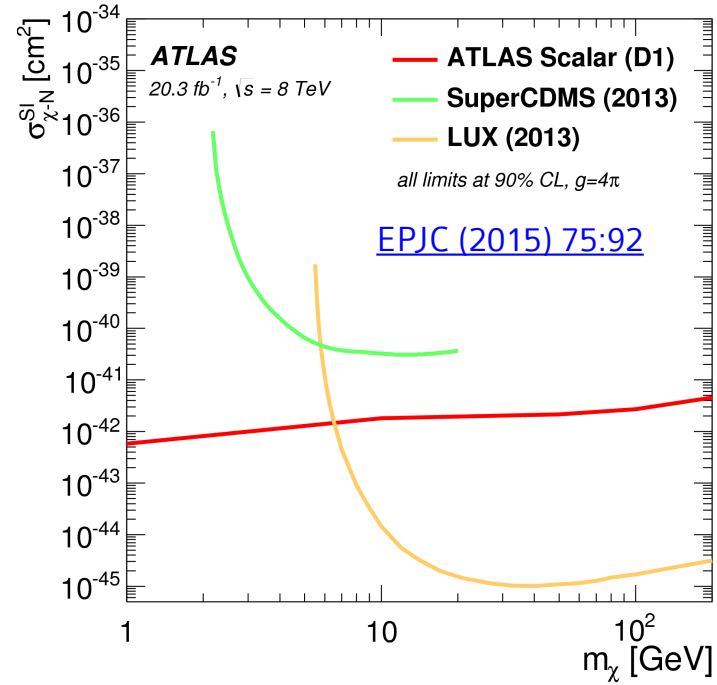
DM with heavy flavors:
favoured for some EFT operators

$$\mathcal{O} = \sum_q \frac{m_q}{M_*^3} \bar{q} q \bar{\chi} \chi,$$



Different signal regions,
backgrounds normalized from control regions



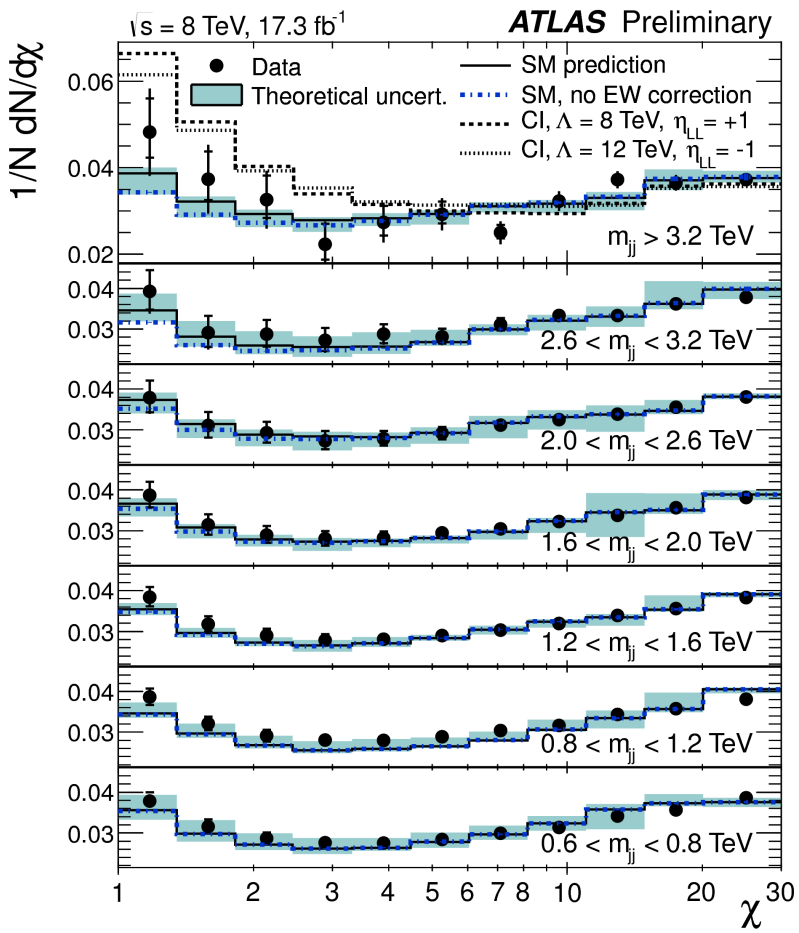


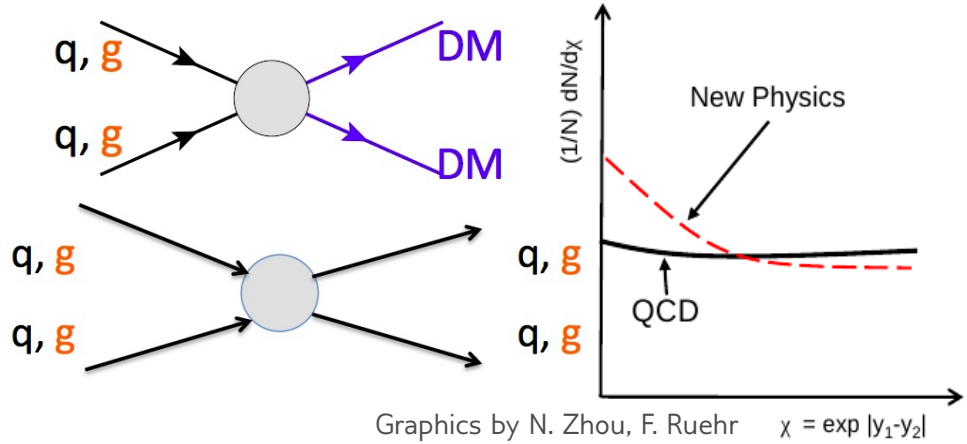
ATLAS: ttbar->all-hadronic: EPJC (2015) 75:92
single lepton stop search: JHEP 11 (2014) 118

CMS: ttbar->semileptonic: CMS-PAS-B2G-14-004
ttbar->dilepton: CMS-PAS-B2G-13-004

BEYOND MET+X: EFT CONSTRAINTS FROM DIJETS

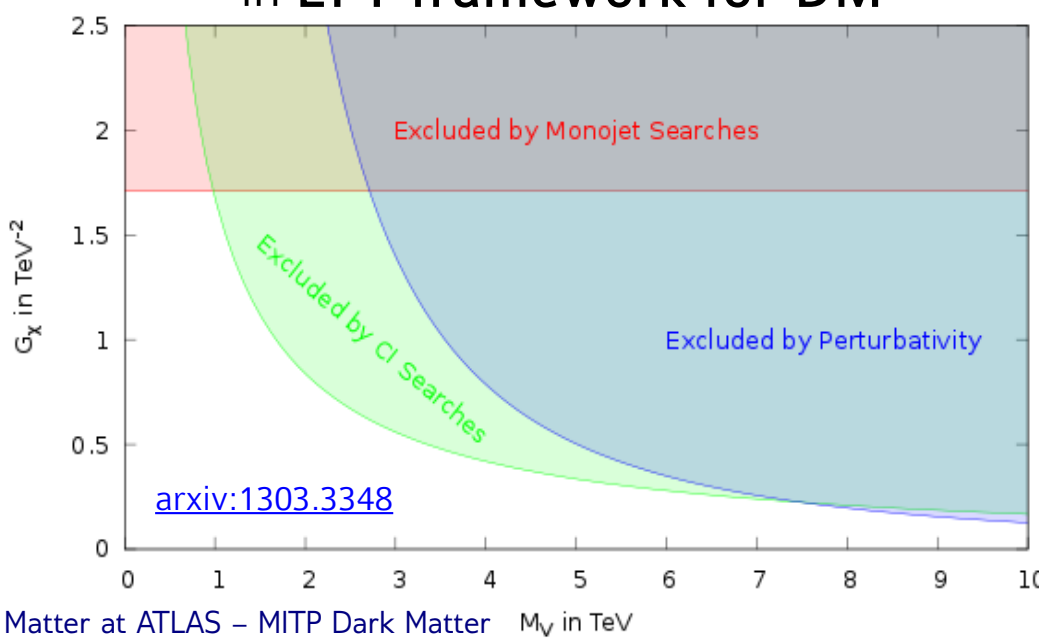
Dijet angular distributions
probe contact interactions





Graphics by N. Zhou, F. Ruehr

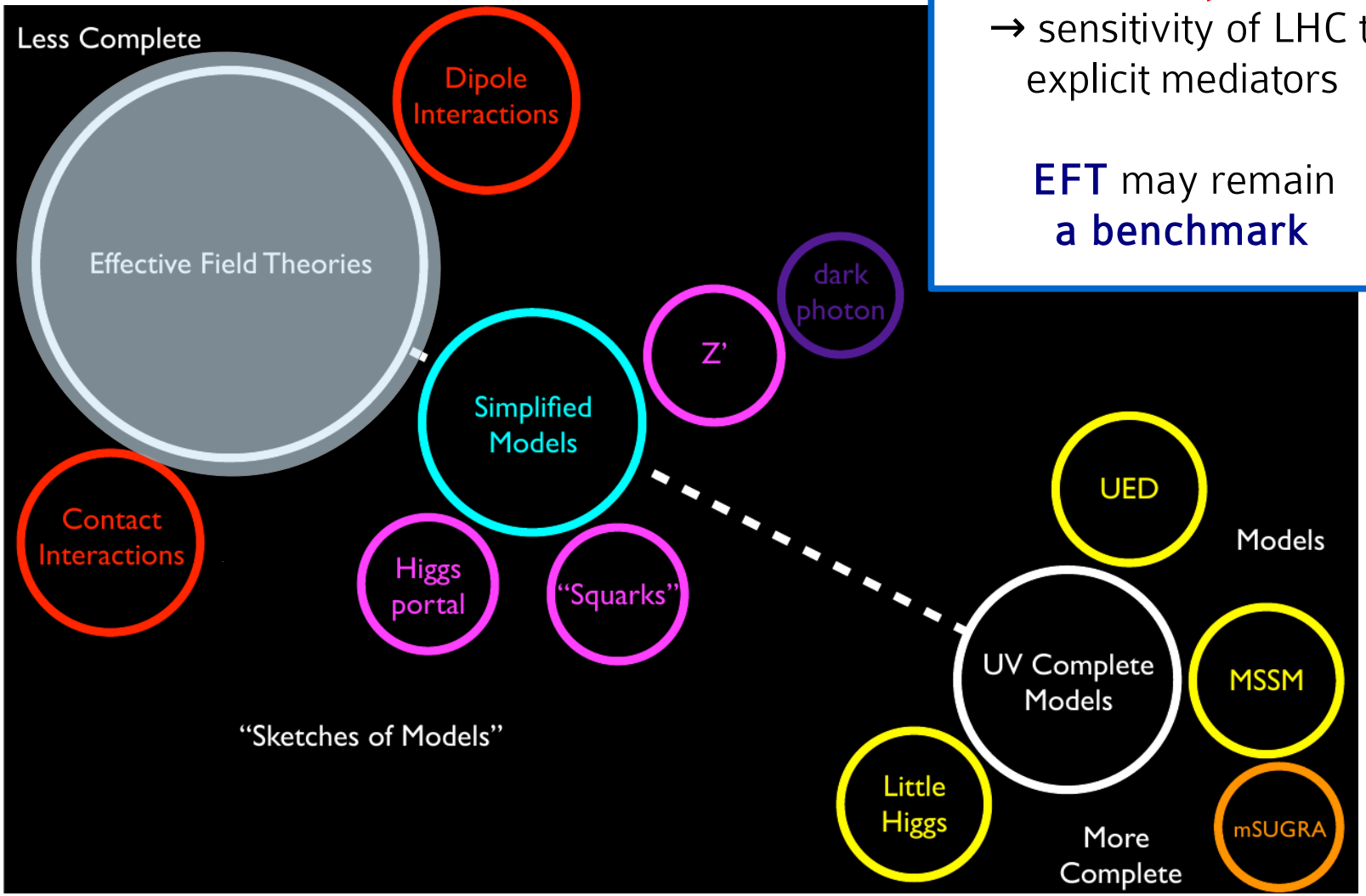
→ can **reinterpret** constraints in **EFT framework for DM**



