Test of global symmetries

(LFU and LIV)

of the Standard Model in the top quark sector

With CMS at LHC

JRJC 2023

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IP2I Lyon - CMS

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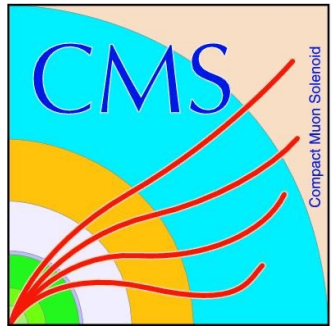
PHAST
PHYSIQUE
ET ASTROPHYSIQUE
UNIVERSITÉ DE LYON

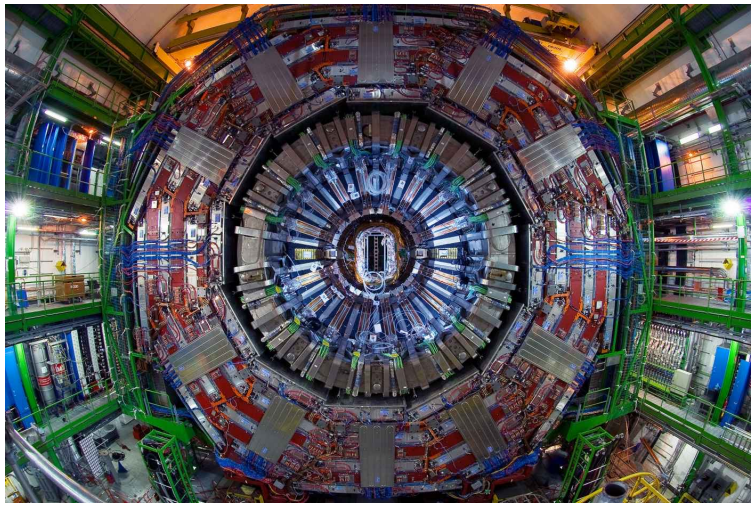


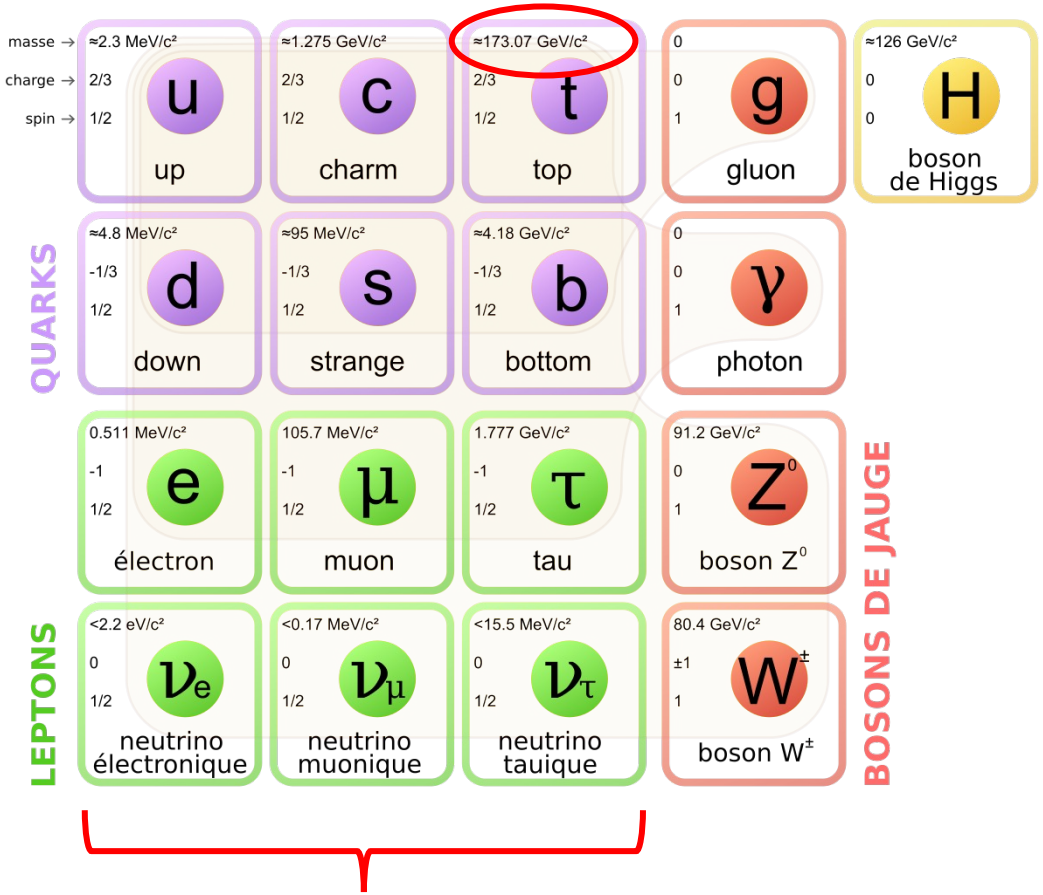
Motivations - LFU

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



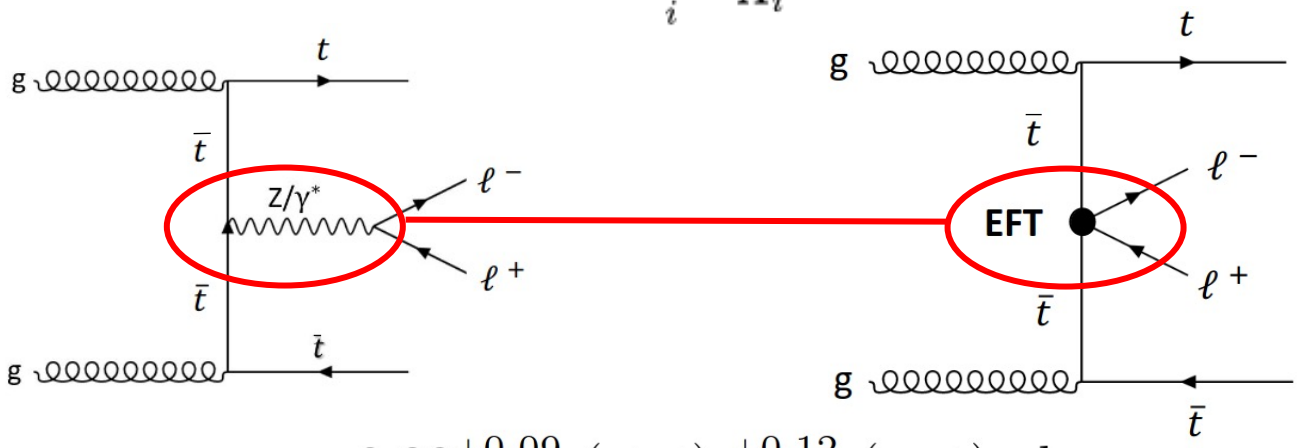


3 generations that differ only by their masses according to the Standard Model

Goals

Modeling the violation of lepton flavor universality with an effective theory

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



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

CMS collaboration (1711.02547)

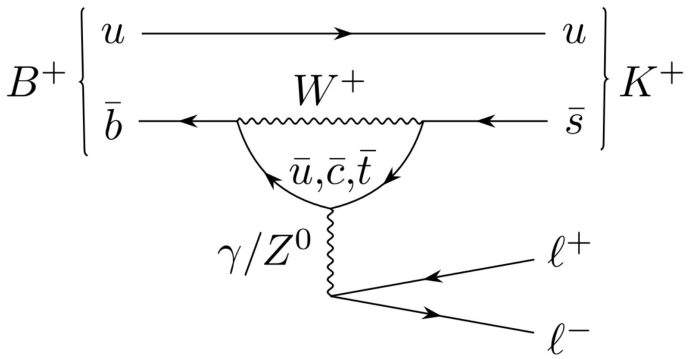
Measurement of the SM $t\bar{t}\gamma^*$ process, never measured at the LHC

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)

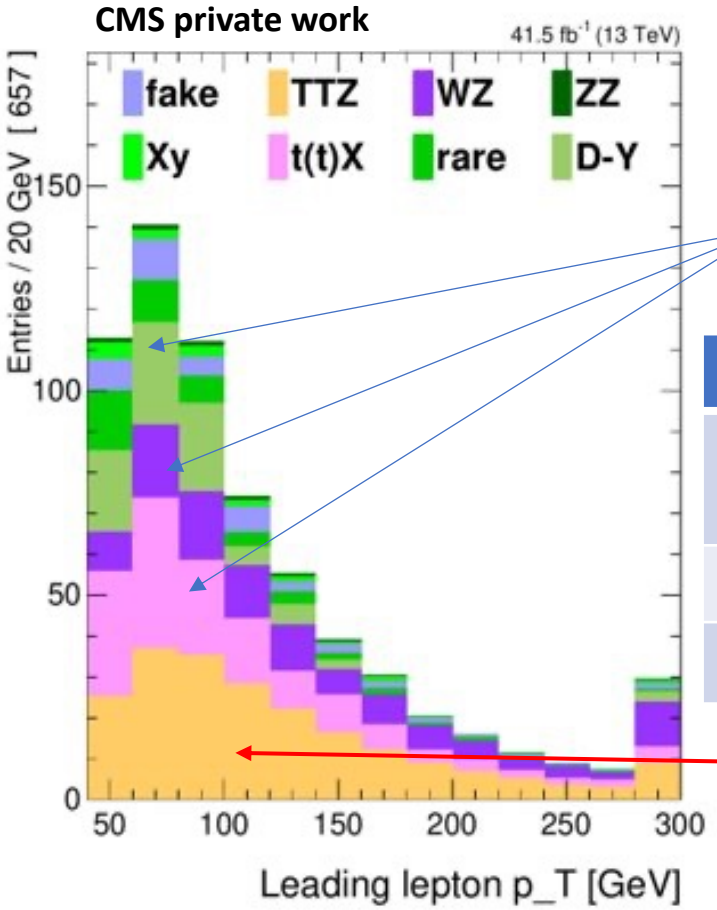
Example of an EFT operator :

