Search for New Physics with Multiparticle Correlations and Cosmological Analogies

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Conference on High Energy Physics

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Two-particle rapidity correlations

$$C_2(y_1,y_2)=\rho(y_1,y_2)-\rho(y_1)\rho(y_2)$$

← 2-particle rapidity correlation function

$$\rho(y)=\frac{1}{\sigma_{in}}\frac{d\sigma_{in}}{dy},\ \rho_2(y_1,y_2)=\frac{1}{\sigma_{in}}\frac{d^2\sigma_{in}}{dy_1dy_2}$$

one- and two-particle densities

$$\int dy_1dy_2\,C(y_1,y_2)=D^2-<n>$$ (= 0 for *independent* emission)

$$K_2(y_1,y_2)=\frac{C_2(y_1,y_2)}{\rho(y_1)\rho(y_2)}=\frac{1}{\sigma_{in}}\frac{d^2\sigma_{in}}{dy_1dy_2}/\frac{1}{\sigma_{in}{}^2}\frac{d\sigma_{in}}{dy_1}\frac{d\sigma_{in}}{dy_2}-1$$

$$F_2=\frac{<n(n-1)>}{<n>^2}=\frac{D^2}{<n>^2}-\frac{1}{<n>}+1,\quad D^2=<n^2>-<n>^2$$

Scaled factorial moment

Generalization to *higher-orders* is straightforward:

I.M.Dremin and W.J.Gary, Phys. Rept.349 (2001) 301

E.A. De Wolf, I.M. Dremin, W. Kittel, Phys. Rep. 270 (1996) 1

2-particle azimuthal and (pseudo)rapitity correlations

$$R(\Delta\eta,\Delta\phi)=\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

$$\Delta\eta=\eta_1-\eta_2 \quad ; \quad \Delta\phi=\phi_1-\phi_2$$

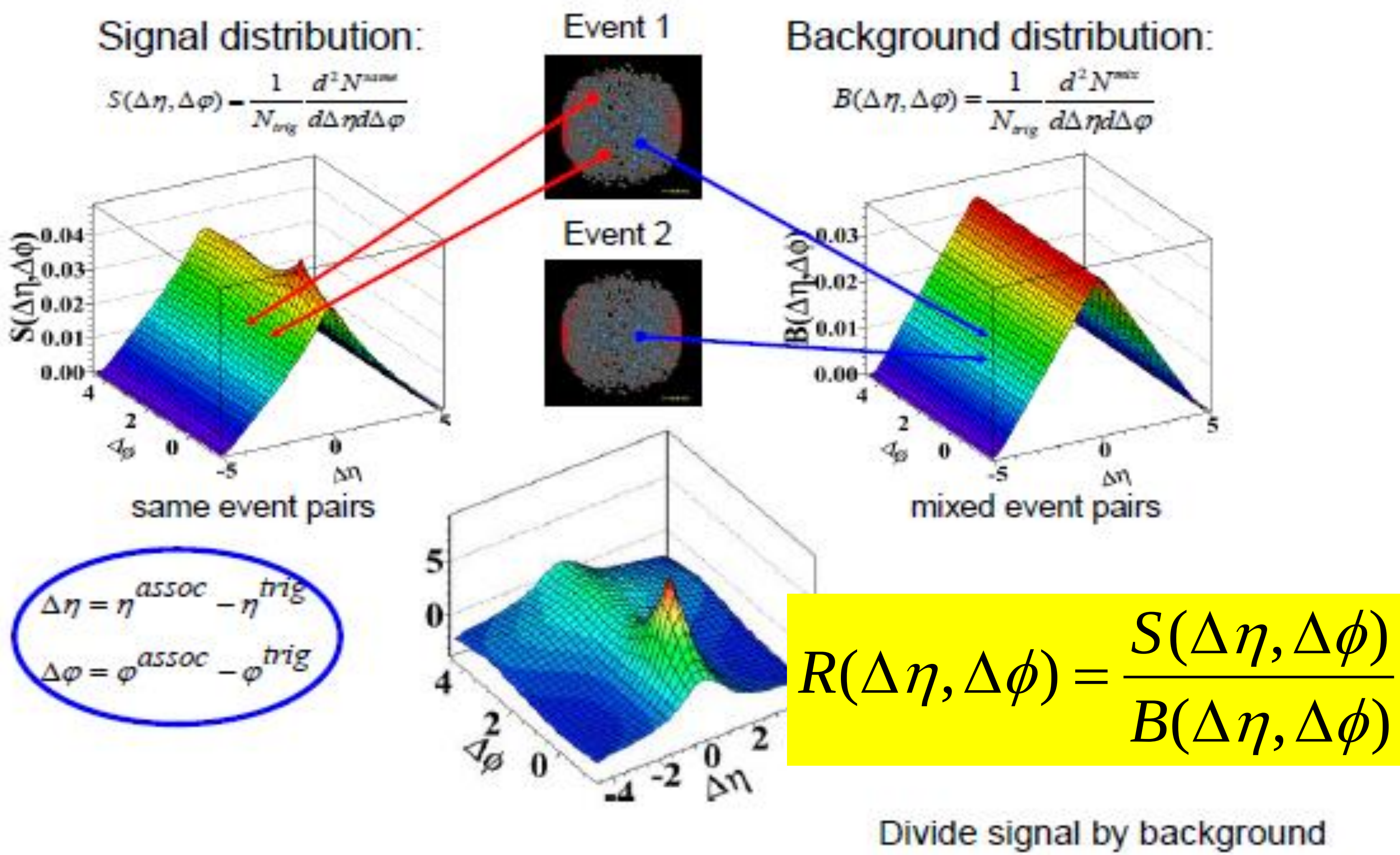
$S(\Delta\eta, \Delta\phi)$: particle pair distribution from ***the same*** event

$B(\Delta\eta, \Delta\phi)$: particle pair distribution from ***different*** events

Complex structure of 2-dimensional plot in pp, pA and AA collisions

seen by ALICE, ATLAS, and CMS at the LHC

2-particle azimuthal and (pseudo)rapitity correlations

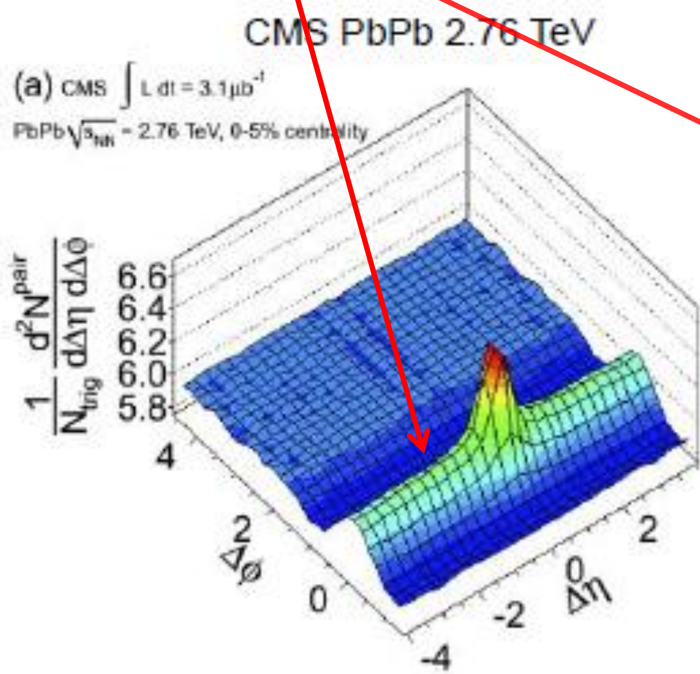


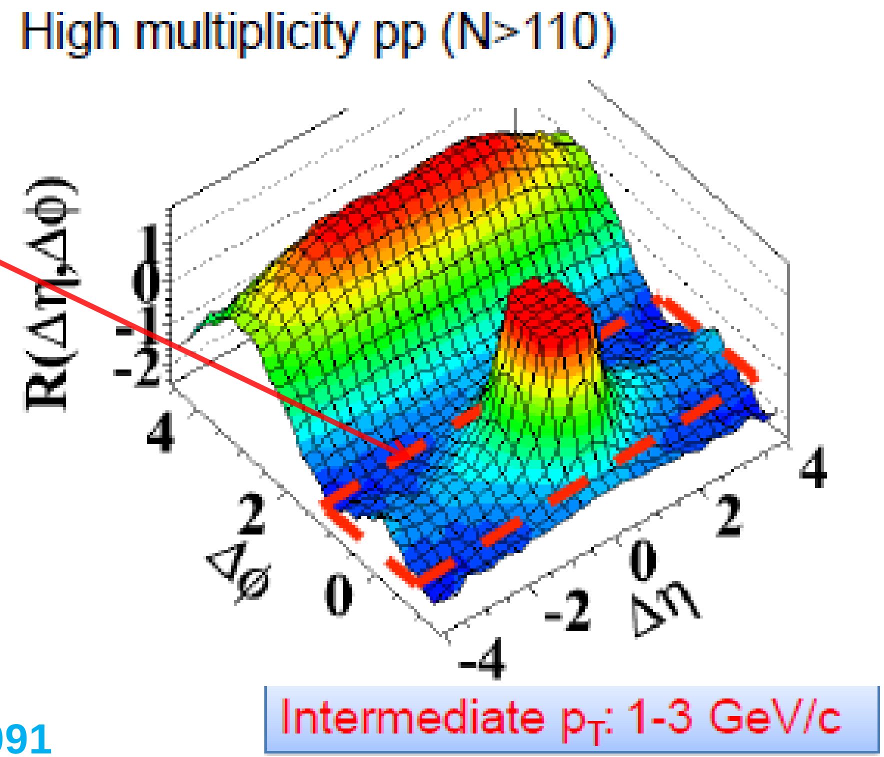
S(Δη, Δϕ): particle pair ***signal*** distribution from ***the same*** event