arxiv:1303.3348

RUN-1/RUN-2: MOVING TO SIMPLIFIED MODELS

Tim Tait, DM@LHC 2013

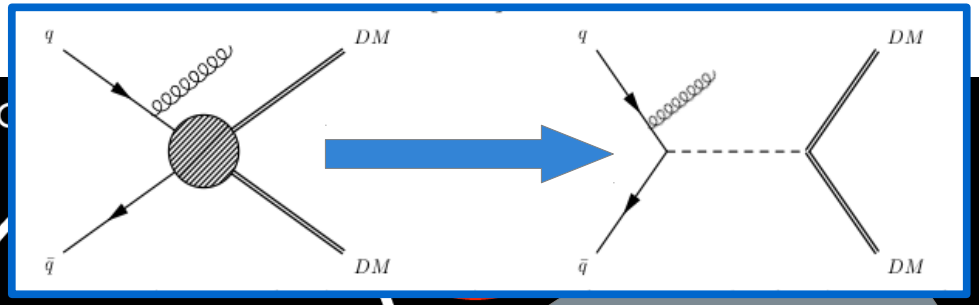


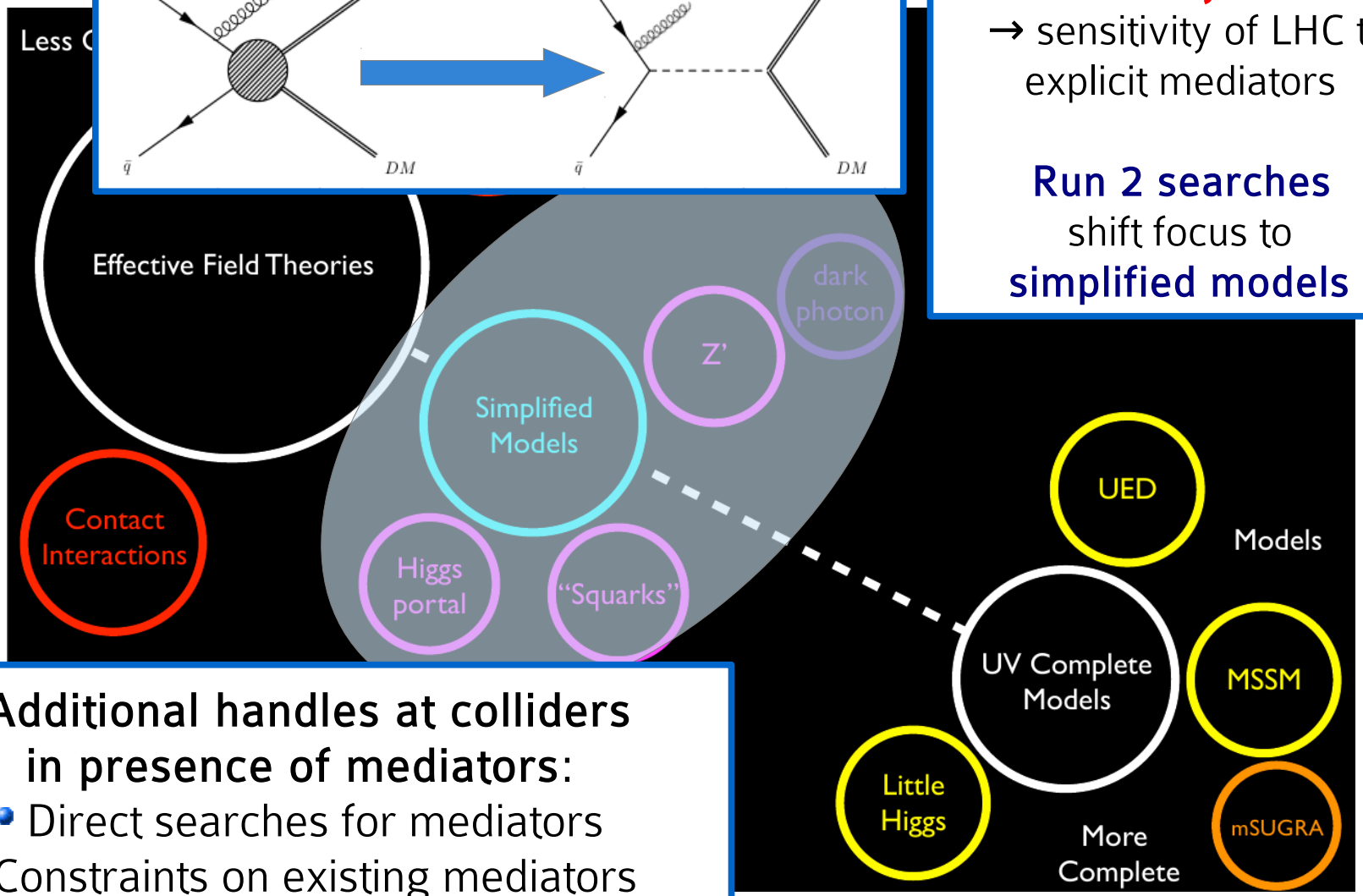
EFT validity issues:
→ sensitivity of LHC to explicit mediators

EFT may remain **a benchmark**

RUN-1/RUN-2: MOVING TO SIMPLIFIED MODELS

CMS: arXiv:1408.3583





EFT validity issues:
→ sensitivity of LHC to explicit mediators

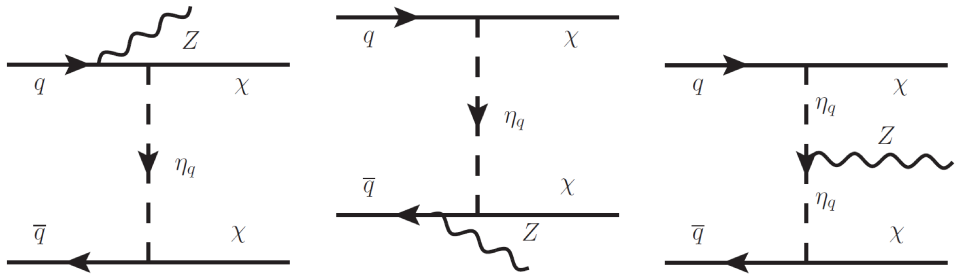
Run 2 searches shift focus to **simplified models**

Additional handles at colliders in presence of mediators:

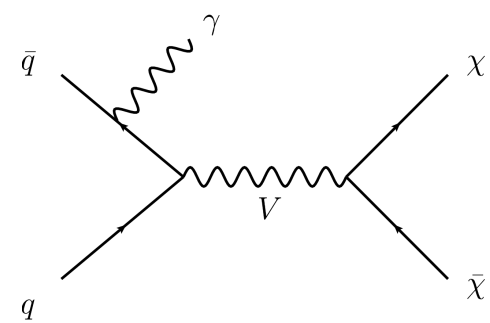
- Direct searches for mediators
- Constraints on existing mediators
  - Additional search signatures

