



Universidade do Minho  
Escola de Ciências



LABORATÓRIO DE INSTRUMENTAÇÃO  
E FÍSICA EXPERIMENTAL DE PARTÍCULAS  
*partículas e tecnologia*



Fundação  
para a Ciência  
e a Tecnologia

UIDP/50007/2020, LA/P/0016/2020

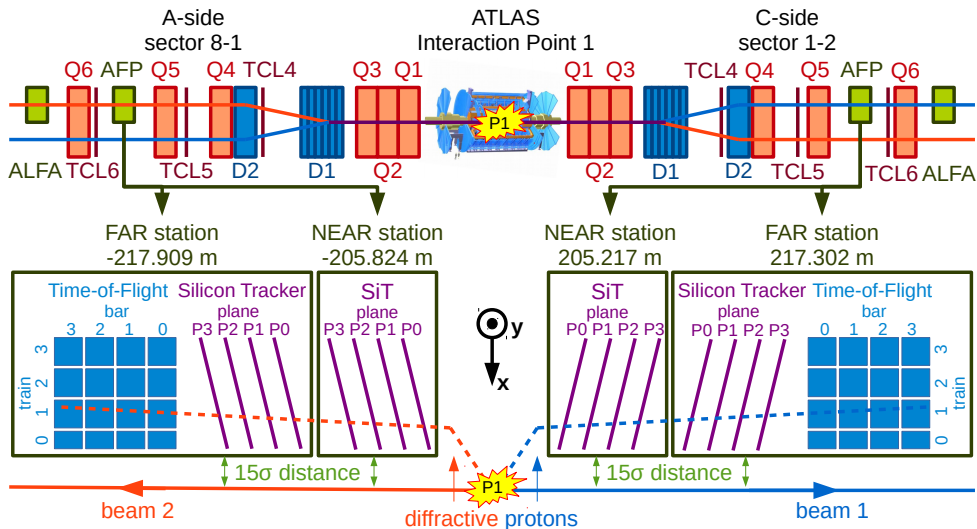
# Search for new physics at the LHC using the missing mass method

**Maura Barros**, Nuno Castro, Marek Taševský

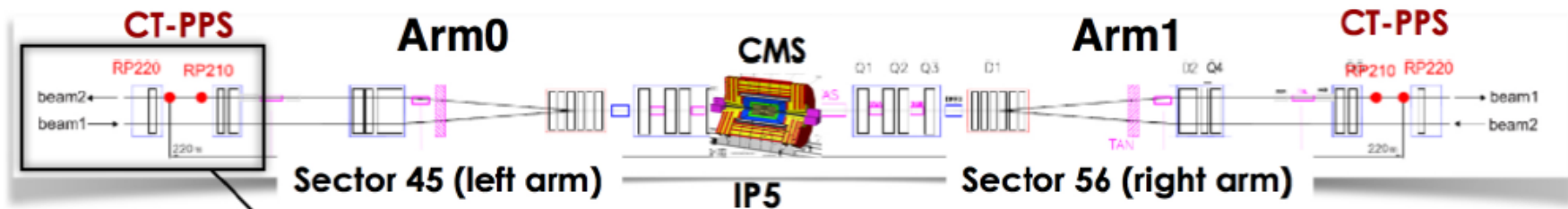
Forward Physics and QCD at the LHC and EIC

23<sup>rd</sup> - 27<sup>th</sup> October, 2023

# Forward Physics at the LHC



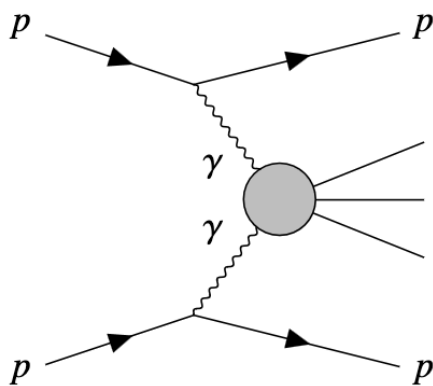
[AFP TDR, CERN-LHCC-2015-009]