B(Δη, Δϕ) : particle pair ***background*** distribution from ***different*** events

Ridge structure

``Ridge” structure ***extending over Δη at Δϕ = 0***



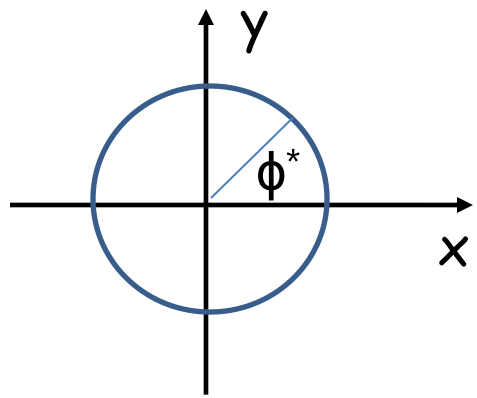


CMS Collab. J. High Energy Phys. 1009 (2010) 091

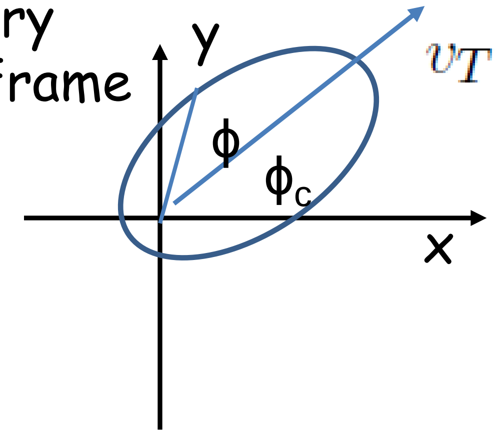
- **Expected** in heavy-ion collisions (*hydro, high density*)
- **Unexpected** in pp (and pA) interactions
- **Similarity in pp *and* heavy-ion collisons!**
- ***No explanation*** **so far, while many models proposed**

Correlated-cluster model

cluster reference frame



laboratory reference frame



Lorentz boost γ_T

- Azimuthal dependence

1) ***Isotropic* cluster emission**

2) ***Isotropic* particle emission in clusters:** $w^*(\phi^*) = \text{constant}$

- **Gaussians** for *cluster and particle* distributions inside clusters

$$\rho^{(c)}(y_c, \phi_c) \sim \exp\left[-\frac{y_c^2}{2\delta_{cy}^2}\right], \rho^{(1)}(y, \phi; y_c, \phi_c) \sim \exp\left[-\frac{(y-y_c)^2}{2\delta_y^2}\right] \exp\left[-\frac{(\phi-\phi_c)^2}{2\delta_\phi^2}\right]$$

The cluster correlation length $\delta_{cy}^2 \gtrsim \delta_y^2 \lesssim 1$ the cluster decay "width", and the cluster azimuthal decay "width"

$$\boxed{\delta_\phi \sim \frac{1}{\upsilon_T \, \gamma_T}}$$

M.-A .Sanchis-Lozano, ESG, Phys. Lett. B 766 (2017) 170

Correlated-cluster model

$$R(\Delta y, \Delta\phi) = \frac{s(\Delta y, \Delta\phi)}{b(\Delta y, \Delta\phi)}$$

$$= \frac{s^{\rm SR}(\Delta y, \Delta\phi) + s^{\rm LR}(\Delta y, \Delta\phi)}{b(\Delta y, \Delta\phi)} = 1 + \frac{h^{\rm SR}(\Delta y, \Delta\phi)}{\langle N_{\rm c}\rangle} + \frac{\langle N_{\rm c}(N_{\rm c}-1)\rangle}{\langle N_{\rm c}\rangle^2}\, h^{\rm LR}(\Delta\phi)$$

Reduces at large $\langle N_c \rangle$

Short-range contribution:

$$h^{\rm SR}(\Delta y, \Delta\phi) = \frac{e_{\rm s}^{\rm SR}(\Delta y, \Delta\phi)}{e_{\rm b}(\Delta y, \Delta\phi)} = \exp\left[-\frac{(\Delta y)^2}{4\delta_y^2}\right] \exp\left[-\frac{(\Delta\phi)^2}{4\delta_\phi^2}\right]$$

Long-range contribution:

$$h^{\rm LR}(\Delta y, \Delta\phi) = \frac{e_{\rm s}^{\rm LR}(\Delta y, \Delta\phi)}{e_{\rm b}(\Delta y, \Delta\phi)} \simeq \exp \cancel{\left[\frac{(\Delta y)^2}{4(\delta_y^2 + \delta_{cy}^2)}\right]} \exp\left[-\frac{(\Delta\phi)^2}{2(2\delta_\phi^2 + \delta_{c\phi}^2)}\right]$$

near-side ridge

For $\delta^2_{cy} >> \delta^2_y$

≈ 0.1 radians (p_T ≈ 1 GeV)

MAIN RESULT: **The *ridge* effect of 2-particle *correlations at small Δϕ over a wide (pseudo)rapidity range* is naturally explained within a model of clusters *correlated in the transverse plane***

M.-A .Sanchis-Lozano, ESG, Phys. Lett. B 766 (2017) 170

3-particle correlations

$$C_3(1,2,3) = \rho_3(1,2,3) + 2\rho(1)\rho(2)\rho(3) - \rho_2(1,2)\rho(3) - \rho_2(2,3)\rho(1) - \rho_2(1,3)\rho(2)$$

$$\rho_3(y_1, y_2, y_3, \phi_1, \phi_2, \phi_3) = \frac{1}{\sigma_{\rm in}} \frac{d^6\sigma}{dy_1 dy_2 dy_3 d\phi_1 d\phi_2 d\phi_3}\,.$$

3-partice density

Correlation function ratio:

$$c_3(\vec{\Delta y}, \vec{\Delta\phi}) = \frac{s_3 + 2b_3 - s_{123} - s_{231} - s_{132}}{b_3}\,,$$

$\vec{\Delta y}, \vec{\Delta\phi}$ for $\Delta y_{ij}, \Delta\phi_{ij}$

, $\vec{y} = (y_1, y_2, y_3)$, $\vec{\phi} = (\phi_1, \phi_2, \phi_3)$

Signal (*s*):

$$s_3(\vec{\Delta y}, \vec{\Delta\phi}) = \int d\vec{y}\; d\vec{\phi}\; \vec{\delta}(\Delta y)\; \vec{\delta}(\Delta\phi)\; \rho_3(\vec{y}, \vec{\phi})$$

$$d\vec{y}\; d\vec{\phi} = dy_1 dy_2 dy_2\; d\phi_1 d\phi_2 d\phi_3$$

$$\vec{\delta}(\Delta y) = \delta(\Delta y_{12} - y_1 + y_2)\; \delta(\Delta y_{13} - y_1 + y_3)$$

Background (*b*):

$$b_3(\vec{\Delta y}, \vec{\Delta\phi}) = \int d\vec{y}\; d\vec{\phi}\; \vec{\delta}(\Delta y)\; \vec{\delta}(\Delta\phi)\; \rho(y_1, \phi_1)\; \rho(y_2, \phi_2)\; \rho(y_3, \phi_3)$$

$$s_{123}(\vec{\Delta y}, \vec{\Delta\phi}) = \int d\vec{y}\; d\vec{\phi}\; \vec{\delta}(\Delta y)\; \vec{\delta}(\Delta\phi)\; \rho(y_1, \phi_1)\; \rho_2(y_2, \phi_2, y_3, \phi_3)$$

+ permutations

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Phys. Rev. D 96 (2017) 074012

Correlated-cluster model: 3 clusters

$$c_3(\vec{\Delta y},\vec{\Delta\phi}) = \frac{s_3^{(1)}(\vec{\Delta y},\vec{\Delta\phi}) + s_3^{(2)}(\vec{\Delta y},\vec{\Delta\phi}) + s_3^{(3)}(\vec{\Delta y},\vec{\Delta\phi})}{b_3(\vec{\Delta y},\vec{\Delta\phi})}$$

$$= \frac{1}{\langle N_c\rangle^2}\, h^{(1)}(\vec{\Delta y},\vec{\Delta\phi}) + \frac{\langle N_c(N_c-1)\rangle}{\langle N_c\rangle^3}\, h^{(2)}(\vec{\Delta y},\vec{\Delta\phi}) \;+\; \frac{\langle N_c(N_c-1)(N_c-2)\rangle}{\langle N_c\rangle^3}\, h^{(3)}(\vec{\Delta y},\vec{\Delta\phi})$$

