Dark Matter Searches at CMS at $\sqrt{s} = 13$ TeV

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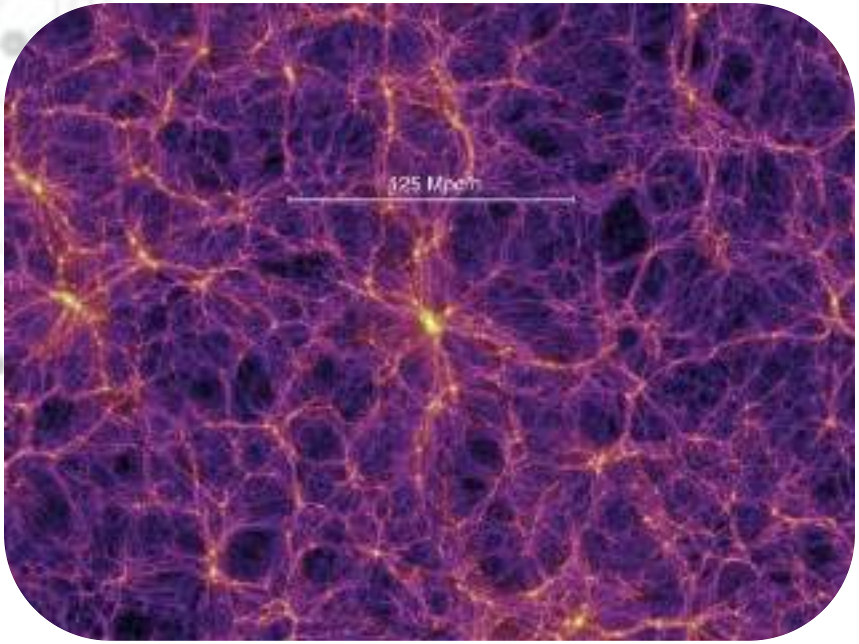
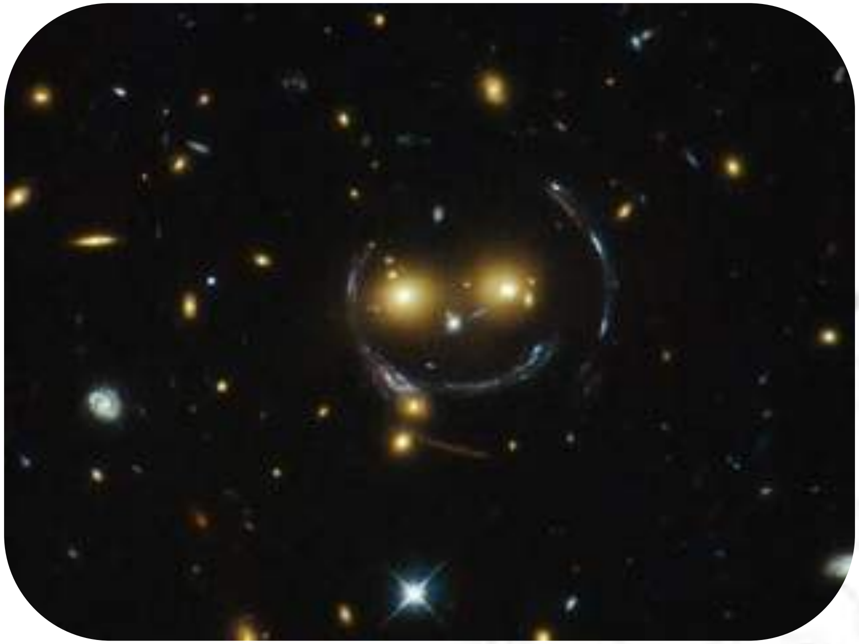
CERN

CMS

Introduction and Motivation



Simulation of dark matter filaments in the universe.



Gravitational lensing from dark matter.

Introduction and Motivation

- What is dark matter (DM) and why do we care?

