Dark Matter @ ATLAS

experimental challenges and 13 TeV results

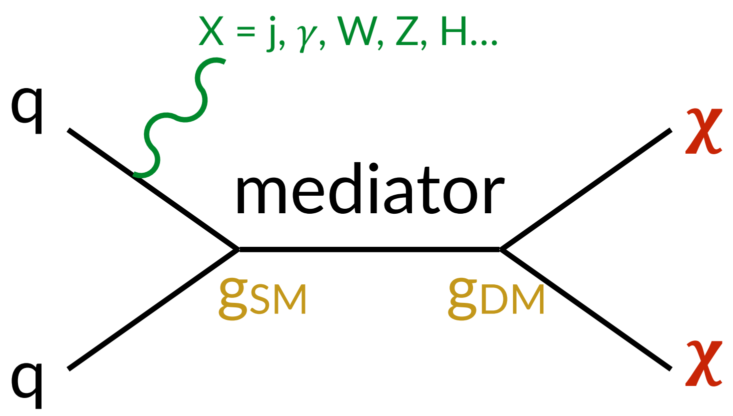
Valerio Ippolito

Harvard University

on behalf of the ATLAS collaboration

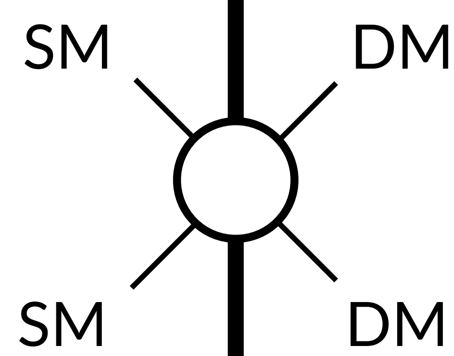
Two Experimental Strategies

MET + X

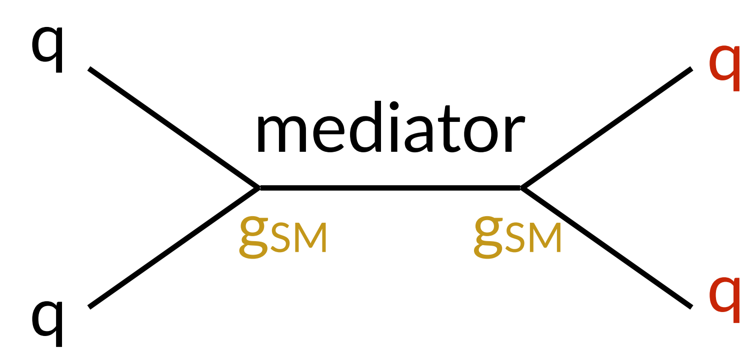


e.g. mono-X simplified models (1507.00966), SUSY

- 👍 look directly for DM
- 👀 constrain elusive bkg from known processes at the TeV scale (e.g. Zνν+jets)
- ❗ particle reco/ID at very high p_T
- 🔧 pile-up at trigger and reco-level



DI-X

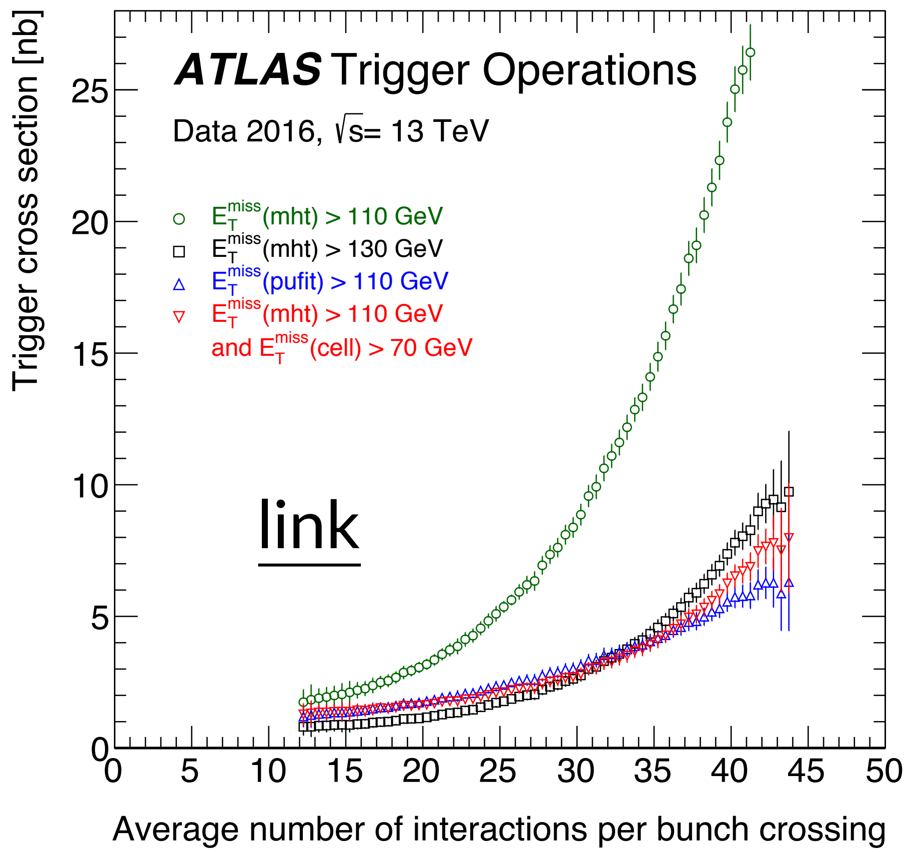


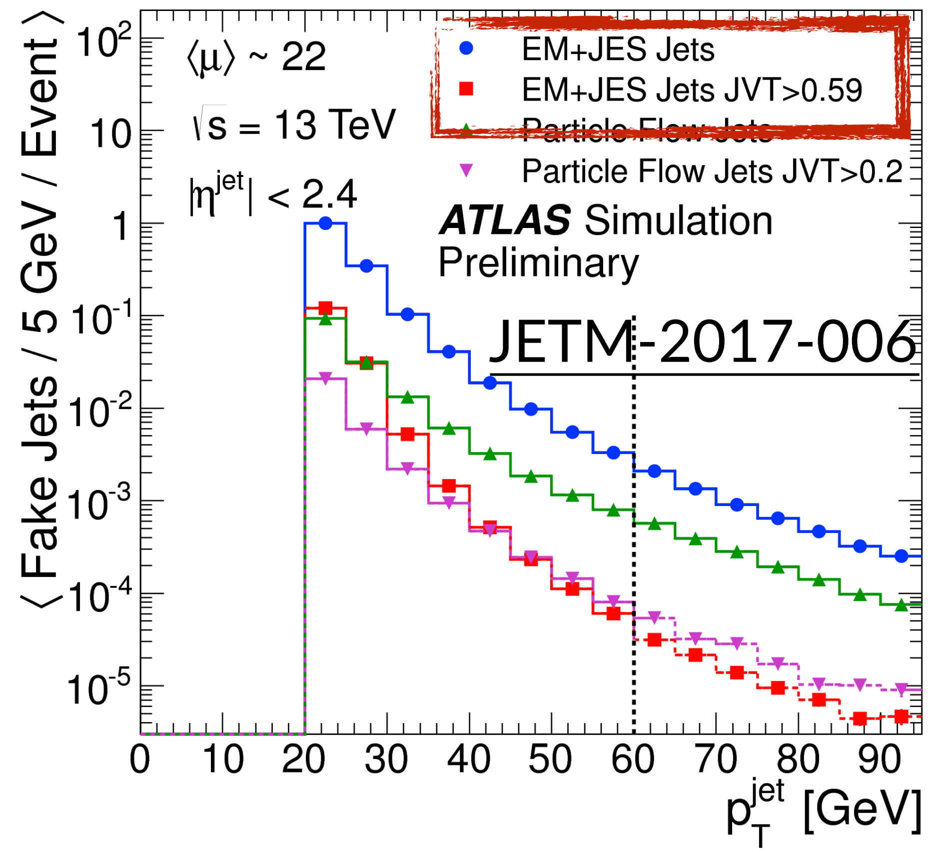
e.g. di-jet, di-lepton, ttbar

- 👍 look for the SM-DM mediator(s)
- 👀 trigger rate is a limitation (e.g. di-jet)
- ❗ energy calibration at very high p_T
- 🔧 need data scouting or clever signatures to reach O(100 GeV) masses

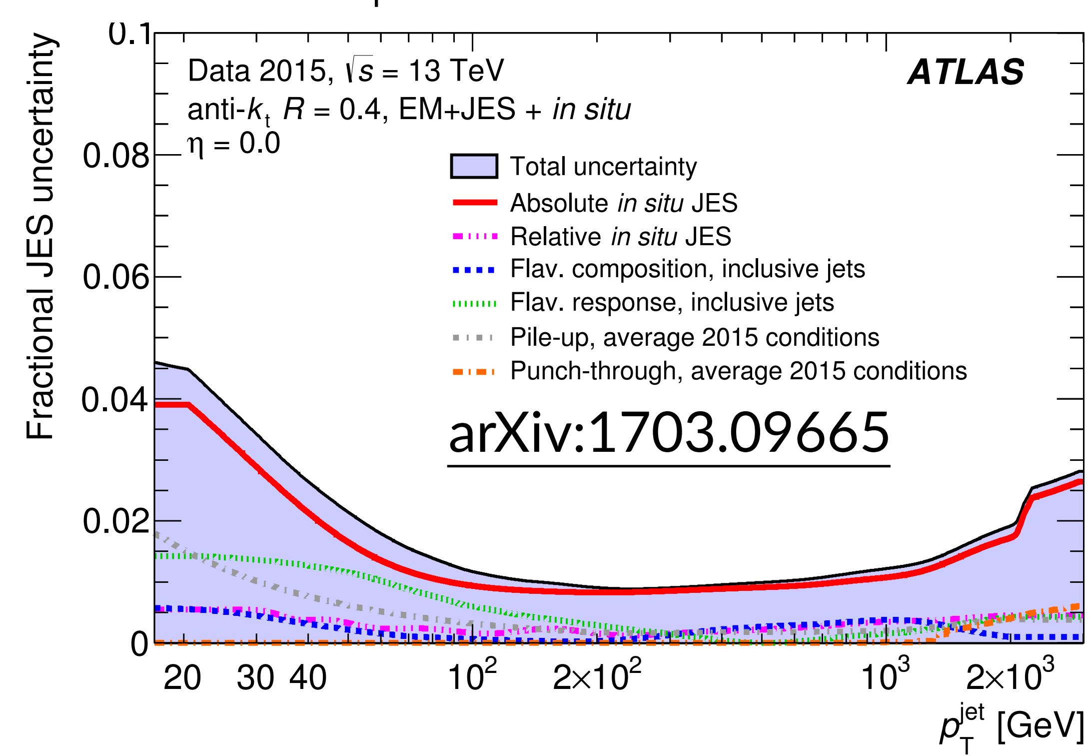
Weapons of DM Reconstruction / I

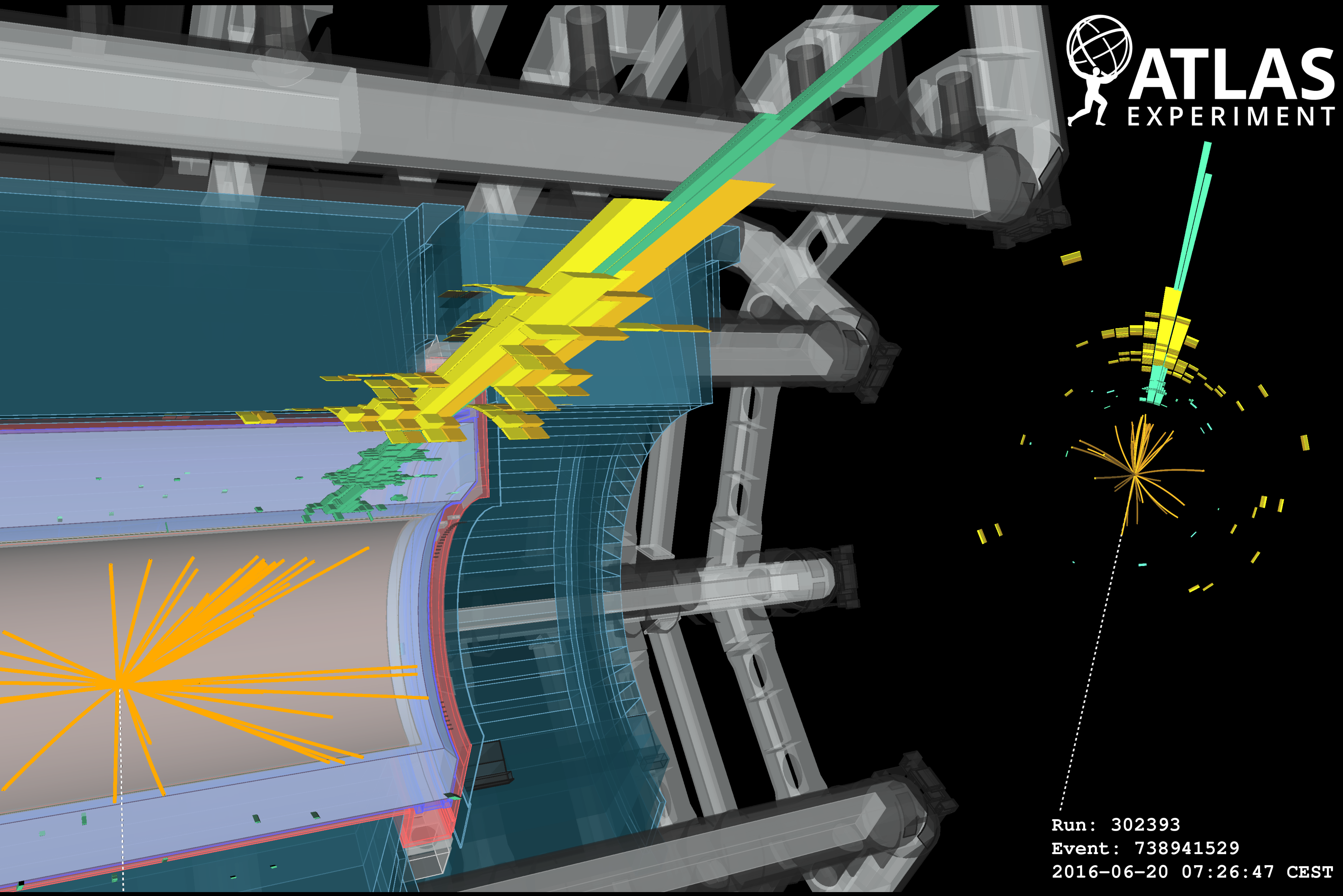
robust MET & jet reco/calibration techniques at all momenta





- pile-up is a limitation to MET trigger performance: need sophisticated algorithms to retain sensitivity to softer signals (e.g. spin-0 interactions)
- understanding of calorimeter response paramount for accurate JES uncertainty




ATLAS
EXPERIMENT
Run: 302393
Event: 738941529
2016-06-20 07:26:47 CEST

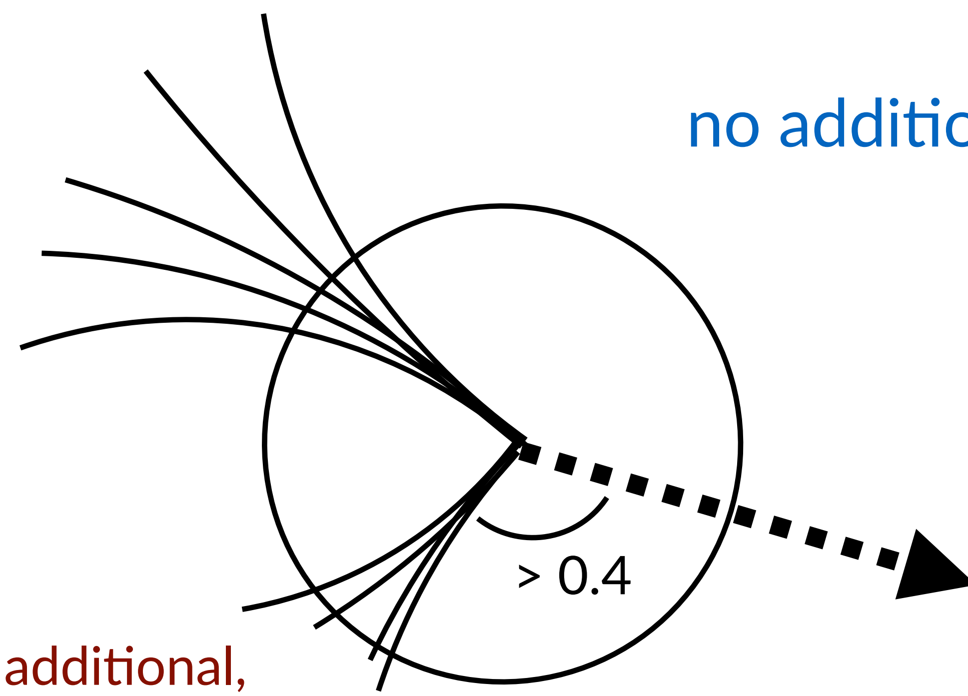
MET + JETS NEW!

ATLAS-CONF-2017-060

best channel if tagging object comes from ISR! (pay only α_s)

jet

high-pT (250 GeV)
central (|η|<~2.4)
tight quality

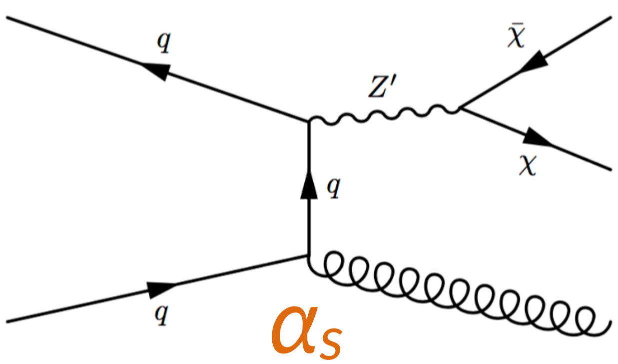


no additional electron or muon

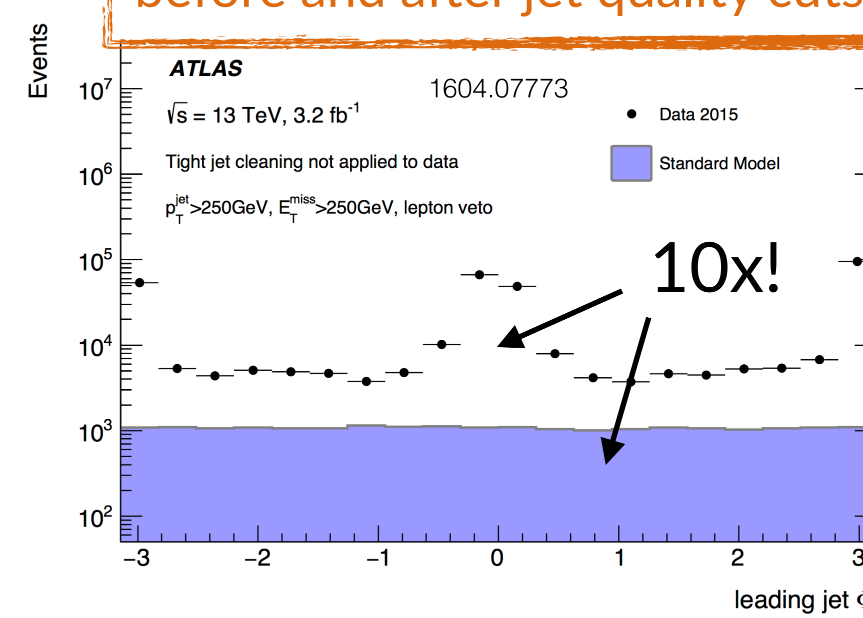
+ trigger
MET > 70 GeV
(fully efficient above 200 GeV)

additional, softer jets
(up to 3)

MET
> 250 GeV



before and after jet quality cuts

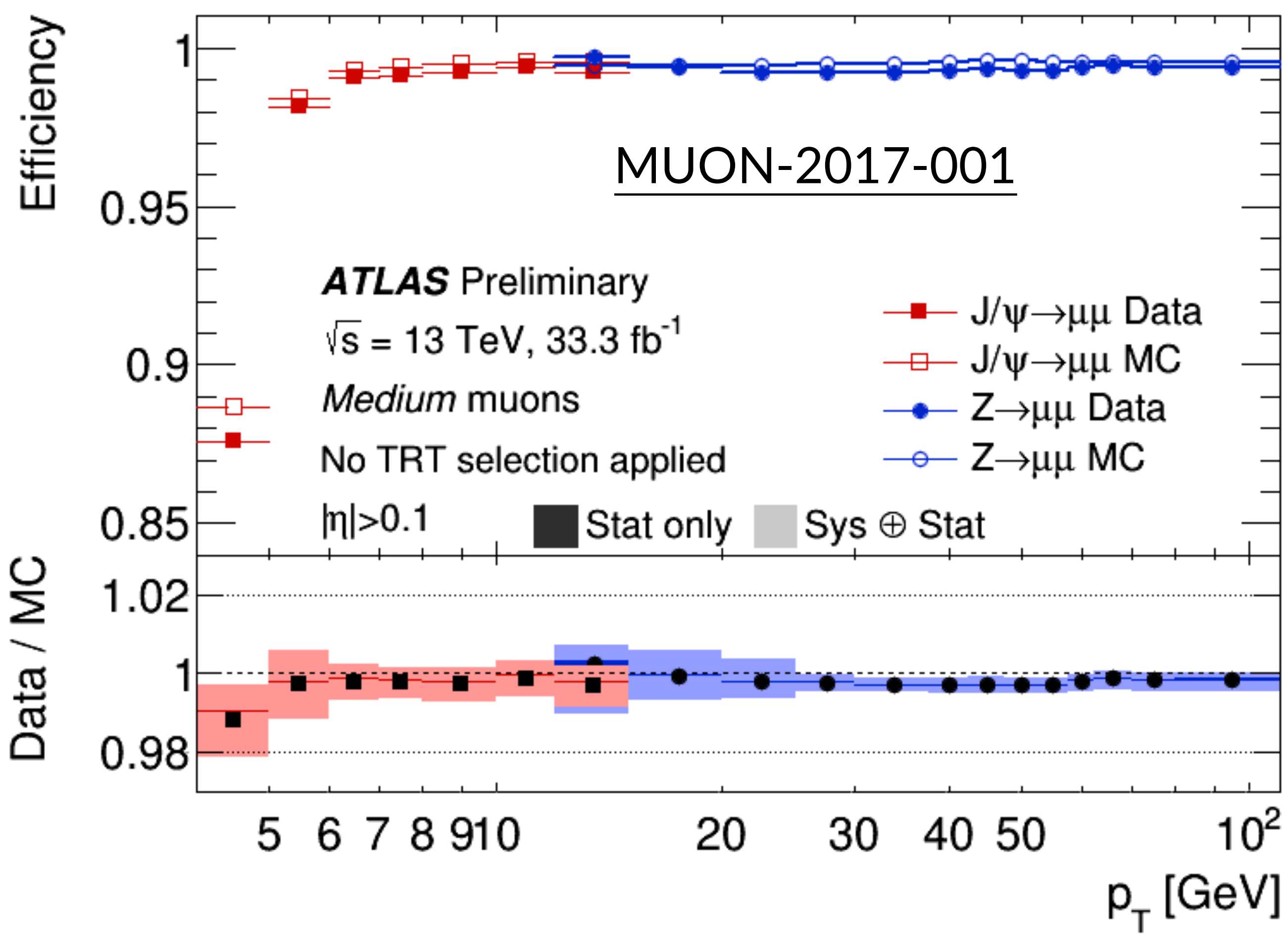


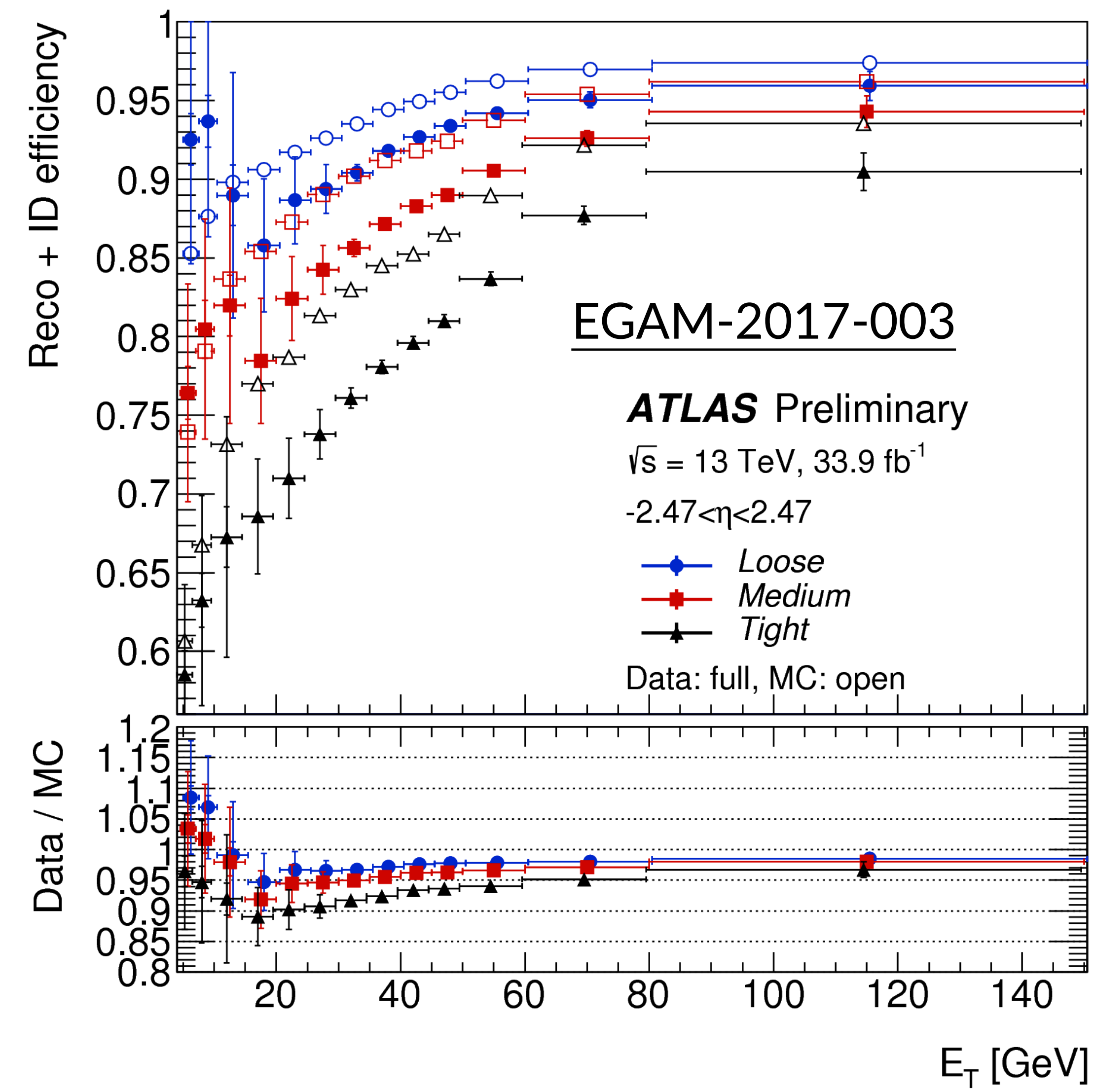
same signature as

- Z(νν) + jets, W(τ[qq']ν) + jets…
  - normalisation from simultaneous fit to p_T(W/Z) distributions in lepton control regions
- use calorimeter segmentation to reject beam & instrumental background

Weapons of DM Reconstruction / II

excellent lepton reconstruction performance





- crucial to exploit W/Z physics at the TeV scale
- you need to trust your lepton reco/ID uncertainty to be able to constrain SM backgrounds from the data (notably Zvv+jets!)

Control Regions

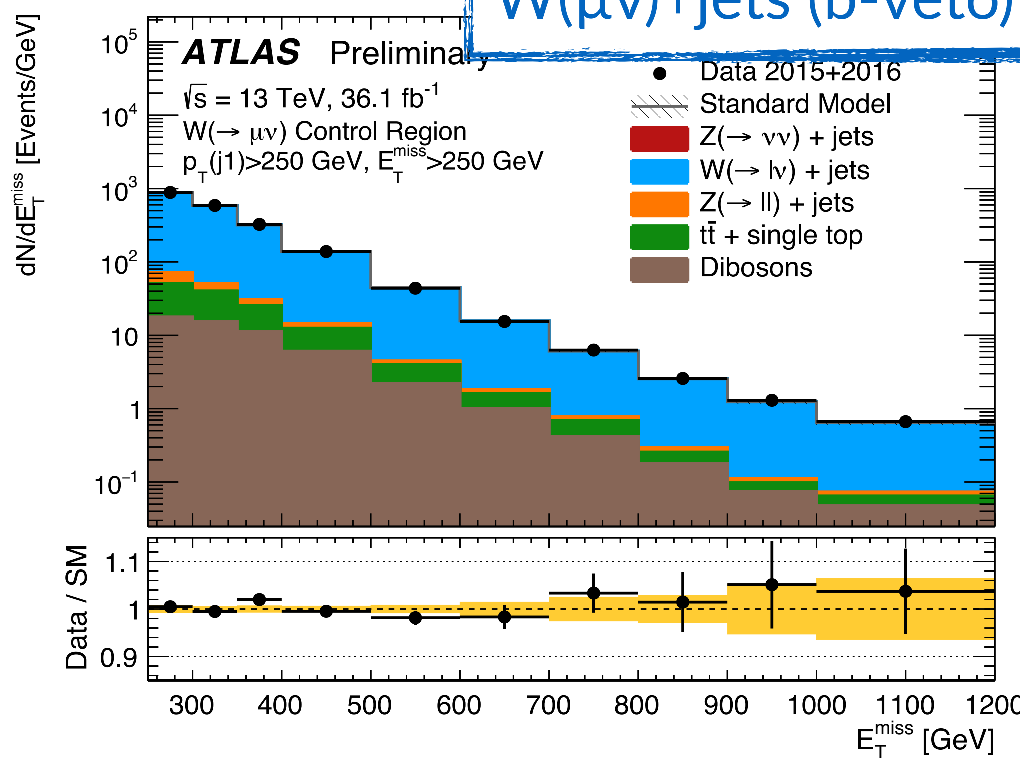
NEW!

results of CR-only fit

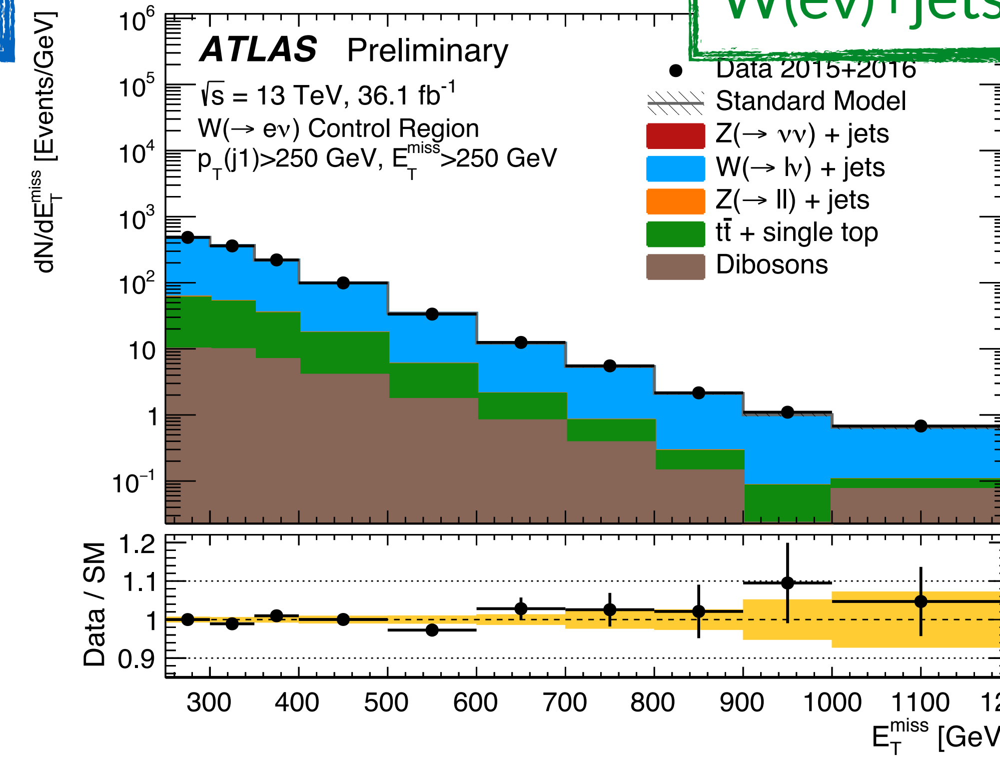
fit parameters:

- W/Z normalisation (common also to Z(νν)+jets)
- ttbar/single-t normalisation
- shape uncertainties

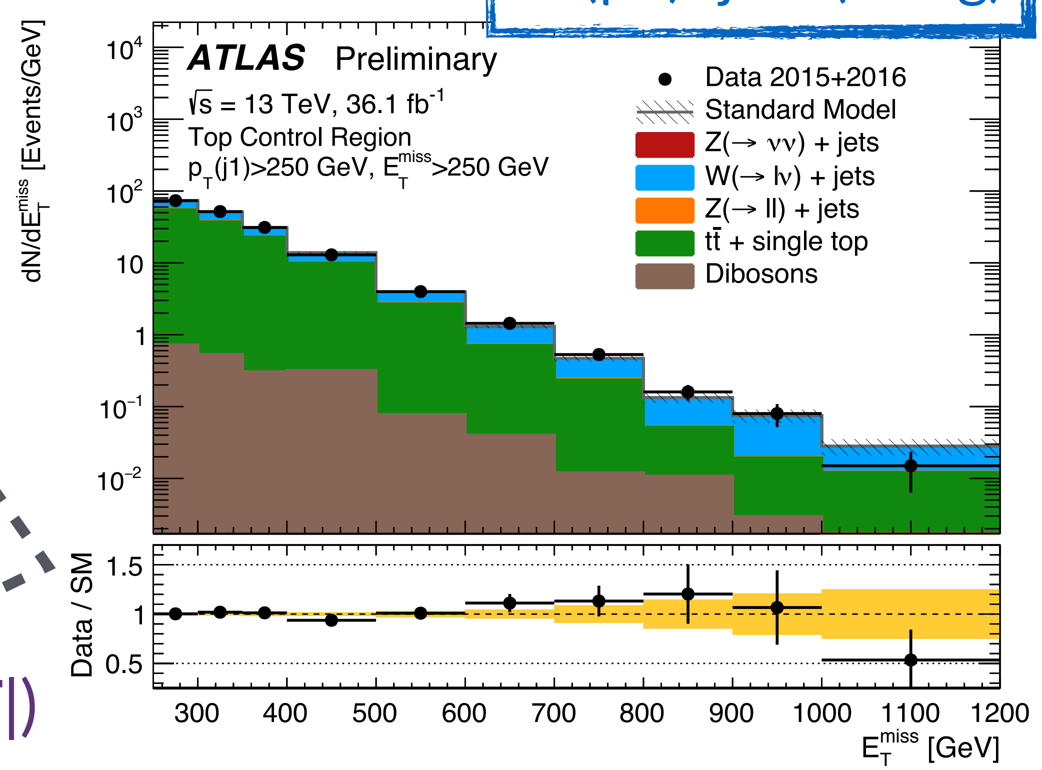
W(μν)+jets (b-veto)



