Probing Higgs Physics with Vector-Boson Scattering

Marc Thomas

NExT PhD Workshop 2014

arXiv:1405.1617
A. Belyaev, E. Boos, V. Bunichev, Y. Maravin,
A. Pukov, R. Rosenfeld, M. Thomas

Plan

- **Background**
  - *Longitudinal* vector bosons, vector boson scattering (VBF), Higgs boson and unitarity.
- **Goal of study**
  - ***Model independent*** measurement of ***HVV coupling***, (C_V) using longitudinal vector boson scattering in VBF.
- **Results**
  - Selecting longitudinal vector bosons and measuring HVV coupling using 3 main observables.
- **Future Plans**

Longitudinal Vector Bosons (V_L)

- $V_L = W^{\pm}_L, Z_L$
- Originate from EWSB

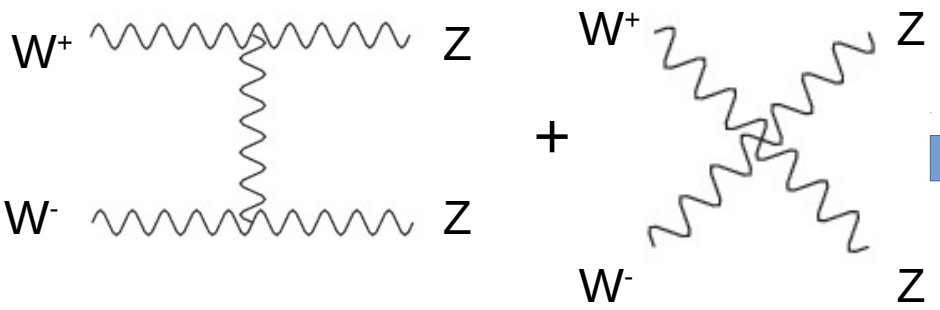
$$\Phi = \begin{pmatrix} i\pi^+ \\ \frac{1}{\sqrt{2}}\left((h+v)+i\pi^0\right) \end{pmatrix}$$

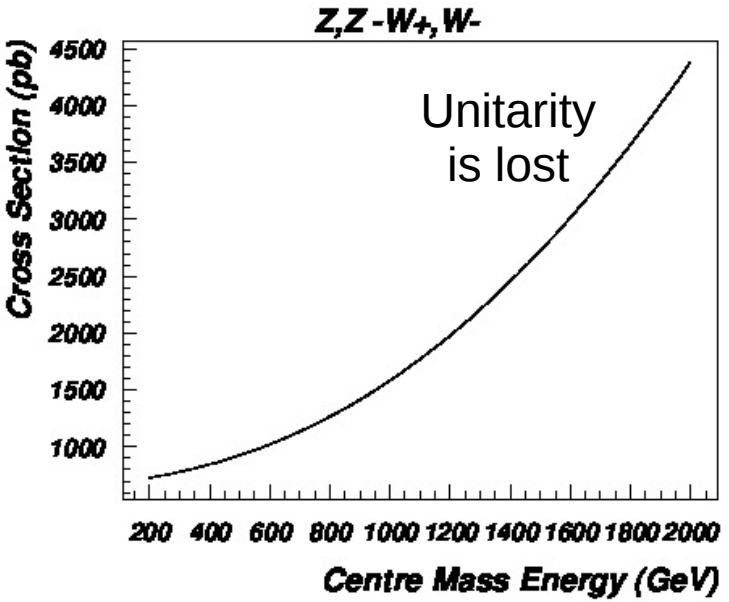
$$D\Phi^\dagger D\Phi \rightarrow (\tfrac{1}{2}gv)^2 W^+_\mu W^{-\mu} - \tfrac{1}{2}gv(\partial_\mu \pi^+)W^{-\mu}$$

$$+\partial_\mu \pi^+ \partial^\mu \pi^- + \ldots + \ldots$$

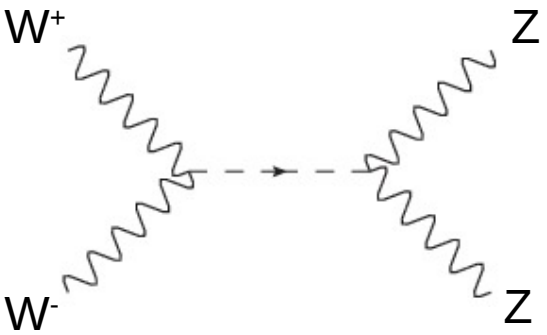
- Goldstone becomes the longitudinal component of vector bosons.

