HL-LHC: Dark matter at CMS

Deborah Pinna

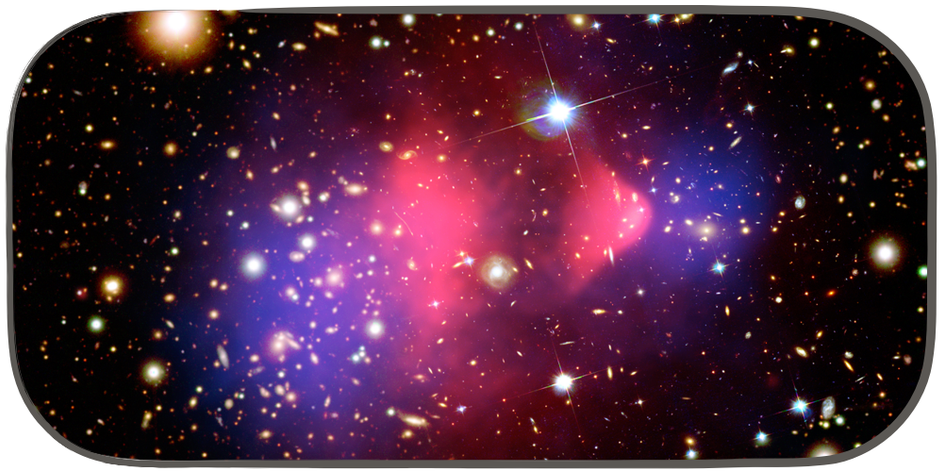
on behalf of the *CMS Collaboration*

HL/HE LHC Meeting

Fermilab, 4-6 April 2018

The dark matter mystery

DM evidence



DM nature

assume weak interaction with SM

DM interaction:

scalar, pseudoscalar
vector, axial-vector

X= j, tt, t, Z

investigate specific interactions and final states

DM production

particle colliders

more details in M. Buckley's talk

The dark matter mystery

DM evidence

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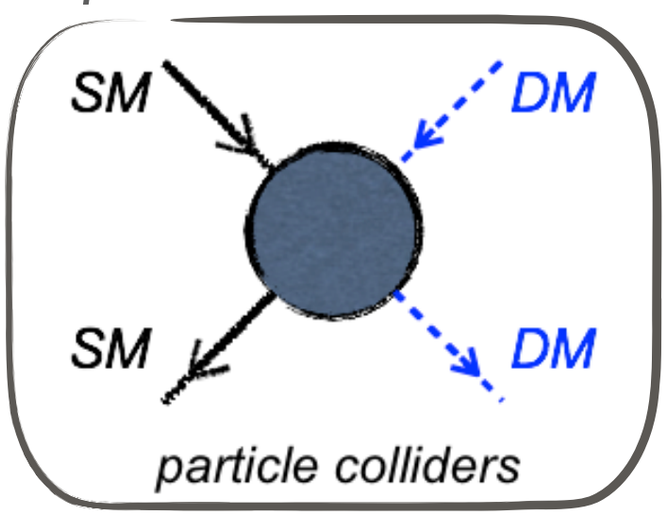
DM production



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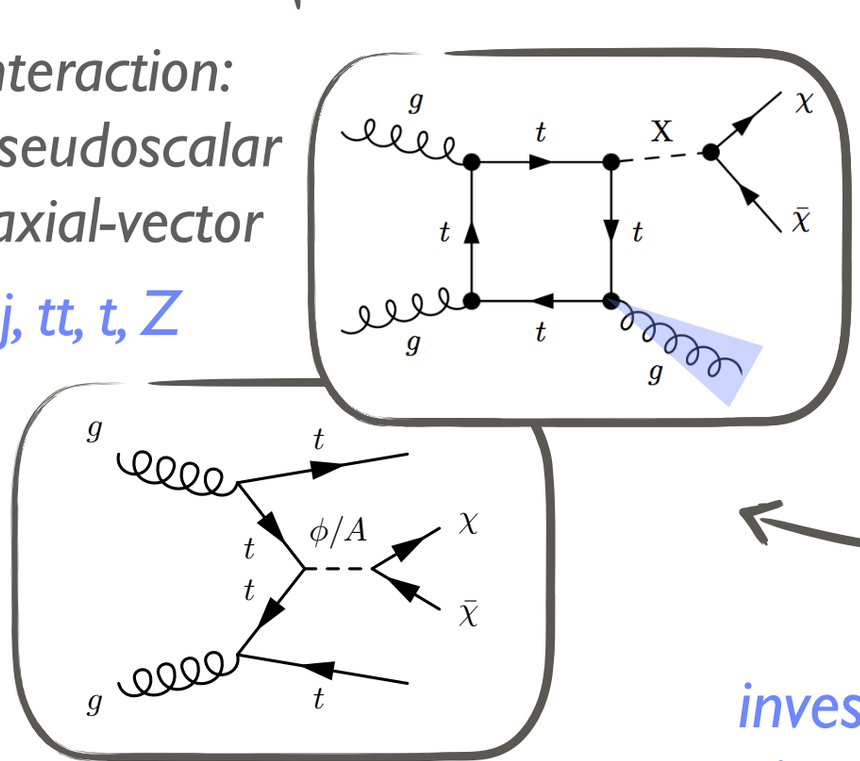
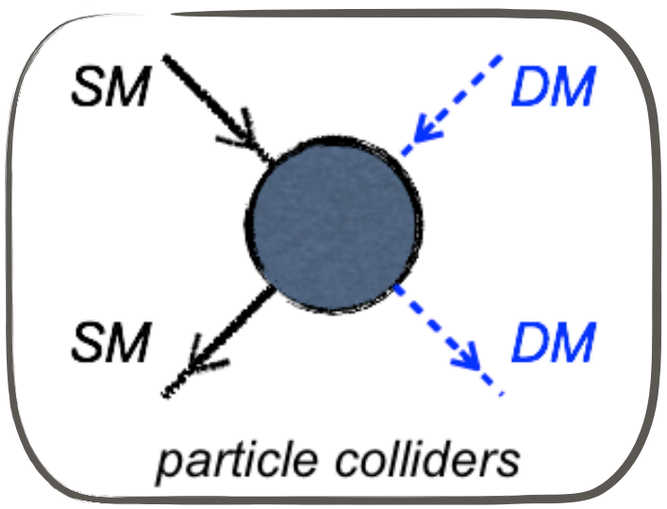


DM production



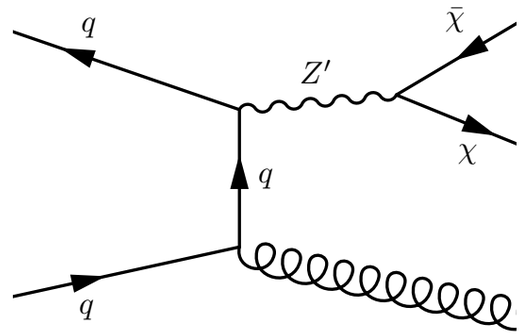
investigate specific interactions and final states

more details in M. Buckley's talk

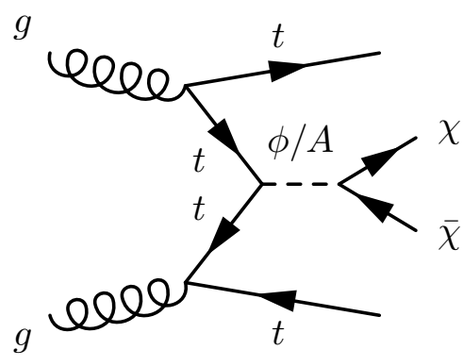
Dark matter phenomenology

Which type of events do we study at colliders? different types of interactions can be assumed

	vector	*axial-vector*
spin-1 mediator	$g_q \sum_q V_\mu \bar{q}\gamma^\mu q$	$g_q \sum_q A_\mu \bar{q}\gamma^\mu\gamma^5 q$
spin-0 mediator	*scalar*	*pseudoscalar*
	$g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$	$g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f}\gamma^5 f$



spin-1 mediator



spin-0 mediator

Results and plans discussed in this talk

X	*based on*	*Mediator*	*Sensitivity at HL-LHC*	*Result for HL-LHC*
jets	*CMS-EXO-16-037, 12.9 fb^{-1} 13 TeV*	spin-1, spin-0	3000 fb^{-1}, HL detector parameters	*CMS-FTR-16-005*
tt	*CMS-EXO-17-014, 35.9 fb^{-1} 13 TeV*	spin-0	3000 fb^{-1}	*planned*
t	Pheno paper, Phys. Rev. D 96, 035031	spin-0	3000 fb^{-1}, HL detector parameters	*planned*
Z	*CMS-EXO-XX-YYY, 35.9 fb^{-1} 13 TeV*	spin-1	3000 fb^{-1}	*planned*

Dark matter phenomenology

Which type of events do we study at colliders? different types of interactions can be assumed