SELECTED SIMPLIFIED MODEL RESULTS: 8 TEV MET+X

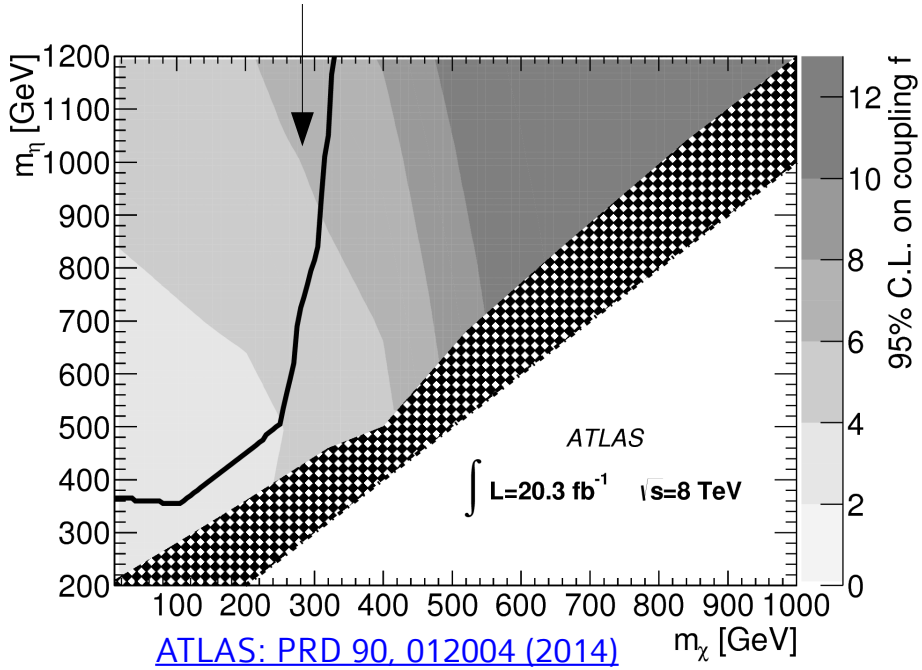
Z → ll + MET



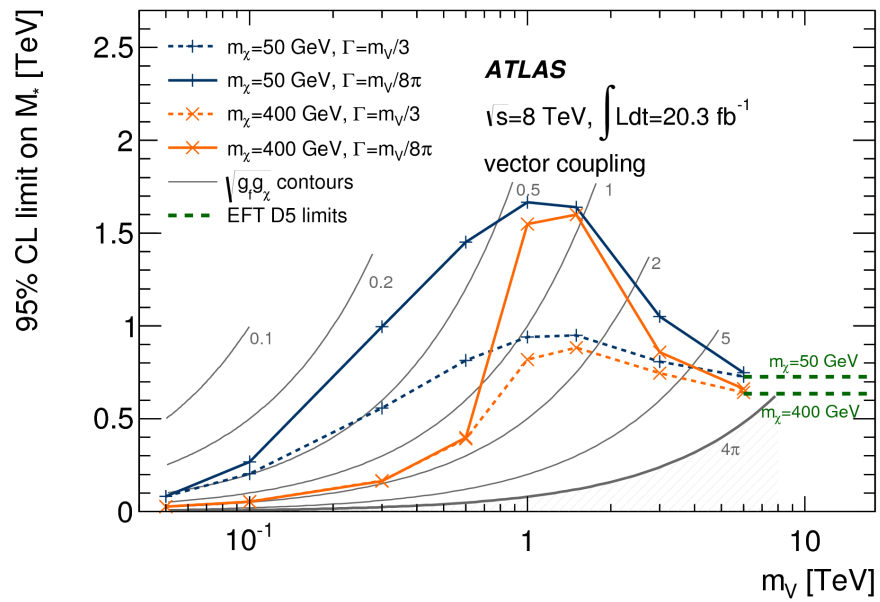
Photon + MET



Region excluded wrt thermal relic



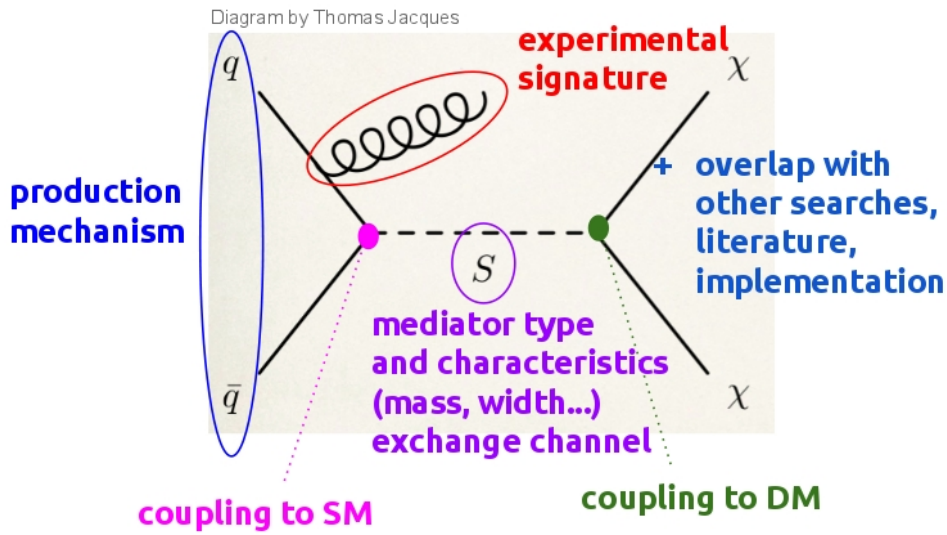
ATLAS: PRD 90, 012004 (2014)



ATLAS/CMS Dark Matter Forum:

experiment/theory discussion towards Run-2 DM searches

Many possibilities to be used as building blocks:



https://twiki.cern.ch/twiki/bin/view/LHCDMF/WebHome
Mailing list: lhc-dmf@cern.ch

This Forum will agree upon:

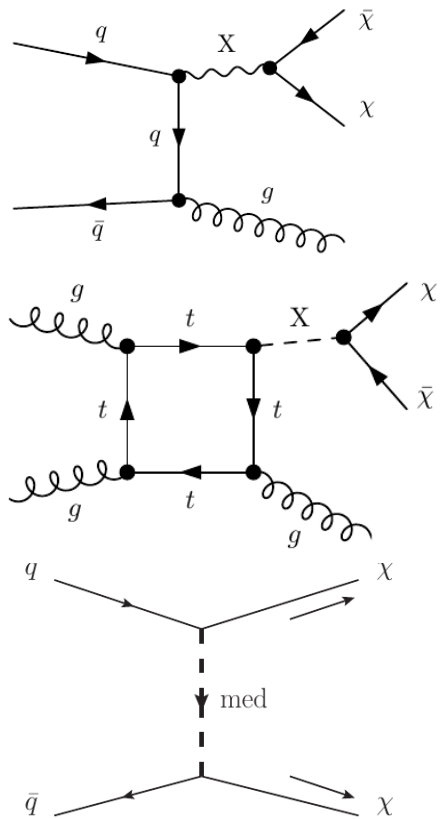
- Prioritized **set of simplified models**
- Common **model implementation and details** (e.g. matching, scales) towards MC generation of benchmarks
- **EFT validity** assessment procedure

This Forum will document:

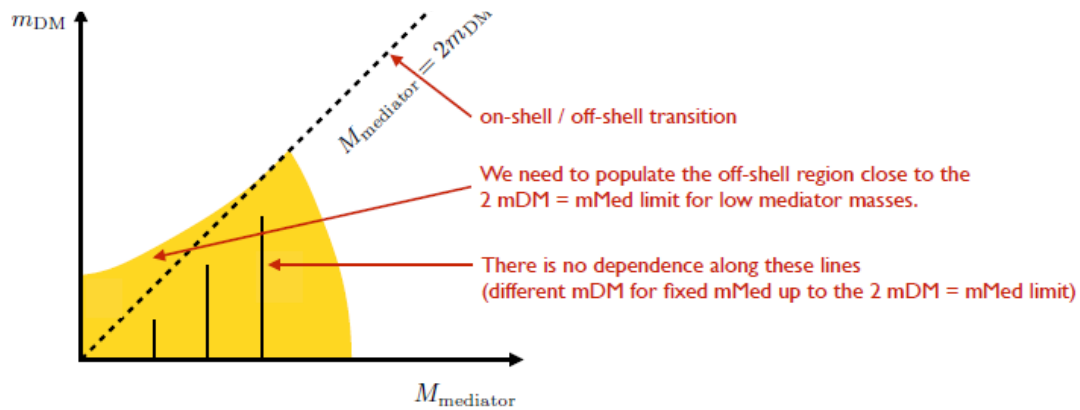
models and choices (arXiv write-up + SVN repository)

Run-2 benchmark choices being finalized – examples:

Prioritized list of models for jet+MET search



Idea:
Only simulate models/points
with distinct kinematics
leave rescaling/reinterpretation to theorists



Plan for monojet parameter scan (D. Salek's talk at DM Forum 12/03/2015)

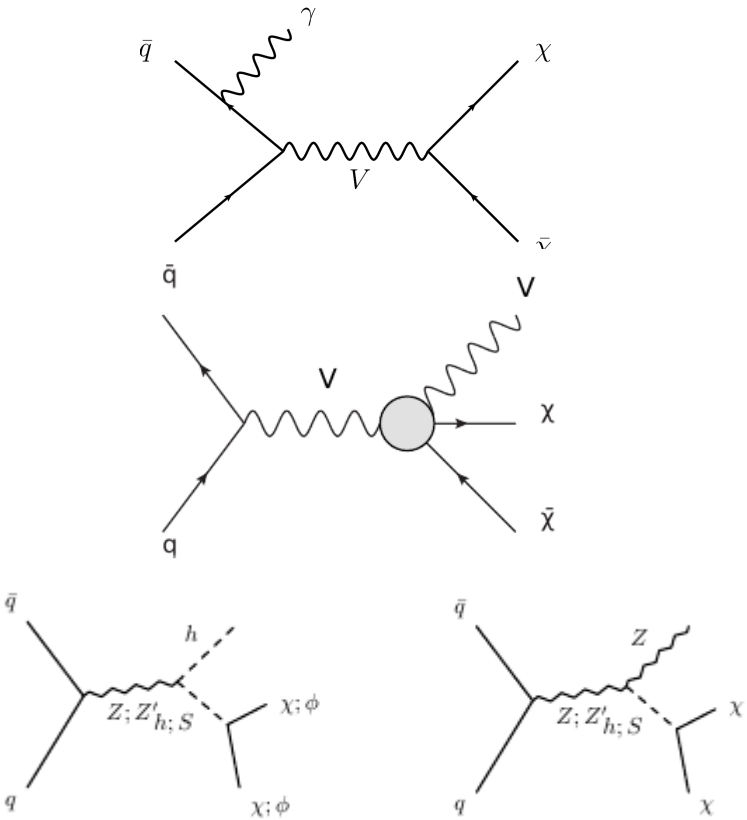
Study of choice of benchmark points for vector operator

http://arxiv.org/abs/1411.0535
http://arxiv.org/abs/1409.2893

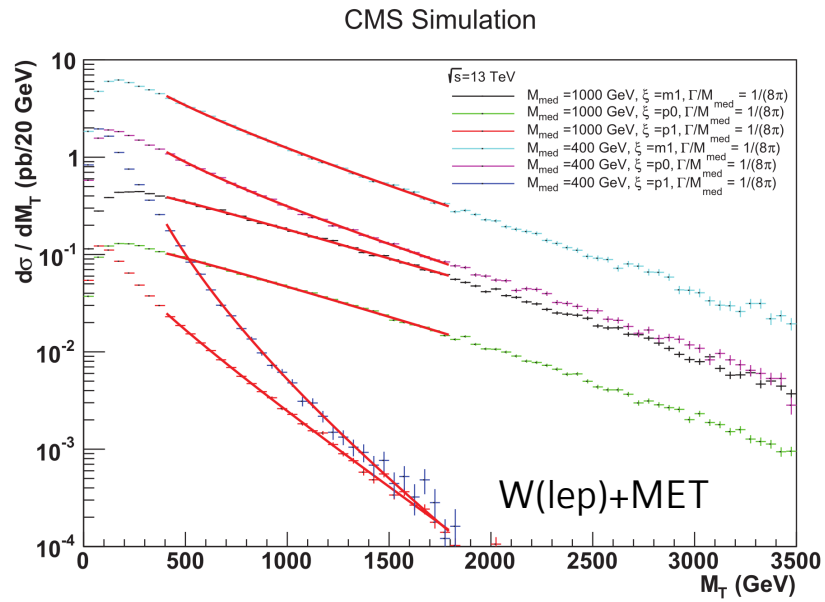
SELECTED SIMPLIFIED MODEL RESULTS: ATLAS/CMS DM FORUM

Run-2 benchmark choices being finalized – examples:

