Journées rencontres jeunes chercheur 2023

Session : Beyond the Standard Model

Search for a new leptonically decaying neutral vector boson in association with missing transverse energy in proton–proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector

Laboratoire d'Annecy de physique des particules
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1 - The **ATLAS** experiment at the **LHC**

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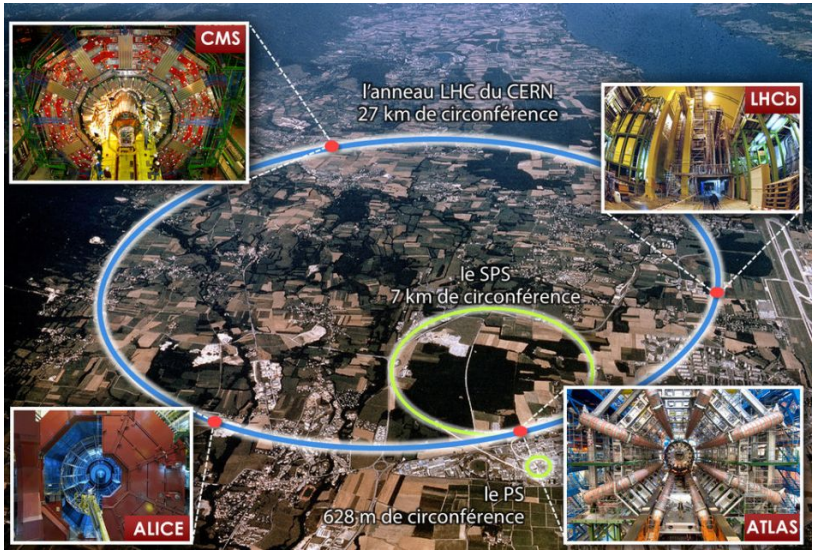
★ *Large Hadron Collider* (LHC)

- Proton collider (and heavy ion)
  - ➢ √s = 13.6 TeV
  - ➢ Collision rate = 40 MHz

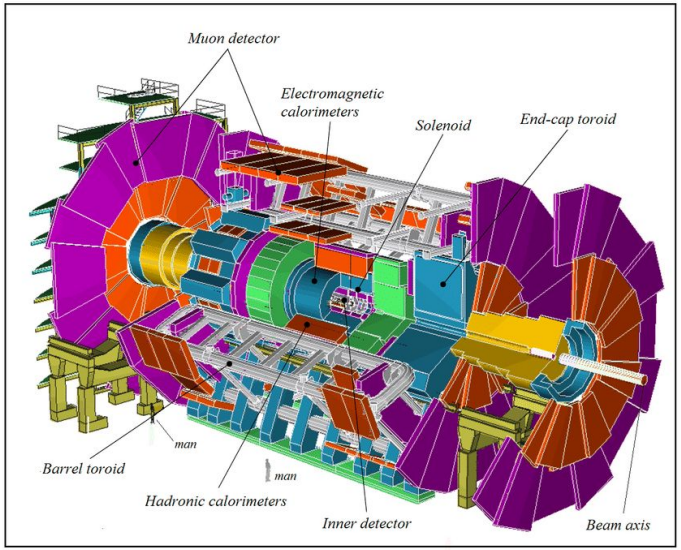
- Localisation : Geneva
  - ➢ 4 collision points
    - ■ LHCb, Alice, CMS et **ATLAS**!

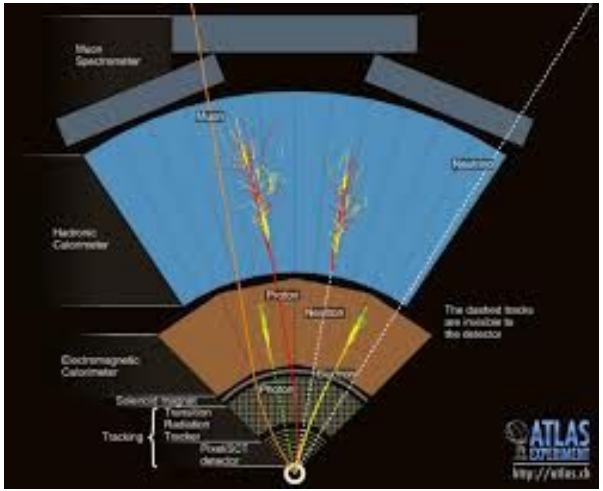


1 - The **ATLAS** experiment at the **LHC**

★ A Toroidal LHC ApparatuS (ATLAS)

- General purpose detector
- Composed of layers of sub-dectectors :
  - Tracker : position, charge, momentum
  - Calorimeter (electromagnetic and hadronic) : energy, position
  - Muon spectrometer : Momentum, position





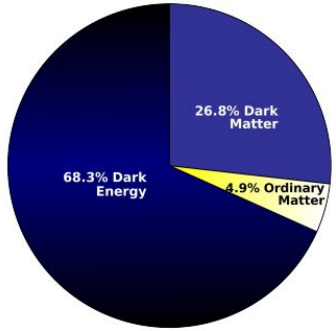
- weakly interactive particle like neutrinos are not directly detected

2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

Standard Model (SM) is working very well

But... some questions remain...

dark matter, dark energy, gravity…



Need to look beyond !