Reducing at large ‹N_c›

ridge effect

Three-particle three-cluster contribution

for $\delta^2_{cy} >> \delta^2_{y}$ and $\delta^2_{c\Phi} >> \delta^2_{\Phi}$

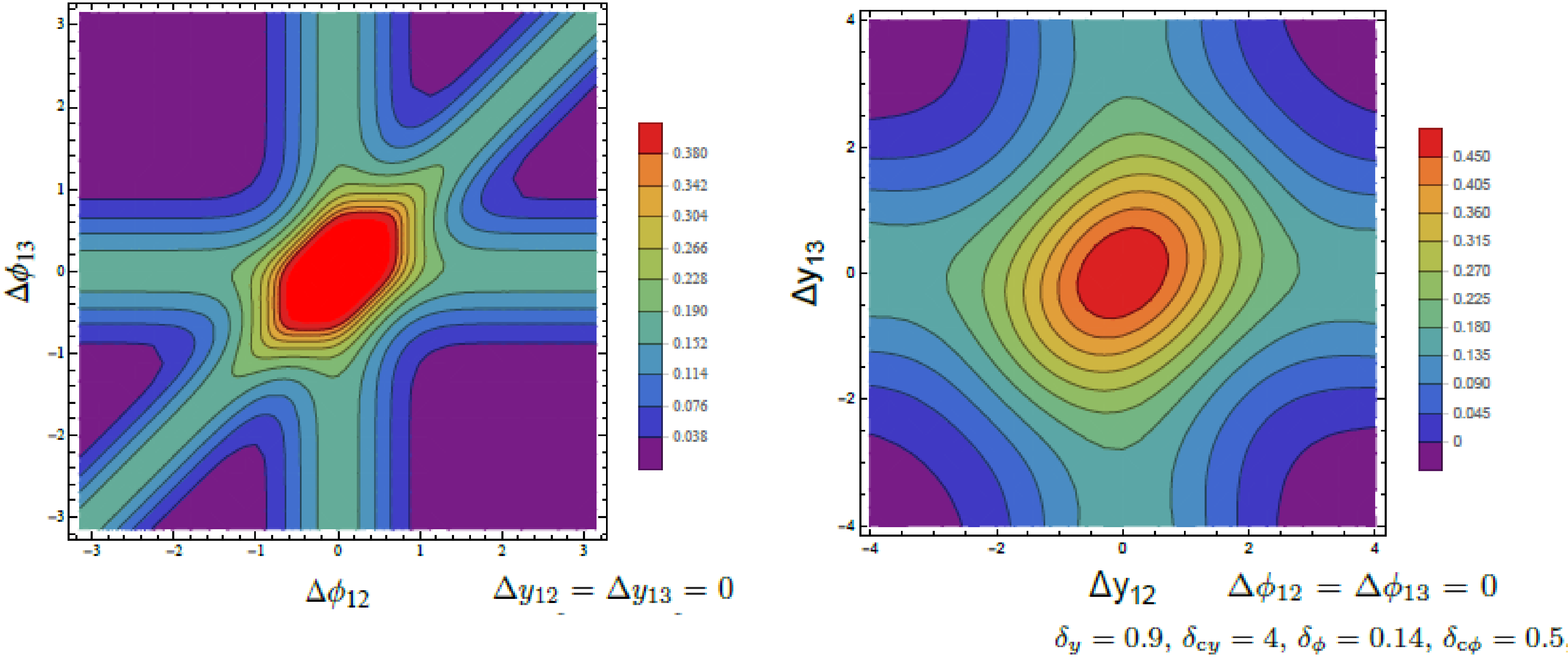
$$h^{(3)}(\Delta y_{12},\Delta y_{13},\Delta\phi_{12},\Delta\phi_{13}) \sim \exp\left[\frac{(\Delta y_{12})^2 + (\Delta y_{13})^2 + -(\Delta y_{12})(\Delta y_{13})}{3\delta^2_{cy}}\right]$$

$$\times \left(\exp\left[-\frac{(\Delta\phi_{12})^2 + (\Delta\phi_{13})^2 - \Delta\phi_{12}\Delta\phi_{13}}{\delta^2_{c\phi}}\right] + \exp\left[-\frac{(\Delta\phi_{12})^2}{2\delta^2_{c\phi}}\right] + \exp\left[-\frac{(\Delta\phi_{13})^2}{2\delta^2_{c\phi}}\right] + \exp\left[-\frac{(\Delta\phi_{12})^2 + (\Delta\phi_{13})^2 - 2\Delta\phi_{12}\Delta\phi_{13}}{2\delta^2_{c\phi}}\right]\right)$$

MAIN RESULT: The *ridge* effect of 3-particle *correlations at small Δϕ over a wide (pseudo)rapidity range* is natural and to be observed as predicted in model of clusters *correlated in the transverse plane*

M.-A .Sanchis-Lozano, ESG, Phys. Rev. D 96 (2017) 074012

Correlated clusters: 3-part. contour plots



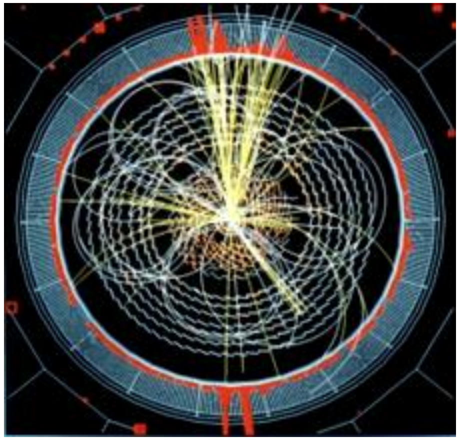
Left panel: *structured asymmetric* two-dimensional plot, results from the *two correlation scales* – a *short-range* azimuthal correlation scale set by *single cluster decay* vs. *long-range* correlation length *from* $h^{(3)}$ *term of three cluster formation*, the *ridge effect due to transversly correlated-cluster emission*

Right panel: rather *structureless* plot dominating by *sinlge cluster decay* short-range correlation scale

M.-A .Sanchis-Lozano, ESG, Phys. Rev. D 96 (2017) 074012

Usually expected signatures of New Physics @ LHC

Mainly on the transverse plane:



> Lower background

> Expected signatures such as

- high-p_T jets, leptons or photons
- missing transverse energy/momentum
- displaced vertices …
- mass peaks

LHC potential must be fully used

***Novel* signals should not be overlooked however, e.g.**

- related to multiparticle production (***soft*** physics)
- **but *tagged by hard signals***

diffuse signal

May be helpful for ***discovery*** of a new stage of matter (**Hidden/Dark Sector**) manifesting in the parton cascade of high-energy pp collisions.

Not an easy task!

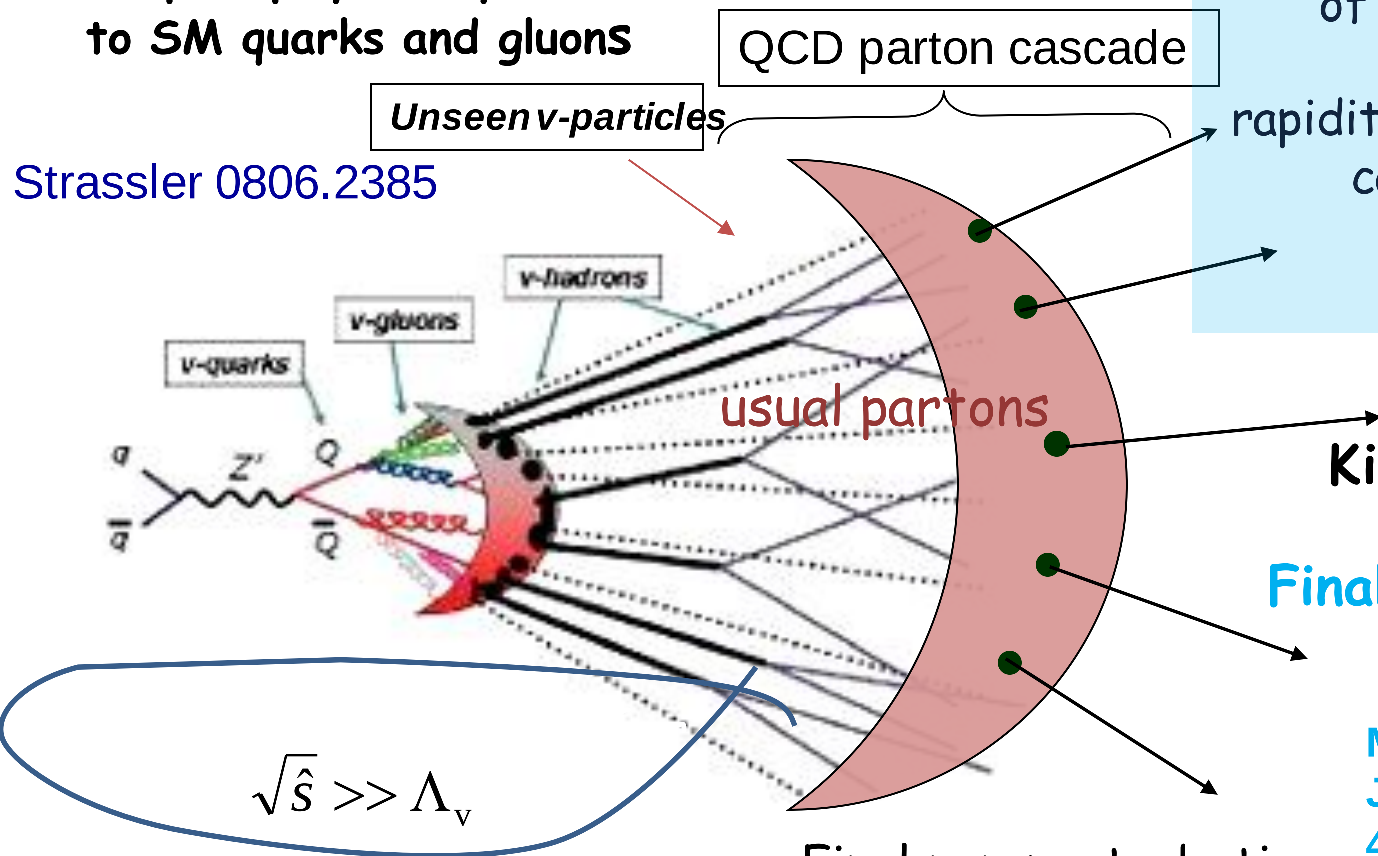
Techniques related to the quest for QGP in heavy-ion collisions

