Hidden sectors with two-particle angular correlations

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- "Two-particle angular correlations in the search for new physics at future e+e− colliders," Proc. LCWS2023, eConf C2305153 (2023), arXiv:2307.14734 [hep-ph] ← particle level
- "Exploring hidden sectors with two-particle angular correlations at future e^+e^- colliders," arXiv:2312.06526 [hep-ph] ← detector level (ILC)
- Presentations in LCWS2023, 2nd ECFA w/s 2023, SUSY2024, LCWS2024, ICHEP2024, Corfu2024
- To be presented in 3rd ECFA w/s 2023 by Redamy Perez-Ramos

Two-particle angular correlations

- Powerful method to uncover collective effects resulting from high particle densities
- Ridge structure observed in heavy-ion, *p*Pb, *pp* collisions
- Also seen in e^+e^- ➜ ALEPH archival data analysis
  - high-track multiplicity

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

ridge

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

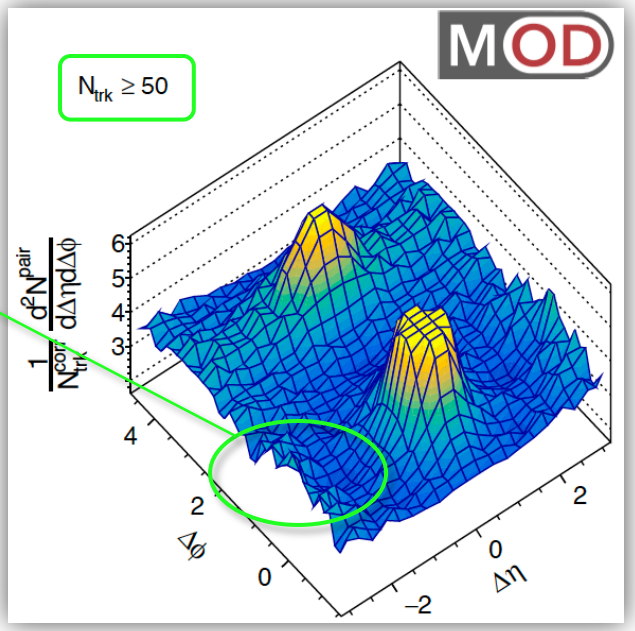
$$S(\Delta y, \Delta\phi) = \frac{1}{N_{pairs}} \frac{d^2N^{same}}{d\Delta y \Delta\phi}$$

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

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

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

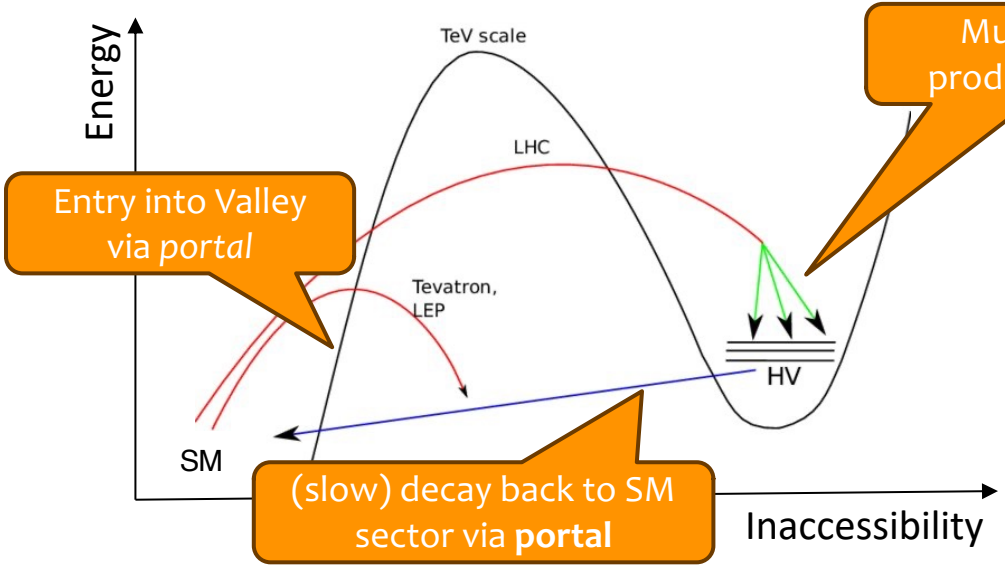
$$N_{mix} = \iint \frac{d^2N^{mix}}{d\Delta y d\Delta\phi} d\Delta y d\Delta\phi$$