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

Signal

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

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

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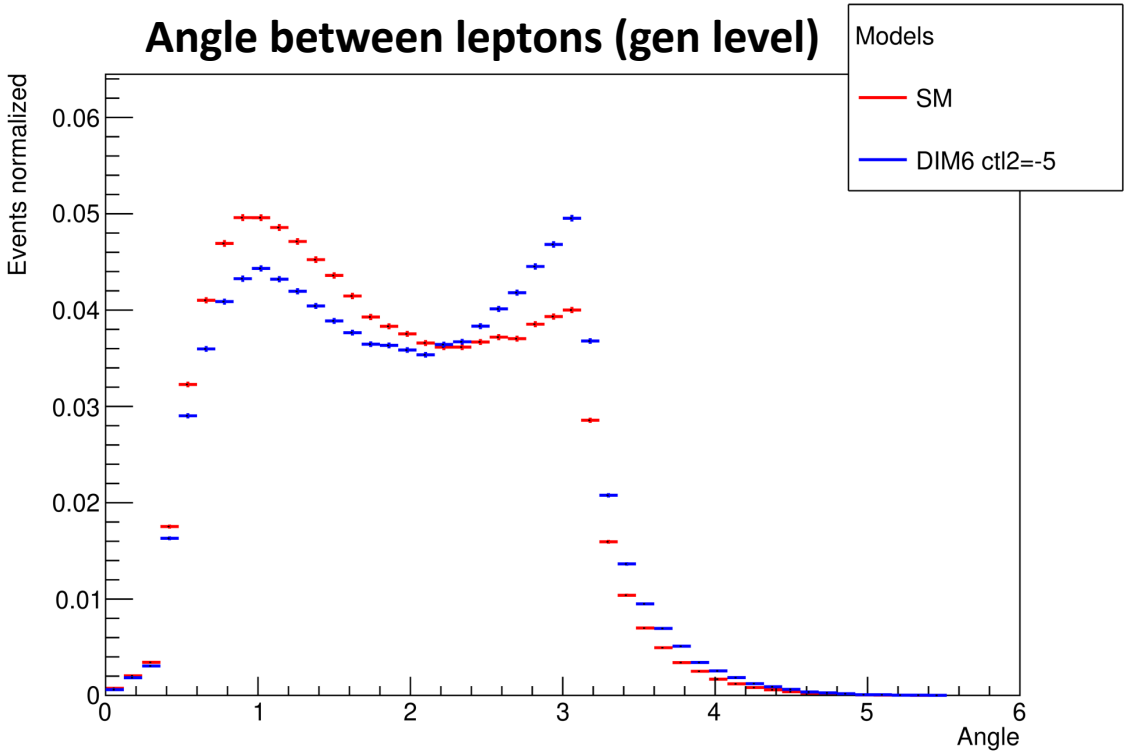

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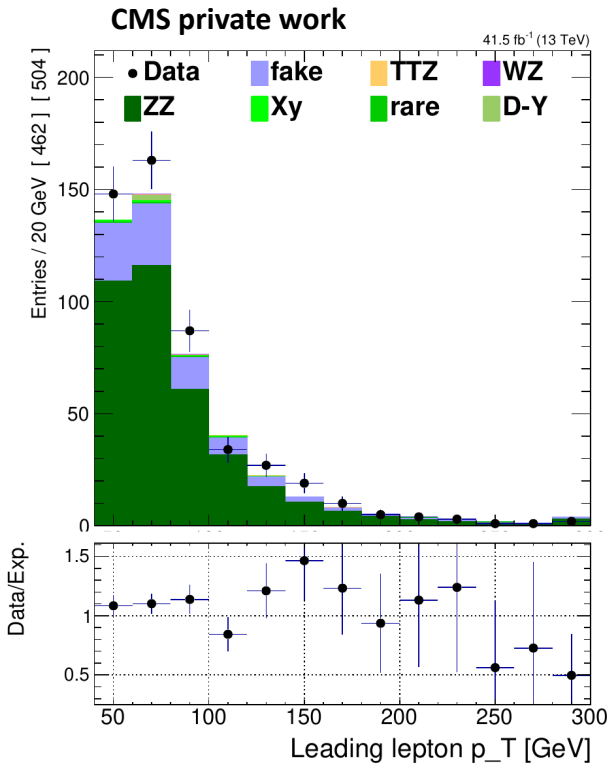
Analysis – Control regions

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



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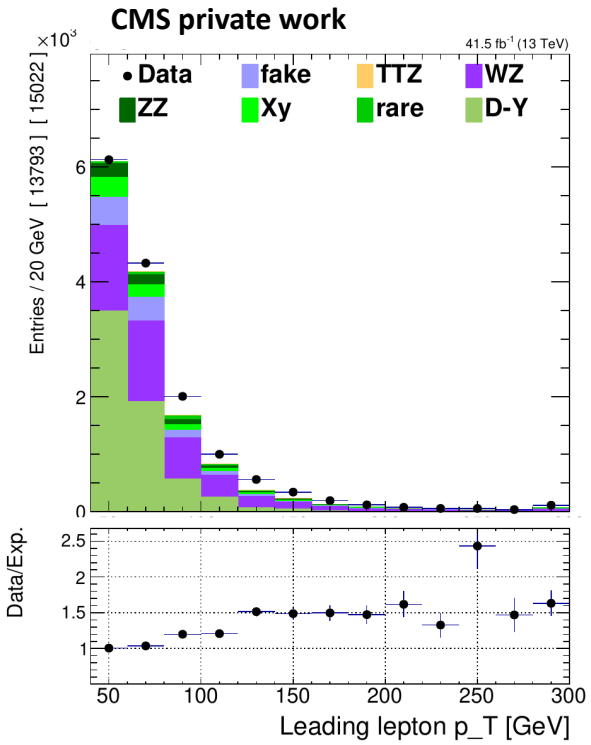

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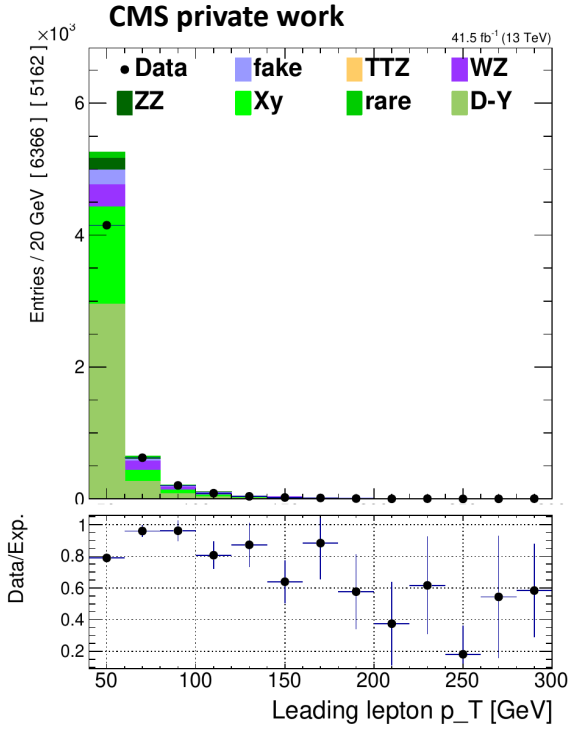

$\mathbf{X}\gamma$

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

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

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

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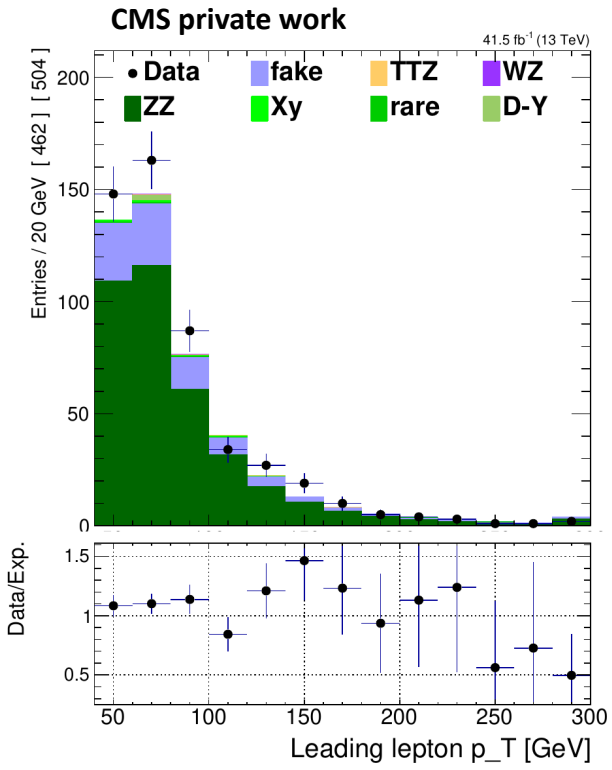

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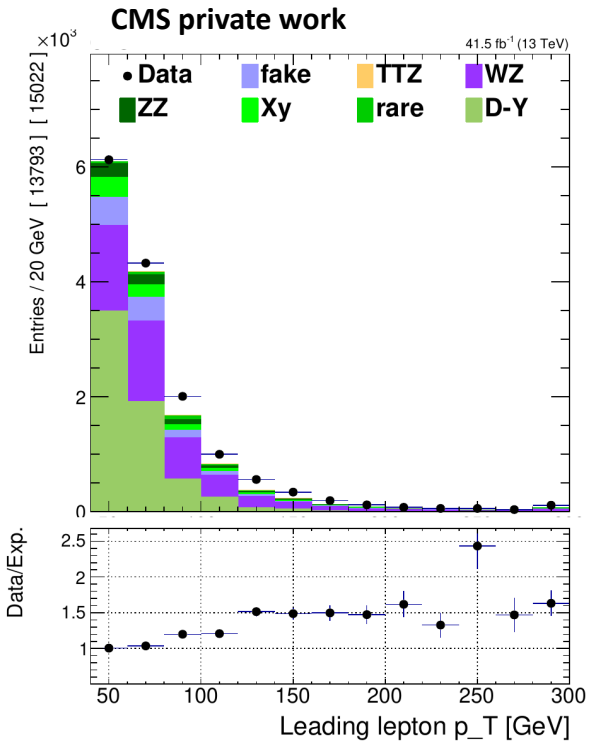