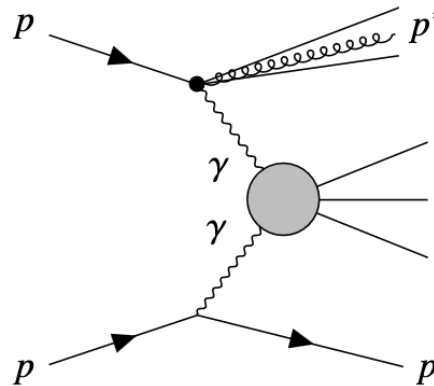
[CT-PPS TDR, CERN-LHCC-2014-021]

# Photon-induced Processes at Proton Collisions

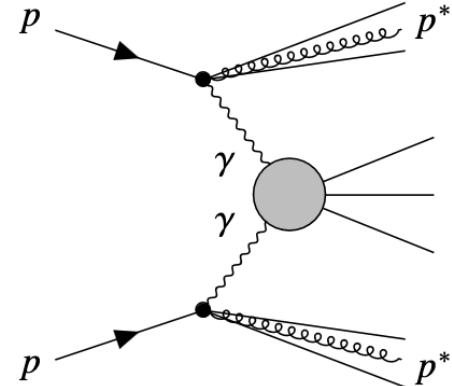
- **Exclusive** or **elastic** photon production: photon is considered to be radiated from the proton and there is no proton disintegration
- **Inelastic** production: there is proton disintegration. There are two types:
  - **Single-dissociative**: One photon production is inelastic
  - **Double-dissociative**: Both photon productions are inelastic



Elastic



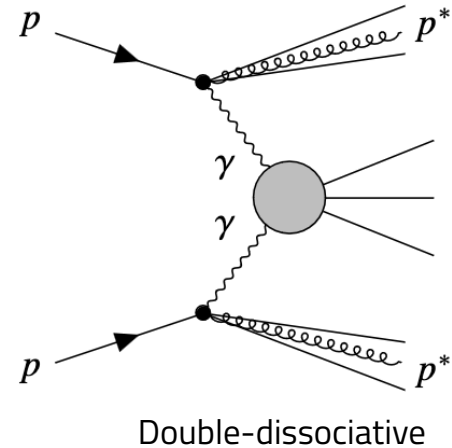
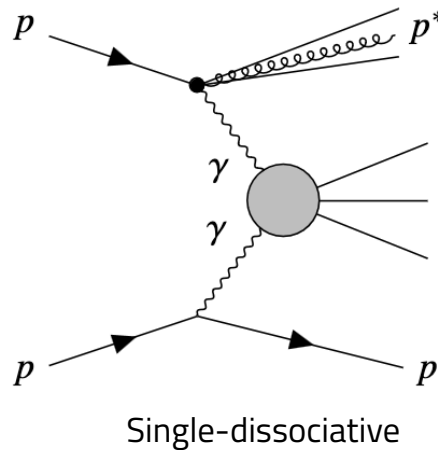
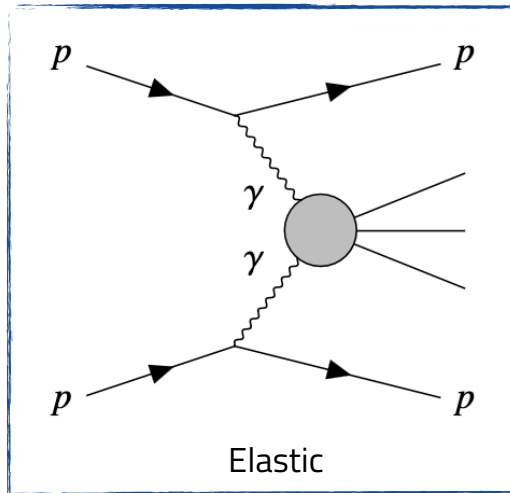
Single-dissociative



Double-dissociative

# Photon-induced Processes at Proton Collisions

- **Exclusive** or **elastic** photon production: photon is considered to be radiated from the proton and there is no proton disintegration
- **Inelastic** production: there is proton disintegration. There are two types:
  - **Single-dissociative**: One photon production is inelastic
  - **Double-dissociative**: Both photon productions are inelastic