Hidden Valley + SM shower

Depending on the model parameters

Some v-particles can be stable, decay outside the detectors, **or promptly decay back to SM quarks and gluons**

Strassler 0806.2385



Final non-perturbative hadronization

Multiplicity distributions of final state particles and rapidity/azimuthal correlations can be affected by the extra step in the cascade

Kind of diffuse signal

Final state SM particles

M.-A .Sanchis-Lozano, Int. J. Mod Phys. A24 (2009) 4529

One more (and different) step than in conventional QCD-parton showers

Estimates

$$M_h \approx 350-1000\,\mathrm{TeV}, \quad \Lambda_h \approx 10-100\,\mathrm{GeV}$$

M.-A .Sanchis-Lozano, ESG,
Phys. Rev. D 102 (2020) 035013

$$t_h = \frac{M_h}{\Lambda_h^2}\,(\approx 1\,fm) \qquad t_f = \frac{\Lambda_h}{\Lambda_{QCD}^2} + \frac{M_h}{\Lambda_h^2} \approx 5-10\,fm$$

$$\phi_0 = \frac{2\pi}{\ln\left(t_f / t_h\right)} \approx \pi \text{ radians } = 180^0$$

Very long range azimuthal correlations can be expected!

Maximum angle (causality) in a linearly expanding universe

Such long range azimuthal correlations suggest uncovering the existence of a hidden/dark matter stage on top of the QCD parton cascade

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MDPI Physics 1 (2019) 84

Effect of NP contribution in 3-step cascade

Two-particle density
$$\frac{1}{\sigma_{\rm in}}\frac{d^2\sigma}{d\phi_1 d\phi_2} = \int d\phi_{\rm s}\, \rho^{(\rm s)}(\phi_{\rm s})$$
$$\times \left[\int d\phi_{\rm c}\; \rho^{(\rm c)}(\phi_{\rm c};\phi_{\rm s})\; \rho_2^{(1)}(\phi_1,\phi_2;\phi_{\rm c}) + \int d\phi_{\rm c1}d\phi_{\rm c2}\; \rho_2^{(\rm c)}(\phi_{\rm c1},\phi_{\rm c2};\phi_{\rm s})\; \rho^{(1)}(\phi_1;\phi_{\rm c1})\rho^{(1)}(\phi_2;\phi_{\rm c2})\right]$$
$$+ \int d\phi_{\rm s1}d\phi_{\rm s2}\; \rho_2^{(\rm s)}(\phi_{\rm s1},\phi_{\rm s2}) \approx e^{-\frac{(\phi_{s1}-\phi_{s2})^2}{2\delta_{s\phi}^2}}$$
$$\times \int d\phi_{\rm c1}d\phi_{\rm c2}\; \rho^{(\rm c)}(\phi_{\rm c1};\phi_{\rm s1})\; \rho^{(\rm c)}(\phi_{\rm c2};\phi_{\rm s2})\; \rho^{(1)}(\phi_1,\phi_{\rm c1})\; \rho_1^{(1)}(\phi_2;\phi_{\rm c2})$$

We use again Gaussians to parametrize the effect of a hidden/dark sector

$$C(\Delta\phi) \approx \exp\left[-\frac{(\Delta\phi)^2}{2\underbrace{(\delta_{s\phi}{}^2 + 2\delta_{c\phi}^2 + 2\delta_{\phi}^2)}_{\delta_{s\phi}^2}}\right] \quad , \quad \delta_{s\phi}{}^2 >> \delta_{c\phi}{}^2 >> \delta_{\phi}{}^2$$

M.-A .Sanchis-Lozano, ESG, Phys. Lett. B 781 (2018) 505

3-particle correlations in 3-step cascade

Focusing on azimuthal variable

$$\frac{1}{\sigma_{\rm in}}\frac{d^3\sigma}{d\phi_1 d\phi_2 d\phi_3} = \int d\phi_{\rm s}\ \rho^{(\rm s)}(\phi_{\rm s})$$

$$\times\ \Big[\rho^{(\rm c)}(\phi_{\rm c};\phi_{\rm s})\ \rho_3^{(1)}(\phi_1,\phi_2,\phi_3;\phi_{\rm c}) + \rho_2^{(\rm c)}(\phi_{\rm c1},\phi_{\rm c2};\phi_{\rm s})\ \rho^{(1)}(\phi_1;\phi_{\rm c1})\rho_2^{(1)}(\phi_2,\phi_3;\phi_{\rm c2})$$

$$+\ \rho_3^{(\rm c)}(\phi_{\rm c1},\phi_{\rm c2},\phi_{\rm c3};\phi_{\rm s})\ \rho^{(1)}(\phi_1;\phi_{\rm c1})\rho^{(1)}(\phi_2;\phi_{\rm c2})\rho^{(1)}(\phi_3;\phi_{\rm c3})\Big] + \int d\phi_{\rm s1}d\phi_{\rm s2}\ \rho_2^{(\rm s)}(\phi_{\rm s1},\phi_{\rm s2})$$

$$\times\ \Big\{\Big[\rho^{(\rm c)}(\phi_{\rm c1};\phi_{\rm s1})\ \rho^{(\rm c)}(\phi_{\rm c2};\phi_{\rm s2})\ \rho^{(1)}(\phi_1,\phi_{\rm c1})\ \rho_2^{(1)}(\phi_2,\phi_3;\phi_{\rm c2},\phi_{\rm c3}) + \ \text{combinations}\Big]$$

$$\Big[+\ \rho^{(\rm c)}(\phi_{\rm c1};\phi_{\rm s1})\ \rho_2^{(\rm c)}(\phi_{\rm c2},\phi_{\rm c3};\phi_{\rm s2})\ \rho^{(1)}(\phi_1;\phi_{\rm c1})\ \rho^{(1)}(\phi_2;\phi_{\rm c2})\ \rho^{(1)}(\phi_3;\phi_{\rm c3}) + \ \text{combinations}\Big]\Big\}$$

$$+\int d\phi_{\rm s1}d\phi_{\rm s2}d\phi_{\rm s3}\ \rho_3^{(\rm s)}(\phi_{\rm s1},\phi_{\rm s2},\phi_{\rm s3})$$

$$\times\ \Big[\rho^{(\rm c)}(\phi_{\rm c1};\phi_{\rm s1})\ \rho^{(\rm c)}(\phi_{\rm c2};\phi_{\rm s2})\ \rho^{(\rm c)}(\phi_{\rm c3};\phi_{\rm s3})\ \rho^{(1)}(\phi_1;\phi_{\rm c1})\ \rho^{(1)}(\phi_2;\phi_{\rm c2})\ \rho^{(1)}(\phi_3;\phi_{\rm c3})\Big]$$

$$\Delta y_{12} = y_1 - y_2 \quad , \quad \Delta y_{12} = y_1 - y_2, \quad \Delta\phi_{12} = \phi_1 - \phi_2 \quad , \quad \Delta\phi_{13} = \phi_1 - \phi_3$$

M.-A .Sanchis-Lozano, ESG, Phys. Lett. B 781 (2018) 505

3-particle correlations from three hidden sources

$$c_3(\Delta\phi_{12},\Delta\phi_{13}) = \frac{1}{\langle N_s\rangle^2}h^{(1)}(\Delta\phi_{12},\Delta\phi_{13}) + \frac{1}{\langle N_s\rangle}h^{(2)}(\Delta\phi_{12},\Delta\phi_{13}) + h^{(3)}(\Delta\phi_{12},\Delta\phi_{13})$$

Reducing at large ‹N$_c$›

Three-particle contribution from three hidden sources

for $\delta^2_{s\Phi} >> \delta^2_{c\Phi} >> \delta^2_{\Phi}$

$$h^{(3)}(\Delta\phi_{12},\Delta\phi_{13}) \sim \exp\left[-\frac{(\Delta\phi_{12})^2+(\Delta\phi_{13})^2-\Delta\phi_{12}\Delta\phi_{13}}{3\delta^2_{c\phi}+\delta^2_{s\phi}}\right]$$

$$+\ \exp\left[-\frac{(\Delta\phi_{12})^2}{2(2\delta^2_{c\phi}+\delta^2_{s\phi})}\right] + \exp\left[-\frac{(\Delta\phi_{13})^2}{2(2\delta^2_{c\phi}+\delta^2_{s\phi})}\right] + \exp\left[-\frac{(\Delta\phi_{12})^2+(\Delta\phi_{13})^2-2\Delta\phi_{12}\Delta\phi_{13}}{2(2\delta^2_{c\phi}+\delta^2_{s\phi})}\right]$$

MAIN RESULT: The *effect of NP to be observed* in the three-particle correlations on top of the ridge phenomenon is predicted in the model of clusters *correlated in the transverse plane*