Prioritized list of models for W/Z/γ+MET searches



see this talk for literature

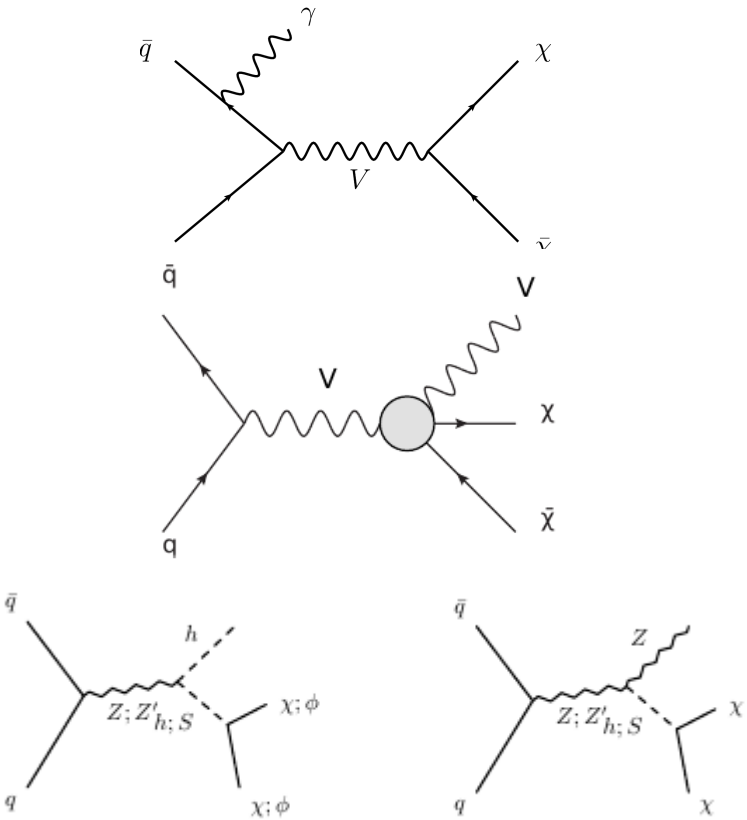


Generator-level plot from K. Hepfner's talk at DM Forum 16/02/15

Study of choice of benchmark points for searches with W/Z/gamma

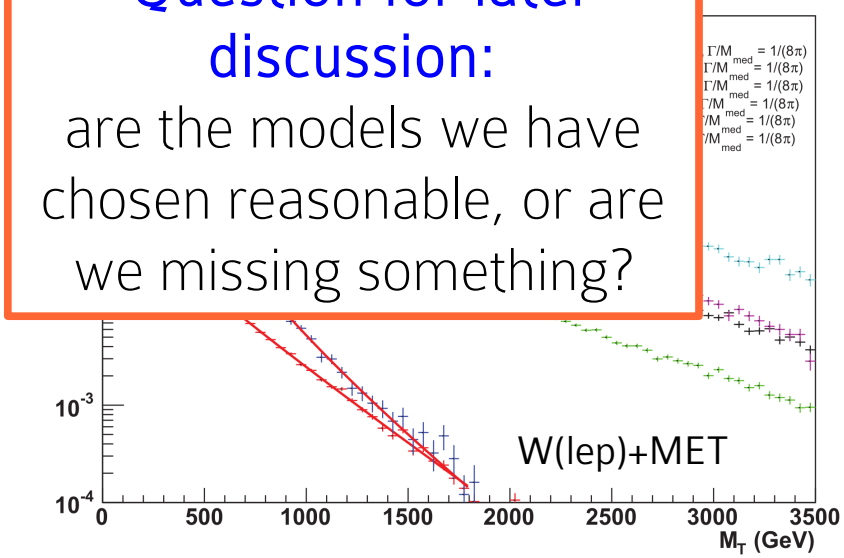
Run-2 benchmark choices being finalized – examples:

Prioritized list of models for W/Z/γ+MET searches



see this talk for literature

Question for later discussion:
are the models we have chosen reasonable, or are we missing something?



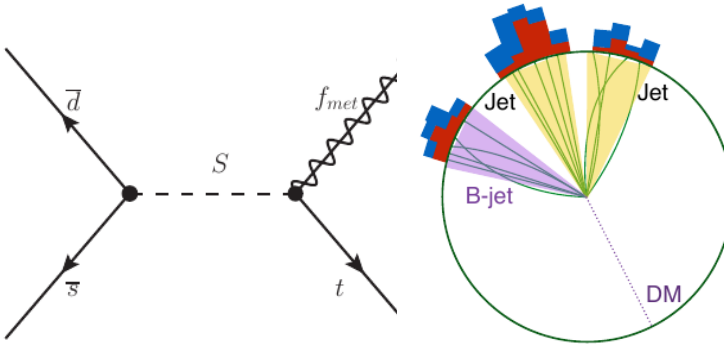
Generator-level plot from K. Hepfner's talk at DM Forum 16/02/15

Study of choice of benchmark points for searches with W/Z/gamma

SPECIFIC SIMPLIFIED MODELS: SINGLE-TOP DARK MATTER

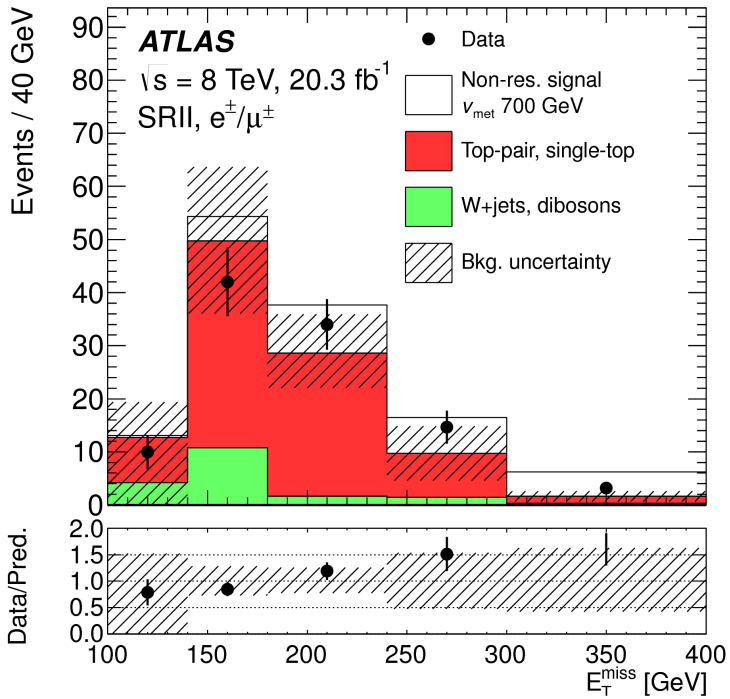
Many BSM models predict single top+MET
→ group main characteristics
in simplified models (resonant/non resonant)

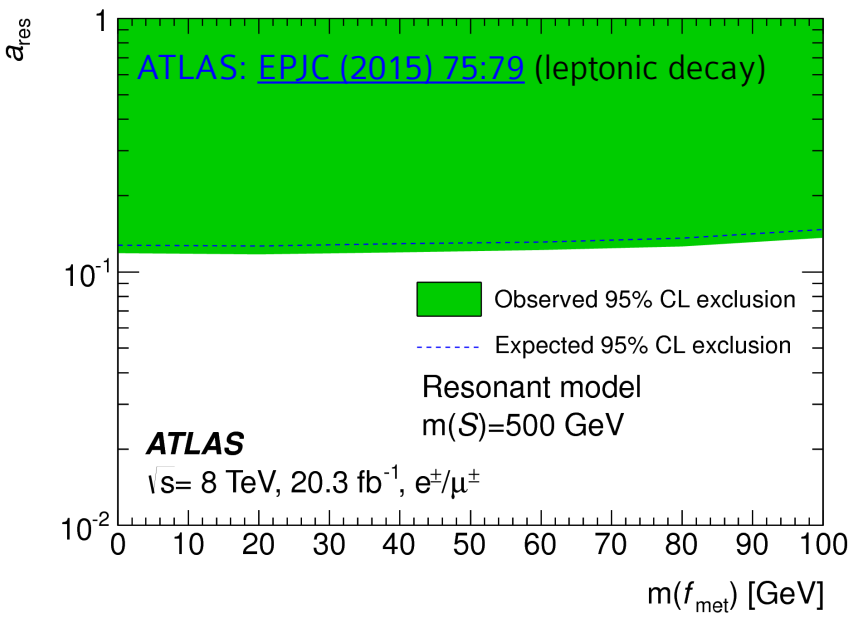
Example: resonant model, all-had



Graphics by D. Berry

Background estimation (main: ttbar,t,V+jets):
use transfer factors from data control regions

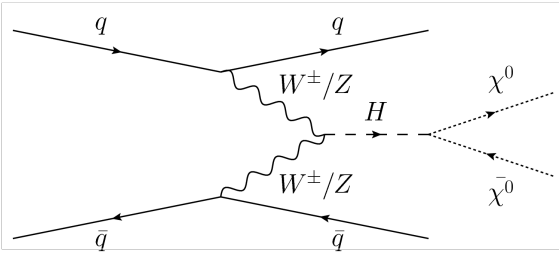


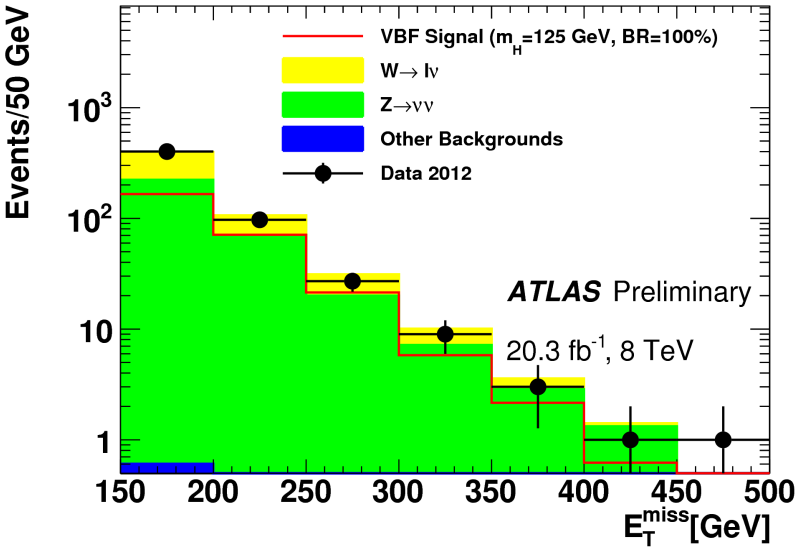


HIGGS-MEDIATED DARK MATTER: RESULTS AND PROSPECTS

Higgs boson could **mediate DM/SM interactions**
→ search for enhancements of **invisible decays / coupling modifications**

