Search for Z'-pair production decaying into Dark Matter and boosted Jets at CMS

Claudio Andrea Manzari, Matteo Cremonesi, Siew Yan Hoh, Bo Jayatilaka

Final Presentation

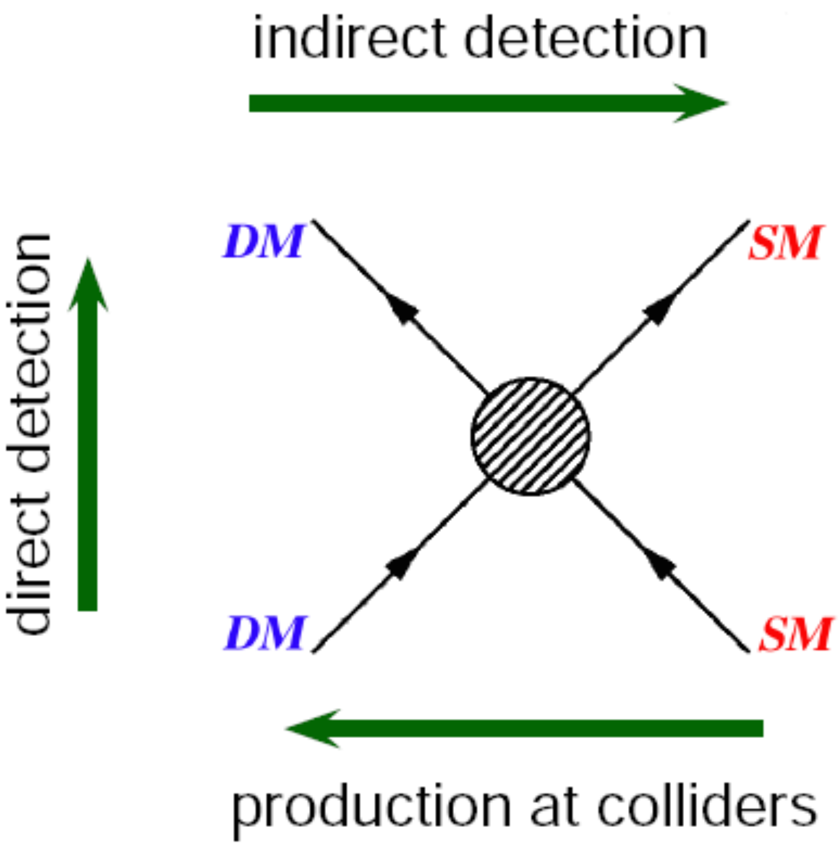
09-27-2017

Introduction

- From **cosmological observations,** 85% of the matter comprised of dark matter (**DM**)
- What we know:
  - DM does not interact electro-magnetically
  - DM interacts gravitationally

We know nothing about
its nature and properties

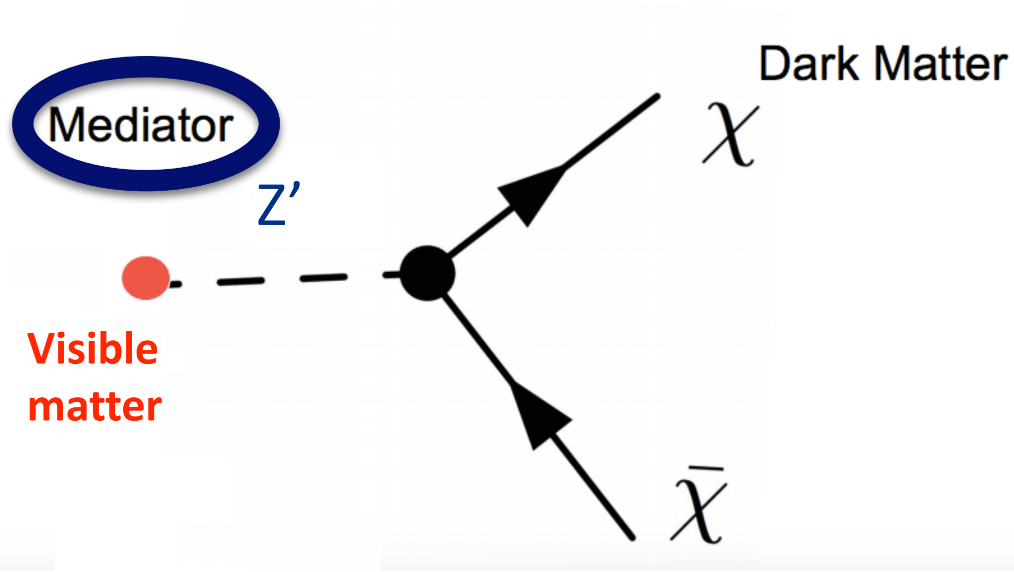
Search for Dark Matter



- **Collider approach**: DM production by colliding SM particles at high energies

Why at Colliders

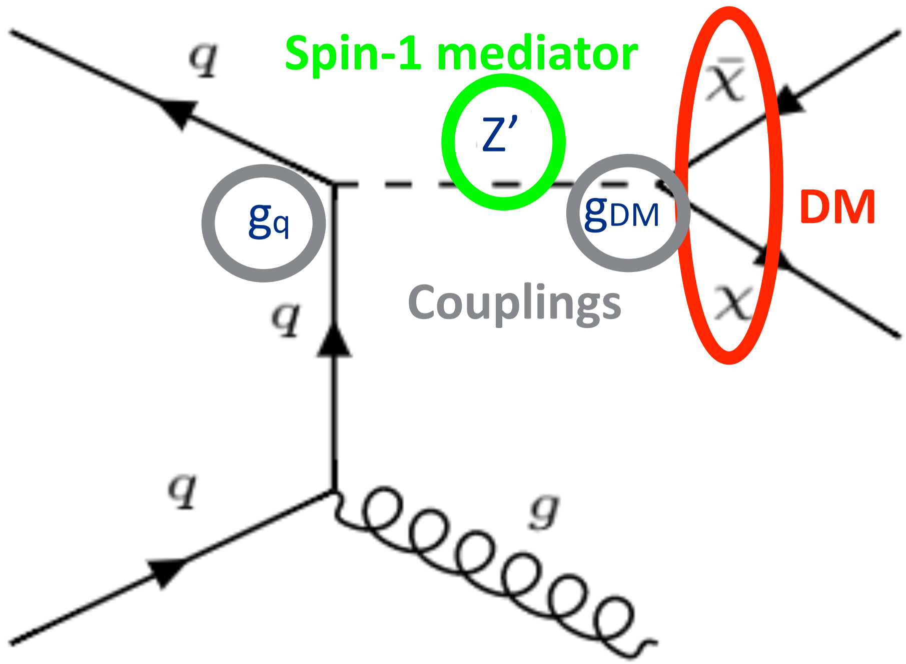
- If DM interacts, it does through a **mediator**
- At colliders, unique possibility to search for the mediator and measure its properties
  – mass, spin



From EFT to Simplified Models

Model described by a small number of **free parameters**:

- **M_{med}, M_{DM}, g_{SM}, g_{DM}**
- shapes of kinematic distributions not altered by coupling variations
  - **g_{SM}=0.25, g_{DM}=1(spin-1)**
  - **g_{SM}=1, g_{DM}=1(spin-0)**