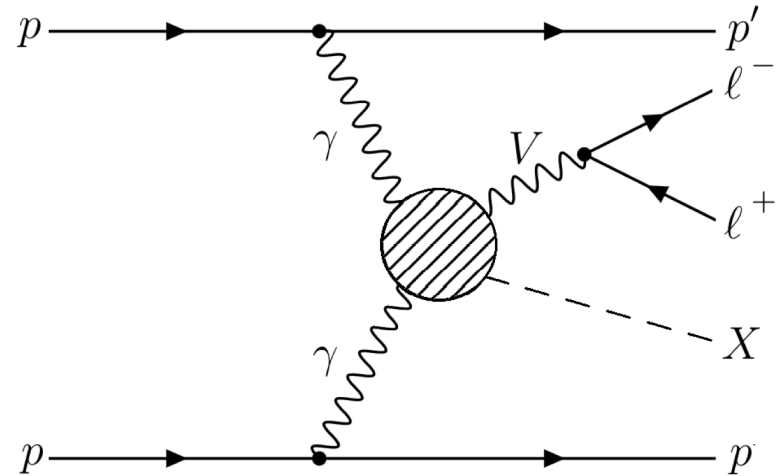


# Missing Mass Method

- **Elastic** production of  $V+X$
- **Model independent** search
- Takes into consideration the **visible particle** properties:

$$m_X^2 = (E_{\gamma\gamma} - E_{ll})^2 - (\vec{p}_{\gamma\gamma} - \vec{p}_{ll})^2$$

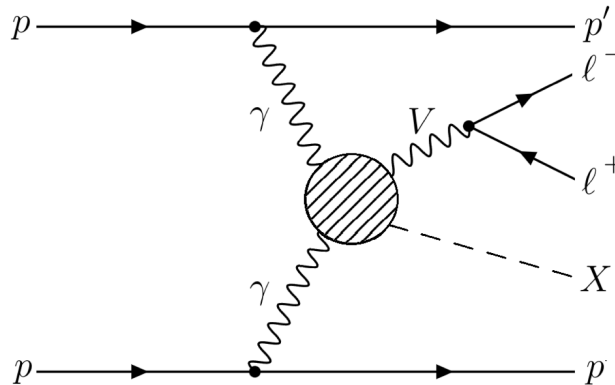
- **Photon properties** are derived from the **proton** on each side of the **forward proton detector**
- **Leptons** are measured in the **central** detector



Double proton tagged events

# Considered Signals

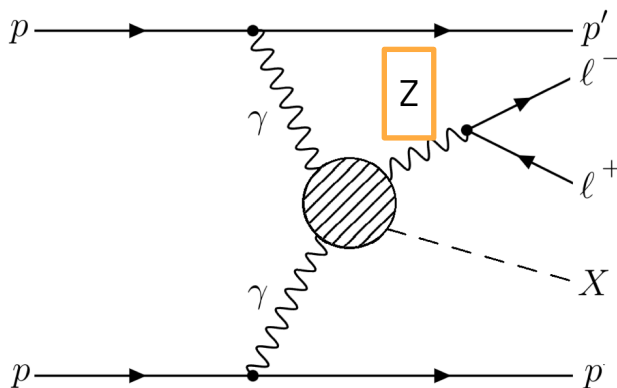
- The analysis strategy does not require any signal model choice. However, for results interpretation a specific signal should be chosen
- $m_V = Z$  mass;  $m_X = 400, 600, 800, 1000, 1200$  GeV
- PDF: MSHT20qed\_nnl0; Pythia8: version 8.245
- $V$  decays into muons



Process	Generator	Events
Z + X	SuperChic v4.2	50 000
Z + H	MadGraph v3.5.1	50 000

# Considered Signals

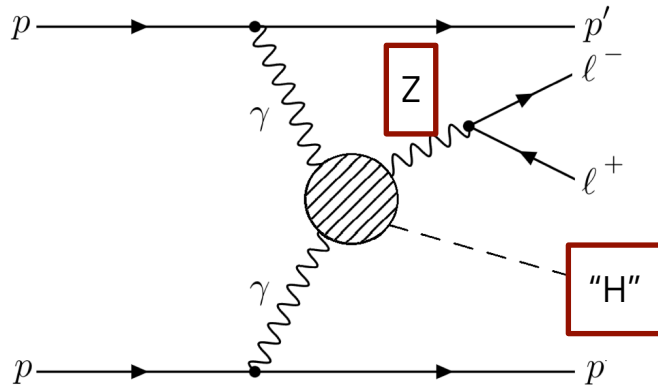
- The analysis strategy does not require any signal model choice. However, for results interpretation a specific signal should be chosen
- $m_V = Z$  mass;  $m_X = 400, 600, 800, 1000, 1200$  GeV
- PDF: MSHT20qed\_nnl0; Pythia8: version 8.245
- $V$  decays into muons



