



HAL
open science

Test of global symmetries (LFU and LIV) of the Standard Model in the top quark sector with CMS at LHC

D. Amram

► **To cite this version:**

D. Amram. Test of global symmetries (LFU and LIV) of the Standard Model in the top quark sector with CMS at LHC. Journées de Rencontre Jeunes Chercheurs 2023, Oct 2023, La Rivière in Saint-Jean-de-Monts, France. in2p3-04908117

HAL Id: in2p3-04908117

<https://in2p3.hal.science/in2p3-04908117v1>

Submitted on 23 Jan 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Test of global symmetries (LFU and LIV) of the Standard Model in the top quark sector With CMS at LHC

JRJC 2023

David Amram

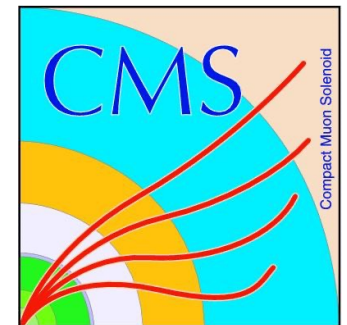
Under the supervision of Nicolas Chanon
IP2I Lyon - CMS

24 octobre 2023



ÉCOLE
DOCTORALE
52

PHAST
PHYSIQUE
ET ASTROPHYSIQUE
UNIVERSITÉ DE LYON

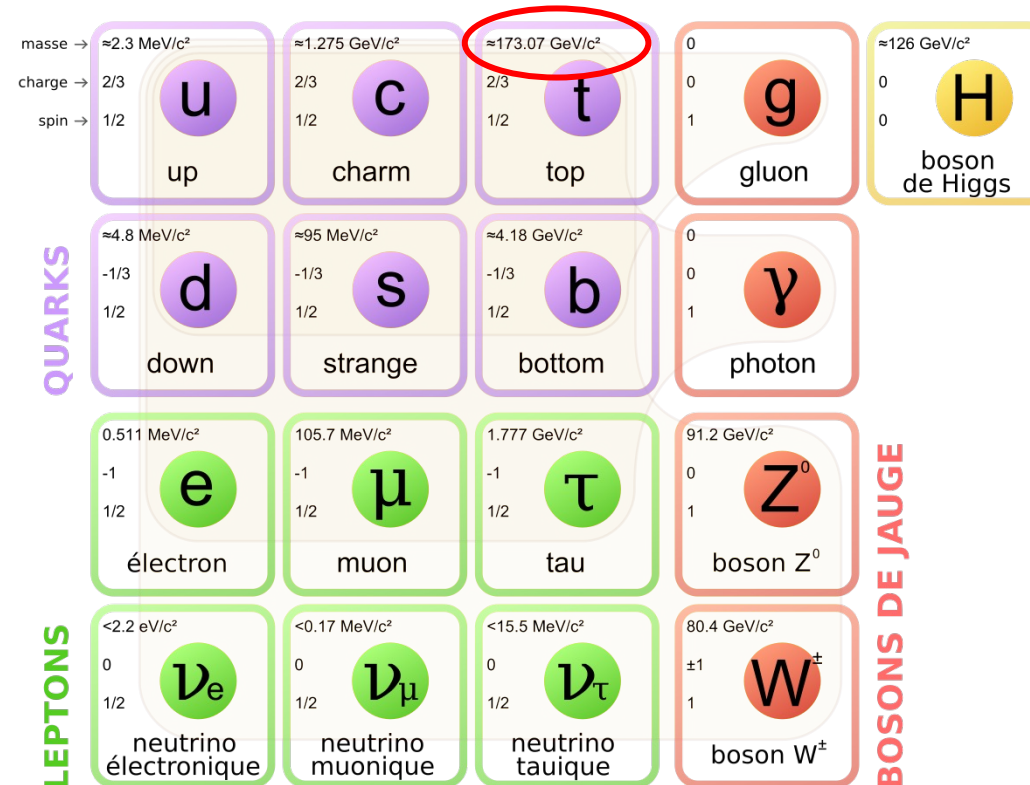
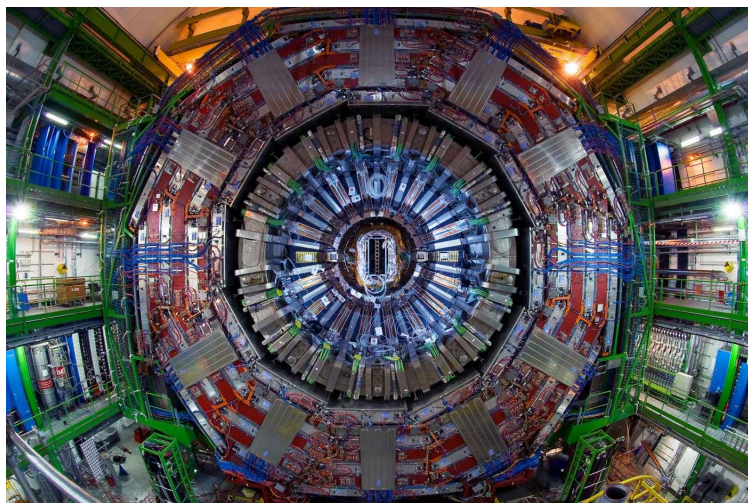


Motivations - LFU

The top quark is the **heaviest elementary particle** in the Standard Model.

Many models beyond the SM predict a **special coupling** of the top quark with new resonances at high energy scales.

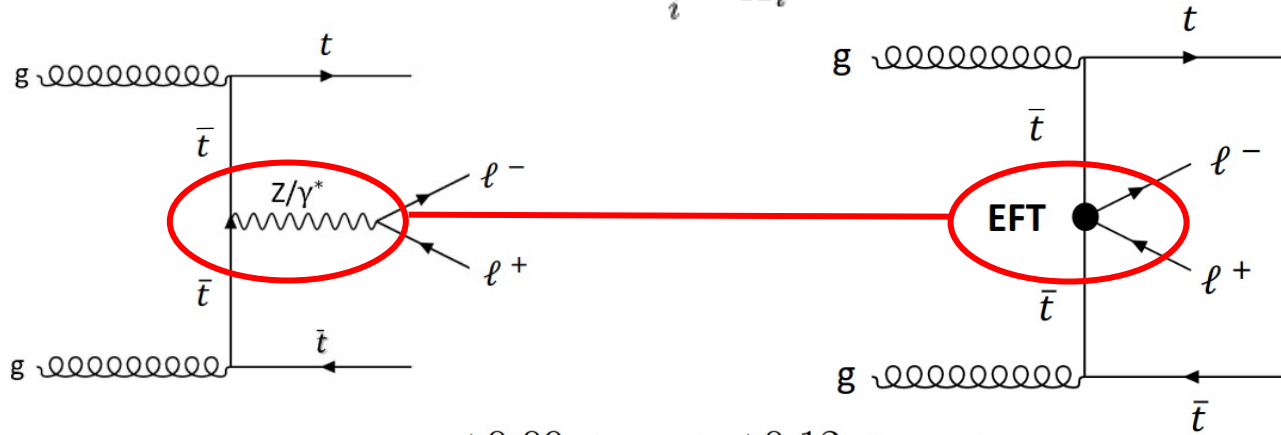
Testing **lepton flavor universality** with top quarks at CMS



3 generations that differ only by their masses according to the Standard Model

Modeling the violation of lepton flavor universality with an effective theory

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_i \frac{c_i^{(6)}}{\Lambda_i} O_i + h.c.$$



Measurement of the SM $t\bar{t}\gamma^*$ process, never measured at the LHC

Measurement of the effective coupling between the top quark and leptons using the EFT, separately for electrons and muons

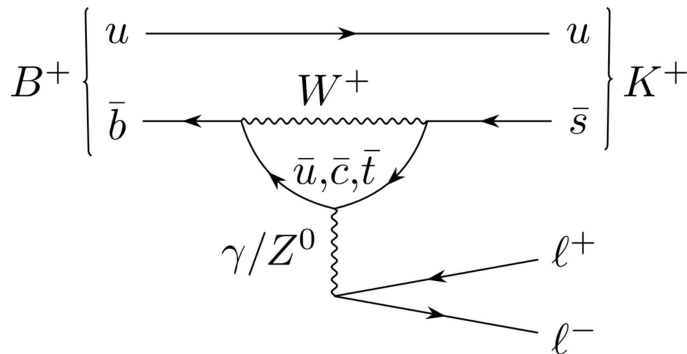
We are studying the multi-lepton channel (3 or 4 leptons in the final state)

$$\sigma_{t\bar{t}Z/\gamma^*} = 0.99_{-0.08}^{+0.09} \text{ (stat)} \quad {}_{-0.11}^{+0.12} \text{ (syst) pb}$$

CMS collaboration
(1711.02547)

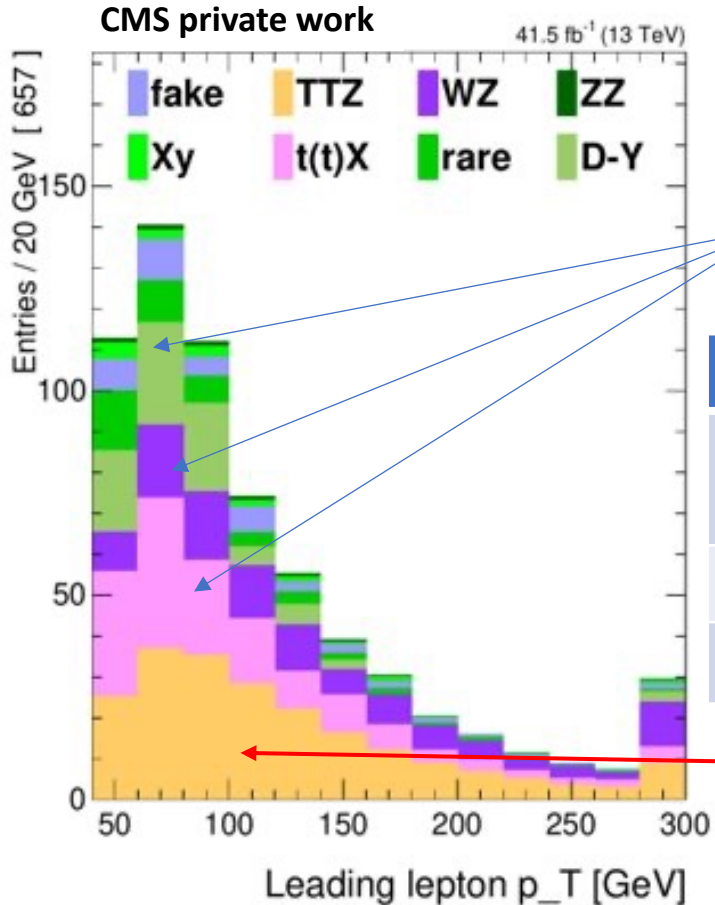
Example of an EFT operator :

$$O_{lt}^{(ij)} = (\bar{l}_i \gamma^\mu l_j)(\bar{t} \gamma^\mu t) \text{ et } O_{et}^{(ij)} = (\bar{e}_i \gamma^\mu e_j)(\bar{t} \gamma^\mu t)$$