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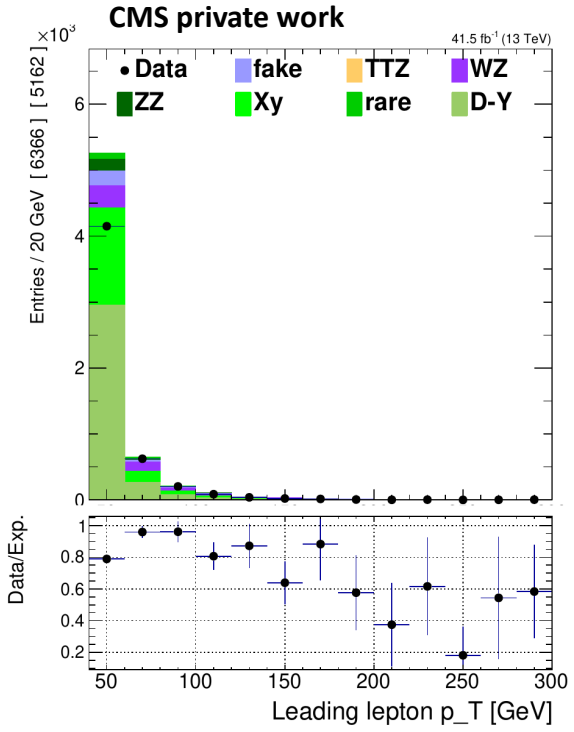

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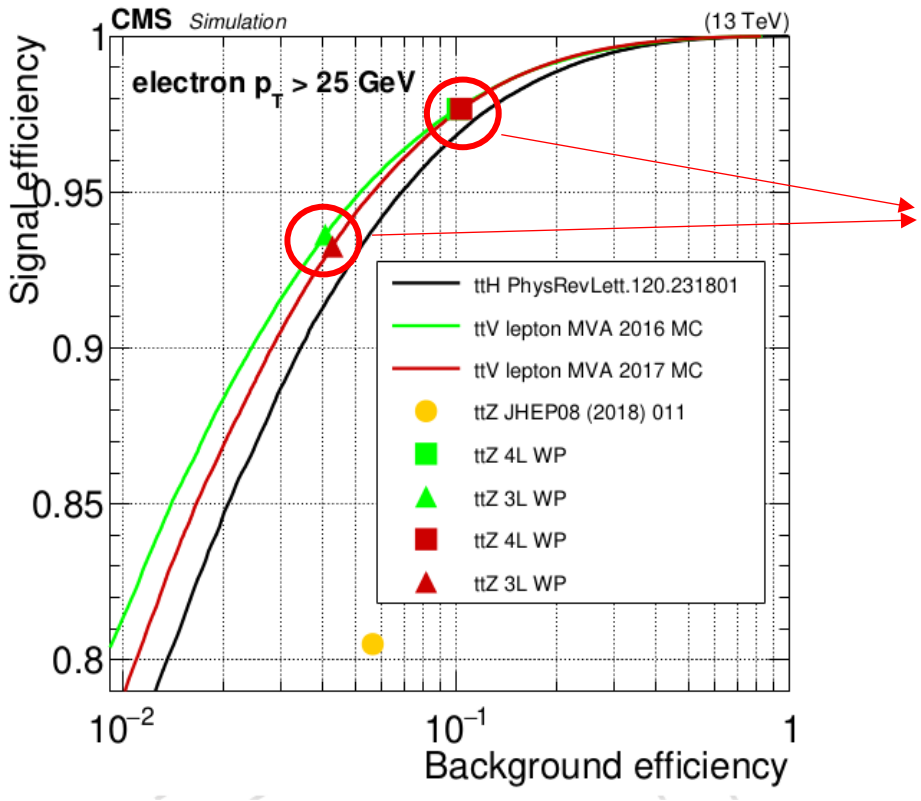
Improved lepton identification using a multivariable discriminant (LeptonMVA)



Great signal efficiency

CMS Collaboration (1907.11270)

The goal is to i**mprove background rejection**

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

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

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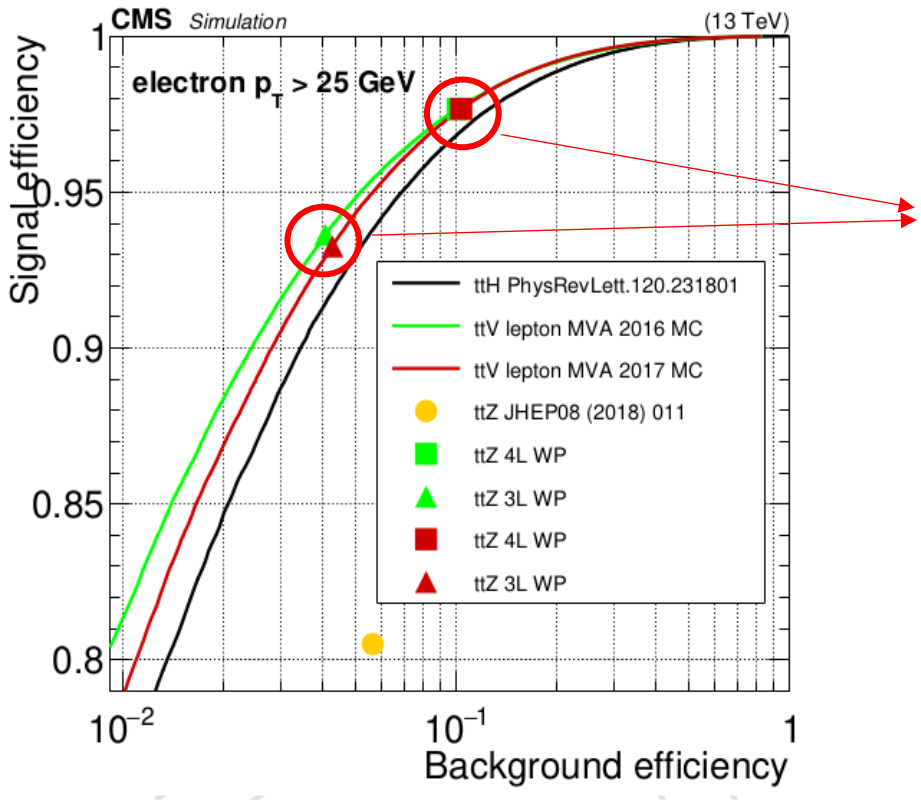

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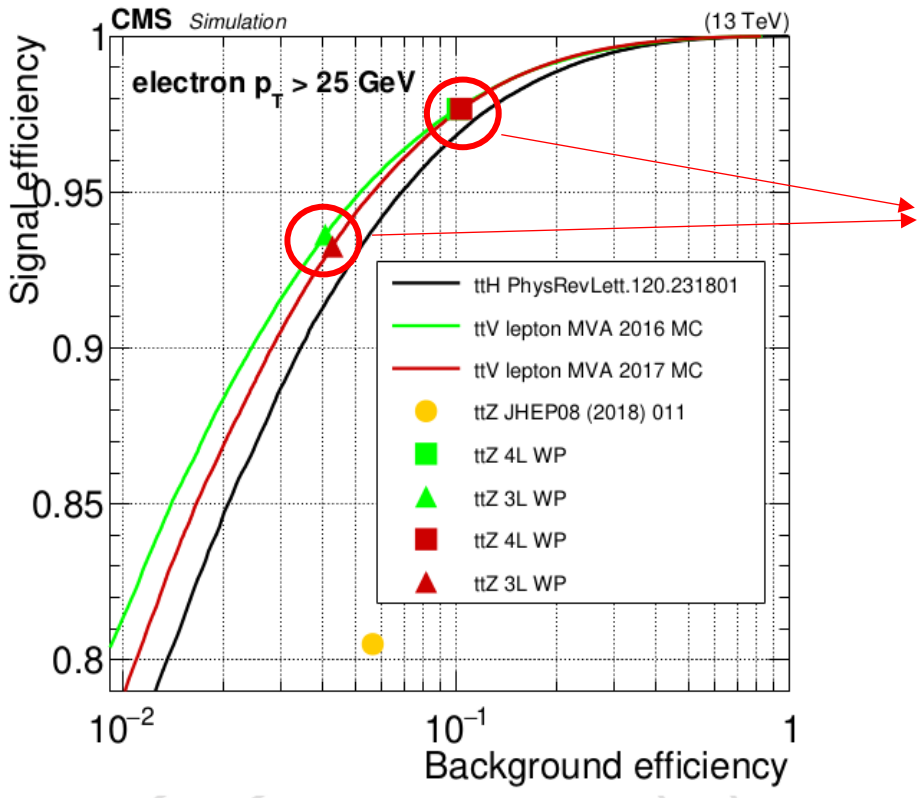