- Non-baryonic, makes up most of the mass in the universe.

- Purely astrophysical evidence – galaxy formation, galactic rotation curves, gravitational lensing.

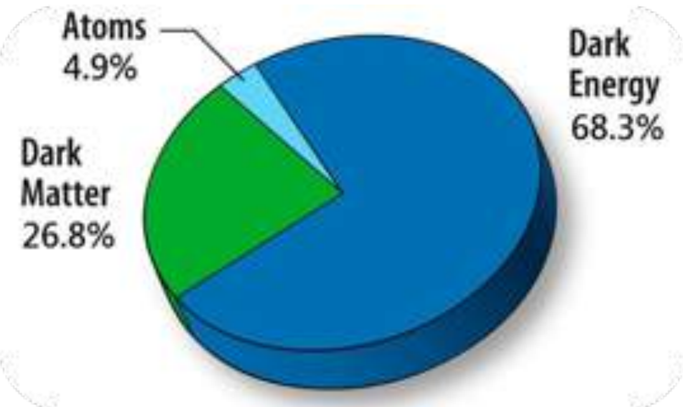


Fig. 1: Components that make up the energy density of the universe.

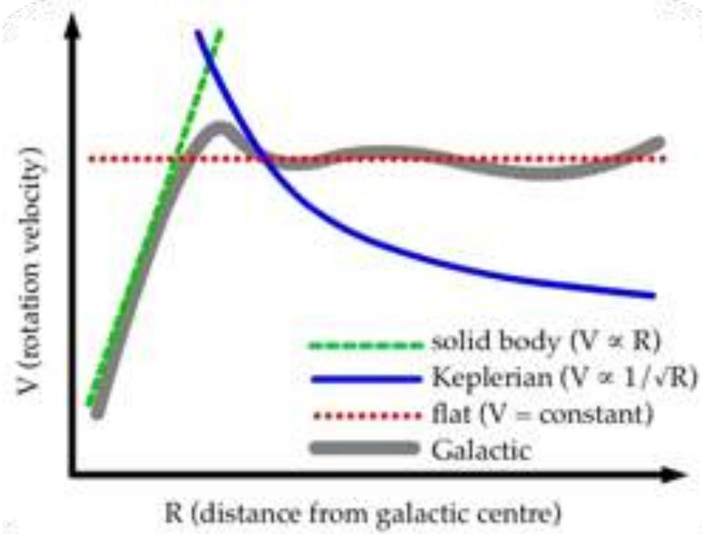


Fig. 2: Typical galactic rotation curve with standard kinematic curves.

- Know it must be electrically neutral, “cold” (non-relativistic), and stable.

Introduction and Motivation

- No description of DM in the Standard Model (SM). Forces search for new physics.

- Three main types of DM searches – direct (DM recoiling from SM particles), indirect (annihilation), **production** (particle collisions).

- I will focus on production: fitting BSM theories to LHC data with CMS.

- Ideally, will make a discovery! Or at least set limits on DM mass and other properties in different theoretical frameworks.