Connection between top quark physics and B physics

Analysis – Signal Region



Background

	4 leptons	3 leptons
P_T	> 40, 10, 10, 10 GeV	> 10 GeV
OSSF pairs	1	1
N_{jets}	> 1	> 2

Signal

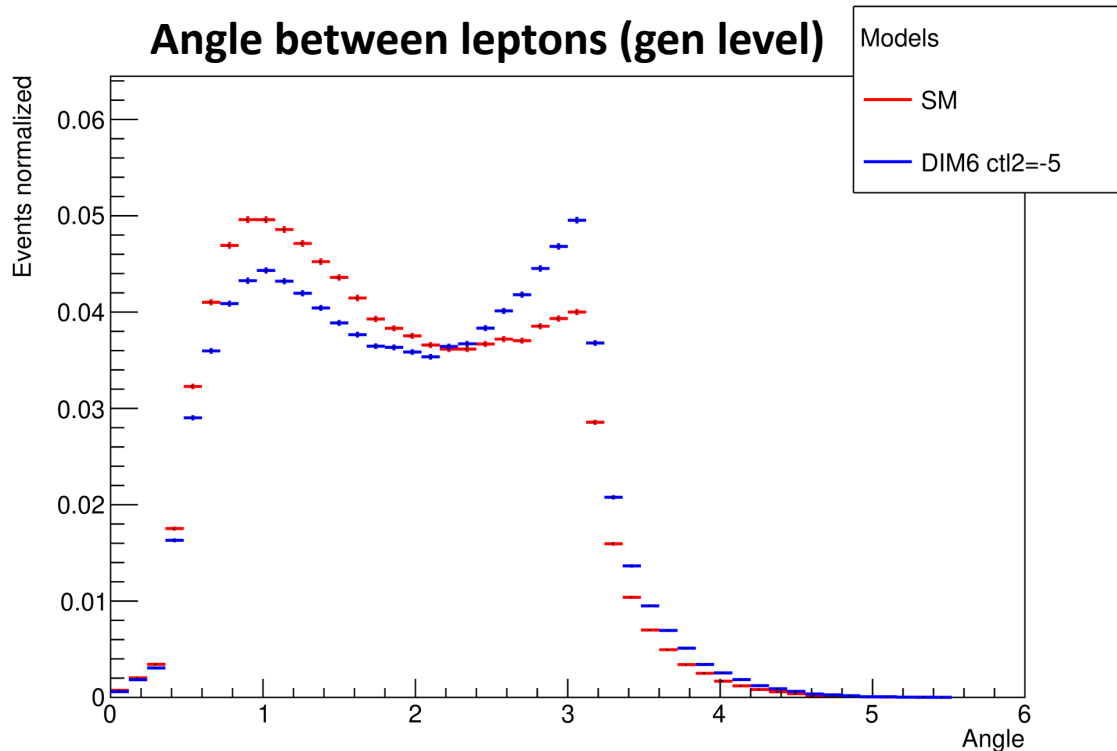
This signal region will be used to :

- 1) Measure the process $t\bar{t}\gamma^*$ (inside $t\bar{t}Z$ in this plot)
- 2) Measure the EFT coefficients for lepton flavor violation

Variable to test to extract the signal :

- The invariant mass of the leptons
- The angles between the leptons
- Advanced methods such as MEM and machine learning

Analysis – Signal Region



This signal region will be used to :

- 1) Measure the process $t\bar{t}\gamma^*$ (inside $t\bar{t}Z$ in this plot)
- 2) Measure the EFT coefficients for lepton flavor violation

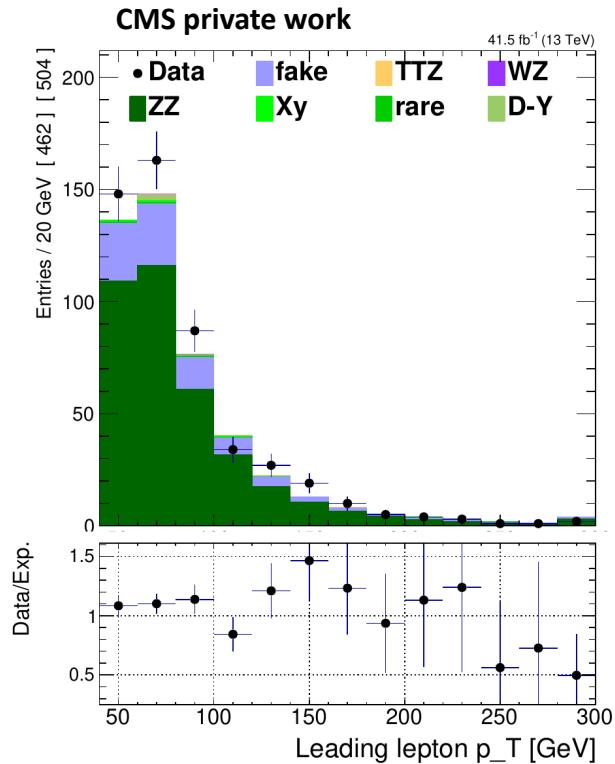
Variable to test to extract the signal :

- The invariant mass of the leptons
- The angles between the leptons
- Advanced methods such as MEM and machine learning

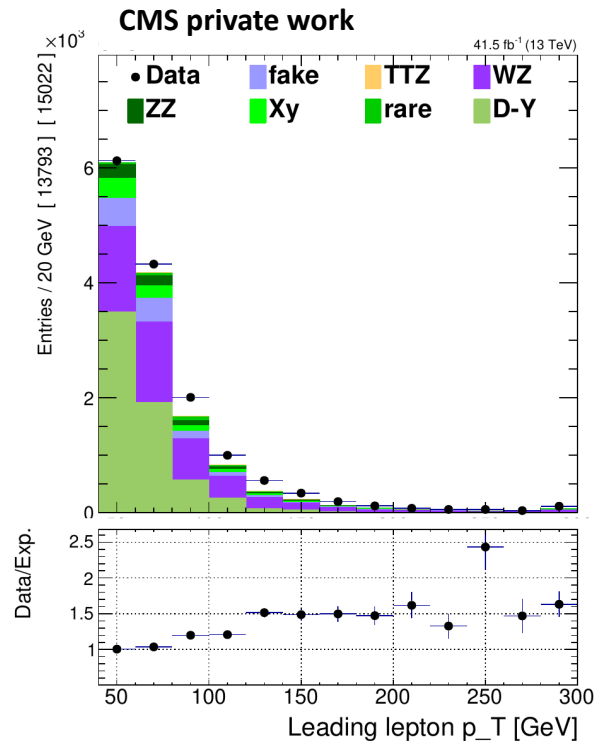


Analysis – Control regions

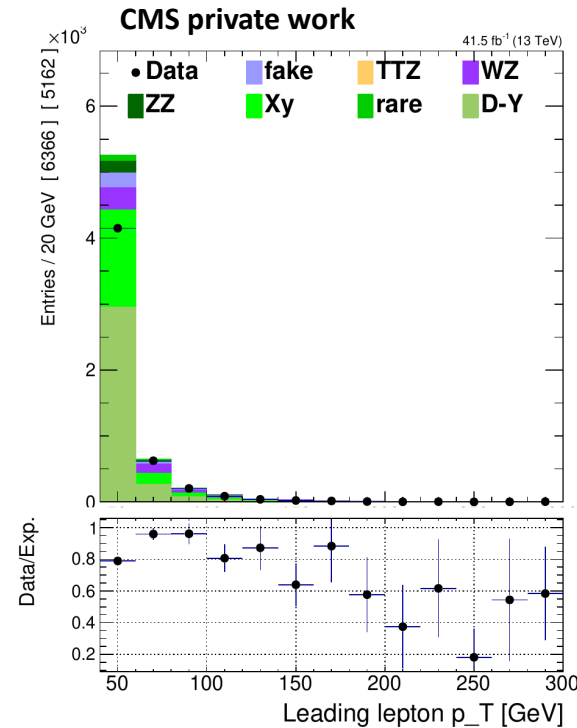
The control regions are **ZZ** (3-4l), **WZ**, $X\gamma$



ZZ



WZ



$X\gamma$

(conversion $\gamma \rightarrow l^+l^-$)

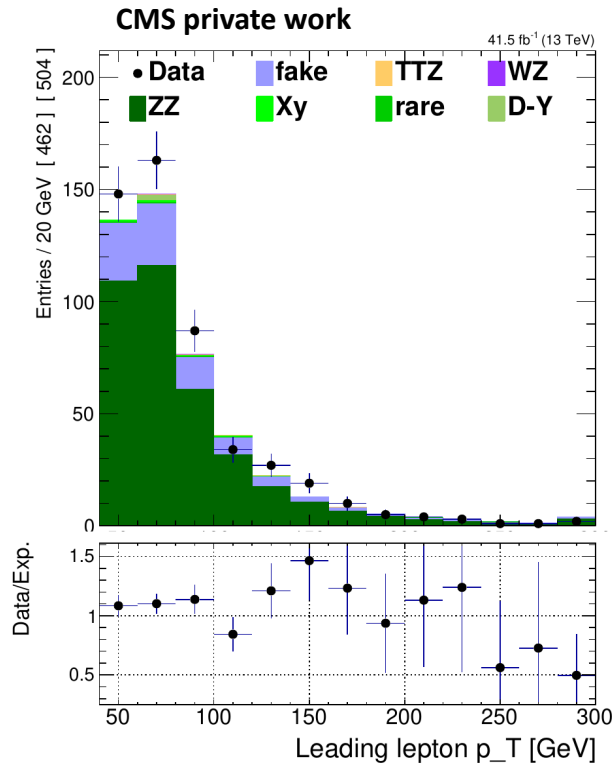
The goal is to **control the background processes**

Monte Carlo – data agreement will be improved after adding the recommended corrections

