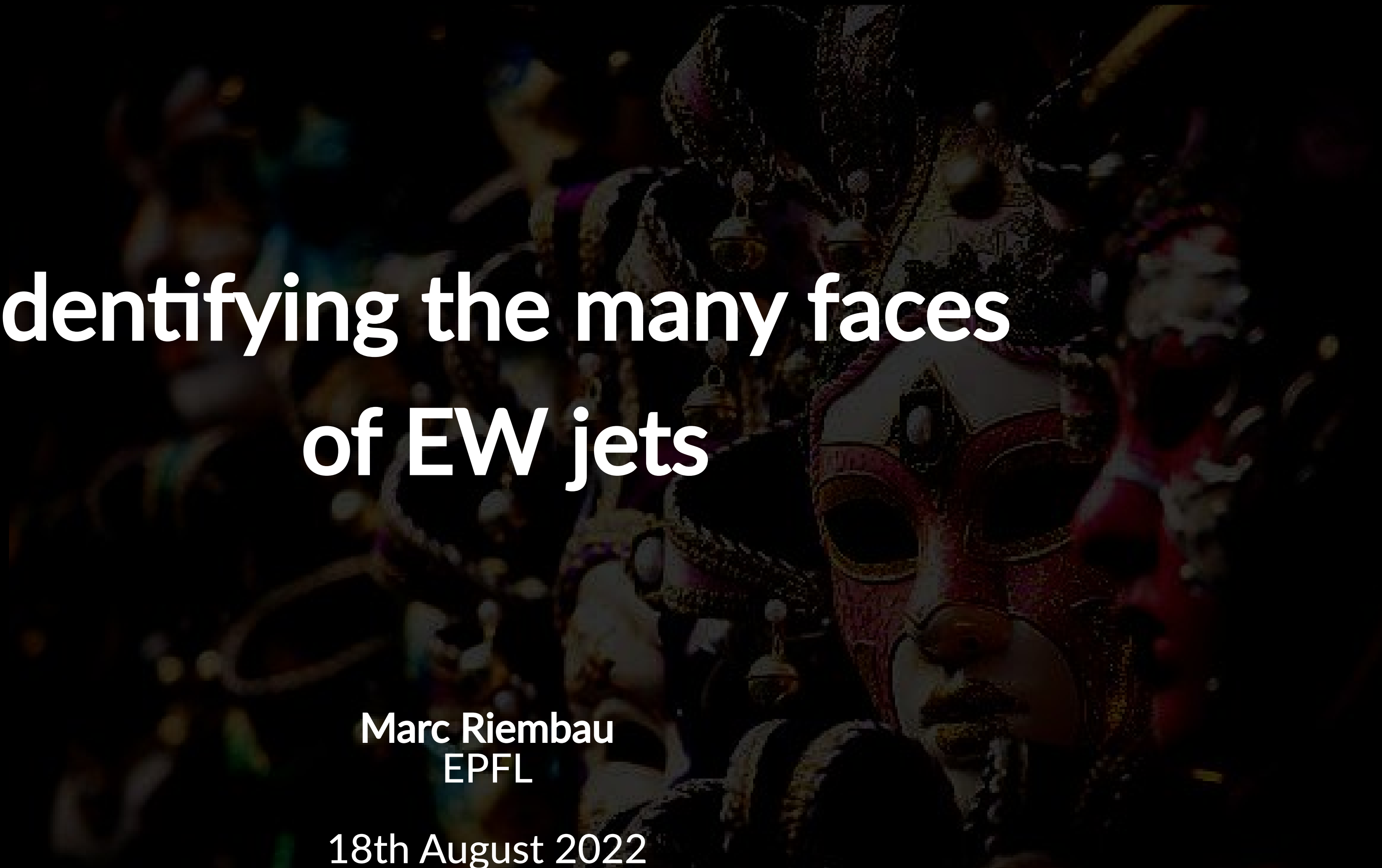


Identifying the many faces of EW jets

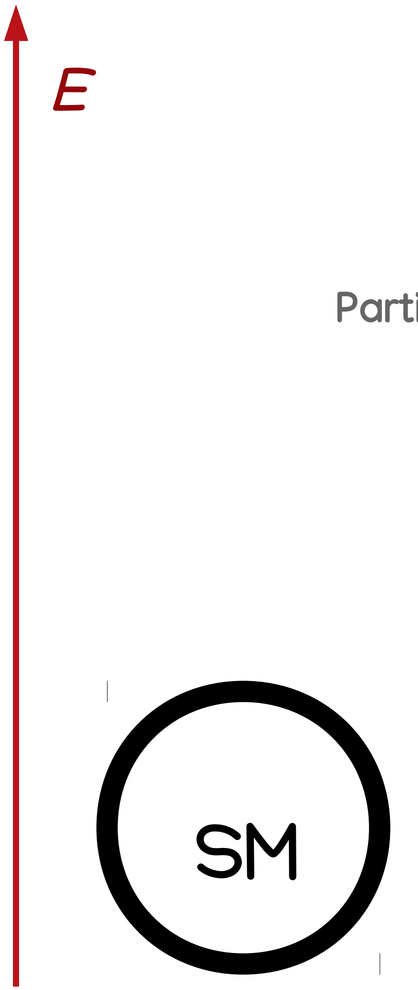
Marc Riembau
EPFL

18th August 2022

Based on **2207.03511,** with Lorenzo Ricci

EPFL

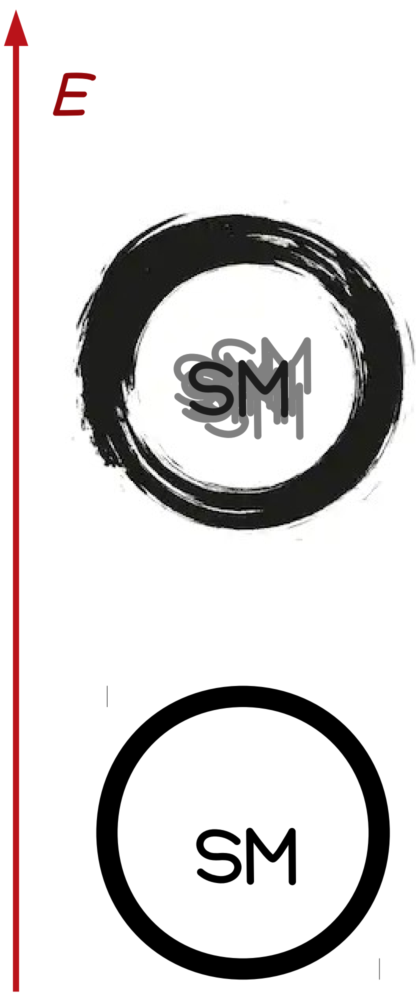
$$\mathcal{L}\,?$$



Particle Physics is back to the origin, is again the exploration of the unknown.