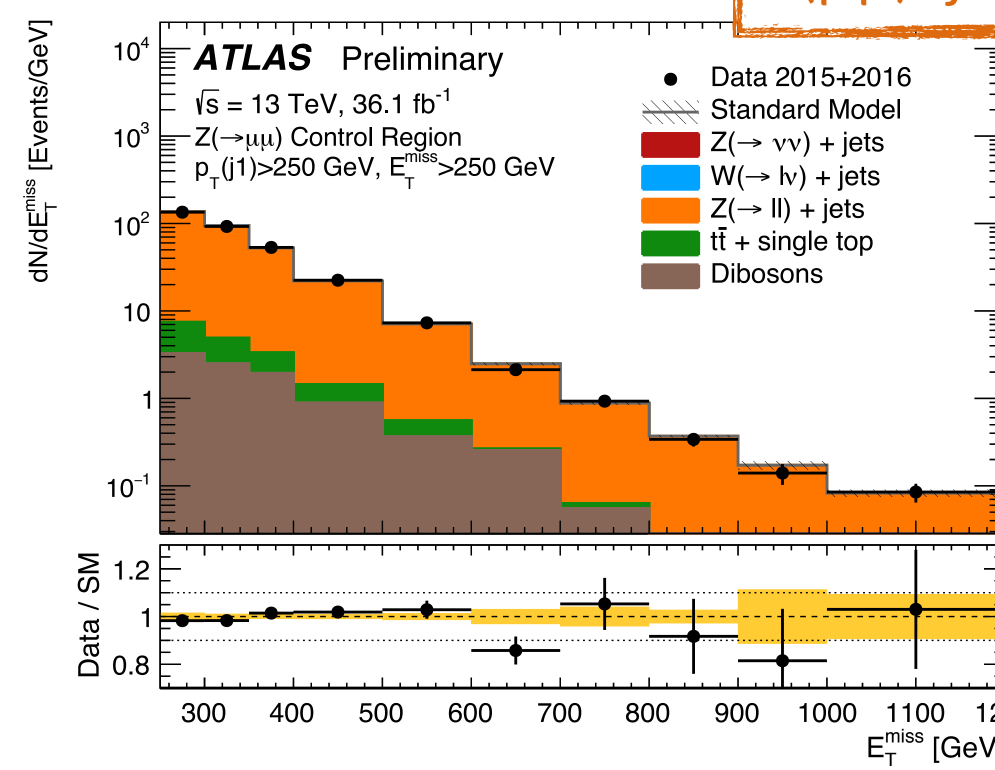
W(eν)+jets



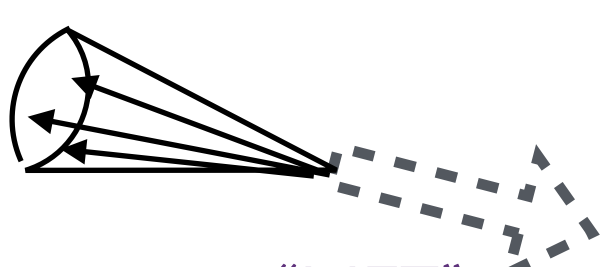
W(μν)+jets (b-tag)



Z(μμ)+jets



jet



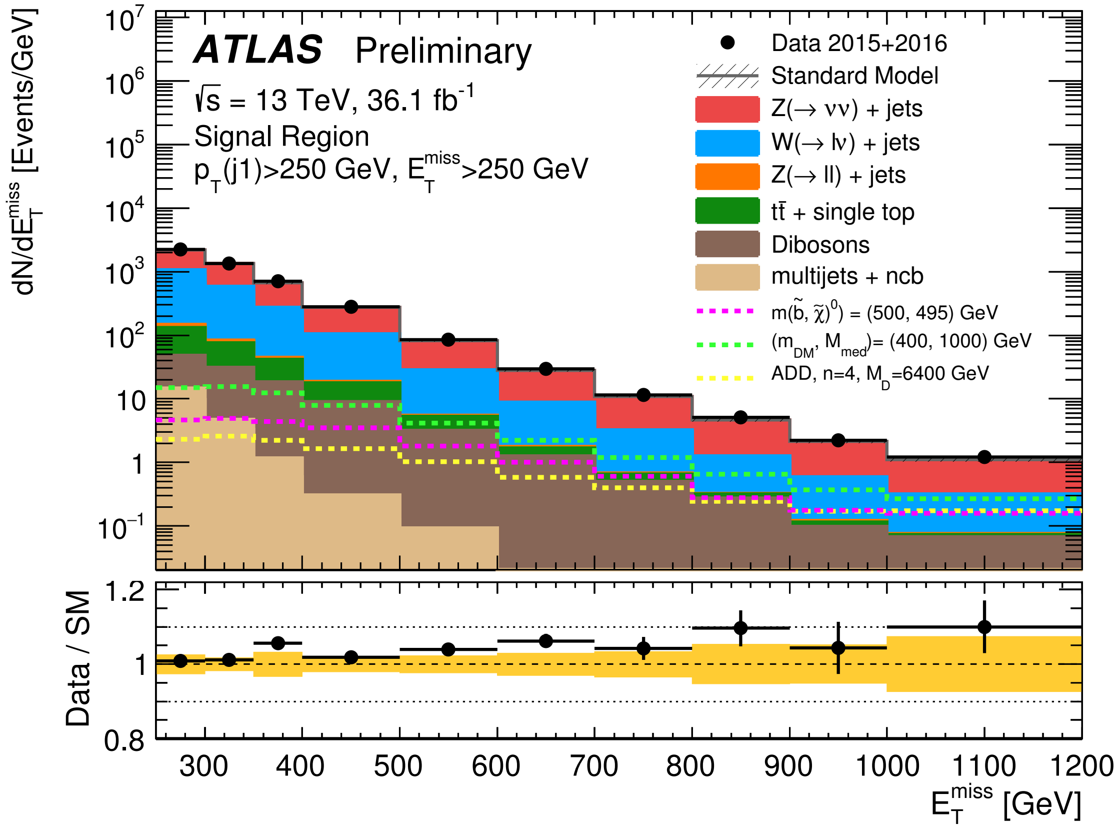
"MET"

(|$p_T^{(lep's)}$+MET|)

RESULTS

NEW!

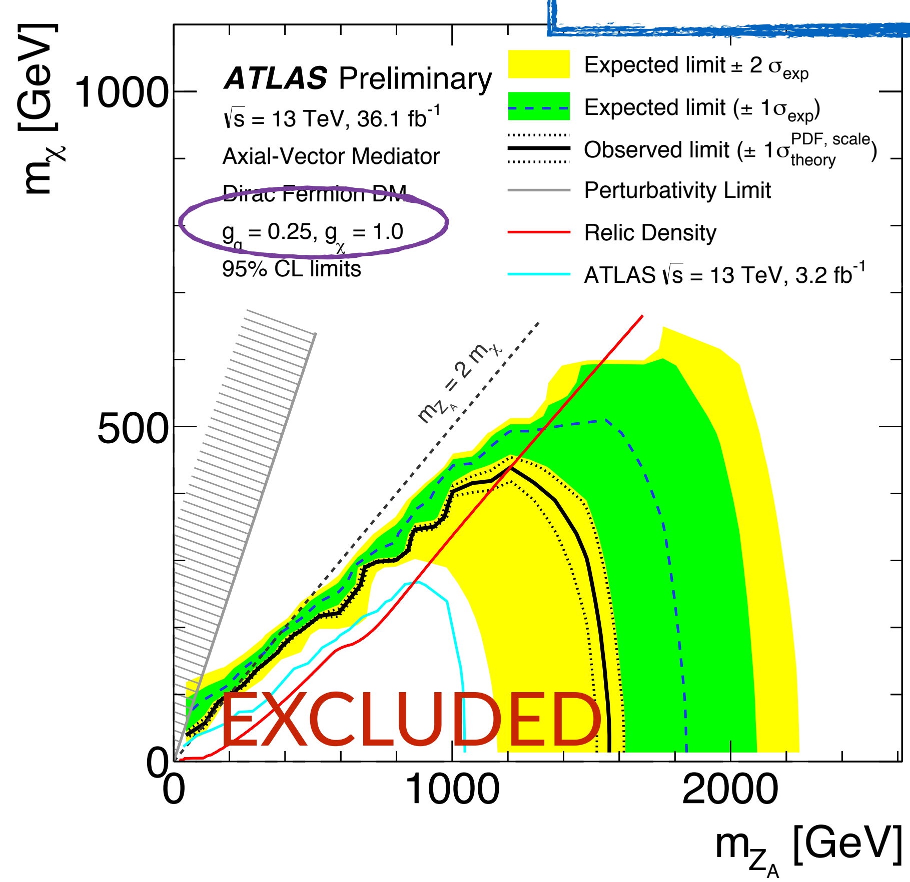
results of CR+SR fit



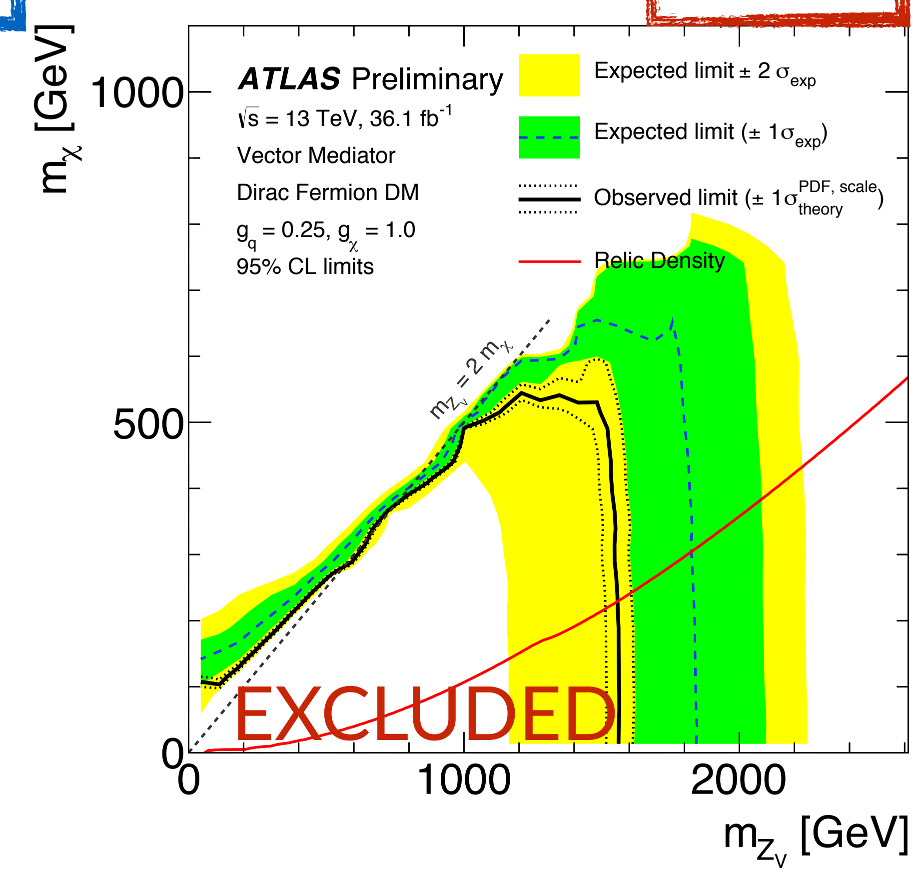
- W/Z modelled at NLO QCD & EW
  - Sherpa [NLO(LO) for 1,2(3,4) partons] ⊕ theory reweighting based on p_T(W/Z) [arXiv:1705.04664]
- 2-5% uncertainty on SR background
  - theo: 0.7-1% for the W(lv)/Z(ll)->Z(vv) extrapolation
  - exp: electron/muon efficiency, jet energy scale/reso
- probing s-channel (J^P=0^-, 1^+, 1^-) DM-SM interactions
  - pseudoscalar: cannot yet exclude model with g=1

discovery potential depends on assumed interaction and couplings!

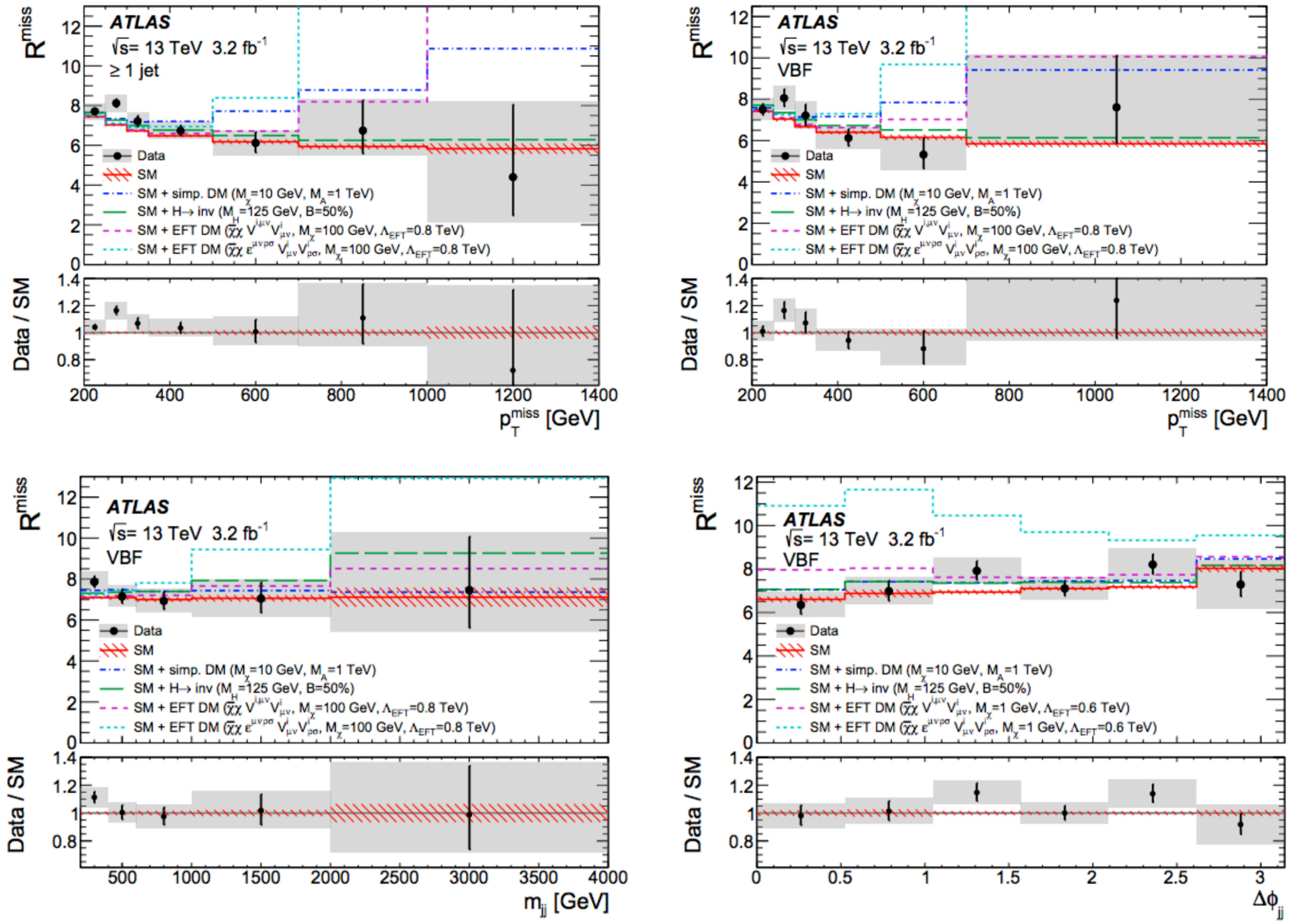
axial-vector



vector

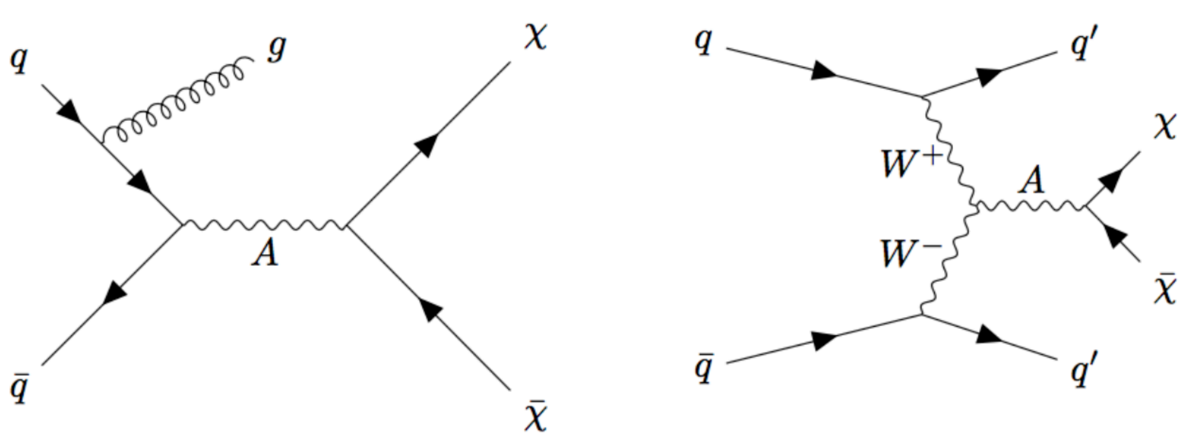


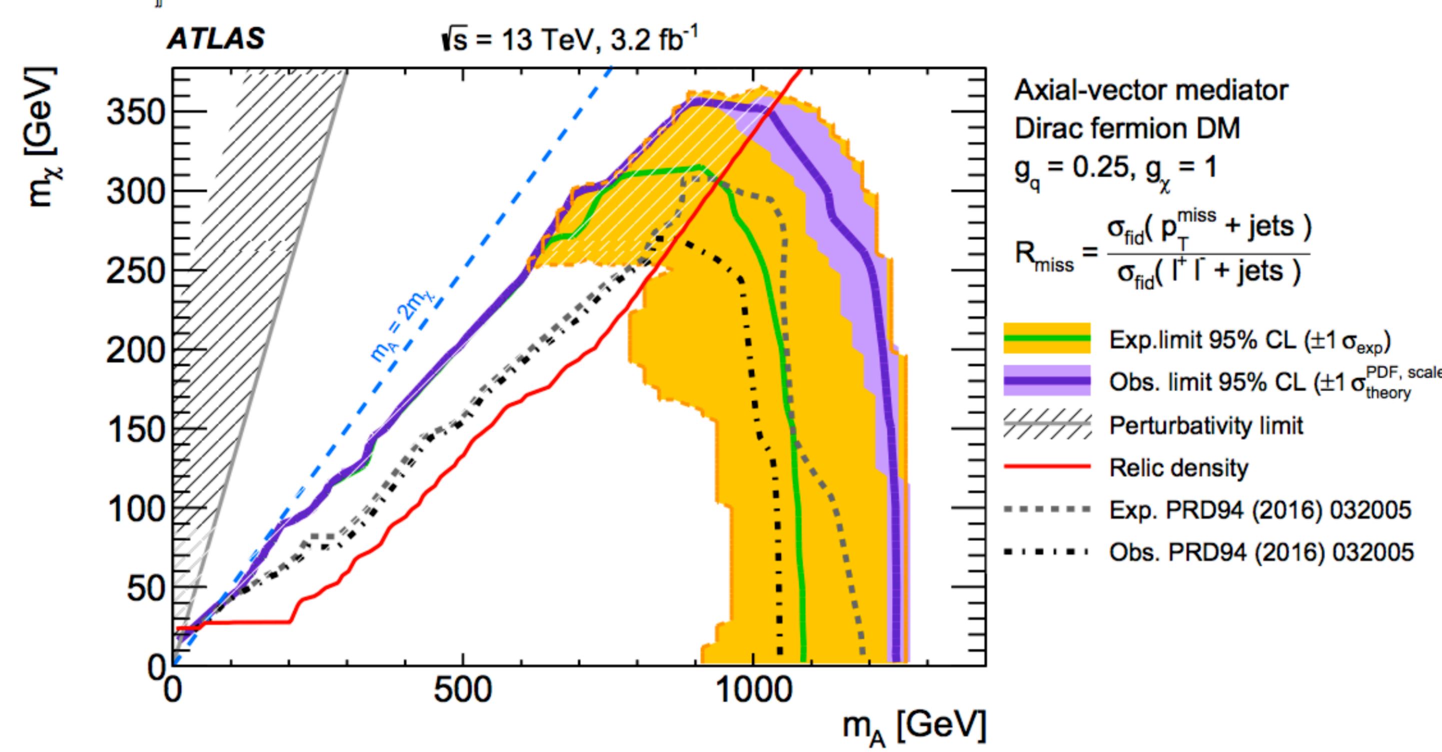
Z(νν)/Z(ℓℓ) CROSS-SECTION RATIO MEASUREMENT NEW!



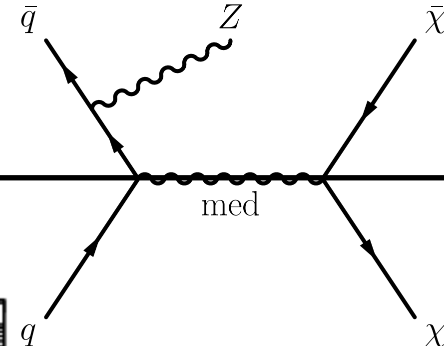
- measure unfolded differential Z(νν)/Z(ll) cross-section ratios
  - performed in “mono-jet” and VBF topologies, vs MET/m_{jj}/ΔΦ(jj)
- can be easily reinterpreted to constrain BSM models
  - e.g. MET+jet simplified models, VBF EFT, H(inv)…
  - s-channel axial-vector: allows for slightly better sensitivity than standard search with 3.2 fb^{-1}

to appear soon!

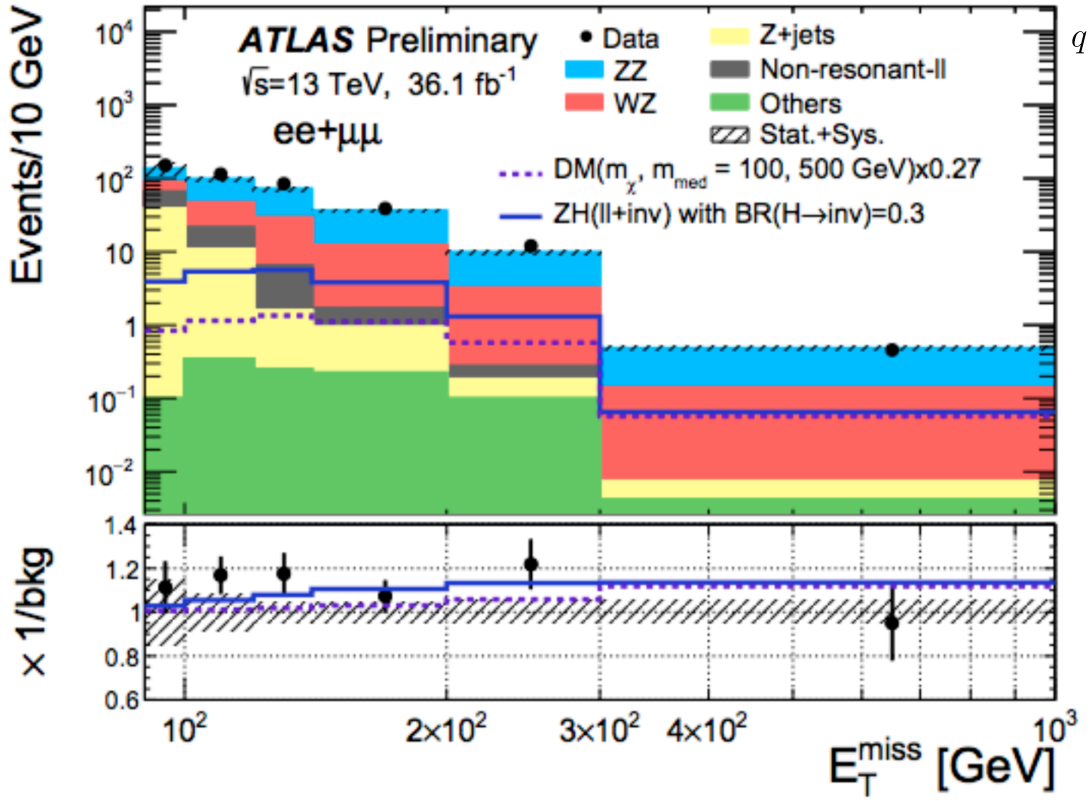




MET+Z(LL) NEW!

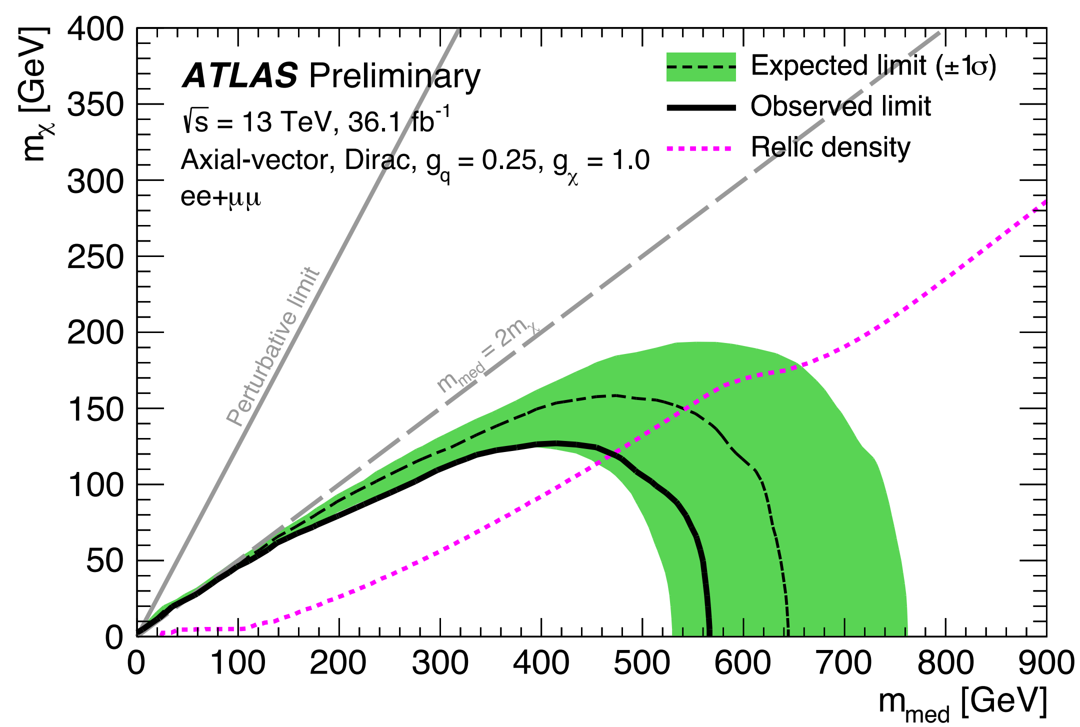


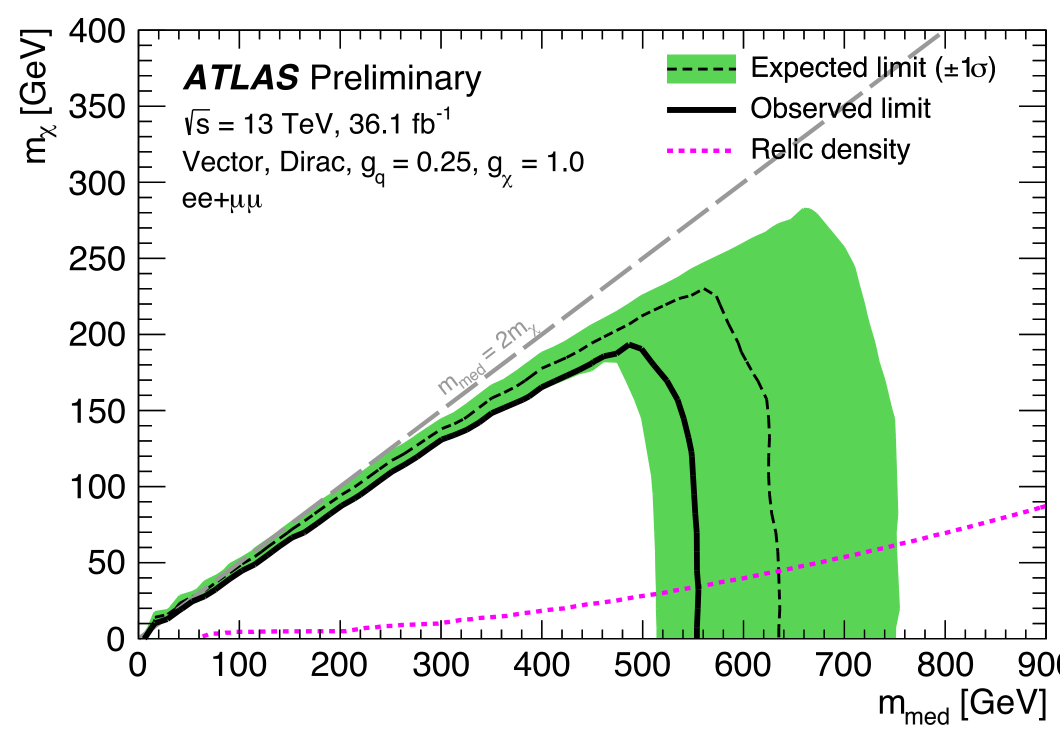
ATLAS-CONF-2017-040



- $e^+e^-/\mu^+\mu^-$ pair compatible with a Z
- MET > 90 GeV, MET/H_T>0.6
- ΔΦ(Z, MET) > 2.7, ΔR(ll) < 1.8, b-veto
- ZZ from simulation, WZ from 3-lepton CR

main uncertainties from ZZ modelling, lepton momentum scale/reso and reco/ID efficiency uncertainties, JES

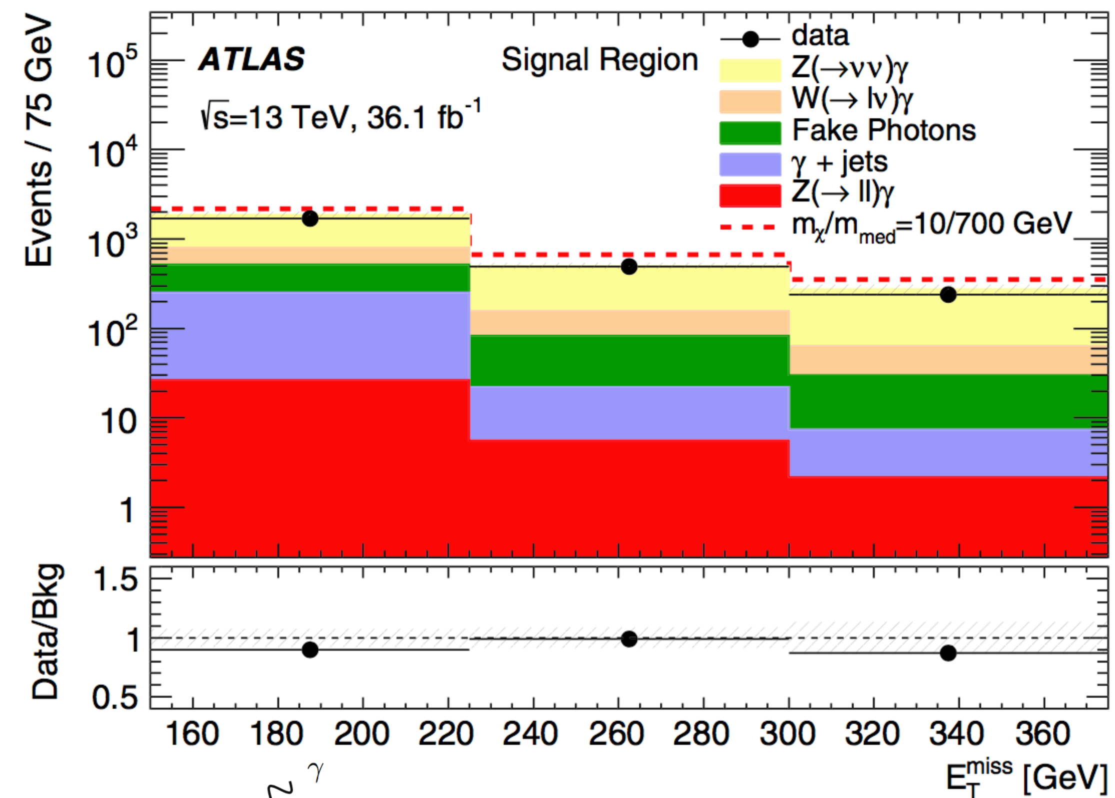


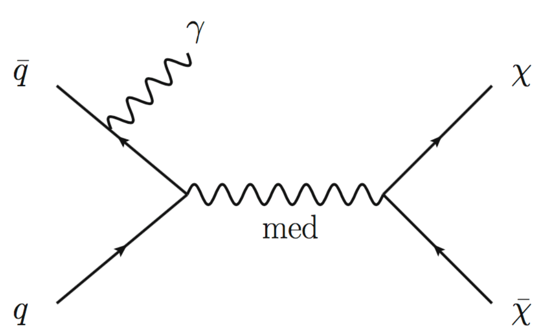


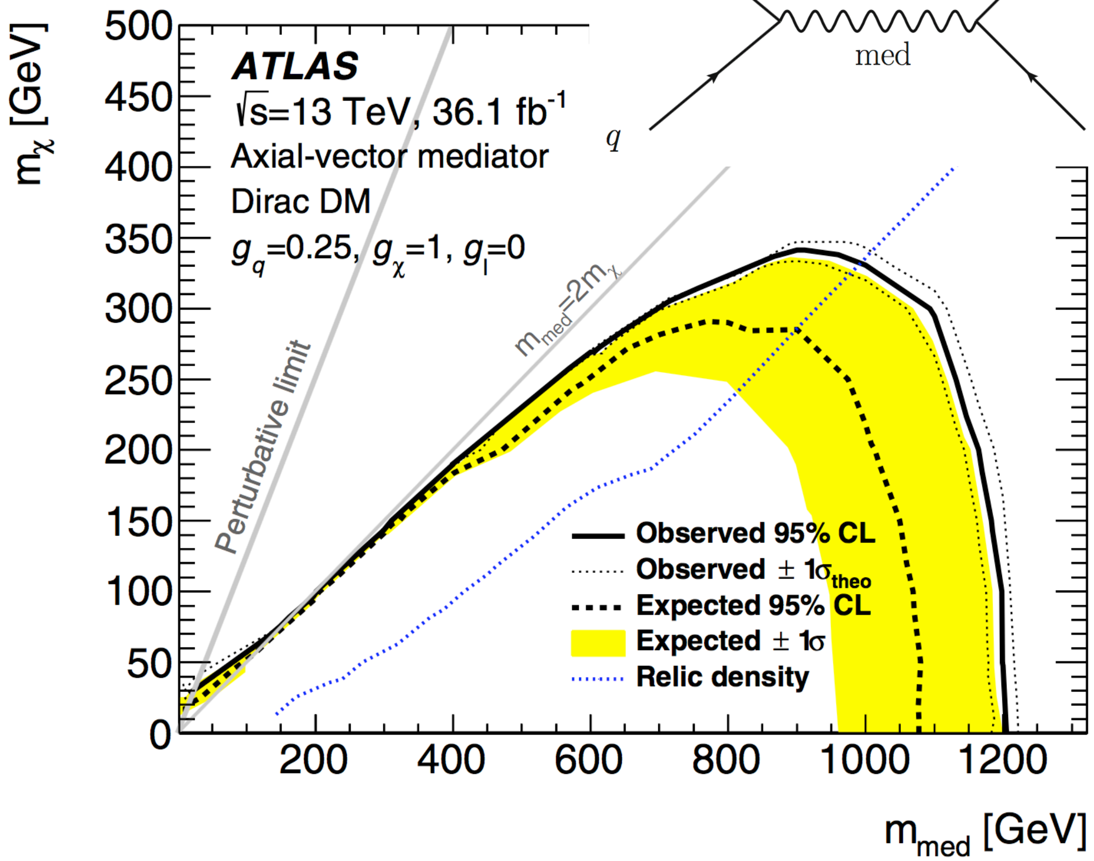
Eur. Phys. J. C 77 , 6 (2017) 393

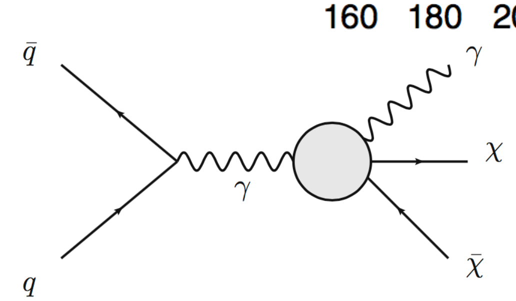
similar strategy as monojet

- dominant uncertainty from jet->γ fake factor (ABCD method, 1-5%)
- e->γ fake factor applied to MET+e events (1.5%)
- jet energy scale (6-1%)
- also sensitive to $\gamma\gamma\chi\chi$ EFT