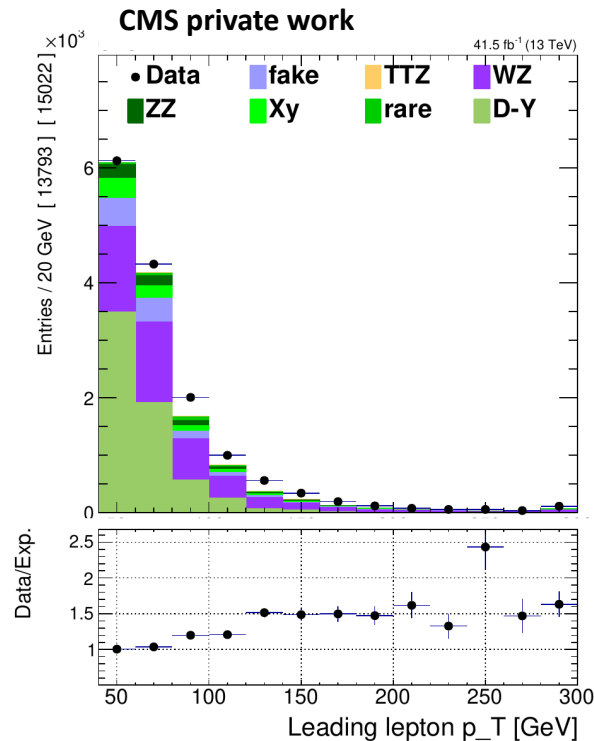


Analysis – Control regions

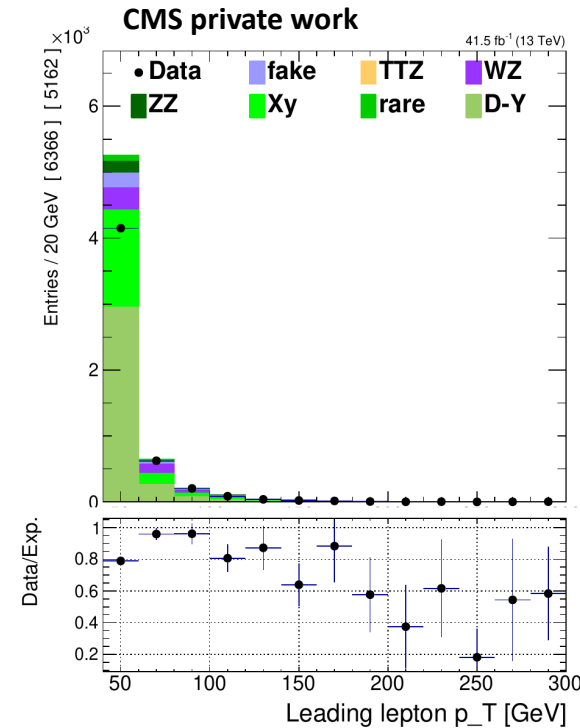
The control regions are **ZZ** (3-4l), **WZ**, $X\gamma$



ZZ



WZ



X γ

(conversion $\gamma \rightarrow l^+l^-$)

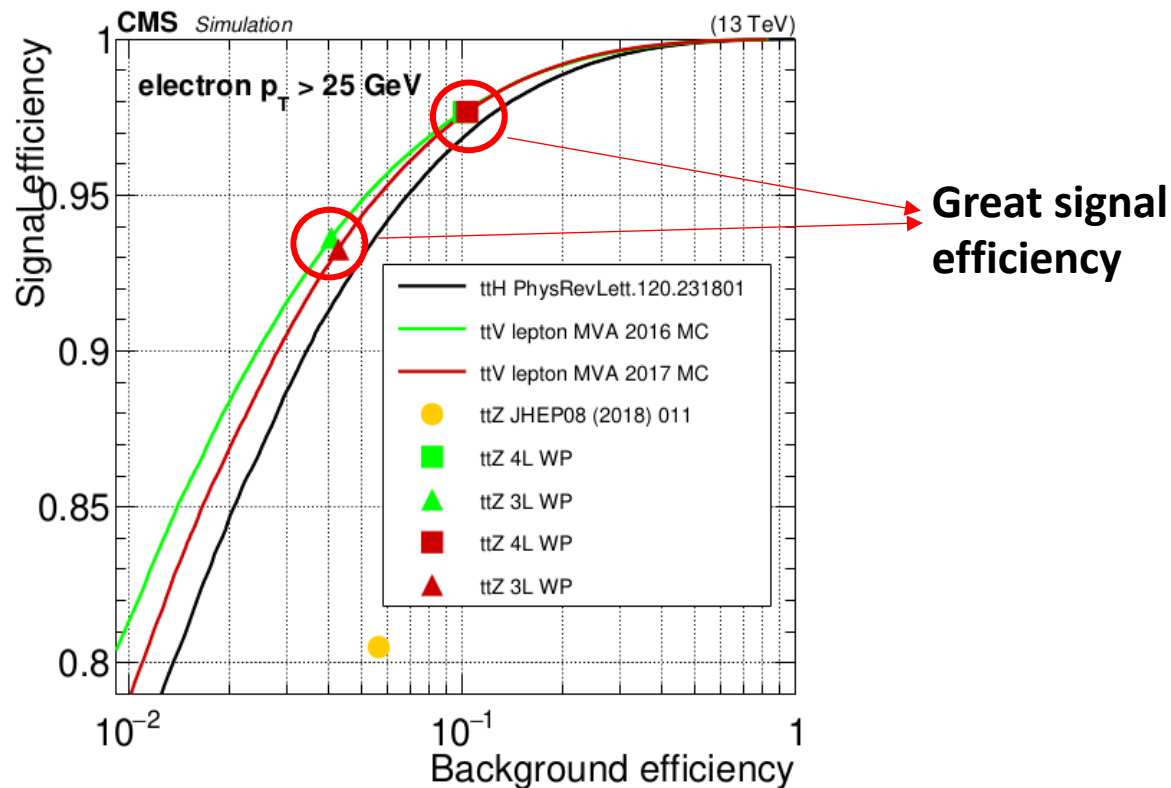
The goal is to **control the background processes**

Monte Carlo – data agreement will be improved after adding the recommended corrections



Analysis – Lepton MVA

Improved lepton identification using a multivariable discriminant (LeptonMVA)



CMS Collaboration (1907.11270)

The goal is to **improve background rejection**

The selection criterion in the analysis has an efficiency of approximately 70%

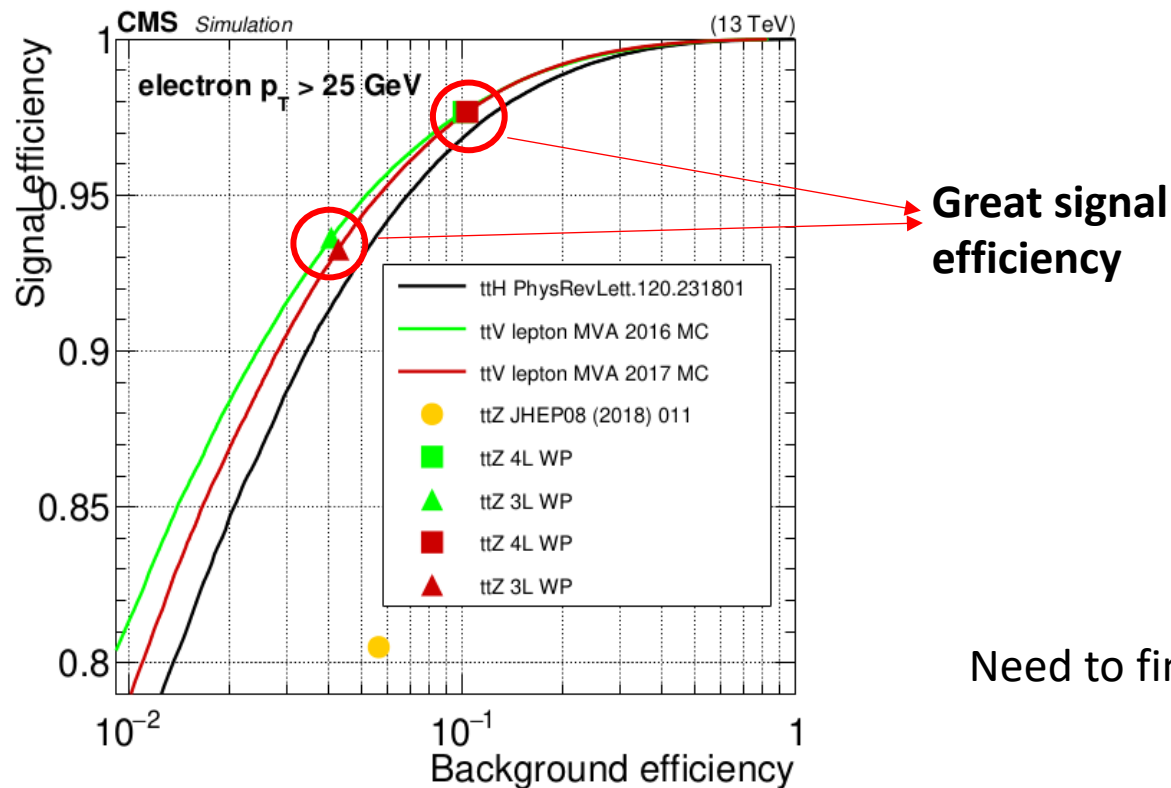
The LeptonMVA **effectively rejects** a substantial amount of **background**

It was developed within the CMS collaboration



Analysis – Lepton MVA

Improved lepton identification using a multivariable discriminant (LeptonMVA)



CMS Collaboration (1907.11270)

The goal is to **improve background rejection**

The selection criterion in the analysis has an efficiency of approximately 70%

The LeptonMVA **effectively rejects** a substantial amount of **background**

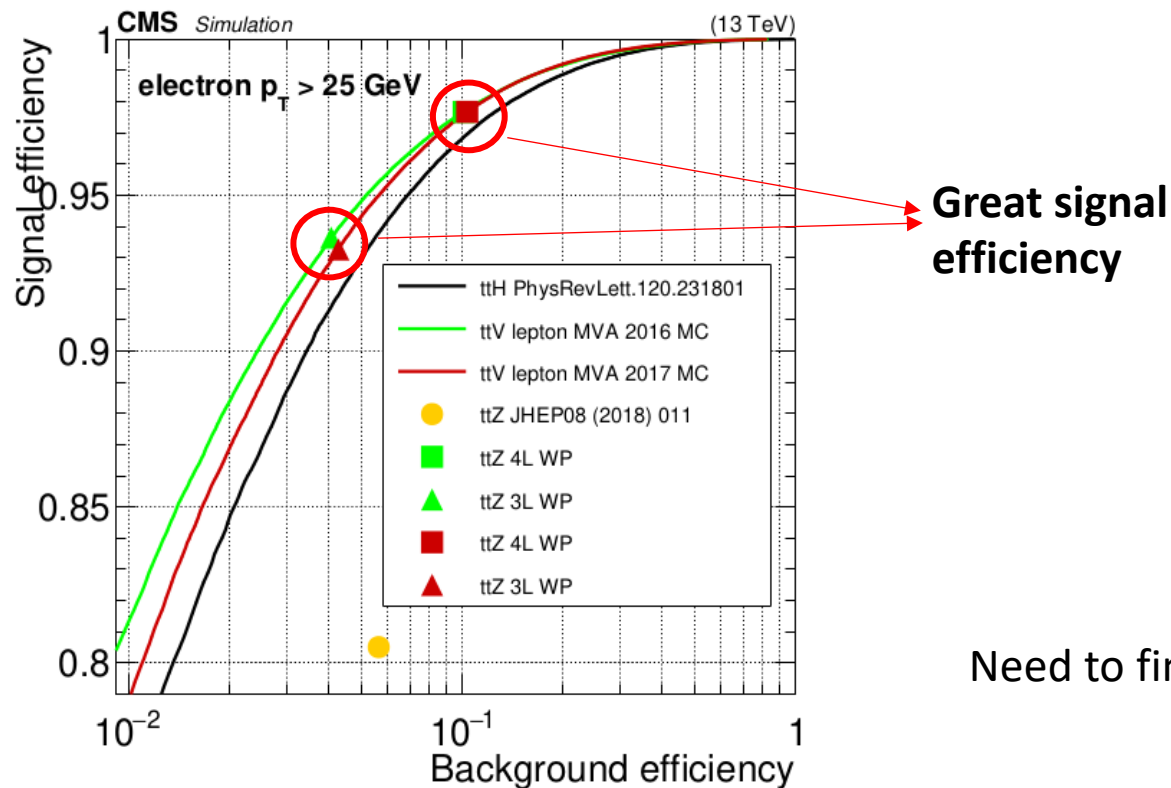
It was developed within the CMS collaboration

