Search for New Physics with the ATLAS Detector

Pedro Urrejola
on behalf of SAPHIR analysis team.

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Introduction

- SAPHIR ATLAS analyzers are currently involved in two type of physics searches.

  * Dark Photon Searches (DP)

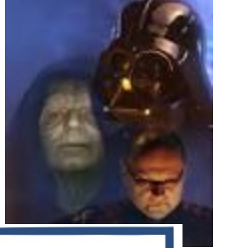
  * Contact Interaction Searches (CI)

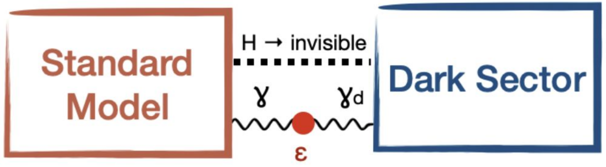
- The searches aim to probe for Physics Beyond the Standard Model (BSM) and to test the limits and precision of SM processes.
- Both searches use the Run-2 full 139 fb^{-1} of data recorded by the ATLAS detector

DARK SECTOR MODEL

- Dark matter could be part of a hidden sector that interacts with SM particles through subtle mixing
- The Higgs boson could work as a portal to a hidden sector by coupling to a dark photon
- So far, most analyses have considered new particles to decay promptly, impacting the design of the detector and reconstruction algorithms.
- The dark photon has a displaced vertex.
- The displaced vertex of the dark photon varies according to its mass and coupling

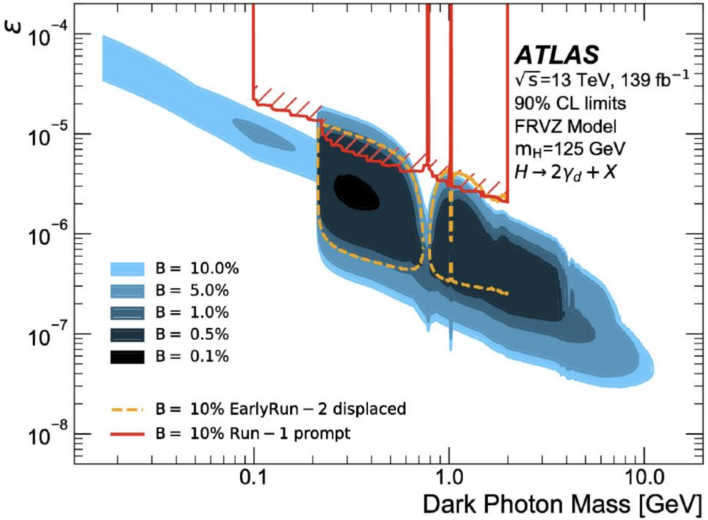
$$c\tau = \frac{1}{\Gamma_{Z_D}^{tot}} \propto \frac{1}{\epsilon^2 m_{Z_D}}$$





Small ε --> long lived yd

ggF/WH paper



DARK PHOTON JET

- Dark Photons would typically be produced with large boost due to their small mass, forming collimated jet-like structures containing leptons (lepton-jets) and/or hadrons

- The analysis divides signal lepton-jets (LJ) into two categories:

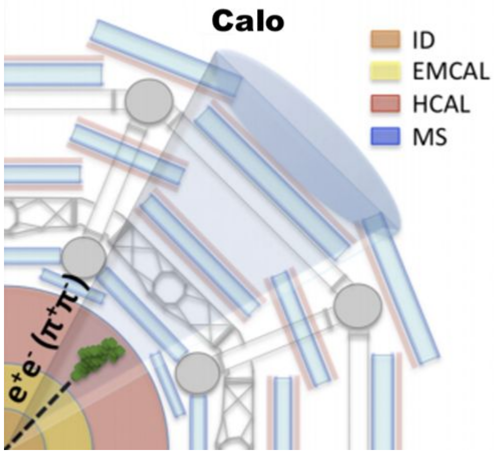
  - Muonic Lepton-Jet
  - Calorimetric (hadronic) Lepton-Jet

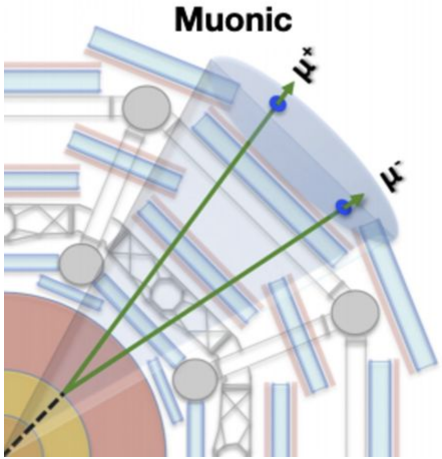
caloDPJ: $\gamma_d \rightarrow e^+e^-/qq$

- Targeting decays in HCAL
- Low EM fraction jets with no matching MS tracks

μDPJ: $\gamma_d \rightarrow \mu^+\mu^-$

- Decays outside ID acceptance
- Pair of MS tracks in R=0,4 cone
- No matching tracks in the ID