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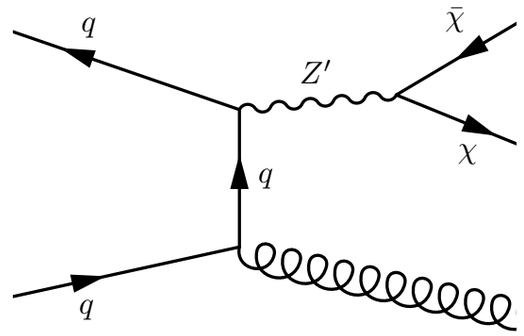
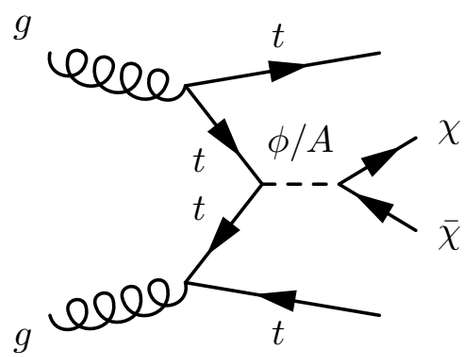


spin-1 mediator



spin-0 mediator

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tt	*CMS-EXO-17-014, 35.9 fb^{-1} 13 TeV*	spin-0	3000 fb^{-1}	*planned*
t	Pheno paper, Phys. Rev. D 96, 035031	spin-0	3000 fb^{-1}, HL detector parameters	*planned*
Z	*CMS-EXO-16-052, 35.9 fb^{-1} 13 TeV*	*spin-1*	*3000 fb^{-1}*	*projection planned*

Data analysis: strategy

1. *DM appear as event excess in E_T^{miss} tail wrt SM*

   - look for excess in region enriched in signal (signal region - SR)

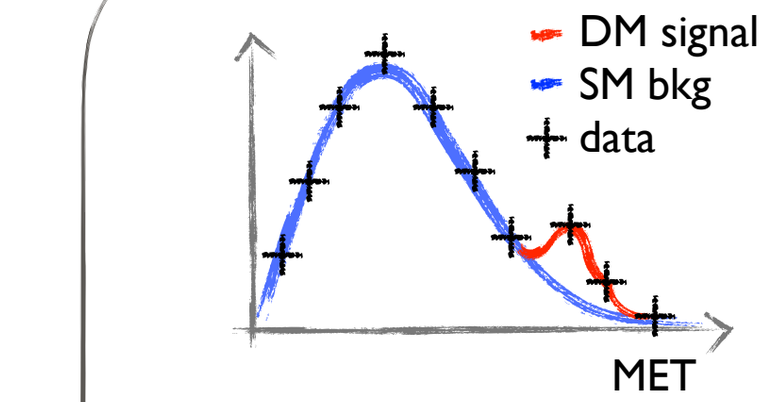
2. *Essential good modeling and evaluation of other processes* in SR (background - bkg)

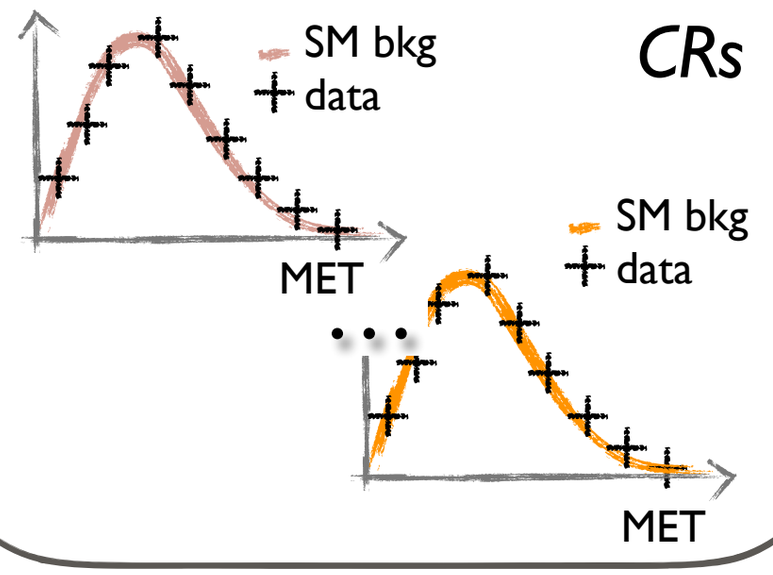
   - improve bkg description from region deprived of signal and enhanced in bkg (control region - CR)

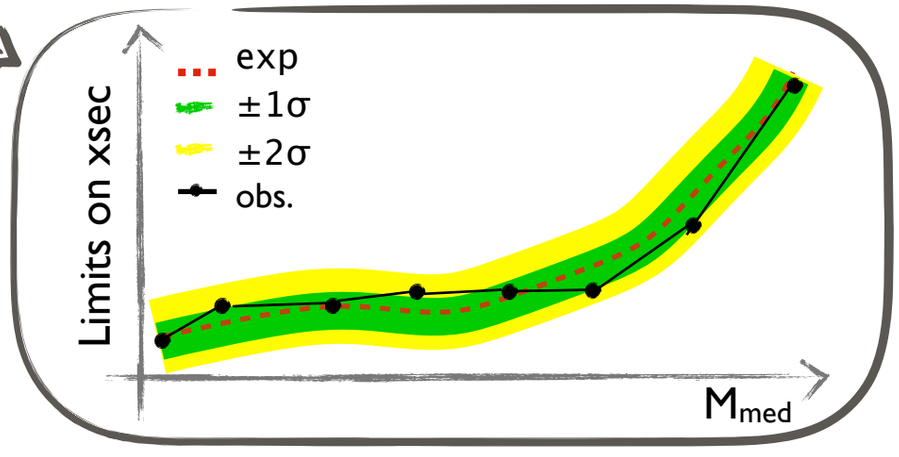
3. *Compare SM predictions with data*

   - *excess of events in data*. Did we find DM?

   - *no excess,* interpret result in terms of theory model parameters



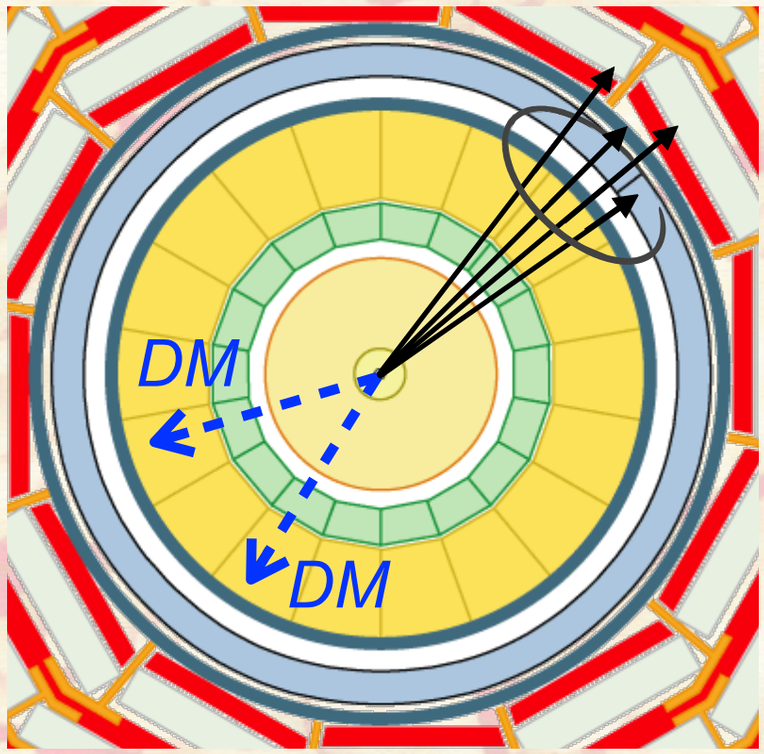




DM+jet search

CMS-FTR-16-005

Signature: large E_T^{miss} and ≥1 high-p_T jet

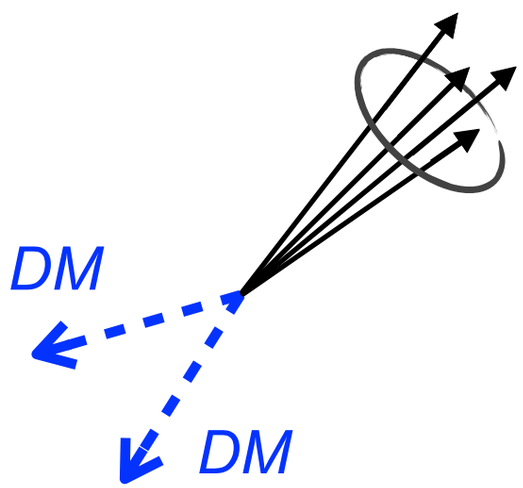


monojet

DM+jet: event selection and strategy

CMS-FTR-16-005

monojet



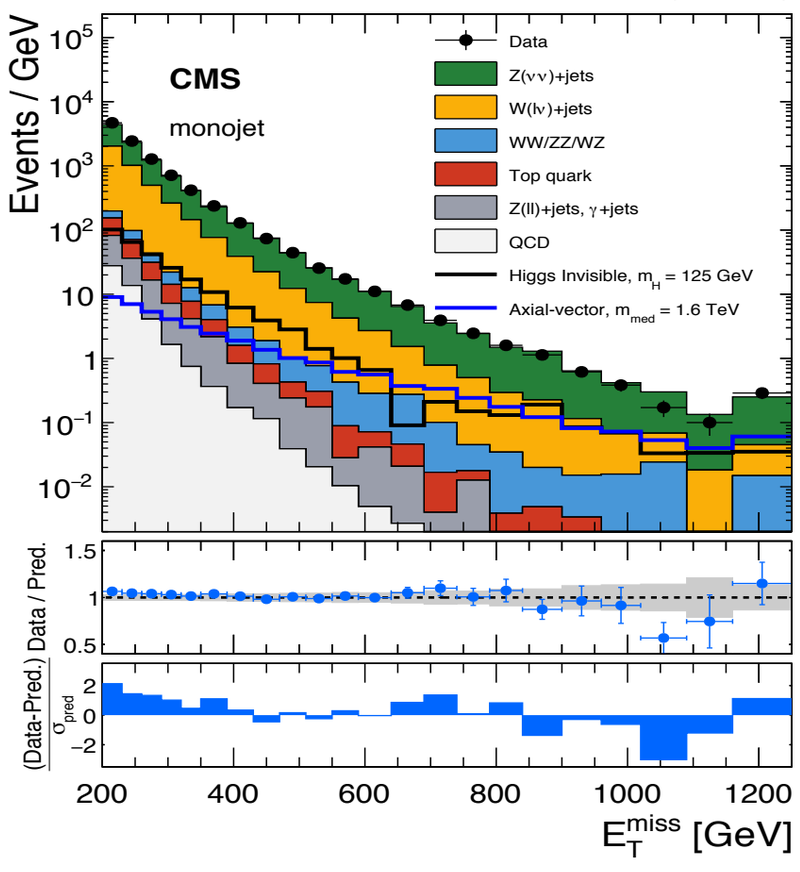
Select events

- leptons veto
- no b-tagged jets
- E_T^{miss} > 200 GeV
- hight p_T jet
- $\Delta\Phi$(jet, E_T^{miss}) > 0.5

