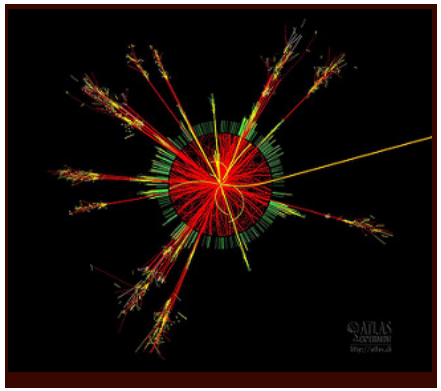
Search for Dark Matter in Mono-Jet Topology at ATLAS



Maria Giulia Ratti

Università degli Studi di Milano and I.N.F.N.

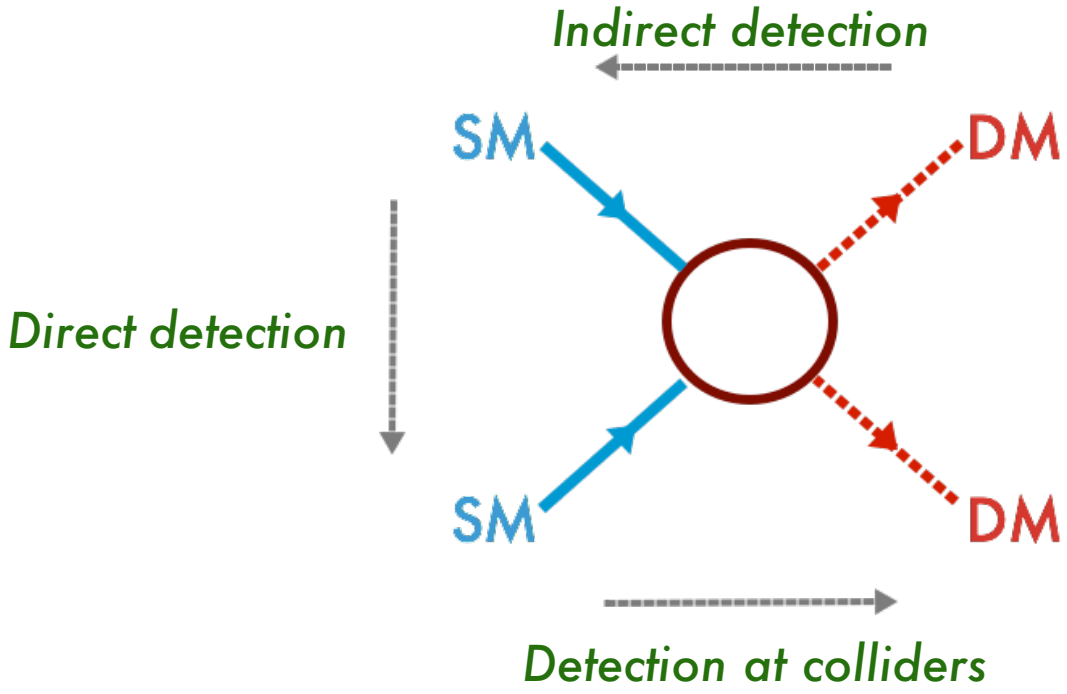
on behalf of the ATLAS collaboration

WORKSHOP ON THE STANDARD MODEL AND BEYOND

CORFU, 03-09-2017

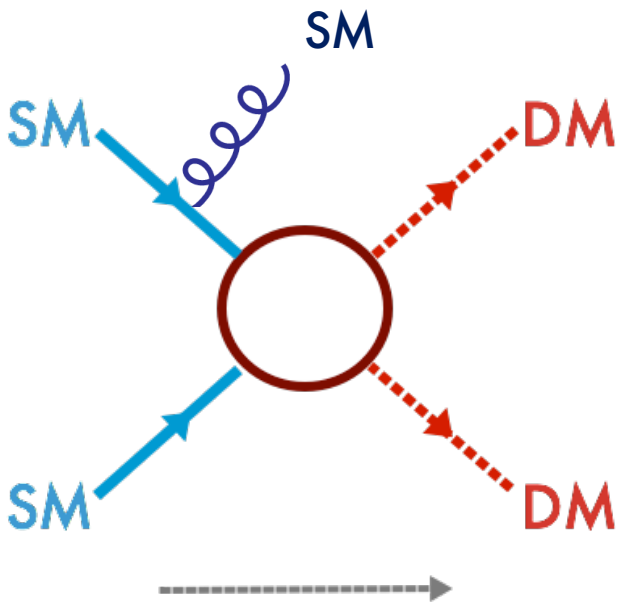
Dark Matter at colliders

- Dark Matter constitutes ~85% of total matter in the Universe
  - DM and SM interact other than gravitationally → weakly
  - establish complementary strategies to detect it



Dark Matter at colliders

- Dark Matter constitutes ~85% of total matter in the Universe
  - DM and SM interact other than gravitationally → weakly
  - establish complementary strategies to detect it