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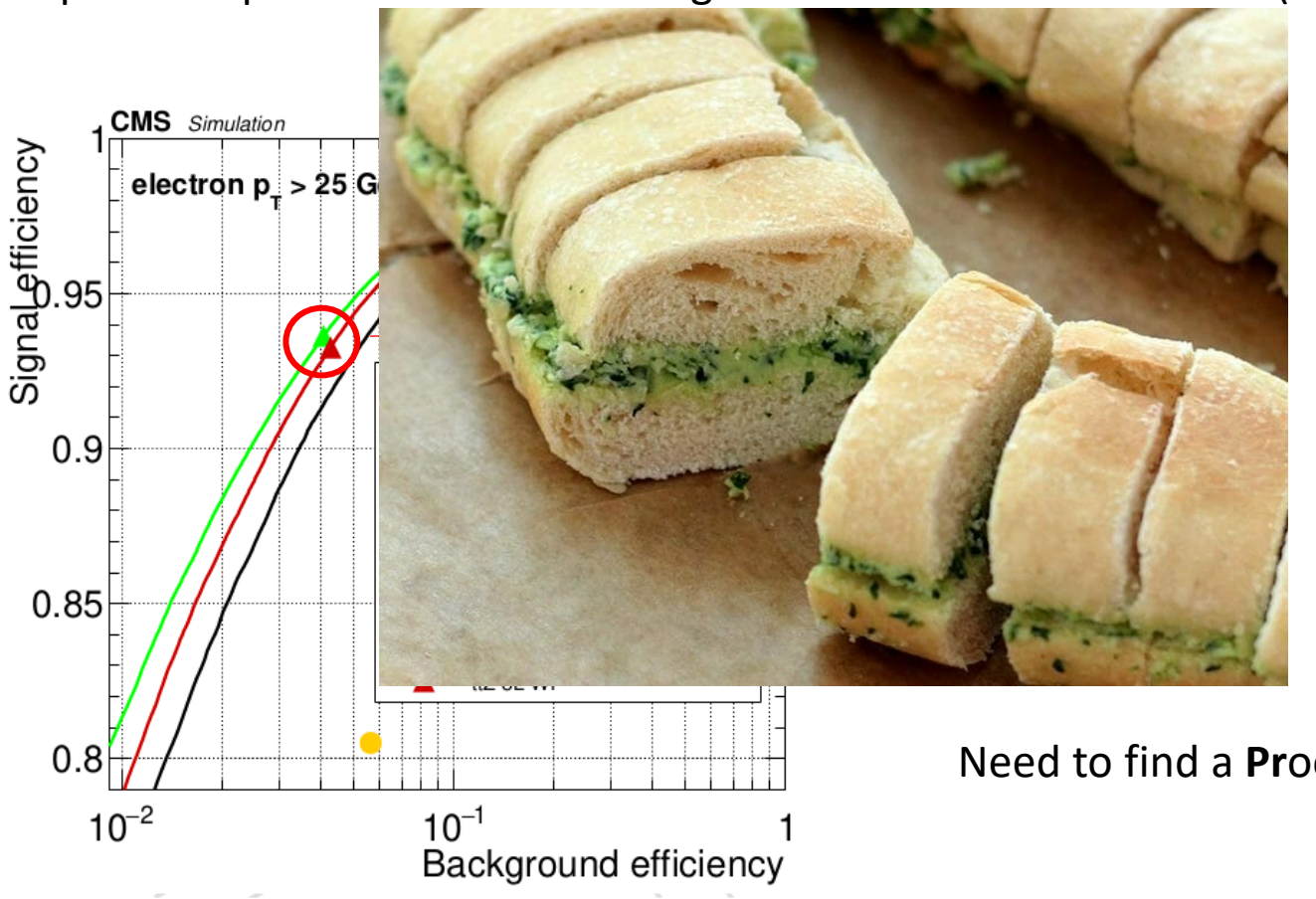

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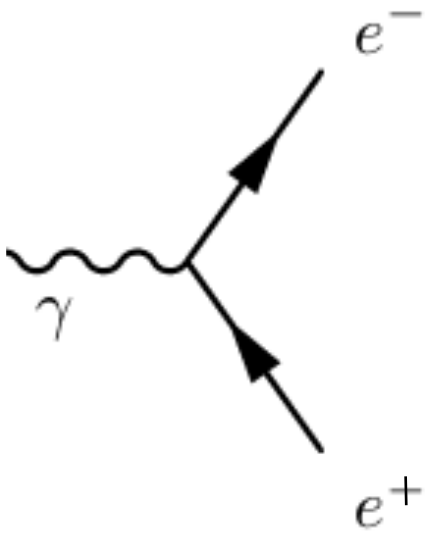
PREFOU

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.



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

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 mesure : $\tilde{\kappa_{tr}} = \frac{1}{1 - \frac{{E_{tr}}^2}{2m^2}}$

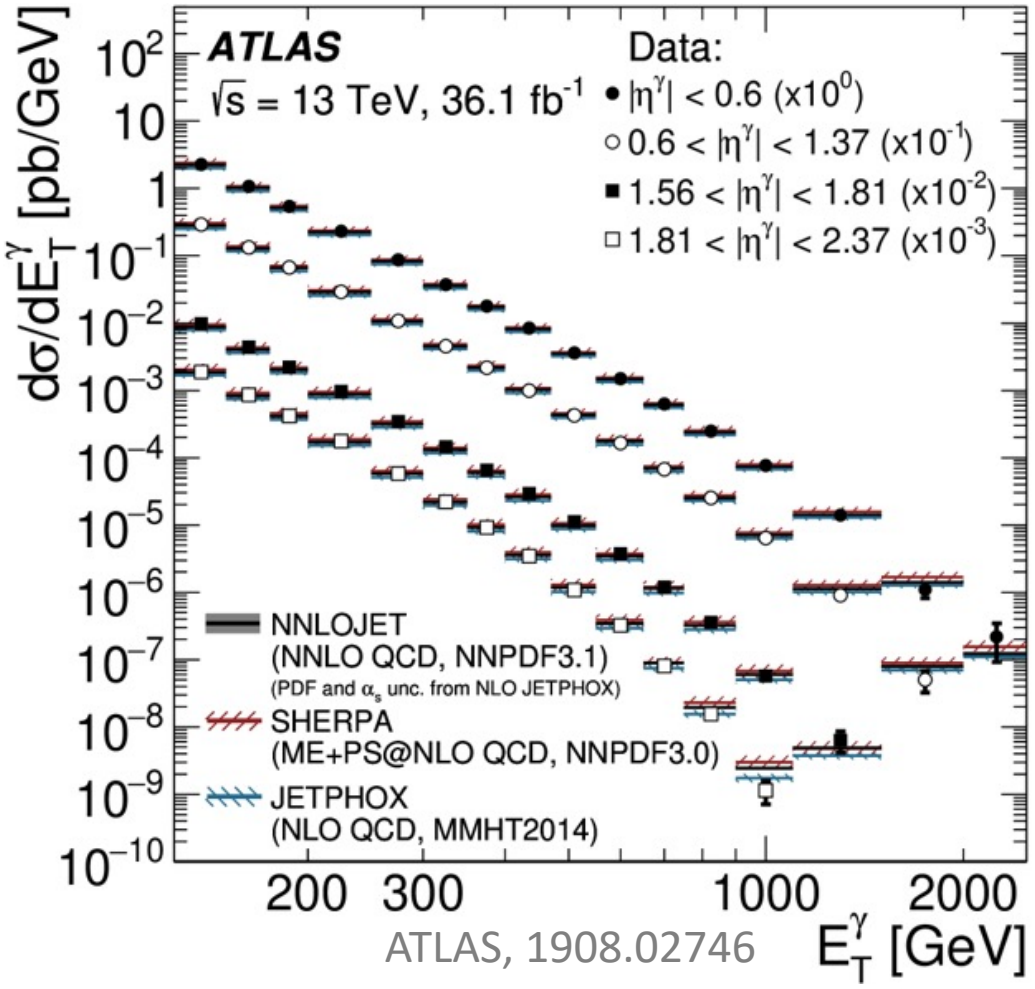
Physically, we need to find the threshold energy at which photons disintegrate in the vaccum.

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

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

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 mesurement by looking at the process : $p\,p \to \gamma\,j\,j(3)$



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 :

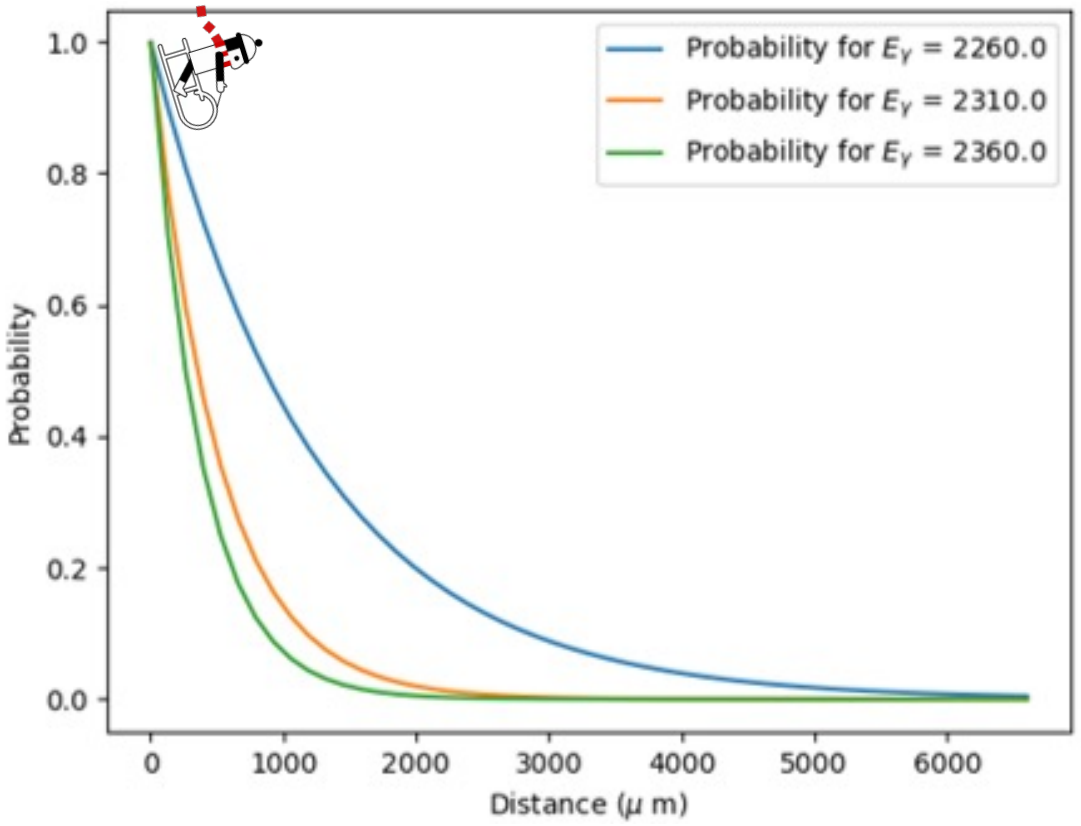
$$\frac{d\Gamma}{dE_e} = \frac{\alpha[(1-\tilde{\kappa}_{tr})[2\tilde{\kappa}_{tr}E_e(E_\gamma - E_e) + (1+\tilde{\kappa}_{tr})m^2)] - \tilde{\kappa}_{tr}{E_\gamma}^2]}{(1+\tilde{\kappa}_{tr})^2\sqrt{1-{\tilde{\kappa}_{tr}}^2}{E_\gamma}^2}$$