Result with 2016 data

- ***Z(vv) and W(lv)+jets*** main background contributions
  - *about 90% of total bkg*
- bkg description improved from data in ***Z(ll) and W(lv)+jets enhanced CRs***

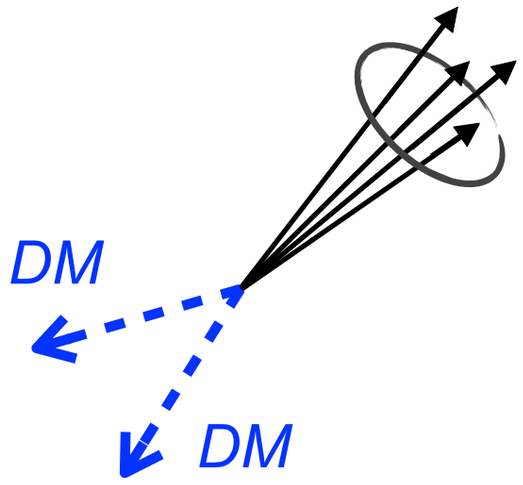
CMS-EXO-16-037 12.9 fb^{-1} (13 TeV)



DM+jet: event selection and strategy

CMS-FTR-16-005

monojet



Select events

- leptons veto
- no b-tagged jets
- E_T^{miss} > 200 GeV
- p_T (jet) > 250 (200) GeV
- $\Delta\Phi$(jet, E_T^{miss}) > 0.5

Sensitivity at HL-LHC

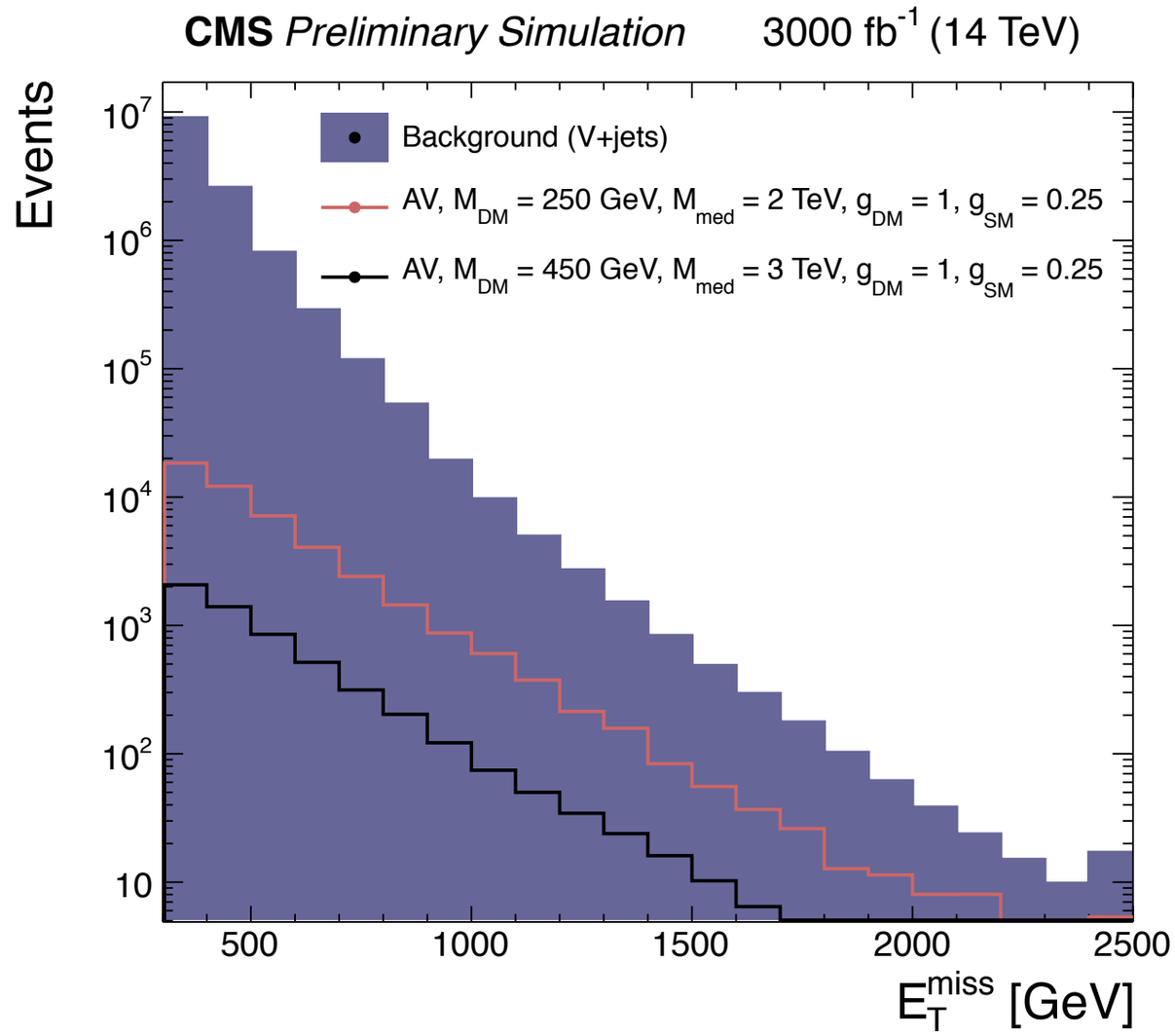
- physics reach with 3000 fb^{-1}
- simulate aspects of the upgraded CMS detector based on *Phase-2 Technical Proposal*
- different systematic scenarios

DM+jet: results

CMS-FTR-16-005

Strategy sensitivity studies at HL-LHC

- *higher trigger thresholds expected at HL-LHC*
- *0 pileup scenario*
  - analysis sensitivity dominated by events at large E_T^{miss}
  - high pileup effects are not expected to cause significant sensitivity decrease
- *monojet signal and V+jets bkg samples*
  - generated at *14 TeV*
  - processed through DELPHES simulation with *Phase-2 detector expected performance*



V+jets taken from simulation

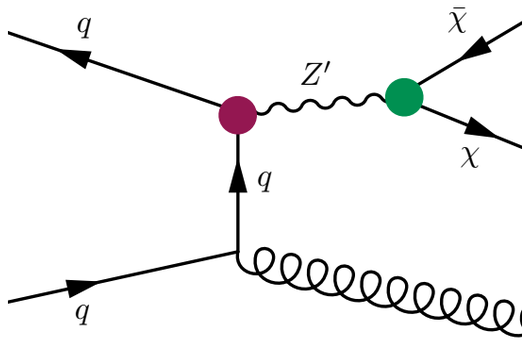
DM+jet: results interpretation

CMS-FTR-16-005

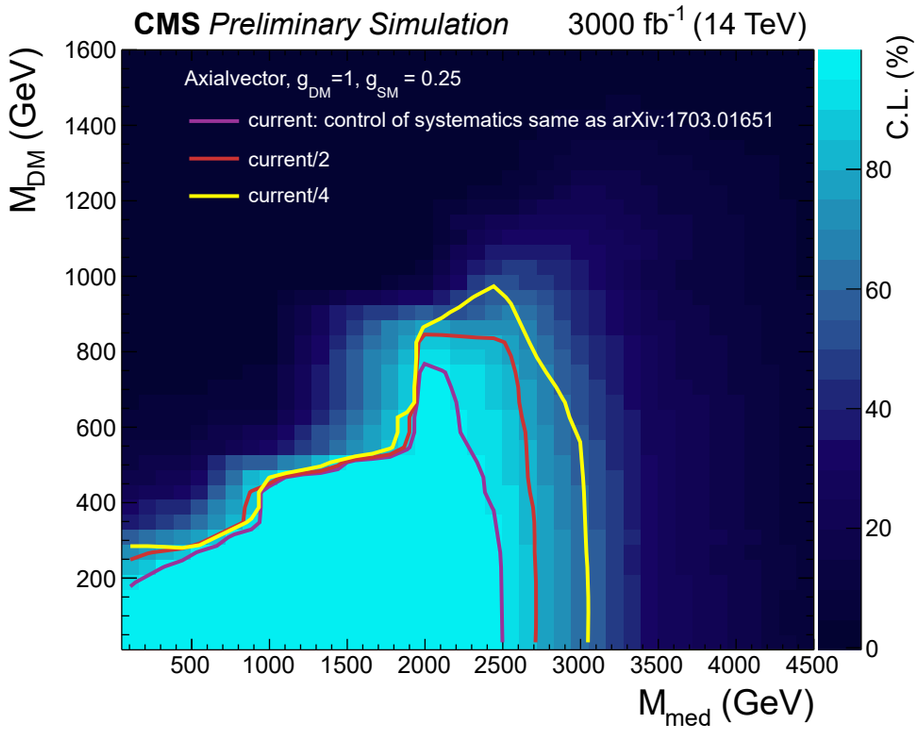
Interpretation in terms of simplified model with Dirac DM *upper limits at 95% CL on cross section*

axial-vector interaction

g_q=0.25 g_{DM}= 1



can be compared to limits on spin-dependent DM-nucleon scattering cross sections



- *Dominating sensitivity region:* tail of the E_T^{miss} distribution
- *Systematic uncertainties scenarios:*
  - *current systematic*, systematic uncertainties on E_T^{miss} distribution as in *arXiv:1703.01651*
  - *current/2*, current systematic scenario reduced by a factor 2
  - *current/4*, current systematic scenario reduced by a factor 4