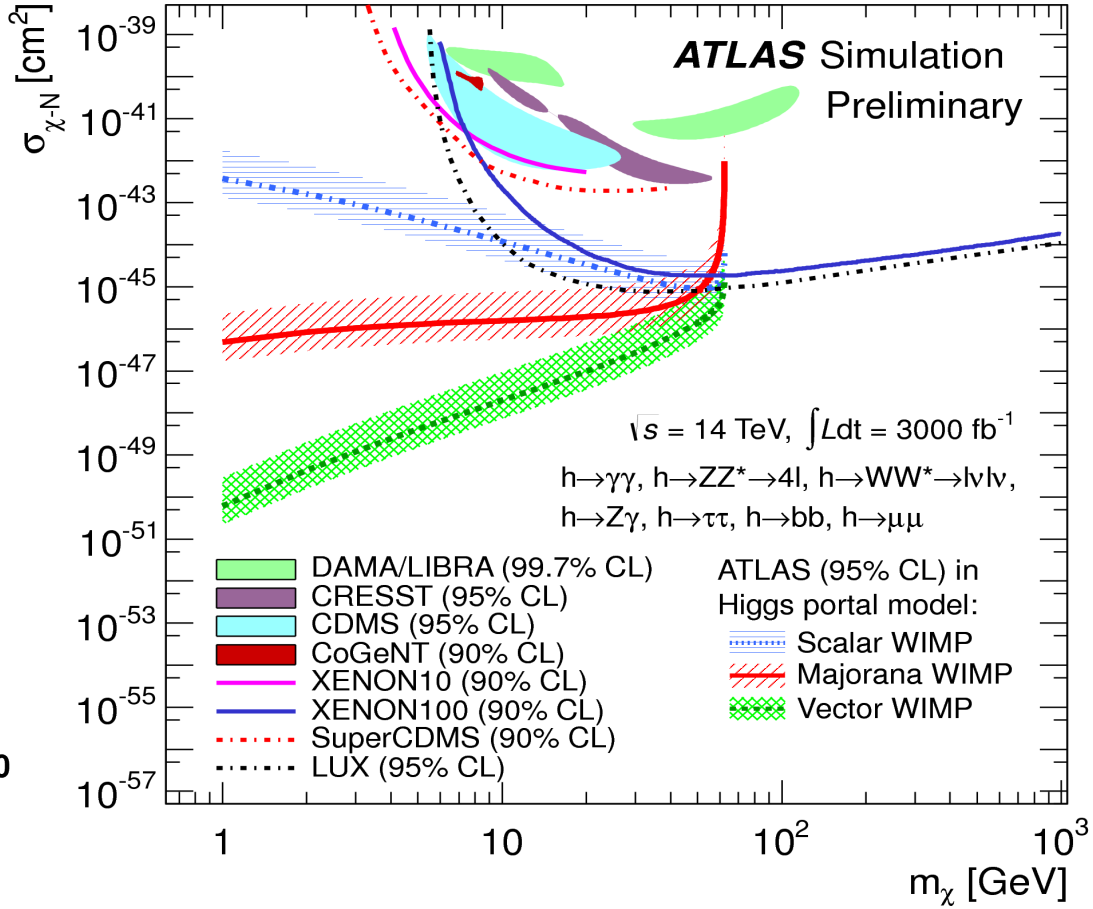
ATLAS-CONF-2015-004



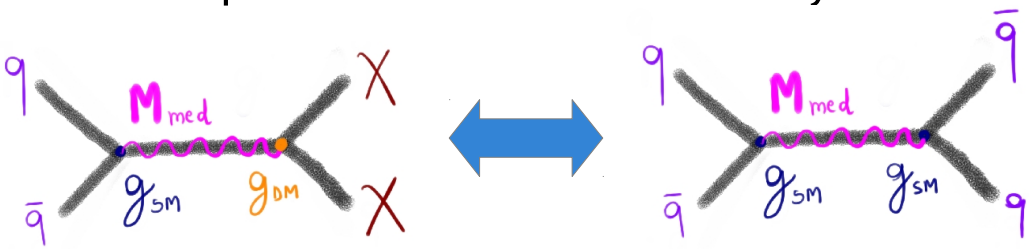


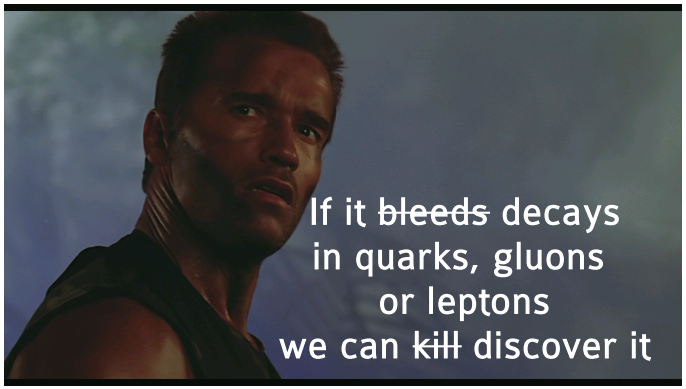
Limit on H → invisible BR: 0.29(0.35)

ATL-PHYS-PUB-2014-017

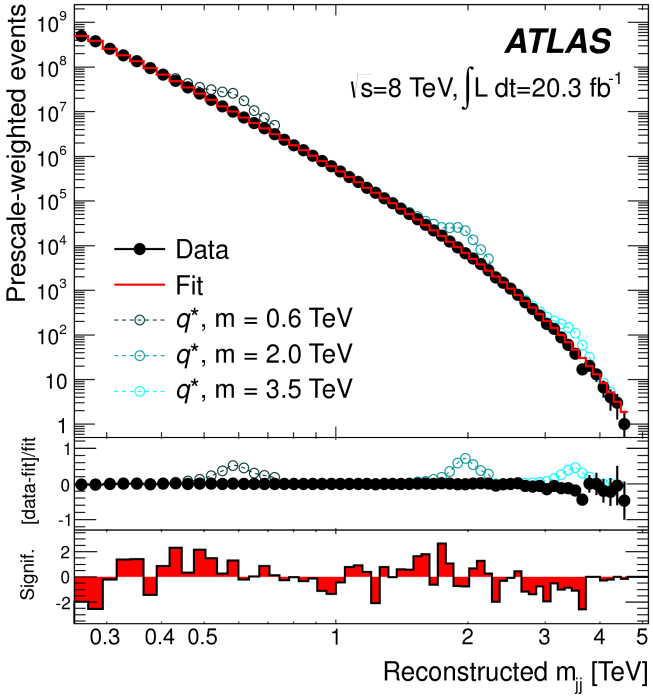


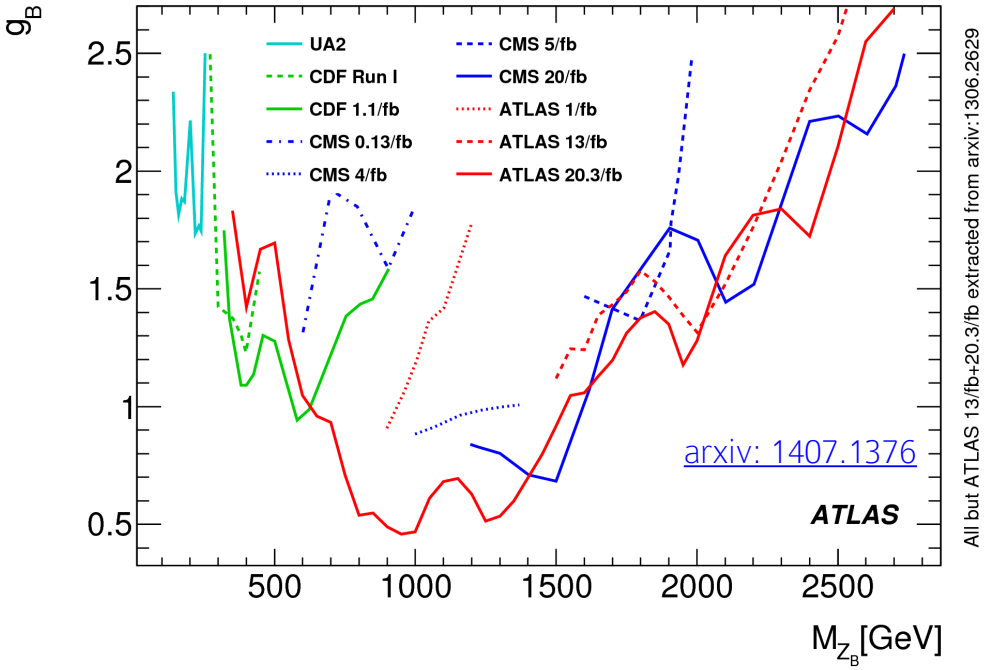
Dijet and dilepton searches
probe mediators directly