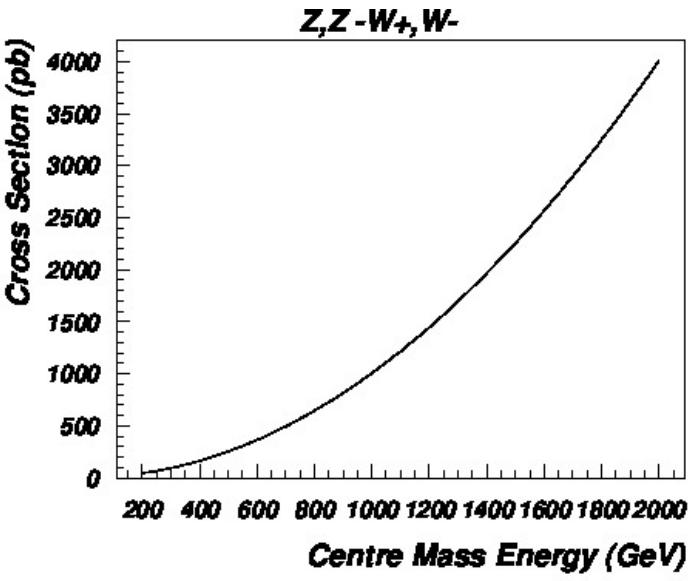
Higgs unitarizes the $V_L, V_L \rightarrow V_L, V_L$ scattering



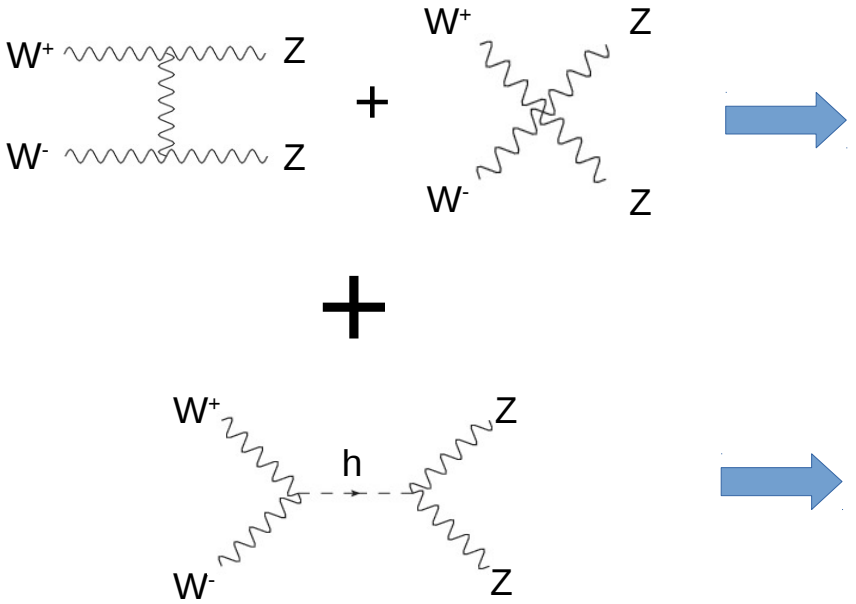


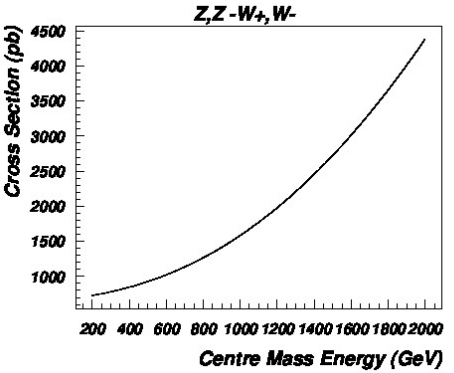
$$\text{Amplitude} \propto s$$
$$\text{Cross section} \propto s^2$$

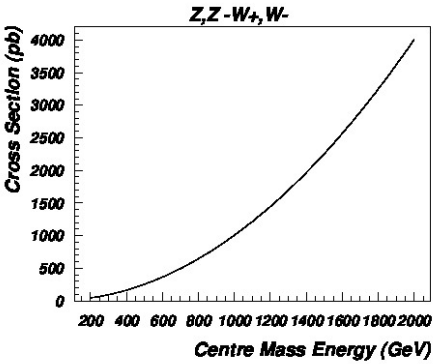




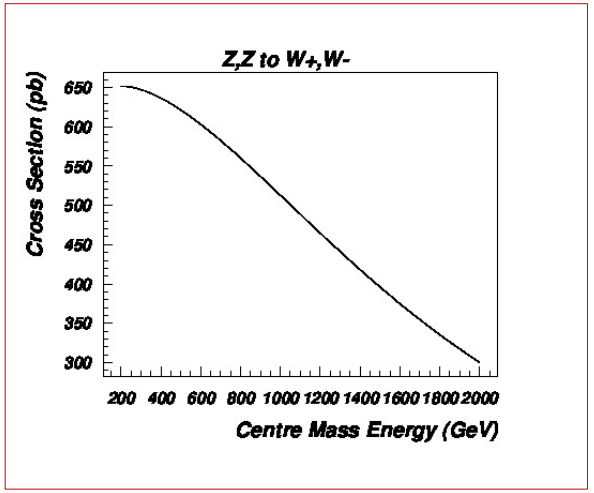
Higgs unitarizes the $V_L,V_L \rightarrow V_L, V_L$ scattering