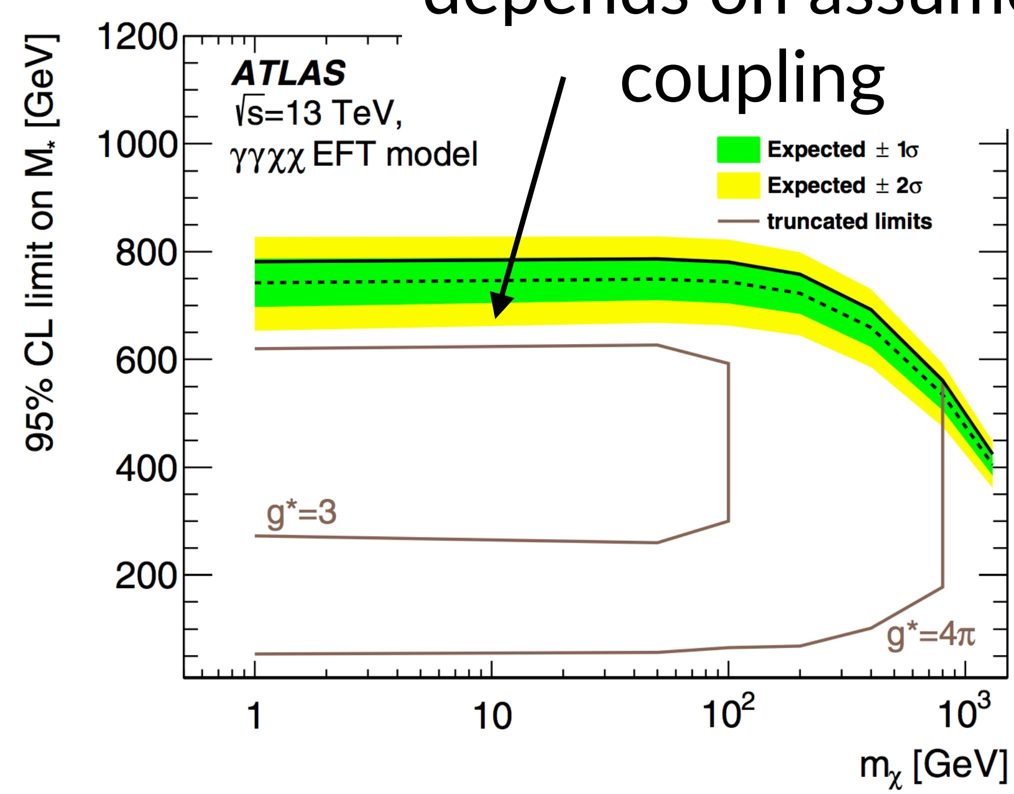






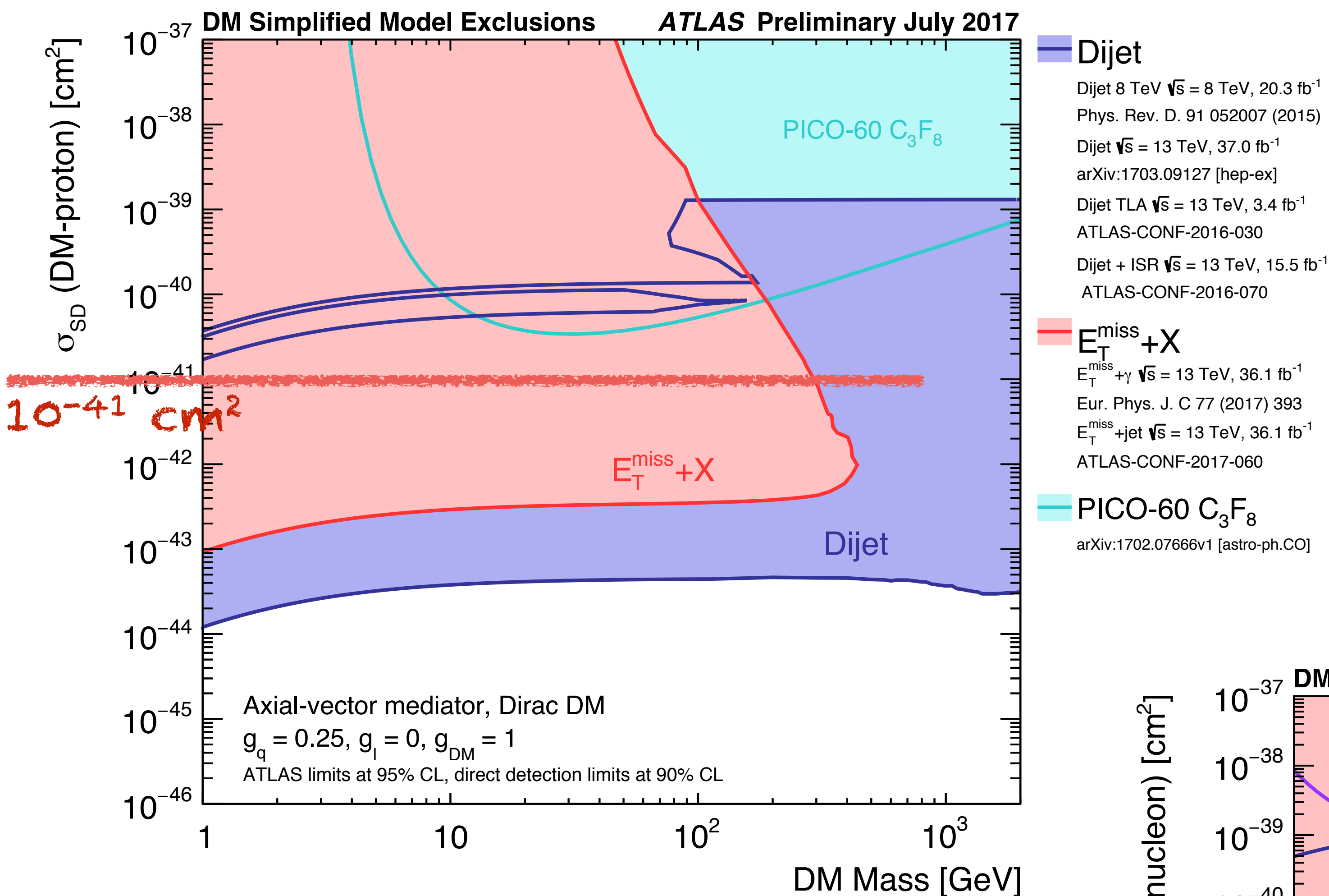


EFT validity (& result) depends on assumed coupling



MET+X VS DI-X NEW!

di-jets: see Attilio Picazio's talk
di-lepton: see Giacomo Artoni's talk



the assumption on new physics couplings strongly influences discovery potential & compatibility with Ωh^2

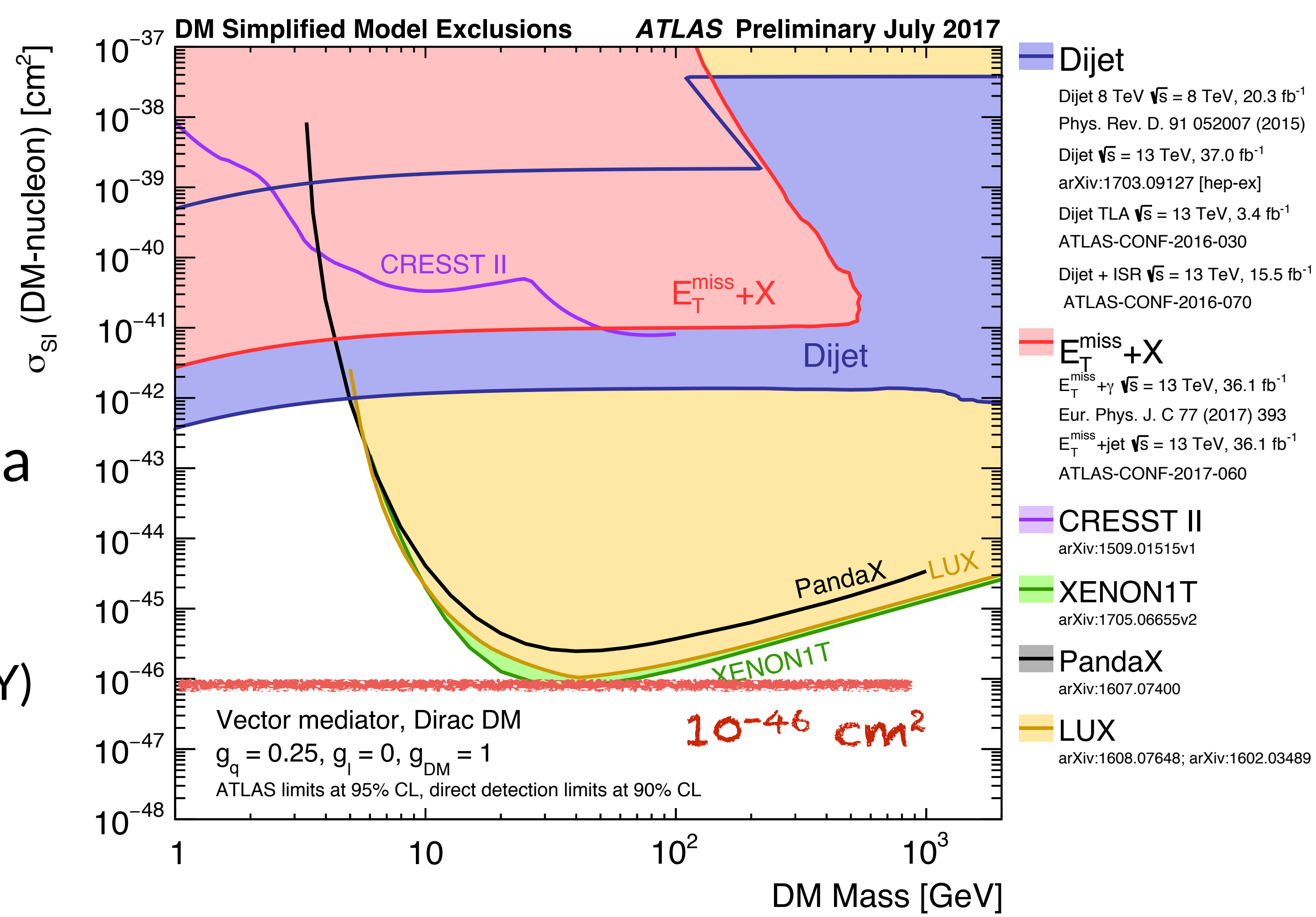
complementary coverage of direct-detection plane by MET+X and di-X results

disadvantage

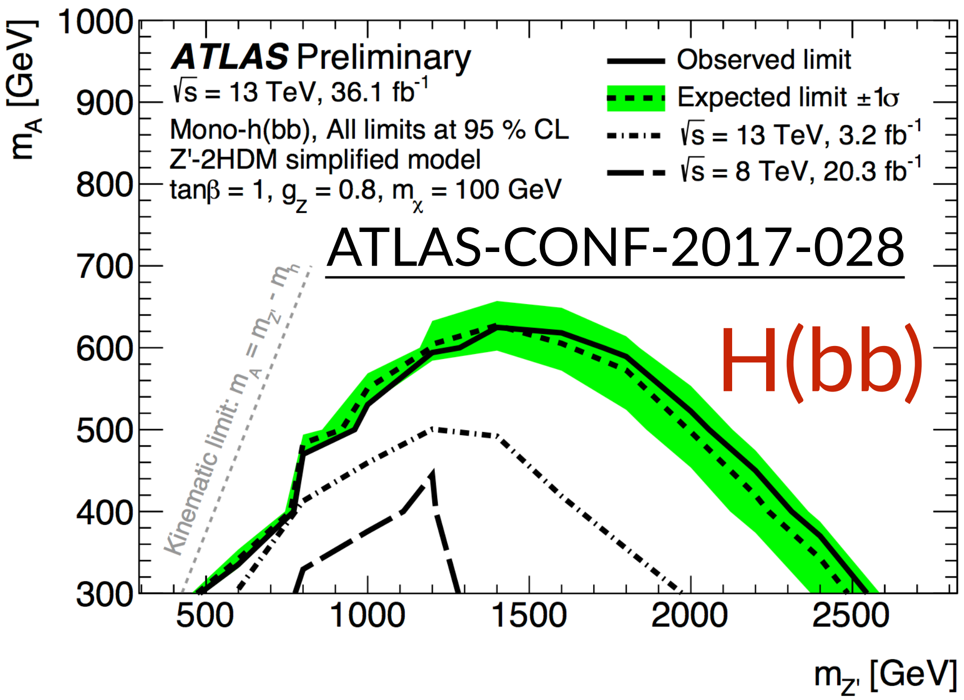
need to explore the parameter space (~2 more degrees of freedom other than masses) -> "re-interpretation"

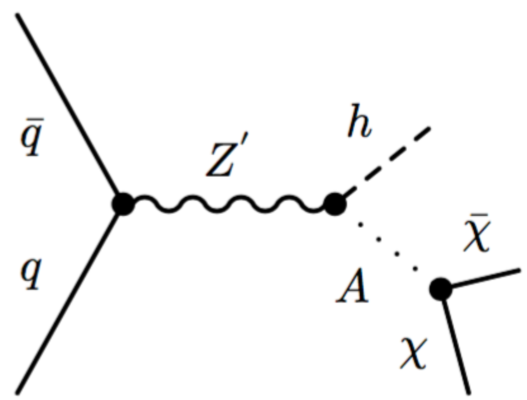
advantage

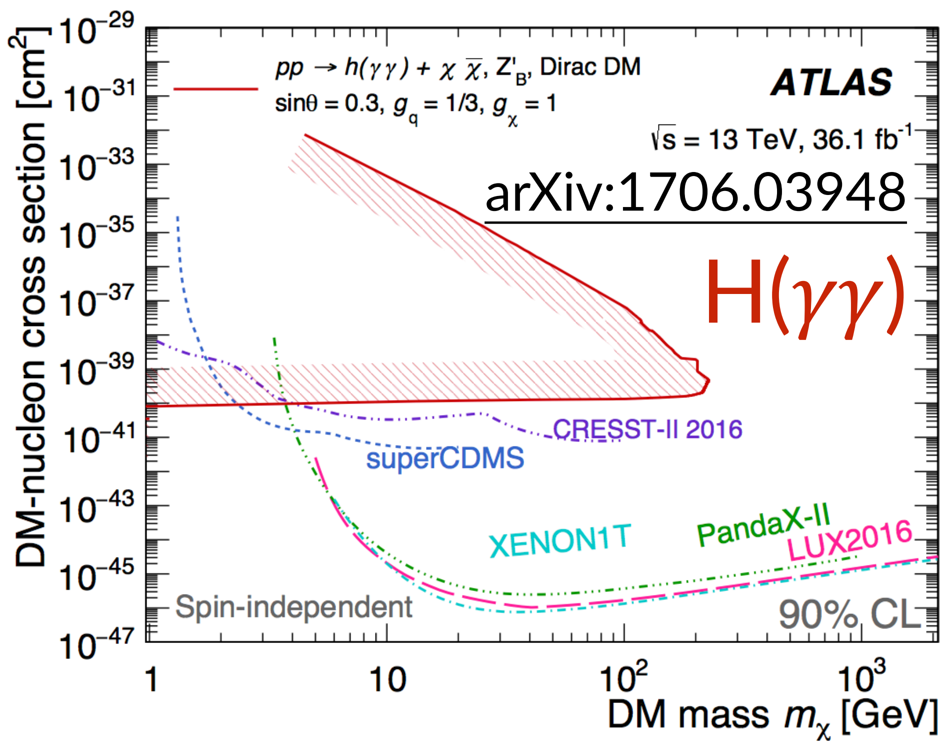
multi-signature: could characterise a discovery and fully probe SM extensions (e.g. SUSY)

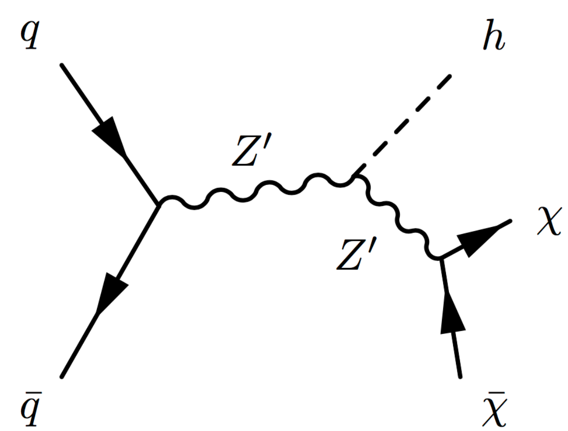


MET+H









Higgs boson as a discovery tool!

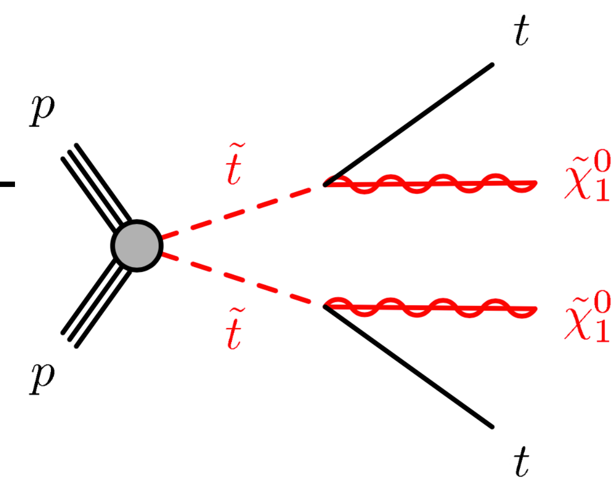
- probe couplings between a new mediator and Higgs sector
- most sensitive channel is H(bb)+MET
  - use m(bb) as discriminant in resolved and boosted regimes (MET </> 500 GeV)
  - bkg from Z(vv)+jet, W+jet and ttbar, 1μ and 2μ/2e CRs

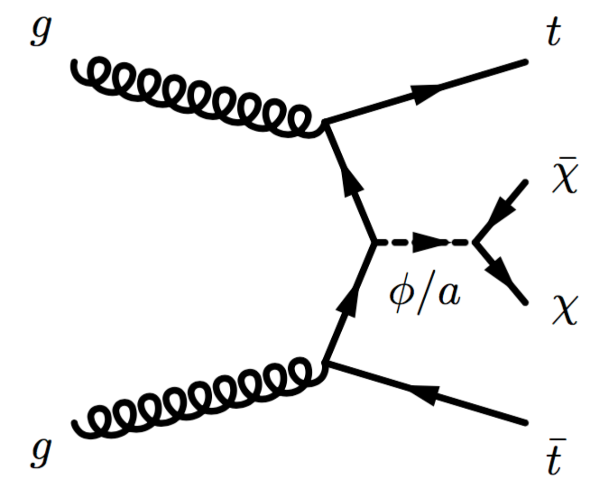
also MET+H(4l) (ATLAS-CONF-2015-059)

see Rainer Roehrig's poster

MET+HF

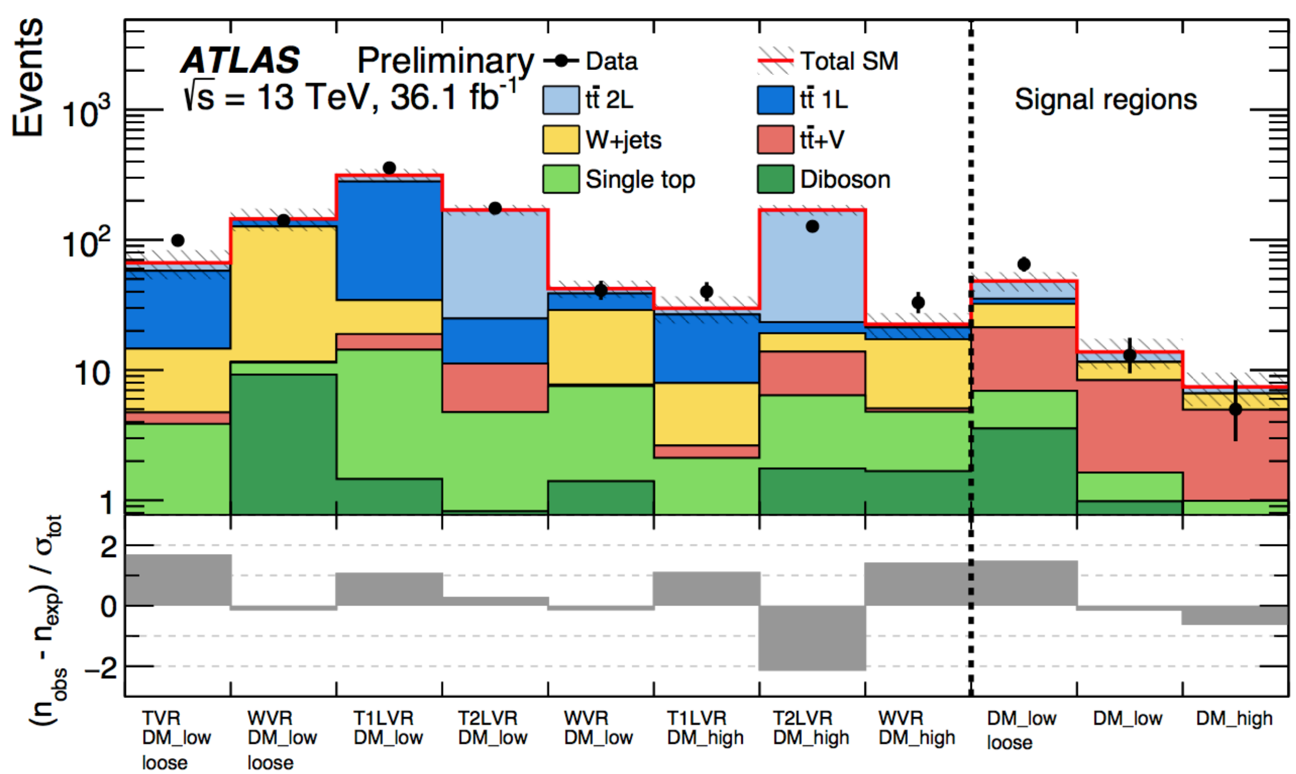
- scalar mediator would couple preferentially to heavy quarks
  - tt+MET (had, 1L, 2L), bb+MET
- same final state as for SUSY 1-lepton EW searches

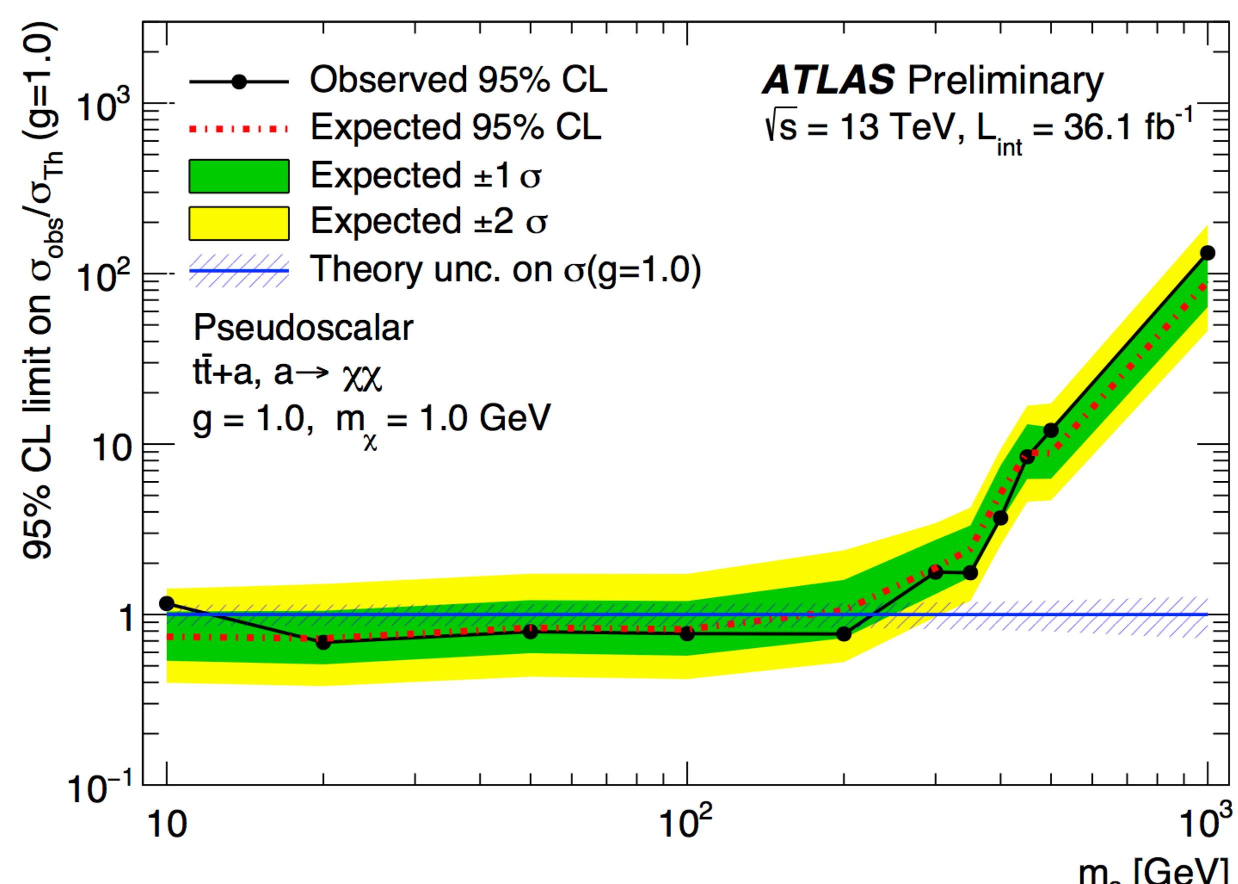




see Yoav Afik's poster

1L: ATL-CONF-2017-037 (this slide)
2L: ATLAS-CONF-2016-076
had: ATLAS-CONF-2016-077
bb: ATLAS-CONF-2016-086

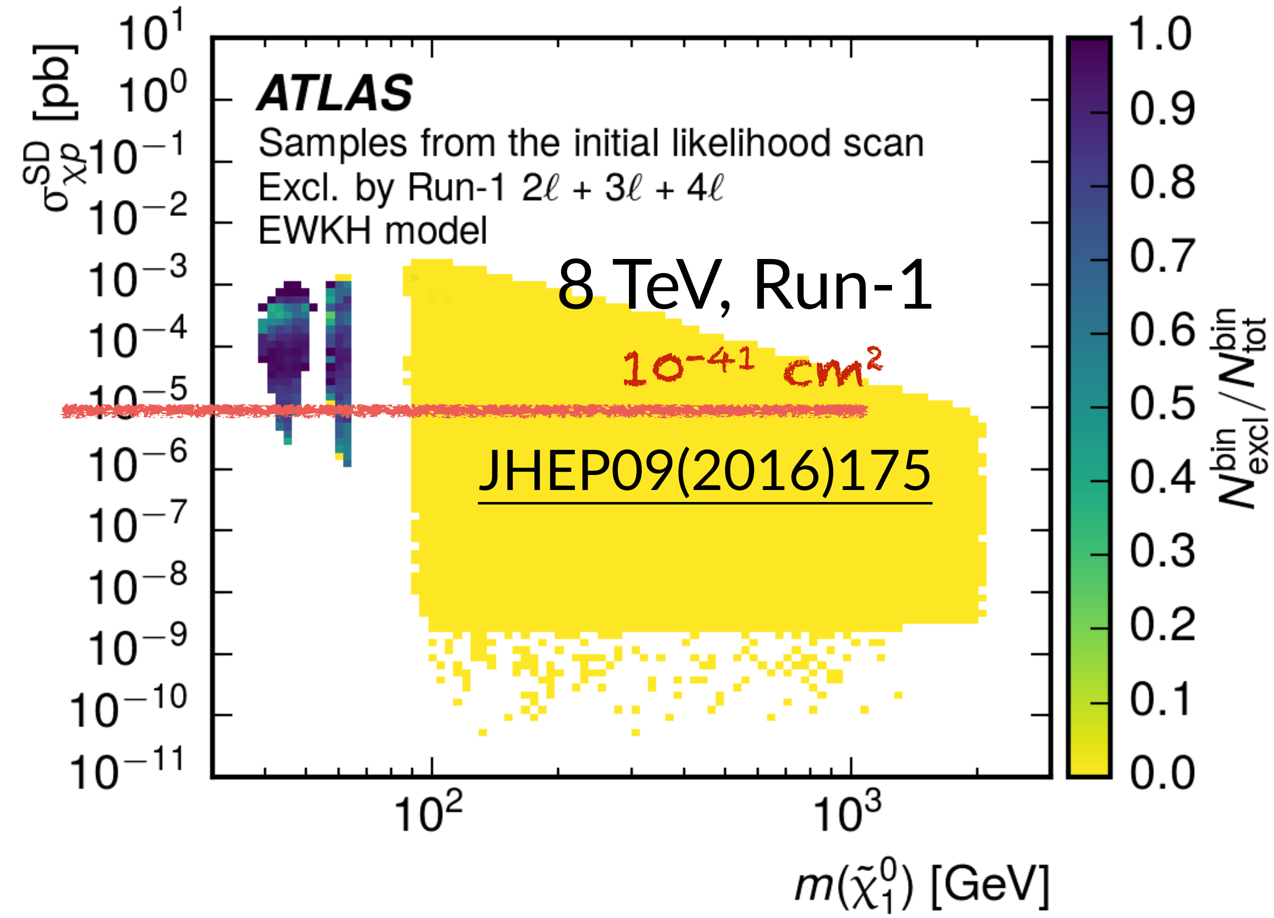




SUSY vs DM

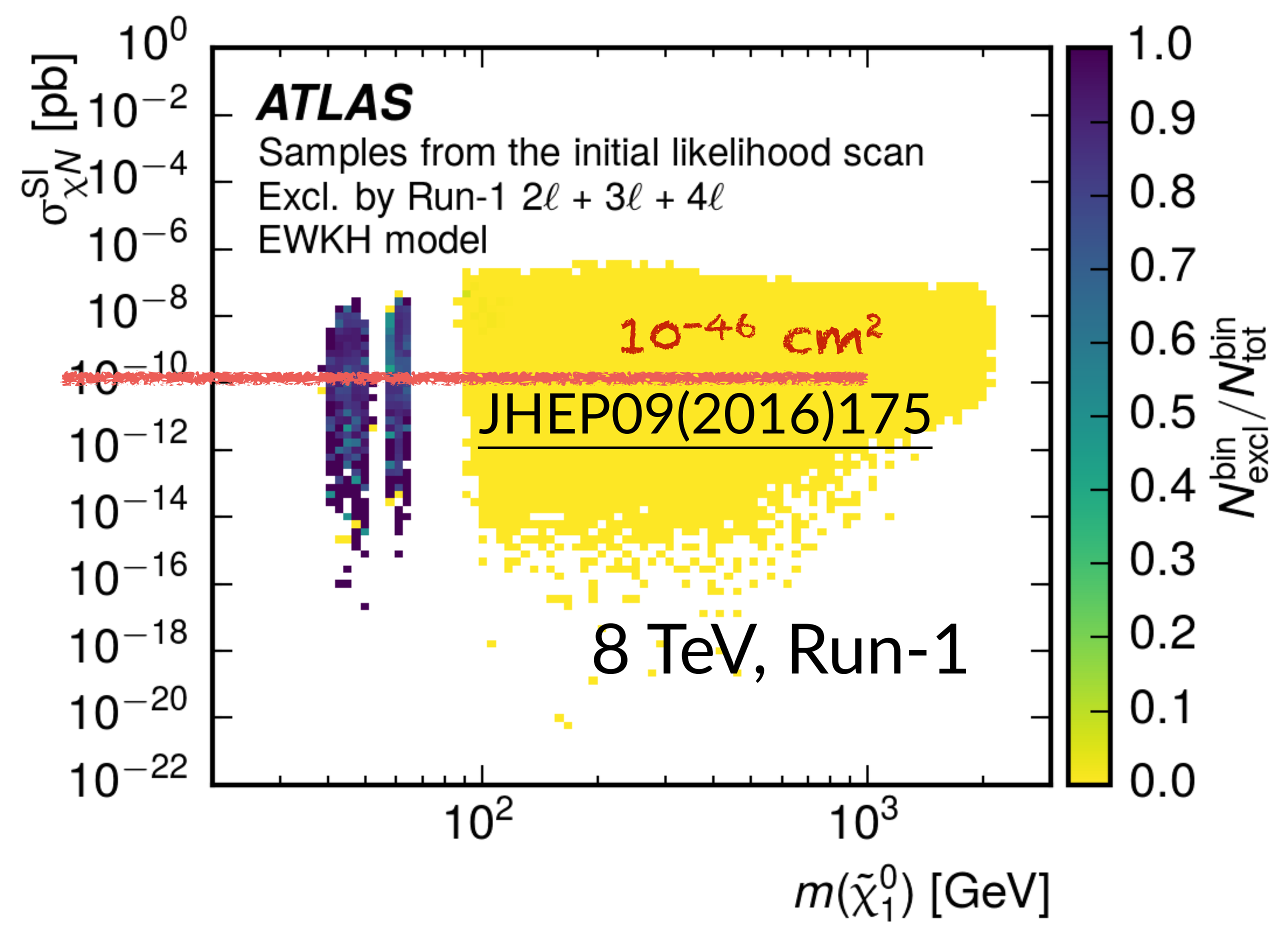
a UV-complete approach to the DM problem

- can investigate impact of EW search results on DM constraints
  - example on the right: 8 TeV results of 2-3-4L with DD, relic density and flavour constraints
    - 13 TeV searches: ATLAS-CONF-2017-035, ATLAS-CONF-2017-039



naturally extends searches to richer signatures

- broader experimental challenges in long-lived scenarios
  - see e.g. ATLAS-CONF-2017-017 and Nora Pettersen's talk



Conclusions (and Beyond)

extensive DM search programme at ATLAS

- complementary to dedicated experiments for m_{DM} <~ 100 GeV
- ATLAS is a telescope for new physics in multiple final states

expected luminosity

now:	36 fb^{-1}
end of 2018:	100 fb^{-1}
end of 2023:	300 fb^{-1}
HL-LHC (~2035):	3000 fb^{-1}

see also https://indico.cern.ch/event/539266

more data, new challenges

- balance between sensitivity to low-momentum signals (e.g. spin-zero) and robustness at very high energy
  - trigger & detector performance are crucial!
- explore lower-cross-section extensions of the SM (SUSY, long-lived particles…)
- may extend LHC reach to m_{DM} ~ 500 GeV in the next ~6 years…

stay finetuned!