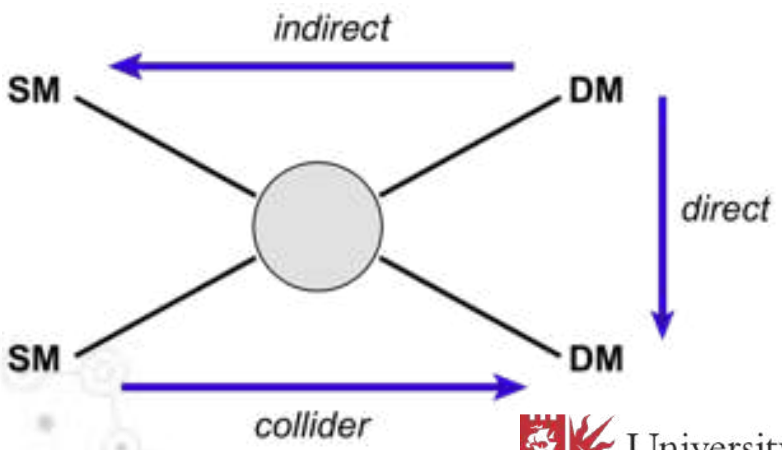
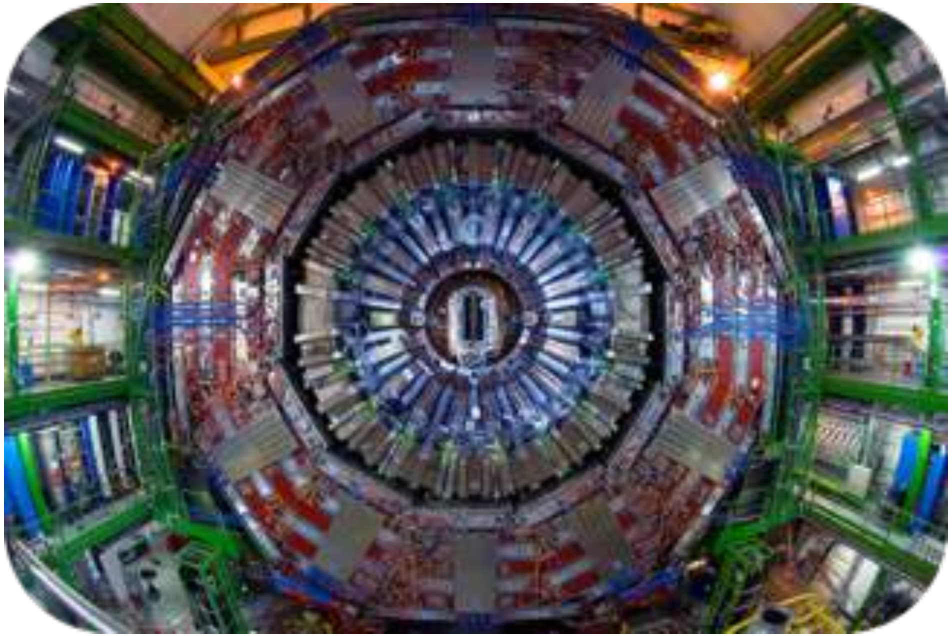


Fig. 3: Illustration of the different dark matter searches.

Analysis and Research



The CMS detector.

Initial work

◎ Revolved around learning software and developing programming skills: MadGraph, ROOT, MadAnalysis; C++, Python.

◎ Learned necessary skills and programs in the context of simulating SM backgrounds for DM searches: $pp \rightarrow t\bar{t}$, $pp \rightarrow W + \text{jets}$, $pp \rightarrow Z + \text{jets}$.

◎ Backgrounds are for a hadronic search as DM final state is usually large $E_{\mathrm{T}}^{\mathrm{miss}}$ and several hadronic jets.