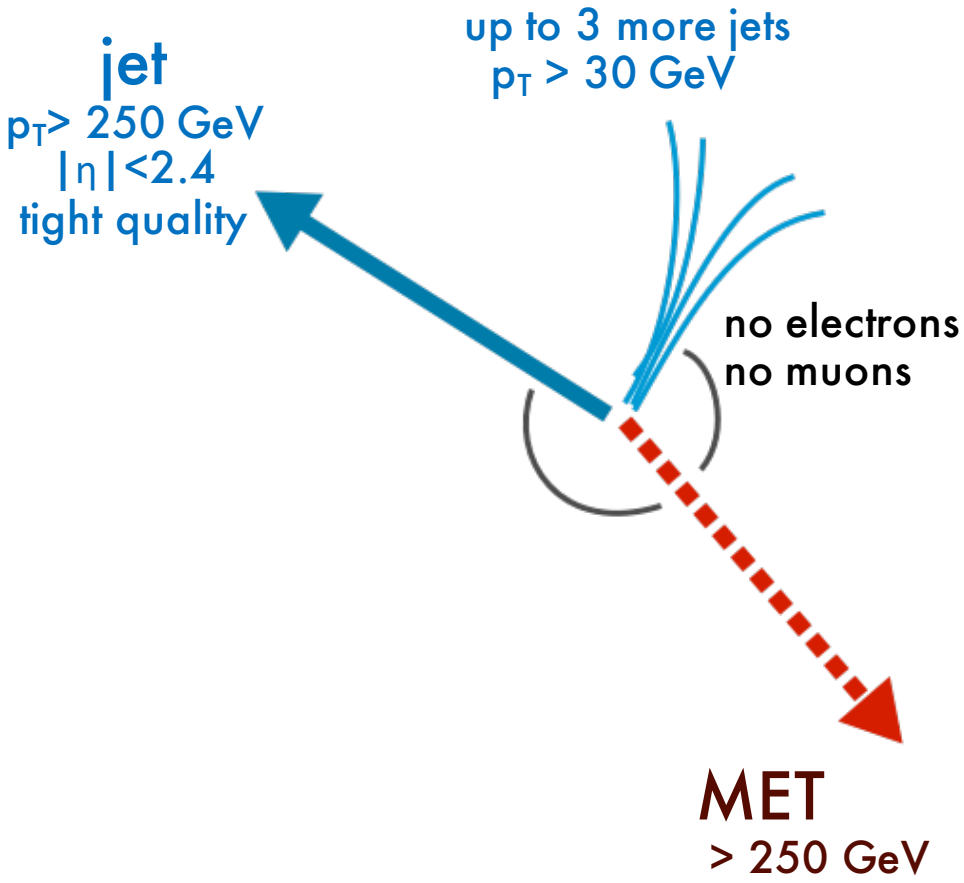


Detection at colliders

Search for direct production of DM pairs
Missing transverse momentum (MET) recoiling against a "visible" X=jet,γ,W,Z,h
MET + jet (or *'Mono-jet'*) best channel if X comes from ISR

