Jet Substructure Methods for Polarization Measurement of Boosted Hadronic W Bosons

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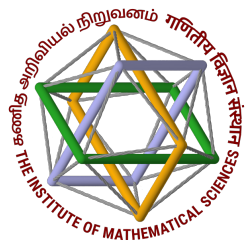
Trends in Astro-particle and Particle Physics (TAPP)



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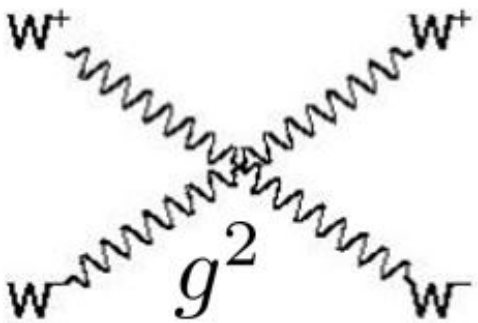
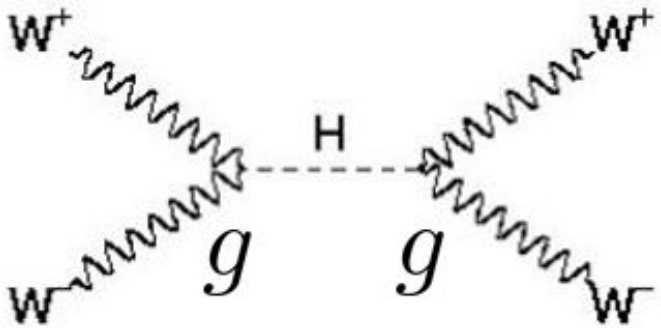
Unitarity of *WW* scattering in the Standard Model





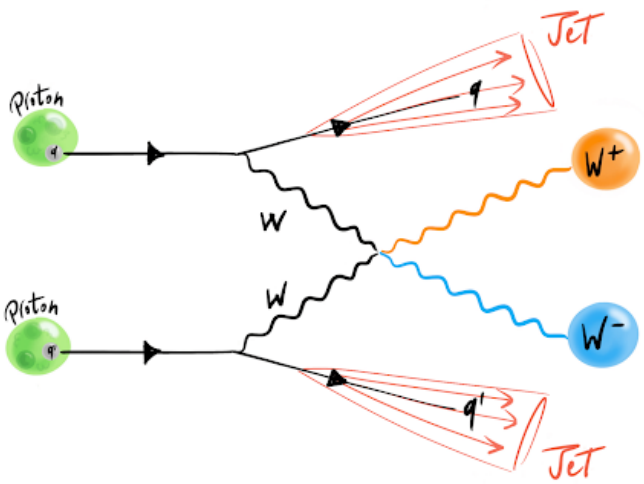
$$\mathcal{A} \sim \frac{g^2 E^2}{m_W^2}$$

$$\mathcal{A} \sim -\frac{g^2 E^2}{m_W^2}$$

At high energies, longitudinal gauge-boson scattering would violate unitarity in the absence of the SM Higgs boson or even if the Higgs boson couplings were not precisely the same as those predicted in the SM.

Measurement of W boson polarization at LHC

The branching fraction of W boson decaying to hadrons is approximately 68%. It would greatly increase our statistical grasp of the polarization fractions, if we were able to measure the polarization of hadronic W bosons.



Vector Boson Scattering

Current Channel: Leptonic

Hadronic Channel:
Advantages

- Greater Statistics
- Reconstruction of full kinematics

Parton level angular distributions

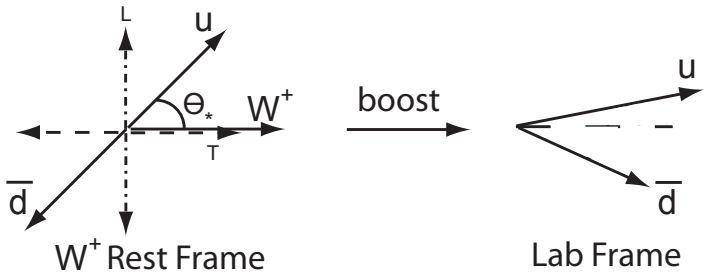
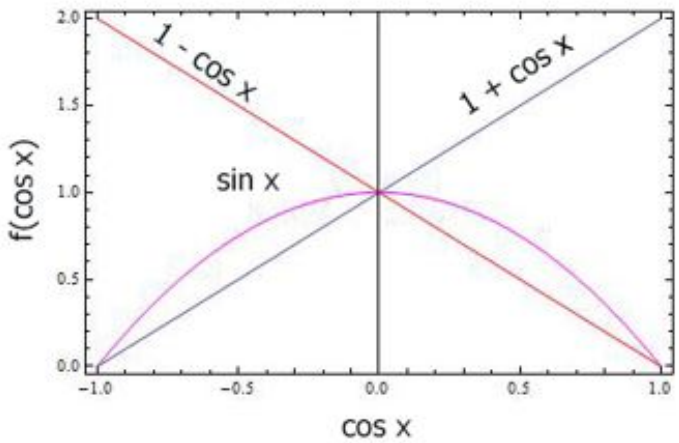