$$\mathcal{L} = \mathcal{L}_{\rm SM}$$

$$\mathcal{L}\,?$$

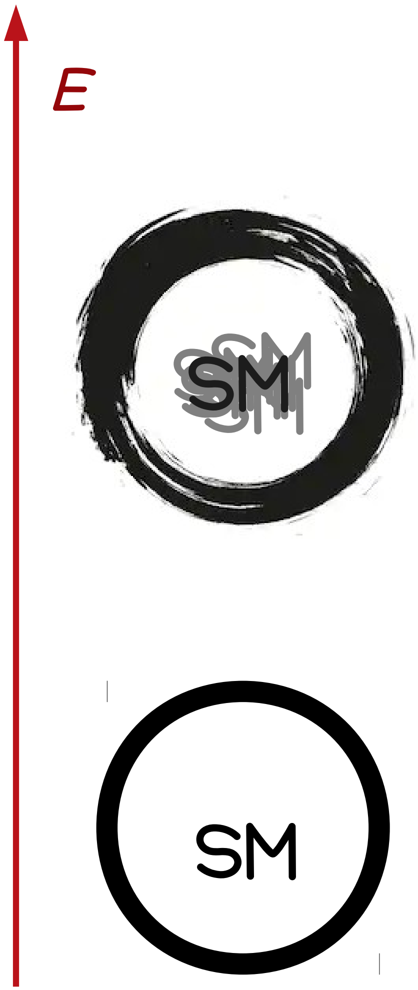


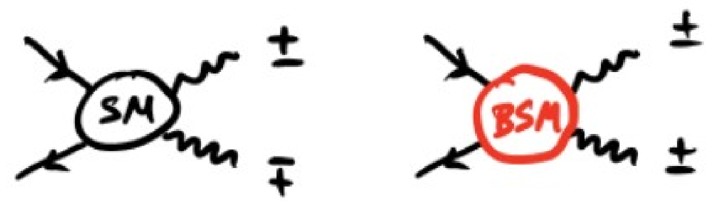
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda}\mathcal{O}_i$$

EFT operators encode information about the heavy dynamics, and tells us in which way the SM is deformed.

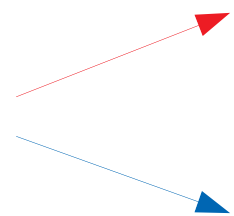
$$\mathcal{L} = \mathcal{L}_{\rm SM}$$

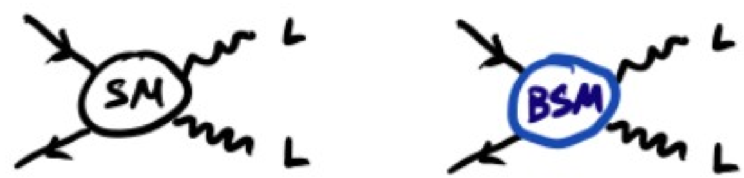
$\mathcal{L}\,?$





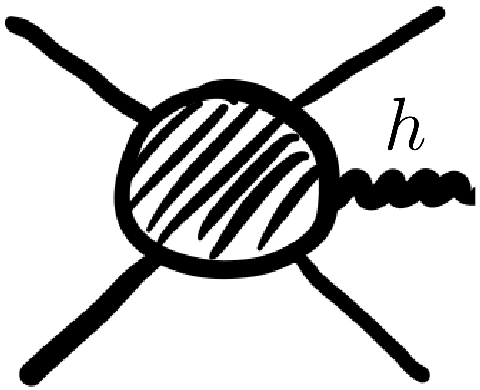
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda} \mathcal{O}_i$$





$$\mathcal{L} = \mathcal{L}_{\rm SM}$$

Decay density matrix

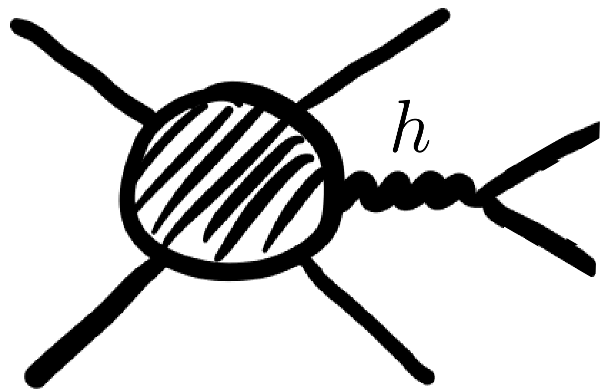


$$\mathcal{A}_{V_h}^{\mathrm{prod}}$$

What does it mean to produce a Vector of helicity h?