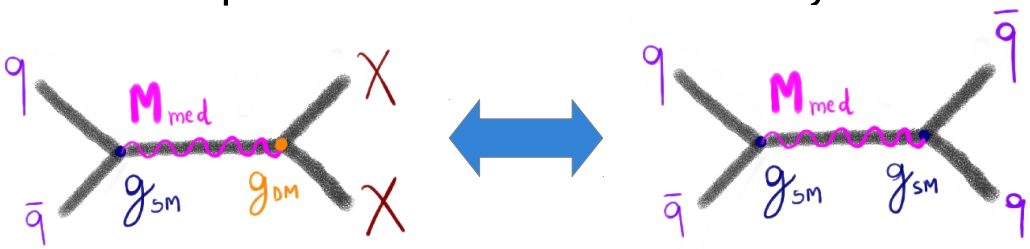
arxiv: 1407.1376

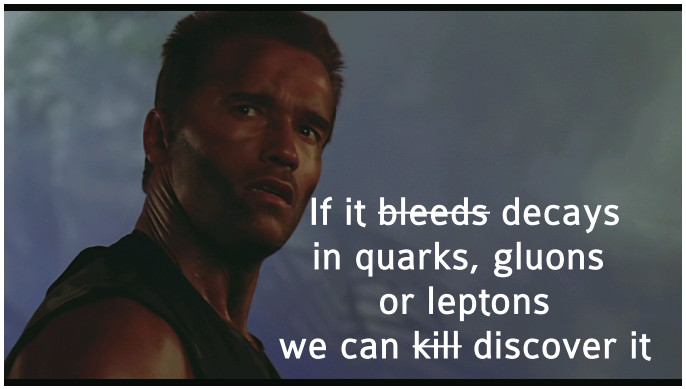




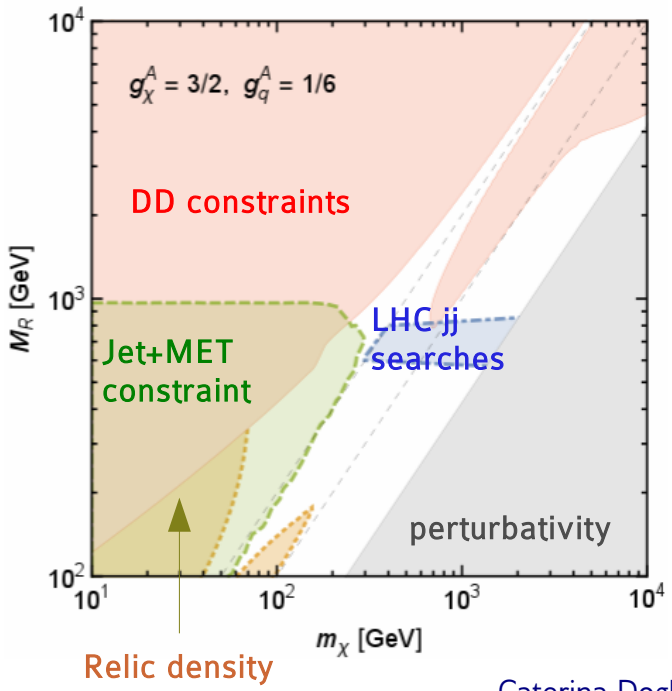
BEYOND MET+X: MEDIATOR CONSTRAINTS FROM DI-X SEARCHES

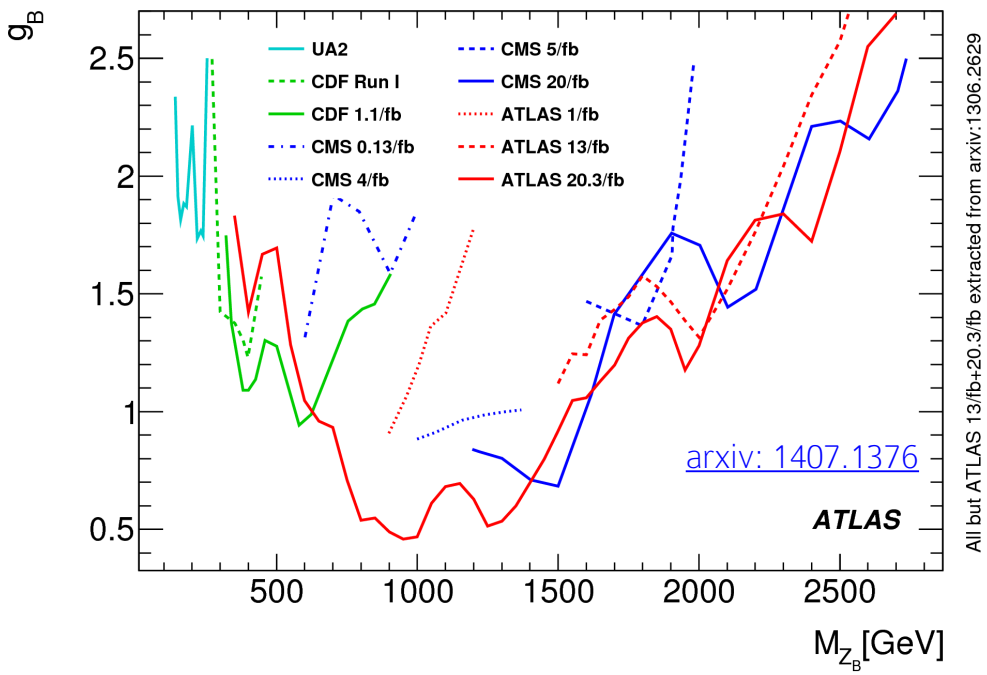
Dijet and dilepton searches
probe mediators directly





arXiv:1503.05916 arXiv:/1501.03490

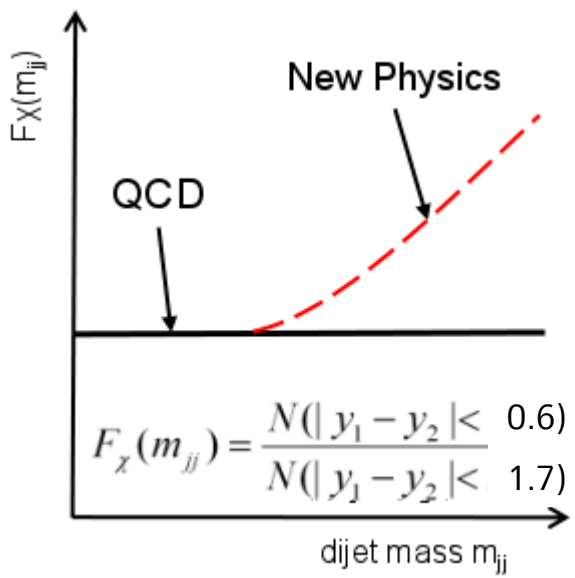




WIDE MEDIATORS

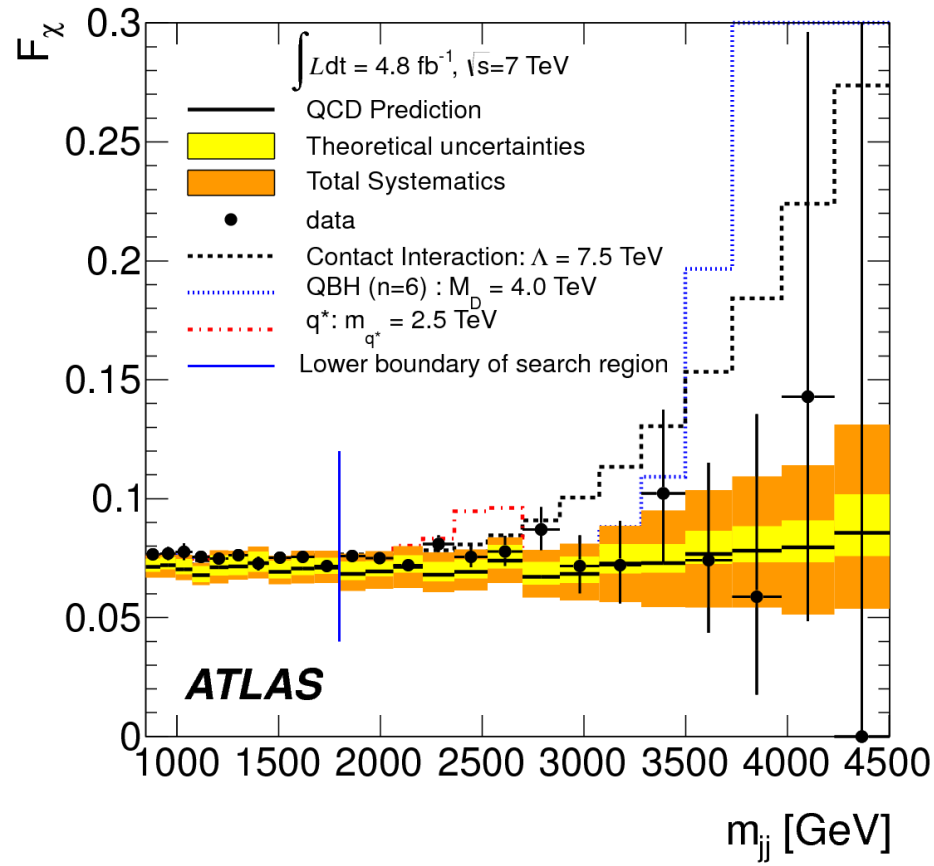
Problem: dijet search background estimation fitted to data may not be sensitive to wide resonances

➞ **Dijet angular searches** are good tools to look for **wide** s-channel mediators



Graphics by F. Ruehr

arXiv:1210.1718



RUN-1 CONCLUSIONS

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2015

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	20.3	M_D		
	ADD non-resonant $\ell\ell$	$2e, \mu$	–	–	20.3	M_S		
	ADD QBH $\to \ell q$	$1\, e, \mu$	1 j	–	20.3	M_{th}		
	ADD QBH	–	2 j	–	20.3	M_{th}		
	ADD BH high N_{trk}	$2\, \mu$ (SS)	–	–	20.3	M_{th}		
	ADD BH high $\sum p_T$	$\geq 1\, e, \mu$	≥ 2 j	–	20.3	M_{th}		
	ADD BH high multijet	–	≥ 2 j	–	20.3	M_{th}		
	RS1 $G_{KK} \to \ell\ell$	$2\, e, \mu$	–	–	20.3	G_{KK} mass		
	RS1 $G_{KK} \to \gamma\gamma$	$2\, \gamma$	–	–	20.3	G_{KK} mass		
	Bulk RS $G_{KK} \to ZZ \to qq\ell\ell$	$2\, e, \mu$	2 j / 1 J	–	20.3	G_{KK} mass 740 GeV		
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\, e, \mu$	2 j / 1 J	Yes	20.3	W' mass 700 GeV		
	Bulk RS $G_{KK} \to HH \to b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV		
	Bulk RS $g_{KK} \to t\bar{t}$	$1\, e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.		
	2UED / RPP	$2\, e, \mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	KK mass 960 GeV		
Gauge bosons	SSM $Z' \to \ell\ell$	$2\, e, \mu$	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z' \to \tau\tau$	$2\, \tau$	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	SSM $W' \to \ell\nu$	$1\, e, \mu$	–	Yes	20.3	W' mass 3.24 TeV		1407.7494
	EGM $W' \to WZ \to \ell\nu\, \ell'\ell'$	$3\, e, \mu$	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W' \to WZ \to qq\ell\ell$	$2\, e, \mu$	2 j / 1 J	–	20.3	W' mass 1.59 TeV		1409.6190
	HVT $W' \to WH \to \ell\nu bb$	$1\, e, \mu$	2 b	Yes	20.3	W' mass 1.47 TeV	$g_V = 1$	Preliminary
	LRSM $W'_R \to t\bar{b}$	$1\, e, \mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to t\bar{b}$	$0\, e, \mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	17.3	Λ 12.0 TeV	$\eta_{LL} = -1$	Preliminary
	CI $qq\ell\ell$	$2\, e, \mu$	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	1407.2410
	CI $uutt$	$2\, e, \mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.35 TeV	$\lvert C_{LL} \rvert = 1$	Preliminary
DM	EFT D5 operator (Dirac)	$0\, e, \mu$	≥ 1 j	Yes	20.3	M_* 974 GeV	at 90% CL for $m(\chi) < 100$ GeV	1502.01518
	EFT D9 operator (Dirac)	$0\, e, \mu$	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	$2\, e$	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	$2\, \mu$	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	$1\, e, \mu, 1\, \tau$	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	VLQ $TT \to Ht + X, Wb + X$	$1\, e, \mu$	≥ 1 b, ≥ 3 j	Yes	20.3	T mass 785 GeV		
	VLQ $TT \to Zt + X$	$2/\geq 3\, e, \mu$	$\geq 2/\geq 1$ b	–	20.3	T mass 735 GeV		
	VLQ $BB \to Zb + X$	$2/\geq 3\, e, \mu$	$\geq 2/\geq 1$ b	–	20.3	B mass 755 GeV		
	VLQ $BB \to Wt + X$	$1\, e, \mu$	≥ 1 b, ≥ 5 j	Yes	20.3	B mass 640 GeV		
	$T_{5/3} \to Wt$	$1\, e, \mu$	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		
Excited fermions	Excited quark $q^* \to q\gamma$	$1\, \gamma$	1 j	–	20.3	q^* mass 3.5 TeV		
	Excited quark $q^* \to qg$	–	2 j	–	20.3	q^* mass 4.09 TeV		
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV		
	Excited lepton $\ell^* \to \ell\gamma$	$2\, e, \mu, 1\, \gamma$	–	–	13.0	ℓ^* mass 2.2 TeV		
	Excited lepton $\nu^* \to \ell W, \nu Z$	$3\, e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV		
Other	LSTC $a_T \to W\gamma$	$1\, e, \mu, 1\, \gamma$	–	Yes	20.3	a_T mass 960 GeV		
	LRSM Majorana ν	$2\, e, \mu$	2 j	–	2.1	N^0 mass 1.5 TeV		
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	$2\, e, \mu$ (SS)	–	–	20.3	$H^{\pm\pm}$ mass 551 GeV		
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\, e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV		
	Monotop (non-res prod)	$1\, e, \mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV		
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV		
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV		