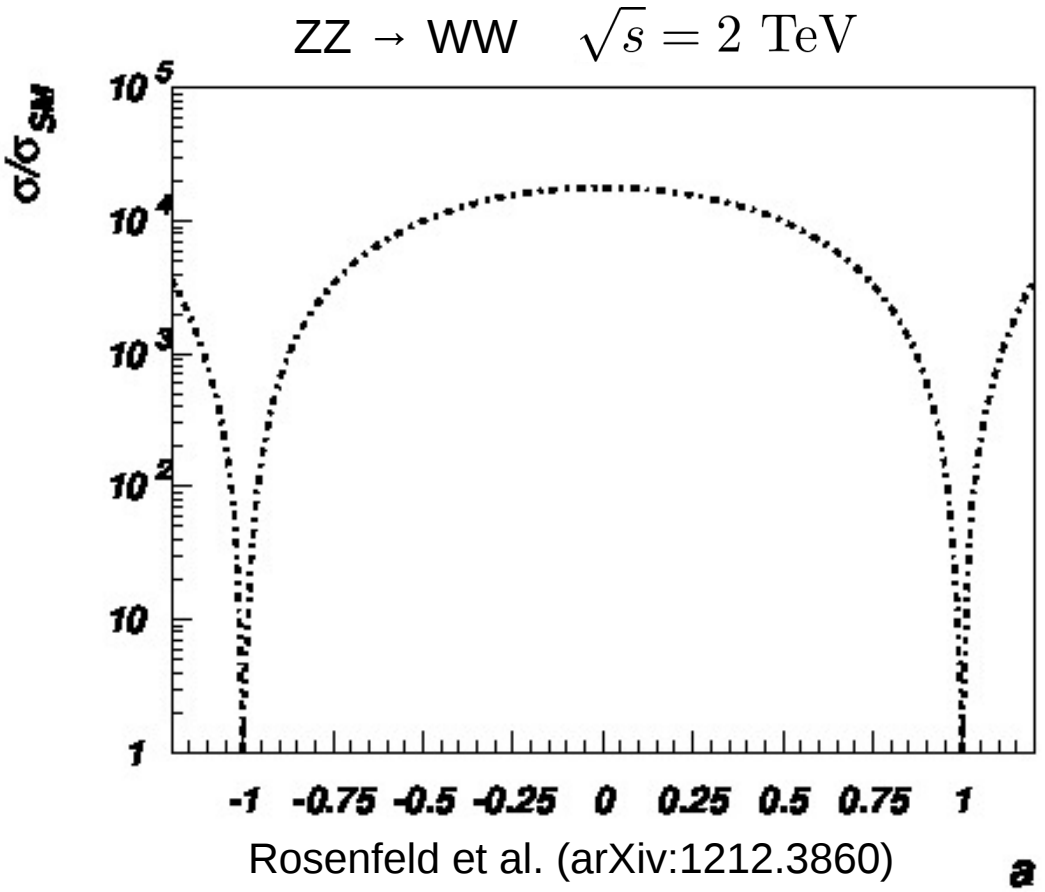
=



- **Cancellation** of terms linear in s from amplitudes of both diagrams.
- **Restores** unitarity.

Cancellation requires **exact** SM coupling

$$\mathcal{L} = C_V g_{SM} h V_L V_L + \ldots \quad \text{where } C_V = 1 \text{ in SM}$$



Rosenfeld et al. (arXiv:1212.3860)

- **Large increases** in $V_L V_L$ scattering, even for **small deviations** (~10%) from SM.
- Could provide **model independent way** to probe Higgs boson coupling to gauge bosons (C_V).

Problem - "Transverse pollution"

- **Transverse pollution**
  - Majority of VV → VV cross section is due to transverse components.