} MET + X

Mono-jets at ATLAS



+ Mono-jets at ATLAS

Experimental challenges

jet
p_T> 250 GeV
$|\eta|$<2.4
tight quality

→ suppress non-collision background

up to 3 more jets
p_T > 30 GeV

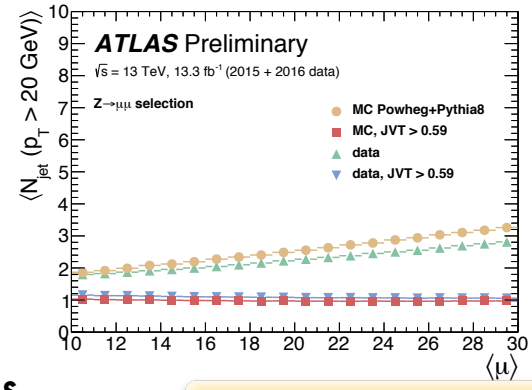
no electrons
no muons

$\Delta\phi > 0.4$

→ suppress fake MET from multi-jets

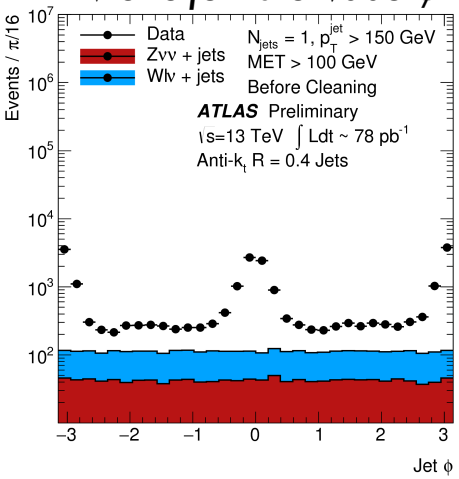
MET
> 250 GeV

Njets vs pile-up

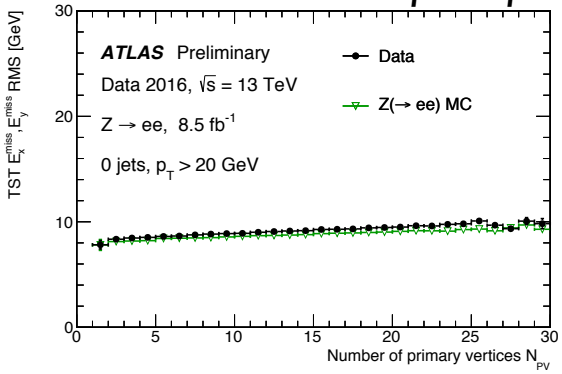


→ remove pile-up jets

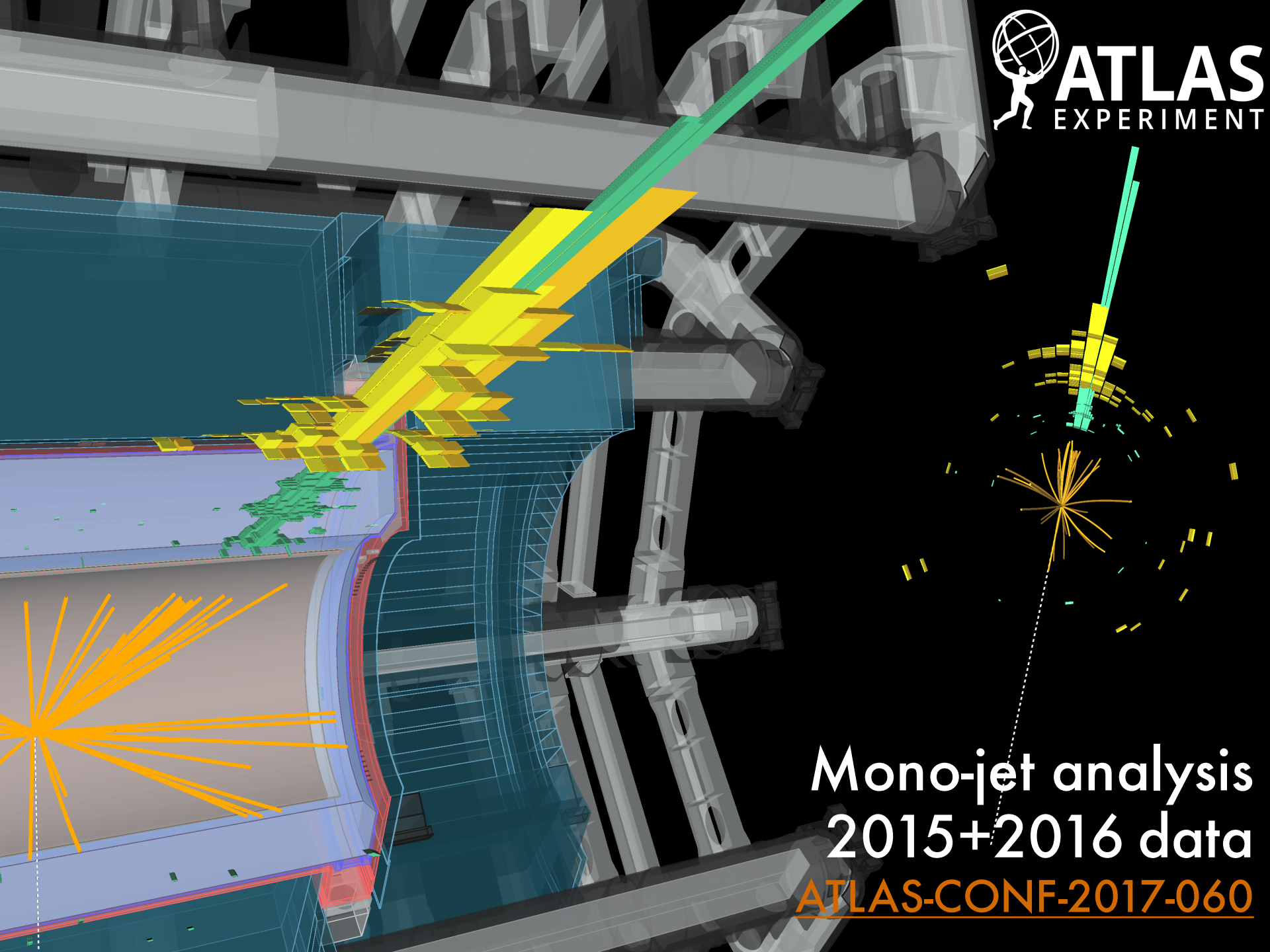
Mono-jet rate vs Jetϕ



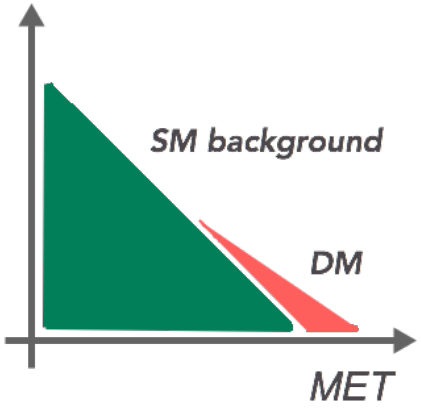
MET resolution vs pile-up



→ be pile-up robust


ATLAS
EXPERIMENT
Mono-jet analysis
2015+2016 data
ATLAS-CONF-2017-060

+ SM backgrounds and Analysis Strategy



- Crucial to measure the SM background precisely
  - Z(vv)+jets (55-70%),
  - W(lv)+jets (35-20%), } V+jets control regions
  - ttbar (~3%) → Top CR
  - Diboson (~2%) → from MC
  - Multi-jet and non-collision backgrounds → data-driven

- Look for an excess of events wrt SM prediction
  - essential to find the best way to estimate the Z(vv)+jets background
  - use ***simultaneously*** the ***shape*** of the "MET" in W/Z+jets & ttbar control regions to constrain the background in the SR
  - this requires to know higher order corrections to W/Z+jets
    - → use state-of-the art perturbative calculations

NEW following approach by Lindert et al. https://arxiv.org/pdf/1705.04664.pdf

Control Regions

E_T^{miss} + μ + jet
- >= 1 b-tags
- no b-tags

E_T^{miss} + $\mu\mu$ + jet

E_T^{miss} + e + jet NEW

Signal Region

E_T^{miss} + jet

NEW indicates a change wrt 2015 analysis

+ Background estimation

We refer to the observable as "E_T^{miss}" both in SR and CRs

- V+jets simulations combined with perturbative corrections
  - → NLO QCD and nNLO EW accuracy
  - → thanks to a one-dimensional reweighting $x \equiv p_T{}^V$

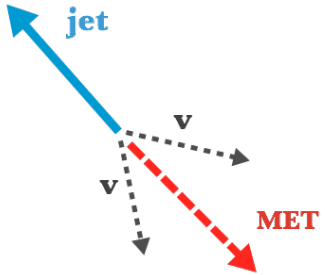
our MC — theory prediction

$$\frac{\mathrm{d}}{\mathrm{d}x}\frac{\mathrm{d}}{\mathrm{d}\vec{y}}\sigma^{(V)}(\vec{\varepsilon}_{\mathrm{MC}},\vec{\varepsilon}_{\mathrm{TH}}) := \frac{\mathrm{d}}{\mathrm{d}x}\frac{\mathrm{d}}{\mathrm{d}\vec{y}}\sigma^{(V)}_{\mathrm{MC}}(\vec{\varepsilon}_{\mathrm{MC}}) \left[\frac{\frac{\mathrm{d}}{\mathrm{d}x}\sigma^{(V)}_{\mathrm{TH}}(\vec{\varepsilon}_{\mathrm{TH}})}{\frac{\mathrm{d}}{\mathrm{d}x}\sigma^{(V)}_{\mathrm{MC}}(\vec{\varepsilon}_{\mathrm{MC}})}\right]$$

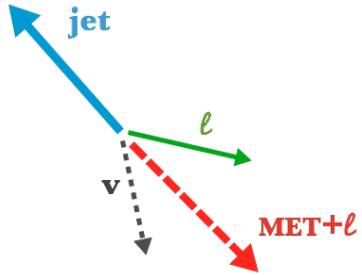
p_T^V distribution in our MC

arxiv: 1705.04664

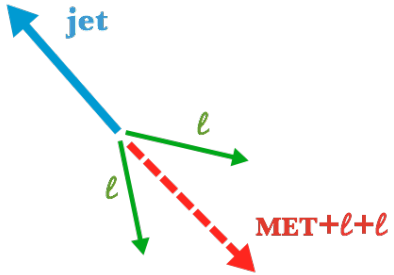
- Binned simultaneous fit of the in 4 CRs and the SR
  - observable captures the p_T^V in the various regions