Process	Generator	Events
Z + X	SuperChic v4.2	50 000
Z + H	MadGraph v3.5.1	50 000

# Considered Signals

- The analysis strategy does not require any signal model choice. However, for results interpretation a specific signal should be chosen
- $m_V = Z$  mass;  $m_X = 400, 600, 800, 1000, 1200$  GeV
- PDF: MSHT20qed\_nnl0; Pythia8: version 8.245
- $V$  decays into muons

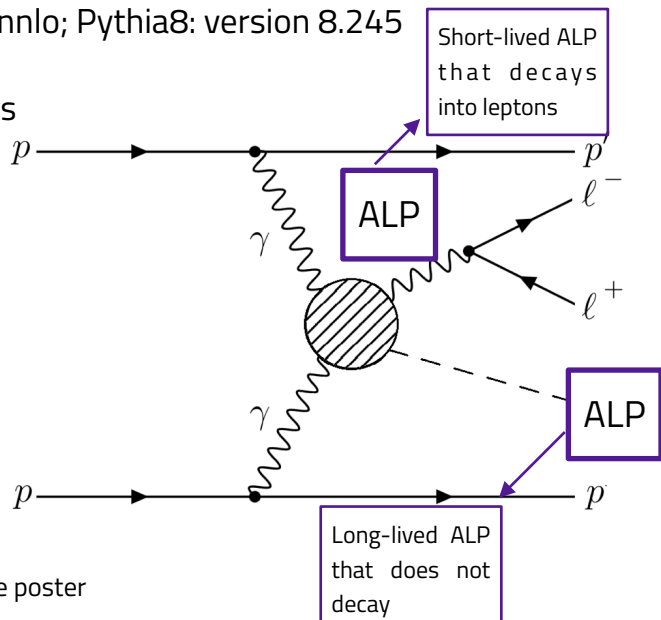


Process	Generator	Events
Z + X	SuperChic v4.2	50 000
Z + H	MadGraph v3.5.1	50 000



# Considered Signals

- The analysis strategy does not require any signal model choice. However, for results interpretation a specific signal should be chosen
- $m_V = Z$  mass;  $m_X = 400, 600, 800, 1000, 1200$  GeV
- PDF: MSHT20qed\_nnlo; Pythia8: version 8.245
- $V$  decays into muons

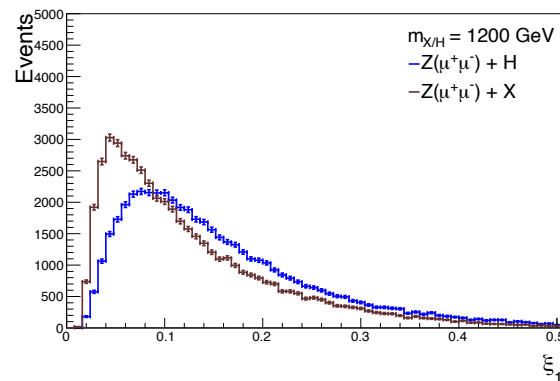
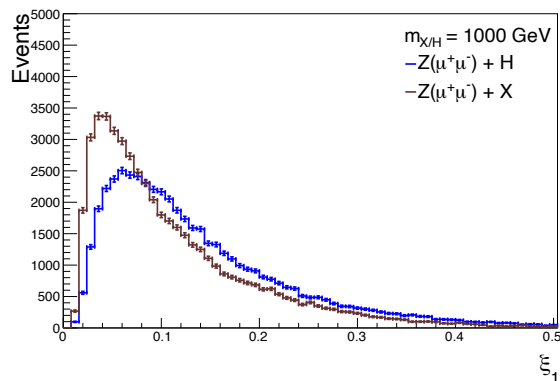
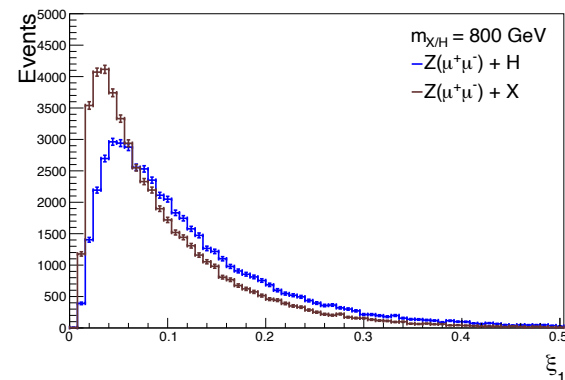
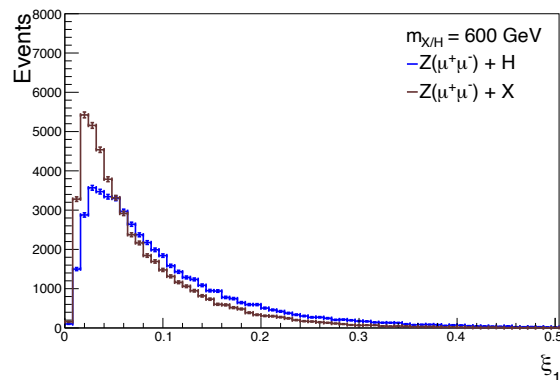
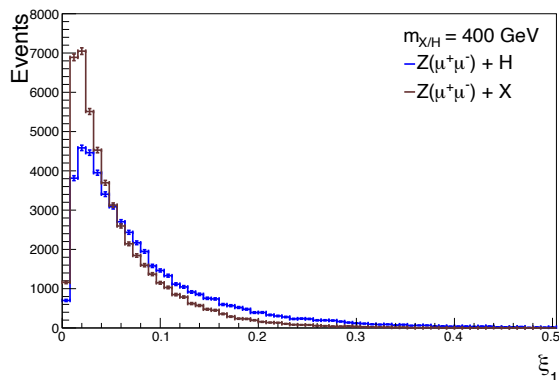


