University of Zurich[UZH]

Dark Matter produced in association with top quark pair

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Supervisor: Prof. Florencia Canelli

Zurich PhD seminar

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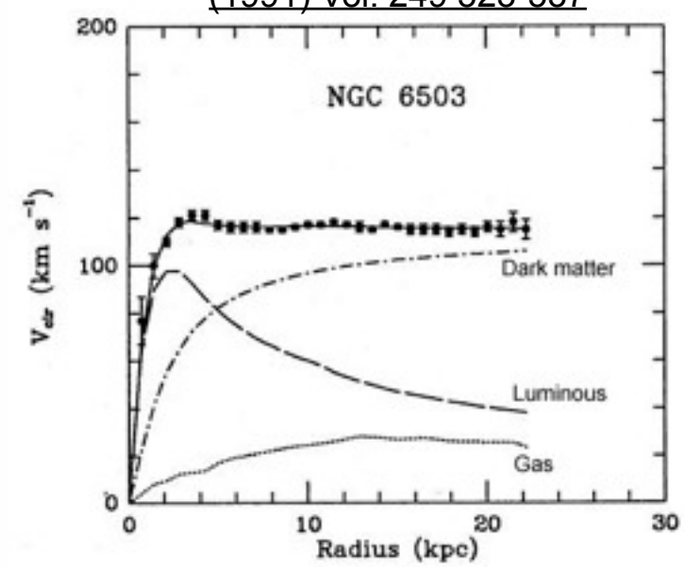
Introduction

- Dark Matter (DM) empirical evidence for new physics beyond Standard Model (SM)

  singular galaxies rotation curves constant beyond luminous region

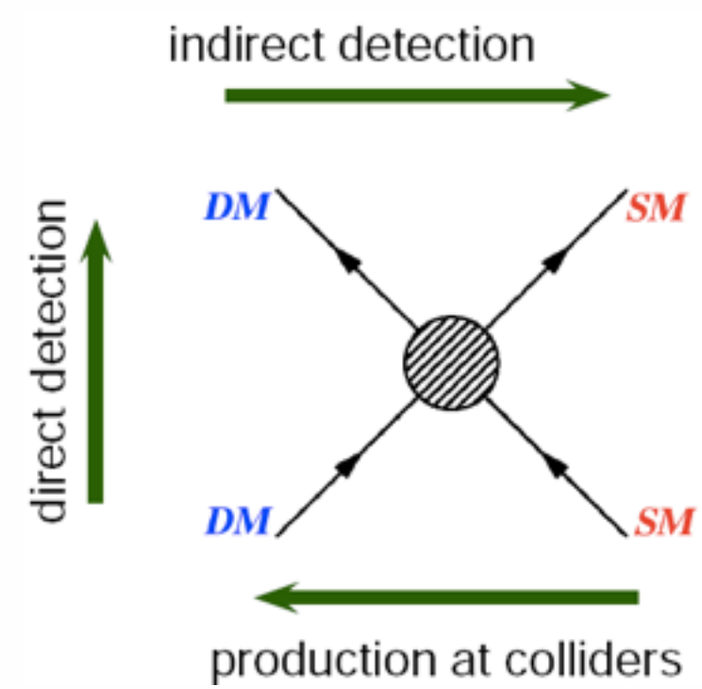
  - velocity is expected to go like $r^{-1/2}$
  - differences explained by non luminous mass

Begeman, K. G., et al., MNRAS (1991) Vol. 249 523-537



- Studies at different scales provide measurements that universe is composed mainly of non-baryonic matter
  - DM abundance ~24% of the universe, five times the amount of baryonic matter

- Discovery potential enhanced with an interplay and complementarity among different experiments:
  - direct searches
  - indirect searches
  - <u>searches for production of DM at colliders</u>

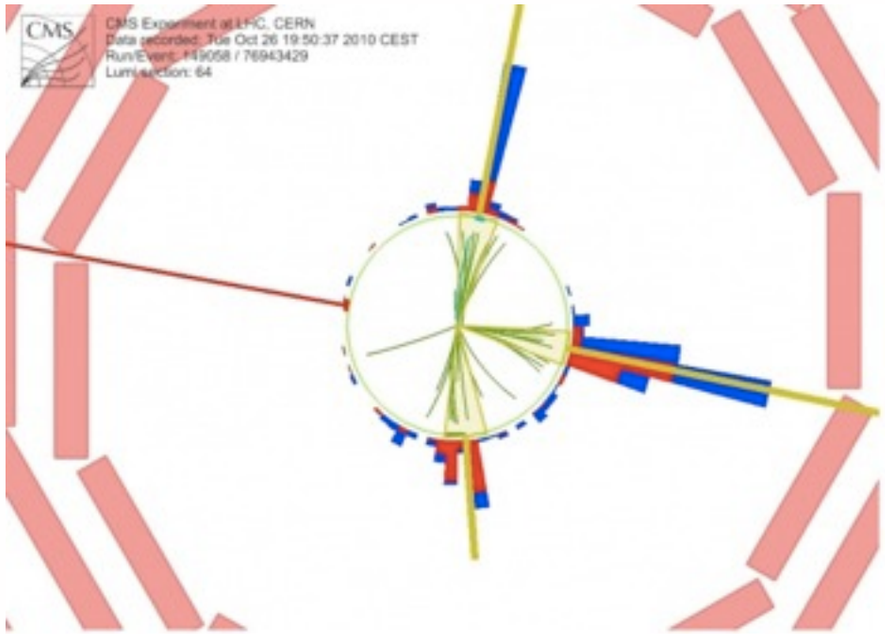


Dark Matter signatures at LHC

In p-p collisions DM could be produced at CMS: very stable weakly interacting particle

- Missing Transverse Energy (MET):
  energy imbalance observed in the plane transverse to the colliding proton beams

- Recoil:
  searches for DM need also visible particles in the event to which DM particle recoil against



If DM interacts with SM sectors different type of interactions can be assumed

Some interactions can be enhanced if DM-SM couplings are Yukawa type? T. Lin et al., 1303.6638

- DM interactions with top quarks would be favored and discovery potential increased

  scalar interaction of Dirac DM χ with a quark q $\rightarrow$ $\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$

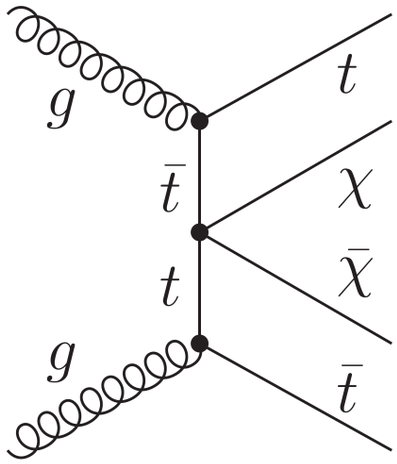
- search never performed in CMS

Interpretation of results

Large variety of DM candidates

- essential model-independent DM searches

EFT



1) Effective Field Theory (EFT): interaction parametrized by effective operators

- EFT approach valid when the momentum transferred Q_{tr} small compared to cutoff scale M_*,

$$Q_{tr} << M_*$$

G. Busoni et al., 1402.1275

- in p-p collisions at LHC Q_{tr} could be of order of TeV, details of mediator are resolved
- UV completion condition $M_* = \left(\frac{m_q M^2}{g_1 g_2}\right)^{1/3}$

→ Solution is to consider explicitly the mediator

Simplified model

2) Simplified models: explicit mediator considered

Interpretation of results

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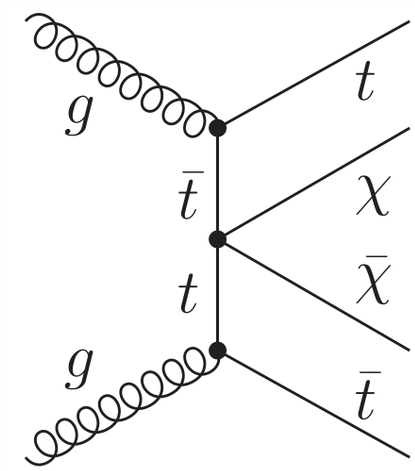
EFT



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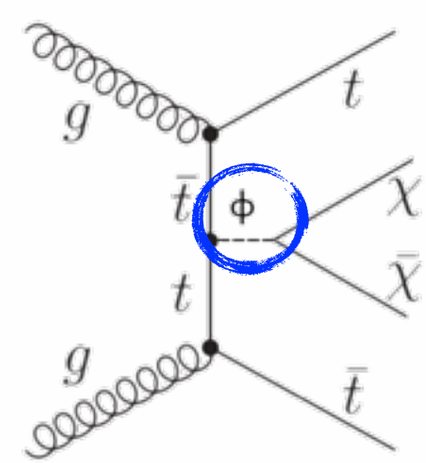
Simplified model



2) Simplified models: explicit mediator considered

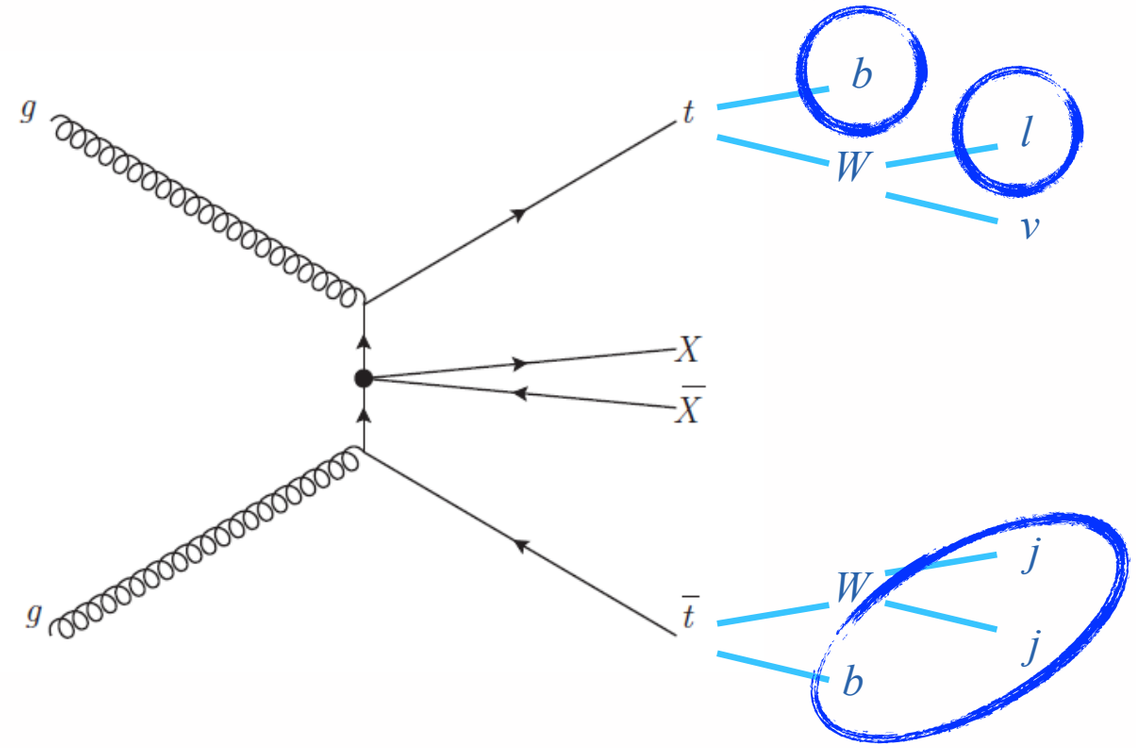
EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

Analysis strategy

(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background



(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

Analysis strategy

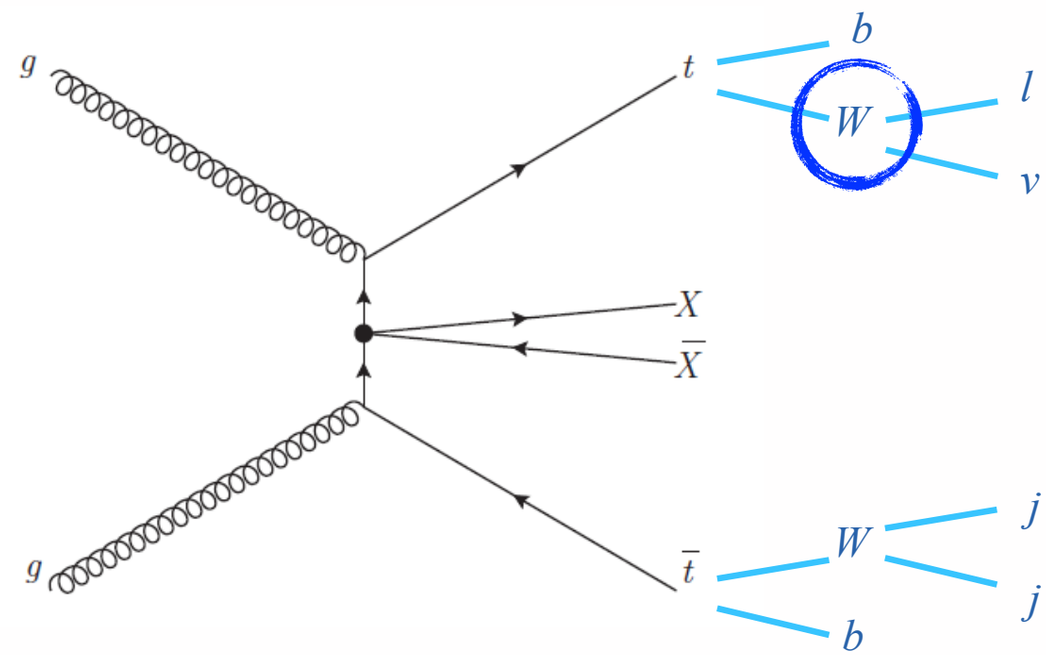
(1) Selection of topology

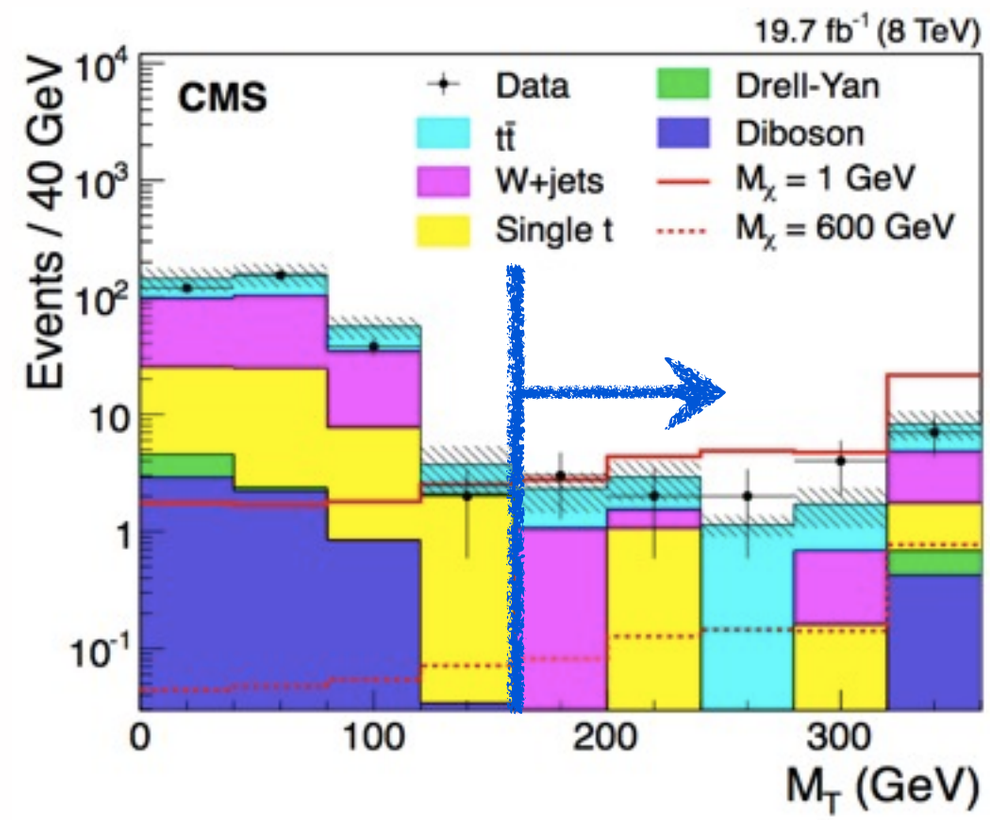
1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- Most W+jets and tt+jets semi-leptonic events $M_T < M_W$. Signal events distributi peaks at higher values

$$M_T = \sqrt{2p_T^{lep} E_T^{miss}(1-\cos(\Delta\phi))} > 160 \text{ GeV}$$





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Analysis strategy

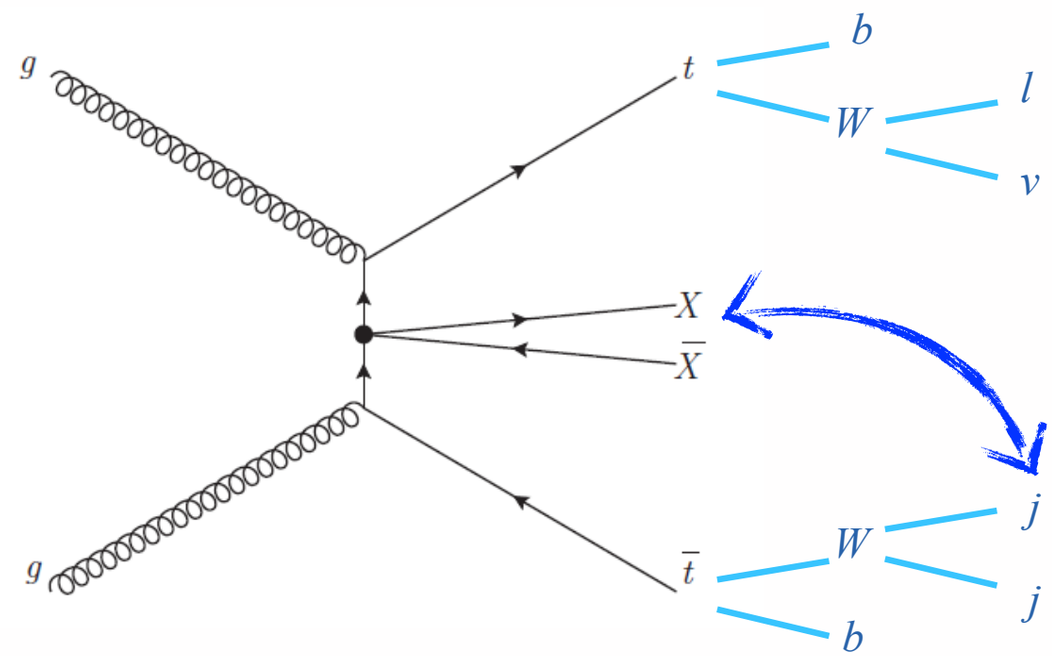
(1) Selection of topology

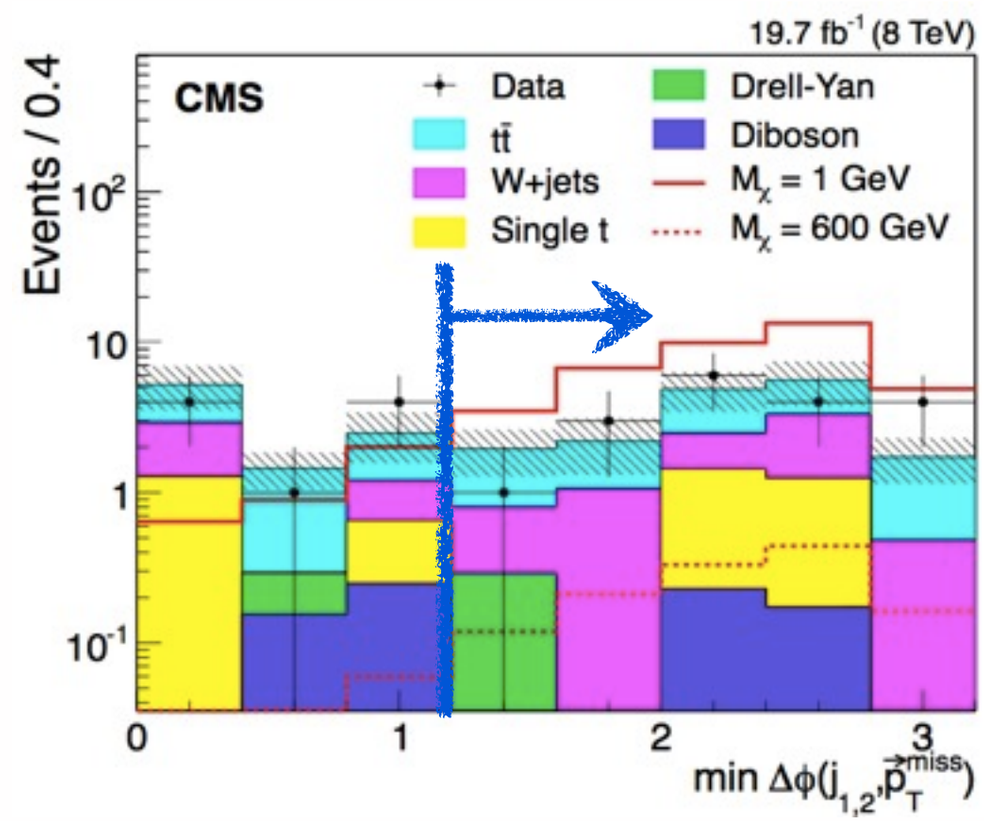
1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- The jets and the MET tends to be more separated in Φ in signal events than in tt and in single top events

$\min(\Delta\Phi_{j1,MET}, \Delta\Phi_{j2,MET}) > 1.2$ GeV





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Analysis strategy

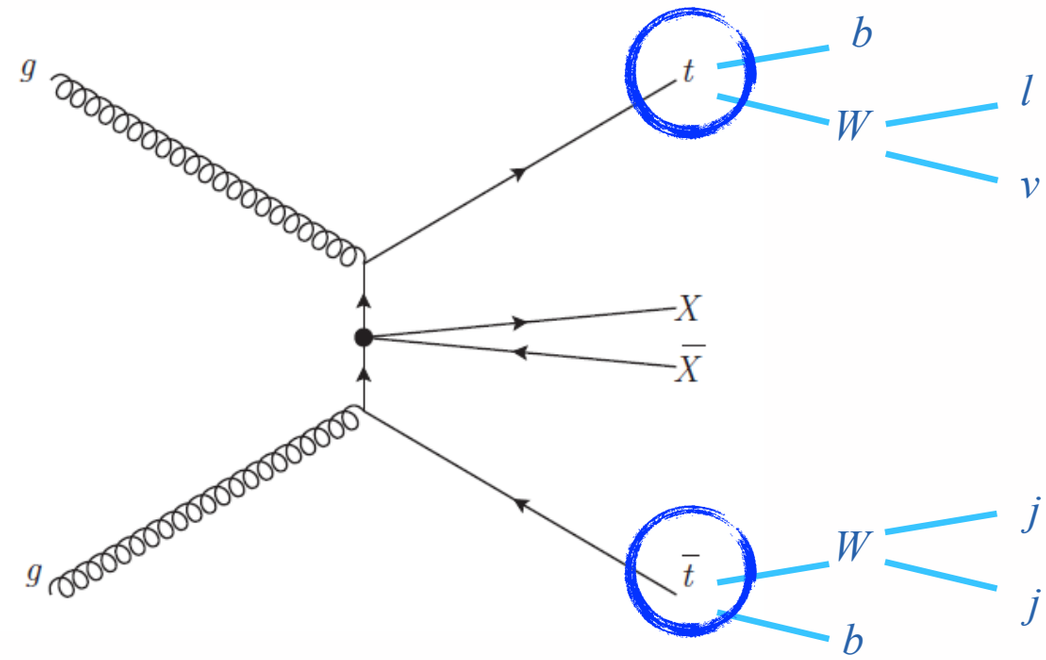
(1) Selection of topology

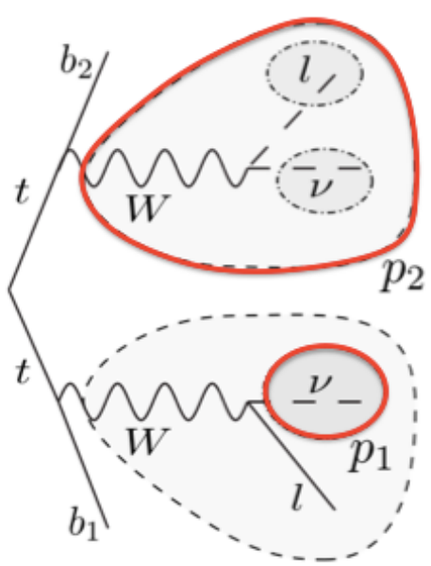
1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

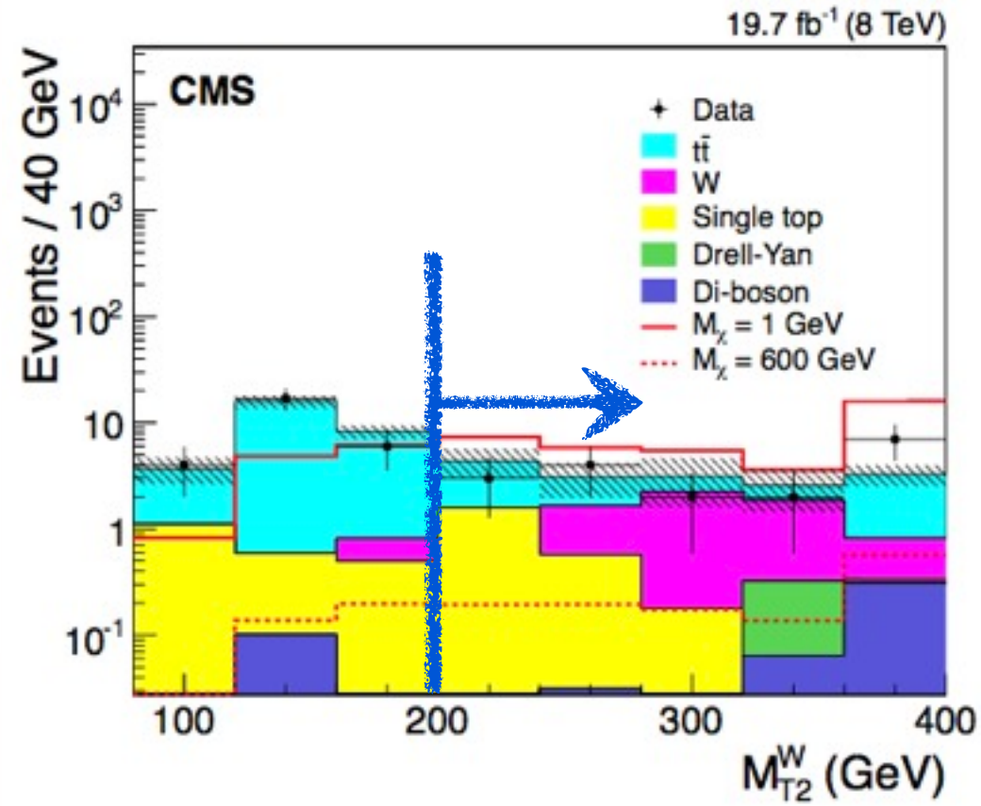
- For most tt+jets di-leptonic events $M_{T2W} < M_{top}$. Signal events distribution shows higher tails

$M^{W}_{T2} > 200$ GeV (see slide 27)





M^{W}_{T2}:
minimal mother particle mass compatible with assumed event topology and daughter mass



EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

Analysis strategy

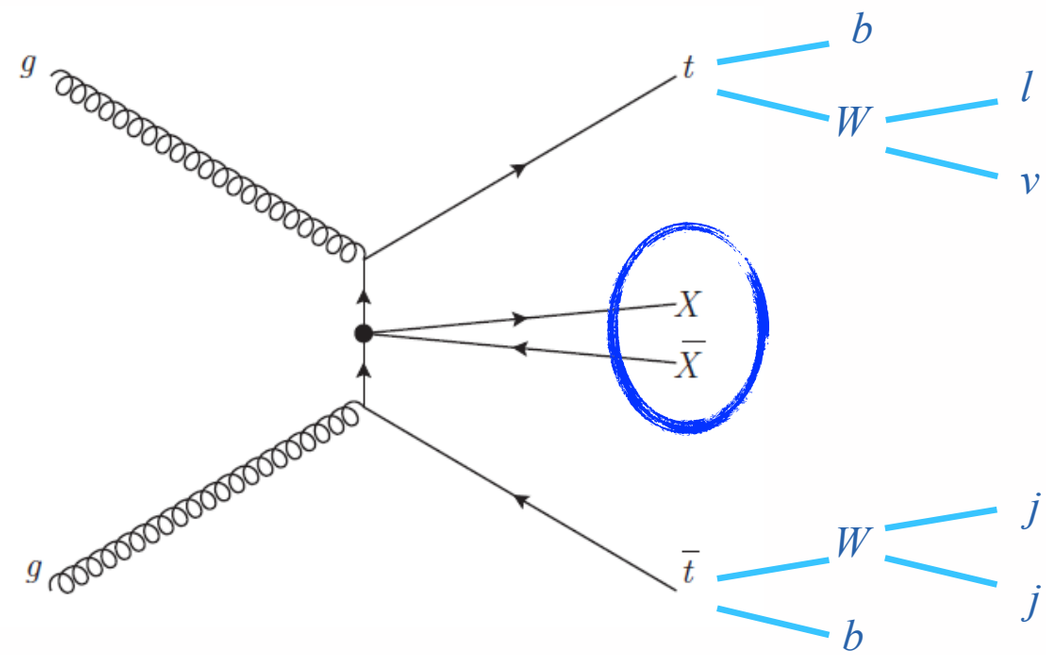
(1) Selection of topology

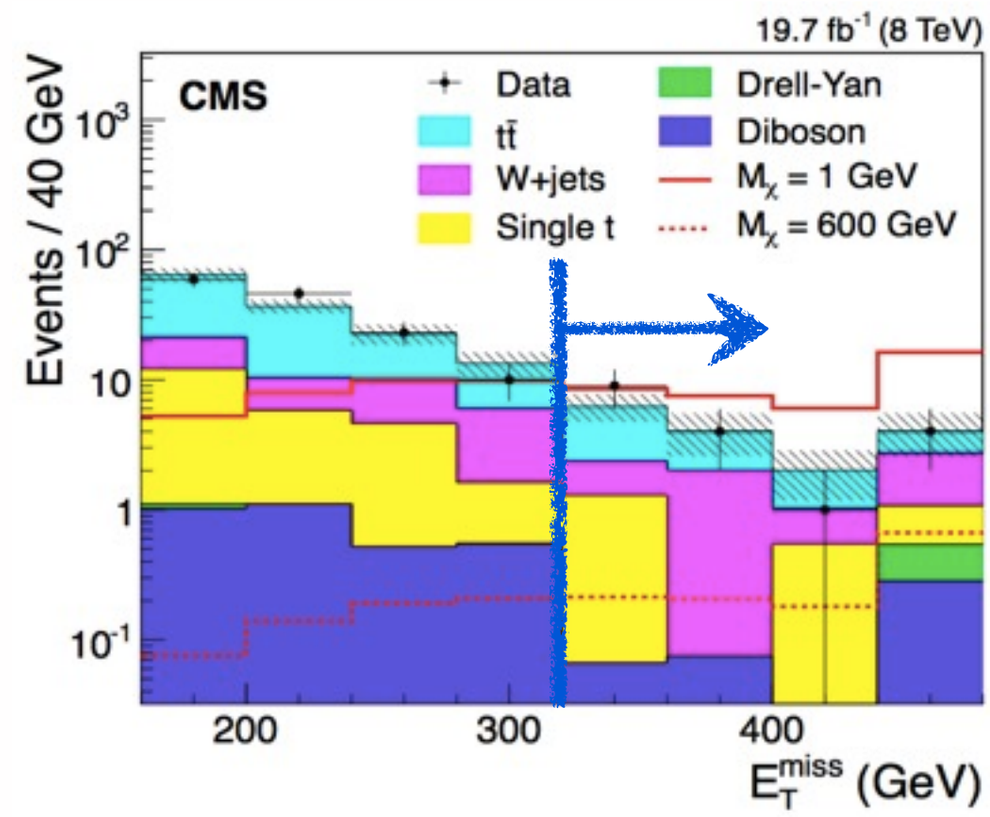
1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- signal has large MET from DM particles which escape detector