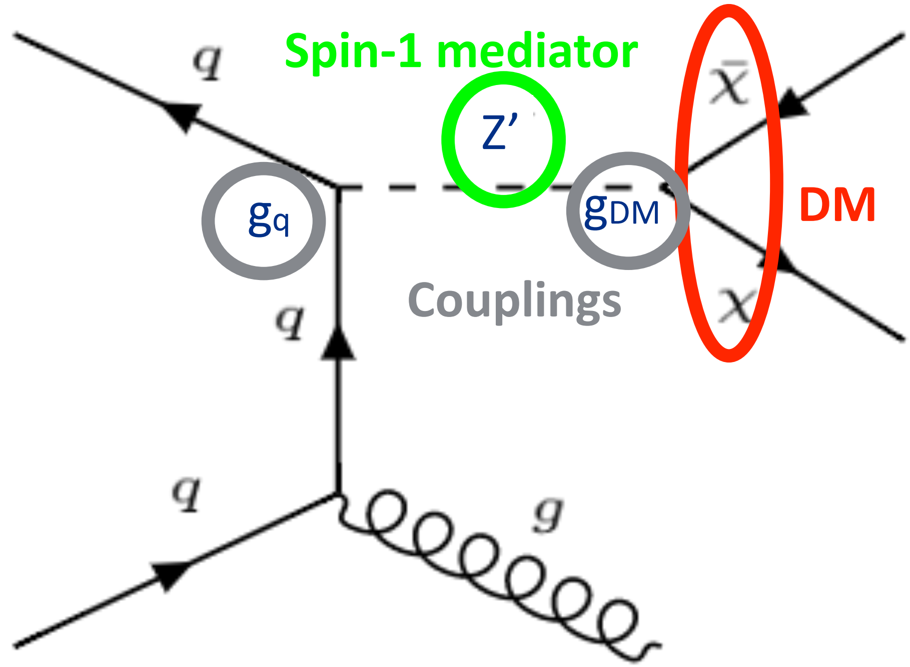


LHC DM Forum, arxiv:1507.00966v1

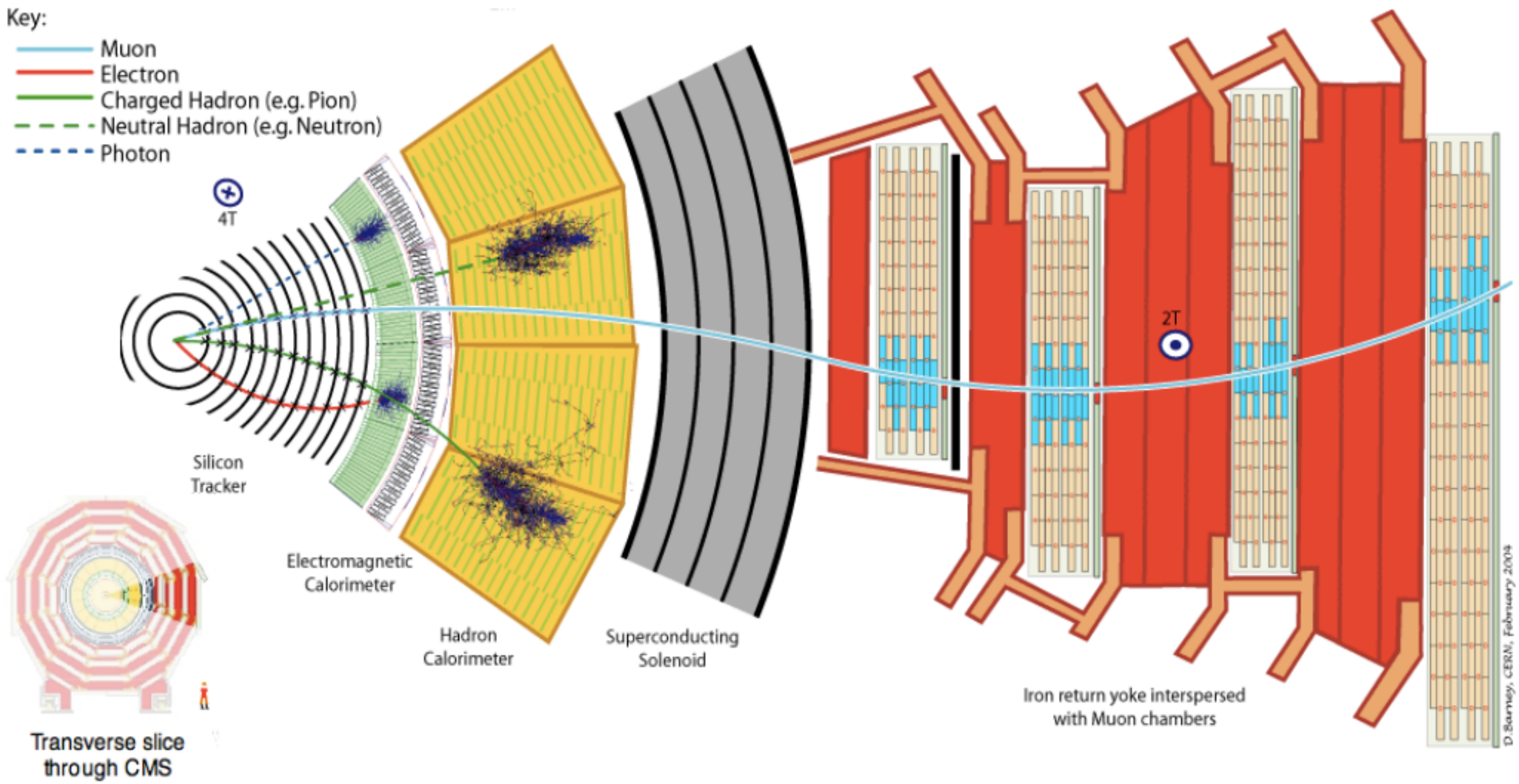
From EFT to Simplified Models

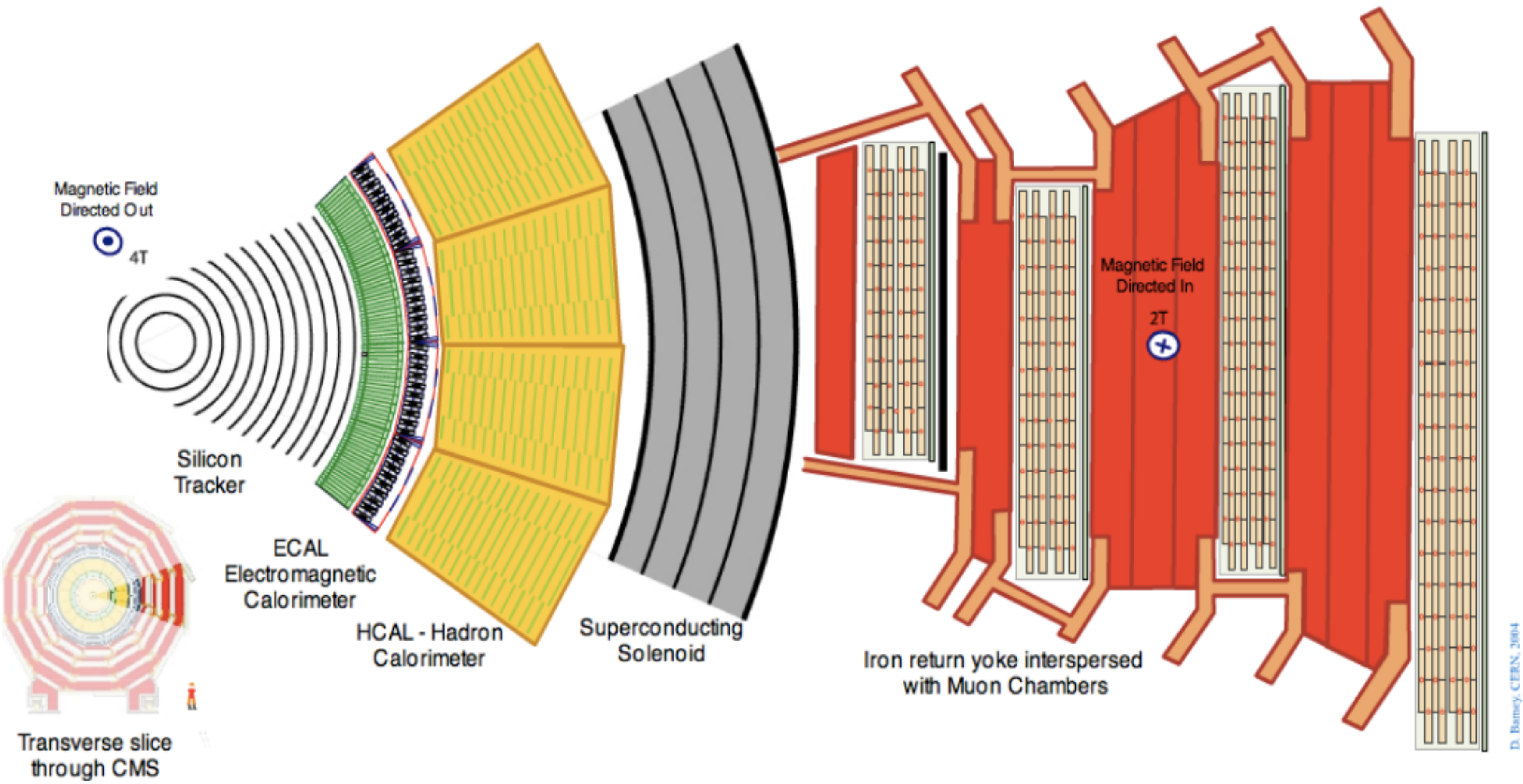
Assumptions:

- **DM:**
  - single particle, Dirac fermion
  - stable and non-interacting
- **Mediator**
  - Axial/Vector, Scalar/Pseudoscalar
  - minimal decay width (e.g. to DM and to quarks)



LHC DM Forum, arxiv:1507.00966v1


Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D.Barney, CERN, February 2004

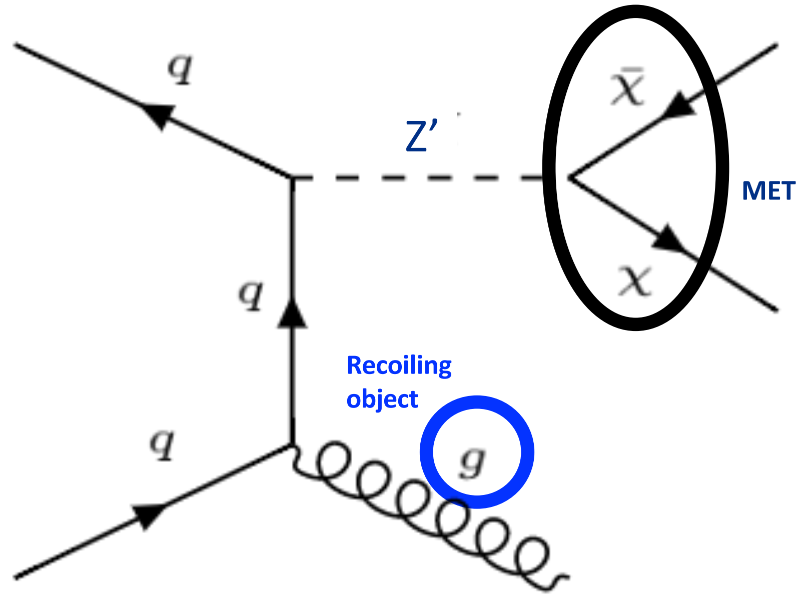

Magnetic Field
Directed Out
4T
Silicon
Tracker
ECAL
Electromagnetic
Calorimeter
HCAL - Hadron
Calorimeter
Superconducting
Solenoid
Magnetic Field
Directed In
2T
Iron return yoke interspersed
with Muon Chambers
Transverse slice
through CMS
D. Barney, CERN, 2004

Mono-X searches

- Collider experiments are **NOT** designed for detecting DM
  - Invisible DM particles escape detection

Experimental approach:

  - trigger events using **recoiling object(s)**
    - Initial state radiation (**ISR**) of a particle X:
      - X = jet/gamma/W/Z
  - measure missing transverse momentum (**MET**)

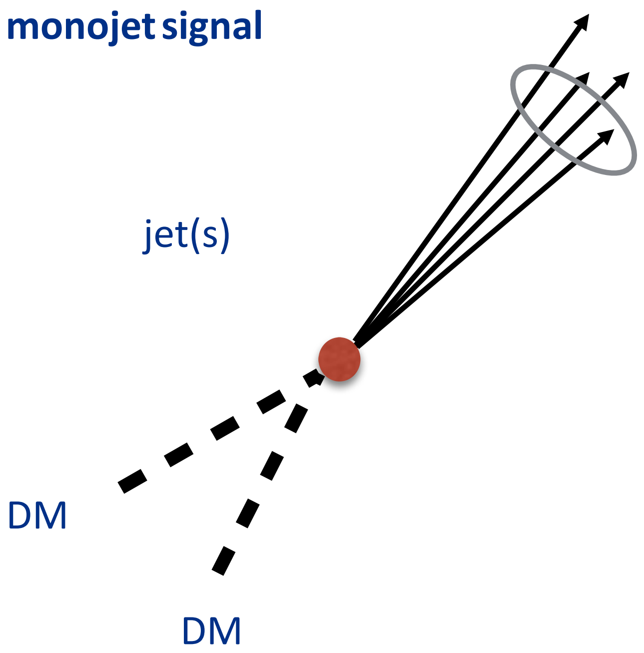


$$MET = -\Sigma_{All\ particles}\ p_T$$

Monojet Signature

Looking for events with:

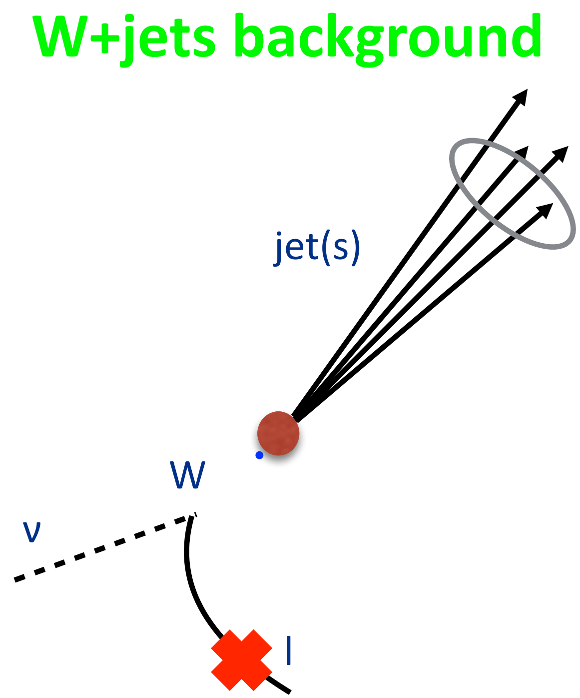
- Large MET
- At least one high Pt jet



Monojet Signature - Background

Looking for events with:

