Search for massive bosons decaying to Wγ and Zγ using the ATLAS detector

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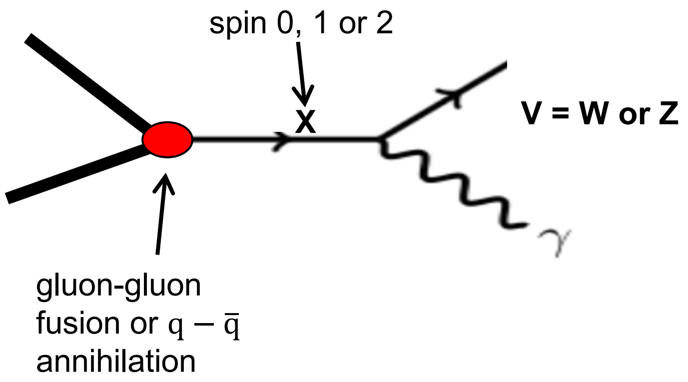
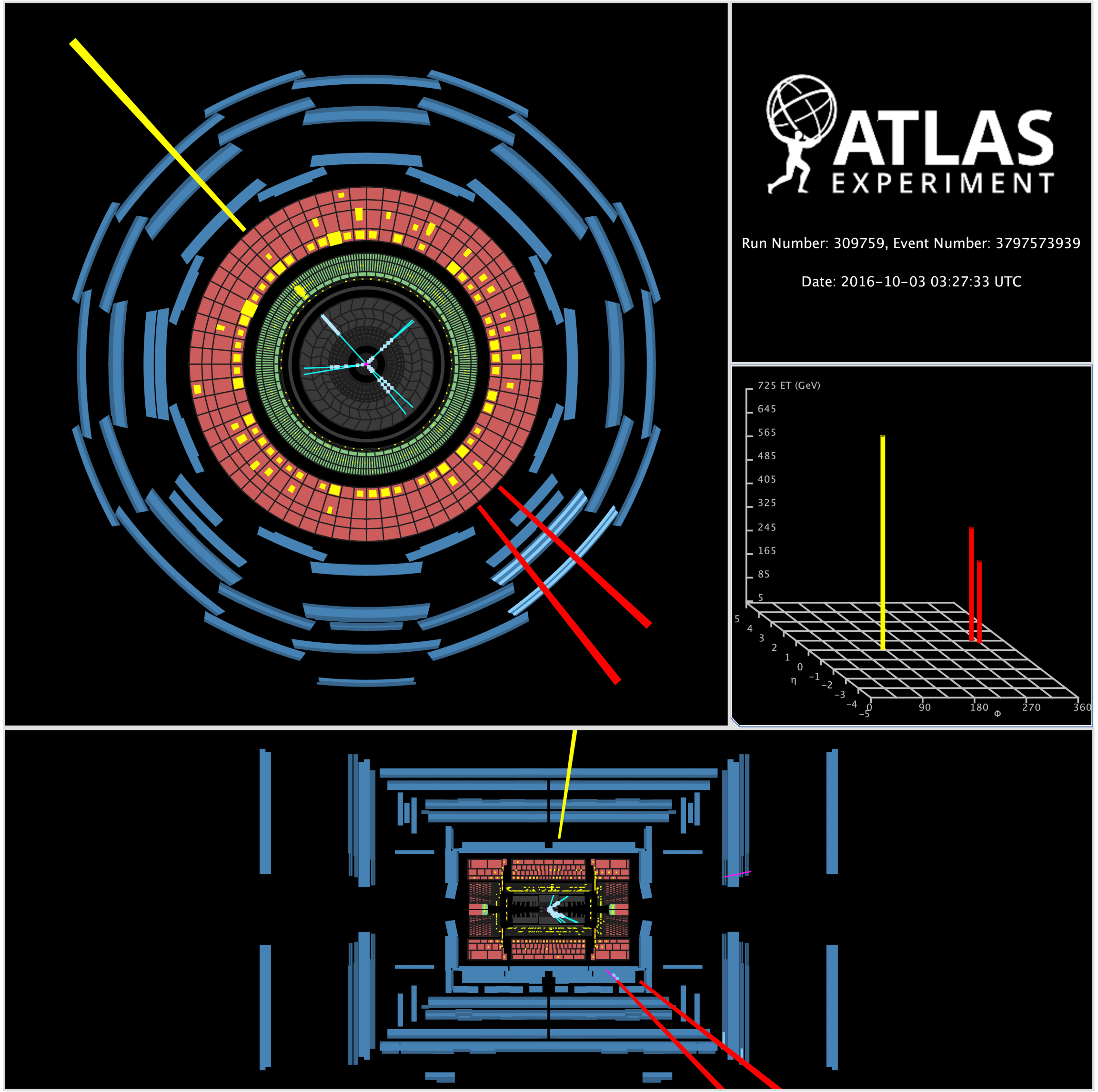
Introduction

- Many proposals for physics beyond the Standard Model predict new massive bosons from additional gauge fields or extended Higgs sectors.
- Possible decays are
  $X \rightarrow V\gamma$ where V is a W or Z boson.



- We describe preliminary results from a generic search for these bosons using data collected with the ATLAS detector exposed to 13 TeV proton-proton collisions from LHC.
- The ultimate goal of our search is to explore the X mass range from 250 GeV to highest energy attained in 13TeV p-p collision.

Search for X → Z(l^+l^-) + γ



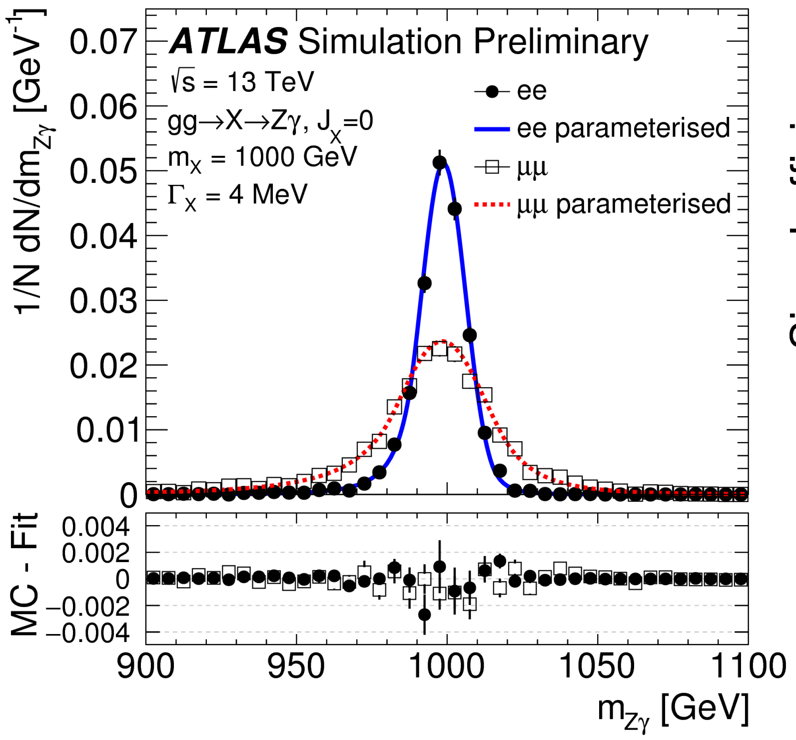
Search for X → $Z(l^+l^-) + \gamma$ (l = e or μ)

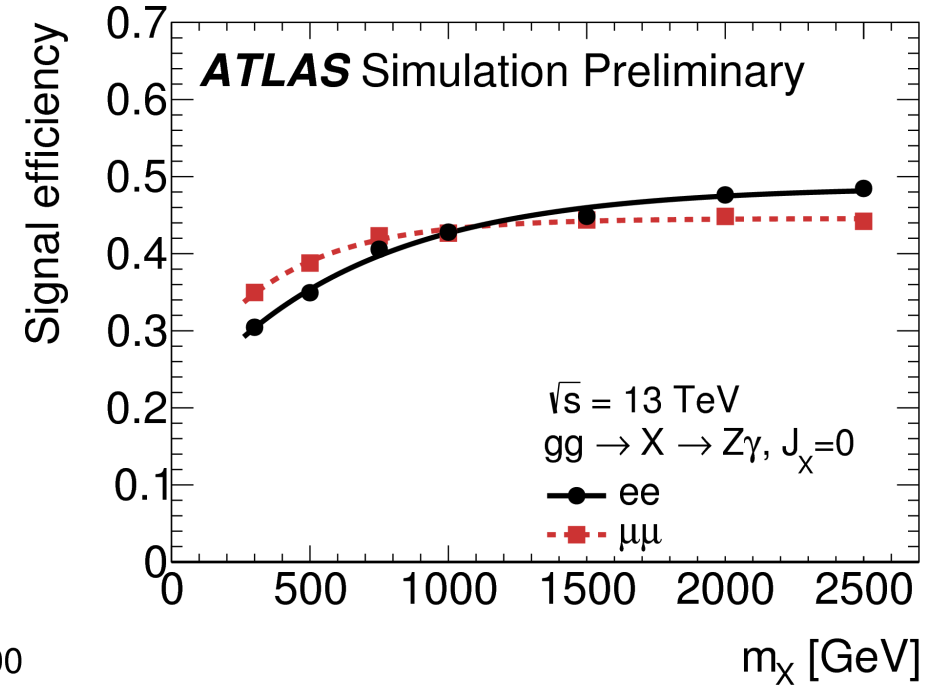
- The results reported here use 36.1 fb^{-1} of data collected by the ATLAS detector in 2015-2016 . HIGG-2016-14
- Events were selected using single electron and muon triggers with a nominal $P_T > 26$ GeV, supplemented by di-lepton triggers with lower thresholds.
- The Z → $l^+ l^-$ bosons are selected using well measured, isolated electron and muon pairs with invariant mass within ±15 GeV of the Z mass.
- The photons are required to be isolated with $|\eta| < 1.37$ or $1.52 < |\eta| < 2.37$ and Pt > 10 GeV .
- The final Z γ event selection requires the photon to have transverse momentum greater than 30% of the Z γ mass.

