IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC Consejo Superior de Investigaciones Científicas
Universitat de València
Ministerio de Ciencia e Innovación
Agencia Estatal de Investigación
Generalitat Valenciana
Plan de Recuperación, Transformación y Resiliencia
GVA NEXT Fondos Next Generation en la Comunitat Valenciana
Financiado por la Unión Europea NextGenerationEU

Investigating hidden sectors at future e+e- colliders through two-particle angular correlations

Emanuela Musumeci (IFIC, Valencia)

in collaboration with

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V. A. Mitsou, E. Sarkisyan-Grinbaum, M.A. Sanchis-Lozano

based on 2312.06526
(Submitted to PRD)

LCWS2024 International Workshop on Future Linear Colliders

09/07/2024

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:

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

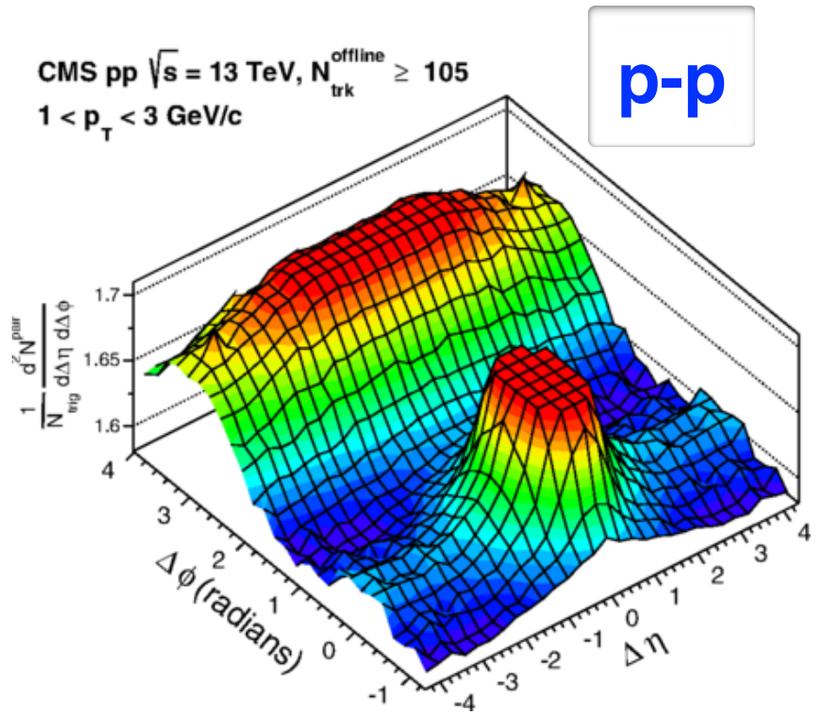
$$N_{pairs} = \int\int \frac{d^2N^{same}}{d\Delta y d\Delta\phi} d\Delta y d\Delta\phi$$

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

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

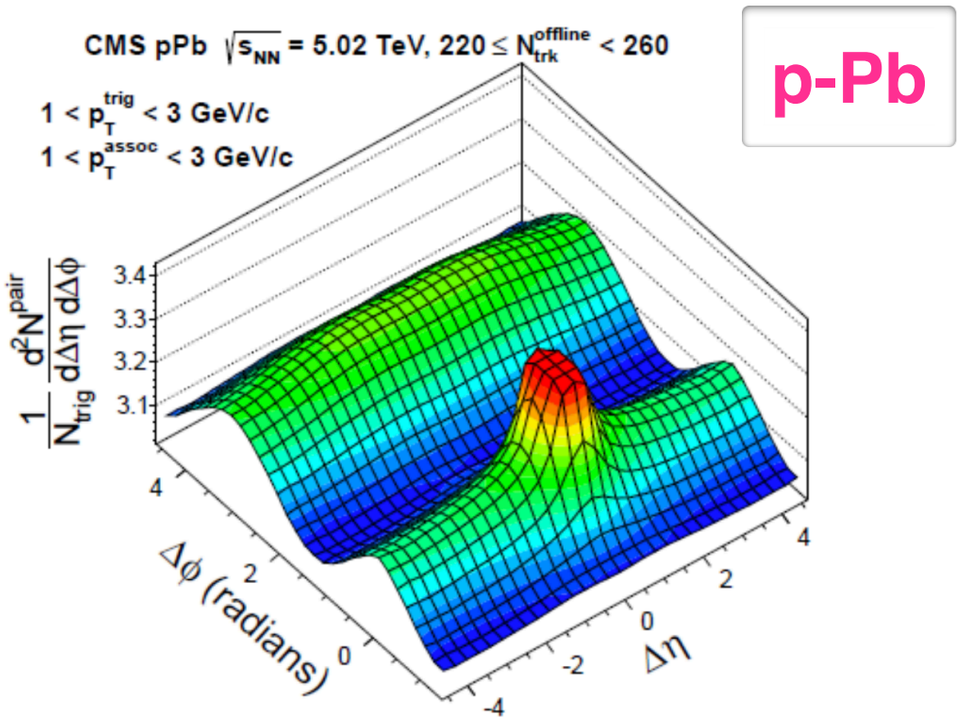
$$N_{mix} = \int\int \frac{d^2N^{mix}}{d\Delta y d\Delta\phi} d\Delta y d\Delta\phi$$

TWO-PARTICLE ANGULAR CORRELATIONS



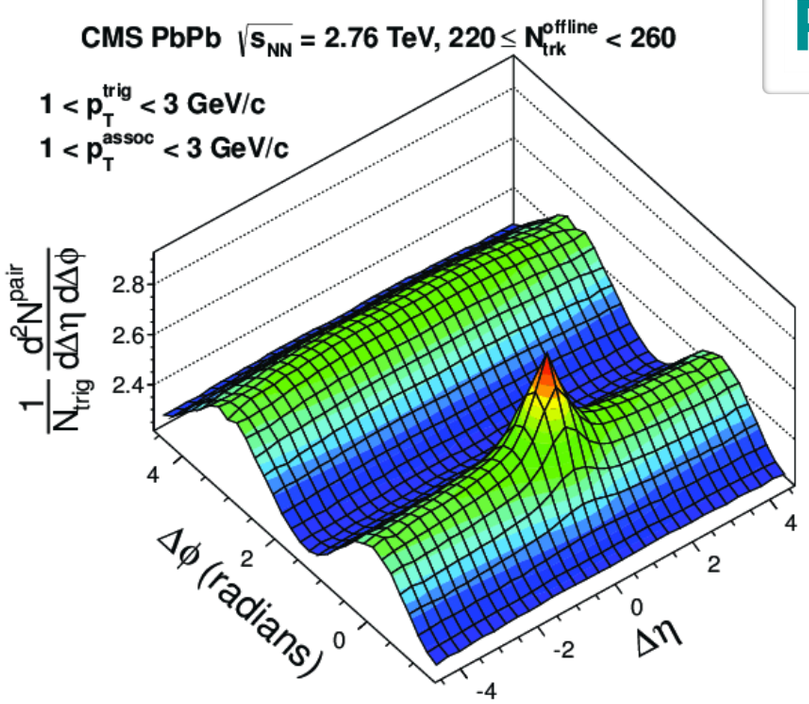
p-p

Phys. Rev. Lett. **116**, 172302



p-Pb

Physics Letters B B724(4)



Pb-Pb

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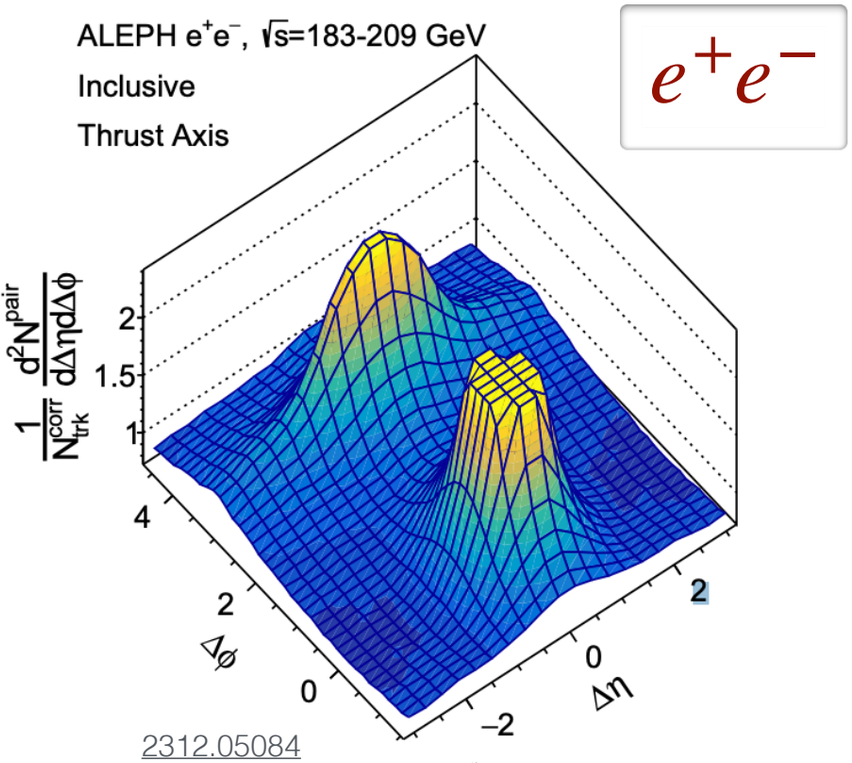
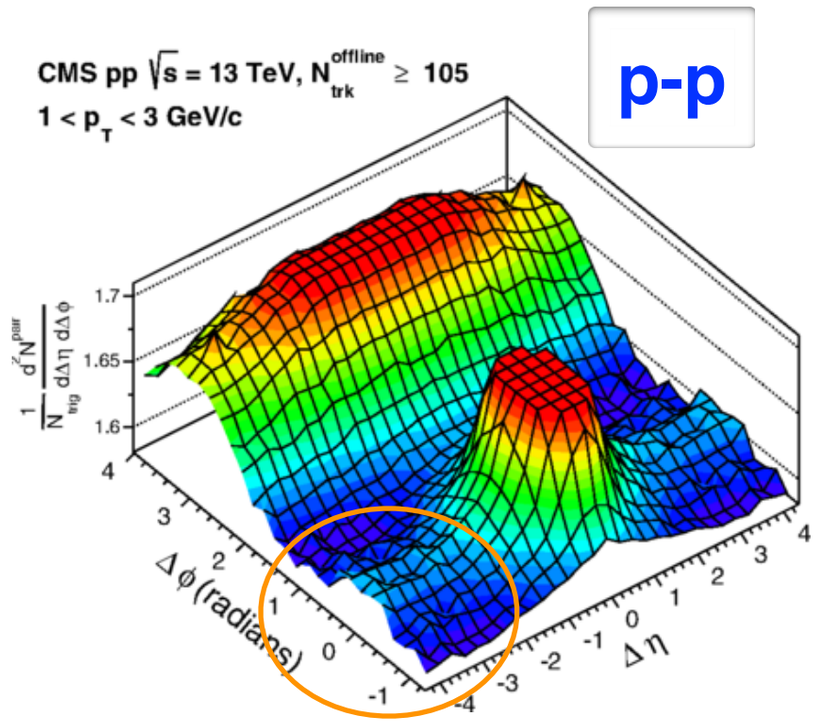