Decay density matrix

$$\sum_h$$

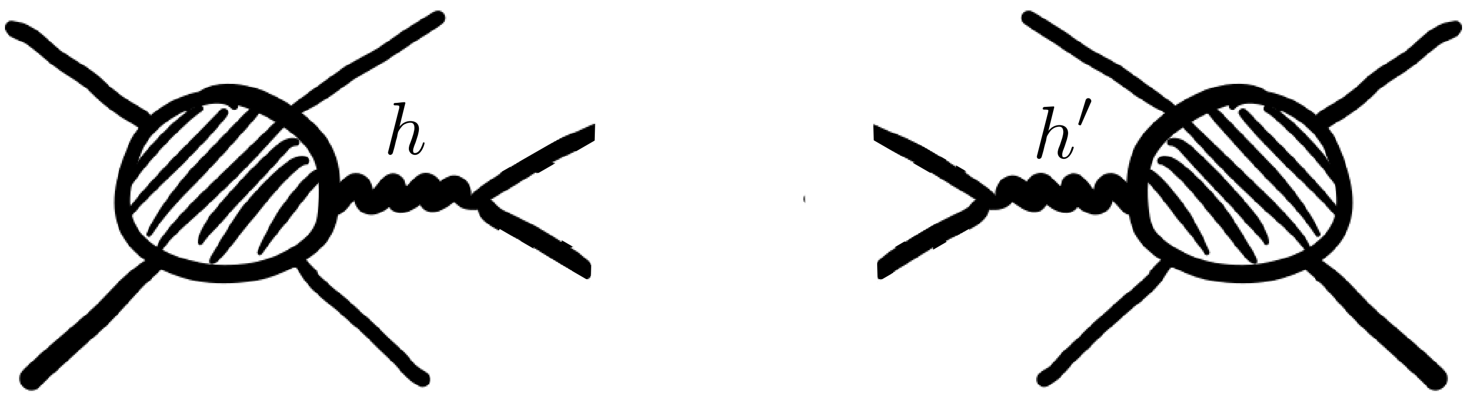


$$\mathcal{A}^{\text{prod}}_{V_h} \; \mathcal{A}^{\text{dec}}_{V_h \to X}$$

It decays, so not a single but a combination of helicities is produced

Decay density matrix

$$\sum_{h,h'}$$



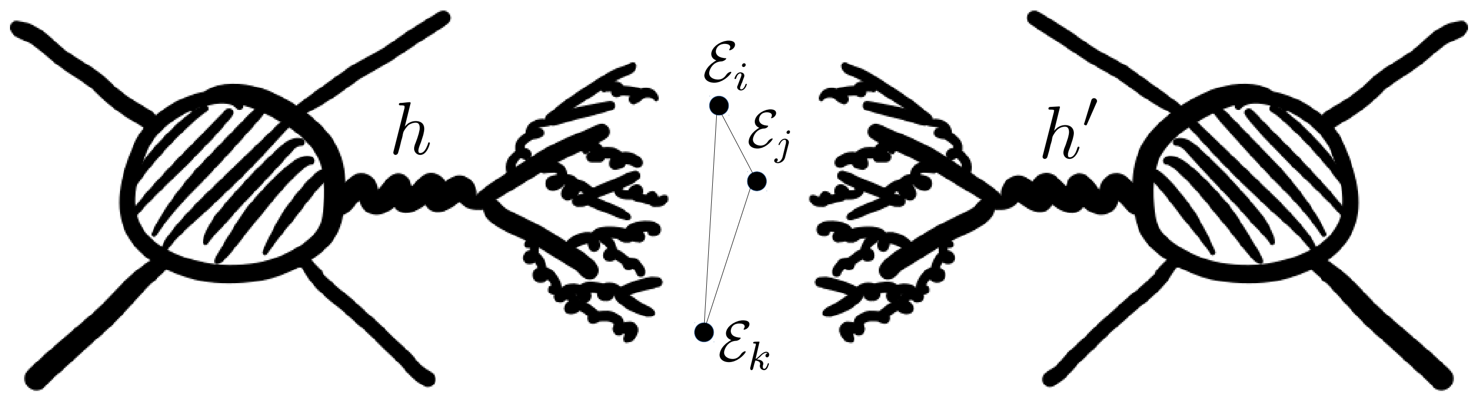
$$d\sigma \;\propto\; \sum_{h,h'} \int d\Pi \; \mathcal{A}^{\mathrm{prod}}_{V_h} \; \mathcal{A}^{\mathrm{dec}}_{V_h \to X} \qquad (\mathcal{A}^{\mathrm{prod}}_{V_{h'}})^* \; (\mathcal{A}^{\mathrm{dec}}_{V_{h'} \to X})^*$$

$$\equiv \; d\rho^{\mathrm{prod},V}_{h,h'} \;\; d\rho^{\mathrm{dec},V}_{h,h'}$$

Full process is determined by the production and decay density matrices

Decay density matrix

$$\sum_{h,h'}$$

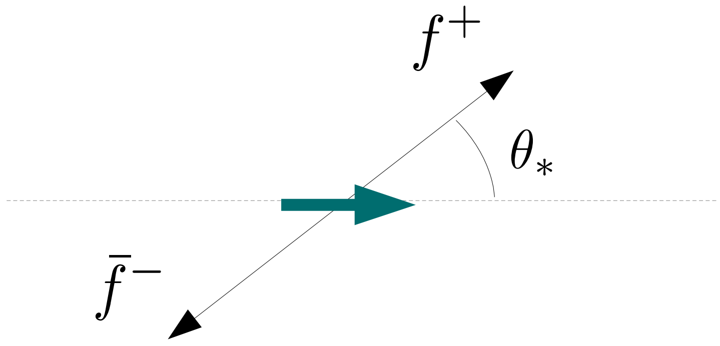


$$d\sigma \;\propto\; \sum_{h,h'} \int d\Pi \; \mathcal{A}^{\text{prod}}_{V_h} \; \mathcal{A}^{\text{dec}}_{V_h \to X} \; \mathcal{E}_1 \cdots \mathcal{E}_N \; (\mathcal{A}^{\text{prod}}_{V_{h'}})^* \; (\mathcal{A}^{\text{dec}}_{V_{h'} \to X})^*$$

$$\equiv \; d\rho^{\text{prod},V}_{h,h'} \;\; d\rho^{\text{dec},V}_{h,h'}[\{\mathcal{E}_1, \ldots, \mathcal{E}_N\}]$$

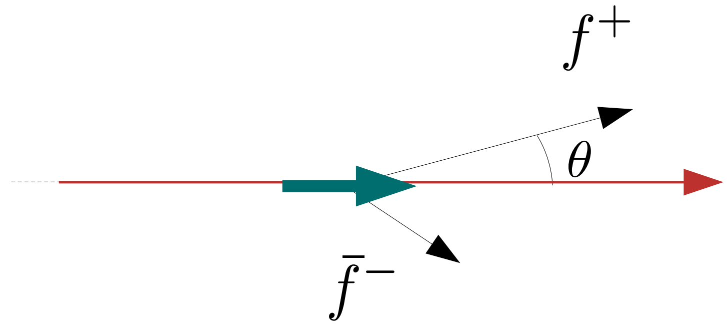
For hadronic decays, we study the density matrix of energy correlators

W rest frame



$$\mathcal{A}_+ \propto e^{i\phi} \frac{1 + \cos\theta_*}{2} \qquad \mathcal{A}_0 \propto \sin\theta_* \qquad \mathcal{A}_- \propto e^{-i\phi} \frac{1 - \cos\theta_*}{2}$$

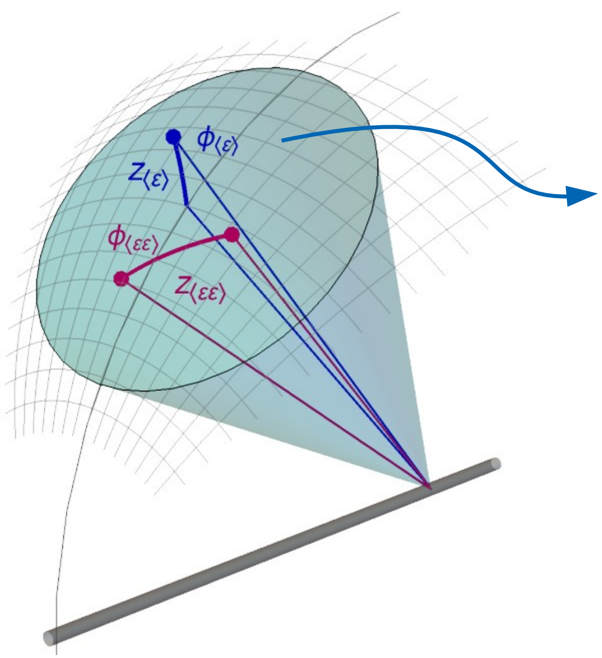
W LAB frame



$$z_\star \equiv \frac{m_W^2}{E_W^2}$$

$$\mathcal{A}_+ \propto e^{i\phi} x \qquad \mathcal{A}_0 \propto \sqrt{x(1-x)} \qquad \mathcal{A}_- \propto e^{-i\phi}(1-x)$$