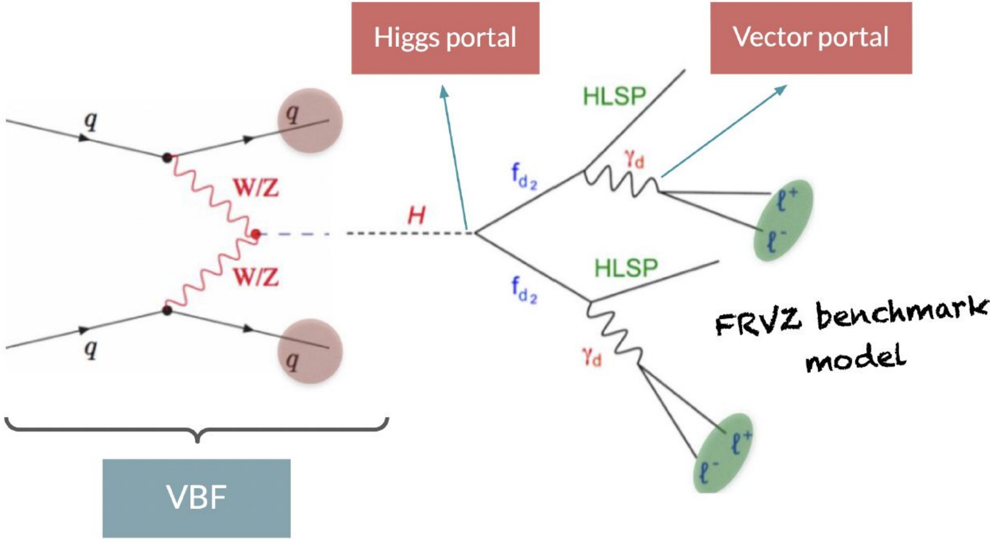


VBF ANALYSIS OVERVIEW

Pre-selection

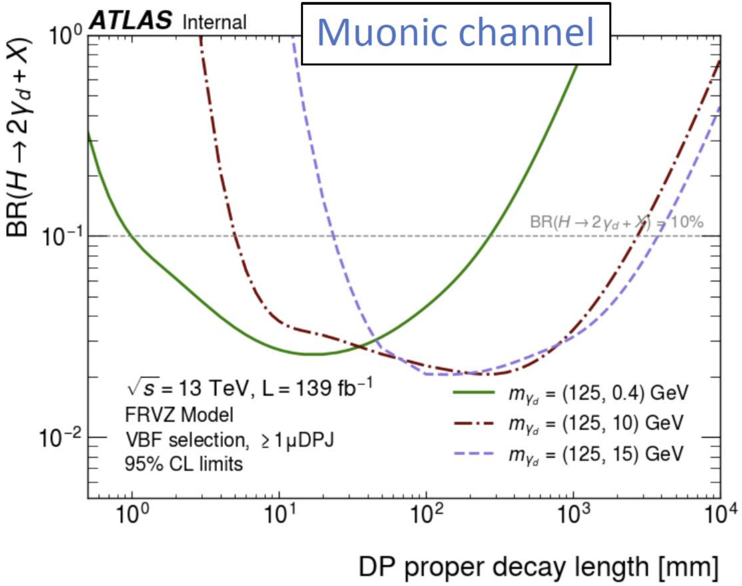
- VBF selection: require a least two jets with $p_T > 30$ GeV, and:
  - $m_{jj} > 1$ TeV, $|\Delta\eta_{jj}| > 3$, $|\Delta\Phi_{jj}| < 2.5$
- Trigger selection:
  - Muonic channel: NarrowScan or Trimuon
  - Calorimetric channel: MET
- Lepton veto (to remain orthogonal to WH analysis)
- B-jet veto (to remove top processes
- At least 1 DPJ
- $\min(\Delta\phi(j_1, \mathrm{MET})) > 0.4$

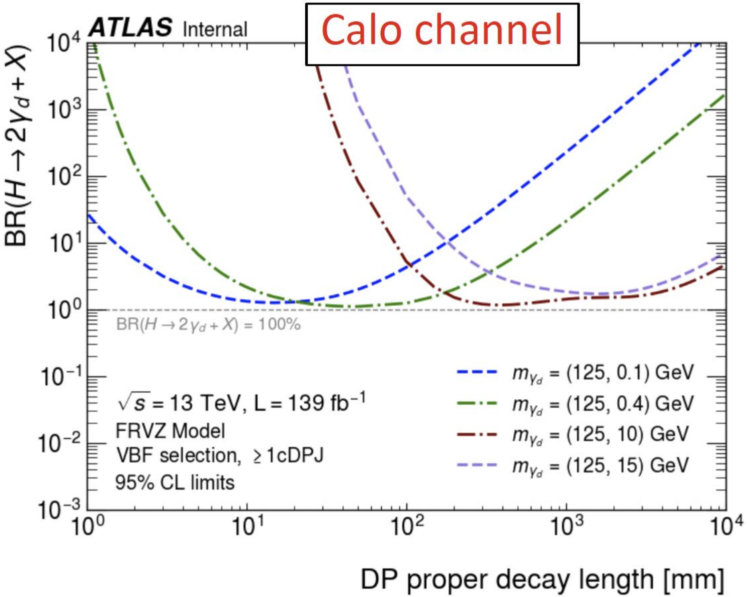
We are working on a Run-2 analysis that looks for a dark photon jet, mediated by a Higgs boson produced by **vector boson fusion VBF**