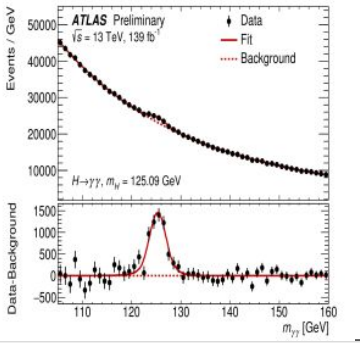
direct searches

Indirect searches

New resonances

Precision measurement of SM processes

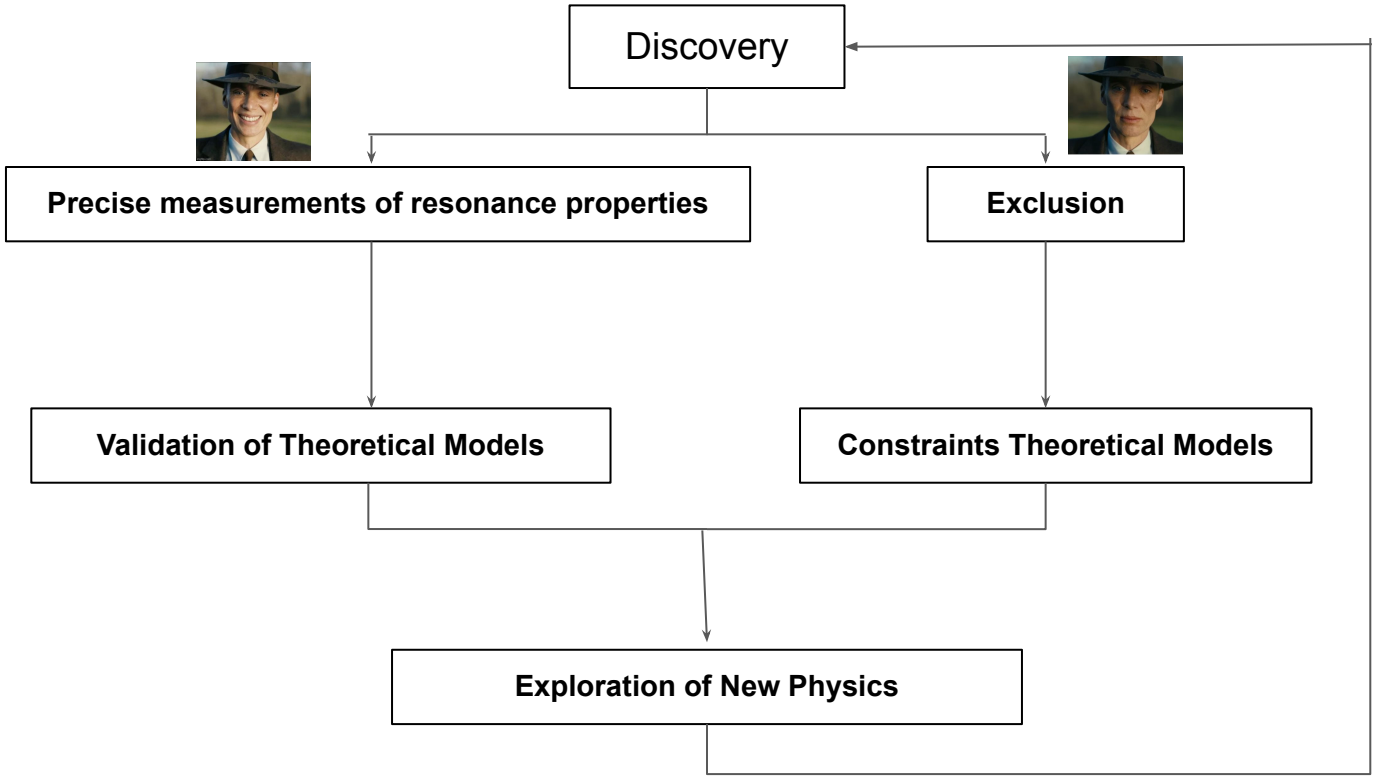
e.g.
Higgs boson discovery



My interest in final state with two leptons

2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ ***AIM***



2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

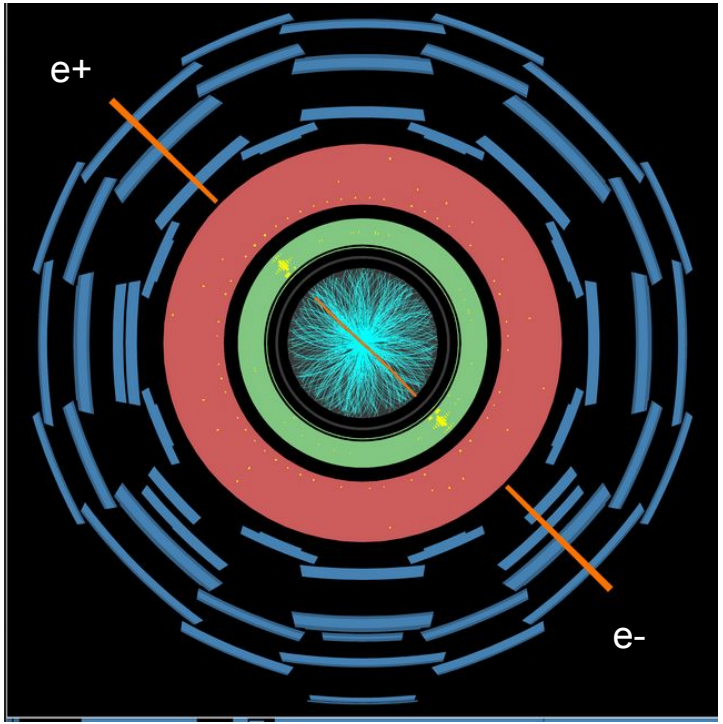
★ *From inclusive to exclusive search*

❖ **Theoretical motivation :**

➢ New Z' gauge boson in BSM theories.

- Additional SU(2) or U(1) gauge symmetry.