e^+e^-

2312.05084

TWO-PARTICLE ANGULAR CORRELATIONS



p-p

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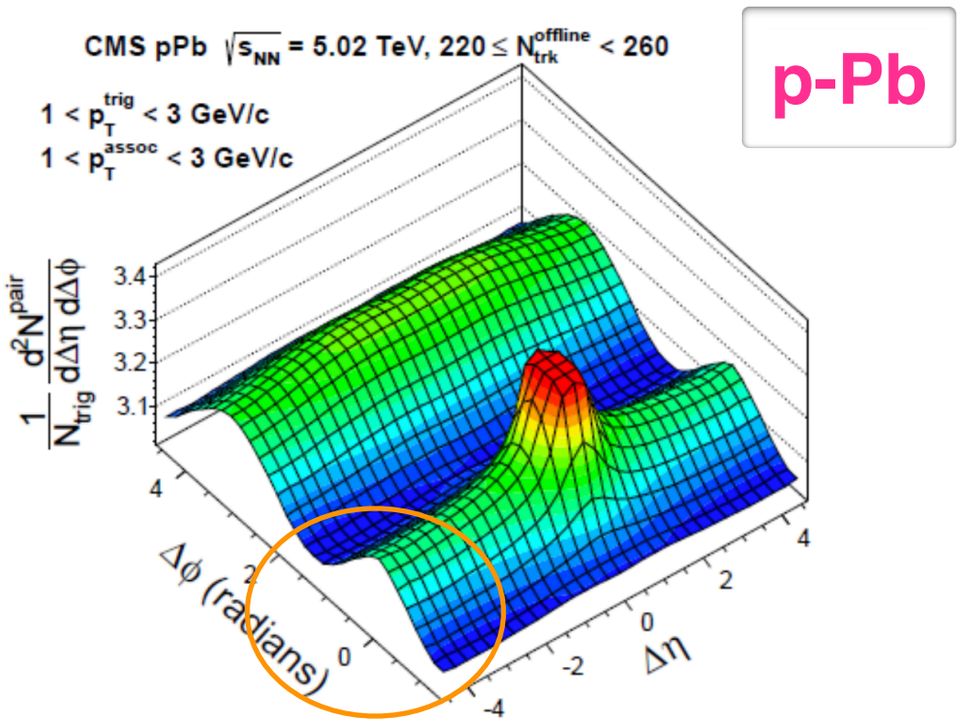

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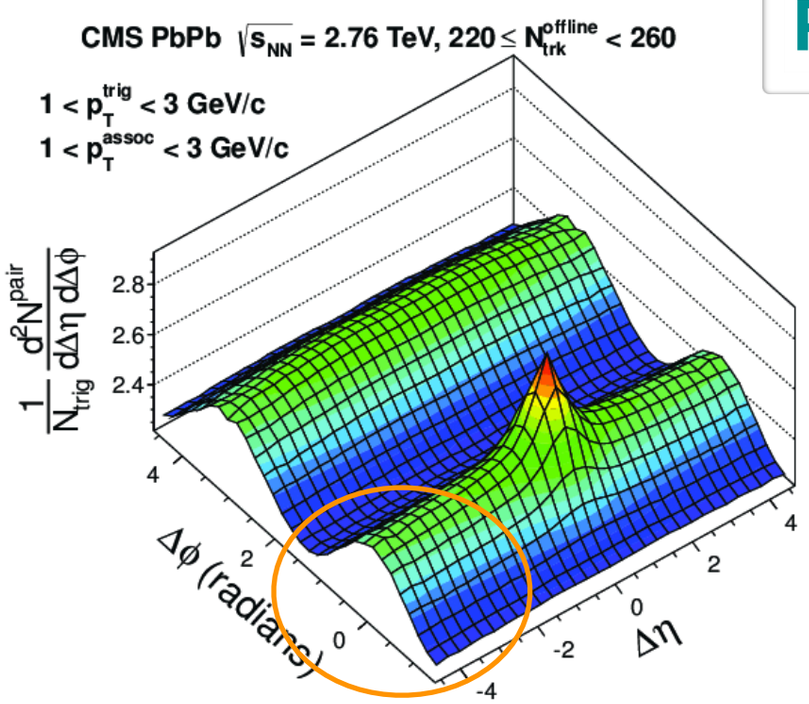
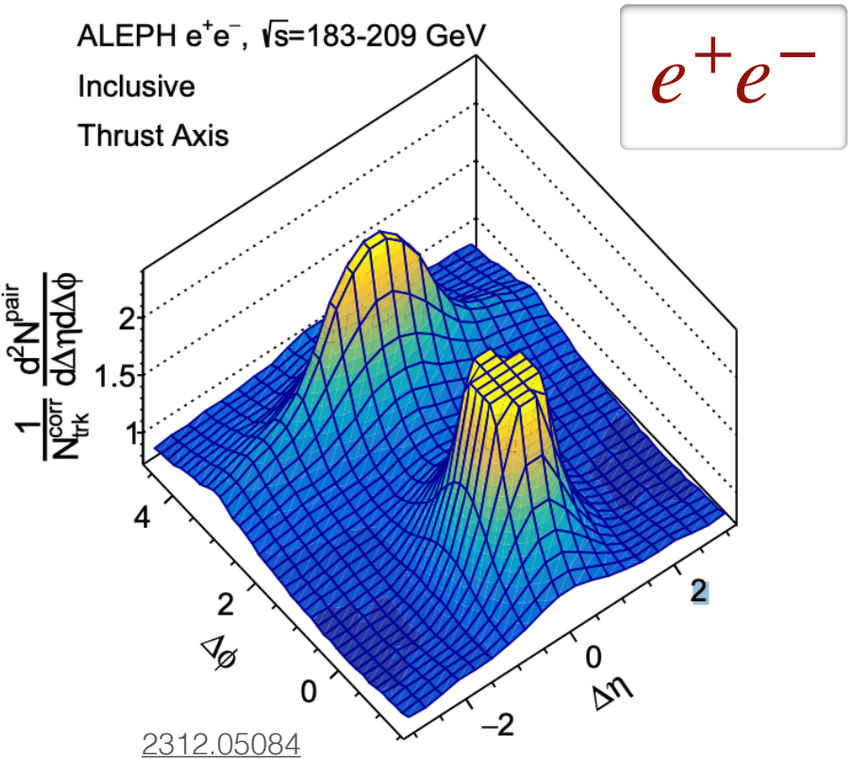
Physics Letters B B724(4)



Pb-Pb

Physics Letters B B724(4)



e^+e^-

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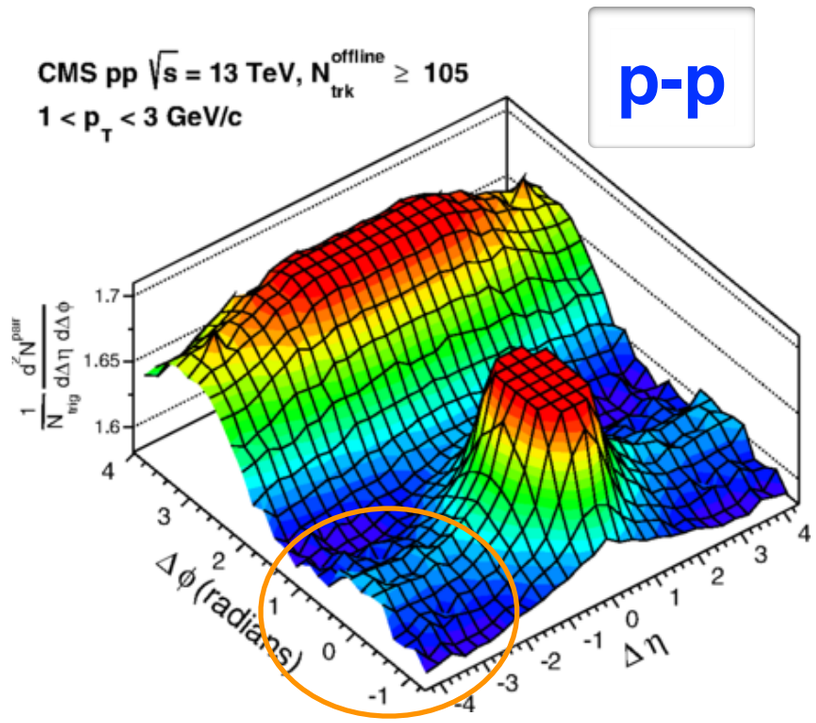