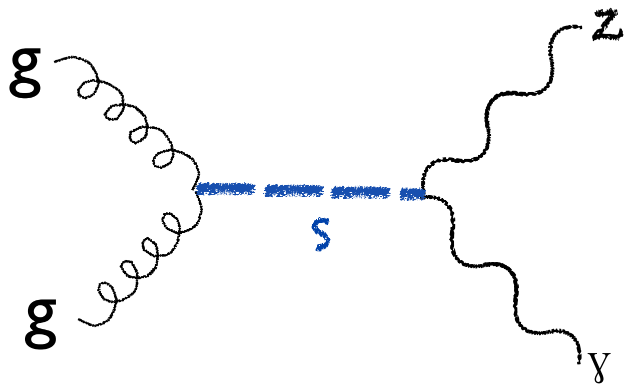
Search for X → Z(l^+l^-) + γ (l = e or μ)

New Results

- In the signal simulation, a scalar boson X is produced via gluon-gluon fusion, and decayed with a narrow (4 MeV) width to a Z boson plus photon. Event samples are generated using POWHEG-BOX interfaced with Pythia, with M_X masses 200 GeV to 2.4 TeV.







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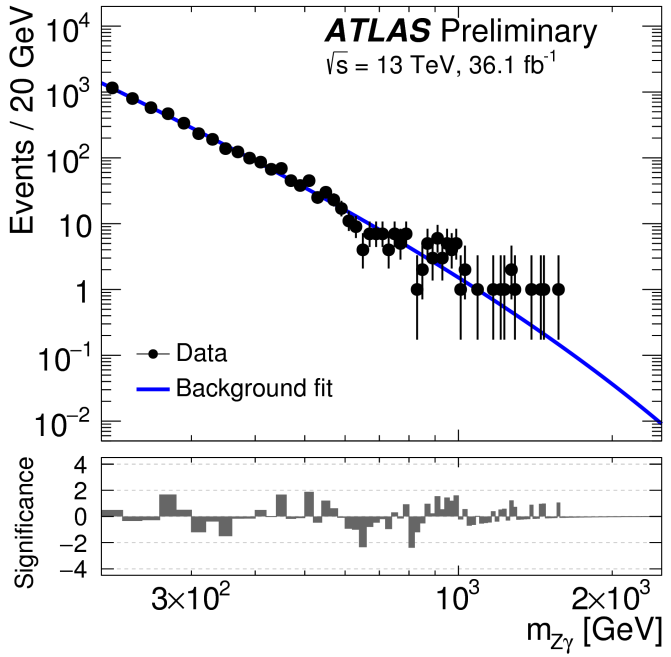
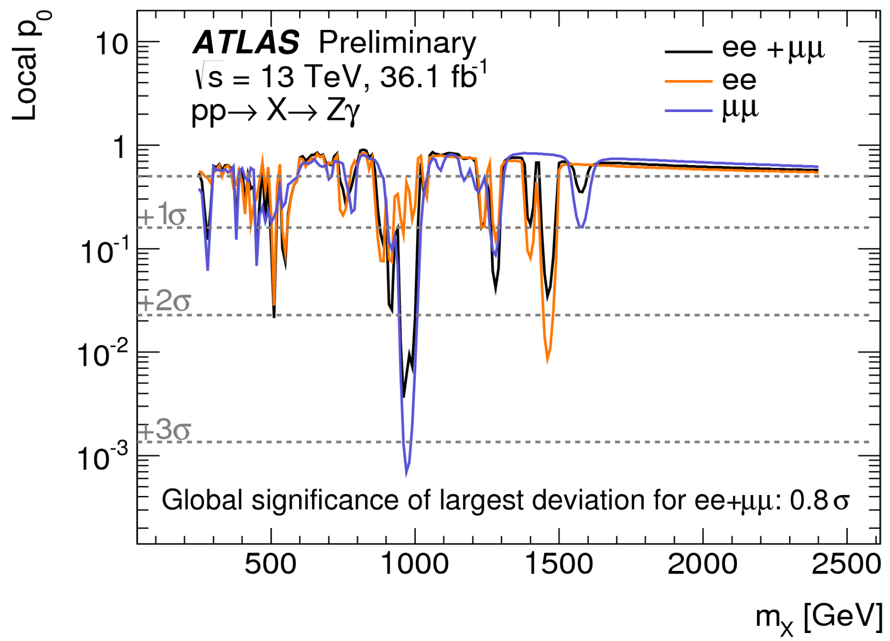
New Results

Search for X → Z(l^+l^-) + γ (l = e or μ)

- The dominant background is SM production of a Z boson plus a photon, with smaller contributions from Z + jets with the hadronic jet misidentified as a photon.

- The background Zγ mass spectrum is smoothly falling and can be parameterized with $f(x) \sim (1 - x^{1/3})^{p1} x^{p2}$ with x = $M_{Z\gamma}$ /$\sqrt{s}$.





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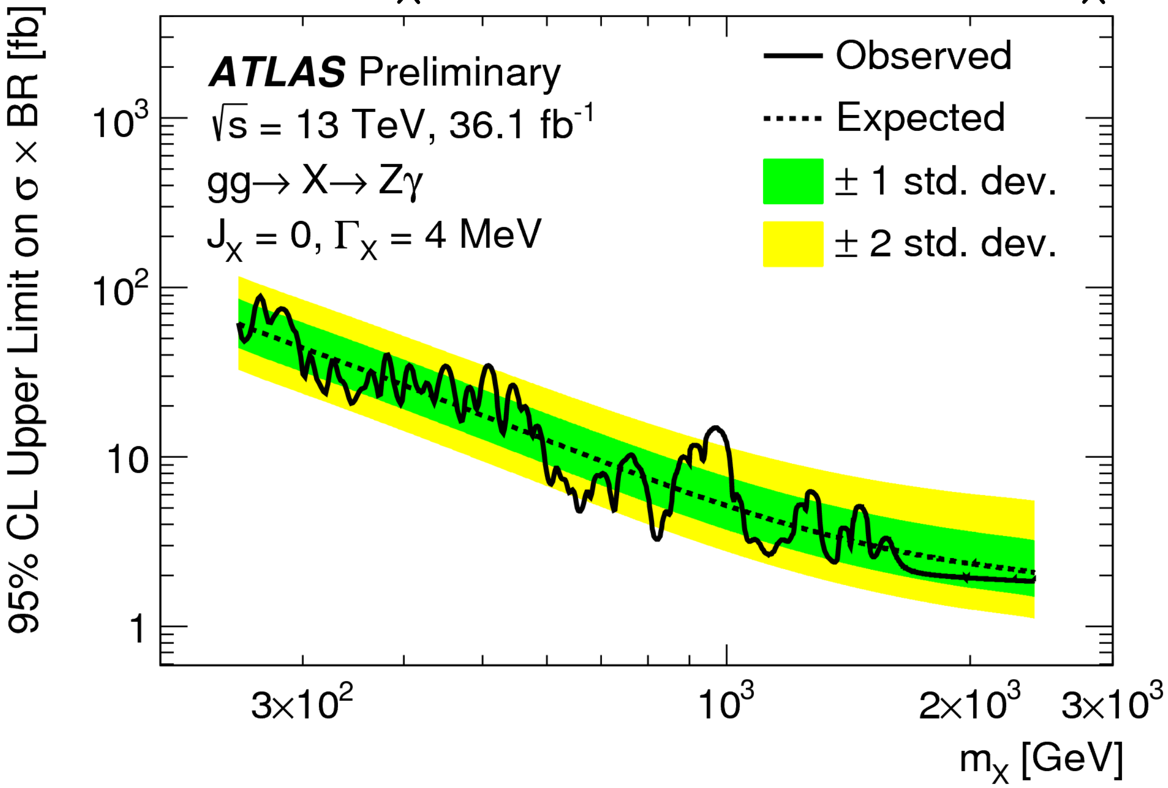
Search for $X \rightarrow Z(l^+l^-) + \gamma$ (l = e or μ)

New Results

- Upper limits on $\sigma_X \times BR(X \rightarrow Z\gamma)$ are set using a profile likelihood method.

- The observed $\sigma_X \times BR(X \rightarrow Z\gamma)$ limits vary from 88 fb at M_X = 250 GeV to 2.8 fb at M_X = 2.40 TeV



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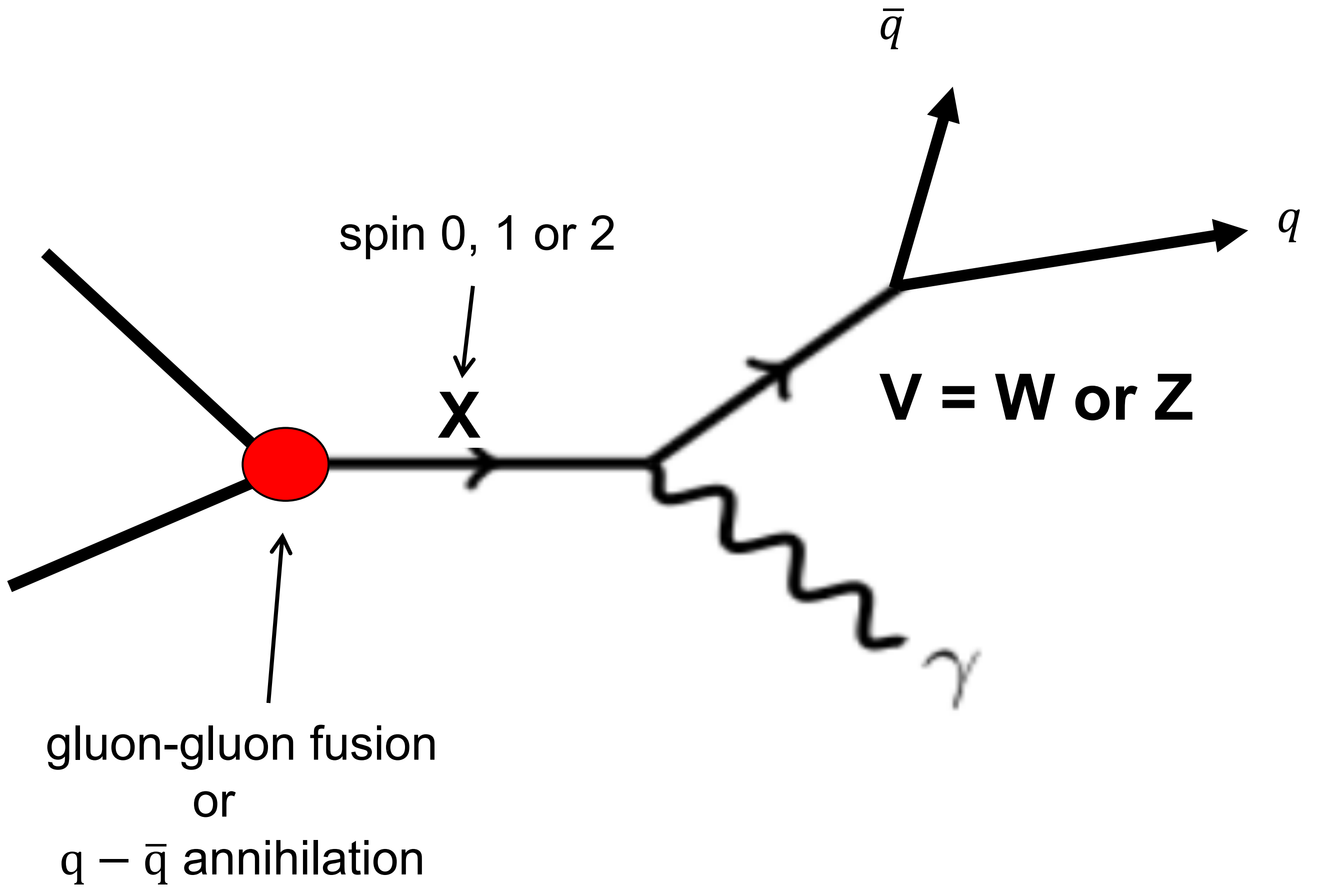
Searches for X → Z/W + γ using Hadronic Z/W decays