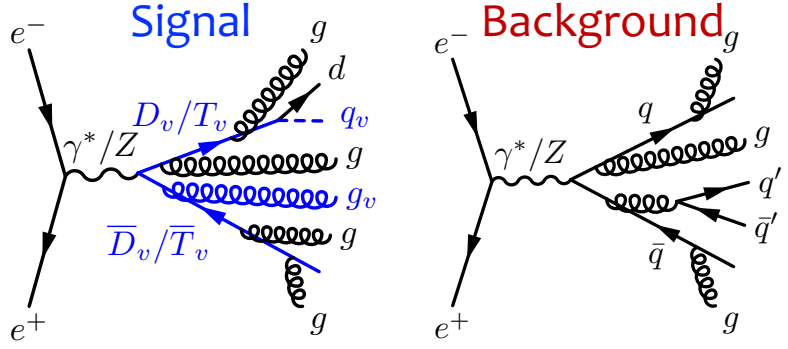


Chen et al, Phys. Lett. B 856 (2024) 138957

Test-bed: Hidden Valley (HV)

√s = 240 GeV
ILD-for-FCC fast detector simulation





- Signal
  - $e^+e^- \to \gamma^*/Z \to \bar{D}_V D_V \to$ hadrons
- Background
  - $q\bar{q}$ production with ISR
  - $W^+W^- \to q\bar{q}q\bar{q}$

Process		σ_{PYTHIA8} [pb]
$e^+e^- \to D_v\bar{D}_v$		
m_{D_v} [GeV]	m_{q_v} [GeV]	
120	100	0.129
120	60	0.137
120	10	0.136
100	50	1.32
$e^+e^- \to q\bar{q}$		13.4
$WW \to 4q$		1.54

FCC-*ee* results

y, ϕ coordinates defined w.r.t. thrust axis

Event selection

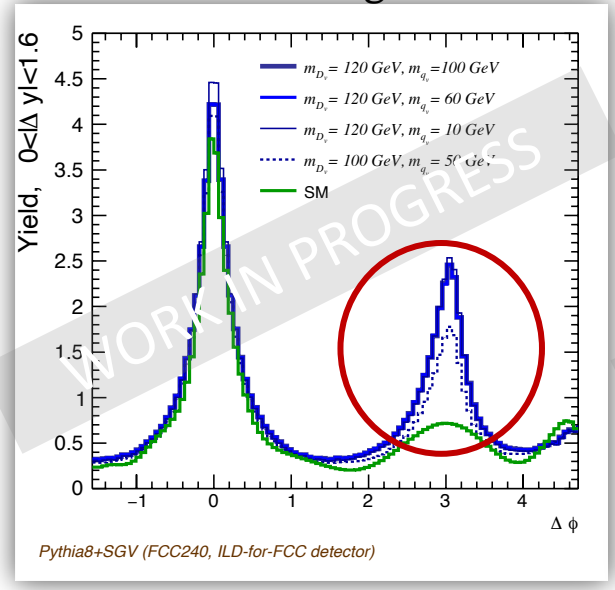
- no secondary vertices
- neutral PFOs* ≤ 22
- charged PFOs ≤ 15
- reconstructed ISR photons
  - $|\cos\vartheta_{\gamma ISR}| < 0.5$
  - $E_{\gamma ISR} < 40$ GeV
- Di-jet invariant mass: $m_{jj} < 130$ GeV
- Leading-jet invariant mass: $E_{jet} < 80$ GeV