$\sqrt{s} = 7$ TeV $\sqrt{s} = 8$ TeV

10^{-1} 1

*Only a selection of the available mass limits on new states or phenomena is shown.

Question for later discussion:

Is what we provide to theorists sufficient for reinterpretation?

~~CONCLUSIONS~~ WAITING FOR RUN-2 TO KEEP SEARCHING FOR DM

Higgs boson discovered, **Dark Matter** still at large
→ looking for DM particle candidates at the LHC

Preparing the ground for Run-2 searches:
LHC results **complementary** to other **DM experiments**

The LHC will be back

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the DM particles unlike the case with the Higgs and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do ~~not~~ want to encourage big experimental searches for DM particles, but we do feel that people performing experiments vulnerable to DM particles should know how they may turn up.

BACKUP SLIDES

EFT OPERATORS FOR MET+X SEARCHES

Name	Initial state	Type	Operator
C1	qq	scalar	$\frac{m_q}{M_\star^2}\chi^\dagger\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_\star^2}\chi^\dagger\chi\alpha_s(G^a_{\mu\nu})^2$
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

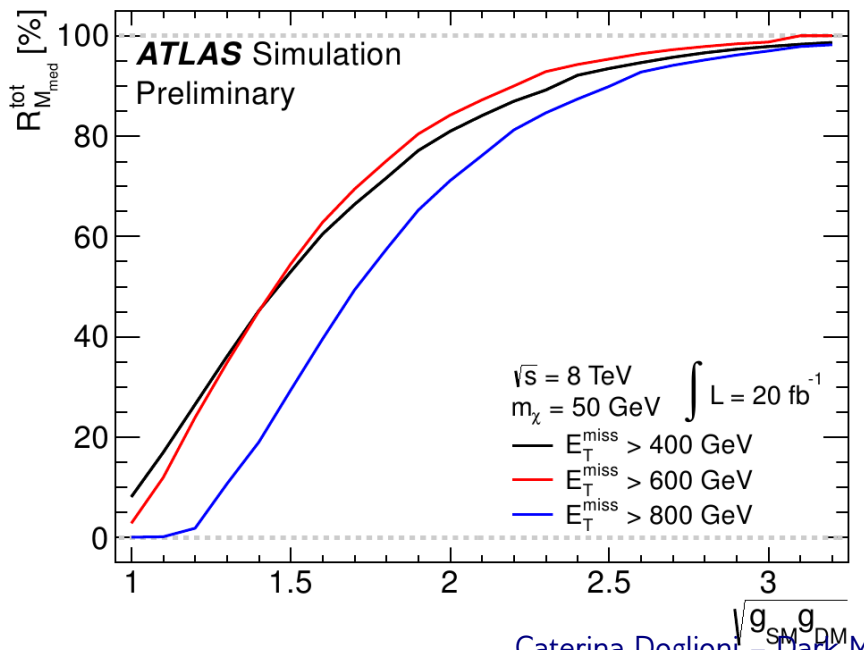
MONO-JET PROSPECTS AND EFT VALIDITY ATL-PHYS-PUB-2014-007

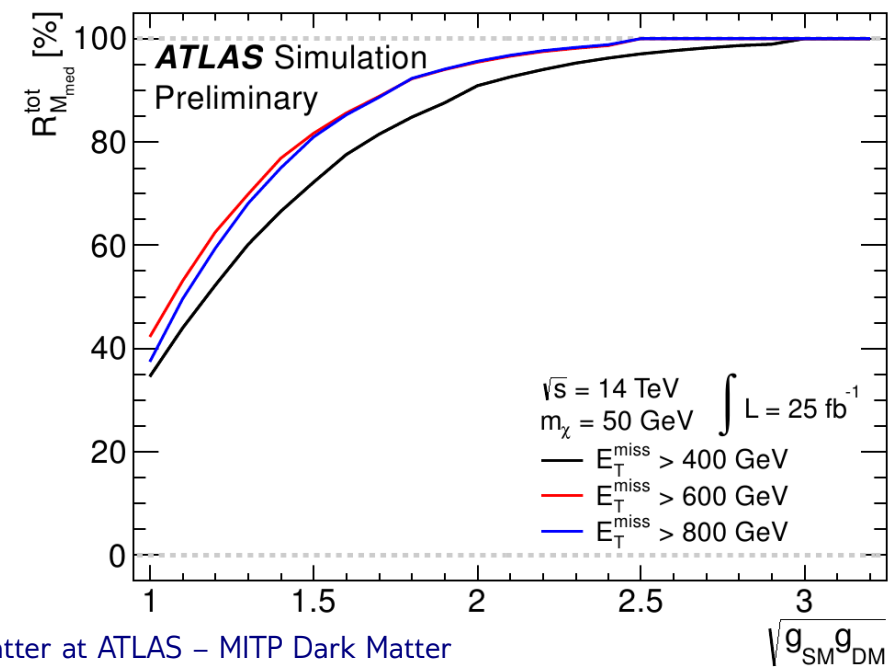
Early DM searches: what do we gain/lose from CoM increase?

- Current monojet analysis: systematically limited at low MET, statistically limited at high MET → How high can we reach in $M*$ at 14 TeV?
- Will we have problems with the EFT validity at a higher CoM energy?

Somehow counterintuitive results! **Competing effects**: $Q_{\rm tr} < \sqrt{g_{\rm SM} g_{\rm DM}} M^*$

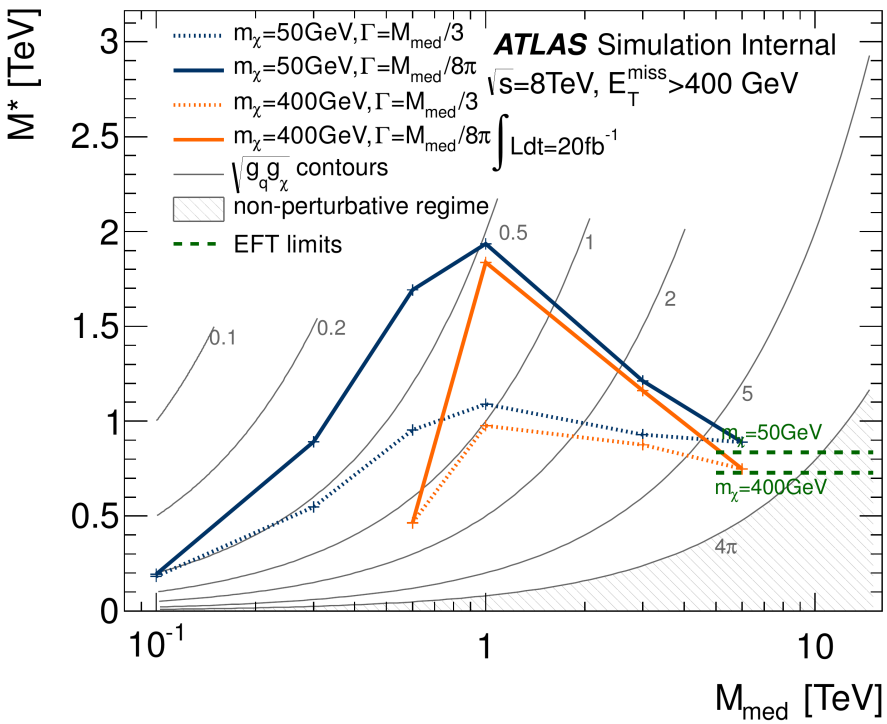
- Higher MET → higher Q_{tr} (weak correlation: MET smeared by detector)
- Increase of reach in M* → higher limits to start with → increased validity

