Probing New Physics at future e^+e^- colliders with two-particle angular correlations

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Two-particle angular correlations

The *two-particle correlation function* is defined as

$$C^{(2)}(\Delta y,\ \Delta\phi) = \frac{S(\Delta y,\ \Delta\phi)}{B(\Delta y,\ \Delta\phi)},$$

where $S(\Delta y, \Delta\phi)$ stands for the density of particle pairs within the same event

$$S(\Delta y,\ \Delta\phi) = \frac{1}{N_{\text{pairs}}}\frac{d^2N^{\text{same}}}{d\Delta y d\Delta\phi},$$

while $B(\Delta y, \Delta\phi)$ represents the density of mixed particle pairs from distinct events

$$B(\Delta y,\ \Delta\phi) = \frac{1}{N_{\text{mix}}}\frac{d^2N^{\text{mix}}}{d\Delta y d\Delta\phi}.$$

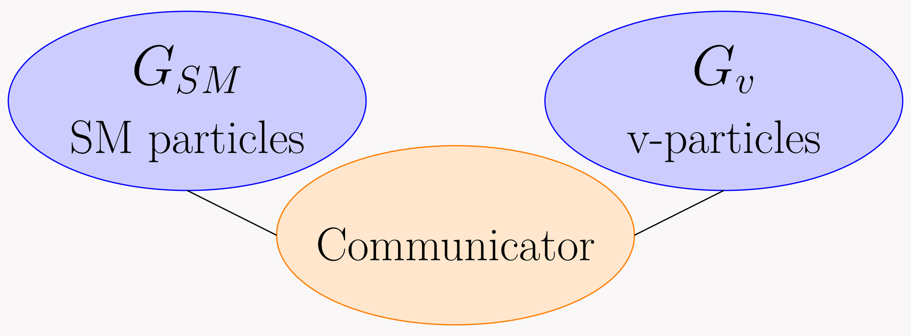
The *azimuthal yield* $Y(\Delta\phi)$ is of particular interest, being defined by integration over a Δy range as:

$$Y(\Delta\phi) = \frac{\int_{y_{\text{inf}}\le|\Delta y|\le y_{\text{sup}}} S(\Delta y,\ \Delta\phi)dy}{\int_{y_{\text{inf}}\le|\Delta y|\le y_{\text{sup}}} B(\Delta y,\ \Delta\phi)dy},$$

where $y_{\text{inf/sup}}$ defines the lower/upper integration limit for different rapidity intervals.

Can the study of two-particle angular correlations be a tool for investigating New Physics?

Hidden Valley Model



The New Physics we explore is a Hidden Valley(HV) model, in which the communicators F_v are pair-produced and can promptly decay as $F_v \to f q_v$, where f is the corresponding particle in the visible sector and q_v is a v-quark belonging to the hidden sector.

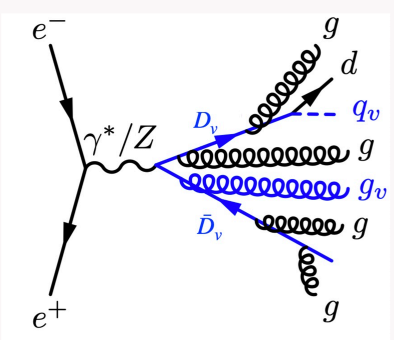
In e^+e^- collisions, F_v can be produced via $e^+e^- \to \gamma^*/Z \to F_v\bar{F}_v \to$ hadrons.

The signature we investigate is a perturbation in the conventional QCD cascade and final hadronization, leading to anomalies in angular correlations.