- TeV scale.

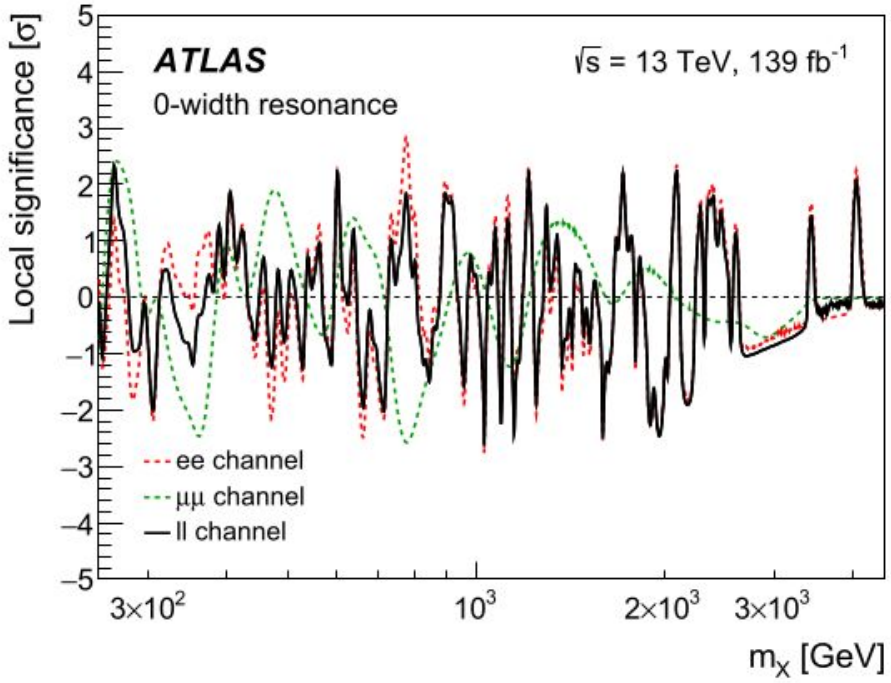
m_ee = 4.06 TeV



2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *From inclusive to exclusive search*

- **Inclusive** search : **pp -> ℓℓ**
  - No discovery found by ATLAS and CMS.

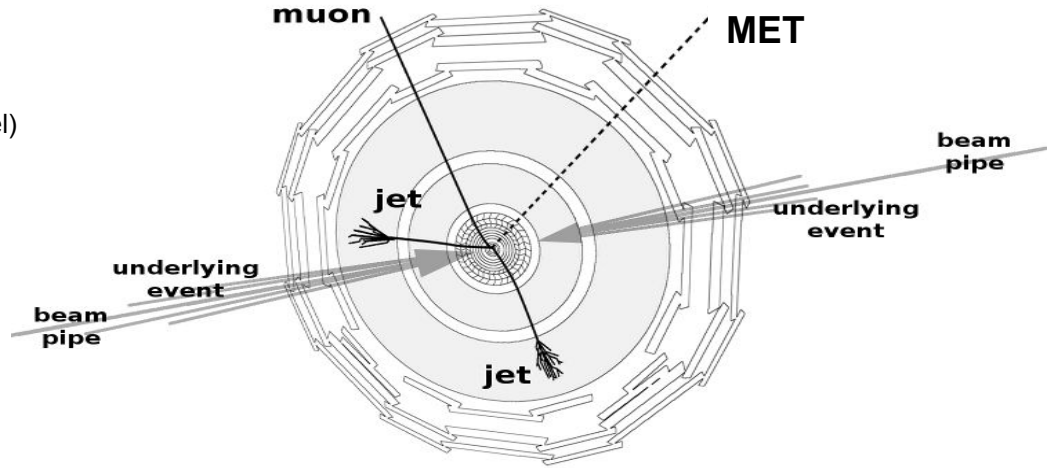


2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *From inclusive to exclusive search*

- My focus : **Exclusive** search : **pp -> ℓℓ + X**
  - **Reduce SM backgrounds** + better sensitivity
  - Channels investigated at LAPP :
    - X = dark matter particles (Z'+**MET** channel)