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

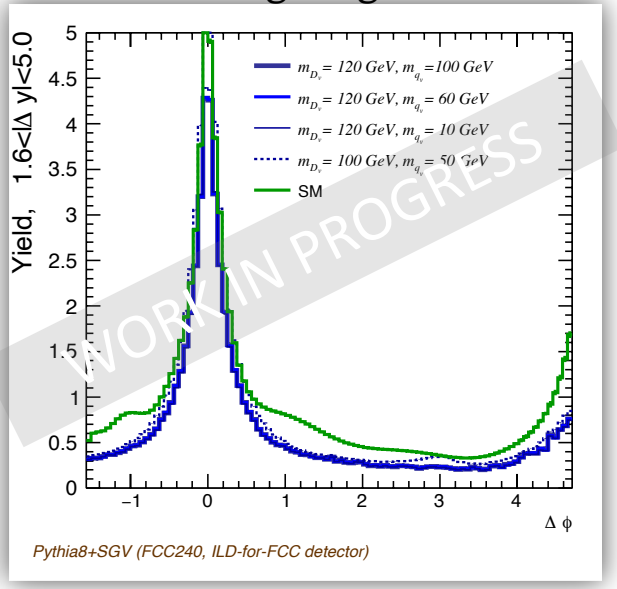
*PFOs: Particle Flow Objects. Detector level particle candidates

- Long-range, near-side ridge in SM due to ISR effect (resonant *Z* production)
- Different behaviour between signal and background
  → **hint of New Physics**