	$\sqrt{s} = 2$ TeV	
Channel	**CX for C_V = 1 (SM) (pb)**	**CX for C_V = 0.9 (pb)**
$Z_LZ_L \rightarrow W_LW_L$	0.13	295
ZZ → WW (full)	610	655

Rosenfeld et al. (arXiv:1212.3860)

- Despite large increases in V_L scattering, the overall effect on spin averaged cross section is moderate.
- **Need a way to isolate the longitudinal components of scattering, to enable us to measure C_V.**

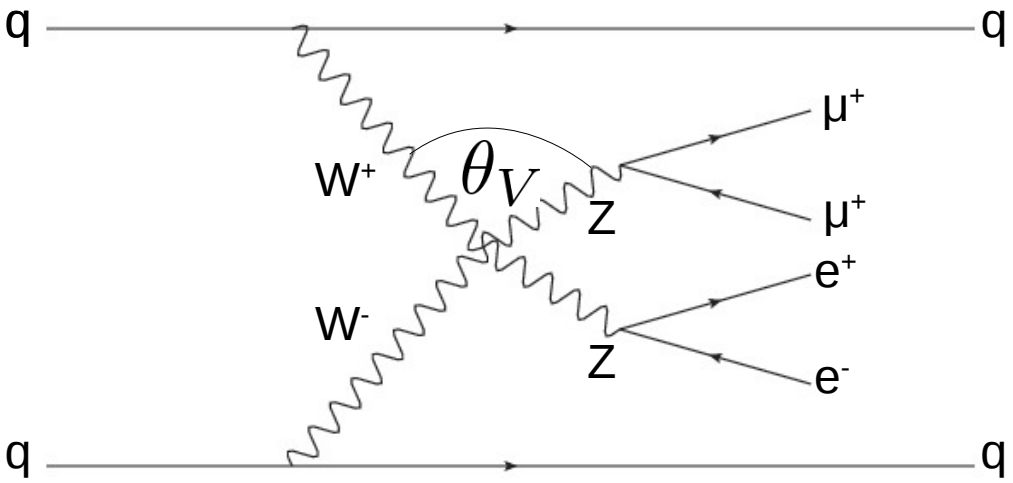
Goal of study

- Devise **optimal cuts** capable of selecting the contribution from the longitudinally polarized gauge bosons.
- Hence increase sensitivity to C_V.
- We show that this is possible using a combination of three main observables.
  - **Observable 1**, θ_V
  - **Observable 2,** θ^*
  - **Observable 3,** $\sqrt{s_{VV}}$ of vector boson scattering

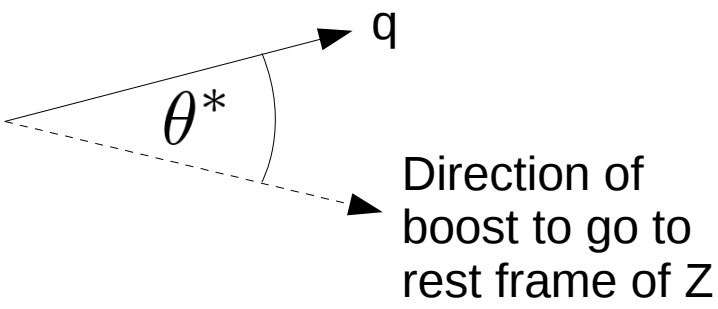
Observables $\theta_V, \theta^*, \sqrt{s_{VV}}$

- θ_V, angle **in rest frame** of vector boson scattering between incoming and outgoing vector.
- θ^*, angle in ***rest frame of decaying boson***, between fermion in the decay products and direction of boost to get to the rest frame.
- $\sqrt{s_{VV}}$ = invariant mass of all decay products.