Need to find a **Proof**, or an **Evidence of Flavor Universality**



Analysis – Lepton MVA

Improved lepton identification using a multivariable discriminant (LeptonMVA)



CMS Collaboration (1907.11270)

The goal is to **improve background rejection**

The selection criterion in the analysis has an efficiency of approximately 70%

The LeptonMVA **effectively rejects** a substantial amount of **background**

It was developed within the CMS collaboration

Need to find a **Proof**, or an **Evidence of Flavor Universality**

PREFOU



Analysis – Lepton MVA

Improved lepton identification using a multivariable discriminant (LeptonMVA)



CMS Collaboration (1907.11270)

The goal is to **improve background rejection**

The selection criterion in the analysis has an efficiency of approximately 70%

The LeptonMVA **effectively rejects** a substantial amount of **background**

It was developed within the CMS collaboration

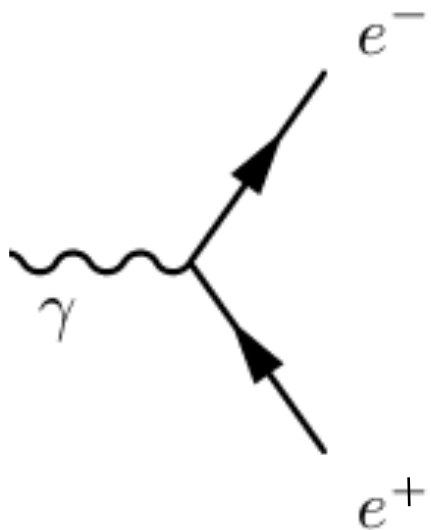
Need to find a **Proof**, or an **Evidence of Flavor Universality**

PREFOU



Phenomenology work: Lorentz invariance

In the presence of Lorentz invariance violation, photons can decay into a pair of fermions in vacuum if $E_\gamma > E_{seuil}$. The idea is to use photons produced at the LHC instead of astrophysical sources to set a $\lim \tilde{\kappa}_{Tr}$. Advantage: the source of the photons is well-defined.



$$E_{seuil} = 2m_f \sqrt{\frac{1 - \tilde{\kappa}_{Tr}}{-2\tilde{\kappa}_{Tr}}}$$

Parameterizing Lorentz invariance violation

The process is **forbidden** by the Standard Model. This would require a modification of the EM Lagrangian :

$$\mathcal{L} = -\frac{1}{4} [\eta^{\mu\rho}\eta^{\nu\sigma} + \kappa^{\mu\nu\rho\sigma}] F_{\mu\nu} F_{\rho\sigma}$$

Predicted signature within the framework of an effective theory, the **SME**

Study of **e+/e-** and **top-antitop** pair decay

For electrons, expected improvement by a **factor of 50** compared to the Tevatron's last data interpretation : $\tilde{\kappa}_{tr} > -5.8 \times 10^{-12}$



Goal

We want to measure : $\tilde{\kappa}_{tr} = \frac{1}{1 - \frac{E_{tr}^2}{2m^2}}$

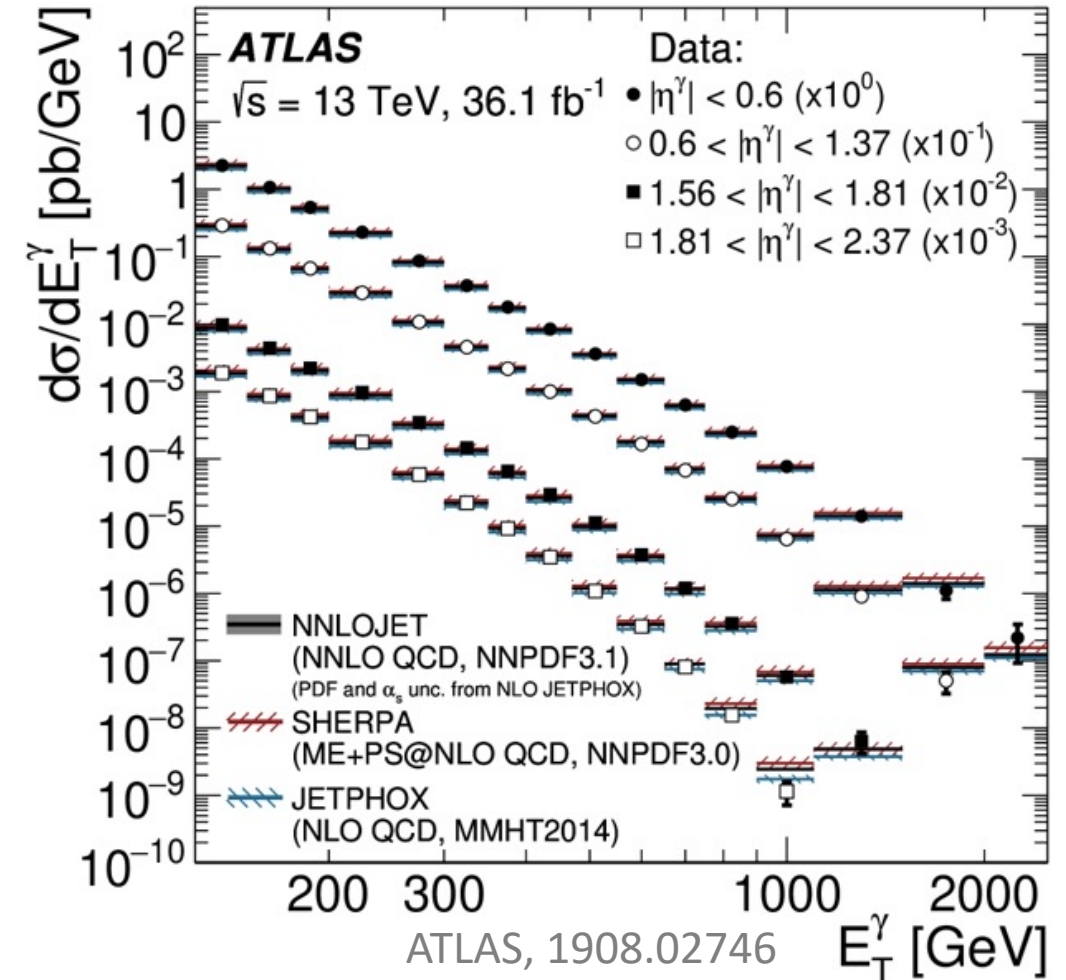
Physically, we need to find the threshold energy at which photons disintegrate in the vacuum.

We will first look at : $\gamma \rightarrow e^+e^-$

Then : $\gamma \rightarrow t\bar{t}$

Therefore, we analyze the number of photons in function of E^γ

For that, we reinterpret the ATLAS' results of E_T^γ for prompt photon measurement by looking at the process : $pp \rightarrow \gamma jj(3)$



Procedure

If the photon has an energy $E > E_{tr}$, then the probability of the photon decaying is given by $1 - e^{-\Gamma x}$ where Γ is the width given by the integral over $[\frac{1}{2}(E_\gamma - \bar{E}), \frac{1}{2}(E_\gamma + \bar{E})]$ of :

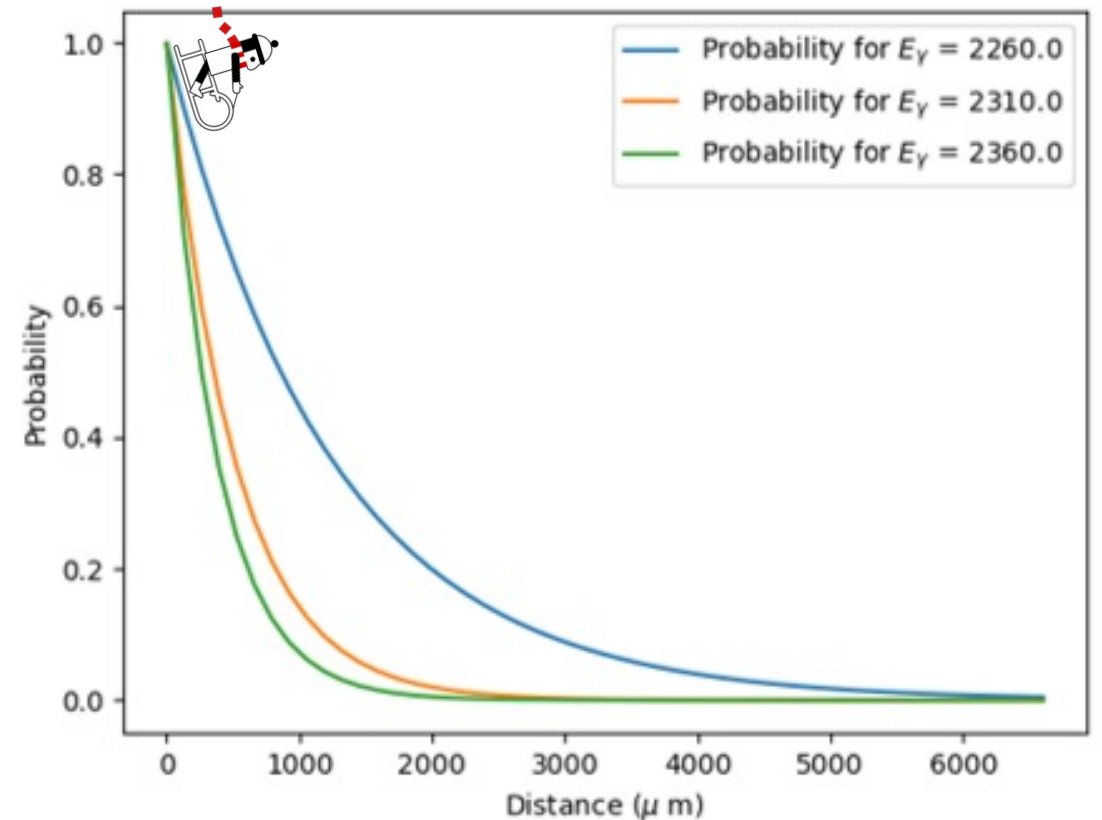
$$\frac{d\Gamma}{dE_e} = \frac{\alpha[(1 - \tilde{\kappa}_{tr})[2\tilde{\kappa}_{tr}E_e(E_\gamma - E_e) + (1 + \tilde{\kappa}_{tr})m^2] - \tilde{\kappa}_{tr}E_\gamma^2]}{(1 + \tilde{\kappa}_{tr})^2 \sqrt{1 - \tilde{\kappa}_{tr}^2 E_\gamma^2}}$$