EPS2017 Posters and Talks with More Information

- dijet resonances
  - T, Attilio Picazio
- dilepton resonances
  - T, Giacomo Artoni
- MET+W/Z(had)
  - P, Xuanhong Lou
- MET+H(bb)
  - P, Rainer Roehrig
- MET+bb/tt
  - P, Yoav Afik
- MET+hadronic activity
  - P, Gabriele Chiodini
- long-lived particle searches
  - T, Nora Emilia Pettersson
- stop pair production
  - T, Tommaso Lari (hadronic)
  - T, Priscilla Pani (leptonic)

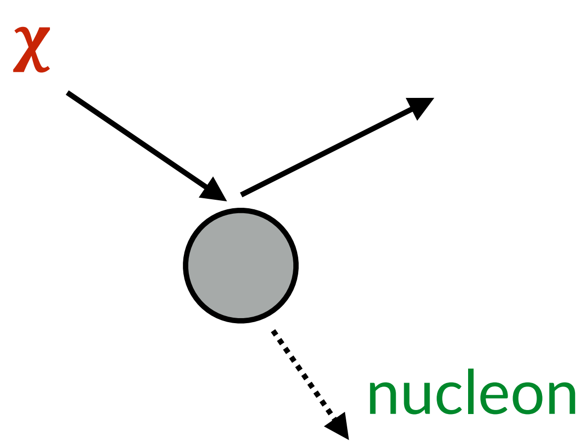
Further Reading

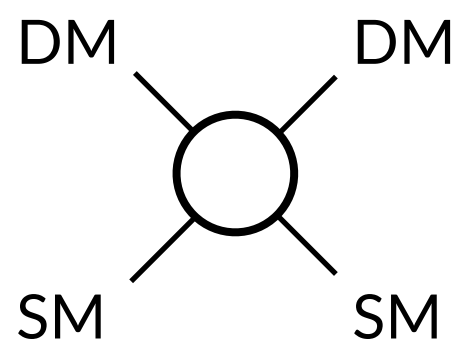
- MET+γ: Eur. Phys. J. C 77 , 6 (2017) 393
- MET+tt(1-L): ATL-CONF-2017-037
- MET+Z(ll): ATL-CONF-2017-040
- MET+W/Z(had): Phys. Lett. B 763 (2016) 251
- MET+jet: ATLAS-CONF-2017-060
- Z(vv)/Z(ll) cross-section ratio: *to appear*
- MET+H(bb): ATLAS-CONF-2017-028
- MET+H(gg): arXiv:1706.03948
- MET+H(4l): ATLAS-CONF-2015-059
- MET+bb: ATLAS-CONF-2016-086
- MET+tt(had): ATLAS-CONF-2016-077
- MET+tt (2-L): ATLAS-CONF-2016-076
- di-jet: http://arxiv.org/abs/arXiv:1703.09127
- di-jet TLA: ATLAS-CONF-2016-030
- di-jet ISR: ATLAS-CONF-2016-070
- dilepton: ATLAS-CONF-2017-027
- ttbar resonance: ATLAS-CONF-2016-014
- summary plots: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/index.html
- SUSY EW 2-3l: ATLAS-CONF-2017-039
- chargino/neutralino tau: ATLAS-CONF-2017-035
- chargino long-lived (disapp track): ATLAS-CONF-2017-017
- SUSY pMSSM scan: JHEP09(2016)175

Backup

Spotting the Invisible

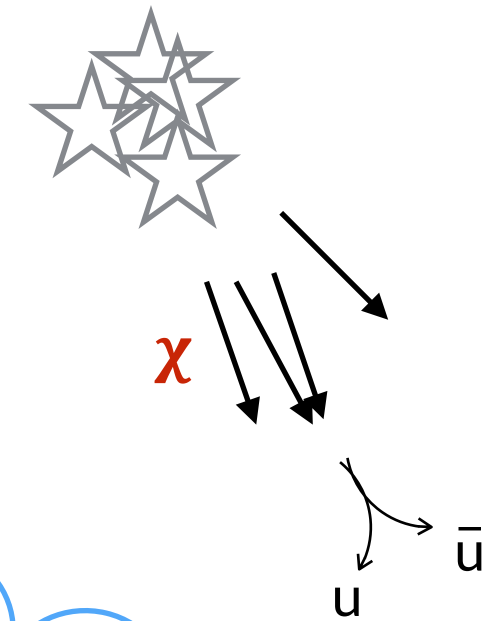
direct detection

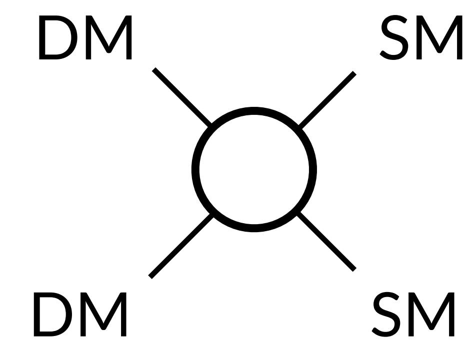


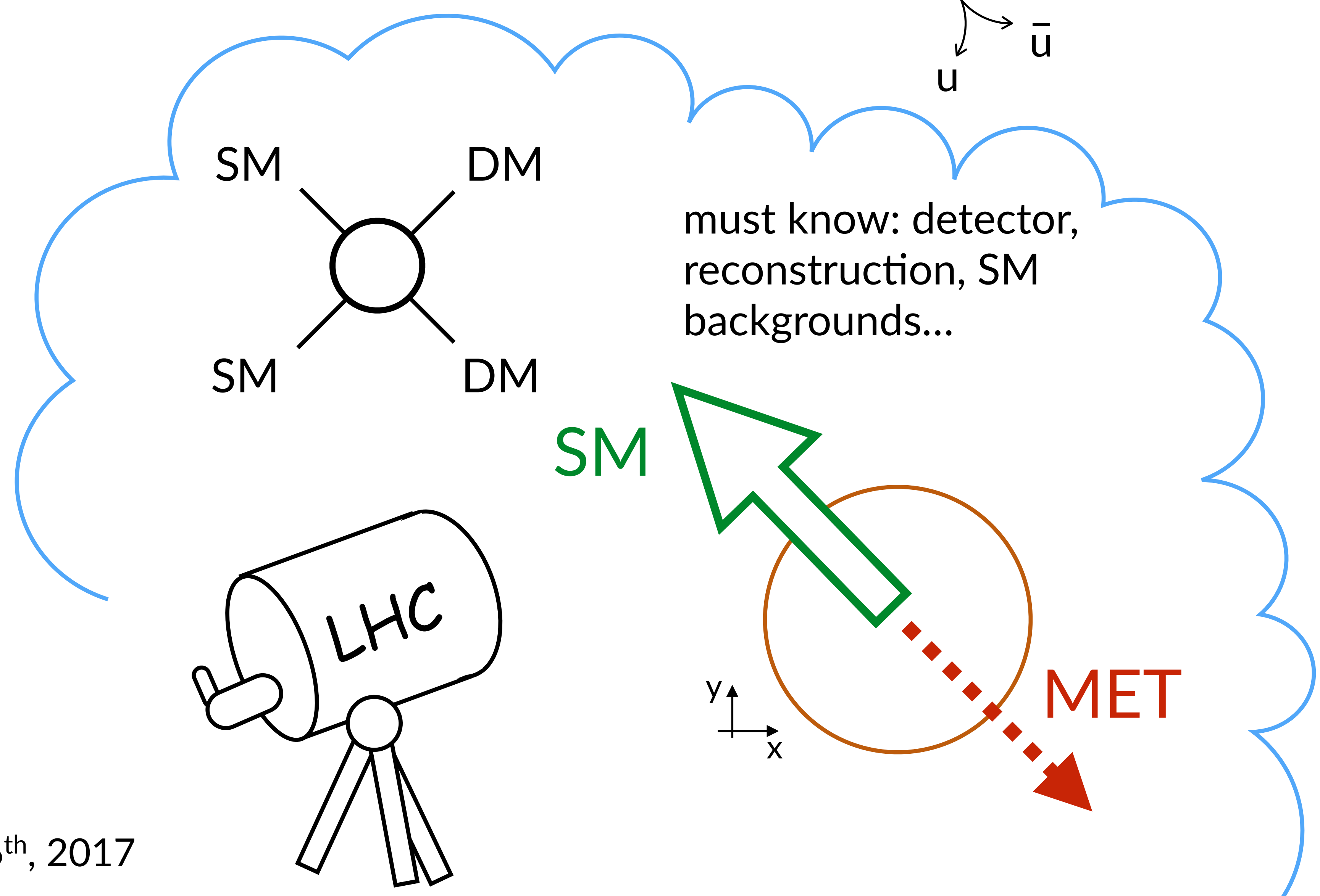


must know: nucleon form factors, DM local density, background levels...

indirect detection







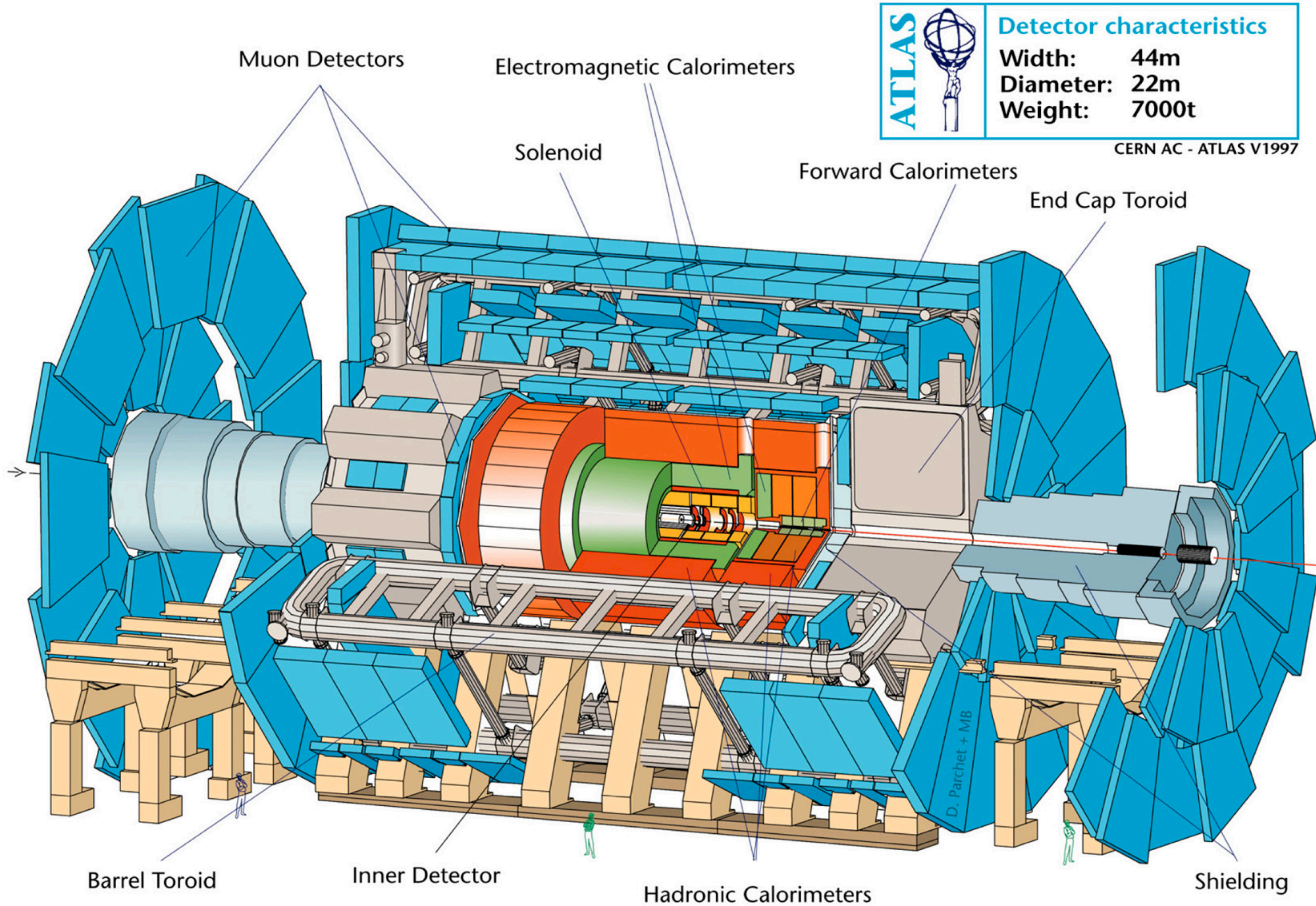
must know: detector, reconstruction, SM backgrounds...

The DM Search Market

can use bb/tt + MET and multiple signatures
(mediator couples à la Yukawa with quark masses)

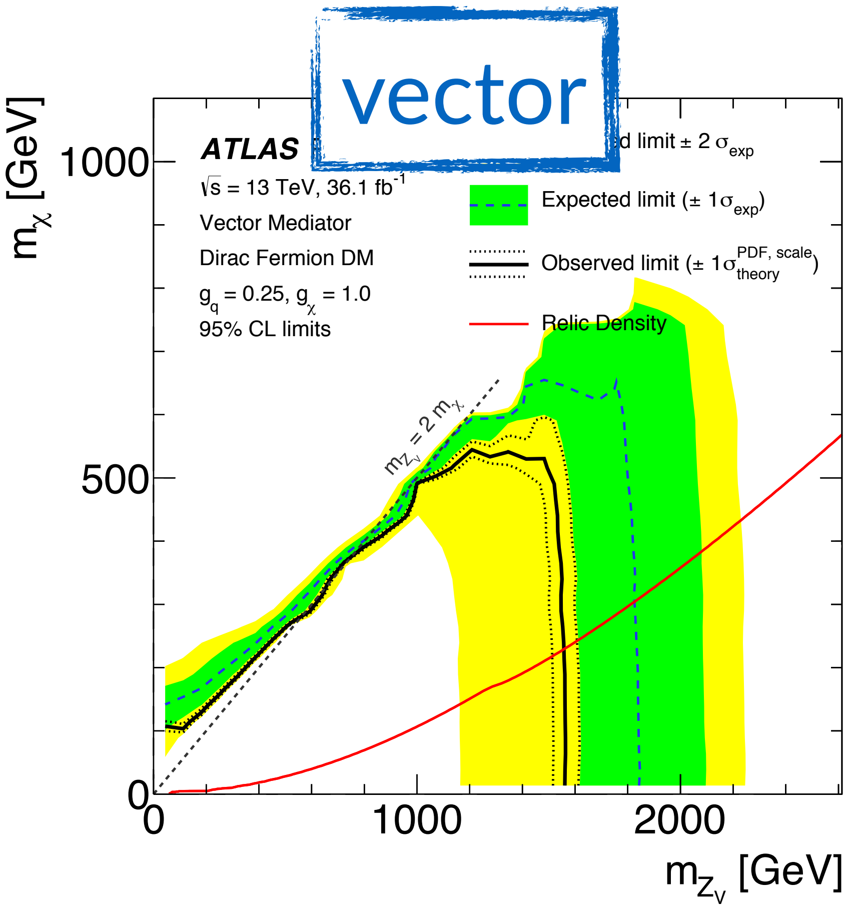
can use jets + MET and confirm with mediator searches
& ancillary channels (MET+gamma, MET+W/Z…)

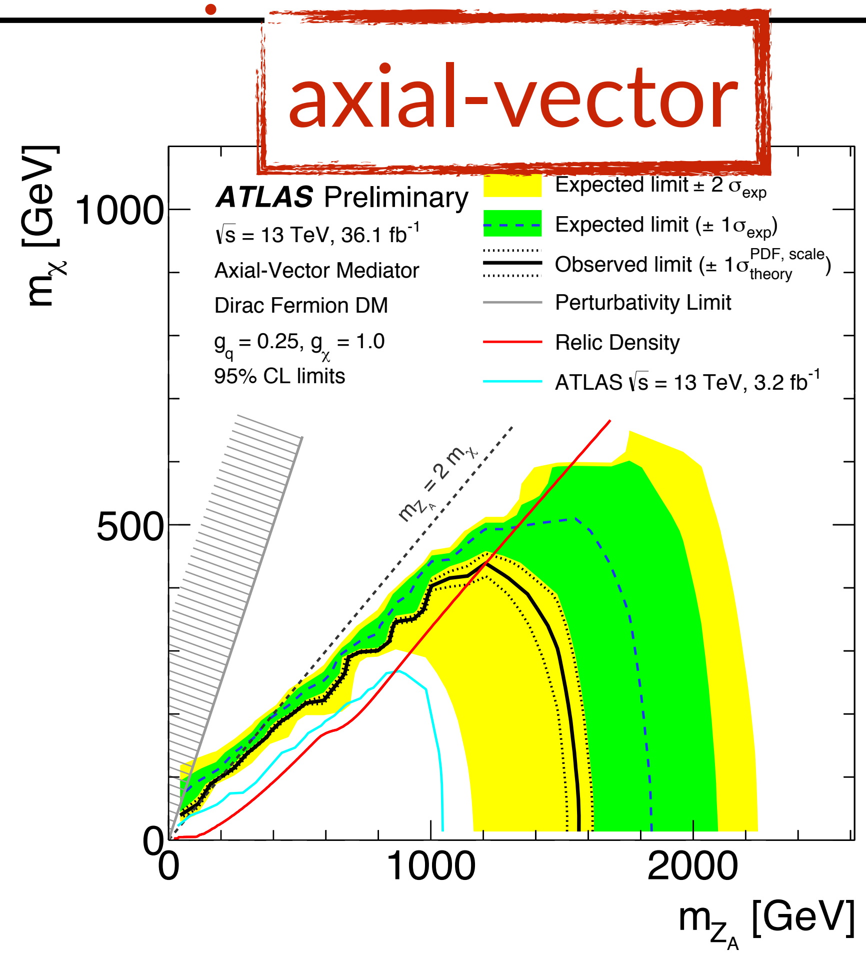
	LHC	direct detection	indirect detection
scalar	low xsec, soft MET	:|	
pseudo-scalar	low xsec, soft MET	:'((velocity suppressed)	:)
vector	large xsec	:) (spin independent)	
axial-vector	large xsec	:((spin-dependent: experimental issue)	

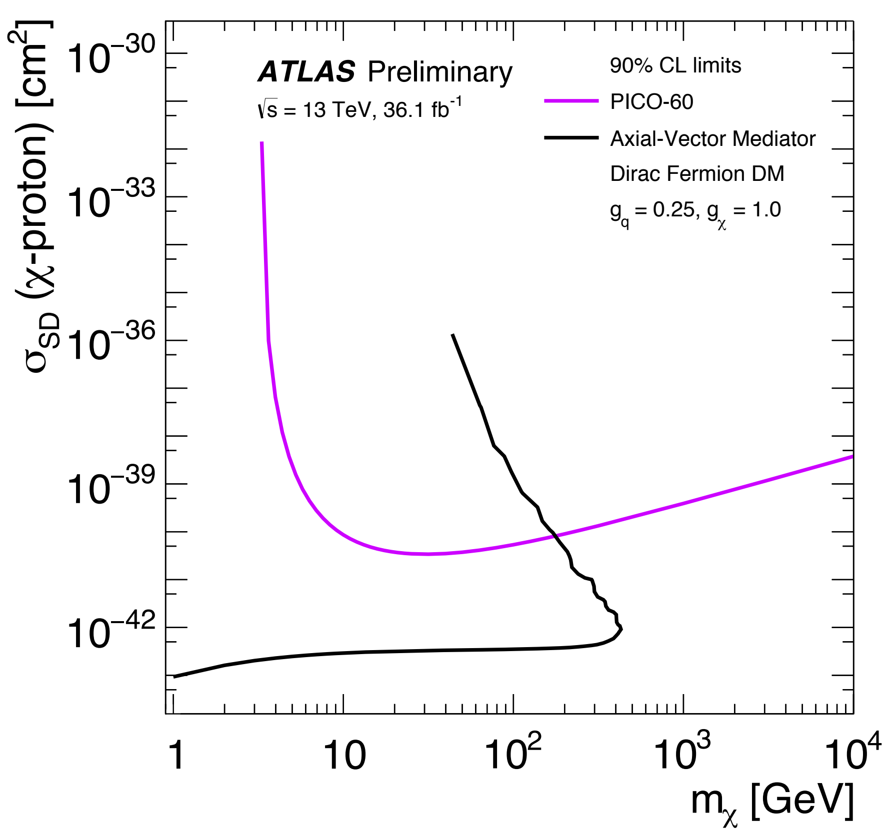


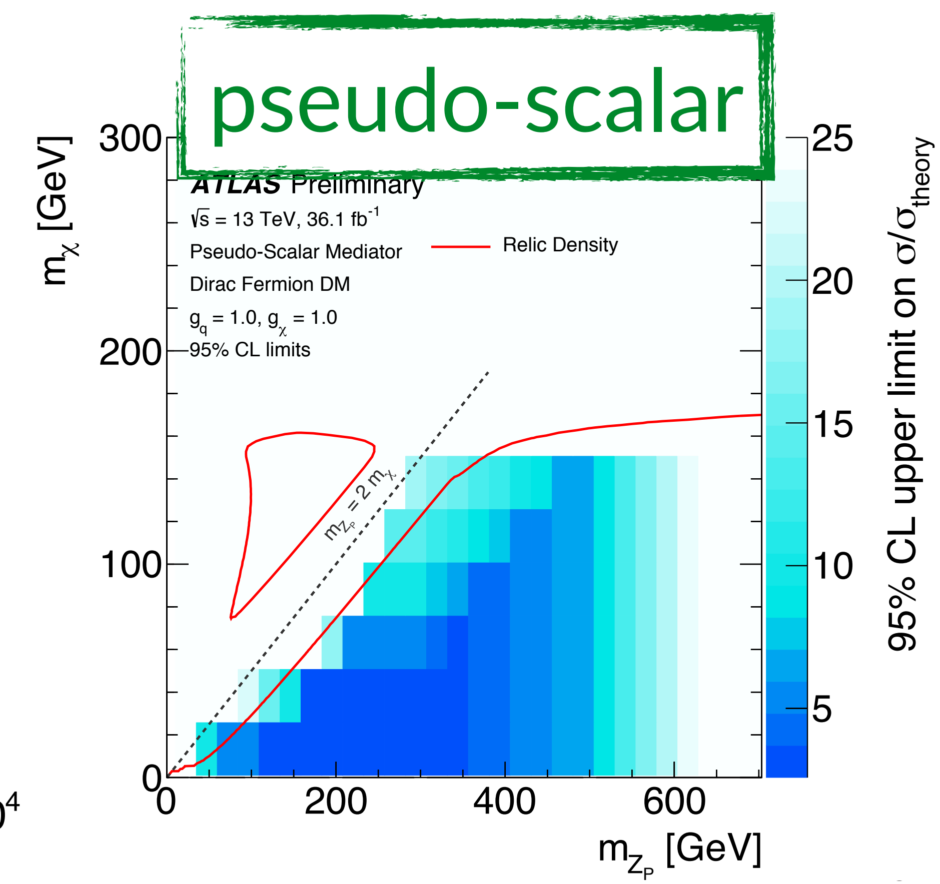
ATLAS
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
D. Parchet + MB
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

MET + JETS RESULTS NEW!



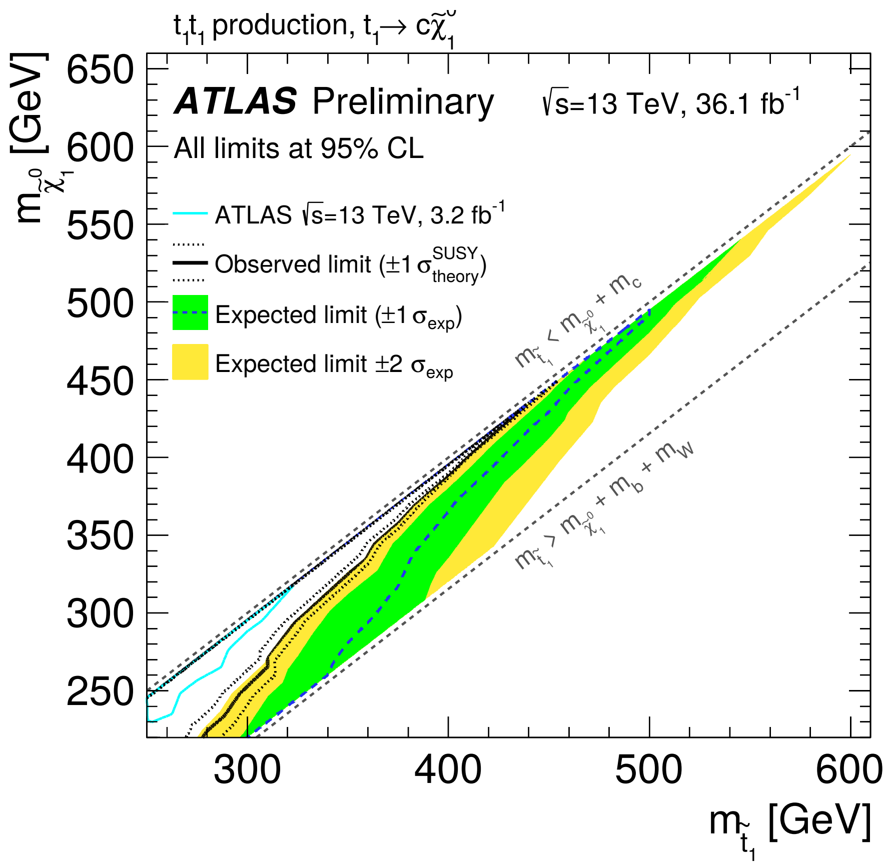


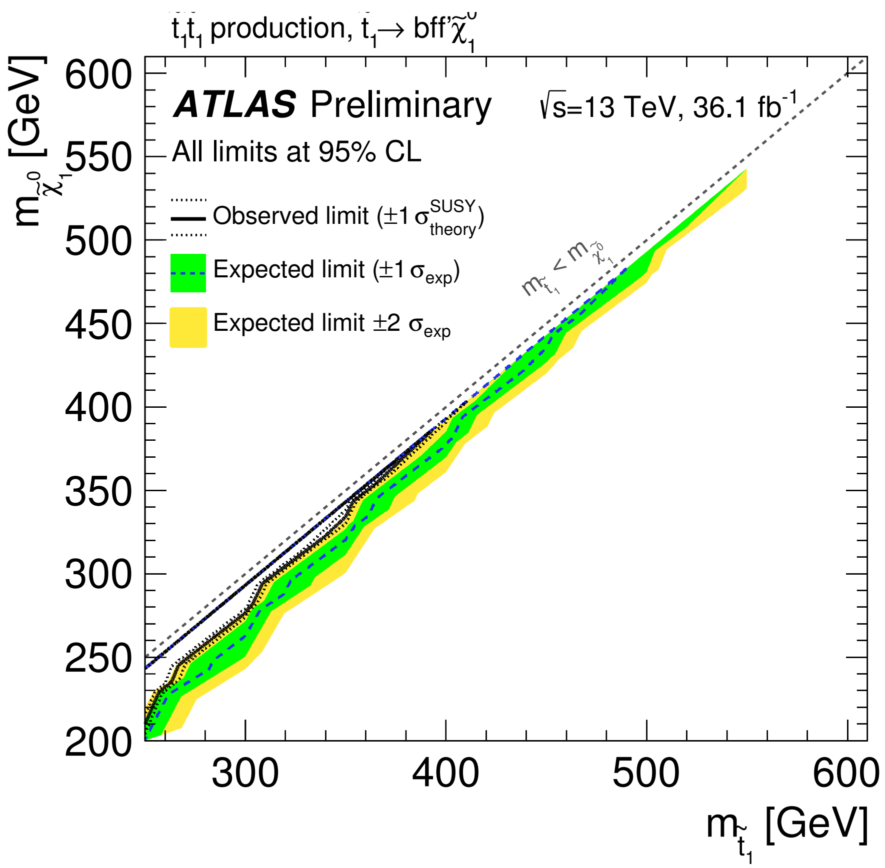


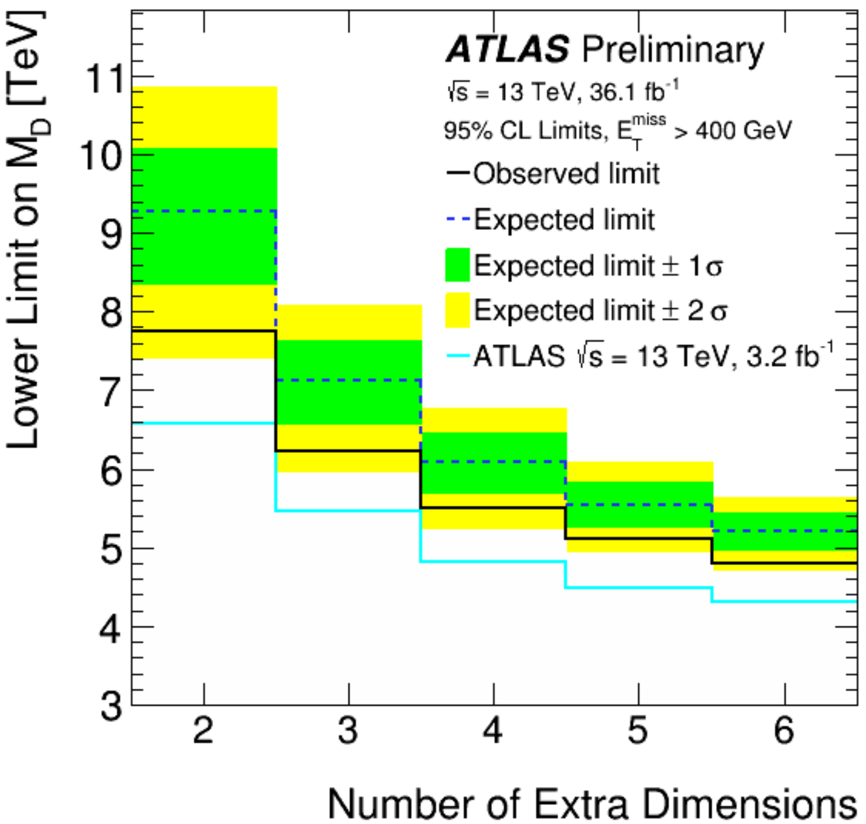


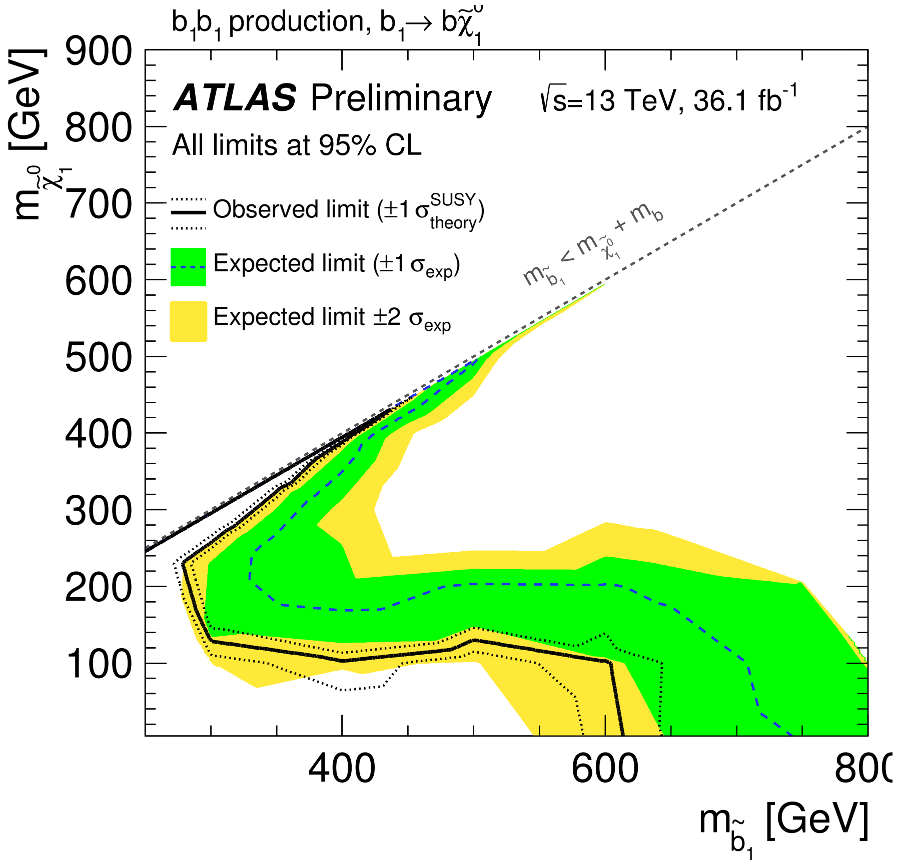
MET + JETS RESULTS (BEYOND DM SIMPLIFIED MODELS)

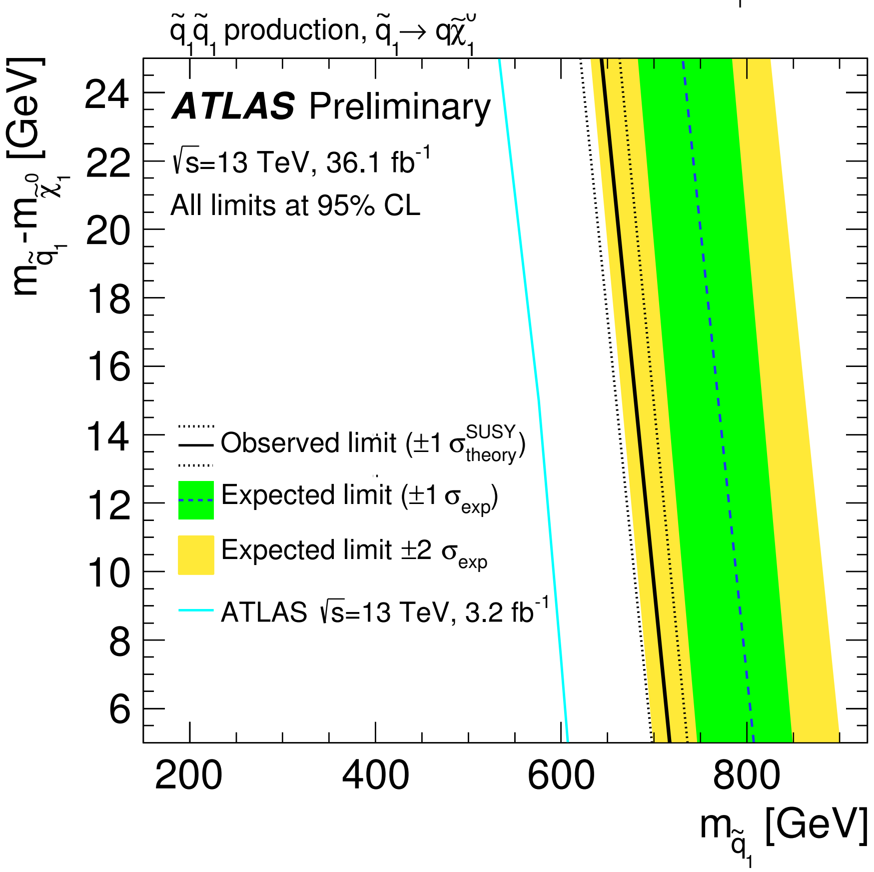
NEW!