Figure 1: LEFT: θ_* is the polar angle of W^+ decay products in its rest frame. RIGHT: Boosting to the lab frame can cause energy asymmetry between the up and anti-down quarks



Distribution of amplitude in terms of cos Θ_*

For transversely polarized W boson

$$\mathcal{M}_{\pm} \propto \frac{1 \mp cos\theta_*}{\sqrt{2}}$$

For longitudinally polarized W boson

$$\mathcal{M}_0 \propto \frac{-sin\theta_*}{\sqrt{2}}$$

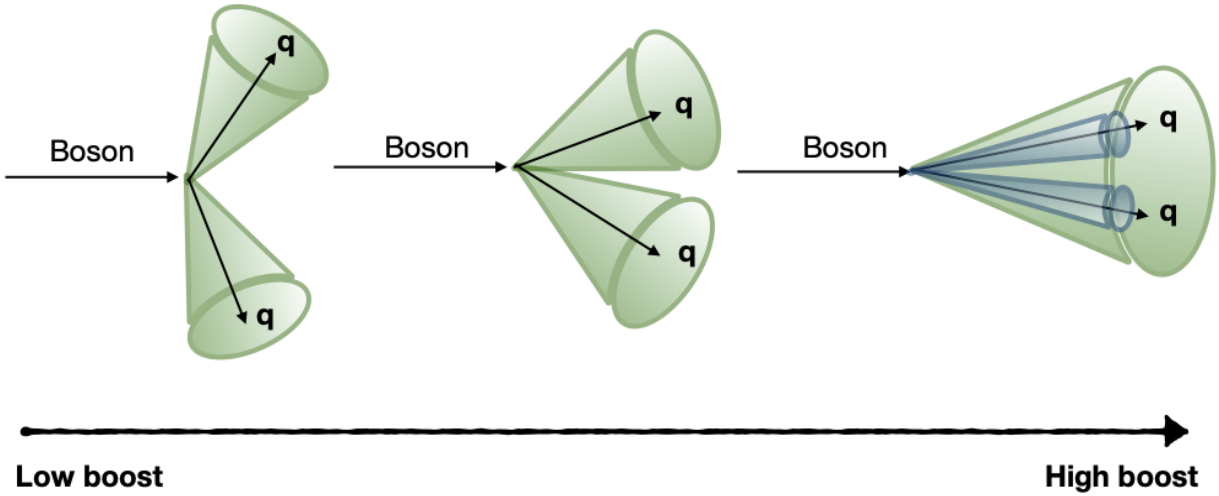
Polarization Meaurement

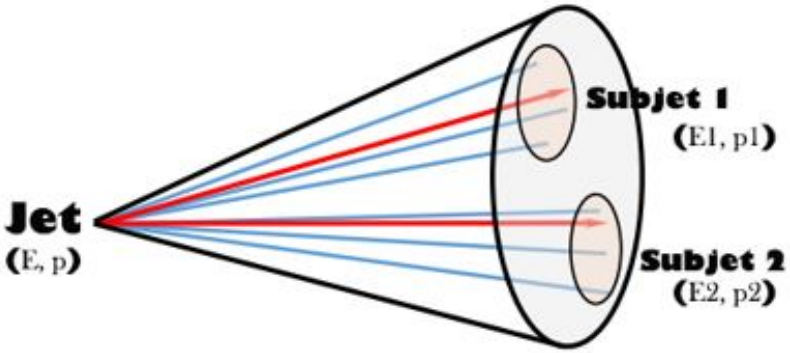
The distribution of the W^+ decay rate as a function of its decay polar angle,

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}|\cos\theta_*|} = \mathrm{f_T}\frac{3}{4}(1+|\cos\theta_*|^2) + \mathrm{f_L}\frac{3}{2}(1-|\cos\theta_*|^2) \quad (1)$$

where, the transverse polarization fraction $\mathrm{f_T}$ and the longitudinal polarization fraction $\mathrm{f_L}$ are related by, $f_T + f_L = 1$