MET > 320 GeV





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EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

Analysis strategy

(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

based on topology differences between bkg and signal

(3) Extract normalization for background

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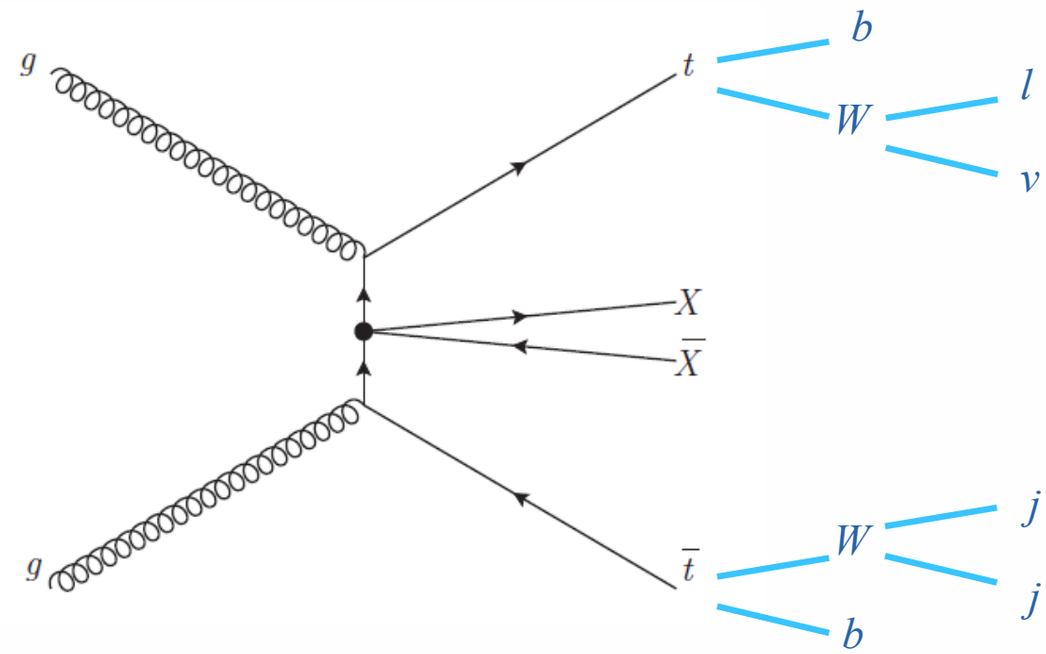
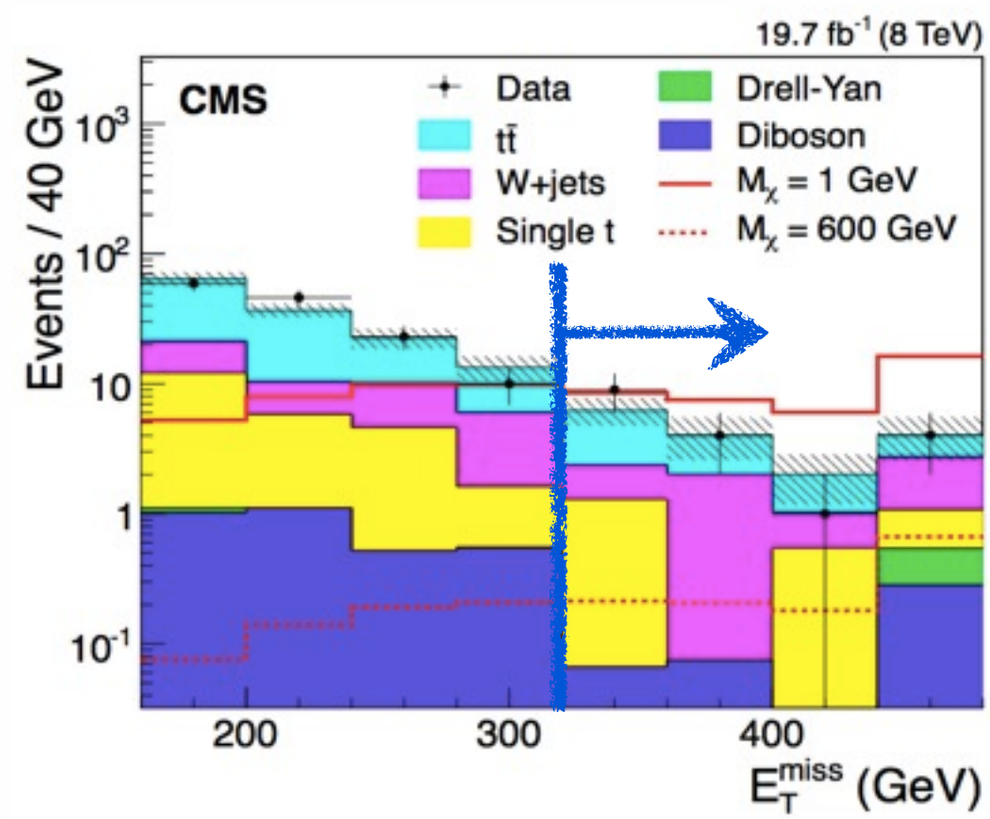
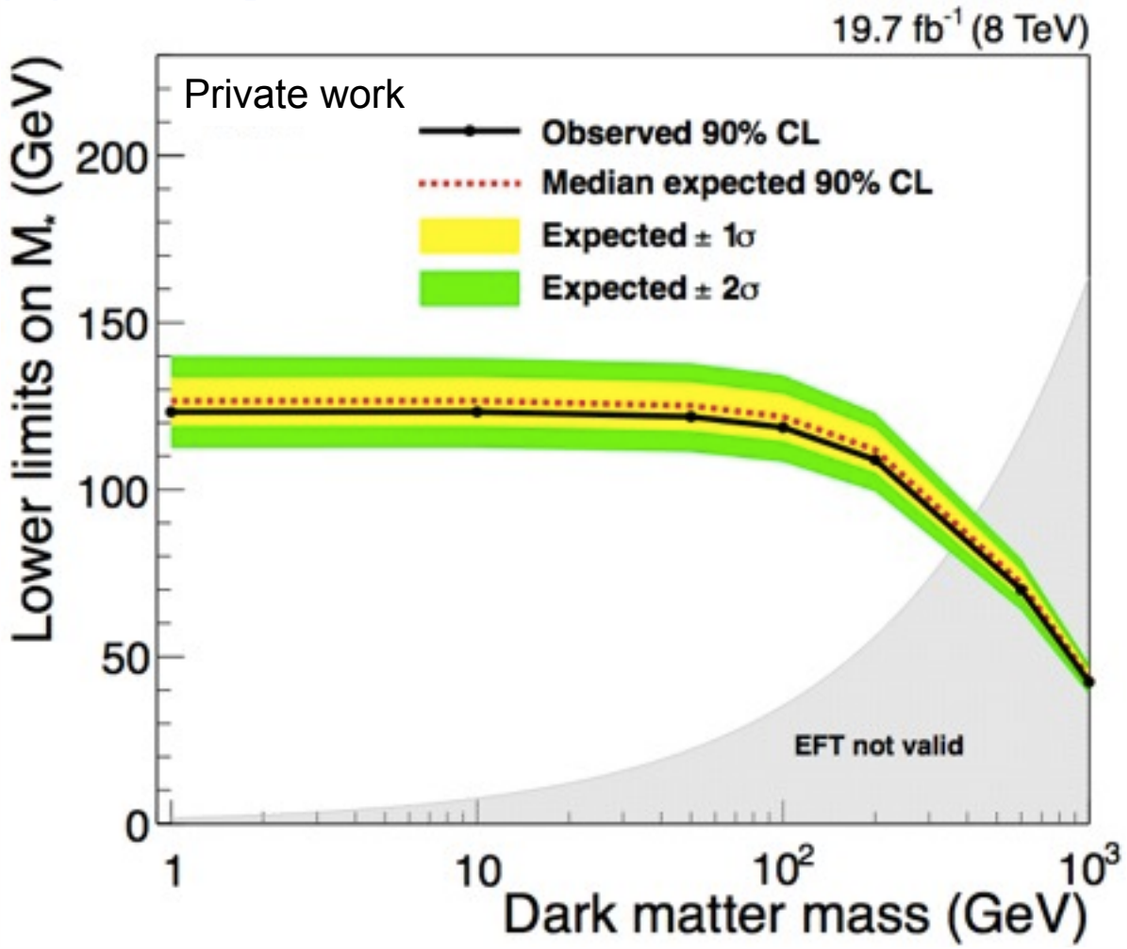




EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

(4) Final yields: no excess in data w.r.t SM predictions



(5) Results

- 90% CL **lower limits on interaction scale M*** for scalar interaction

  → assuming 100 GeV mass DM particle, M* below 118 GeV is excluded

  → excludes DM+tt production cross section > 55 fb for 1 GeV and > 20 fb for 1 TeV

  → excludes DM-nucleon cross section > 1-2×10^{-42} cm^2 for 1-6 GeV DM masses

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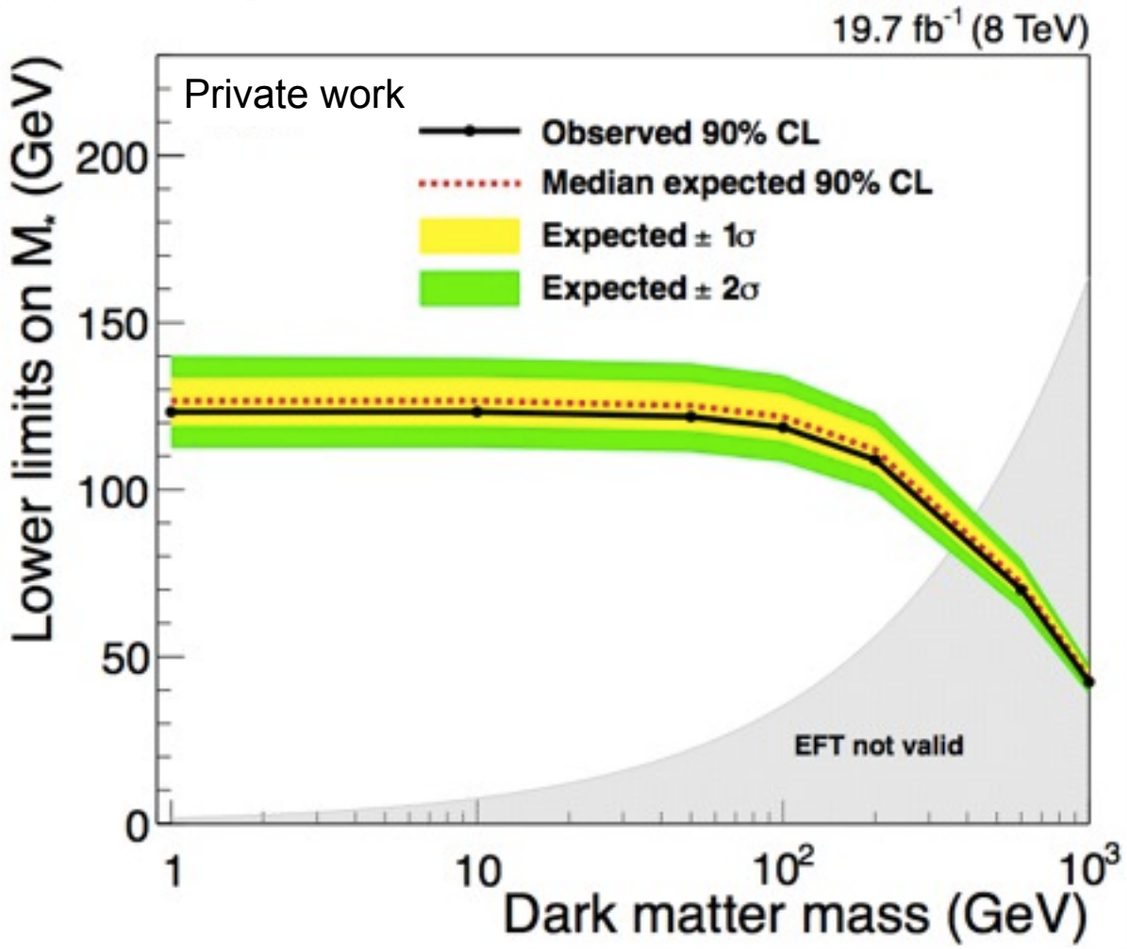

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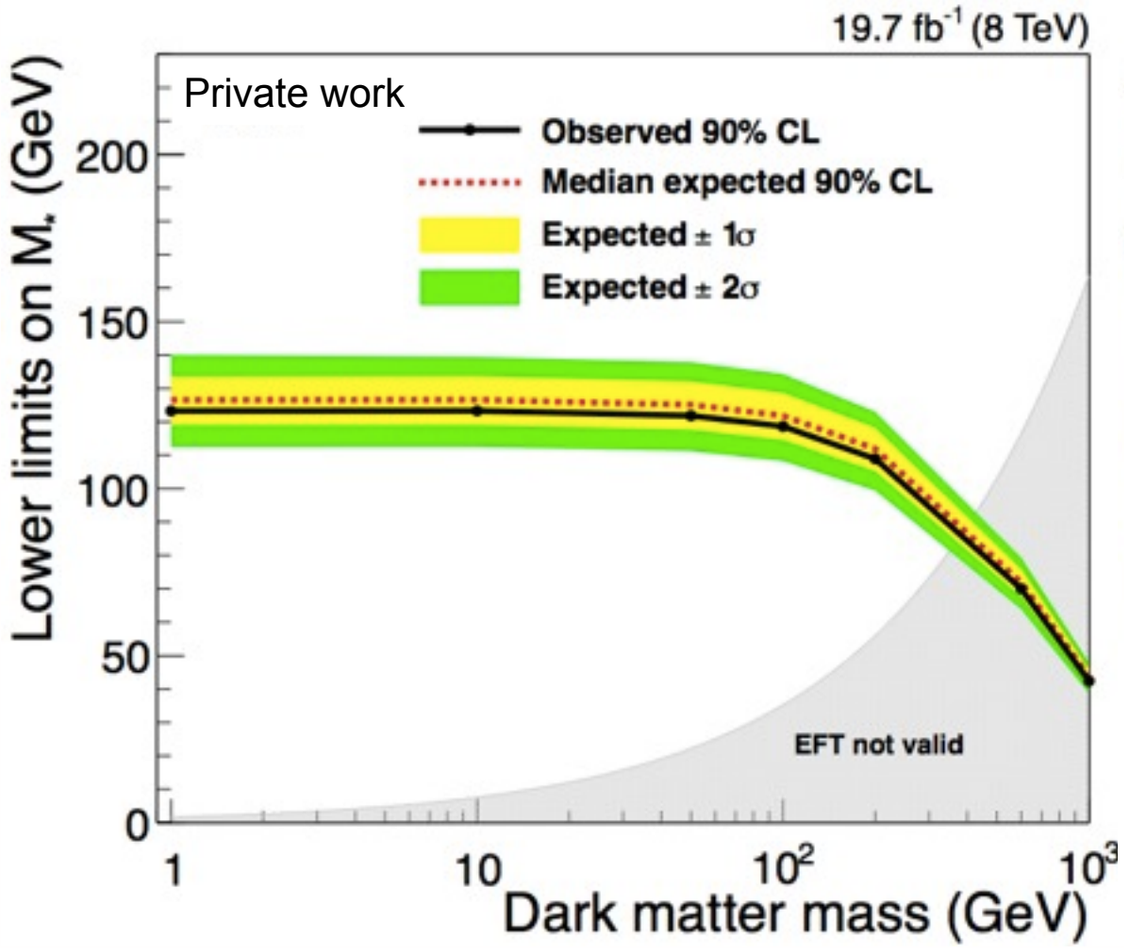

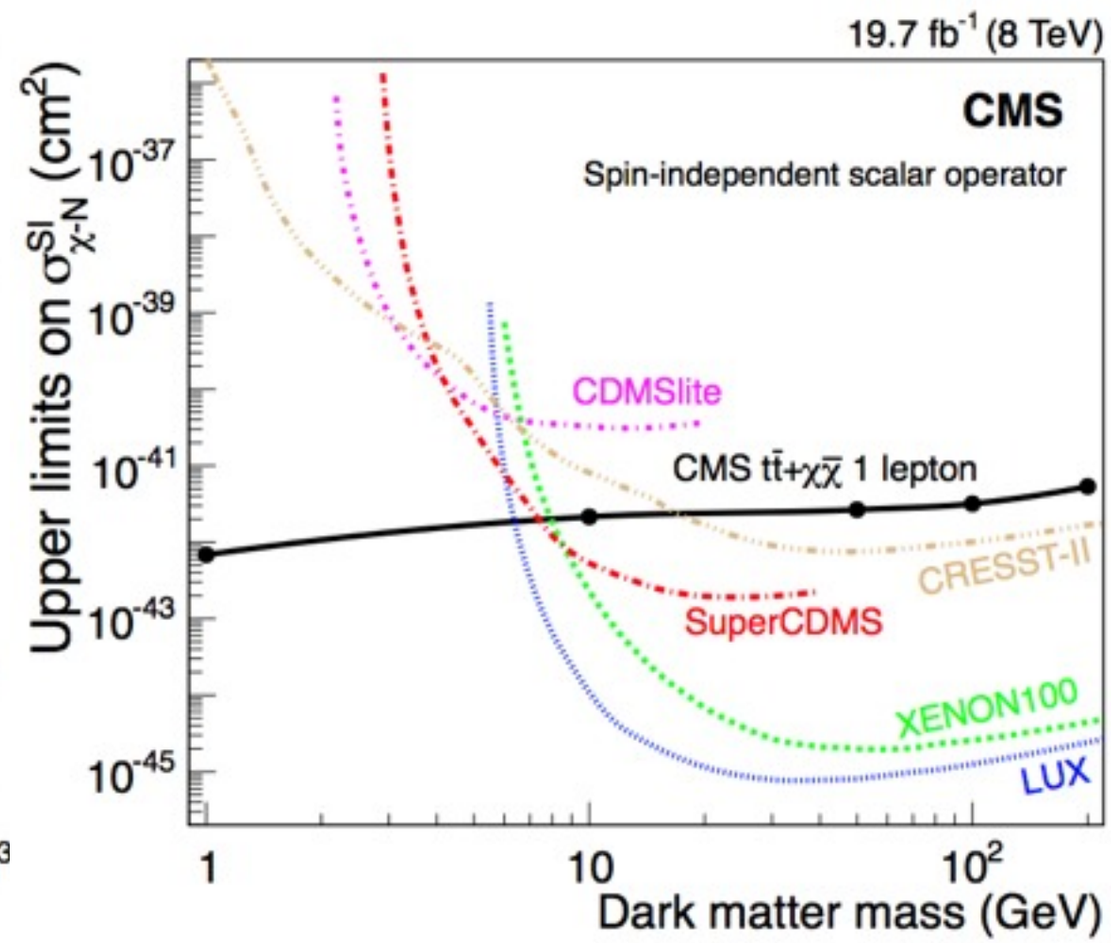

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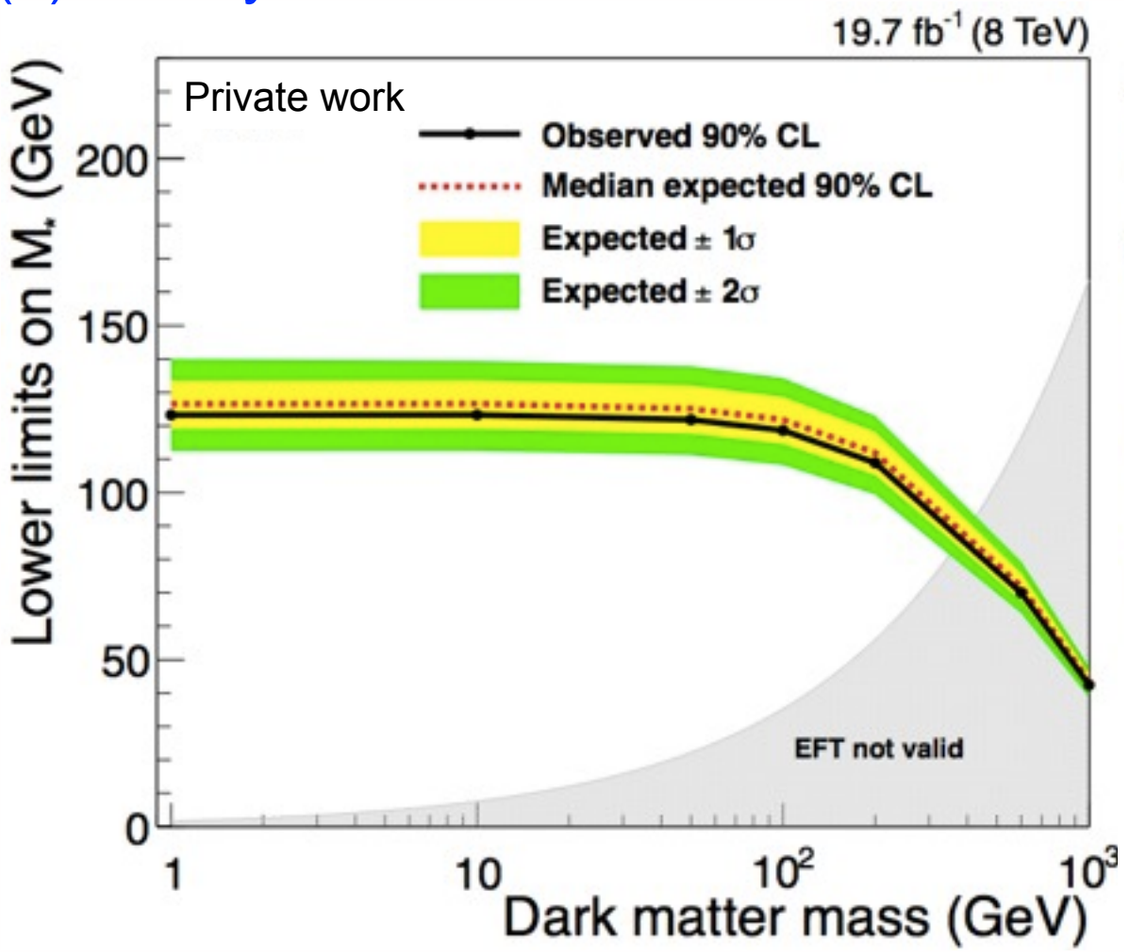

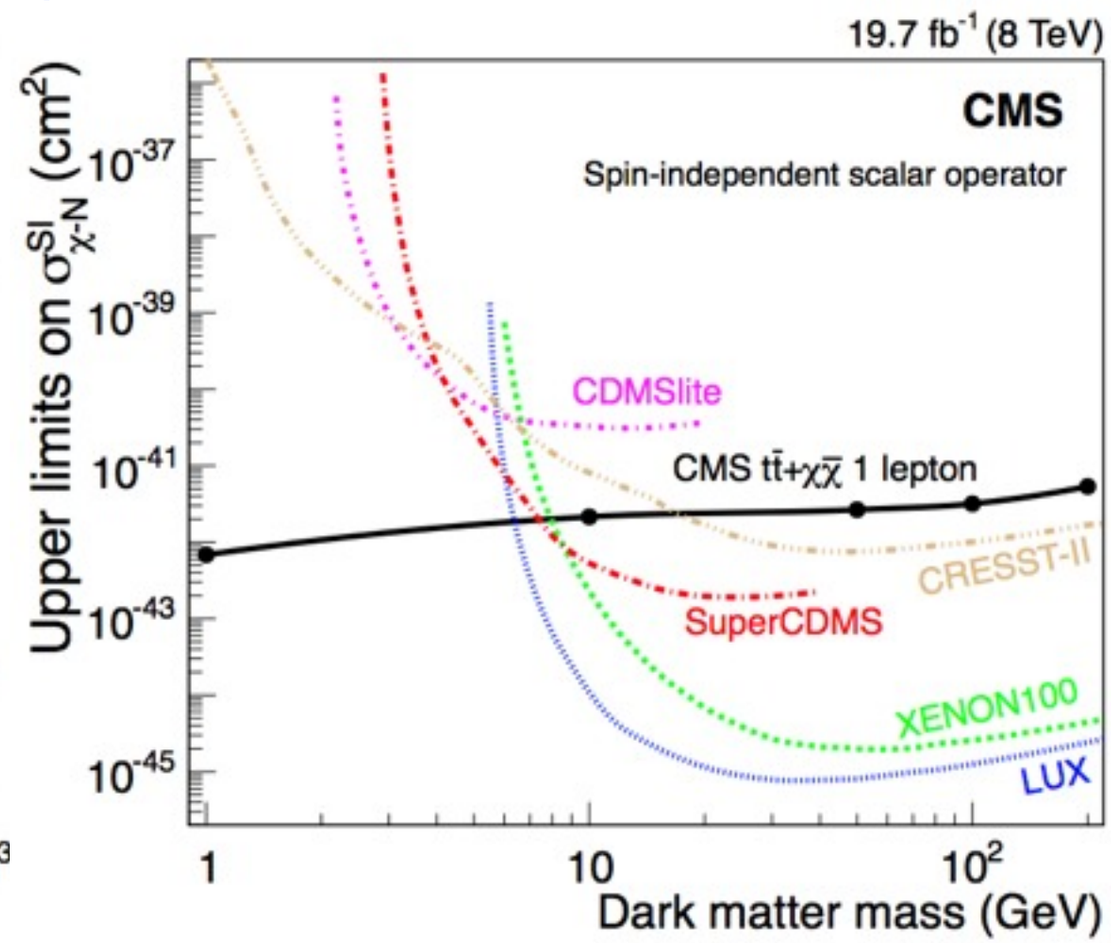

(5) Results

- first CMS results for this channel
- gained experience to develop further the analysis at 13 TeV
- results presented at conferences: DM@LHC, Moriond
- results published CMS-PAS-B2G-14-004, JHEP 1506 (2015) 121

EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

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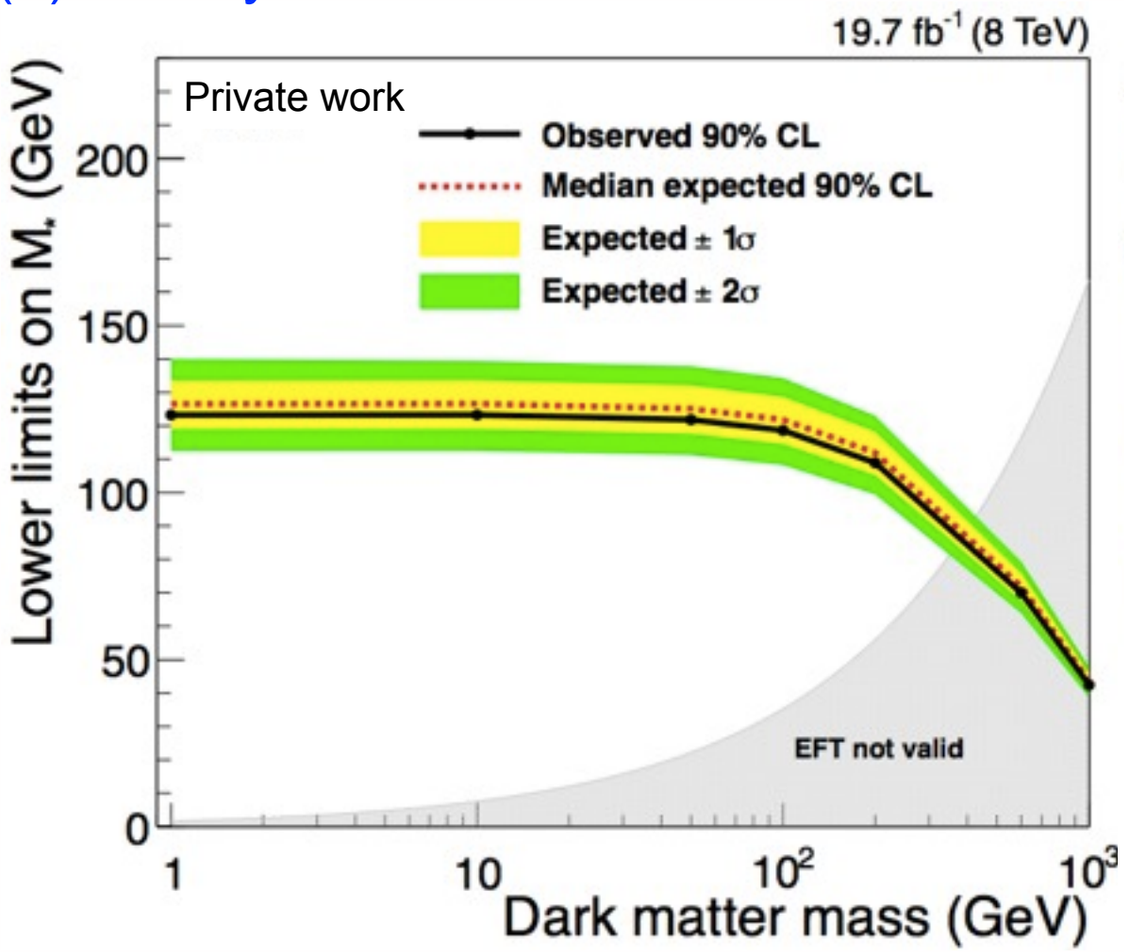

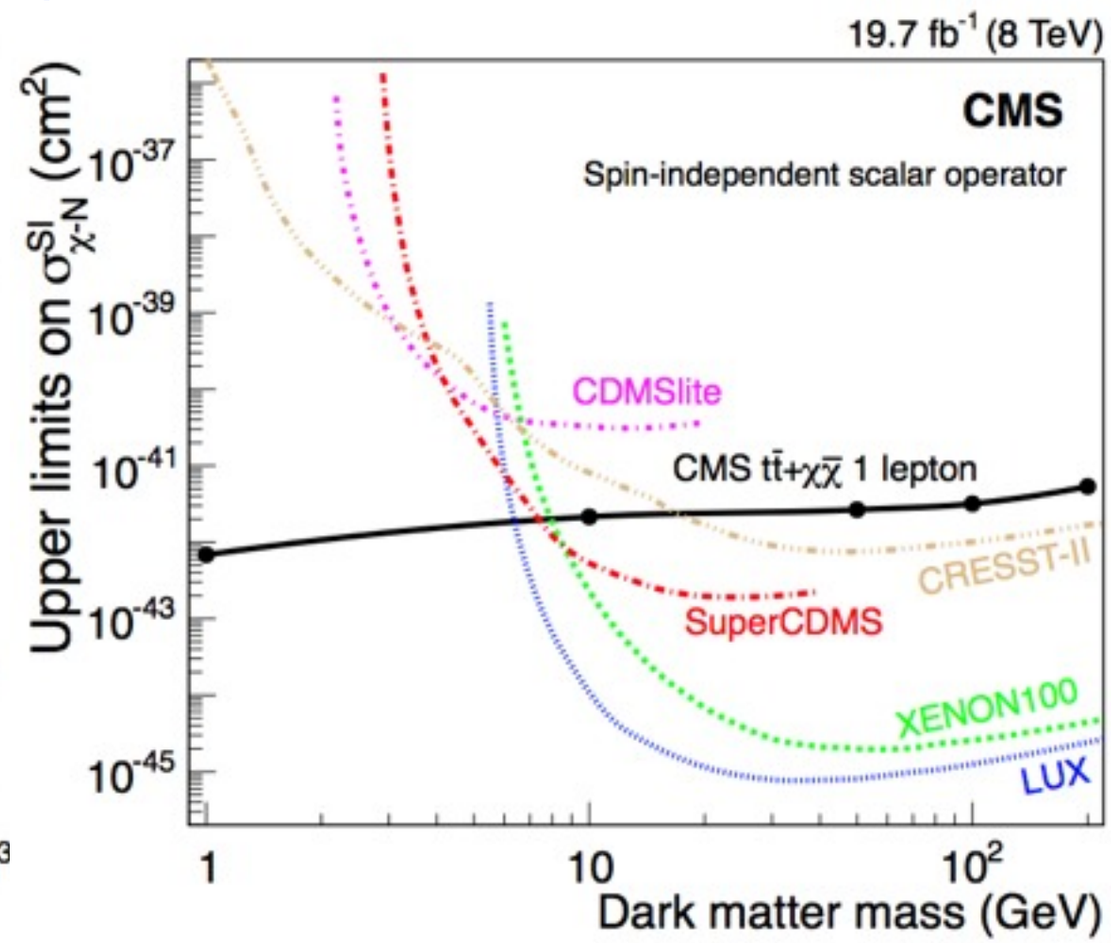

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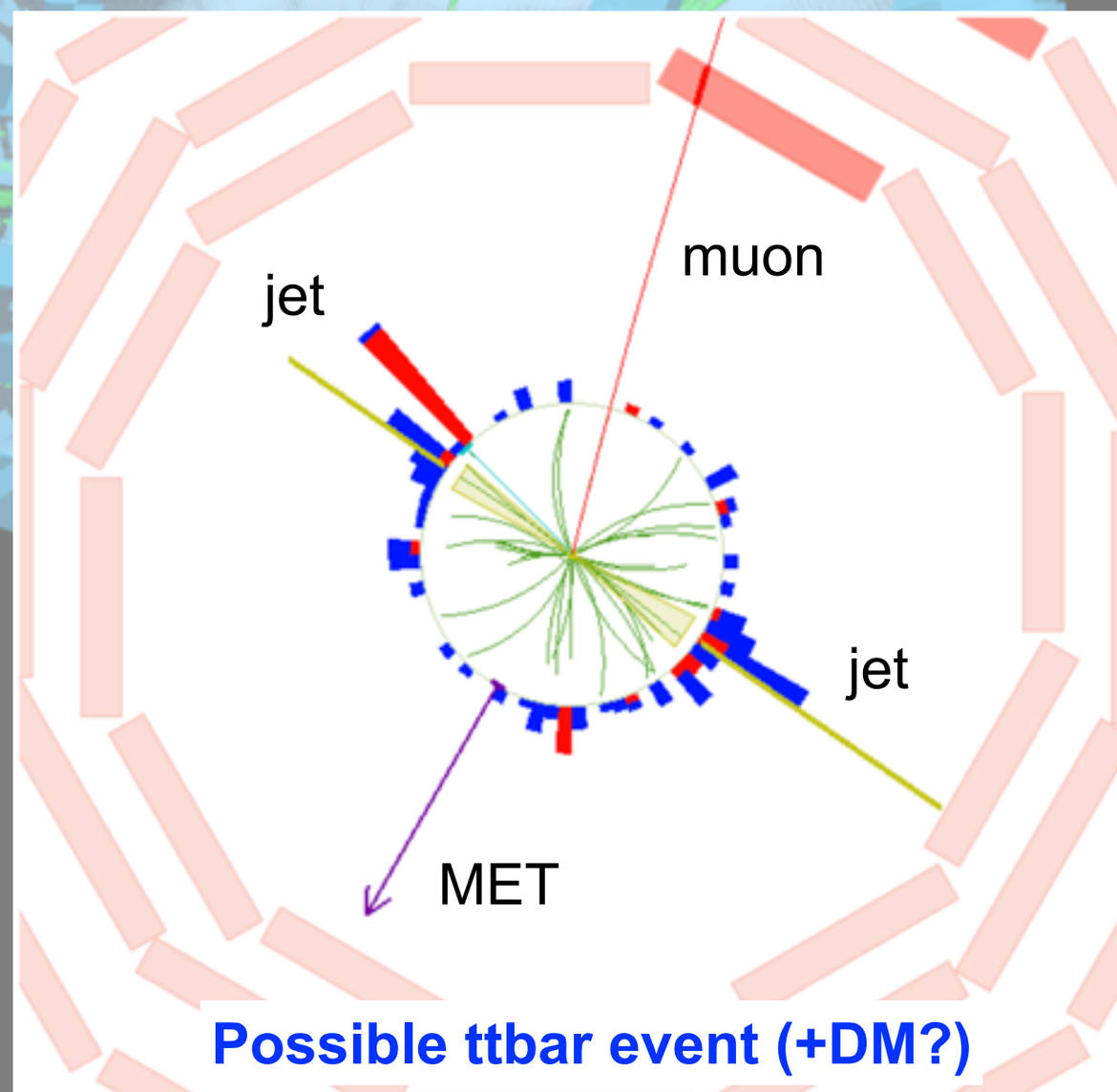
What is next ?