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

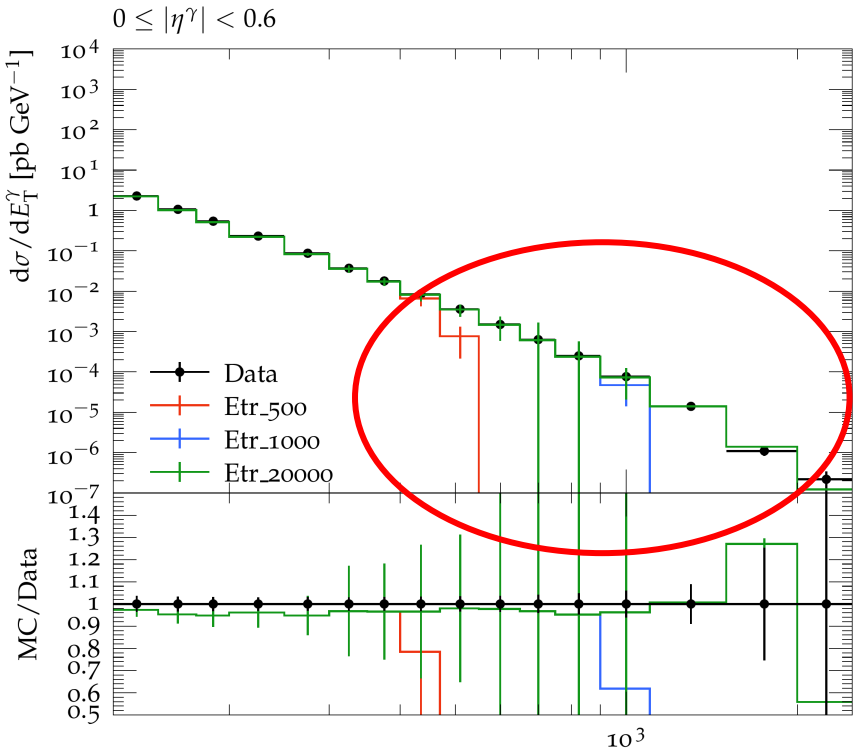
$$\bar{E} = \sqrt{\frac{1+\tilde{\kappa}_{tr}}{1-\tilde{\kappa}_{tr}}[{E_\gamma}^2 + 2(\frac{1}{\tilde{\kappa}_{tr}} - 1)m^2]}$$



Collaboration with University of Maranhao (Brazil)

Procedure

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



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

Event generation with *SHERPA*

↓

Hadronization in *SHERPA*

↓

Data analysis with *RIVET*

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)

Measurement – Statistical test

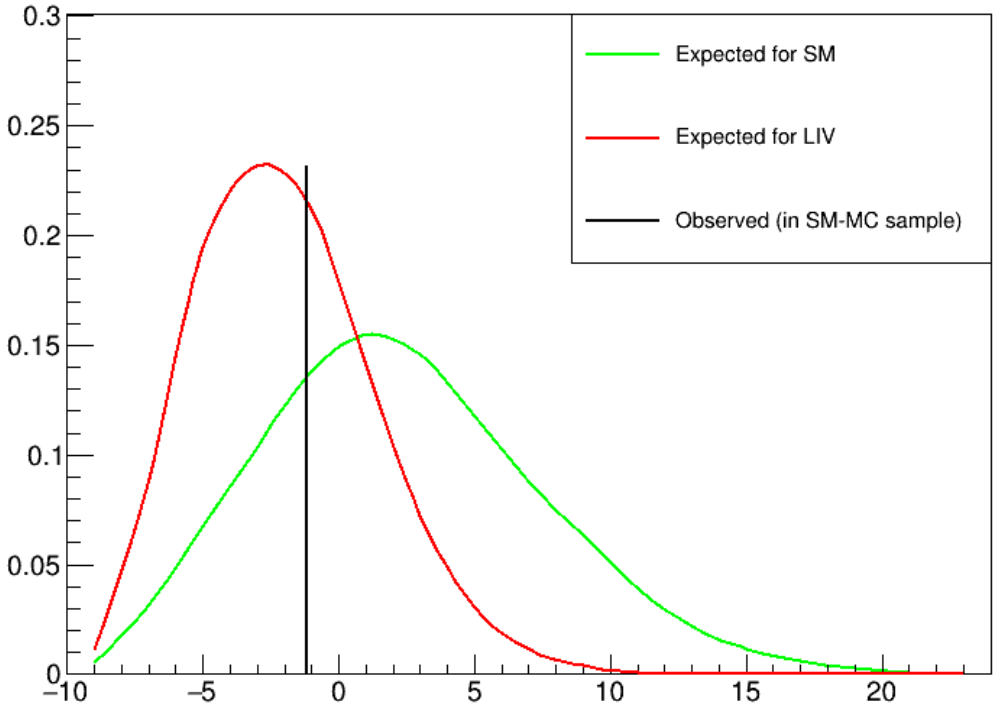
The statistical test is a log likelihood ratio. It is evaluated over the Y variable defined as :

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

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

The data systematic uncertainties are already given by the ATLAS mesurement. They include the **background substraction**, 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.



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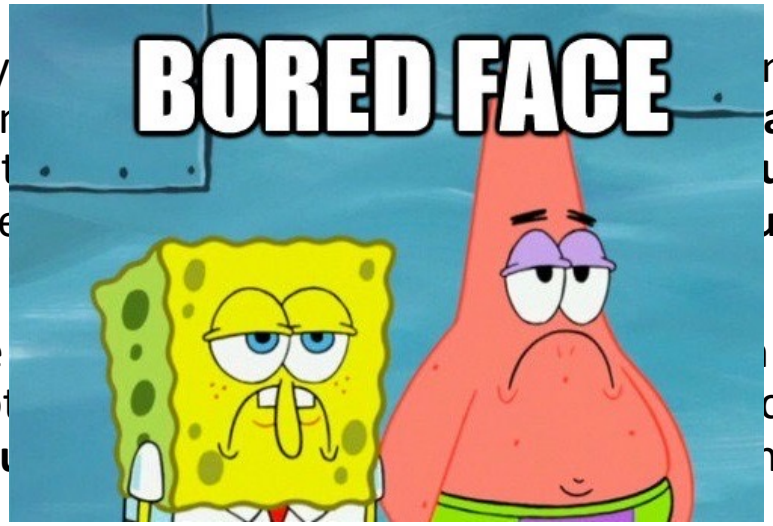

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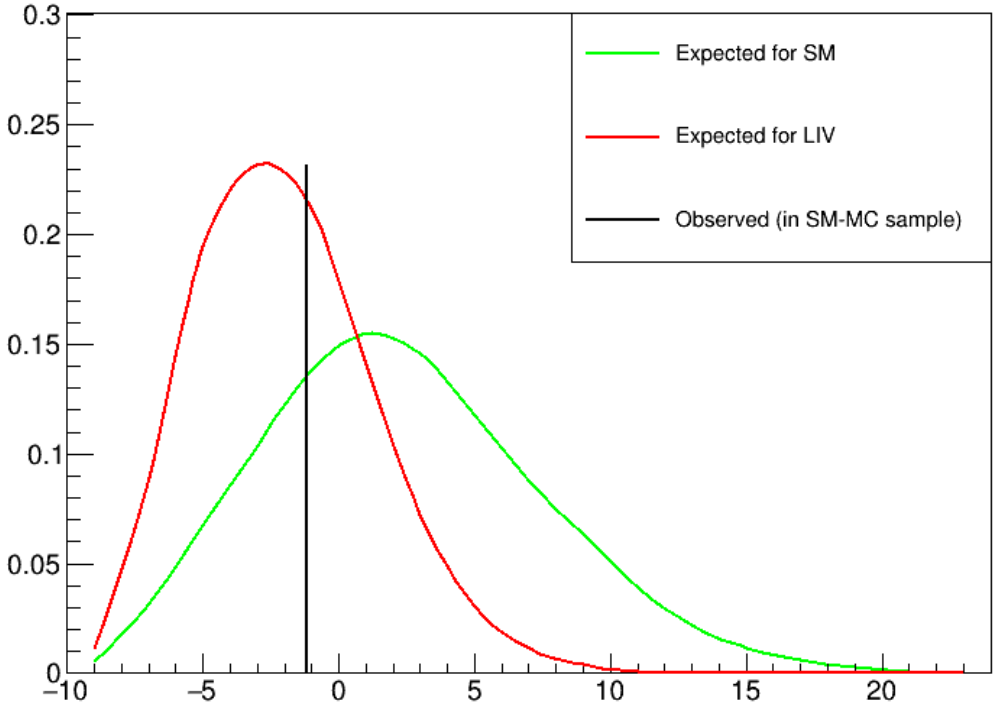