ATLAS detector during collision



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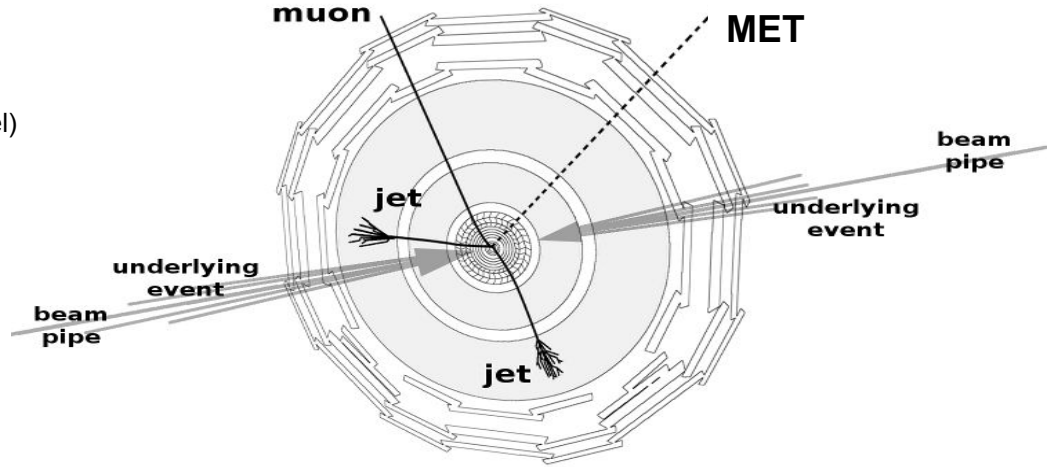

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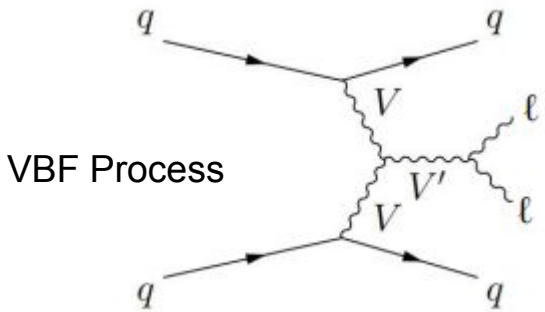
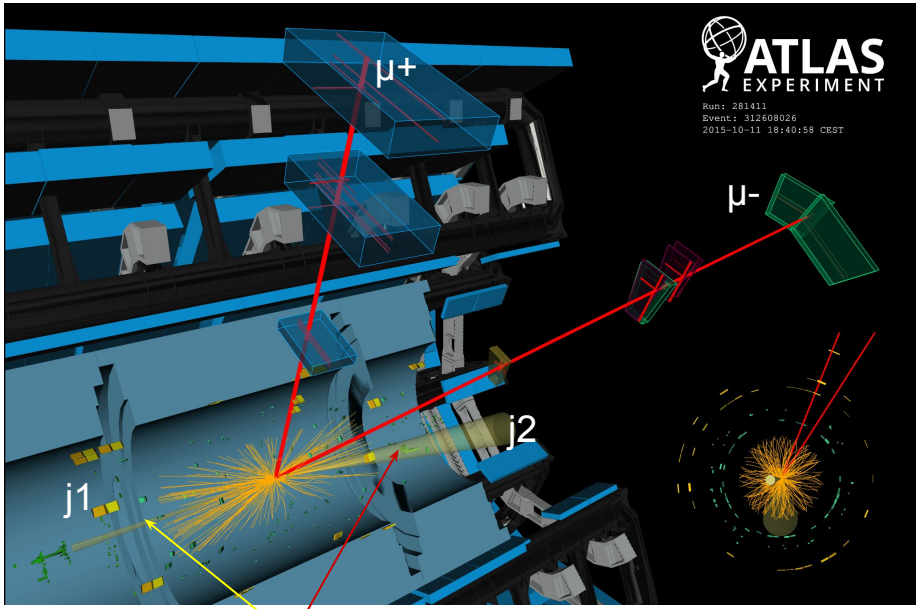
  - **Reduce SM backgrounds** + better sensitivity
  - Channels investigated at LAPP :
    - X = dark matter particles (Z'+MET channel)
    - X = 2 back-to-back jets (**VBF** channel)



VBF Process



forward jets

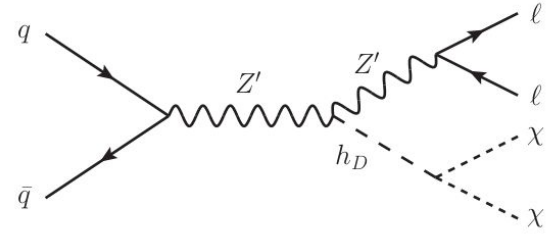
2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Z'+MET benchmark signal models*

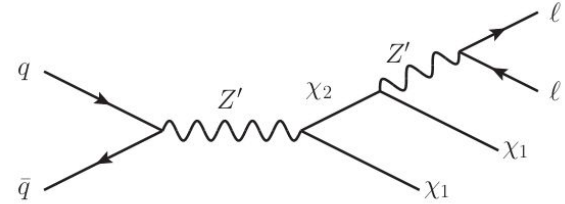
- 2 signal models
- 6 parameters per model :
  - 3 couplings: gq, gl and gD
  - 3 masses
- Z' mass: 200 - 1000 GeV
- Dark sector particles masses :