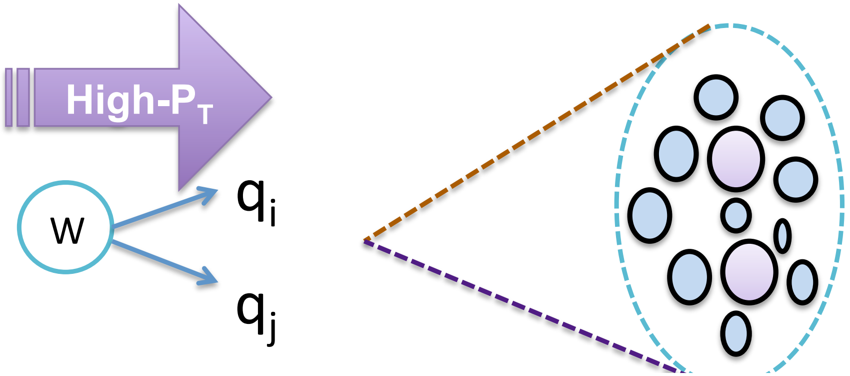


Searches for X → Z/W(q q) + γ

- The sensitivity for searches X → W/Z + g can be improved by capturing a higher fraction of the W/Z bosons from their hadronic decays: BR(W/Z→ $q\bar{q}$) ~ 70%.

- This search uses a selection of events based upon a photon trigger with E_T > 140 GeV, followed by identification of highly boosted W/Z($q\bar{q}$) bosons using fat jets with cone size R = 1.0.

- A jet substructure variable $D_2^{(\beta=1)}$ is used to identify fat jets with 2-jet substructure, to select hadronically decaying W/Z bosons while suppressing jets from single quarks or gluons.



– Boosted Regime: **Single *boson jet***

The boson has high momentum in the lab frame - the outgoing quarks are very close to each other so the jets begin to merge

A. J. Larkoski, I. Moult and D. Neill, Power Counting to Better Jet Observables, JHEP 1412 (2014) 009, arXiv: 1409.6298 [hep-ph].
s = 7 TeV,
[44] A. J. Larkoski, G. P. Salam and J. Thaler, Energy Correlation Functions for Jet Substructure, JHEP 1306 (2013) 108, arXiv: 1305.0007 [hep-ph].

Searches for $X \rightarrow Z/W(q\,q) + \gamma$

- We present here a preliminary study of the efficiency for selecting the $X \rightarrow Z/W(q\bar{q}) + \gamma$ events based upon parton-level generation of the signals;

  Spin 0 (POWHEG box) and Spin 2 (MadGraph) $X \rightarrow Z(q\bar{q}) + \gamma$
  spin 1 (MadGraph) $X \rightarrow W(q\bar{q}) + \gamma$

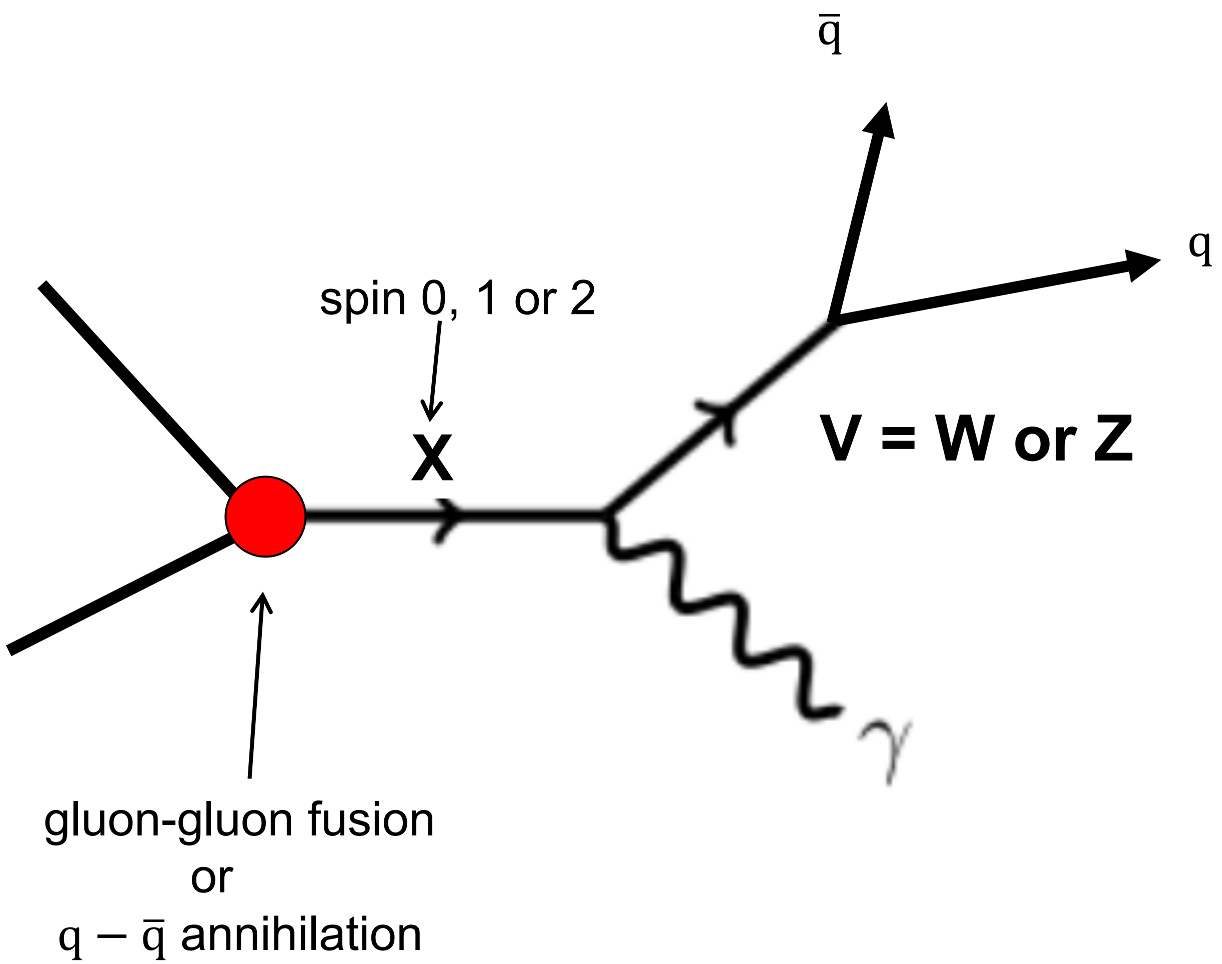
- The selection efficiency of the fat-jet identification of the W and Z bosons depends on the $\Delta R(q - \bar{q})$ decay distribution, and is therefore sensitive to the polarization of the W/Z bosons.

- The signal efficiency is studied as a function of the X boson mass using preliminary kinematic selection criteria.

Preliminary kinematic selection criteria:

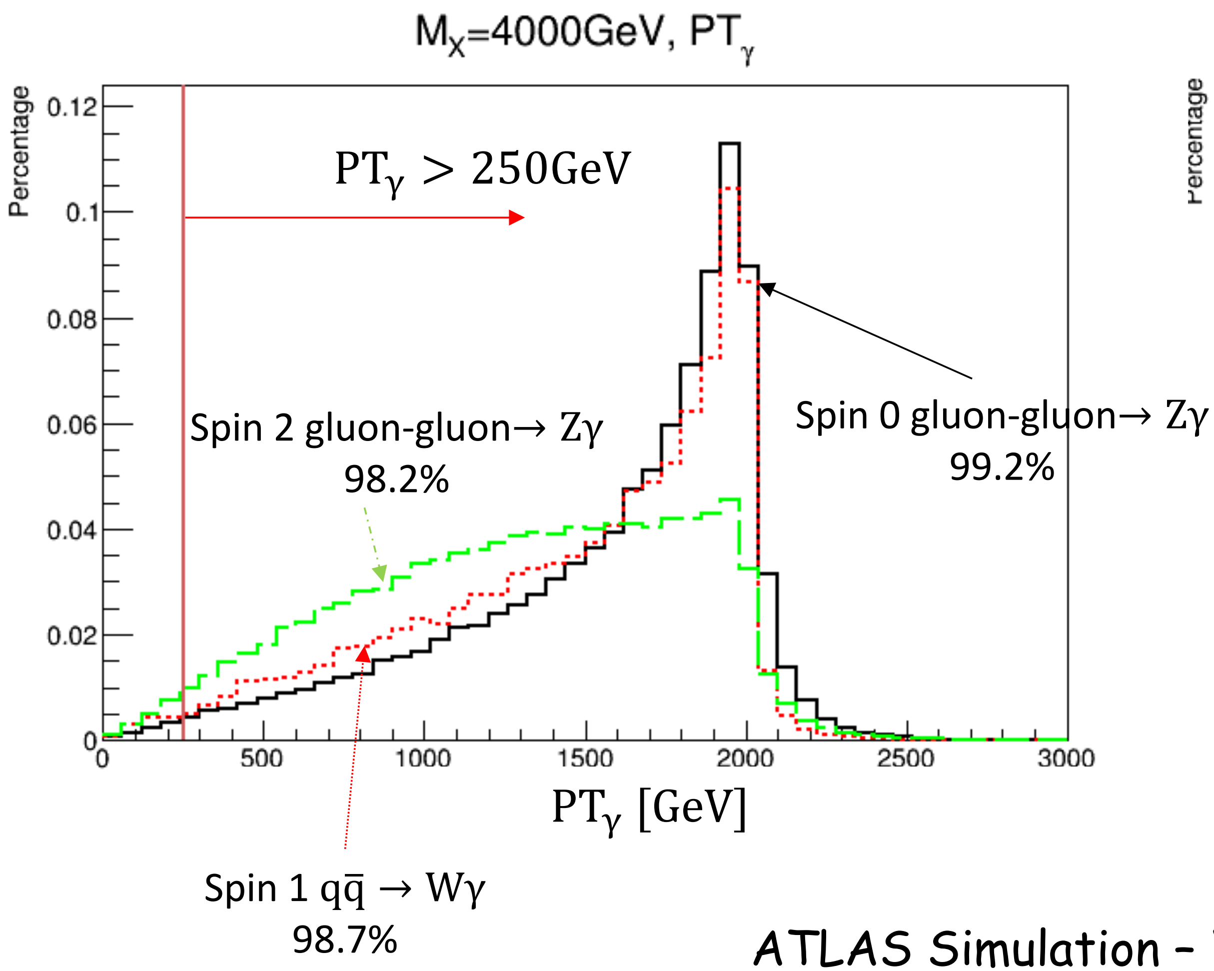
- $|\eta_{q\bar{q}}| < 2$
- $PT_{q\bar{q}} > 200GeV$
- $PT_{\gamma} > 250GeV$
- $|\eta_{\gamma}| < 1.37$

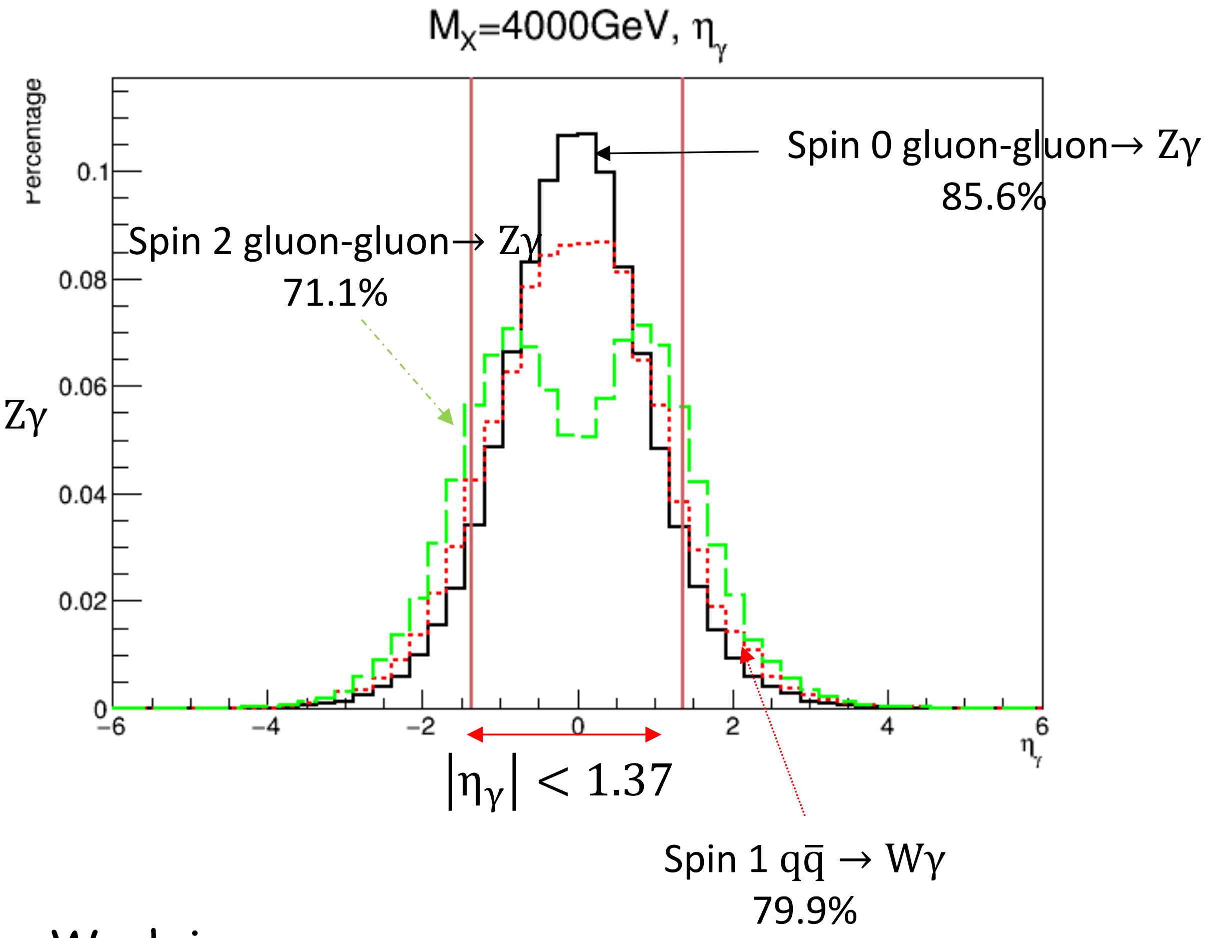
i. Spin 0 $gluon - gluon \rightarrow Z\gamma$
ii. Spin 1 $q\bar{q} \longrightarrow W\gamma$
iii. Spin 2 $gluon - gluon \rightarrow Z\gamma$



Kinematic Cuts

- Plot histograms of PT_γ and η_γ.
- Apply $PT_\gamma > 250\text{GeV}$ and $|\eta_\gamma| < 1.37$ cut separately.
- The selection efficiencies are mostly high.