Full Process

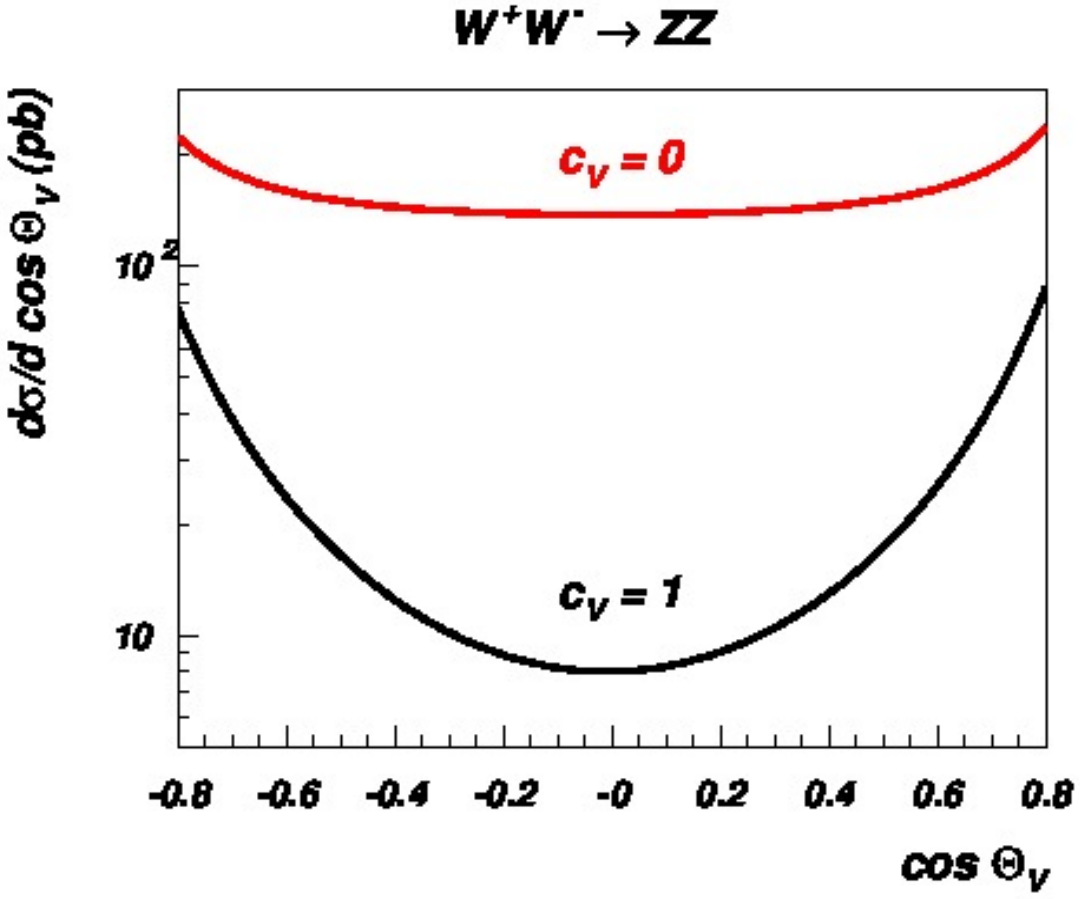


In rest frame of the Z



Observable 1, θ_V

- Overall **increase in cross section** if $C_V = 0$.
- The $C_V = 0$ case has a much larger proportion of ***longitudinally polarized*** bosons.

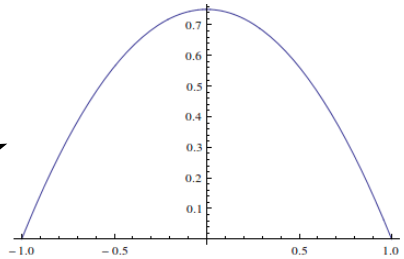


- Therefore cuts which reduce $C_V = 1$ more than $C_V = 0$ should increase the proportion of longitudinally polarized bosons.
- e.g. $|\cos\theta_V| < 0.5$
- Transversely polarised bosons have large t-channel amplitude with much larger forward-backward scattering.

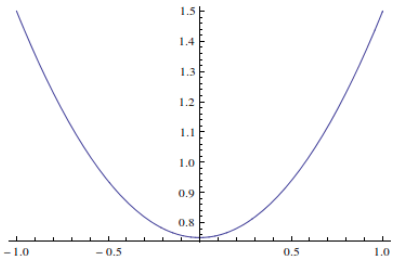
Observable 2, θ^*

- Distribution of decay from transverse and longitudinal polarisations.

$$P_L(\cos\theta^*) = \tfrac{3}{4}(1-\cos^2\theta^*) \quad \textbf{Longitudinal}$$



$$P_\pm(\cos\theta^*) = \tfrac{3}{8}(1\pm\cos\theta^*)^2 \quad \textbf{Transverse}$$