	Dark Higgs	Light Vector
Light dark-sector	$m_\chi = 5$ GeV	$m_{\chi_1} = 5$ GeV
	$m_{h_D} = 125$ GeV	$m_{\chi_2} = m_{\chi_1} + m_{Z'} + 25$ GeV
Heavy dark-sector	$m_\chi = 5$ GeV	$m_{\chi_1} = m_{Z'}/2$
	$m_{h_D} = m_{Z'}$	$m_{\chi_2} = 2m_{Z'}$

Dark Higgs:



Light Vector:



https://arxiv.org/pdf/1504.01386.pdf

2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Analysis strategy*

Search in the dilepton invariant mass spectrum resonances with the run 2 dataset

- Selections to look for interesting events :
  - 2 identified oppositely charged leptons (electrons or muons)
  - Large missing transverse energy (> 55 GeV)
  - b-jet veto
  - …

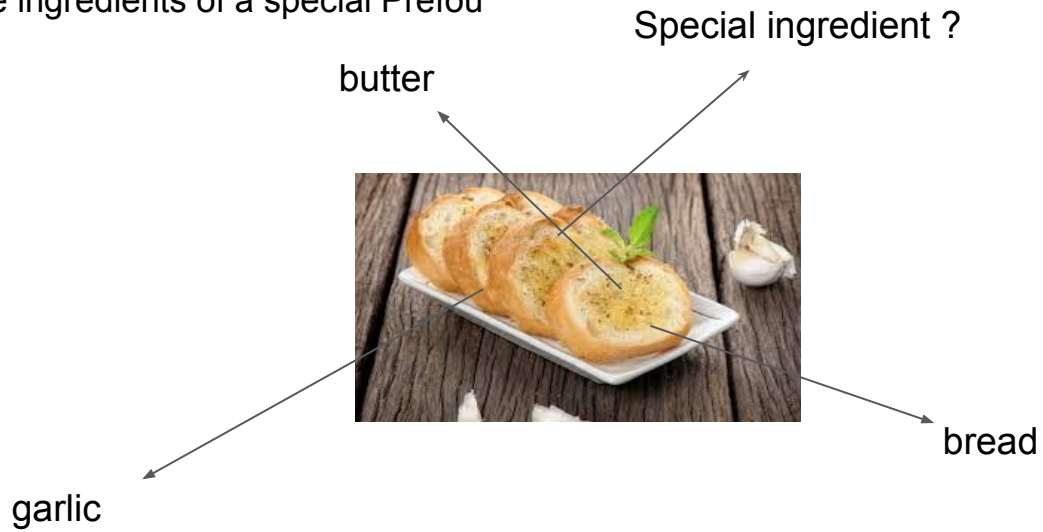
2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Analysis strategy*

Search in the dilepton invariant mass spectrum resonances with the run 2 dataset

- ❖ Test compatibility between SM processes and data
  - ➢ Identified the dominant backgrounds
  - ➢ Same task as trying to find all the ingredients of a special Préfou

★ Special Préfou
- ○ Cooked during 2015-2018
- ○ at 180°C
- ○ stable oven condition



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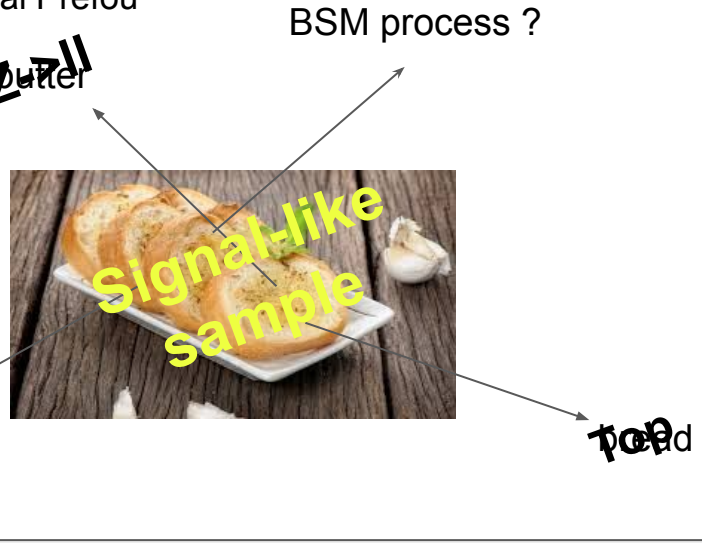
★ *Analysis strategy*

Search in the dilepton invariant mass spectrum resonances with the run 2 dataset

- ❖ Test compatibility between SM processes and data
  - ➢ Identified the dominant backgrounds
  - ➢ Same task as trying to find all the ingredients of a special Préfou

- ★ Signal-like sample
  - ○ Collect during 2015-2018 (Run2)
  - ○ at √s=13 TeV
  - ○ stable beam condition