CMS Experiment at the LHC, CERN
Data recorded: 2015-Jun-03 08:48:32.279552 GMT
Run / Event / LS: 246908 / 77874559 / 86

CMS is back in business taking data at 13 TeV



Possible ttbar event (+DM?)

EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

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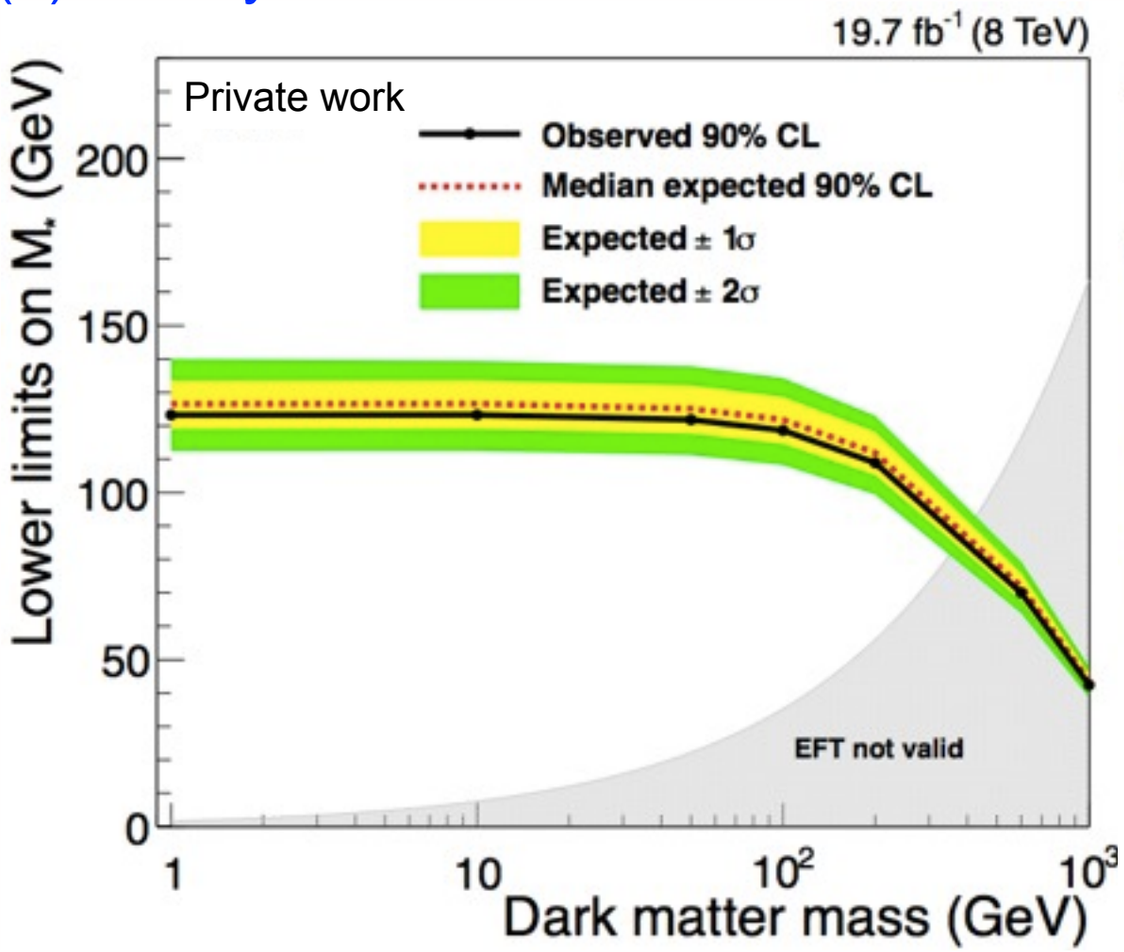

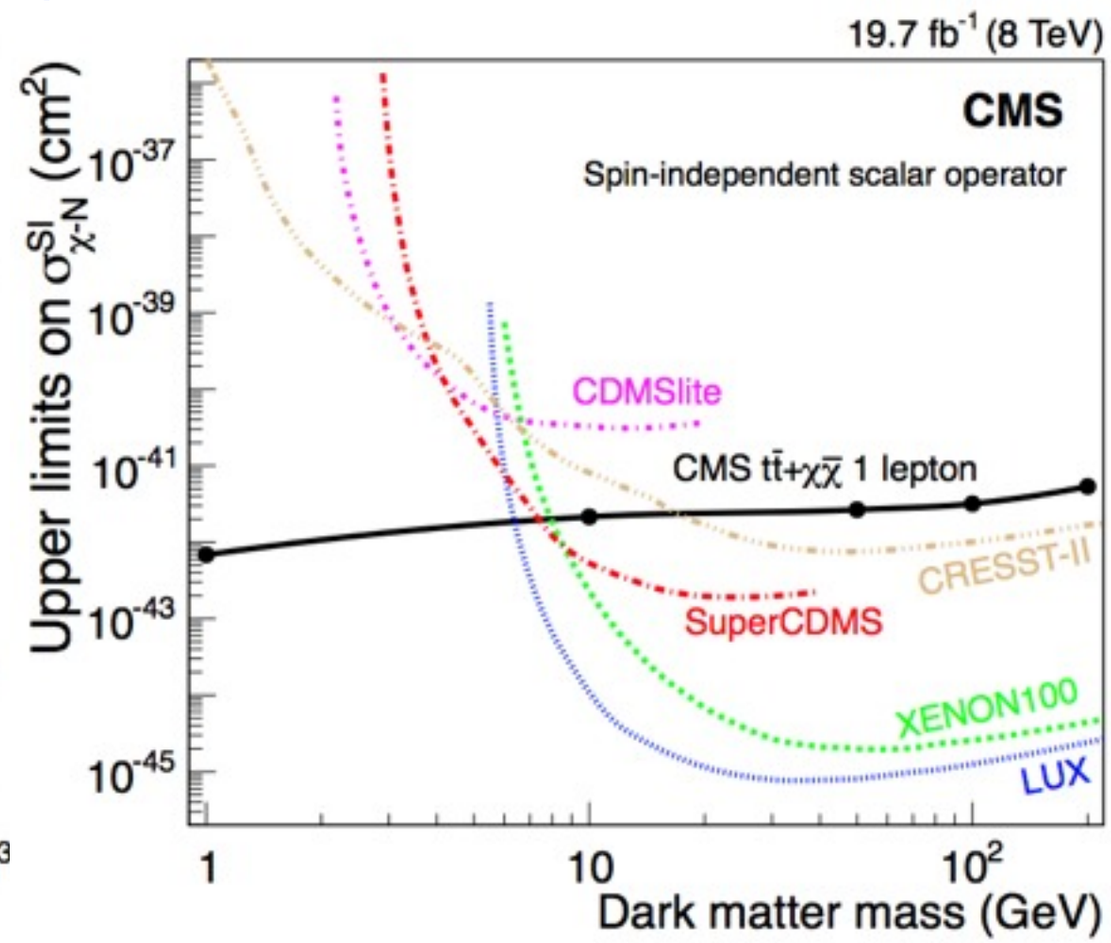

(5) Run 2:

- EFT kept as benchmark
- Hadronic final state also considered: very challenging for high QCD bkg
- Simplified models: new parameters kinematical dependence studies within CMS/ATLAS DM forum, results published DM forum report

Summary

- PhD work with focus on Dark Matter produced in association with top quark pair
  - analysis performed with data collected by CMS at 8 TeV
    semi-leptonic final state investigated, first CMS results for this channel
    - No excess of events observed in the search region
    - Lower limits on interaction scale M_* as a function of DM mass

      Assuming a DM particle of 100 GeV, M_* is excluded at 90% CL below 118 GeV andDM+tt production cross section higher than 37 fb^{-1}
    - work published
  - gained experience to develop further the analysis at 13 TeV
    In addition:
    - hadronic channel also investigated
    - simplified models will be used

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Thank you!

Backup slides

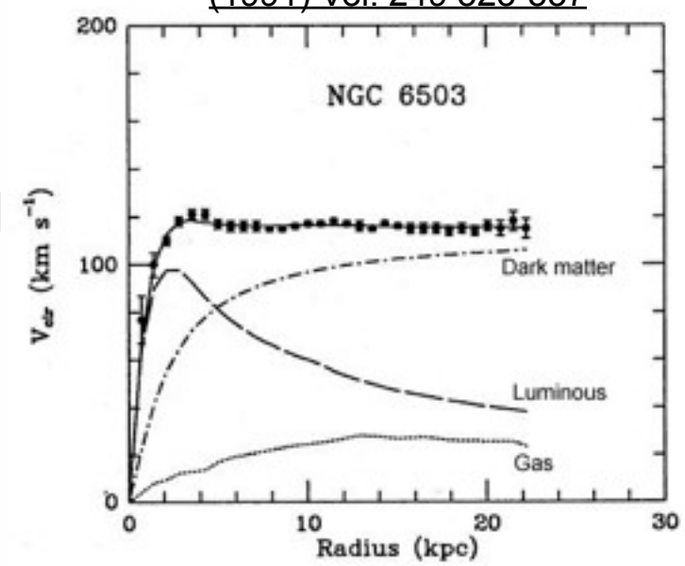
Introduction

- Evidence at different observable length scales for Dark Matter (DM)
  - dispersion velocity of galaxies in galactic cluster too large to be explained by luminous matter
  - rotation curves on singular galaxies constant beyond luminous region

    velocity is expected to go like $r^{-1/2}$

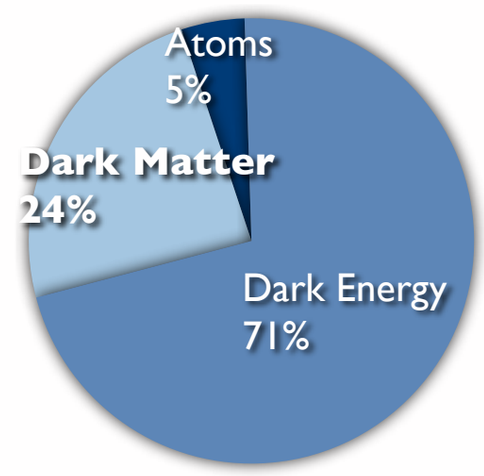
    differences explained by existence of dark matter

Begeman, K. G., et al., MNRAS (1991) Vol. 249 523-537



- Studies at different scales provide measurements that universe is composed mainly of non-baryonic matter

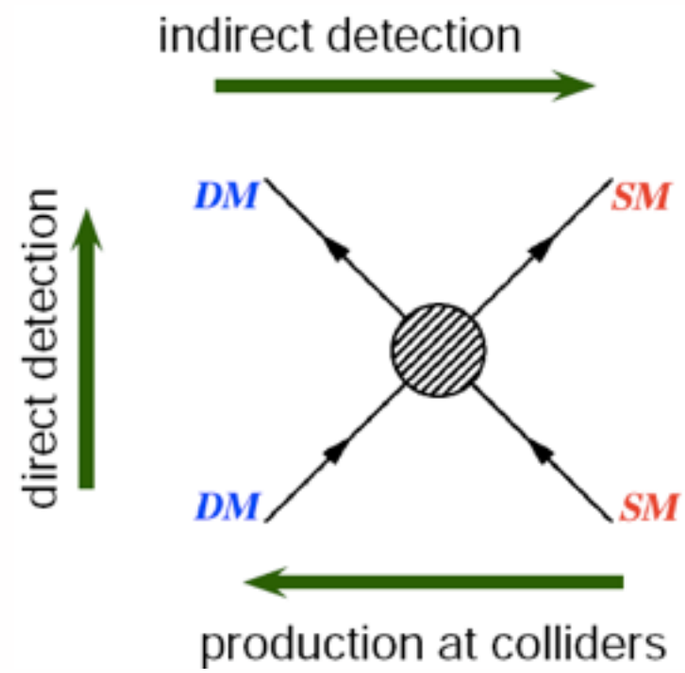
  Dark matter abundance ~24% of the universe, five times the amount of baryonic matter



- Evidence based on gravitational interactions, no information of what is the nature of Dark Matter

Introduction

- Most studied DM candidate: **Weakly Interacting Massive Particle (WIMP)**
  - neutral particle
  - mass in the range ~10 GeV - TeV
  - weak interactions
  - correct relic density
  - may be detected in different ways
- Studies at largest and smallest observable length scales
  - indirect searches:
    products of DM annihilations or decays
  - direct searches:
    scattering DM-heavy nucleons
  - collider searches:
    signature of DM production



Dark Matter signatures at LHC

- In p-p collisions Dark Matter could be produced

  very stable weakly interacting particle which escape detector

  - Missing Transverse Energy (MET)

    Energy imbalance will be observed in the plane transverse to the colliding proton beams

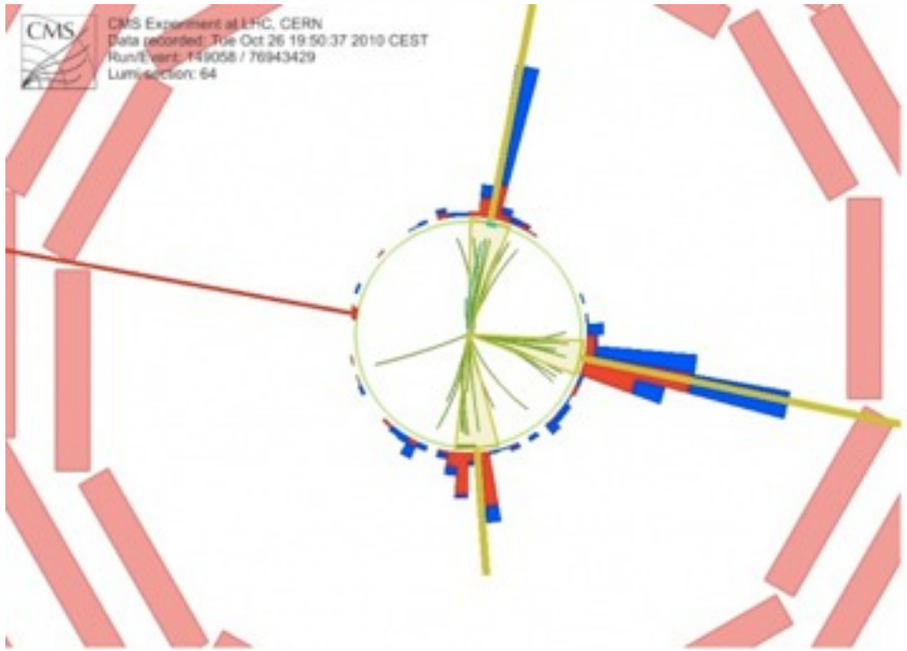
    initial transverse momenta of partons considered negligible, rules of conservations can be applied

$$\mathrm{MET} = \sqrt{\left(\sum_n E_x\right)^2 + \left(\sum_n E_y\right)^2}$$

  - Recoil

    searches for DM need also visible particles in the event to which DM particle recoil against

    searches classified depending on type of visible particles used to “tag” the event



Dark Matter searches at CMS

For which type of events do we look at colliders?

- If DM interacts with SM sectors different type of interactions can be assumed

DM searches performed using data collected by CMS experiment during 2012:

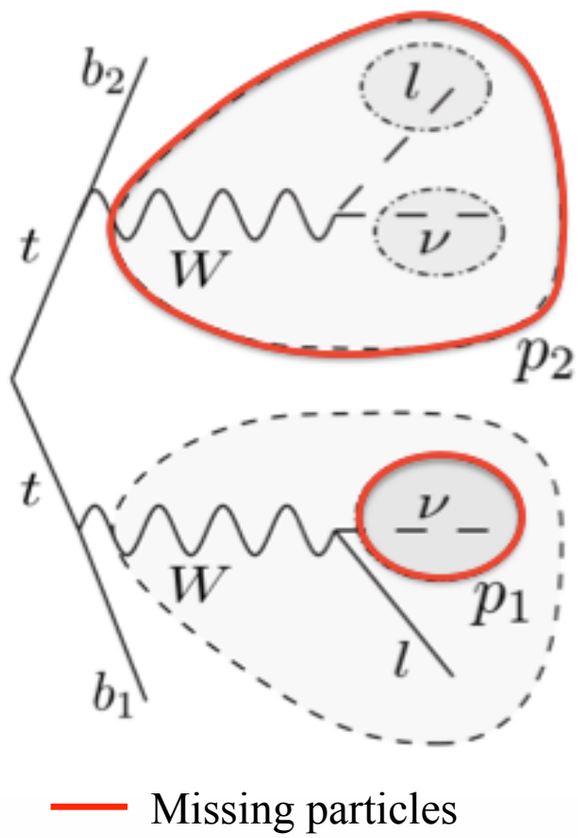
- Mono-jet: vector, axial-vector, scalar (gg) operators
- Mono-photon: vector, axial-vector operators
- Mono-lepton: vector, axial-vector operators

Some interactions can be enhanced if DM-SM couplings are Yukawa type? T. Lin et al., 1303.6638

- DM interactions with top quarks would be favored and discovery potential increased
- search never performed in CMS

DM+tt semi-leptonic 8 TeV backup

M_{T2W} as discriminating variable



Most irreducible background from tt di-leptonic

- Large MET can arise from neutrinos and missing lepton
- M_T higher than W mass because of additional missing particles

Transverse mass M_{T2} can be used to reject background event

- minimal mother particle mass compatible with assumed event topology and daughter particle mass

A variable where the intermediate W are considered on shell can be used

$$M_{T2}^{W} = \min\left\{ m_y \text{ consistent with: } \left[\begin{array}{r} \vec{p}_1^{\,T} + \vec{p}_2^{\,T} = \vec{E}_T^{\text{miss}}\,,\ p_1^2 = 0\,,\ (p_1 + p_\ell)^2 = p_2^2 = M_W^2\,, \\ (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2 \end{array} \right] \right\}$$

it adds other kinematical info w.r.t to other M_{T2} variables

Bai, Cheng, Gallichio, Gu
JHEP 07 (2012) 110

DM + tt ($\longrightarrow blv, bjj$): background

Dominant background (tt+jets, W+jets)

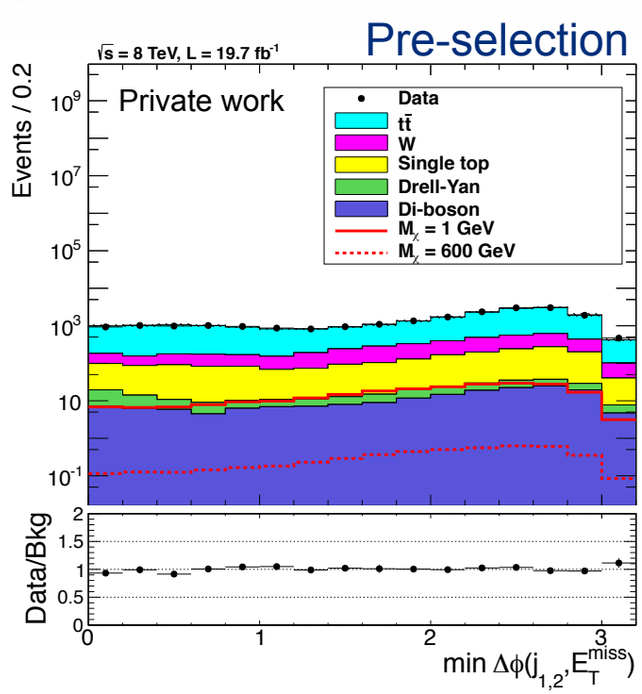
Scale Factors (SFs) extracted in CRs enriched in background composition and negligible signal contribution fitting simultaneously two simulated template distributions to data

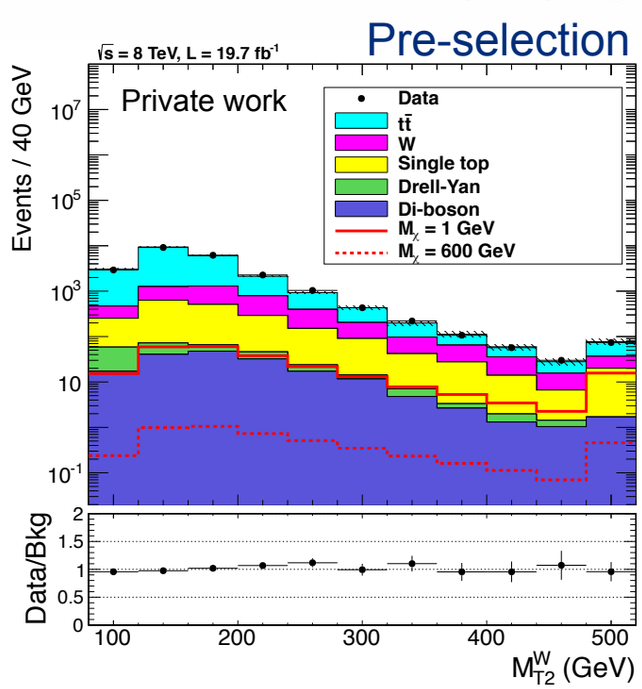
MET in W+jets enriched CR
(pre-selection + M_T>160 GeV)

M_T in tt+jets enriched CR
(pre-selection but 0 b-tag + M_T>160 GeV)

SF(tt+jets)	1.11 ± 0.02 (stat)
SF(W+jets)	1.26 ± 0.06 (stat)

predicted background yields and uncertainties propagated from CR to SR

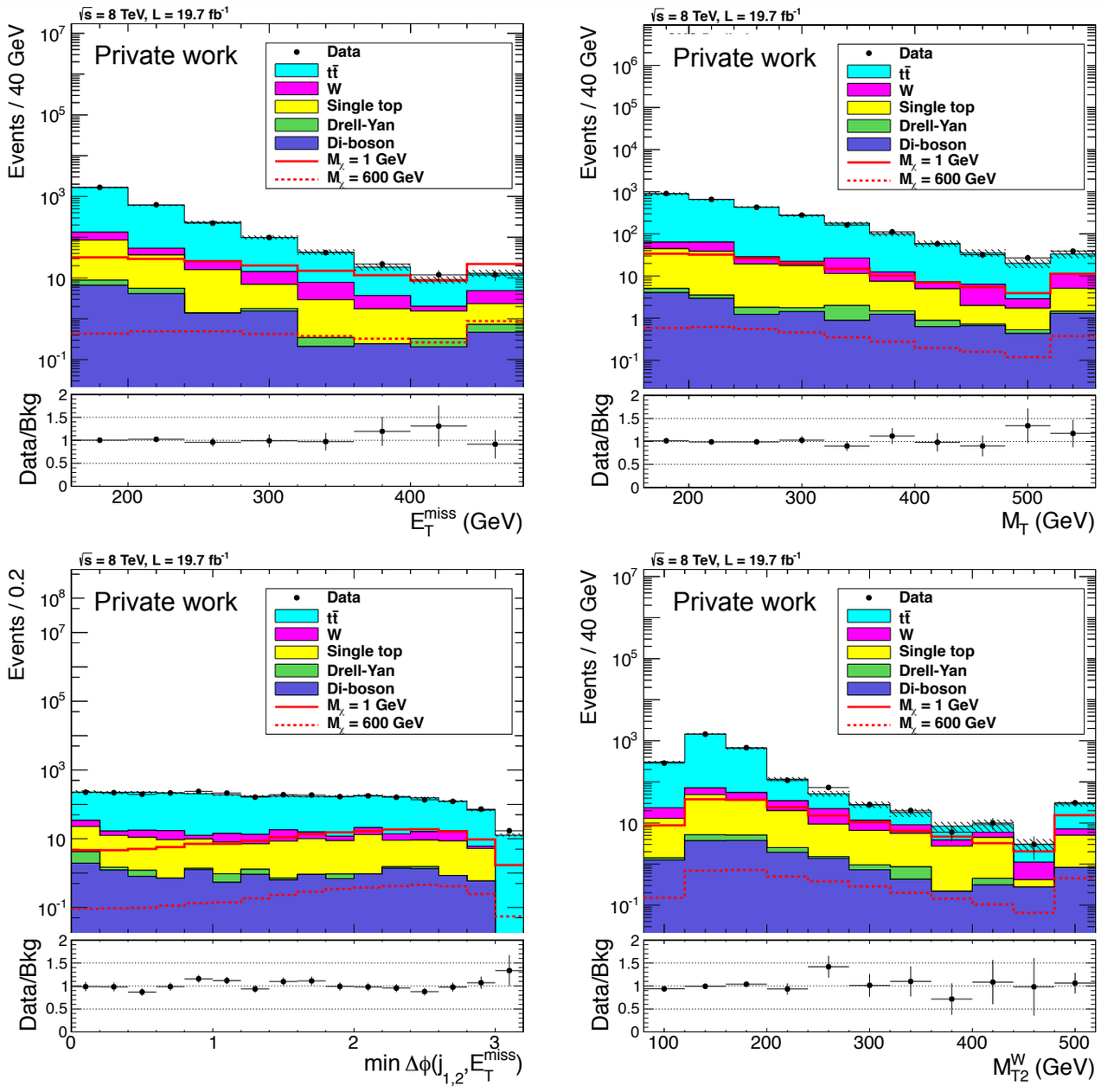




Good agreement between data and simulation is observed after SFs are applied

Data-simulation agreement

Agreement between data and MC samples is used to check the validity of this estimate



CR1 (tt enriched)

- In all distributions good agreement between data and background prediction is observed after SFs applied

Data-simulation agreement

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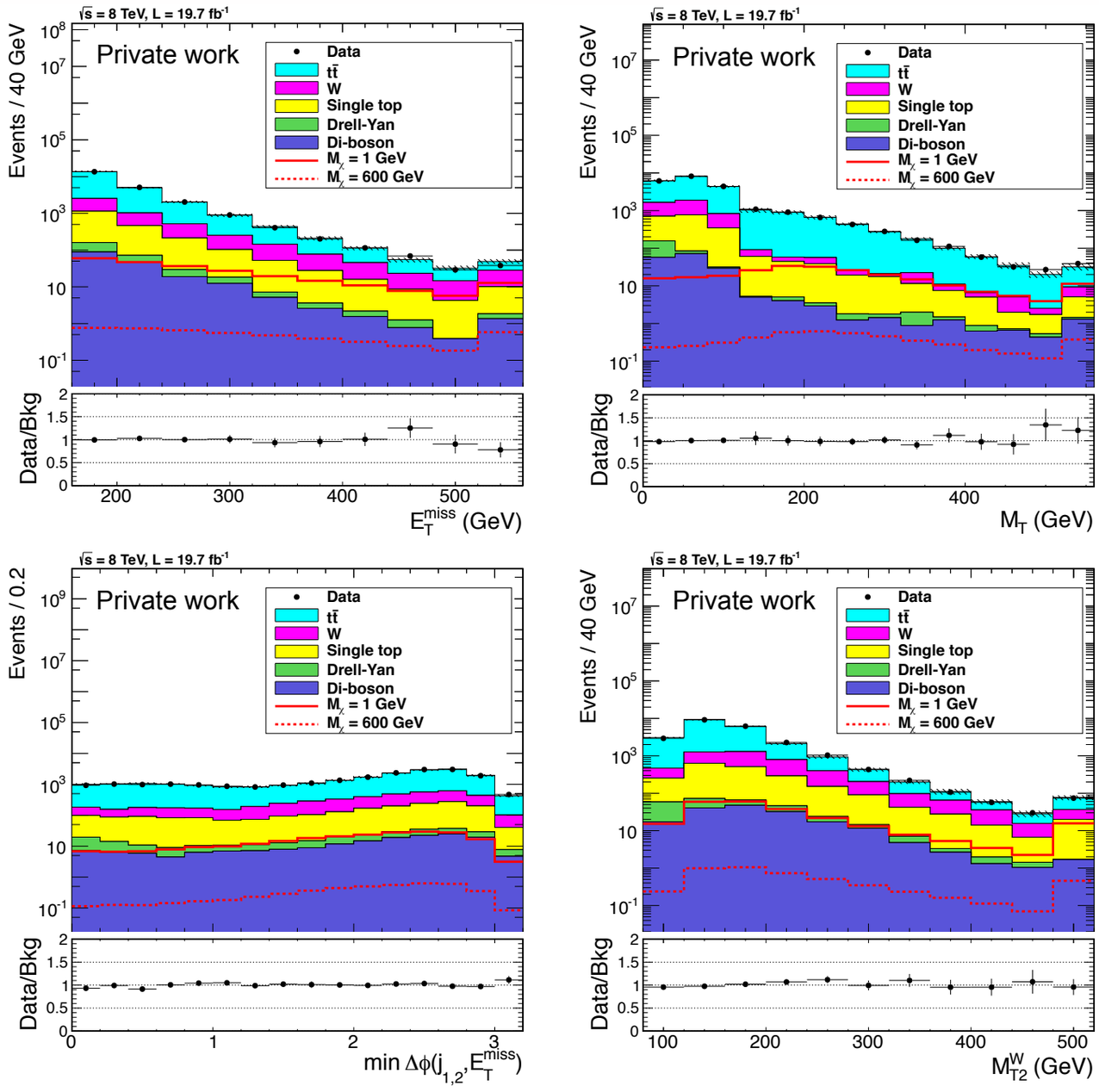