- By fitting,

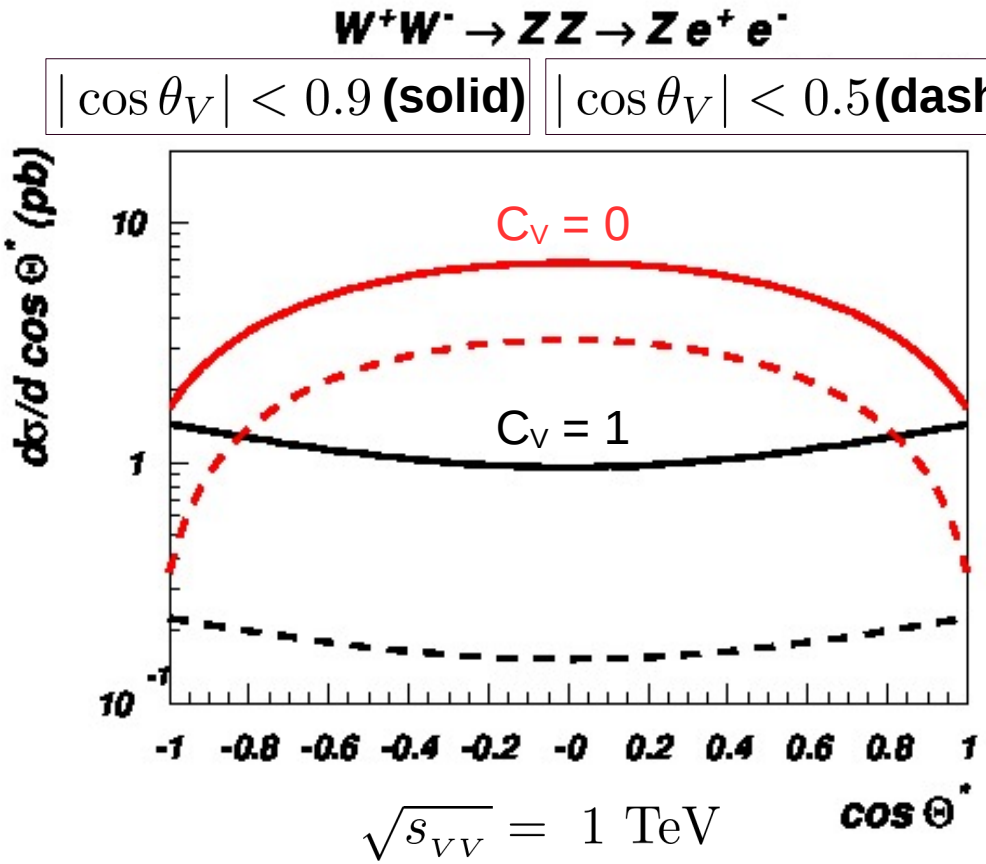
$$P(\cos\theta^*) = f_L P_L(\cos\theta^*) + f_+ P_+(\cos\theta^*) + f_- P_-(\cos\theta^*)$$

with, $f_L + f_+ + f_- = 1$

- We can **reconstruct the average polarizations** of the vector bosons.

Observable 2, θ^*

- **$C_V = 0$** has a much larger cross section for small $\cos\theta^*$ than the **$C_V = 1$** case.
- The cut $|\cos\theta_V| < 0.5$ increases this difference.

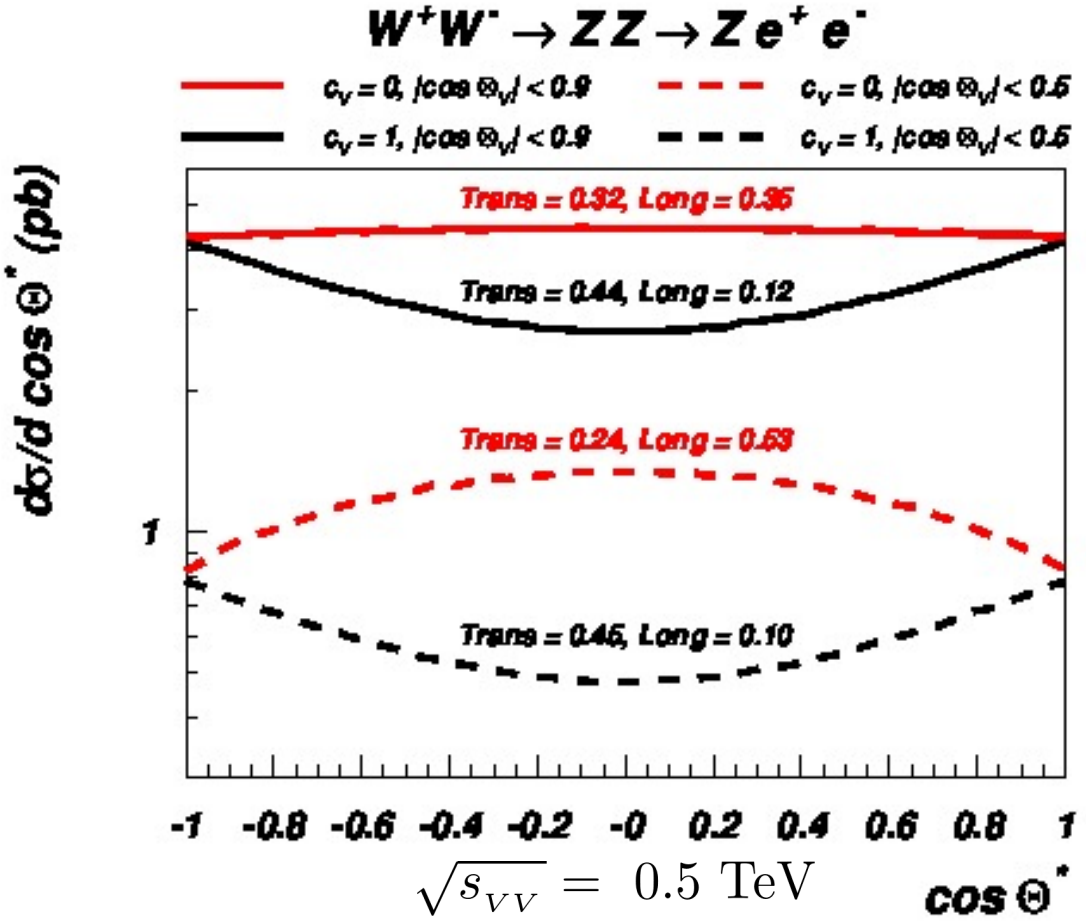


- Suggests optimal cut to increase fraction longitudinally polarised would be cut on both θ_V and θ^*.
- e.g. $|\cos\theta_V| < 0.5$ and $|\cos\theta^*| < 0.5$