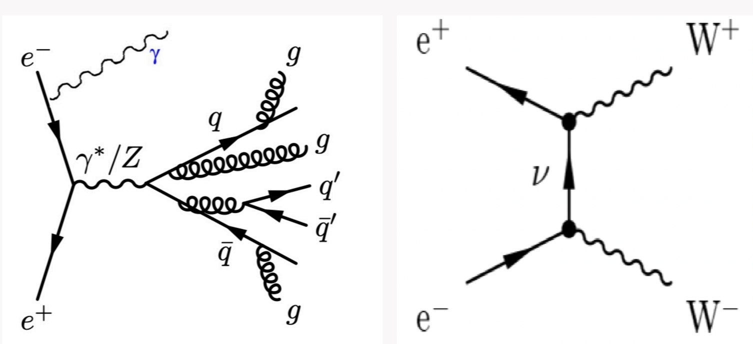
Analysis at detector level

We set $\sqrt{s}$ = 250 GeV, to match the collider's Higgs boson factory phase, considering unpolarized beams.

HV Signal



Background



The HV signal proceeds via the process $e^+e^- \to D_v\bar{D}_v \to$ hadrons (where D_V denotes the lightest communicator, being the hidden partner of the d-quark).

The Standard Model (SM) background is dominated by $q\bar{q}$ production in association with Initial State Radiation (ISR) and 4-quark production via $e^+e^- \to WW$.

Process @ 250 GeV	σ_{PYTHIA} [pb]
$e^+e^- \to D_v\bar{D}_v$	0.12
$e^+e^- \to q\bar{q}$ with ISR	48
$WW \to 4q$	7.4

The thrust reference frame has been used throughout this work.

Tools

- Monte Carlo Event generator: PYTHIA8
- Detector simulation: SGV 3.0 → ILD geometry
- Analysis: ILCSOFT, ROOT

Cuts

- No secondary vertices
- neutral PFOs ≤ 22, charged PFOs ≤ 15
- $|\cos\theta_{\gamma ISR}| < 0.5$ and $E_{\gamma ISR} < 40$ GeV
- $E_{jet} < 80$ GeV and $m_{jj} < 130$ GeV

Distributions

Before cuts

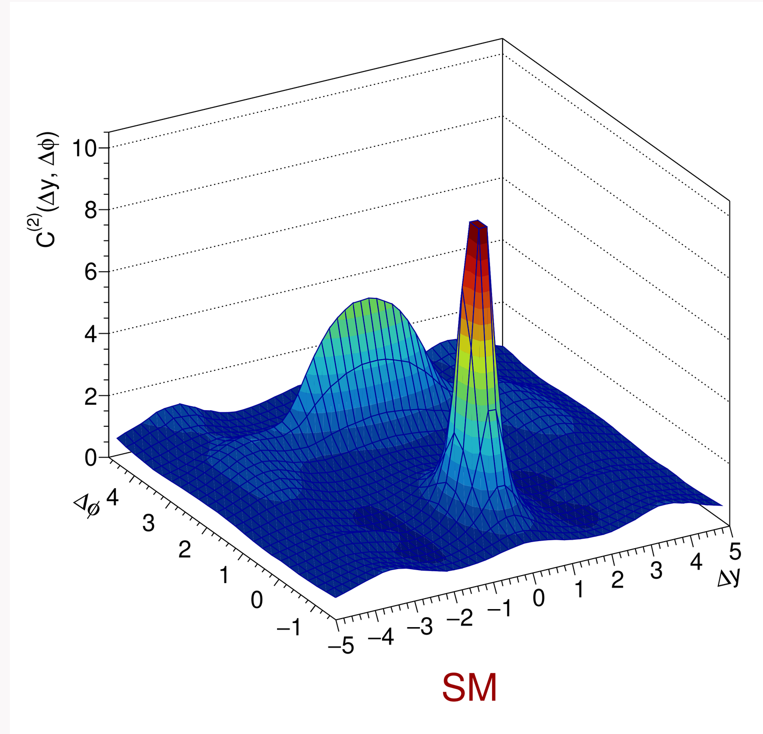


Figure 1: Two-particle angular correlation function for the SM Background before applying selection cuts