Falkowski–Ruderman–Volansky–Zupan

VBF LIMITS ON BR VS DISPLACED VERTEX





- Muonic channel: exclude $BR(H \rightarrow 2\gamma_d + X)$ down to 2% for all mass points
- Calo channel: competitive wrt. ggF/WH only at large DP mass, optimisation ongoing to improve sensitivity
- VBF has stronger exclusion power than ggF/WH at higher γ_d masses

NEXT STEPS

- Timeline:
  - Second Internal Note submitted after Christmas
  - Unblinding in a couple of weeks
  - Paper aiming for Moriond conference (March 2023)

- People involved:
  - Professors: Francisca Garay and Sebastian Olivares
  - Students: Cristobal Chavez, Michael Haacke, Mijail Quiroga, Javier Vidal

- Prospects:
  - Aiming for a Run-3 analysis by taking advantage of the new dedicated Level-1 Muon trigger for displaced vertices
  - Start with the first analysis on ZH production
  - Classify with a machine learning algorithm the Higgs production modes (ggF, VBF, WH, and ZH)

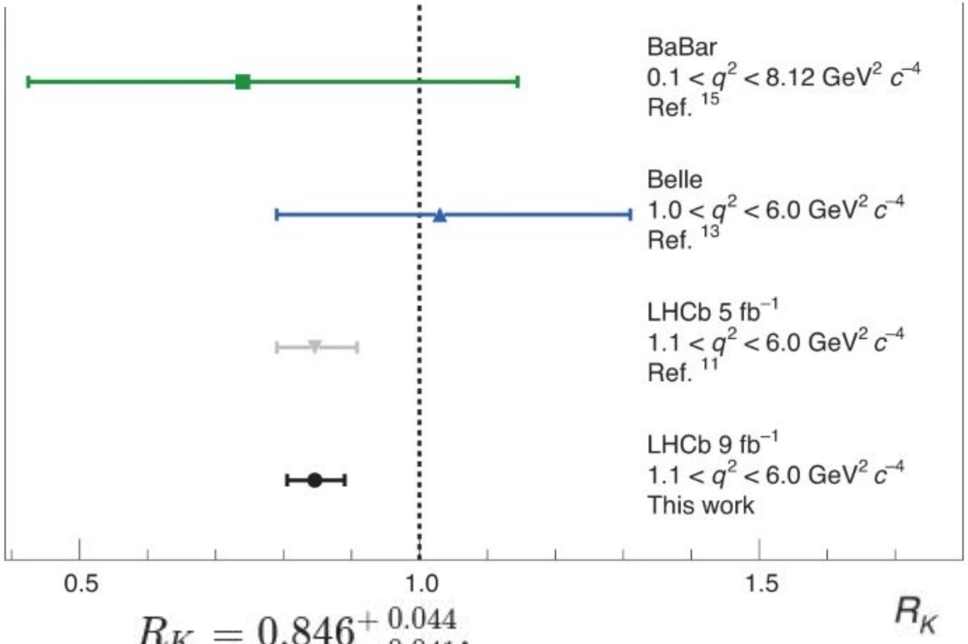
- Looking for students for the new Run-3 analysis!

Contact Interactions

Initially motivated by the lepton flavor universality violation hints in B decays
R_K determined via the double ratio of branching fractions:

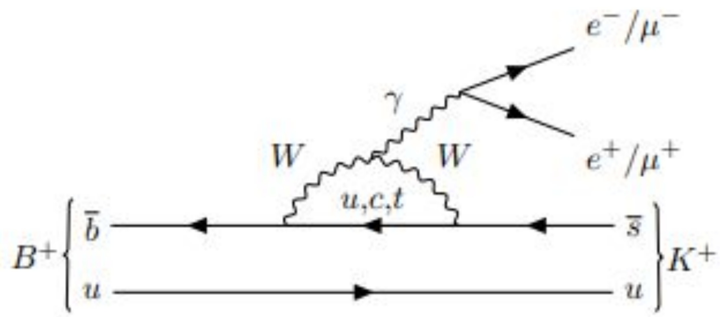
$$R_K = \frac{\dfrac{\mathcal{B}\,(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}\,(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)}}{\dfrac{\mathcal{B}\,(B^+ \to K^+e^+e^-)}{\mathcal{B}\,(B^+ \to J/\psi(\to e^+e^-)K^+)}}$$

Comparison between R_K measurements.

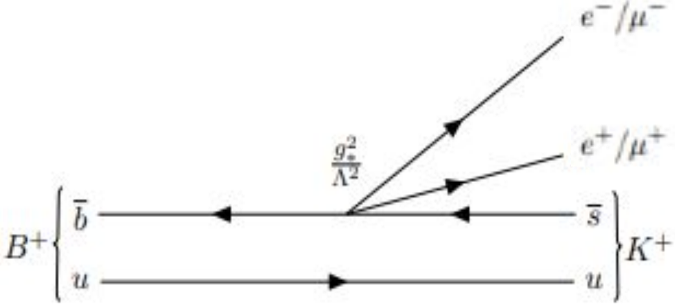


$$R_K = 0.846^{+\,0.044}_{-\,0.041}.$$

Consistent with SM expectation at 0,10% (3,1 σ)