2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Analysis strategy*

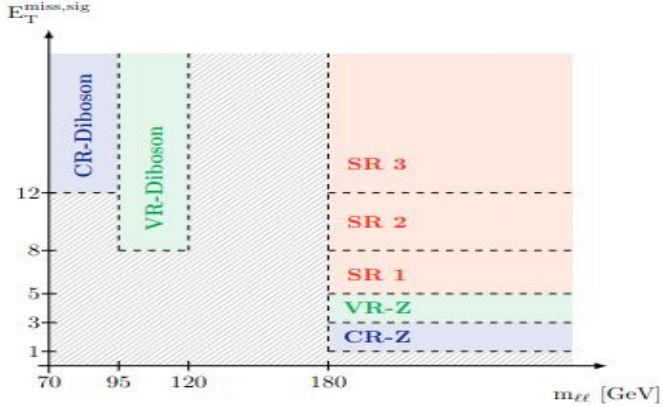
- Generated **signal samples** for Z' mass spreading from **200 GeV to 1 TeV**.
  - Add selection on m_ll > 180 GeV
  - Using MC samples every 100 GeV + morphed samples to have a continuous scan

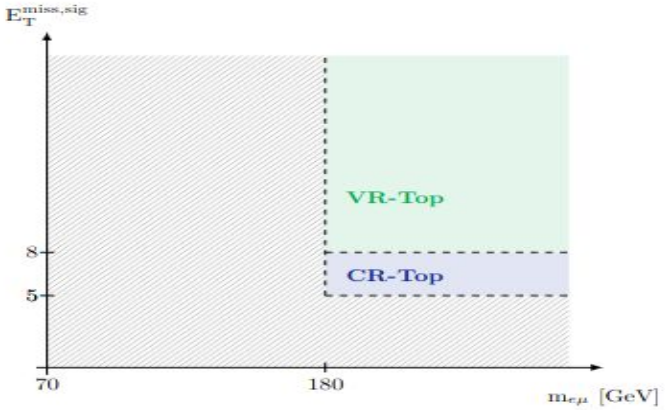
2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Analysis strategy*

- **Signal Region** (SR) :
  - ➢ Signal enriched region
    - search for an excess over the SM backgrounds.
- **Control Region** (CR) :
  - ➢ Region use to improve the modeling of a background.
    - SR-like selection
    - Pure
- **Validation Region** (VRs) :
  - ➢ Regions use to validate the background estimation
    - SR-like selection
    - Pure

→ difficult task !





★ *Statistical Model*

- Profile Likelihood function
  - Use to **estimate the parameter of interests** while taking into account **uncertainty** introduced by **nuisance parameters**.

Parameter of interest (strength of the signal, scale factors of each background)

Gaussian function uses to propagate the NP i in the model.

data

Prediction of signal events in bin i

$$L(\vec{n}|\vec{\theta},\vec{k}) = \prod_i P(n_i|S_i(\vec{\theta},\vec{k}) + B_i(\vec{\theta},\vec{k})) \times \prod_j G(\theta_j)$$

Prediction of background events in the bin i.

Poisson distribution

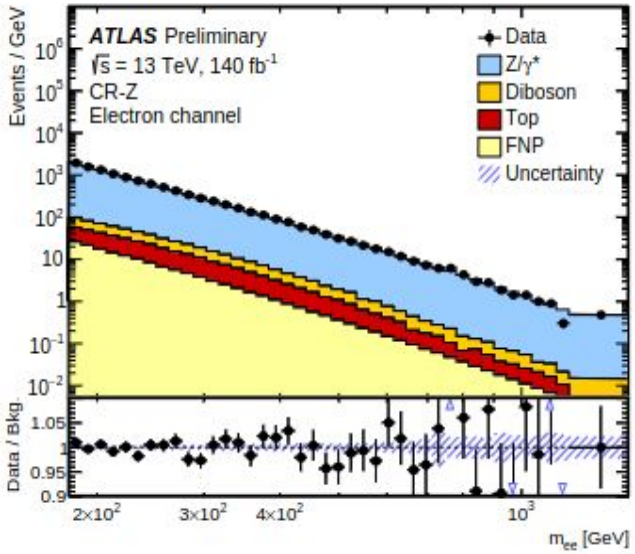
Nuisance parameters (systematics)

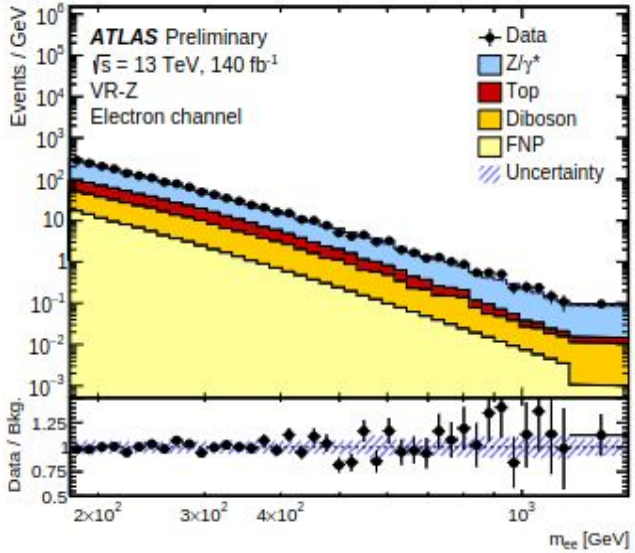
Number of events in bin i.