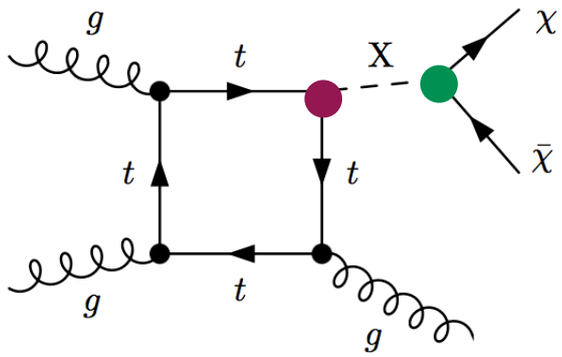
DM+jet: results interpretation

CMS-FTR-16-005

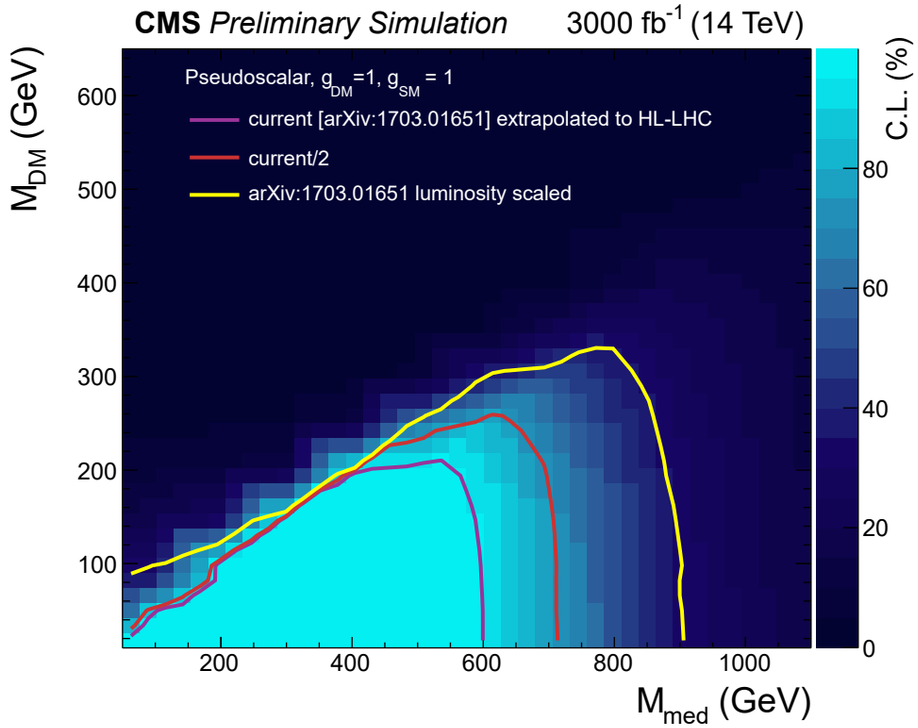
Interpretation in terms of simplified model with Dirac DM *upper limits at 95% CL on cross section*

pseudoscalar interaction

$g_q = 1$ $g_{DM} = 1$



velocity suppressed cross section for DM-nucleon scattering, colliders important probe

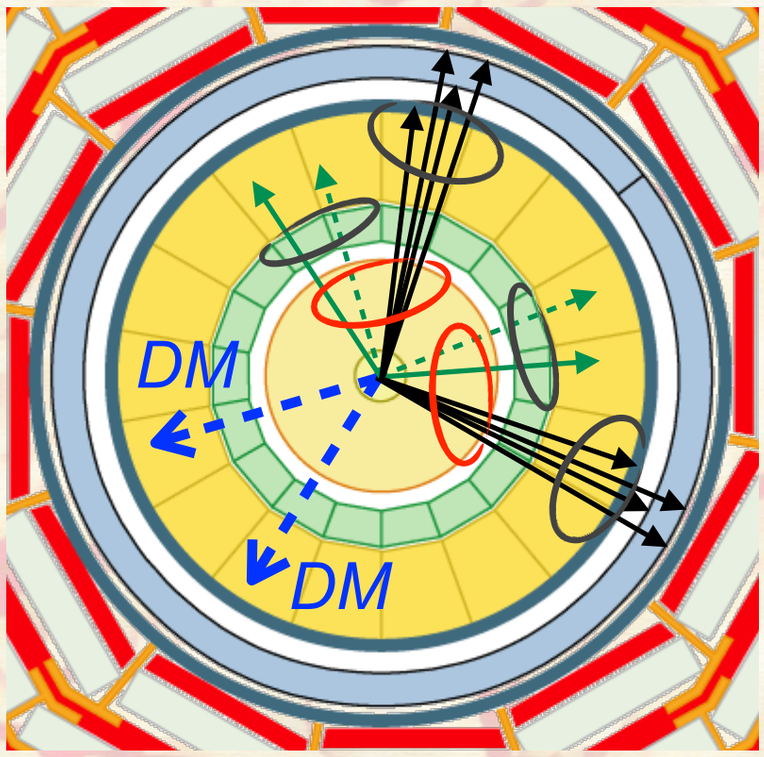


- *Dominating sensitivity region:* bulk/low E_T^{miss} distribution
- *Systematic uncertainties scenarios:*
  - *current systematic*, E_T^{miss} <500 GeV lepton identification/iso efficiency in lepton CRs (1% per leg), E_T^{miss} >500 GeV statistics in CRs (from *arXiv:1703.01651* scaled to lumi)
  - *current/2*, current systematic scenario reduced by a factor 2
  - *current/4*, current systematic scenario reduced by a factor 4

DM+tt search

Planned

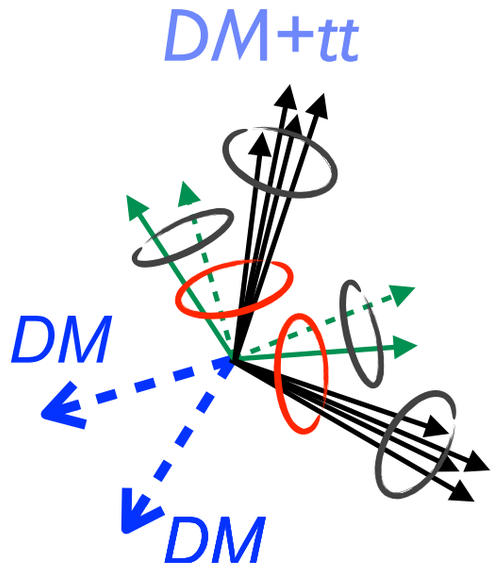
Signature: large E_T^{miss} and 2 top-quarks