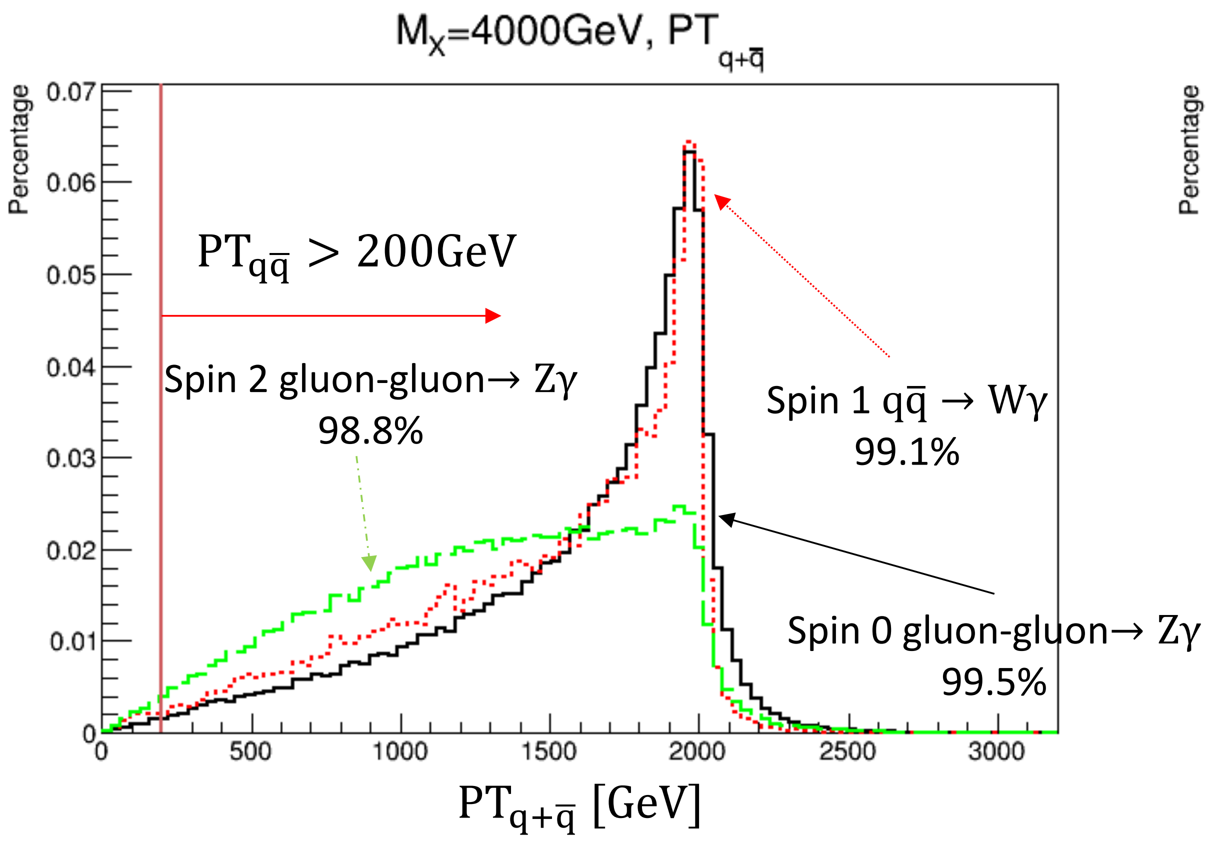


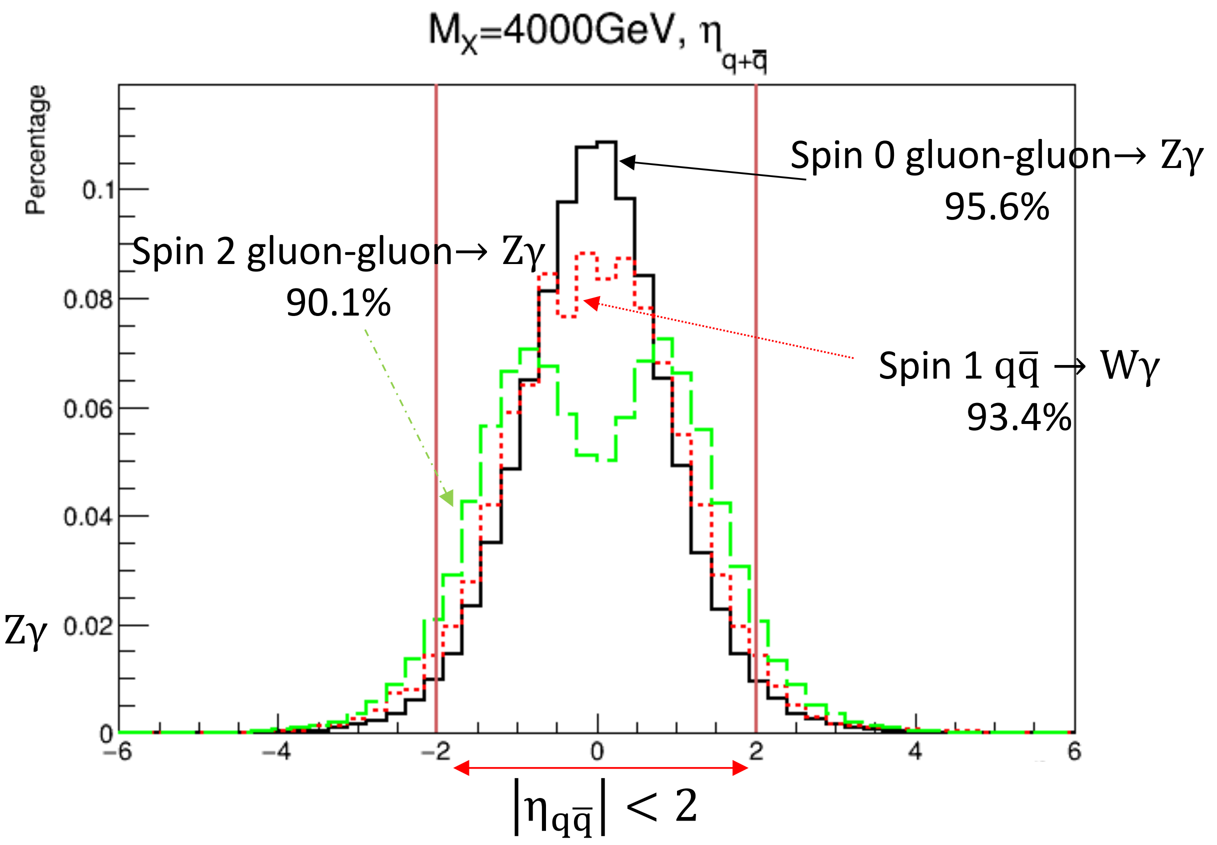


ATLAS Simulation – Work in progress

Kinematic Cuts

- Plot histograms of $PT_{q\bar{q}}$ and $\eta_{q\bar{q}}$.
- Apply $PT_{q\bar{q}} > 200\text{GeV}$ and $|\eta_{q\bar{q}}| < 2$ cut separately.
- The selection efficiencies are high (>90%).

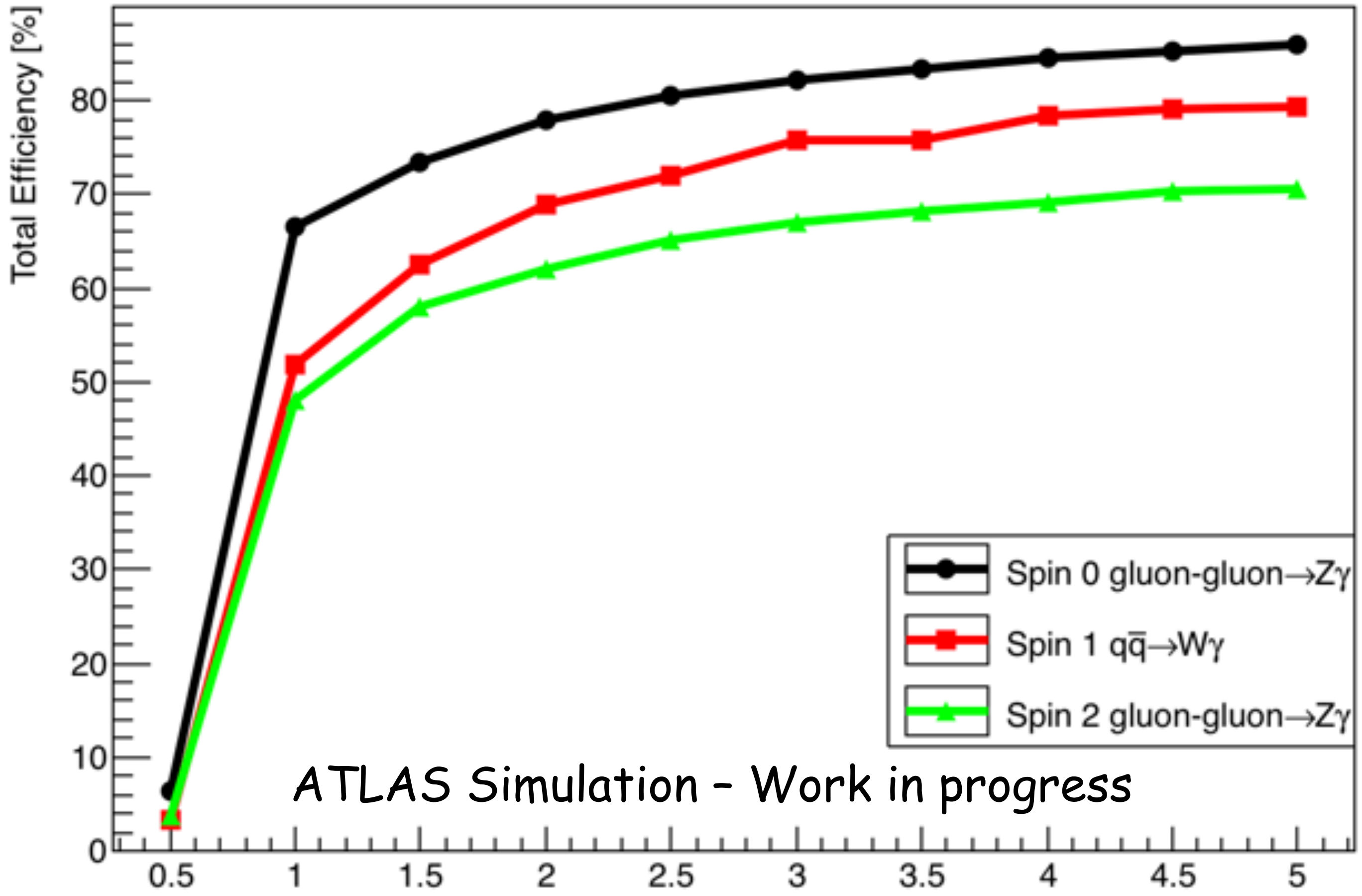




ATLAS Simulation – Work in progress

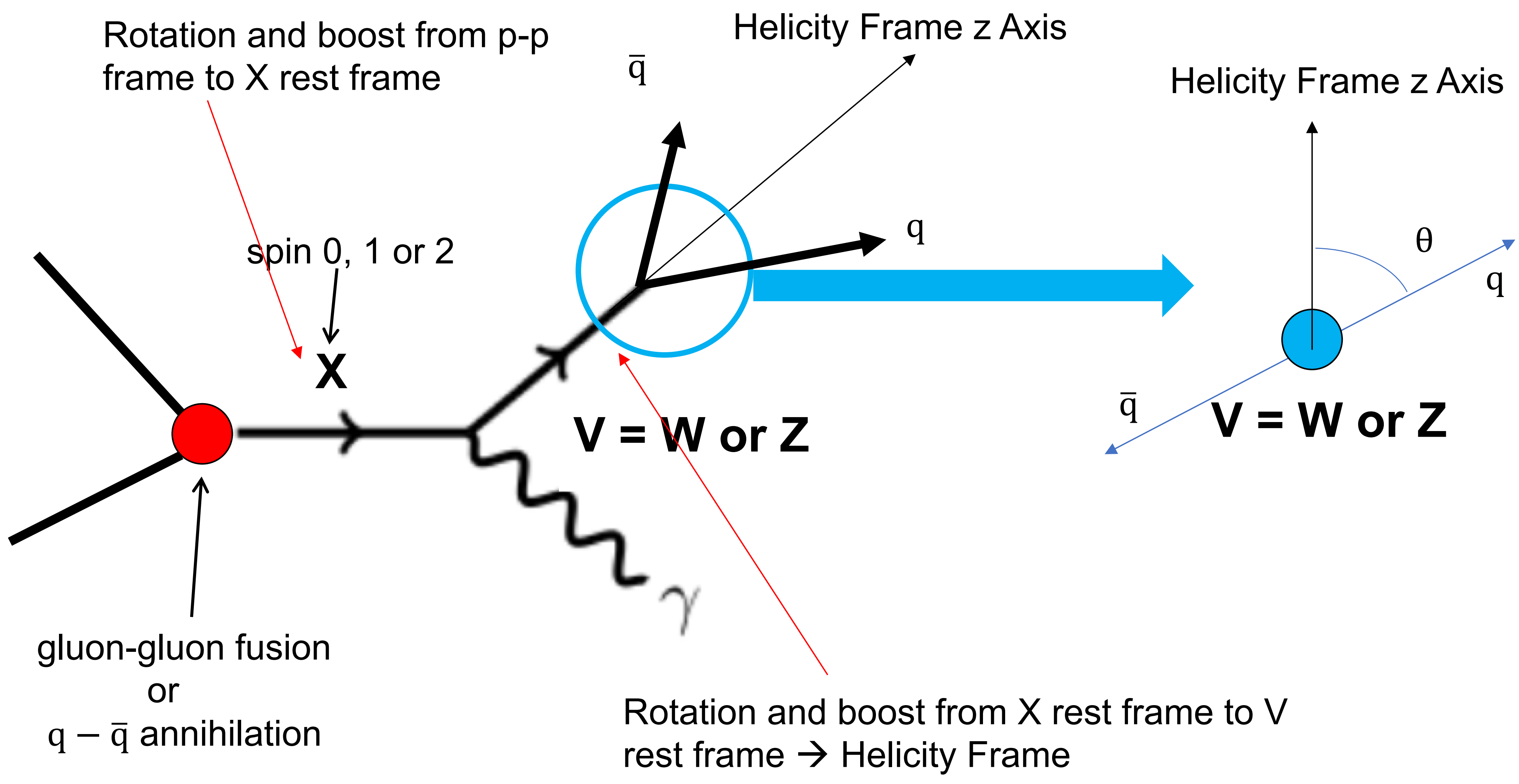
Kinematic Cuts Efficiencies

- Apply $|\eta_{q\bar{q}}| < 2$, $PT_{q\bar{q}} > 200\text{GeV}$, $PT_{\gamma} > 250\text{GeV}$ and $|\eta_{\gamma}| < 1.37$ cut simultaneously to obtain total kinematic selection efficiency.
- The plot shows total efficiency as a function of M_X.