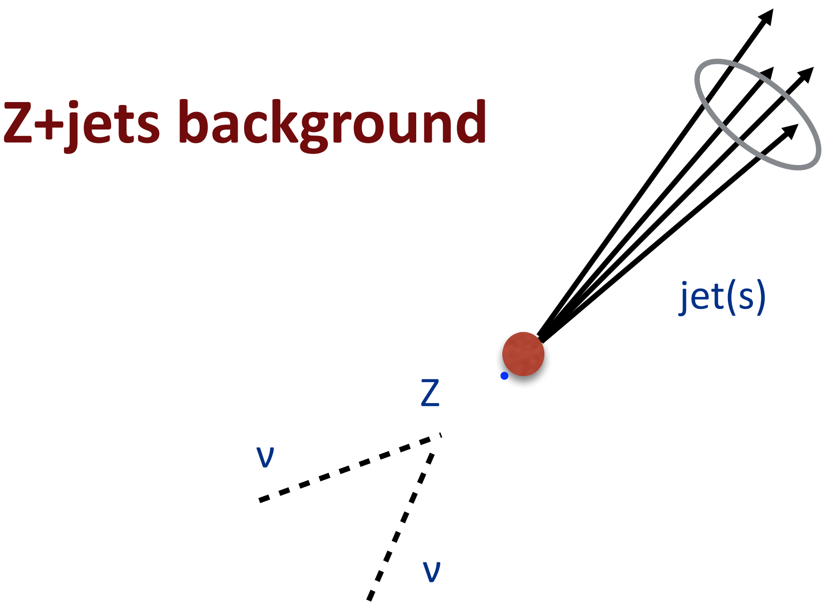
- Large MET
- At least one high Pt jet



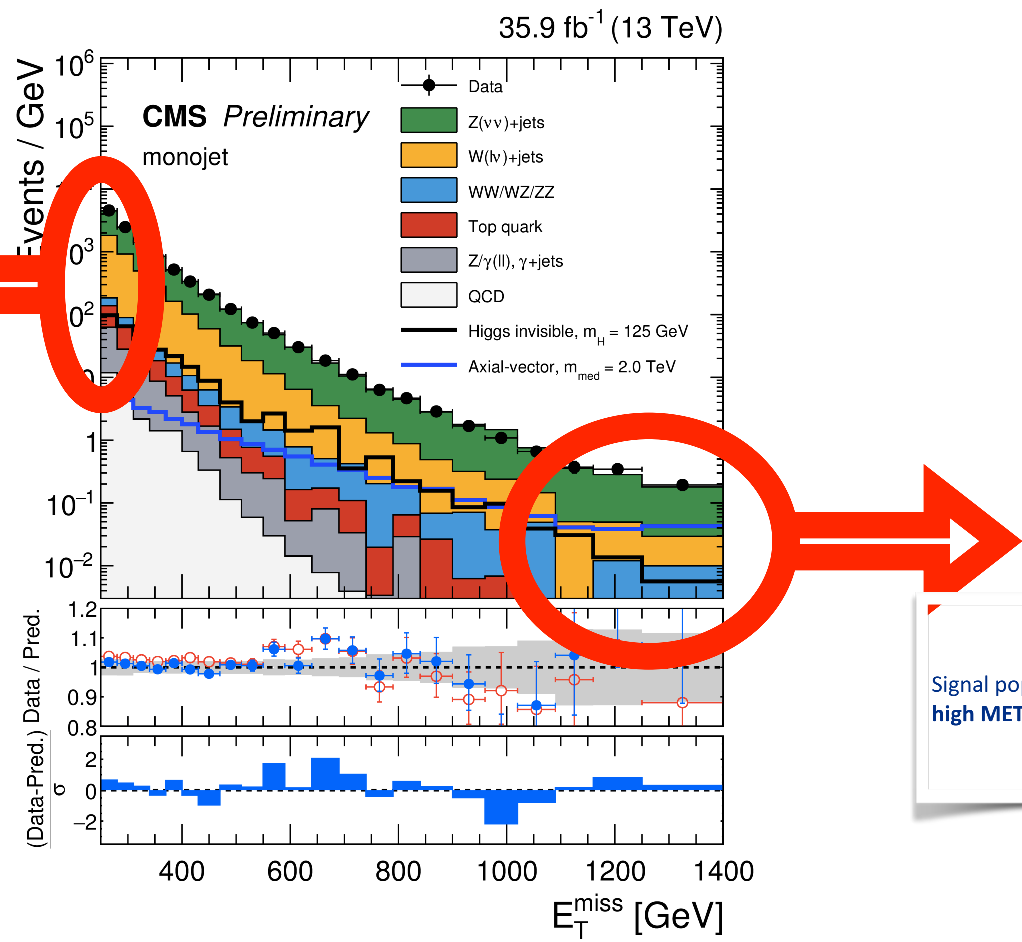
Monojet Signature - Background

Looking for events with:

- Large MET
- At least one high Pt jet



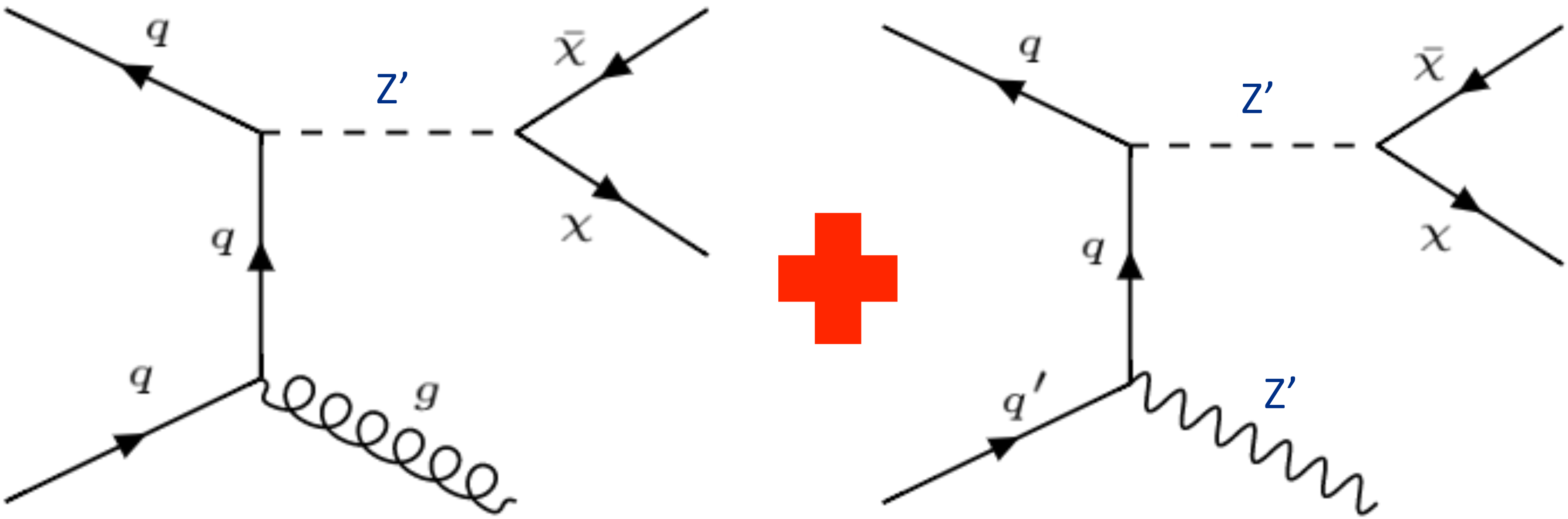
Detection of signal



Largest backgrounds from **W/Z+jets**

Signal populates **high MET**

Mono-Z' Model



Model Generation

Madgraph → Model generation with matrix elements. Quarks in the final state. (Unphysical states).

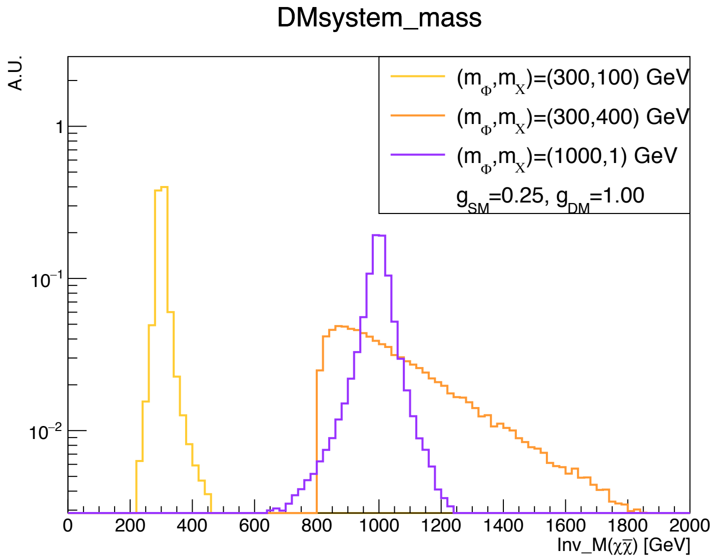
Pythia → Generate parton shower and hadronization. Jet in final state. (Physical states).

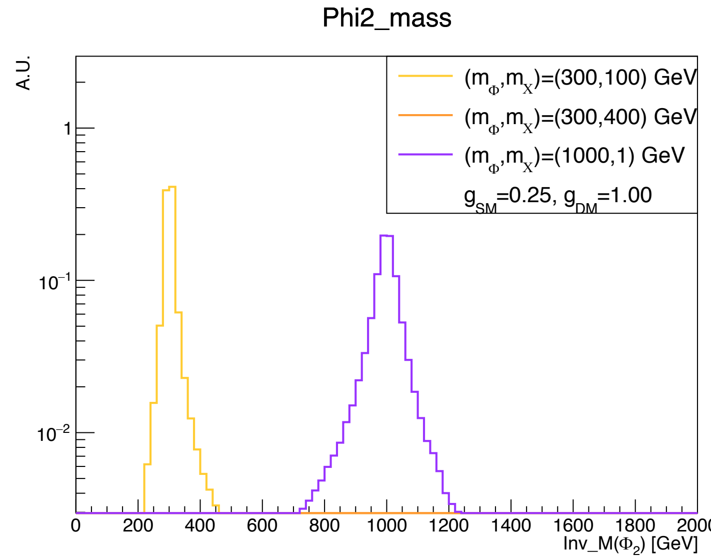
Mass Benchmarks

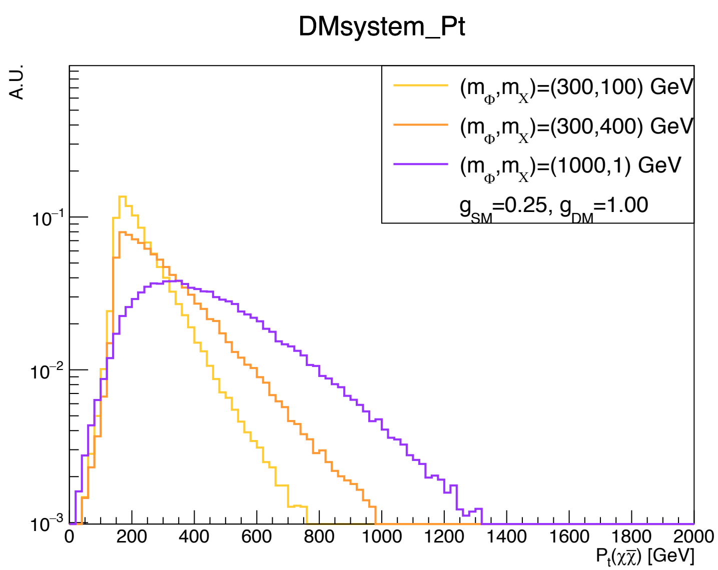
	Mediator Mass	Dark Matter Mass
Resonant case	300 GeV	100 GeV
Heavy Mediator	1000 GeV	1 GeV
Heavy DM	300 GeV	400 GeV

