Exploring hidden sectors at future e^+e^- colliders with two angular particle correlations

Emanuela Musumeci (IFIC, Valencia)

R. Pérez-Ramos, A. Irles, I. Corredoira, V. Mitsou, M.A. Sanchis-Lozano

LCWS2023 INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

SLAC National Accelerator Laboratory, Menlo Park (USA)

18/05/2023

OVERVIEW

- Two particle angular correlations
- Hidden Valley Phenomenology
- Preliminary Results: Signal vs Background
- Summary

TWO PARTICLE ANGULAR CORRELATIONS

- Powerful method to study the underlying mechanisms of particle production
- Uncover possible collective effects resulting from the high particle densities

- Difference in Rapidity

$$\Delta y = y_2 - y_1$$

- Difference in Azimuthal angle:

$$\Delta\phi = \phi_2 - \phi_1$$

$$C_2(\Delta y, \Delta\phi) = \frac{S(\Delta y, \Delta\phi)}{B(\Delta y, \Delta\phi)}$$

Density of particle pairs produced within the **same** event:

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

$$N_{pairs} = \int\int \frac{d^2N^{same}}{d\Delta y d\Delta\phi} d\Delta y d\Delta\phi$$

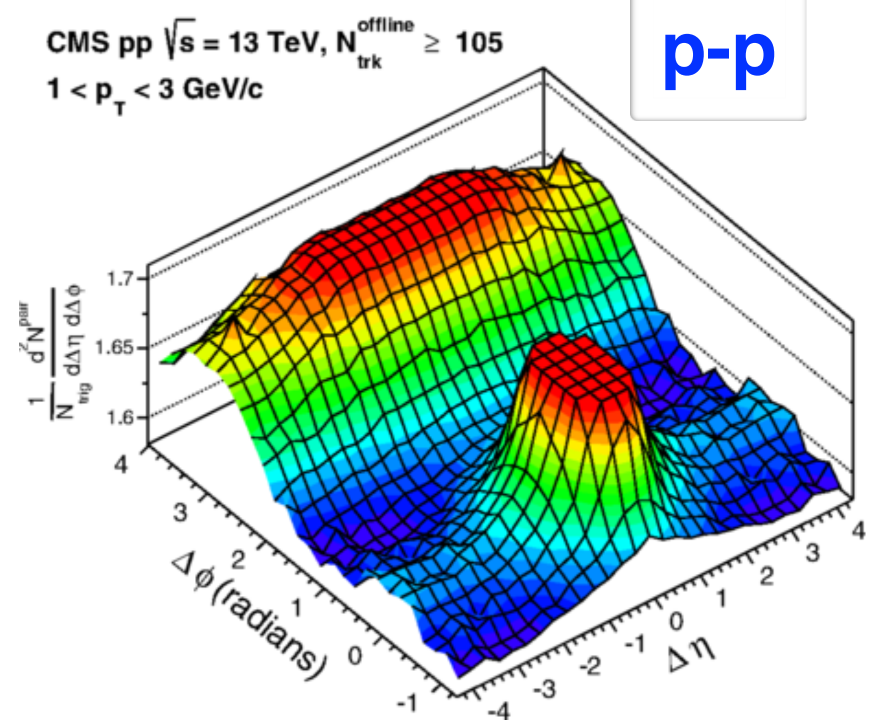
Density of particle pairs produced in the **different** events:

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

$$N_{mix} = \int\int \frac{d^2N^{mix}}{d\Delta y d\Delta\phi} d\Delta y d\Delta\phi$$

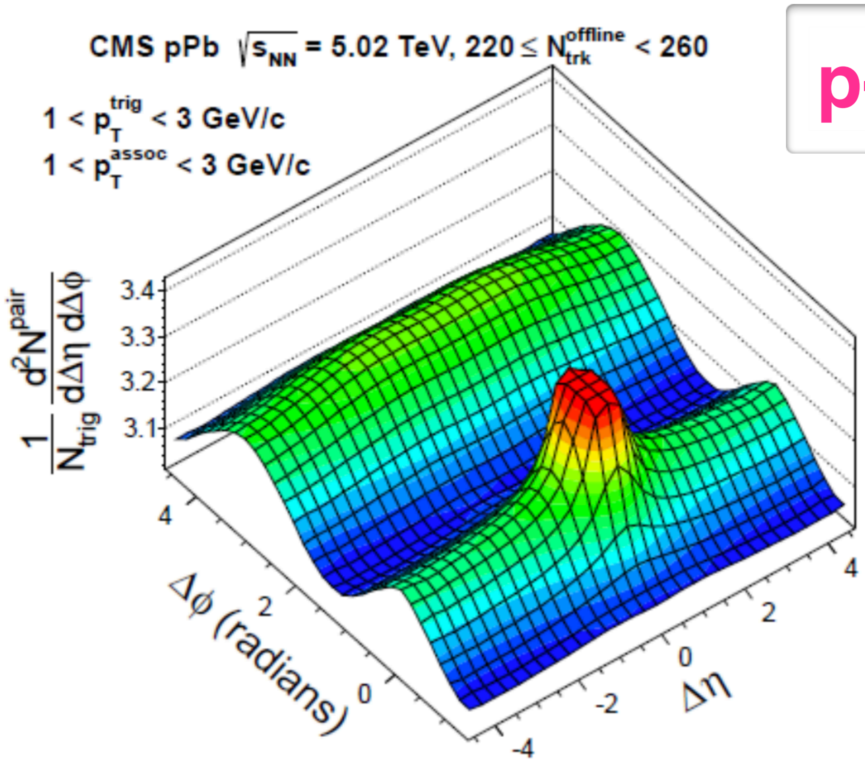
TWO-PARTICLE ANGULAR CORRELATIONS

p-p



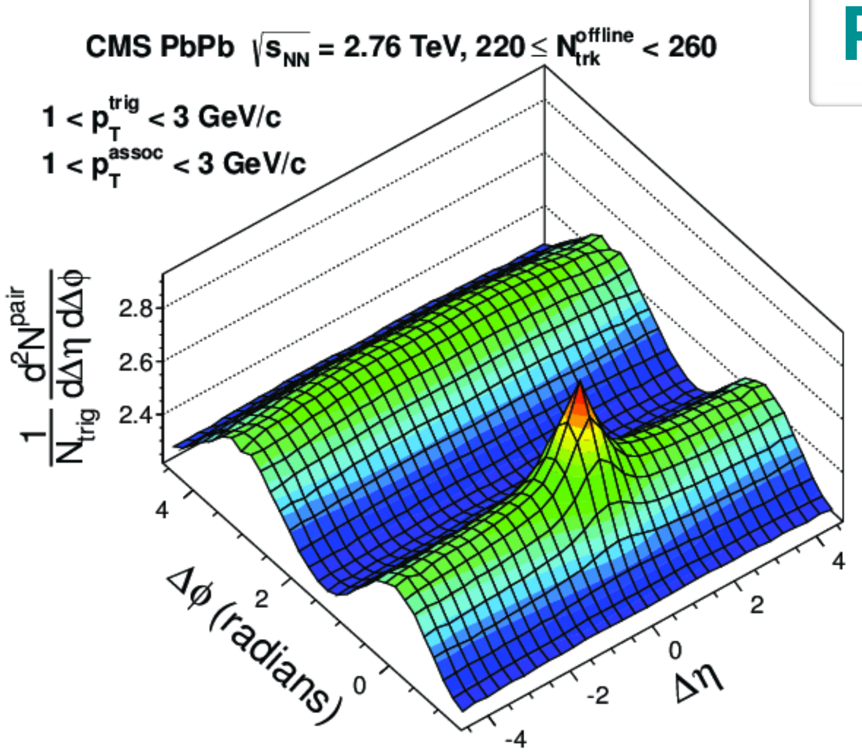
[Physical Review Letters 116(17)](#)

p-Pb



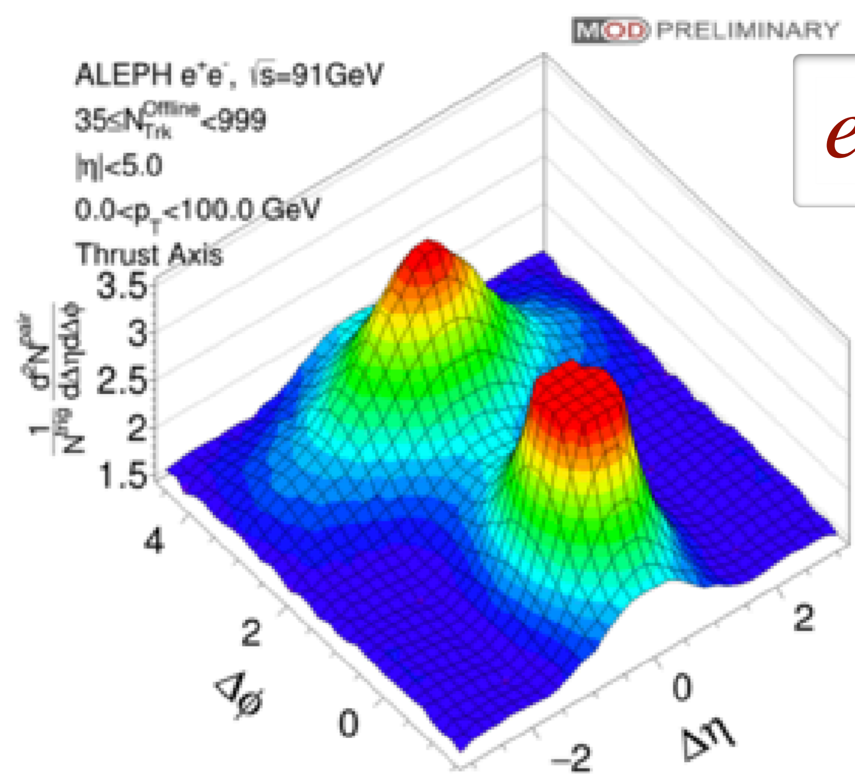
Physics Letters B B724(4)

Pb-Pb



Physics Letters B B724(4)

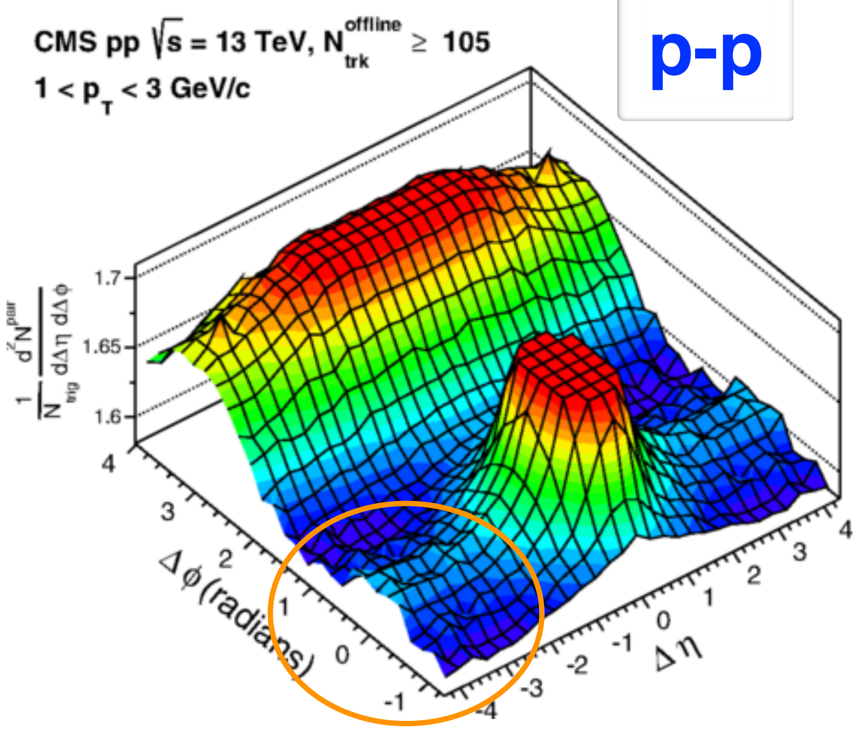
e^+e^-



Phys. Rev. Lett. 123, 212002 (2019)