$p_T^Z \sim$ MET



$p_T^W \sim p_T$(MET+1)



$p_T^Z \sim p_T$(MET+1+1)

$$L \sim \mu N^{sig} + k_{WZ}(N^{Z(\nu\nu)} + N^{W(l\nu)} + N^{Z(ll)}) + k_{top}(N^{ttbar} + N^{t}) + N^{VV} + N^{multijet} + N^{NCB}$$

NEW

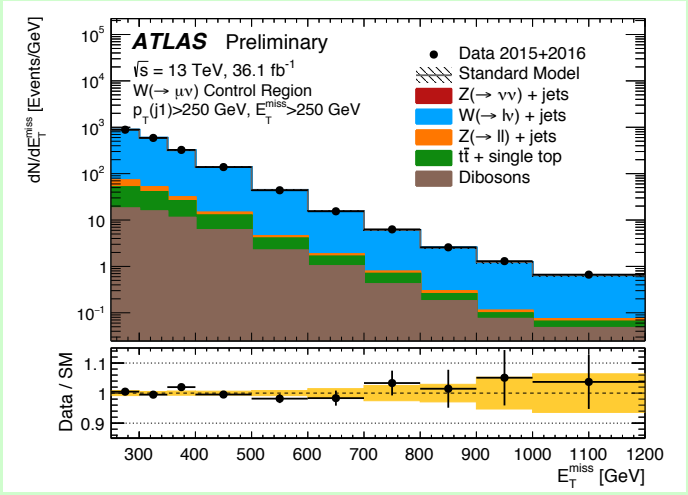
a single k-factor for V+jets
a single k-factor for top

- In addition perform 10 counting experiments for reinterpretation

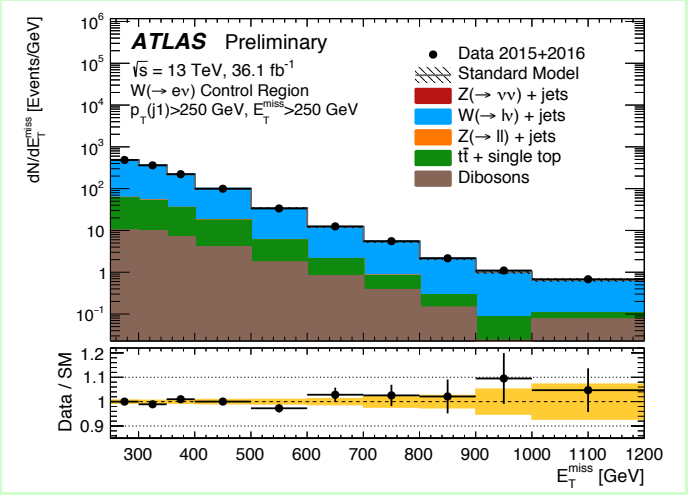
Inclusive (IM)	IM1	IM2	IM3	IM4	IM5	IM6	IM7	IM8	IM9	IM10
E_T^{miss} (GeV)	> 250	> 300	> 350	> 400	> 500	> 600	> 700	> 800	> 900	> 1000

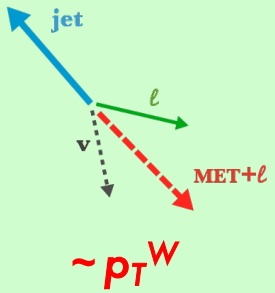
+ Control Regions

W (μν) + jets



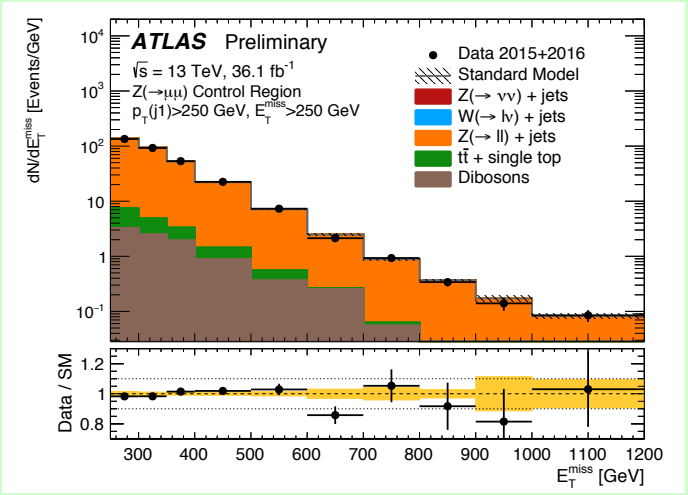
W (eν) + jets

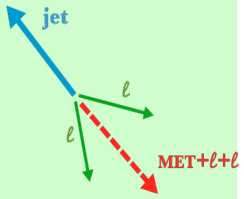




~ p_T^W

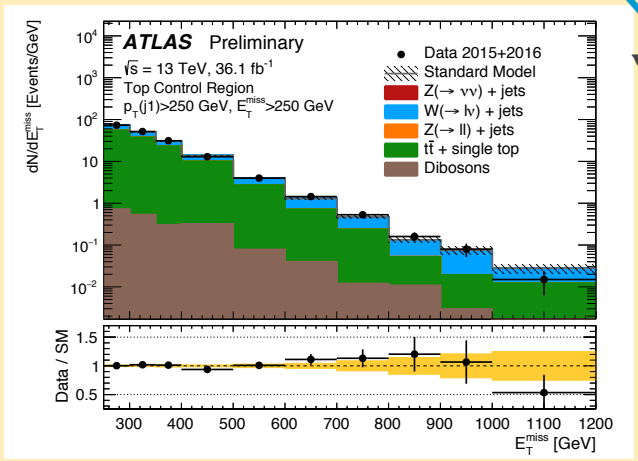
Z(μμ) +jets

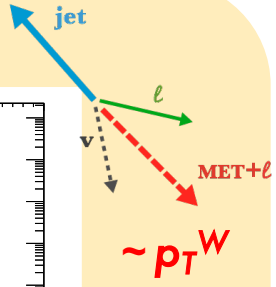




~ p_T^Z

Top (semi-leptonic)