W boson at hadronic level



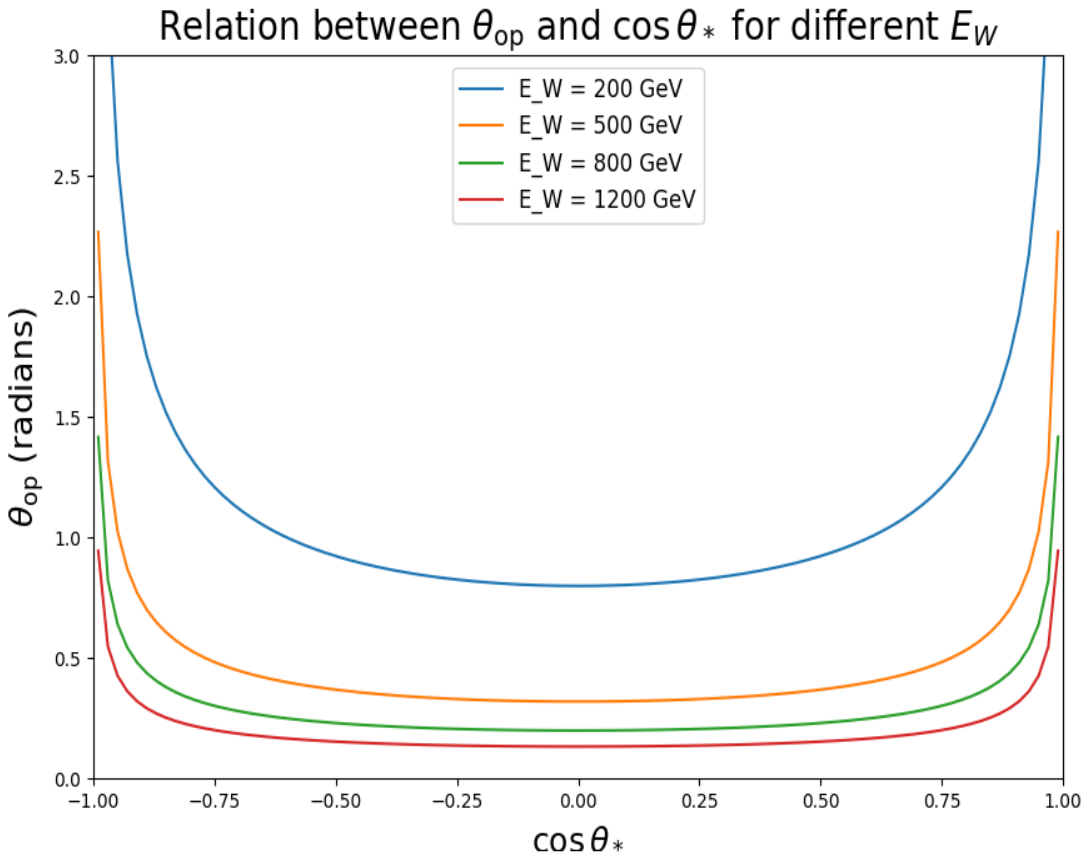


$$sin\theta_* \simeq \frac{2m_W}{E_W}\frac{1}{\theta_{op}}$$

[CMS: hep-ex/1410.4227]

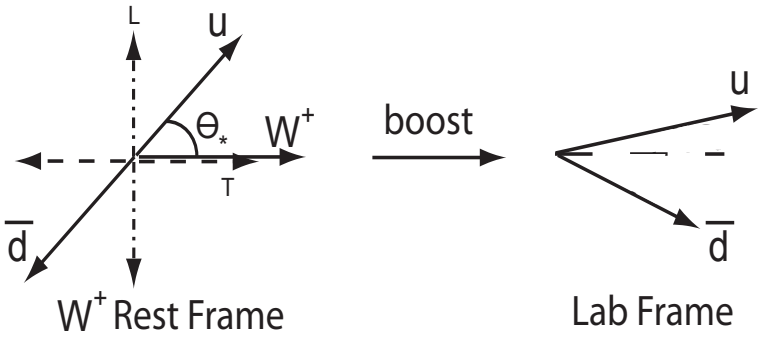
Θ_{op} is the opening angle between two subjets of the fat-jet