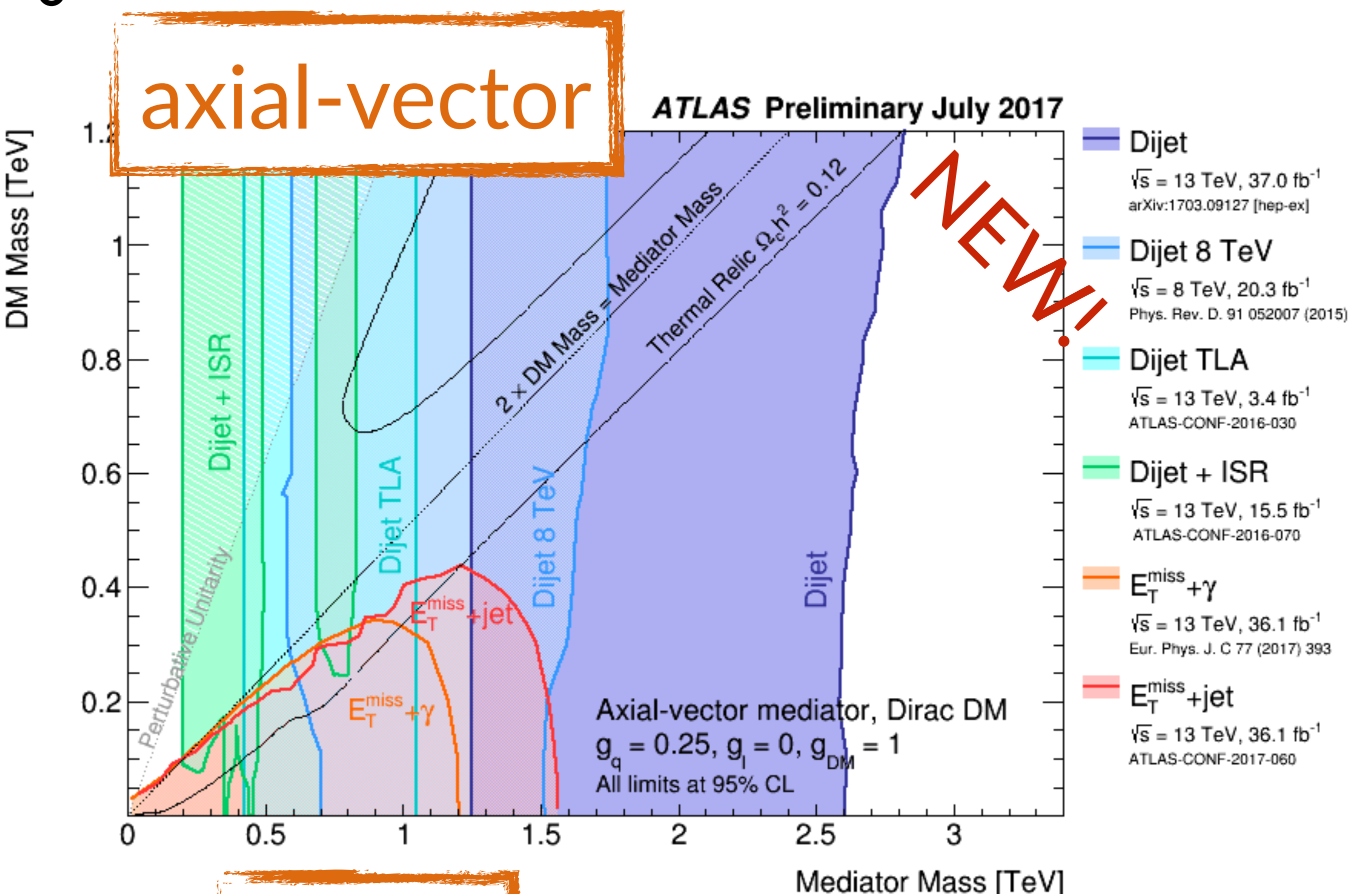


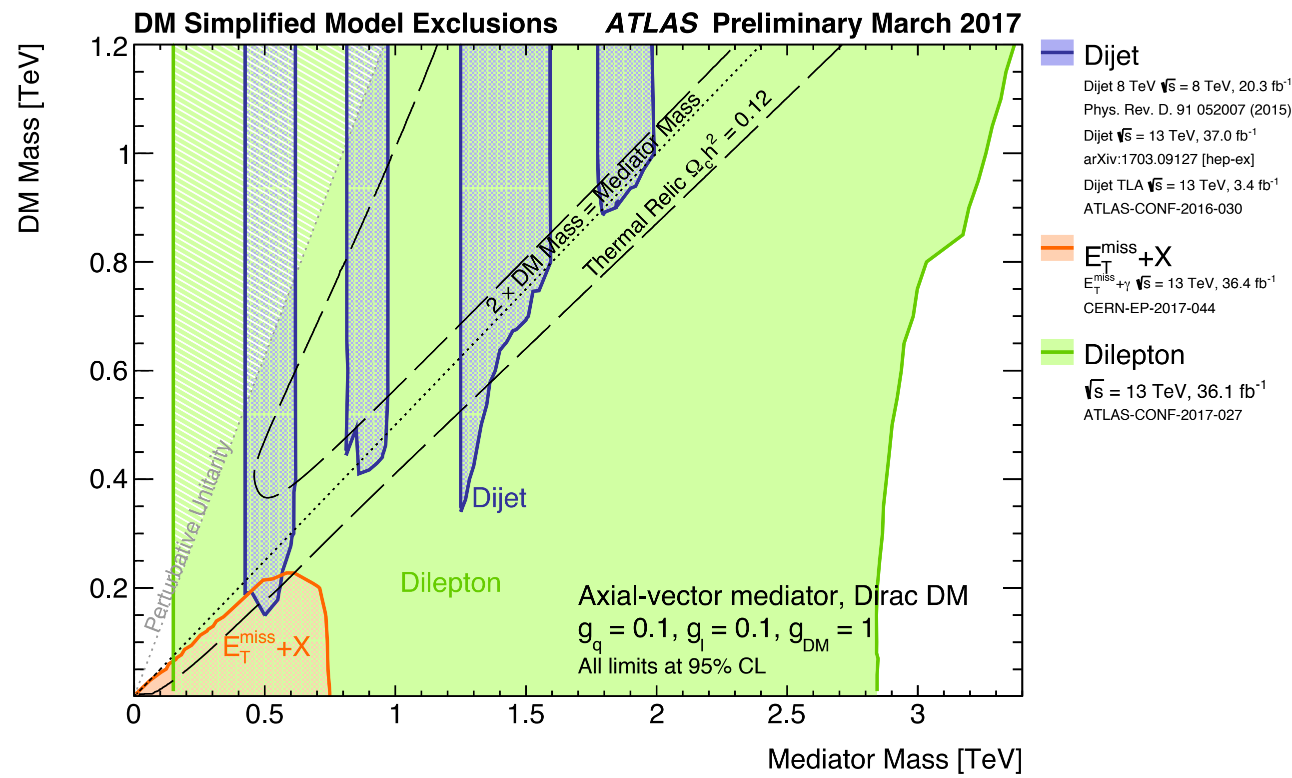


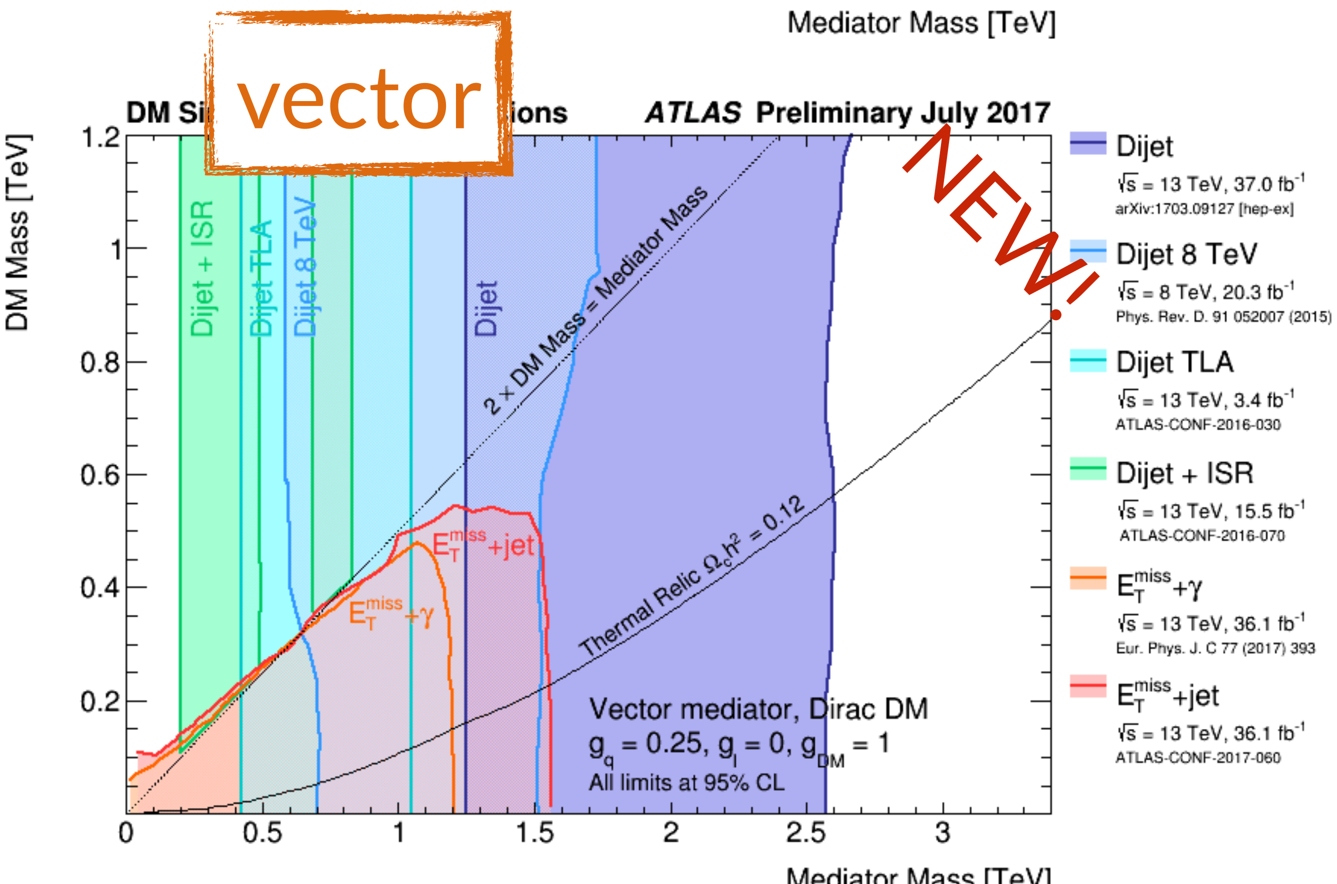
Leptophobic vs Leptophilic

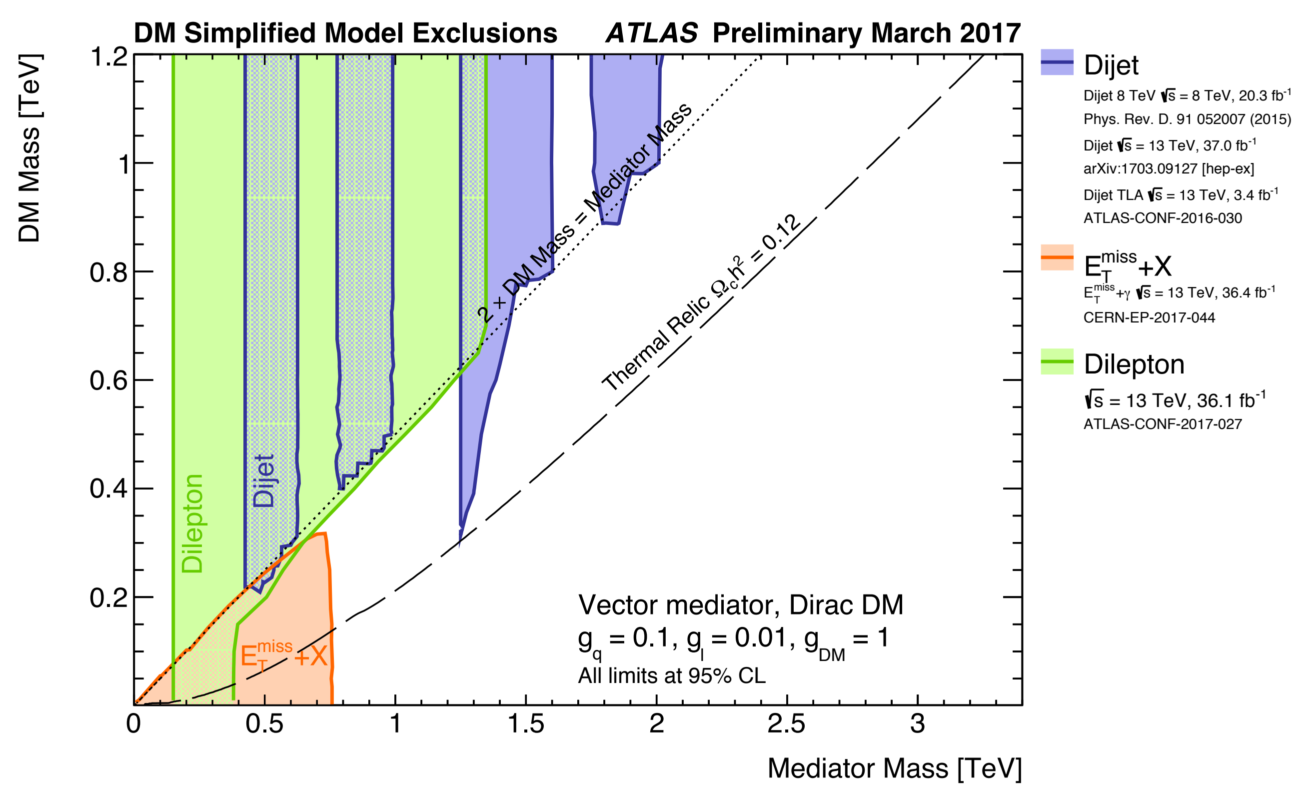
$\sigma_{\mathrm{monojet}} \sim g_q g_{DM}$

$\sigma_{\mathrm{dijet}} \sim g_q^2$









note: results on the right don't have MET+jet

MET+W/Z(HAD)

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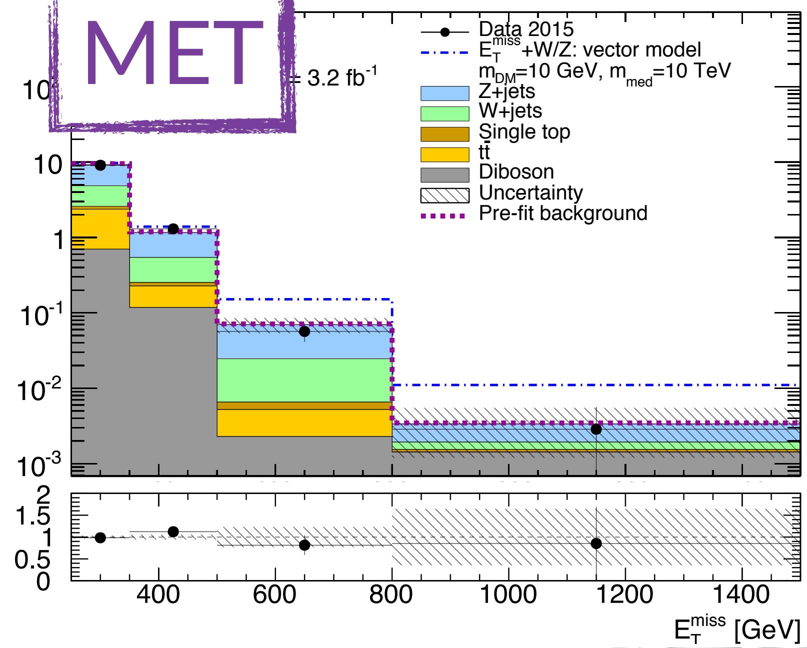
trimmed large-R jet (anti-kT R=1.0), MET > 250 GeV

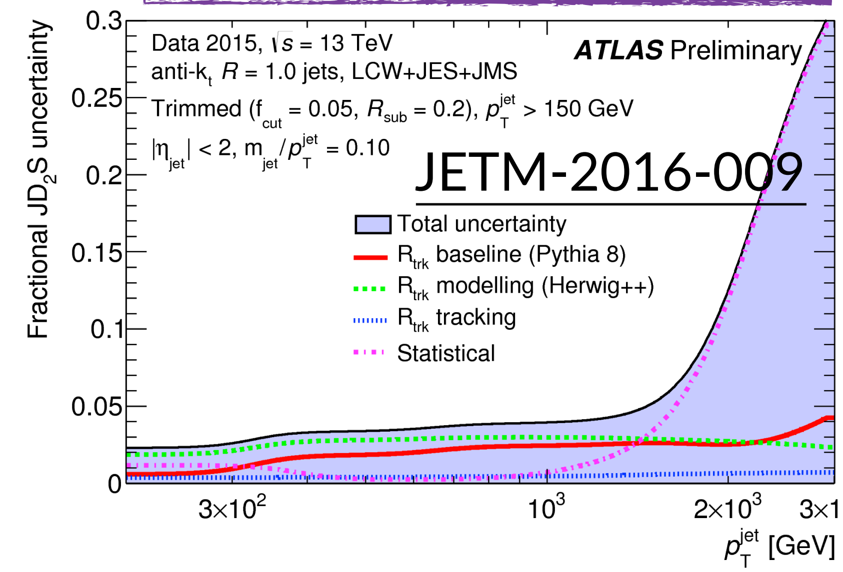
- with 1μ1b CR for reducing ttbar uncertainties

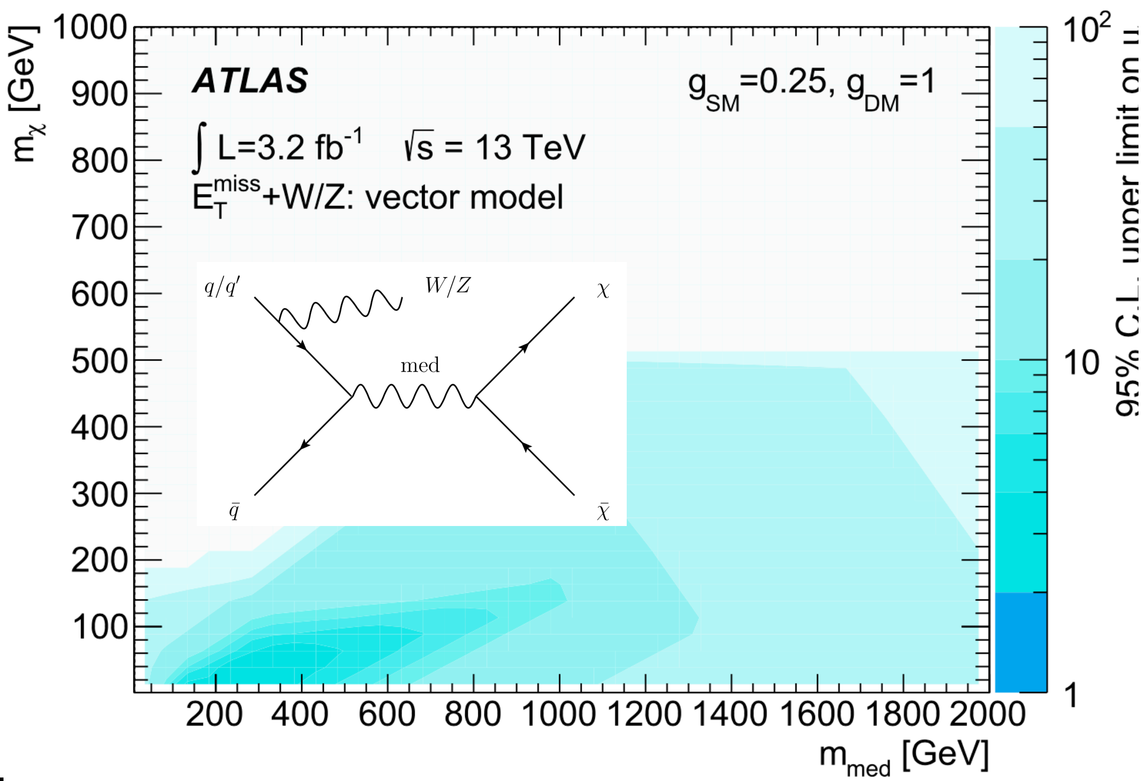
boson tagging based on jet mass and p_T-dependent cut on 2-prongness ("D_2", ε~50%), main uncertainty on total bkg (5-13%)

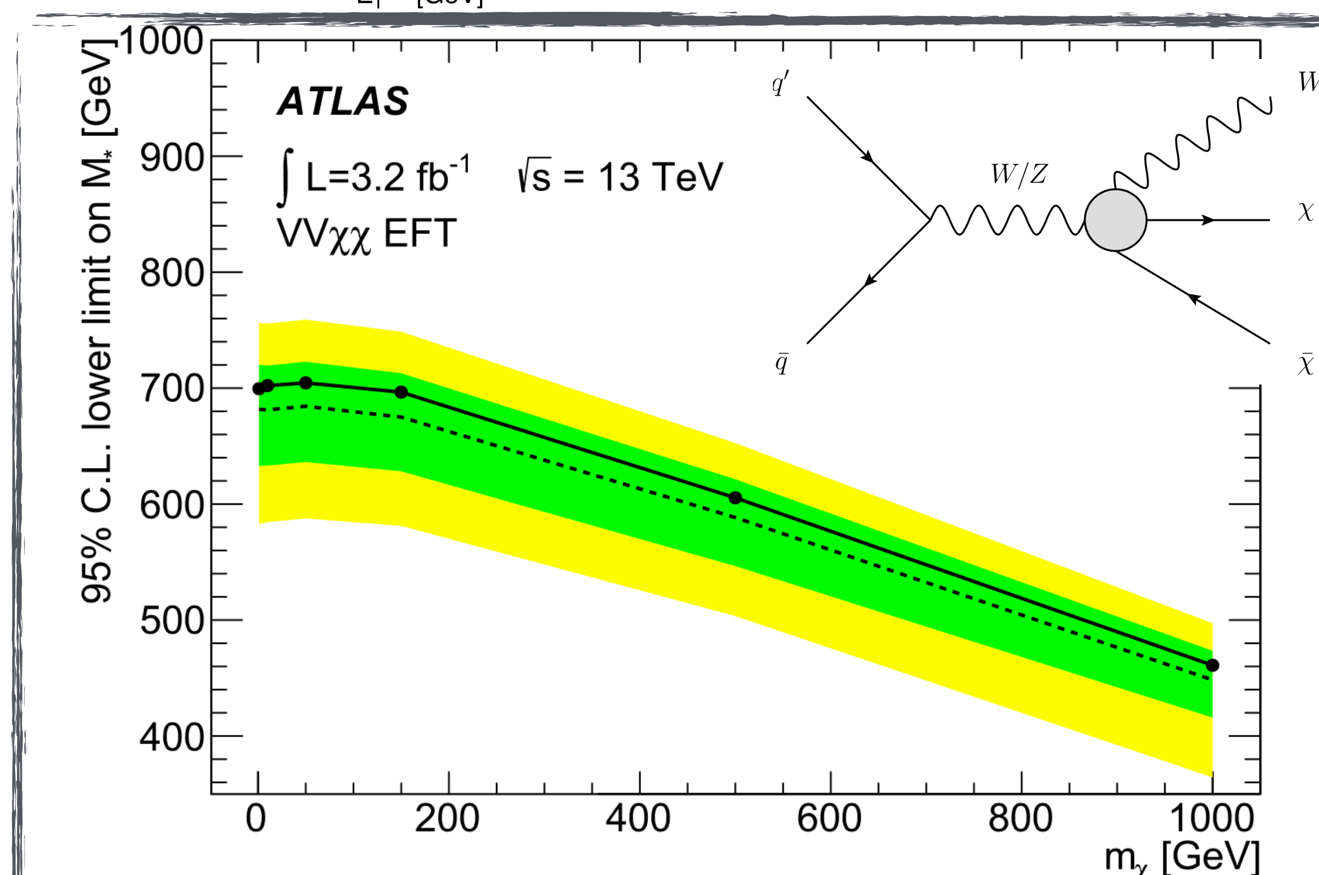
MET



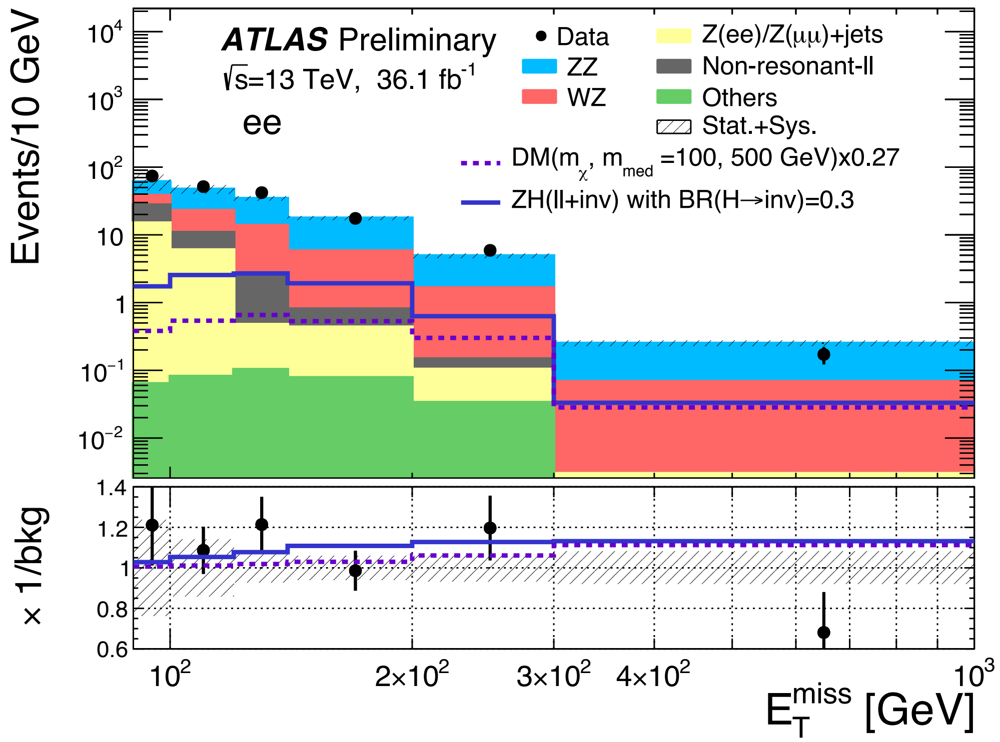
D2 scale uncertainty

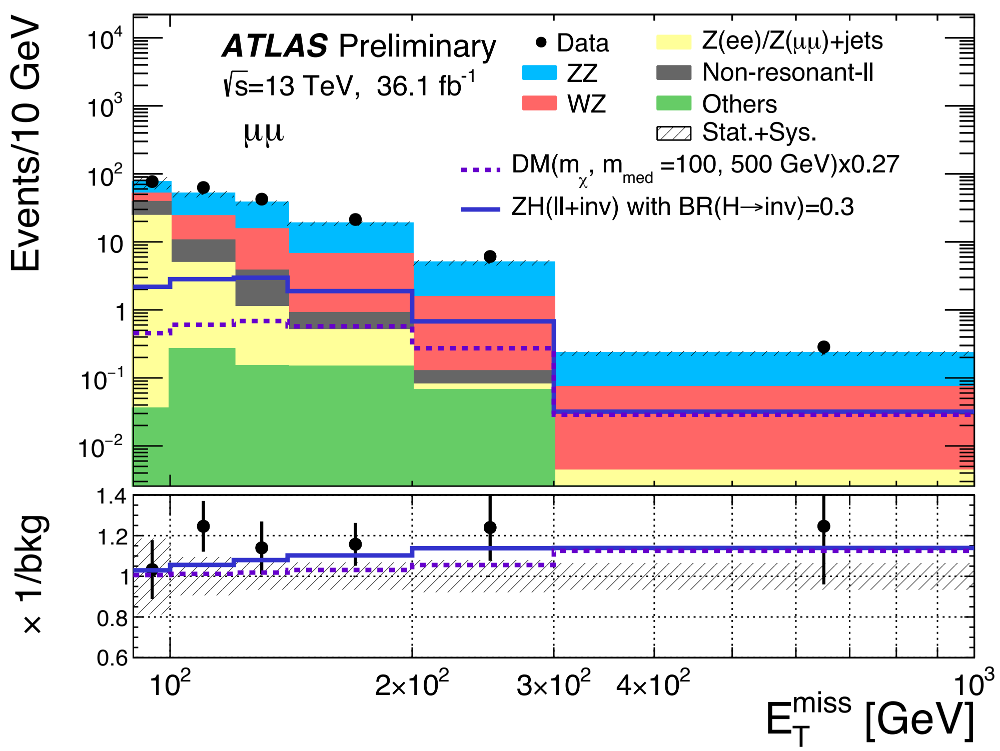






MET+Z(LL) NEW!