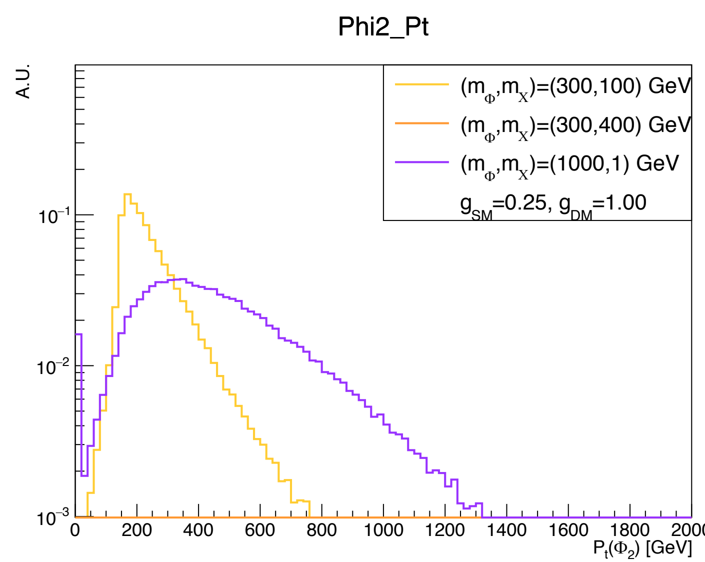
Madgraph Plots – Vector Coupling

100˙000 events



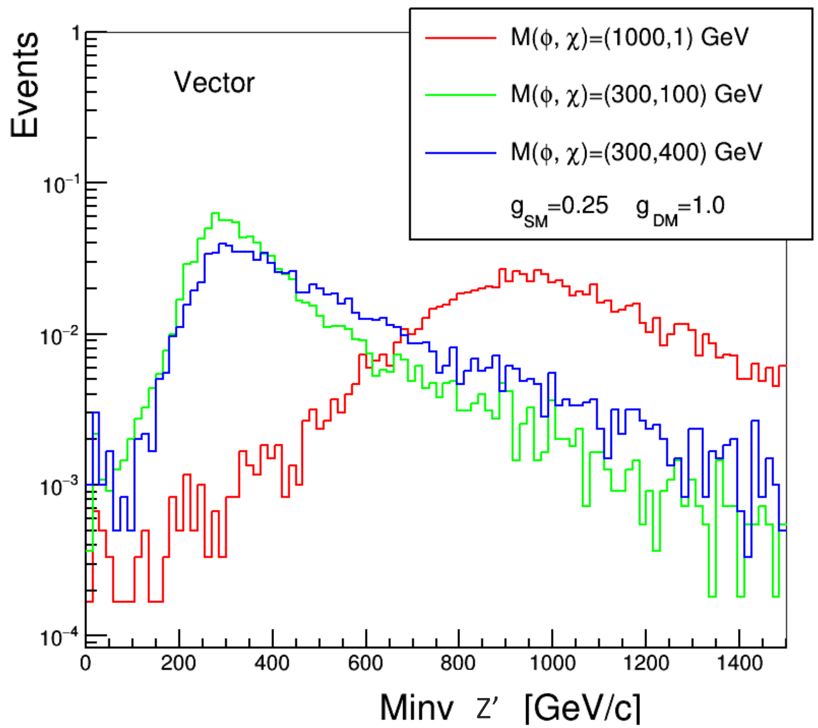


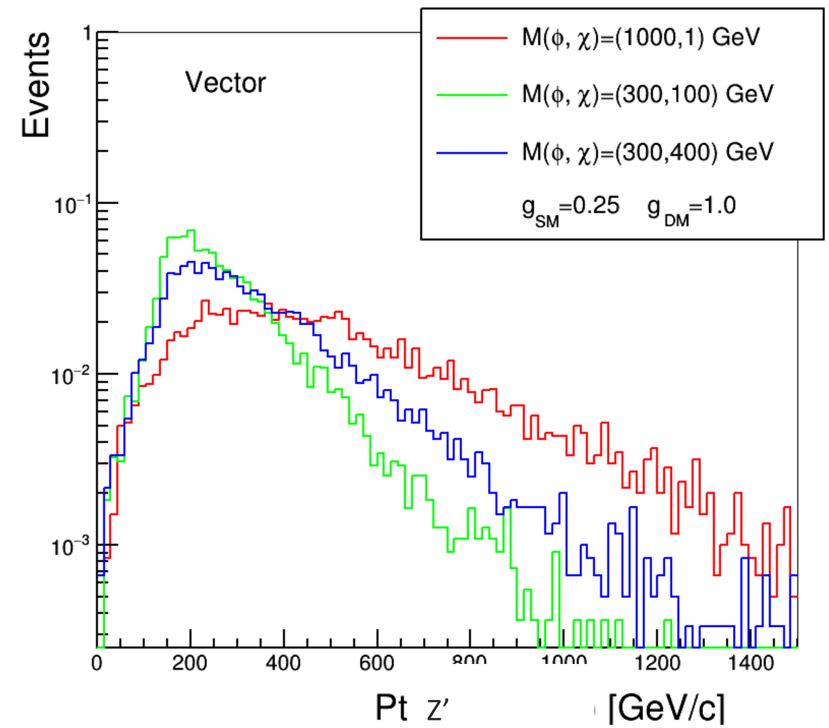




Pythia Distributions – Vector Coupling

6'000 events





- Distributions peak at Mediator mass;

- Generator cut in P_T at 150 GeV;
- Axial distributions similar to Vector ones.

Mass region of Interest

- Online selection (Trigger) on MET ~ 200 GeV ;
- Single particle recoiling against MET --> $\left|P_T^{Z'}\right| = |MET|$;
- $dR = 1.5$ is the CMS jet collection we are interested in;
- $dR \sim \frac{2m_{Z'}}{P_T^{Z'}}$;

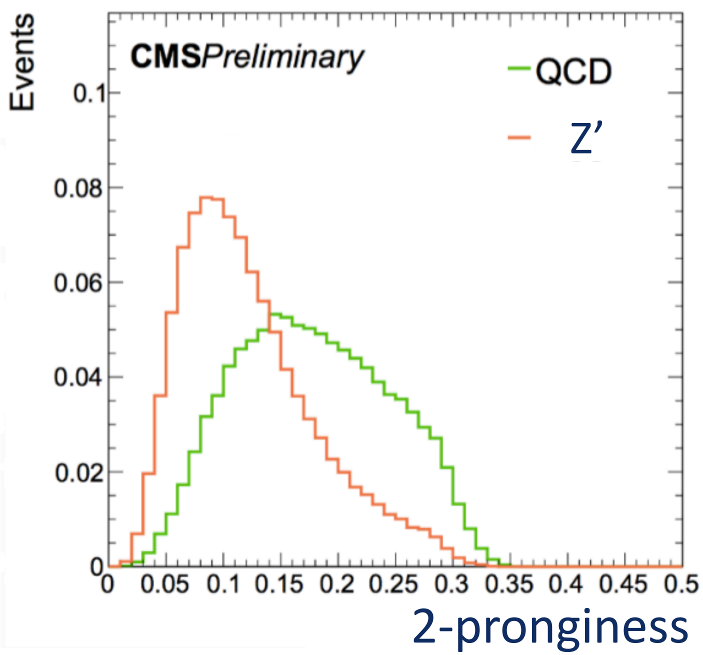
REGION OF INTEREST

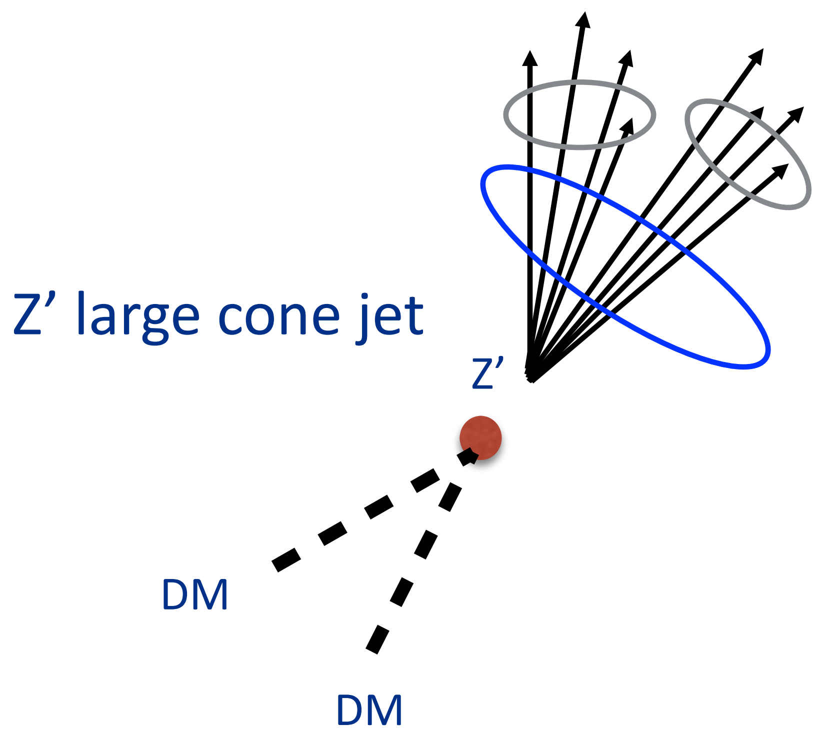
0 – 150 GeV

Identification of Z' Large-Cone Jets

Single high Pt dR=1.5 jet with:

- 2-prong structure identified by studying **jet substructure**





Analysis Strategy

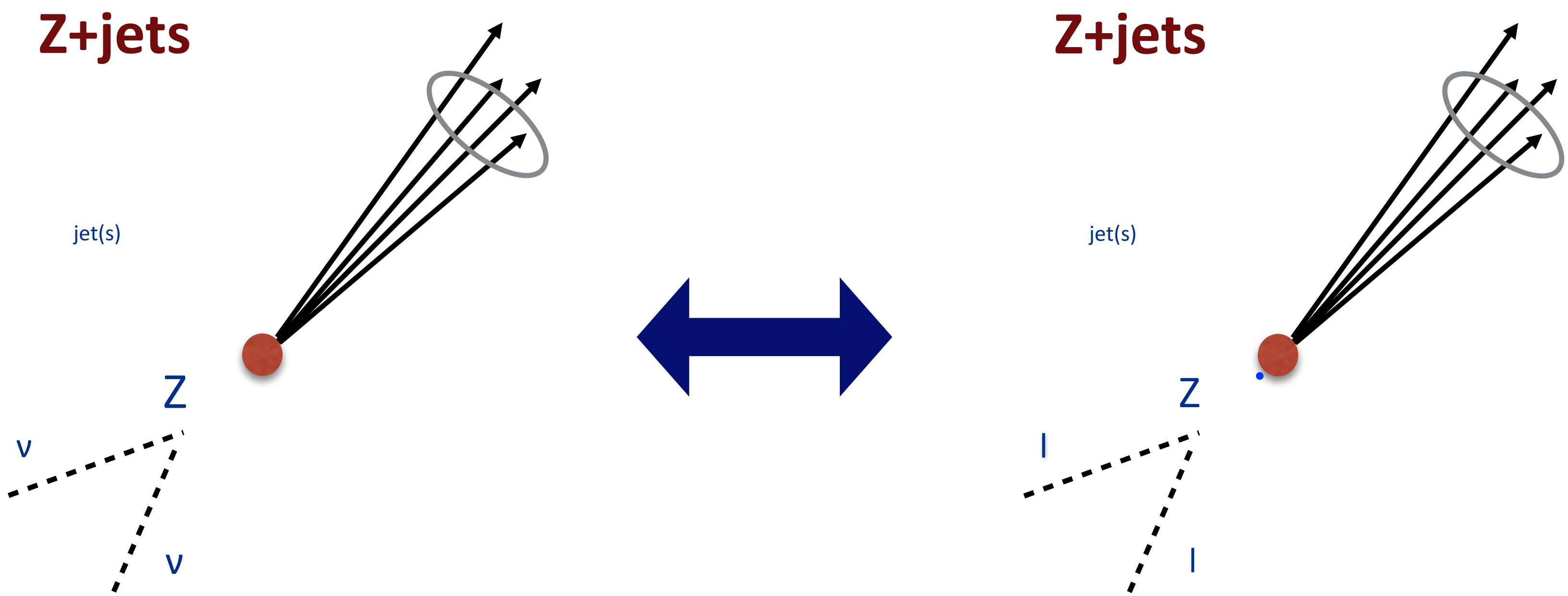
Signal extraction is based on **MET** distribution (**shape analysis**)

Background estimation:

- **Data-driven** model for the main backgrounds
- Data in **bins** of the hadronic recoil in control regions used to derive both the **shape** and **rate** for Z/W+jets backgrounds in the signal region
- Fit performed simultaneously in different categories