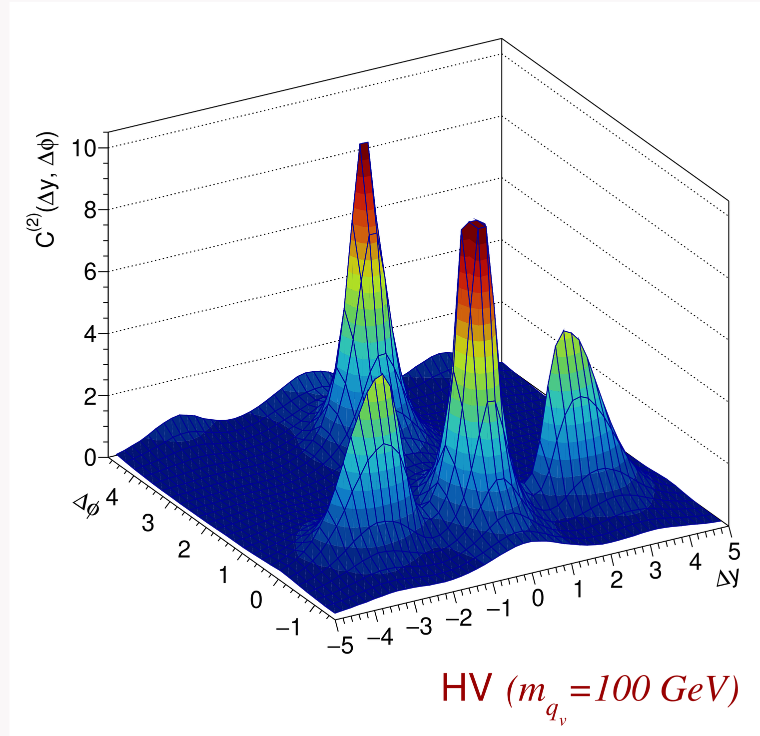


Figure 2: Two-particle angular correlation function for the pure HV Signal before applying selection cuts

After Cuts

The selection cut efficiency shows a drastic reduction of the SM background

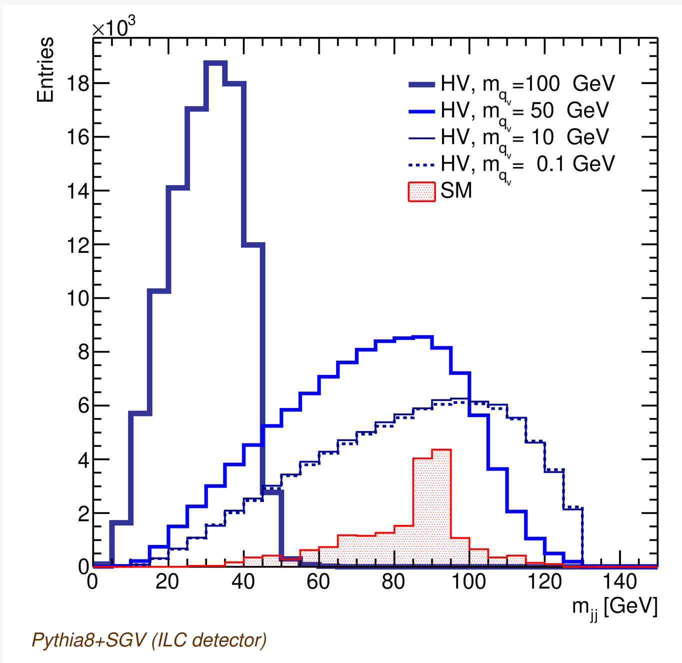


Figure 3: Di-jet invariant mass distributions after selection cuts.