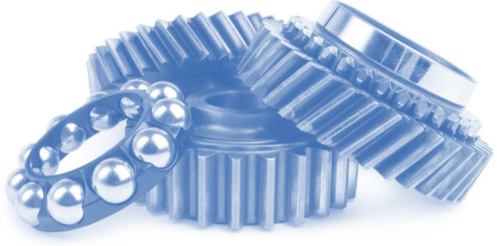
short range



long range



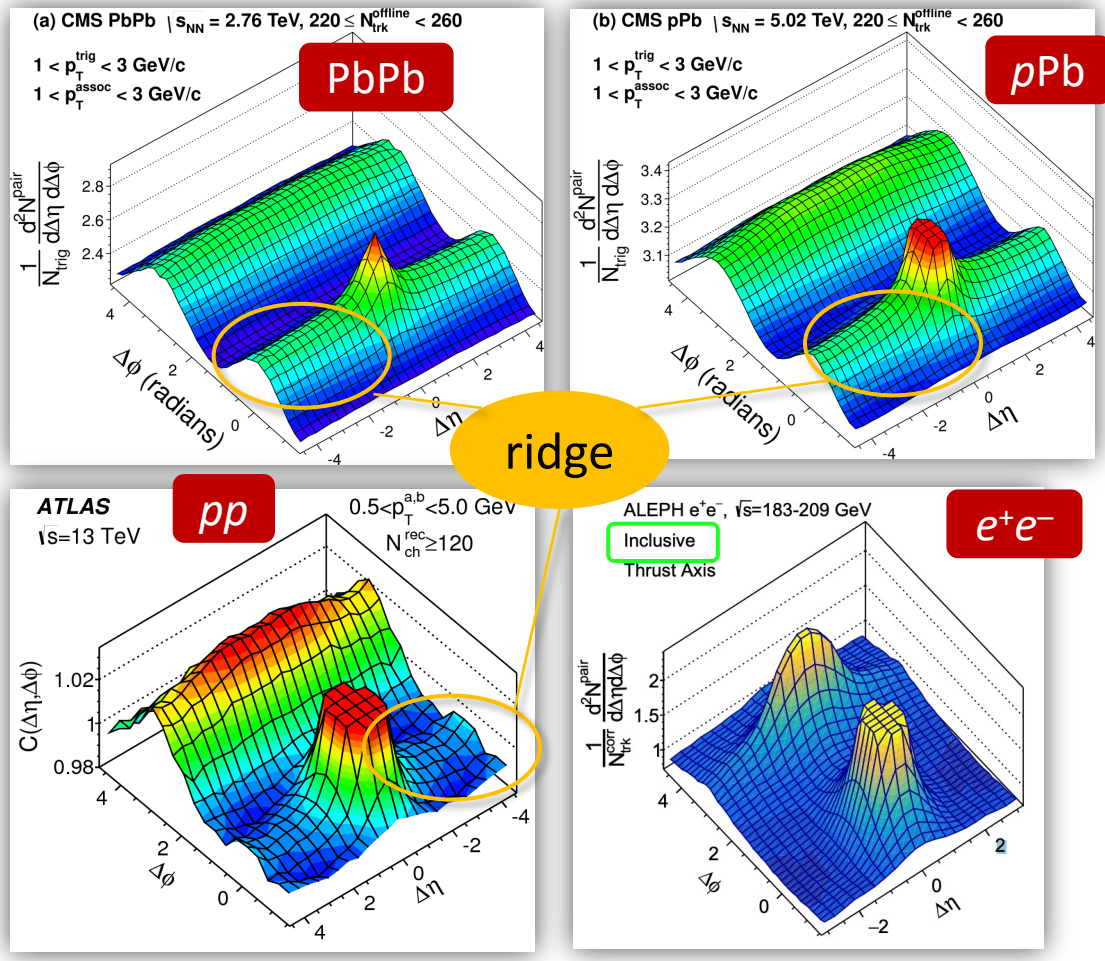
Spares



Two-particle angular correlations in collisions

- Interesting features depending on colliding particles and track multiplicities
- Heavy-ion collisions: ridge structure associated with fluctuating ion initial state

Sanchis-Lozano, Int.J.Mod.Phys.A 24, 4529 (2009)
Sanchis-Lozano & Sarkisyan-Grinbaum, Phys.Lett.B 781, 505 (2018)
Pérez-Ramos, Sanchis-Lozano, Sarkisyan-Grinbaum, Phys.Rev.D 105, 053001 (2022)