Z+Jets Model

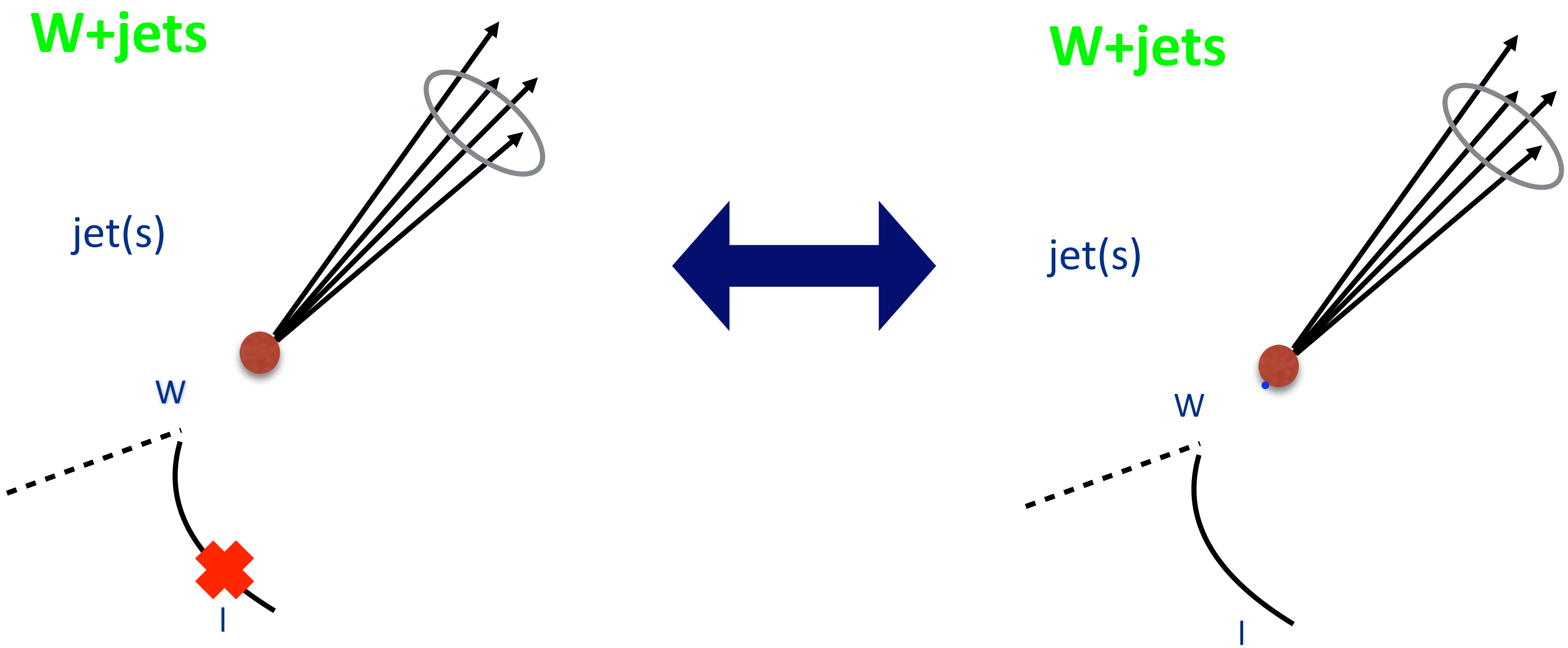
PROXY Di-mu/ele CR



Hadronic Recoil = |Met+ Pt μμ/ee|

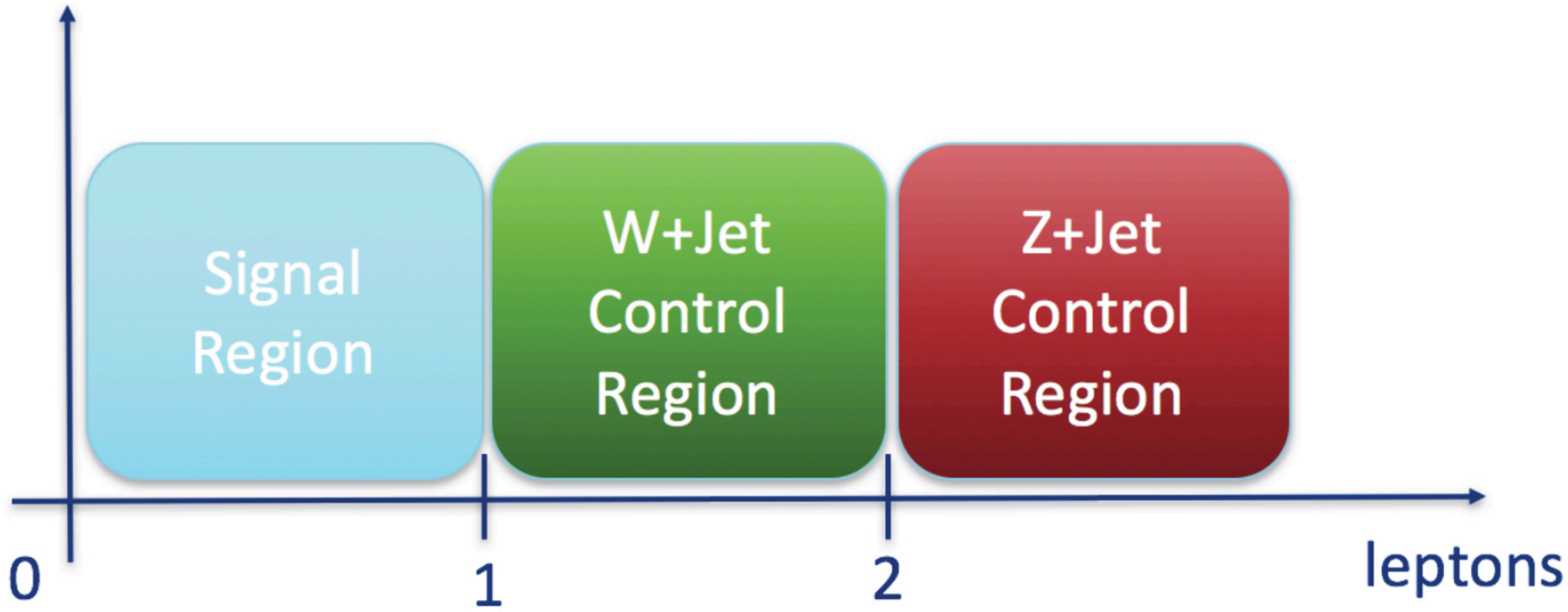
W+Jets Model

PROXY Single mu/ele CR



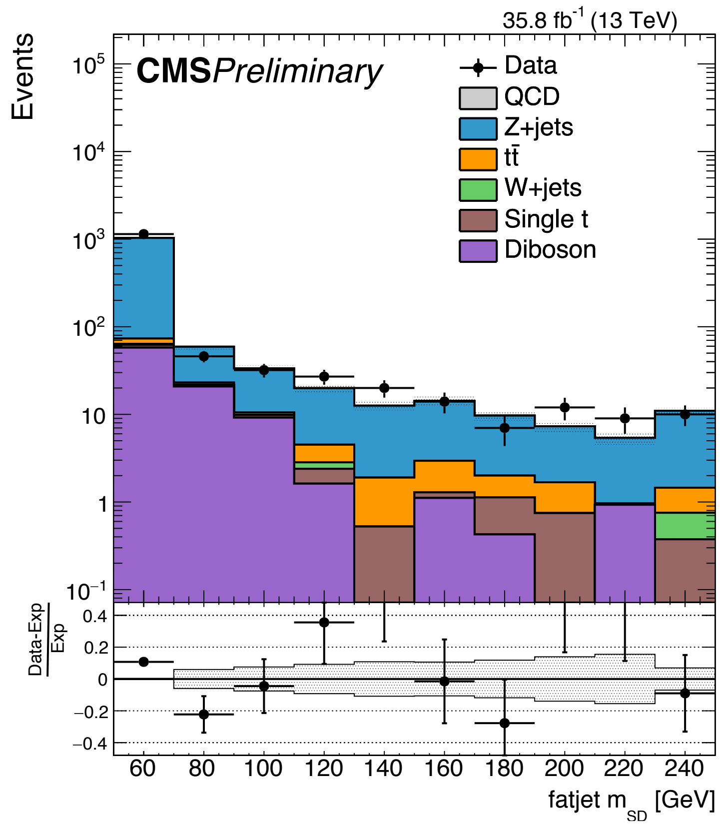
Hadroinic Recoil = |MET + Pt μ/e|

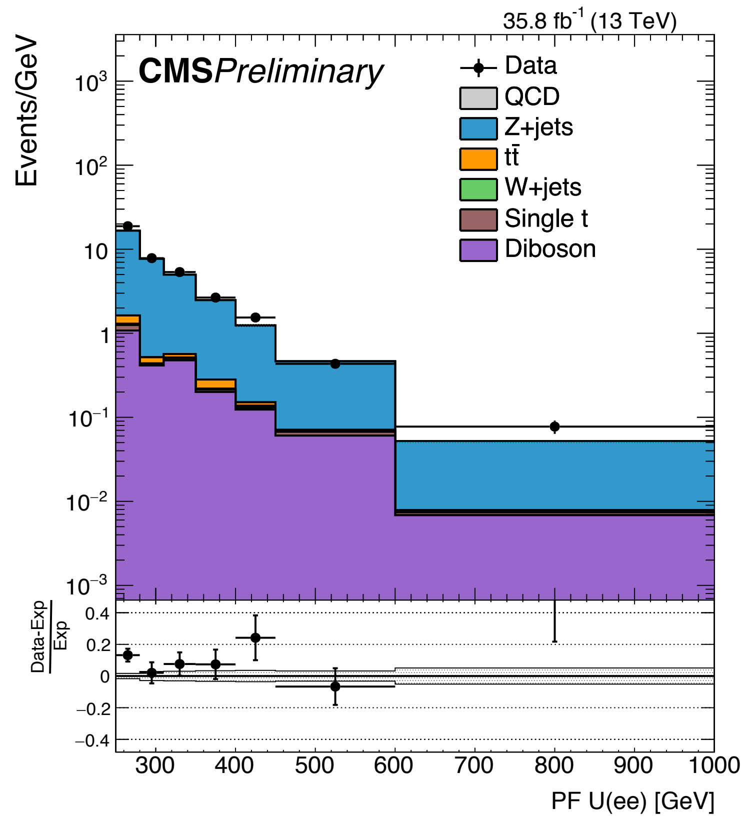
Control Regions



Z+Jet Control Region

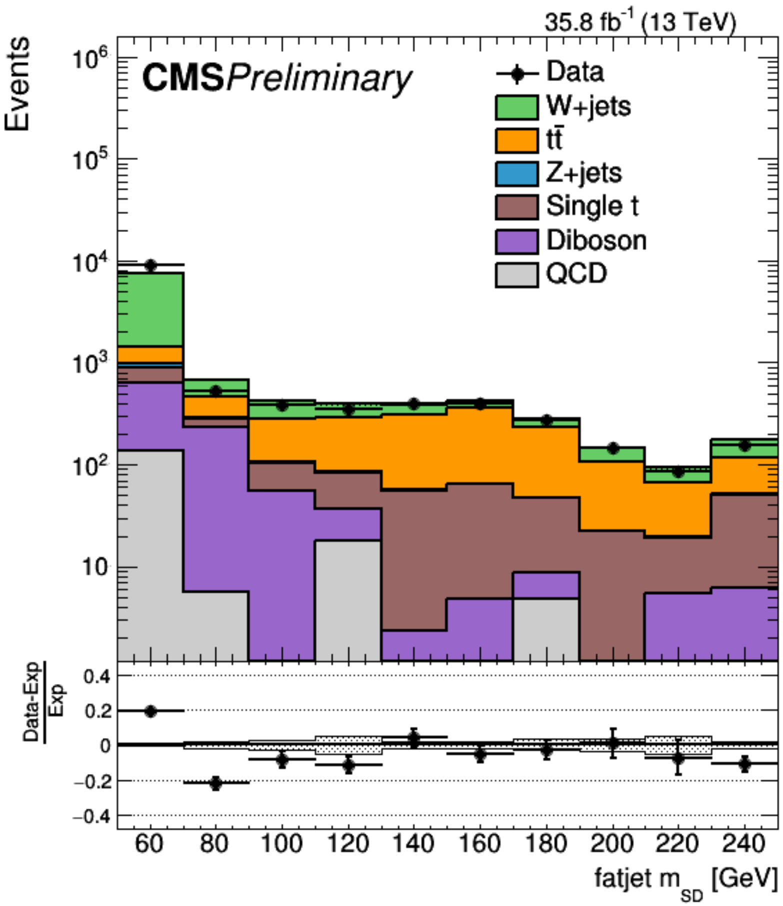
- Two opposite charge leptons: muons or electrons;
- Leptons Invariant Mass in Z mass window;