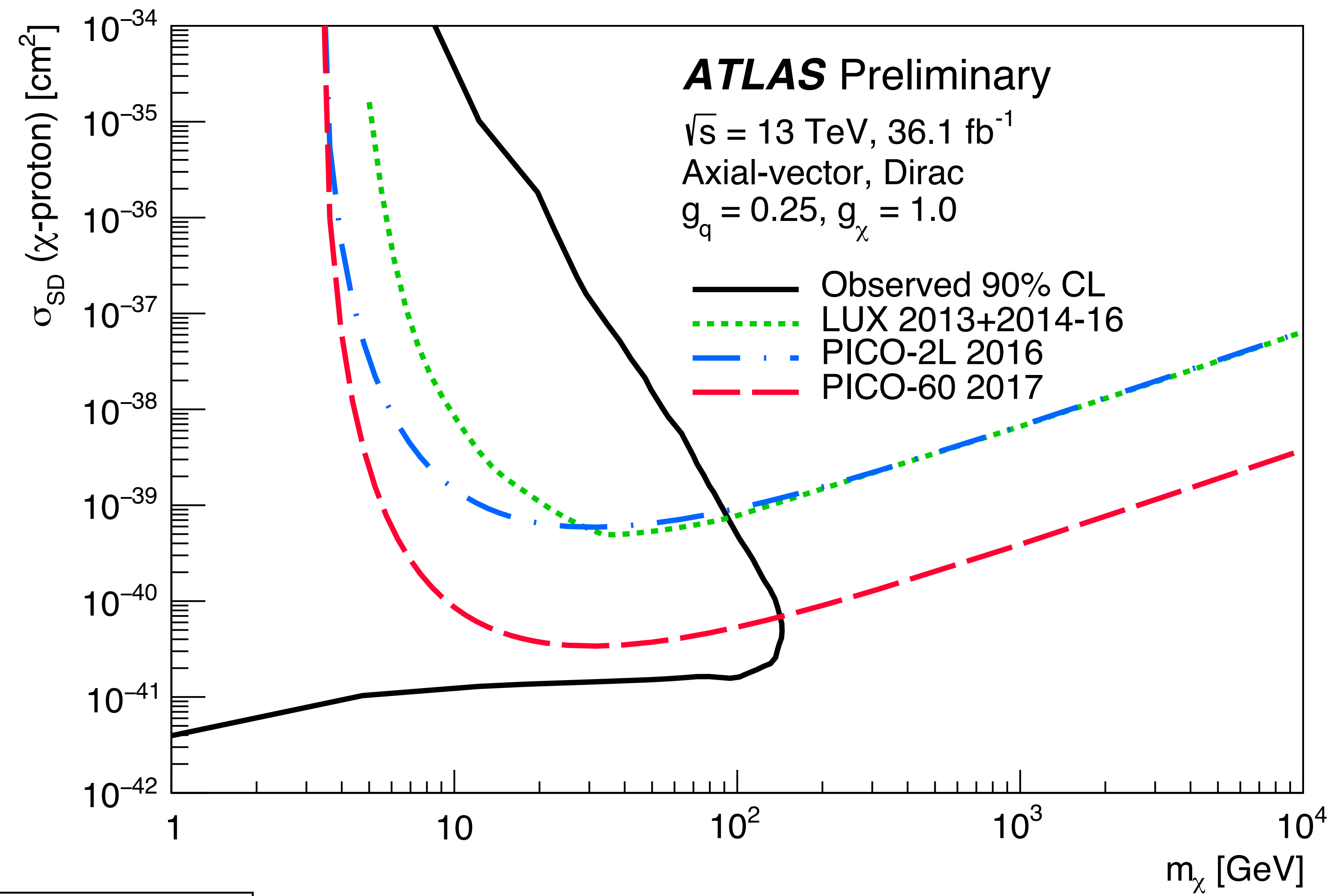
	Selection criteria
Two leptons	Two opposite-sign leptons, leading (subleading) $p_T > 30(20)$ GeV
Third lepton veto	Veto events if any additional lepton with $p_T > 7$ GeV
$m_{\ell\ell}$	$76 < m_{\ell\ell} < 106$ GeV
E_T^{miss} and E_T^{miss}/H_T	$E_T^{miss} > 90$ GeV and $E_T^{miss}/H_T > 0.6$
$\Delta\phi(\vec{p}_T^{\ell\ell}, \vec{E}_T^{miss})$	$\Delta\phi(\vec{p}_T^{\ell\ell}, \vec{E}_T^{miss}) > 2.7$ radians
$\Delta R_{\ell\ell}$	$\Delta R_{\ell\ell} < 1.8$
Fractional p_T difference	$\left\|p_T^{\ell\ell} - p_T^{miss,jet}\right\| / p_T^{\ell\ell} < 0.2$
b-jets veto	$N(b\text{-jets}) = 0$ with b-jet $p_T > 20$ GeV and $\|\eta\| < 2.5$

Final State	ee	$\mu\mu$
Observed Data	437	497
Signal		
$ZH \to \ell\ell + inv$ ($BR_{H\to inv} = 30\%$)	32±1±3	34±1±3
DM ($m_{med} = 500$ GeV, $m_\chi = 100$ GeV) × 0.27	10.8±0.3±0.8	11.1±0.3±0.8
Backgrounds		
$qqZZ$	212±3±15	221±3±17
$ggZZ$	18.9±0.3±11.2	19.3±0.3±11.4
WZ	106±2±6	113±3±5
Z + jets	30±1±28	37±1±19
Non-resonant-$\ell\ell$	30±4±2	33±4±2
Others	1.4±0.1±0.2	2.5±2.0±0.8
Total Background	399±6±34	426±6±28

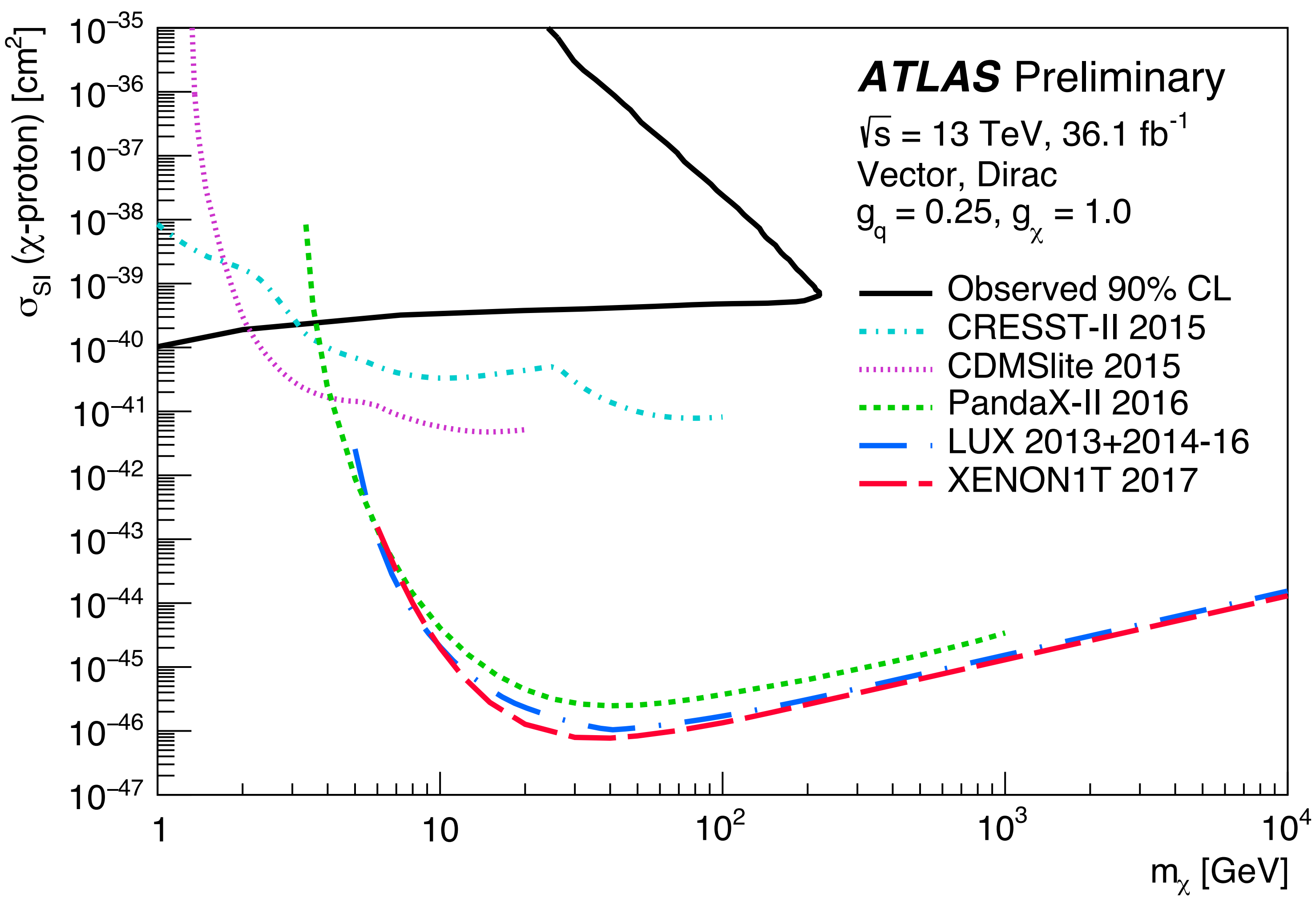
	Exp. $BR_{H\to inv}$ Limit $\pm 1\sigma \pm 2\sigma$	Obs. $BR_{H\to inv}$ Limit
$ee + \mu\mu$	$39\%\ ^{+17\%}_{-11\%}\ ^{+38\%}_{-18\%}$	67%
ee	$51\%\ ^{+21\%}_{-15\%}\ ^{+49\%}_{-24\%}$	59%
$\mu\mu$	$48\%\ ^{+20\%}_{-14\%}\ ^{+46\%}_{-22\%}$	97%

MET + Z(LL)

NEW!



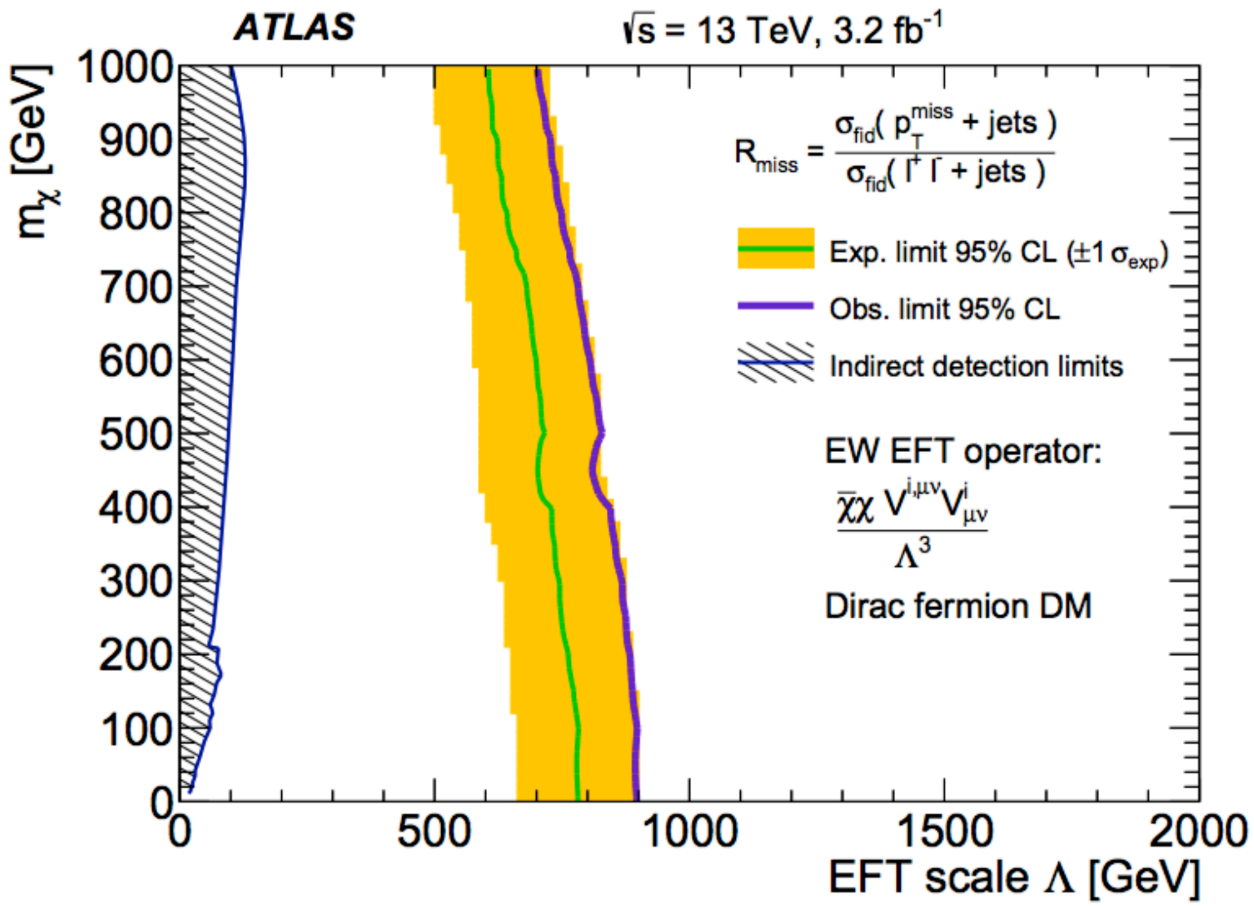
ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
Axial-vector, Dirac
gq = 0.25, gχ = 1.0
Observed 90% CL
LUX 2013+2014-16
PICO-2L 2016
PICO-60 2017
σSD (χ-proton) [cm2]
mχ [GeV]



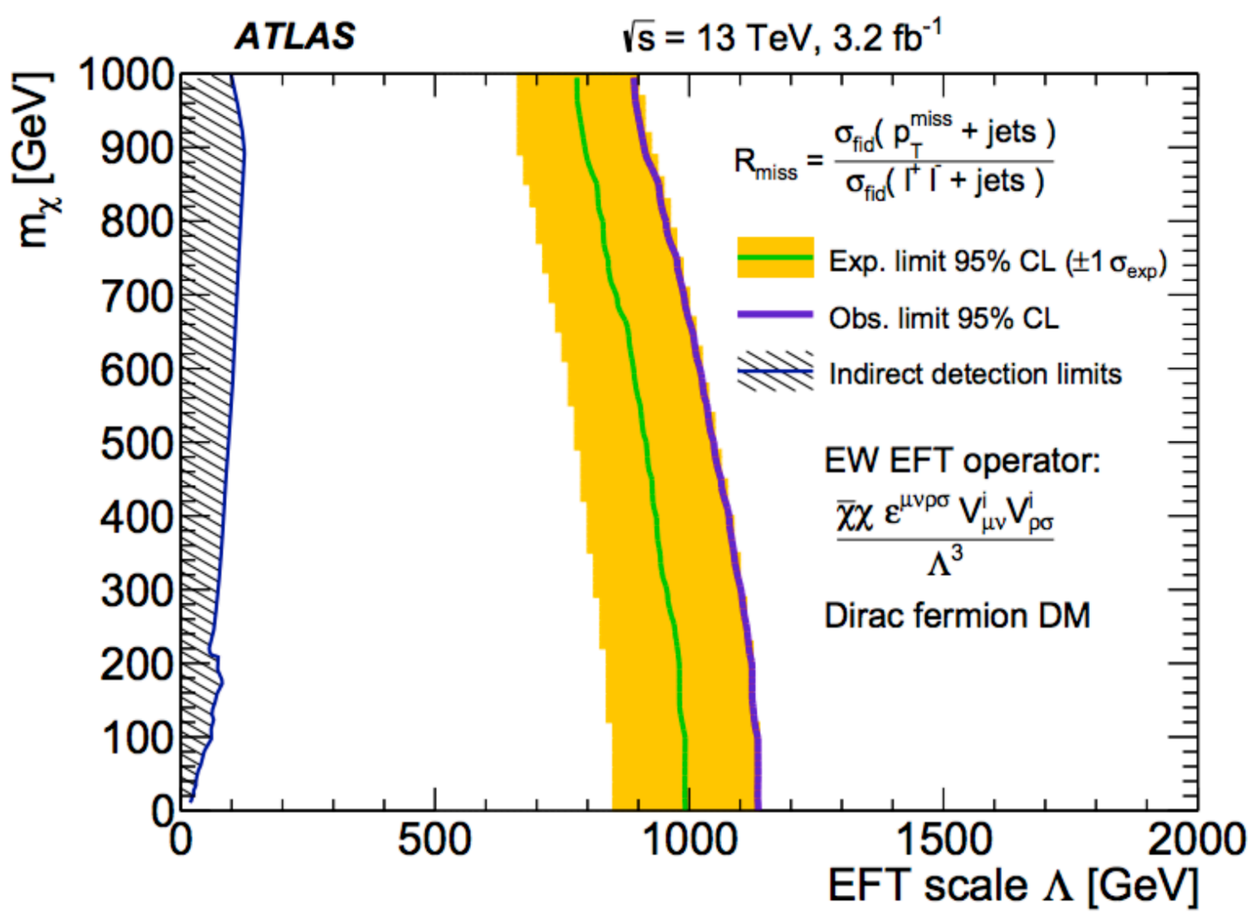
ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
Vector, Dirac
gq = 0.25, gχ = 1.0
Observed 90% CL
CRESST-II 2015
CDMSlite 2015
PandaX-II 2016
LUX 2013+2014-16
XENON1T 2017
σSI (χ-proton) [cm2]
mχ [GeV]

Z(νν)/Z(ll) cross-section ratio measurement

NEW!



VBF EFT model



Z(νν)/Z(ll) cross-section ratio measurement

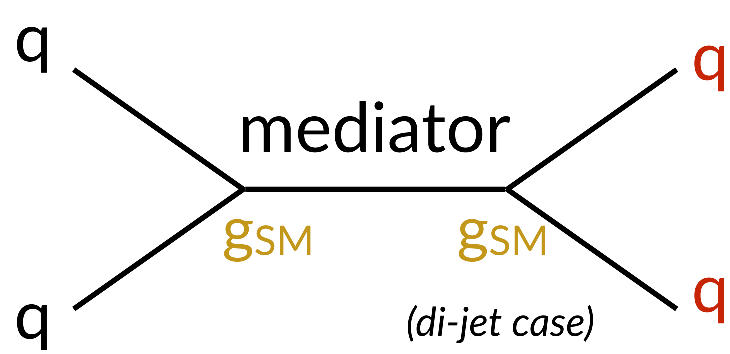
NEW!

Numerator and denominator	≥ 1 jet	VBF
p_T^{miss}	> 200 GeV	
(Additional) lepton veto	No e, μ with $p_T > 7$ GeV, $\lvert\eta\rvert < 2.5$	
Jet $\lvert y\rvert$	< 4.4	
Jet p_T	> 25 GeV	
$\Delta\phi_{\text{jet}_i, p_T^{miss}}$	> 0.4, for the four leading jets with $p_T > 30$ GeV	
Leading jet p_T	> 120 GeV	> 80 GeV
Subleading jet p_T	–	> 50 GeV
Leading jet $\lvert\eta\rvert$	< 2.4	–
m_{jj}	–	> 200 GeV
Central-jet veto	–	No jets with $p_T > 25$ GeV
Denominator only	≥ 1 jet and VBF	
Leading lepton p_T	> 80 GeV	
Subleading lepton p_T	> 7 GeV	
Lepton $\lvert\eta\rvert$	< 2.5	
$m_{\ell\ell}$	66–116 GeV	
ΔR (jet, lepton)	> 0.5, otherwise jet is removed	

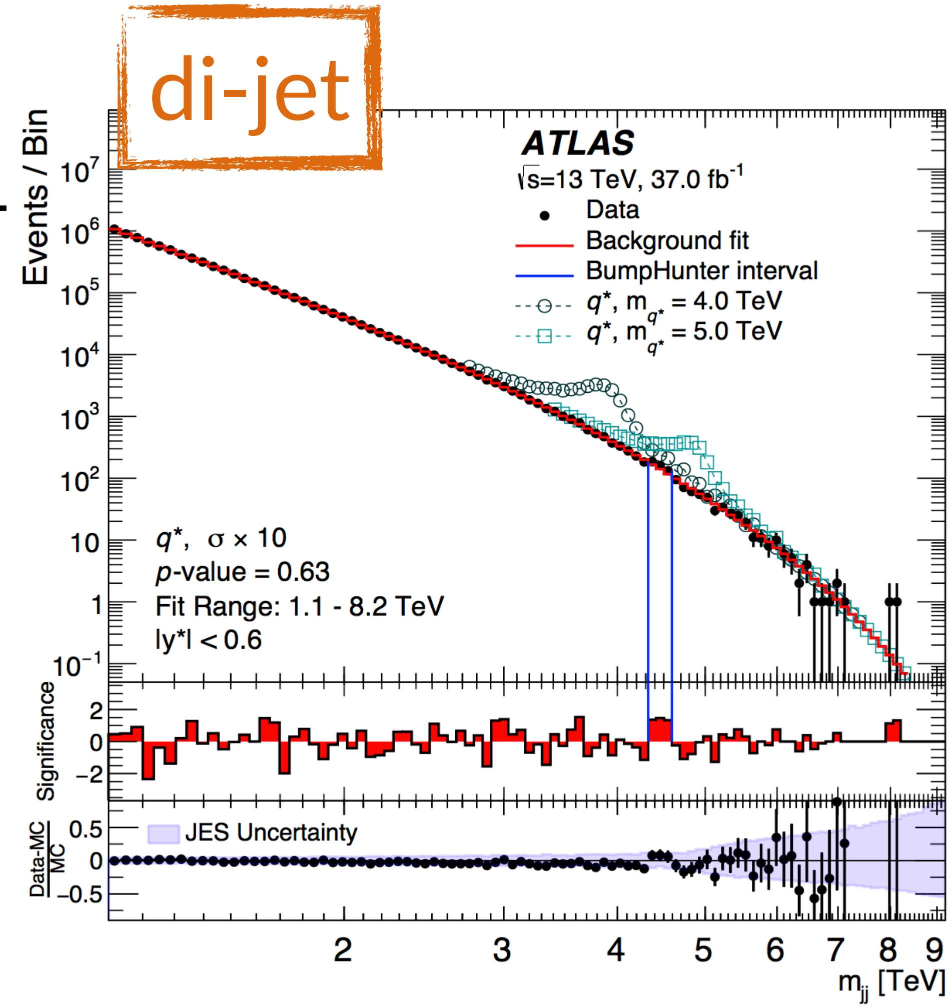
Z(νν)/Z(ll) cross-section ratio measurement NEW!

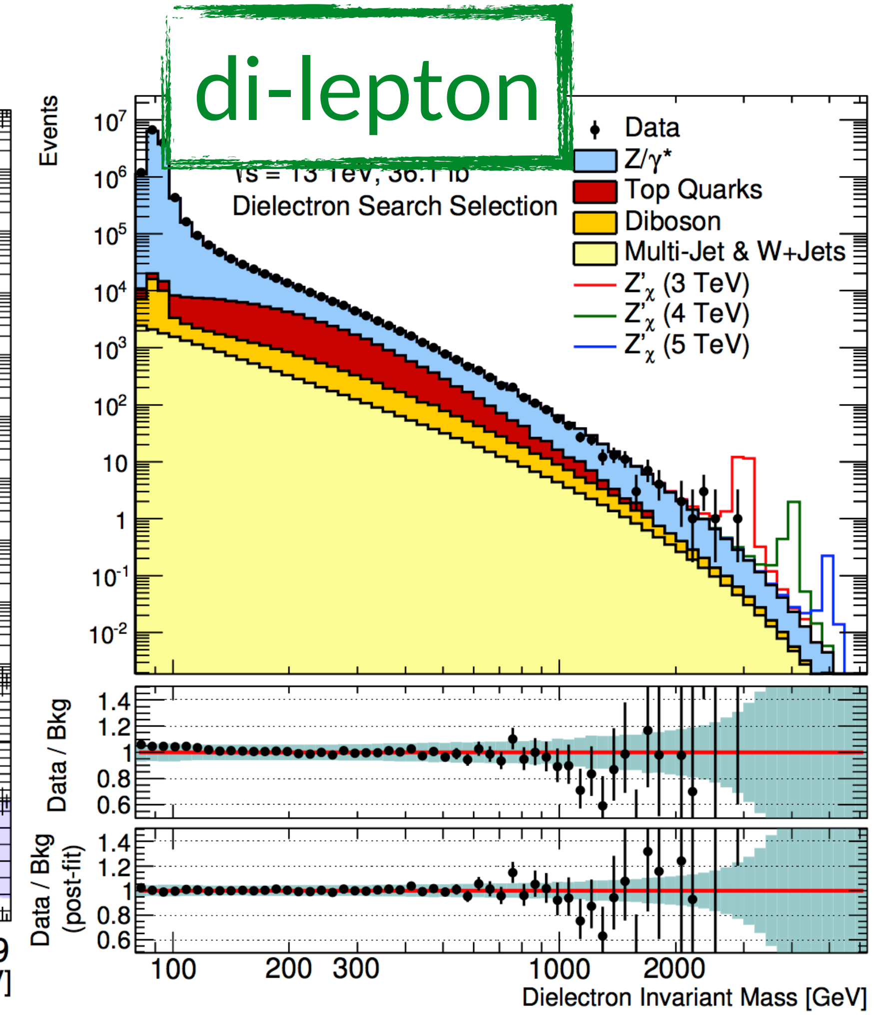
Systematic uncertainty source	Low $p_{\mathrm{T}}^{\mathrm{miss}}$ [%]	High $p_{\mathrm{T}}^{\mathrm{miss}}$ [%]	Low m_{jj} [%]	High m_{jj} [%]
Lepton efficiency	+3.5, −3.5	+7.6, −7.1	+3.7, −3.6	+4.6, −4.4
Jets	+0.8, −0.7	+2.2, −2.8	+1.1, −1.0	+9.0, −0.5
$W \to \tau\nu$ from control region	+1.2, −1.2	+4.6, −4.6	+1.3, −1.3	+3.9, −3.9
Multijet	+1.8, −1.8	+0.9, −0.9	+1.4, −1.4	+2.5, −2.5
Correction factor statistical	+0.2, −0.2	+2.0, −1.9	+0.4, −0.4	+3.8, −3.6
W statistical	+0.5, −0.5	+24, −24	+1.1, −1.1	+6.8, −6.8
W theory	+2.4, −2.3	+6.0, −2.3	+3.1, −3.0	+4.9, −5.1
Top cross-section	+1.5, −1.8	+1.3, −0.1	+1.1, −1.2	+0.5, −0.4
$Z \to \ell\ell$ backgrounds	+0.9, −0.8	+1.1, −1.1	+1.0, −1.0	+0.1, −0.1
Total systematic uncertainty	+5.2, −5.2	+27, −26	+5.6, −5.5	+14, −11
Statistical uncertainty	+1.7, −1.7	+83, −44	+3.5, −3.4	+35, −25
Total uncertainty	+5.5, −5.4	+87, −51	+6.6, −6.5	+38, −27

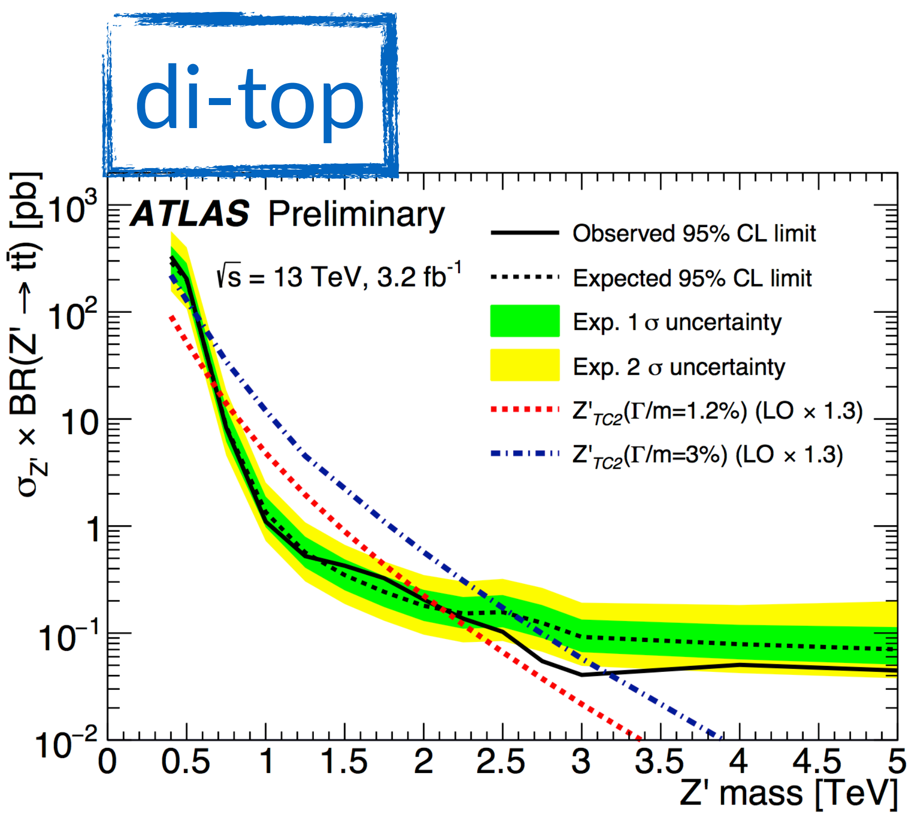
Di-X

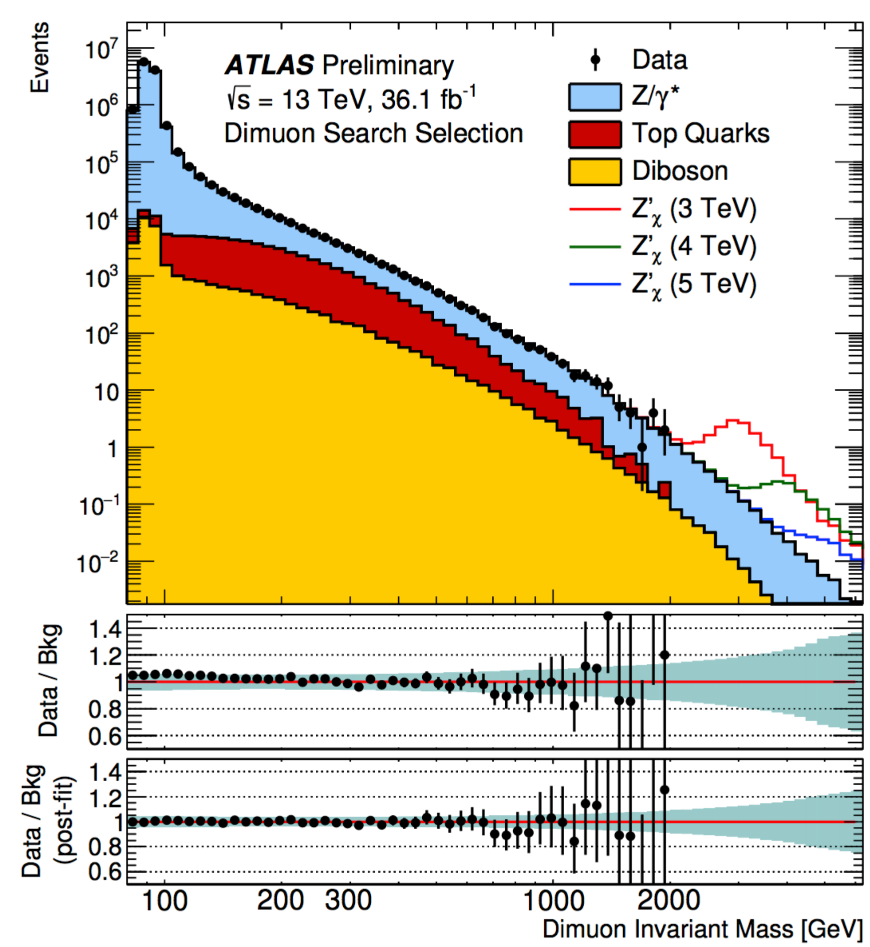


- look directly for the mediator of the SM-DM interaction
  - di-jet below 1 TeV uses data-scouting and ISR tagging
- if mediator couples to leptons, strong constraints from di-lepton searches
  - ttbar resonance searches could also contribute in spin-0 scenarios









Data Scouting ("TLA") @ ATLAS

problem: limited trigger rate -> high pT threshold for single jet triggers

- 100 kHz @ L1 -> pT(single jet) > ~400 GeV

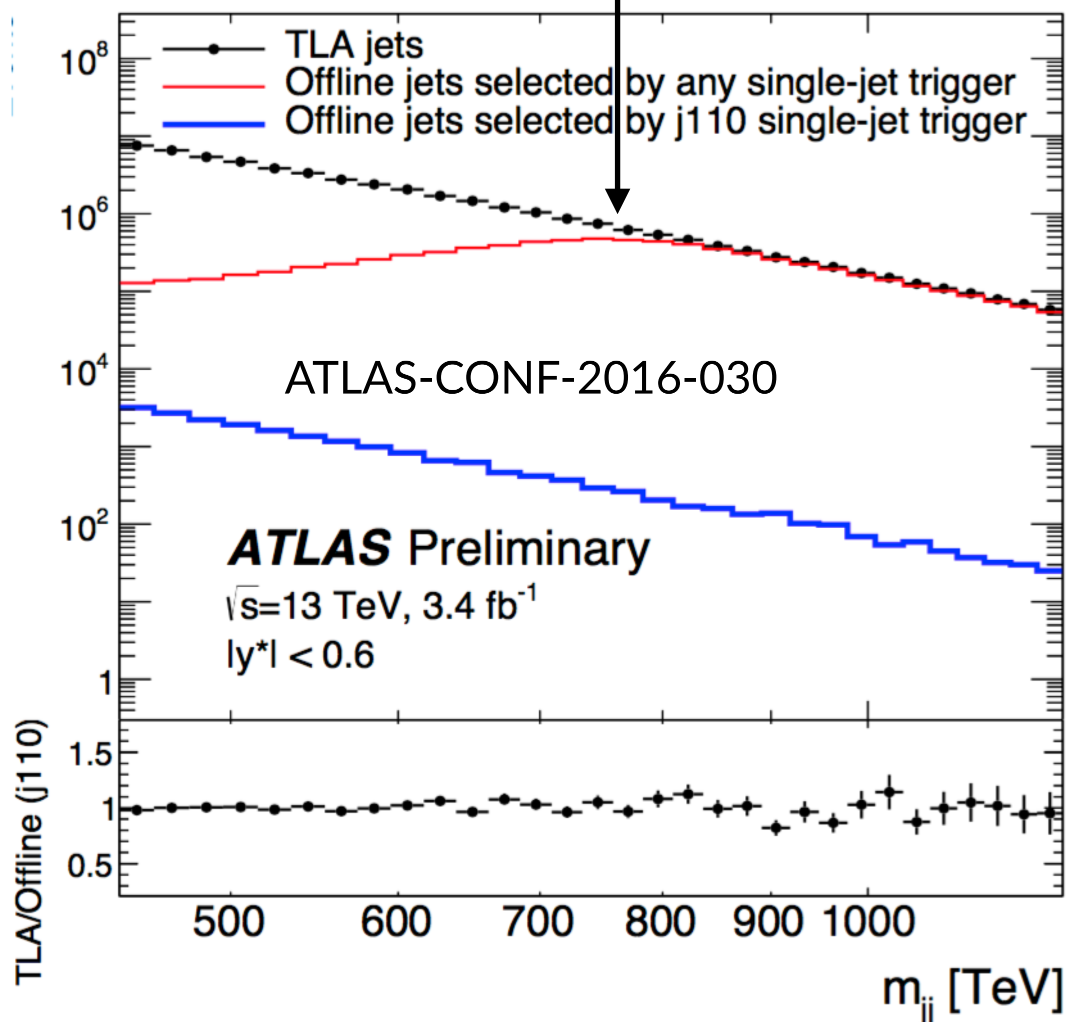
solution: store only minimal jet information

- start with 75 GeV L1 trigger (+2 kHz; EM scale)
- save all HLT jets above 4 GeV (~5% of total event size)
- calibrate them using offline jets
  - no tracking info -> 3.5-5% systematics (mostly due to flavour uncertainties)

dijet search using trigger-level jets

- pT1>185 GeV, pT2>85 GeV
- |y*|<0.3 (for m_{jj}<550 GeV) or < 0.6 (m_{jj}>550 GeV)