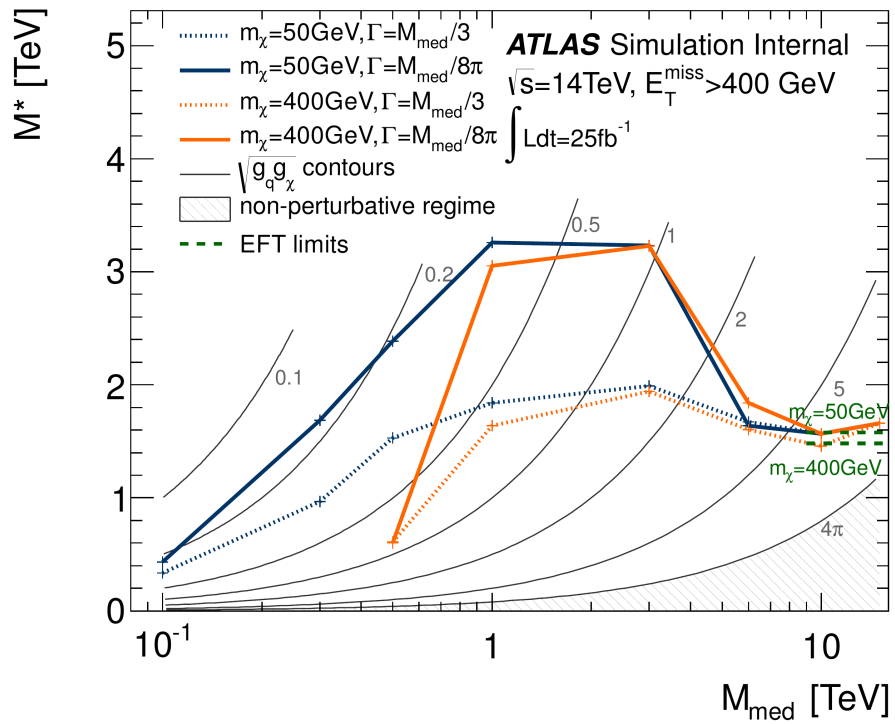




MONO-JET SIMPLIFIED MODEL PROSPECTS

ATL-PHYS-PUB-2014-007
arXiv: 1502.01518

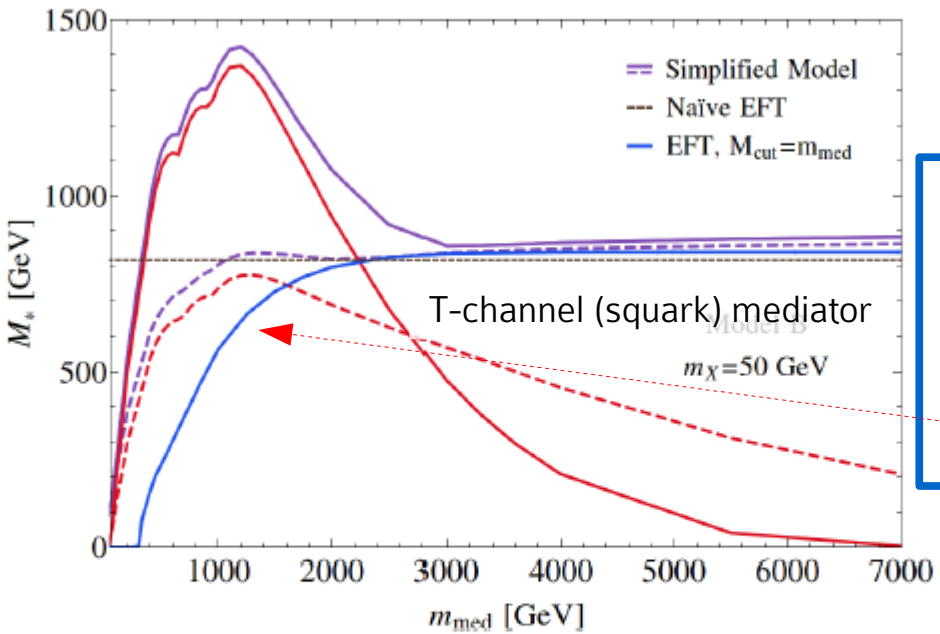




MORE ON EFT VALIDITY TRUNCATION PROPOSAL

arXiv:1502.01518

Comparison with the simplified model



Direct comparison with simplified model: shows very (too?) conservative region after truncation

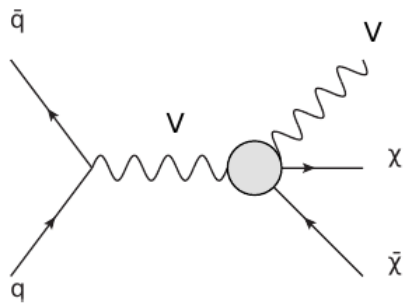
- **Blue line**: from model-independent limit, with the identification

$$M_* = \frac{2\widetilde{m}}{g_{\rm DM}}\,, \qquad M_{\rm cut} = \widetilde{m}\,.$$

- **Red lines**: only from the resonant production of the mediator.

The EFT limit is complemented by the limit from the resonant production.

MODELS WITH DIRECT BOSON-DM COUPLING FOR DIRAC DM



Dimension-7 operators
related by gauge invariance
→ choose benchmark points for k1/k2
that are easy to reinterpret

1. Dimension-5 model

$$\frac{m_W^2}{\Lambda_5^3}\,\bar{\chi}\chi\,W^{+\mu}W_\mu^- + \frac{m_Z^2}{2\Lambda_5^3}\,\bar{\chi}\chi\,Z^\mu Z_\mu$$

Possible choice of initial benchmark

2. Dimension-7 models

$$\mathcal{L} = \frac{1}{\Lambda_{C1,2}^3}\,\bar{\chi}\chi\,\sum_i k_i F_i^{\mu\nu}F_{\mu\nu}^i + \frac{1}{\Lambda_{C3,4}^3}\,\bar{\chi}\chi\,\sum_i k_i F_i^{\mu\nu}F_{\mu\nu}^{\tilde{i}}$$

Possible choice of initial benchmark

scalar

$$\mathcal{L} = \frac{1}{\Lambda_{C5,6}^3}\,\bar{\chi}\gamma^5\chi\,\sum_i k_i F_i^{\mu\nu}F_{\mu\nu}^i + \frac{1}{\Lambda_{C7,8}^3}\,\bar{\chi}\gamma^5\chi\,\sum_i k_i F_i^{\mu\nu}F_{\mu\nu}^{\tilde{i}},$$

pseudoscalar,
(can be reweighted
from scalar)

$$g_{gg} = \frac{k_3}{\Lambda_7^3}$$

$$g_{WW} = \frac{2k_2}{s_w^2\Lambda_7^3}$$

$$g_{ZZ} = \frac{1}{4s_w^2\Lambda_7^3}\left(\frac{k_1 s_w^2}{c_w^2} + \frac{k_2 c_w^2}{s_w^2}\right)$$

$$g_{\gamma\gamma} = \frac{1}{4c_w^2}\frac{k_1+k_2}{\Lambda_7^3}$$

$$g_{Z\gamma} = \frac{1}{2s_w c_w\Lambda_7^3}\left(\frac{k_2}{s_w^2} - \frac{k_1}{c_w^2}\right)$$

Monophoton/monoZ: no different in kinematics from choice of k1, k2 → choose favourable x-sec point

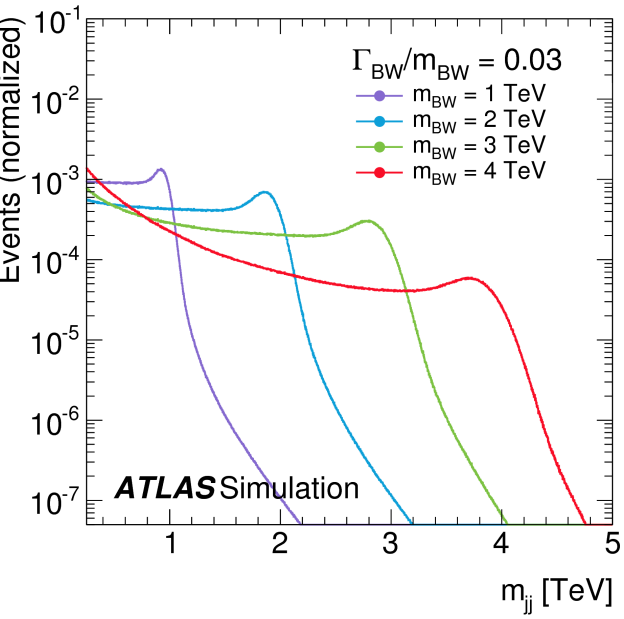
UV-completion is **possible**, but not covered in Forum
Validity criteria under discussion – input?

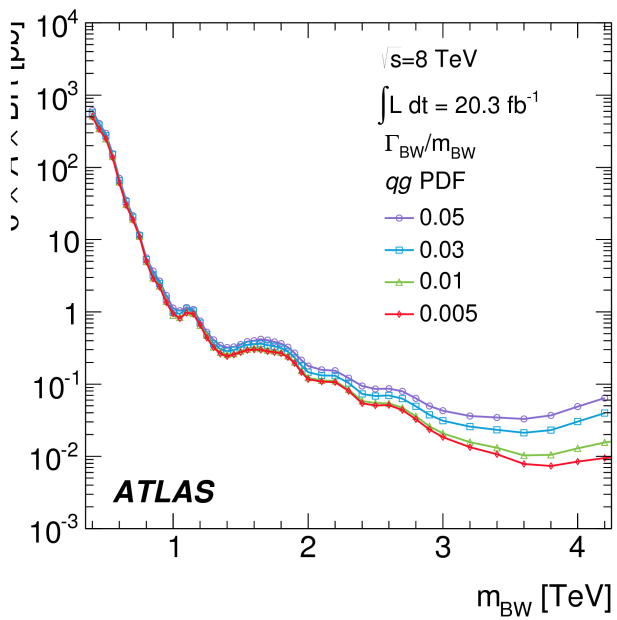
DIJET GENERIC RESONANCE LIMITS

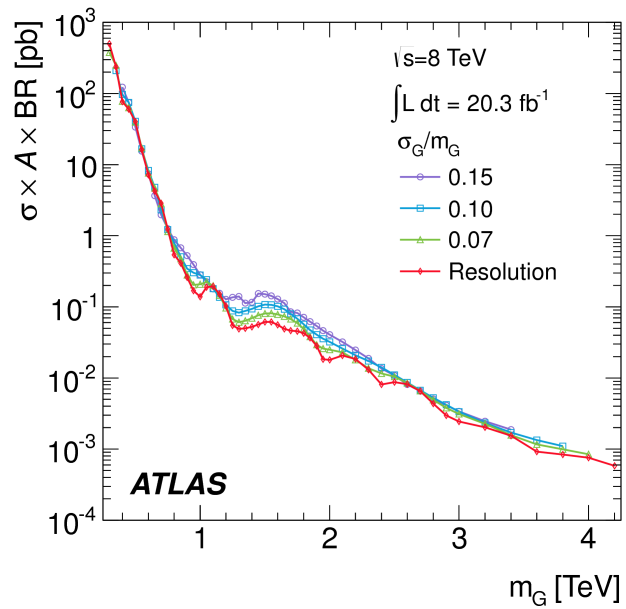
arxiv: 1407.1376

Breit-Wigner (+) PDF effects (+) parton shower (+) detector resolution

Gaussian template







No discoveries yet ➞ **limits** on many new resonant physics models

Reinterpretable results on **generic resonances**