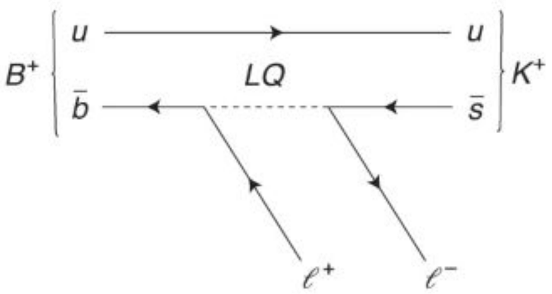


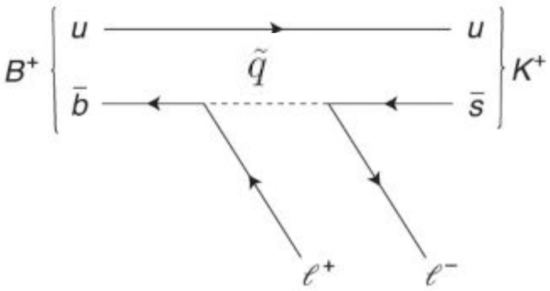
SM 1 loop Penguin Diagram

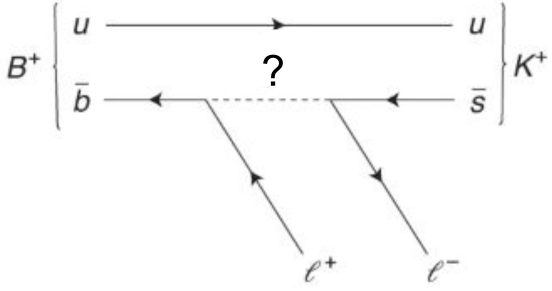


BSM Tree Level Contact Interaction Diagram

The vertex may include different interpretations such as squarks, leptoquarks and others:







STATUS AND PROSPECTS

Previous *bsll* contact interaction ATLAS search already exists, and showed no excess over Standard Model prediction.

Different interpretations or possibilities, we focus on contact interactions integrating out higher energy degrees of freedom working with Effective field Theories (EFT).

In particular we search for three CI vertices:

$$b\bar{b}\ell\ell$$

$$t\bar{u}_i\ell\ell(u_i = u, c)$$

$$t\bar{t}\ell\ell$$

Depending on the EFT, we search for signals with at least 2 Opposite Sign (OS) and Same Flavor (SF) leptons plus 0, 1 or 2 b-jets

$b\bar{b}\ell\ell$ framework

$$\mathcal{L}_{eff} = \frac{g^2}{\Lambda^2} \sum_{i,j=L,R} (\eta_{ij} \bar{b}_i \gamma_\mu b_i)(\bar{\ell}_j \gamma^\mu \ell_j)$$

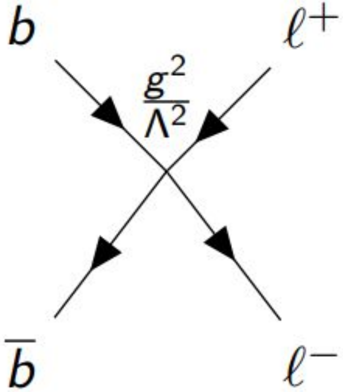
Only b-quarks.
$\ell = \mu, e$.
Λ is the scale of the BSM physics.
All possible chirality structures with $\eta_{ij} = \pm 1$.
We set $g = \sqrt{4\pi}$.

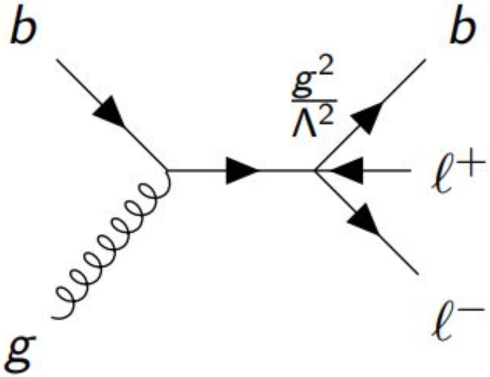
$$\sigma(m_{\ell\ell}) = \sigma^{SM}(m_{\ell\ell}) + \frac{g^2}{\Lambda^2} \cdot \sigma^{SM\times NP}(m_{\ell\ell}) + \frac{g^4}{\Lambda^4} \cdot \sigma^{NP\times NP}(m_{\ell\ell})$$

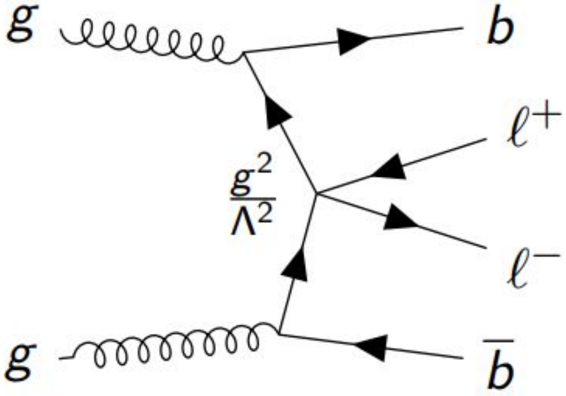
Destructive Interference if <0

$\sigma^{SM\times NP} \propto (\sqrt{s})^2$ and $\sigma^{NP\times NP} \propto (\sqrt{s})^4$ thus, a hard di-lep spectrum is expected.