Measurement – CLs method

The CLs method is used to set upper limit on parameters

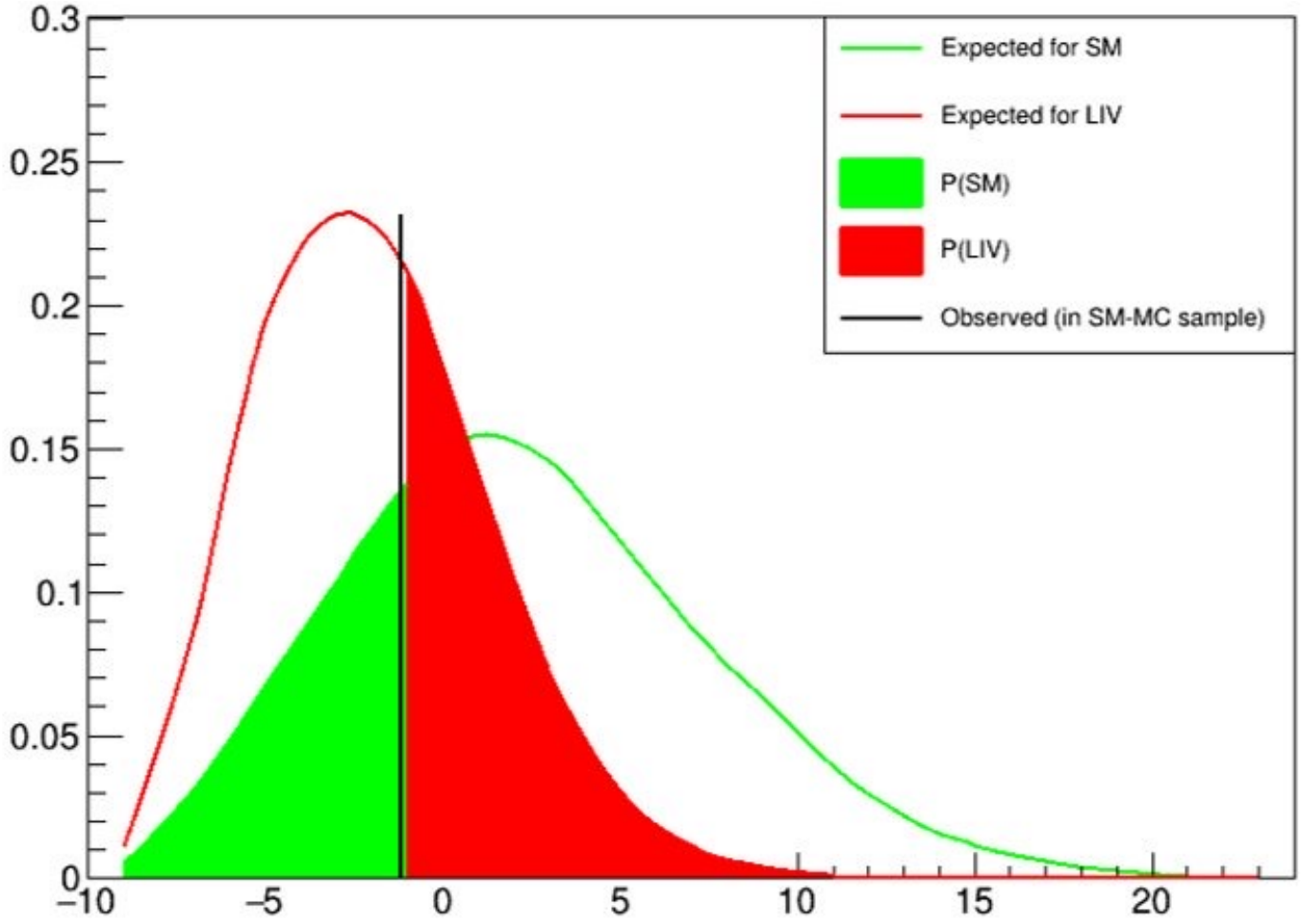
For a statistical test q, we define :

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

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

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

We use CLs < 0.05 by convention



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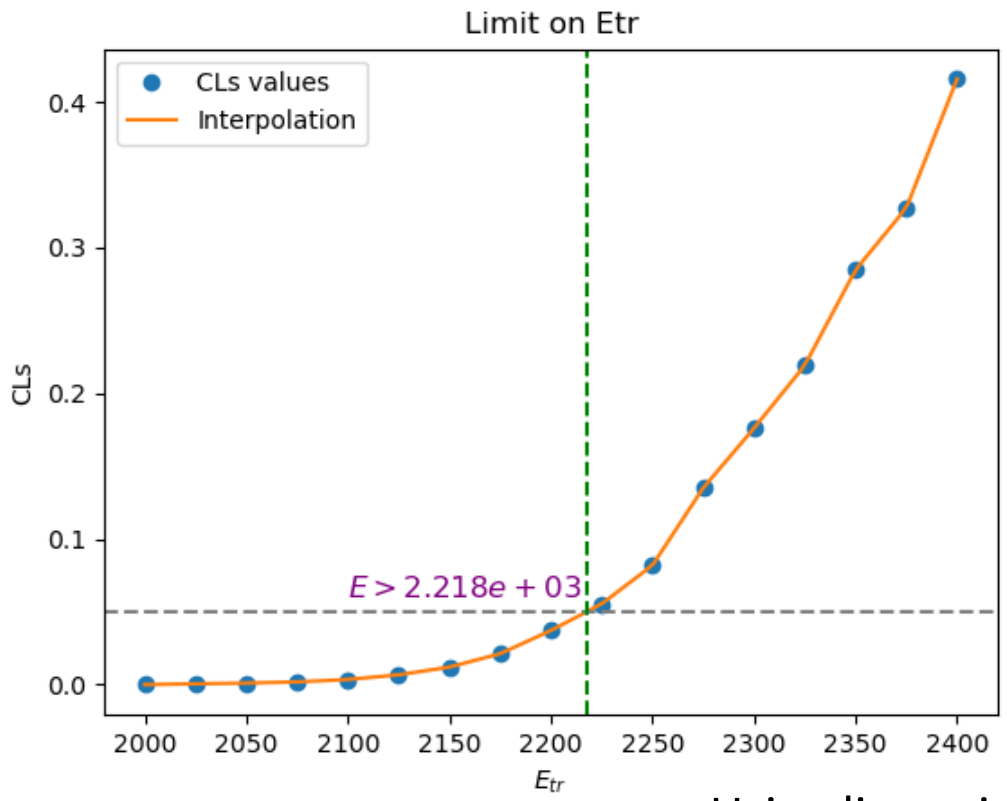
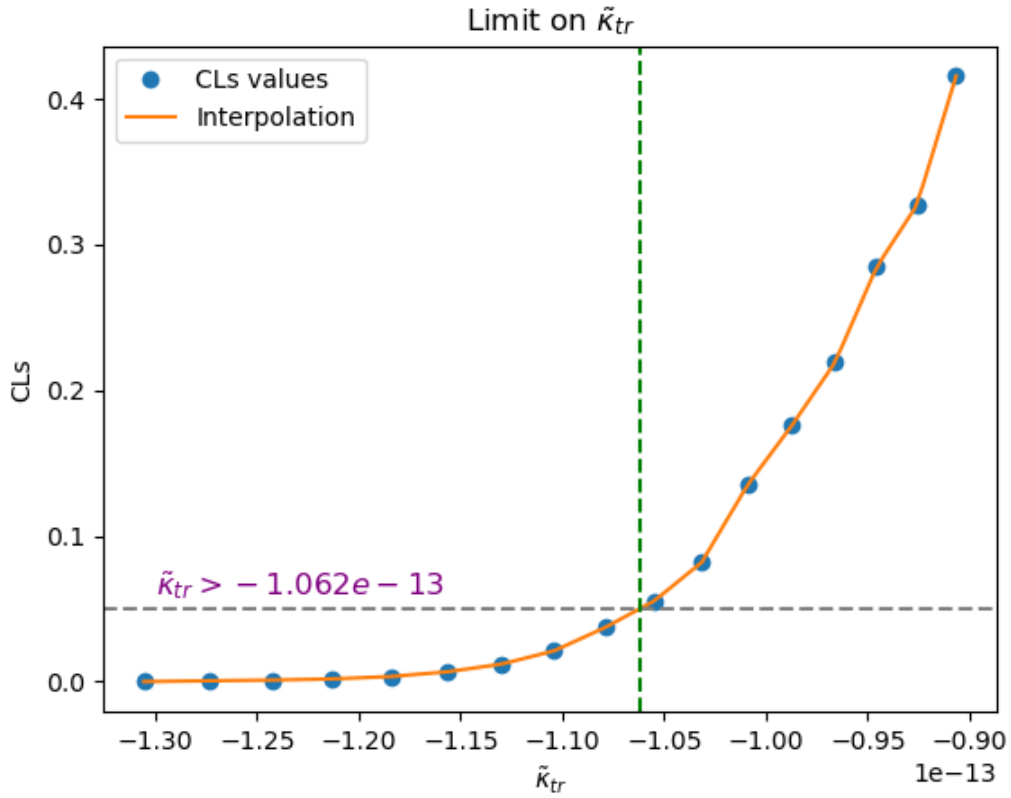


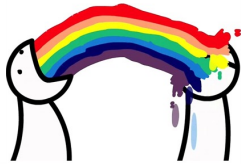


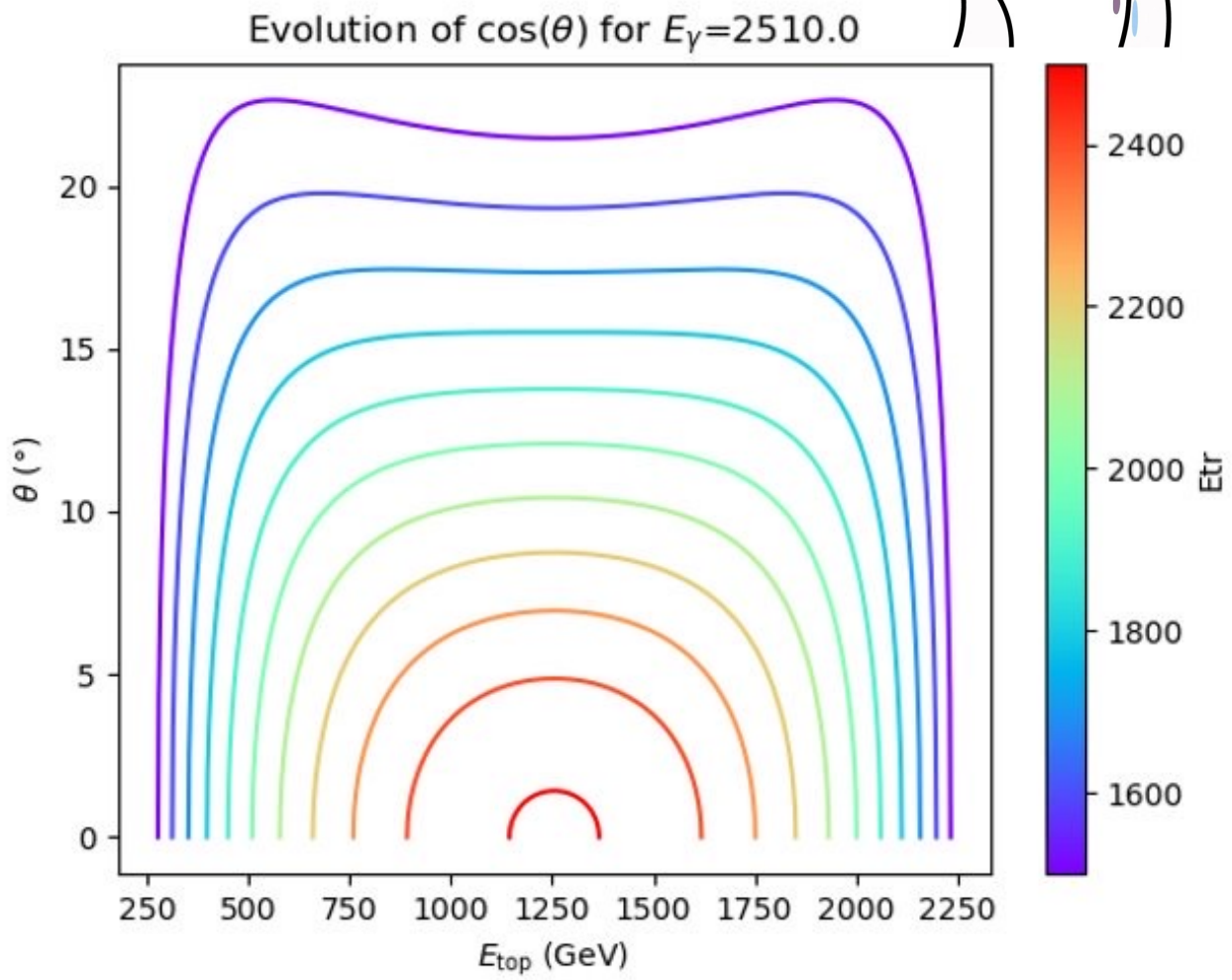
Using linear interpolation between the point,
we can set a boundery on the value :