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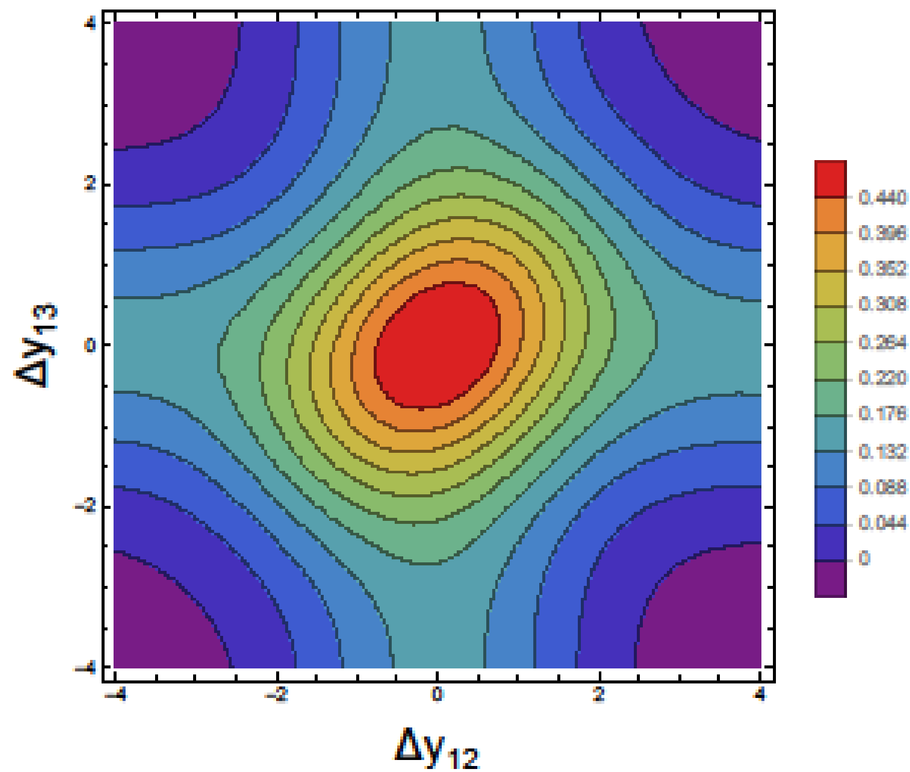
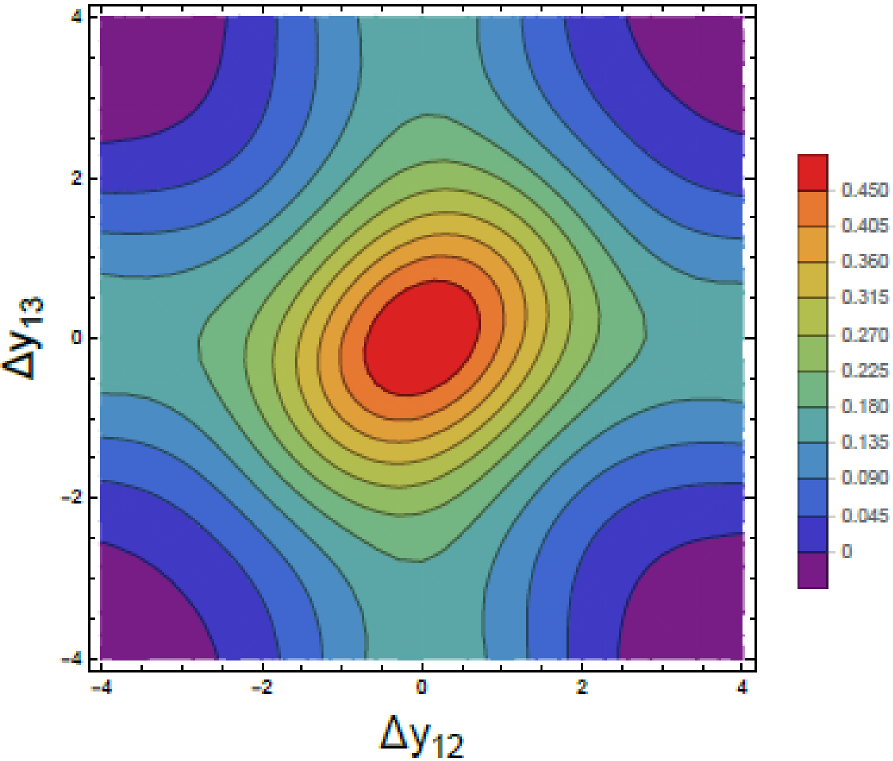
Three-particle pseudorapidity correlations

Almost no difference

NEW PHYSICS





SM

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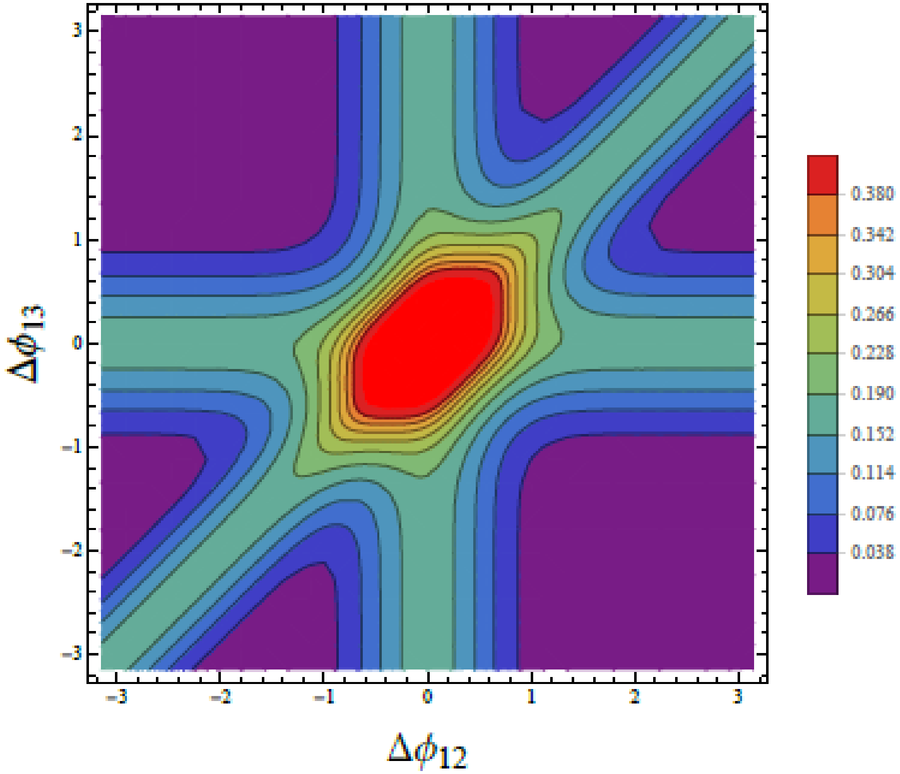
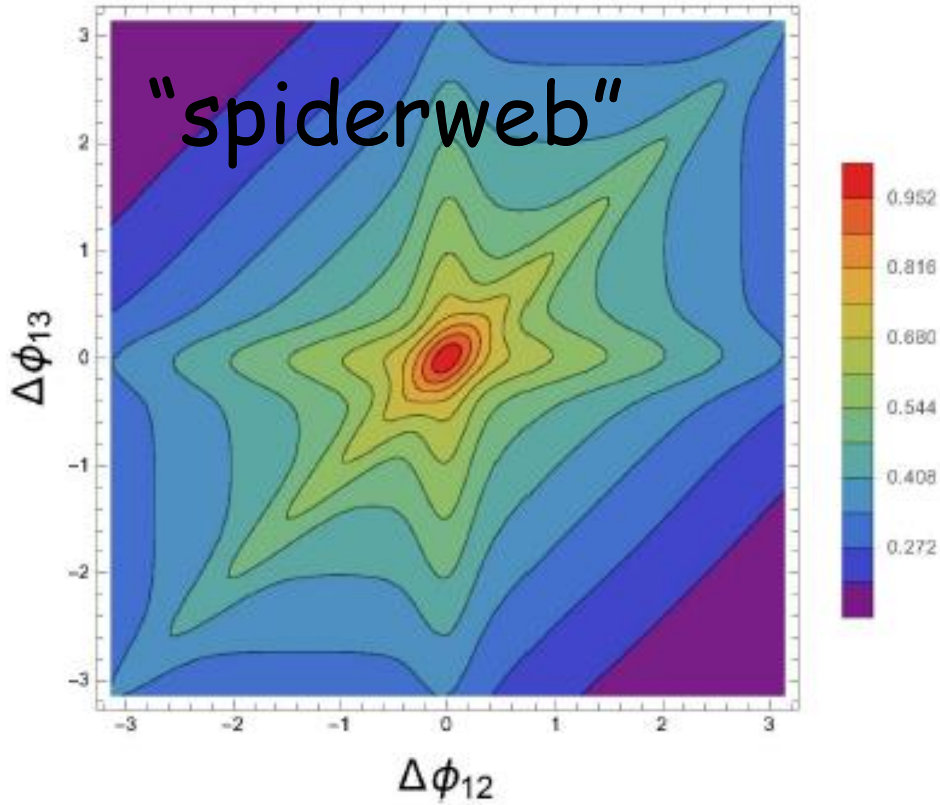
Three-particle azimuthal correlations



SM

NP effects should rather manisfest in azimuth!