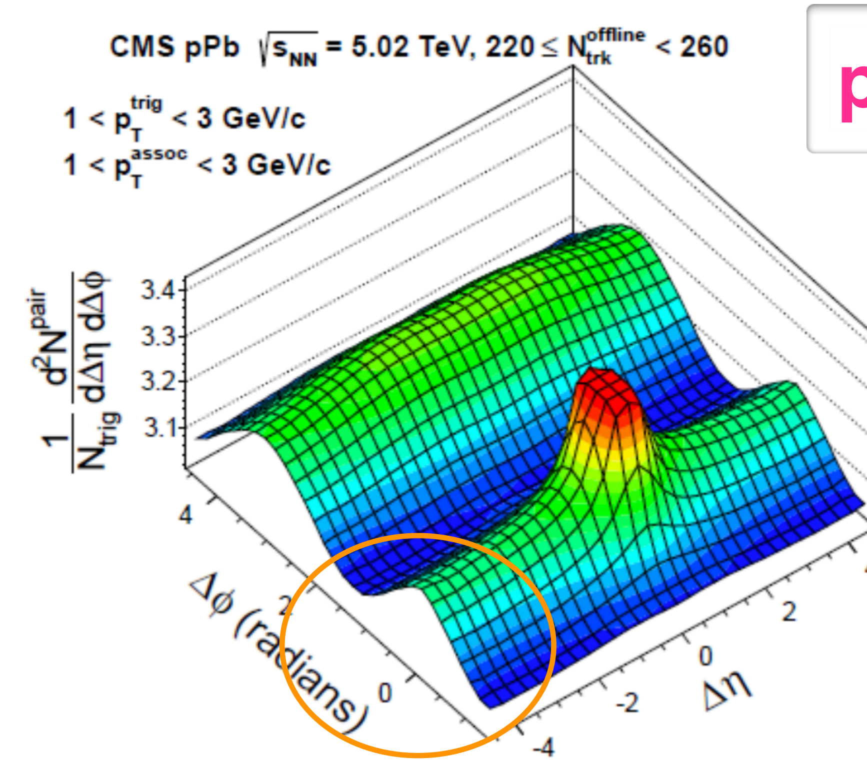
TWO-PARTICLE ANGULAR CORRELATIONS

p-p



Physical Review Letters 116(17)

p-Pb



Physics Letters B B724(4)

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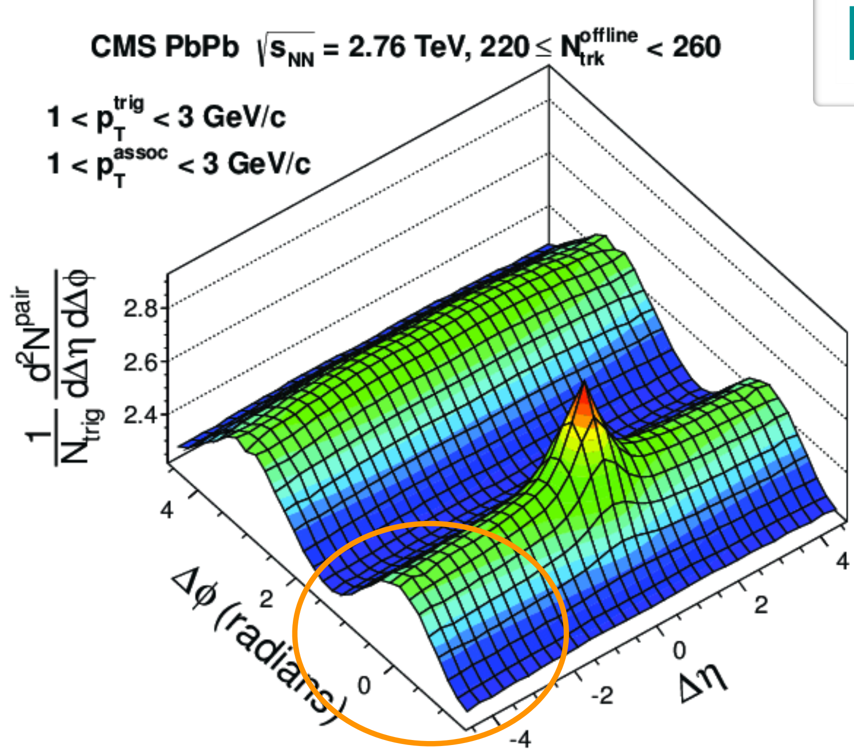
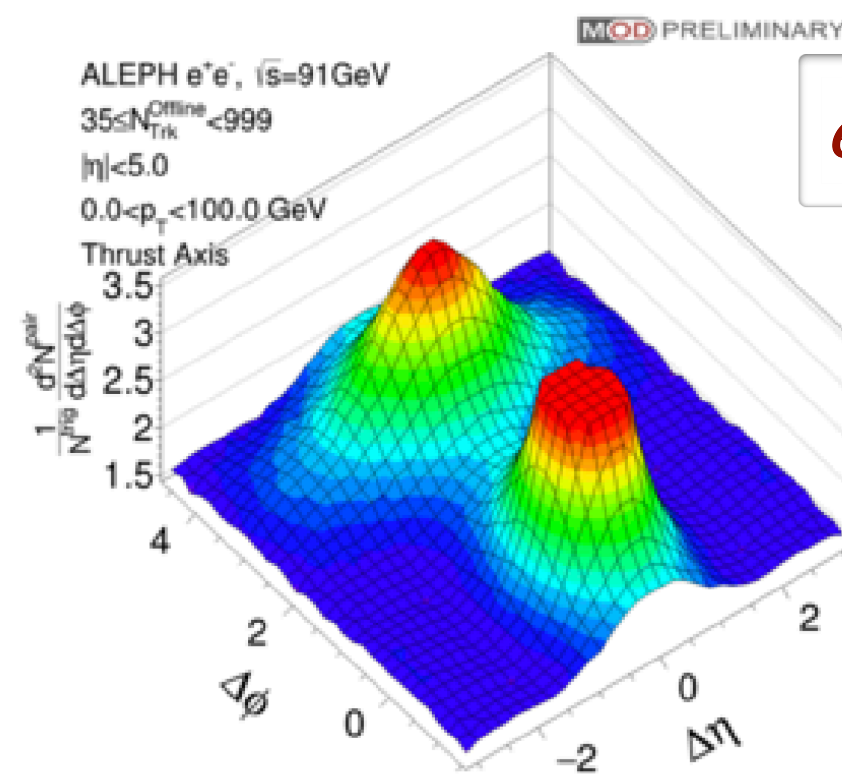


Physics Letters B B724(4)

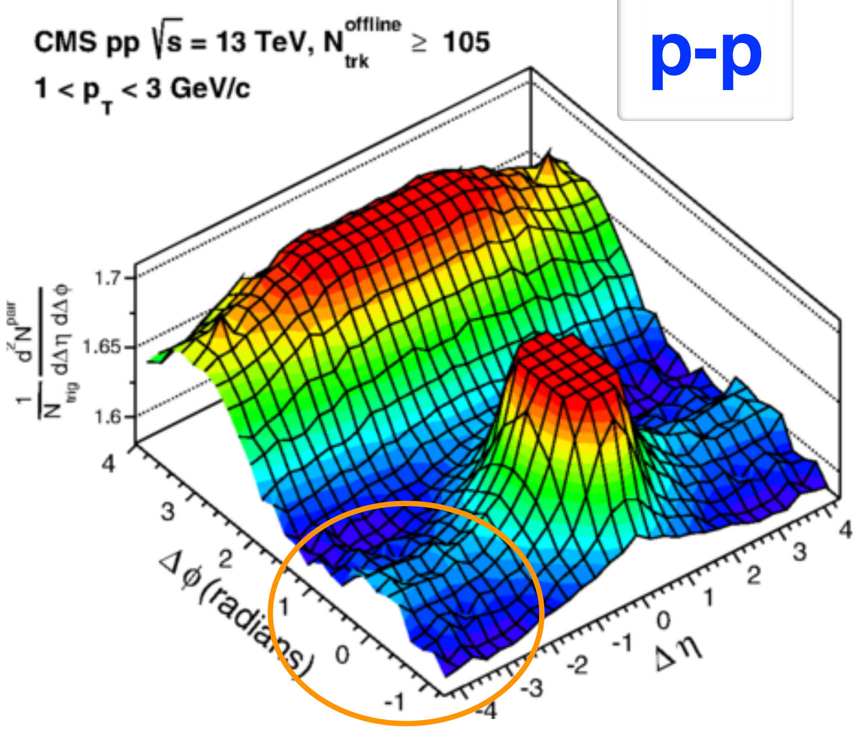
e^+e^-



Phys. Rev. Lett. 123, 212002 (2019)

TWO-PARTICLE ANGULAR CORRELATIONS

p-p



Physical Review Letters 116(17)