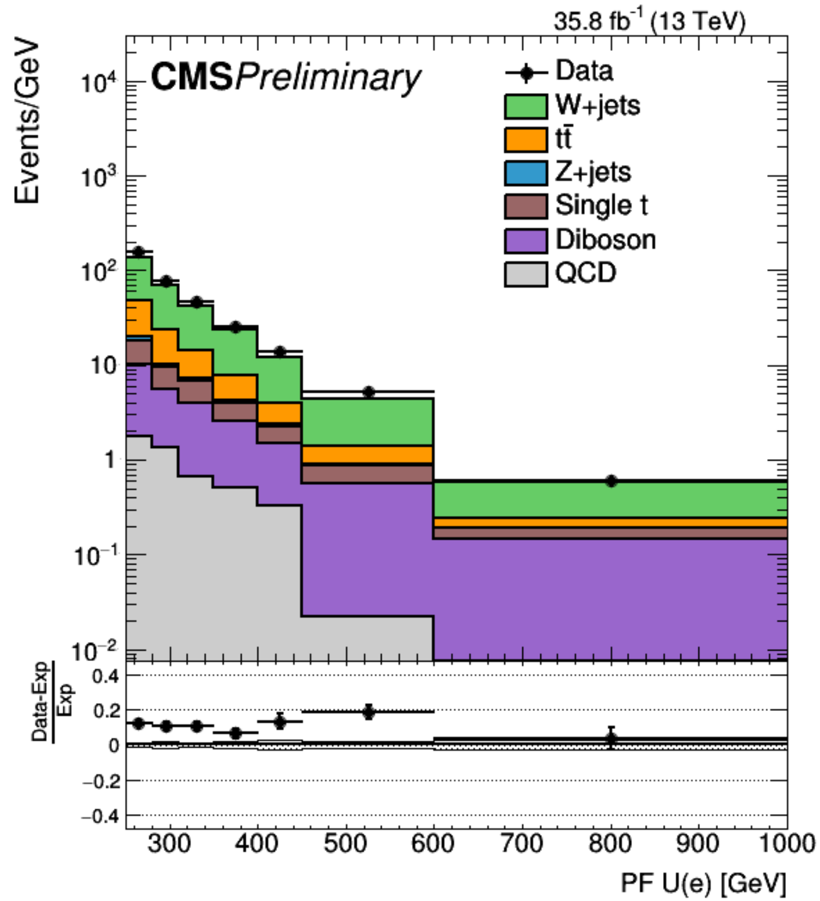




W+Jet Control Region

- One single lepton: muon or electron;





Background Estimation: step 1

Compute data-driven estimation through **transfer factors R**:

- derived in different recoil bins and different categories
- account for:
  - ratio of the cross sections
  - efficiency times acceptance of leptons in the control regions

$$N^{Z\nu\nu}_i = N^{Zll}_i \times R^{Z}_i$$

$$N^{Wl^*\nu}_i = N^{Wl\nu}_i \times R^{W}_i$$

Background Estimation: step 2

Incorporate theory/experimental uncertainties into **R** factors via free parameters **θ**

$$N^{Z\nu\nu}_i = N^{Zll}_i \times R(\theta)^Z_i$$

$$N^{Wl^*\nu}_i = N^{Wl\nu}_i \times R(\theta)^W_i$$

Background Estimation: step 3

Perform fit to find Z/W +jets yields that best accommodate CR observations

- Z/W yields in signal region, $\mu^{Z/W}{}_i$, are included in the fit as free parameters

$$N^{Zll}{}_i = \mu^{Z\nu\nu}{}_i \,/\, R(\theta)^{Z}{}_i$$

$$N^{Wl\nu}{}_i = \mu^{Wl^*\nu}{}_i \,/\, R(\theta)^{W}{}_i$$

Conclusion

- Model generation is running;

- Analysis Strategy already set up;

Future Tasks

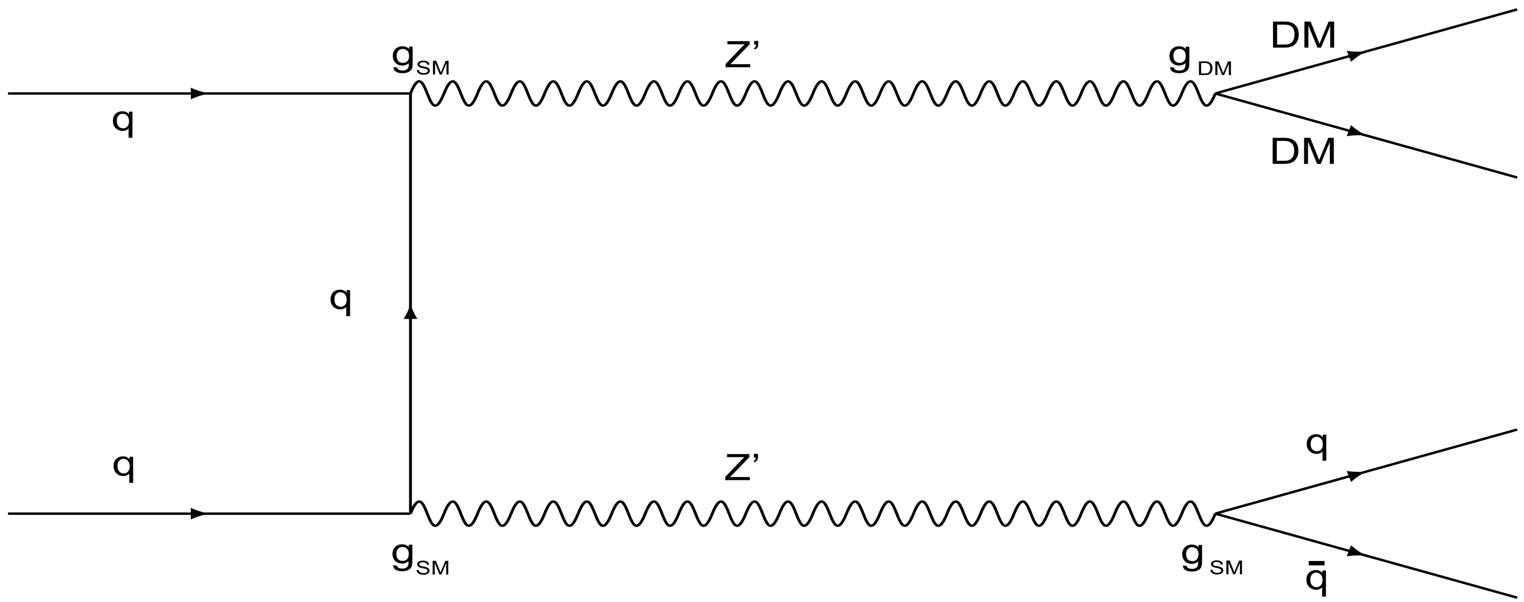
- Extraction of Results

Backup

Process of my work:

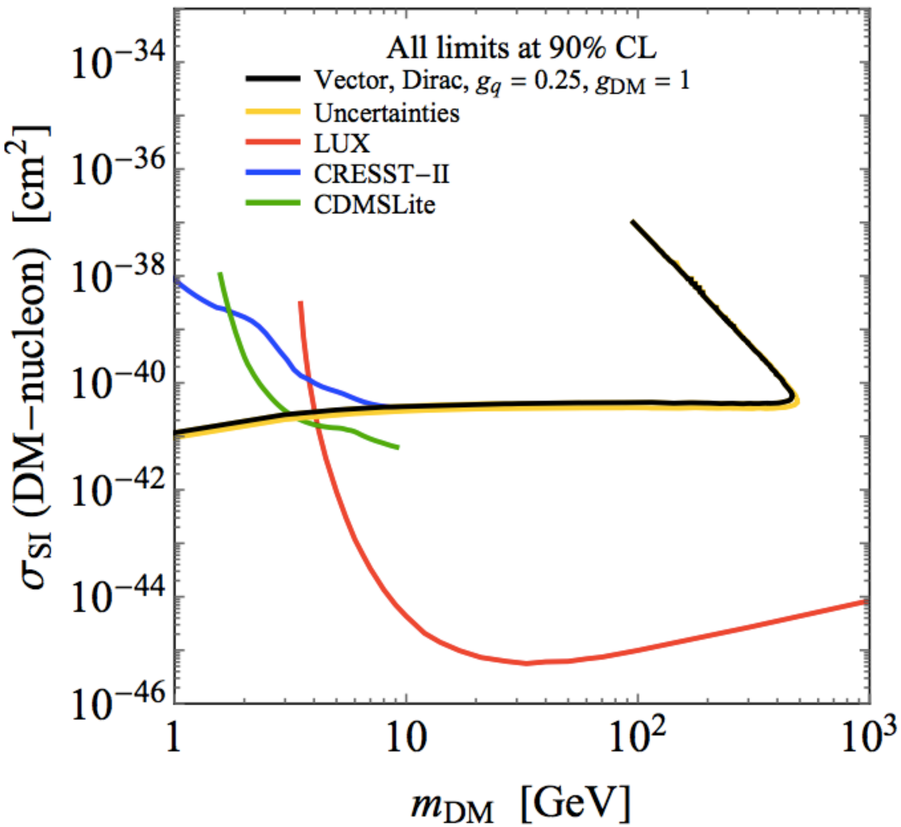
Backup

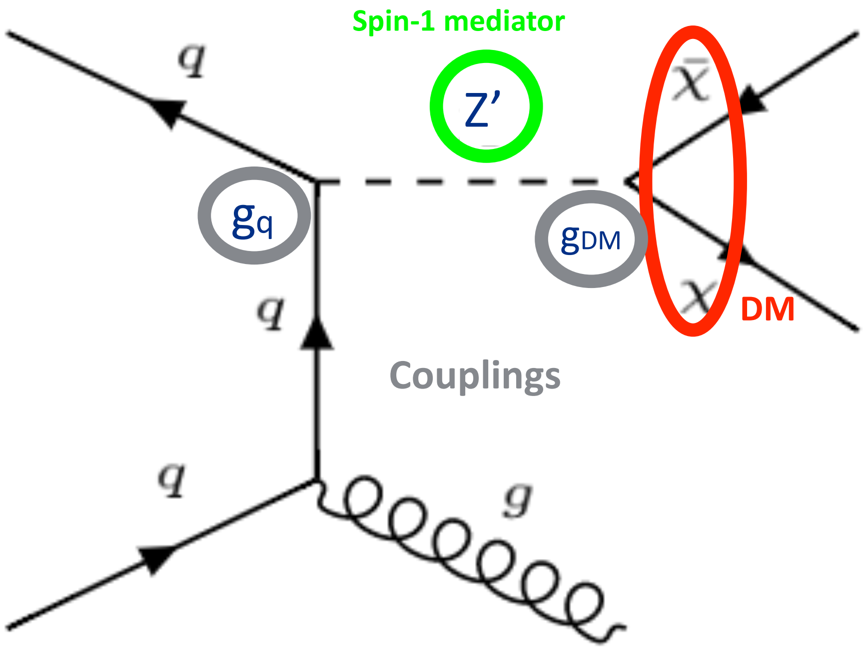
This is the process I will focus on:



From EFT to Simplified Models

Backup



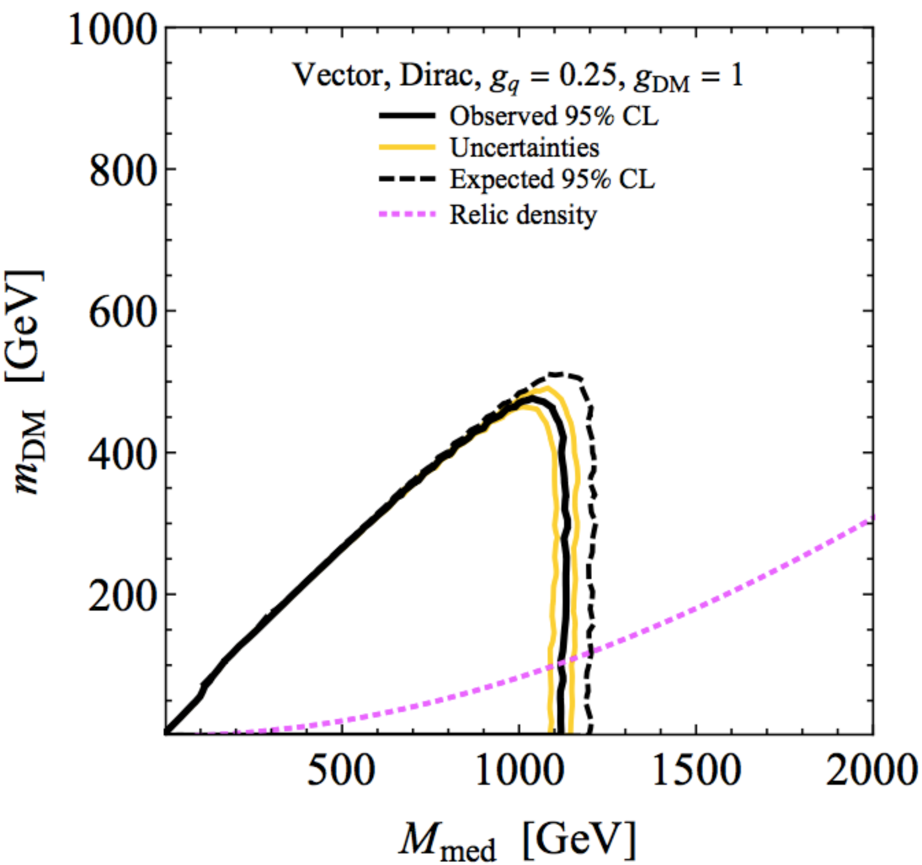


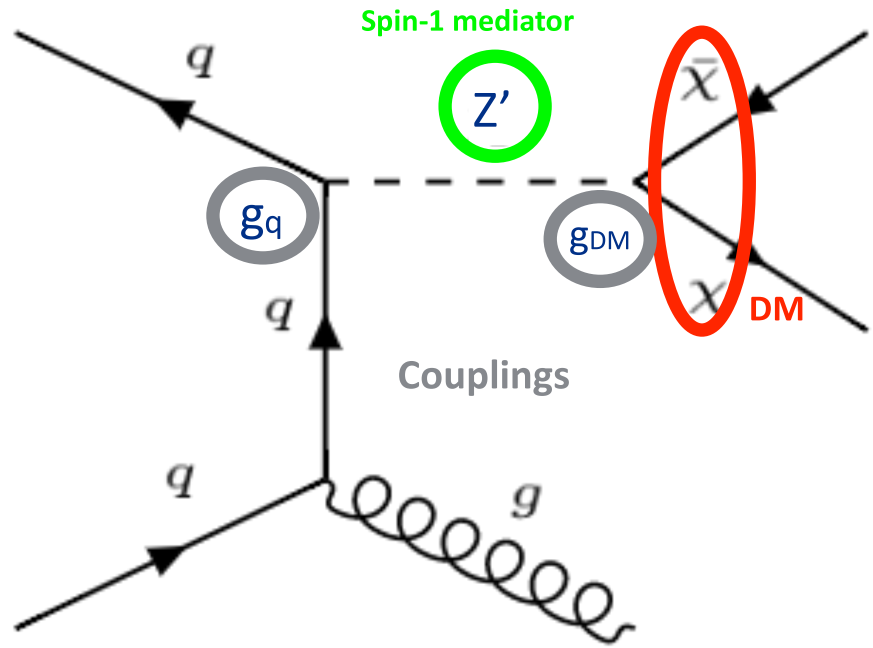
LHC DM WG, arxiv:1603.04156

Fermilab

From EFT to Simplified Models

Backup





LHC DM WG, arxiv:1603.04156

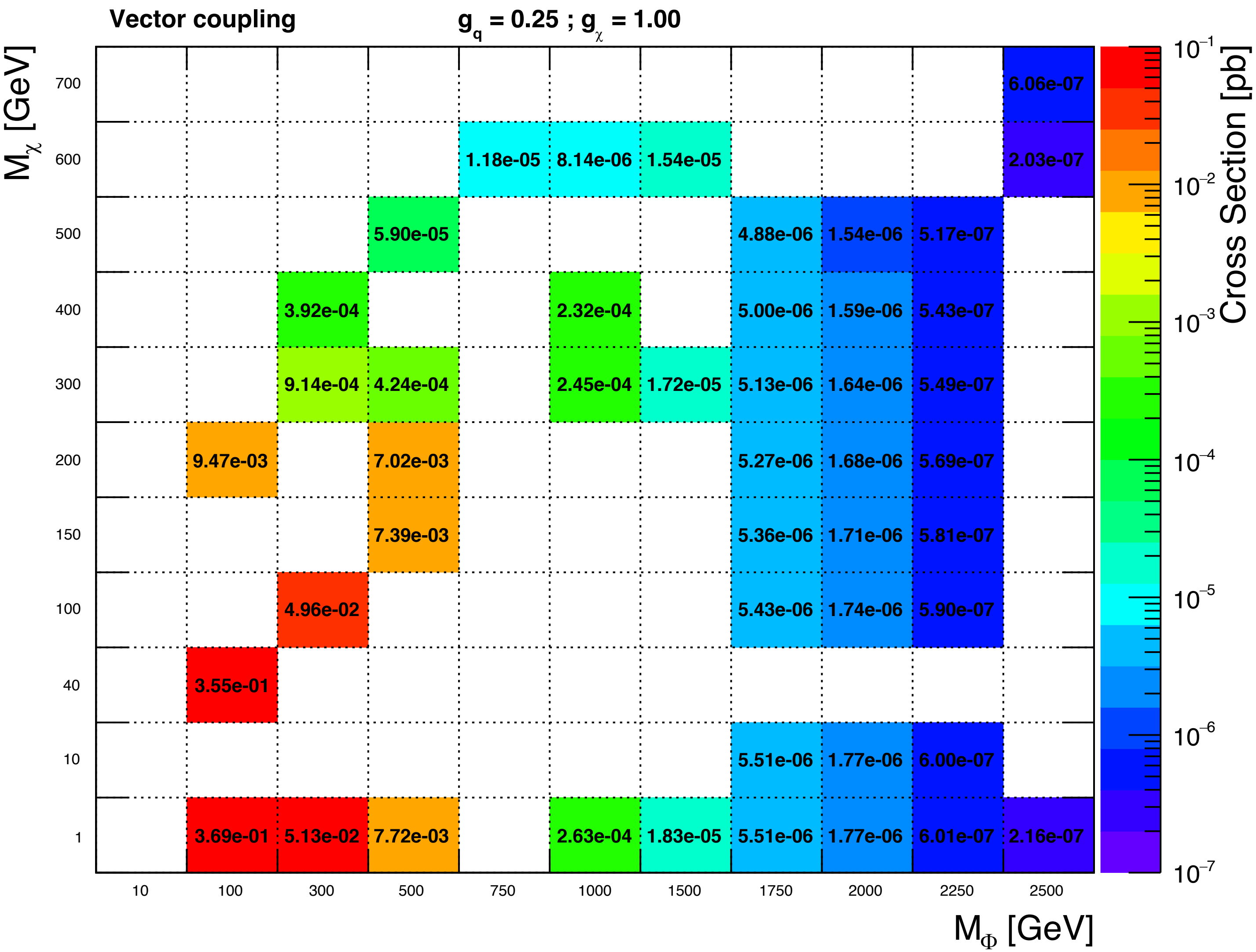
Cross Section Expected

Backup

	Cross Section	Width
Heavy Mediator case	$1.33 * 10^{-5}\ pb$	$3.01 * 10^{1}$
Heavy Dark Matter case	$1.93 * 10^{-6}\ pb$	7.74
Resonant case	$2.32 * 10^{-3}\ pb$	7.78

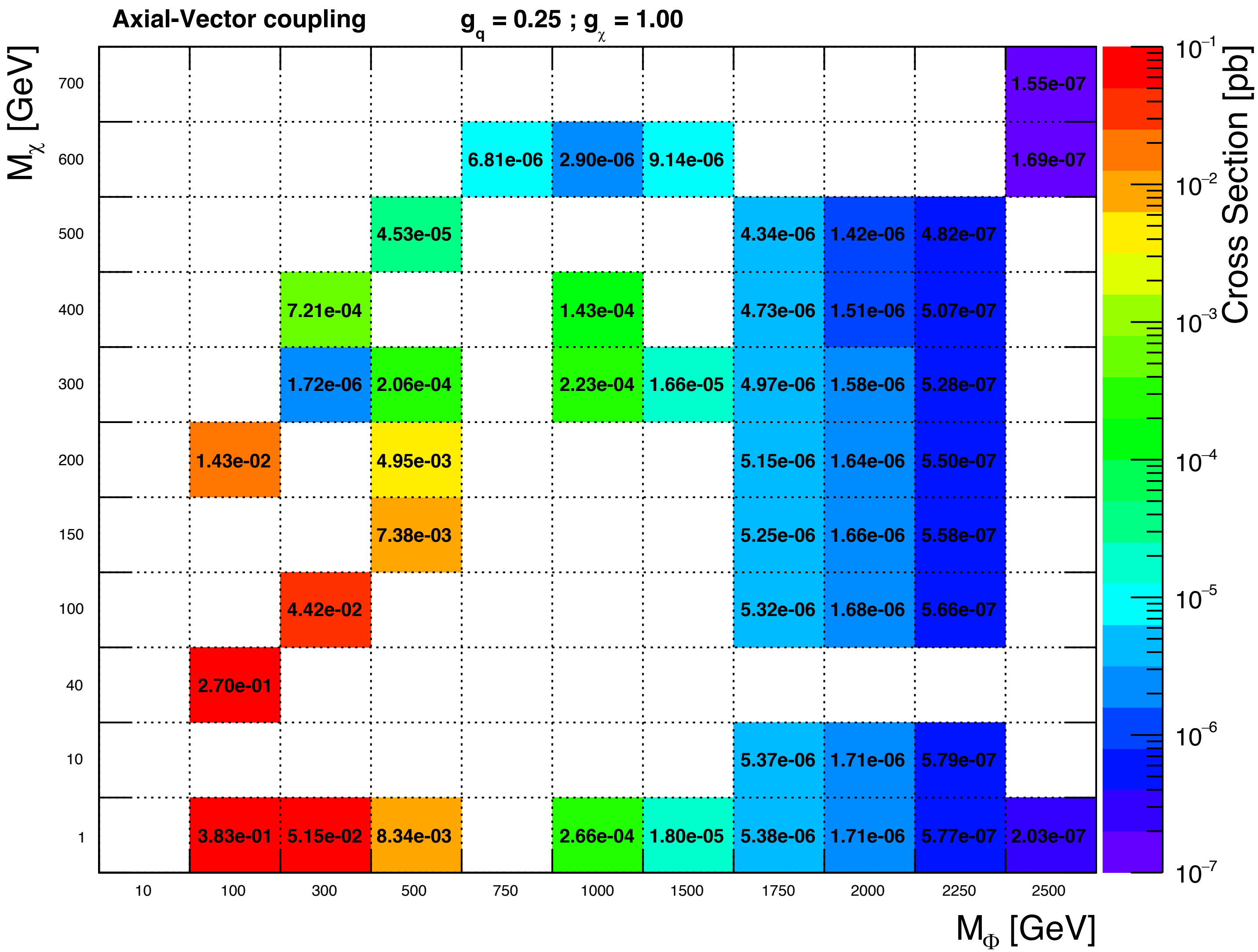
Cross Section expected for different DM & Mediator masses