NEW PHYSICS



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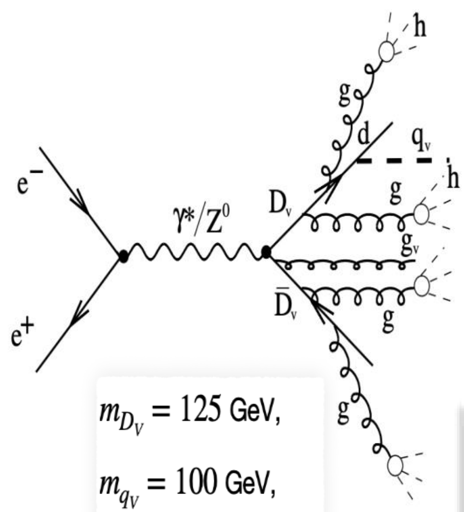
Signal vs background

QCD-like scenario

The HV particles have to be pair-produced

SIGNAL

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



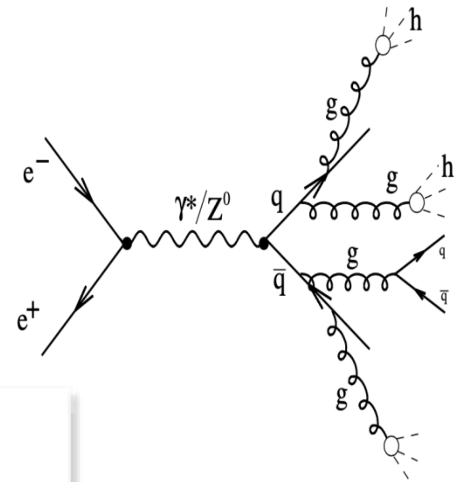
$m_{D_V} = 125$ GeV,

$m_{q_V} = 100$ GeV,

$\alpha_V = 0.1$

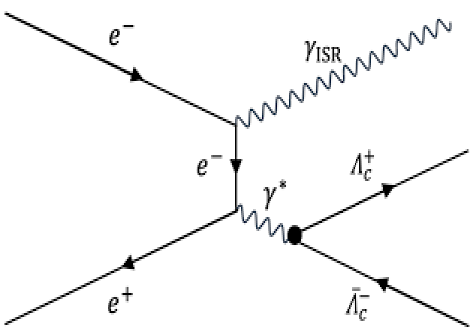
BACKGROUND

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

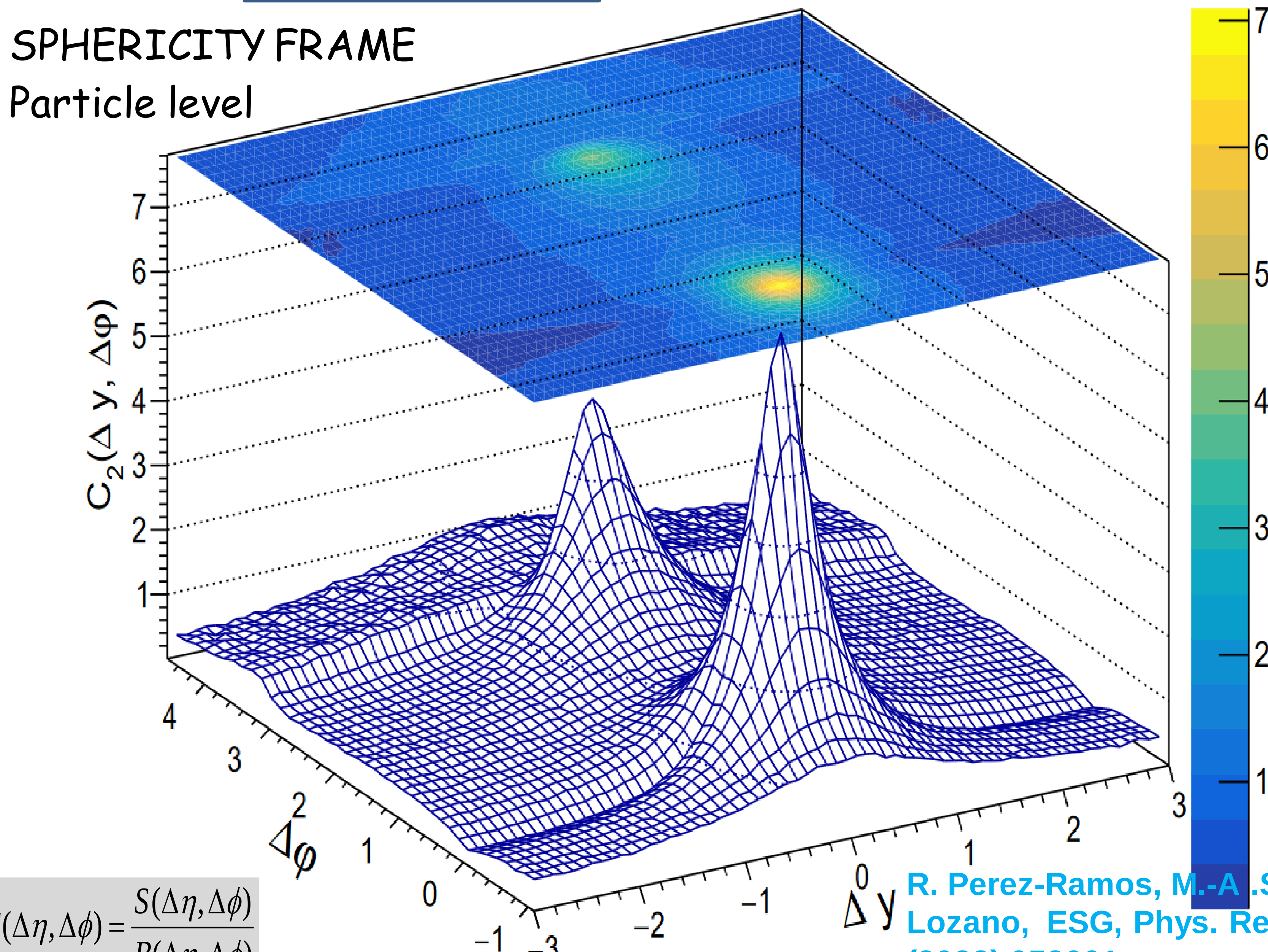


TOOLS:
- Pythia8
- FastJet
- ROOT

We take into account the ISR contribution

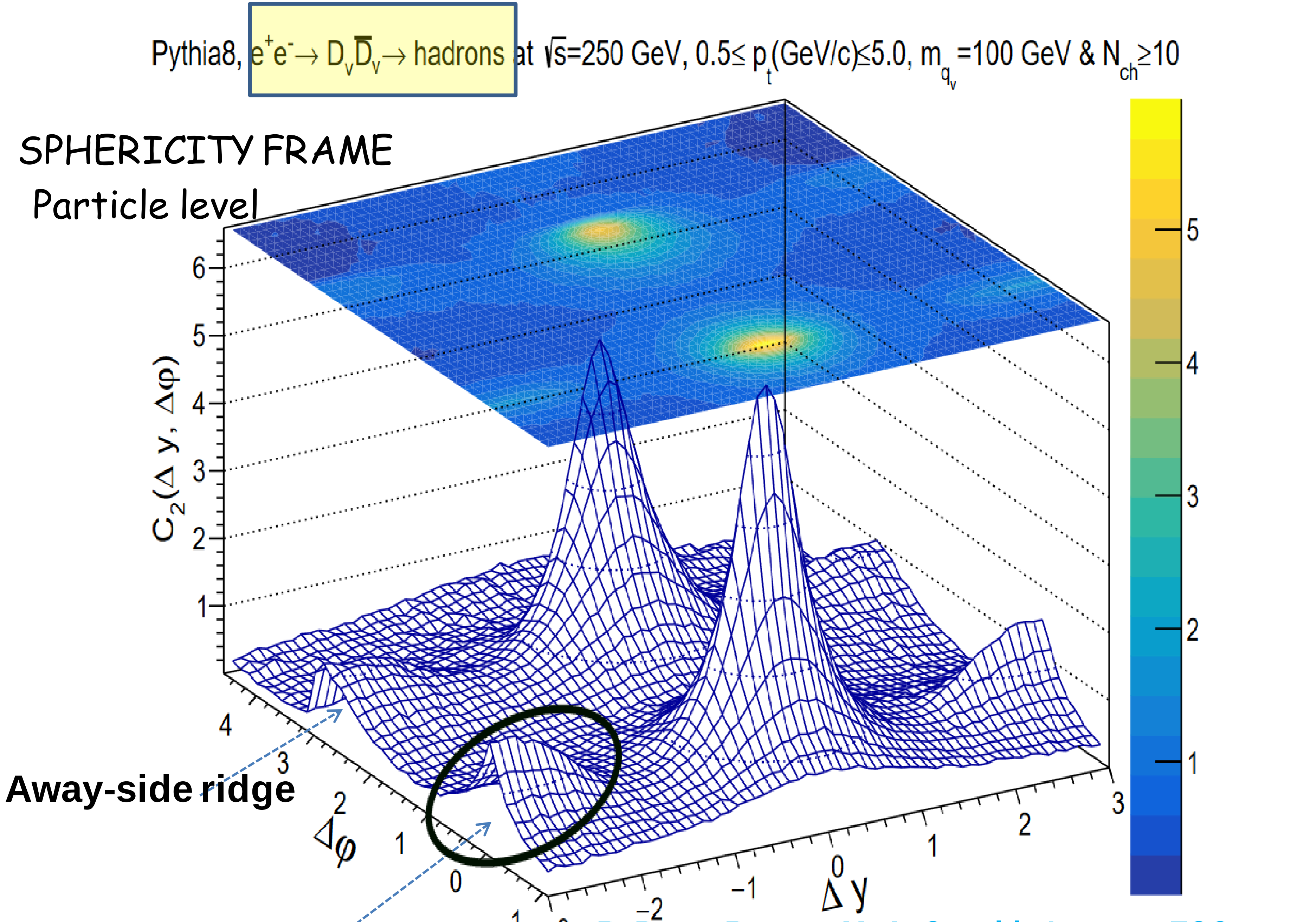


Pythia8, $e^+e^- \to q\bar{q}(n_f=5) \to$ hadrons at $\sqrt{s}$=250 GeV, 0.5≤ p_t(GeV/c)≤5.0 & N_{ch}≥10



$$C(\Delta\eta,\Delta\phi)=\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