p-p

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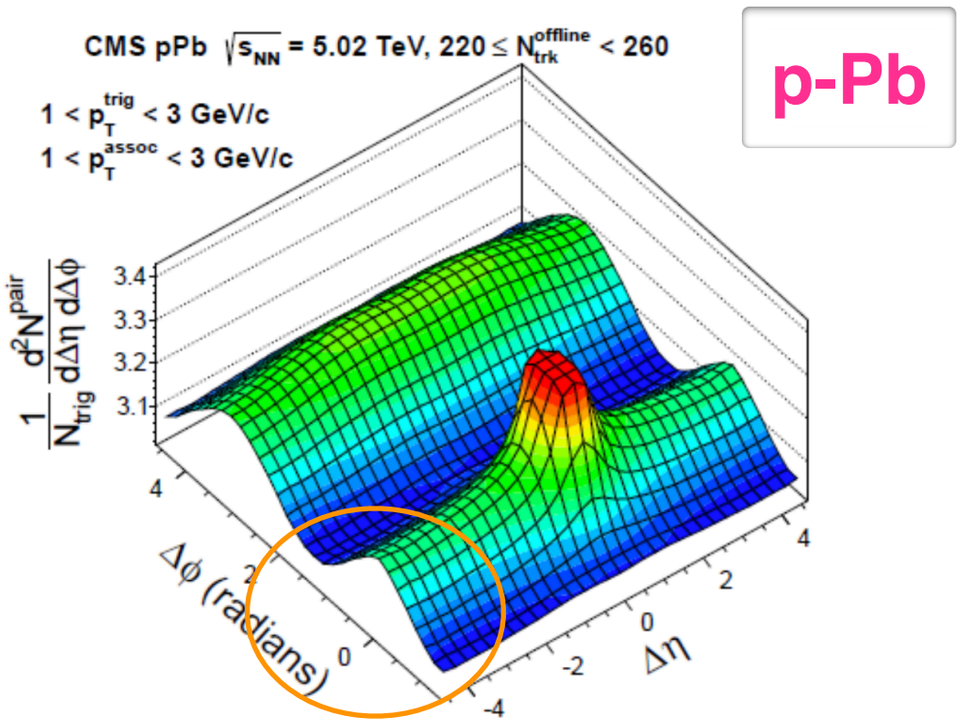

p-Pb

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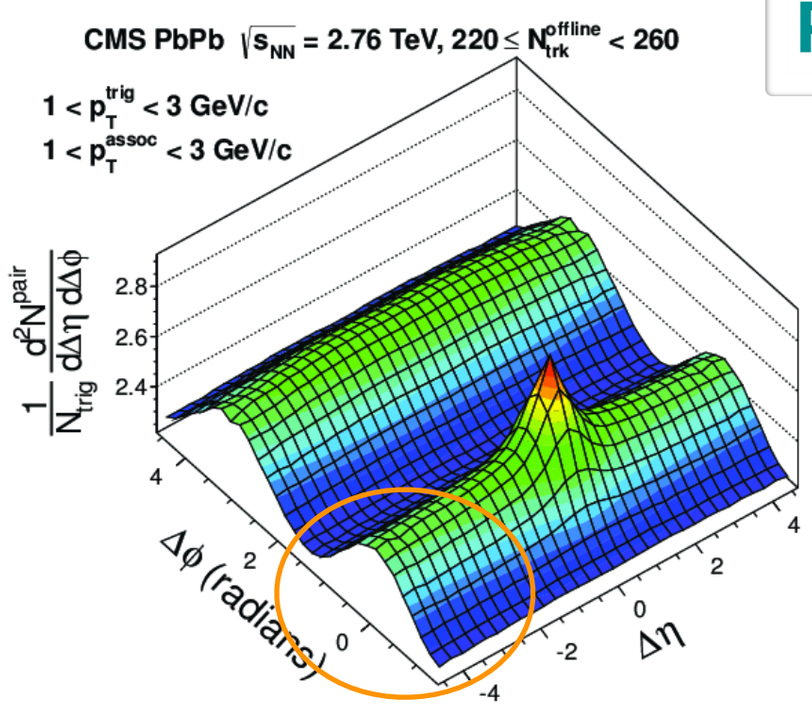
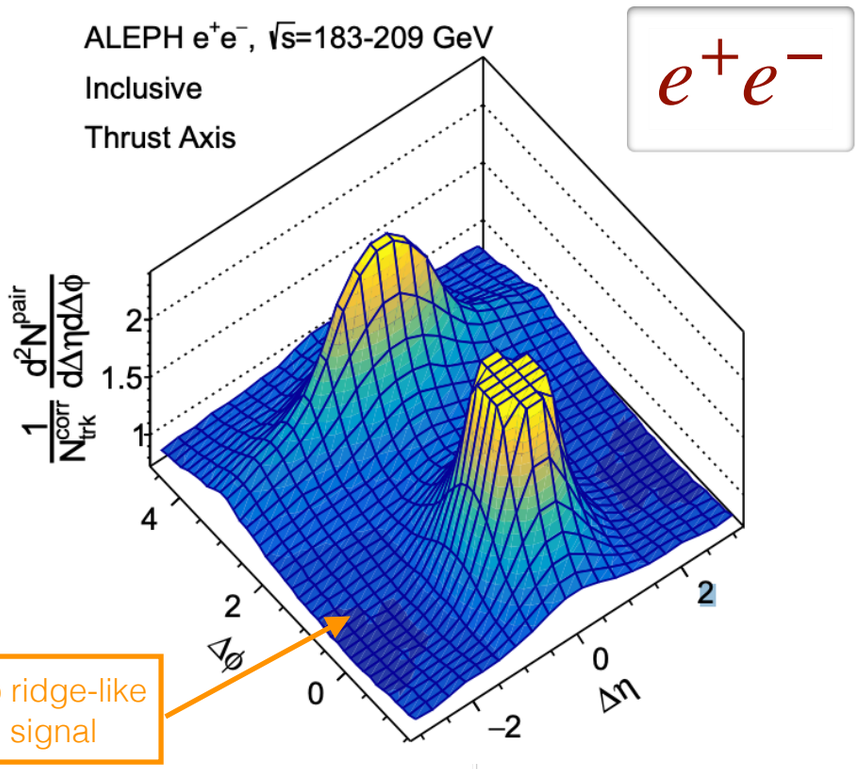


Pb-Pb

Physics Letters B B724(4)