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

Top quark physics

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





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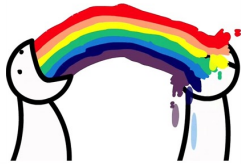
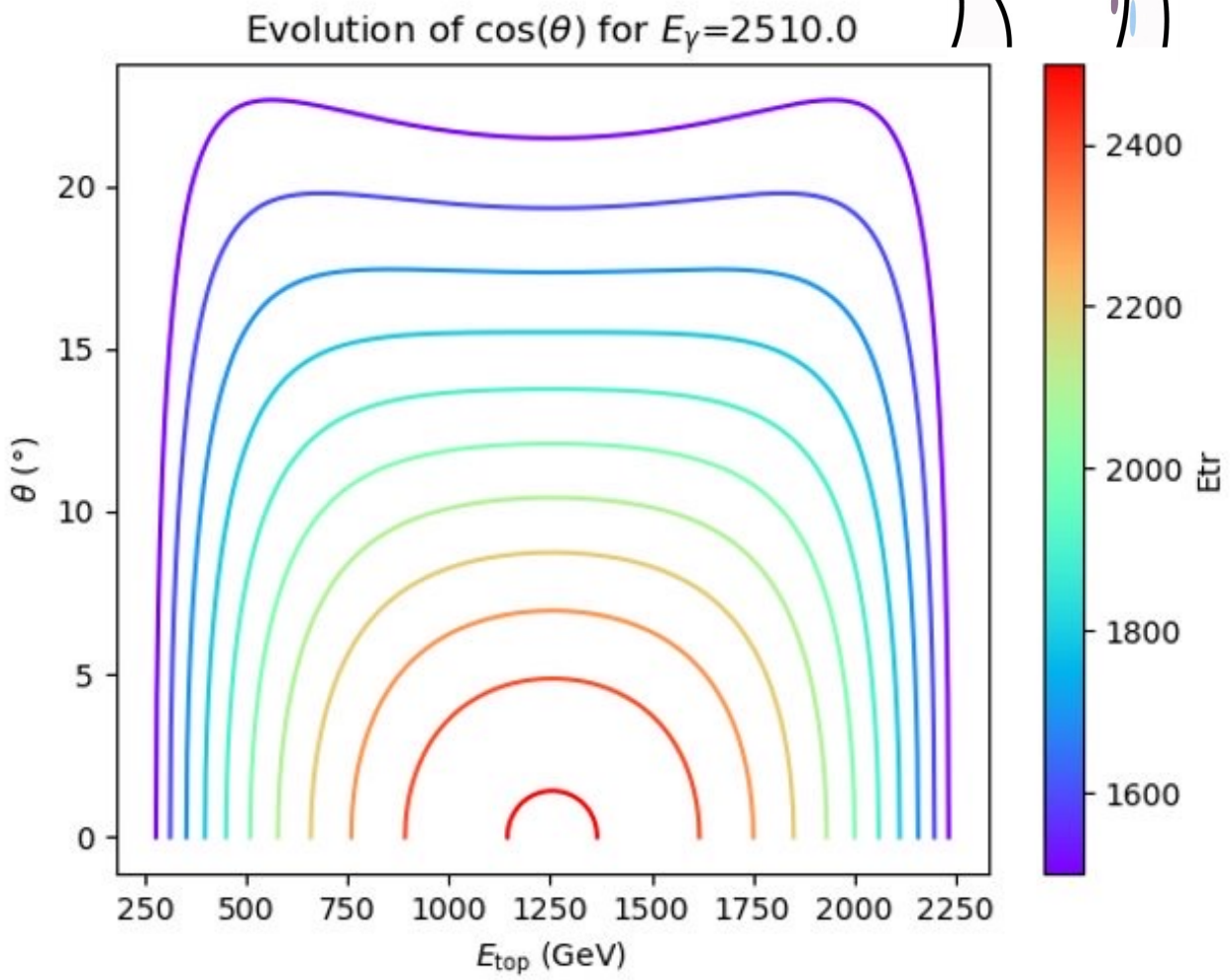
The cinematic could be used to **discriminate** between SM and LIV in order to measure $\tilde{\kappa}_{Tr}$



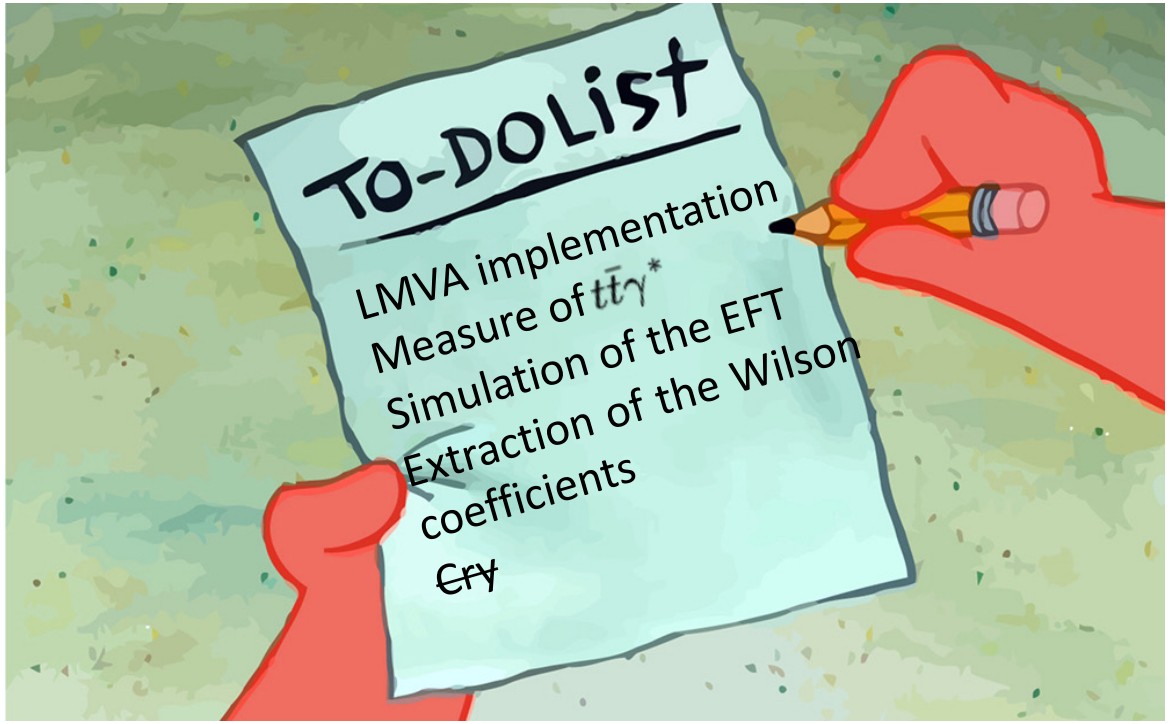


Summary

Lepton Flavor Universality

Implementation of the selection to define control and signal region

Research of discriminating variables



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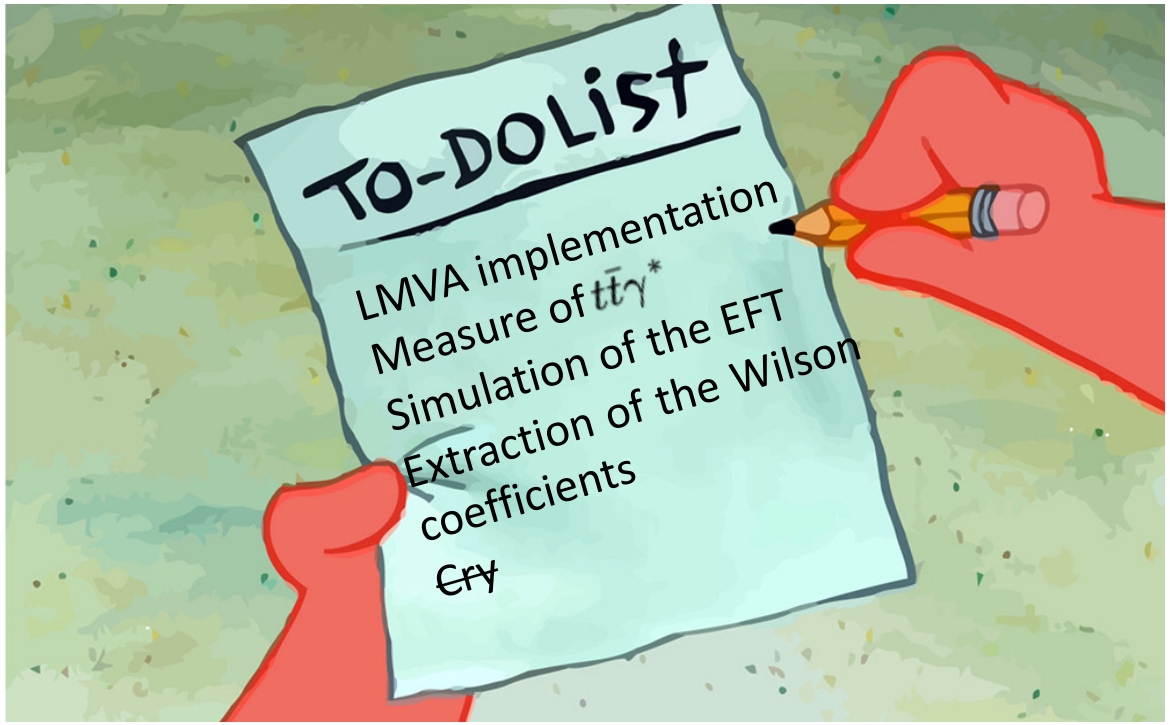