If it decay, we chose at random following the previous function :

$$E_f \in [\frac{1}{2}(E_\gamma - \bar{E}), \frac{1}{2}(E_\gamma + \bar{E})]$$

With

$$\bar{E} = \sqrt{\frac{1 + \tilde{\kappa}_{tr}}{1 - \tilde{\kappa}_{tr}} [E_\gamma^2 + 2(\frac{1}{\tilde{\kappa}_{tr}} - 1)m^2]}$$

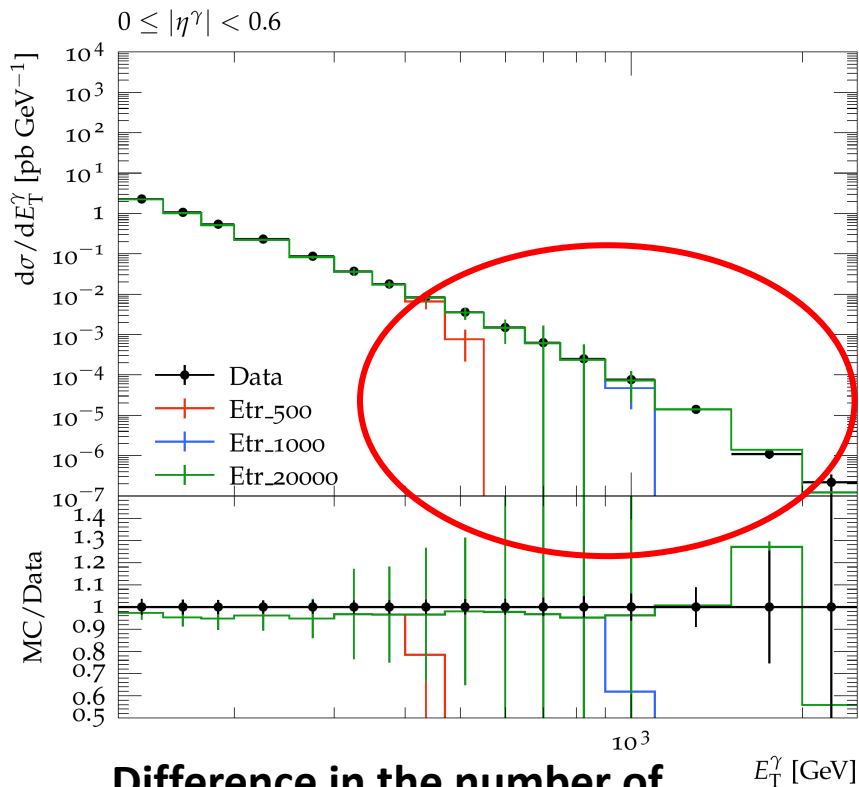


Collaboration with University of Maranhao (Brazil)

Procedure

Reinterpretation of ATLAS data using the statistical method 'Confidence Levels' (CLs).

Event generation with *SHERPA*



Difference in the number of photons used for constraining $\tilde{\kappa}_{Tr}$

The goal is to set a **limit** on $\tilde{\kappa}_{Tr}$

Assessing the **compatibility of experimental observations** with the hypothesis of Lorentz invariance violation

Above the threshold energy, photons produced in collisions convert into fermion pairs and are not reconstructed as photons (thus they do not appear in the plot)



Hadronization in *SHERPA*



Data analysis with *RIVET*

Measurement – Statistical test

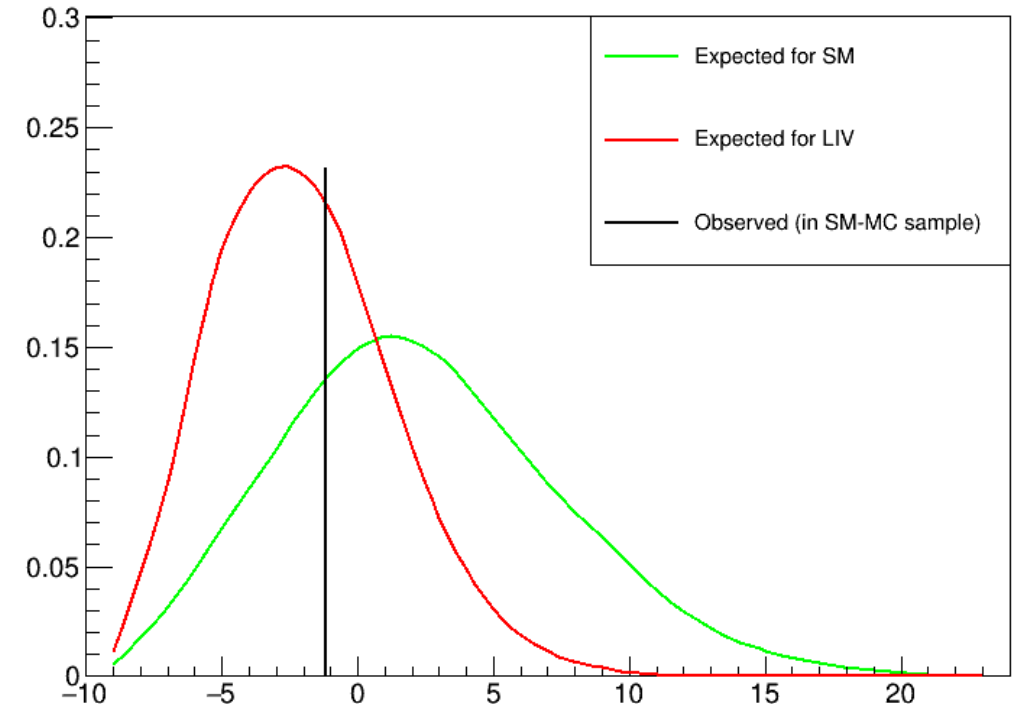
The statistical test is a log likelihood ratio. It is evaluated over the Y variable defined as :

$$Y \sim \mathcal{P}(X) \text{ with } X \sim \mathcal{N}(\mu_i, \sigma_i)$$

where μ_i is the bin value and σ_i the systematic uncertainty.

The data systematic uncertainties are already given by the ATLAS measurement. They include the **background subtraction**, the **unfolding**, the **pile-up**, the **trigger efficiency**, the **luminosity measurement**, the photon **energy scale** and **resolution**.

The Monte Carlo statistical uncertainties are taken from the local MC and not from the ATLAS values. The theory uncertainties are **added in quadrature** with the data systematical uncertainties.



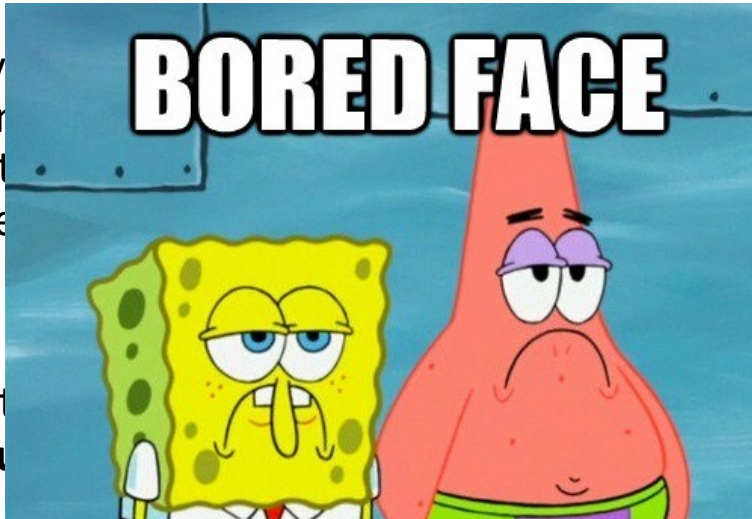
Measurement – Statistical test

The statistical test is a log likelihood ratio. It is evaluated over the Y variable defined as :

$$Y \sim \mathcal{P}(X) \text{ with } X \sim \mathcal{N}(\mu_i, \sigma_i)$$

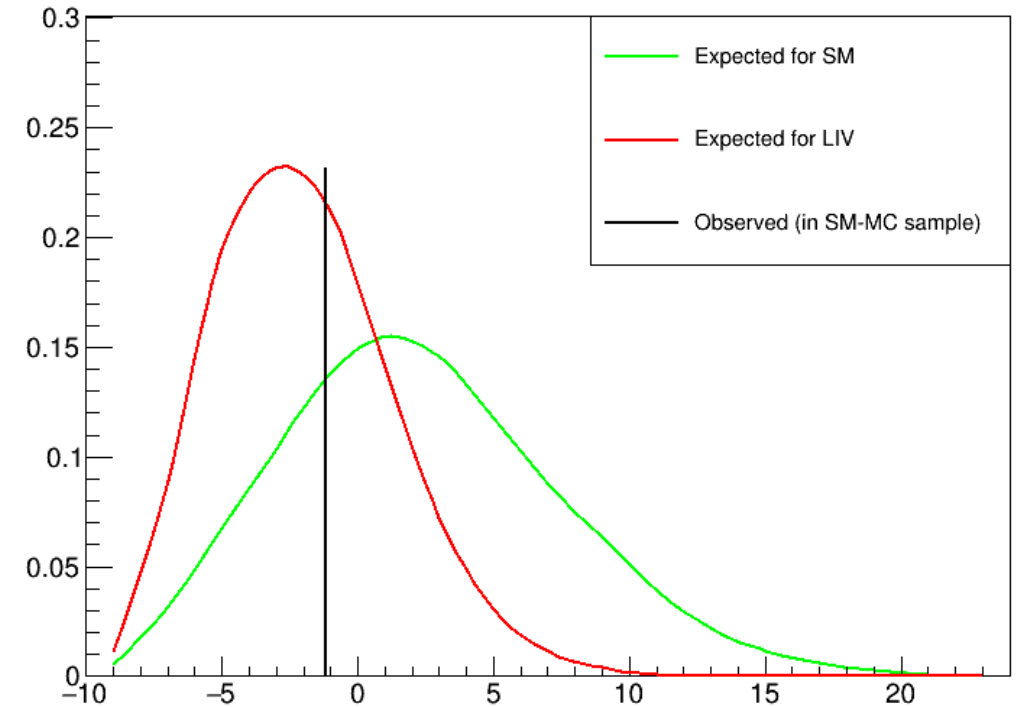
where μ_i is the bin value and σ_i the systematic uncertainty.

The data systematics are unfolded, the measurement is unfolded, the measurement is unfolded.



In the ATLAS action, the luminosity is constant.

The local uncertainties are added in quadrature.