PRE-SELECTION

- In all distributions good agreement between data and background prediction is observed after SFs applied

Systematic uncertainties

- **Uncertainties on backgrounds**

  normalization uncertainties covered by SFs
  shape uncertainties constrained in CRs and SFs propagated in SR

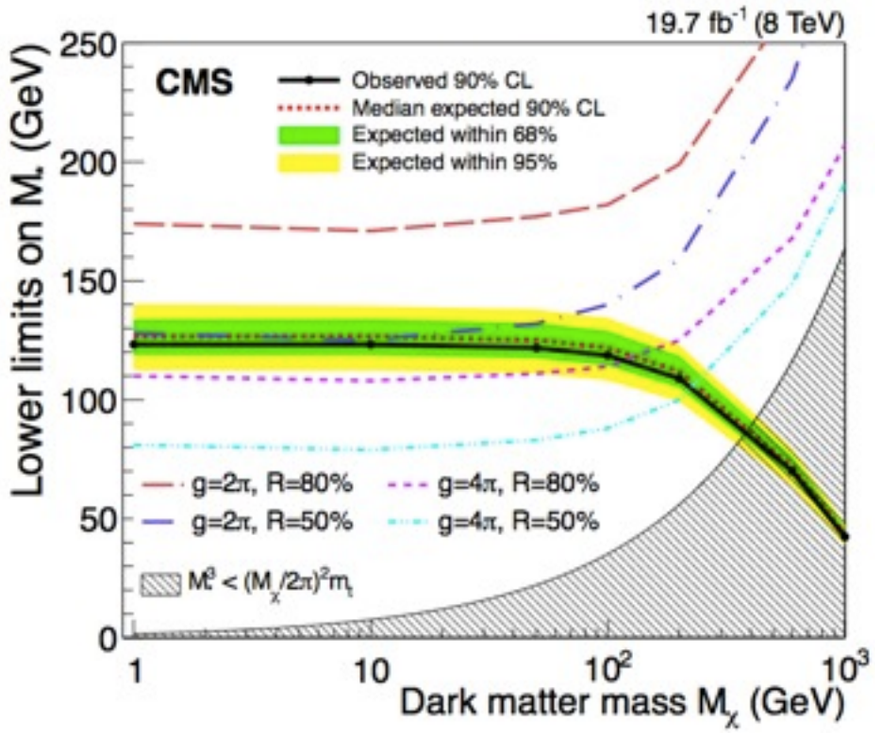
- **Uncertainties on signal**: 5-6%

Source of systematic uncertainties	Relative error on total background (%)
50% normalization error of other bkg in deriving SFs	10
SF_{W+jets} (CR tests)	13
$t\bar{t}$+jets top p_T reweighting	3.9
Jet energy scale	4.0
Jet energy resolution	3.0
b-tagging correction factor (heavy flavor)	1.0
b-tagging correction factor (light flavor)	1.8
Pileup model	2.0

- Limits are calculated using the CL_S technique with ROOSTATS software package. Frequentist treatment of nuisance parameters

Results: lower limits on M_*

M_χ (GeV)	Yield (±stat ±syst)	Signal efficiency (%) (±stat ±syst)	σ_{exp}^{lim} (fb)	σ_{obs}^{lim} (fb)
1	$38.3 \pm 0.7 \pm 2.1$	$1.01 \pm 0.02 \pm 0.05$	47^{+21}_{-13}	55
10	$37.8 \pm 0.7 \pm 2.1$	$1.01 \pm 0.02 \pm 0.05$	46^{+21}_{-13}	54
50	$35.1 \pm 0.6 \pm 1.9$	$1.20 \pm 0.02 \pm 0.06$	39^{+18}_{-11}	45
100	$30.1 \pm 0.4 \pm 1.7$	$1.46 \pm 0.02 \pm 0.07$	32^{+14}_{-9}	37
200	$18.0 \pm 0.2 \pm 1.0$	$1.73 \pm 0.02 \pm 0.08$	27^{+12}_{-8}	32
600	$1.26 \pm 0.02 \pm 0.07$	$2.40 \pm 0.03 \pm 0.11$	19^{+9}_{-6}	23
1000	$0.062 \pm 0.001 \pm 0.003$	$2.76 \pm 0.04 \pm 0.13$	17^{+8}_{-5}	20



- Values below the observed limit are excluded

- The grey area represent only minimal requirement on M_* for the EFT to be valid. There could be other areas on the plane where the EFT breaks down

EFT DM + tt ($\longrightarrow blv, bjj$) at 8 TeV

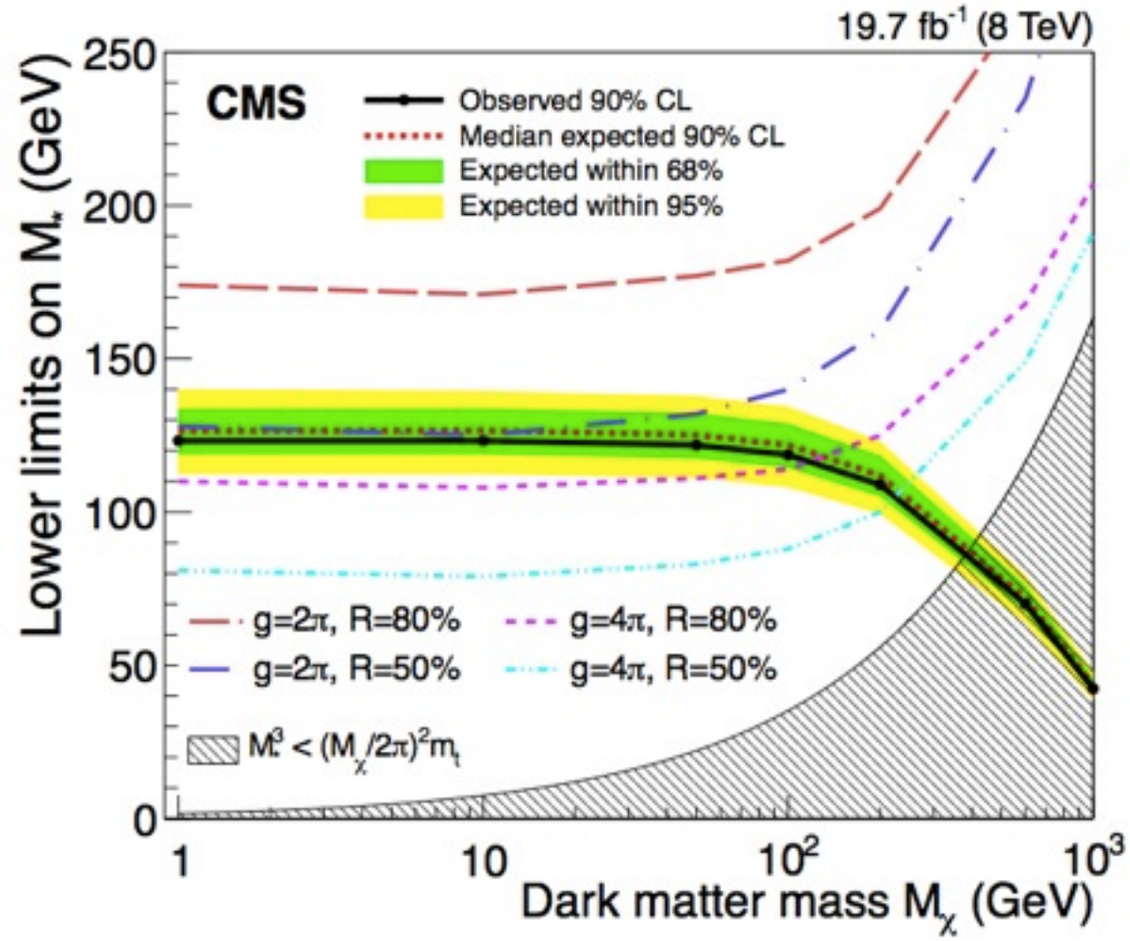
(4) Final yields

M_χ=1GeV M_*=100 GeV

Source	Yield (±stat ±syst)
$t\bar{t}$	$8.2 \pm 0.6 \pm 1.9$
W	$5.2 \pm 1.8 \pm 2.1$
Single top	$2.3 \pm 1.1 \pm 1.1$
Diboson	$0.5 \pm 0.2 \pm 0.2$
Drell–Yan	$0.3 \pm 0.3 \pm 0.1$
Total Bkg	$16.4 \pm 2.2 \pm 2.9$
Data	18

main systematics on total background

13% from background estimation



(5) Results

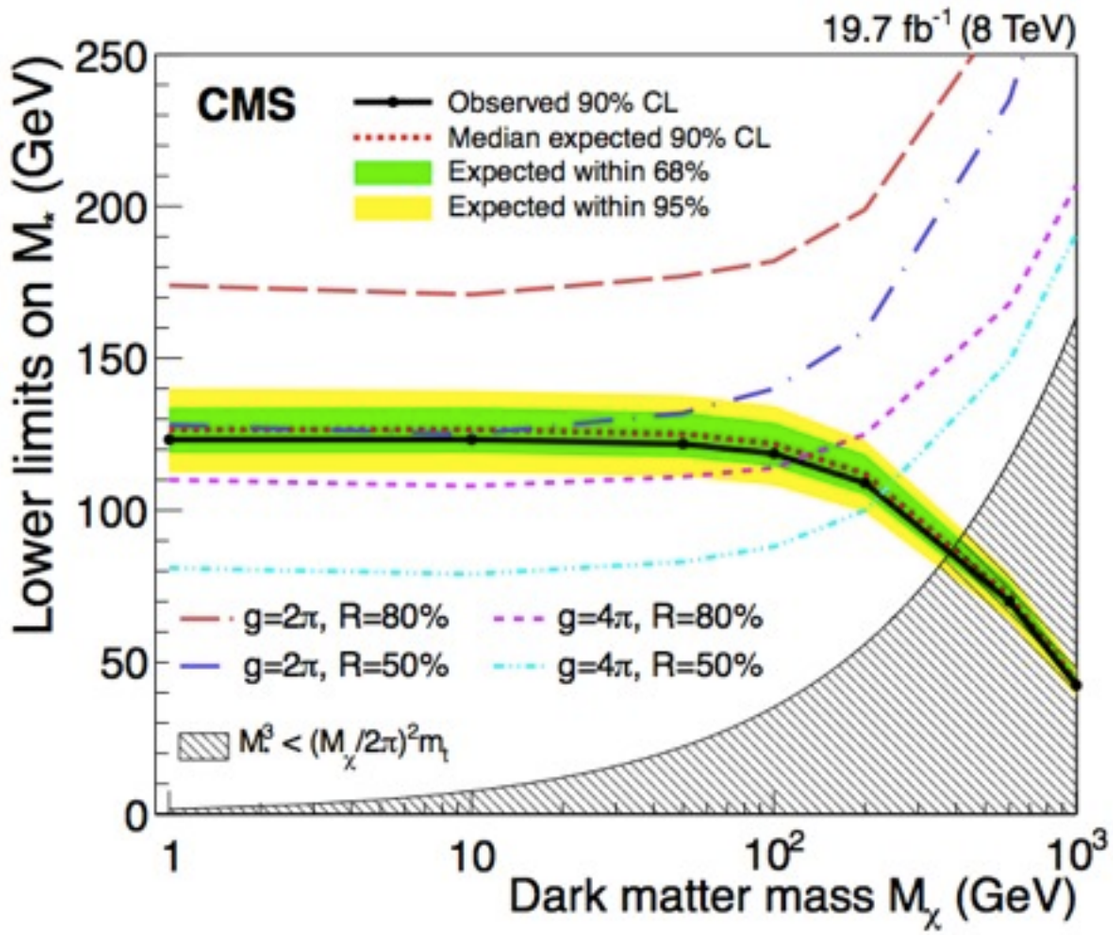
- 90% CL **lower limits on interaction scale M_*** for scalar interaction

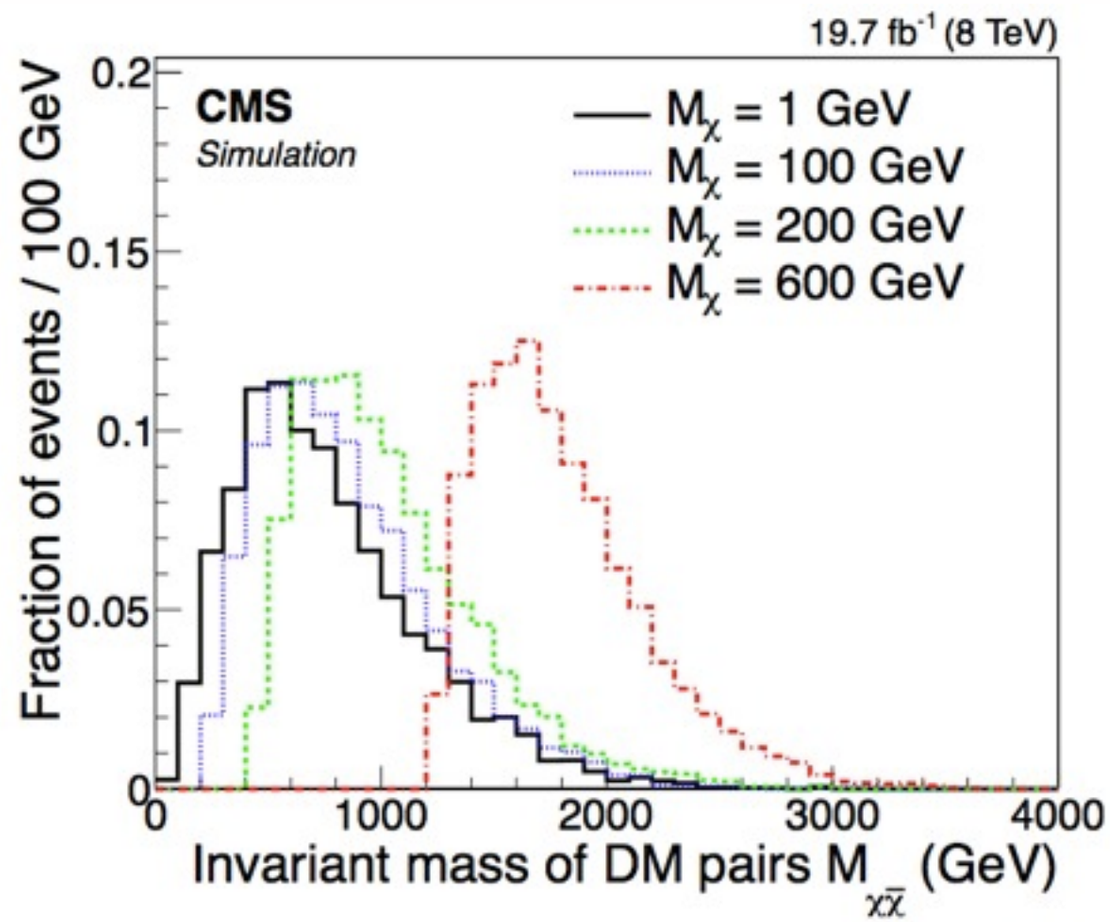
  → Assuming 100 GeV mass DM particle, M_* below 118 GeV is excluded

- 90% CL upper limits on tt+DM production cross section

  → Cross sections higher than 55 fb for 1 GeV and higher than 20 fb for 1 TeV DM mass are excluded

Results: limits



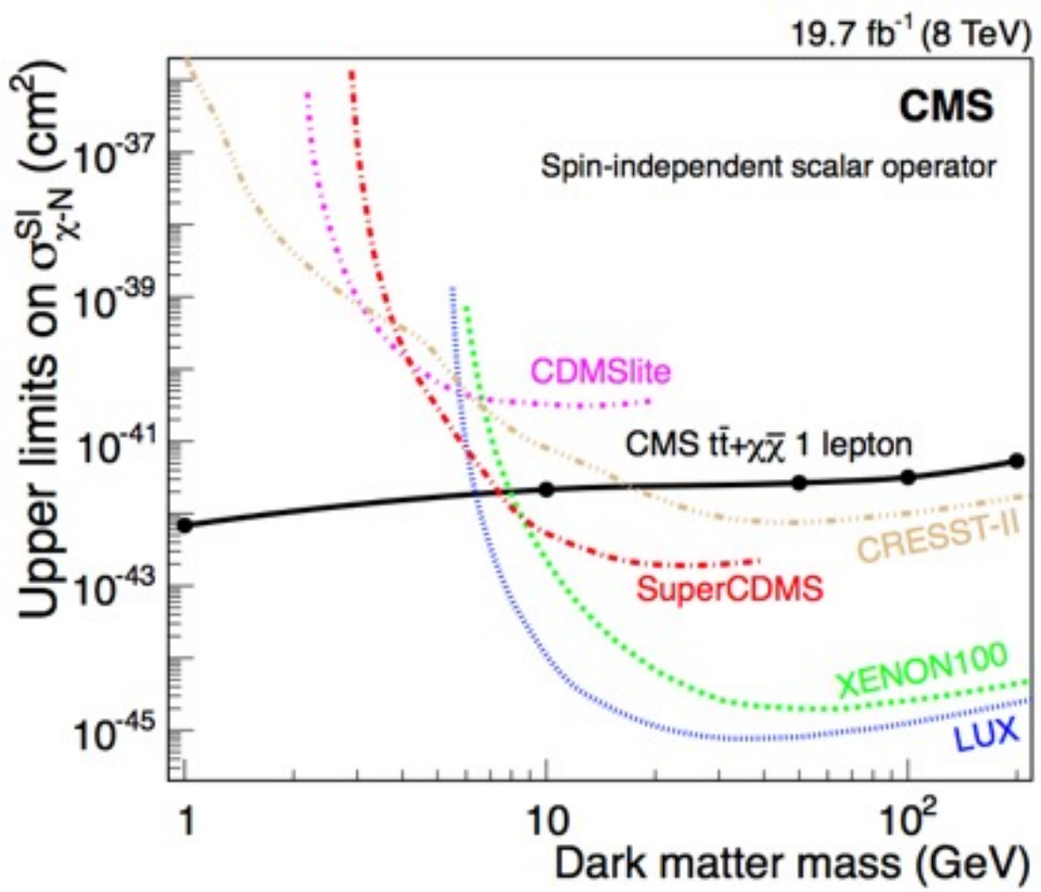


Results: cross section limits

- Can be translated in upper limits on DM-nucleon cross section for comparison with results from direct detection experiment

$$\sigma_0^{D1} = 1.60 \times 10^{-37}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{20\mathrm{GeV}}{M_*}\right)^6$$

μ_χ reduced mass DM-nucleon system



Excluded dark matter-nucleon cross sections higher than $1 - 2 \times 10^{-42}$ cm^2 for DM masses from 1 to 6 GeV

Physics objects

- Trigger: single-lepton triggers: single-electron, single-muon with p_T > 24 and 27 GeV

	Electrons	Muons	Jets
Reconstruction	ECAL driven algorithm	Tracker and global muon algorithms	anti-kT clustering algorithm with a cone size of ΔR = 0.5
	standard muon identification criteria	standard muon identification criteria	
Selection	Loose $p_T \geq 30$ GeV, $\lvert\eta\rvert < 2.5$	Tight $p_T \geq 30$ GeV, $\lvert\eta\rvert < 2.1$	$p_T \geq 30$ GeV $\lvert\eta\rvert < 4.0$
	$I_{rel} < 0.1$ in ΔR=0.3	$I_{rel} < 0.12$ in ΔR=0.4	b-tagging with medium working point CSV algorithm $\lvert\eta\rvert < 2.4$

Physics objects

MUON IDENTIFICATION CUTS

Variables	cuts
isGlobalMuon	true
isPFMuon	true
χ^2/d.o.f.	< 10
Number of muon hits	> 0
Number of pixel hits	> 0
Number of matched stations	> 1
Number of tracker layers	> 5
d_{xy}(vtx)	< 0.2 cm
d_z(vtx)	< 0.5 cm
pfIso04/p_T, $\Delta\beta$ corr.	< 0.12

ELECTRON IDENTIFICATION CUTS

Variables	tight cuts
$\lvert d_0(\text{vtx})\rvert$	< 0.02 cm
$\lvert d_z(\text{vtx})\rvert$	< 0.1 cm
$\sigma_{i\eta i\eta}$	< 0.01(barrel), < 0.03(endcap)
$\lvert\Delta\eta_{\text{in}}\rvert$	< 0.004(barrel), < 0.005(endcap)
$\lvert\Delta\phi_{\text{in}}\rvert$	< 0.03(barrel), < 0.02(endcap)
H/E	< 0.12(barrel, < 0.10(endcap)
$\lvert 1/E - 1/p\rvert$	< 0.05
pfIso03/p_T	< 0.1
Matched conversion?	false
Missing hits	0

JET IDENTIFICATION CUTS

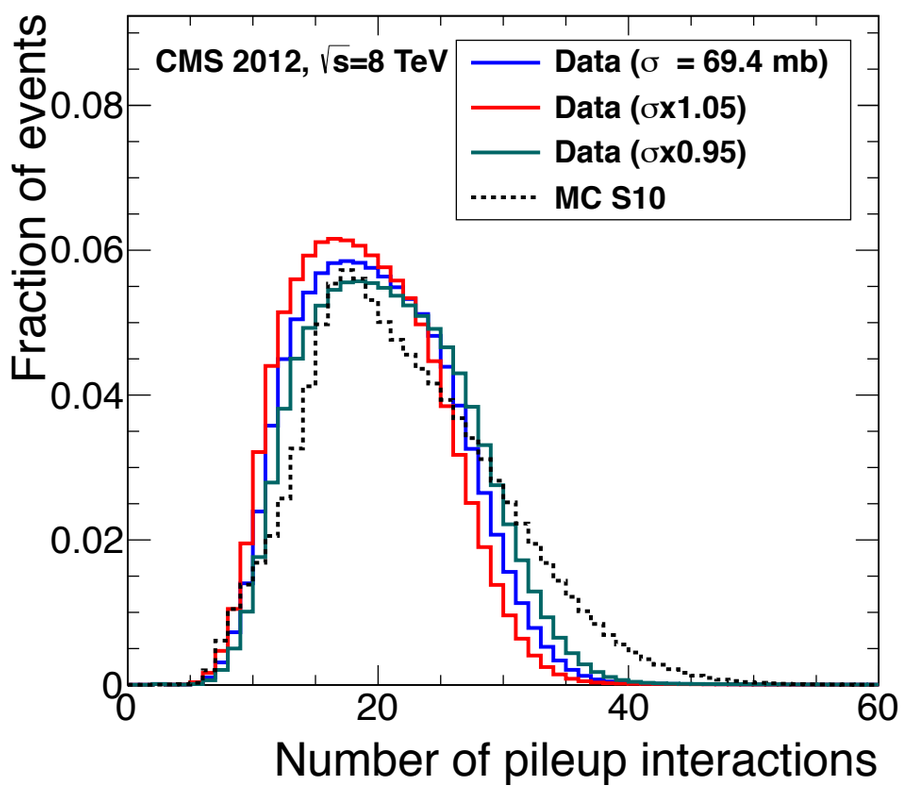
PF Jet ID	Cuts
Neutral hadron fraction	< 0.99
Neutral EM fraction	< 0.99
Number of constituent	> 1
Below for $\lvert\eta\rvert < 2.4$ only	
Charged hadron fraction	> 0
Charged multiplicity	> 0
Charged EM fraction	< 0.99

Pileup reweighting

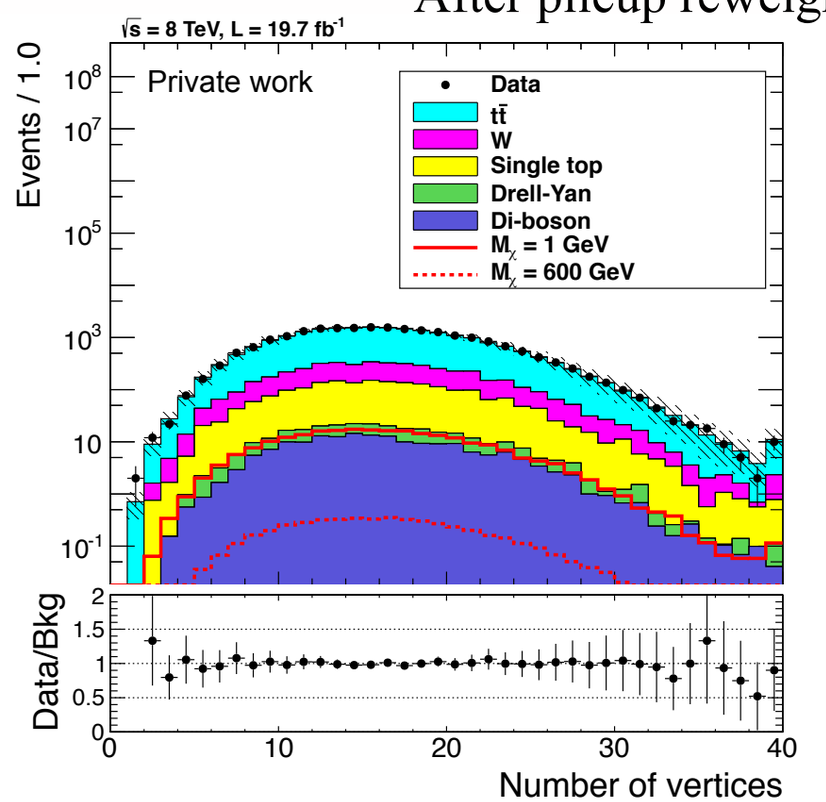
Pileup distribution different in MC w.r.t data

- MC number pileup reweighted to match data
- Data distribution re-calculated with ±5% variation on cross section to cover pileup mis-modeling syst. unc.

Good agreement data-MC after pileup reweighting



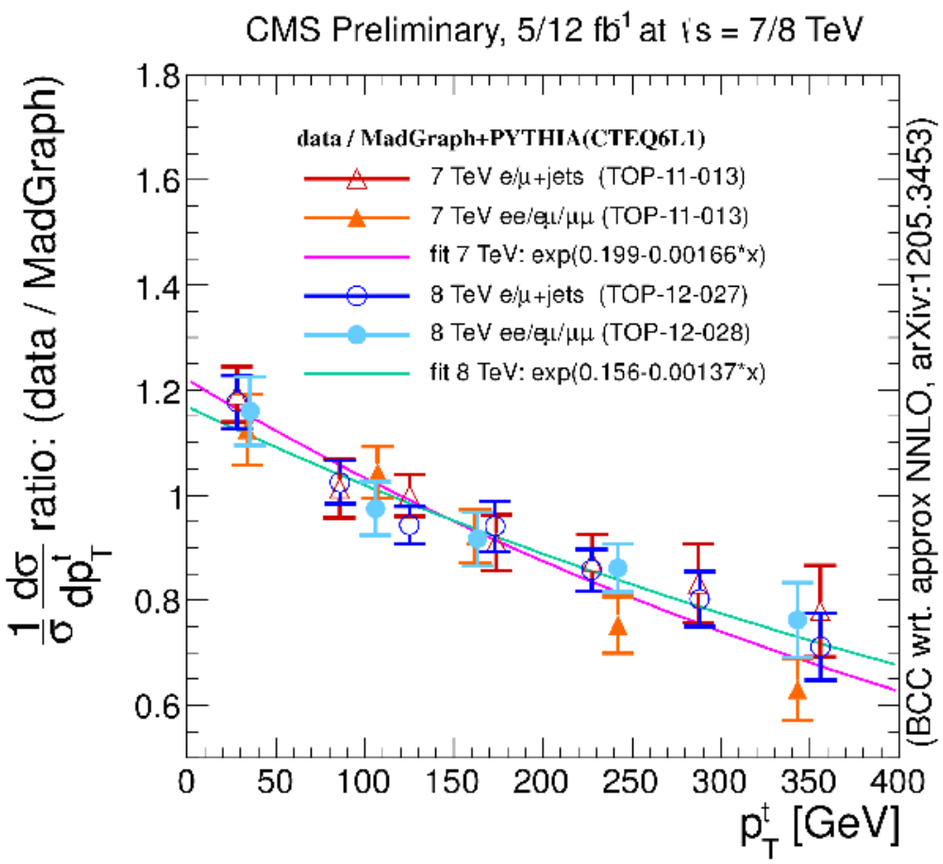
After pileup reweighting



Top p_T reweighting

p_T distribution of leptons and jets from tops softer in data w.r.t Madgraph simulation

- Top differential cross section measurement provide SFs for correction
- Each event weighted by geometric mean of SFs from 2 tops (assumed flat > 400 GeV)
- Syst. unc.: no SF, SF applied twice



$$SF = e^{0.156 - 0.00137 \times p_T}$$

Physics objects: b jets

b jets

b-tagging algorithm: **C**ombined **S**econdary **V**ertex (CSV)

- Standard CMS b-tagging algorithm
- Used to identify jets likely to come from b quarks fragmentation-adronization
- Exploits long lifetime of b hadrons

  large impact parameter and presence of a secondary vertex as input
- Continuous output: allows selection of optimal working points

Efficiencies, mis-tag rates

for CSV > 0.90 b quark tag: 50%
c quark tag: 6%
light quark tag: 0.15 %

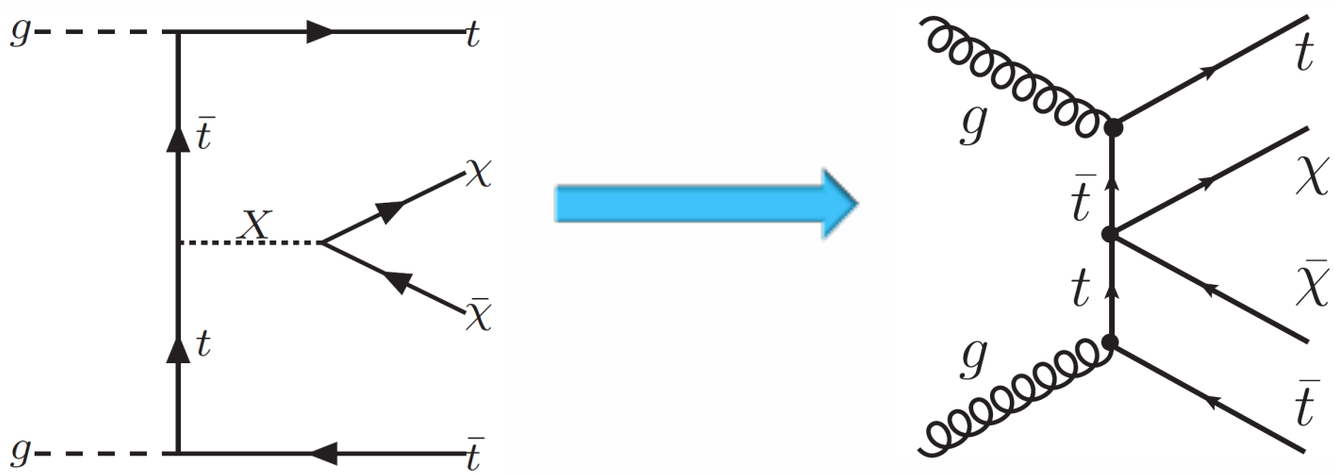
for CSV > 0.50 b quark tag: 72%
c quark tag: 23%
light quark tag: 3 %

Effective Field Theory backup

Effective Field Theory

- Supposing a heavy mediator of mass M in the s-channel coupling to DM and SM with couplings g_1 g_2.