Depending on the production channel, there could be 0, 1 or 2 b-jets in the final states

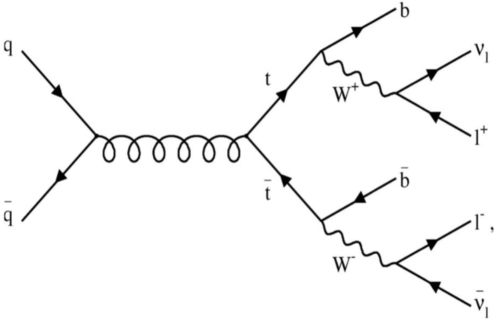




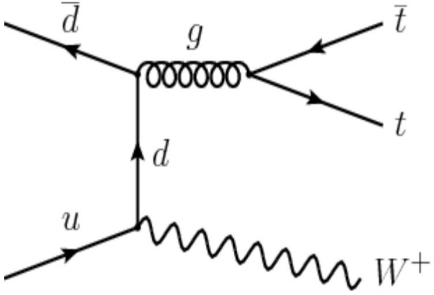


Dominant Background:

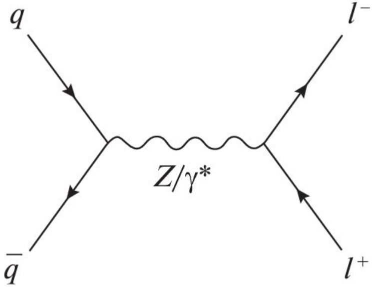
ttbar



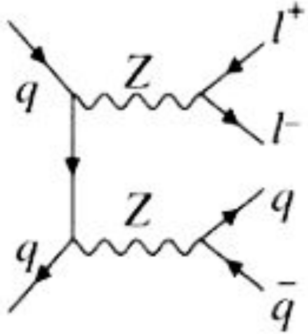
ttbar+Z/W



Drell-Yan (Z/γ)



Diboson (VV)

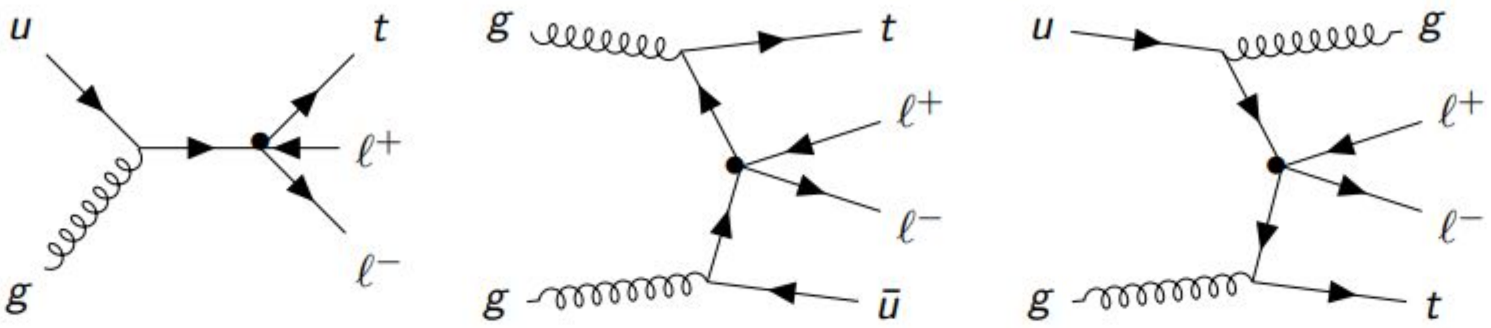


$t\bar{u}_i\ell\ell$

$$\mathcal{L}_{tu\ell\ell} = \frac{1}{\Lambda^2} \sum_{i,j=L,R} \left[V_{ij}^{\ell} \left(\bar{\ell}\gamma_\mu P_i \ell\right) \left(\bar{t}\gamma^\mu P_j u\right) + S_{ij}^{\ell} \left(\bar{\ell} P_i \ell\right) \left(\bar{t} P_j u\right) + T_{ij}^{\ell} \left(\bar{\ell}\sigma_{\mu\nu} P_i \ell\right) \left(\bar{t}\sigma_{\mu\nu} P_j u\right) \right]$$

Up-type quarks: $u = u, c$.

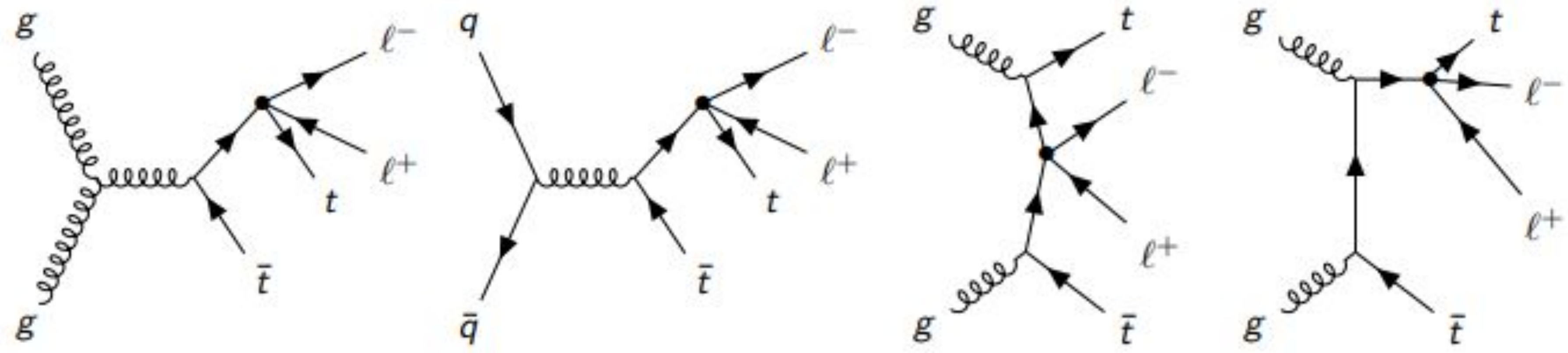
V_{ij}, S_{ij}, T_{ij} are the couplings of the vector, scalar and tensor scenarios