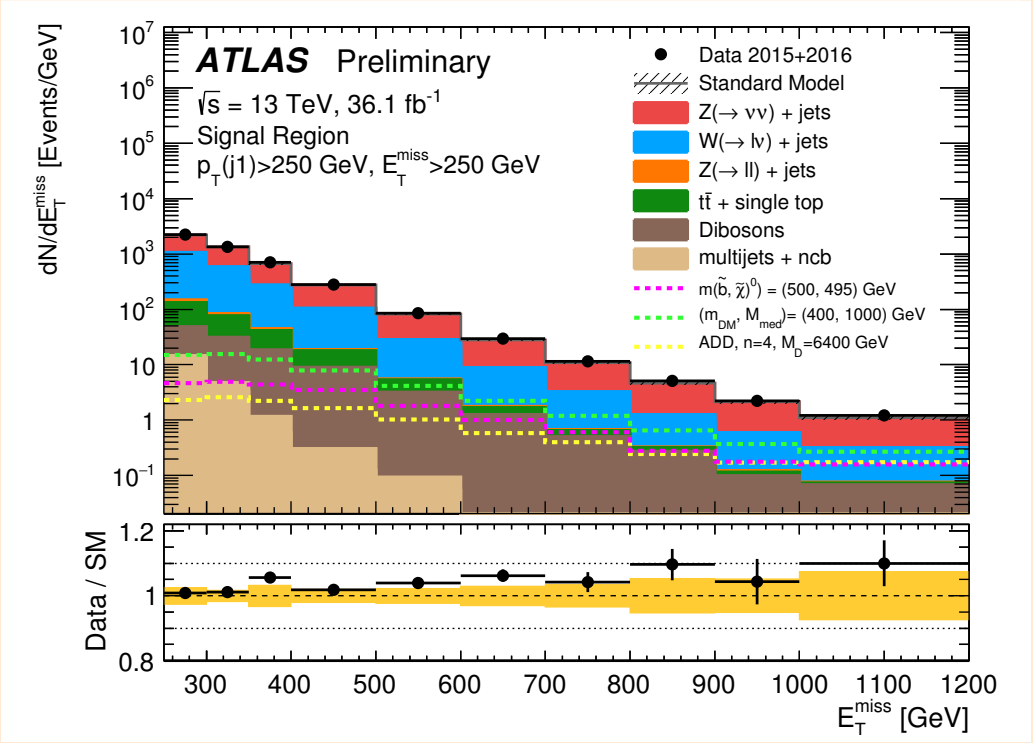




~ p_T^W

+ Results

Signal Region

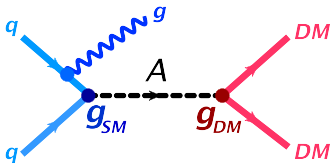


… no significant deviations from SM prediction

- Major systematic components:
  - lepton efficiency
  - jet/MET scale&reso
- Reached high precision in the bkg prediction uncertainty σ_{bkg}
  - **~2%** at 'low' MET
  - **~7%** in the TeV regime

→ sizeable improvement wrt to 2015 analysis:
~ halved σ_{bkg}

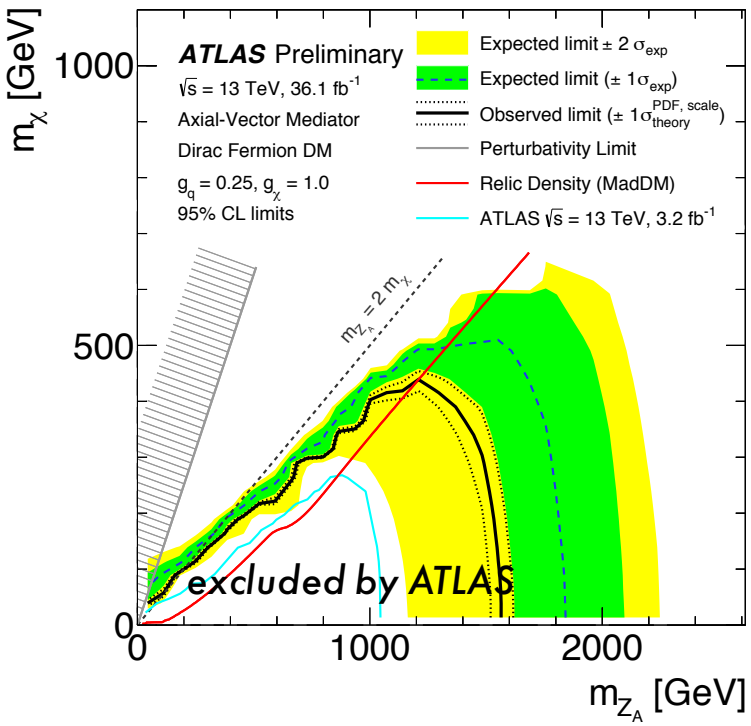
+ Dark Matter Results
(a selection of)