2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Results*

- Background modeling :
  - ➢ Z->ll CR and VR post fit result in the electron channel

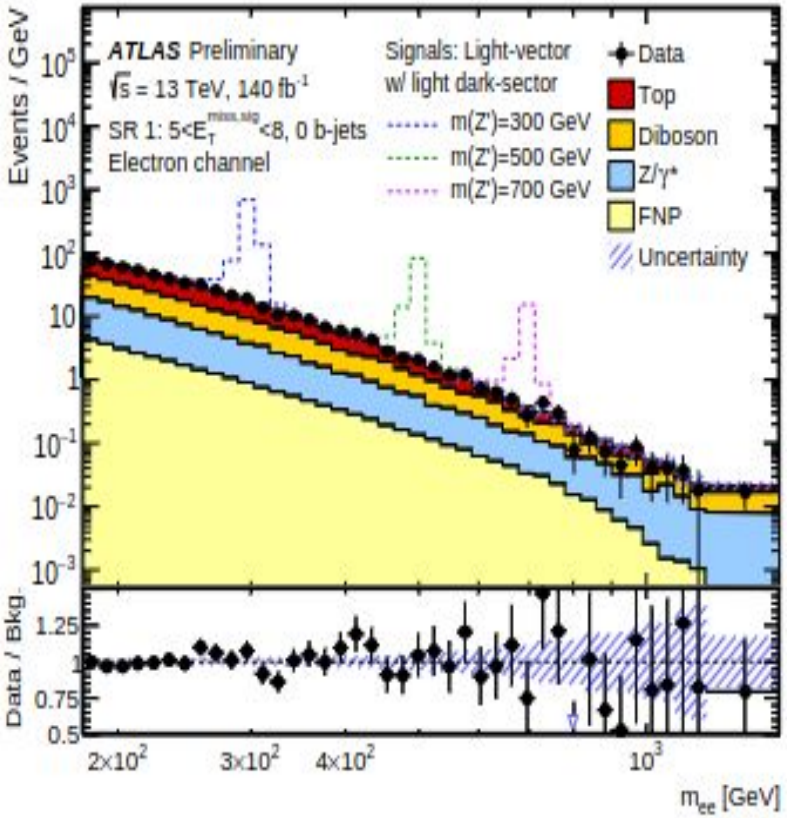




2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Results*

❖ Signal region post fit :



2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Results*

❖ Signal region fit :

	CR-Z	CR-Top ($e\mu$)	CR-Diboson	SR-bin1	SR-bin2	SR-bin3
Observed	125359	45003	1161	6508	2340	801
Total Background	125 360 ± 350	45 010 ± 210	1158 ± 33	6490 ± 80	2370 ± 40	786 ± 20
Drell-Yan	118 700 ± 800	62.7 ± 2.0	60 ± 4	1100 ± 140	58 ± 4	14.9 ± 0.7
Top	2420 ± 180	40 600 ± 500	47 ± 5	3180 ± 210	1450 ± 90	379 ± 26
Diboson	2780 ± 140	3400 ± 170	1036 ± 34	1880 ± 90	750 ± 35	350 ± 15
Fakes	1500 ± 600	900 ± 400	15.5 ± 2.5	330 ± 180	110 ± 70	41 ± 26
LVM LDS, $m_{Z'} = 245$ GeV	0 ± 0	0 ± 0	0 ± 0	1 ± 8	1 ± 7	1 ± 7

Very good agreement with the Standard Model

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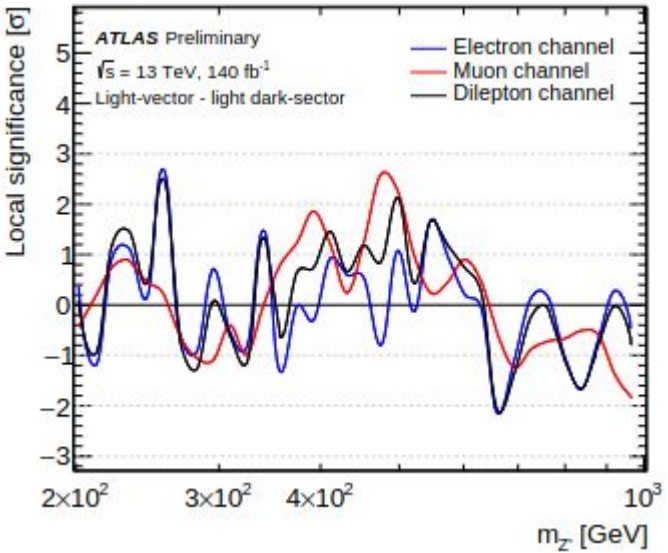
Very good agreement with the Standard Model