Backup



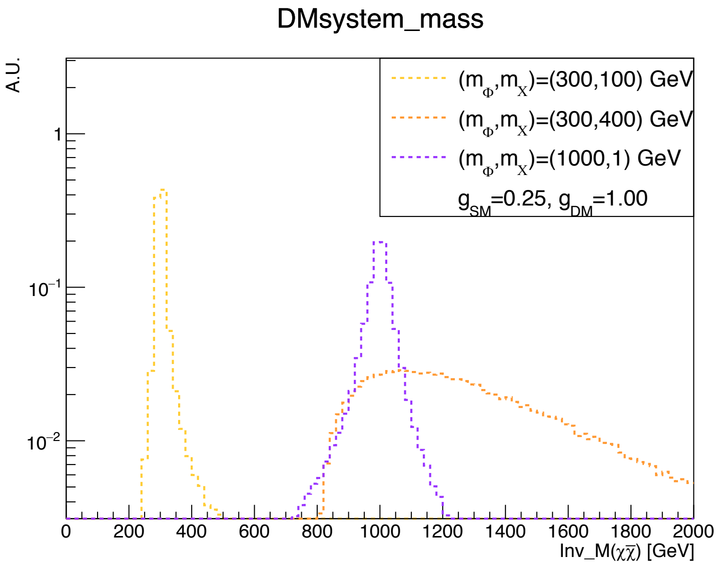
Cross Section expected for different DM & Mediator masses

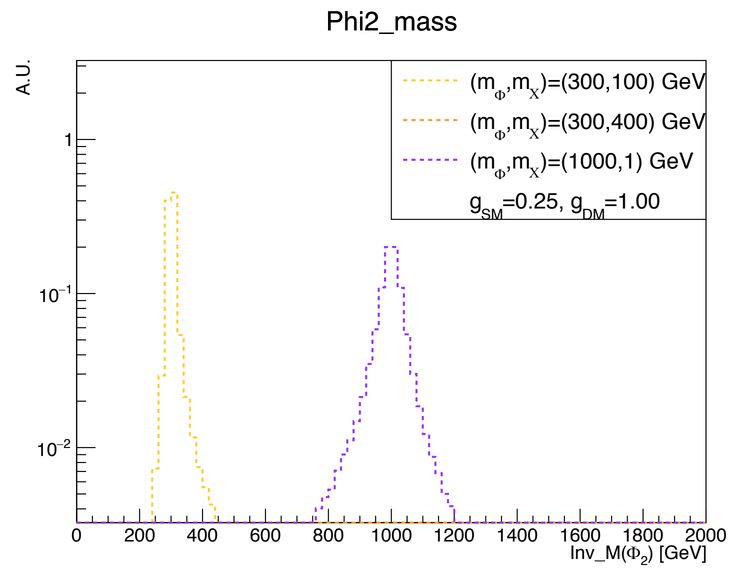
Backup

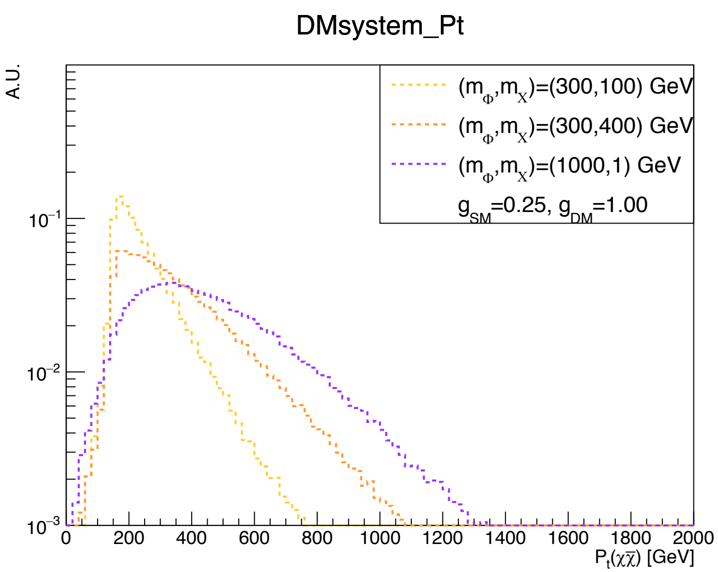


Madgraph Plots – Vector Coupling

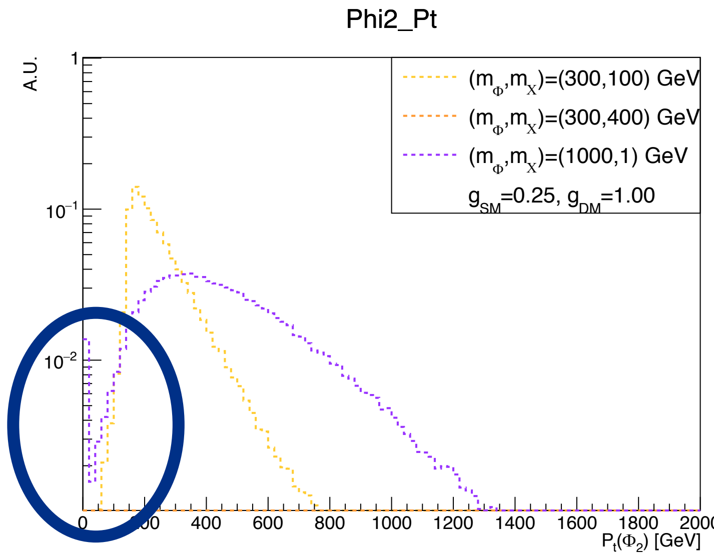
100˙000 events





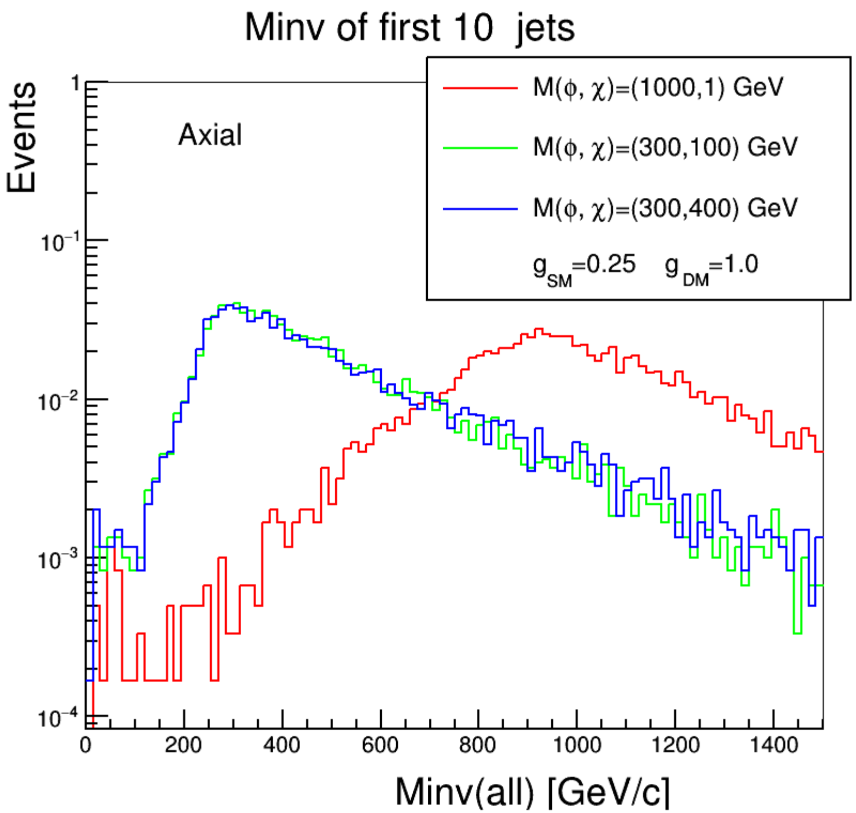


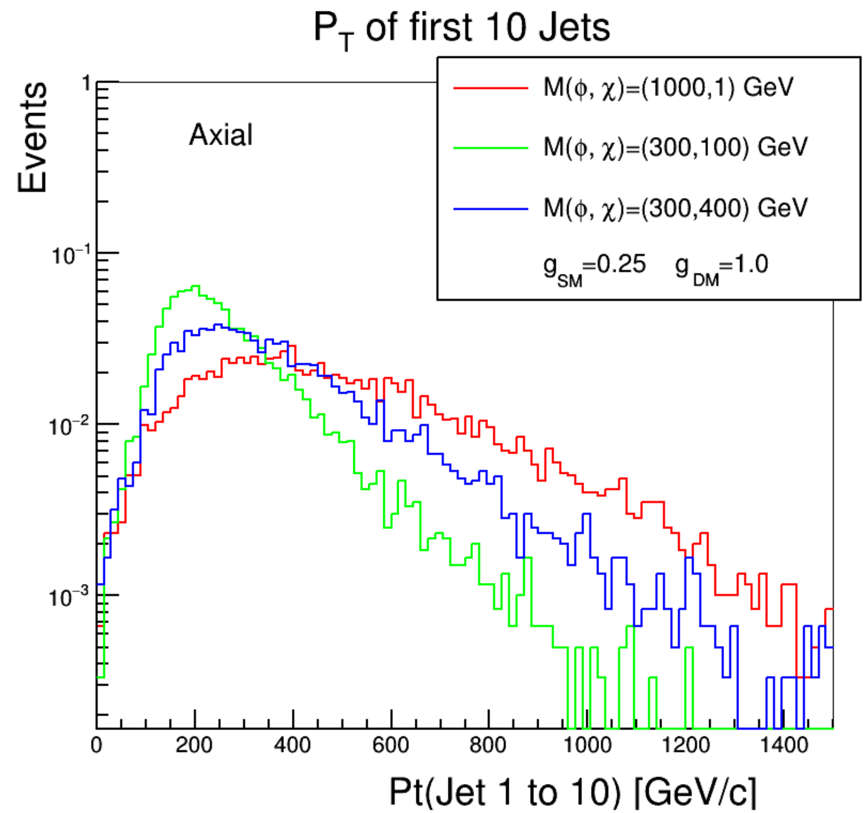
Generator Issue



Pythia Distributions – Axial Coupling

6˙000 events





- Distributions peak at Mediator mass;

- Cut in P_T at 150 GeV;

Backup