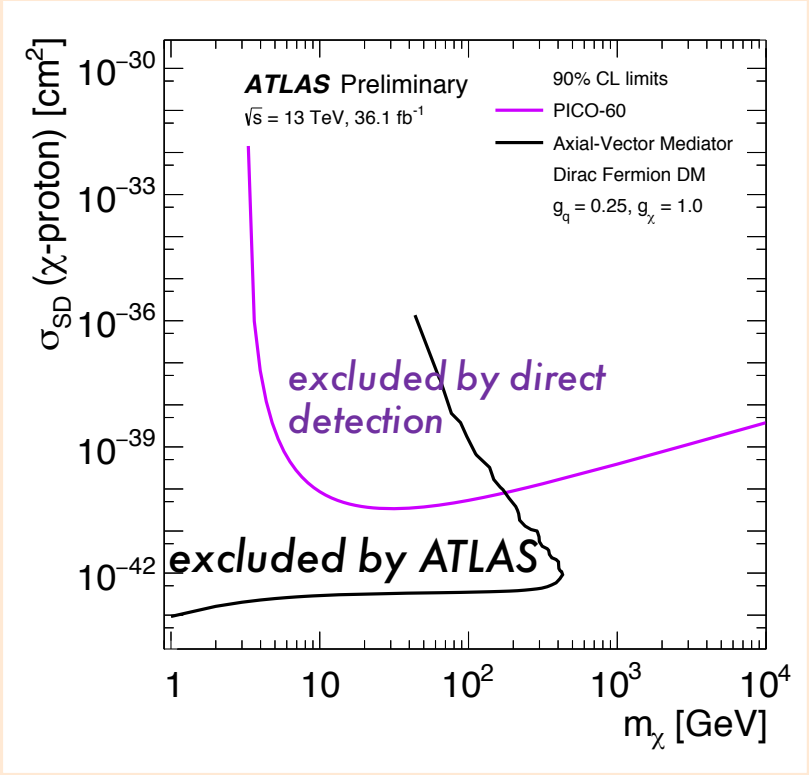


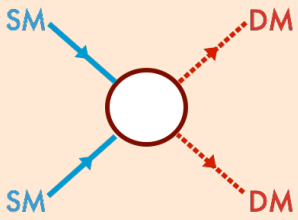
A axial-vector spin-1 jet from ISR
g_{SM}=0.1 g_{DM}=0.25

ATLAS/CMS DM forum recommendations: arxiv: 1507.00966

Exclusion limit in m_{DM} – m_A plane





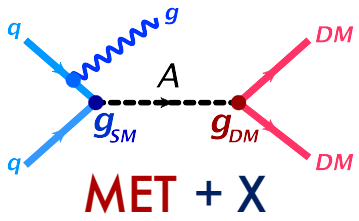


Exclusion limit in DM-proton σ – m_{DM}

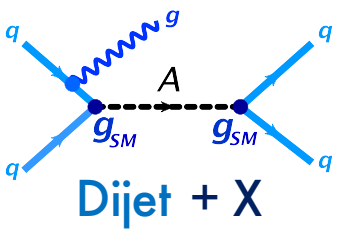
+ Dark Matter Results
(a selection of)