2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Results*

❖ Local significance



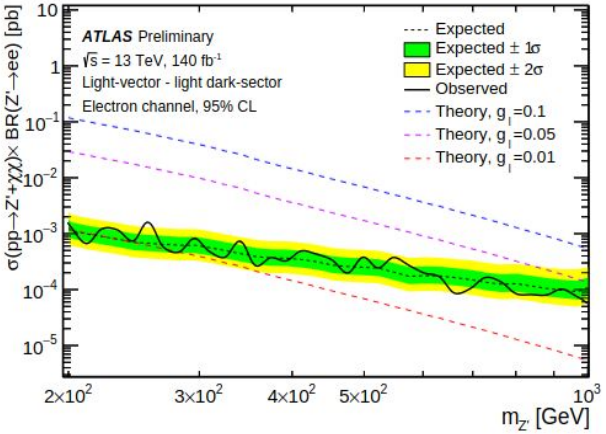
background only hypothesis

→ No excess above 3σ

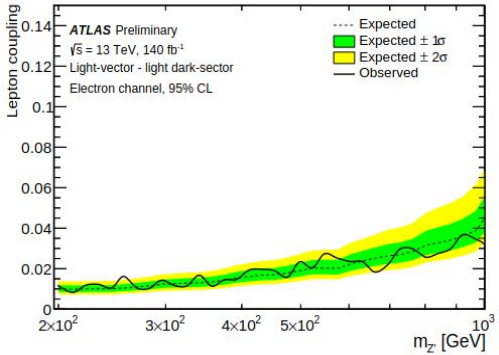
2 - Analysis : **Search for a new leptonically decaying neutral vector boson in association with missing transverse energy**

★ *Results*

❖ Limits on the Z' cross-section as a function of mZ'



None of the simulated signal points using a Z'll coupling of gl = 0.01 are excluded



Lepton coupling limits extracted from the cross-section limits

3 - Conclusion

3 - Conclusion

- A search for a new leptonically decaying neutral vector boson in association with missing transverse energy in proton–proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector has been presented.

- No excess found over the SM backgrounds
  - ➢ New limits set (cross-section and coupling)
    - An order of magnitude better than the inclusive search!

SR SELECTION

Variable	SR-bin 1	SR-bin 2	SR-bin 3
$E_{\mathrm{T}}^{\mathrm{miss,sig}}$	5 – 8	8 – 12	> 12
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 55	–	–
Num. b-jets (85% WP)	0	0	0
m_{ll} [GeV]	> 180	> 180	> 180

SR BKGS ESTIMATIONS

	SR-bin 1		SR-bin 2		SR-bin 3	
	ee	$\mu\mu$	ee	$\mu\mu$	ee	$\mu\mu$
$Z/\gamma^* \to \ell\ell$	14.5%	18.6%	1.4%	4.5%	0.4%	3.5%
$Z/\gamma^* \to \tau\tau$	0.8%	0.5%	1.1%	0.6%	1.9%	0.8%
$V + \gamma$	1.8%	2.0%	0.6%	0.6%	0.9%	0.5%
$t\bar{t}$	44.2%	41.2%	53.0%	52.9%	39.0%	42.9%
Single-top	10.3%	9.7%	14.0%	13.0%	14.7%	12.6%
$VV \to \ell\ell\nu\nu$	26.3%	25.5%	27.2%	25.3%	38.0%	33.9%
VV (other)	2.1%	2.5%	2.6%	3.1%	5.1%	5.8%

BINNING

$$\text{binwidth} = \frac{\log(x_{max}) - \log(x_{min})}{n_{bins}}.$$

$E_{\mathrm{T}}^{\mathrm{miss,sig}}$

$$E_{\mathrm{T}}^{\mathrm{miss,sig}} = \frac{|\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}|}{\sqrt{\sigma_{\mathrm{L}}^2(1-\rho_{\mathrm{LT}}^2)}}$$

σL is the longitudinal component of the total transverse momentum resolution for all objects in the even

ρLT is the correlation factor between the parallel and perpendicular components of the transverse momentum resolution for each object

CONTROL REGION SELECTION

	CR-Z	CR-Top	CR-Diboson	SRs
Channel	$ee, \mu\mu$	$e\mu$	$ee, \mu\mu$	$ee, \mu\mu$
m_{ll} [GeV]	> 180	> 180	$[70, 95]$	> 180
Num. b-jets	0	-	0	0
$E_{\mathrm{T}}^{\mathrm{miss,sig}}$	1–3	5–8	> 12	$5-8,\ 8-12,\ > 12$

CONTROL REGION PURITY

	Channel	Z+jets	Top	Diboson	Fakes
CR-Z	ee	**93.7%**	2.1%	2.1%	2.0%
	$\mu\mu$	**95.5%**	2.2%	2.2%	0.2%
CR-Top	$e\mu$	0.1%	**90.9%**	7.4%	1.6%
CR-Diboson	ee	5.8%	4.2%	**87.3%**	2.7%
	$\mu\mu$	6.1%	5.6%	**87.5%**	0.8%

VALIDATION REGION SELECTION

	VR-Z	VR-Top	VR-Diboson	SRs
Channel	ee, $\mu\mu$	$e\mu$	ee, $\mu\mu$	ee, $\mu\mu$
m_{ll} [GeV]	> 180	> 180	95–120	> 180
Num. b-jets	0	0	0	0
$E_{\mathrm{T}}^{\mathrm{miss,sig}}$	3–5	> 8	> 8	5–8, 8–12, >12