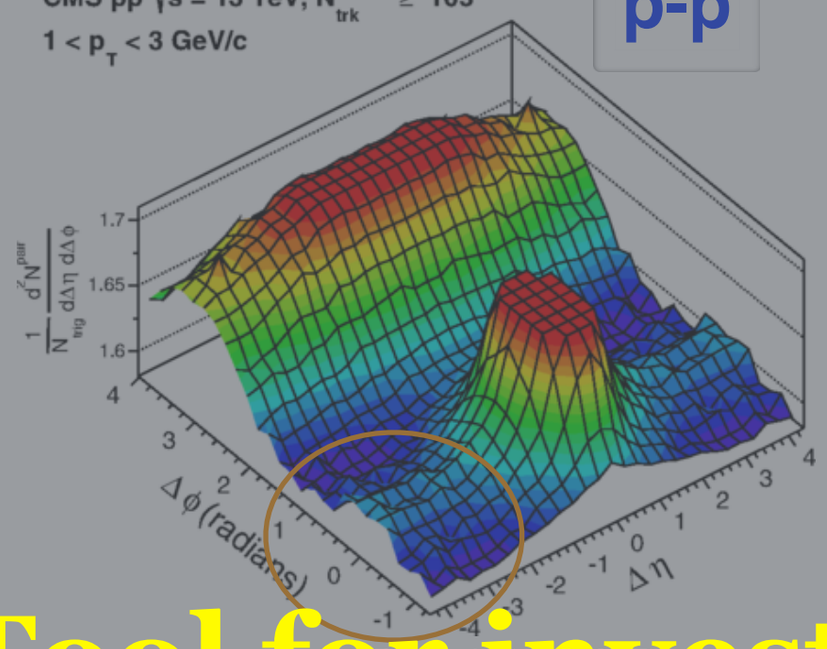


e^+e^-

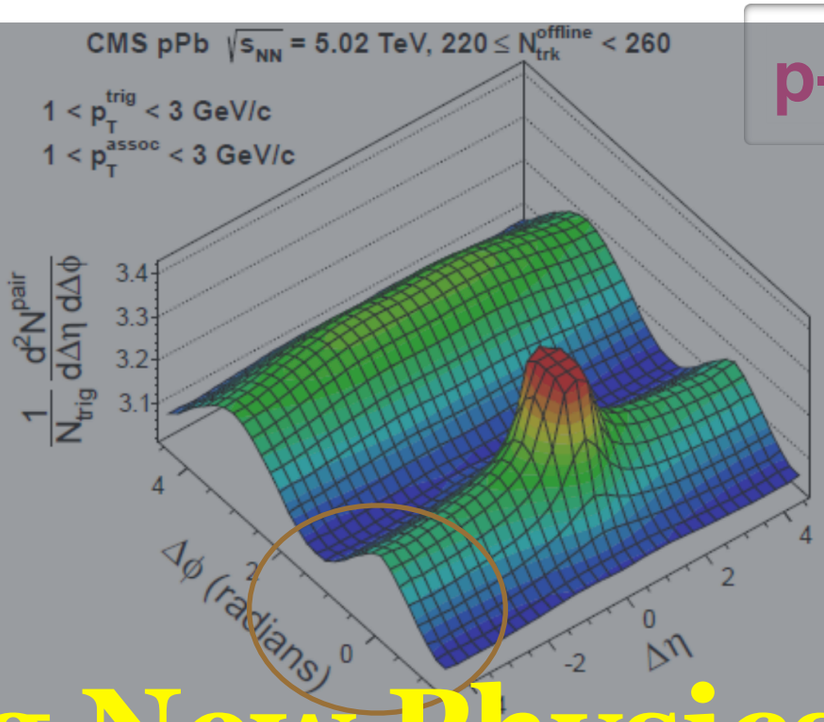
2312.05084

TWO-PARTICLE ANGULAR CORRELATIONS

p-p

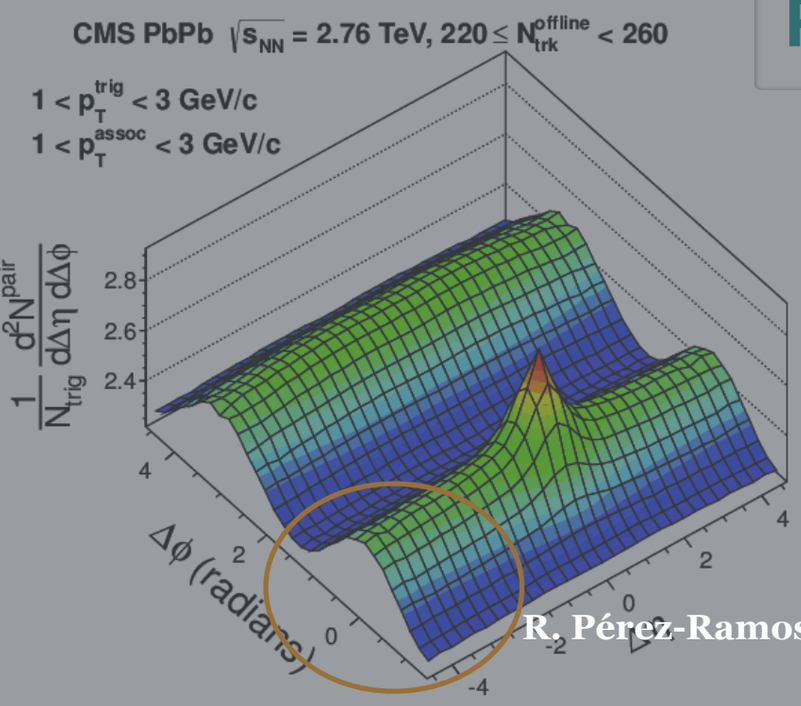


p-Pb



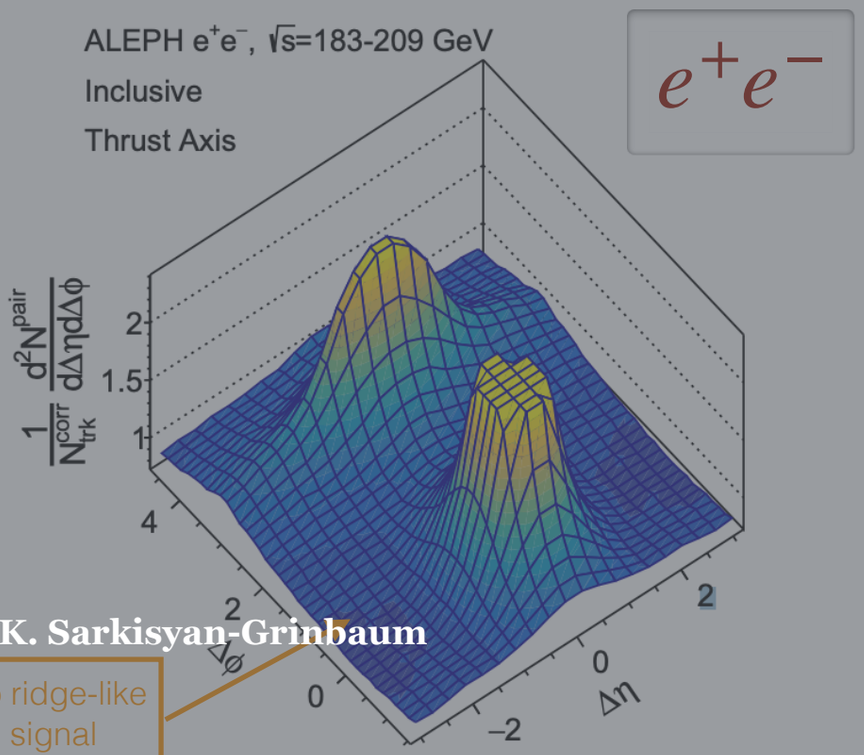
Tool for investigating New Physics?

Pb-Pb



Physics Letters B B724(4)

e^+e^-



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

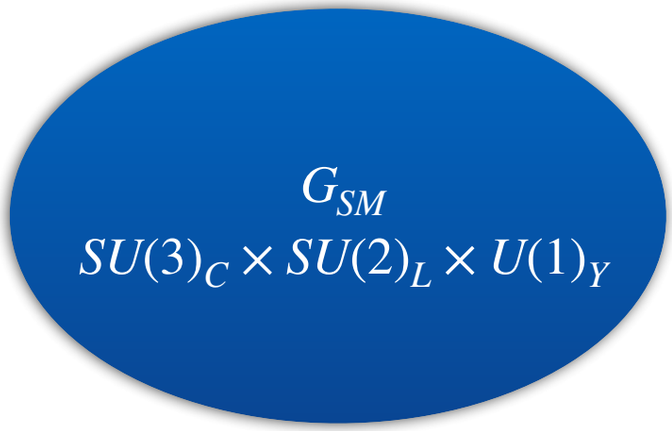
Phys. Rev. D 105, 053001

No ridge-like signal

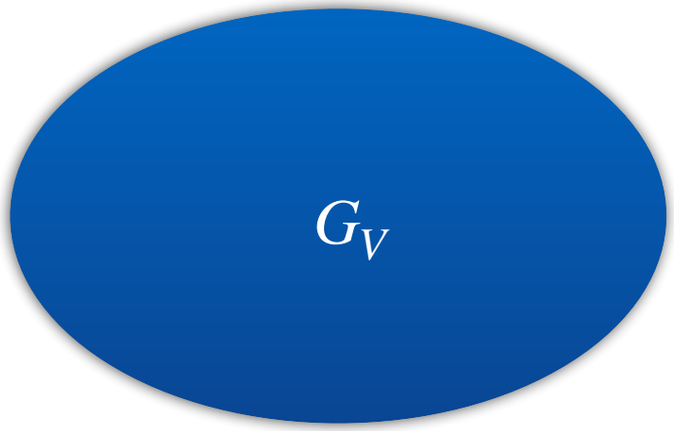
2312.05084

HIDDEN VALLEY PHENOMENOLOGY

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



SM particles



v-particles
($\mathcal{O}$(GeV) scale)

HIDDEN VALLEY PHENOMENOLOGY

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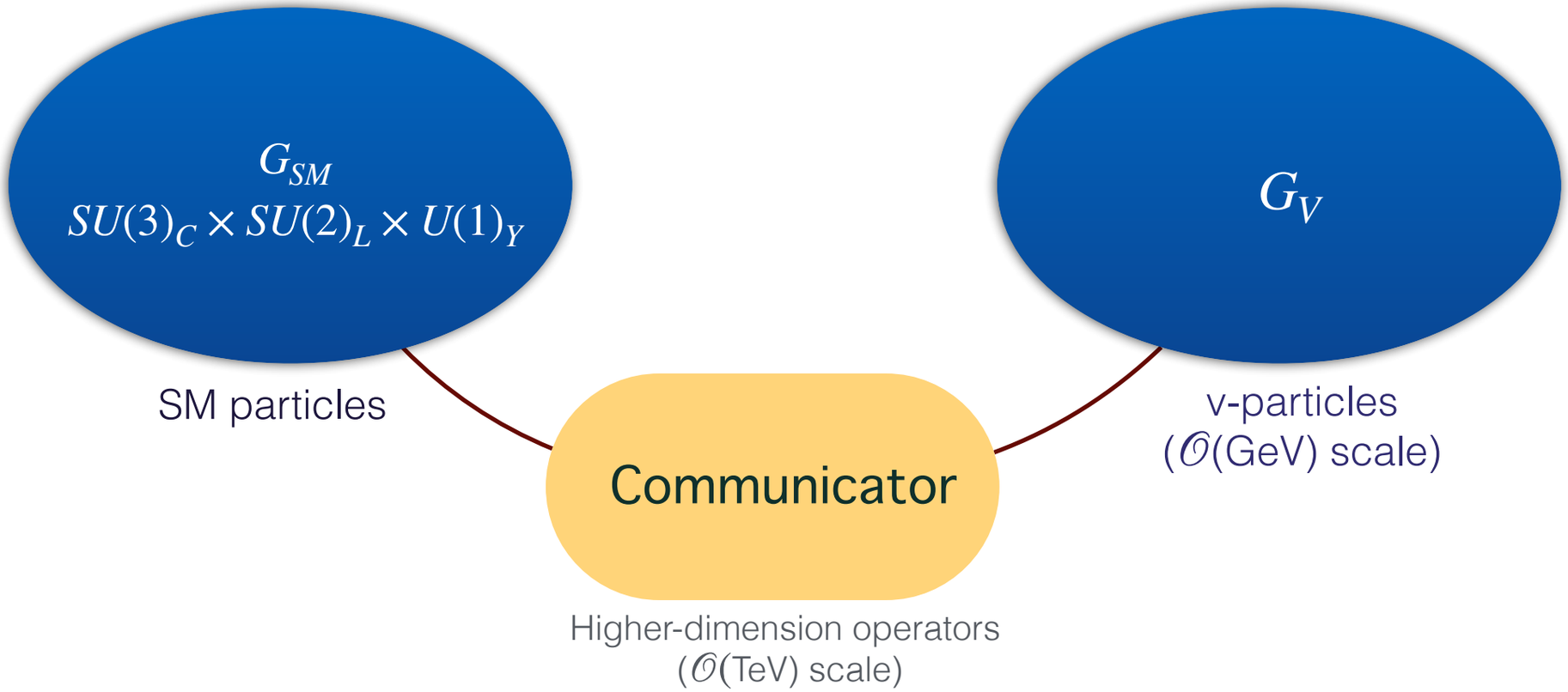
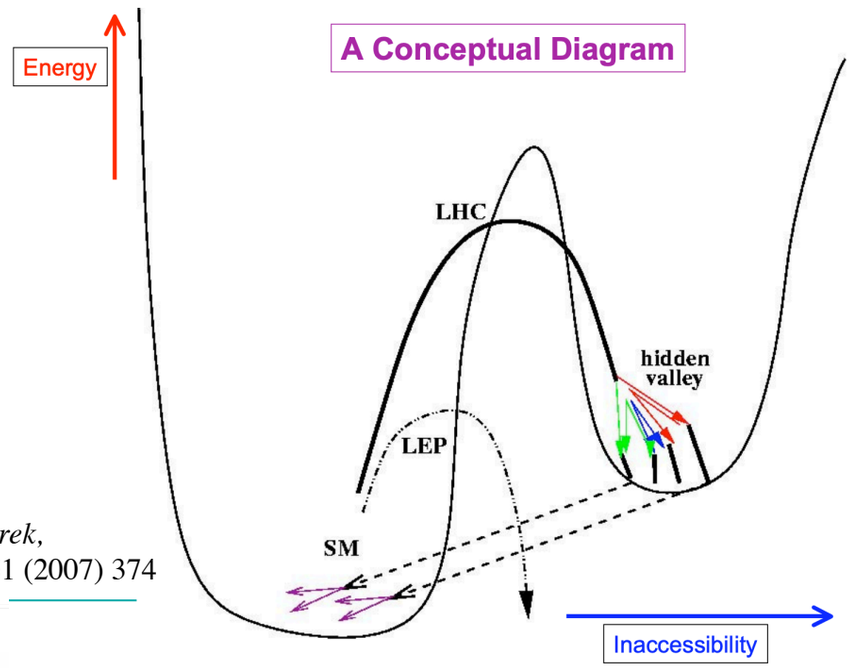