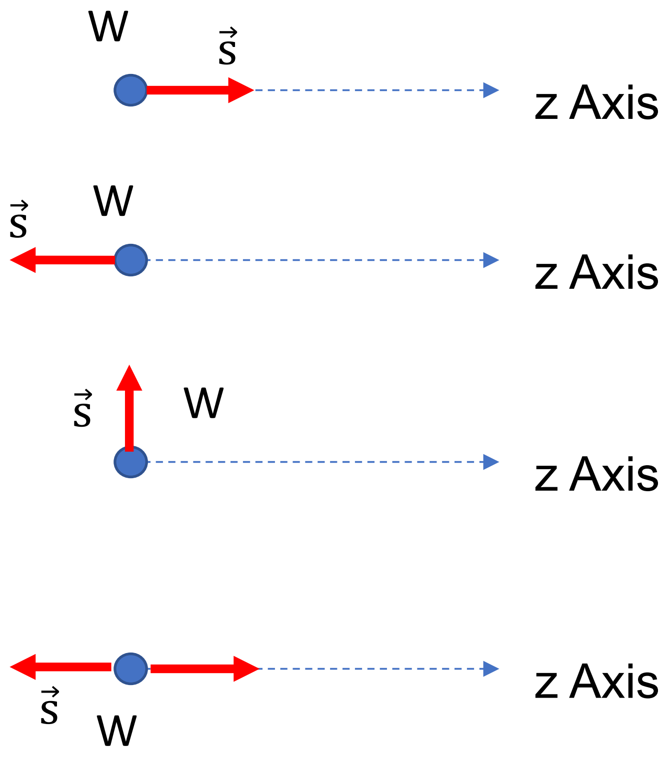
M_X [TeV]

Helicity Frame



Decay Polarizations

- $\cos\theta_{\bar{q}}$ distribution in the helicity frame is a measure of the decay polarization.
- The distribution is different for different W/Z production channels.
- The SM electroweak decay of the W predicts the following helicity-frame angular distributions for various W polarization states :



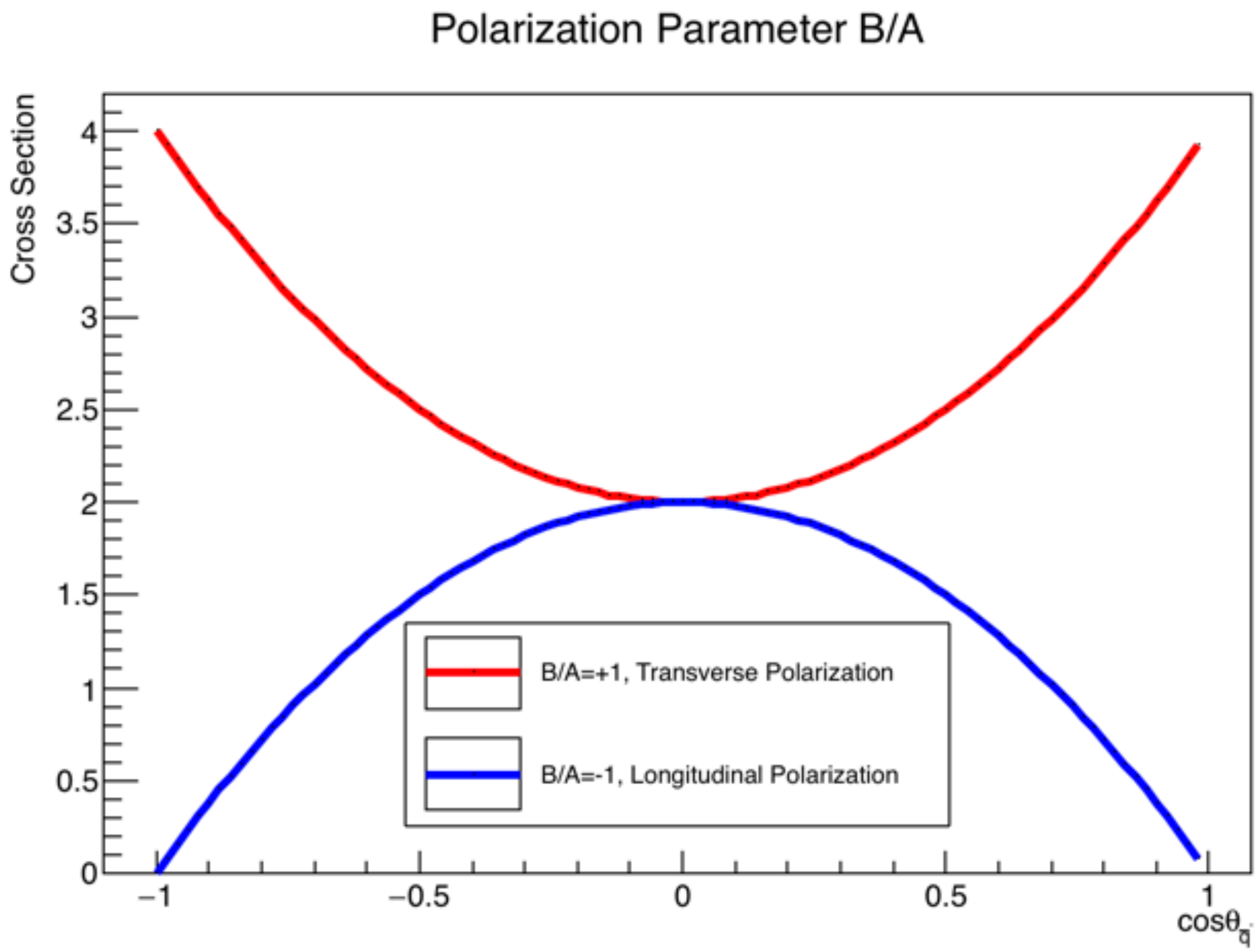
h = +1, $\frac{dN}{d\cos\theta} \sim (1-\cos\theta)^2$

h = -1, $\frac{dN}{d\cos\theta} \sim (1+\cos\theta)^2$

h = 0, $\frac{dN}{d\cos\theta} \sim \sin\theta^2 = 1-\cos\theta^2$, Longitudinal Polarization

h = ± 1, $\frac{dN}{d\cos\theta} \sim 1+\cos\theta^2$, Transverse Polarization

Interpretation



Cross Section= $A + B\cos\theta^2 = A[1 + \frac{B}{A}\cos\theta^2]$

$\frac{B}{A} = +1 \Longrightarrow$ Transverse Polarization

$\frac{B}{A} = -1 \Longrightarrow$ Longitudinal Polarization

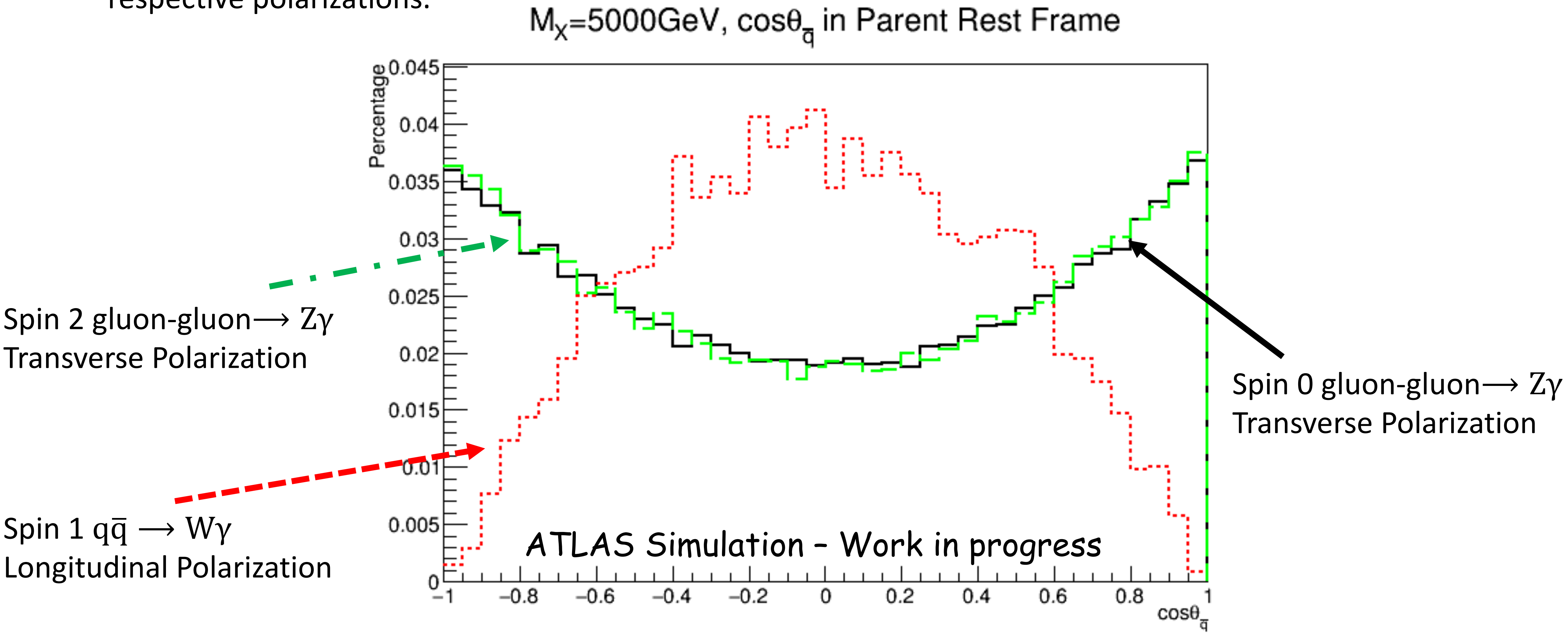
- Fit $\cos\theta_{\bar{q}}$ distributions to obtain $\frac{B}{A}$ as measures of W/Z polarization
- Repeat as a function of M_X