$t\bar{t}\ell\ell$

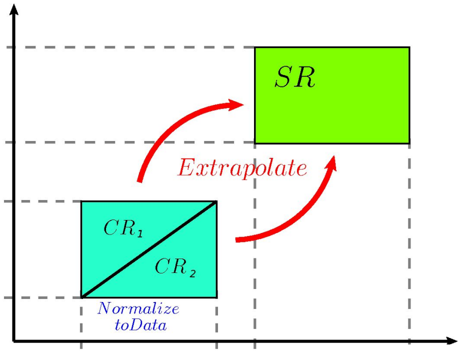
$$\mathcal{L}_{tt\ell\ell} = \frac{1}{\Lambda^2} \sum_{i,j=L,R} \left[V_{ij}^{\ell} \left(\bar{\ell}\gamma_\mu P_i \ell\right)\left(\bar{t}\gamma^\mu P_j t\right) + S_{ij}^{\ell}\left(\bar{\ell} P_i \ell\right)\left(\bar{t} P_j t\right) + T_{ij}^{\ell}\left(\bar{\ell}\sigma_{\mu\nu} P_i \ell\right)\left(\bar{t}\sigma_{\mu\nu} P_j t\right)\right]$$

V_{ij}, S_{ij}, T_{ij} are the couplings of the vector, scalar and tensor scenarios



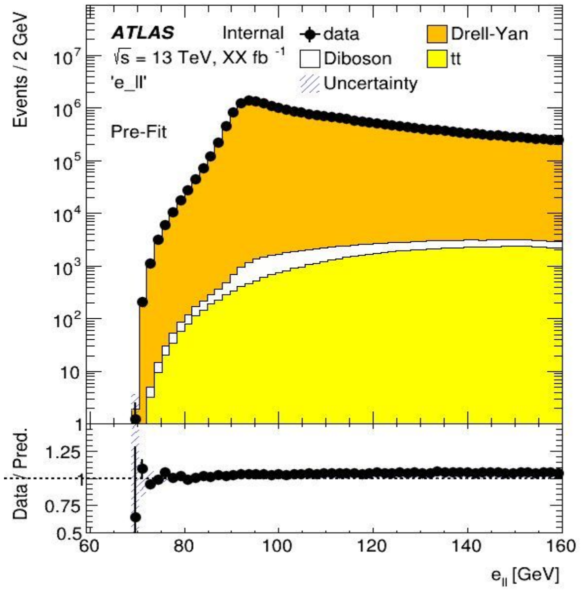
All processes have 2 leptons, jets and at least 2 b-jets from top decay in the final states

Strategy



- Build Control Regions for the three dominant Backgrounds:
  - Top
  - Diboson
  - Drell-Yan

Work In Progress



- Normalize Background to Data in the Control Regions, get normalization factors (NF).

- Normalization factors are then used to extrapolate background rates to the associated SR.

- The small statistical uncertainties on the background prediction in the CR, extrapolated to the stringent SR phase space, narrows the influence of possibly large systematic uncertainties in such extreme scenarios.

SR	Z-CR	VR	CR-top
Preselection			
$p_T^{\mathrm{lead.lep}} > 65 GeV$, $p_T^{\mathrm{jets}} > 30 GeV$			
$ee/\mu\mu$			$e\mu$
$m_{\ell\ell} > m_{\ell\ell}^{min}$	$70 GeV < m_{\ell\ell} < 110 GeV$	$110 GeV < m_{\ell\ell} < 400 GeV$	$m_{\ell\ell} > 130 GeV$
1,2 b-tagged jets			
To be added: $N_j > 2/3/4$			

SRs: looking at the tail of $m_{\ell\ell}$.

Using $e\mu$ to estimate the Top background.

Using the $m_{\ell\ell}$ window around the Z-peak for the estimation of Z+jets.

Top background at high $m_{\ell\ell}$: extrapolation.

To be added: Multijet.