Lorentz Invariance Violation

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

Still no LIV observation

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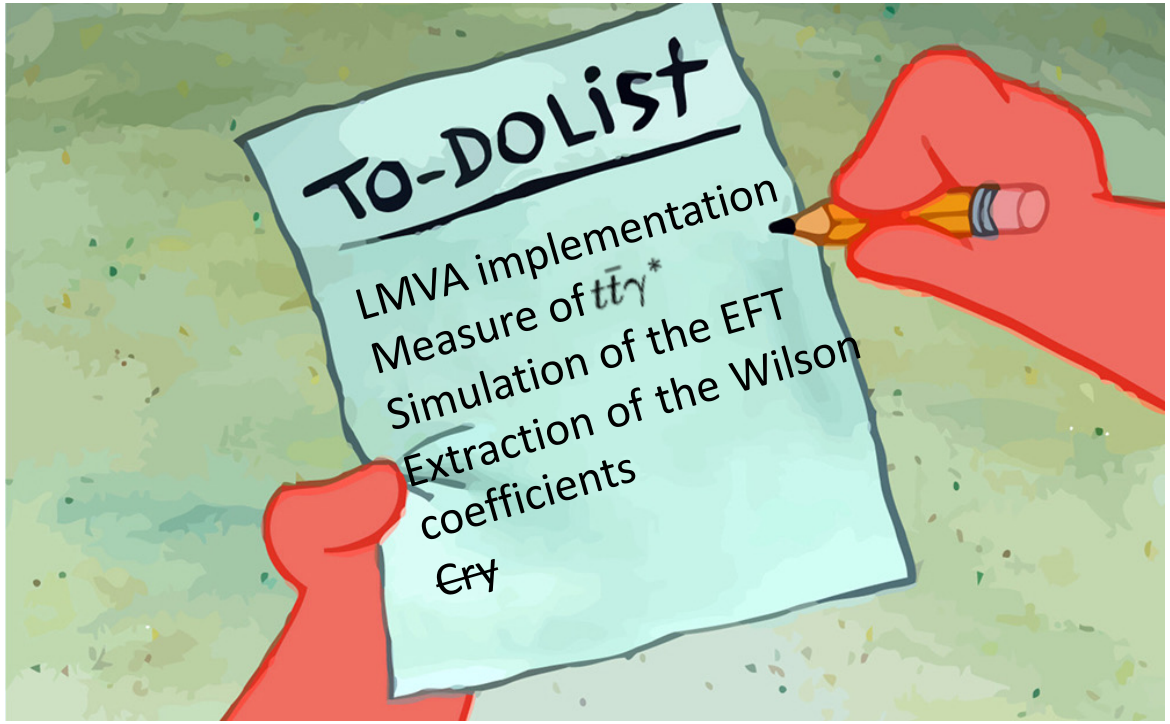

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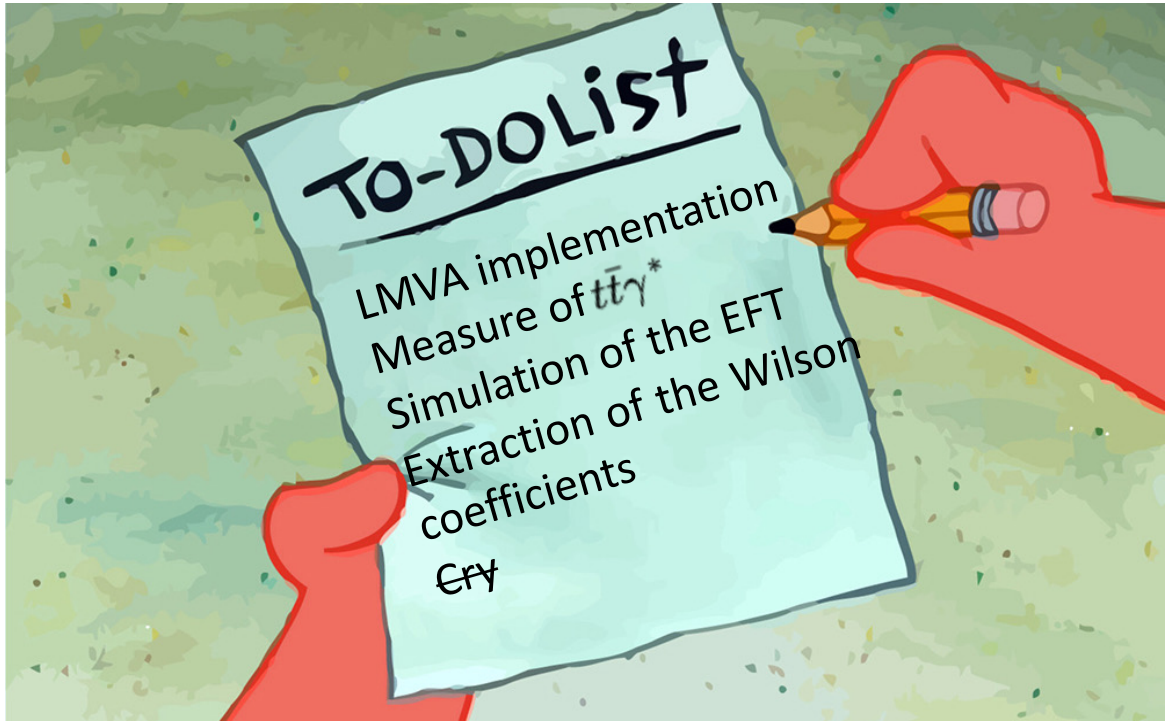

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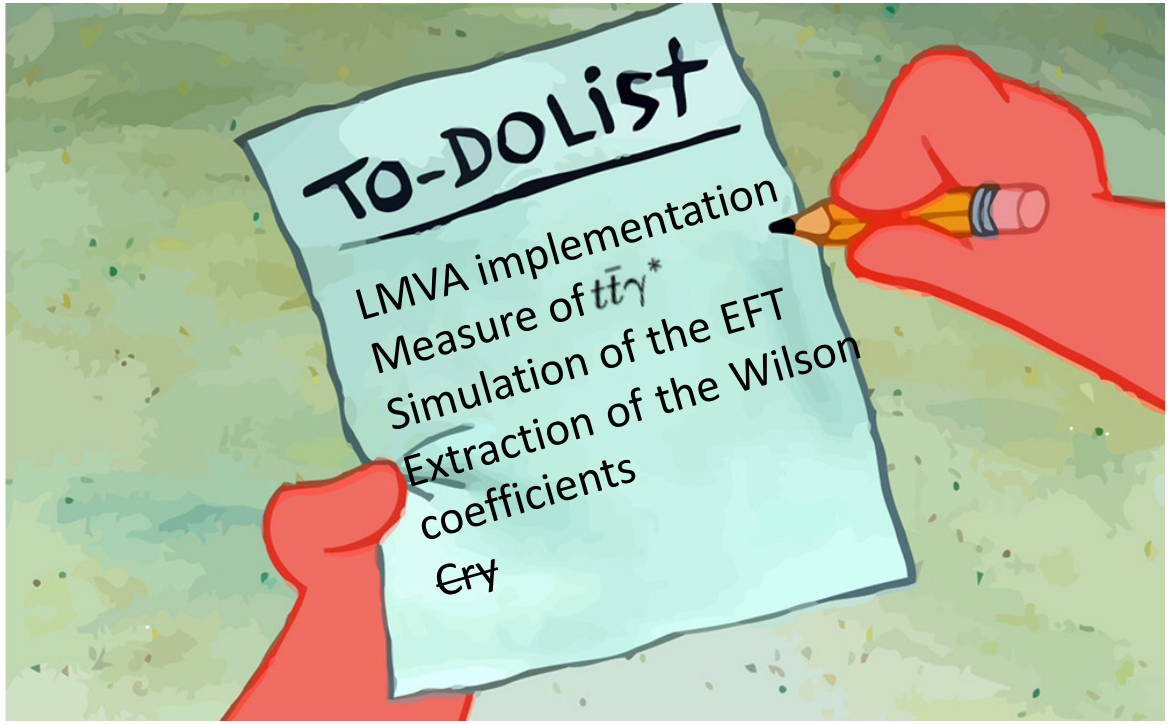

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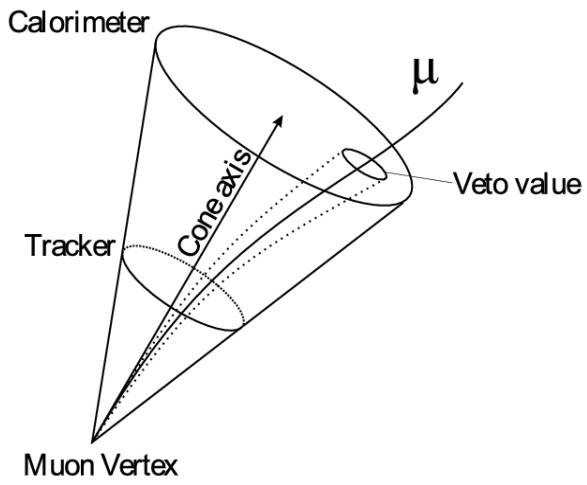


Very attention
Wow
Wow
VIA 9GAG.COM
Much thank you
Wow
So Presentation

Backup

I have no backup