Decay Polarizations

Assumptions:

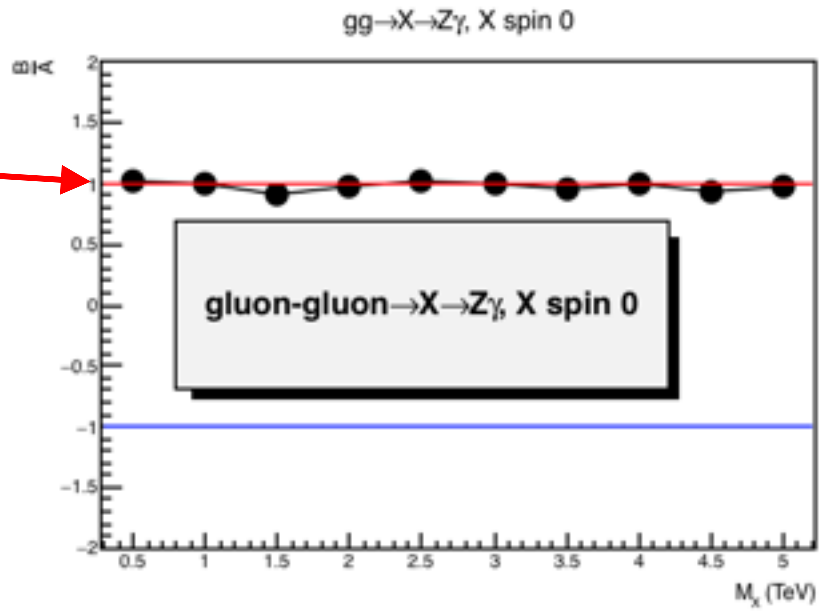
1. Do not distinguish $q\bar{q}$
2. Do not distinguish $W^{\pm}$

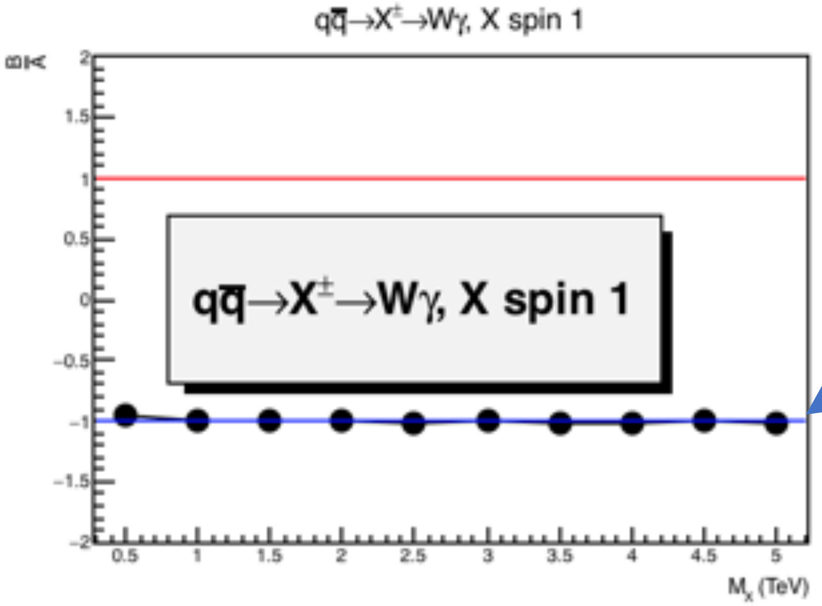
The plot shows an example of $\cos\theta_{\bar{q}}$ distribution for $M_X = 5\text{TeV}$ of 3 production channels and their respective polarizations.