Measurement – CLs method

The CLs method is used to set upper limit on parameters

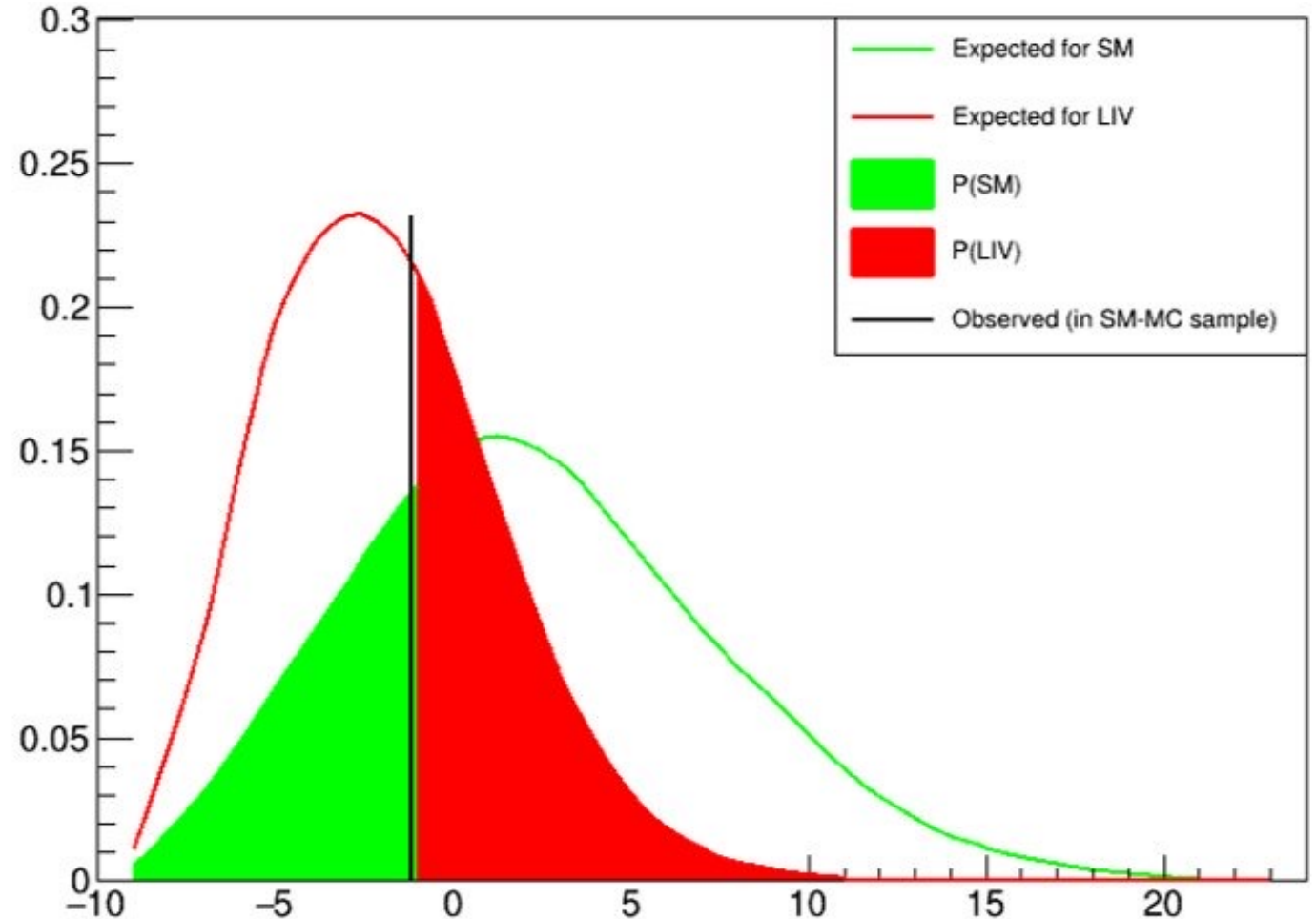
For a statistical test q , we define

$$CL_{s+b} = p_{s+b} = P(q > q_{obs} | s + b) = \int_{q_{obs}}^{\infty} f(q | s + b) dq$$

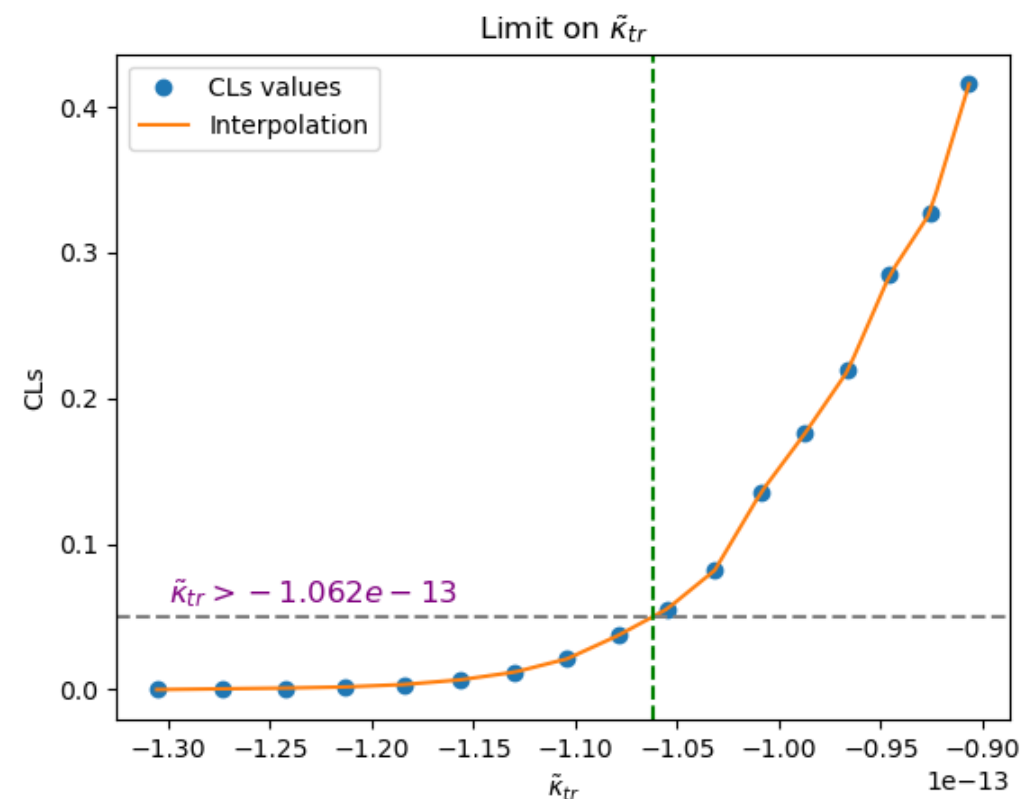
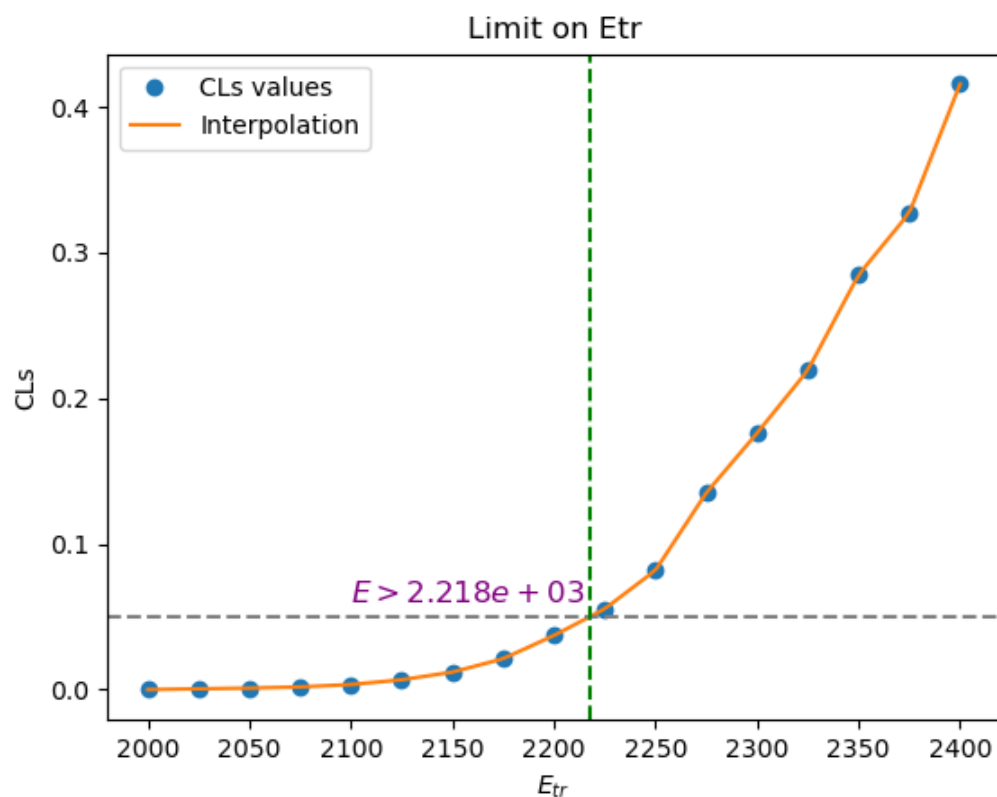
$$CL_b = 1 - p_b = 1 - P(q < q_{obs} | b) = 1 - \int_{-\infty}^{q_{obs}} f(q | b) dq$$