R. Perez-Ramos, M.-A .Sanchis-Lozano, ESG, Phys. Rev. D 105 (2022) 053001



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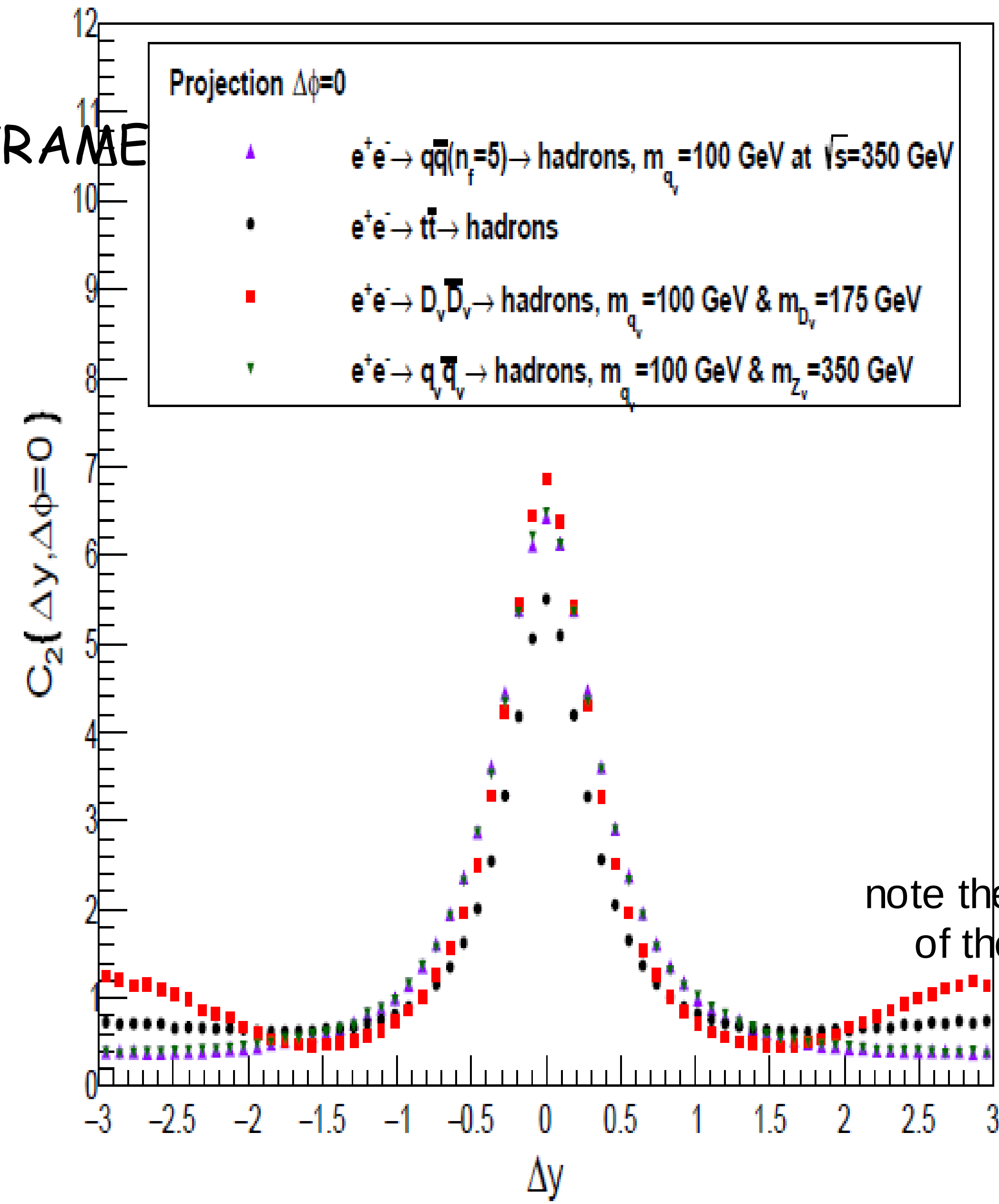
SPHERICITY FRAME