θ_{op} is a poor proxy variable



θ_{op} is a poor proxy variable

Proxy Variable p_θ



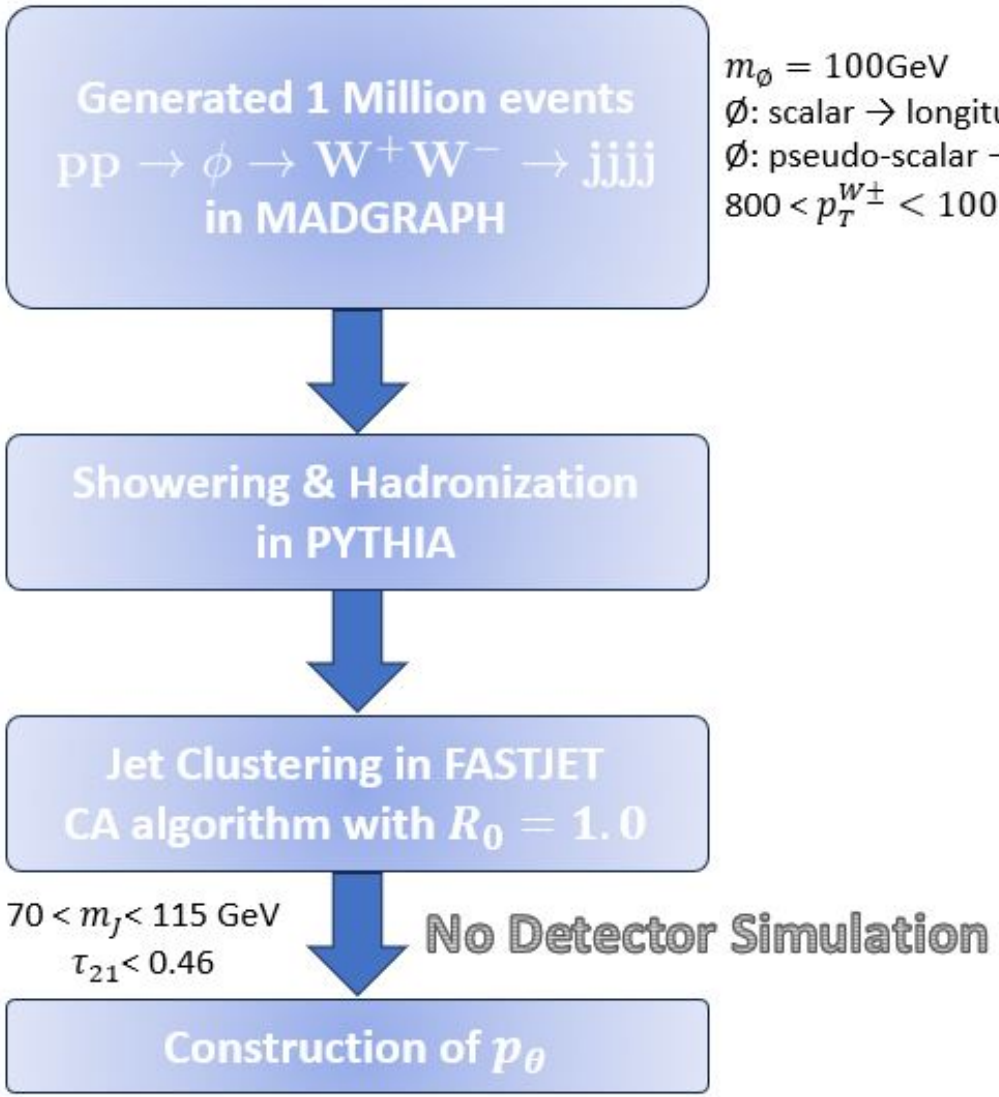
Potential observable in the lab frame at parton-level that can distinguish between longitudinal and transverse W^+ bosons,