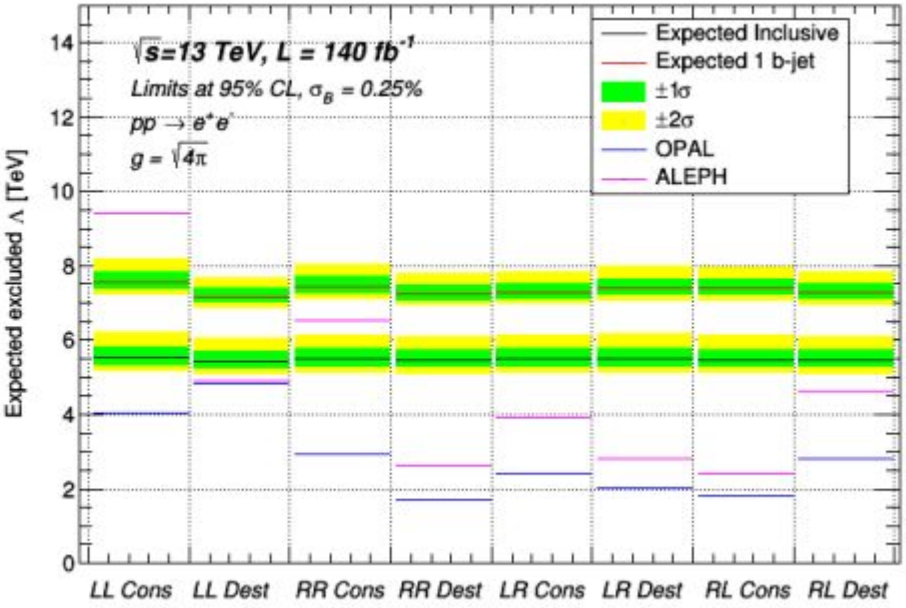
To be added: minimum number of jets.

Currently working on the optimization of Signal Regions:

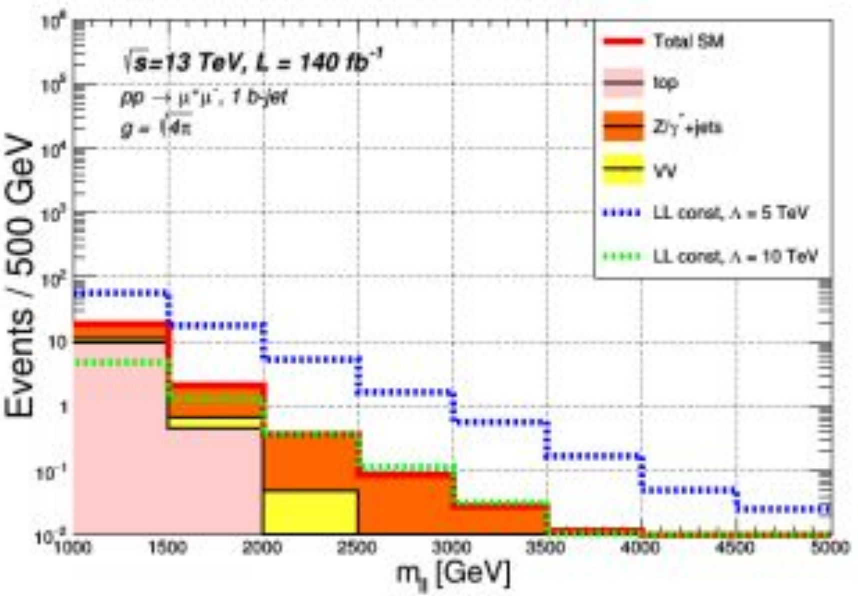
Key Variables: $m_{\ell\ell}$ *N_b-jets*

Other Variables: *lep_pt, jet_pt, N_jets*

For the *bbll* EFT, the most Sensitive channel is LL Const in 1 b-jet region.



incl: mll>2TeV 1 b-jet: mll>1.5 TeV



Kinematic distributions for the di-muon invariant mass

- Timeline:

Contact Interaction interpretation within the dilepton + X analysis is part of 1 Paper aiming to summer conferences in 2023.

A second paper aims to measure the μμ/ee ratio with selections on the number of b-jets.
This is a SM precision analysis using an “unfolding” procedure.
This second analysis is in initial stages. Timescale: Moriond 2024.

- People involved:

Pedro Urrejola (PostDoc) & Felipe Arellano (Graduate Student, Master)

After december 2022 LHCb resuls:

The results are compatible with the SM at 0.2σ level

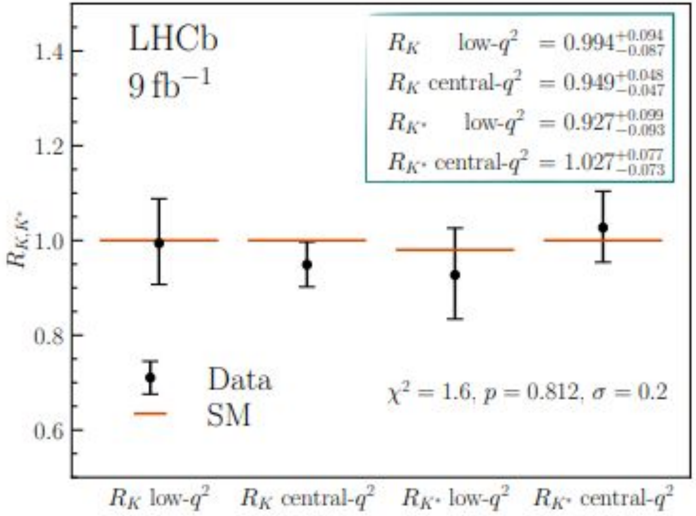
In-depth revision and understanding of electron misidentification in this analysis

I personally take these results in a very conservative and even skeptical manner.