Process to be added in MadGraph: work in progress

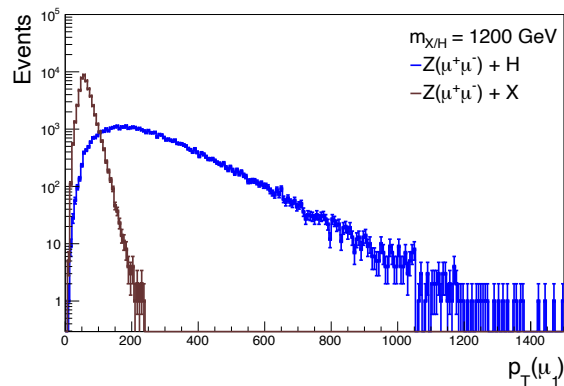
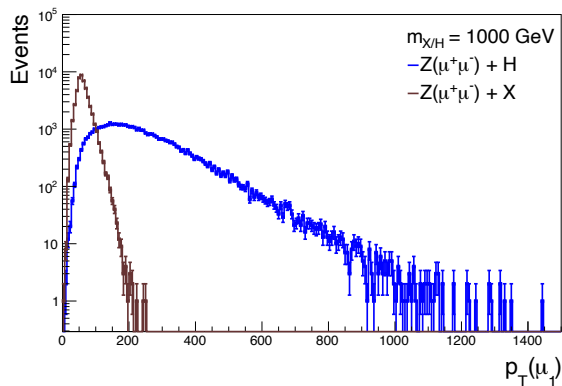
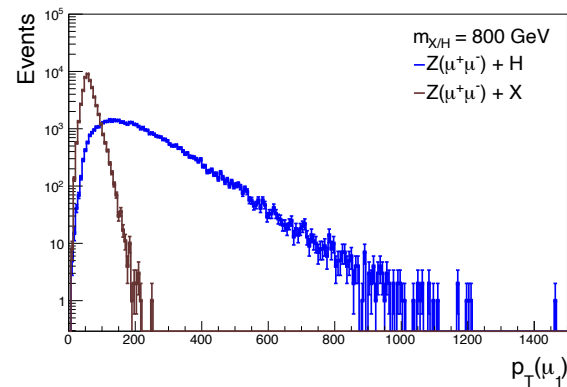
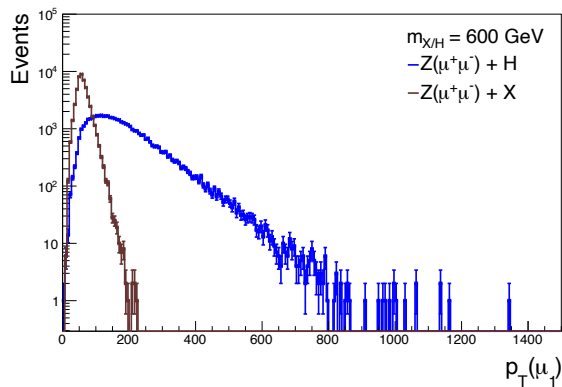
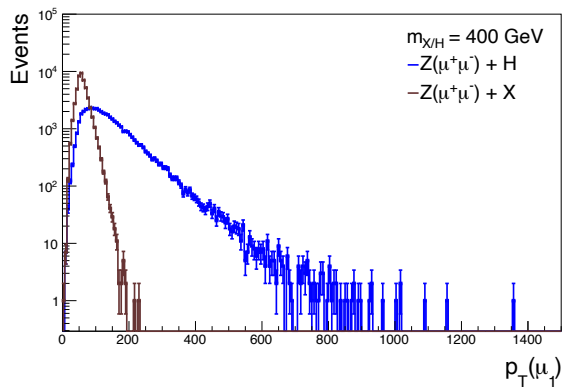
Process	Generator	Events
Z + X	SuperChic v4.2	50 000
Z + H	MadGraph v3.5.1	50 000