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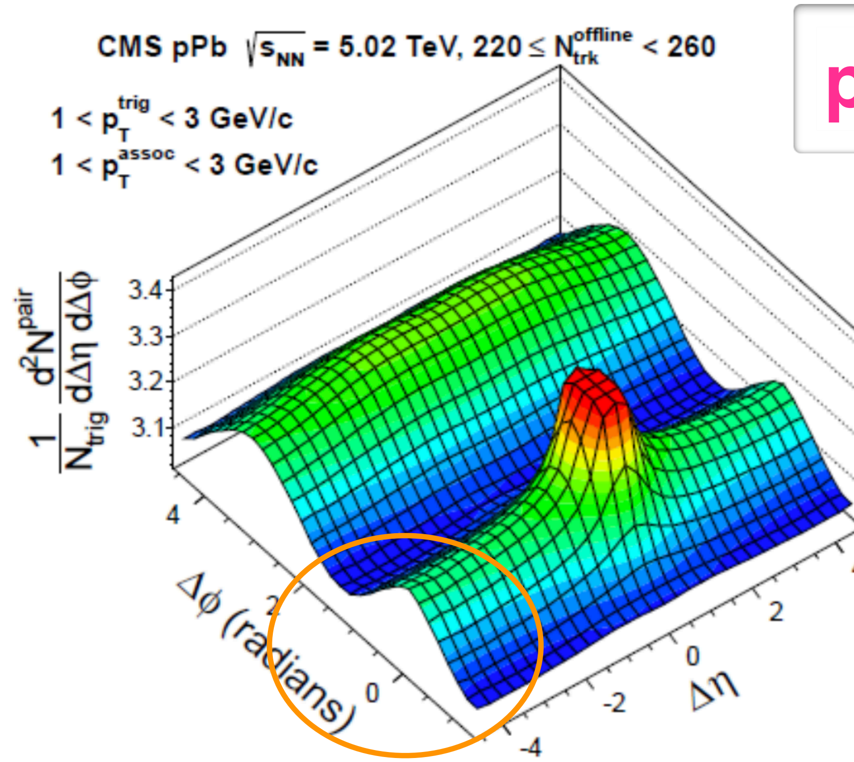
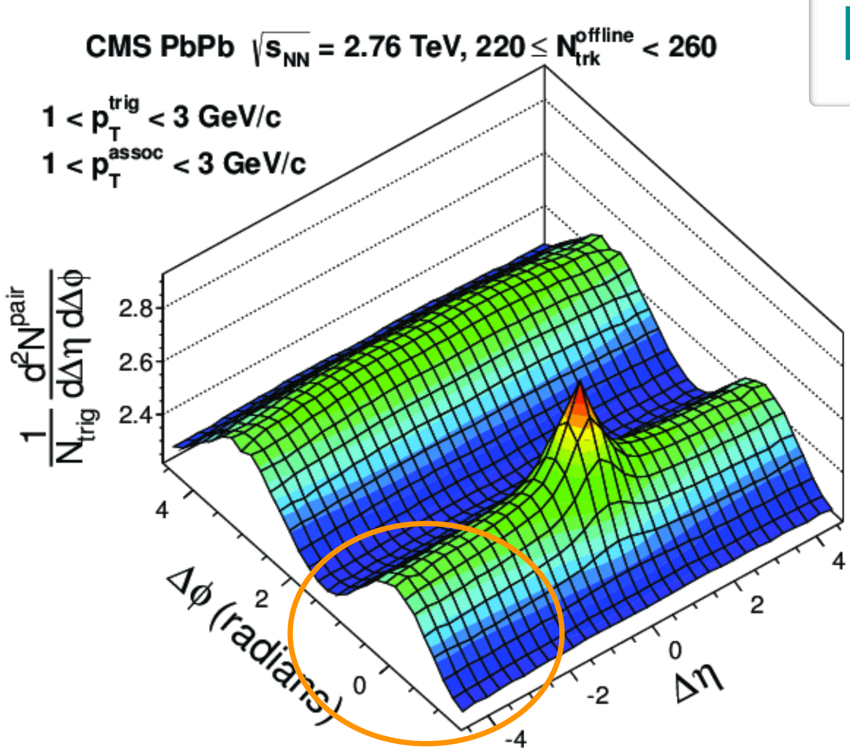


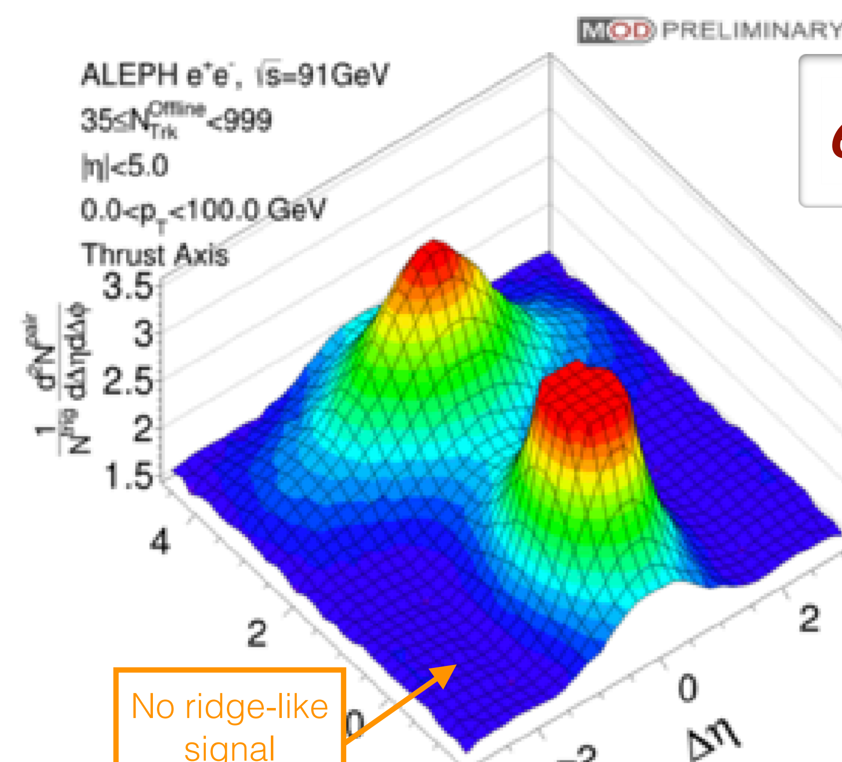
Physics Letters B B724(4)

Pb-Pb



Physics Letters B B724(4)

e^+e^-

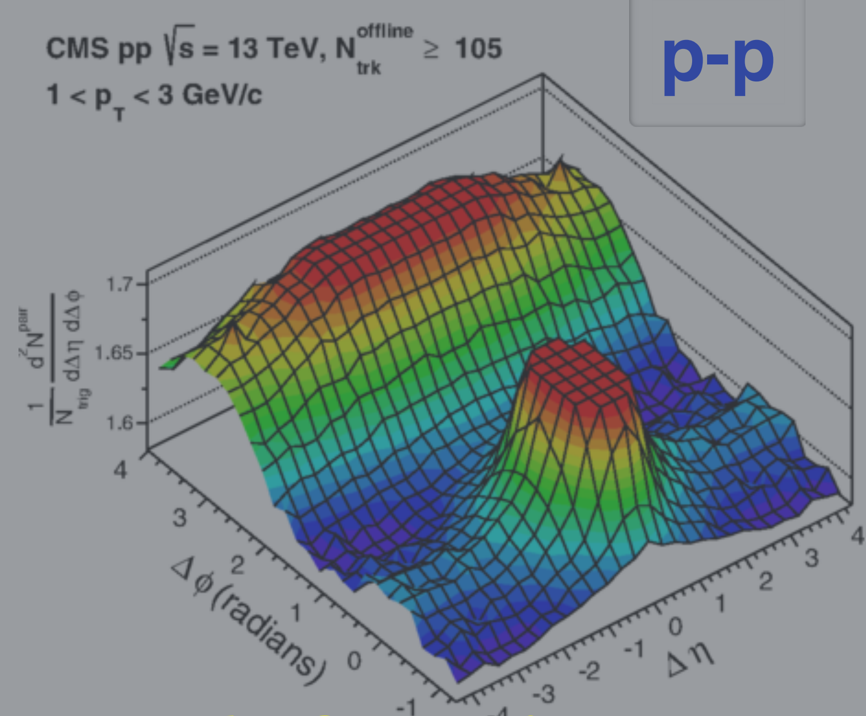


No ridge-like signal

Phys. Rev. Lett. 123, 212002 (2019)

TWO-PARTICLE ANGULAR CORRELATIONS

p-p



Physical Review Letters 116(17)

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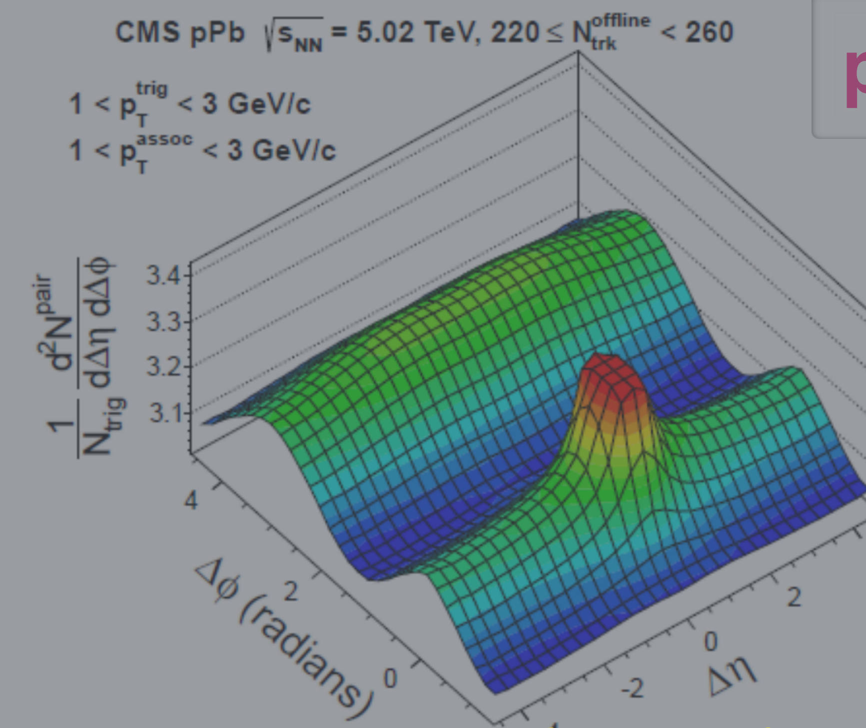
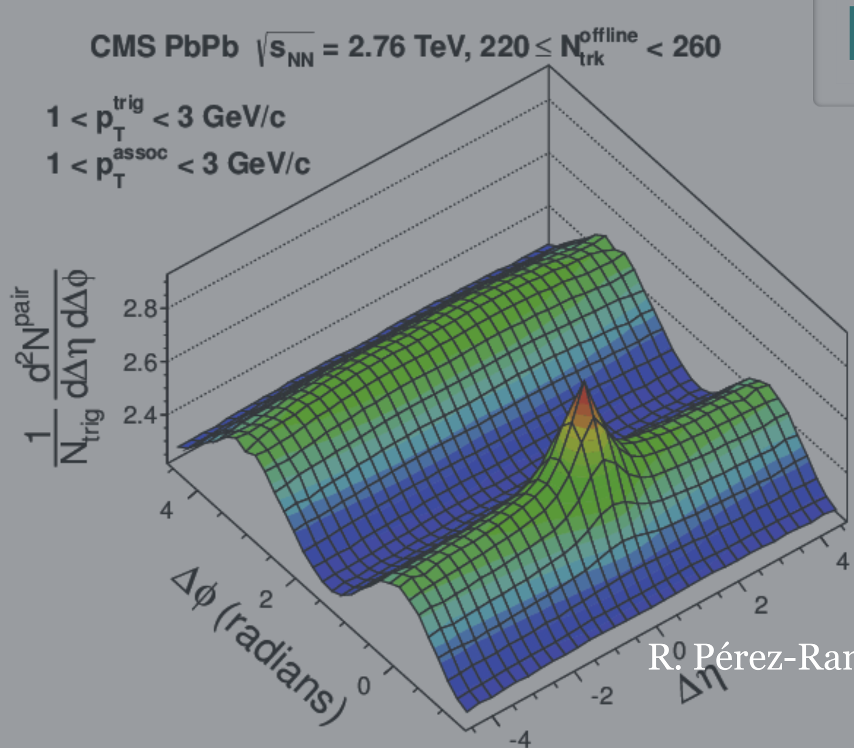


Physics Letters B 724(4)

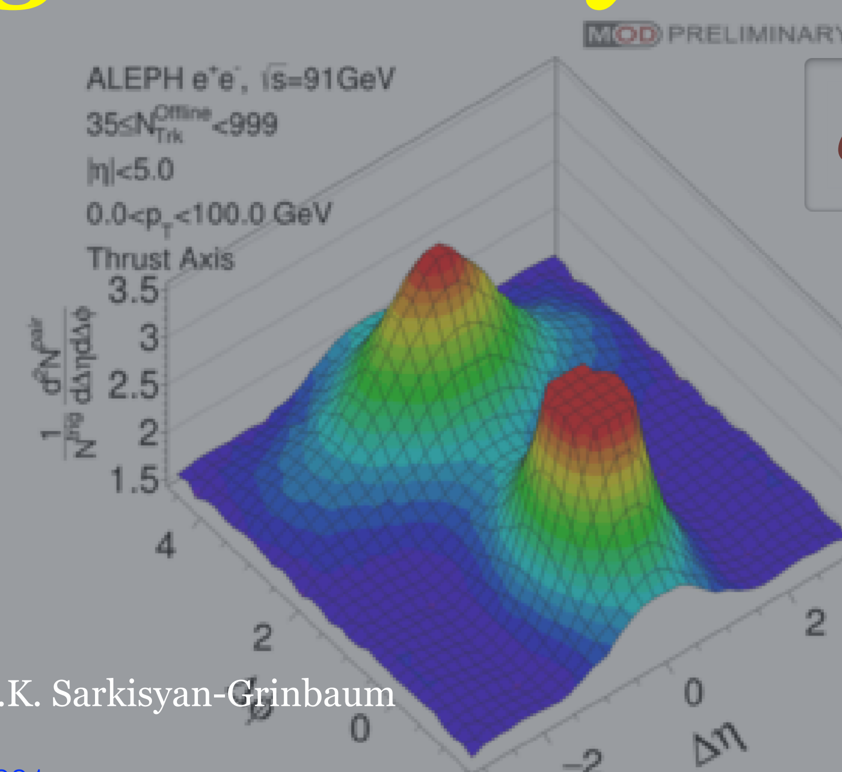
Tool for investigating New Physics?