Strassler & Zurek,
Phys.Lett.B 651 (2007) 374

HIDDEN VALLEY PHENOMENOLOGY

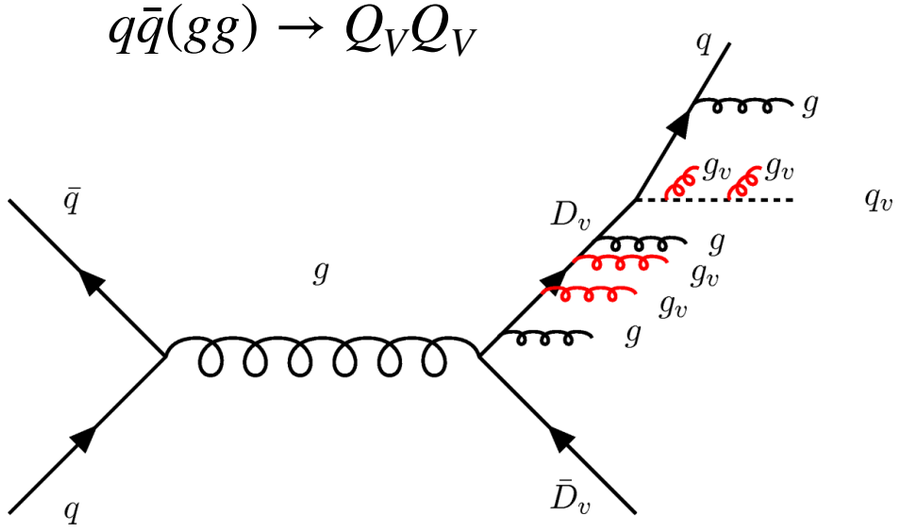
QCD-like scenario

Communicator: F_V

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

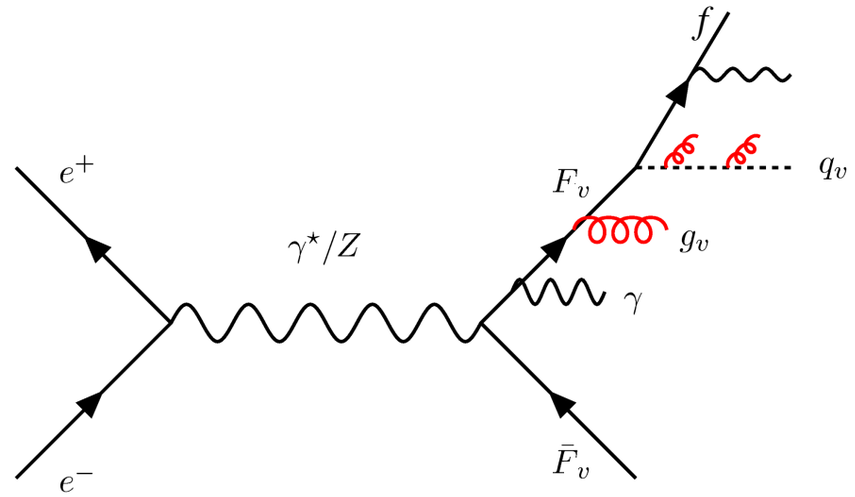
pp collisions

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



e^+e^- collisions

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



JHEP 1009:105,2010
L Carloni, T Sjöstrand

HIDDEN VALLEY PHENOMENOLOGY

QCD-like scenario

Communicator: F_V

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  - $E_V \to e q_V$
  - $Q_V \to q q_V$

Signature

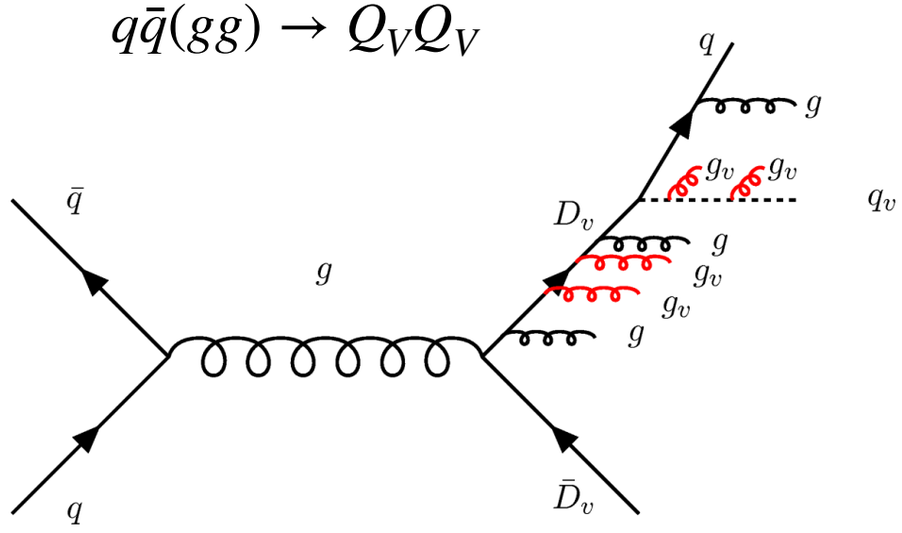
Perturbation in conventional QCD cascade and final hadronisation

↓

anomalies in angular correlations

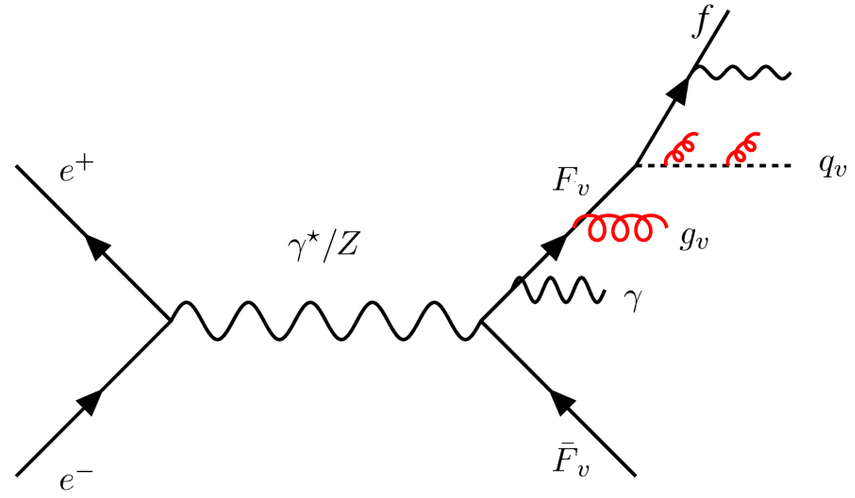
pp collisions

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



e^+e^- collisions

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



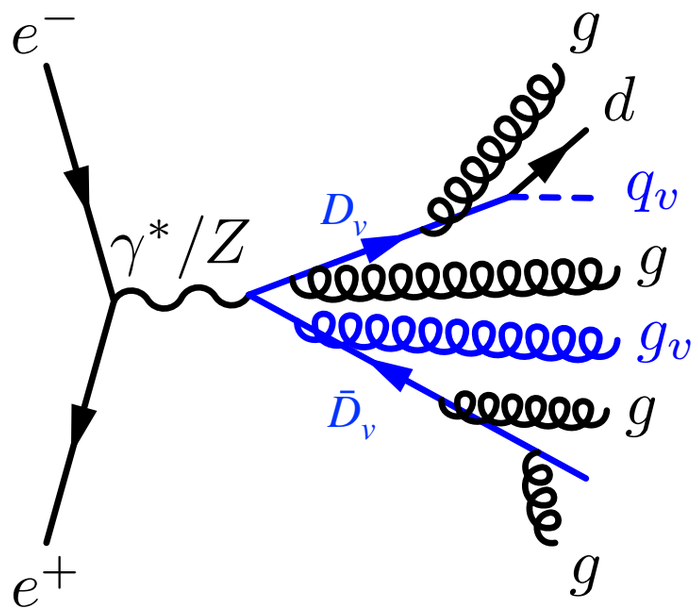
JHEP 1009:105,2010
L Carloni, T Sjöstrand

SIGNAL VS BACKGROUND

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

SIGNAL

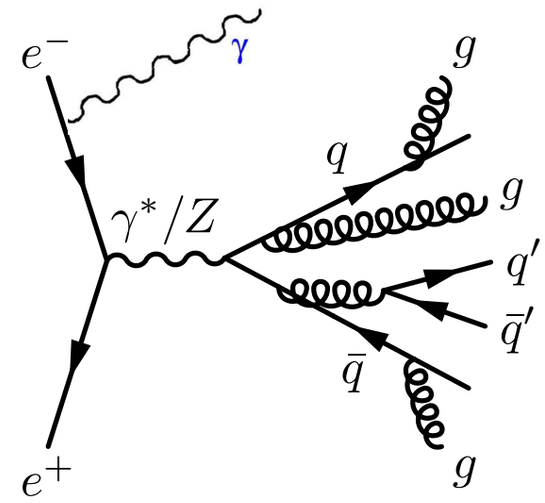
$e^+e^- \to \gamma^*/Z^0 \to D_V\bar{D}_V \to$ hadrons



m_{D_V} = 125 GeV
$\alpha_v = 0.1$

BACKGROUND

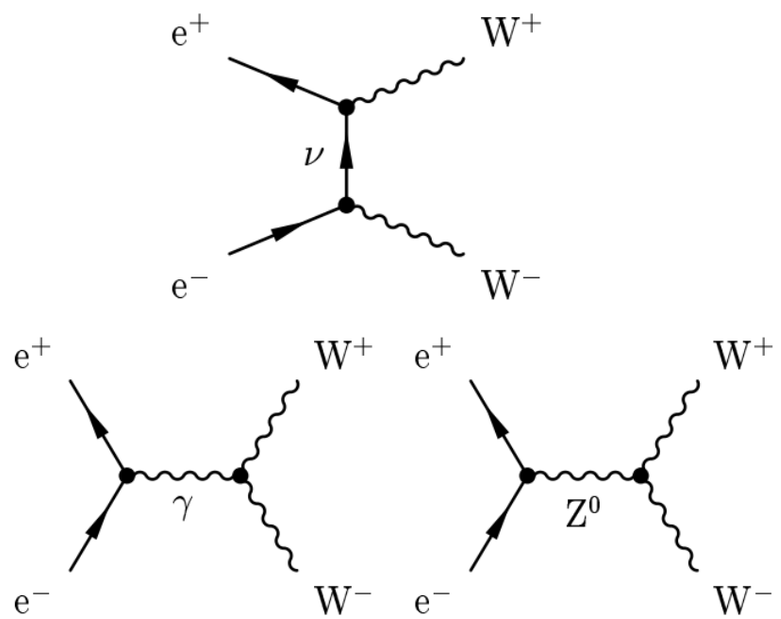
i) $q\bar{q}$ production with ISR



No polarised beam

Process	σ_{PYTHIA8} [pb]
$e^+e^- \to D_v\bar{D}_v$	
$m_{q_v} = 0.1$ GeV	0.13
$m_{q_v} = 10$ GeV	0.12
$m_{q_v} = 50$ GeV	0.12
$m_{q_v} = 100$ GeV	0.12
$e^+e^- \to q\bar{q}$ with ISR	48
$WW \to 4q$	7.4