Phys.Lett.B 724 (2013) 213

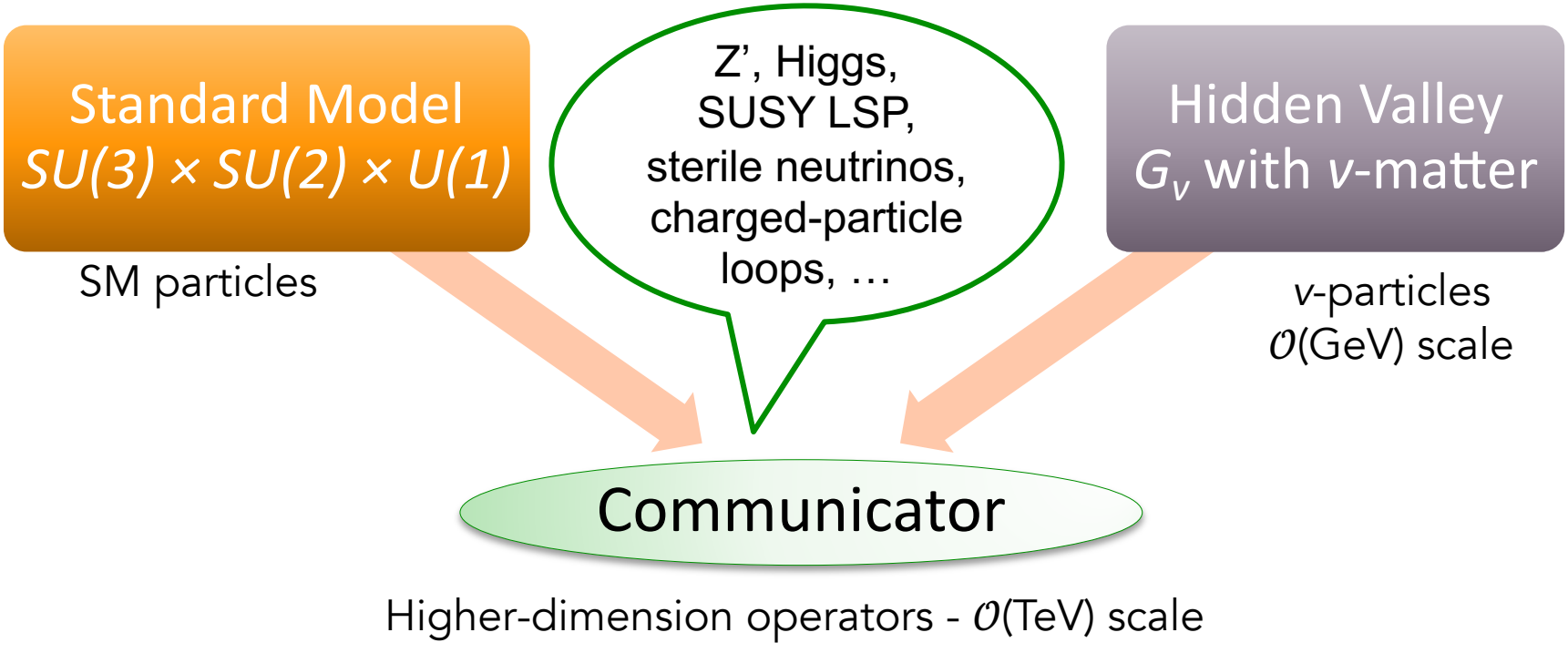
Phys.Lett.B 724 (2013) 213

Phys. Rev. Lett. 116 (2016) 172301

Chen et al, Phys. Lett. B 856 (2024) 138957

Hidden Valley (HV)

"Meta-model": large class of theoretical scenarios



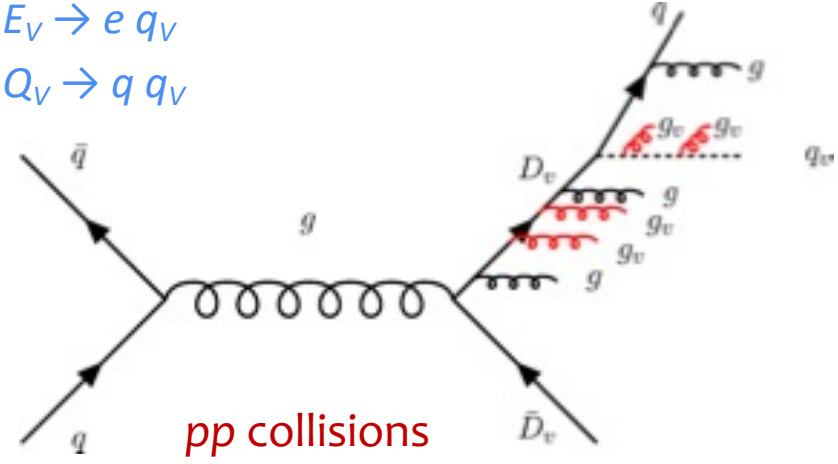
Strassler & Zurek, Phys.Lett.B 651 (2007) 374

QCD-like HV scenario

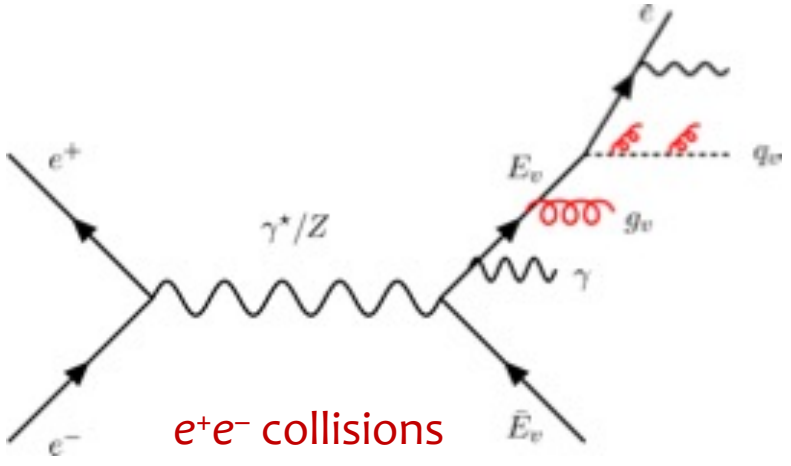
- Communicator: F_V
- Charged under G_{SM} and G_V
- Pair-produced in collisions
- v-quarks, q_V, and v-gluons, g_V
- Prompt decays
  - $F_V \rightarrow f\, q_V \longrightarrow$ hadrons
  - $E_V \rightarrow e\, q_V$
  - $Q_V \rightarrow q\, q_V$