Pb-Pb



Physics Letters B B724(4)

e^+e^-



Phys. Rev. Lett. 123, 212002 (2019)

R. Pérez-Ramos, M.A.Sanchis-Lozano, E.K. Sarkisyan-Grinbaum

Phys. Rev. D **105**, 053001

HIDDEN VALLEY PHENOMENOLOGY

The term *Hidden Valley* refers to a wide class of models

G_{SM}

$SU(3)_C \times SU(2)_L \times U(1)_Y$

SM particles

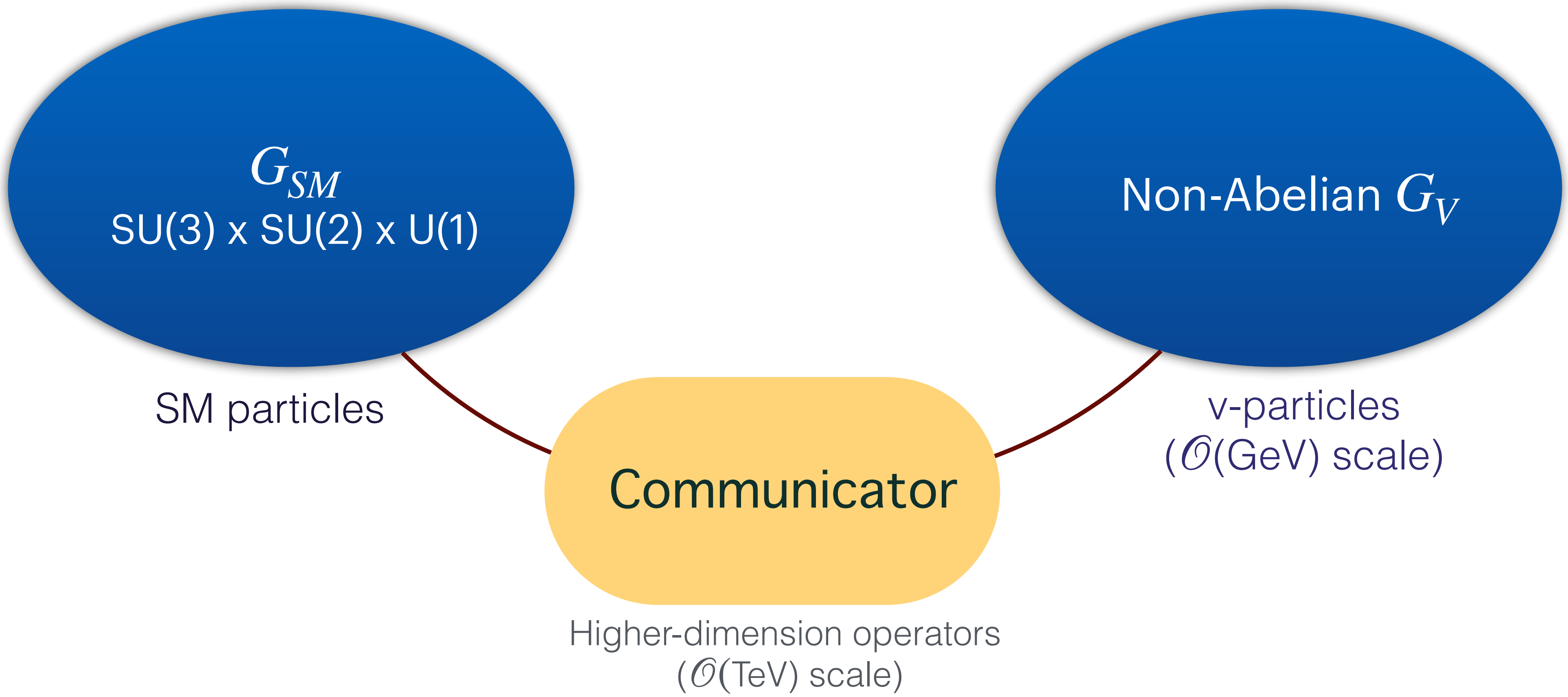
Non-Abelian G_V

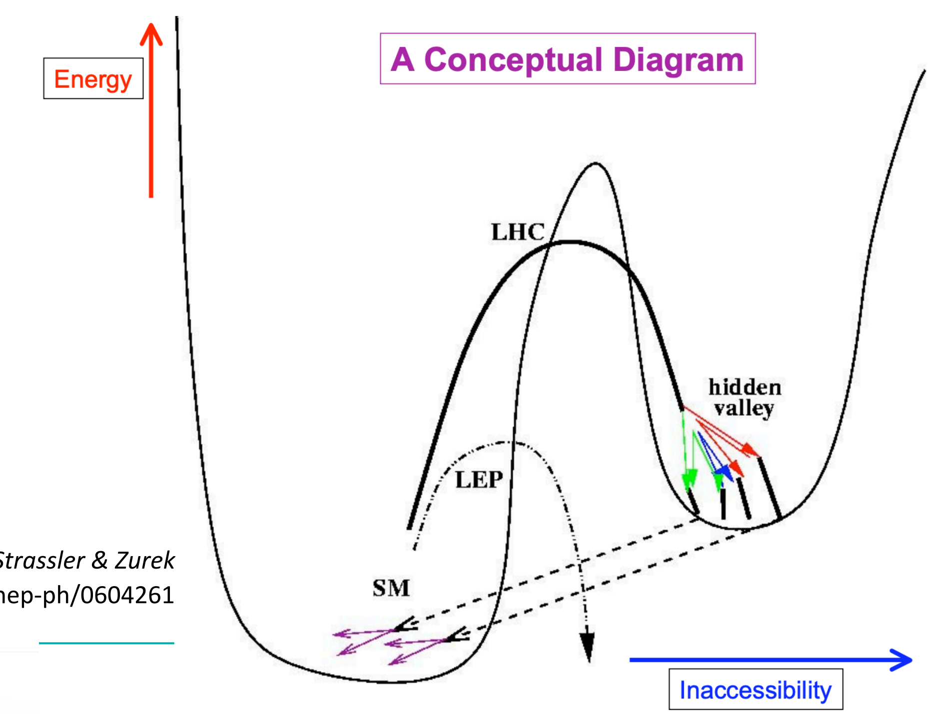
v-particles

($\mathcal{O}$(GeV) scale)

HIDDEN VALLEY PHENOMENOLOGY

The term *Hidden Valley* refers to a wide class of models





Strassler & Zurek
hep-ph/0604261

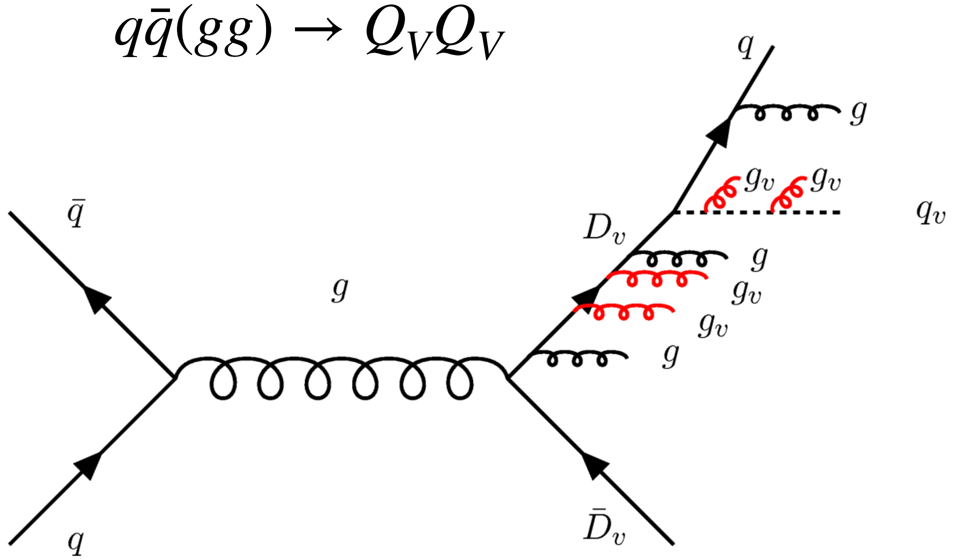
QCD-like scenario

Communicator: F_V

- mirror partner of the SM charged quarks and leptons
- Charged under G_{SM} and G_V
- Pair-produced
- (Prompt) decays: $F_V \to fq_V \longrightarrow$ hadrons
  - $E_V \to eq_V$
  - $Q_V \to qq_V$

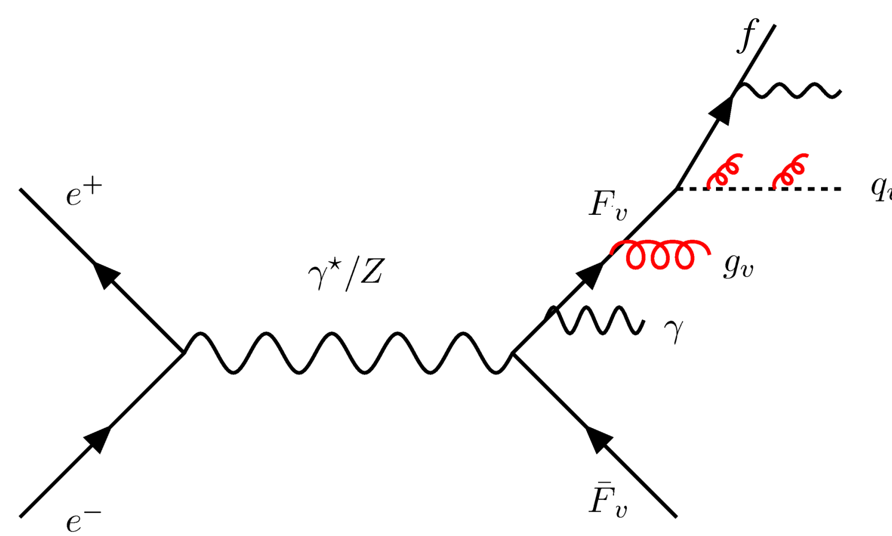
pp collisions

$q\bar{q}(gg) \to Q_V\bar{Q}_V$



e^+e^- collisions

$e^+e^- \to \gamma*/Z^0 \to F_V\bar{F}_V$



JHEP 1009:105,2010
L Carloni, T Sjöstrand

PRELIMINARY RESULTS: SIGNAL VS BACKGROUND

TOOLS:

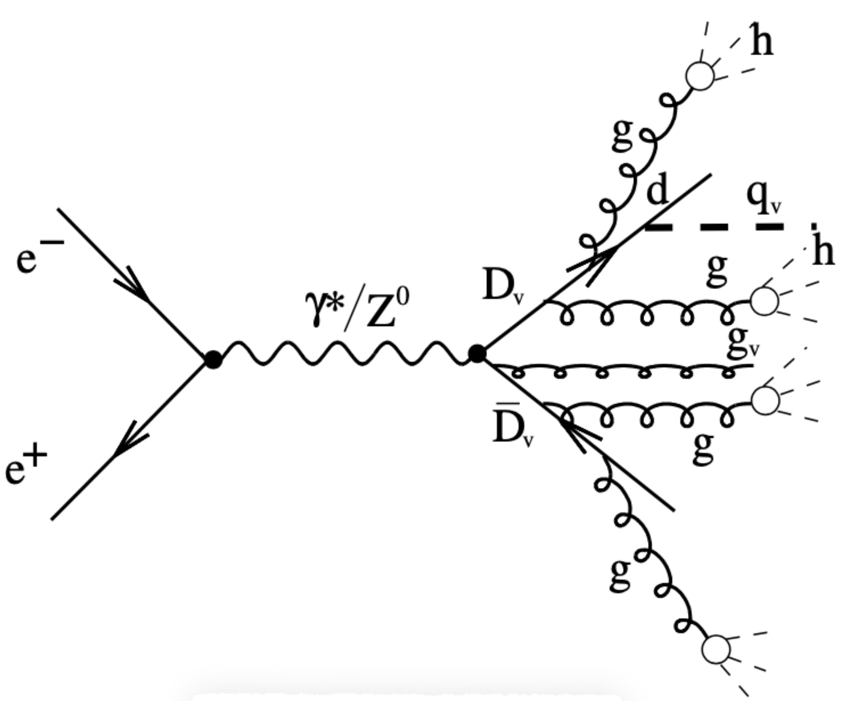
- Pythia8
- FastJet
- ROOT

$$\sqrt{s} = 250 \text{ GeV}$$

SIGNAL

$e^+e^- \to \gamma^*/Z^0 \to D_V\bar{D}_V \to$ hadrons

$\sigma_{HV} = 0.12$ pb



$m_{D_V} = 125$ GeV,

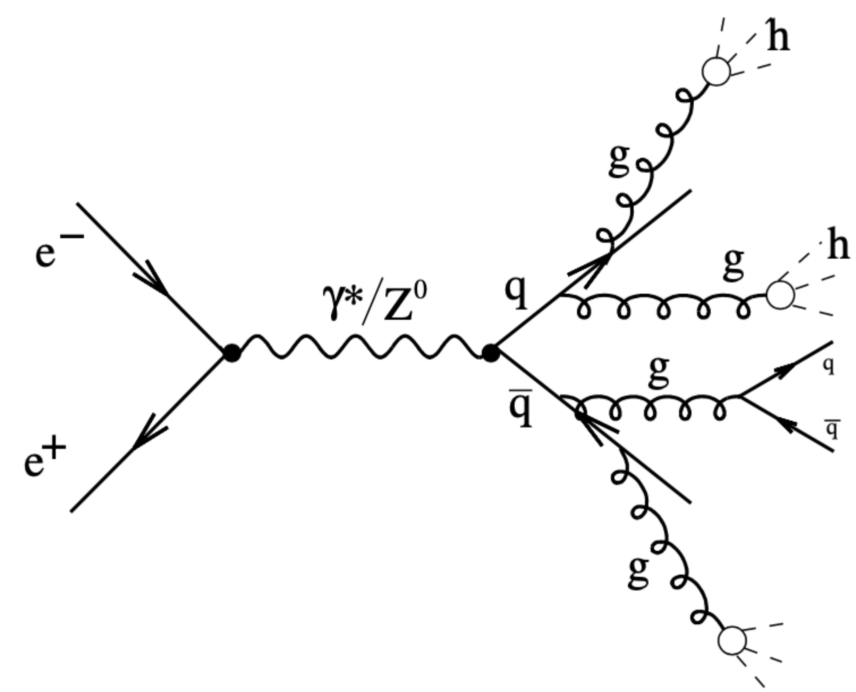
$m_{q_V} = 100$ GeV,

$\alpha_V = 0.1$

BACKGROUND

$e^+e^- \to \gamma^*/Z^0 \to q\bar{q} \to$ hadrons

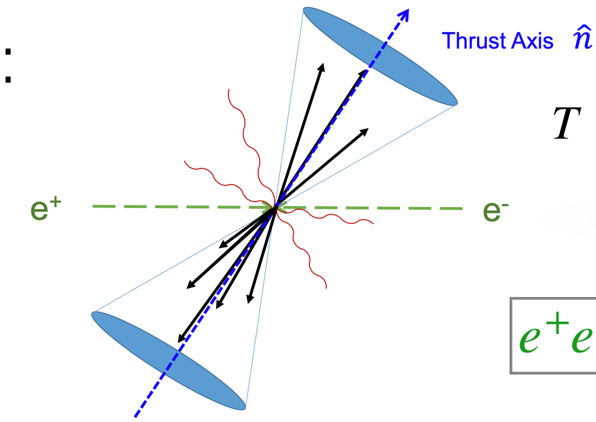
$\sigma_{bckg} = 12.2$ pb



PRELIMINARY RESULTS: SIGNAL VS BACKGROUND

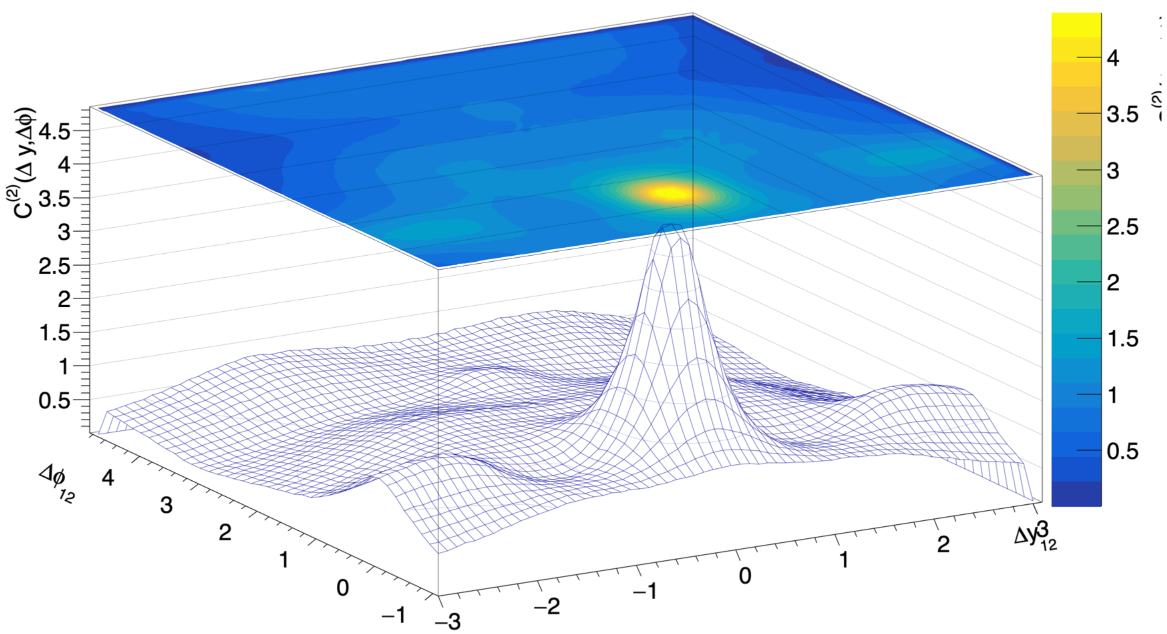
$\sqrt{s} = 250$ GeV

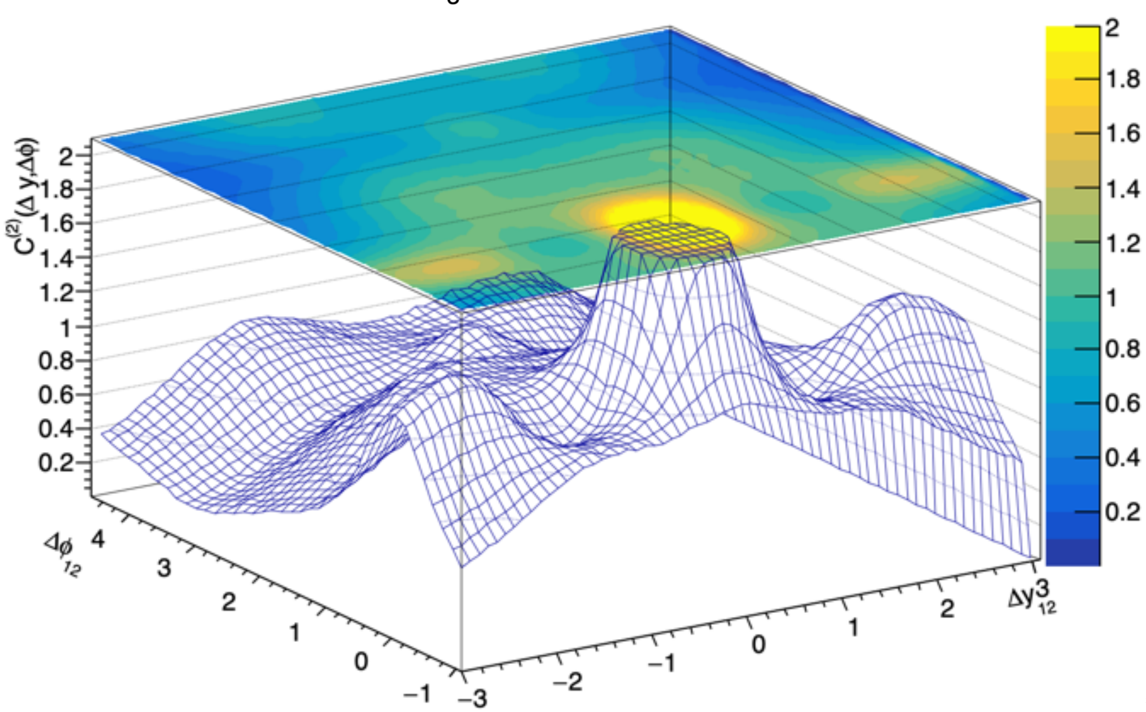
Thrust Axis:



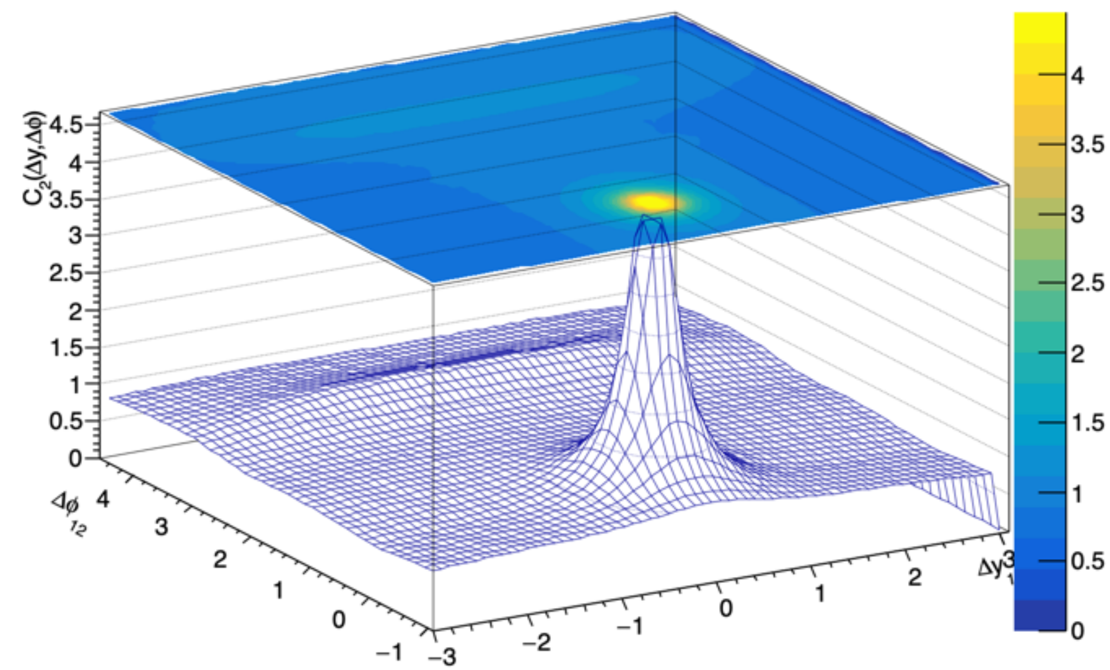
$$T = \max_{\vec{n}} \frac{\sum_i |\vec{p_i} \cdot \vec{n}|}{\sum_i |\vec{p_i}|}$$

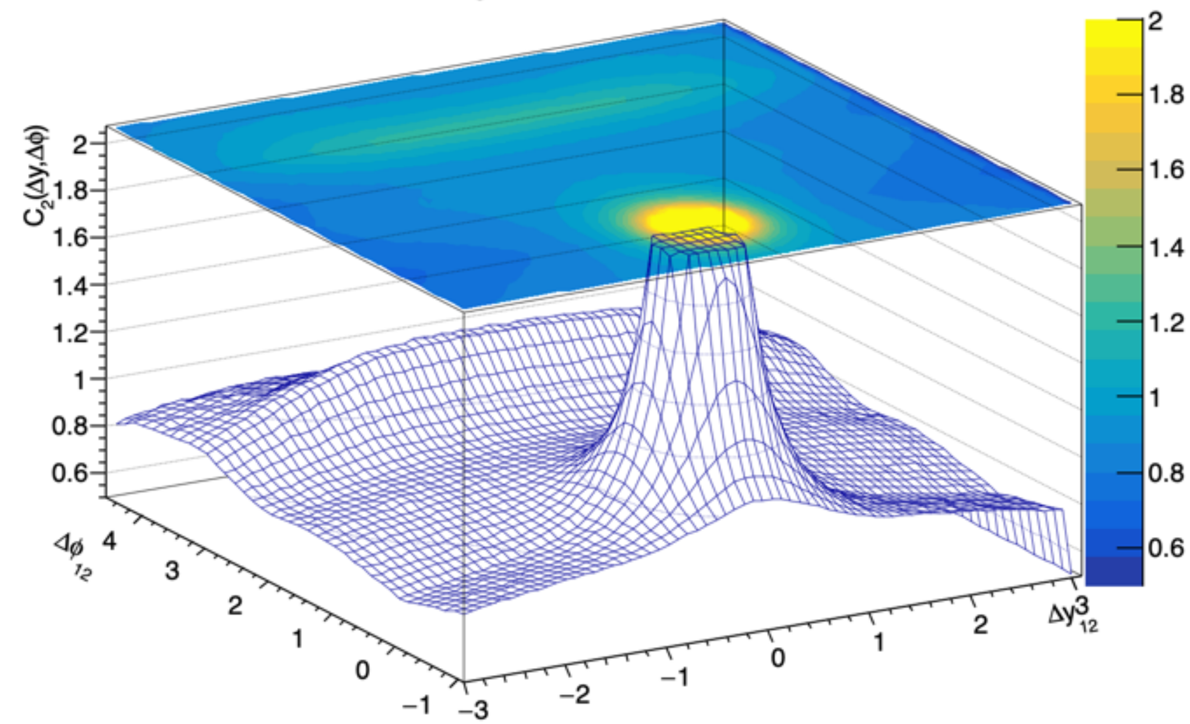
$e^+e^- \to \gamma^*/Z^0 \to D_V\bar{D}_V \to$ hadrons





$e^+e^- \to \gamma^*/Z^0 \to q\bar{q} \to$ hadrons

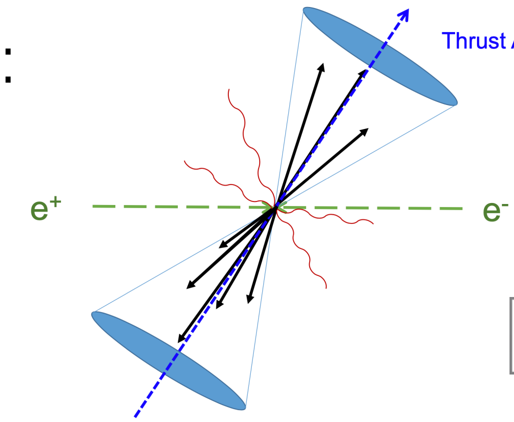




PRELIMINARY RESULTS: SIGNAL VS BACKGROUND

$\sqrt{s} = 250$ GeV

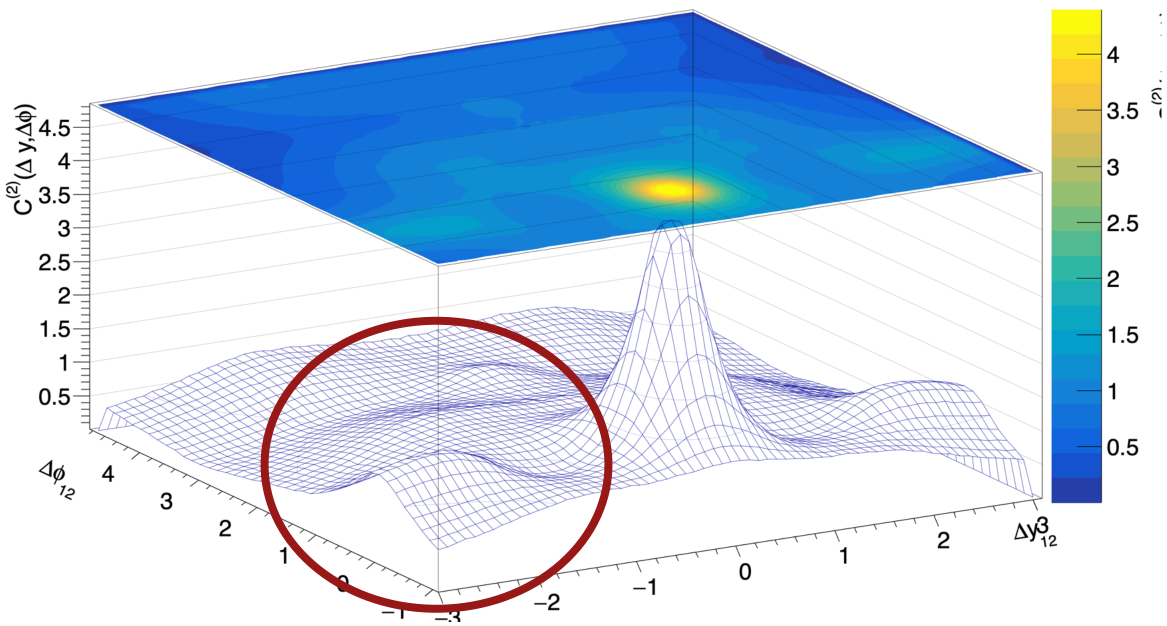
Thrust Axis:

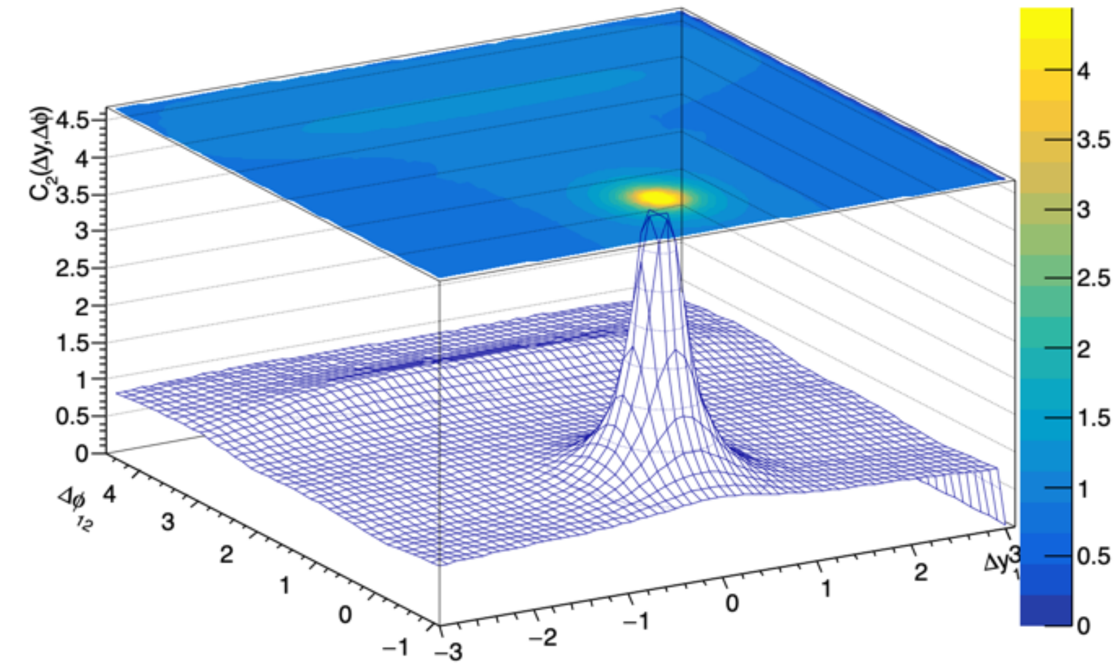


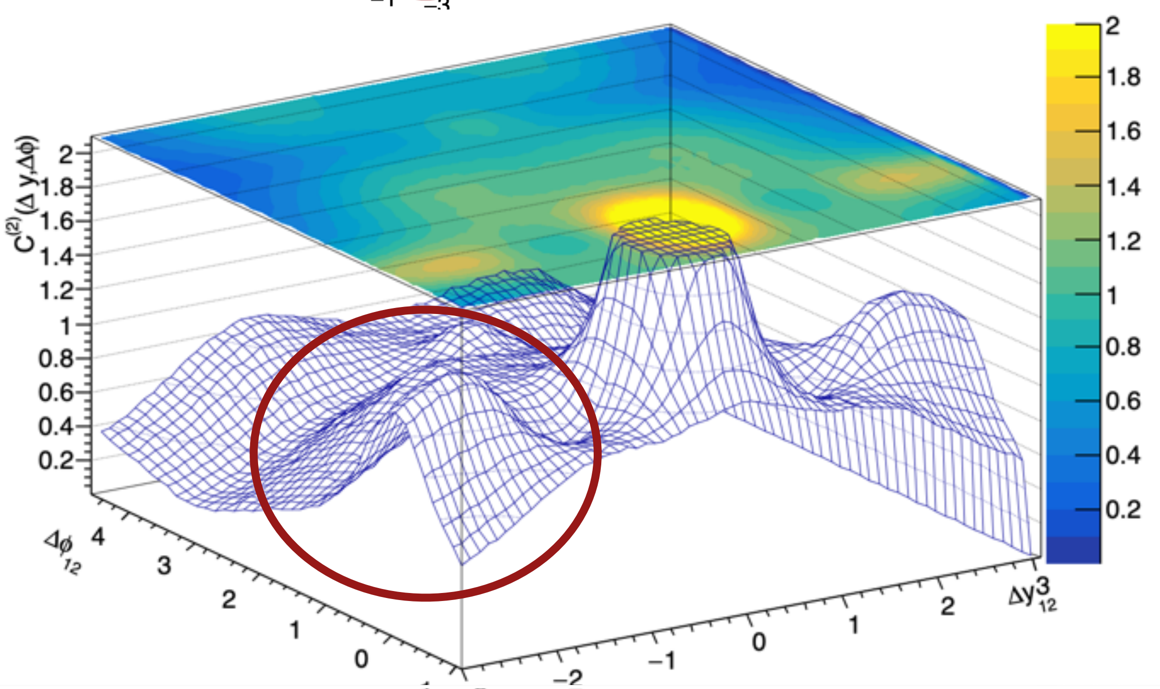
$$T = \max_{\vec{n}} \frac{\sum_i |\vec{p_i} \cdot \vec{n}|}{\sum_i |\vec{p_i}|}$$

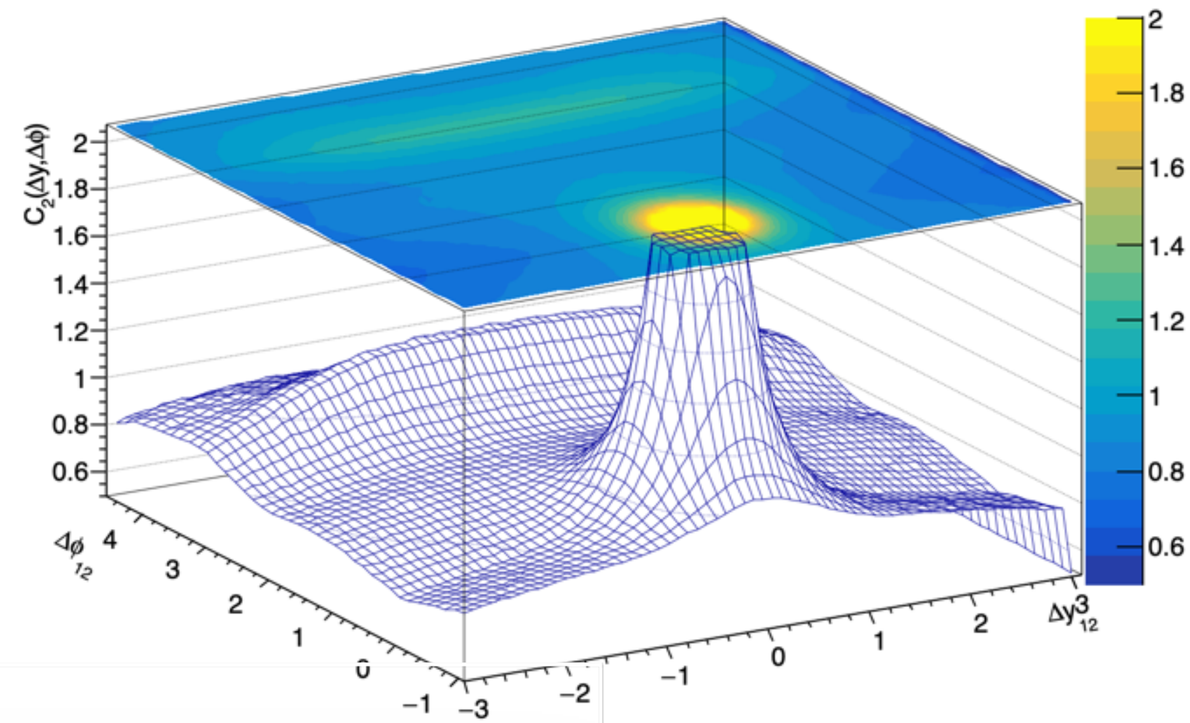
$e^+e^- \to \gamma^*/Z^0 \to D_V\bar{D}_V \to$ hadrons

$e^+e^- \to \gamma^*/Z^0 \to q\bar{q} \to$ hadrons









PRELIMINARY RESULTS: SIGNAL VS BACKGROUND

Cuts applied

$\sqrt{s} = 250$ GeV

$\mathscr{L} = 2$ ab^{-1}

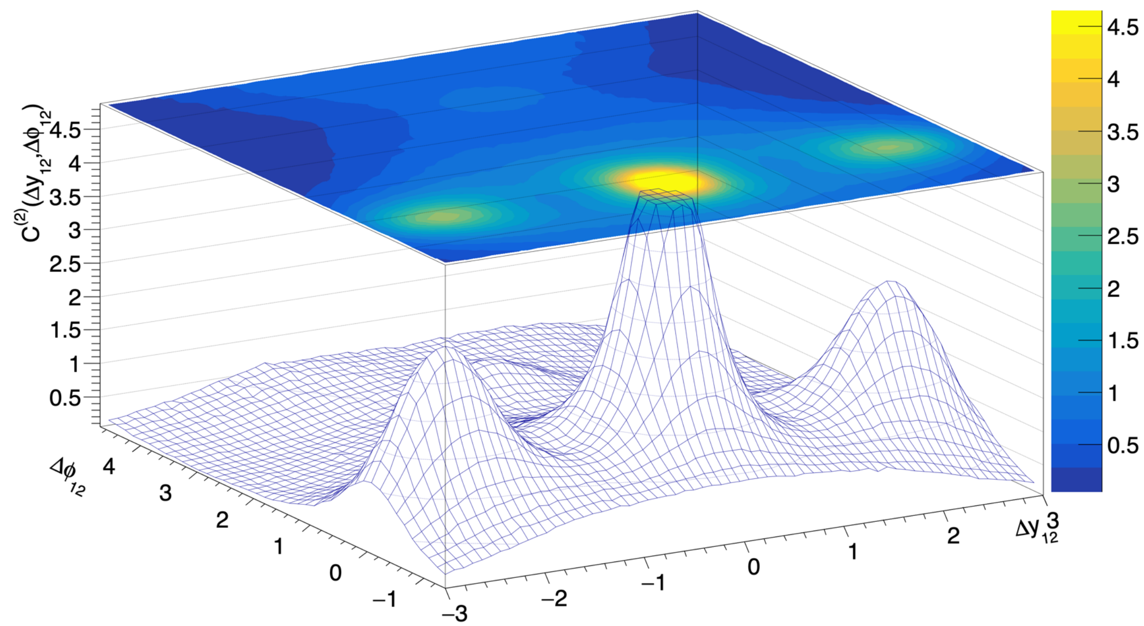
- $|\cos\theta| < 0.95$
- $p_T > 0.3$ GeV
- $200 < m_{jj} < 230$ GeV
- $T < 0.85$

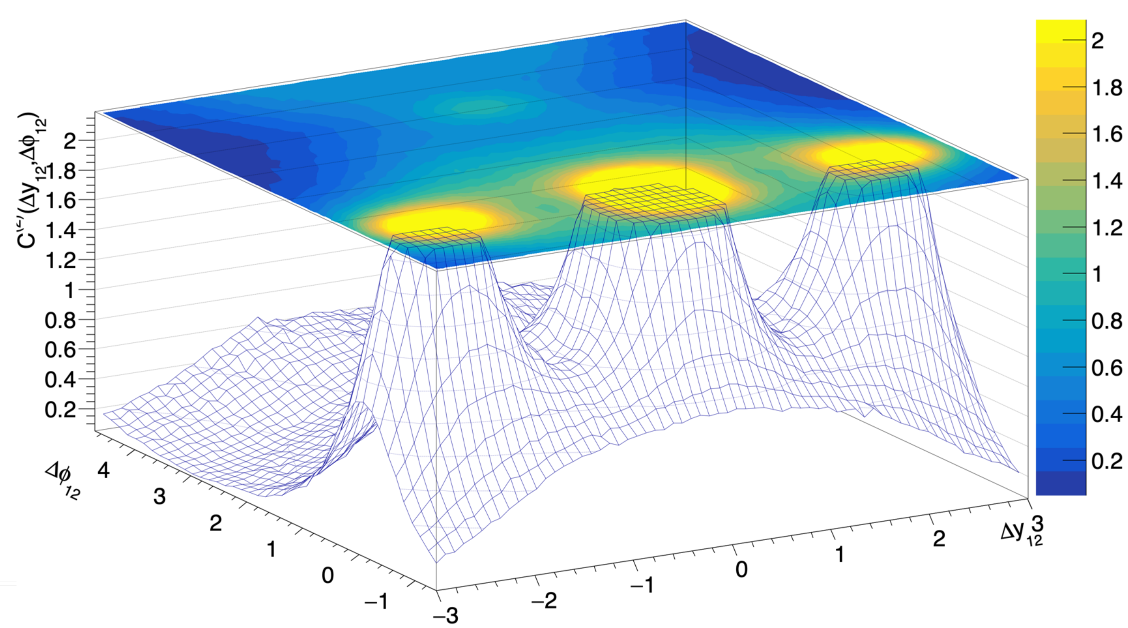
$e^+e^- \to \gamma^*/Z^0 \to q\bar{q} \to$ hadrons