$$\cos\theta_* = \frac{\Delta E}{p_W}$$

Construction of a proxy variable at hadron level in the W^+ lab frame,

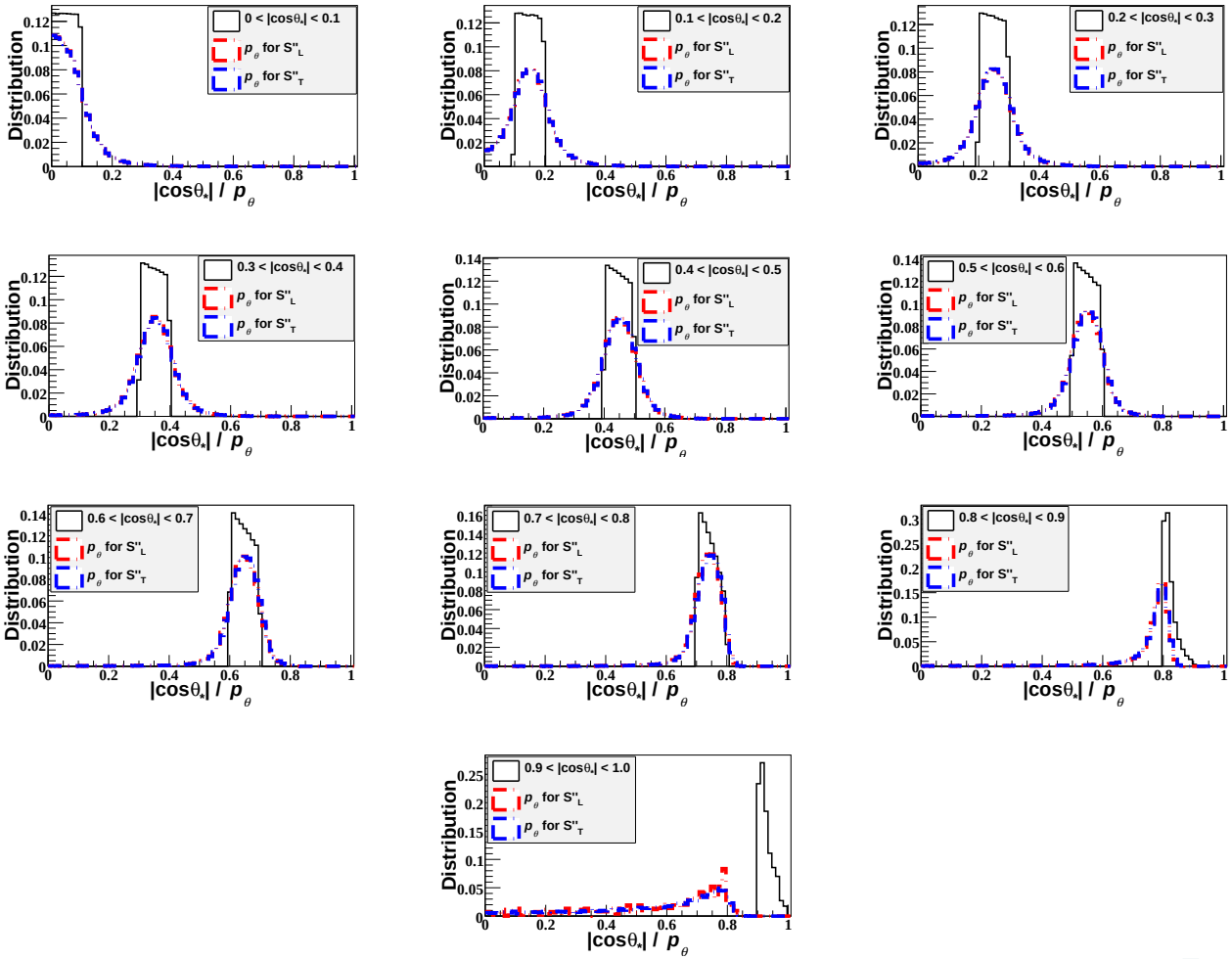
$$p_\theta = \frac{|\Delta E^{\rm reco}|}{p_W^{\rm reco}}$$