DM+tt

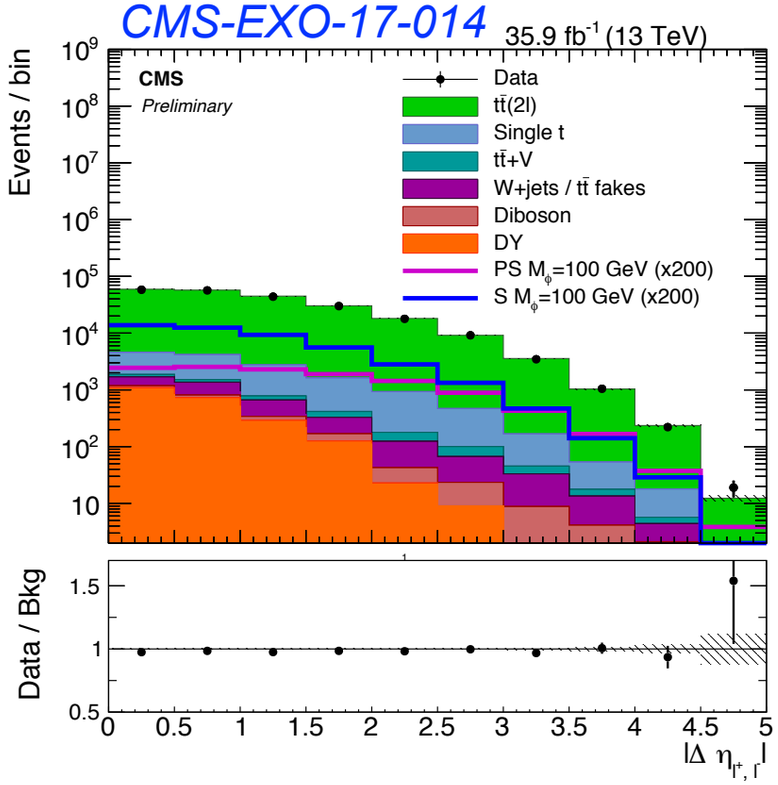
DM+tt: event selection and strategy

Planned



Select events

- 2 lepton: isolated ee, μμ, eμ
- ≥ 2 jets, ≥ 1 b-jet
- E_T^{miss} > 50 GeV



Analysis strategy with 2016 data

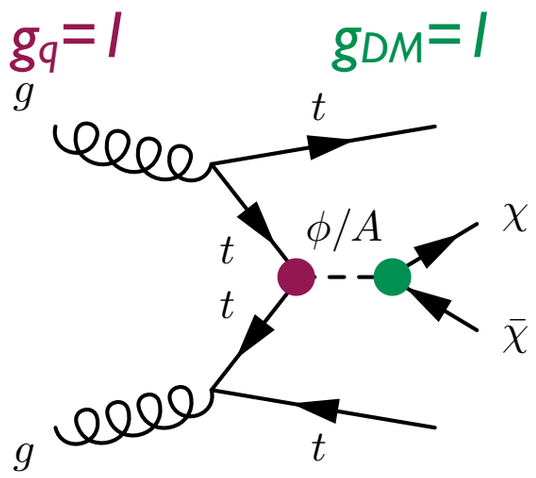
- multivariate discriminant built from MET-related and spin-sensitive variables
  - *BDT discriminant distribution used to extract results*
- nature of mediator from spin correlation properties of the *tt* system
  - *scalar interaction has SM-like tt spin*
  - *pseudoscalar interaction shows significant deviations*

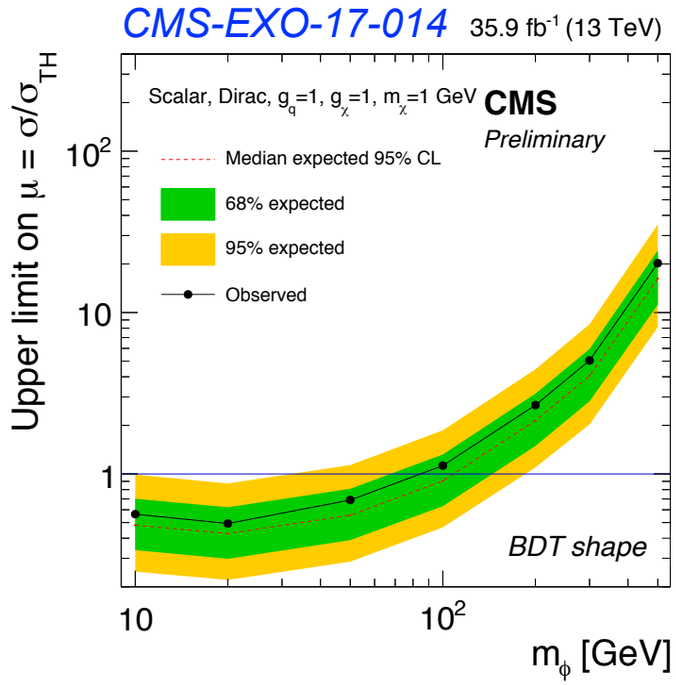
DM+tt: results interpretation

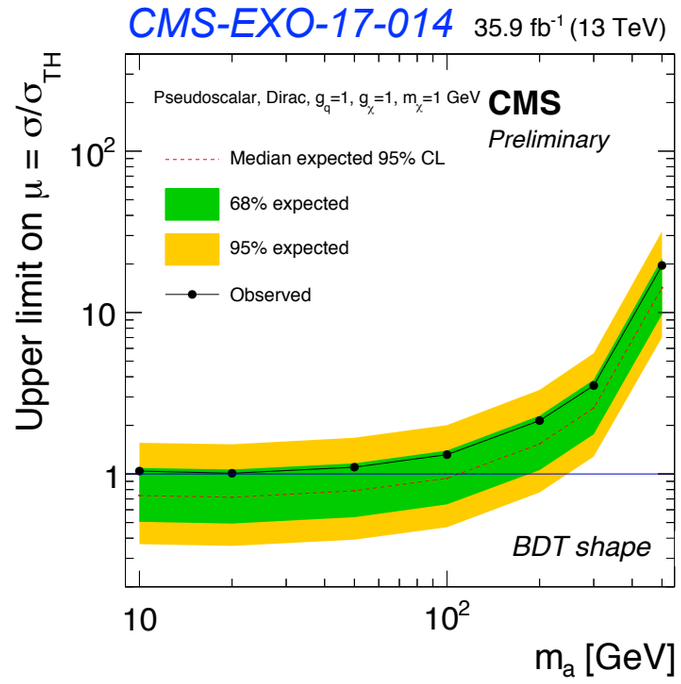
Planned

Interpretation in terms of simplified model with Dirac DM *upper limits at 95% CL on cross section*

scalar/pseudoscalar interaction







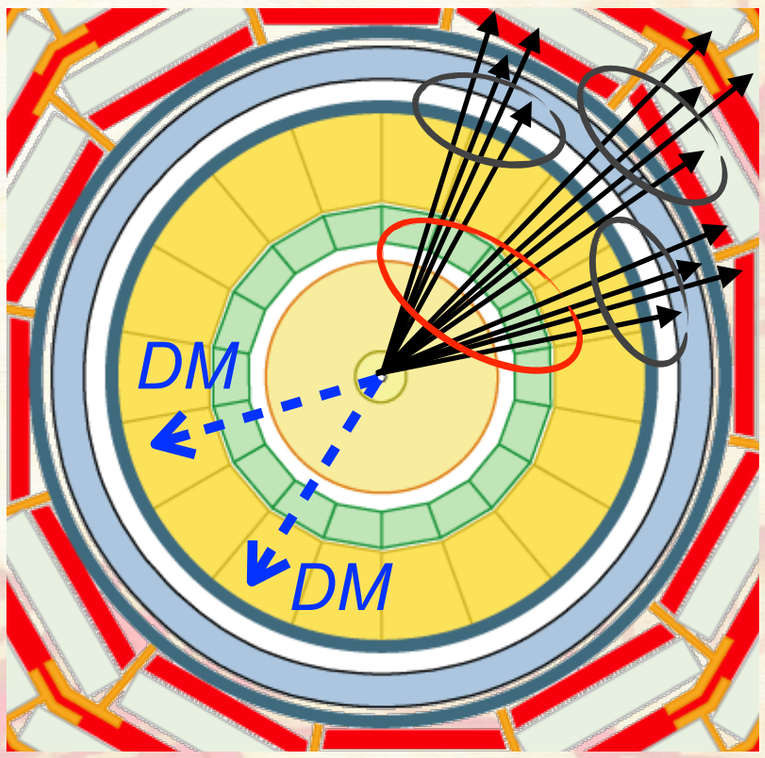
Strategy sensitivity studies at HL-LHC

- *Projections of limits* from current analysis scaling result *to 3000 fb^{-1} lumi*
  - include estimate of systematic uncertainties expected at HL-LHC
- Sensitivity estimate on the *discrimination between scalar and pseudoscalar* mediator hypotheses

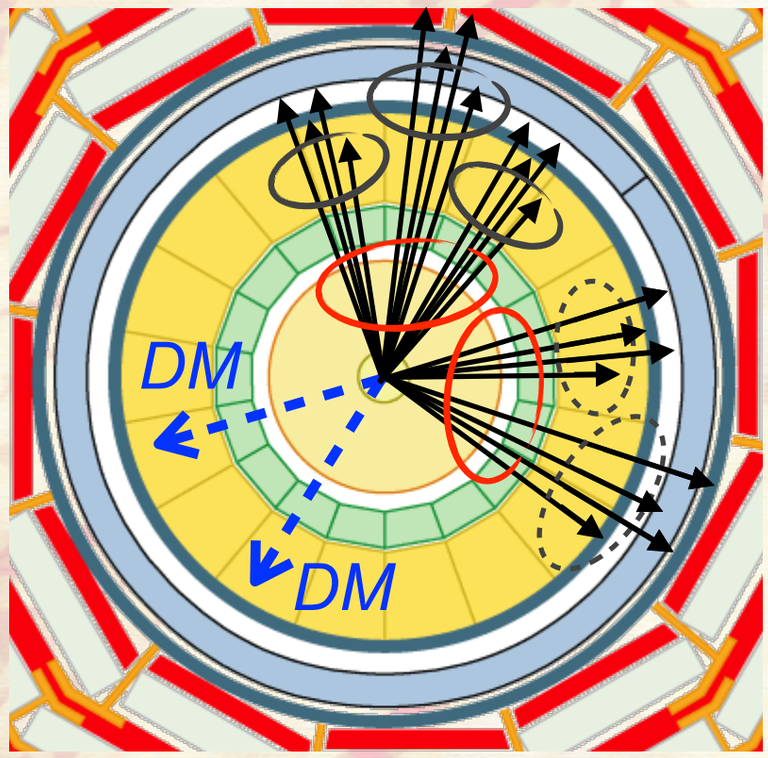
DM+top search

Planned

Signature: large E_T^{miss} and 1 top-quark



DM+top: t-channel



DM+top: tW-channel

D.P, A. Zucchetta,
M. R. Buckley, F. Canelli
Phys. Rev. D 96, 035031

DM+top: phenomenology

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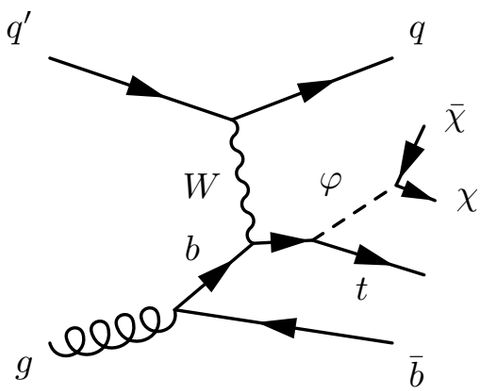
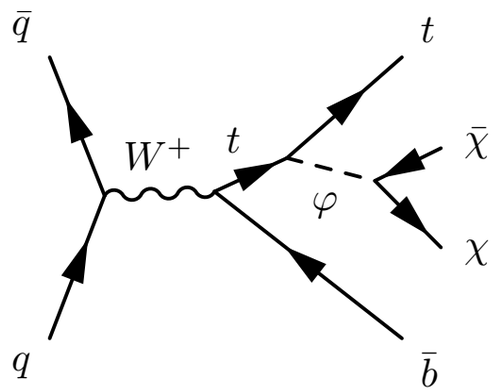
Simplified model describing *DM+tt* production also predicts *DM+single top processes (DM+top)*