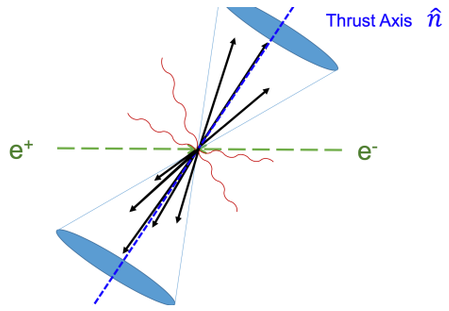
ii) WW —> 4q



ANALYSIS AT DETECTOR LEVEL

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

Thrust Axis:



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

TOOLS

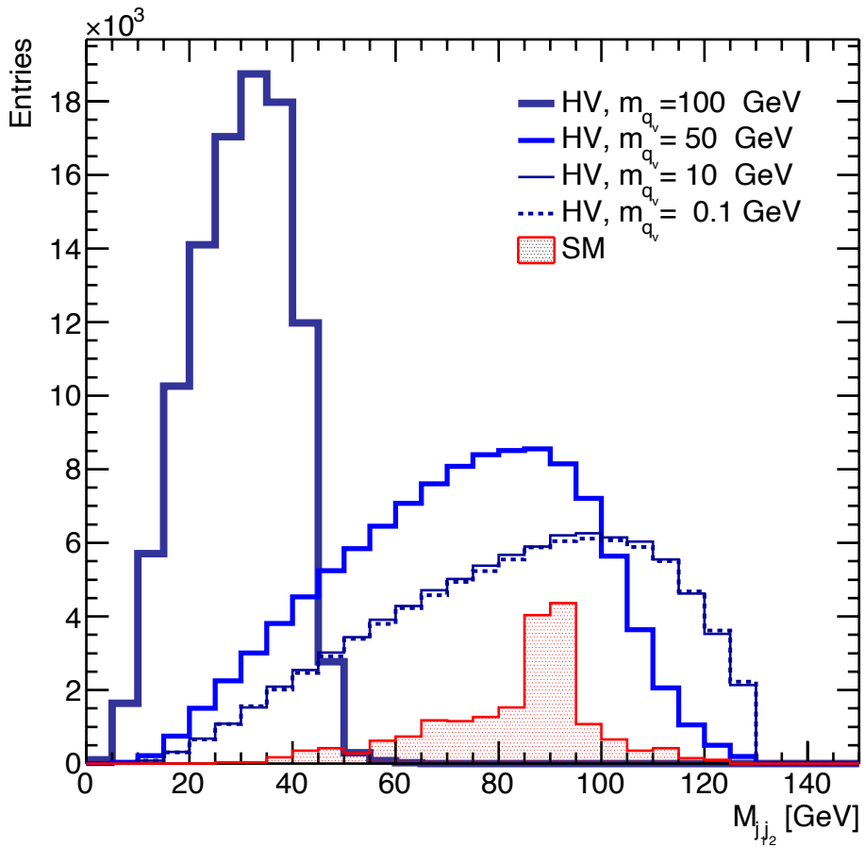
- Monte Carlo event generator:
  - ➡Pythia8
    - ‣HepMC output
- Fast detector simulation
  - ➡ SGV 3.0
    - ‣ From HepMC files —> LCIO-DST
    - ‣ ILD geometry
- Analysis
  - ➡ ILCSoft (https://github.com/QQbarAnalysis/QQbarAnalysis)
  - ➡ ROOT (https://github.com/airqui/AFBhq2021)

ANALYSIS AT DETECTOR LEVEL

$$\sqrt{s} = 250\ \text{GeV}, \mathscr{L} = 2\ \text{ab}^{-1}$$

CUTS

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



Pythia8+SGV (ILC detector)

Process	σ_{PYTHIA8} [pb]	Efficiency [%]	$< N_{\text{ch}} >$
$e^+e^- \to D_v\bar{D}_v$			
$m_{q_v} = 0.1$ GeV	0.13	36	12.4 ± 3.7
$m_{q_v} = 10$ GeV	0.12	36	12.4 ± 3.7
$m_{q_v} = 50$ GeV	0.12	42	11.4 ± 3.5
$m_{q_v} = 100$ GeV	0.12	42	6.5 ± 2.1
$e^+e^- \to q\bar{q}$ with ISR	48	$\lesssim 0.01$	9.9 ± 3.4
$WW \to 4q$	7.4	$\lesssim 0.001$	-