# Forward Proton Properties

Protons' fractional momentum loss:  $\xi = 1 - \frac{|p_z|}{6500}$



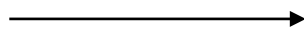
# Di-Lepton Properties



# Selection Cuts

- Forward Proton detector cuts:

- $0.02 < \xi_{1,2} < 0.20$



Z+X

About 32% of the events are rejected

Z+H

About 38% of the events are rejected

- Central Detector cuts:

- 2 muons with opposite charge and:

- $p_T > 14$  GeV



About 1.5% of the events are rejected

About 10% of the events are rejected

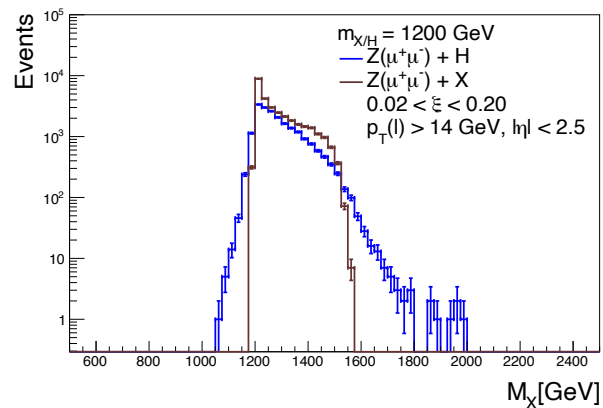
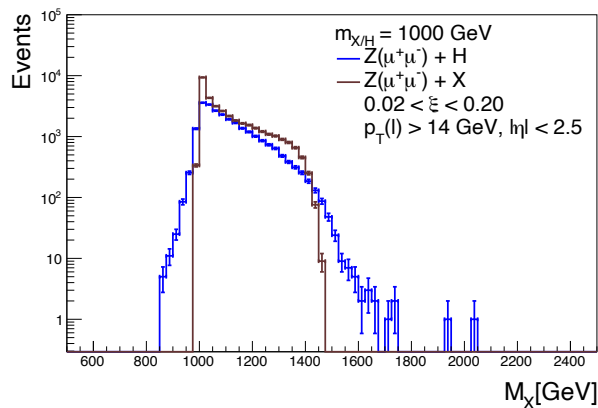
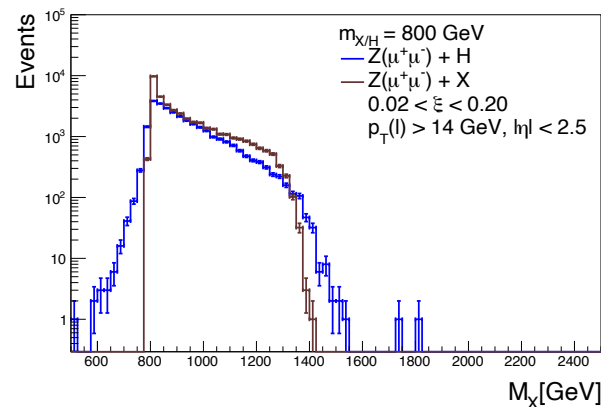
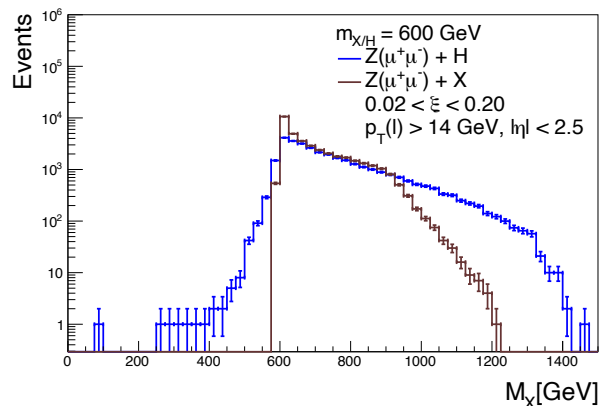
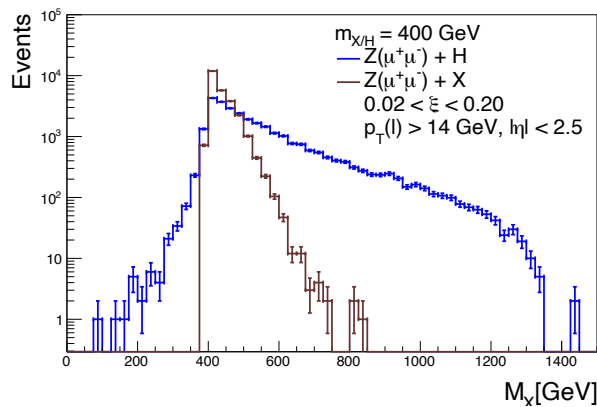
- $|\eta| < 2.5$