$$CL_s = \frac{CL_{s+b}}{CL_b}$$

We use $CL_s < 0.05$ by convention



Measurement – CLs method

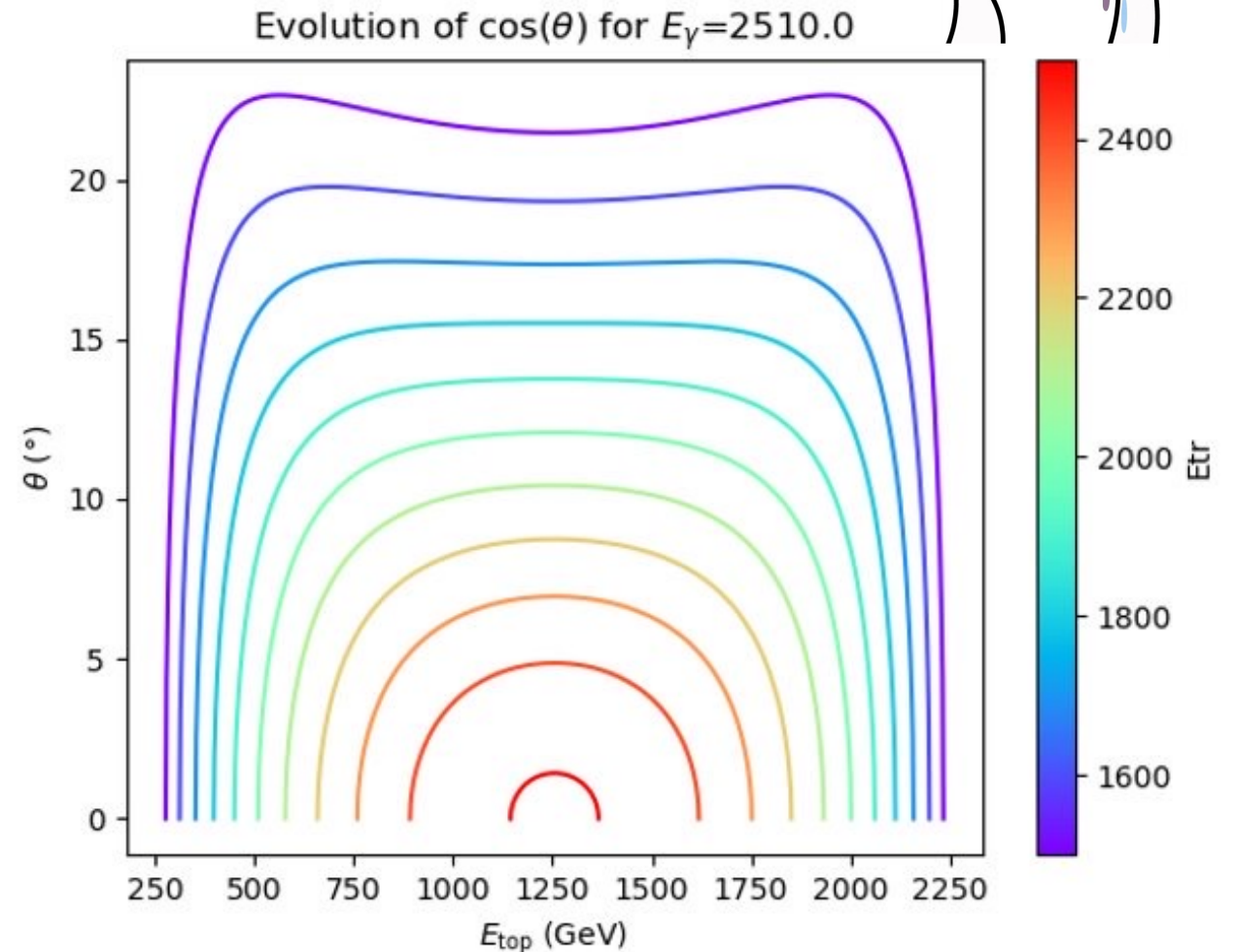


Using linear interpolation between the point,
we can set a boundary on the value :

$$\tilde{\kappa}_{tr} > -1.062e-13$$

Top quark physics

A similar analysis can be done by looking at the desintegration in **top quark pair**



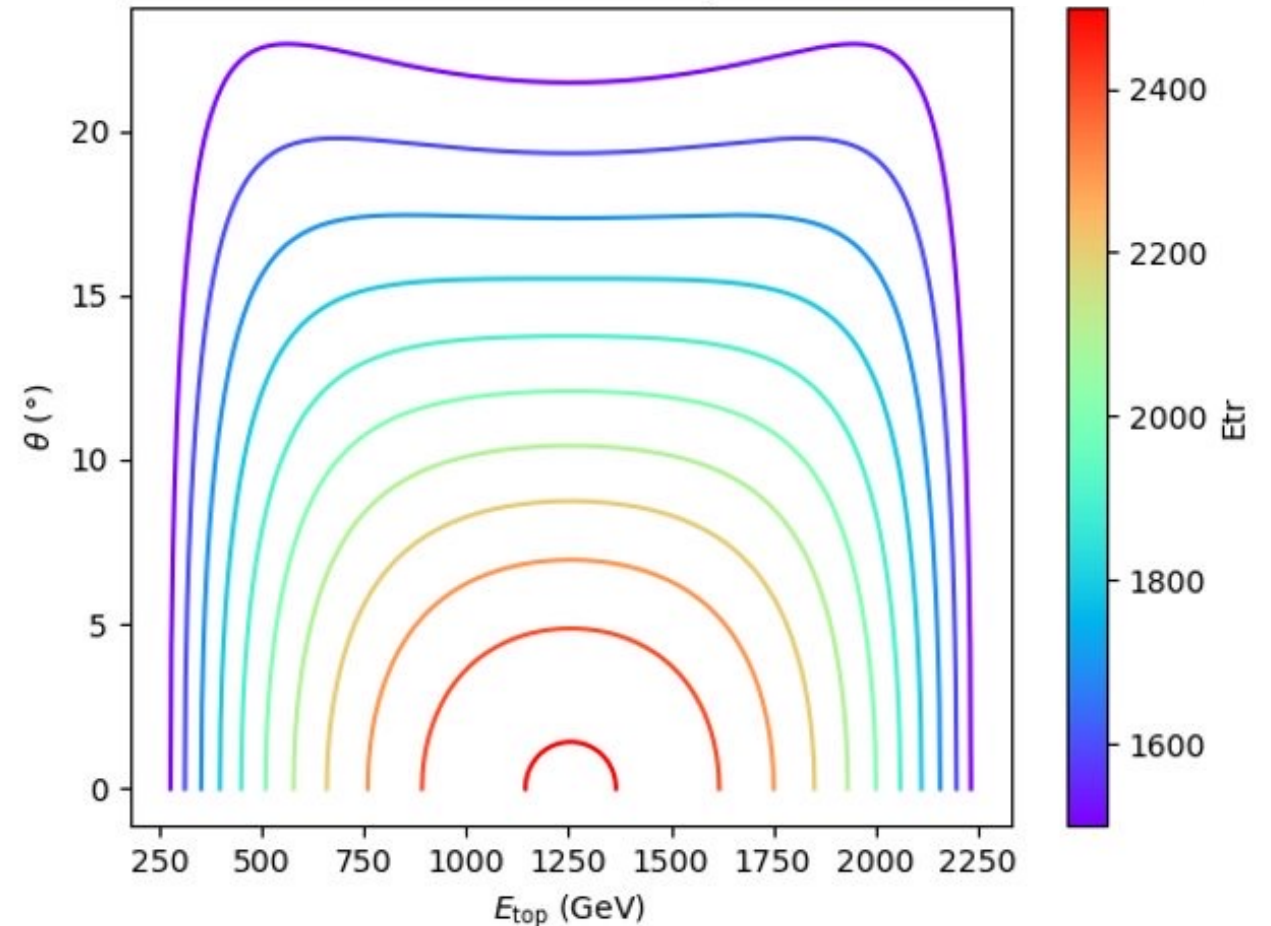
Top quark physics

A similar analysis can be done by looking at the desintegration in **top quark pair**

The cinematic could be used to **discriminate** between SM and LIV in order to measure $\tilde{\kappa}_{Tr}$

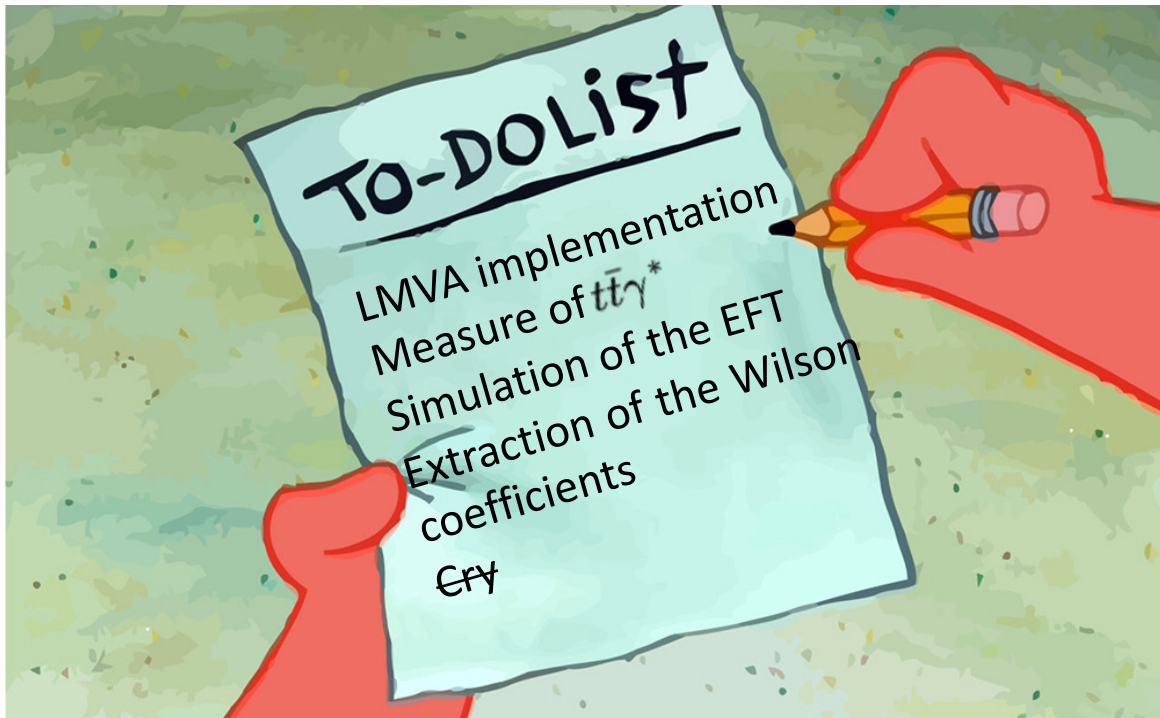


Evolution of $\cos(\theta)$ for $E_\gamma=2510.0$



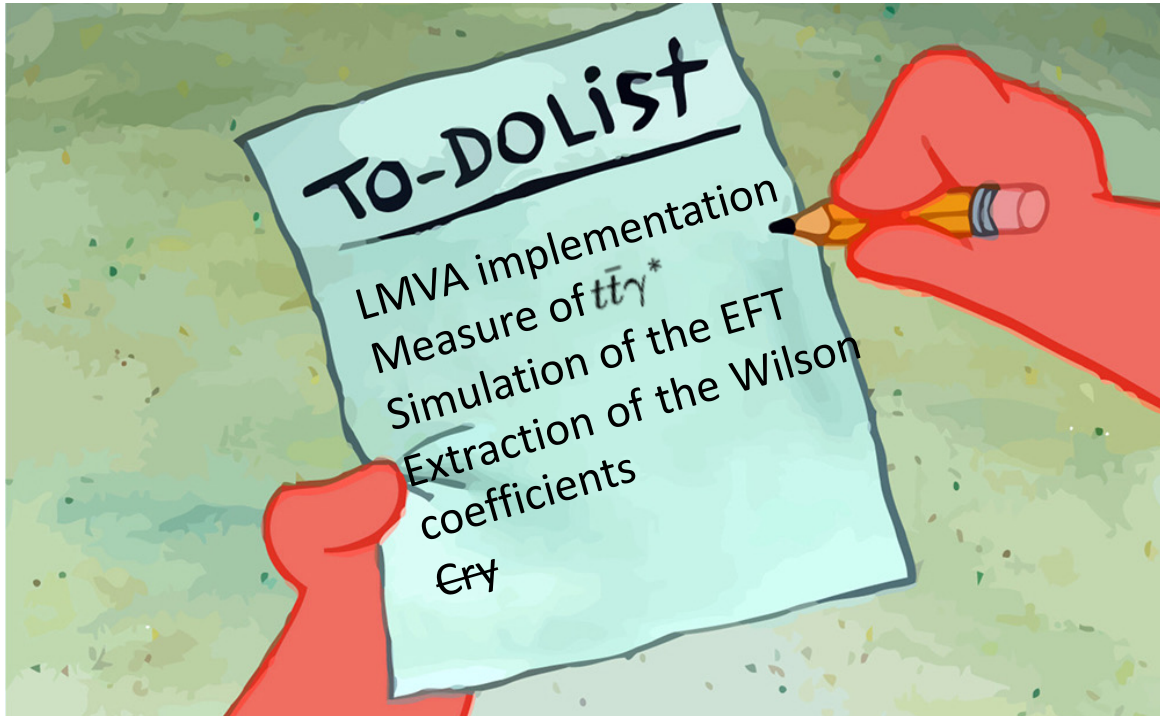
Lepton Flavor Universality

Implementation of the selection to define control and signal region
Research of discriminating variables