Fitting to find V_L component

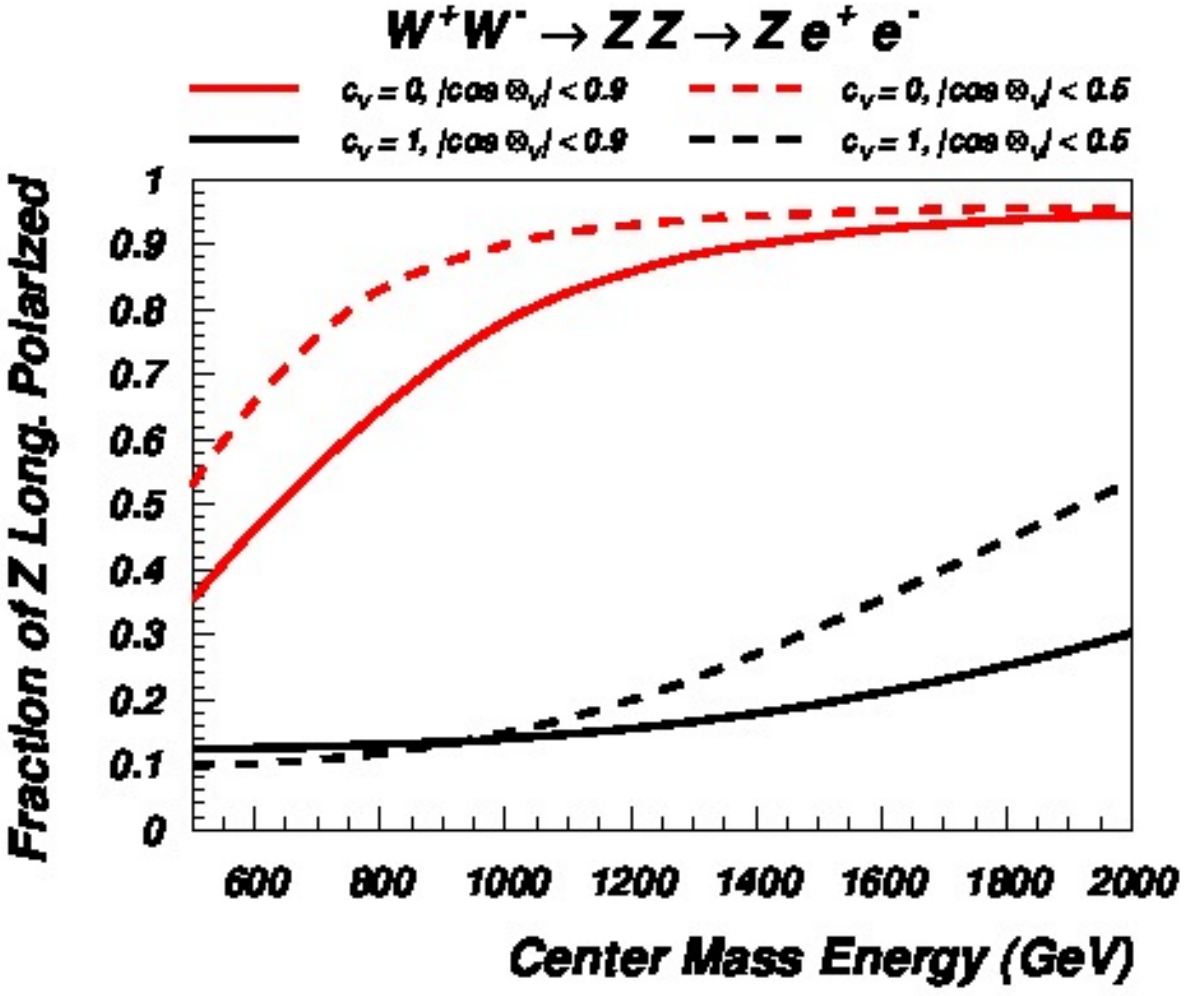
$$P(\cos\theta^*) = f_L P_L(\cos\theta^*) + f_+ P_+(\cos\theta^*) + f_- P_-(\cos\theta^*)$$

$$P_L(\cos\theta^*) = \tfrac{3}{4}(1 - \cos^2\theta^*) \qquad P_\pm(\cos\theta^*) = \tfrac{3}{8}(1 \pm \cos\theta^*)^2$$



- When $C_V = 0$, the proportion of longitudinally polarised boson is higher as expected.
- $|\cos\theta_V| < 0.5$ cut increases proportion of longitudinal bosons.