Signature

Perturbation
in conventional QCD cascade
and final hadronisation
⇩
anomalies in angular correlations
e.g. *ridge*-like structures



pp collisions



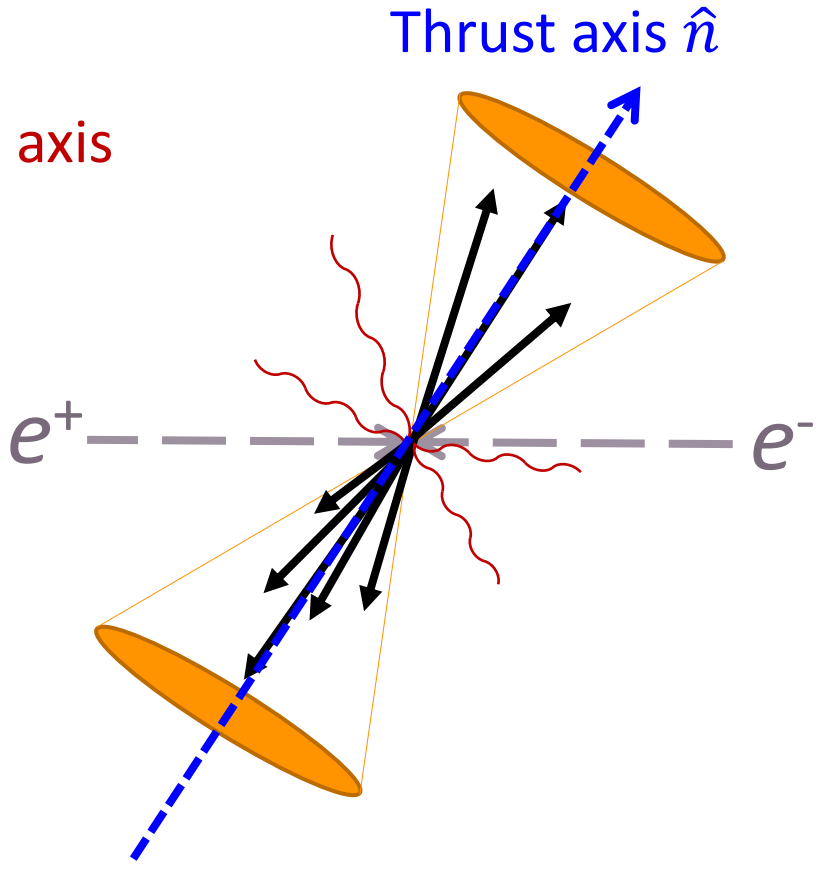
e^+e^- collisions

Carloni & Sjöstrand, JHEP 09 (2010) 105

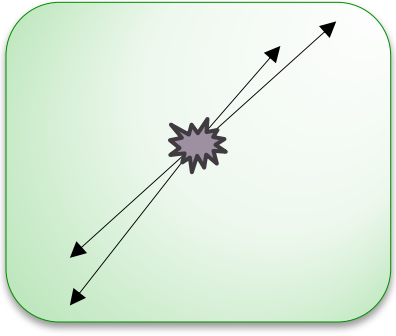
Correlation-related variables

- Angular correlations → event shape
- *y*, *φ* coordinates defined w.r.t. thrust axis

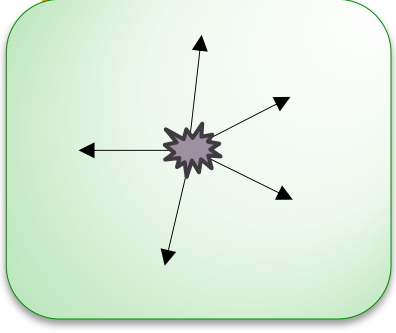
$$T = \max_{\vec{n}} \frac{\sum_i |\vec{p_i} \cdot \hat{n}|}{\sum_i |\vec{p_i}|}$$



T = 1
"pencil"-like event



T = 0.5
spherically
symmetric event



Higher energies (particle level)

- In the HV sector, $T_v T_v$ channel appears
- tt(bar) production appears in the SM background
- Contribution from SM decreases with the energy

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

PYTHIA HV codes

name	partner	code	name	partner	code
D_v	d	4900001	E_v	e	4900011
U_v	u	4900002	ν_{Ev}	ν_e	4900012
S_v	s	4900003	MU_v	μ	4900013
C_v	c	4900004	ν_{MUv}	ν_μ	4900014
B_v	b	4900005	TAU_v	τ	4900015
T_v	t	4900006	ν_{TAUv}	ν_τ	4900016
g_v		4900021			
γ_v		4900022			
q_v		4900101			

Carloni & Sjöstrand, JHEP 09 (2010) 105