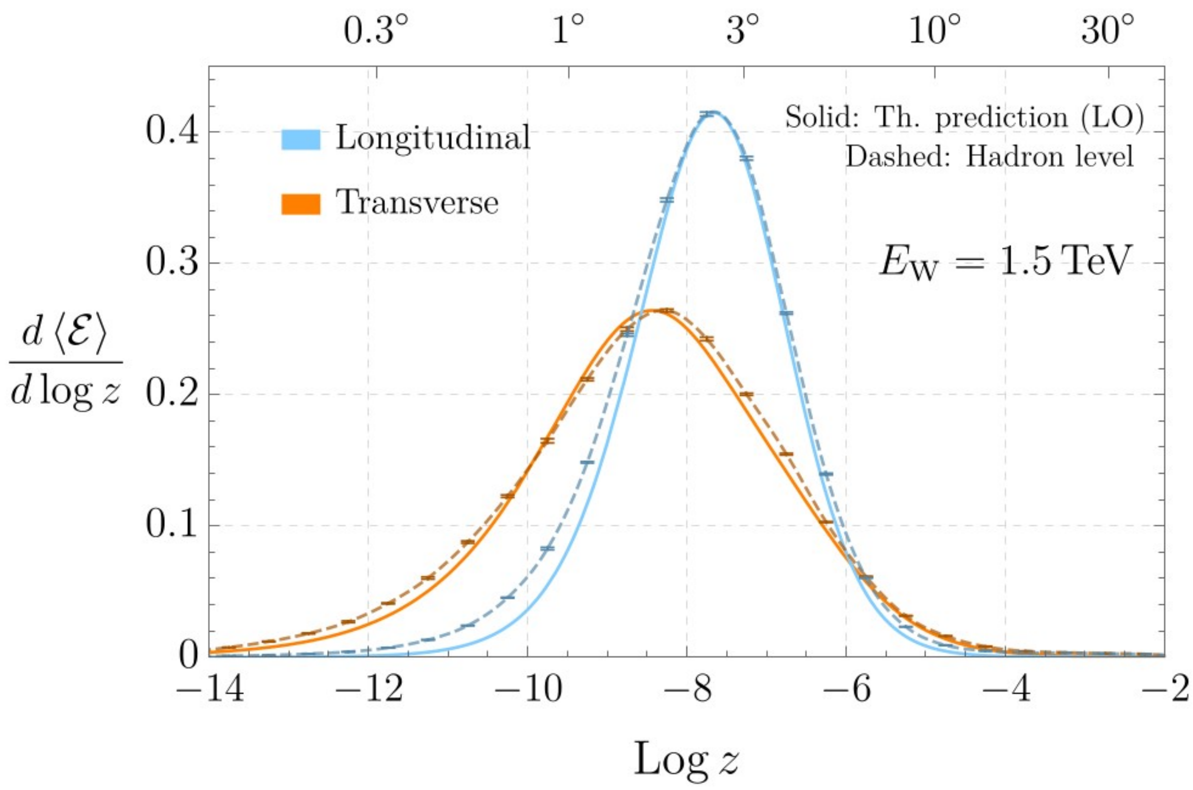
This LO calculation gives a good prediction for the one-point correlator



$$x(z) = \frac{1}{1 + 4z/z_\star}$$

$$z \ll z_\star \quad \Rightarrow \quad \mathcal{A}_+ \sim 1, \quad \mathcal{A}_0 \sim \sqrt{z/z_\star}, \quad \mathcal{A}_- \sim z/z_\star$$