Observable 3, $\sqrt{s_{VV}}$

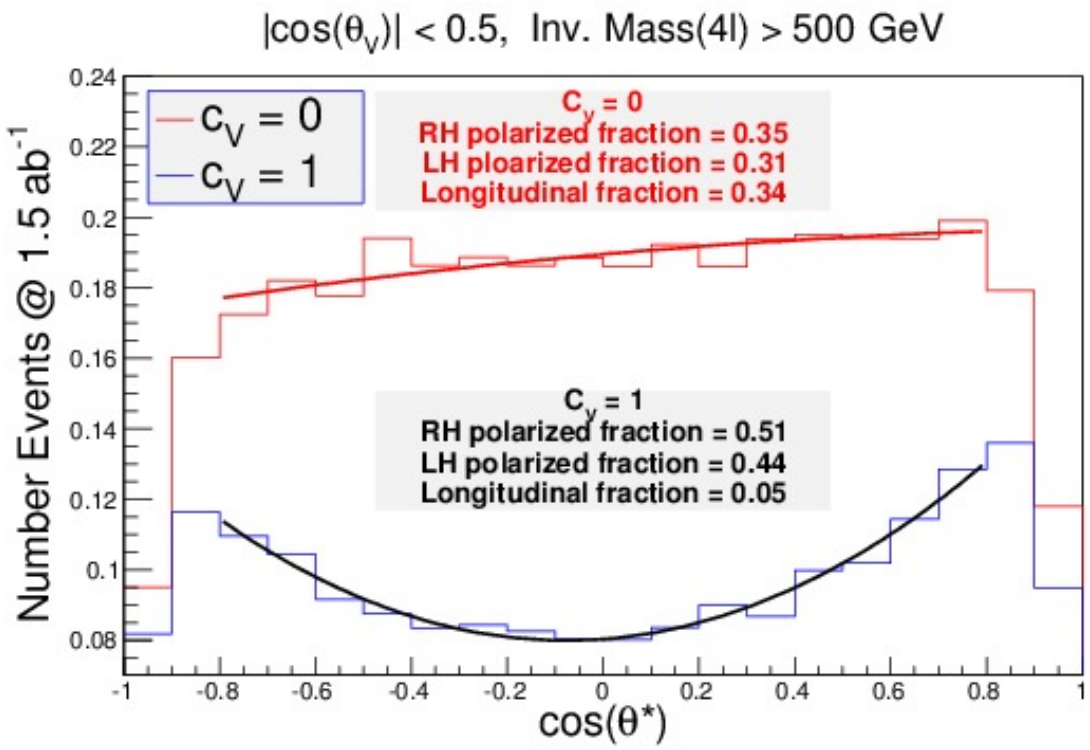


- Fitting function used to plot fraction of Z longitudinally polarized vs $\sqrt{s_{VV}}$
- As $\sqrt{s_{VV}}$ increases, longitudinal polarisation dominates.
- To be expected as $\sigma(V_L V_L \to V_L V_L) \propto s$
- **Cut for higher** $\sqrt{s_{VV}}$ will also increase fraction longitudinally polarised.

Will this work at the LHC?

- So far only discussed VV → VV at parton level.
  - Full process at LHC much messier.
  - Cuts may not work as well.
- Need to study **LHC sensitivity** to probe fraction of longitudinal polarisation and therefore measure C_V.
- Ongoing work, so far studied,
  - $pp \to jjZZ \to e^+e^-\mu^+\mu^-jj$
  - $(p = u, \bar{u}, d, \bar{d})$
- Plan to extend to all relevant processes and decays.

Fit again to find how well cuts work in fuller process?



$$pp \to jjZZ \to e^+e^-\mu^+\mu^-jj$$

- Cuts used
  - $|\cos\theta_V| < 0.5$
  - Invariant mass (4l) > 500 GeV.
- **Large increase in longitudinal fraction** from 0.05 to 0.34, for $C_V = 1$ vs $C_V = 0$.
- Very small cross section for studied process, but should be ~ x 250 if semi-leptonic decays and complete set of processes (ZZ, WW, WZ) included.
- Expect sensitivity to C_V at approx 10% with 100 fb^{-1}.

Future plans

- Optimization of cuts.
- Complete study for full set of processes and decays.
- Study for C_V consistent with experimental errors (C_V ~ 0.8 to 1).

Conclusions

- Shown that a combination of cuts on 3 variables can isolate the longitudinal components of vector boson scattering.
- Should give alternative, model independent way of measuring C_V.