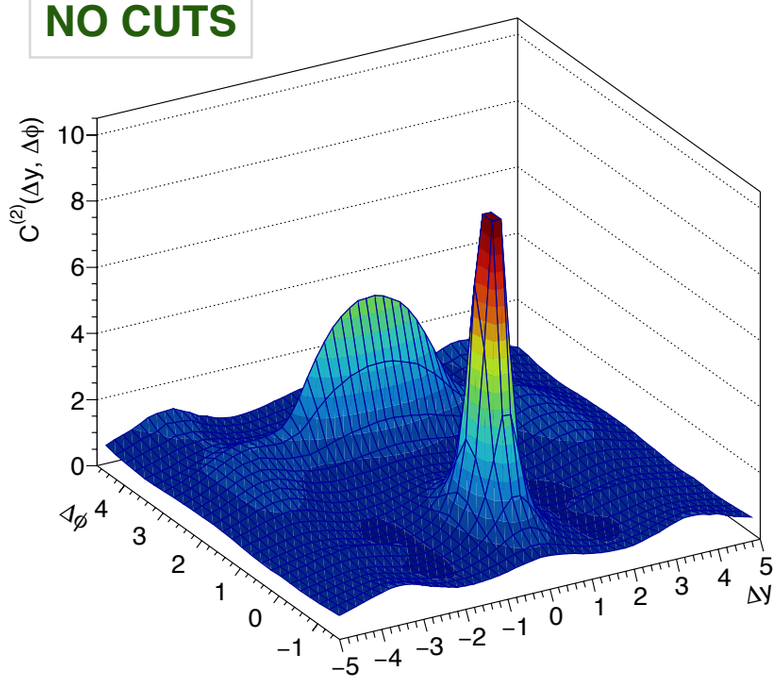
ANALYSIS AT DETECTOR LEVEL

$\sqrt{s} = 250\ \text{GeV}, \mathscr{L} = 2\ \text{ab}^{-1}$

BACKGROUND

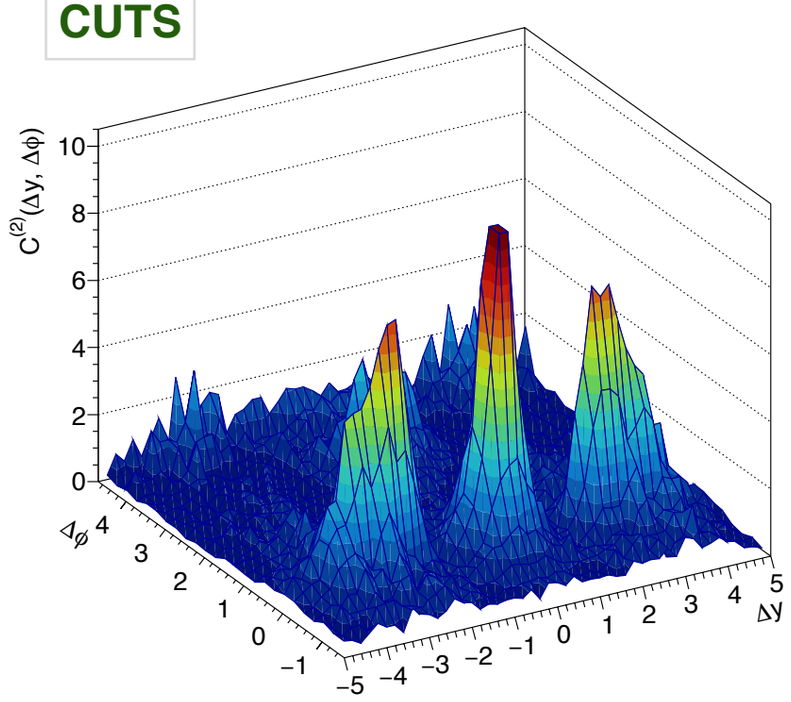
Thrust axis

NO CUTS



SM

CUTS

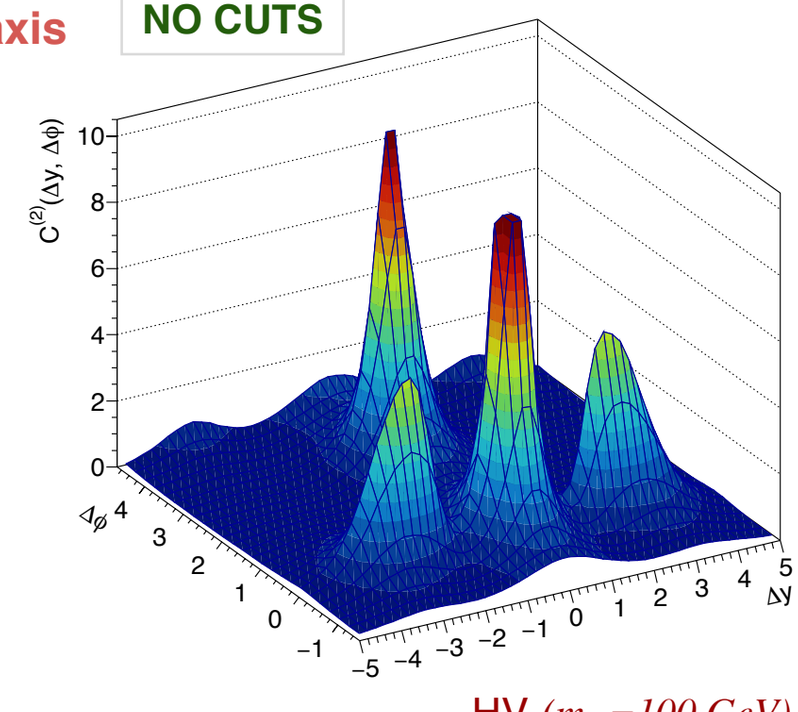


SM

SIGNAL

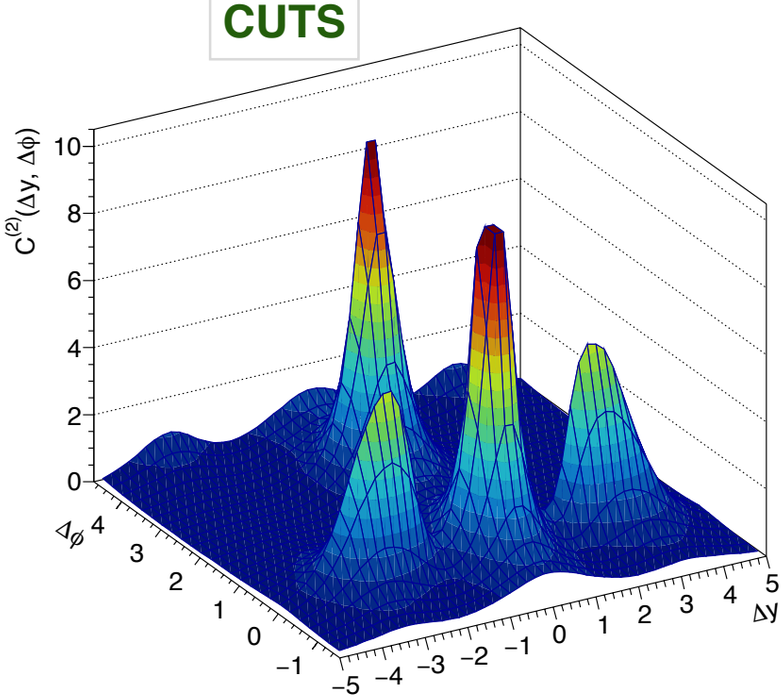
Thrust axis

NO CUTS



HV (m_{q_v} =100 GeV)

CUTS



HV (m_{q_v} =100 GeV)

ANALYSIS AT DETECTOR LEVEL

Yield

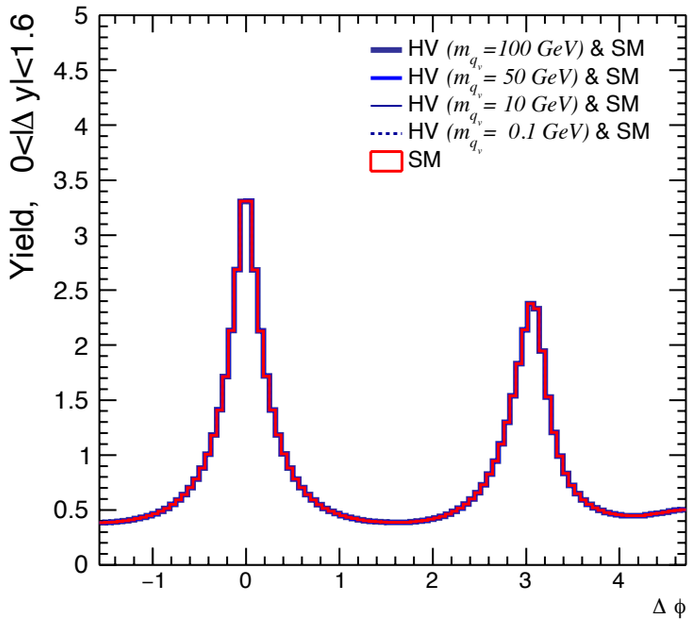
$$Y(\Delta\phi) = \frac{\int_{y_{inf} \leq |\Delta y| \leq y_{sup}} S(\Delta y, \Delta\phi) dy}{\int_{y_{inf} \leq |\Delta y| \leq y_{sup}} B(\Delta y, \Delta\phi) dy}$$

ANALYSIS AT DETECTOR LEVEL

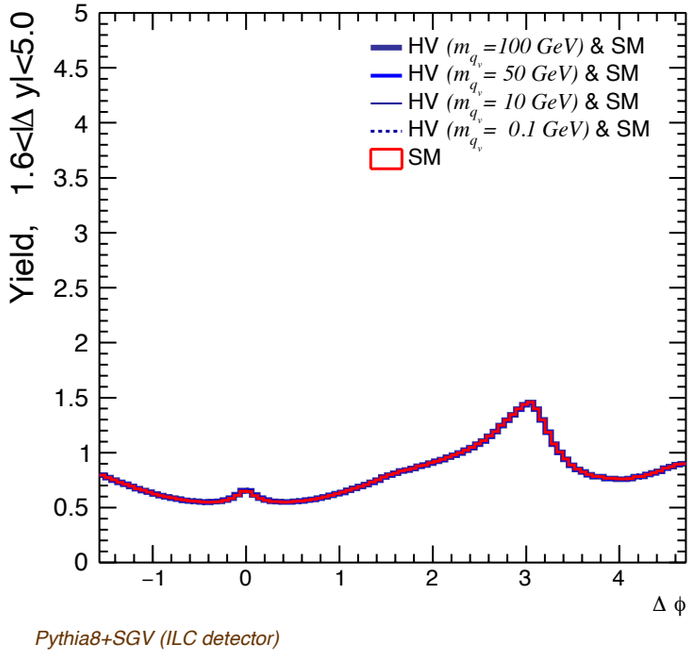
Yield

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

NO CUTS

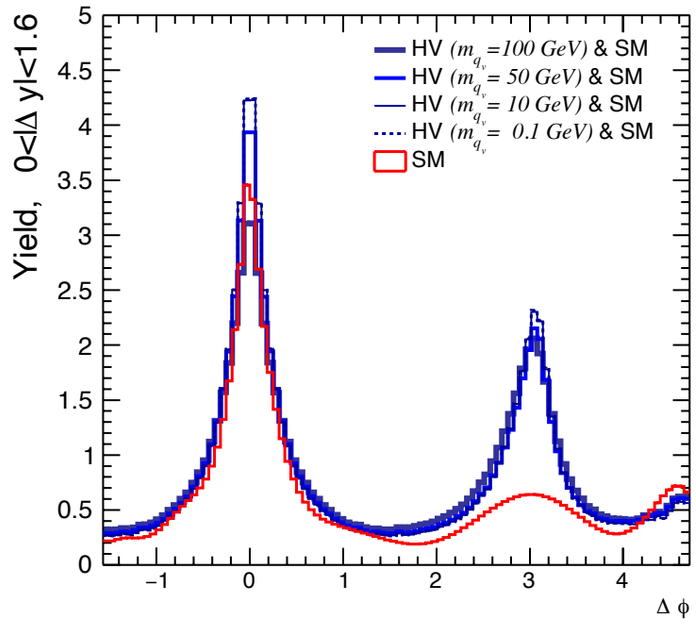


Pythia8+SGV (ILC detector)

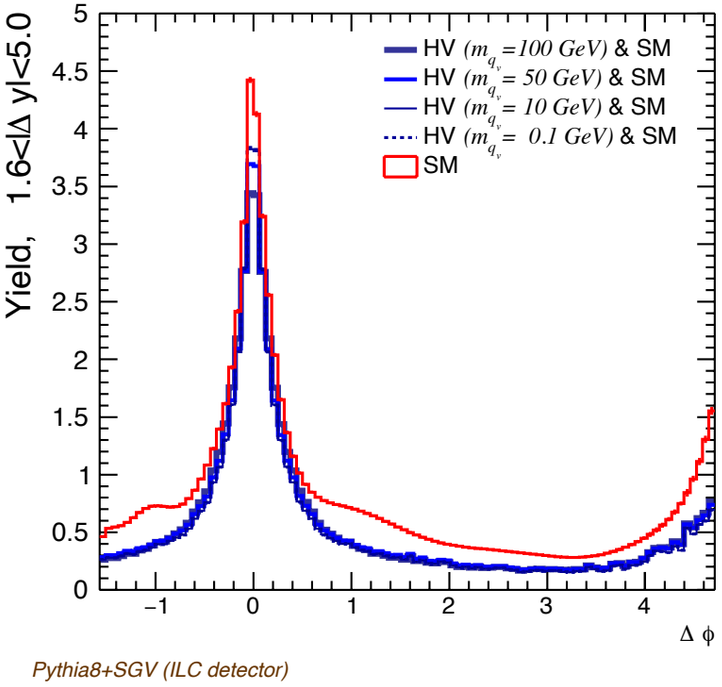


Pythia8+SGV (ILC detector)

CUTS



Pythia8+SGV (ILC detector)



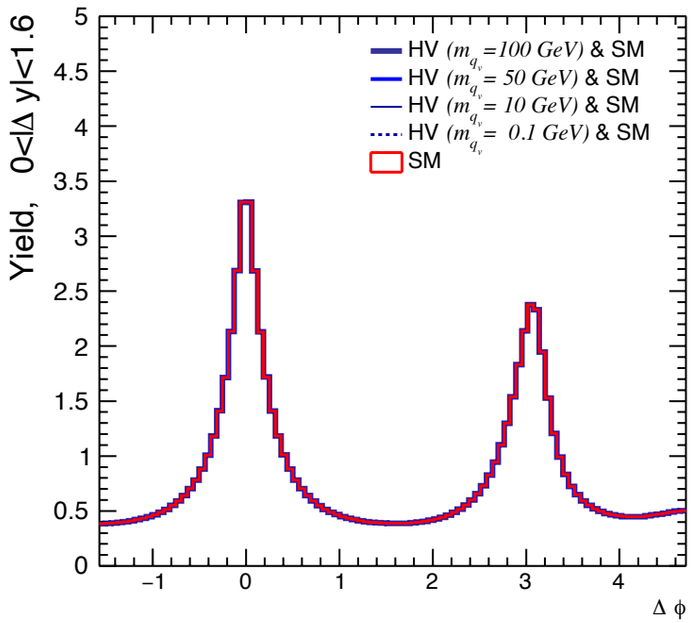
Pythia8+SGV (ILC detector)