Lepton Flavor Universality

Implementation of the selection to define control and signal region
Research of discriminating variables



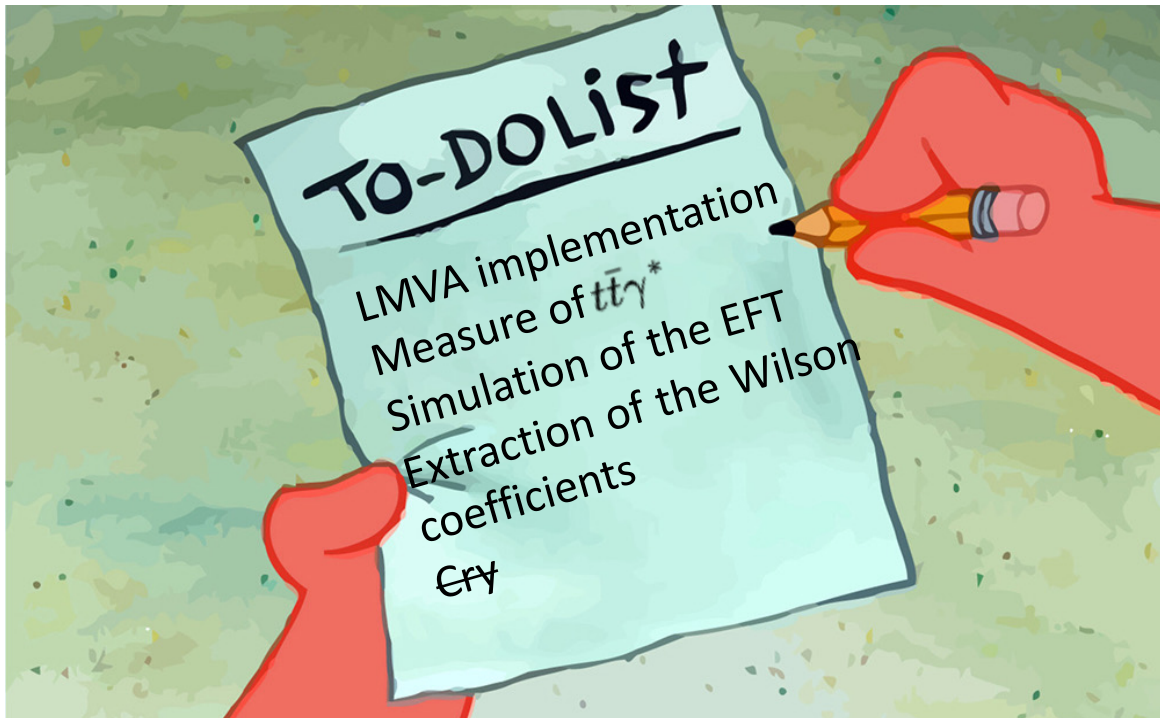
Lorentz Invariance Violation

Put a constrain on the LIV coefficient around 50 times better than the previous measurement

Still no LIV observation

Lepton Flavor Universality

Implementation of the selection to define control and signal region
Research of discriminating variables



Lorentz Invari

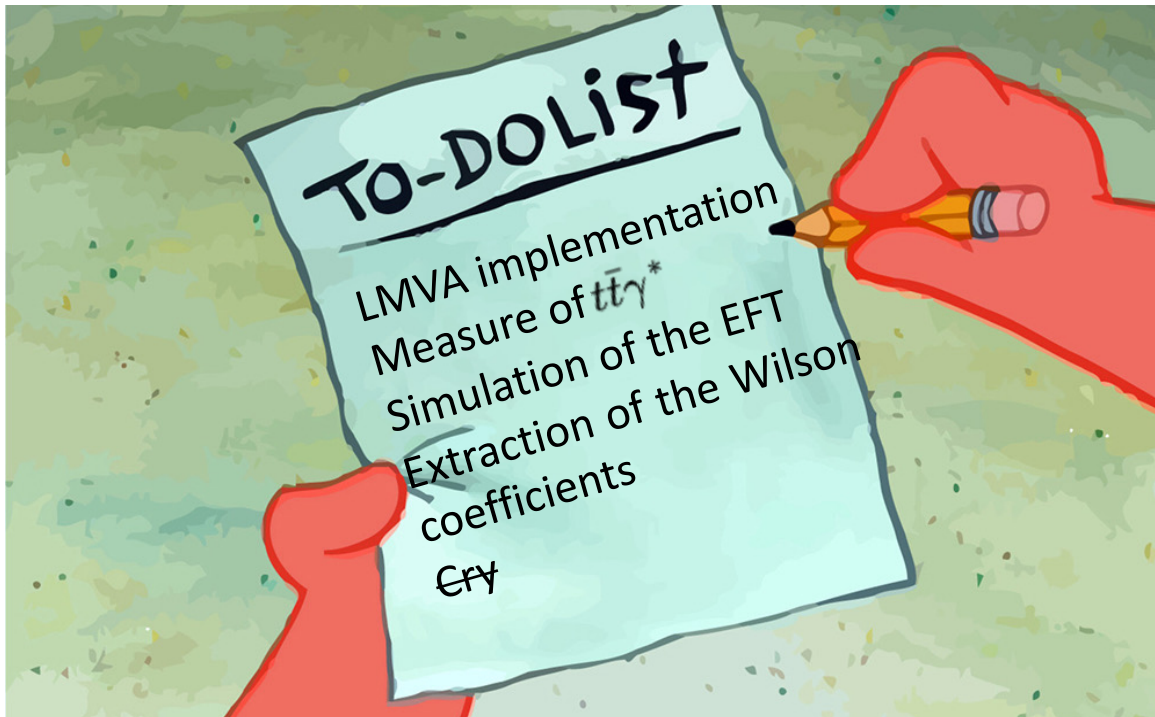
Put a constrain on the LIV
times better than the pr

Still no LIV observation



Lepton Flavor Universality

Implementation of the selection to define control and signal region
Research of discriminating variables



Lorentz Invariance Violation

Put a constrain on the LIV coefficient around 50 times better than the previous measurement

Still no LIV observation

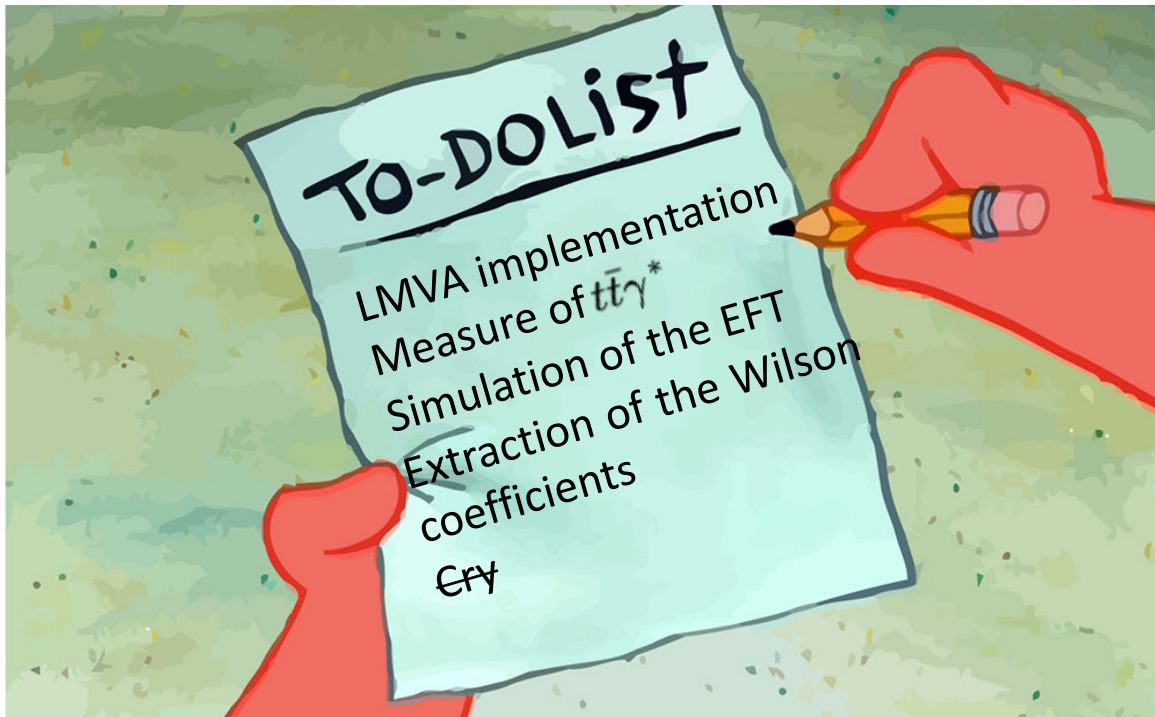
EPR task

Optimisation of the HCAL isolation cone size



Lepton Flavor Universality

Implementation of the selection to define control and signal region
Research of discriminating variables



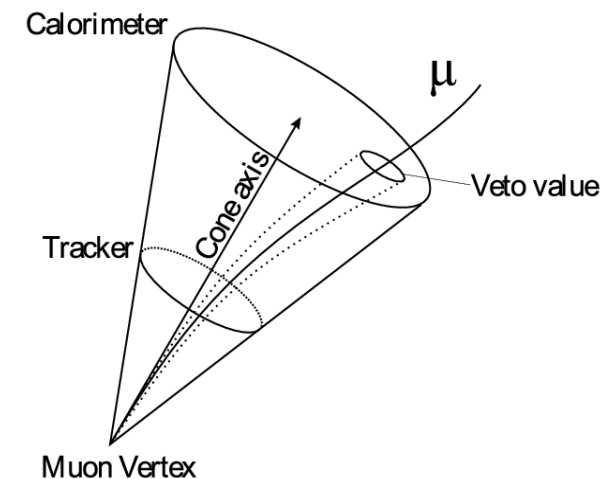
Lorentz Invariance Violation

Put a constrain on the LIV coefficient around 50 times better than the previous measurement

Still no LIV observation

EPR task

Optimisation of the HCAL isolation cone size





Very attention

Wow

Wow

Much thank you

Wow

So Presentation

VIA 9GAG.COM

memecreator.com

Backup



ON DOES NOT SIMPLY

ASK ME QUESTION

imgflip.com

I have no backup