One-point Energy Correlator

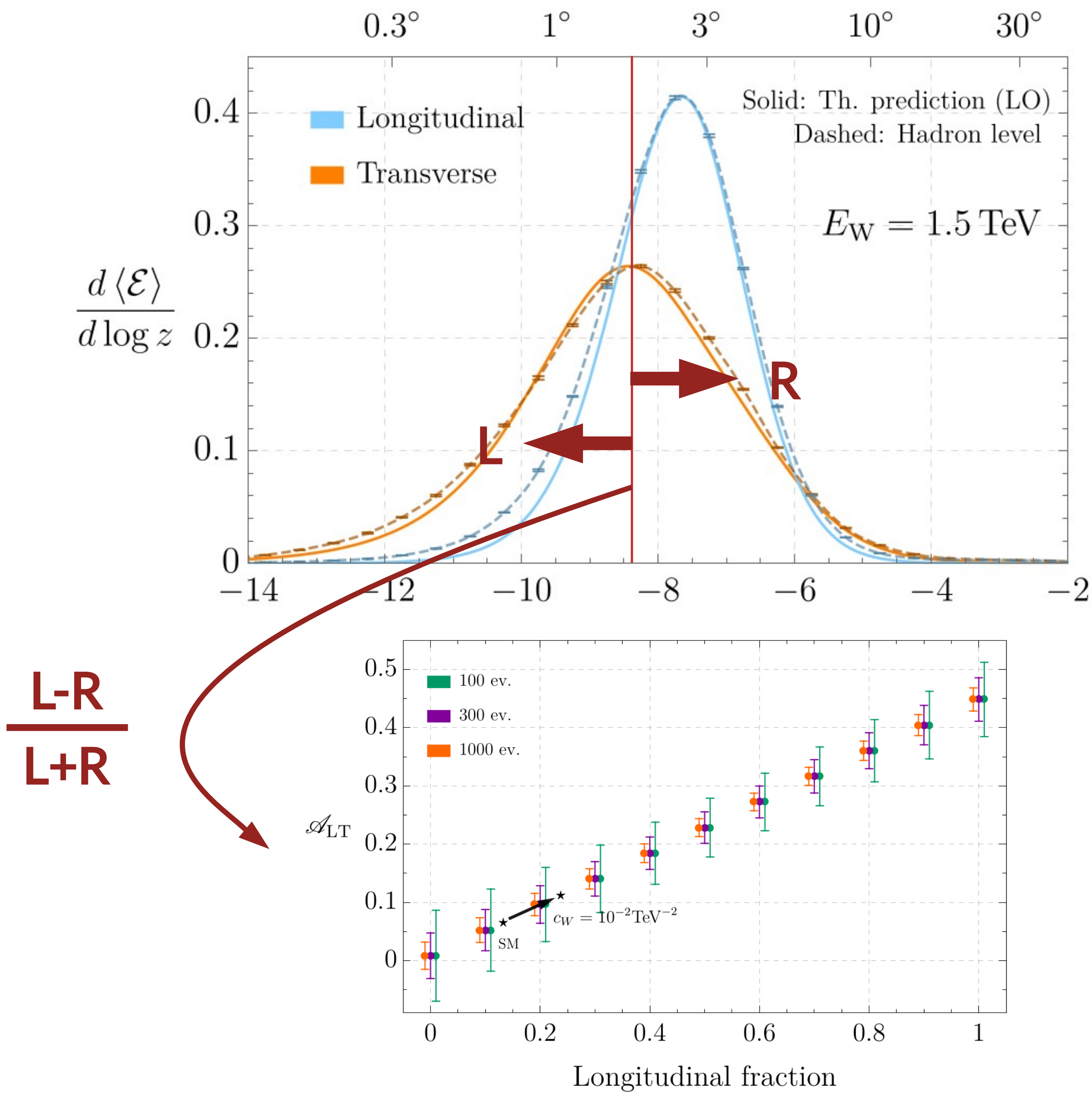


– Basic kinematics explains Transverse and Longitudinal distributions' shape

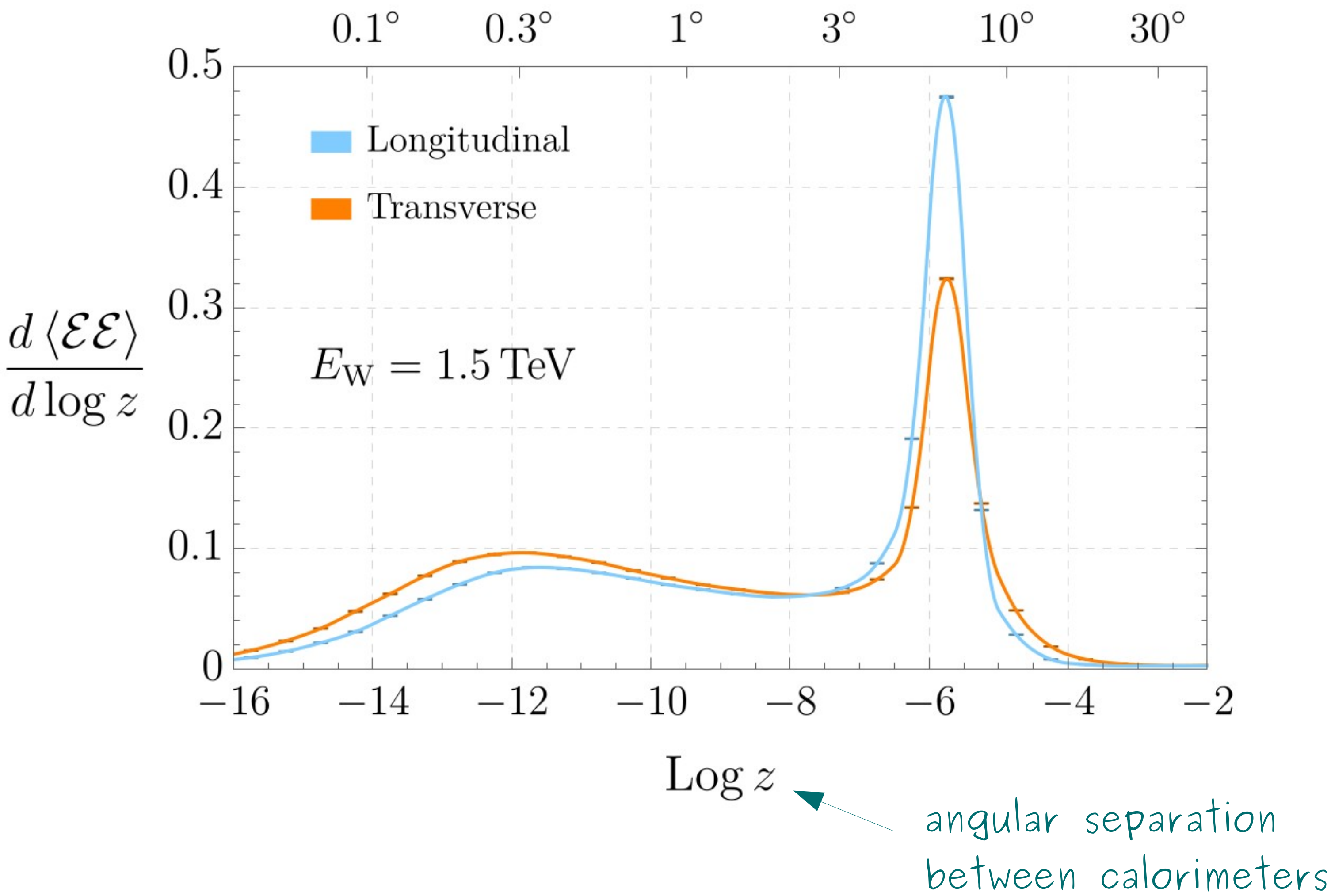
– Transverse jets tend to deposit more energy in the central region (small z)

– Recall: this is from ensamble of events. Individual events very different.

One-point Energy Correlator



Two-point Energy Correlator



The z dependence of the two-point correlator cannot be used to separate L and T

Off-diagonal entries: Interference

$$d\rho^V_{hh'} \sim e^{i\Delta h \phi}\,, \quad \Delta h \equiv h - h'$$

– Inclusive quantities not sensitive to interference

– Ignorance on "which quark" the calorimeters are placed: $\begin{matrix} \phi \to \pi + \phi \\ x \to 1 - x \end{matrix}$ redundancy

– Two types of interference:

$$|\Delta h| = 2$$

Transverse – Transverse interference

Redundancy acts trivially, easy

$$|\Delta h| = 1$$

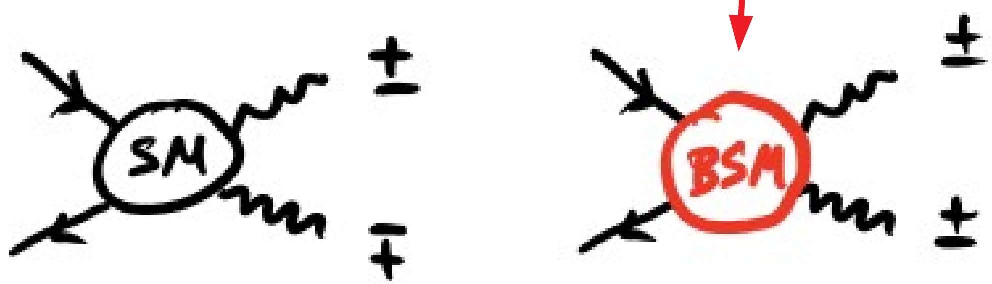
Transverse – Longitudinal interference

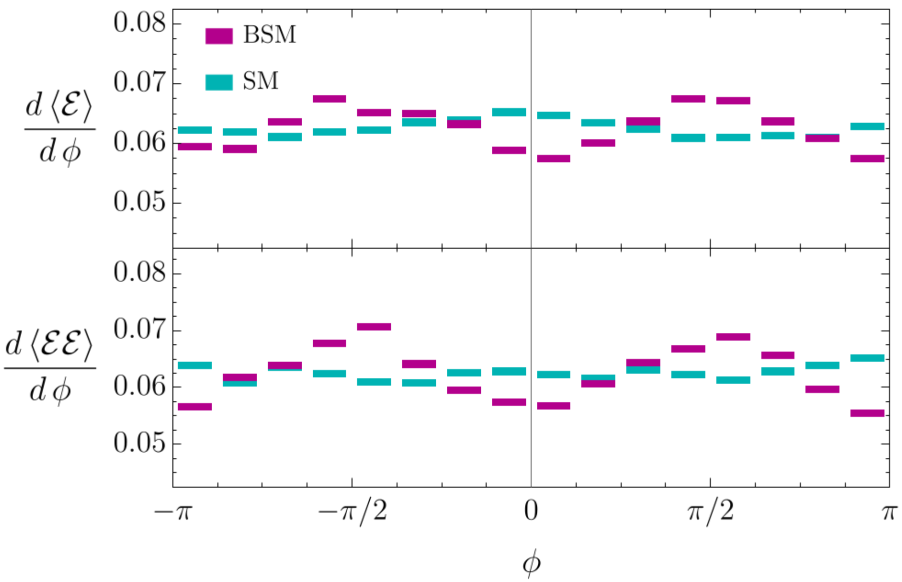
Redundancy acts nontrivially,
each process needs dedicated study