Construction of templates

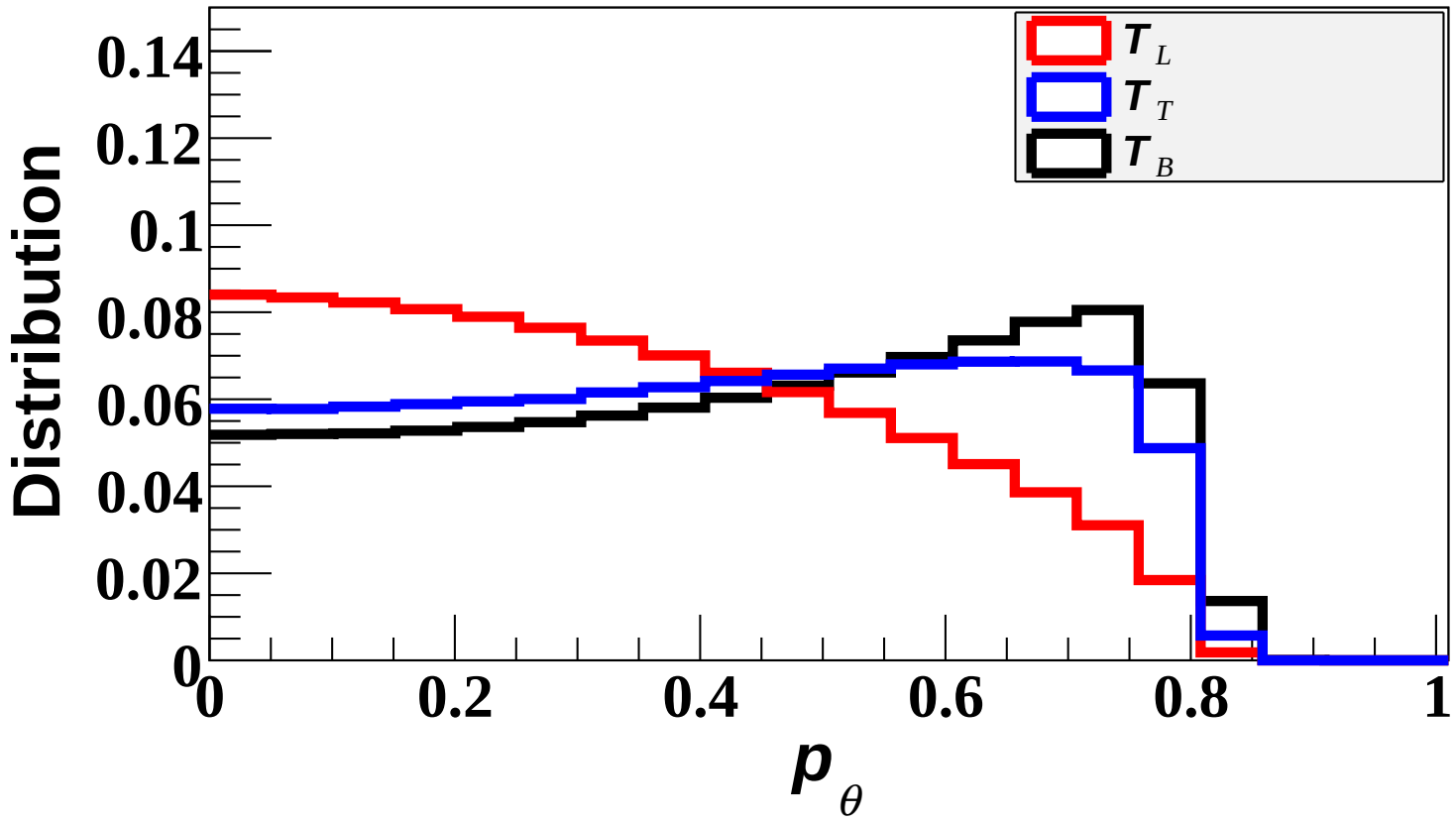


Efficacy of p_θ

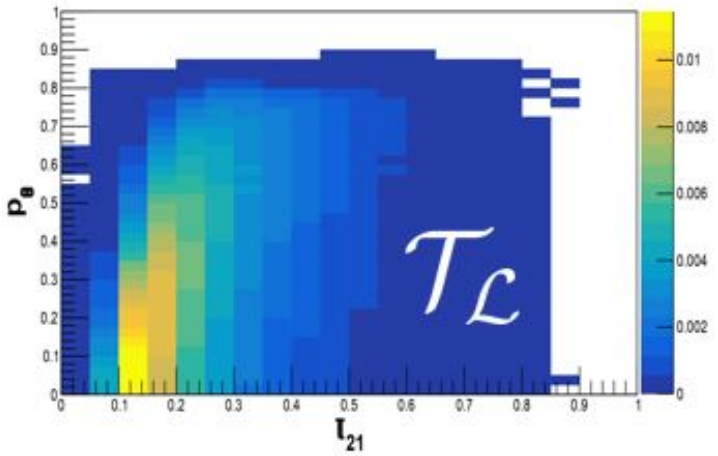
p_θ is a **good proxy** variable for $|cos\theta_*| \lesssim 0.9$