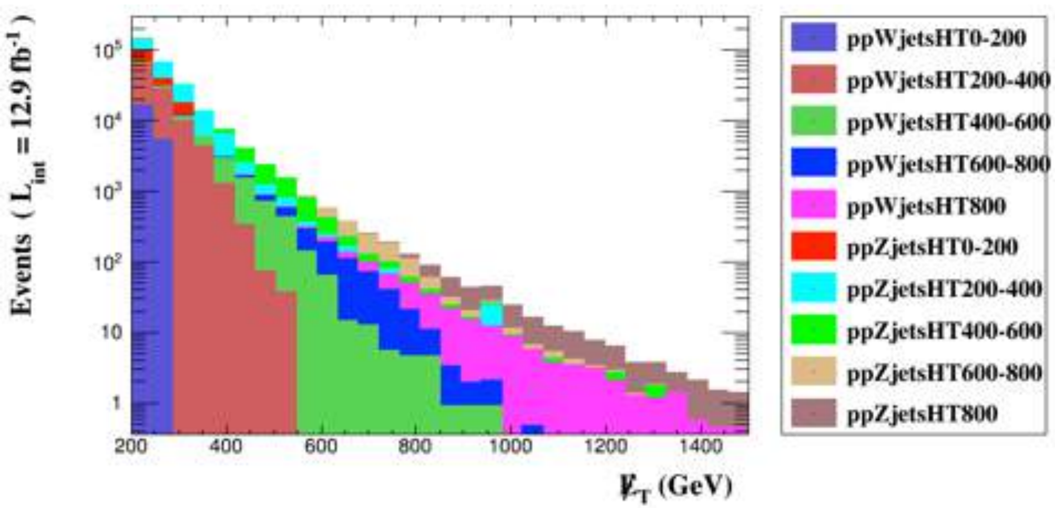


Fig. 4: MadAnalysis histogram of $E_{\mathrm{T}}^{\mathrm{miss}}$ for simulated hadronic backgrounds at different H_{T} intervals.

SUSY cut flow tables

- My first proper task for the CMS RA1 group. Needed to produce signal region cut flow tables for 2015 paper (In: *Eur. Phys. J. C* 77 (2017) 294).

- Motivation: useful for understanding signal behaviour from cuts; the use of a cut flow that maximises signal and minimises background; inventing new variables that achieve this (like α_T).

- Helped me learn the RA1 workflow and software for future analyses.

- Analysed SUSY SMS (Simplified Model Spectra) models – Monte Carlo events that have one decay mode with a 100% branching fraction.

- First, made trees from miniAODs of the models (~ 1 TB data generated). Then, skimmed over them with the cut flow and made the tables.

- As a reward, I was added to the internal authors' list for the paper (yay!).

SUSY cut flow tables

Event selection	Benchmark model (m_{SUSY}, m_{LSP})					
	T1qqqq (1300, 100)	T1qqqq (900, 700)	T2qq_8fold (1050, 100)	T2qq_8fold (650, 550)	T2qq_1fold (600, 50)	T2qq_1fold (400, 250)
Before selection	100	100	100	100	100	100
Event veto for muons and electrons	99	100	100	100	100	100
Event veto for single isolated tracks	94	91	96	95	96	95
Event veto for photons	92	90	95	94	95	95
Event veto for forward jets ($\|\eta\| > 3.0$)	81	78	82	81	80	80
$n_{jet} \geq 2$	81	78	81	72	80	75
$p_T^{j_1} > 100\,GeV$	81	71	81	57	79	66
$\|\eta^{j_1}\| < 2.5$	81	70	81	55	79	65
$H_T > 200\,GeV$	81	69	81	50	79	60
$H_T^{miss} > 130\,GeV$	77	50	78	33	71	40
$H_T^{miss} / E_T^{miss} < 1.25$	74	44	75	28	65	33
H_T-dependent α_T requirements ($H_T < 800\,GeV$)	74	30	71	15	50	17
$\Delta\phi^*_{min} > 0.5$	22	18	44	10	33	13
Four most sensitive n_{jet} event categories	22	13	43	5.5	31	6.1

Table 1: A cut flow table from the 2015 paper’s auxiliary material.

SUSY and DM signal model analysis

- Current task is to analyse the SUSY SMS and heavy flavour DM models for the 2016 paper.

- Initial focus is to produce efficiency plots and analyse systematic uncertainties for the SMS models.