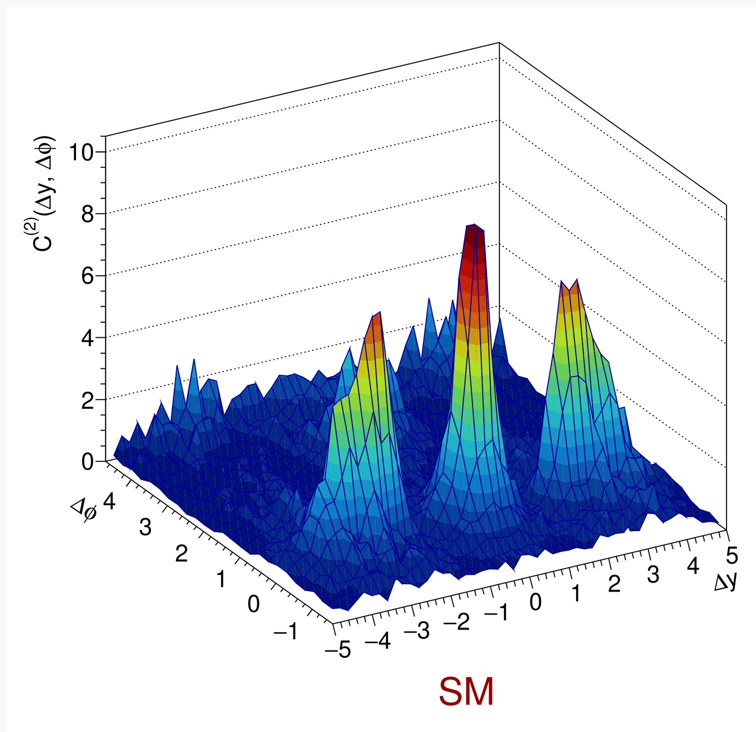


Figure 4: Two-particle angular correlation function for the SM Background

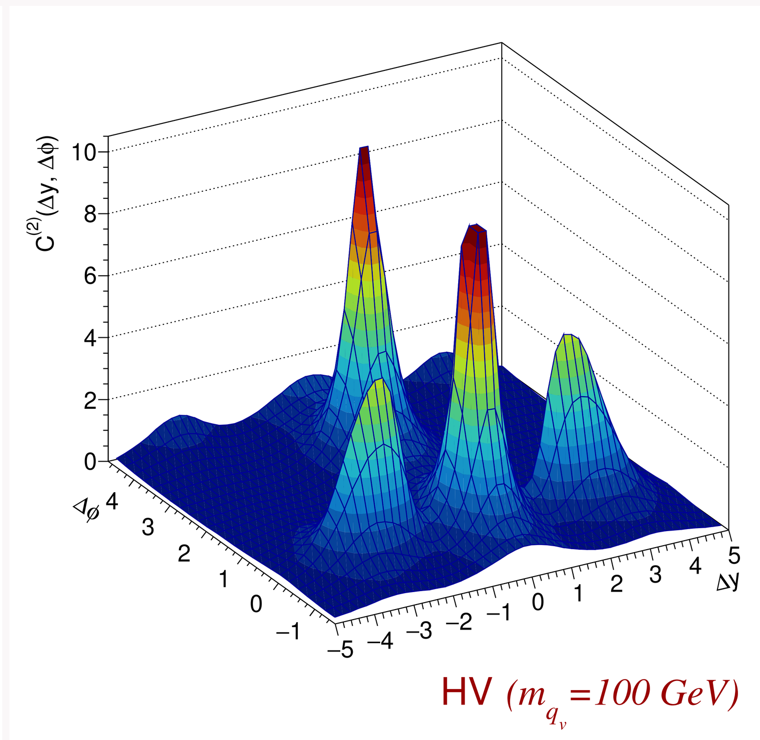


Figure 5: Two-particle angular correlation function for the pure HV Signal

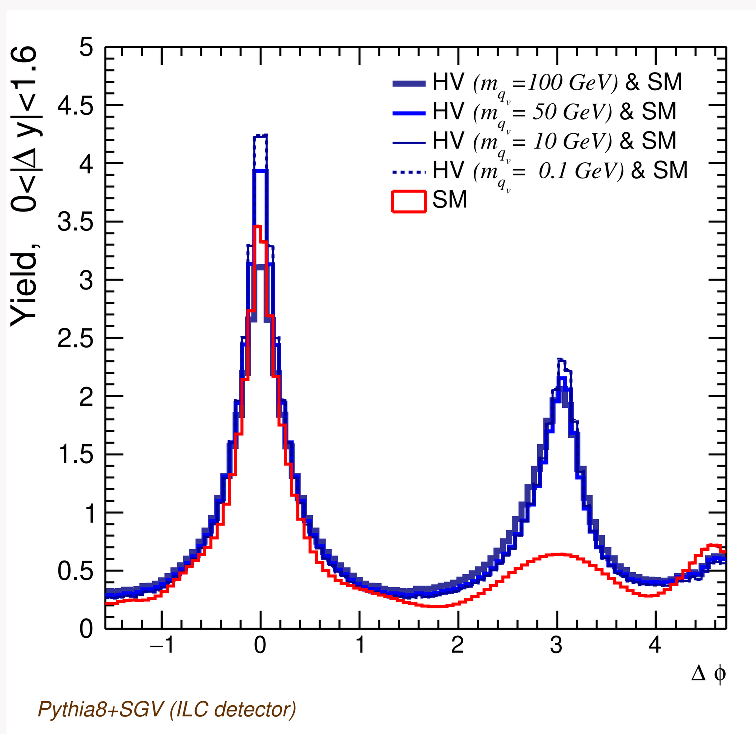


Figure 6: Yield Y($\Delta\phi$) for both HV+SM signal(blue) and SM background (red) for the $0 < |\Delta y| < 1.6$ interval.

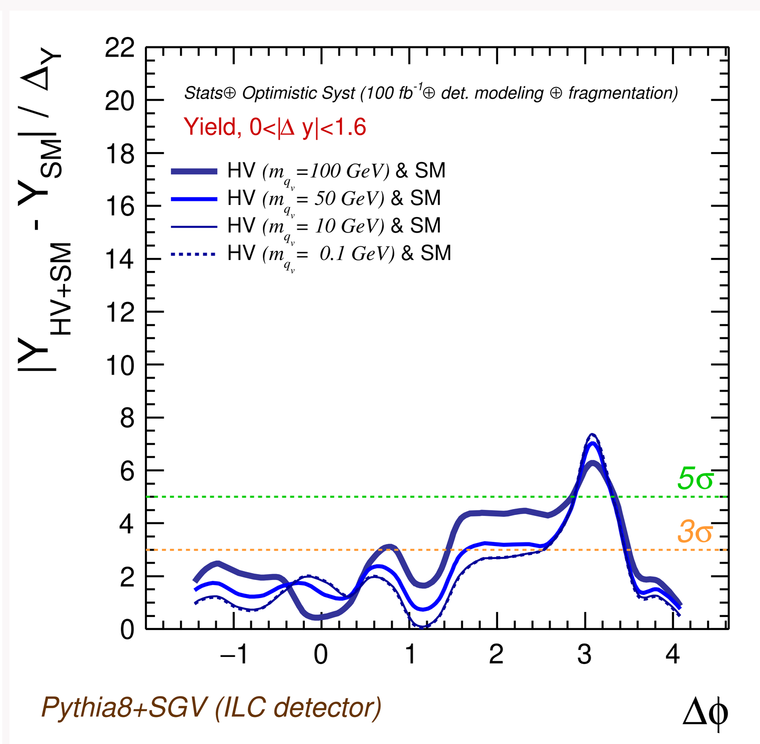


Figure 7: Expected experimental sensitivity for HV after collecting 100 of integrated luminosity.

In the $0 < |\Delta y| \le 1.6$ range, a sizeable peak at $\Delta\phi \sim \pi$ characterises the HV scenario, unlike the pure SM case. This remarkable discrepancy of shapes could potentially serve as a valuable signature of a hidden sector, complementary to more conventional searches.

Conclusions

The analysis of two-particle angular correlations can serve as a complementary tool to traditional methods in the search for new phenomena beyond the Standard Model physics. This study investigates the discovery potential for hidden sectors at future e^+e^- colliders through two-particle angular correlations, focusing on a QCD-like hidden valley model.

References:

[1] EM et al, *Exploring hidden sectors with two-particle angular correlations at future e^+e^- colliders*, , **2312.06526**

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