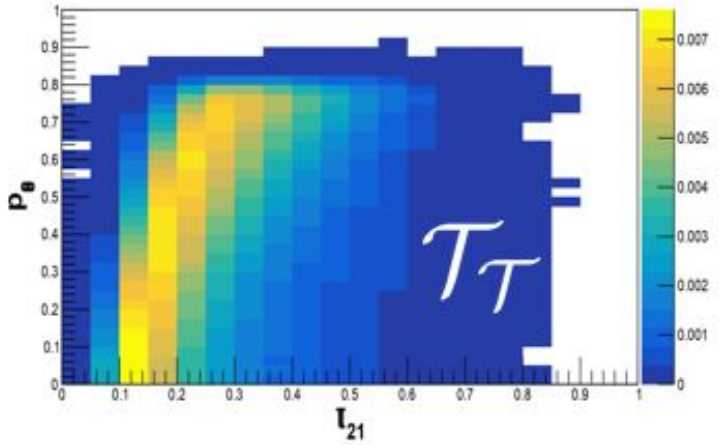


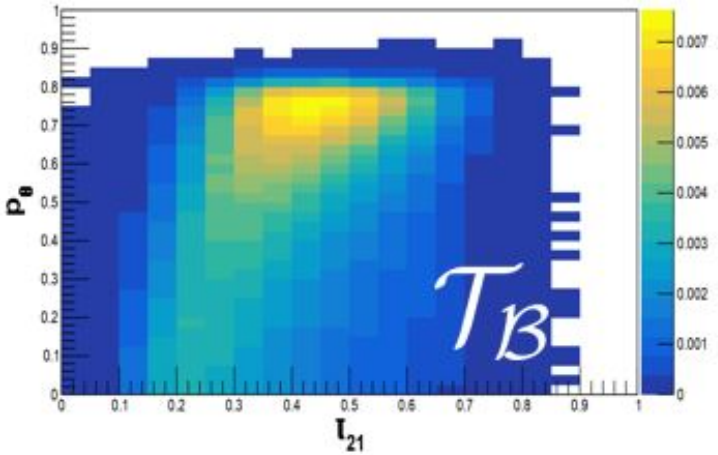
1D Templates



2D Templates

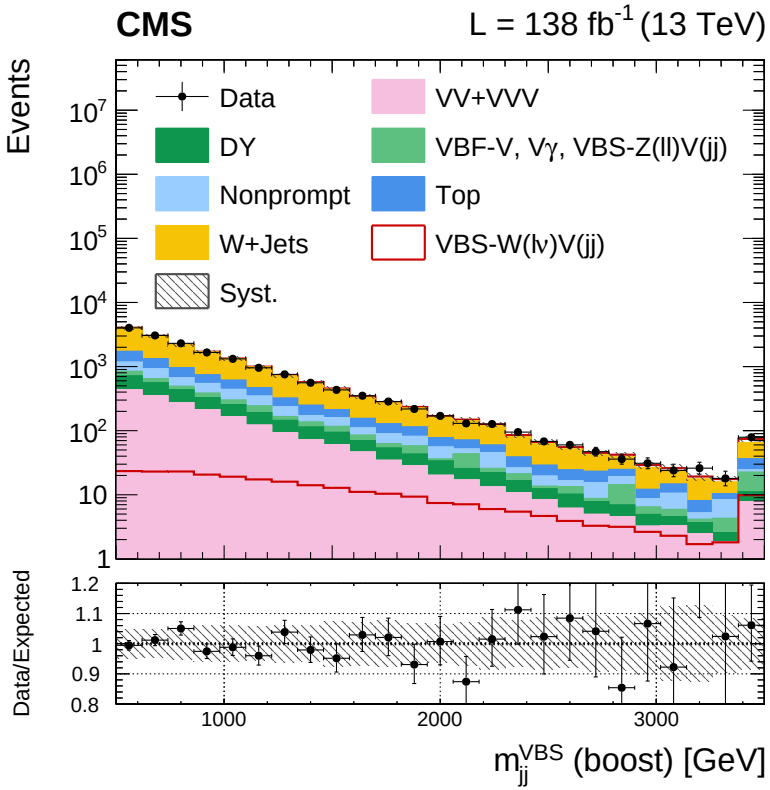






$$\frac{d^2N}{dp_\theta d\tau_{21}} = N_{\text{tot}} \left(f_L \mathcal{T}_L + f_T \mathcal{T}_T + f_B \mathcal{T}_B \right)$$

Event rate for VBS at CMS



Expected WW scattering events + background at 13 TeV LHC with 3000 fb^{-1} of data