Almost no events are rejected

About 2.5% of the events are rejected

# Missing Mass



# Summary

- Several signals were studied using both SuperChic and MadGraph
- The forward proton detectors acceptance is the factor that reduces most the number of events
- Next steps:
  - Generate events with the ALP model

**Search for New Physics at the LHC using the Missing Mass Method**

Maura Barros      Nuno Castro      Marek Taševský

Forward Physics and QCD at the LHC and EIC      23–27th October, 2023

---

**Motivation**

Exclusive New Physics production: **two leptons + missing mass**  
 @ **two tagged protons**

Model independent search by using the missing mass method

$$m_X^2 = (E_{\gamma\gamma} - E_{ll})^2 - (\vec{p}_{\gamma\gamma} - \vec{p}_{ll})^2$$

Photon's properties are derived from protons measured in AFP

$$E_{\gamma} = \Delta E_p + \Delta E_{\gamma}; \quad p_{x\gamma} = 0; \quad p_{y\gamma} = 0; \quad p_{z\gamma} = \Delta E_p - \Delta E_{\gamma}$$


---

**Signals**

**Z+X**

- SuperChic simplified MC model
- Cross-section:  $\frac{d\sigma}{dM^2} \sim e^{-\xi} \text{Chic}$
- Does not have influence on the kinematics
- Z decays into **muons**. Decay into electrons also implemented

**Z+H**

- MadGraph process generated tweaking the SM
- Z+H photon-induced process:
- Z decays into **muons**
- H decays to **not decay** and has **variable mass**
- Same couplings as the SM ones

Selection Cuts:  $0.02 < \xi < 0.2, p_T(\mu^\pm) > 14 \text{ GeV}, |\eta(\mu^\pm)| < 2.5$

X Mass	Generated Events	$\xi$ cut	$p_T$ cut	$\eta$ cut
400	26689	26277	26277	
600	38158	37580	37576	
800	50 000	39844	39255	39251
1000		35358	34826	34826
1200		30919	30498	30498

X Mass	Generated Events	$\xi$ cut	$p_T$ cut	$\eta$ cut
400	34105	30293	28817	
600	37360	33348	32456	
800	50 000	33263	29963	29415
1000		28031	25330	24980
1200		22896	20624	20358

---

**Missing Mass Distributions**

**Under Study: ALP hypothesis**

Special thanks to Mikael Duda from the University of Granada and Lucian Halvati-Largu from the University College London for providing the theoretical models used in this study  
 We acknowledge the support of FCT, COMPETE2020, Portugal2020, FEDER and FEDER-ERDF through the PTDC/FIS/00176/2014, UIDB/00017/2020, UIDP/00017/2020, LA/P/0016/2020

SPH490/19/006/2021

**Thank you!**