- *not been investigated yet at colliders*

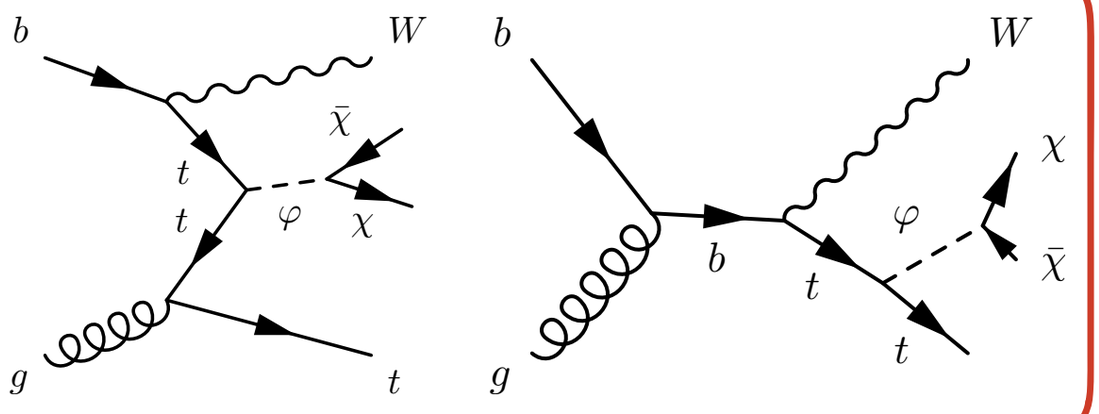
mediated by virtual t-channel W



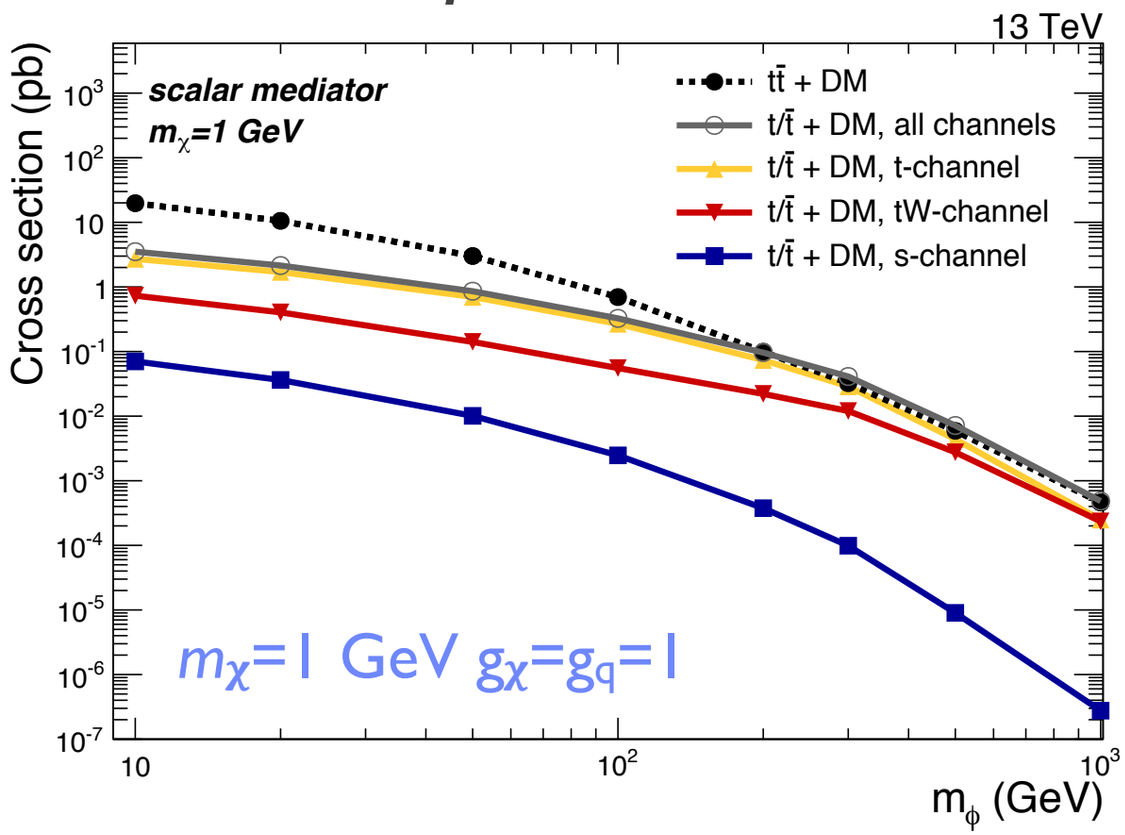
mediated by virtual s-channel W



associated production with W boson



Similar DM+tt vs DM+top for pseudoscalar



- *Note*
  - up to now only FCNC processes (mono-top)
  - *DM+top* process has non-boosted topology

D.P, A. Zucchetta,
M. R. Buckley, F. Canelli
Phys. Rev. D 96, 035031

DM+top: event selection

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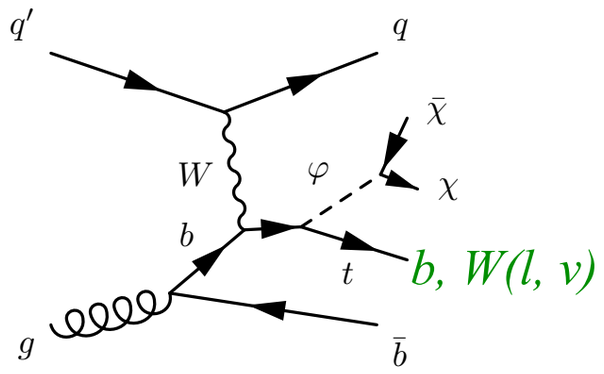
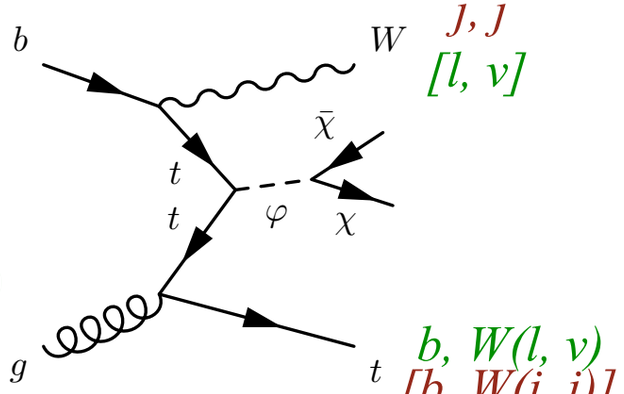
- What is the impact of the new channel on existing analyses?
  - consider similar existing data analysis and asses DM+top sensitive
  - compare to *DM+tt* 2015 data analysis *(CMS-PAS-EXO-16-005)*

single lepton

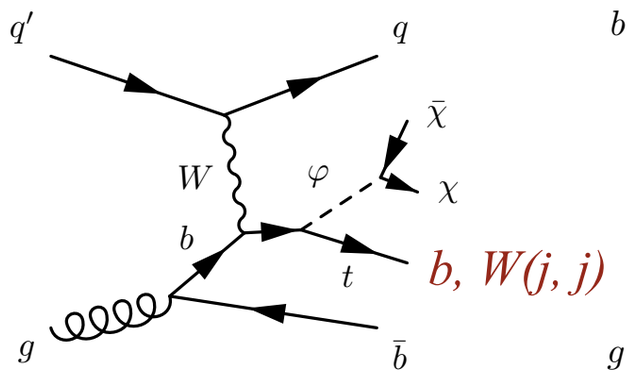


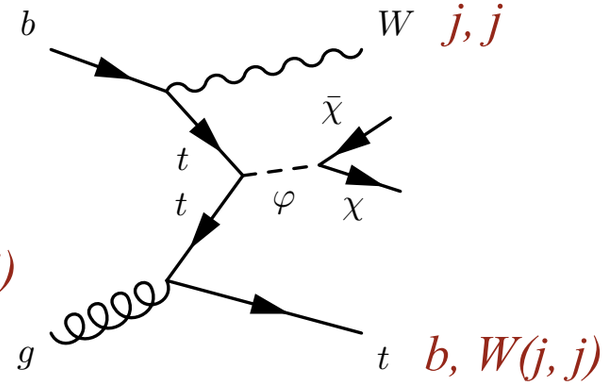


- 1 lepton: isolated e,μ
- ≥ *3 jets,* ≥ *1 b-jet*
- MET > 160 GeV

major bkg: tt(2l), W+jets

hadronic





- MET trigger
- leptons veto: e,μ
- ≥ *4 jets,* ≥ *2 b-jet*
- MET > 200 GeV

major bkg: tt(1l), W+jets, Z(νν)