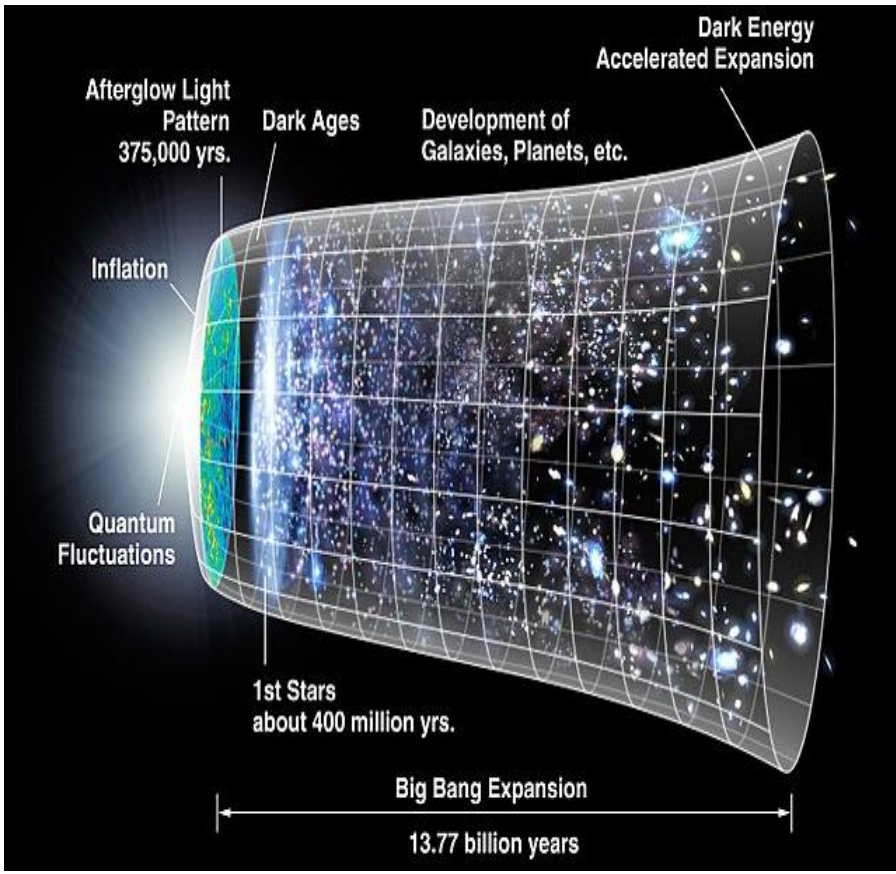
Particle level

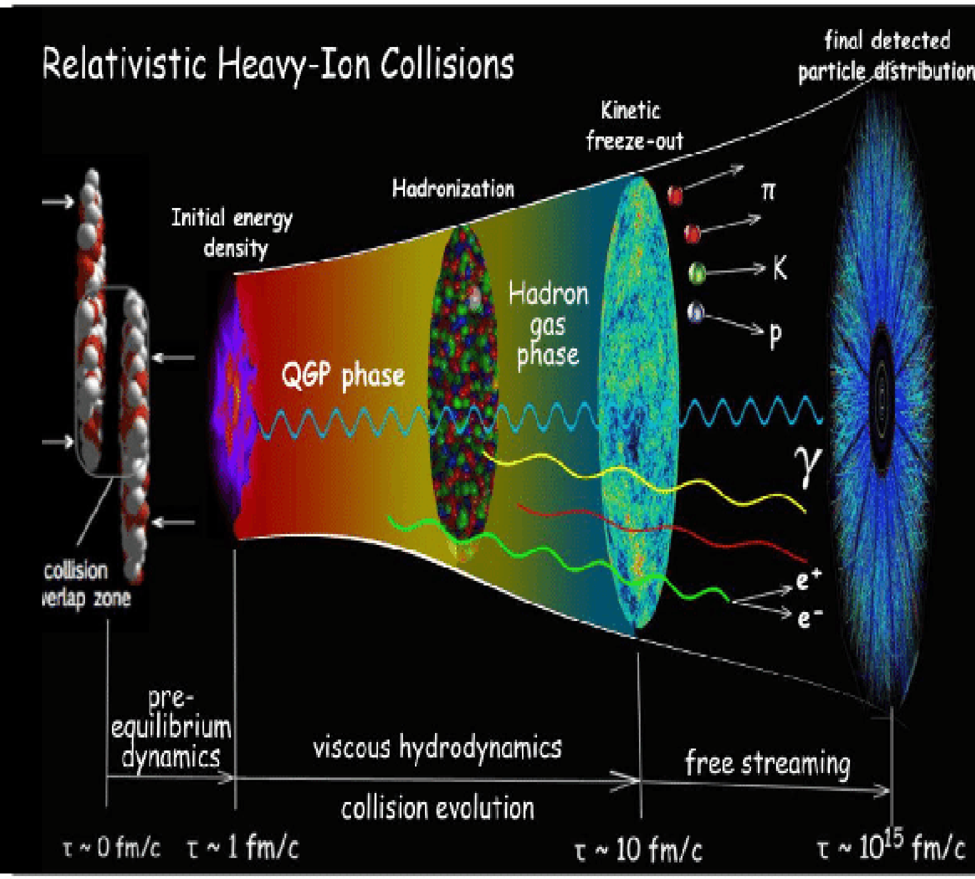


note the interpolating position of the top-antitop channel

R. Perez-Ramos, M.-A .Sanchis-Lozano, ESG, Phys. Rev. D 105 (2022) 053001

Heavy-ion collision analogy with universe evolution

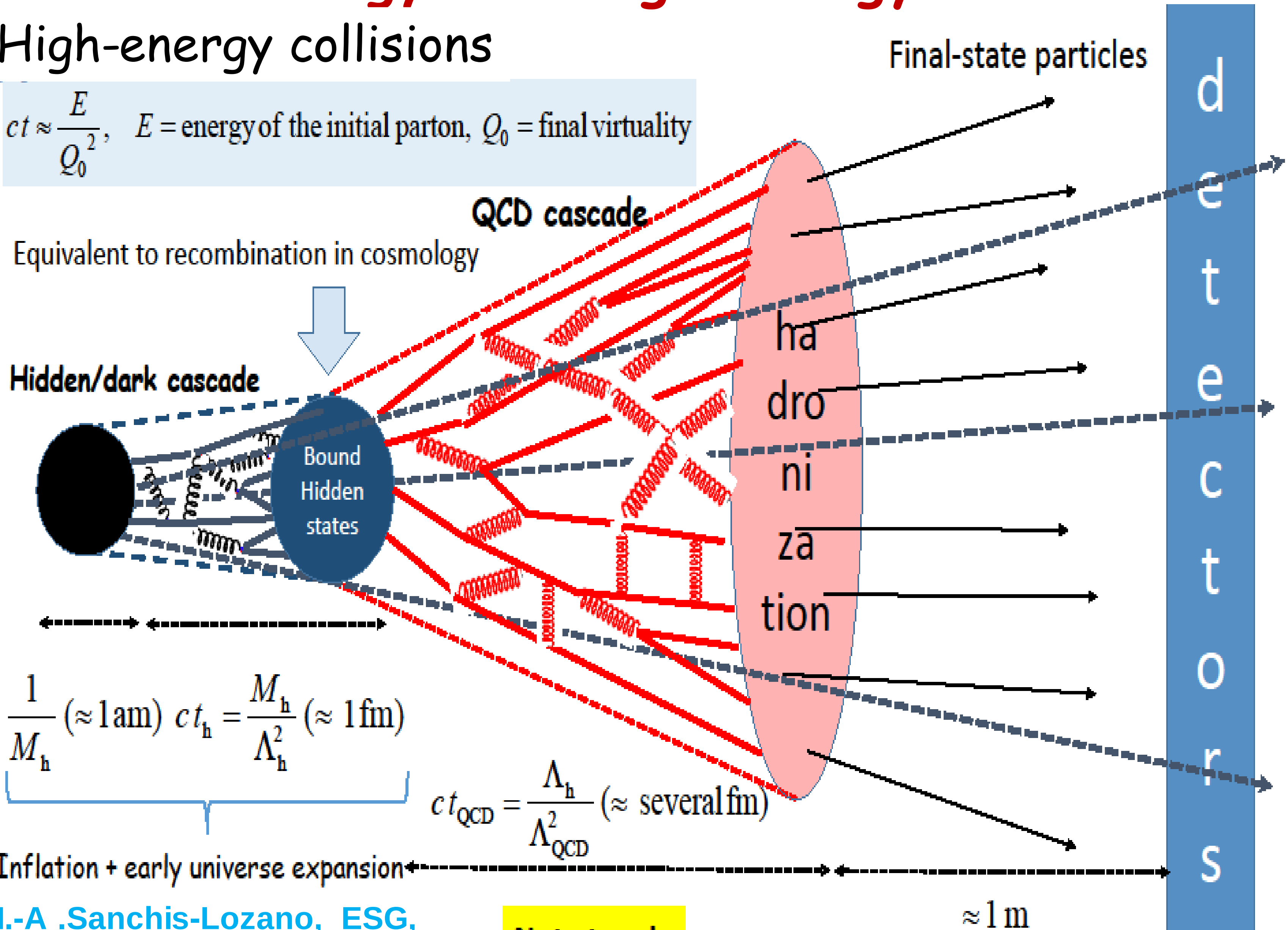




Analogy with high-energy collisions

High-energy collisions

$$ct \approx \frac{E}{Q_0^2}, \quad E = \text{energy of the initial parton}, \; Q_0 = \text{final virtuality}$$



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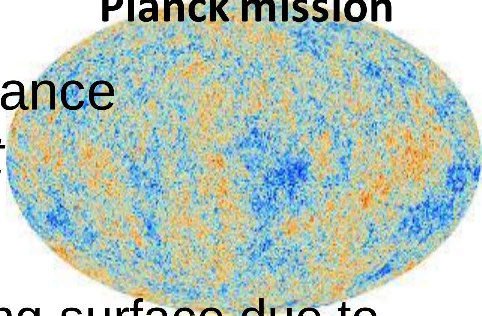
Phys. Rev. D 102 (2020) 035013

Not at scale

Cosmic analogy of pp collisions

Planck mission



Maximum fluctuation distance at any cosmic time t

$$\lambda_{\max}(t) = 2\,\pi\, R(t)$$

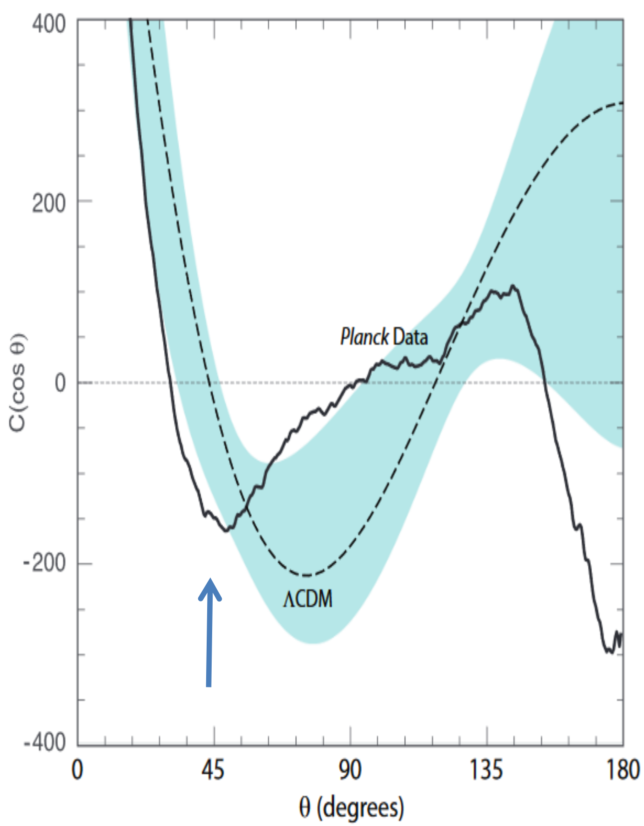
$$C(\cos\theta) \equiv \langle T(\hat{\mathbf{n}}_1) T(\hat{\mathbf{n}}_2)\rangle = \frac{1}{4\pi}\sum_l (2l+1) C_l P_l(\cos\theta)\,.$$

$R_h = c\,t$ universe

F. Melia, arXiv:1207.0015 [astro-ph.CO]

The distance to the last scattering surface due to the expansion is given by

$$\text{Linear}: \; a(t) = \frac{t_f}{t} \qquad r_{rec} = c\int_{t_{rec}}^{t_f} \frac{dt'}{a(t')} = c t_f \int_{t_{rec}}^{t_f}\frac{dt'}{t'} = c t_f \ln\left(\frac{t_f}{t_{rec}}\right)$$



The maximum angular size of any fluctuation associated to the last scattering surface should be of order

$$\theta_{\max} = \frac{\lambda_{\max}(t_{rec})}{R(t_{rec})}$$

where the proper distance to the last scattering surface is

$$R(t_{rec}) = a(t_{rec})\, r_{rec} = a(t_{rec})\, c\, t_f \ln\left(\frac{t_f}{t_{rec}}\right) = c\, t_{rec} \ln\left(\frac{t_f}{t_{rec}}\right)$$

$$\theta_0 = \frac{2\pi}{\ln\left(t_f / t_{rec}\right)} \approx \frac{\pi}{4}\,\text{rad} \approx 45^0$$

$$t_{rec} = 380000 \text{ years}$$

$$t_f = 1.38 \text{ Gyears}$$

Conclusions

- **A model of the clusters correlated in the transverse plane provides an explanation of the two-particle *ridge* effect and predicts the ridge phenomenon to hold in three particle correlations**

- **New physics (hidden/dark sector) signatures are shown to be directly tested by experiments using (multi)particle correlations (with the selection cuts *to enhance* NP effect)**

- **An intriguing common explanation is proposed upon the assumption of an unconventional early state: an expanding universe before recombination/decoupling up to present days vs formation of hidden/dark states in high energy collisions followed by QCD cascade to hadrons**

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THANK YOU!

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