  Considering only the lowest order operators in the EFT approach is connected to the propagator expansion



$$\frac{g_1 g_2}{Q_{tr}^2 - M^2} = -\frac{g_1 g_2}{M^2}\left(1 + \frac{Q^2}{M^2} + \mathcal{O}\left(\frac{Q_{tr}^4}{M^4}\right)\right) \simeq -\frac{g_1 g_2}{M^2} \text{ for } Q_{tr}^2 << M^2$$

the coefficient of the effective operator should match to reproduce the UV theory, i.e. for D1

$$M_* = \left(\frac{m_q M^2}{g_1 g_2}\right)^{1/3}$$

Effective Field Theory

- In general the EFT field theory is valid when $Q_{tr} << M_*$

- The validity of the truncation of the propagator expansion requires

$$Q_{tr} < M$$

from the assumed UV details (heavy mediator, s-channel) $M_* = \left(\frac{m_q M^2}{g_1 g_2}\right)^{1/3}$

from kinematics $Q_{tr} > 2m_\chi$

assuming most strongly coupled scenario in the perturbative regime $\sqrt{g_1 g_2} < 4\pi$

$$\sqrt{\frac{M_*^3}{m_q}} > \frac{M_\chi}{2\pi}$$

- This is a very minimal requirement on M_* and it depends on the details of the UV completion

DM+tt semi-leptonic 13 TeV backup

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis

(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

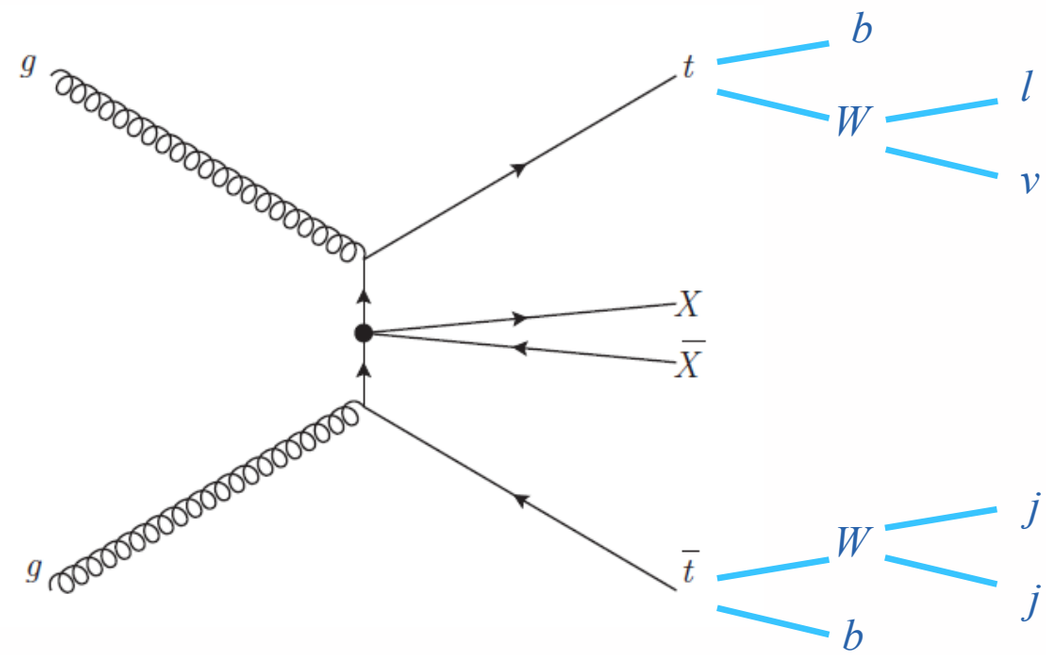
(2) Rejection of background

based on topology differences between bkg and signal

(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation



What it is new:

- shape of measured MET distribution used as additional information to improve discovery potential, shape analysis
- in addition to bkg normalization also bkg shape distribution constrained from data

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Background estimation procedure

background contributions N_i^{SR} in SR estimated from data in dedicated CR with a scale factor ρ_i determined from data as a function of MET

$$N_i^{\mathrm{SR,\,est}} = N_i^{\mathrm{CR,\,data}} \times \rho_i \,,$$

$$\rho_i = \frac{N_i^{\mathrm{SR,\,sim}}}{N_i^{\mathrm{CR,\,sim}}} \,.$$

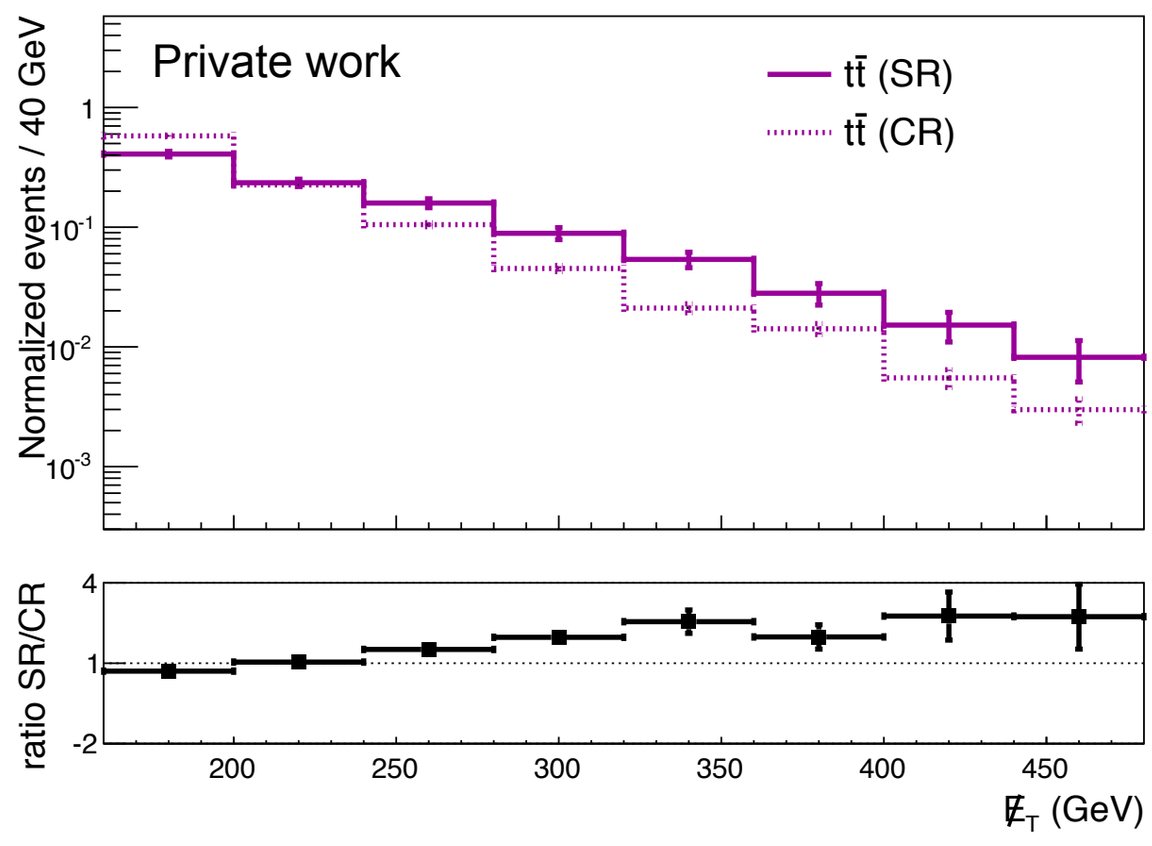
main backgrounds for DM+tt semi-leptonic channel

tt+jets:

very similar topology to signal events, high MET for di-leptons events with one missed lepton

W+jets:

missing diagrams in simulation given a bad descriptions events at high MET/M_T values



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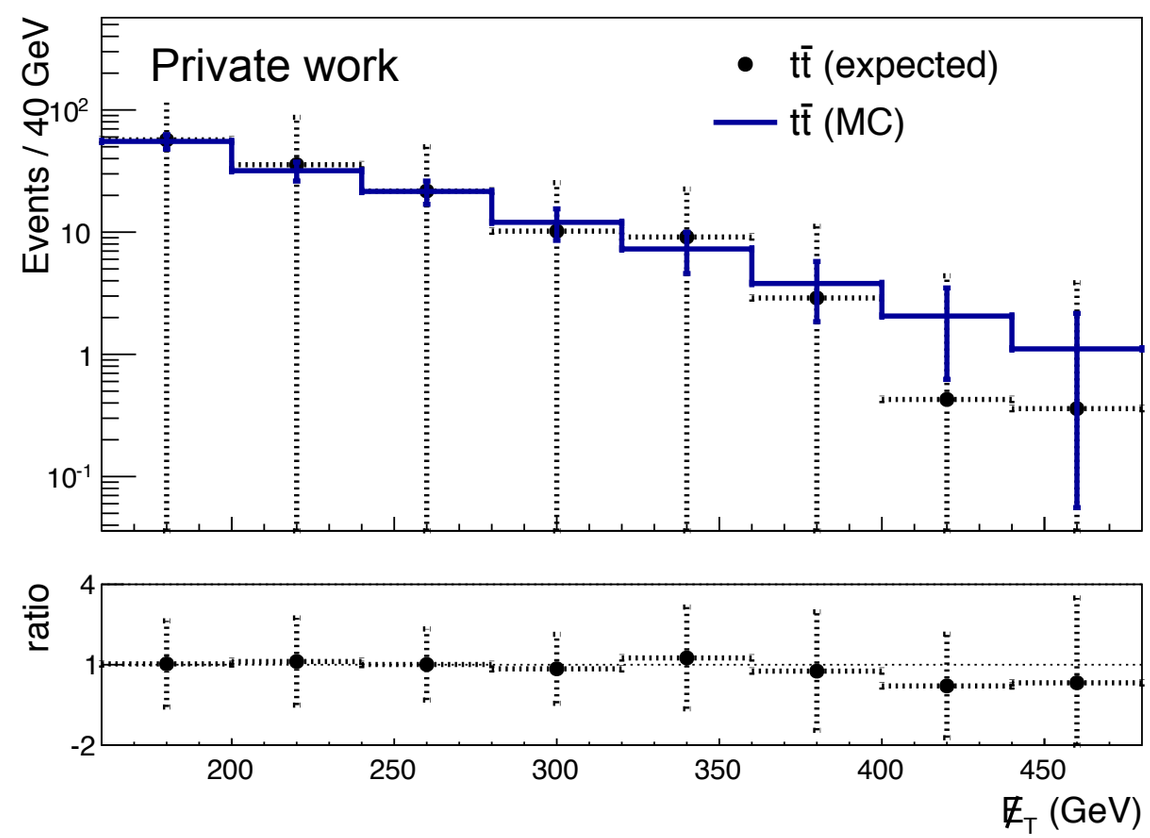
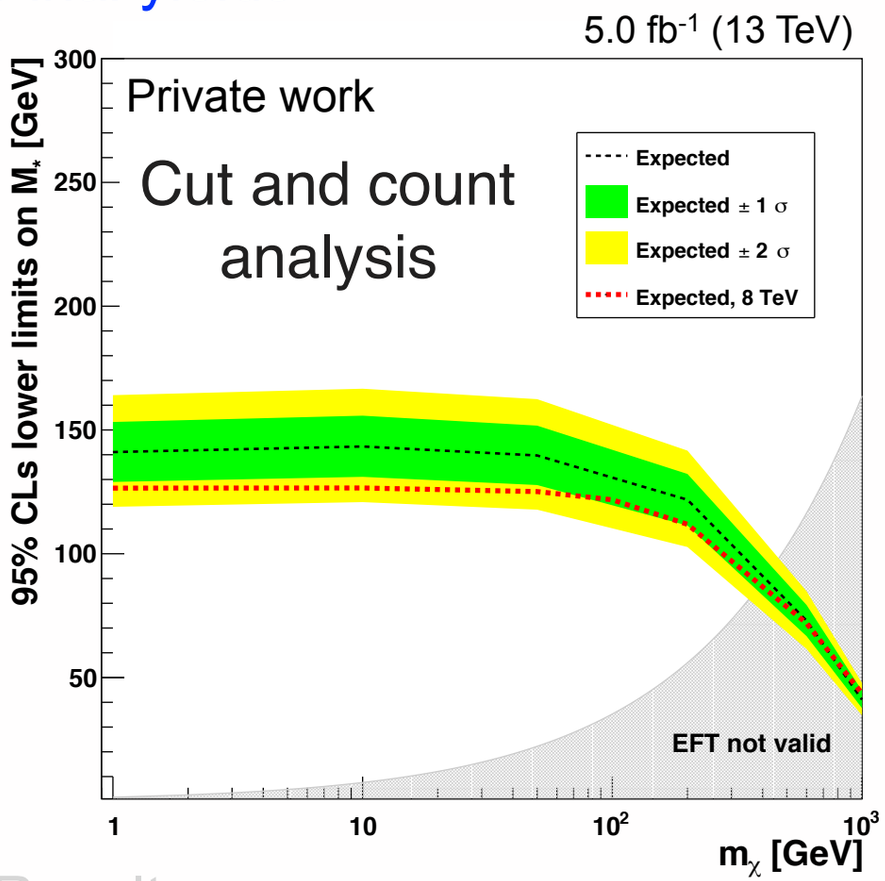
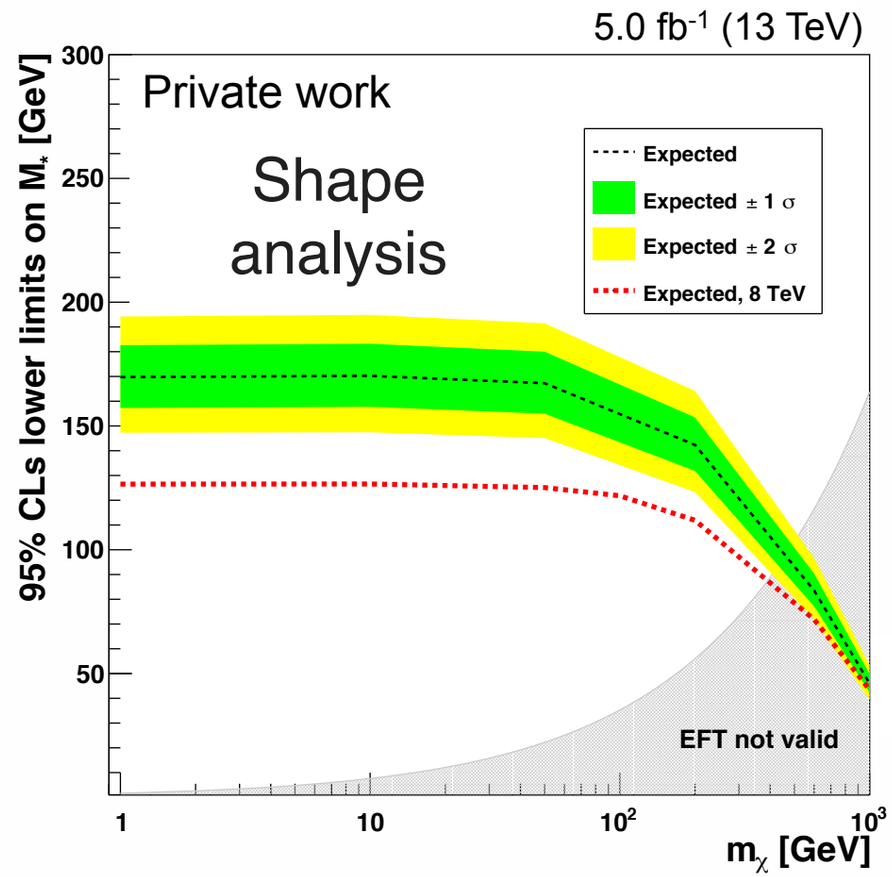


EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

(4) Final yields





(5) Results

- 90% CL **lower limits on M*** for scalar interaction

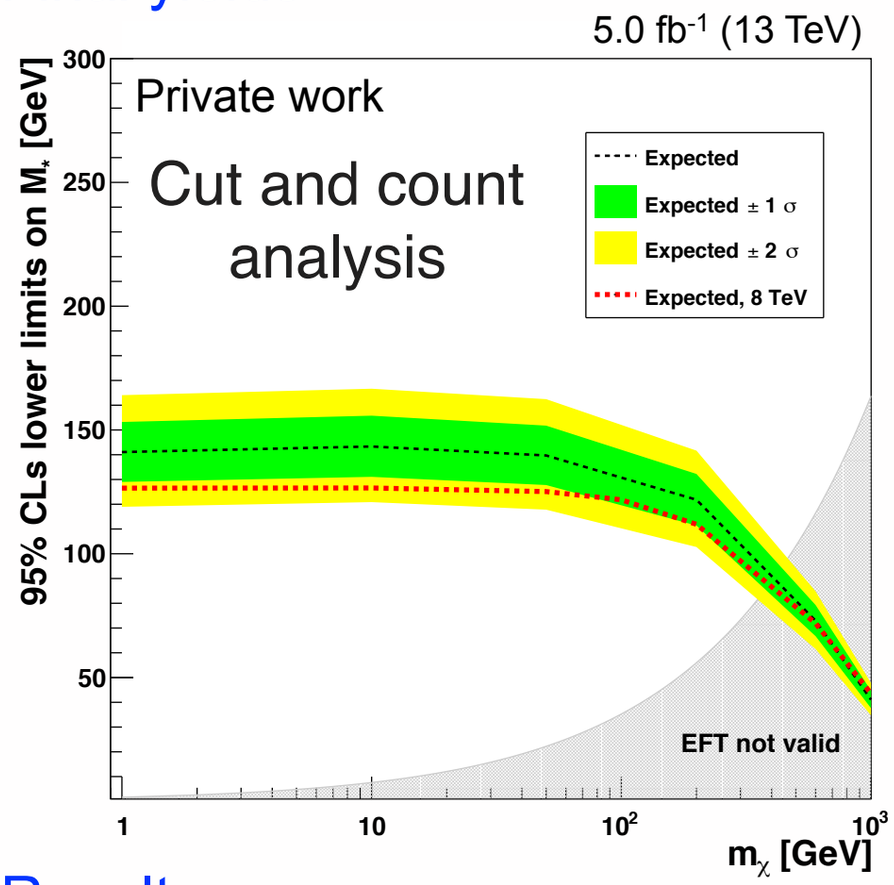
  → Assuming 100 GeV mass DM particle, excluded M* below 140 GeV is excluded for cut and count 170 GeV for shape analysis

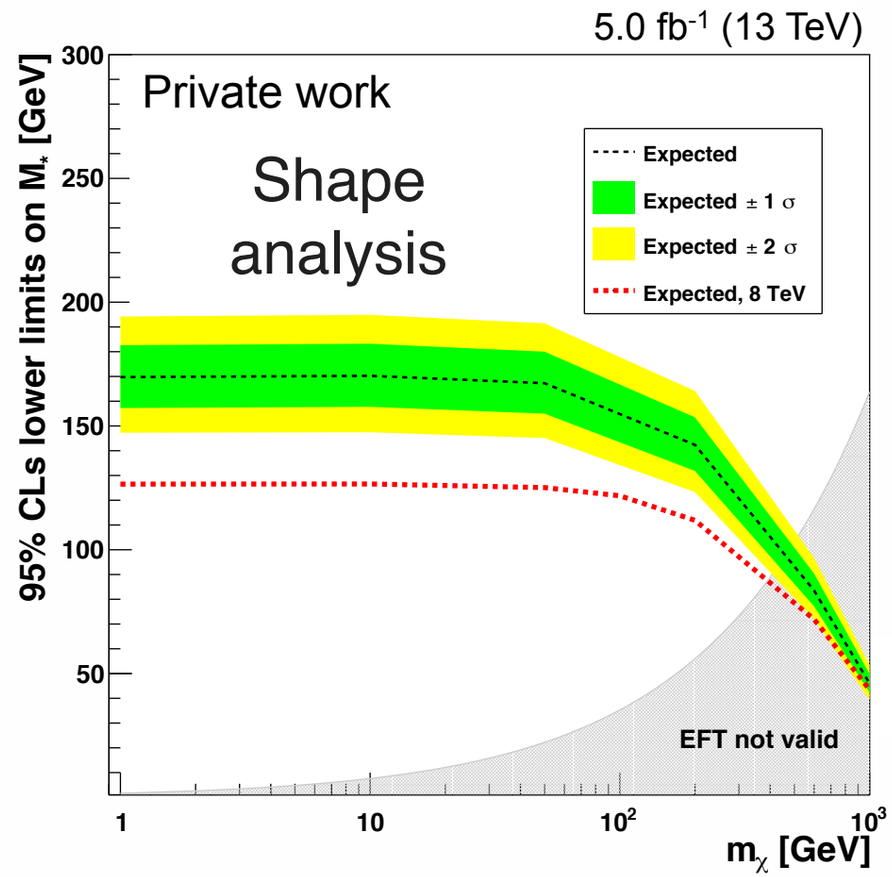
- improvements from shape analysis of ~18% w.r.t cut and count analysis

- improvements w.r.t 8 TeV analysis already after few months of data taking!

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

(4) Final yields





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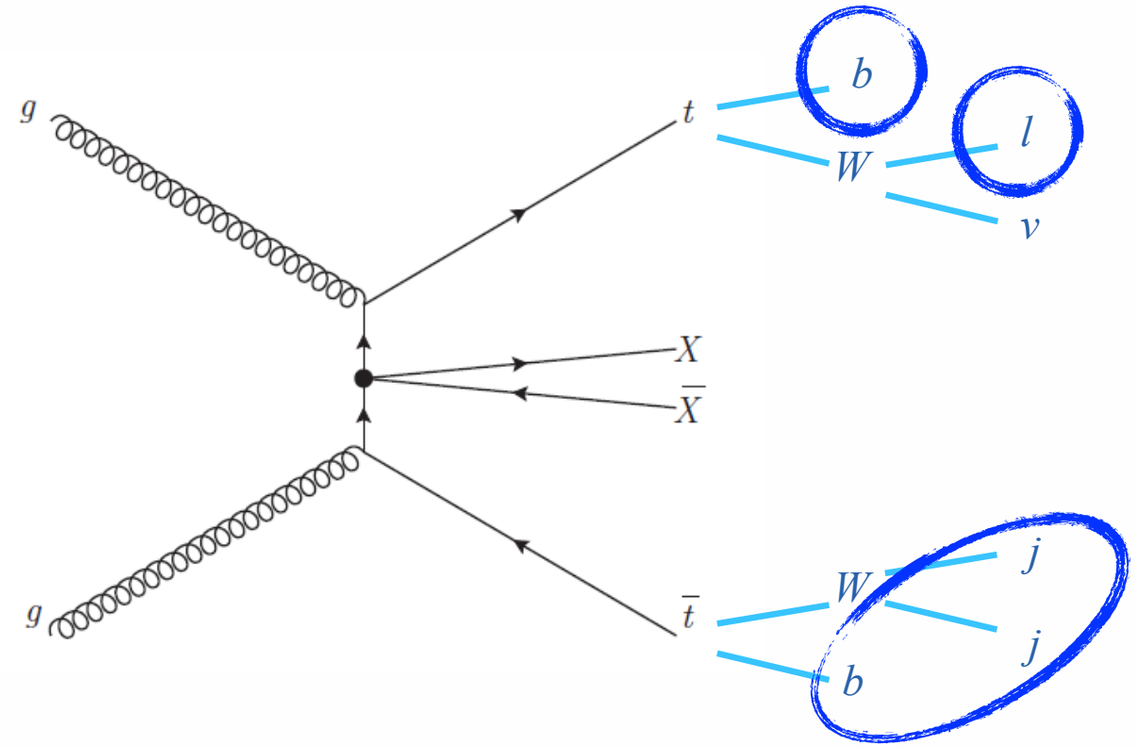
EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis

(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged



(2) Rejection of background

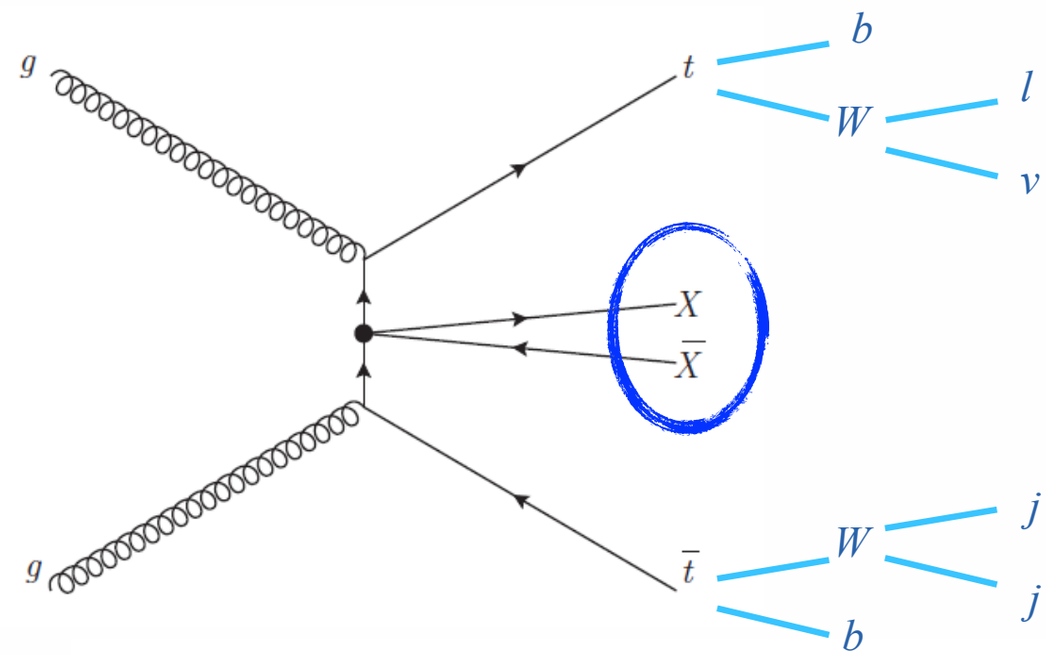
(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis



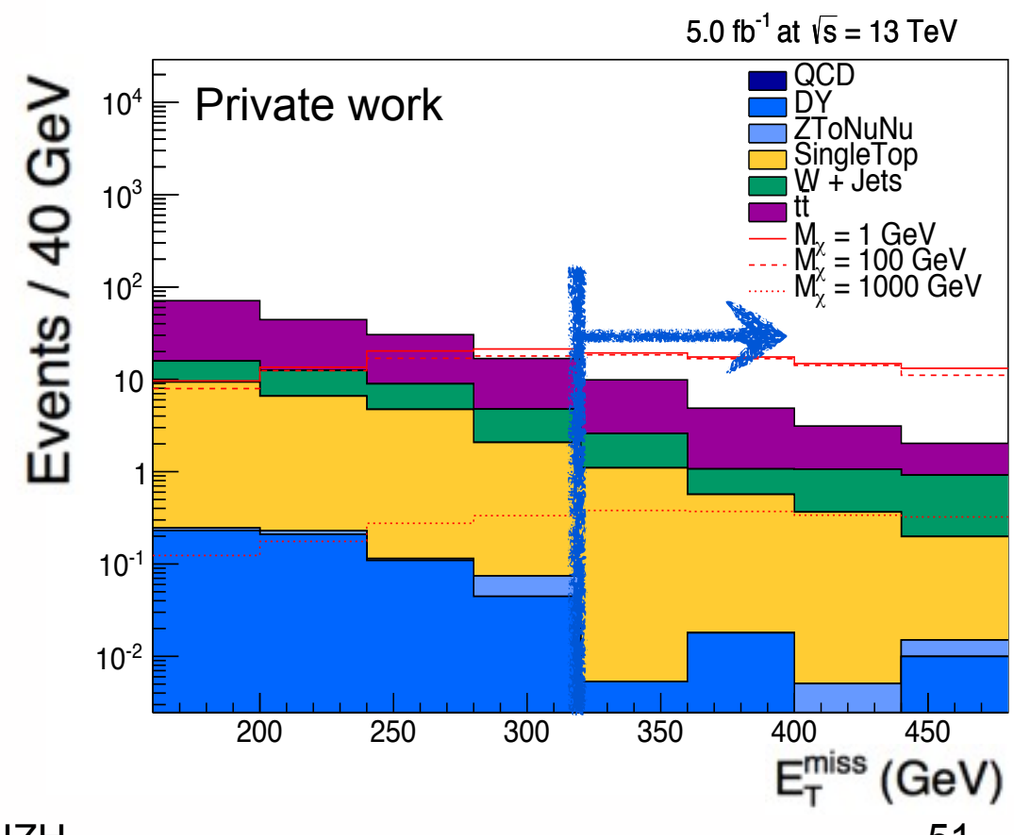
(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- signal has large MET from DM particles which escape detector

MET > 320 GeV



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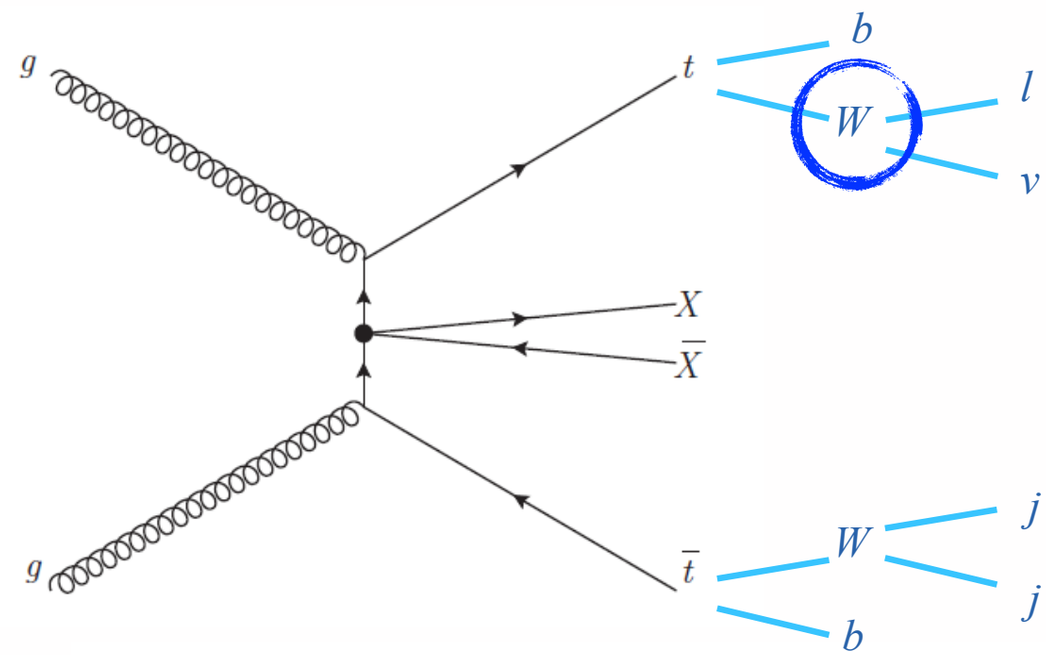
tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis