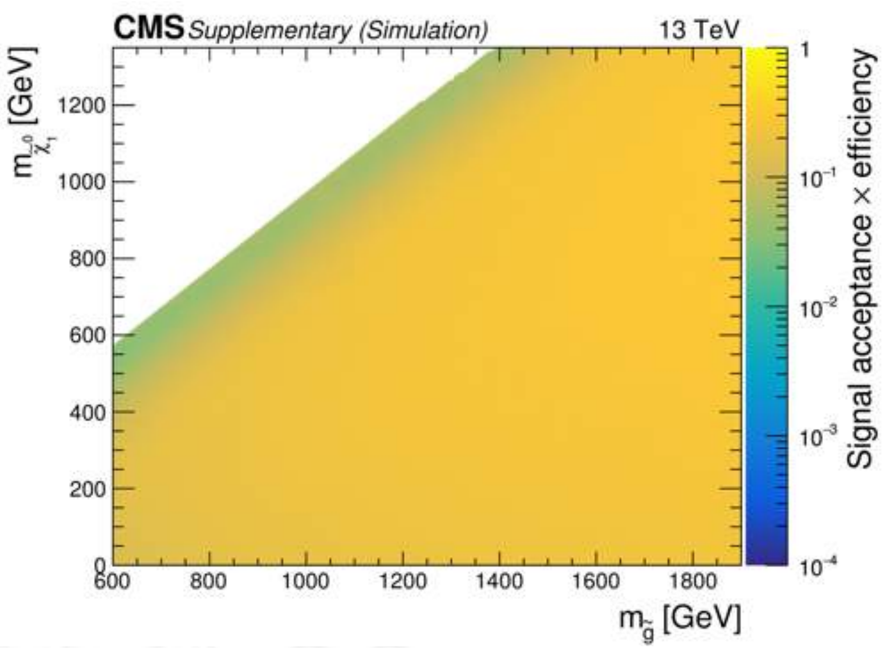


Fig. 5: Efficiency plot for T1bbbb model (from 2015 aux. material).

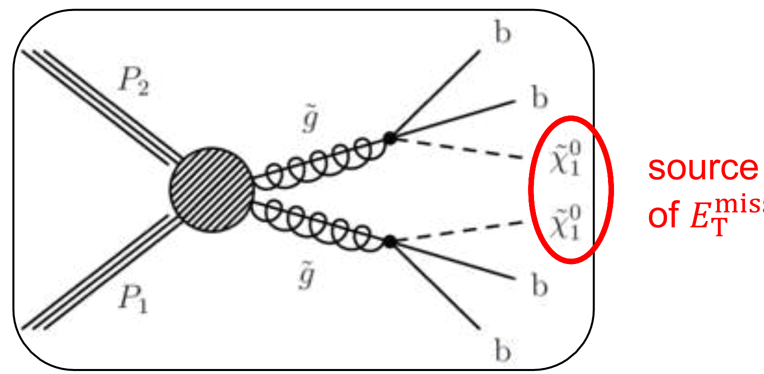


Fig. 6: Feynman diagram for SMS model T1bbbb.

Service Work (Experimental Physics Responsibility)

Jet Energy Corrections in the L1 Trigger

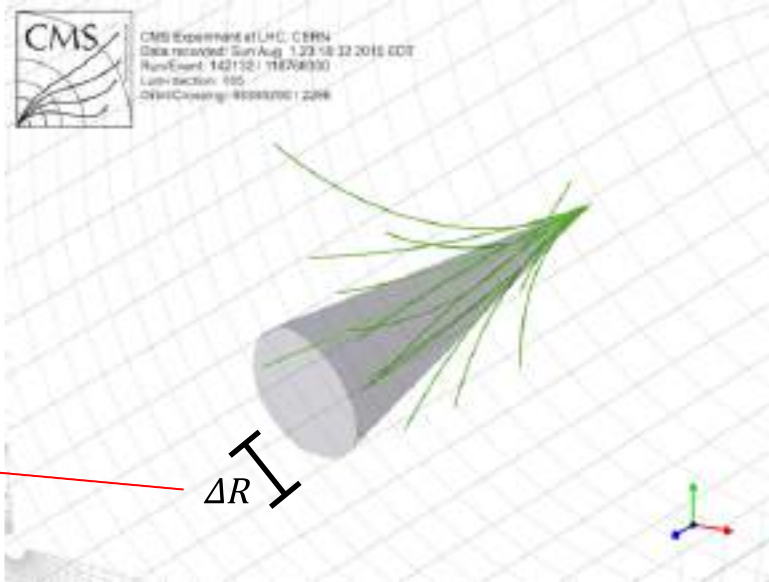
- Six months of service work required for authorship in CMS papers.