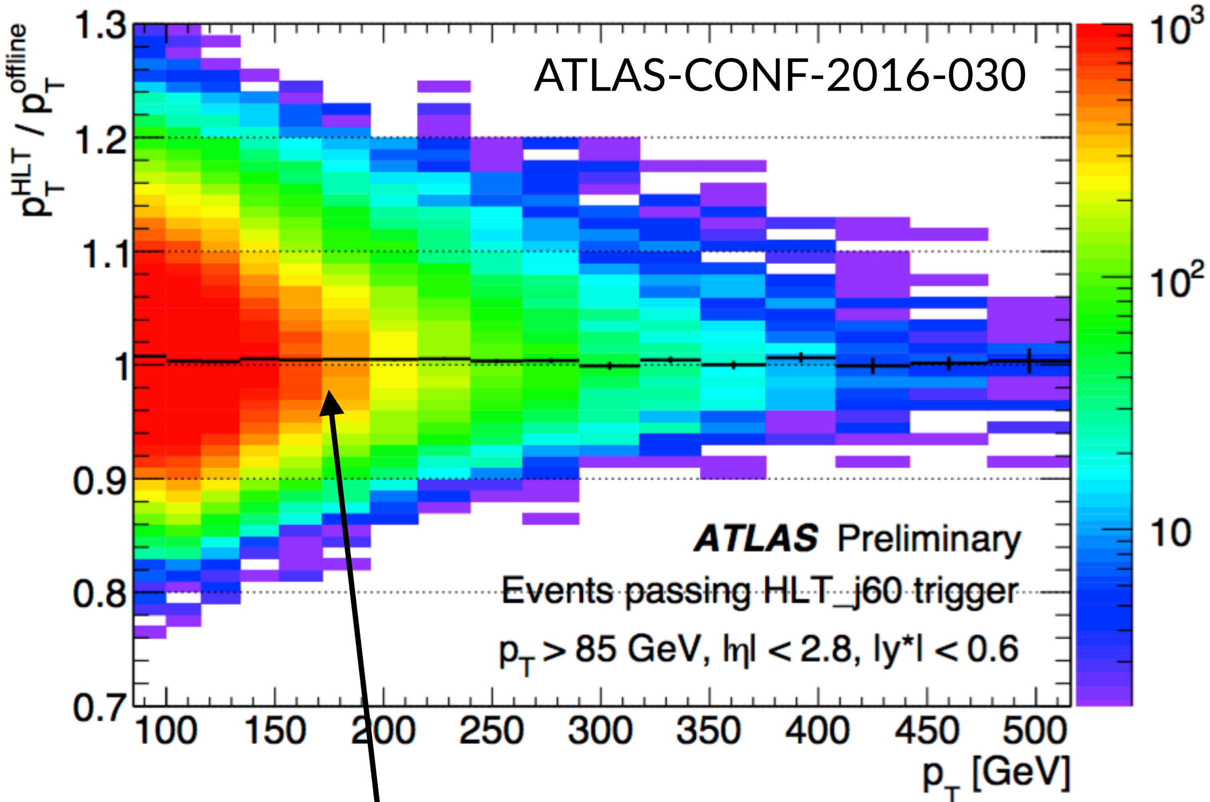
first unprescaled single jet trigger at p_T > 400 GeV



"offline" dijet search

Trigger-level Jets vs Offline Jets

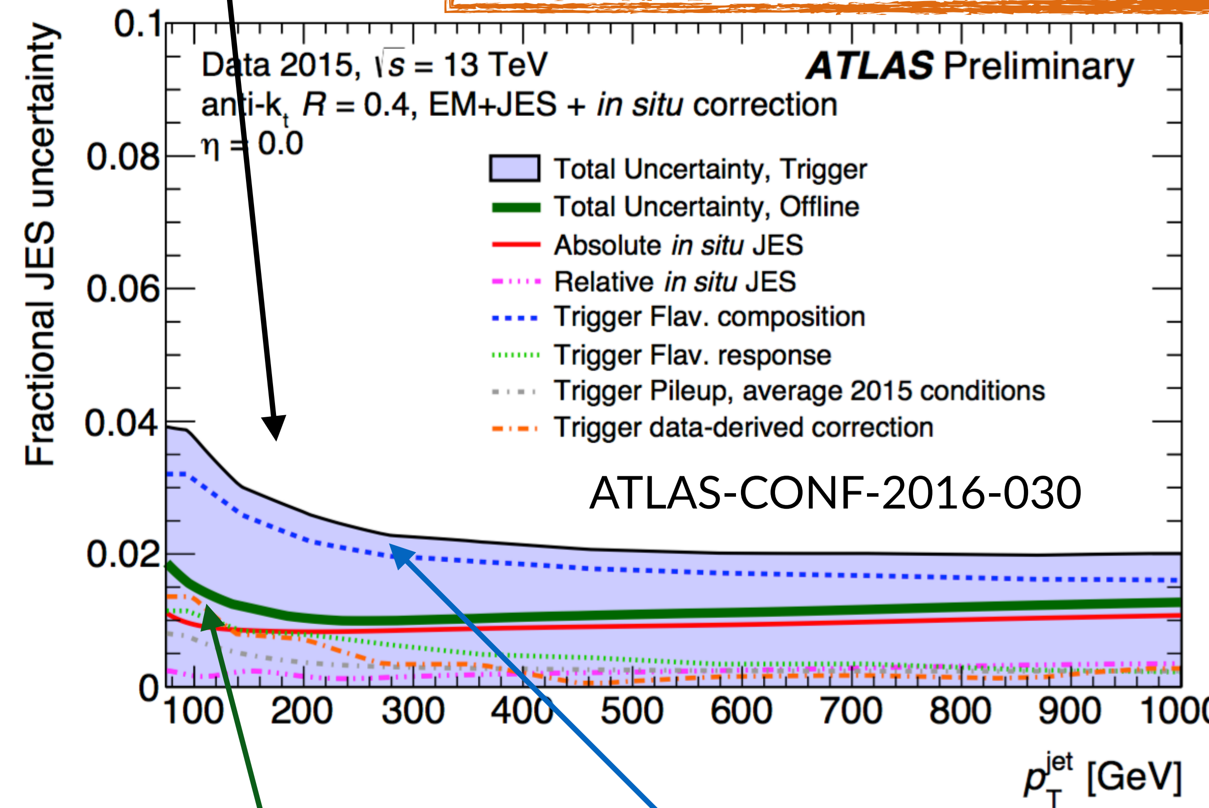
pT(trigger)/pT(offline) vs pT



trigger/offline pT response within ~1%

trigger jet total

energy scale uncertainty



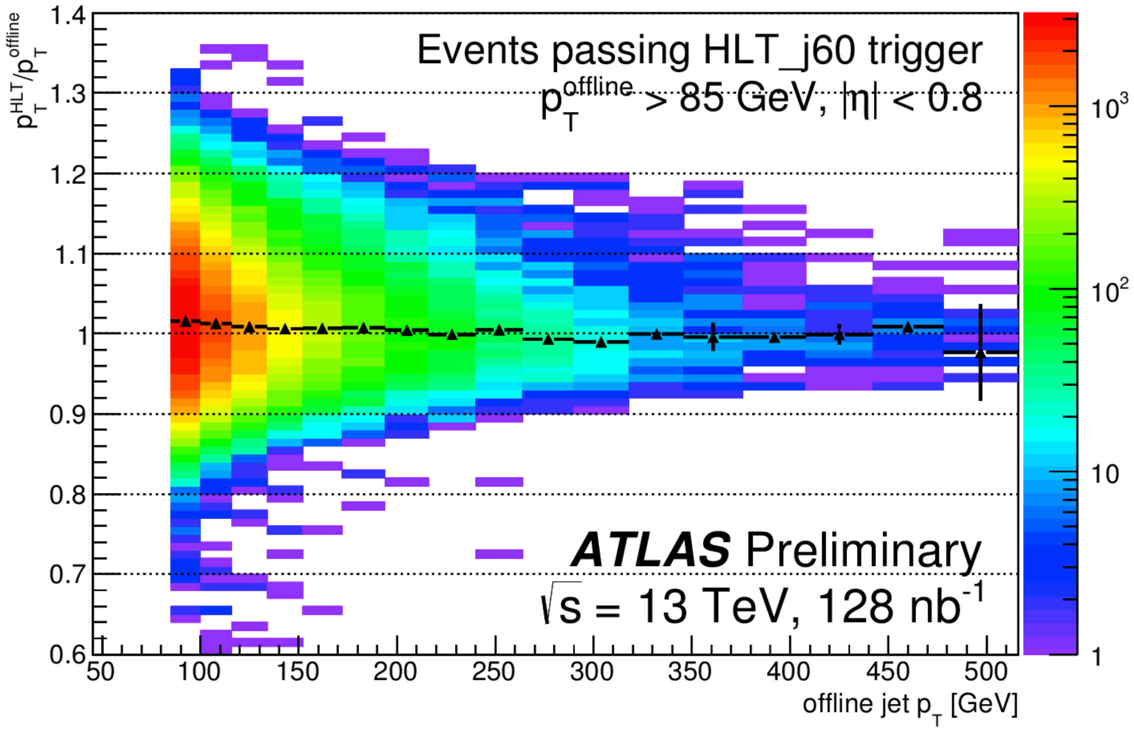
offline jet total

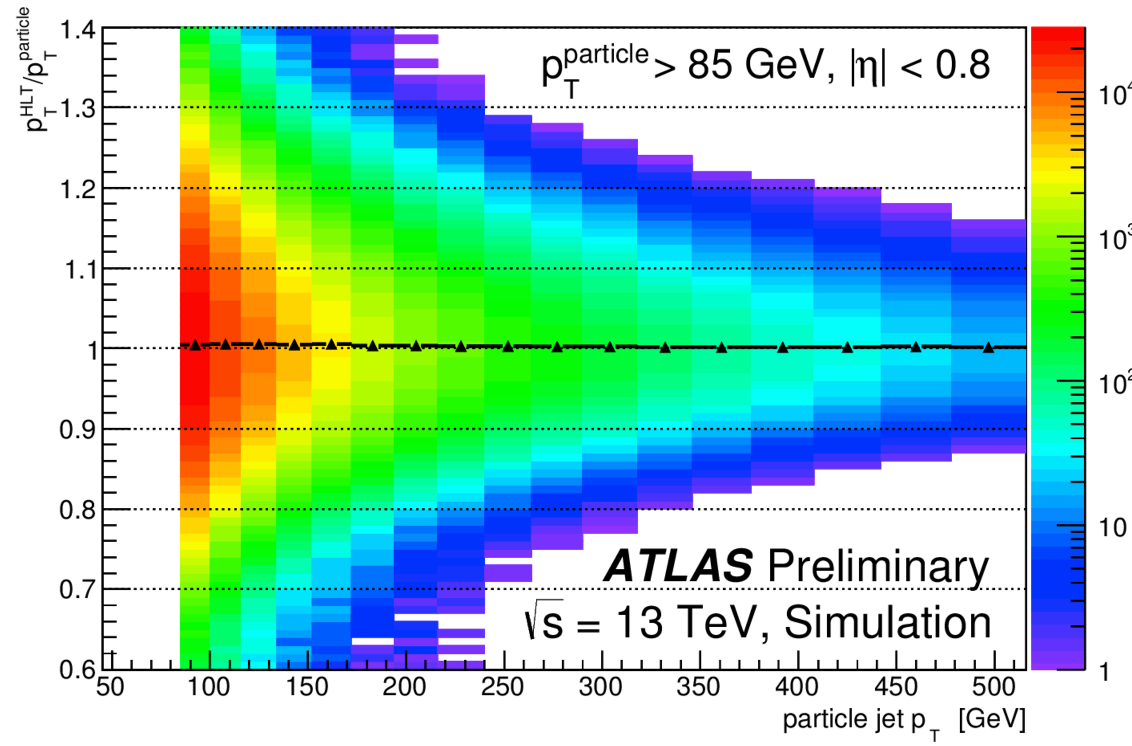
flavour composition (q vs g)

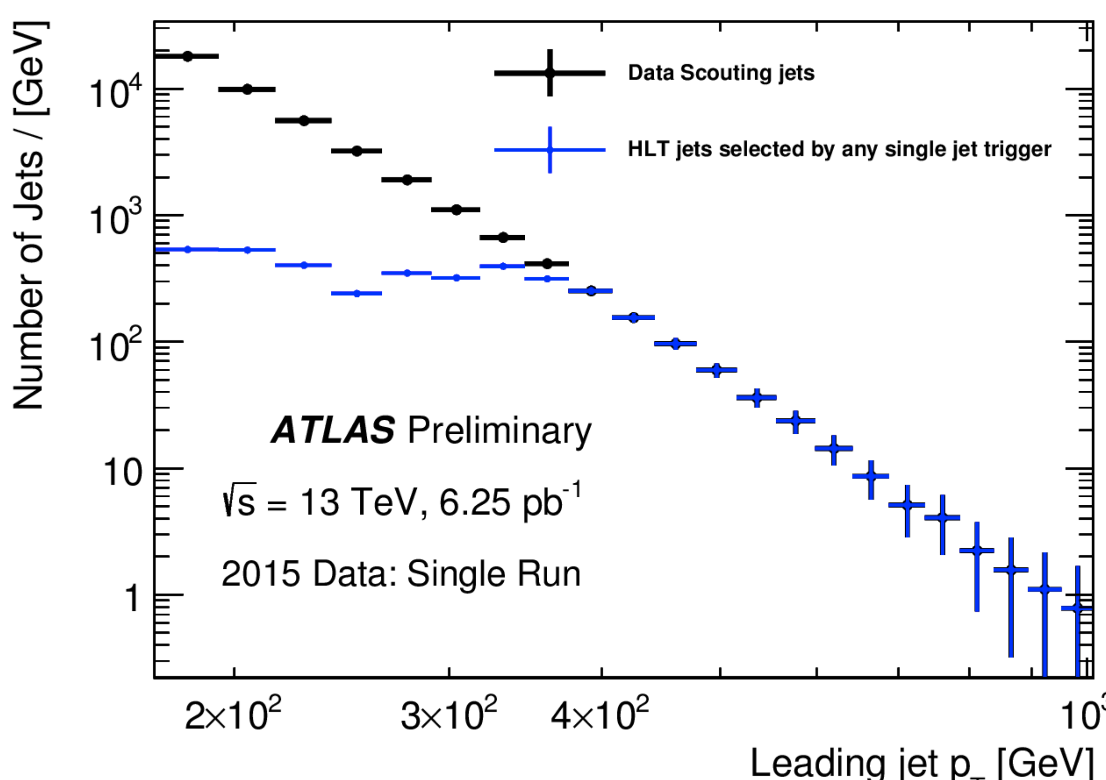
trigger-level tracking/ vertexing info would help!

TLA JETS

ATL-COM-DAQ-2016-012

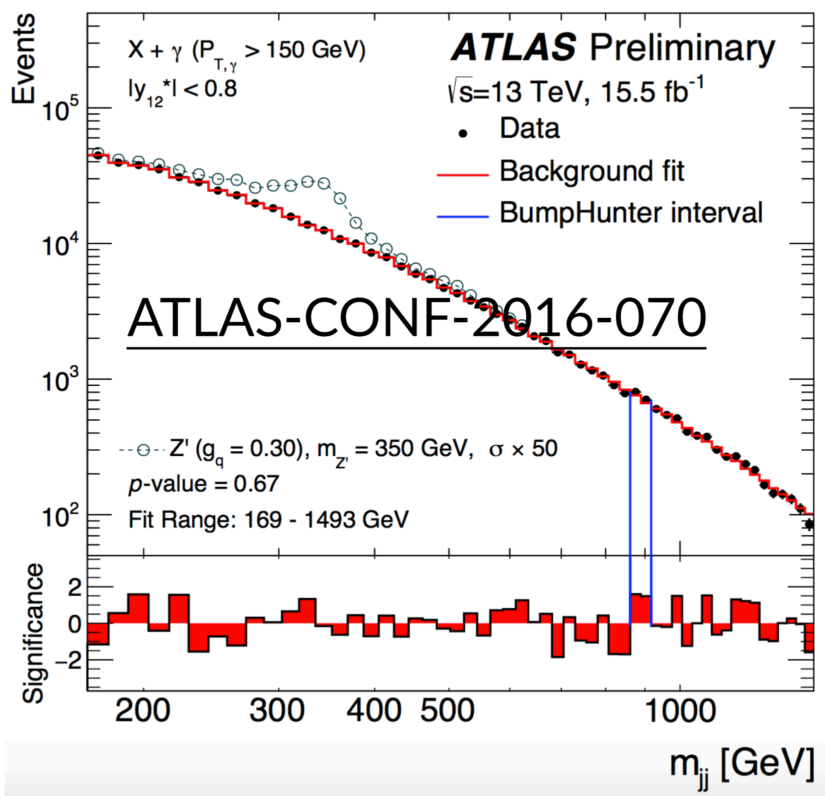


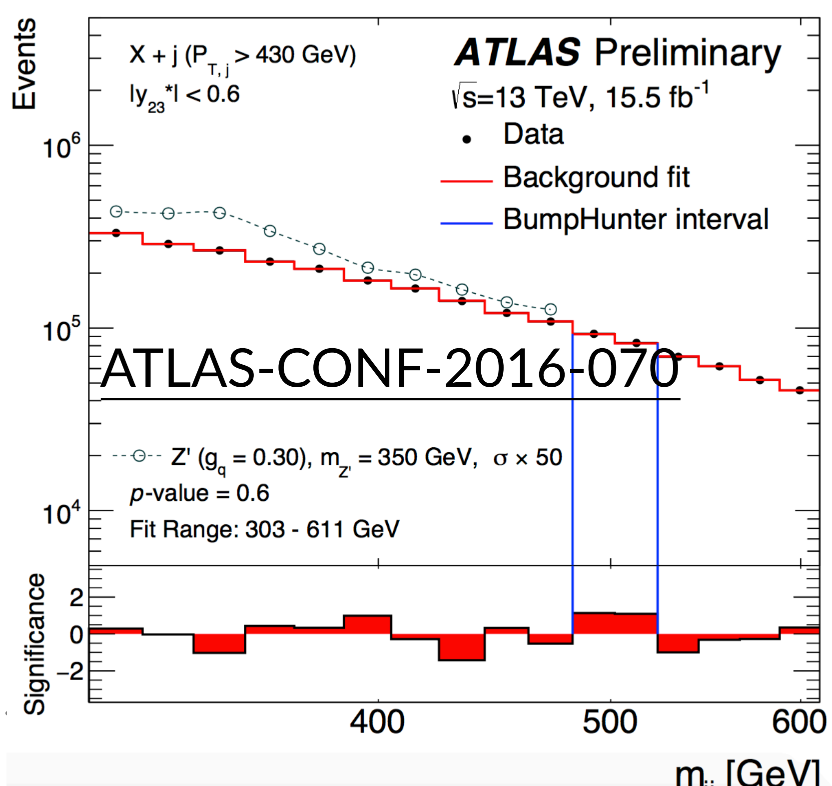




Dijet search strategies, compared

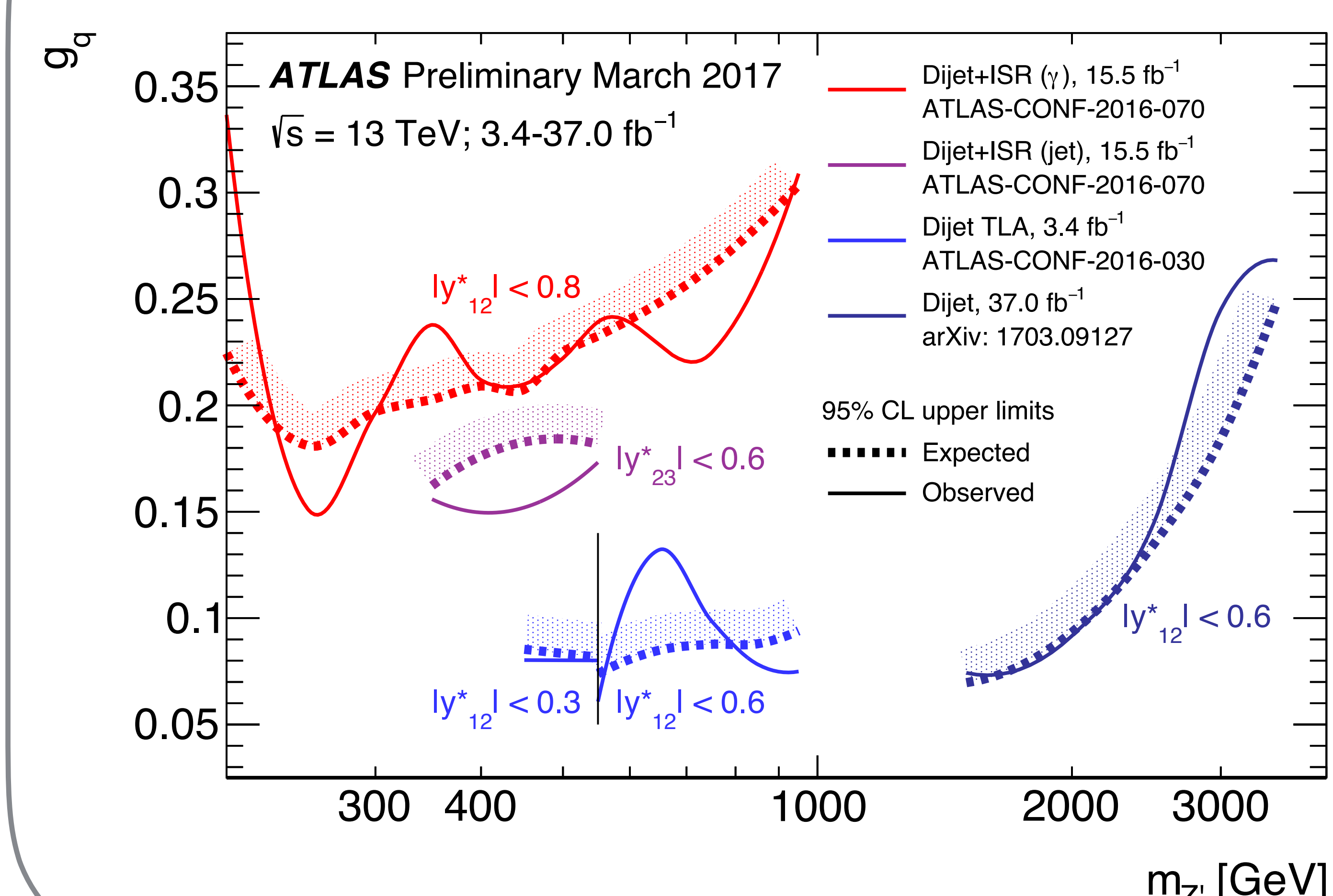
dijet+ISR photon/jet





- ISR photon
  - one photon with pT>150 GeV
  - 2 jets with p_T > 25 GeV, |y*|<0.8
- ISR jet
  - one jet with pT > 430 GeV
  - 2 jets with pT > 25 GeV, |y*|<0.6
- extend range to lower masses

the overall picture



The Future: challenges & complementarity

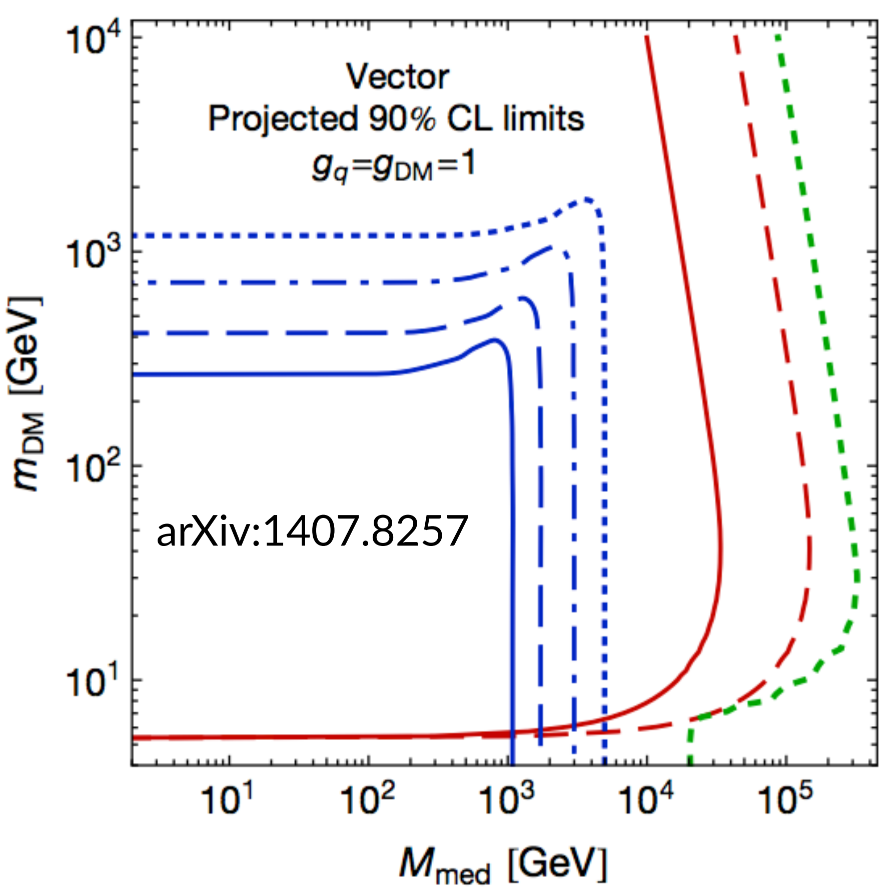
expected luminosity

now: 36 fb^{-1}
end of 2018: 100 fb^{-1}
end of 2023: 300 fb^{-1}
HL-LHC (~2035): 3000 fb^{-1}

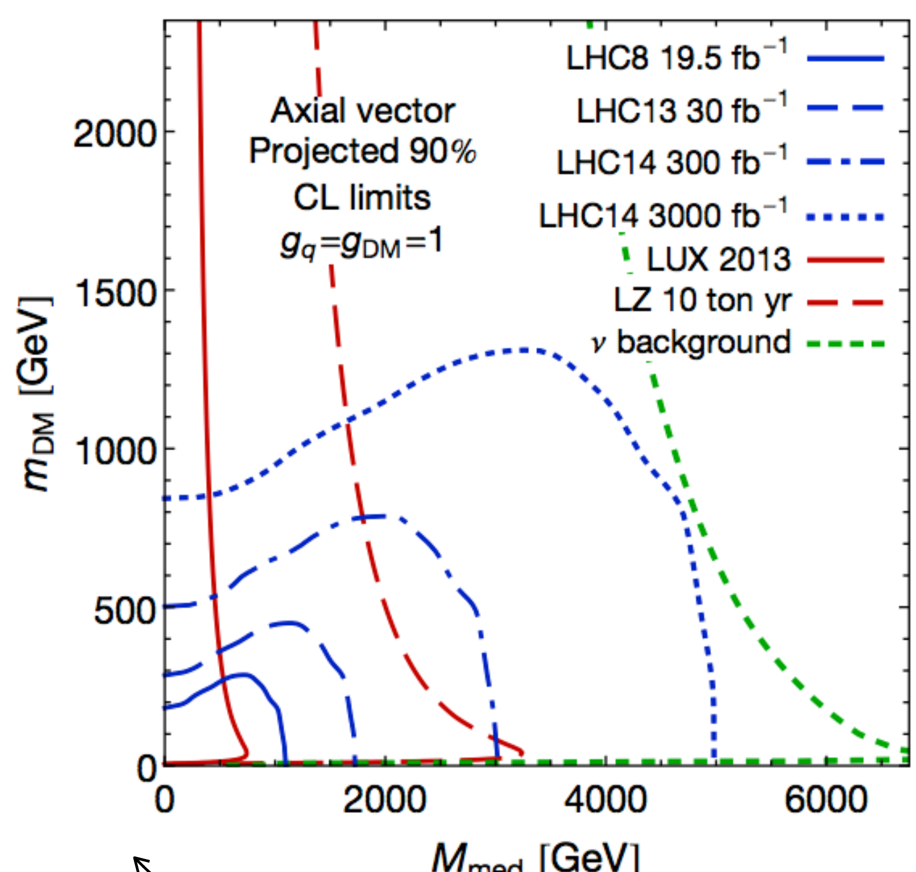
see also https://indico.cern.ch/event/539266

- balance between sensitivity to low-momentum signals (e.g. spin-zero) and robustness at very high energy
  - trigger & detector performance are crucial!
- explore lower-cross-section extensions of the SM (SUSY, long-lived particles…)

vector



axial-vector

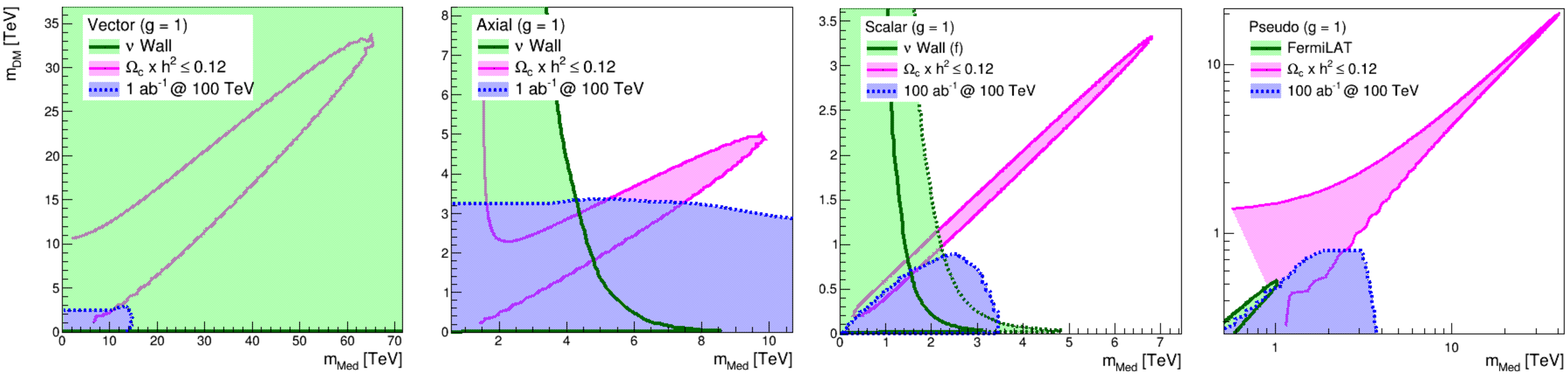


could extend the m_{DM} sensitivity up to 0.5 TeV in ~6 years (mind the couplings!)

region to the left of each curve is expected exclusion; LHC := "mono-jet"

Beyond the LHC

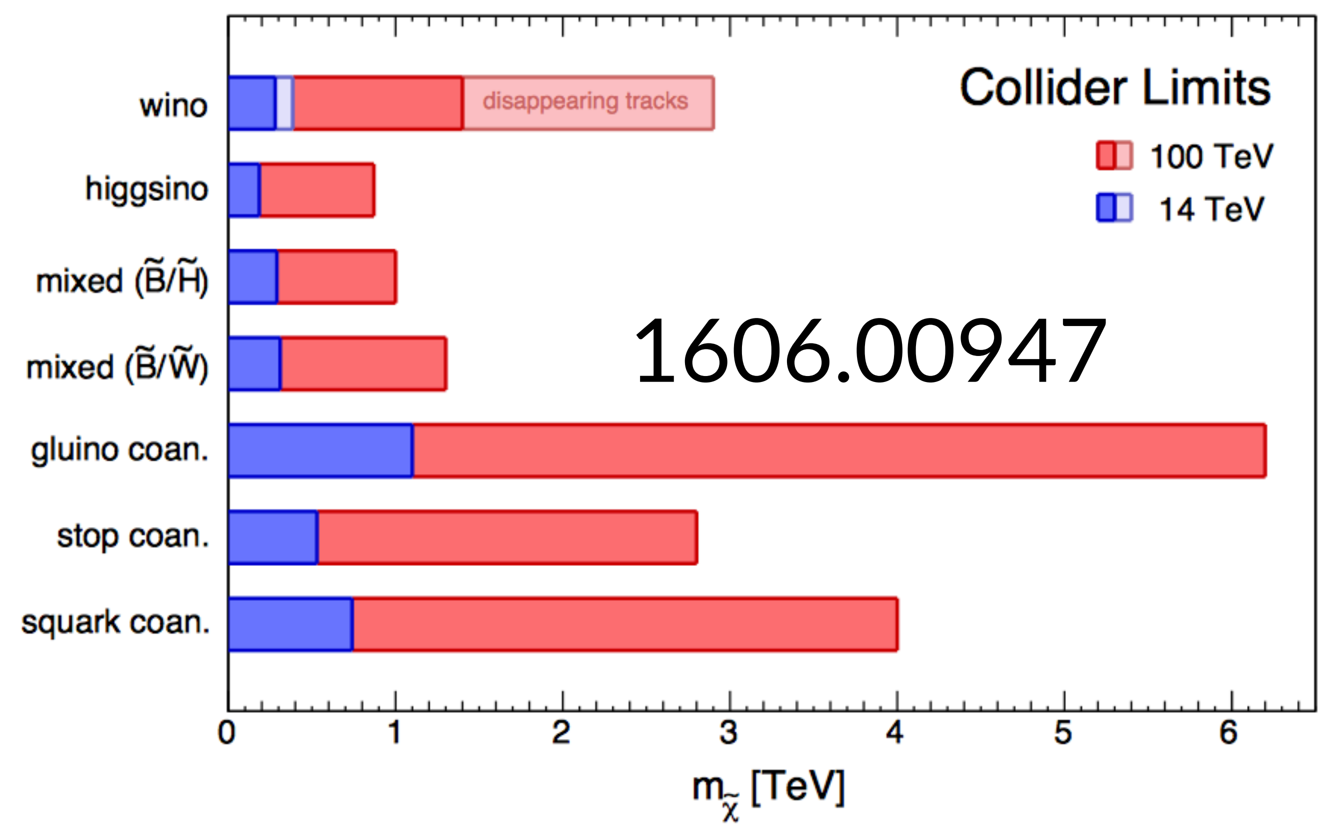
vector | axial-vector | scalar | pseudo-scalar



green: xsec <= neutrino bkg
blue: 1000 fb^{-1} @ 100 TeV
red: compatible with measured relic density

(for some choice of the couplings)

a higher-energy circular collider may push sensitivity to the TeV scale



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HOW DO OUR SIMPLIFIED MODELS TALK TO DIRECT DETECTION?