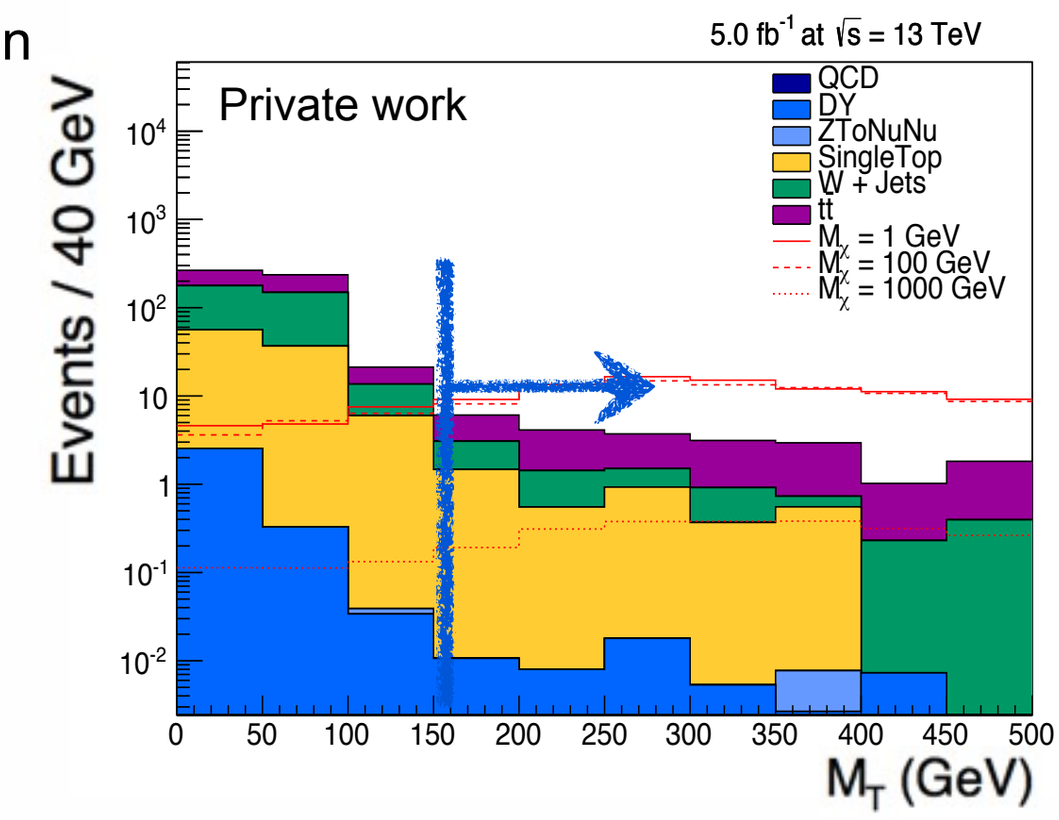
(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- Most W+jets and tt+jets semi-leptonic events $M_T < M_W$. Signal events distribution peaks at higher values

$$M_T = \sqrt{2 p_T^{lep} E_T^{miss} (1 - \cos(\Delta\phi))} > 160 \text{ GeV}$$



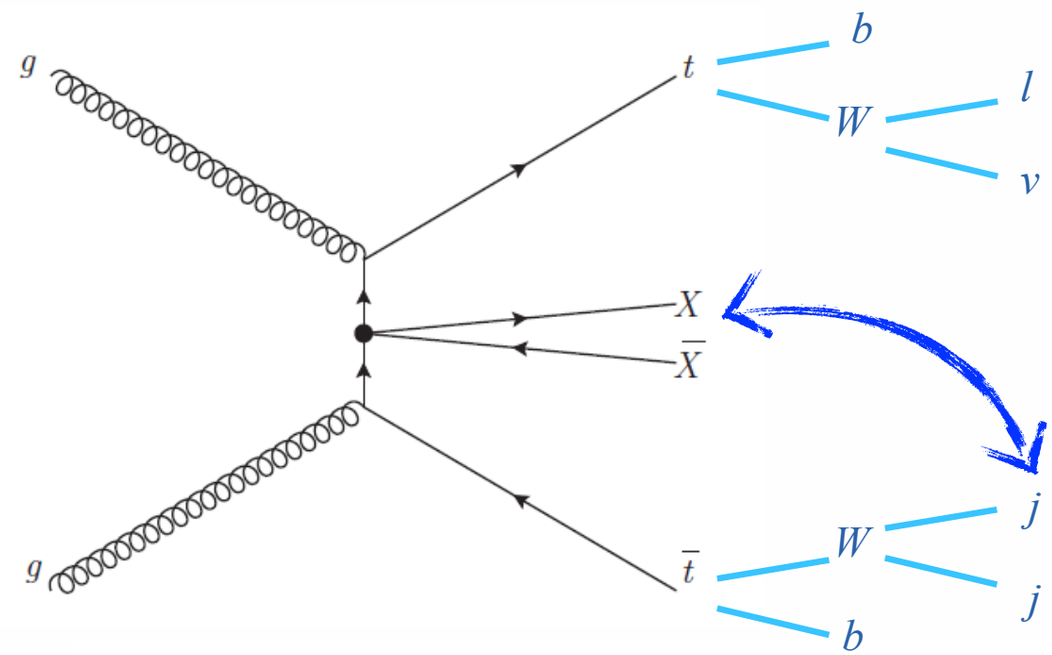
(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis



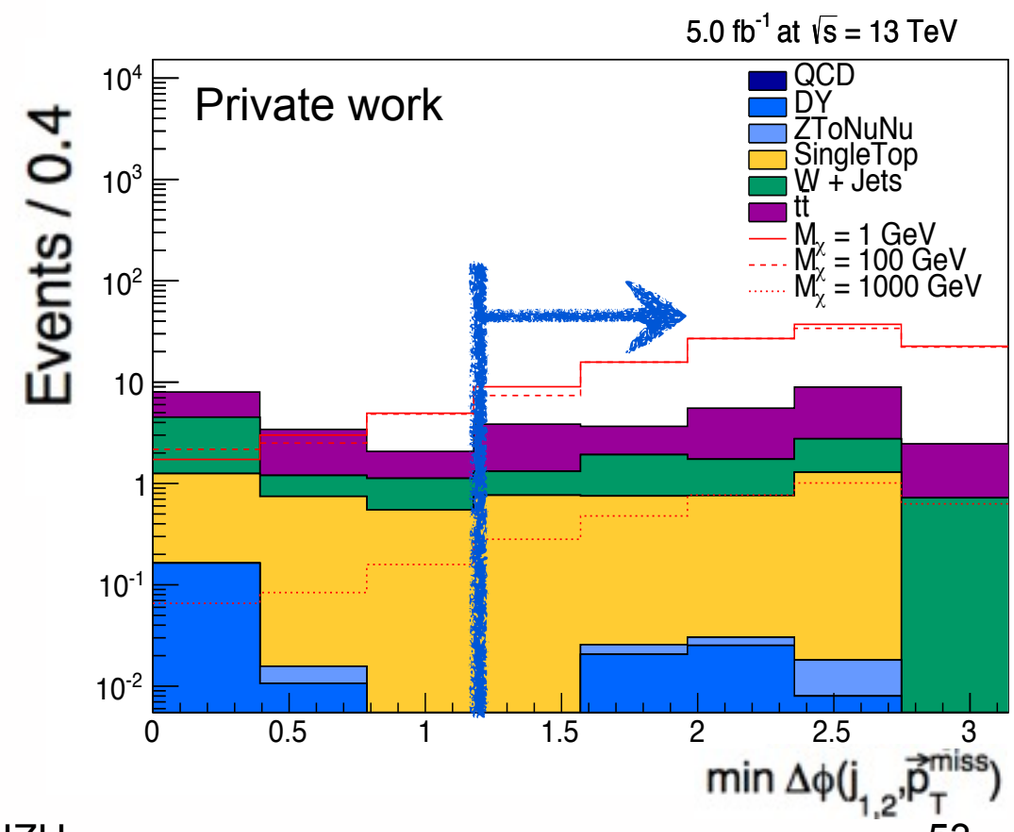
(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- The jets and the MET tends to be more separated in Φ in signal events than in tt and in single top events

$$\min(\Delta\Phi_{j1,MET}, \Delta\Phi_{j2,MET}) > 1.2 \text{ GeV}$$



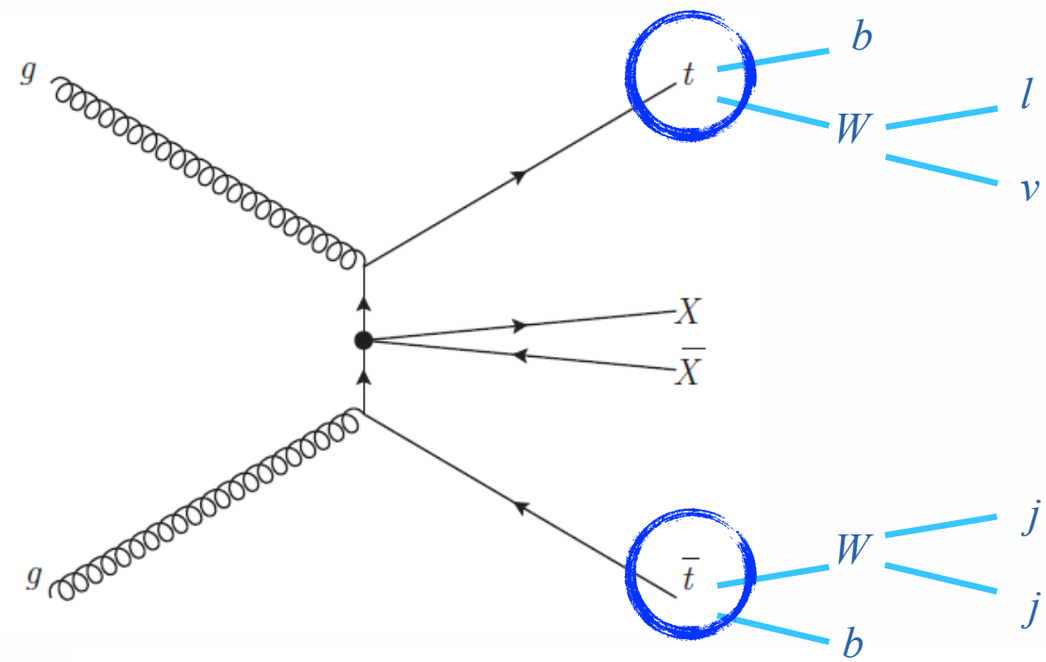
(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis



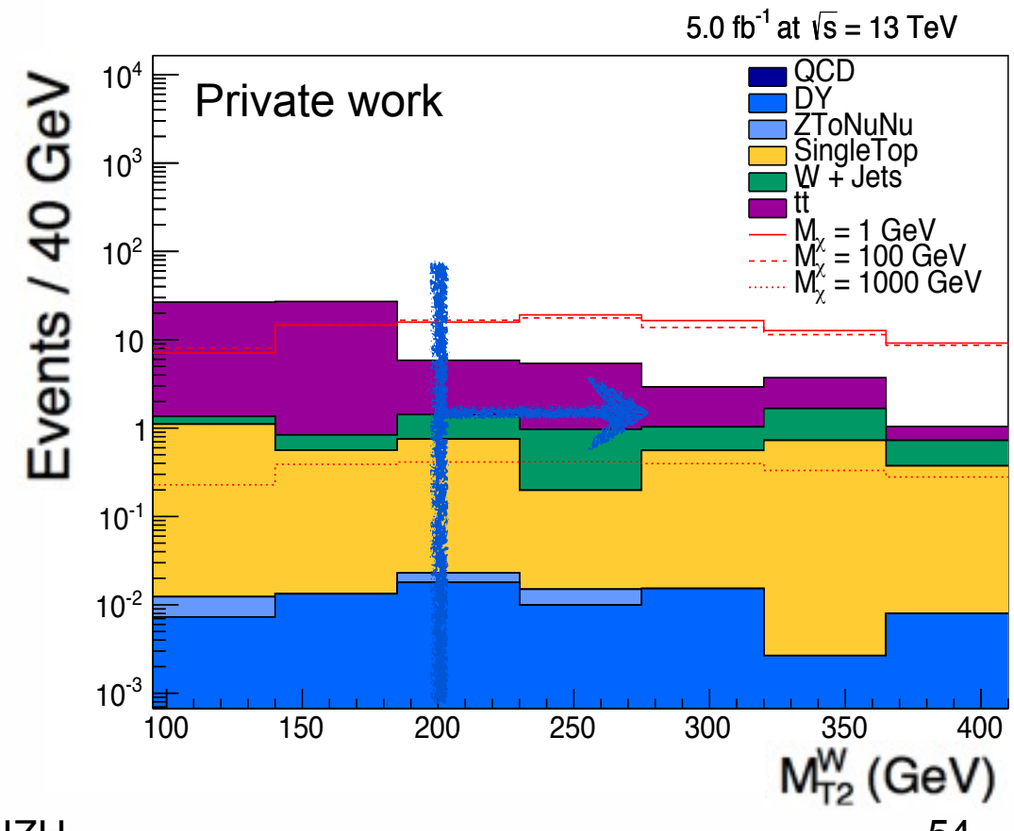
(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

- For most tt+jets di-leptonic events $M_{T2W} < M_{top}$. Signal events distribution shows higher tails

$M_{T2W} > 200$ GeV (see slide 20)



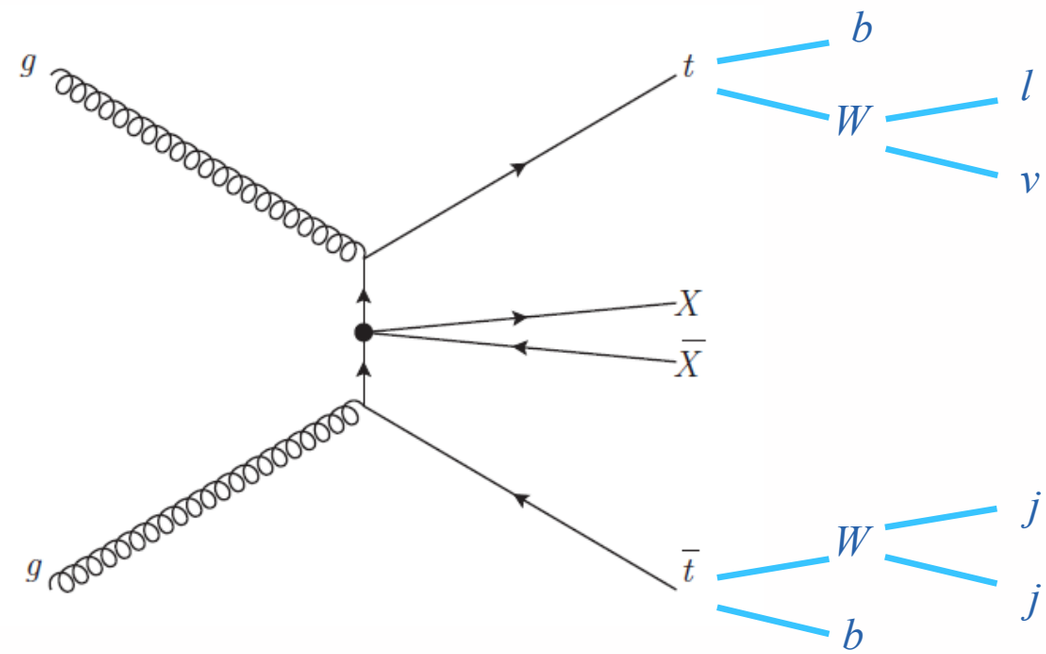
(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

Analysis strategy: similar to 8 TeV analysis



(1) Selection of topology

1 lepton, at least 3 jets, at least 1 b-tagged

(2) Rejection of background

Variable	Cut
MET	> 320 GeV
$M_T = \sqrt{2p_T^{lep} E_T^{miss}(1-\cos(\Delta\phi))}$	> 160 GeV
min($\Delta\Phi_{j1,MET}$, $\Delta\Phi_{j2,MET}$)	> 1.2
M_{t2W}	> 200 GeV

Cut and count analysis:
full selection
Shape analysis:
full selection except MET selection

(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson: simulation

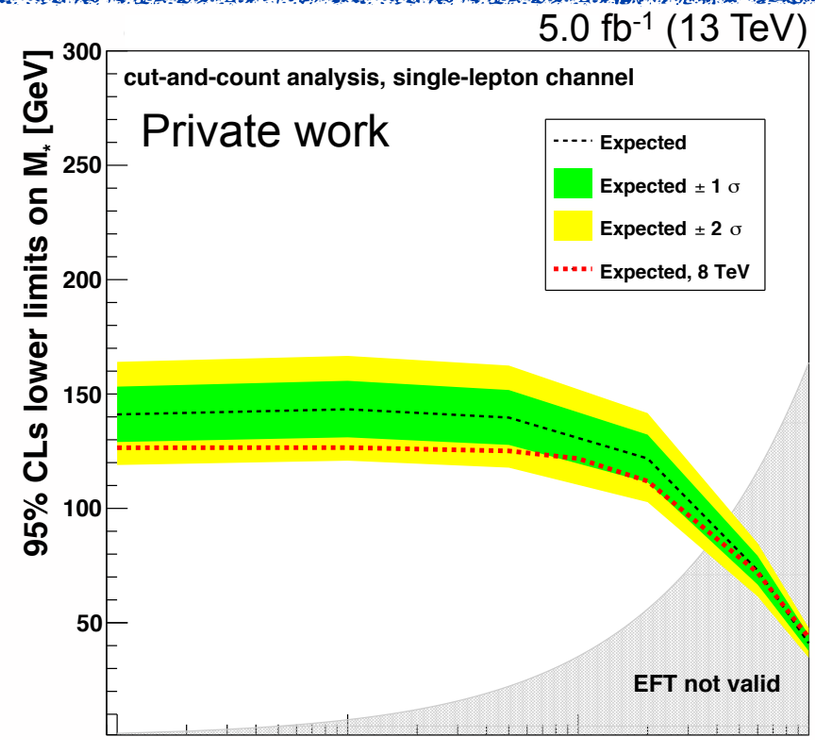
EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

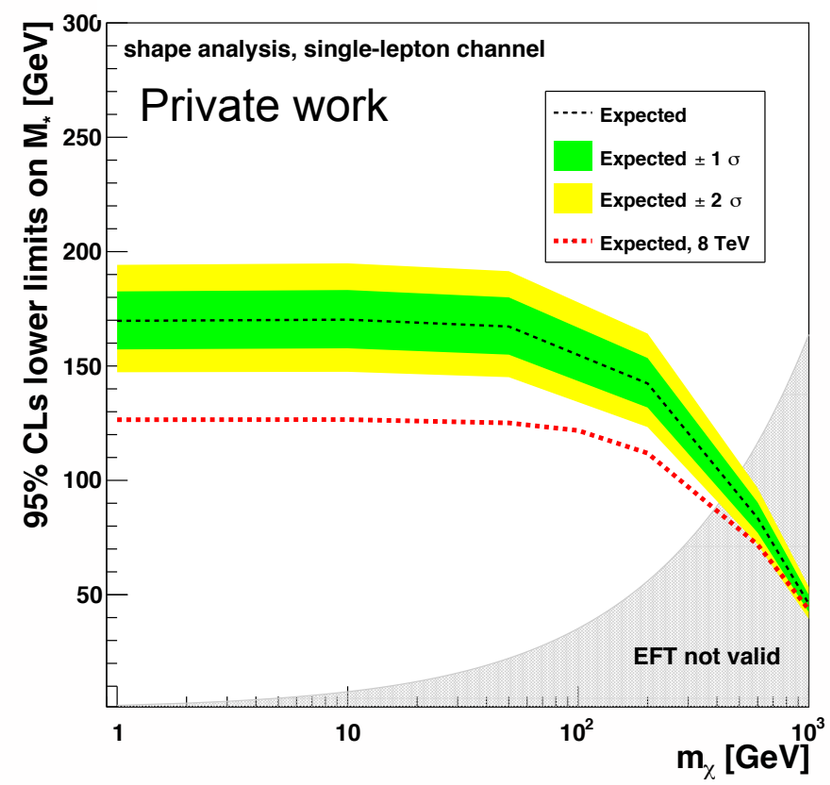
(4) Final yields

M_χ=1GeV M_*=100 GeV, L= 5 fb^{-1} (Private work)

Source	Yield cut and count	Yield shape
Data	-	-
Signal	11.3	161.0
Total Bkg	23.9	186.3
tt	15.8	136.2
W+jets	4.8	24
Single top	3.3	25.4
Drell-Yan	0.1	0.7
Z(vv)+jets	0.0	0.1
QCD	0.0	0.0

Work in progress on yields systematics





(5) Results

- 90% CL **lower limits on M_*** for scalar interaction

  → Assuming 100 GeV mass DM particle, excluded M_* below
  140 GeV is excluded for cut and count
  170 GeV for shape analysis

- improvements w.r.t 8 TeV analysis already after few months of data taking!

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

(4) Final yields

M_χ=1GeV M_*=100 GeV, L= 5 fb^{-1} (Private work)

Source	Yield cut and count	Yield shape
Data	-	-
Signal	11.3	161.0
Total Bkg	23.9	186.3
tt	15.8	136.2
W+jets	4.8	24
Single top	3.3	25.4
Drell-Yan	0.1	0.7
Z(vv)+jets	0.0	0.1
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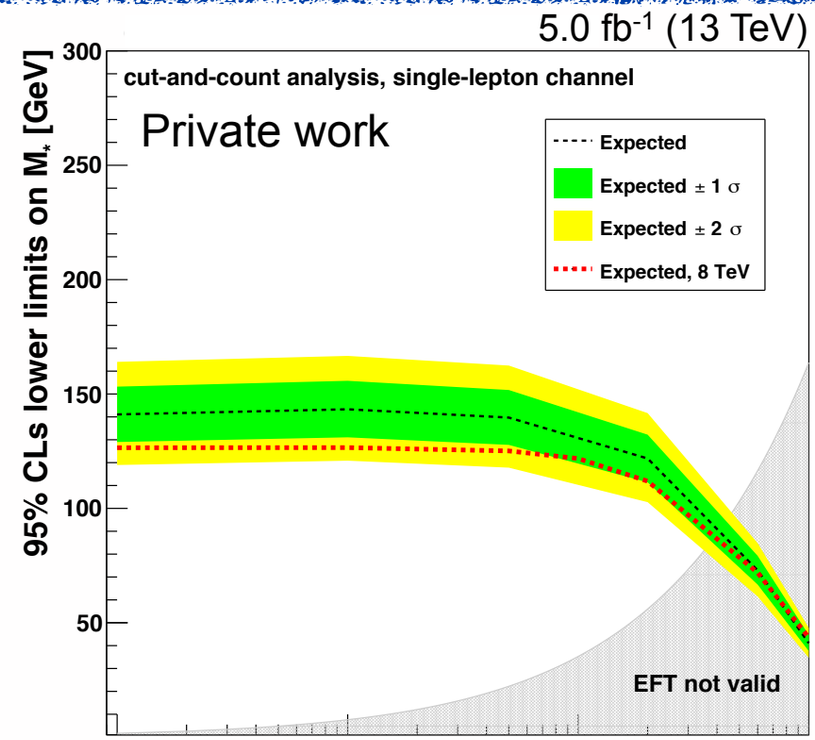

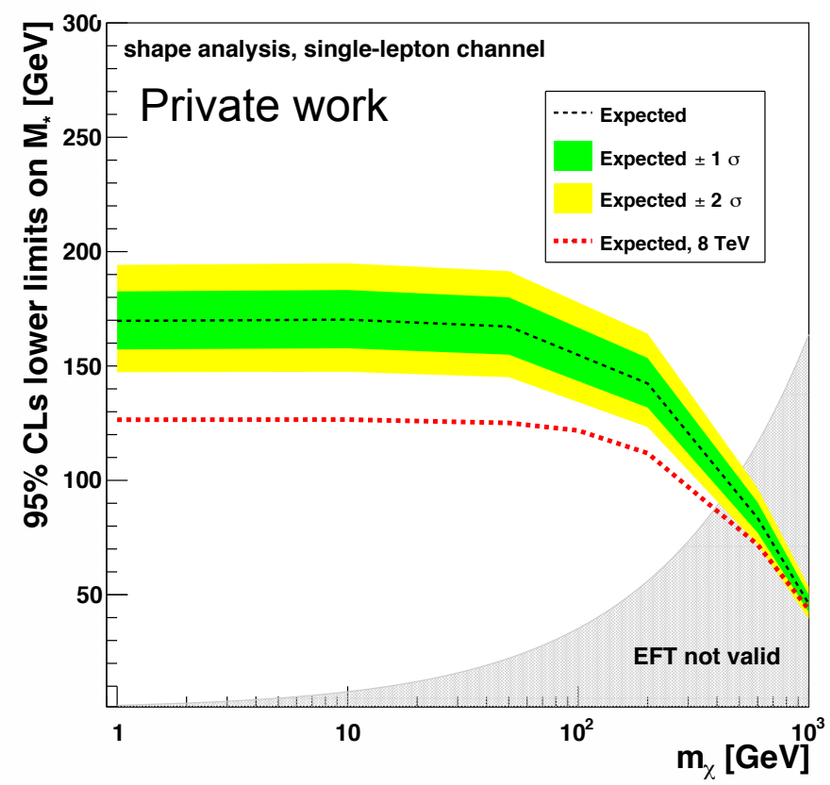

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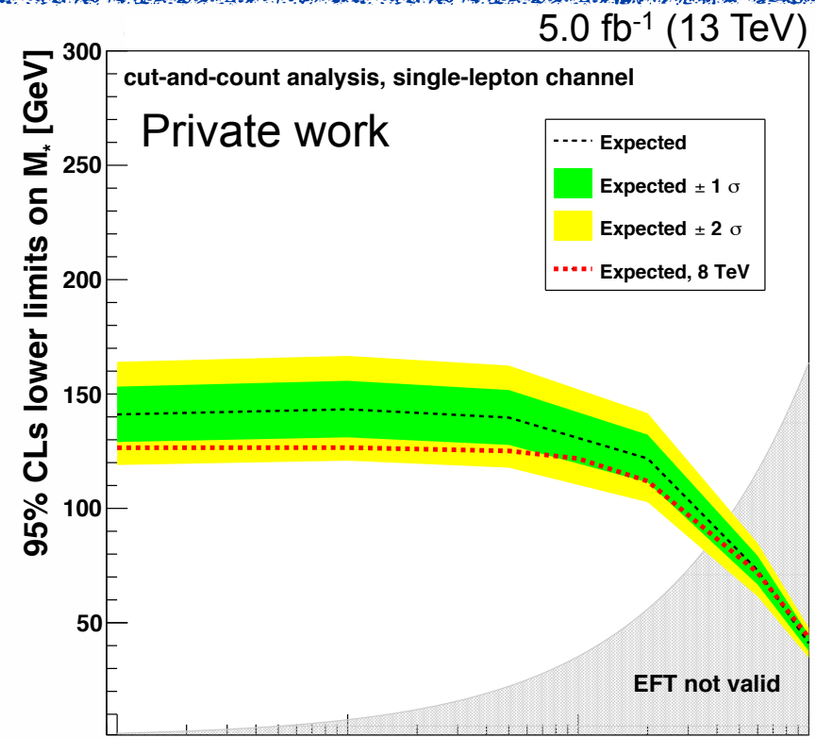
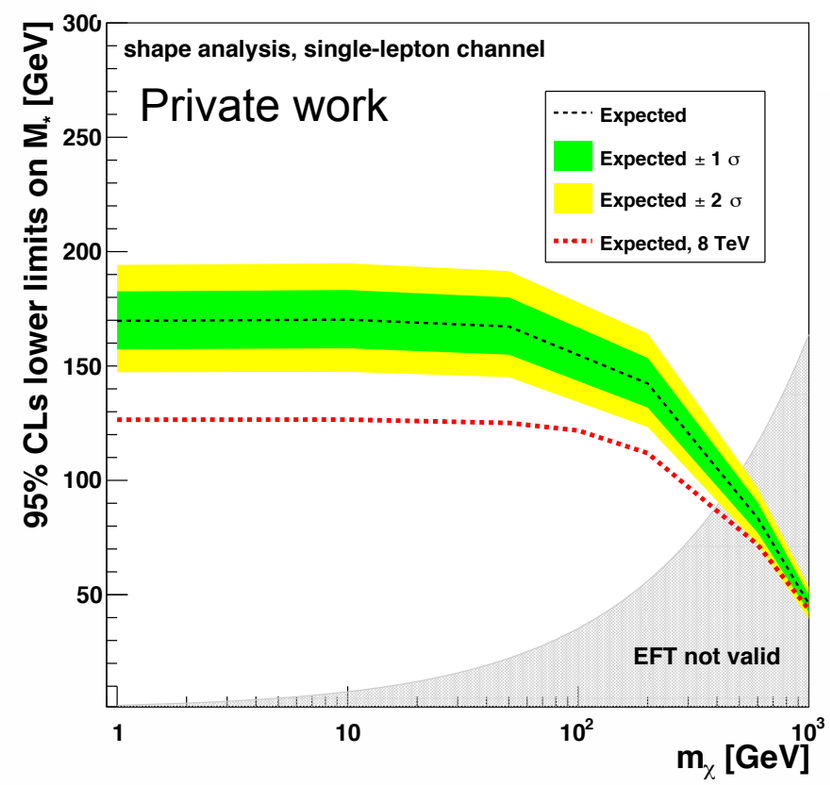




DM+tt hadronic 13 TeV backup

EFT DM + tt ($\longrightarrow bjj, bjj$) at 13 TeV

University of Zurich[UZH]

Analysis strategy:

(1) Selection of topology

lepton veto, at least 4 jets, at least 2 b-tagged

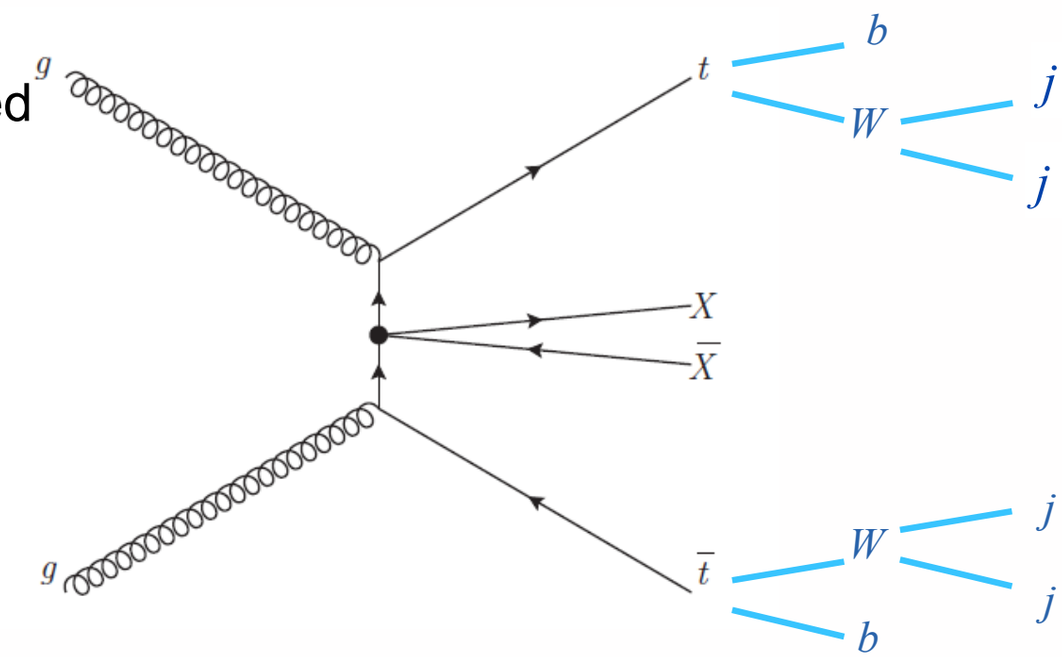
(2) Rejection of background

based on topology differences between bkg and signal

(3) Extract normalization for background

tt+jets, QCD: from data

Drell-Yan, single top, Di-boson, W+jets: simulation



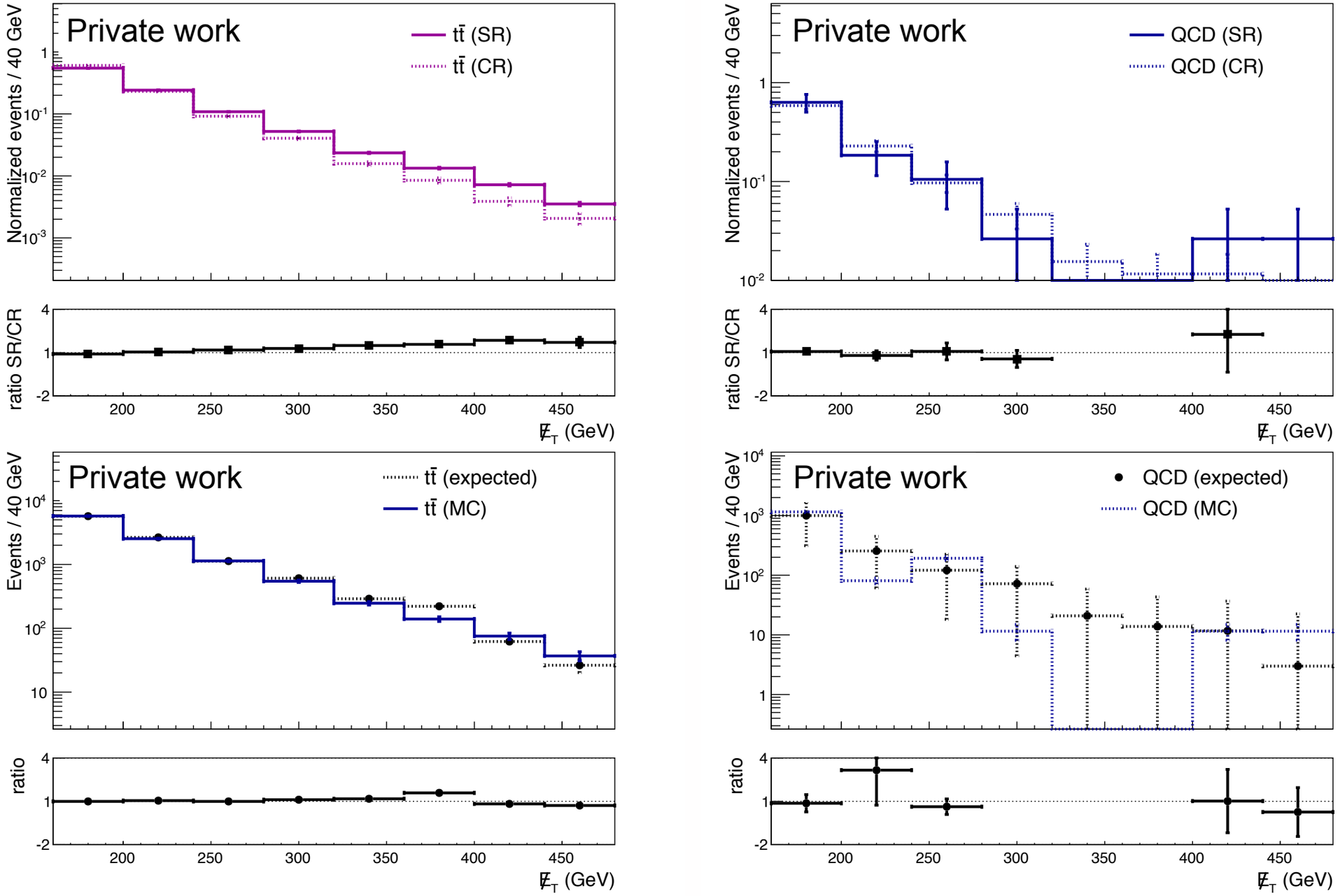
What it is new:

- higher BR but very high bkg contributions at high MET values
- shape of measured MET distribution used as additional information to improve discovery potential, shape analysis
- in addition to bkg normalization also bkg shape distribution constrained from data

EFT DM + tt ($\longrightarrow bjj, bjj$) at 13 TeV

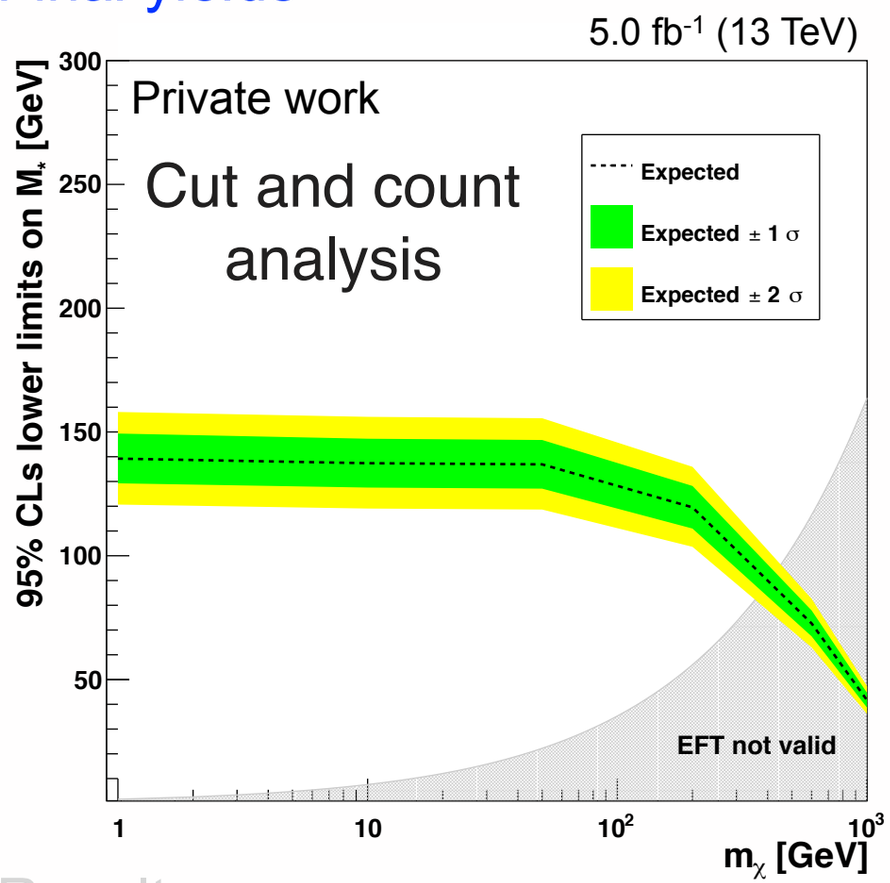
Background estimation procedure same as for semi-leptonic channel

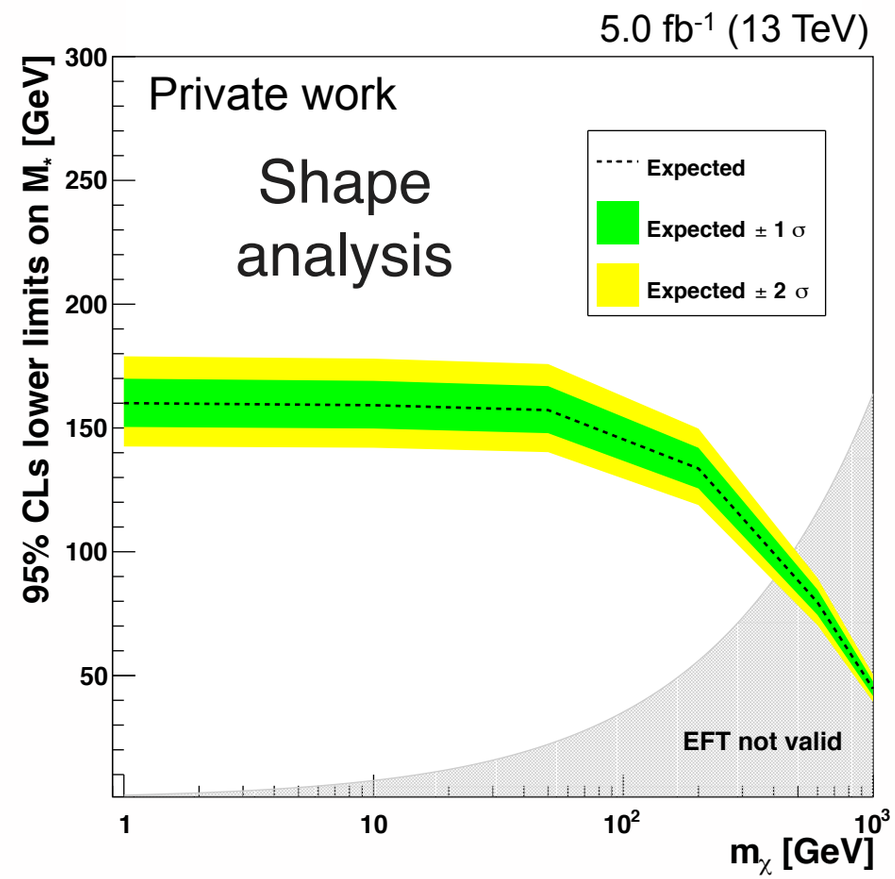
for QCD the SF applied is constant as a function of MET



EFT DM + tt ($\longrightarrow bjj, bjj$) at 13 TeV

(4) Final yields





(5) Results

- 90% CL **lower limits on M*** for scalar interaction

  → Assuming 100 GeV mass DM particle, excluded M* below 140 GeV is excluded for cut and count 170 GeV for shape analysis

- improvements from shape analysis of ~18% w.r.t cut and count analysis

- improvements w.r.t 8 TeV analysis already after few months of data taking!

EFT DM + tt ($\longrightarrow bjj, bjj$) at 13 TeV

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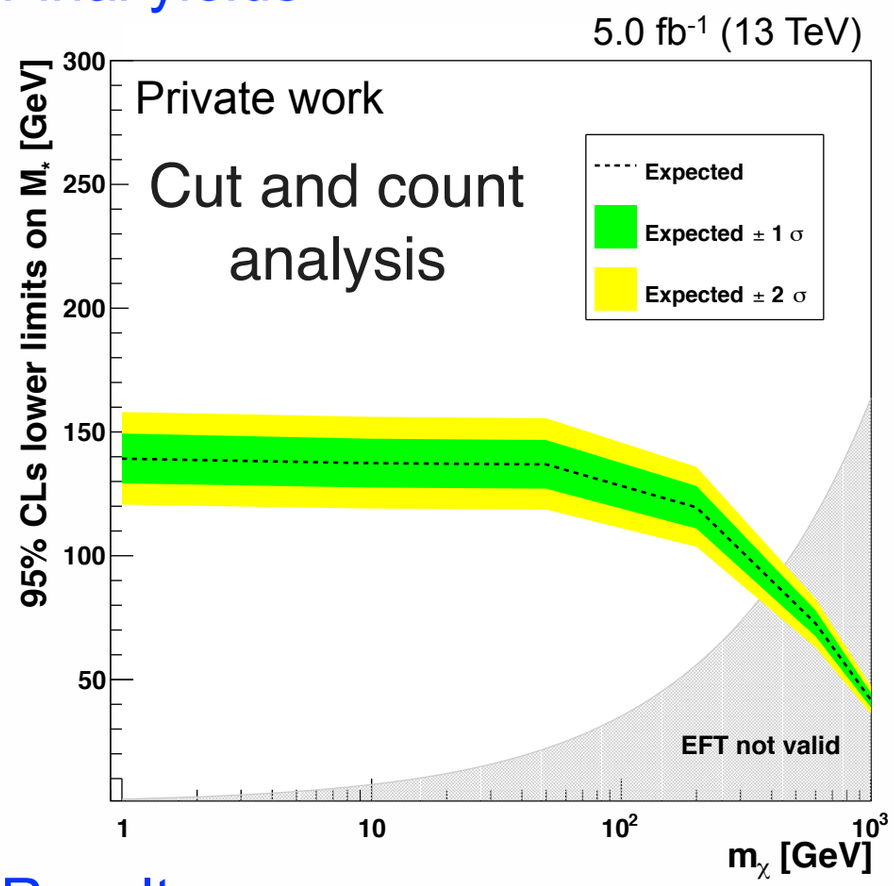

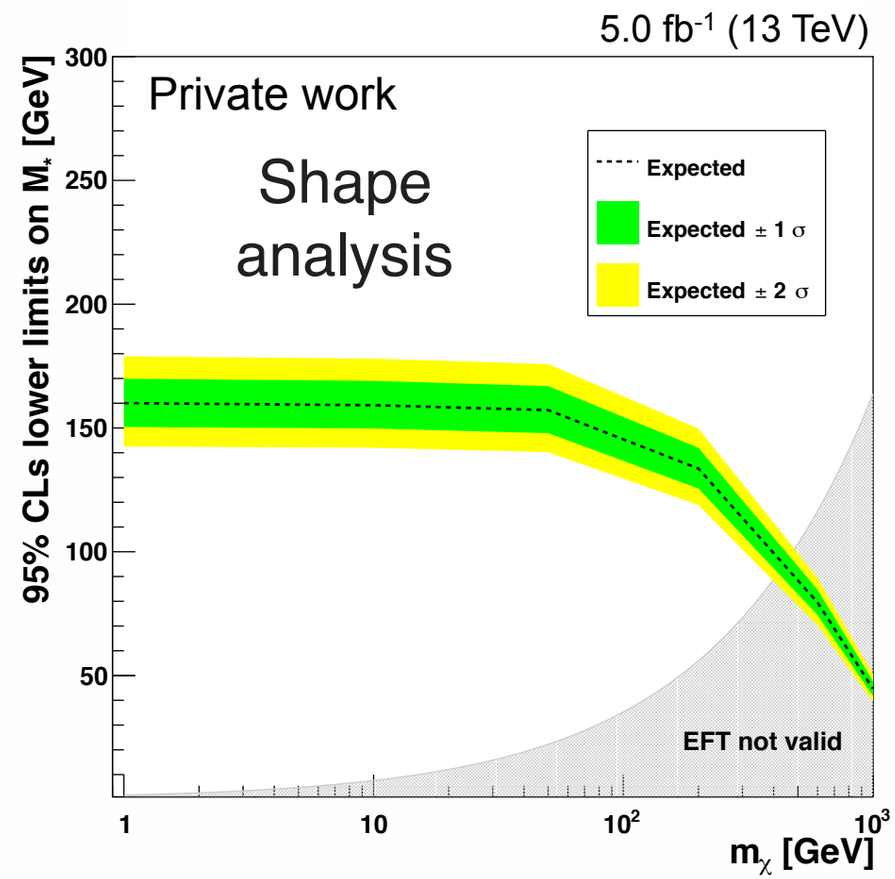

(5) Results

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- good sensitivity from hadronic channel, comparable with semi-leptonic one

- improvements w.r.t 8 TeV analysis already after few months of data taking!

EFT DM + tt ($\longrightarrow bjj, bjj$) at 13 TeV

University of Zurich[UZH]

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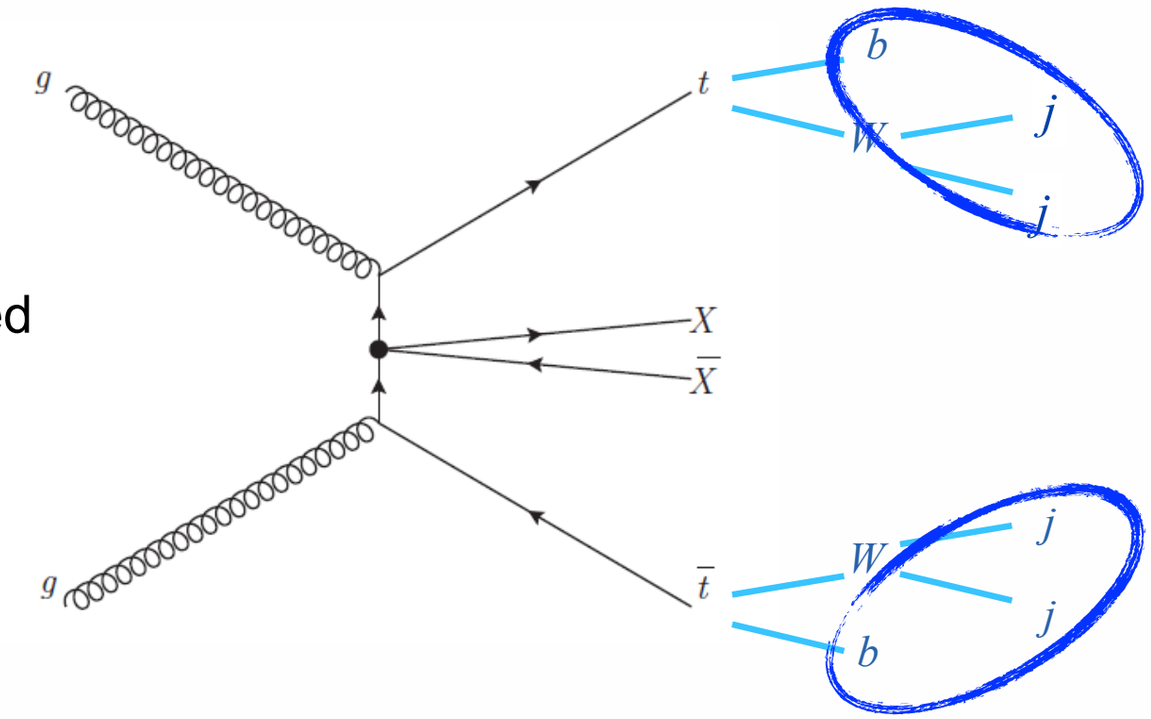

(2) Rejection of background

(3) Extract normalization for background

tt+jets, W+jets: from data

Drell-Yan, single top, Di-boson, W+jets: simulation

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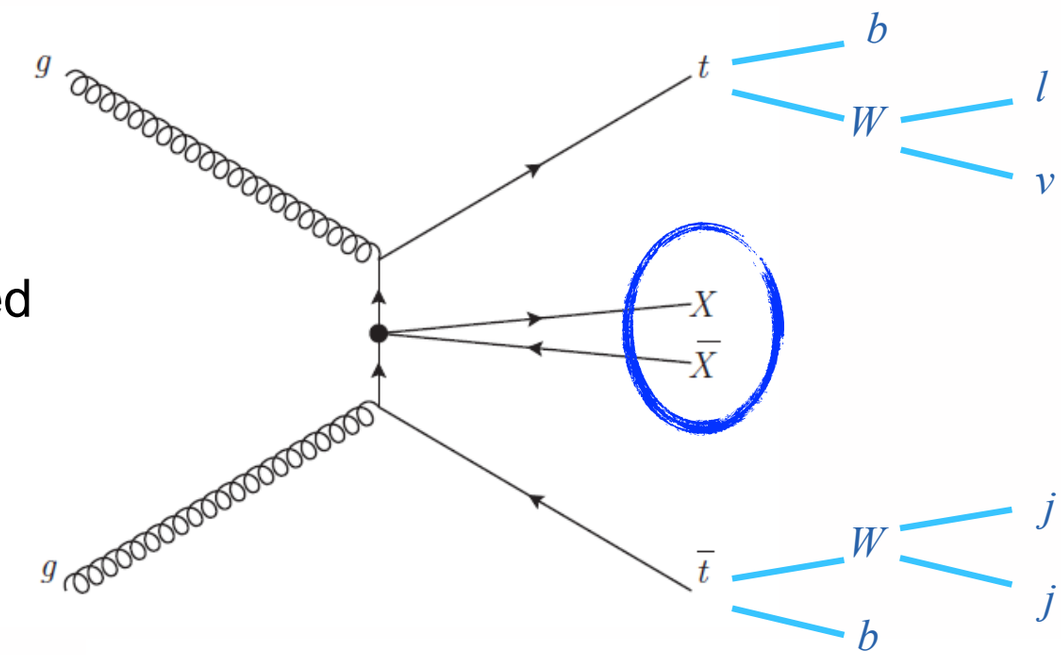
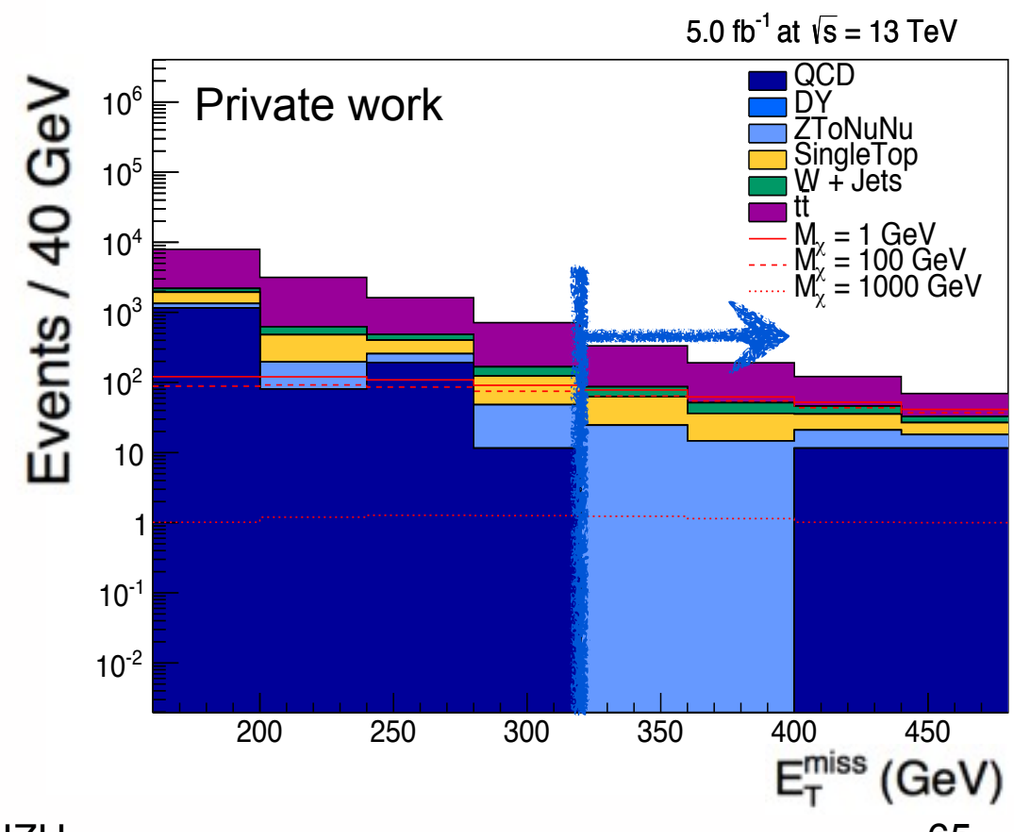


(2) Rejection of background

- signal has large MET from DM particles which escape detector

MET > 320 GeV



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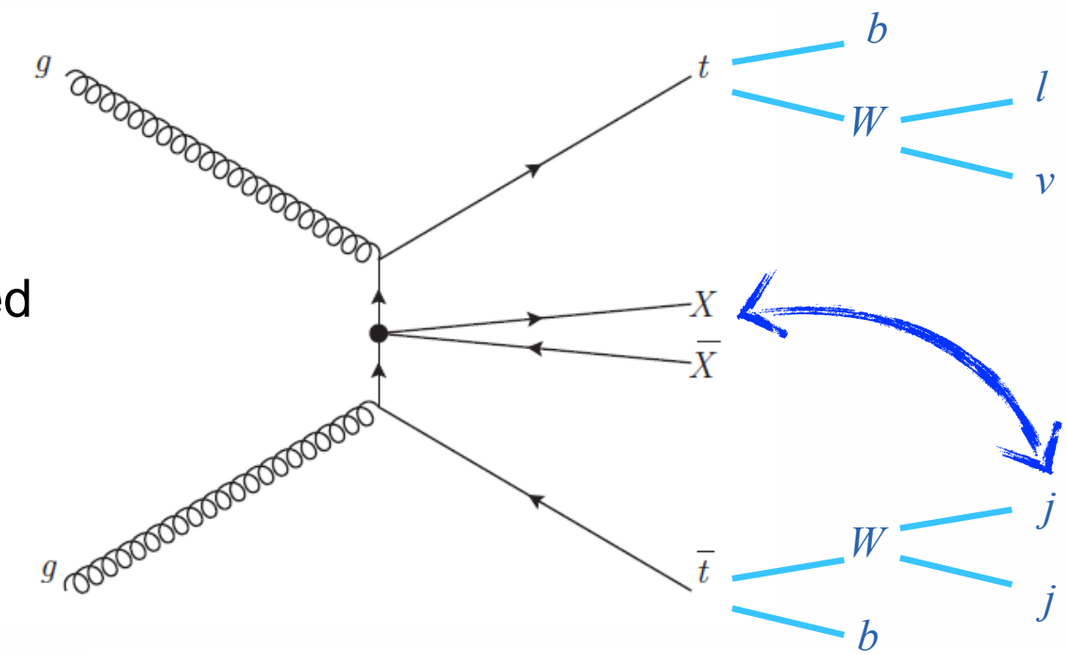
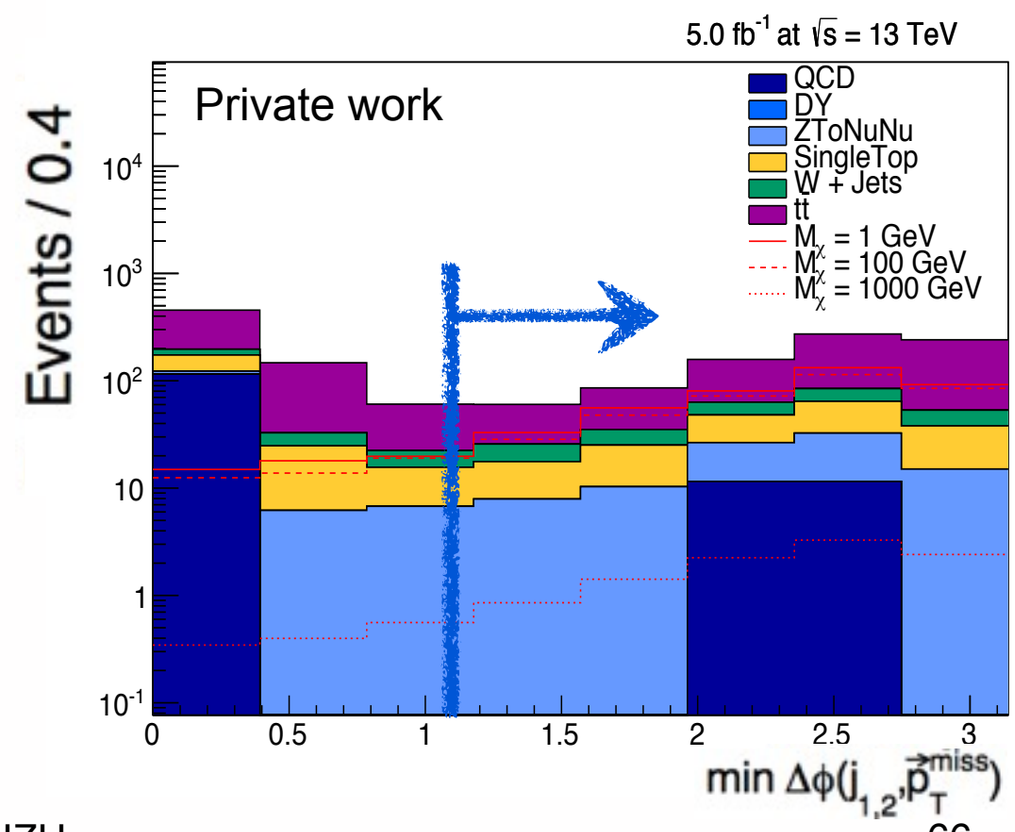


(2) Rejection of background

- The jets and the MET tends to be more separated in Φ in signal events than in tt and in single top events

$\min(\Delta\Phi_{j1,MET}, \Delta\Phi_{j2,MET}) > 1.2$ GeV



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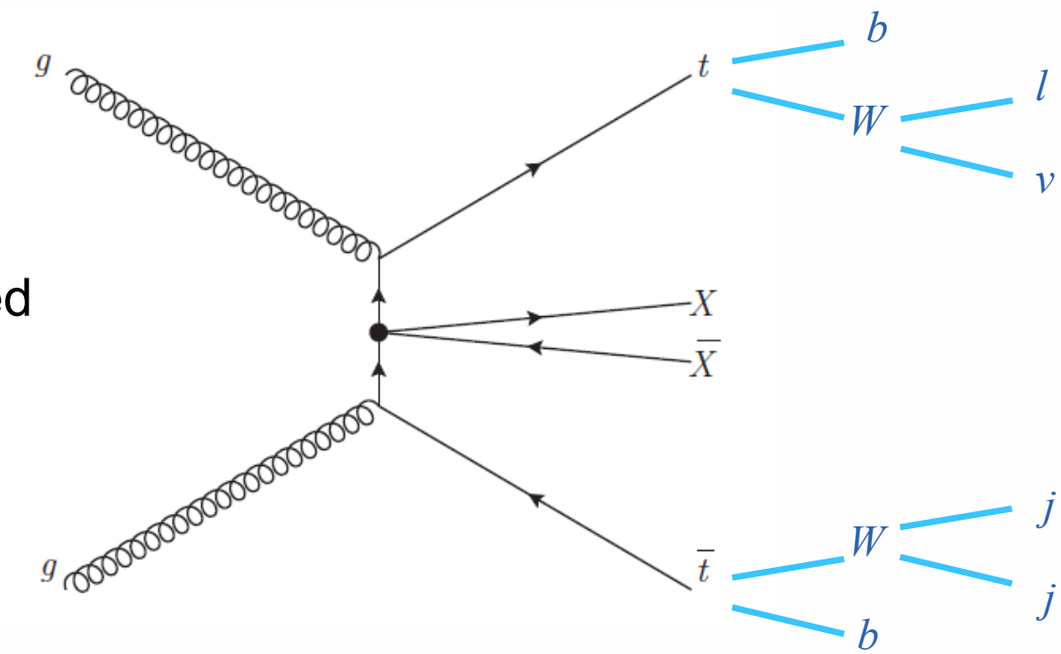

(1) Selection of topology

lepton veto, at least 4 jets, at least 2 b-tagged

(2) Rejection of background

Variable	Cut
MET	> 320 GeV
$\min(\Delta\Phi_{j1,MET}, \Delta\Phi_{j2,MET})$	> 1.2

Cut and count analysis:
full selection
Shape analysis:
full selection except MET selection

(3) Extract normalization for background

tt+jets, QCD: from data

Drell-Yan, single top, Di-boson, W+jets: simulation

EFT DM + tt ($\longrightarrow blv, bjj$) at 13 TeV

(4) Final yields

M_χ=1GeV M_*=100 GeV, L= 5 fb^{-1} (Private work)

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Total Bkg	814.1	14249.9
tt	553.7	10505.2
Single top	100.3	1206.3
Z(vv)+jets	68.87	470.2
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Work in progress on yields systematics

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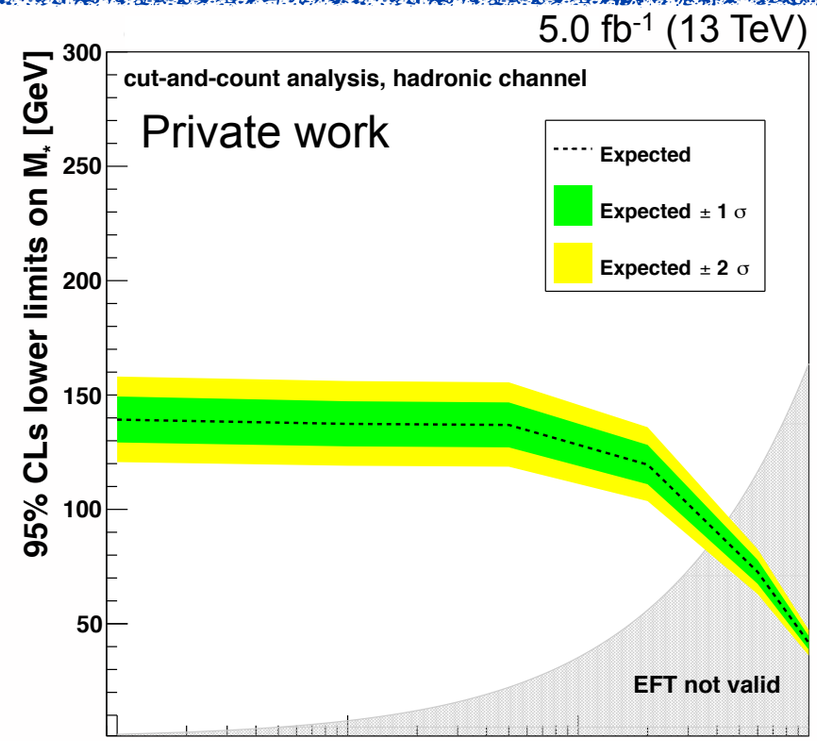