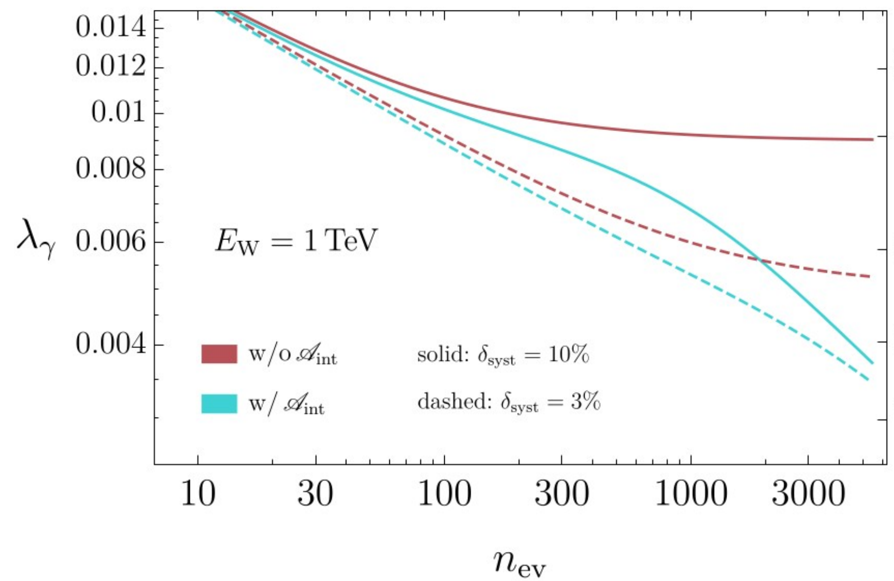
Off-diagonal entries: Interference

$$\mathcal{O}_{3W} = \epsilon^{ABC} W^A_{\mu\nu} W^B_{\nu\rho} W^C_{\rho\mu}$$

$$|\Delta h| = 2$$



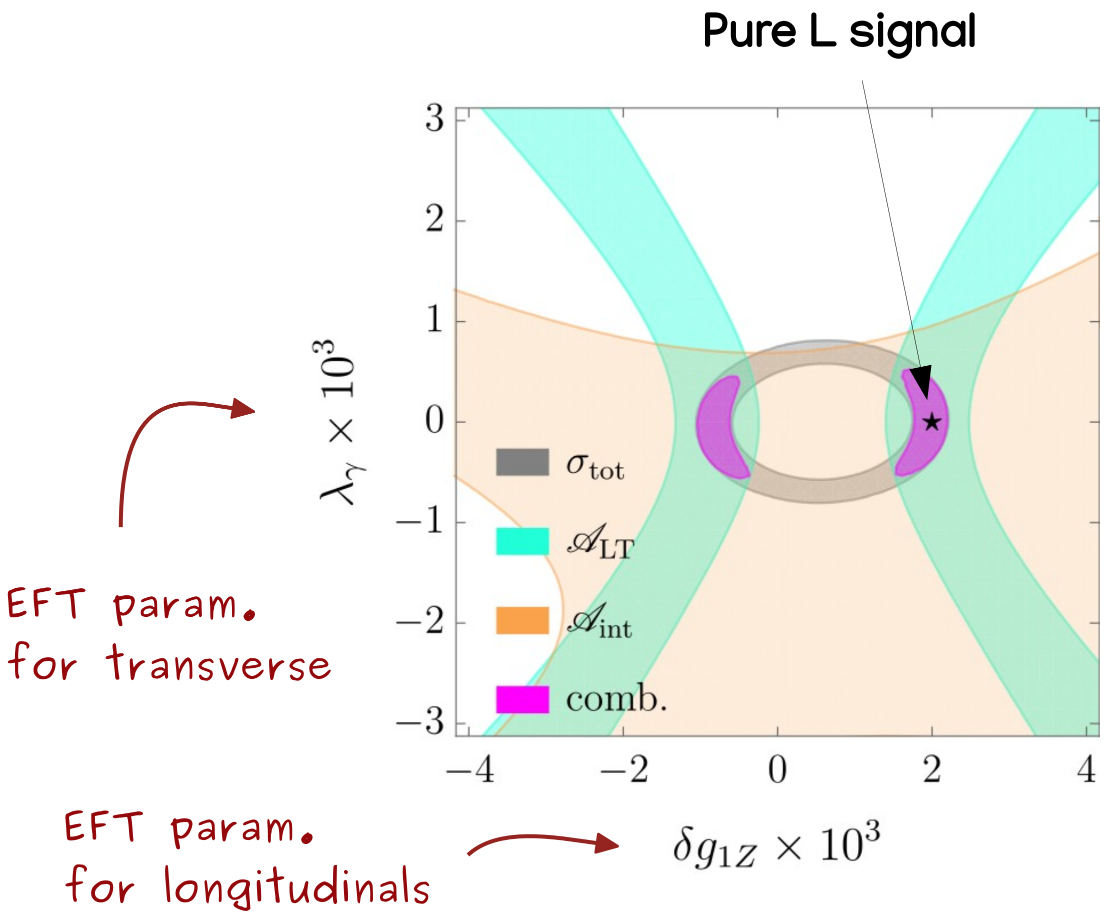




– Interference pattern shows up in the azimuthal dependence of the Ecs

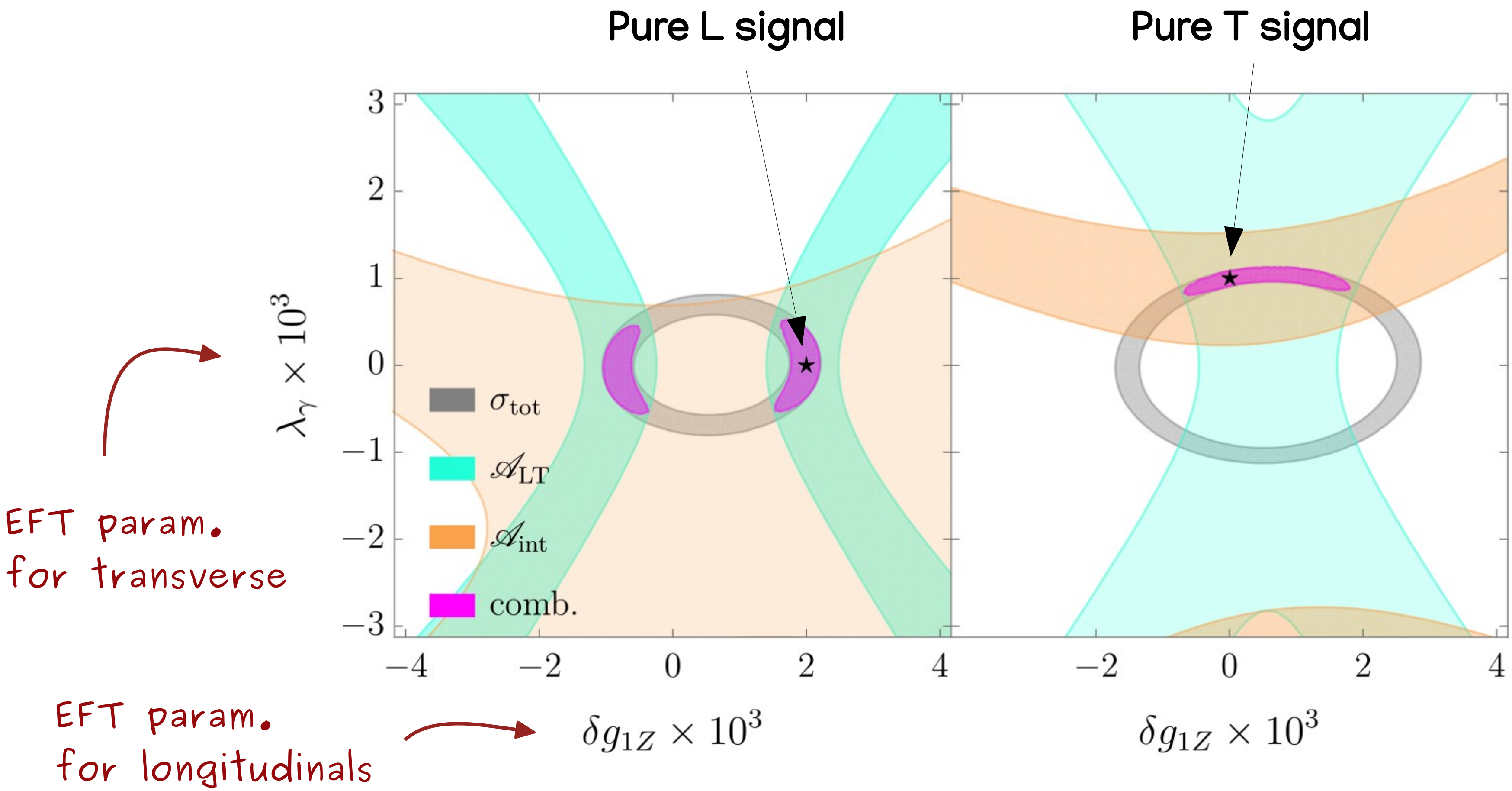
– Measuring the interference leads to linear sensitivity to BSM effects

Impact on BSM scenarios



The one-point correlator identifies the excess coming from an anomalous production of longitudinal modes

Impact on BSM scenarios



The one-point correlator identifies the excess coming from an anomalous production of longitudinal modes

The azimuthal dependence of the correlators identifies the interference term

Towards the LHC

Problem: LHC is not a monoenergetic beam of W bosons.

Part I of the solution:

$$\frac{E_i}{E_J} = \frac{p_{T,i}}{p_{T,J}} + \mathcal{O}(z_\star^{1/2})$$

$$\frac{z}{z_\star} = \frac{\Delta R^2}{R_\star^2} + \mathcal{O}(z_\star^{1/2})$$