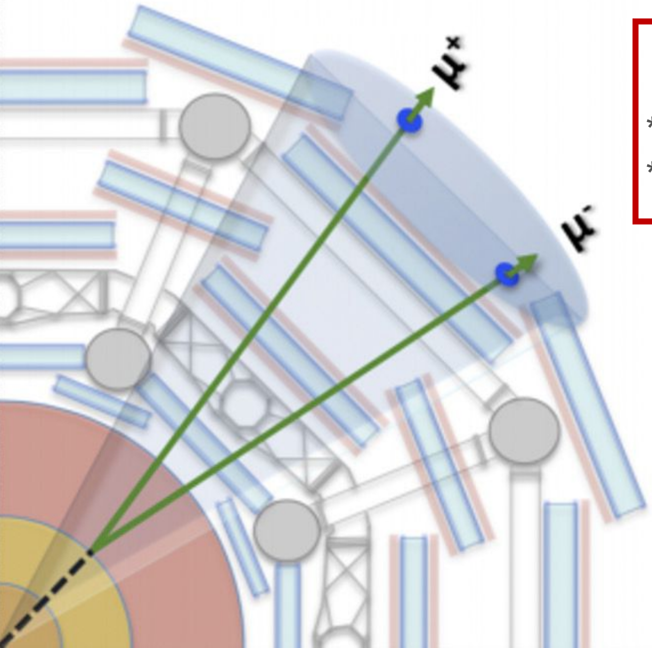
¿Is our motivation Gone?

Not much.

LHCb previous results were an extra motivation, the motivation now is similar to any other LHC search. LFU is not an SM or hard theoretical requirement.



MUONIC CHANNEL SELECTION



Trigger

- Narrow Scan targets μDPJ
- Trimuon optimal for 4-γ_d scenario

Further selection

- DPJ centrality (wrt. VBF jets) > 0.7
- MET > 100 GeV

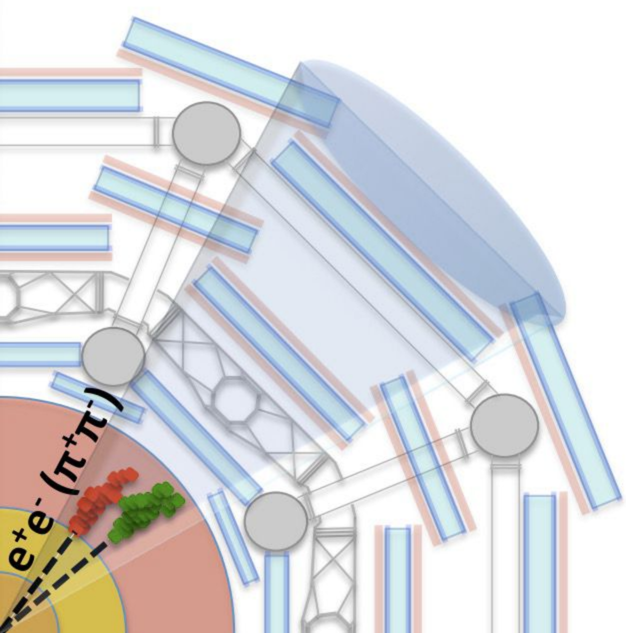
μDPJ

* Reject cosmics: μ DNN score > 0.5
* Veto MS crack : 1.0 ⩽ $|\eta|$ ⩽ 1.1

ABCD selection

- μDPJ charge = 0
- μDPJ ID track isolation < 2 GeV

HADRONIC CHANNEL SELECTION



Trigger

- MET

Further selection

- MET > 225 GeV

caloDPJ quality cuts

- BIB tagger score > 0.2 – rejects BIB
- Exclude calorimeter overlap region
- Jet vertex tagger score < 0.4

ABCD selection

- caloDPJ tagger score > 0.9
- caloDPJ ID track isolation < 2 GeV

Object definition and event selection.

Trigger: Loose Di-electron and Medium Single Muon

Feature	Criterion
Pseudorapidity range	$\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.47$
Energy calibration	es2018_R21_v0 (ESModel)
Transverse energy	$E_T > 25$ GeV
Track to vertex association	$\lvert d_0^{BL}(\sigma)\rvert < 5$ $\lvert\Delta z_0^{BL}\sin\theta\rvert < 0.5$ mm
Identification	Medium (and LooseAndBLayer for Matrix Method)
Isolation	FCTight

Electron Definition

Feature	Criterion
Selection working point	High-pT
Isolation working point	TightTrackOnly_VarRad
p_T cut	25 GeV
$\lvert\eta\rvert$ cut	$\lvert\eta\rvert < 2.5$
d_0 significance cut	$\lvert d_0^{BL}(\sigma)\rvert < 3$
z_0 cut	$\lvert\Delta z_0^{BL}\sin\theta\rvert < 0.5$ mm

Muon Definition

Jets: Anti kT with R=0.4 (b-jets: DL1r at 85%)

Observable	Requirement
Jet cleaning	LooseBad
BatMan cleaning	No
p_T	> 20 GeV
$\lvert\eta\rvert$	< 4.5
JVT	> 0.5 for $p_T < 60$ GeV, $\lvert\eta\rvert < 2.4$

Missing Energy:

Reconstruction: Form Jets

Calibration: Using Soft track-based term.

Overlap Removal: eμ, jμ, je