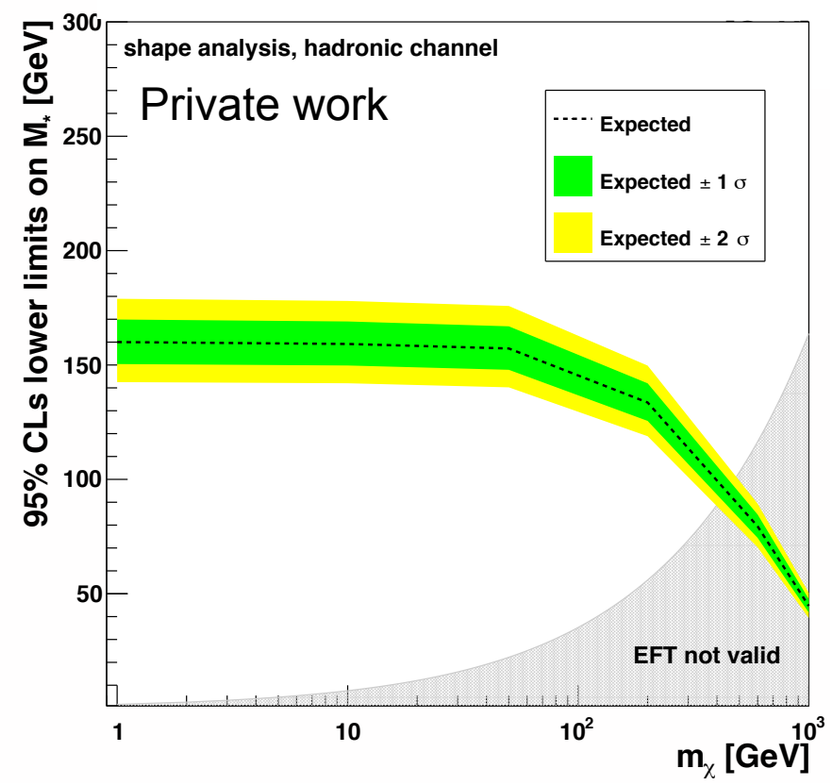

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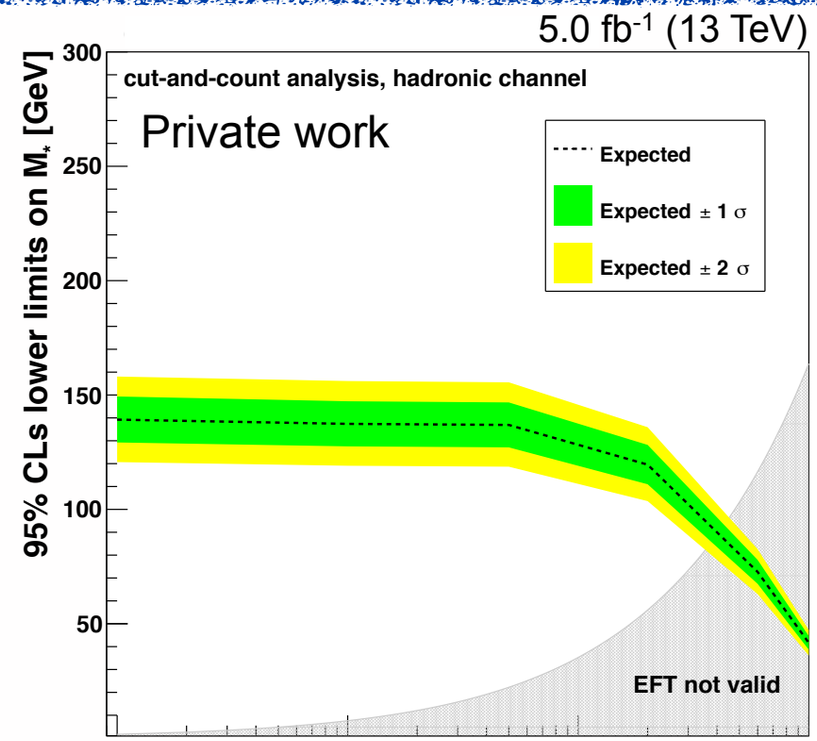

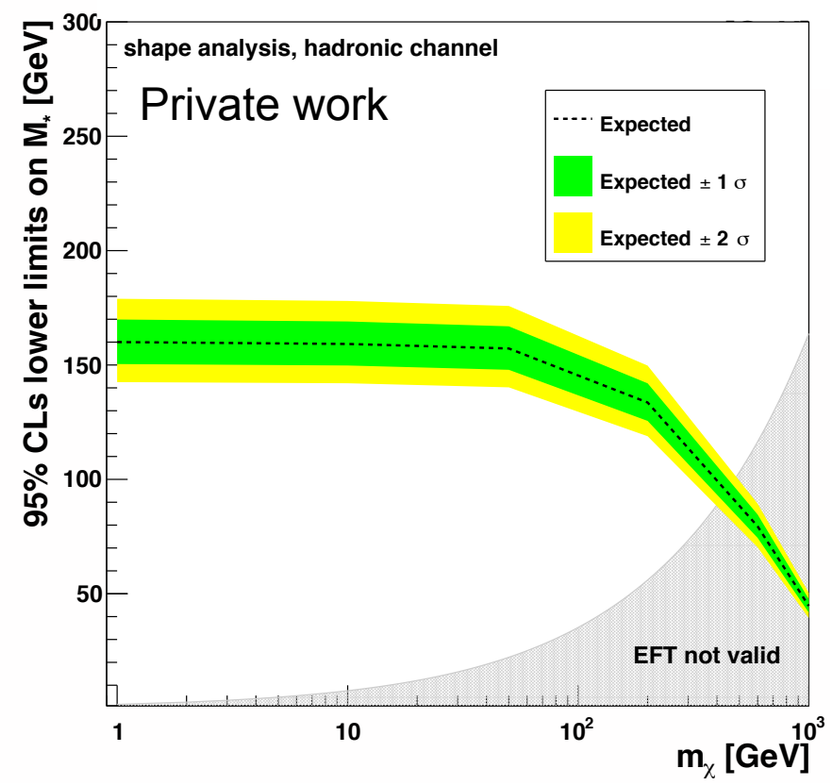

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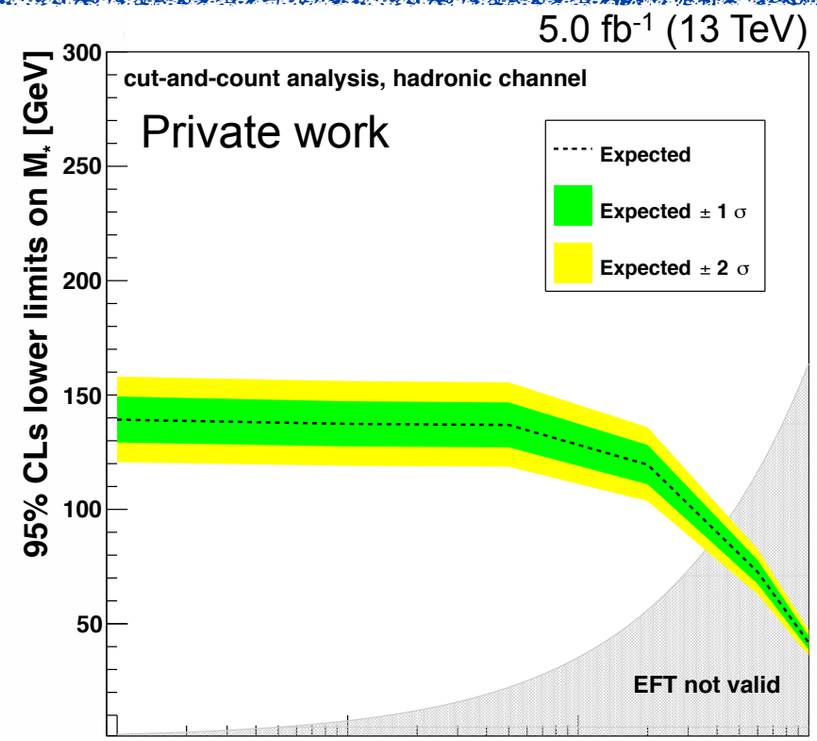

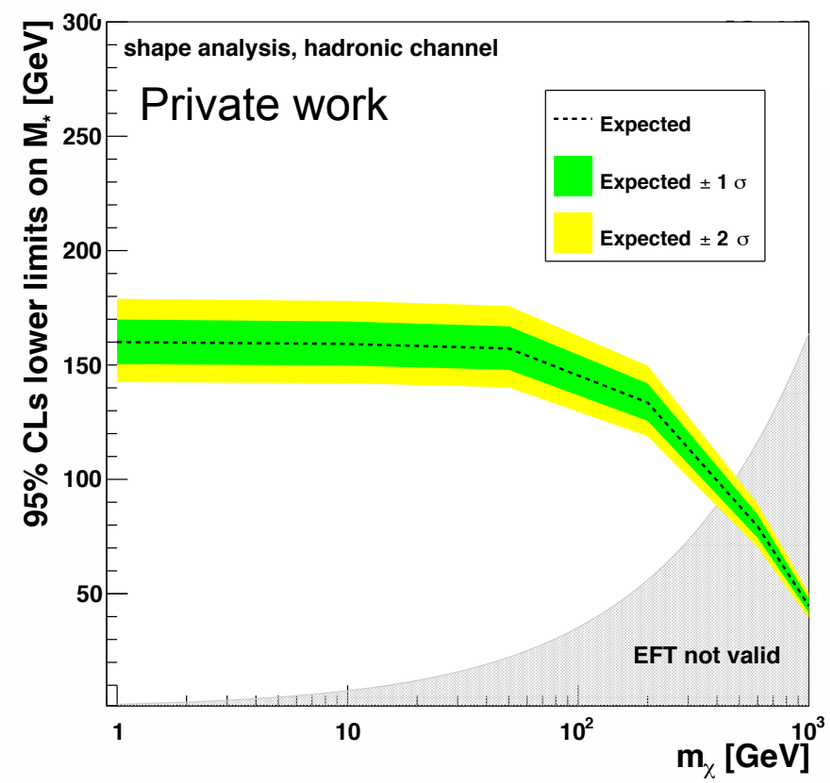

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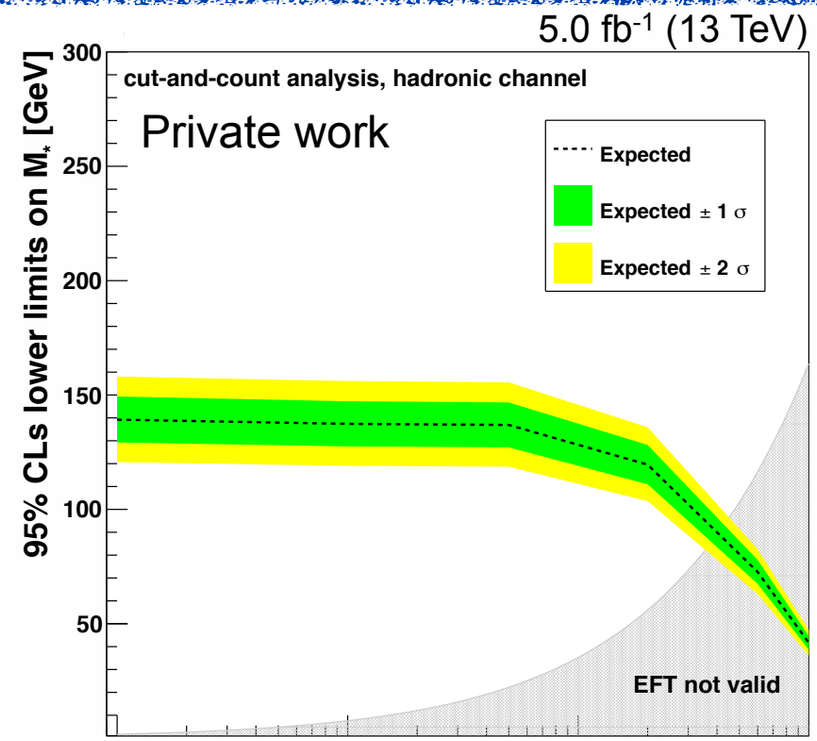
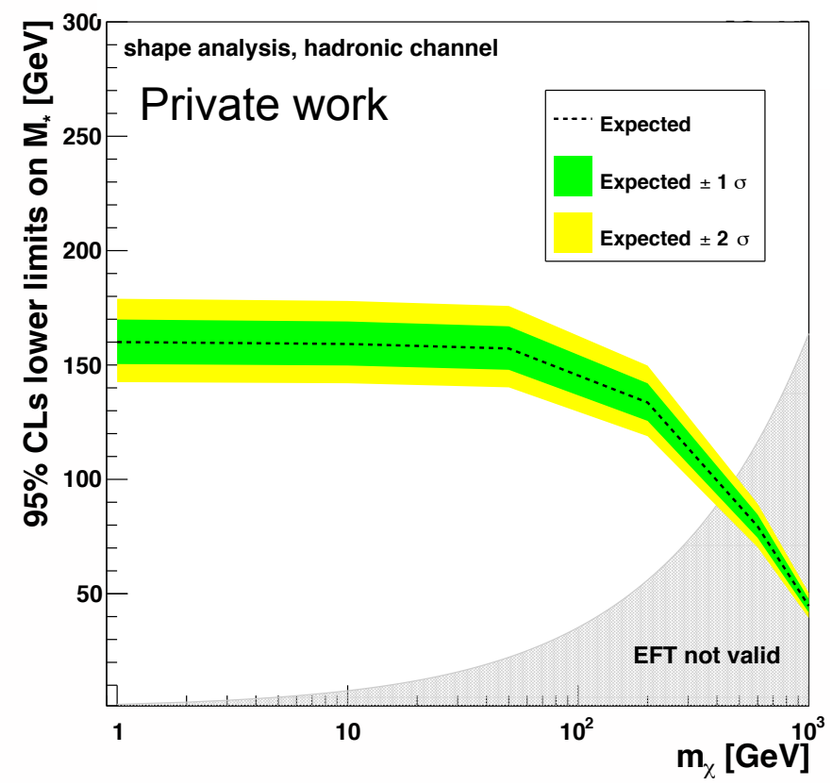




Simplified models backup

Simplified model for DM+tt

Assumptions:

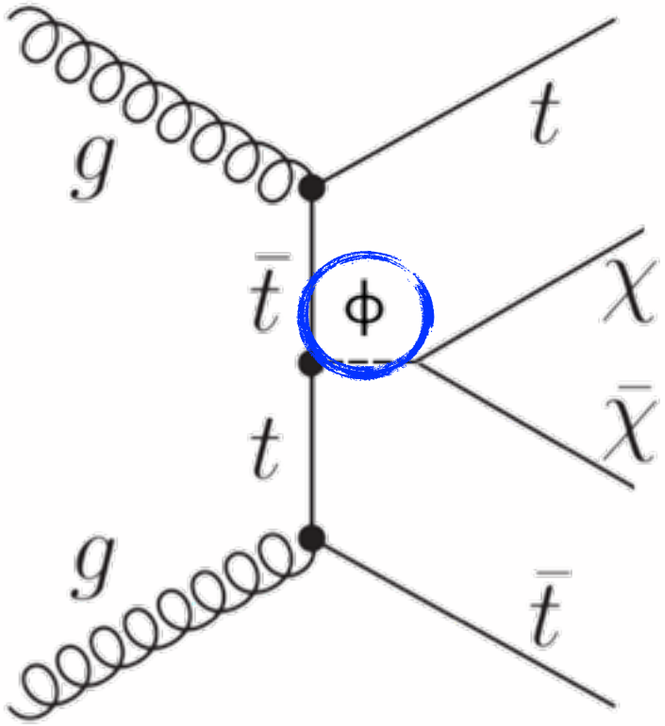
(1) mediator is scalar or pseudo-scalar

allowing s-channel production which requires only minimal extension of SM. Scalar will give LHC signatures in different channels

(2) DM is a Dirac particle

(3) SM couplings are Yukawa type

(4) DM couplings are not Yukawa type



Simplified model for DM+tt

Assumptions:

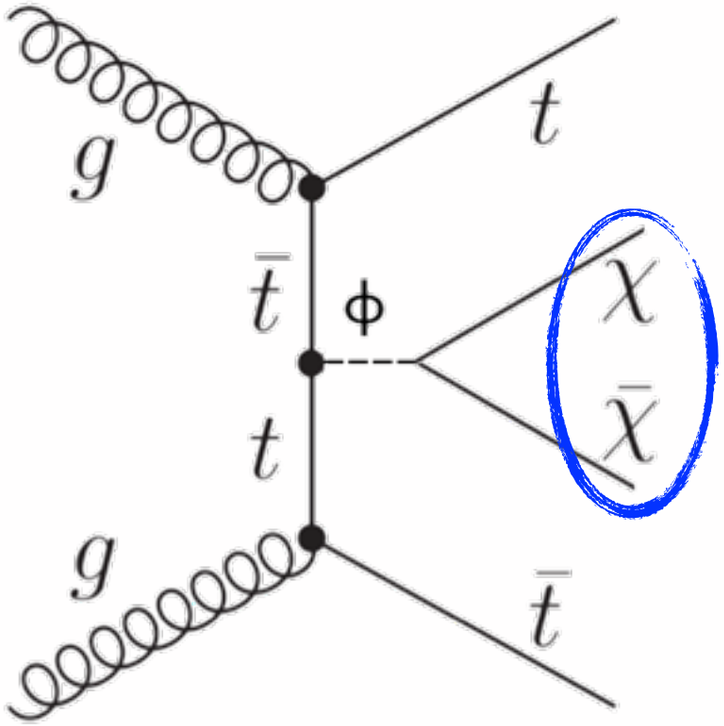
(1) mediator is scalar or pseudo-scalar

(2) DM is a Dirac particle

fermionic DM is arbitrary choice, results can be translated to scalar DM case but requires additional parameters

(3) SM couplings are Yukawa type

(4) DM couplings are not Yukawa type



Simplified model for DM+tt

Assumptions:

(1) mediator is scalar or pseudo-scalar

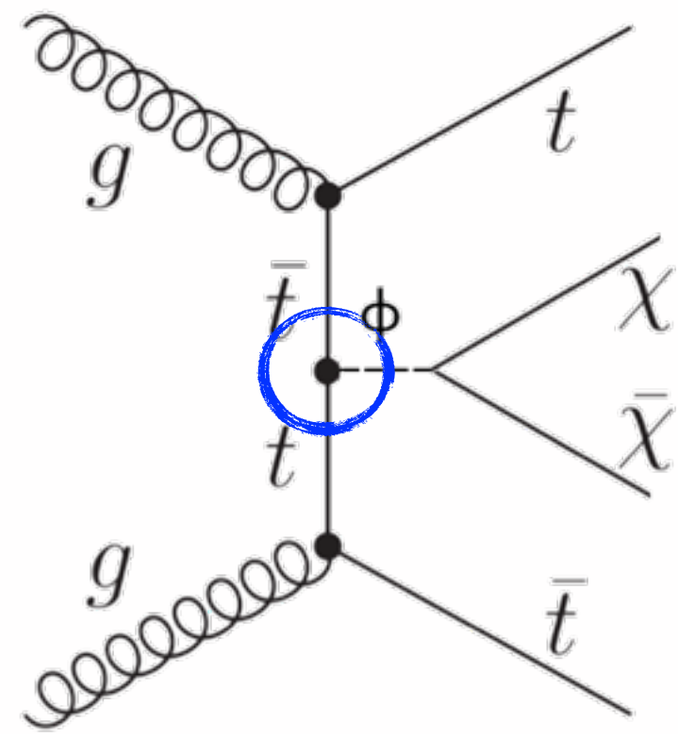
(2) DM is a Dirac particle

(3) SM couplings are Yukawa type

fermion couplings proportional to the SM Yukawa couplings, using the Minimal Flavor Violating assumption, avoiding introducing precision constraints from flavor measurements

→ dominant couplings to top quarks

(4) DM couplings are not Yukawa type



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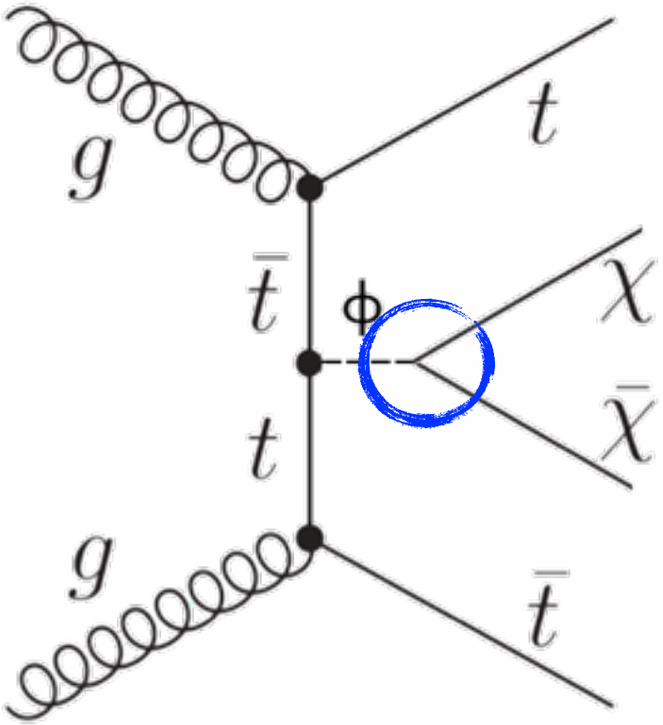

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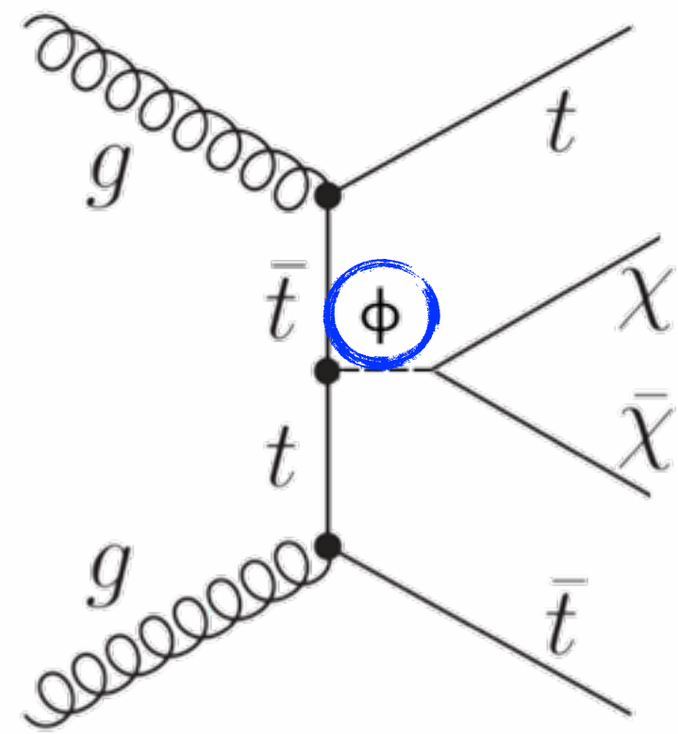

Parameters:

(1) Mediator mass M_ϕ

(2) Mediator width Γ_ϕ

(3) DM mass, M_χ

(4) Couplings: coupling mediator-SM (g_{SM}), coupling mediator-Dark Matter (g_{DM})

Can we avoid to scan on certain parameters? Save computation time!

- Need to check kinematic distributions
- Only few combinations could be produced and rescaled to other possible cases

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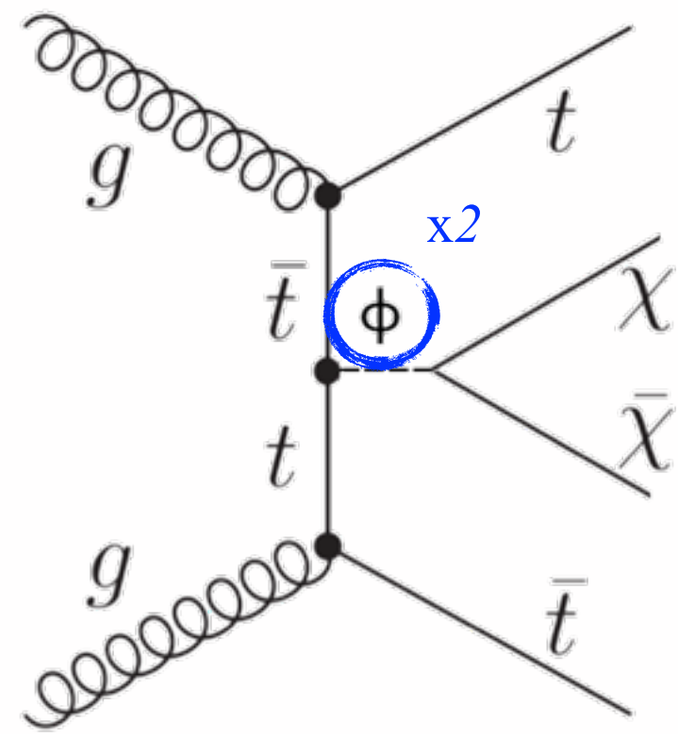

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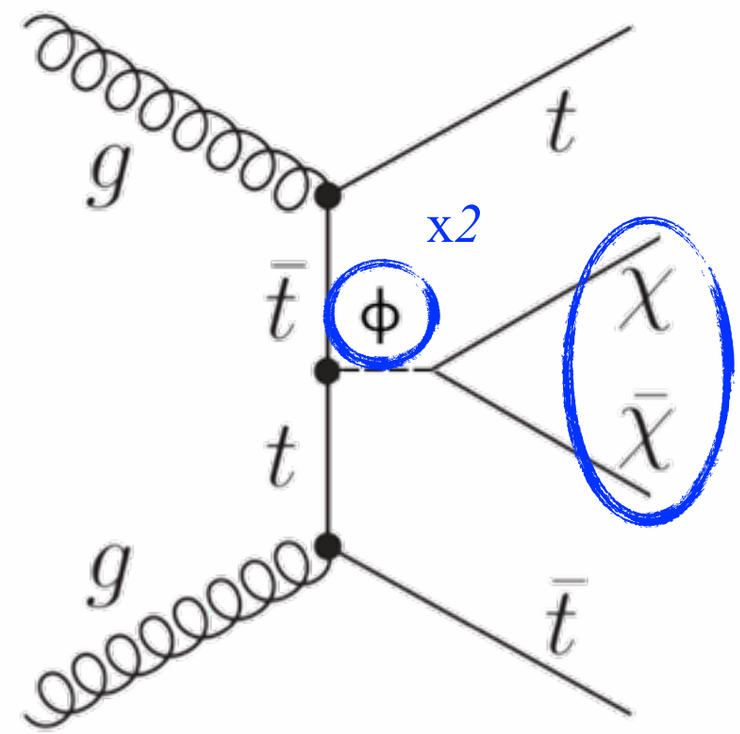

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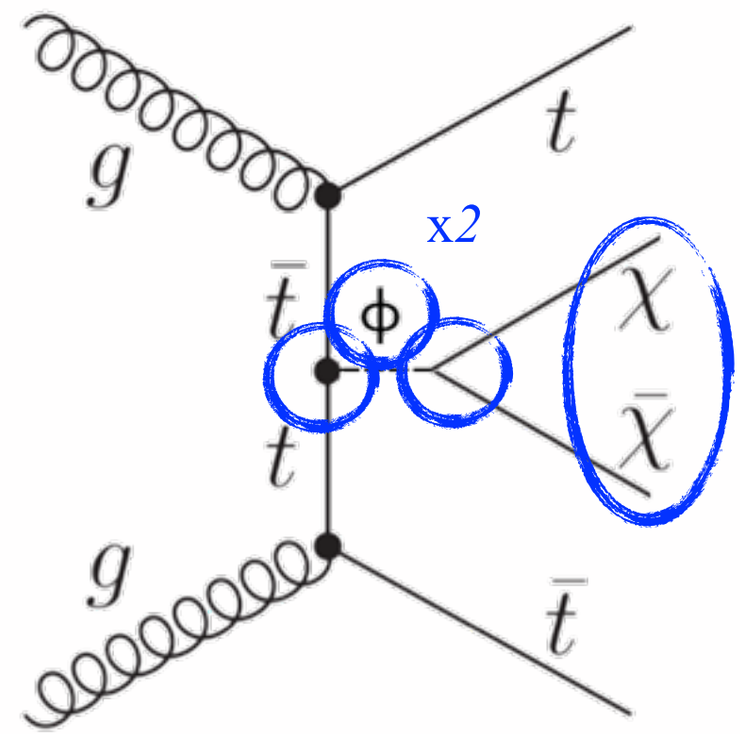

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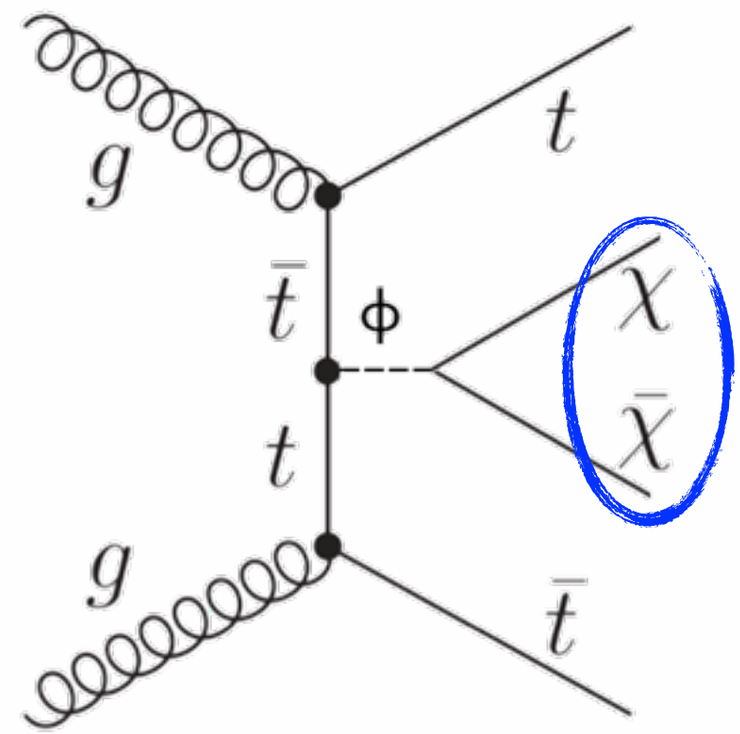

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(1) Mediator mass M_ϕ

(2) Mediator width Γ_ϕ

(3) DM mass, M_χ

(4) Couplings: coupling mediator-SM (g_{SM}), coupling mediator-Dark Matter (g_{DM})

Can we avoid to scan on certain parameters? Save computation time!

- Need to check kinematic distributions
- Only few combinations could be produced and rescaled to other possible cases

Simplified model for DM+tt

Work done inside the CMS/ATLAS DM forum, results published DM forum report

(1) Mediator mass M_ϕ

kinematics depends on this parameter

(2) Mediator width Γ_ϕ

Kinematics changes seen only close to threshold

(3) DM mass, M_χ

On-shell (2Mchi < Mphi): kinematics independent of Mchi

Off-shell (2Mchi > Mphi): kinematics depends on Mchi

(4) Couplings: coupling mediator-SM (g_{SM}), coupling mediator-Dark Matter (g_{DM})

small couplings will have very small cross-section already cross section ~fb for $g_{SM} = g_{DM} = 1$