A axial-vector spin-1 jet from ISR
$g_{SM,}$=0.1 g_{DM}=0.25

ATLAS/CMS DM forum recommendations: arxiv: 1507.00966

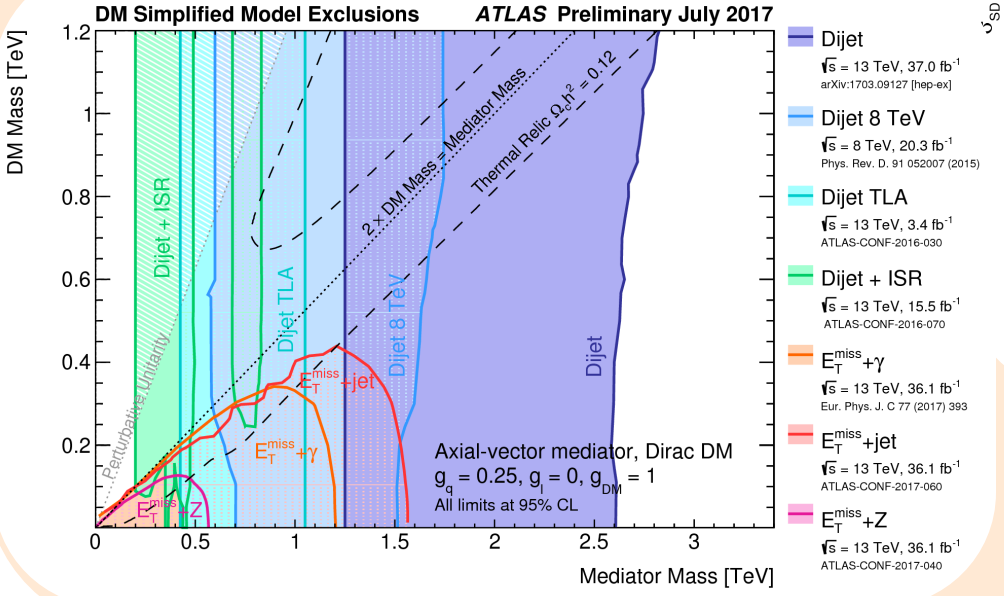


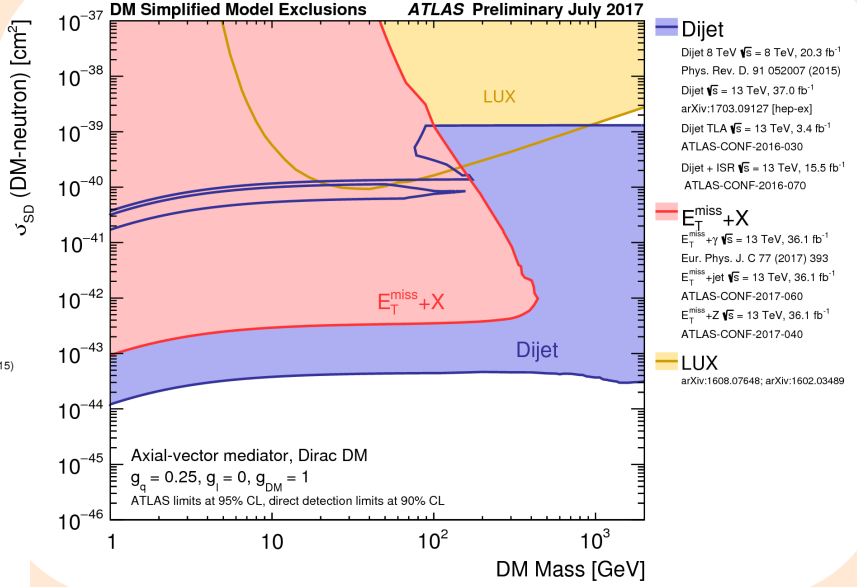
MET + X



Dijet + X

Exclusion limits in m_{DM} – m_A plane

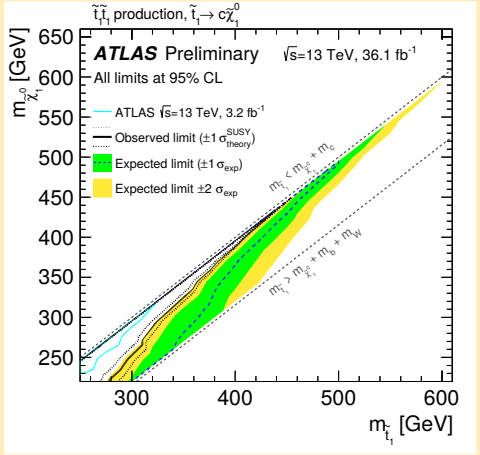




Exclusion limits in DM-proton σ – m_{DM}

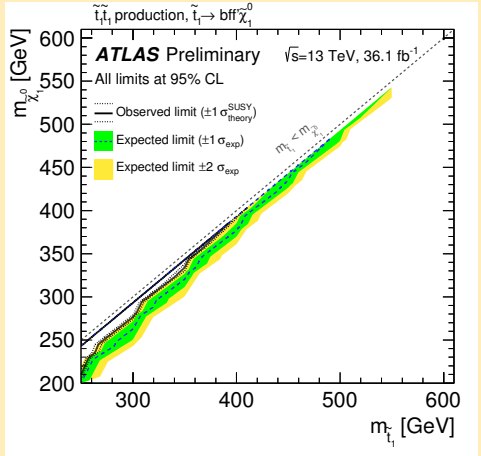
+ More DM/SUSY/Add Interpretations

SUSY



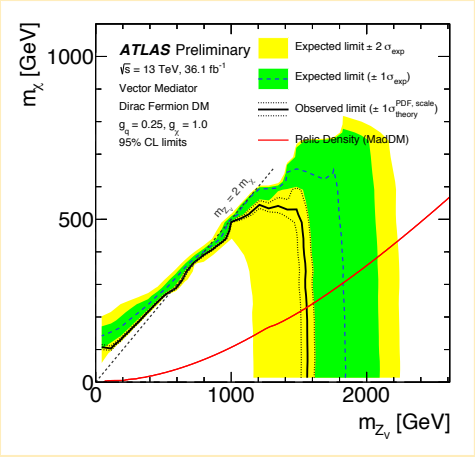
$$\tilde{t}_1 \to b + ff' + \tilde{\chi}_1^0$$

SUSY



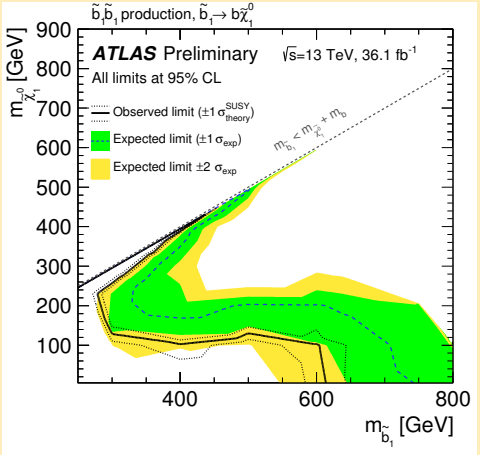
$$\tilde{t}_1 \to b + ff' + \tilde{\chi}_1^0$$

DM



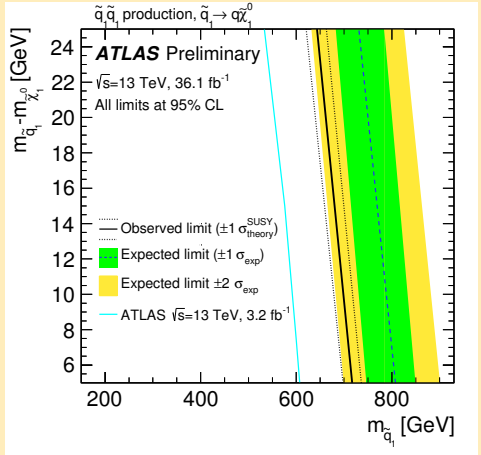
vector interaction

SUSY



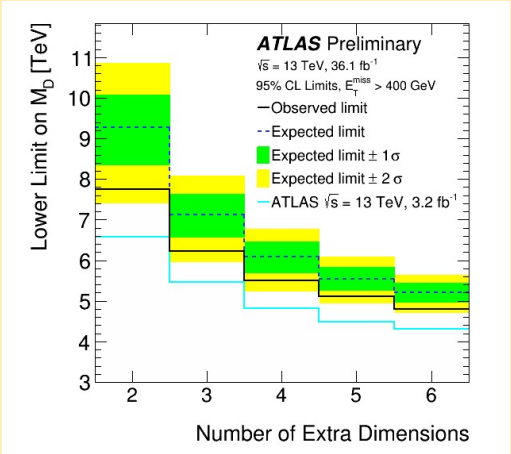
$$\tilde{b}_1 \to b + \tilde{\chi}_1^0$$

SUSY

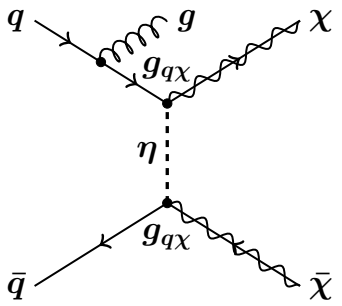


$$\tilde{q} \to q + \tilde{\chi}_1^0$$

ADD



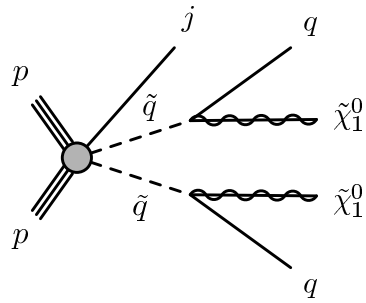
Conclusions



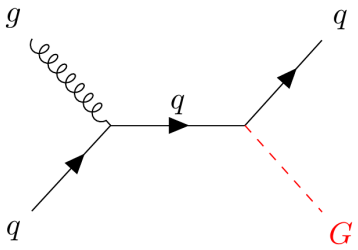
- ATLAS mono-jet analysis with 2015+2016 data

ATLAS-CONF-2017-060→ https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-060/

  - sizeable sensitivity improvement wrt to previous search
  - paper with more DM interpretations soon to be out…



- More data ahead, new challenges
  - try to go lower in MET (work in region where trigger is not at plateau?)
  - improve precision with constraint from γ+jets data
  - use additional discriminating variables



Stay tuned !