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DM+top: sensitivity

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Planned

Impact on existing limits: improvements obtained including *DM+top* events in addition to *DM+tt*

Upper limits on DM production cross section

following similar approach of CMS DM+tt analysis:

- no shape information → counting experiment
- data and SM bkg events from *CMS-EXO-16-005*

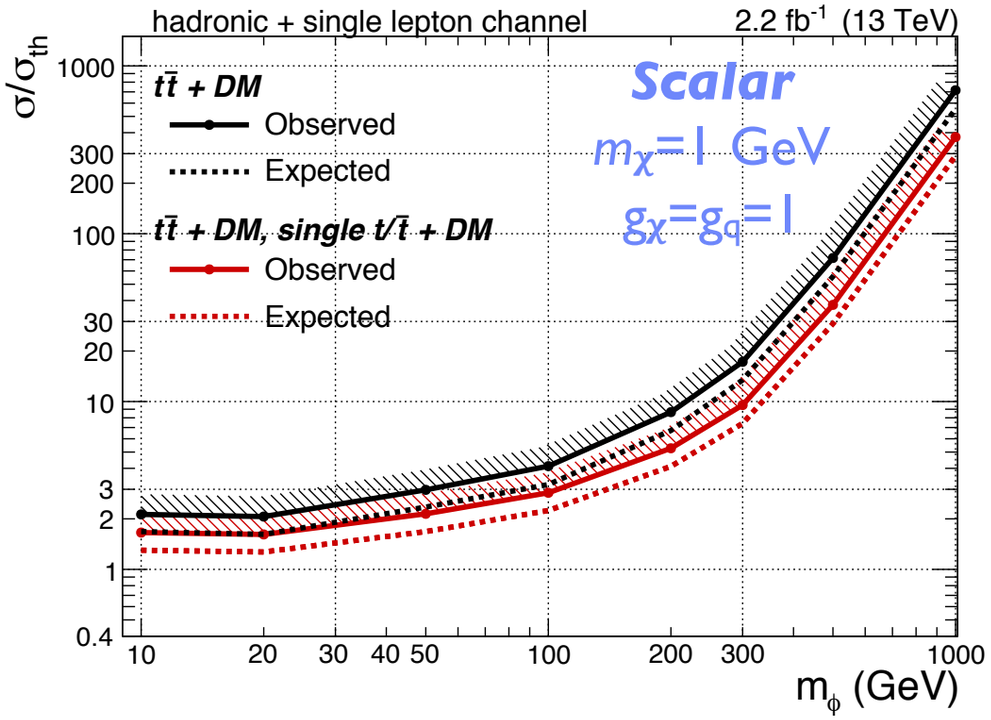
Sensitivity projection:

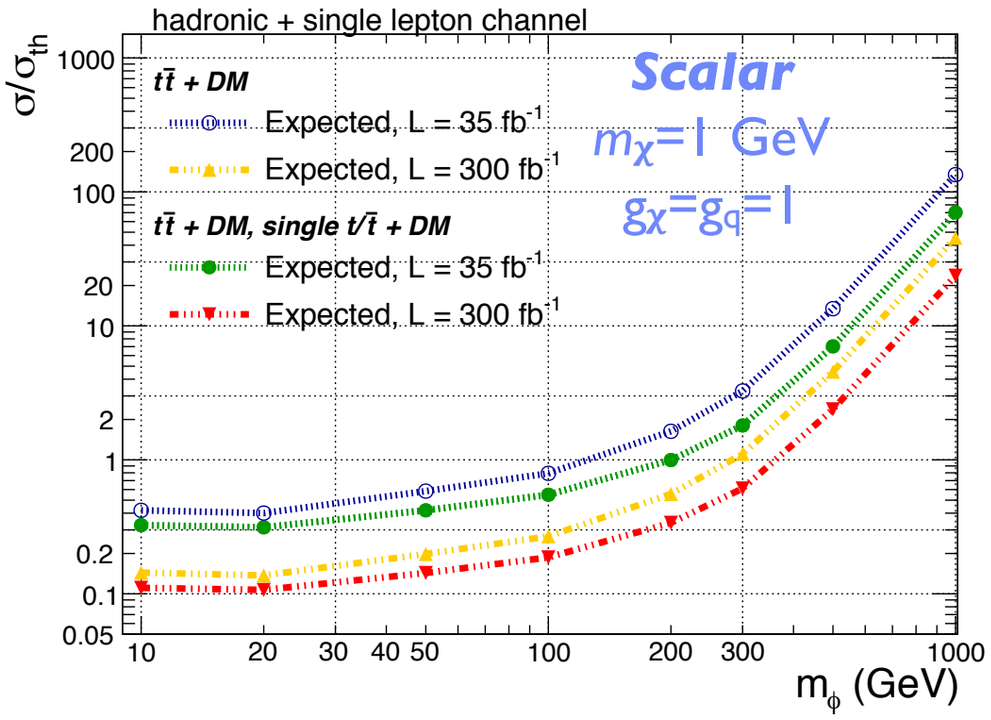
2016 dataset of 35 fb^{-1}

2023 dataset of 300 fb^{-1}

- *Assumptions*
  - 2015 PU scenario (11 on average for BX)
  - signal uncertainty proportional to lumi
  - bkg uncertainties scale as √lumi

improvements in range 30% to factor 2 without optimizing selection for DM+top





D.P, A. Zucchetta,
M. R. Buckley, F. Canelli
Phys. Rev. D 96, 035031

DM+top: sensitivity

BOSTON UNIVERSITY

Planned

Impact on existing limits: improvements obtained including *DM+top* events in addition to *DM+tt*

Upper limits on DM production cross section

following similar approach of CMS DM+tt analysis:

- no shape information → counting experiment
- data and SM bkg events from *CMS-EXO-16-005*

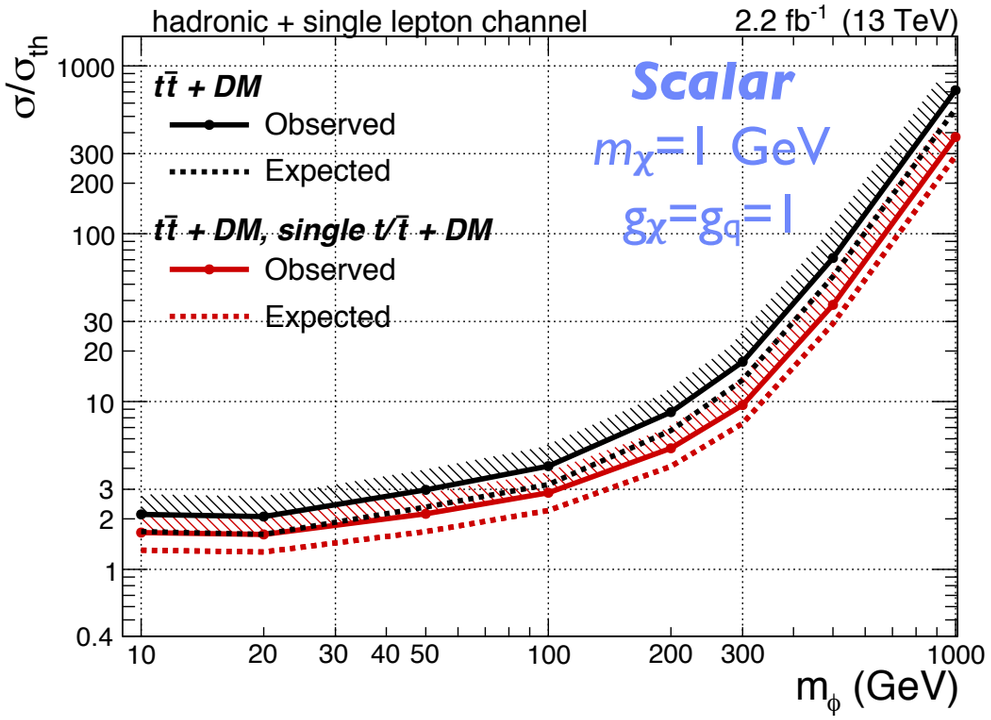
Sensitivity projection:

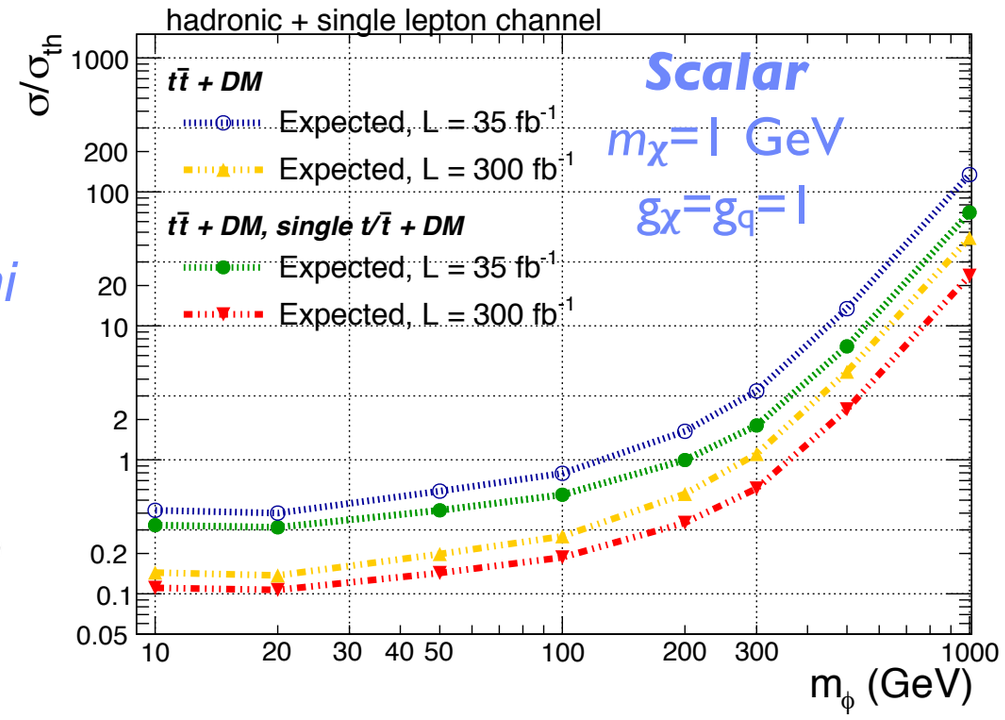
2016 dataset of 35 fb^{-1}

2023 dataset of 300 fb^{-1}

Strategy sensitivity studies at HL-LHC:

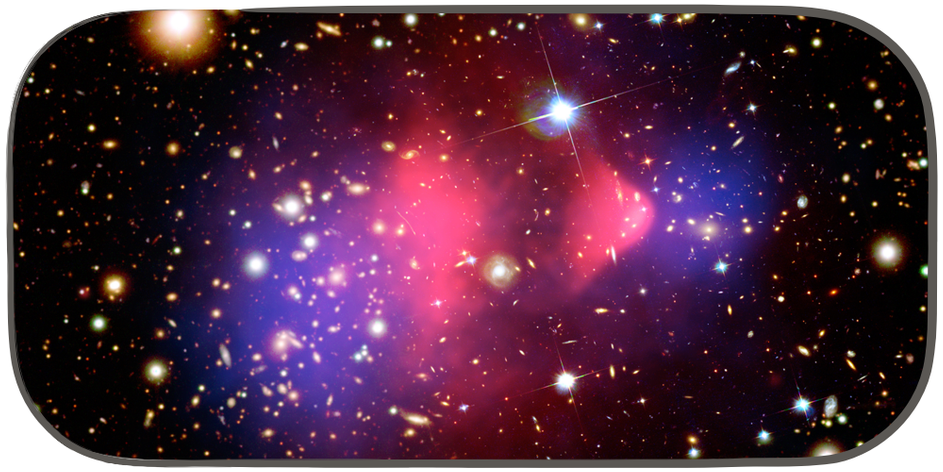
- *limits projections* using DM+tt analysis selection
- 200 and 0 PU scenarios, 14 TeV and *3000 fb^{-1} lumi*
- signal and background simulation including *Phase-2 detector expected performance*
- scale systematic uncertainties to HL-LHC scenario





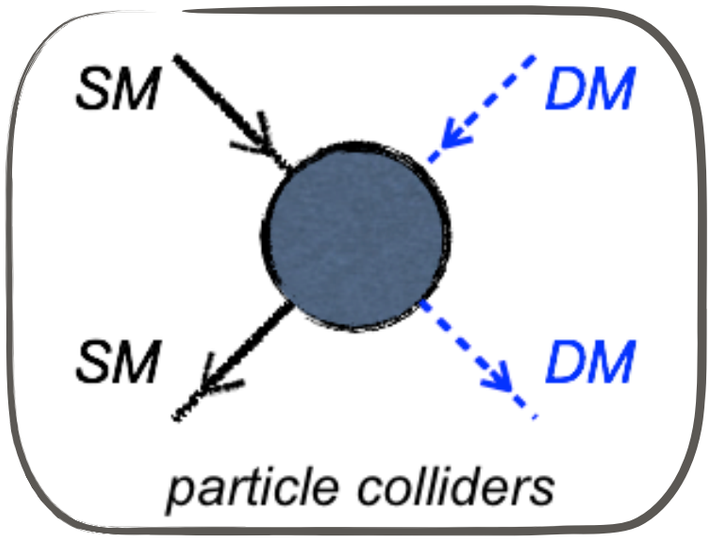
Summary

DM evidence



assume weak interaction with SM

DM production



describe process in most general way: simplified models

DM nature

DM+jets: CMS-FTR-16-005

DM+top: planned

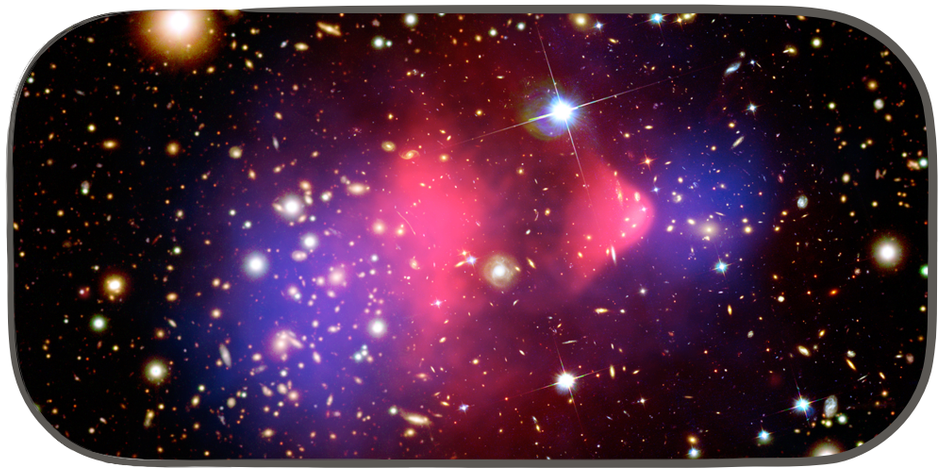
DM+tt: planned

different interactions/channels investigated

DM discovery one of top priorities of HL-LHC

Summary

DM evidence



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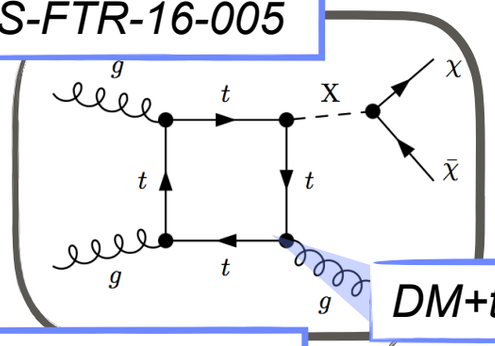
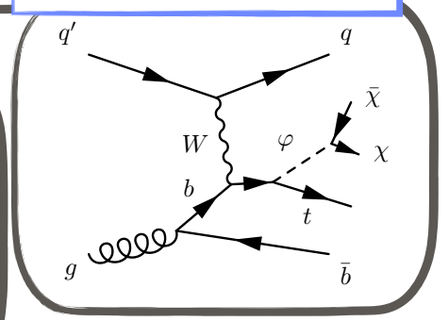
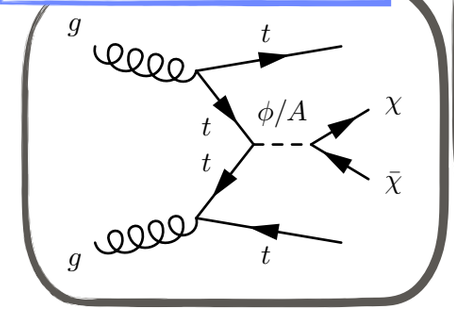


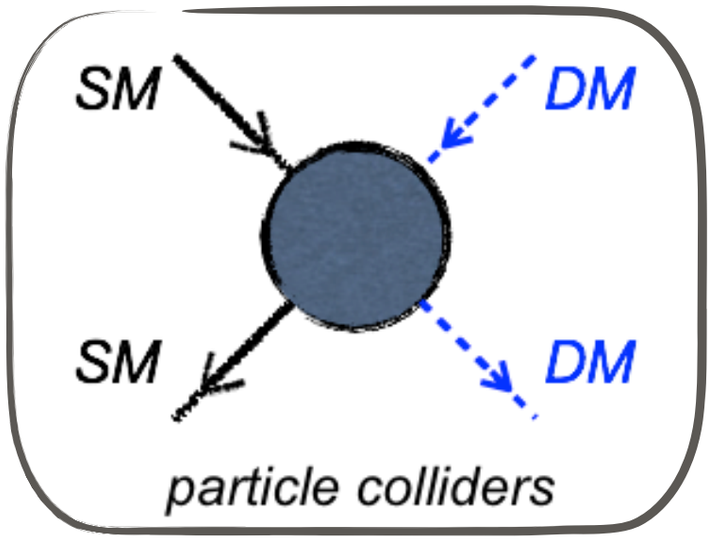
DM+top: planned



DM+tt: planned



DM production



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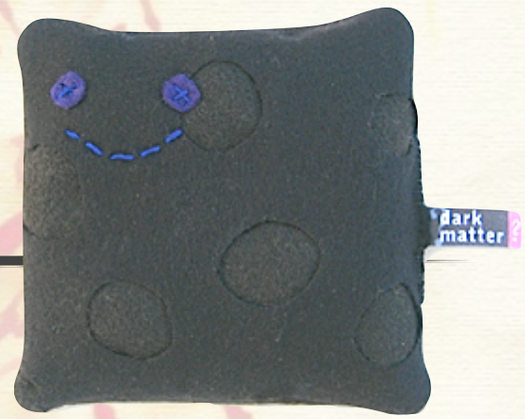
Thank you!



Backup