- Jet Energy Corrections (JECs, Calorimeter Layer-2) are necessary to compensate for non-uniform detector response (p_T- and η-dependent).

- Need reference jets to compare against given L1 jets. Ntuples of L1 jets *without* corrections need to be made, then matched to reference jets using the ΔR variable.

Fig. 7: A jet at CMS with tracks and an isolation cone.

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

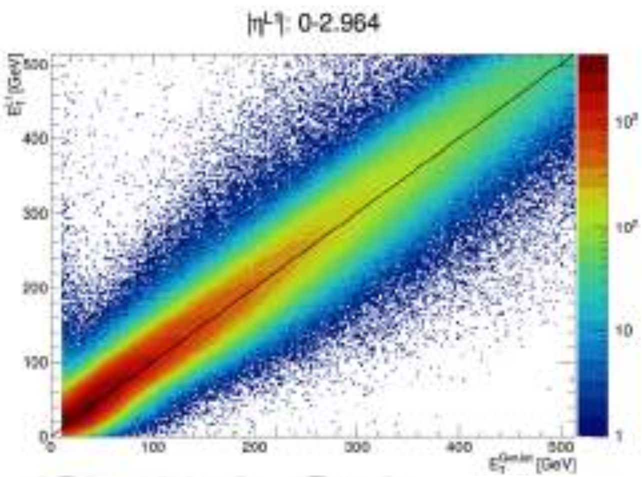


Jet Energy Corrections in the L1 Trigger

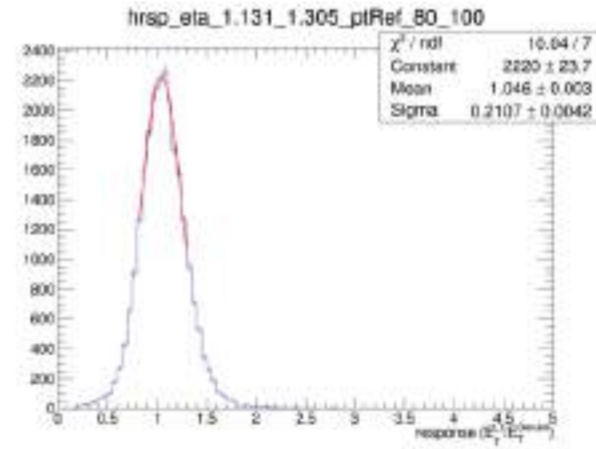
- Each L1 jet is inspected in descending p_T, and a reference jet with $\Delta R < 0.25$ is searched for and matched to the L1 jet. Then repeated for all L1 jets.

- Next, calibrations are derived. Correction graphs as a function of p_T for each $|\eta|$ bin are plotted and Gaussian correction curves are fitted to them.

- Finally, do closure tests. Involves remaking ntuples *with* corrections, then rematch to reference jets to check corrections. Pass plots to the Trigger Studies Group to continue the long chain of corrections/calibrations.



Figs 8 and 9: two of the several hundred plots that are output from JECs. Left – L1 jets vs reference. Right – correction curve.



Future Research

Future research and prospects

- Short term goals – finish 2016 signal model analysis for RA1, and continue with JECs when needed.

- STFC summer school in September. Should be useful to get up to speed with theory aspect.

- LTA at CERN from October for up to 18 months.

- Long term goals – analyse LHC Run-2 data to search for dark matter. Will use SUSY and branch out into different theories (axions, Kaluza-Klein, sterile neutrinos, etc.).

- Will have access to largest dataset ever recorded. Will be able perform most precise searches and sensitive measurements to date for DM.