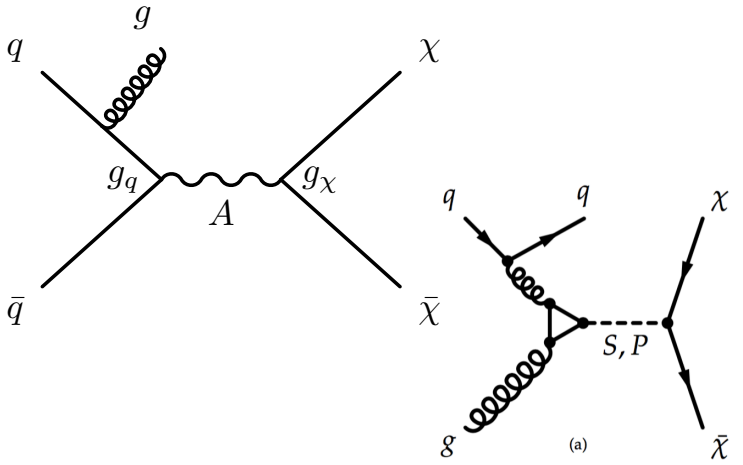
BACK-UP

+ Useful links

- ATLAS Mono-jet 2015+2016 results:
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-060/
- ATLAS Exotics summary plots:
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/
- ATLAS Exotics public results:
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- ATLAS Jet/Etmiss public results:
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetEtmissPublicResults
- LHC DM Working group documents:
  - Benchmark models: https://arxiv.org/abs/1507.00966
  - Presentation of results for MET+X: https://arxiv.org/abs/1603.04156
  - Presentation of results for MET+X and Dijet: http://arxiv.org/pdf/1703.05703
- Precise predictions for V+jets dark matter backgrounds:
  https://arxiv.org/abs/1705.04664

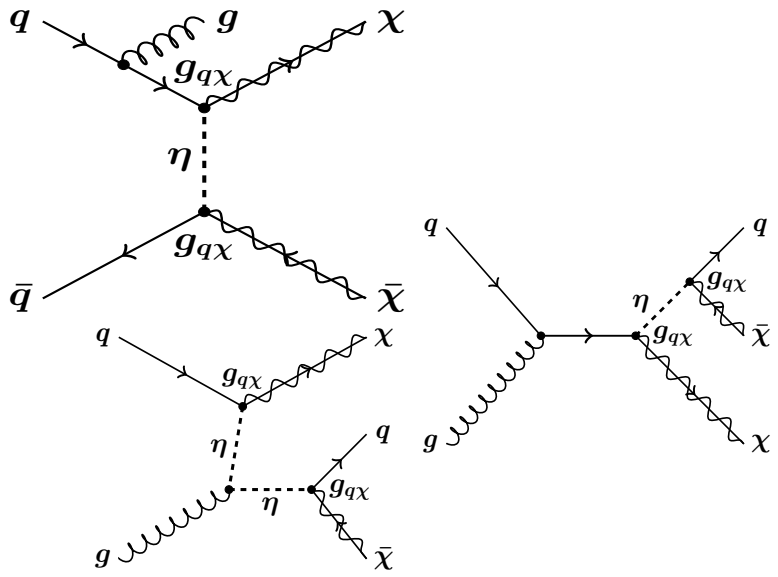
+ Dark Matter Models

Simplified models to describe Dark Matter pair production (ATLAS/CMS DM forum 1507.00966)



Axial-vector (and vector) mediator and pseudo-scalar mediators, s-channel

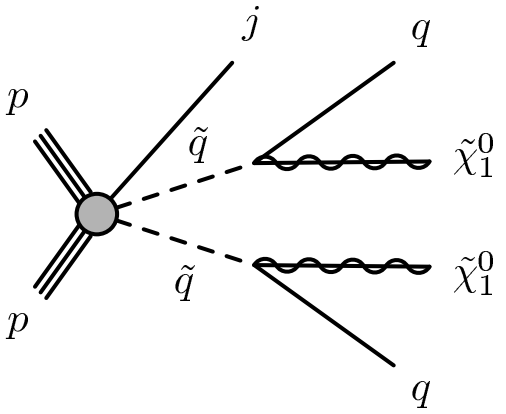
- jet from ISR
- mediator has spin 1, couples to all generations of quarks
- 4 free parameters: m_A, m_χ, g_q, g_χ
- minimal mediator width



Scalar colored mediator, t-channel

- jet either from ISR or from mediator decay
- mediator has spin 0, couples to first two generations of quarks
- 3 free parameters: m_η, m_χ, $g_{q\chi}$
- minimal mediator width

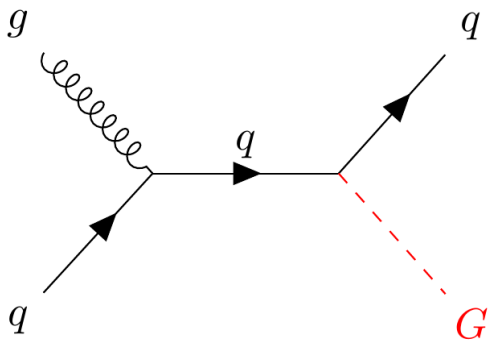
+ SUSY and ADD



SUSY Squark pair production

- compressed scenarios: p_T of quark and LSP are low, system is boosted by ISR jet
- parameters: squark mass, $\Delta m \equiv m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$
- four scenarios considered:

$$\tilde{q} \to q + \tilde{\chi}_1^0 \qquad \tilde{t}_1 \to c + \tilde{\chi}_1^0$$
$$\tilde{b}_1 \to b + \tilde{\chi}_1^0 \qquad \tilde{t}_1 \to b + f f' + \tilde{\chi}_1^0$$



ADD Large Extra-Dimensions

- n additional dimensions compatcified are assumed, where gravity propagates, scale M_D is the fundamental scale of the 4+n-dim theory
- gravitons escaping the extra dimensions => E_T^{miss}
- limits on M_D as a function of the n := #extra-spatial dimensions assumed