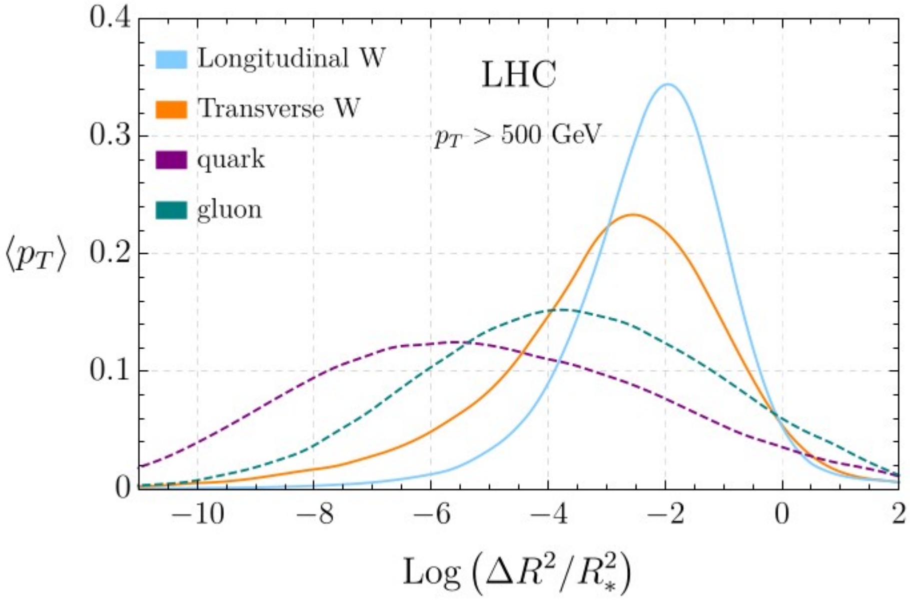
$$R_\star^2 = 4m_V^2/p_{T,J}^2$$

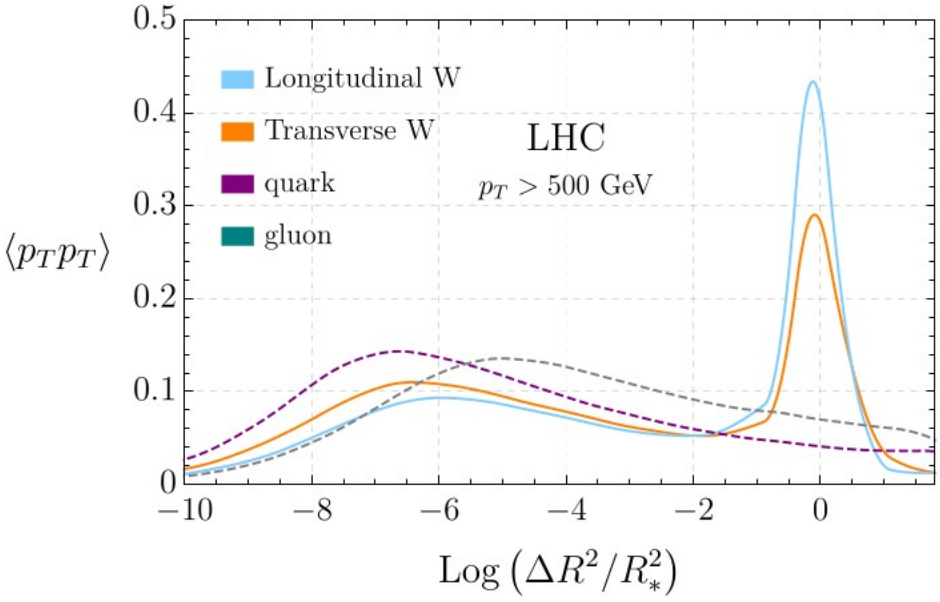
Up to $\mathcal{O}(z_\star^{1/2})$, energy and angular ratios are equivalent to boost invariant objects.

Part II of the solution:

Up to $\mathcal{O}(z_\star)$, amplitudes only depend on the ratio $\frac{z}{z_\star}$, not on z alone

Towards the LHC

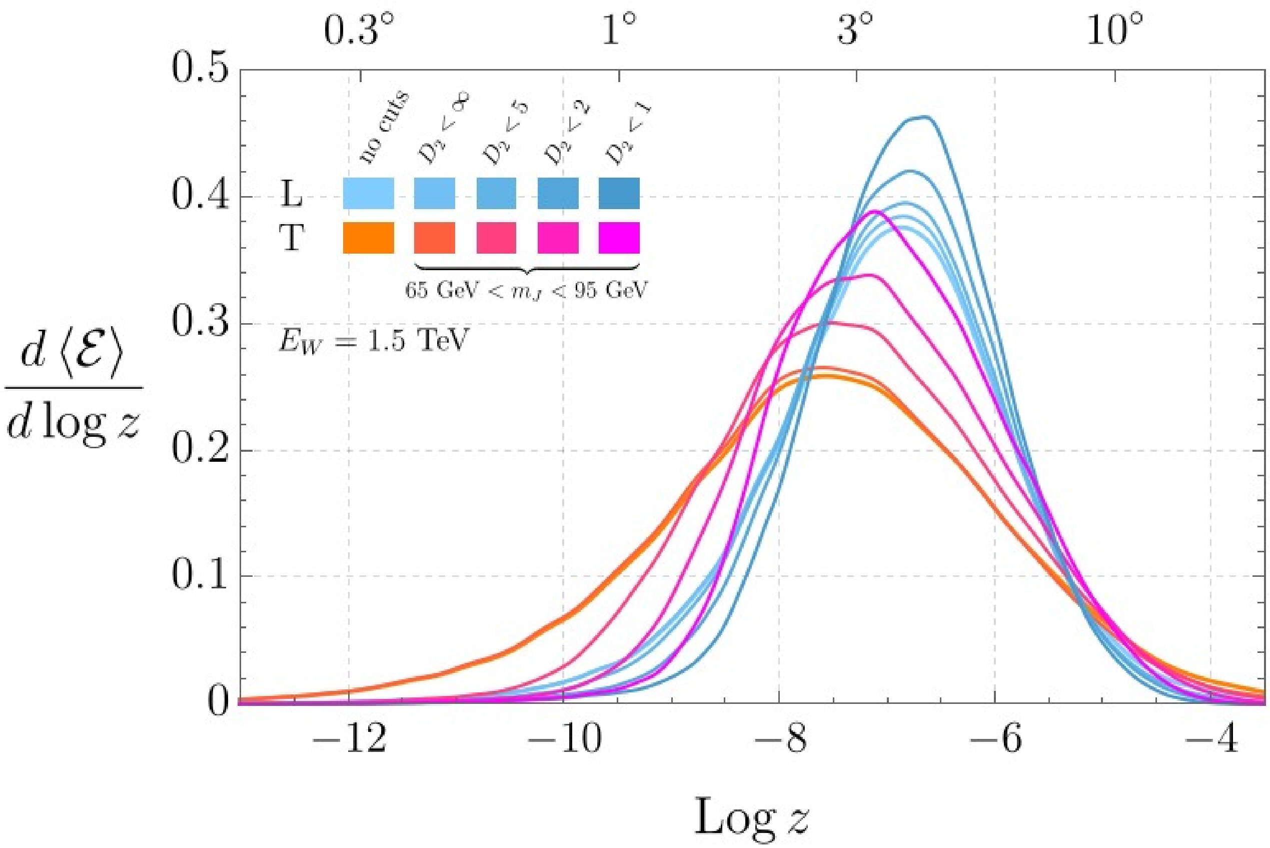




By rescaling the angular separations and using boost invariant variables, pT correlators of W jets at the LHC are identical to Energy Correlators of a monoenergetic W boson beam.

Towards the LHC

Impact of selection cuts to the one-point correlator:



– Jet mass and n_track have irrelevant impact.

– D_2, however, has a strong bias towards cutting off more Transv. than Long.

– The reason is kinematical: low z is in one-to-one with having all energy deposited in a single q, which leads to larger D_2 values.

– Polarization studies require revisiting QCD vs EW discrimination.

Conclusions

Angular separation z of one-pont EC discriminates L and T vector bosons

Azimuthal dependence of one- and two-point EC shows $|\Delta\Phi|=2$ interference

EC are useful to characterize BSM physics

Impact of QCD jets and selection criteria needs to be explored further

Thank you!