ANALYSIS AT DETECTOR LEVEL

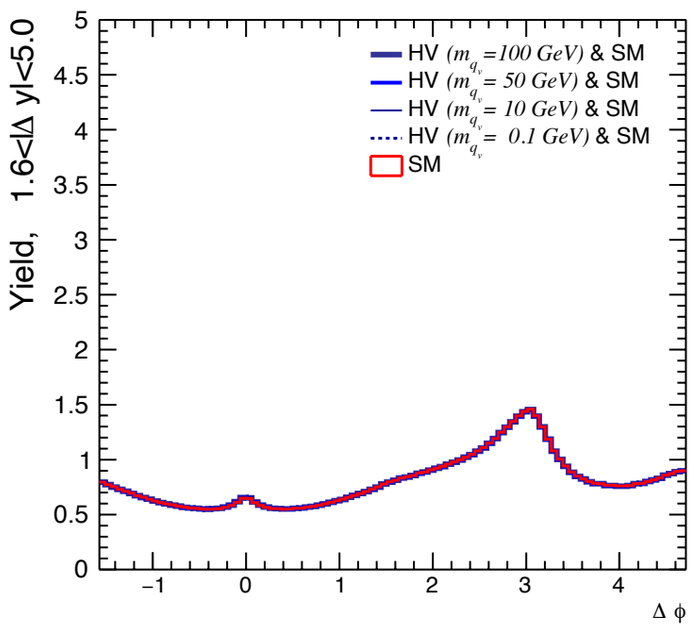
Yield

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

NO CUTS

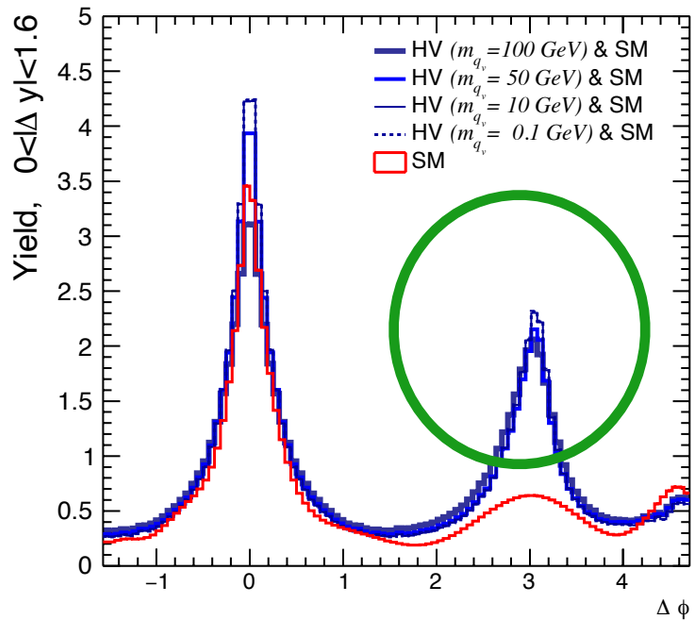


Pythia8+SGV (ILC detector)



Pythia8+SGV (ILC detector)

CUTS



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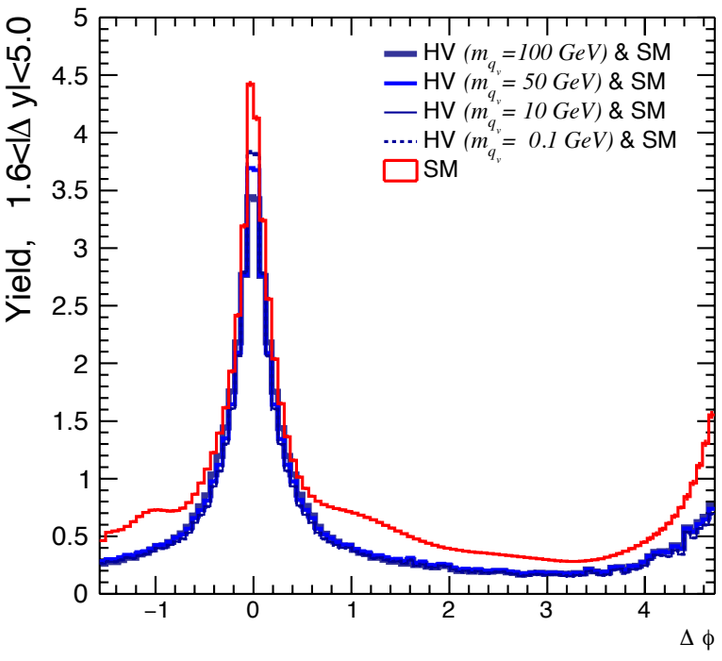


Pythia8+SGV (ILC detector)

ANALYSIS AT DETECTOR LEVEL

Uncertainties

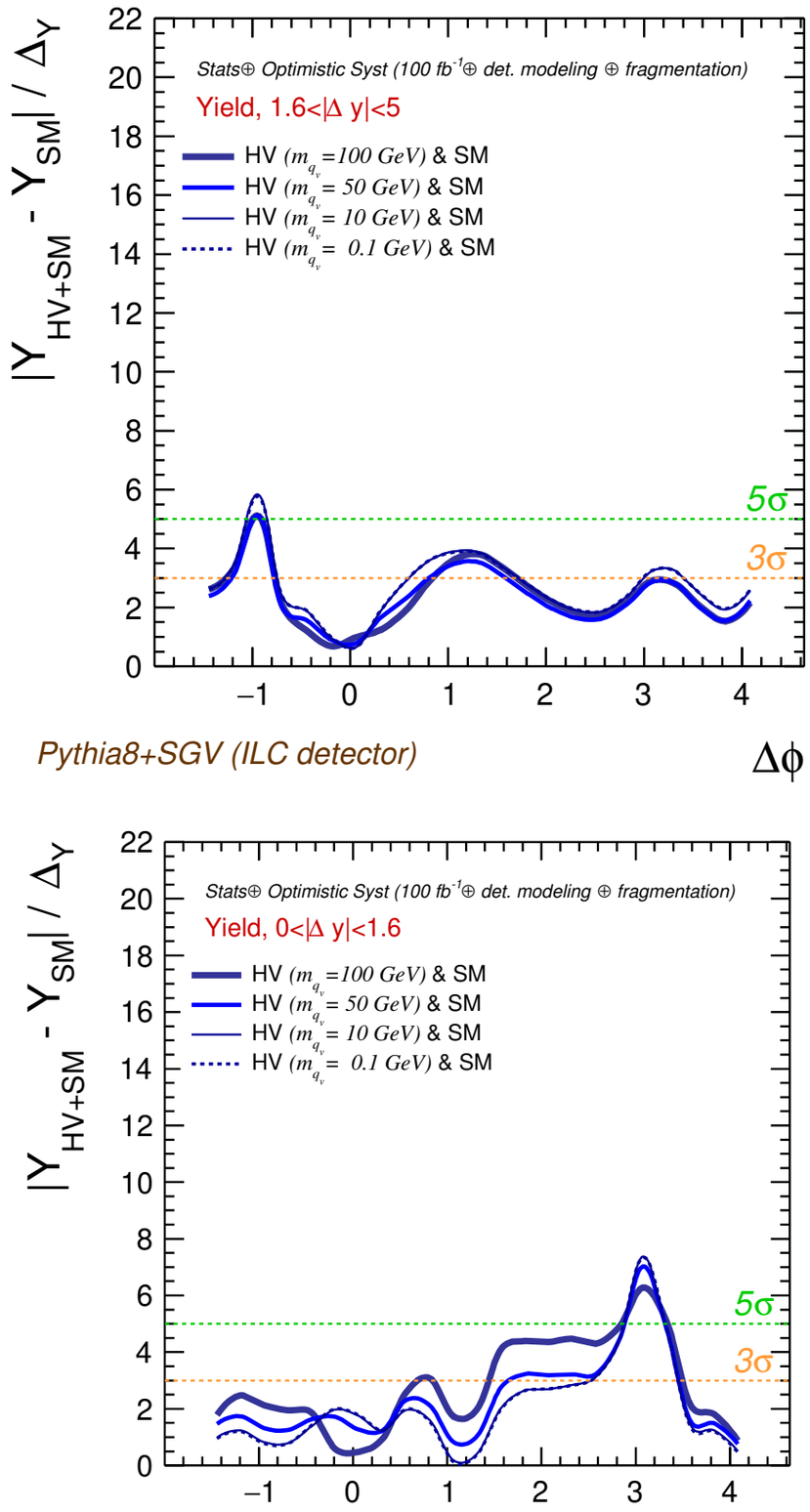
Statistical :

Collected Luminosity

$\mathscr{L} = 100\ \text{fb}^{-1}$

Systematic:

- **Detector modeling**
  - **Bin by Bin comparison**
- **Fragmentation, Hadronisation**
  - **Pythia8 VS Herwig**



The total uncertainty is composed of the addition in quadrature of :

- the statistical uncertainty for the expected number of events
- the systematic uncertainties of Y_{SM}

OUTLOOK AT HIGHER ENERGIES

@ Particle Level

Process	$\sigma_{\sqrt{s}=500\text{GeV}}$ [pb]	$\sigma_{\sqrt{s}=1\text{TeV}}$ [pb]
	$m_{D_v} = 250$ GeV	$m_{D_v} = 500$ GeV
$e^+e^- \to D_v\bar{D}_v$	2.4×10^{-2}	4.4×10^{-3}
	$m_{T_v} = 250$ GeV	$m_{T_v} = 500$ GeV
$e^+e^- \to T_v\bar{T}_v$	9.5×10^{-2}	1.8×10^{-2}
$e^+e^- \to q\bar{q}$ with ISR	11	2.9
$e^+e^- \to t\bar{t}$	0.59	0.19
$WW \to 4q$	3.4	1.3

SUMMARY

❖ The analysis of the long-range angular particle correlations can provide valuable insights into the initial state of matter on top of QCD partonic shower

❖ We investigate the *observability of hidden sectors* at future e^+e^- colliders with two-particle angular correlations at $\sqrt{s} = 250$ GeV

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

❖ An outlook at $\sqrt{s} = 500$ GeV and $\sqrt{s} = 1$ TeV was performed

Thanks for your attention!