DD looks for non-relativistic nucleus-DM scattering

- 90% CL limits on σ_{SI} and σ_{SD}, vs m_{DM}
  - SI ($J^{PC}=0^+, 1^+$) usually shown assuming $\sigma^p=\sigma^n$

$$\sigma_{\rm SI} = \frac{f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4}$$

0^+ $$\sigma_{\rm SI} \approx 1.1 \times 10^{-39}\ {\rm cm}^2 \cdot \left(\frac{g_{\rm DM}\, g_q}{1}\right)^2 \left(\frac{1\ {\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

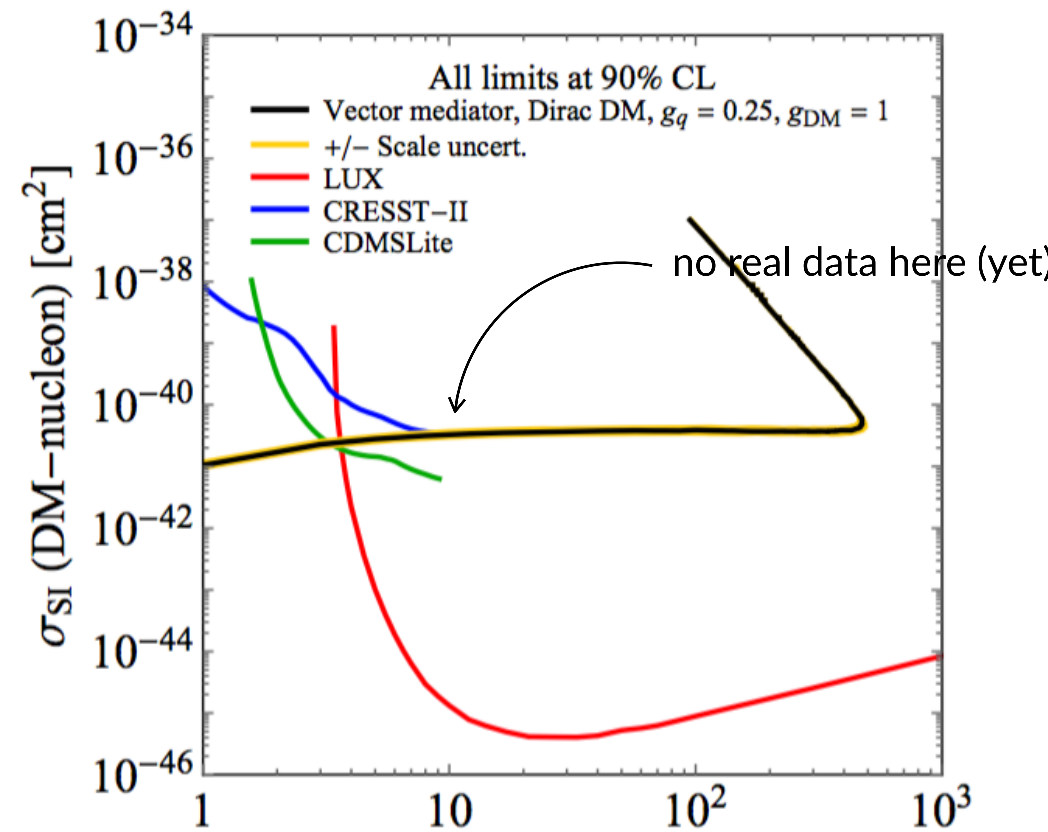
0^- $\sigma_{\rm SI} \approx 0$ (suppressed by velocity dependent terms)

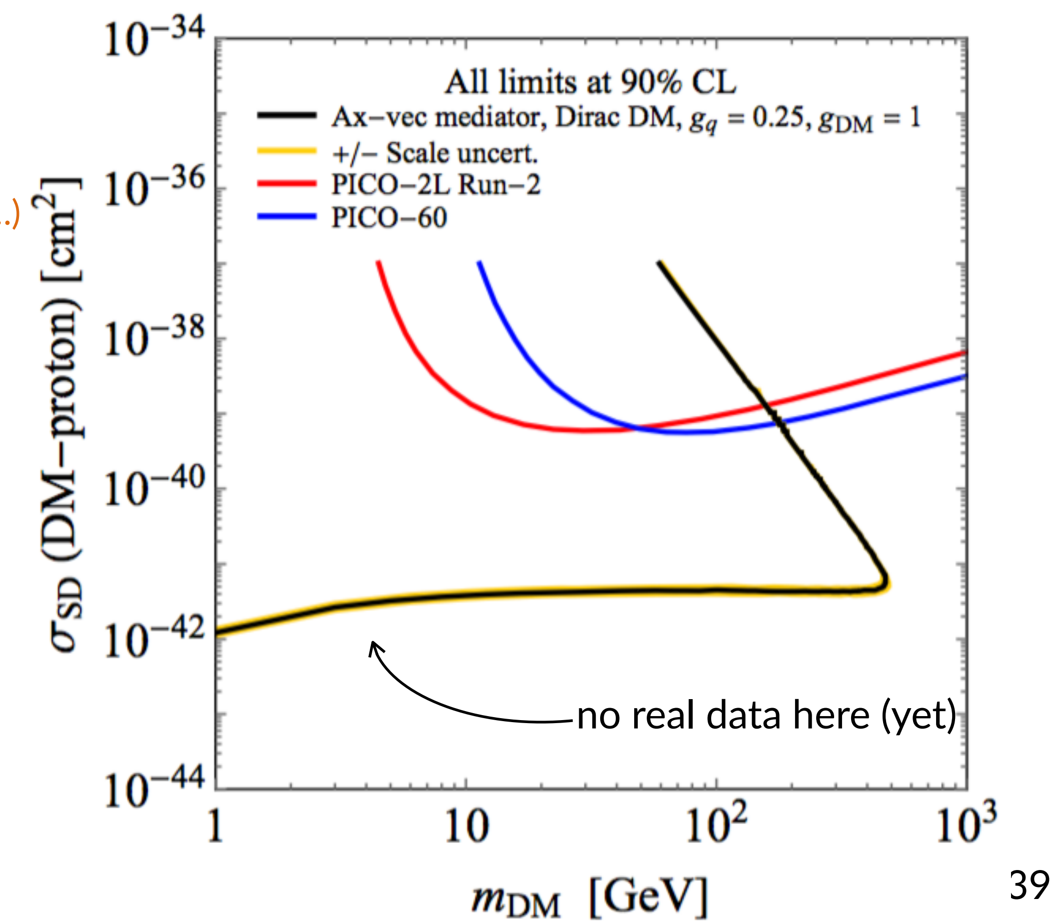
1^+ $$\sigma_{\rm SI} \approx 6.9 \times 10^{-43}\ {\rm cm}^2 \cdot \left(\frac{g_{\rm DM}\, g_q}{1}\right)^2 \left(\frac{125\ {\rm GeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

  - SD ($J^{PC}= 1^-$) sensitive to either p (PICO, ...) or n (LUX, XENON100, ...), through isotope spin (σ^p more difficult, need odd #p...)
    - LHC result is the same for p and n
    - Ice-cube limit depends on assumed annihilation channel - weak for qq, no comparison possible for WW/ll which we exclude from our models ☞ not to be shown

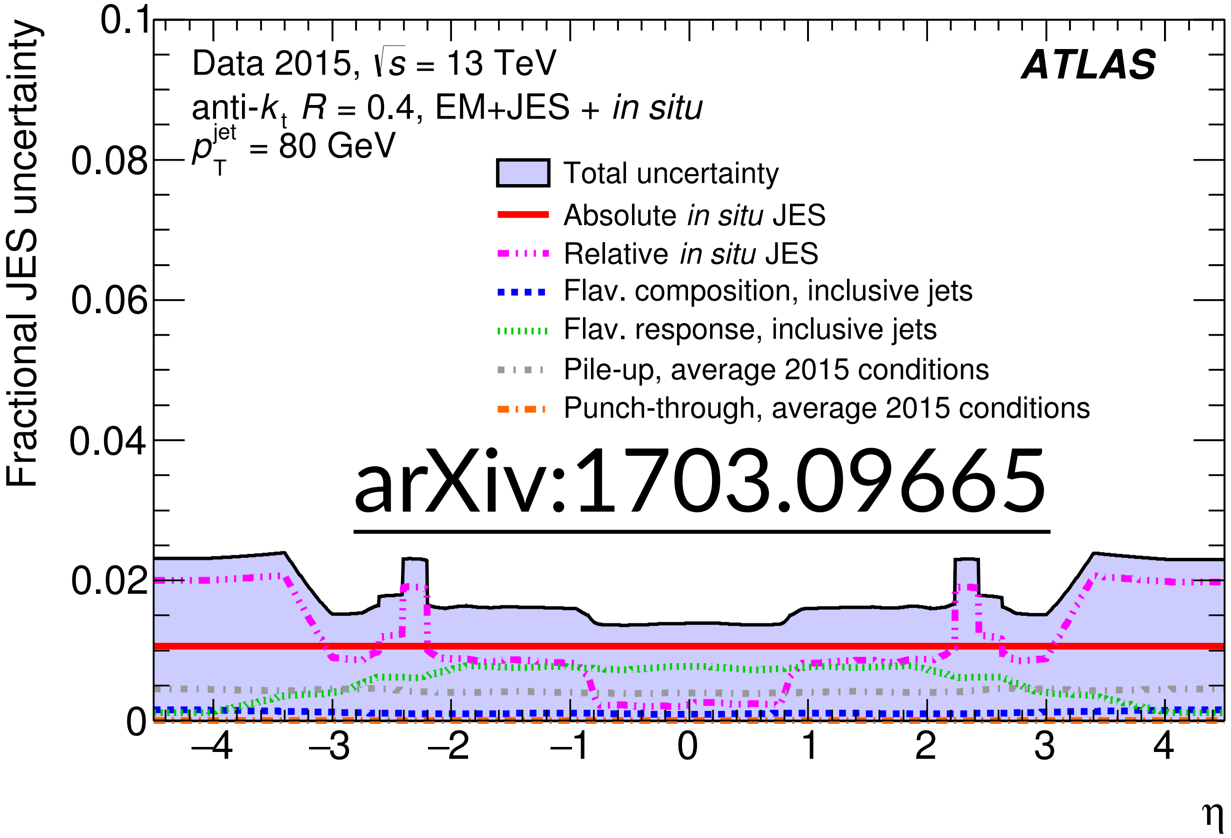
$$\sigma_{\rm SD} = \frac{3\, f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4}$$

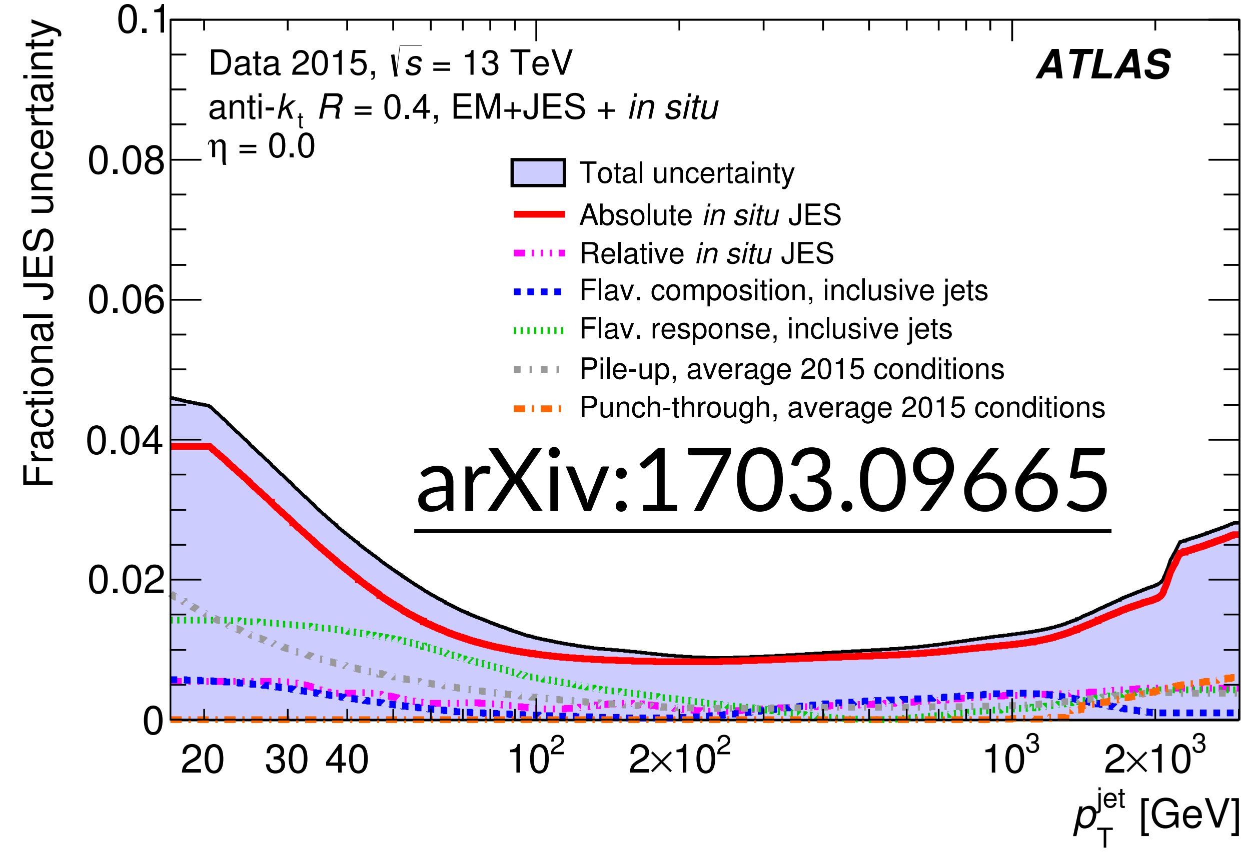
1^- $$\sigma^{\rm SD} \approx 3.8 \times 10^{-41}\ {\rm cm}^2 \cdot \left(\frac{g_{\rm DM}\, g_q}{1}\right)^2 \left(\frac{1\ {\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

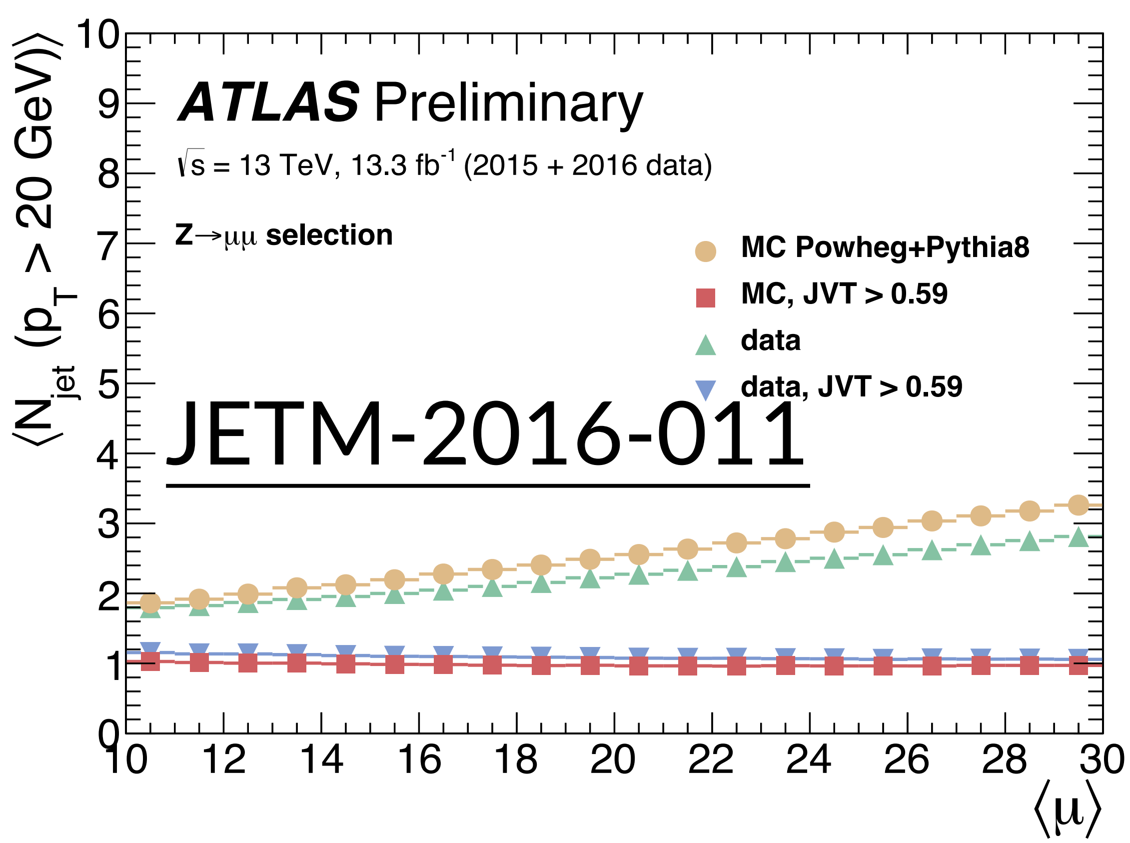


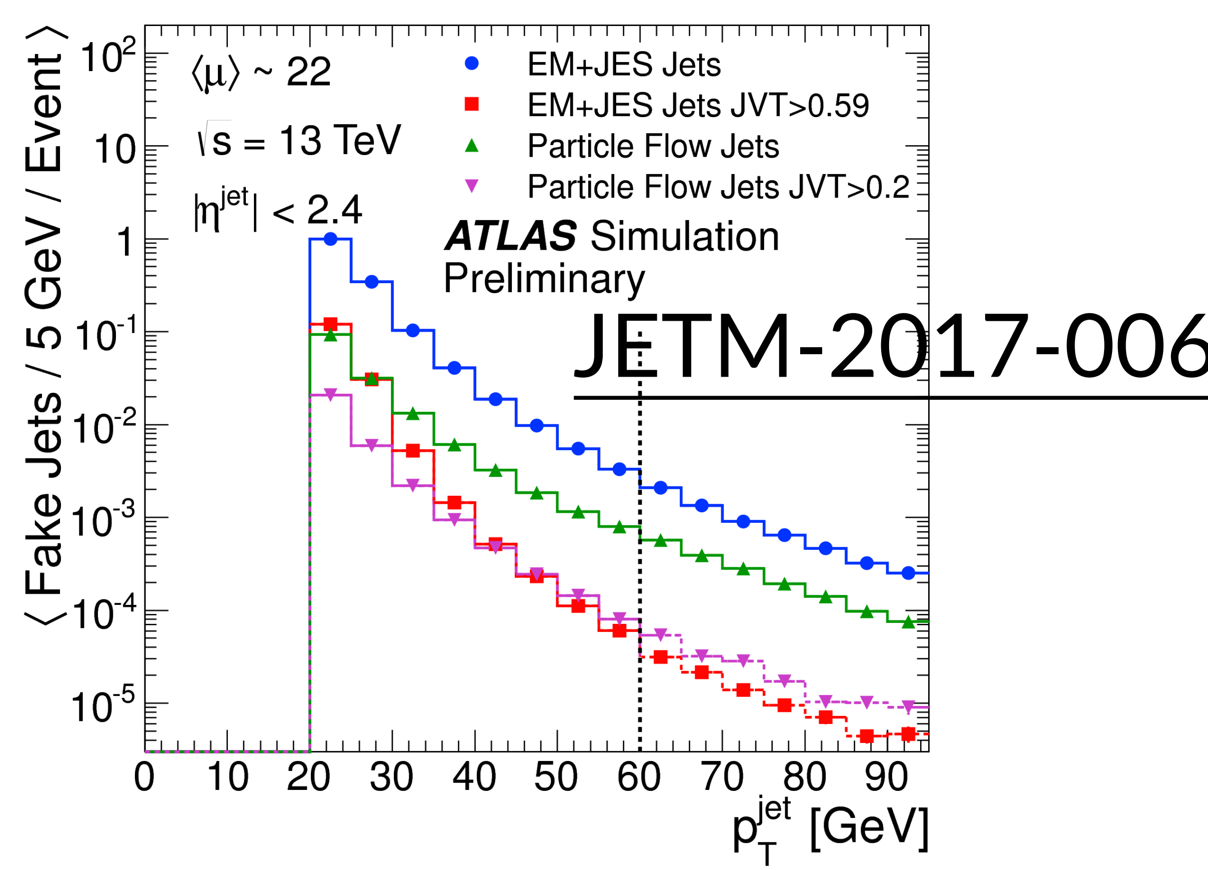


Jet reconstruction



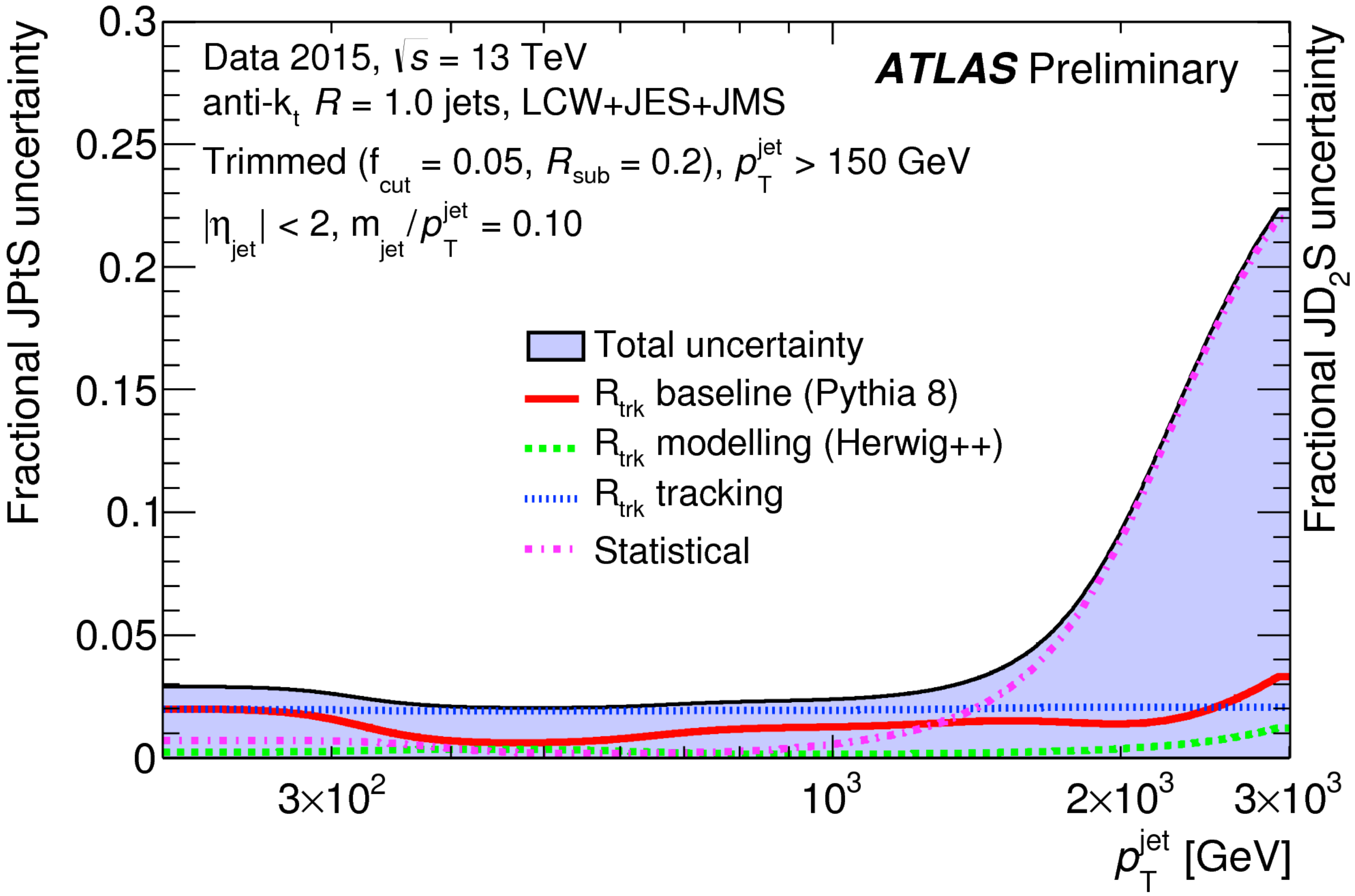


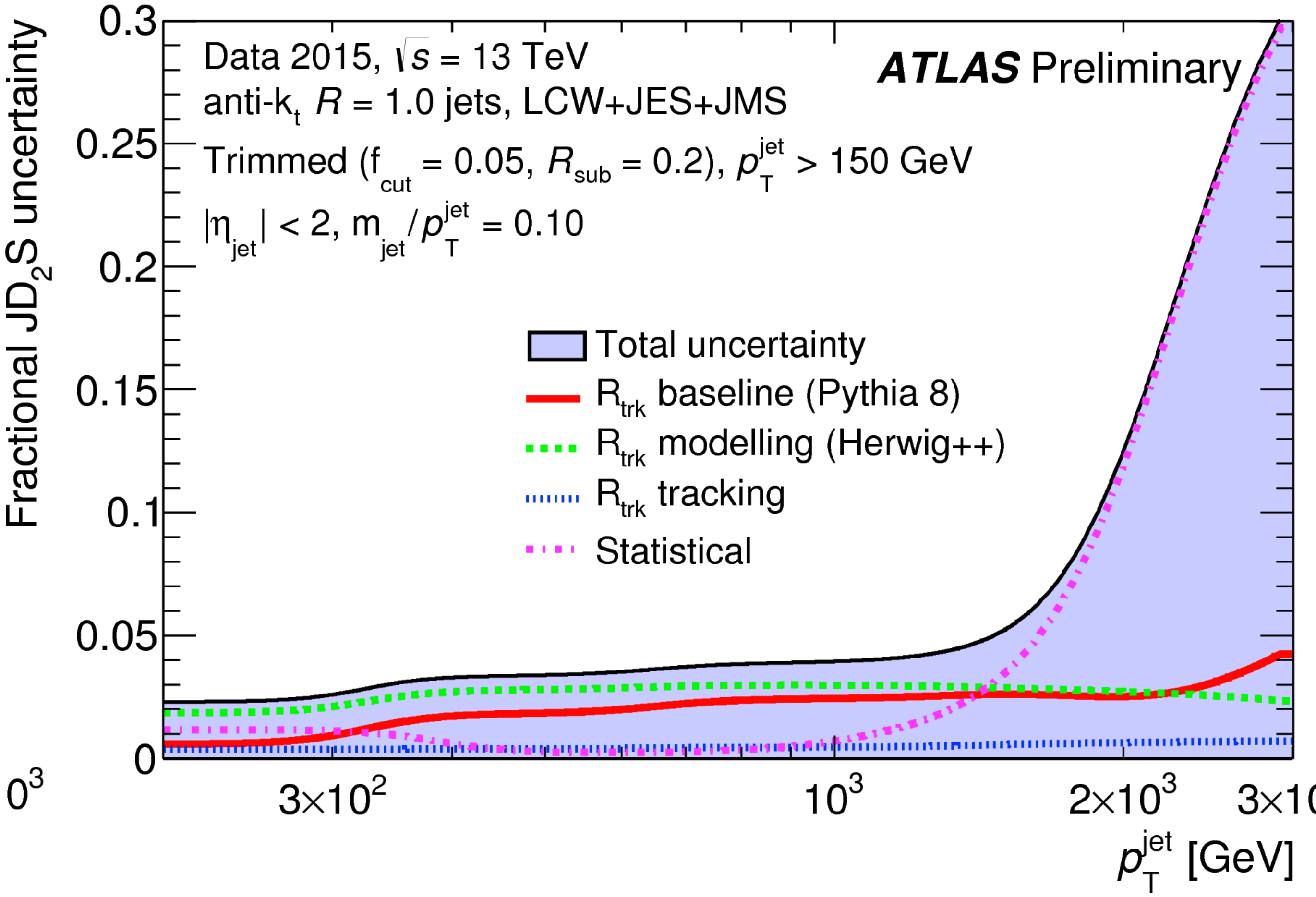




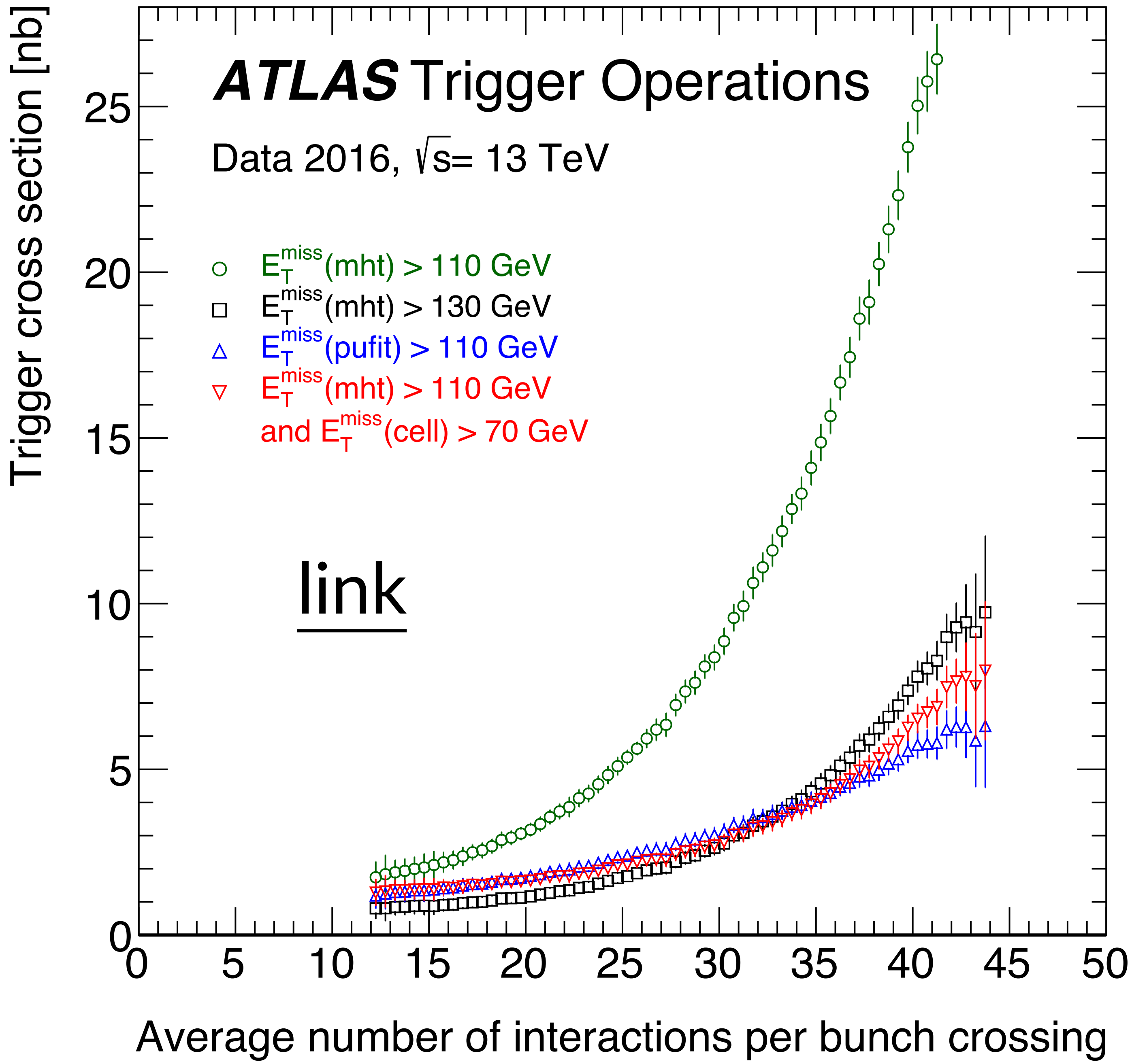
Large-R jets

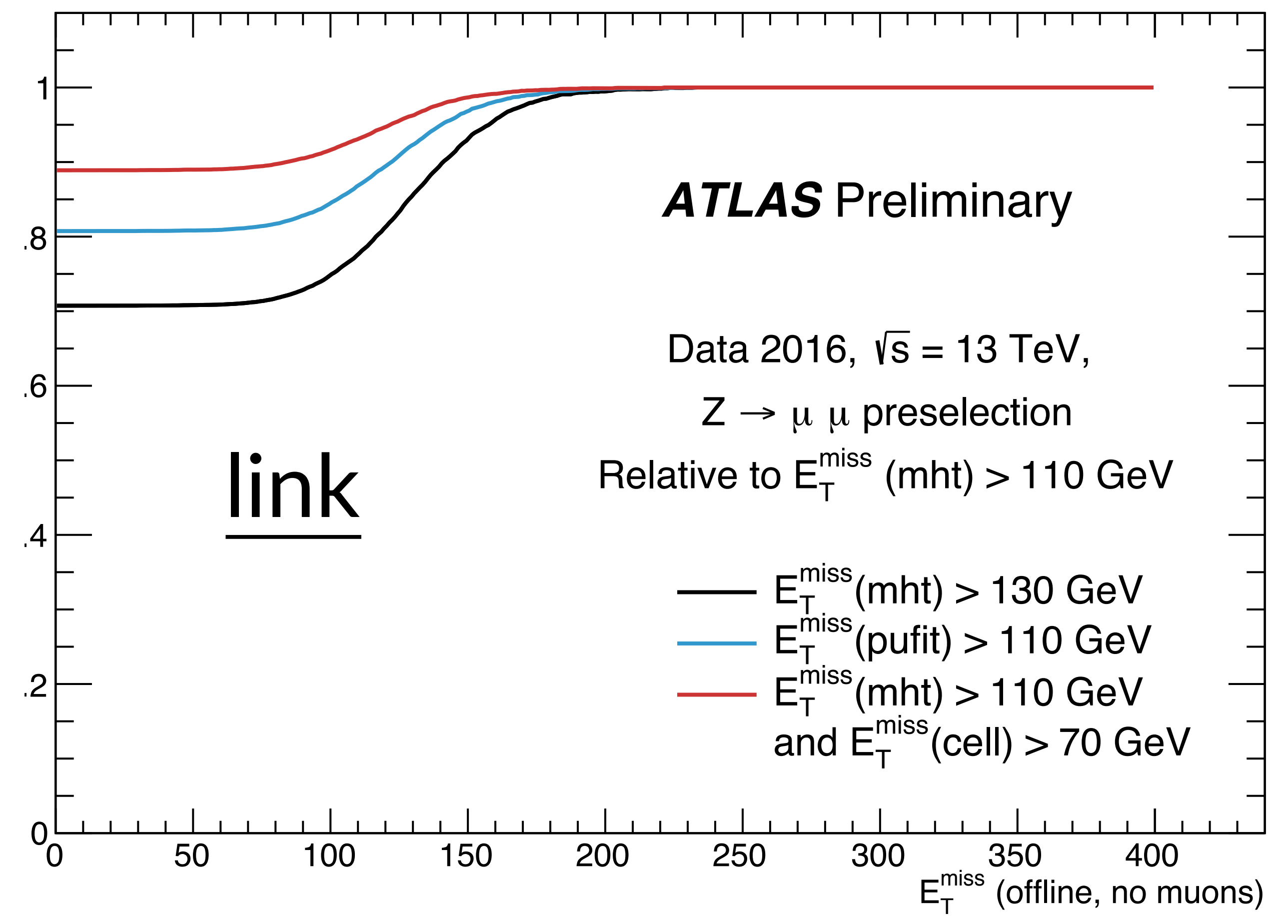
JETM-2016-009





MET trigger


ATLAS Trigger Operations
Data 2016, √s= 13 TeV
E_T^{miss}(mht) > 110 GeV
E_T^{miss}(mht) > 130 GeV
E_T^{miss}(pufit) > 110 GeV
E_T^{miss}(mht) > 110 GeV
and E_T^{miss}(cell) > 70 GeV
link
Trigger cross section [nb]
Average number of interactions per bunch crossing


ATLAS Preliminary
Data 2016, √s = 13 TeV,
Z → μ μ preselection
Relative to E_T^{miss} (mht) > 110 GeV
link
E_T^{miss}(mht) > 130 GeV
E_T^{miss}(pufit) > 110 GeV
E_T^{miss}(mht) > 110 GeV
and E_T^{miss}(cell) > 70 GeV
E_T^{miss} (offline, no muons)