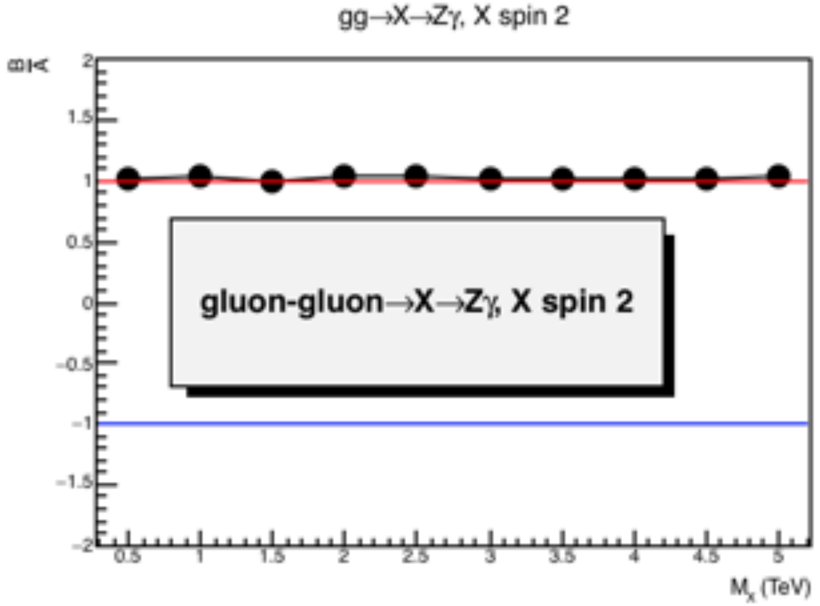
Decay Polarizations

Transverse Polarization





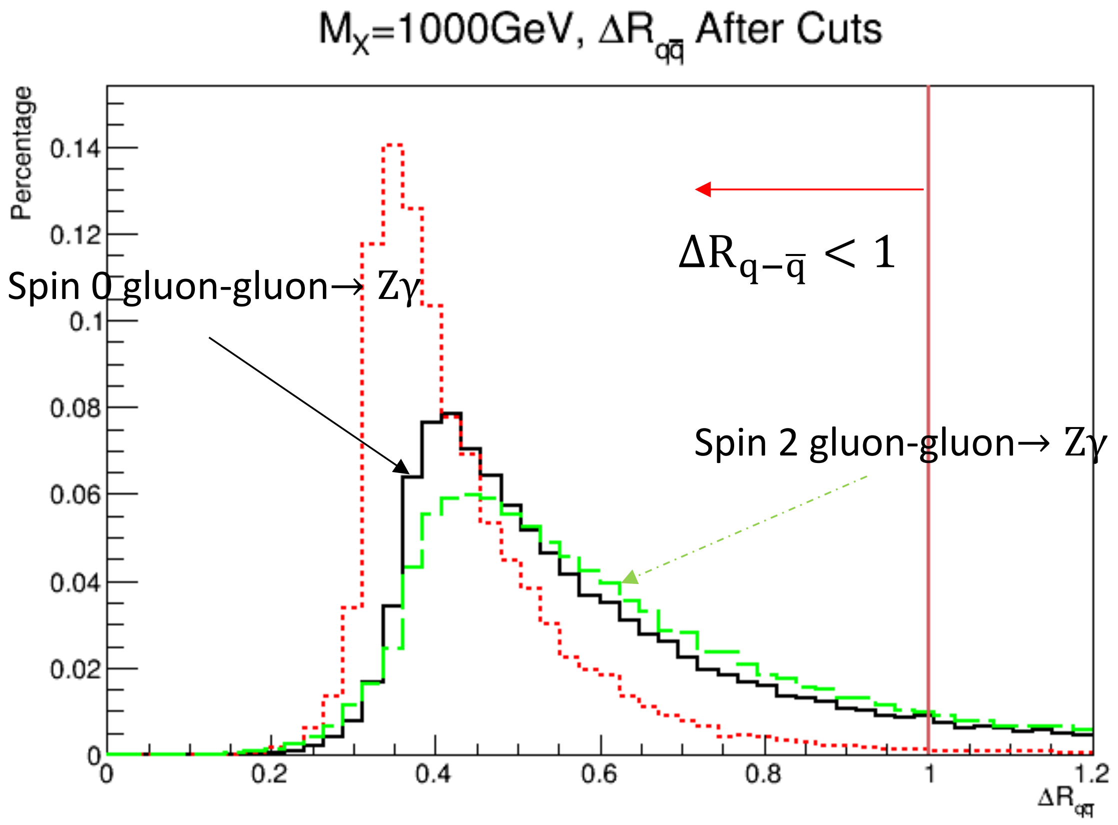
Longitudinal Polarization

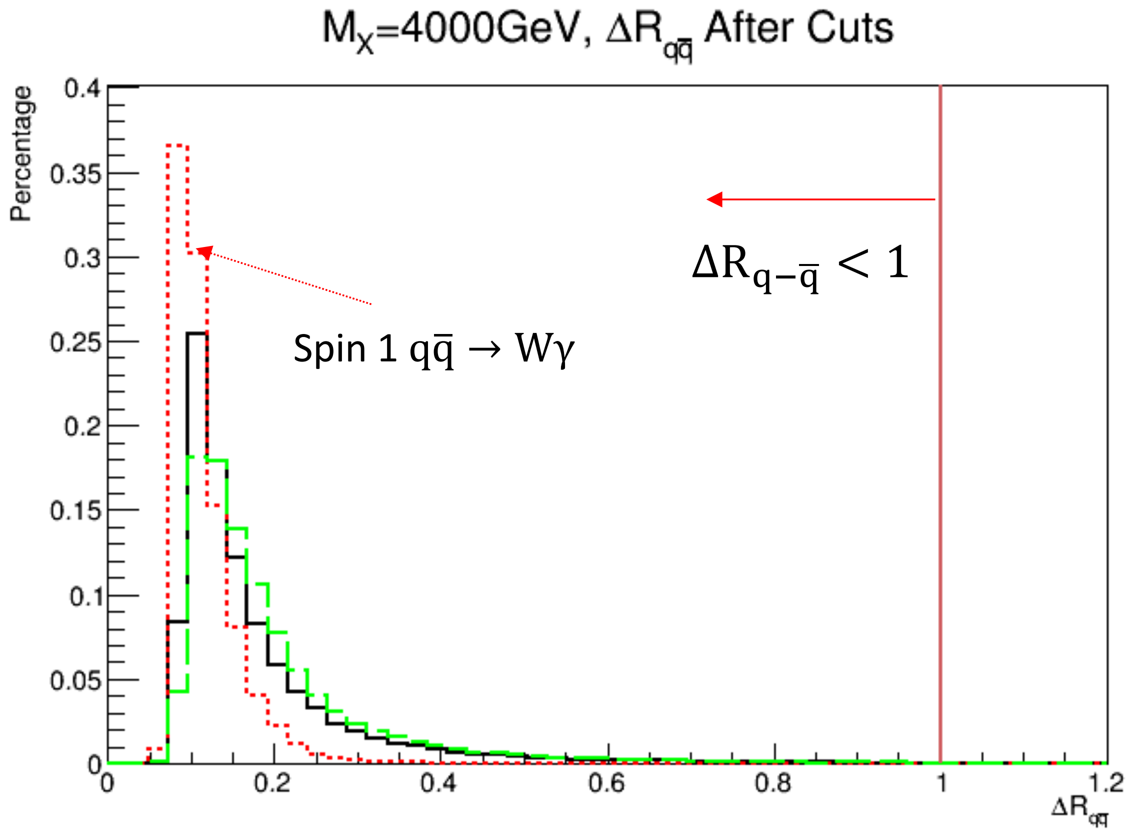


ATLAS Simulation – Work in progress

Identification of W/Z

- Fat jet identification cone of $\Delta R_{q-\bar{q}} = \sqrt{\Delta\eta^2_{q-\bar{q}} + \Delta\varphi^2_{q-\bar{q}}} < 1$
- $\Delta R_{q-\bar{q}}$ plots of $M_X = 2\text{TeV}, 4\text{TeV}$ after kinematic selection cuts.
- Good containment on the parton level.
- Real data has extra inefficiencies due to jets.





ATLAS Simulation – Work in progress

Summary

- The ATLAS collaboration is carrying out a broad search for high mass bosons decaying to Z γ and W γ final states.

- Preliminary results using 36.1 fb^{-1} of data have been analyzed and place cross section limits on spin 0 production of X → Z γ with Z decays to $e^+ e^-$ and $\mu^+ \mu^-$ pairs.

  The limits for $\sigma_X \times BR(X \to Z \gamma)$ range between 88 fb for m_x = 250 GeV and 2.8 fb for m_x = 2.4 TeV .

- The search sensitivity will be improved by using 36 fb^{-1} data and including highly boosted W/Z bosons with hadronic decays.

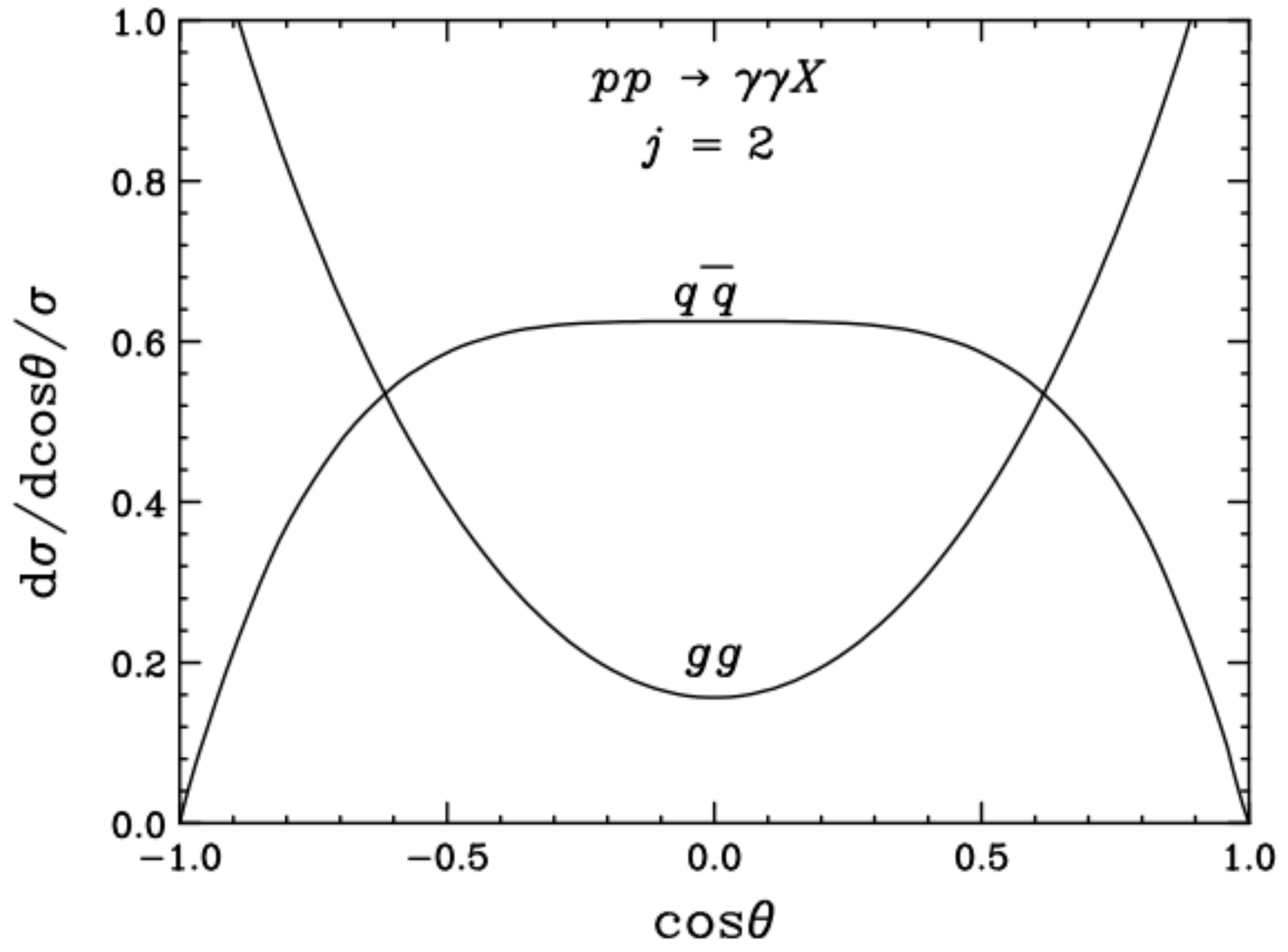
- Preliminary studies have been done to determine selection cuts for spin 0 and spin 2 X → Z γ and spin 1 X → W γ decays.

- These show the potential for extending the search sensitivity for X → V γ decays for higher X masses

Thank You

Back up

$\cos\theta$ Distribution of Spin 2 Resonance



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Kinematic Cuts

- $|\eta_{q\bar{q}}| < 2$
- $PT_{q\bar{q}} > 200GeV$
- $PT_{\gamma} > 250GeV$
- $|\eta_{\gamma}| < 1.37$

Channel: Zγ Spin 0					
Mass of Zγ /GeV	$PT_{\gamma} > 250GeV$ Efficiency	$|\eta_{\gamma}| < 1.37$ Efficiency	$PT_{q\bar{q}}$ Efficiency	$|\eta_{q\bar{q}}|$ Efficiency	Total Efficiency
500	14.76	68.89	54.42	85.50	6.31
1000	86.34	75.78	91.60	90.78	66.58
1500	94.23	78.79	96.27	93.20	73.29
2000	96.80	81.52	97.90	93.82	77.97
2500	97.98	83.10	98.68	94.50	80.40
3000	98.60	84.09	99.12	95.09	82.20
3500	98.98	84.72	99.35	95.31	83.26
4000	99.22	85.64	99.51	95.59	84.62
4500	99.36	86.03	99.59	95.73	85.30
5000	99.46	86.36	99.66	95.90	85.84

Channel: Wγ Spin 1					
Mass of Zg/GeV	PT_{γ} Efficiency	$|\eta_{\gamma}|$ Efficiency	$PT_{q\bar{q}}$ Efficiency	$|\eta_{q\bar{q}}|$ Efficiency	Total Efficiency
500	8.16	57.58	47.50	75.88	3.28
1000	81.02	66.26	88.02	84.24	51.74
1500	91.45	70.68	94.35	88.29	62.42
2000	95.37	75.42	97.01	89.83	68.93
2500	97.04	76.37	98.10	91.52	72.07
3000	97.69	78.76	98.53	92.55	75.82
3500	98.59	78.38	99.10	92.89	75.80
4000	98.71	79.93	99.10	93.37	78.27
4500	99.12	80.51	99.42	93.39	79.08
5000	99.30	80.46	99.60	93.53	79.39

Channel: Zγ Spin 2					
Mass of Zg/GeV	PT_{γ} Efficiency	$|\eta_{\gamma}|$ Efficiency	$PT_{q\bar{q}}$ Efficiency	$|\eta_{q\bar{q}}|$ Efficiency	Total Efficiency
500	12.82	61.93	35.75	79.35	3.68
1000	71.72	65.10	81.38	83.76	48.09
1500	86.96	67.10	91.55	86.23	58.06
2000	92.52	68.23	95.35	87.89	62.08
2500	95.17	69.51	96.98	88.91	65.15
3000	96.67	70.25	97.83	89.60	67.00
3500	97.54	70.76	98.36	89.85	68.28
4000	98.17	71.14	98.84	90.11	69.24
4500	98.48	71.60	99.02	90.29	70.28
5000	98.77	71.64	99.20	90.36	70.57