Eff.$\simeq$1.70 %

$e^+e^- \to \gamma^*/Z^0 \to D_V\bar{D}_V \to$ hadrons

Eff.$\simeq$50.8 %



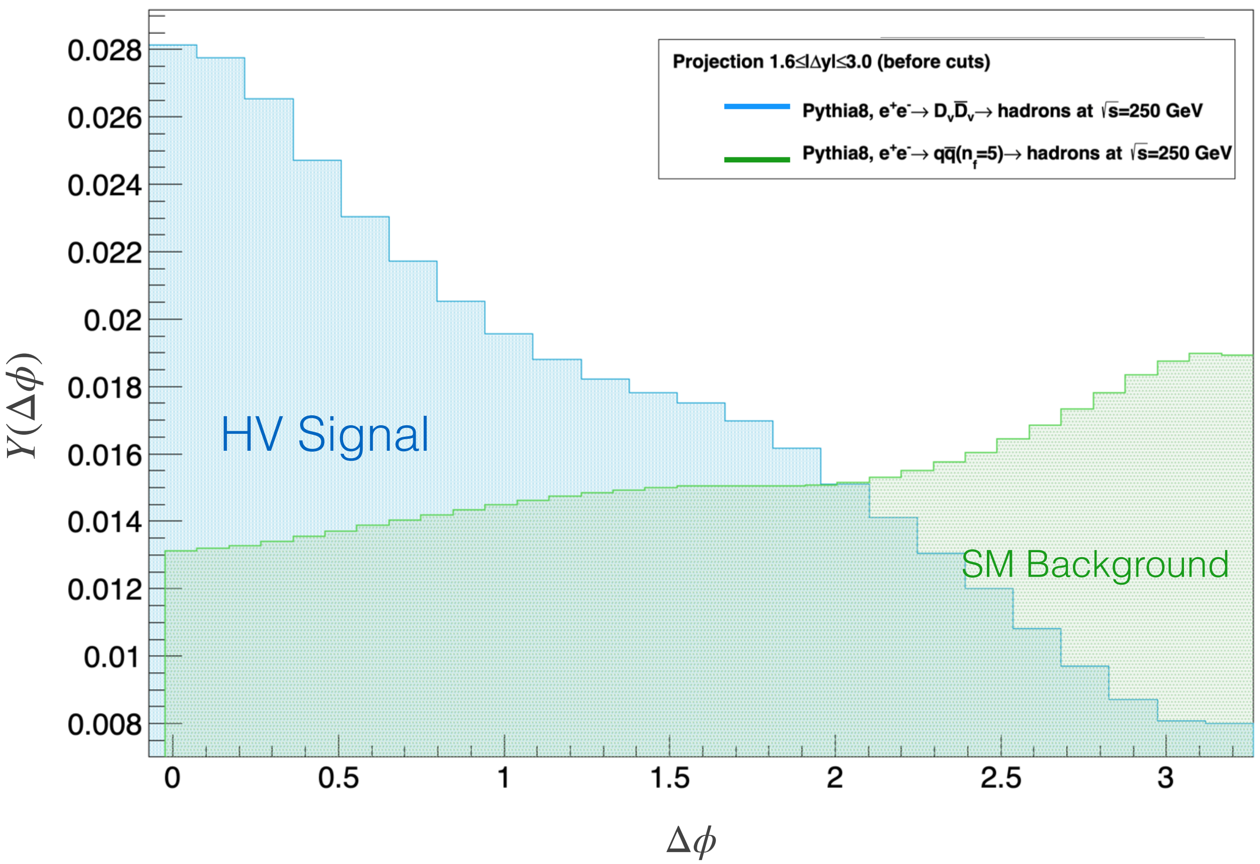


PRELIMINARY RESULTS: SIGNAL VS BACKGROUND

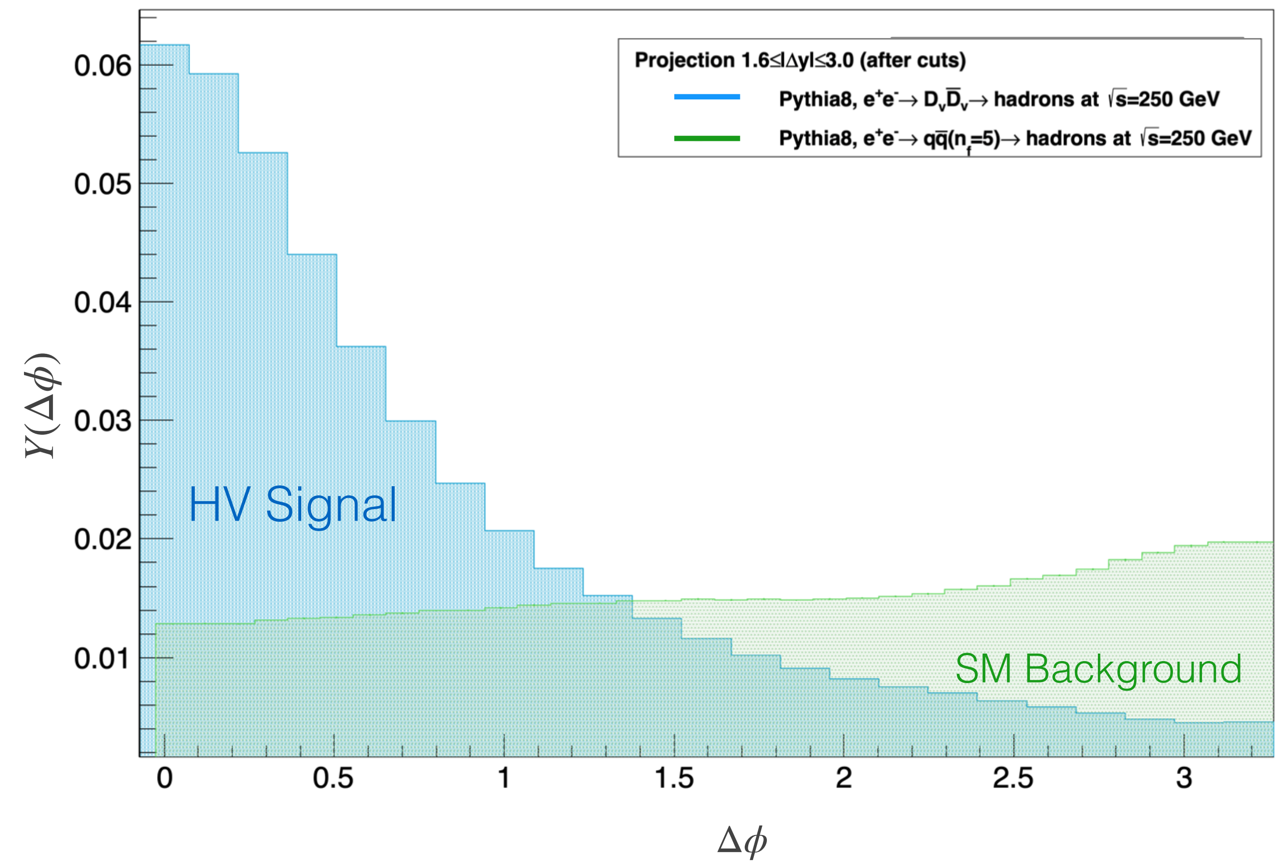
Yield

$$Y(\Delta\phi) = \frac{\int_{1.6\leq|\Delta y|\leq 3.0} S(\Delta\phi, \Delta y) d\Delta y}{\int_{1.6\leq|\Delta y|\leq 3.0} B(\Delta\phi, \Delta y) d\Delta y}$$

Before cuts



After cuts



SUMMARY

❖ The analysis of the long-range angular particle correlations can provide valuable insights into the initial state of matter

❖ We investigate the *observability of hidden sectors* at future e^+e^- colliders with two angular particle correlations

❖ Our preliminary results indicate that the study of angular correlations in multiparticle production *might be useful to uncover* the existence of New Physics

❖ Next steps:

- Including detector effects (*in progress*)
- Exploring higher energy configurations ($\sqrt{s} = 0.5 \rightarrow 1$ TeV)

Thanks for your attention!

BACKUP SLIDES

PRELIMINARY RESULTS: SIGNAL VS BACKGROUND

Cuts applied

- $\sigma_{HV} = 0.12$ pb
- $\sigma_{bckg} = 12.2$ pb

- $|\cos\theta| < 0.95$
- $p_T > 0.3$ GeV
- $200 < m_{jj} < 230$ GeV
- $T < 0.85$

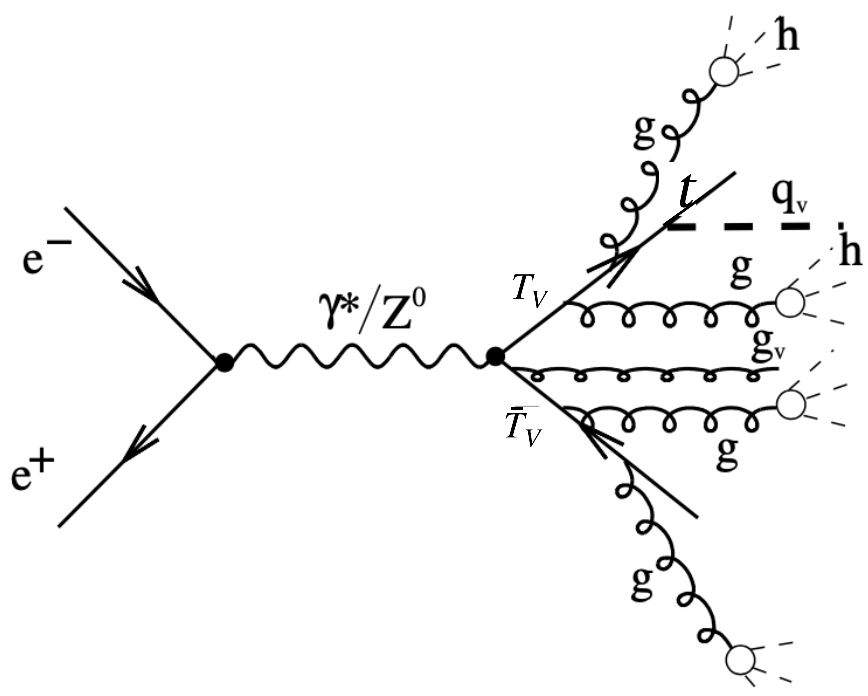
	HV Signal (Eff. %)	Background (Eff. %)	S/B	$S/\sqrt{B+S}$
$\sqrt{s} = 250,\ \mathcal{L} = 2\ ab^{-1}$ GeV				
$200 \leq m_{jj} \leq 230$	83.74	18.11	0.04560	97.46
$200 \leq m_{jj} \leq 240$	87.21	40.43	0.02314	68.79
$200 \leq m_{jj} \leq 250$	100	79.47	0.01351	56.54

	HV Signal (Eff. %)	Background (Eff. %)	S/B	$S/\sqrt{B+S}$
$\sqrt{s} = 250\ GeV,\ \mathcal{L} = 2\ ab^{-1}$				
T<0.95	94.97	42.11	0.10285	133.37
T<0.90	79.22	18.14	0.19918	162.68
T<0.85	60.64	9.34	0.2960	166.81
T<0.80	41.80	4.74	0.4022	155.18
T<0.75	23.51	2.04	0.5256	127.55
T<0.70	7.9	0.73	0.4935	72.41
T<0.65	0.48	0.13	0.1684	11.78

$\sqrt{s} = 0.5 \rightarrow 1$ TeV

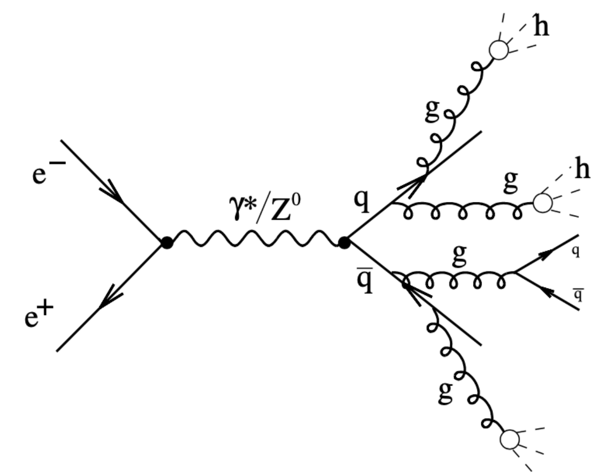
SIGNAL

- $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow T_V\bar{T}_V \rightarrow$ hadrons



BACKGROUND

- $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow q\bar{q} \rightarrow$ hadrons



- $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow t\bar{t} \rightarrow$ hadrons