QCD Background $\sim$ 55336 events

Hadronic boosted W bosons $\sim$ 2164 events

Longitudinal W $\sim$ 425 events, Transverse W $\sim$ 1739 events

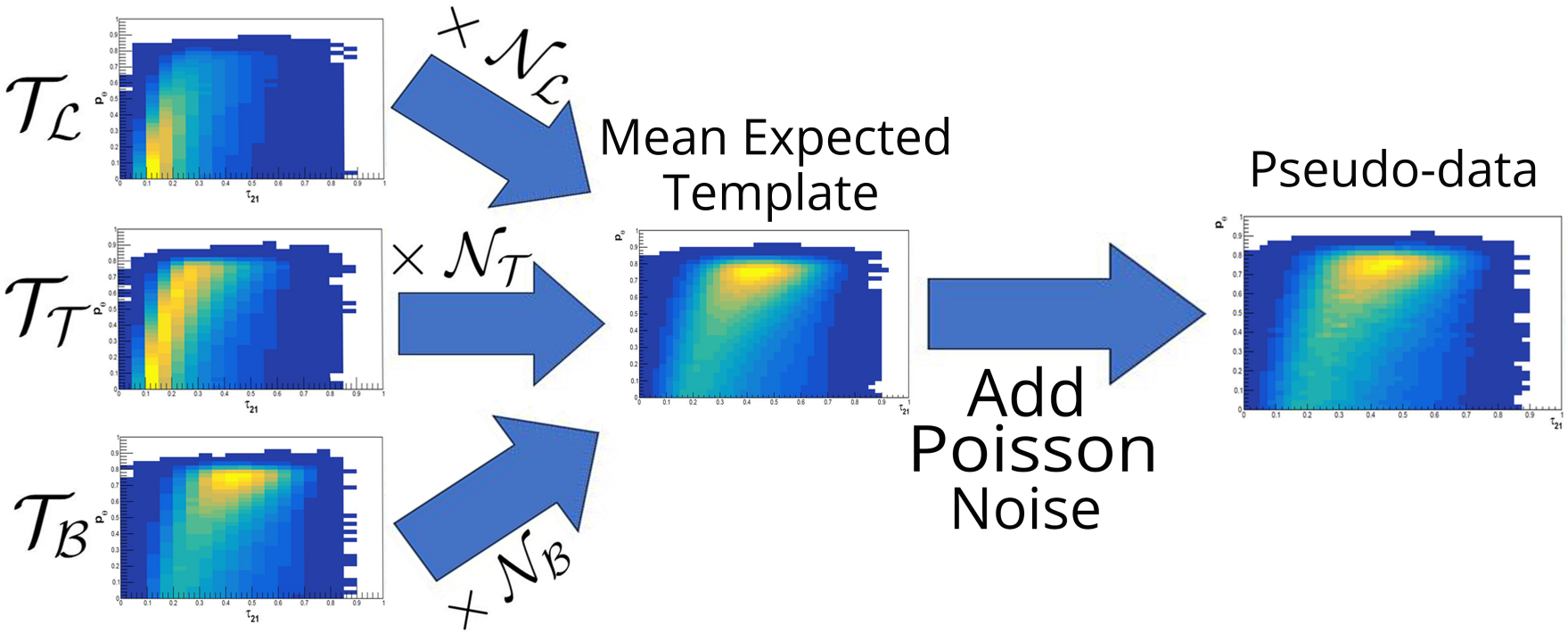
Expected WW scattering events + background at 13 TeV LHC with 10000 fb^{-1} of data

QCD Background $\sim$ 185578 events

Hadronic boosted W bosons $\sim$ 7214 events

Longitudinal W $\sim$ 1417 events, Transverse W $\sim$ 5797 events

Pseudo-Data from 2D Template



$$\chi^2 = \sum_i \left(\frac{\mathcal{T}^i_{\text{pseudo-data}} - \mathcal{T}^i_{\text{pred}}}{\sigma^i} \right)^2 \text{ where}$$

$$\mathcal{T}_{\text{pred}} = N_L^{\text{fit}} \mathcal{T}_L + N_T^{\text{fit}} \mathcal{T}_T + N_B^{\text{fit}} \mathcal{T}_B$$

Results

True Values	Reconstructed Values
$\mathcal{L} = 3ab^{-1}$	
$f_L = 0.0074$ $f_T = 0.030$ $N_{tot} = 57500$	$f_L = 0.0079 \pm 0.0082$ $f_T = 0.030 \pm 0.010$ $N_{tot} = 57784 \pm 240$
$\mathcal{L} = 10ab^{-1}$	
$f_L = 0.0074$ $f_T = 0.030$ $N_{tot} = 192792$	$f_L = 0.0075 \pm 0.0045$ $f_T = 0.030 \pm 0.006$ $N_{tot} = 193078 \pm 439$

Transverse polarization fraction can be extracted at 20-30% level in the hadronic decays at HL-LHC.

Longitudinal polarization fraction can not be distinguished from zero.

Take-home messages

1. A new technique is proposed to measure longitudinal and transverse polarization fraction of hadronic decays of boosted W boson
2. Introduces a new jet-substructure observable p_θ which is a proxy for the decay polar angle of W boson in its rest frame
3. Distribution of p_θ is sensitive to the polarization of W boson
4. p_θ has lower reconstruction errors as compared to other proxy
5. Helps to measure the transverse W boson polarization fraction in VBS at HL-LHC to within a 20% error
6. If longitudinal W boson polarization in VBS is enhanced in a BSM scenario. then this technique maybe useful to detect such new physics

Thanks For Your Attention!

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